Colloquium Report 2

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Science with the Atacama Large Millimetre Array

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Astronomy, one of the oldest Sciences has captured the fascination of mankind throughout history and will probably do so for the unforeseen future. For millennia our ancestors looked up into the night sky in wonder, and now we have reached the technological ability to explore our solar system and the universe itself. Historically, all observations have been done in the visible range of the Electromagnetic (EM) spectrum due to technological constrains. Only after James Clerk Maxwell developed the theory of electric and magnetic forces in the 1900 century was it realised that EM waves could exist with any wavelength.[1] This discovery laid the foundation to modern astronomy, where not only visible light observations are possible. Nowadays observations in the whole range of the EM spectrum are carried out.

Dr John Richer, who is the UK Project Scientist for the Atacama Large Millimetre Array (ALMA) began his presentation with an overview of this magnificent new telescope. ALMA is the largest astronomical project in existence costing ≈ $1.4bn and will be completed at the end of 2013. The telescope array is located on the Chajnantor plain of the Chilean Andes at an altitude of 5050 m above sea level, which makes it the highest astronomical observatory in the world. Figure 1 shows a composite map of different scaled images to illustrate its location.

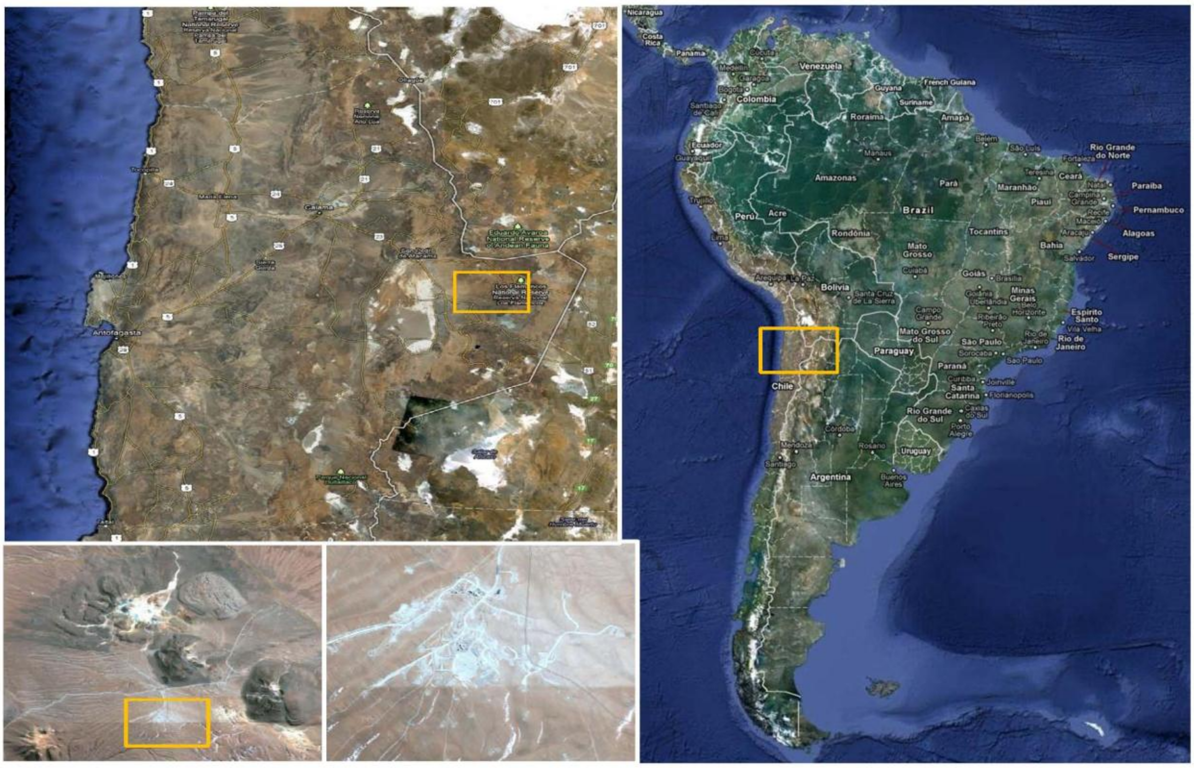

Figure 1: Location of ALMA

When finished it will comprise 66 antennas; fifty 12 m antennas for sensitive, high resolution imaging, four additional 12 m antennas providing total power, and twelve 7 m antennas comprising the ALMA Compact Array (ACA), enhancing the fidelity of wide field imaging. Through the advanced design of fully mobile antennas 40 different configurations with 216 pads are available for positioning the antennas in baselines from 150 m to 16 km as it will act as a single giant telescope with a variable diameter. Figure 2 envisages an artist's impression of an antenna setup with the transporter in the lower right moving an antenna to another pad. As of March 2012 thirty four antennas have been delivered to the Chajnantor Plain.

Figure 2: Artists impression of an antenna configuration of ALMA and the transporter to the lower right

Operating at an altitude of 5050 m as mentioned before, proves to be ideal for millimetre and submillimetre wavelength studies, as pressure broadened molecular spectral lines can be experienced at low altitudes limiting the sensitivity and resolution of the instrument. Transmittance or opacity to various wavelengths of EM radiation in Earth atmosphere is

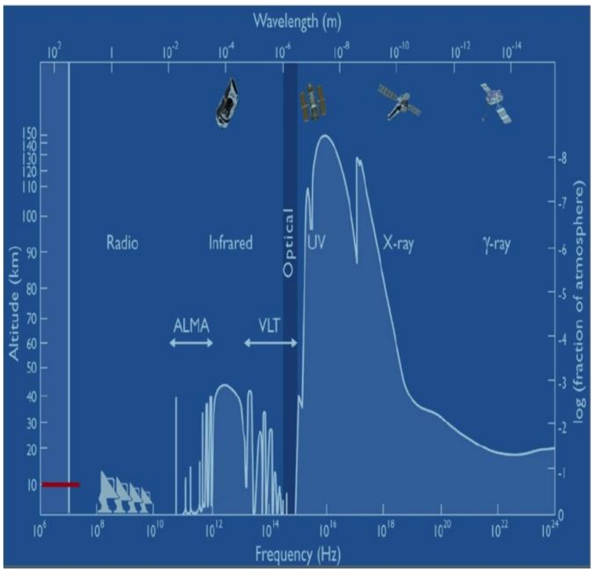

Figure 3: Earths atmospheric transmittance

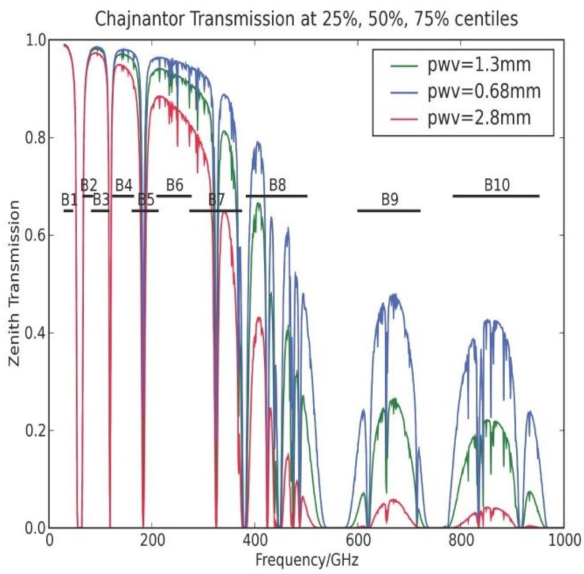

Figure 4: Transparency of the atmosphere above ALMA site as a function of frequency

shown in Figure 3, while the transparency of the atmosphere above the ALMA site as a function of frequency is shown in Figure 4. Due to the dry conditions at the plain the amount of precipitable water vapour (pwv) is also very low at the location at around 0.5 mm. This allows for fewer variations in the electrical path length through the atmosphere. Also shown in Figure 4 is the frequency coverage of the ALMA receiver bands as numbered black horizontal lines. These receiver bands range from 31.3 GHz to 950 GHz. This corresponds to wavelengths of 9.58 x 10^{-3} m to 3.16 x 10^{-4} m. For observations, antennas are coupled to create an interferometer measuring a Fourier component of the light source. Computers will then use fast Fourier transform in order to obtain images from the interferometer data. The antennas are capable of measuring 2000 Fourier components at any one time. The antennas have a field of view of 60 arcsecs (") at 100 GHz/3mm. The bandwidth of the array will be 8 GHz and will have two polarisations, therefore producing IQUV imaging. Spatial resolution is dependent on the observing frequency and the maximum baseline of the array. The resolutions range from 0.7 " at 675 GHz to 4.8 " at 110 GHz for the most compact configuration with 125 m baseline and 6 mas at 675 GHz to 37 mas at 110 GHz for the most extended configuration of 16 km baseline. In order to correct any atmospheric effects, adaptive optics is utilised. This is a technology inside the optical system to improve performance by reducing the effect of wavefront distortions.

After giving the introduction Dr Richer went on in his presentation to talk about the three basic "Level 0" science goals which drive the technical requirements. These are:

1. To detect spectral line emission from CO or [COII] in a normal galaxy like the Milky Way at a redshift of z = 3, in less than 24 hours of observations.

2. To image gas kinematics in protostars and protoplanetary disks around Sun-like stars at 140 pc distance, enabling the study of their physical, chemical and magnetic field structures and the detection of the gaps created by planets undergoing formation in the disk.

3. To provide precise images at 0.1 " resolution. Precise means representing within the noise level the sky brightness at all points where the brightness is greater than 0.1% of the peak image brightness. This applies to all objects transiting at > 20° elevation.

Leading on from these requirements, prospective areas of study were discussed. The millimetre and submillimetre wavebands utilized by ALMA are unique in astronomy in containing more than 1000 radio spectral lines of interstellar and circumstellar molecules as well as the thermal continuum spectrum of cold dust in space. These wavelengths in the EM spectrum are the only opportunity to detect cold dust and molecules far away in young, high-redshift galaxies in the early Universe, and nearby in low-temperature cocoons of protostars in our own Galaxy. This also includes observing fine-scale kinematic details in young stellar disks that can potentially form planets, and in old ejected stellar envelopes that are forming dust grains and enriching the interstellar medium with carbon and other elements.

The design specifications that will enable ALMA to study these regions are as follow:

- Angular Resolution of around 0.25" Full width half maximum (FWHM) – this will provide sufficient for observations as the nearest protostars are around 200 pc away.
- Spectral Resolution of 0.25 km/s – This moderate spectral resolution is chosen in order to provide a larger instantaneous bandwidth as the sound speed of the gas should be a fraction of a km/s, but the non-thermal motions will broaden the lines.
- Receivers of bands 6, 7, and 9 – in order to detect the strong spectral features of the molecules within the hot cores. Also very excited lines within the hotter inner regions may be observed.

Other processes related to star formation can also be studied. This will include measuring the dust emission in debris disk, observing molecular outflows and jet generation. Currently within jet generation only the length of the jets can be resolved, however with ALMA's resolution of a few AU test models of the jets can be made. Excellent astrometric performance will enable ALMA to accurately measure the proper motion of outflows and test these models. Equation 1 describes the astrometry ALMA is capable of.

$$\Theta = 0.2'' \left(\frac{D}{100\,pc}\right)^{-1} \left(\frac{v}{100\,kms^{-1}}\right) \left(\frac{t}{1\,year}\right) \qquad \text{Equation (1)}$$

Another area of study is the origin of galaxies and their epoch of re-ionisation. This re-ionisation is thought to be complete at a redshift of z=6. By measuring the properties of galaxies at z=7-12, ALMA hopes to provide crucial tests of the current models of the universe. Current studies into this area are limited as the optical brightness of distant galaxies are minimal, however ALMA will operate at a 1mm wavelength, a wavelength at which the optical brightness of the galaxy is independent of its redshift.

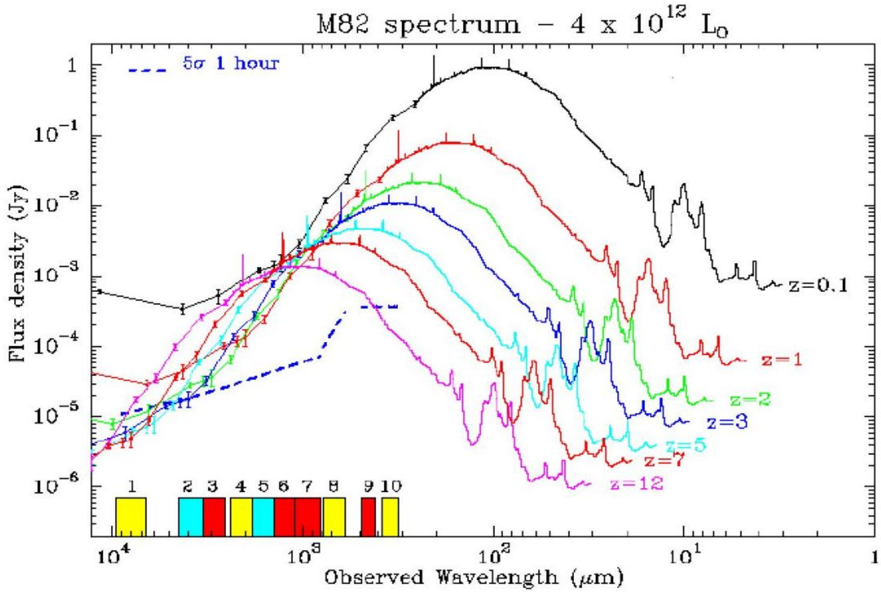

Figure 5: Graph of the observed wavelength against the flux density of M82 for different red-shifts

The graph in Figure 5 illustrates the 1 mm wavelength observations. All the redshift lines cross at 1 mm which indicates that if you observe at such a wavelength, the optical brightness of the galaxy will be independent of the redshift.

Before using ALMA for observations proposals will be submitted to the Joint ALMA Observatory (JAO). After approving these proposals, observations will be scheduled in blocks. Calls for proposals for the so called Cycle 0 will be open with observations to start in September 2011. This incorporates 16 twelve metre antennas and 3 frequency bands. No observations will be made at the actual site as it will be too expensive and dangerous to do so. For this purpose ALMA Regional Centres (ARCs) have been created in Charlottesville (USA), Tokyo (Japan), Garching (Germany) and Manchester (UK). These centres provide user support for all aspects of observing, preparation and data analysis.

Although ALMA is developing rapidly there are still lots of obstacles to overcome. These include risk of earthquakes and volcano eruptions, setting up the power system and preserving the surrounding Chilean wildlife.

Referees Report

I attended several colloquia and lectures over the past few months and years for this module and my course study. They include:

Dr Serena Viti	University College London	The origin of Molecular emission in galactic and extragalactic star forming regions
Dr Dirk Froebrich	University of Kent	Astrophysics and the Anthropic Principle
Dr Gbenga Oduntan	University of Kent	Where does Space Begin?
Dr Michael Tarbutt	Imperial College London	How round is the electron and why does it matter?
Prof Ofer Lahav	University College London	Testing The Dark Energy Paradigm and Beyond

These and other Kent Physics Centre lectures provided me with a wide spectrum of speakers to compare with Dr Richer. Dr Richer's talk was an informative journey through the exciting new possibilities that the Atacama Large Millimetre Array will provide. The talk lasted for about 50 minutes and described the physical parameters of the facility, scientific and engineering challenges, goals and possibilities. The length was appropriate and the talk was not overwhelmingly scientific, since the audience for these colloquia's are mostly undergraduate students. The speaker spoke clearly, in good English, did not appear nervous and did not lose his string of thoughts by the disruptions of several late arrivals. He spoke confidently and without the aid of notes. This demonstrates his knowledge of the subject and that he was well prepared for the presentation. He rarely broke eye contact with the audience, and spoke with an enthusiasm that helped to keep the attention of the audience and spark interest about the subject.

Dr Richer kept the audience occupied with lots of images of the on-going work at the ALMA construction side and anecdotes from his time at the Chajnantor plain. A PowerPoint presentation was used and the slides were not overloaded with information like some of Prof Lahav slides. The colloquium gave many examples of why current radio telescopes are not adequate to forward our knowledge of the universe. Dr Richer successfully used graphs and data from studies using other instruments in order to clearly illustrate how ALMA will benefit future research. This illustrates that research into the specifications of existing radio telescopes had been done and how these could be improved had been well thought over prior to designing ALMA.

On the other hand the slides of the PowerPoint presentation were not well ordered or structured, with many of the points and pictures repeated and placed in unusual positions on the slide. This made it difficult to follow the talk and link the slides to the point being discussed in an orderly fashion. Also the length of the presentation was not consistent with the number of slides presented. There were 68 slides in total, many of which were unnecessary images that did not add to the overall presentation. Another weakness was that at the end of the presentation, questions ask were not answered in a concise manner. Dr Richer seemed to avoid giving straight answers to questions that picked out flaws with the project, and he was largely biased with the responses he offered.

In summary, despite the weaknesses discussed in this report, Dr John Richer's colloquium, 'Science with the Atacama Large Millimetre Array' provided an interesting and thought provoking insight into this fascinating new observatory. This talk was especially interesting for me and other ASSA students, because the new possibilities this telescope offers will steer astronomical observations to new frontiers and we are at a point of our course were we soon will benefit from newly build telescopes like ALMA for our own work and scientific discoveries.

References

Images Front page:
www.almaobservatory.org and Dr John Richer's presentation 'Science with the Atacama Large Millimetre Array'
Figure 1: courtesy of Google Maps at http://maps.google.com
Figure 2: http://www.almaobservatory.org/en/visuals/images/?g2_itemId=1480
Figure 3,4,5: Dr John Richer's presentation 'Science with the Atacama Large Millimetre Array'

[1] National Radio Astronomy Observatory. 2003. Pre-History of Radio Astronomy [internet]. Available at: <http://www.nrao.edu/whatisra/hist_prehist.shtml > [accessed 14 March 2012]

'Observing with ALMA, A Primer', Herzberg Institute of Astrophysics & University of Calgary