

Report on the ESO/ALMA Conference

ALMA 2019: Science Results and Cross-Facility Synergies

held in Cagliari, Italy, 14–18 October 2019

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The Atacama Large Millimeter/submillimeter Array (ALMA) is the largest and most sensitive millimetre/submillimetre array on the planet, with the highest spatial resolution. Since it began operating, ALMA has routinely been at the forefront of science in this wavelength regime, delivering ground-breaking discoveries. The ALMA 2019 science conference was organised as one of a series of meetings held at regular intervals for the worldwide ALMA community, the previous one being held in Indian Wells, USA in 2016. At the start of Cycle 7 of observations, the ALMA 2019 conference provided an opportunity for the community to reflect on the multitude of scientific results from the facility, with special emphasis on the results from the first rounds of ALMA Large Programmes, the long baselines and high-frequency capabilities, the new solar and very long baseline interferometry (VLBI) modes, as well as the synergy between ALMA and other observatories.

Motivations

The ALMA observatory on the Chajnantor plateau in the Atacama desert in Chile is the largest and most sensitive submillimetre and millimetre array available. Its 66 antennas provide sub-arcsecond resolution in this wavelength regime. With eight receivers currently operating and a further two under construction, the frequency range from 35 to 950 GHz will ultimately be accessible with high spectral resolution. In addition, polarisation and VLBI measurements are being conducted with ALMA. It is a highly successful observatory, as evidenced by its ever-growing worldwide user base and more than 1600 publications after seven years of operation. ALMA is an important facility across a wide range of science topics, including cosmology, galaxies in the distant universe, nearby galaxies, the Galactic centre, interstellar matter and star formation, astrochemistry, circumstellar discs, exoplanets, the Solar System, stellar evolution and the Sun. The ALMA project is

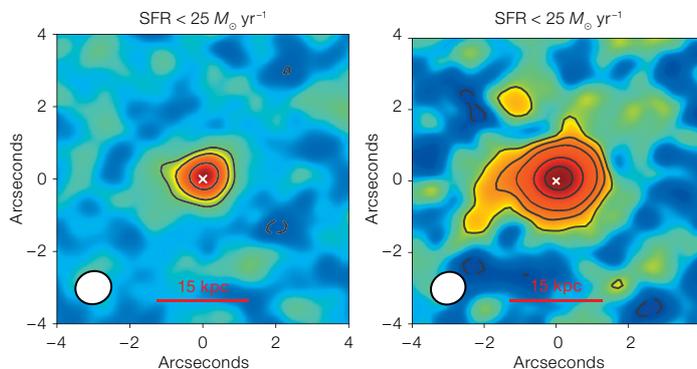


Figure 1. Extended [CII] emission observed in the circumgalactic medium of stacked ALPINE galaxies, from the talk by Michele Ginolfi.

a joint effort by three regions: Europe (ESO), North America (USA, Canada and Taiwan) and East Asia (Japan, Taiwan and Korea), and in addition to topical and regional meetings, the worldwide ALMA community meets every 2–3 years for a truly global conference. Earlier examples include the ALMA science meetings in Puerto Varas (Chile, 2012), Tokyo (Japan, 2014) and Indian Wells (USA, 2016). In October 2019, it was Europe's turn to organise the community-wide science meeting in a joint effort between ESO and INAF – Cagliari in Italy.

A major theme of the meeting was the focus on Large Programmes and their initial results. Large Programmes (> 50 hours of observing time) were introduced in Cycle 4 (2016–2017), which saw the approval of two of them. A further four Large Programmes were approved in each of Cycle 5 and Cycle 6. In order to showcase the results from these Large Programmes we invited a key collaborator from each of the Cycle 4 and Cycle 5 Large Programmes to present their results. Since Large Programmes can run up to two cycles, observations for Cycle 6 Large Programmes were not yet completed at the time of the conference. Nevertheless, some initial results from the Cycle 6 programmes were presented in the contributed talks. Other main themes included synergies with other facilities which were taken into account when creating the science programme, and the priorities from the ALMA 2030 Development roadmap which were a major topic, in particular in the poster presentations.

The programme was organised according to the five science categories of the ALMA proposal submission process, with four invited talks in each of the science

categories I through IV, and two invited talks in science category V, which only receives about half the observing proposals compared to each of the other four science categories. Broadly, the five science categories are:

- i. Cosmology and the high-redshift Universe;
- ii. Galaxies and galactic nuclei;
- iii. Interstellar medium (ISM), star formation and astrochemistry;
- iv. Circumstellar discs, exoplanets and the Solar System;
- v. Stellar evolution and the Sun.

The programme also included an observational talk to open the conference and a conference summary, yielding a total of 20 invited talks covering a diverse range of topics. The science categories were divided over sessions consisting of two or three blocks of talks each and we alternated between topics during the week in order to enhance interaction between the categories. Most presenters have made their slides available on Zenodo¹, and the majority of the poster presentations can also be found on Zenodo at the same URL.

Summaries of talks and highlights from sessions

Session I on Cosmology and the high-redshift Universe was spread over Monday, Wednesday and Friday and included both the opening and closing sessions of the conference. Three Large Programmes were discussed in the context of this session. Roberto Decarli gave a presentation on the ALMA Spectroscopic Survey in the Hubble Ultra Deep Field (ASPECS) which is a spectroscopic survey in Bands 3 and 6 (3 and 1.3 mm) of a significant

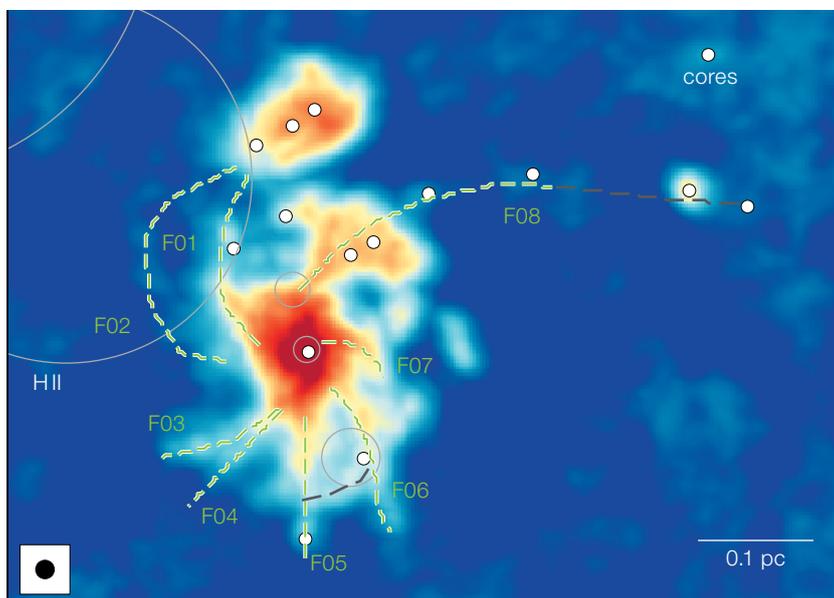
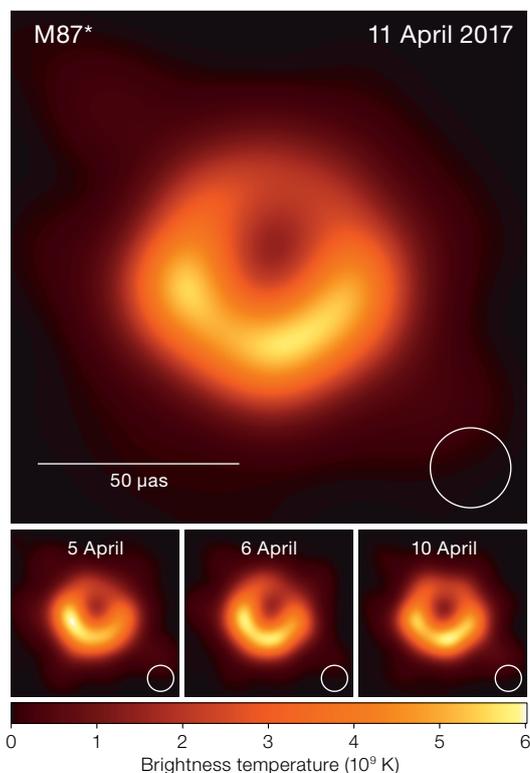


Figure 2. (Left) The iconic image of the shadow of the supermassive black hole in the centre of M87 as detected by the Event Horizon Telescope collaboration, and presented by Shep Doleman.

Figure 3. (Above) Converging filaments leading towards the formation of the super star cluster Sgr B2. From the talk by Alvaro Sanchez-Monge.

part of the Hubble Ultra Deep Field, in order to follow the evolution with redshift of the interstellar gas and dust reservoirs of galaxies. The first results show that the gas masses do indeed follow the star formation history of the Universe and the survey also boasts the deepest 1.3-mm continuum map ever. From Michele Ginolfi we heard about the ALMA Large Programme to INvestigate [CII] at Early times (ALPINE), which uses [CII] emission lines and continuum measurements to study star formation and galactic evolution at high redshift. In addition to analysing the sample, it has been possible to stack all galaxies and study the extent of [CII] emission in the circumgalactic medium, a result also highlighted by Seiji Fujimoto in a contributed talk. The presence of carbon demonstrates that galaxies are able to enrich their circumgalactic medium with the products of nucleosynthesis early in the history of the Universe — at redshifts $5 < z < 7$. In another contributed talk, Kotaro Kohno reported on preliminary results from a Cycle 6 Large Programme, the ALMA lensing cluster survey. Further talks in Session I also covered topics related to cluster formation — see, for example, the contributions by Axel Weiss — and the Sunyaev-

Zeldovich effect (talks by Luca Di Mascolo and Tony Mroczkowski). Loretta Dunne presented a calibration of atomic and molecular gas and dust mass determinations at different redshifts.

Session II, dealing with galaxies and galactic nuclei, was spread over sub-sessions on Tuesday, Wednesday and Thursday. This session featured the spectacular results on the imaging of the black hole shadow in M87 by the Event Horizon Telescope. In an invited talk, Shep Doleman reported on the observations and detailed data analysis behind the discovery. In a related contributed talk, Lindy Blackburn discussed VLBI observations at 3 mm of the immediate surroundings of Sgr A*, and the modelling required to interpret the observations. In addition, two Large Programmes were discussed. Sergio Martín reported on the ALMA Comprehensive High-resolution Extragalactic Molecular Inventory (ALCHEMI), which is doing a spectral line survey of NGC 253 in five different bands. The PHANGS Large Programme, which aims to study resolved star formation in ~ 50 nearby galaxies, was presented by Eva Schinnerer. She showed the participants stunning maps of the distribution

of molecular gas through, for example, CO(2-1) emission in spiral galaxies, revealing a distribution distinctly different from that of the ionised gas tracing the star formation. The ratio of ionised and molecular gas emission also varies greatly between galaxies. Studies of CO clouds in Local Group galaxies were presented by Atsushi Nishimura for M33, and by Katie Jameson for the Small Magellanic Cloud, the latter being a full survey of the bar of the SMC with the Atacama Compact Array (ACA). Quasars and active galactic nuclei were the topics of several of the other talks in this session, with special attention going to the dynamics of the torus and outflows, and the chemistry in these environments.

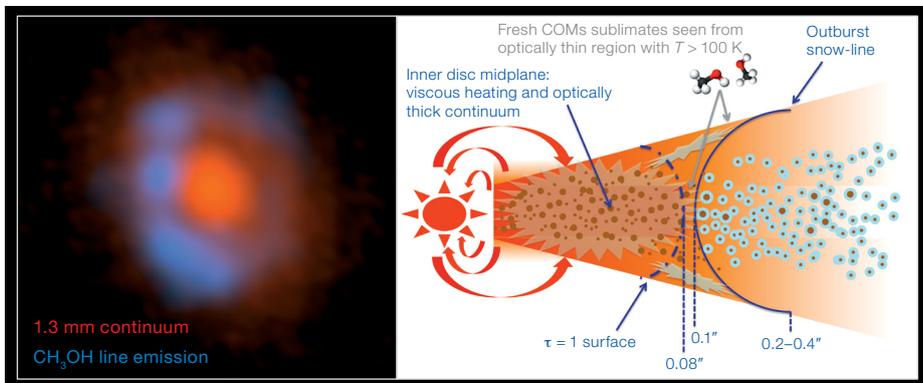
Session III covered the interstellar medium, star formation and astrochemistry in sub-sessions spread over the first three days of the conference. The highlights of this session include the discussion of the Large Programme “ALMA transforms our view of the origin of stellar masses” (ALMA-IMF) by Fabien Louvet, who showed results determining the initial cloud mass function in 15 massive star-forming regions within 6 kpc traced in different molecular lines, also revealing

Figure 4. The detection of a ring of methanol around V883 Ori representing the first detection of complex organic molecules associated with planet formation. From the talk by Jeong-Eun Lee.

filaments and outflows in these regions. Spectacular images showing converging filaments leading to the formation of the super star cluster Sgr B2 were presented by Alvaro Sanchez-Monge. This session also featured several talks on ALMA polarisation measurements tracing magnetic fields in the ISM and star-forming regions, as well as other astrophysical environments. Chat Hull delivered a talk on enhanced polarisation in the outflow cavities of young stars, while Tanmoy Laskar discussed the detection of polarised emission from the reverse shock associated with a gamma-ray burst, revealing a very low polarisation fraction of less than 1%.

Session IV on circumstellar discs, exoplanets and the Solar System was spread over two days. Sean Andrews presented an overview of the Disk Substructures at High Angular Resolution Project (DSHARP) Large Programme on small-scale structure in a sample of 18 protoplanetary discs, showing a range of discs, rings and asymmetries in continuum emission, some of which could be assigned to the interaction with newly formed planets. Several talks, including those by Jeong-Eun Lee and Ilse Cleeves addressed the chemical evolution of planet-forming discs. Cleeves modelled the effect of X-ray flaring by the host star on the circumstellar disc in comparison with observations, while Lee follows the formation of complex organic molecules (COMs), and their “snow lines”. The topic of molecular snow lines was also addressed by Chunhua Qi in a contributed talk, who imaged the distribution of molecules susceptible to freeze-out, and secondary molecules able to trace this freeze-out. From Anna Miotello, we heard about the correlation and calibration between dust masses and molecular gas masses derived for protoplanetary discs.

Session V on stellar evolution and the Sun was the shortest session and was naturally split into a session on the Sun on Monday and a session on evolved stars on Thursday. Progress on solar astronomy with ALMA was reported



by Sven Wedemeyer, Dale Gary and Stephen White, demonstrating the complementary contributions from ALMA to other facilities to studying the dynamic structure of the Sun at timescales shorter than 1 second. Thanks to its broad frequency coverage, ALMA can be used to probe the solar chromosphere at different depths. The session on evolved stars contained a few more talks on a range of topics. Leen Decin presented the initial progress of the Cycle 6 Large Programme ALMA Tracing the Origins of Molecular In dUst-forming oxygen-rich M-type stars (ATOMIUM), while Daniel Tafoya observed strongly collimated outflows in some evolved stars.

Owing to an overwhelming response to the poster session, posters were displayed in two sessions, with a change-over in the middle of the week. The poster sessions were very well attended. Four posters were highlighted by the poster prize committee, and their presenters, Philipp Weber, Sandra Treviño-Morales, Aleksandra Hamanowicz and Atefeh Aghababaei, were each given the opportunity to deliver a short talk on the same topic on the final day of the conference.

Main conclusions & ways forward

Looking back, it is safe to conclude that the conference was successful in bringing together the scientific community using ALMA, and in presenting an overview of the science currently being done with the telescope. In particular, impressive results from the first two cycles of

Figure 5. Simultaneous imaging of the same part of the Sun at different wavelengths using different facilities, the first image on the second row being an ALMA Band 6 image. From Sven Wedemeyer’s talk.

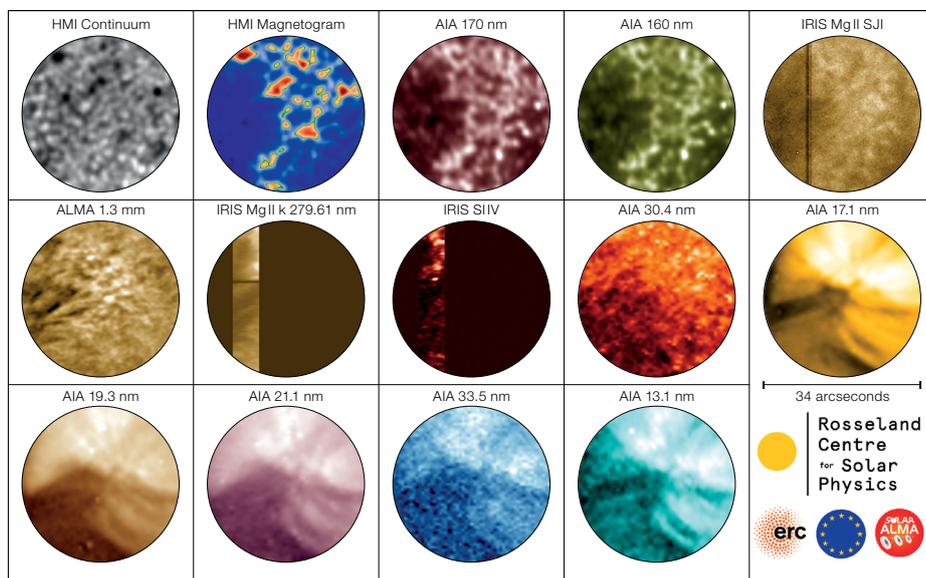




Figure 6. A poster made from a group photo of the participants.

Large Programmes were presented, as well as the detailed story behind the already famous image of the shadow of the black hole at the centre of M87. Specialised observing modes, such as polarisation, solar observations and VLBI, were well represented in the oral and poster presentations, along with the more standard line and continuum observations tracing interstellar and circumstellar gas and dust, in both the nearby and distant Universe. There is clearly a need for this kind of global ALMA meeting, and the consensus is that a next one should be organised in about 2022. Perhaps one of the key points of that meeting could be the synergy with other facilities as this aspect remained somewhat underexamined in the ALMA 2019 conference.

Demographics

The Science Organising Committee (SOC) sought fair representation from the community. We had four invited speakers in science categories I through IV listed above, and two invited speakers in science category V, which represents the proportionally smaller size of the scientific community, as evidenced by the observing proposal pressure in this category. The PIs, or designated representatives, of all of the six Cycle 4 and 5 Large Programmes were amongst the 18 invited speakers, and the remaining 12 spots were filled by science area, where we aimed to achieve gender and regional

balance. In this case, the term regional refers to the three ALMA executives or regions (Europe, North America and East Asia). Two more invited talk slots were reserved for an overview of the status of the observatory by the ALMA director, and the conference summary.

The SOC selected the contributed talks based on scientific merit, although in cases with equal scoring of multiple abstracts for a single remaining slot, gender and regional balance considerations were taken into account. In total, exactly half of the invited speakers were women, and approximately one third of the contributed talks were delivered by women.

The conference proved to be very popular during the registration phase, and the venue limit of 250 participants was exceeded overnight on the day of the abstract submission deadline for contributed talks. We thus had to close registration, even though the originally planned registration deadline was later, and were forced to waitlist about 70 registrants. The waitlisting was done after the contributed talk selection and was primarily based on the scientific merit of the submitted abstract. As a result of cancellations in the weeks following the announcements of the contributed talk schedule, the waitlist fortunately disappeared completely and ultimately everyone who had wanted to attend the conference and had been registered by the abstract submission deadline was able to attend.

The conference was attended by 216 participants. An additional 17 participants from Japan were not able to make it as a typhoon hit the Tokyo metropolitan area on the weekend before the start of the conference, which prevented many participants departing for Italy. Of the participants, 29 were students at the time of the conference. We encouraged the conference attendees to participate in an anonymous demographic survey and received 182 responses. Of these respondents, 55.5% (101) indicated they were male, 44.0% (80) female and 0.5% (1) of the respondents preferred not to say their gender. The geographical origin of the respondents, based on their current affiliation, was well distributed over the ALMA regions, with 45.1% (82) from Europe, 30.2% (55) from Asia, and 20.9% (38) from North America. A further 3.3% (6) were from South America, and 0.5% (1) was from Australia. None of the respondents was based in Africa.

Acknowledgements

The ALMA 2019 conference was jointly organised by ESO and the Osservatorio Astronomico di Cagliari (INAF) and was financially supported by INAF, RadioNet and ESO. The conference also hosted an itinerant “Inspiring Stars” exhibition from the IAU, in Italian.

Links

¹ Presentations and posters from meeting available via Zenodo: <https://zenodo.org/communities/alma2019cagliari>