NANOGrav Collaboration & Pulsars Timing Array

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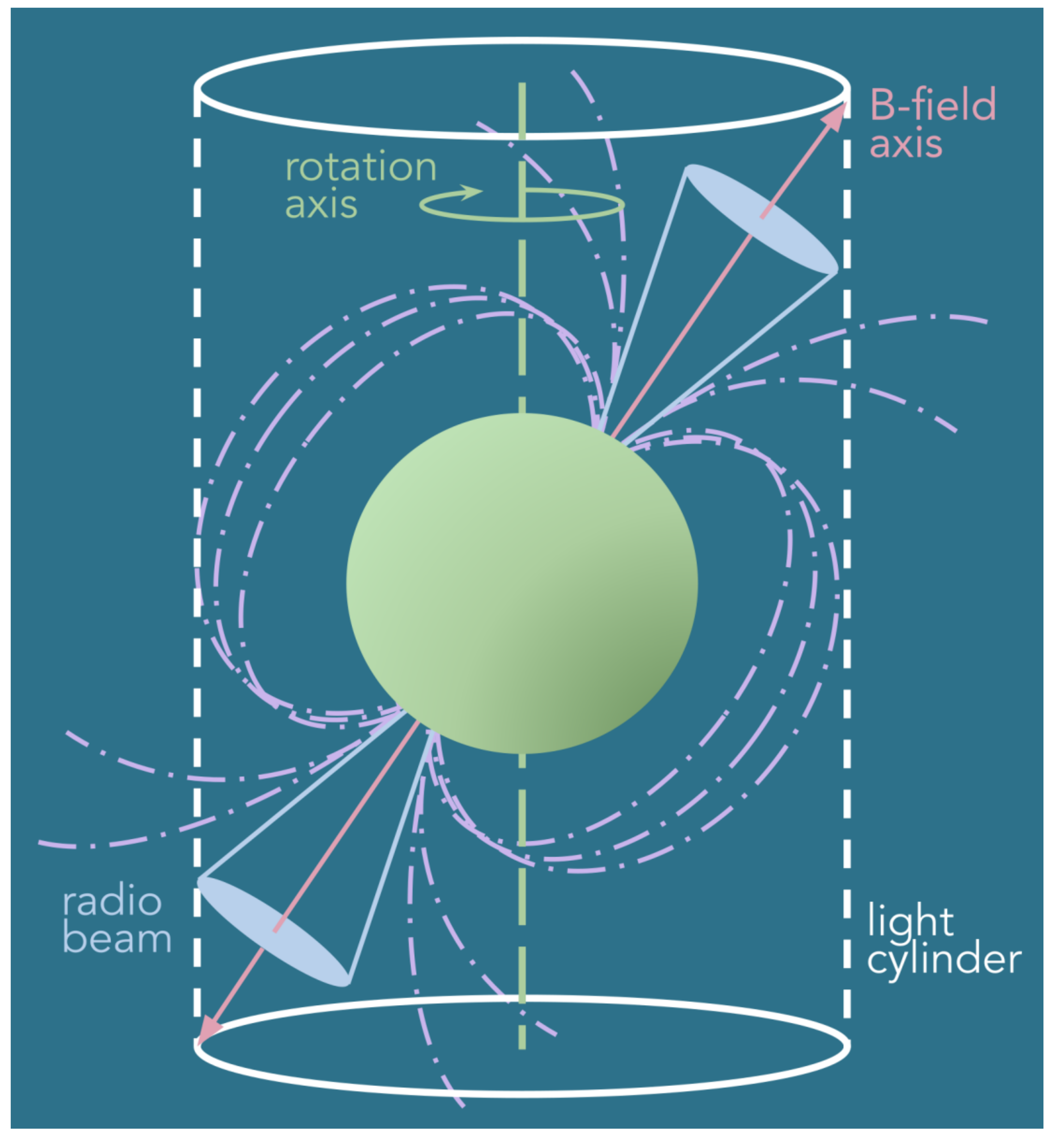
Introduction to PTAs

- Pulsar Timing Arrays (PTAs) leverage the extreme precision of pulsar timing to detect faint gravitational wave signals. By monitoring a network of millisecond pulsars, PTAs are sensitive to tiny timing shifts that could reveal passing gravitational waves.
- This global effort is driven by international collaborations, including NANOGrav (North America) – [4], the EPTA (Europe) – [3], the PPTA (Australia) – [2], and the IPTA (worldwide) – [4], pooling resources and data to amplify detection capabilities.

Pulsars as Cosmic Clocks

Pulsars emit radio waves with remarkable regularity, acting as highly stable cosmic clocks. In order to detect these tiny variations, the alignment of the pulsar's emission with Earth's line of sight is crucial; the signal must be observed at the right angle for the timing shifts to be measured accurately. PTA are then able to create a very precise pulsar timing model predicted the Time of Arrival (ToA) of the pulse



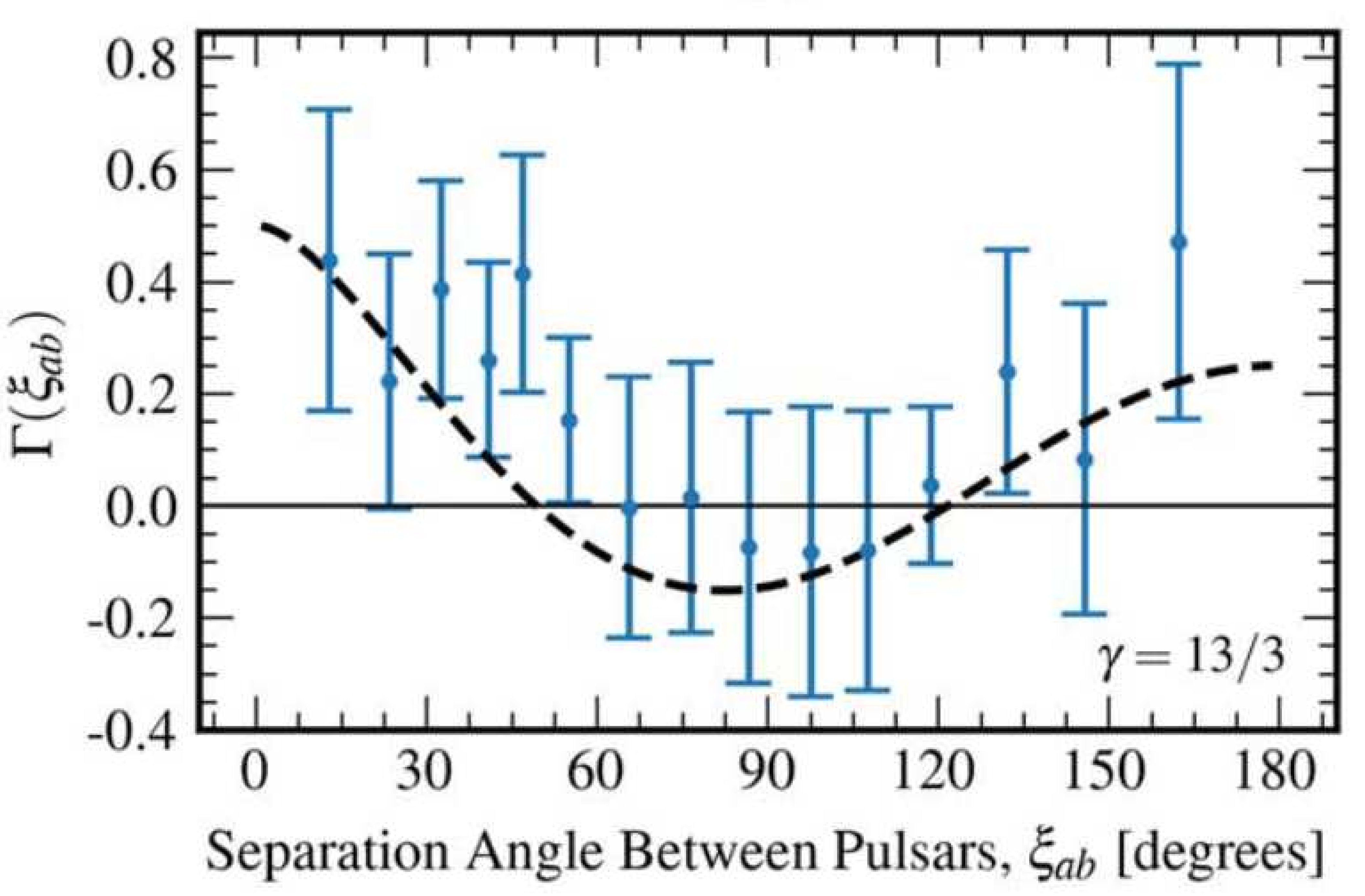
Cartoon diagram of the "anatomy" of a pulsar, showcasing the radio beams that form the lighthouse effect which we observe with our telescopes. *Credit: Thankful Cromartie*

The PTA Network

A Pulsar Timing Array (PTA) network acts as a vast gravitational wave observatory by coordinating observations of multiple pulsars across different regions of the sky.

- **Array Selection**: Only the most stable and precisely timed millisecond pulsars are selected, allowing for sensitivity to extremely small timing variations. For example, NANOGrav monitors over 70 carefully selected pulsars, distributed across the sky to maximize the array's reach and coverage.
- **Coordinated Observing**: PTAs coordinate globally to analyze pulsars' timing data collectively. This cooperation increases detection sensitivity by combining measurements from multiple observatories, creating a network effect that enhances precision.
- **Detecting Tiny Variations**: PTAs search for consistent, minuscule timing shifts in the ToA across the pulsars in the array. These shifts—if found in a correlated pattern—provide a signal of gravitational waves as they distort space-time on cosmic scales.

Hellings and Down Curve



Hellings & Down angular correlation measured from 2,211 distinct pairs in the 67-pulsar network. The black dotted line shows the correlation model model of Hellings & Down. – [1]

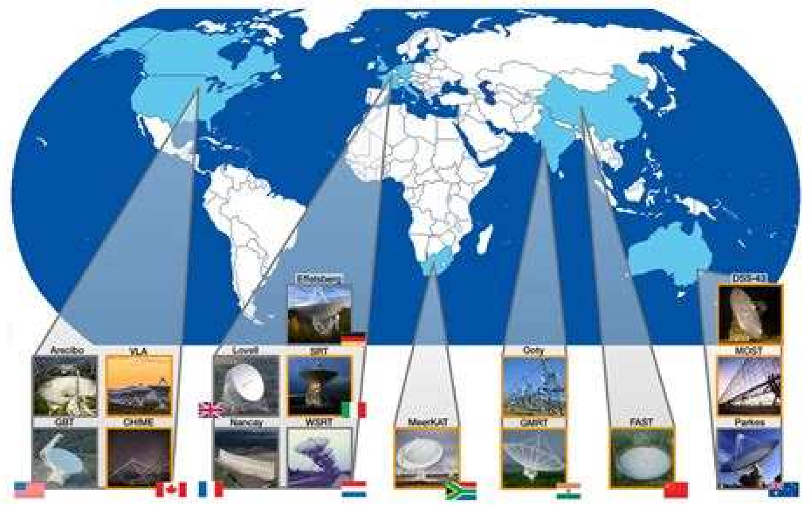
- **Expected Signal Pattern**: As gravitational waves pass through space, they create slight changes in pulsar timing. These changes are not random; they follow a predictable pattern based on the relative positions of pulsars in the sky, which is plotted as the Hellings and Downs curve.
- **Astrophysical Confirmation**: By matching observed timing correlations to this pattern across multiple pulsars, PTAs can attest for a strong evidence of an astrophysical origin rather than noise or local effects.

Data Analysis

For each pulsar, PTAs construct a timing model based on the expected pulse arrival times. This model serves as a baseline for detecting any subtle deviation. By comparing observed pulse times to this baseline, PTAs calculate timing residuals, capturing any unmodeled variation. Then PTAs filter out noise sources—such as interstellar medium effects or clock errors—to improve sensitivity to potential gravitational wave signals.

Future Directions

- **Expanding Pulsar Arrays**: Increasing the number of precisely timed millisecond pulsars in PTAs will enhance detection sensitivity, enabling the observation of fainter and more distant gravitational wave sources.



Radio telescopes of the International Pulsar Timing Array (IPTA). A future prospect for time observation. *Credit: https://nanograv.github.io/optimalobs/*

- **Enhanced Data Sharing and International Collaboration**: The IPTA seeks to unify data and methods from all PTA projects globally, amplifying discovery potential and improving detection confidence through teamwork.
- **Towards a Gravitational Wave Background**: One key goal is to confirm the presence of a low-frequency gravitational wave background from distant, unresolved supermassive black hole mergers.

References

[1] Agazie et al. The nanograv 15 yr data set: Evidence for a gravitational-wave background. 2023.

[2] Andrew Zic et al. The parkes pulsar timing array third data release, 2023.

[3] Antoniadis et al. The second data release from the european pulsar timing array: Iii. search for gravitational wave signals. 2023.

[4] G Hobbs, A Archibald, Z Arzoumanian, D Backer, M Bailes, N D R Bhat, and Burgay. 2010.

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