Fermi Observations of the Hard Gamma-ray Blazar PG 1553+113

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We report the observations of PG 1553+113 with the *Fermi Large Area Telescope* (*Fermi* LAT). This is the first detailed study of PG 1553+113 in the GeV energy regime and it allows us to fill a gap of three decades in energy in its spectral energy distribution, to model its broadband emission and to estimate its redshift.

Abstract:

We find PG 1553+113 to be a **steady** source with a **hard** spectrum that is best fit by a **power-law** in the *Fermi* energy band. We combine the *Fermi* data with archival radio, optical, X-ray and very high energy (VHE) gamma-ray data to model its broadband spectral energy distribution and find that a **simple, one-zone synchrotron self-Compton model** provides a reasonable fit. PG 1553+113 has the softest spectrum of all the VHE sources and, one of the hardest spectra measured by *Fermi*. Thus, it has the **largest spectral break** of any gamma-ray source studied to date, which could be due to the absorption of the intrinsic gamma-ray spectrum by the extragalactic background light (EBL). Assuming this to be the case, a parameterization of the EBL was used to absorb the spectrum from PG 1553+113 measured with *Fermi* (200 MeV - 157 GeV) to find the redshift which gave the best fit to the measured VHE data (90 GeV - 1.1 TeV). Using this method, we estimate the redshift of PG 1553+113 to be $z = 0.75^{+0.04}_{-0.05}$ stat , which would make PG 1553+113 the **most distant VHE source** detected so far, a result consistent with it having the largest gamma-ray spectral break. We show that, should the assumptions made in the estimation of this redshift be incorrect, the value derived here can be considered to be an **upper limit**.

1. *Fermi* Observations:

The nominal observing mode of the *Fermi* LAT is "Sky Survey" meaning that every 3 hours, all of the sky is exposed. In this way, a detailed map of the high energy gamma-ray sky (> 200 MeV) is compiled over time. Presented here is the analysis of the *Fermi* LAT data from a region of 10° radius centred on PG 1553+113 from 4 August 2008 to 22 February 2009. Figure 1 shows the resulting counts map. These data were analyzed using the standard *Fermi* analysis software[1] (ScienceTools v9r10; IRF P6_V3_DIFFUSE). There are two other *Fermi* sources within 10° of PG 1553+113. These sources, lying at angular separations of 1.8° and 5.5° from PG 1553+113 were modeled in our analysis so that they could be subtracted out along with the extragalactic diffuse gamma-ray emission, the residual instrumental background and the galactic diffuse emission. The angular resolution of *Fermi* is such that the signal from PG 1553+113 is not significantly contaminated by the emission from these neighbouring sources. The flux and photon index lightcurves are shown in Figure 2. No evidence for variability was found for either quantity during the course of these obervations.

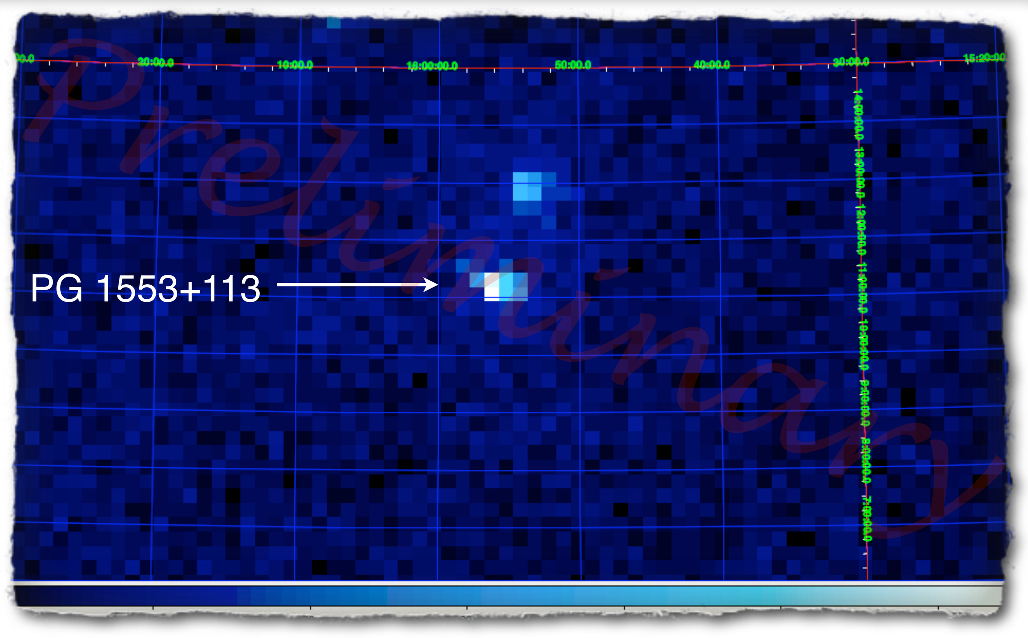

Fig. 1: Counts map of the PG 1553+113 field of view.

1.1 *Fermi* Spectrum:

PG 1553+113 was detected by *Fermi* with a statistical significance of ~49σ and an integral flux I (E > 200 MeV) of 5.00 ± 0.31 × 10^{-8} cm^{-2} s^{-1} in the high energy (HE) regime. The most energetic photon in the *Fermi* data is at 157 GeV. The *Fermi* data are well described by a power-law such that the differential photon flux, $F(E)$, is given by:

$$F(E) = \frac{dN}{dE} = F_0 \left(\frac{E}{E_0}\right)^{-\Gamma}$$

where F_0 is the differential flux at energy, E_0 and Γ is the photon index. We find a differential flux of 2.60 ± 0.18 × 10^{-9} cm^{-2} s^{-1} GeV^{-1} at the decorrelation energy of 2.4 GeV and a photon index of 1.68 ± 0.03. The very high energy (VHE) spectrum has a mean photon index of 4.21 ± 0.25. This combination of a very soft VHE spectrum and a very hard HE spectrum means that PG 1553+113 has a significant spectral break in the gamma-ray regime.

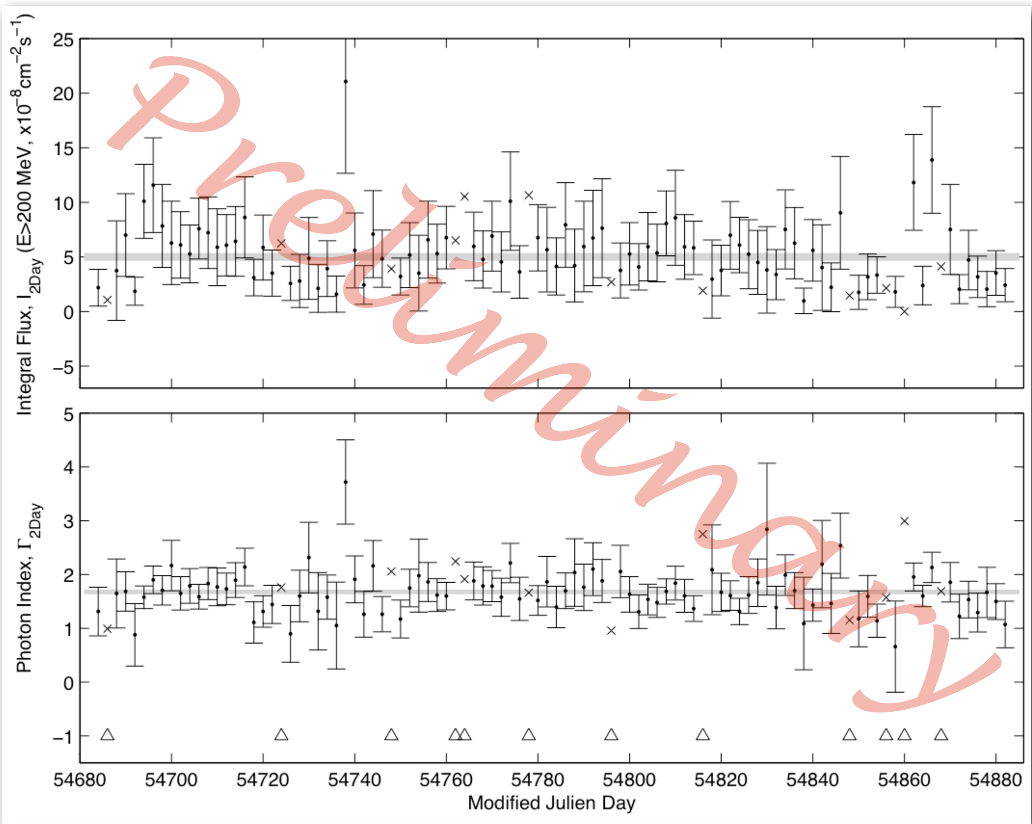

Fig. 2: Flux and photon index lightcurves (2-day bins).

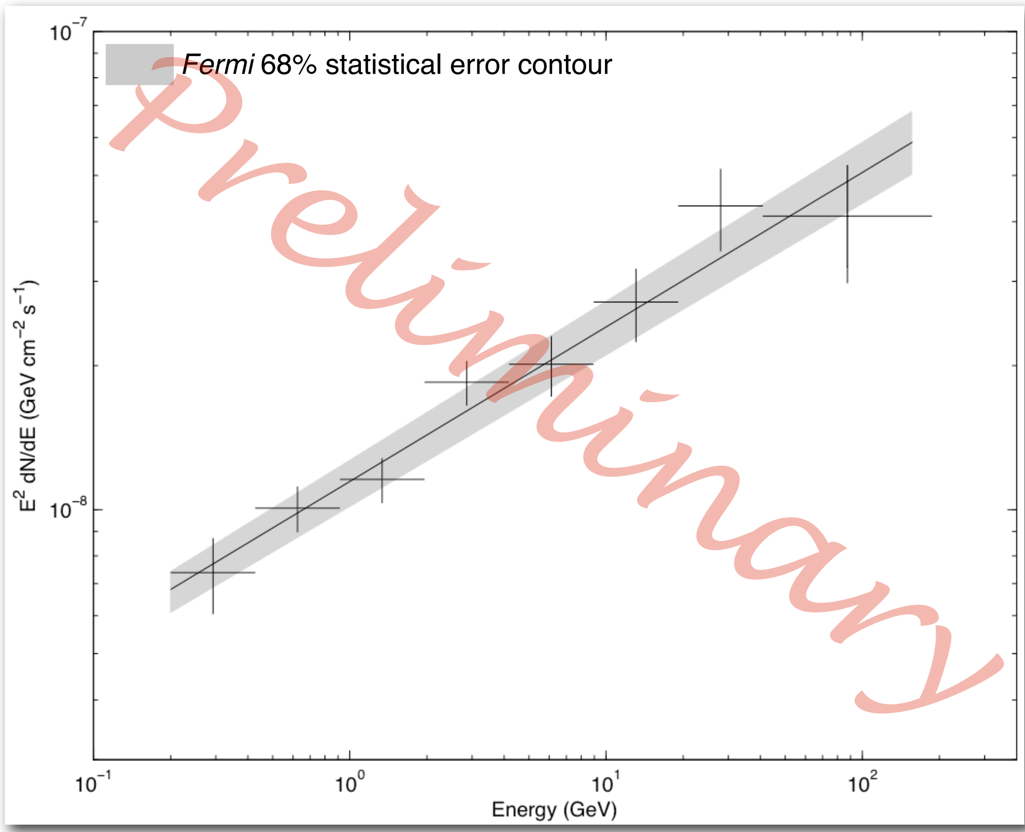

Fig. 3: *Fermi* differential flux spectrum.

2. Redshift of PG 1553+113:

Despite many dedicated observing campaigns the redshift of PG 1553+113 remains unknown[2,3,4,5,6,7,8]. Gamma-ray data can be used indirectly to estimate redshifts because the gamma rays pair-produce with the EBL photons thus introducing a redshift-dependent absorption feature on the spectrum[9,10,11,12]. The *Fermi* data and non-simultaneous H.E.S.S. (2 datasets)[13,8] and MAGIC (2 datasets)[14,15] data were analysed together to find the redshift that best fits their joint spectrum. Based on the consistency of the gamma-ray fluxes (both VHE and HE) and of the measured VHE spectra we make the assumption that PG 1553+113 was in a non-flaring state during all of these observations. We also assume that any departures from the power-law spectrum measured by *Fermi* up to 1 TeV are dominated by absorption of gamma rays by the EBL and use the parameterisation of Franceschini et al. (2008)[16] to find the level of EBL, and therefore the redshift, which best fits the measured data and find that a redshift of z = 0.75 gives the best χ^2 fit to the measured VHE data (Fig. 4). When the *Fermi* 68% uncertainty-contours are subjected to the same fitting procedure we obtain the statistical error on the redshift determination for that EBL[16] giving us a range from z = 0.70 – 0.79. We note that the systematic uncertainty on the energy scale was not taken into account in these calculations. This is on the order of 10-15% for VHE gamma-ray telescopes[17,18]. If the assumptions made in our calculations are incorrect, the estimated redshift is an upper limit.

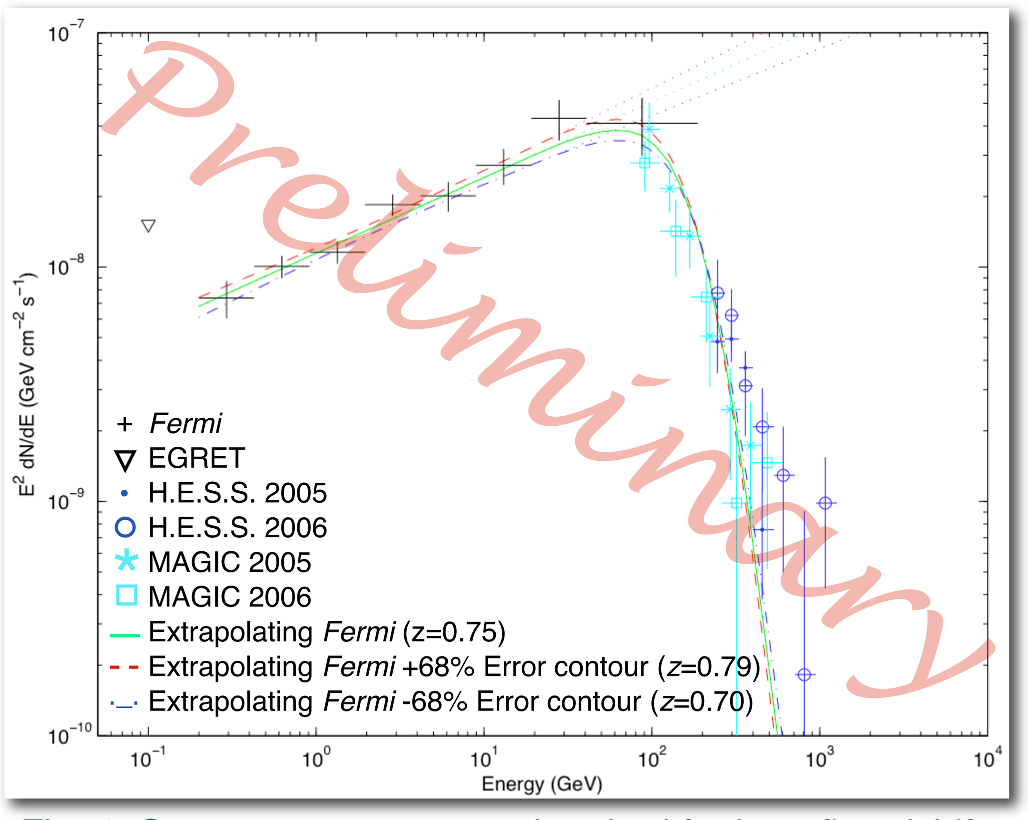

Fig. 4: Gamma-ray spectrum absorbed for best-fit redshift.

3. Spectral Energy Distribution:

All of the PG 1553+113 gamma-ray data were combined in turn with archival X-ray data and each dataset was modeled with a single-zone synchrotron self-Compton (SSC) model[19,20] (Fig. 5). By altering only the distribution of the e$^-$s that produce the synchrotron emission, a good fit to the overall SED was found for each of the X-ray flux states and, for all of these model realisations the VHE component of the SED did not change significantly: the magnitude of the changes in the SED above 200 GeV are on the order of the VHE statistical measurement uncertainties. This consistency of spectral shape implies that the gamma-ray flux could remain consistent with the state seen during the VHE observations even in the presence of the large changes in the X-ray flux level that have been detected. Such behaviour was observed with simultaneous datasets from PKS 2155-304[20]. During previous observations however when it was in a flaring gamma-ray state there was strong correlation between the X-ray and VHE fluxes[21]. This behaviour is an indication that the hard X-ray flux of BL Lacs can change significantly without resulting in detectable activity in the gamma-ray regime except for at the peak of the SED. In such a scenario, the e$^-$s producing the variable X-ray emission are at higher energies than those upscattering the bulk of the synchrotron photons to the VHE regime; the scatterings of the variable hardest X-rays are suppressed mostly due to Klein-Nishina effects but also due to the decreasing target photon density.

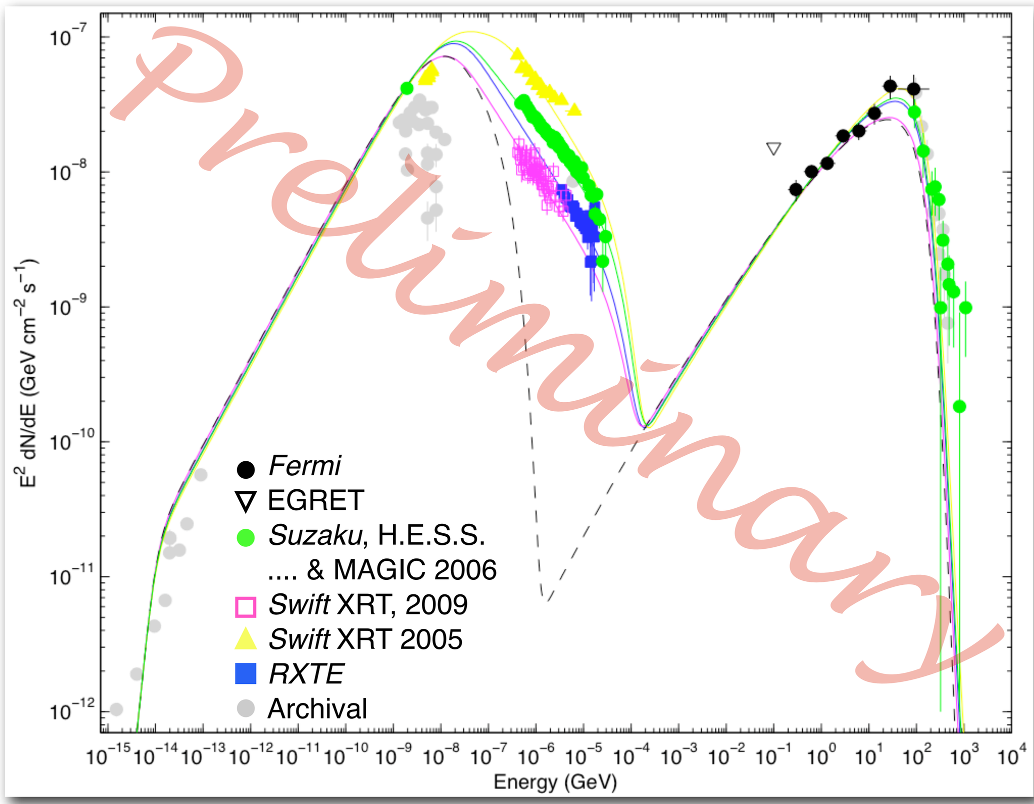

Fig. 5: SSC model fitted to each of the X-ray datasets.

[1]Atwood W. B., et al. 2009, ApJ, 697, 1071; [2]Falomo, R., & Treves, A. 1990, PASP, 102, 1120; [3]Falomo, R., Scarpa, R., & Bersanelli, M. 1994, ApJS, 93, 125; [4]Carangelo, N., Falomo, R., Kotilainen, J., Treves, A., & Ulrich, M.-H. 2003, in Astronomical Society of the Pacific Conference Series, Vol. 299, High Energy Blazar Astronomy, ed. L. O. Takalo & E. Valtaoja, 299; [5]Sbarufatti, B., Treves, A., & Falomo, R. 2005, ApJ, 635, 173; [6]Sbarufatti, B., Treves, A., Falomo, R., Heidt, J., Kotilainen, J., & Scarpa, R. 2006, AJ, 132,, 1; [7]Treves, A., Falomo, R., & Uslenghi, M. 2007, A&A, 473, L17; [8]Aharonian, F., et al. 2008, A&A, 477, 481; [9]Costamante, L., Aharonian, F., Horns, D., & Ghisellini, G. 2004, New Astronomy Review, 48, 469; [10]Dwek, E., & Krennrich, F. 2005, ApJ, 618, 657; [11]Stecker, F. W., Baring, M. G., & Summerlin, E. J. 2007, ApJ, 667, L29; [12]Krennrich, F., Dwek, E., & Imran, A. 2008, ApJ, 689, L93; [13]Aharonian, F., et al. 2006a, A&A, 448, L19; [14]Albert, J., et al. 2007, ApJ, 654, L119; [15]Albert, J., et al. 2009, A&A, 493, 467; [16]Franceschini, A., Rodighiero, G., & Vaccari, M. 2008, A&A, 487, 837; [17]Aharonian, F., et al. 2006b, A&A, 457, 899; [18]Albert, J., et al. 2008, ApJ, 674, 1037; [19]Band & Grindlay 1985; [20]Aharonian, F., et al. 2009, ApJ, 696, L150; [21]Costamante, L. 2008, International Journal of Modern Physics D, 17, 1449.