European Commission
Horizon 2020
European Union funding
for Research & Innovation

ARGOS

Conceptual Design Study

Designing a Next-Generation
Radio Telescope for
Multi-Messenger Astronomy

Introduction to Argos

John Antoniadis

DDF2024

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INSTITUTE OF ASTROPHYSICS
FOUNDATION FOR RESEARCH AND TECHNOLOGY HELLAS

FORTH
INSTITUTE OF COMPUTER SCIENCE

UNIVERSITY OF PIRAEUS
RESEARCH CENTER

Max-Planck-Institut
für Radioastronomie

DE LA RECHERCHE À L'INDUSTRIE
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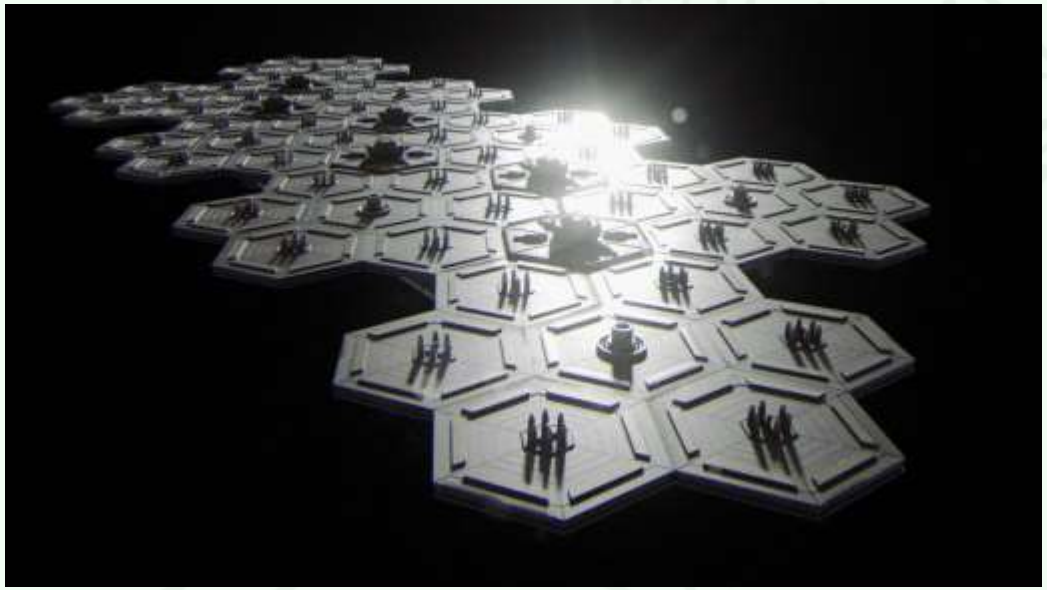
ARGOS

[ˈɑːgɒs] Ἄργος Πανόπτης, "All-seeing Argos" : A *many-eyed* giant in Greek Mythology, the guardian of **the heifer-nymph Io and the son of Arestor.**

…a popular name for telescopes



Argos Subspace Radio Telescope Array in service with Starfleet since 2259

Argos array picked up techno-signatures in Carl Sagan's "Contact" (played by the VLA in the movie)

ARray for **G**igahertz **O**bservation**S**

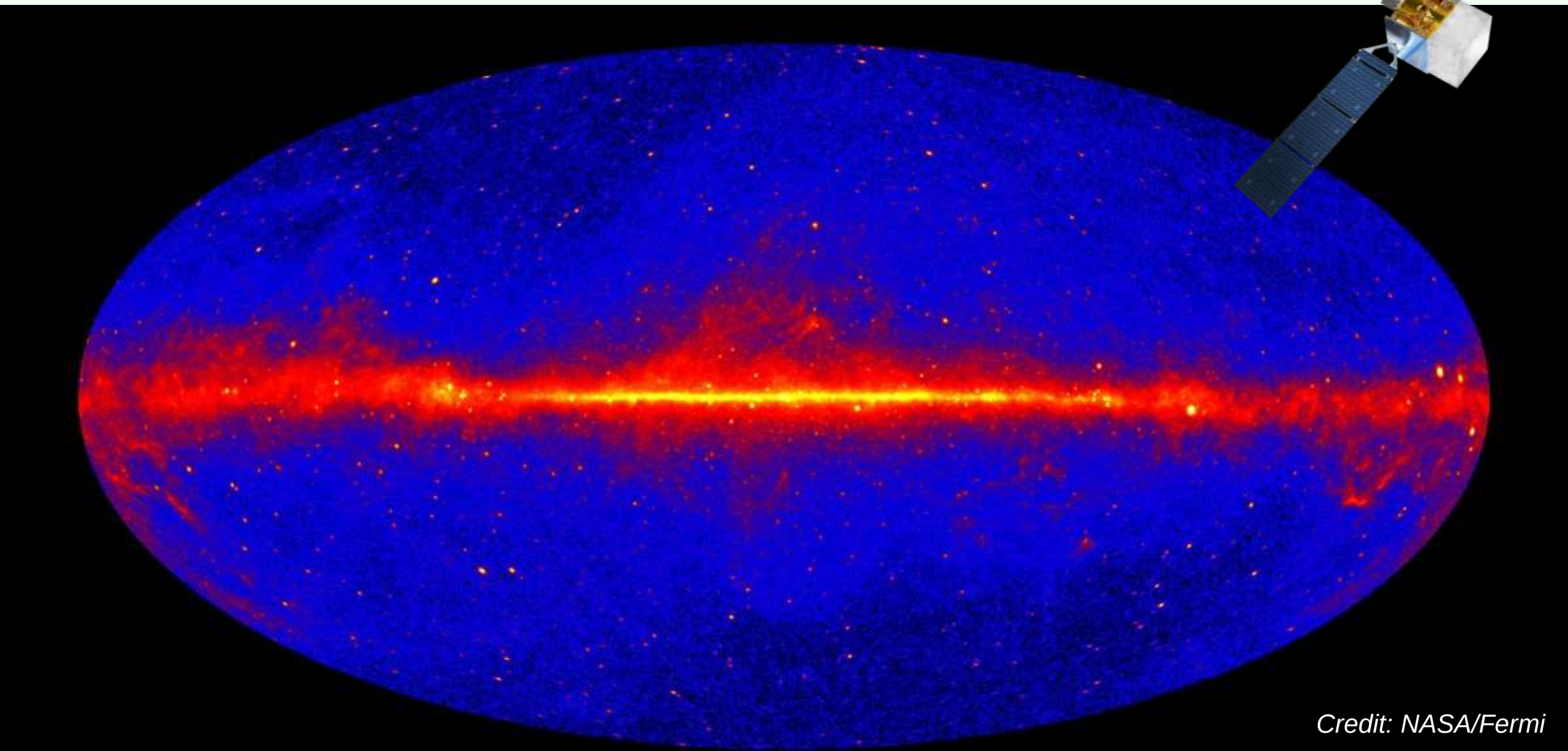
A telescope that combines broad frequency coverage, wide field, high sensitivity, high time and spatial resolution at GHz frequencies

…at a low price

Also: a facility that produces science-ready data with low lattency

Why bother? *From discoveries to high-impact science*

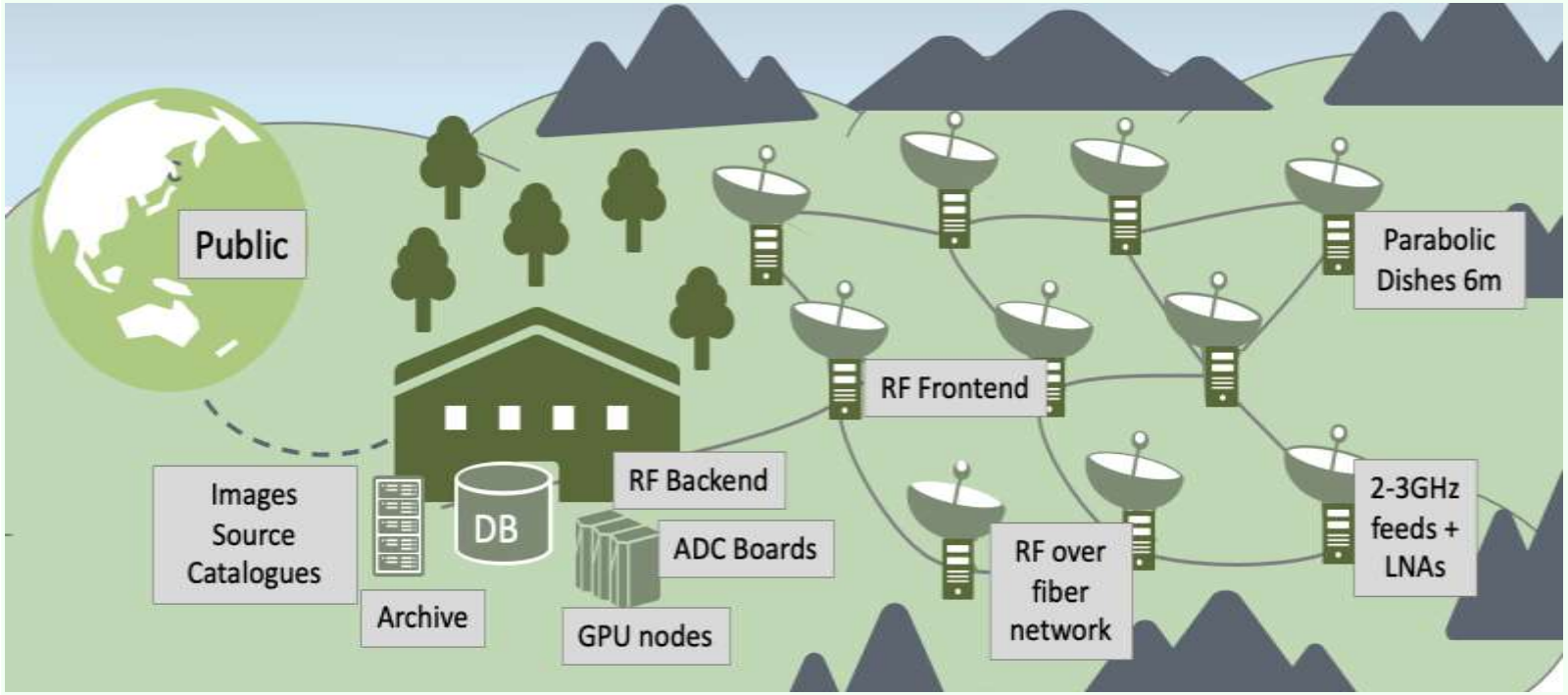
Why bother? *Panoptic surveys* are revolutionizing astronomy



Credit: NASA/Fermi

ARGOS system overview

antennas	~1200 x 6m
collecting area	33,000 m^2
instantaneous FoV	~9.6 deg^2
system temperature	Ambient LNAs (<35K)
apperture efficiency	>70%
resolution	5”
tracking	EL/AZ
frequency	1—3 GHz
SEFD	6.3 Jy
rms noise/beam [30 min]	2.3 μJy
pulsar sensitivity [10 min]	0.02 mJy
survey speed figure-of-merit	10^8 deg^2 m^4 MHz / K^2
FRB localisation accuracy	O(1”)
Cost (construction)	<50,000 €/dish — 60 M€



Why this design?...main advantages

- Low-cost → 60M EUR construction cost
- Scalability → 50K EUR / element for full array (please adopt an antenna)
- Expansibility / Modularity → Science modules subscribe to same data stream
- Complementarity to other facilities → Wide-field/High-res; freq coverage, long/lat. EU priorities
- Incentives for private-sector involvement → COTS components / tech with spill-over applications
- Legacy value → Science-ready data

The ARGOS Science Themes

Fundamental Physics
Pulsars

The Dynamic Universe
Imaging

The Evolving Universe
Pulsar Timing Arrays

The Violent Universe
Multi-messenger

Cosmology
Fast Radio Bursts

Next-generation telescopes
Technology exploitation

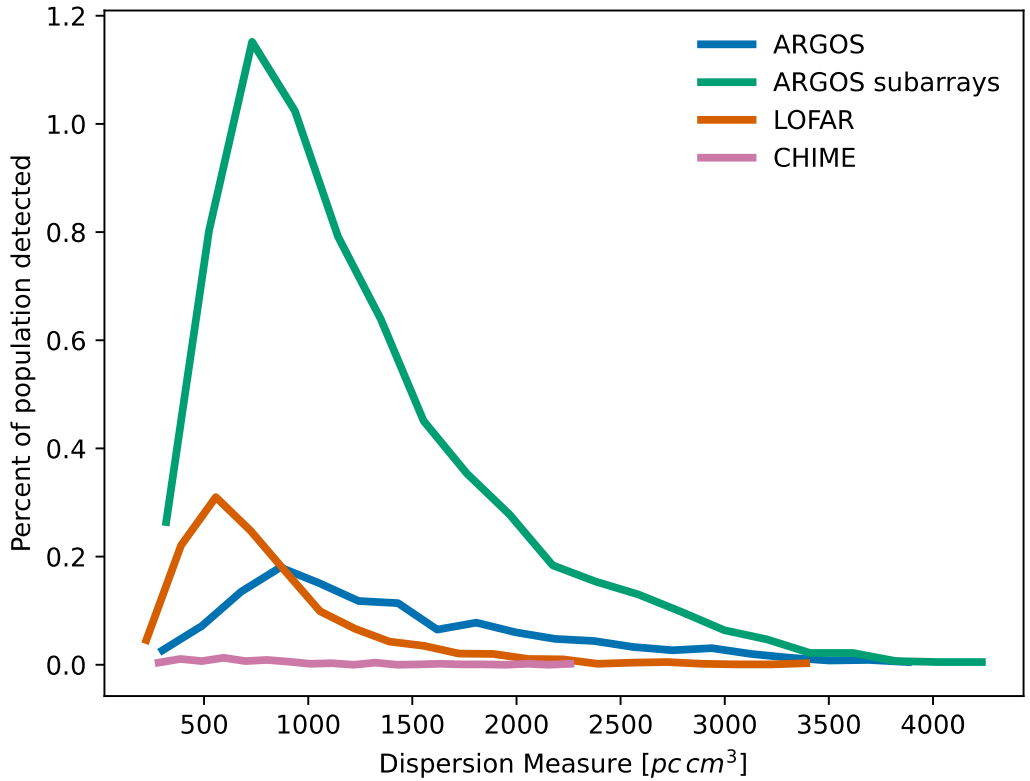
Fast Radio Bursts

ARGOS will be a superb FRB discovery engine

Key specifications

10 deg^2 field of view, 1—3 GHz, 4km baselines, SKA-MID1 level collecting area, 250kHz channels, 30μsec time resolution, default search mode for dispersion measures up to 3000 pc cm^{-3}, sub-arraying, low-lattency alerts

- **Commensal mode**
- **One well-localised (<5”) FRB per hour***
- **Sensitive to z>3 FRBs**
- **Flux, polarization, DM, RM information**
- **Automated low-latency triggers**

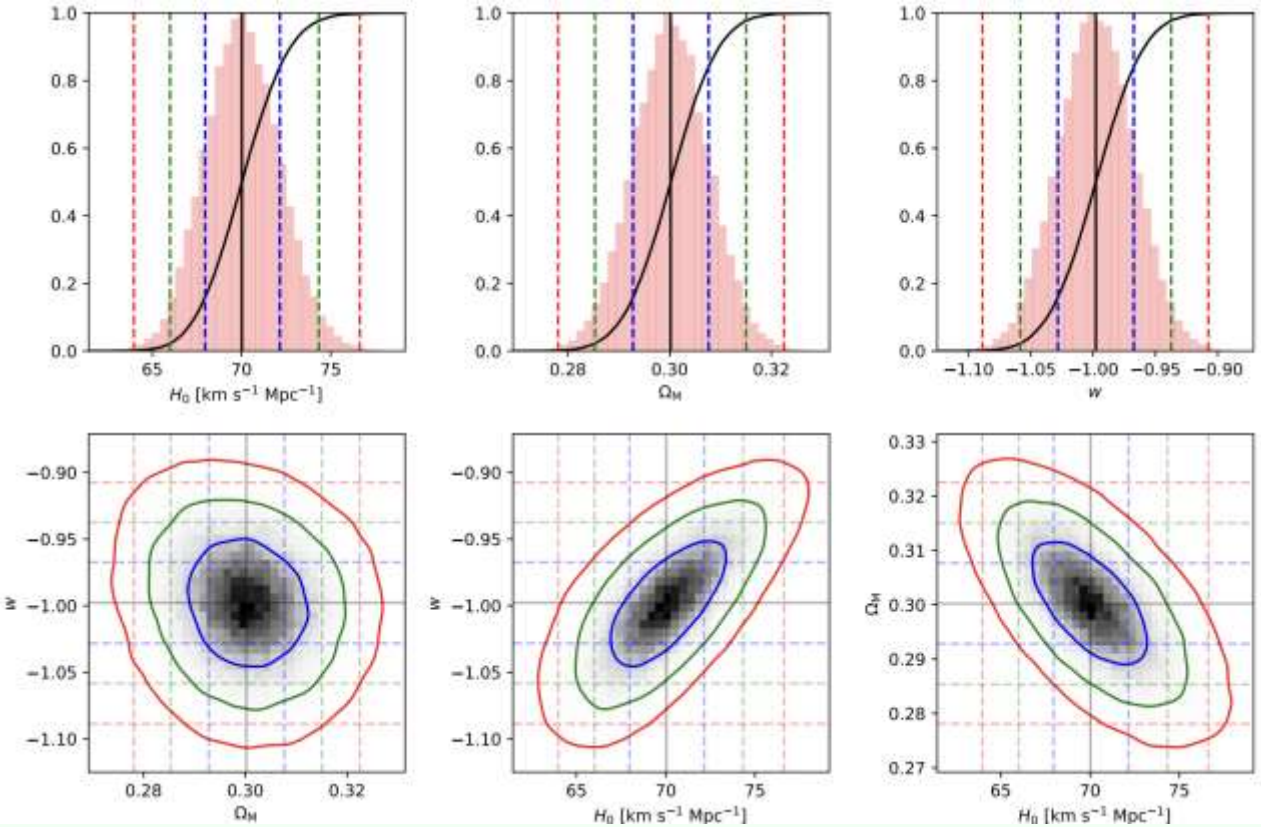


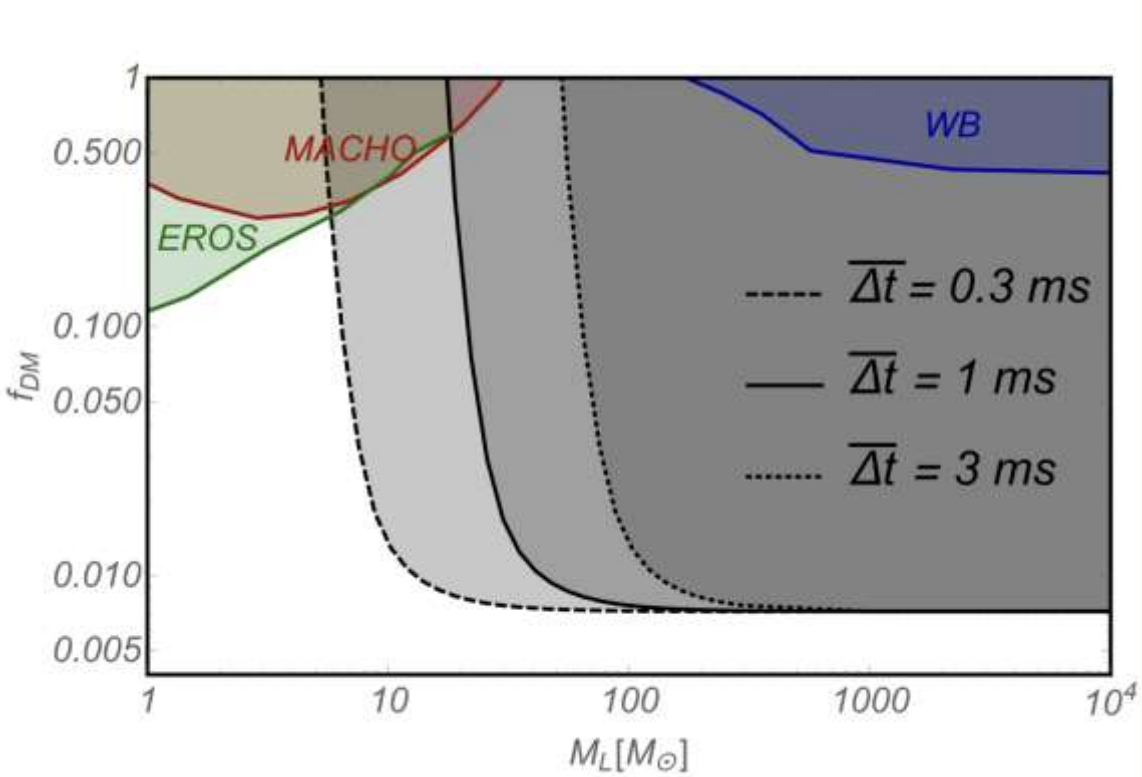
Rate simulation (T2.2) assuming 70% uptime for ARGOS core, 20% channel corruption due to RFI

*5 – 10 unique sources per day; 20 – 60 bursts

Ultra-high precision cosmology with FRBs

2-5 strongly-lensed FRBs per year; will enable high precision cosmology and dark matter searches





Wuckniz et al. (2020)

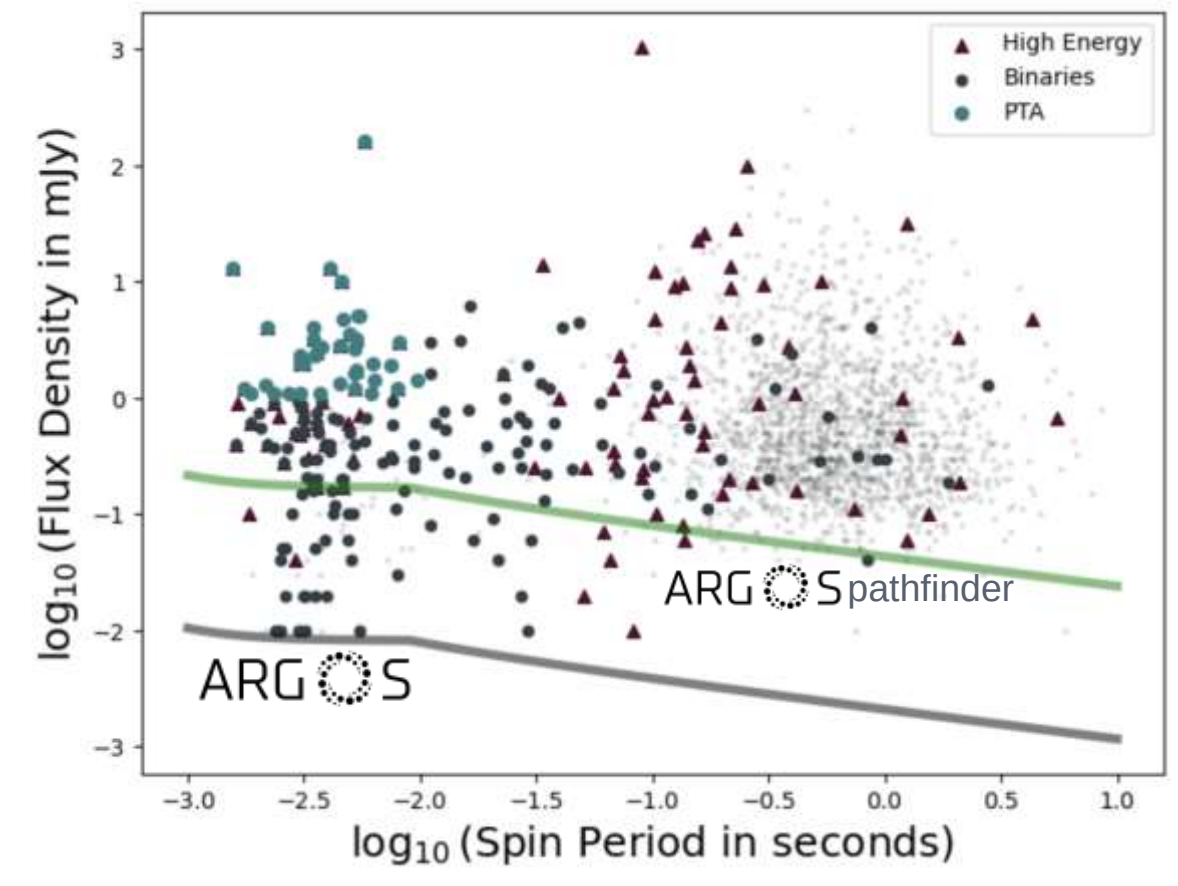
Munoz et al. (2016)

Pulsars

Key specifications

Up to 16 phased beams, 1—3 GHz, 4km baselines, SKA-MID1 level collecting area, 20kHz channels, 1μsec time resolution, coherent de-dispersion, sub-arraying, dynamic spectra, automated TOA generation

- approximately 1 pulsar per square degree on average → several 100s of pulsars per day;
- Coherent de-dispersion of known sources to maximize SNR
- Sub-banded times of arrival
- Flux, polarization information, DM, RM information



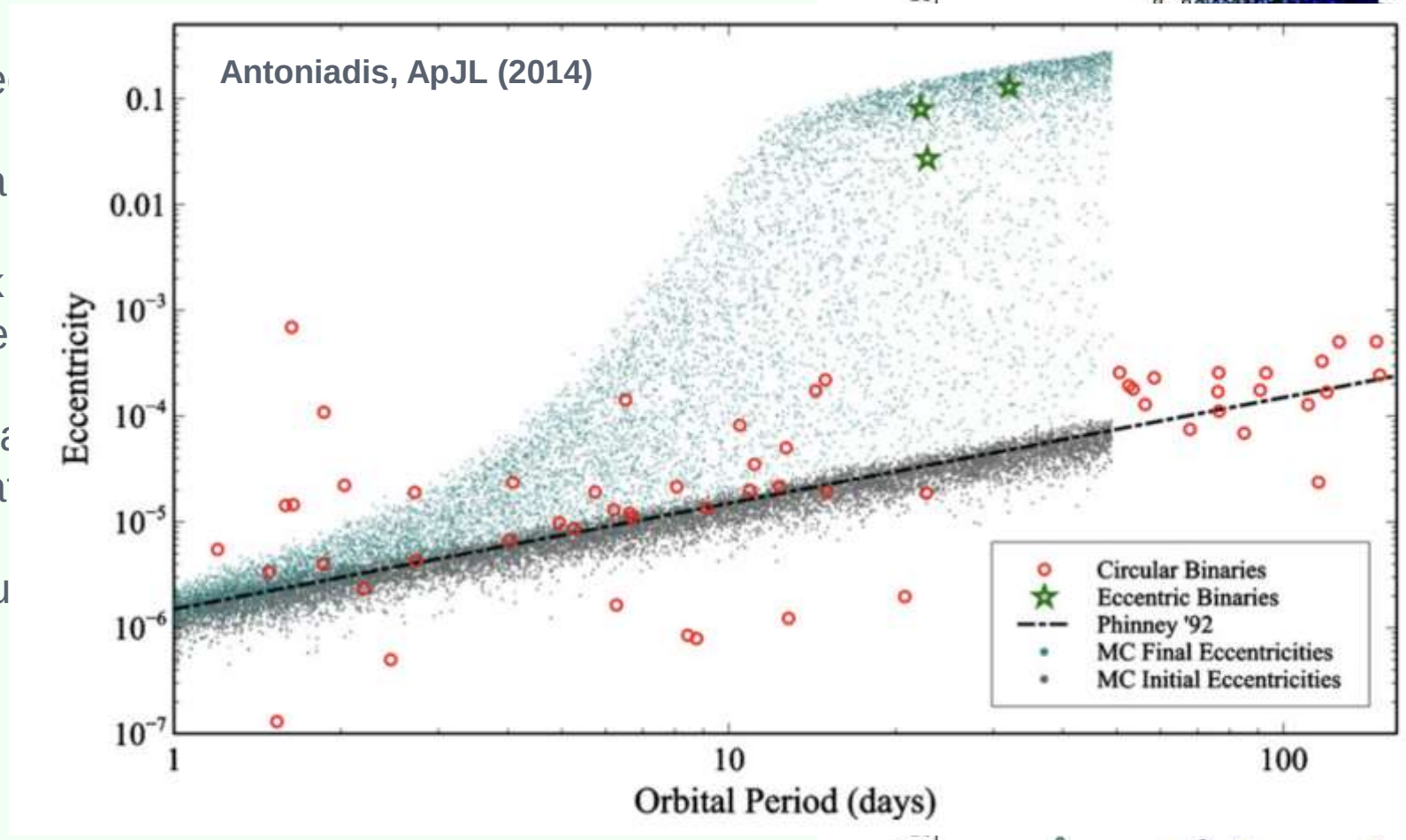
Pulsars: SKA/FAST follow-up

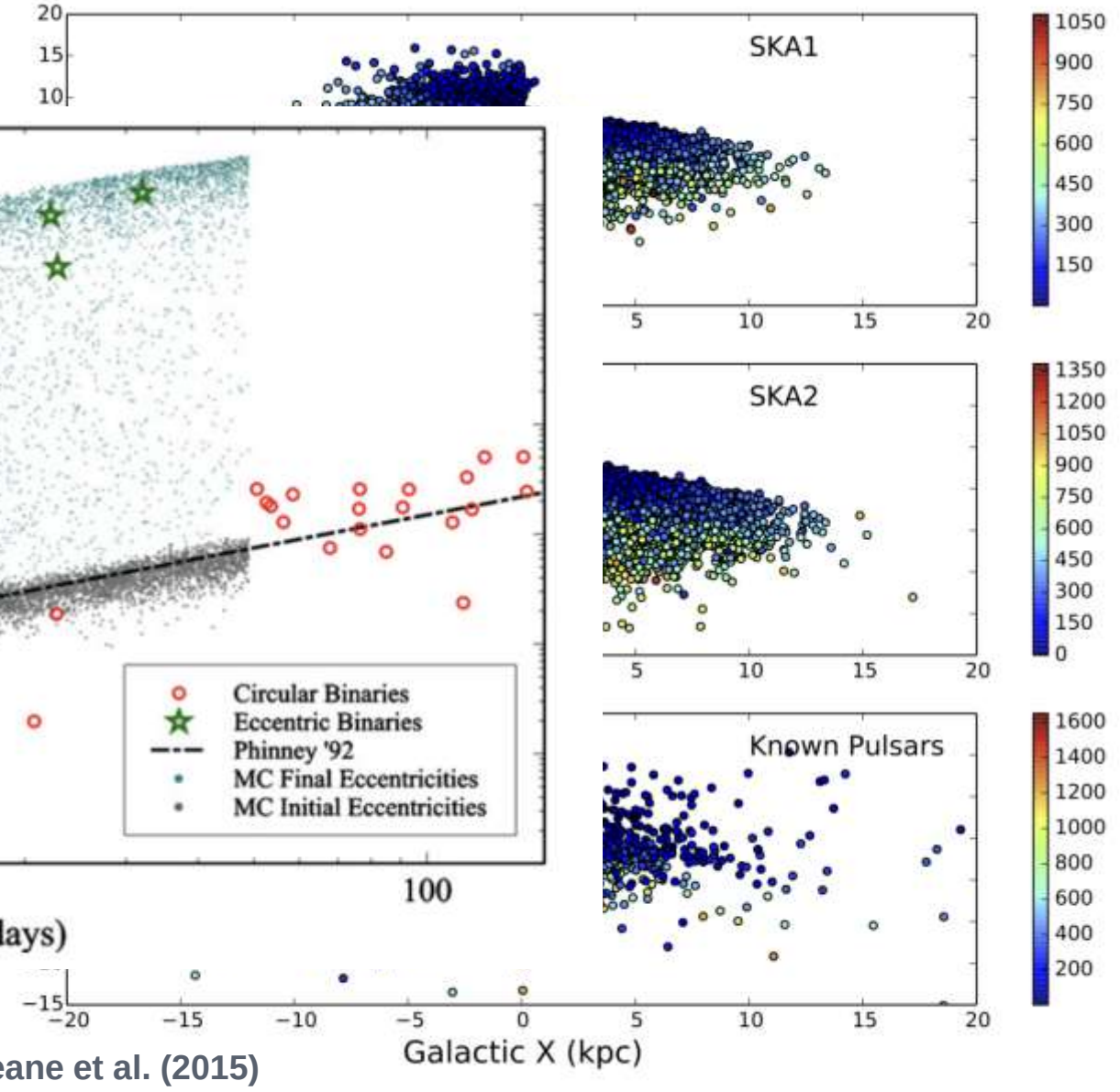
Urgent ne
seeks to
counterpa

Filterbank
discoverie

VLBI ca
determina

Robust flu
provide
statistics





Keane et al. (2015)

Pulsar timing arrays

ARGOS

EPTA

CPTA

NANOGrav
Physics Frontiers Center

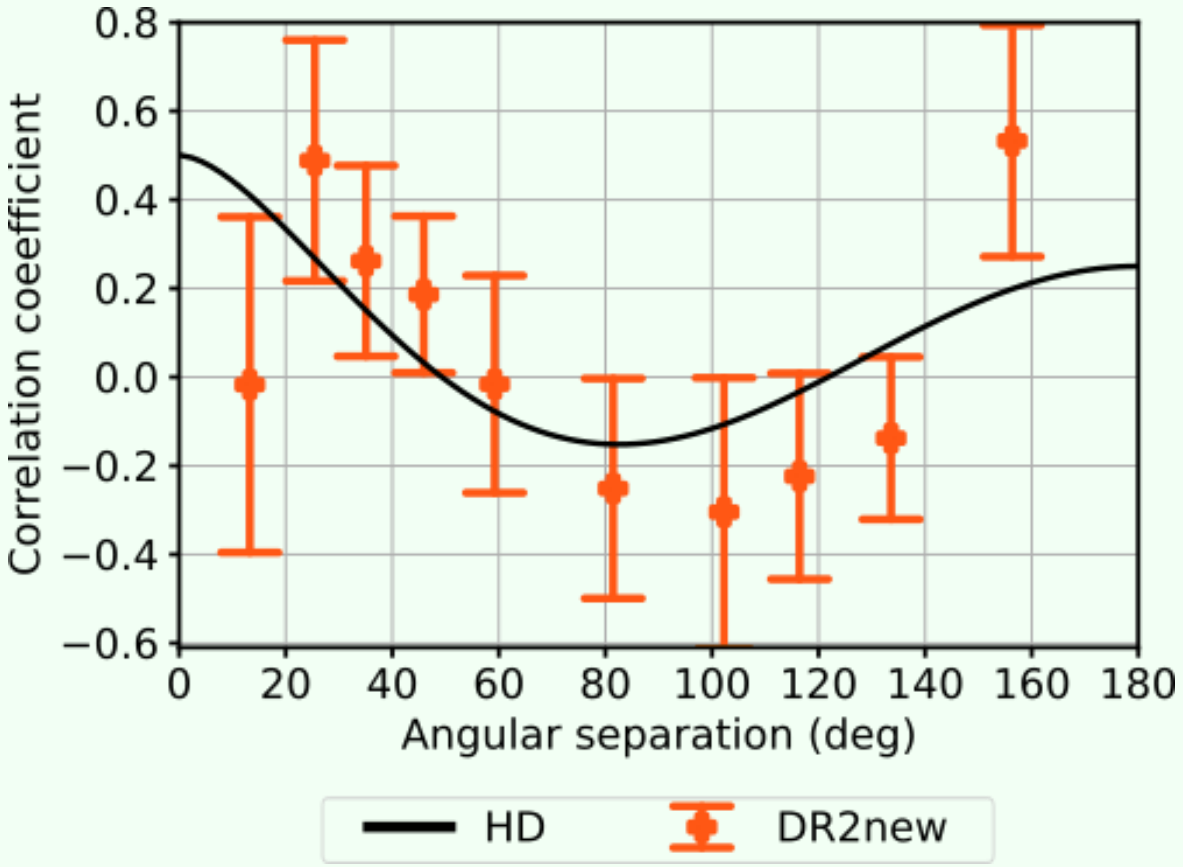
PPTA

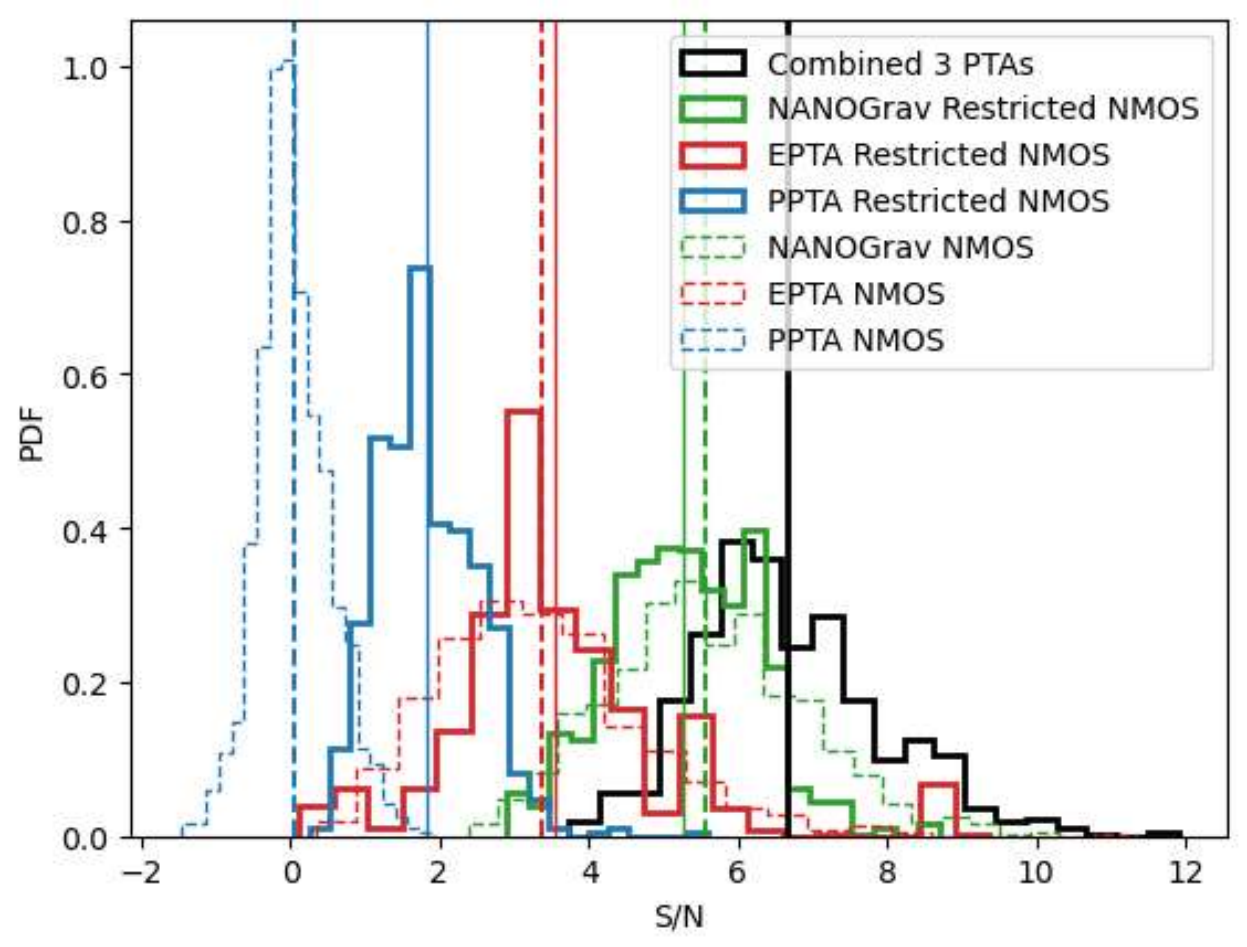
InPTA
Indian Pulsar Timing Array

INTERNATIONAL PULSAR TIMING ARRAY
IPTA

The EPTA DR2 – A new GW window

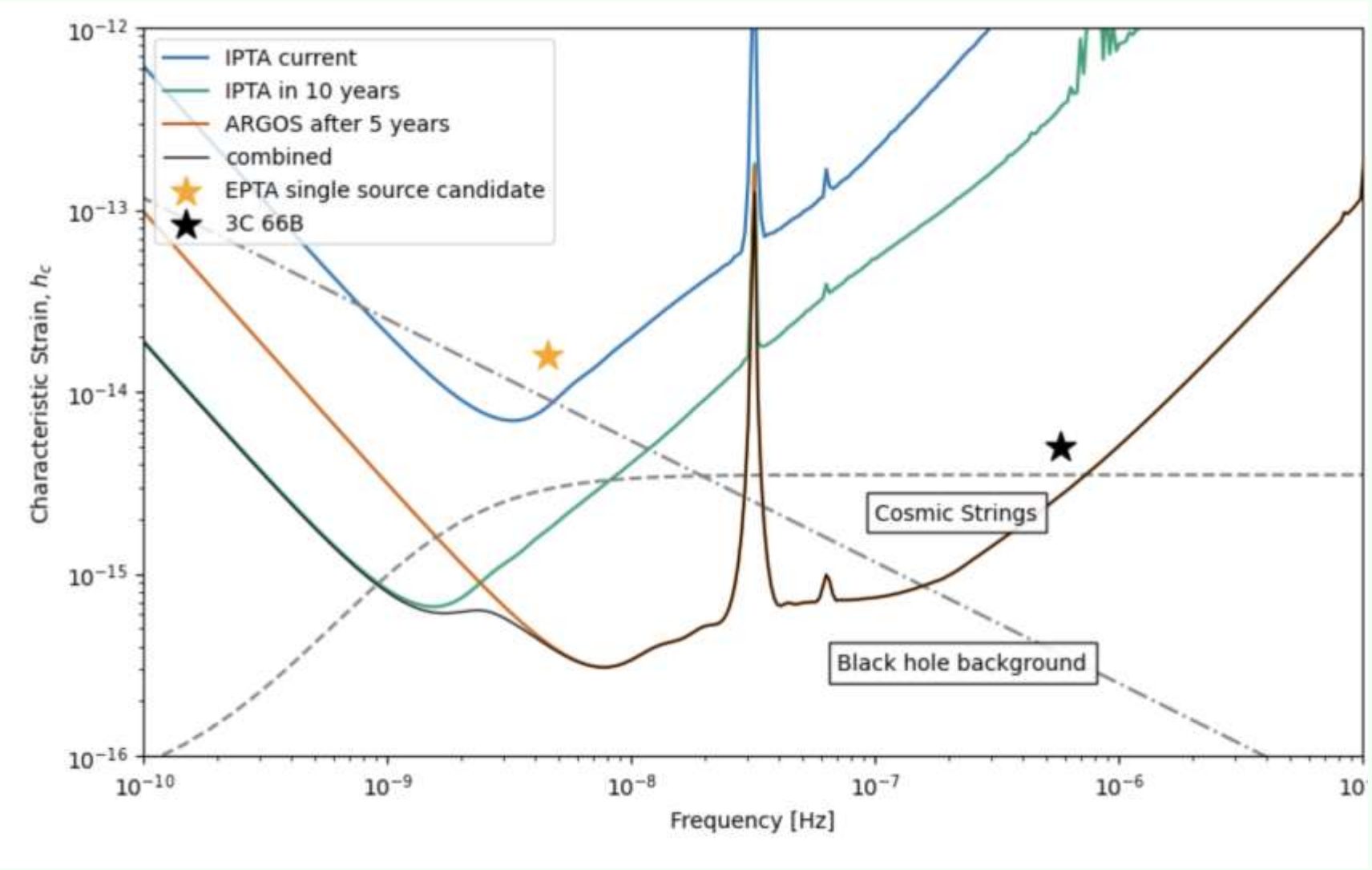
Signal consistent with a nanohertz stochastic GW background. Also detected by NANOGrav





EPTA, InPTA, IPTA (Antoniadis et al. 2023a-e, Smarra et al 2023, Agazie et al. 2024)

PTA science with ARGOS



Projected sensitivity assuming 70% uptime, 20% channel corruption due to RFI, 30 PSRs, SNR=1000

ARGOS will improve PTA sensitivity in three ways

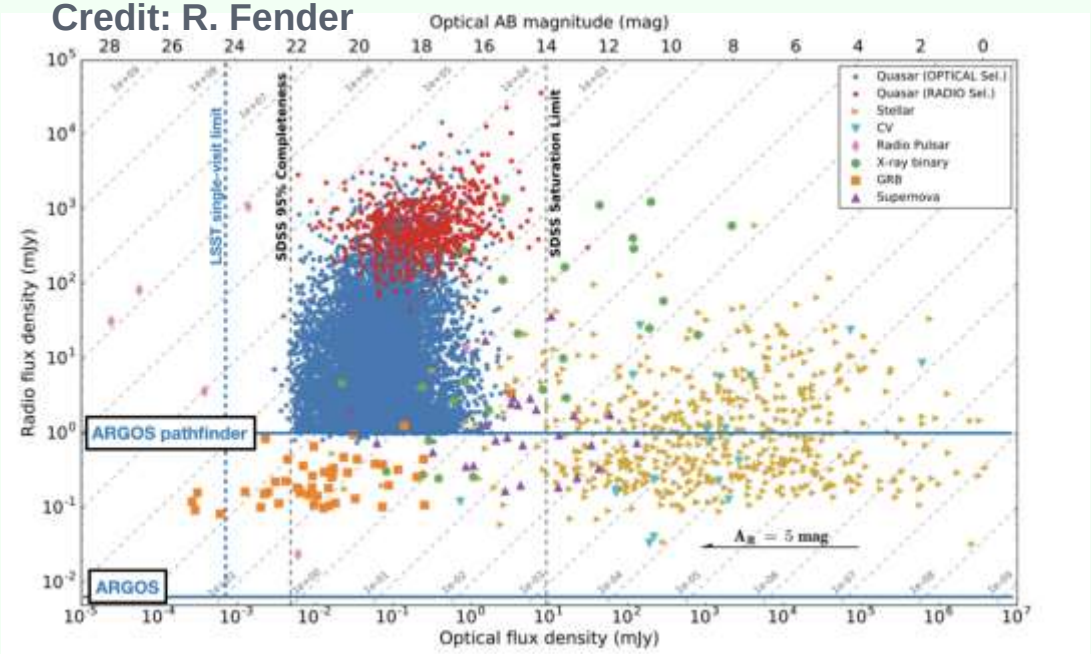
- ✓ Broadband TOAs + monitoring of profile changes and ISM will enable effective removal of timing noise
- ✓ Large number (>10^6) of high SNR TOAs
- ✓ High cadence will extend sensitivity to μHz frequencies. **This is critical as backgrounds of different origins are expected to differ most at higher frequencies.**

Also, key requirement for multi-messenger astrophysics.

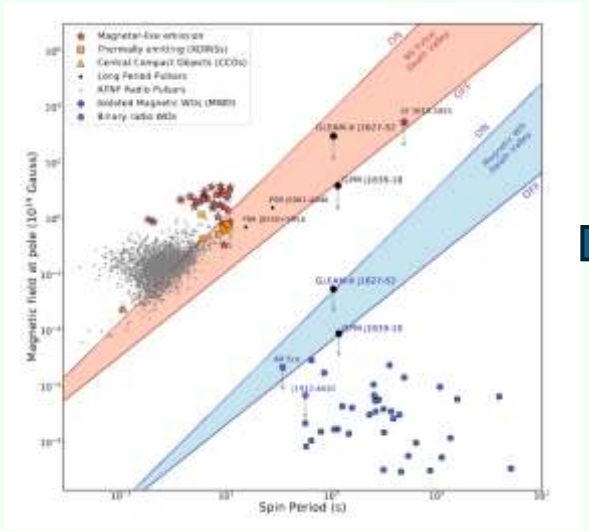
Imaging and image-plane transients

- High-cadence, full-Stokes imaging of 500 deg^2 per day
- Light curves and transient alerts
- Follow-up of multi-messenger triggers
- Full-stokes images,
  visibilities,
  source catalogues,
  classifications,
  triggers

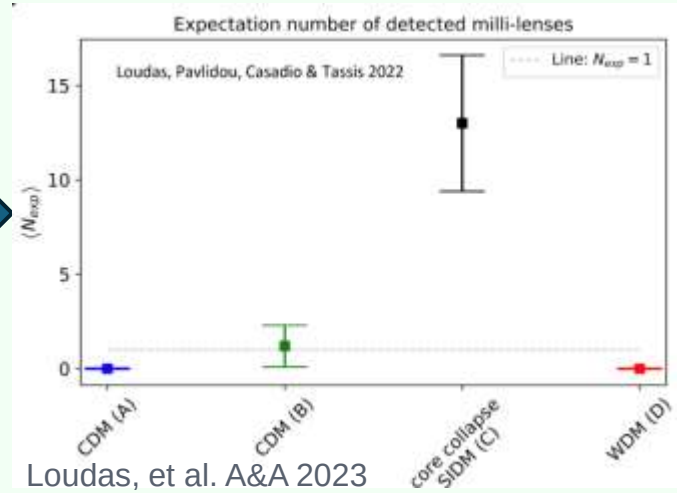
Credit: R. Fender



few seconds



few years



Rea et al. (2023) ApJL; Hurley-Walker et al., 2023, Nature (incl. Barr & Men)

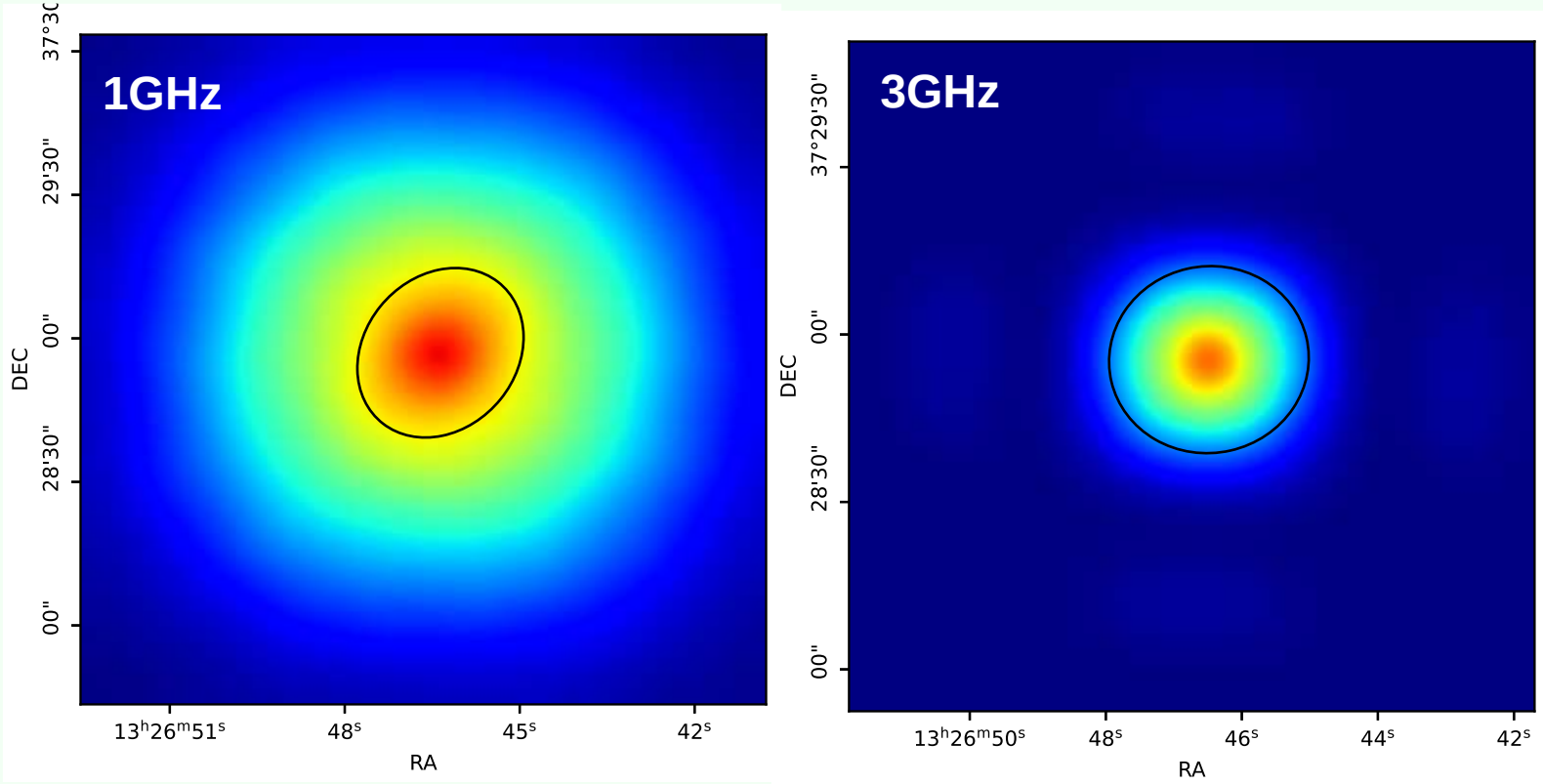
Loudas, et al. A&A 2023

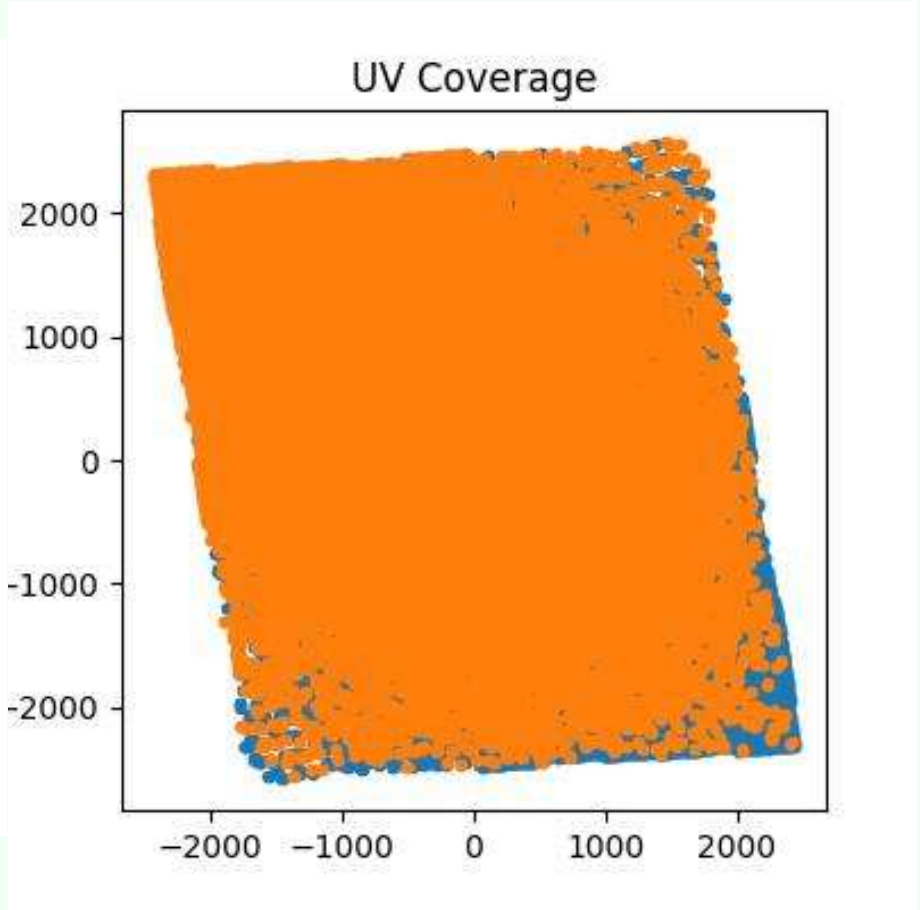
Imaging and image-plane transients

ARGOS imaging

Key specifications

Regular 32x32 grid (<530m) + gaussian random (< 4 km) configuration, AI-based flagging and classification





Snapshot (5min) UV coverage and dirty beam profiles for a dec=+40º source (T2.2)
https://github.com/wchenastro/Mosaic

The ARGOS Conceptual Design Study

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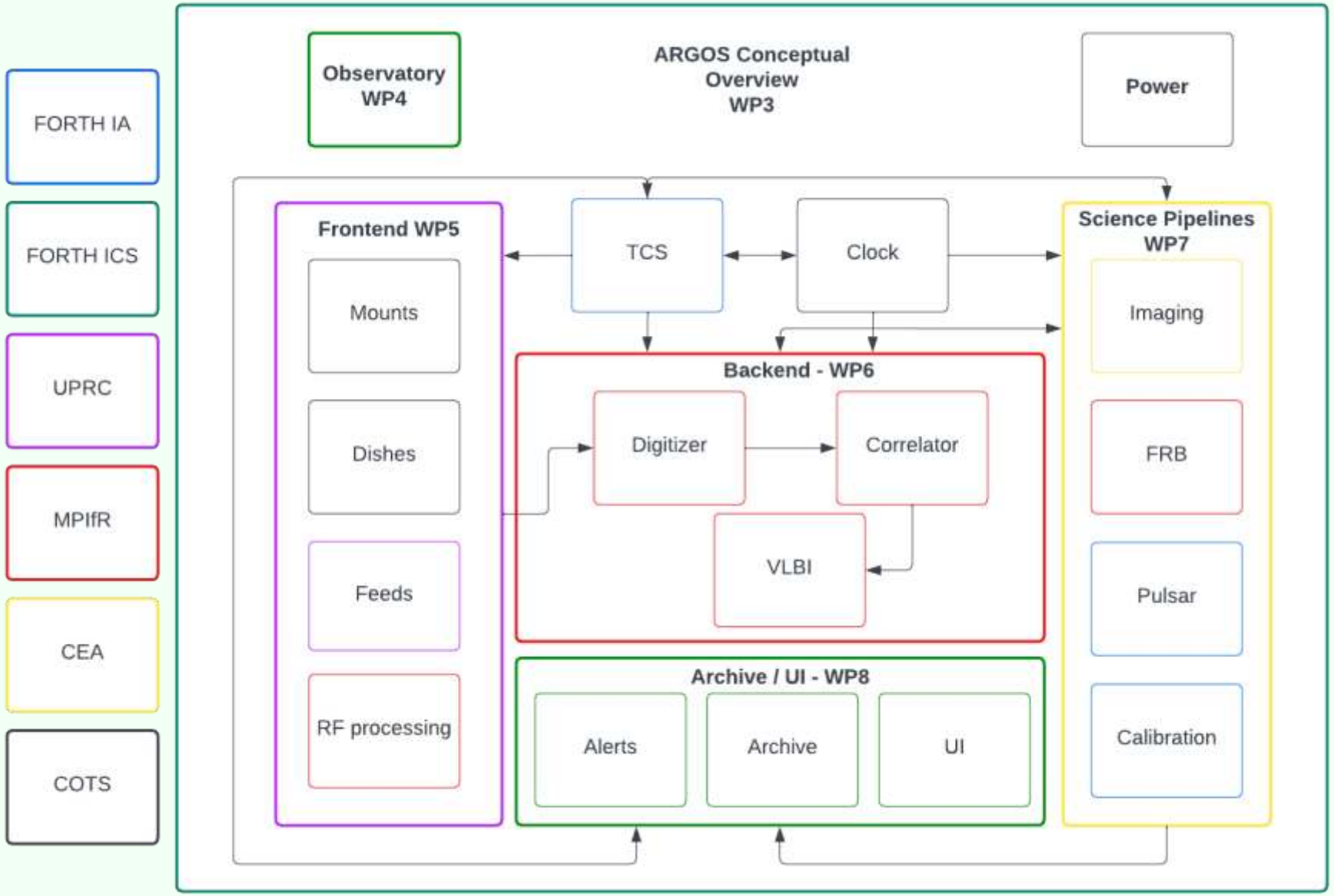
Timeline

We are here

Final Deliverables:
10-dish prototype
detailed fully-costed design

Structure


FORTH IA
FORTH ICS
UPRC
MPIfR
CEA
COTS
Observatory WP4
ARGOS Conceptual Overview WP3
Power
Frontend WP5
Mounts
Dishes
Feeds
RF processing
TCS
Clock
Backend - WP6
Digitizer
Correlator
VLBI
Archive / UI - WP8
Alerts
Archive
UI
Science Pipelines WP7
Imaging
FRB
Pulsar
Calibration

Frontend and Digital Feed

ANTESKY

FOAM ELECTRONICS

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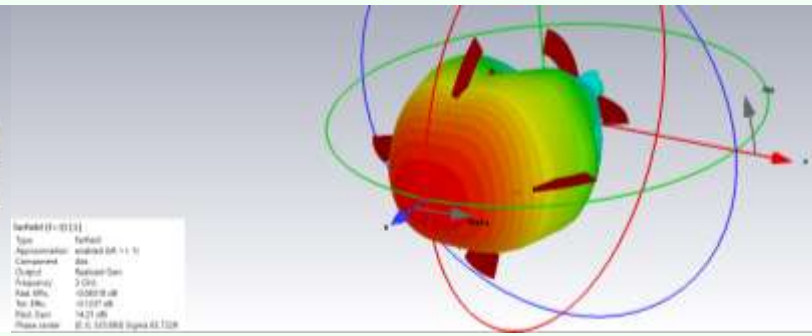
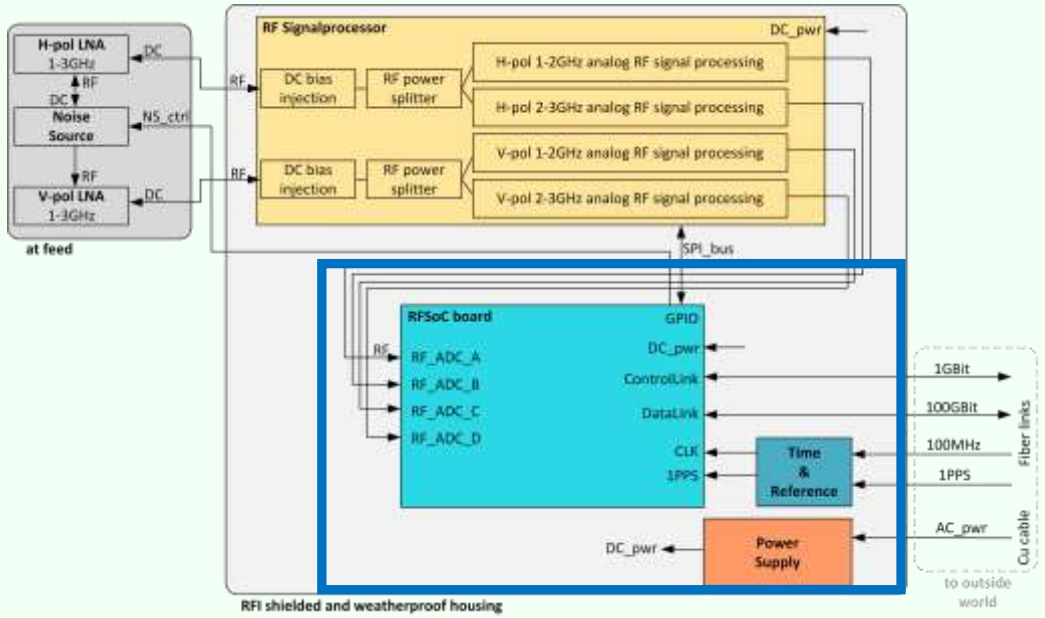




Low-cost mass fabrication of the feed system

GOLDEN DEVICES
Imagine. Create. Progress.

UNIVERSITY OF PIRAEUS RESEARCH CENTER

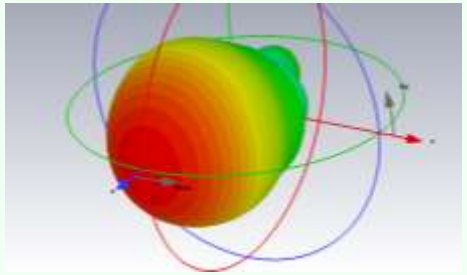
SLS (Selective Laser Sintering) **3D-printing** →

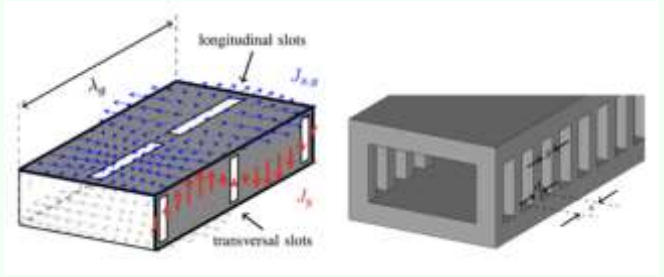
- (a) lightweight structure (3kg)
- (b) reduced production time
- (c) low fabrication cost
- (d) durability

Key Innovations

- Monolithic structures with non-radiating slots
- Nickel coating, 7-50μ
- Plastic coating and front cover (EM transparent; FDM – ASA ($\varepsilon r = 2.8$, $\tan\delta = 7 \times 10^{-3}$)

Current status: Factory acceptance tests for the first prototype

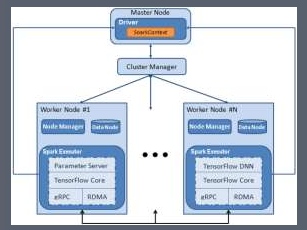




Backend / Correlator

Tensor-core beamforming and correlation (80 dual-L40 nodes for 1200 antennas)

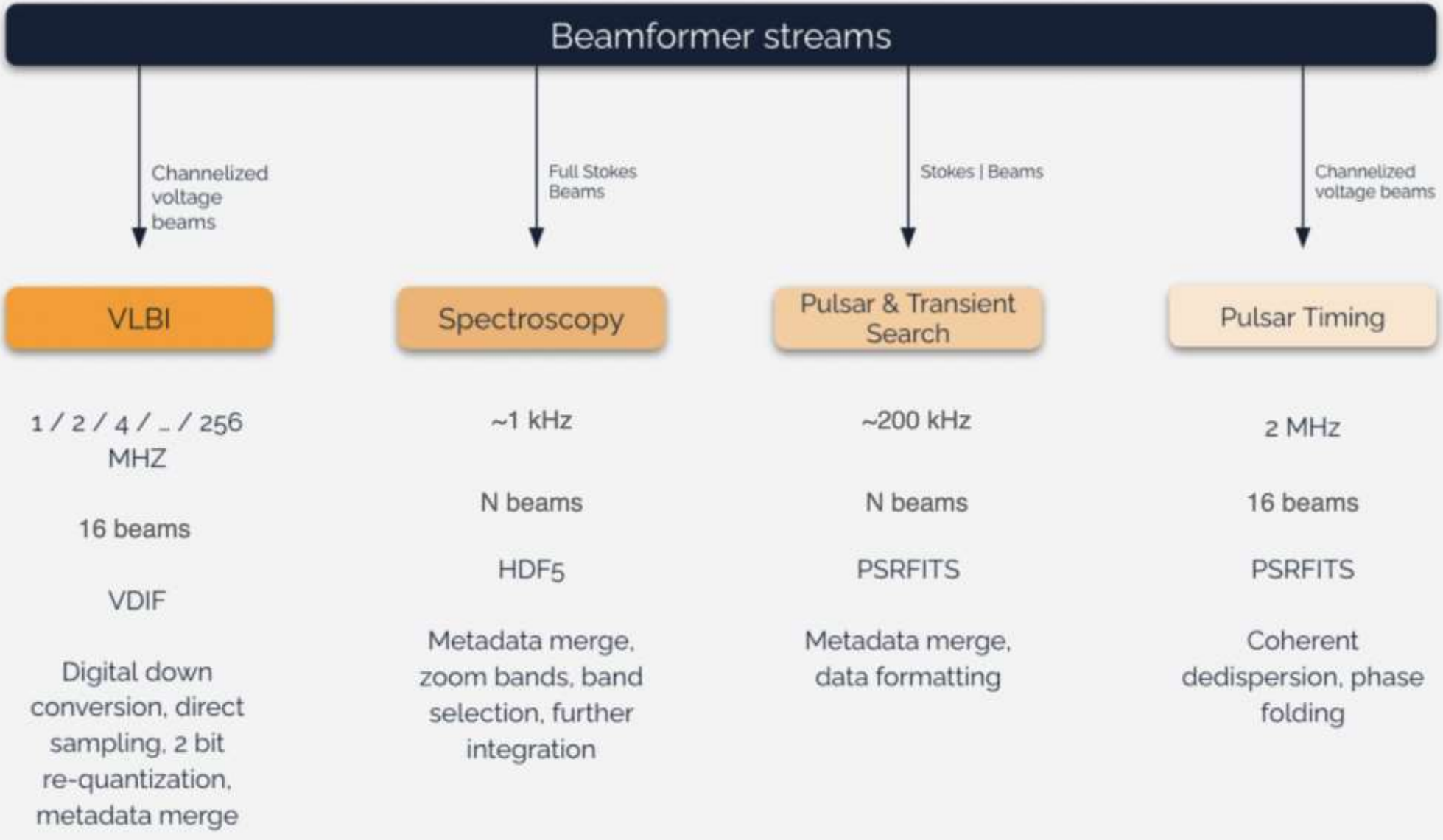
Science-ready products, classifications and alerts



Unified hyper-converged virtualised compute architecture for the correlator and the science nodes

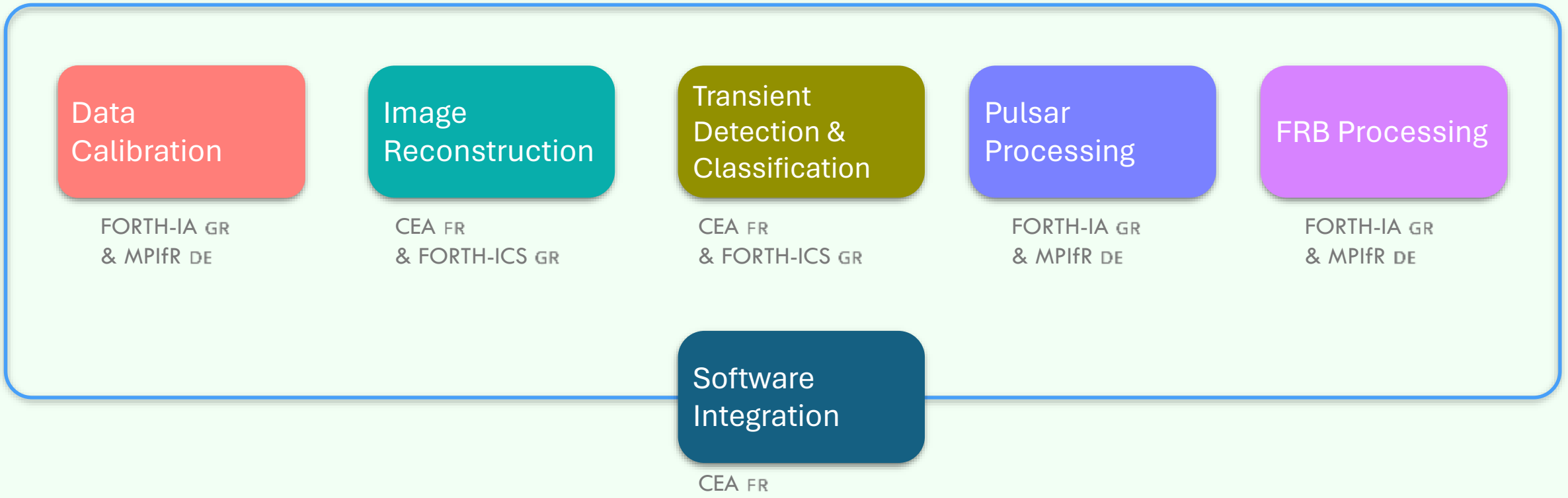
ARGOS

Backend / Correlator



Science Pipelines

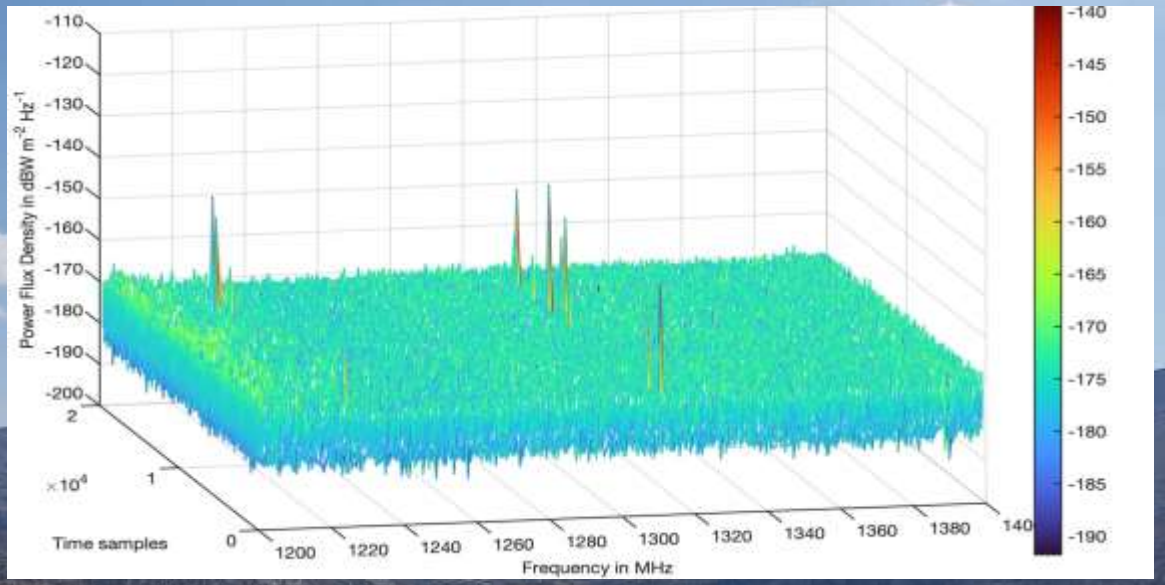
Current Development effort

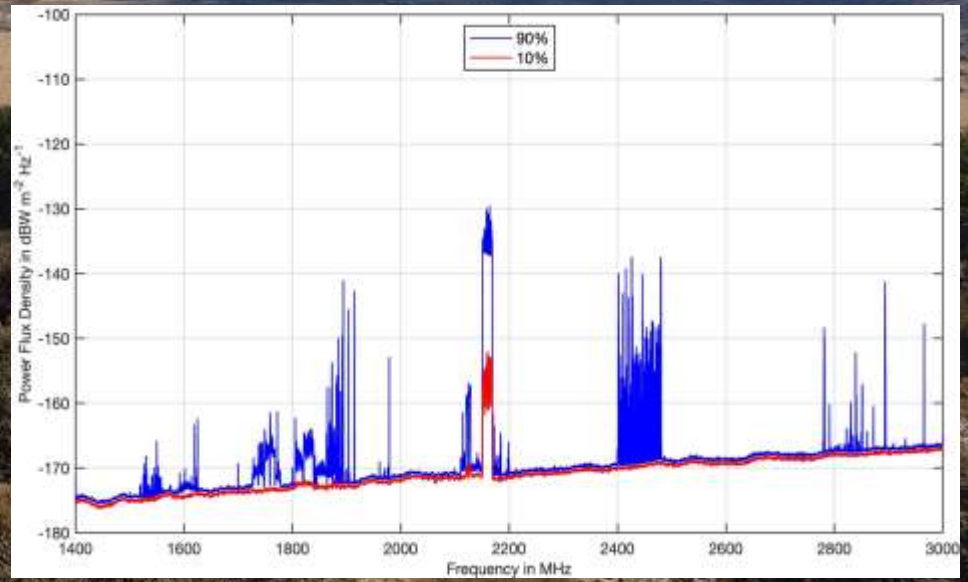


Candidate Sites (mostly in/around Crete)

Candidate Sites (mostly in/around Crete)

Nida Plateau





Join us!

Several ways; start here http://argos.ia.forth.gr/ and follow the links

- Sign up for the newsletter
- Participate in the Science Working Group (john@ia.forth.gr)
- workshops (TBD, Q2 2025 in Crete)
- ***White Paper (2024)***
- Apply for jobs

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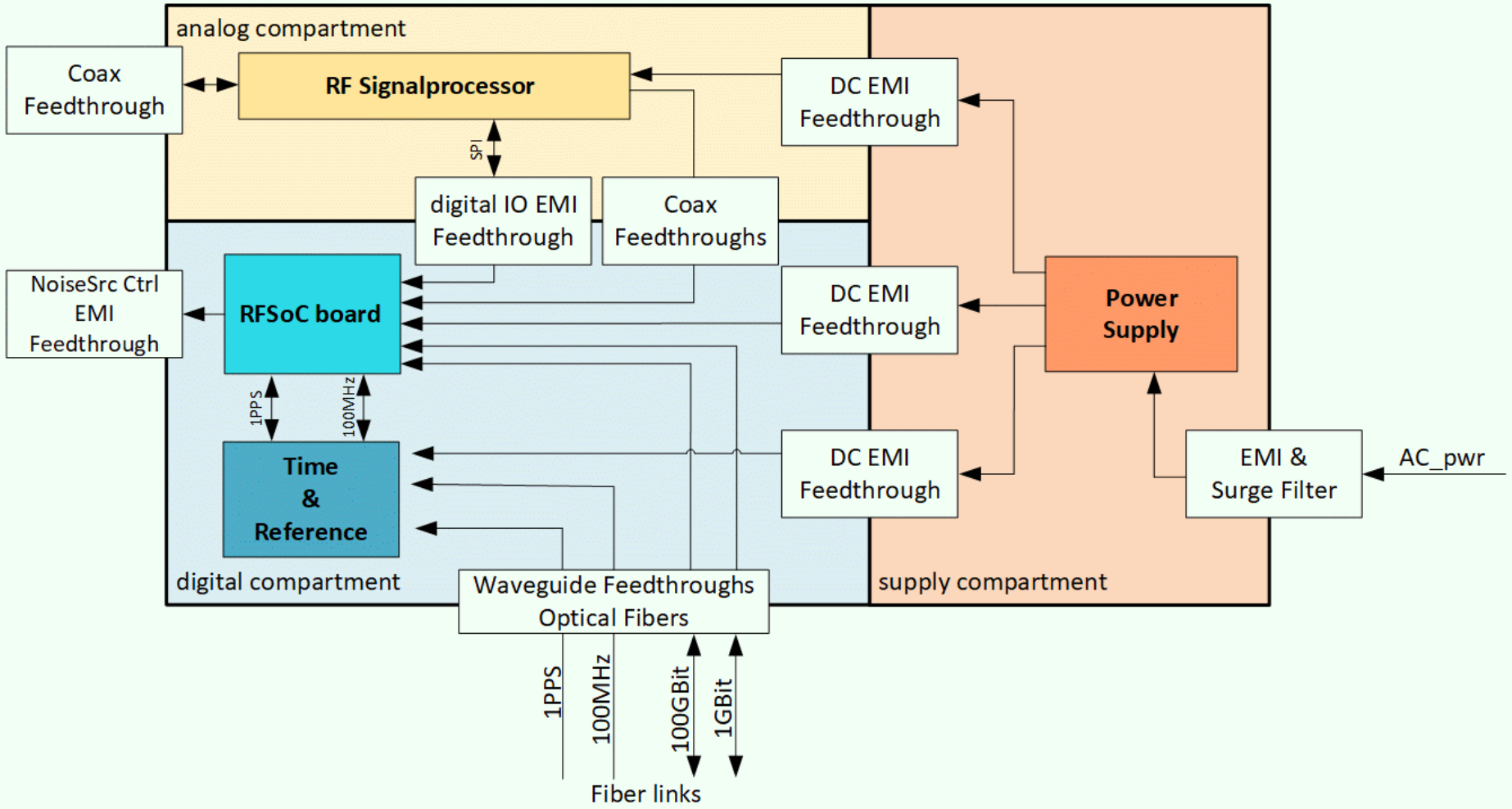
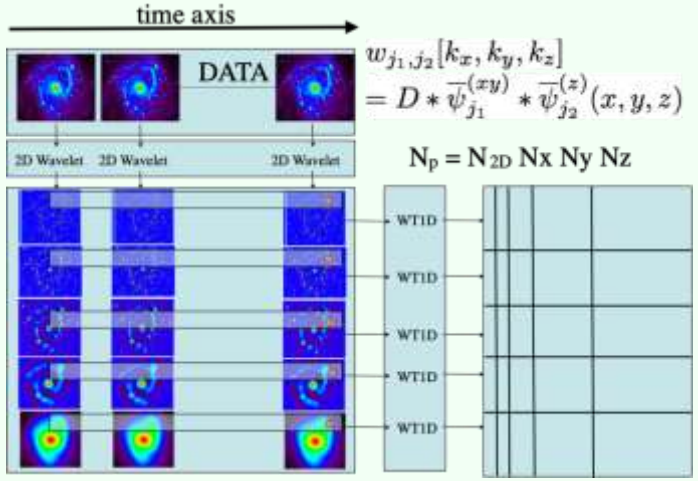
Frontend and Digital Feed

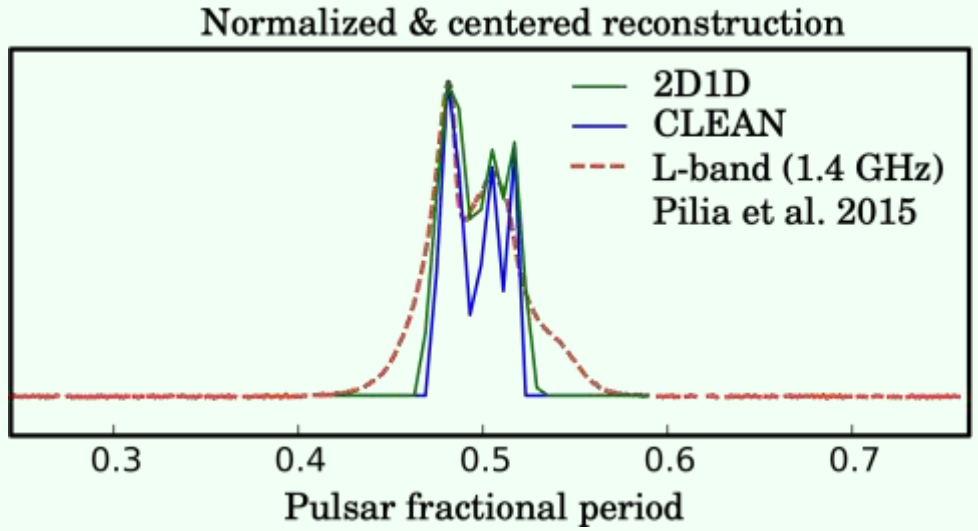


WP7 Signal Processing

Wavelets

- 2D and 3D image reconstruction software developed
- Outperforms community standard techniques such as CLEAN
- Needs to be benchmarked on ARGOS simulations

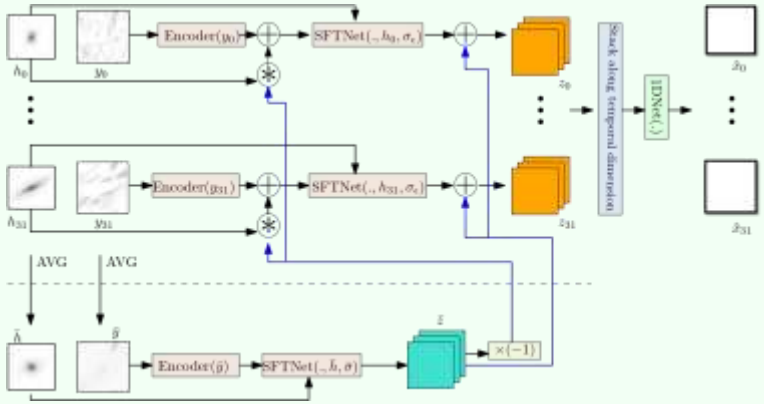


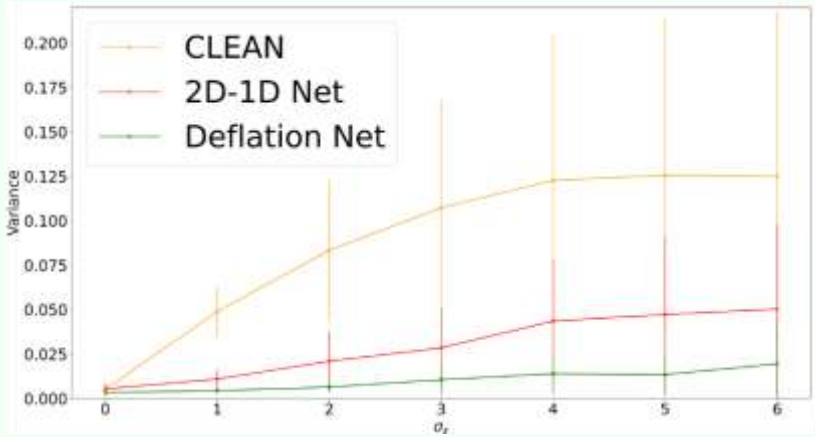


arXiv 2306.13909

Neural Networks

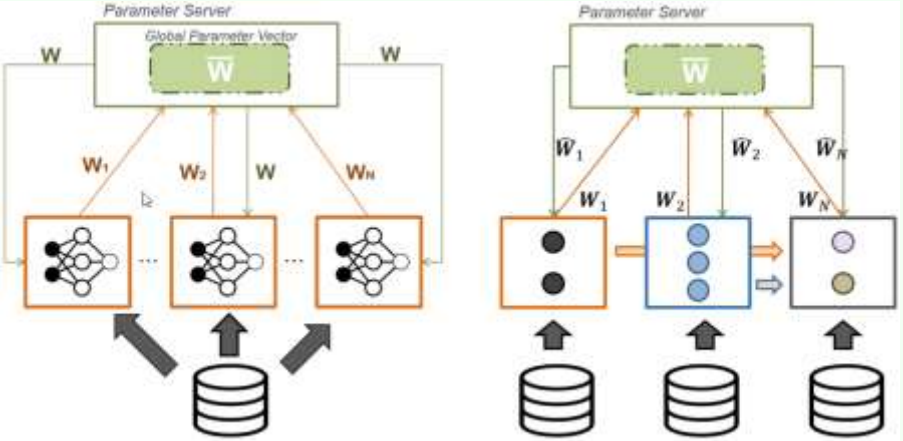
- 3D (2D + 1D) neural network implementations developed
- Outperforms community standard techniques such as CLEAN
- Paper published by Chiche et al. (2023)





WP8: Archive, Alerts, UI

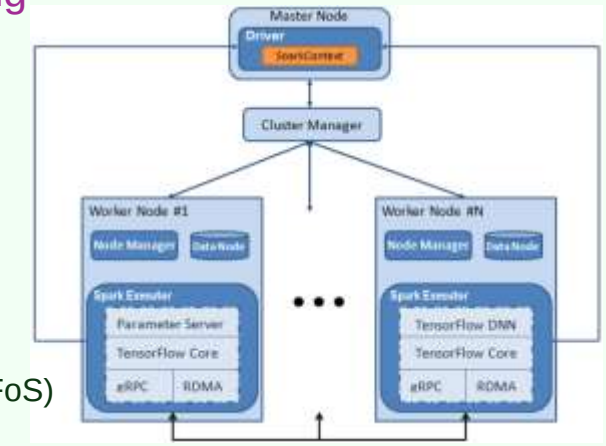
GPU-based architectures for accelerated DL execution & optimal management of cluster resources



Data parallelization

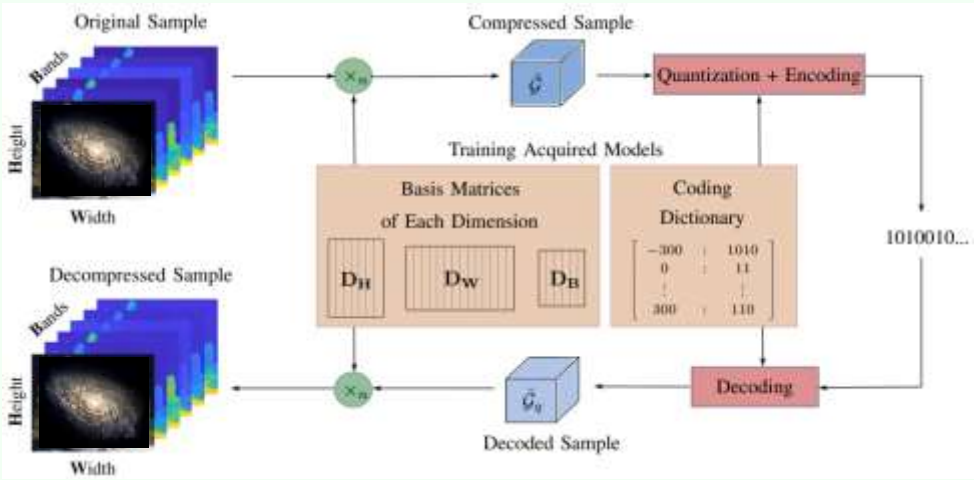
Model parallelization

Services @ Apache Spark for large-scale data storage & distributed processing



TensorFlowOnSpark (TFoS)

Tensor decomposition learning for compression & recovery of high-dimensional signals



WP9: Dissemination, exploitation, communication

Dissemination in numbers

- 12 peer-reviewed papers in 2023
- 15 invited talks and colloquia
- 3 press releases
- 2 MSc theses
- 3 (+1) PhD students
- 4 BSc student theses (in prep.)

ΔΙΑΣΤΗΜΑ

ΑΡΓΟΣ: Εξασφαλίστηκαν τα πρώτα κονδύλια για νέο ραδιοτηλεσκόπιο στον Ψηλορείτη

Στην πιλοτική φάση θα εγκατασταθούν στο Αστεροσκοπείο του Σκίνακα 16 παραβολικές κεραίες.

BBC NEWS

Home | Israel-Gaza war | War in Ukraine | Climate | Video | World | UK | Business | Tech | Science

Science

Scientists pick up shock waves from colliding galaxies

Έξι διαφορετικά τηλεσκόπια στην Ευρώπη επιβεβαιώνουν: Τα βαρυτικά κύματα υπάρχουν

Νέα επιστημονικά δεδομένα στον δρόμο προς την εξερεύνηση της δημιουργίας του Σύμπαντος, με τη συμμετοχή του Ινστιτούτου Αστροφυσικής του ΙΤΕ

29 ΑΥΓΟΥΣΤΟΥ 2022 / 13:38

Ραδιοτηλεσκόπιο "ΑΡΓΟΣ": Το ΙΤΕ ανοίγει ένα νέο παράθυρο στο Σύμπαν

Ευρωπαϊκής σύμπραξης ηγείται το Ινστιτούτο Αστροφυσικής του ΙΤΕ - Σημαντική ευρωπαϊκή χρηματοδότηση 3 εκ. ευρώ

nature

Monster gravitational waves spotted for first time