Pulsars and the Interstellar Medium

Probing Interstellar Turbulence and Its Intermittency Through Observation of a Millisecond Pulsar

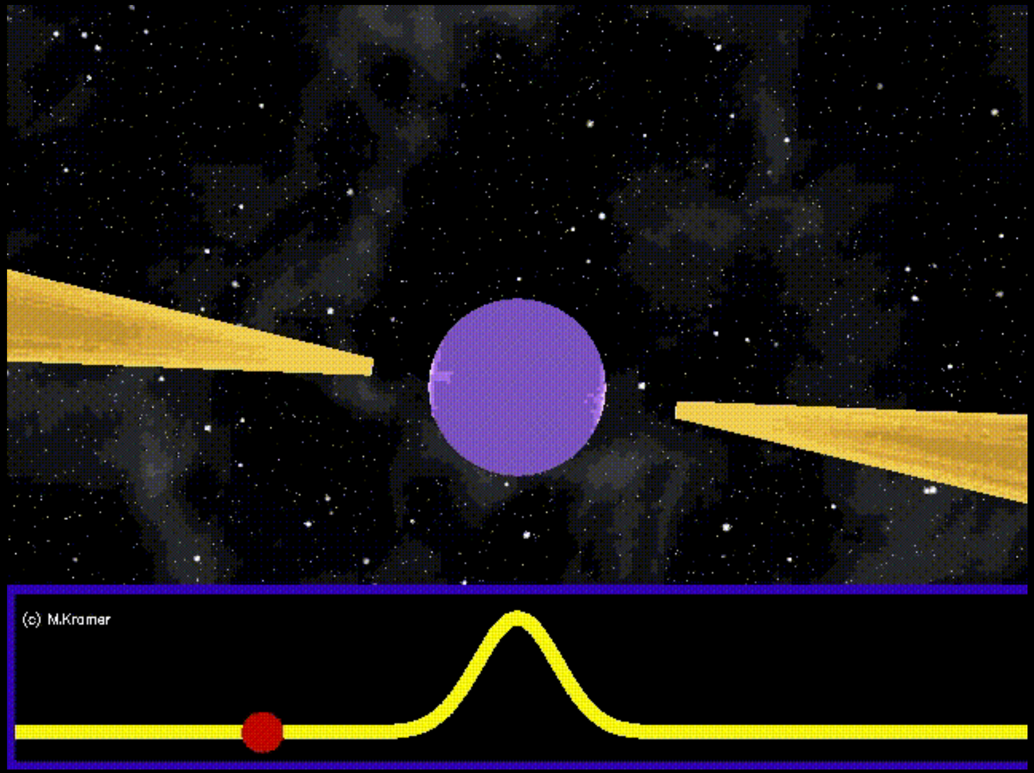
Abra Geiger

Professor Jim Cordes and Professor Shami Chatterjee

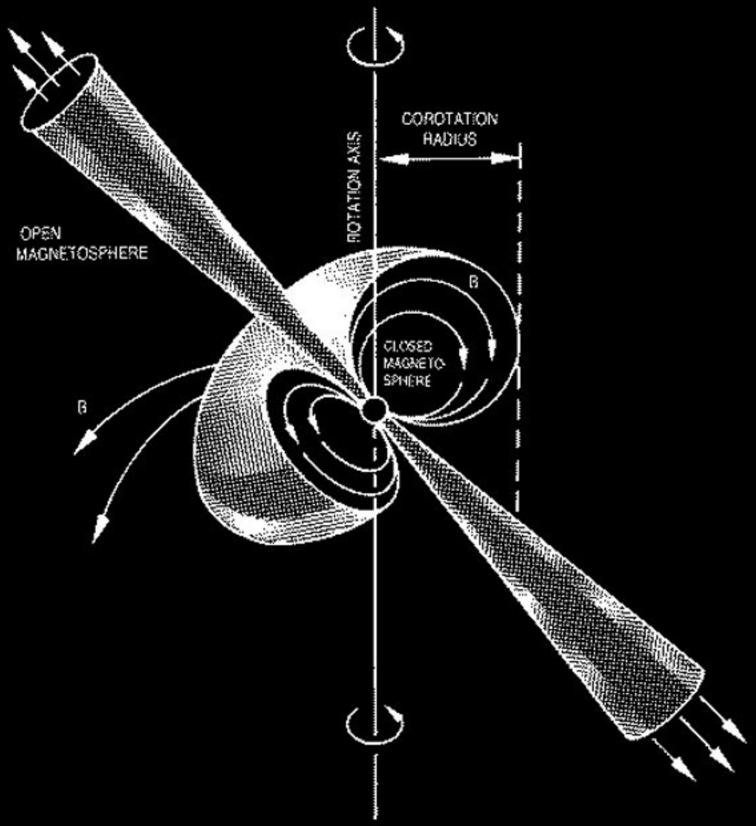
Pulsars

Quick Facts:

- Pulsars are neutron stars
- Remnants of supernovae
- 1 solar mass with a radius of 10 km
- Extreme gravitational and magnetic fields
- Protons and electrons cannot exist separately



Pulsars - Comparable to condensing the sun into the size of Ithaca!



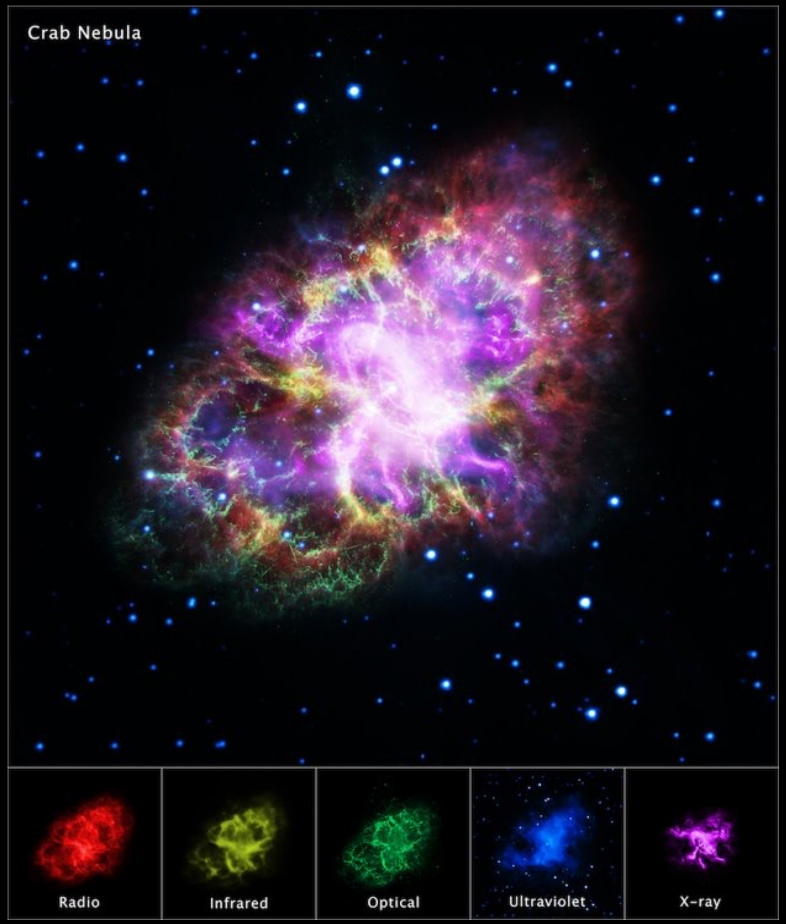


Image Credit: JPL

Why do we care?

- Extreme physics
- Stellar Evolution
- General Relativity and Alternative Theories of Gravity
- Equation of State of Nuclear Matter
- And...

Image Credit: Jay Young

Image Credit: Aurore Simonnet / NANOGrav

Gravitational Waves!

Why Do We Care?

Evidence for gravitational wave background thanks to Pulsar Timing Arrays (PTAs)!

NANOGrav
Physics Frontiers Center

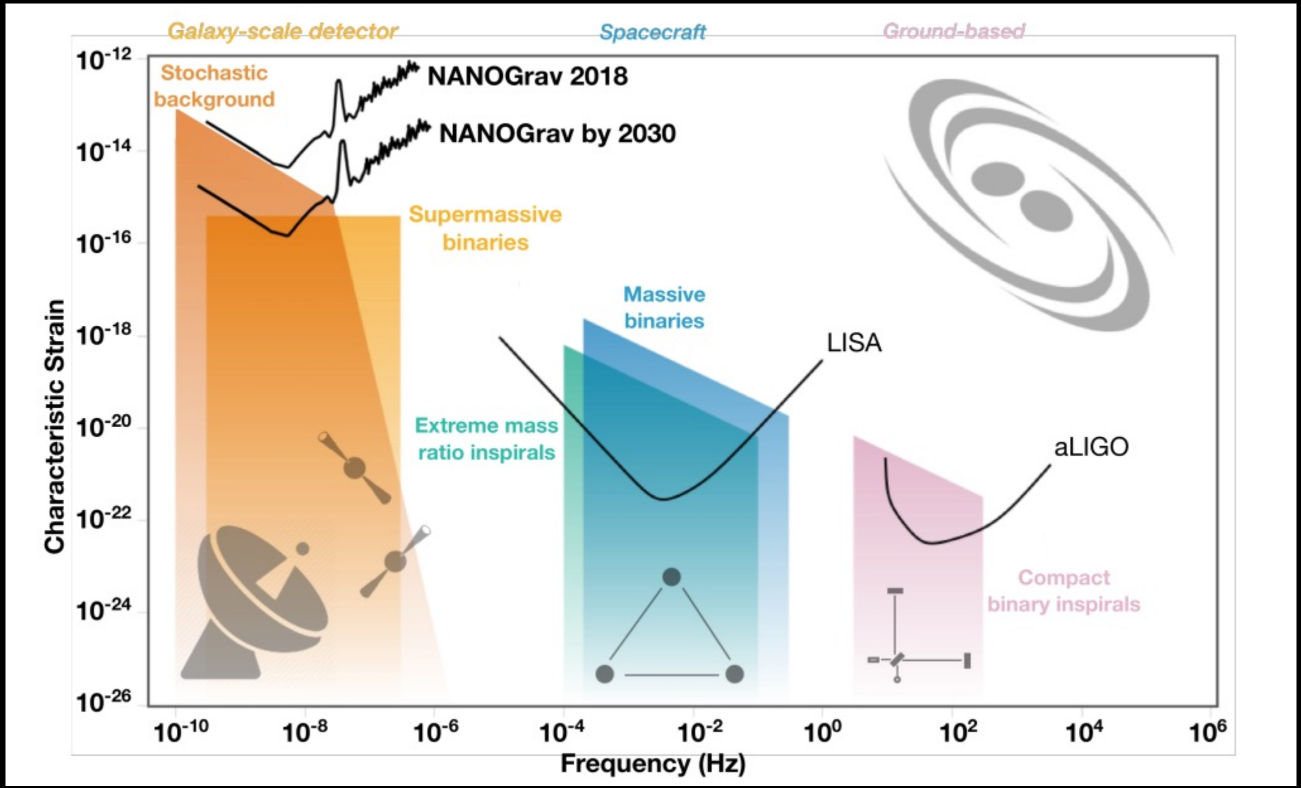


Image Credit: NANOGrav

Why Do We Care?

Pulsar Timing

- Probing our galaxy with astrophysical clocks
- Millisecond Pulsars (MSPs)

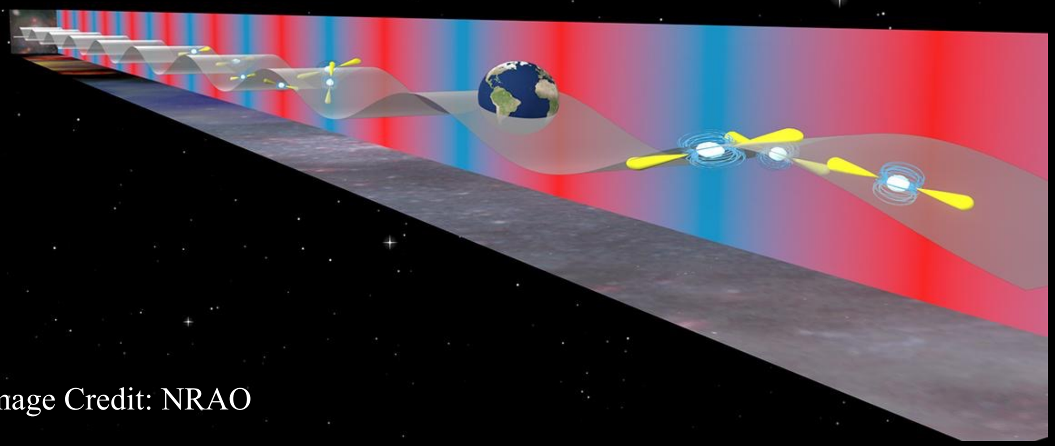
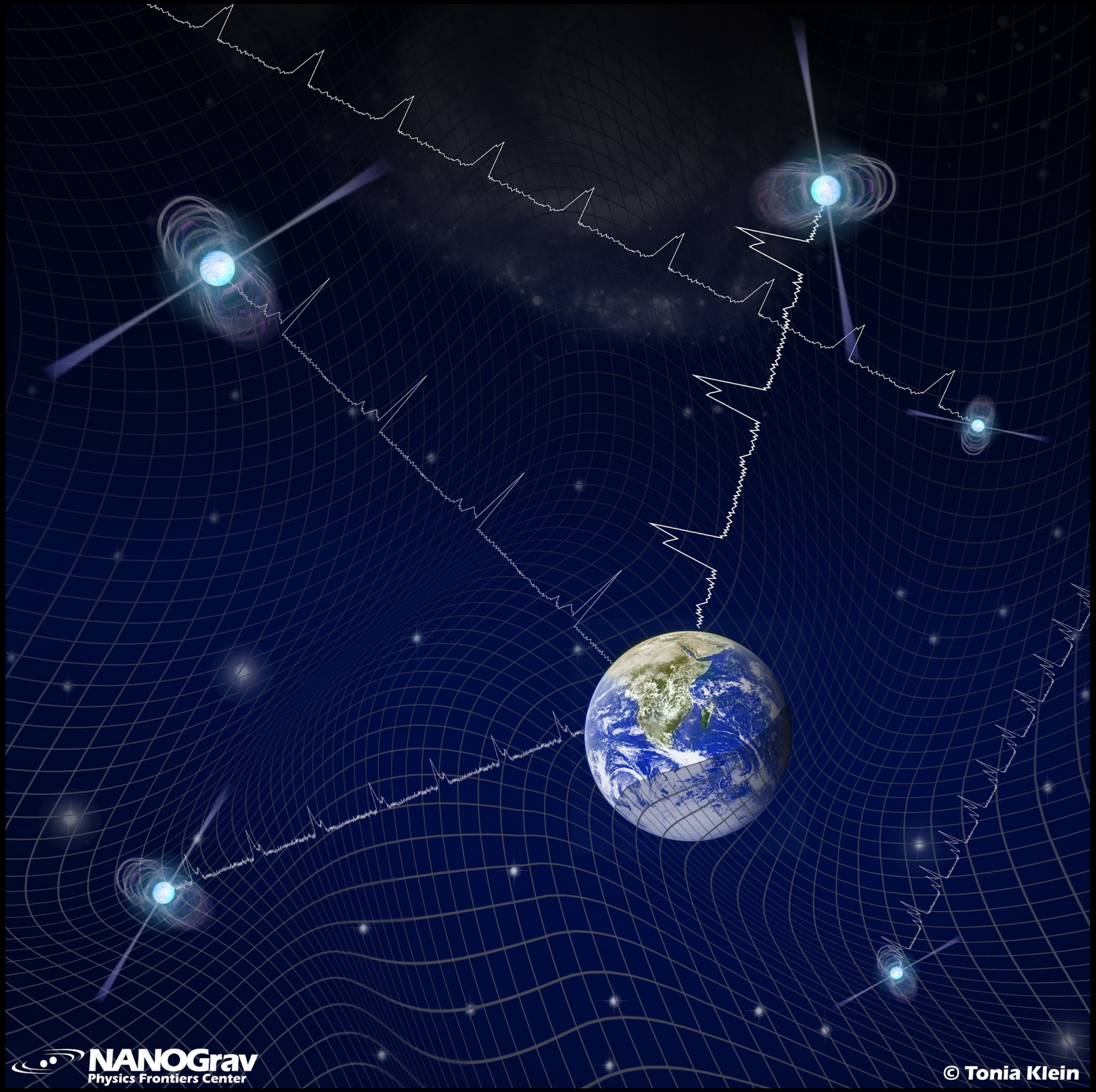


Image Credit: NRAO

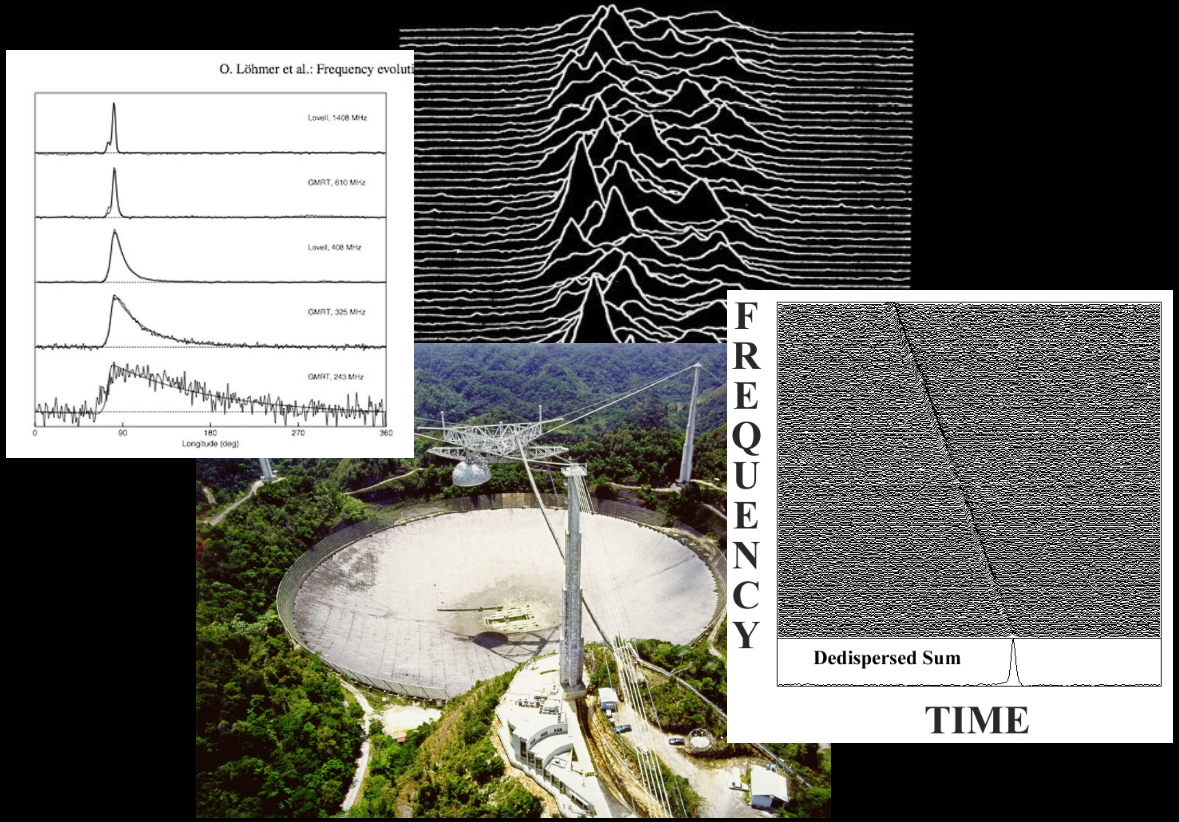


Noise in Pulsar Timing

Precision pulsar timing is necessary for gravitational wave detection

Noise sources:

- Detector
- Pulse Jitter
- Interstellar Noise
- And more



Noise in Pulsar Timing – Interstellar Medium

- Turbulent gas and dust
- Propagation effects
- Dependent upon frequency of observation

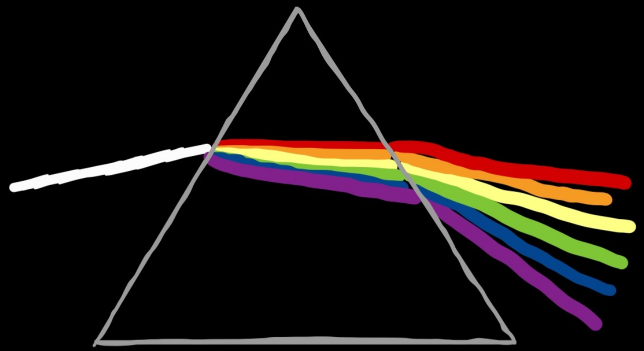
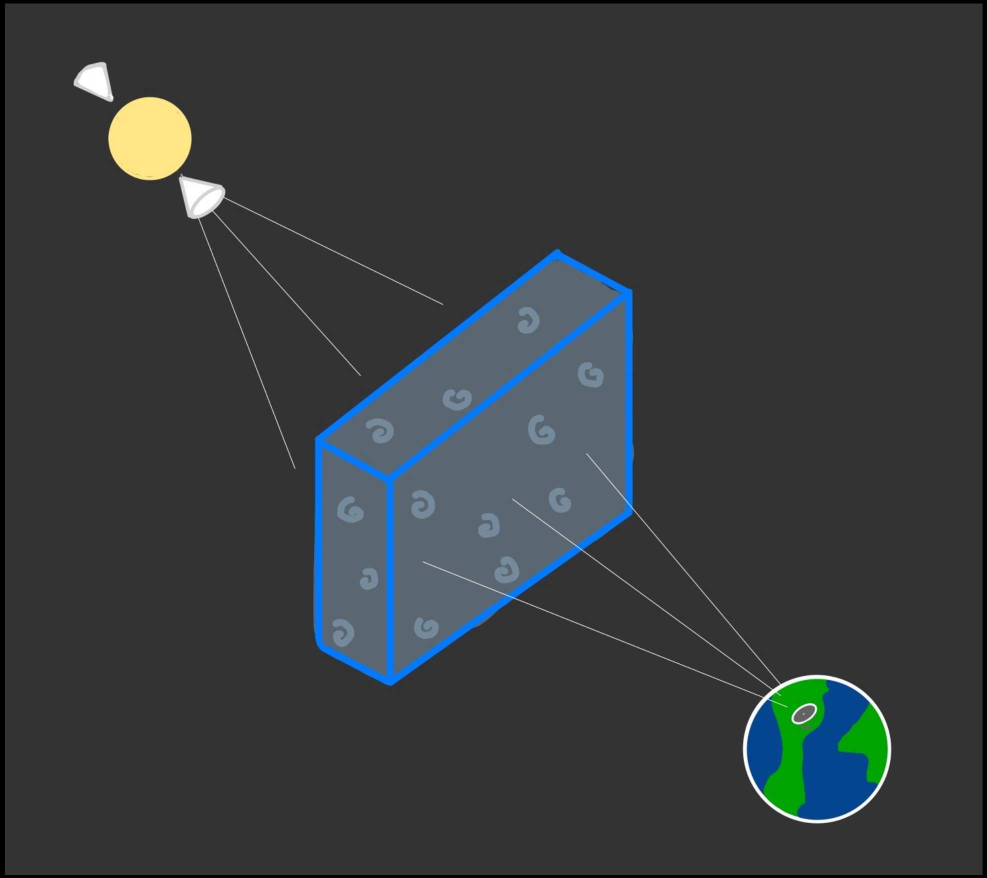


Image Credit: HST; NASA/ESA

Noise in Pulsar Timing – Scattering

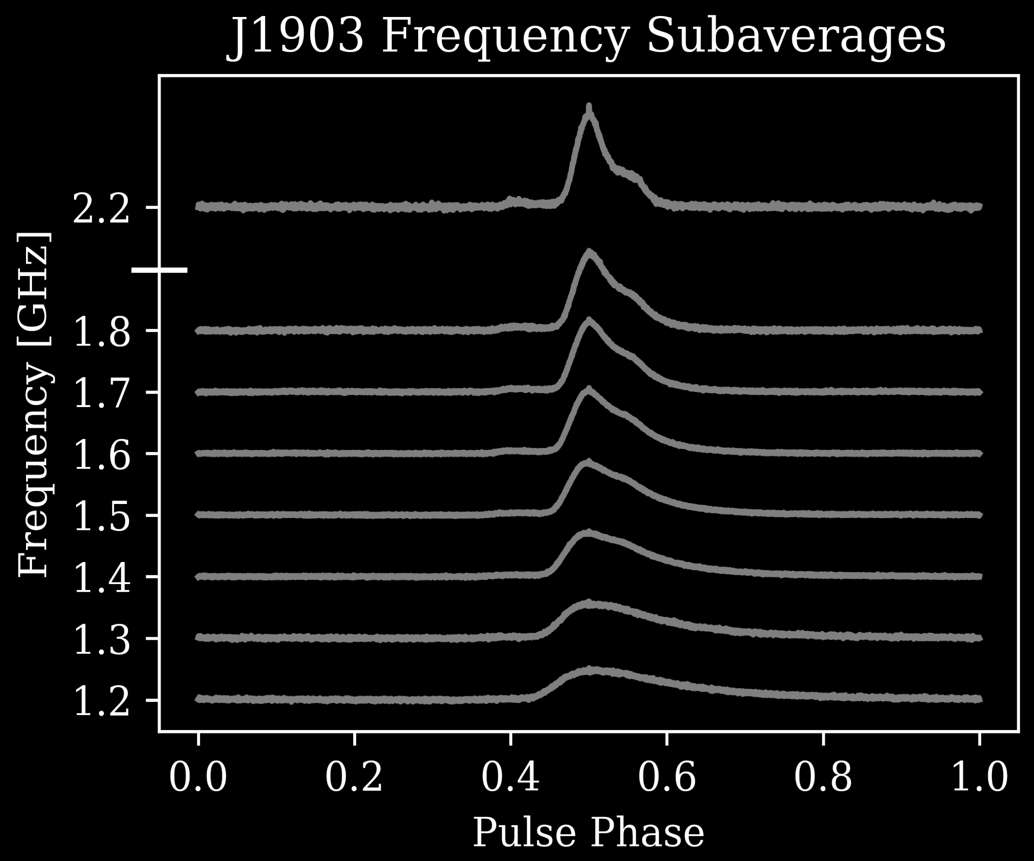
- Multipath propagation broadens the pulsar image

- Shape directly related to spectrum of turbulence



Noise in Pulsar Timing – Scattering

- Multipath propagation broadens the pulsar image
- Shape directly related to spectrum of turbulence
- J1903+0327 is a millisecond pulsar (MSP) advantageous for a scattering analysis



Methods

Profile = intrinsic shape * pulse broadening function (PBF)

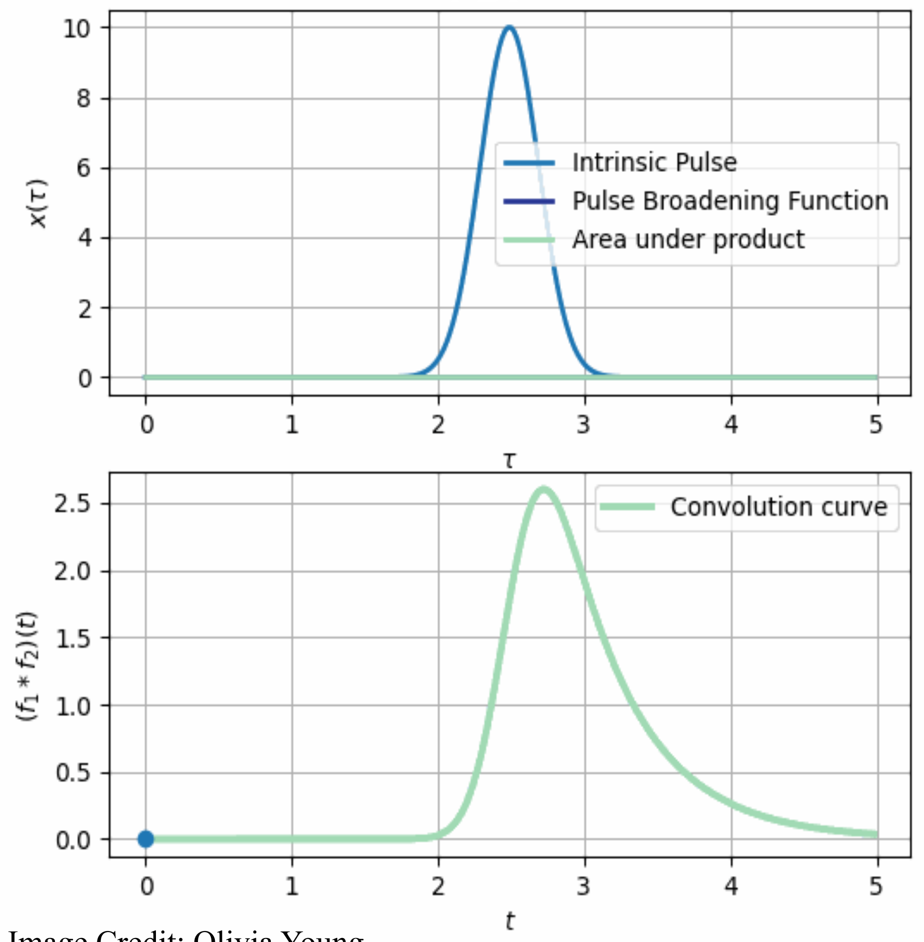
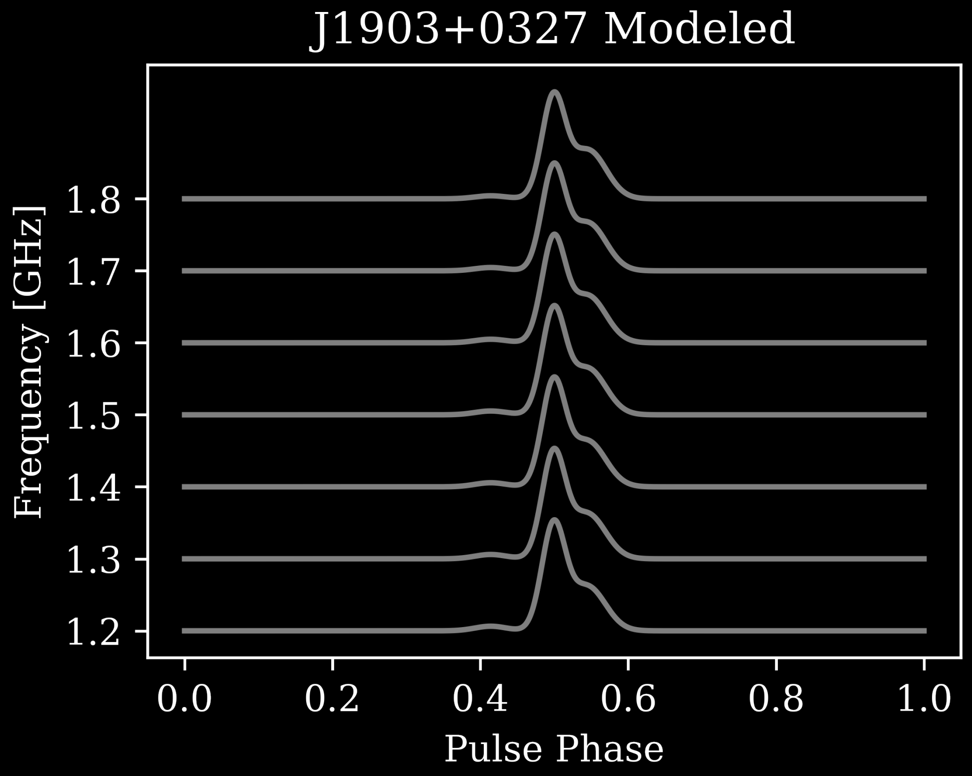


Image Credit: Olivia Young

Methods

Profile = intrinsic shape * pulse broadening function (PBF)

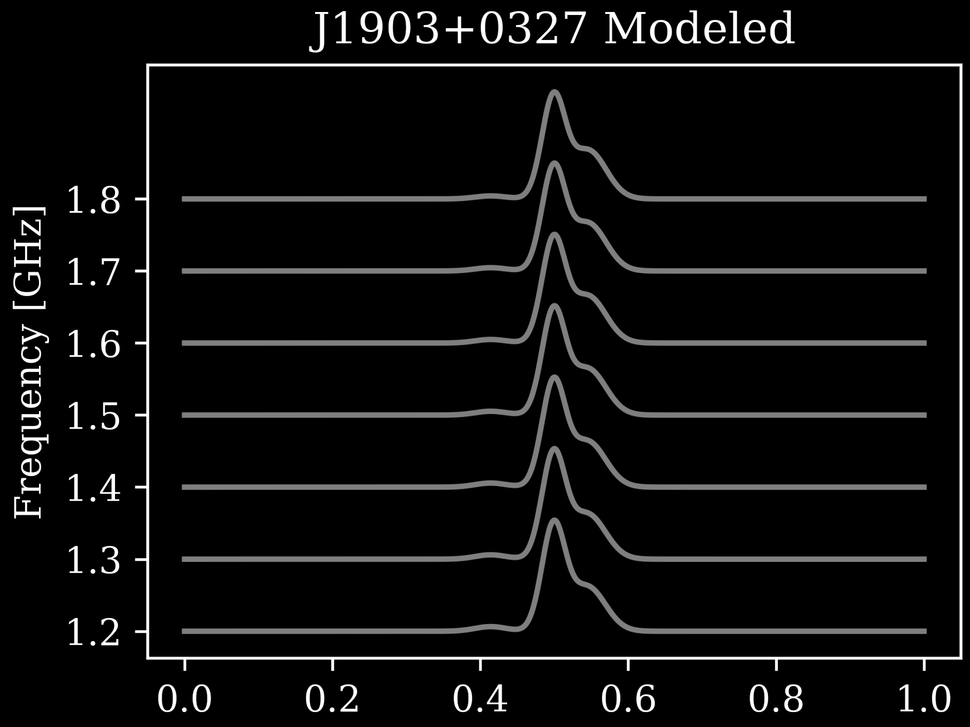
- Model Intrinsic Shape

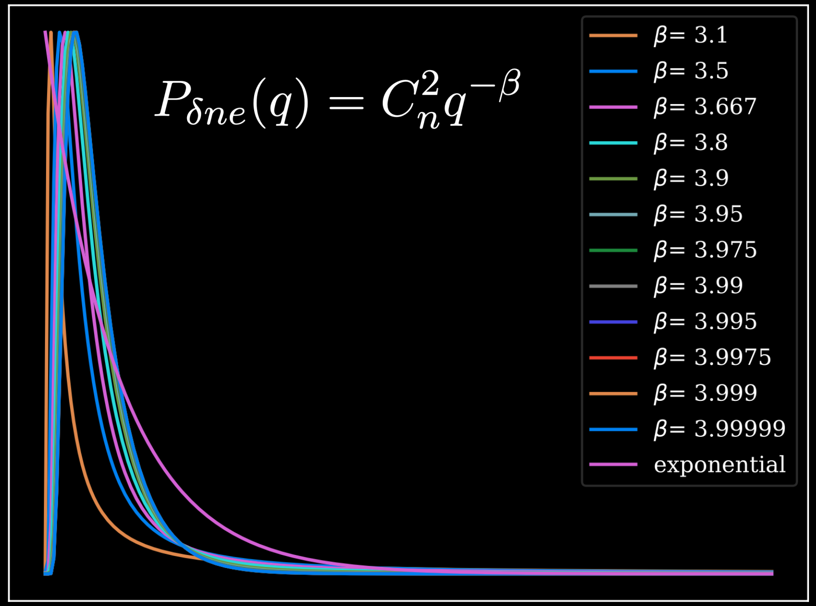


Methods

Profile = intrinsic shape * pulse broadening function (PBF)

- Model Intrinsic Shape
- Fit for best PBF
    - Informative regarding turbulence in ISM

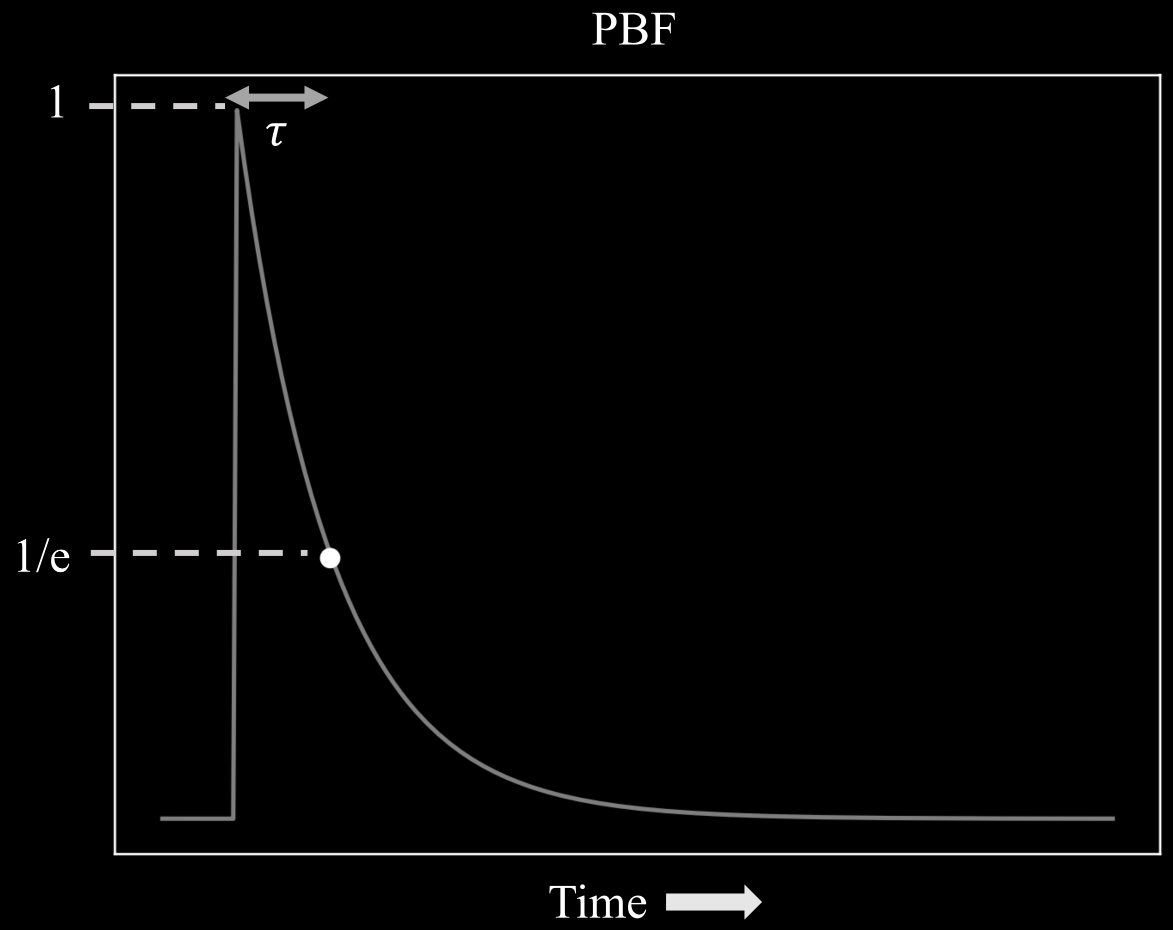




Methods

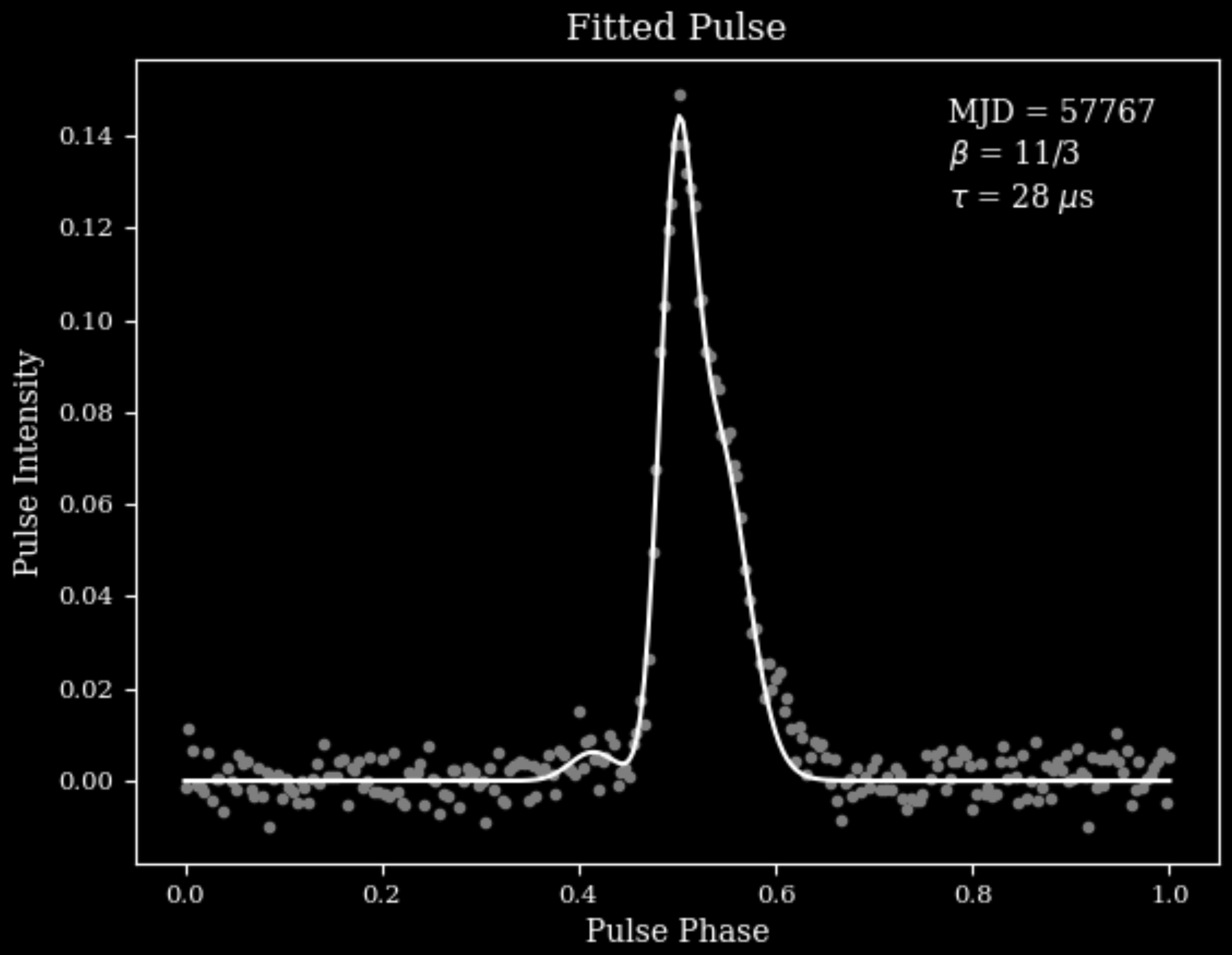
Profile = intrinsic shape * pulse broadening function (PBF)

- Model Intrinsic Shape
- Fit for best PBF
  - Informative regarding turbulence in ISM
- τ: where PBF decays to 1/e of maximum



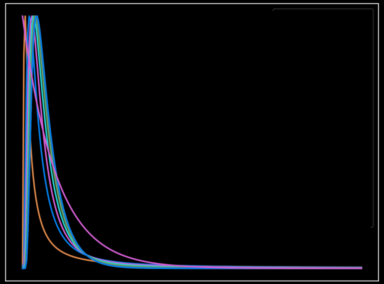
$P_{\delta ne}(q) = C_n^2 q^{-\beta}$

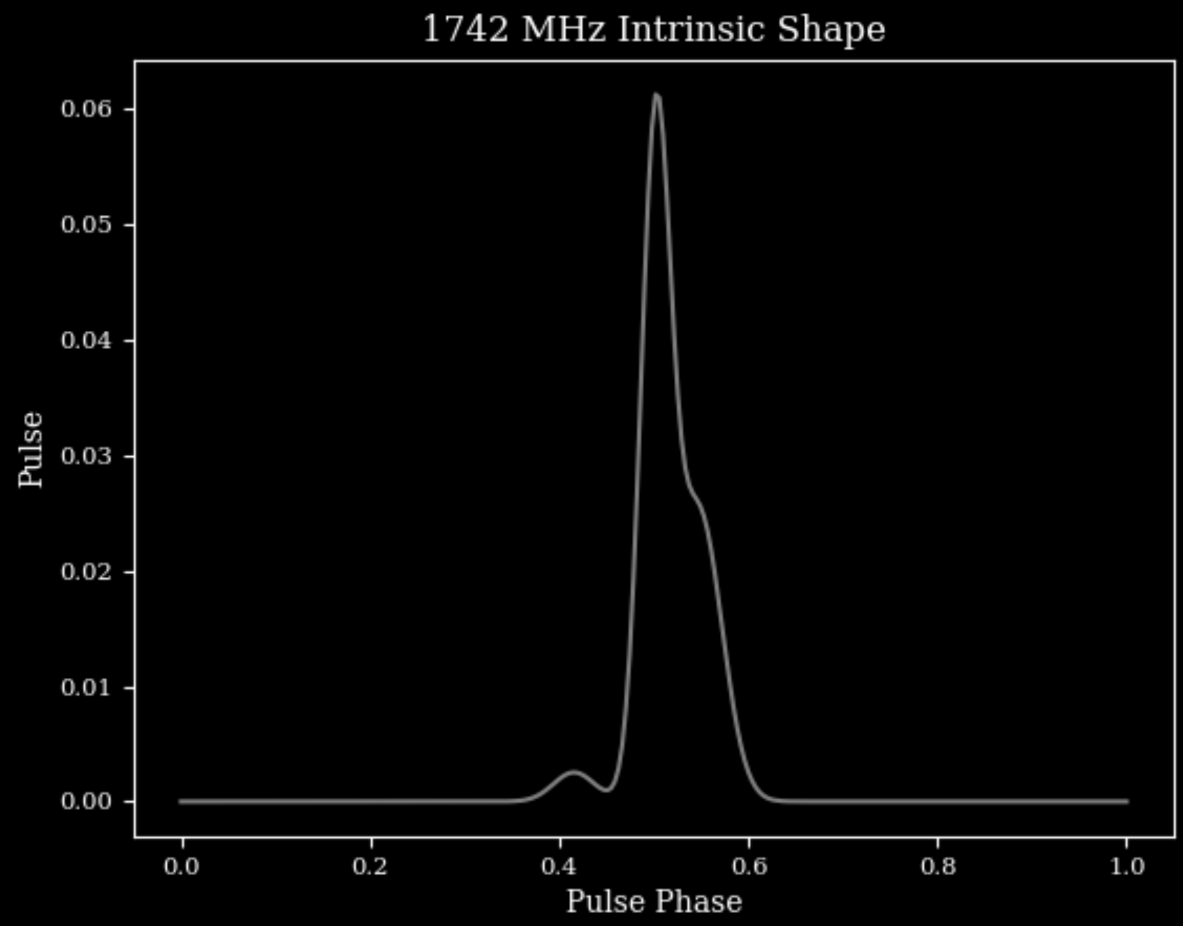
Methods - Fitting Example



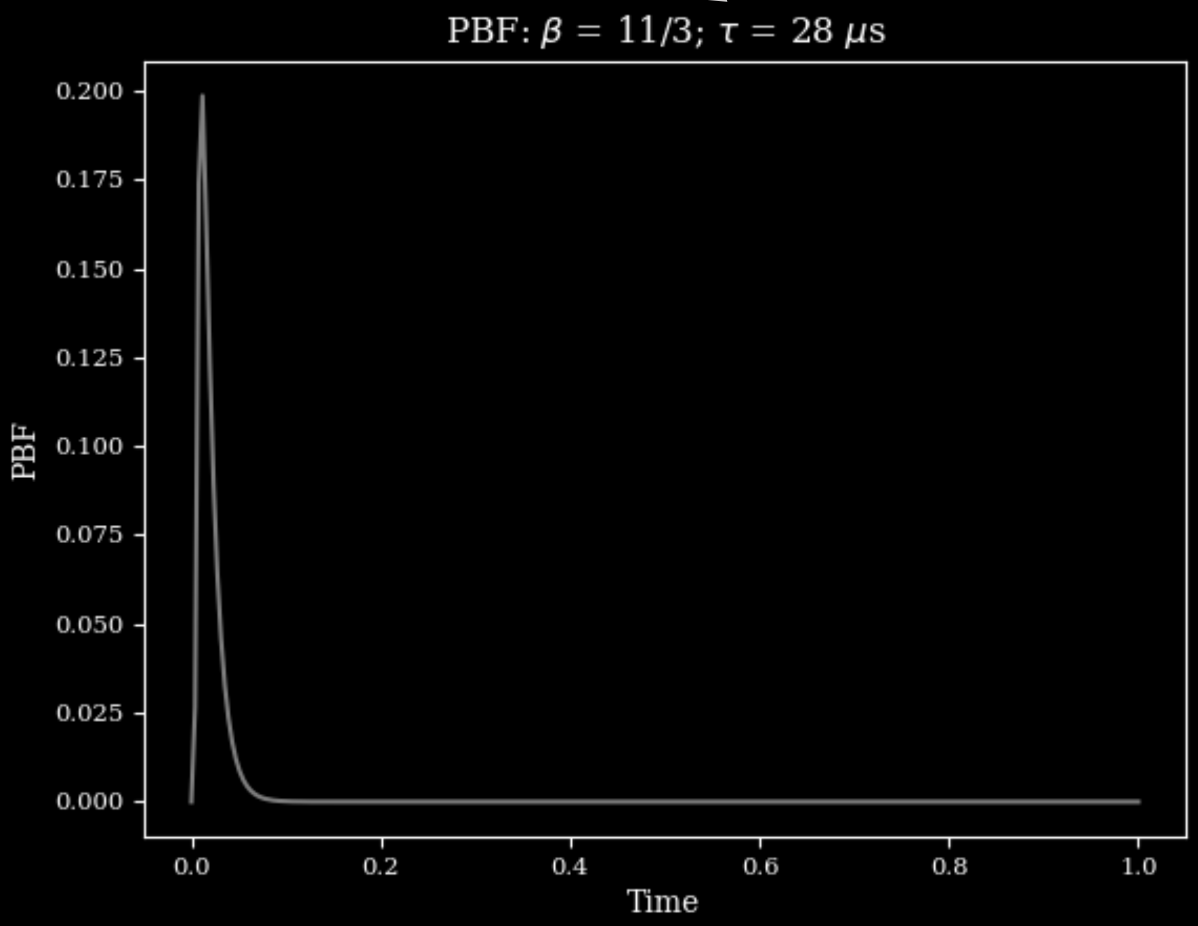
Methods - Fitting Example

$$P_{\delta ne}(q) = C_n^2 q^{-\beta}$$



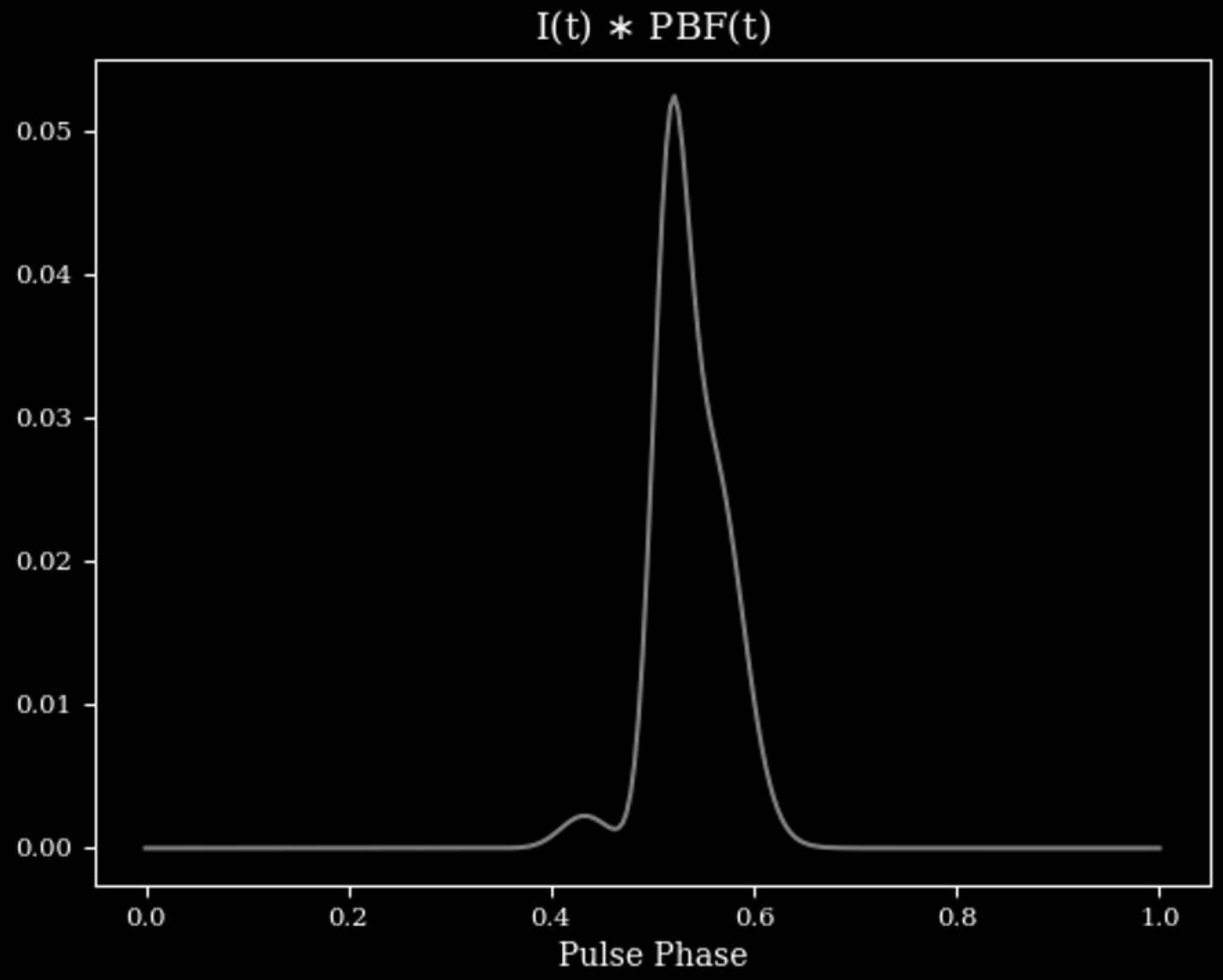


*



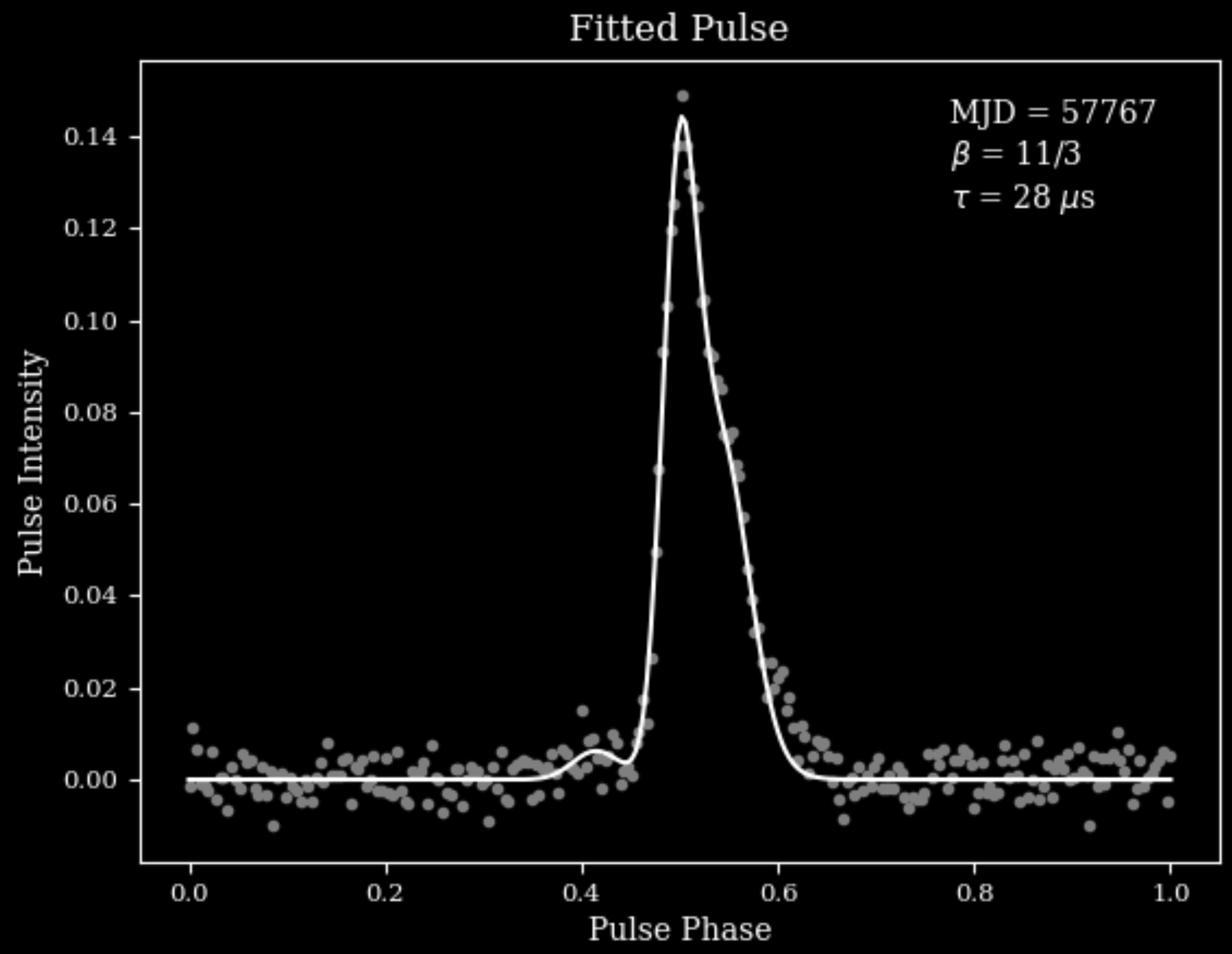
$P_{\delta ne}(q) = C_n^2 q^{-\beta}$

Methods - Fitting Example



$$P_{\delta ne}(q) = C_n^2 q^{-\beta}$$

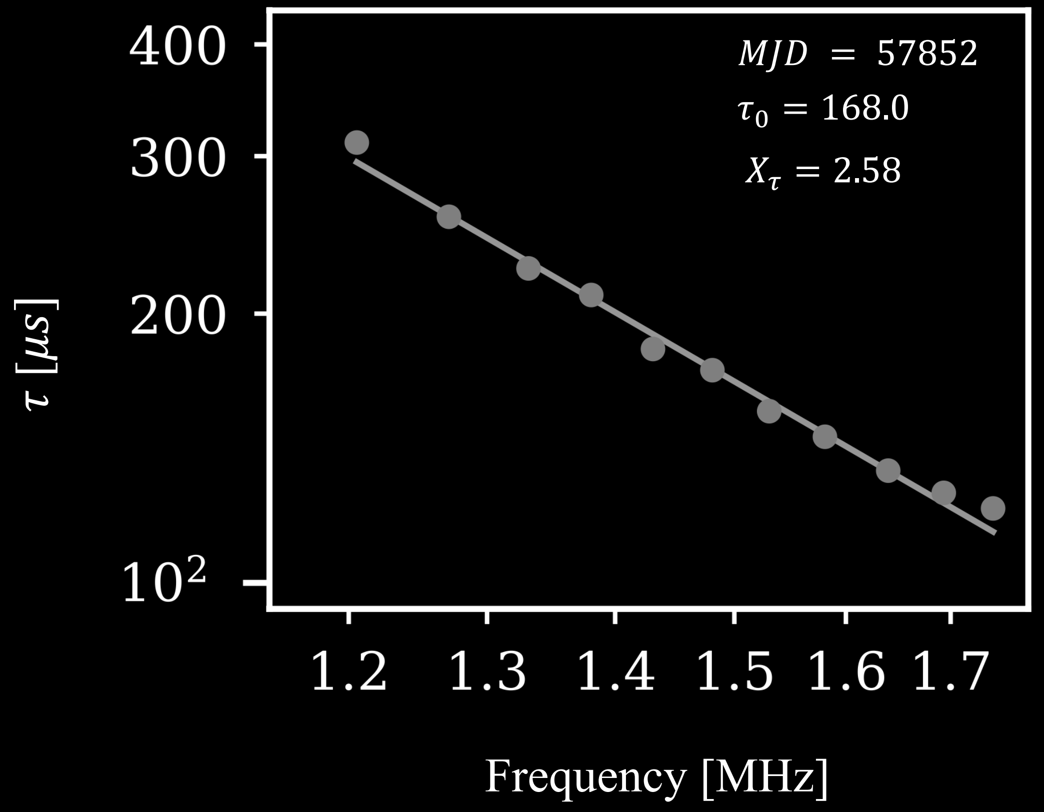
Methods - Fitting Example



Methods - Tau versus Observing Frequency

Scattering is greater at lower frequencies

$$\tau_d = \tau_0 \left(\frac{\nu_d}{\nu_0}\right)^{-X_\tau}$$

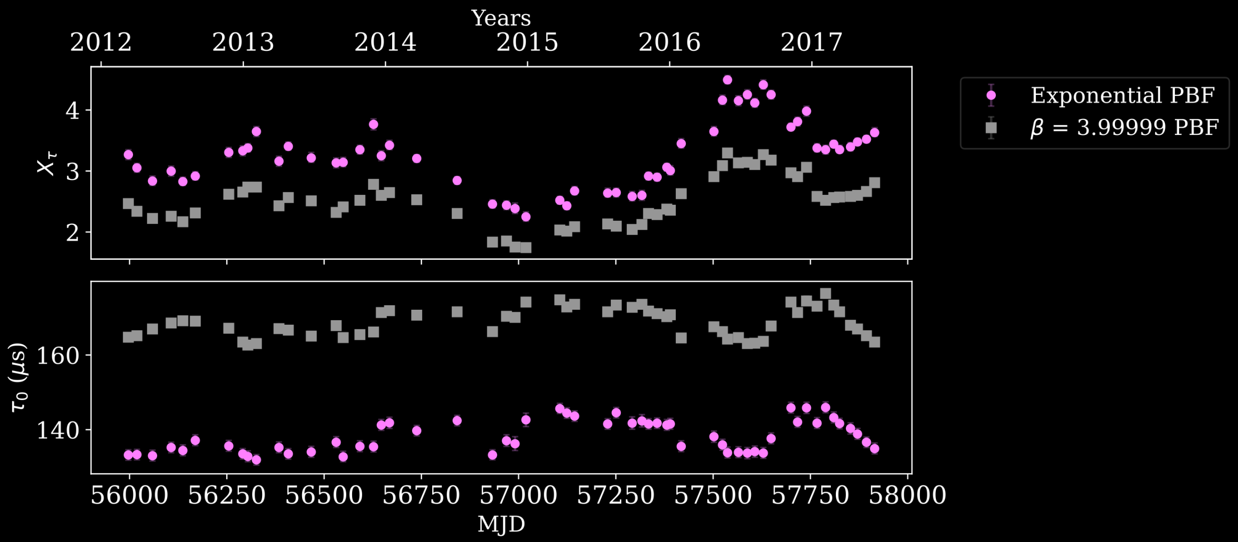


Results – Scattering Timeseries

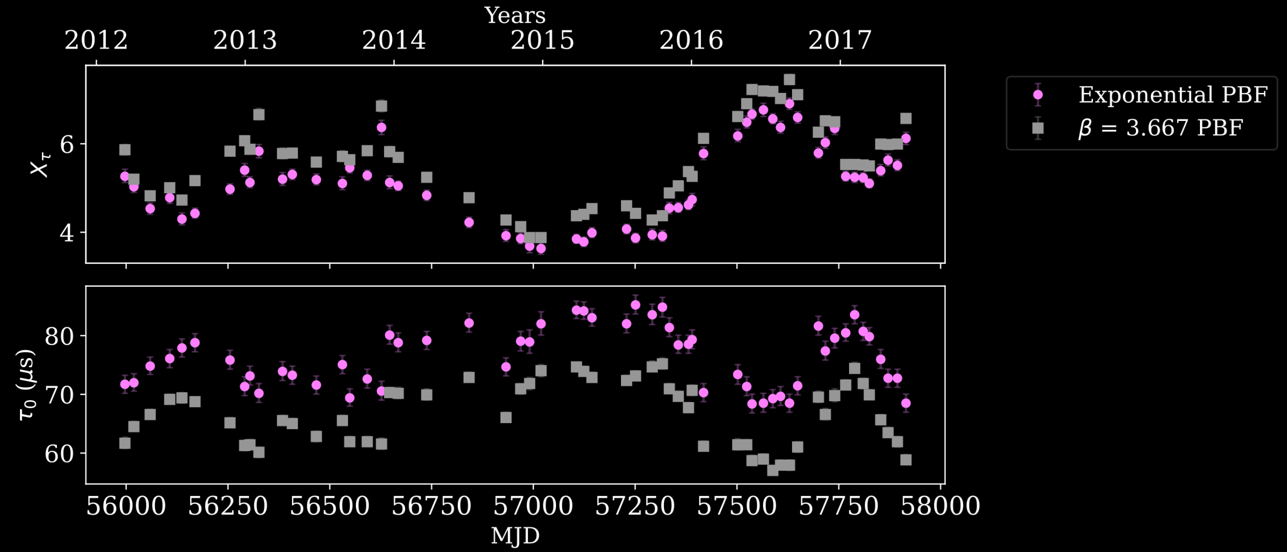
$$P_{\delta ne}(q) = C_n^2 q^{-\beta}$$

$$\tau_d = \tau_0 \left(\frac{\nu_d}{\nu_0}\right)^{-X_\tau}$$

Intrinsic Gaussian



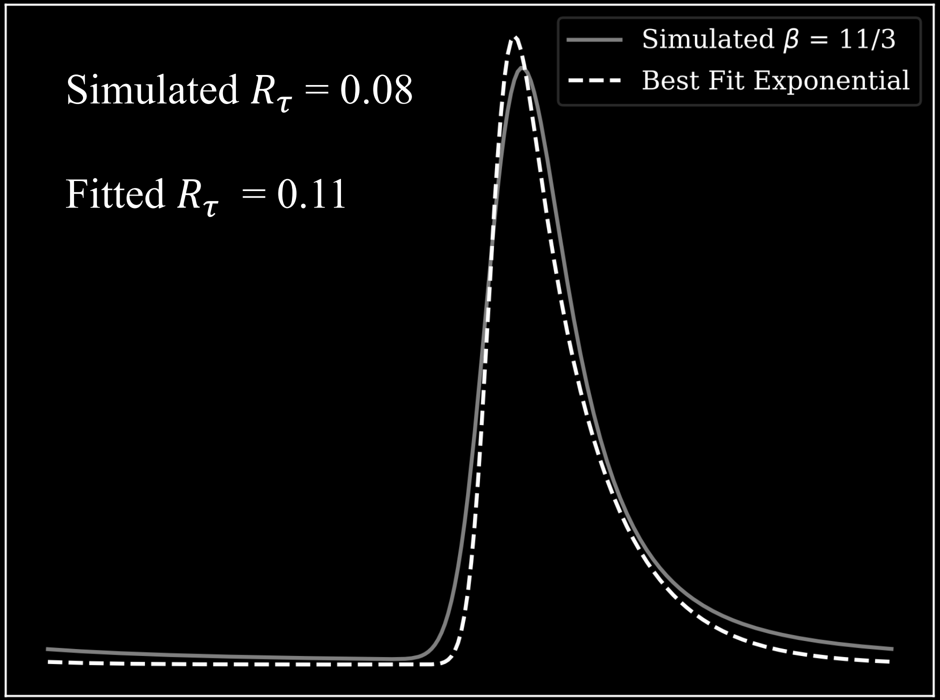
Modelled Intrinsic



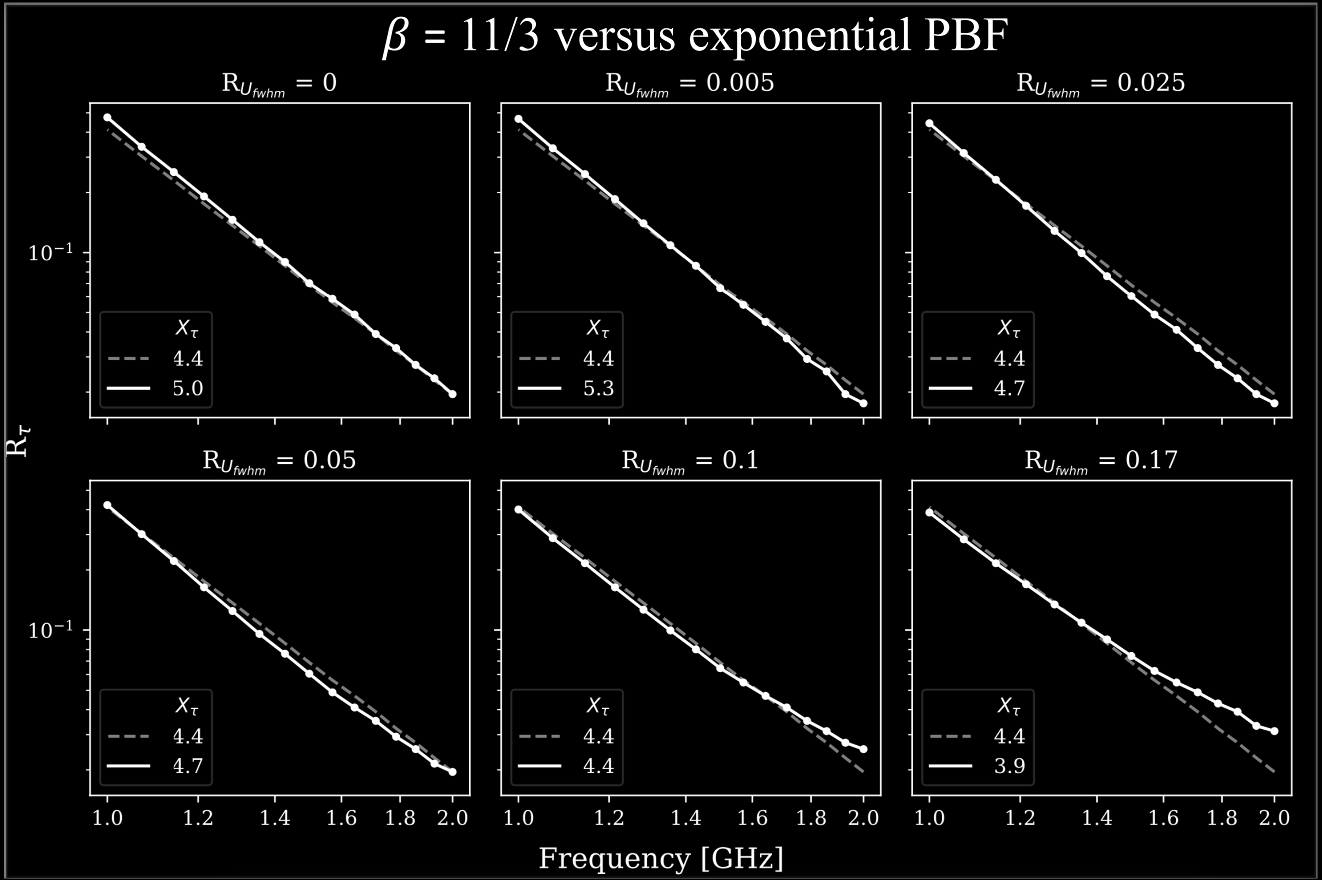
Results - Simulations

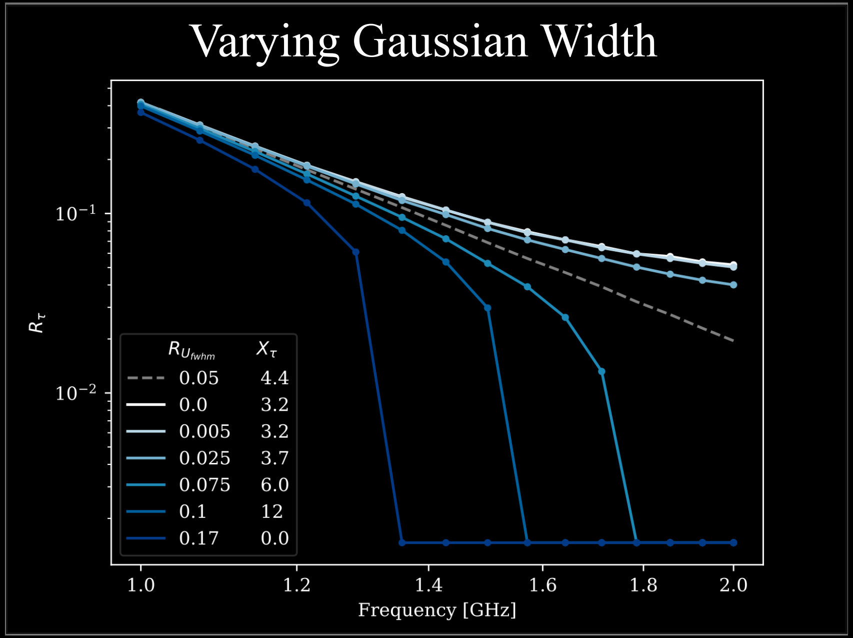
- Intrinsic and PBF shape assumptions are very important for correct tau measurement – more than expected

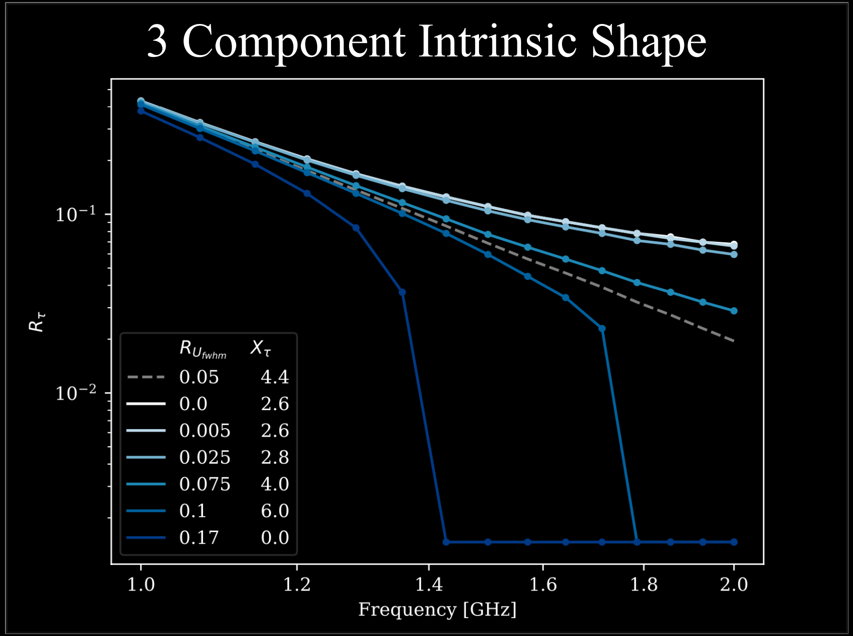
- Simulation –three key cases:
  - Exponential vs extended medium PBFs
  - Varying intrinsic width
  - Complex intrinsic shape



Results – Simulations







Discussion and Conclusions

- J1903+0327 scattering is highly variable over time
- Likely explained by a refraction timescale
  - Approximately 1-2 years for this pulsar, consistent with observed variations
- Assumptions of intrinsic and PBF shape are extremely important for scattering analysis

Future Work & Connection to My Goals

Future Work

- Converge to a better intrinsic and PBF shape
- More general scattering implications

Connection to my goals

- Astrophysics research experience
- Coding, data management, and communication

Thank You!

Questions?

Pulsars

Why Do We Care?

Noise in Pulsar Timing

Methods

Results

Discussion & Conclusions

Future Work

Find out more!

Special thanks to Jim Cordes, Shami Chatterjee, Michael Lam, Thankful Cromartie, Stella Ocker, Sashabaw Niedbalski, Ben Jacobson-Bell, Carey Felius, Garrison Jorge, the Nexus Scholars Program, and many more!