Development of Phased Array Feed Italian Contribution

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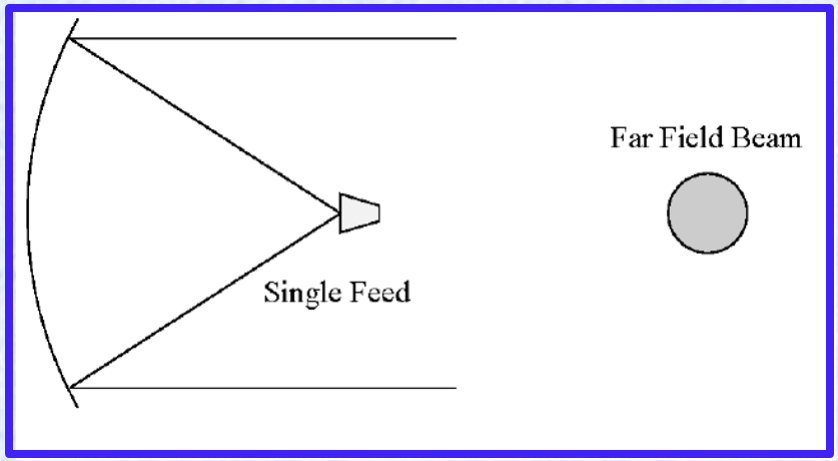
On behalf of the INAF PAF Team and of the PHAROS2 International Collaboration

Overview

- Introduction to Phased Array Feed (PAF) and difference with cluster of feed-horns (multibeam);
- SKA Advanced Instrumentation Programme on PAFs;
- The PHAROS2 PAF programme and Italian contribution;
- Future perspectives.

Cluster of feed-horns and Phased Array Feeds



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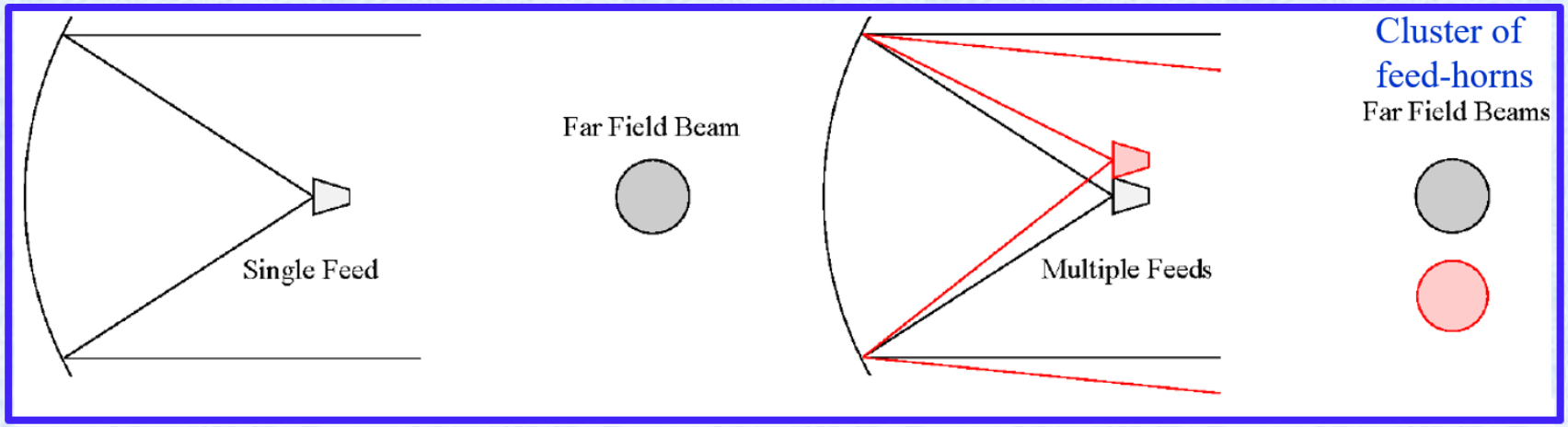
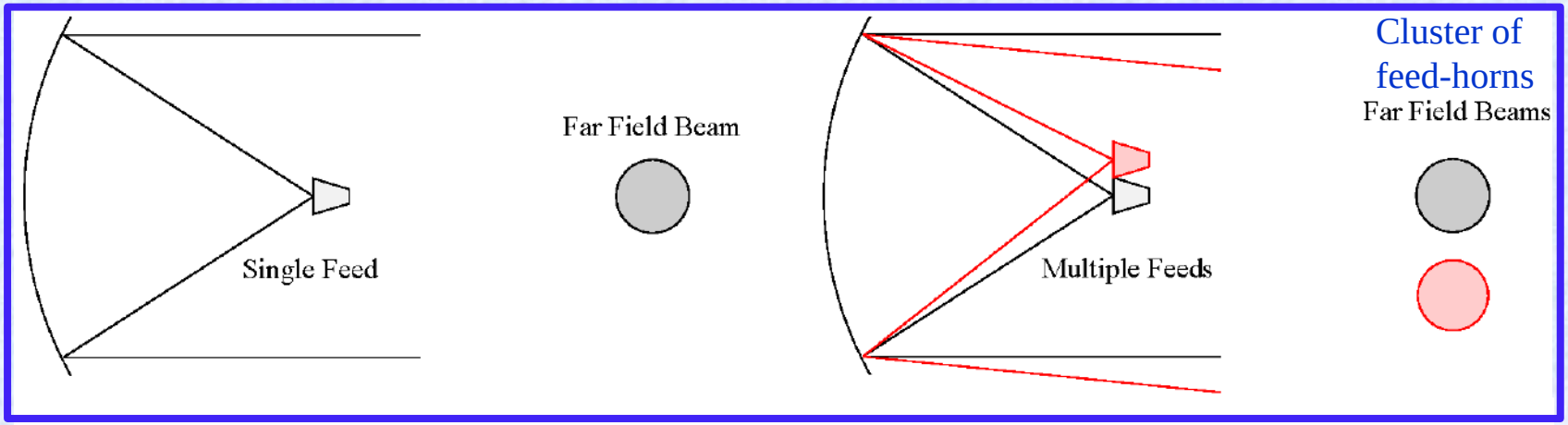
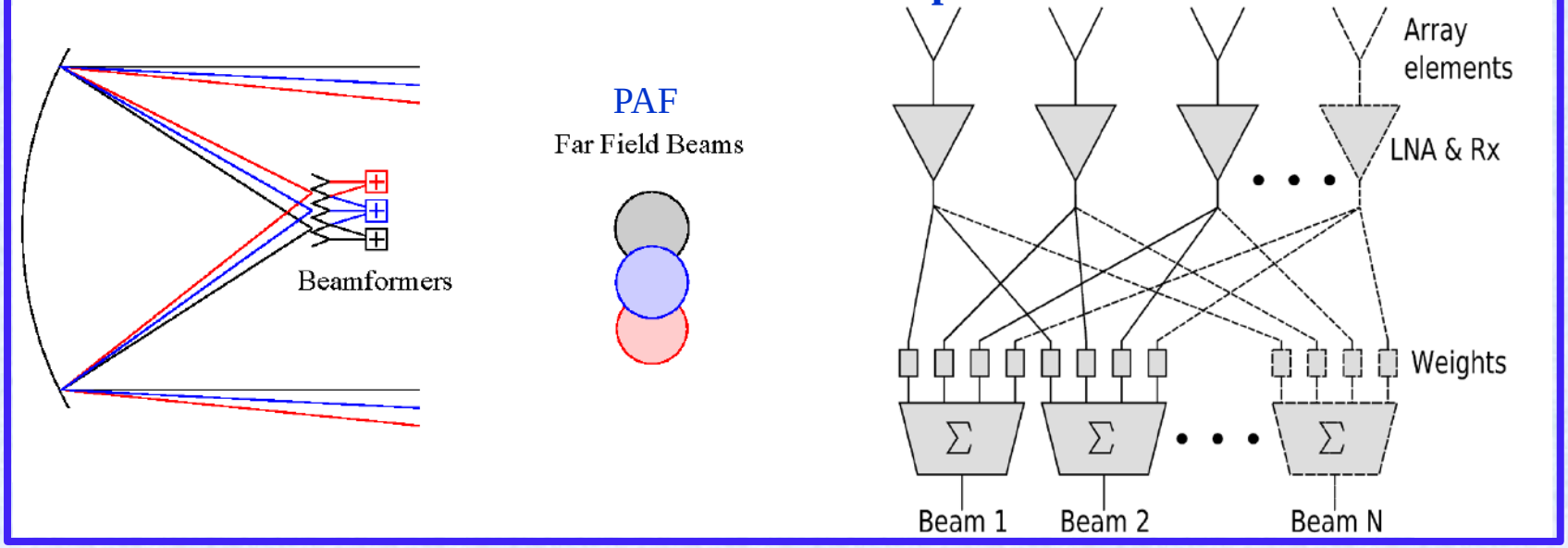


Cluster of feed-horns and Phased Array Feeds



PAF with antenna elements separation ≈λ/2:



Advantages of Phased Array Feeds

- Achieve complete coverage of the available radio telescope Field of View (FoV) with multiple simultaneous beams;
- Frequency-invariant properties: reflector optimally illuminated at any frequency (high antenna efficiency over very wide freq. band);
- Reduction of bandpass ripples;
- Correct for off-axis aberration;
- Compensate for large-scale distorsion of dish surface errors;
- Direct one or more beams towards calibrators while observing the astronomy source of interest (reduces total observation time);
- Radio Frequency Interference (RFI) mitigation;
- Improvement of the beams polarization purity;
- Possibility to perform electronic de-rotation of the astronomical field during source tracking;
- Reconfigure the properties of the beams in real time;
- Elaborate observations in post-processing using a post-correlation beam former;

Example of existing L-band PAFs

Aperitif

ASKAP

FLAG

Some of the PAFs under development

- Parkes cryo PAF 700-1900 MHz;
- FAST cryo PAF 1050-1450 MHz;
- Effelsberg cryo PAF 2500-3500 MHz,
- ALPACA – Upgrade of FLAG;
- NCRA GMRT PAF
- UMan S-band PAF

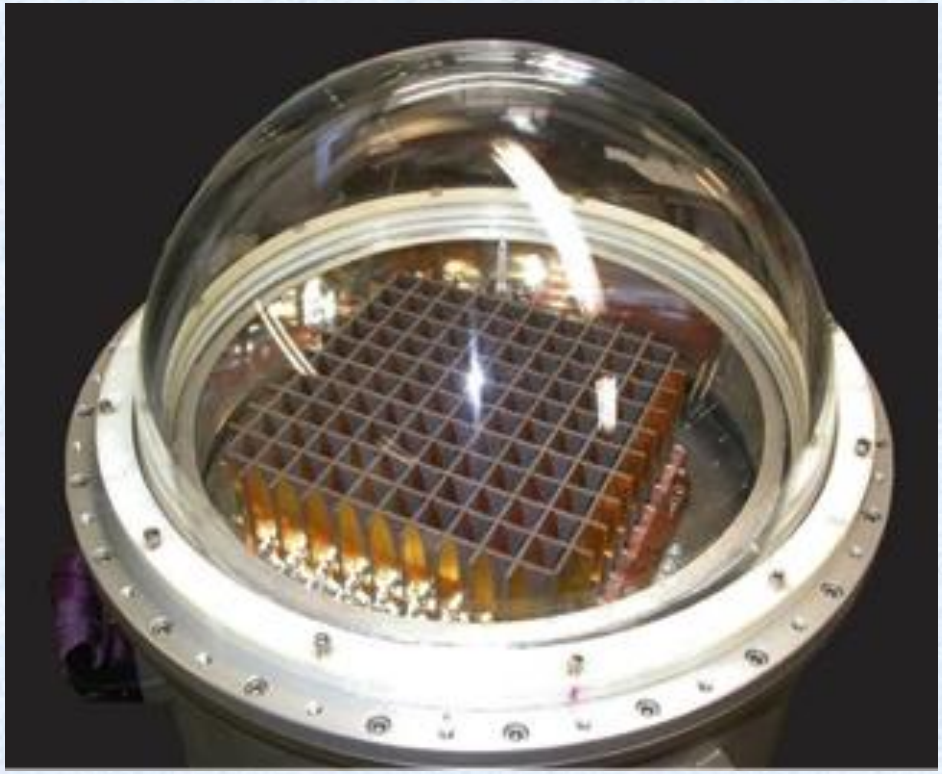
SKA PAF Advanced Instrumentation Programme (AIP)

- PAF technology is not part of SKA1. The SKA Observatory includes a SKA Observatory Development Programme (SODP) of telescope development towards SKA2 for enhancements/extensions of SKA1;
- SKA1-Mid antennas have been designed to incorporate PAF receivers in the future. PAF technology might find application in SKA-Mid;
- The SKA AIP on PAF was established in 2016. Nine international institutions are part of the PAF Consortium, including INAF;
- The SKA AIP on PAF is currently funded by in-kind contributions of the member institutes that are focussed on their own PAF R&D programs – with no real focus on SKA PAFs yet;

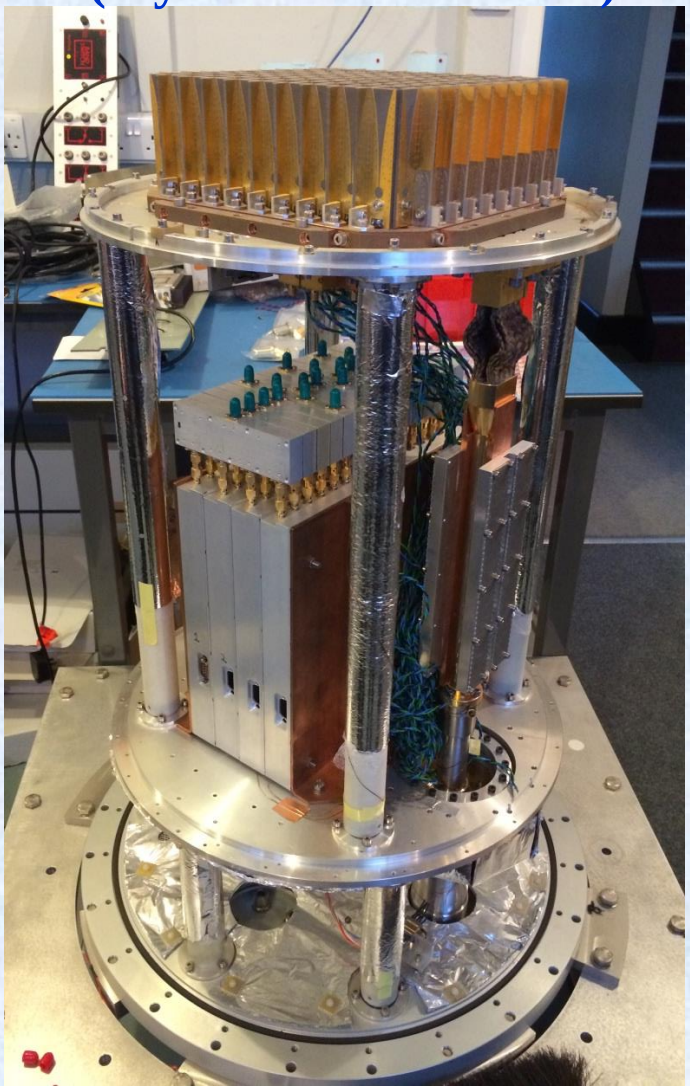
PHAROS: PHased Arrays for Reflector Observing Systems

- Collaboration started >12 years ago. Originally, 7 international partners involved;
- Goal: develop a demonstrator of a cryogenically cooled PAF;
- Array of 10x11 dual-pol. Vivaldi antennas;
- 24 active antennas in one polarization at ≈20 K;
- Four 13-element analog beamformers at ≈70K;
- C-Band, 4-8 GHz;

Vivaldi array and vacuum window:



PHAROS PAF (cryostat internal view):



PHAROS2: upgrade of PHAROS PAF

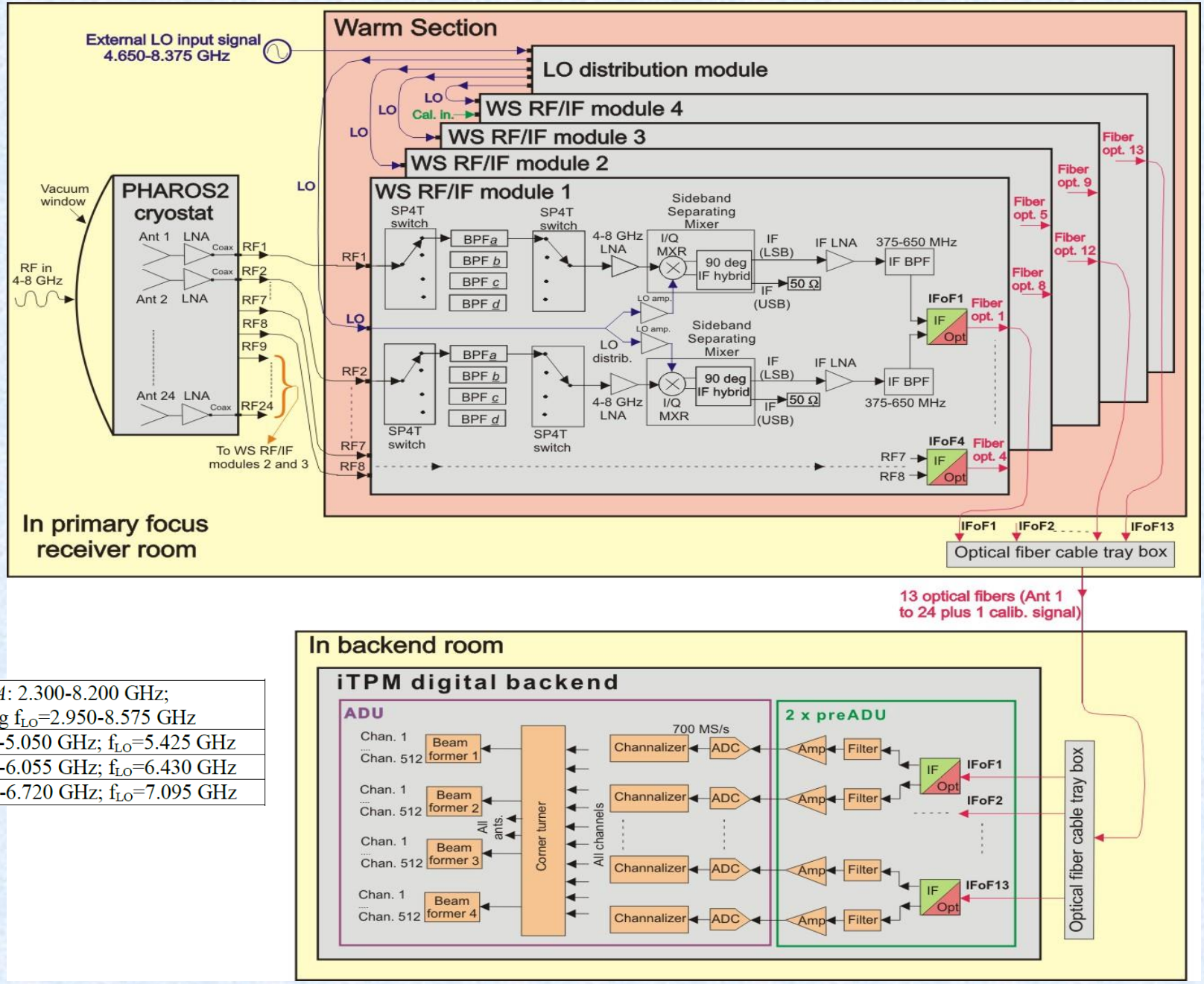
- Demonstrator of possible technologies for the SKA;
- One of the Work Packages of the PAF SKA AIP;
- A collaboration of five institutes:

- New cryogenic Low Noise Amplifiers (commercial);

INAF leadership

- INAF Digital Back-End based on iTPM hardware;
- INAF C-band multi-channel heterodyne receiver (Warm Section) to deliver ≈275 MHz bandwidth to the iTPM Digital Back-End;

Architecture of PHAROS2

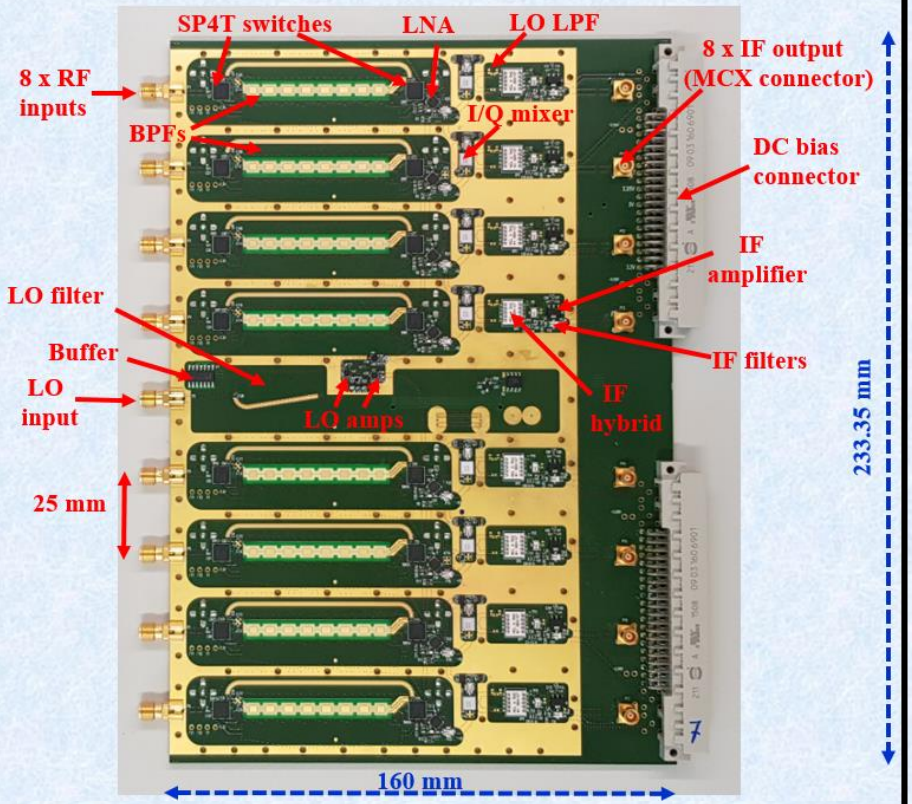


BPF-A: 2.300-8.200 GHz; LO tuning f_{LO}=2.950-8.575 GHz
BPF-B: 4.775-5.050 GHz; f_{LO}=5.425 GHz
BPF-C: 5.780-6.055 GHz; f_{LO}=6.430 GHz
BPF-D: 6.445-6.720 GHz; f_{LO}=7.095 GHz

Eight-channel C-band Warm Section Heterodyne Rx Module

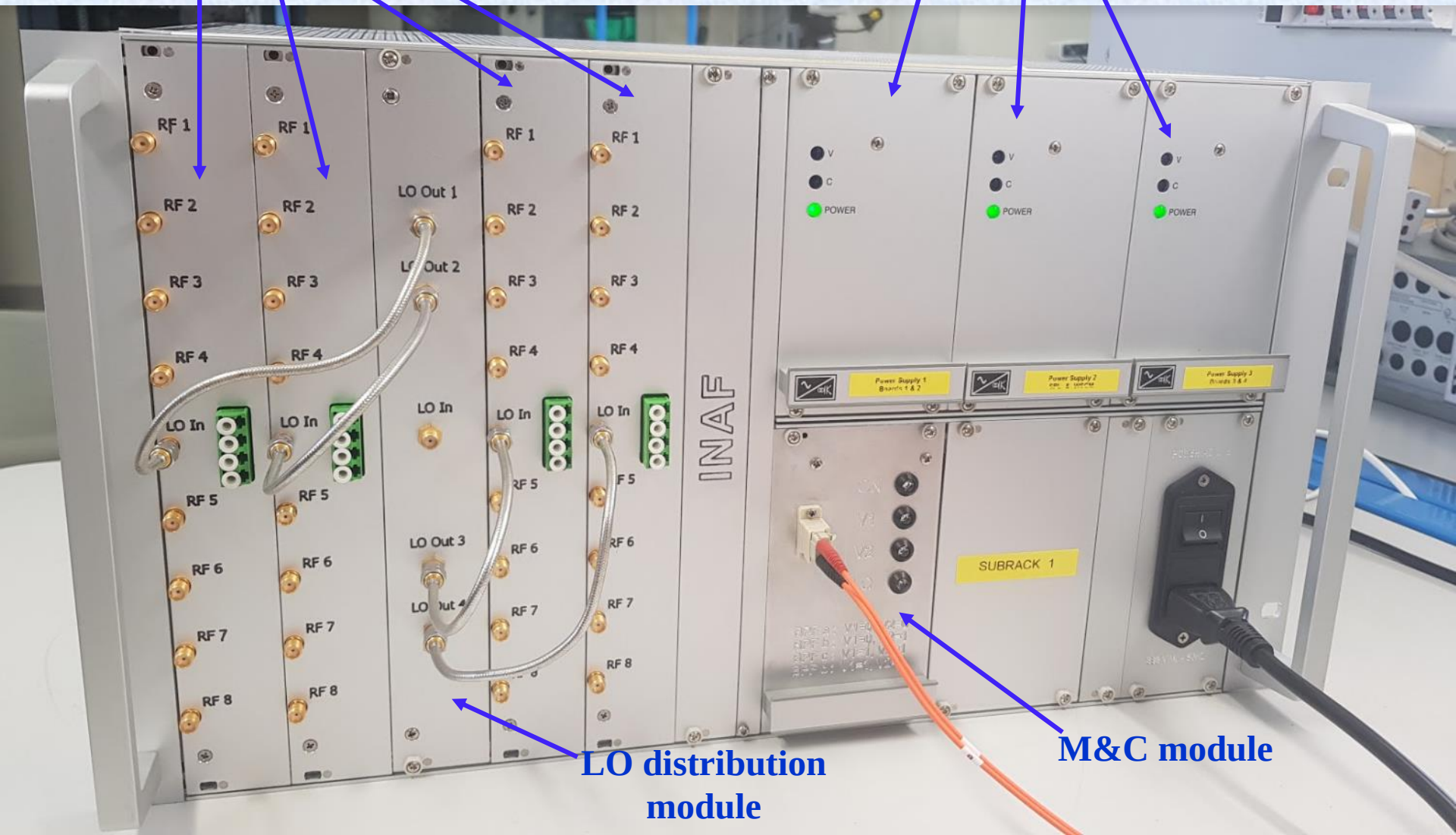
RF: 2.3-8.2 GHz; IF: 375-650 MHz

One eight-channel C-band board:



Two eight-channel modules assembled with IF over fiber (IFoF) optical transmitters:

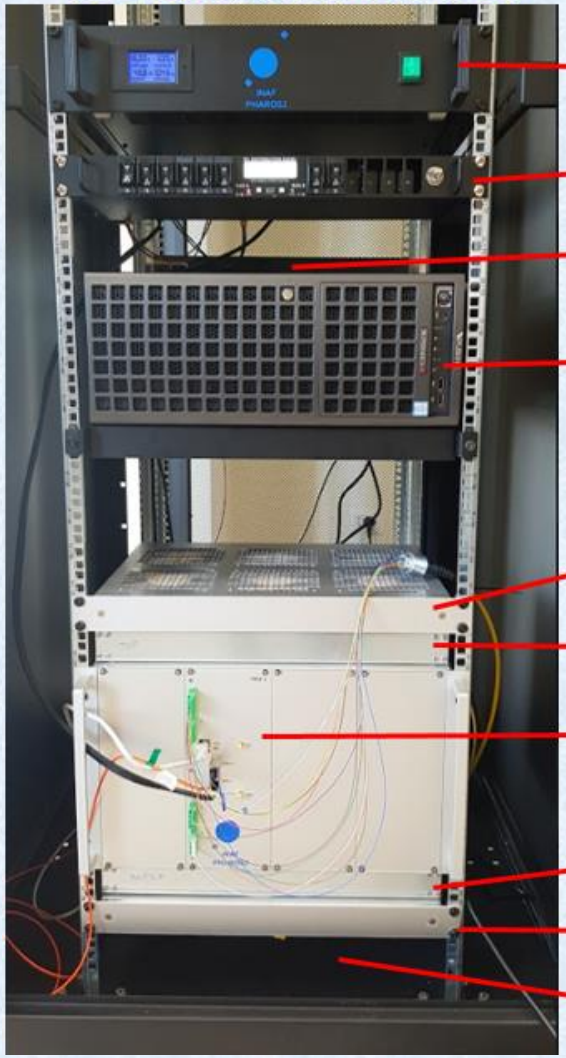
32-channel C-band Warm Section Heterodyne Receiver for PHAROS2 developed at INAF



PHAROS2 Digital Back-End

Four beams, ≈275 MHz BW each. Beamforming in the iTPM-FPGAs for 24 single-pol. antenna elements. Each beam provided with time-integrated spectra (pulsar search, on-the-fly mapping) and with non integrated spectra (pulsar timing).

BE cabinet front view



Power supply (2U)

Power distributor (1U)

Switch 1G (1U)

Server (4U)

Air blower (1U)

Air deflector (1U)

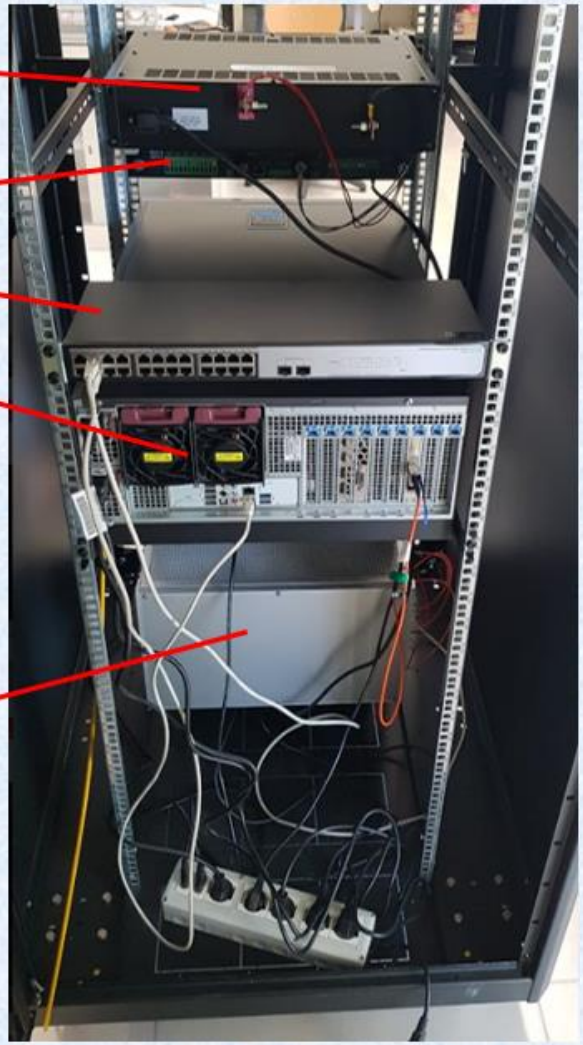
Subrack with one iTPM (6U)

Air deflector (1U)

Air blower (1U)

Empty slot for air circulation (2U)

BE cabinet rear view



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University of Malta

PHAROS2 mounted on 25-m Pickmere antenna (UK)

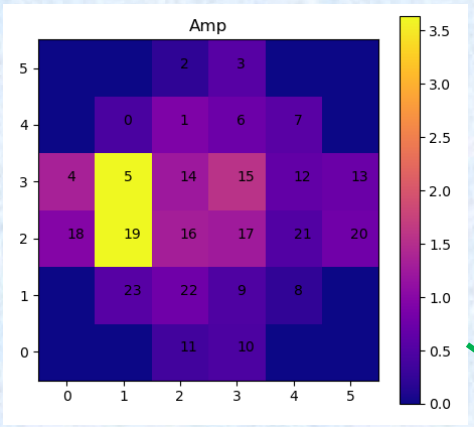
First-ever C-band cryogenic PAF installed on a radio astronomy antenna

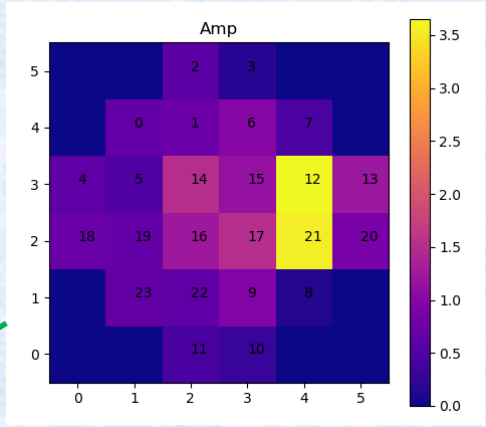
INAF ISTITUTO NAZIONALE DI ASTROFISICA

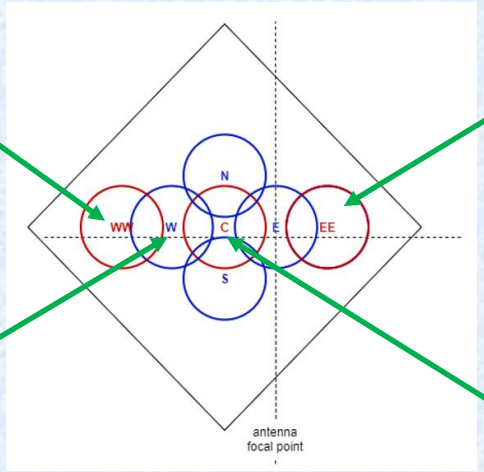
MANCHESTER 1824
The University of Manchester

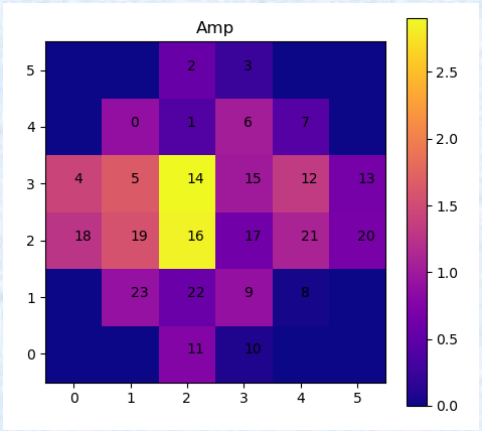
Test results of PHAROS2 on Pickmere antenna

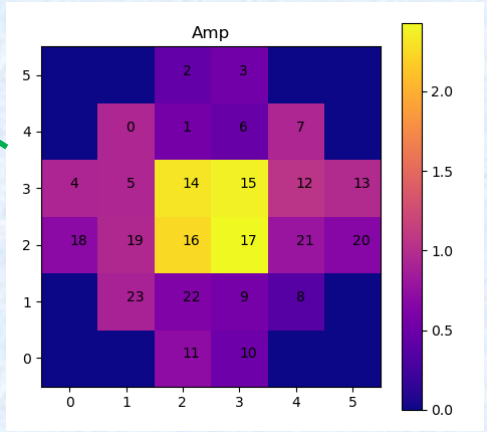
Amplitude weights of four test beams formed on Cyg A, around 6.5GHz:









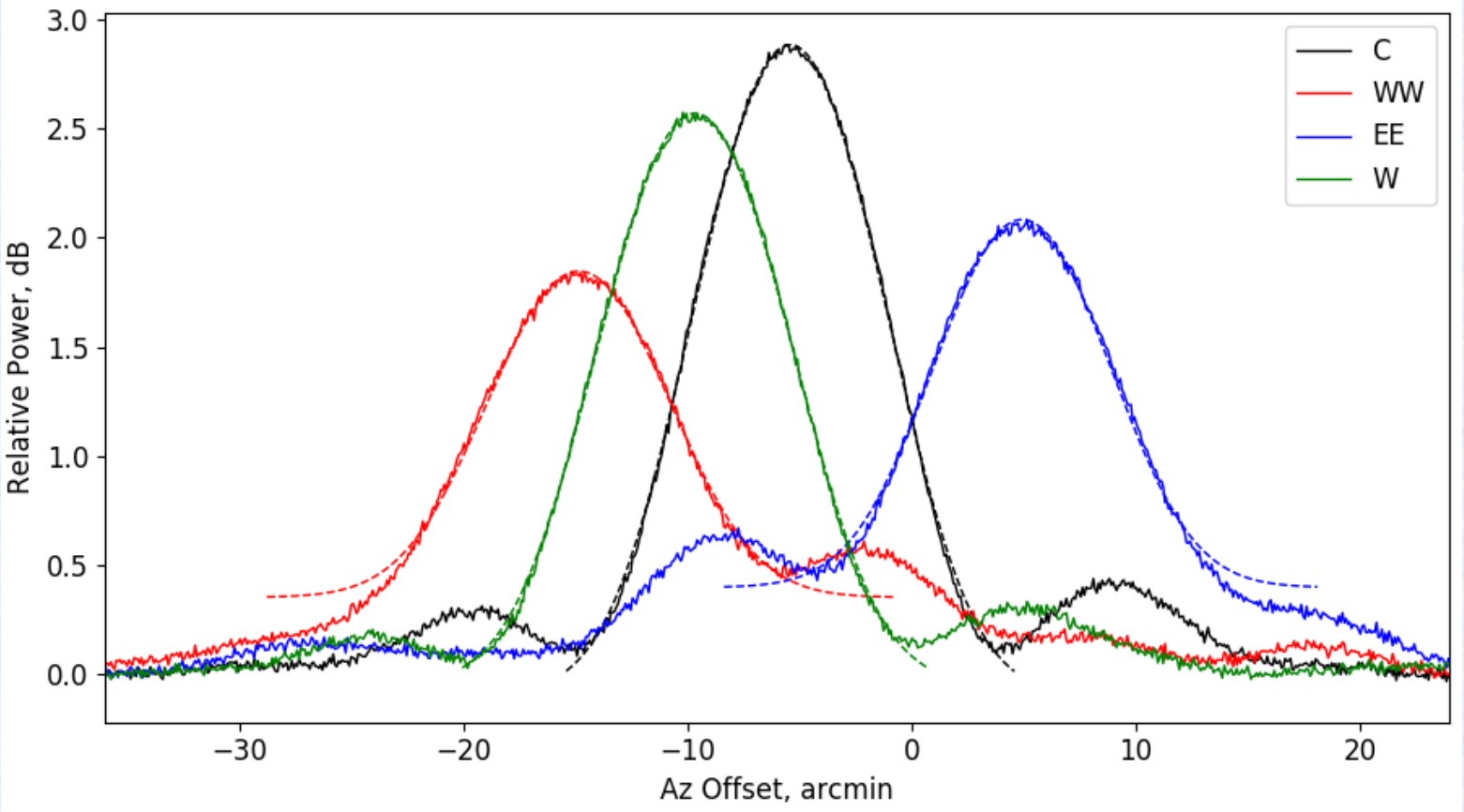


Test results of PHAROS2 on Pickmere antenna

…resulted in four well-formed beams!

Beams tested on Cas A yield approx. SEFDs:
C: 480Jy, W: 550Jy, WW: 1100Jy, EE: 1000Jy,

All with approx. 9 arcmin HPBW and centred at the intended offset



Future perspectives

- Develop a demonstrator of a cryogenic PAF with antennas and LNAs integrated in a compact module for extended C-band (3.0-7.7 GHz) based on RFSoC (Radio Frequency System-on-Chip) technology. The instrument will be entirely developed by INAF using state-of-the-art breakthrough technologies;

- Test the demonstrator on a radio astronomy antenna;

- Verify INAF PAF technologies with reduced hardware (a few beams & reduced BW);

- Develop the key technologies, capability and design knowledge for PAF systems enabling to commence a specific SKA PAF design in 2024.