Periodicity Detection with Stingray

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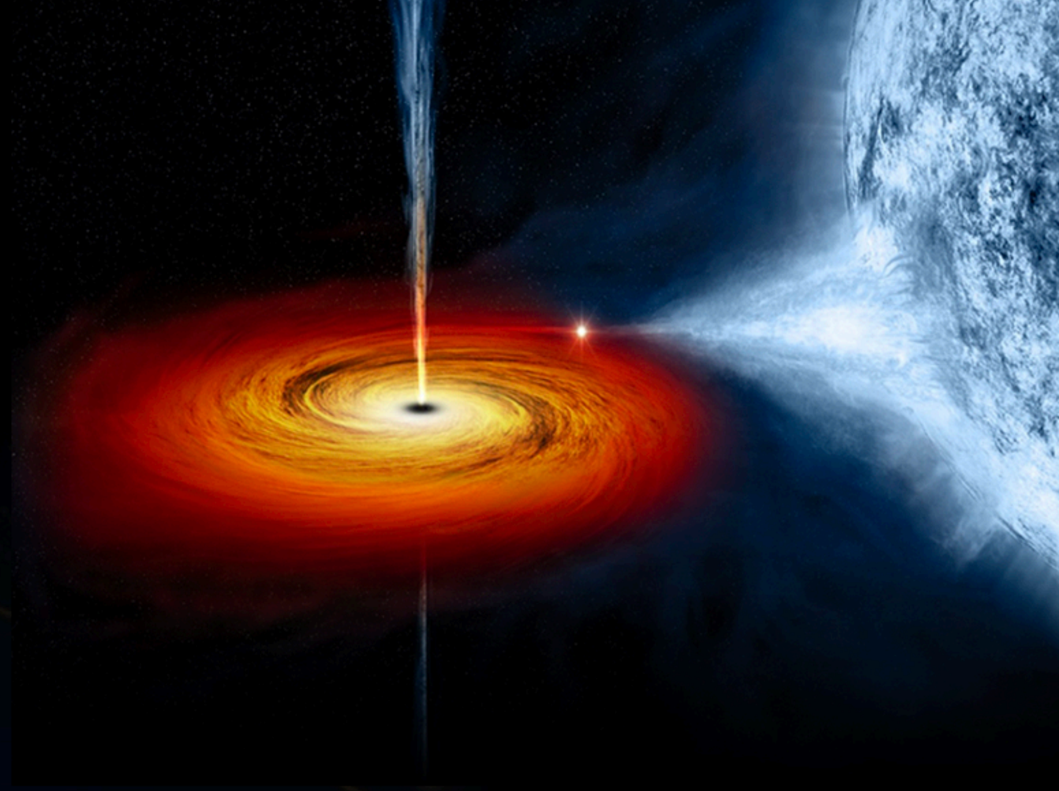
eScience Institute, University of Washington



eScience Institute
ADVANCING DATA-INTENSIVE DISCOVERY IN ALL FIELDS

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These materials:

https://github.com/tloredo/AAS237-TimeSeries

Documentation:

https://stingray.readthedocs.io/en/latest/index.html

Tutorials:

https://github.com/stingraysoftware/notebooks

Iconic 60s Theme Song:

https://youtu.be/sgkk-MMif-4?t=50

Terminology:

“energy” = photon energy (i.e. photon wavelength)

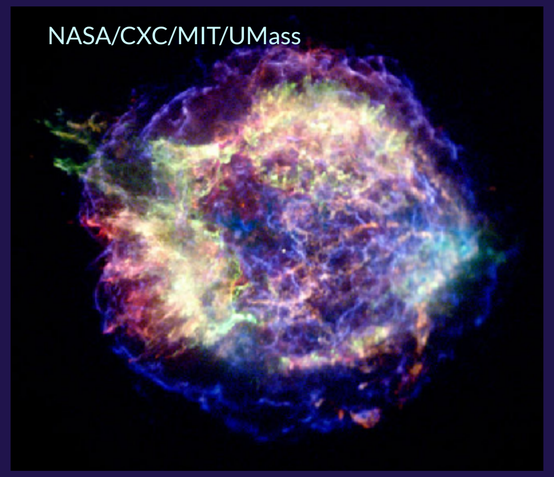
“frequency” = Fourier (temporal) frequency

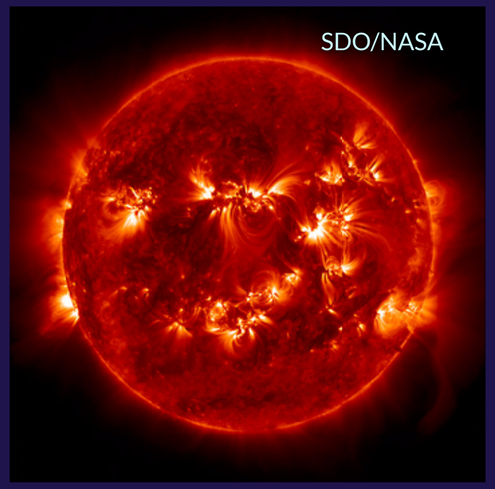
Terminology*:

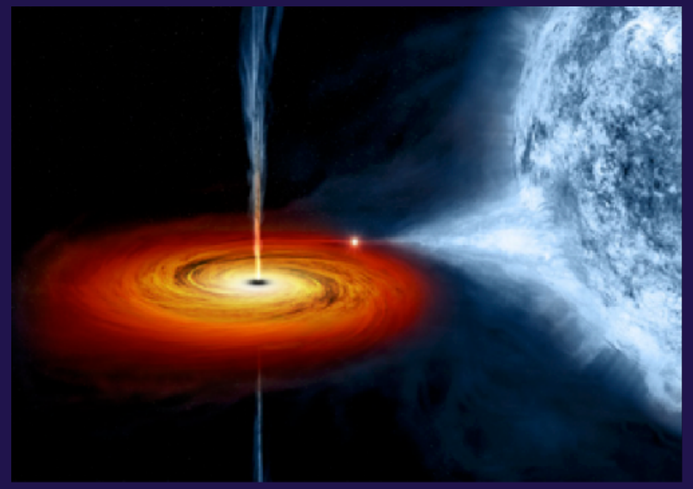
“periodogram” = an observed random realization of a stochastic process

“power spectrum” = the underlying physical process that generated the observation

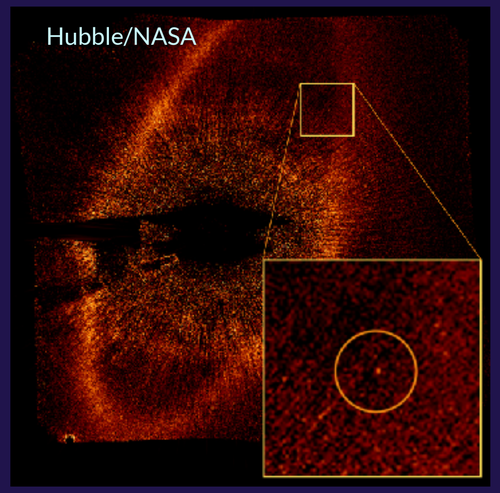
***except in Stingray**

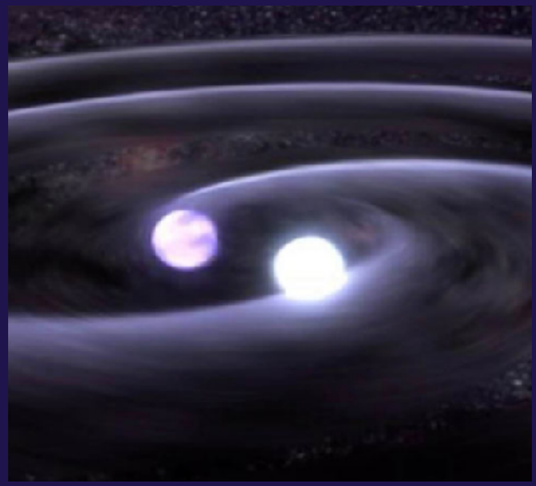






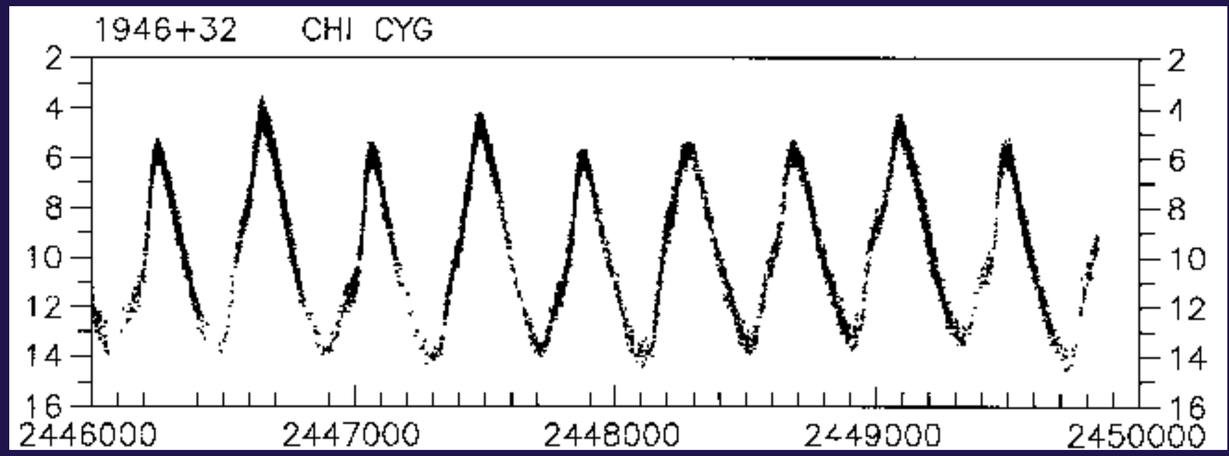
Almost all things in the sky are variable.





stars

stars


1946+32 CHI CYG
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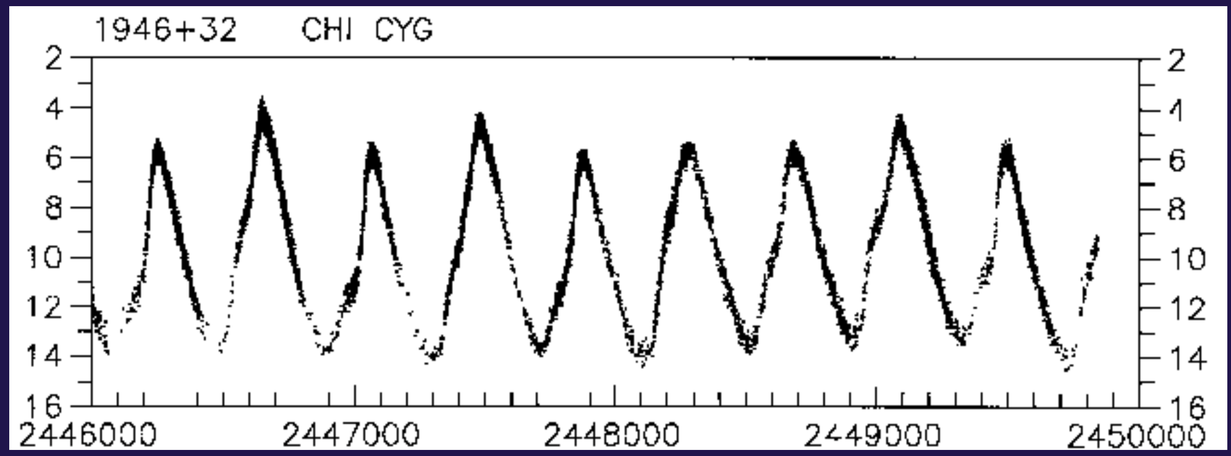
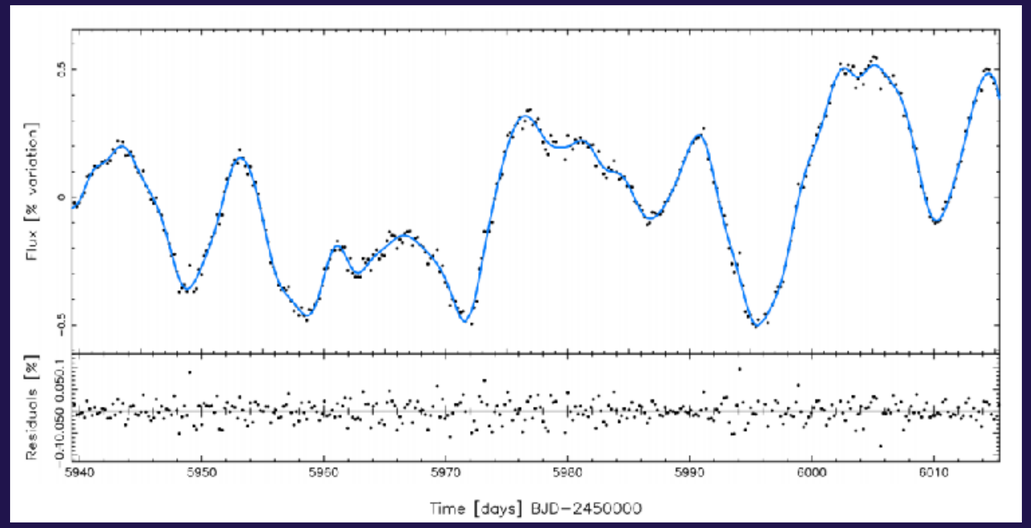
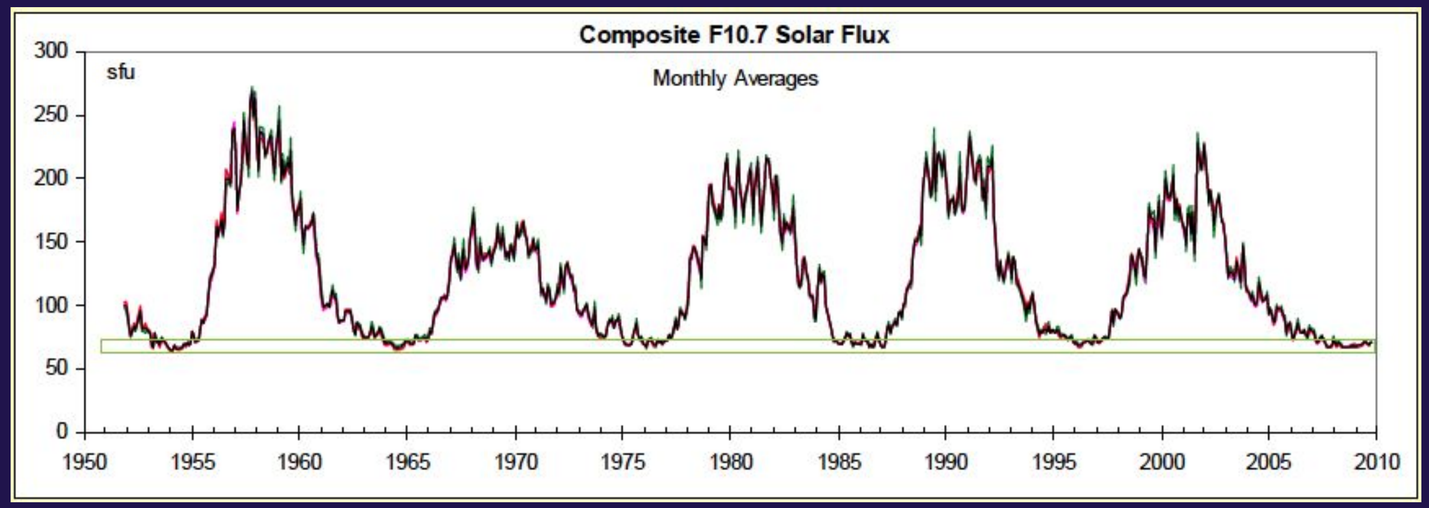
stars



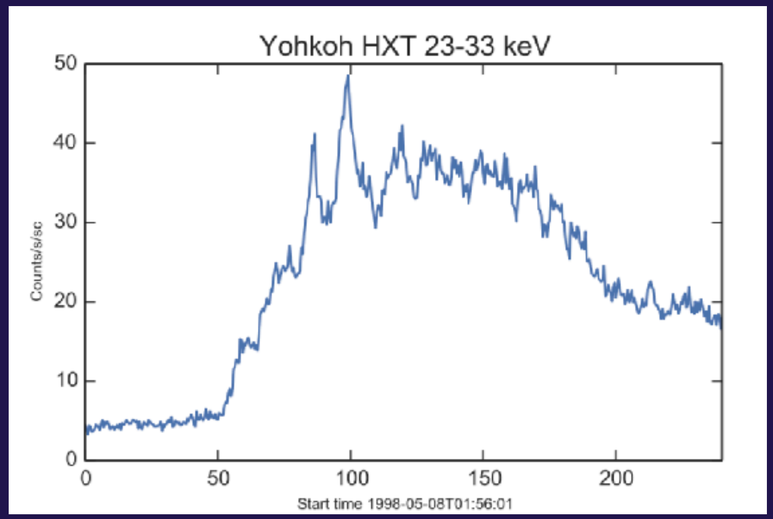


Haywood et al (2014)

the sun

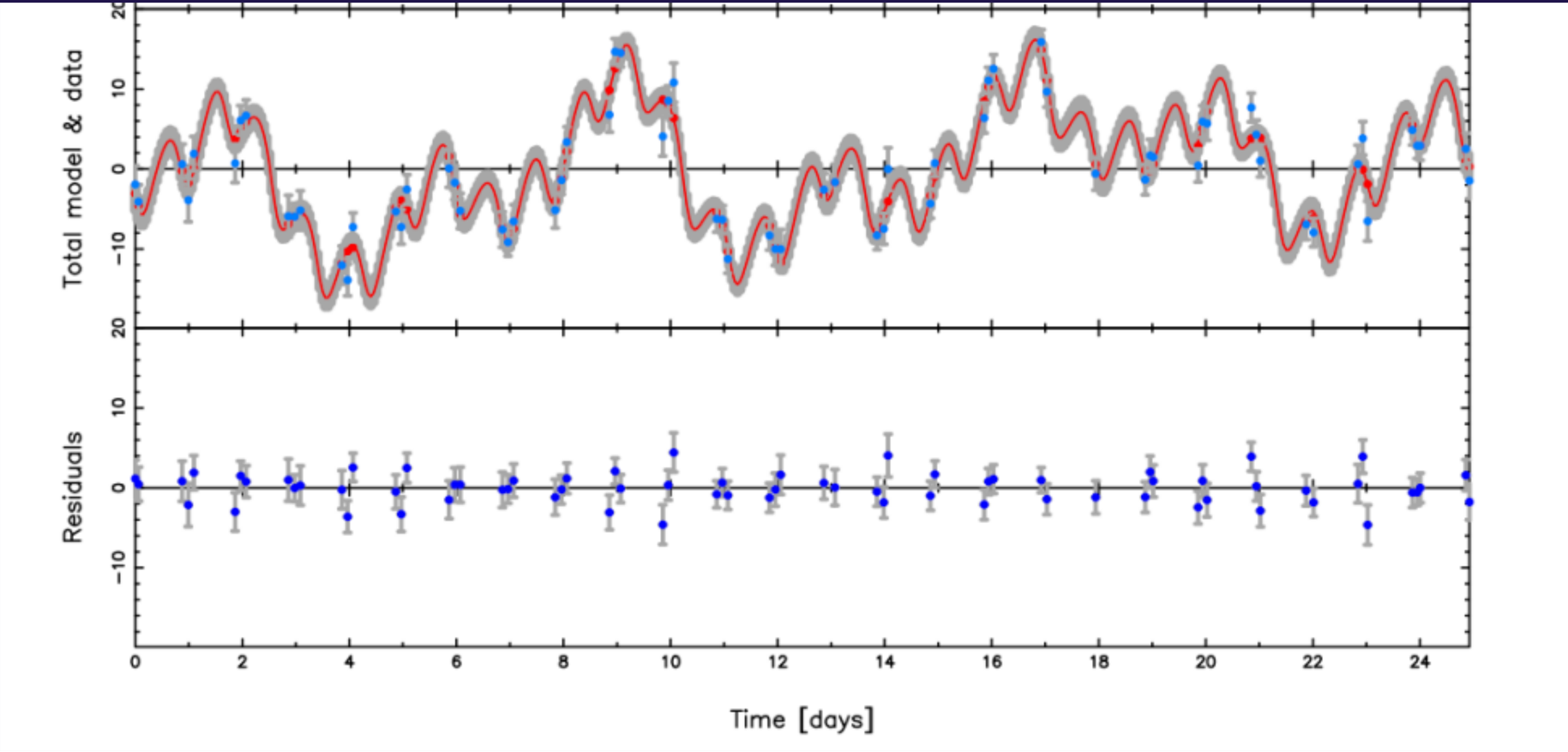


Svalgaard (2010)



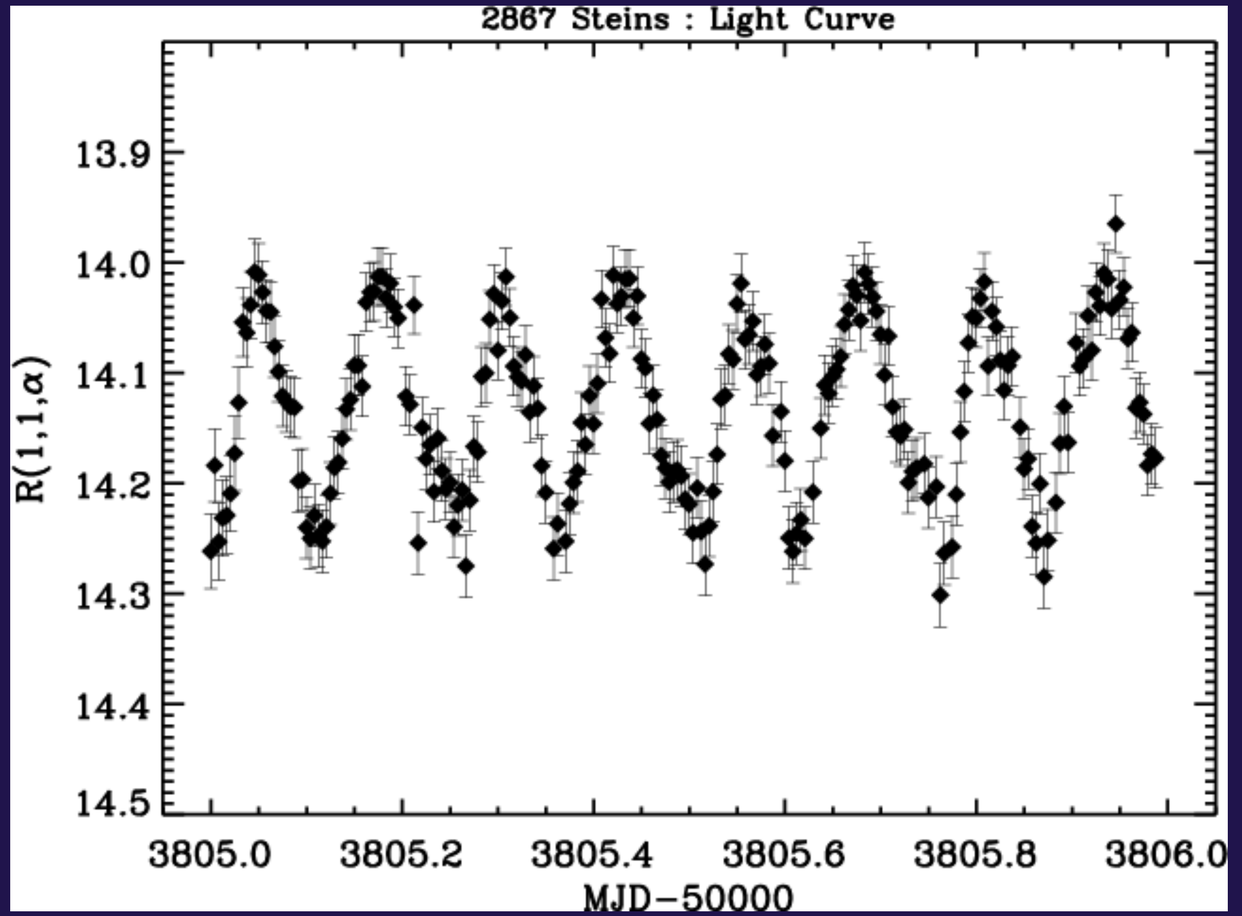
Inglis et al (2016)

(exo)planets

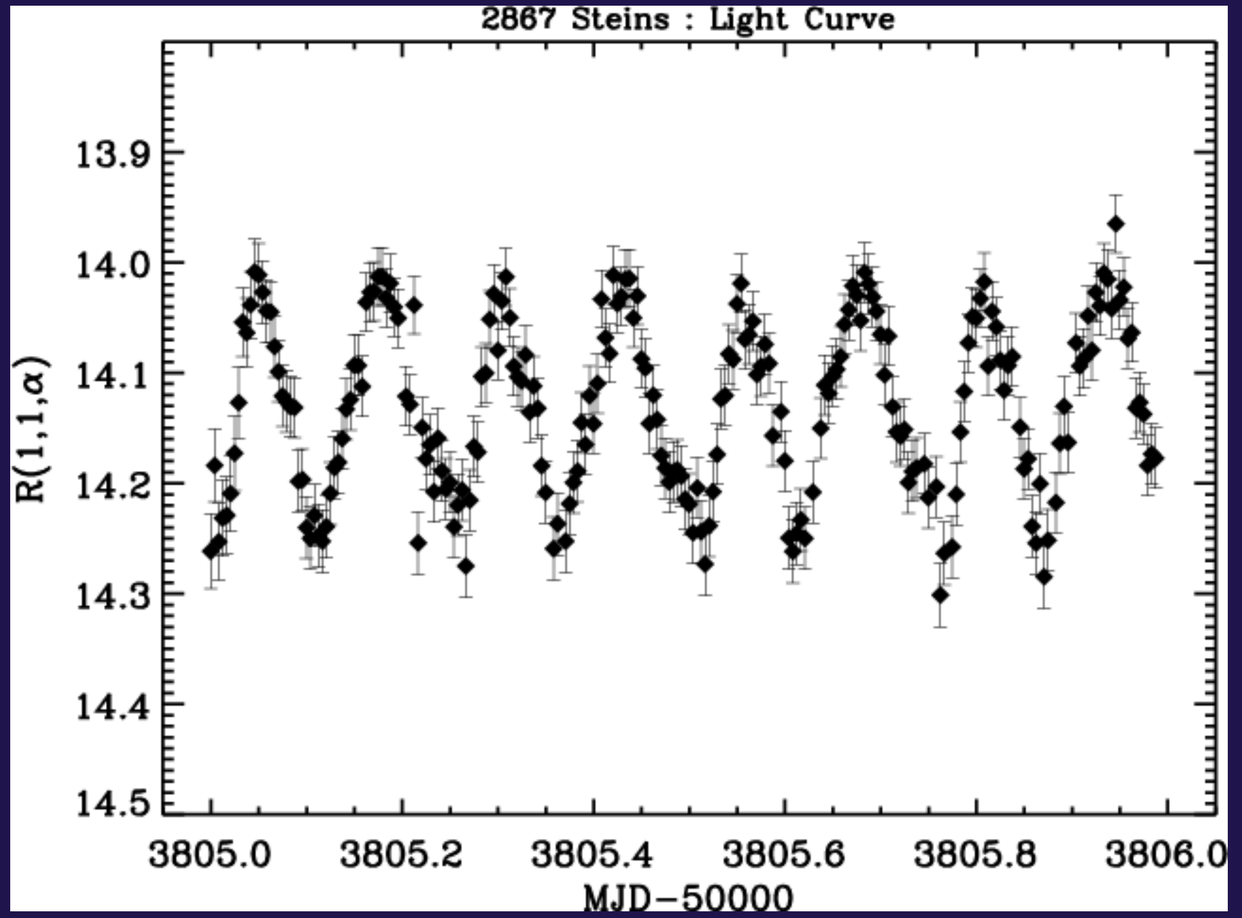


Haywood et al (2014)

asteroids


2867 Steins : Light Curve
13.9
14.0
14.1
14.2
14.3
14.4
14.5
R(1,1,α)
3805.0
3805.2
3805.4
3805.6
3805.8
3806.0
MJD−50000

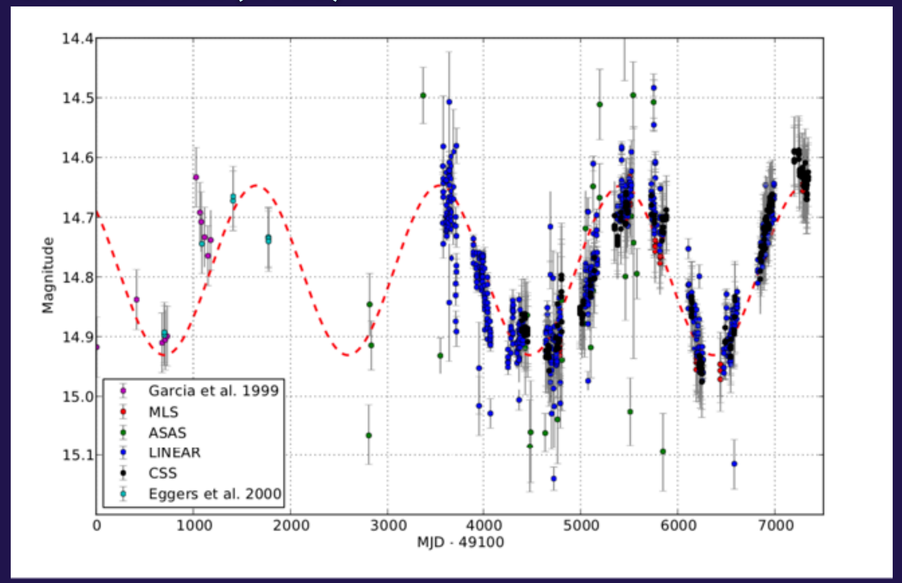
asteroids



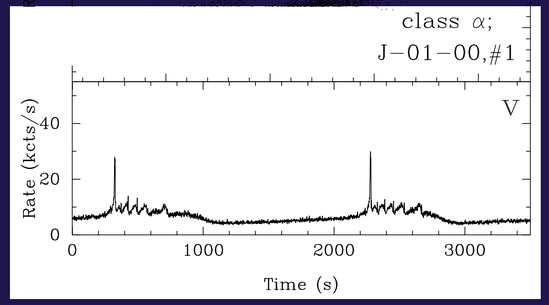
Lamy et al (2008)

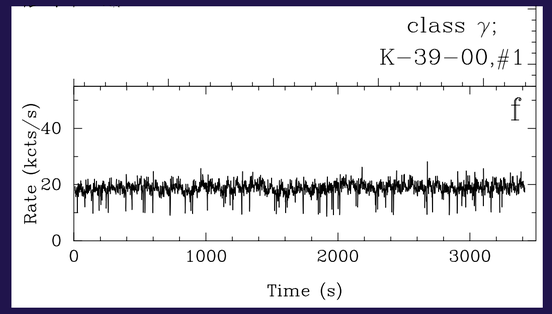
black holes

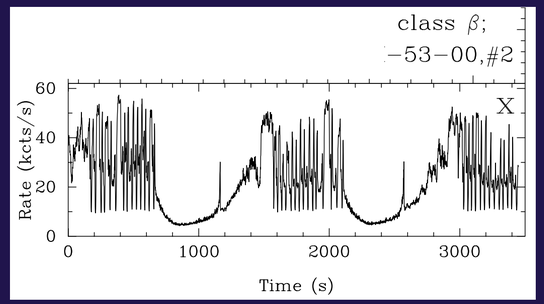
Graham et al (2015)



Belloni et al (2000)





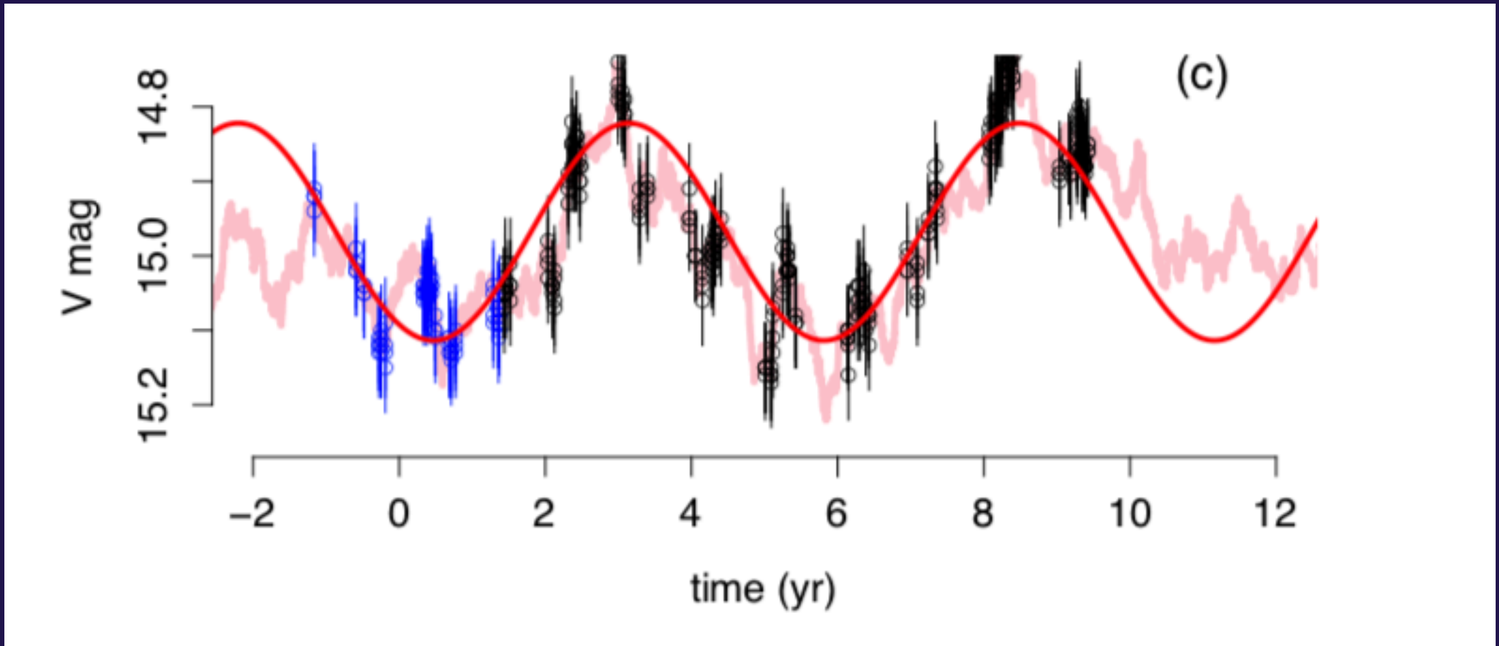


large

small

How do we tell whether something is periodic?

Are the data points in this light curve drawn from a periodic process?



* go to menti.com
* code: 45 43 63 4

*see: pareidolia

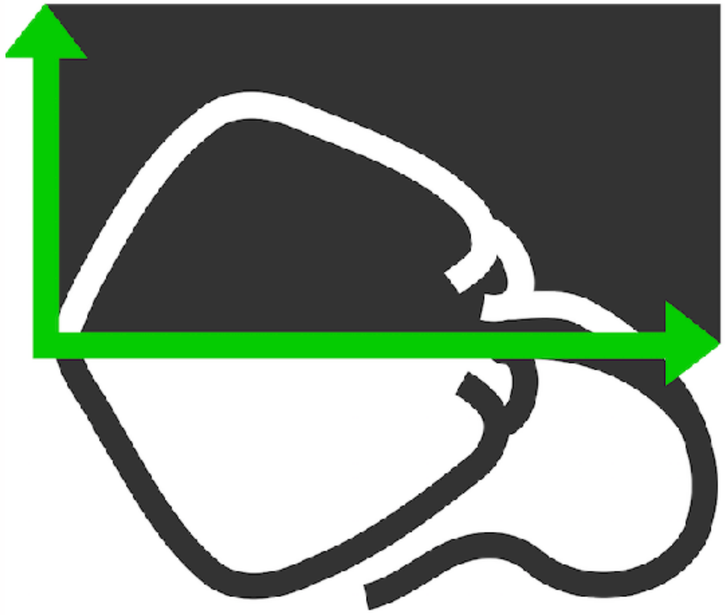
the human brain is prone to overfitting* + see spurious patterns

(awesome for survival, less awesome for science)

*see: pareidolia

(awesome for survival, less awesome for science)

Let’s find out how to look for periods together …



Stingray

The Next Generation
Spectral-Timing Software

- 3 lead developers/maintainers (Huppenkothen, Bachetti, Stevens)
- ~10 contributors
- 5 completed Google Summer of Code Projects
- astropy-affiliated project
- provides functionality for HENDRICS and DAVE

https://github.com/StingraySoftware

Huppenkothen et al (2019)

Top-level functionality

Events
Lightcurve
Powerspectrum / Crossspectrum
AveragedPowerspectrum / AveragedCrossspectrum
Crosscorrelation / Autocorrelation
Bispectrum
Lag-Energy Spectra
supporting functionality: statistics, good time intervals, I/O

Sub-modules

pulse
modeling
simulator
deadtime

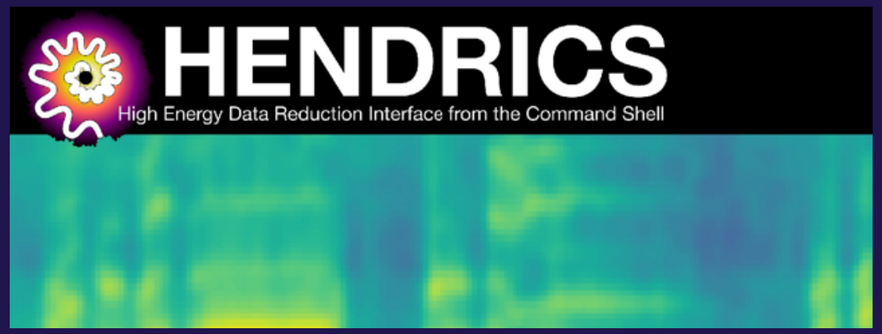
Where to get help

https://stingray.readthedocs.io

https://github.com/stingraysoftware

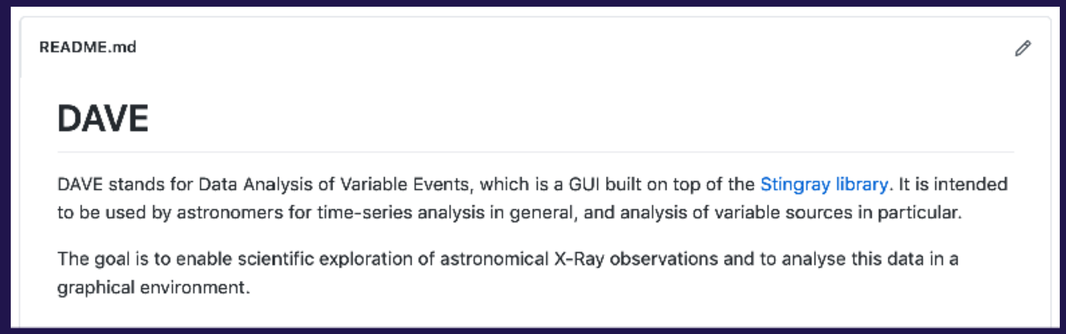
join the slack!

Extensions + Connections to other Packages



https://hendrics.readthedocs.io

command-line functionality built on Stingray



https://github.com/StingraySoftware/dave

GUI for exploratory data analysis

https://docs.lightkurve.org

easy conversion between Lightcurve objects

Current + Future Work

- fix bugs (there are always bugs)
- improve API (aka: what were we thinking?!)
- improve documentation (there is never enough documentation)
- performance + memory optimization (current GSoC project)
- better integration with current X-ray missions
- rework the modeling interface (e.g. autodiff)
- better integration with spectral modeling packages
- better integration with astropy.timeseries and lightkurve
- higher-order Fourier products

How to get involved

- find bugs (and report them as a GitHub Issue)
- fix bugs (as a GitHub Pull Request)
- make feature requests (also via GitHub Issue)
- implement new features (also via GitHub Pull Request)
- test documentation/tutorials (and report mistakes/fix bugs etc)
- ...

Don't know where to start?

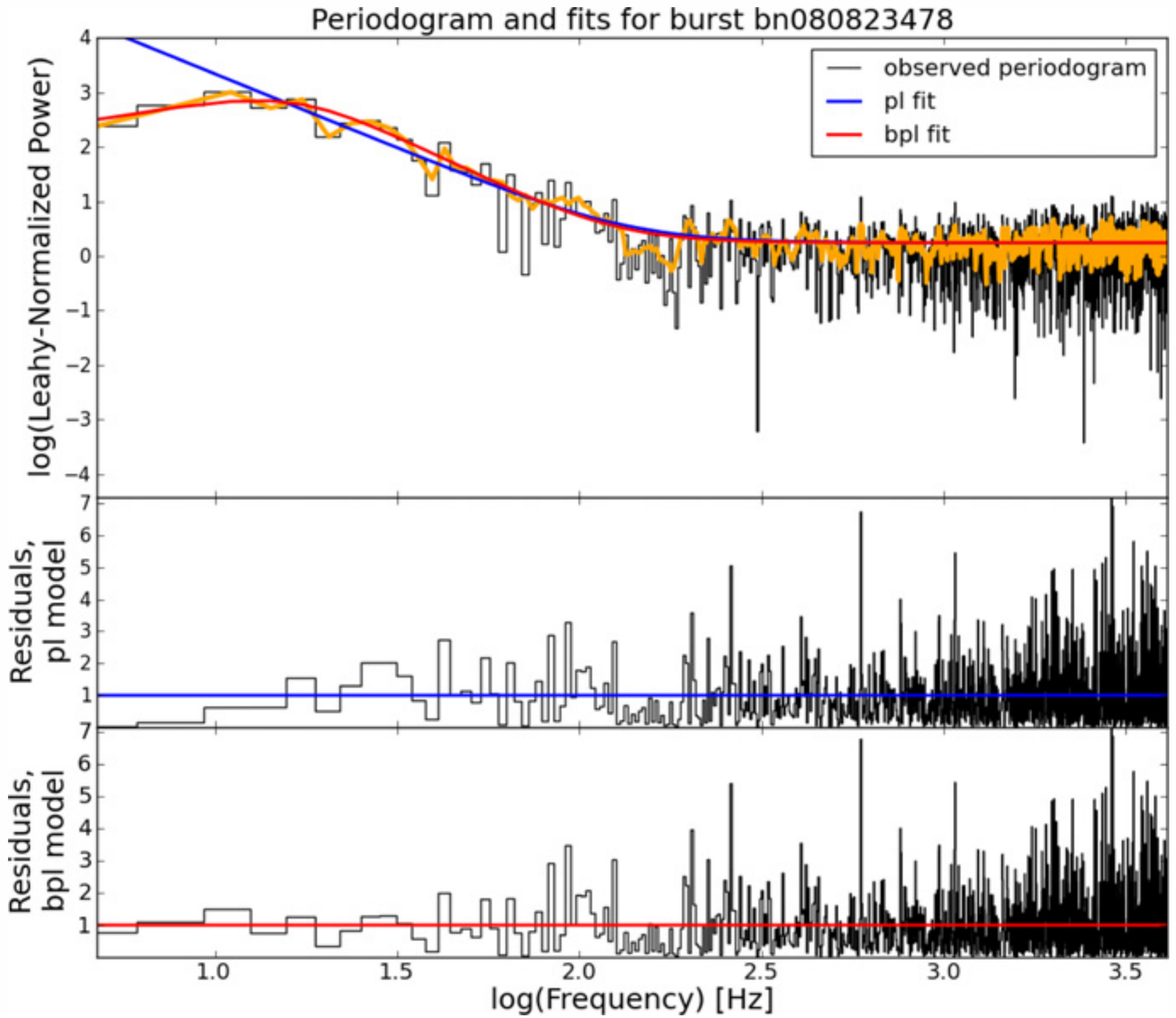
- "Good First Issue" tag on GitHub
- join the slack + ask us! We'll help :)

Let’s go and open a notebook …

AAS_PeriodicityDetection.ipynb

Model Fitting Approaches to Periodicity Detection

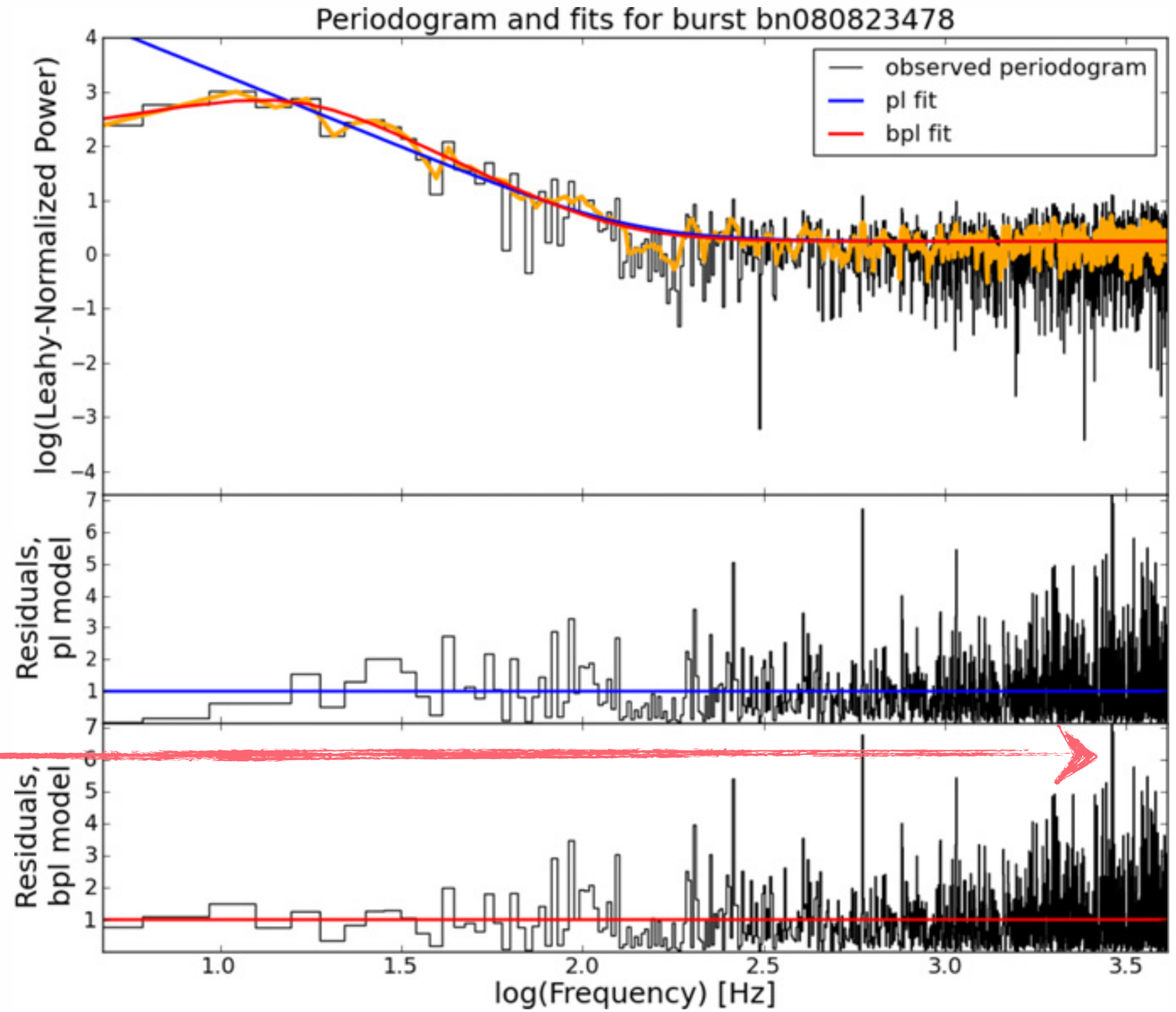
Step 1: Fit a broadband model



Vaughan (2010), Huppenkothen et al (2013)

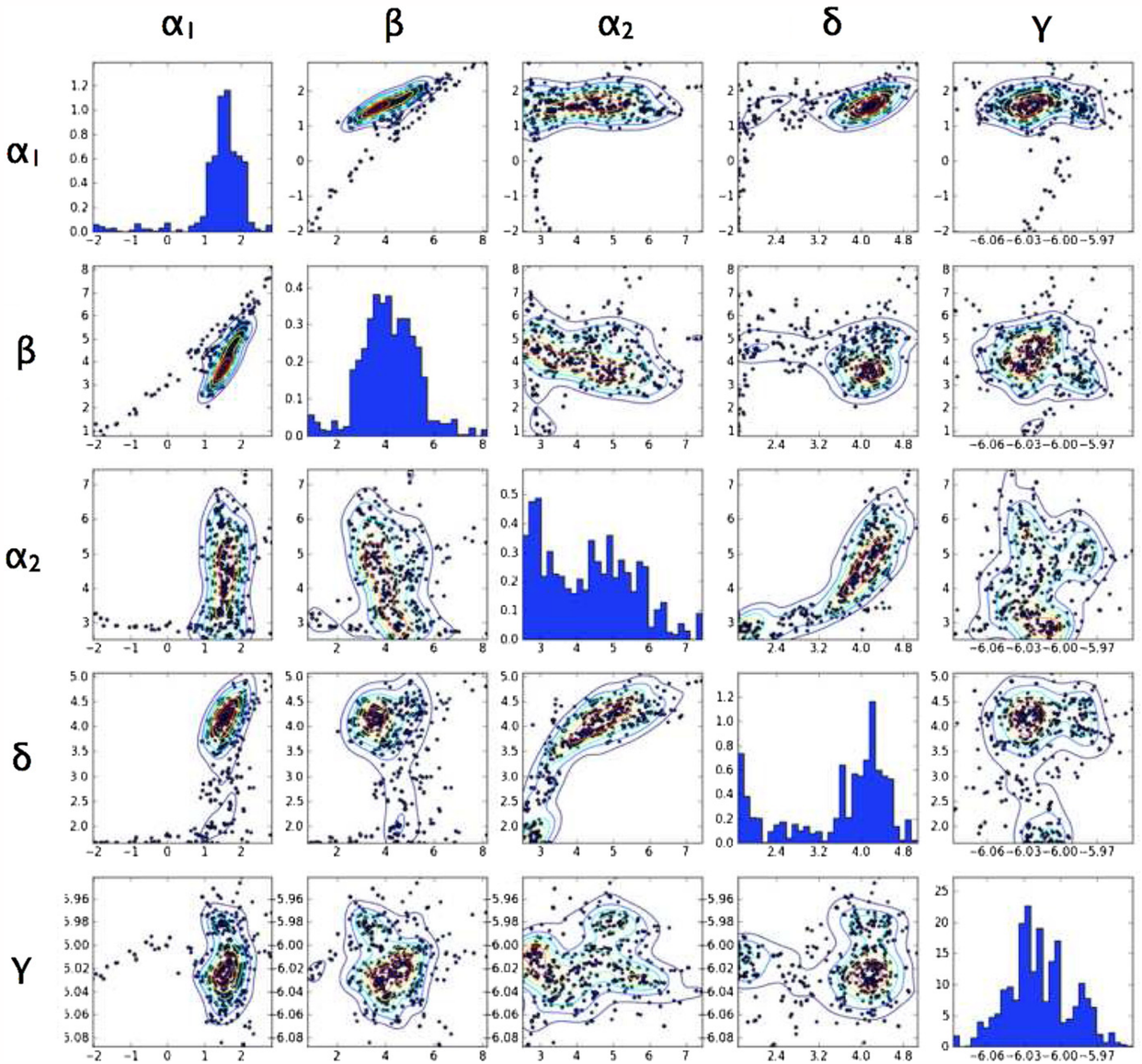
Step 1: Fit a broadband model

Step 2: Pick the highest outlier



Vaughan (2010), Huppenkothen et al (2013)

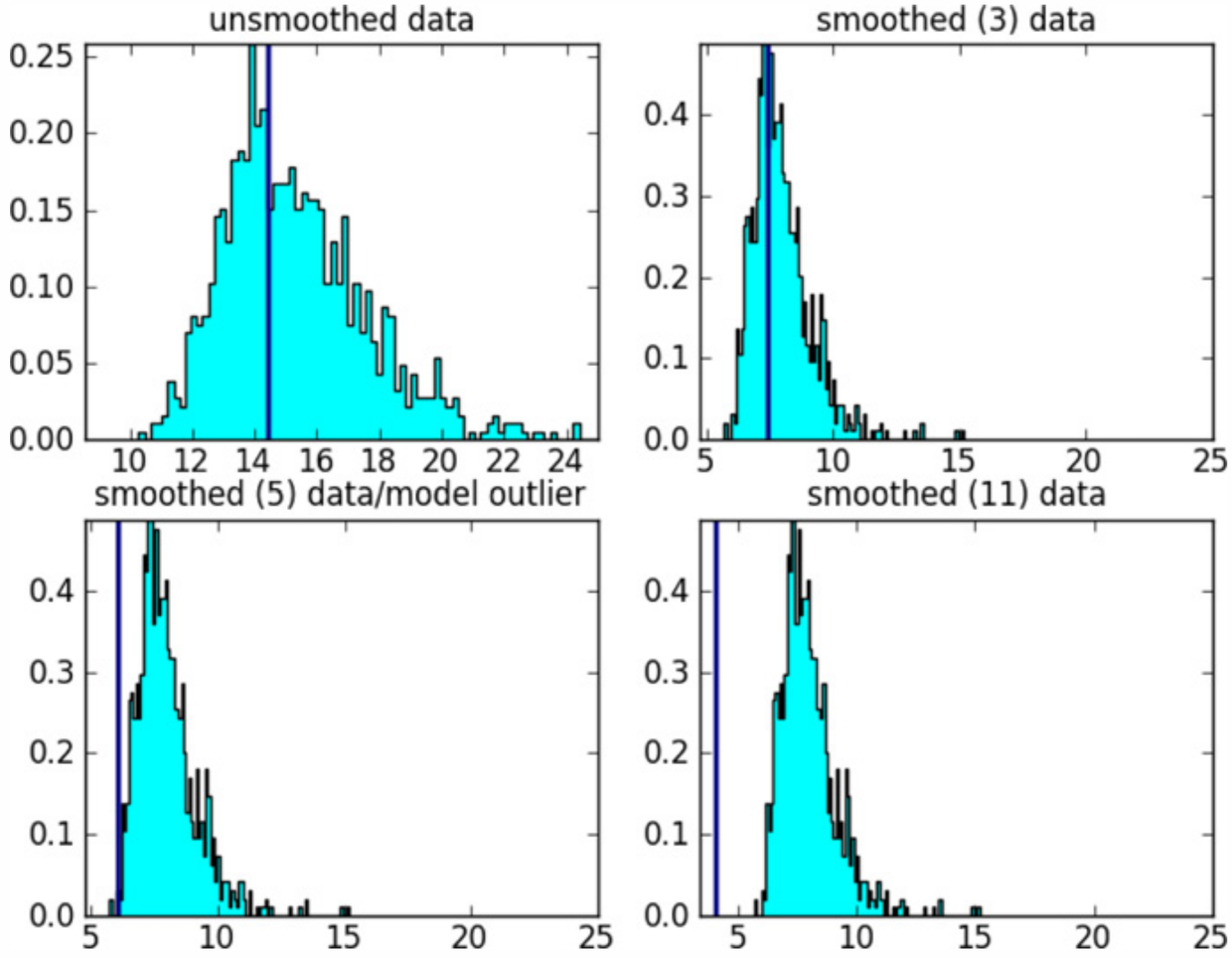
Step 3: Simulate parameters from the broadband model



Vaughan (2010), Huppenkothen et al (2013)

Step 4:

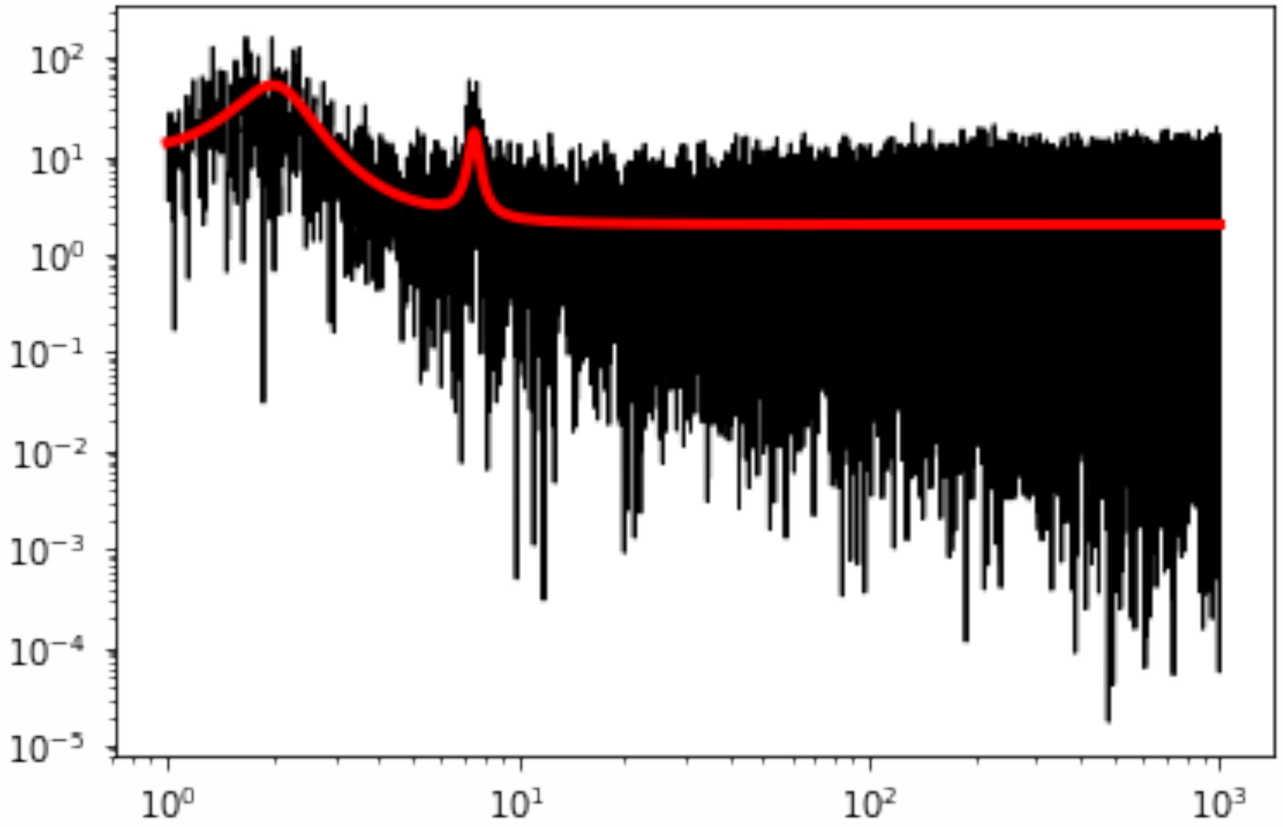
* Simulate periodograms,
* fit with same broadband model,
* pick highest outlier
* build empirical distribution
* derive p-value



Vaughan (2010), Huppenkothen et al (2013)

Model Fitting Approaches to QPO Detection

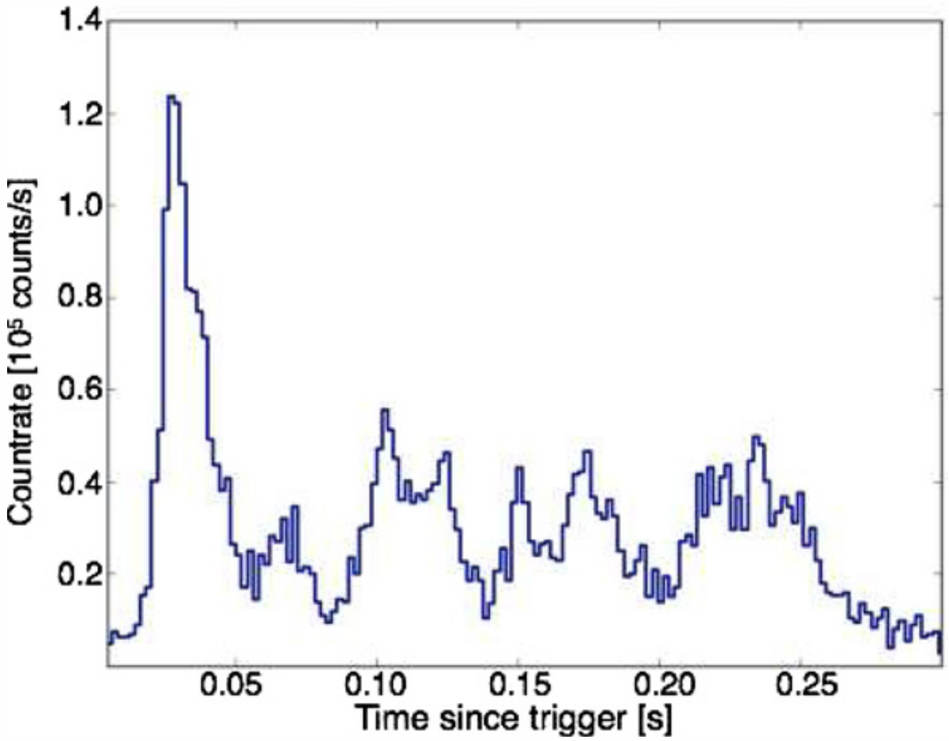
Instead of highest outlier, use likelihood ratio test between models with and without QPO as a test statistic.



Vaughan (2010), Huppenkothen et al (2013)

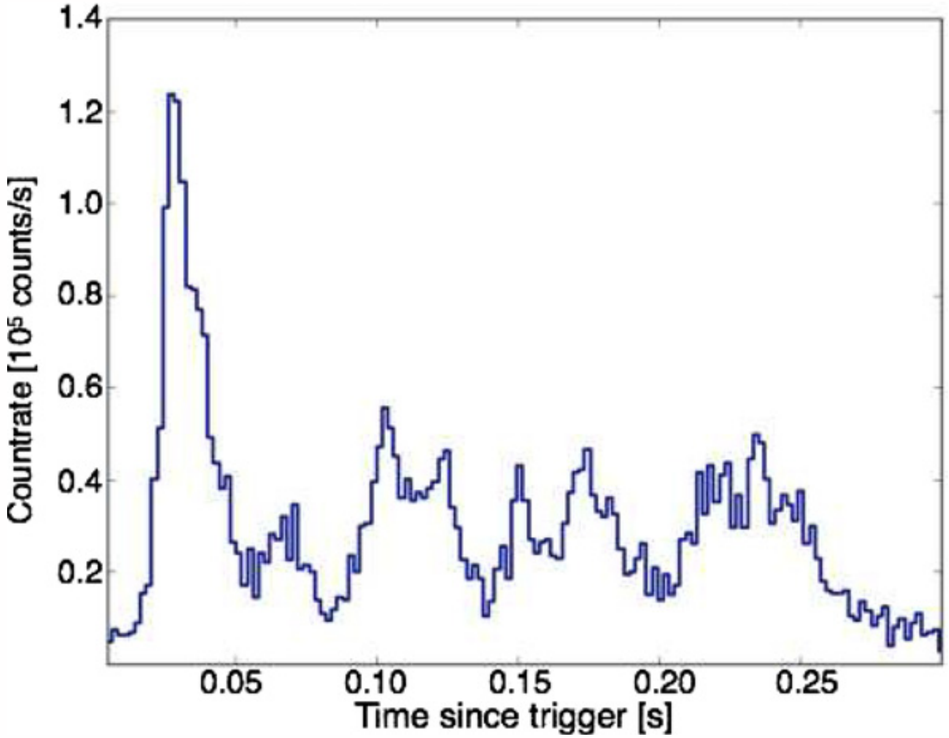
What about transients?

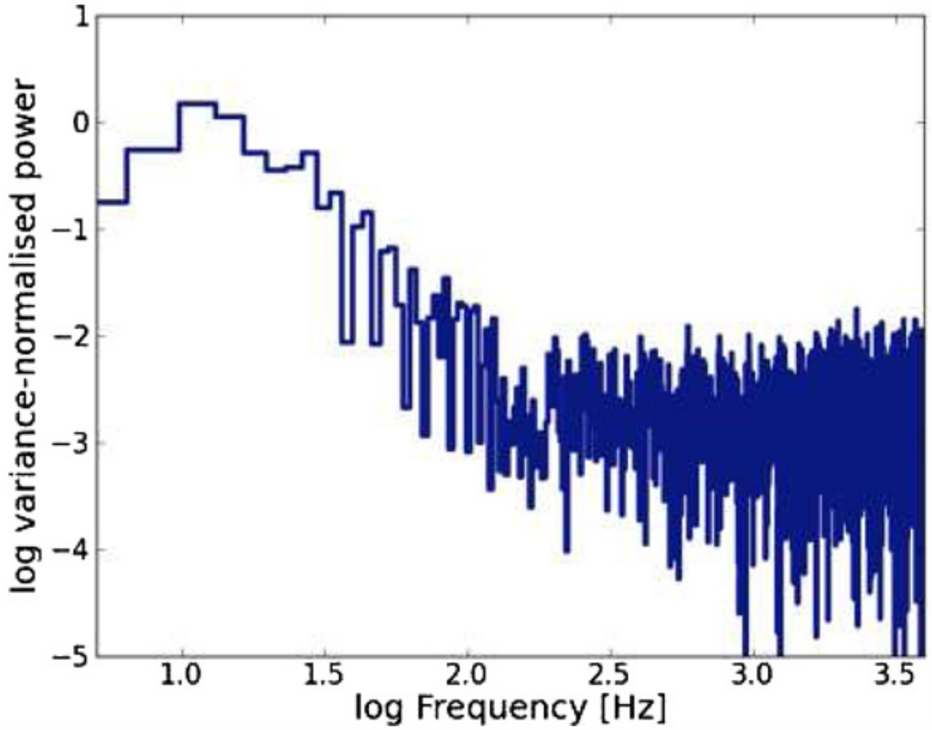
What about this light curve?



Vaughan (2010), Huppenkothen et al (2013)

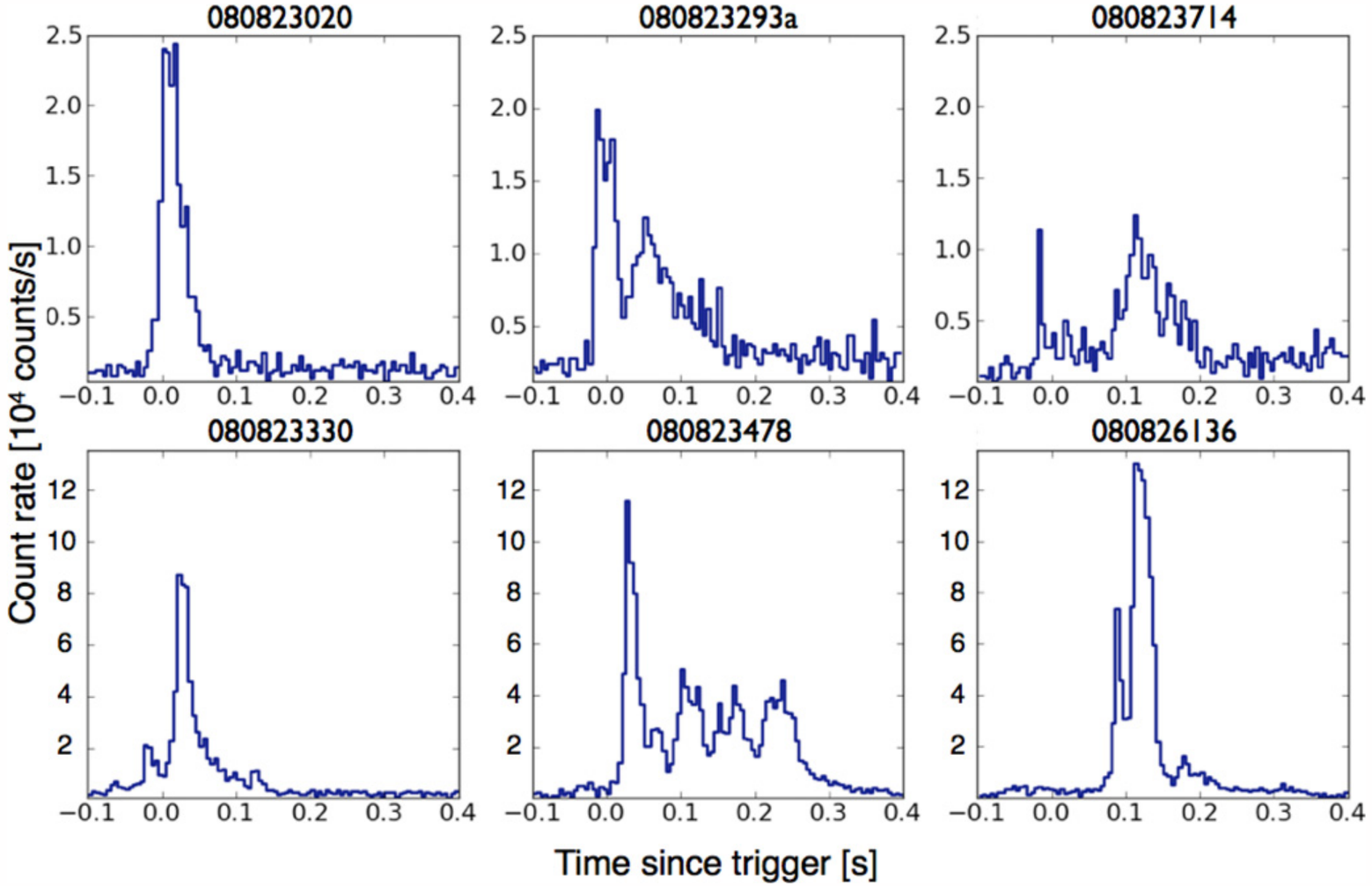
What about this light curve?





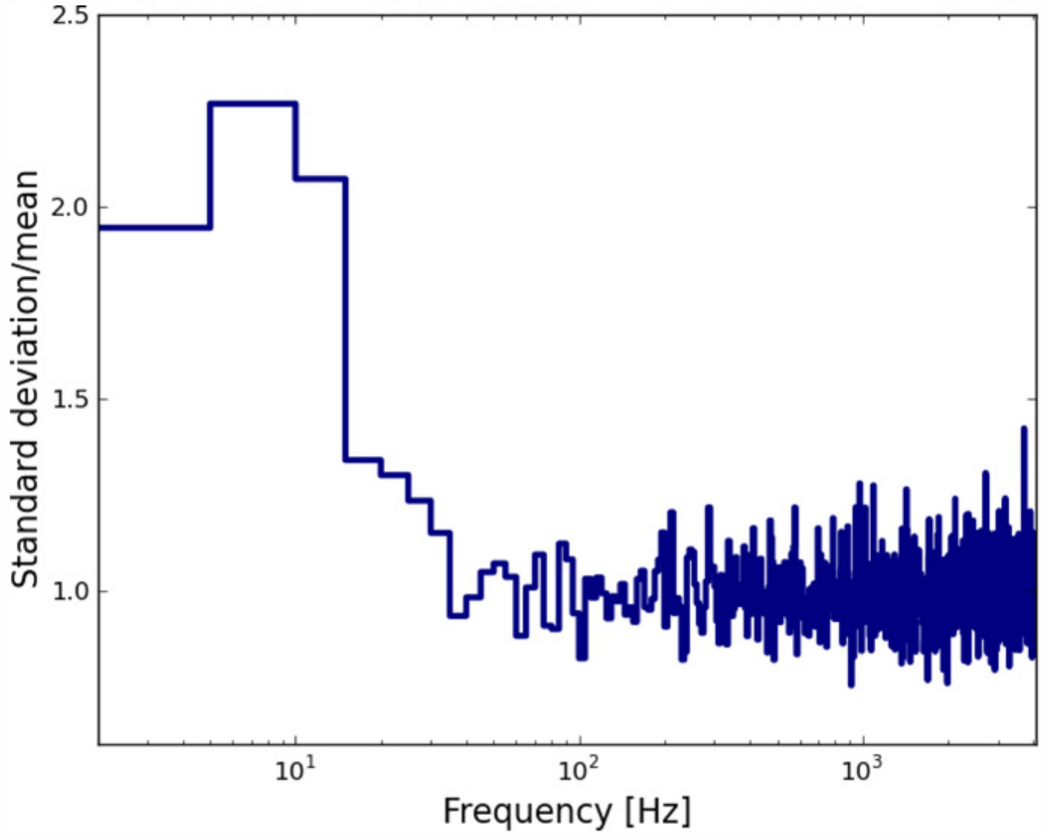
Vaughan (2010), Huppenkothen et al (2013)

What about any of these?



Huppenkothen et al (2013)

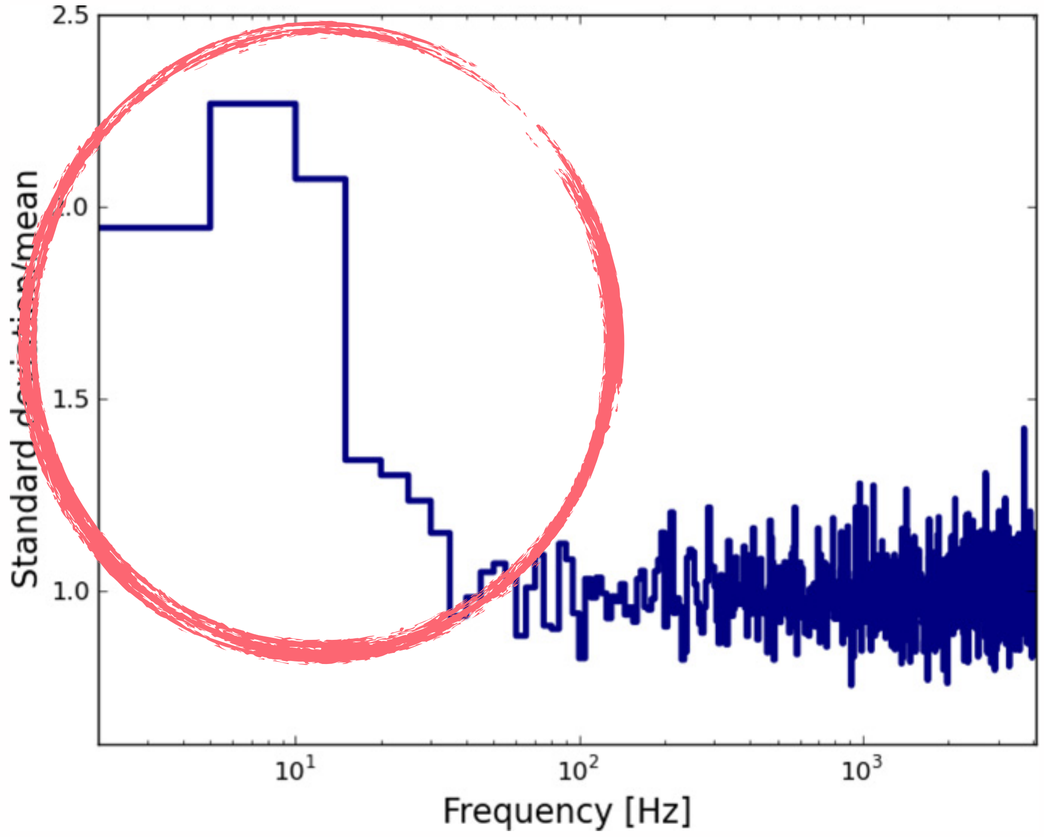
The variance at low frequencies is lower than expected



This is not a noise process!

Huppenkothen et al (2013)

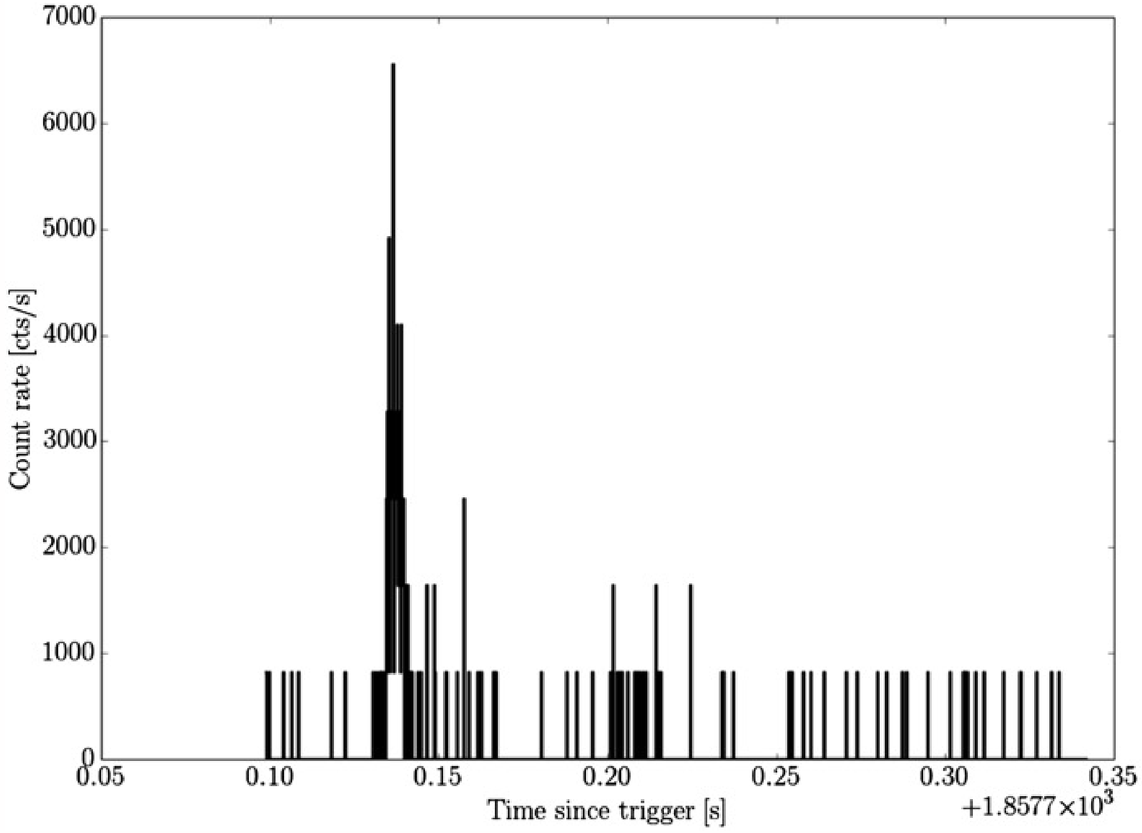
The variance at low frequencies is lower than expected

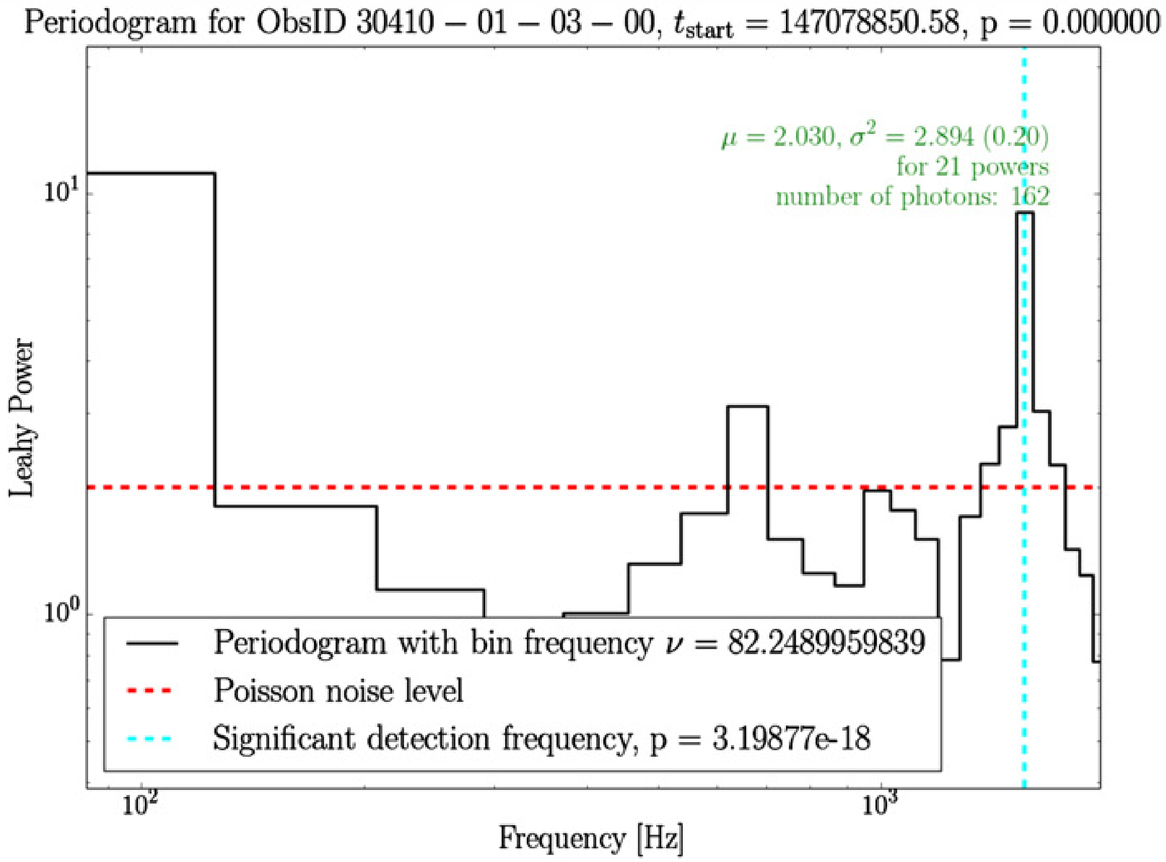


This is not a noise process!

Huppenkothen et al (2013)

Pitfall: very few events





Huppenkothen et al (2014)

Some conclusions

1) Check your assumptions

2) Don’t change your data, adjust your model

3) Use the simplest model you can get away with

4) Sometimes, testing against multiple null hypotheses can give you a better picture