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Astronomy looks into the Future – the role of European Infrastructures

Star Dust: placing Astronomy into human context

Astronomy is one of the most ancient sciences that humanity has ever pursued. Since the dawn of civilisation, mankind has gazed at the night sky, awed and inspired by its black emptiness, the apparent immutability of the heavens, and wondered. Through the study of the heavens mankind has always sought to discover its place in the scheme of things, its connection to the divine, and its ultimate fate.

Mankind has evolved from these early times, we live now in a technological era of high precision instrumentation, of large scale infrastructures to pursue knowledge. Yet we still gaze at the skies, wondering where we come from, and where ultimately we will go. The goal of modern Astronomy is still to answer these ancient, meaningful questions. It is a quest for knowledge that is driven by mankind's endless curiosity, by its need to understand, and it is fuelled by its inventiveness and ingenuity. New technological advances lead to new discoveries, but also to new questions.

More than ever before we peer into the distant, primordial Universe, discover tantalising traces of the Big Bang, realise that visible matter is but one small constituent of a virtually unknown universe, full of exotic dark matter and energy with counterintuitive properties, which could even relate to the fabric of space-time itself. The discovery of extra-solar planets is now daily news, and their size is getting closer and closer to that of Earth: the first planets to be discovered were several times the size of Jupiter, now they are several times the size of Earth!

The Solar System is being explored as never before, and most probes are European: SOHO monitors the Sun, Mars Express sends to Earth stereoscopic images of Mars with unparalleled resolution, Cassini (in collaboration with NASA) orbits Saturn, Huygens sent us its signals to unveil Titan's surface, to name just a few. The venerable Hubble Space Telescope continues to obtain data and images of interesting objects that are not only relevant from the scientific points of view, but are regarded nowadays as masterpieces in their own right from the aesthetic point of view.

Astronomy enters the Big Science Era

Astronomy is traditionally seen as a science run in isolated observatories, usually associated to Universities: the image of the lonely stargazer, silhouetted against the starry sky sitting behind the telescope peering into the finder, is a familiar one. And yet nowadays nothing could be further from daily reality of an observatory. As the quest to observe fainter, more distant objects with ever increasing resolution continues, so does the complexity of the instrumentation and the size of the telescopes.

Only a few years ago 3-meter class telescopes were considered the top of their class: now we speak of 8-10 meter class telescopes such as ESO's Very Large Telescope (VLT), the Keck and Gemini Telescopes. In radio-astronomy, single dish radio telescopes of 100 meter diameter are far from uncommon – examples are the iconic Lovell Telescope at Jodrell Bank, or the Effelsberg Telescope at MPIfR Bonn.

Reality is however even more exciting than this. Using the physics principle of interferometry, astronomers and engineers have found the way to link several telescopes together to form a "super-telescope" with unprecedented resolution: the VLTi uses the four VLT telescopes with outstations and high precision laser interferometry to this effect, and VLBI, Very Long Baseline Interferometry, uses similar principles to combine the radio signals from radio telescopes in Europe with those in Japan, China, South Africa, America (and even in space), to form a radio telescope the size of Earth!

Telescopes like this herald the beginning of the Era of e-Infrastructures for Astronomy. Fibre optic links are now being used to upgrade telescope arrays such as e-MERLIN in the UK and e-VLBI, while Géant and GRIDs are used to transfer data at high speed for analysis. It is therefore more common nowadays to find astronomers peering at computer screens, away from the telescope and its instrumentation, rather than in the dome itself.

With the increase in size of telescopes, with the everyday use of computers and of all the advantages that modern technology can bring to science, so the data acquisition and storage needs have increased at a phenomenal rate. Multi-wavelength studies of the same object often call for standardisation of data acquisition techniques, and modern-day observatories are nowadays also centres of advanced IST. The creation of the Virtual Observatory Alliance, of which the European Virtual Observatory is an important component, is yet another step towards the globalisation of astronomy. Through the VO anyone with a computer will be able to access anywhere in the world data acquired and stored by different telescopes.

The implications of this are profound: data will be accessible also to professional astronomers in Universities and research institutes in countries which cannot afford to build their own observatories and would otherwise be cut off from mainstream science. Non-professionals will also be able to access the VO, such as schools and amateur astronomers, and the public at large will be able then to see for themselves the return of the knowledge produced by astronomy in terms of scientific education, of fostering a culture of scientific investigation and curiosity in the new generations, and maybe also of contributing, in a very small but significant way, to the advance of human understanding.

The future of European Astronomy: the need for new Research Infrastructures

European astronomers however are not resting on their laurels. The next generation of big infrastructures for astronomy is already on the drawing board, and astronomy is set to become ever bigger, with global projects where Europe can play a leading role and propel European astronomy into a new era.

The Atacama Large Millimetre Array (ALMA), under construction now in northern Chile's 5-km high Altiplano, is a Europe-USA-Japan partnership, where Europe is represented by the European Southern Observatory, ESO. ALMA will be able to peer through dust clouds and show us details of how stars, planets and perhaps life itself form, and it will be able to return images of the universe when it was only 20% of its present age. ALMA's current basic design includes 64 parabolic antennas of 12m diameter, connected together to form an interferometric array.

The Extremely Large Telescope (ELT) is a very ambitious concept for a new optical telescope. A 50m telescope is under study by a group led by Lund University, while a whopping 100m concept is now being designed at ESO in collaboration with European Universities and industries. With such a machine, astronomers will be able to detect objects thousand of times fainter than the faintest ones we can see today, to image extra-solar planets and determine the composition of their "atmospheres", peer into the deepest reaches of the universe and witness the birth of the first stars and galaxies.

The Square Kilometre Array (SKA) will be to radio astronomy what the ELT is to optical astronomy. The SKA will bring about a revolution in radio astronomy through the construction of an array of radio telescopes with a completely new concept. It will be the first aperture synthesis telescope with multiple independent fields of view (up to 100 at a time), capable of scanning the sky a million times faster than current instruments, and it will integrate state-of-the-art computing hardware and software on a massive scale. The SKA will be capable of peering deep into space at such things as gamma-ray bursts, extra-solar planets, evolving galaxies, dark matter and possibly even back to the Big Bang, where it all began.

With a data collecting area of one million square metres, a radio telescope array of this size would be too much for any one country or region to handle, and this is why the SKA was conceived as global, with an international consortium including the EU, South Africa, Australia, India, China, Canada and the USA busy working on design studies and demonstrators paving the way for the final SKA. As in the case of the ELT, the European SKA consortium is in a leading position.

EU support to European Research Infrastructures in Astronomy

Europe has world-class infrastructures for astronomy, is a leader of technological innovation applied to astronomical instrumentation in the first instance, but with very real industrial applications. European industry is world leader in mirror fabrication and adaptive optics applied to optical telescopes, while European electronics engineers are at the forefront of the R&D needed to continually improve receivers at the foci of radio telescopes, to name but a couple of outstanding examples.

Funding for research in Astronomy and for the development of Research Infrastructures is a prerogative of national funding programmes. The Research Infrastructures action of the European Commission aims to work in partnership with funding agencies of Member States, Associates States and interested countries outside the EU to develop synergies, to optimise the investment of existing resources, to foster integration and thus help structure the European Research Area.

During the Sixth Framework Programme the Research Infrastructure action has co-funded several projects in support of existing and new infrastructures of European (and international) relevance for Optical Astronomy, Radio Astronomy, Planetology and Astroparticle Physics. They are examples of how Research and Innovation through technological development can build a European Research Area.

The projects

RadioNet has pulled together all leading radio astronomy facilities in Europe to produce a focused, coherent and integrated project that will significantly enhance European radio astronomy . RadioNet ensures that key developments in radio astronomy are supported on a European-wide basis, pooling a broad range of skills, resources and expertise to provide a critical mass that ensures that progress is made quickly and efficiently, via a broad-based, yet well-focused scientific and engineering collaboration.

Its counterpart in optical astronomy is OPTICON, the Optical Infrared Coordination Network for Astronomy. OPTICON contributes to the continual development of the European astronomical community, high-technology research, and planning for next generation sophisticated facilities by bringing together all the national agencies and international organisations which fund, operate, and develop Europe's optical and infrared astronomical telescopes, instruments and observatories.

ILIAS brings together scientists from across Europe working in the young and growing field of Astroparticle Physics. This exciting area of research merges astrophysics and particle physics to allow simultaneous study of both areas through direct detection of the natural radiations and particles in the Universe. ILIAS assists and enhances Astroparticle Physics work in Europe in order to improve integration of existing work and better structure the European Astroparticle Physics community; to improve the existing physical infrastructures available to the scientists and their operation; to consolidate current world-leading positions and better prepare the community as a whole for the future.

EuroPlaNet's main objective is to achieve a long term integration of Planetary Sciences in Europe through the networking of European research groups active in this field. EuroPlaNet aims at increasing the science return from European and international planetary missions, with initial emphasis on the Cassini-Huygens mission to Saturn and its moons.

The SKADS Design Study aims at developing and demonstrating the Aperture Array concept suitable for Square Kilometer Array. During the next four years the 32-institute SKADS consortium - comprising the leading European radio astronomy and engineering institutes, in partnership with Australian, Chinese, Canadian, Indian, Russian and American research teams - will design cutting-edge (enabling) technologies, i.e. broad-band radio frequency (RF) antenna arrays, robust RF amplifiers, ultra-fast analogue to digital converters and signal processing techniques, high data throughput networks, and precise time and frequency transfer techniques via optical fibres. These will ultimately be incorporated into the broader international SKA project.

The ELT DS (Extremely Large Telescopes Design Study) is a very ambitious project led by ESO in cooperation with all major European Universities, research institutes and leading industries in the field. It builds on existing European design studies, on the leading industrial and academic expertise Europe has developed in the relevant fields, and gathers resources across European academic and industrial communities for a preparatory effort on crucial components, subsystems and concepts for a 100m-class optical-infrared telescope.

Two other ESO-led projects will be presented. ALMA Enhancement is conceived as an enhancement of the ALMA baseline project and aims to construct and install six receivers on ALMA to study star-forming regions in the water vapour lines at the 1.8mm wavelength band, with the aim of combining the resulting ALMA data with the European Space Agency's Herschel mission data. VO-TECH's partners seek to deploy Virtual Observatory capabilities in data centres and observatories across the entire electromagnetic spectrum. For this, they will work closely coupled with OPTICON and RadioNet. The project will provide a platform for a long-term European VO research infrastructure and capability.

Astronomy as support for industry

The technologies and know-how developed for and through astronomy can have many applications in industry. Here are just a few examples:

- Precision metrology: mirror alignment and fabrication require knowledge of measurements with extremely small tolerances, just as the pointing of telescopes needs extreme precision in mechanical and electrical engineering. Know-how gained through such work has wide ranging applications across industry.
- Navigation Systems: perhaps an obvious example is the navigation system, which is becoming used more and more by individuals as well as companies and governments. Without general relativity your navigation system would not know where you are! Improved knowledge gained in the astronomy domain is therefore key for the reliability of the future European navigation system (Galileo).
- CCDs: the continuous requirements for high resolution imaging for astronomy pushed the development of CCDs that ultimately find uses in other products, such as digital cameras.
- Better communication systems: the need to detect ever fainter radio signals has led to the development of ever more sensitive receivers. This technology then has applications in radio and TV communication as well as the defence industry and security
- Geant, Grid technologies and super-computers: these new Information and Communication technologies are tested every day by astronomy research. The new generation of telescopes needs ever increasing computing power – examples are IBM's BlueGene and LOFAR. Astronomy research infrastructures are therefore key to supporting the development of future European super-computing and communication facilities. The applications of these will be available to industry in a few years;