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Report on the ESO Workshop

ALMA Development Workshop

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Tony Mroczkowski[1]
Carlos De Breuck[1]
Ciska Kemper[1,2]

[1] ESO
[2] Academia Sinica, Institute of Astronomy & Astrophysics (ASIAA), Taipei, Taiwan

The Atacama Large Millimeter/Submillimeter Array (ALMA) is the most sensitive observatory spanning millimetre and submillimetre wavelengths. To maintain this position, however, a vibrant and concerted development programme is necessary. Since each partner region in ALMA conducts its own development programme, we hosted an international workshop at ESO to promote further cross-regional discussion of our parallel development efforts. As we describe here, an overriding goal for this was to align our development activities with the goals of the 2030 ALMA development roadmap — a report recently produced by ALMA to provide guidance on what directions we want the ALMA observatory to go in, and how to get there.

Motivations

ALMA[1] is the world's most sensitive facility for millimetre/submillimetre astronomical observations, and will soon be fully operational in all of the originally planned bands (35–950 GHz). Over the last seven years, ALMA has continuously delivered exciting and often surprising results in all areas of astronomy[2], from observations of the first galaxies to the multiphase gas in large-scale structures, and from forming protoplanetary discs to observations of the Sun.

ALMA is a collaboration among three partner regions — Europe (through ESO), North America (USA, Canada and Taiwan), and East Asia (Japan, Korea and Taiwan) — with Chile. In order to keep ALMA at the forefront of technology, each ALMA partner has a continuous development programme. Within Europe, ALMA activities are coordinated through ESO. Since each region conducts and funds its activities differently, we focus here on the EU-ALMA development programme. ESO strives to closely involve the Member State institutes in this programme by issuing calls for EU-ALMA development studies every three years.

In 2016, we decided to coordinate a workshop on ALMA development with that year's call for studies, and found the workshop to be an overwhelming success (Laing, Mroczkowski & Testi, 2016). The result was that proposals submitted to that call were well focused on ALMA's development goals at the time. Following this success, we chose to host the 2019 ALMA Development Workshop at ESO's headquarters in Garching, and timed the meeting to fall just after the announcement of the 2019 call for development studies.

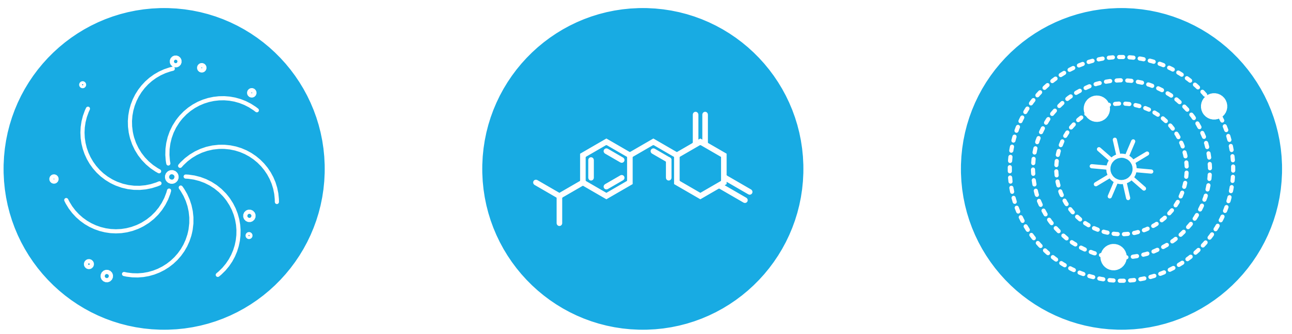

Figure 1. Key science drivers for ALMA, from the ALMA Development Roadmap.

A major theme of the meeting was where ALMA should be by the year 2030. Since 2016, the landscape for ALMA development has changed. Band 1 (35–50 GHz) production is fully under way in East Asia, while the final Band 2 (officially 67–90 GHz, though efforts towards a much wider bandwidth design are ongoing) is now entering Phase 1, which sees the construction of six pre-production cartridges. With a clear path in place to complete the original suite of ALMA bands, ALMA leadership has begun formalising the requirements for the next decade of operations. This effort is known as the 2030 ALMA Development Roadmap[3] and it was released in June 2018.

The 2030 roadmap outlines three new key science drivers for ALMA (see Figure 1), and provides four recommendations. These are as follows (quoting directly from the roadmap)[3]:

1. Origins of Galaxies: Trace the cosmic evolution of key elements from the first galaxies ($z > 10$) through the peak of star formation ($z = 2$–4) by detecting their cooling lines, both atomic ([C II], [O III]) and molecular (CO), and dust continuum, at a rate of 1–2 galaxies per hour.
2. Origins of Chemical Complexity: Trace the evolution from simple to complex organic molecules through the process of star and planet formation down to Solar System scales (~ 10–100 au) by performing full-band frequency scans at a rate of 2–3 protostars per day.
3. Origins of Planets: Image protoplanetary discs in nearby (150 pc) star formation regions to resolve the Earth-forming zone (~ 1 au) in the dust continuum at wavelengths shorter than 1 mm, enabling detection of the tidal gaps and inner holes created by planets in the process of forming.

The specific development priorities set out in the ALMA Roadmap, ranked in order of priority, are as follows:

- Broadening the receiver bandwidth by at least a factor of two, and upgrading the associated electronics and correlator.
- Upgrading the existing receiver bands, where the highest priority is given to receivers operating in the 200–425 GHz region, followed by receivers covering frequencies lower than 200 GHz, and, finally, higher than 425 GHz.
- Enhancing the long-term capabilities of the ALMA archive.
- Performing exploratory studies on potential future development paths, where ESO specifically prioritises feasibility studies into the extension of the maximum baseline length by a factor of 2–3, as well as the applicability of focal plane arrays.

We note that the first two items have the principal aim of increasing the observing speed of ALMA, while the latter two increase the scientific capabilities of ALMA.

Summaries of talks and highlights from sessions

Here we summarise the invited talks and highlight discussions from dedicated sessions and contributed talks. All talks and posters are hosted on Zenodo[4] and are linked to the workshop programme[5].

The opening talks were delivered by the ESO Director General, Xavier Barcons, and the ALMA Director, Sean Dougherty. These overviews were followed by a summary of the ongoing work to update the ALMA receiver and backend electronics specifications, originally defined two decades ago, and by regional overviews from each of the ALMA partners. Overall, there was broad agreement with our vision for ALMA's future.

First and foremost, everyone agrees that lower receiver noise temperature is in ALMA's interest, particularly in the so-called workhorse bands — Bands 3, 6 and 7. However, as we approach the limits of technology (current receivers have 4–10 times the quantum noise limit, which is the ultimate limit for standard receiver technologies), the noise in a fixed bandwidth is dominated by the atmospheric contribution. The largest gains to be had in imaging speed might be easiest to obtain by expanding ALMA's bandwidth (currently < 8 GHz). For example, doubling the bandwidth would result in a factor of two increase in imaging speed for any observation requiring broad bandwidth or needing continuum sensitivity. Any expansion of the receiver bandwidth entails expansion of the backend electronics — digitisers, data transport, and correlator. This implies that a significant number of the most compelling hardware upgrades must be coordinated amongst several development groups, and therefore the exact parameters of any potential bandwidth improvement must be carefully defined.

Frédéric Gueth and Christophe Risacher from the Institut de Radioastronomie Millimétrique (IRAM) and Keith Grainge from the Square Kilometre Array reported on ongoing and planned development and construction activities at their respective observatories. We also heard about the ongoing ALMA Band 1 (35–51 GHz) production, and the prototype development for ALMA Band 2 (67–116 GHz), both of which had been mentioned earlier in the context of completing the original suite of ALMA bands. On the second day, the programme included presentations on the higher-frequency technologies being developed, which are especially applicable to Bands 6–10, and receiver control software that will find more optimal operational parameters for the existing ALMA receivers.

Next, the topics moved to the backend electronics that will take advantage of the upgraded receivers. Crystal Brogan introduced the project to upgrade the current correlator — currently functioning with decades-old hardware — to have higher spectral resolution and a doubling of the existing bandwidth, followed by much discussion of more ambitious projects to build an entirely new correlator.

On the final day, we heard about improvements to ALMA's software and observing capabilities, including improved proposal generation tools, improved observing modes (for example, solar high-cadence and extended baselines), and more sophisticated and rigorous imaging and analysis techniques. Notably, the ALMA Science Archive project called "Additional Representative Images for Legacy" (ARI-L) is now underway to bring the Cycle 2–4 data in the ALMA archive up to the level of Cycle 5 and later, directly addressing one of the ALMA Development Roadmap priorities. We are in an era of data-driven science, and ARI-L will make the ALMA archive much more conducive to such work. Also, a web-based replacement for the

Figure 2. Workshop photo outside the ESO Supernova, showing that we chose a week of lovely weather in Garching.

current Java-based ALMA Observing Tool (ALMA-OT) is in the works and will improve compatibility going forward. Most users will welcome this, as the vast majority of user tickets related to the ALMA-OT are essentially Java support issues, not issues with the tool itself.

Main conclusions & ways forward

Throughout the workshop, it was clear that ALMA is not a project that will be neatly completed — which is the impression one sometimes gets as we race to build the final bands in the original ALMA band definition. Rather, ALMA is an ongoing and vibrantly active project. Only through continued development can ALMA remain a competitive, groundbreaking observatory. The breadth of work presented in the talks showed that the next decade will continue to be as exciting for ALMA as the first has been. To achieve this ambitious goal, the ALMA executives showed a clear willingness to collaborate.

Demographics

The workshop was attended by 79 registered participants, only 12 of whom were female (15%). The Science Organising Committee sought fair representation from the community, but sadly the gender balance within the applications was particularly poor. We feel this reflects much of the skewed gender ratio in teams working on ALMA-related technology development, which we are striving to improve. In future, groups within ALMA should be encouraged to increase the visibility of women within their groups, rather than consistently choosing only male group members to present group efforts.

The balance for regional representation was better, with attendees coming from all three regions defined in the ALMA collaboration and Chile in the following percentages:

- 66% Europe;
- 14% North America;
- 11% East Asia;
- 9% Chile (South America).

Since this was a small workshop, all abstracts submitted by the deadline were accepted. Submissions coming after this deadline were given posters.

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References

Laing, R., Mroczkowski, T. & Testi, L. 2016, The Messenger, 165, 47

Links

[1] ALMA observatory: https://www.almaobservatory.org/en/home/
[2] ALMA Press Releases: https://www.almaobservatory.org/en/category/press-release/
[3] The ALMA Development Roadmap (Carpenter et al., 2018): https://www.almaobservatory.org/en/publications/the-alma-development-roadmap/
[4] Zenodo link to the workshop presentations: http://doi.eso.org/10.18727/0722-6691/5058, https://zenodo.org/communities/almadevel2019/search?page=1&size=50
[6] The workshop programme: http://www.eso.org/sci/meetings/2019/ALMADevel2019/program.html