INTERNATIONAL PROJECTS: POSSIBLE LINKS WITH THE ITALIAN TELESCOPES

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Outline:

1. ALMA Band 2+3 receiver
2. PHAROS/PHAROS2 receiver
3. BRAND receiver

ALMA Band 2+3

1. The project:

- The ALMA Band 2+3 receiver is a prototype being developed by a group of European institutes, coordinated by ESO, that will cover the entire frequency range from 67 GHz to 116 GHz in a single receiver cartridge
- INAF is participating in the project through the IASF-Bologna and the Osservatorio di Arcetri, coordinated by Fabrizio Villa and Renzo Nesti
- From a scientific point of view, the installation of the ALMA And 2+3 prototype on SRT would open to the Italian community a hardly investigated but extremely interesting spectral window. It would open the possibility of connecting SRT to the mm-VLBI networks
- From a technical point of view would allow to test a state-of-the-art receiver, designed for ALMA, on an Italian facility. It would save space in the focal position. It would allow to reach the maximum frequencies (up to 115 GHz) originally planned for SRT with a very large effective bandwidth
- The advantage for the Band 2+3 consortium would be the possibility of testing the prototype on a real antenna.

ALMA Band 2+3

2. Scientific drivers:

- Interest of the Italian community as demonstrated by the White Paper "*Italian Science Case for ALMA Band 2+3*" (Beltrán et al. 2015: https://arxiv.org/abs/1509.02702). See also, "*The Science Case for ALMA Band 2 and Band 2+3*" (Fuller et al. 2016: https://arxiv.org/abs/1602.02414)

- Science cases include those specific of Band W, discussed in the Call for Ideas (see Alessandra's presentation) or in the receivers under development (see Carlo's presentation)

- Main scientific drivers of encompassing Band 2 and Band 3 in a single receiver cartridge:

Galactic science

- Low-excitation lines of deuterated species
- Formation of complex organic molecules (COMs)

Extragalactic science

- Cool gas in nearby galaxies
- Properties and evolution of dense gas in nearby galaxies
- Molecular outflows and AGN fueling/feedback cycle

ALMA Band 2+3

2. Scientific drivers:

- Deuterium is produced by primordial nucleosynthesis and destroyed in stars. In the local Universe [D/H] ~ 10^{-5} but in interstellar clouds, in particular in pre-stellar cores, [D/H] can be higher than 0.1 (Caselli & Ceccarelli 2012 for a review).

- Deuterated species Important: to study initial conditions and evolution of pre-stellar and protostellar cores; probes of the cold and dense mid-plane of proto-planetary disks; can help to understand the origin and evolution of water on Earth (solar system objects)

- Band 2+3 could trace the ground rotational transitions of deuterated species simultaneously with the fundamental transitions of their hydrogenated species.

Molecule	Transition	Frequency (GHz)	Molecule	Transition	Frequency (GHz)
CH_2D^+	1(1,0)-1(1,1)	67.273			
$D^{13}CO^+$	(1-0)	70.733	$H^{13}CO^+$	(1-0)	86.754
$D^{13}CN$ (1-0)	(1-0)	71.175	$H^{13}CN$	(1-0)	86.339
DCO^+ (1-0)	(1-0)	72.039	HCO^+	(1-0)	89.189
CCD (1-0)	(1-0)	72.098 – 72.200	CCH	(1-0)	87.284
DCN (1-0)	(1-0)	72.415	HCN	(1-0)	88.630
$DN^{13}C$ (1-0)	(1-0)	73.368	$HN^{13}C$	(1-0)	87.091
DNC (1-0)	(1-0)	76.306	HNC	(1-0)	90.664
DOC^+ (1-0)	(1-0)	76.386	HOC^+	(1-0)	89.487
N_2D^+ (1-0)	(1-0)	77.108	N_2H^+	(1-0)	93.172
HDO	1(1,0)-1(1,1)	80.578	H_2O	1(1,0) - 1(0,1)	556.936
CH_2DOH	1(1,0)-1(0,1)	85.297	CH_3OH	1(0, 1)- 0(0, 0)	48.372
Ortho-NH_2D	1(1,1)0-1(0,1)0	85.926	NH_3	1(0,0)-0(0,1)	572.598

ALMA Band 2+3

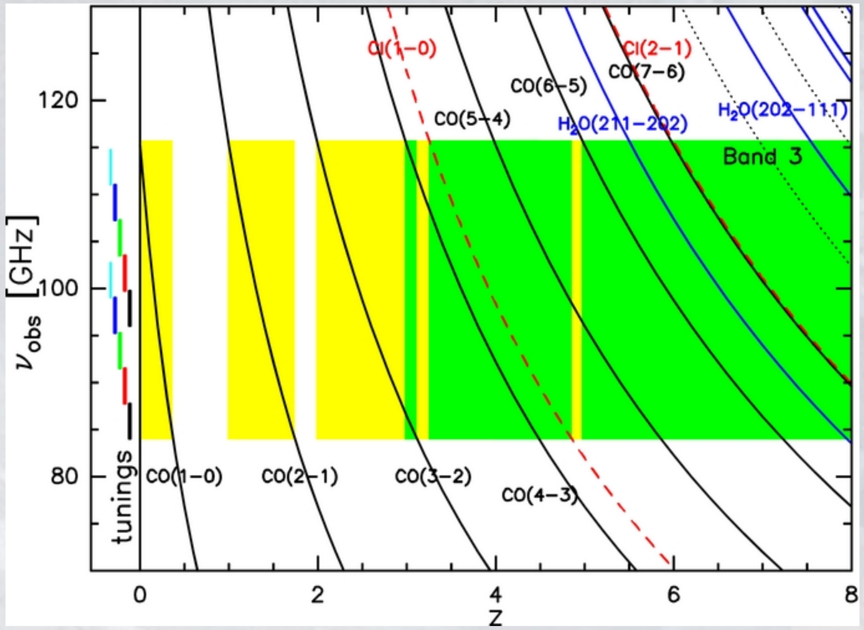
2. Scientific drivers:

- The main Extragalactic science driver of Band 2+3 is the study of redshifted CO for both a more efficient redshift determination and characterization of the cool gas content of galaxies over the epoch of galaxy formation

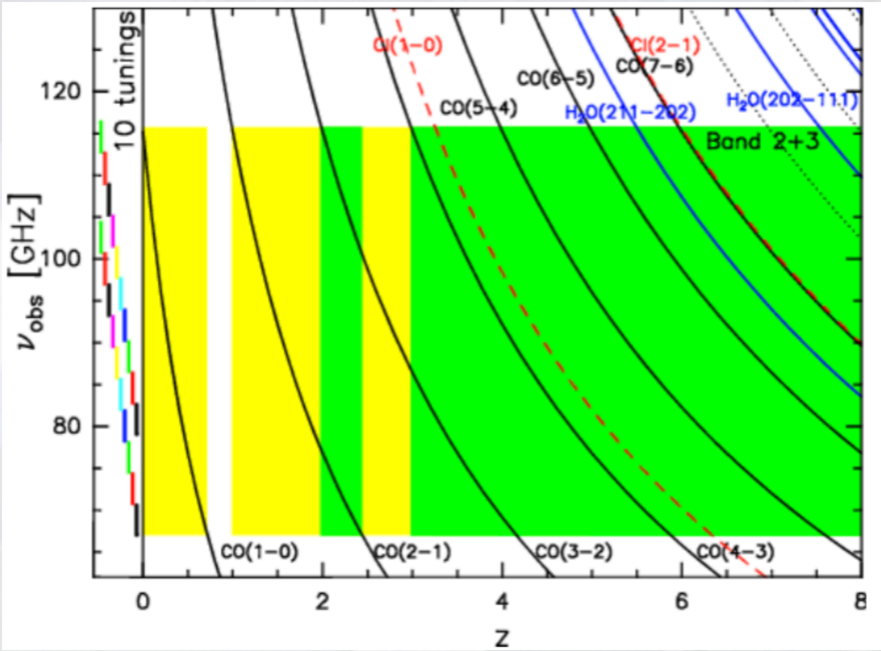
- The lowest excitation CO lines available in Band 2+3 are the best suited for redshift determination, in particular in the "redshift desert" ranges 0.37< z<0.99 and 1.74<z<2.00

- The low-J transitions are also fundamental to accurately estimate the cool molecular gas mass and make it possible a complete assessment of excitation conditions.

Band 2



Band 2+3



Green: redshifts where 2 or more lines provide an unambiguous redshift
Yellow: redshift range where 1 line is detectable

The "redshifted desert" would be reduced to the range 0.72<z<0.99

ALMA Band 2+3

3. Technical design:

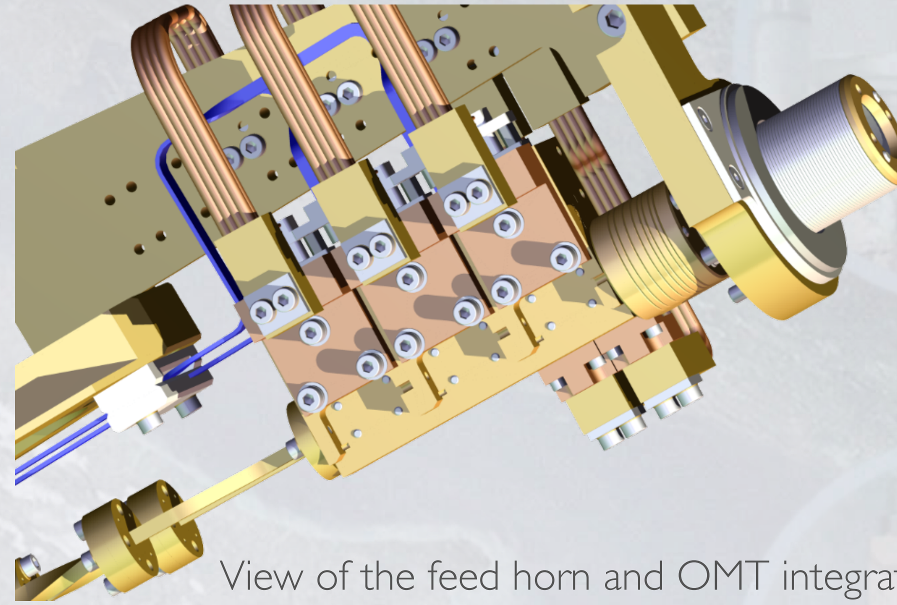
- The broadband ALMA Band 2+3 will cover the entire frequency range from 67 to 116 GHz, with an effective bandwidth of at least 8 GHz

Cold Cartridge Assembly

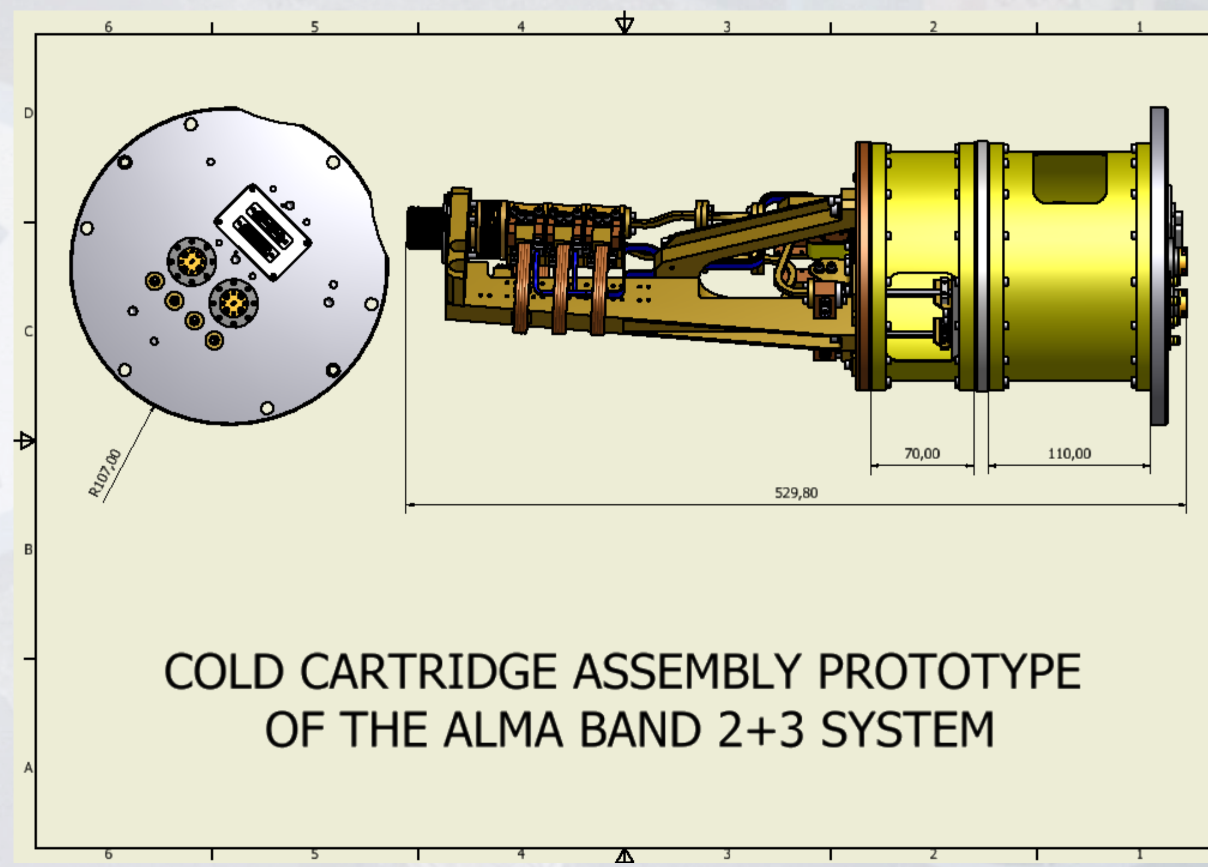
ALMA Band 2+3

3. Technical design:

- The broadband ALMA Band 2+3 will cover the entire frequency range from 67 to 116 GHz, with an effective bandwidth of at least 8 GHz
- The thermal architecture of the cartridge is arranged with two thermal links and shield respectively at 110 K and 15 K



View of the feed horn and OMT integrated into the Band 2+3 cold cartridge assembly



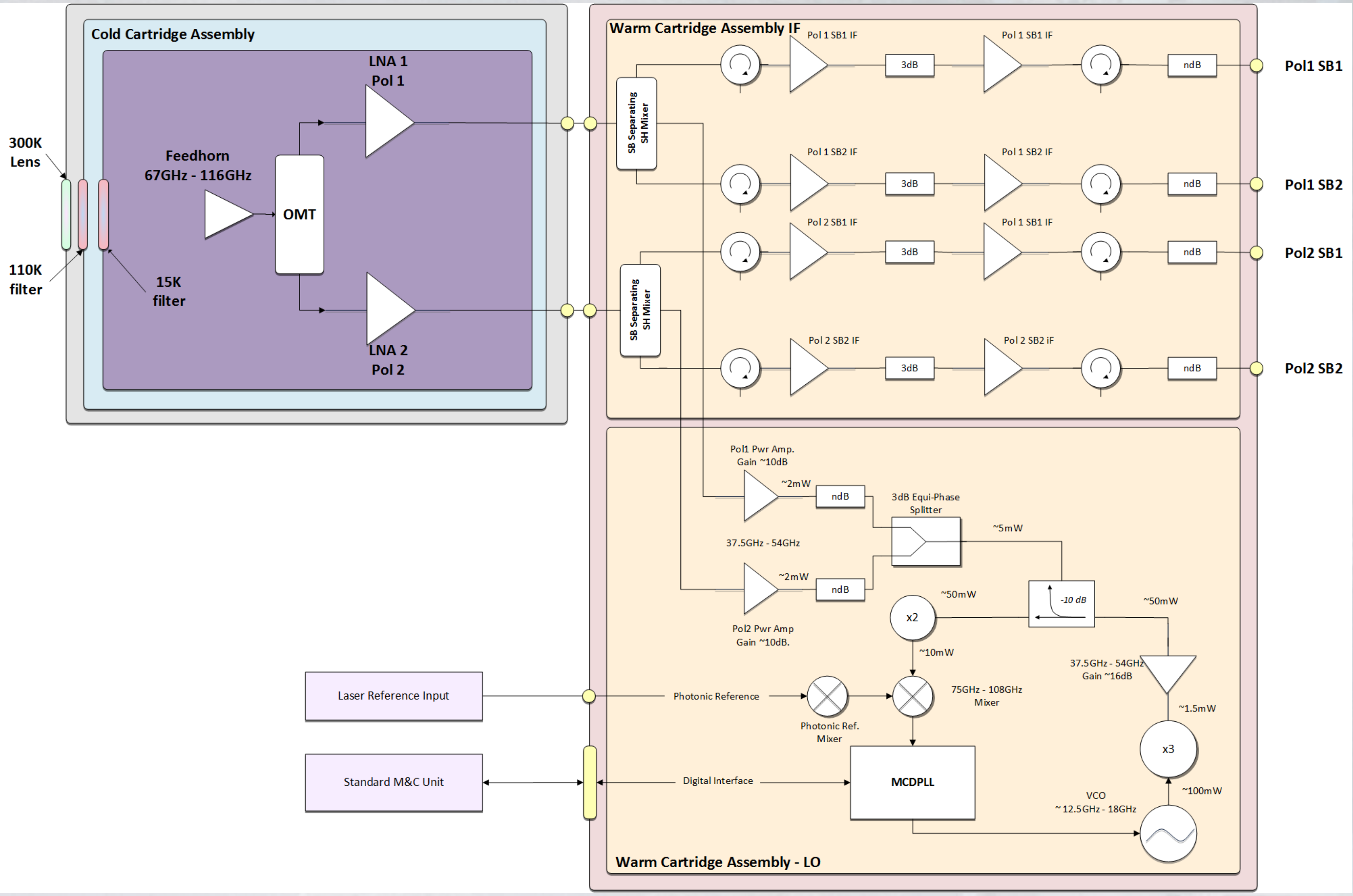
Main dimensions of the Cold Cartridge Assembly

ALMA Band 2+3

3. Technical design:

- The electrical interface with the cartridge is characterized by simplicity, with the presence of an extremely reduced number of I/O channels. The inputs are DC power, two reference signals (optical and radio), and control and sensor monitoring lines.

- Four output IF signals are present in the 4-12 GHz band that correspond to the LSB-USB pair of each of the two orthogonal linear polarizations (Pol-0 and Pol-1) in which the received signal is separated.

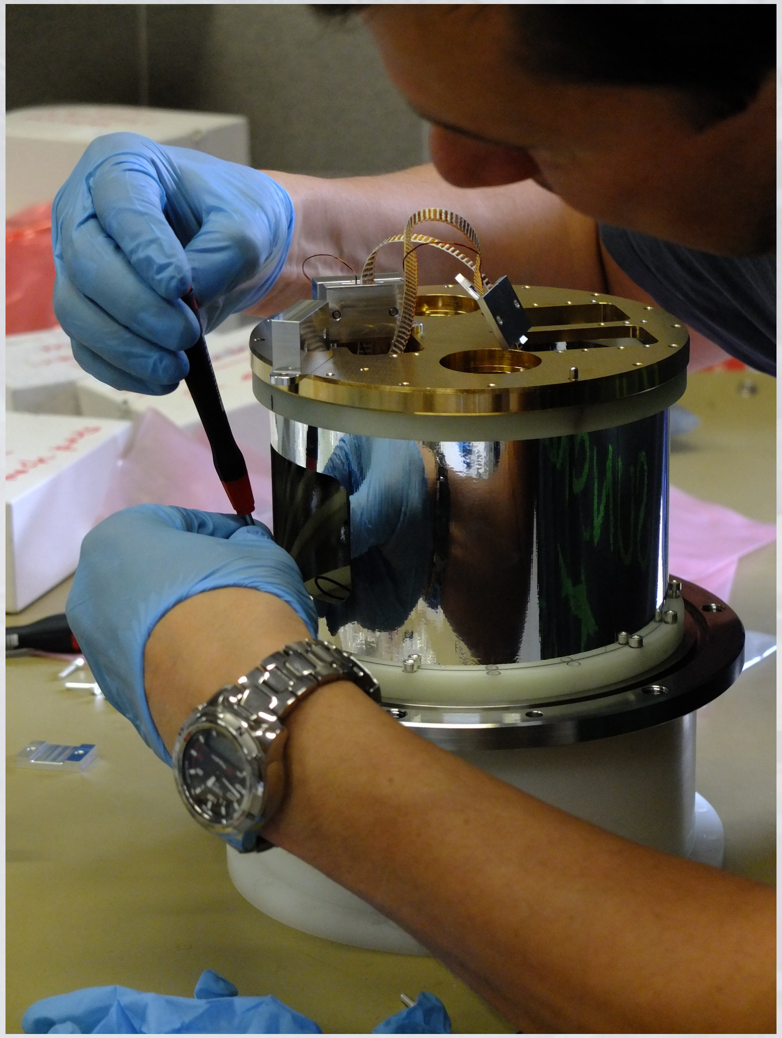


Receiver scheme of the prototype

ALMA Band 2+3

4. Status:

- The optical performances of the prototype were measured to be in line with ALMA specifications during an extensive test campaign carried out at ESO. T_{sys} of 40 K.
- The prototype mounts inside the state-of-the-art detectors and it has been integrated at IASF.
- A cryogenic noise test campaign has started this winter/spring with the aim of verifying and characterizing the prototype at operational condition. Up to now, T_{sys} of 50 K.



Integration of the Band 2+3 Cold Cartridge Assembly at IASF-Bologna

ALMA Band 2+3

5. Installation at SRT:

- The concept of cartridge developed for the various ALMA receivers would make it easier the installation of such receiver in the SRT receiver system, with minimal complications in terms of electrical, thermal, and mechanical interfaces, and in terms of ancillary parts to be expressly developed.

- It will be necessary to develop a suitable cryostat, as well as to optimize, if needed, the optical match with the SRT antenna. The thermal architecture of the cartridge is arranged with two thermal links and shield respectively at 110 K and 15 K and, taking into account the extremely small size of the cartridge, it is compatible with the thermo-mechanical interface systems available on SRT.

- The budget for its implementation at SRT is 80,000 euros, which includes the cryostat, the vacuum system, the cold head and the mechanics to install the receiver at the Gregorian focus.

SRT

PHAROS/PHAROS2

1. The project:

- Phased Arrays for Reflector Observing Systems (PHAROS) is a C-band cryogenically cooled low noise Focal Plane Array system which has been developed as part of a European technology demonstrator project within the framework of Radionet FP5.

- Within the framework of the SKA Phased Array Feed (PAF) Advanced Instrumentation Program (AIP), of which INAF is part of, PHAROS will be upgraded to a new instrument, named PHAROS2, that will re-use most part of the existing PHAROS hardware.

- INAF is participating in the project coordinated by Alessandro Navarrini

- PHAROS and PHAROS2 will be initially installed on the Lovell Telescope at Jodrell Bank.

- There is an informal agreement that PHAROS2 could be installed on SRT after 2018

PHAROS/PHAROS2

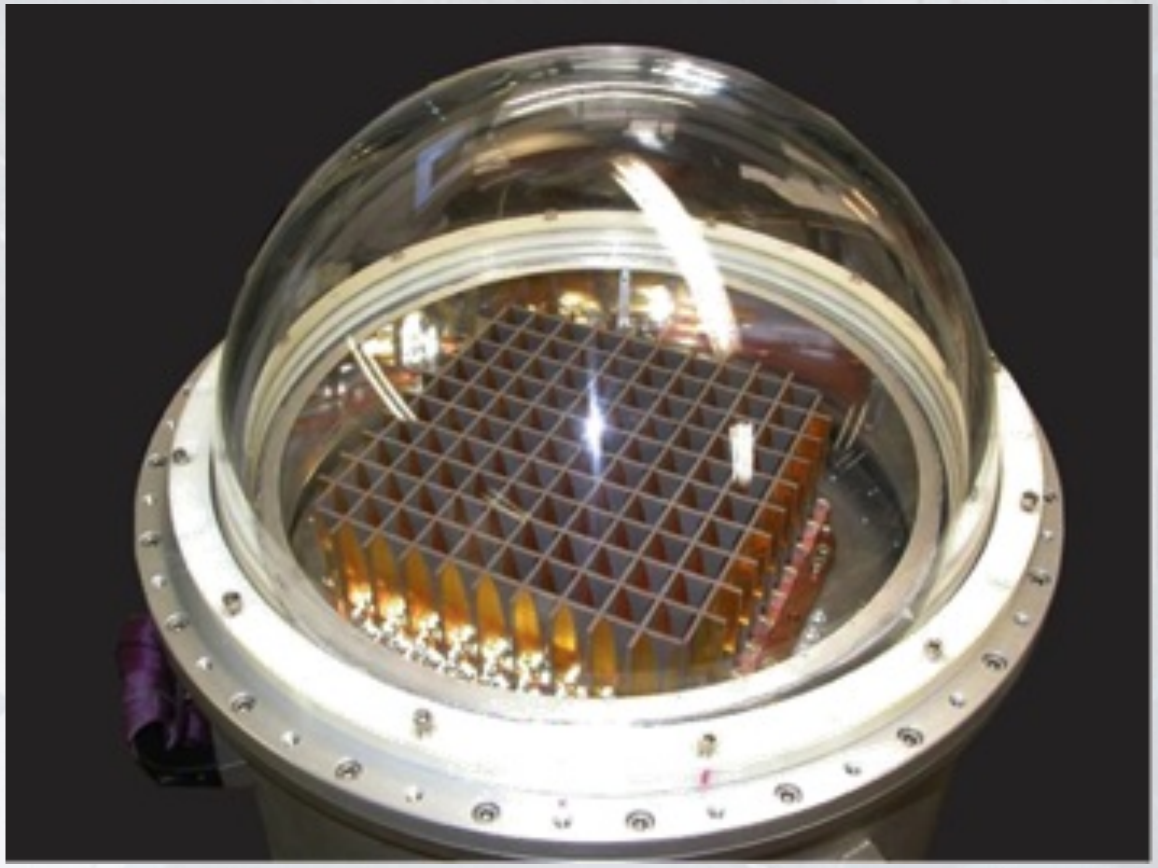
2. Science drivers:

- The PHAROS2 project is a technology demonstrator project and has no scientific drivers associated to it.
- But, three proposals presented in the Call for Ideas asked for band C PAF front-ends (see Alessandra's presentation)

PHAROS/PHAROS2

3. Technical design:

- PHAROS will be mounted at the primary focus of a large parabolic reflector to perform radio astronomy observation across the 4-8 GHz range

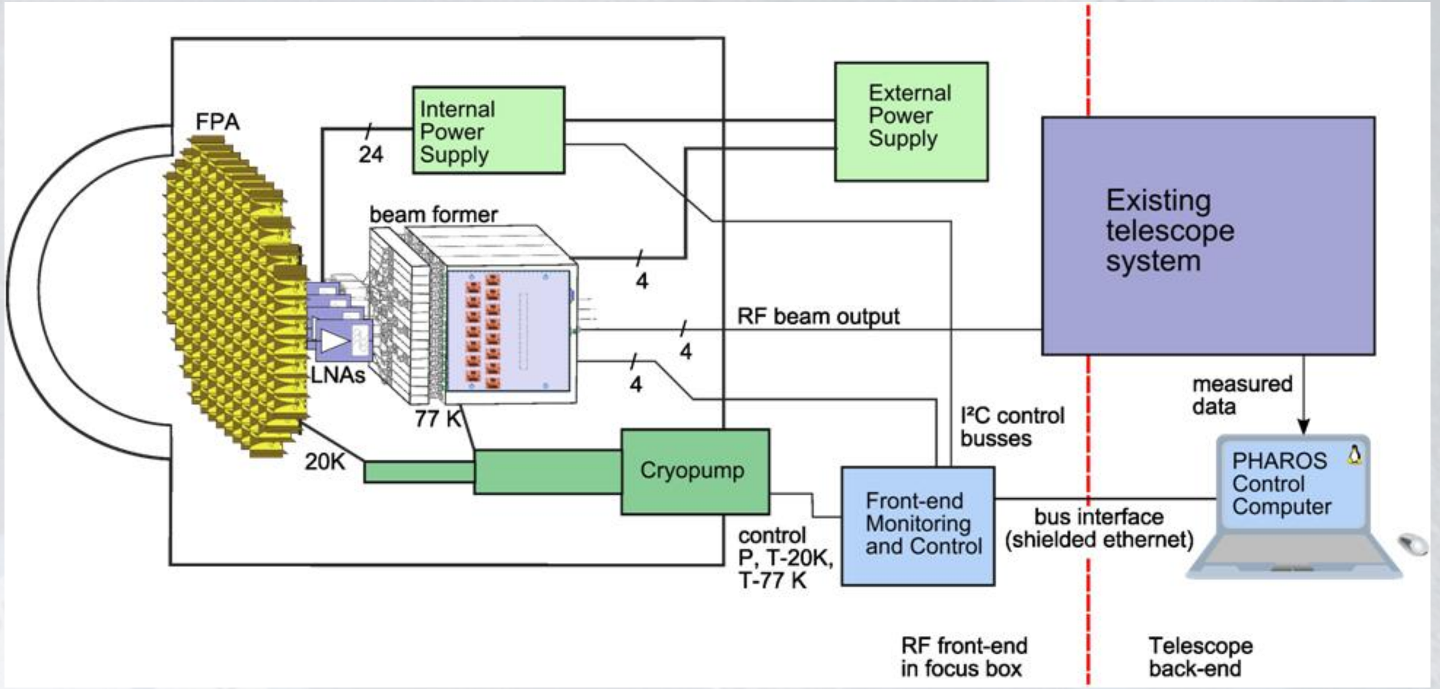


Focal plane array of PHAROS Vivaldi antennas and vacuum window

PHAROS/PHAROS2

3. Technical design: PHAROS

- The phased array feed consists of 220 elements Vivaldi array cooled to 20 K along with 24 LNAs mounted directly behind the active antenna elements.
- The LNAs are followed by low-loss low thermal conduction RF connections to the analog beam forming system designed to operate at 77 K.
- The RF signals of the active elements are distributed to the beam formers by passive splitters, while the non-active elements are terminated into 50 Ω loads.
- Four beam former modules are available, each with 13 RF inputs and 13 individually controllable phase and amplitude control units, along with 13 amplifiers to make up for system losses.
- The last stage of beam forming is a 16-way Wilkinson combiner (three inputs terminated). Each analog beam former is responsible for the amplitude and phase weightings of 13 elements in order to produce a single (compound) one-polarization beam.

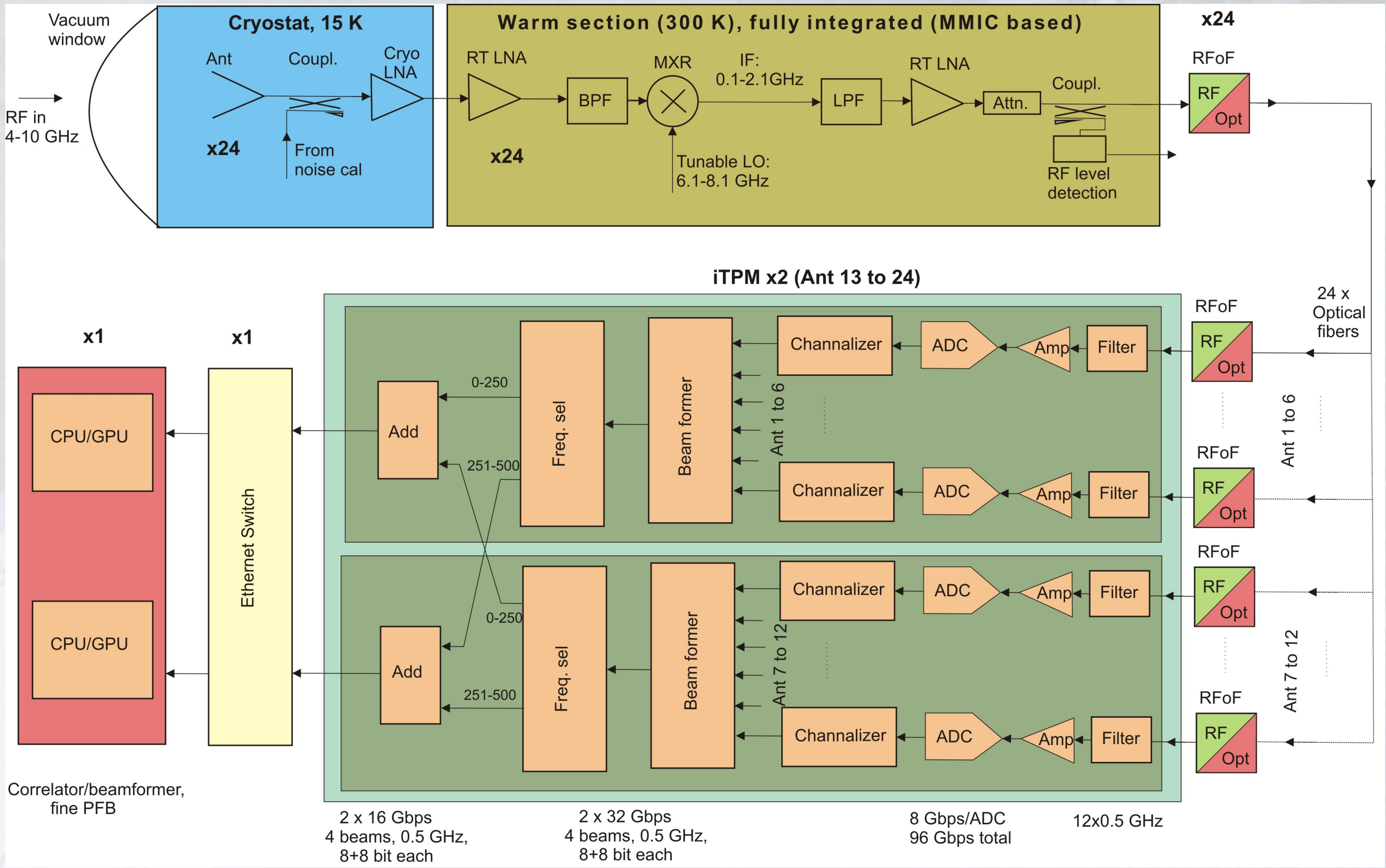


PHAROS system diagram showing the main parts of the instrument

PHAROS/PHAROS2

3. Technical design: upgrade PHAROS2

- Upgraded PHAROS2 would have the following features:
- New focal plane array of antennas (possibly with extended RF frequency coverage, beyond the current 4-8 GHz band).
- New cryogenic LNAs with state-of-the-art performance to replace the existing ones. Goal is to integrate low-power consumption ultra-low noise LNAs with antennas in a compact module without coaxial interconnections.
- A down conversion system from RF to baseband.
- Signal transportation with analog RFoF optical links.
- iTPM digital backend (LFAA digital beamformer based on FPGAs) to perform digitization, coarse frequency channelization and pre-beamforming. Beamforming in GPU boards, mounted in high class PCs .
- 4 independent beams digitally formed using 24 active elements (baseline design). 9 independent beams digitally formed using 37 active elements.



Schematic diagram of a possible design concept for the PHAROS2 Phased Array Feed.

PHAROS/PHAROS2

4. Status:

- The SKA PAF program is expected to end by the end of 2018.

PHAROS2

4. Installation at SRT:

- It has to be installed at primary focus: overcrowded. It would have to replace either dual-band L-P or multi-beam S.
- New mechanical support structure will have to be built at the primary focus
- PHAROS2 uses a local oscillator to down-convert the frequency, that will have to be installed at the primary focus. Need to decide the best solution.
- The Tile Processing Modules (TPM) PHAROS2 backend will have to be added to the backend room.
- An alternative could be to install it at a different focus, but for this a viability study would be necessary.

SRT

BRAND

1. The project:

- The BRoad-bAND EVN (BRAND) is a wide-band receiver under development in the framework of the Radionet4 Project, that will cover a very broad band, from 1.5 to 15.5 GHz. This would allow multi-band simultaneous observations in the 18 to 2 cm range.
- The motivation of this project is the fact that some EVN stations lack of a frequency agility system, so the switching time among different wavelengths take from seconds to hours, depending on the station.
- The Italian referent for the project is Gino Tuccari.
- BRAND, that will be devoted to astronomical observations in the EVN consortium, will be installed at all the EVN antennas. Some mechanical constraints at each EVN station will have to be taken into account to allow its installation.
- Having BRAND installed at SRT could be a good opportunity in particular to perform geodetic studies since a classical S/X receiver is neither available nor planned.
- BRAND could be an interesting possibility also for Medicina and Noto, given their successful and long-standing participation in international VLBI and geodetic observations.

BRAND

2. Scientific drivers:

- Multi-wavelength VLBI mapping: fringe-fitting over very wide frequency range; determination of the ionosphere; precise registration of simultaneous images at different frequencies.
- Multi-wavelength spectroscopy: study several different maser types in different frequency bands simultaneously; alignment of different maser species, e.g. determine conditions in complex flow patterns.
- Multi-wavelength polarimetry: variations of polarized emission as a function of frequency over a very wide frequency range; precise unambiguous rotation measures; improve studies of physical conditions of various astronomical objects.
- Multi-wavelength single-dish: flux variation studies in several bands simultaneously especially interesting for intraday variability; rotation measures over large bandwidths; pulsar observations over a wide frequency range with no timing ambiguities.
- Geodetic VGOS compatibility: joint observations with geodetic VGOS antennas would be possible; precise positions of astronomical antennas celestial reference frame.
- Two proposals presented in the Call for Ideas asked for a BRAND-like receivers (see Alessandra's presentation)

BRAND

3. Technical design:

- Technical development will start from the already available 2-12 GHz linear polarization feed designs.
- A feed system design for the primary focus will be the main aim of the project (to be tested on the Effelsberg antenna), as well as an investigation of secondary focus mounting (by adding a lens).
- The receiver will be cooled and its analogue part will consist of cooled LNA, post- amplifiers and HTS RFI filters.
- The chain will be processed digitally (no frequency conversion; digital polarization conversion from linear to circular; additional digital RFI mitigation; local RFI 'fingerprint' determination at stations; multi-band total power detector; multi-band polarimeter and spectrometer).

BRAND

4. Installation at SRT:

- Some mechanical constraints at each EVN station will have to be taken into account to allow its installation.
- Some critical issues have to be taken into account: 21 cm not available and the feed performance in the designs today available in term of cross-polarization are poor, about 18 dB (EVN requests 28-30 dB for the antennas). The SRT primary focus is very crowded. The installation of BRAND would increase the problems.
- It will have to satisfy the requirements of both SD and VLBI observations.

SRT

SUMMARY

- ALMA Band 2+3: prototype that will cover the entire frequency range from 67 GHz to 116 GHz in a single receiver cartridge. High interest of the scientific community. Prototype at its final laboratory tests. Some electrical, thermal, and mechanical interfaces will have to be expressly developed to install it at SRT. Budget of 80000 euros.
- PHAROS/PHAROS2 project: technological demonstrator to build a C band PAF. The INAF involvement in the SKA AIP project should allow to gain sufficient expertise to start building a new generation of PAF receivers, highly requested by the Italian scientific community in the Call for Ideas.
- BRAND project: foresees the involvement of INAF, aims at building a new generation ultra-wide band (UWB) receiver for VLBI, suited for any kind of astronomical observing modes and for geodetic studies. The actual interest in the will depend on its final design and capabilities. Some critical issues raised.