Searching for anisotropies in the GWB - a path to unveil its origin

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SUSY 2024, IFT | June 13, 2024

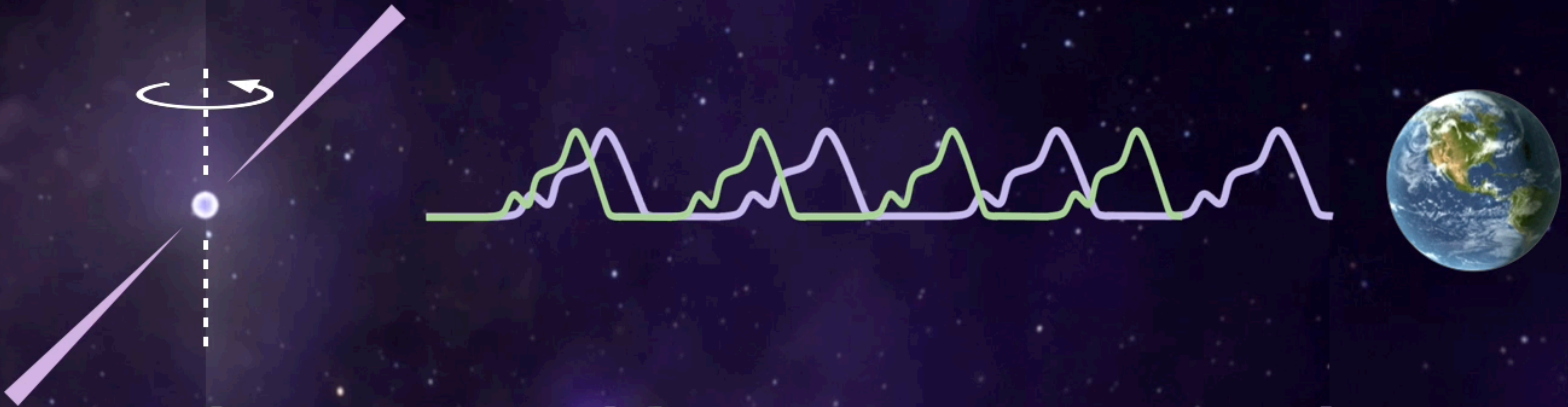
DESY.

NANOGrav
Physics Frontiers Center

PULSARS

Animation by NASA's Goddard Space Flight Center

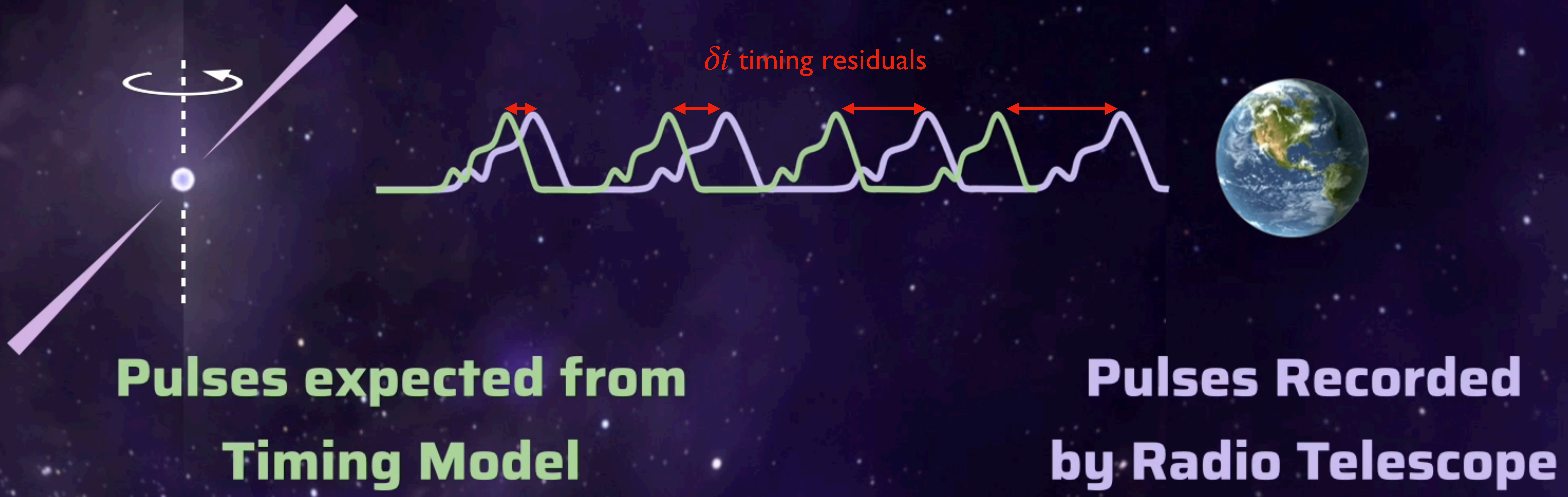
TIMING RESIDUALS



Pulses expected from Timing Model

Pulses Recorded by Radio Telescope

TIMING RESIDUALS

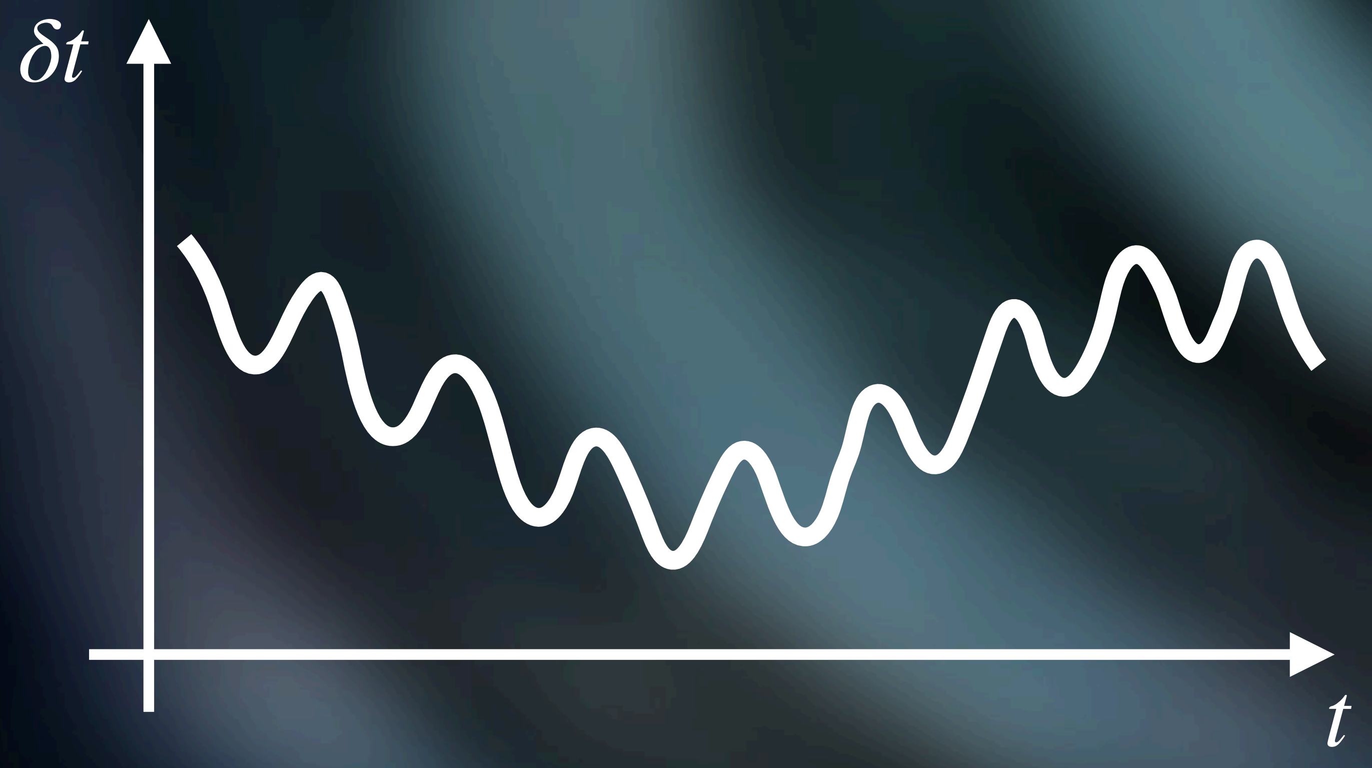


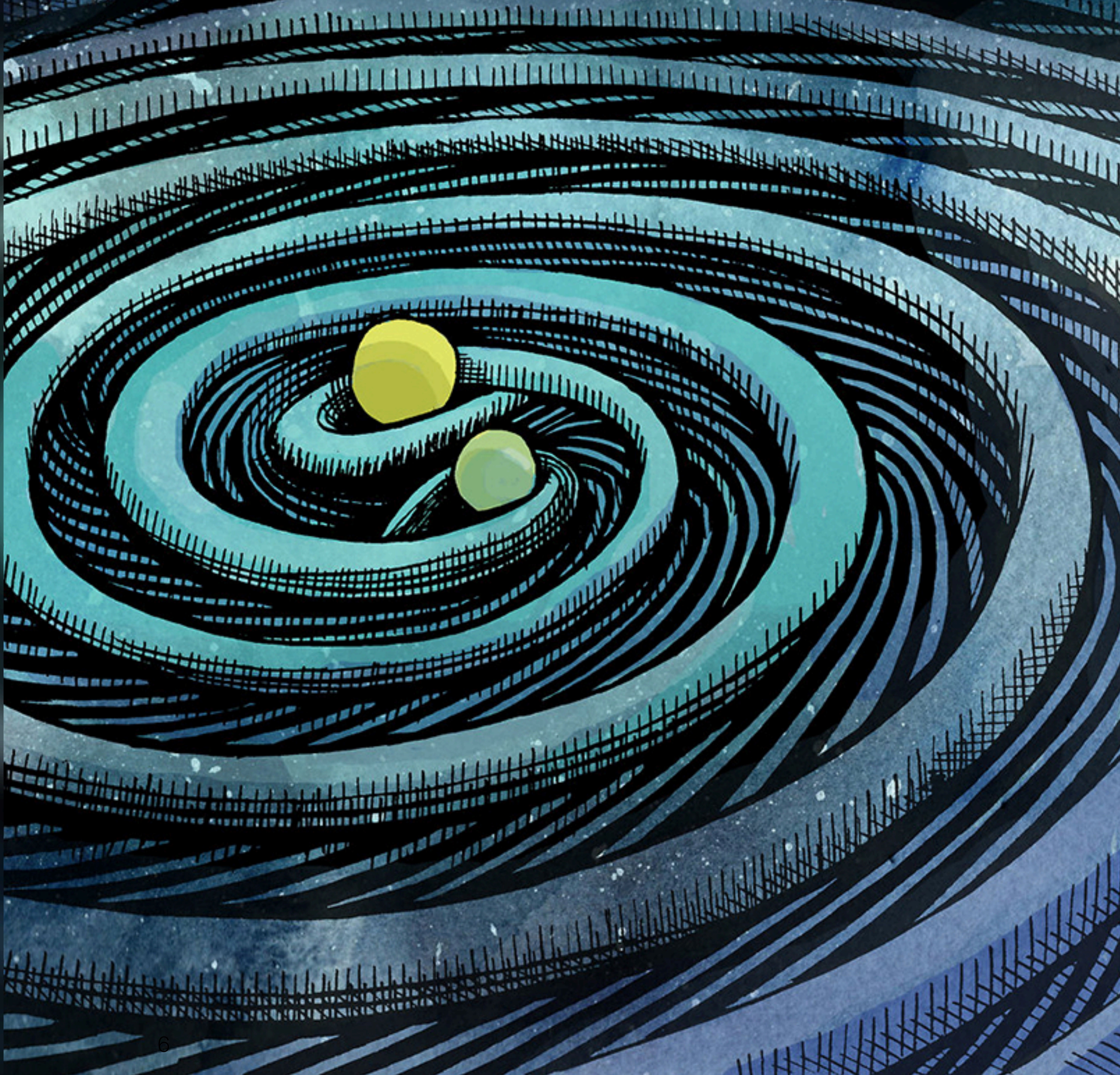
A GALAXY-SIZE DETECTOR FOR GWs

credits Keyi "Onyx" Li / NSF / NANOGrav

CONTINUOUS WAVE

$$h_{ij}(t, \mathbf{x}) = \sum_{A=+,\times} e_{ij}^{A}(\hat{n}) \cos\left[\omega(t - \hat{n} \cdot \mathbf{x})\right]$$

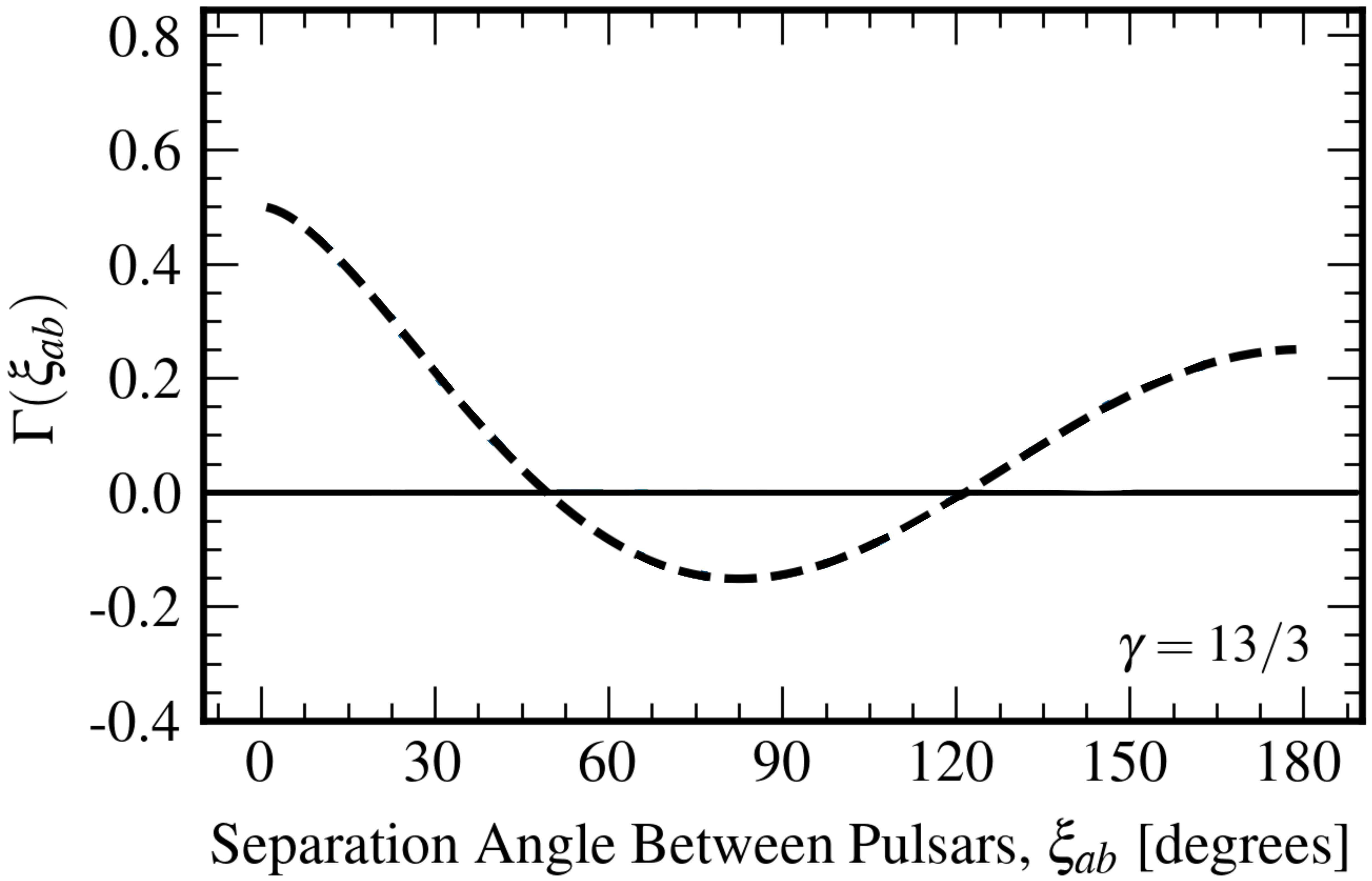




GW BACKGROUND

$$h_{ij}(t, \mathbf{x}) = \sum_{A=+,\times} \int df \int d^2\hat{n}\; \tilde{h}_A(f, \hat{n})\; e_{ij}^{A}(\hat{n})\, e^{-2\pi i f(t - \hat{n}\cdot x)}$$

HELLINGS & DOWNS CURVE



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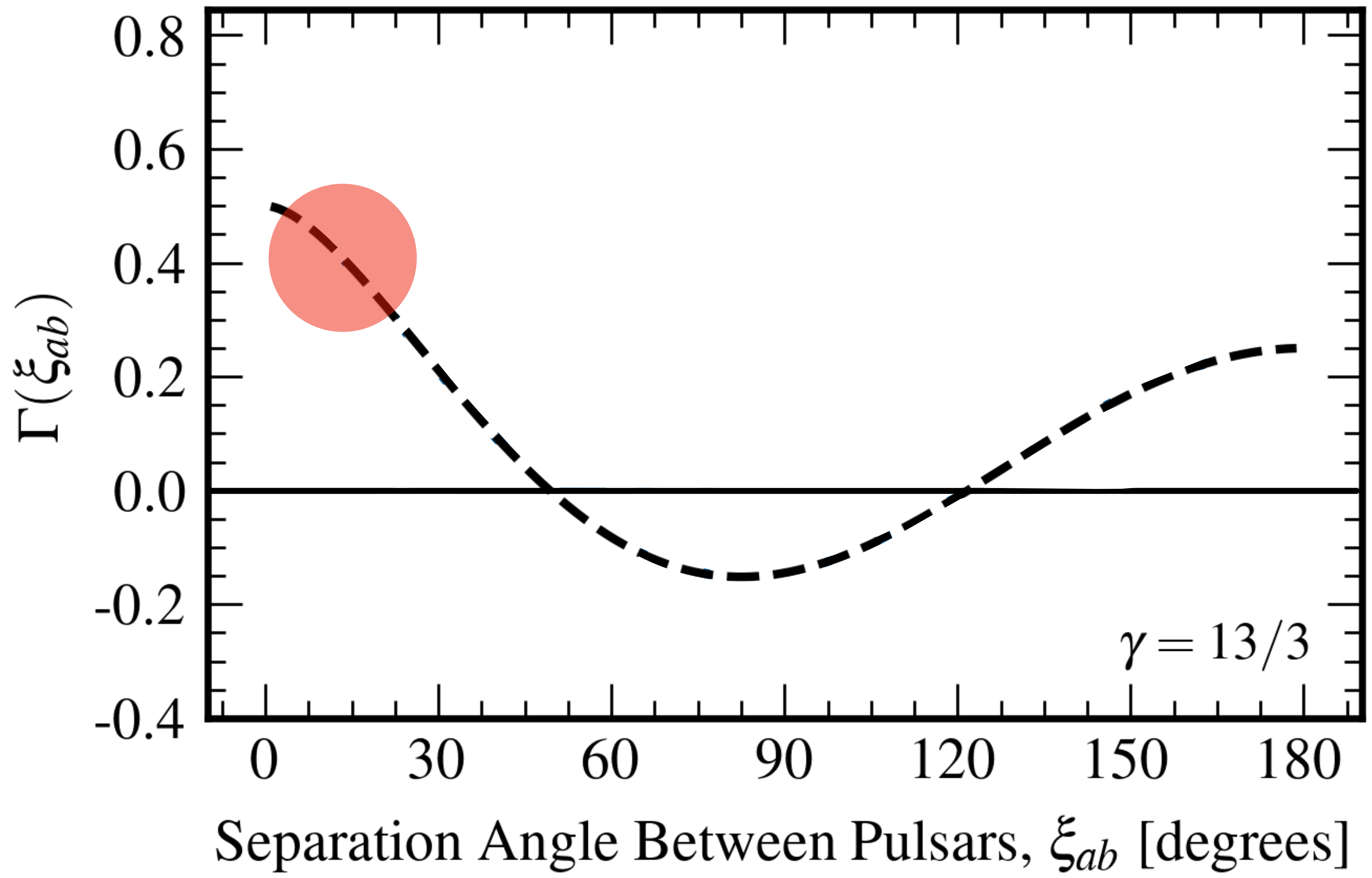

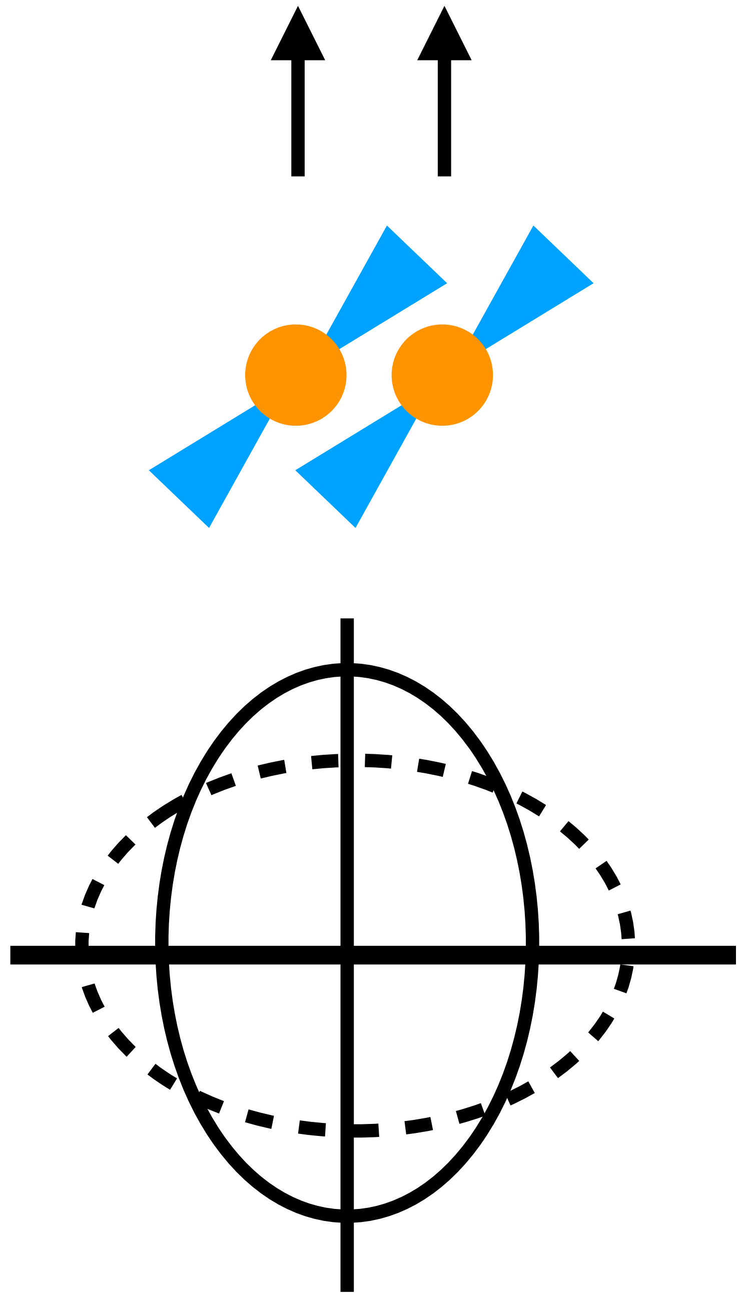

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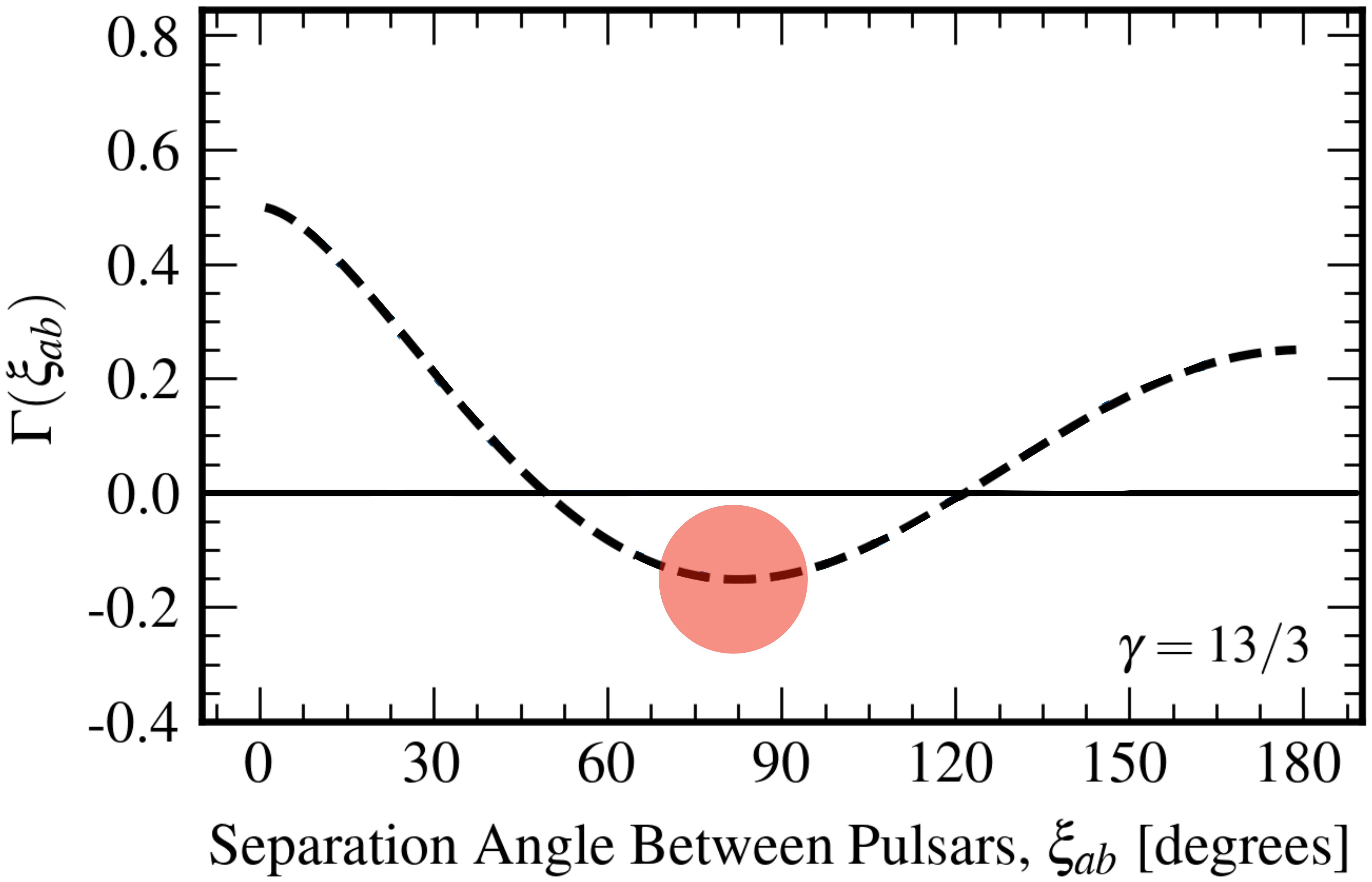

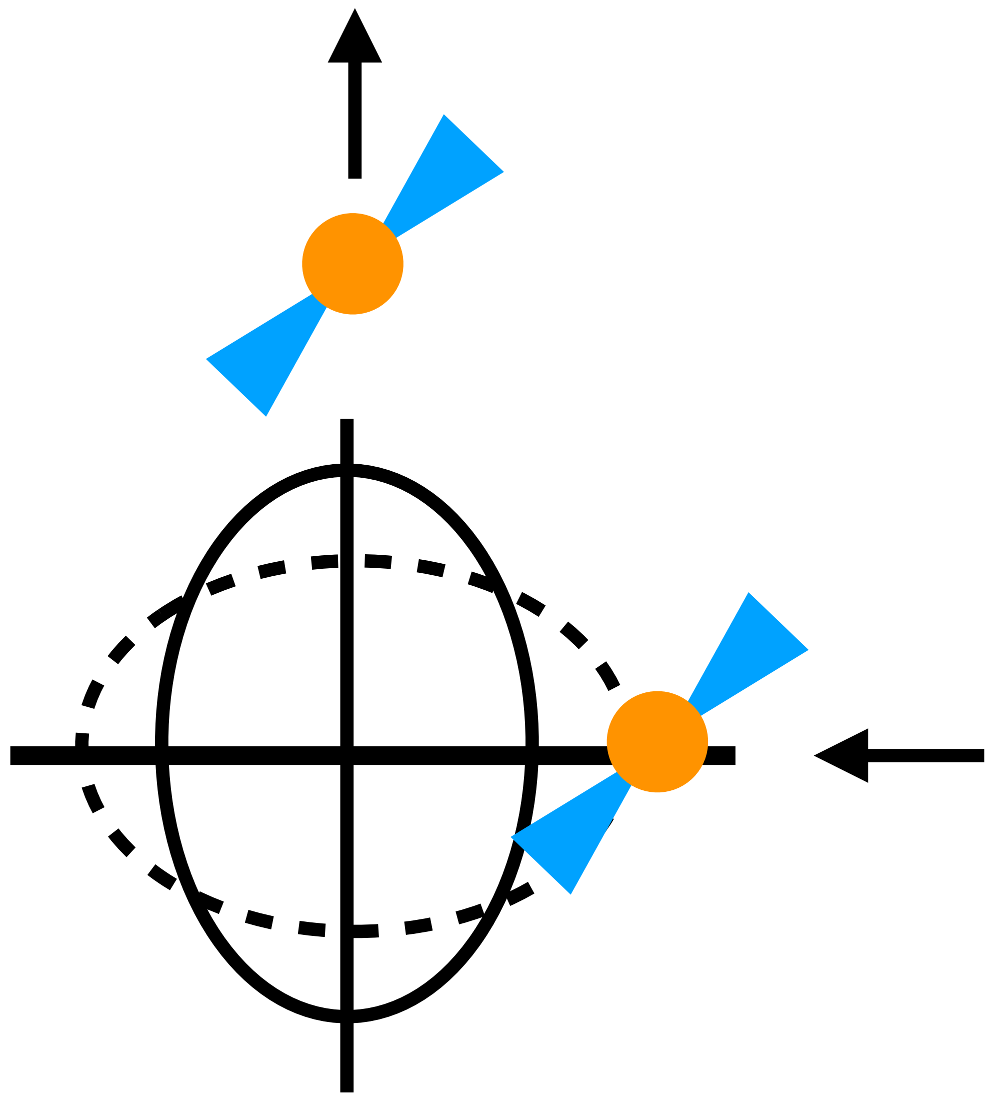

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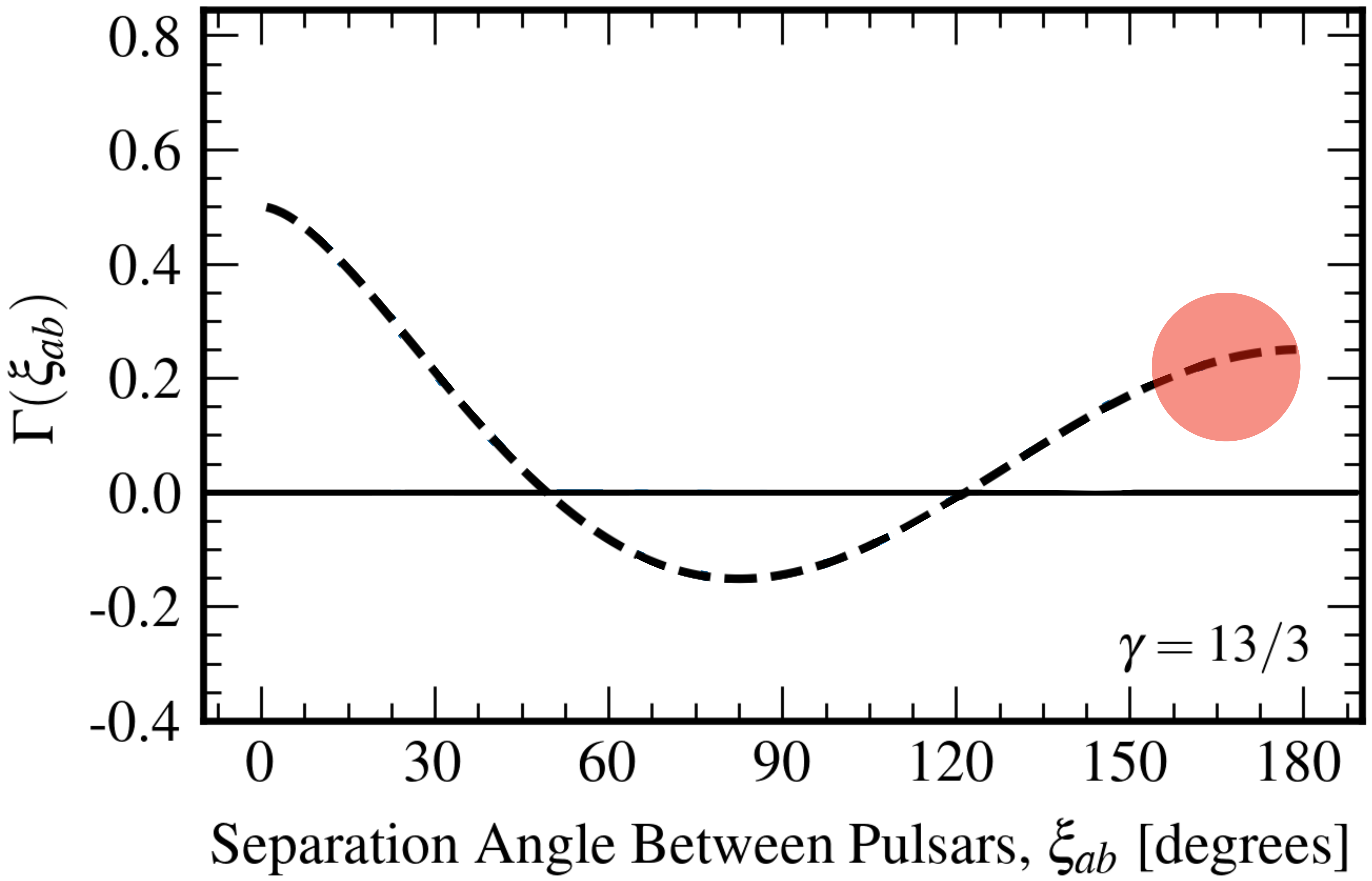
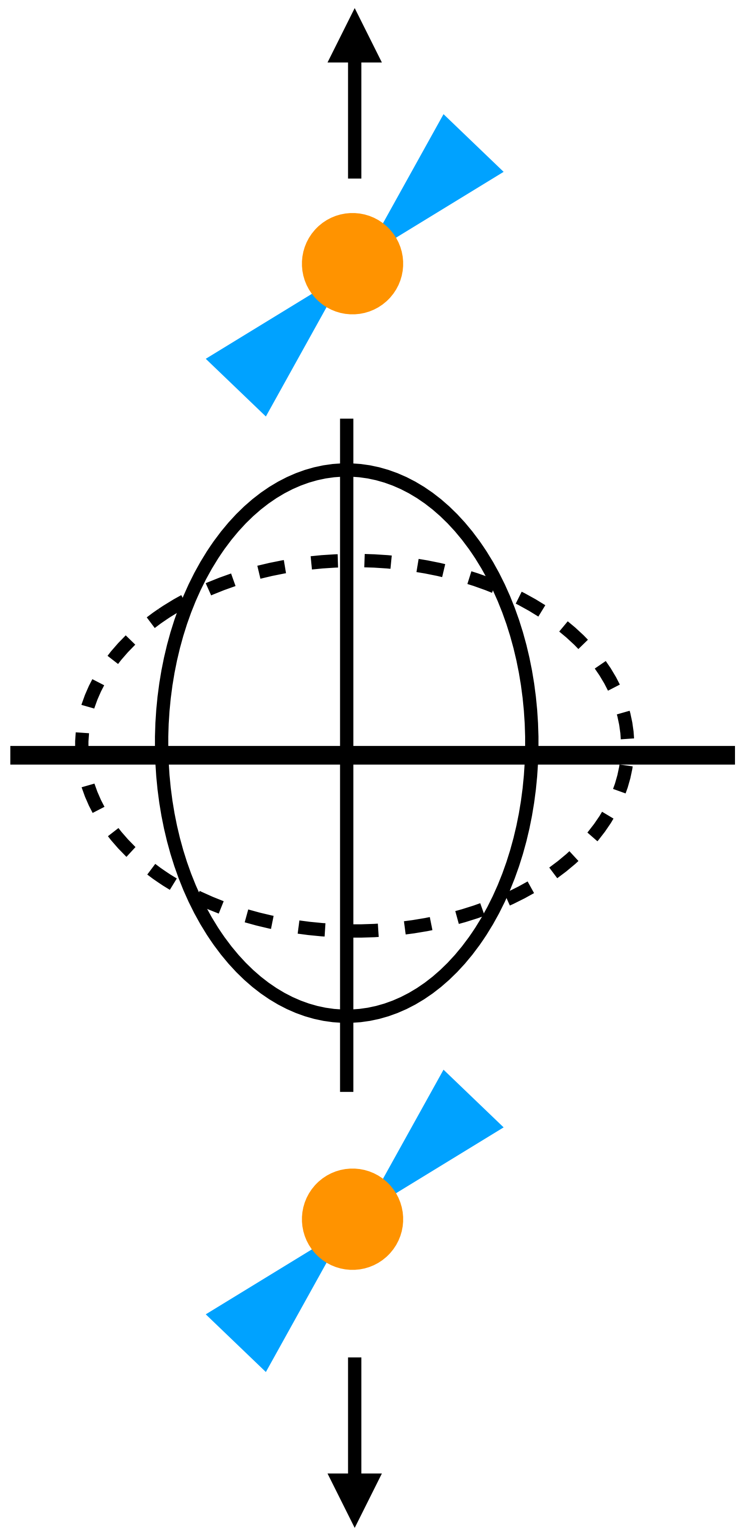
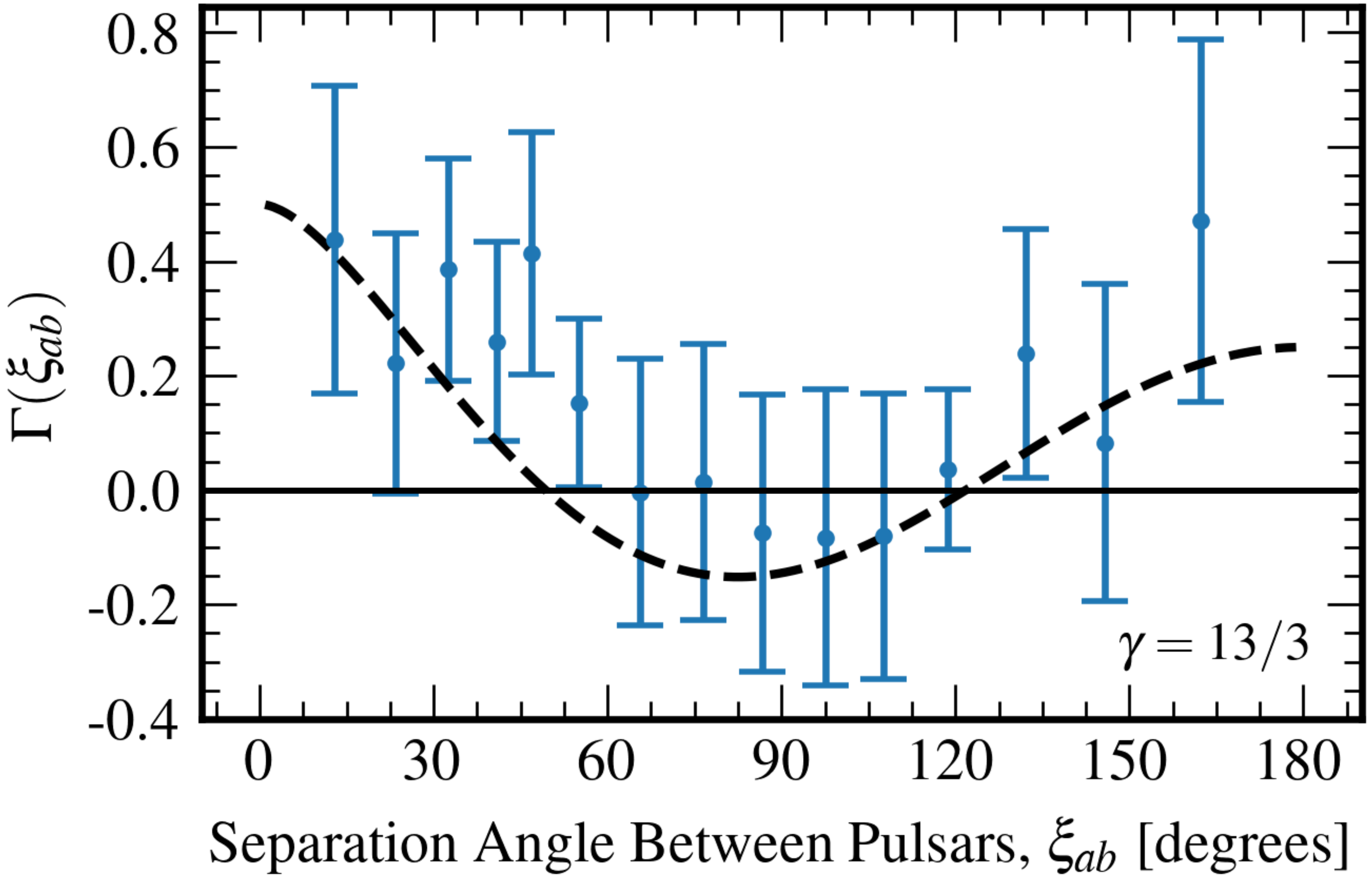




EVIDENCE FOR GWB

Agazie et al. [2306.16213]



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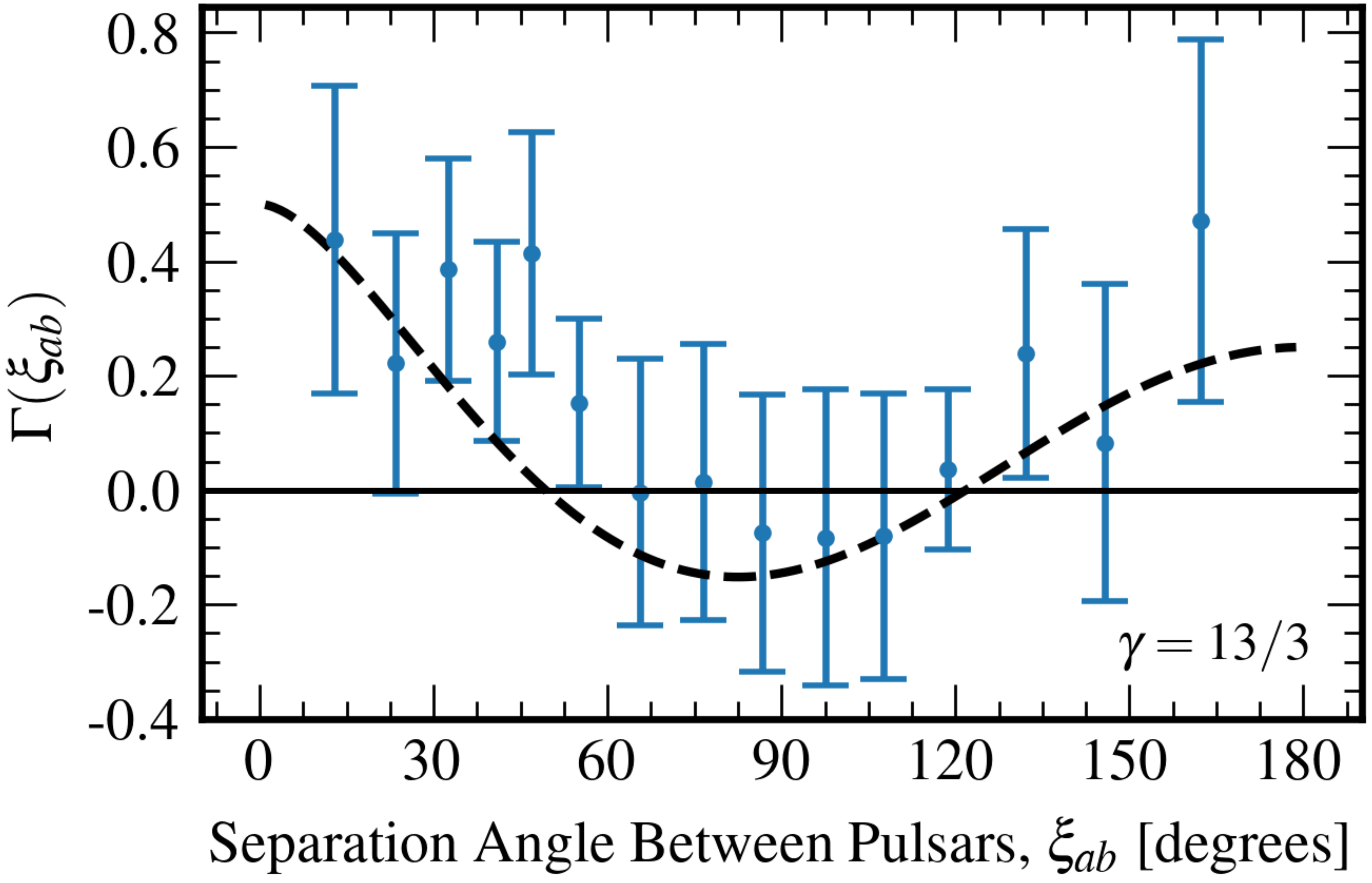

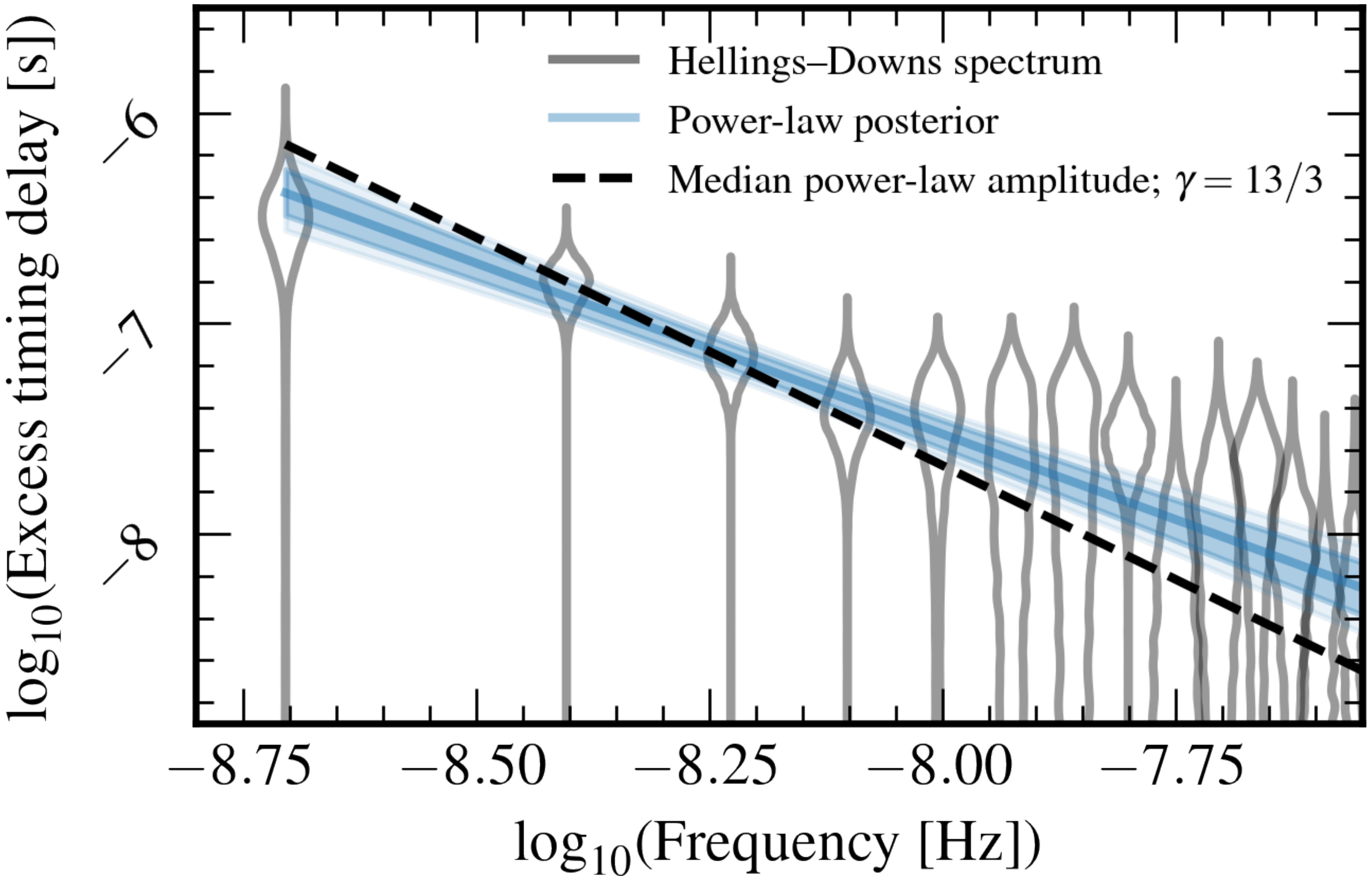

what is the source?

THE PRIMARY SUSPECT

COSMOLOGICAL SOURCES

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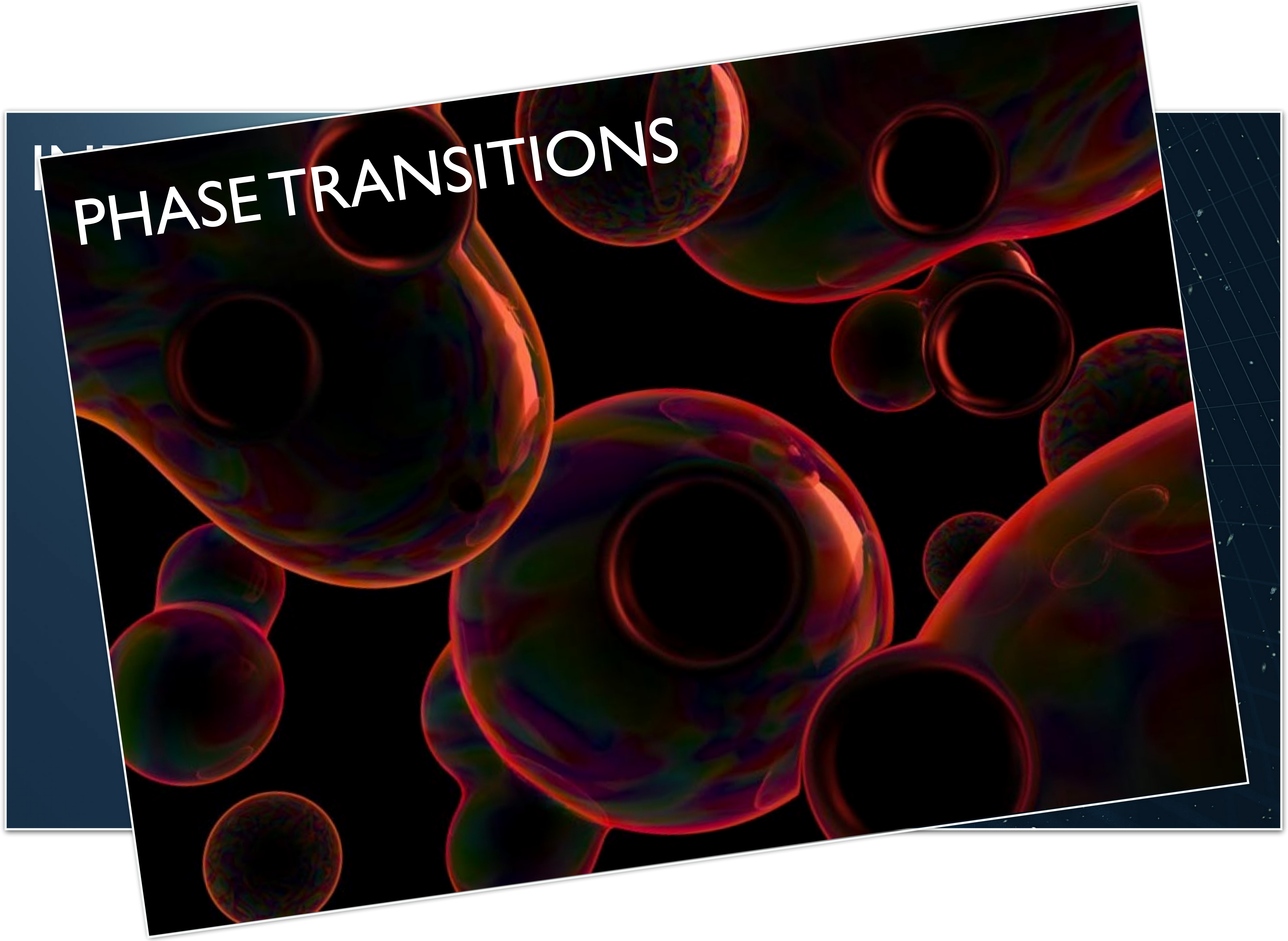
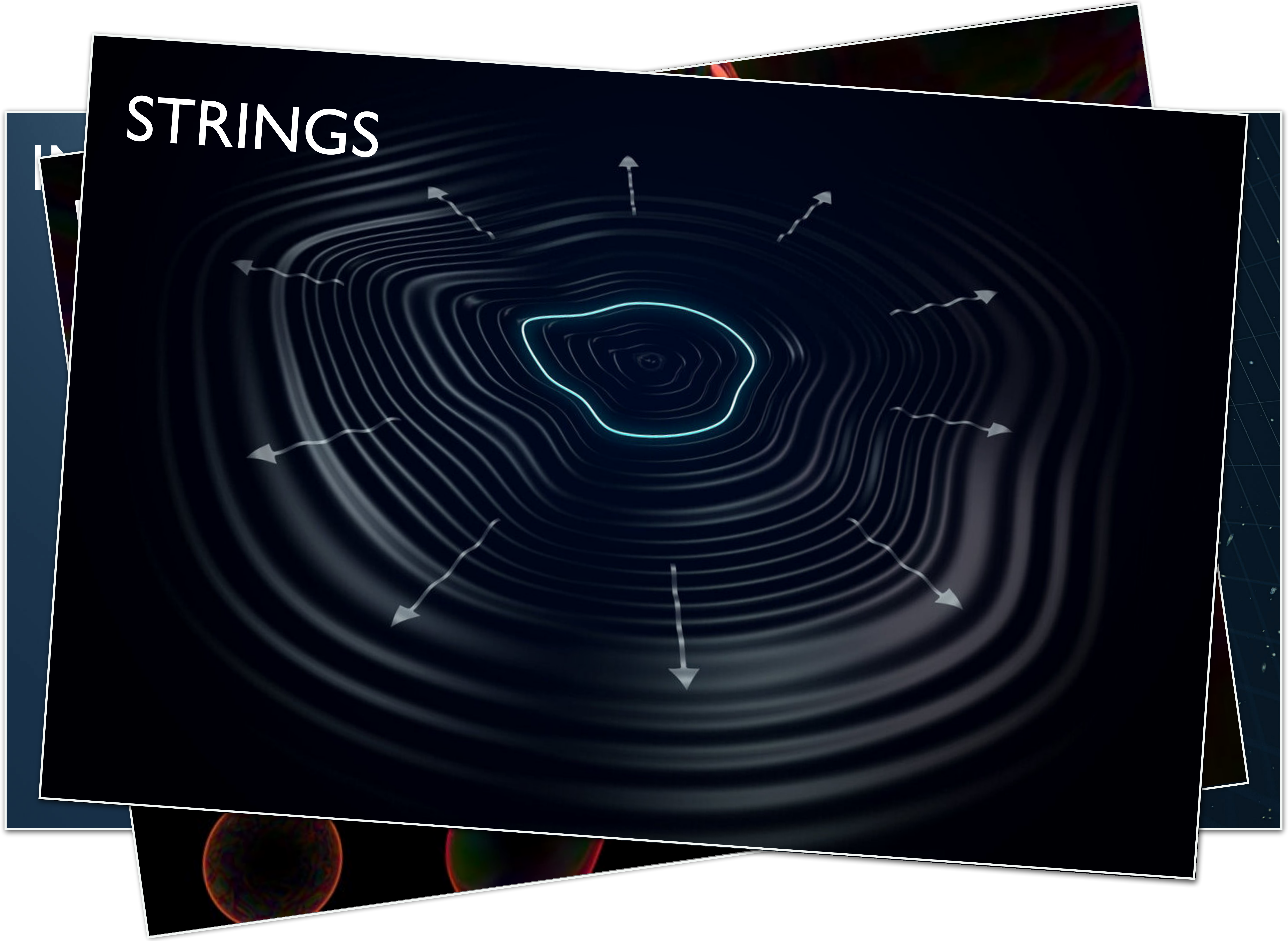
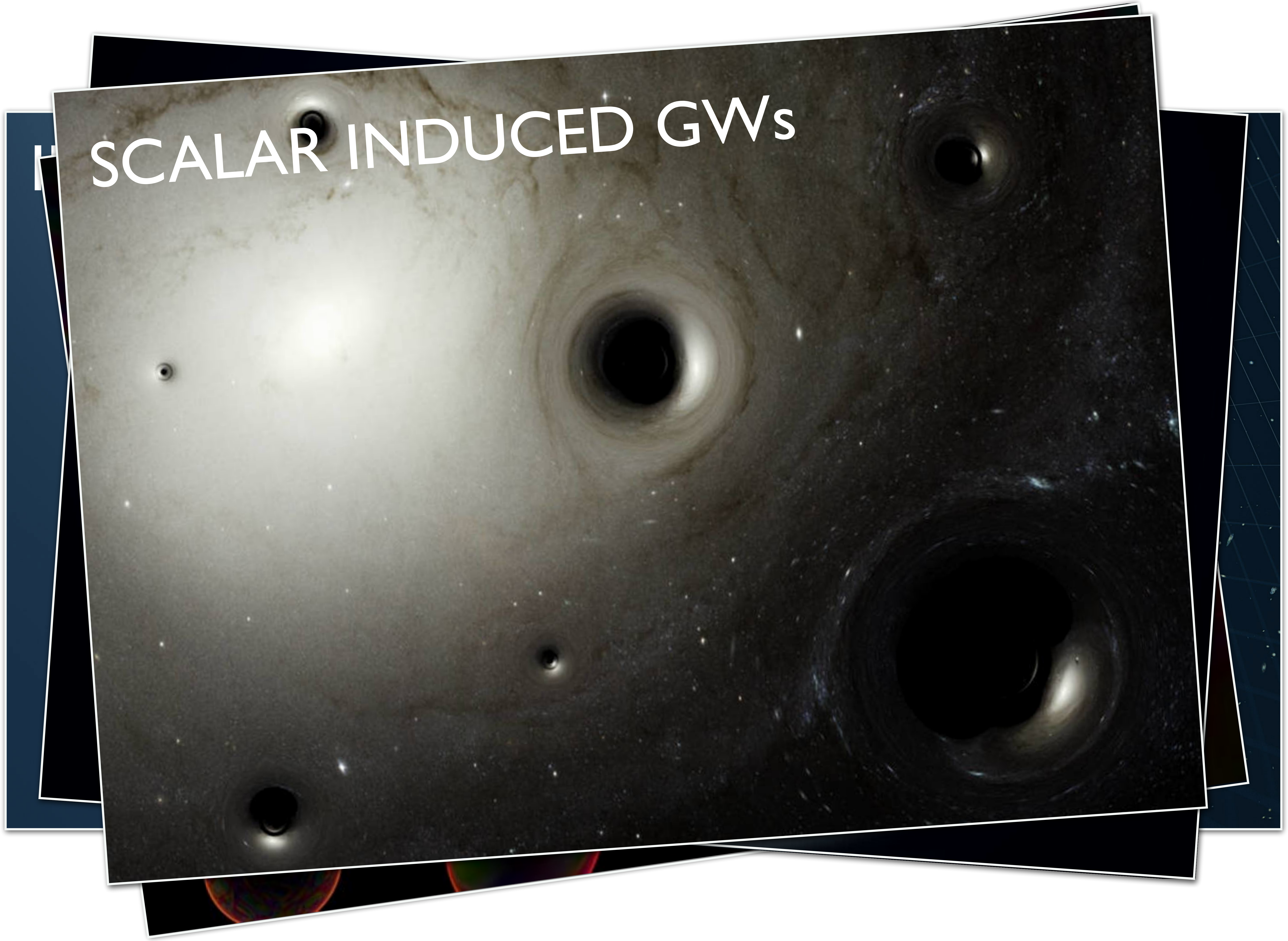


COSMOLOGICAL SOURCES

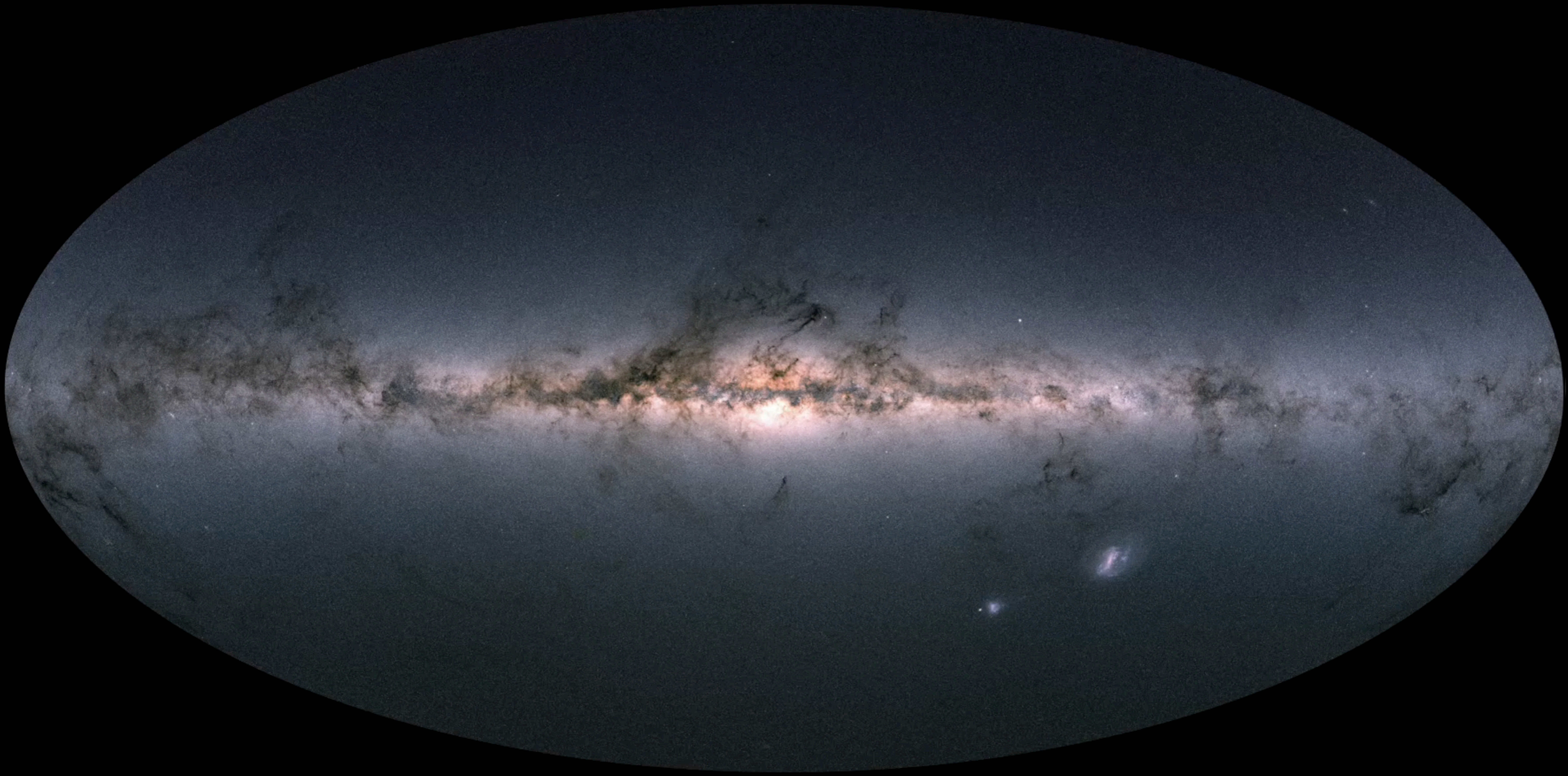


COSMOLOGICAL SOURCES



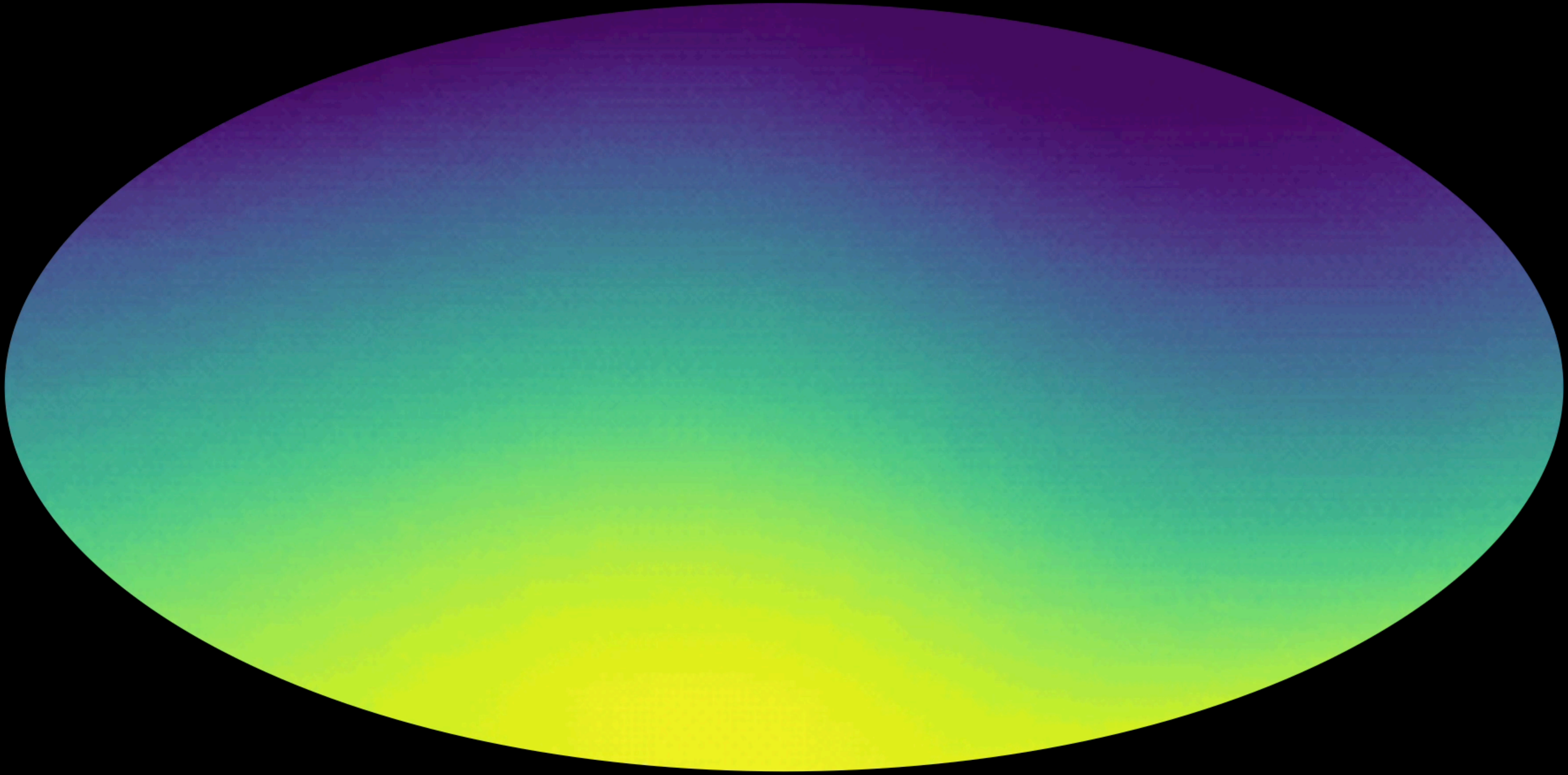
astrophysics or cosmology?

ANISOTROPIES



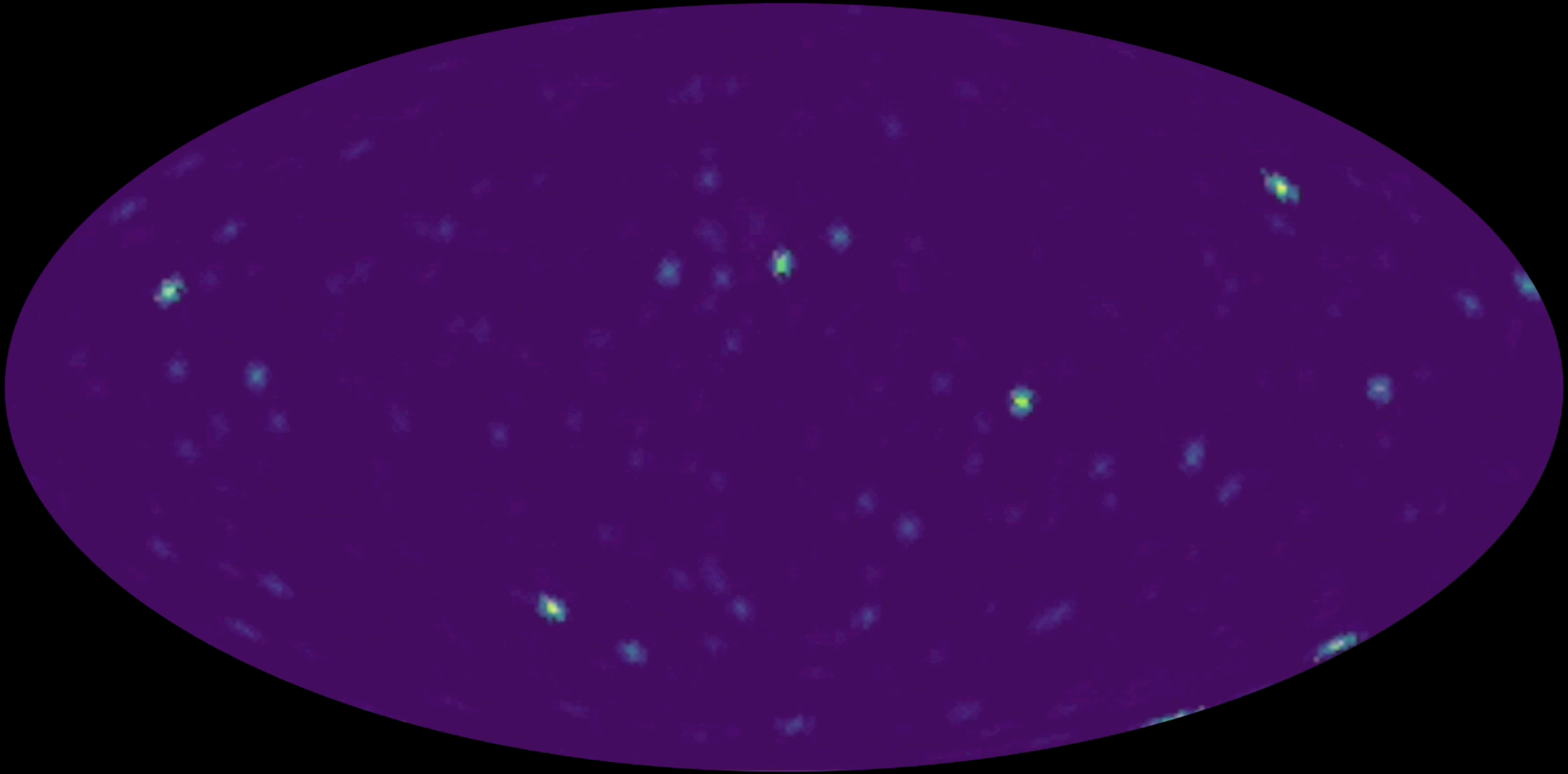
Credit: ESA/Gaia/DPAC

ANISOTROPIES



Simulated Data

ANISOTROPIES



Simulated Data

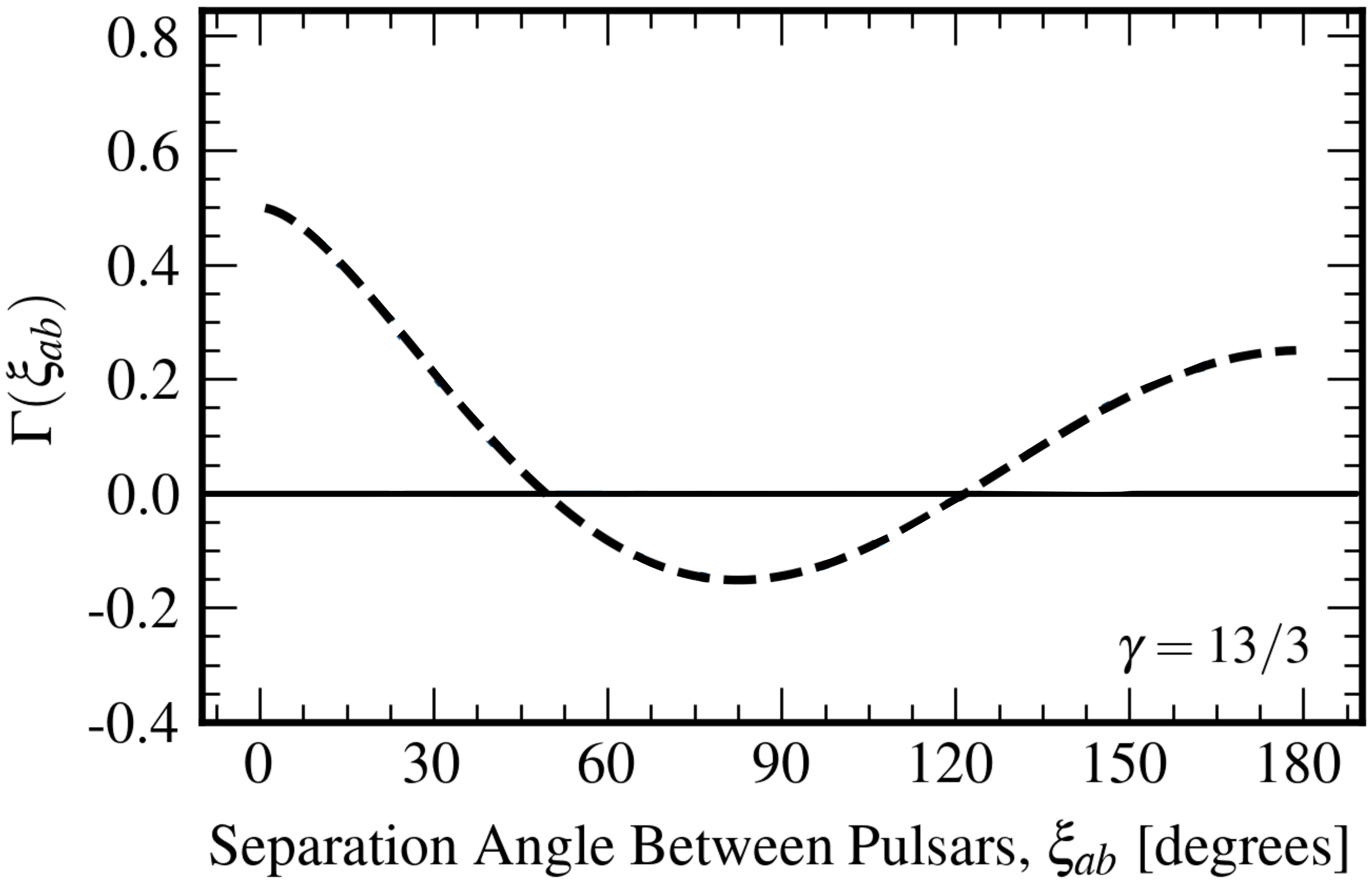
ANISOTROPIES

$$\Gamma_{ab} \propto \sum_k R_{ab,k} \cdot P_k$$

pulsars correlations

PTA response function

GWB power



for P_k = const, Γ_{ab} reduces to the HD overlap reduction function

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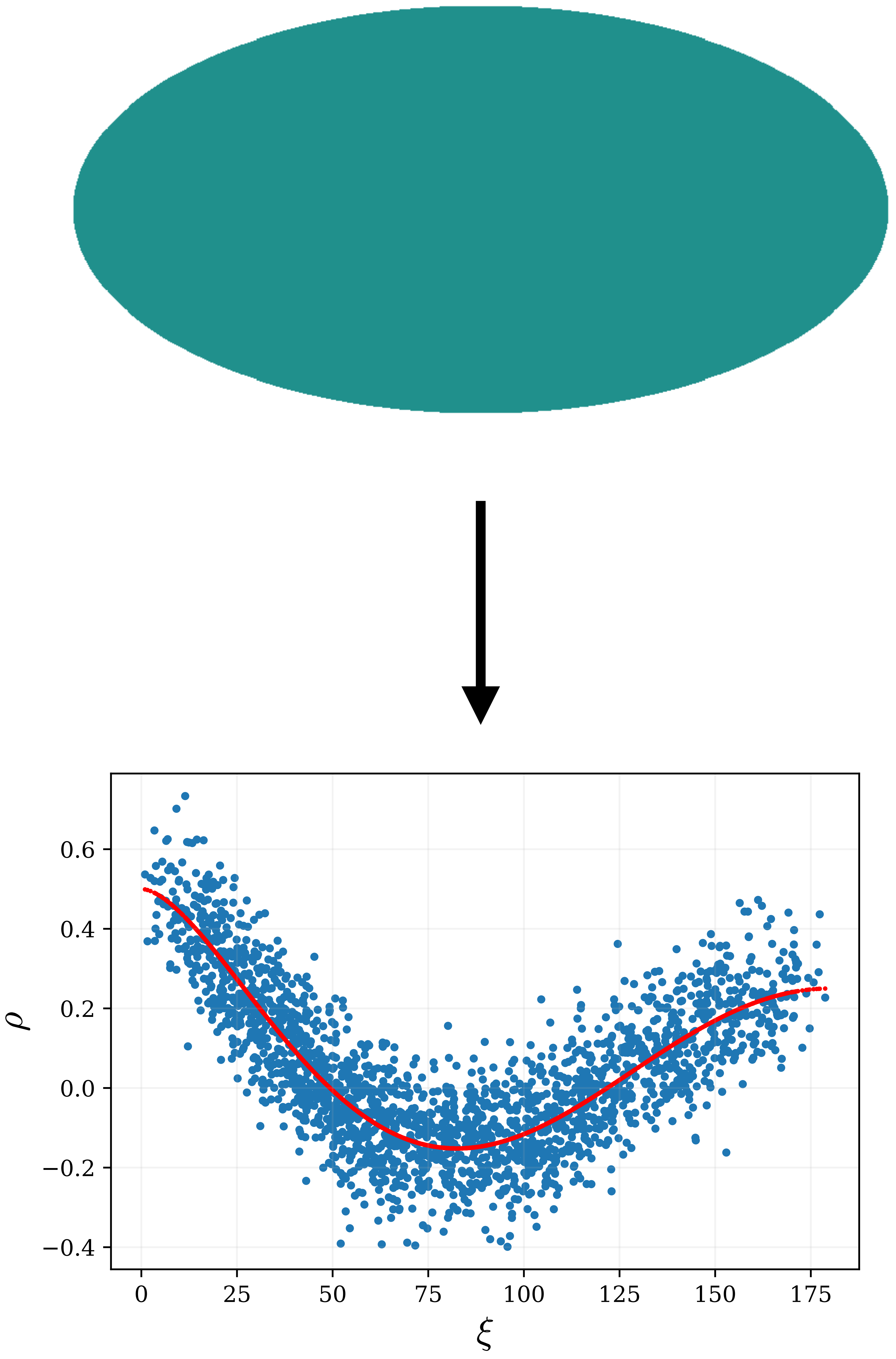

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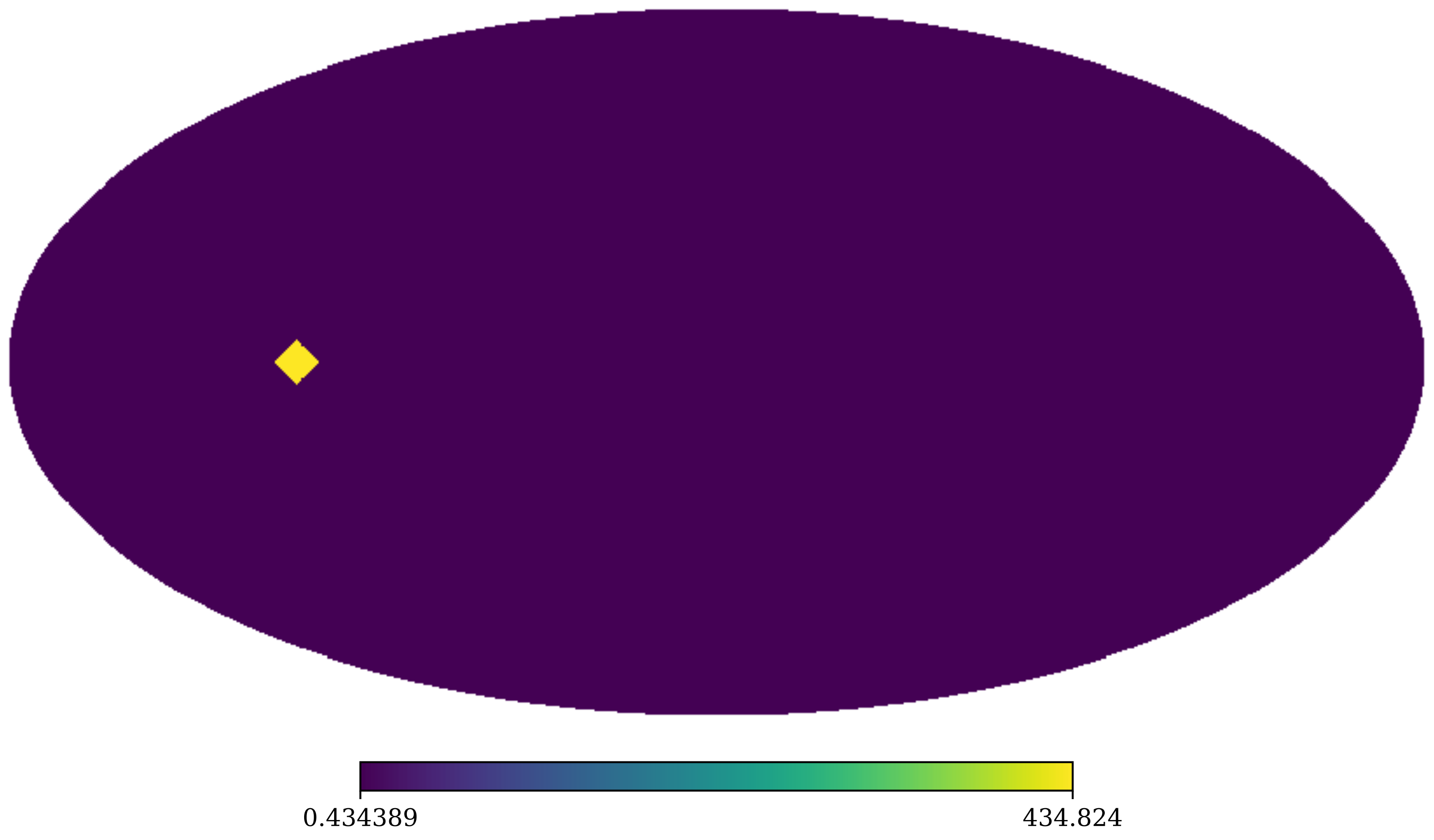

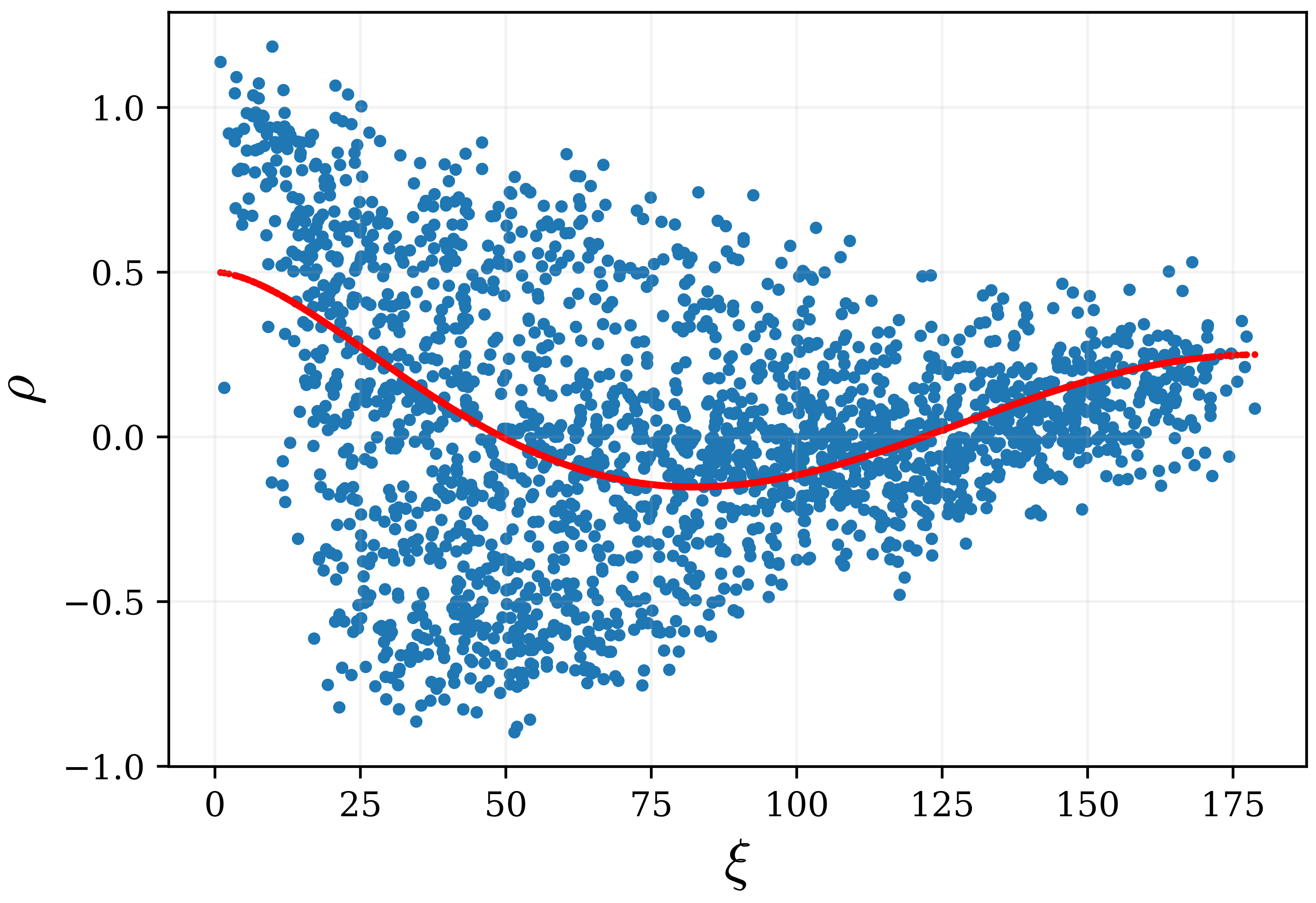

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pulsars
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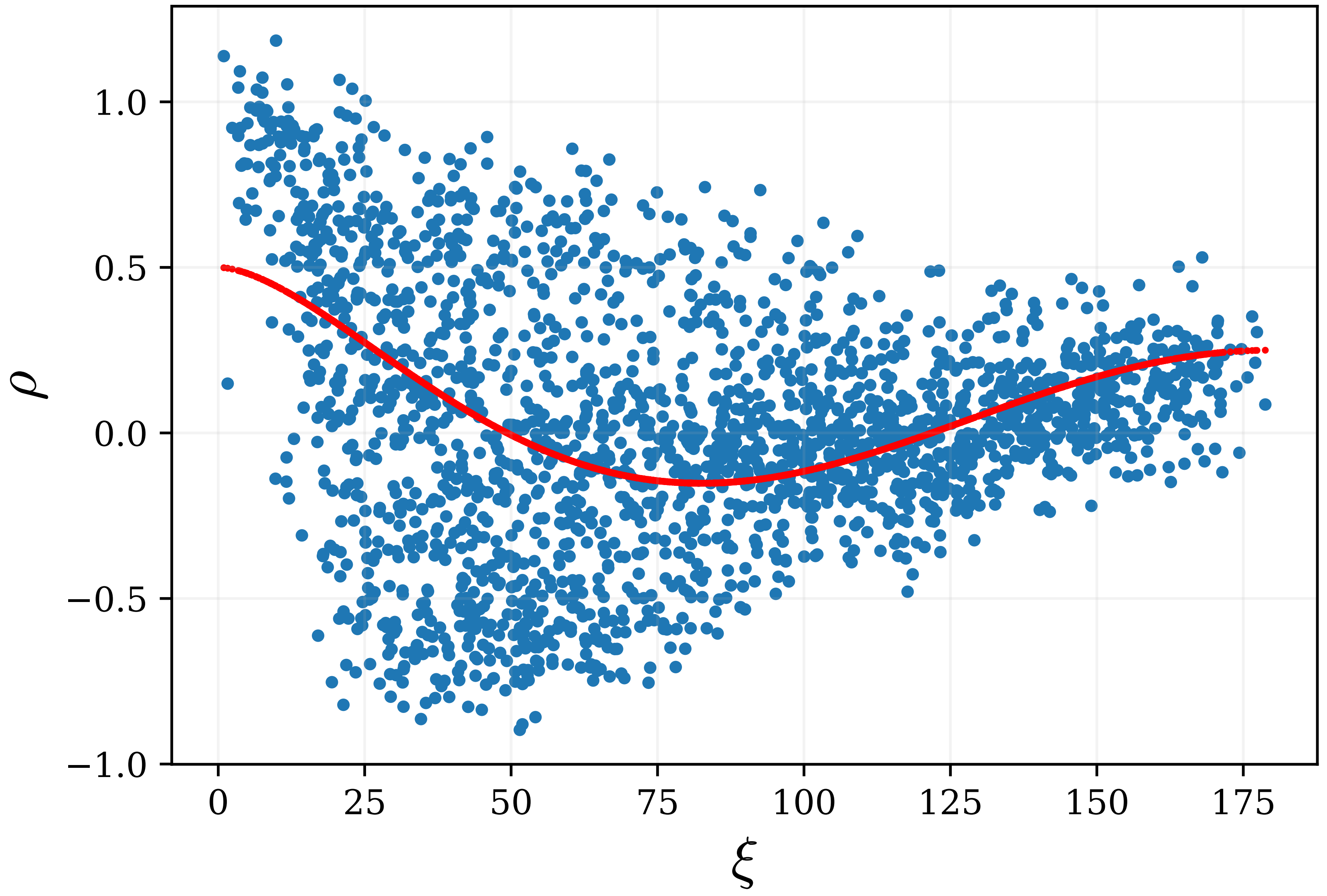
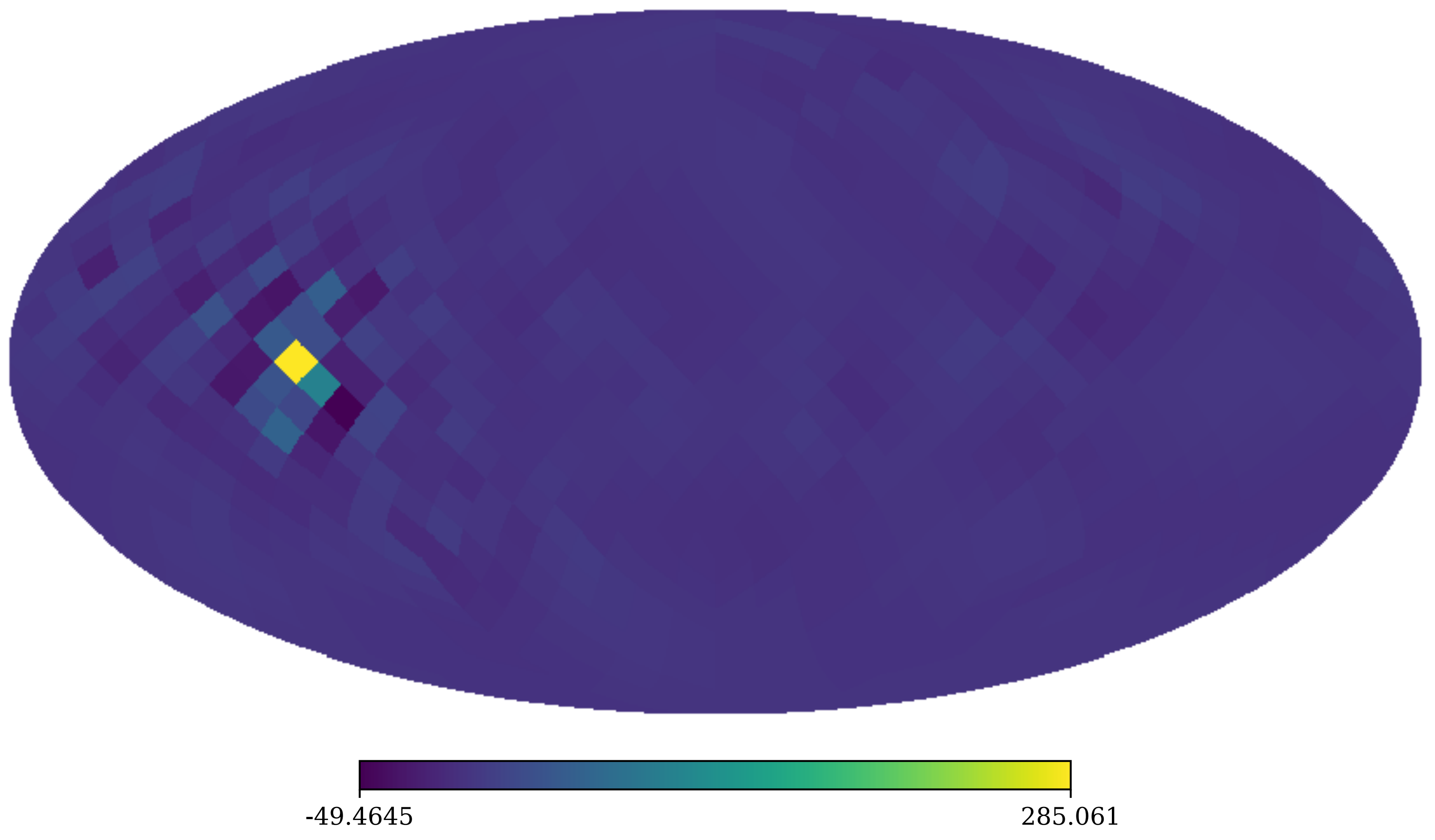
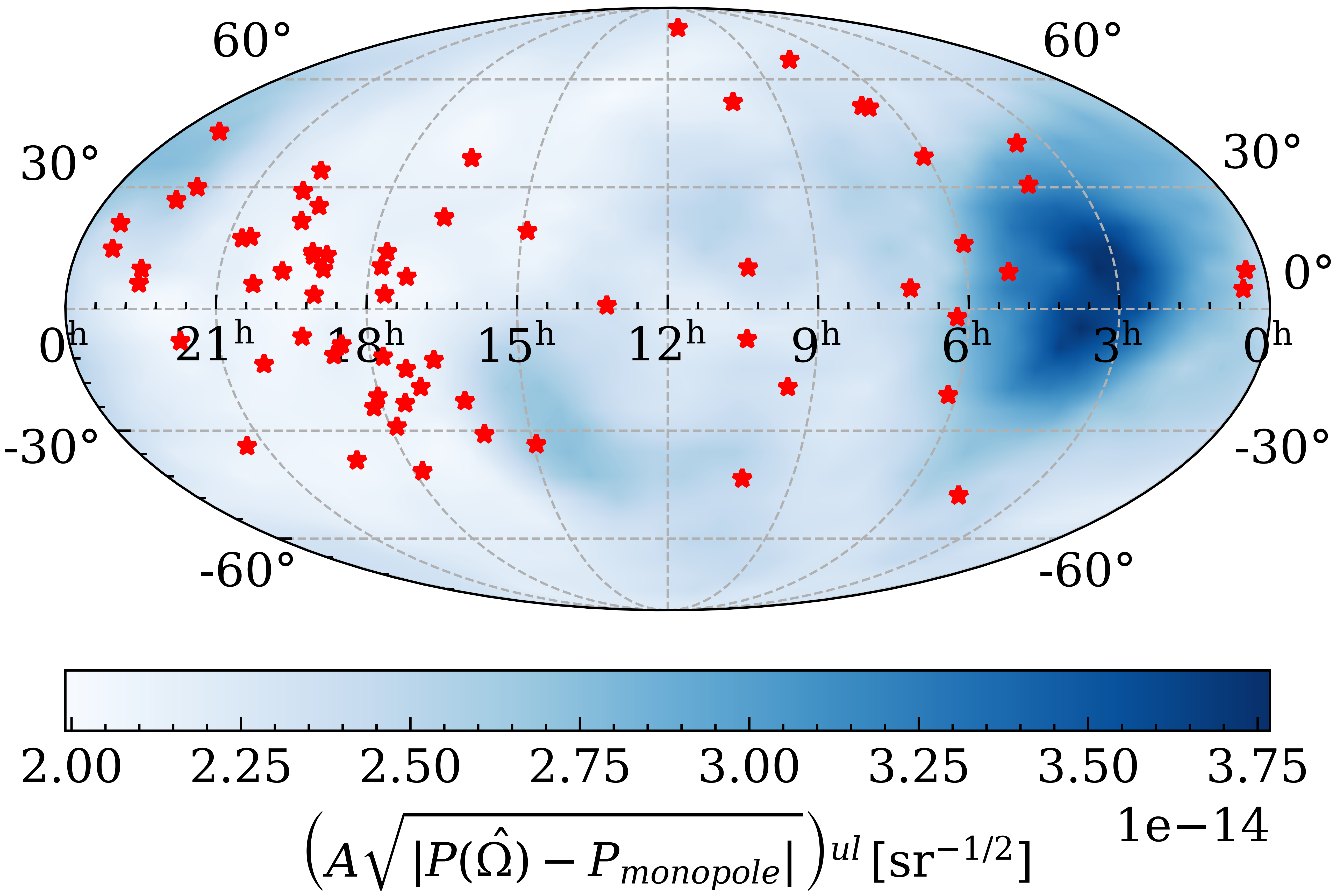




ANISOTROPIES UPPER LIMITS



Agazie et al. [2306.16221]

PARAMETER DEPENDENCE

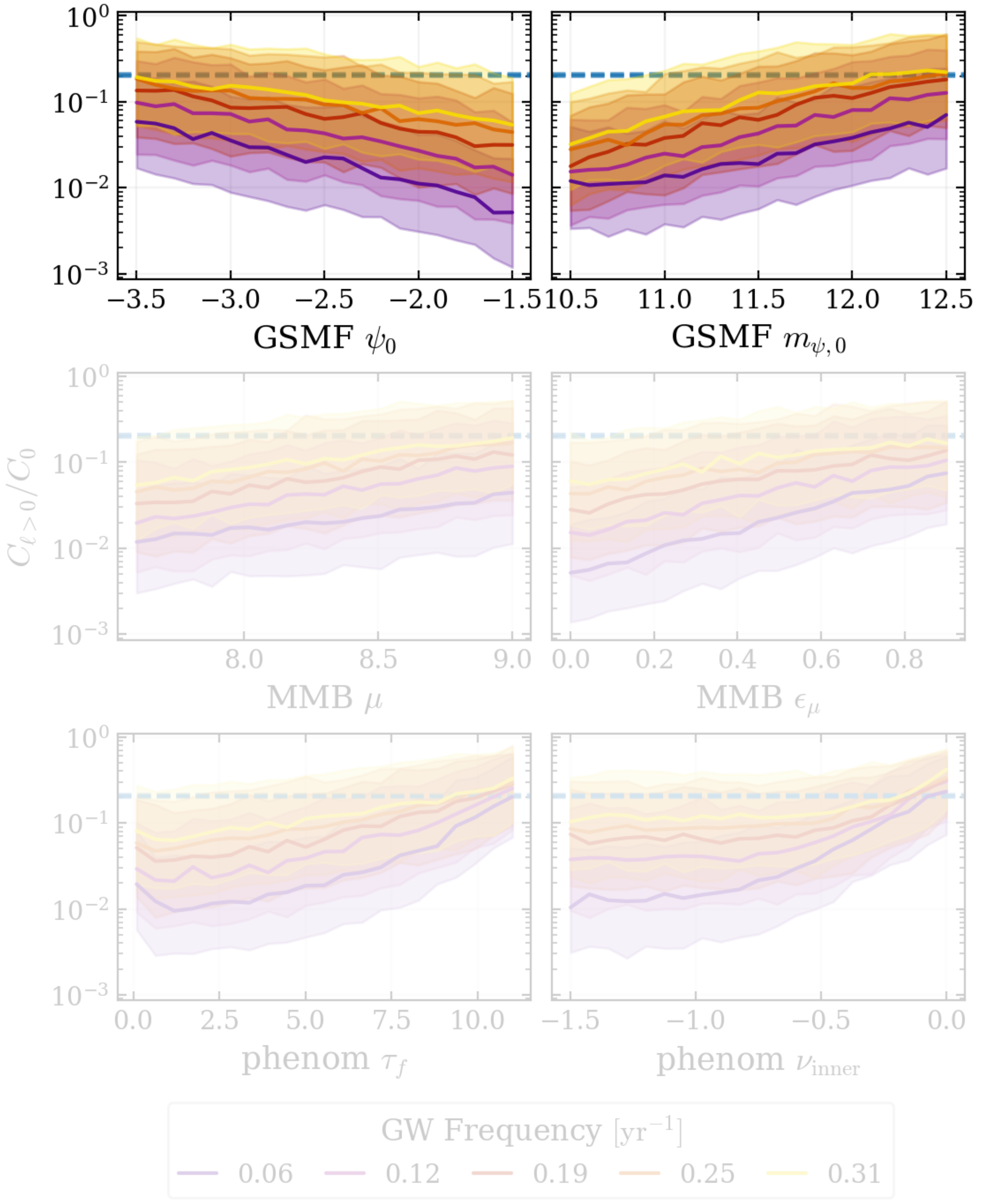
Gardiner, Kelley, Lemke, AM [2309.07227]

number density of galaxies per decade of stellar mass

$$\Psi(m_{\star 1}, z') = \ln(10)\Psi_0 \cdot \left(\frac{m_{\star 1}}{M_\psi}\right)^{\alpha_\psi} \exp\left(-\frac{m_{\star 1}}{M_\psi}\right)$$

$$\log_{10}\left(\Psi_0/\mathrm{Mpc}^{-3}\right) = \psi_0 + \psi_z z$$

$$\log_{10}\left(M_\psi/M_\odot\right) = m_{\psi,0} + m_{\psi,z} z$$

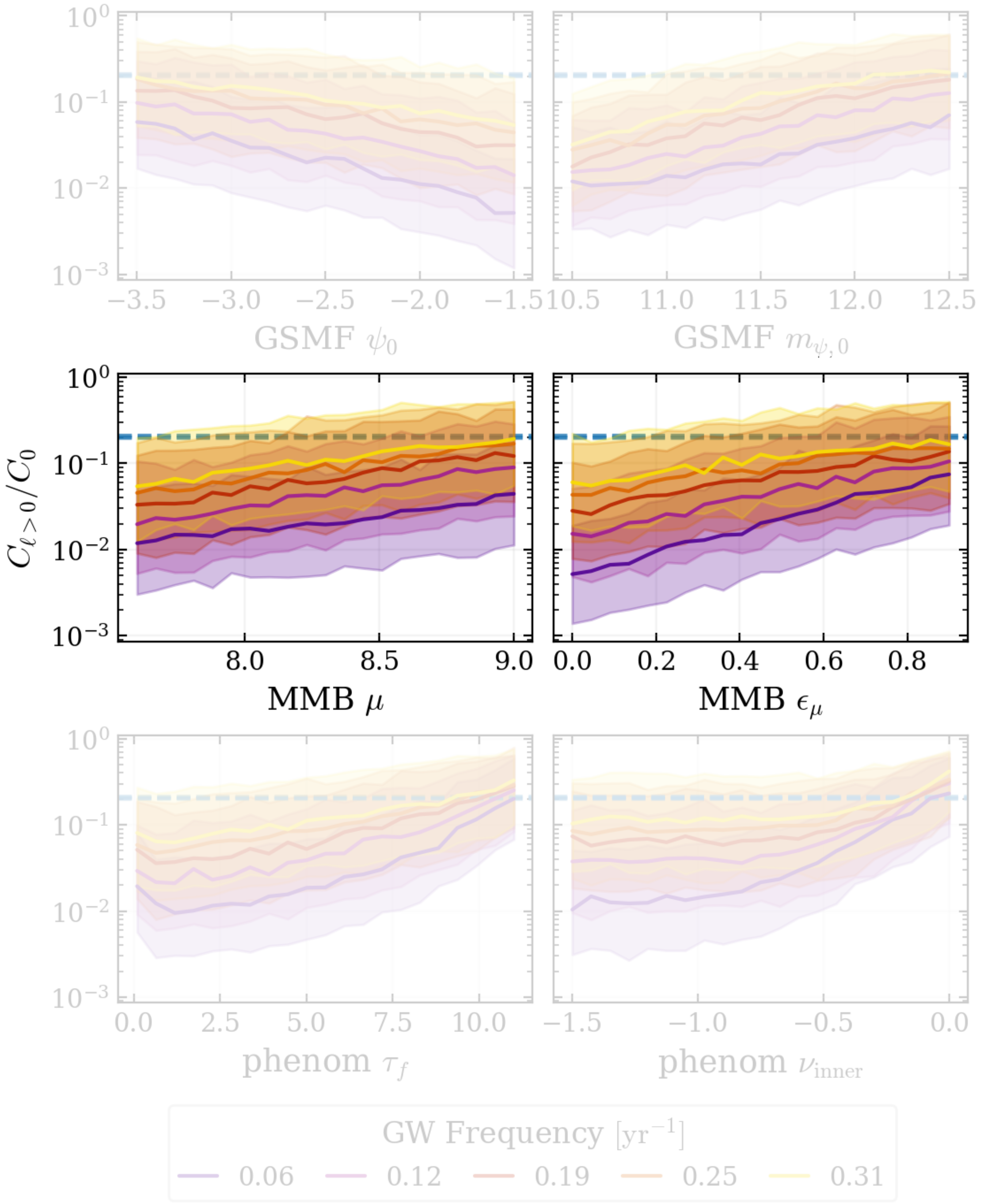


Gardiner, Kelley, Lemke, AM [2309.07227]

PARAMETER DEPENDENCE

relation between SMBH and host galaxy mass

$$\log_{10}\left(M_{\mathrm{BH}}/M_{\odot}\right) = \mu + \alpha_{\mu}\log_{10}\left(\frac{M_{\mathrm{bulge}}}{10^{11}M_{\odot}}\right) + \mathcal{N}\left(0, \epsilon_{\mu}\right)$$



PARAMETER DEPENDENCE

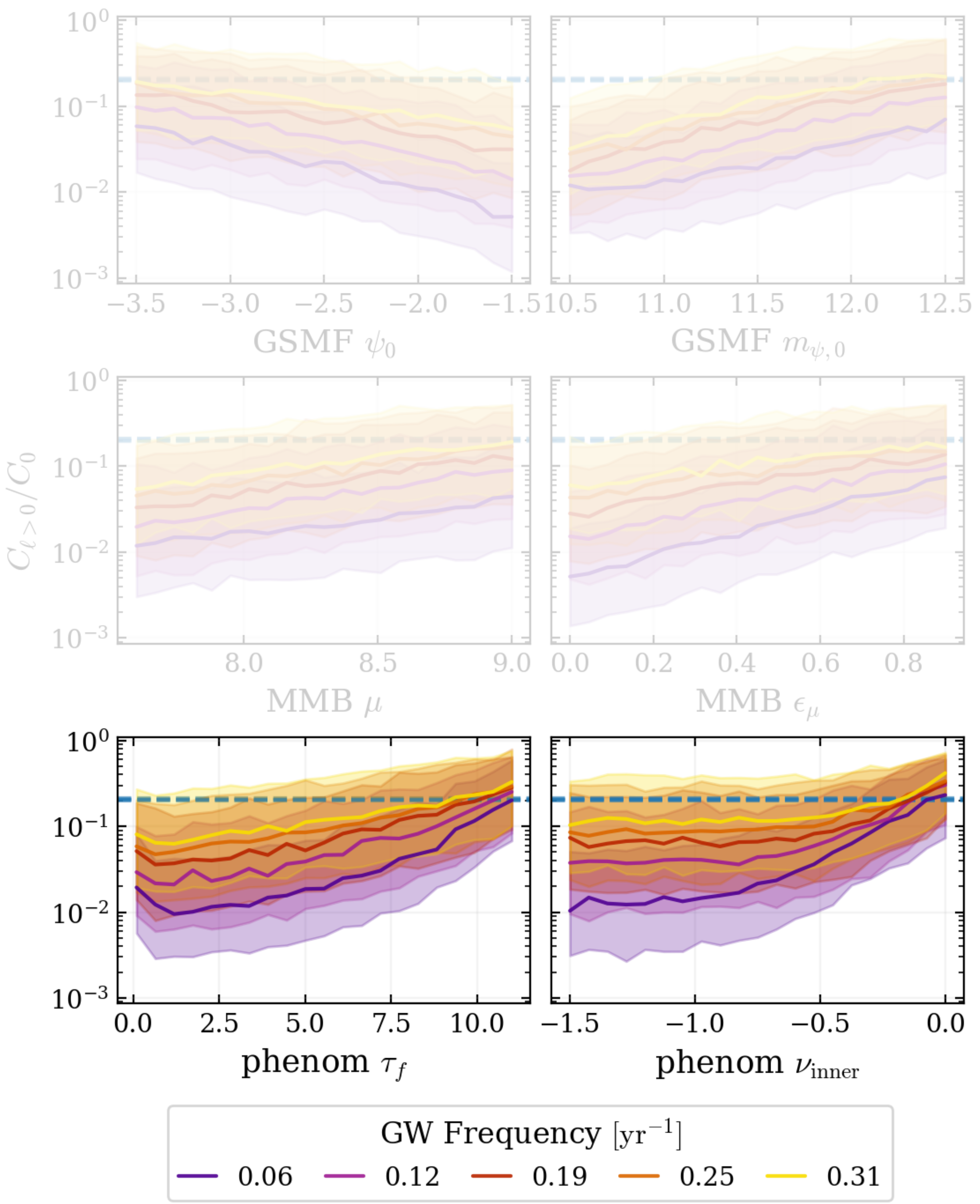
Gardiner, Kelley, Lemke, AM [2309.07227]

binary evolution model

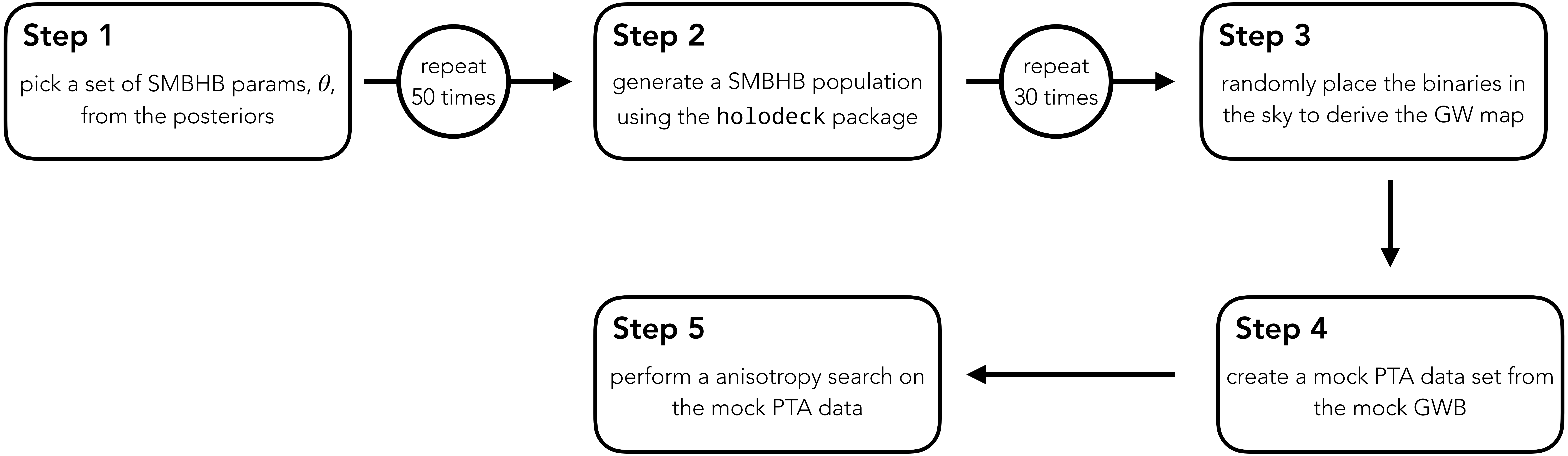
$$\frac{da}{dt} = -\frac{64G^3}{5}\frac{m_1 m_2 M}{a^3} + H_a\left(\frac{a}{a_c}\right)^{1-\nu_{\rm inner}}\left(1+\frac{a}{a_c}\right)^{\nu_{\rm inner}-\nu_{\rm outer}}$$

GW emission

phenomenological model for
environmental effects



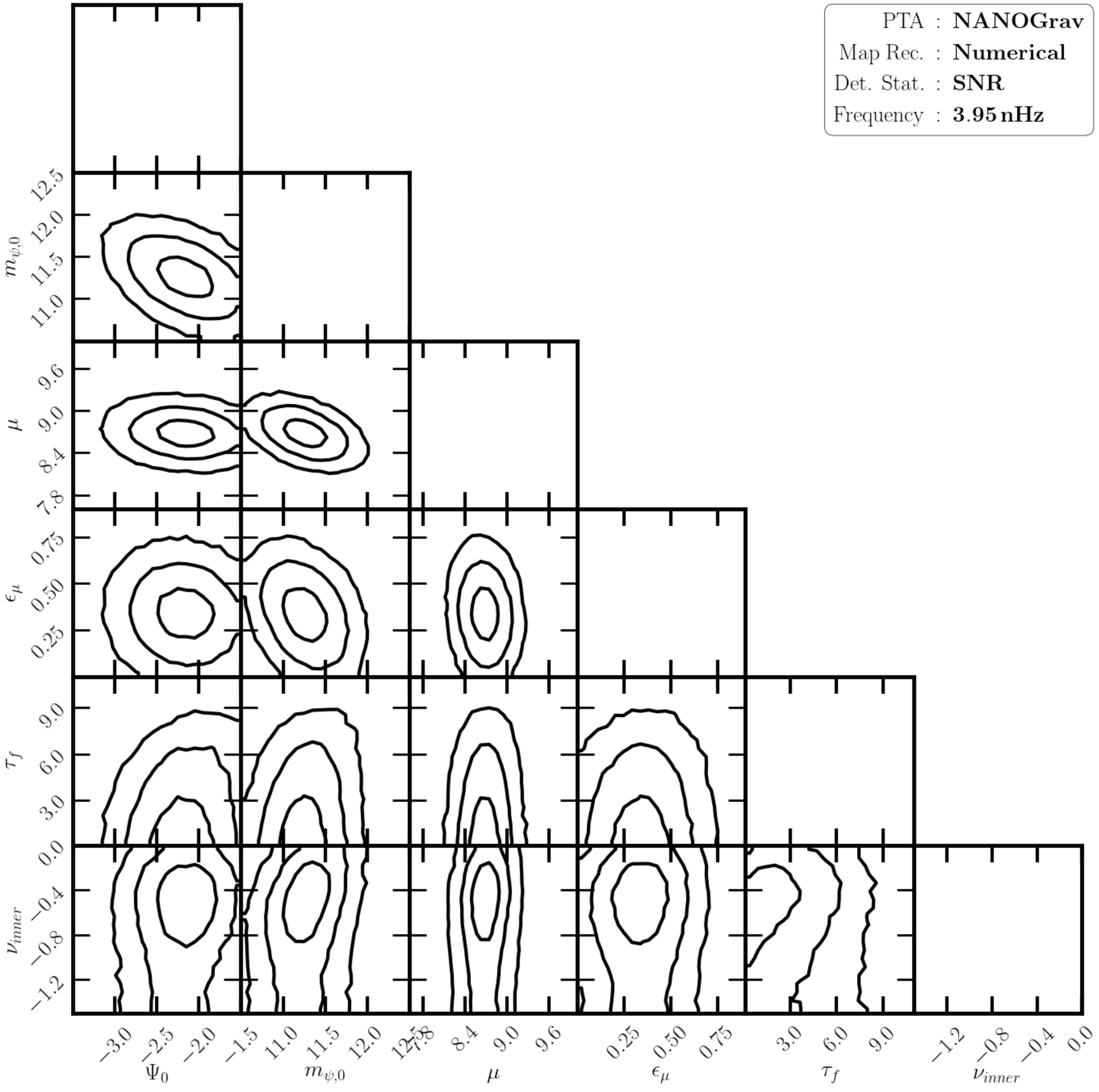
FORECAST PIPELINE



the anisotropy detection probability for the parameter set θ is estimated as

$$p_\theta \sim \frac{\#\ \text{detections}}{\#\ \text{realizations}} = \frac{\#\ \text{detections}}{1500}$$

DETECTION PROBABILITIES



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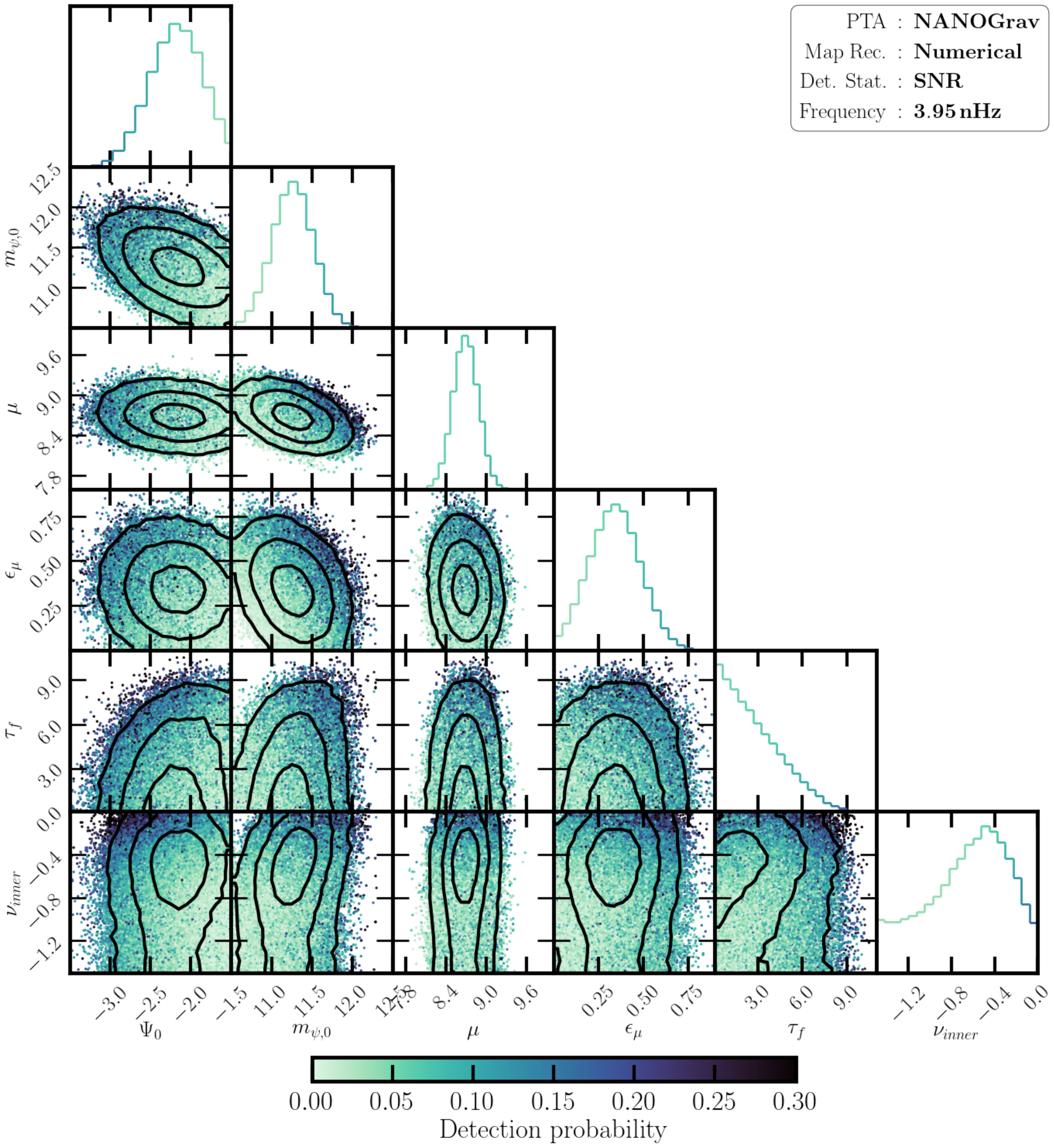
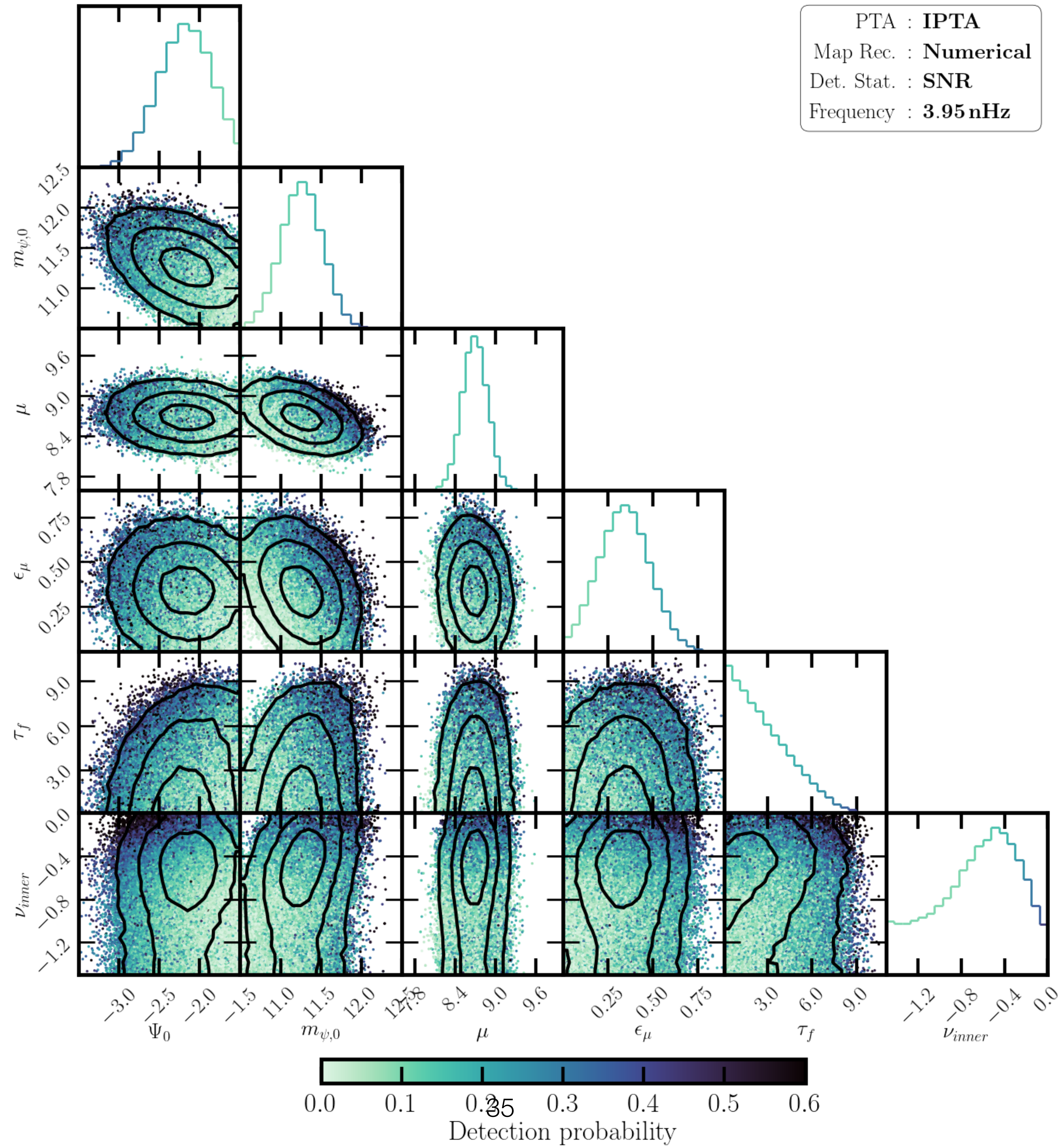


Lemke, AM, Gersbach., in preparation

ANISOTROPIES



Lemke, AM, Gersbach., in preparation

CONCLUSIONS

evidence for a GWB in the nHz band

source is still unknown: astrophysics or cosmology?

GWB anisotropies can help us discriminate between sources

the current null anisotropy detection is not in tension with an astrophysical origin