GeV Variability of Blazars with GLAST-LAT

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The GLAST LAT is an all-sky monitor which will yield continuous 0.02-300 GeV monitoring for hundreds of blazars, with sampling down to ~1 day for the brightest sources.

Long-term monitoring yields the high quality light curves (evenly-sampled, uninterrupted, long-duration) which are key for break-throughs in AGN variability science!

Example: How RXTE monitoring revolutionized AGN variability science

Before RXTE: EXOSAT, with its < 3 day long-looks, allowed us to probe short-term variability only.

RXTE's Proprtional Counter Array (PCA) has yielded long-term X-ray light curves for 25-30 Seyferts & blazars since its 1995 launch, probing variability on timescales from hours to 10 years.

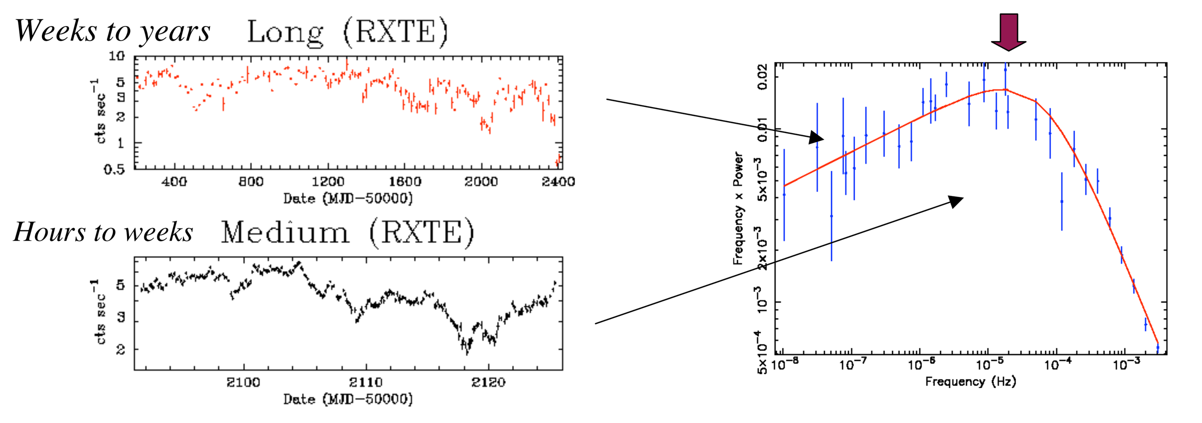
Seyfert (disk-dominated) AGN exhibit rapid, aperiodic X-ray variability that likely originates in the innermost regions of these compact accreting objects. Thanks to RXTE, broadband power spectral density functions (PSDs) for over a dozen Seyferts have yielded characteristic variability timescales T_b (``breaks" in the PSD), at a few days or less (e.g., Uttley et 2002, Markowitz et al. 2003).

(cont'd in right panel)

Example: How RXTE monitoring revolutionized AGN variability science (cont'd)

Correlations with M_{BH}: T_b scales linearly with M_{BH} (Markowitz et al. 2003): relatively more massive black hole systems display ``slower" variability. The T_b - M_{BH} relation extrapolates 6-7 orders of magnitude down to X-ray Binaries (XRBs), and the broadband PSD shapes of Seyferts & XRBs are consistent, suggesting that Seyferts & XRBs are mass-scaled versions of each other (e.g., Edelson & Nandra 1999).

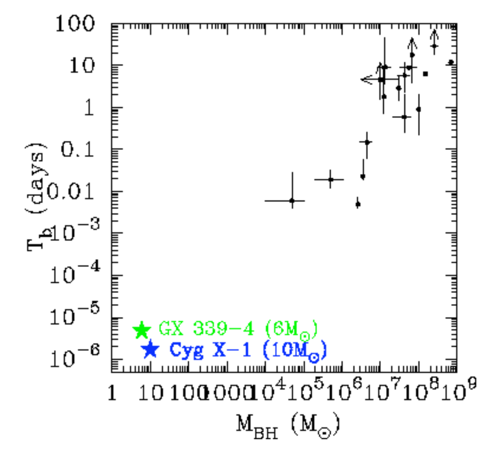
Long-term **X-ray/optical** correlations have enabled us to test reprocessing models (e.g., Uttley et al. 2003).

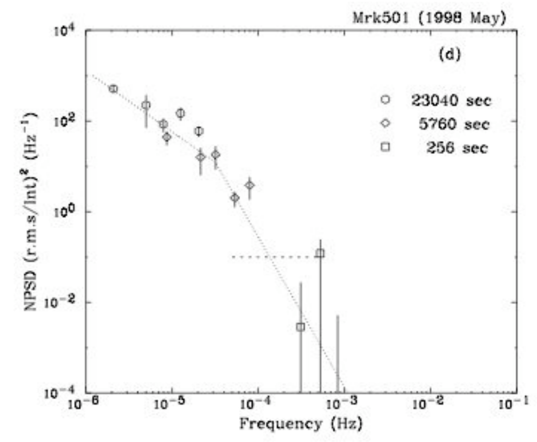


Complementary multi-timescale light curve sampling using RXTE (**left**) has enabled us to construct broadband PSDs for Seyferts (**right**) and identify PSD "breaks" corresponding to characteristic X-ray variability timescales of a few days or less. (from Markowitz et al. 2003 and McHardy et al. 2005)

In contrast, much less is known about the X-ray variability properties of **blazar (jet-dominated) AGN.** Commonly, X-ray data on blazars are obtained only as a part of multi-λ campaigns as a part of ToO observations triggered during outbursts.

Preliminary PSDs on a few blazars also show breaks on timescales of ~ a few days (Kataoka et al. 2001, 2002). That is, variability on timescales < T_b is suppressed, indicating a limit on the size of the variability region d ~ T_b c Γ), where Γ is the bulk Lorentz factor. If the jet is collimated to an angle 1/Γ, the X-ray variability site is located ≥ a distance D ~ T_b c Γ^2 from the black hole, providing a lower limit to location of shocks, for instance.





Left: The correlation between M_{BH} and PSD break timescale T_b in Seyferts (black points) extrapolates to XRBs (Markowitz et al. 2003). **Right:** Preliminary PSD for Mkn 501; from Kataoka et al. (2001)

Long-Term Monitoring with GLAST-LAT

The only GeV timescales defined so far are crude "doubling timescales" (e.g., Cheng et al. 1999). However, after GLAST is launched, accumulation of LAT data will yield a vast GeV AGN variability database complementary to that obtained by RXTE monitoring of AGN. **In other words, GLAST will do for γ-ray AGN variability what RXTE did for AGN X-ray variability.** This will allow progress in several key areas, including multi-wavelength correlations, broadband PSD measurement, characterization of the GeV variability at multiple flux levels, probing the nature of the overall variability process, and testing variability links between blazars and Seyferts.

LAT Variability Science 1: Multi-wavelength Campaigns During Outbursts

The LAT will identify blazar flares and trigger multi-wavelength campaigns on bright outbursts, which are critical for measuring the time-variable broadband SED and testing emission models (SSC, EC, etc.); this is covered in detail by many other posters and talks at this Symposium.

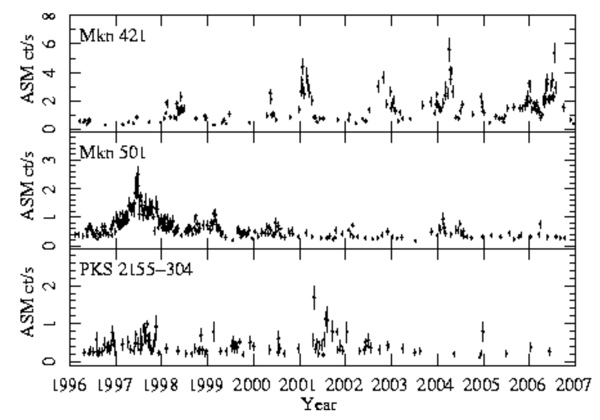
Short-timescale/intensive observations during flares can identify the fastest variations (light crossing, synchrotron cooling or particle acceleration timescales); interband lags can identify relative locations of the multi-wavelength emission sites and constrain the jet composition.

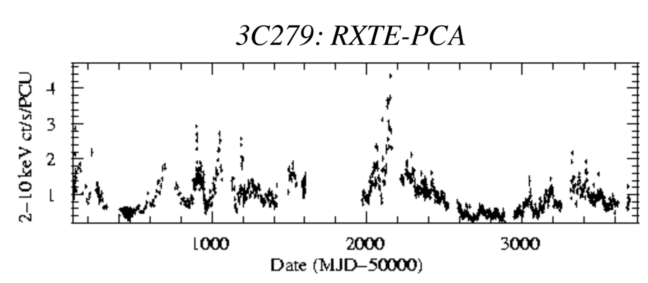
But long-term monitoring is complementary: we can study slowly-varying/long-duration flares (e.g., PKS 2005-489, Perlman et al. 1999). For example, in the TeV, flares can be seen to be long-standing, lasting several weeks (e.g., Krawczynski et al. 2004).

LAT Variability Science 2: Long-Term Interband Correlations

X-RAYS: The RXTE mission has been extended until at least Feb. 2009; there will be overlap between GLAST and RXTE from GLAST's launch (November 2007) up to that point. The RXTE All-Sky Monitor (ASM) can track the brightest X-ray flares (> 20 mCrb). In addition, last week, I proposed RXTE PCA Cycle 12 long-term monitoring of 5 HBL targets on the GLAST Sources of Interest list: Mkn 421, Mkn 501, PKS 2155-304, 1ES 1959+650 & H1426+428. If those targets are accepted, we'll be able to compare high-quality (evenly-sampled, uninterrupted, long-duration) simultaneous long-term X-ray/γ-ray light curves!

For HBLs, simultaneous GeV/X-ray monitoring data will constrain the high-energy part of the synchrotron hump (emission from the most energetic particles).





Left: RXTE-ASM light curves of 3 HBLs, binned to a minimum S/N of 7σ, 5σ & 3σ from top to bottom. **Right:** Archival RXTE-PCA light curve of the FSRQ 3C279.

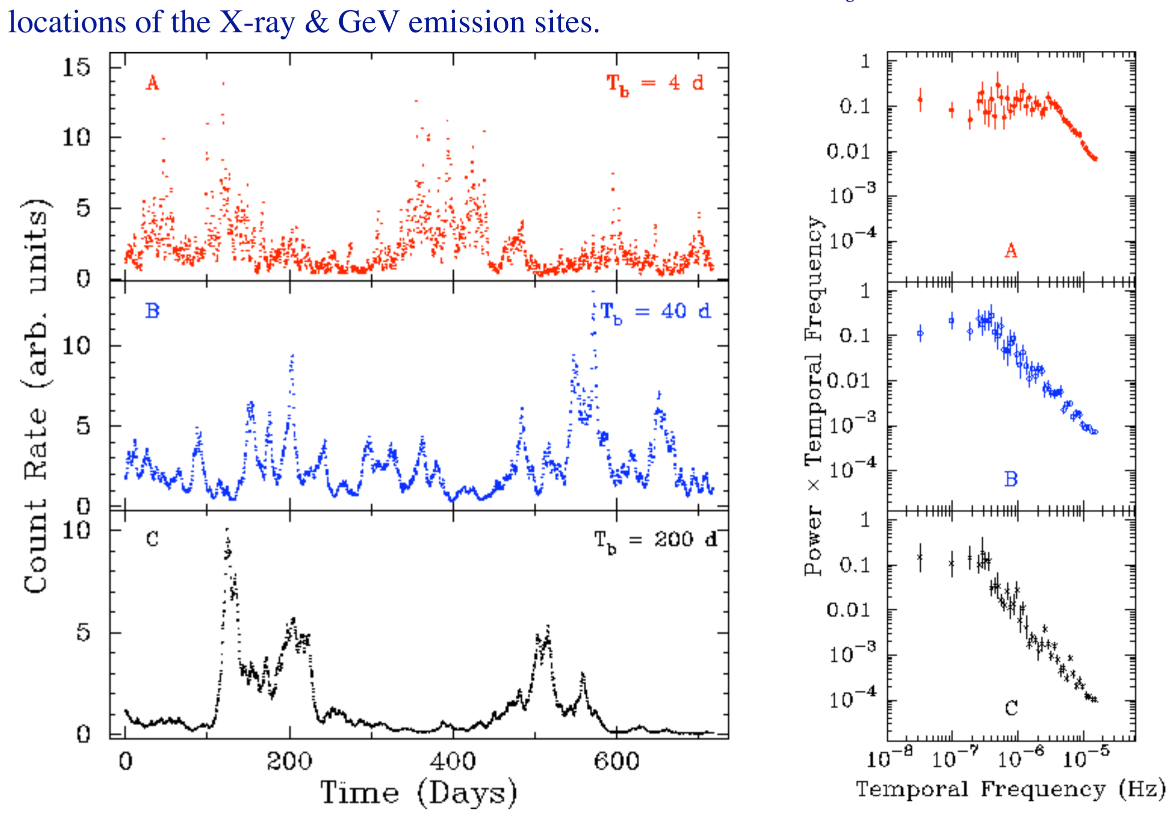
RADIO: Concurrent VLBI and radio flux monitoring will test for correlations between GeV activity and radio ejections. See, e.g., talk by M. Kadler and poster by M. Lister for the MOJAVE collaboration.

Are there "Orphan GeV Flares"? The best example so far is the TeV orphan flare in 1ES1959+650 (Krawczynski et al. 2004). One-zone SSC models usually explain the SEDs of HBL blazars, but models with a second zone or relativistic protons are usually required to explain orphan flares.

LAT Variability Science 3: Measuring Broadband PSDs

For the first time in the γ-rays, we will construct PSDs spanning 3-4 decades of temporal frequency, allowing us to potentially identify characteristic GeV variability timescales.

Does GeV T_b correlate with M_{BH}, as is the case with Seyferts? Do relatively more-massive sources display "slower" variability and/or longer, sustained flares? Do GeV T_b's correlate with luminosity or z? Comparing X-ray & GeV T_b's could indicate the relative locations of the X-ray & GeV emission sites.



Left: Simulated GLAST-LAT light curves, assuming one flux point every 8 orbits (46 ksec), for a duration of 2 years. Each light curve was simulated using a PSD with a broken power-law form, with $P(f) \propto f^{-1.0}$ at temporal frequencies $f < 1/T_b$, where T_b is the observed (not intrinsic) PSD break timescale, and $P(f) \propto f^{-2.5}$ for $f > 1/T_b$. T_b increases from the top panel towards the bottom panel, simulating relatively ``slower" variability and less frequent flaring episodes. In the top panel (light curve A), flares are relatively frequent and short-lived, with a typical flare ``lifetime" of about a week (~1-3 × T_b). In the light curve in the bottom panel (C), flares are not frequent, but typically last for a couple months. **Right:** The broadband PSDs for each of the three light curves in the left figure. They span ~ 3 decades of usable temporal frequency. The PSDs are plotted in $f \times P(f)$ space to visually accentuate the changes in power-law slopes below and above the breaks. This figure shows that an array of PSD break timescales and shapes can easily be discerned with GLAST.

LAT Variability Science 4: Quantifying GeV Variability at multiple flux levels (including quiescence)

Can we constrain the nature of the variability process? Large flares in blazars likely arise from the sudden acceleration of relativistic electrons, related to bulk injections of new particles (Mastichiadis & Kirk 1997) and/or strong internal shocks (Marscher & Gear 1985), but the exact variability mechanisms are not understood: what controls the rate and duration of flares? *Can one continuous process explain the GeV variability process at all flux levels, as is the case with Seyferts?*

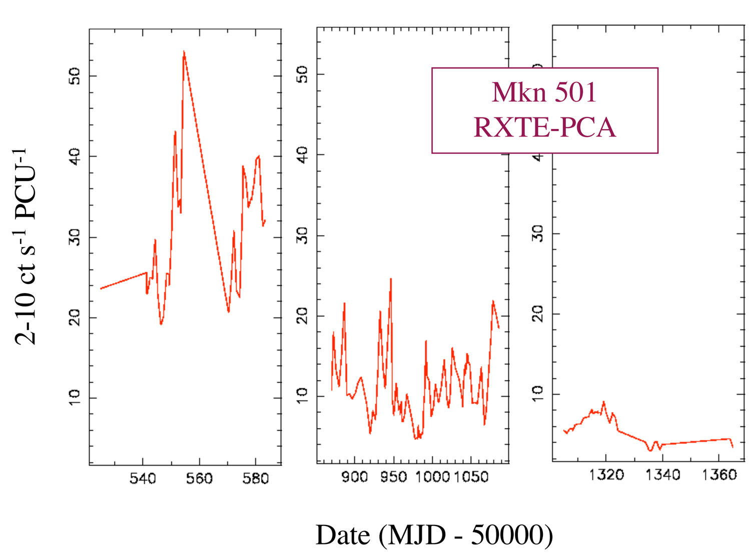
There is a **correlation between flux and absolute rms variability amplitude in the X-ray** light curves of Seyferts and XRBs (Uttley & McHardy 2001):sources are more strongly variable at higher fluxes. Zhang et al. (2005) identified a similar correlation in the X-ray light curves of PKS 2155-304. This argues against discrete, shot-noise type models (e.g., Merloni & Fabian 2001) and supports inwardly-propagating fluctuations in the local accretion rate in the disk (Lyubarskii 1997; see Uttley et al. 2005). *Does the GeV emission of blazars obey this relation, also?*

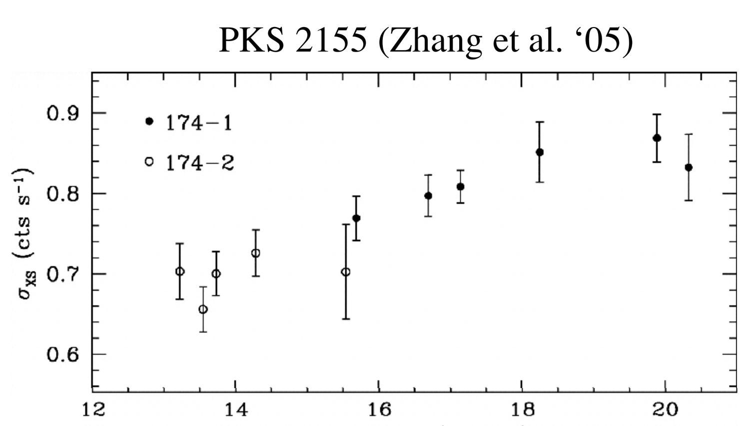
LAT Variability Science 5: Exploring Blazar/Seyfert links and Disk-Jet Connections

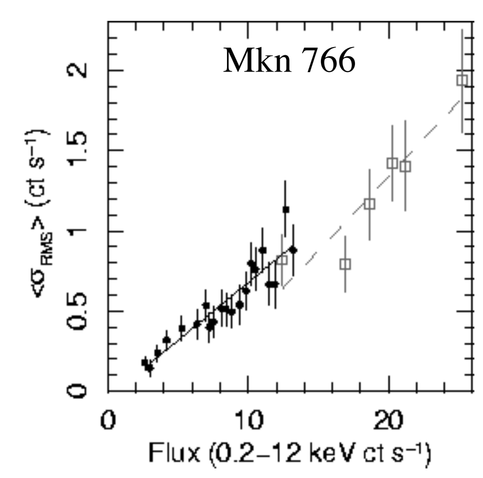
Tentatively, it appears that X-ray T_b's are roughly the same for Seyferts and Blazars. Since the jet is launched from the disk, it is not unreasonable that the disk should exert a strong influence on the jet.

The presence of a GeV rms-flux relation in blazars could, speculatively, be consistent with blazar jets which ``passively" reprocess variable disk flux, with the dominant variability mechanism existing in the disk, not the jet.

Do the GeV light curves show non-linearity? Uttley et al. (2005) noted that introducing a high degree of non-linearity to a typical Seyfert light curve makes positive flares stand out more, yielding a ``spiky" light curve that resembles those of blazars, with large flares dominating over a relatively calmer and lower level of flux. In fact, the simulated blazar light curves in the figure in section 3 were generated from a broken power-law PSD form (similar to that for Seyferts), but with non-linearity added to the simulated light curves.







Left: RXTE-PCA archival light curve of Mkn 501, with tentative visual suggestions that the source is more variable at higher flux.

Middle: X-ray RMS-flux relation for the HBL PKS 2155-304, using XMM-pn data (Zhang et al. 2005).

Right: X-ray RMS-flux relation for the Narrow Line Seyfert 1 Mkn 766, using XMM-pn data (Markowitz et al. 2007)

LAT Variability Science 6: Quantifying frequency of outbursts

What's the typical number of outbursts per year for each blazar? Does that correlate with M_{BH}, L_{Bol}/L_{Edd}, or object type? In the X-rays, Krawczynski et al. (2004) noted a very tentative indication that flare duty cycle may correlate with MBH in a small sample of 7 TeV blazars.

Quantifying frequency of outburst (e.g., as a function of flare size and duration) could provide a test-bed for internal shock models (Spada et al. 2001), wherein blobs are ejected with varying bulk Lorentz factors and collide in the jet.

SUMMARY

Long-term GeV blazar monitoring data obtained uisng GLAST-LAT is complementary to short term observations of just the brightest flares: With LAT light curves, we will:

--Test interband correlations & constrain the SED; search for 'orphan' flares.

--Quantify GeV variability at all fluxes, including quiescence; test for an rms-flux relation; constrain the nature of the overall variability process.

--Measure broadband GeV PSDs for blazars, measure GeV characteristic variability timescales and compare to those in the X-rays.

Comparing characteristic GeV variability characteristics of blazars to X-ray variability characteristics of blazars and Seyferts may provide an additional sense of ``unification" between Seyferts and blazars in terms of variability processes.

References: Arévalo, P. & Uttley, P. 2006, MNRAS, 367, 801; Bao, G. & Abramowicz, M. 1996, ApJ, 465, 646; Barth, A. et al. 2003, ApJ, 583, 134; Cheng, K.S. et al. 1999, A&A, 352, 32; Cui, W. 2004, ApJ, 605, 662; Edelson, R. & Nandra, K. 1999, ApJ, 514, 682; Kataoka, J. et al. 2001, ApJ, 560, 659; Kataoka, J. et al. 2002, MNRAS, 336, 932; Krawczynski, H. et al. 2004, ApJ, 601, 151; Lyubarskii, Y.E. 1997, MNRAS, 292 679; Markowitz, A. & Edelson, R. 2004, ApJ, 617, 939; Markowitz, A. et al. 2003, ApJ, 593, 96; Marscher, A. & Gear, W. 1985, ApJ, 298, 114; McHardy, I. et al. 2004, MNRAS, 348, 783; McHardy, I. et al. 2005, MNRAS, 359, 1469; McHardy, I. et al. 2006, Nature, 444, 730; Merloni, A. & Fabian, A.C. 2001, MNRAS, 328, 958; Nandra, K. et al. 2000, ApJ, 544, 734; Perlman, E. et al. 1999, ApJ, 523, L11; Spada, M. et al. 2001, MNRAS, 325, 1559; Uttley, P. & McHardy, I.M., 2001, 323, L26; Uttley, P. et al. 2002, MNRAS, 332, 231; Uttley, P. et al. 2003, ApJ, 584, L53; Uttley, P., McHardy, I.M. & Vaughan, S. 2005, MNRAS, 359, 345; Zhang, Y.H. et al. 2005, ApJ, 629, 686