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Solar research with ALMA: Czech node of European ARC as your user-support infrastructure

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Abstract.

ALMA (Atacama Large Millimeter/sub-millimeter Array) is by far the largest project of current ground-based observational facilities in astronomy and astrophysics. It is built and operated in the world-wide cooperation (ESO, NRAO, NAOJ) at altitude of 5000m in the desert of Atacama, Chile. Because of its unprecedented capabilities, ALMA is considered as a cutting-edge research device in astrophysics with potential for many breakthrough discoveries in the next decade and beyond. In spite it is not exclusively solar-research dedicated instrument, science observations of the Sun are now possible and has recently started in the observing Cycle 4 (2016-2017).

In order to facilitate user access to this top-class, but at the same moment very complicated device to researchers lacking technical expertise, a network of three ALMA Regional Centers (ARCs) has been formed in Europe, North America, and East Asia as a user-support infrastructure and interface between the observatory and users community. After short introduction to ALMA the roles of ARCs and hint how to utilize their services will be presented, with emphasis to the specific (and in Europe unique) mission of the Czech ARC node in solar research with ALMA. Finally, peculiarities of solar observations that demanded the development of the specific Solar ALMA Observing Modes will be discussed and the results of *Commissioning and Science Verification* observing campaigns (solar ALMA maps) will be shown.

Introduction

ALMA (Atacama Large Millimeter/sub-millimeter Array) is current cutting-edge observational facility in the astrophysical research constructed and operated in the world-wide international cooperation in Chile. Because of its unique parameters it brings potential for many break-through discoveries in space research and fundamental physics and represents a key ground-based device in the field for the next decade and beyond. Nevertheless, its utilization for regular users even with a high-quality background in astrophysics might become cumbersome because of lack of their expertise in the ALMA technology and ALMA service software. In order to increase scientific return and to support excellence in research, the main partners in the ALMA consortium – ESO (Europe), NRAO (U.S.) and NAOJ (Japan) – decided to form a user-support infrastructure – the network of three ALMA Regional Centers / ARCs, located at the respective organizations. The main goal of this infrastructure is direct support (on-line and face-to-face) to the ALMA user community at all stages of their ALMA oriented research projects. Furthermore, the ARCs contribute to the further development of ALMA helping with the ALMA SW and infrastructure tests and promoting new possible ALMA capabilities.

The European ARC is formed as a coordinated distributed network of seven nodes centered around ESO. One of the nodes is hosted at the Astronomical Institute of Academy of Sciences in Ondřejov, Czech Republic. The Czech node of the European ARC provides the standard user services to the local, European, as well as international ALMA users' community. In addition to that it contributes to the further development of ALMA observatory by definition and commissioning of a new observing mode targeted to solar research with ALMA.

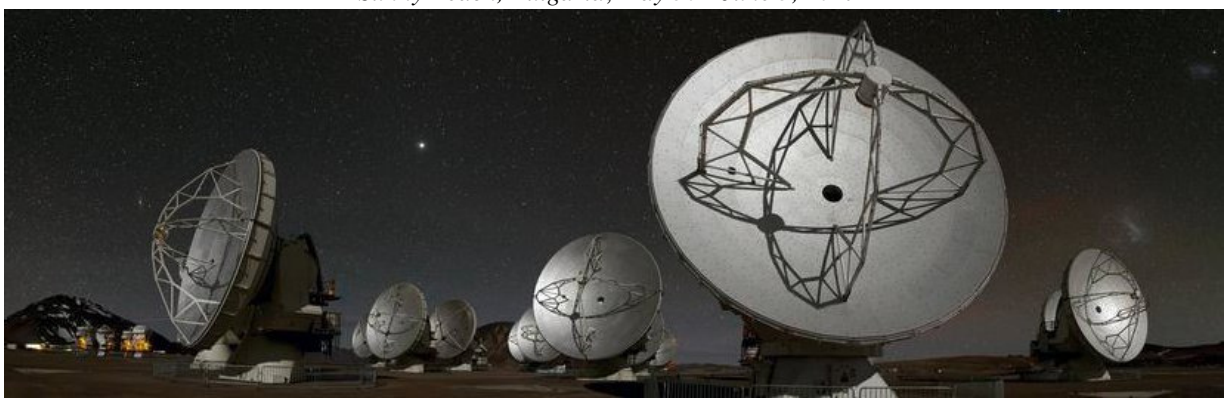

Fig. 1: ALMA Observatory by night (http://www.almaobservatory.org).

ALMA Observatory

ALMA (Atacama Large Millimeter/sub-millimeter Array) is the far largest project of current ground-based observational facility in astronomy and astrophysics. It has been recently built in a literally world-wide international cooperation of European Southern Observatory (ESO), U.S. National Radio Astronomy Observatory (NRAO) and National Astronomical Observatories of Japan (NAOJ) in the altitude of 5000m in the desert of Atacama, Chile. Because of its unpreceded capabilities ALMA is considered as a top research device in astrophysics with potential to many breakthrough discoveries for the next decade and beyond.

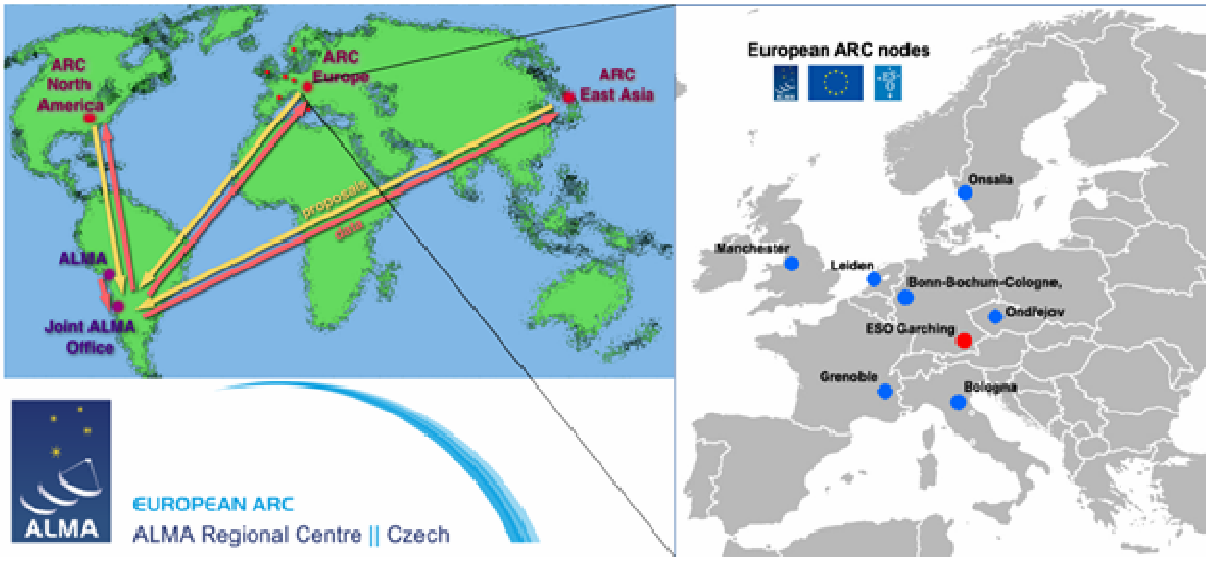

Fig. 2: Relations of JAO and ARCs and the structure of the European ALMA Regional Center.

ALMA is a complex system of more than sixty high-precision antennas connected as an interferometer (see Fig. 1). The main ALMA array, consisting of fifty 12m dishes, is supplemented by twelve 7m antennas for proper mapping of larger scales in the observed sources (known as Atacama Compact Array - ACA), and next four 12m Total Power (TP) dishes for scanning of the most extended sources. With this setup it can observe celestial objects with unpreceded spatial resolution as good as 5 milliarcseconds which is far too better than current (and planned) optical telescopes. Moreover, ALMA is observing in the range of millimeter and sub-millimeter wavelengths that has not been – because of technical difficulties – covered so far at all, and opens thus a completely new window to the Universe. And, in addition to that, ALMA provides multi-frequency images with an excellent spectral resolution down to 30 kHz in the broad range of frequencies of 30GHz – 1THz. These properties together with its high sensitivity make ALMA a unique tool for research in many

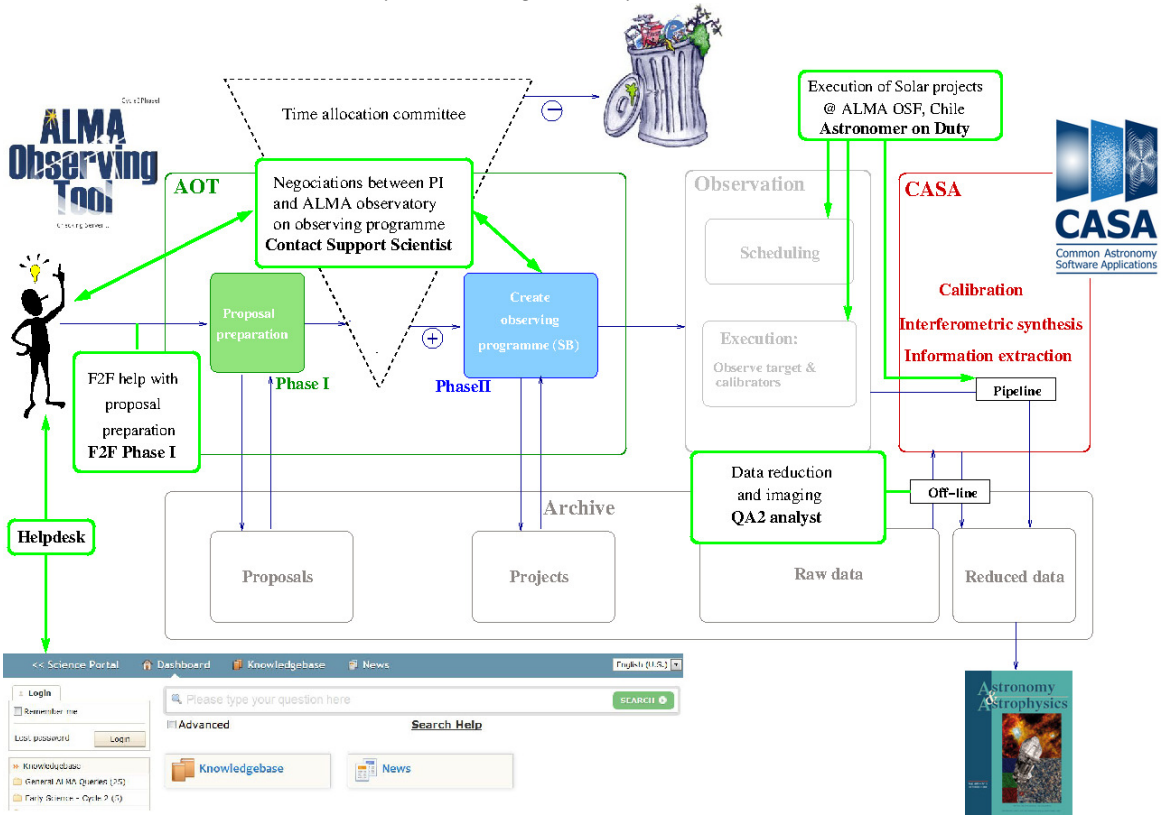

Fig. 3: ALMA infrastructure and the project flow with points of engagement (light-green frames) of the ARC-node staff into the project.

branches of astrophysics ranging from the physics of the Sun (Karlický et al., 2011; Wedemeyer et al., 2016) and solar system objects, through research of stars and their formation, interstellar matter, astrochemistry, exoplanets, and galaxies up to cosmology and the Universe as a whole

Role of ARCs and ARC nodes

In order to increase accessibility of ALMA to much broader scientific community and strengthen thus the scientific return, the Joint ALMA Observatory (JAO) created a support infrastructure – the network of ALMA Regional Centers (ARCs) – the European (EU ARC) operated by ESO, the North American (NA ARC) by the NRAO, and the East Asia (EA ARC) managed by NAOJ – the partner institutions that participated in the ALMA construction and development and that jointly operate the observatory (Fig. 2, left).

The main role of ARCs is to serve as an interface layer between the ALMA observatory and the research community. In accomplishing this task the ARCs and their nodes (see below) namely:

- Provide support (also personal – face-to-face/F2F) to the members of research community in proper usage of ALMA in all stages of their research projects (help with proposal submission, negotiations with the ALMA astronomers on technical details of the project, scientific data reduction and quality assurance, etc. – in the case of solar observations we even serve personally at ALMA/OSF as Astronomers on Duty / AoDs) – see Fig. 3.
- Spread the technical knowledge and awareness of ALMA among the research community (workshops/schools, training).
- Help the ALMA developers (e.g. tests of infrastructure and user SW, laboratory molecular spectroscopy – updates of spectral line catalogues).
- Promote and define user-community driven enhancements of ALMA (e.g. new observing modes – solar).

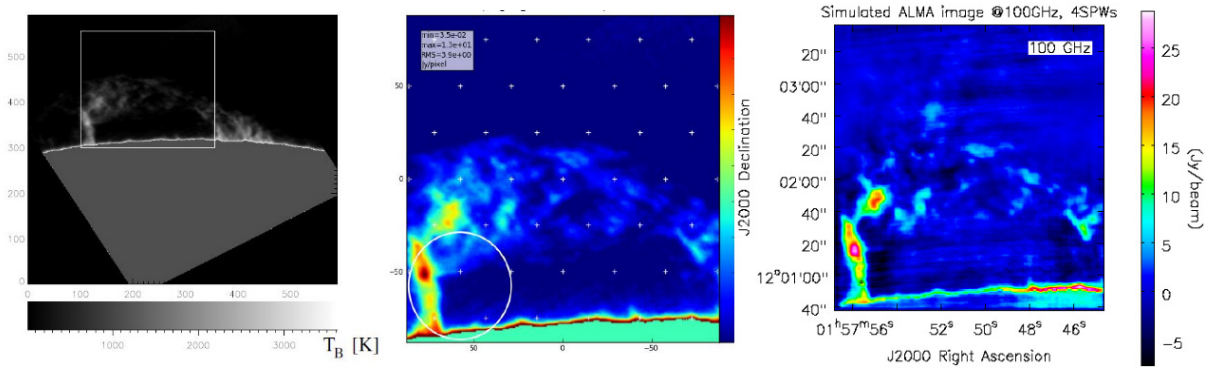

Fig. 4: Model brightness temperature (left), ALMA pointings at the background of ideal radio map (middle), and simulated ALMA image (right) of the prominence at 100GHz (ALMA Band 3; Heinzel et al., 2015).

Unlike the NA and EA ARCs, the European ARC is not a compact infrastructure but it has been formed as a distributed network of nodes centered around the ESO headquarters in Garching. One of the seven EU ARC nodes has been in 2009 established at the Astronomical Institute ASCR (AI ASCR) in Ondřejov (see Fig. 2, right), since 2016 being one of *National Research Infrastructures* listed in the European Roadmap of RIs.

EU ARC – Czech node: Specific Services for European solar-physics community

The node in Ondřejov is unique among the European ARC network because of its expertise in solar research with ALMA. The node has been established in 2009 and since then its staff is acquiring experience with technical details of ALMA observatory as well as user-level software and pre- and post-observing procedures. We have participated in many tests of ALMA Observing Tool (AOT), Helpdesk system, ALMA archive and CASA. Since Cycle 0 (2012) we are providing standard services to the community in non-solar research, namely, our staff members act as *Contact Support Scientists* (CSS) and work as *QA2 analysts* – the executive workers who make calibration and interferometric synthesis/imaging, whose final product is than delivered via ESO to the PI of respective projects. For solar-oriented projects we serve as *Astronomers on Duty* directly in Chile (Fig. 3).

Besides the expertise in ALMA technology the CZ-node staff is experienced in solar physics and solar radio research in dm and cm wavelength range, and the radiative transfer theory and computing – all the branches have decades long tradition at the Institute. Therefore, three members of the CZ node staff are part of international *ALMA Solar ObsMode Development Team* (Fig. 5) that takes part in the solar mode commissioning and testing.

This combined expertise makes the Czech node the primary access point of European solar-physics ALMA user community to the observatory. What can we do for you?

- Help with proposal preparation (so called Phase I). Both on-line (via Helpdesk tickets) and face-to-face (f2f) support is possible – we can support your stay at our node during consultations. It is advisable to use ALMA visibilities simulations in your proposal – we have expertise in that (Fig. 4)
- Help with converting your project into observing program in ALMA OT (Phase II) and its execution in Chile (AoD).
- In addition to standard calibration/imaging in frame of QA2 we can do this in a specific way customized to the science goals of your project.
- Help with science data interpretation.

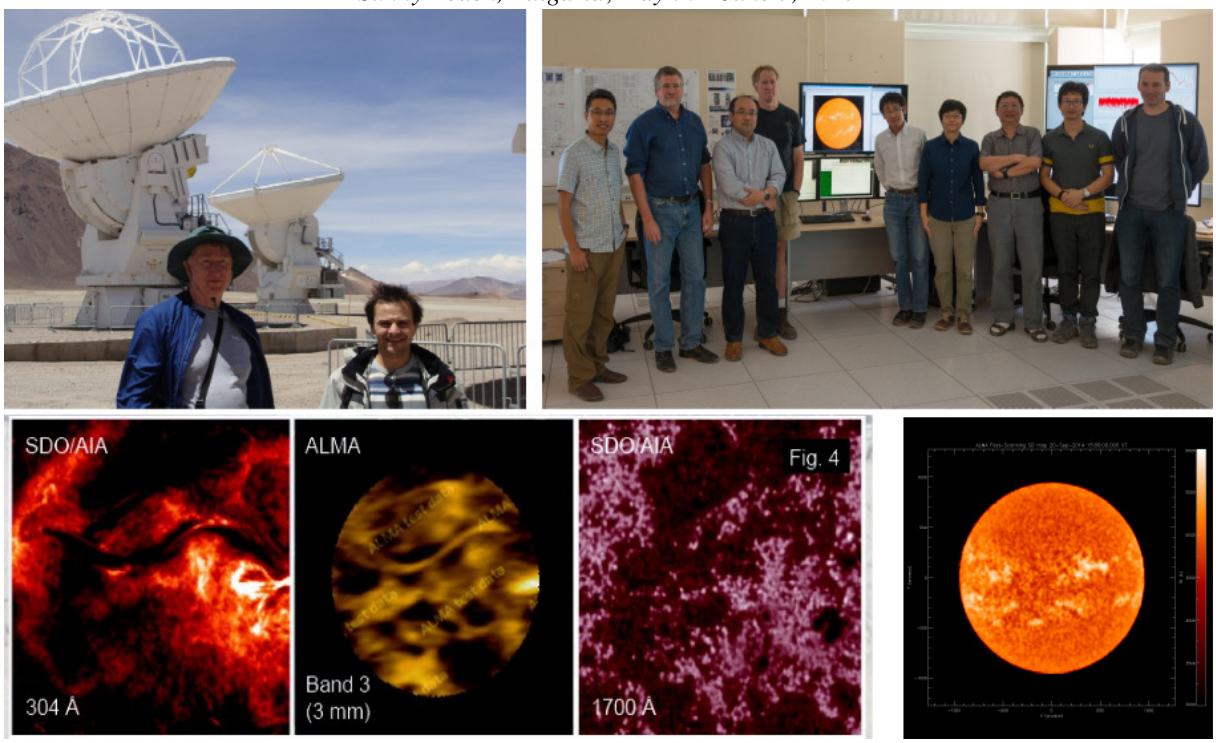

Fig. 5: Solar ALMA Observing Campaign (solar mode commissioning and science verification – CSV) 2014 and 2015: Part of Solar ALMA ObsMode Development Team (top) and sample of the CSV results: Interferometric image of filament at 100GHz compared with AIA observations (bottom left), single-dish image of the Sun at 100GHz (bottom right). Results of the campaign acquired by the team has been recently published in Shimojo et al (2017) and White et al. (2017)

Conclusions

ALMA is a recent cutting-edge ground-based astrophysical instrument for observations in the microwave and terahertz wavelength range. It is now ready to observe also the Sun and study its activity. In order to overcome difficulties with access to the ALMA observatory implying from the huge complexity of the ALMA systems (and lack of specific technical knowledge among general user community) ALMA has created three ALMA Regional Centers – ARCs in Europe, US, and East Asia, serving as a user support infrastructure and the link between the observatory and the community. The European ARC works as a distributed network of seven nodes coordinated by ESO. The node located in Ondřejov, Czech Republic, is specifically targeted at solar research with ALMA and it is ready to assist you with all aspects of your prospective solar-oriented ALMA science.

Acknowledgments

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