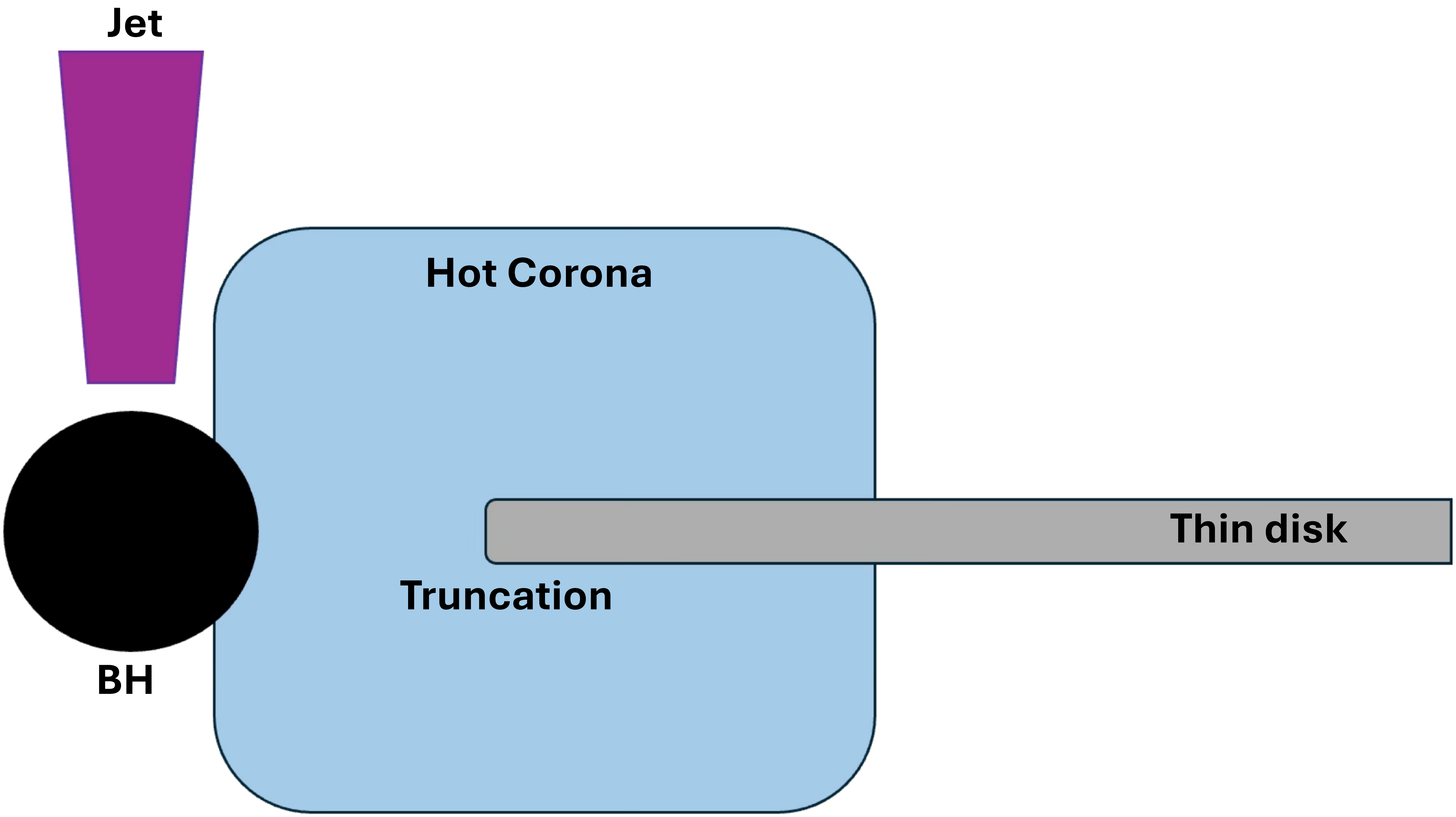
Spectral-timing correlation of independent variability components in Cygnus X-1

Seth Rowan Larner
Michael A. Nowak, Victoria Grinberg, Jörn Wilms

Fast Variability Reveals Structure



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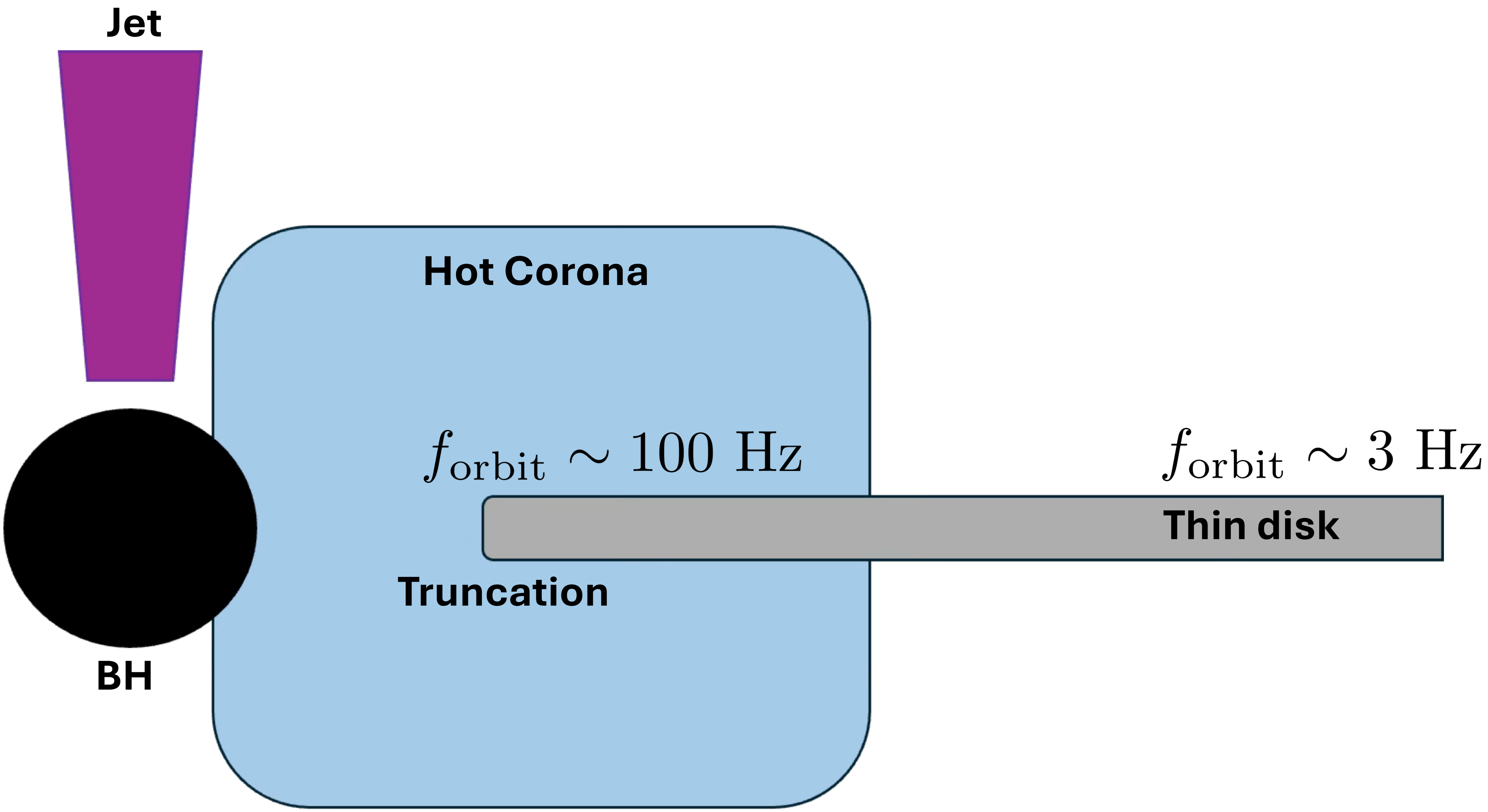

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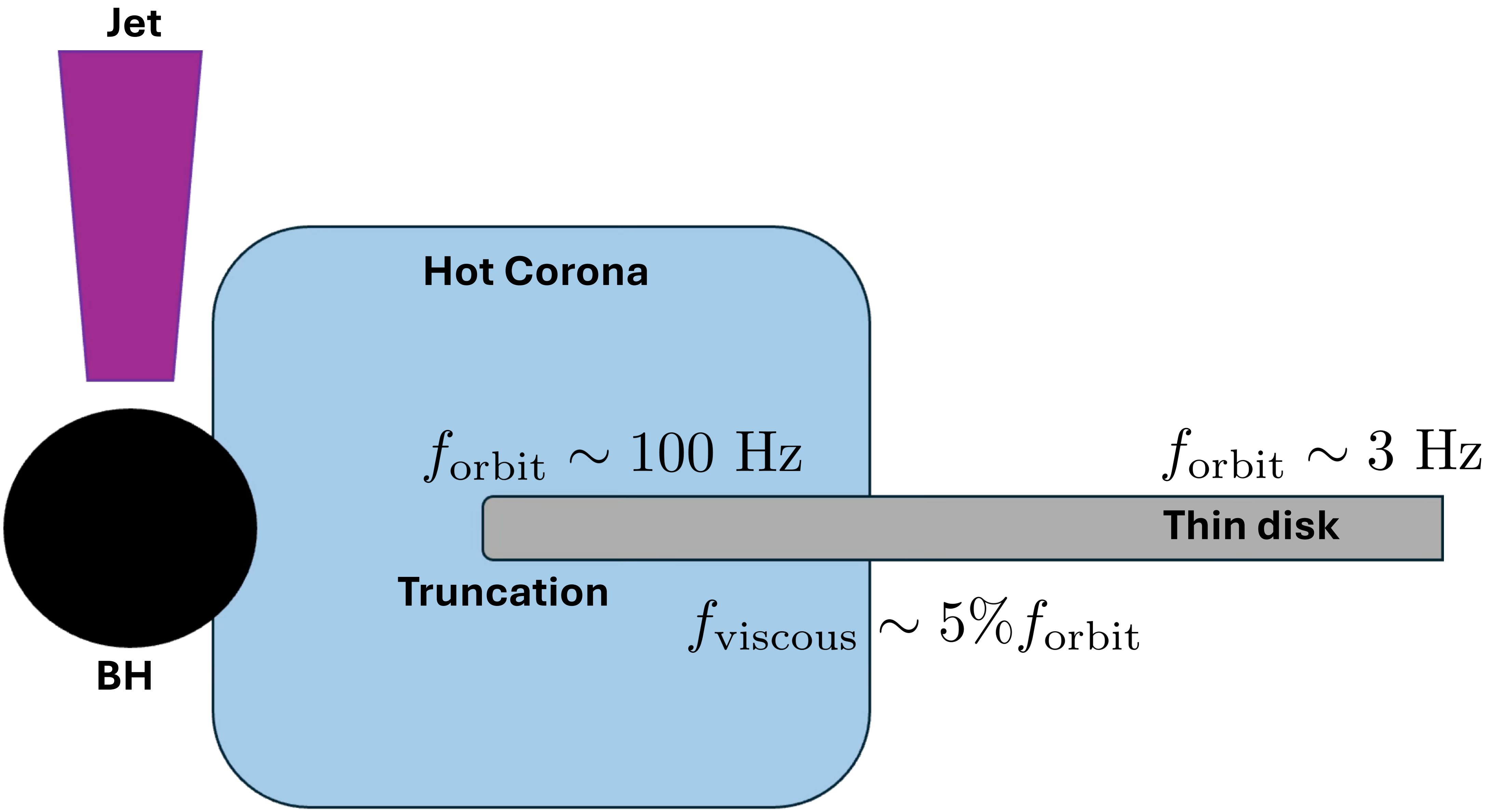

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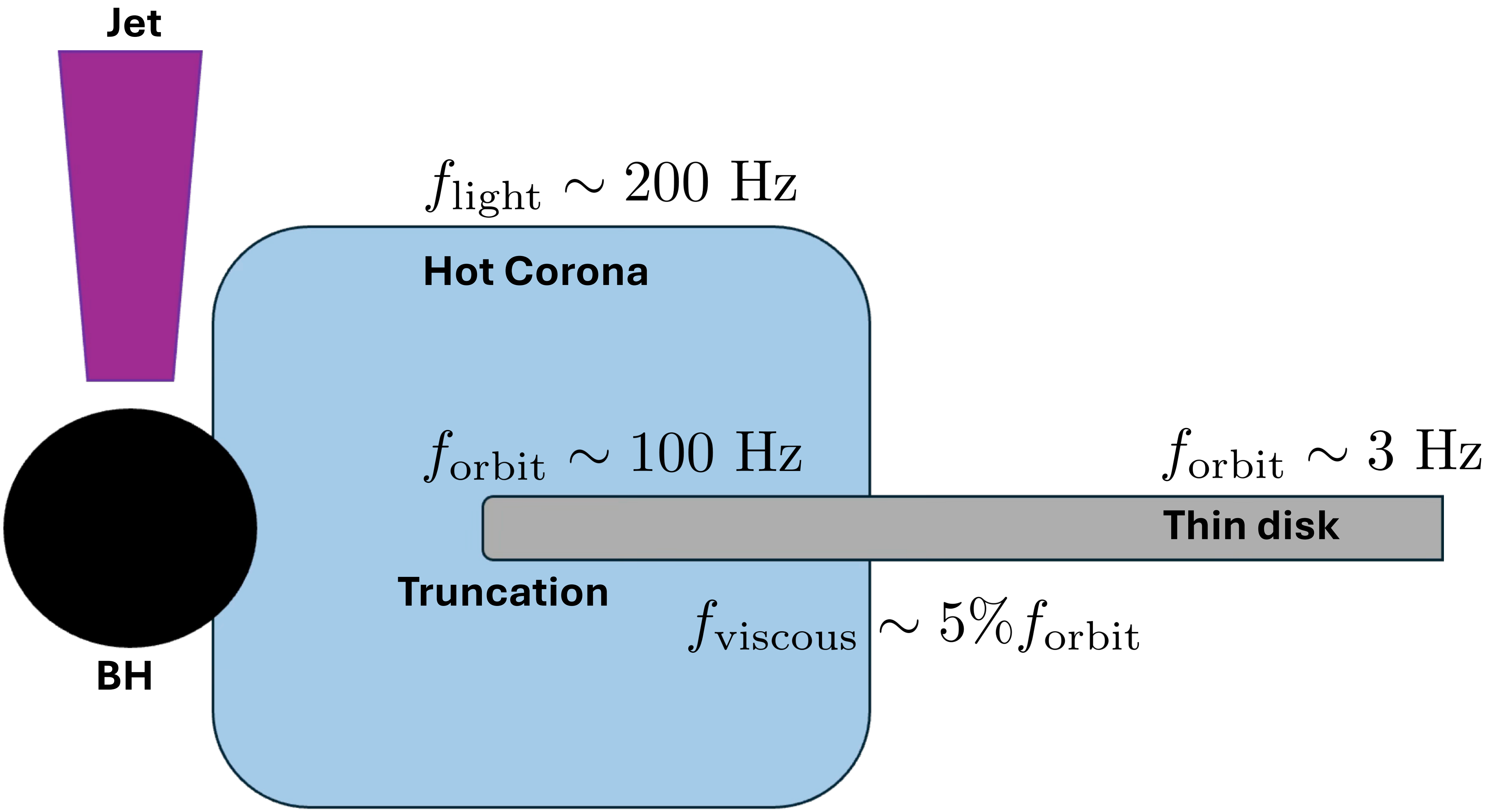
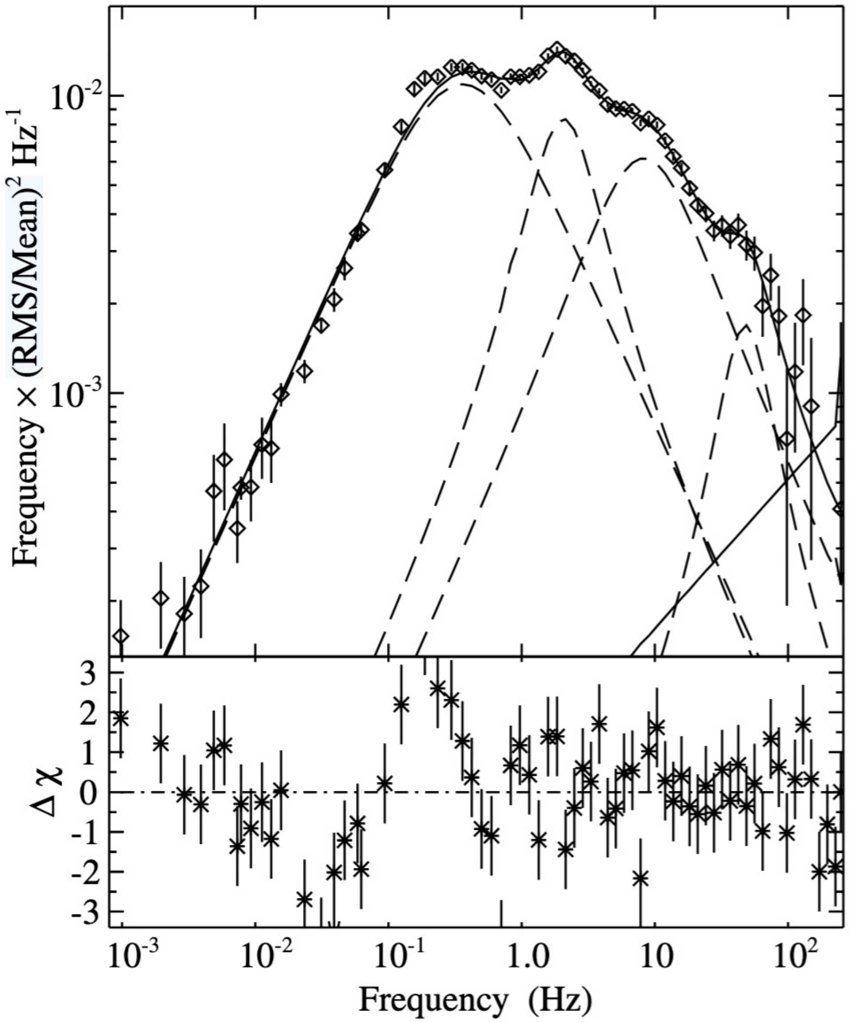
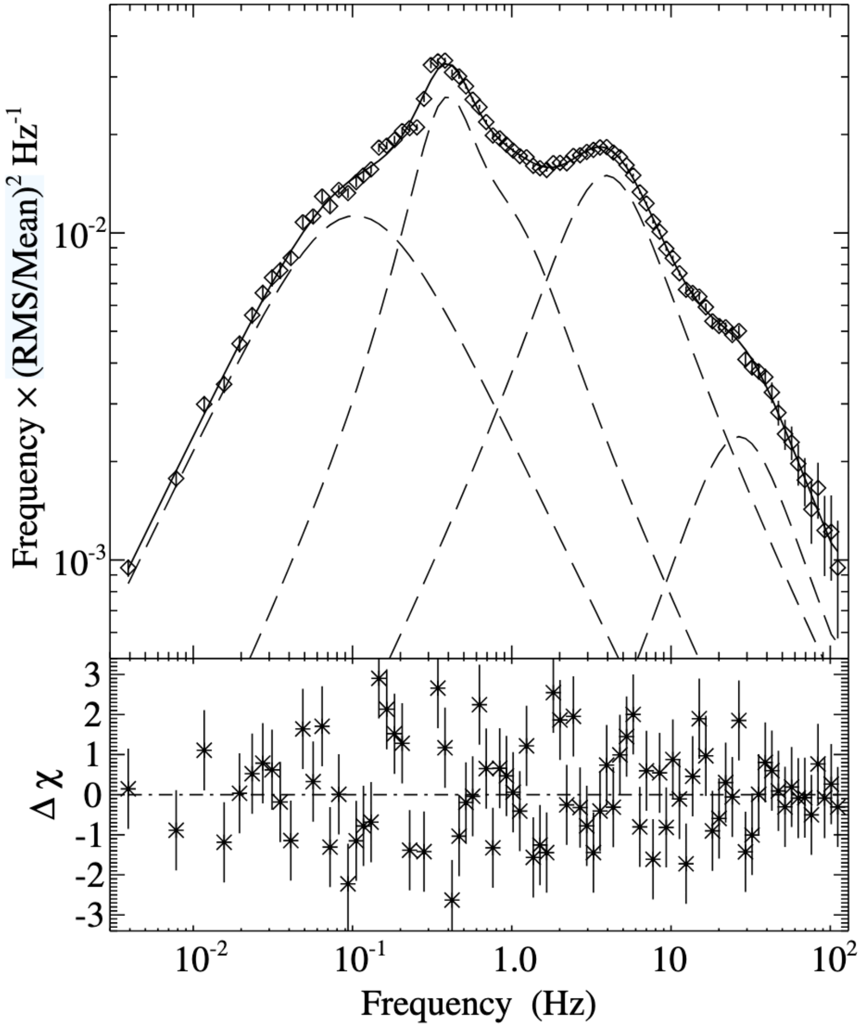


Variability Splits into Components

Cyg X-1

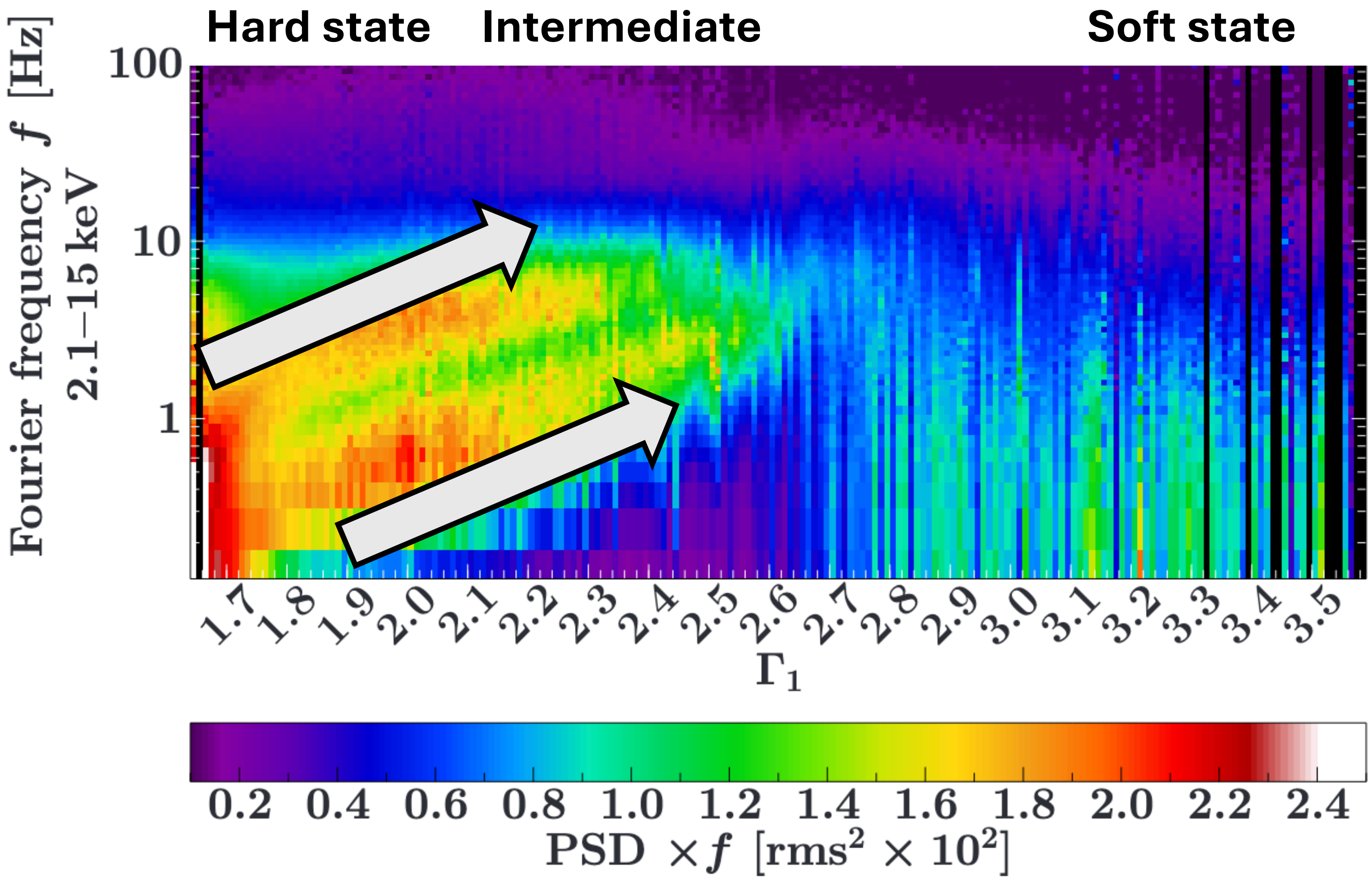


GX 339-4



Nowak 2000

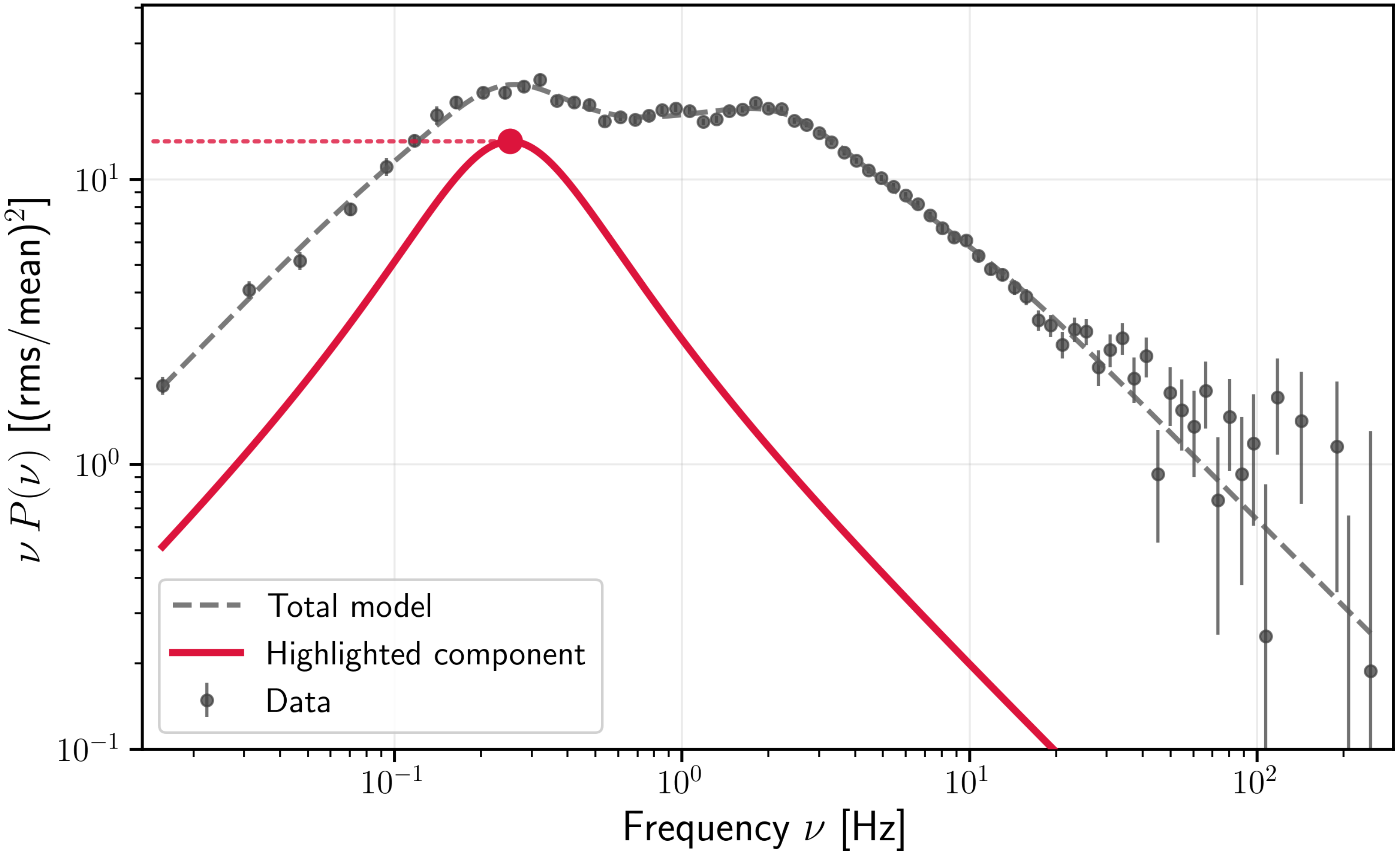
Cyg X-1 Variability Tracks State



- Power moves to higher frequencies as source softens
- Two clear tracks visible
- Featureless at soft states

Grinberg+ 2014

Can We Track *Each* Component?



- Components described by:
  - **Power**
  - Central frequency
  - Quality factor
  - Phase difference

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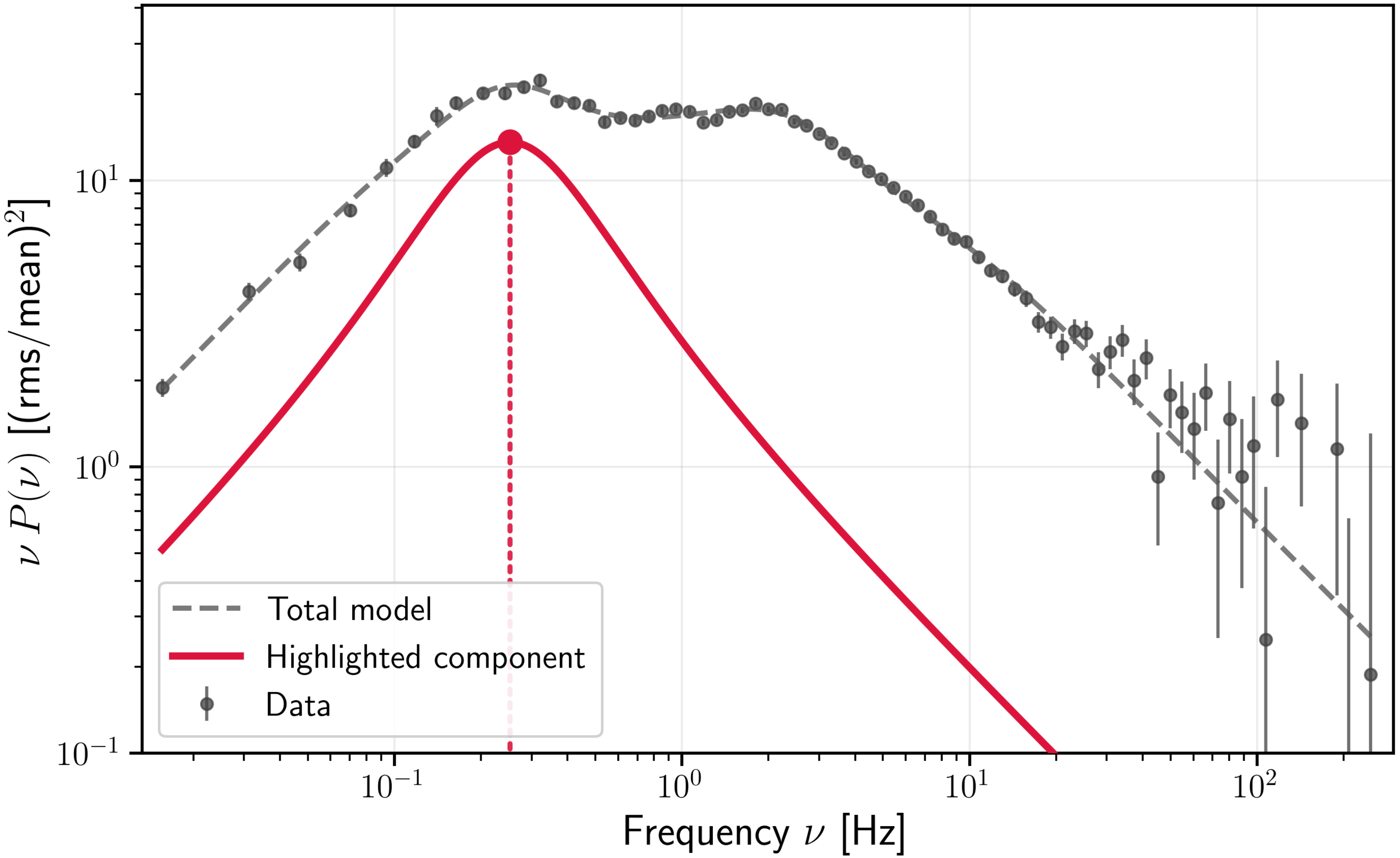

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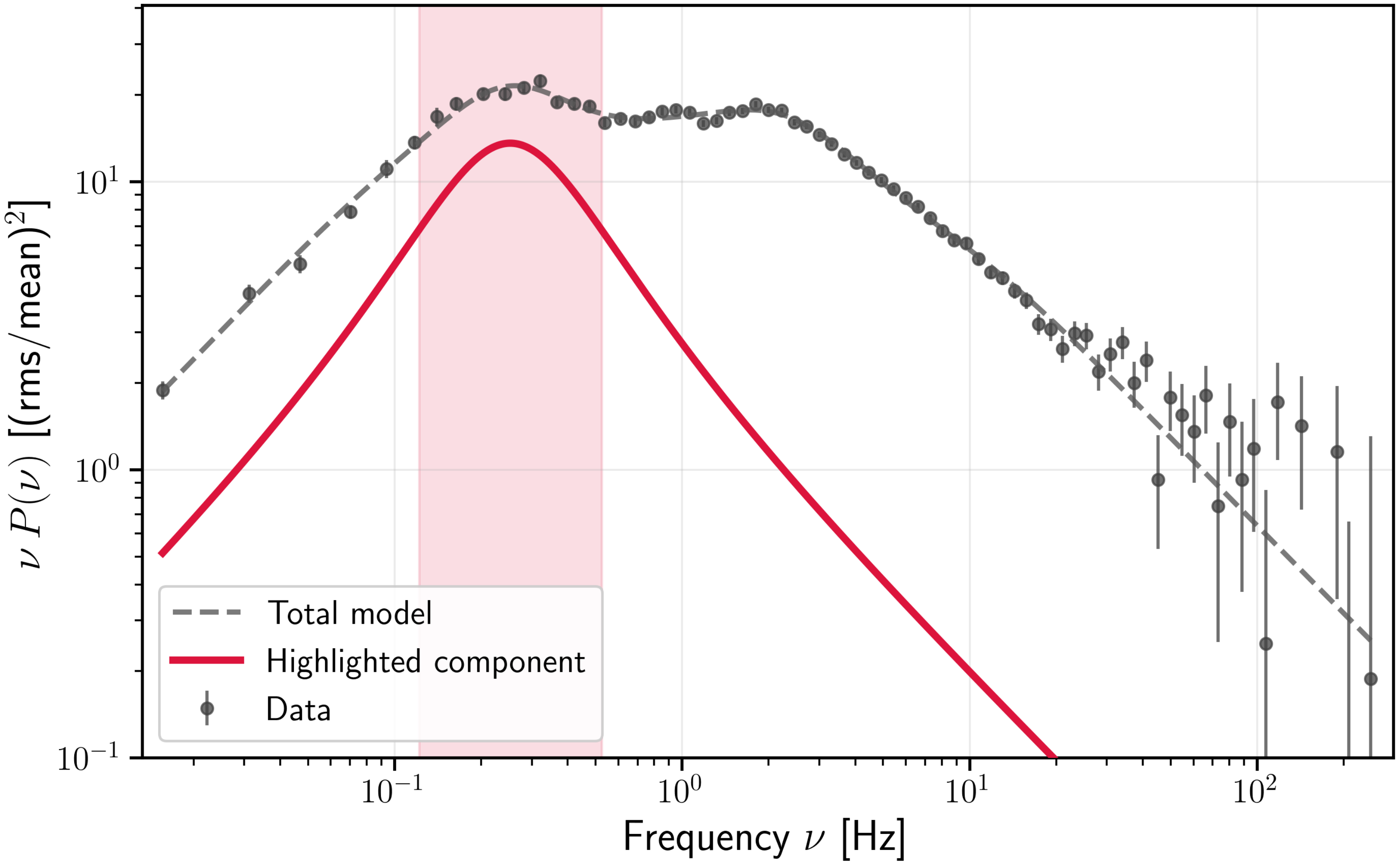

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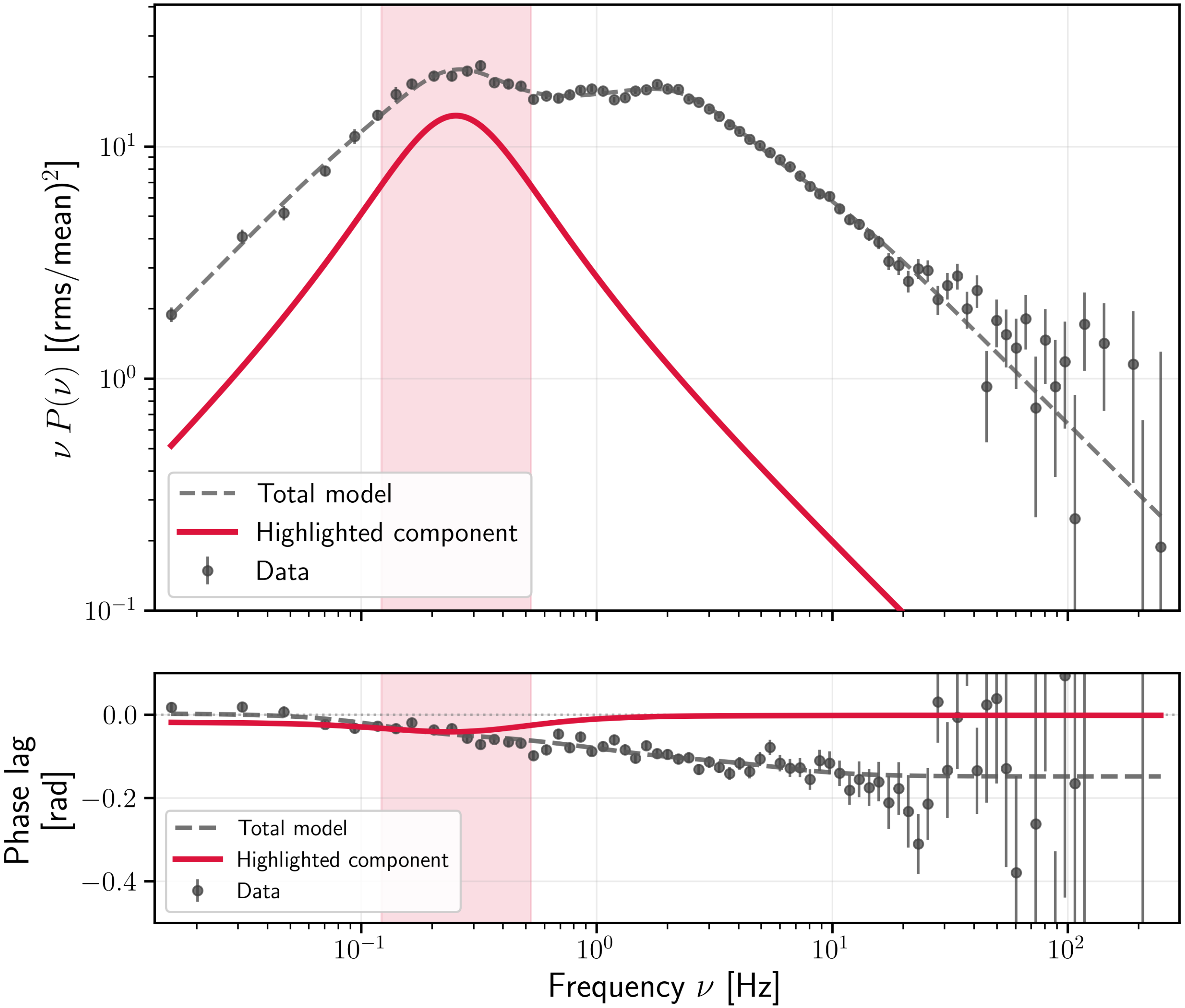

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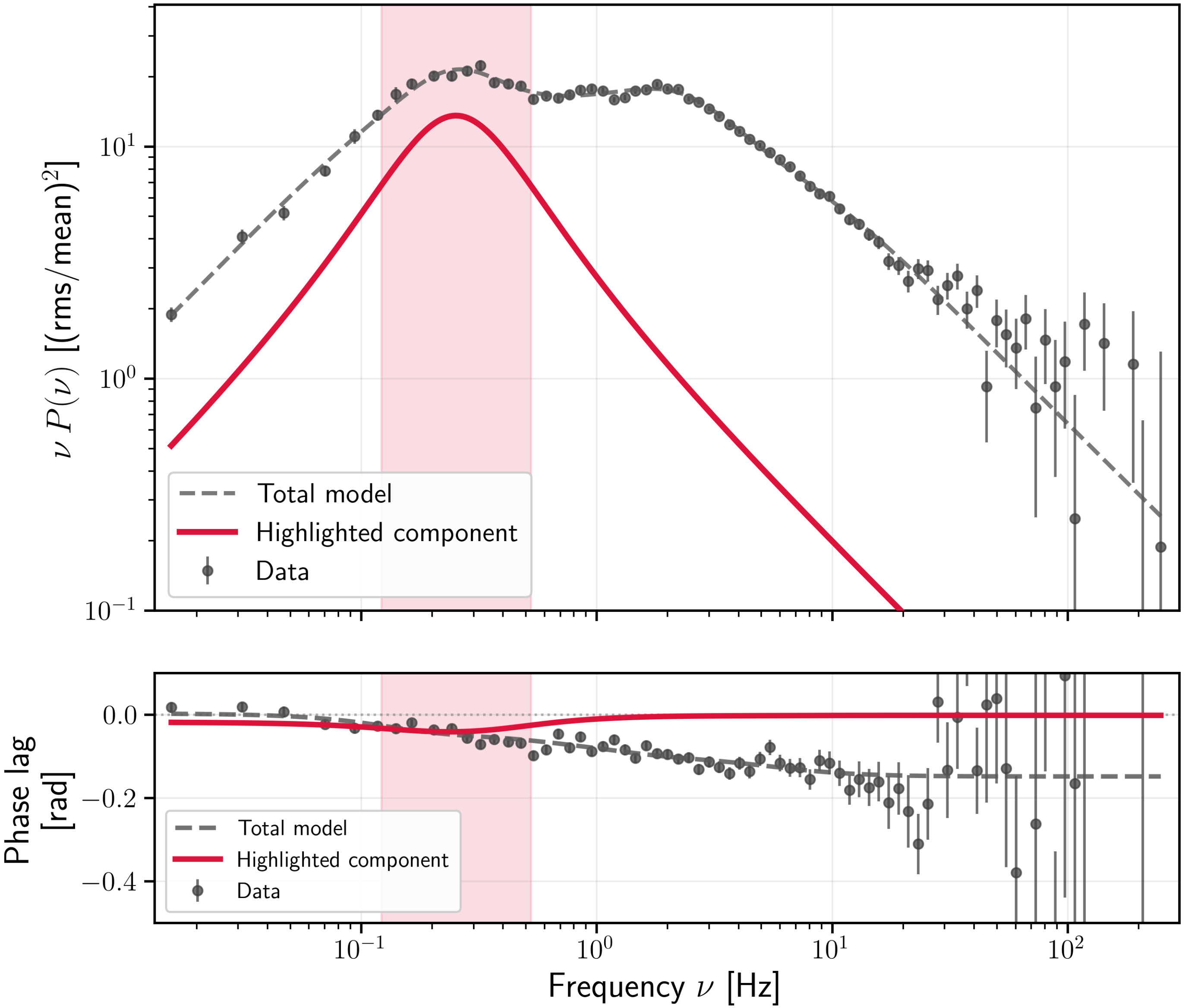
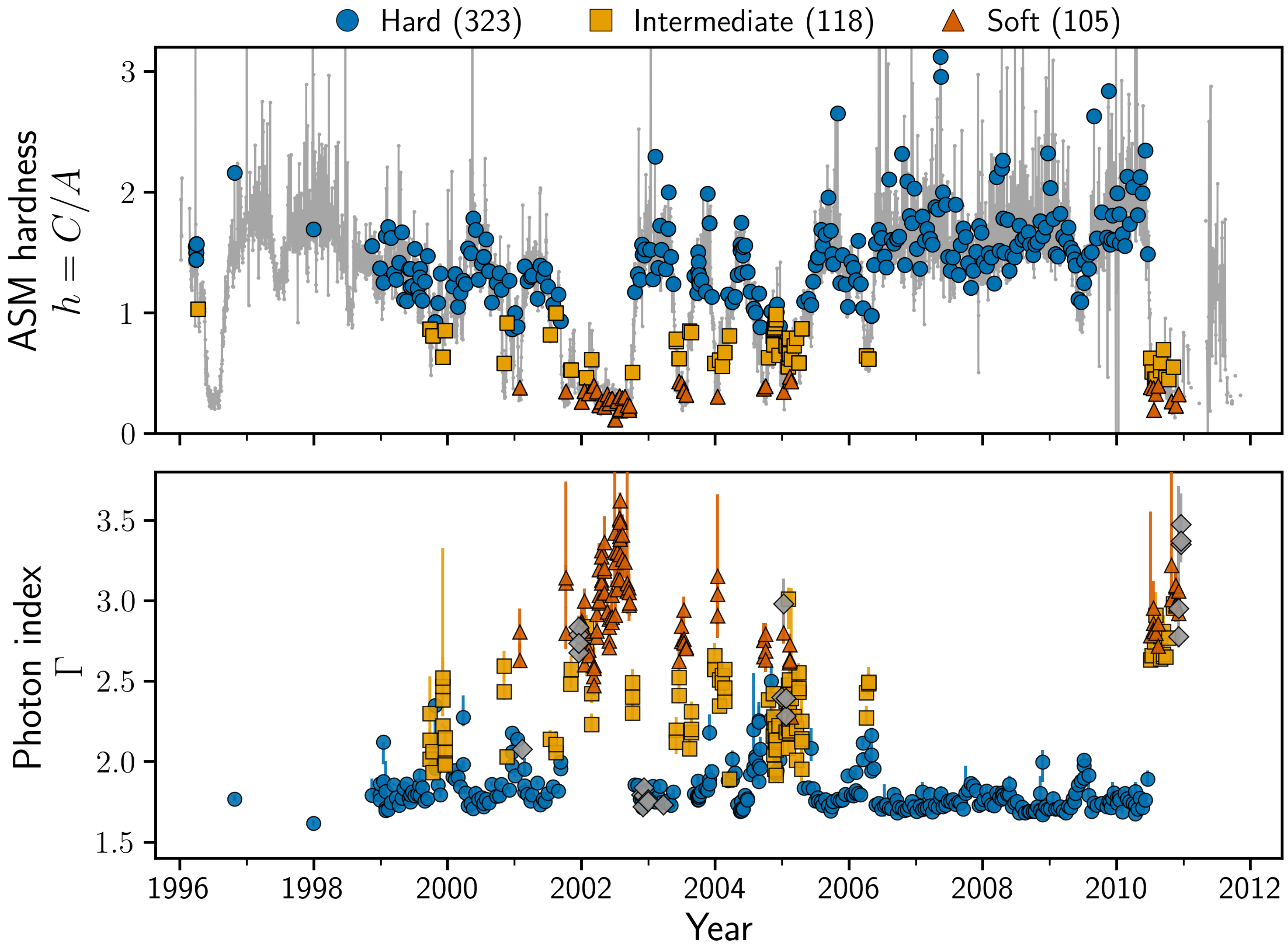


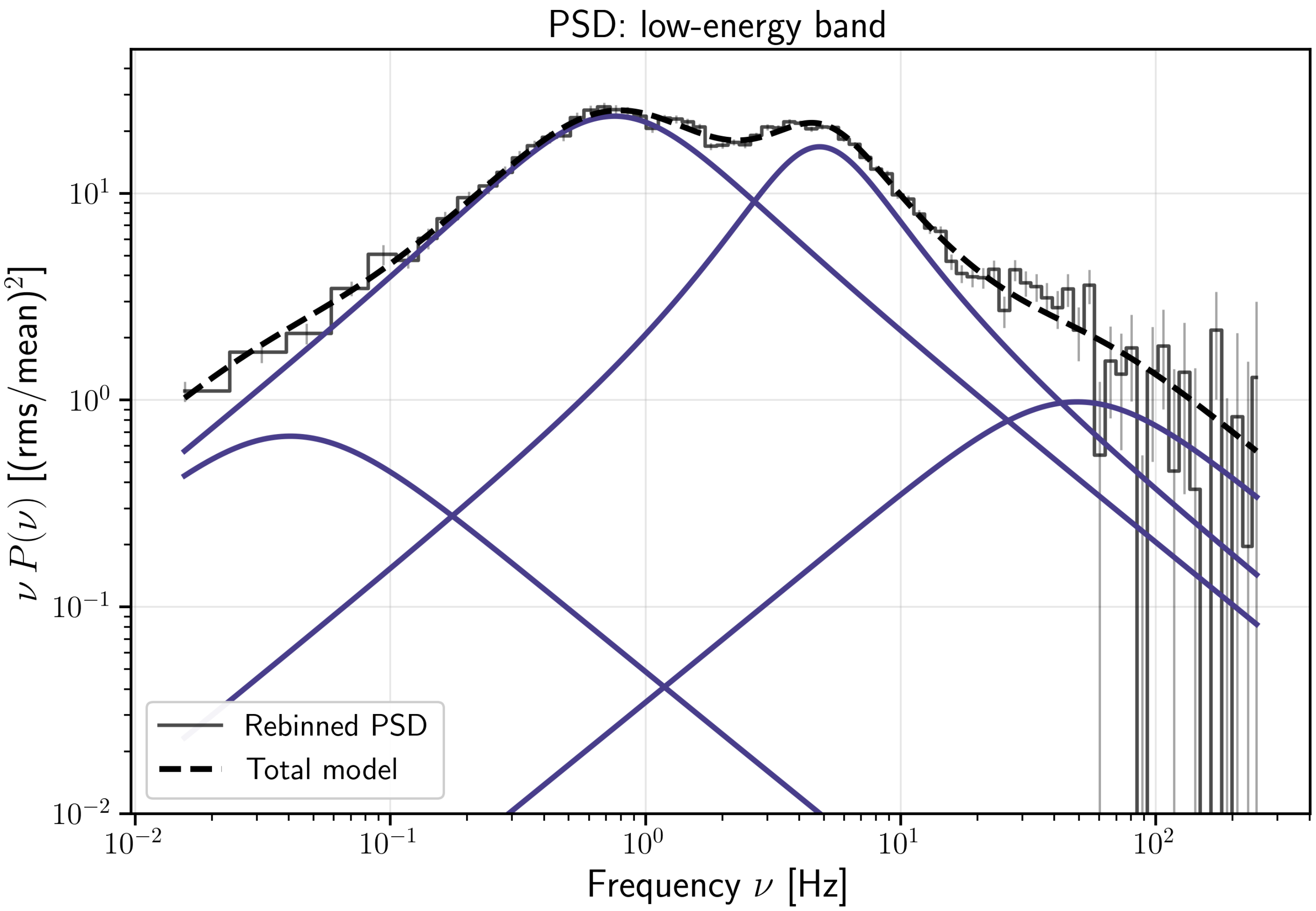
- Components described by:
  - Power
  - Central frequency
  - Quality factor
  - Phase difference
- **Features should evolve smoothly with spectral changes**

Archival Cygnus X-1 RXTE Campaign



- 1,912 orbits
- 3.91 megaseconds
- ASM data sorts into hard, intermediate, soft states
- Multiple successful and failed state transitions
- Spectral modeling for each orbit

Step 1: Model Independent Components



- Simultaneously model power spectrum in two energy bands and cross spectrum
- Cross spectrum reveals phase lag and intrinsic coherence

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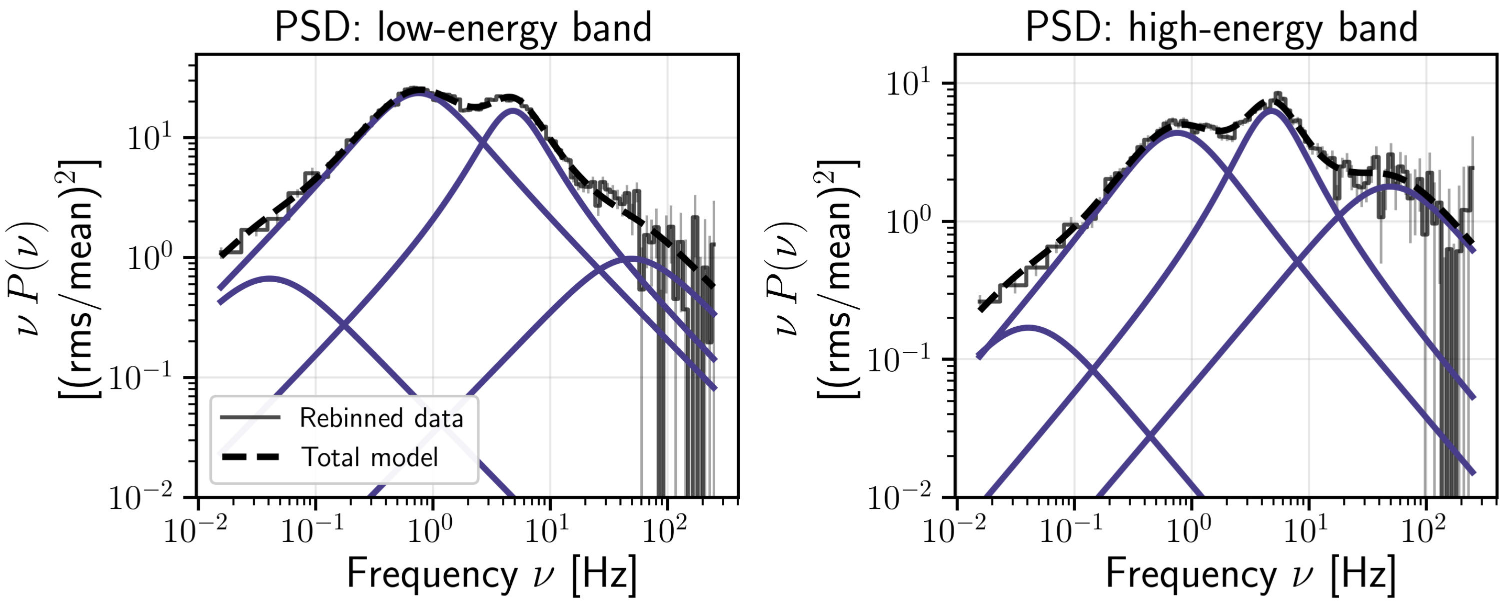

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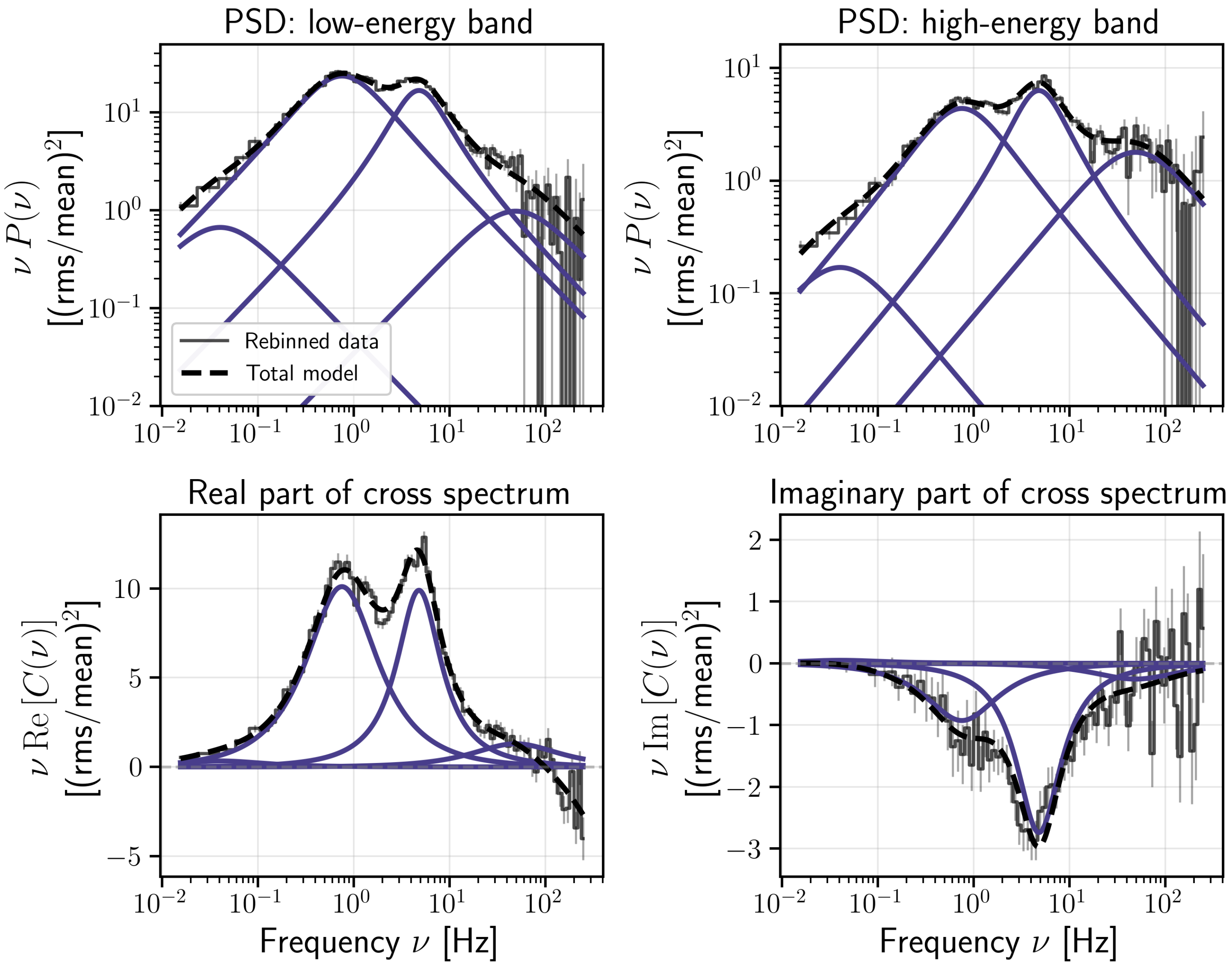

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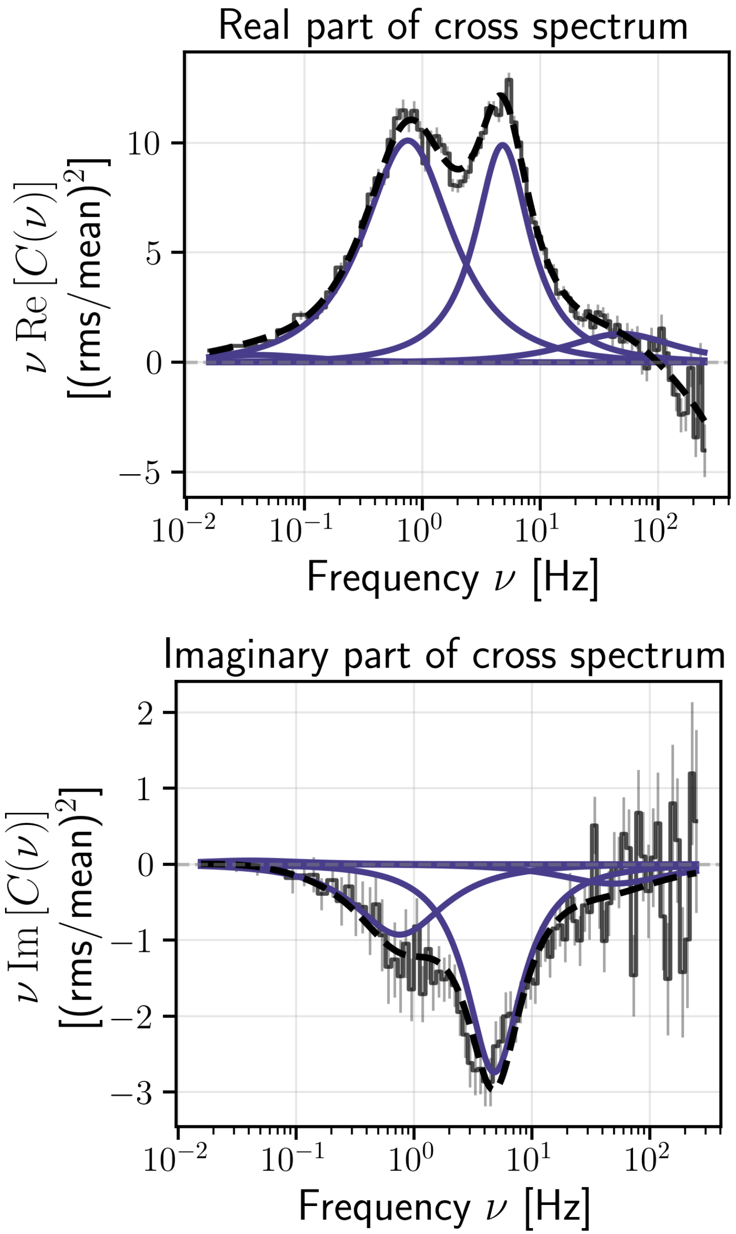

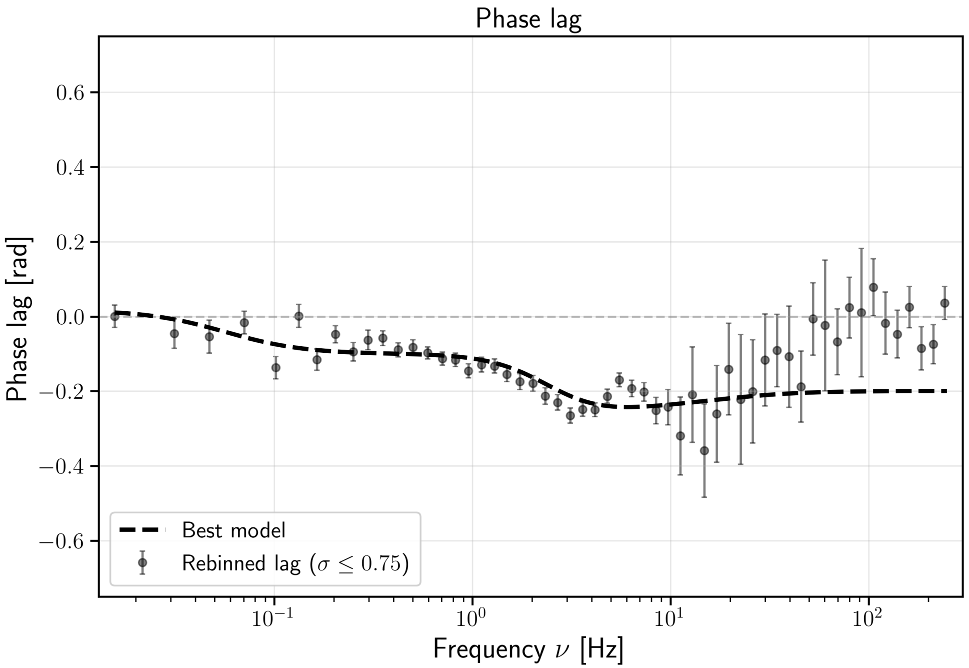

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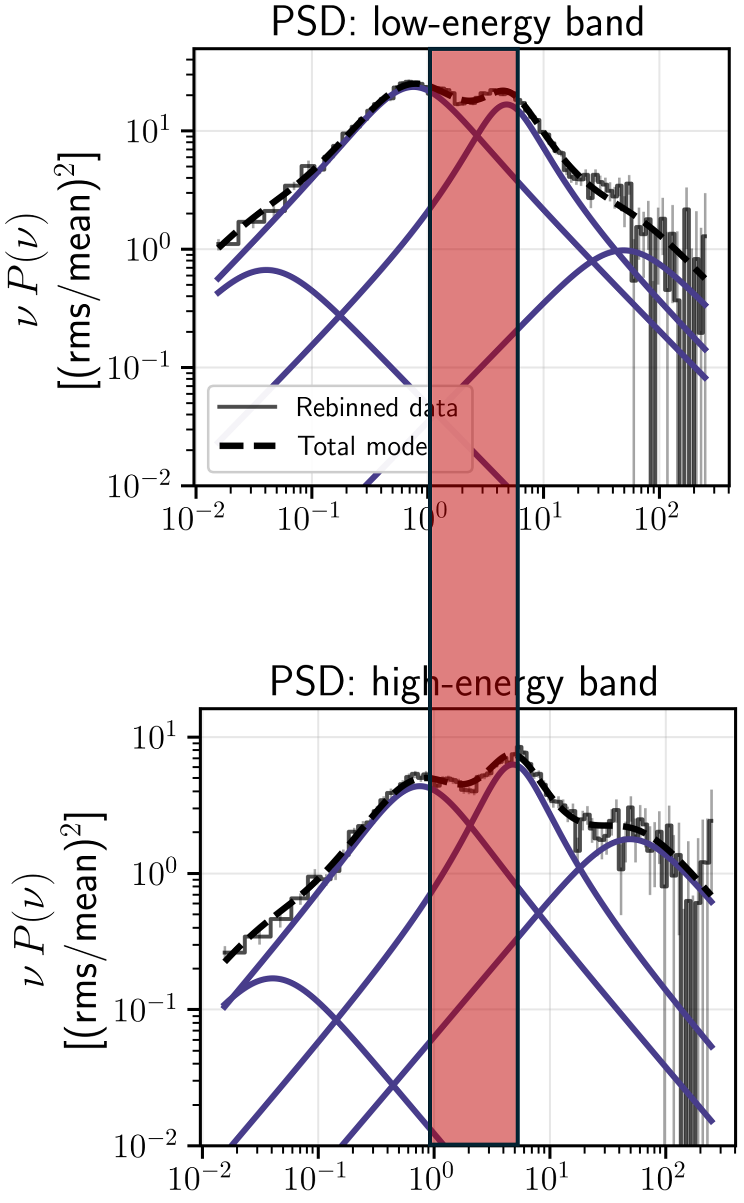

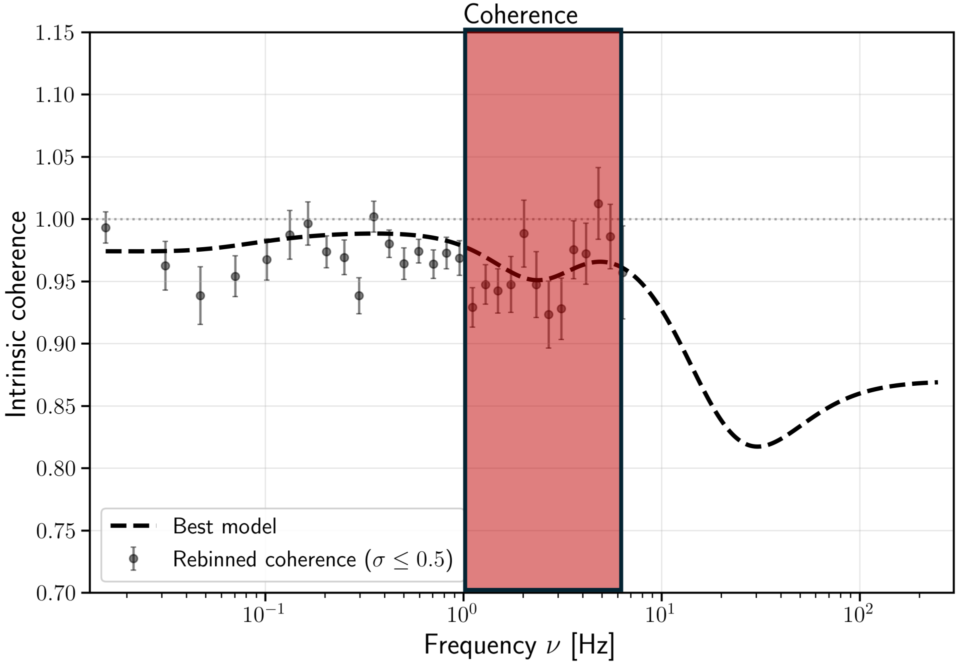

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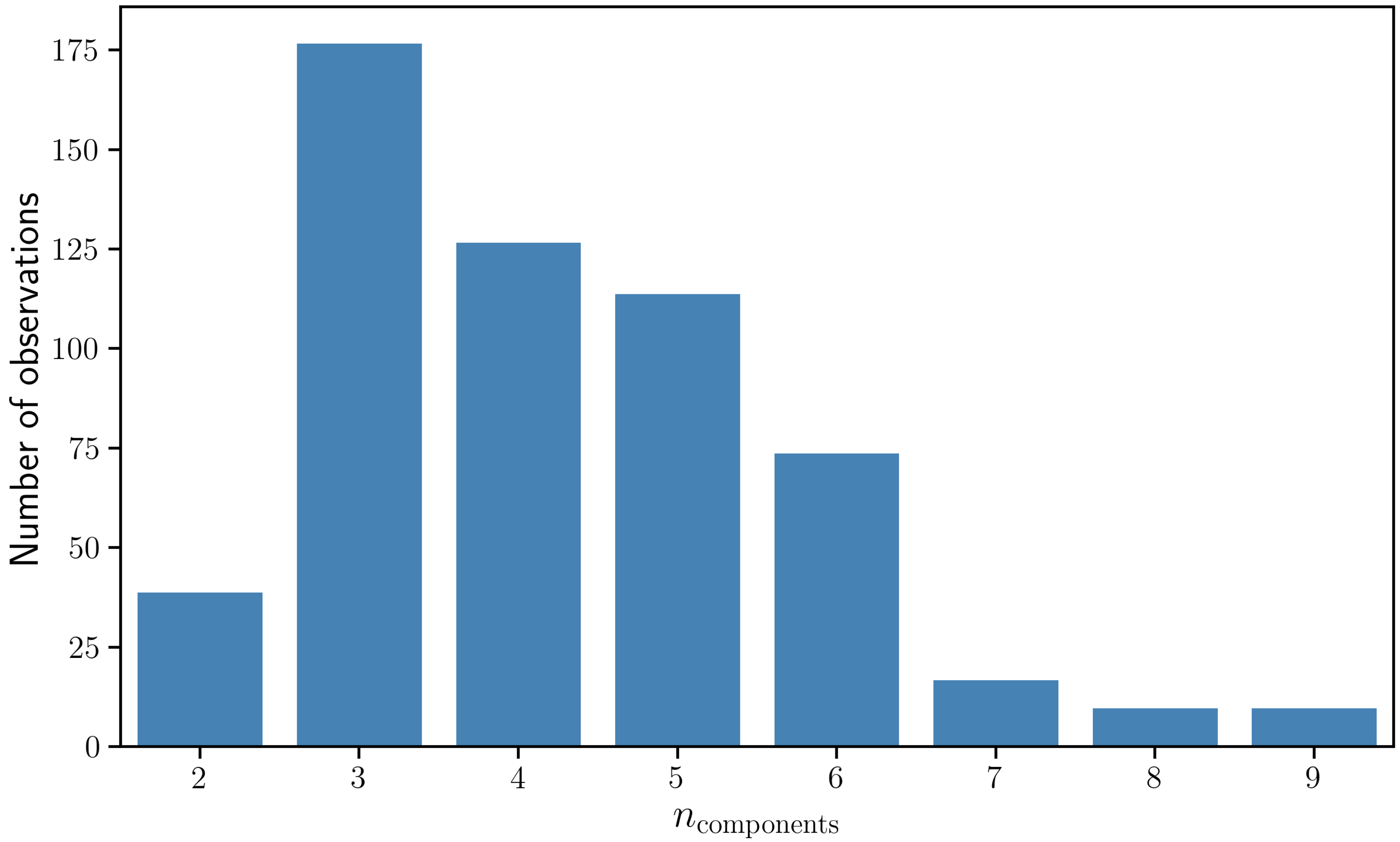

- Most observations need 3-5 Lorentzian components
  - Bayesian information criterion selected

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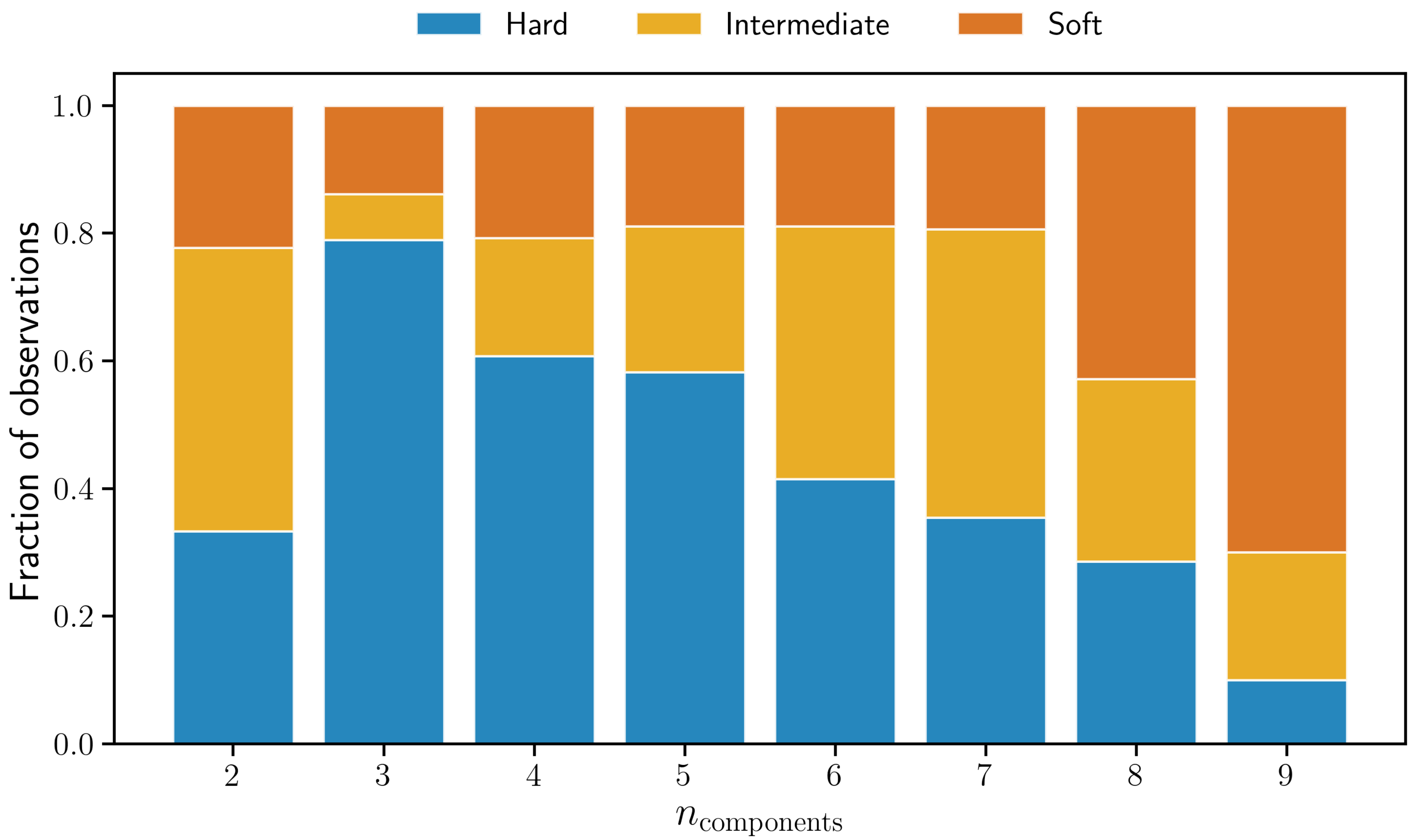
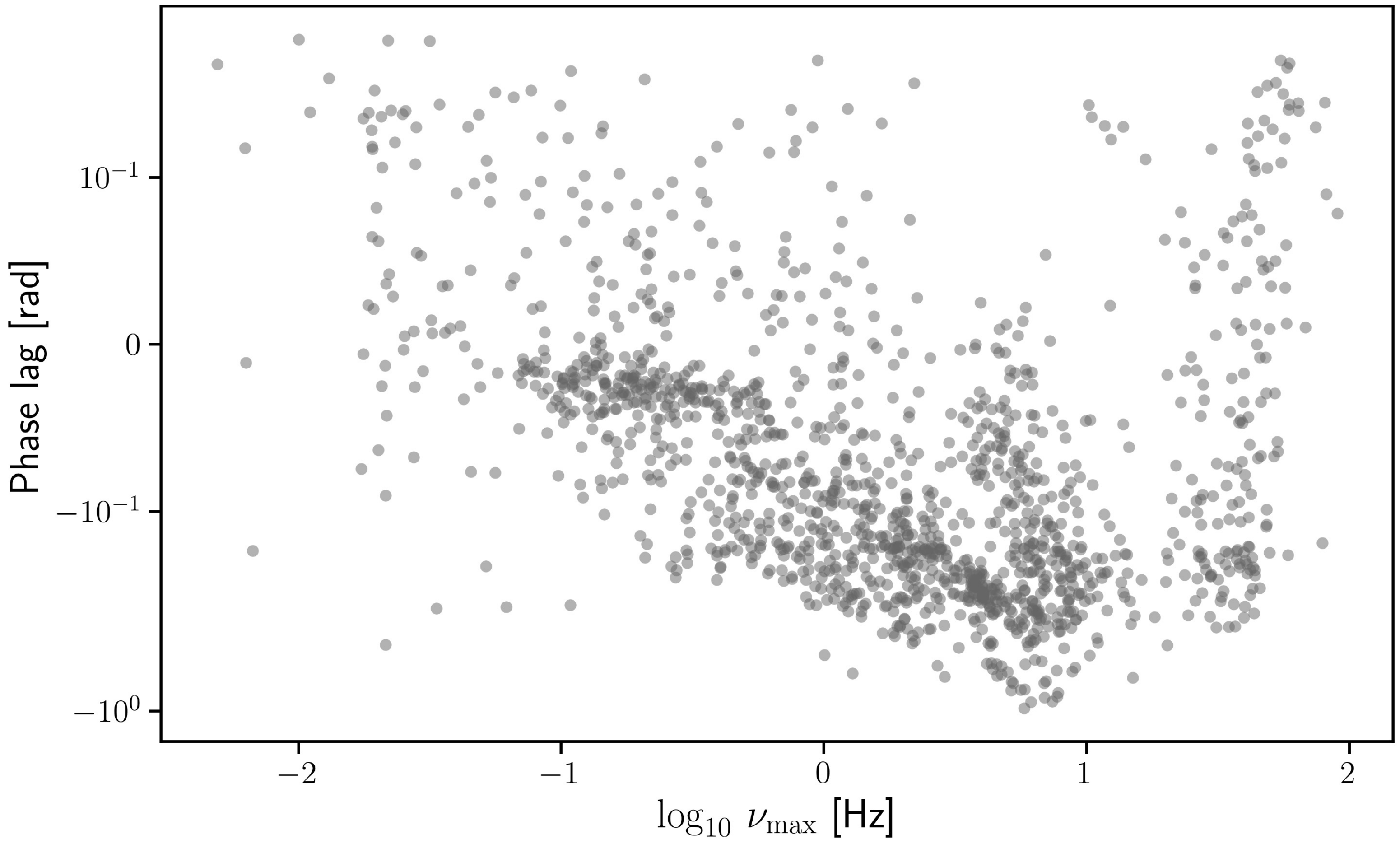


- Most observations need 3-5 Lorentzian components
  - Bayesian information criterion selected
- More complexity at softer spectral states
  - Variability becomes featureless

Step 2: Cluster the Components



- Focus on hard and intermediate states
- How do the variability components we observe group in feature space?

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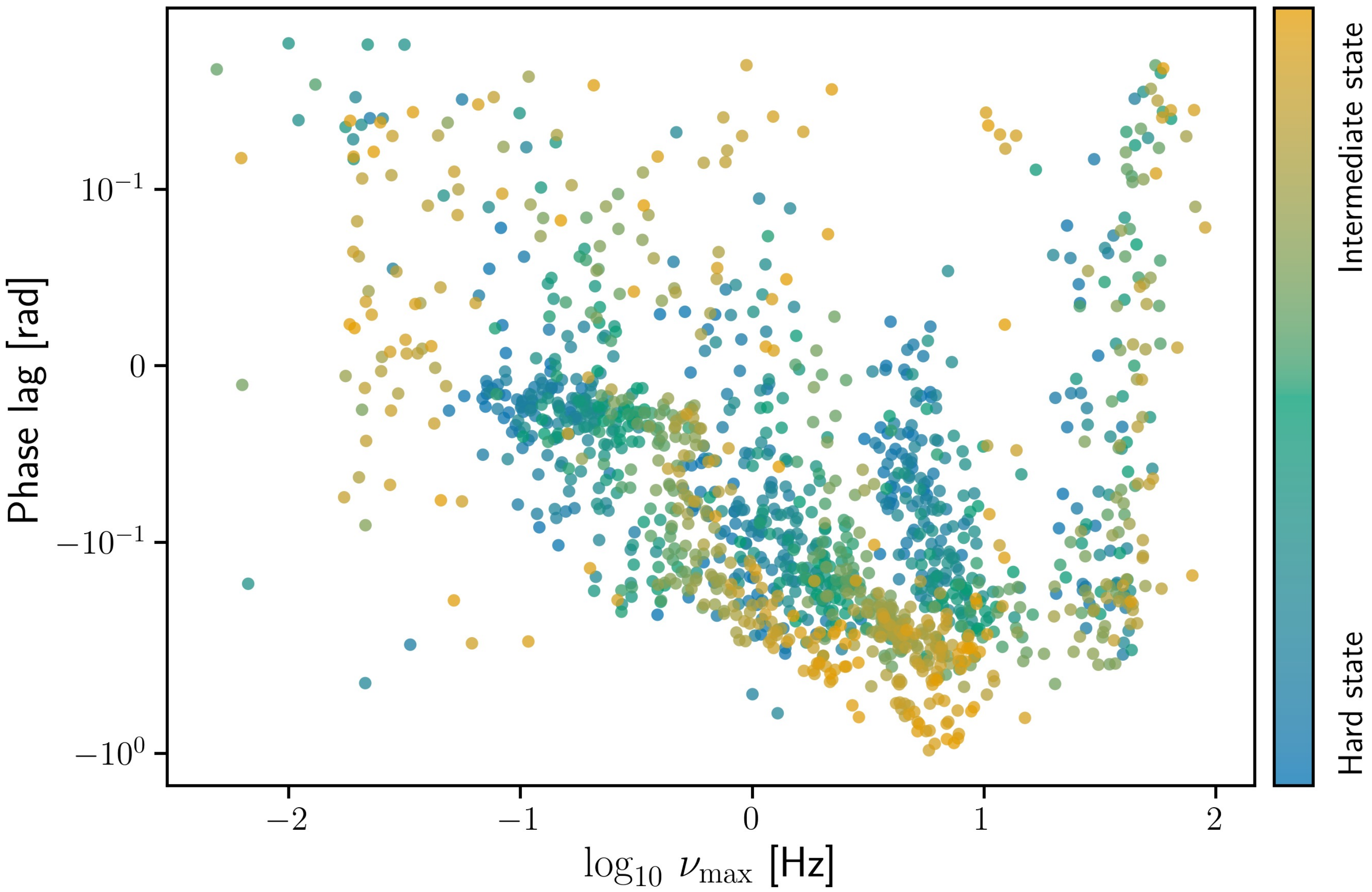

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- Observe groups evolve with spectral state

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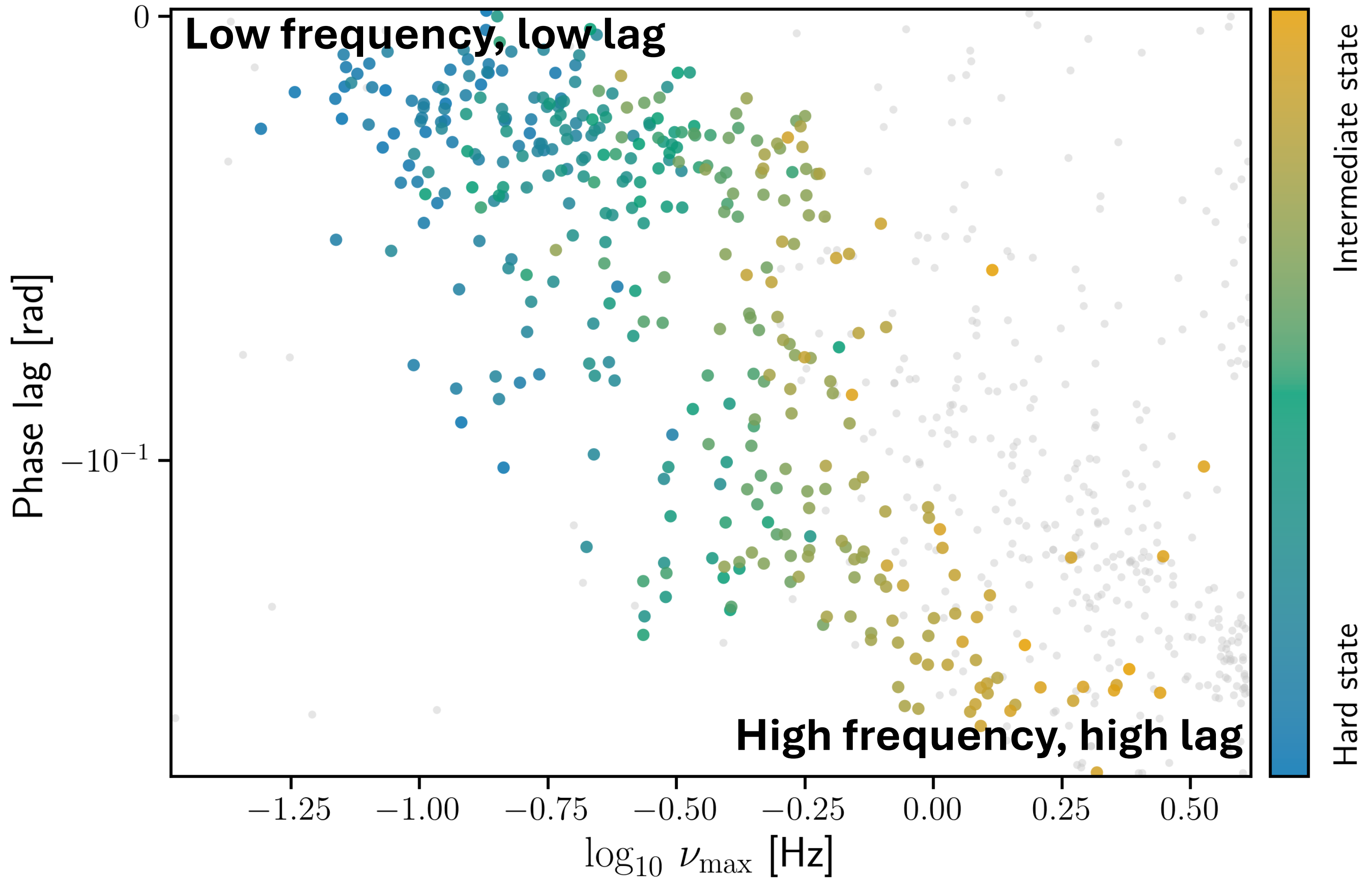

- Focus on hard and intermediate states
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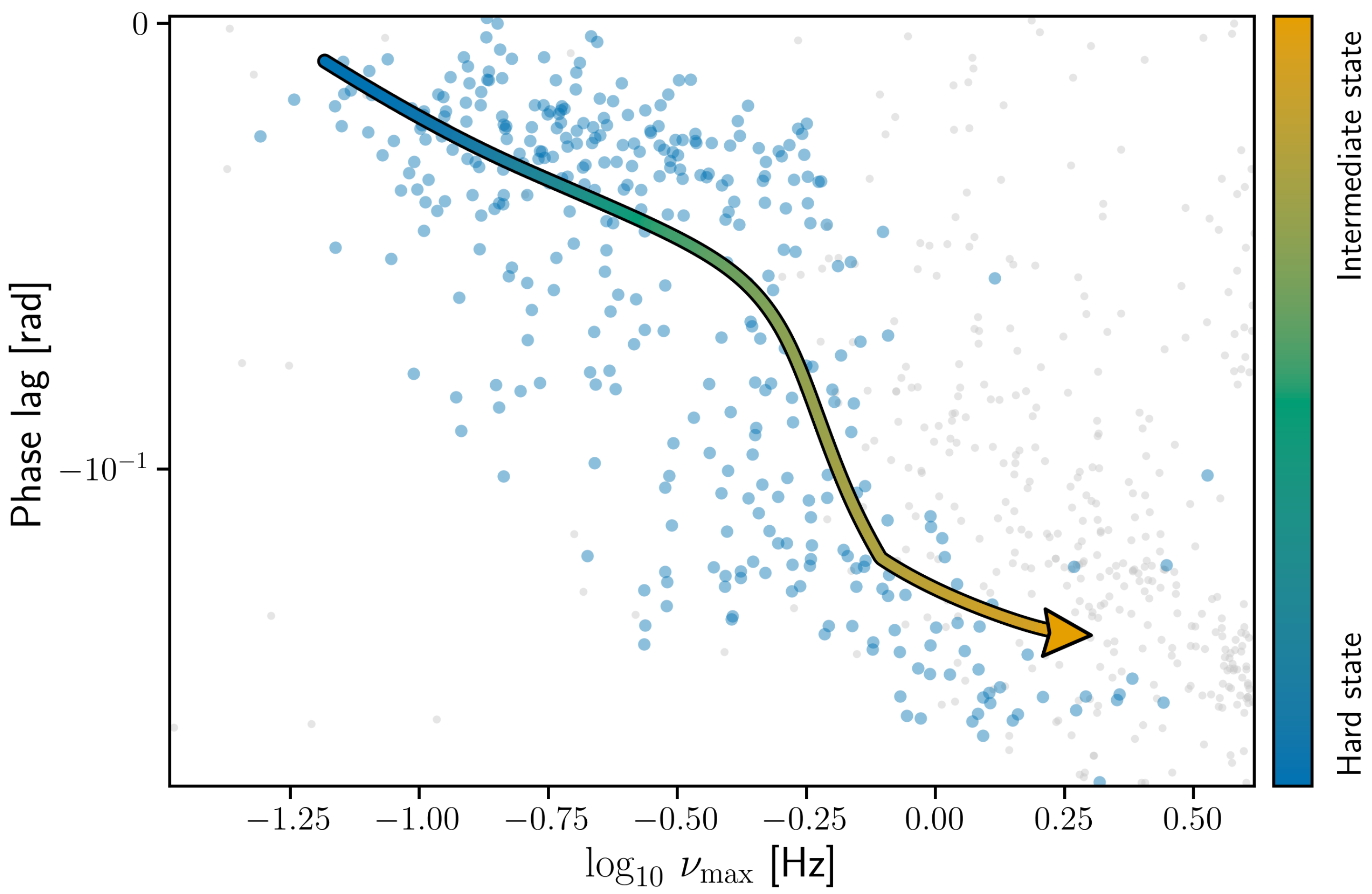

- Focus on hard and intermediate states
- How do the variability components we observe group in feature space?
- Observe groups evolve with spectral state
- Reveal changes to variability with spectral state
- Model these changes with smooth tracks
  - Moving deconvolved Gaussian-mixture means clusters

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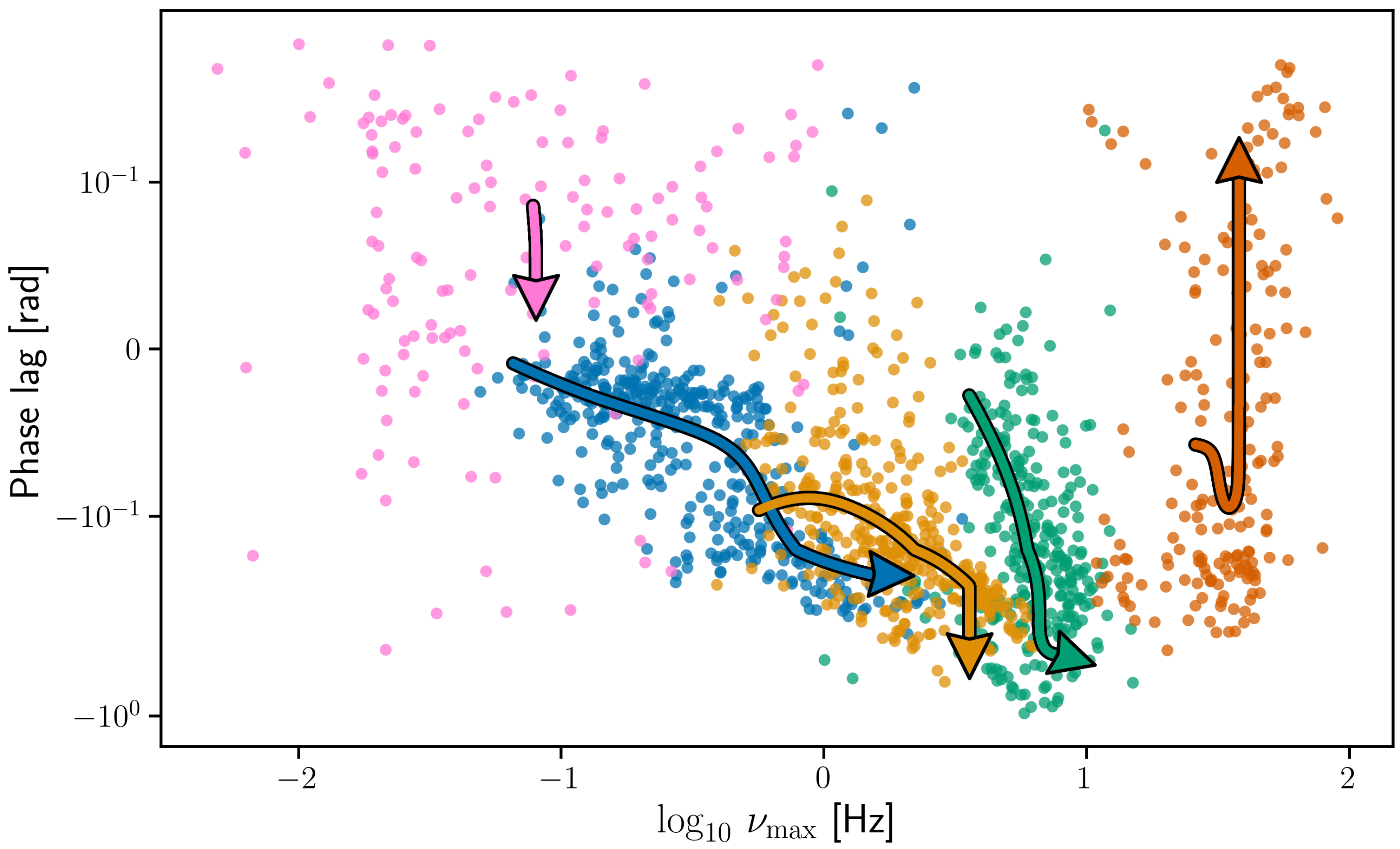

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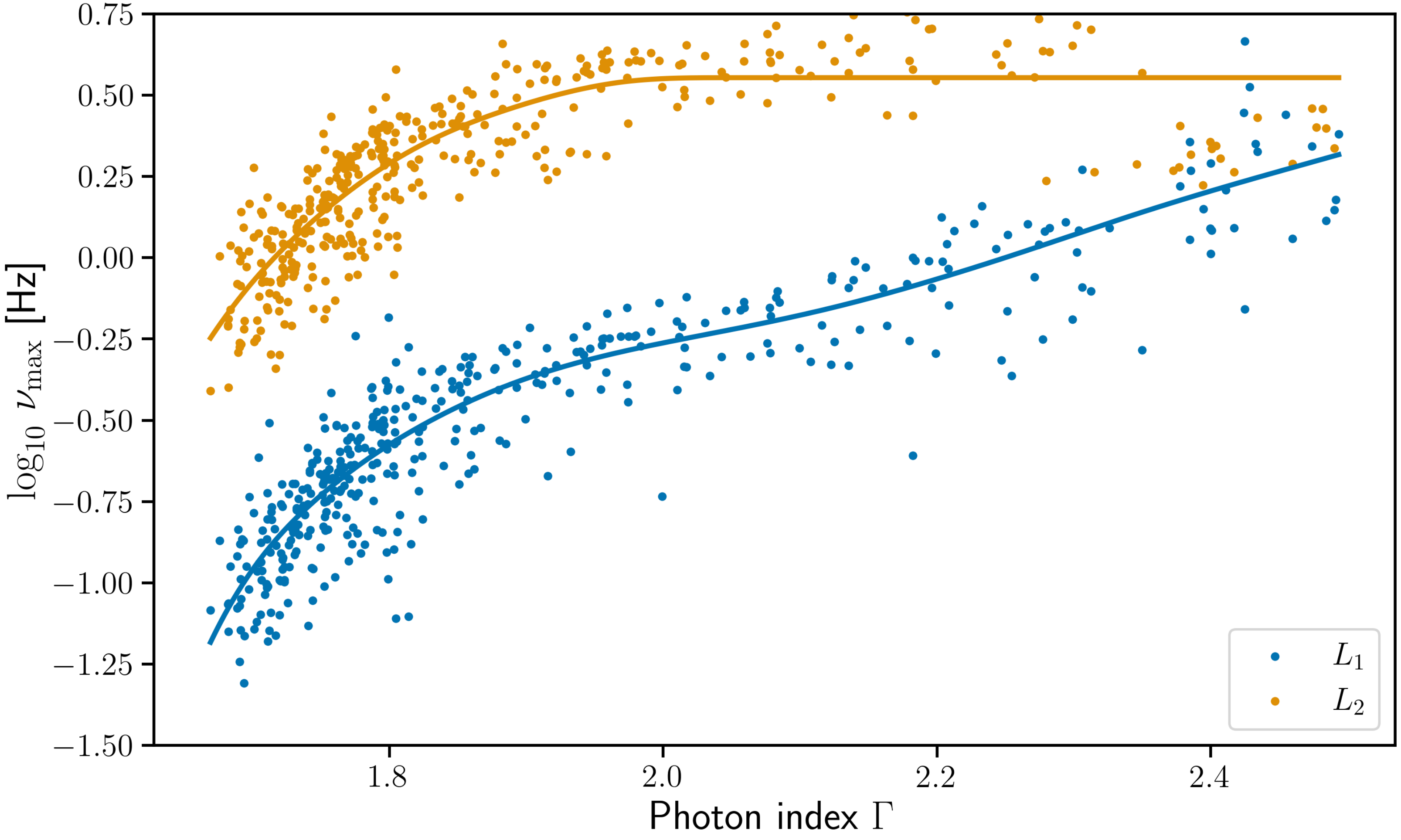
Two Primary Components Always Appear



- Components increase in frequency when softening

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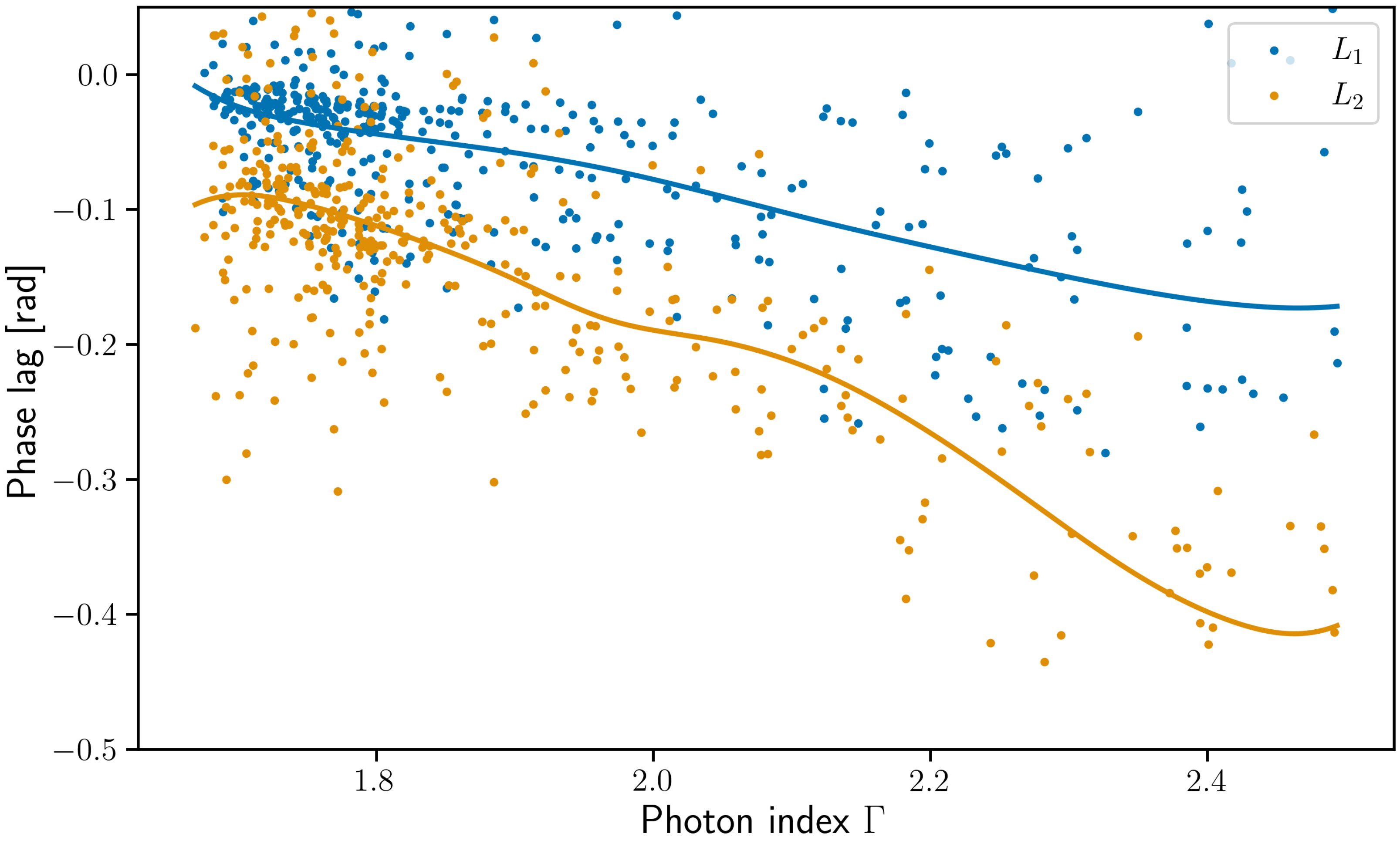
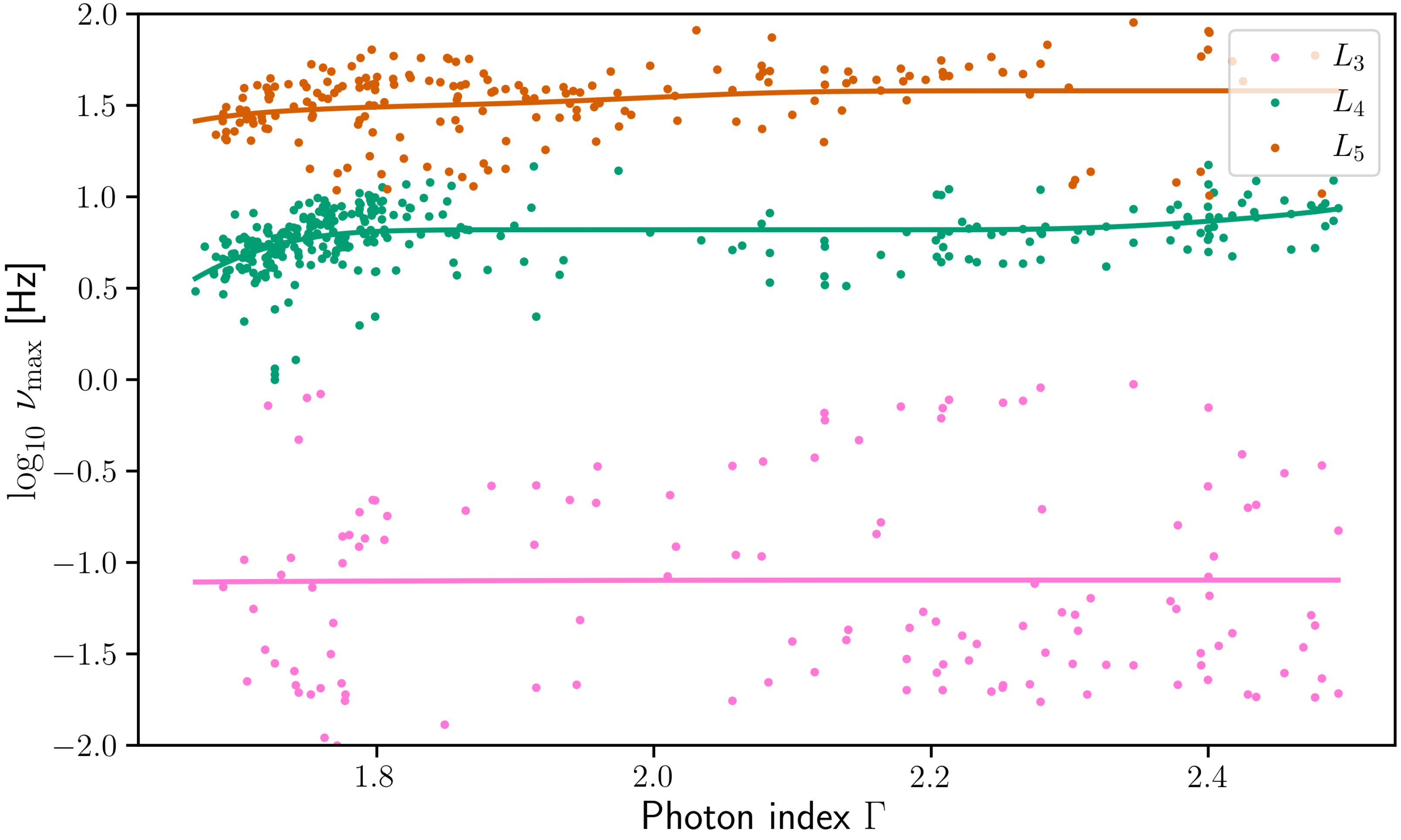


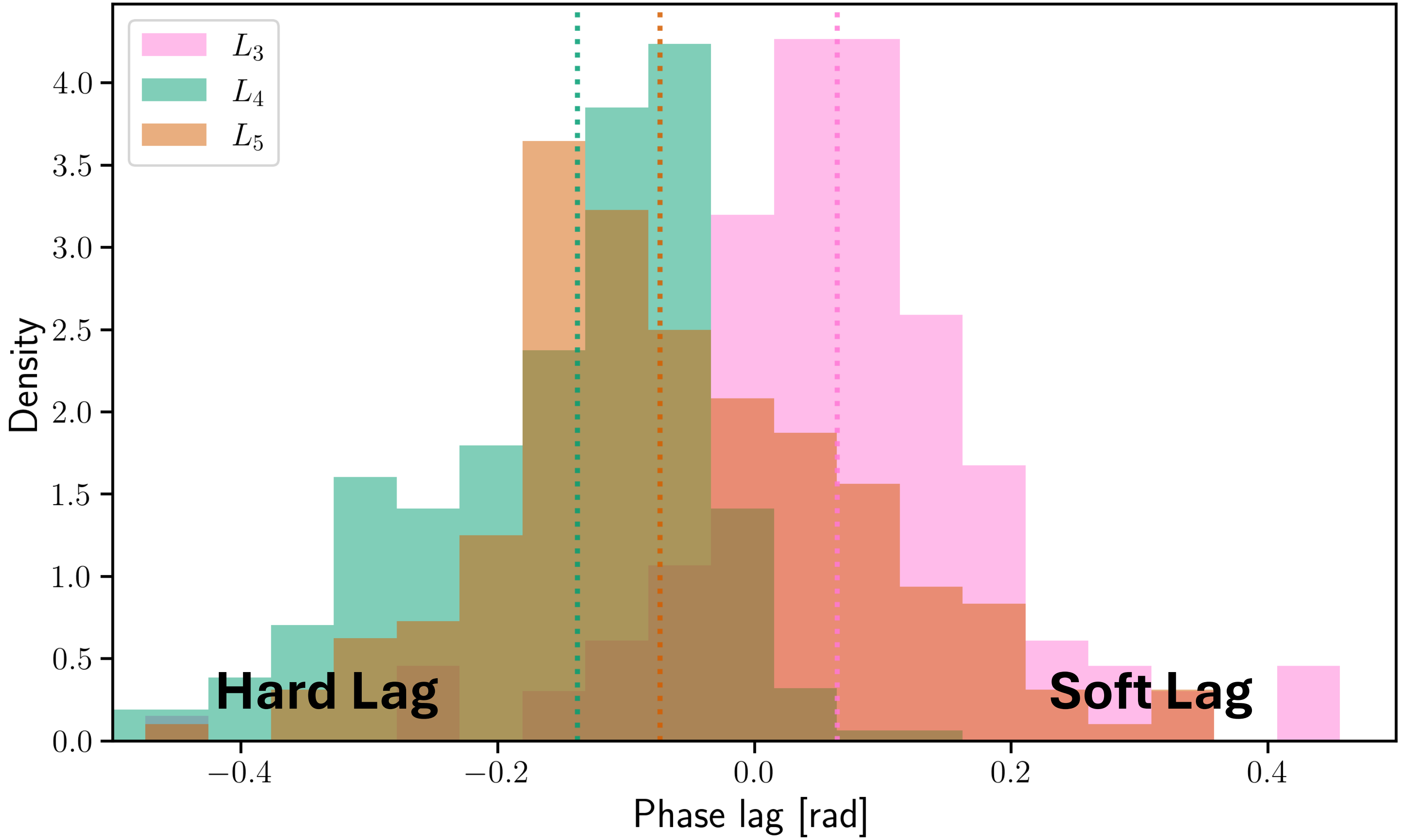
- Components increase in frequency when softening
- Hard lags get more extreme when softening

Low and High Frequency Are Sporadic



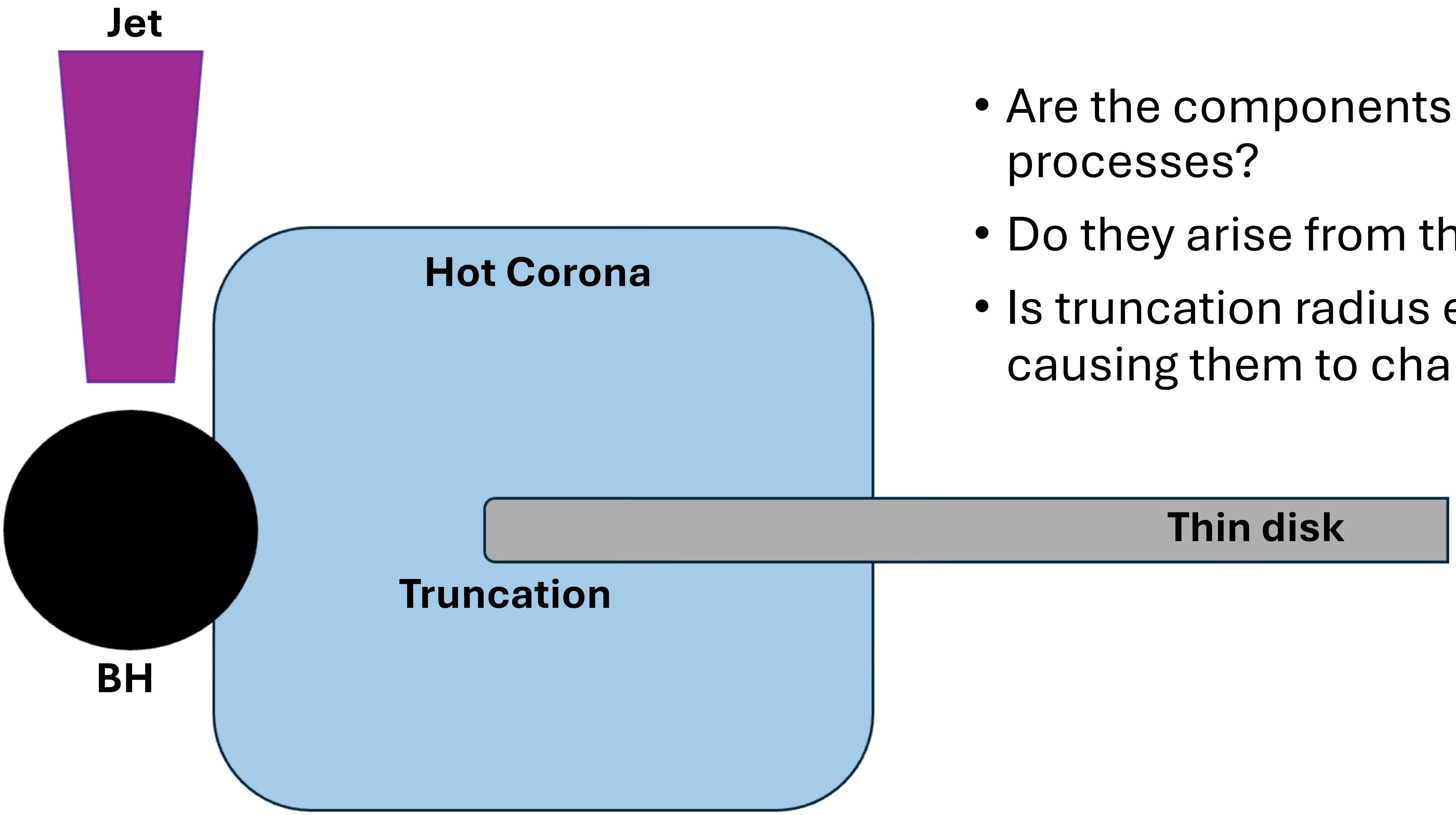
- Very high frequency
- High frequency
- Low frequency
- Flatter with spectral index
  - Unlike the main components

Low and High Frequency Are Sporadic



- Very high frequency
  - Hard lag
- High frequency
  - Hard lag
- Low frequency
  - Soft lag
- Flatter with spectral index

How do components map to physical structure?



- Are the components physical processes?
- Do they arise from the disk?
- Is truncation radius evolution causing them to change?

Summary

- Successfully model Cygnus X-1 RXTE campaign variability with sum of independent components
  - Model accurately describes intrinsic coherence and net phase lag
- Model is physics agnostic and components grouped objectively
- Identify 5 distinct classes of components which evolve smoothly with spectral state
  - Each component carries its own phase lag which add together