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IAR's 60th anniversary: Prospects for low-frequency radio astronomy in South America (November 15-18, 2022)
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OPTICAL SYSTEM FOR A MM/SUB-MM 12M APERTURE RADIOTELESCOPE

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RESUMEN

Los radiotelescopios modernos aprovechan al máximo el espacio disponible (cabinas) para llenarlas con el mayor número posible de detectores. Por este motivo, es fundamental utilizar sistemas ópticos (comúnmente conocidos como sistemas ópticos terciarios) que acoplen los detectores con la antena. El radiotelescopio LLAMA, un emprendimiento entre Argentina y Brasil, que se instalará durante 2023/2024 a 4860 m en Alto Chorrillos, Provincia de Salta en el norte de Argentina, no es una excepción. En este trabajo presentaré, en primer lugar, el NACOS-FL (Nasmyth Cabin Optical System for First Light), el sistema óptico desarrollado para la fase de Primera Luz del LLAMA, que permitirá poblar una de las cabinas Nasmyth de la Antena y que actualmente se encuentra en proceso ensamblaje, integración y verificación (*Assembly Integration and Verification* o AIV) en Brasil. En segundo lugar, presentaré el sistema óptico complementario para alcanzar el NACOS-LT (*Long Term*), el sistema óptico completo que permitirá poblar la segunda cabina Nasmyth de la antena.

ABSTRACT

Modern radio telescopes make extensive use of their available space (cabins) to fill them with as many detectors as possible. For this reason, it is essential to use optical systems (commonly known as tertiary optical systems) that couple the detectors with the antenna. The LLAMA radiotelescope, an enterprise between Argentina and Brazil, to be installed during 2023/2024 at 4860 m in Alto Chorrillos, Province of Salta in northern Argentina is not an exception. In this job, I will present, firstly, the NACOS-FL (Nasmyth Cabin Optical System for First Light), the optical system developed for the First Light phase of LLAMA, which will allow populating one of the Nasmyth cabins of the Antenna and it is currently in the AIV (Assembly Integration and Verification) process in Brazil. Secondly, I will present the complementary optical system to reach the NACOS-LT (Long Term), the complete optical system which will allow the population of the antenna's second Nasmyth cabin.

Key Words: Astronomical instrumentation — Radio telescopes — LLAMA

1. LLAMA RADIOTELESCOPE

The LLAMA radiotelescope (Lepine et al. 2021; Romero 2020), acronysm of Large Latin American Millimeter Array, consists on the installation and operation of a millimeter/sub-millimeter 12 m aperture antenna in Alto Chorrillos (∼4800 m above see level), in the Salta province of Argentina. The antenna, designed to observe in the 30 to 950 GHz frequency range, has a cassegrain configuration (Romero 2020) and three available cabins for the installation of receivers/detectors (i.e. the central Receiver/Cassegrain cabin named Cab-Cass, and two lateral Nasmyth cabins, named Cab-A and Cab-B respectively). The LLAMA radiotelescope has the same optical features and architecture as APEX (Gusten et al. 2006) (Fig. 1).

Modern radiotelescopes make extensive use of their available space (i.e. cabins) to fill them with as many receivers as possible for the detection of the signal coming from the sky. For LLAMA, It was decided at early stages of the project that six ALMA[2]-like single-pixel, dual polarized heterodyne receivers (e.g. Fig. 2) would be installed inside cryostats (Fig. 3) in the Nasmyth cabins. Receivers for bands 5 (163-211 GHz), 6 (211-275 GHz) and 9 (602-720 GHz) in Cab-B for the First Light (FL) phase of the project, a phase to validate the technical/scientific capabilities of the radiotelescope, and a mayor upgrade for a Long Term (LT) phase which will include bands 6, 7 (275-373 GHz) and 9 in Cab-A and bands 1 (35-52 GHz), 2+3 (67-116 GHz) and 5 in Cab-B, letting the cassegrain cabin available for future installation of multi-detectors cameras to take advantage of its available field of view (∼10 '). To accomplish this strategy, it is essential the use of a tertiary optical systems that couples the receivers with the antenna. In LLAMA, the tertiary optical system was baptized as NACOS (NAsmyth Cabin Optical System).

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[2]https://www.almaobservatory.org/en/home/

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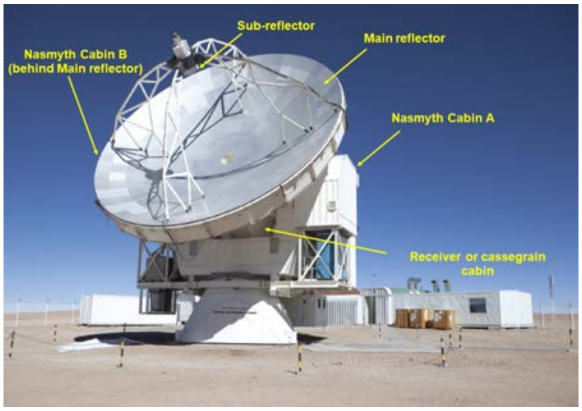

Fig. 1. The Atacama Pathfinder EXperiment (APEX) in Chile. Credit: ESO

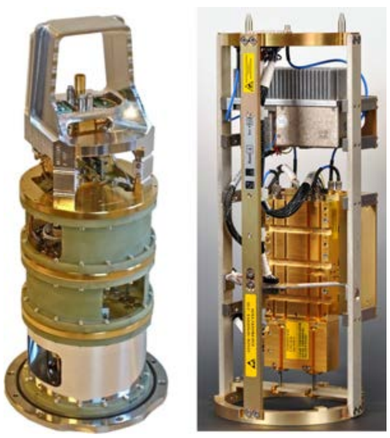

Fig. 2. ALMA band 5 cartridge.

2. NACOS SYSTEM

NACOS is the system responsible of re-focusing the antenna's cassegrain focus into the receivers' focii placed in the Nasmyth cabins. the basic requirements for the system are: i) to maximize the antenna aperture efficiency for all detectors at the same time, ii) to keep the optical aberrations as low as possible, iii) to allow the antenna user the selection between each receiver (frequency) for the single band observation mode or even capable of multi-band observations by splitting the sky signal through the implementation of beam splitters (e.g. dichroic filters and/or polarizing grids). NACOS was divided into two stages, a reduced version to be implemented during the First Light phase of the project (NACOS-FL), and the complete version to be implemented in the Long Term phase of the project (NACOS-LT). Each phase of the project comprises the installation of different receivers (Table 1).

NACOS-FL was design in 2017 as a frequency independent optical system, based on the implementation of a Gaussian Beam Telescope (GBT), which basically consists of a pair of focusing elements (mirrors M3 and M4 for NACOS-FL) separated by the sum of their focal lengths (Goldsmith P. 1998), a very useful and desirable feature in systems that operates over broad bandwidths. A series of flat mirrors needed to properly fold the beams completes the optics configuration (Fig. 4). Some of the flat mirrors are capable to be moved by the use of motors, such Flat grid, which can be set into the optical path, for band 5 channel selection, or out of it, allowing the rotating R-flat mirror to select between bands 6 or 9. NACOS-FL was manufactured in Brazil during 2018-2019 in the company ALFA Ferramentaria, where currently is under the Assembly Integration and Verfication (AIV) stage of its development.

NACOS-LT, as well as NACOS-FL, consists of a frequency independent design formed by mirrors M1A, M2A and M3A for Cab-A configuration, and for the same M3 and M4 mirrors used in NACOS-FL for Cab-B configuration. For Cab-A, some flat mirrors needed to fold the beam complete the system. In the NASS-A structure, the rotating mirror

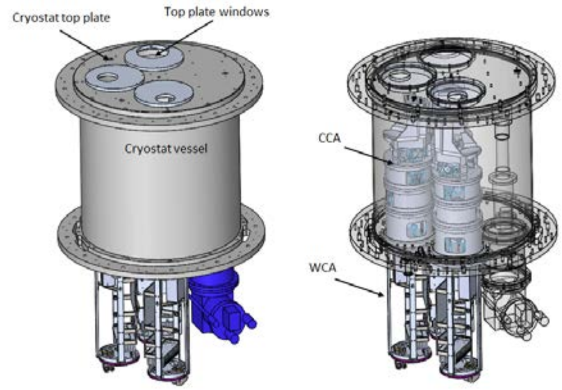

Fig. 3. The LLAMA cryostat.

TABLE 1

LLAMA RECEIVERS CONFIGURATION

Cab (phase)	Band	Freq. (GHz)	λ_0 (mm)
Cab-B (FL)	5	163-211	1.60
Cab-B (FL)	6	211-275	1.23
Cab-B (FL)	9	602-720	0.45
Cab-A (LT)	6	211-275	1.23
Cab-A (LT)	7	275-373	0.93
Cab-A (LT)	9	602-720	0.45
Cab-B (LT)	1	35-50	7.06
Cab-B (LT)	2+3	67-116	3.28
Cab-B (LT)	5	163-211	1.60

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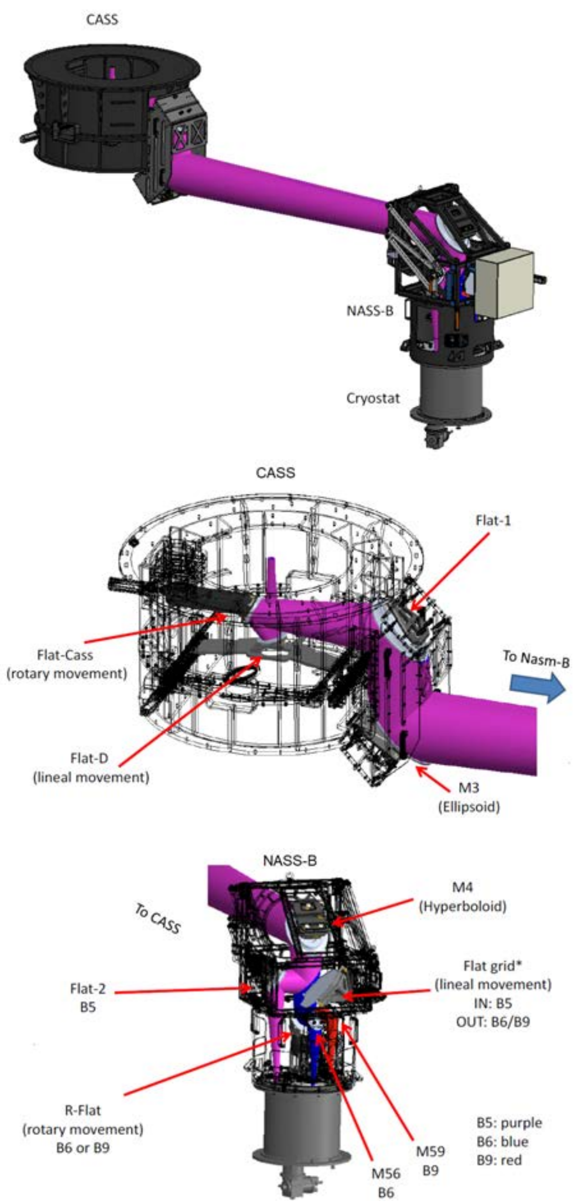

Fig. 4. NACOS-FL configuration.

R-Flat allows the selection of the observation channel (Fig. 5). NACOS-LT optical performance was analized and otpimized through physical optics simulations performed with the GRASP[3] software. The beam of the central frequency (661 GHz) of band 9 produced by the optical system at the Nasmyth focal plane, obtained by simulations, is shown in Fig. 6.

The manufacturing and assembly of M1A mirror (the first mirror for the Cab-A optical path) and its rotating support is under progress (Fig. 7).

For Cab-B, some flat mirrors will need to be re-

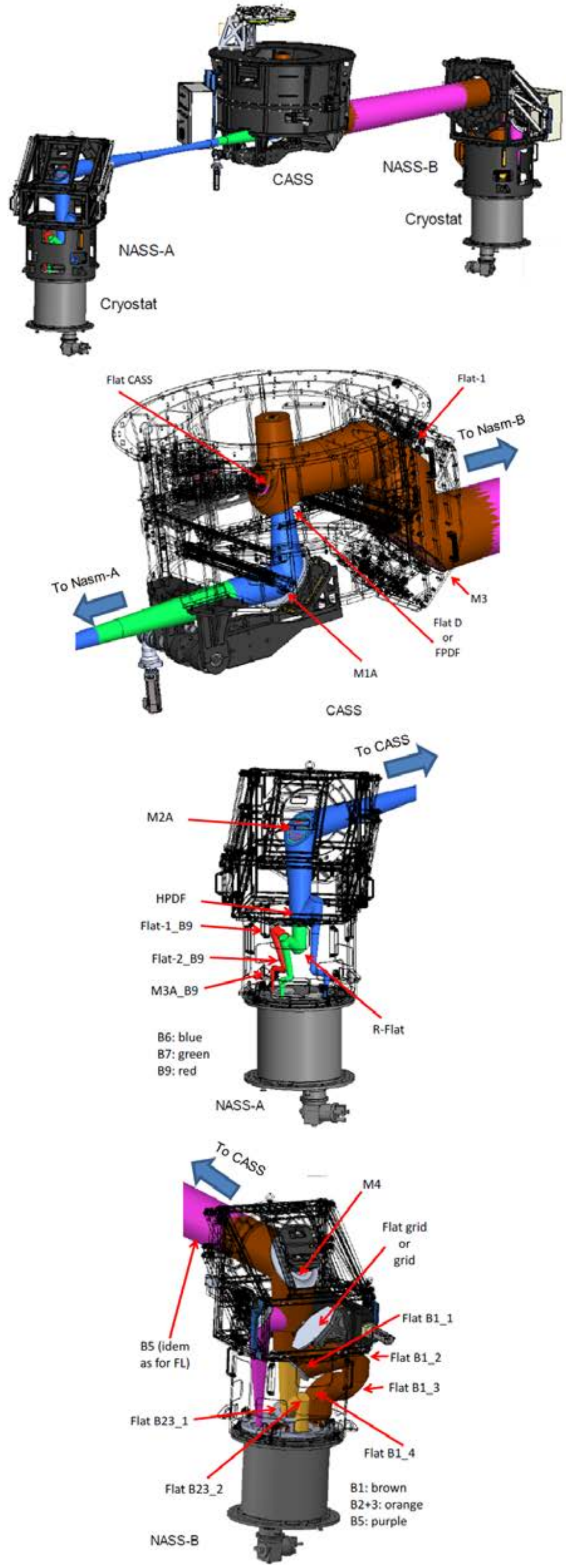

Fig. 5. NACOS-LT configuration.

[3]https://www.ticra.com/

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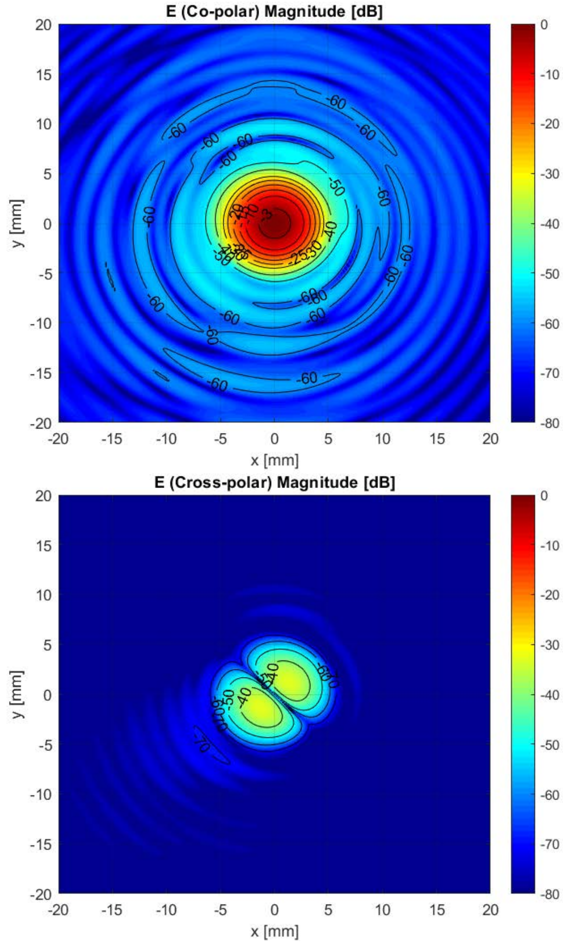

Fig. 6. Simulated B9 beam (661 GHz) at Nasmyth focal plane. Top: Co-polar plot. Bottom: Cross-polar plot.

Fig. 7. M1A mirror assembly installed at the bottom of the CASS structure.

Fig. 8. CASS handling and integration in the Cab-CASS fixture.

Fig. 9. NASS-B integration in the Cab-B interface fixture.

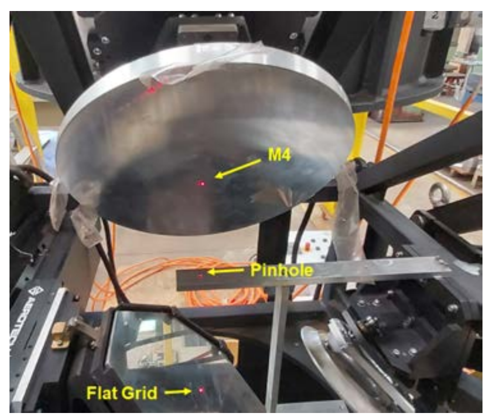

Fig. 10. Optical alignment. In the figure mirrors M4 and Flat Grid, plus an in between beam path pinhole are shown. the laser dot can be seen in the center of the mirrors.

placed by others, to properly propagate the beam along the optical path (Fig. 5). The selection of the observation cabin is carried out by interposing the Flat D mirror in the CASS structure in the optical path. Flat D in for selecting Cab-B and out for Cab-A. In a future upgrade of NACOS-LT, Flat D is expected to be replaced by a high pass dichroic filter (HPDF) allowing simultaneous observations in both cabins. Extending the inclusion of HPDF's in the Nasmyth cabins (such as HPDF in Cab-A and polarizing grid in Cab-B) will allow the simultaneous observations up to four bands.

3. NACOS-FL AIV

The Assembly, Integration and Verification (AIV) is being carried out in the facilities of the ALFA Ferramentaria company, located in Araraquara city, Sao Paulo state in Brazil. The process started at the end of 2018 and comprised activities such as the assembly and adjustment of the two optomechanical sub-systems (i.e. CASS and NASS-B) that conform NACOS-FL; the calibration and adjustment of the movable mirrors; the testing of the integration process of both sub-systems in the radiotelescope by using dedicate manufactured assisting-equipment, together with the implementation of structural fixtures that emulate the cabins environment and their interfaces (Fig. 8 and 9); the optical alignment of the system by using the reflection of a laser in the center of the mirrors and by tracking the propagation of the laser beam throughout the optical axis of the system (qualitative alignment as shown in Fig. 10). A final fine tune (quantitative) alignment is expected to be performed in the near future through the implementation of a positioning sensor device into the alignment system for measuring the offset and tilt of the beam along the system.

4. CONCLUSIONS

The NACOS optical system for the LLAMA radiotelescope was described. The reduced version of the system, which will be implemented in the First Light phase of the project, is close to completing its AIV process and being ready for shipment to Argentina. The full version of the system to be implemented in the Long Term phase of the project is currently in the process of design optimization. The first optical element (M1A) that will allow the use of the Nasmyth A cabin is being manufactured.

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