Multi-Timescale Variability in Gamma-ray Blazars

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Blazars through Sharp Multi-Wavelength Eyes. Málaga, Spain 30 May - 3 June 2016
**Fermi-LAT and blazar variability**

**Variability**
- How do we characterize blazar variability?
  - Duty cycle, time asymmetry, power spectrum etc

**MW Correlations**
- How are gamma-ray and radio/optical/X-ray emission related?
- Where in the jet are the gamma-rays produced?
Fermi-LAT and blazar variability

Averaged Power Density Spectra

- 60 FSRQs
- Power law fit
  (slope = 1.19 +/- 0.03)
- 12 LSP BL Lacs
  (slope = 1.31 +/- 0.07)
- 13 ISP BL Lacs
  (slope = 1.12 +/- 0.05)
- 13 HSP BL Lacs
  (slope = 0.83 +/- 0.06)

Preliminary

No persistent breaks found in PDS of individual sources

Power Density Spectra in radio, optical, X-ray typically power-laws with index 1 to 2

Malaga 2016

Stefan Larsson
Gamma-ray variability:
1. Spectral: Harder-when-brighter (FSRQs) mixed (BL Lacs)
2. Time asymmetry: No
3. PDS: Power law index ~ 0.8 - 1.3
   No persistent break (= characteristic time scale)

Next question: Stationary/Non-stationary?
   Linear/Non-linear?
Explaining X-ray blazar variability

2. What we can learn from Galactic X-ray Binary Sources and Seyfert Galaxies

Over the last decade there have been many observations of the X-ray variability of Seyfert galaxies and GBHs with RXTE and considerable effort has been put into modelling these observations. It is now clear that X-ray variability is a red-noise process, with coupling between variations on long and short timescales. We understand how variability timescales scale with mass and accretion rate and we have a model which can explain the origin of these variations. In the following sections I will discuss the main diagnostic observations which have lead us to our present understanding of GBH and Seyfert galaxy variability and I will test these observations against those diagnostics. In particular I will discuss the rms-flux relationship and the scaling of characteristic timescales. I will also briefly mention the measurement of the lag between the hard and soft X-ray bands as a function of Fourier frequency, although this interpretation is somewhat more complex in the case of blazars. I will concentrate here on the two best observed blazars, ie 3C273 and 3C279.

3. The rms-flux relationship

3.1 Non-beamed black hole systems

Following discussions regarding the relative merits of measuring powerspectra in terms of absolute power or rms power, it was found that the rms variability of GBH lightcurves (ie the integral of the PSD over the observable frequency range) varies linearly with flux (Fig.2, left panel, from [22]). It was also found that a linear rms-flux relationship applies to Seyfert galaxies (eg Fig.2, right panel, and [17, 15]).

Fig.2. Left Panel

\textbf{rms-flux relationship for Cyg X-1} [22].

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{rms-flux_Cyg_X-1}
\caption{rms-flux relationship for Cyg X-1 derived from observations by RXTE and EXOSAT, and from previous observations, unfolded from the observational sampling pattern.}
\end{figure}

The fact that short timescale variations (ie those that determine the rms) decrease in amplitude when the long timescale variations (ie those that determine the mean flux level) decrease means that there must be a link between variations on different timescales. Thus the overall flux variations must be the result of a multiplicative, rather than additive, process. A model which can produce such variations was proposed by Lyubarskii [7]. In this model, variations are reproduced within the viscous timescale associated with the inner edge of the accretion disc and the overall PSD shape is quite consistent with the Lyubarskii/Kotov/Churazov emission model.

4. Powerspectra and Scaling of Characteristic Timescales

The X-ray powerspectral densities (PSDs) of GBHs and Seyfert galaxies can be described very well as red-noise processes, such as would be produced by the variability processes described above. Seyfert galaxies, in particular, have PSDs which, at low frequencies are described by simple powerlaws, ie

$$P(\nu) \propto \nu^{-\alpha}$$

with $$\alpha \sim 1$$. Above a particular frequency, $$\nu_B$$, or time scale $$T_B = 1/\nu_B$$, the PSD steepens to $$\alpha \geq 2$$. This timescale may correspond to the viscous timescale as well as the overall PSD shape is quite consistent with the Lyubarskii/Kotov/Churazov emission model.

Figure 6:

\textbf{PSD of 3C273}, derived from observations by RXTE, and from previous observations, unfolded from the observational sampling pattern.
A Possible Scenario for Blazar X-ray Variability

Illustration from McHardy (2008):

Accretion rate fluctuations at various disk radii

Figure 9: A possible geometrical scenario to explain blazar variability. Variations are generated within the accretion disc and propagate inwards to modulate inner X-ray emitting regions and also the X-ray emitting region in the jet.

Figure 10: The X-ray emission scenario shown in Fig. 9 explained in words.

Illustration from McHardy (2008):
In addition to power spectra, the RMS-Flux relation is should also be used as a test of models

Marscher (2014)
The RMS-Flux relation at gamma-ray energies

Full sample: 127 high significance AGN (3FGL)

This analysis: 16 FSRQs, 6 year light curves (6 day binning) for 2 (3C 279 and PKS 1510-089) also 7 year, 1 day binned light curves.

Method: Compute RMS directly from light curve using 20 or 72 day segments (sampling time scales: 2-20 days and 12-72 days respectively)

Analysis: RMS vs Flux (and RMS/Flux vs Flux)

Questions: Is the RMS-Flux relation linear?
Is it the same over time?
Implications for variability models?
The RMS-Flux relation at gamma-ray energies

RMS-Flux for 6 year LAT light curves (with 6-day binning)
Points are for individual segments (error bars include measurement noise but not red noise)
The RMS-Flux relation at gamma-ray energies

- 3FGL J1224.9+2122
- 3FGL J1229.1+0202
- 3FGL J1256.1-0547 3C 279
- Preliminary
The RMS-Flux relation at gamma-ray energies

No evidence for a non-variable component
3C 279 RMS-Flux based on 1 day binned Fermi LAT light curve (7 years of data)

A second order polynomial provides a better fit than a linear relation when all data is used.
The RMS-Flux relation at gamma-ray energies

2015 June

Fermi-LAT: > 100 MeV
(1 day bin)

2008 Aug-2010 Aug

2013 Nov – 2014 Apr

7 year Fermi light curve (2008 Aug. – 2015 Aug.)

1. 2013 December 20      :   6.0 x 10^{-6} ph cm^{-2} s^{-1}
2. 2014 April 03       :   6.4 x 10^{-6} ph cm^{-2} s^{-1}
3. 2015 June 16        : 24.3 x 10^{-6} ph cm^{-2} s^{-1}

Greg Madejski, KIPAC/Stanford
The RMS-Flux relation at gamma-ray energies

3C 279 RMS-Flux for the first (+) and second (diamonds) 3.5 years of Fermi-LAT observations (flux binned)

Non/slow-variable component?

Talk by Masaaki Hayashida yesterday

Overlapping PDS is consistent with constant RMS/Flux

(But for a linear RMS-Flux relation, RMS/Flux will be constant only if the RMS-Flux line goes thorough origo)
Summary

• We have investigated the RMS-Flux relation at gamma-ray energies for 16 FSRQs

• The preliminary analysis suggests that the relation is typically linear but with a slope that may change with time

• A more weakly variable components might be present in some sources but their contribution is typically small.

• The RMS-Flux should be considered in models of blazar variability.