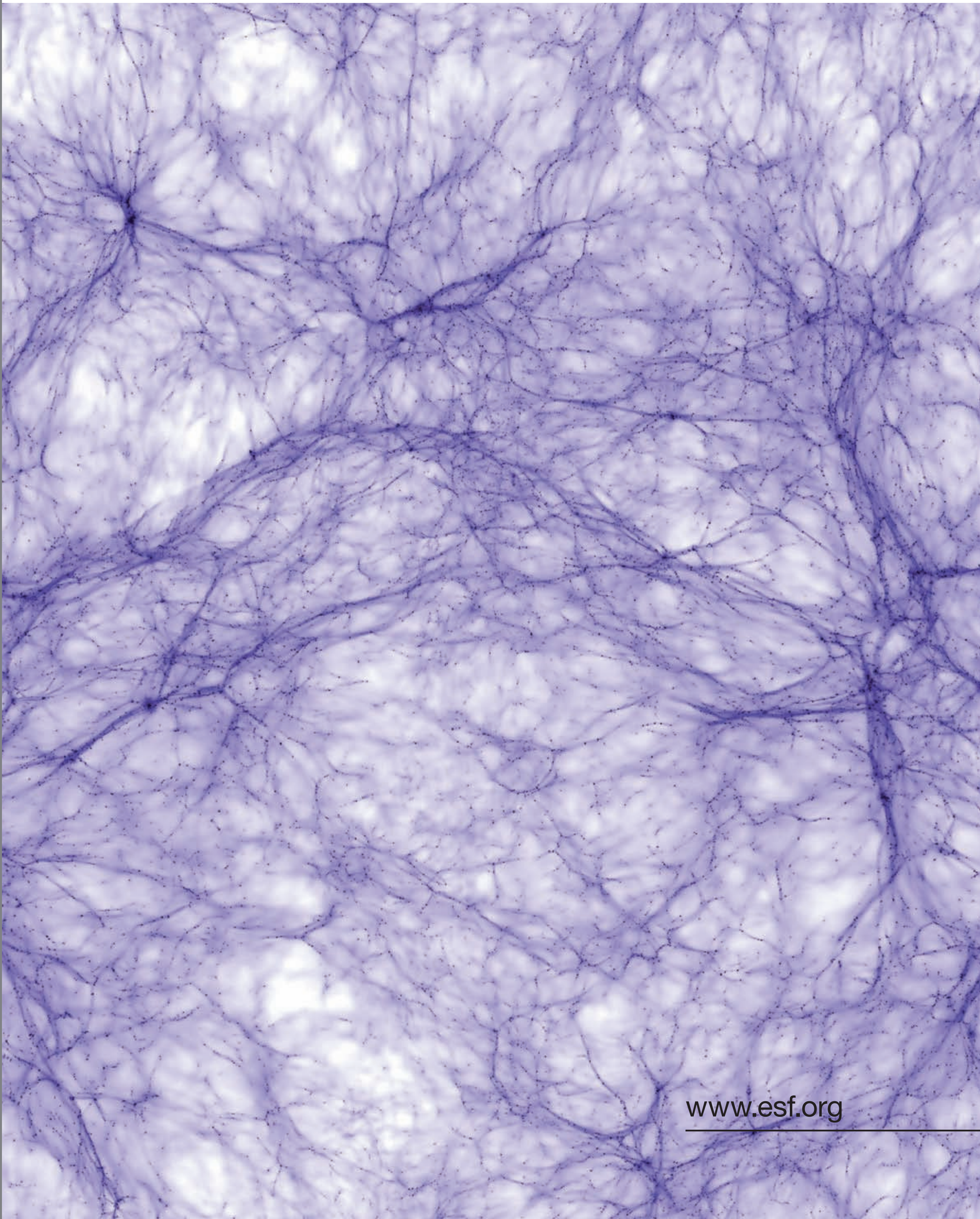
European Science Foundation
SETTING SCIENCE AGENDAS FOR EUROPE

RESEARCH NETWORKING PROGRAMME

COMPUTATIONAL ASTROPHYSICS AND COSMOLOGY (AstroSim)

Standing Committee for Physical and Engineering Sciences (PESC)



www.esf.org

Introduction

The European Science Foundation (ESF) was established in 1974 to create a common European platform for cross-border cooperation in all aspects of scientific research.
With its emphasis on a multidisciplinary and pan-European approach, the Foundation provides the leadership necessary to open new frontiers in European science.
Its activities include providing science policy advice (Science Strategy); stimulating co-operation between researchers and organisations to explore new directions (Science Synergy); and the administration of externally funded programmes (Science Management). These take place in the following areas: Physical and Engineering Sciences; Medical Sciences; Life, Earth and Environmental Sciences; Humanities; Social Sciences; Polar; Marine; Space; Radio Astronomy Frequencies; Nuclear Physics.
Headquartered in Strasbourg with offices in Brussels, the ESF's membership comprises 75 national funding agencies, research-performing agencies and academies from 30 European countries.
The Foundation's independence allows the ESF to objectively represent the priorities of all these members.

AstroSim aims to bring together European computational astrophysicists working on a broad range of topics from the stability of the solar system to the formation of stars and galaxies. Understanding our origins and the formation of structure in the universe is a challenging multidisciplinary research activity that brings together observational, experimental and theoretical researchers with a broad range of expertise. The systems that we attempt to model are complex and involve a range of physical processes operating over enormous lengths and timescales. Computational techniques developed by researchers in Europe since the 1960s have played a central role in advancing this subject, developing theories for structure formation, testing cosmological models and solving the complex non-linear problems inherent in gravitational and hydrodynamical astrophysical processes. Understanding the strong interplay between different scales is essential for a complete theory and true understanding of the formation and evolution of astrophysical objects. Our aims are to strengthen the existing European activities in computational astrophysics, avoiding fragmentation as this field grows in strength and to exchange expertise through an active programme of conferences, workshops, training schools and exchange visits. Our scientific objectives are to refine our computational techniques and multiscale modelling in order to develop and test theories of structure formation in readiness for the grand challenge European projects planned by ESO and ESA over the coming decades.

The running period of the ESF AstroSim Research Networking Programme is for five years from September 2006 to August 2011.

Funding opportunities from AstroSim

- Conferences and workshops
- Graduate and training schools
- Short and long term visits
- Exchange grants for young researchers
- Lecture series
- Sabbatical support

See www.astrosim.net for further details, deadlines and application forms.

Cover Figure:
The cover image shows the distribution of baryons in a 100Mpc^3 region of the universe. The simulation was carried out on the MareNostrum Supercomputer with the adaptive mesh code RAMSES by Romain Teyssier.

Computational Astrophysics & Cosmology: Context and Status Report

In the past decade a combination of satellite and ground-based observational experiments have mapped and quantified the observed universe to an unprecedented precision. The fundamental parameters that govern the evolution and future of the universe have been measured. We know the matter and energy densities and primordial fluctuation spectrum – the initial conditions for cosmic structure formation – to a few percent. However, only a small fraction of the universe has been physically identified and understood – the dominant components of matter and energy remain a mystery. We believe that most of the mass in the universe is a new fundamental particle that links astrophysics with particle physics and super-symmetry, while the dark energy may be some property of the vacuum or extra dimensions. Furthermore, even processes where only the well known physics of baryons operate are not very well understood, such as in the formation of stars and planets. Central to this proposal is to understand how the material in the universe arranges itself into the wide range of observed structures from planets to stars to galaxies.

Numerical simulations have played a central role in understanding observational phenomena. They are the theorist's tool for solving complex non-linear problems. Notable successes of simulations have included an understanding of how galaxies can undergo morphological transformation by merging and interactions, the structure of dark matter haloes within a collisionless hierarchical cosmology, the large-scale pattern of galaxy clustering, the formation of galaxy clusters and the global properties of the intra-cluster medium (ICM). On smaller scales, simulations have helped us to understand the dynamics of self-gravitating stellar and galactic systems, the flow of gas in galaxies and the fuelling of nuclear black holes, the formation of the first stars and instabilities in self-gravitating disks on different scales. Stellar evolution is now almost a closed subject, solved by complex numerical modelling of stellar structure and the appropriate physical processes. Notable problems also await solution, including the final stages of stellar evolution, the origin of Earth-like planets, the long-term stability of the solar system, black hole formation and the interplay between black holes and accretion disks, the central evolution of dense stellar systems, star formation and the formation of galactic disks and the detailed properties of the ICM in galaxy clusters. Whilst theoreticians are still trying to understand how galaxies assemble themselves from the dark matter and baryons in the universe, observers are acquiring exquisite multiwavelength data for over a million galaxies. They have high resolution spectral information, colour maps, element abundances and kinematical data for individual galaxies. Theorists have not yet succeeded in making a realistic disk galaxy from first principles via direct simulation. Similar problems exist on other astrophysics scales. Whilst astronomers are cataloguing the properties of numerous extra-solar planetary systems, theorists have yet to form a single realistic solar system via computational techniques. Despite these difficulties, theorists are not so far behind and we believe that many of these problems will be solved in the coming decade if sufficient resources and support are provided for this community.

Figure 2: The dark matter distribution of the Milky Way halo at present day simulated with 200 million particles by Juerg Diemand using the parallel treecode PKDGRAV.

Figure 1: The MareNostrum Supercomputer in Barcelona

Objectives and Envisaged Achievements

Our ultimate scientific objectives are to construct and test theories of structure formation that are powerful enough to compare with forthcoming observational data, and to make predictions for the grand challenge European Southern Observatory (ESO) and European Space Agency (ESA) programmes that will take place over the next decade. We aim at building a large-scale coordinated effort amongst European computational astrophysicists that should match the notable efforts of the large teams typically involved in the large observational programmes that characterise this decade. Several major barriers remain and we face the following difficulties:

- The range of scales in mass, length and time is vast. Important physical processes that are occurring below the resolution limit of our simulations are included in a phenomenological way.
- Initial conditions are often quite idealised, difficult to construct and can influence the final results.
- Astrophysical fluid codes are extremely sophisticated yet different techniques are often not rigorously examined through comparative tests.
- Research can be fragmented, with no European-wide forum for discussion and collaboration.

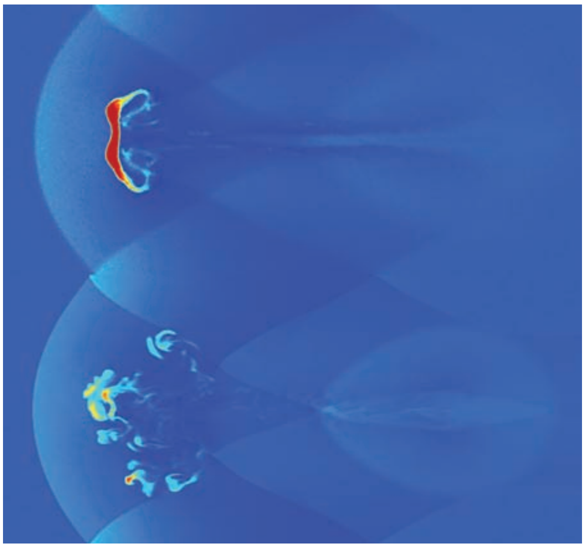


Figure 3: A gas cloud moving through a low density medium at high speed simulated with Smoothed Particle Hydrodynamics (top) and Adaptive Mesh Refinement (bottom) codes carried out by Oscar Agertz.

AstroSim aims to overcome these issues by bringing together computational astrophysicists and cosmologists working on a wide spectrum of problems in astronomy. A platform for funding will be provided for exchange visits with emphasis given to interdisciplinary collaborations. Two large computational astrophysics conference will be organised that will bring the entire community in Europe together. Several specifically focused workshops will be supported by grants each year and graduate training schools will be funded.

One of the major scientific goals of this AstroSim programme is to create collaborations between astrophysicists working on the scales important to each other's problems. For example, a theory of star formation requires knowledge of large-scale processes in galaxies such as gravitational-driven turbulence in the ISM. The final stage of star formation provides the initial conditions for the onset of planet formation. Star formation and feedback processes are all included as unresolved sub-grid processes in current cosmological simulations. Europe has leading experts on each of these scales and by combining our expertise we can create realistic initial conditions; the end state of one simulation may be the starting point to grid model for another group. The processes resolved in one simulation might be used to motivate a sub-grid model in a simulation on a different scale.

AstroSim will allow us to follow up and extend these tests to include additional problems, such as radiative transfer and MHD. We will use the programme to publicise and involve the entire community of researchers who are developing and using algorithms for simulating astrophysical fluids. Our aim is to stress the codes and ensure that we understand the systematic numerical effects whilst learning the strengths and weaknesses of different techniques.

Expected Benefit from European Collaboration

The main benefits of the AstroSim programme will be the achievement of the following goals:

- Forge new collaborations between researchers that do not currently exist.
- Train young researchers in the field of computational astrophysics & cosmology.
- Bring together the ideas and resources of top European research groups.
- Promote, at a European and world level, outreach from computational research.
- Enable European researchers to stay at the forefront of research in this field.
- Utilise the existing and planned supercomputing resources to their full extent.
- Support the grand challenge science projects of European astronomy by constructing detailed theoretical models of astrophysical systems.

The broad objective of AstroSim is to support high quality science and to act as a catalyst for its development through planning and implementation. We believe that it is a timely period to invest resources in computational astrophysics. European investment in observational astrophysics and cosmology is at a record level because of the impact of this field on the public sector, its role in training people for jobs outside academia, motivating the next generation of scientific researchers and facilitating the fundamental goal of understanding our origins and place in the universe.

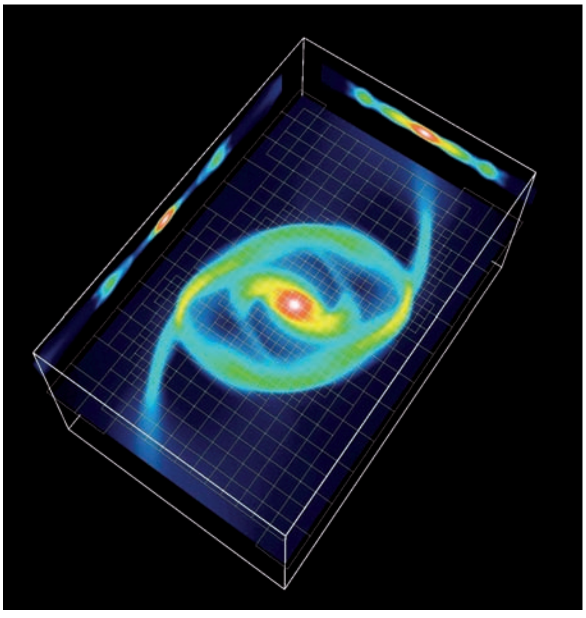


Figure 4: Collapse of a gravitating gas cloud simulated with the Adaptive Mesh Magnetohydrodynamics code NIRVANA by Udo Ziegler

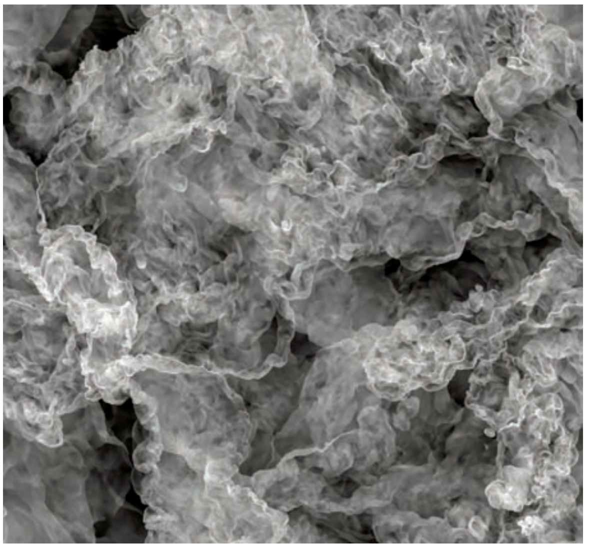


Figure 5: Stars form within the turbulent gaseous interstellar medium of galaxies. The picture shows a supercomputer simulation of astrophysical turbulence. © Alexei Kritsuk

The overall European capacity to train and transfer knowledge will be increased by bringing together the expertise and skills of the entire community, sharing and combining resources and knowledge, disseminating results and tools including analysis and visualisation software and coordinating a combined attack on understanding the multiscale physics relevant to astronomical systems. Computational astrophysics is a research topic that attracts many young researchers and which helps reverse the trend in western countries of fewer and fewer young people being attracted by research in the sciences. The overall European capacity to train and transfer knowledge will be increased by bringing together the expertise and skills of the entire community, sharing and combining resources and knowledge, disseminating results and tools including analysis and visualisation software and coordinating a combined attack on understanding the multiscale physics relevant to astronomical systems.

Computational astrophysics is a research area where European scientists are well established and are highly prominent. In order to maintain this position and to tackle the complex scientific problems discussed earlier, it is essential that strong collaborations exists within the European community. These research goals will not be solved by an individual nor by a single institute, but rather by the concerted effort of groups of experienced researchers. In the longer term, we specifically plan long-term collaborations between the different nodes forged during the network that will continue beyond the funded period.

Activities

Workshops and conferences
AstroSim promotes collaboration through training and stimulation of ideas by mobility of human resources in addition to training schools and workshops. Please see the website www.astrosim.net for further information about these initiatives.

Two major conferences in computational astrophysics in 2008 and 2011 will gather well over 200 people each year and will be open to international researchers and will span the entire remit of computational astrophysics, from the three-body problem to the origin of large-scale structure in the universe. We will provide funding to support scientific workshops and conferences that have a main theme on computational astrophysics.

Training
AstroSim promotes interaction and exchange visits between scientists in Europe with co-funding and grants for both long- and short-term visits. AstroSim will support the organisation of schools for students and young researchers where experts in the various fields of the programme will be invited to give courses.

Grants
Short-term visits can be awarded every year to promote the mobility of researchers and students. This will provide the establishment or the strengthening of scientific links at the individual level. These grants are complementary to workshops and conferences in achieving the goals of the programme.

Exchange grants, fellowships or long-term visit grants can be awarded to specific individual projects within the programme. These are for projects aiming to facilitate the transfer of knowledge and techniques relevant to the individual and the hosting research group. These grants can also be awarded to promote the visit to Europe of experts from all over the world.

Information database
We are constructing an informative website for the entire computational astrophysics community – a forum for information, discussion and dissemination of results. Such a database/website does not exist and would be a useful resource for the European and worldwide community. Our code comparison website resulting from the Wengen exploratory workshop is already a significant database and will grow over the next year as more tests are carried out and results archived and analysed. We anticipate that this database will be a significant resource and possibly become a standard reference for groups who wish to compare existing or new codes under development.

How to apply
Applications from any researcher in any European institution will be considered. Only electronic submissions from the website will be considered. Please check the website www.astrosim.net for further information, deadlines and links to the application forms.

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For the latest information on this Research Networking Programme consult the AstroSim websites:
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www.esf.org/astrosim

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