Signature of vector dark matter in NANOGrav?

arXiv: 2311.10148 [hep-ph]

In collaboration with Debtosh Chowdhury, Subhendra Mohanty & Suraj Prakash

High-Energy physics symposium, Department of Physics, IIT Kanpur
February 3, 2024

Outline

- NANOGrav
- Pulsar Timing Array
- Hellings - Downs Correlation
- HD + Saphiro delay
- Ultralight Vector dark matter

NANOGrav

The Astrophysical Journal Lettersmacro qq(^", 951:L9 (78pp), 2023 July 1 https://doi.org/10.3847/2041-8213/acda9a

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The NANOGrav 15 yr Data Set: Observations and Timing of 68 Millisecond Pulsars

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The NANOGrav Collaboration

Talk by Subhendra Mohanty

NANOGrav

The Astrophysical Journal Lettersmacro qq(^", 951:L9 (78pp), 2023 July 1 https://doi.org/10.3847/2041-8213/acda9a

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The NANOGrav Collaboration

Katie Mack
@AstroKatie

Q: Is NANOGrav the only group doing this?
A: Not at all! There's a huge international group of pulsar timing array collaborations (see: PPTA, EPTA, CPTA) all announcing results today. NANOGrav got the first detection but combining data from all is crucial for learning more.
13/n

6:19 · 29 Jun 23 · **43.7K** Views

Credit: X

Talk by Subhendra Mohanty

Pulsar Timing Array

Opportunities for detecting ultralong gravitational waves

M. V. Sazhin

Shternberg Astronomical Institute, Moscow

(Submitted June 14, 1977)

Astron. Zh. **55**, 65–68 (January–February 1978)

The influence of ultralong gravitational waves on the propagation of electromagnetic pulses is examined. Conditions are set forth whereby it might be possible to detect gravitational waves arriving from binary stars. There are some prospects for detecting gravitational radiation from double superstars with masses $\mathfrak{M}_1 \approx \mathfrak{M}_2 \approx 10^{10} \mathfrak{M}_\odot$.

PACS numbers: 97.80.–d, 97.60.Gb, 95.30.Gv

THE ASTROPHYSICAL JOURNAL, **234**:1100–1104, 1979 December 15

PULSAR TIMING MEASUREMENTS AND THE SEARCH FOR GRAVITATIONAL WAVES

STEVEN DETWEILER

Department of Physics, Yale University

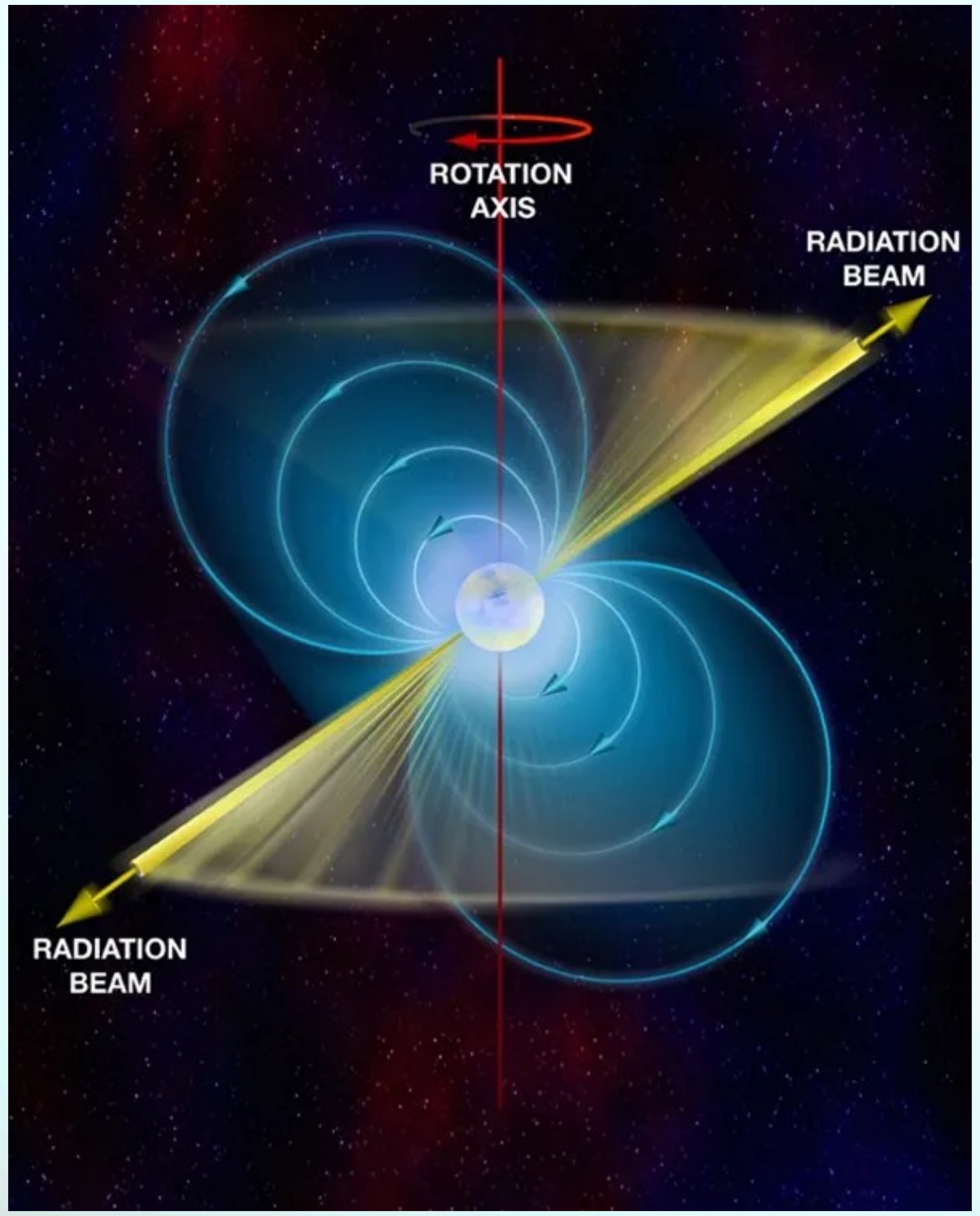
Received 1979 June 4; accepted 1979 July 6

ABSTRACT

Pulse arrival time measurements of pulsars may be used to search for gravitational waves with periods on the order of 1 to 10 years and dimensionless amplitudes $\sim 10^{-11}$. The analysis of published data on pulsar regularity sets an upper limit to the energy density of a stochastic background of gravitational waves, with periods ~ 1 year, which is comparable to the closure density of the universe.

Subject headings: cosmology — gravitation — pulsars — relativity

Pulsar Timing Array

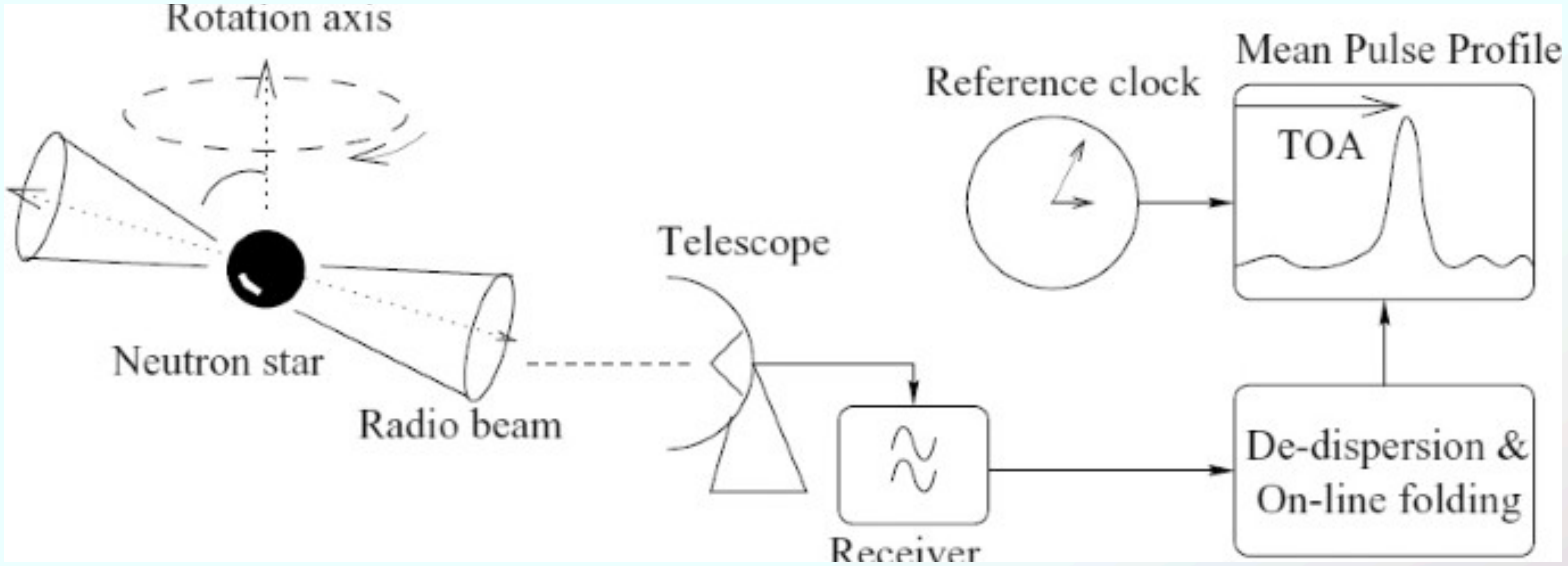


Credit: Bill Saxton, NRAO

- Pulsars are rotating Neutron Star
- Emit Electromagnetic radiation at regular intervals

Talk by Tapobrata Sarkar

Pulsar Timing Array



Credit: Larimer & Kramer

Pulsar Timing Array

Credit: HOTHARDWARE

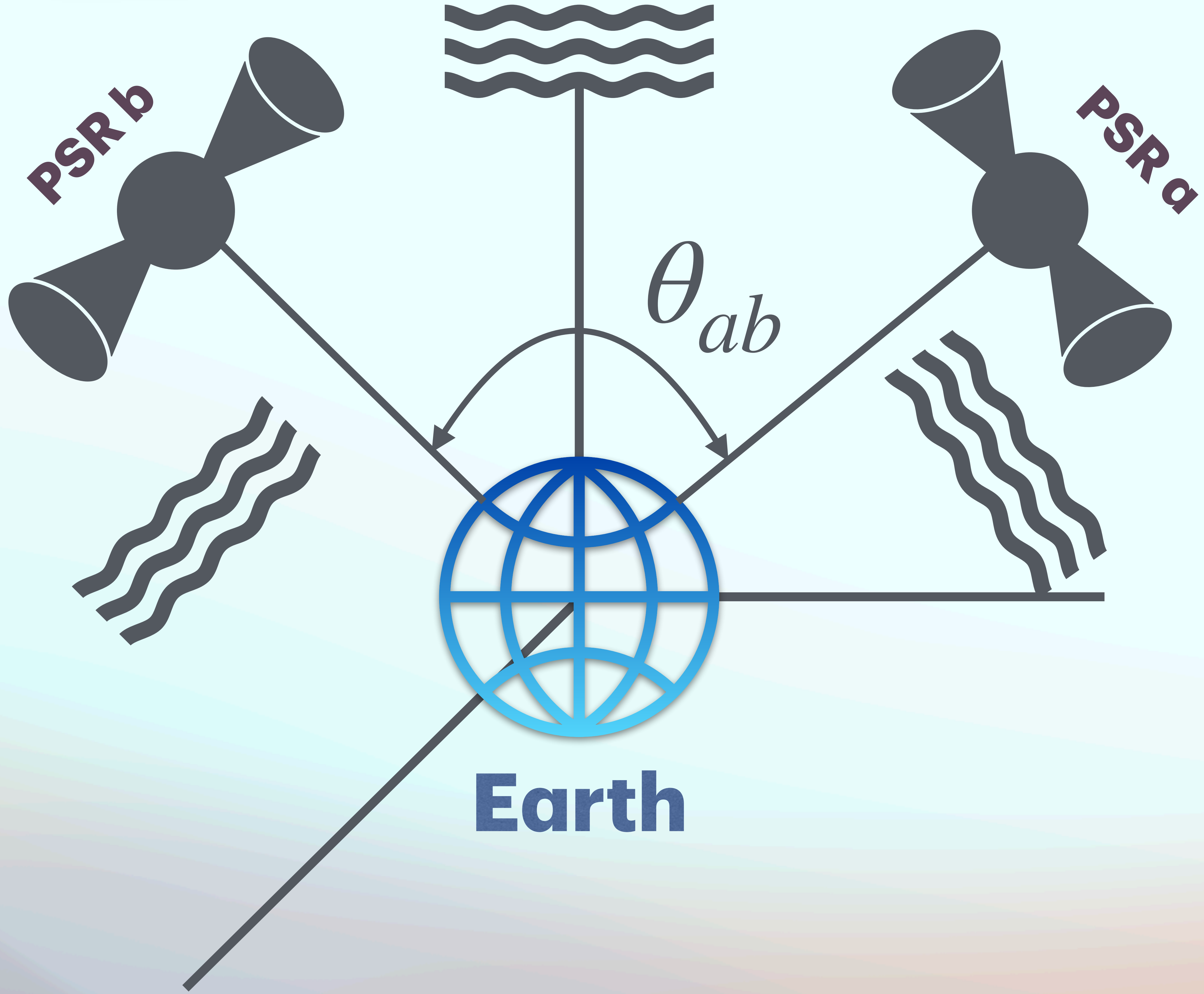
Timing Residual

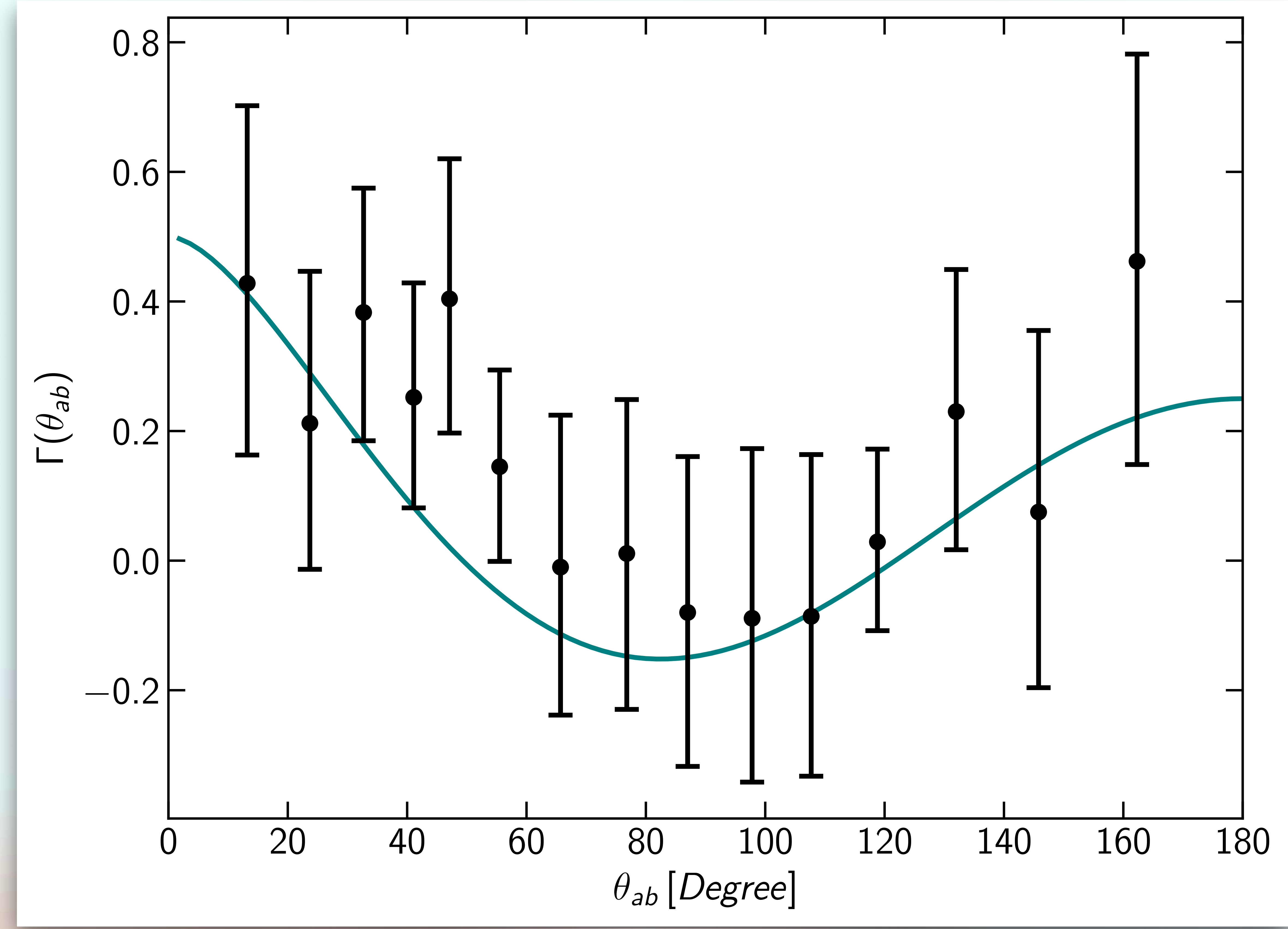
- Observe a pulsar and measure the time of arrival (TOA) of its pulse
- Find a model which gives the best fit to the TOA
- Calculate the timing residual

$$R = TOA - (TOA)_{model}$$

- For a perfect model with noiseless background : $R = 0$

Hellings - Downs Correlation: SGWB



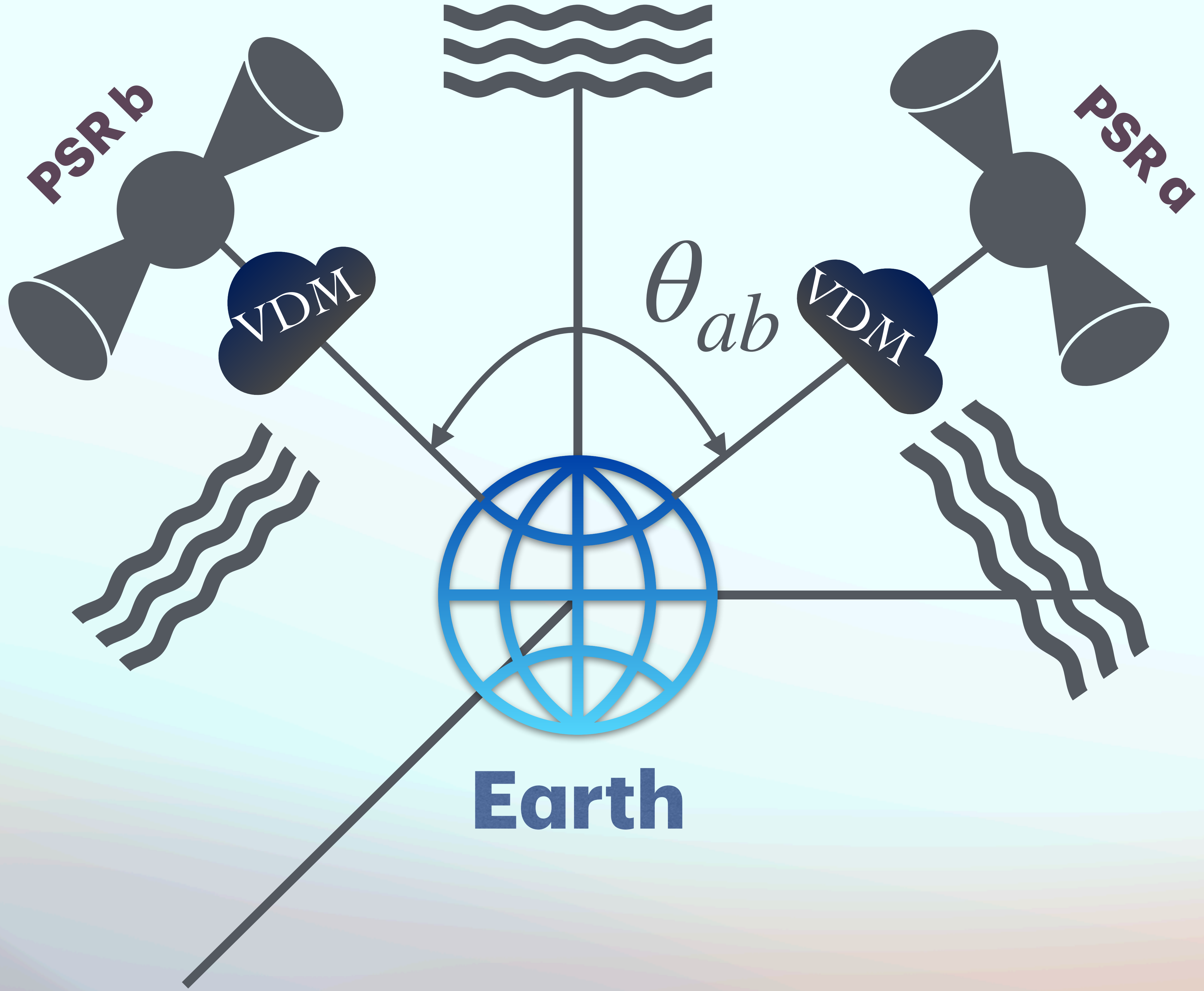


$$\Gamma_{HD}(\theta_{ab}) = \frac{3}{2}\frac{1-\cos\theta_{ab}}{2}\ln\left(\frac{1-\cos\theta_{ab}}{2}\right) - \frac{1}{4}\frac{1-\cos\theta_{ab}}{2} + \frac{1}{2}$$

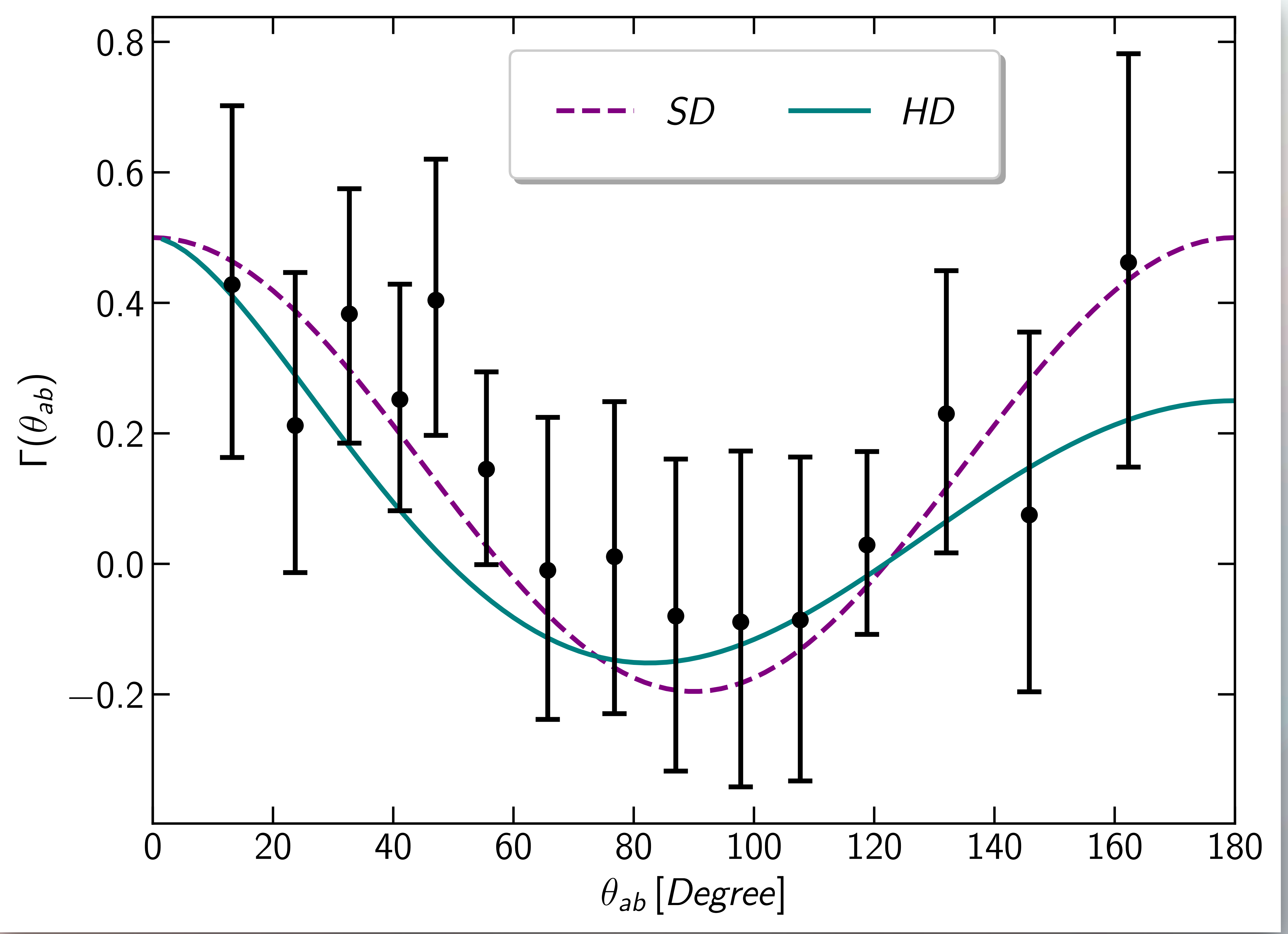
Hellings & Downs, Astrophys. J., 1983

Agazie et al., Astrophys. J. Lett., 2023

Shapiro Time Delay



$$\xi_{ab}^{(2)}(\theta_{ab}) = \frac{1}{1+\beta}[\Gamma_{SD}(\theta_{ab}) + \beta\Gamma_{HD}(\theta_{ab})]$$

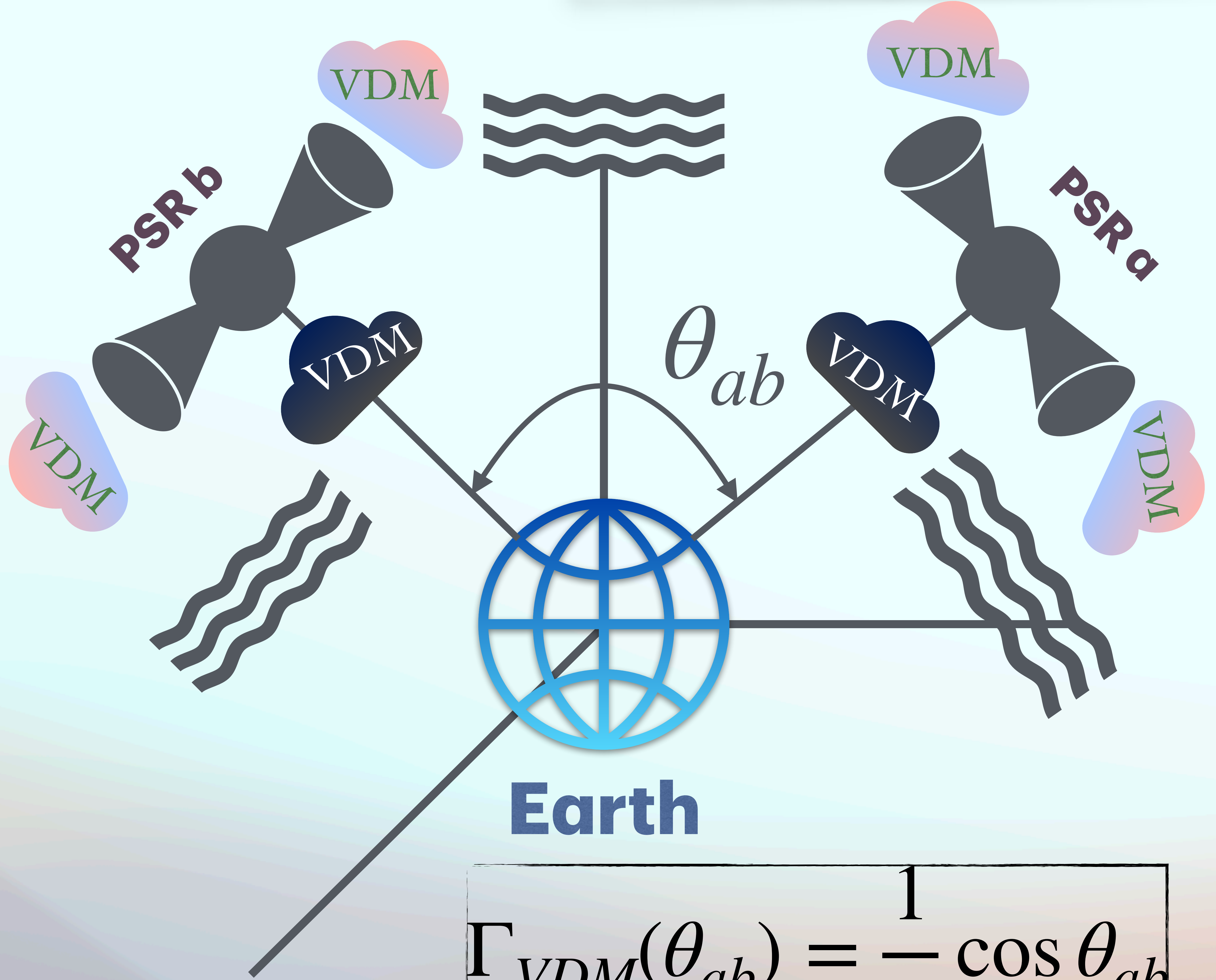


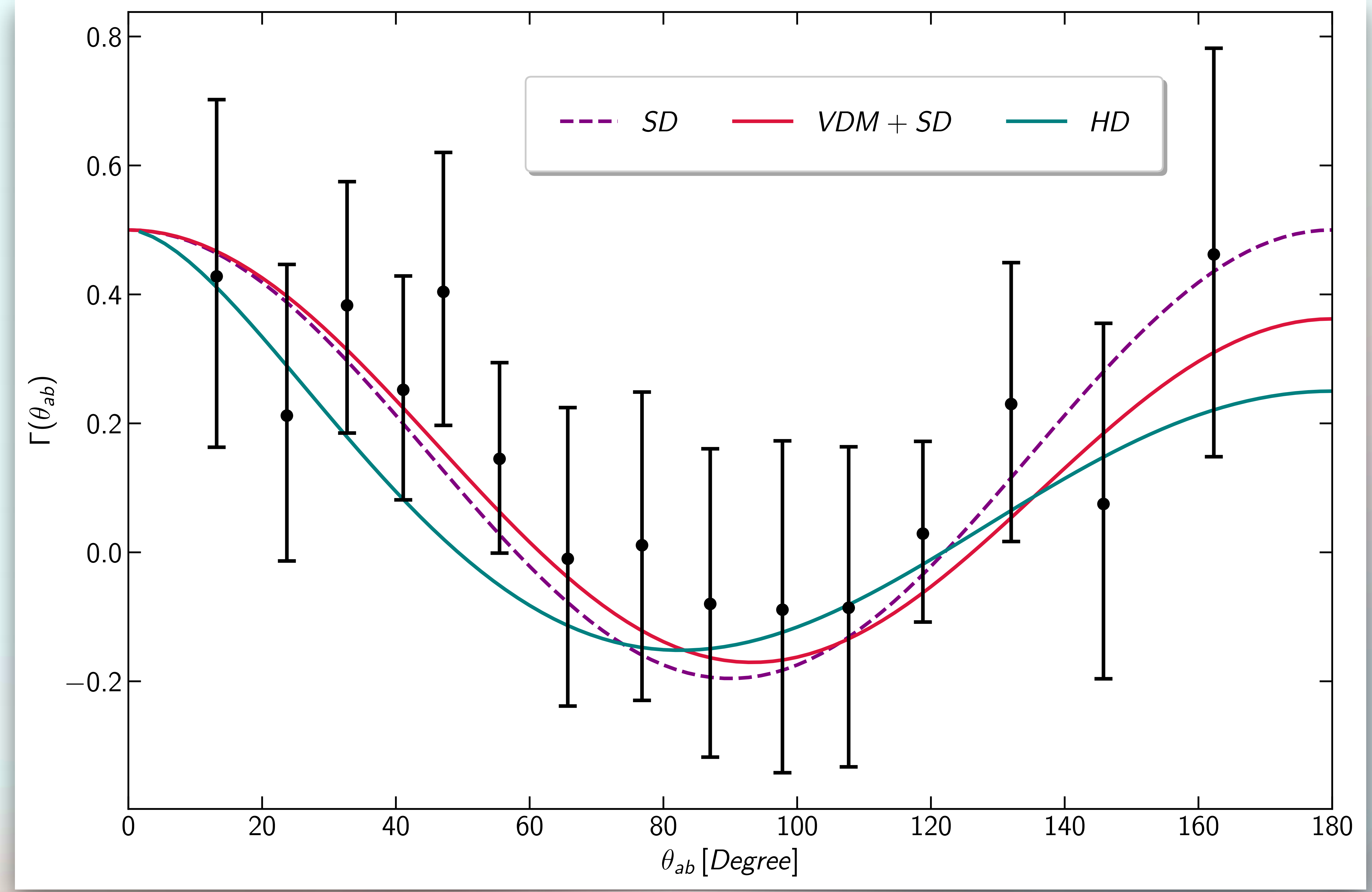
$$\Gamma_{SD}(\theta_{ab}) = \frac{5}{138}P_0(\cos\theta_{ab}) + \frac{64}{138}P_2(\cos\theta_{ab})$$

Agazie et al., Astrophys. J. Lett., 2023

Omiya et al., Phys. Rev. D, 2023

Vector dark matter





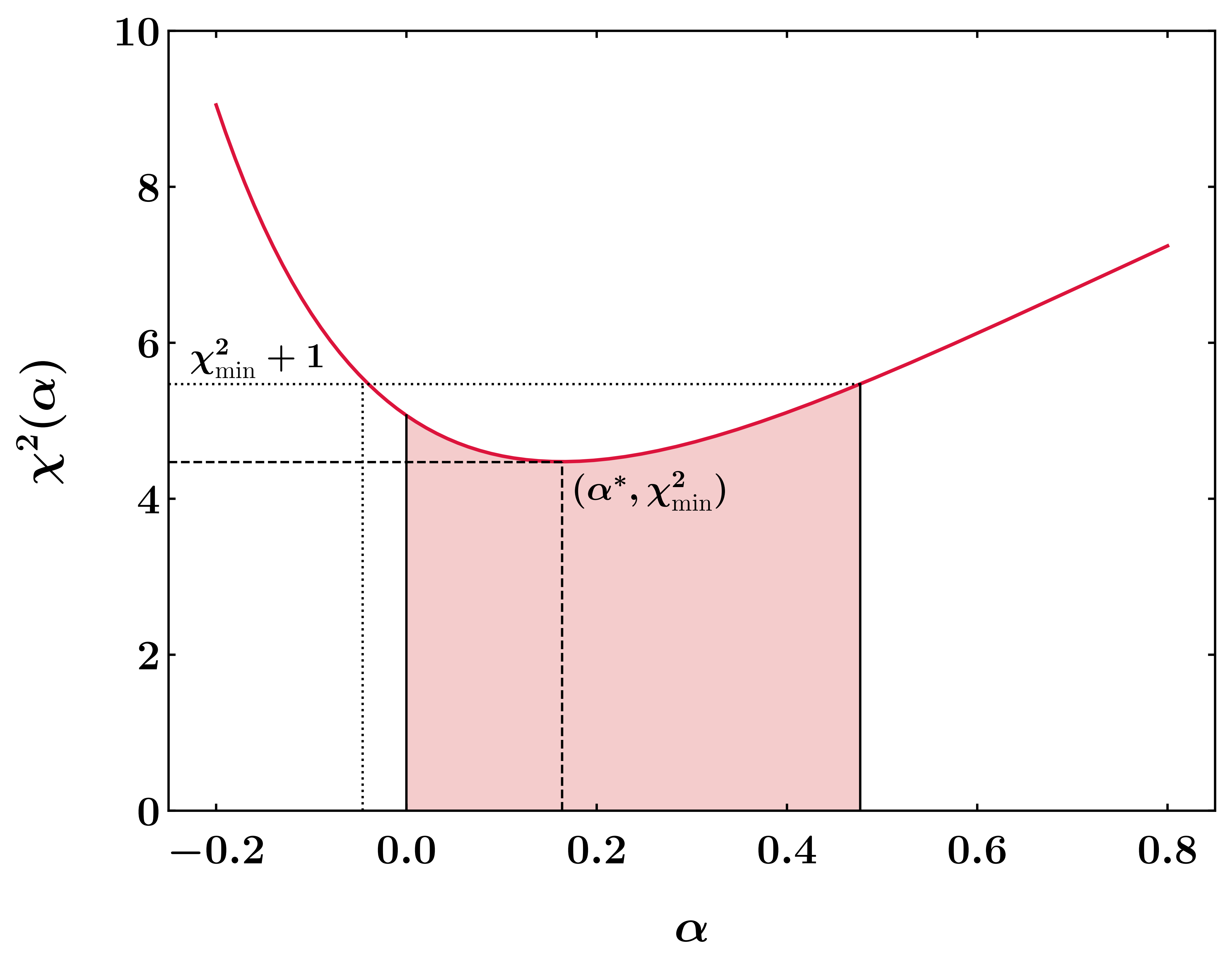
$$\Gamma_{VDM}(\theta_{ab}) = \frac{1}{2}\cos\theta_{ab}$$

$$\xi^{(3)}_{ab}(\theta_{ab}) = \frac{1}{1+\alpha}[\Gamma_{SD}(\theta_{ab}) + \alpha\Gamma_{VDM}(\theta_{ab})]$$

Agazie et al., Astrophys. J. Lett., 2023

Chowdhury, AH, Mohanty, Prakash, arXiv: 2311.10148 [hep-ph]

Fitting NANOGrav data



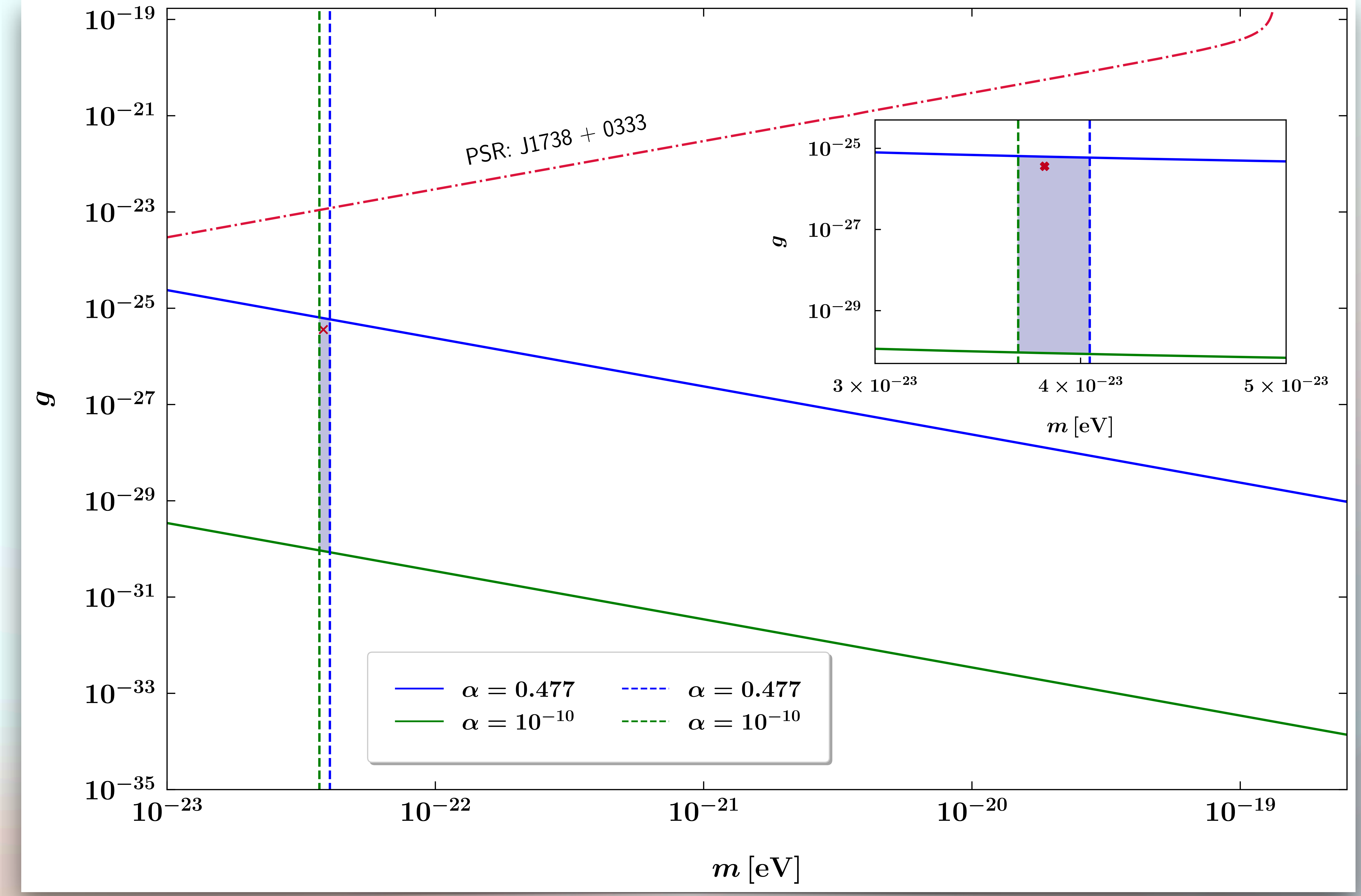
χ^2_{min} value in three scenarios:

- Hellings – Downs : 94.3
- HD + Shapiro delay : 5.068
- Shapiro delay + VDM : 4.47

Chowdhury, AH, Mohanty, Prakash,
arXiv: 2311.10148 [hep-ph]

VDM parameter space

- Solid lines are obtained from the best fit values of α
- The vertical lines highlights the constraint on the dark matter mass from the amplitude of the observed signal



Chowdhury, AH, Mohanty, Prakash, arXiv: 2311.10148 [hep-ph]

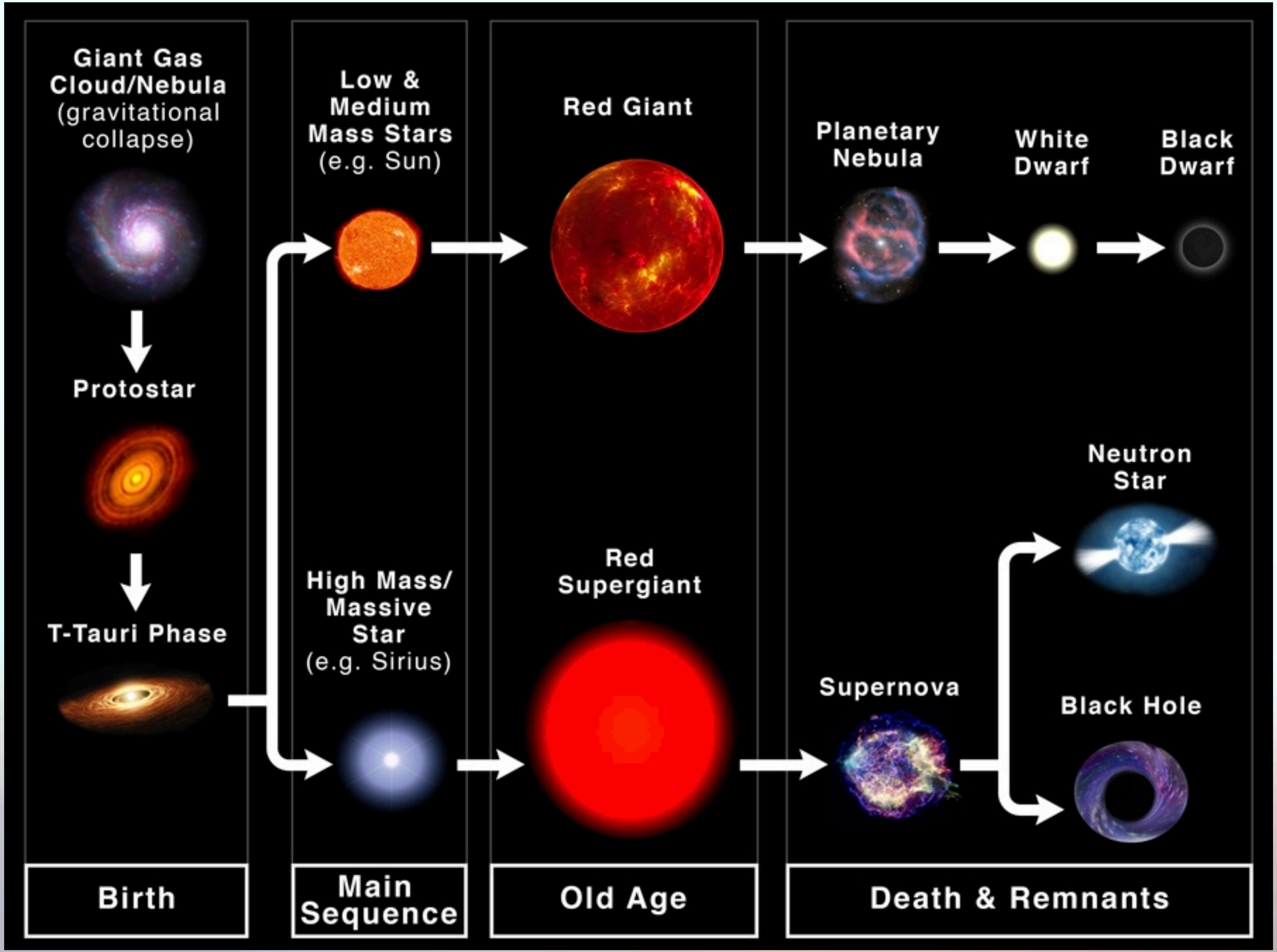
Take Away

- A **non-gravitational** source of pulsar oscillation offers a better fit to the NANOGrav data as compared to standard HD correlation for stochastic gravitational wave background.

- We are statistically incentive to accept that PTA results offer evidence for ultra-light vector dark matter!

- Future observations of pulsar timing by PTA collaborations may be able to enhance the statistical significance of vector dark matter explanation or rule it out.

Thank You!



Credit : ScienceFacts

- Neutron star is the last stage of a stellar evolution
- These are very dense objects

$$\xi_{ab}(\theta_{ab}) = \Phi_{HD}\Gamma_{HD}(\theta_{ab}) + \Phi_{SD}\Gamma_{SD}(\theta_{ab}) + \Phi_{VDM}\Gamma_{VDM}(\theta_{ab})$$
$$= [\Phi_{SD}(\Gamma_{SD}(\theta_{ab}) + \beta\Gamma_{HD}(\theta_{ab}) + \alpha\Gamma_{VDM}(\theta_{ab}))]$$

$$\tilde{\xi}_{ab}(\theta_{ab}) = \frac{1}{1+\beta+\alpha}[\Gamma_{SD}(\theta_{ab}) + \beta\Gamma_{HD}(\theta_{ab}) + \alpha\Gamma_{VDM}(\theta_{ab})]$$

Minimization of χ^2 demands β to be **negligibly small**