The first GeV flare of the radio-loud narrow-line Seyfert 1 galaxy PKS 2004 – 447

Andrea Gokus[1,2], V. S. Paliya[3], on behalf of the *Fermi*-LAT Collaboration,
S. M. Wagner[2], P. G. Edwards[4], J. Stevens[4], J. Wilms[1]
[1]Remeis Observatory/ECAP, [2]University of Würzburg, [3]Aryabhatta Research Institute of Observational Sciences, [4]CSIRO

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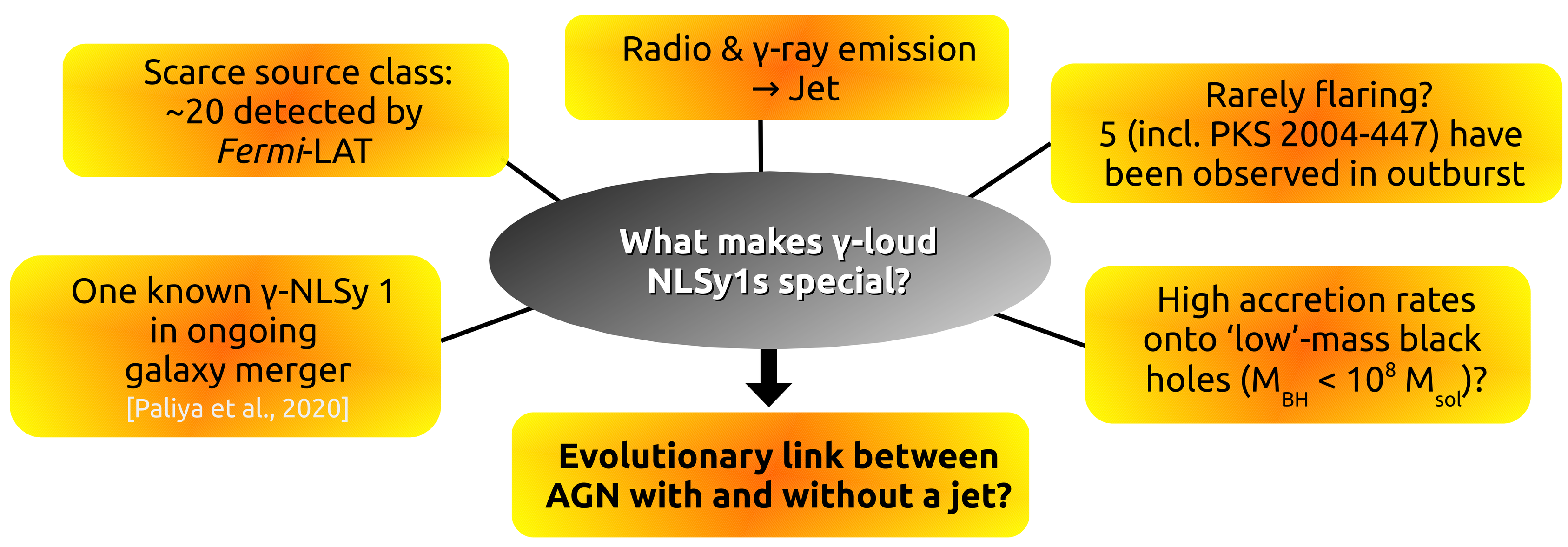
For more information, please contact
Andrea Gokus (andrea.gokus@fau.de) and
Vaidehi S. Paliya (vaidehi.s.paliya@gmail.com)

The extragalactic gamma-ray sky observed with *Fermi*-LAT is dominated by blazars, with only a handful of narrow-line Seyfert 1 (NLS1) galaxies detected in 10 years of observation. Flares from this elusive source class are among the rarest events that the *Fermi*-LAT has seen so far, and we are presenting the analysis on one such event from the radio- and gamma-ray loud source PKS 2004–447.
On 2019 October 25, PKS 2004–447 showed its first bright γ-ray flare since the beginning of the *Fermi* mission. We obtained multi-wavelength follow-up observations with *Swift*, *XMM-Newton*, *NuSTAR*, and ATCA, and studied the variability across all energy bands, with a focus on short timescales in the γ-ray emission. We modelled the broadband spectral energy distribution (SED) data with a leptonic model during different activity states of the source.
The observations of PKS 2004–447, and γ-NLSy1 in general, point to a scenario in which these objects could be considered to belong to the blazar subclass of radio-loud emitters.

Narrow-line Seyfert 1 galaxies and their γ-loud outliers

The optical spectra of Seyfert galaxies include broad and narrow, forbidden lines alike [1]. They are typically hosted in spiral galaxies and do not exhibit jets. They belong to the radio-quiet class of AGN.
Narrow-line Seyfert 1 (NLSy1) galaxies are formally defined by untypically narrow broad lines (FWHM (Hβ) ≤ 2000 km/s), while being proportionally strong with regard to the forbidden [O III] λ5007 Å line [2].
However, a small number of these sources are indeed radio-loud (~7%, e.g., [3]), and among those sources, a few have been found to be γ-emitters. Those are the interesting outliers of the NLSy1 class.



Dynamical SEDs

We constructed four SEDs with data taken during different activity states of PKS 2004–447 and used a simple one-zone synchrotron and inverse Compton model.
The emission region is assumed to be a spherical blob that reaches over the full cross-section of the jet. We do not include additional emission regions in our model, explaining why the radio data are not taken into account for the fit. We assume a black hole mass of $7 \cdot 10^7\ M_{sol}$.
The SEDs are shown in Fig. 2. While the SED during the low state is built from archival data taken in 2012, the time ranges covered by the other SEDs is marked on the light curves in Fig. 1.

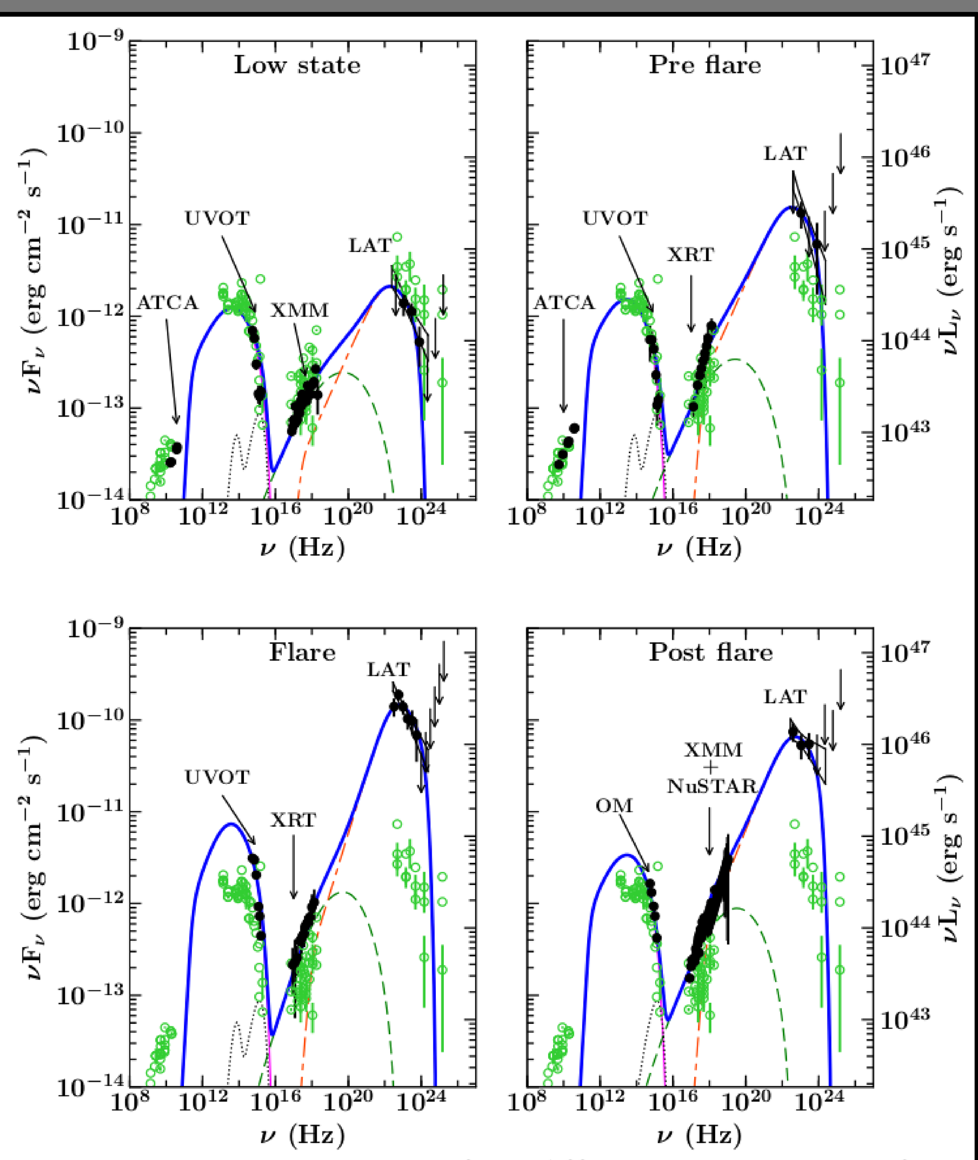


Figure 2: SEDs for 4 different activity states of PKS 2004–447. The black data points are the data modelled in each epoch, while the green open circles are archival data for comparison.

Except for the low state, Compton dominance is visible in each SED. Although the low-energy peak significantly rises during the flare as well, the increase in γ-ray emission, which marks the high-energy peak, is more dominant. While during and after the flare the soft X-ray emission up to 10 keV can be attributed to synchrotron-self Compton, the hard X-ray and γ-ray emission is best explained with external Compton emission.
We explain the large increase in γ-ray emission with an increased Doppler boosting caused by additional motion of the emission region with respect to the external photon field. The increase in optical-UV fluxes can be described with a supply of fresh, energetic electrons.
Comparing the flaring state SEDs of all γ-NLSy1s with a comparable outburst reveals several similarities, including the spectral hardening in the X-rays during bright states, and the Compton dominance. Overall, their behaviour during flares is also similar to those of blazars, especially flat-spectrum radio quasars.

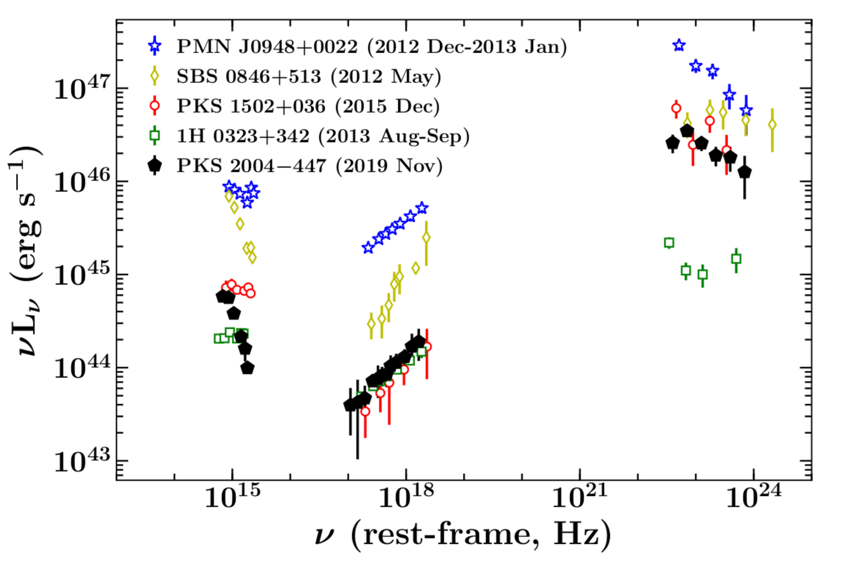


Figure 3: Comparison of the flaring state SEDs of the five γ-NLSy1 sources.

The peculiar source PKS 2004–447 and its flare in 2019

This southern-hemisphere AGN has a redshift of z = 0.24 [4] and is the radio-loudest of all known γ-NLSy1s. The γ-ray emission of PKS 2004–447 was detected during the first year of the *Fermi* mission [5], and did not show strong short-time fluctuations, until October 2019.
Its radio emission is very similar to that of compact-steep spectrum (CSS) sources [6,7], which are very rare among γ-ray emitting AGN. Although classified as a NLSy1 galaxy, PKS 2004–447 lacks several characteristics that are typical for NLSy1s, like the soft excess below 2 keV in its X-ray spectrum [8], and strong Fe II emission [6].

On 2019 October 25, the Flare Advocate service of *Fermi*-LAT registered a flare by PKS 2004–447, during which the daily averaged flux exceeded the catalog flux value by a factor of ~55 [9]. The flare lasted 3 days.
The overview of the multi-wavelength light curves (Fig. 1 below) shows the γ-ray emission in the top, the X-ray emission in the middle, and the optical-UV emission in the bottom panel. The grey-ish marked time ranges are the periods used for our dymanic SED modelling.
Applying a basic χ^2-test to all light curves, we find that the emission across all energy bands is variable for the time considered in our analysis, which is from 2019 September 27 until 2019 November 19.

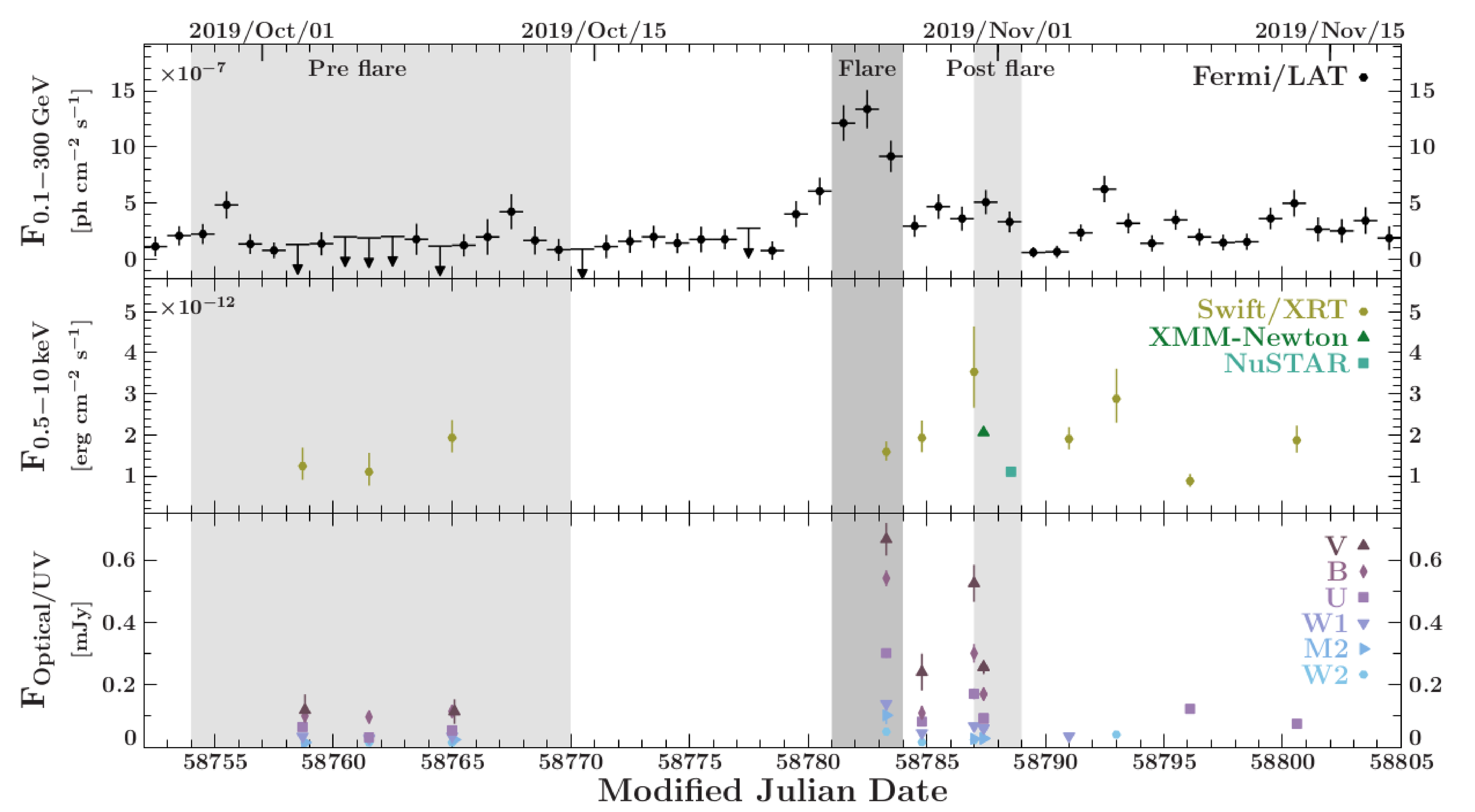


Figure 1: Multi-wavelength light curves of PKS 2004–447.

γ-ray variability at short time scales

Taking a deeper look at the sub-daily binned γ-ray light curves, we want to study the sub-structure of the flare using a combination of the Bayesian-block algorithm and the HOP algorithm [11].
The 6- and 3-hour binned light curves reveal that a short flare occurred ~ 1 day before the main flare. A second short flare is found ~ 8 days after the main flare, for which we also find an indication for a flux-doubling time of 2.2 hour at the 3σ level. The substructure in the 6- and 3-hour binned light curves cannot be resolved further during the main flare with the Bayesian blocks due to the limit of sensitivity.
In addition, we find the highest flux ever measured for this source in the 3-hour binned light curve, which corresponds to an isotropic γ-ray luminosity of ~ $3 \cdot 10^{47}$ erg/s.

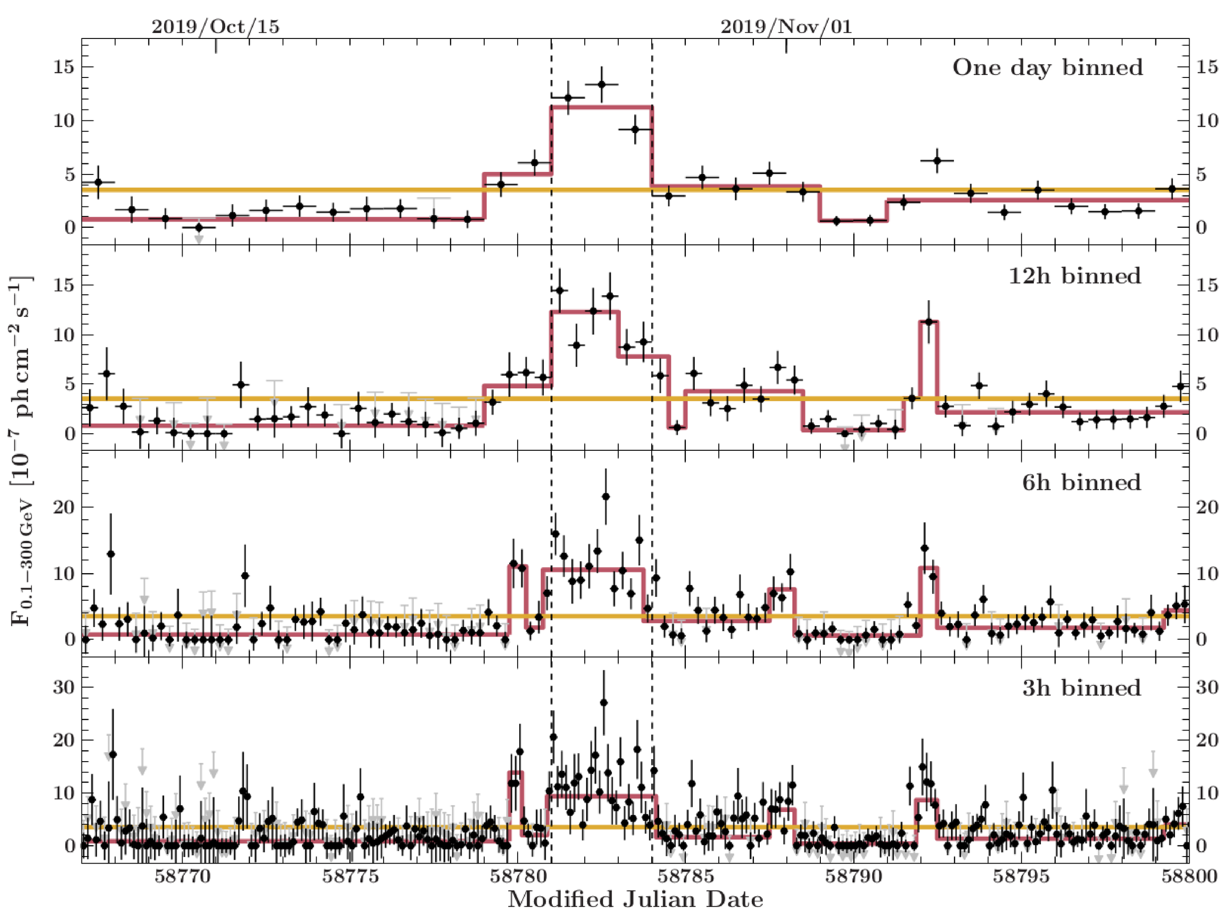


Figure 4: Differently binned γ-ray light curves. The yellow line marks the mean flux, while the Bayesian blocks are shown via the red line.

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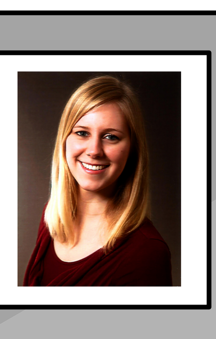
About the author:
Andrea Gokus is a PhD candidate researching high-energetic processes in blazars using multi-wavelength data. She is passionate about public outreach, good SciFi stories, and her dog Amos.



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