Ripples in a Stormy Sea

– Quasi-Periodic Oscillations in the Fermi Gamma-Ray Burst Monitor –

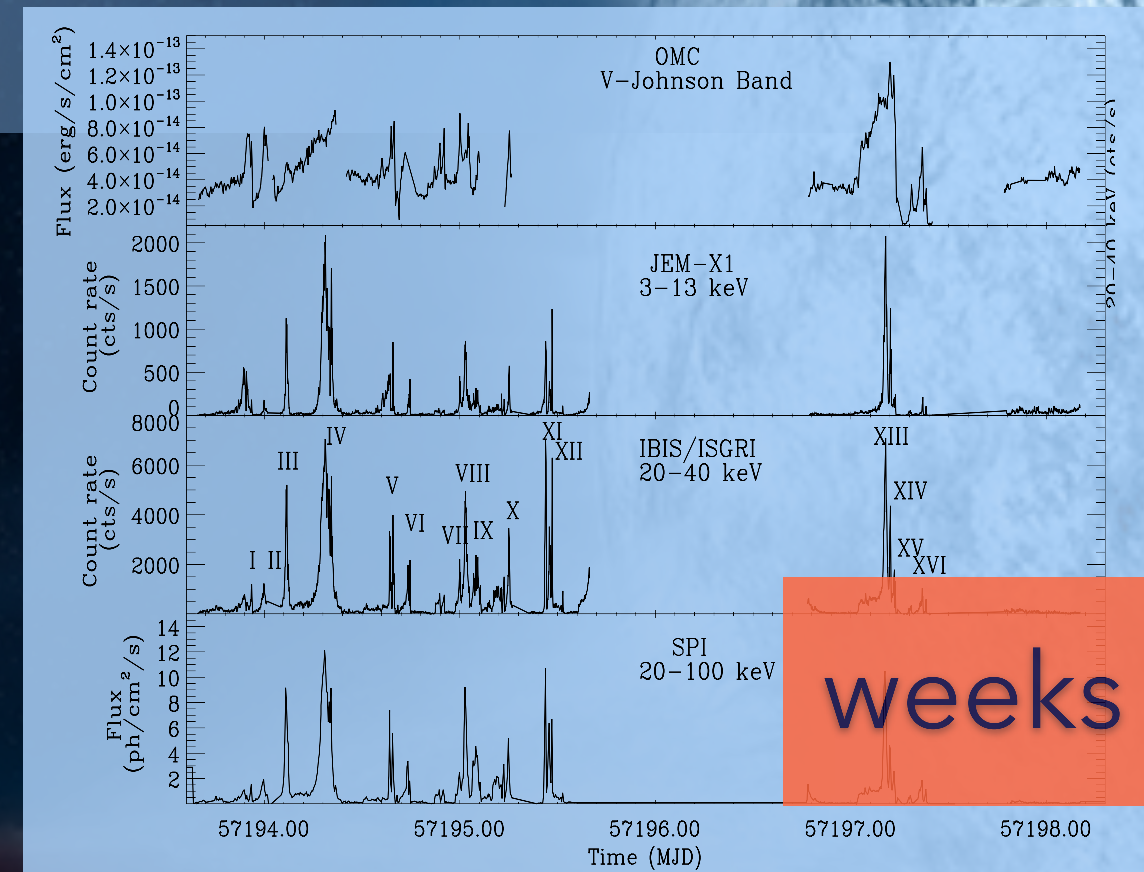
Daniela Huppenkothen

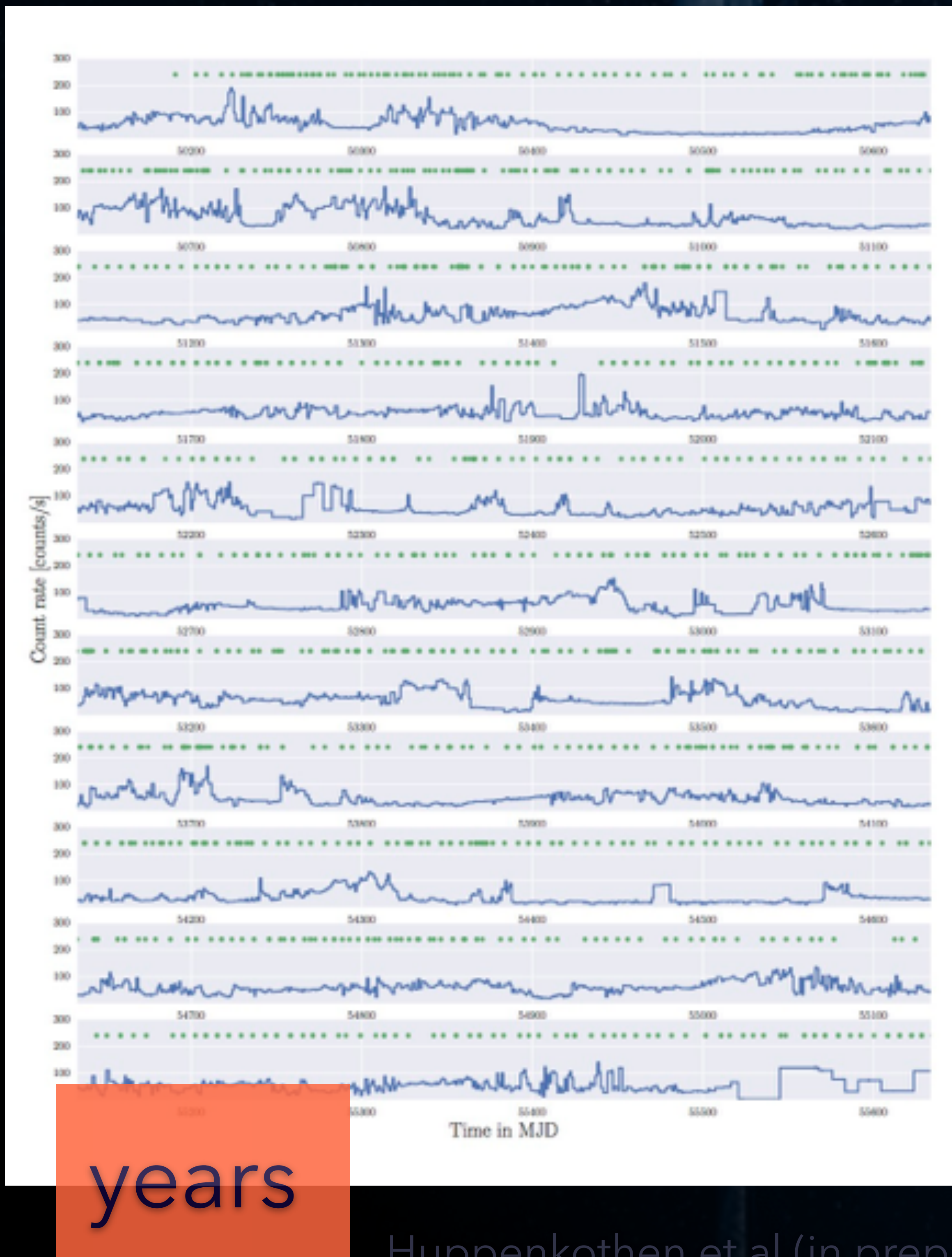
Moore-Sloan Data Science Fellow,
New York University

NYU Center for Data Science

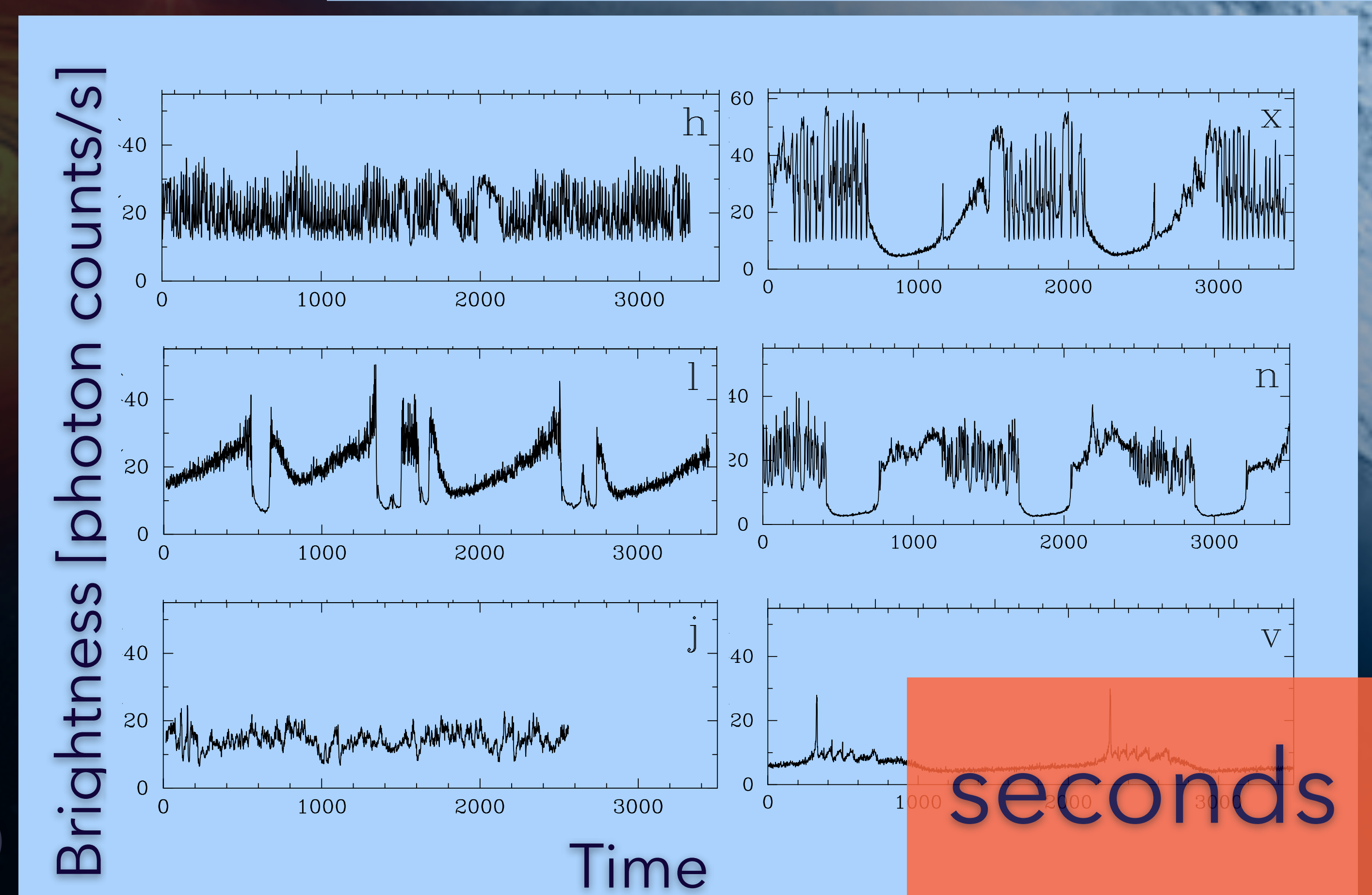
X-ray sources are variable

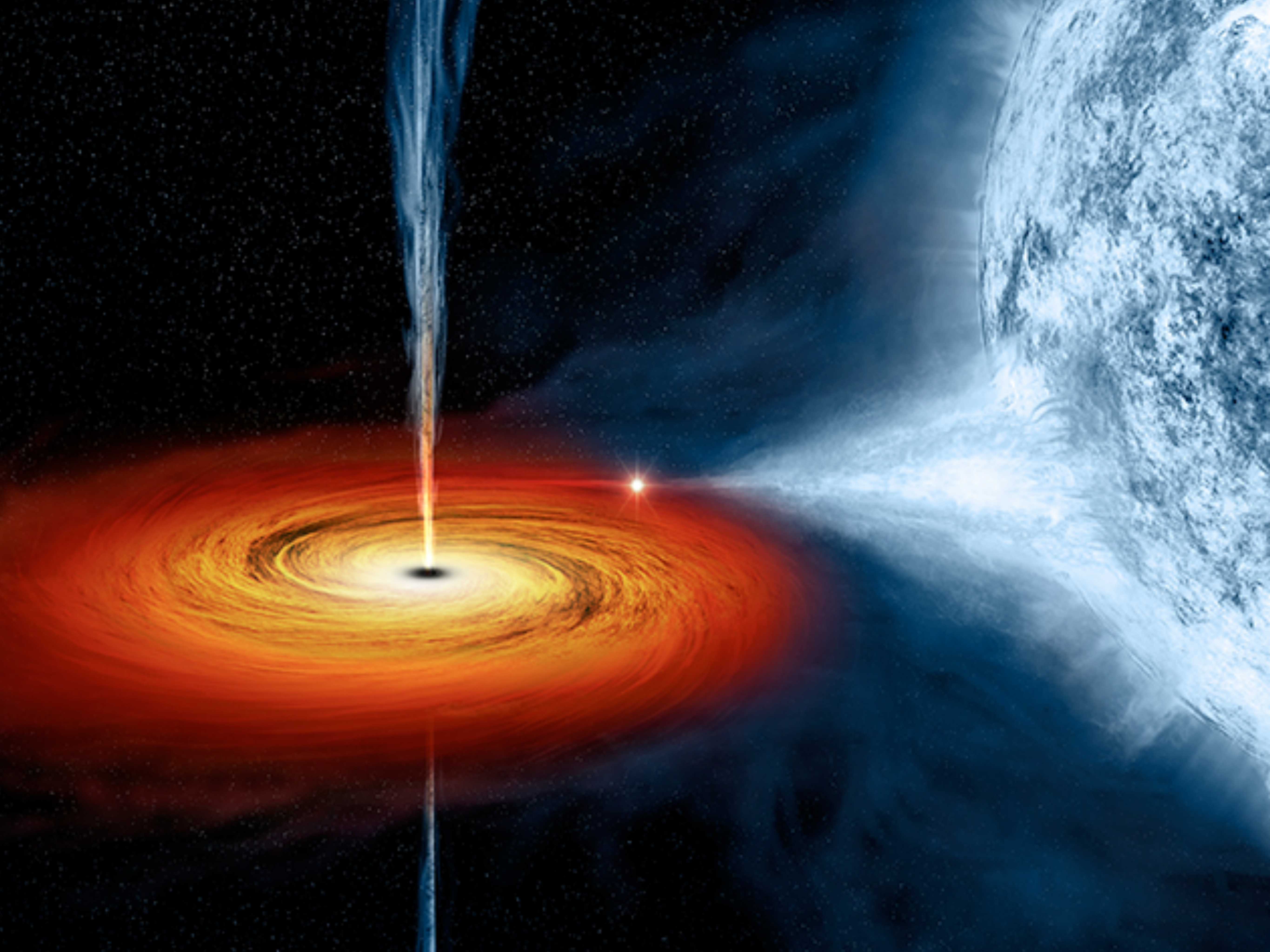
Rodriguez et al (2015)

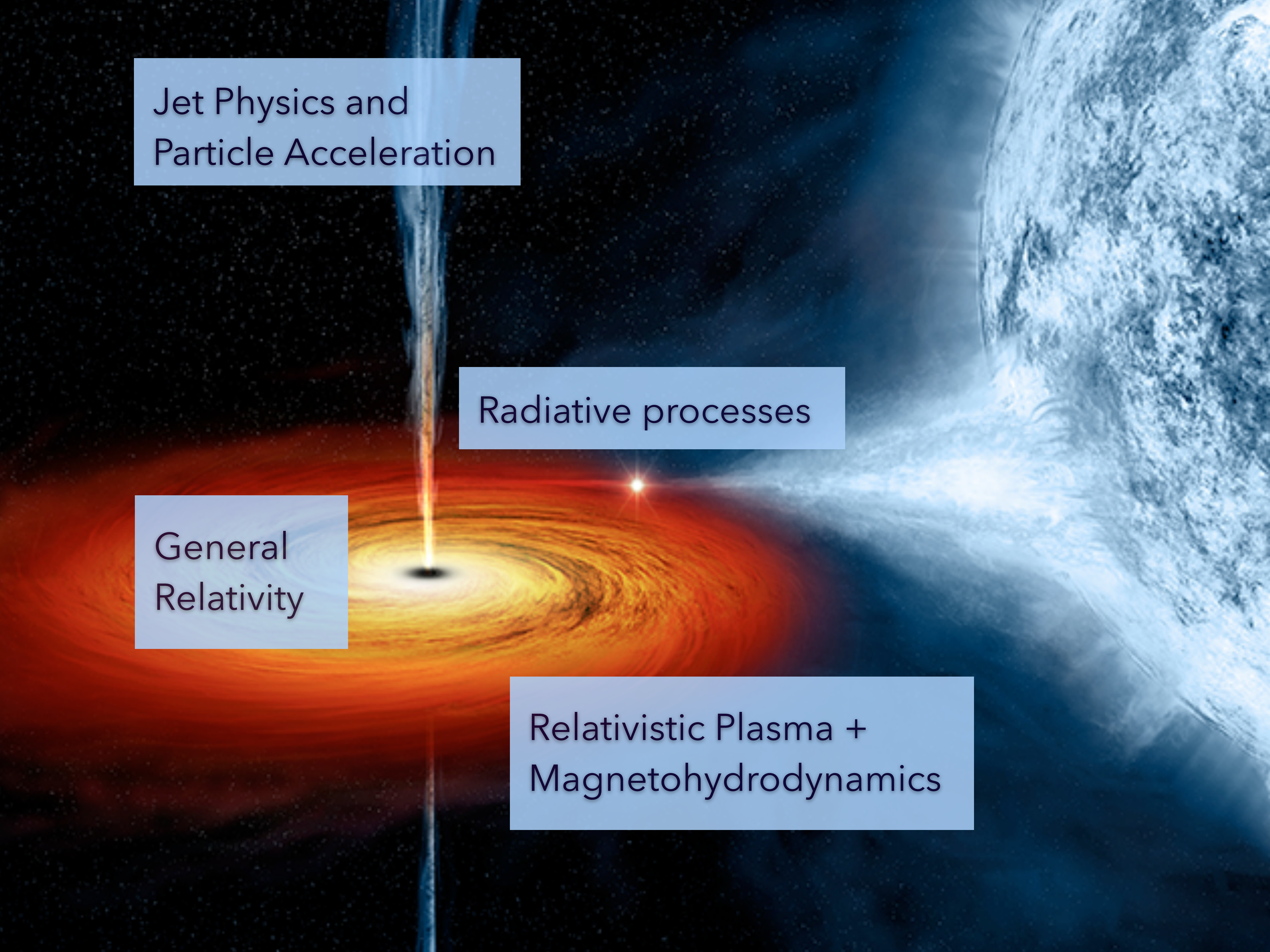


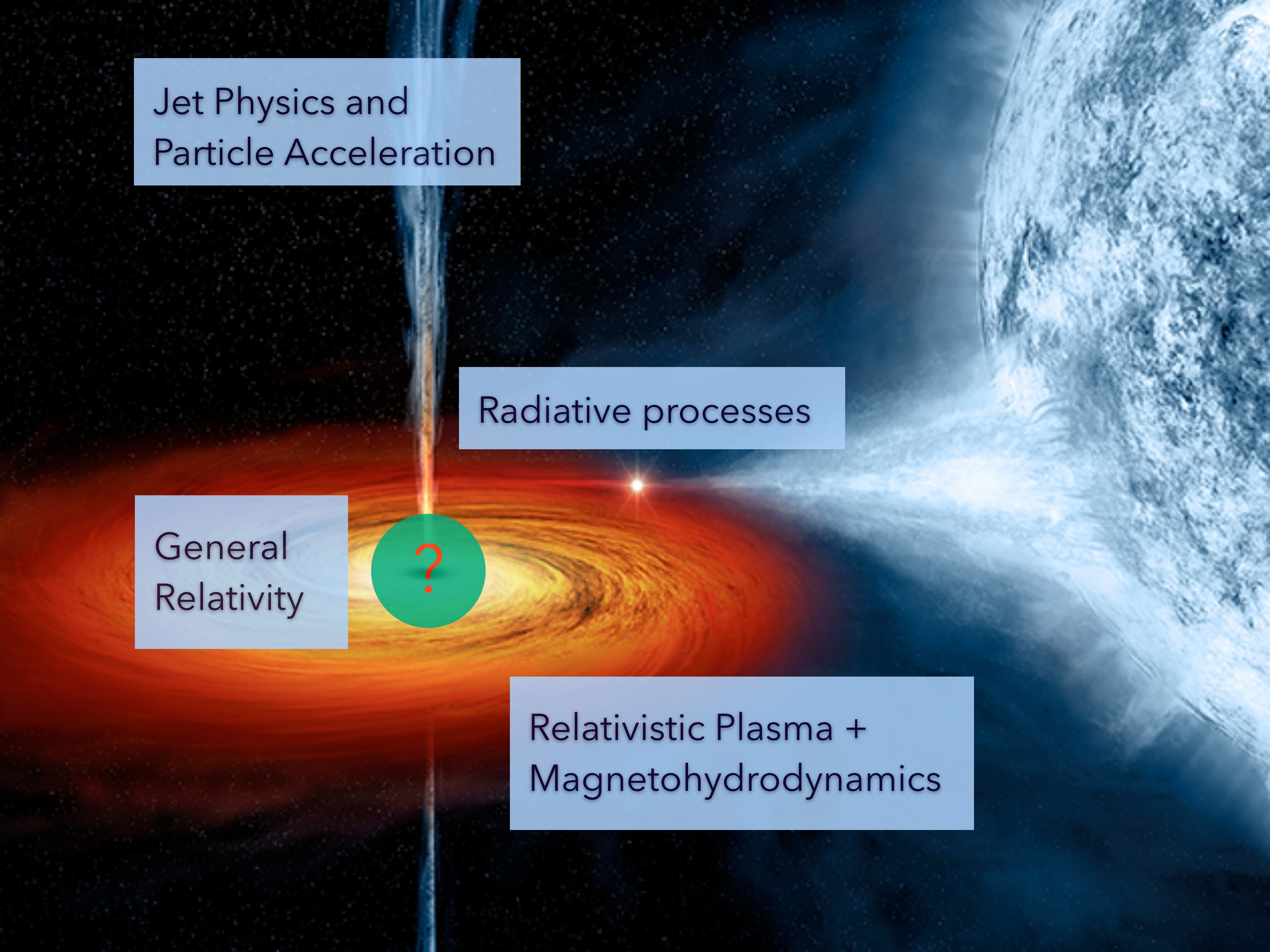


Huppenkothen et al (in prep)






Jet Physics and
Particle Acceleration
Radiative processes
General
Relativity
Relativistic Plasma +
Magnetohydrodynamics


Jet Physics and Particle Acceleration
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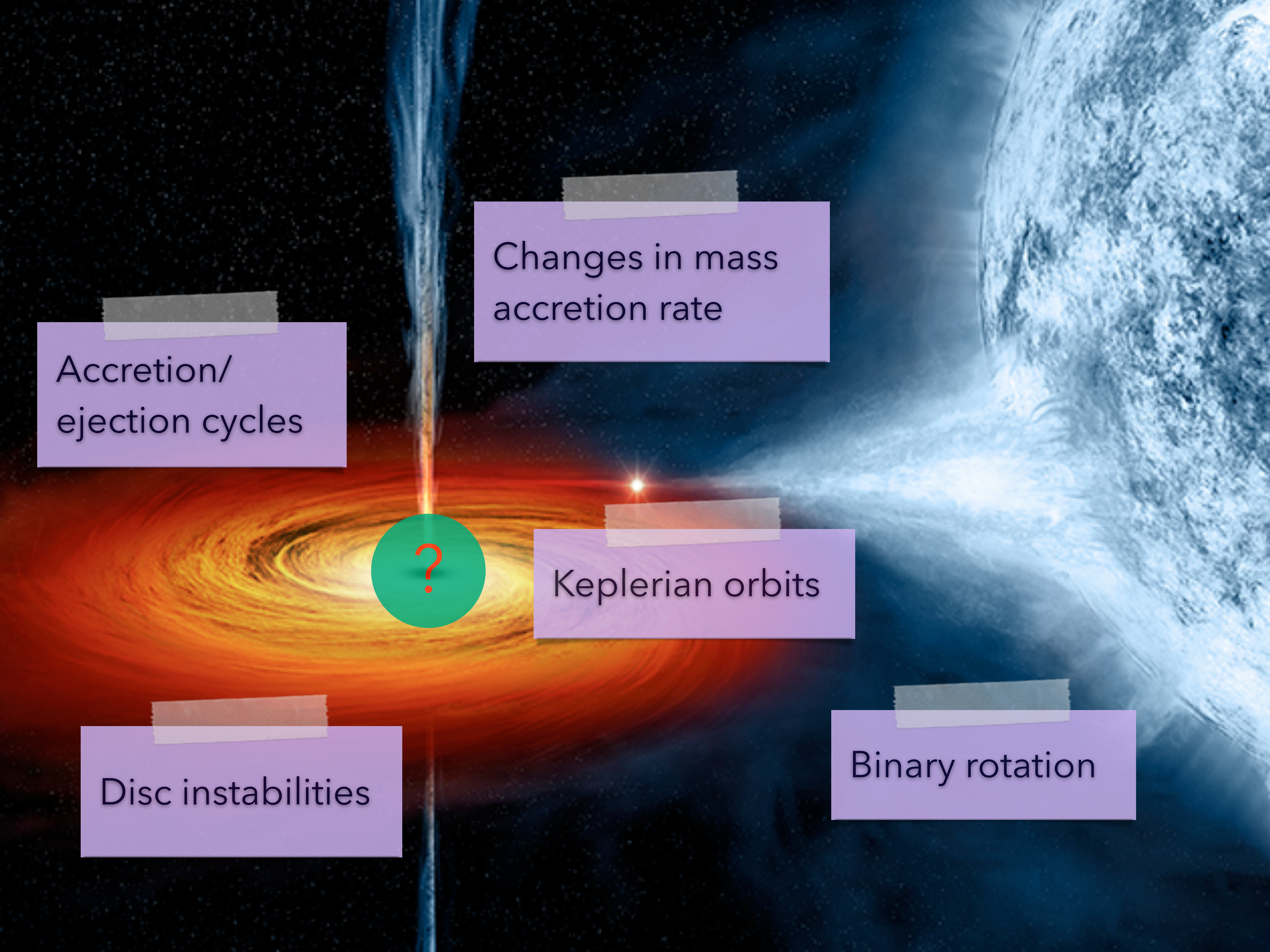
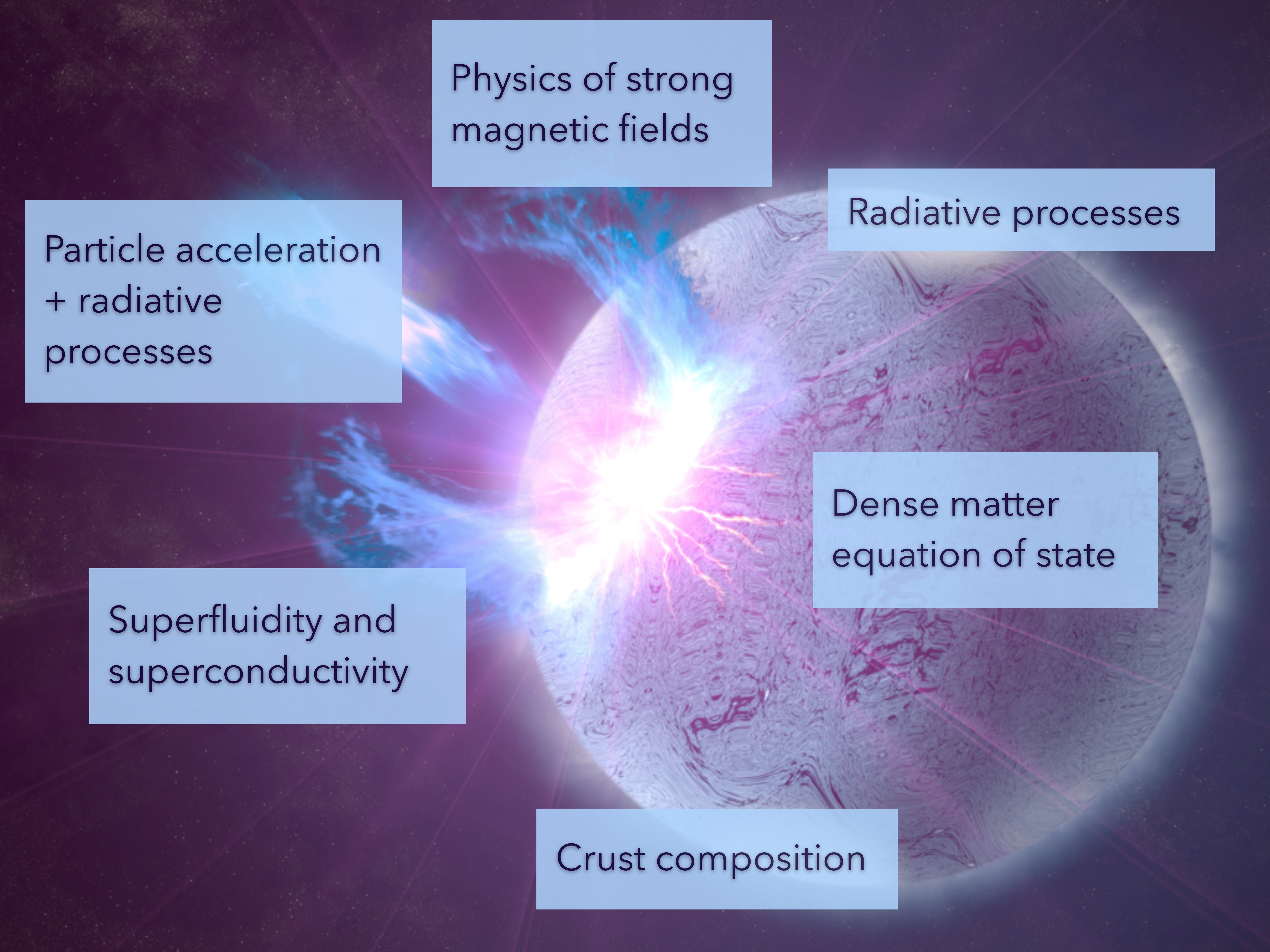
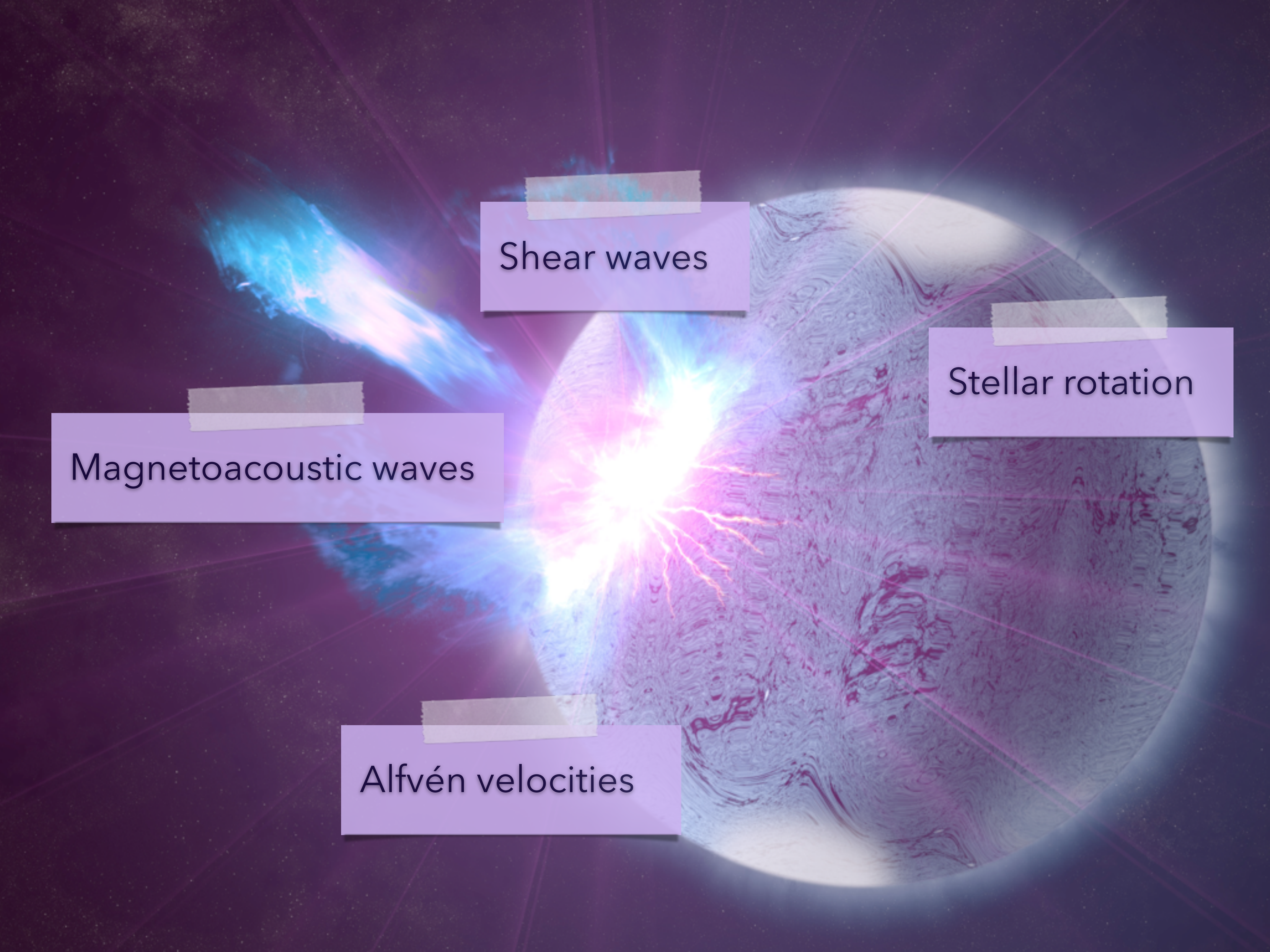

Changes in mass accretion rate
Accretion/ ejection cycles
?
Keplerian orbits
Disc instabilities
Binary rotation

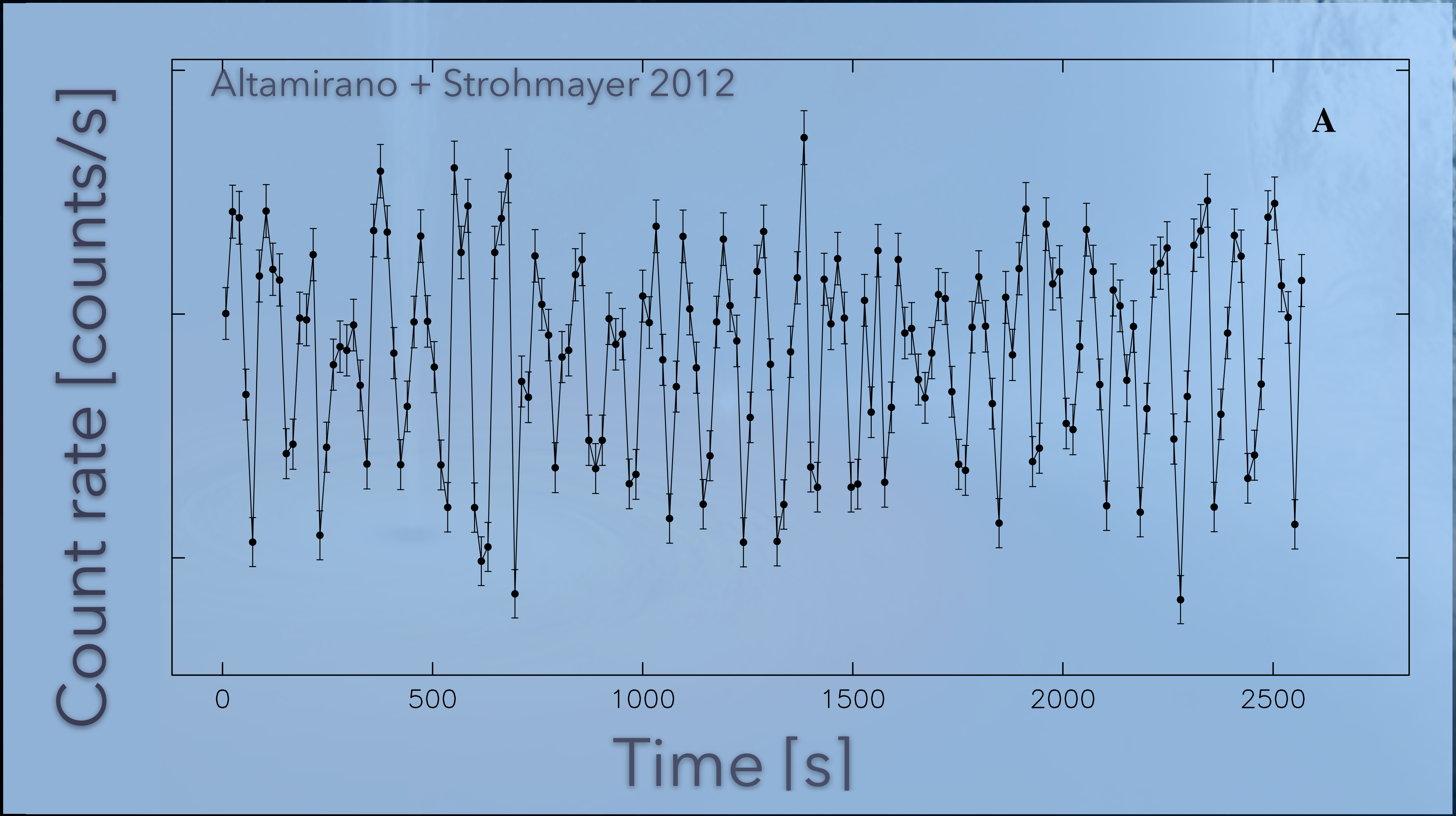

Physics of strong magnetic fields
Radiative processes
Particle acceleration + radiative processes
Dense matter equation of state
Superfluidity and superconductivity
Crust composition


Shear waves
Stellar rotation
Magnetoacoustic waves
Alfvén velocities

A Short QPO* Primer

*quasi-periodic oscillation

H1743-322



Task: find characteristic time scales in this light curve!

A Short QPO* Primer

*quasi-periodic oscillation

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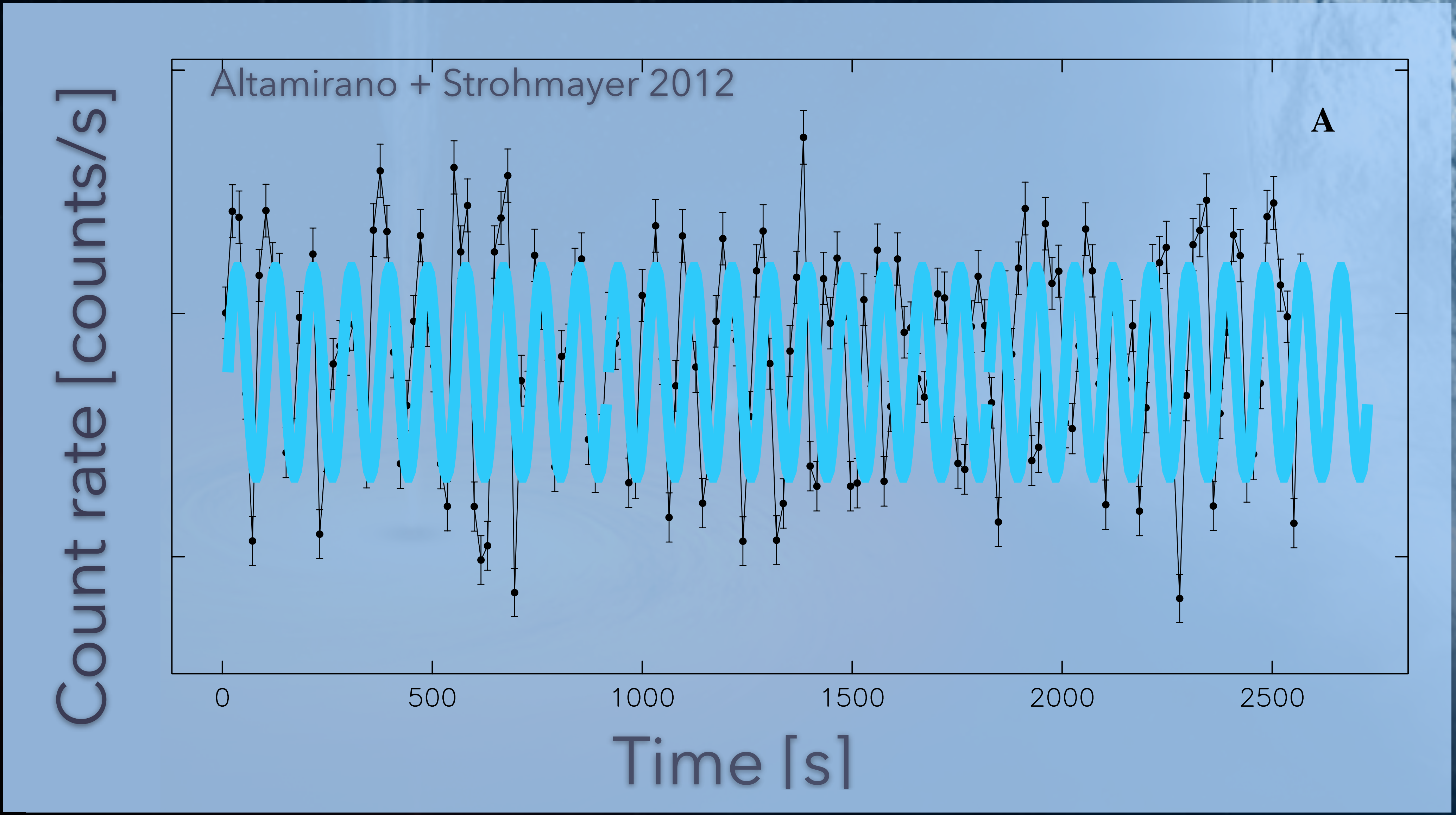


Task: find characteristic time scales in this light curve!

The human brain is awesome
at pattern recognition

*see: pareidolia

Corollary: the human brain is prone to overfitting* + see spurious patterns

(awesome for survival,
less awesome for science)

*see: pareidolia

uman

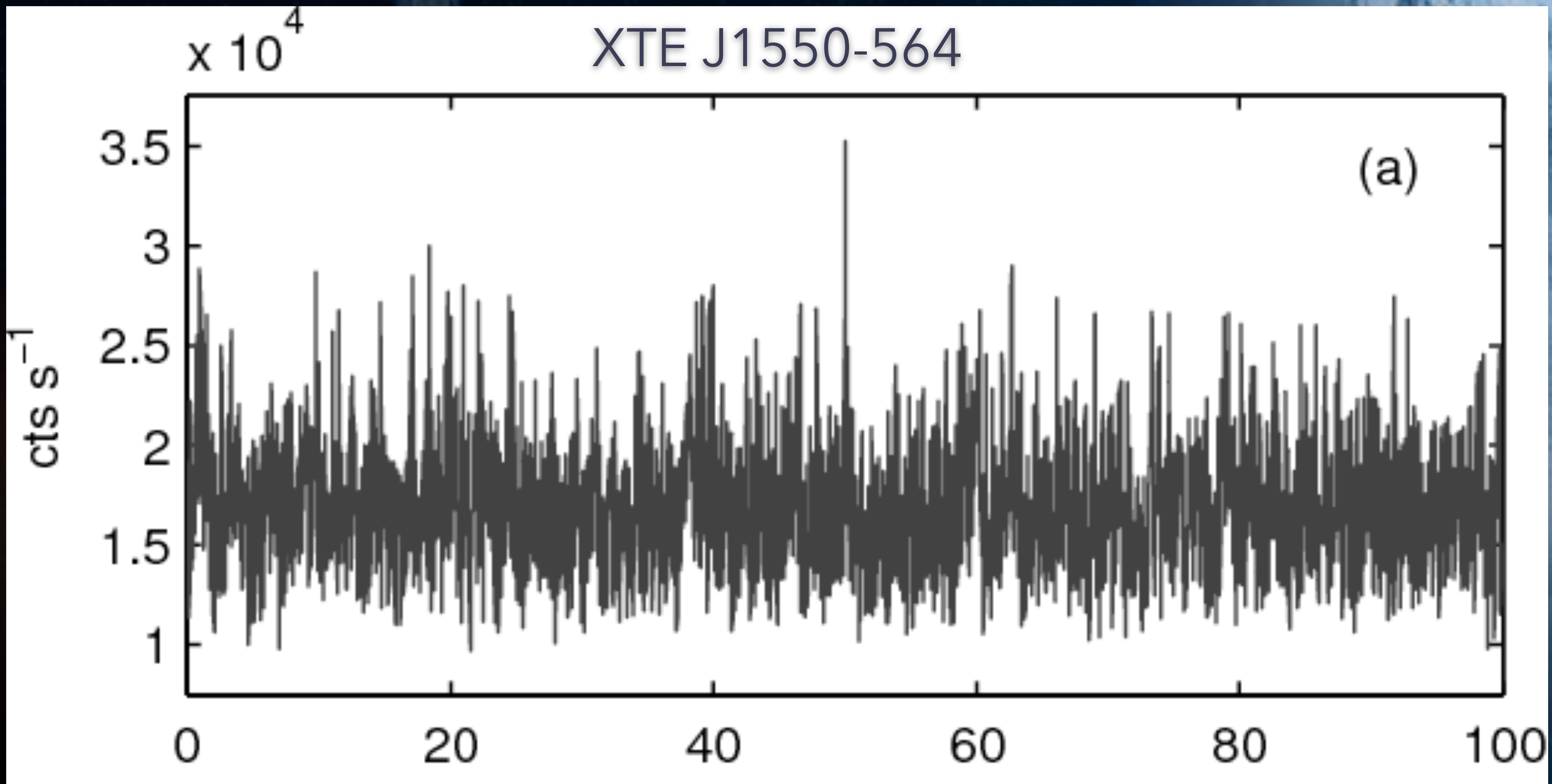
ee sp

By Viking 1, NASA [Public domain], via Wikimedia Commons

(awesome for survival,
less awesome for science)

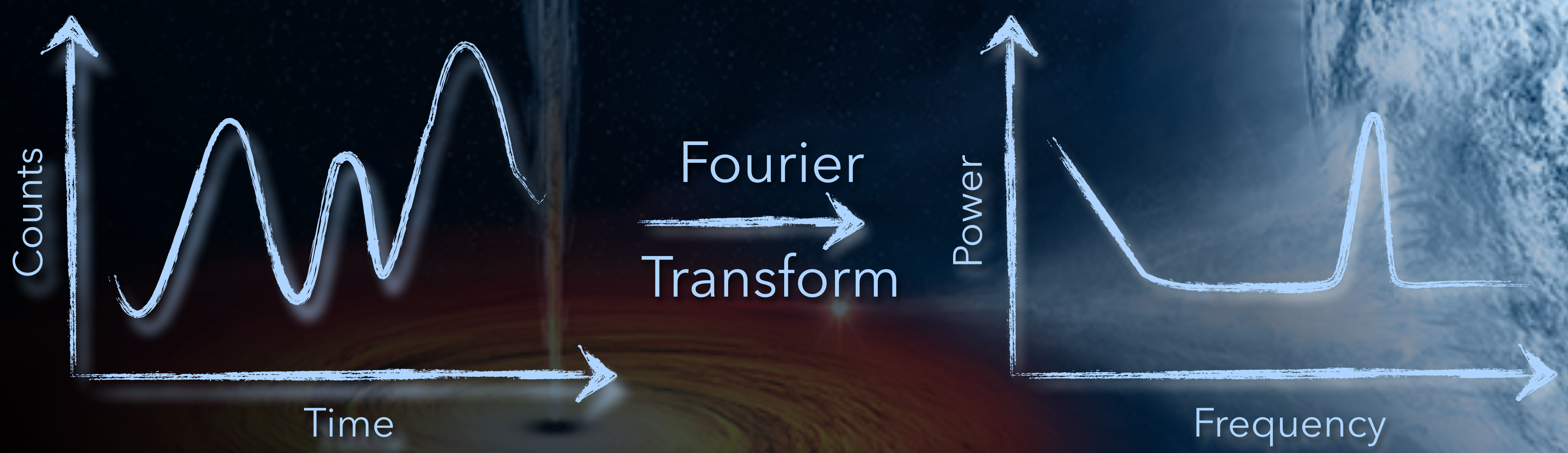
QPO*s are not always visible!

*quasi-periodic oscillation



Lachowicz+Done, 2010

The Fourier Transform is Your Friend



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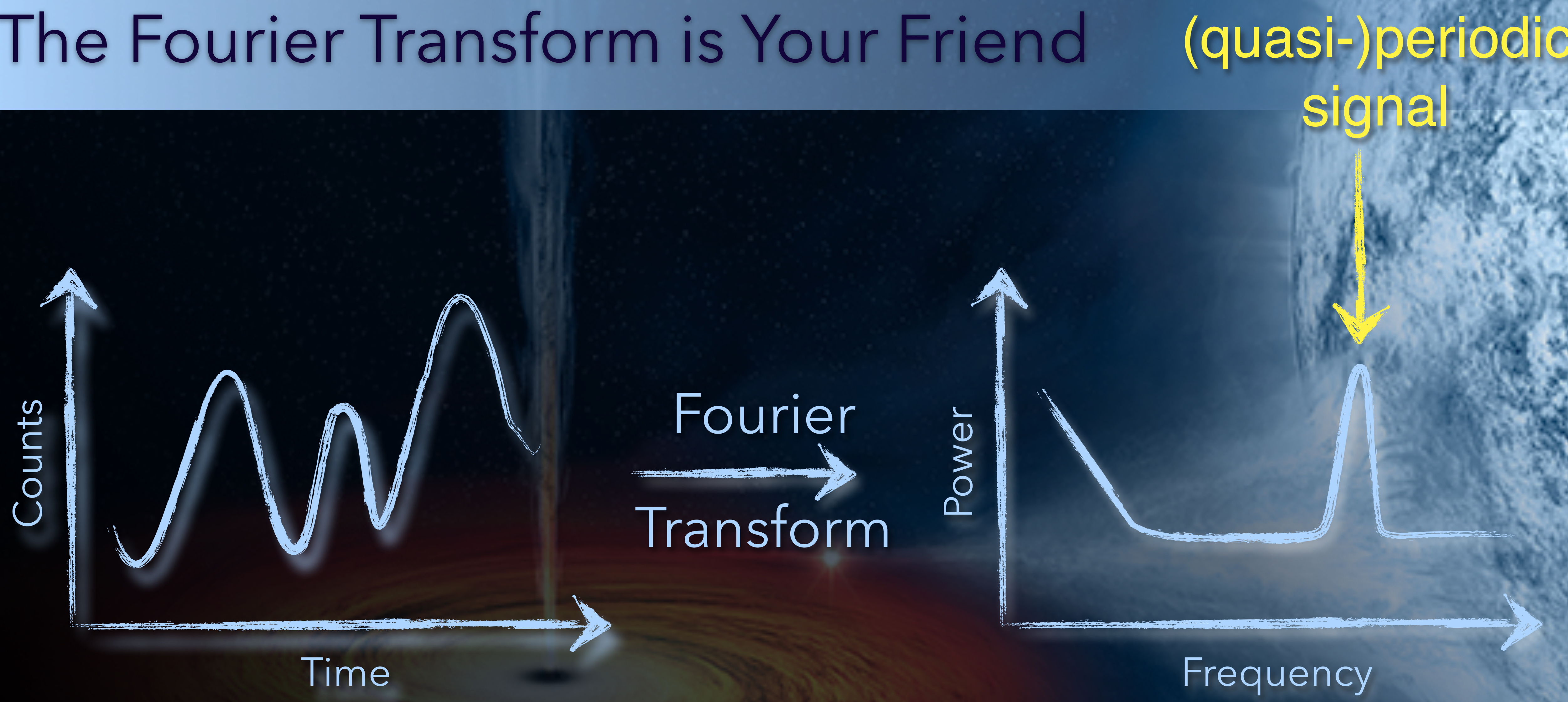

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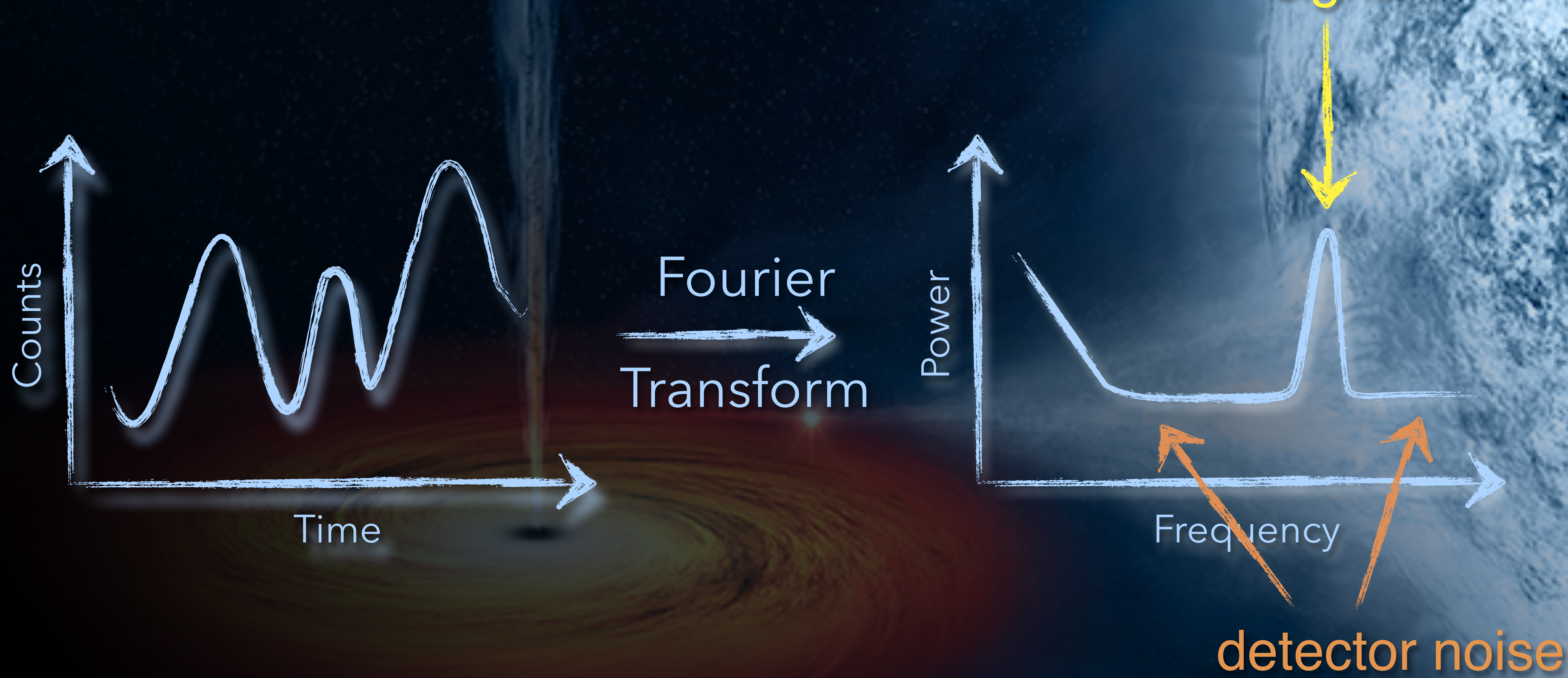

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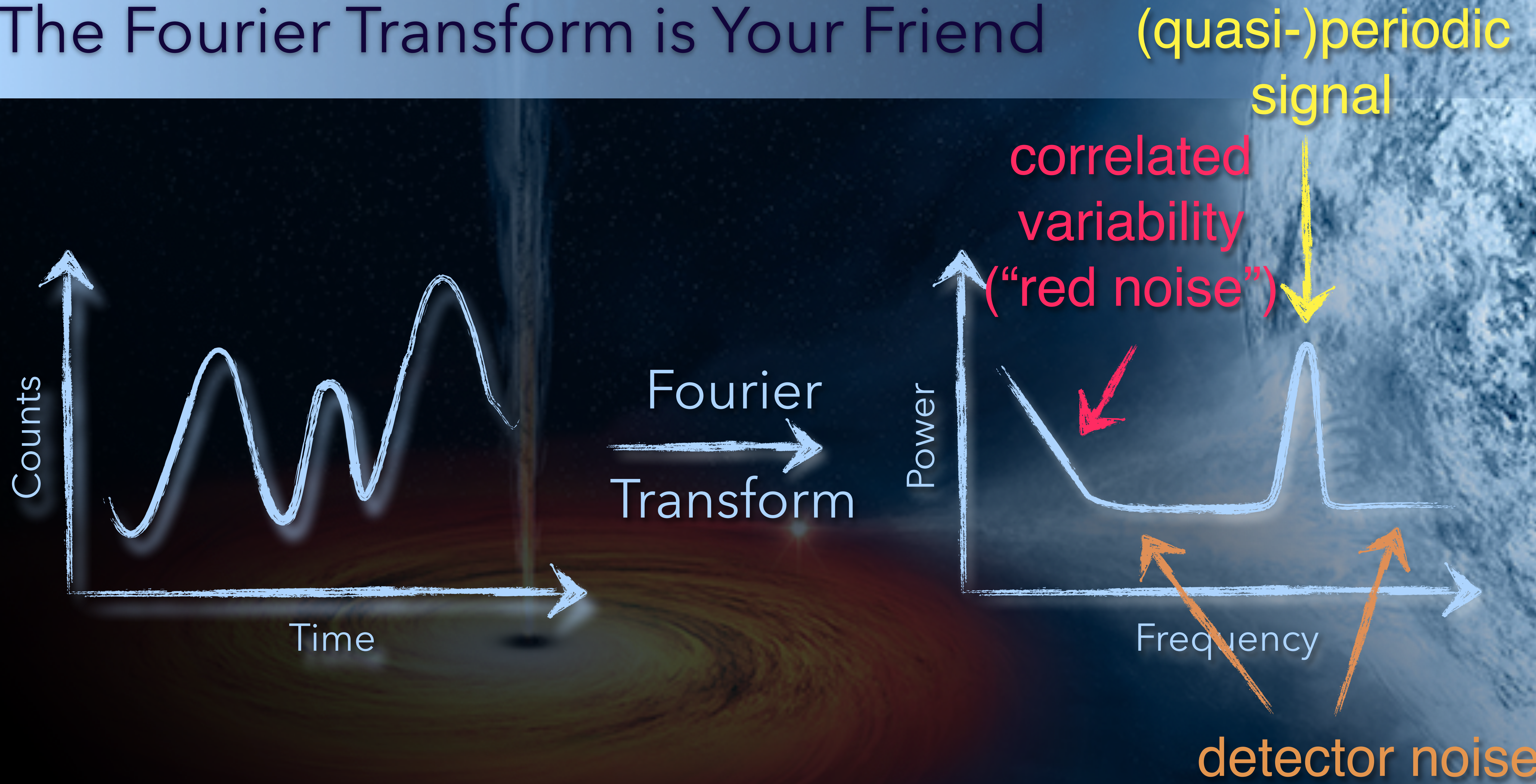

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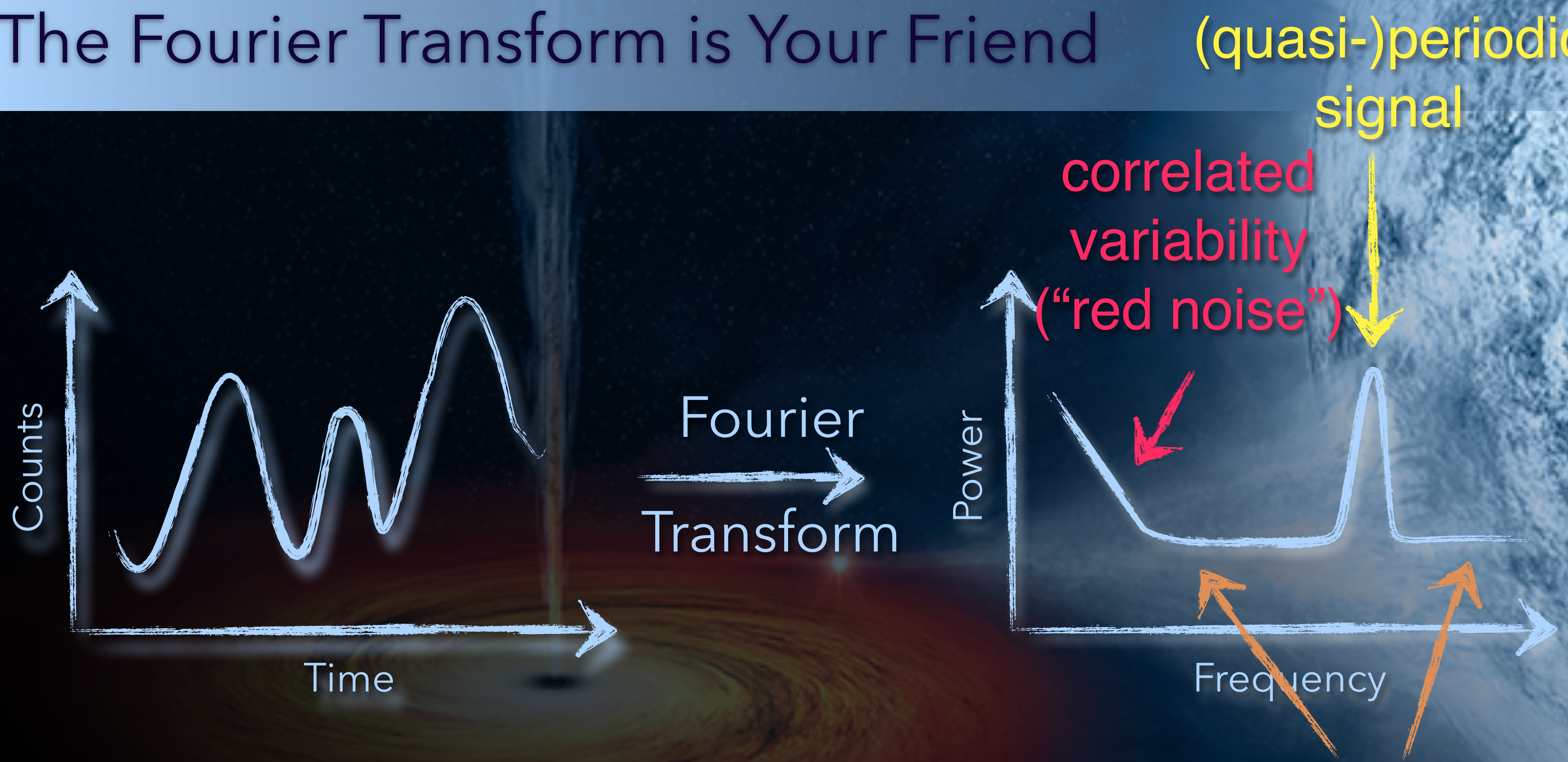
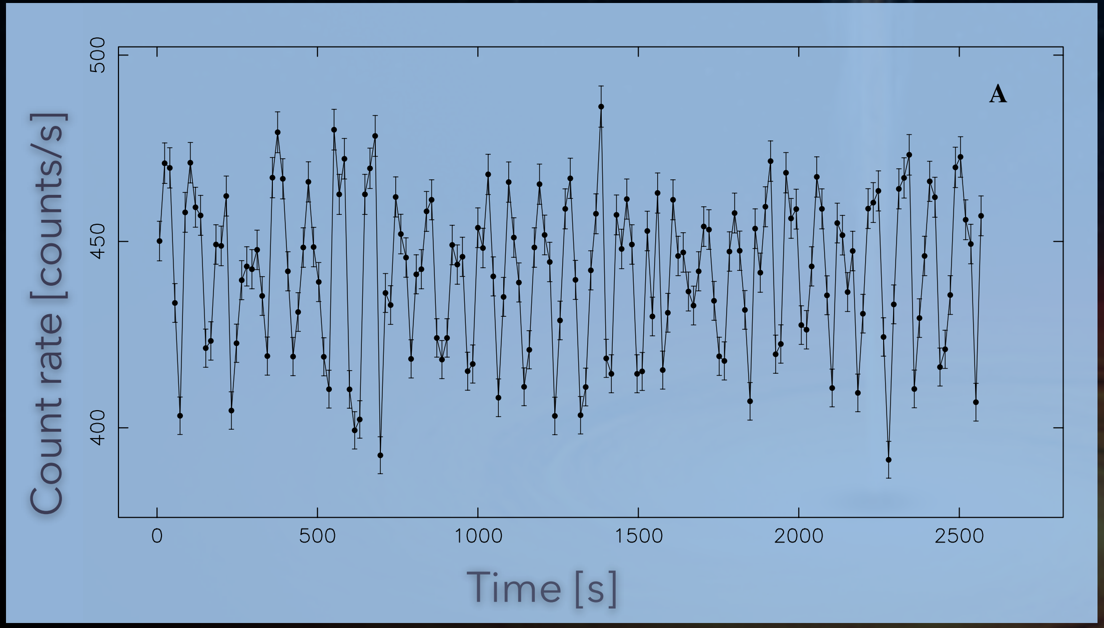


Stationarity

Evenly Sampled Time Series

An Example: X-ray Binaries

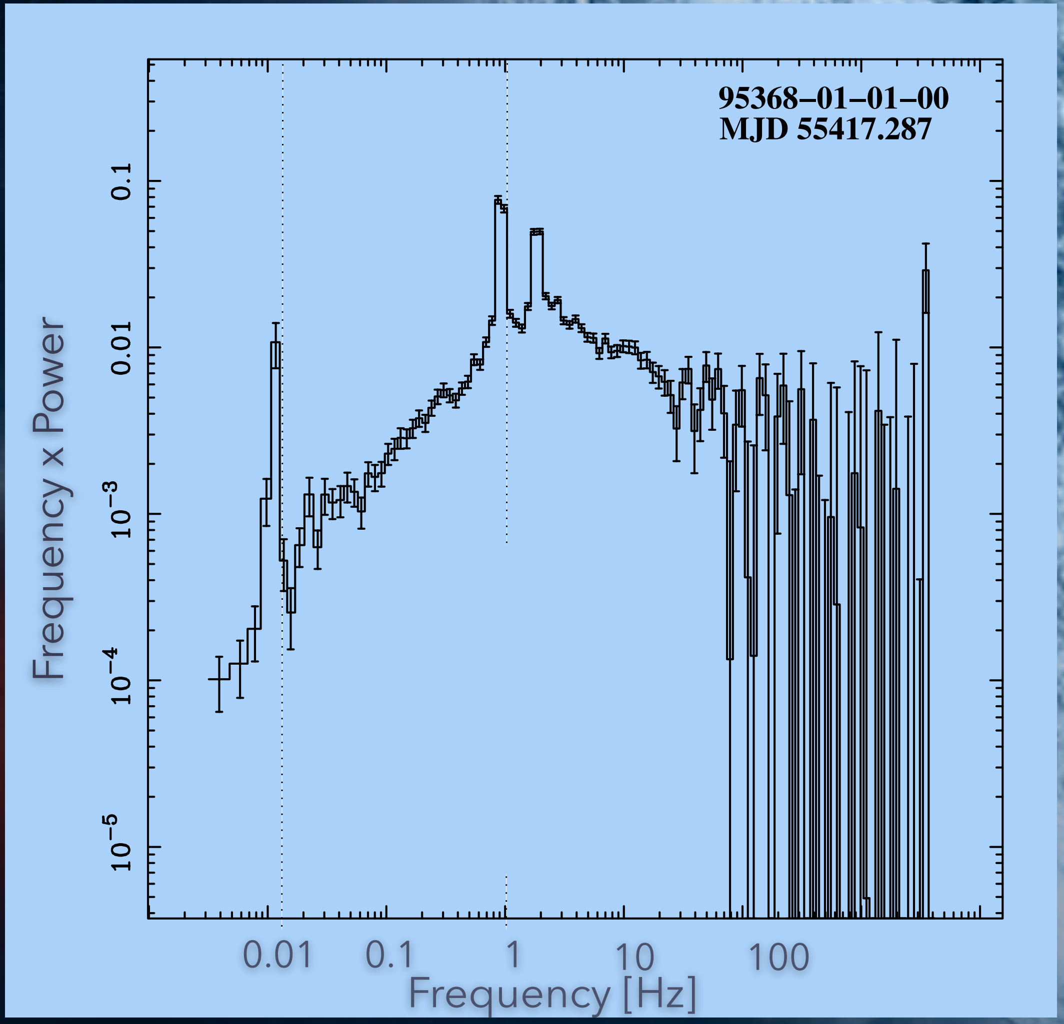
H1743-322



Altamirano + Strohmayer 2012

Fourier

Transform



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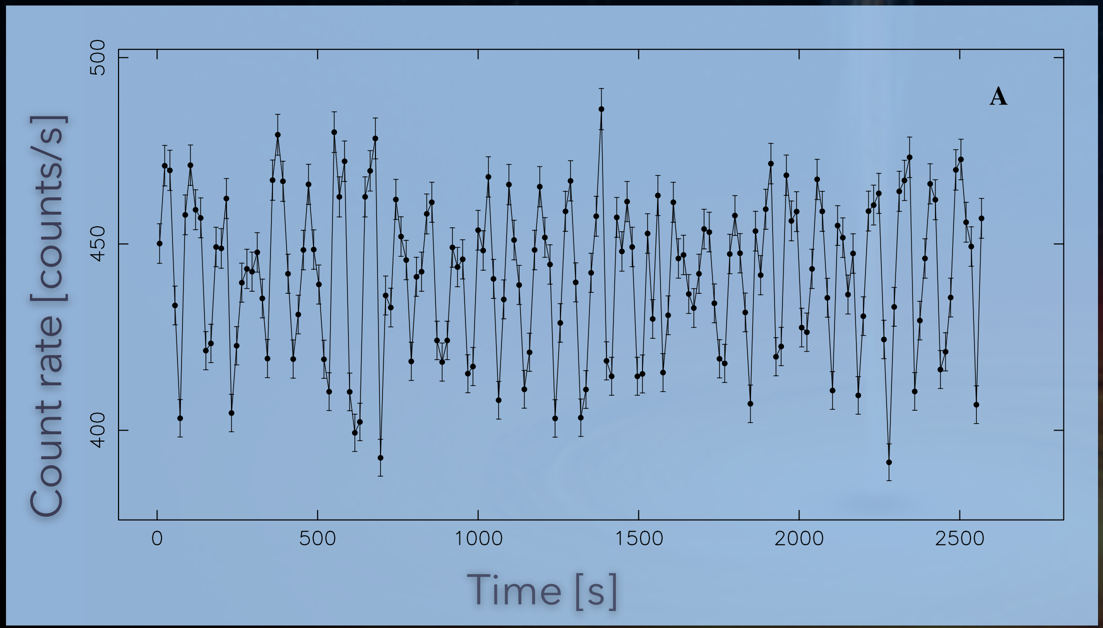

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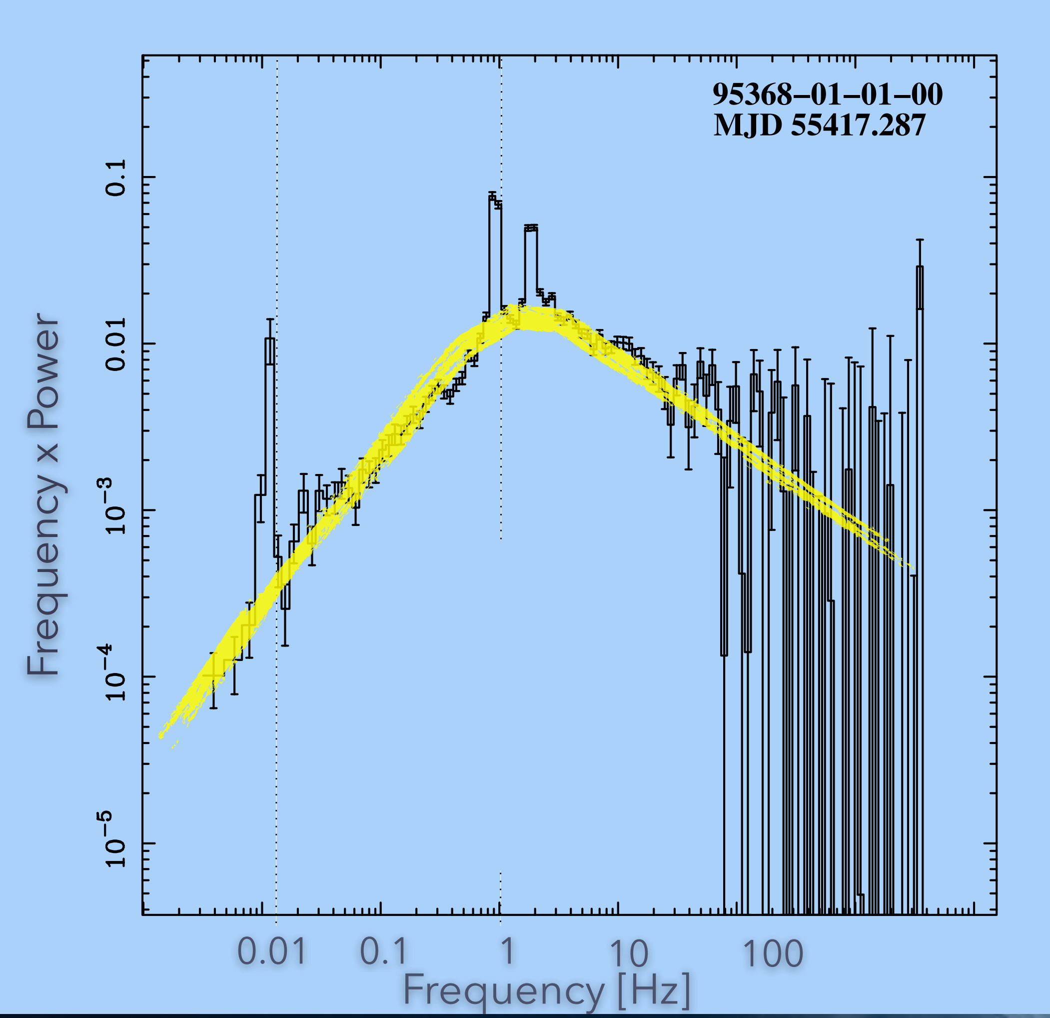

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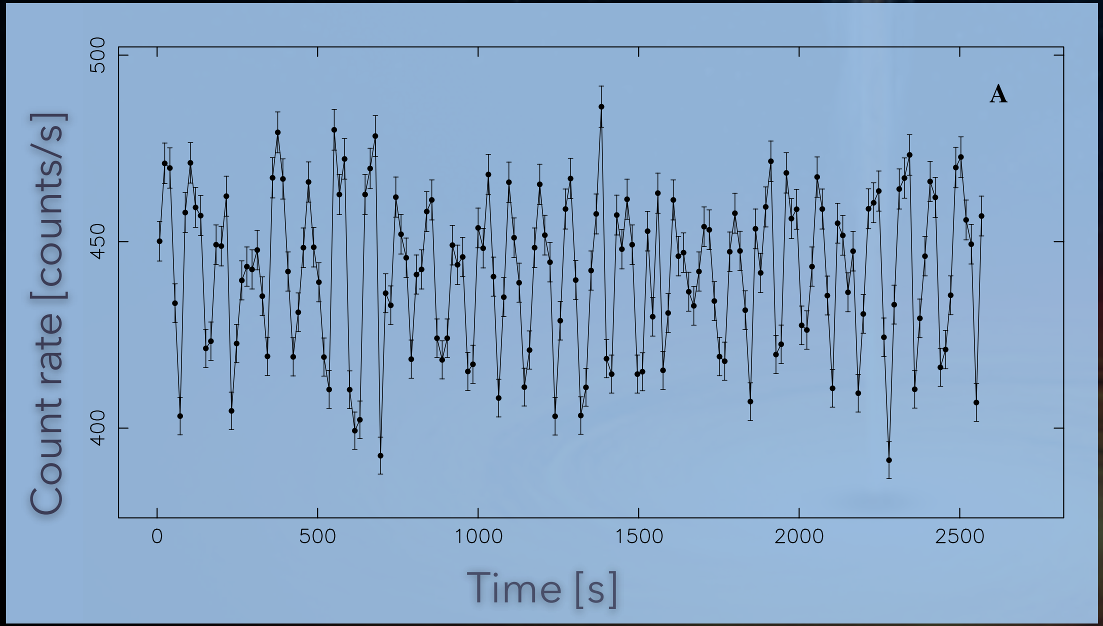

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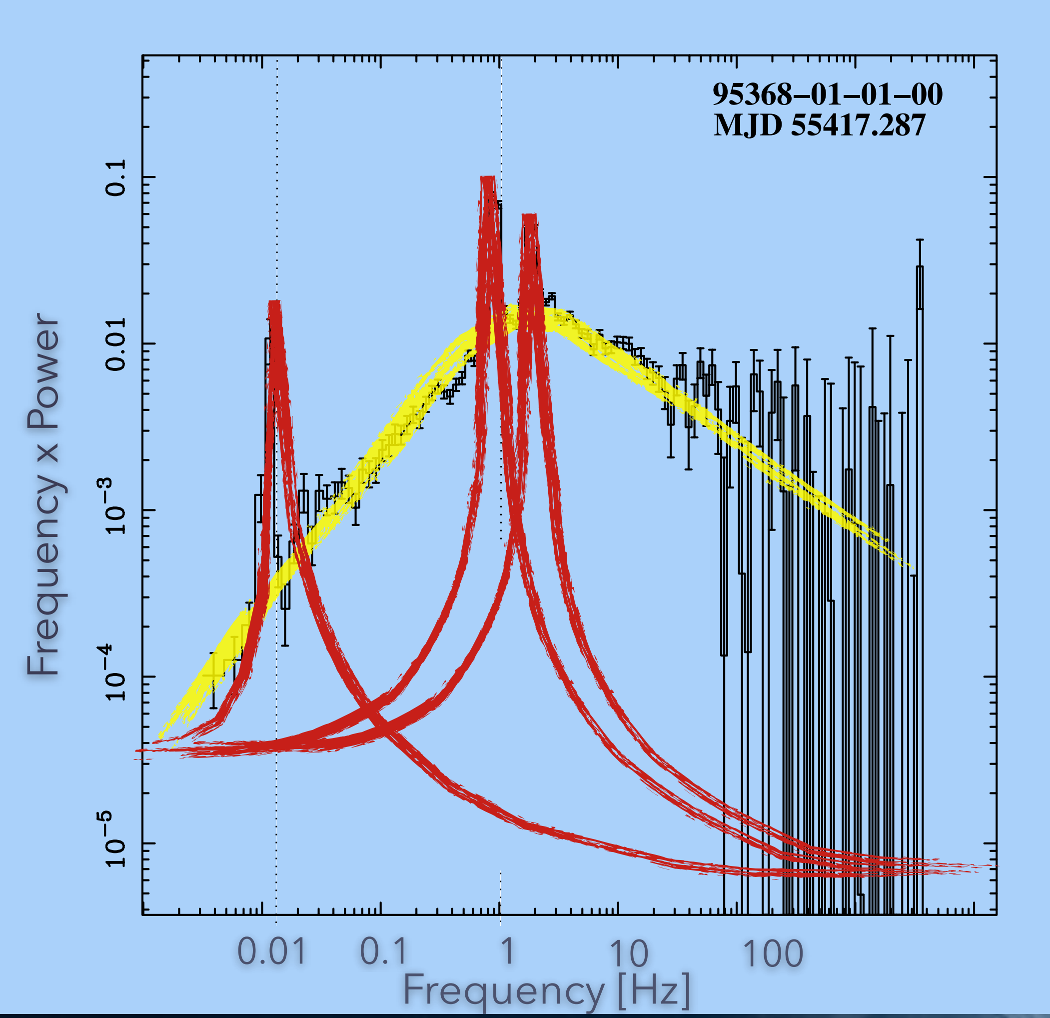
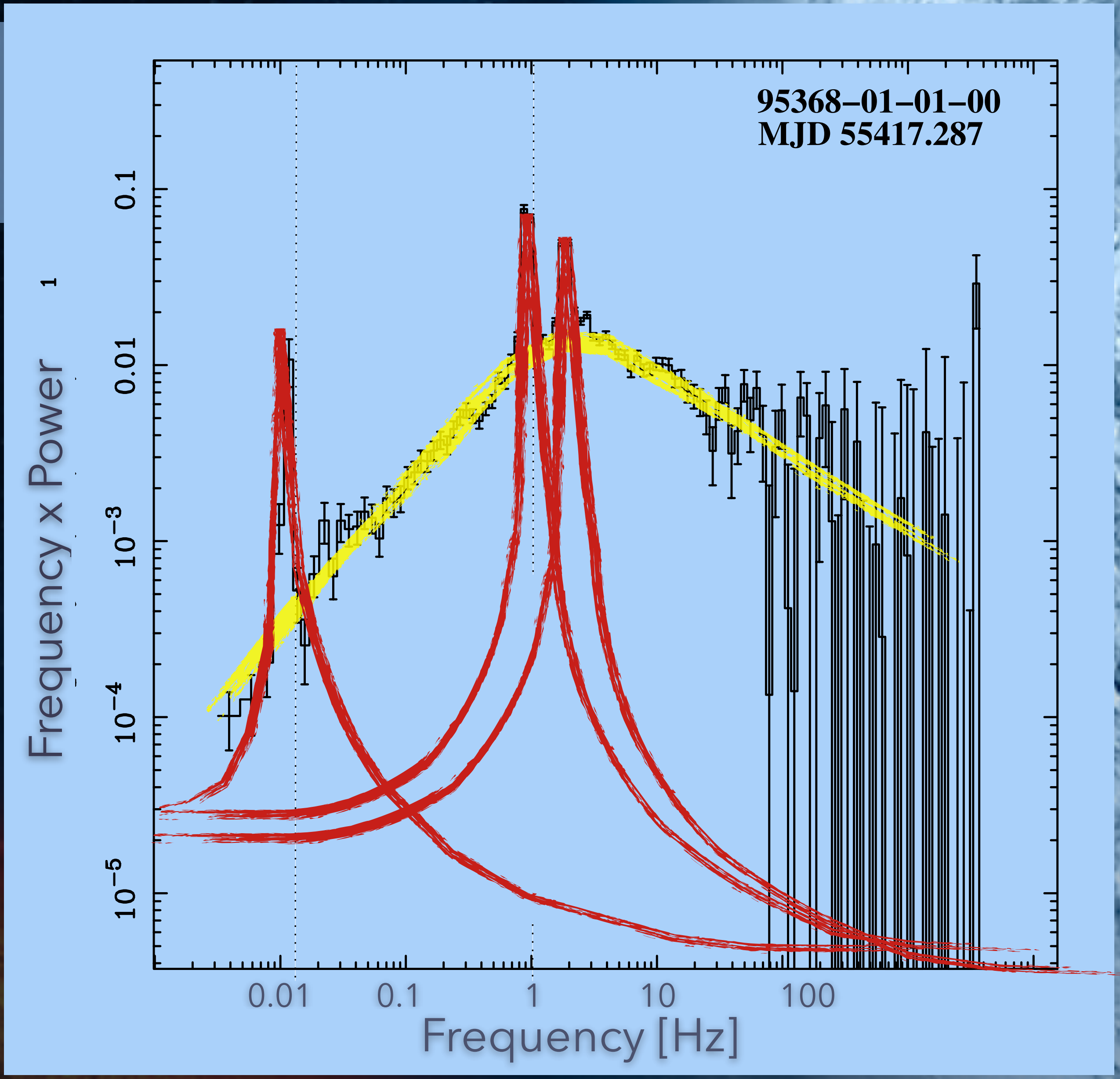


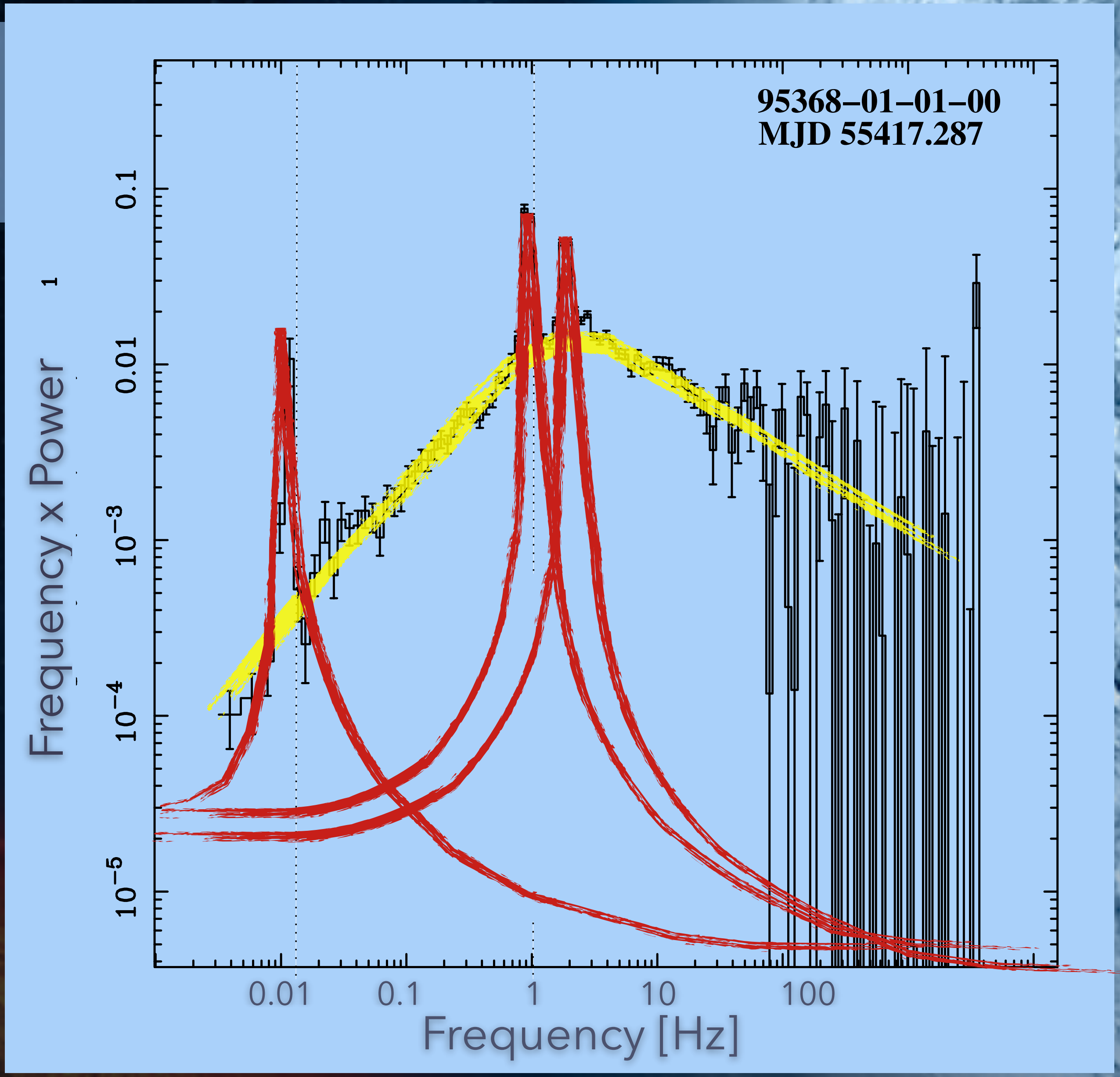
QPO Properties



Altamirano + Strohmayer 2012

QPO Properties

excess power at well-defined frequency range



Altamirano + Strohmayer 2012

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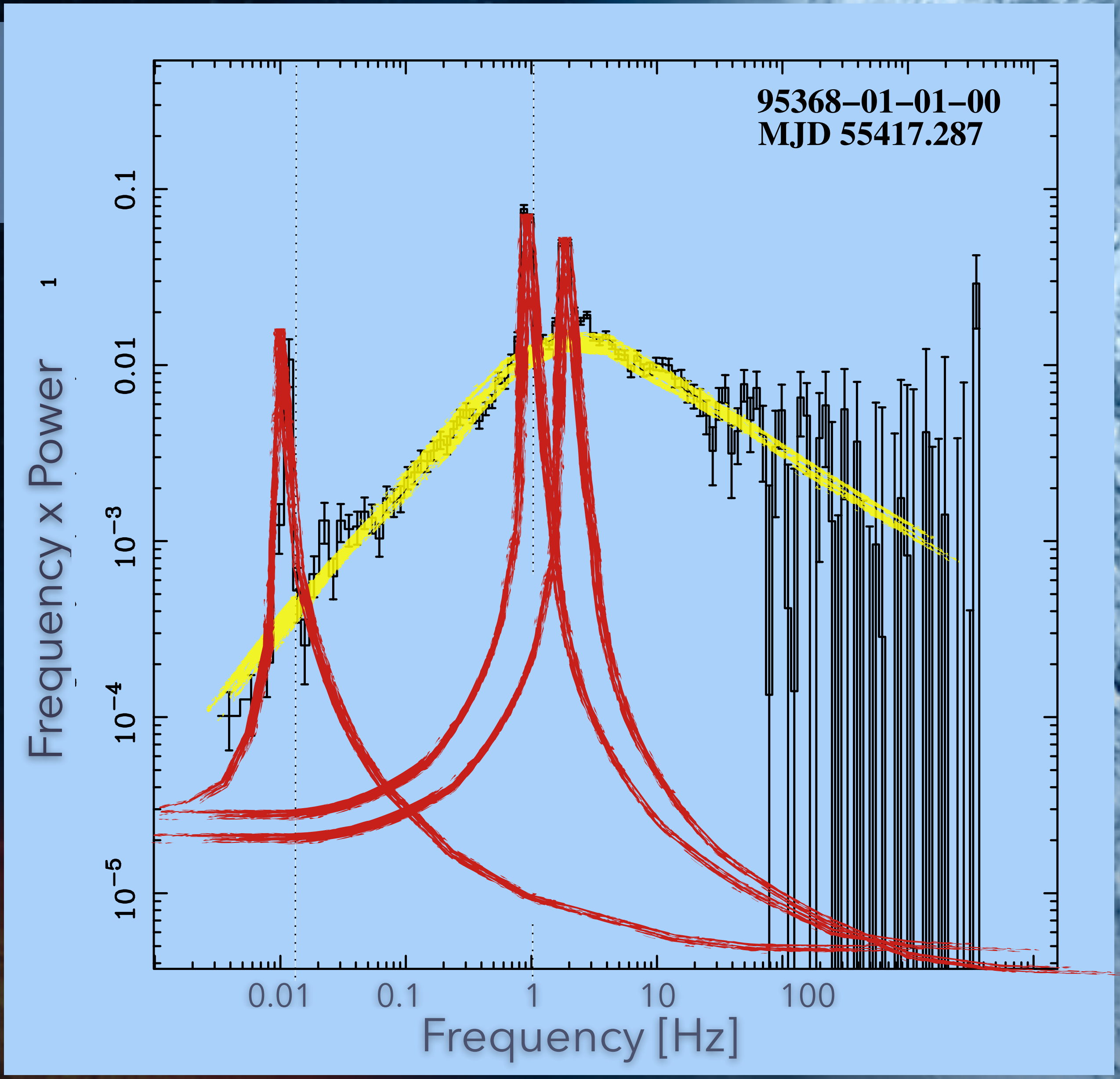
usually Gaussian or Lorentzian



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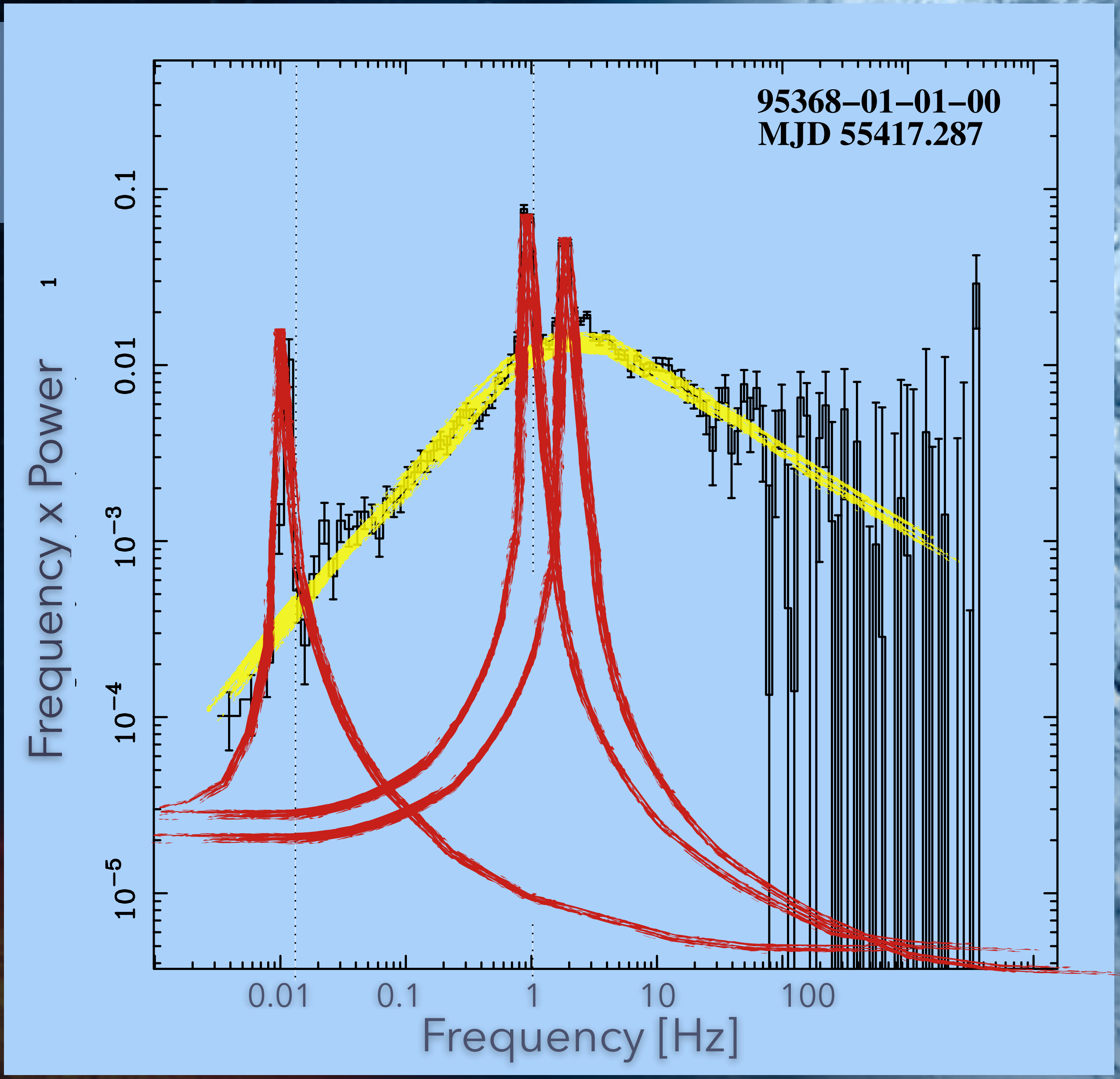

Altamirano + Strohmayer 2012

2 < centroid frequency/width < some large number

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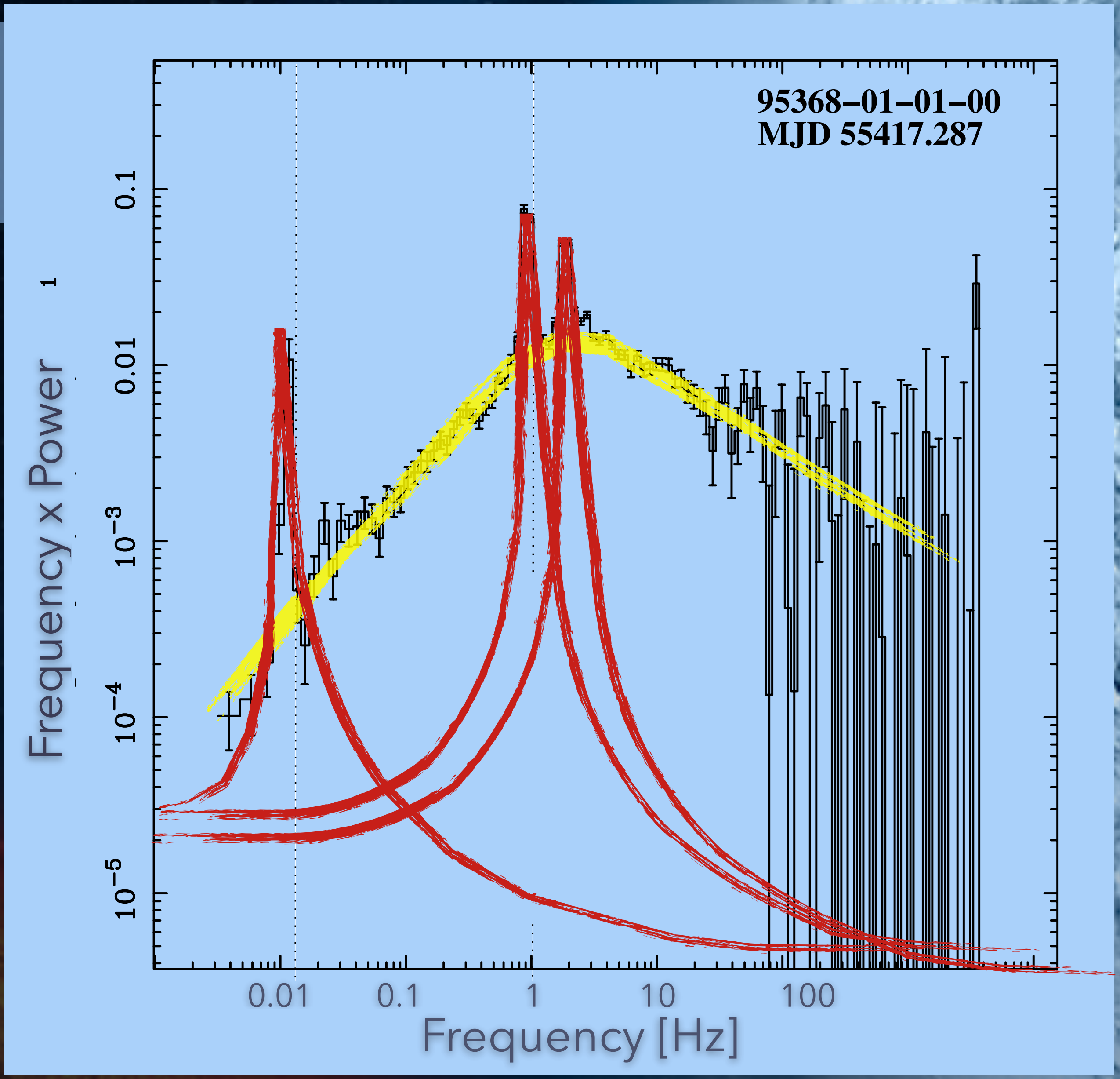

Altamirano + Strohmayer 2012

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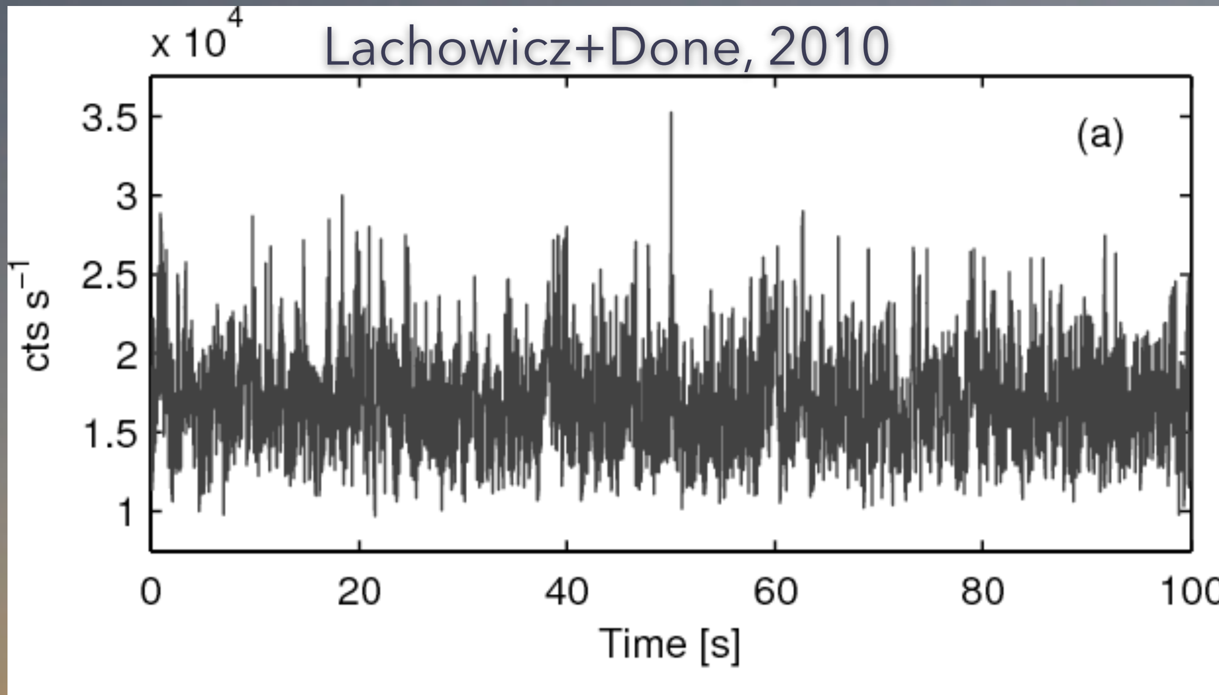
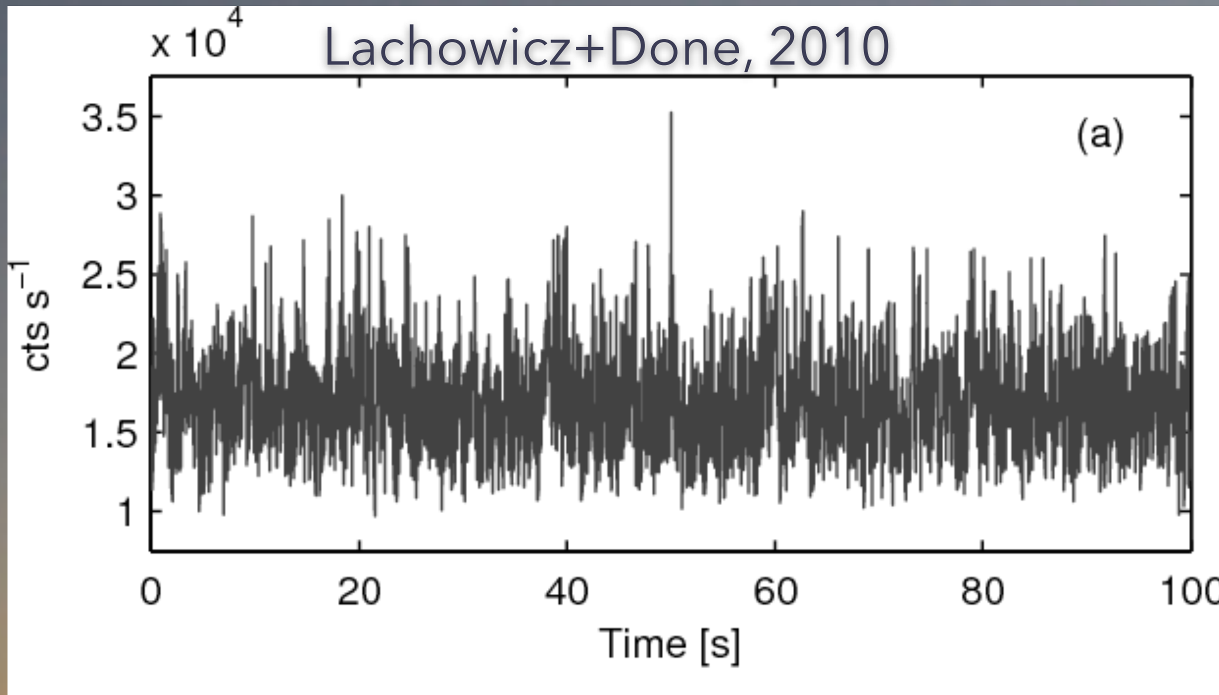
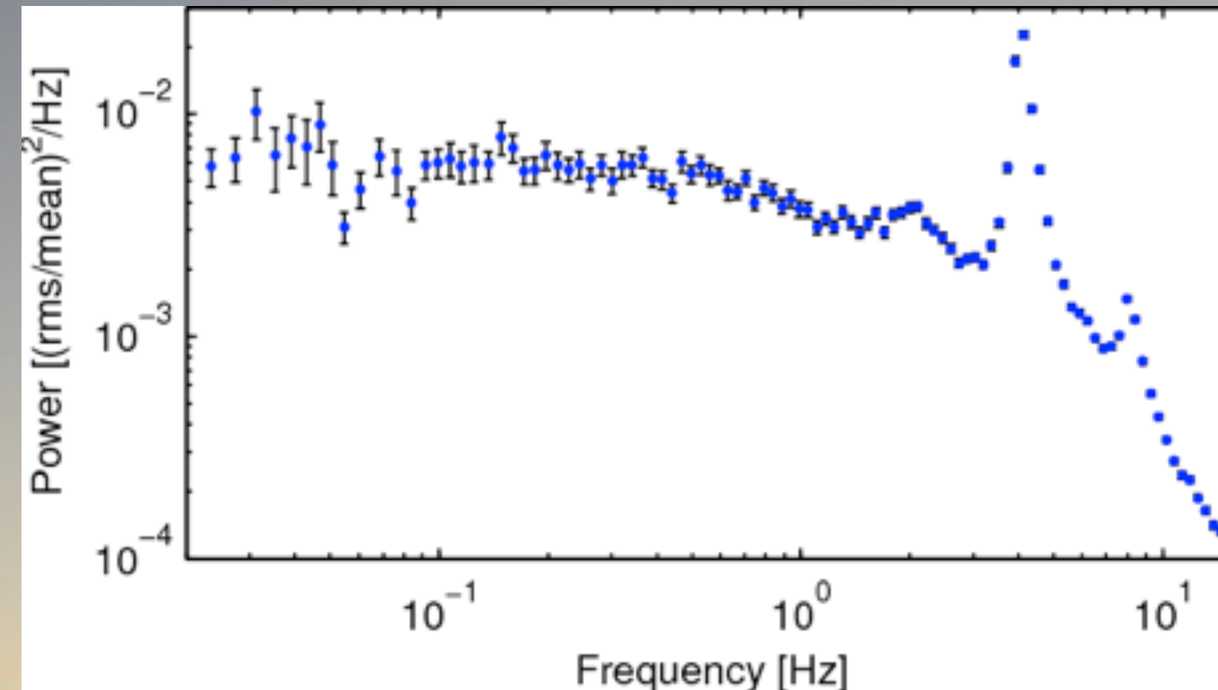
QPO definition largely arbitrary and empirical!

But Fermi/GBM detects predominantly bursts!

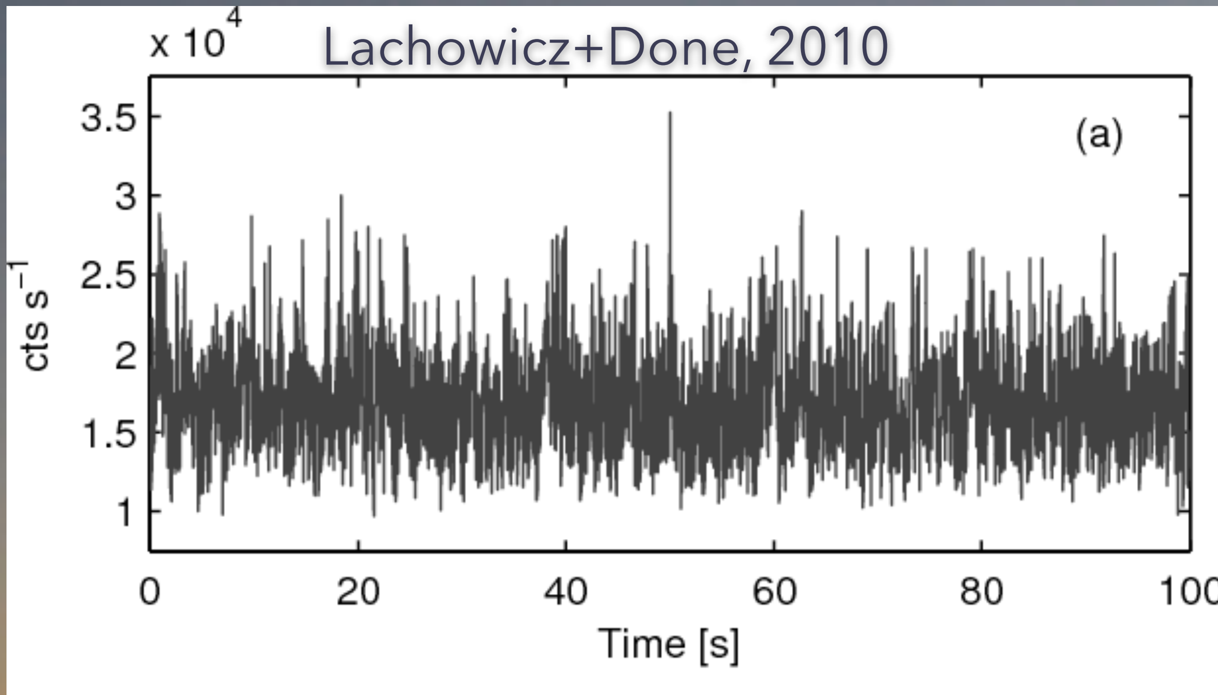


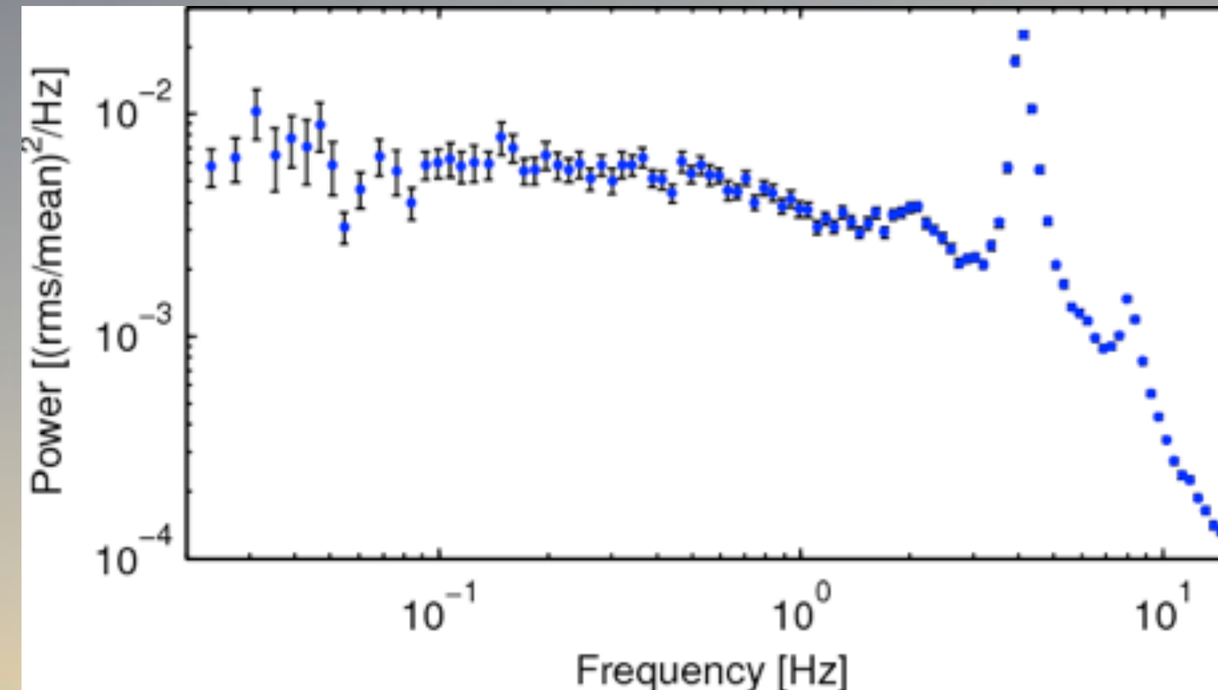
Lachowicz+Done, 2010
x 10^4
(a)
cts s^-1
3.5
3
2.5
2
1.5
1
0
20
40
60
80
100
Time [s]





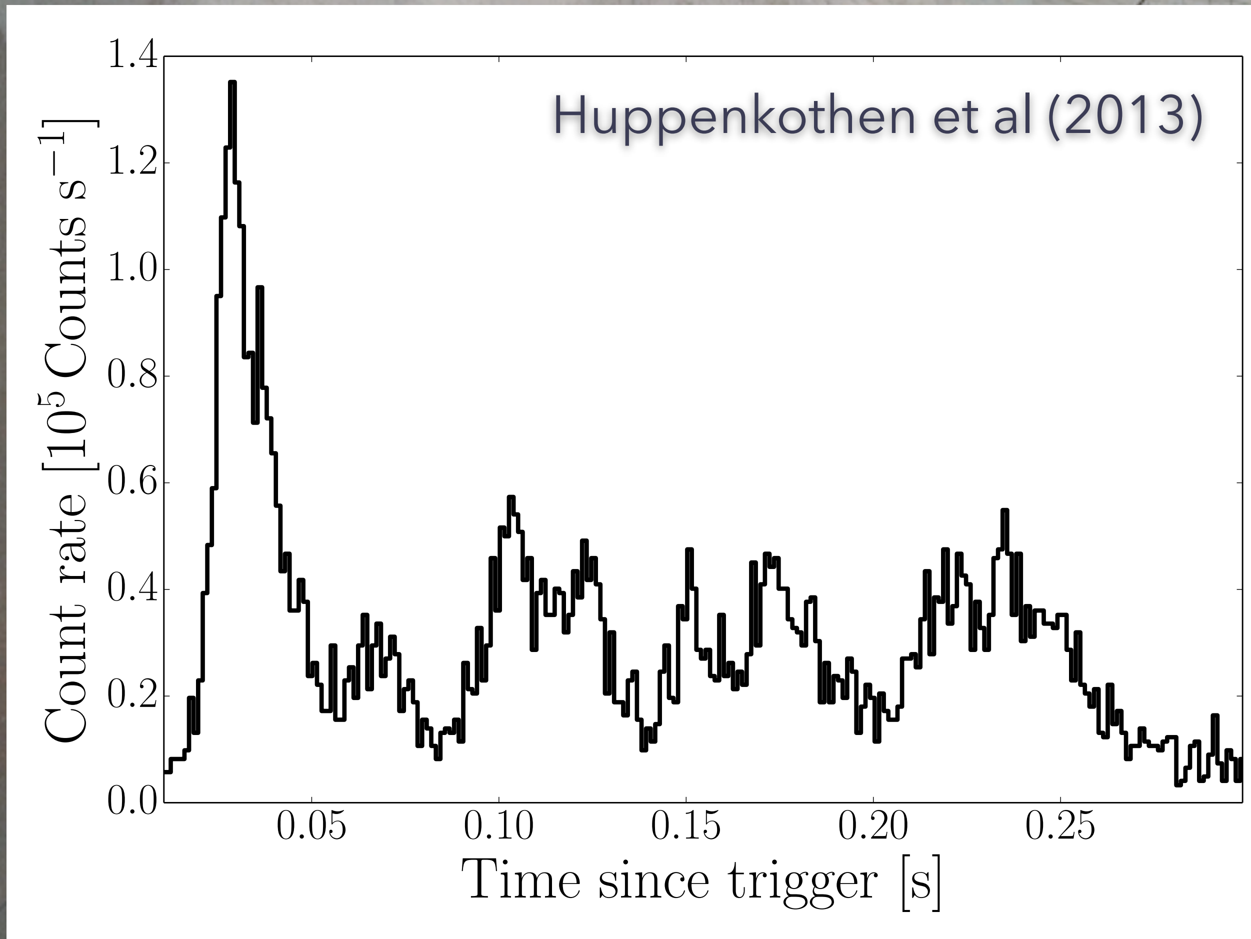
credit: Richard Freeman,
flickr.com/photos/freebird710/, CC licensed





stationary noise processes

Willem van de Velde the Younger, “The Gust”



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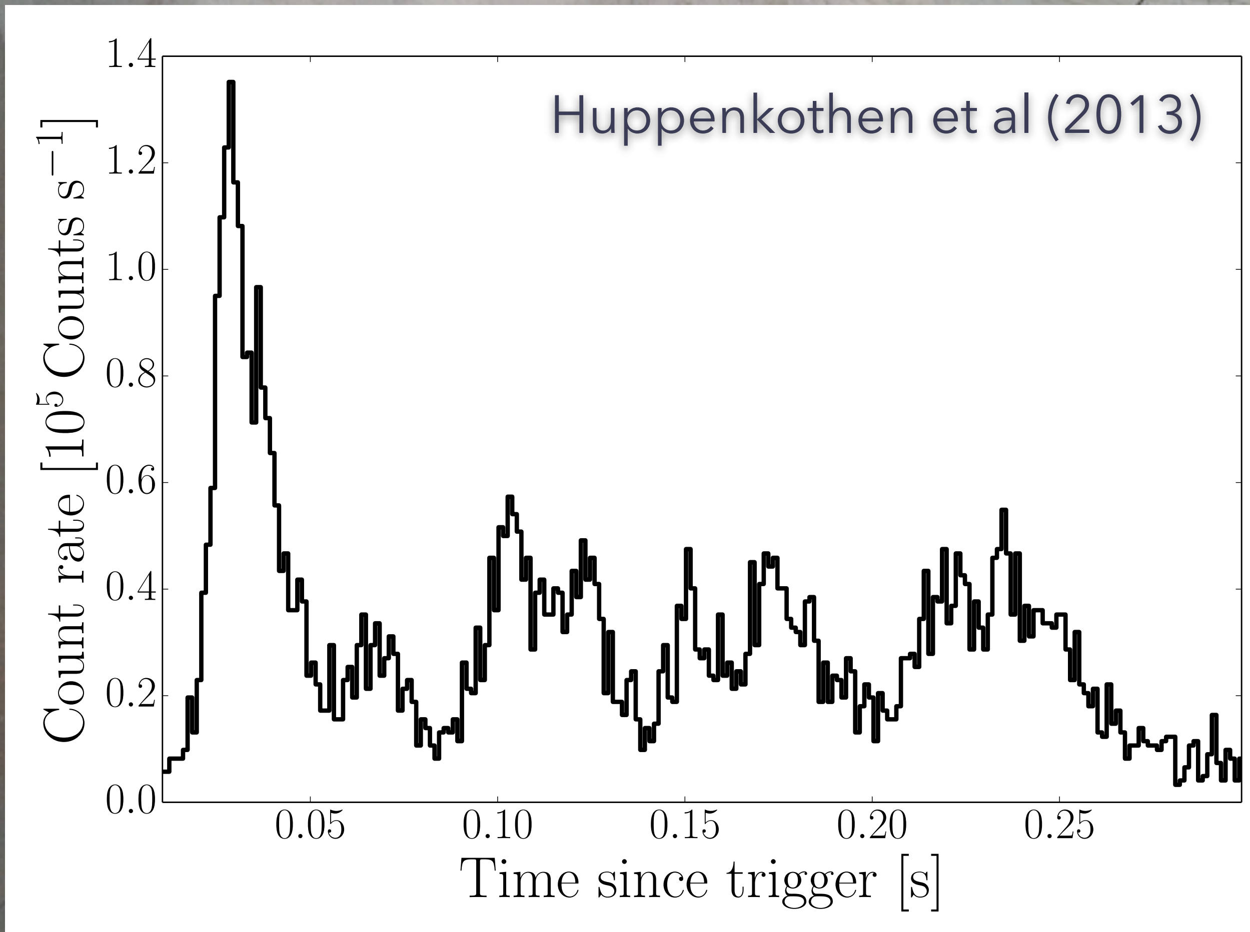

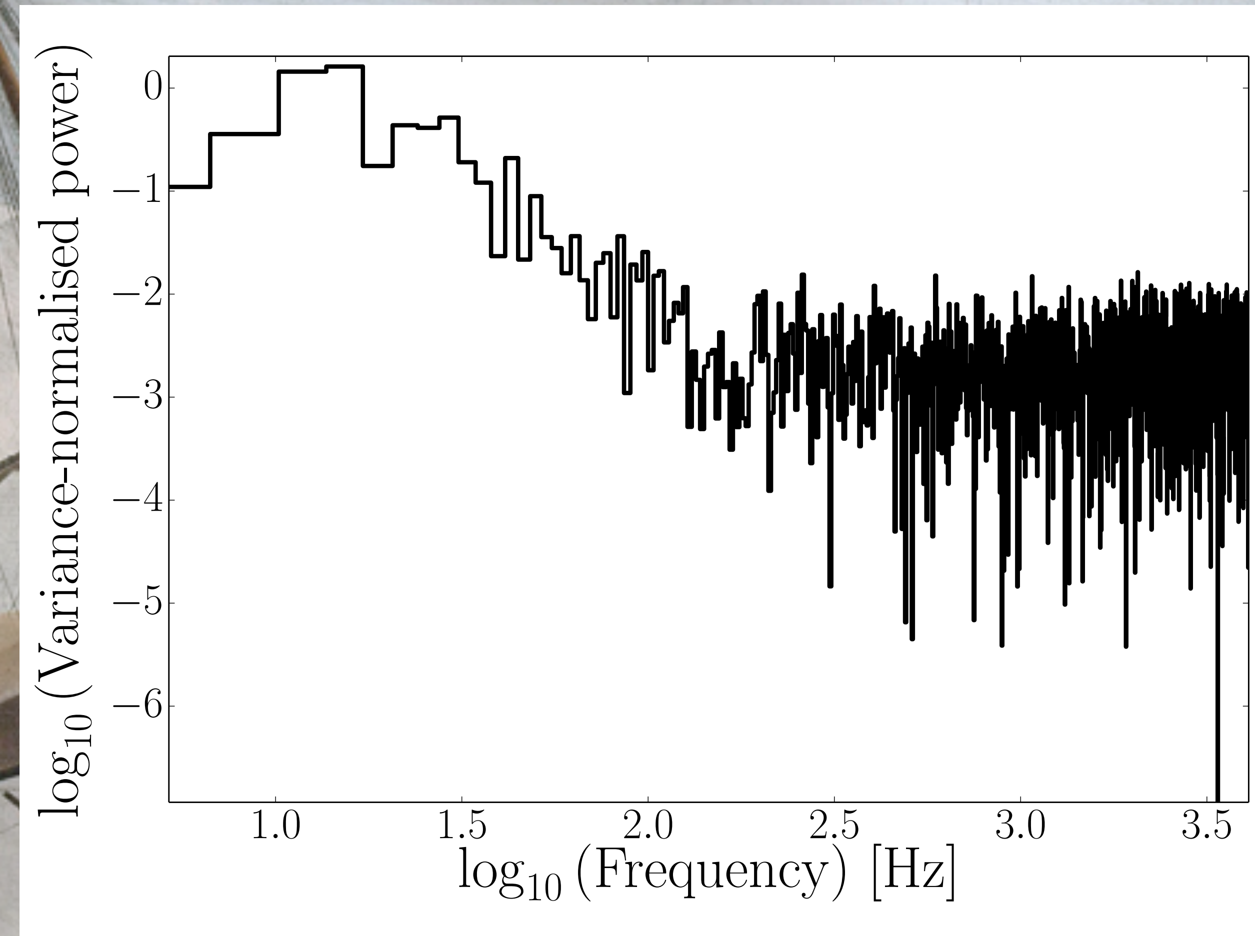

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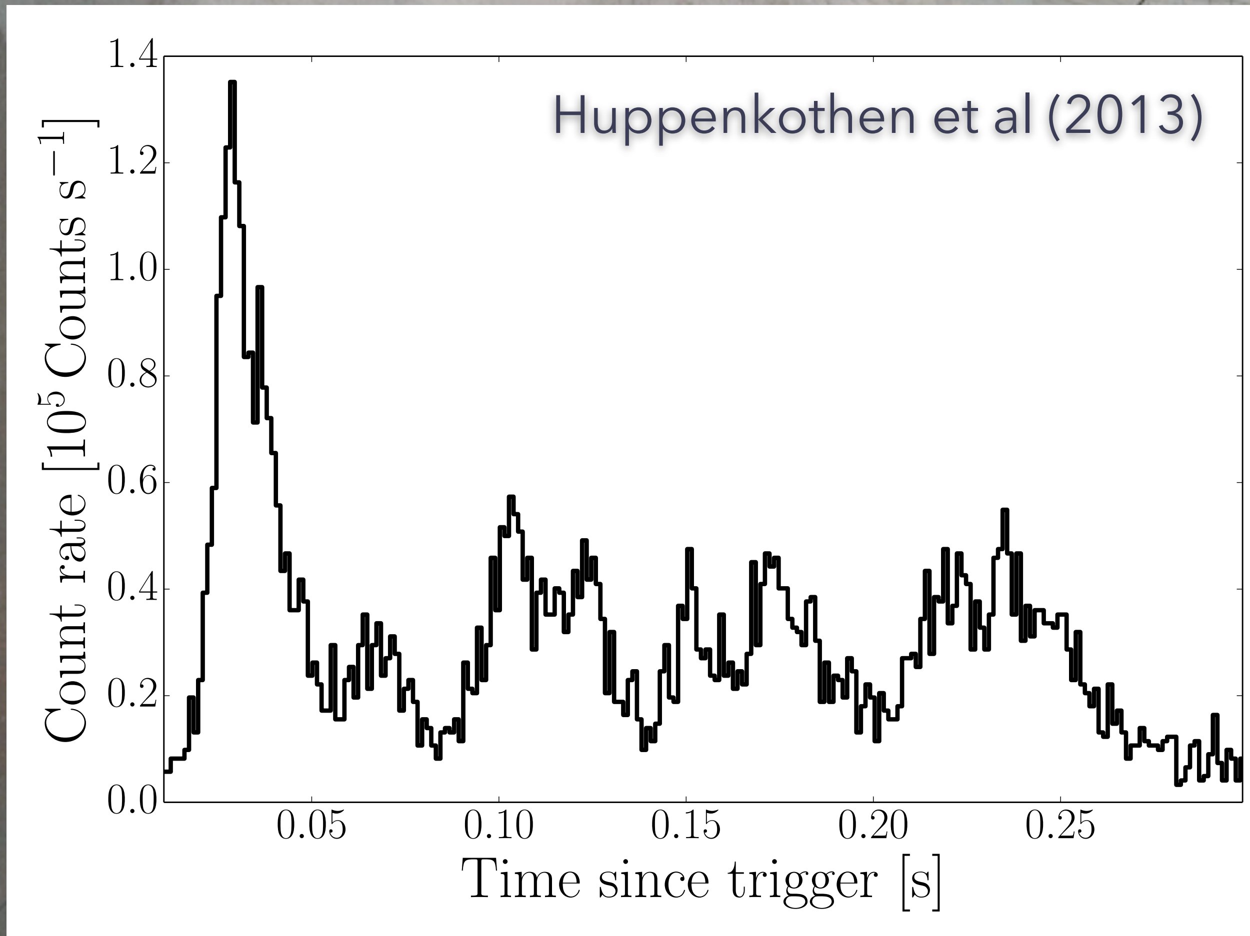

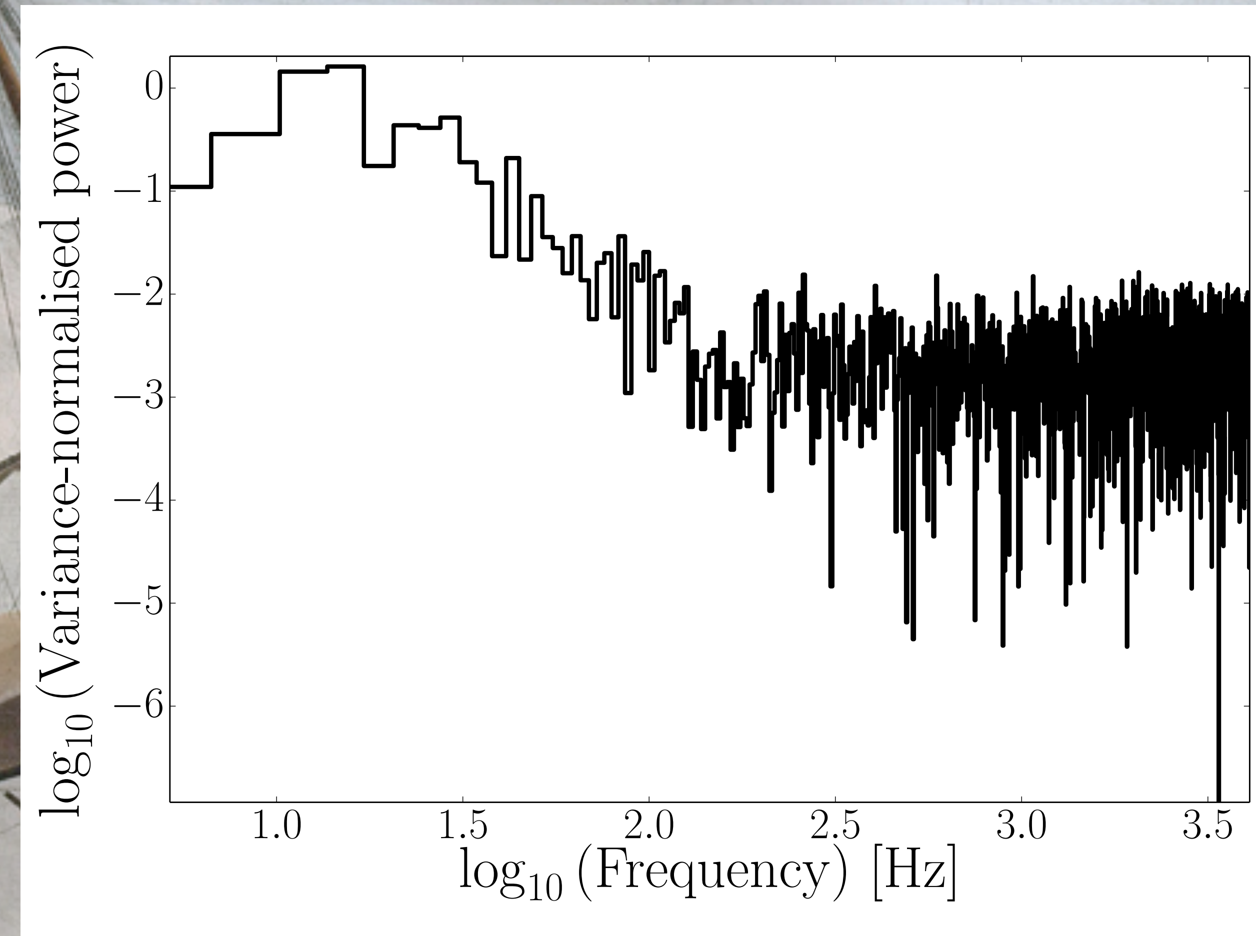

breaks stationarity

assumption in bad ways!

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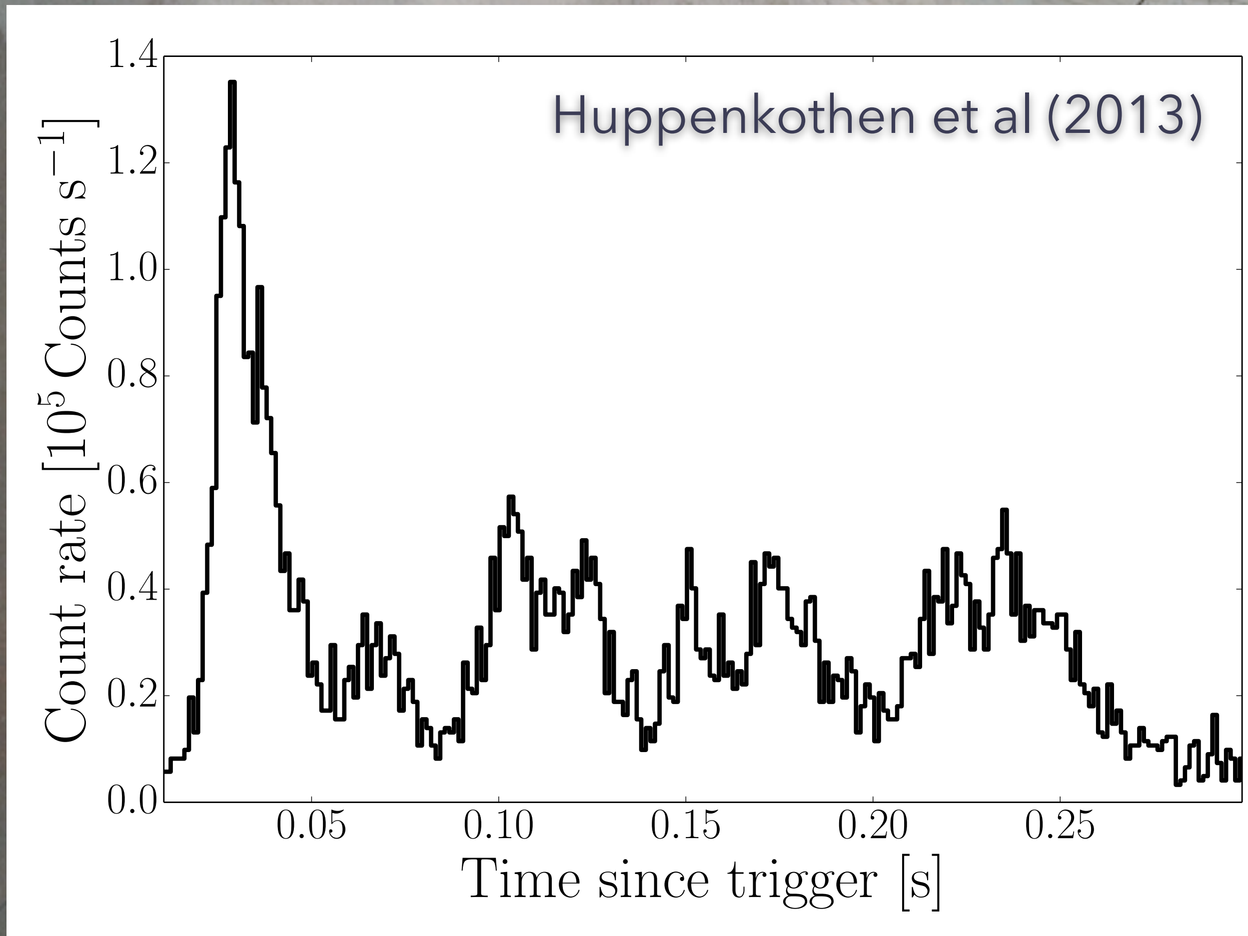

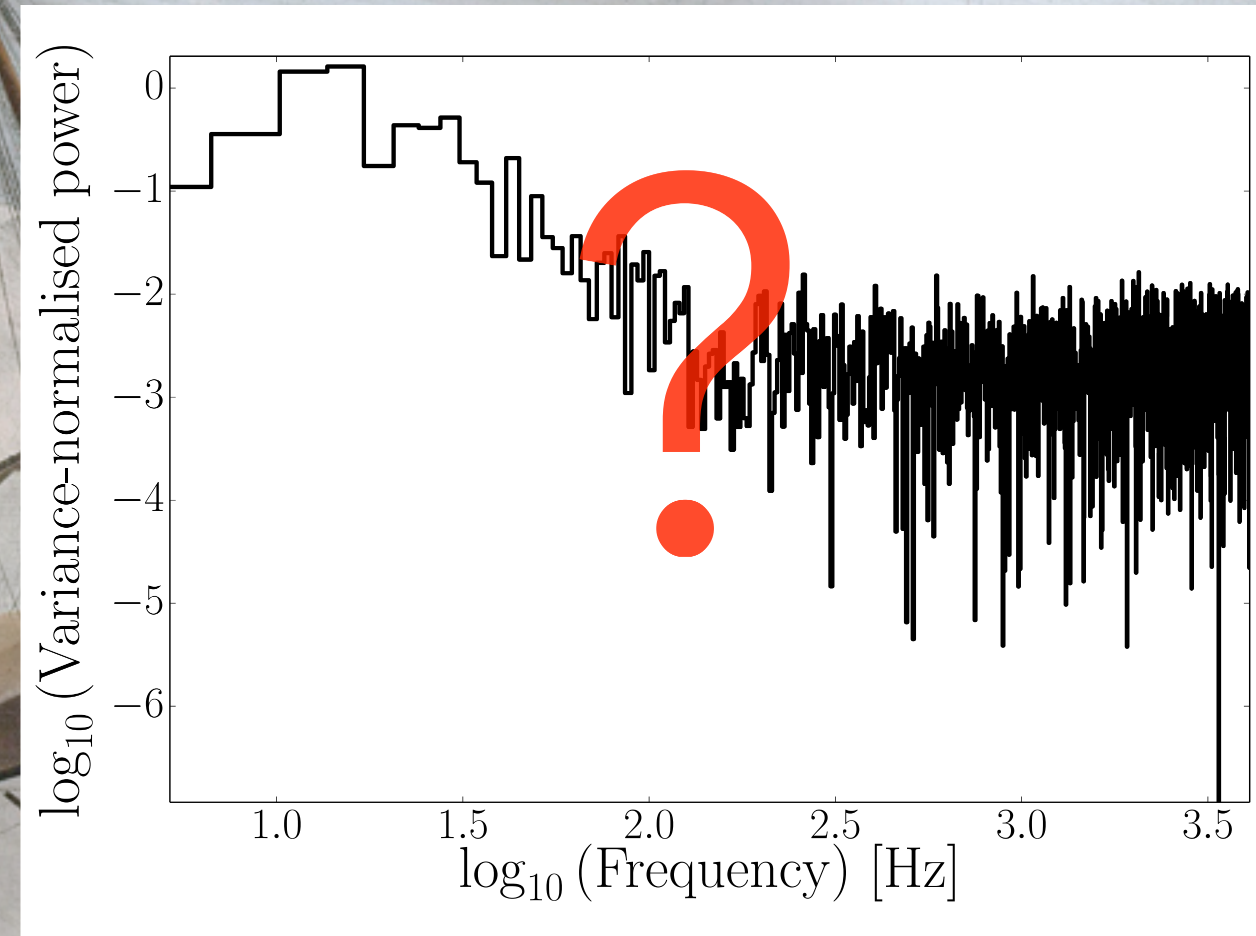

breaks stationarity

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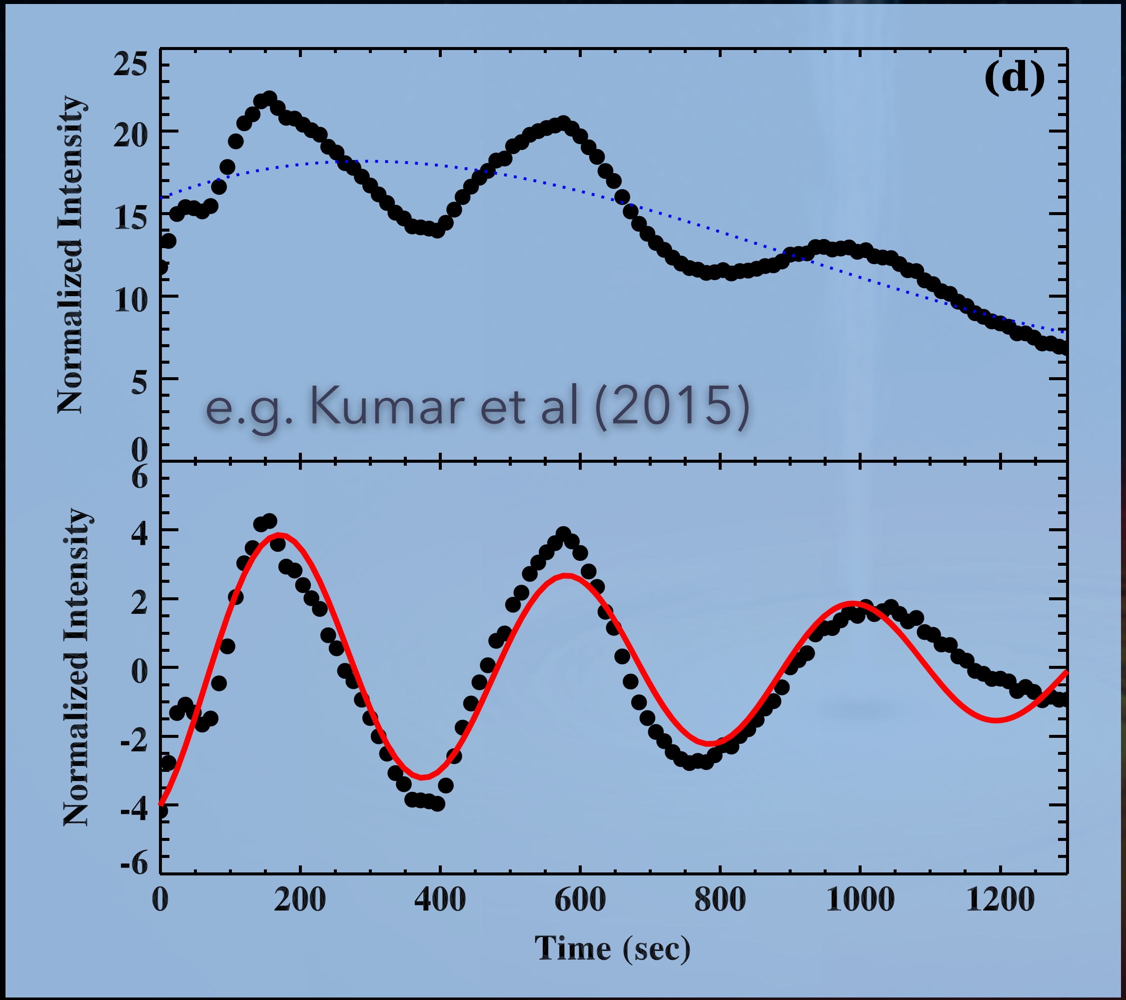
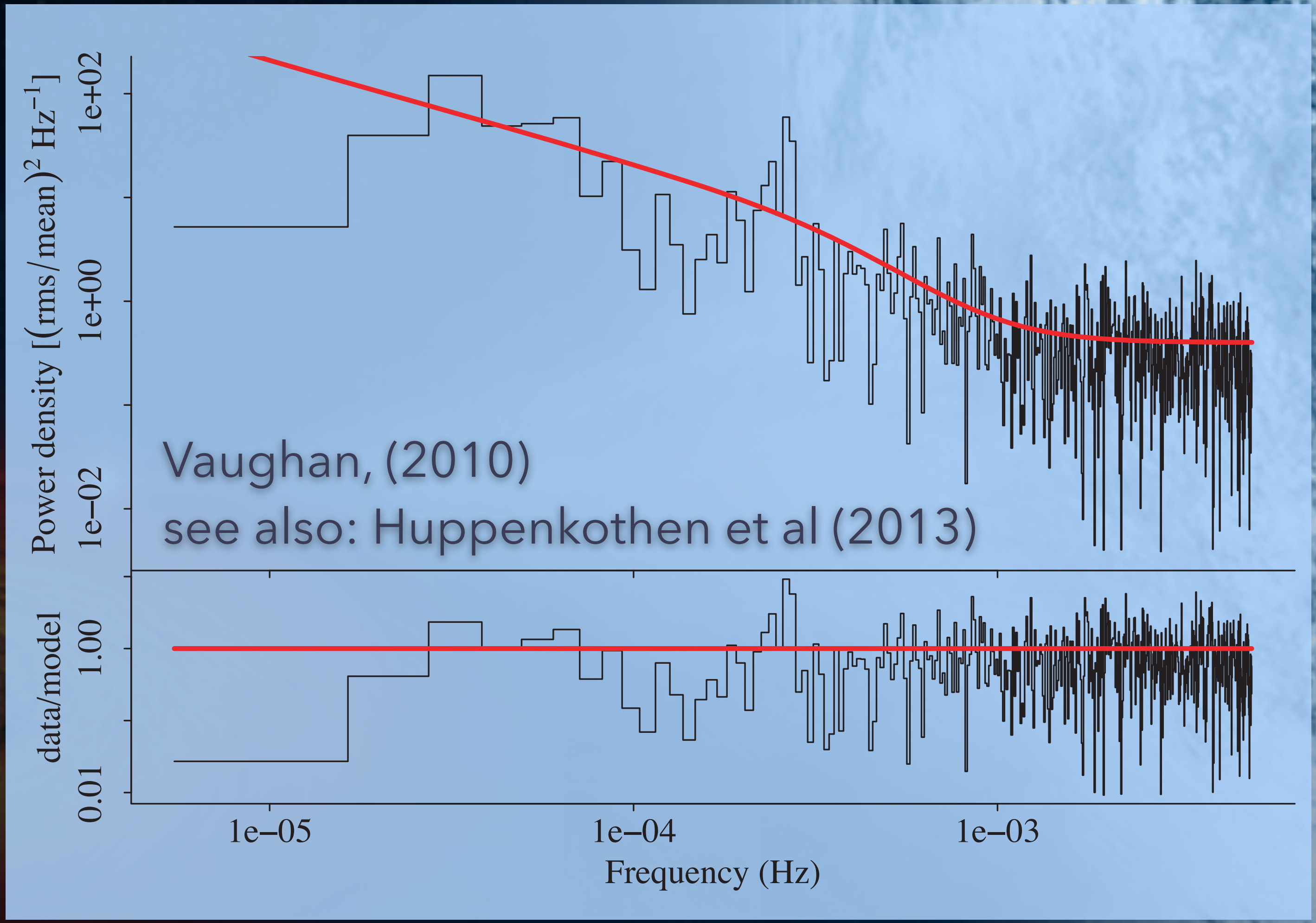
Willem van de Velde the Younger, "The Gust"

Possible Solutions Are Model Dependent





also: wavelets

R: http://www.star.le.ac.uk/sav2/index.html
Python: https://github.com/dhuppenkothen/BayesPSD
https://github.com/dhuppenkothen/stingray
(spring 2016)

QPOs in the
Fermi Gamma-Ray Burst Monitor

Solar Flares

most prolific in QPO detections

usually in conjunction with other instruments

advantage: can image the sun!

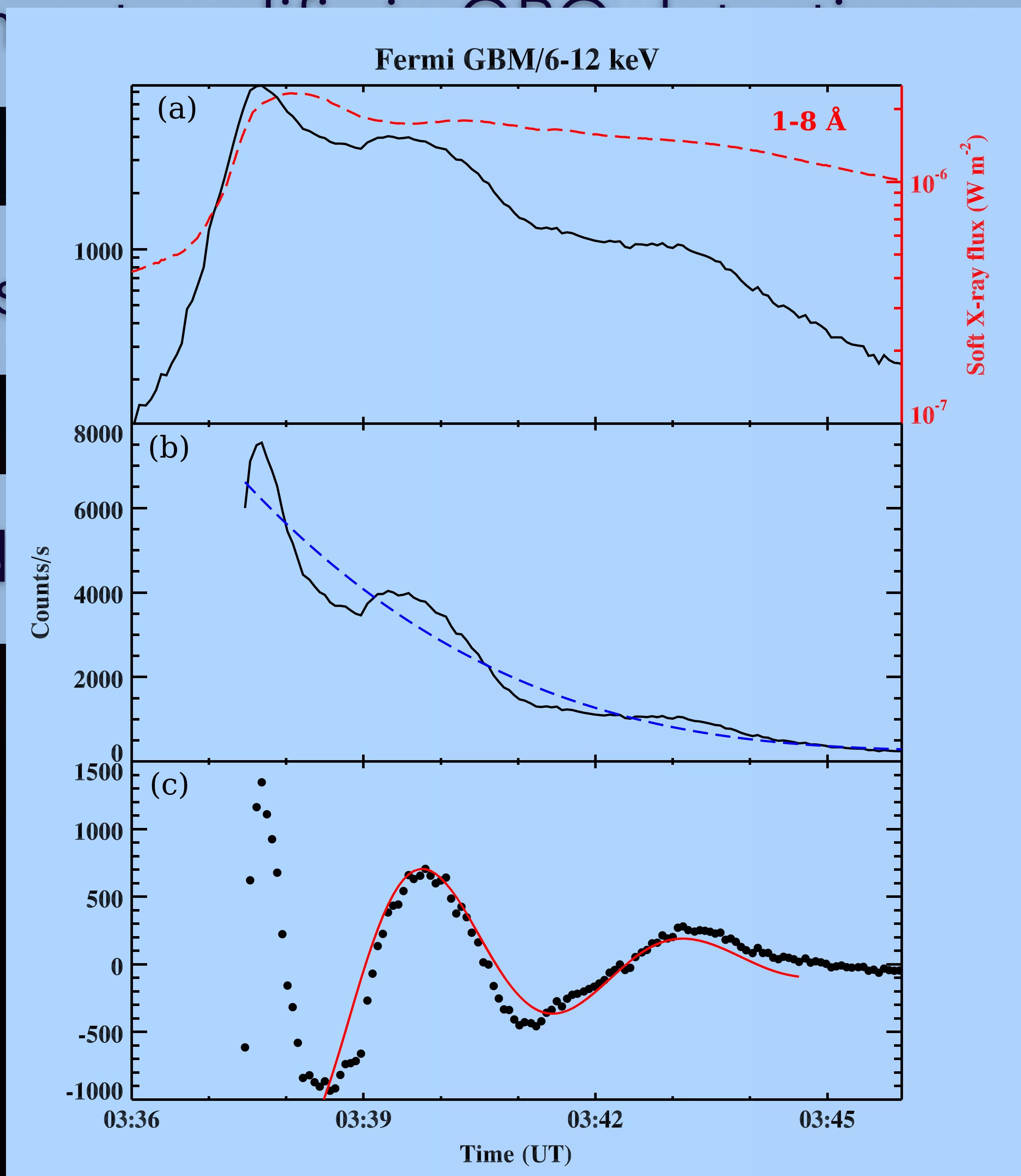
Solar Flares

n

us

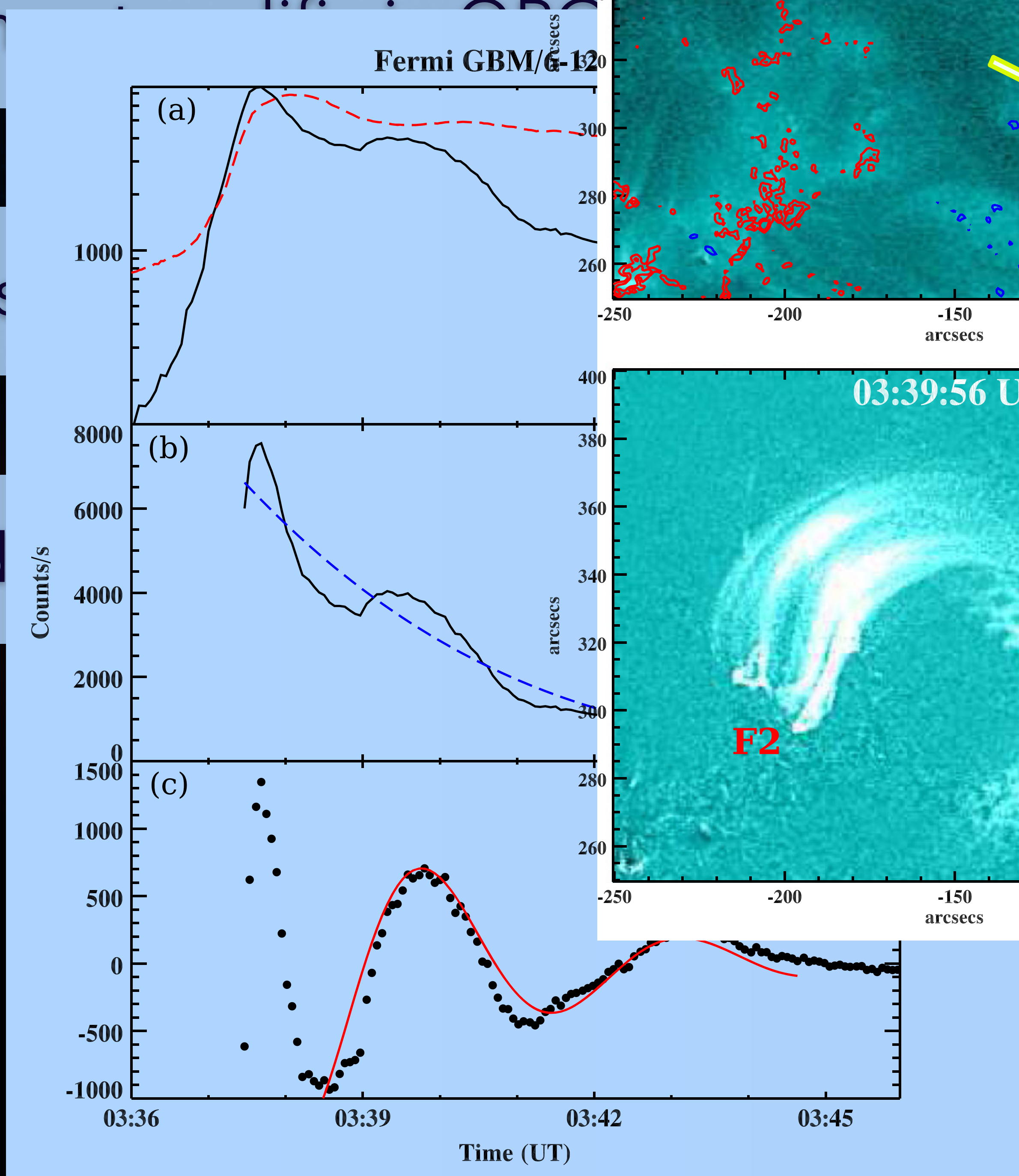
struments

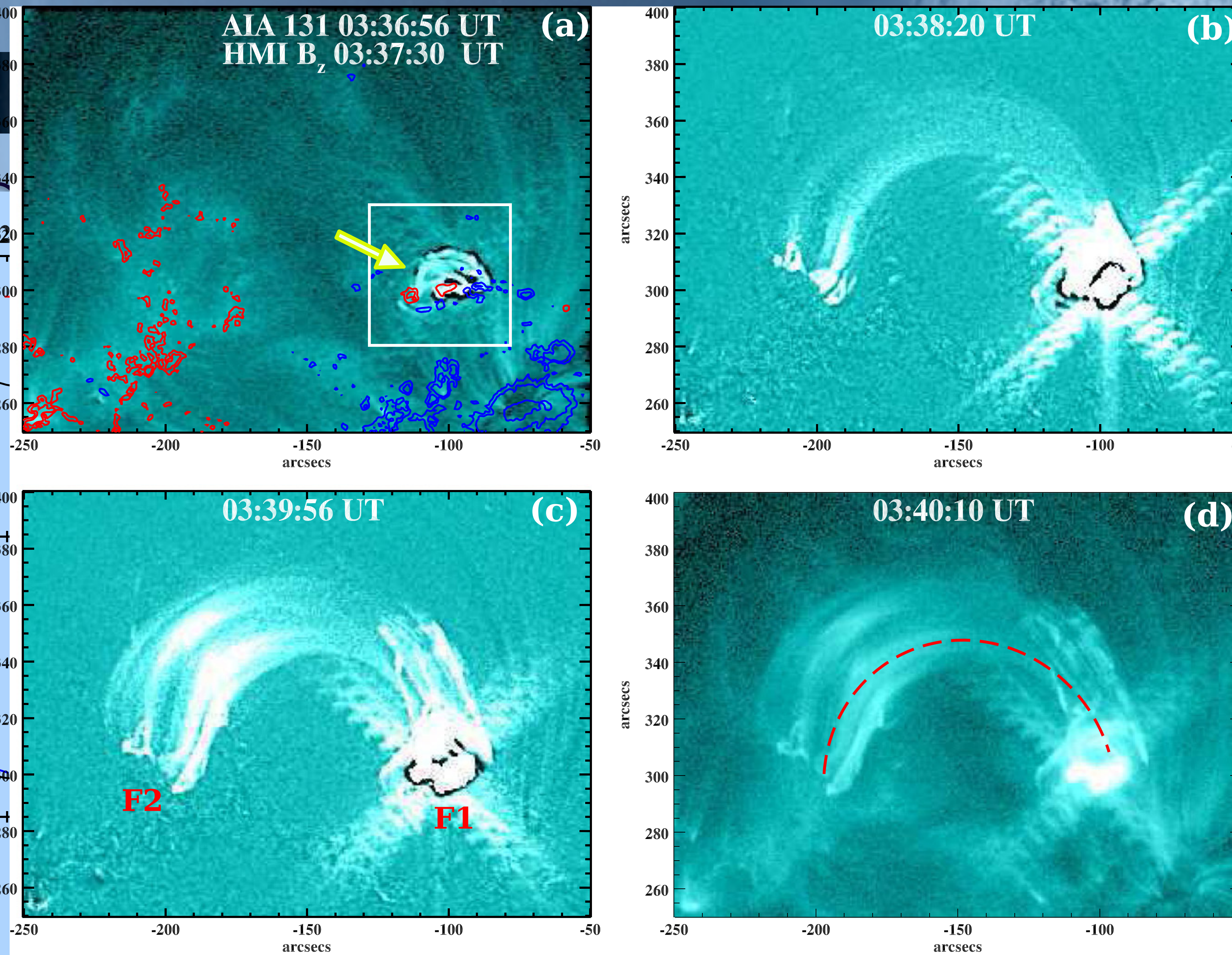
ad



Kumar et al (2015)

Solar Flares





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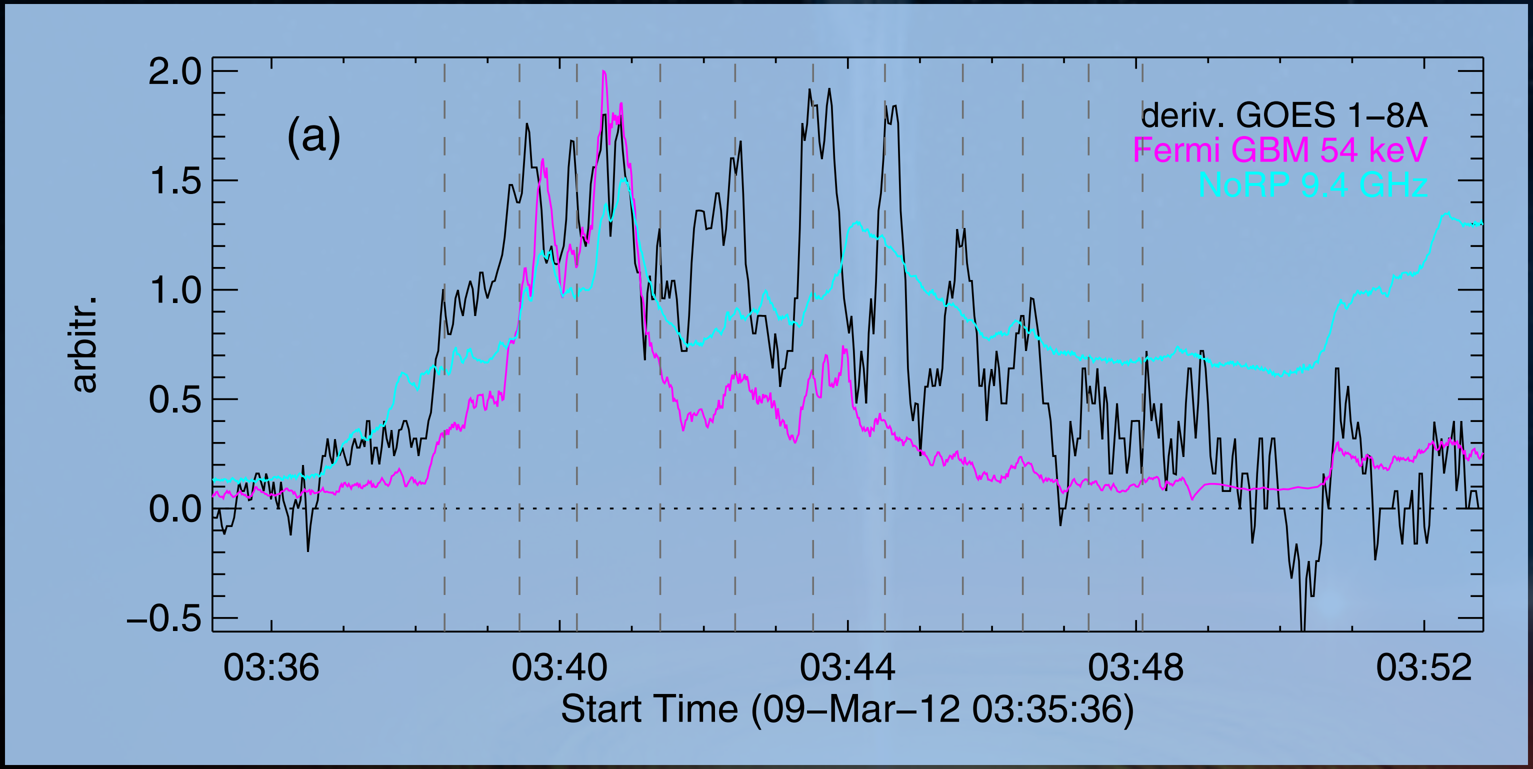
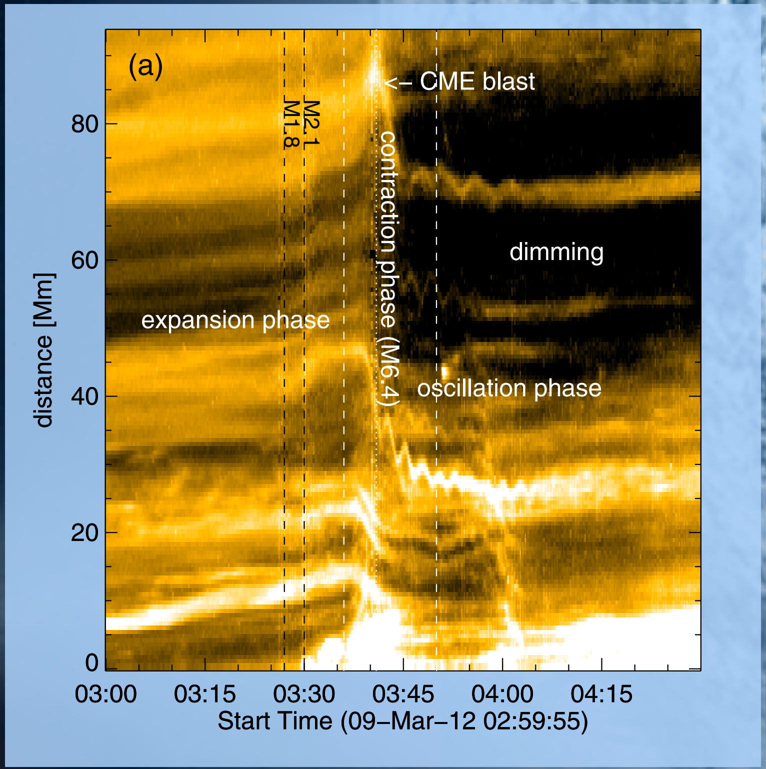
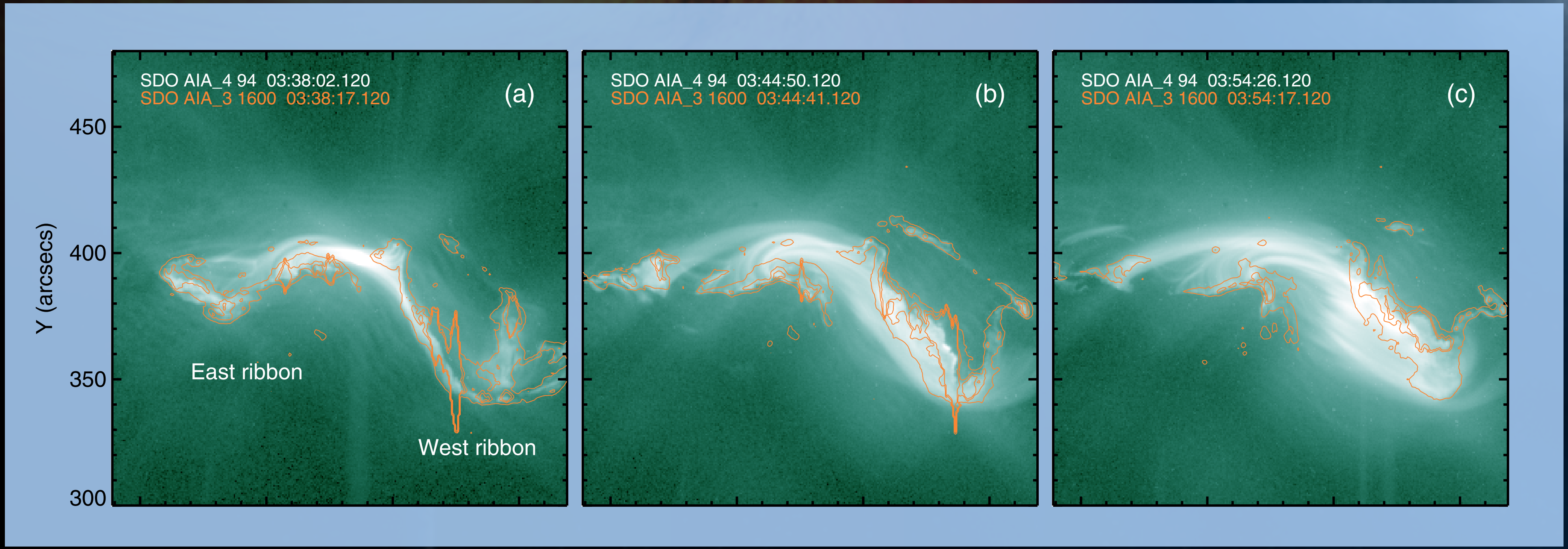




e.g. Simões et al (2013)



Solar Flares

arbitr.

e.g.

QUASI-PERIODIC PULSATIONS IN SOLAR AND STELLAR FLARES: RE-EVALUATING THEIR NATURE IN THE CONTEXT OF POWER-LAW FLARE FOURIER SPECTRA

A. R. Inglis[1,3], J. Ireland[1,4], and M. Dominique[2]
[1] Solar Physics Laboratory, Heliophysics Science Division, NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA
[2] Solar-Terrestrial Center of Excellence, Royal Observatory of Belgium, Avenue Circulaire 3, B-1180, Brussels, Belgium
Received 2014 August 15; accepted 2014 October 29; published 2015 January 6

ABSTRACT

The nature of quasi-periodic pulsations (QPPs) in solar and stellar flares remains debated. Recent work has shown that power-law-like Fourier power spectra are an intrinsic property of solar and stellar flare signals, a property that many previous studies of this phenomenon have not accounted for. Hence a re-evaluation of the existing interpretations and assumptions regarding QPPs is needed. We adopt a Bayesian method for investigating this phenomenon, fully considering the Fourier power-law properties of flare signals. Using data from the PROBA2/Large Yield Radiometer, *Fermi*/Gamma-ray Burst Monitor, Nobeyama Radioheliograph, and *Yohkoh*/HXT instruments, we study a selection of flares from the literature identified as QPP events. Additionally, we examine optical data from a recent stellar flare that appears to exhibit oscillatory properties. We find that, for all but one event tested, an explicit oscillation is not required to explain the observations. Instead, the flare signals are adequately described as a manifestation of a power law in the Fourier power spectrum. However, for the flare of 1998 May 8, strong evidence for an explicit oscillation with $P \approx 14$–16 s is found in the 17 GHz radio data and the 13–23 keV *Yohkoh*/HXT data. We conclude that, most likely, many previously analyzed events in the literature may be similarly described by power laws in the flare Fourier power spectrum, without invoking a narrowband, oscillatory component. Hence the prevalence of oscillatory signatures in solar and stellar flares may be less than previously believed. The physical mechanism behind the appearance of the observed power laws is discussed.

300

Solar Flares

e.g.

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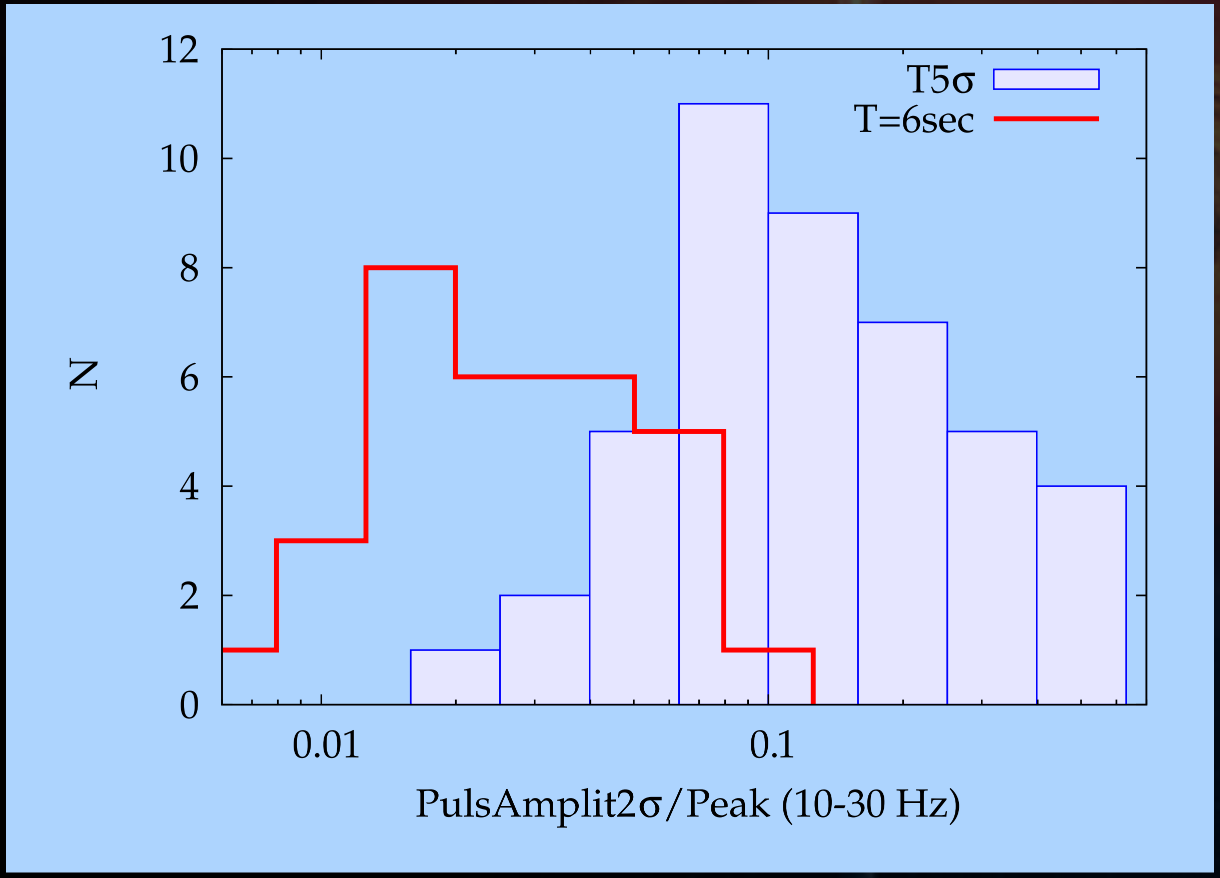
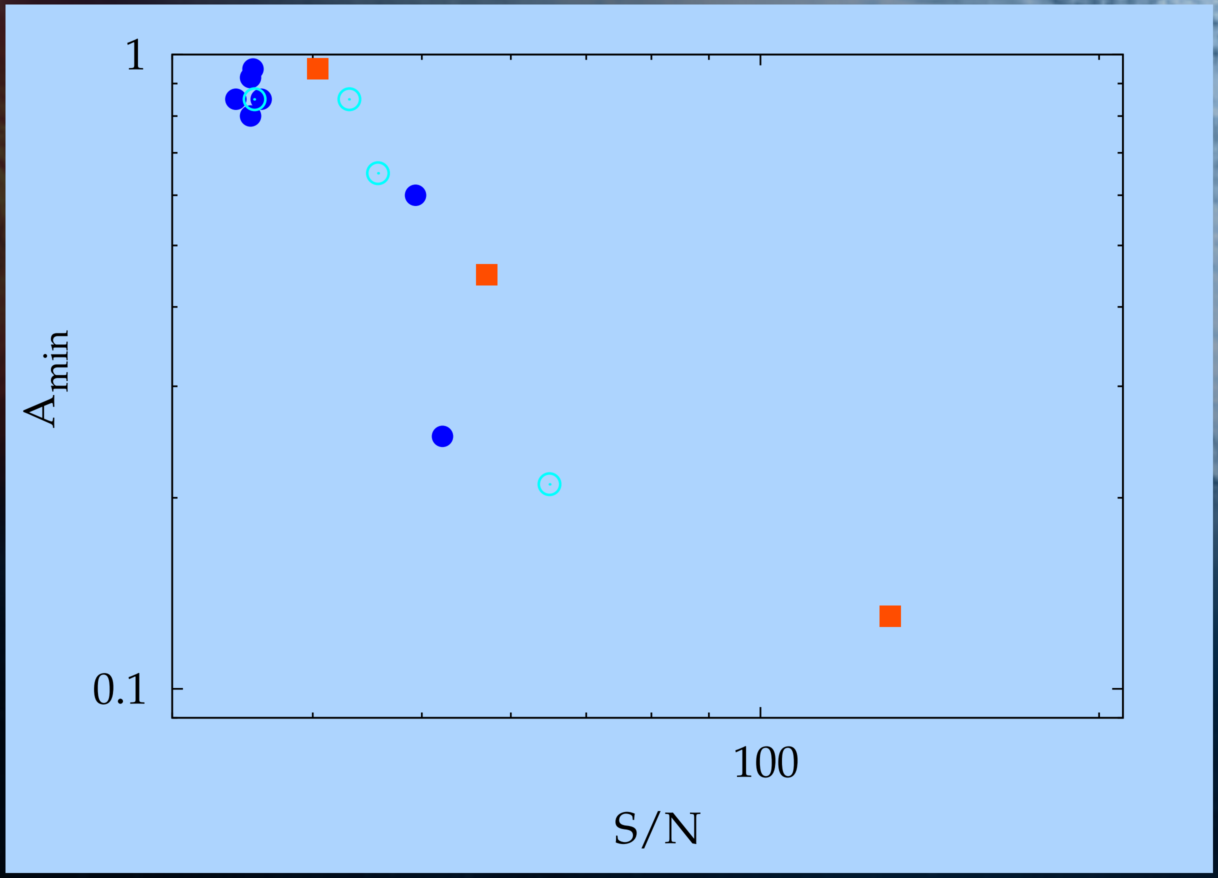
Gamma-Ray Bursts

search of 44 short GRBs with Fermi/GBM, Swift/BAT and BATSE

none found, but useful upper limits!



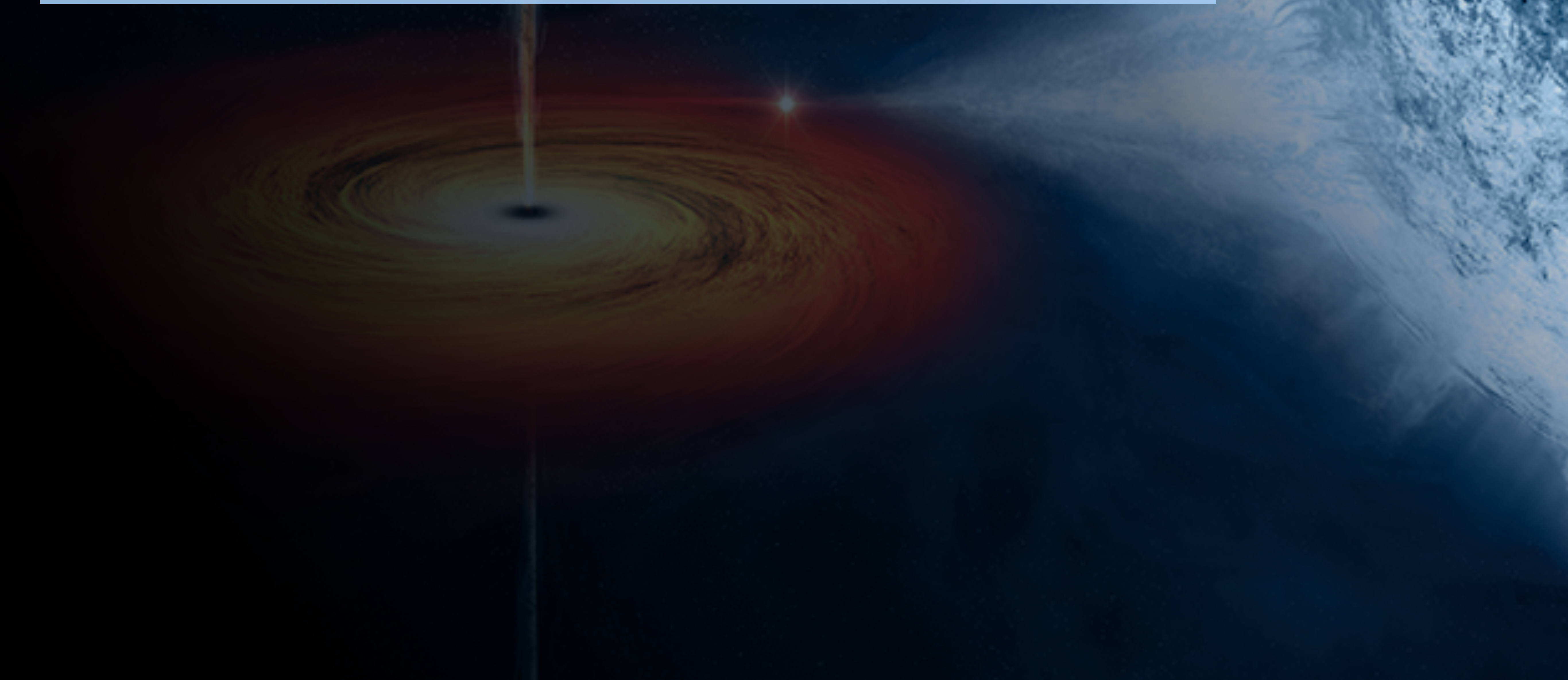


Dichiara et al (2013)

X-ray Binaries: A 0535+26 and V404 Cygni

the canonical QPO sources!

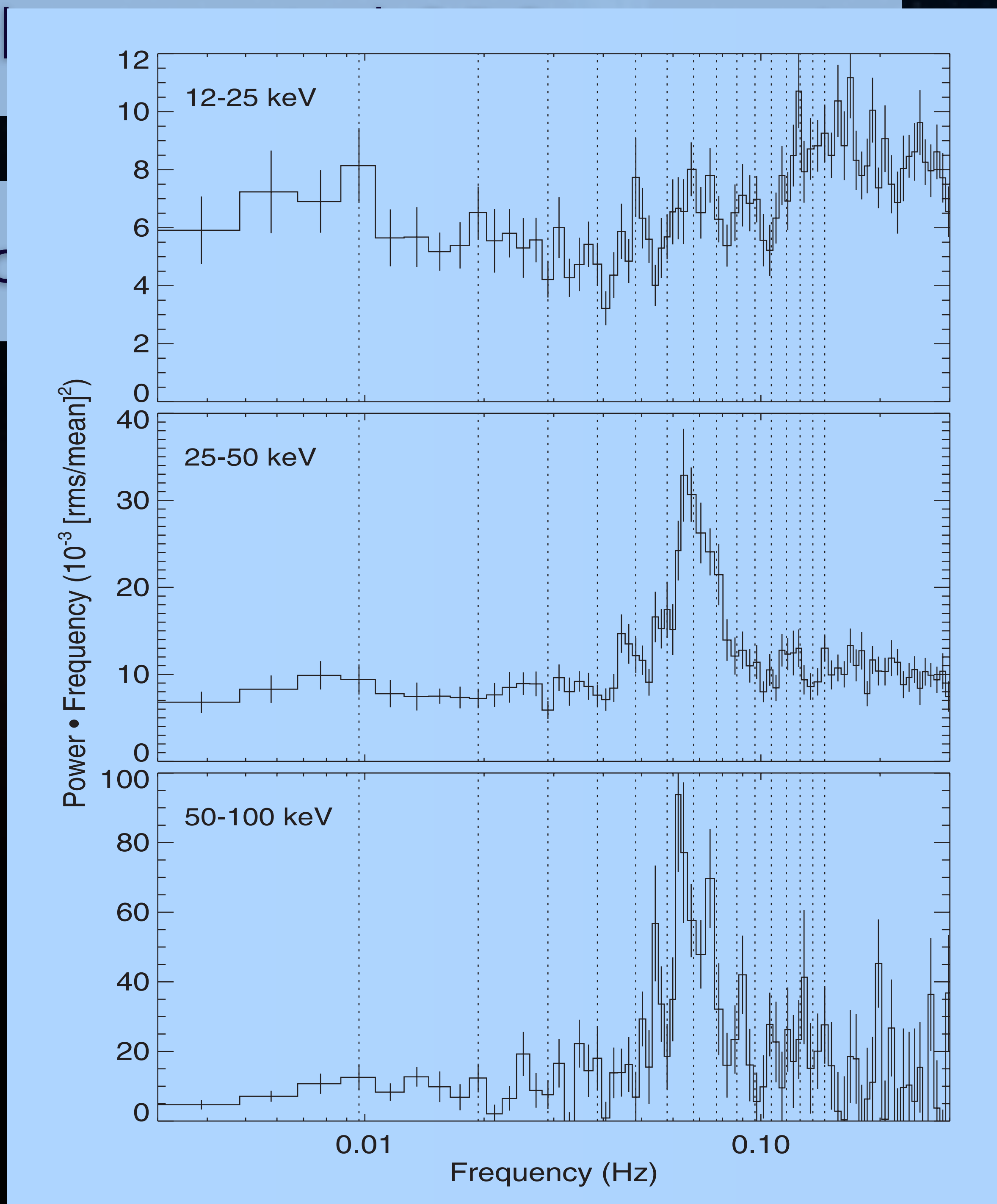
only two sources with Fermi/GBM QPO detections?



X-ray Binaries: A 0535+26 and V404 Cygni

tl

c ... l QPO detections?



Camero-Arranz et al (2012)

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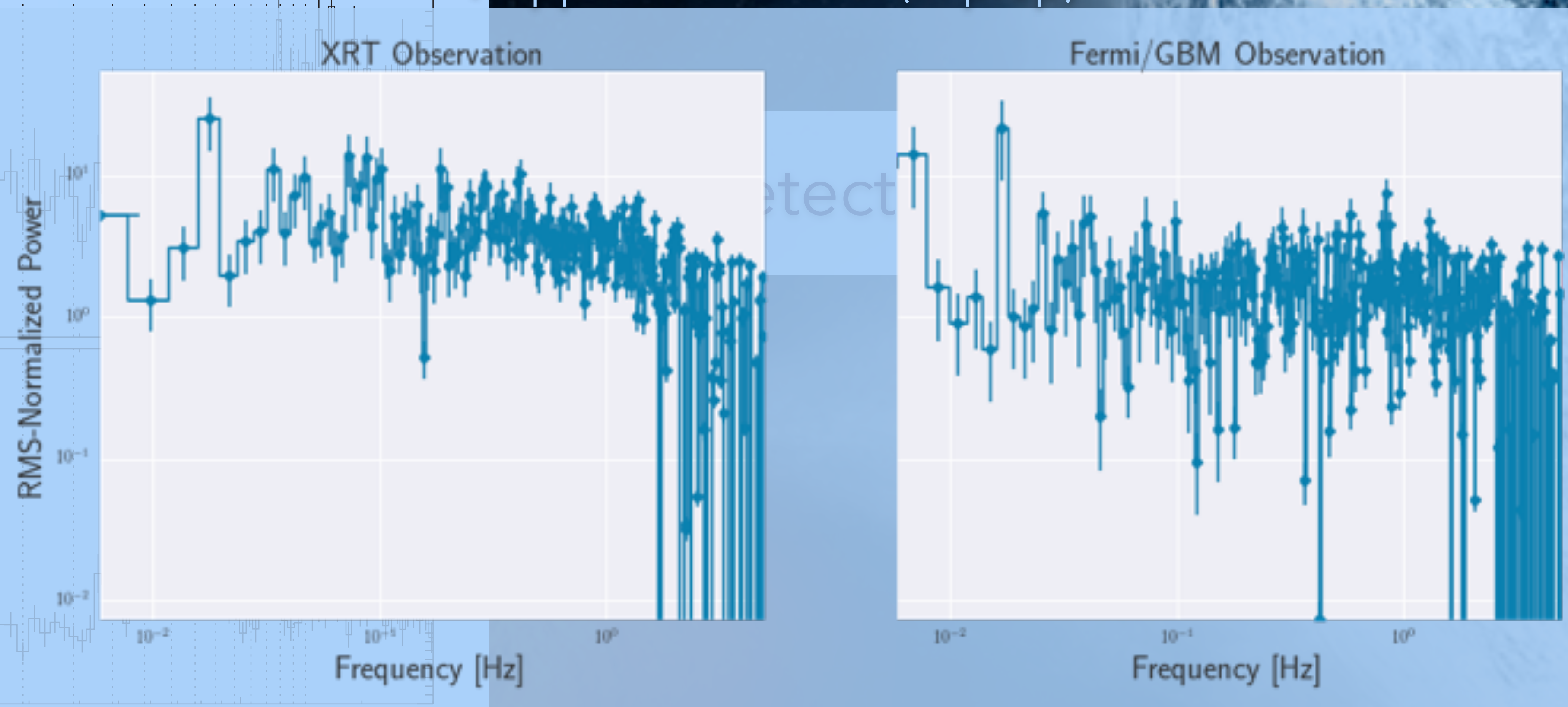
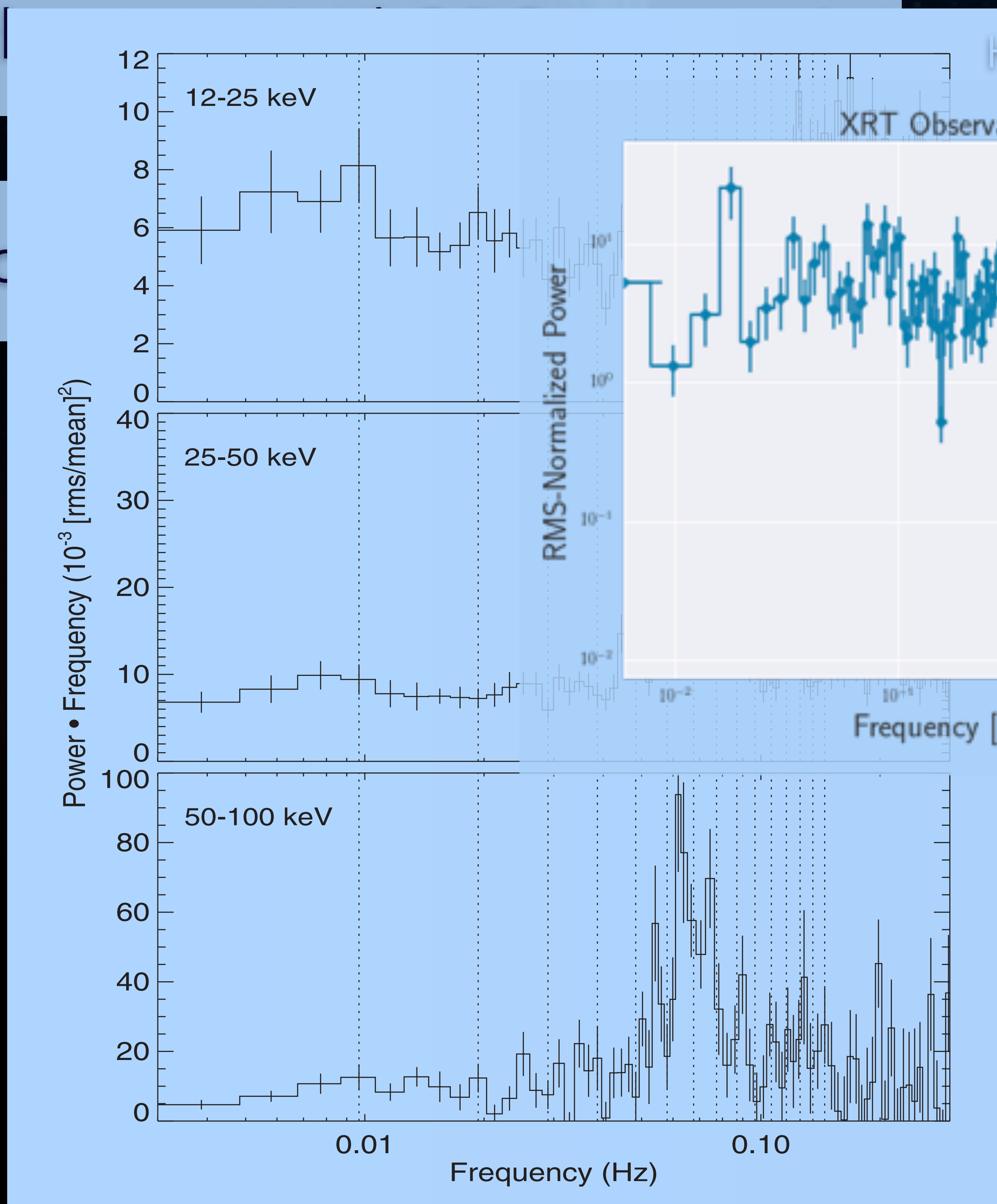
Huppenkothen et al (in prep)





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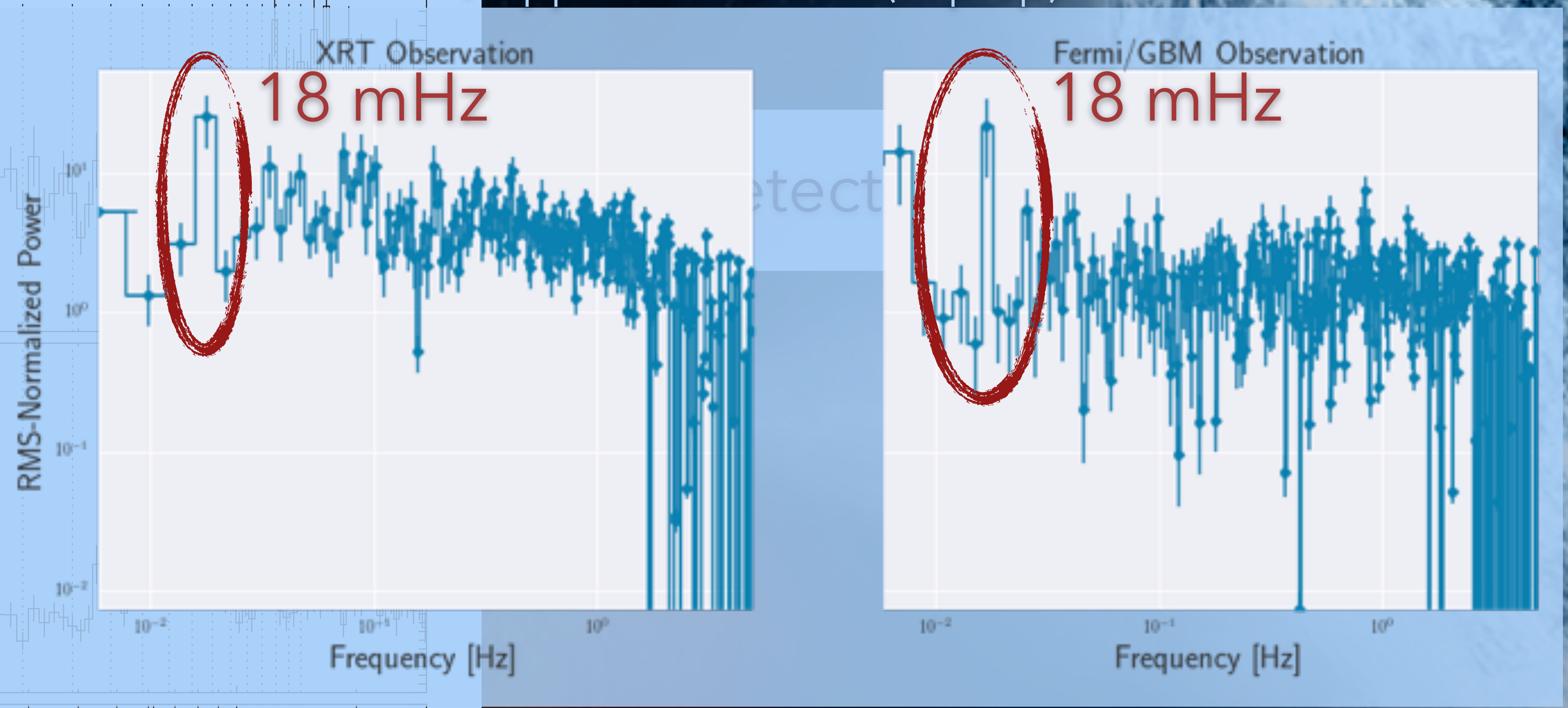
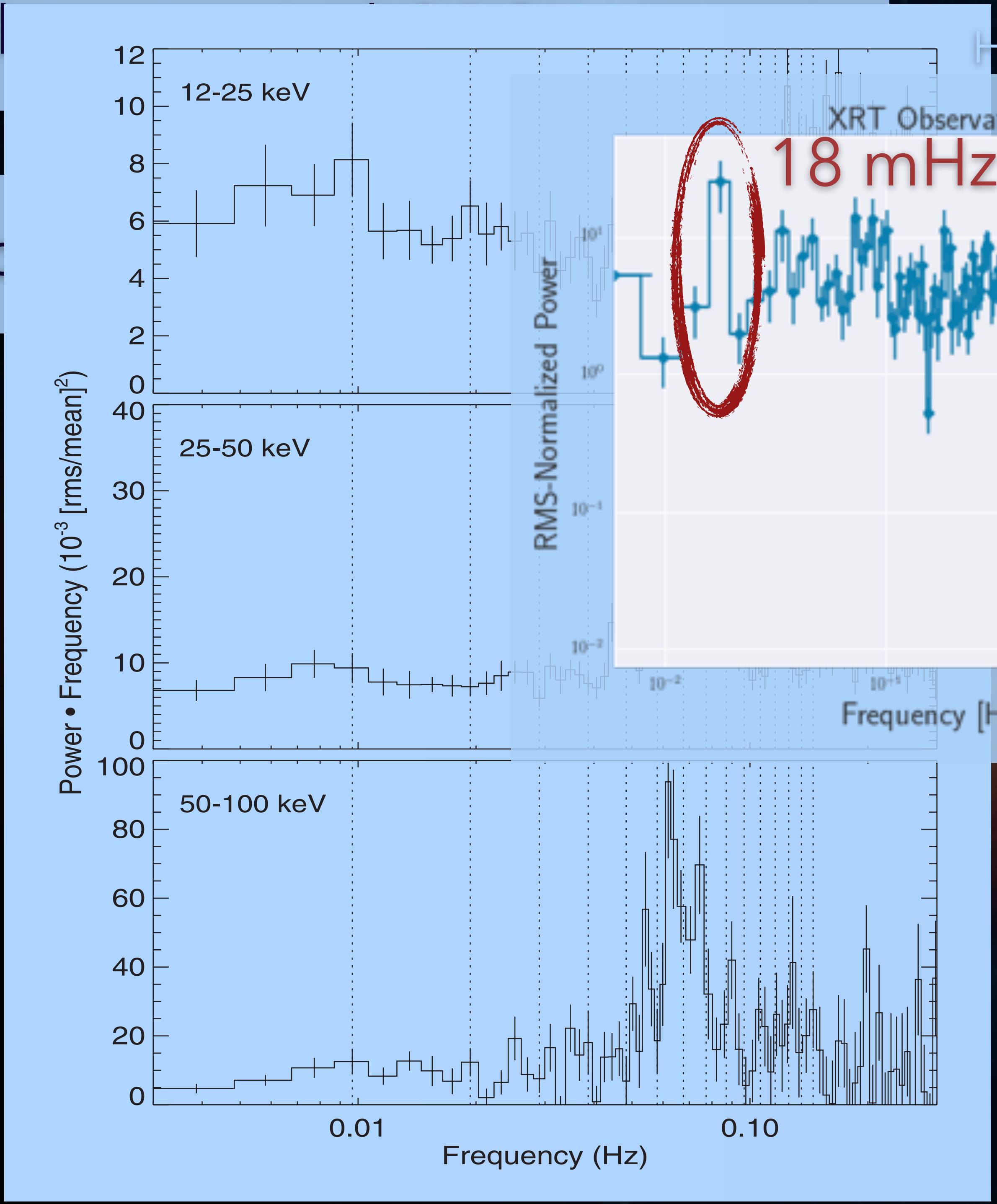
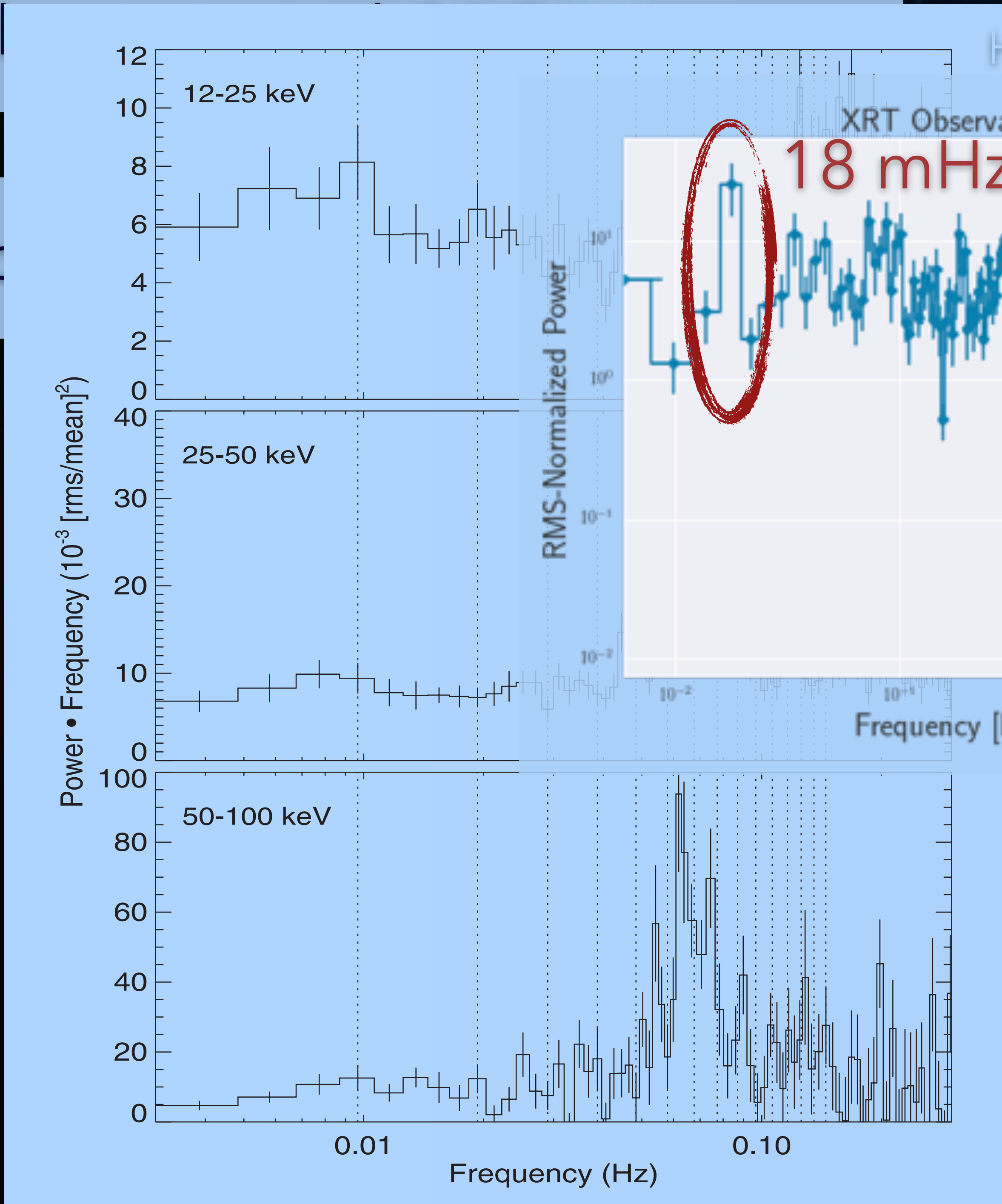
Huppenkothen et al (in prep)





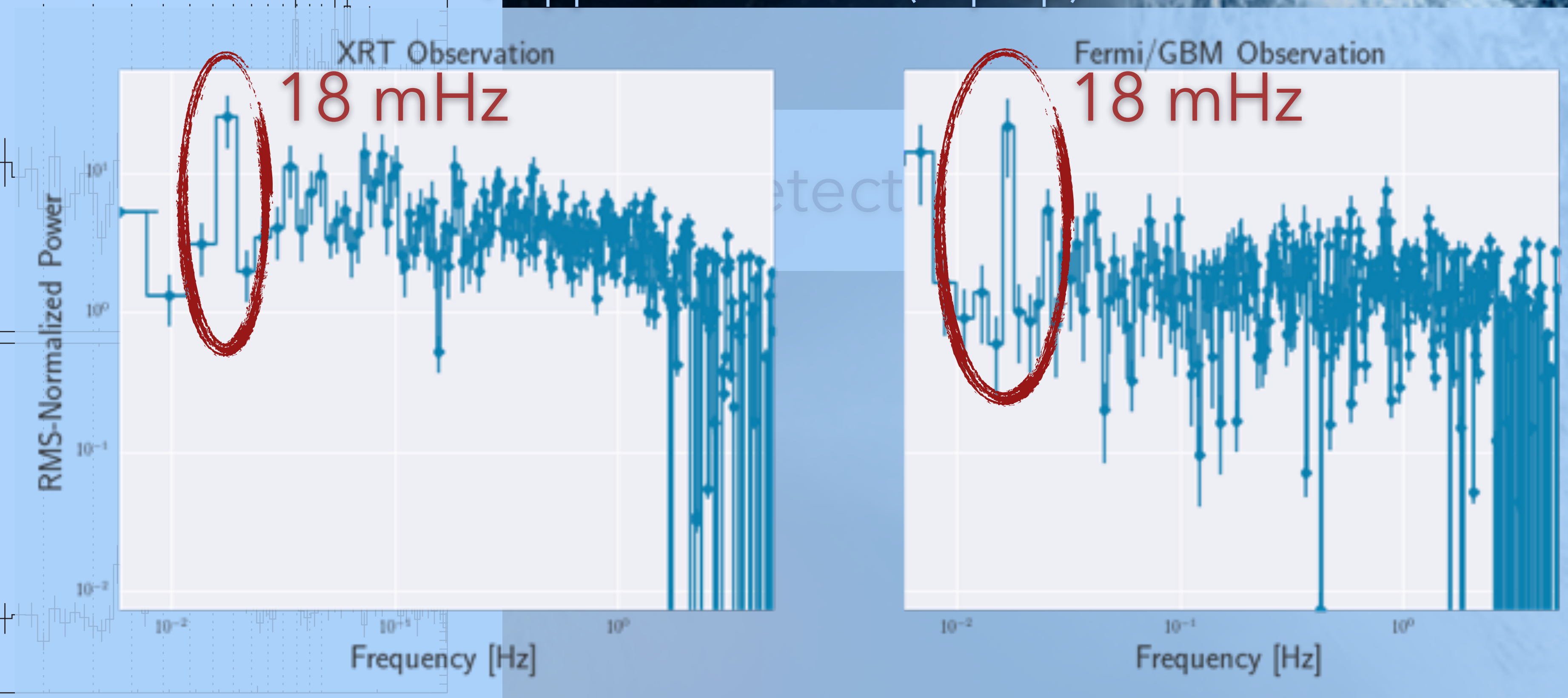
Camero-Arranz et al (2012)

X-ray Binaries: A 0535+26 and V404 Cygni



Camero-Arranz et al (2012)

Huppenkothen et al (in prep)



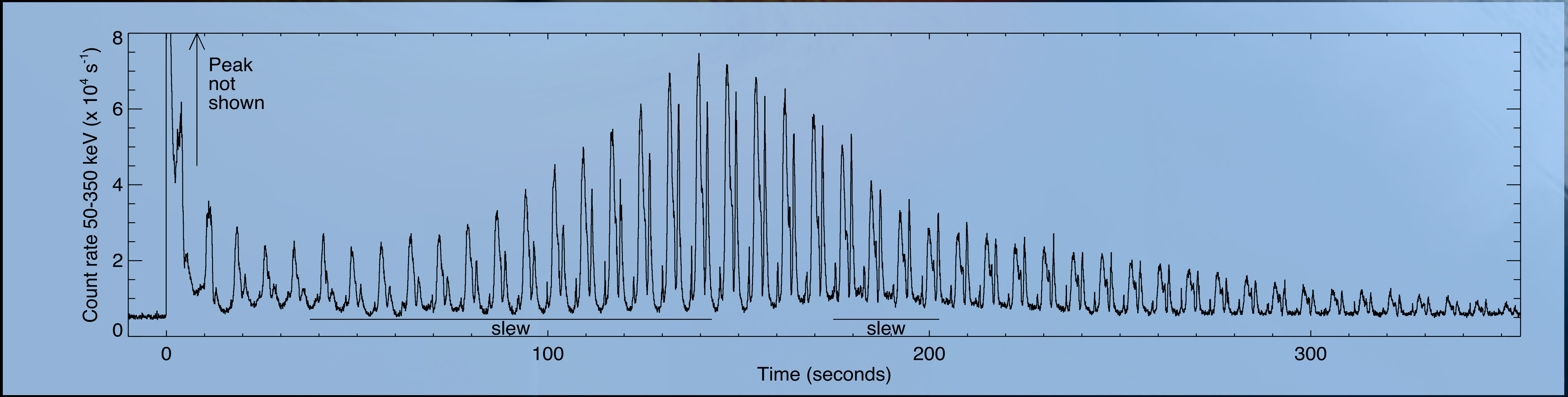
see also Peter Jenke's talk in this session!

Magnetars

QPOs seen in giant flares: believed to be neutron star quakes

constrain neutron star equation of state

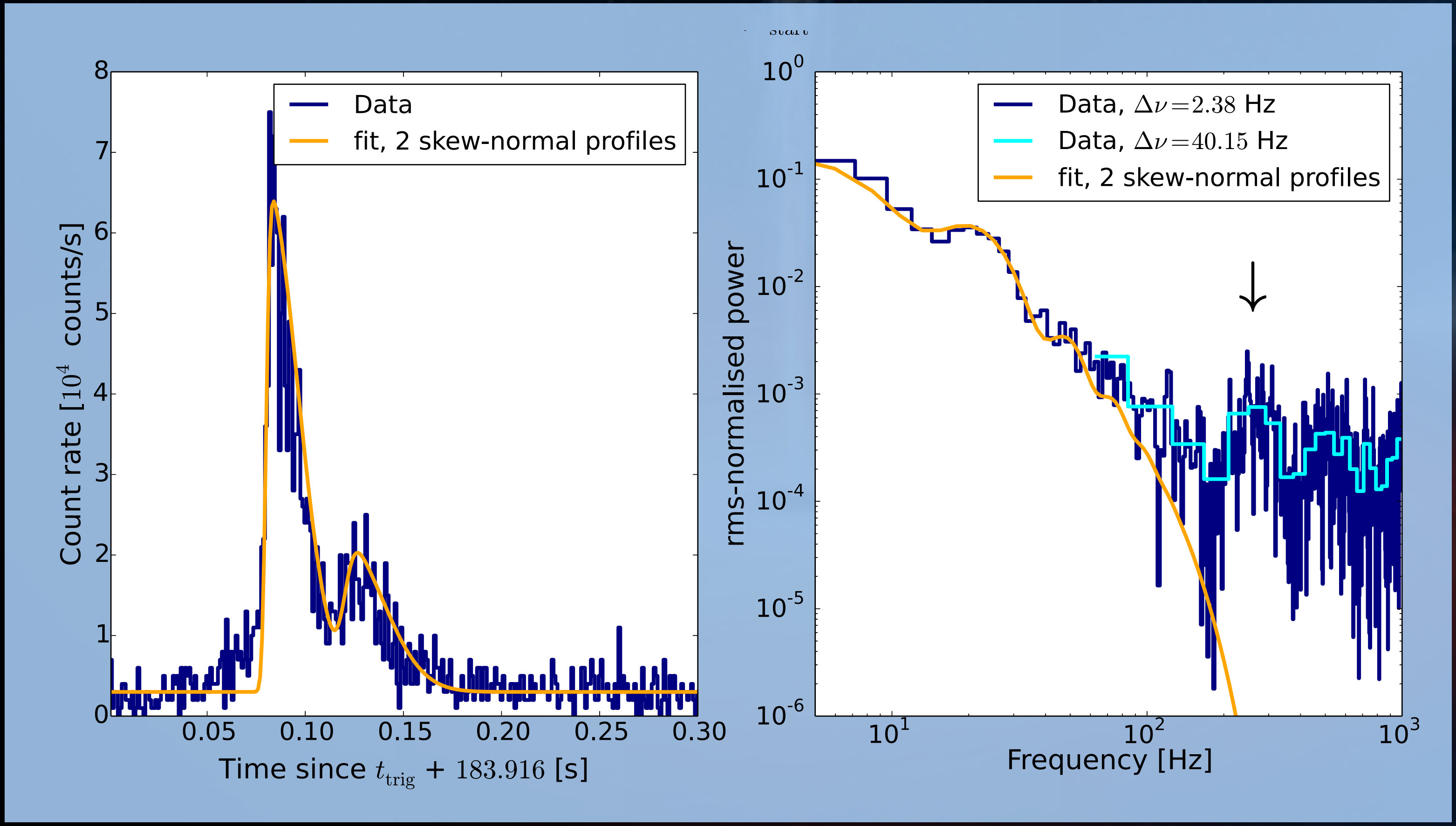
only few giant flares: search short bursts

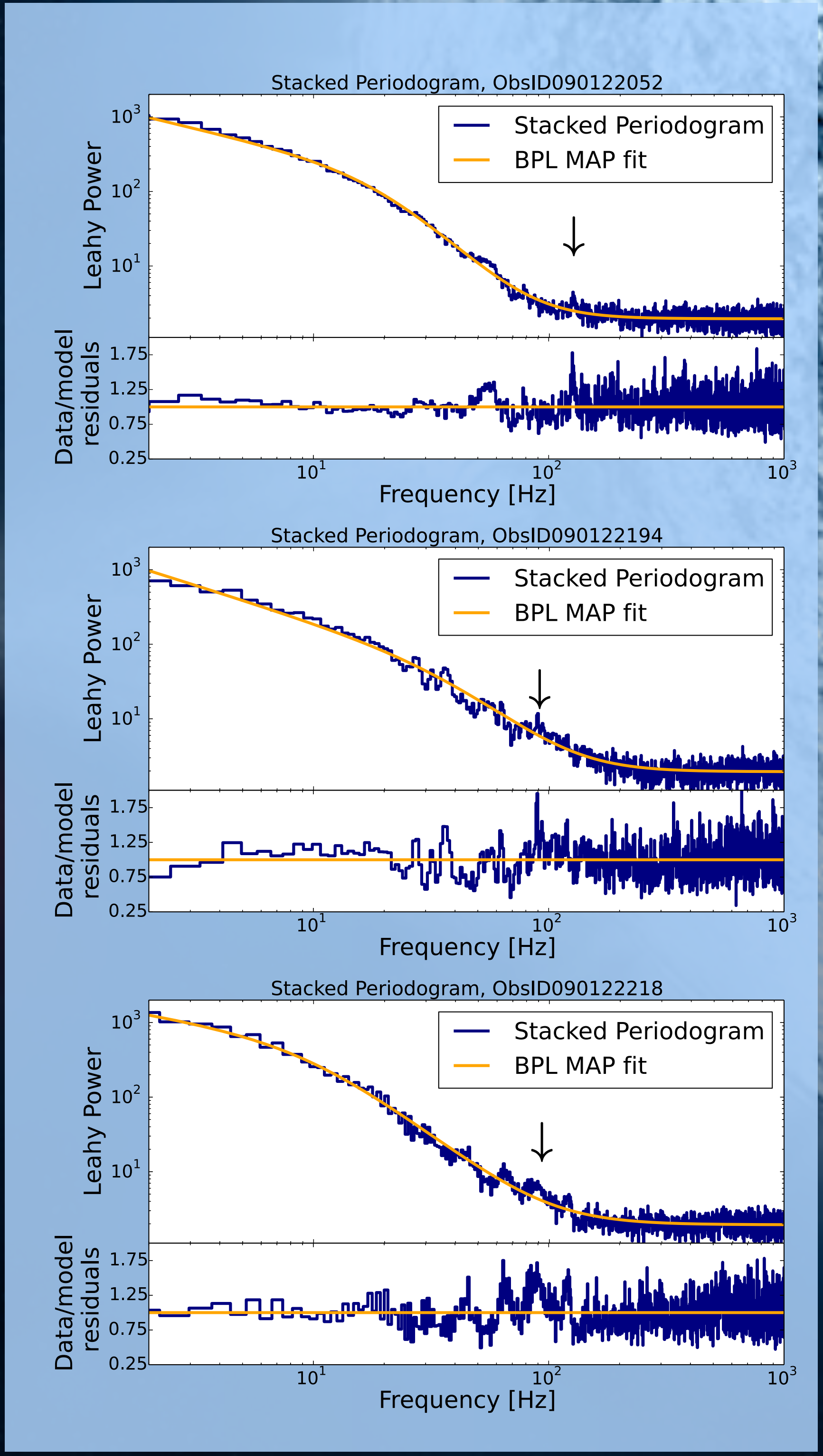


Palmer et al (2005)

Magnetars

only few giant flares: search short bursts





Huppenkothen et al (2014)

Future Directions: better methods!

stationarity assumption of Fourier transform problematic

empirical models will get us only so far: need light curve models!

move QPO detection back into the time domain!

Future Directions: observations

Fermi/GBM is a great tool for monitoring + sample studies

CTTE data allows of contemporaneous studies at high time resolution with other instruments

spacecraft motion make timing on long timescales complex

CTTE data could be used more?

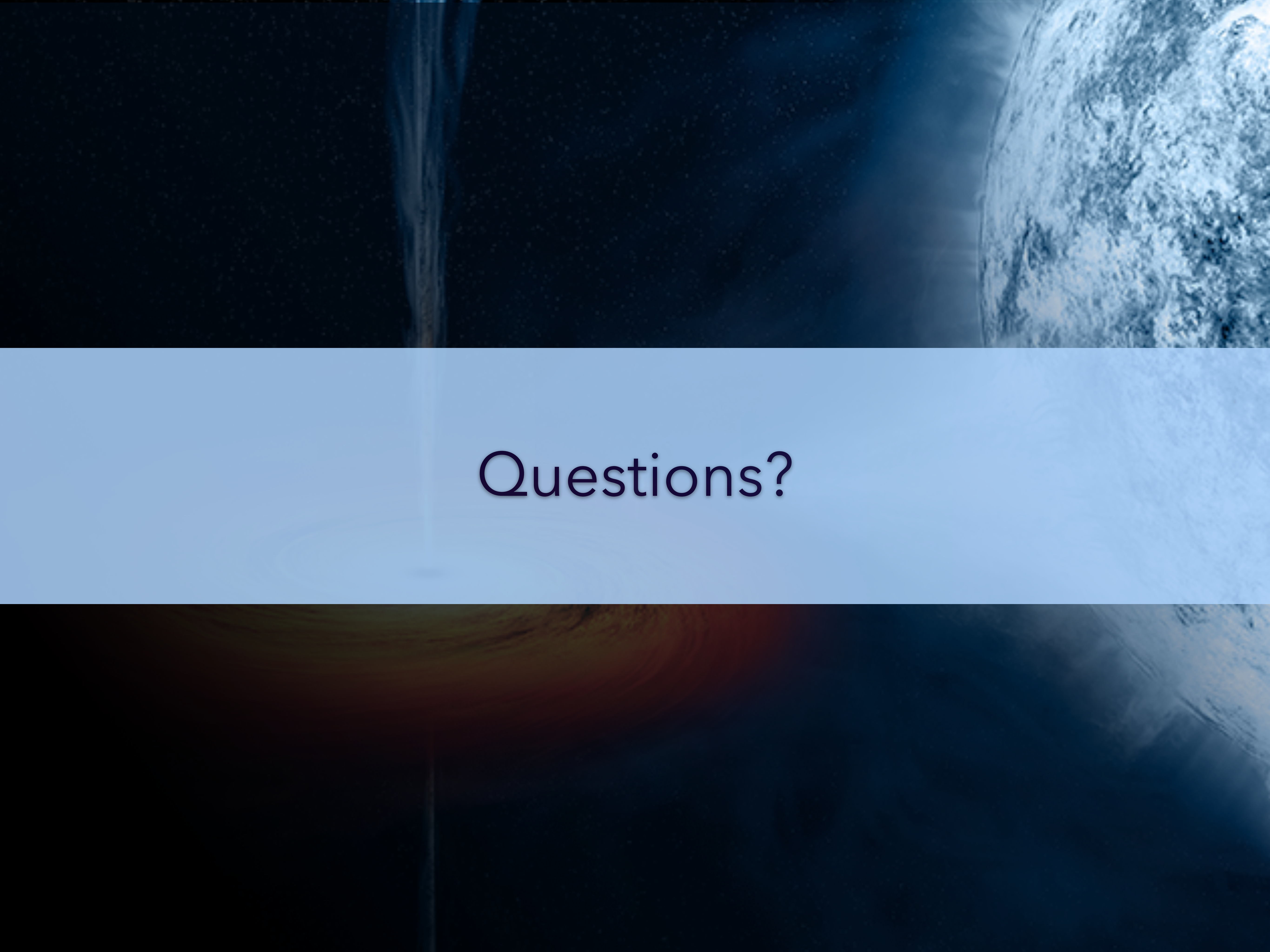
Conclusions

Many high-energy sources have characteristic time scales that can be probed using high-resolution X-ray data

Fermi GBM's triggers and CTTE data provide excellent data for timing studies at high time resolution

QPO detections in Fermi/GBM solar flares, magnetar bursts and X-ray binaries have led to progress in understanding the underlying physical phenomena

Future progress includes methods + efficient use of CTTE data


Questions?