ALMA/THz astronomy

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I. Capabilities

The frequency range from $\approx 30 - 1000$ GHz is key to unveil the cold Universe: the formation of planets and stars in the Galaxy, the formation of complex molecules and chemistry in the interstellar medium of the Galaxy, as well as the interstellar medium, gas inflows and outflows in nearby and distant galaxies. Currently, the state-of-the-art telescope covering this wavelength range is the Atacama Large Millimeter/submillimeter Array (ALMA), situated in the Atacama desert in Chile. With 8 bands covering the frequency range $84-950$ GHz, large bandwidth of The 8 GHz, and 66 antennas, ALMA has proved to be capable of observing proto-planetary disks around stars in the Milky-Way, to very distant galaxies within the first billion years of the Universe. Its pathfinder, the Atacama Pathfinder Experiment (APEX), has been very successful at carrying out surveys of the interstellar medium in the Milky-Way, nearby and distant galaxies, in varying levels of detail. In addition to ALMA and APEX, other sub-mm and mm telescopes situated in the northern hemisphere, such as the James Clerk Maxwell Telescope (JCMT), NOrthern Extended Millimeter Array (NOEMA), the 30-meter telescope in Spain (30M), and Large Millimeter Array (LMT) are exploring similar regimes albeit at lower resolution and sensitivity than ALMA.

Locally, the Australia Telescope Compact Array (ATCA) is currently the only telescope that allows access to competitive regimes, as several molecular emission lines of very distant galaxies redshift to frequencies accessible from ATCA (e.g. [6], [7], [8]). However, the frequency coverage, spatial resolution and sensitivity of ALMA is superior to ATCA.

II. Current status

ALMA is a very competitive instrument to get access to, and Australia can only access it in the 5% of the time ALMA dedicates to open skies. This makes the pressure factor for accessing much larger than for member agencies of ALMA (including the European Southern Observatory; ESO). Despite this, Australian astronomers have managed to be quite successful at getting time with 6, 8 and 2 proposals led by Australian astronomers ranked in the highest priority tier for ALMA in 2016, 2017 and 2018, respectively. In addition, 2 out of the 10 large programs currently being carried out with ALMA have Australian astronomers as members (e.g. [13], [14]). However, the limitations of open skies access are important: no leadership of large programs is allowed, and the pressure factor can be > 7.

APEX is also very attractive for Australian astronomers, with 5 Australian-led proposals being submitted just in the period 103, for a total of 160 hrs. Because both ALMA and APEX are southern hemisphere telescopes, the overlap with existing and future Australian astronomy endeavours is optimal.

In the northern hemisphere the access situation is similarly limited: Australian astronomers are not eligible to be Principal Investigators on JCMT or LMT observing proposals, and can only access NOEMA and the 30M telescope if their proposals are judged “excellent” (and with the amount of time reserved for open skies being variable). Even in the case of success, observations are logistically challenging as the remote observing tools are not well developed for NOEMA and the 30M telescope, meaning that travelling to France/Spain is necessary.

Below, we summarise the areas of involvement Australian astronomers have in the sub-mm/mm astronomy. It is important to highlight that these areas are all associated to key questions for the next decade highlighted in the decadal plan.

(i) The Galaxy. GHz-THz instruments have unveiled over 200 different molecules beyond our Solar System (without counting isotopologues). Those molecules are fundamental in helping us understand key phases in the formation of low and high-mass stars, the formation of dust grains in supernovae, circumstellar envelopes and the interstellar medium, and ultimately the formation of complex organic molecules that give rise to life. Astronomers in Australia are already heavily involved in these projects (e.g. [3], [15]).

(ii) Nearby Universe. GHz-THz instruments have enabled the detection of hundreds of molecular lines in local star-bursting galaxies, and allowed detailed studies of giant molecular clouds and the interstellar medium of galaxies in the nearby Universe. In some cases, powerful outflows of cold gas have been studied in detail. Australian astronomers are involved in ALMA large programs focused on the study of nearby galaxies, and are starting to probe the connection between the atomic (best studied with ASKAP) and molecular gas (accessed with ALMA; e.g. [2], [9], [14]).

(iii) Distant Universe. sub-mm and mm telescopes offer a unique opportunity to probe star formation and cold gas in a large cosmic time window, out to the first billion years of the Universe. These studies are key to understand the powering

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of supermassive black holes, the strongest starbursting events in the Universe, the formation of dust and the multi-phase interstellar medium of galaxies. Australian astronomers are involved in ALMA large programs exploring the distant Universe and have led a number of high priority proposals in this area (e.g. [1], [4], [5], [10], [11], [12]).

III. Future engagement and benefit

The synergies between key Australian facilities, such as the SKA, ASKAP and MWA in the radio, and HECTOR, SAMI and TAIPAN in the optical, and ALMA/APEX are very strong and could pave the way to transformational science. ASKAP and MWA are investing significant time in exploring the Galaxy and Magellanic Clouds, as well as the atomic hydrogen content and star formation of nearby and distant galaxies. ALMA and APEX can provide the counterpart view to the colder regions of star formation and molecular clouds, together offering a comprehensive view of the interstellar medium of galaxies. ALMA can also provide information on the kinematics of the cold gas in galaxies, that would complement the stellar and ionised gas kinematics being explored by SAMI and HECTOR. Australian astronomers are also using Keck and VLT to explore star formation and the kinematics of distant galaxies, which would benefit from ALMA to get a full perspective of their conditions. Such studies should also lead us to unveil the sources of reionisation. In addition, ALMA is likely the only way to secure spectroscopic redshifts above $z \approx 7$ until the 30m-class telescopes come online.

ALMA will continue to be the prime telescope for high sensitivity/high resolution studies in the next several decades, as no other plans are in place for better telescopes. In addition, ESO is studying the possibility of a large mm/sub-mm antenna, Atacama Large-Aperture Submm/mm Telescope[1] (AtLAST), to carry out survey science in this wavelength range. The latter would be a prime telescope to complement the large surveys being carried out and planned in Australia.

Full membership of ESO would give us more access to ALMA, APEX and AtLAST (if funded), and because the community has already proved their success even under high pressure, open skies access, a positive outcome is highly likely. If ESO full membership is not achieved, the community risks surrendering leadership in carrying out the transformational science that would come from the synergies between Australian facilities, from radio to optical, and ALMA/APEX/AtLAST, becoming less attractive internationally.

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