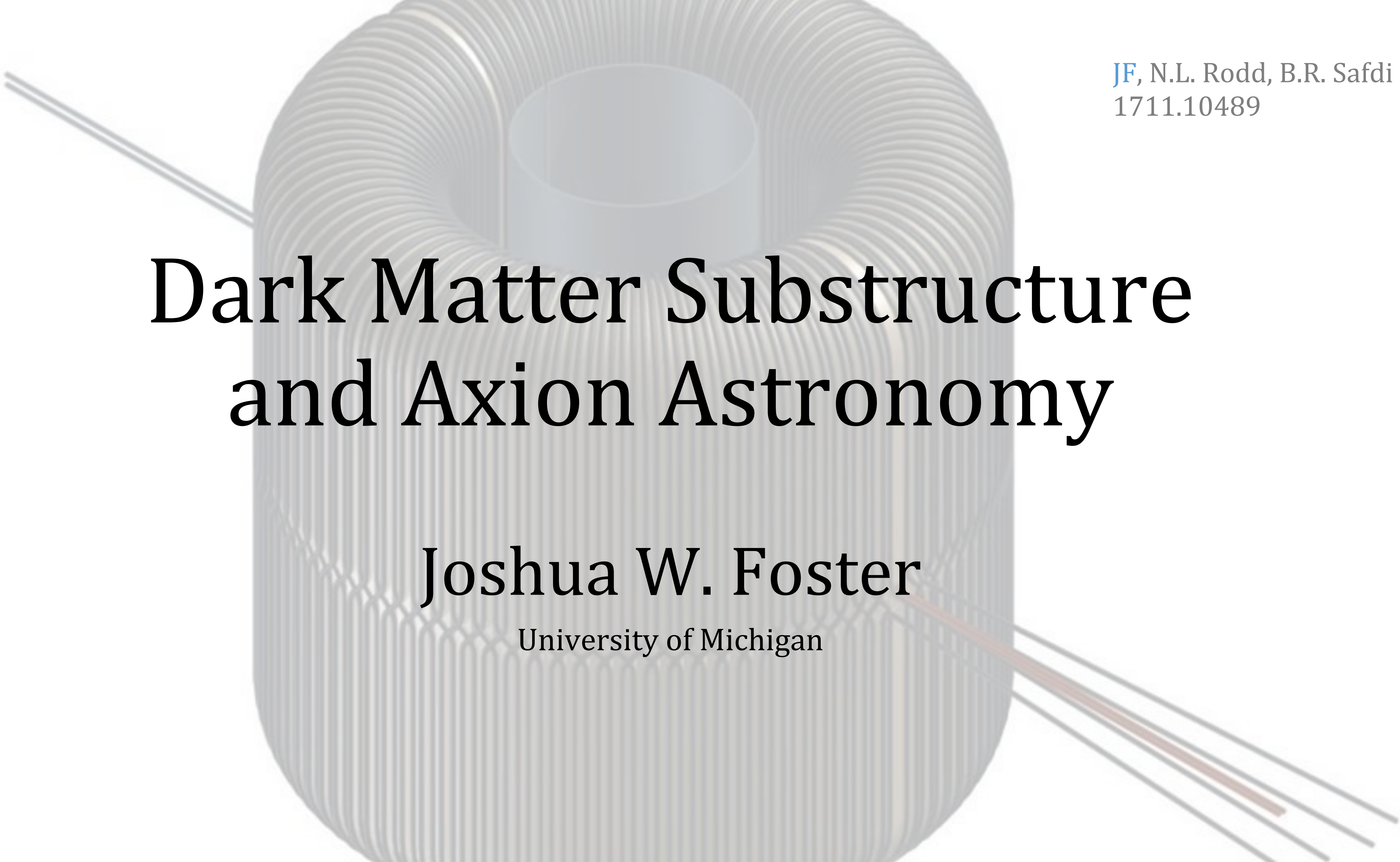
JF, N.L. Rodd, B.R. Safdi
1711.10489



Dark Matter Substructure and Axion Astronomy

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University of Michigan

Axions as the Dark Matter

- QCD axion introduced as a solution to the strong CP problem

$$\mathcal{L}_{\mathrm{QCD}} \supset \left(\bar{\theta} - \frac{a}{f_a}\right) \frac{g^2}{32\pi^2} \mathrm{Tr} G_{\mu\nu} \tilde{G}^{\mu\nu}$$

- Axion-like particles motivated by UV theories
- Viable DM candidate, rich phenomenology
- Generic photon coupling

$$\mathcal{L}_{\mathrm{EM}} \supset g_{a\gamma\gamma} a F_{\mu\nu} \tilde{F}^{\mu\nu}$$

ABRACADABRA

A Broadband/**R**esonant **A**pproach to **C**osmic **A**xion **D**etection with an **A**mplifying **B**-field **R**ing **A**pparatus

- Ampere's law modified by axions

$$\nabla \times \mathbf{B} = \frac{\partial E}{\partial t} - g_{a\gamma\gamma}\left(\mathbf{E} \times \nabla a - \mathbf{B}\frac{\partial a}{\partial t}\right)$$

- Time-varying axions induces magnetic flux
- Broadband and Resonant readout modes
- Protoype built – data and analysis soon

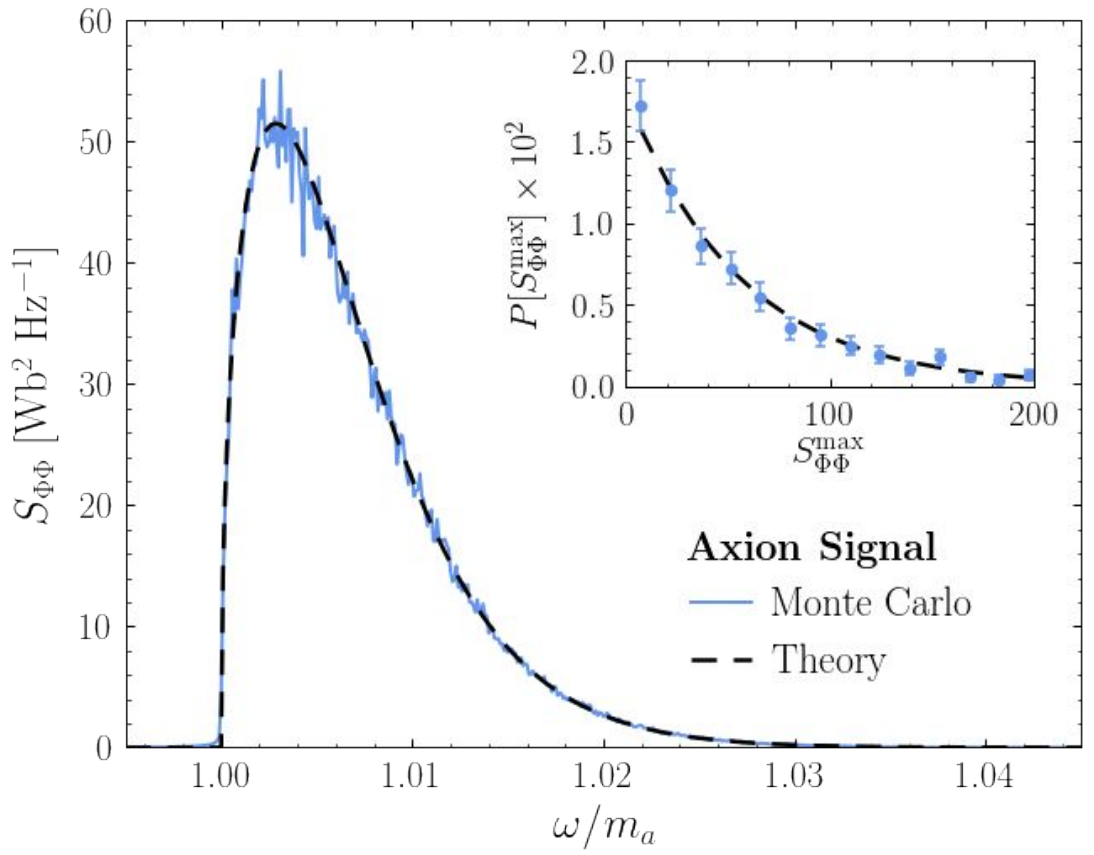
Axion Signal at Direct Detectors

- Experiments measure axion field up to some scaling

$$\Phi(t) = \sqrt{A}\sum_i^{N_a} \cos\left[m_a\left(1+\frac{v_i^2}{2}\right)t + \phi_i\right]$$

- Calculable power spectral density
  - exponential distribution at each frequency

$$\langle S_{\Phi\Phi}(f)\rangle = A\frac{\pi f(v)}{m_a v} + S_{\Phi 0}$$



Likelihood Analysis Framework

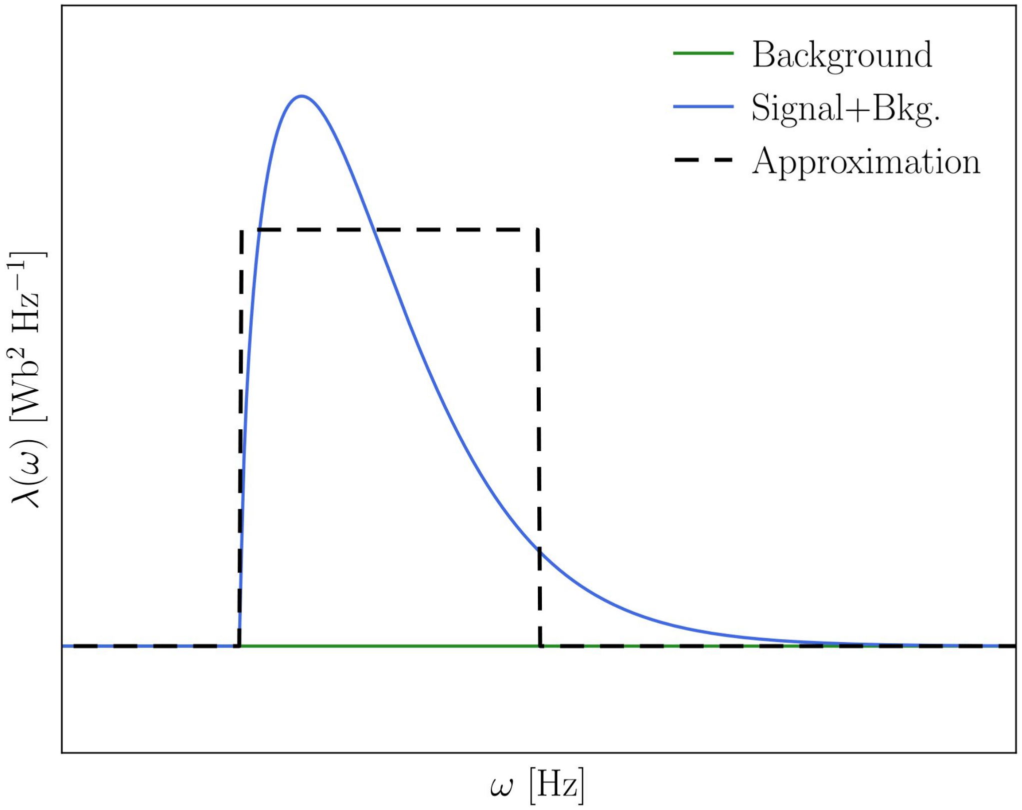
- Compute the likelihood of observed data assuming model and parameters

$$p(S_{\Phi\Phi}|M,\theta) = \prod_k \frac{1}{\lambda_k(\theta)} e^{-S_{\Phi\Phi}(k)/\lambda_k(\theta)}$$

$$\lambda_k(\theta) = \langle S_{\Phi\Phi}(f|M,\theta)\rangle$$

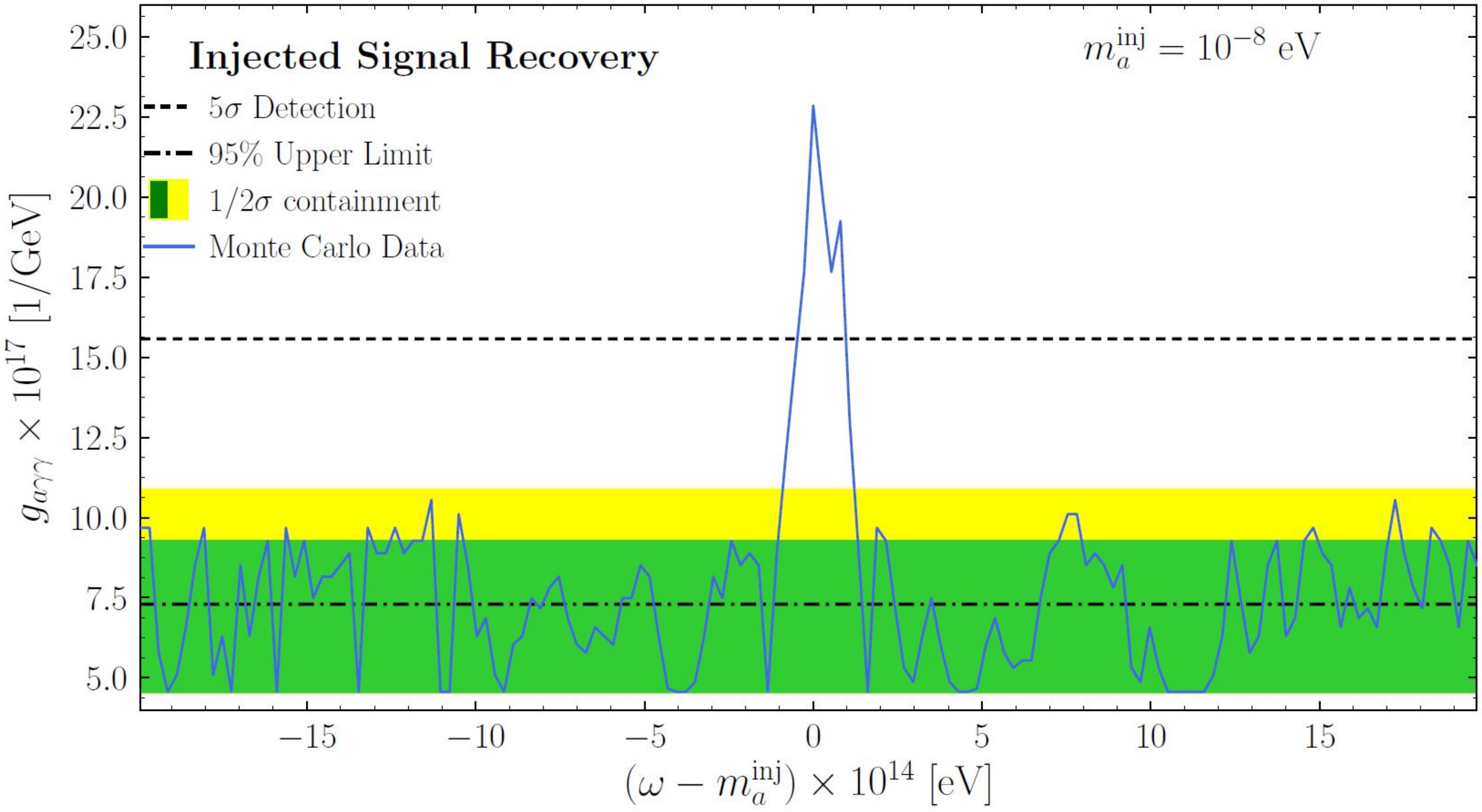
- Test Statistic (TS) as a goodness-of-fit test

$$TS = 2\log\frac{p(S_{\Phi\Phi}|M_{\mathrm{signal}},\hat{\theta})}{p(S_{\Phi\Phi}|M_{\mathrm{null}},\hat{\hat{\theta}})}$$



Signal Analysis Example

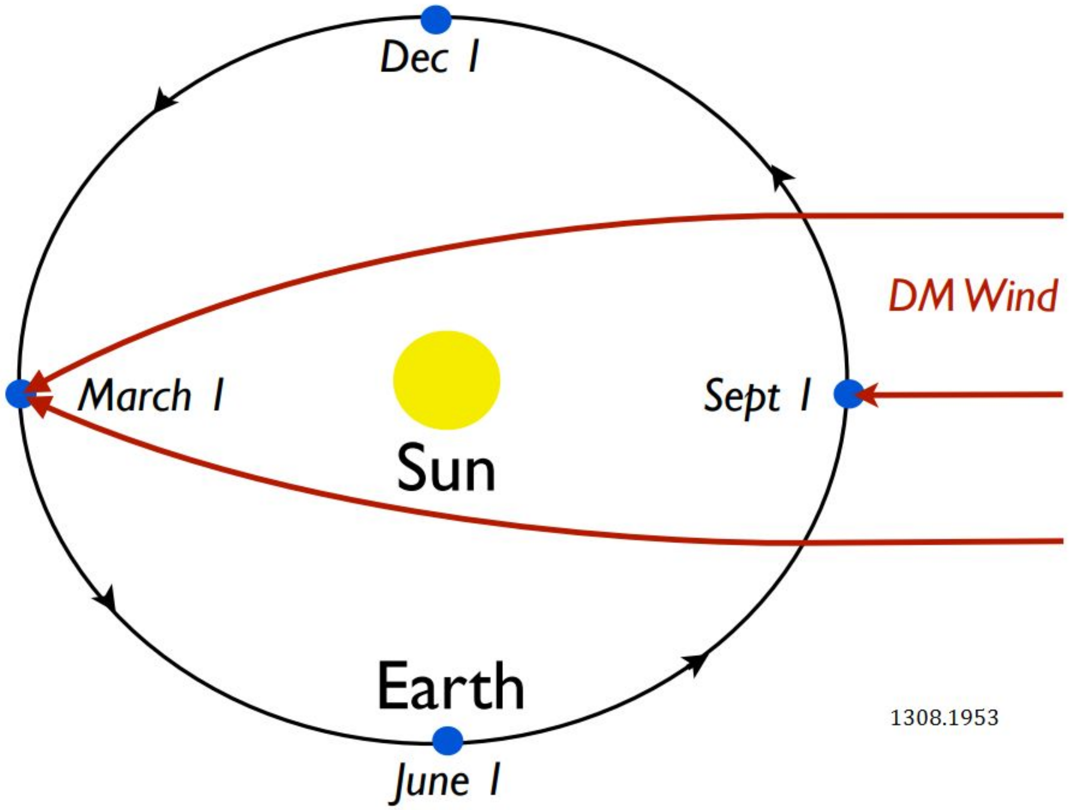
Coupling Strength



Axion Mass

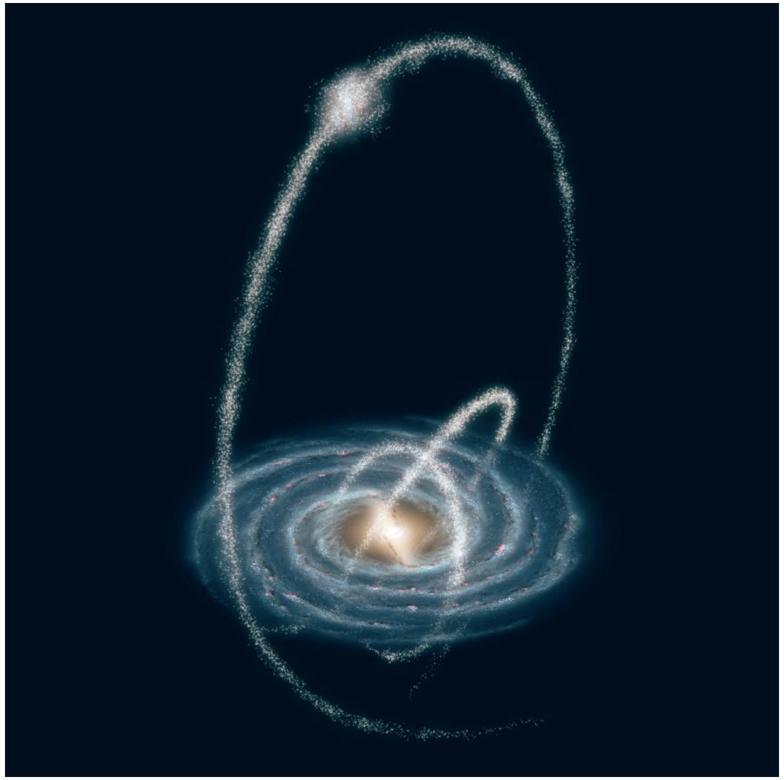
Annual Modulation

- Lab velocity varies over the year
  - ± 30 km/s
- Gravitational focusing by sun
- Apparent time-dependent speed distribution

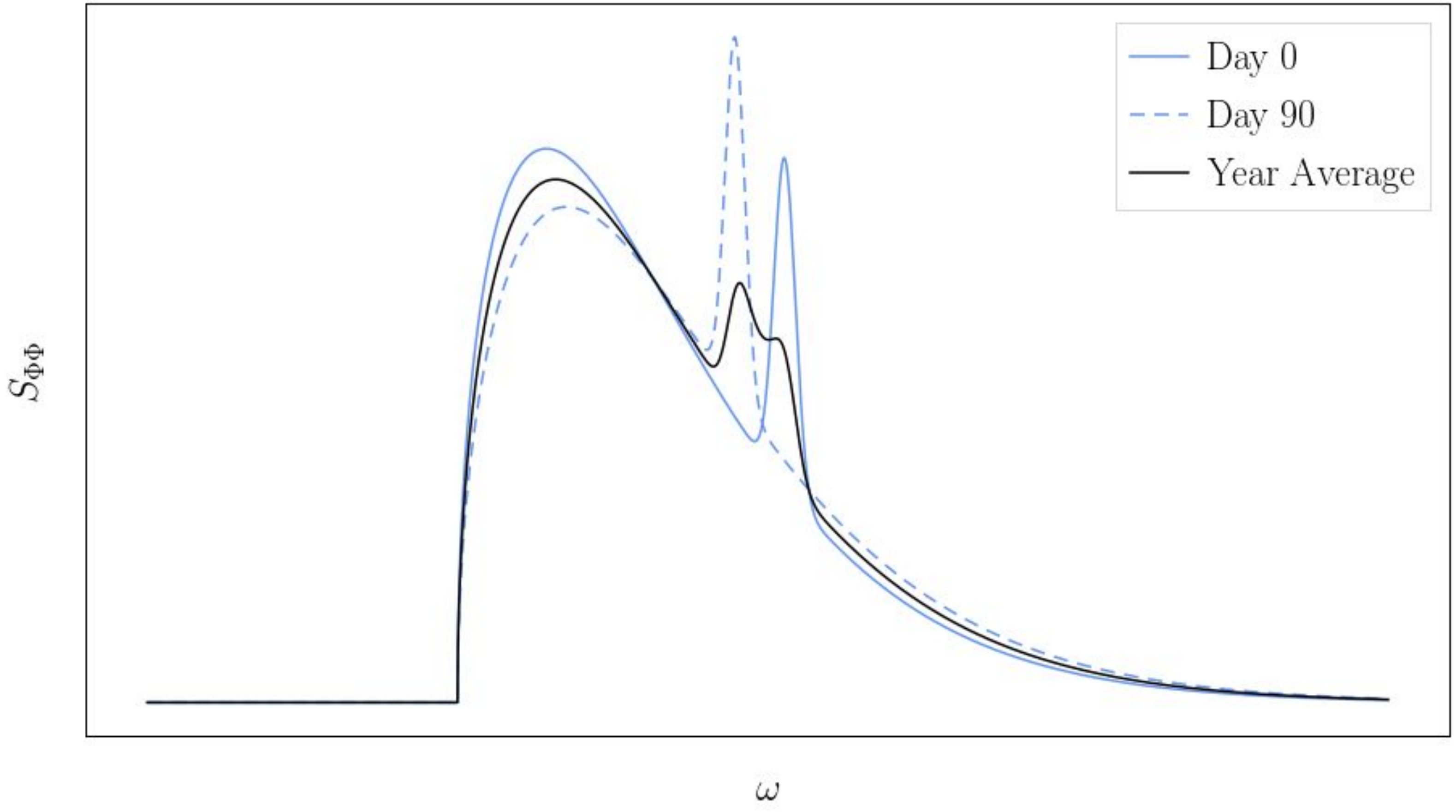


DM Substructure

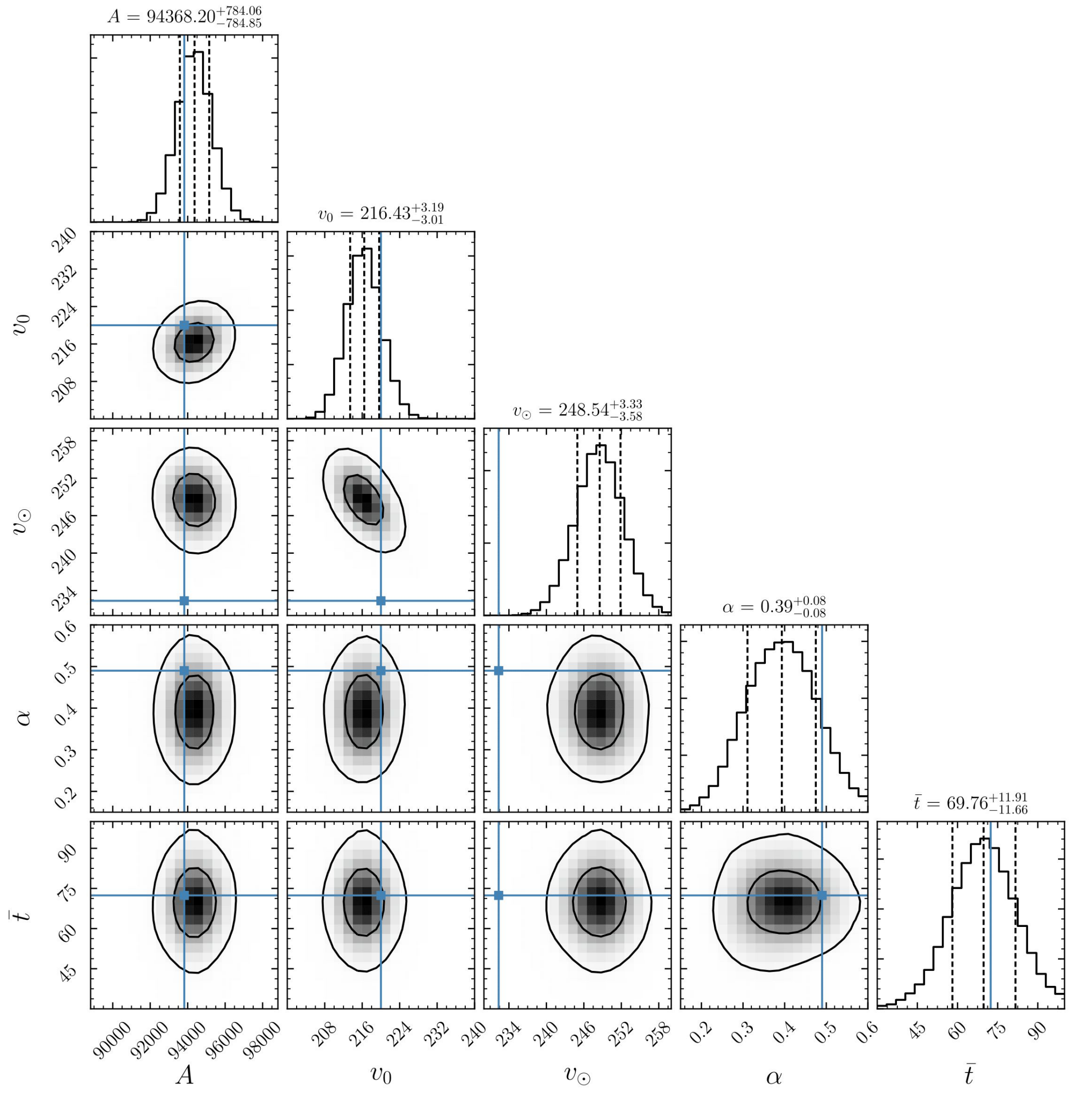
- Local substructure contributes to local speed distribution
- Small dispersion
- Significant annual modulation



Time-Dependent Data Analysis

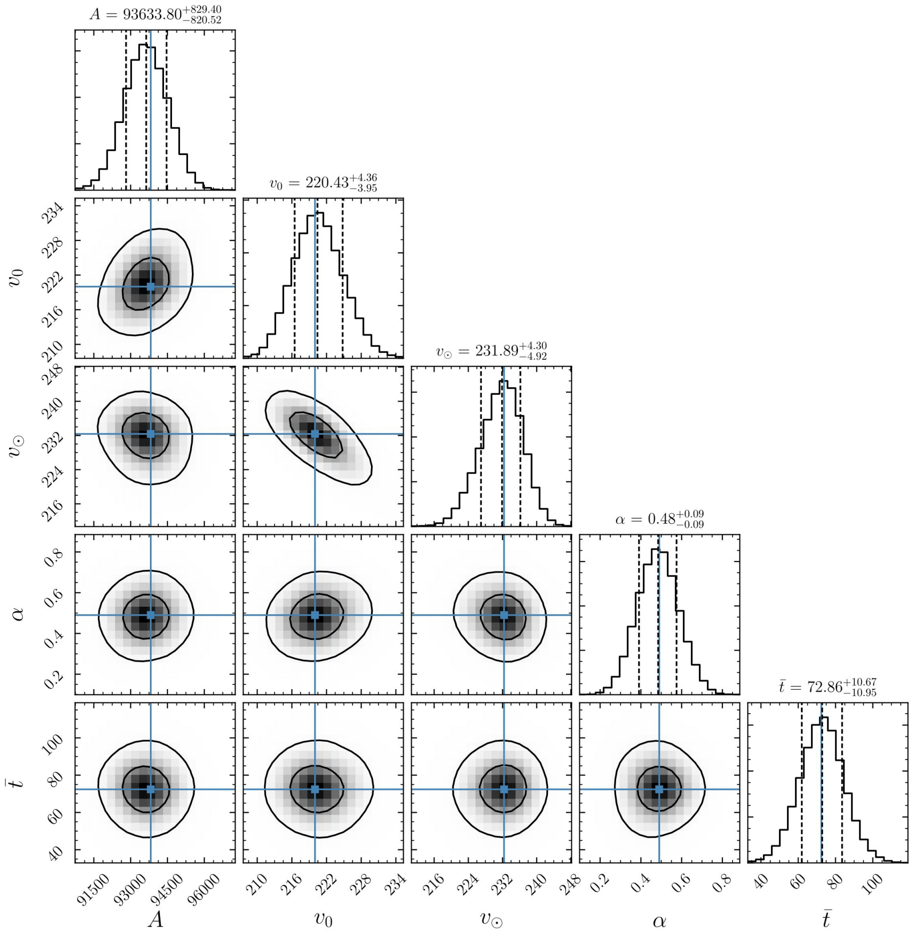


Signal Analysis Example

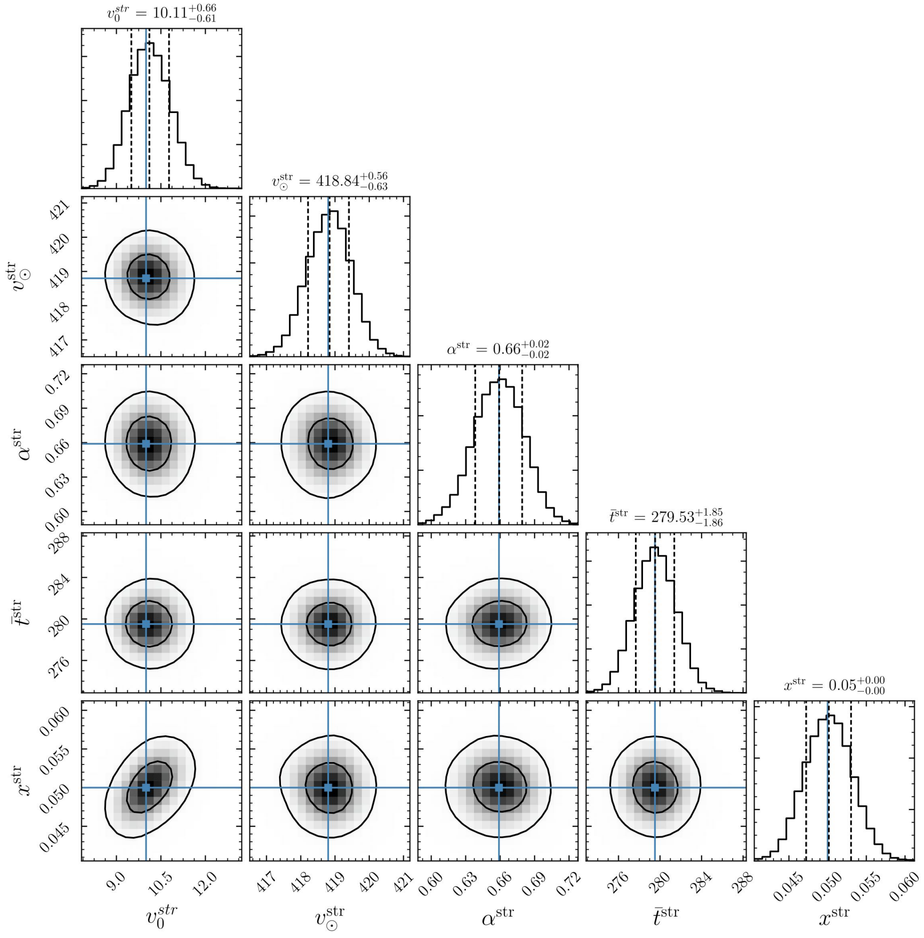


Signal Analysis Example

SHM Signal Verification



Stream Reconstruction



Current Status

- Working, well-tested analysis framework
- ABRACADABRA results soon
- How can we help you?

Backup Slides

Substructure-Enhanced Sensitivity