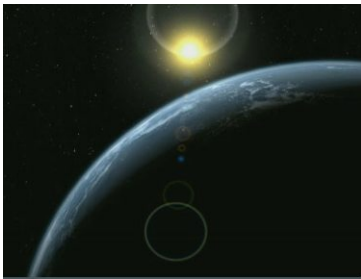


ASTROPHYSICAL VIRTUAL OBSERVATORY - *Observing the Digital Sky*

By Lars Lindberg Christensen

Astronomy through history



The first humans to watch the waxing and waning of the Moon and to use the setting Sun to mark the passage of the seasons took the first steps along a path that leads directly to today's modern observatories and high-tech instruments. Nowadays an astronomer is more likely to study an image of the Universe stored on a computer screen than to stare at the night sky - straining to catch the faintest signals from remote objects.

The earliest astronomical observations were made with the naked eye and recorded on clay tablets or papyrus. As the sophistication of the instruments used for observations has improved, so astronomy has advanced. Although some of the fundamentals laid down long ago are still valid today – for example the basis for the modern brightness scale for stars was first set out in the star catalogue compiled by the Greek astronomer Hipparchus in the 2nd century BC.



Throughout history technological advances have ushered in new and fundamental changes in our perception of the physical world. The Danish astronomer Tycho Brahe used a mural quadrant to make accurate measurements of the motions of the planets. The unprecedented accuracy of his measurements led Kepler to formulate his famous laws describing the motion of the planets, overturning the age-old paradigm that placed the Earth at the centre of the Universe.

Later Kepler's laws contributed to the theory of gravitation developed by Isaac Newton.

In 1609 Galileo was the first to use a telescope to look out into space. This new invention at once revolutionised astronomy and opened new windows on the Universe. Amongst Galileo's startling discoveries were the dark seas of the Moon, moons around Jupiter and sunspots.

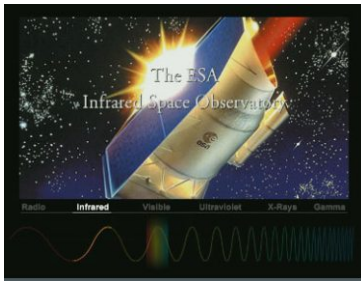


More recently, at the beginning of last century, Edwin Hubble used the great Californian telescopes at Mount Palomar and Mount Wilson - then the largest in the world - to discover the expansion of the Universe and subsequently to confirm Albert Einstein's recently published Theory of General Relativity.

Astronomers have always relied heavily on the different instruments and technologies available to them. Technology and scientific advance have always been closely coupled.

Contemporary and future observatories

For hundreds of years, science was the province of individuals or small groups, using whatever means they had. However, as astronomers seek to extract ever more intractable information from remoter objects a new trend has emerged. Larger projects, larger instruments, larger research collaborations, and larger amounts of data are needed to probe ever further out into the

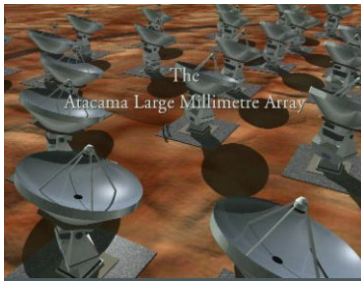


Universe. This new trend requires innovative technological solutions to ensure efficient communication between collaborating groups and high speed computing to handle massive amounts of data.

Today's instruments - on the ground and in space - observe the sky over a whole range of wavelengths not visible to our own eyes - from radio and infrared to ultraviolet, X-ray and gamma radiation, resulting in the discovery of many completely new astrophysical phenomena that require expert interpretation.

Many of the astronomical space observatories, such as the Infrared Space Observatory and the XMM-Newton X-Ray Telescope were built and are operated by the European Space Agency. Others, like the Hubble Space Telescope are collaborative projects between ESA and NASA. All these sophisticated instruments are accessible to all scientists throughout the world.

In the future, instruments such as the Next Generation Space Telescope, a deployable 6-metre infrared telescope, and ALMA, an array of 64 microwave telescopes, as well as enormous ground-based optical telescopes as large as 100 metres in diameter, will pave the way for more discoveries. They will show us planets around other stars and the first stars and galaxies in the making.



From galaxy to astronomer

Modern computers and data processing techniques have transformed astronomy. Observations are no longer recorded on photographic plates, but the incoming light from stars and galaxies is collected by the telescope and then converted into digital signals. These digital images are stored in computer archives and are accessible to astronomers over the Internet.

Astronomers all over the world, not only those who originally made a particular observation, can access and use the data to pursue their own research.

For example, one astronomer may collect an image to study the structure of a particular galaxy, while another scientist may use exactly the same image to study the stars in the image. The same valuable data, collected by sophisticated and costly instruments, can be used many times over in different projects by different groups across the world.



Ground- and space-based telescopes observe the same sky at different wavelengths and the resulting images are often startlingly different, but the archiving process for these very different observations is now technically very similar. Observations of stars, nebulae or galaxies taken with a multitude of instruments can be combined easily. A new, multi-wavelength window has opened on the Universe and has revealed new, sometimes unexpected physical phenomena for further study.

The digital flood

Modern observatories observe the sky continuously and data accumulates remorselessly in the digital archives. The growth rate is impressive and many hundreds of terabytes - corresponding to many thousands of billions of pixels - are already available to scientists. The real sky is being digitally reconstructed in the databanks!

However, reaching this digital sky will soon become a problem. The efficiency of modern instruments and detectors is doubling every 12 months, while the power of our computers doubles 'only' every 18 months and, even worse, the capacity of the current network doubles only every 20 months or so.

To illustrate the data flood that astronomers will have to face in the future: some of the telescopes planned for the next decade will deliver so many images in one night that it will take more than a month to transfer the data over the Internet as we know it today...!

This is not only a technological issue. Astronomers are not yet trained to deal with such a diverse and expansive set of data, nor is our brain equipped to analyse the millions and millions of available images simultaneously. We may have clear scientific goals and we may have the necessary data - but we have not yet developed the tools and methods to extract the relevant data from amongst the flood of images available.

Astrophysical Virtual Observatory

A new way of thinking, a new frame of mind, a new approach is needed.

The digital sky has the potential to become a vital tool with novel and fascinating capabilities that are essential for astronomers to make progress in their understanding of the Cosmos.

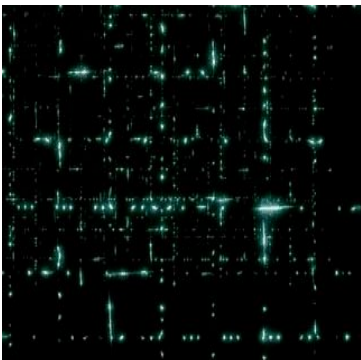
To solve the technological and operational issues, a new, powerful observing tool is needed to enable astronomers to extract data from the digital sky efficiently. The Astrophysical Virtual Observatory or AVO.

Astronomers can obtain information about rare objects, which are potentially crucial for resolving fundamental questions about the Universe by searching for them in the digital sky. A search of the 'real' sky would be too costly and would take far too long.

For example, astronomers will be able to retrieve the elusive traces of the passage of minor asteroids to reconstruct their orbit, size and eventual fate by pasting together observations taken at different times.

Or, when an old star in a distant galaxy explodes in an extremely energetic firework display called a supernova, astronomers will be able to go back and examine previous images of the same galaxy, taken before the event and readily available in the digital sky. They will be able to pinpoint the star shortly before it exploded, thereby adding invaluable data to the theoretical study of the evolution of stars.

GRID



Fortunately, astronomers are not alone in their battle against the data flood. Many areas of research are facing similar problems. A solution has been envisaged and major scientific and technological organisations, are experimenting with it.

The solution is called GRID.

GRID is a new concept for using the World Wide Web. It will improve the efficiency of information exchange across the Network, but more importantly, it will offer distributed super-computing capabilities to its users.

Using GRID technology and the Astrophysical Virtual Observatory, astronomers will no longer need to transfer large quantities of data over the network. The data will remain at their own home sites, in the different digital archives at the data centres. The GRID super-computing capability at each data centre will carry out the data analysis and relay the results back to the astronomer.

For example, astronomers can ask the AVO to find out how many galaxies are likely to host massive black holes at their centres by simply specifying the characteristic features of a typical candidate object.

AVO, thanks to the GRID technology, will launch several browsing and analysis procedures across the Internet that will operate in parallel on different data sets located at different centres. Only the result of the analysis - here a list of possible candidate black holes - will be delivered to the astronomer, who can then refine the search by sending out further queries across the Web.

Conclusion

We are at the beginning of a new era, where data collected by a multitude of sophisticated telescopes can be used globally and repeatedly to achieve substantial progress in our quest for knowledge.

*“Those whose pursuit of knowledge takes them to the summit of the world,
Whose intellect penetrates the depths of the universe,
To them the sky shall be an upturned goblet
From which, their heads thrown back, they shall drink to intoxication.”*

Omar Khayyam (1048-1122, Nishapur, Persia (Iran))
The Rubaiyat