Gamma-ray Pulsar Timing Array
GPTA

γPTA

Fermi
Gamma-ray Space Telescope

ipta 2026
Student Week

Serena Valtolina

About me…

- EPTA and GPTA member
- Defended my PhD at AEI Hannover (Germany) last September
- Now a postdoc at MPIfR (Bonn, Germany) + Astron

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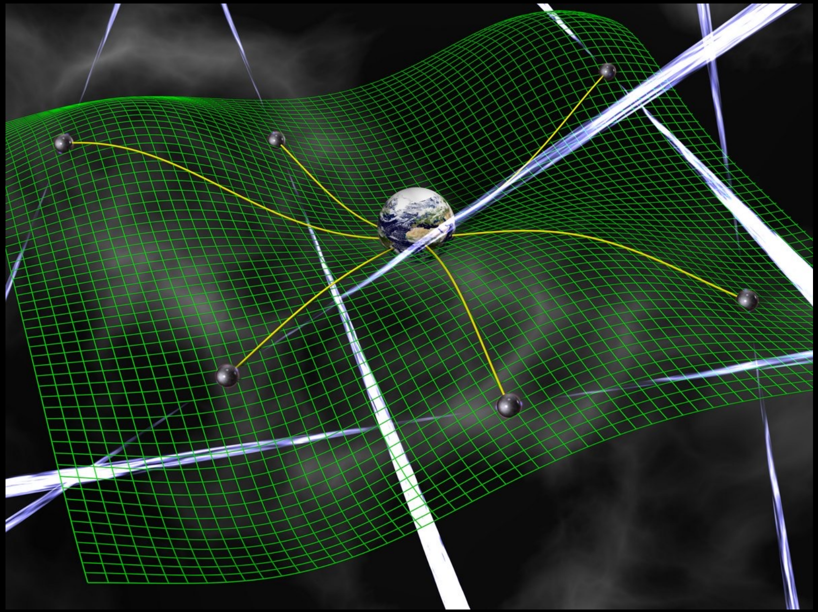
GIGA
Advancing Gravitational Wave Astrophysics

MAX-PLANCK-INSTITUT
FÜR RADIOASTRONOMIE

ASTRON

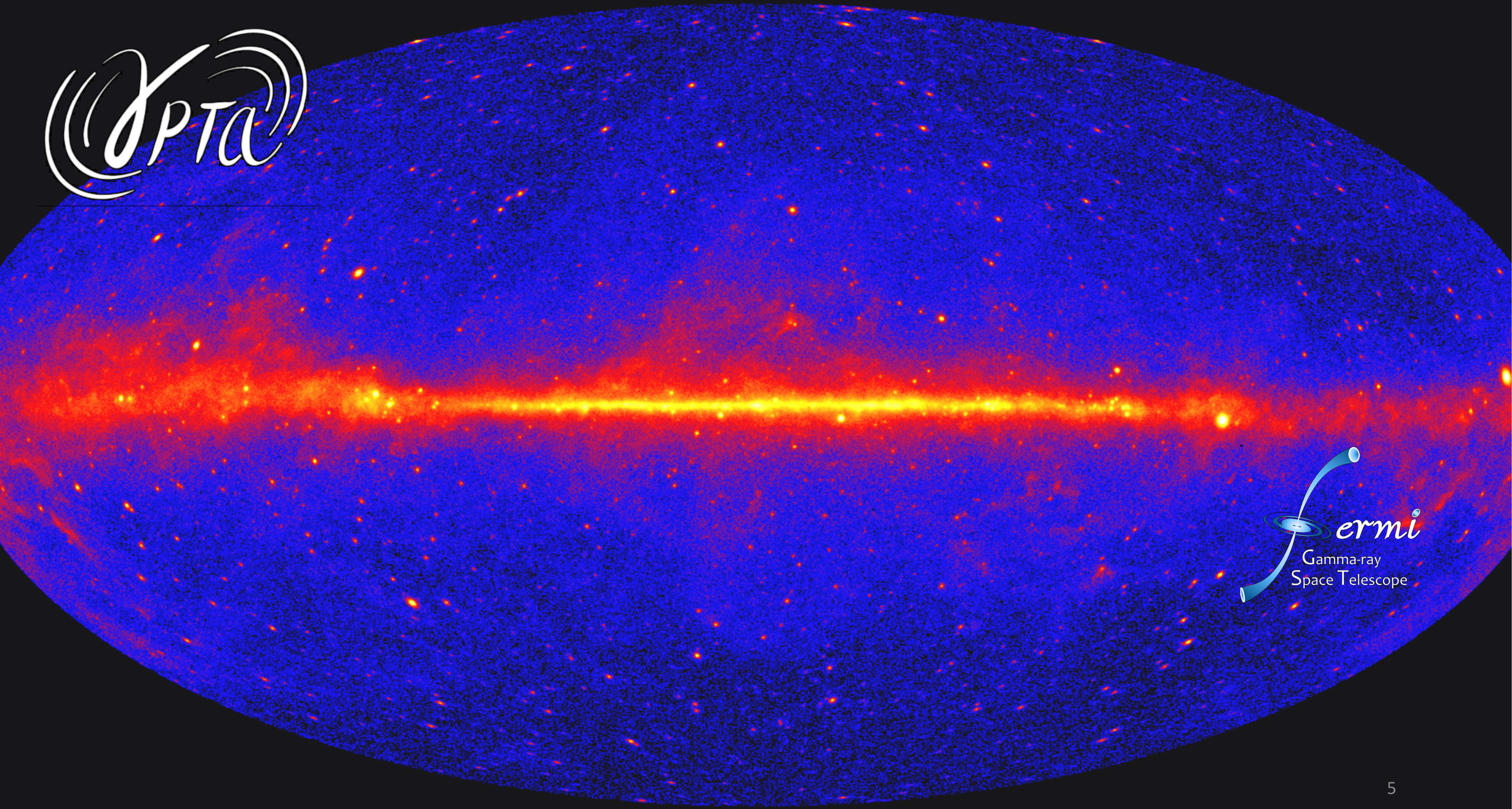
EPTA

Radio PTAs



[Figure credit: David Champion]

[Figure credit: Thankful Cromartie]


Fermi
Gamma-ray
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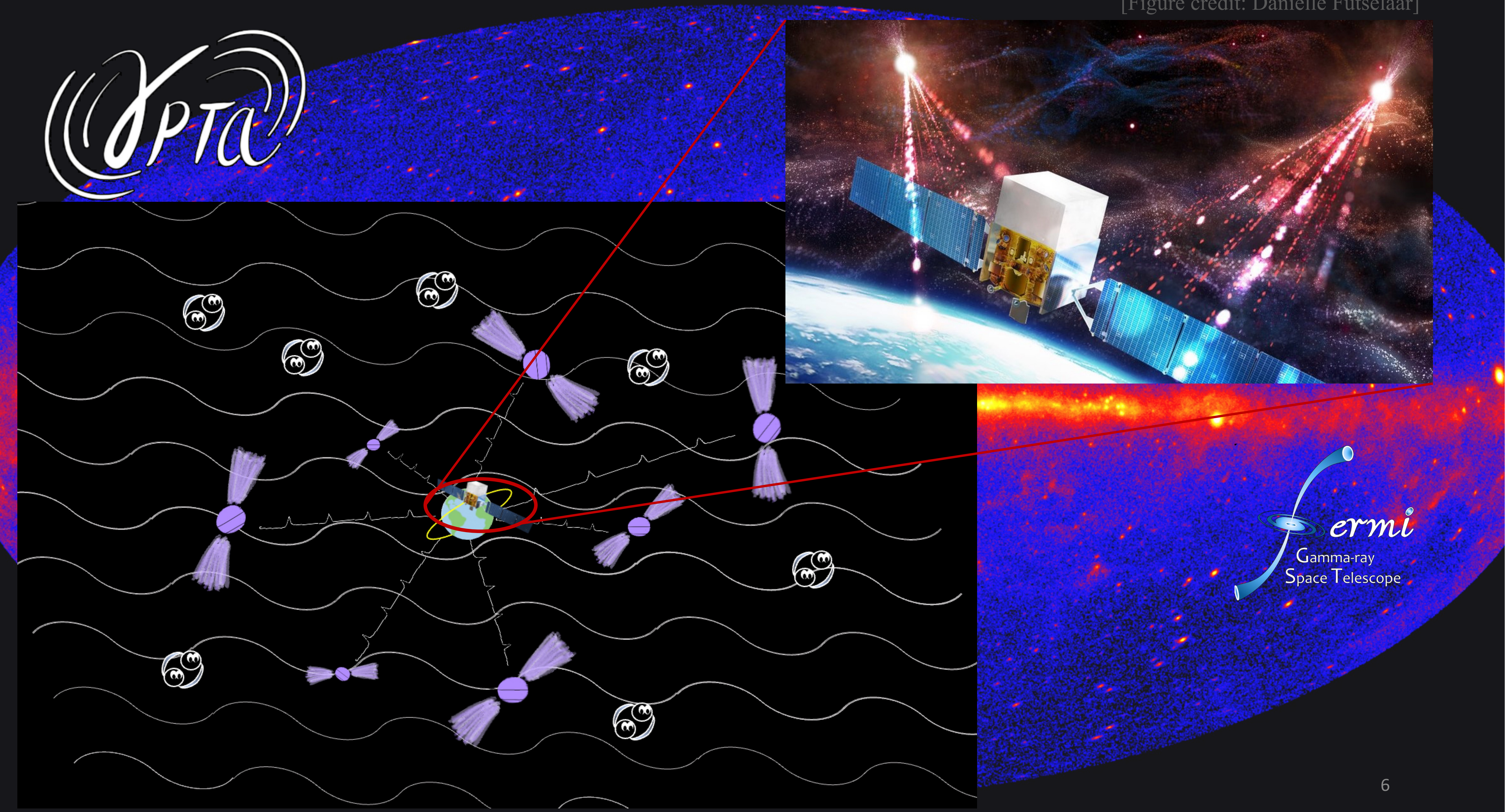
[Figure credit: Danielle Futselaar]
γPTA
Fermi
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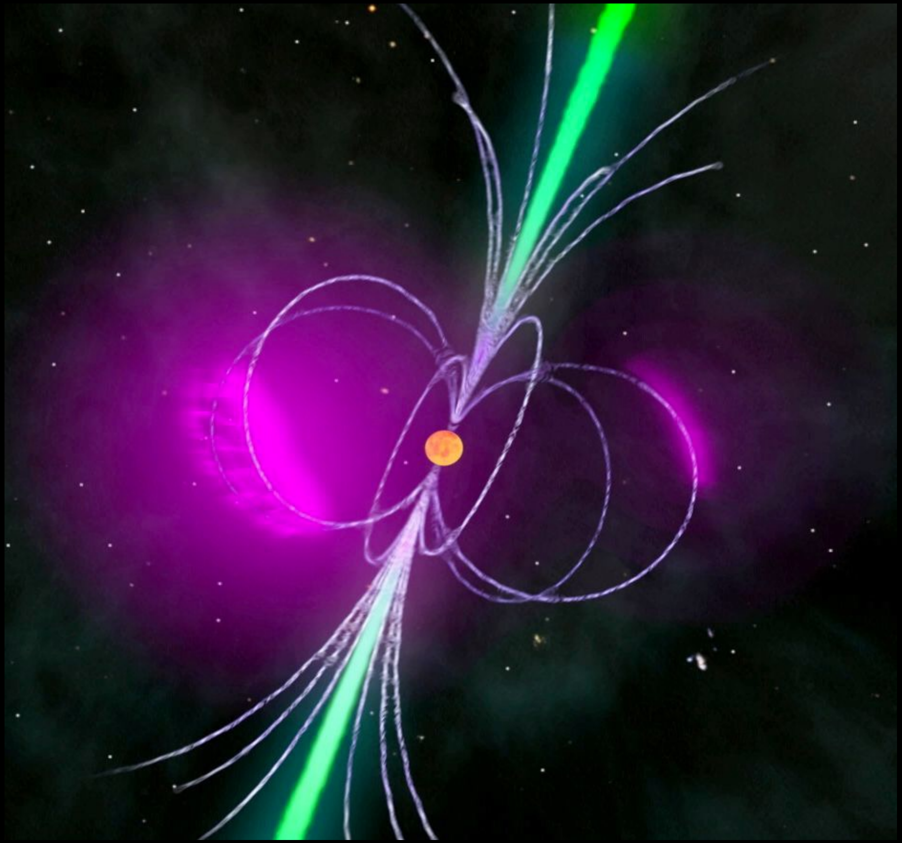
Space Telescope

Pulsar emission

Gamma-ray emission

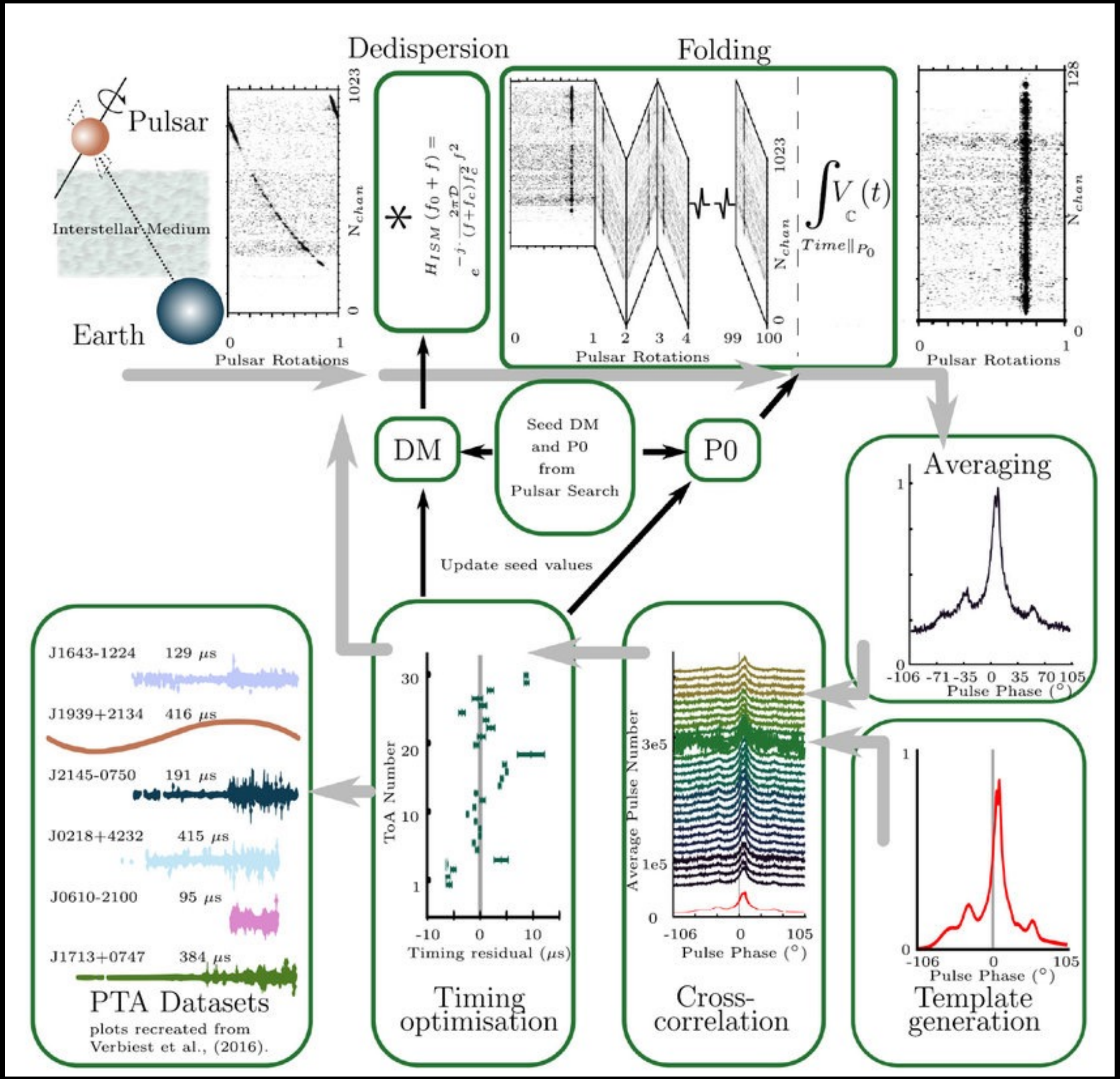
Formed high in the magnetosphere, likely through curvature radiation from relativistic charged particles



Radio emission

Generated closer to the stellar surface, in the polar cap region from dense pair plasma

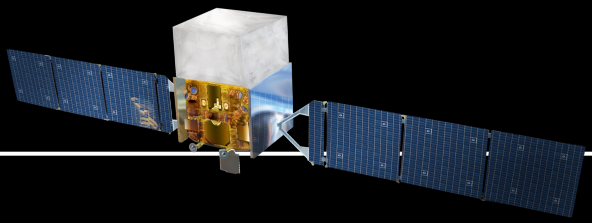
Radio PTAs



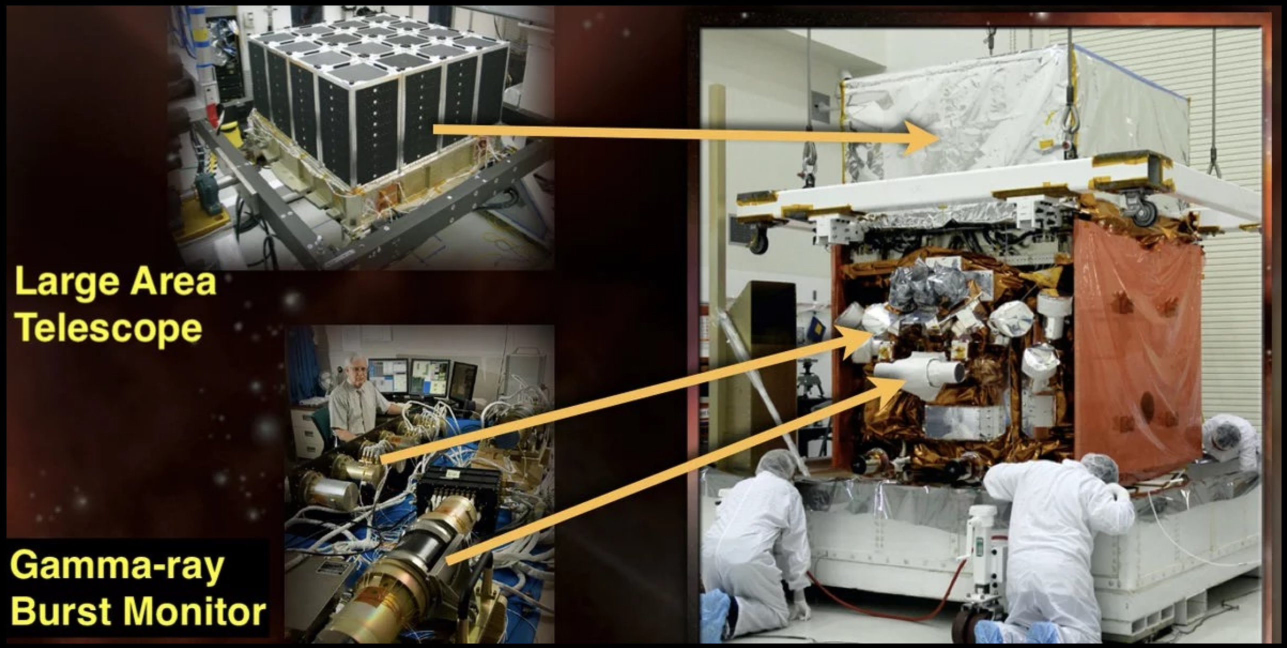
[Figure credit: Golam Shaifullah and Joris Verbiest]

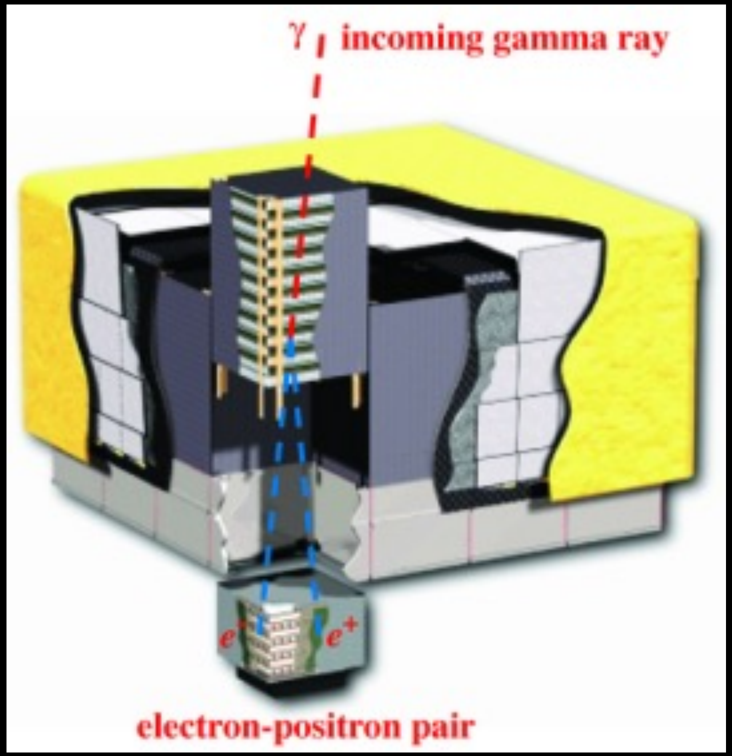
Data Products:
TOAs and timing residuals

Gaussian statistic

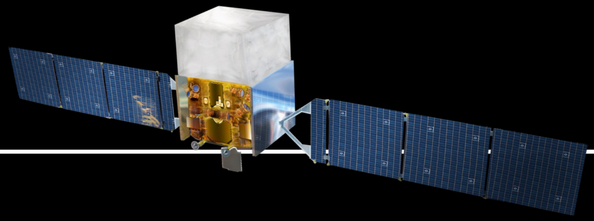


Gamma-ray PTA





[Figure credit: Fermi LAT collaboration]



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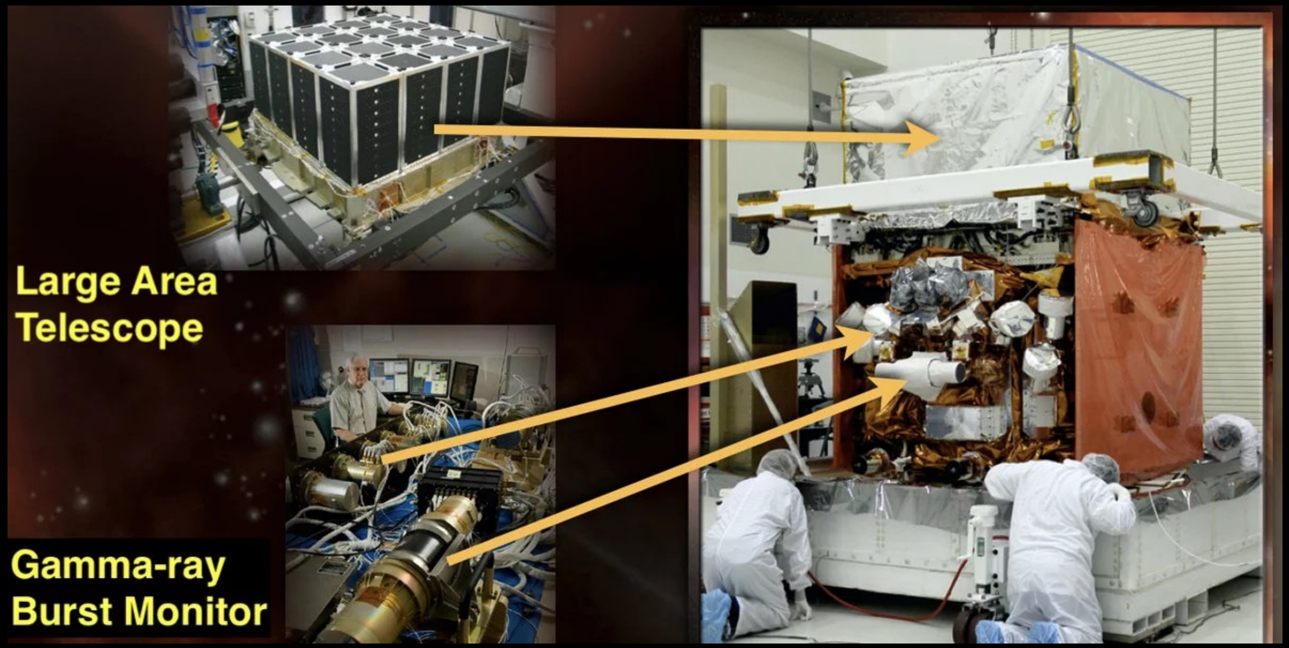
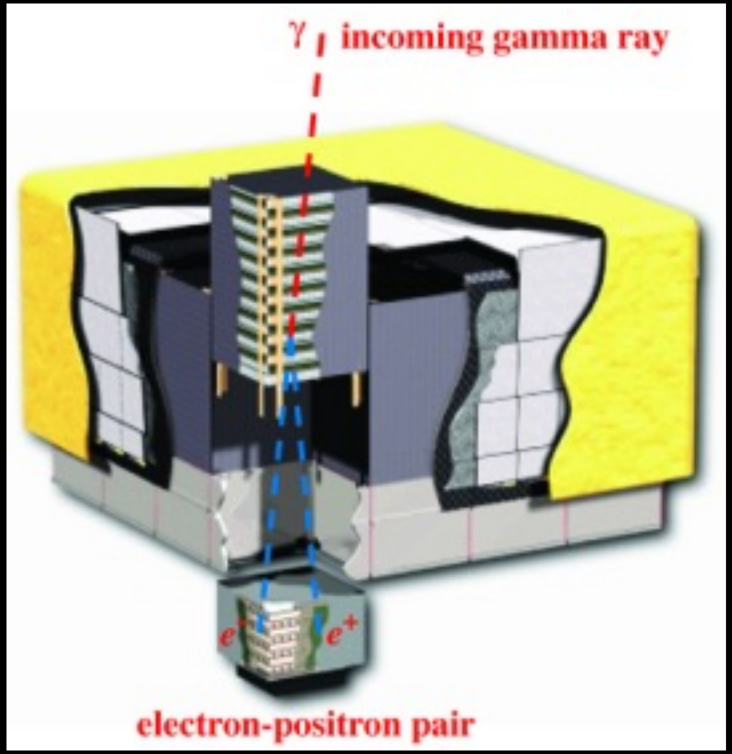
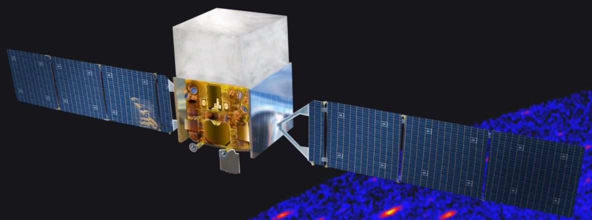


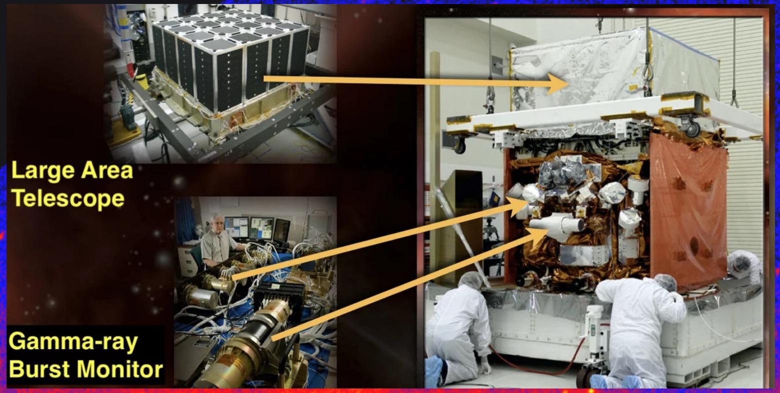


For most pulsars we see 1 single photon every few days…

[Figure credit: Fermi LAT collaboration]

Gamma-ray PTA





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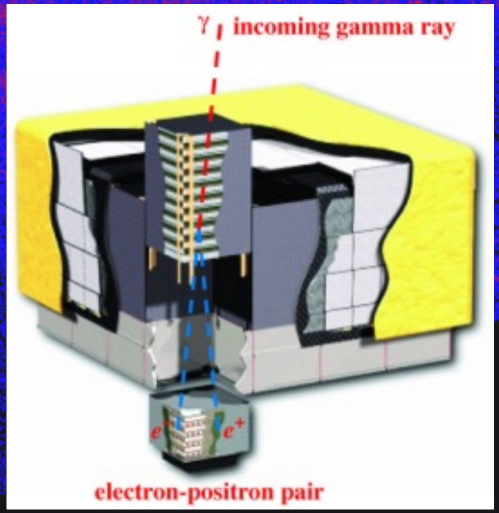

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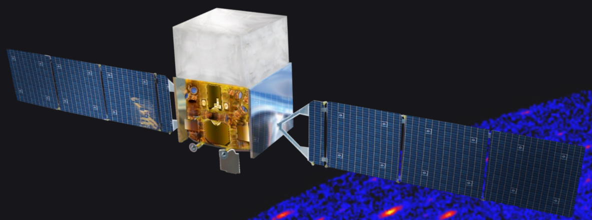
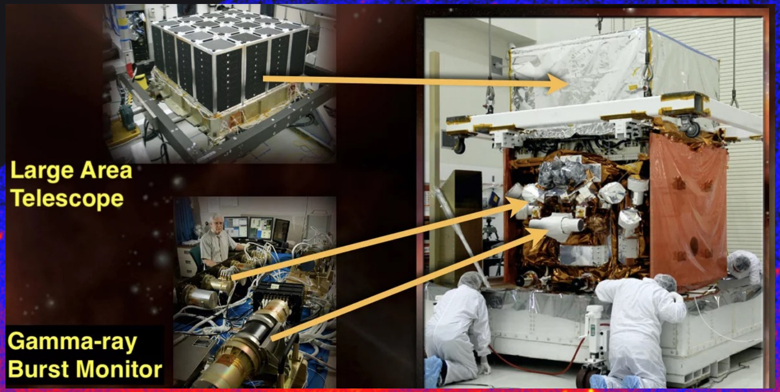
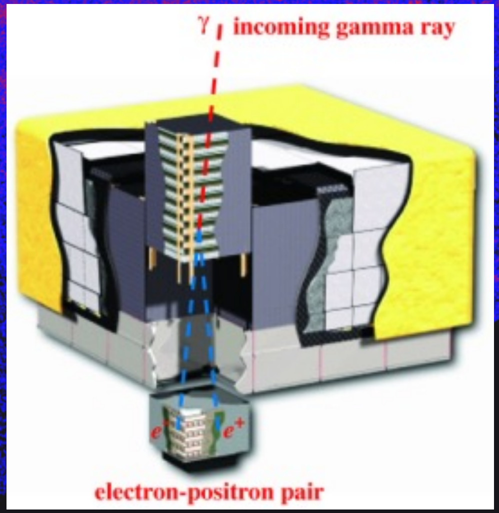




For most pulsars we see 1 single photon every few days…
… and we are not even sure it comes from the pulsar



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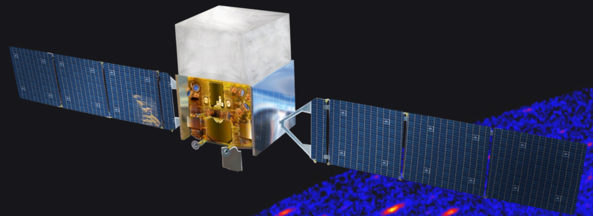

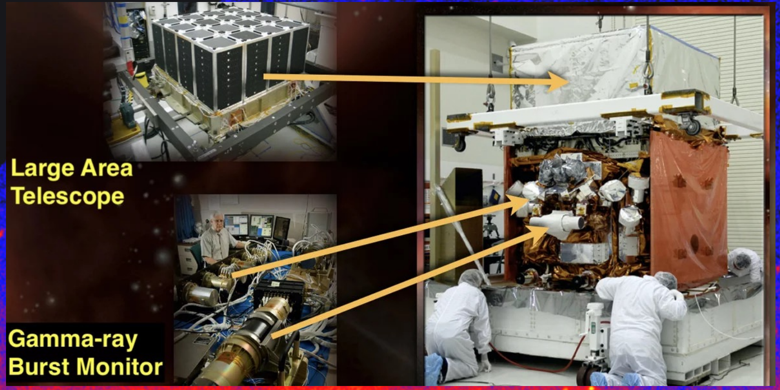

<u>Data Products:</u>
Individual photon observations: (E, n, t)

Poissonian statistic

Folding observations into TOAs is problematic

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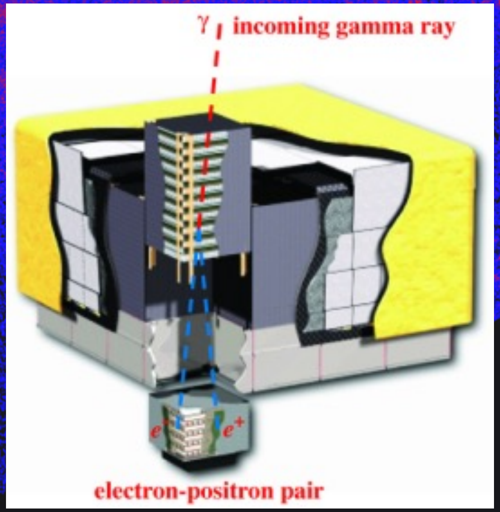

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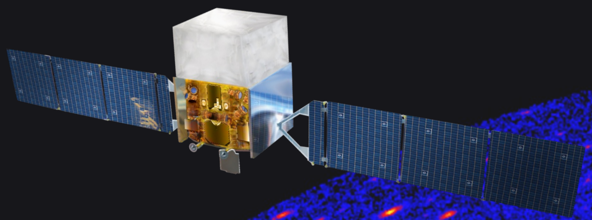

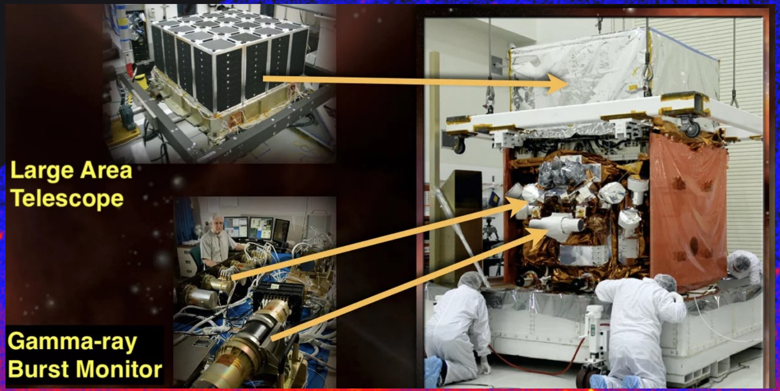

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Without TOAs you can't use tempo2, enterprise, discovery etc…☹

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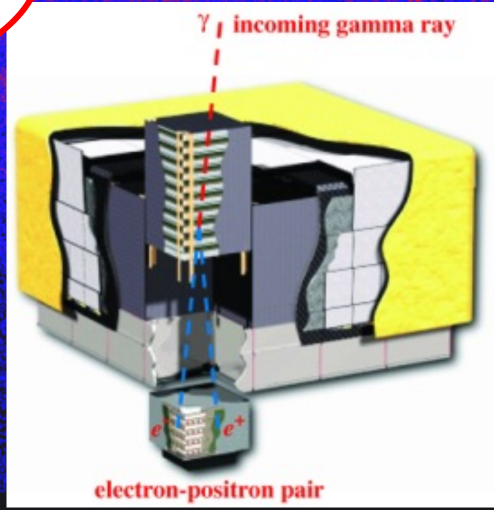

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PTA Experiments

Radio PTAs

[Figure credit: Thankful Cromartie]

Gamma-ray PTA

[Figure credit: Danielle Futselaar]

Strengths

Challenges

PTA Experiments

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Strengths

- High signal-to-noise

Challenges

- Combining data between different telescopes
- Data gaps
- DM modelling, solar wind, ISM etc.

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Strengths

- Unaffected by interstellar medium -> easy noise models
- Continuous dataset in time and space
- Same instrumental setup for all observations

Challenges

- Low signal-to-noise
- Limited sky resolution

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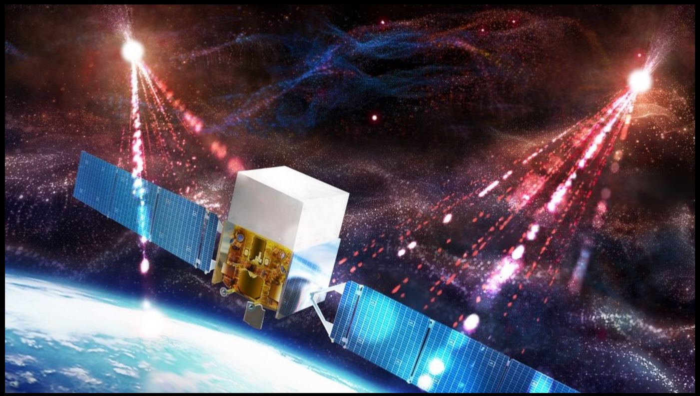

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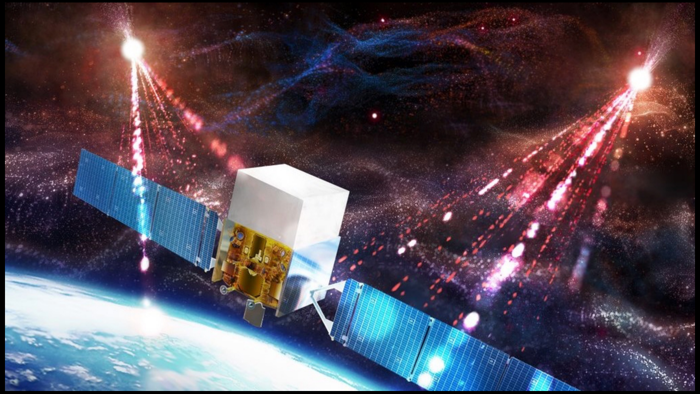

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GPTA in action!

2022

A Gamma-ray Pulsar Timing Array Constrains the Nanohertz Gravitational Wave Background

The Fermi-LAT Collaboration*,†

DR1: 35 pulsars, 12.5 years

First GWB upper limit for the GPTA
(contact M. Kerr, A. Parthasarathy)

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2025/2026

New sampling scheme for photon timing (shoogle)

Timing Gamma-ray Pulsars with Gibbs Sampling

C. J. Clark, S. Valtolina, L. Nieder, and R. van Haasteren,

Likelihood in Fourier domain (methods paper)

Regularizing the pulsar timing array likelihood: A path toward Fourier space

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Updated GWB limit from GPTA DR1

An updated constraint for the Gravitational Wave Background from the Gamma-ray Pulsar Timing Array

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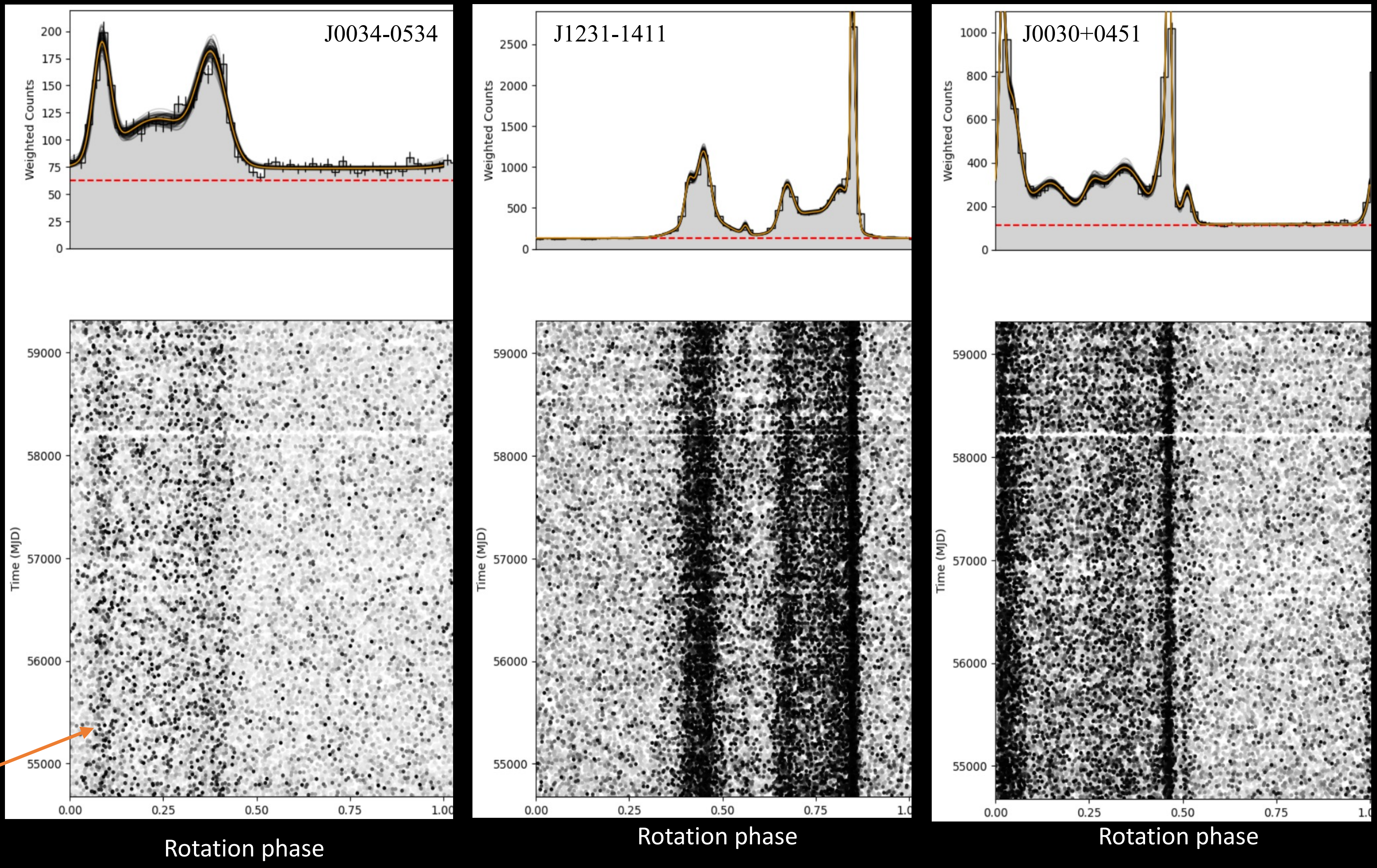
Second data release in preparation! Stay tuned

DR2: >70 pulsars, 17 years

Photon timing

Parameters to evaluate:
- Timing model parameters
- Template parameters
- Timing noise parameters and hyperparameters
- Orbital period variations (for spider pulsars)

Probabilities (Poissonian statistic)



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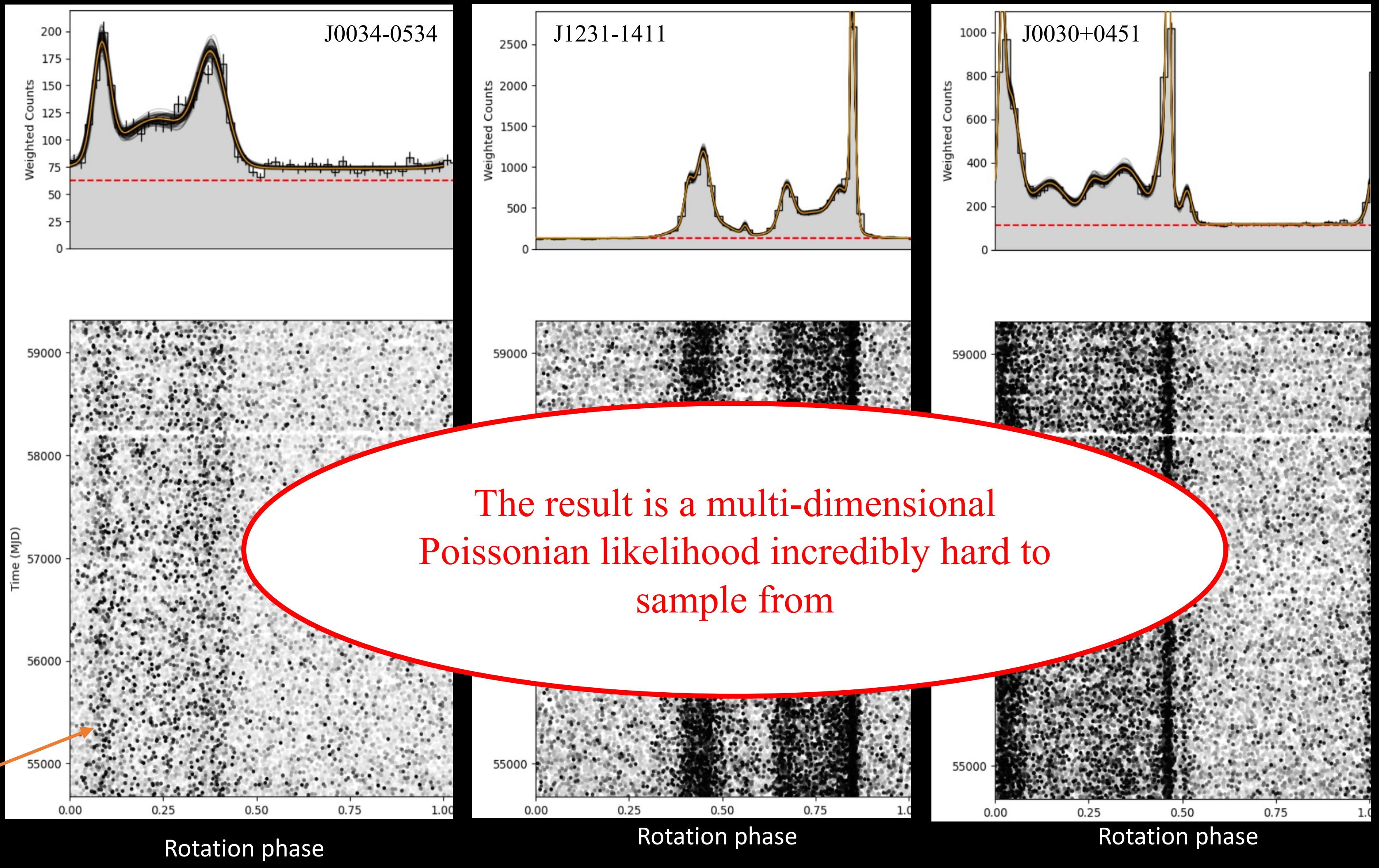


Probabilities
(Poissonian statistic)

Gibbs sampling

Instead of sampling both parameters A and B from the pull distribution: $p(A, B|d)$

You sample from the conditional probabilities in loop: $p(A|B, d)$ and $p(B|A, d)$

Photon timing with shoogle

Parameters to evaluate:
- Timing model parameters
- Template parameters
- Timing noise parameters and hyperparameters

+

Latent variable (z):
pulse template peak assignment

Gibbs sampling scheme

Sample *template*
given *timing model*

Assign *z*
given *timing model and template*

Sample *timing noise*
given *template and z*

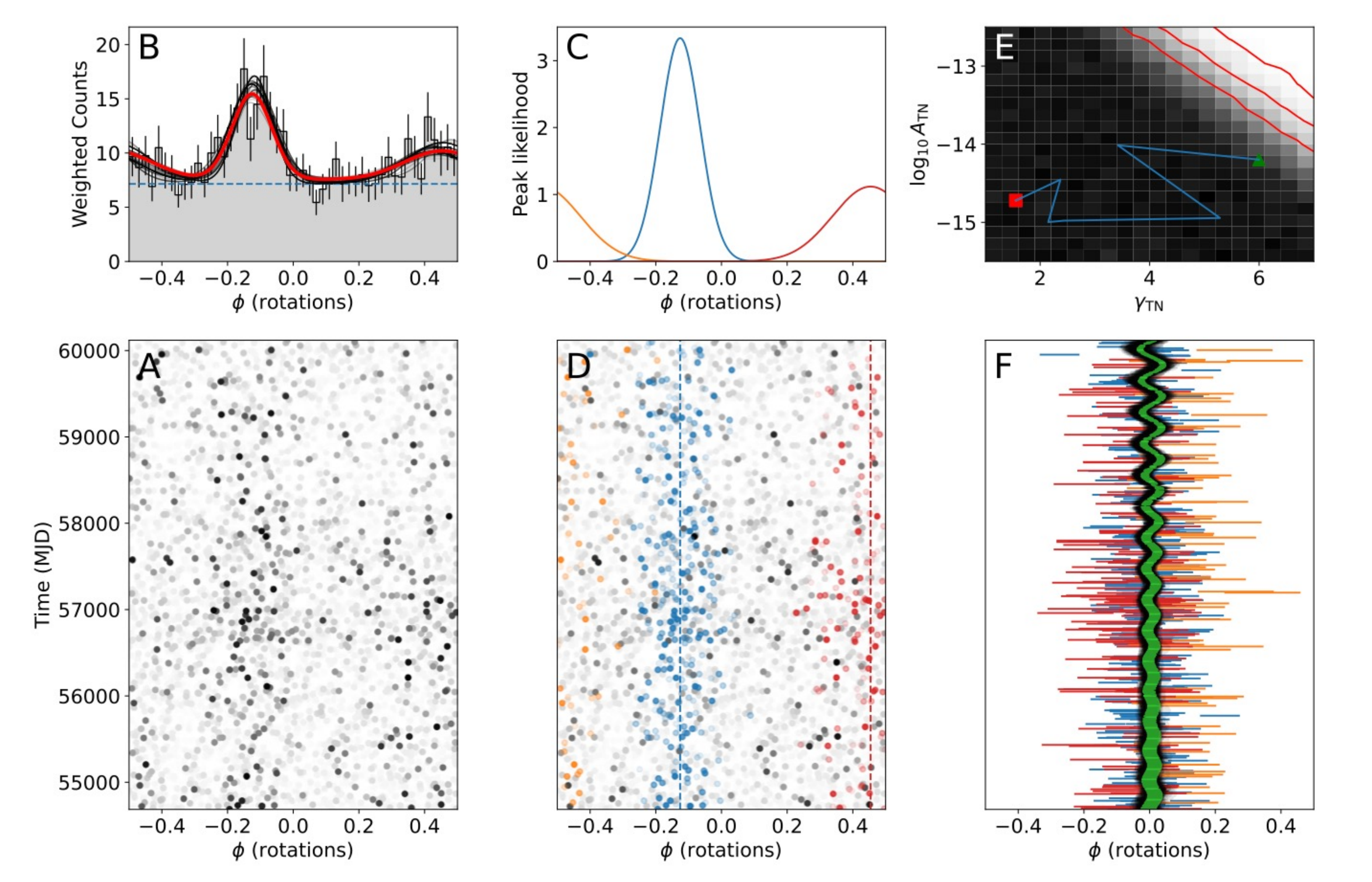
Sample *timing model*
given *z, timing noise and template*

End: when all posteriors reached convergence

Timing Gamma-ray Pulsars with Gibbs Sampling

C. J. Clark, S. Valtolina, L. Nieder, and R. van Haasteren,

Photon timing with shoogle

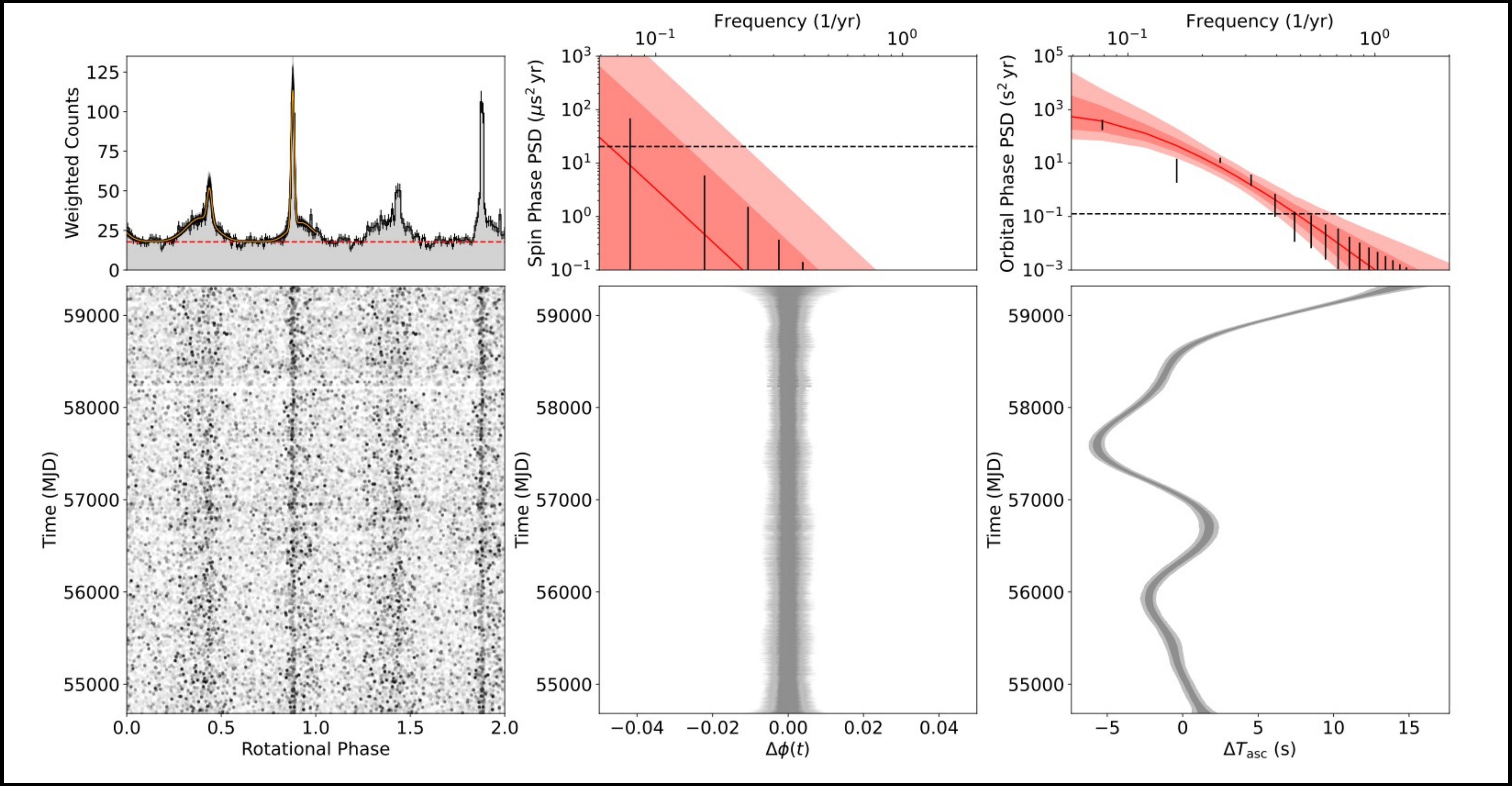


Pulsar J1526-2744, C. Clark et al. 2026

Photon timing with shoogle

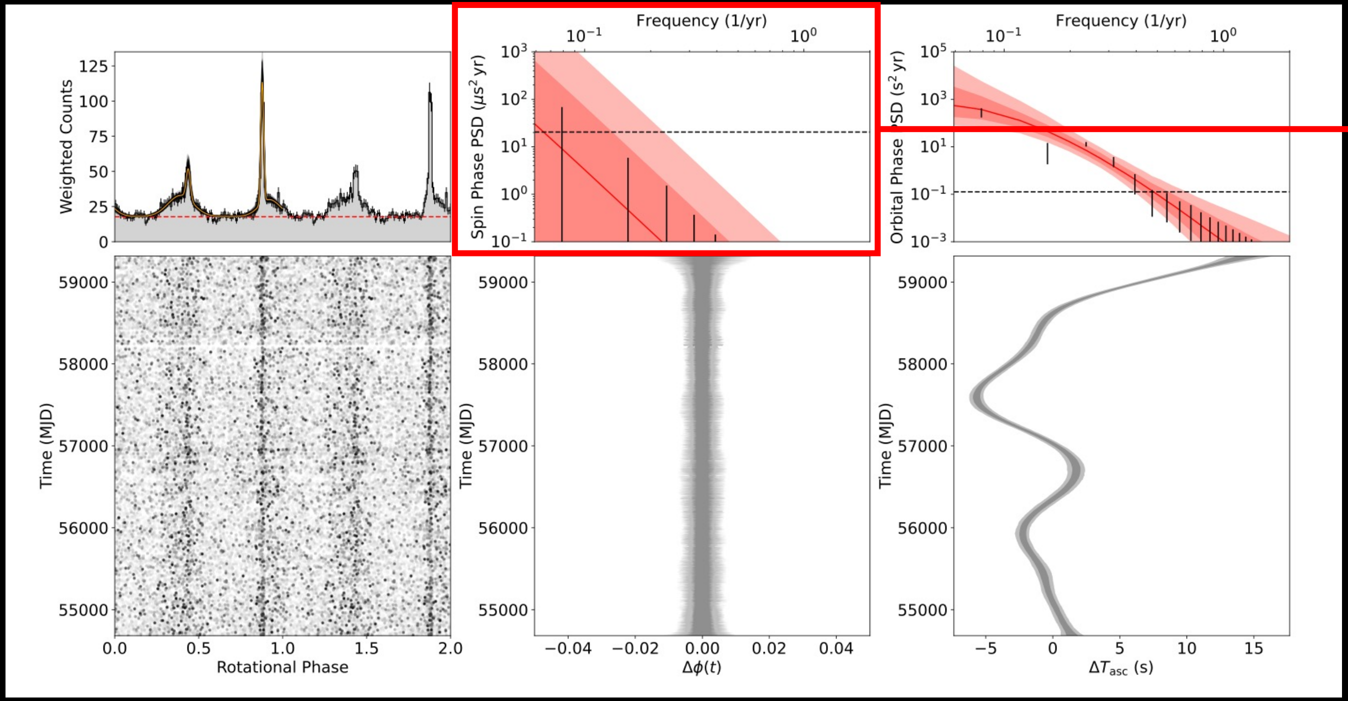
TIMING NOISE (red noise)

Orbital period variations



Pulsar J1959+2048, C. Clark et al. 2026

Photon timing with shoogle



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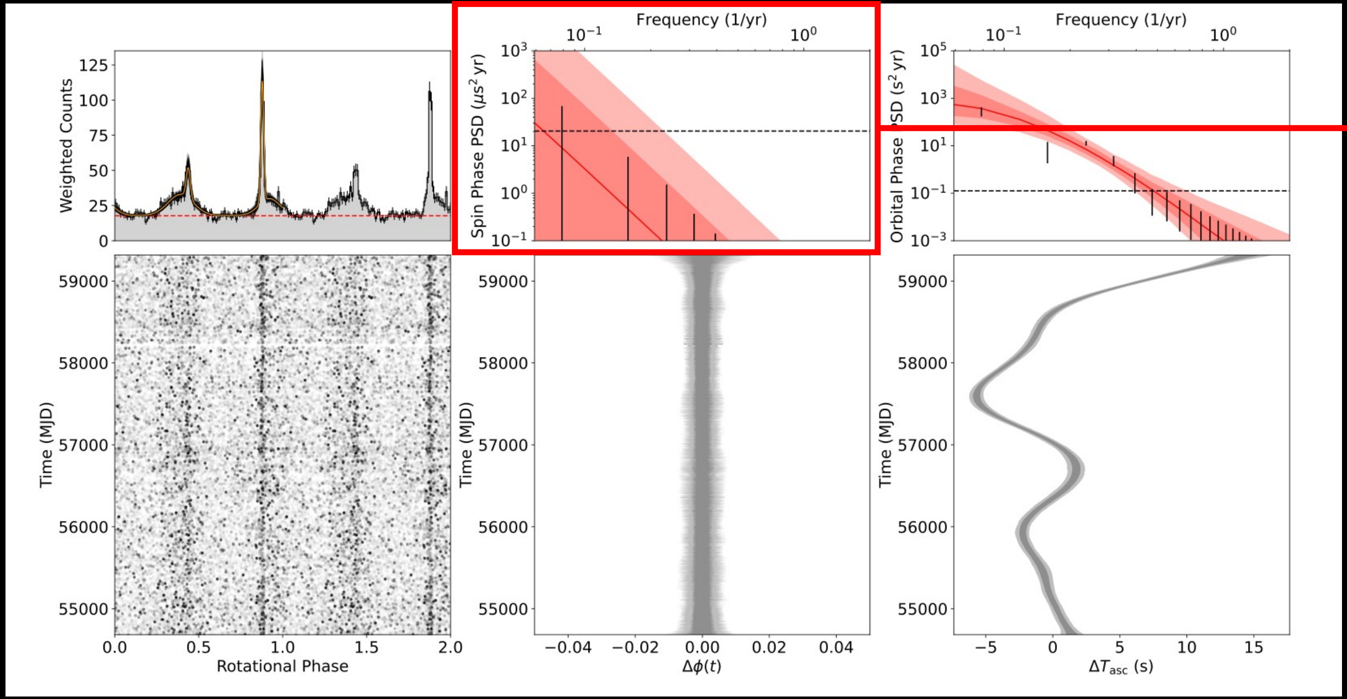
Timing noise (red noise) modelled as a Gaussian process at frequencies k/Tobs

Photon timing with shoogle



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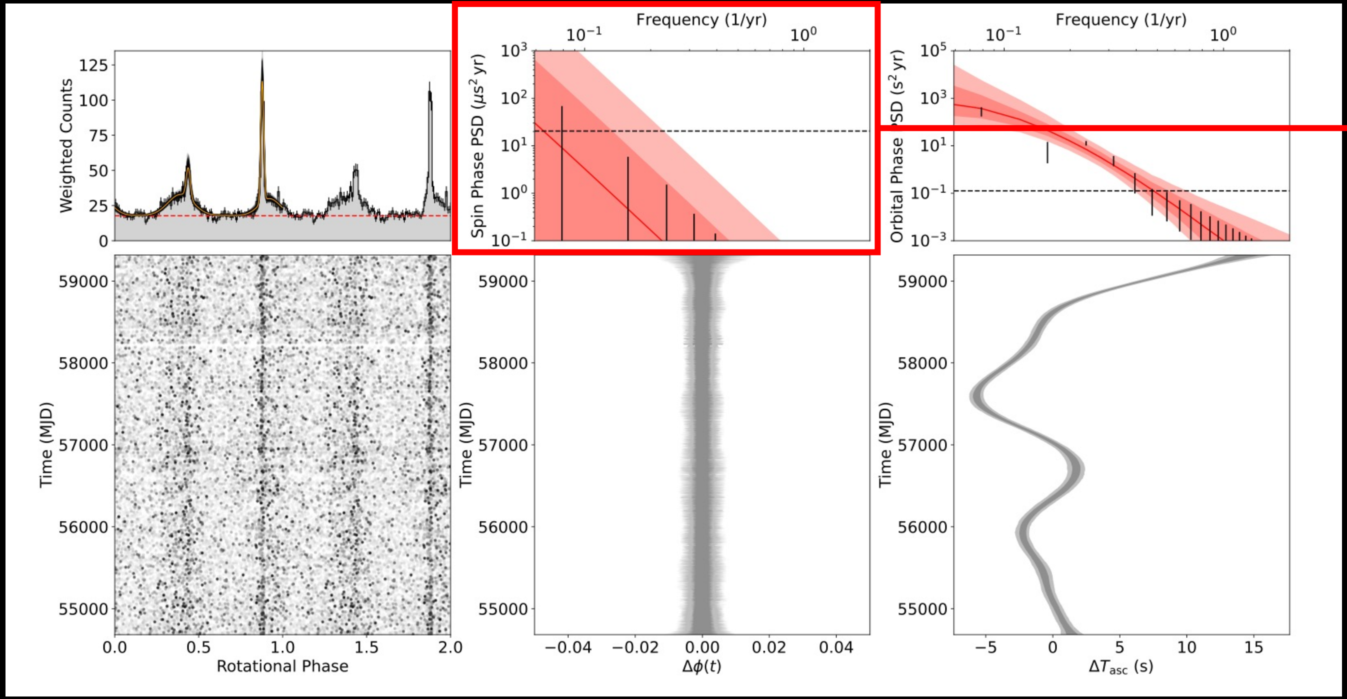
Timing noise (red noise) modelled as a Gaussian process at frequencies k/Tobs

$$\delta t = \sum a_k \cos(2\pi f_k t) + b_k \sin(2\pi f_k t)$$

Photon observations are not TOAs!!!

Photon timing with shoogle



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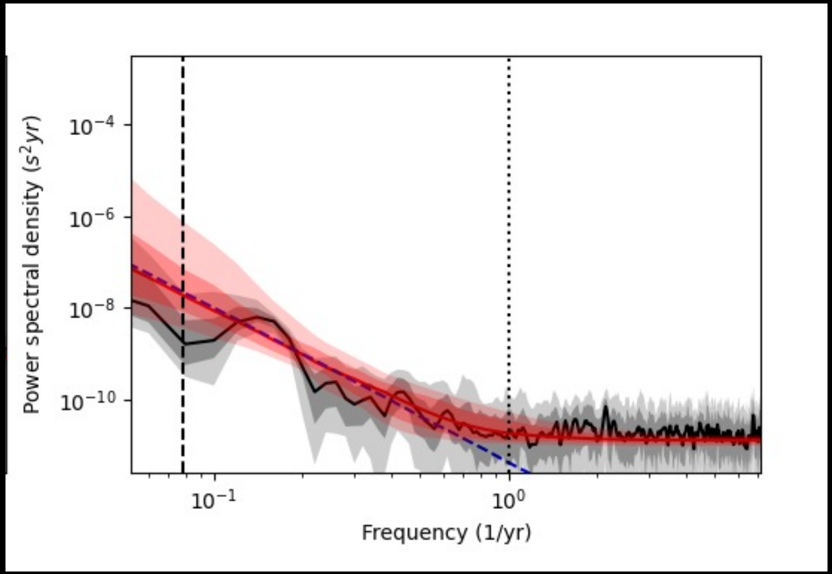

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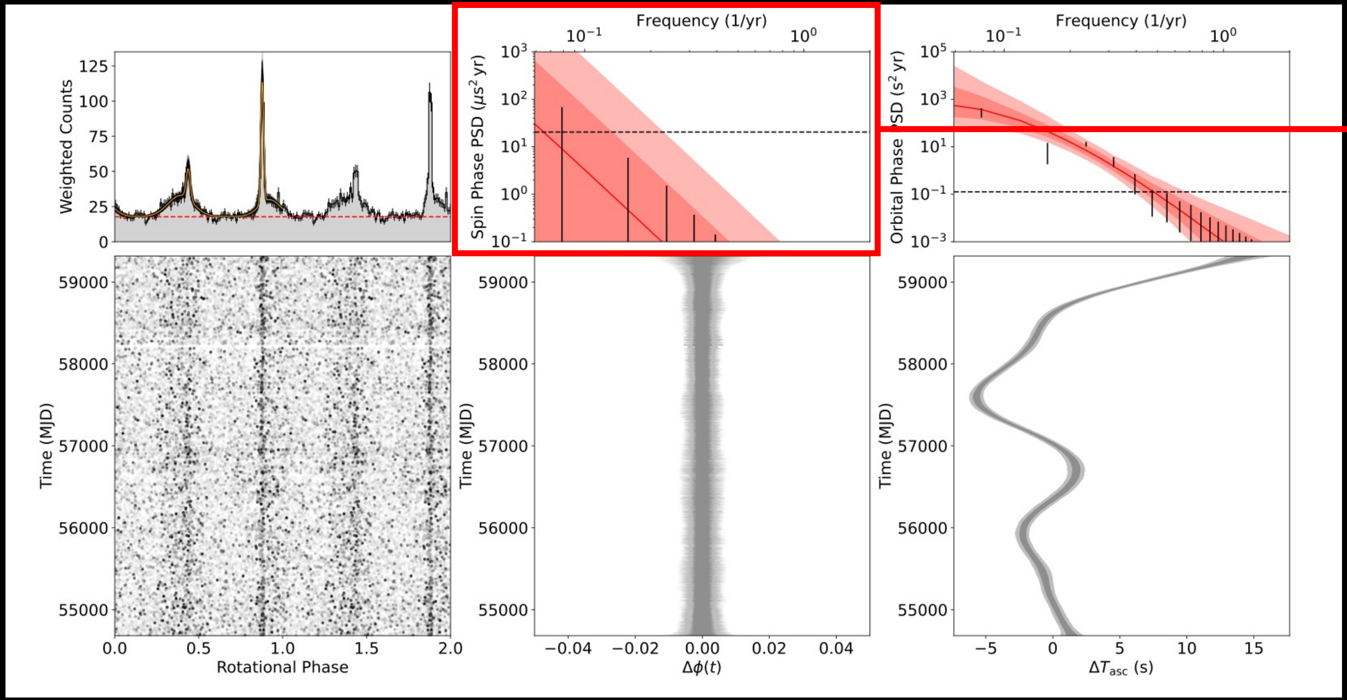

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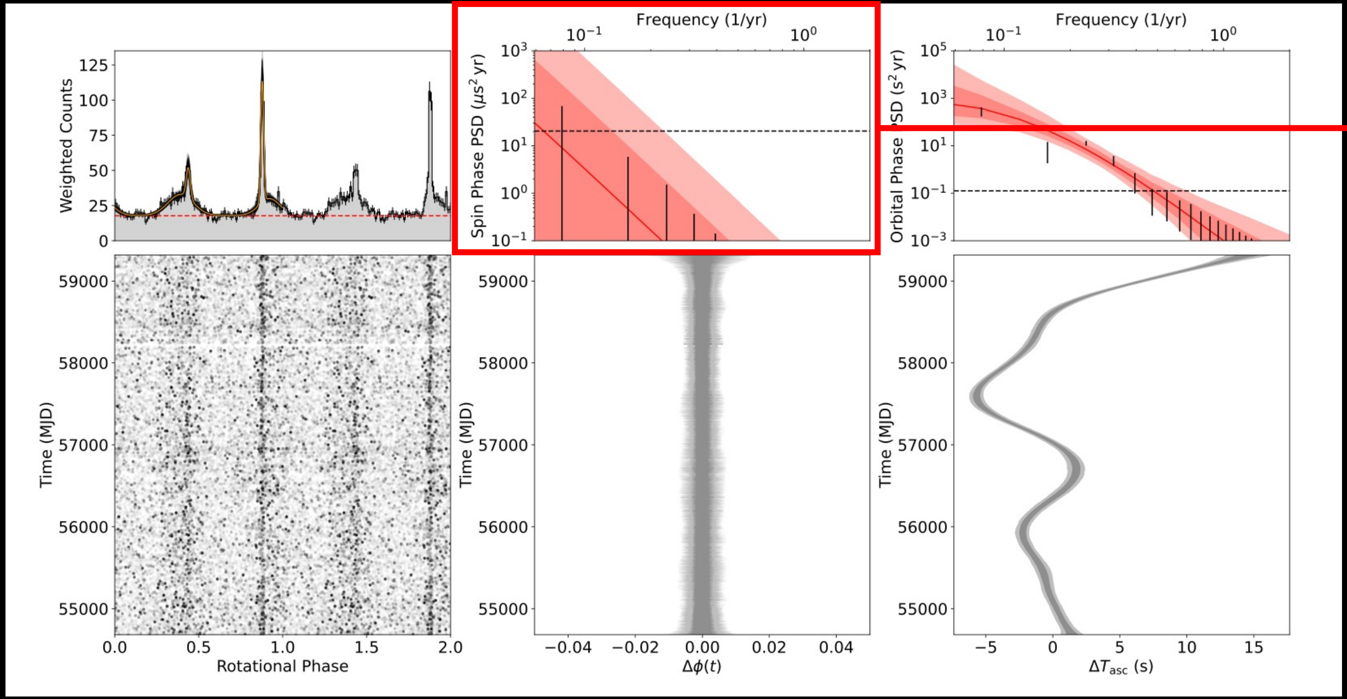
<u>Data Products:</u>

Individual photon observations: (E, n, t)

$\downarrow$

Multinormal posterior distribution of Fourier coefficients

Photon timing with shoogle



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Multinormal posterior distribution of Fourier coefficients

Input for


Regularizing the pulsar timing array likelihood: A path toward Fourier space

Serena Valtolina* and Rutger van Haasteren†

A new PTA likelihood in Fourier domain

Regularizing the pulsar timing array likelihood: A path toward Fourier space

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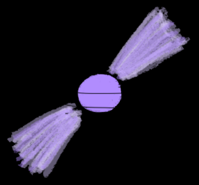
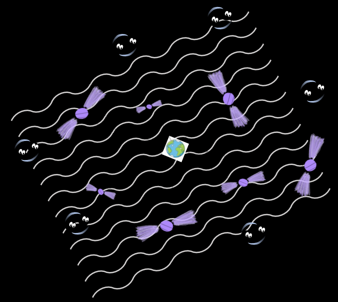
- It allows us to divide the PTA analysis in **2 steps**:



1. analyze each pulsar *individually*
   focus on signals NOT covariant with the GWB

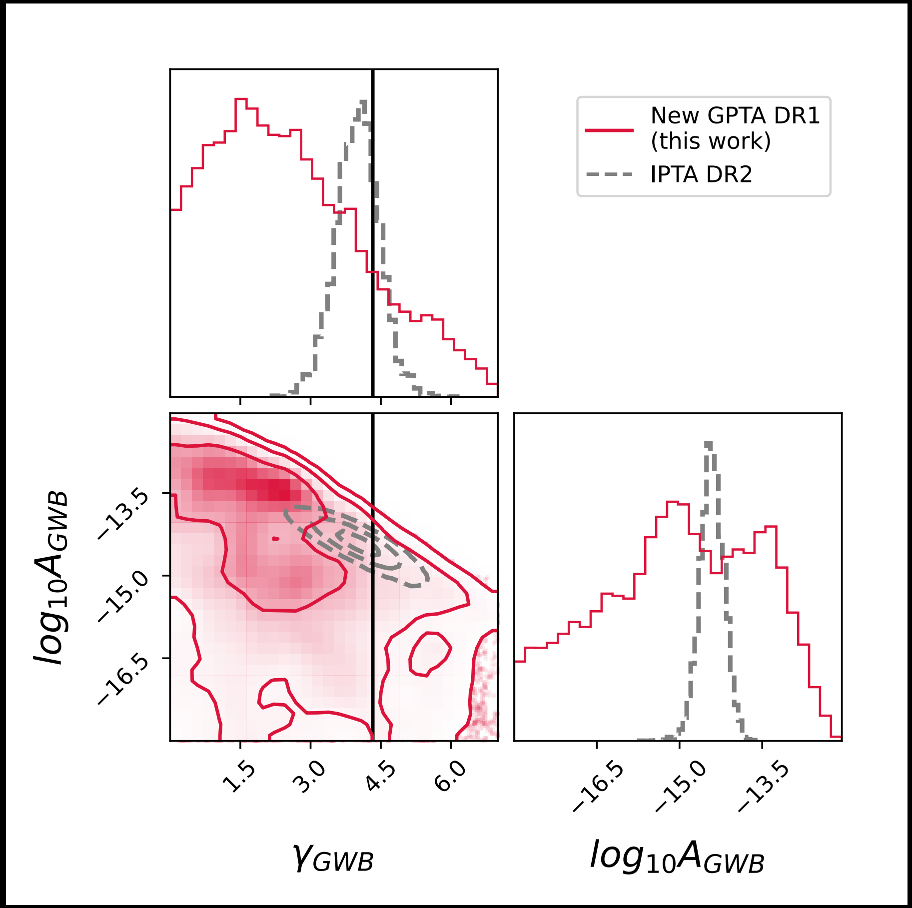
Posterior of the Fourier coefficients describing the signals covariant with GWB



2. analyze the *full array* of pulsars
   focus on the GWB and the signals covariant with it (RN, DMvar …)

- It can be applied to both **Gamma-ray PTA** and radio PTA data!

Updated GWB constraint from the GPTA



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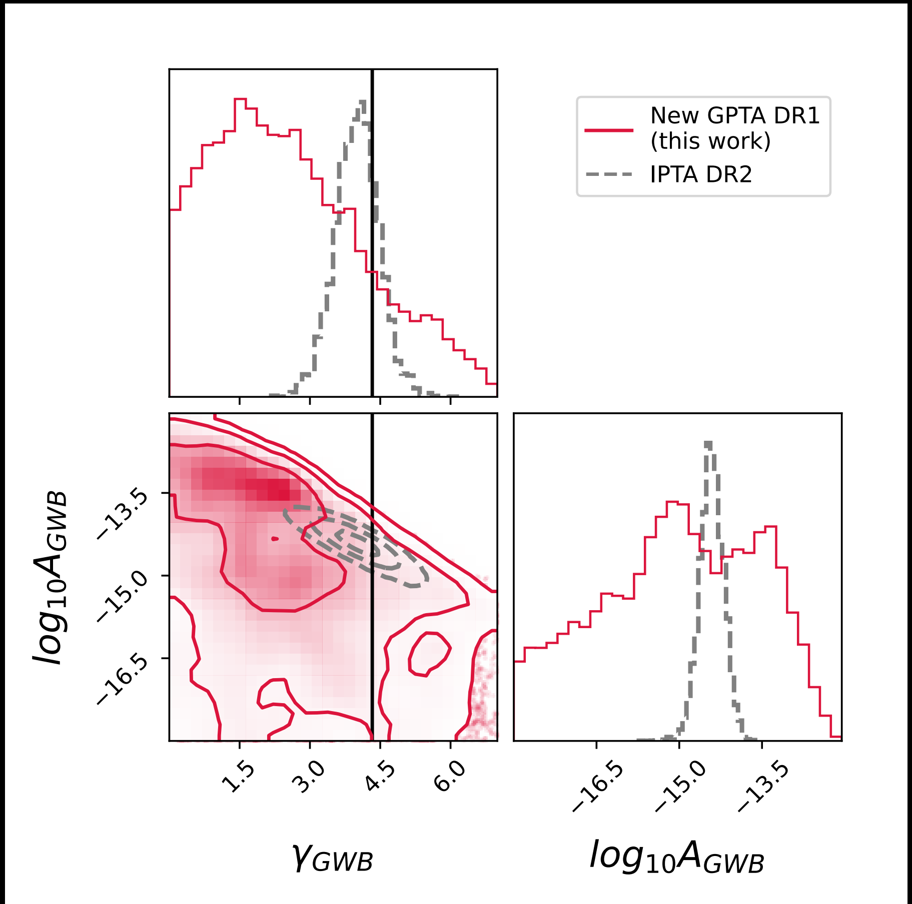

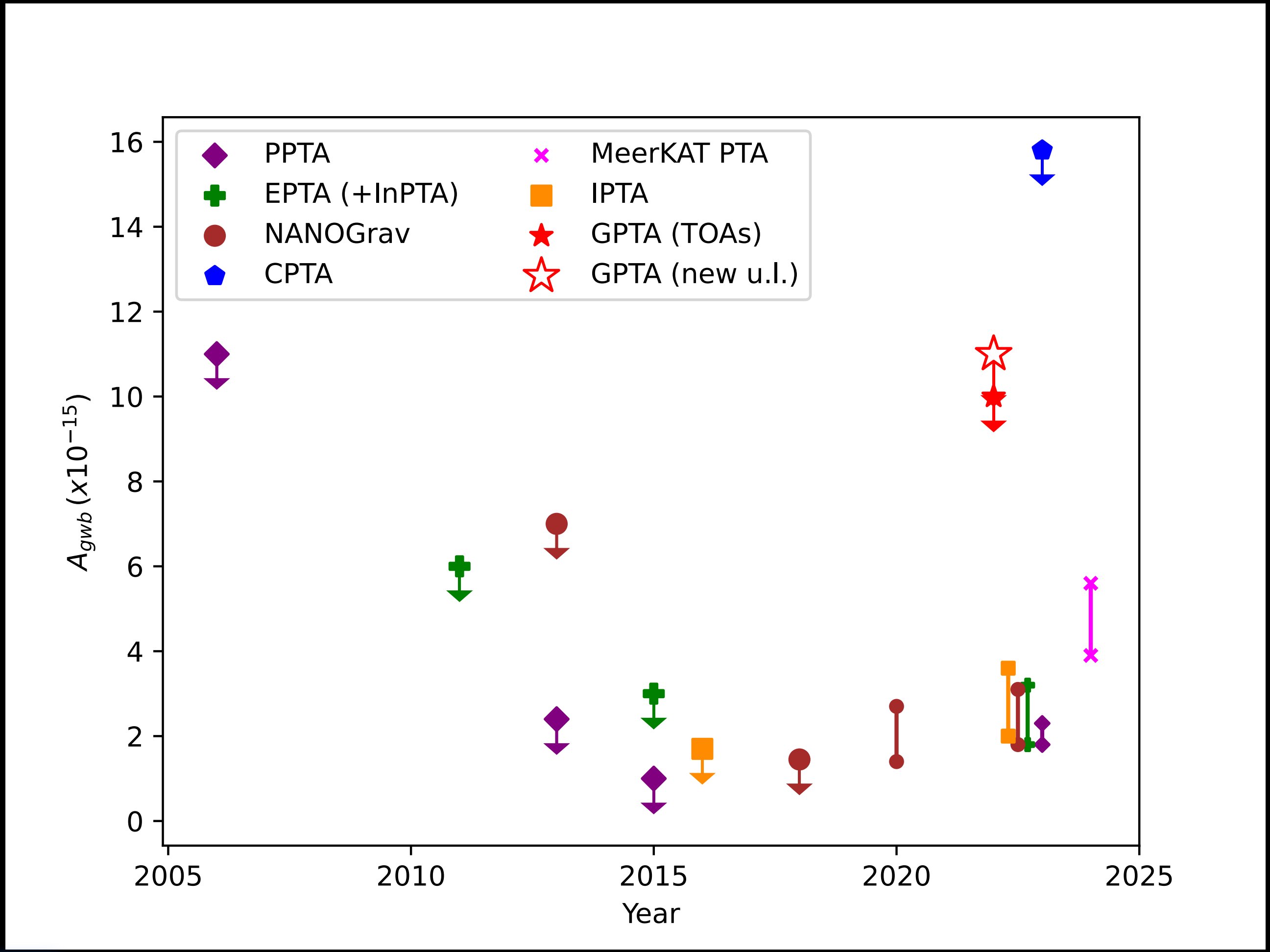

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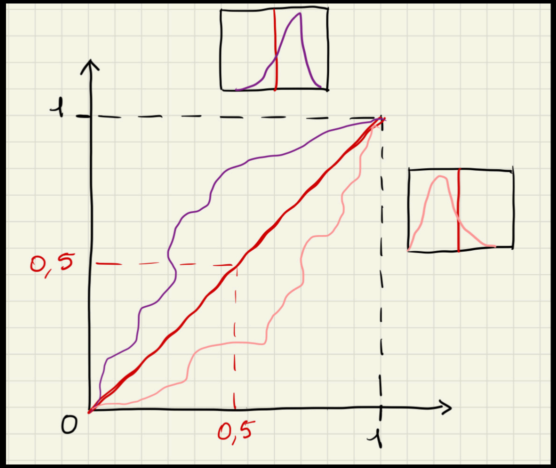
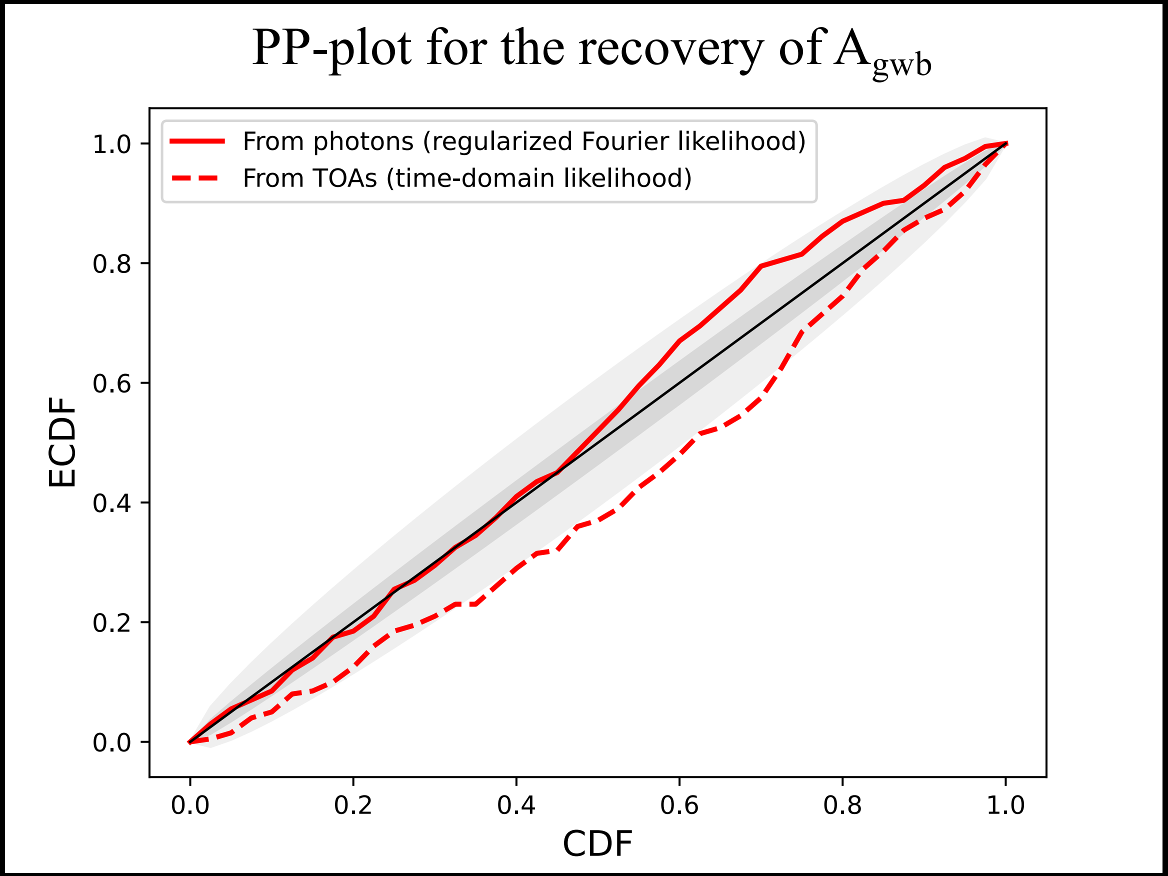
Updated upper limit: $A_{gwb} < 1.2 \times 10^{-14}$

TOAs vs photons: simulations

200 simulated GPTA datasets: 35 pulsars and 12,5 years of observations



Photons + regularized likelihood method resulted *statistically more robust* than the TOAs method.



Valtolina et al. 2026

Why Gamma-ray PTA?

- Fully independent proof of the GWB

- No interaction with the interstellar medium -> better noise models -> better timing noise constraints for radio experiments

- Uniform sky coverage and observation baseline

- Inclusion of spider pulsars

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