Recent results from Pulsar Timing Arrays

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2nd EuCAPT symposium

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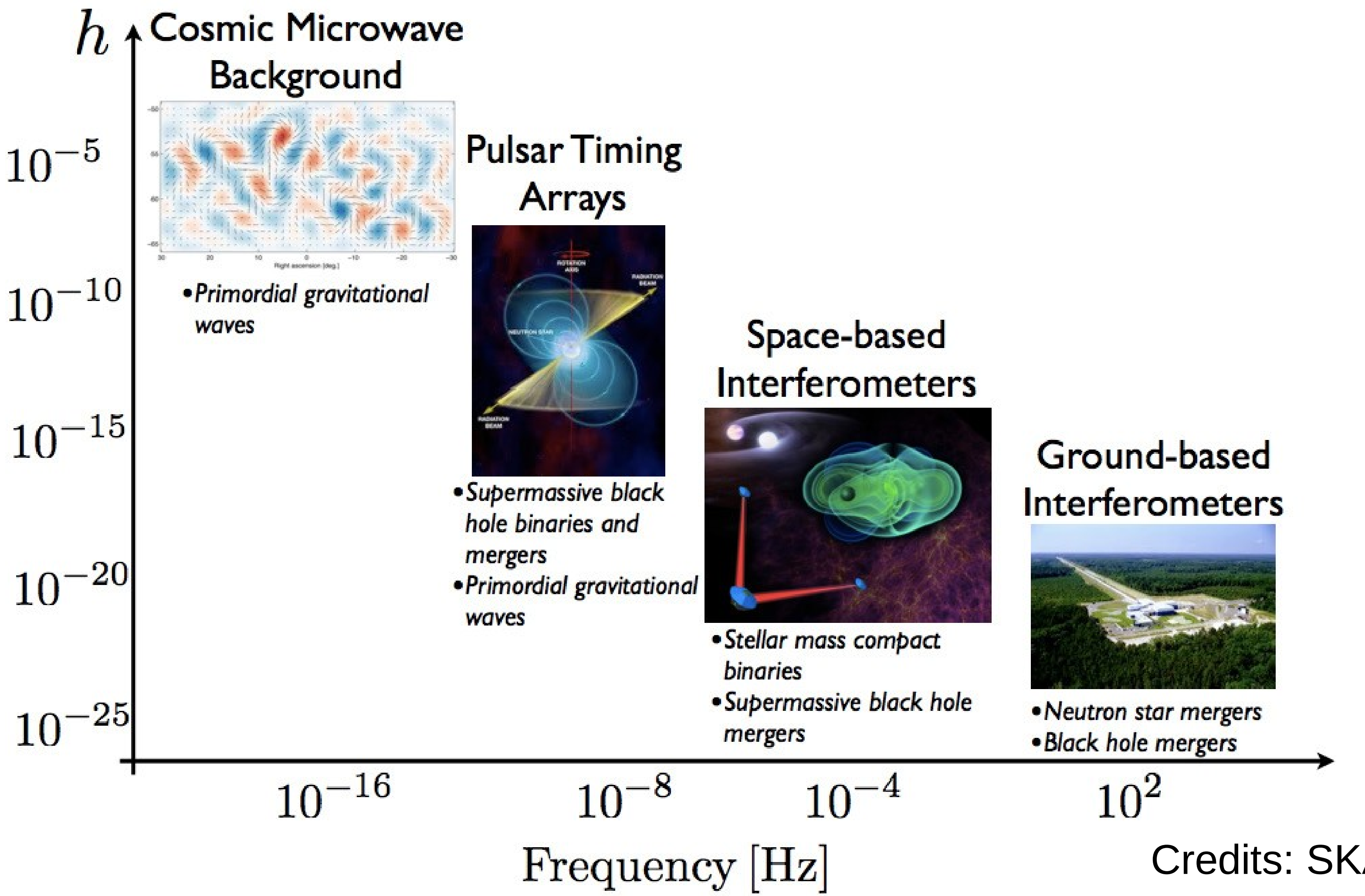
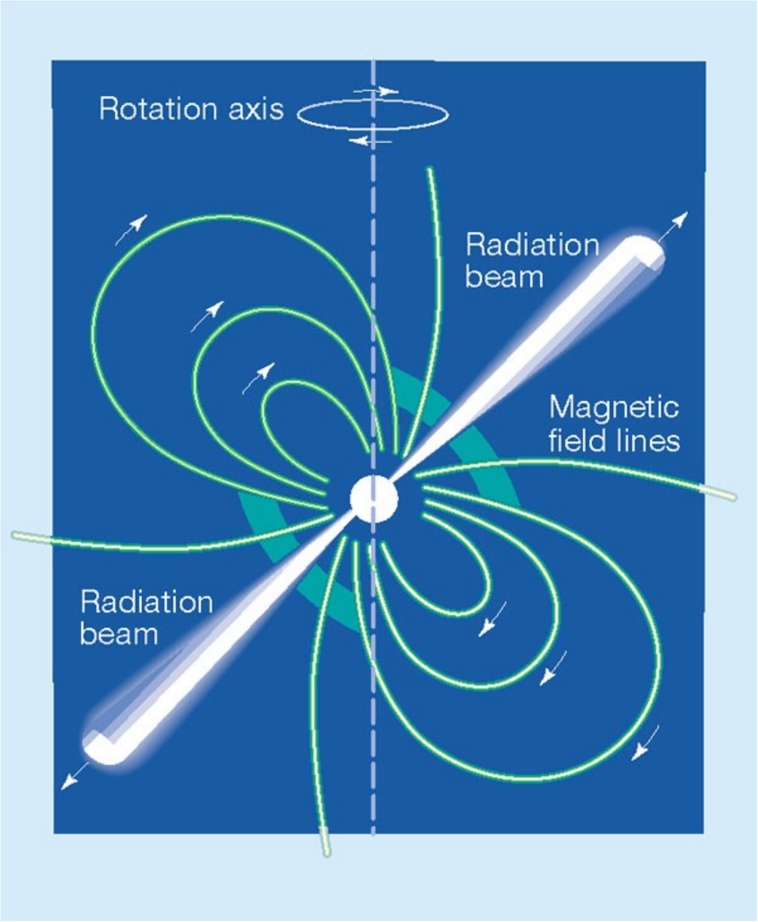
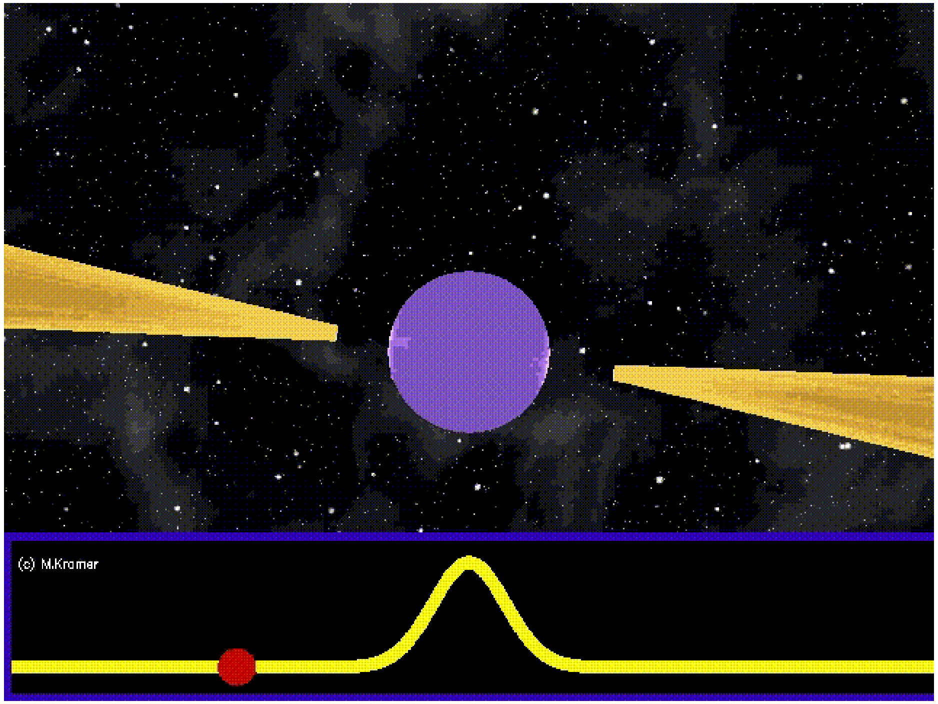
Gravitational Waves



Credits: SKAO

Pulsar Timing Array – Pulsar

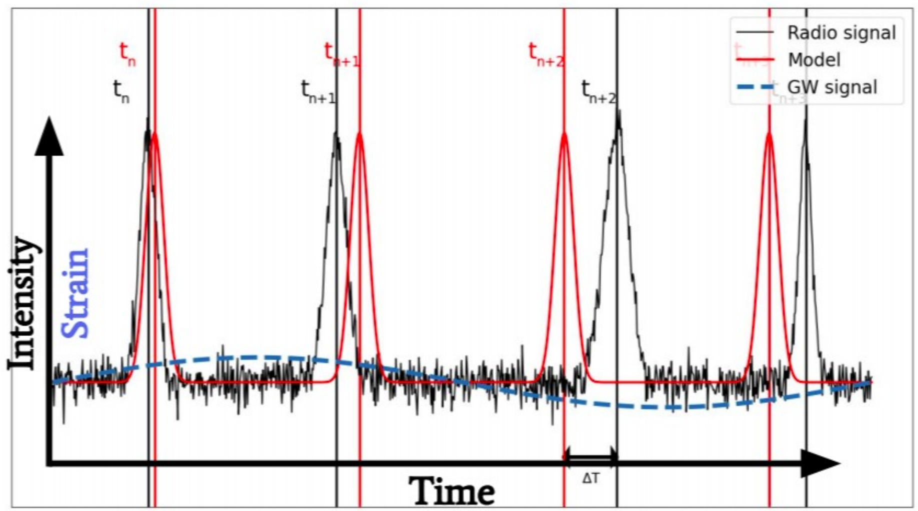




Credits: M. Kramer

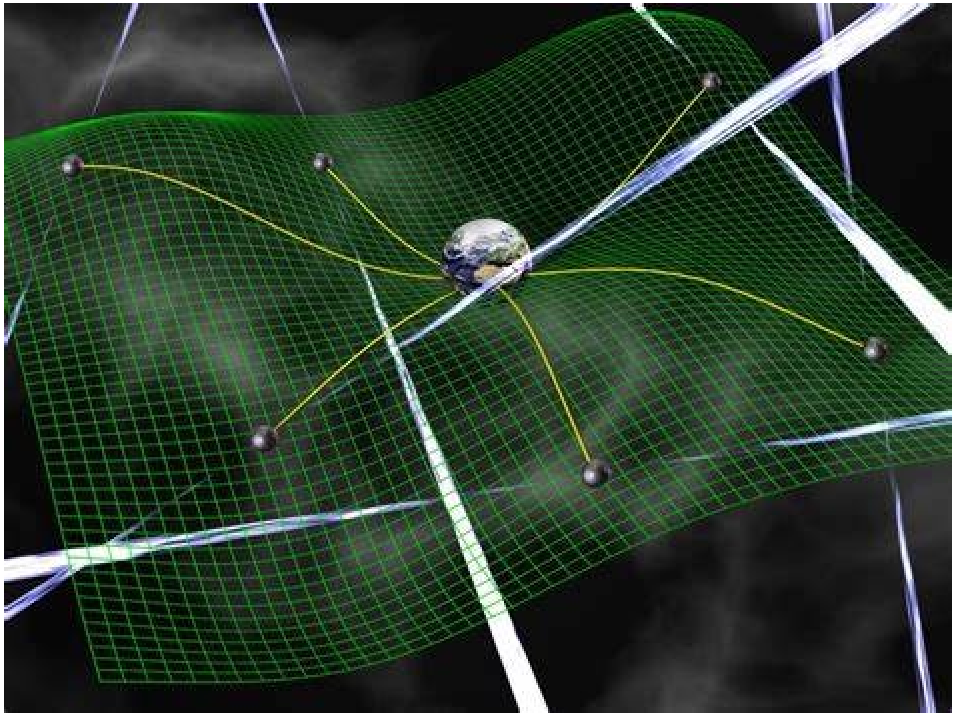
Pulsar Timing Array – Timing

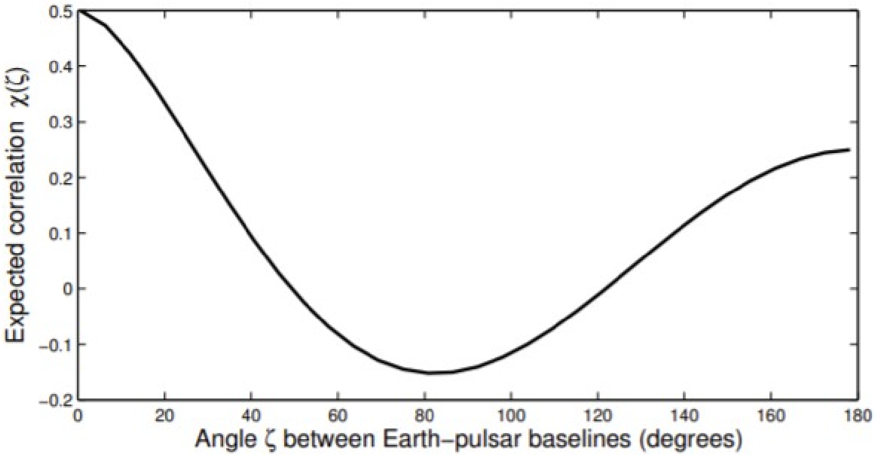
Credits: FAST
Radio Telescope



Credits: M. Falxa

Pulsar Timing Array – Array



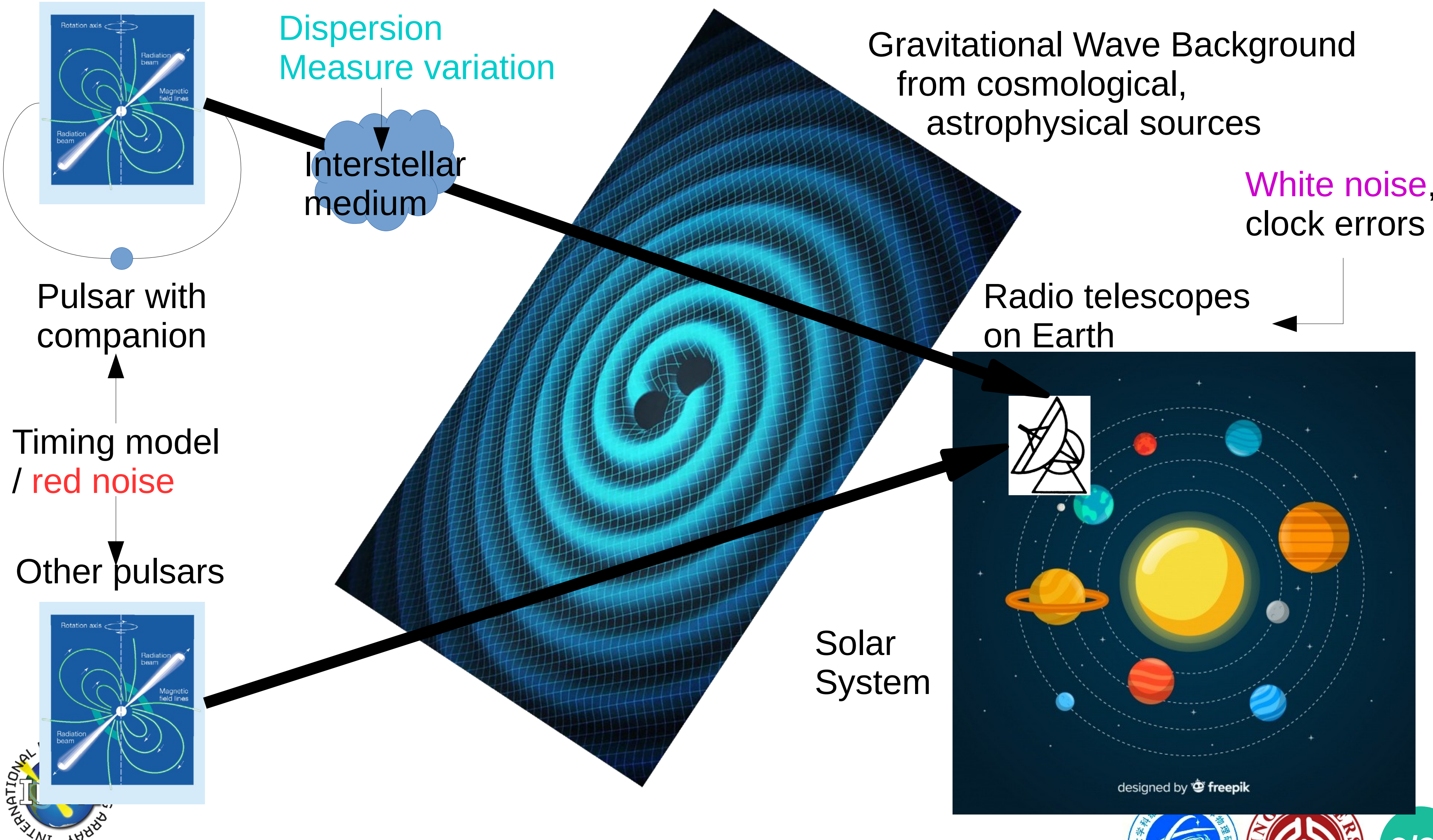


Hellings and Downs 1983

Credits: D. Champion

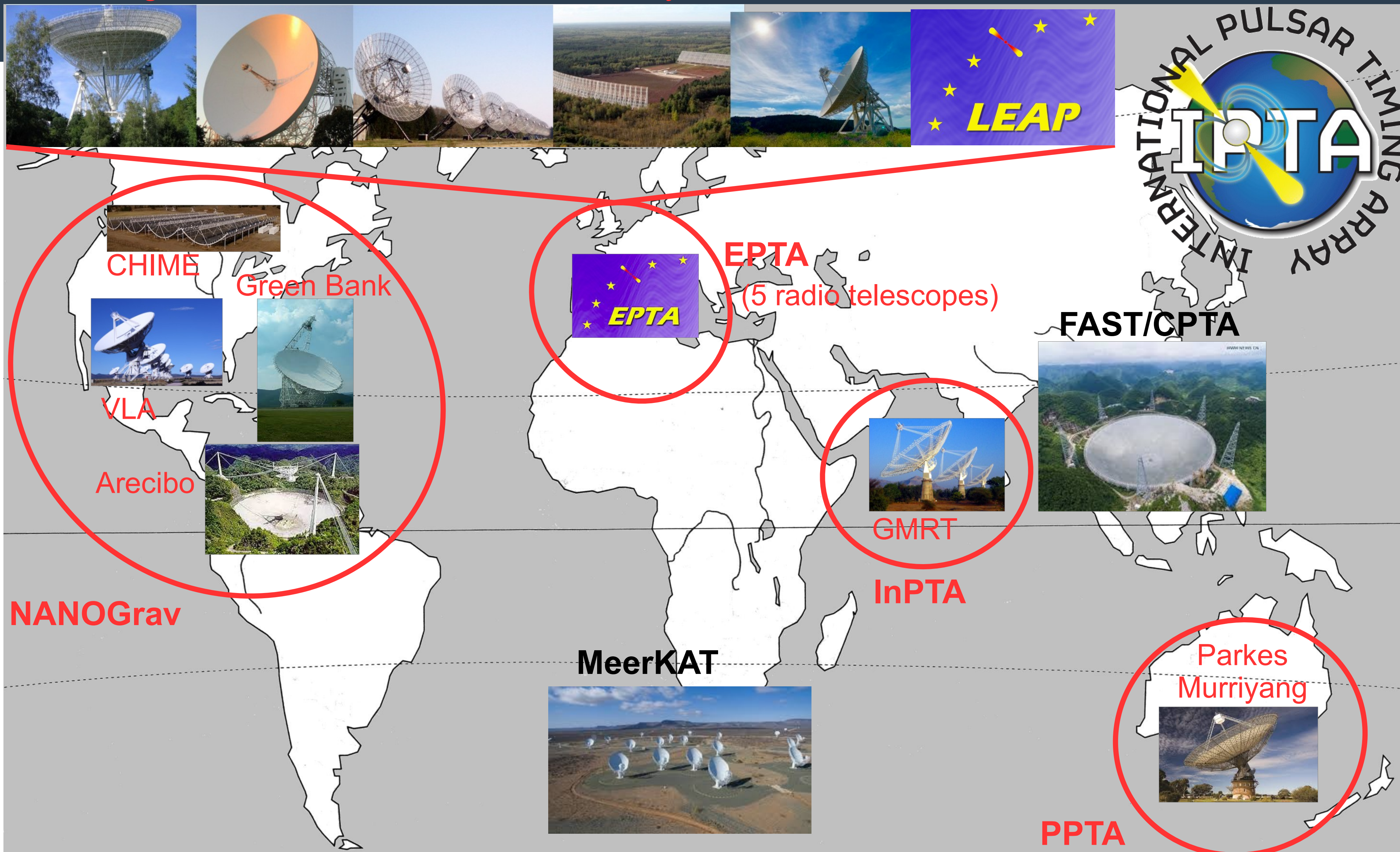
$$\Gamma_{\alpha\beta} = \delta_{\alpha\beta} + \frac{1}{2} - \frac{1}{4}\Big(\frac{1-\cos(\zeta_{\alpha\beta})}{2}\Big) + \frac{3}{2}\Big(\frac{1-\cos(\zeta_{\alpha\beta})}{2}\Big)\ln\Big(\frac{1-\cos(\zeta_{\alpha\beta})}{2}\Big)$$

Gravitational Wave Background

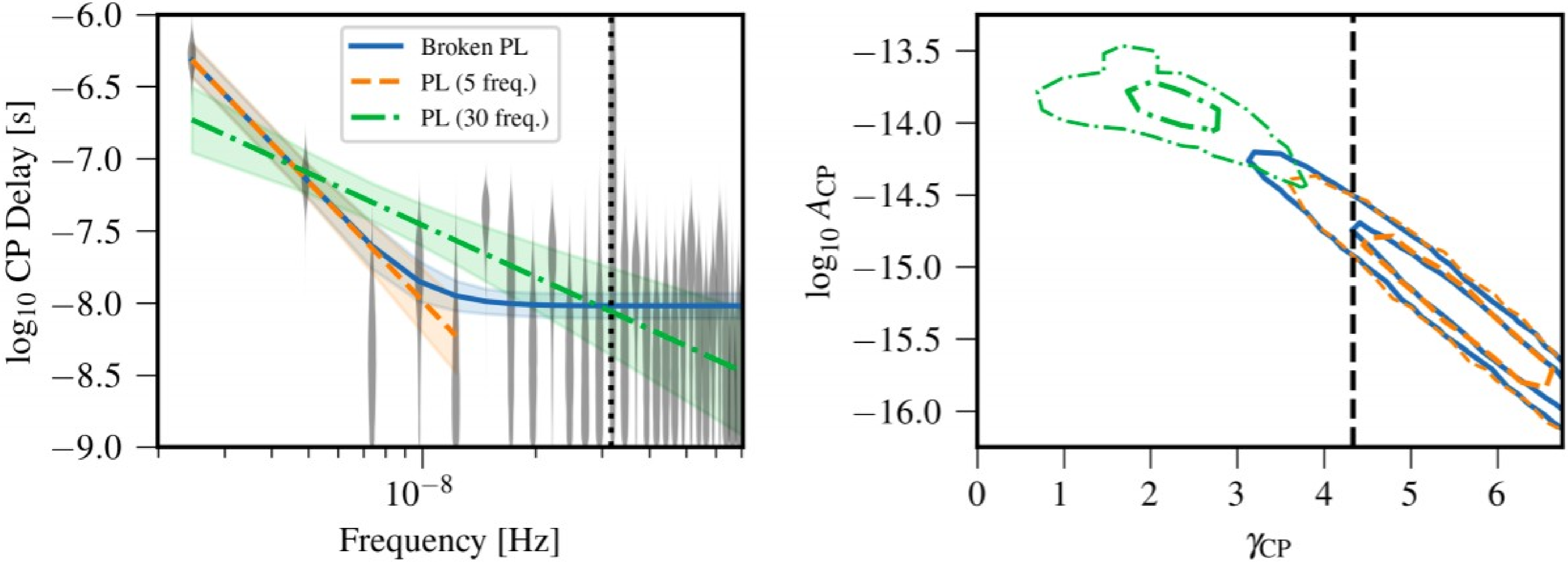


International Pulsar Timing Array

Effelsberg Jodrell Westerbork Nancay Sardinia LEAP



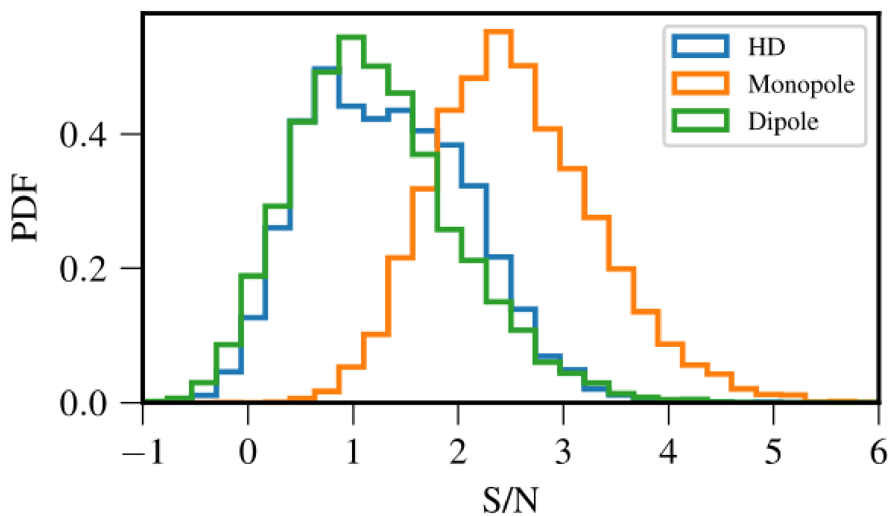
NANOGrav 12.5yr

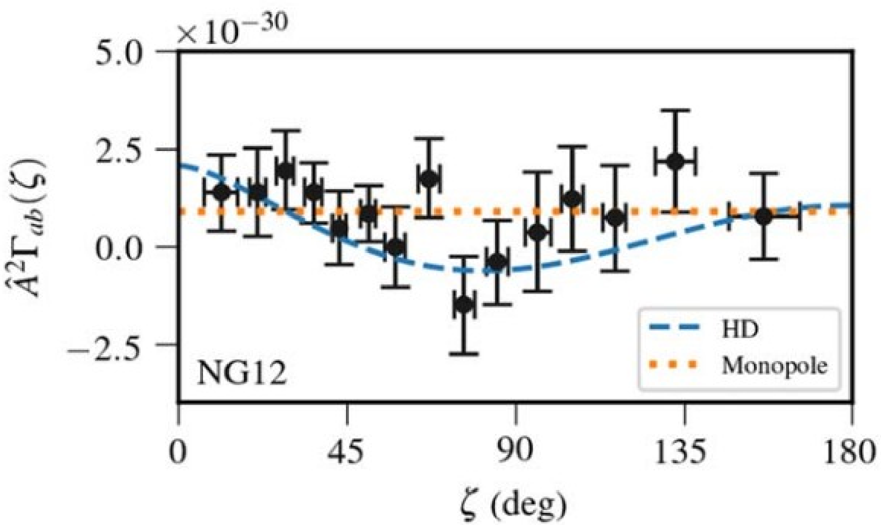


45 millisecond pulsars with up to 13 years of observations

Arzoumanian et al. (NANOGrav) 2020
Lead: J. Simon

NANOGrav 12.5yr

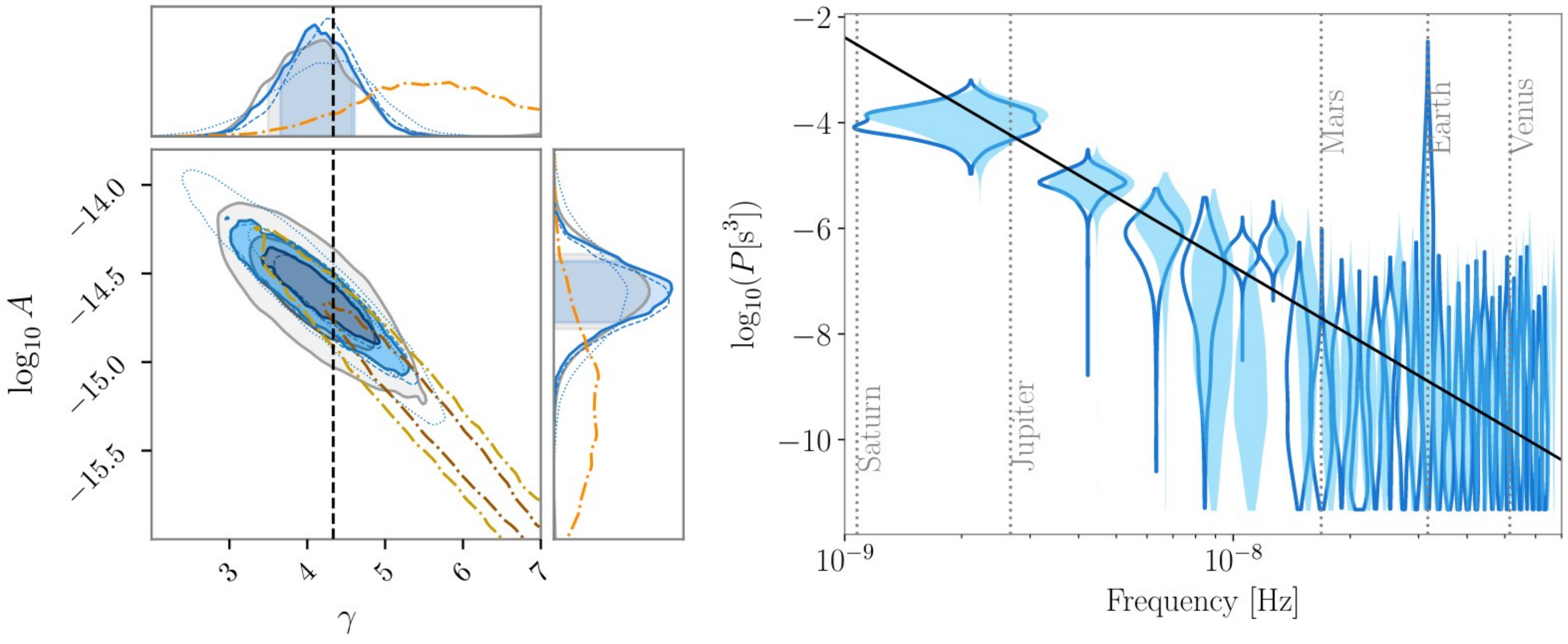




No conclusive evidence for the detection of a Gravitational wave background !

Arzoumanian et al. (NANOGrav) 2020
Lead: J. Simon

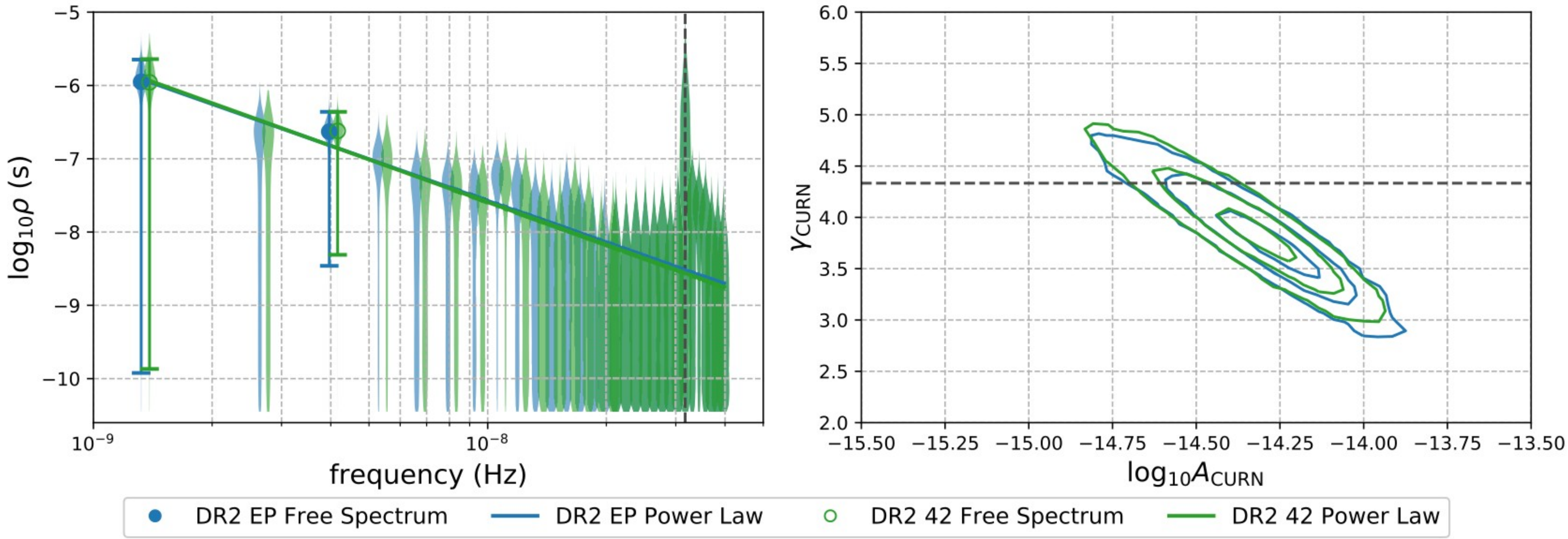
PPTA DR2



26 millisecond pulsars with up to 15 years of observations

Goncharov et al. (PPTA) 2021

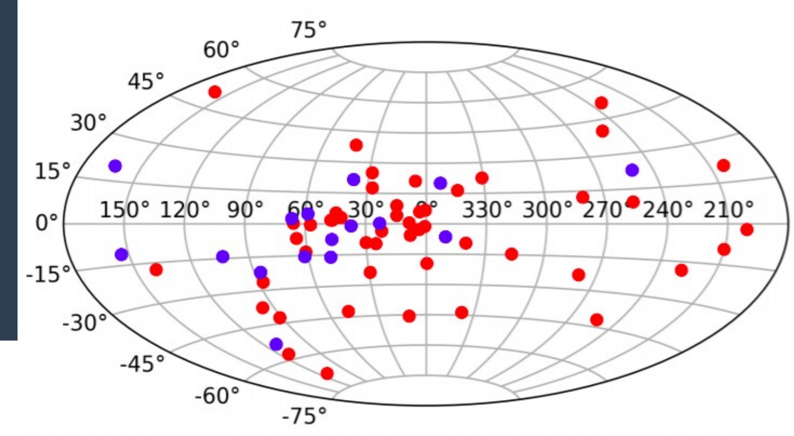
EPTA DR2

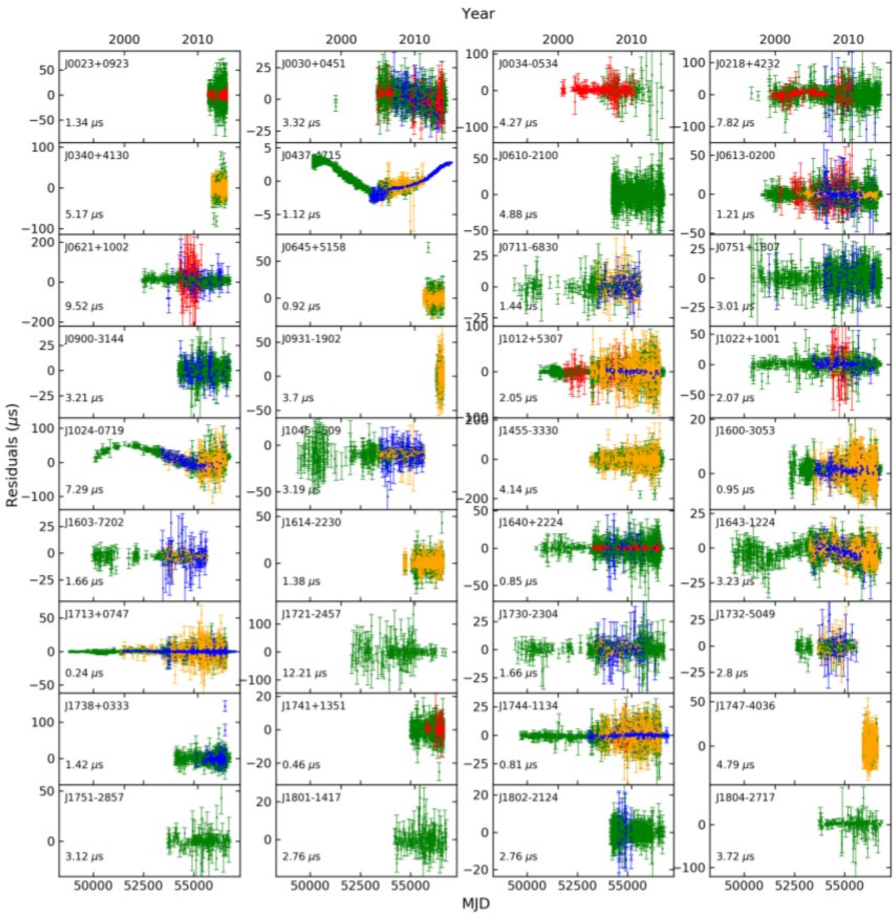


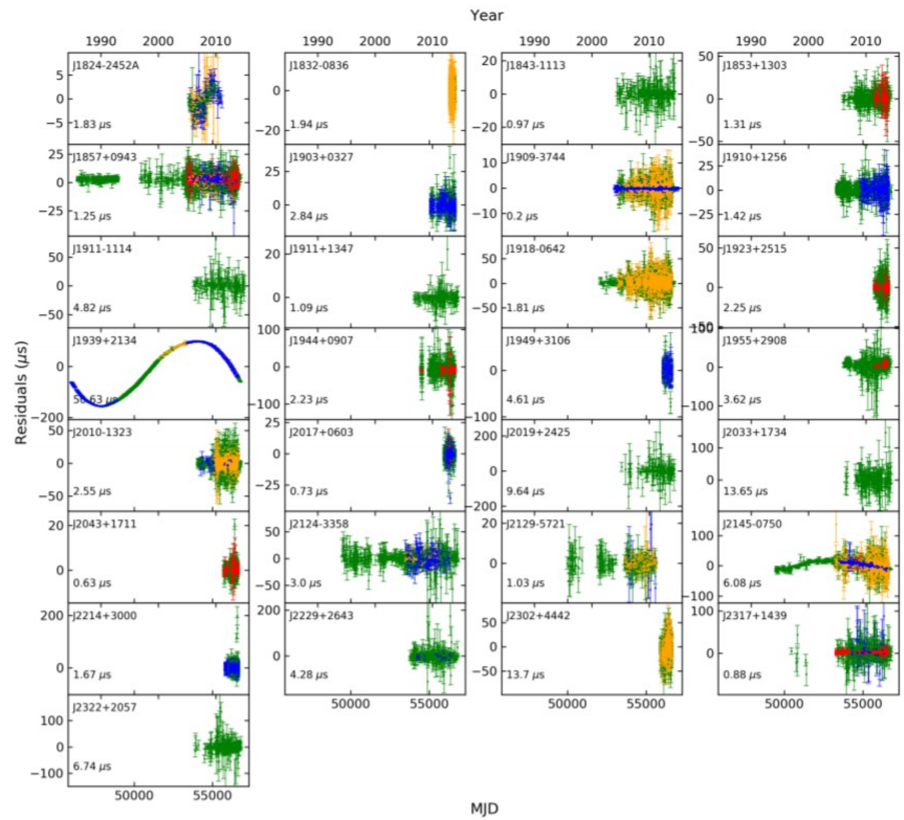
6 millisecond pulsars with up
to 24 years of observations

SC et al. (EPTA) 2021

IPTA Data release 2





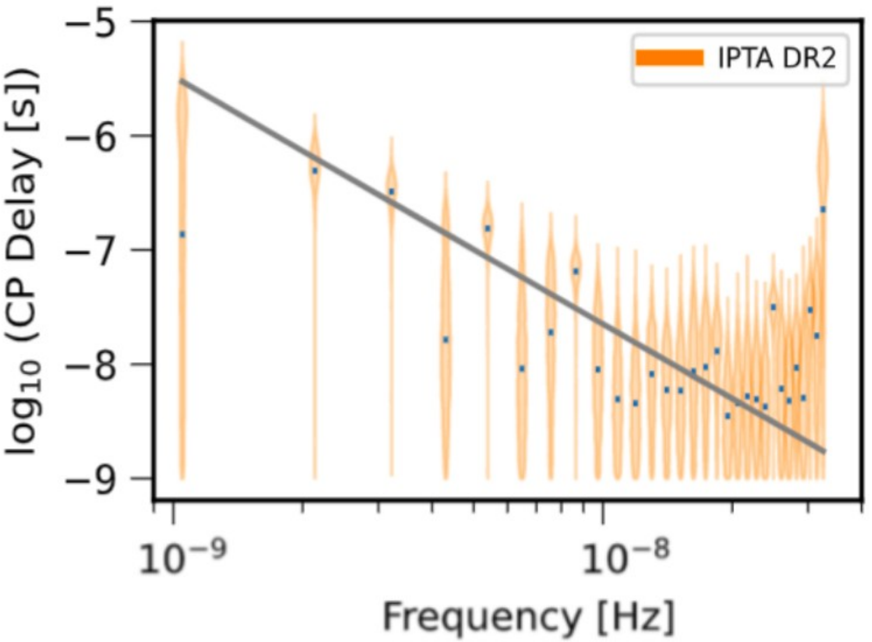


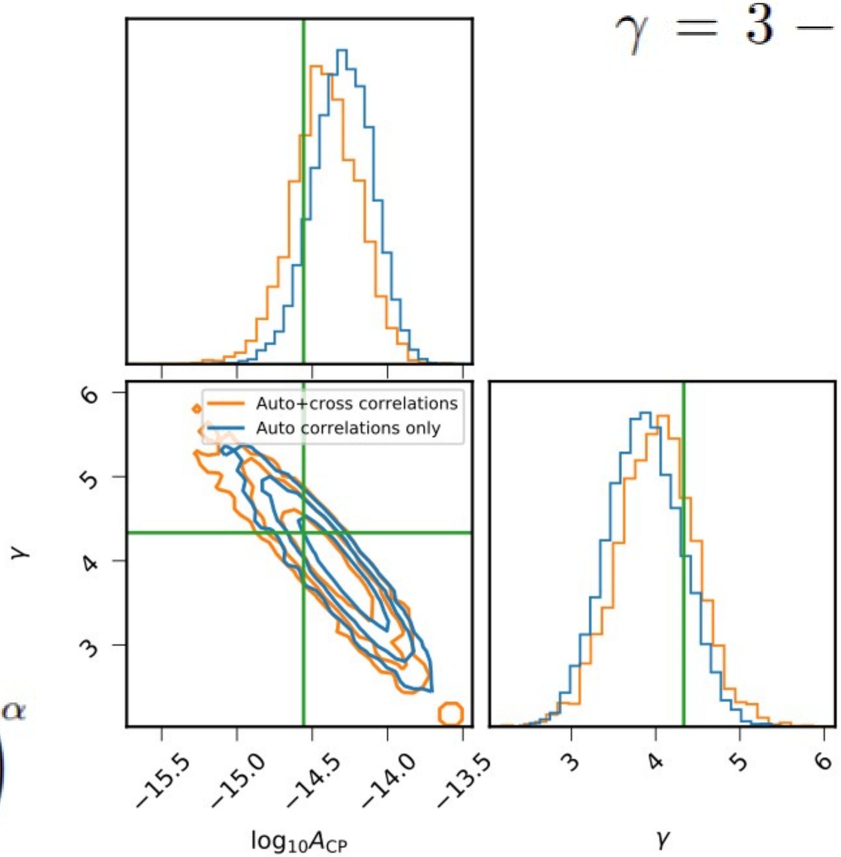
IPTA DR2: EPTA DR1 + NG9 + PPTA DR1e (Perera et al. 2019)
65 millisecond pulsars with up to 30 years of observations with up to 8 radio telescopes worldwide and ~100ns precision

IPTA DR2 – Bayesian Analysis

$$S_{GW} = \Gamma_{\alpha\beta} A_{GW}^2 f^{-\gamma_{GW}}$$

$$\gamma = 3 - 2\alpha$$





$$S_{ij}(f) = \Gamma_{ij} \frac{h_c^2}{12\pi^2 f^3} \qquad h_c(f) = A_{\mathrm{GWB}} \left(\frac{f}{f_{\mathrm{yr}}}\right)^{\alpha}$$

IPTA DR2: Antoniadis et al. 2022
Paper lead: SC, figures: N. Pol

IPTA DR2 – Bayesian Analysis

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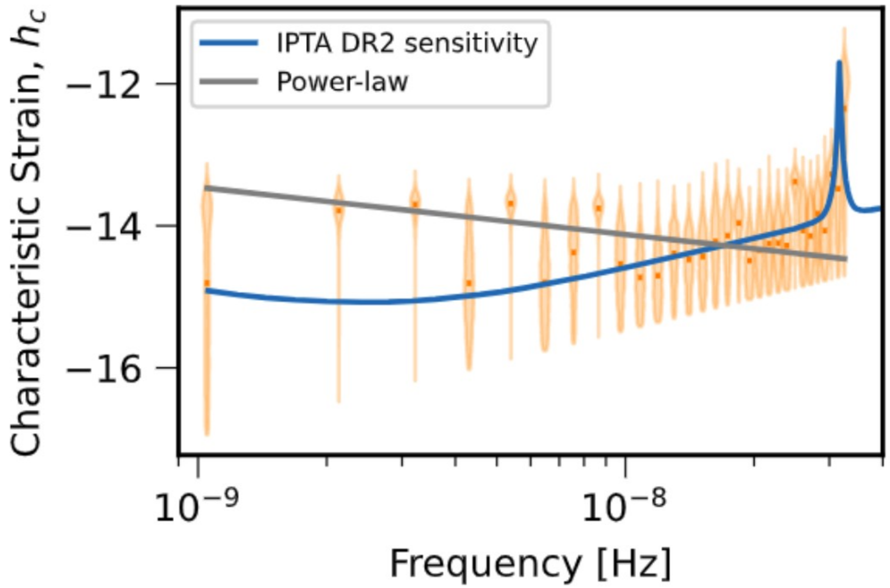

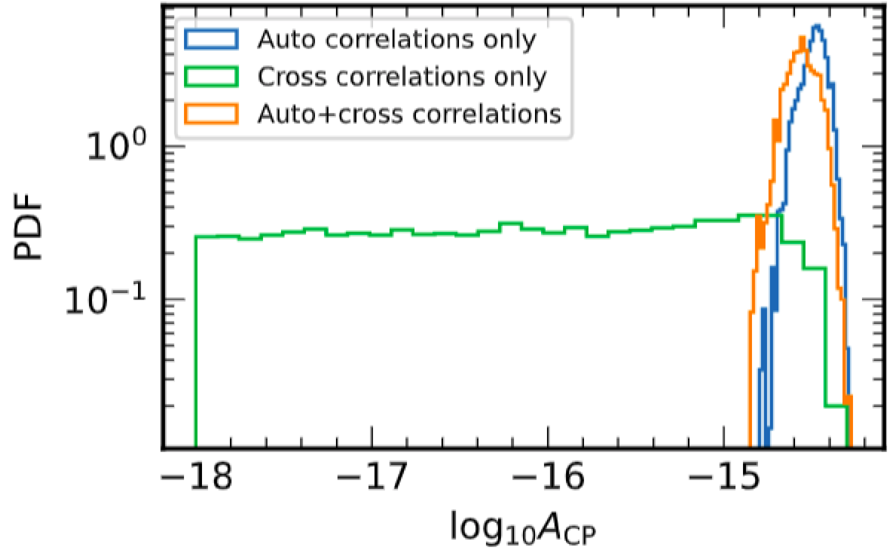

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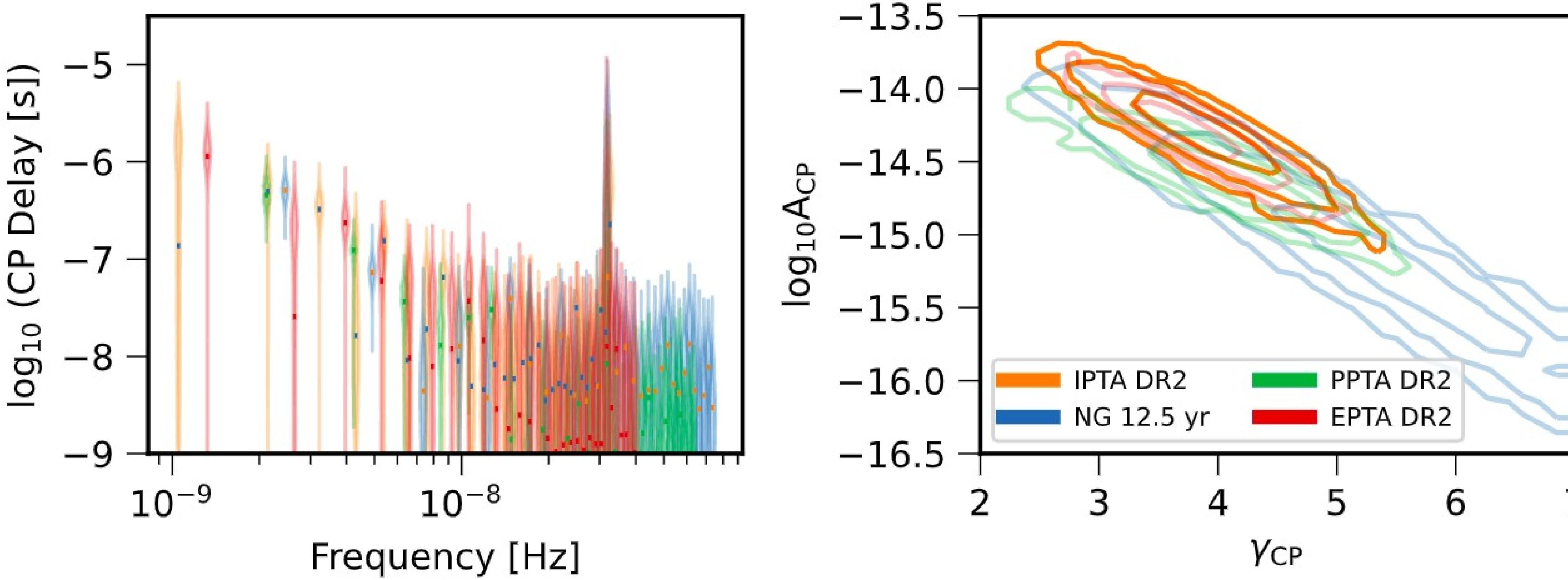
No conclusive evidence for the detection of a Gravitational wave background !

IPTA DR2: Antoniadis et al. 2022
Paper lead: SC, figures: N. Pol

$h_c = 3 \times 10^{-15}$ at 1/(1yr)
$\gamma = 13/3$; $\alpha = -2/3$

IPTA DR2 – Comparison



NANOGrav 12.5: Arzoumanian et al. 2020, PPTA DR2: Goncharov et al., 2021, EPTA DR2: SC et al., 2021

All three PTAs independently find a consistent uncorrelated spectrally-similar noise process

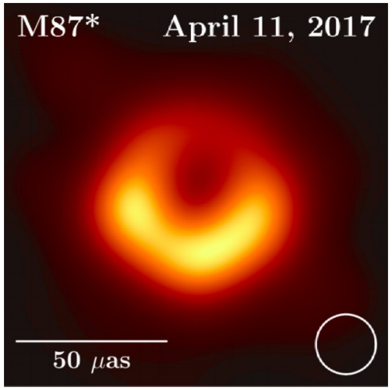
IPTA DR2: Antoniadis et al. 2022
Paper lead: SC, figures: N. Pol

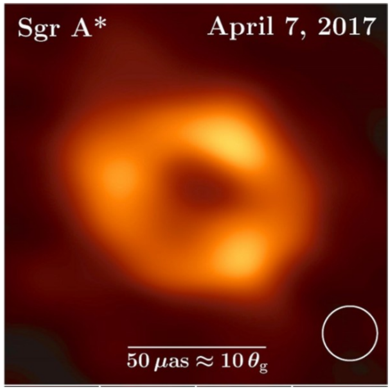
Interpretation

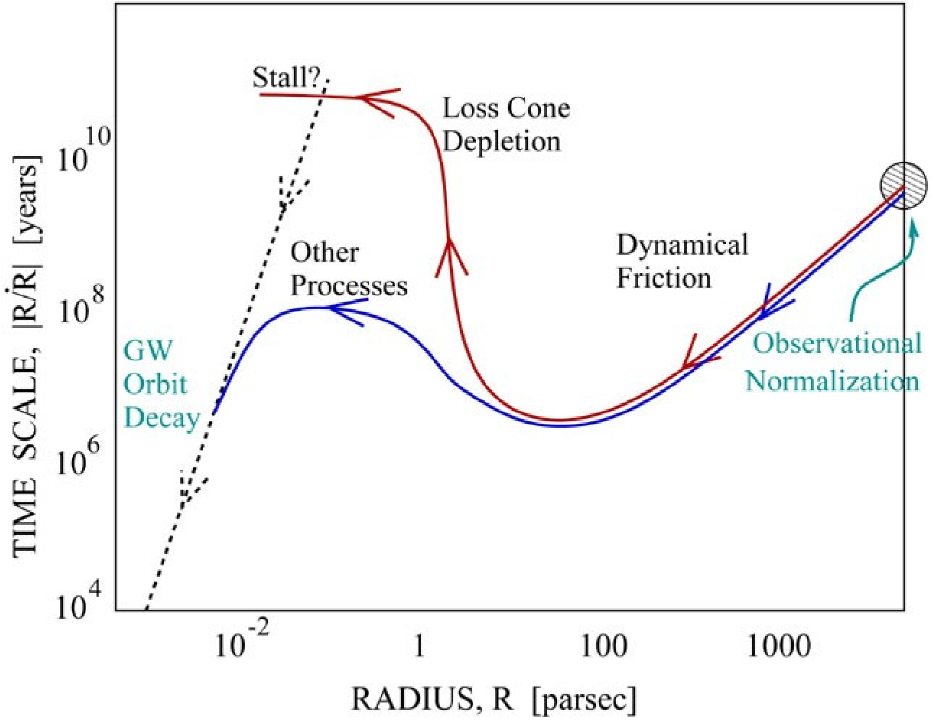
Credits: J. Turner

Supermassive black hole binaries

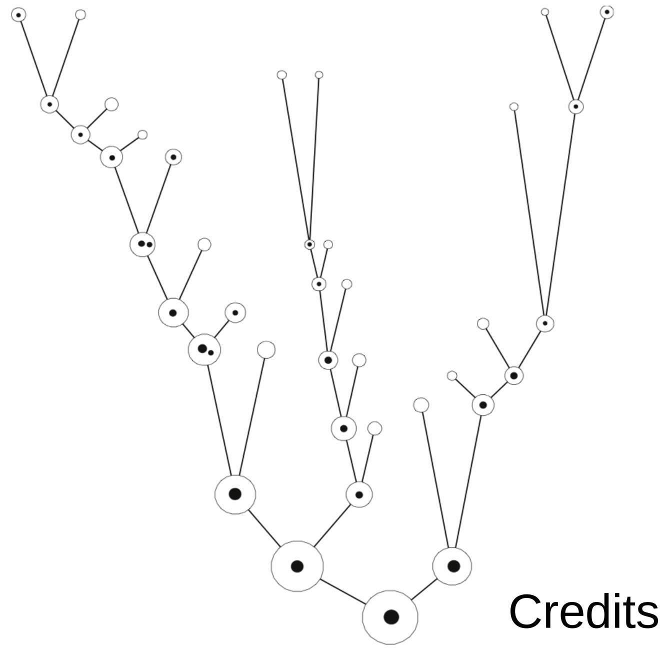
Credits: EHT





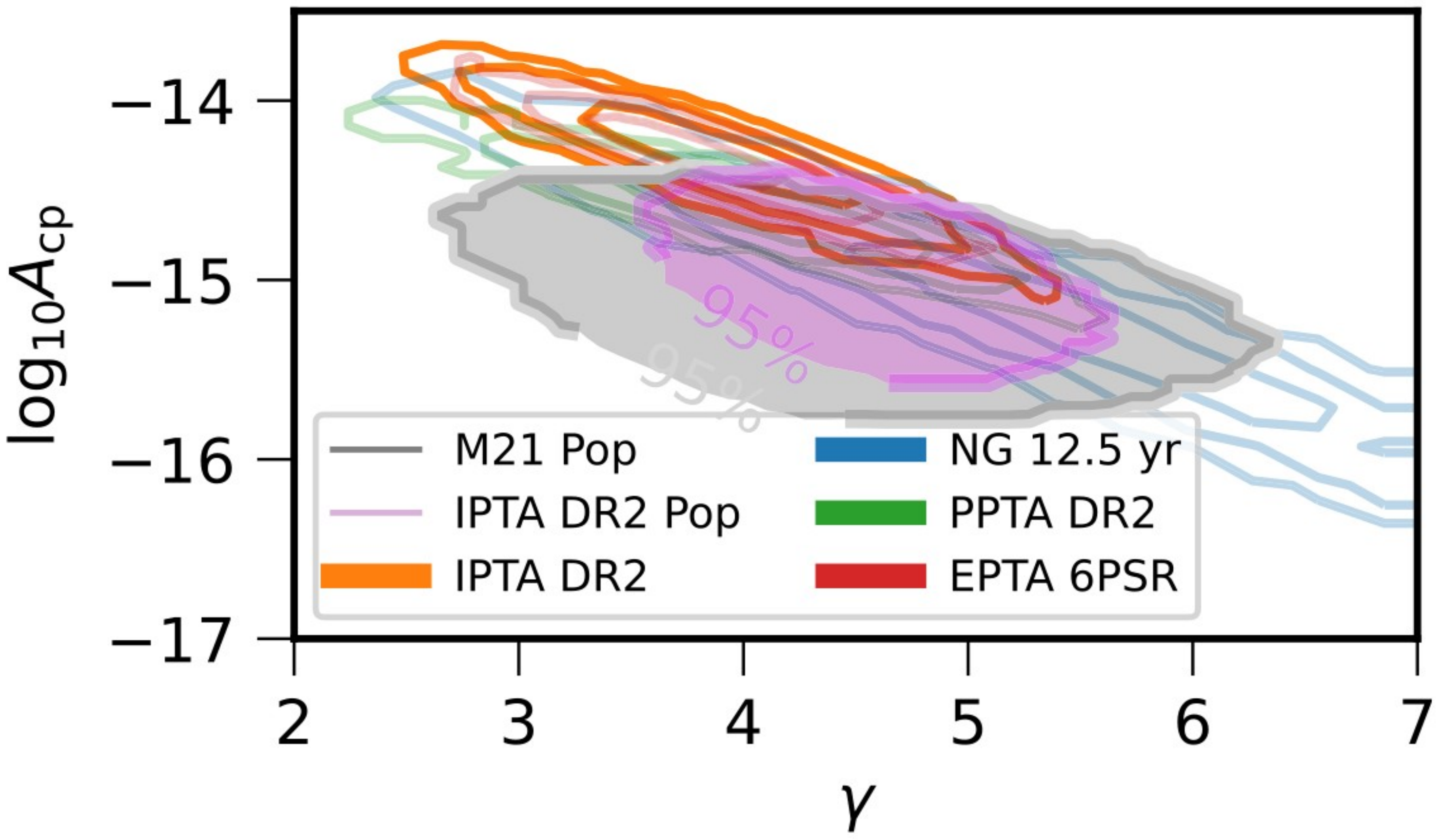


Vasiliev et al. 2015



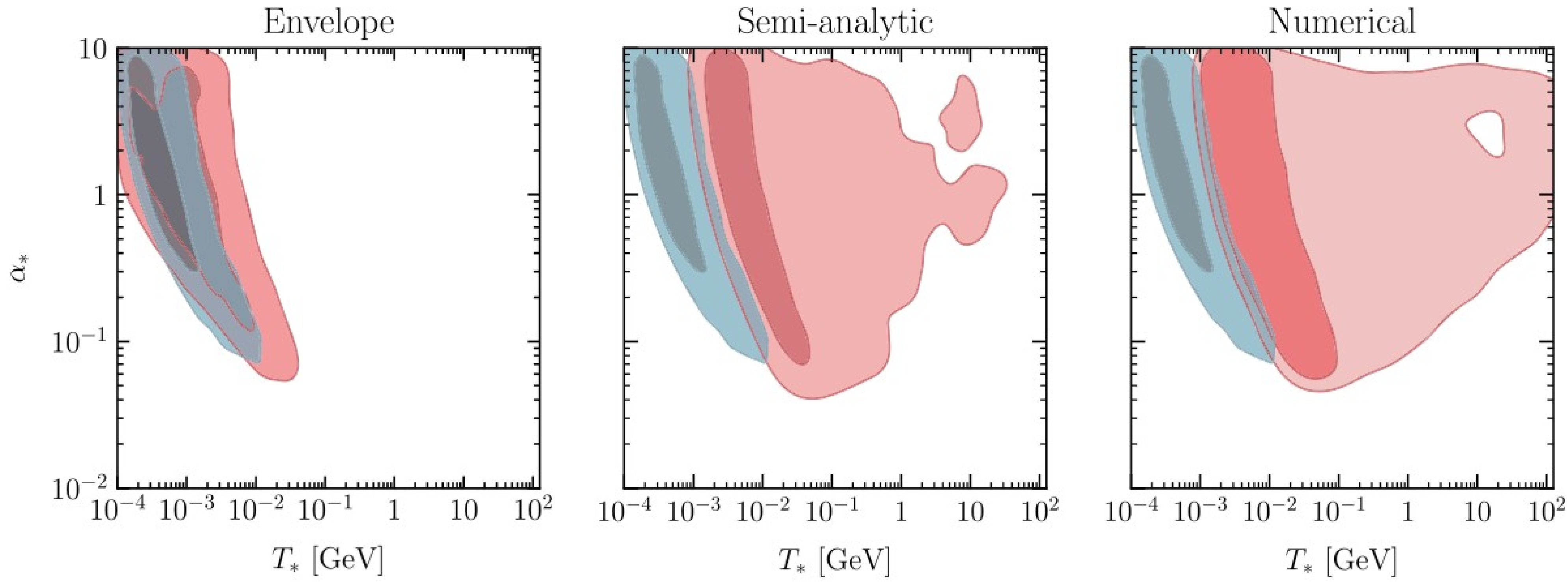
Credits: M. Volonteri

IPTA DR2 – Astrophysical Inference



IPTA DR2: GWB Search (in prep.)
Paper lead: SC, figures: N. Pol

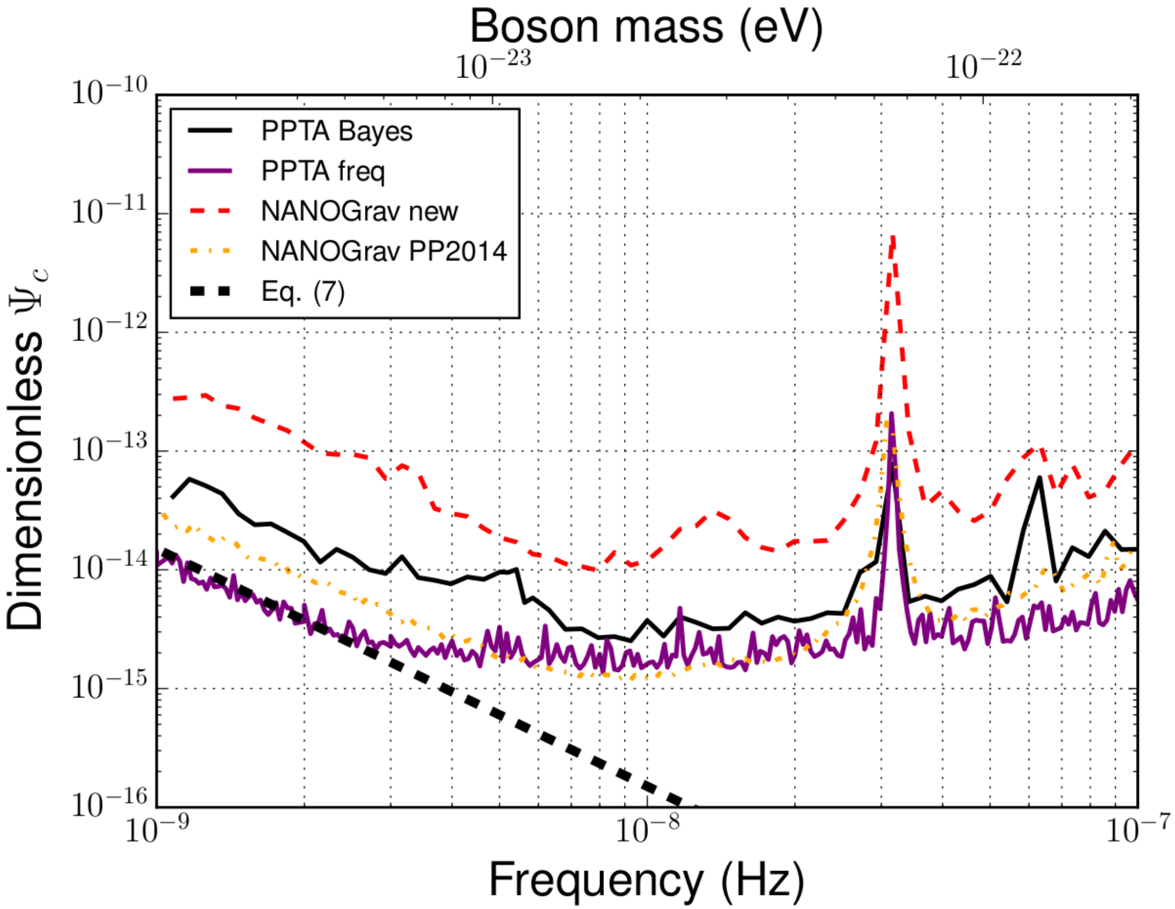
NANOGrav 12.5yr – Phase transitions



$$h^2\Omega(f) = \mathcal{R}\Delta(v_w)\left(\frac{\kappa\alpha_*}{1+\alpha_*}\right)^p\left(\frac{H_*}{\beta}\right)^q\mathcal{S}(f/f_*^0),$$

Arzoumanian et al. (NANOGrav) 2021
Lead: A. Mitridate

PPTA – Fuzzy Dark Matter

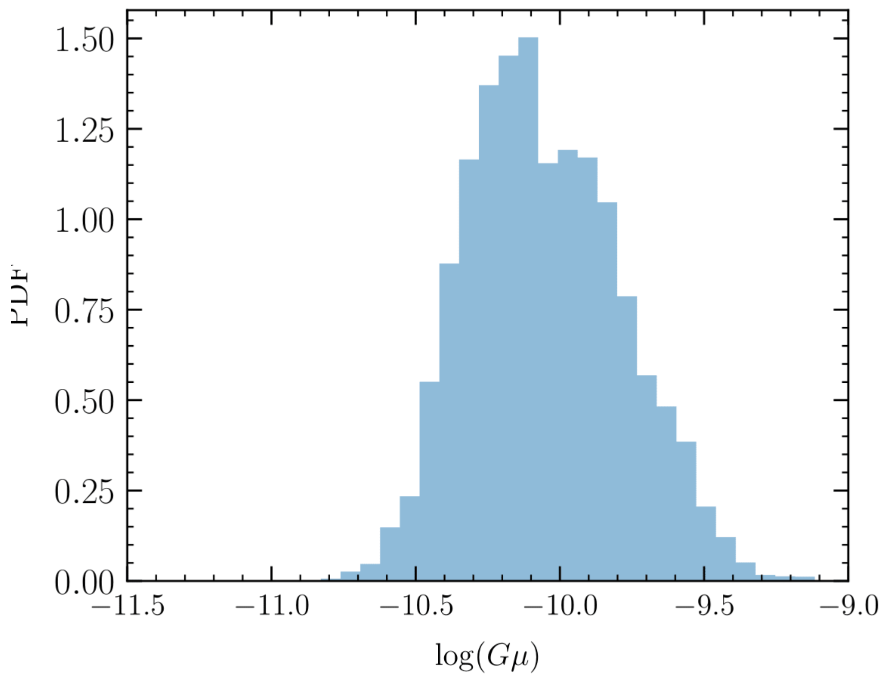


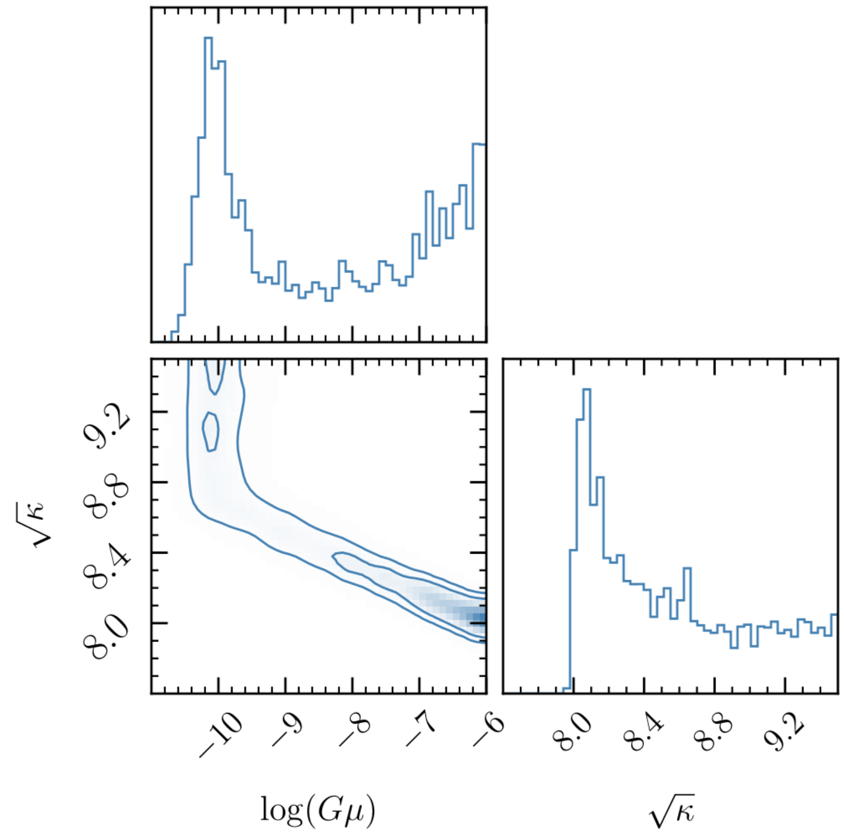
Porayko et al. 2018

$$\Psi_c = \frac{G\rho_{\rm SF}}{\pi f^2} \approx 6.1 \times 10^{-18} \left(\frac{m}{10^{-22}\,{\rm eV}}\right)^{-2} \left(\frac{\rho_{\rm SF}}{\rho_0}\right)$$

IPTA DR2 – Cosmic strings

PRELIMINARY



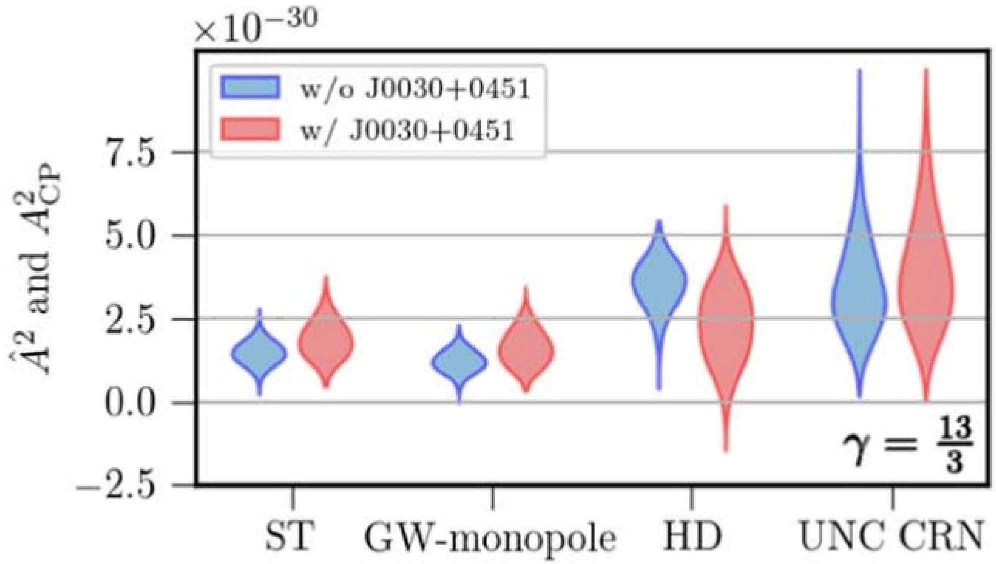


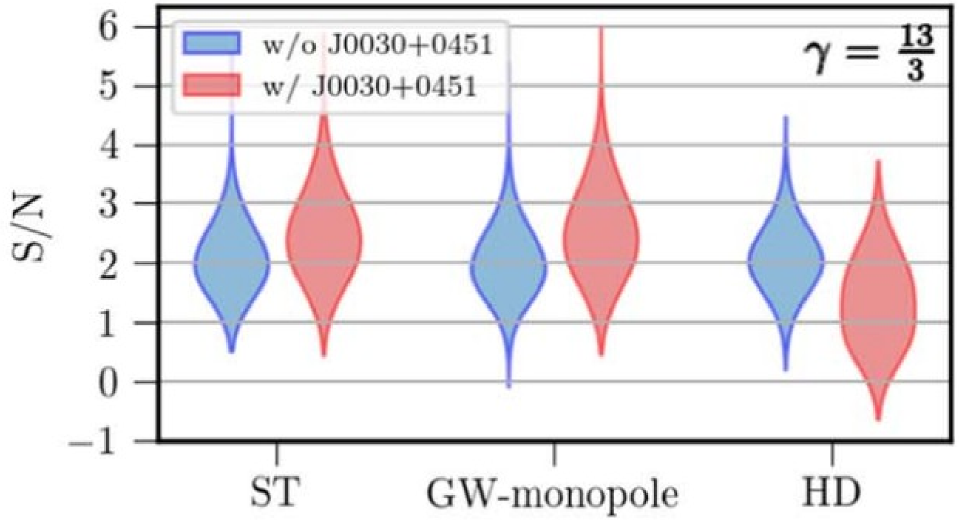
Figures: preliminary IPTA work, courtesy of A. Mitridate

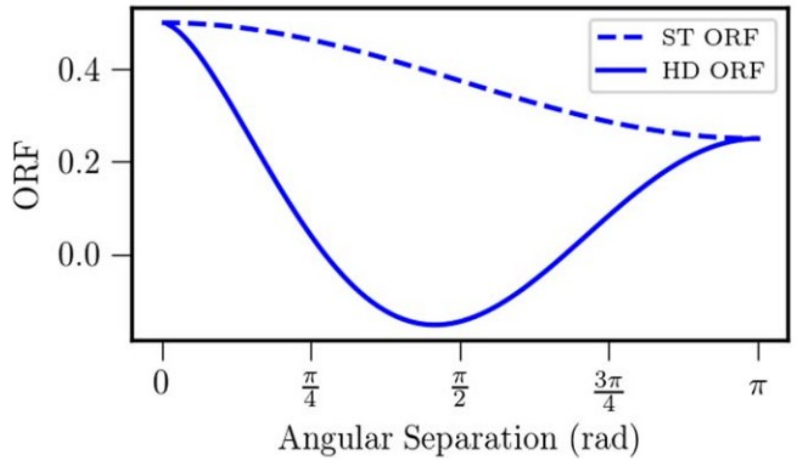
$$\Gamma_d = \frac{\mu}{2\pi} \exp\left(-\pi\kappa\right) , \quad \kappa = \frac{m^2}{\mu} ,$$

Theory: Buchmuller, Domcke, Schmitz, 2021

NANOGrav 12.5yr – Alternative polarizations





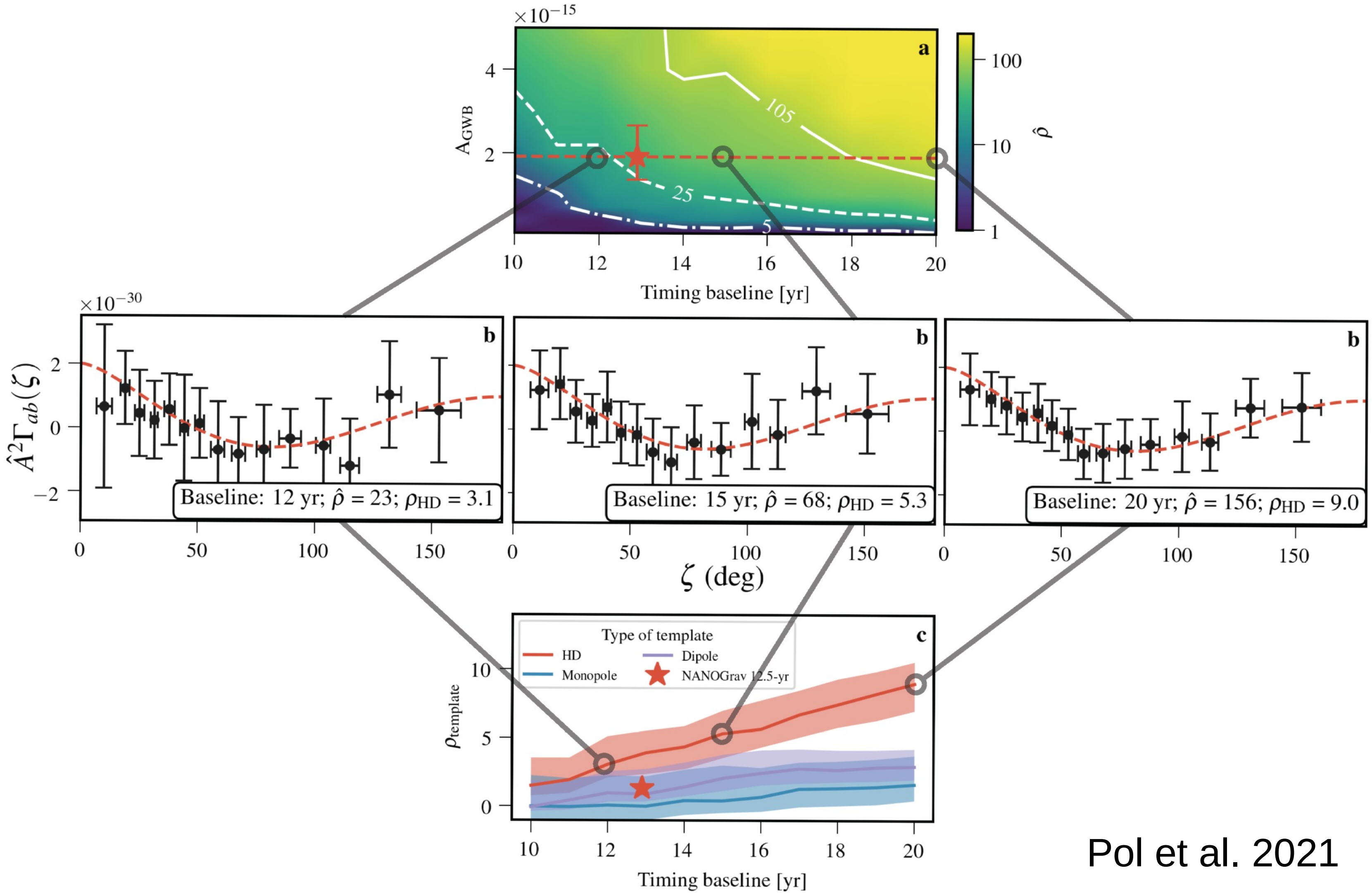


Arzoumanian et al.
(NANOGrav) 2021
Lead: N. Laal

Towards the detection of a GWB with Pulsar Timing Arrays

- Preliminary analyses of independent PTA data sets show consistent signs of a GWB, but no conclusive evidence for the Hellings-Downs correlation
- A characteristic strain of 2 – 3 x 10^{-15} can be explained by a local number density of supermassive black hole binaries of 1 – 30 x 10^{-4} per Mpc^3
- NANOGrav: 12.5yr dataset (ApJL, 905, L34), working on 15yr data set
- PPTA: DR2 (ApJL, 917, L19), working on extended data set
- EPTA: 6 pulsars for the DR2 (MNRAS, 508, 4970), working on increasing number of pulsars to 25
- IPTA DR2 GWB search (MNRAS, 510, 4873)
- Coordinate efforts on the IPTA level: plan for simultaneous publication of results from the regional PTAs around the end of 2022 (checked by external committee)
- Best chance of detecting a GWB when using a combined data set, preparations for next data combination DR3 started (including InPTA data, possibly also data from MeerKAT, CHIME, FAST)

What to expect for the future ?



Pol et al. 2021