July 2017 meeting review by Richard Godley

Speaker: Neil Phillipson

Subject: “ALMA - Supercomputer Astronomy"

Neil is an astronomer by profession. For 7 years he ran an astronomy shop and now he designs and builds private observatories. He has recently been working on an astronomy village of observatory houses in Bulgaria.

ALMA stands for Atacama Large Millimeter / submillimetre Array. This is a single telescope of unique design and is the most expensive land-based telescope ever built. It has been developed through a partnership between astronomers in North America, Europe and east Asia in co-operation with Chile, and is the largest single astronomy project in history. It became operational in 2013. Despite its uniqueness the ALMA project is not as widely known as it should be.

As its name suggests it was designed to observe emissions in the millimeter and submillimeter wavelengths of the electromagnetic spectrum. We know that visible light is only a small part of the spectrum and that we can also feel heat in the infrared part of the spectrum and be burned by ultraviolet radiation. Electromagnetic waves at different wavelengths are indicative of different source temperatures. The millimeter and submillimeter wavelengths indicate a source with a very low temperature, typcally between 1 and 10 Kelvin, i.e. not much above absolute zero. Earth's atmosphere absorbs much of the emissions in these wavelength ranges.

Why do we want to observe radiation in the millimeter and submillimeter ranges anyway? When we do so we are observing radiation from cold objects, and things in the process of being formed are typically cold. So this means protoplanetary disks, star-forming nebulae and early-stage galaxy formation can be observed and this helps us to understand our cosmic origins.

Trying to achieve this presented astronomers with a number of challenges. These included atmospheric emisisons and atmospheric attenuation (absorption by water vapour) and noise in the detector. A space=based telescope might have seemed a better solution. So why is ALMA on the ground?

The answer is that size matters. A 12 metre telescope could have been launched but it would only have had the same resolution in arc seconds of a Celestron C14. We couldn't launch anything that would perform better than a C14. So a ground-based telescope it is, then.

To do this astronomers knew the ideal places would be ones with a dry atmsophere, cool temperatures, and away from population centres but not so remote that transporting equipment was too difficult. Stable weather conditions were also required. There were only 5 possible locations on Earth, of which the Himalayas, Greenland and Antartica are too remote. Mauna Kea in Hawaii was the choice of the American team but conditions are not perfect there. A site at an altitude of 5,000 metres near Llano de Chajnantor in Chile became the chosen location.

Amongst the various co-operating countries the US had planned the MMA (MilliMeter Array), Europe the LSA (Large Submillimeter Array) and Japan both the LMA (Large Millimeter Array) and LMSA (Large Submillimeter Array). Once all parties were looking at the same site the US and European projects were combined as ALMA and with Japan it became the Enhanced ALMA, but ended up still being called ALMA.

The array consists of 66 antennae, 50 provided by the US and Europe and 16 by Japan. The American and European antennae have a diameter of 12 metres, while those provided by Japan consist of 4 that are 12 metres in diameter and 12 that are 7 metres in diameter. It was agreed that usage of the array would be divided up in such a way that Chile uses it for 10% of the time, with the remaining 90% being divided up so that the US and Europe have 37.5% each and Japan has 25%.

The antennae were constructed at an altitude of about 3,500 metres and transported up to the site at 5,000 metres. Each antenna can be moved around the site by transporters so that the array can stretch from a mimimum configuration diameter of 150 metres up to a maximum configuation of 16 kilometres in diameter.

The dishes are operated as an interferometer, and effectively the array has the resolution of a single telescope with a diameter of the size of the whole configuration.

The dish of each antenna is of a Cassegrain design and they are accurate to 25 microns. It can see 10 times the detail of the Hubble Space Telescope.

Data from the antennae is processed, digitised and encoded at the dish and then transmitted to the Array Operations Site (AOS) where the signal is converted back to analogue. ALMA's supercomputer, 'the Correlator' has 134 million processors and can perform 7 quadrillion operations per second. Operators of the 'Correlator' have to wear oxygen masks and carry breathing apparatus because of the altitude at which they are working.

After four years of operation we have some results from ALMA and these are published on an ESO (European Southern Observatory) blog with accompanying images. ALMA has detected water in the universe, at a signature wavelength of 1.64mm. We can point ALMA at anything and know very quickly whether water is present or not.

Neil showed a number of images from ALMA, and some comparison images from the Hubble Space Telescope. The images from ALMA are superior. All of the ALMA images we saw were from the last 6 months.

We saw detail in the spiral arms of LL Pegasi. The galaxy A2744 YD4 in the Abell Cluster is the most distant observed target. This is a very young object and we can see it thanks to gravitational lensing. It started forming about 600 million years after the birth of the universe.

In our own galaxy stars are forming at a rate of about one solar mass per year, but we observe a rate of star formation of 20 solar masses per year in distant galaxies and so we know that the early universe produced stars at a faster rate than is the case now. We also saw an ALMA image of a protoplanetary disk around the star HD169142.

ALMA can even image the Sun, which seemed most unlikely since the wavelengths it is observing in are indicative of very low temperaures, but within the photosphere there are layers at low temperatures.

Neil showed an ALMA image of interacting galaxies, as another example of how ALMA has improved image detail compared with Hubble. ALMA has been able to prove that the reality of the Sumyaev / Zel'dovich effect, which relates to distortion of radiation in the Cosmic Microwave Backround in galaxies.

ALMA has been able to capture the highest resolution image ever of Betelgeux, and it can be seen as disk in the image we saw, rather than just as a point of light.

We were extremely grateful to Neil for giving us this wonderful talk and showing such wonderful images, and also for the use of his projector when Alex Vincent showed various images subsequently. This review cannot replicate the images we saw. You had to be there. Meanwhile, following a number of questions and answers, those who were present thanked Neil in the customary way.