Multimessenger Searches for Supermassive Black Hole Binaries

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PPTA

Overview

- What is a pulsar timing array?
- Current status of PTAs:
  - PTAs are on the verge of something exciting!
- How can we bring multimessenger astrophysics to PTAs?
- The search for a supermassive black hole binary
- Using PTAs as cosmological probes

Pulsars

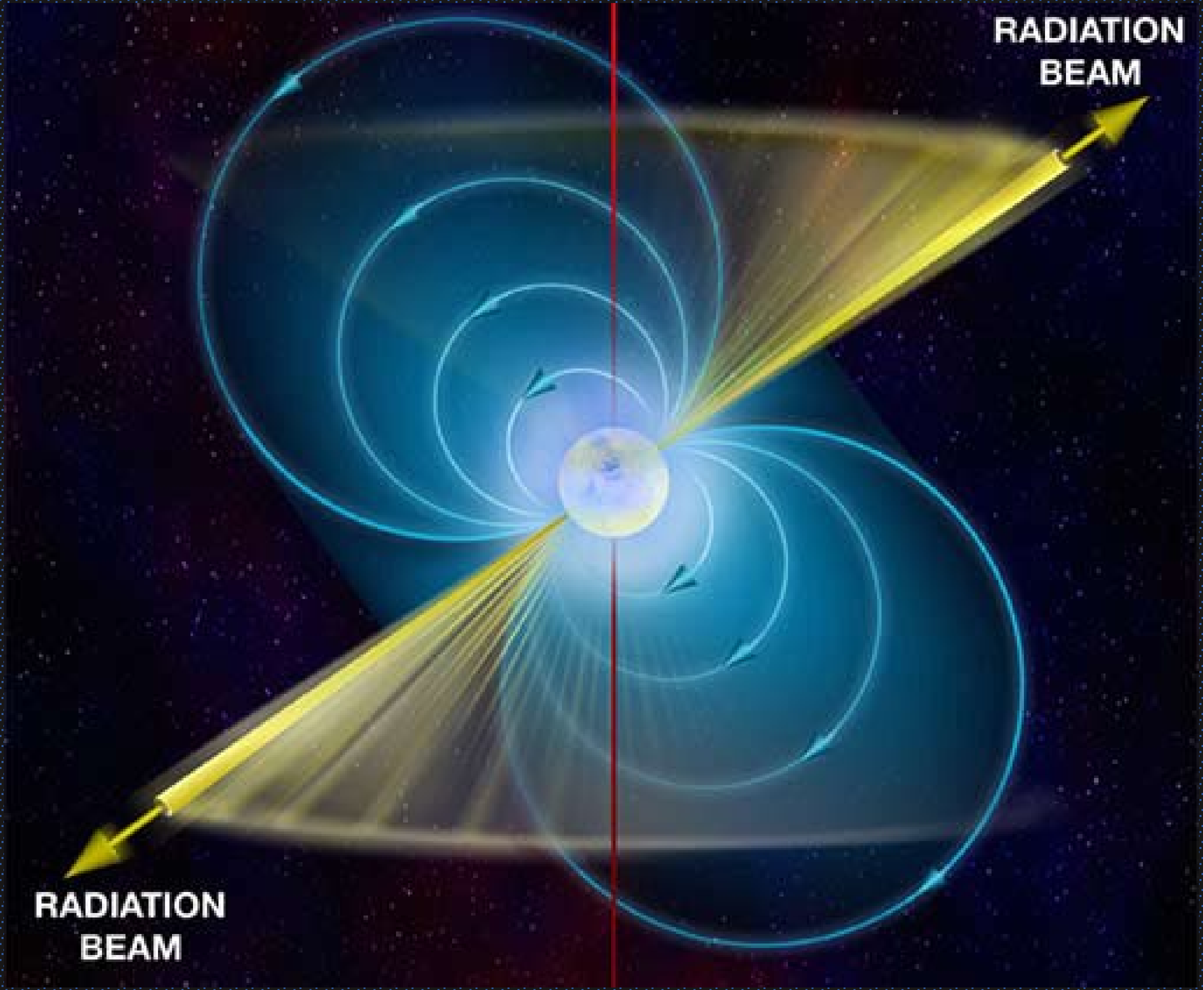


Image credit: NRAO

Pulsars

- Precise timers
- Act as cosmic clocks
- Periodicity modelled to <100ns

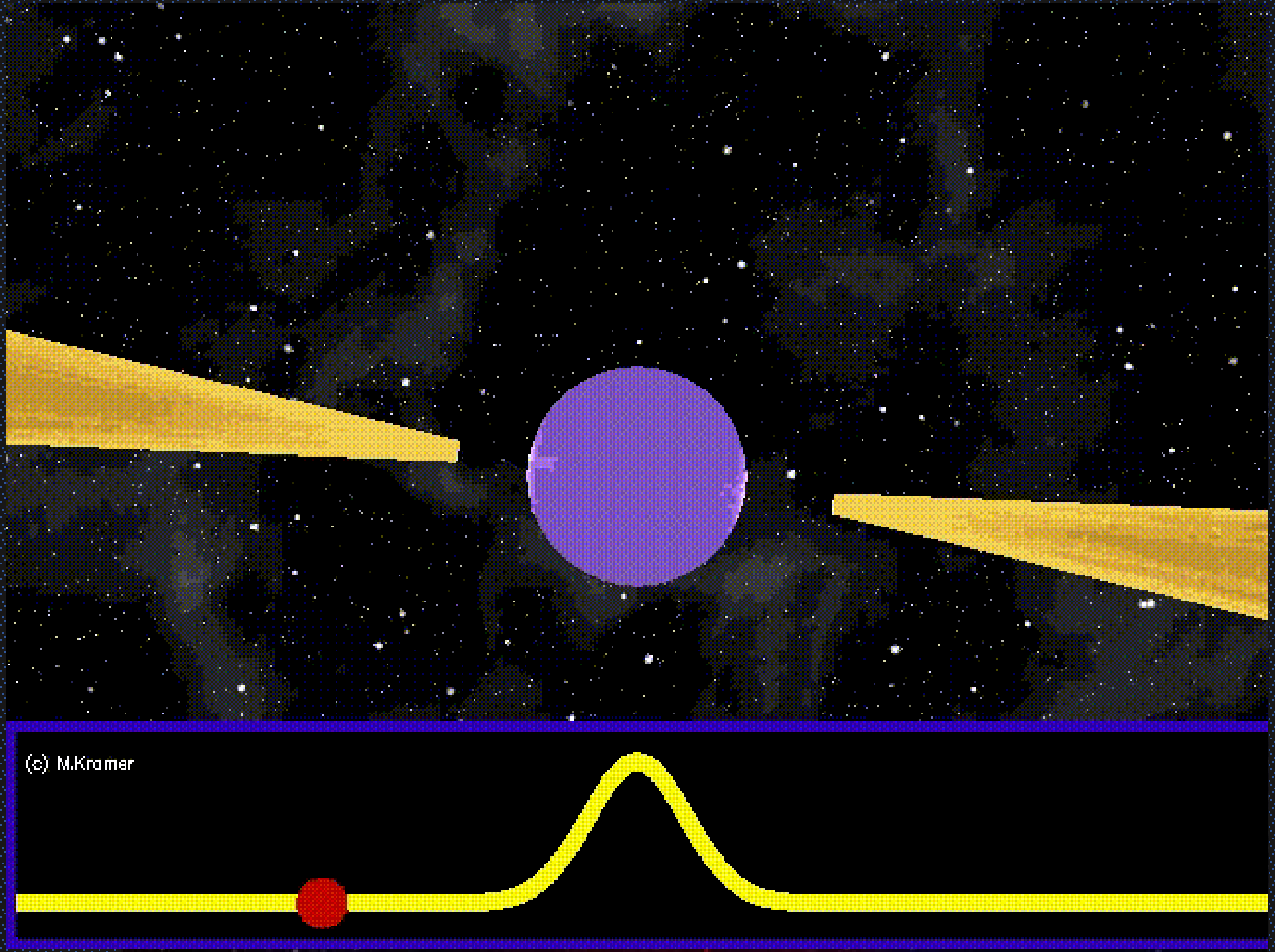


Image credit: Michael Kramer

Pulsar Timing Arrays

- Observe dozens to hundreds of pulsars
    - Observe 1-2x per month
- Measure the time at which a pulse is detected
- Gravitational waves produce delays-advances in pulse arrival times
- Observe pulsars using radio telescopes

Image credit: Daniëlle Futselaar


Green Bank Telescope, WV, US
Arecibo Observatory, PR, US
Nancay Radio Telescope, Nancay, France
Very Large Array (VLA), NM, US
Lovell Telescope, Cheshire, UK
Meerkat, MNP, South Africa
LOFAR, Exloo, Netherlands
FAST, Jinke Village, China
Parkes Observatory, Parkes, Australia
GMRT, Pune, India
WSRT, Westerbork, Netherlands
Effelsberg 100-m Radio Telescope, Effelsberg, Germany

Pulsar Timing Arrays

- Measure TOAs of many pulsars

Image credit: Zic et al., 2023

Pulsar Timing Arrays

- Measure TOAs of many pulsars
- Correlation between TOAs → Stochastic Gravitational Wave Background

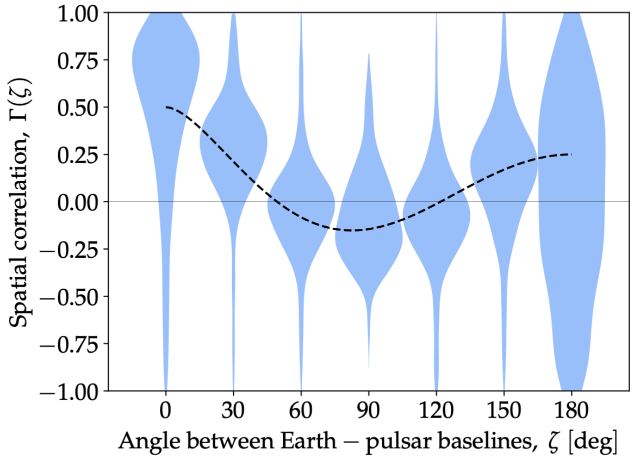
Image credit: Agazie et al., 2023

Pulsar Timing Arrays

- GWB recent results
- 2-4.6σ evidence!
- Can we push PTAs further?

NANOGrav 15yr

EPTA DR2



PPTA DR3

Agazie et al., 2023

Goncharov et al., 2025

Reardon et al., 2023

Continuous Gravitational Waves

Continuous Gravitational Waves

- CGWs from supermassive black hole binaries
- Do not see inspiral/merger → "continuous"

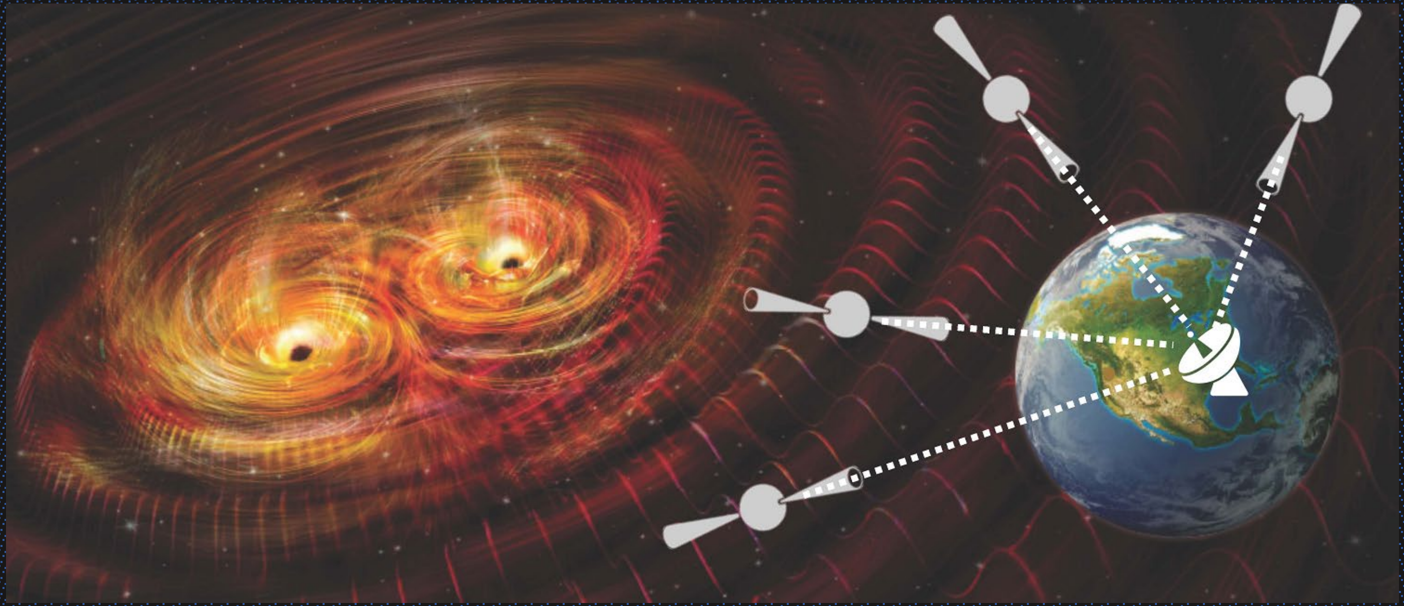


Image credit: NR Fuller / Science

Continuous Gravitational Waves

- Recent PTA all-sky CGW searches

NANOGrav 15-yr

EPTA DR2

PPTA DR3

Agazie et al., 2023

Antoniadis et al., 2023

Zhao et al., 2025

Going Multimessenger!

- Target a specific source
- Use information from electromagnetic (EM) observations
  - Quasars with periodic light curves, etc.
- Search a smaller region of parameter space
- Increases sensitivity

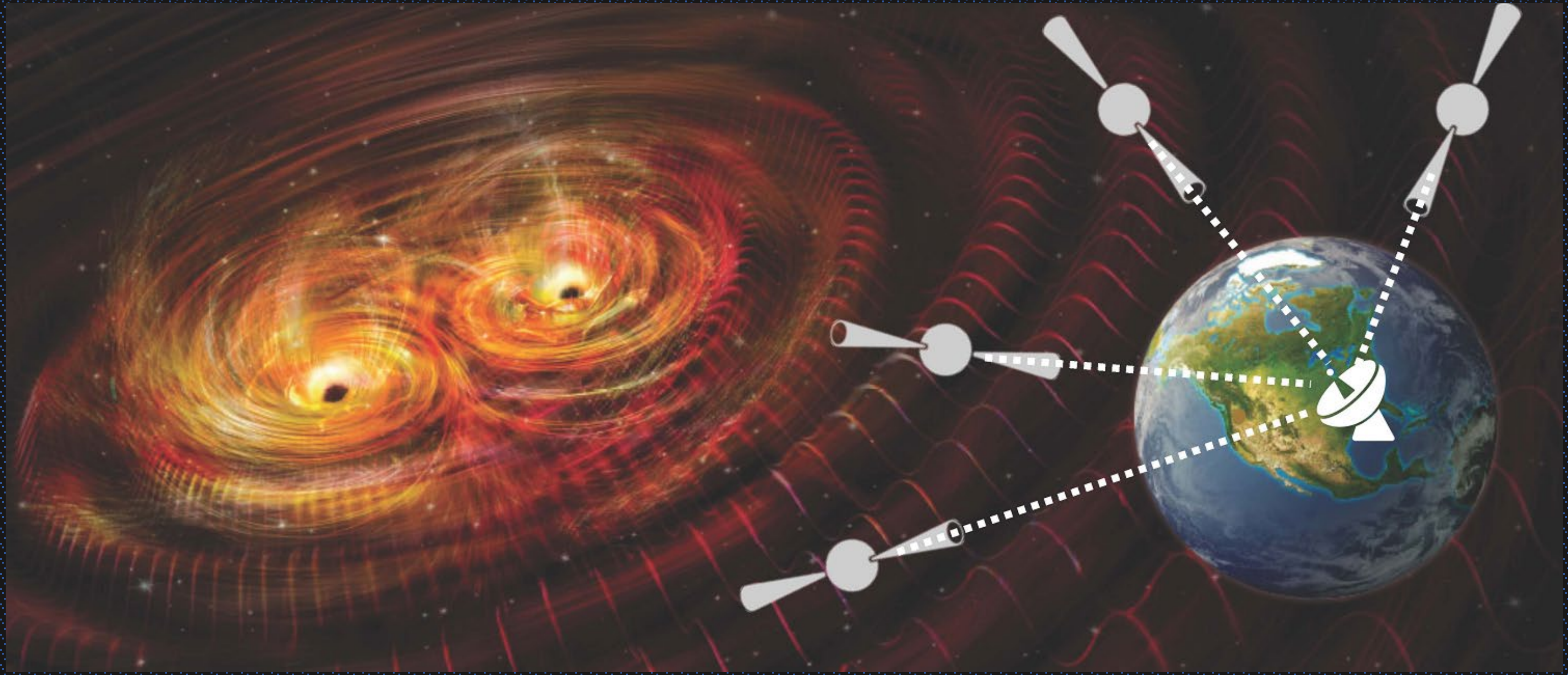


Image credit: NR Fuller / Science

Favourite Source for PTAs

- Orbital motion in radio core first proposed by Sudou et al. 2003

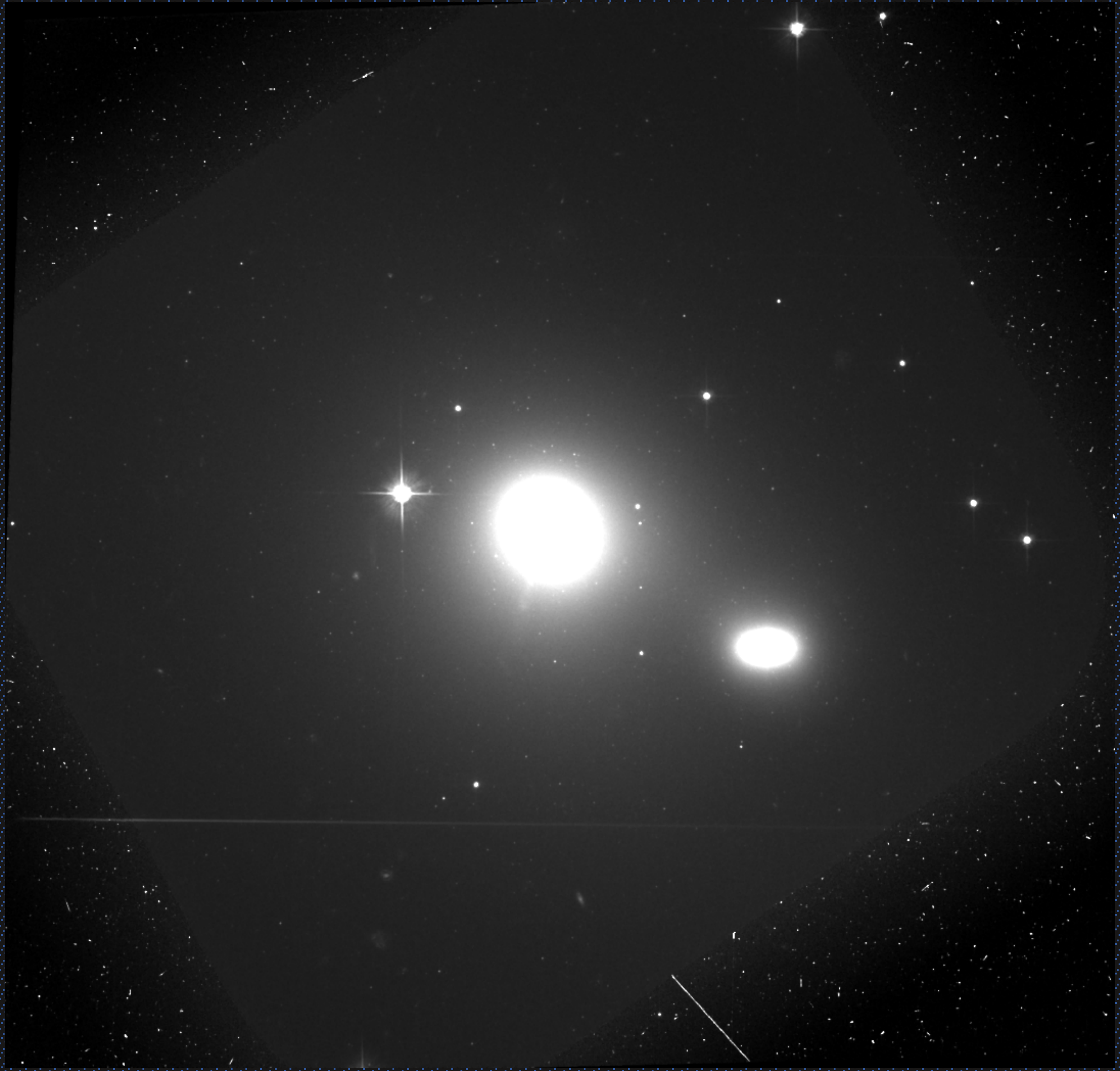


Image Credit: Hubble Legacy Archive

3C 66B

- Orbital motion in radio core first proposed by Sudou et al. 2003
- Initial model:
  - Period: 1.05 ± 0.03 years
  - Chirp mass: $1.3 \times 10^{10}\ M_{\odot}$

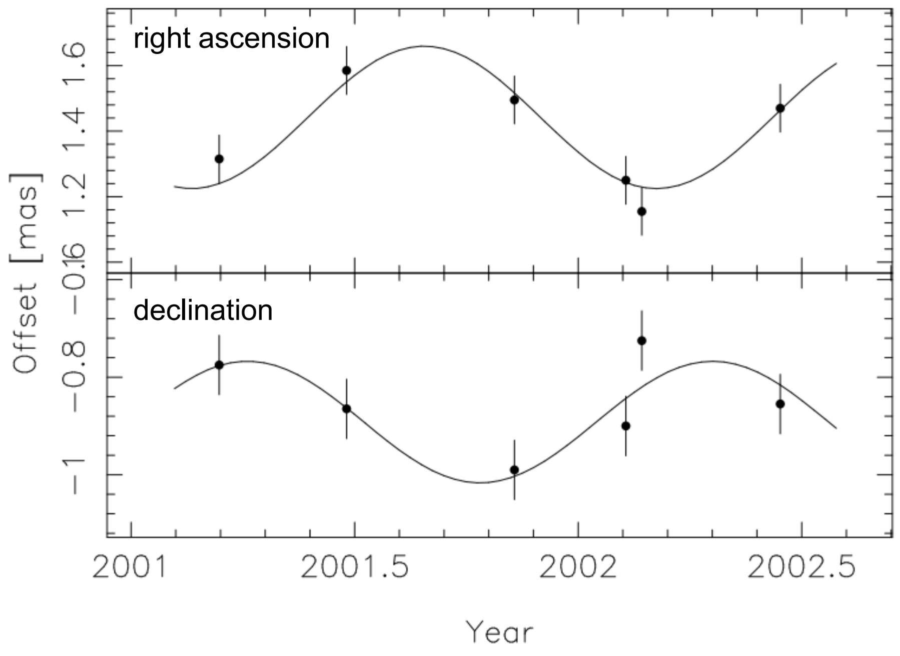


Image Credit: Sudou et al., 2003

3C 66B

- Orbital motion in radio core first proposed by Sudou et al. 2003
- ~~Initial model:~~
  - ~~Period: 1.05 ± 0.03 years~~
  - ~~Chirp mass: $1.3 \times 10^{10}\ M_\odot$~~
- Ruled out by Jenet et al. 2004
- New upper limit: $7 \times 10^{9}\ M_\odot$

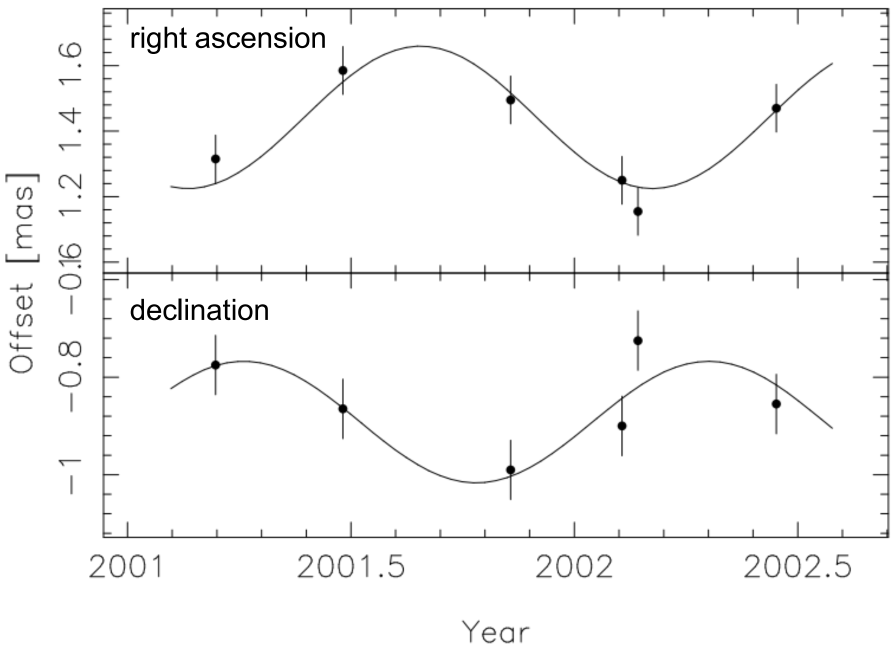


Image Credit: Sudou et al., 2003

3C 66B

- Model updated by Iguchi et al. 2010
- Updated model:
  - Period: 1.05 ± 0.03 years
  - Chirp mass: $7.9 \times 10^{8}\, M_{\odot}$

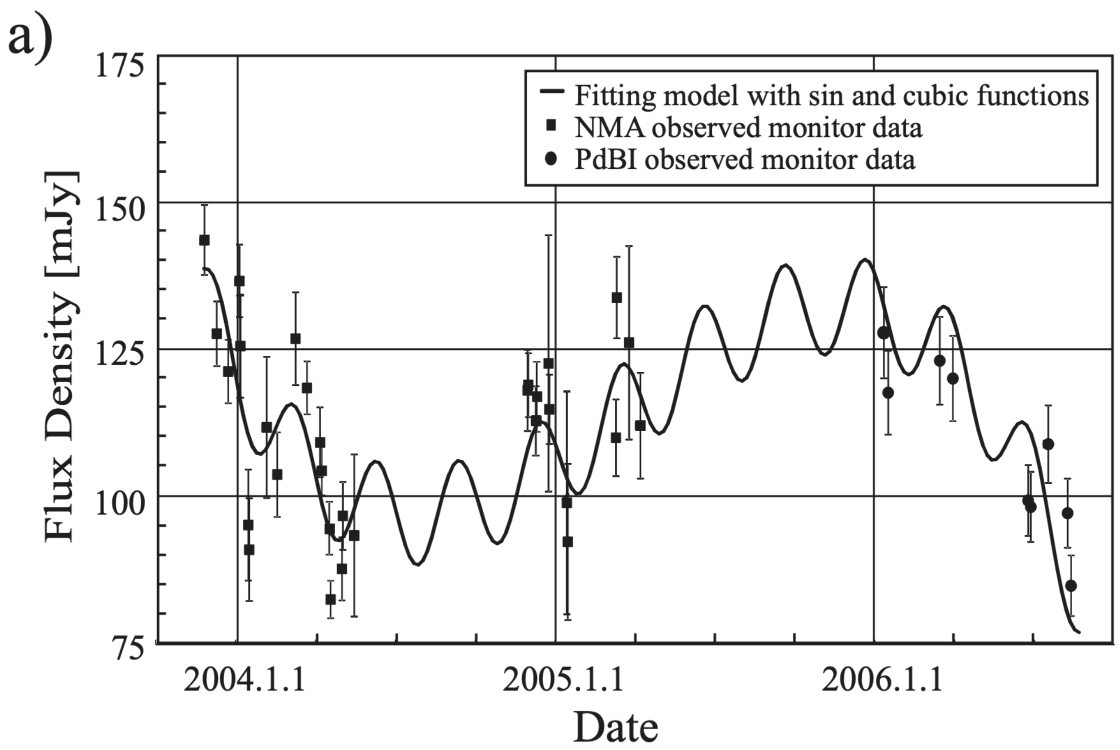
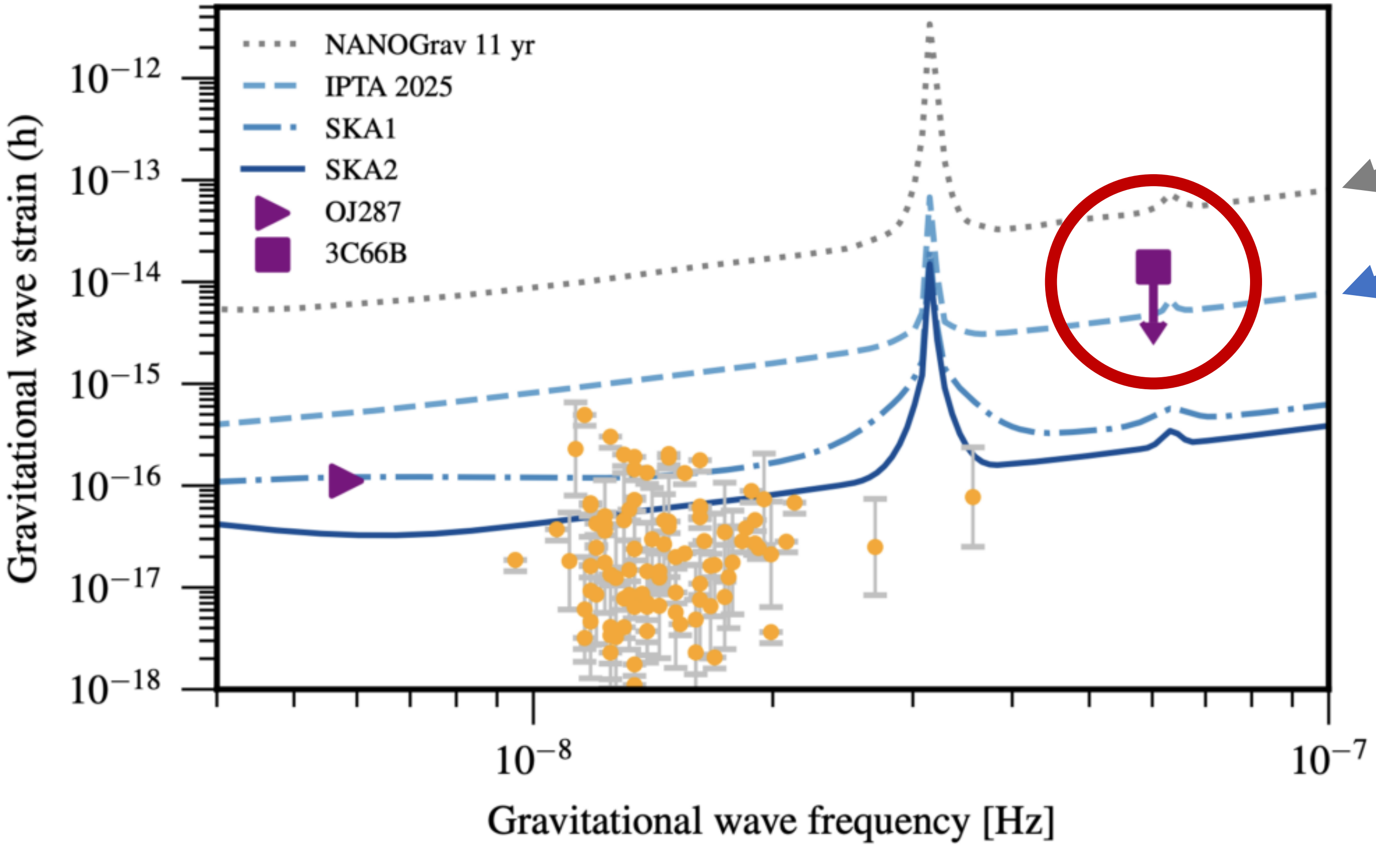


Image Credit: Iguchi et al., 2010

3C 66B

Xin et al., 2021



2020 upper limit

Coming in 2026?

Previous Upper Limits

NANOGrav 11-year dataset

- Upper limit on Mass:
  $1.65 \times 10^9 M_\odot$

NANOGrav 12.5-year dataset

- Upper limit on Mass :
  $1.41 \times 10^9 M_\odot$

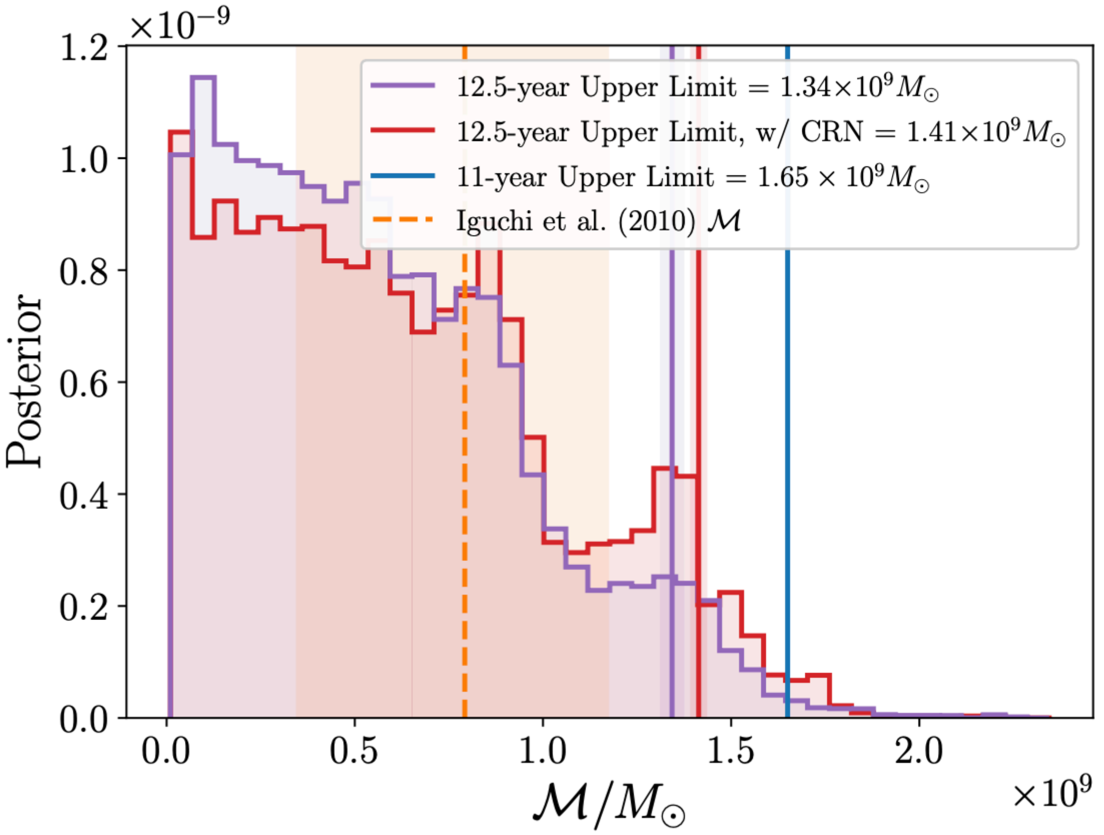


Image Credit: Arzoumanian et al., 2023

Search in PPTA DR3

Our work! Published in ApJL today!

- Upper Limits:
  - $6.90 \times 10^8 \, M_\odot$
  - $10.63 \times 10^8 \, M_\odot$
- Could improve upper limits with joint-likelihood search

Iguchi median value:

$7.90 \times 10^8 \, M_\odot$

NANOGrav 15yr Searches

- Targets 114 sources
- Slightly better constraints on 3C 66B

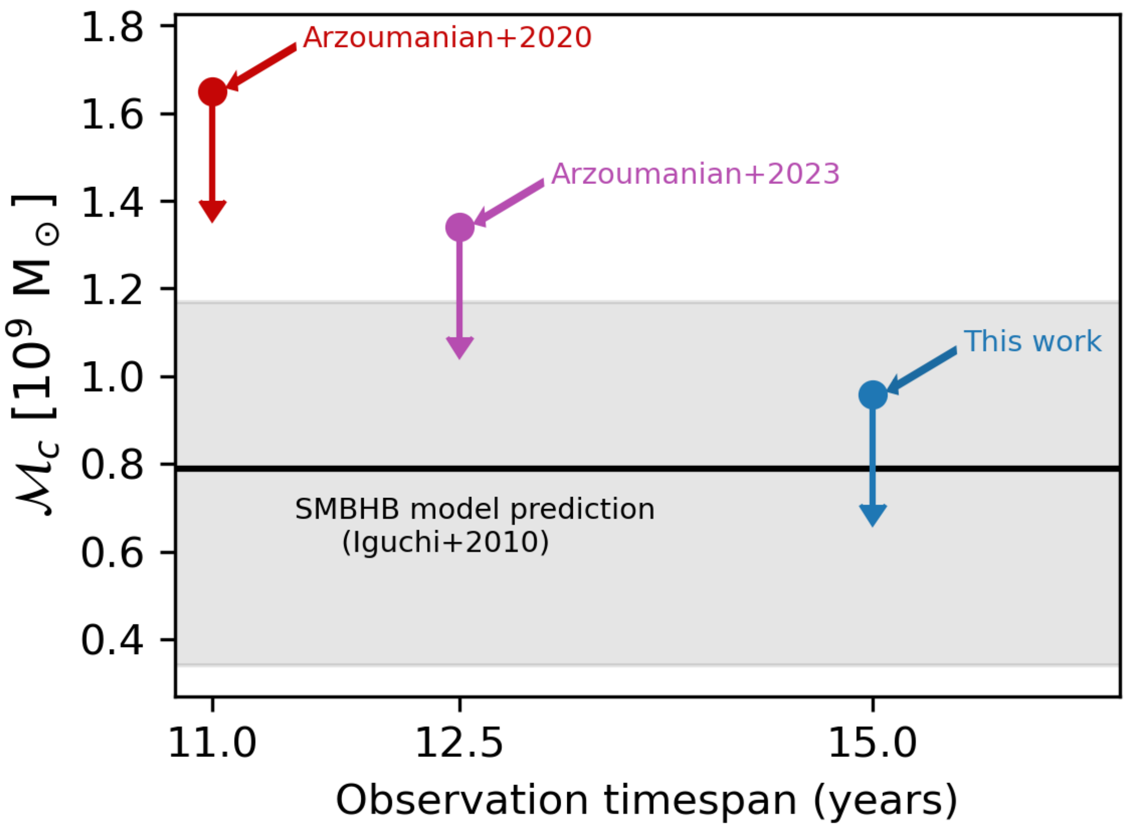


Image Credit: Agarwal et al., 2025

NANOGrav 15yr Searches

- Targets 114 sources
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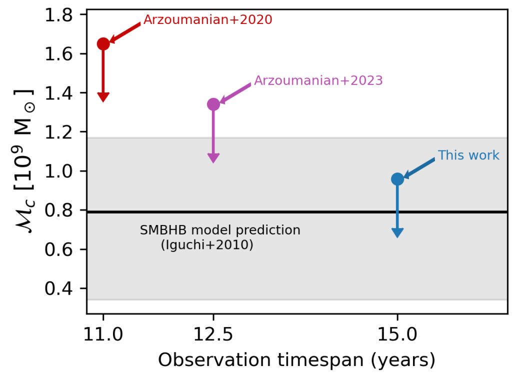
- 2 CGW candidates with marginal evidence



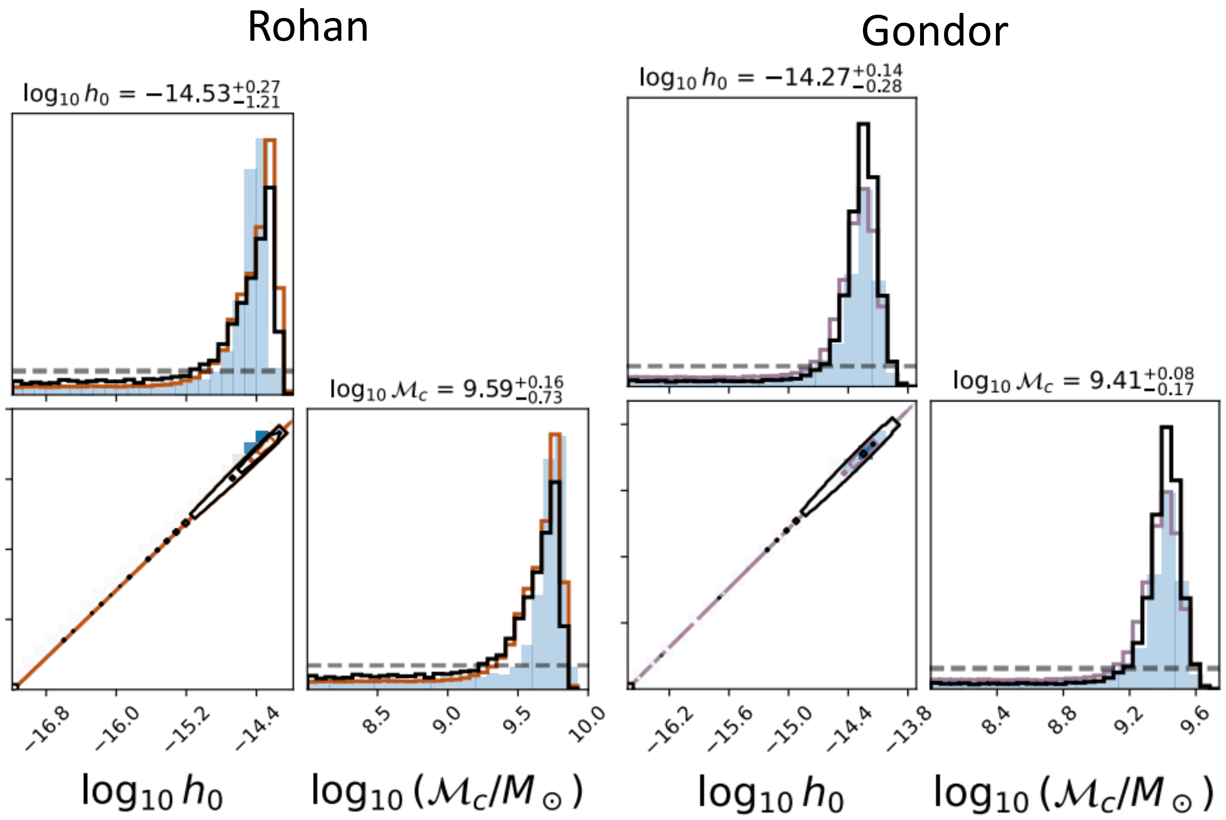
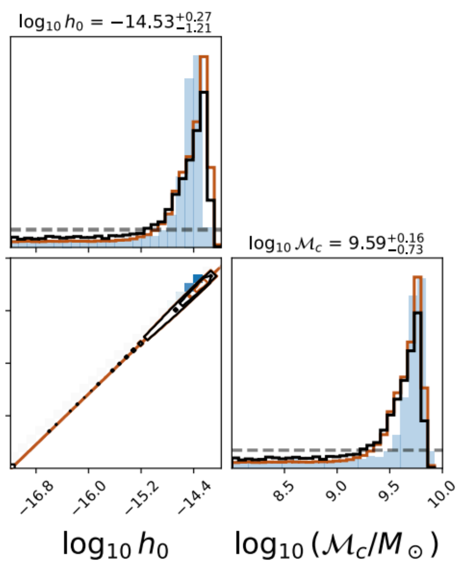


Image Credit: Agarwal et al., 2025

NANOGrav 15yr Searches

- Targets 114 sources
- Slightly better constraints on 3C 66B
- 2 CGW candidates with marginal evidence
- Rohan ruled out in PPTA DR3
- Noise source or noise model?

Rohan



Gondor

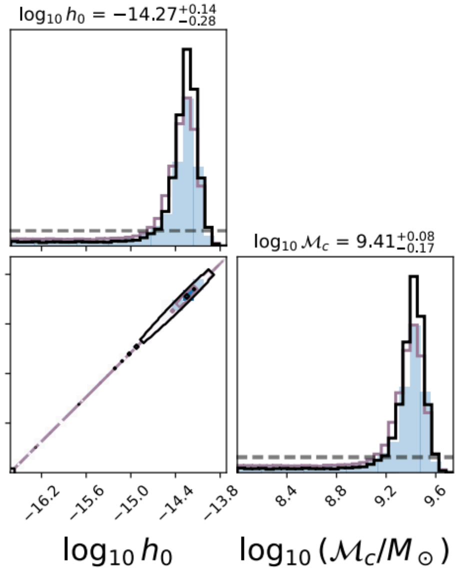
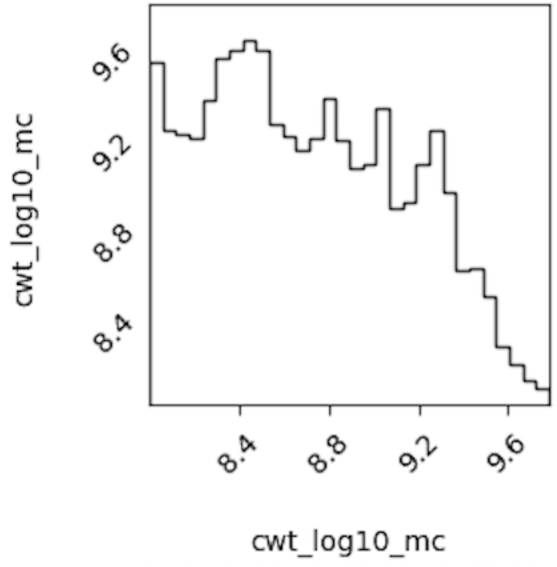


Image Credit: Agarwal et al., 2025

Rohan PPTA DR3



Why are targeted searches important?

PPTA All-Sky Search

Zhao et al., 2025

Targeted search sensitivity

Cosmology

- Placed constraints on H_0 with 3C 66B
- Simulated realistic Chinese Pulsar Timing Array data
  - Best results with 40 pulsars and 40 years
  - Requires bright CGW sources
    - consistent with the observed level of the apparent GW background
- Precision of a few km/s/Mpc is achievable

Shubhit Sardana

Preliminary!

Summary

- PTAs are in a very exciting time!
- 2-4.6σ evidence for GWB background
- Targeted search for the SMBHB in 3C 66B partly rules out parameter space allowed by electromagnetic observations
- PTAs might become useful cosmological probes

Back-up Slides

Taking “multimessenger” further!

- Joint likelihood approach
- Allows for tighter posterior constraints
- Planning similar search on 3C 66B

Image Credits: Charisi et al., 2025

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