



Improving our Understanding of Star Formation with Supercomputers

Damien Lecarpentier

The mechanisms leading to the formation of stars are still poorly understood. Using DEISA's computational resources, a German project team performed simulations of two of the most important physical processes involved in the phenomenon – turbulence and gravity - which will help to improve our understanding of the star formation process. The GRAVTURB project was conducted in 2008 by three researchers from the Universities of Heidelberg and Würzburg

Star formation is one of the most important phenomena occurring in the universe, yet the mechanisms that lead to it remain poorly understood. "This is because star formation takes a very long time, relative to the life span of a human individual", explains **Christoph Federrath**, researcher at the Institute for Theoretical Astrophysics, Heidelberg, and leader of the GRAVTURB project. "Take, for example,

the case of the Orion Nebula (the closest region of massive star formation to Earth, situated south of Orion's belt): there, the process can take around two million years! It is, therefore, simply impossible to directly observe the whole phenomenon that leads to the formation of stars."

In order to overcome this problem, astrophysicists usually combine direct observations of different star-forming regions, at different evolutionary stages, and numerical modelling. Computer simulations play an increasingly important role in astrophysics, and can contribute to improving our understanding of star formation. In the GRAVTURB project, such simulations have allowed the team to investigate the combined effects of gravity and turbulence (i.e., gravoturbulence) on the process leading to the transformation of dense gas into stars.

Integrating turbulence and self-gravity in simulations

The properties and manner of evolution of a star are closely related to its mass: stars of different masses (e.g. low-mass and high-mass stars) are thought to form as a result of different mechanisms. The determination of the statistical distribution of mass in newly formed stars – the stellar initial mass function – is one of the central keys to improving our understanding of star formation.

The main objective of the GRAVTURB project was to accurately model the mass distribution of stellar objects forming in the turbulent interstellar medium (i.e., the matter mostly made of gas that exists between the stars within a galaxy), including self-gravity.

Self-gravity is the gravitational attraction caused by the gas itself, and acting upon itself,

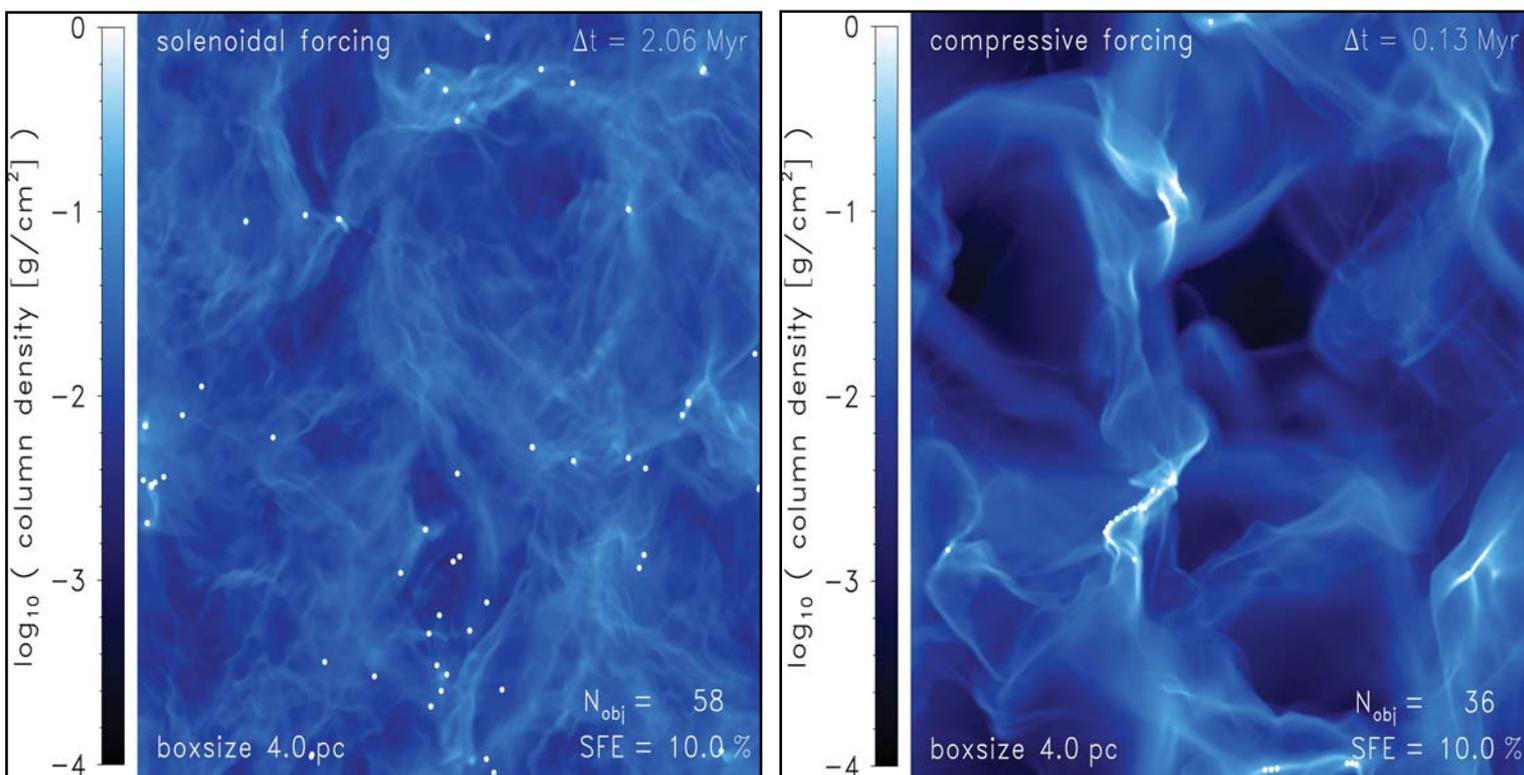


Fig.1. Spatial distribution of gravoturbulent gas for solenoidal turbulence forcing (left) and compressive turbulence forcing (right). The interplay of supersonic turbulence and gravity creates a complex network of gas compressions in shocks, where cores and stars (white dots) are most likely form. In the case of solenoidal forcing it takes roughly 2.06 million years for significant star formation with a star formation efficiency of 10 percent. In contrast, compressive forcing produces stars at a much higher rate, such that the same star formation efficiency is already reached after 0.13 million years

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causing dense gas clouds to collapse under their own weight. This phenomenon is known to be a major factor in the process leading to star formation, particularly in its later stages.

“Turbulence and self-gravity are the two most important physical processes in star formation. Supersonic turbulence (i.e. random and chaotic gas motions moving faster than the speed of sound waves travelling through the clouds) creates density enhancements in the interstellar medium, which form the seeds of the gravitational collapse of dense gas into stars. Supersonic turbulence tends to compress the gas locally into dense cores. These cores, in turn, can collapse due to their self-gravity to form single stars or stellar systems”, Federath explains.

“Our previous simulations did not include the effects of self-gravity. However, we know that self-gravity is the physical mechanism that eventually leads to the collapse of the dense gas seeded by turbulent motions. In the GRAVTURB project, the effects of self-gravity were integrated into our simulations”.

Simulating the formation, accretion and resulting mass distributions of collapsed objects in high resolution

An accurate study of star formation processes requires supercomputing capacities capable of providing high-resolution numerical simulations. “The star formation process covers roughly six orders of magnitude in length scale, ranging from an entire molecular cloud down to the scales of individual stellar objects, which is enormous”, according to Federath. “Even by using the most powerful modern supercomputers, we are still unable to cover the full range of length scales involved within a single calculation.”

Hence the utility of the DEISA infrastructure for astrophysicists. “DEISA provides access to Europe’s best supercomputing facilities enabling us to study star formation processes in detail”, Federath notes. “In the GRAVTURB project, a complex system of equations describing the spatial and temporal evolution of the gas had to be solved in three dimensions. This required powerful massively parallel supercomputers”.

Thanks to DEISA’s computing resources, the project team was able to reach an unprecedented level of detail in their simulations. “Within the DECI framework, we were able to study the formation, accretion (i.e. growth)



Fig. 2. Christoph Federath

and resulting mass distributions of collapsed objects in high-resolution numerical simulations of driven supersonic turbulence”, says Federath.

The team was also able to investigate the influence of two extreme kinds of turbulence forcing – a mechanism by which turbulent gas motions are excited – on the formation of stars: “solenoidal” forcing, which mainly excites rotational gas motions (vortices), and “compressive” forcing, where the gas is directly compressed in colliding gas streams.

“We found that compressive turbulence forcing turns gas into collapsed and accreting objects on timescales at least one order of magnitude faster than solenoidal forcing. This result has important implications for analytical models of the star formation rate (i.e., the rate at which gas is turned into stars) based on the density statistics of supersonic turbulence. In particular, our results show that the ratio of solenoidal to compressive modes of the turbulence must be taken into account in a consist-

ent theory of turbulence-regulated star formation.”

Realistic simulation of star formation in clouds is the ultimate goal

The GRAVTURB project enabled the German team to develop and test the code modules necessary both for the present work and for future studies, which will also include the effects of magnetic fields on star formation.

Currently, the team is working on a follow-up project at the Leibniz Supercomputing Center (LZR) in Munich. “The DEISA framework allowed us to study the mass distribution of dense cores. In the follow-up study, we aim to resolve the accretion disks that form around individual stars. This will allow us to probe the mass distribution of stars themselves, rather than the dense cores alone”, says Federath. “

Future numerical simulations will also include detailed modelling of the thermal physics involved by solving the equations for the formation and destruction of chemical species (i.e., atoms, molecules, ions, etc.) in the interstellar medium”, he adds. “This will allow us to predict the spatial distribution of these chemical species, which we can then compare with observational maps of nearby star-forming regions. For this purpose, we have recently applied for DECI-5 computing time (project CONVERGE). These future simulations will include a simplified chemical network allowing us to predict the spatial distribution of observed chemical species. The ultimate goal is to have a sufficiently realistic simulation (including all of the necessary physical processes) of the formation and evolution of stars in clouds, which we can then compare directly to observational data obtained with modern telescopes in order to test different star formation scenarios.”

Technical box

The simulations in the GRAVTURB project were performed on the SGI Altix 4700 at the Leibniz Supercomputing Center (LRZ), Germany, and on the IBM pSeries 575 Huygens system at the SARA Computing and Networking Services in the Netherlands. A total of 550,000 CPU hours were allocated to the project. The amount of CPU hours was split equally in order to run parallel simulations at LRZ and SARA. One simulation used a purely solenoidal divergence-free turbulence forcing, while the second used a purely compressive curl-free turbulence forcing, both including self-gravity. The whole star formation process covers roughly six orders of magnitude in length scale, from the size of a typical molecular cloud (10 pc = 3.1×10^{14} km) down to a few astronomical units (1 AU = 1.5×10^8 km, which is the distance from the Sun to the Earth). This required the performance of adaptive mesh refinement simulations, covering part of this vast range of length scales.

More information: www.deisa.eu/science/deci/projects2007-2008/GRAVTURB

DEISA Extreme Computing Initiative Awards 2010

Europe's HPC infrastructure DEISA has announced the latest resource allocations on Europe's most powerful supercomputers. Fifty scientific projects have been awarded supercomputing resources totalling more than 60 million processor hours, through the DEISA Extreme Computing Initiative.

These DEISA Extreme Computing (DECI) projects will each have access to resources at one or more of the 11 DEISA partner sites which operate fourteen of the Top 100 most powerful supercomputers in the world, including the only two European computers in the Top 10.

Through DECI, now in its fifth year, scientists are tackling a wide range of scientific challenges in materials science, astronomical science, particle and plasma physics, earth sciences, biological sciences and engineering. Successful projects are chosen for their

potential to achieve ground-breaking scientific results through the use of supercomputers, enabling them to run more detailed and accurate simulations of scientific problems than was previously possible. Multi-national proposals are especially encouraged and the latest projects to be supported include RBflow, an engineering project with ten partners from four countries in Europe, the USA, Japan and China, and SolarAct, an astronomy collaboration with involving researchers from four European countries and from the USA. Staff from DEISA will work closely with the researchers on each project, providing specialist applications support to optimise the scientific codes and deploy them on the most appropriate architecture.

Alison Kennedy, Coordinator of DECI said, "DEISA is delighted to be able to provide compute resources and applications enabling assistance to researchers in so many innovative

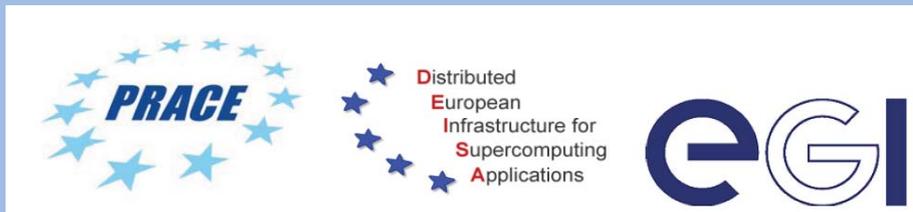
projects. This year, we attracted 75 proposals from 21 European countries. This shows the wide appeal and relevance of DECI across Europe."

Dr Janis Rimshans, the first Latvian DECI applicant said "DEISA support for our project related to simulation of critical phenomena in many-particle systems is very important in supplying us with access to new architectures and technologies, which up to now have been inaccessible for us."

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Information about the DECI-5 projects
www.deisa.eu/science/deci/projects2009-2010/science/deci/projects2009-2010



BoF session at SC'09: "European HPC and Grid Infrastructures"

Schedule: Tuesday, Nov 17, from 05:30PM - 07:00PM in Room D135-136

Abstract:

EGI, the European Grid Initiative, represents an effort to establish a sustainable European grid infrastructure. Its foundations are the National Grid Initiatives (NGIs) and the EGI Organization (EGI.eu). The first phase of EGI implementation is prepared to start in May 2010. DEISA is a consortium of the most powerful supercomputer centres in Europe, operating supercomputers in a distributed but integrated HPC infrastructure. It regularly hosts the most challenging European supercomputing projects and prepares a turnkey operational solution for a future integrated European HPC infrastructure. PRACE, the Partnership for Advanced Computing in Europe, prepared the creation of a persistent pan-European HPC infrastructure to support world-class science on world-class systems. PRACE will become operational in 2010 and deploy up to five leadership systems at renowned partner sites. For EEF, the recently formed European E-Infrastructure Forum will present its ideas on a future European compute ecosystem.

Agenda:

- "European HPC and Grid Infrastructures", *Konstantinos Glinos, European Commission*
- "The Distributed European Infrastructure for Supercomputing Applications", *Hermann Lederer, Max Planck Society*
- "The Partnership for Advanced Computing in Europe", *Thomas Eickermann, FZJ*
- "The European Grid Initiative", *Ludek Matyska, Masaryk University*
- "The European e-Infrastructure Forum", *Bob Jones, CERN*
- General Discussion

<http://scyourway.nacse.org/conference/view/bof159>

You will also find DEISA at the joint booth with PRACE in the exhibiton area. The booth number is 2973. Welcome!

