Detecting Low-Frequency Gravitational Waves with Pulsar Timing Arrays

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Gravitational Wave Spectrum

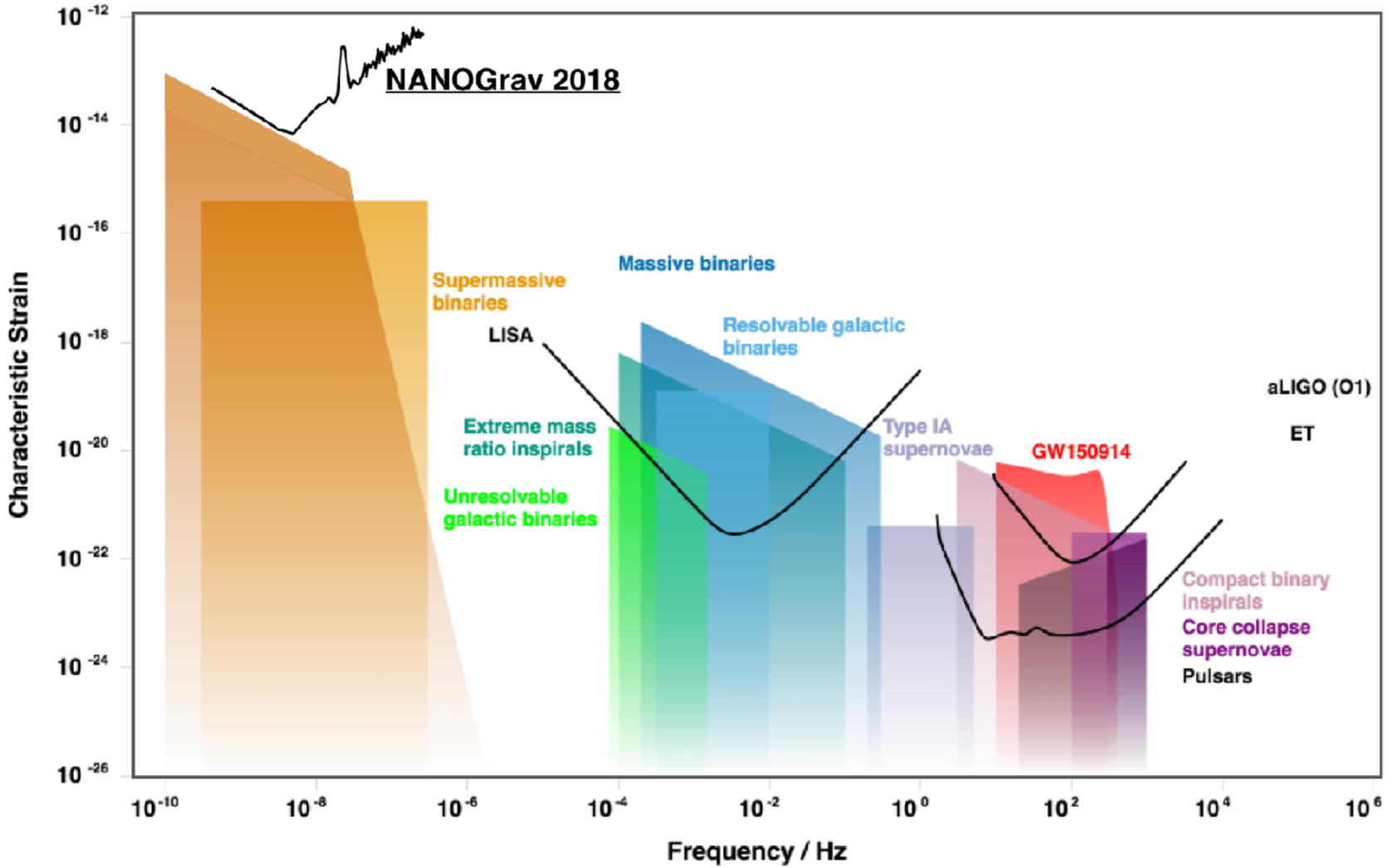
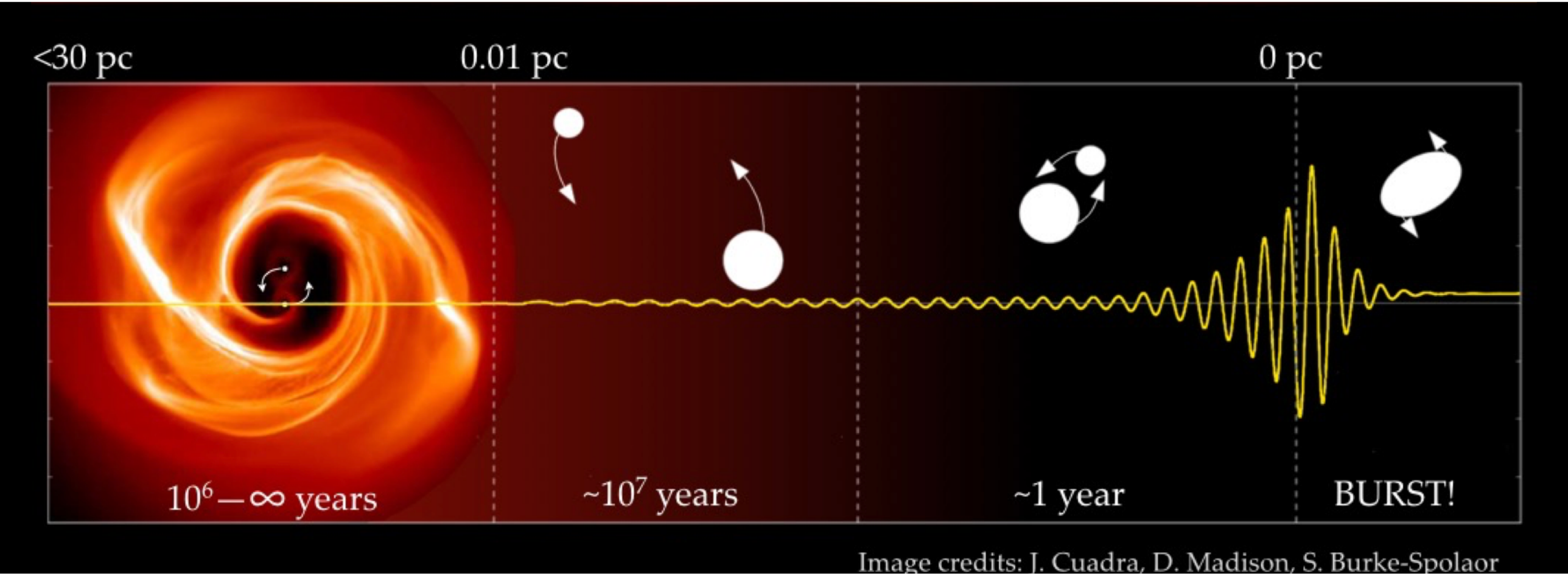


Figure credit: Moore, Cole, Berry (2014); modified by S.R. Taylor

Supermassive Black Hole Binaries



Stochastic Background

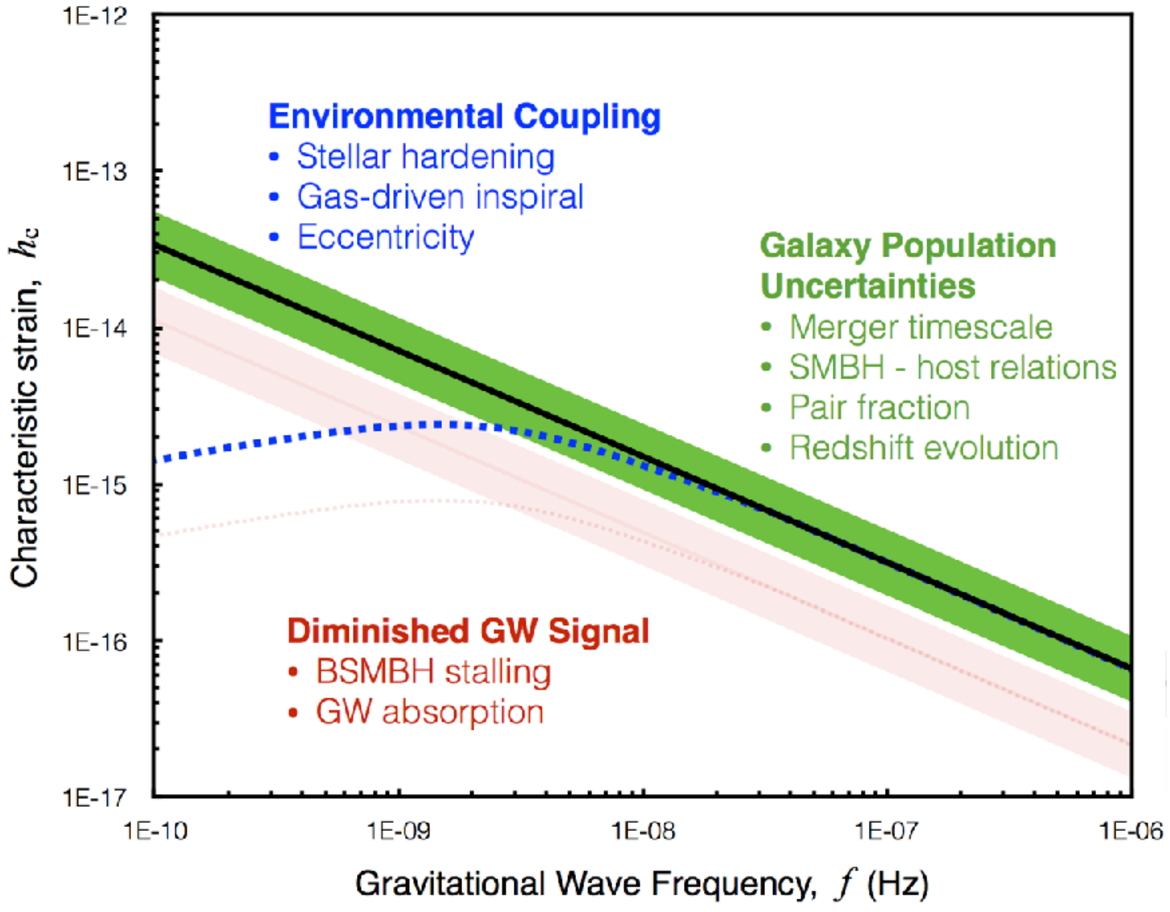


Image credit: S. Burke Spolaor 2015

If circular binaries evolve only due to GW emission, the stochastic background is

$$h_c(f) = A_{\rm gw} \left(\frac{f}{f_{1\,\rm yr}} \right)^{-2/3} .$$

If binaries evolve due to GW emission and environmental coupling,

$$h_c(f) = A_{\rm gw} \frac{(f/f_{1\,\rm yr})^{-2/3}}{[1 + (f_b/f)^{\kappa}]^{1/2}} .$$

If binaries are eccentric, there is a flattening of the GW spectrum at low frequencies.

Cosmic Strings

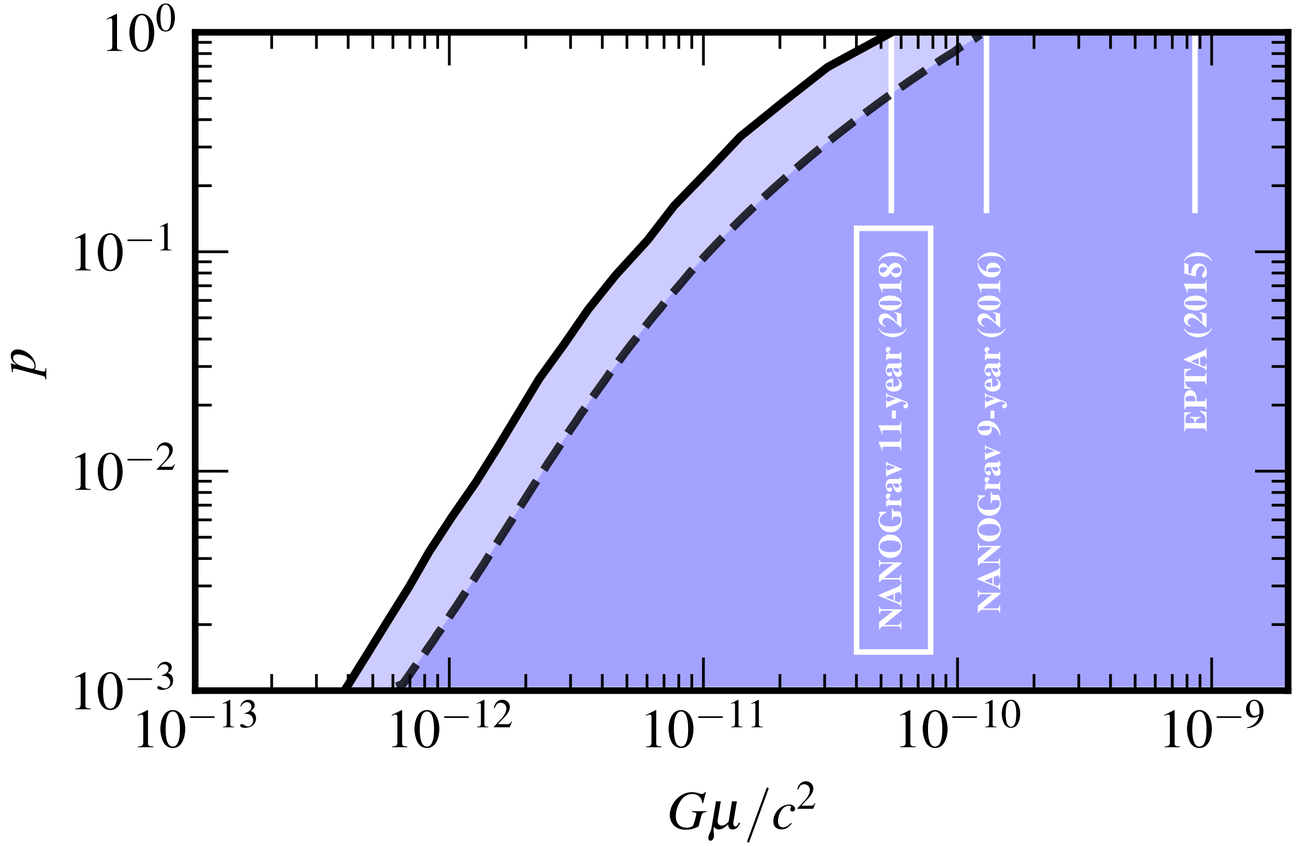


Figure credit: Arzoumanian et al. (The NANOGrav Collaboration), 2018

Cosmic strings are spacetime defects formed during early-Universe phase transitions.

Small loops emit GWs and decay (Vilenkin 1985).

PTAs can place limits on the reconnection probability and string tension.

Pulsars

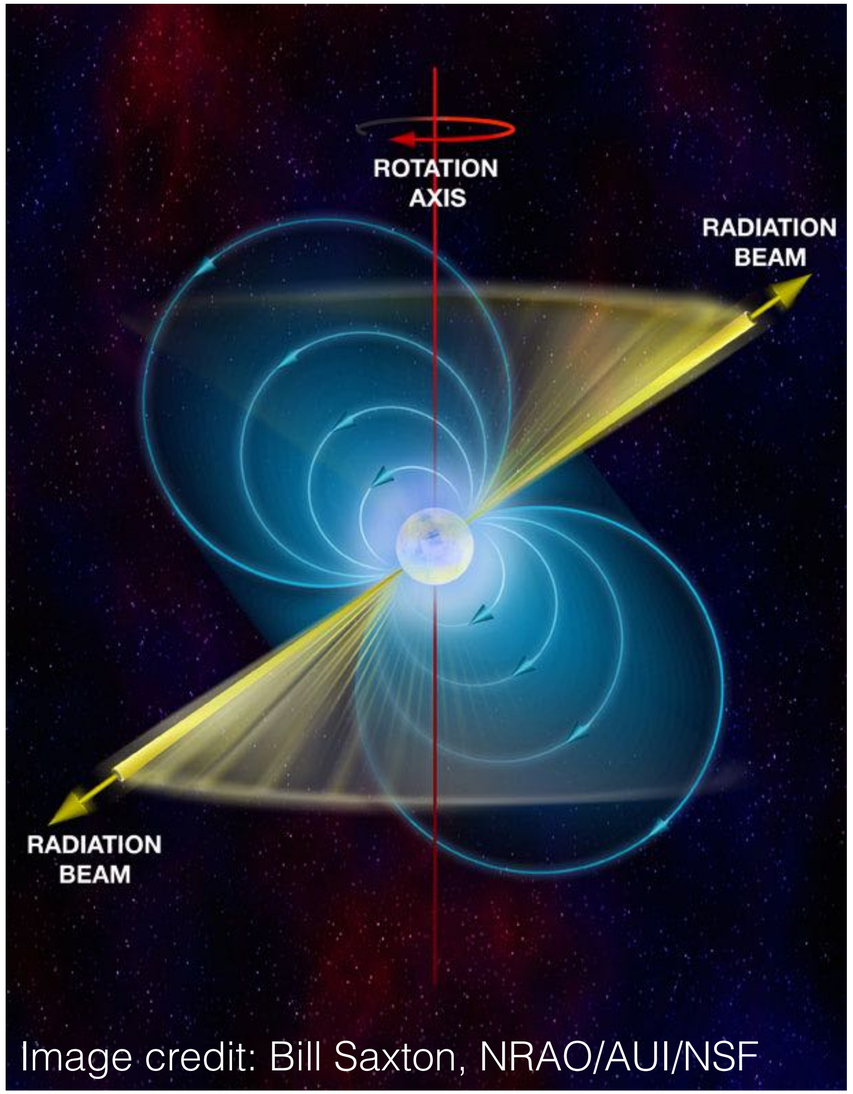


Image credit: Bill Saxton, NRAO/AUI/NSF

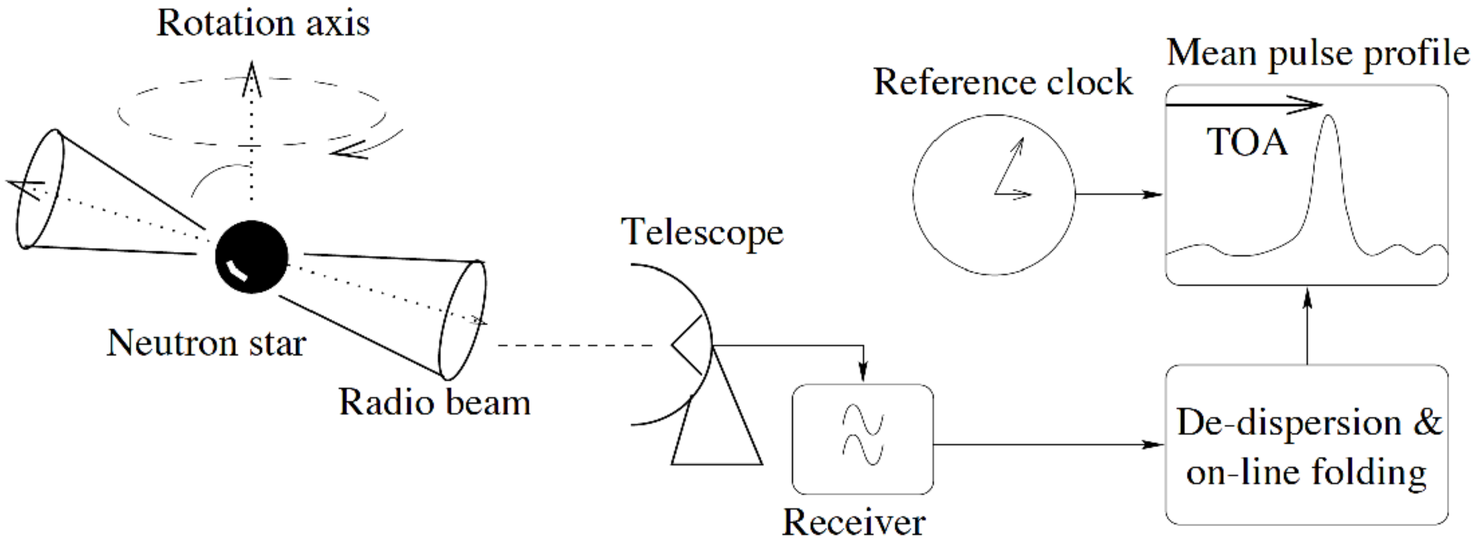


Image credit: Lorimer and Kramer, *The Handbook of Pulsar Astronomy*

Pulsar Timing Arrays

Gravitational waves induce correlated changes in the pulse times of arrival.

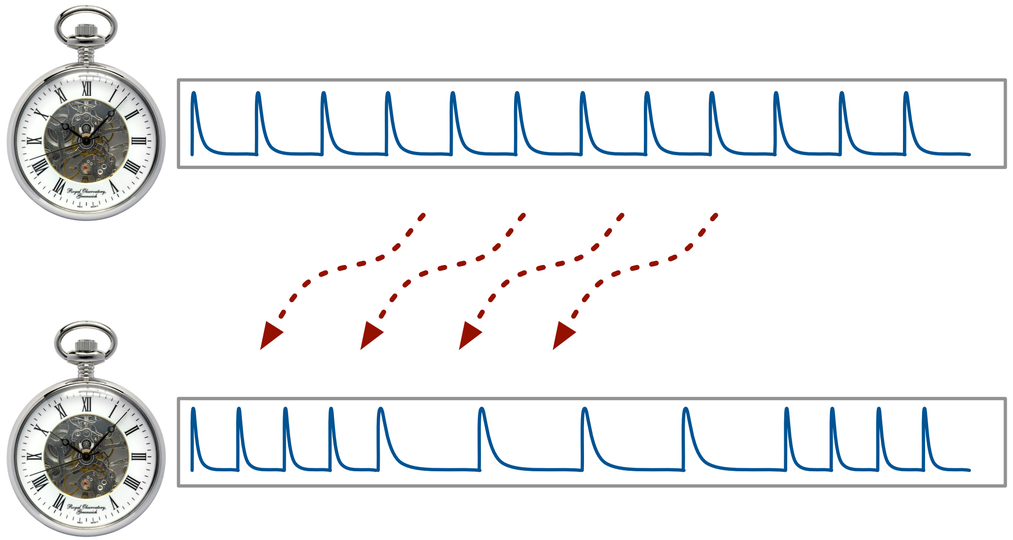


Image credit: S. Chatterjee

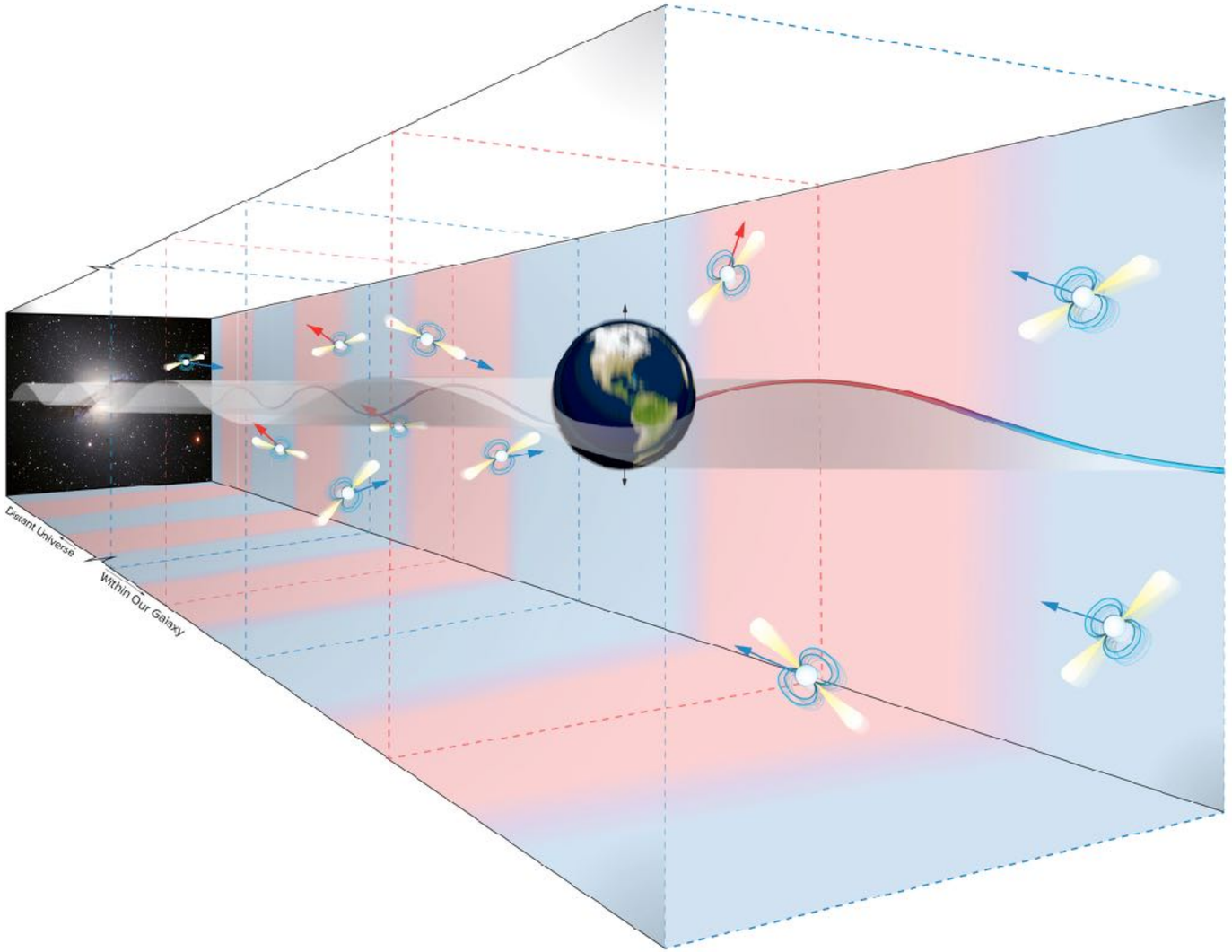


Image credit: NRAO

North American Nanohertz Observatory for Gravitational Waves

Image credits: NRAO/AUI, NAIC, CHIME Collaboration

The International Pulsar Timing Array

Image credits: NRAO/AUI, NAIC, EPTA, ATNF/CSIRO, Google maps

Limits on the Stochastic Background

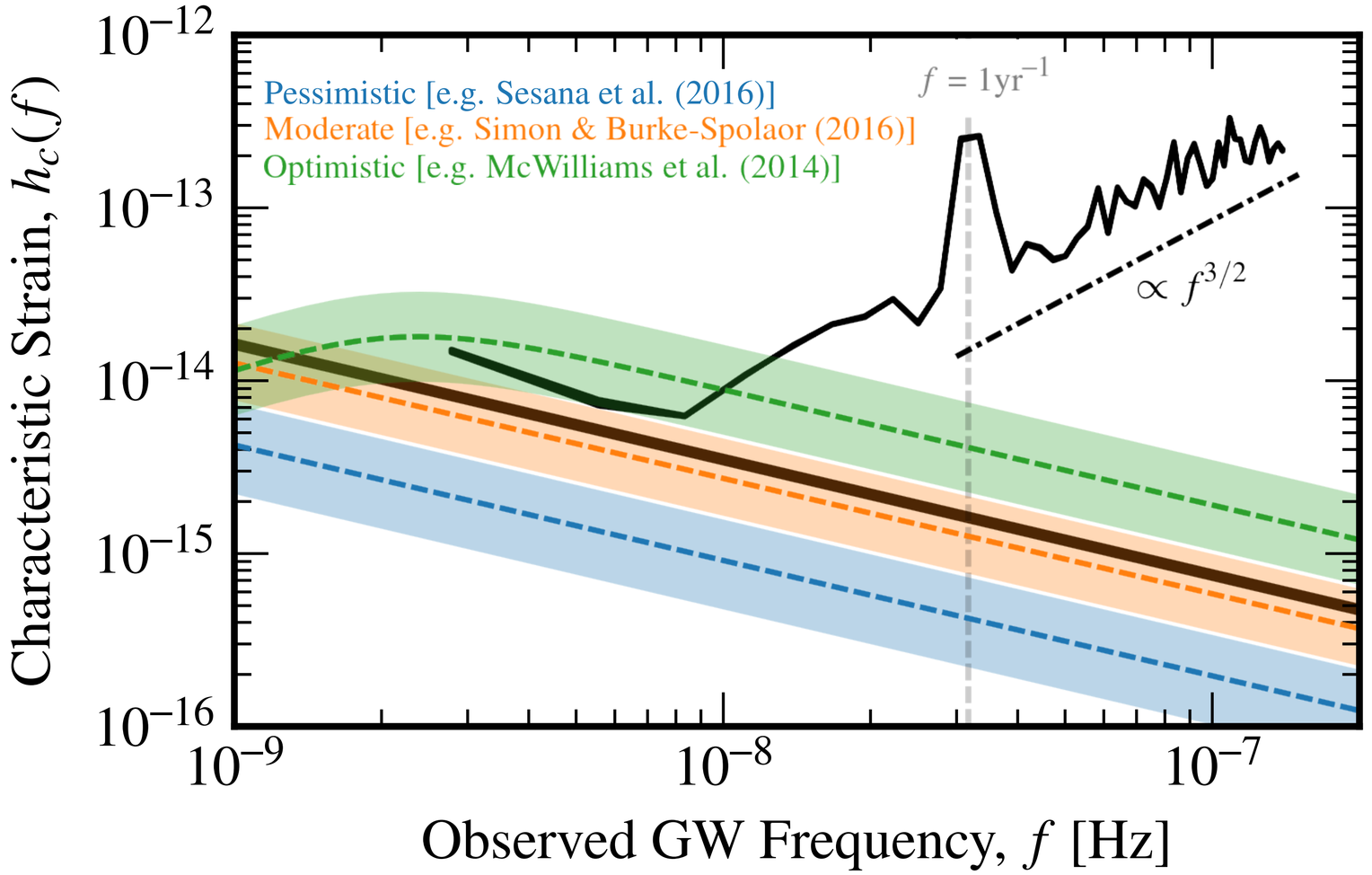


Figure credit: Arzoumanian et al. (The NANOGrav Collaboration), 2018

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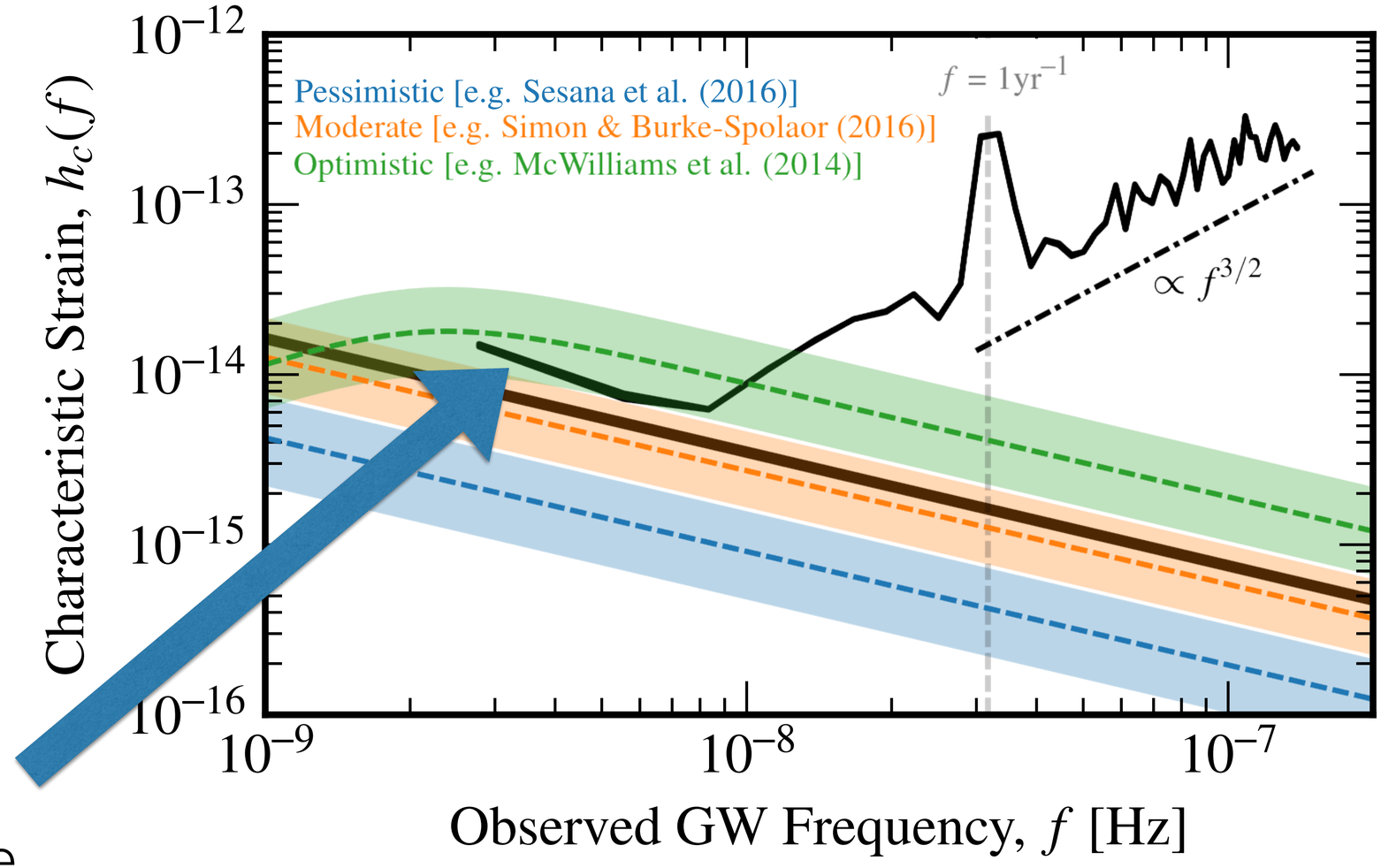

Low-frequency cutoff set by total observation time

Figure credit: Arzoumanian et al. (The NANOGrav Collaboration), 2018

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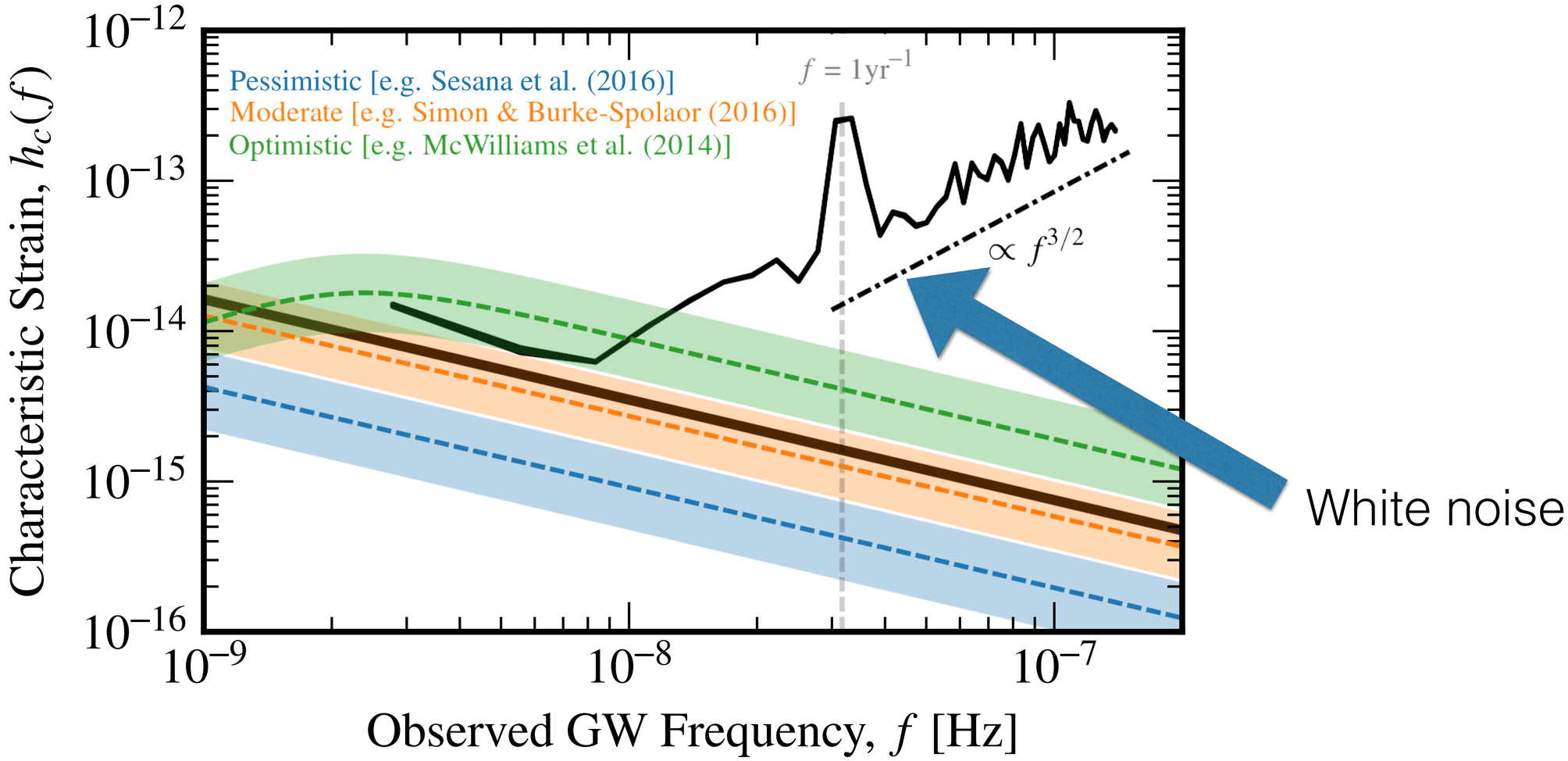

Figure credit: Arzoumanian et al. (The NANOGrav Collaboration), 2018

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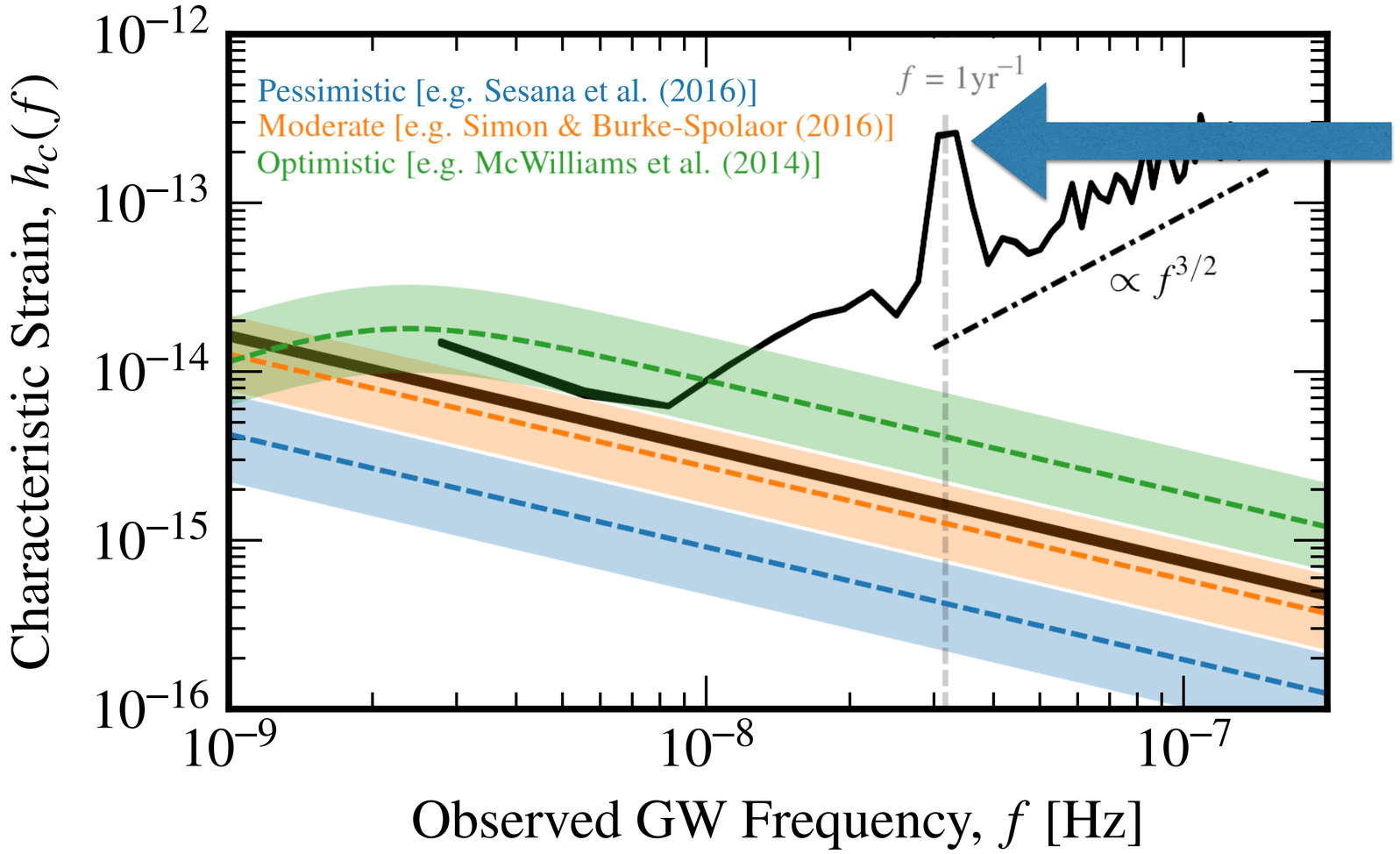

Decreased sensitivity at f = 1/(1 yr)

Figure credit: Arzoumanian et al. (The NANOGrav Collaboration), 2018

Solar System Ephemeris Error

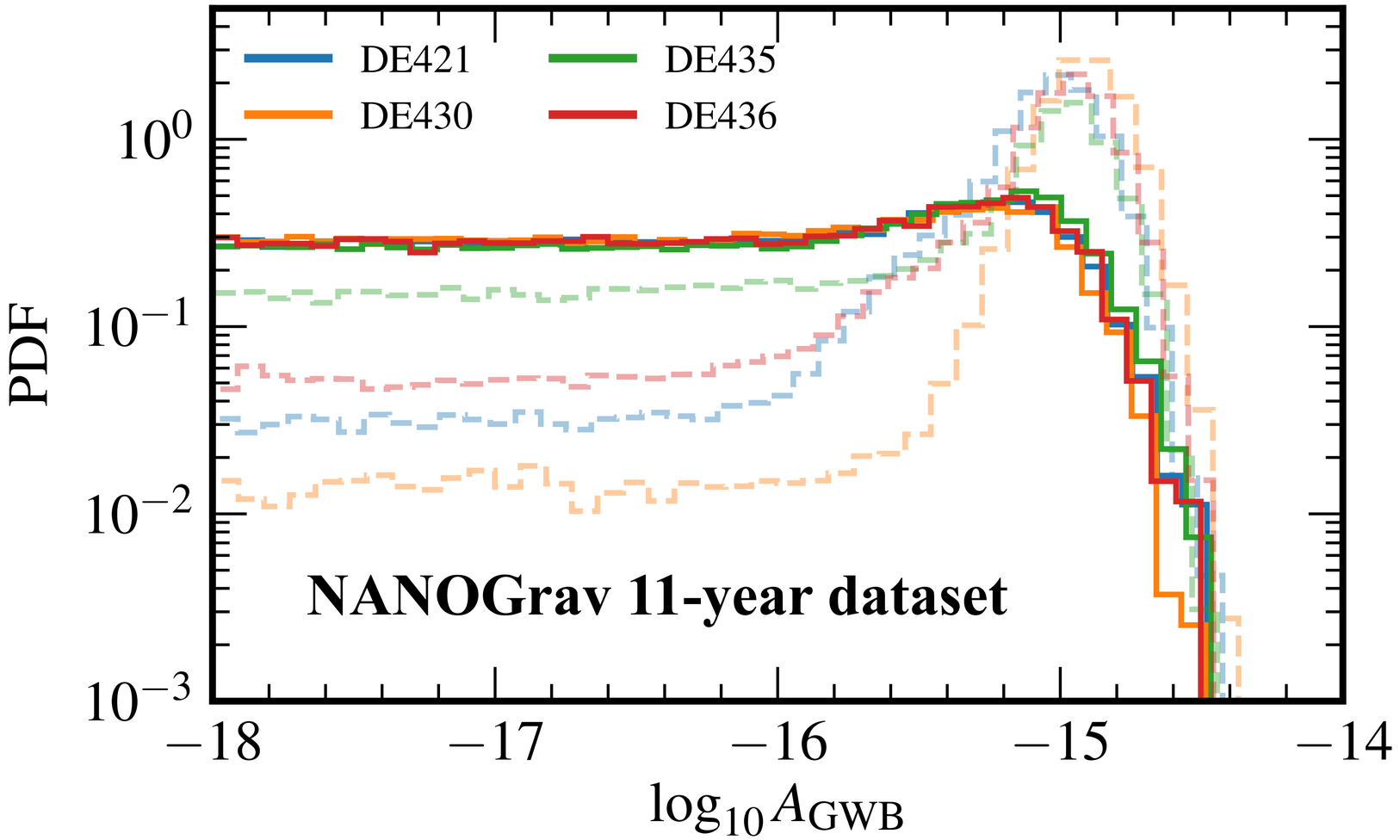

Figure credit: Arzoumanian et al. (The NANOGrav Collaboration), 2018

Different ephemerides give different Bayes factors for a common red process

All ephemerides give the same result when we include ephemeris uncertainty in our model through `BayesEphem`

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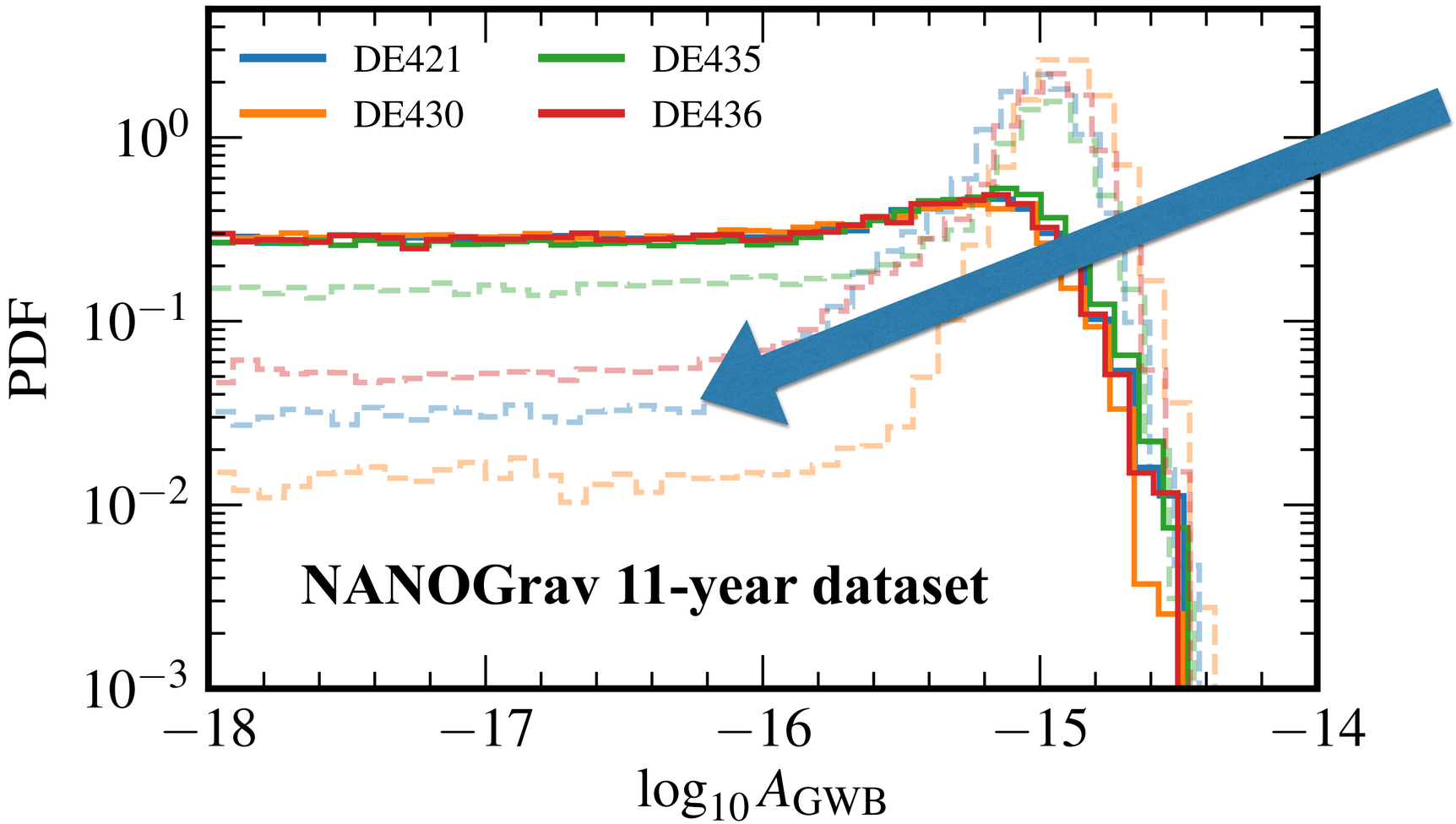

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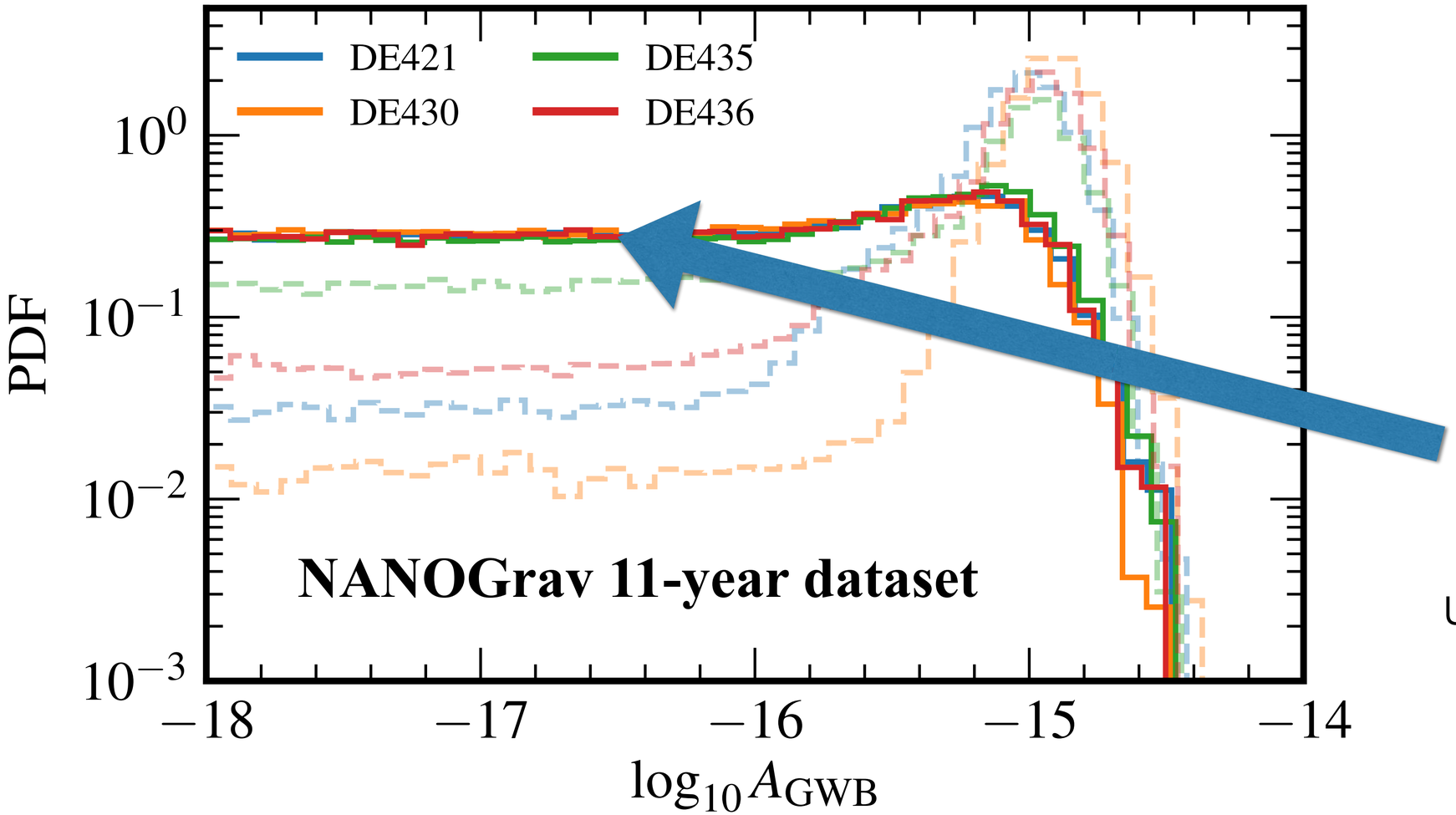

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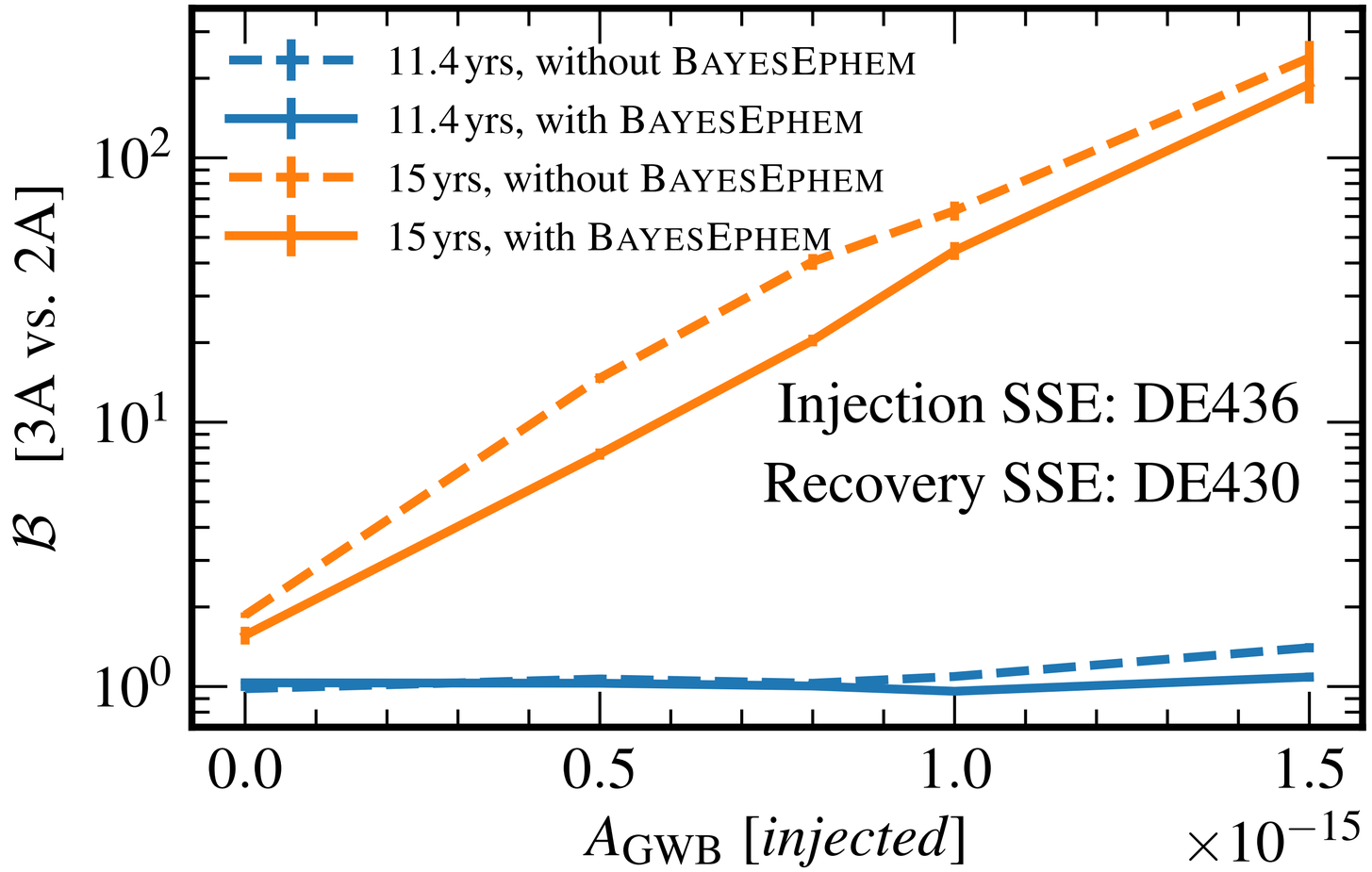
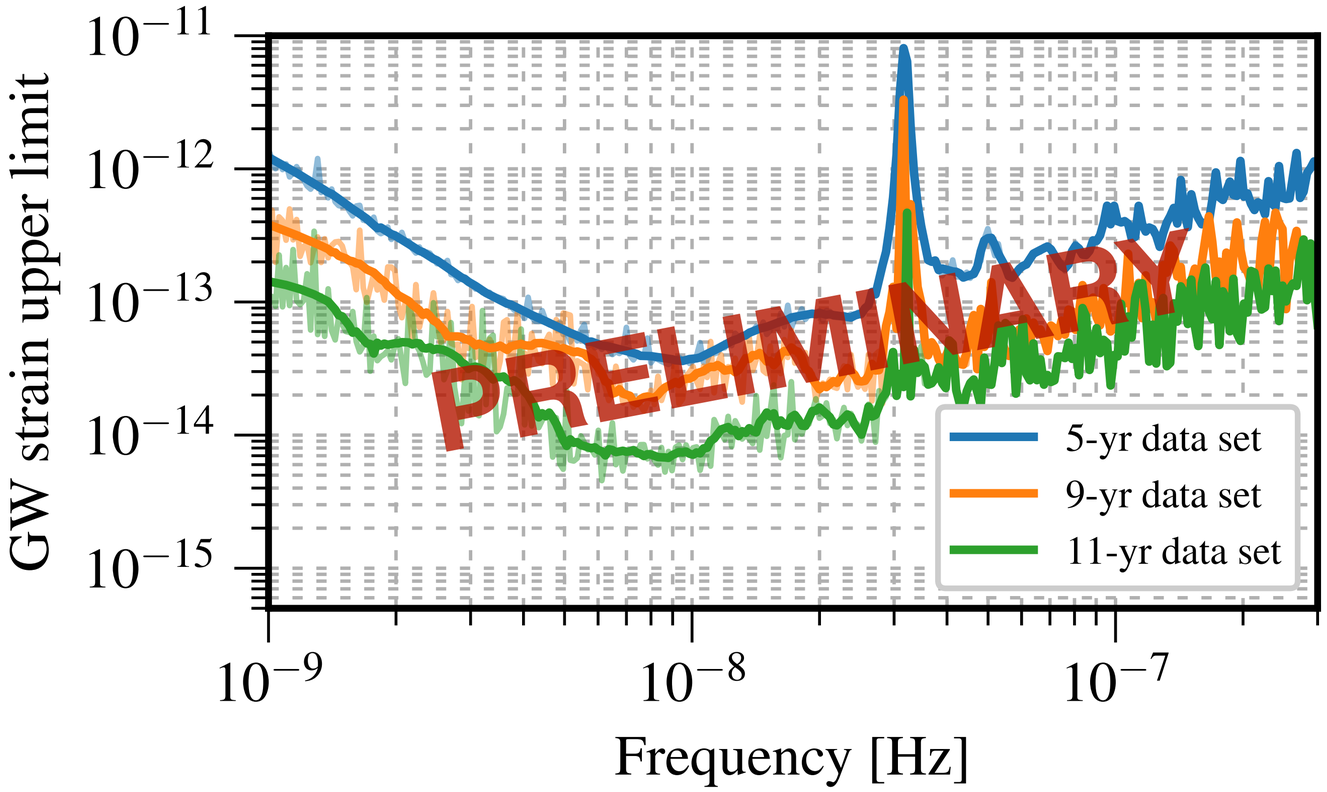


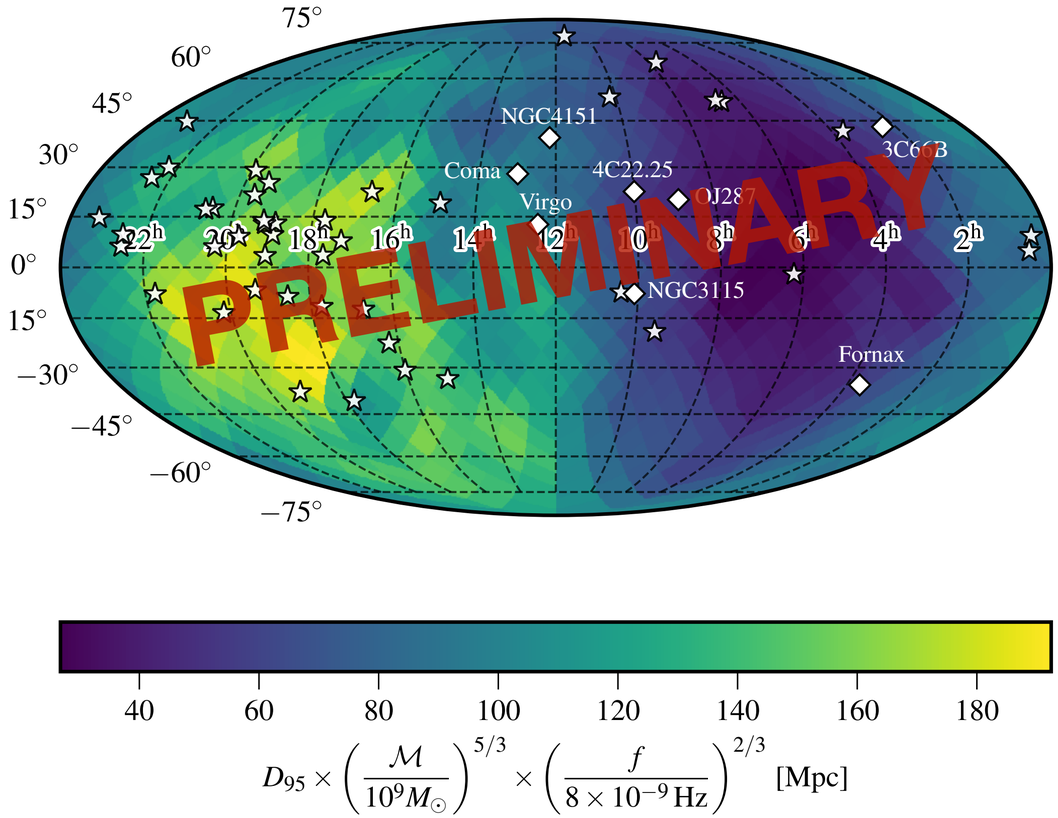
With longer observation times, we can distinguish between the stochastic background and Solar System ephemeris error.

Figure credit: Arzoumanian et al. (The NANOGrav Collaboration), 2018

GWs from Individual SMBHBs

An upcoming paper will present limits on GWs from individual SMBHBs from the NANOGrav 11-yr data set.





We set lower limits on the distances to individual SMBHBs for given chirp masses.

Conclusions

- Pulsar timing arrays are sensitive to low-frequency gravitational waves with frequencies between 1 nHz and 1 μHz.
- PTAs detect GWs by looking for correlated changes in the times of arrival of pulsars.
- The primary sources in this band are supermassive black hole binaries.
- PTAs are already being used to do astrophysics (SMBHBs, cosmic strings).
- Detection of the stochastic background is expected within the next 3 - 7 years (Taylor et al. 2016).