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RFI monitoring at the Atacama Large Mm/submm Array, ALMA

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Abstract

We give here an overview of the plans of the JAO spectrum management office for monitoring of RFI at the ALMA operations site.

1 Introduction

ALMA is an international collaboration on a global level, that comprises Executive Offices in Europe (ESO), East Asia (NAOJ), North America (NRAO) and the Joint ALMA Observatory (JAO) in Chile. The JAO provides the unified leadership and management of the construction, commissioning and operation of ALMA, with operations in three different sites: Santiago Central Office (SCO), the Operation Support Facilities (OSF) at 3000 m not far from San Pedro de Atacama, the Array Operation Site (AOS) at 5000 m on Llano de Chajnantor Altiplano.
ALMA is a radio interferometer comprised of 66 high-precision parabolic antennas (radio telescopes). They have different design and application: 50x 12-m antennas are the main interferometer, with baselines up to 16 km; 12x 7-m antennas are the compact array; 4x 12-m antennas are used as single dish telescopes.

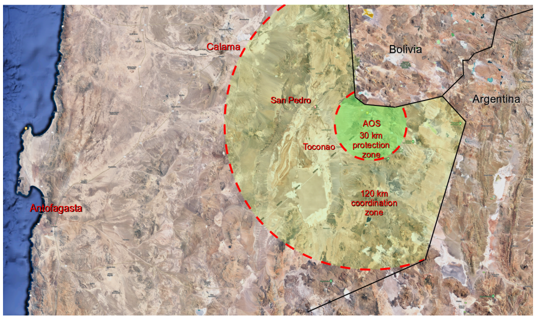

Figure 1. The protection and coordination zones are defined within the Chilean national territory but the border to Bolivia and Argentina is just a few km away. The protection zone would extend over Bolivia. The coordination zone would extend over Bolivia and Argentina. No agreement exists between Chile, Bolivia or Argentina to extend the zones outside the Chilean territory.

In 2003, the Government of Chile awarded a 50-year land concession on the Llano de Chajnantor. This land concession, known as the ALMA Concession, is subject to Exempt Resolutions of the Sub-secretariat of Telecommunications (SubTel) of the Ministry of Transport and Telecommunications of the Republic of Chile. These resolutions give ALMA the authorization as "receiving only antennas" to use the ALMA radio receivers covering the frequency range from 35 GHz to 950 GHz in 10 non-contiguous bands. These resolutions also define: 1) a protection zone "with a radius of 30 km within national territory, inside which the installation of any other radio communications system will not be authorized to any third parties operating on the receiving frequency bands" (sort of a quiet zone); 2) a coordination zone "with a radius of 120 km within national territory" where coordination means that SubTel will ask the opinion of ALMA on requests by third parties that "SubTel deems could interfere or affect the operation of the radio telescope." Also, in case ALMA detects "any emissions that affect the operation of the radio telescope, they will notify this Sub-secretariat for its coordination." These two zones are defined as ALMA Radio-Quiet Zone (RQZ) in ITU-R report RA.2259-1.

2 Risk of RFI at ALMA

The ALMA observing spectrum, from 35 to 950 GHz, is such that 93% of it is above 100 GHz and naturally protected by the atmospheric water vapor absorption against interference. Moreover, the ALMA site is quite isolated on the 5000 m Chajnantor plateau and unlikely to be reached by RF emissions from urban areas. Nevertheless ALMA is exposed to the risk of RFI both from the ground and from the sky: in fact, 7% of the ALMA RF spectrum is below 100 GHz and the 1st intermediate frequency band is defined between 4 and 8 or 12 or 18 GHz depending on the receiver, and the 2nd intermediate frequency band is between 2 and 4 GHz, therefore somewhat exposed to the risk of RFI.

From the ground: The protection and coordination zones can only prevent RFI from within Chilean national territory. Bolivia and Argentina are just a few km away and no agreement exists between Chile, Bolivia or Argentina to protect ALMA from the outside of the Chilean territory.

From the sky: Radio emission from artificial satellites crossing the sky over ALMA are not regulated by the Chilean national authority SubTel. International regulations, such as the recognition of the ALMA Radio-Quiet Zone by the International Telecommunication Union (see ITU-R report RA.2259-1) do not protect ALMA from eventual RFI from artificial satellites.

There is growing concern about possible RFI from satellite constellations, which have seen rapid growth in recent years. SpaceX's Starlink Generation-1 satellites have downlinks to gateway stations in the range 37.5–42.0 GHz that fall in ALMA Band-1. SpaceX's Starlink Generation-2 satellites have downlinks to gateway stations in the range 71.0–76.0 GHz that fall in ALMA Band-2. AST's Bluewalker3/Bluebird satellites have downlinks to gateway stations in the range 37.5–42.5 GHz that fall in ALMA Band-1. SpaceX's ESIAFI-2 satellites have downlinks to gateway stations in 123–130 GHz, 158.5–164 GHz, 167–174.5 GHz falling in ALMA Band-4 and Band-5.
There is a significant risk of RFI to ALMA from downlinks to gateway stations. At the moment in Chile there are seven Starlink gateway stations, the closest to ALMA is at 540 km (Caldera), one Amazon Kuiper and one OneWeb, and all of them have license from the Chilean authority to operate only up to ~ 20 GHz but this could change at any time.

3 RFI monitoring at ALMA

No RFI has been detected so far in ALMA science data that can be related to emissions from satellites. We assume that the satellites are not emitting in the ALMA frequency bands as they pass over Chile, but we don't actually know that for certain. We are planning regular RFI monitoring at ALMA with multiple objectives:

1) Create a database of RFI, possibly done using the ALMA antennas and receivers, thus reaching a sensitivity level comparable to ALMA single-dish science observations and covering exactly the same RF spectrum.

2) Use that database of RFI characteristics (power levels, frequencies, coordinates,...) to design and develop mitigation strategies (e.g. excision in the data reduction software) and coordinated operations (e.g. boresight avoidance, see [1])

3) Monitor the evolution in time of the RF environment at the ALMA site. This is especially important now that ALMA is going to be upgraded by extending the 1st intermediate frequency band up to 20 GHz (Wideband Sensitivity Upgrade, WSU, see [2]).

4 Main advantages of RFI monitoring at ALMA

Regular RFI surveys provide a snapshot of the RF environment at a given time. By doing regular RFI monitoring we can identify new interference in a timely manner. It is needed to compile a RFI database that can be useful in many ways, e.g. to develop mitigation measures, to plan the observations or to define protection requirements. Also, it provides a data set of RFI evidence that can be very useful for reporting to the administrations. Some properties of RFI monitoring should be: a) Try to cover as much as possible of the RF range of the receivers used for science; b) Have high sensitivity to be able to distinguish RFI from astronomical signals; c) Be able to identify the coordinates of the emitter, on the ground or in the sky

5 Challenges

Radio astronomy receivers are designed to detect very weak signals coming from the Universe, so they have an extreme sensitivity that cannot be matched by an RFI monitoring device. Also, the requirement for such a device are competing: high angular/spatial resolution to identify the position of the emitter, high spectral resolution to identify the emitting channels, short integration time for fast response needed to track the motion of the satellites in the sky, all that with high sensitivity. Strong RFI can be monitored with less sensitive receivers but weak RFI won't be identified/monitored (e.g. higher harmonics, sidelobe-to-sidelobe interference, out-of-band emissions, aggregated noise, etc.)
RFI monitoring at ALMA is particularly challenging because of the very large spectral coverage, from 35 to 950 GHz, the high frequency of the ALMA bands with 93% of the ALMA spectrum above 100 GHz, the very high sensitivity of the receivers with low noise floor. Only one RFI survey has been done at ALMA to date, in 2002, with a very limited frequency range 10 MHz to 18 GHz (see [3]) using three different types of antennas (bi-conical, log-periodic, horn). The RF range of this survey is well below the ALMA spectrum starting at 35 GHz. Also, after ~ 23 years, the RF environment has likely changed and this old survey is not representative of the actual conditions.

6 Plans for RFI monitoring

We are exploring two possible approaches for RFI monitoring at ALMA:

1) Use a dedicated RFI monitoring device or design and build our own. A few options are being considered.
We are exploring the feasibility of building an all-sky RFI monitor device based on a 3D-printed Luneburg metalens ([4]), in collaboration with Francisco Pizarro (PUCV, Chile) and Oscar Quevedo-Teruel (KTH, Sweden). A proposal has been submitted to the Chilean National Agency for Research and Development (ANID).
An alternative would be to borrow one of the RFI monitoring systems (ASM) in development at NRAO in Charlottesville by David Bordenave and Chris De Pree within the National Radio Dynamic Zone (NRDZ) initiative of the NSF.
Another option would be to borrow the 72–90 GHz portable receiver for RFI monitoring developed at the Yebes Observatory (Spain) by Marta Bautista Durán and José Antonio López Pérez. It was used at the IRAM 30-meter telescope of Pico Veleta to identify RFI at 76–77 GHz from car radars. This device would cover most part of the ALMA Band-2

receiver (67–90 GHz) and could identify eventual Starlink Generation-2 downlinks emissions to gateway stations in the range 71–76 GHz.

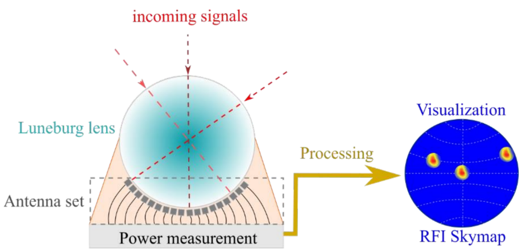

Figure 2. A sketch of the RFI monitoring device considered for a development study. A Luneburg lens feeds a 3D array of antennas that receive signals through the lens depending on the angle of incidence. The signals are then digitized and processed to be displayed as a sky map.

2) Use the existing ALMA systems. We have a total of 66 antennas, we can use 1 or 2 antennas and a correlator sub-array for technical tasks with no impact on science operations. ALMA antennas are fast (4°/s) and in principle we should be able to track LEO satellites when they cross the sky over the ALMA site, using the same ALMA antennas and the same receivers used for science observations. LEO satellites have an apparent angular speed that does not exceed 1°/s in most of the cases. A few satellites on lower orbits might be faster (e.g. recently launched or being deorbited). One difficulty is that the ALMA control software is not designed to track fast moving objects such as LEO satellites and we need to develop some custom software to enable this capability.
A few preliminary tests have been done in 2024 using ALMA 7-m and 12-m antennas in sidereal tracking, we have collected several hours of data during tens of satellite transits across or in the proximity of the antenna's main beam. These tests have been done using ALMA receiver Band-1 in the frequency range 35 to 50 GHz (USB receiver, 8 GHz total bandwidth x 2 linear polarizations). The beam size at 40 GHz is 2.6 arcmin in a 12-m antenna and 4.5 arcmin in a 7-m antenna. The ALMA correlator has been used to acquire data in both time-domain (low resolution) and frequency-domain (high resolution) modes. The spectral setup defined 4 partially overlapping basebands of 2 GHz width for a total of 8 GHz in the RF range from 37 to 44 GHz, as follows: 37–39, 38–40, 39–41, 40–42 and 39–41, 40–42, 41–43, 42–44.
No RFI has been detected, as expected given that no gateway station is in the vicinity of ALMA (the closest being at 540 km) and that the gateway stations in Chile have been licensed by the Chilean authority to operate only up to 20 GHz.

7 Conclusions

As new technologies allow the use of ever higher frequencies to ensure greater bandwidth and as the number of satellites in orbit continues to grow, RFI at mm/submm wavelengths will become an increasingly serious concern for ALMA. Continuous monitoring, advanced detection techniques, and effective mitigation strategies will be essential. Furthermore, collaboration between the scientific community, industry, and regulatory agencies will be key to balancing the needs of radio astronomy with the expansion of ground-based and space-based global telecommunications infrastructure.

References

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