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Updates on the INAF C-band PAF development project

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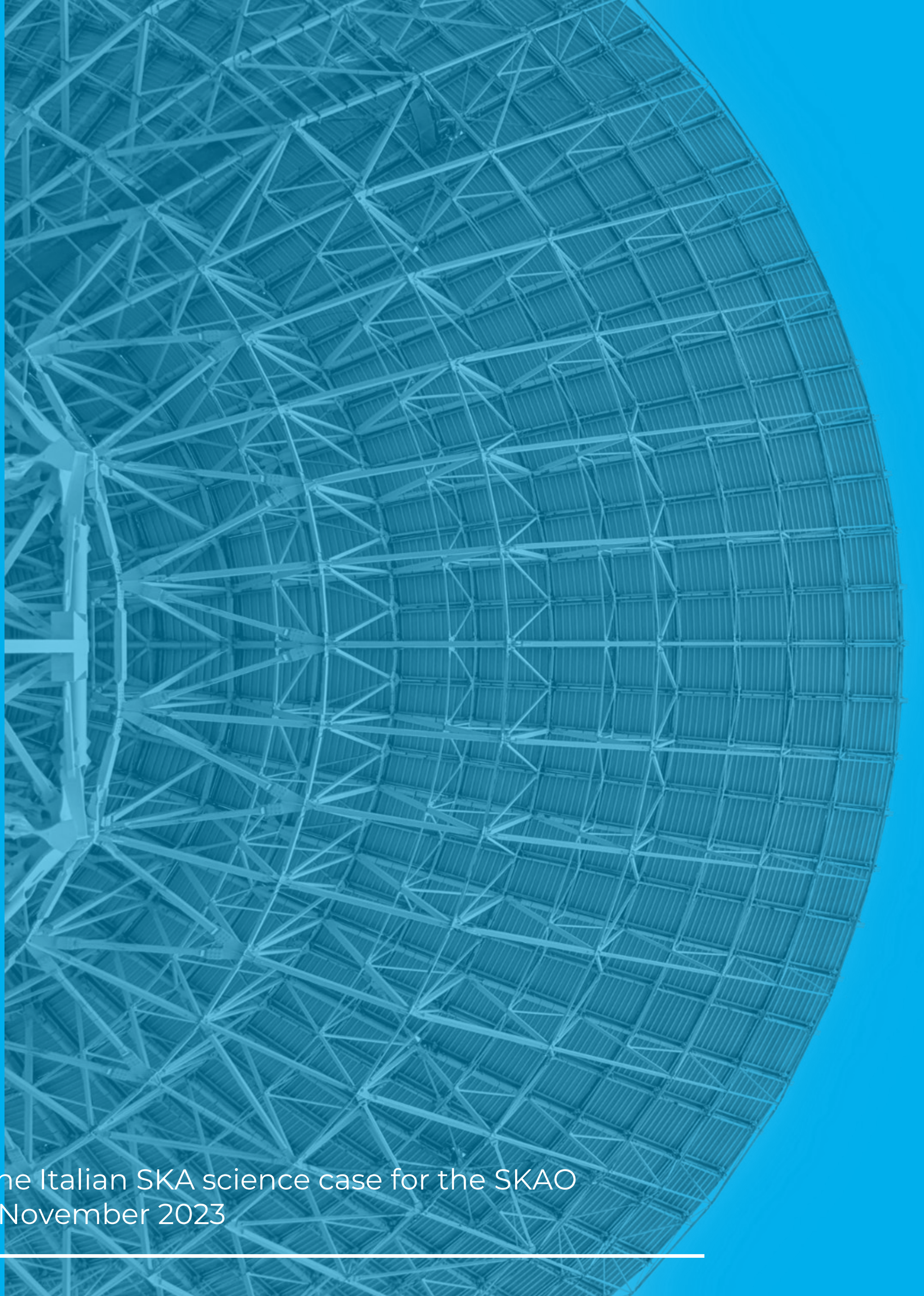


The Fourth National Workshop on the SKA project - Sharpening the Italian SKA science case for the SKAO

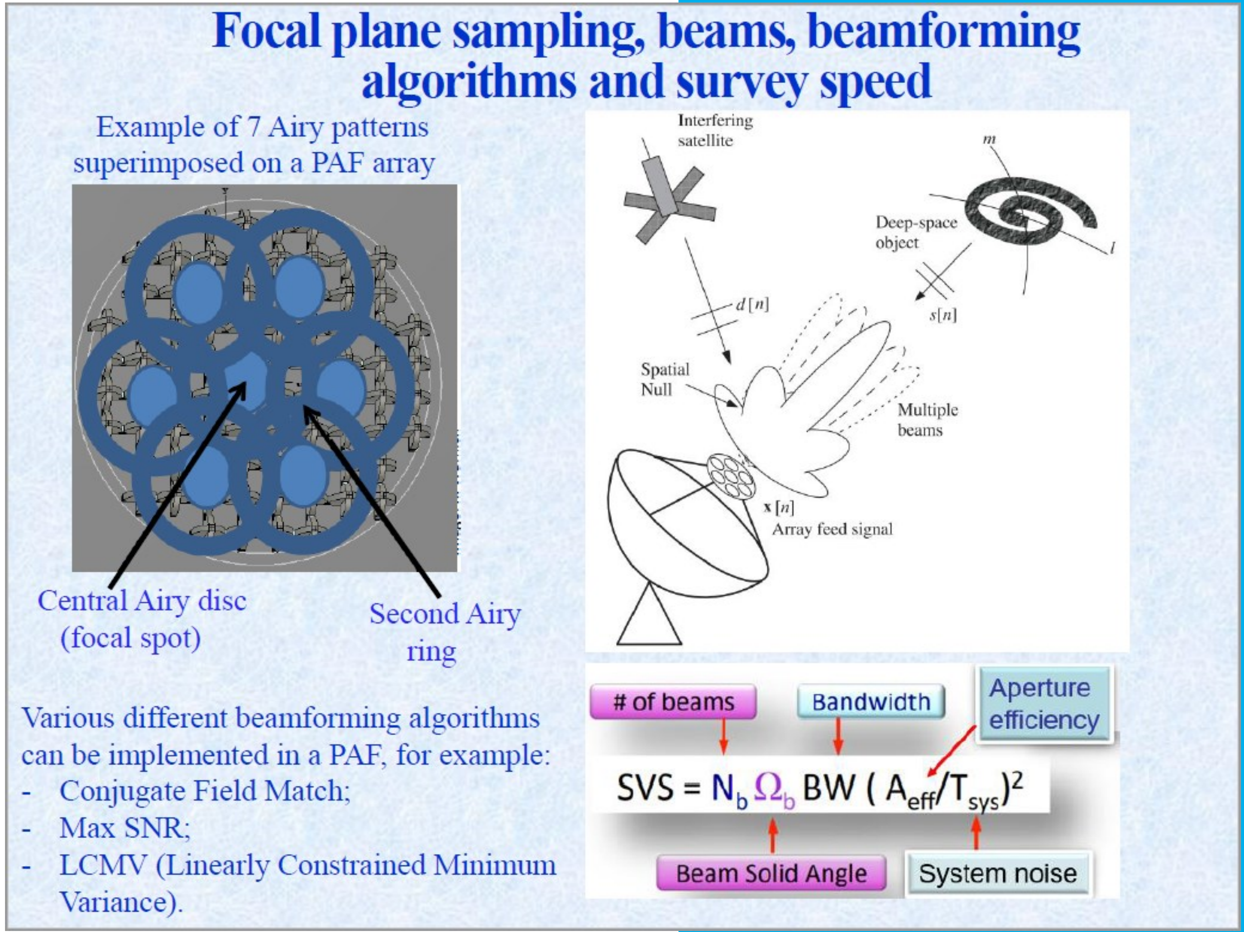
University of Catania, 27th November 2023

OVERVIEW

Introduction to Phased Array Feed (PAF)

- **A Phased Array Feed is made of closely packed antenna elements (d~λ/2) that, by spatially sampling the focal plane, can synthesize multiple independent beams and be set to Nyquist-sample the Sky (unlike array of feed-horns that require few interleaved pointings).**

- **Beam shapes and directions are controlled electronically by weighting the amplitudes and phases of the signals applied to the individual antennas by a beamformer.**



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Advantages of a Phased Array Feed

1. Possibility to achieve complete coverage of the Radio Telescope Field of View with multiple simultaneous beams;
2. Increase of the survey speed if compared to a single pixel feed;
3. Improve antenna efficiency over very wide frequency band;
4. Correct for off axis aberration;
5. Reduction of bandpass ripples;
6. Compensate for large scale distortions of dish surface errors;
7. Direct one or more beams towards calibrators while observing the astronomy source of interest;
8. Radio Frequency Interference mitigation;
9. Improvement of the beam polarization purity;

10\. Possibility to perform electronic de rotation of the astronomical field during source tracking;

10\. Reconfigure the properties of the beams in real time;

11\. Elaborate observations in post processing using a post correlation beam former;

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 PAF AIP was established in 2016 in Cagliari. Eight International Institutions were part of the PAF Consortium , including INAF. The PAF Consortium expired in June 2020;
- The SKA AIP on PAF was 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;

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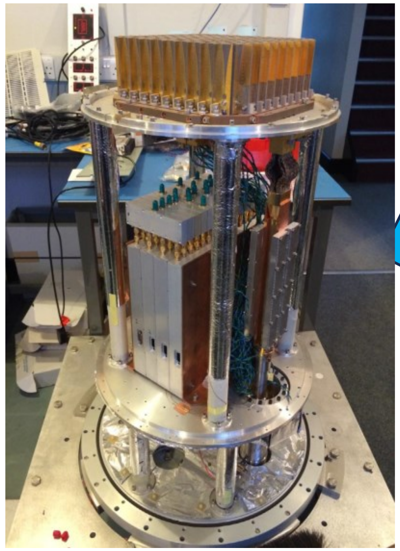
SKA SQUARE KILOMETRE ARRAY Italy

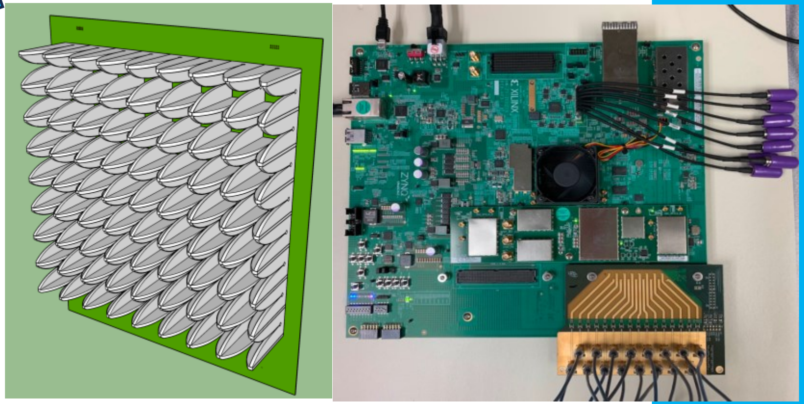
SKA SQUARE KILOMETRE ARRAY PHASED ARRAY FEED

Status of the INAF - PAF



PHAROS internal view of the Cryostat

PHAROS2 mounted on 2019 at the 25-m Pickmere antenna



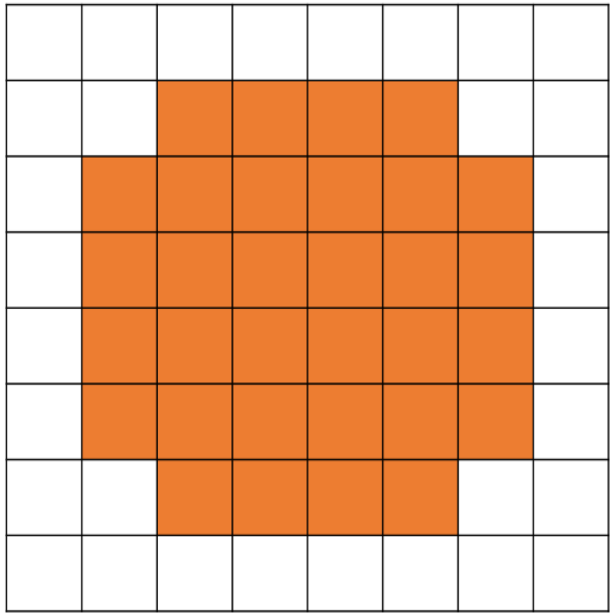
C-band PAF based on RFSoC

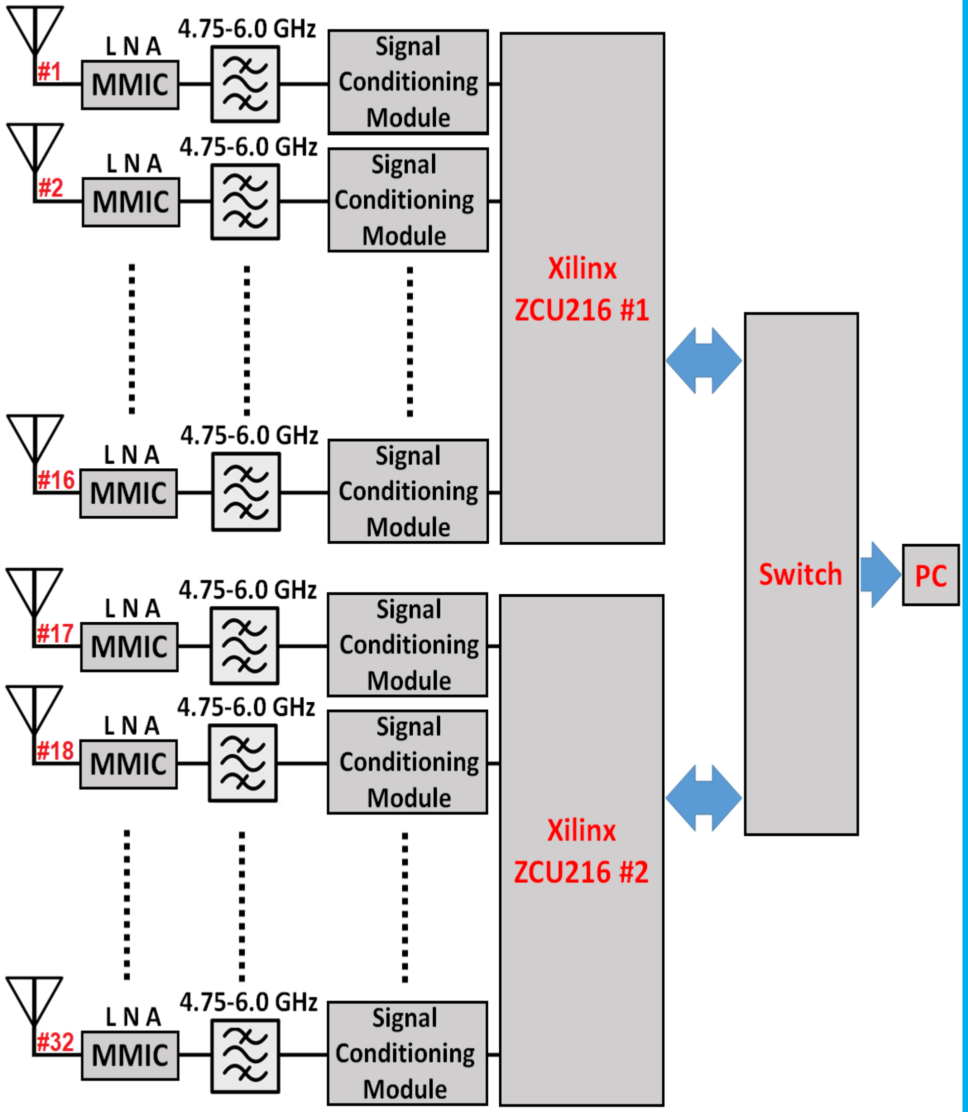
Status of the INAF - PAF

32-element PAF with two digital RFSoC boards

(connected to a 100 Gbps network switch and a PC)

Schematic of dual-pol 8×8 array with inner 32 active antennas in one pol





Status of the INAF - PAF

Our goals

- Develop a demonstrator of a cryogenic PAF with antennas and LNAs integrated in a compact module for extended C band based on RFSoC technology;
- Design and build a small Room Temperature PAF demonstrator in C-band based on RFSoC with up-scalable architecture;
- Direct sampling of the RF signals up to 6 GHz eliminates the need of downconversion (no Warm Section required);
- Four synthesized beams (in future > 30 beams), ≈ 1 GHz BW;
- Fully-integrated design based on an 8×8 array of dual-pol antennas, with 32 active elements;
- Two RFSoC boards, each digitizing 16 inputs, 1.25 GHz BW;
- Optimized for best sensitivity;
- Test the demonstrator on the INAF antennas (SRT, Medicina and Noto);

Status of the INAF - PAF

SRT main technical specifications

Primary Mirror D=64 m; Secondary Mirror D=7.9 m

Gregorian Configuration with shaped surfaces

Active Surface: Primary mirror adjustable with 1116 actuators

0.3-115 GHz frequency coverage

Six focal positions: Primary, Gregorian, & four Beam Wave Guide

Can host up to 20 dual polarization receivers: mono feed, dual frequency, multibeam, phased array feeds;

Primary surf. accuracy: $\approx$180 μm RMS

Max antenna efficiency: $\approx$ 60 %

Frequency agility

Pointing accuracy (RMS): 2 ÷ 5 arcsec

SCIENTIFIC motivations for a C-band PAF

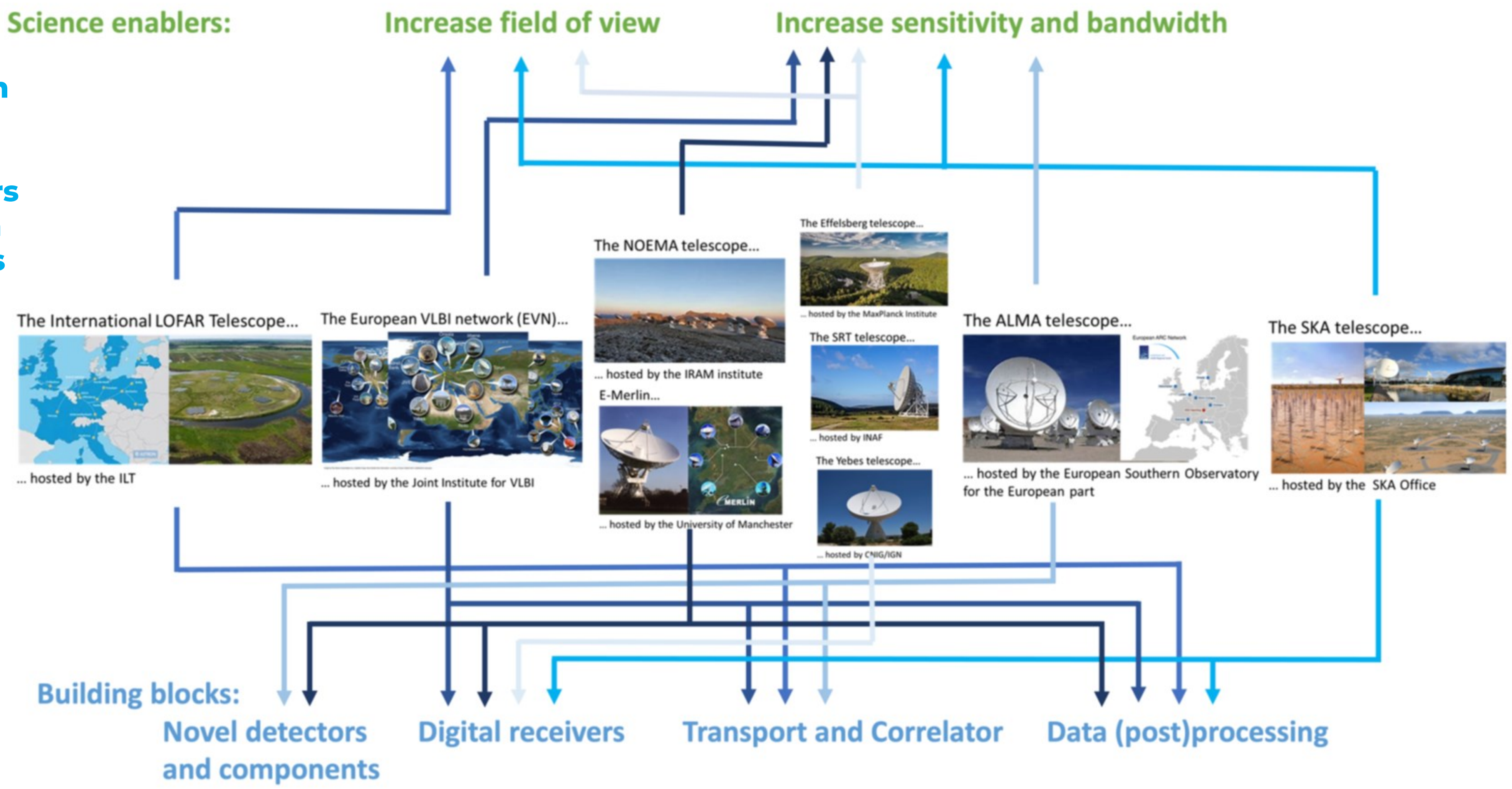
- C-band continuum surveys and polarization measurement;
- CMB foregrounds;
- Gamma Ray Burst and Gravitational Wave event follow-ups;
- Fast Radio Bursts search;
- Flat spectra transients/pulsars, like magnetars;
- Excited rotational states of OH near 6.03 GHz;
- Zeeman effect, star formation;
- CH3OH line (6.7 GHz) survey of methanol masers;
- Gas kinematics, Ultra Compact HII region;
- Formaldehyde line emission at 4.8 GHz;
- Polarization mapping of Galaxy Clusters and SNRs;
- Hydrogen recombination lines around 5 GHz;
- Galactic Centre high DM pulsar search;
- SETI and other Science

PAFs in the WORLD

- Parkes cryo PAF 700-1900 MHz
- FAST cryo PAF 1050 – 1450 MHz;
- Effelsberg cryo PAF 2500 – 3500 MHz;
- ALPACA cryo PAF 1300-1700 MHz for GBT;
- NCRA GMRT 550 – 900 MHz PAF;
- UMan S-band PAF;
- 36 ASKAP antennas PAF 700 – 1800 MHz;
- APERTIF @ WSRT 11130 – 1750 MHz with 40 beams

RADIOBLOCKS "New science in Radio Astronomy: applying cutting-edge technology to enhance the entire data chain, from receiver to final output"

Project funded with 10 M€ coordinated by JIVE ERIC between 33 partners including European industry companies



https://radioblocks.eu/

HORIZON-INFRA-2022-TECH-01 RADIOBLOCKS

WBS

WP1 – Project management

WP2 - Development of common building blocks in cutting edge frontend technologies;

WP3 - Development of building blocks for multipixel (PAF/FPA) receivers;

WP4 - Development of common building blocks needed for the development of new correlators;

WP5 -The implementation of a generic software toolkit to handle the post-processing of the resulting (very) large data streams; WP5

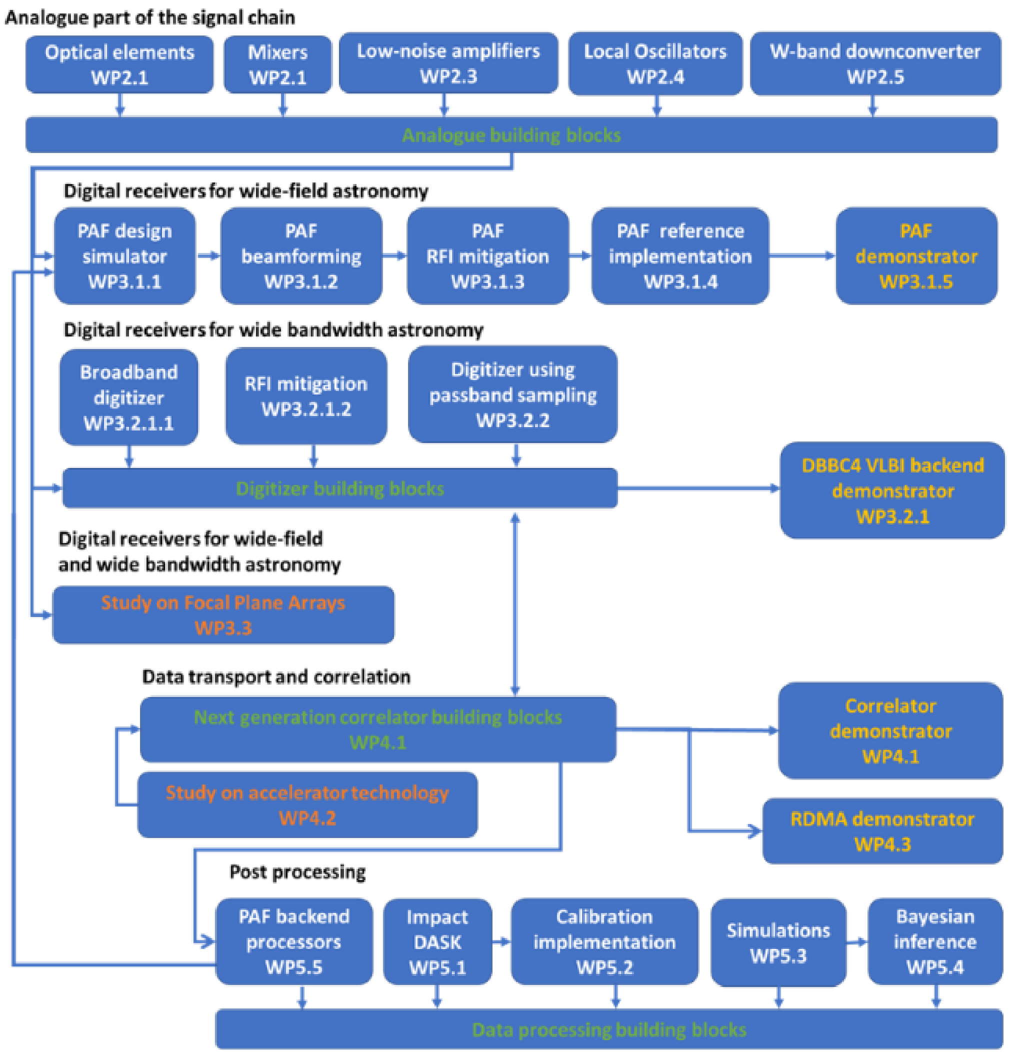


Figure 3: Connections between elements of RADIOBLOCKS

CONCLUSIONS

- PAFs have great advantages over multibeam receivers, speeding up mapping of extended sources;
- Radio astronomy PAFs are being developed for various bands, covering the frequency range from 700 MHz to ~ 8 GHz;
- The number of facilities considering PAF's is increasing. Most large single dish facilities have or have plans towards PAF's (Effelsberg, FAST, GBT, JBO, Parkes, SRT);
- Interferometers, such as APERTIF and ASKAP, adopt PAFs;
- PAF technology is not part of SKA1;
- INAF is part of the PAF SKA Advanced Instrumentation Program;
- INAF has contributed to develop the PHAROS and the PHAROS2 C-band PAF demonstrators and is developing a new demonstrator whose technologies could find application on SKA and on the Italian radio astronomy antennas;
- A steady improvement in PAF sensitivity is demonstrated, both for room temperature as well as cryocooled systems;
- For competitiveness, capital and operational costs of PAF's (including power consumption) needs to be reduced, in particular for PAF's proposed to be built in significant quantities;
- Constant improvement of digital backend capabilities might enable PAF developments at relatively low-cost in the future.

THANK YOU!

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