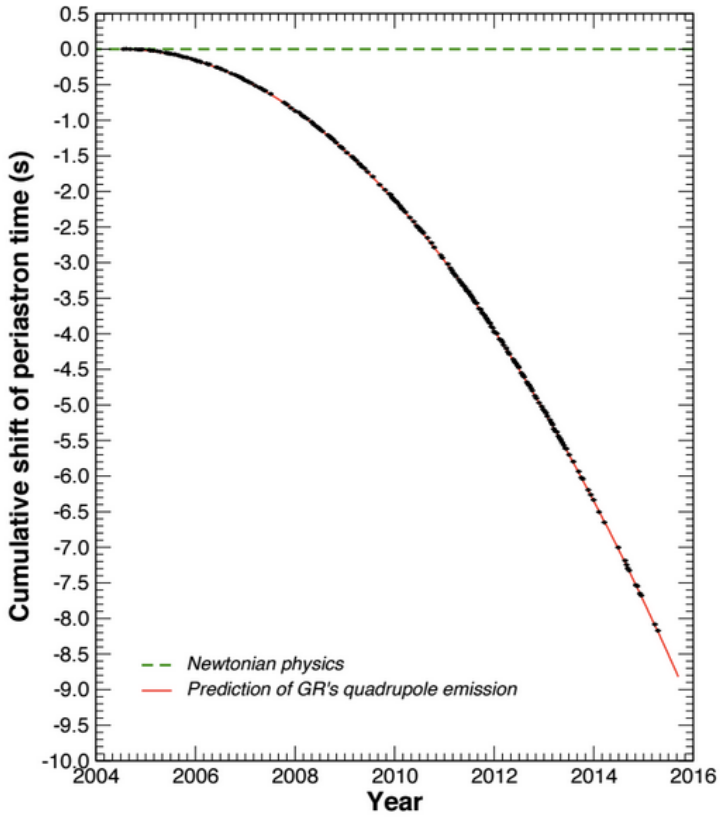
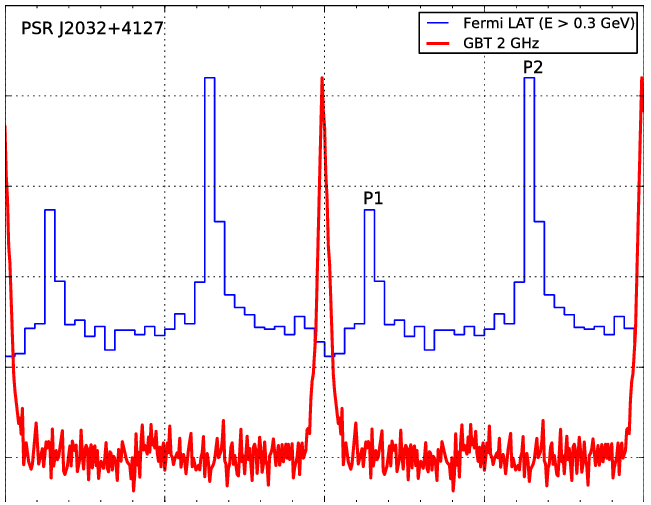
Pulsar Astronomy With Single Dishes

Physics Frontiers Center

Science Goals

- Low-frequency gravitational wave detection and characterization.
- Tests of gravity and general relativity.
- Pulsar emission physics.
- Population modeling and constraints on supernova kick velocities and neutron star birthrates.
- Studies of stellar evolution and binary interaction.
- Probing Galactic ISM and magnetic fields.





All can be done with single dishes

- Spatial resolution not necessary (aside from a few niches…)
- Collecting area, wide bandwidths, high time and frequency resolution, and instrumental fidelity are key requirements.

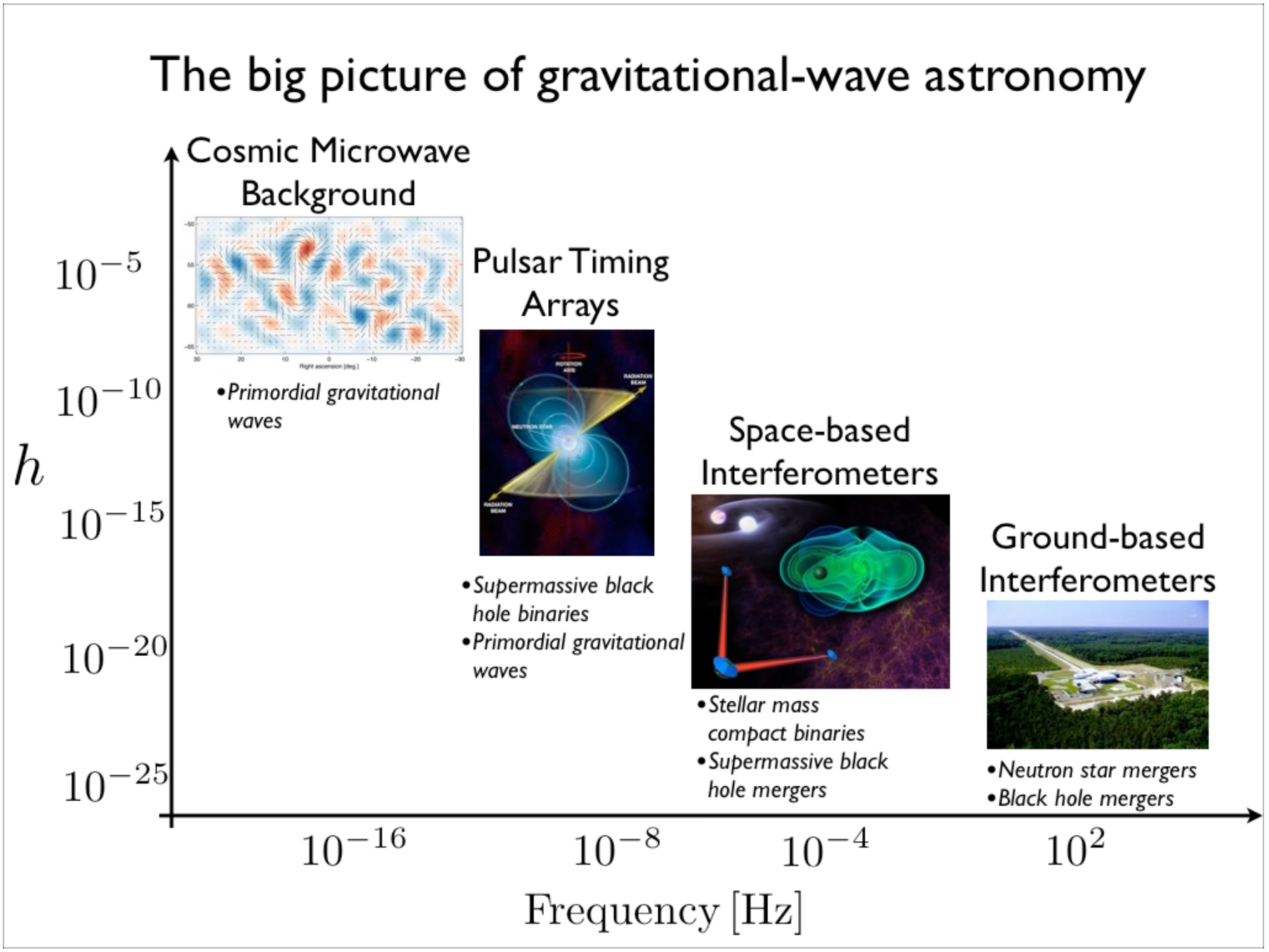
They can also be done with arrays, with some advantages

- Multiple beams allows efficient searches or timing of multiple pulsars at once.

And some disadvantages

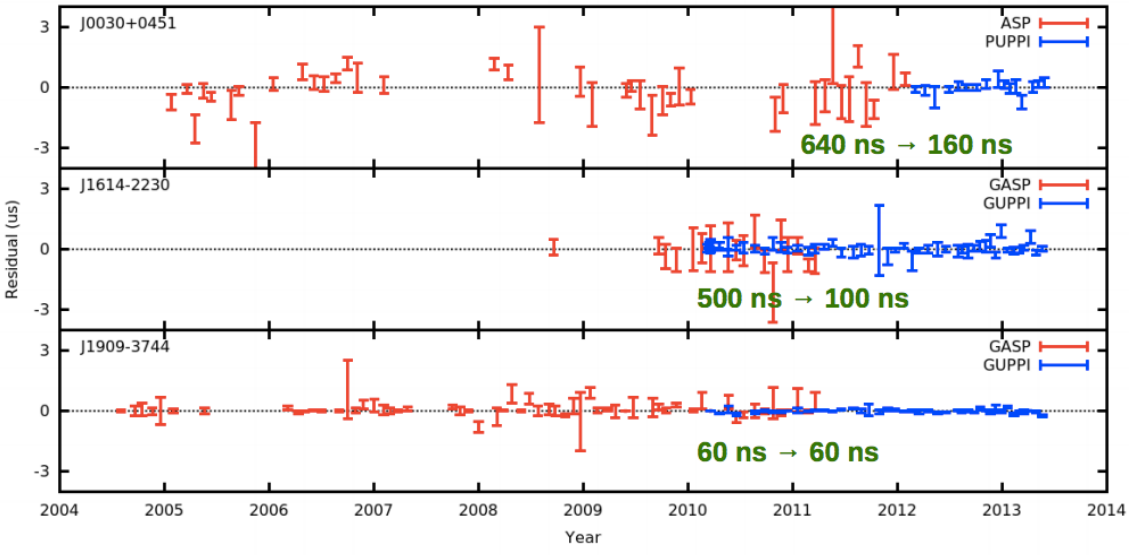
- Calibration and phasing the array adds complication.

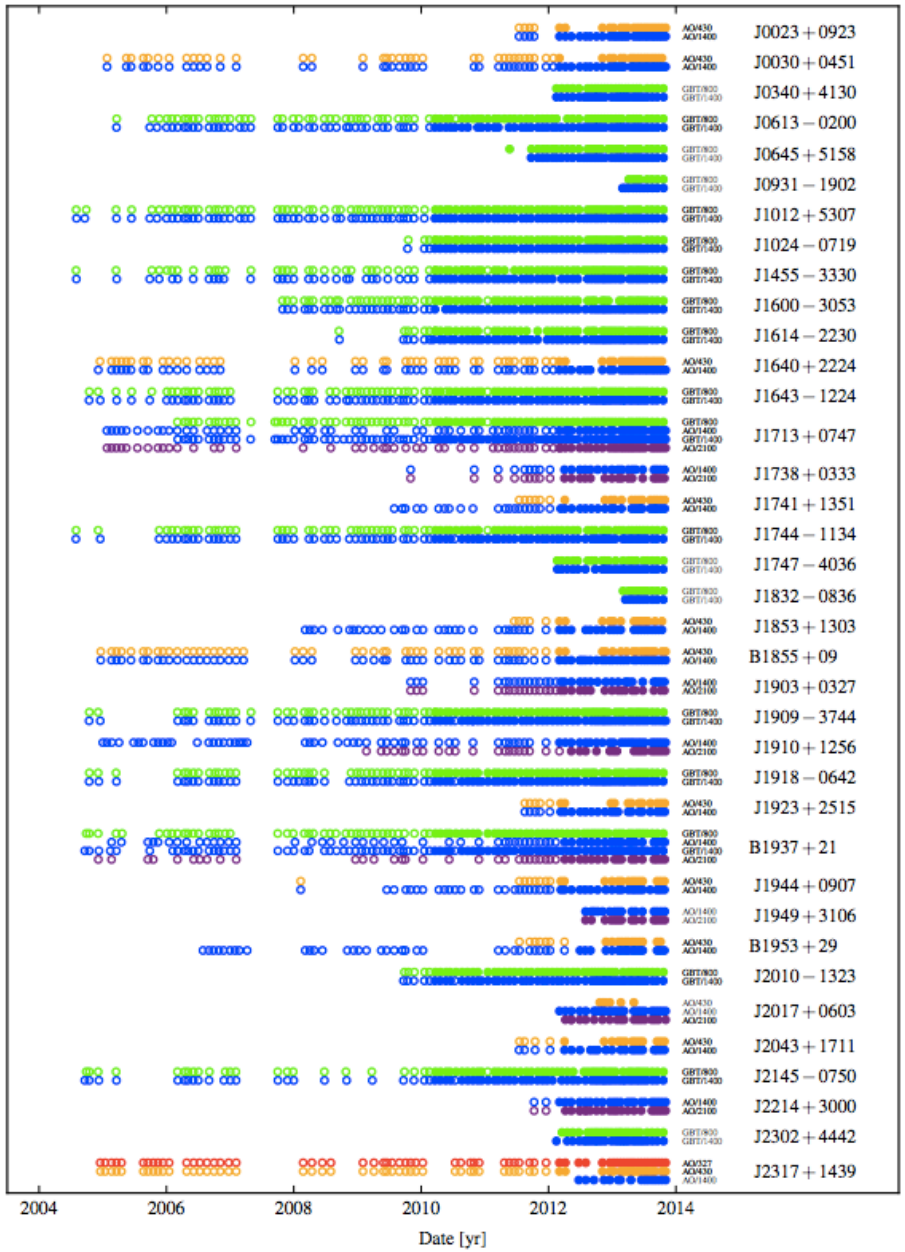
NANOGrav


The big picture of gravitational-wave astronomy
Cosmic Microwave Background
•Primordial gravitational waves
Pulsar Timing Arrays
•Supermassive black hole binaries
•Primordial gravitational waves
Space-based Interferometers
•Stellar mass compact binaries
•Supermassive black hole mergers
Ground-based Interferometers
•Neutron star mergers
•Black hole mergers
h
10^{-5}
10^{-10}
10^{-15}
10^{-20}
10^{-25}
10^{-16}
10^{-8}
10^{-4}
10^{2}
Frequency [Hz]

Timing Program

We use roughly 10% of the time on each telescope to observe 50 pulsars at two frequencies (800 MHz to 3 GHz) every three weeks for roughly 20-30 minutes.





Current Status

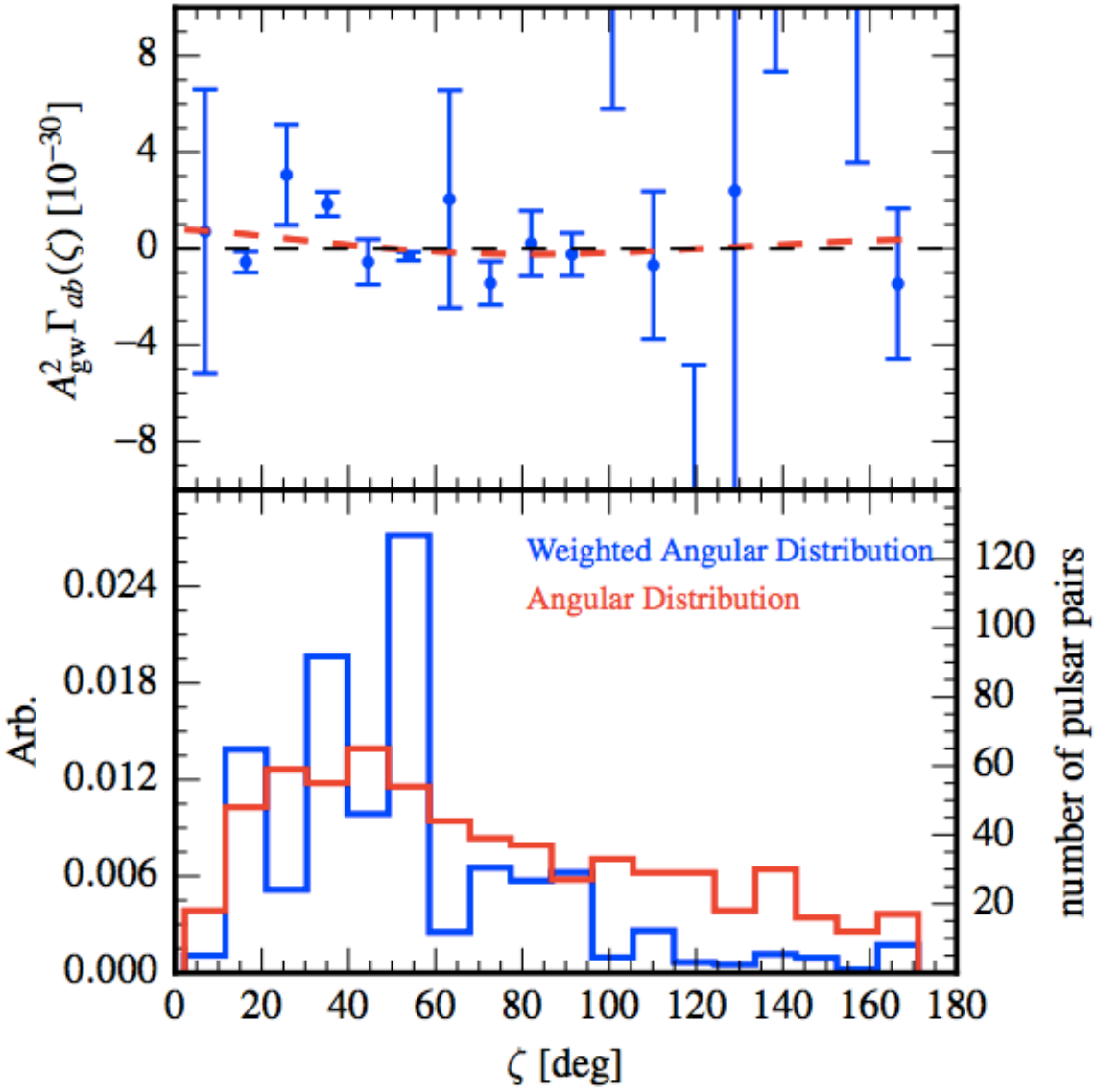
$h_c < 1.5 \times 10^{-15}$ $(f=1\ yr^{-1})$

Previous limit with five-year data release was

$h_c < 7 \times 10^{-15}$ $(f=1\ yr^{-1})$

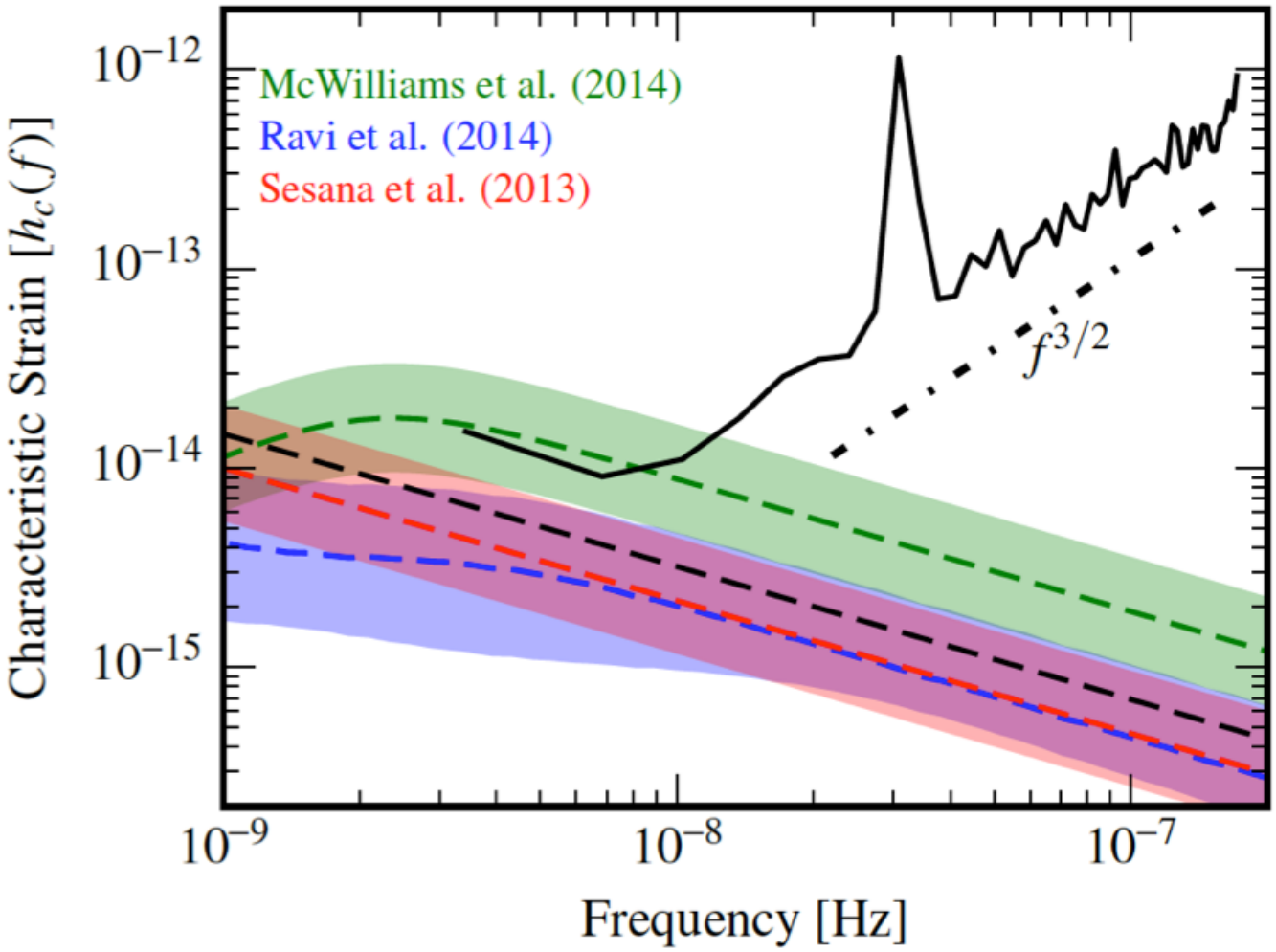
Huge improvement!

(11 year data release forthcoming….it's complicated!)



Arzoumanian et al. 2016, ApJ, 821, 13

Most recent SB limits are beginning to rule out SMBH formation and evolution models



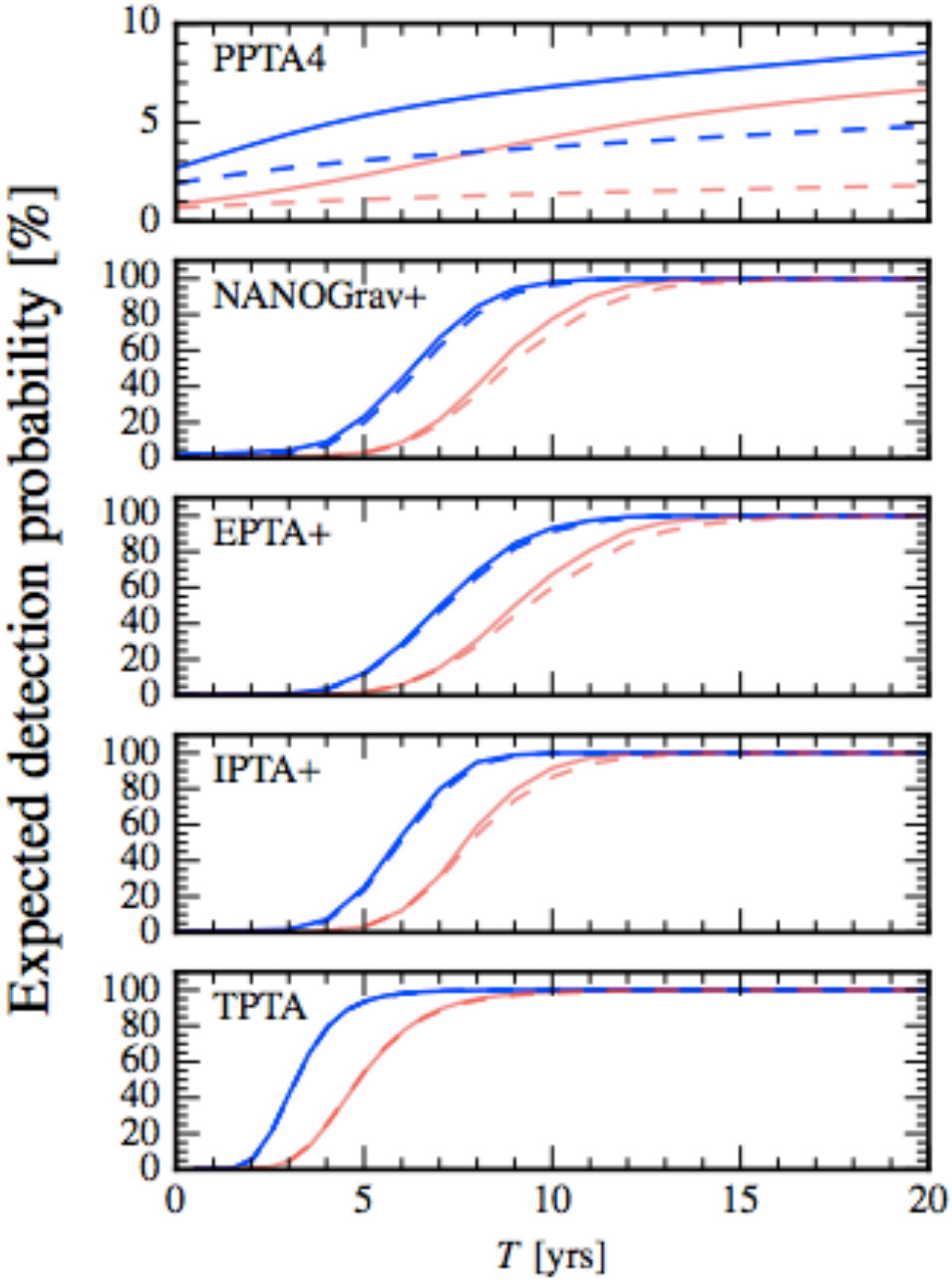
Arzoumanian et al. 2016, ApJ, 821, 13

We are doing astrophysics already! Need to raise awareness if broader astrophysics community!

Time-To-Detection Analysis

A large number of MSPs is the most important ingredient for detection.

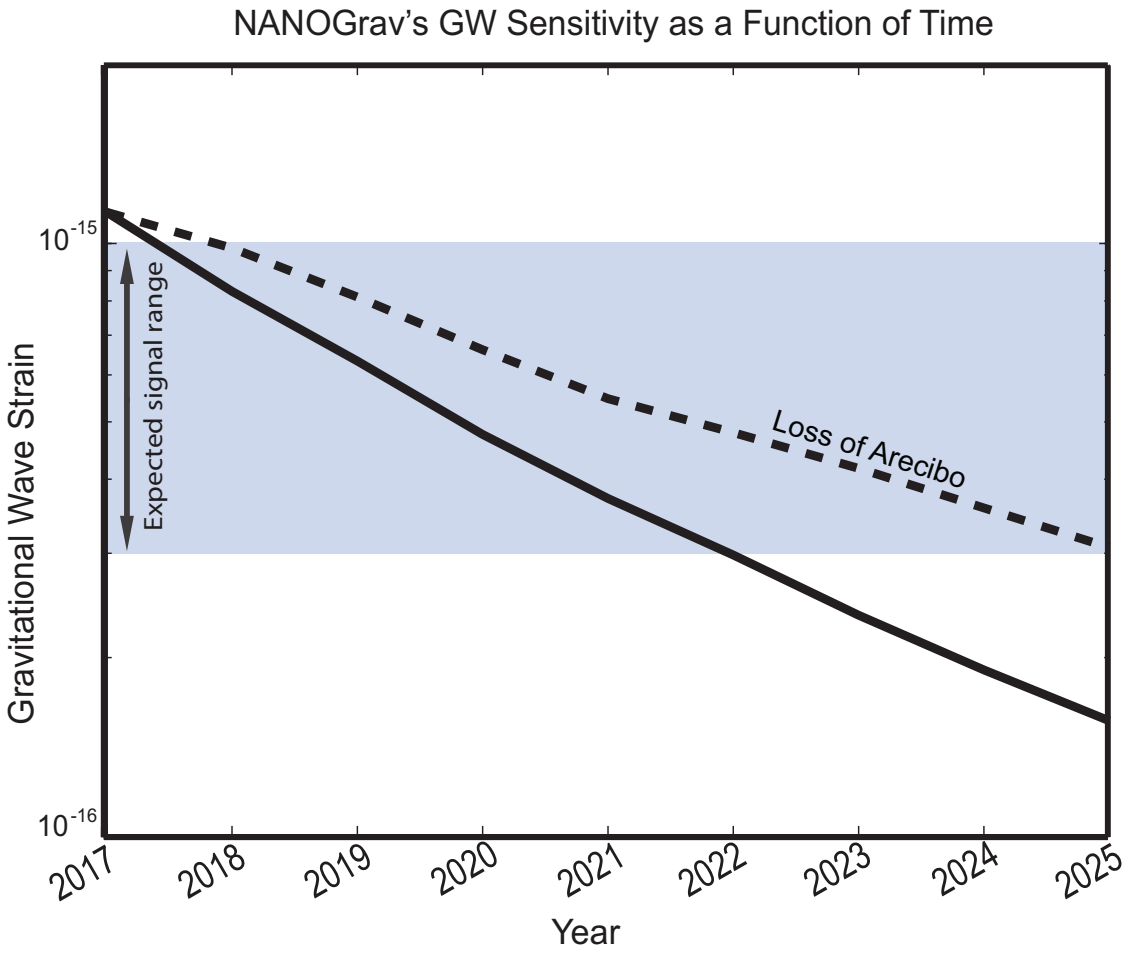
We expect detection within 5-10 years…..if we keep our telescopes.



Taylor et al. 2016, ApJL, 819, 1

If we lose a telescope:

Losing either telescope results in roughly half the sensitivity and increase in time to detection by several years.



NANOGrav Requirements

- We need frequent (~weekly) observations of many (~100) MSPs over wide bandwidths (800 MHz to 3 GHz) or quasi-simultaneously at two frequencies with large telescopes and low-temperature receivers.

- NANOGrav science for the next decade requires *either* continued access at current (and with time increased) levels to the GBT *and* Arecibo OR a new facility before the end of the decade.

- Continued timing is critical. We cannot “take a break and pick up where we left off”.

- There simply will not be sufficient time available on MeerKAT, FAST, or VLA (or any other planned instruments).

Use Other Existing Telescopes?

- There simply will not be sufficient time available on MeerKAT, FAST, or VLA (or any other planned instruments). MeerKAT will time mostly Southern pulsars. FAST will not do high precision timing for some time, and our access is unclear. We would never get required time on VLA (or ngVLA) and it's less efficient and we don't get the necessary low-frequency lever arm.

- There is a broad international effort (through the IPTA) but NANOGrav data dominate the sensitivity.

- We are receiving $14.5M from NSF over five years for PFC. We need to maintain US leadership.

Costs

- A new facility would optimally be a North American MeerKAT-like telescope.
- Status quo: require $10M a year for the GBT and Arecibo for pulsar science, or $100M over next decade.
- New facility: $100M(?) for construction of few-GBT collecting area 500 MHz - 3 GHz instrument plus $5M a year for operations.
- Cheaper in the short term to keep GBT and Arecibo alive. In the long term?