GWEN

Gravitational Wave European Network

From Astrophysical Theory to Detection and Understanding

PART B: Start Page

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B1 SCIENTIFIC QUALITY OF THE PROJECT

B1.1 Research Topic

Building on the highly successful current EU Research Training Network "Sources of Gravitational Waves" (SOGW), we propose to develop an extended cross-disciplinary project aimed at developing a deeper understanding of how gravitational waves (GWs) may be emitted by black holes (BHs), neutron stars (NSs) and supernovae (SN). This project is being called GWEN (Gravitational Wave European Network) and it will be carried out by a broad collaboration of researchers, mainly coming from the EU countries.[1, 2] SOGW successfully developed both a European community of researchers, and a set of advanced theoretical tools and techniques for them to use (which have also been made available to the world community). This has strengthened the foundations of an emerging and very exciting new frontier for astronomy, cosmology, and physics research: *Gravitational Wave Astronomy* (GWA). GWs were predicted by Einstein near the beginning of the last century, but have not yet been directly observed although strong indirect evidence for their existence is provided by observations of binary pulsars [23]. Now, for the first time, we are in a position not only to detect these waves directly but also, in part through the efforts of SOGW, to make detailed theoretical calculations to predict and interpret the signals which will be found. The new GWEN project will enlarge the community, extend the range of tools developed and apply them to the most important problems in GWA.

As eagerly anticipated for nearly a decade, a number of major wide-band interferometric GW observatories are now for the first time taking data (including the European GEO600 and VIRGO as well as LIGO and TAMA outside Europe). These instruments join the existing resonant bar detectors (including the European Explorer, Nautilus and Auriga) which are also part of an ongoing programme moving towards increasingly higher levels of sensitivity. These developments are placing enormous pressure on the community to *study realistic sources of GWs, and predict the signals which they will produce in the detectors.* GWEN will address this urgent and exciting issue by building on the foundation created by SOGW in three important directions: by (*a*) adding the most recent, state-of-the-art microphysics to the present tools, and applying them to calculations of the most promising sources of GWs; (*b*) including in GWEN, data analysis (DA) experts working to design algorithms based on such calculations, and (*c*) working with existing projects in Grid Computing, to help provide the necessary computational techniques for both the theoretical and experimental communities in GWA. This will be accomplished by adding some of Europe's (and the world's) strongest groups with expertise in these new areas, by drawing on additional strengths in groups in SOGW, and by including two of the leading US centres for both theory and detection of GWs as partners (with travel funds only) in this project. GWEN will also develop new tools for the next generation of GW detectors, including the space based detector LISA, a joint ESA-NASA space mission [1], planned for launch in about a decade. Together, these GW observatories, armed with results from GWEN, will create a new window on the Universe, providing information that is either difficult or impossible to obtain by traditional observations using electromagnetic waves or neutrinos.

Accurate GW waveforms are required to probe the fundamental nature of gravity and uncover the unique physical and astronomical information which GWs carry. GWs can give us information about nuclear and particle physics (for which NSs present a potentially invaluable laboratory) and the nature of BHs. Also, they can contribute to our understanding of cosmology (e.g., in determining the Hubble constant without using the "distance scale ladder" [16] and in improving our understanding of the dark energy [17]). However, theoretically determined waveforms are crucial not only for understanding the physical content of the detected GWs, they are also required for detection. Physical information in the data may be extracted through template matching techniques [7, 8], which *presuppose* that reliable sample waveforms are known. Without theoretical templates to search against, it may be difficult or impossible to dig out the very weak GW signal, buried deep in detector noise. Accurate theoretical templates both enhance the chances of detection and provide the only means of achieving a physical understanding of the sources which we seek to study.

We propose with GWEN to train a new generation of EU researchers to populate this emerging research field, and to exploit and extend the results of SOGW by including experts in both microphysics and data analysis, thus making GWA a reality. The tools developed by GWEN will be shared with the worldwide community. GWEN will also exploit and develop new software and Grid and computer technologies to create a collaborative infrastructure, leveraging other existing research efforts to accomplish its goals.

[1] A hyperlinked PDF version of this proposal, with links to relevant material: references, web sites, black hole collisions simulation movies, etc., can be found at http://gwen.eu-network.org (username: XXXX, password: XXXX).

[2] A list of all acronyms used in this proposal is given in Appendix B10.3

B1.2 Project Objectives

The objectives of the current EU Research Training Network "Sources of Gravitational Waves" (SOGW), on which GWEN will be built, were focused on the development of basic tools and techniques needed for theoretical studies of GW sources, and on the creation of a community to use them. Other projects outside the Network concentrated on the development of data analysis (DA) algorithms needed to detect signals, and still others focused on detailed microphysics needed to represent realistic astrophysical sources. GWEN will put all these elements together, drawing on untapped strengths in SOGW nodes, and adding several nodes that provide crucial expertise outside SOGW. GWEN will be organised in a fundamentally different way, by *application area*, vertically integrating and extending relevant tools and techniques developed previously to solve the most important problems in GW source modelling, with direct application to their signature as seen in detectors. GWEN will also have *horizontal* integration teams (see B4.1) to ensure that developments common to all application areas are properly connected. We feel very strongly that it is highly likely that the work of GWEN will lead to breakthroughs in this field, *possibly helping to identify and understand the first gravitational wave signals ever detected.* The four primary objectives of the GWEN project are summarised as follows:

Objective A: Training As in SOGW, GWEN's primary objective will be training a new generation of young researchers (YRs) to further build this community. Not only is this essential for GWA science, but demand for researchers in this emerging research field has grown more rapidly than supply, in contrast to other research areas. The number of faculty positions in Europe and the USA in related areas has grown dramatically in the last years, and funding levels are rising (a joint NSF-NASA report recently recommended further increasing US funding in this area by a factor of 5!). While traditionally YRs in this field have been trained in the US, SOGW has taken an important step towards creating a European community to help fill the void.

New YRs will be trained in the use, extension, and application of the tools and techniques developed by SOGW to a core set of urgent astrophysics problems (cf. Sec. B1.5). Most training will be carried out locally through the interaction with senior researchers, in the context of solving scientific problems, but YRs will also receive unique training in innovative Grid and other computational technologies, rapidly being deployed across Europe and the rest of the world; some GWEN members are experts in Grid applications. A career development programme will be set up for each YR to best profit from expertise throughout GWEN.

Objective B: Tools The aim of this objective is the extension and standardisation of tools and techniques developed by SOGW to include more sophisticated microphysics, and their delivery to a wider community. The basic tools and techniques developed in SOGW, including 3D numerical codes, perturbative techniques, and post-Newtonian (PN) approximation techniques, will be systematically extended and standardised so as to be *shareable and interoperable across groups*, as needed to study the most important sources of GWs detailed in Objective C. Extensions to existing tools will be driven by the needs of those specific applications. New nodes with unique expertise in microphysics have joined GWEN, providing crucial components required for realistic modelling of both young and mature NSs. GWEN will continue to make its extended tools available to the wider community through meetings and schools it will hold, as SOGW has done.

Objective C: Core Astrophysics This objective concerns detailed studies of the most important sources of gravitational waves for existing detectors. We stress that, in contrast to during the SOGW, *these detectors are now in operation, taking data.* Therefore, it is most urgent to focus efforts on the sources that are considered most likely to be detectable now. In order to fulfill the needs of GWA, the capabilities developed during SOGW must be extended in two important directions: (1) They must be extended to include more detailed and realistic microphysical effects, from advanced supranuclear equations of state (EOS) to (relativistic) magnetohydrodynamics (MHD), and (2) the signals produced must be communicated to DA experts to see how the information can best be used to detect and interpret real GW signals. As detailed in the work plan in Sec. B1.5, we will focus most of the effort for this Objective on the study of the following GW sources:

Binary systems. Coalescing binaries, especially binary BHs, are considered among the strongest and most likely sources of GWs to be seen by the first generation of detectors now taking data. In conjunction with YR training, GWEN will extend existing tools to carry out the most realistic possible studies of different binary systems and determine how best to use these studies to enhance the signal-to-noise ratio in detector data, and ideally, to use these studies to help interpret signals which may be discovered for the first time.

BH Binaries: In order to model astrophysical BH binaries, one must account for the fact that BHs may spin rapidly. This leads to a large parameter space which must be covered by the theoretical models, and over which a GW search must be carried out. This leads to challenges for both numerical relativity and data analysis. In GWEN we will extend current equal mass binary BH initial data models developed by the LUTH group to include arbitrary mass ratios and spin configurations. Through a combination of improved formulations of the Einstein equations, gauge conditions, and nested grid refinement, simulations of various orbital configurations will be carried out and the GWs extracted. These calculations will be used to provide information for detectors, such as time scales, frequency bands, and any characteristic features in the wave output that will help distinguish different astrophysical binary BH merger scenarios. In parallel, we will combine perturbative post-Newtonian and non-perturbative re-summation techniques to provide *effective* and *faithful* detection templates that depend on fewer parameters yet have high overlaps with the expected physical signals.

NS and BH-NS binaries: The merger of two NSs also involves, besides the complications of the two-body problem in full General Relativity (GR), a variety of processes from which important physical information can be extracted. Making use of the relativistic hydrodynamics code developed by SOGW, the `Whisky` code, we plan to simulate the coalescence of a binary systems of NSs in full GR. The code will also be extended to include the solution of the equations of ideal MHD and the possibility of simulating matter with a realistic EOS. The experience gained in the simulation of NS binaries will be used when simulating BH-NS binaries.

Post-Newtonian studies: To check the reliability of the numerical simulations in full GR in the weaker gravitational field regime, the post-Newtonian framework will be generalised to include MHD and realistic EOS. This will allow us to study the onset of relativistic deviations from the Newtonian theory under general conditions. Furthermore, the post-Newtonian framework will be used to analyse initial data for numerical simulations in order to establish their GW content.

NS and BH genetics. Both NS binary merger and gravitational core collapse will lead to the formation of a hot, rapidly and differentially rotating, and, most likely, wildly pulsating proto-neutron star (PNS). The fate of this remnant, and the emerging gravitational-wave signal, depends on many complicated pieces of physics. During the first minute or so the PNS will cool mainly due to neutrino emission. This (as well as magnetic field effects) leads to the redistribution of angular momentum and contraction of the object. During this phase the PNS may suffer various dynamical instabilities, which could lead to significant GW signals. For up to about one minute the PNS evolves in a quasistationary way. This means that these objects can be studied both by full nonlinear computations and perturbatively (assuming an adiabatically evolving background).

PNS evolutions: We plan to extend existing codes for spherical symmetry to calculate equilibrium models of a rigidly and differentially rotating PNS to include realistic finite temperature EOSs and exotic compositions (hyperons, deconfined quarks). This, coupled to some simplified neutrino transport, will be used to study the quasi-stationary evolution of a rotating PNS. Having the evolutionary sequences of young PNSs as background allows us to study, at the perturbative level, the effects that thermal gradients and chemical stratification have on GW emission and instabilities.

Gravitational collapse of an NS to a BH: We will use the `Whisky` code to simulate the gravitational collapse of NSs whose rest masses cannot be supported against gravity in the absence of (differential) rotation. GWs from these events have so far been computed only in 2D simulations and little is known about how non-axisymmetric perturbations will evolve during the collapse.

Non-spherical supernovae (SN) core collapse: The collapse of the rotating core of a massive star to a NS is considered a promising source of GWs. Even in the case of an initially slowly rotating core the effects of rotation can become significant. There exists no efficient transport mechanism for angular momentum during core collapse, and hence the core will spin up significantly. We will study in full GR the influence of the angular momentum on the dynamics of the collapse and on the characteristics of the GW signal. In order to obtain more reliable theoretical GW signals we plan to include realistic EOS, an improved description of neutrino-matter interactions and a simplified description of neutrino transport processes. We will aim to develop data analysis algorithms that allow us to use GW data to draw important conclusions about the SN dynamics.

Linear and nonlinear dynamics of toroidal neutron stars (TNSs): TNSs are expected to form as a result of gravitational collapse, binary NS merger or disruption and could be the central engine in gamma-ray bursts. We will simulate the dynamics of these objects in full GR to establish the development of the “runaway” instability and calculate the corresponding emission of GWs. Furthermore, a systematic study of the oscillation properties of thick discs will be carried out in the background spacetimes of rotating and nonrotating BHs. As an interesting added benefit, the obtained results may improve our understanding of the X-ray signals from various accreting systems.

Dynamical instabilities: Using the `Whisky` code as well as perturbative methods, we plan to simulate the onset and development of various dynamical instabilities in rapidly and differentially rotating stars. The focus will be on triaxial instabilities, their lifetimes, and detailed GW signals.

NS forensics. About one minute after its formation a hot PNS will have cooled below 10^{10} K. When it reaches this temperature the remnant has contracted to a radius of about 10 km, and a NS is born. As the nascent NS cools further, the outer layers will freeze to form the crust composed of nuclei, while the core fluid is expected to undergo a phase-transition to a superfluid state. Mature NSs are thought to contain several superfluid/superconducting components, and may have cores composed of exotic particles. Both young and mature NSs can be significant GW sources. In particular, they may suffer secular GW driven instabilities (e.g. through the so-called r-modes) and they may develop asymmetries generated by accretion or the internal magnetic field structure. It is expected that accreting NSs in low mass X-ray binaries (LMXBs) will be particularly important GW sources. By studying the GWs from mature NSs we can hope to probe much exotic physics that would be impossible to study in any other way.

Secular instabilities: A rotating NS may develop secular instabilities driven by, for example, GW emission. GWEN will investigate the nature of such instabilities in realistic NSs, taking into account all the relevant exotic physics associated with the elastic crust, superfluidity, exotic particles and magnetic fields. We will also study key dissipative effects like hyperon bulk viscosity, superfluid mutual friction, and neutrino emission.

Isolated NSs: Mature NSs may radiate GWs because of asymmetries in the crust or the internal magnetic field. This may lead to the system being freely precessing. GWEN will model the relevant crust dynamics, and study non-axisymmetries generated by the internal magnetic field.

Accreting NSs in LMXBs: These systems may be highly relevant sources of persistent GWs. We will investigate this possibility in detail, accounting for the detailed physics associated with crust-core boundary layers, exotic viscosities and the internal magnetic field configuration. We will also model the accretion torque and the time variability of the emerging GW signal, which will allow us to design a suitable data analysis strategy.

Objective D: LISA With this objective, we aim to develop new analysis techniques for LISA and its sources. LISA is an extraordinary GW detector planned to operate in orbit around the Sun in about a decade. Among the sources that LISA is expected to observe, the infall of small BHs into rapidly spinning supermassive BHs will be of primary interest to GWEN. Such events will not only facilitate a clear understanding of the two-body problem but also help in testing uniqueness theorems about BHs. As a stellar mass BH in a highly eccentric orbit is captured by a supermassive BH its orbit will be dragged and continuously turned by the strong spin-orbit coupling. This coupling leads to a rapid precession of the orbital plane causing a continuous change in the polarisation pattern of the source observed by LISA. Such spin-orbit modulations depend on as many as 10 system parameters and lead to very complex waveform shapes. Even by the time LISA flies we are not likely to have powerful enough computational resources to carry out a matched filter search for these signals. It is, therefore, a matter of great urgency to invent robust search strategies that are insensitive to detailed phasing of the waveforms, in a Grid environment.

Radiation reaction: GWEN will use a combination of perturbative and numerical techniques to improve existing crude approximations in the calculation of waveforms and address the complicated problem of GW radiation reaction for extreme mass-ratio binary systems.

Search algorithms: We aim to develop a hierarchical time-frequency search algorithm to capture these signals. The idea is to first clean the data to get rid of non-Gaussian noise and then perform a time-frequency search. [UWC] has pioneered the development of geometrical signal analysis techniques which GWEN will apply to find which system parameters are relevant in a search, how to choose templates for matched filtering, how well the various parameters can be measured, and so on.

Summary: Our community is in a unique period in the history of relativity and astrophysics: the first GW observations are actually under way just as the theoretical and simulation community is achieving the ability to study astrophysically realistic problems. This should indeed be a very exciting period for astronomy and astrophysics; GWEN will help Europe lead the world in this endeavor.

B1.3 Scientific Originality of the Project

The current EU Research Training Network "Sources of Gravitational Waves" (SOGW) has become the world leading collaboration in the study of sources of GWs, and contains a unique expertise that, in many areas, represents the state-of-the-art internationally. Including new partners, the new GWEN project will advance the state-of-the-art across virtually all areas of relevance to GWA, from source simulation, to detection of the signals themselves and their physical interpretation, to Grid technologies. By leveraging and using work of other EU-funded astrophysics and Grid projects, and by utilising widely adopted and shared collaborative technologies, results of GWEN will be shared across, and have impact on, many diverse communities.

B1.3.1 Tools of the Trade

The primary tools needed for the study of GW are computational codes and techniques, various approximation schemes and computational technologies, including the emerging area of Grids.

Codes and techniques. The `Cactus` Computational Toolkit, developed at [AEI], [IAAT], and now [LSU] and elsewhere, is the most advanced framework for the simulation of Einstein equations. Its modular, collaborative design was created specifically for large collaborations like GWEN and was used extensively in SOGW. It provides portability, parallelism, elliptic solvers, nested and adaptive meshes, remote steering, and other advanced capabilities which have gained it the prestigious Gordon Bell Prize in 2001. As an important product of the collaborative spirit of SOGW, a new 3D, relativistic hydrodynamics solver, the `Whisky` code, has been constructed to simulate generic fluids in curved spacetimes. `Whisky` has been constructed within the `Cactus` framework and makes use of high resolution shock capturing (HRSC) techniques, which provide state-of-the-art accuracy in the solution of the hydrodynamic equations. GWEN will also make use of three additional tools, namely `Lorene,` `Nada` and `Triana`. The first is a multi-patch spectral solver package developed to compute very accurate binary initial data of various types. The second is a fully relativistic, non-vacuum 2D code using HRSC techniques, designed to complement `Whisky` and perform highly accurate simulations of sources with predominant axisymmetry, but in dynamical spacetimes. The third is a Java-based, Grid-aware environment for data analysis (DA) and data mining. The combination of `Cactus`, providing the evolution of the Einstein equations, with `Lorene`, providing accurate initial data, and `Whisky`, providing the evolution of the matter, will allow GWEN to investigate any astrophysical scenario in which strong and rapidly varying gravitational fields are present. `Cactus`, `Whisky`, `Lorene,` `Nada` and `Triana` all employ the most advanced computational techniques available and promise to provide very accurate simulations of sources of GWs and data analysis. GWEN will use them in numerous applications, continuing their development for the astrophysics communities around the world. Perturbative and post-Newtonian techniques play a fundamental role in SOGW, both in numerical simulations and in stand-alone approaches. This will continue in GWEN, where, in synergy with the numerical techniques, they will help modelling astrophysical phenomena.

Grid technologies. `Cactus` plays a fundamental role in Grid Technology (GT) research projects. [AEI] and [UWC] are leaders in the development of GT to various application areas, including numerical relativity and GWA. Combined with the EU-funded GridLab and UK-funded GridOneD projects, they enable GWEN research to take unique advantage of emerging GTs. A GWEN Virtual Organisation (VO) of computational resources will be set up and used, applications developed in GWEN will leverage GridLab's Grid Application Toolkit (GAT) and Portal for accessing Grid infrastructure.

B1.3.2 Physical Systems to be Studied

Binaries. Realistic treatments of NS and BH formation and collision processes are major scientific challenges in many ways, requiring development of advanced analytical and numerical methods, and incorporation of the most advanced physics and astrophysics. While the inspiral and merger of compact binaries is one of the most promising sources of GWs [11, 12], reliable theoretical waveform information will be crucial both to the interpretation of such observations and to greatly enhance the detection rate. Fully relativistic nonlinear calculations will be required to provide such detailed information. Simulations of dynamic BHs are very difficult [18, 3], limiting the length of time they can be evolved accurately. The most advanced 3D calculations of binary BH merger have been carried out within SOGW and will be extended in GWEN [2]. Binary NS systems have been studied for some years in Newtonian theory, but only fairly recently in full GR [20, 21, 13] and using artificial viscosity based hydrodynamic solvers which prevent a very accurate description of the shocks expected at merger. These preliminary results indicate that a number of issues still await clarification and, most importantly, more accurate treatments. The advanced numerical methods implemented in `Whisky` will provide this additional accuracy and compute the coalescence of both NS-NS and BH-NS binary systems. Initial data for these latter configurations is not yet available and will be computed with the `Lorene` package. The results will be used to develop the appropriate data analysis tools.

Gravitational collapse of stellar cores and NSs. Models of the gravitational collapse of the core of a massive star at the end of its thermonuclear evolution have become increasingly advanced. State-of-the-art 1D and 2D models in Newtonian gravity include multi-flavour, frequency-dependent Boltzmann neutrino transport, a detailed treatment of neutrino-matter interactions and a realistic EOS [15, 6, 14]. Studies in GR have been limited to axisymmetry with polytropic EOS [9, 10, 19]. A similar progress has been achieved in the collapse of an unstable NS, a process which does not involve as extreme changes in the length scales, but where the gravitational field is stronger and varying more rapidly. In this case the determination of the GWs from the collapse has been hampered by the difficulty of stably evolving the newly formed BH for a sufficiently long time. As a result, calculations have so far been restricted to 2D [22]. Using the expertise with single vacuum BH evolutions, the `Whisky` code and the experience on microphysics available within GWEN, we will calculate the dynamics and the GW signals from the collapse of both stellar cores and unstable NSs in 3D GR.

Young and mature NSs. The end product of a binary merger or supernova core collapse is an extreme object, with very high temperatures, rotating rapidly and differentially, oscillating wildly and prone to suffering dynamical instabilities leading to significant GW signals. So far, however, only quasi-stationary evolutions of hot non-rotating PNS have been studied. In GWEN we will obtain a more realistic picture of this scenario, modelling the thermal evolution of the remnant, the dissipative redistribution of angular momentum, and accounting for the backreaction of the emitted GWs on the system. Such investigation is needed to assess the likelihood that dynamical instabilities develop, and will lead to a much improved understanding of the GW signals from NS births. Mature NSs may also radiate GWs in many ways: either through secular instabilities, by deformations induced by crustal stresses or intense magnetic fields, or as a consequence of accretion in binary systems. All these possibilities, however, require a detailed physical description before reliable predictions for the GW signals are possible. In particular, it is essential to establish the role played by exotic particles and superfluid components, as well as to put tighter constraints on the properties of the stellar crust and the strength and topology of the magnetic fields present. GWEN will tackle this challenging task by combining astrophysical and particle physics expertise with existing expertise in NS physics and approximation methods.

Dynamics and seismology of TNSs. So far, studies of the nonlinear dynamics of toroidal NSs (TNSs), which are high-density disks around BHs, have been carried out either in Newtonian physics or in stationary BH spacetimes. These studies will be improved upon by including the contribution of the self-gravity of the TNSs to the global spacetime. Using the `Nada` code, GWEN will establish whether these objects suffer generically from the “runaway” instability. Furthermore, GWEN will investigate long-standing issues such as the generation of an extreme Kerr BH via transfer of angular momentum from the TNS and the emission of GWs as a result of mass accretion. The seismology of thick relativistic discs is still unexplored, but could provide insights for astrophysics and GWA. GWEN will carry out a systematic study of the seismology of geometrically thick discs by investigating axisymmetric and non-axisymmetric oscillations in the spacetimes both of a rotating and of a nonrotating BH. These studies will be conducted with simplified (vertically averaged) disc models as well as in fully 2D treatments, and the results will be compared to fully numerical simulations

Data Analysis (DA). Unlike most electromagnetic wave telescopes GW antennas are coherent detectors, tracking the phase of the GW signal. Consequently, the signal-to-noise ratio grows in proportion to the square-root of the number of signal cycles in a detector’s frequency band. This approach, called *matched filtering*, is used to search for GWs from those sources whose signal is known sufficiently accurately. However, besides placing a severe burden on theoretical models and computational costs, matched filtering performs poorly when the evolution of the signal is not known accurately. The computational and analytical technology developed by SOGW allows, for the first time, a number of sophisticated calculations of GW sources. Many of these problems, however, are too complex, and the computational resources still insufficient, to provide an accurate phasing of the signals. Therefore, GWEN endeavors to explore new algorithms that make optimum use of all the physics that can be computed by theoretical modelling. The ultimate aim is to create a liaison between the DA and source modelling groups, in order to design algorithms best suited to the sources in question.

B1.4 Research Method

In order to achieve its research objectives, GWEN will use large scale numerical codes and approximation techniques developed in the current EU Research Training Network "Sources of Gravitational Waves" (SOGW), to study NS/BH interactions, stellar collapse scenarios, and isolated systems, which generate GWs. GW signals computed in this way will be brought into the GW data analysis (DA) pipeline to see how best they may be deployed by experimenters actually collecting the data. This way we expect to learn which theoretical calculations are most crucial to support the experiments. As GW observatories are already online, it is urgent to develop a comprehensive, community wide focus to develop and exploit these approaches for the fullest possible understanding of the most likely GW sources.

GWEN employs a well thought-out, highly interdisciplinary research method to train YRs not only in their respective disciplines, but in their abilities to draw from a variety of available methods, technologies and colleagues to solve problems. The work has been organised vertically by scientific topic, building on the synergistic approach of varied computational tools and approximation techniques developed for studying sources of GWs by the SOGW project. Each topic spans the entire process from studies of sources to impact on data analysis (DA), drawing on all tools and domain specific knowledge needed, including (*a*) Computational and Grid technologies; (*b*) Analytic approximation schemes; (*c*) New physical effects that could not be included before (e.g., nuclear equations of state and MHD); (*d*) Extraction of physically relevant information (e.g., time scales, frequency ranges, waveforms) for GWA; (*e*) Implications on DA needed to search for real signals in detector data already being taken. Tasks will be grouped into various Focus Groups, distributed across objectives as shown in work plan Table B1.2 and managed as described in Sec. B4.1. In order to achieve the training (**Objective A**), YRs will be given a focus problem in one of the scientific subareas contained in **Objective C**, in the context of the overall "pipeline" from theoretical modelling to DA and detection. Details of the training programme are given in Sec. B2.1 (also see Sec. B1.5 especially Table B1.5).

In order to develop further the tools for the scientific focus problems (**Objective B**), YRs will need to be trained in appropriate analytic and computational techniques used and developed in SOGW and elsewhere. The basic techniques of perturbation theory and post-Newtonian approximations, computational algorithms, nuclear astrophysics, hydrodynamics, MHD, data analysis techniques etc., will be taught as needed through educational programmes at the various GWEN nodes, and made available across GWEN (and throughout the world) through "Access Grid" video conferencing and web based presentation materials. Theoretical researchers in GWA should be familiar with all these techniques in order to study the breadth of relevant processes in the Universe (e.g., nuclear equations of state are not critical to binary BH mergers, but are critical to the study of binary BH-NS problems). Such a breadth of expertise does not exist in a single node, and therefore can only be collected for a comprehensive training programme through a collaboration like GWEN.

The expertise needed in the basic techniques to be used, e.g., finite differencing, nested grids, certain decompositions of Einstein's equations, perturbative techniques, hydrodynamics and MHD, equations of state, time-frequency analysis, etc., are already highly developed within the GWEN collaboration. They can be expected to lead to very powerful analytic, computational and data analysis tools for the study of the scientific focus areas, which will be combined as needed for application to study the sources of GWs in **Objectives C** and **D**. For example, the complementary perturbative and fully computational approaches can be combined and applied to binary source evolution, to extend merger calculations and extract accurate waveforms. Tools will be openly shared across the GWEN collaboration, and later made available to the larger worldwide community.

The results of these studies will be used directly in testing DA techniques developed within GWEN. Various types of output from these source studies, such as waveforms, time scales, frequency ranges, etc, will be used to test the efficacy of algorithms developed to find signals in simulated and real data collected by detectors. Results of these studies will be fed back to the researchers studying the GW sources to help them target their efforts to be as *useful as possible for present-day GWA* (**Objective C**), and to help them prepare and plan for studies that will be needed for the future (**Objective D**).

GWEN is particularly innovative in its use of collaborative computational science and Grid technologies. The `Cactus` framework provides abstractions of many high performance computing techniques, so that researchers armed with a knowledge of basic concepts, such as parallelism, adaptive meshes, etc. do not have to waste time implementing the complex details of message passing, parallel I/O, etc. They are able to focus on the *science* tools they need, quickly developing them, and having them run, in parallel, on every computational resource at their disposal. The collaborative design of `Cactus` makes it easy to share modules with others, and to build on existing modules developed elsewhere in the world. For example, the advanced spacetime evolver developed jointly by [AEI], [UIB], and [LSU] will be used by [MPG.MPA] for core collapse and [AUTH/UA] for binary NS studies. Code modules are stored in a central CVS repository. When improvements are made by and GWEN group, they are checked back into the repository (only after passing extensive test suites!) for all groups in the worldwide collaboration to use.

Working with the projects described below, GWEN will take unique advantage of novel Grid technologies presently under development. A GWEN *Virtual Organisation* (VO), of computing resources worldwide, will be developed to facilitate the collaborations and computations. GWEN "Portlets" will be developed by GridLab to provide web-based access to all systems, codes, and results, normally scattered across many machines worldwide. Using a single certificate-based login, and remote visualisation technologies authorised members of collaborative groups of researchers within GWEN will be enabled to browse their worldwide shared global file space, examine results, visualise them, share parameter files, etc. Training can also be enhanced using these new technologies. YRs will be immersed in their use as they are deployed.

Leverage. SOGW was very effective in leveraging other projects and so will be GWEN. SOGW used existing codes and computational frameworks, and also cultivated a community, as a crucial component of its research method. The ratio of total participants attending SOGW meetings to those funded by it was typically 7:1. Other groups have joined SOGW, increasing its size from 10 to 15 nodes in GWEN, including several *Regional Nodes* (Secs. B3.1, B3.3) themselves now comprised of 2-3 sites, bringing the total number of partners to 20. This has forged closer links between groups both locally and internationally. Also, as attested in Appendix B10.2, several external groups around the world plan to work with GWEN to achieve common goals.

The expertise of GWEN and its wider collaboration is considerable, but it can achieve its ambitious goals, and have as much impact, only because it also *works with and builds on the results of other, major, externally funded projects*. Cooperation between GWEN and other efforts represents major technology transfer from some of the largest collaborative projects in computational science and astrophysics to date (see Appendix B10.2).

Several projects predating GWEN, including the NSF BH and NASA NS Grand Challenges, and the NSF Astrophysical Simulation Collaboratory (NSF-ASC), were funded collectively at over $8M across a dozen US institutes. Together they developed many tools that provided the foundation for SOGW, and on which we continue to build. GWEN members participated in those projects, and are now providing valuable experience and expertise. The collaborative `Cactus` Framework was developed out of lessons learned from the NSF-BH project, `Whisky` was inspired by the public GR3D code of the NASA-NS project, and the collaborative portal, remote visualisation, and Grid technologies GWEN will use are based on the work of the GridLab, GriKSL and NSF-ASC projects. The German SFB project, involving [AEI], [FSU], [MPG.MPA], and [IAAT] supports a postdoc at each site who will help train Early Stage Researchers in GWEN (hence German GWEN sites ask primarily for Early Stage Researchers). Supporting projects (see letters included in Appendix B10.2) include:

DFG-supported SFB/TR project (http://hpcs3.tpi.uni-jena.de/∼sfb/). Led by Neugebauer, this smaller 5-institute project on GW will share codes and expertise with GWEN, and through its Experienced Researchers at [AEI], [FSU], [MPG.MPA], and [IAAT], it will help train GWEN Early Stage Researchers.

DFN-Verein supported GriKSL project (http://www.griksl.org). Led by GWEN Network Coordinator Seidel, this cooperative project between [AEI] and the Konrad-Zuse-Zentrum develops advanced remote visualisation and data management technologies that will also be applied to GWEN.

EU-funded GridLab project (http://www.gridlab.org). Led by Nabzryski, this 14 institute, 6M Euro project will work closely with GWEN to introduce advanced collaborative and Grid technologies. GridLab and GWEN have two nodes in common.

EU-Funded Gridstart project (http://www.gridstart.org). Led by Parsons, this project coordinates activities across many EU-funded Grid projects. Gridstart will help to identify GWEN needs, connecting it to appropriate EU Grid efforts.

EU-funded DEISA project (http://www.deisa.org). Led by Alessandrini, this FP6 project connects major EU computing centres and aims to provide badly needed (by GWEN and many projects) HPC Grid resources to all EU researchers.

B1.5 Work Plan

The GWEN work plan is summarised in this section. Tasks are distributed across Focus Groups (FGs), as shown in Table B1.2. The detailed involvement of the individual GWEN teams is given in Figure B1.1. In the tables each task is given the expected number of months to completion from the project start. Those tasks that should be completed in a definite time period (e.g., 24 months) can be considered as milestones, to be delivered by the midterm review or final report as appropriate. Ongoing projects are those with indefinite time periods, that will likely continue, by the GWEN-trained and established community, beyond the duration of the funding. As in SOGW, simulation codes, associated collaborative, visualisation, and distributed computing infrastructure will be made available, with extensive documentation, to the worldwide research communities.

Objective A: Training YR Training is the main priority for GWEN. The cross-disciplinary nature of GW science makes it an area of research that warrants the training of the European researchers of tomorrow. All GWEN teams have significant experience in training YRs. Within GWEN, YRs will be mentored by senior researchers while solving highly relevant scientific problems (Objectives B, C and D below have a substantial and continuous scientific training aspect). At the same time, frequent interactions with researchers of other teams provide an opportunity to benefit from expertise that would otherwise not be available. This format proved very successful within SOGW. The YRs will be given frequent opportunities to present their results, at local seminars, GWEN meetings as well as international conferences. Training in key skills concerning presentations, writing up of scientific results and general issues concerning personal career development will be provided within a context that reflects the international nature of today's scientific community. The YRs will be encouraged to take responsibility for the day-to-day management of their research, involving decisions about expenditure and organisation. YRs will also play a key role in organising the GWEN meetings, and will be expected to help plan an advanced school for YRs (as they did in the SOGW school held in Trieste in September 2003) towards the end of the network.

The entire GWEN project will be trained in use of `Cactus`, computational techniques, CVS, visualisation, etc. Video conferencing will be set up at each member site, and didactic sessions for YRs will be provided drawing on the expertise gained during SOGW. The outcome should be a generation of European YRs that are able to carry out research at the frontiers of modern science and who would be extremely employable both in academia and industry. Training represents a Focus Group described in Sec. B4.1, and *detailed elements of the GWEN training plans are listed in Table B1.1.*

Objective B: Tools This Focus Group will extend tools needed for the primary physics problems (Objective C), and develop them into well documented, interoperable community standards, by outfitting them with compatible, platform independent file formats, and integrating them into `Cactus` where possible. These tools will be made available beyond GWEN to the wider community. *Listed below are the* **milestones** *expected to be reached for this Focus Group, while Figure B1.2 shows the planned timeline.*

B1. Refinement of evolution methods, formulation of Einstein equations, and development of appropriate gauge conditions for stable evolutions (*planned duration:* `24 months`).

B2. Continued testing and development of AMR provided by `Carpet` (*planned duration:* `21 months`).

B3. Development of consistent boundary conditions for use with hyperbolic formulations of the Einstein equations. Study of BH excision techniques for long term stability of orbiting black holes (*planned duration:* `21 months`).

B4. Refinement of GR hydrodynamics algorithms, and continued development of `Whisky` (*planned duration:* `18 months`).

B5. Development of the axisymmetric, non-vacuum, fully GR `Nada` code, implementing the cartoon technique, introduction into `Cactus` (*planned duration:* `18 months`).

B6. Development of a relativistic MHD code in Cactus (*planned duration:* `18 months`).

B7. Development of the `Lorene` library for enhanced binary initial data, especially data for mixed BH and NS binaries, and integration into `Cactus` (*planned duration:* `30 months`).

B8. Development of non-linear perturbative schemes, for studying mode-coupling in pulsating PNS in weakly nonlinear regimes (*planned duration:* `24 months`).

B9. Development of a perturbative formalism for extracting asymptotic wave forms on a finite grid in non-vacuum spacetimes (*planned duration:* `24 months`).

B10. Development of `Triana` for efficient GW DA (*planned duration:* `24 months`).

B11. Development (with Grid partners GridLab, GriKSL, Gridstart) of Grid tools for GWEN (Portals, Virtual Organizations, data management tools, remote visualisation tools; *planned duration:*`24 months`).

Objective C: Core Astrophysics Objective C is split into multiple Focus Groups. Impact of results on Data Analysis (DA) will be considered where possible, as organised by Cognisant Scientist for DA (Sec. B4.1). *Listed below are the* **milestones** *expected to be reached for this Focus Group, while Figure B1.3 shows the planned timeline.*

Binary Systems:

C1. Using `Lorene` continue studies of 3D Meudon BH Data. Comparison with perturbation theory; this task will exploit the results of B7 (*planned duration:*`30 months`).

C2. Using `Whisky`, study of the GWs from merging binary NS models; comparison with perturbation theory in post-Newtonian and close limit approximation, where appropriate; this task will exploit the results of B1, B2, and B4 (*planned duration:* `24 months`).

C3. Using `Whisky`, study of the binary mass-function leading to the formation of systems composed of a BH surrounded by a TNS; this task will exploit the results of B1, B2, and B4 (*planned duration:*`12 months`).

C4. Using `Whisky` and perturbative techniques, study tidal disruption and GWs emission from the merging of a star-BH binary system; this task will exploit the results of B1, B2, B4, and B9 (*planned duration:* `24 months`).

NS and BH Genetics:

C5. Development of a quasi-adiabatic perturbative framework for PNS, incorporating the relevant thermal effects as well as neutrino dissipation, magnetic field generation, and gravitational-radiation reaction; this task will exploit the results of B8 (*planned duration:*`24 months`).

C6. Study of the pulsation properties of PNS, accounting for non-adiabatic effects, strong internal stratification, heat transfer effects due to neutrino processes and convective instabilities; this task will exploit the results of B8 and C5 (*planned duration:* `24 months`).

C7. Using `Whisky`, systematic study of collapse of *uniformly* and *differentially* rotating NSs in 3D and associated GW emission and disc formation; this task will exploit the results of B1, B2, and B4 (*planned duration:* `24 months`).

C8. Using `Whisky`, carry out a systematic study of the bar-mode instability and shearing instabilities in differentially rotating stars. Compare to results from perturbation theory; this task will exploit the results of B1, B2, and B4 (*planned duration:* `24 months`).

C9. Development of a relativistic code for nonspherical supernova core collapse (*planned duration:* `24 months`).

C10. Study of Newtonian magneto-rotational core collapse (*planned duration:*`24 months`).

C11. Systematic investigation of axisymmetric and non-axisymmetric oscillations of geometrically thick, relativistic discs; this task will exploit the results of B5 (*planned duration:* `24 months`).

C12. Using `Nada` and BH perturbation theory, study the onset and development of the runaway instability in self-gravitating discs. Model the GW emission from runaway accretion. Study the transfer of angular momentum to a BH and the dynamics when the BH reaches the extreme Kerr limit; this task will exploit the results of B5 and C11 (*planned duration:* `24 months`).

NS Forensics:

C13. Study of oscillation modes of rapidly rotating relativistic stars. Formulation of outgoing wave boundary condition. Assess stability of various classes of modes; this task will exploit the results of B1, B2, B4 and of perturbative techniques (*planned duration:* `24 months`).

C14. Evaluation of the effect of exotic particle physics on the r-mode instability, including hyperon bulk viscosity and deconfined quark cores. Account for superfluid effects (*planned duration:* `24 months`).

C15. Development of framework for studying the dynamics of neutron star crusts. Investigation of the role of deformations due to internal (toroidal) magnetic fields. Study GW emission for stars with ultrastrong magnetic fields (*planned duration:* `24 months`).

C16. Model GW signal for LMXBs radiating via *i)* crustal deformations, *ii)* r modes or *iii)* magnetic field deformations. Account for variability of accretion torque according to observed X-ray flux and devise a suitable data analysis strategy (*planned duration:* `12 months`).

Data Analysis:

C17. Development of data analysis tools on the Grid tailored to search for and measure the parameters astrophysical sources studied by GWEN; this task will exploit the results of C1–C16 (*planned duration:* `24 months`).

C18. Liaising with GWEN nodes to identify potential sources to search in GW data; this task will exploit the results of C1–C16 (*planned duration:* `24 months`).

Objective D: LISA This Focus Group concentrates on development of algorithms that will be needed to support the future, space-based LISA detector, to fly in about a decade. *Listed below are the* **milestones** *expected to be reached for this Focus Group, while Figure B1.4 shows the planned timeline.*

D1. Implement approximate frequency-domain regularisation of point particle radiation reaction in Teukolsky formalism for rotating BHs, and assess nature of GW signals (*planned duration:* `30 months`).

D2. Using `Lorene`, develop a formalism for studying time evolutions of direct metric perturbations for rotating black holes. Consider matching to nonlinear evolutions. Study infall along general orbits in Kerr spacetime and extract GW signal; this task will exploit the results of B7 (*planned duration:* `24 months`).

D3. Use signal models and the method of principal components to identify the most important search parameters. Use MonteCarlo simulations to explore the dependence on the physical parameter values; this task will exploit the results of C1–C16 (*planned duration:*`12 months`).

D4. Investigate if time-frequency analysis can be employed to achieve near optimal sensitivity in searches and study their statistical properties (*planned duration:* `12 months`).

D5. Explore how well the parameters of the source such as the masses and spins of the bodies, direction and distance to the source, can be estimated, paying special attention to carrying out strong field tests of GR (*planned duration:* `12 months`).

A schematic diagram showing the interconnections among the different Objectives is shown in Figure B1.5. Note how the Objectives “Tools” (B1–B11) are developed to be used in the applications of Objectives “Core Astrophysics” (C1–C16) and “LISA” (D1–D5) .

A1	create formal individual career development plans for each YR; ensure plans known to all partners
A2	monitor each YR's progress and make adjustments as needed
A3	provide a local environment with mentoring in main scientific project, including research meetings, seminars, and regular supervision by appointed senior researcher
A4	provide broad scientific training going beyond a specific discipline; include Network-wide mentoring by remote researchers in complementary disciplines
A5	provide Experienced Researchers with opportunities for mentoring and teaching of students, other YRs
A6	coordinate YR training and research topics across GWEN, making adjustments if necessary
A7	organise training at All-Hands meetings and summer schools
A8	provide training and experience in teamwork at local and international levels
A9	provide training in project and grant management, e.g., by involving YRs in Newsletter, report writing
A10	assist YRs in developing leadership skills
A11	provide training in computational techniques, visualisation etc.
A12	provide `Cactus` training
A13	provide training and experience in Grid based computing
A14	provide training in web-based technology by disseminating GWEN results on dedicated web-pages
A15	provide training in collaborative tools (CVS, project web-pages etc)
A16	provide a research environment that supports and encourages development of innovation and creativity
A17	provide experience in independent scientific learning
A18	provide training in communication skills (e.g., critiques of talks) and tools (presentation tools, etc)
A19	assist development of scientific writing skills through publications, proposal writing, etc
A20	aid development of language skills
A21	facilitate networking and career management (writing CVs, job applications etc)

Table B1.1: Tasks for the Training Focus Group that would contribute towards Objective A in the GWEN work plan. As described in text above and also in Sec. B4.1, a Cognisant Scientist in charge of training will work to coordinate these tasks across the project, monitor YR progress, and make adjustments as necessary to ensure their success.

Teams	Objective						
	A. Training	B. Tools	C. Core Astrophysics				D. LISA
			Binary Systems	Genetics	Forensics	Data analysis	
T-01 Potsdam [AEI]	⊗	⊗	×	×	×	×	×
T-02 Jena [FSU]	×	×	×	×	×		×
T-03 Paris [GReCO/LUTH/APC]	×	×	⊗	×	×	×	×
T-04 Valencia [UVEG/UA/UB]	×	×	×	⊗	×		
T-05 Palma [UIB]	×	×				⊗	×
T-06 Thessaloniki [AUTH/UA]	×	×	×	×	⊗		×
T-07 Rome [URLS]	×	×	×	×	×	×	
T-08 Trieste [SISSA]	×	⊗	×	×	×		
T-09 South of England [SoE]	⊗	×	×	×	×		⊗
T-10 Cardiff [UWC]	×	×	×			⊗	⊗
T-11 Garching [MPG.MPA]	×	×		⊗	×		
T-12 Tübingen [IAAT]	×	×	×	×	×		
T-13 Warsaw [CAMK]	×	×	×	×	×	×	×
T-14 Baton Rouge [LSU]	×	×	×			×	
T-15 Penn State [PSU]	×	×		×	×	×	×

Table B1.2: The distribution of tasks will be organised across the 4 Objectives into a number of Focus Groups (FGs). The initial composition of FGs, which are managed as described in Sec. B4.1, is shown. Each vertical column represents a FG, that will be led by a Cognizant Scientist (Cog). Data Analysis (DA) Focus Group tasks are integrated into the three source classes and are not described separately. Teams expected to play coordinating roles, with a Cog for each FG, are indicated by ⊗. Not shown are the various natural activities (secondary Objectives) which occur when results of specific Objectives are compared, checked, and used by the other teams.

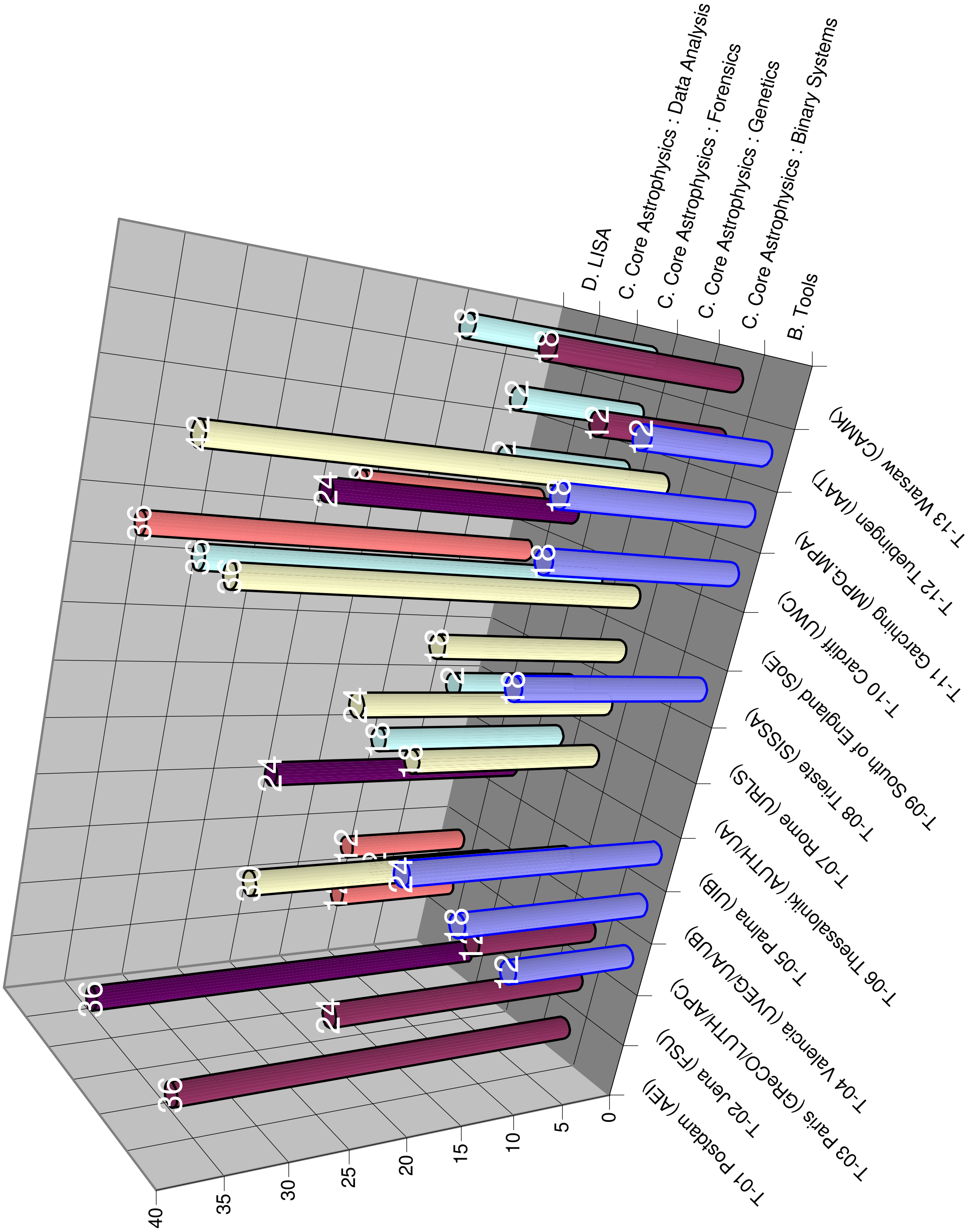
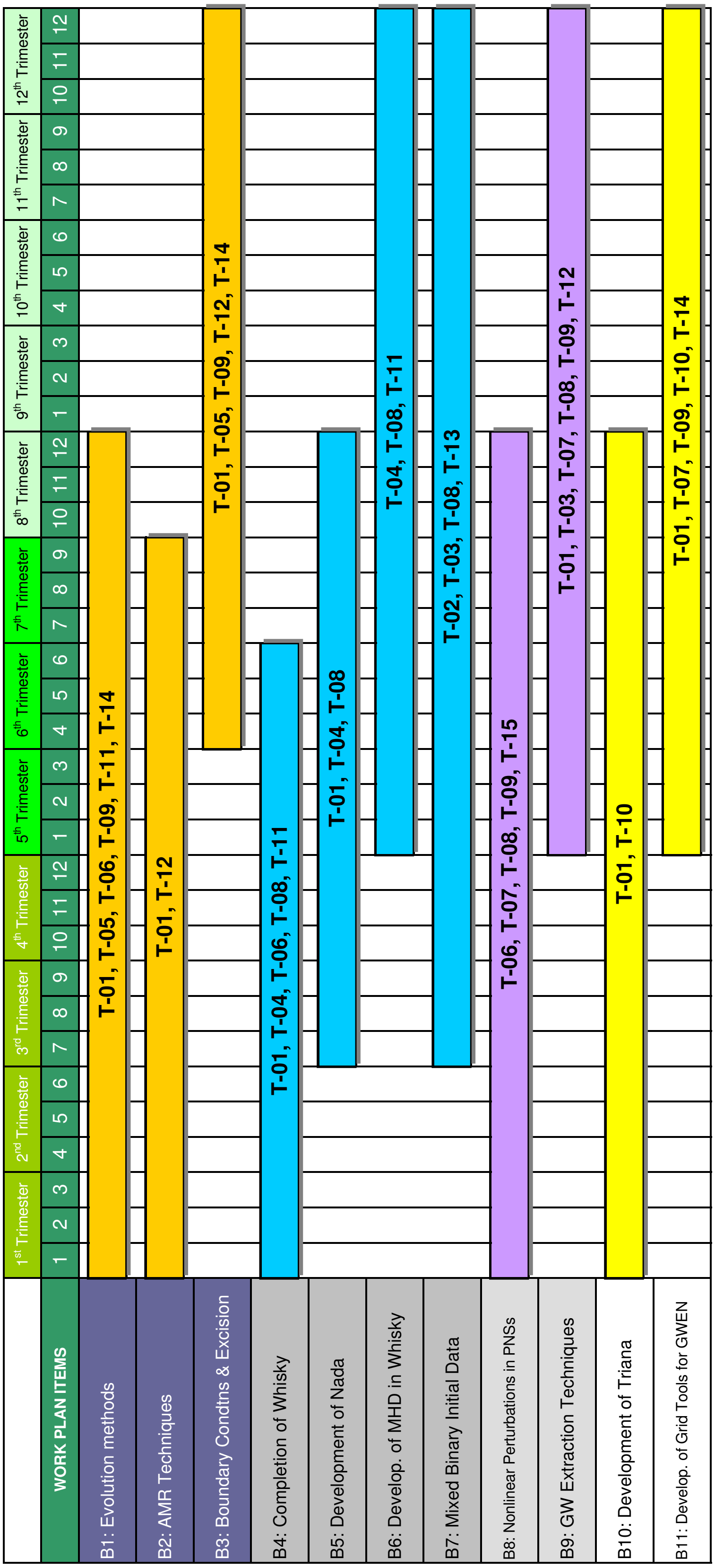


Figure B1.1: YR months distributed by Science Objectives and Teams.



T-01	Postdam (AEI)	T-09	South of England (SoE)
T-02	Jena (FSU)	T-10	Cardiff (UWC)
T-03	Paris (GReCO/LUTH/APC)	T-11	Garching (MPG.MPA)
T-04	Valencia (UVEG/UA/UB)	T-12	Tuebingen (IAAT)
T-05	Palma (UIB)	T-13	Warsaw (CAMK)
T-06	Thessaloniki (AUTH/UA)	T-14	Baton-Rouge (LSU)
T-07	Rome (URLS)	T-15	Penn State (PSU)
T-08	Trieste (SISSA)		

Figure B1.2: Gantt Diagram for the Objective Plan B: Tools

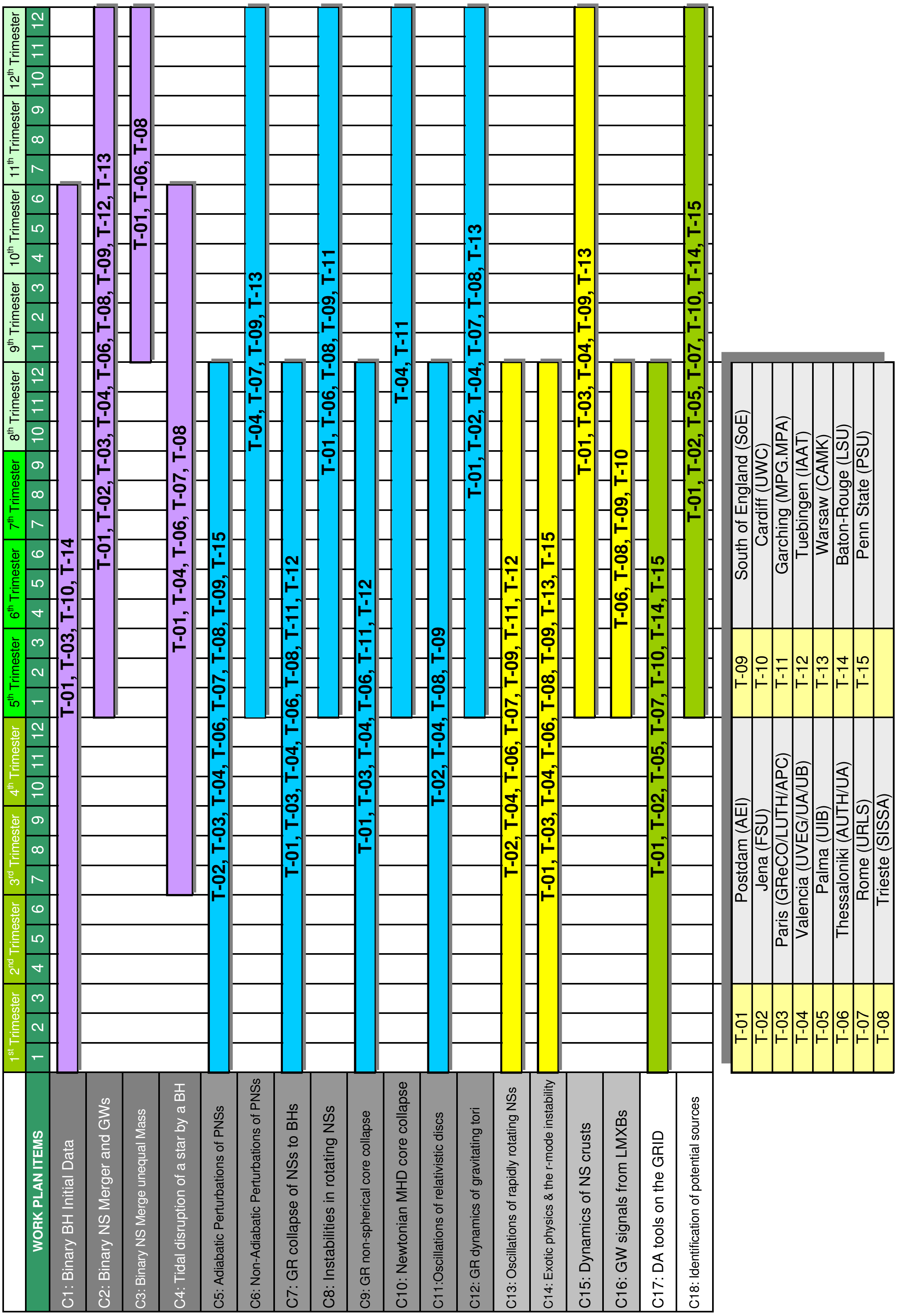
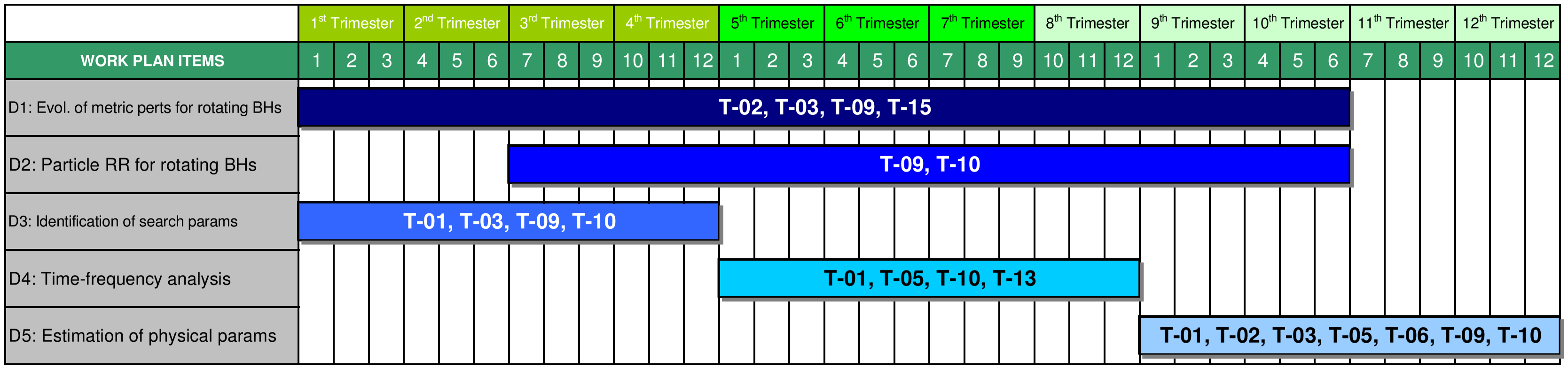


Figure B1.3: Gantt Diagram for the Objective Plan C: Core Astrophysics



T-01	Postdam (AEI)	T-09	South of England (SoE)
T-02	Jena (FSU)	T-10	Cardiff (UWC)
T-03	Paris (GReCO/LUTH/APC)	T-11	Garching (MPG.MPA)
T-04	Valencia (UVEG/UA/UB)	T-12	Tuebingen (IAAT)
T-05	Palma (UIB)	T-13	Warsaw (CAMK)
T-06	Thessaloniki (AUTH/UA)	T-14	Baton-Rouge (LSU)
T-07	Rome (URLS)	T-15	Penn State (PSU)
T-08	Trieste (SISSA)		

Figure B1.4: Gantt Diagram for the Objective Plan D: LISA

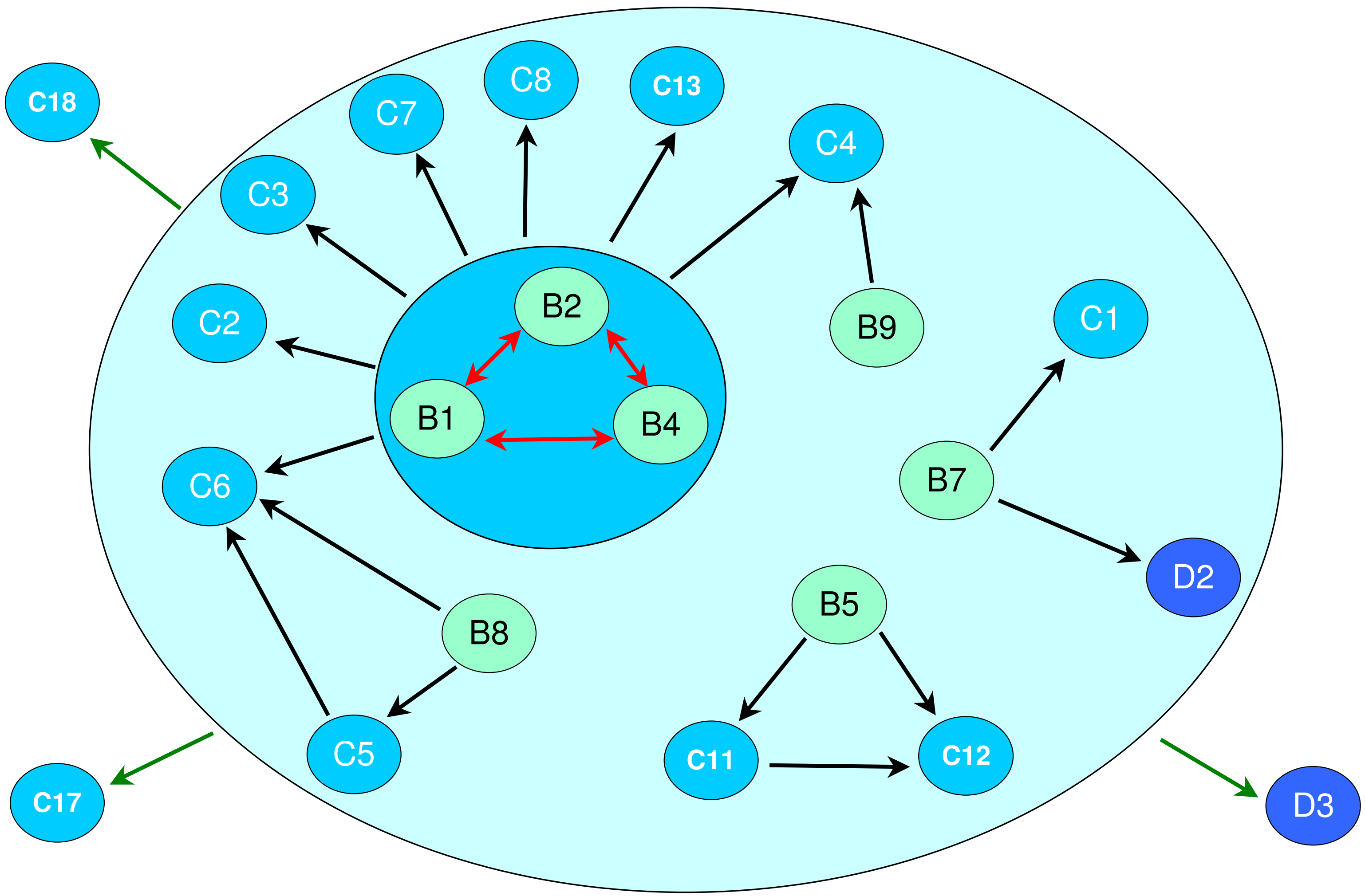


Figure B1.5: Schematic diagram showing the interconnections among the different Objectives. Note how the Objectives "Tools" (B1–B11) are developed to be used in the applications of Objectives "Core Astrophysics" (C1–C16) and "LISA" (D1–D5).

B2 TRAINING AND/OR TRANSFER OF KNOWLEDGE ACTIVITIES

B2.1 Content and Quality of the Training and Transfer of Knowledge Programme

The primary objective (Sec. B1.2) of GWEN is to train a large group of Young Researchers (YRs) in scientific and computational skills crucial to the emerging area of Gravitational Wave Astronomy (GWA). The needs of this research field are extremely diverse, requiring expertise that no single group, or even a single research community, can possess: astrophysics, general relativity, numerical analysis, data analysis and computer science, to name only the largest areas. They have been brought together in the GWEN collaboration to form a coherent training programme. Within the collaboration the projects will be organised vertically (by physics rather than method of approach), so that each YR will receive broad training touching all aspects of the project, from source study and modelling/simulation to data analysis.

Each node has the research infrastructure and critical mass of experienced researchers to provide adequate support, training, and mentoring in their given areas of expertise, and office/computing infrastructure needed to support basic research (See B3.1). To further enhance training and research integration of teams, "Regional Nodes" have been created in four locations (See B3.3). All of the original SOGW nodes participate in GWEN, and each has done an excellent job of training YRs in both the scientific and computational techniques, as well as in collaborative skills needed to work in this field. The training programme will draw upon expertise not only from GWEN, but also from cooperative projects described in Sec. B1.4.

The everyday interaction of the experienced researchers with PhD students and postdocs is the most important element of training. However, from our experience in SOGW, we cannot overemphasise the positive effect on the morale and productivity that being part of a large, enthusiastic, and friendly international network has on the YRs. All-hands meetings are important for building this feeling of community, but also to give YRs a first chance at testing their ideas and presentation skills. They facilitate the informal exchange of new ideas and questions, and the building of a consensus about where the project is going. Shortly after the initiation of the project, a meeting of all the groups will provide initial training on `Cactus` and Grid technologies, discussion of videoconferencing capabilities at each site, and refinement of the scientific goals and timelines described in the work plan. Afterwards, the entire GWEN collaboration will assemble every 8 months.

Smaller informal meetings, mainly of young researchers, are best suited to addressing technical issues that have been identified. Working groups also crystallise around web-based project pages. Conference calls are already an everyday tool of SOGW, and will be extended into videoconferencing. Nevertheless it is absolutely essential for the groups to have frequent personal contact with each other. GWEN will continue both short and long term exchange visits between groups for broad-based training and specific project development. Longer-term placements (several months) of YRs across the groups are perhaps the most effective way of transmitting expertise between groups and mixing their research styles and traditions.

The balance between Early Stage and Experienced Researchers is chosen to reflect both the scientific needs of the project and the available personnel at each site. In cases where Experienced Researchers are needed to carry out urgently needed advanced research and development, their training will be directed along the lines of preparing them to take on more responsibilities needed to work in this field as faculty members, such as helping to advise students, organising a sub-area of the research to be carried out across different sites, helping to prepare reports, writing auxiliary grant proposals, etc. Early Stage Researchers will be trained not only in the basic methods and techniques required to advance their subject area, but also in the kinds of "soft skills" needed for collaborative work in a geographically and culturally distributed environment.

GWEN will be driven significantly through input from YRs. Both Early Stage Researchers and Experienced Researchers will be asked to help organise meetings, invite senior members of the collaboration to give presentations, suggest tutorials on topics they feel are needed to fill in holes in their own background, etc. GWEN will not only give them such duties, it will also explicitly encourage them to give many of the presentations at the Network and other meetings, and also by first requiring questions and comments from the YRs, and only then allowing senior members to speak. As in SOGW YRs will write Newsletter contributions, help develop and maintain web pages, and so on. YR input was sought on both the format and a number of topics covered at Network meetings, and the last all-hands meeting of SOGW was organised completely by YRs. These steps were found to be very effective in creating a training programme, and will be continued and strengthened in GWEN.

Our training programme has already started, as one of the last acts of SOGW was an extensive international school for over 75 YRs held in Trieste in September, 2003, based on the results derived from SOGW.

T-01 Potsdam [AEI] will train one Early Stage Researcher (36 months) to develop data analysis (DA) algorithms and routines for analyzing signals expected from binary inspirals, and one Early Stage Researcher (36 months) to work with the [GReCO/LUTH/APC] group to develop various binary types from `Lorene` into `Cactus`, and to carry out evolutions, in conjunction with [LSU], [GReCO/LUTH/APC], [SISSA], and [AUTH/UA]. Both Early Stage Researchers will work with [UWC] and [GReCO/LUTH/APC] to learn how to use results in DA development. [AEI] will also hire an experienced research programmer (not as a YR) to provide (absolutely critical) support for GWEN in ongoing tool development in parallel computing, `Cactus`, `Lorene`, and Grid technologies, training, handling CVS, mailing lists, video conferencing, etc., for the entire GWEN collaboration. This person will spend significant time training YRs at other partner sites as well.

T-02 Jena [FSU] will train one Early Stage Researcher (36 months) in the construction of realistic initial data and radiation reaction expressions, into a form which would be useful for numerical applications for various GW sources, in close collaboration with [AEI] and [GReCO/LUTH/APC]. Further training of the Early Stage Researcher will be in the estimation of source parameters from GW observations.

T-03 Paris [GReCO/LUTH/APC] Regional Node will train one Experienced Researcher (24 months) in simulating binary-type sources of GW, mainly through the object-oriented library for NR (`Lorene`). With [AEI] he/she will bring Lorene into the `Cactus` framework, and help make it and other tools available to other teams ([AEI], [MPG.MPA] and [UVEG/UA/UB]) for the core-collapse study or for the use of spectral elliptic solvers ([IAAT]). This YR will benefit from the group's long experience in spectral methods applied to relativistic astrophysics. A second Experienced Researcher (24 months) will develop analytical tools based on Post-Newtonian calculations, to predict with high accuracy the GW waveforms emitted by binaries of spinning and non-spinning compact objects, in collaboration with [UWC], [FSU] and [AEI].

T-04 Valencia [UVEG/UA/UB] Regional Node will train two Experienced Researchers (24 months each) to work, respectively, in the physics of protoneutron stars and in numerical simulations of stellar core collapse using `Lorene` (i.e., spectral methods, for the geometry, and high-resolution shock-capturing schemes, for hydrodynamics). The first task will be carried out together with [URLS], [AUTH/UA] and [SoE], while the latter task will be done in collaboration with the [GReCO/LUTH/APC] and [MPG.MPA] nodes.

T-05 Palma [UIB] will train two Experienced Researchers, 24 months each. One to work with [AEI] and [LSU] on improved formulations of Einstein's equations for numerical relativity and development of appropriate gauge conditions for stable numerical evolutions. The second YR will be trained with [AEI], [URLS], [LSU], and [UWC] on GW data analysis techniques.

T-06 Thessaloniki [AUTH/UA] Regional Node will train one Experienced Researcher (36 months) to work on nonlinear and linear simulations of pulsations in rotating relativistic stars. With [UVEG/UA/UB] and [AEI], she/he will be trained in developing and applying new hydrodynamical methods and mesh-refinement techniques that will enable an efficient computation of pulsations modes in 3D simulations. In parallel, the perturbative framework for instabilities will be extended to rapidly rotating proto-neutron stars, in collaboration with [SoE], [URLS], and [UVEG/UA/UB].

T-07 Rome [URLS] will train one Experienced Researcher (36 months) to help coordinate the effort on Proto-Neutron Star evolution, by developing an appropriate theoretical framework in the perturbative approach, and by investigating the physical processes that affect the equation of state of matter at supranuclear density, in close collaboration mainly with [UVEG/UA/UB], [SoE] and [AUTH/UA]. This requires a multidisciplinary background from general relativity to nuclear physics and hydrodynamics, and therefore an Experienced Researcher.

T-08 Trieste [SISSA] will train one Experienced Researcher (36 months) to help coordinate applications of `Whisky`, in particular with [AEI], [AUTH/UA], [GReCO/LUTH/APC], and [UVEG/UA/UB]. This task will require considerable experience in the hydrodynamics and the physical intepretation of results. The YR will gain experience in advanced computational methods and in the use of supercomputer facilities.

T-09 South of England [SoE] Regional Node will train (i) one Experienced Researcher (36 months, Southampton) to coordinate LISA source modelling, with the main task to develop a numerical framework for attacking the GW radiation reaction problem for small bodies in general orbits around a massive Kerr BH, with [AEI], [PSU] and [FSU], and (ii) one Experienced Researcher (36 months, Portsmouth) in non-linear perturbation theory that will be applied to the numerical study of pulsations of PNS and of oscillation modes and mode-coupling of rotating NS and BH, in collaboration with [UVEG/UA/UB], [URLS] and [AUTH/UA]. In addition, [SoE] will train an Early Stage Researcher (36 months, Southampton) in the area of GWs from mature NS. Issues concerning secular instabilities in rotating NSs will be studied in collaboration with [AUTH/UA], [SISSA], [URLS], [GReCO/LUTH/APC] and [PSU]. The involved microphysics requires collaboration with [UVEG/UA/UB] and [CAMK]. GW from isolated NS and accreting NS in LMXB will be investigated together with [AEI], [AUTH/UA] and [SISSA], while the relevant DA issues would be approached in discussions with [UWC]. The use of invariant exact methods for wave extraction from numerical codes will be investigated with [AEI].

T-10 Cardiff [UWC] will train one Early Stage Researcher (36 months) in data analysis for small black holes falling into a rapidly rotating supermassive black hole. He/she will interact with [AEI] and [SoE] to understand the nature of the waveform. Cardiff will also train an Experienced Researcher (24 months) to identify and prioritise sources that must be searched for in GEO and LIGO data, coordinate the development of search algorithms, and carry out some of the DA tasks, most notably binary black hole searches and transients emitted by neutron stars. This task will involve collaboration among *all* the nodes in GWEN with a direct significant contribution from other Cardiff personnel.

T-11 Garching [MPG.MPA] will train 2 Early Stage Researchers (36 months) in investigations of rotational supernova core collapse. The training will concentrate on the microphysics aspects of core collapse, but will also involve multidimensional GR hydrodynamics, the final stages of stellar evolution, neutron star physics, and the extraction of gravitational wave signals from hydrodynamic simulations. The training will be provided by one of the world-leading research groups in supernova core collapse in close collaboration with the teams at [UVEG/UA/UB], [SISSA], [FSU], [GReCO/LUTH/APC] and [AEI].

T-12 Tübingen [IAAT] will train one Early Stage Researcher (36 months) in the field of relativistic astrophysics, applying and extending GR hydro codes (eq. `Whisky`). The group has substantial accumulated experience in the field (with emphasis on neutron star physics, black hole evolution and relativistic hydro), and is thus ideally suited for the training of a Early Stage Researcher.

T-13 Warsaw [CAMK] will train one Early Stage Researcher (36 months) in numerical simulations of the hydrodynamic flows associated with the NS-NS and BH-NS binary merger. The YR will learn techniques of relativistic astrophysics and develop computational skills, followed by a stage of extensive numerical computation and the studies of specific realistic cases, including detailed treatment of the microphysics. The Early Stage Researcher will be supervised in close collaboration with colleagues in [SISSA]and [SoE].

T-14 Baton Rouge [LSU] and T-15 Penn State [PSU] request only travel support to be able to attend GWEN meetings. They have Access Grid videoconferencing technology to participate in training courses and lectures conducted by the GWEN collaboration. [LSU] will train 2 students and at least 1 postdoc from independent sources, to work with [SoE], [AEI] and [UIB] on improved formulations of Einstein's equations for numerical relativity, with [AEI], [UIB], and [UWC] on DA techniques, and with [SoE] and [AUTH/UA] on NS mode calculations. [LSU] will also provide substantial contact with the actual data being taken with some of the present bar and interferometric detectors, and with the experimental physicists in charge of theinstruments. These contacts will help the YRs deal with data analysis issues arising from the measured noise, and will guarantee that their efforts result in practical applications of their work to push the frontier in GWA. [PSU] will develop a perturbative time-evolution evolution approach to the GW radiation reaction problem with [SoE], which is of key importance for the LISA effort within GWEN. Members of the PSU team will continue key collaborations with the nodes at [SISSA], [GReCO/LUTH/APC], [FSU], [SoE], and [AUTH/UA] which were initiated during the SOGW project. On the numerical relativity side, PSU will assist the members of GWEN in the development of stable codes for solving the nonlinear Einstein equations, working with [LSU], [SoE], [UIB] and [AEI]. Finally, interaction with the members of the Center for GW Physics at [PSU], and involvement with their visitor and conference programme, will raise the profile of the research carried out within, and the YRs of, GWEN in the USA and beyond.

B2.2 Impact of the Training and/or Transfer of Knowledge Programme

As described throughout the proposal, Gravitational Wave Astronomy (GWA) is an emerging field of research in which Europe can play a special role. Firstly, as detailed in Sec. B5, Europe is investing heavily in large-scale GW-detection facilities (e.g., in GEO600, Virgo, LISA, and in resonant bar detectors like Explorer, Nautilus and Auriga), but with relatively minor attention given to the development of the new scientific community needed to support them. Secondly, the experimental and theoretical aspects of GWA are of a new type that demand and drive novel computing, networking, and Grid scenarios. The GWEN project is in perfect resonance with the EU's heavy investment in Grid infrastructure and middleware initiatives. These investments in Grids need to be targeted to and used by specific application areas; GWA offers unique opportunities in this respect.

With the funds received, GWEN will train almost 20 researchers in the multidisciplinary techniques needed for investigating GW physics. As well as the computer science mentioned above, these include: numerical simulation techniques using finite difference and spectral methods, perturbative and approximation techniques (used in conjunction with the simulations) and pattern recognition techniques necessary for detecting weak signals in a noisy background. Also, as has already happened with the SOGW project, GWEN will trigger the training of many other researchers in related areas, both through cooperating with relativity and astrophysics groups and through close associations with other major projects in Grid computing (see support letters in Appendix B10.2). These highly skilled researchers will make use of the latest technologies coming out of other EU programmes, and they will enable the science of GWA to reach the highest possible level in Europe. Also, by helping to steer EU-Grid projects, GWEN will develop its training in Grid technologies to a higher level. The benefits will not only be scientific. Those YRs who subsequently choose to follow non-academic careers will have opportunities in many areas of industry which need people skilled in collaborative, multidisciplinary approaches to problem-solving and in the use of the emerging Grid technology.

The proposed mixture of Early Stage Researchers and Experienced Researchers will allow GWEN to train a maximal number of PhDs *and* experienced postdocs in these new areas. Given budget limitations Experienced Researchers will typically be appointed for two years, with a possible extension to a third year through local funding sources, while Early Stage Researchers will be appointed for the 3 years needed for their PhD studies. Early Stage Researchers will generally be placed in groups with the largest number of existing postdocs funded from other sources (e.g., German sites will train only Early Stage Researchers). Because data from detectors is already being taken, a number of Experienced Researchers must be trained immediately in the advanced theoretical and computational techniques needed for analysis and interpretation of this data.

GWEN will use many techniques to ensure transfer of knowledge to YRs. Strategically, by collecting groups with many different areas of expertise, and by choosing scientific problems that require a coordinated and collaborative approach to the solution, there will be a natural focus to bring groups together. Furthermore, by associating GWEN tightly with external Grid projects, new technology elements will be integrated into the training, from which YRs and senior researchers alike will benefit. Practically, GWEN will build on techniques that were found to be very effective in the SOGW project, and introduce new ones based on emerging conferencing and Grid technologies that were not available previously.

In GWEN we will work very hard to ensure effective and innovative training of YRs through:

GWEN Meetings. We will organise "All-Hands Meetings" every 8 months, where members from all nodes will be expected to attend. These meetings will contain several pedagogical review talks, usually chosen by YRs. Research presentations will be made by the Cognizant Scientists in charge of various Objective-driven Focus Groups (see Secs. B4.1,B1.2,B1.5). YRs will be especially encouraged to ask questions; in SOGW, senior members were not even allowed to ask questions until YRs had a chance to go first! All YRs will be given chances to make presentations, with constructive feedback from the senior researchers. GWEN will invite members of its associated projects (e.g., GridLab, GriKSL, SFB, DEISA, GEO600, etc) to give presentations as well, and to interact with GWEN project members. Likewise, YRs and other GWEN members will attend meetings of the other projects for cross-disciplinary exposure.

Topic focussed meetings, secondments, and visits. As in SOGW, GWEN ensures that adequate attention is given to small, focused meetings where work is planned, discussed, and done. Meetings of half a dozen researchers, lasting a under a week, will be held where training and discussions take place, and papers or computer code are written. Following the SOGWcustom, extended visits of YRs to partner nodes for weeks or months will be organised. YRs and senior researchers will also visit partner nodes to give talks and collaborate.

Training Schools. Where appropriate, YRs will be sent to summer training programmes in topics of interest (e.g., NATO, [SISSA], Bad Honnef, etc). GWEN will itself hold an advanced training school, based on the training and research programme, at the end of the project, just as SOGW did in September 2003. That school on sources of GWs was organised locally by [SISSA] and [URLS], but combined lecturers from all the nodes of SOGW. Financial support to this school came from various organisations, including the US NSF. GWEN will also partner with workshops organised by other groups for additional training (e.g., the Bulgarian GAS workshop

Telephone and Video conferencing. Telephone conferencing will be carried out regularly by Cognizant Scientists to keep their Focus Groups organised. But GWEN will also carry out regular video conferencing, using Access Grid (AG) technologies. Some GWEN partners are already equipped with advanced AG compatible conferencing, but a request is being made in the proposal to equip *all* sites with PC-based technology so that GWEN-wide conferencing is possible. Organisational meetings will be held this way, as will pedagogical lectures and courses, organised by the Cognizant Scientist for Training. Intercontinental training sessions within GWEN will be organised by the [PSU] node, which already has experience organising such meetings in the US. Finally, numerous training courses in Grid and computing technologies are carried out over the AG system, many originating at supercomputing centres in the USA. All GWEN members will be able to take part.

Development of web pages, use of CVS, mailing lists, FAQ. SOGW was relatively advanced in its use of electronic technologies for training and organisation; GWEN will extend this. A detailed web site will be prepared to organise all aspects of the project including archiving of instructional materials and copies of presentations and storing mailing lists for the different working groups. CVS will be used extensively for collaborative paper writing and code development.

Training in advanced computing technologies. The research programmer hired to support this project will not only maintain and develop computational technologies for GWEN, but he/she will also spend time at various GWEN nodes to better train YRs and others in the use of Grid technologies, CVS, and so on, *on site*. Through these visits, he/she will collaborate directly in the development of parallel I/O, adaptive meshes, etc, tailored to the needs of the research being carried out.

GWEN will have profound impact on GWA at all levels: local, regional, national, and international. GWA is a new research area, for which large experimental facilities are being built worldwide, but which does not yet have a sufficiently large, experienced community trained to carry out the theoretical and data analysis needed. To address this issue, a joint NSF-NASA report recently recommended increasing funding for training YRs in this areas by a factor of 5 in the US. Within Europe, GWEN addresses this by fostering development of regional collaborations, supported by national government agencies, by creating strong collaborations among many nodes within the EU, and by integrating interested groups in eastern Europe.

Outside Europe, GWEN addresses this problem at the highest international level by developing unusually strong partnerships with leading US groups, the LIGO project, and its scientific community ([LSU] Coordinator Gabriela Gonzales is a LIGO project leader). GWEN NC Seidel and others have taken positions at [LSU] (Seidel and Gabrielle Allen maintain joint appointments at [AEI]), ensuring very tight integration of the US groups. Computational training for GWEN will be coordinated by Allen, while Lehner [LSU] who heads a large multi-institutional NSF ITR project, will be US activities coordinator for GWEN. Joan Centrella of NASA will serve on the GWEN International Advisory Board.

There are many ways in which this training programme will assist YRs in developing their future careers. Specific steps to be taken by GWEN are discussed above and in Secs. B3.1, B4.2, B4.3, B5. GWEN also goes beyond these specific training steps by providing the YRs with experience in a cooperative international environment, and exposure in GW and HPC communities. The collaborations and organisation of GWEN will introduce YRs to a wide variety of disciplines and working styles so that they can choose among multiple career directions, either immediately after training or later. Through GWEN's highly interactive nature, YRs will gain unusually strong international exposure (e.g. to collaboraters in the USA, Mexico and Japan). Finally, we stress that an important component of the training will be to prepare YRs in the non-scientific skills which they will need in the future: presentation and discussion of their results to a critical audience, proposal preparation, use of computational resources, organisation. In fact, the SOGW YRs were involved in the preparation of this proposal, giving them an appreciation of what awaits them if they choose to stay in academic careers!

B2.3 Planned Recruitment of Early-stage and Experienced Researchers

The total numbers of Early Stage Researchers and Experienced Researchers to be trained by the network are listed in Table B2.1. A total of 324 person months (48%) will be devoted to Early Stage Researchers and 348 person months (52%) to Experienced Researchers.

We have already identified a number of candidates for many of the proposed positions. In the case of Experienced Researchers many of these are candidates involved, either as Early Stage Researchers or locally funded predocs, in the current EU Research Training Network “Sources of Gravitational Waves” (SOGW).

For vacancies for which we do not already have candidates identified, we will advertise through widely used electronic newsletters (MacCallum’s GR list, and *Matters of Gravity*), electronic bulletin boards, and contacts with colleagues in other institutions. The Cactus group operates mailing lists for interaction among developers and physicists, on which positions will also be advertised. These Cactus lists have often put us in touch with YRs whose existence we would not otherwise have known. Possibilities for YRs in GWEN were advertised at the Advanced School for young researchers, organised by SOGW, in Trieste in September 2003, which was attended by many students from Europe, the USA, and Asia. We note that some GWEN partners have previously recruited excellent YRs from Eastern Europe, a practice that will be encouraged in GWEN.

Beyond the new Polish GWEN node [CAMK] we note the involvement of unfunded partners in Romania and Bulgaria, which GWEN will assist with training and research. The Bulgarian GAS training workshop was attended by several SOGW members, and GWEN will partner with GAS 2004 for training YRs in eastern Europe. Half a dozen members of the Bulgarian team attended the recent SOGW School in Trieste, and 4 members of the Romanian group are currently visiting [AEI] through its visitor program. GWEN Coordinator Seidel is a Co-PI on a NATO proposal for a Bulgarian School in 2004.

So far the collaboration has had no shortage of interested students and postdoctoral applicants. In fact, some nodes in the group receive many more high quality graduate student applications than they can accept in a given year. The presence of a European Network involved in common projects will allow us to encourage such applicants to join projects with the smaller institutions in the network. This transfer of applicants has already proven a successful means of distributing students and researchers in SOGW.

Candidates for YR positions will be selected on the basis of their educational background, their interests, and expertise and availability at individual GWEN nodes. Bright students and postdocs without computational experience will be given training in the advanced computational methods used within GWEN. Typical appointments for Early Stage Researchers will be for 3 years, envisaging that each appointment will be for the duration of PhD studies, while typical appointments for Experienced Researchers will be for 2 years. This strategy allows us, given limited resources, to train a larger number of YRs while maintaining a good balance between Early Stage Researchers and Experienced Researchers.

It is important to understand that some nodes are effectively unable to recruit predocs from other EU countries for training at their sites due to either language requirements (eg., a proven knowledge of Greek is required to qualify for predoc training at [AUTH/UA]), or the required length of studies (5 years in some cases). By contrast, other partners, especially the German sites, have significant existing support for postdocs (who can assist in training predocs). (The German sites have, for these reasons, requested to train only predocs).

GWENs area of research, falling roughly in the areas of physics, astronomy, and computation, has been traditionally populated largely by men. We have striven to address this inequality at every opportunity within SOGW and in comparison, with GWEN we made important steps forward in creating both role models and opportunities for female scientists. For example:
(i) While SOGW had no women on its international advisory board, with GWEN we have already confirmed Joan Centrella as a member. In comparison, for example, the Fachbeirat (Advisory Board) of the AEI has no women among its dozen members.
(ii) SOGW had one woman as Local Coordinator, in GWEN we now have four (LSU, Palma, Paris, and Rome).
(iii) SOGW had one woman in charge of workpackages, in GWEN we have several.

In addition, encouragement for applications from female and minority candidates for positions will be made clear in the text of any advertisements, and all nodes will ensure that selection procedures are carried out appropriately. We hope that the presence of more women in senior positions at various nodes in the network will provide positive examples and encourage female YRs that an attractive career path exists in the field of gravitational wave physics.

Table B2.1: GWEN personnel effort: recruitment and joint-activities

Network Team	Early-stage and experienced researchers to be financed by the contract: Early-stage researchers to be financed by the contract (person-months) (a)	Early-stage and experienced researchers to be financed by the contract: Experienced researchers to be financed by the contract (person-months) (b)	Early-stage and experienced researchers to be financed by the contract: Total (a+b) (c)	Other professional research effort on the network project: Researchers likely to contribute (number of individuals) (d)	Other professional research effort on the network project: Researchers likely to contribute (person-months) (e)
T-01 Potsdam [AEI]	72		72	18	299
T-02 Jena [FSU]	36		36	9	90
T-03 Paris [GReCO/LUTH/APC]		48	48	16	248
T-04 Valencia [UVEG/UA/UB]		48	48	12	265
T-05 Palma [UIB]		48	48	8	137
T-06 Thessaloniki [AUTH/UA]		36	36	10	258
T-07 Rome [URLS]		36	36	6	126
T-08 Trieste [SISSA]		36	36	7	210
T-09 South of England [SoE]	36	72	108	16	352
T-10 Cardiff [UWC]	36	24	60	12	212
T-11 Garching [MPG.MPA]	72		72	8	159
T-12 Tübingen [IAAT]	36		36	8	90
T-13 Warsaw [CAMK]	36		36	10	202
T-14 Baton Rouge [LSU]				8	34
T-15 Penn State [PSU]				8	29
Totals	324	348	672	154	2579

B3 QUALITY/CAPACITY OF THE NETWORK PARTNERSHIP

B3.1 Collective Expertise of the Network Teams

The following pages of this section describe each research team in the GWEN collaboration, outlining their complementary and interlocking areas of expertise needed to carry out the proposed training and scientific programmes. The GWEN collaboration partners have extensive experience of working successfully together: 10 of the institutes participated in a very successful current EU Research Training Network “Sources of Gravitational Waves” (SOGW); four additional EU institutes have joined this group for the GWEN proposal, having already attending meetings of SOGW, and 2 US institutes, who have long-standing collaborations with various members of the GWEN collaboration, have also joined. In order to further enhance the integration of the teams, four sites have formed *Regional Nodes* as discussed elsewhere, and are listed as such below. Two of the GWEN participants, [AEI] and [UWC], are primary partners in the EU-funded GridLab project, developing Grid technologies for both numerical relativity and GW communities, which will be utilised in GWEN.

T-01 Potsdam [AEI], Germany
Astrophysical Relativity, Max-Planck-Institut für Gravitationsphysik (Albert-Einstein-Institut)

Founded in 1995, the AEI has three distinct but overlapping theoretical divisions (mathematical, astrophysical, and quantum relativity) and an experimental division (related to GWA). In pursuing its research it supports large-scale computer calculations, both in-house and in collaboration with other sites in the EU and USA. It participates in a number of international GW and Grid projects, such as GEO600, LISA, GridLab, GriPhyN.

The AEI numerical relativity (NR) group has over a dozen researchers, experienced in 3D NR, colliding BHs, GWs, horizons, perturbation theory of NS/BHs, hyperbolic systems, gauges, and GR hydrodynamics. It is a leader in computational science (CS) and parallel computing. It developed the `Cactus` Code and Computational Toolkit, a centrepiece of this proposal, is a leading partner in the GridLab Project, which will support GWEN with Grid tools, and leads the GriKSL project to develop Grid visualisation techniques. Its expertise in the areas of NR, and in collaborative CS and Grid environments, essential for the projects in Sec. B1.5, compliments expertise found in other GWEN partners. The NR group has close connections with GW detector projects. Schutz leads the data analysis (DA) team for the GEO600 detector, that could actually make the first detections of GWs during GWEN. At [AEI] Cutler and Papa lead development of GW data analysis (DA) algorithms and the study of possible GW sources, and are involved in GriPhyN.

[AEI] has recently acquired a 256 processor pentium cluster ("Peyote") for simulations, and a 360 processor athlon cluster ("Merlin") for GEO600 DA. Other relevant infrastructure includes a new data visualisation system and two Access Grid nodes for video conferencing. [AEI] has computer allocations at RZG, NCSA, NERSC, PSC, SDSC, LRZ and elsewhere for simulations proposed in GWEN. Many staff at other GWEN nodes were once associated with the AEI groups. Synergistic collaborations between the [AEI] and other nodes, strengthened by the SOGW, are especially strong in BH evolutions ([GReCO/LUTH/APC], [UIB]), GR hydrodynamics ([SISSA], [UVEG/UA/UB], [AUTH/UA], [MPG.MPA], [SoE]), on post-Newtonian formulations ([GReCO/LUTH/APC], [FSU]) and with [UWC] and [UIB] on DA.

The [AEI] group is very experienced in the successful training of YRs. Seidel's group has produced over a dozen Diplom and PhD theses in physics and CS, as has Schutz's. They have supervised about 2 dozen postdocs, many going to faculty positions. In GWEN, E. Mueller will assist YRs in career issues, and give seminars on EU and other programmes. Researchers from the SFB project (Sec. B1.4) will help train YRs. Seidel's group have also delivered numerous tutorials on `Cactus`, Grid Computing, and general HPC issues. It developed, and extensively documented `Cactus`, the Portal, and Grid Application Toolkit GWEN will use. [AEI] is a founding member of the worldwide Apples With Apples project to develop and premote standard and open tests for NR codes, and its involvement in computing would provides unique training opportunities for YRs, as well as promotional/employment possibilities. SOGW BH collision simulations led to a movie produced for the Discovery channel, which was also used by US NSF and DOE heads to promote GWA!

GWEN member Schutz is managing director of *Living Reviews in Relativity*, which contains excellent, current, pedagogical reviews helpful for YRs (many written and updated by GWEN members). Schutz is also author of two widely used textbooks on GR and Differential Geometry, and has just published new book at relativity for high school students.

PERSONNEL

Edward Seidel (Network Coordinator, Prof., *NR and CS*, 25%), Bernard F. Schutz (AEI Director, Prof., *GWs, DA*, 15%) and Curt Cutler (Prof., *DA*, *NS structure*, 15%), Gabrielle Allen (*NR*, `Cactus`, *Grid*), Sascha Husa (*NR*, *mathematical relativity*), Maria Alessandra Papa (*DA*), Denis Pollney (*NR*), (Research Scientists, 50%), Elke Mueller (Scientific coordinator, *career programmes*, 5%); Thomas Radke, Steve White (Research Programmers, `Cactus`, *Grid*, *Viz*, 50%); Ian Hawke, Christiane Lechner, Erik Schnetter, Jonathan Thornburg (Postdocs, 50%); Mihaila Chirvasa, Frank Herrman, Frank Löffler, Christian Ott, Bernd Reimann, Anil Zenginoglu (Graduate students, *NR*, `Cactus`, *relativistic hydrodynamics*, 50%)

PUBLICATIONS

3D Grazing Collision of Two Black Holes., M. Alcubierre, W. Benger, B. Brügmann, G. Lanfermann, L. Nerger, E. Seidel, and R. Takahashi. *Phys. Rev. Lett.*, 87:271103, 2001; gr-qc/0012079.
The Cactus framework and toolkit: Design and applications, T. Goodale, G. Allen, G. Lanfermann, J. Massó, T. Radke, E. Seidel, and J. Shalf, In *Vector and Parallel Processing - VECPAR'2002, 5th International Conference, Lecture Notes in Computer Science*, Berlin. Springer.

T-02 Jena [FSU], Germany
Gravitational Theory Group, Theoretisch-Physikalisches Institut, Friedrich-Schiller-Universität

The Gravitational Theory Group at the Institute of Theoretical Physics of the University of Jena is the largest group in General Relativity at a University in Germany. The research of the group is related to celestial objects and astrophysical processes. The group has outstanding records in *(i)* approximate solutions of the general-relativistic problem of motion of compact binary systems up to the third (including three-and-a-half) post-Newtonian order; *(ii)* the gravitational wave emission from supernovae, compact binary systems, and rotating oscillating discs of dust; *(iii)* exact and almost exact-analytical general-relativistic solutions of rotating bodies; and in *(iv)* light-propagation effects in gravitational fields.

Over the past ten years, the FSU team interacted strongly with various teams of the current EU Research Training Network (SOGW) namely ([GReCO/LUTH/APC], [AUTH/UA], [AEI], [UVEG/UA/UB], [SoE]) as well as the new nodes in GWEN ([MPG.MPA], [IAAT], [CAMK]). Quite recently, in collaboration with T. Damour and P. Jaranowski from, respectively, the [GReCO/LUTH/APC] and [CAMK] sites, Schäfer succeeded in the unique derivation of the dynamics of binary black holes at the third post-Newtonian order of approximation. For implementation in numerical codes, particularly for [SoE], the Jena node (G. Faye, a YR in SOGW, and Schäfer) optimised the third-and-half post-Newtonian gravitational radiation-reaction force. Recently, on the analytical side, the Jena node made essential contributions to the generalisation of the conformal flatness condition to more realistic conditions (CFC+ and beyond). This is specifically important for the numerical investigations at the [AEI], [UVEG/UA/UB], [MPG.MPA], and [GReCO/LUTH/APC] nodes.

For fast rotating bodies, Neugebauer developed a minimal surface formalism to efficiently get its general relativistic motion by numerical means (implemented by [IAAT]). Meinel and his collaborators developed a highly accurate spectral method providing a precise treatment of relativistic Dyson rings as well as of the bifurcation properties of highly flattened spheroids. The exact analytical solution of the general relativistic rigidly rotating disk of dust has been derived by Neugebauer and Meinel, and, at the first post-Newtonian order, the corresponding oscillations and gravitational wave emitting solutions has been obtained by Schäfer and W. Kley, now at [IAAT]. Finally, Schäfer's collaboration with K. Kokkotas from the [AUTH/UA] node resulted in an approximate but self-consistent treatment of the gravitational radiation damping and inspiraling of tidally interacting NS binaries. He also contributed the radiation reaction part to numerical simulations of highly evolved NS binaries undertaken at the [MPG.MPA] node (M. Ruffert, H.-T. Janka).

The infrastructure of the [FSU] node, including computational facilities, provides for efficient collaborations with the other sites. The broad experience of the [FSU] node with analytical tools will strongly support the numerical activities of the other sites of the planned Network. For the solution of hyperbolic and elliptic problems in three and more dimensions, G. Zumbusch has developed numerical schemes, based on sparse grids and finite differences, adaptive grid refinement techniques, parallel implementations thereof and parallel loadbalancing methods. These have been run on large self made Linux clusters and in grid computing environments. The training infrastructure at [FSU] is enhanced by the German Research Project (SFB) on GWA of which it part along with [AEI], [IAAT] and [MPG.MPA].

PERSONNEL

Gerhard Schäfer (Local Coordinator, Prof., *relativistic gravitational physics, analytical techniques*, 40%)
Gernot Neugebauer (Prof., *theoretical gravitational physics, mathematical methods*, 15%)
Reinhard Meinel (Prof., *theoretical astrophysics, mathematical methods*, 15%)
Gerhard Zumbusch (Prof. , *numerical mathematics*, 15%)
Andreas Kleinwächter (Research Scientist, *mathematical gravitational physics*, 15%)
David Petroff (Postdoc, *theoretical gravitational physics, analytical techniques*, 50%)
Achamveedu Gopakumar (Postdoc, *analytical gravitational physics, approximate solutions*, 25%)
Christian Königsdörffer (Graduate student, *analytical mechanics, approximate solutions*, 25%)
Dörte Hansen (Graduate student; *relativistic hydrodynamics, analytical and numerical solutions*, 50%)

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Dimensional regularization of the gravitational interaction of point masses, T. Damour, P. Jaranowski, and G. Schäfer. *Phys. Lett. B*, 513:147, (2001); gr-qc/0105038
Relativistic Dyson rings and their black hole limit, M. Ansorg, A. Kleinwächter, and R. Meinel, *Astrophys. J. Lett.* 582:87, (2003); gr-qc/0211040

T-03 Paris [GReCO/LUTH/APC], France (Regional Node)
Laboratoire de l'Univers et de ses Théories, Observatoire de Paris-Meudon; and
Gravitation Relativiste et Cosmologie, Institut d'Astrophysique de Paris

This Regional Node combines two distinct groups in Paris, LUTH and GReCO respectively, described below.

LUTH (formerly DARC) at the Observatoire de Paris is a leading department in relativistic gravitational physics and astrophysics, and has performed outstanding work in the field of relativistic dynamics of isolated astrophysical systems. The recent activities of the group have focused on *(i)* the preparation of relativistic initial data for binary NS and binary BH mergers, *(ii)* the numerical study of various instabilities in isolated rotating neutron stars (viscosity-driven instability, CFS instability), *(iii)* the numerical study of gravitational collapse in tensor-scalar theories, *(iv)* the computation of rotating NSs and strange quark stars, *(v)* the relativistic description of the interaction between the superfluid interior and the solid crust of neutron stars, and *(vi)* relativistic magnetohydrodynamics. The LUTH team has developed spectral methods for relativity and hydrodynamics, which have been implemented by means of the C++ library `Lorene`. LUTH studies of the NS and strange quark star physics are performed via a long term collaboration with [CAMK]. Other collaborations are ongoing with the South of England [SoE] node on superfluid neutron star models; with [UVEG/UA/UB] and [MPG.MPA] node on the construction of a multi-technique numerical code (spectral methods / high resolution shock capturing) for accurate computations of 3D gravitational collapse; with the [AEI] and [SISSA] for which LUTH team is providing the initial data for the binary NS and binary BH coalescence. More recently, a collaboration has started with [IAAT] on the numerical solution of the conformal field equations. LUTH has access to the training (Centre International d'Ateliers Scientifiques) and computing (Service Informatique de l'Observatoire) facilities of the Observatoire de Meudon. As a group, it has five SGI workstations (four Origin 200 and a R12000 Octane) and three Intel-P4 servers with 6 Gb of memory.

GReCO (formerly DARC) at the Institut d'Astrophysique de Paris is a leading group in relativistic gravitational physics and primordial cosmology. The main activities of the general-relativity team of GReCO concerned with: *(i)* two-body equations of motion within the PN formalism for binaries made of compact objects, *(ii)* last stages of inspiraling black holes through analytical PN techniques, *(iii)* GW templates for precessing binaries made of black holes and/or neutron stars, *(iv)* scalar-tensor theories, *(v)* relativistic superfluid neutron stars, *(vi)* GWs from primordial universe, *(vii)* quantum noise in advanced configurations of GW detectors. The general-relativity team of GReCO has ongoing collaborations with VIRGO and American LIGO, and it plans to develop solid collaborations with the Cardiff [UWC], Potsdam [AEI] and Jena [FSU] nodes, on data-analysis for inspiraling binaries and PN calculations. The Institut d'Astrophysique de Paris is a member of the European Association for Research in Astronomy and a Marie Curie training site. Furthermore, part of GReCO members are involved in the new group "Astroparticle and Cosmology" (APC) that will form in the new site of Paris 7 University starting from 2005.

PERSONNEL

Alessandra Buonanno (Local Coordinator, Research Scientist, *compact binaries, analytical techniques, advanced GW detectors*, 75%), Luc Blanchet (Senior Research Scientist, *general relativity, analytical techniques*, 75%), Silvano Bonazzola (Senior Research Scientist, *hydrodynamic instabilities, numerical techniques*, 50%), Brandon Carter (Senior Research Scientist, *general relativity, neutron stars*, 30%), Thibault Damour (Prof., *general relativity, analytical techniques*, 10%), Joaquin Diaz-Alonso (Research Scientist, *nuclear matter*, 10%), Gilles Esposito-Farèse (Research Scientist, *general relativity, analytical techniques*, 10%), Eric Gourgoulhon (Research Scientist, *numerical techniques, NSs*, 75%), David Langlois (Research Scientist, *perturbation theory, neutron stars*, 10%), Jérôme Novak (Research Scientist, *numerical techniques, gravitational collapse*, 75%), Christophe Sauty (Assoc. Prof., *magneto-hydrodynamics*, 10%), Jose-Luis Jaramillo (post-doc, *black hole physics, 75%*), Nicolas Chamel (Graduate student, *neutron stars*, 50%), François Limousin (Graduate student, *numerical techniques, general relativity*, 75%), Zakaria Meliani (Graduate student, *magneto-hydrodynamics*, 30%), Samaya Nissanke (Graduate student, *general relativity, analytical techniques*, 30%).

PUBLICATIONS

Binary black holes in circular orbits. II. Numerical methods and first results, P. Grandclément, E. Gourgoulhon & S. Bonazzola, *Phys. Rev. D* **65**, 044021 (2002); gr-qc/0106016

Gravitational wave inspiral of compact binary systems to 7/2 Post-Newtonian order, L. Blanchet, G. Faye, B.R. Iyer and B. Joguet *Phys. Rev. D* **65**, 061501 (2002); gr-qc/0105099

T-04 Valencia [UVEG/UA/UB], Spain (Regional Node)
Relativistic Astrophysics Group, Departamento de Astronomía y Astrofísica, Universidad de Valencia

The group in Valencia has carried out extensive work on *hydrodynamical simulations of relativistic flows* (stellar core collapse, relativistic jets – both, extragalactic and from collapsars – and accretion onto compact objects) and on the physics of compact objects (properties of dense matter, structure and cooling of PNSs). During the last years the group has succeeded in extending modern high-resolution shock-capturing techniques (HRSC) to solve the system of equations of relativistic (special and general) hydrodynamics. The specific contributions of the group to the current EU Research Training Network were to provide theoretical ingredients allowing for the development of the `Whisky` code, and to numerically simulate different astrophysical scenarios in general relativity (GR): *(i)* axisymmetric stellar core collapse, both using the so-called Conformally Flatness approximation of GR (CFC), and the characteristic formulation (with [MPG.MPA] and [SoE]), *(ii)* nonlinear pulsations of both, axisymmetric and three-dimensional, rotating relativistic stars (quasi-radial modes, r-modes; with [AUTH/UA], [AEI], and [SISSA]), *(iii)* thick accretion discs around black holes (runaway instability, TNSs; with [SISSA], and [GReCO/LUTH/APC]), and *(iv)* gravitational waves from perturbed compact objects (PNSs, NSs; with [URLS]). Two members of the group, Miralles and Pons, have made relevant contributions to the field of cooling of PNSs. Pons has contributed in identifying the properties of the isolated NS RX J1856-3754. [UVEG/UA/UB] has ongoing research collaborations, which have already result in publications, with network scientists at the [AEI], [AUTH/UA], [MPG.MPA], [GReCO/LUTH/APC], [SISSA], [SoE], and [URLS], nodes. In particular, with [GReCO/LUTH/APC], (and, currently, also with [MPG.MPA],) we started a line of research aimed at the construction of a *hybrid* multidimensional relativistic hydrodynamics code which combines spectral (using `Lorene`) and HRSC methods. A long collaboration, spanning more than ten years, exists between [UVEG/UA/UB], and [MPG.MPA], in the study of relativistic jets, stellar core collapse and, more recently, in the extension of HRSC schemes to relativistic magnetohydrodynamics. A recent numerical study of rotating stellar core collapse, in the CFC approach, has provided a broad catalogue of gravitational waveforms. Along this line, we have started a collaboration with [FSU] and [MPG.MPA] nodes to extend that study to more general spacetimes (CFC+). Researchers of [UVEG/UA/UB] have, currently, collaborations with scientists in USA (SUNY, Stony Brook) and Russia (Ioffe Institute at St. Petersburg and IZMIRAM at Moscow). In the period 1998-2002, the group has published over 80 papers in refereed journals, has trained 3 YRs all of which have gone on to postdoc positions. Most of the experienced researchers in the group participated in SOGW. Font was employed as a postdoc in [AEI] and [MPG.MPA]; Pons, was employed as a postdoc in [URLS]. [UVEG/UA/UB] and [UIB] organised the 4th EU-Network meeting in Palma (September, 2002). *Two groups* at the Universities of *Alicante (UA)* and *Barcelona (UB)* lead by Miralles and Lobo, respectively, have joined [UVEG/UA/UB], defining a *Regional Node*. UA and UB are interested, respectively, in the physics of compact stars and the detection of gravitational waves. Currently, the University of Valencia does not possess adequate computational infrastructure, hence, we ask for an additional budget for durable equipment (see Sec. B7). Required HPC resources will be made available by [AEI].

PERSONNEL

Jose Maria Ibáñez (Local Coordinator, Prof., *relativ. hydrodynamics, numerical techniques*, 50%), Jose Maria Martí (Associate Prof.,*relativ. hydrodynamics, numerical techniques*, 30%), Armando Pérez (Associate Prof., *neutrino physics, NSs*, 40%), Jose Antonio Font (Associate Prof., *relativ. hydrodynamics, numerical techniques*, 75%), Jose Antonio Pons (Research Scientist, *NSs, relativ. hydrodynamics*, 100%), Olindo Zanotti (Postdoc, *relativ. hydrodynamics*, 100%), Pablo Cerdá (Graduate student, *relativ. hydrodynamics, stellar core collapse*, 100%), Manuel Perucho (Doctoral Student, *relativ. hydrodynamics, numerical techniques*, 30%). Juan Antonio Miralles (UA; Prof., *NSs, neutrino transport*, 60%), Jose Francisco Pérez (UA; Graduate student, *NSs, neutrino transport*, 60%), Aberto Lobo (UB; Associate Prof., *signal extraction, GW spherical detectors, LISA*, 40%), Carlos Pino (UB; Graduate student, *signal extraction, GW spherical detectors, LISA*, 50%).

PUBLICATIONS

Riemann Solvers in General Relativistic Hydrodynamics, Ibáñez, J.Mª, Aloy, M.A., Font, J.A., Martí, J.Mª, Miralles, J.A., Pons, J.A., in *Godunov Methods: Theory and Applications*, Ed. E.F. Toro (Kluwer Academic/Plenum Publishers, New York), 485–496, (2001); `astro-ph/9911034`.
Evolution of protoneutron stars with quarks, Pons, J.A., Steiner, A.S., Prakash, M., Lattimer, J.M., *Phys. Rev. Let.*, **86**, 5223-5226, (2001); `astro-ph/0102015`

T-05 Palma [UIB], Spain
Relativity Group, Departament de Física, Universitat de les Illes Balears

In the last decade [UIB] has contributed to the formulation of Einstein's field equations in a way which is specially suitable for NR. Recently the [UIB] group is also playing an important role in the development of gravitational wave data analysis algorithms and the study of possible GW sources. [UIB] is a member of the LIGO scientific collaboration and has a close collaboration with the GEO600 detector. Sintes is the chair of the detector characterisation group in GEO600 and is involved in the GriPhyN working group dealing with the application of Grid computing to LIGO data analysis. [UIB] has strong collaborative links with both the NR and GW groups at [AEI] and with other GWEN nodes, in particular [UWC], [URLS], and [LSU]. Both Massó and Sintes were key members of the [AEI]group for several years. Massó is one of the original authors of the `Cactus` Framework, which serves as a basic tool for the whole network and as the computational framework for all NR activities at [UIB].

The [UIB] group has demonstrated its ability to train YRs during the current EU Research Training Network: two of them, coming from different areas of research, are now successfully working in numerical relativity and have gained significant expertise in `Cactus`-based code development. YRs benefit from the broad expertise of the Palma relativity group, which apart from the core topics NR and GW, extends to other relevant subfields such as cosmology and mathematical relativity. In addition, with the incorporation of Sintes, we are one of the nodes with access to real GW interferometer data, which provides excellent opportunities for the training of YRs. Together with [UVEG/UA/UB], [UIB] has organised one of the SOGW-meetings in September 2002, and has hosted the yearly Spanish Relativity meeting twice.

[UIB]'s expertise and research interests as relevant to GWEN focus on numerical relativity and gravitational wave data analysis: Bona is a leading expert on the development of hyperbolic formulations of the Einstein field equations. An innovative new approach to deal with typical instabilities in such evolution systems, currently developed at [UIB], deals with the problem of breaking the general covariance of Einstein's equations by the traditional splitting into evolution equations and constraints. By considering a covariant extension of Einstein's field equations, where additional variables measure the deviation from the constraint surface, all Einstein equations can be treated consistently, without breaking covariance. Supplemented by suitable coordinate conditions, these equations determine the time evolution of all these variables without any constraint. An ongoing collaboration with [LSU] aims at developing stable boundary conditions for numerical relativity codes. The group is also carrying out research on refined numerical algorithms based on flux limiter methods studying, in particular, the advantages of these methods in terms of stability and accuracy.

Sintes is an expert both on astrophysical data analysis and detector characterisation. The latter aims at giving support to the detector commissioning and the different astrophysical data analysis searches (ongoing collaboration with [AEI] and [UWC]). In collaboration with [AEI] and [URLS], Sintes develops efficient algorithms to search for gravitational radiation from neutron stars, which are already in use to process first science data from LIGO and GEO600. Furthermore Sintes has contributed several packages to the LIGO Algorithm Library (LAL) and has experience with the integration of existing data analysis codes into a Grid environment. Available computational infrastructure include an 8 node NT cluster and a new 8 node Linux cluster devoted to NR and DA. Furthermore the group has access to central university computing facilities in Palma, but additional supercomputer time can be obtained through the CESCA HPC facilities in Barcelona.

PERSONNEL

Alicia Sintes (Local Coordinator, Assoc. Prof., *gravitational wave interferometry, data analysis*, 50%), Carles Bona (Prof., *numerical relativity*, 50%), Jaume Carot (Assoc. Prof., *theoretical source analysis*, 50%), Manuel Luna (Graduate student, *detection of gravitational waves*, 100%), Lluis Mas (Prof., *theoretical source analysis*, 10%), Joan Massó (Assoc. Prof., *numerical relativity*, 10 %), Carlos Palenzuela (Graduate student, *numerical relativity*, 100%), Joan Stela (Assoc. Prof., *numerical relativity*, 10%).

PUBLICATIONS

General-covariant evolution formalism for Numerical Relativity, C. Bona, T. Ledvinka, C. Palenzuela, M. Zacek, *Phys. Rev. D* **67** 104005 (2003); gr-qc/0302083.
A 3+1 covariant suite of Numerical Relativity Evolution Systems, C. Bona, T. Ledvinka, C. Palenzuela, *Phys. Rev. D* **66** 084013 (2002); gr-qc/0208087.

T-06 Thessaloniki [AUTH/UA], Greece (Regional Node)
Relativity Group, Department of Physics, Aristotle University of Thessaloniki;
Relativity Group, Department of Physics, National and Kapodistrian University of Athens

Thessaloniki has a tradition in Relativistic Astrophysics, being the largest relativity group in Greece with expertise in several areas in general relativity and cosmology and currently focused primarily in the numerical study of sources of GWs and developing detection techniques.

In recent years, members of the group have provided significant contributions in several specific topics in GW physics, such as in *Pulsating Relativistic Stars* (spectral properties and GW instabilities), *Numerical Relativity* (simulations of rotating, collapsing and binary NSs), *Coalescing Binary Systems* (tidal effects waveform extraction) an *GW Data Analysis* (higher-order post Newtonian effects and Monte-Carlo simulations). Prof. K. D. Kokkotas (the Local Coordinator) is one of the leading scientists in the field of GW emission from perturbed NSs and BHs, having initiated and developed the field of “GW Asteroseismology”. He has discovered new families of oscillation patterns of relativistic stars and contributed in the study of their instability properties. He is author of many review articles in the field and he is one of the main review speakers in the field worldwide. His work includes numerical and analytic techniques and extends also to the data analysis of gravitational waves. Dr. N. Stergioulas is an expert in rotating relativistic stars and numerical relativity. He has extensive experience in developing and applying numerical methods for computing equilibrium initial data, linear perturbations and nonlinear 3D simulations of relativistic stars. In recent years, he has obtained the first computation of neutral modes of rapidly rotating stars in full general relativity and the first 3D simulation of nonlinear pulsations of rotating stars. Currently, he is participating in the development of one of the main numerical codes `Cactus/Whisky` to be used by several groups in the proposed network. The group also has a broader interest in relativistic magnetohydrodynamics and high-frequency variabilities in accretion disks.

The group will act as a Regional Node in Greece for GWEN, representing also the Department of Physics, University of Athens. Dr. T. A. Apostolatos, is a leading European expert in GW data analysis, who joined Athens coming from the Caltech group. In GWEN he will participate in projects that aim at extracting important physical information from detected sources of gravitational waves. On research related to the present proposal, there are ongoing projects with most groups from the current EU Research Training Network ([AEI], [GReCO/LUTH/APC], [SISSA], [SoE], [URLS], [UVEG/UA/UB]) as well as with new nodes in the present proposal ([CAMK], [IAAT], [MPG.MPA], [LSU], [PSU]). The group also had a recent bilateral research programme with [CAMK] and is participating in a similar programme between [GReCO/LUTH/APC] and [CAMK]. There are also close ties with research groups in the USA and Japan.

The Aristotle University of Thessaloniki is the largest academic and research institution in Greece. The senior members of the relativity group have extensive experience in teaching and training undergraduate students in physics and mathematics and graduate students in computational physics and relativity. In recent years, the group has awarded three PhDs and trained three European postdocs. Access to European and US supercomputing resources is provided through a high-speed connection via GEANT/GTRN. The group will be one of the main users of a new grid of seven 64-processor clusters in Greece (installed by the EU-funded HELLAS-GRID project, one of which at AUTH). The group has successfully organised one of the large network meetings of the current EU Research Training Network as well as a recent regional conference in gravitational physics.

PERSONNEL

Kostas D. Kokkotas (Local Coordinator, Assoc. Prof., *BH and NS perturbation theory*, 50%), Nikolaos Spyrou (Prof., *relativistic astrophysics*, 33%), Demetrios Papadopoulos (Assoc. Prof., *gravitational waves and relativistic cosmology*, 33%), Nikolaos Stergioulas (Lecturer, *rotating relativistic stars and numerical relativity*, 50%), Theocharis Apostolatos (Lecturer - UA, *GW data analysis*, 50%), Miltiadis Vavoulidis (Graduate student, *GW-instabilities of rotating NSs*, 100%), Nikolaos Tsakiris (Grad. student, *nonlinear simulations of rotating NSs*, 100%), V. Moschovitis (Grad. student - UA, *rotating NSs*, 100%), G. Pappas (Grad. student, UA, *relativistic astrophysics*, 100 %), T. Sotiriou (Grad. student, UA, *astrophysical MHD*, 100 %).

PUBLICATIONS

The r-mode instability in rotating neutron stars, N. Andersson and K. D. Kokkotas, *Int. J. Mod. Phys. D* **10**, 381-442 (2001); `gr-qc/0010102`

Nonlinear r-modes in rapidly rotating relativistic stars, N. Stergioulas and J.A. Font *Phys. Rev. Let.* **86**, 1148 (2001); `astro-ph/0011083`

T-07 Rome [URLS], Italy
Relativity Group, Dipartimento di Fisica, Universita' di Roma "La Sapienza"

The research activities of the [URLS] group cover two major areas of interest: *relativistic astrophysics* and *data analysis*. Valeria Ferrari (Local Coordinator) has a long experience in the theory of stellar perturbations and the numerical simulation of GW sources. Her work on a new formulation of stellar perturbations theory (with S. Chandrasekhar) in the early 90's revived interest in that subject, and disclosed new relativistic effects such as the existence of new classes of modes and the coupling between axial and polar modes from the dragging of inertial frames. With her group in Rome, she has subsequently expanded and applied this theory, to simulate the phases of coalescence preceeding the merger of NS binary systems, and to identify the imprint left on the gravitational signals by the internal structure of the coalescing bodies. A procedure was developed to compute the spectral properties of the GW background produced by cosmological populations of astrophysical sources, merging observation-based information on star formation history with knowledge of GW emission by various sources. She has more than 20 years of experience in teaching and training YRs, and has lectured graduate courses on General Relativity and on GW Sources at the Universities of Rome and Chicago. In the last five years she has trained 8 undergraduate students, 5 PhD students and 3 postdocs. All of the PhD students have found postdoc positions in Europe. She was elected to the Committee of the International Society on General Relativity and Gravitation in 1995, and is the national coordinator of a project financed by the Instituto Nazionale di Fisica Nucleare (INFN), the funding agency of gravitational experiments in Italy, for the study of the theory and phenomenology of gravitational waves in support of experiments.

Pia Astone has worked in data analysis since 1988 and is a member of the Rome experimental group that develops resonant antennas (EXPLORER and NAUTILUS). She collaborates with the VIRGO experiment on data analysis filtering techniques for the detection of monocromatic sources. She has provided important contributions to the development of algorithms for the detection of impulsive signals and for the implementation of coincidences procedures. Omar Benhar is an expert in nuclear physics. He contributed to the development of many-body approaches suitable for studying the properties of NS-matter, such as CBF (Correlated Basis Function) perturbation theory. Over the last decade, he also worked extensively on the problem of lepton interactions with atomic nuclei and nuclear matter.

Due to the complementarity knowledge of the group member, we can train YRs n the theory of stellar perturbations, on the processes of nuclear physics that affect the early evolution of a NS and its final structure, and on the procedures needed to extract gravitational signals buried in detector noise. We believe that the multidisciplinary training the Rome group can offer, and our links with the Italian experimental groups (EXPLORER, NAUTILUS, AURIGA, VIRGO), will provide YRs with a rather unique opportunity to become familiar with some of the most interesting aspects of the physics of GWs.

[URLS] has ongoing collaborations with [UVEG/UA/UB] and [AUTH/UA], established during (SOGW) and advanced by exchanging post-docs. Rome hosted Dr. J. Pons from Valencia, and Dr. E. Berti from Rome is now at [AUTH/UA]. L. Gualtieri is collaborating with [SoE] on analytical developments of the theory of stellar perturbations relevant for the study of rotating NSs.

The group has access to HPC facilities at Cineca, (Bologna), and together with [SISSA], is creating a Beowulf cluster for numerical relativity, (*Albert100*) (Parma), with a speed of 100 GFLOPS, a memory of 120 GBytes, and 1.5TBytes mass storage. In June 2000, together with [SISSA], the group organised a very successful international conference on Gravitational Wave Sources in Trieste, as well as the SOGWschool in September 2003.

PERSONNEL

Valeria Ferrari (Local Coordinator, Prof., *BH and stellar perturbations*, 50%), Omar Benhar (Senior Research Associate, *nuclear physics*, 50%), Pia Astone (Senior Research Associate, *data analysis*, 50%), Leonardo Gualtieri (Postdoc, *stellar perturbations*, 100%), Christian Casalvieri (Graduate student, *Stellar Perturbations*, 50%), Stefania Marassi (Graduate student, *rotating stars* 50%).

PUBLICATIONS

Non-radial oscillation modes as a probe of density discontinuities in neutron stars, G. Miniutti, J. A. Pons, E. Berti, L. Gualtieri, and V. Ferrari, *Mon. Not. R. Astron. Soc.*, **338**, 389, (2003); astro-ph/0206142
Resonant mass detectors:present status, Pia Astone, invited talk given at the 4th Amaldi conference, Perth July 2001, *CQG* **19**, 1227, (2002)

T-08 Trieste [SISSA], Italy
Astrophysics Group, International School for Advanced Studies

[SISSA] is a special institute within the Italian university system, devoted to postgraduate training and research in various branches of physics and mathematics. The Astrophysics Sector consists of thirty-six people (including eight permanent staff) and Relativistic Astrophysics is one of its main research lines. Working within the areas of GWEN there are two staff members, one advanced fellow, one post-doc and three PhD students.

The Local Coordinator for GWEN will be Luciano Rezzolla. Following his PhD at [SISSA], he was a postdoc for three years at Urbana-Champaign (Illinois) and at NCSA. He worked there on the Binary Black Hole Grand Challenge, gaining an extensive background in numerical relativity, and also studied the r-mode instability in NSs. Since returning to [SISSA], he has worked in general relativistic hydrodynamics (GRH), on the oscillation modes of NSs and TNSs, and on the electrodynamics of rotating NSs. With some of the PhD students, he has played a key role in developing the `Whisky` code as an integrating part of the `Cactus` Framework and will further coordinate its use for the planned projects as well as being involved in studies of the physics of PNSs and old NSs. John Miller has been based in Italy for the last 15 years after moving from Oxford with Dennis Sciama. He has been working on a range of problems in relativistic astrophysics and, in particular, in GRH, on accretion flows onto compact objects, and on the rotational properties and microphysics of NSs. Koji Uryu is an expert in the calculation of initial data for binary systems of compact objects. His contribution to GWEN will be focused on the solution of the stationary binary BH problem in GR. Shigeyuki Karino, an expert of oscillation modes of compact objects, will join [SISSA] from Tokyo as a postdoc in the spring. Thee graduate students, Luca Baiotti, Bruno Giacomazzo and Pedro Montero-Muriel (who is presently funded by SOGW), are mainly working on GRH with applications to the coalescence of NS binaries, the properties of tori around BHs and the collapse to form BHs. In the coming years, they will help in the inclusion of GR-MHD within these calculations.

[SISSA] has a long track-record in computational physics and is presently deeply involved in the construction of multi-purpose codes such as `Whisky` and `Nada`, the latter being developed entirely in [SISSA]. Because of its role as a graduate school, [SISSA] can provide excellent training both in the physics for the GWEN project, and for the computational science needed for numerical relativity, providing training on running and developing codes using the `Cactus` Framework (including `Whisky`) and the use of HPC resources. The group is making use of HPC facilities at Cineca, (Bologna) and together with [URLS] is responsible for the creation and use of a Beowulf cluster for numerical relativity, *Albert100* (Parma), with 64 processors. [SISSA] is also deeply committed to the creation of a European community of GWA. In June 2000, to mark the start of SOGW, together with [URLS], the group has organised in Trieste a very successful conference on sources of GWs, which has led to a substantial book of proceedings. In September 2003, to mark the end of SOGW, [SISSA] and [URLS] have organised in Trieste an *Advanced School* on sources of GWs with lecturers coming almost exclusively from members of SOGW. The School was then followed by an *International Conference* giving the students of the School the opportunity of coming in contact with researchers from all over the world working on sources of GWS. The two meetings have been extremely successful, with a record participation of young researchers from Europe and abroad. The lecture notes of the School, the proceedings of the Conference, and the impressions collected by the participating students are available on the web.

There are close existing collaborations with the groups at [AEI] (`Whisky` code), [SoE] and [URLS] (NS oscillations), [UVEG/UA/UB] (GRH, `Nada` code), [AUTH/UA] (rotating NSs), [GReCO/LUTH/APC] (NS binaries) and [CAMK] (accretion). All of these collaborations will continue within GWEN.

PERSONNEL

Luciano Rezzolla (Local Coordinator, Assoc. Prof., awaiting appoint., *GRH and GR-MHD, perturbation theory*, 50%) John Miller (Assoc. Prof., *NS physics and accretion*, 33%), Koji Uryu (Advanced Fellow, *relativistic binaries*, 100%), One post-doc appointed in the spring (*perturbation theory*, 100%), Luca Baiotti, Bruno Giacomazzo and Pedro Montero-Muriel (Graduate students, *GRH and GR-MHD*, 100%).

PUBLICATIONS

Gravitational waves from the merger of binary neutron stars in a fully general relativistic simulation, M. Shibata and K. Uryu, *Prog.Theor.Phys.*, **107**, 265 (2002); `gr-qc/0203037`

r-mode Oscillations in Rotating Magnetic Neutron Stars, L. Rezzolla, F. K. Lamb, and S. L. Shapiro, Astroph. Journ. **531**, L141 (2000); `astro-ph/9911188`

T-09 South of England [SoE], United Kingdom (Regional Node)

School of Mathematics, Southampton University; **Institute of Cosmology and Gravitation, University of Portsmouth**; **Department of Physics, University of Oxford**

The [SoE] node combines some of the main centres for classical General Relativity in the UK and has ongoing collaborations with many of the nodes of GWEN ([AUTH/UA], [SISSA], [FSU], [UVEG/UA/UB], [UWC], [URLS], [LSU], [PSU], [AEI]). The research of [SoE] extends from the development of mathematical tools to relativistic astrophysics. The node has significant expertise in numerical relativity and GW source modelling. In numerical relativity the group is focusing its efforts on (i) understanding the asymptotic nature of the waveforms that are emitted by compact objects, and (ii) improving the formulation of Einstein's equations for numerical use, and (iii) investigating problems involving relativistic hydrodynamics. The group's work on GWs is focused on oscillations and instabilities in NSs, utilising and developing relativistic perturbation theory.

N. Andersson (Local Coordinator; Southampton) is a Philip Leverhulme Prize fellow in Astrophysics. He is an expert on the dynamical properties of NS and BH in the framework of GR. He discovered the r-mode instability in rotating NSs and has made significant contributions towards the understanding of this mechanism as a GW source. His recent research interests involve the dynamics of superfluid stars. He has collaborated with Kokkotas ([AUTH/UA]) and Schutz ([AEI]) for more than 10 years, and has strong links with [PSU].

M. Bruni (Portsmouth) has as his main interest the development and application of perturbation theory in general relativity and cosmology. Together with G.F.R. Ellis he developed a covariant and gauge invariant perturbation approach which has been extensively applied in cosmology. Within GWEN, his interest is focused on the modeling of GW sources using analytical and approximate techniques to study nonlinear effects and aid physical interpretation of results from numerical codes and to provide methods for wave extraction.

C. Gundlach (Southampton) has been working for the last ten years in the fields of gravitational collapse and numerical relativity. He is an authority on the mathematical understanding of critical phenomena in gravitational collapse. Dr. Gundlach has been collaborating on the `Cactus` numerical relativity code for several years, working on BH excision, boundary conditions and apparent horizon finding. More recently he has been working on implementing and testing hyperbolic formulations of the Einstein equations within `Cactus`.

J.C. Miller (Oxford) is a specialist in relativistic astrophysics with applications to both compact objects and early-universe cosmology. Much of his work involves GR hydrodynamics, with extensive use of numerical computing. Current projects include investigating non-stationary accretion onto black holes and the properties of compact stars with standard and non-standard equations of state. Within GWEN, he is particularly interested in studying the behaviour of merged objects formed after the coalescence of a neutron-star binary. He provides a strong link between [SoE] and [SISSA], as well as with the astrophysics group in Oxford.

J.A. Vickers (Southampton) is an expert on the asymptotic structure of spacetime and on how GWs emitted by a source may be described in terms of the geometry of null infinity. In particular, he has worked on quasi-local definitions of mass and angular momentum and their use in numerical relativity.

[SoE] has an excellent track record in supervising and guiding YRs. Given the broad expertise of the group, [SoE] can provide high quality training in both astrophysical and mathematical relativity as well as the computational aspects of GWEN. The group has access to local Beowulf clusters and the PPARC funded UKAFF machine (a 128 processor Origin 3800). Additional leverage is provided by Computer Science groups (led by Prof. S. Cox and Dr. M. Baker), who will support the training of GWEN YRs in Grid computing.

PERSONNEL

N. Andersson (Local Coordinator, Reader, *GW source modelling*, 50%); M. Bruni (Senior Lecturer, *exact and approximate methods in GR*, 50 %); J. Miller (Prof., *relativistic astrophysics*, 30%); C. Gundlach (Lecturer, *numerical relativity*, 50%); C. Clarkson (Lecturer, *perturbation theory* 50%); J.A. Vickers (Prof., *mathematical relativity*, 15%) K. Glampedakis, G. Calabrese (postdocs, *GW source modelling/numerical relativity* 100%) K. Ananda, K. Grosart, B. Haskell, I. Hinder, A. Maniopoulou, A. Nerozzi, A. Passamonti, F. White (graduate students, *GW source modelling, numerical relativity*, 67% each)

PUBLICATIONS

Gravitational waves from instabilities in relativistic stars, N. Andersson, *Class. Quantum Grav.*, **20**, R105 (2003); astro-ph/0211057

Two-parameter nonlinear space-time perturbations: Gauge transformations and gauge invariance, M. Bruni, L. Gualtieri and C. F. Sopuerta, *Class. Quantum Grav.*, **20**, 535 (2003); gr-qc/0207105

T-10 Cardiff [UWC], United Kingdom
Relativity Group, Department of Physics and Astronomy, Cardiff University

[UWC] has been a world leader in the study of GW sources, the development of data analysis algorithms and software. The group provided the theoretical impetus for the GEO600, Advanced LIGO and LISA instruments and a member of these projects. It has, therefore, vast experience in handling real data. The group is involved in the FP5 GridLab project and leads the UK's GridOneD project. [UWC] has strong collaborative links with institutions around the world including [AEI] (Schutz, and his data analysis group), [GReCO/LUTH/APC] (Blanchet, Buonanno, Damour), [UIB] (Sintes), [LSU] (Gonzalez), [PSU] (Owen, Finn). Sathyaprakash is a Visiting Professor at IHES (Damour) and was on a year's sabbatical at [AEI] during 01-02. He was on the Advisory Board for the SOGW network. Romano is a co-Chair of the Stochastic Analysis group of the LIGO Scientific Collaboration and Schutz is a member of the LISA International Science Team. The research interests of the [UWC] group relevant to this proposal are: *(i) Studying astrophysical and cosmological sources of GWs,* most notably, primordial (Grishchuk, Romano) and astronomical (Regimbau) backgrounds, instabilities in NSs (Schutz), late stage evolution of BH binaries (Sathyaprakash, Cokelaer), and small BHs tumbling into rapidly spinning supermassive BHs (Babak). *(ii) Characterising GW detector and noise background* using data from environmental and instrumental monitors and by employing time-domain, frequency-domain and time-frequency techniques (Balasubramanian, Babak, Cokelaer, Churches). *(iii) Developing efficient search algorithms and analysis of real data,* in particular, search algorithms for gravitational radiation from inspiralling and merging NS and BH binaries (Balasubramanian, Babak, Churches, Cokelaer, Sathyaprakash, Schutz), transients of unknown shape such as radiation from supernovae and BH collisions (Balasubramanian and Sathyaprakash), continuous waves from NS (Regimbau, Schutz), and GW backgrounds by coincidence experiments (Regimbau, Romano). *(iv) Development of a Java-based, Grid-aware problem solving environment, called Triana,* for data analysis and data mining. Triana can handle vast amounts of data, do resource and data discovery, carry out distributed computing, wrap legacy codes and avail of the Grid Application Toolkit which helps in transparently exploiting grids in applications (Churches, Schutz, Shields, Taylor, Wang).

Currently, [UWC] is deeply involved in the analysis and interpretation of data from GEO600 and LIGO projects. The search tools and packages developed by the group are being used in GEO600 and LIGO for astrophysical searches, detector diagnostics and data mining. The work of the [UWC] group on sources and data analysis is supported by a large Beowulf cluster with a sustained speed of 80 GFLOPS and a memory of 80 GBytes. The group has a large robotic tape storage facility and also 18 TBytes of disk space. Moreover, being UK's Regional Grid Centre, [UWC] has access to high-speed network, immersive 3D visualisation hardware, and Access Grid facility. All these resources will be at the disposal of the group for training purposes, enabling the development of the computational skills along side the physics needed to take part in GWEN. Recent PhD students at Cardiff who have moved onto other places include Gabrielle Allen (first [AEI], Research Scientist, now [LSU], faculty), Kostas Glampedakis ([SoE], postdoc), Ian Jones (first [SoE] now [PSU], postdoc), Ed Porter, (Paris, postdoc) and Wolfram Schmidt ([MPG.MPA], PhD); and our recent Postdocs are Nils Andersson ([SoE], Reader), Sukanta Bose (Washington, Asst. Prof.) and Marco Bruni ([SoE], Lecturer).

PERSONNEL

Staff: B.S. Sathyaprakash (Local Coordinator, Prof., Leverhulme Fellow, *black hole binaries, data analysis*, 30%), L. Grishchuk (Prof., *primordial background*, 10%), J. Romano (Senior Lecturer, *stochastic backgrounds*, 10%), B. Schutz (Prof., *relativistic instabilities, Triana, data analysis*, 10%), I. Taylor (Lecturer, *Triana, Grid*, 10%), **Postdocs:** S. Babak (*LISA sources, black hole binaries, data analysis*, 100%), R. Balasubramanian (*burst searches, detector characterisation*, 100%), D. Churches (*Triana, black hole binary searches*, 100%), T. Cokelaer (*black hole binaries, detector characterisation, data analysis*, 100%), T. Regimbau (*astronomical backgrounds, continuous wave sources*, 100%), M. Shields (*Triana interface, Grid*, 10%), I. Wang (*Triana, Grid, Peer-to-peer computing*, 10%),

PUBLICATIONS

Templates for stellar mass black holes falling into super-massive black holes, B.S. Sathyaprakash and B.F. Schutz, *Class. Quant. Grav.* **20**, S209 (2003); gr-qc/0301049.
Detecting a stochastic background of gravitational radiation: Signal processing strategies, B. Allen and J. Romano, *Phys. Rev. D.* **59**, 102001 (1999).

T-11 Garching [MPG.MPA], Germany
Max-Planck-Institut für Astrophysik

Research at [MPG.MPA] covers a broad range of topics in theoretical astrophysics. Major areas of interest include stellar evolution, nuclear and neutrino astrophysics, supernovae, astrophysical fluid dynamics, high energy astrophysics, radiative processes, galaxy formation and evolution, gravitational lensing, the large-scale structure of the Universe, particle astrophysics and cosmology. The [MPG.MPA] group has always placed considerable emphasis on computational astrophysics and has therefore access to forefront computing facilities. In particular, the hydrodynamics group at [MPG.MPA] has an outstanding record of multidimensional hydrodynamic simulations of various astrophysical phenomena, and the supernova group is presently one of the world leaders in the field. The broadness of the research performed at [MPG.MPA], make it an ideal place for students to get superb training in astrophysics and numerical hydrodynamics.

Major achievements have been obtained at [MPG.MPA], concerning both the development of new state-of-the-art numerical methods and codes, and their application to front-line astrophysical questions including the simulation of special and general relativistic flows (M.A. Aloy, H. Dimmelmeier, J.A. Font T. Leismann, E. Müller, L. Scheck), the modeling of neutrino interactions and neutrino transport in core collapse supernovae (R. Buras, H.-T. Janka, M. Rampp), and the simulation of nucleosynthesis and clump formation in core collapse supernovae (H.-T. Janka, K. Kifonidis, E. Müller, T. Plewa).

The hydrodynamics group at [MPG.MPA], has a more than ten years long successful collaboration with [UVEG/UA/UB] in the fields of relativistic jets, relativistic hydrodynamics and stellar-core collapse. Within the last three years this collaboration performed a pioneering study of the dynamics of rotational core collapse and of the resulting gravitational wave signature using the so-called Conformally Flatness Condition (CFC). Last year [FSU] joined this effort in order to extend the CFC approximation to CFC+, which we expect will allow us to study numerical solutions of the Einstein equations under even more extreme relativistic conditions. In addition, very recently [MPG.MPA], [UVEG/UA/UB], and the Paris-Meudon node [GReCO/LUTH/APC] have begun a collaboration to marry the spectral solver package LORENE developed at Meudon with the 2D CFC (and when available with the CFC+) code used at [MPG.MPA]. This marriage will provide the necessary tool to tackle 3D GRHD problems. Finally, [MPG.MPA], is about to collaborate with [AUTH/UA] in the computation of eigenmodes of rotating neutron stars using CFC (CFC+).

PERSONNEL

Ewald Müller (Local Coordinator, research group leader, *supernovae, numerical hydrodynamics*, 50%), Miguel Angel Aloy (Postdoc, *relativistic hydrodynamics, numerical techniques*, 50%), Harald Dimmelmeier (Postdoc, *relativistic hydrodynamics, numerical techniques*, 50%), H.-Thomas Janka (Senior research scientist, *neutrino physics, supernovae, neutron stars*, 25%), Konstantinos Kifonidis (Postdoc, *nucleosynthesis, supernovae, numerical techniques*, 33%), Tobias Leismann (Graduate student, *relativistic magnetohydrodynamics*, 100%), Leonhard Scheck (Graduate student, *supernovae, neutrino transport, numerical techniques*, 33%) Burkhard Zink (Graduate student, *relativistic hydrodynamics, numerical relativity*, 100%).

PUBLICATIONS

Relativistic simulations of rotational core collapse. I. Methods, initial models, and code tests, Dimmelmeier, H., Font, J.A., Müller, E., *Astron. Astrophys.*, **388**, 917, (2002); astro-ph/0204288

Relativistic simulations of rotational core collapse. II. Collapse dynamics and gravitational radiation, Dimmelmeier, H., Font, J.A., Müller, E., *Astron. Astrophys.*, **393**, 523, (2002); astro-ph/0204289

T-12 Tübingen [IAAT], Germany
Institute of Astronomy & Astrophysics, University of Tübingen

Research at the Theoretical Astrophysics and Computational Physics Groups of the Institute of Astronomy & Astrophysics [IAAT] covers a wide variety of topics which include: accretion disk theory, cataclysmic variables, star- and planet formation, NS physics, theoretical and numerical relativity, relativistic astrophysics, and numerical hydrodynamics. Additionally, the group has accumulated significant knowledge in the general field of Computational Astrophysics, which brings a valuable addition to the other nodes. The [IAAT] is participating actively (with about 10 positions altogether) in two Special Research Programmes (SFBs) of the German Science Foundation (DFG), with topics very fruitful for this project. As a University, several courses are taught which deal with related scientific topics. This provides valuable training conditions for students, as well as a good environment for Experienced Researchers.

The theoretical research groups at [IAAT] have a long-standing experience in the overall field of Computational Astrophysics. We have developed our own numerical tools for solving the time dependent equations of hydrodynamics, including radiation transport in multi-dimensions. Here different approaches, particle- and grid-based methods have been developed, applying multi-grid and parallel techniques. During the last years, new successful methods have been developed to solve the vacuum field equations to evolve for example a single black hole stably for a long time. This has been done within the framework of the `Cactus` environment (from [AEI]), for which the adaptive mesh-refinement module (or "thorn") (`Carpet`), was developed in [IAAT]. `Carpet` is is important for *all* codes using `Cactus`. New numerical methods for solving the conformal field equations, which allow for an optimal wave-extraction at infinity, have been constructed. A spectral code for providing initial data for time evolution with the conformal field equations is currently being developed using [GReCO/LUTH/APC]'s `Lorene` package. Extensive work has been performed on the internal structure and linear oscillations of NSs and BHs. Recently, the team has also begun to work on the problem of template construction and data analysis for the detection of gravitational waves, jointly with the GEO 600 team in Hannover.

The Theoretical Astrophysics and Computational Physics groups at the [IAAT] have long time collaborations with [AUTH/UA] on NS structure and oscillations with several joint publications. Strong connections exist with [FSU] and [MPG.MPA] on stellar collapse and NS mergers. This includes the evolution of the field equations using the conformally flat approach. With [SISSA] collaborations exist on NS physics and the study of relativistic accretion disks. With the [AEI] and the USA node [PSU] long term collaborations exist on solving the vacuum Einstein equations, finding optimal choices for gauge conditions, and on horizon finders. There are strong connections with the [AEI] as well as [LSU] on numerical analysis of the discretised Einstein equations. [IAAT] has also taken part in the Apples With Apples project. The [IAAT] hosts two Linux-Clusters (with 192 and 32 processors) and has CPU-time at Computer the centre in Stuttgart.

PERSONNEL

Willy Kley (Local Coordinator, Prof, *theoretical astrophysics*, 15%)
Jörg Frauendiener (Lecturer, *numerical relativity*, 15%)
Hans-Peter Nollert (Postdoc, *neutron star oscillations*, 20%)
Jochen Peitz (Postdoc, *relativistic astrophysics*, 30%)
Matthias Kunle (Postdoc, *Relativistic SPH*, 35%)
Roland Speith (Postdoc, *SPH Methods*, 35%)
Daniel Kobras (PhD Student, *Numerical Relativity*, 50%)
Wolfgang Kastaun (PhD Student, *Numerical Relativity*, 50%)

PUBLICATIONS

Numerical evolution of axisymmetric, isolated systems in general relativity, Frauendiener, J., Hein, M. *Phys. Rev. D*, **66**, 124004 (2002); gr-qc/0207094

Introduction to Isolated Horizons in Numerical Relativity, Dreyer, O., Krishnan, B., Schnetter, E., Shoemaker, D., *Phys. Rev. D*, **67**, 24018 (2003); gr-qc/0206008

T-13 Warsaw [CAMK], Poland
N. Copernicus Astronomical Center

[CAMK] is the main astronomical institution in Poland. The [CAMK] team specialises in dense-matter microphysics and in physics and astrophysics of compact stars (NSs, BHs, and strange quark stars (SSs)). Both domains are crucial for GWEN projects.

Prof. P. Haensel (Local Coordinator) is an expert on dense-matter microphysics and on the structure, evolution and dynamics of NS. His most significant results in microphysics, important for GWEN, are related to neutrino processes in neutron stars and dissipative processes in neutron star cores. These processes will be a crucial input for studies of secular instabilities in rotating NS planned by [SoE].

Dr. J.L. Zdunik is a former student of Prof. Haensel. His most important results are connected with neutron stars and strange stars. The work of Haensel and Zdunik (1990) on crustal heating in accreting neutron stars is crucial for understanding the soft X-ray transients in quiescence. This Haensel-Zdunik model was very recently generalised and updated. All this should be taken into account in the [SoE] studies of instabilities in accreting binary NS. Haensel, Zdunik, and Schaeffer constructed first detailed models of SS (1986); rotational properties of SS were studied in collaboration with [GReCO/LUTH/APC].

Prof. E. Szuszkiewicz is an expert in the theory of astrophysical accretion disks around NS and BH. She is now involved in the studies of incipient instabilities in accretion disks and their observational consequences for diverse astronomical phenomena. She and Prof. F. Ferrari from the Szczecin University will bring their expertise in computing the hydrodynamics of accretion flows onto black holes with the inclusion of detailed microphysics. This background will be extremely useful in helping to improve calculations for the merged objects formed after the coalescence of a NS-NS and BH-NS systems. They also have ongoing collaboration with the [SISSA] and [SoE] groups.

Rapid rotation of SSs is also the topic of an ongoing collaboration of the [CAMK] group with Stergioulas at [AUTH/UA], in which the 2D numerical code developed by the [AUTH/UA] team is being used. The merger of the components of compact-star binaries is a promising source of GW bursts. The work of two experts in relativistic astrophysics, Prof. T. Bulik and Prof. W. Kluzniak ([CAMK]) on the NS-NS, NS-BH, and BH-BH binaries (statistics and evolution) in the Galaxy is particularly important for the prediction of the detectability of GW from coalescing compact-stars binaries.

Prof. A. Krolak (Institute of Mathematics) and his former student Dr. P. Jaranowski (University of Bialystok) are specialists in the modeling GW sources (inspiralling NS-NS and NS-BH binaries, collaboration with [FSU]), relativistic calculations of NS-NS binaries dynamics relevant for GW (collaboration with Damour [GReCO/LUTH/APC]) and GW data analysis (collaboration with VIRGO team).

Since 1991, the [CAMK] team has a strong collaboration links with [GReCO/LUTH/APC]. The work performed in collaboration with Gourgoulhon and Bonazzola from [GReCO/LUTH/APC] on the rapid rotation of neutron stars and strange stars (Gondek-Rosinska, Haensel, Zdunik) has been highly recognised. The collaboration with [GReCO/LUTH/APC], involving also M. Bejger (Graduate Student) is computationally based around the use of `Lorene`, implemented at [CAMK] within the CVS system. Computing facilities at [CAMK] consist of a large network of fifty powerful workstations and PCs under Linux. Within GWEN [CAMK] will train one YR in relativistic hydrodynamics (NS-NS and BH-NS merger, see Sec. B4.3).

PERSONNEL

Pawel Haensel (Local Coordinator, Prof., 50%), Andrzej Krolak (Prof., 50%), Piotr Jaranowski (Associate Prof., 50%), Julian L. Zdunik (Associate Prof., 67%), Wlodzimierz Kluzniak (Associate Prof., 22%), Tomasz Bulik (Associate Prof., 22%), Ewa Szuszkiewicz (Associate Prof., 50%), Franco Ferrari (Associate Prof., 50%), Dorota Gondek-Rosinska (Research Associate, 100%), Michal Bejger (Graduate Student, 100%).

PUBLICATIONS

A unified equation of state of dense matter and neutron star structure, F. Douchin and P.Haensel, *Astron. Astrophys.* **380** (2001) 151; `astro-ph/0111092`

Bulk viscosity in superfluid neutron star cores. III. Effect of $^{-}\Sigma$ *hyperons*, P. Haensel, K.P. Levenfish, and D.G. Yakovlev, *Astron. Astrophys.* **381** (2002) 1080; `astro-ph/0110575`

T-14 Baton Rouge [LSU], USA
Louisiana State University, Hearne Institute for Theoretical Physics

[LSU] is one of two important collaborating groups (with [PSU]) who will participate in GWEN without EU personnel funding. We request only travel funding for these institutions so they can participate in GWEN All-Hands Meetings. As described below [LSU] brings unique strengths to GWEN, and will work closely with its European members, directly participating in and supporting its scientific research, and expanding the breadth of training and experiences for GWEN YRs.

[LSU] has one of the world's leading groups in the study of Einstein's equations for numerical relativity, and also experimental gravitational wave astronomy (GWA). One of the two LIGO detectors is located just next to [LSU], which has for this reason become one of the most active groups in the world in these areas. LIGO is the by far the world's largest gravitational wave detector, and is the single largest project supported by the US National Science Foundation. In addition to this, [LSU] hosts the only active gravitational wave detector in the USA that uses resonant bar technology.

[LSU] codes are based on the `Cactus` framework, and it will work with GWEN to develop more accurate and stable algorithms for nonlinear evolutions of all GW sources under study via numerical relativity. The group has pioneered the use of advanced numerical analysis techniques to discretise the Einstein equations. The resulting codes are showing unusual promise of long term stability in the situations in which they have been tested, and work is apace in generalising them to full general relativity for the binary BH problem. Pullin has worked closely with [AEI], Thessaloniki, and South of England members on applying perturbation theory to black hole and neutron star spacetimes. Lehner and Tiglio have worked closed with [AEI], including several visits, on formulations and algorithms for evolution systems in numerical relativity. The newfound presence of Seidel, Allen, Diener and others from [AEI]ensures very tight coupling between the sites.

Tohline's work on numerical simulations in Newtonian gravity provides an important complement to the fully relativistic calculations that will be carried out by GWEN. This brings crucial leverage to the studies of dynamical and secular instabilities of rotating stars to be carried out by GWEN, and is expected to generate collaboration with, in particular, [SoE] and [AUTH/UA].

The LSU LIGO group, including Gabriela González, works on the commissioning of the LIGO Livingston detector; in the characterization of the data taken in science runs (including data calibration); and in data analysis issues: González is the co-chair of the LIGO Science Collaboration working group on data analysis searching for inspiral sources of gravitational waves, in which the [UWC]is also heavily involved. The expertise on experimental issues and practical data analysis problems will add considerable breadth to the whole GWEN effort. It is expected that any plausible waveforms that are generated in the network can be used for mining the data deeper for signals, and upon their finding, on their astrophysical interpretation; the group at LSU can provide the crucial connexion between theory and application to real data.

[LSU] also hosts one of the fastest supercomputers in the world, the 1024 node "Supermike" cluster, which will be made available to GWEN. [LSU] has video conferencing infrastructure on site which are already being used to interact with EU GWEN nodes and to particate in seminars and training programmes.

PERSONNEL

Gabriela González (Local Coordinator, Asst. Prof., *gravitational wave interferometry, data analysis*, 10%)
Edward Seidel (Principal Coordinator (AEI), FPS Prof., *numerical relativity, computational science*, 25%)
Jorge Pullin, (Local Coordinator, Hearne Chair in Theoretical Physics, *classical and quantum gravity, perturbation theory*, 10%),
Joel Tohline, (Prof., *neutron star perturbations, neutron star collisions*, 10%)
Gabrielle Allen, (Assoc. Prof., *computational science, numerical relativity*, 10%)
Luis Lehner (Asst. Prof., *numerical relativity, formulations of Einstein Equations*, 10%)
Peter Diener, (Asst. Prof.-Research, *numerical relativity*, 10%)
Manuel Tiglio (Postdoc., *black hole binaries, numerical relativity*, 10%)

PUBLICATIONS

Convergence and stability in numerical relativity, G. Calabrese, J. Pullin, O. Sarbach, M. Tiglio, *Phys. Rev. D*, **66**, 041501, (2002).
Calibration of the LIGO detectors for the first LIGO scientific run, R. Adhikari. G. González, M. Landry, B. O'Reilly, *Class. Quantum Grav.* **20** (7 September 2003) S903-S914.

T-15 Penn State [PSU], USA
Penn State Center of Gravity

The Penn State Center of Gravity (PSCG) is one of two important collaborating groups (the other [LSU]) who will participate in GWEN without their own personnel funding. We request only travel funding for these institutions so they can participate in GWEN All-Hands Meetings. As described below, [PSU] brings unique strengths to GWEN and will work closely with its European members, directly participating in and supporting its scientific research, and expanding the breadth of training and experiences for GWEN YRs.

The PSCG hosts two main centers of gravity research. One is the Center for Gravitational Physics and Geometry (CGPG) established in 1993 under the direction of Abhay Ashtekar. The second is the Center for Gravitational Wave Physics (CGWP), an NSF Physics Frontiers Center established in 2001 with a total budget of $1 million/yr (director Sam Finn). One of the main missions of CGWP is to organize frequent conferences and meeting aimed at bringing different communities of researchers together and facilitating the development of GWA. The research at [PSU] ranges from efforts in quantum gravity and mathematical general relativity to gravitational wave phenomenology, data analysis and numerical relativity. Several GWEN nodes have long established collaborations with the members of [PSU]. For example, N. Andersson ([SoE]) and K.D. Kokkotas ([AUTH/UA]) spent three and one months, respectively, visiting CGWP during 2002. Another indicator of the close collaboration between [PSU] and European node members is the large number of postdocs and graduate students that have worked at a given time in both sides of the Atlantic (K. Camarda, S. Brandt, W. Tichy, J. Baker, P. Papadoupolous, J. Rouff, E. Schnetter, D.I. Jones, U. Sperhake, B. Krishnan, H.-P. Nollert).

Pablo Laguna (the Local coordinator) has significant expertise in computational relativity and astrophysics, and together with Bernd Brügmann heads the [PSU] numerical relativity group. Brügmann recently moved to [PSU] having spent many years at [AEI]. His main research interests concern BH simulations within numerical relativity. Deirdre Shoemaker will join [PSU] in the Fall of 2004. She is also a numerical relativist. Her main research interest is the interface between source simulations and data analysis. Also currently at [PSU], Ian Jones (postdoc) was a member of SOGW and continues to collaborate with colleagues in [SoE], [AUTH/UA], [FSU] and [SISSA] on GWs from NS. Experienced Researcher Ulrich Sperhake (postdoc) graduated from [SoE] and was supported by SOGW as a postdoc in [AUTH/UA]. His research is focussed on numerical relativity and nonlinear perturbation theory. Experienced Researchers Nina Janssen (postdoc) and Wolfgang Tichy (postdoc) recently joined [PSU] having held postdoc positions at [AEI]. Their main research interests concern BH simulations.

Interaction with [PSU] brings leverage for GWEN in several ways. Involvement with the CGWP conference programme provides a high profile forum for distributing the results of GWEN to colleagues in the USA and beyond. The numerical relativity effort at [PSU] largely complements that of the European groups and closer collaboration will further enhance target efforts. The group uses the `Cactus` framework in their `Maya` code for BH simulations, which *i)* facilitates direct sharing of initial data and analysis modules with other members of GWEN, and *ii)* allows direct comparison and benchmark testing of obtained results. [PSU] will work with GWEN to develop a perturbative framework for evolutions of rotating BHs. The ultimate aim being an improved understanding of GW radiation reaction and the details of gravitational captures, which is a key problem for LISA. This framework will also be used to improve current approaches to nonlinear-perturbative matching used at the last stages of BH merger (the so-called Lazarus approach).

PERSONNEL

Pablo Laguna (Local Coordinator, Prof., *numerical relativity, BH binaries*, (10%)
Lee S. Finn, (Prof., Director CGWP, *GW physics*, 10%), Bernd Brügmann, (Assoc. Prof., *numerical relativity*, 10%), Benjamin J. Owen, (Assis. Prof., *GW physics*, 10%) Deirdre Shoemaker, (Assis. Prof., *numerical relativity*, 10%), David I. Jones, Ulrich Sperhake, Nina Jansen, Wolfgang Tichy (Postdocs, *numerical relativity, BHs & NHs physics*, 10% each)

PUBLICATIONS

Moving black holes via singularity excision, D. Shoemaker, K. Smith, U. Sperhake, P. Laguna, E. Schnetter, D. Fiske, preprint (2003), `gr-qc/0301111`.
Bounding the mass of the graviton using binary pulsar observations, Lee Samuel Finn, Patrick J. Sutton, Phys. Rev. D **65** (2002), 044022, `gr-qc/0112018`.

B3.2 Intensity and Quality of Networking

GWEN is a cross-disciplinary effort aimed at training YRs through collaborative research projects with relevance for GWA. GW research combines a variety of areas, ranging from astrophysics and nuclear physics, to computational science and signal processing. Training in the broad range of skills required for GWA is not available at any single institution, hence the need for strengthening existing collaborations and forging new ones. The main aim of GWEN is to train a new generation of YRs in various issues crucial for GWA. GWEN also has significant socio-political aspects. Multiple GWEN teams are located in Less Favoured Regions ([AEI], [FSU], [AUTH/UA], [UIB], [CAMK]). In addition, the proposal incorporates travel support for collaborating partners from less favoured countries such as Romania and Bulgaria to take part in GWEN meetings.

Basic Communication. Collaboration between GWEN nodes will be carried out in a number of ways, extending connections and collaborative work habits formed within current EU Research Training Network "Sources of Gravitational Waves" (SOGW), which has already established strong lines of communication between many nodes. For nodes in such a diversity of locations, a great deal of the communication will be carried out through email and telephone calls including teleconferencing. We will also make use of innovative electronic means of collaboration, such as video conferencing, grid tools (e.g. Portals developed through the EU GridLab project) and leveraging technology developed by the DFN-Verein GriKSL network project.

Collaborative Use and Development of the Cactus Code. The modular, decentralised structure of `Cactus` allows for code modules to be co-developed by various teams, maintained and distributed through the central CVS repository in [AEI]. At any time, any member of the collaboration can create a customised simulation code needed for a particular physics simulation, composing the most recent versions of specific modules required. This has proven extremely effective during SOGW in the rapid development of `Whisky`, a relativistic hydrodynamics code developed as `Cactus` modules by a number of GWEN nodes. Through using `Cactus`, this code has been easily coupled to fully relativistic spacetime evolution systems, and has immediate access to independently developed tools, such as horizon finders and gravitational wave extraction techniques. Codes developed in `Cactus` are parallelised and can be compiled and run on platforms from laptops to any supercomputer architecture, maximising GWEN's effectiveness in using existing computational resources. To increase standardisation and interoperability, pre-existing codes (e.g., `Nada`) will be integrated into `Cactus`.

Video Conferencing. To allow the best possible interaction between nodes, we will use Access Grid (AG) based video conferencing. Some nodes ([AEI], [MPG.MPA], [UWC]) have installed AG systems to hold meetings between distributed locations and take part in remote training courses. A request for funds to add basic systems in nodes without this capability is included in Sec. B7. We are aiming to develop internet conferencing courses for YRs that would be carried out in conjunction with the Network training programme.

GWEN Web Pages. The GWEN web site (http://gwen.eu-network.org), an extension of the site for SOGW, will serve as a central information and coordination point. The pages are maintained with CVS with all GWEN members contributing to the relevant results, newsletters, meetings, papers, presentations, codes, documentation, computing information, etc. contained there. YRs will be encouraged to make significant contributions.

GWEN Newsletter. A newsletter, published each 6 months, will give network participants an overview of research activities at the various nodes. Importantly, this newsletter is organised by the YRs, allowing them to publicise their research and place it in the context of the network. Examples of such newsletters, published during the course of SOGW, can be found at http://www.eu-network.org/Documents/Newsletter.html).

Focus Groups. The different Focus Groups will maintain *project pages* containing training information, progress and results for the different tasks. Focus Groups will coordinate themselves through mailing lists, (maintained at [AEI]). These lists allow ideas to be exchanged among active researchers in a given field, and are archived for later reference. A number of such lists have been created and used profitably in SOGW.

Visitor Exchanges. Electronic contact alone is rarely sufficient for a successful collaboration, and we plan to have frequent visitor exchanges between the nodes. The [AEI] node in particular can be used as a central meeting point, with a vigorous visitor programme, including workstations and office space, which will be used to support this network. We will also work to exchange the Experienced Researchers and students supported by the Network for both short and longer term visits, as described elsewhere (Sec. B2.2, B4.1).

All-Hands Meetings. Regular (8 monthly) meetings of the entire GWEN collaboration will discuss progress and ensure global collaboration across the Network. In SOGW, such meetings proved very successful and well attended, attracting a much larger portion of the community than directly involved in the network.

B3.3 Relevance of Partnership Composition

GWEN is based on (a) numerous existing collaborations that predate SOGW, (b) greatly extended collaborations that resulted from SOGW, (c) *new* collaborating partners attracted by SOGW but not yet fully developed, and (d) cooperations that will be developed between GWEN and existing EU-funded projects in computation and Grid research. GWEN will have much stronger collaborations with US partners (especially through LSU).

The original SOGW training network was born from the need of separate groups around the EU to develop tools required for their scientific research and a close-knit, collaborative community required to tackle problems too large and complex for any one group. It was built on numerous existing collaborations, as partners had trained members of other partners. SOGW dramatically strengthened this community, creating a matrix of strong collaborations that did not exist previously. These developments are summarised in Appendix B10.4.

GWEN will build new collaborations and strengthen existing ones in several ways. The most important is the fundamental organisation of the work plan, from the tool/technique development orientation required for SOGW to the vertically oriented scientific Focus Groups in GWEN. These Focus Groups will extend and apply these tools in a synergistic way, as needed, to both realistic studies of GW sources and detailed analyses of their impact on GW detector data. This organisation will reshuffle existing collaborations, taking what is needed from each one and applying it to new tasks. At the same time, because of the enlarged scope of the scientific problems, entirely new partners are included ([UWC], [LSU], [MPG.MPA], [PSU], [IAAT], and [CAMK]). Research groups in present SOGW nodes are now integrated in the project ([AEI], [GReCO/LUTH/APC], [UVEG/UA/UB], and [AUTH/UA]). Other groups bring critical expertise in microphysics (e.g., [MPG.MPA], [CAMK], and [IAAT]), additional sources of GW ([MPG.MPA], [PSU], [LSU]), and GW data analysis (e.g., [UWC], [LSU], [GReCO/LUTH/APC], [AEI], and [PSU]).

Several GWEN partners bring in additional sites, organising *Regional Nodes*, further leveraging the training and scientific power of the network. Each Regional Node includes several research groups that did not participate in SOGW, building and strengthening local ties, bringing about an international partnership The [UVEG/UA/UB] Regional Node includes research groups in Barcelona and Alicante, the [GReCO/LUTH/APC] Regional Node includes research groups in Paris and Meudon, the [AUTH/UA] Regional Node integrates a group in Athens, and the South England Regional Node includes Oxford and Portsmouth.

New collaborations will be developed through close ties to partner projects in computational science and Grid computing. In addition to the GridLab, Gridstart, GriKSL, and DEISA projects, all of whom have agreed to support GWEN, the [SoE] group is now able to involve computational science experts. Finally, we stress that GWEN expects to develop further collaborations through its open, standards-based approach to code development and research. Numerous groups in Eastern Europe, Asia, Africa, and the Americas have already committed to work with GWEN (see letters in Appendix).

GWEN partners include two important members outside the EU, who will fund YRs from their own sources, but strongly participate in GWEN. We request only travel money for these partners to be able to attend GWEN meetings. [PSU] and [LSU] are among the leading centres of research in the US GW community. Recently, GWEN coordinator Seidel, Allen, and others have accepted joint positions between [LSU]and [AEI], ensuring very strong connections (see, e.g, Appendices for details). Previous work of [LSU] on well-posedness, numerical evolution, and boundary conditions is very important to the central mission of GWEN. [LSU] and [AEI] jointly develop *Cactus*. [LSU] provides important links to the world's most advanced GW detector, LIGO. [PSU] provides unique expertise on perturbation theory, used by [AEI], [SoE] and [AUTH/UA], and its Center for Gravitational-Wave Physics (CGWP) gives a perfect platform for GWEN result dissemination within the US community, and will help organise video conferencing and cross-Atlantic training sessions for YRs. The inclusion of [PSU] and [LSU] within GWEN broadens the training possibilities for YRs, brings in critical scientific expertise, and guarantees that the results of GWEN will reach a worldwide audience.

GWEN project partners are highly connected to industry. GWEN will be dependent on high performance networks; some partners have worked closely with commercial and government funded network providers on Grid computing experiments, winning multiple prizes at major conferences, including the Gordon Bell Prize. This work led to close connections with Deutsche Telekom, Force10 Networks, and other companies. Some of the partners have developed close relations with computer vendors; notably Cisco, Compaq/HP, Intel, Microsoft, SGI, and Sun, all of which have supported [AEI] or [LSU]. These contacts are important GWEN, leading to benefits ranging from special code optimisations to employment possibilities for YRs.

B4 MANAGEMENT AND FEASIBILITY

B4.1 Proposed Management and Organisational Structure

The YRs will be trained to draw on a wide range of techniques, in a collaborative way, with colleagues spread across the EU and beyond, while keeping focused on the concrete goal of detecting and understanding GWs. This requires strong and well-defined management. The structure outlined here will be finalised in the consortium agreement. Learning from experiences from SOGW, GWEN will have a more distributed and coordinated management structure (shown in Fig. B4.1), separating administrative and scientific/training issues.

Administrative Management: GWEN Management, organising and leading the project, comprises the *Network Coordinator* (NC) Seidel (SOGW leader), and a *Deputy Coordinator* (DC), John Miller from [SISSA] and Oxford [SoE]). The DC may substitute for the NC in case of absence. The Network Coordinator handles contacts with the EC, leads negotiations in the contract preparation phase, organises the central needs of GWEN and prepares required EU reports. An *Administrative Steering Committee* (ASC), comprised of the NC, DC and all Europe-based Local Coordinators, will handle GWEN administrative and financial issues and be responsible for overall scientific and training success. ASC meetings (generally closed) will be chaired by the NC. The ASC will appoint a secretary to take and circulate notes and agendas of all ASC meetings. ASC communications via Email (mail list) will be archived. Decisions regarding GWEN funding, administration, and organisation will generally be made by consensus of the ASC (this was always achieved in SOGW). When necessary GWEN will have a closed voting procedure to make decisions, requiring a quorum of at least 2/3 of the ASC members. In that case, each Local Coordinator (or proxy) will cast one vote. Measures will pass by a simple majority, over which the NC will have veto power, forcing a 2/3 majority to carry the measure.

Vertical and Horizontal Integration: GWEN is a project comprising several scientific, technical and training tasks spread over four different objectives. As shown in Fig. B1.5, significant interaction exists between tasks in each Objective, as well as across different Objectives. GWEN has a team of senior members who identify tasks and prioritize them to ensure that they are properly carried out, and that they receive inputs from all other relevant tasks. For example, Alicia Sintes will be in-charge of *vertical integration* of all data analysis (DA) in Objective C by identifying tasks and distributing them to various nodes, ensuring that DA software development takes place under a common standard. At the same time, there are thematic areas that cover several Focus Groups and for which it is important that a seamless flow of information and transfer of techniques takes place. We have selected senior members of GWEN to be in charge of the *horizontal integration* of these thematic areas. The full list of people in-charge of integration is given in Table B4.1 where we also show the relations among the thematic areas and the Focus Groups.

Scientific Management: A first ASC task will be to appoint a *Scientific Steering Committee* (SSC), to actively organise GWEN training and scientific aspects. The SSC will be comprised of the NC, DC and *Cognizant Scientists* (Cogs) in charge of the scientific, training, and outreach domains. At its first meeting (chaired by the NC) the SSC will elect (by consensus) SSC officers including chair, co-chair, and secretary. SSC communications via email will be archived. Cogs are not necessarily members of the ASC, and could even be external collaborators (see, e.g., Appendix B10.2), but will generally be senior researchers. The precise SSC composition will be determined at the first ASC meeting, but the expected structure is described here. SSC meetings will be generally open to the collaboration. The SSC will also include a peer elected *YR Ombudsperson* to represent issues of importance to all GWEN YRs (gathered anonymously if required).

As illustrated by the structure of Table B1.2, a number of GWEN *Focus Groups* (FG) will be created initially for each of the primary interdisciplinary topics described in the work plan. Each FG will be headed by a Cog, and will assign a lead YR. Other Cogs will be appointed for Outreach (e.g. web sites, assembling PR materials, broadcasting training sessions on the worldwide Access Grid, connection to external projects, etc.) and Training. As the project progresses, the number of Cogs may be changed, as decided by the ASC.

Cogs will ensure that their projects remain on track, that there is sufficient coordination with other FGs, and that goals and milestones are achieved. Cogs will report on the progress of their areas during each SSC Meeting, and will organise presentations representing their area (often assigned to YRs) at each GWEN meeting. Each 6 months, Cogs will provide the SSC chair with a 1-page (maximum) written report listing current progress, expected progress for the coming 6 months, and details of publications from the FG.

Meetings: “All-Hands” meetings of the entire GWEN project will occur every 8 months, with the first meeting organised immediately after the project beging. The ASC and SSC will meet (possibly by telephone/video) at least every four months. Cogs will organise their FGs much more tightly, via calls, visits, exchanges, etc.

Training: The Training Focus Group will coordinate YR training throughout GWEN and will *(i)* track PhD and research topics of GWEN YRs, *(ii)* coordinate/publicise training lectures, courses and material provided in GWEN, *(iii)* direct the training content of GWEN meetings, *(iv)* solicit short reports at six month intervals from YRs on their progress, problems, and training requests, *(v)* advertise relevant external training opportunities to the YRs, *(vi)* solicit advice from the SSC on appropriate training, *(vii)* report often to the NC.

Via these and other methods the Training Focus Group will ensure that *(i)* YRs are well trained across all relevant areas, e.g. astrophysics, GR, numerical analysis, computation, Grids, DA, *(ii)* YRs are trained in a wide range of essential skills such as document and proposal preparation, delivering talks, *(iii)* YRs are well known and involved in the widespread community, *(iv)* training sites provide adequate infrastructure for training, *(v)* all YRs are taking part in exchange visits to other nodes, and relevant workshops/conferences, *(vi)* YRs are provided with career advice. The Cog for training will also assign duties within GWEN for e.g. web site maintenance, newsletters, documentation. As in SOGW, YRs will be encouraged to assume appropriate management responsibilities, providing additional areas of training and helping the functioning of the network.

External Guidance: GWEN will seek guidance and advice on scientific progress and direction from an *International Advisory Board* (IAB), approved by the ASC, formed of leading researchers from Europe and abroad. (GWEN has already agreed to appoint Jean-Pierre Lasota (Paris), IAB chair for SOGW, as GWEN IAB chair, and additionally Joan Centrella (NASA), Jim Hough (Glasgow), Masaru Shibata (Tokyo) as IAB members (all have agreed)). The IAB will be invited to every all-hands meeting, will meet privately to discuss its progress and report to GWEN as they see fit (e.g. public and private meetings, written reports). Travel for IAB members will be paid by GWEN, as requested in the budget. An IAB was found to be a very important part of SOGW, where IAB members (from the US, Europe, and Israel) attended every Network meeting (5 occasions), and provided valuable input on the progress. Two of the members of the present board were so enthusiastic that they have joined the GWEN collaboration! GWEN management will solicit guidance from the EU Programme Officer as appropriate and also draw on local [AEI] support for project management.

Coordinating Infrastructure: The GWEN website (building from the existing SOGW site) will provide central coordination for results, newsletters, meeting summaries, papers, codes, documentation, computational information. GridLab `GridSphere` portal software will be used to create an improved collaborative environment with interactive calendars, news server, etc. As for SOGW, extensive use will be made of (archived) mailing lists (hosted at [AEI]). All codes, but also documentation, papers, reports, tools/codes and web pages will be distributed and collaboratively developed using the SOGW/GWEN CVS repository. A bug/feature/task-tracking system will be created (leveraging existing `Cactus`/GridLab tools) for the GWEN project.

Financial Management: GWEN funds will be distributed to partners at the start of the project to allow nodes autonomy over their own budgets and to reduce administrative overheads (following good experiences with the same procedure in SOGW). The community contribution to management-related expenses will be primarily used to fund the necessary node audits and to provide the coordinating node with a part-time administrative assistant (who is already providing assistance for SOGW).

Dissemination/Outreach: An Outreach Focus Group covers dissemination of GWEN results, and connections to external projects and groups in the EU and beyond. This FG will *(i)* monitor/record GWEN publications and talks, *(ii)* establish a GWEN identity using webpages, talk templates, etc, *(iii)* ensure that existing external collaborators are being included and leveraged adequately, *(iv)* expand the GWEN collaboration and training opportunities. Long term dissemination will be ensured, during and after GWEN, through GWEN's web site, a code repository containing freely available codes and tools used in the project, publications from in key journals, and successful training of the YRs who remain in the field.

Intellectual Property: GWEN members have extensive experience with intellectual property and software licensing. Authorship is generously attributed, and is generally alphabetical (strong priorities, e.g., major student work, will generally lead to first-authorship). The YR Ombudsperson will represent the student interests to ensure their contribution is adequately acknowledged. Software (notably the `Cactus` framework and `Lorene`) developed by SOGW is already freely available under public licenses. GWEN intends to distribute modules and documentation developed for relativity and astrophysics to aid the worldwide community, after having been adequately tested and used for the primary research topics which they support in GWEN.

Thematic Areas	Objective						
	A. Training	*B. Tools*	*C. Core Astrophysics*				*D. LISA*
			Binary Systems	*Genetics*	*Forensics*	*Data analysis*	
	G. Allen [AEI]	**P. Diener [LSU]**	**E. Gourgoulhon [GReCO/LUTH/APC]**	**J. Pons [UVEG]**	**N. Stergioulas [AUTH]**	**A. Sintes [UIB]**	**J. Romano [UWC]**
Mathematical Methods: **C. Bona [UIB]**	×	×	×		×		×
Relativistic Hydrodynamics: **L. Rezzolla [SISSA]**	×	×	×	×	×		
post-Newtonian Approximations: **G. Schäfer [FSU]**	×		×	×	×		×
Perturbative Approximations: **N. Andersson [SoE]**	×	×	×	×	×	×	×
Astrophysics inputs to DA: **B.S. Sathyapraksh [UWC]**			×	×	×	×	×

Table B4.1: The full list of GWEN members in-charge of vertical and horizontal integrations. Shown with crosses are the relations among the thematic areas and the Focus Groups.

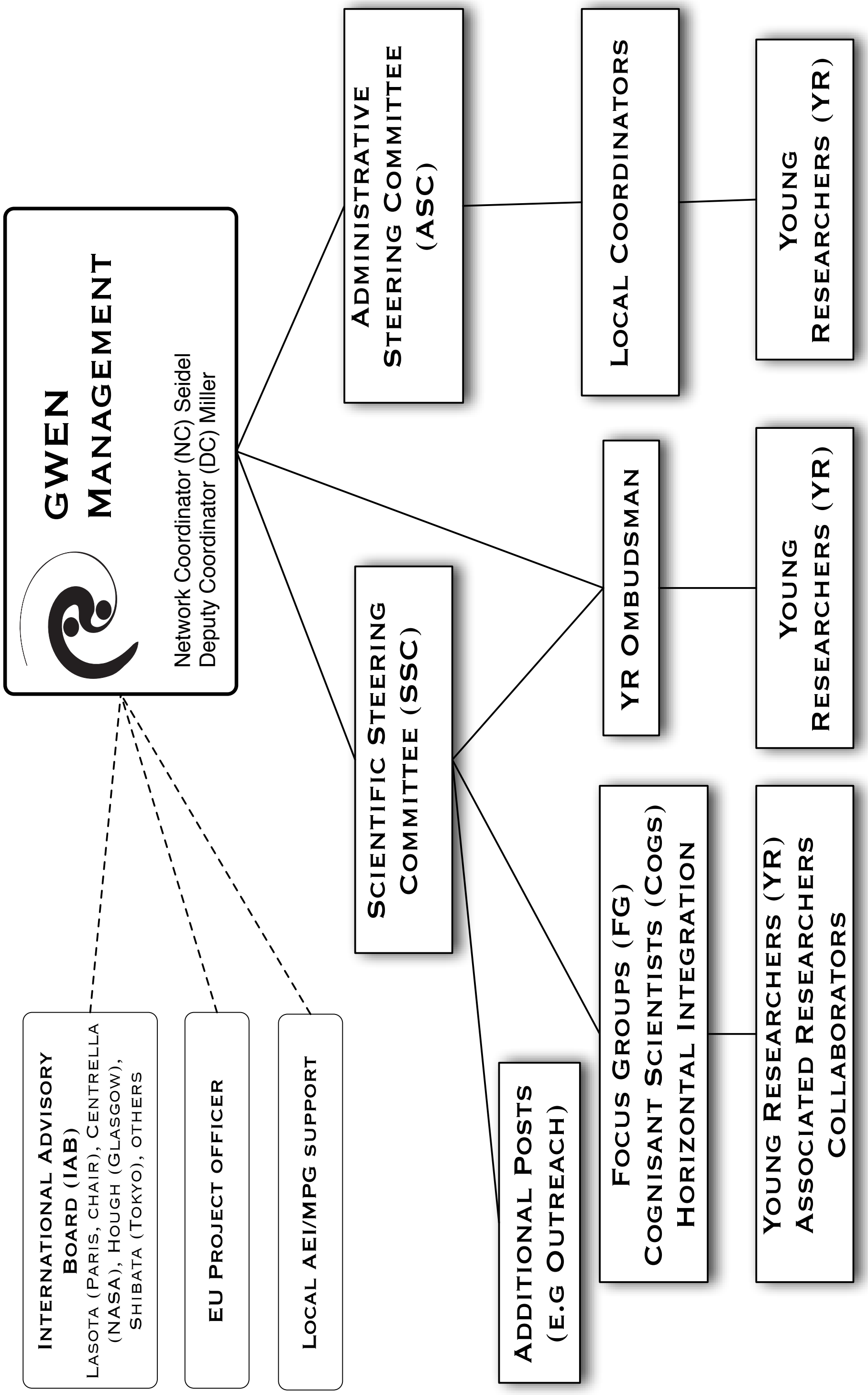

Figure B4.1: Management Structure for GWEN

B4.2 Management Know-how and Experience of Network Coordinator

Network Coordinator (NC) Seidel has extensive experience leading large scale projects both in Europe and the US, and in developing and maintaining widespread international collaborations to supplement and extend them. Seidel has 20 years experience in numerical relativity and the development of collaborative computing technologies to be used throughout GWEN. In recent years he has become a recognised leader in Grid computing technologies, especially in the area of application frameworks for the Grid (he is the Co-Chair of the *Applications Research Group* of the Global Grid Forum (GGF)). These different areas of expertise are all important to GWEN's interdisciplinary mission, and are widely utilised by it.

The competence and capability of Seidel in managing a project such as GWEN is clearly illustrated by the success of the current EU Research Training Network "Sources of Gravitational Waves" (SOGW) which he leads. SOGW, involving 10 EU sites and several collaborating sites in the US, is the forerunner of GWEN. The SOGW project has been highly successful, as viewed by its Young Researchers (YRs), senior participants and Local Coordinators, and by the international research community. Confidence in Seidel's management of GWEN is demonstrated by the fact that *all* member institutes of SOGW are taking part in GWEN, and are joined now by two members of the SOGW Advisory Board. SOGW has served as a coordinating body for a much larger group of researchers than those funded by SOGW; recent SOGW meetings have been attended by around 70 participants from many sites worldwide, while only 10 YRs are funded by the project itself!

SOGW has worked very hard to ensure that the YRs achieve their goals, are well trained, and are integrated into both the Network and the larger international communities which will be important for their future careers. SOGW was used by the European Commission as an example of "Best Practice" in a recent conference on the 6th Framework Programme. Experiences obtained through leading the successful SOGW allows Seidel to make various improvements in GWEN's organisation and training program to be even stronger than SOGW. Appointment of Deputy Coordinator Miller, and creation of horizontal management coordinators (See. B4.1) and Regional Nodes, will help to more tightly integrate all subprojects and participants than in SOGW.

Seidel has experience in other large scale projects of great relevance to GWEN. He is the leader of the [AEI] numerical relativity group, one of the strongest, and the largest research group in this area in the world. He was a founding member of the GridLab project, a much larger 5th Framework Programme in Grid computing led by Jarek Nabrzyski, but involving [AEI] (Allen, Schutz, Seidel) and [UWC] (Sathyaprakash), with a strong focus on application support for the Grid. The aims of GridLab and other Grid projects overlap with computational needs of GWEN; partly through Seidel's involvement, GridLab and other projects (GGF, Gridstart, DEISA, etc.; see Appendix B10.2) will support GWEN with training on and development/customisation of Grid technologies (Portals, Virtual Organisations, Grid Application Toolkits, etc., as described in Sec. B1.3). Seidel also leads the DFN-Verein Gigabit (GriKSL) project, developing the capability to exploit high speed networks for remote simulation and visualisation, distributed computing, and collaborative technology. These various Grid technologies will all be made available to GWEN participants. The `Cactus` Framework, used extensively to enable SOGW to develop computing tools for GWA, and the wider relativity/astrophysics communities, as well as an increasing number of other disciplines, from climate modeling to chemical engineering, originated in Seidel's group. `Cactus` is now further developed and maintained by the LSU group and a growing worldwide collaboration of computational researchers.

Previously, Seidel was involved in two large scale projects of a similar nature in the US. He was a Principal Investigator (PI) in both the American NSF Black Hole Grand Challenge Project ($4M over 5 years), a collaboration of 8 US universities, and the NASA Neutron Star Project ($1.4M over 3 years), a collaboration of 6 institutes including [AEI] in Potsdam. Both of these were similar in nature to SOGW, although carried out at earlier stages in the development of this field. He was also a PI in the NSF "Astrophysical Simulation Collaboratory" (ASC) project, just ending in 2003, involving 5 US institutes and the [AEI]; and technologies from the ASC, such as its Portal and various `Cactus` technologies, will be used in GWEN. The synergies between these projects illustrate the capabilities of Seidel not only to organise and manage large projects, but importantly to leverage and connect expertise from different fields (the GridLab and GriKSL projects both use the large scale simulations of SOGW as example applications for their research and development).

Although GWEN is a large Network and ultimate responsibility rests with the Coordinator, administrative, scientific and training in GWEN will be distributed in a highly coordinated fashion through the steps described throughout the proposal. Seidel will additionally be assisted by highly competent staff at [AEI] and [LSU] .

B4.3 Management Know-how and Experience of Network Teams

T-01 Potsdam [AEI]: Max-Planck-Institut für Gravitationsphysik (Albert-Einstein-Institut) The Potsdam site of [AEI] hosts 24 permanent staff, 29 postdocs, and 25 students, researching mathematical, astrophysical, and quantum relativity. The Hannover site, containing the [AEI] experimental branch operates the joint German-British detector GEO600. In addition to the management expertise of the GWEN Network Coordinator B4.2, [AEI] is very experienced in managing large projects and in training YRs. It has the been the principal site for numerous large scale projects of this type, importantly including the current EU Research Training Network "Sources of Gravitational Waves" (SOGW) for which [AEI] is the coordinating node. But it also offers GWEN other unique advantages. Its visitor programme is used to support dozens of visitors from around the world each year; SOGW took advantage of this to bring together various Focus Groups, as will GWEN. [AEI] has also run international schools on various areas of theoretical physics, including numerical relativity. It has staff specifically tasked with helping foreigners relocate to Germany and Europe generally, who will be made available to GWEN YRs. [AEI] Scientific Coordinator E. Mueller will work to give career training for all GWEN YRs, giving seminars of EU and other programmes relevant to their career development. The Research Programmer to be hired by GWEN will take advantage of the [AEI] group's expertise and facilities to support and train all GWEN partners in many areas of modern scientific computing, visualisation, Grid, and conferencing technologies, and administer centralised GWEN computational facilities (CVS, mailing lists, website, etc.) maintained at [AEI].

T-02 Jena [FSU]: Physikalisch-Astronomische Fakultät, Friedrich-Schiller-Universität The Gravitational Theory Group at the University of Jena has 3 professors, 4 additional staff positions (two are permanent), and 4 PhD students. The group is experienced in networking through SOGW. The group is a member of the new German Research Network (DFG-Sonderforschungsbereich/Transregio) on Gravitational Wave Astronomy (PI: G. Neugebauer, Co-PI: G. Schäfer) which comprises three Universities and two Max Planck Institutes, including the GWEN nodes [AEI], [IAAT], and [MPG.MPA]. The experienced researchers brought in by this research project will contribute to the training of an GWEN Early Stage Researcher in Jena. For several years, the research of the Gravitational Theory Group was supported by the Max Planck Society in the form of a research group (Arbeitsgruppe Gravitationstheorie) of limited duration. G. Schäfer spent two years at the Département d'Astrophysique et de Cosmologie (DARC), Observatoire de Paris-Meudon (predecessor of [GReCO/LUTH/APC]), and four years at [MPG.MPA]. The infrastructure of the FSU site, including computational facilities, allow for an efficient collaboration with the other sites. Longstanding collaborations of senior members of the Jena node with most of the senior members of the other nodes make the management of the collaboration easy. The broad experience of the FSU site with analytical tools will strongly support the numerical activities of the other sites of the planned Network. To strengthen this part, the FSU node has involved G. Zumbusch, previously involved in three different German Networks (SFB 256, 350, 611) and in a grid computing network (DFN gigabit testbed west), to support the mixed analytic-numerical developments at the FSU site locally, and also Network-wide if appropriate.

T-03 Paris [GReCO/LUTH/APC]: Laboratoire de l'Univers et de ses Théories (LUTH) and Gravitation Relativiste at Cosmologie (GReCO) Both groups originated from the Département d'Astrophysique Relativiste et Cosmologie (DARC), which was one of the ten network teams involved in current EU Research Training Network "Sources of Gravitational Waves" (SOGW). In the 1999-2002 period there have been 3 young researchers working with senior staff members involved in this proposal, all of them have now other post-doc positions and are taking advantage of the experience gained in the group, in numerical and scientific fields. LUTH is financially supported both by the Observatoire de Paris and the Centre National de la Recherche Scientifique (CNRS). It is mainly focusing on theoretical astrophysics and has 33 staff members, 3 post-docs and 18 PhD students. Researchers that are involved in this proposal are also part of a French collaboration, supported by the CNRS, on numerical techniques, together with the Mathematics and Physics Department of Tours University and the Applied Mathematics Department of Pierre et Marie Curie University (Paris VI). GReCo is physically located at the Institut d'Astrophysique de Paris, and financially supported by the CNRS and Pierre et Marie Curie University (Paris VI). It is composed of three teams working in primordial cosmology, general-relativity and ultra-high energy physics, and it has 11 staff members, 2 postdocs and 3 PhD students. The general-relativity team of GReCO is composed of 5 staff members and 1 PhD student. It has strong interactions with both VIRGO and LIGO, in providing theoretical gravitational waveforms based on PN techniques for binaries made of compact objects, in the data-analysis and in designing advanced configurations of laser-interferometer gravitational-wave detectors. Some members of GReCO will eventually move to the new "Astroparticle and Cosmologie" (APC) group in 2005. LUTH and GReCO have also regular exchanges with other network teams involved in this proposal ([CAMK], [UVEG/UA/UB], [MPG.MPA], [SoE], [UWC], [FSU] and [AEI]).

T-04 Valencia [UVEG/UA/UB]: Departamento de Astronomia y Astrofisica (DAA), Universidad de Valencia is a well established astronomical research centre specially focused on theoretical astrophysics and cosmology. The DAA has 16 academic staff, 3 Advanced Fellows (under the so called *Ramón y Cajal* programme), 3 post-docs (two of them under contract by RTN networks) and 5 PhD students. DAA has participated as a node in a previous TMR networks and nowadays is currently involved in three RTN networks. There are also several national and regional grants supporting research projects. The research directions of DAA also include observational groups working in radioastronomy and high energy astrophysics (INTEGRAL). In the last five years, seven students successfully obtained PhD. degrees, and all now have research/academic related jobs. Researchers who will work in the network have participated in previous TMR and RTN networks, as well as several national and regional grants. Furthermore, the DAA has hosted four individual Marie-Curie return fellows. As a result, the department administration has extensive experience in the financial management of EU contracts. Scientific relations with staff at [MPG.MPA], [FSU], [GReCO/LUTH/APC], [AEI], [URLS], [AUTH/UA], and [SISSA], are close, with frequent exchange visits. Together with some of these groups will provide much of the coordination of the network's simulation and code development programmes. Valencia's group is currently training one YR, funded by the Spanish Ministery of Science and Technology, to work with [FSU], and [MPG.MPA], in the study of rotational stellar core collapse within the CFC+ approach. Valencia's node will manage the funds of the *Regional Node* defined by the participation of members from the Universities of Barcelona (UB) and Alicante (UA), as was mentioned in Sec. B3.1.

T-05 Palma [UIB]: Relativity Group, Departament de Física, Universitat de les Illes Balears The Palma relativity group is a well established group supported by research grants from the Spanish Ministry of Science and Technology and the local Government of the Balearic Islands. The group has also been involved in NATO networks and in SOGW. The research of the group covers different fields of gravity and relativity: symmetries in general relativity, exact solutions; numerical relativity; and gravitational wave data analysis. The senior group members have supervised several Ph.D students, the majority of them being now well established researches. The group trains about two undergraduate students per year, under the so-called 'proyecto final de carrera', and has now 2 Ph.D. students (Mr. Palenzuela and Mr. Luna) working on numerical relativity and gravitational wave detection. Two post-docs, Dr. Ledvinka and Dr. Zacek, have been trained successfully under SOGW in the field of numerical relativity. The group has a long track-record of participation to large collaborations both in numerical relativity (Massó. is one of the original authors of `Cactus`) and in GW data analysis (Sintes is the chair of the GEO detector characterisation working group and has contributed to the LIGO Algorithm Library (LAL)). Research links also exist with [AEI], [UWC], [URLS], [UVEG/UA/UB] and [LSU] groups, with frequent exchange visits.

T-06 Thessaloniki [AUTH/UA]: Department of Physics, Aristotle University of Thessaloniki The Aristotle University of Thessaloniki (AUTH) is the largest academic and research institution in Greece, with several dozens of Departments involved in numerous EU-funded research programmes in the last 20 years. The management of all research programmes is done very efficiently through the Research Committee of the AUTH. The Department of Physics is the largest in Greece, with more than 1000 enrolled undergraduate students, about 150 graduate students and 100 permanent staff members. The relativity group is part of the Astrophysics, Astronomy & Mechanics section, which has 14 staff members, 5 post-docs and 10 PhD students. One former European post-doc of the relativity group has been a Marie-Curie fellow, while the section is currently participating in two RTN networks (gravitational waves and solar physics), each supporting one European post-doc. In addition, members of the relativity group and of the section have participated in several bilateral research programmes with Poland, Netherlands, Germany, the UK etc. The relativity group has close research collaborations and frequent exchanges with nearly all nodes of the present EU network on gravitational-wave sources as well as with the new nodes included in the present proposal and with other groups in the USA and Japan. These collaborations have lead to the publication of nearly 60 papers in refereed journals in the last five years, most of which involved young researchers. In the last five years, members of the relativity group have supervised three PhDs who have moved to academic or research positions as well as a large number of Diploma theses in general relativity (several students obtained fellowships and continued their graduate studies at Departments in Europe or US). The relativity group is participating in SOGW, in which it has coordinated the research in one area (time evolutions of linear perturbations) and was responsible for another sub-area (nonlinear simulations of isolated stars). The group has successfully hosted one of the large network meetings. Funds associated with the participation in the proposed network of members from the University of Athens will be managed by the relativity group through the Research Committee of the AUTH.

T-07 Rome [URLS]: Physics Department, University of Rome "La Sapienza" The Physics Department of the University of Rome "La Sapienza" has a tradition in theoretical and applied research that dates back to the days of Enrico Fermi. It hosts experiments and groups that are leaders in many fields of physics that include elementary particles, condensed matter, astrophysics and cosmology.

Resonant bar detectors for gravitational waves were introduced in Europe by the Rome group lead by Edoardo Amaldi in the sixties, and since then the experimental group has become a leader in that research activity. It includes a strong data analysis team and it is also part of the VIRGO collaboration. Being involved in important scientific collaborations, the Department is used to managing big projects. In the last three years it has been administrating 6 TMR European Networks, as well as research projects funded by the Italian Space Agency (ASI) and by the Italian Ministry for Universities and Research (MIUR). The Physics Department is also a leading institution in higher education, with 157 faculty members and 1292 undergraduate students. It has two PhD programmes, in Physics and in Astronomy and Astrophysics, which involve, on the whole, an average of 50 students.

The Rome Relativity Group is part of the Theoretical Group of the Physics Department, and actively interacts with the gravitational wave experimental group. The three senior members (V. Ferrari, O. Benhar, P.Astone) have long experience in training students and post-docs in fields of physics that range from general relativity to nuclear physics and data analysis. The group has close collaborations with [SISSA], [UVEG/UA/UB], [SoE] and [AUTH/UA], with frequent exchange visits. During SOGW it has exchanged a post-doc with [UVEG/UA/UB] and [AUTH/UA]. The group is supported by research grants of the Italian Ministry for Universities and Research (MIUR) and of the Instituto Nazionale di Fisica Nucleare (INFN), which is the funding agency for gravitational wave experiments in Italy.

T-08 Trieste [SISSA]: Settore di Astrofisica, Scuola Internazionale Superiore Studi Avanzati SISSA in Trieste is one of Italy's leading centres for higher education and research. It has a scientific staff consisting of 50 professors and researchers, 40 Experienced Researchers and advanced fellows, and 160 graduate students. SISSA is part of a scientific campus together with the International Centre for Theoretical Physics (ICTP) and the Department of Theoretical Physics (DFT) of the University of Trieste. Scientific research at SISSA is organised in sectors. At present there are 8 sectors, covering various branches of Physics, Mathematics and Biology. The Astrophysics sector has 8 faculty members, 3 advanced fellows, 5 postdocs, and 21 graduate students. It carries out research in topics ranging from early-Universe cosmology, over structure formation and physics of galaxies, to relativistic astrophysics. The research in relativistic astrophysics is focused on neutron-star physics, accretion onto compact objects, numerical relativity and sources of gravitational waves. In collaboration with the Trieste Observatory, the Astrophysics Sector is responsible for a Data Processing Centre for the Planck Surveyor mission of the European Space Agency. SISSA is presently involved in 4 RTN networks. The Astrophysics sector is a node of one these (SOGW) and was also a node in a previous TMR network. In addition to this, the sector is a recipient of funds from the Italian Ministry for Universities and Research (MIUR), the Italian Institutes for Astrophysics (INAF) and Nuclear Physics (INFN), as well as the Italian Space Agency (ASI). It is also running bilateral research agreements with Sweden (Chalmers Univ.), Poland (Szczecin Univ.), the Czech Republic (Opava Univ.) and the UK (Univ. of Oxford). SISSA is also deeply involved with the training of YRs. It has an extensive range of advanced courses in related topics which are followed by its own students and also by students from the neighbouring ICTP and the University of Trieste. Some of the academic staff of the Astrophysics sector also hold regular seminars and courses in other national and international centres. In SOGW, the SISSA relativistic astrophysics group has participated actively in a number of research areas and has trained 3 students and 2 Experienced Researchers in all aspects of gravitational wave research with independent funds, as well as having a European student supported from Network funds. In addition to this, the relativistic astrophysics group has coordinated the construction of the relativistic hydrodynamics code `Whisky`, an important symbol of the collaborative spirit of the Network. There are close collaborations with staff at [AEI], [AUTH/UA], [CAMK], [GReCO/LUTH/APC], [SoE], [URLS], and [UVEG/UA/UB], with frequent exchange visits. A number of papers have been published in refereed journals as a result of these collaborations. This very active level of cooperation and mobility will continue with GWEN, in which the SISSA relativistic astrophysics group intends to train a European Experienced Researcher and further coordinate the use of `Whisky` in a number of applications.

T-09 South of England [SoE] The University of Southampton Relativity Group is one of two research groups within the Applied Mathematics Group in the School of Mathematics. All areas on mathematics in the School, namely Pure, Applied, Statistics and Operational Research, were rated internationally excellent in the last UK Research Assessment Exercise in 2002. The Relativity Group consists currently of 2 Professors, one Reader and one Lecturer, together with two postdocs and and 9 Research Students. The groups research interests include numerical relativity, source modelling, critical phenomena, gravitational collapse, mathematical relativity and computer algebra in GR. One of the staff members is the holder of a Philip Leverhulme Prize Fellowship, which is a prestigious award for outstanding research achievements.

The Institute of Cosmology and Gravitation (ICG) (formerly the Cosmology and Relativity Group) in Portsmouth is a very active group of researchers who were awarded a grade 5 in the 2001 UK Research Assessment Exercise in recognition of their international excellence. ICG staff consist of 2 Professors and an Emeritus, 2 Readers, 2 Senior Lecturers and one Temporary Lecturer. It currently has 6 Experienced Researchers, and 10 PhD students, one funded by the SOGW and another 3 working on GW projects.

[SoE] has a long and successful track record of supervising both Postdoctoral Fellows and Research Students. In particular, ICG is part of an International PhD programme in Astrophysics and Gravitation (Dr Bruni is the Local Coordinator), together with four other EU universities. In the last two years [SoE] students have obtained postdoc positions in various international research groups, and our Experienced Researchers have all found a position after their time in the [SoE] groups. Earlier this year an Experienced Researcher, Dr Jose-Maria Martin-Garcia, who had completed an EPSRC-funded post-doctoral fellowship, was awarded a Marie-Curie fellowship to carry out research in [AEI]. Around the same time a PPARC-funded postdoc, Dr Ian Jones, took up a postdoc position in [PSU], while Dr Ulrich Sperhake left to take up an SOGW position in [AUTH/UA] for a period before joining [PSU]. Dr Carlos Sopuerta, an Experienced Researcher who previously was a Marie Curie Fellow and then an EPSRC-funded post-doctoral fellow, has recently moved to [PSU]. Another former [SoE] research student, Dr Denis Pollney, now plays a key role in the Numerical Relativity Group in [AEI]. After graduating, Virginia Re took up a postdoc position in Birmingham. The nodes most recent PhD graduate, Anna Watts, is due to take up a position at NASA-Goddard after Christmas.

The groups in the [SoE] node run both external and internal seminar series, as well as joint colloqia and extensive international visitor programmes. The [SoE] research interests can be demonstrated by the topics which the current postgraduate students are working on, namely: Dynamics of differentially rotating NS, GW from rotating NS, rotating superfluid stars, perturbations of BH, hyperbolic formulations of GR, wave extraction in numerical evolutions, the radiation reaction problem for GWs and exact methods for characterising NS spacetimes. The members of [SoE] played a key role in the SOGW. Southampton also hosted the Third Network Meeting and The Midterm Review, and so has a significant experience of managing important aspects of an EU Network. Moreover, [SoE] has extensive experience of managing research grants in general, as it has been involved with some ten different British and European grant agencies. In particular, the [SoE] groups have had several EU funded Marie Curie fellows in the last few years.

T-10 Cardiff [UWC]: Cardiff University is the largest Welsh University, recently rated the UK's seventh best institution for research. The Department of Physics and Astronomy, to which the Relativity Group belongs, is growing rapidly, doubling its staff in astronomy from 7 to 14 in the past four years. The Department has vast experience in managing large projects thanks to the involvement of its members in international ground- and space-based astronomy projects such as BLAST, BOOMERAMG, HST, NGST, SCUBA2, SPIRE, gravitational wave experiments GEO600, LISA and LIGO and Grid projects GridOneD and GridLab. Participation in these international projects warrants careful planning, timely execution and management via constant communication between our partners using all forms of modern communication, including Access Grid.

The group's GW research is focussed on (a) detector characterisation (DC), (b) algorithms to search for astrophysical sources and cosmological backgrounds, (c) search for astrophysical transient sources in data from

GEO and LIGO, and (d) data mining and interpretation. The group has developed many software monitors for detector debugging and was specifically charged by the LIGO Scientific Collaboration (LSC) to implement the templates and algorithms it discovered to search for binaries of black holes and neutron stars. In collaboration with another LSC group at the University of Wisconsin at Milwaukee, Cardiff has successfully accomplished this goal.

Research in software for data analysis (DA) is focussed on developing generic Grid technology for the group's Java-based problem solving environment called `Triana.` This activity is supported by the `GridOneD` (funded by PPARC) and GridLab (funded by EU) projects. The aims of these projects are to: (a) support developers and users to easily integrate diverse legacy applications, (b) provide a data-mediation layer for data-type translation between legacy and Java applications, (c) extend the Triana implementation to include plug-in services that are needed for it to be used within a Grid context, and (d) create a JXTA applications API and use this to implement a peer-to-peer (P2P) version of Triana.

The group trains its predocs and postdocs in both source studies and DA as well as in computational science warranted by such studies. Involvement in international collaborations, such as GEO600, LSC and GridLab, helps the young researchers to gain invaluable experience in proper planning and timely execution of research programmes and in collaboratively working with research groups world over.

The Cardiff group will manage the DA tasks in GWEN, liaising between theory and DA groups, coordinating algorithm development tailored to specific astrophysical sources and their application to real data.

T-11 Garching [MPG.MPA]: Max-Planck-Institut für Astrophysik The Max-Planck-Institut für Astrophysik (MPA) is one of the 80 autonomous research institutes within the Max-Planck-Gesellschaft. Although MPA scientists are mainly working on problems in theoretical astrophysics, they also participate in a number of observational projects. At any given time the MPA has about 40 scientists working on long-term positions at postdoctoral level and above, up to 15 foreign visitors brought in for periods of varying length under a vigorous visitor programme, and more than 30 graduate students. The students are mostly enrolled for degrees in one of the two large universities in Munich. A number of the senior staff at MPA have teaching affiliations with one or other of these universities. The MPA is also actively participating in the *International Max-Planck Research School on Astrophysics* which was founded in 2000 on an initiative of the Max-Planck Society. It is open for students from all countries world wide.

Since 1996 the MPA is part of EARA, a European Association for Research in Astronomy which links it to the Institut d'Astrophysique de Paris, the Leiden Observatory, the Institute of Astronomy, Cambridge, and the Instituto Astrofísico de Canarias in a programme dedicated to fostering inter-European research collaborations. Such collaborations are also supported by membership in a number of EC-funded networks, some of which are coordinated by the MPA, dealing with the physics of the intergalactic medium, the cosmic microwave background, gravitational lensing, and accretion onto black holes, compact stars and protostars, type Ia supernova explosions, and gamma-ray bursts. As a consequence of the various European TMR and RTN networks involving MPA in the past and presently (8 up to now), its administration has extensive experience in the financial management of EC contracts, and its senior scientists have comprehensive know-how in training of young researchers. The MPA is also a Marie Curie training site (HPMT-CT-2000-00132).

T-12 Tübingen [IAAT]: Institute of Astronomy & Astrophysics, University of Tübingen The Institute of Astronomy & Astrophysics of the University of Tübingen [IAAT] is a well established astronomical research centre. It has 4 full professors, about 15 additional academic staff positions (not all permanent), and 24 PhD students in the field of Astronomy/Astrophysics. The [IAAT] node has extended experience in experimental astronomy, is involved actively in several projects in High-energy astrophysics (ROSAT, XMM, INTEGRAL, HEXE), Optical and UV Astronomy (ORFEUS, WSO). On the theoretical side, the institute is coordinating the Special Research Project SFB 382 ("Numerical Simulations on Super-Computers") funded by the German Science Foundation, and is Co-PI on the SFB-TR7 ("Gravitational Wave Astronomy") together with [FSU], [AEI], and [MPG.MPA]. These two projects alone provide the institute with about 10 pre-/post-doc positions. Several scientific research topics at the [IAAT] are related to the GWEN proposal.

The [IAAT] group administrates some of the largest funds and research grants in the Physics Faculty, and as such it has extensive experience in managing larger projects. The institute already has long term scientific connections to the other participating institutions [AEI], [FSU], [MPG.MPA], [AUTH/UA], and [GReCO/LUTH/APC] with frequent contacts and visits, which will be very fruitful for the network. The teaching experience at the University Institute is extensive and provides an ideal environment for European students.

T-13 Warsaw [CAMK]: N. Copernicus Astronomical Center [CAMK] is the largest of the Polish astronomy institutes. While being a research institute of the Polish Academy of Sciences, it is largely autonomous. The [CAMK] budget is obtained directly from the KBN (State Committee for Research). Moreover, [CAMK] has its own financial administration and accounting. Financial managing and hiring of the personnel is done directly by the [CAMK] director. The scientific staff consists of 35 Assistant/Associate Professors and 14 Professors, plus 6 Experienced Researchers. There are now 16 graduate students at [CAMK] Graduate School, leading to some 4-5 PhDs per year. The [CAMK] scientists are working on astrophysics and on cosmology. The [CAMK] researchers direct Polish teams in major international programmes such as INTEGRAL, FIRST, and the SALT (South African Large Telescope) consortium; the Polish participation in these international programmes is administrated by [CAMK]. Seminars (both a weekly colloquium and a Journal Club) are in English. The senior members of the [CAMK]-GWEN team have long experience in the training of YRs. Haensel has long experience in training YRs in dense-matter microphysics and neutron-star physics (in the last two decades, he supervised four PhDs in Poland and five PhD students in France). Zdunik is specialised in neutron-star EOS, structure, and dynamics, and has supervised one YR in this domain. Bulik trained three YRs in topics such as gamma-ray bursts modeling and population-studies of NS-NS, BH-NS, BH-BH binary systems in the Galaxy. In the past decade, Kluzniak trained three YRs in the domains of relativistics astrophysics (accretion disks around NS and BH) and dense matter microphysics (nucleon superfluidity), who got their PhDs at the University of Wisconsin at Madison (USA). Szuszkiewicz trained two YRs in the theory of accretion disks around BH. Krolak supervised one YR in the relativistic theory of NS-NS binary inspiralling and related GW radiation. All these senior members of the [CAMK] team are ready to train in their domain of competence not only the two YRs which the team asks to be funded by GWEN, but also GWEN YRs from the other teams (particularly [SoE], [SISSA], [UVEG/UA/UB]): this could be accomplished if they spend a fraction of their 36 month GWEN contracts at [CAMK]. Senior [CAMK] team members were and are now Principal Investigators of numerous 3-year KBN Research Grants (administrative support and accounting being supplied by the [CAMK] institute). Since 1992, Haensel has been the Polish Coordinator of the France-Poland Astronomy Program, involving thirty Polish and twenty five French researchers, and administrated on the Polish side by [CAMK].

T-14 Baton Rouge [LSU]:Louisiana State University The relativity group at [LSU] has three professors in theory, three professors in experiment and two professors in astrophysics theory. Of these, the two relativity theorists, one of the experimentalists and one of the astrophysicists participate in this proposal. The group has currently four postdoctoral researchers and two graduate students. We expect four new graduate students to join the research group next year. The [LSU] group has access to the fastest supercomputer in the world that is controlled entirely by a university ”Supermike” at [LSU] with 1025 Pentium class nodes. The supercomputer is run by [LSU]s CAPITAL centre for computational science. The profile of research at [LSU] , in which numerical codes are written based on a strong analytic foundation and using the latest cutting edge numerical analysis tools, will complement very well the strengths of GWEN. [LSU] also has strong links with the LIGO project (the Livingston detector being located 50 kilometers away). The experimental group is also heavily involved in data analysis of LIGO and GEO600 data within the international LIGO Science Collaboration. This is particularly crucial since the results obtained within GWEN, and the detailed data analysis strategies developed, must be implemented in the detection pipeline. This requires an understanding of the many complicated issues associated with the detailed operation of the detectors. Interaction with the LIGO group at [LSU] would add this dimension to the GWEN project.

T-15 Penn State [PSU]: Penn State University, Center for Gravitational Wave Physics Penn State University hosts two main centres of gravity research. Particularly important for GWEN is the recently inaugurated Center for Gravitational-Wave Physics (CGWP, director L.S. Finn), an NSF Physics Frontiers Centre with a total budget of $5 million. The CGWP organises frequent conferences and meetings aimed at bringing different communities of researchers together and facilitating the development of GWA. In addition to this, the Center for Gravity (director A. Ashtekar) is a world leading centre for quantum gravity research. The running of these high profile centres requires a clear management structure, which involves advisory boards from many other instutitions. The involvement of [PSU] brings leverage for GWEN in different ways. Participation in the CGWP conference programme provides a high profile forum for distributing the results of GWEN to colleagues in the USA and beyond. The CGWP also runs an intensive visitors program, from which several members of GWEN have already benefited. Finally, there is a significant overlap in research interests. In fact, several YRs from the SOGW groups are now enjoying postdoc positions at [PSU]. Involvement of [PSU] in GWEN would allow these YRs to remain in contact with their EU collagues, which could significantly raise their chances of finding permanent employment in Europe.

B5 RELEVANCE TO THE OBJECTIVES OF THE ACTIVITY

GWEN is very important at an EU level for fundamental scientific and economic reasons. Through its commitments to GEO600, VIRGO, and LISA, Europe alone is spending of order 500 Million Euros on the gravitational wave detectors themselves, while the worldwide commitment is of order 1 Billion Euros. Yet the amount of effort to build an EU community of scientists to study the sources, along with the appropriate theoretical and computational tools they need, absolutely critical to the success of these projects, has been insufficient to achieve its goals, and is comparatively tiny. Not only is a project like GWEN important to the EU's future in science and technology, it is also a relativity small investment that is anticipated to have significant impact.

This is not only a problem in the EU: the recent joint NSF-NASA panel recommended funding increases in training of YRs by a factor of 5 to meet the demands of US based efforts, and to provide researchers to fill the rapidly growing number of faculty positions in this area. Commenting further, the report says:

> *"However the needs outlined here are met, the effort should be configured in such a way as to foster the training of new people in this field, both graduate students and more senior researchers who come in from adjacent fields. The effort should also foster the development of critical sized groups and collaborations, which include people who create and maintain computational science infrastructure, as well as numerical-relativity, numerical astrophysics, and applied mathematics researchers."*

As stressed throughout the GWEN proposal, there are many benefits to be gained by undertaking such an effort at the European Community level. First and foremost is the benefit, or rather the *necessity*, of pulling together elements of various relativity, astrophysics, computational science, and Grid communities, whose combined expertise is needed to solve important problems in one of the most exciting areas of science to emerge in this new century. A realistic solution of just one scientific problem proposed here, say the study of mergers of binary Neutron Star-Black Hole systems, and its impact on detecting and understanding the gravitational wave signals buried in the detector data, requires a high level of expertise in all disciplines mentioned.

These disciplines are all well represented in Europe, and through GWEN and its strong partnerships with other EU projects (See Sec. B1.4 and Appendix B10.2), we are creating a well connected meta-community that serves it constituents. There are several interlocking communities that mutually depend on each other:

- **GW Detector Community**. In the EU, the largest current projects include the GEO600 and VIRGO detectors, while LISA will fly in about a decade. This community has just begun to take data, and has two primary needs: (a) It desperately requires theoretical calculations of the sources of GW it intends to observe, and an analysis of the impact of these calculations on its data analysis, in order to enhance the signal-to-noise ratio and to interpret what it finds. (b) It will produce prodigious amounts of data at multiple sites, which will require new algorithms and prodigious amounts of computer processing for analysis to be done. It has become a major driver of EU and US Grid projects.

- **Theoretical Relativistic Astrophysics Community**. Previously highly fragmented in Europe, this community has become better integrated, and developed basic tools for studying GW sources, through the SOGW project. It is however highly demanding of collaborative tools and computational resources, and is also developing a need for Grids [4], and further, requires much closer connection to the GW detector community to know how to properly target its capabilities.

- **Computing and Grid Communities**. These communities are developing powerful and far reaching technologies, but must become much better connected to their application groups, including both astrophysics and experimental communities if its technologies are to be useful.

The EU has the raw materials to become the best in the world for each of these emerging areas of science and technology, but cannot do so without proper coordination and links between them. GWEN provides these links, creating a multidisciplinary community in which YRs are immersed and trained. Individual groups (and even individual communities) *cannot* provide the required training and expertise. Such training in the required areas can only be carried out at an EU, and international level. GWEN helps ensure the future of GWA as one of the main thrusts of science in this coming century, adds value across other communities by training YRs to take advantage of newly developed computational/collaborative tools they require, and integrates YRs from many parts of Europe and the rest of the world. In doing so, these activities also help ensure that the EU takes advantage of its promise to become the world leader in all three areas discussed above: GWA, theoretical relativistic astrophysics and cosmology, and Grid computing.

Each of these communities suffers from fragmentation. GWEN will work, through a structured, vertically integrated approach to scientific problems (from theoretical study to data analysis as described especially in Sec. B1.4) and its use of highly collaborative software and Grid technologies, to increase the amount of integration within its community. Further, by fundamentally building-in Grid technologies to its scientific and management work, and by channeling each scientific Focus Group towards implications of its work on data analysis, it will act to integrate the Grid and detector communities as well.

As described in Secs. B1.4, B3.1, B3.3, several GWEN partners are bringing in additional sites to their nodes, organising *Regional Nodes*. Such organisation will help to strengthen national communities for research and training, and will help build incentives and direction for national research programmes. Regional nodes build local strength, that can then leveraged at national and EU levels. These combined groups, having a more coherent structure, gain better chances for funding from national sources, and have a stronger voice at the EU level in Brussels. For example, there is a great need for large scale computing facilities that do not readily exist in the EU. As argued in at least two Expressions of Interest submitted to the 6th Framework Programme, DEISA (http://www.deisa.org/) and EDSN (http://www.aei-potsdam.mpg.de/∼eseidel/EDSN/), although badly needed, local scientific groups have previously not had a strong enough voice to make these needs understood or even known. Developing these Regional Nodes helps address such issues at both national and EU levels.

The outcome of GWEN will not only be a well trained and more coherent interdisciplinary community (and some of the most exciting science ever done in astrophysics and cosmology), but a lasting legacy of intertwined scientific and computational communities. We expect links forged between the scientific research groups in GWEN to continue long after the project ends, as they will continue to find new exciting problems in astrophysics, cosmology, and beyond for decades to come. YRs trained in GWEN will stand much better chances of finding long term employment in this growing field than ever before. Positions are being created in this area at a rate never before seen, and GWEN will attract and cultivate a pool of talented researchers, with the skills needed, to fill them. But just as importantly, the connections GWEN will establish between the various scientific, computational, and Grid communities are also expected to be long term. There are many important problems in the science of gravitational wave astronomy that will put increasing demands on the even the most spectacular increases in computational power. Once connections between these communities are made, we expect them to work together to develop new computing paradigms to support this science through the coming decades [4].

B6 ADDED VALUE TO THE COMMUNITY

GWEN is a perfect example of establishing a European Research Area. Until three years ago, most European research groups in GW physics suffered from a sense of isolation, due to limited interaction, and limited means to exchange visitors and employ YRs. As a result, much of the great potential of European researchers in this scientific area remained untapped. SOGW enabled ten research groups to form very close and extended collaborations, which have already produced highly significant scientific results and have trained a new generation of YRs in this field. GWEN will ensure that Europe remains at the forefront of this important scientific area. The GWEN collaboration is larger than any other similar effort world-wide and is initiated at a moment when large-scale European research facilities (the British-German GEO600 and French-Italian VIRGO GW detectors) are in urgent need of theoretical support to maximise their scientific output. Thus, in a very short time, SOGW has given a significant momentum to this community. Simply put, GWEN will build on SOGW to firmly establish the European gravitational physics community as an undisputed world leader in one of the most exciting and high profile areas of science to emerge in this new century. This will have dramatic and lasting impact on the attractiveness of Europe for researchers, and increase its competitiveness for decades to come.

The collaborative, cross-disciplinary nature of GWEN provides a set of common-focus problems whereby research groups across many countries, and different communities (especially the Grid and GWA communities) will work closely together (e.g., see discussion in Sec. B5). In addition to inter- and intra-community building effects at the EU level, this also has rather specific, tangible, and immediate benefits to those involved. For example, the Grid and collaborative technologies that will need to be developed and deployed to support GWEN will give users across the entire collaboration access to established European research facilities, including high performance computing facilities (e.g. RZG, LRZ, EPCC, and others) and the GEO600 and VIRGO gravitational wave detectors themselves. Such facilities are currently only available in a few countries, but through GWEN and its Grid-based partners, research groups from all participating European countries and beyond will be given access to facilities that their national funding agencies would not be able to provide.

Multiple GWEN nodes, and a number of collaborating institutions (e.g., see support letters from Fiziev in Bulgaria and Vulcanov in Romania) are from less-favoured regions in the EU, and special attention is given to supporting and integrating them into the training and research programs of GWEN. While these groups have a high scientific potential, they suffer from isolation and/or poor funding. For example, [AUTH/UA] suffers from low national spending on research and from the absence of large-scale research facilities (e.g. supercomputers). The GWEN node from the new EU member Poland is highly respected scientifically, but is not yet fully integrated with other European groups. The Romanian and Bulgarian groups have a high level of talent in theoretical and computational physics, but due to both isolation and low funding levels they have been unable to apply their abilities to the most important problems in GW and Grid research areas, or they simply do not get the attention they deserve. GWEN will enable groups from less-favoured regions to to train their own students, and better develop their scientific potential, through new collaborations, programs, and projects generated by GWEN. Being a part of GWEN will lead to further pressure on the funding agencies in less favoured regions to provide the support and equipment that these groups need. As also argued in Sec. B5, by participating in GWEN, these groups can develop a higher level of coherence, gain more exposure to EU programs, and a stronger voice in driving future policy decisions in the European Research Area.

Through GWEN, sites will be trained in the use of advanced collaborative technologies, such as Grid Portals and video conferencing systems. The introduction of these technologies – particularly in the less favoured regions – should have dramatic impact on local training as well as providing opportunities to become fully integrated with partner sites. A part of the cost of GWEN will be spent on hardware and software specifically used to facilitate the interconnection between various groups (Access Grid based video conferencing). These systems and the experience with them gained from participating in the project can be naturally extended to other activities, such as online teaching, online seminars, etc. Sites will not only be able to participate in an increasing array of training and research presentations on recent scientific and technological advancement via the Access Grid, they will also be able to *give* presentations to students and researchers in the EU, the US, and elsewhere, further promoting European research and development.

It is important to note that GWEN will impact on the integration of other communities that may seem to have no connection to GWA. As scientists and engineers attempt to solve more and more complex problems, virtually all domains are facing similar issues of finding ways to draw together varied expertise, training their YRs in multidisciplinary methods and technologies, and moving towards collaborative community standards and frameworks. Collaborative technologies used and developed within the GWEN collaboration are already having impact on other disciplines in Europe and elsewhere. For example, climate modelers, plasma physicists, and geophysicists are all attempting to build common frameworks in their separate communities for exactly the same reasons. GWEN has an unusually strong commitment to work with such diverse communities to learn from, and contribute to them. The `Cactus` framework, developed at the AEI and elsewhere, is being supported for use in these communities. In return, improvements in technologies and algorithms made for these communities feed back to aid the GWEN project. For example, the CompFrame workshop held in Utrecht in February, 2003 (`http://www.phys.uu.nl/~steen/Wspage/workshop.html`) was inspired by cross-disciplinary work already taking place between the numerical relativity and climate modeling communities, made possible through `Cactus`. Through the Tools and Training parts of the work plan, GWEN will work with other communities in the EU and elsewhere to exploit inter-community leverage. (For example, see support letter from van der Steen in Appendix B10.2.)

Europe suffers from a lack of YRs who will form the next generation of scientific leaders. Competitive research efforts in the USA have attracted a large number of European researchers in the field of GWA, thus reducing the number of available researchers in Europe even further. Several of the young researchers of the SOGW have already moved to post-doctoral positions in US groups. GWEN will reverse this trend. Not only will it enable European YRs that are currently employed outside Europe to return, it will make it very attractive for them to do so. European groups will be strengthened and will become more attractive to researchers of all nationalities. SOGW has fostered an internationally recognised community and formed solid long-term collaborations between groups, so that they are now more capable of attacking leading-edge scientific problems and produce scientific results that are comparable or exceed in importance corresponding results from outside Europe. GWEN continues this promising direction.

All groups that participate in the project give equal employment opportunities irrespective of gender. Although the gender balance in the specific scientific area is currently not ideal, in recent years several female post-docs and graduate students have joined research groups that participate in GWEN. There appears to be a trend towards gender balance in the astrophysics community, and GWEN will attempt to strengthen this trend through its hiring policies, and by providing female YRs with role models and opportunities to present their own research.

The activities planned in GWEN will enhance and strengthen research and training programs carried out within the collaboration, and among its partner projects. It will also reach broader educational foundations in the EU and elsewhere. Most of the groups in GWEN are based at universities. Graduate and undergraduate students at these universities also benefit from the presence of European post-docs or graduate students and from the frequent exchange of visitors, who regularly give seminars and lectures. Students at these institutions thus become familiar with the research effort undertaken at a European level. The experience from SOGW has shown that through this interaction, many students now prefer to join European groups for their graduate studies over corresponding groups in the USA, thus contributing to reducing the percentage of highly qualified students that is lost to countries outside Europe. The universities participating in the project also benefit from the sharing of research facilities. The senior members in these groups are heavily involved in teaching and training students and the experience and know-how they obtain through their participation in GWEN will be transferred to their local academic environment, augmented by our use of Grid technologies.

Finally, we note that the kind of research carried out within GWEN is extremely interesting and accessible to other researchers, and to the public, and is attractive for education and promotion of science and technology at a worldwide level. Numerous studies supported by SOGW led to beautiful scientific visualisations of colliding black holes, and of gravitational waves, that graced the covers of magazines worldwide, including National Geographic, Science et Vie, Scientific American, and others. A 90 second movie of one of our simulations was shown on the Discovery Channel in a beautifully produced program shown internationally in 2002 (with credit given to our EU project). The same movie was shown by the Director of the US National Science Foundation, and the head of the US DOE Science Division, at major conferences last year, again, with credit given to our EU project. Hence, especially with the strong possibility that gravitational waves will actually be detected during GWEN (and perhaps even because of it) it is clear that the research and training program we propose can have dramatic impact both at a European and worldwide level.

B7 INDICATIVE FINANCIAL INFORMATION

Participation of Researchers Not Appointed By GWEN (Column A) Travel funds are requested for each node for researchers not funded by the project to travel to GWEN meetings and workshops/conferences highly relevant for the project. Such trips will usually be within the EU (all GWEN meetings will be at EU nodes). The amount requested is related to the need of the node. The amount requested by [AEI] covers not only the Potsdam researchers travel needs, but an additional amount of x Euros to provide a travel fund allocatable by the ASC in cases of additional need by nodes (x) and for bringing researchers from collaborating sites in candidate countries outside GWEN to All-Hands meetings (x).

Expenses Relating to Organisation and Implementation of GWEN (Column B) Regular and convenient contact between GWEN members, wherever they are, is essential for the smooth running of the network, both for the organisation of the Administrative and Scientific Steering Committees, and for the scientific and training collaborations. An important medium is by phone calls, either person-to-person or via conference calls. Based on our experience in the current EU Research Training Network "Sources of Gravitational Waves" (SOGW), we estimate the cost of such calls to be x Euros for hosting conference calls (to [AEI]), and x Euros per node (x for regional nodes) for taking part in international calls.

[AEI] requests x Euros to hire an experienced research programmer to provide support for GWEN in ongoing tool development in parallel computing, `Cactus`, `Lorene`, and Grid technologies, training, handling CVS, mailing lists, video conferencing, etc., for the entire GWEN collaboration. An additional x Euros is requested for the programmer to be able to visit partner sites for development of codes and training of YRs.

To promote general awareness of GWEN in both the astrophysics and wider communities, we request a modest x for public relation costs, including for example strategic placement of GWEN gadgets such as mugs, pens, and promotional fliers.

Management Activities of GWEN (Column C) [AEI] suffers the main administrative burdens for GWEN, and requests x Euros for a part-time administrative assistant to serve the network. To cover the costs of the required audit, and incidental administrative costs, we request x Euros for each EU node (x for [AEI]). [AEI] requests x Euros towards phone costs related to GWEN management.

The International Advisory Board will provide critical input to GWEN, both for guidance on the directions of GWEN research and training and for dissimentation of results and achievements and outreach to other groups and communities. Travel costs of x Euros for the IAB to attend GWEN All-Hands meetings are requested which will be administrated by [AEI].

Towards the incidental administrative costs of organising GWEN meetings, we request x Euros for each meeting (5 All-Hands Meetings and 1 Summer School) totalling x Euros. This will be distributed to the organising nodes by [AEI], as meeting locations are chosen by the Administrative Steering Committee.

Durable Equipment for GWEN (Column D) The training and community aspects of GWEN will be enhanced by making good use of collaborative technologies. Teleconferencing, email and webpages were all used to good effect in SOGW. With GWEN we will expand collaborative and training possibilities by including a GWEN web portal (provided by the GridLab project) and by the use of basic video-conferencing. A full powered Access Grid node for any site would today cost between x and x Euros. After discussions with experts we are confident that a basic set up could be provided at any site for only x Euros, by restricting the number of participants able to fully take part (e.g. by using personal headsets rather than expensive echo cancelling microphones, using a single fixed camera rather than multiple motorised ones, using smaller displays). This set up will allow GWEN YRs (one or two at each site) to be able to interact with each other, and to take part in training tutorials and seminars (provided both by GWEN and now at many different supercomputer centres, e.g. NERSC, NCSA, OSC), and will allow the GWEN management (ASC, SSC) to include video abilities in their meetings. Specification, set up and training for the equipment will be provided by [AEI]. We request funds to provide basic facilities at each node (including all sites of regional nodes, e.g. 3 setups for [UVEG/UA/UB]). [AEI], [MPG.MPA], and [UWC] have existing facilities and request no funds.

Four nodes of the network have insufficient local funds to supply adequate computational infrastructure for YRs, and for this reason we request funds for nodes to purchase workstations (e.g. dual-processor linux boxes) suitable for development work. Access to additional computational resources for these YRs will be made available from [AEI].

Table B7.1: GWEN indicative financial information

Indicative financial information on the network project (excluding expenses related to the recruitment of early-stage and experienced researchers)				
Network Team No.	Contribution to the research/ training / transfer of knowledge expenses (Euro)		Management activities (including audit certification) (Euro)	Other types of expenses / specific conditions (Euro)
	(A)	(B)	(C)	(D)
T-01 Potsdam [AEI]	x	x	x	-
T-02 Jena [FSU]	x	x	x	x
T-03 Paris [GReCO/LUTH/APC]	x	x	x	x
T-04 Valencia [UVEG/UA/UB]	x	x	x	x
T-05 Palma [UIB]	x	x	x	x
T-06 Thessaloniki [AUTH/UA]	x	x	x	x
T-07 Rome [URLS]	x	x	x	x
T-08 Trieste [SISSA]	x	x	x	x
T-09 South of England [SoE]	x	x	x	x
T-10 Cardiff [UWC]	x	x	x	-
T-11 Garching [MPG.MPA]	x	x	x	-
T-12 Tübingen [IAAT]	x	x	x	x
T-13 Warsaw [CAMK]	x	x	x	x
T-14 Baton Rouge [LSU]	x	-	-	-
T-15 Penn State [PSU]	x	-	-	-
Totals	x	x	x	x

B8 PREVIOUS PROPOSALS AND CONTRACTS

B8.1 Current EU Network

The GWEN project is based on a current EU Research Training Network "Sources of Gravitational Waves" (SOGW) financed in the framework of the FP5 Improving Human Potential programme. As detailed throughout this proposal, GWEN extends and carries on the solid base achieved in SOGW in several new directions.

The essential information for the FP5 SOGW Network is:

a) **Network Name or Acronym:** Sources of Gravitional Waves

b) **Contract Number:** HPRN-CT-2000-00137

c) **Contract Period:** 01/08/2000 to 31/07/2003 (termination date extended (no cost extension) since original contract to 31/01/2004)

The current EU Research Training Network "Sources of Gravitational Waves" is fully described at the project web site http://www.eu-network.org.

B8.2 Previous FP6 Application

An application for an earlier version of GWEN was submitted at the last call (3 April 2003). The proposal number was FP6-504885. This was positively evaluated with a score of 85.0% but it seems unlikely that sufficient funding will be available to support it and we have been strongly encouraged to resubmit the proposal. We have agreed with the Commission that if money is ultimately available to fund the original GWEN proposal (from the first call), we will withdraw this proposal. However, improvements outlined below, made in this proposal, will be carried out if funding is found from either call.

We have noted the referee comments made for this previous application and have endeavoured to strengthen certain points. In particular, we have improved:

- the definition of the management structure;
- the structuring as regards milestones for the project;
- the number of women in management roles;
- the description of how the smaller nodes are integrated into the project; also Southampton and Portsmouth have been joined as a single "South of England" node together with Oxford where we are now also represented.

Various other improvements and updates have been included throughout the text.

B8.3 Other Sources of Community Support

T-01 [AEI]

Major node of a EU research project GridLab, funded by FP5 IST Programme (IST-2001-32133). GridLab will provide training and transfer of knowledge for computation science skills and technologies, primarily in Grid computing. [AEI] is in charge of developing the Grid Application Toolkit, Grid Portals, and developing and implementing scenarios with a `Cactus` Grid Toolkit

T-04 [UVEG/UA/UB]

A Marie Curie Fellowship has been submitted by Dr Olindo Zanotti (ref.number: FP6-500410) in the field of relativistic accretion discs.

T-09 [SoE]

A Marie Curie Fellowship has been awarded to Gioel Calabrese (currently at [LSU]) to join the SOuthampton group in Dec. 2003 to work in the field of numerical relativity.

A Marie Curie Fellowships is being submitted by Dr Federico Piazza in the field of gravitation and cosmology.

Node of the EDEN proposal for a European Dark Energy Research and Training Network, if successful [SoE] would be funded for a postdoc for one year.

T-10 [UWC]

Node of the GridLab project (see [AEI] above) in-charge of developing Workflow application toolkit and leading the PPARC-funded GridOneD project.

B9 OTHER ISSUES

B9.1 Ethical Issues

The research proposed for GWEN does not impinge on any of the raised ethical issues, nor does it raise any safety issues of significance.

Does the research presented in this proposal raise sensitive ethical questions related to:	**YES**	**NO**
Human beings		**X**
Human biological samples		**X**
Personal data (whether identified by name or not)		**X**
Genetic information		**X**
Animals		**X**

B9.2 Interdisciplinary Computing Aspects

Some of the members of the GWEN collaboration are among the most active in the world in engaging and promoting interdisciplinary computing. As demonstrated throughout this proposal, GWEN members are also leading or are deeply involved in other major projects in computation and Grid computing, and work with scientists from many disciplines. (See, e.g., Sec. B1.4 and support letters in Appendix B10.2.) We elaborate on a few examples here.

Network Coordinator Seidel is founding member and co-chair of the Applications Research Group of the Global Grid Forum (GGF), which meets 3 times per year around the world. This group provides input to the GGF on what developments ate needed in the Grid community to support various applications communities, from chemical engineering to bio-informatics, and including the GWEN community. Related to this role, he, senior GWEN member G. Allen, and other colleagues have been invited to organise half a dozen workshops at major computing conferences on frameworks for high performance computing, Grid applications, etc. These experiences have provided valuable experience and contacts that will aid GWEN.

One of the requirements of GWA, and most modern research disciplines, is large scale computation. A European-wide high performance computing facility, much like those that exist in the USA, is an important need missing from the EU landscape. As discussed in Sec. B5, this need led members of current EU Research Training Network "Sources of Gravitational Waves" (SOGW), in collaboration with Nabzyski of GridLab, to submit an Expression of Interest to the EU to construct a European Distributed Supercomputing Network (EDSN). They actively sought and received backing of dozens of leading EU-based scientists and engineers in many disciplines. Such a facility would do much to fill the need for supercomputing facilities in Europe. The leader of a related EOI called DEISA, that is being submitted as a 6th Framework Infrastructure project, has written a support letter for GWEN promising to work cooperatively with us to provide needed computational support if funded. (See Appendix B10.2.)

SOGW has demonstrated a ready willingness to engage with actors outside the field, for example with collaborating in the testing and development of new Grid tools. Various members have worked with Lawrence Berkeley Labs (LBL), NCSA, and other sites to enter a number of competitions at computing conferences, often based on Binary BH or NS codes developed by SOGW and its predecessors. These efforts have led to a a number of prestigous prizes, including the Gordon Bell Prize, Bandwidth Challenge, and HPC Challenge awards, and others. These experiences feed back directly to improve codes being used in GWEN. Additionally, SOGW members have been invited to be early adopters of the US "TeraGrid" facility for its simulations.

Another mode of outreach for current EU Research Training Network is through the computational tools which are created. The `Cactus` code has attracted the interest of the Climate Modeling community, in particular a group at Utrecht in The Netherlands, which has invested a considerable about of time and resources in integrating their codes into the `Cactus` framework. One of the leaders of this effort, Aad van der Steen, has written a letter of support for GWEN. (See Appendix B10.2.) The Climate Modeling community has considered a large variety of computing frameworks, and has organised an effort to make the various frameworks aware of each other, and to help them collaborate. There is now an awareness and effort to make the frameworks compatible with each other, and perhaps join them up.

The `Cactus` framework used in GWEN is a highly modular, multi-displinary package which is designed to facilitate collaboration not only among researchers within a given field, but across quite different fields whose only similarity may be their requirements for computational infrastructure. Improvements in technologies and algorithms made by any other community feed back directly to aid GWEN, and in turn infrastructure developed for GWEN will aid other communities. The CompFrame workshop held in Utrecht in February, 2003 (http://www.phys.uu.nl/ steen/Wspage/workshop.html) was inspired by cross-disciplinary work already taking place between the numerical relativity and climate modeling communities, made possible through `Cactus`. The close connection with and use of Grid computing technologies within GWEN will provide further opportunity to interact with other communities.

Recently this modularity provided by `Cactus` has been exploited in a workshop [5] for numerical relativity. The intent was to compare systems of evolution equations for GR, separately from other aspects such as initial data, boundary conditions, numerical methods, I/O, etc., to evaluate empirically which perform best for some standard 'test problems' in Numerical Relativity. The results from activities such as these will directly benefit GWEN and the Astronomy community, and will help to foster the use of Numerical Relativity in Astronomy.

B9.3 Education and Engagement with the Wider Society

We expect GWEN to maintain a high international profile in the scientific and computing communities, but also in the wider public. Much of our activity will be visible via a web site maintained at [AEI], through lectures given by GWEN members at international meetings, and through our involvement in the wider community (for example several SOGW members taught courses in a 2002 Astrophysics Summer School on the Black Sea).

GWEN is expected to provide education on gravitational wave astrophysics at many levels. Members of the collaboration are routinely invited to present public science lectures. The SOGW website prompts many questions from school children and the broader community. The [AEI]holds an annual “Open Day”, providing displays of research activities taking place at the institute, and a chance for the general public to interact with and ask questions of the scientists.

The science education based media provides an important channel for outreach and education. Significant research events are published as press releases, and appear in national and local newspapers and popular science magazines. Work of SOGW members appeared on the cover of National Geographic and in Scientific American. In June 2002 the Discovery Channel showed a movie of coalescing binary BHs which had been generated, using real data, by current EU Research Training Network. This same movie clip is used in presentations and publications at all levels, providing further exposure of network research to the general public.

Topics such as “black holes”, “neutron stars” and “gravitational waves” are very popular with the general public and especially with school children. GWEN members are often invited to give talks to school classes at all levels, and are regularly sent questions by email concerning matters in gravity. Researchers in our community thus have a unique opportunity to leverage young people's interest in *Star Trek* science fiction, and encourage new generations of scientists. Such a responsibility is taken seriously, and in particular it is recognised that encouraging and inspiring younger girls in science is one way to address today's gender gap in the subject.

B10 APPENDICES

B10.1 References in GWEN Proposal Part B

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B10.2 Letters in Support of the GWEN Project

In this Appendix, we include some example supporting letters from leaders of other research groups and projects cooperating with GWEN. These projects range from the largest EU funded projects in Grid computing to leaders of important complementary research groups in Asia, Mexico and the USA. This sample of supporting letters gives an indication of the kind of broad, cross-disciplinary impact the GWEN project can have in developing the worldwide community needed in gravitational wave astronomy.

*** Support Letters removed in public version ***

B10.3 Acronyms

Node Names The full name of each node is listed below:

T-01	[AEI]	Max-Planck-Institut für Gravitationsphysik (Albert-Einstein-Institut)
T-02	[FSU]	Friedrich-Schiller-Universität
T-03	[GReCO/LUTH/APC]	Observatoire de Paris
T-04	[UVEG/UA/UB]	Universidad de Valencia
T-05	[UIB]	Universitat de les Illes Balears
T-06	[AUTH/UA]	Aristotle University of Thessaloniki
T-07	[URLS]	Universita' di Roma "La Sapienza" Dipartimento di Fisica
T-08	[SISSA]	Astrophysics Group, International School for Advanced Studies
T-09	[SoE]	South of England
T-10	[UWC]	Cardiff University
T-11	[MPG.MPA]	Max-Planck-Institut für Astrophysik
T-12	[IAAT]	Institute of Astronomy & Astrophysics, University of Tübingen
T-13	[CAMK]	N. Copernicus Astronomical Center
T-14	[LSU]	Louisiana State University
T-15	[PSU]	Pennsylvania State University

Acronyms The following acronyms are used in this document (sorted alphabetically):

2D	two dimensional
3D	three dimensional
AMR	adaptive mesh refinement
ASC	Administrative Steering Committee
ASC	Astrophysics Simulation Collaboratory
BH	black hole
CCM	Cauchy-Characteristic Matching
CFC	conformally flatness condition
CFS	Chandrasekhar-Friedman-Schutz
CGWP	Center of Gravitational Wave Physics, Penn State, USA
Cog	Cognizant Scientist
CS	computational science
CVS	Concurrent Versioning System
DA	data analysis
DEISA	Distributed European Infrastructure for Supercomputing Applications
DFG	German Science Foundation
EARA	European Association for Research in Astronomy
EOS	equation of state
EPCC	Edinburgh Parallel Computing Centre
ESA	European Space Agency
FG	Focus Group
GAT	Grid Application Toolkit
GEANT	Gigabit European Academic Network
GTRN	Global Terabit Research Network
GR	general relativity
GW	gravitational wave
GWA	Gravitational Wave Astronomy
GWEN	Gravitational Wave European Network
HRSC	high resolution shock capturing
I/O	input/output
LAL	LIGO Algorithm Library

LIGO	Laser Interferometer Gravitational Wave Observatory
LISA	Laser Interferometer Space Antenna
LRZ	Leibniz Rechenzentrum, Munich
LMXB	low mass x-ray binary
MHD	magnetohydrodynamics
MPG	Max-Planck-Gesellschaft
NASA	National Air and Space Administration (USA)
NATO	North Atlantic Treaty Organization
NERSC	National Energy Research Scientific Computing Center, Berkeley, CA, USA
NC	Network Coordinator
NCSA	National Center for Supercomputing Applications, U. of Illinois, USA
NR	numerical relativity
NS	neutron star
NSF	National Science Foundation (USA)
PI	Principal Investigator
PNS	proto-neutron star
PSC	Pittsburgh Supercomputing Center, U. of Pittsburgh, USA
R-MHD	relativistic-magnetohydrodynamics
RZG	Rechenzentrum-Garching, Germany
SDSC	San Diego Supercomputing Center, U. of California, San Diego, USA
SSC	Scientific Steering Committee
SFB	Sonderforschungsbereich (Special Research Programme), a German research project in GWA funded by the DFG
SN	supernova or supernovae
SOGW	current EU Research Training Network “Sources of Gravitational Waves”
SS	strange quark stars
TNS	toroidal neutron star
USA	United States of America
VO	virtual organization
YR	young researcher (trained in SOGW or to be trained in GWEN)
ZIB	Konrad-Zuse-Zentrum, Berlin

Definitions of Young Researchers For reference, the definitions of Young Researchers are:

- Young Researcher
  A Young Researcher is within 10 (full-time equivalent) years of the start of Ph.D. studies.
- Early Stage Researcher
  Means researchers who have at the time of the appointment no more than 4 years (full-time equivalent) research experience since obtaining the diploma which gives them direct access to doctoral studies in the country in which the diploma was obtained and who do not have a doctoral degree.
- Experienced Researcher
  Means researchers who have at the time of the appointment a doctoral degree or a (full-time equivalent) research experience of 4-10 years since obtaining the diploma which gives them direct access to doctoral studies in the country in which the diploma was obtained.

B10.4 Description of Existing Collaborations in GWEN

The success of GWEN will hinge on the collaborations between the nodes. All of the participating nodes in GWEN have a long history of collaboration. Existing links were strengthened and many new ones forged during SOGW. As well as personal exchanges and visits a number of ongoing projects, both on particular astrophysical problems and on the development of tools and techniques, were strengthened by the participation in SOGW. The broad range of existing collaborations is illustrated in section B3.1.

The `Lorene` project, largely developed by [GReCO/LUTH/APC], predates SOGW. However, in part due to links fostered by SOGW, `Lorene` is now the focus of collaborations with [CAMK], [UVEG/UA/UB], [MPG.MPA], [AEI] and [IAAT].

The `Cactus` code is a very broad collaborative project based at [AEI] and [LSU], but with strong input from [UIB], [PSU], [IAAT] and others. This framework is important for other tools, including `Carpet` and `Whisky`.

The `Carpet` mesh refinement code also predates SOGW. Originally developed at [IAAT] and [PSU], projects launched in SOGW using `Carpet` now also link [AEI] and [MPG.MPA].

The `Whisky` project, initiated during SOGW, draws heavily on the YRs at [AEI] and [SISSA], and also includes strong collaboration with [AUTH/UA], [UVEG/UA/UB] and planned work with [MPG.MPA], [SoE] and [IAAT].

There already exists many collaborative astrophysics projects between nodes. Many of the nodes participate in the LIGO scientific collaboration, particularly [UIB], [AEI], [UWC], [URLS], [LSU] and [PSU]. Similarly there are very close ties between [UIB], [UWC] and [AEI] in the GEO600 project.

Work on neutron stars draws together many nodes. [AUTH/UA], [SISSA], [UVEG/UA/UB] and [SoE] all collaborate on the calculation of instabilities of neutron stars. Work on the pulsation modes of rotating stars links [AUTH/UA], [SoE] and [AEI], with new collaborations with [MPG.MPA], [UVEG/UA/UB] and [GReCO/LUTH/APC] underway. A close and long running collaboration between [GReCO/LUTH/APC] and [CAMK] has performed work on neutron star structure. Other work on neutron star structure and physics also links [GReCO/LUTH/APC], [CAMK], [SoE], [AUTH/UA], [URLS], [UVEG/UA/UB] and [SISSA]. Other work on hydrodynamics includes the long running and extremely successful collaboration on relativistic jets linking [UVEG/UA/UB] and [MPG.MPA].

A variety of projects have looked at formulations of and approximations to the Einstein equations. The close ties between [GReCO/LUTH/APC], [FSU] and [CAMK] have produced major advances in post-Newtonian theory. Extensions to the conformal flatness approach to GR are being worked on by [FSU], [MPG.MPA] and [UVEG/UA/UB]. Work on formulations of Einstein's equation for NR links a large number of groups, with the ties between [AEI] and [UIB] strengthening. This is also an area where there already exists substantial collaboration with [PSU], [LSU] and [IAAT]. The calculation of initial data for binary systems has coupled [GReCO/LUTH/APC], [AEI] and [SoE]. Work on radiation reaction has linked [AUTH/UA], [FSU] and [MPG.MPA].

Many nodes have also worked together on the organization of meetings and conferences, often as part of SOGW. One meeting was organised jointly by [UIB] and [UVEG/UA/UB], and other meetings by members of the regional nodes at [SoE] and [GReCO/LUTH/APC]. Outside of SOGW, [URLS] and [SISSA] jointly organised a meeting and school held in Trieste.

A long personal history of collaboration also exists between many of the nodes. An illustrative example is [UVEG/UA/UB], where current members have spent large amounts of time, either visiting or on postdoctoral research, at the nodes in [AEI], [GReCO/LUTH/APC], [URLS], [AUTH/UA], [SISSA] and [MPG.MPA]. Similar links can be found throughout the nodes of GWEN.

B10.5 Joint publications from the current EU Research Training Network

We list here all collaborative papers (i.e. with authors from more than one node) poduced so far within SOGW; indicated in boldface are the names of the YRs.

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Gravitational Wave European Network

From Astrophysical Theory to Detection and Understanding

PART B: End Page

MARIE CURIE ACTIONS
Human Resources and Mobility (HRM) Activity
Call Identifier: FP6-2002-Mobility-1
Research and Training Network (RTN)

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