Modeling stochastic variability of Fermi/LAT blazars

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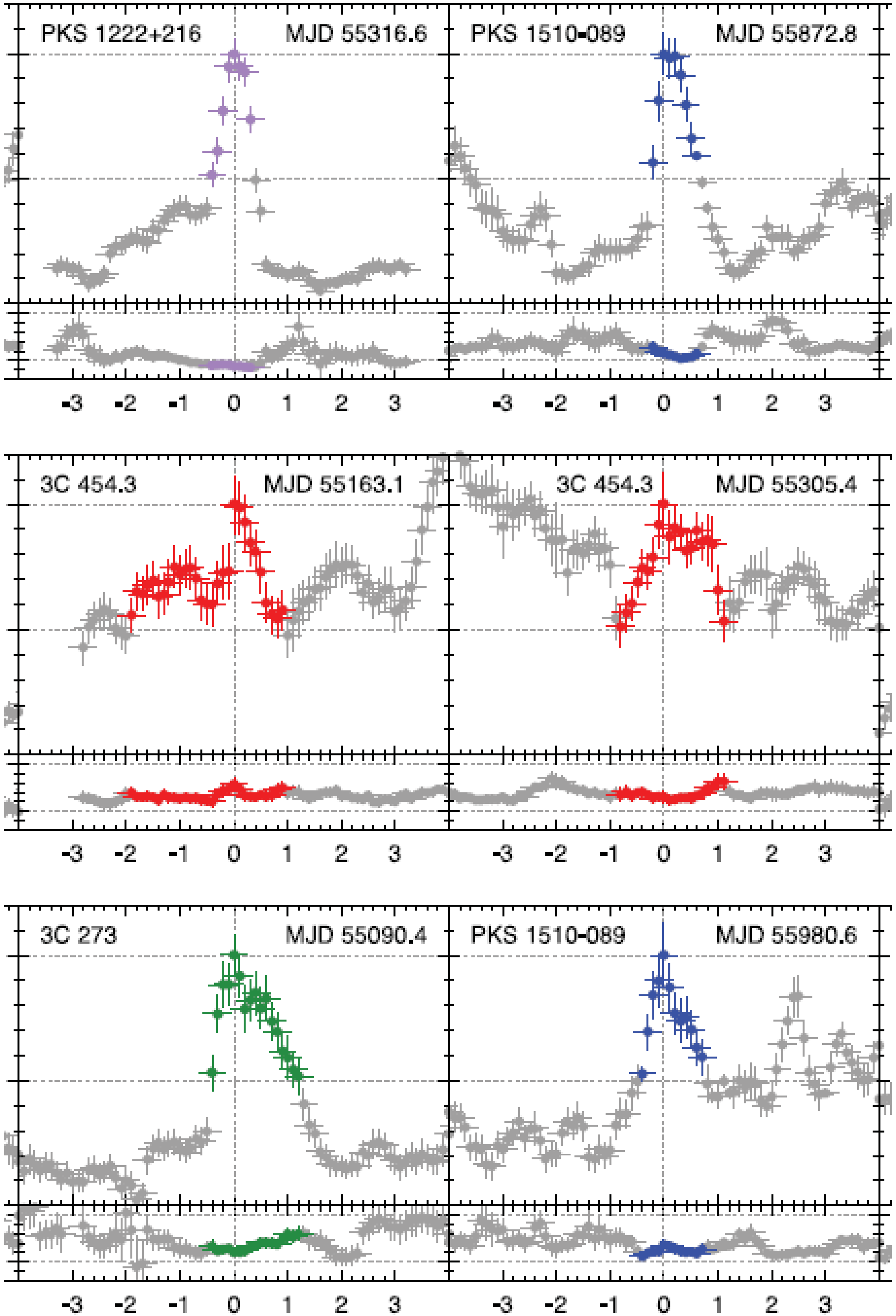
Introduction



Questions:

1. Are the flares a signature of a distinctive variability process?

2. Is the γ-ray blazar variability consistent with a stochastic process?

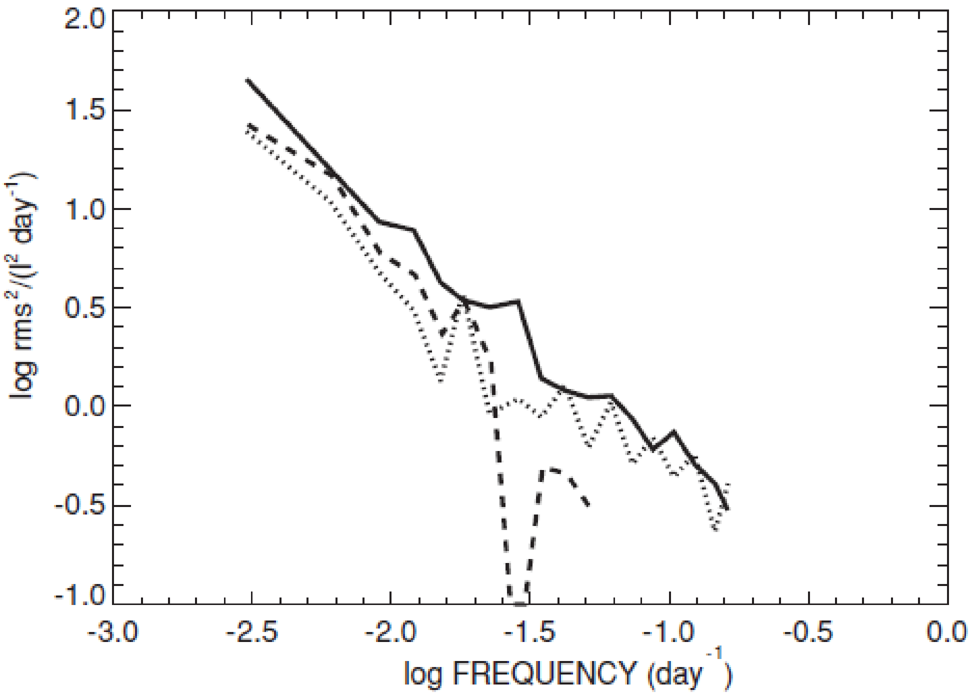
Nalewajko (2013)

Fermi/LAT brightest blazar flares

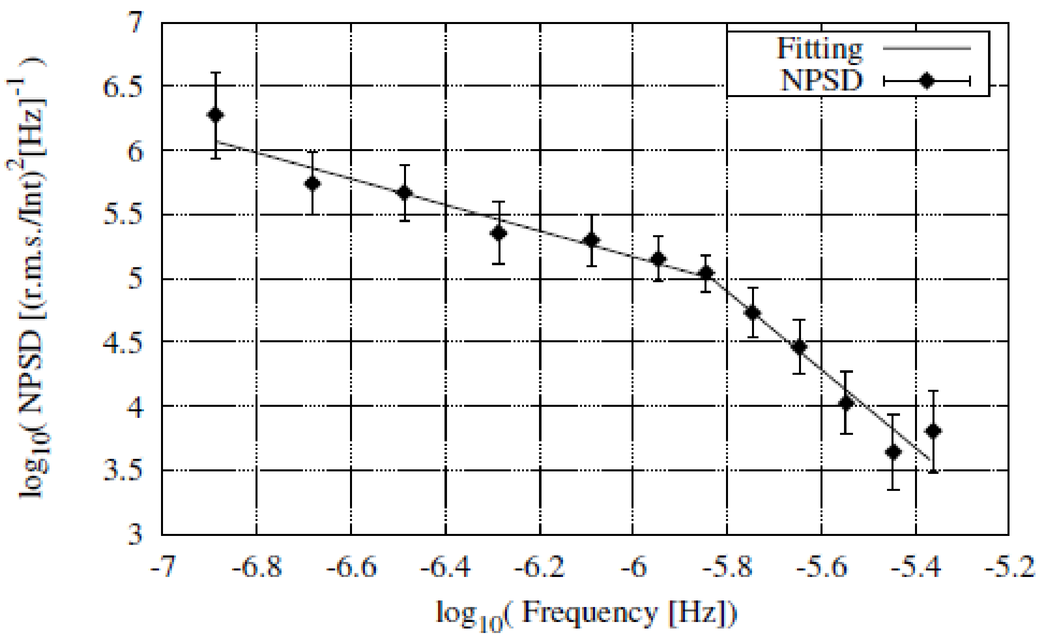
Flux doubling/halving timescales

Blazar γ-ray characteristic timescales of variability

The first 11 months of the Fermi/LAT data



The first 4 years of the Fermi/LAT data



Sample PSDs:

Solid – 9 bright FSRQs
Dashed – 13 fainter FSRQs
Dotted – 6 bright BL Lacs

Adbo+2010

Individual PSDs of 15 blazars.

Characteristic timescale detected only in 3C 454.3

Nakagawa & Mori 2013

Our approach – fitting light curves in the time domain

Key advantages:

Parametrized stochastic process, PSD parameters derived directly from the lightcurves.

No spectral distortions due to irregular/sparse sampling, red noise leak, aliasing because the Fourier transforms are not performed.

Bayesian approach, rigorous statistical inference based on **the likelihood function,** i.e., the probability of the measured lightcurve as a function of the PSD parameters.

posterior dist. of parameters given the data $\propto$ *Likelihood* $\times$ *prior*

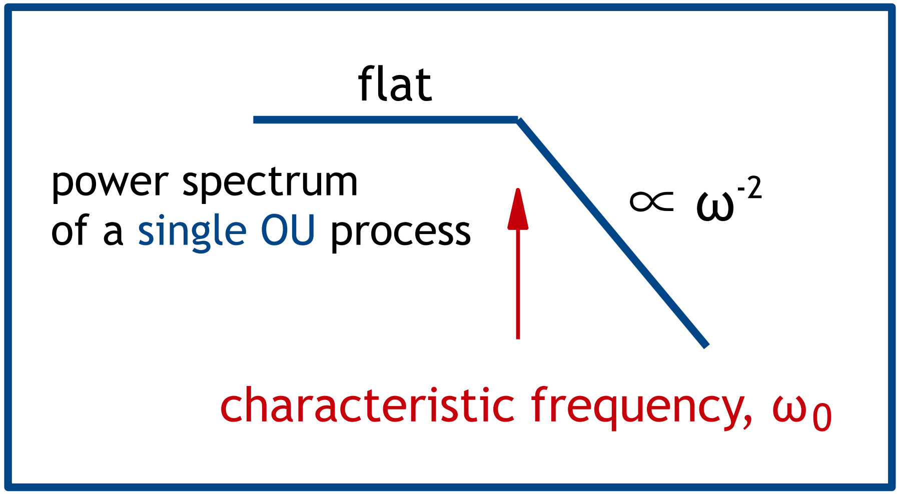
Markov Chain Monte Carlo (MCMC) to sample from the posterior probability distribution for the model **parameters**, e.g. PSD characteristic timescales.

Reliable estimates of the parameter **uncertainties.**

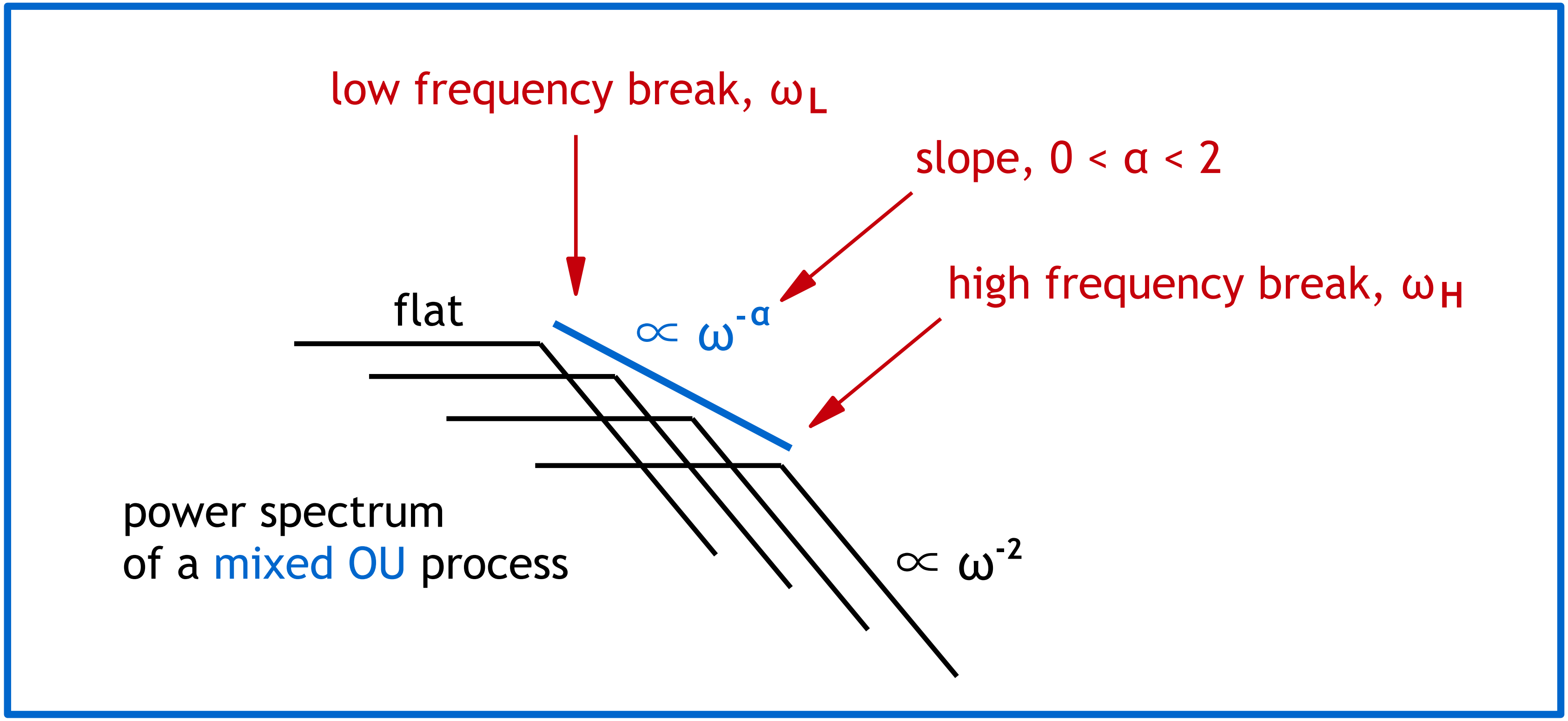
Computationally efficient.

Our approach – simple model

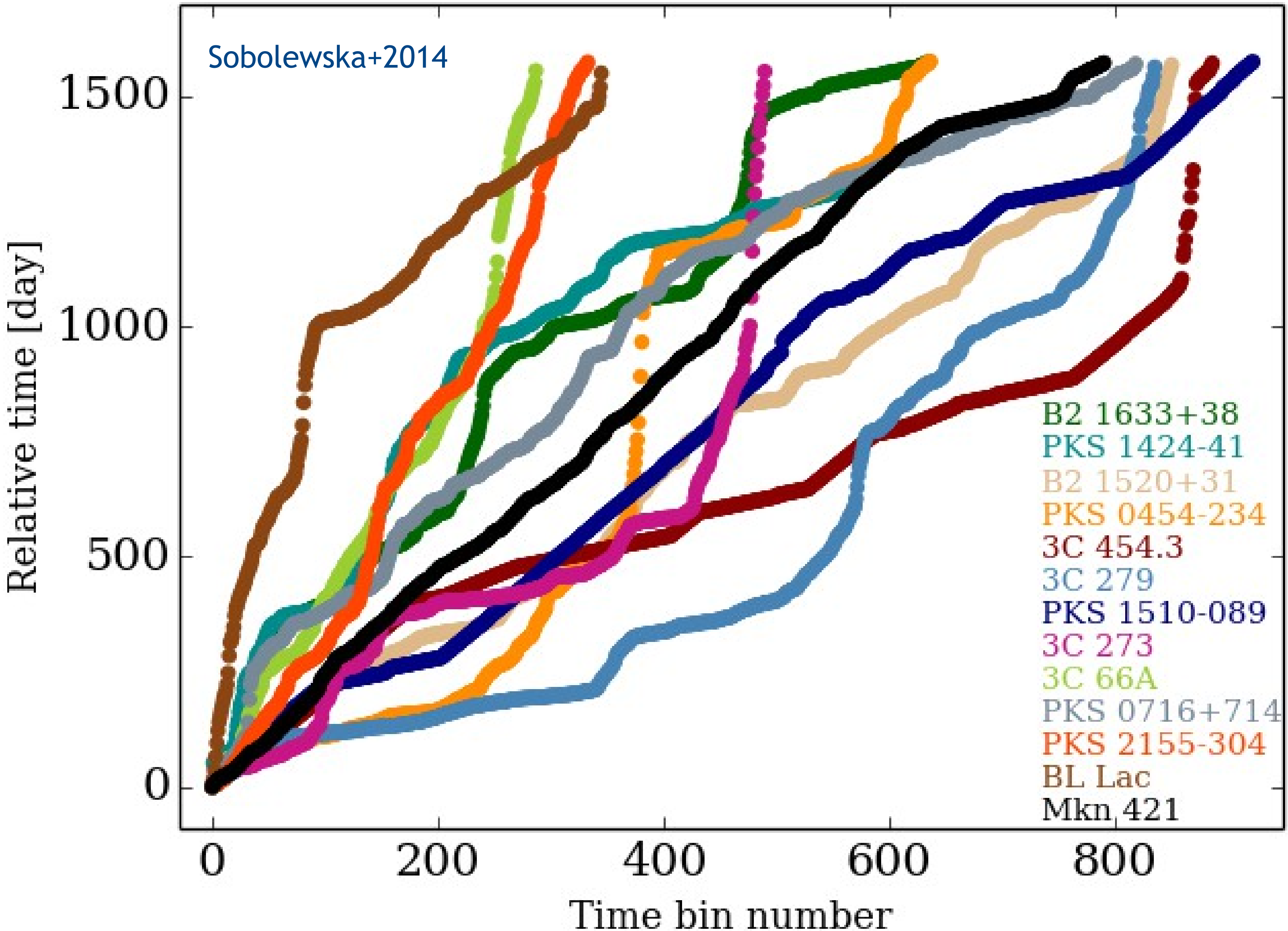
Ornstein-Uhlenbeck, OU
Continuous time 1st order autoregressive, CAR(1)
Damped Random Walk, DRW



Kelly et al. 2009, 2011

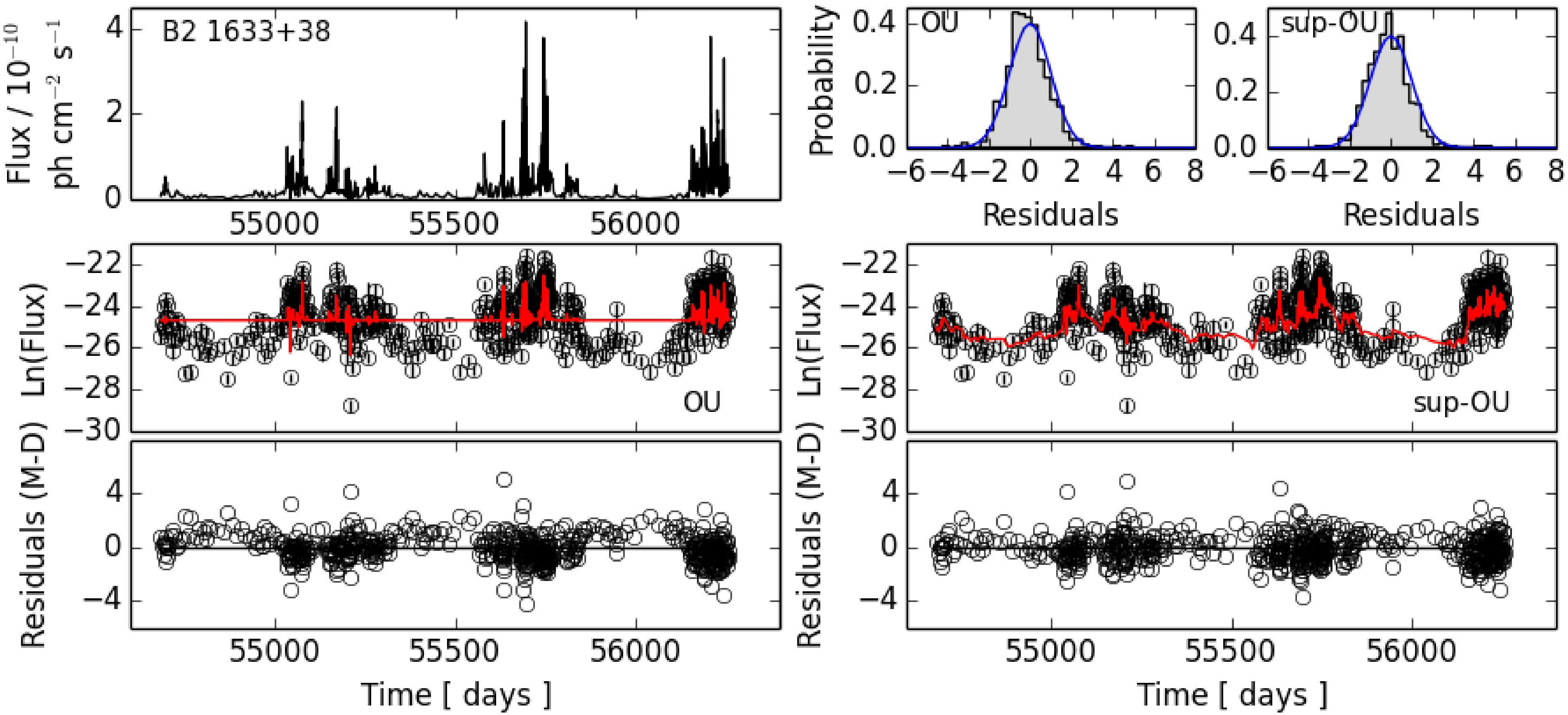


The γ-ray variability of the Fermi/LAT blazars



The γ-ray variability of the Fermi/LAT blazars

Sobolewska+2014



single process

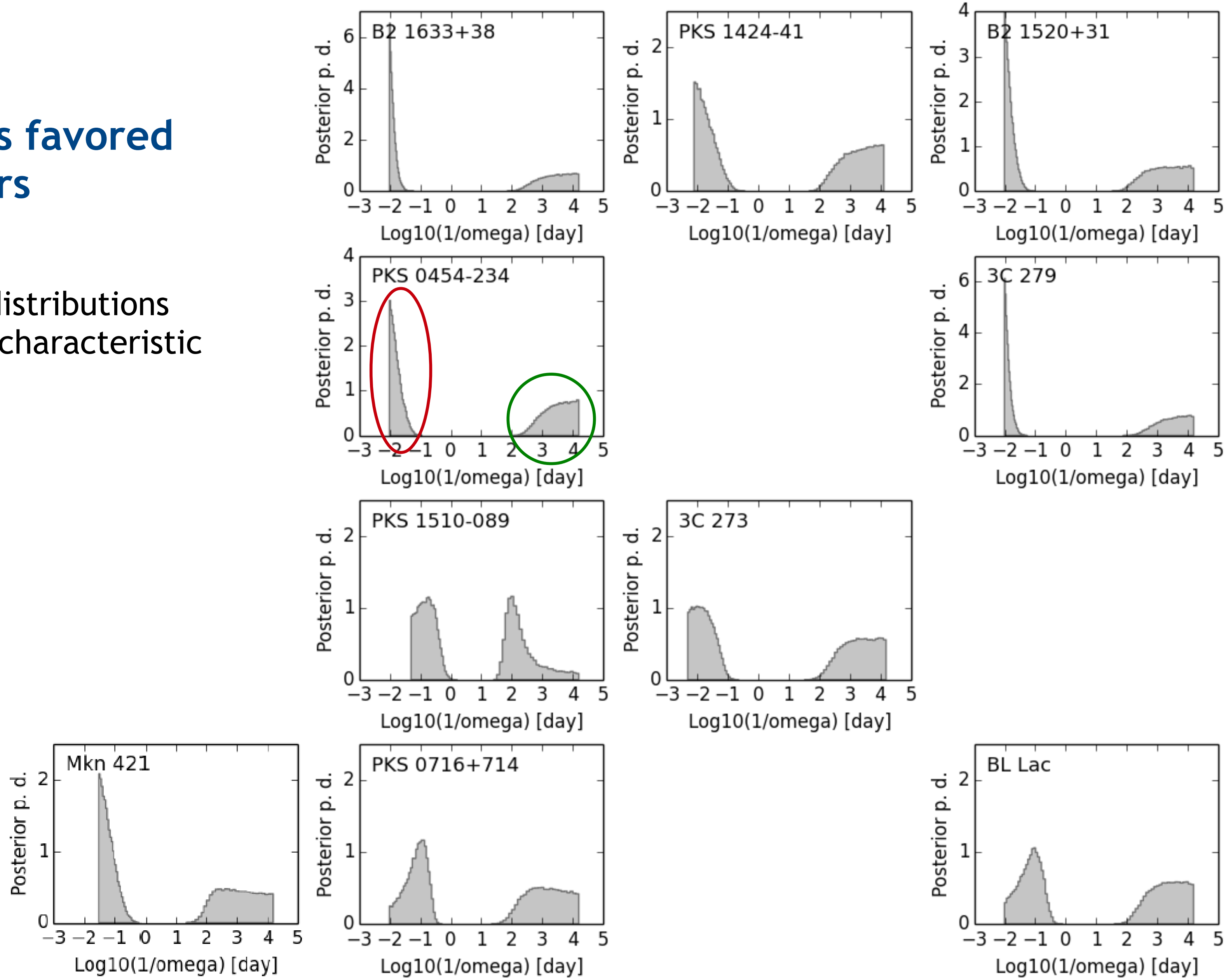
mixed process

The γ-ray variability of the Fermi/LAT blazars

Mixed OU process favored in 10 of 13 blazars

Posterior probability distributions of the short and long characteristic timescales.

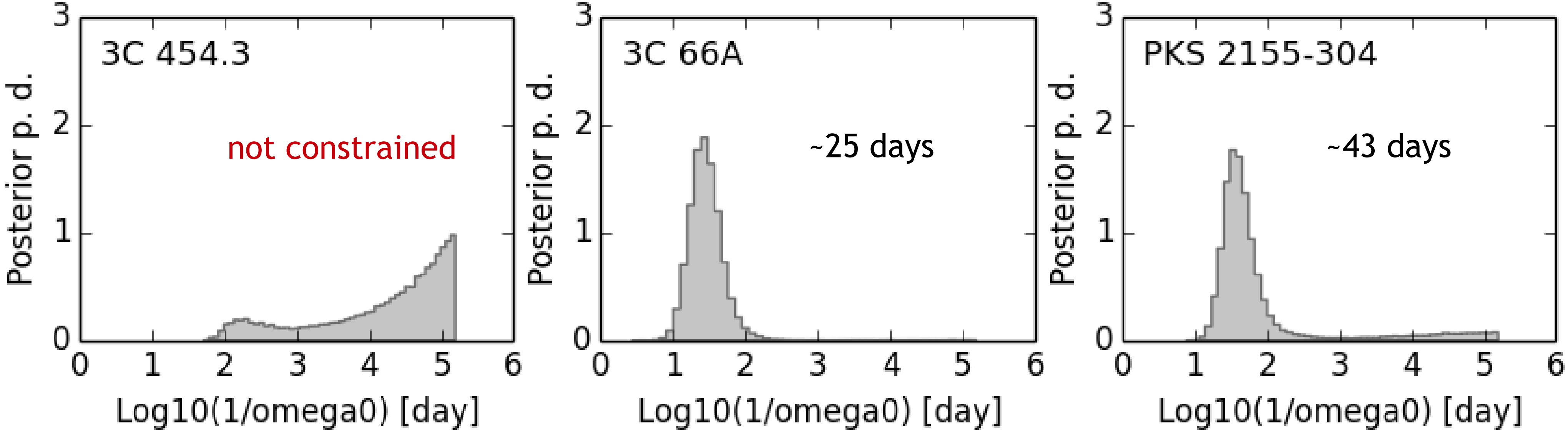
Sobolewska+2014



The γ-ray variability of the Fermi/LAT blazars

Single OU process sufficient in 3 of 13 blazars

Posterior probability distributions of the characteristic timescale



Sobolewska+2014

Our approach – generalized model

CARMA(p, q)

Continuous time autoregressive moving average process (Kelly+2014).

autoregressive coefficients

AR

white noise process

$$\frac{d^p y(t)}{dt^p} + \alpha_{p-1}\frac{d^{p-1}y(t)}{dt^{p-1}} + \ldots + \alpha_0 y(t) = \beta_q \frac{d^q \epsilon(t)}{dt^q} + \beta_{q-1}\frac{d^{q-1}\epsilon(t)}{dt^{q-1}} + \ldots + \epsilon(t).$$

MA

moving average coefficients

The PSD of a CARMA process
is a sum of Lorentzian functions.

Centroids, widths and normalizations are
the free parameters.

Our approach – generalized model

CARMA(p, q)

Continuous time autoregressive moving average process (Kelly+2014).

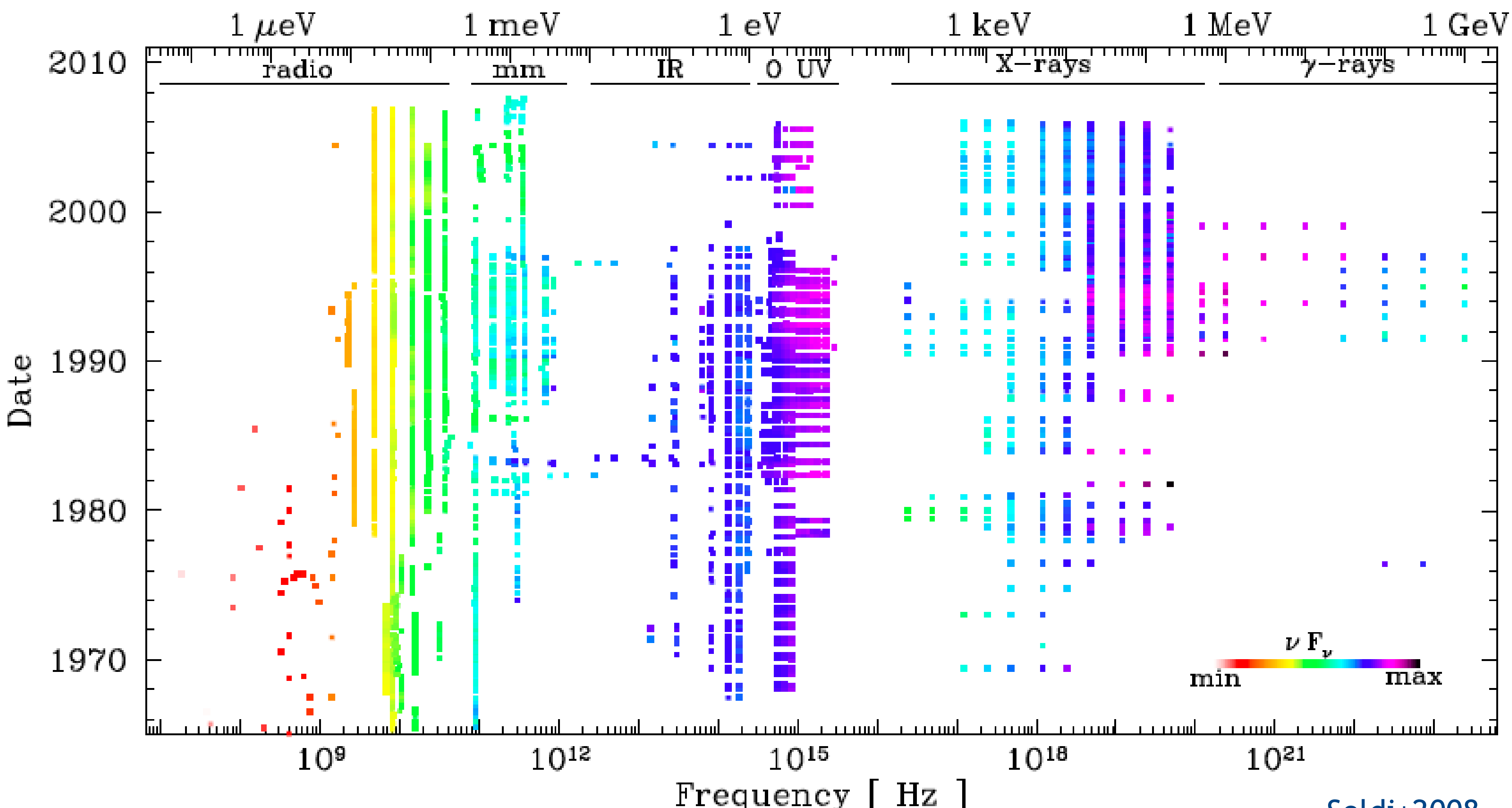
CARMA(p=1, q=0) = CAR(1)

$$\frac{d^p y(t)}{dt^p} + \alpha_{p-1}\frac{d^{p-1} y(t)}{dt^{p-1}} + \ldots + \alpha_0 y(t) =$$

$$\beta_q \frac{d^q \epsilon(t)}{dt^q} + \beta_{q-1}\frac{d^{q-1}\epsilon(t)}{dt^{q-1}} + \ldots + \epsilon(t).$$

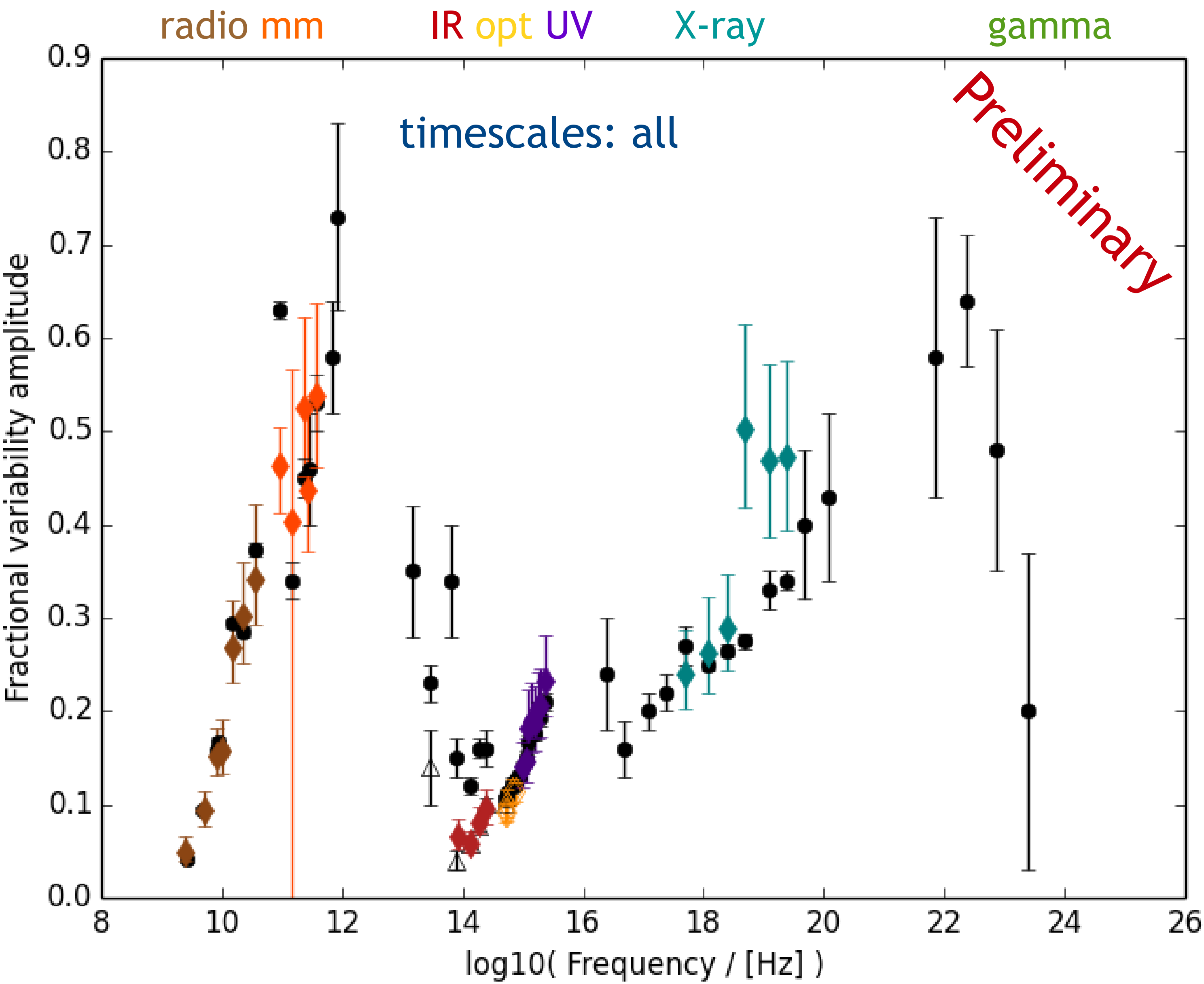
Variability of 3C 273 from radio to γ-rays

We use the CARMA code (Kelly+2014) to infer the PSD of 3C 273 in energy bands with >100 measurements.



Soldi+2008

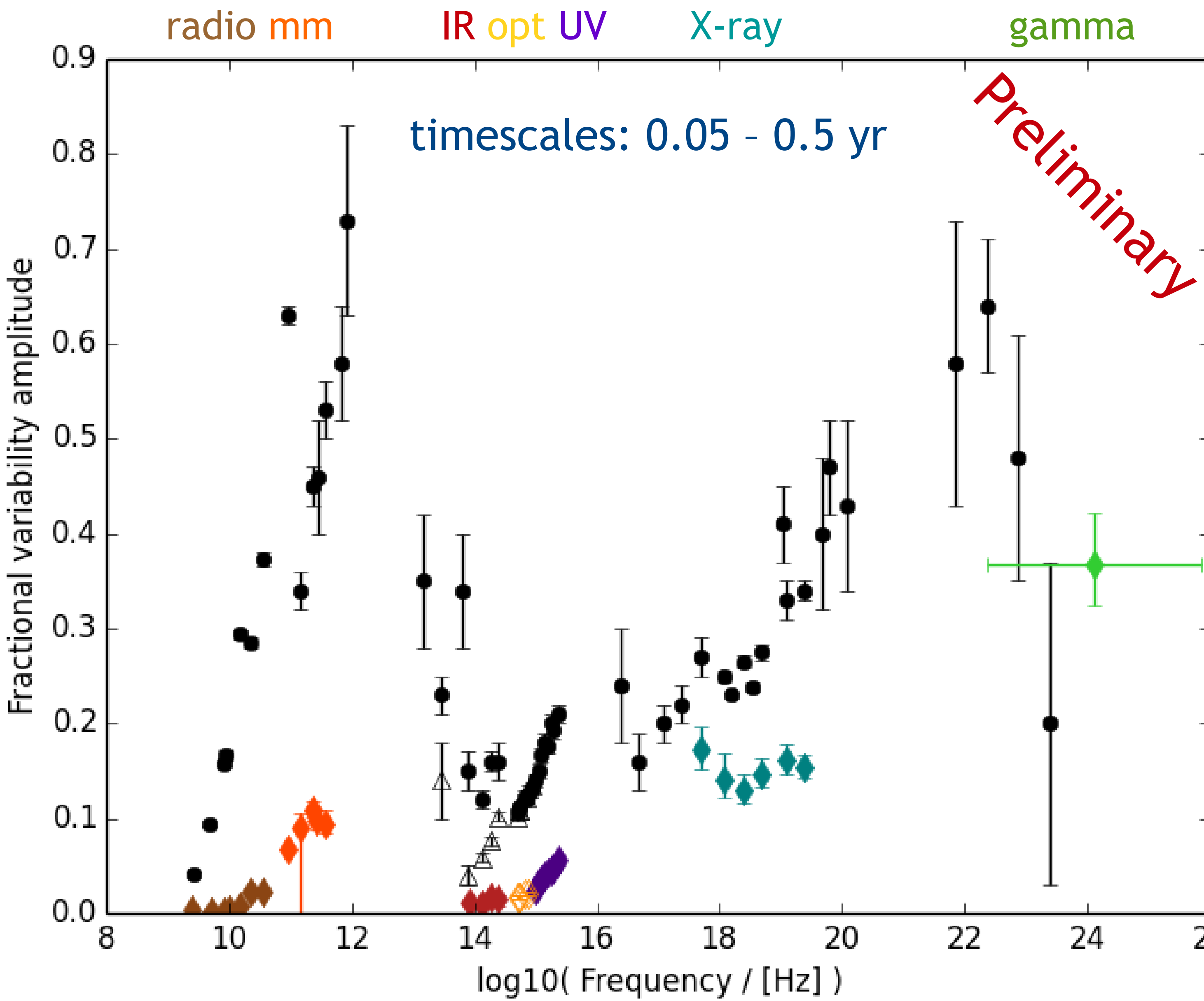
Variability of 3C 273 from radio to γ-rays



Soldi+2008 (black)

Sobolewska+2015 (in prep.)

Variability of 3C 273 from radio to γ-rays



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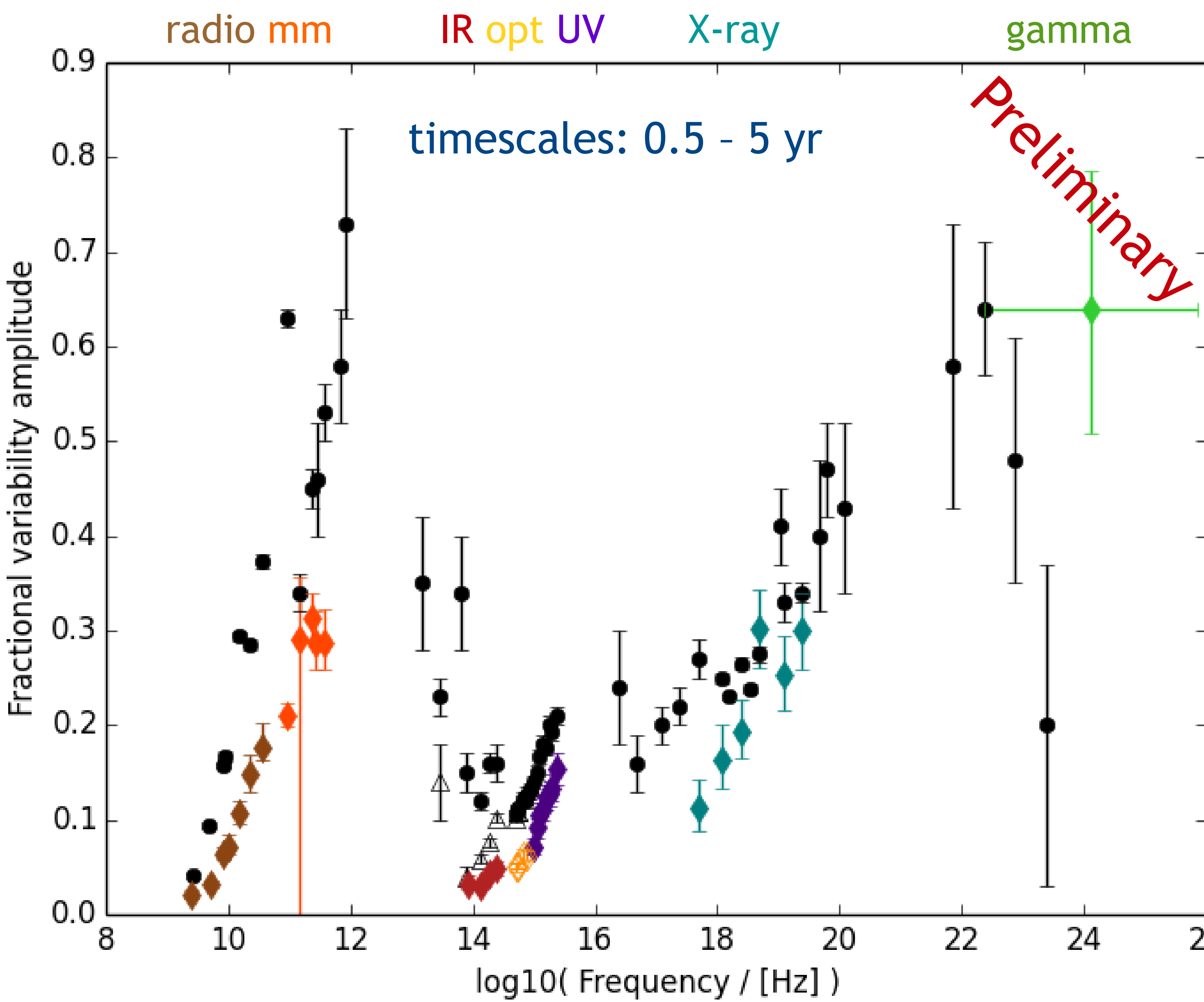
Variability of 3C 273 from radio to γ-rays



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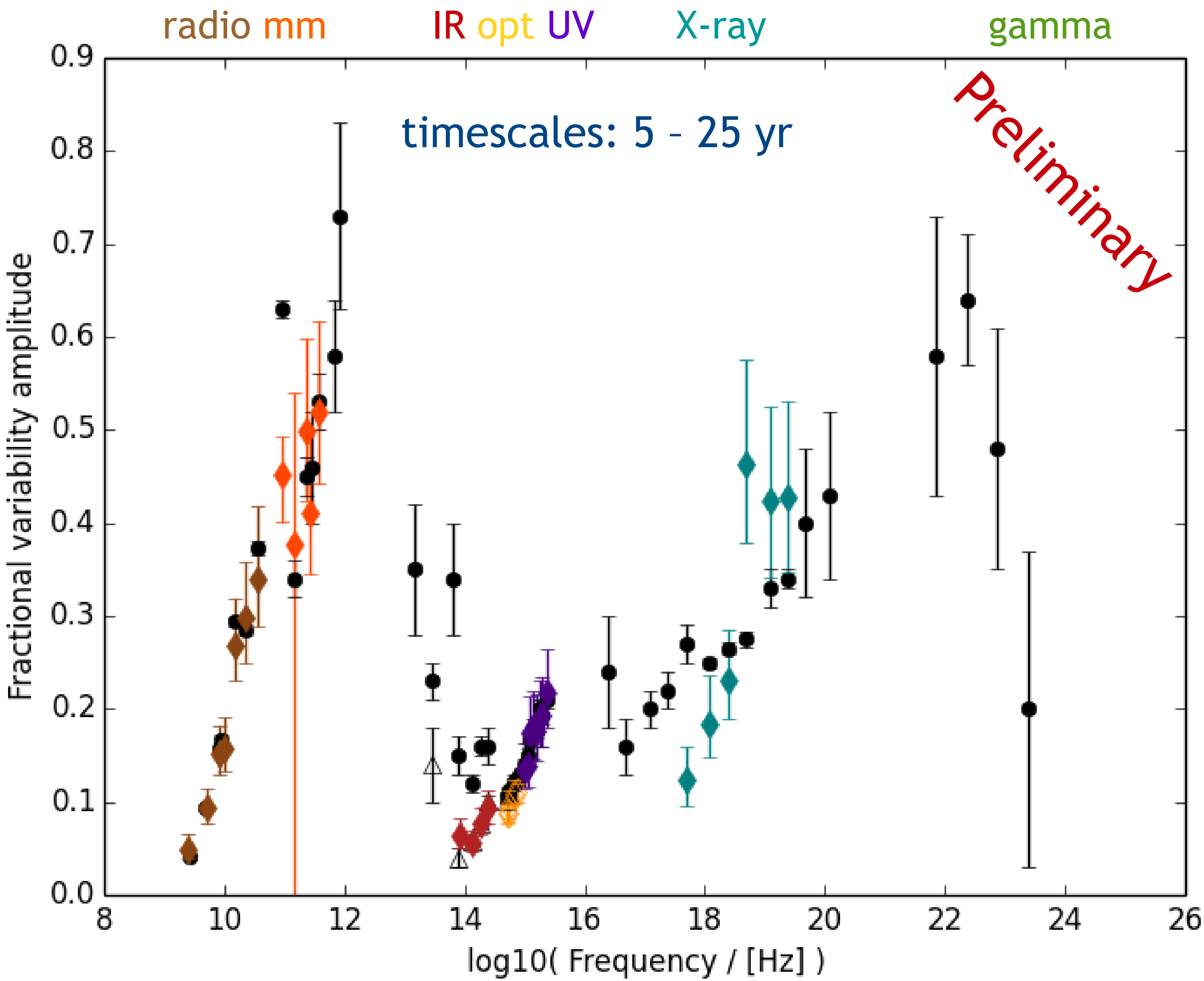

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Summary

A method of estimating the variability features of a light curve, in particular its PSD (Kelly+2009, 2011, 2014).

Irregular sampling and measurement errors are fully accounted for.

Application 1:

The Fermi/LAT γ-ray lightcurves of blazars consistent with the single or mixed OU process.

Characteristic time scales constrained in two BL Lac type sources. Limits derived for the remaining sources.

Constraints on the PSD slopes for sources in the sample.

Application 2:

Multiwavelength timescale-resolved variability study of 3C 273 (preliminary).