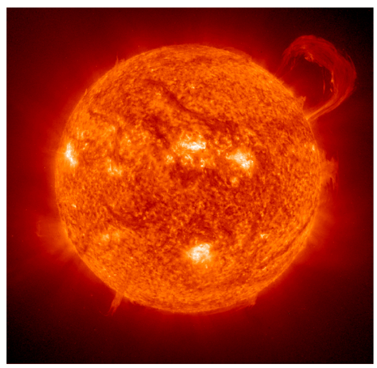
Computational Science: Astrophysics

Institute for Theoretical Astrophysics, University of Oslo

Planned start: Fall 2018



Why Computational Astrophysics

Roughly speaking, astrophysics is the study of anything and everything outside the Earth's domain, including the Moon, the Planets, interplanetary space and the Solar Wind, the Sun, the stars, the Milky Way, Galaxies, Galaxy Clusters, and the birth, evolution and structure of the Universe itself. Astrophysics is a field where there is little "laboratory" work, instead contact with reality must necessarily go via various remote sensing methods. This is perhaps the reason that astrophysicsts were amongst the first to develop numerical techniques to model quite complicated systems and to use high performance computers as a laboratory, or test bed, to confront their theories with observational reality.

In particular, at the Institute of Theoretical Astrophysics (ITA), computational astrophysics is mainly concentrated on three subjects: solar atmospheric modeling, extragalactic studies, and the evolution of structure in the Universe.

Computational Solar Physics. Sufficiently stable to nurture life during the last 4 billion years, and modern humans the last 100,000 years, the Sun is nevertheless a variable star. While the total solar irradiance only varies of order 0.1% during the 11-year solar cycle, the high-energy portion of the solar output can vary by several orders of magnitude on timescales of minutes. Solar activity - sun spots and active regions, UV and X-ray emission, the million degree corona, flares, coronal mass ejections, the acceleration of energetic particles - is increasingly interfering with human activity as our society's dependence on sensitive electronic equipment grows and as we venture beyond the Earth's magnetosphere and into the solar system proper. There is thus a pressing need to understand the workings of the energetic Sun.

At the ITA we have a goal of solving the problems of understanding and explaining the active sun. This means that we wish to build numerical models of the solar atmosphere good enough that we can construct synthetic spectral lines and images that can be directly compared with the observations. We have access to the best observables; members of the solar group at the ITA are Co Investigators on ESA's SOHO mission, NASA's IRIS and SDO missions, and JAXA's Hinode mission, as well as having 42 days of observing time at the worlds premier solar telescope, the Swedish 1-meter Solar Telescope on La Palma (Canary Island). To model the Sun we have constructed the Bifrost code, currently the worlds most advanced code for modeling the solar chromosphere and corona, and a code that we plan to expand to incorporate more advanced physics such as Generalized Ohm's Law, Multi-Fluid dynamics, and particle effects on relevant subregions. This set of tools gives us a fighting chance of solving the puzzles that confront us, but also the chance of involving our students in exciting work at the forefront of science with a mix of observational, theoretical, and/or numerical tasks.

Computational Extragalactic Astronomy and Cosmology. Galaxies are the building blocks of the Universe. Our home Galaxy, the Milky Way, hosts tens of billions of stars like the Sun, and the Universe contains about one to two hundred billions of galaxies. Galaxies come with different varieties, some with grand design spiral arms like the Milky Way, some with the shape of an ellipsoidal, and still some galaxies look completely irregular. Virtually all large galaxies (including the Milky Way) harbour supermassive black holes (SMBHs) at their centre. The vast space between galaxies are filled with gaseous intergalactic medium. Following the underlying dark matter structure, the gas accretes onto galaxies, and fuels the star formation and black hole growth within them. In turn, the stars and supermassive black holes inject energy, momentum, radiation and metals (elements with atomic number larger than Helium) into the surrounding gas which impact the subsequent accretion and star formation. When and how did the first galaxy form from the initial quantum perturbations? How do galaxies evolve throughout the cosmic history? What causes the galaxy population to be so diversified? And how do supermassive black holes form and co-evolve with the host galaxies? How did the radiation from first stars and black holes transform the intergalactic gas? These are some of the central questions we want to address in modern cosmology.

Simulating such complex and non-linear systems numerically is a highly challenging task, one needs to not only cover a large dynamic range, but also model simultaneously many physical processes (gravity, hydrodynamics, turbulence, star formation, black hole formation, radiation, magnetic field and perhaps cosmic rays etc.). At the ITA, we simulate cosmological galaxy formation with state-of-the-art hydrodynamic codes and sophisticated models of physical processes, including the one that has successfully simulated the world's first realistic Milky Way-like galaxy. We also developed a world-leading radiative transfer code to produce synthetic observations to confront simulations with the data. We have local expertise on observations of high-redshift galaxies using first-rate gravitational lensing data from the large Sloan Giant Arc Survey and the future Euclid satellite, as well as multi-wavelength data from major ground-based and space telescopes like HST, Keck, ALMA, GAIA and the upcoming JWST on galaxies at both early Universe and current epoch. It is the golden age for cosmology and extragalactic astronomy and students will be involved in exciting and fruitful projects at the ITA.

Study environment. This is new program at the University of Oslo and through various activities, spanning from common meetings and field trips to various social gatherings, we will gradually build up a top learning environment where you will thrive as a student and learn to develop your scientific creativity. The University of Oslo offers a rich and active student environment with more than 200 student lead activities and organizations.

Studies abroad. All study options offer possibilities for stays abroad. Planning a semester or more abroad or performing parts of your thesis at a collaborating institution is something we highly recommend. As a student in this program you have a number of interesting international exchange possibilities. The involved researchers have extensive collaborations with other researchers worldwide. These exchange possibility range from top universities in the USA, Asia and Europe as well as leading National Laboratories in the USA. Don't hesitate to get in touch with the contact person of your study option in case you plan to spend some time abroad. Studies at other institutions can be planned from the very first semester of this Master of Science program.

Students at the University of Oslo may choose to take parts of their degrees at a university abroad. The University of Oslo has exchange agreements with other universities in different parts of the world. The MN Faculty has additional exchange agreements with many universities abroad.

Career prospect. A significant aspect of this program is the ability to offer new educational opportunities that are aligned with the needs of a 21st century workforce. Many companies are seeking individuals who have knowledge of both a specific discipline and computational modeling. And candidates who are capable of modeling and understanding complicated systems in natural science, are in short supply in society. The computational methods and approaches to scientific problems that you will learn when working on your thesis project are very similar to the methods you will use in later stages of your career. To handle large numerical projects demands structured thinking and good analytical skills and a thorough understanding of the problems to be solved. This knowledge makes the students unique on the labor market.

Career opportunities are many, from research institutes, universities and university colleges and a multitude of companies. The program gives an excellent background for further studies, with a PhD as one possible goal.

The program has also a strong international element which allows students to gain important experience from international collaborations in science, with the opportunity to spend parts of the time spent on thesis work at research institutions abroad.

Successful astrophysics students have learned a large variety techniques to attack abstract problems. These are skills that have applications far outside of the study of "stars". To give you a taste of possible careers we have compiled a set of interviews of our alumni where they explain the relevance of their educations to their careers.