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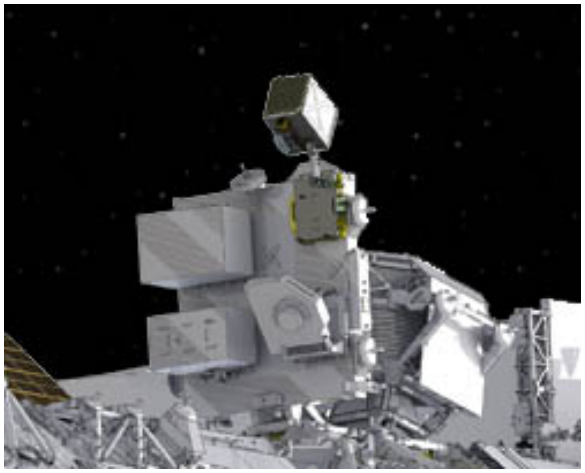

NICER follow-up of the flaring blazar BL Lacertae

Filippo D'Ammando

INAF-IRA Bologna

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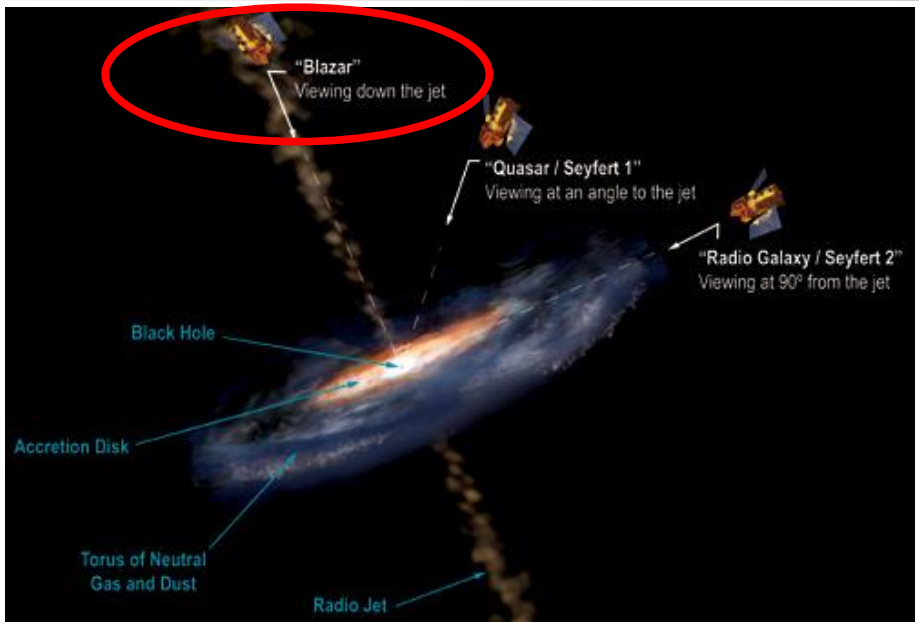
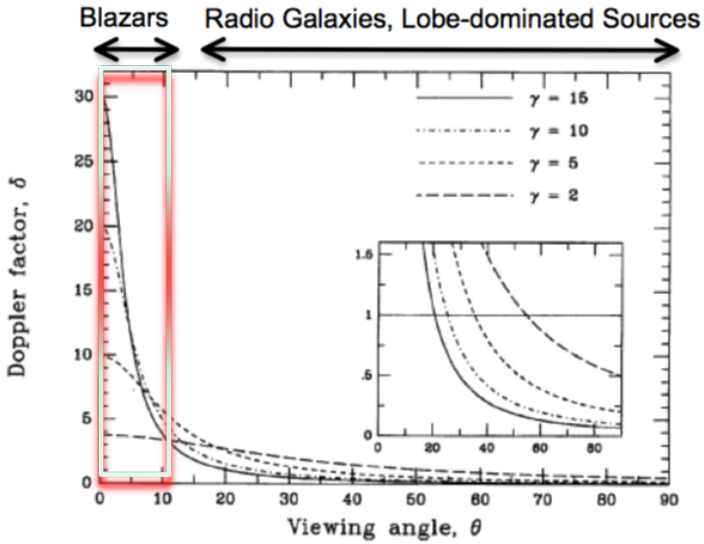
Blazars





Doppler factor $\delta = [\ \Gamma\ (1 - \beta \cos\theta)\ ]^{-1}$

$\Gamma = (\ 1 - \beta^2\ )^{-½}$ bulk Lorentz factor, θ viewing angle

- flux density enhanced $F_\nu\ (\nu) = \delta^{2+\alpha}\ F'_{\nu'}\ (\nu)$
- variability time scale decreased $\Delta t = \Delta t'/\delta$
- frequencies blue-shifted $\nu = \delta\nu$
- variable emission over all the EM spectrum
- unpredictable variability
- time scales from minutes to years

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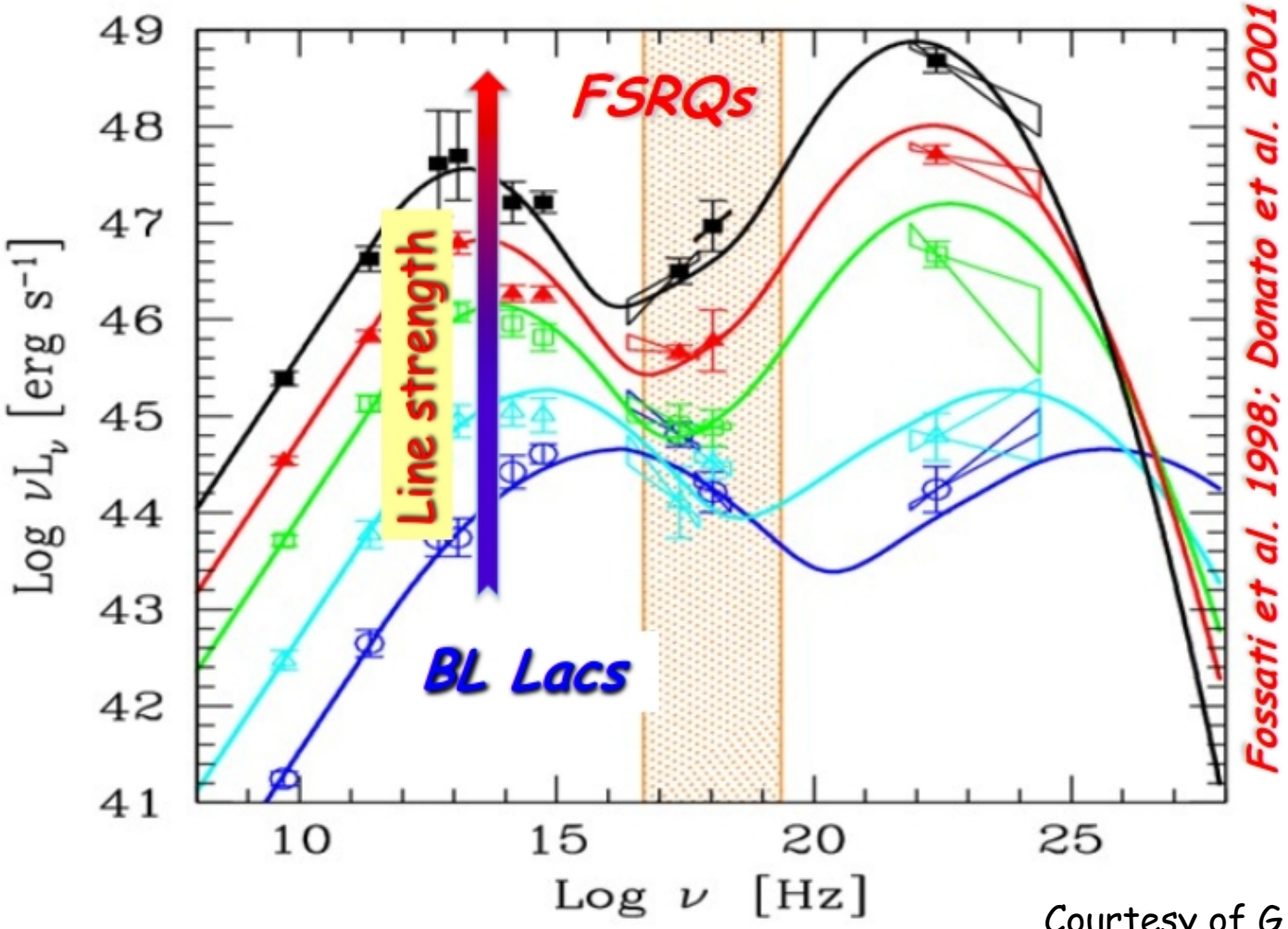
FSRQ and BL Lacs



Courtesy of G. Ghisellini

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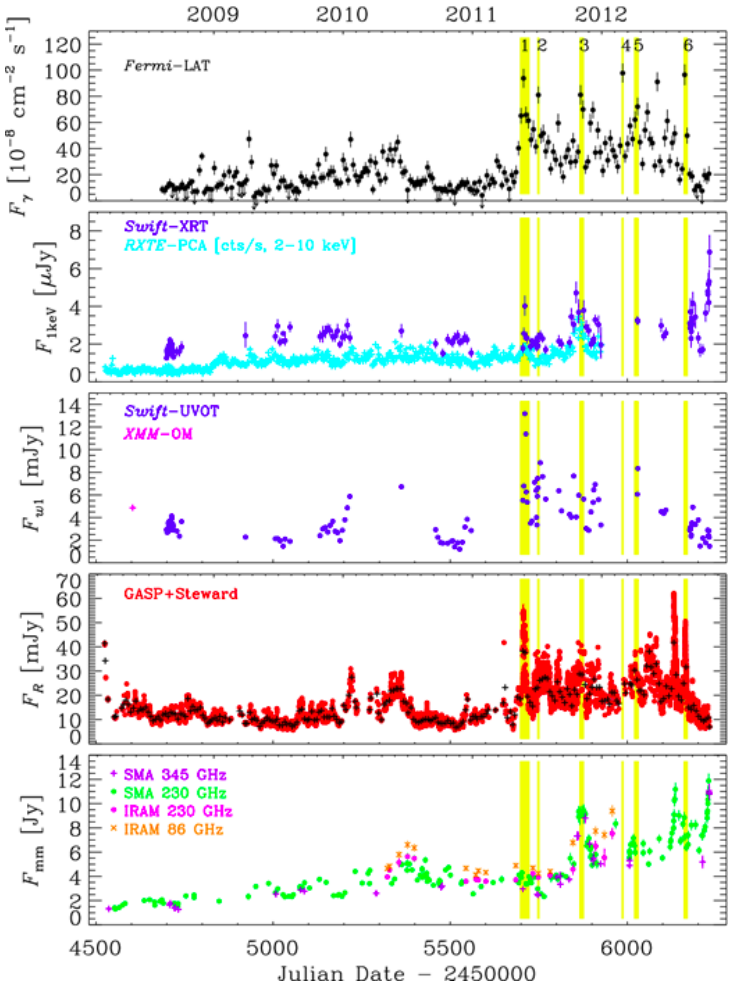
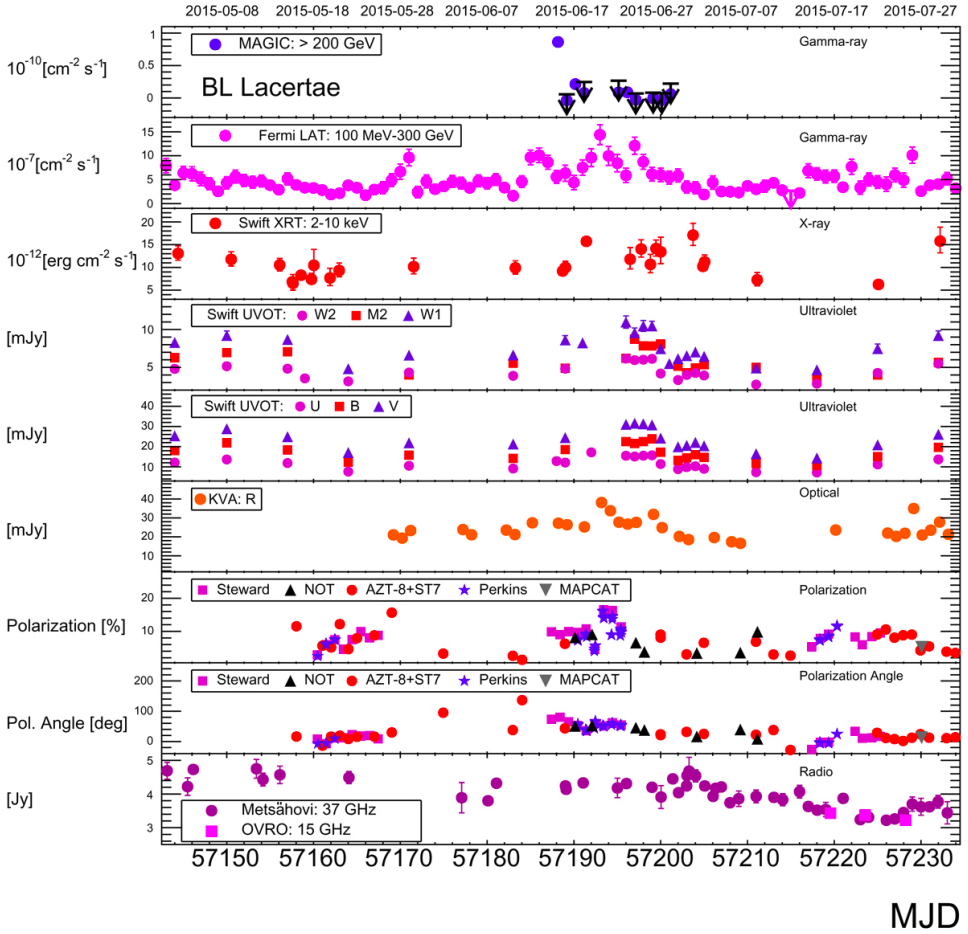
BL Lacertae

BL Lacertae has been the target of several observational campaigns in the last two decades from radio to very high energies



Raiteri+13, MNRAS, 436, 1530



Acciari+19, A&A, 623, A175

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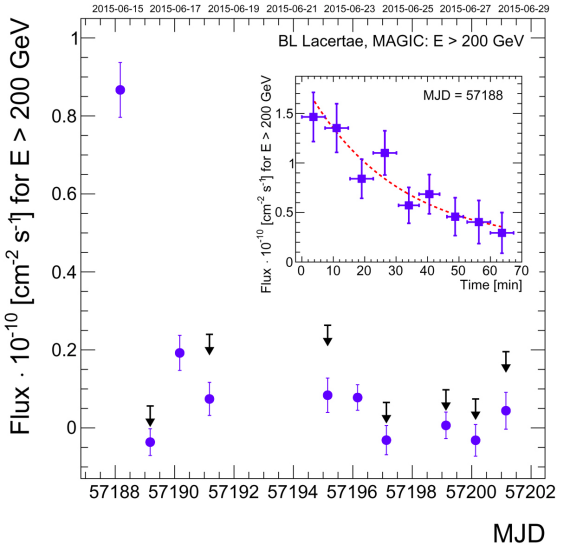
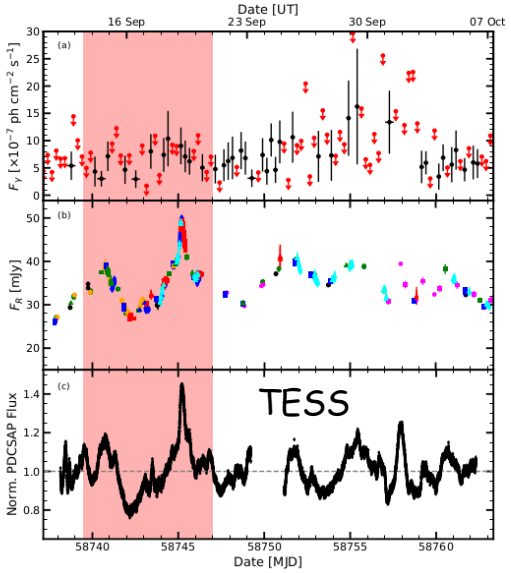
BL Lacertae

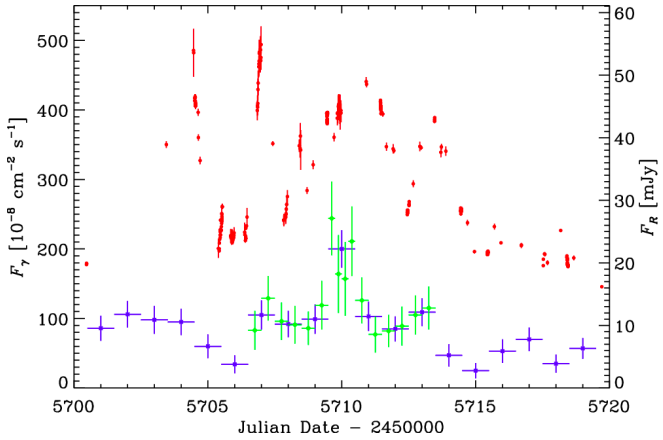
Fast flux variability has been observed from BL Lacertae in optical, HE and VHE γ-rays



Acciari+19, A&A, 623, A175



Weaver+20, ApJ, 900, 137



Raiteri+13, MNRAS, 436, 1530

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Strong γ-ray flaring activity in 2020 Aug-Oct

Fermi-LAT detection of record gamma-ray flare in BL Lacertae contemporaneous with record optical flaring

ATel #13964; ***Roopesh Ojha (NASA/GSFC/UMBC) and Janeth Valverde (LLR/Ecole Polytechnique) on behalf of the Fermi Large Area Telescope Collaboration***
*on **22 Aug 2020; 15:10 UT***
Credential Certification: Roopesh Ojha (Roopesh.Ojha@gmail.com)

Subjects: Optical, Gamma Ray, >GeV, AGN, Blazar, Quasar

Referred to by ATel #: 14032, 14065, 14072, 14081, 14318, 14334, 14356

MAGIC detection of very-high-energy gamma-ray flaring activity from BL Lacertae during the current historical optical and high-energy gamma-ray flare

ATel #13963; ***Oscar Blanch (IFAE-BIST, Barcelona), on behalf of the MAGIC collaboration***
*on **22 Aug 2020; 13:11 UT***
Credential Certification: Oscar Blanch (blanch@ifae.es)

Subjects: Gamma Ray, TeV, VHE, Blazar

Referred to by ATel #: 14032, 14065, 14081, 14318, 14334, 14356

Fermi-LAT detection of record gamma-ray flare in BL Lacertae contemporaneous with record X-ray flare

ATel #14072; ***I. Mereu (INFN Perugia) on behalf of the Fermi Large Area Telescope Collaboration***
*on **7 Oct 2020; 20:56 UT***
Credential Certification: Isabella Mereu (mereuisabella@gmail.com)

Subjects: Optical, Ultra-Violet, X-ray, Gamma Ray, >GeV, AGN, Blazar, Quasar

Referred to by ATel #: 14081, 14096, 14318, 14330, 14334, 14356

Detection of a bright very-high-energy gamma-ray flare from BL Lac with the MAGIC telescopes

ATel #14032; ***Oscar Blanch (IFAE-BIST, Barcelona), on behalf of the MAGIC collaboration***
*on **20 Sep 2020; 18:46 UT***
Credential Certification: Oscar Blanch (blanch@ifae.es)

Subjects: Gamma Ray, TeV, VHE, Blazar

Referred to by ATel #: 14065, 14081, 14318, 14356

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NICER, Swift and NuSTAR follow-up observations

Swift detection of record X-ray flare of BL Lacertae

ATel #14069; ***Filippo D'Ammando (INAF-IRA Bologna)***
*on **7 Oct 2020; 10:44 UT***
Credential Certification: Filippo D'Ammando (dammando@ira.inaf.it)

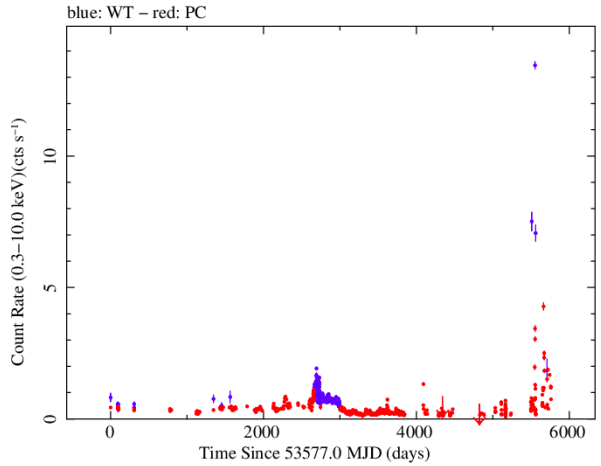
Subjects: Optical, Ultra-Violet, X-ray, AGN, Black Hole, Blazar

Referred to by ATel #: 14072, 14081, 14096, 14318, 14334, 14350, 14356, 14548

Tweet

After the increase of activity observed in optical, UV, and X-rays by Swift on 2020 October 5 (ATel #14065), a new Swift observation of BL Lacertae was performed on October 6 (04:15:06-04:31:00 UTC) for the same Target of Opportunity request.

Swift/XRT data were taken during 2020 October 6 in Windowed Timing mode for a net exposure of about 1.0 ksec. Taking into consideration the Swift/XRT observations performed during 2005-2020, on 2020 October 6 BL Lacertae reached the highest count rate in the 0.3-10 keV energy range observed so far (see Swift-XRT Monitoring of Fermi-LAT Sources of Interest; Stroh & Falcone, 2013, ApJS, 207, 28).



https://www.swift.psu.edu/monitoring/data_new/BLLacertae/lightcurve.png

NuSTAR and NICER follow-up observations of the flaring blazar BL Lacertae

ATel #14096; ***Filippo D'Ammando (INAF-IRA Bologna)***
*on **15 Oct 2020; 11:18 UT***
Credential Certification: Filippo D'Ammando (dammando@ira.inaf.it)

Subjects: X-ray, AGN, Black Hole, Blazar

Referred to by ATel #: 14318, 14334, 14342, 14350, 14356, 14548

Tweet

Following the historical maximum flux of the blazar BL Lacertae observed in optical, UV, X-ray, and gamma-rays (ATel #14065, #14069, #14072), NuSTAR observed the source for a DDT request (PI: D'Ammando) between 2020 October 11 14:05:18 UTC and October 12 07:15:00 UTC, for an effective exposure time of 30.7 ks. The source is detected across the energy interval 3-79 keV in the quick look data, at a net count rate of about 0.23 counts/s for both the focal plane modules.

The data were reduced by performing the standard data reduction procedure, using the NuSTAR Data Analysis Software nustardas v1.9.2 with a caldb version 20200912 and assuming 70 arcsec circle as the source region. The count rate shows an increasing trend in the second part of the NuSTAR observation. Preliminary analysis has been performed fitting the 3-79 keV X-ray spectra with an absorbed power-law with the Galactic absorption corresponding to a hydrogen column density of n_H = 3.4 x 10^21 cm^-2 (Raiteri et al. 2010, A&A, 524, 43). The fit results in a photon index of 1.69 +/- 0.03 and an observed (i.e. not corrected for Galactic extinction) flux in the 3-79 keV energy range of (2.53 +/- 0.06) x10^-11 erg cm^-2 s^-1. The flux observed on 2020 October 11-12 is a factor of two higher than the values observed by NuSTAR during 2019 September 14-19 (Weaver et al. 2020, ApJ, 900, 137), confirming the high activity state of the source. The photon index estimated on 2020 October 11-12 is harder than the value estimated in 2019 over the entire observing period.

BL Lacertae has been observed also by NICER for a DDT request (PI: D'Ammando) between 2020 October 11 17:35:04 UTC and October 12 23:13:06 UTC for an effective time of 14.7 ks. The source is detected across the energy interval 0.3-5.0 keV in the quick look data, with an average count rate of 3.85 counts/s. Variations of the count rate up to a factor of two has been observed across the observation. Preliminary analysis shows that the joint NICER and NuSTAR spectrum in the 0.3-79 keV energy range is better described by a broken power-law than a single power-law. The spectral index obtained below and above the break is 2.41 +/- 0.06 and 1.56 +/- 0.03, respectively, with a break energy of 2.32 (+0.10, -0.12) keV. Leaving the Galactic absorption value free to vary we found n_H = (2.7 +/- 0.1) x 10^21 cm^-2.

We thank the NuSTAR PI, Fiona Harrison, for approving the DDT request, and the NuSTAR SOC for carrying out the observation and the excellent support.

We thank the NICER PI, Keith Gendreau, and the operation team for the rapid approval and execution of the DDT request. NICER is a 0.2-12 keV X-ray telescope operating on the International Space Station. The NICER mission and portions of the NICER science team activities are funded by NASA.

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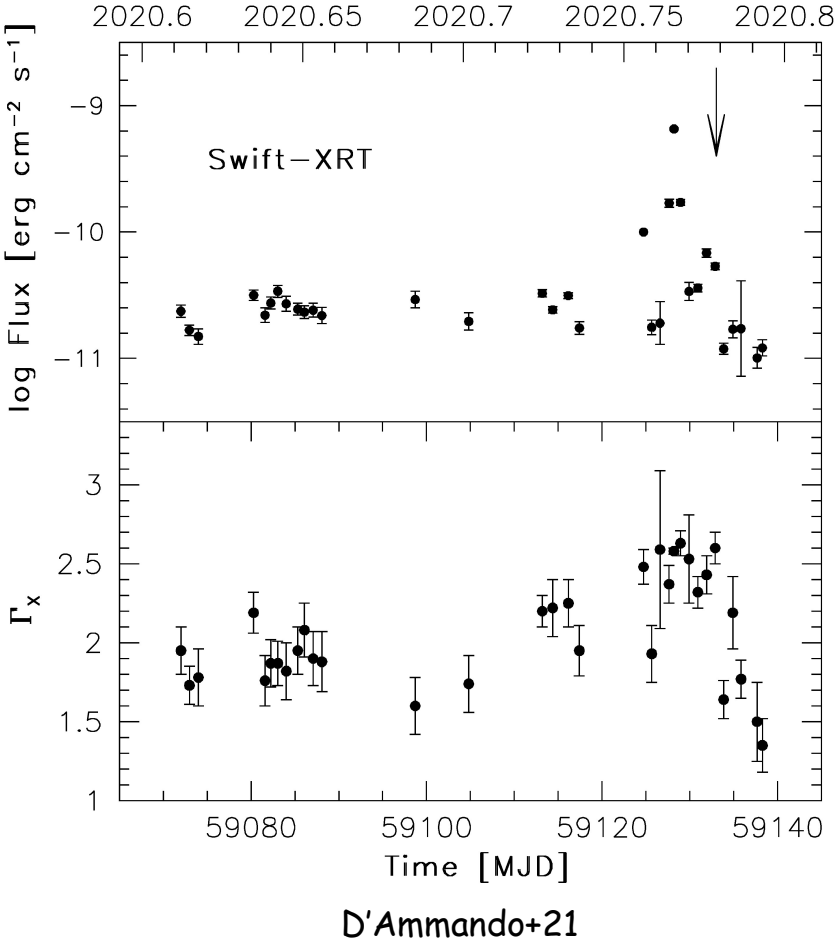
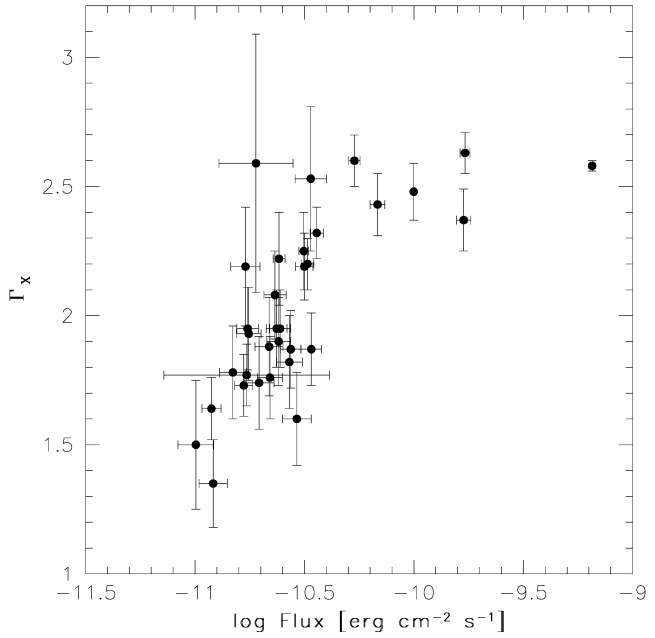
Swift observations in 2020 Aug-Oct

Between 2020 August 11 and October 16 the X-ray flux (0.3-10 keV) varies between 1.0×10^{-11} and 6.5×10^{-10} erg cm $^{-2}$ s^{-1}, reaching ***the historical maximum flux in X-rays***



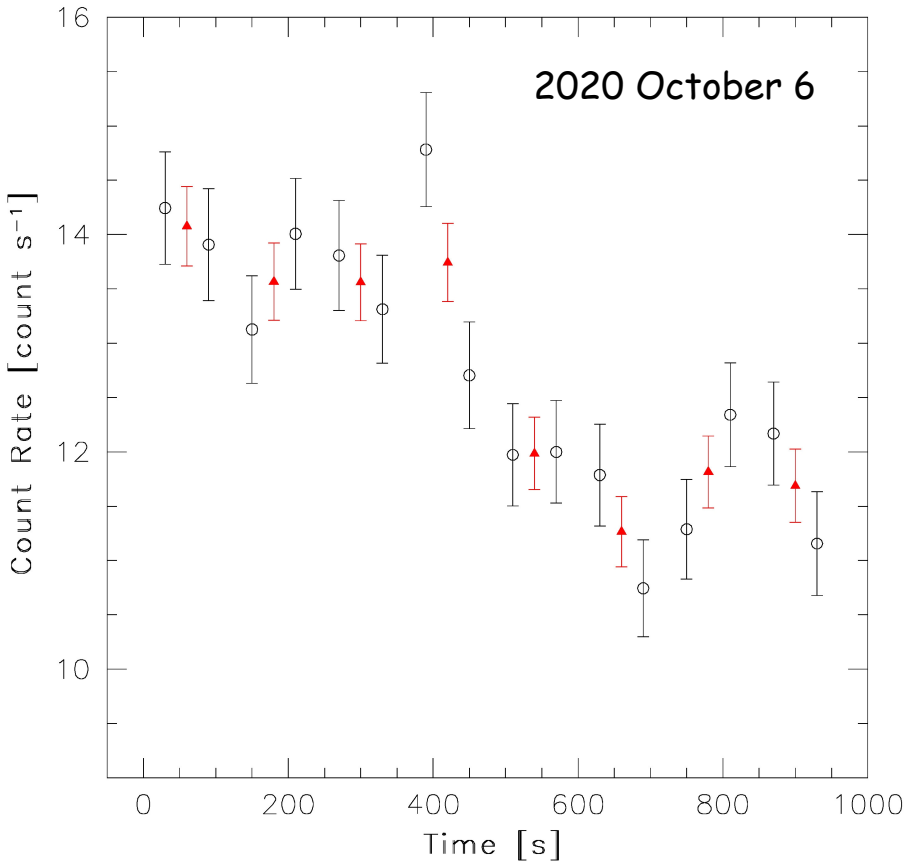
D'Ammando+21



A softer-when-brighter behaviour in BL Lac has been observed during 2020 Aug-Oct by XRT, indicating a potential increase of the synchrotron emission during bright states

Rapid variability detected by XRT

After the background has been subtracted and potential instrumental artifact and pile-up have been corrected, a significant (> 3-σ) change of the count rate has been observed in consecutive bins on both the **60-s** and **120-s** time-scales, suggesting a *very compact emitting region*



Based on causality argument: $R < c\, t\, \delta/(1+z) = 1.7 \times 10^{13}$ cm (δ=10)

The light crossing time for SMBH is $t_{lc} = 2GM_{BH}/c^3 = 3560$ s, therefore $t_{lc}/\delta = 356$ s

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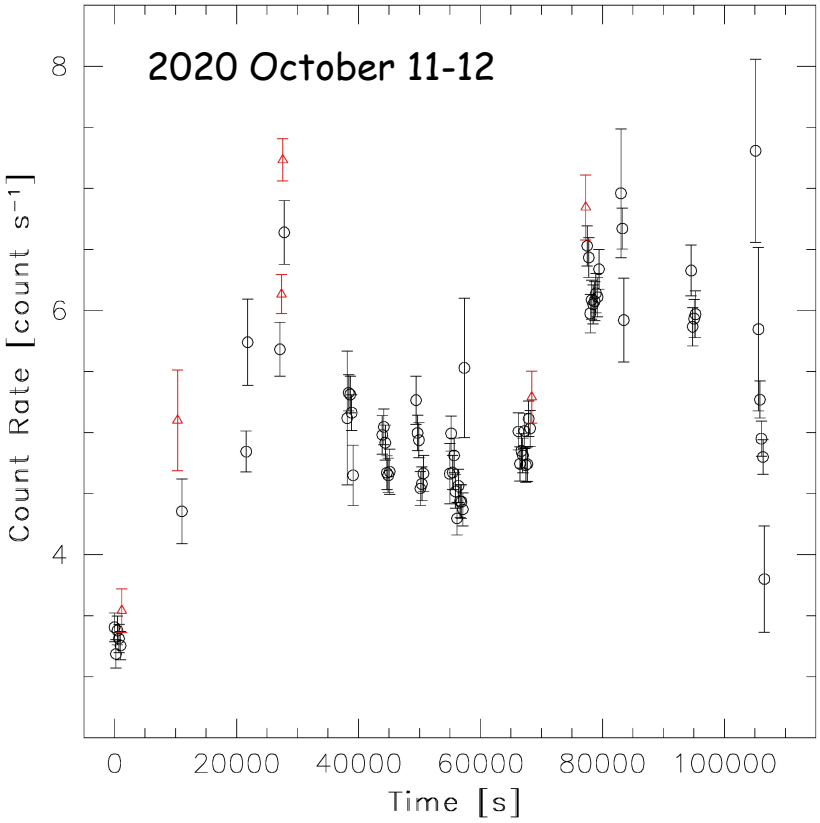
NICER observations of BL Lacertae

NICER observed BL Lacertae on 2020 October 11-12 for an effective time of 14.7 ks. The 0.4–5 keV light curve shows variability (by factors of up to two) across the observation, with a count rate varying between 3.15 and 7.30 count s^{-1}



3 episodes of significant change of activity have been observed in the 240-s light curve

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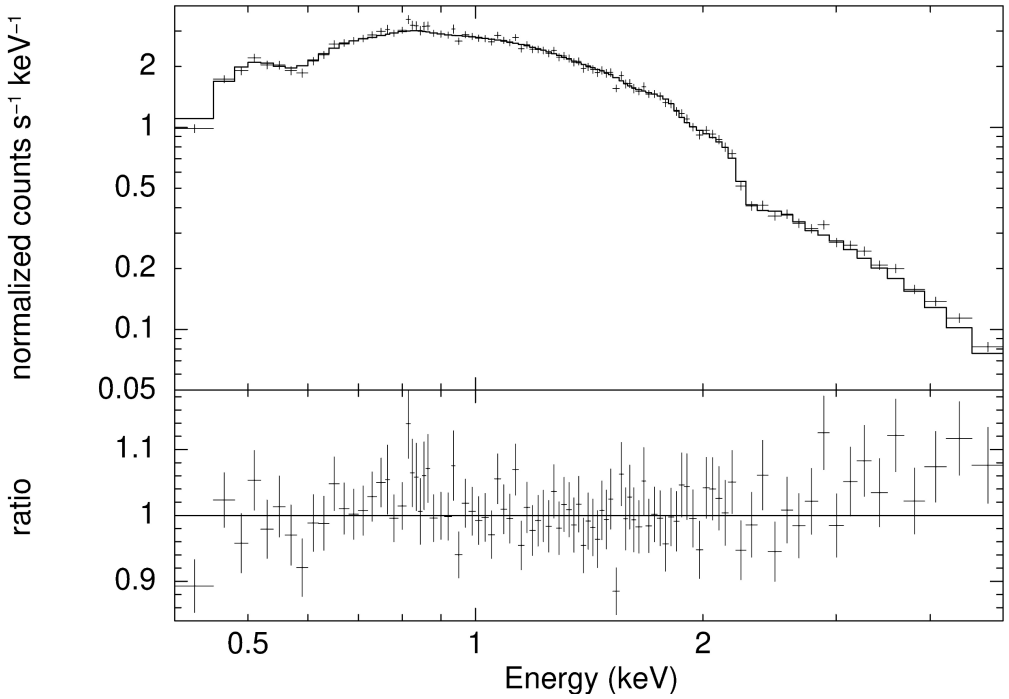
NICER observations of BL Lacertae



- Absorbed *power-law* with a **photon index of 2.06±0.01** and N_H= 2.7×10^{21} cm^{-2} (χ^2/dof = 527.11/457)
- Absorbed *log-parabola* with a slope α = 2.10±0.02 and a negative curvature parameter of β = −0.19±0.05, suggesting a concave X-ray spectrum (χ^2/dof = 490.80/456). The 0.3–10 keV/0.4–5.0 keV flux range is (1.62±0.01)×10^{-11} / (1.13±0.01)×10^{-11} erg cm^{-2} s^{-1}
- Leaving the N_H value free to vary there is a slight improvement of the fit (χ^2/dof = 481.13/455) with larger uncertainties on the spectral parameters: N_H=(3.1±0.3)×10^{21} cm^{-2}, α = 2.32±0.12, β = −0.48±0.16

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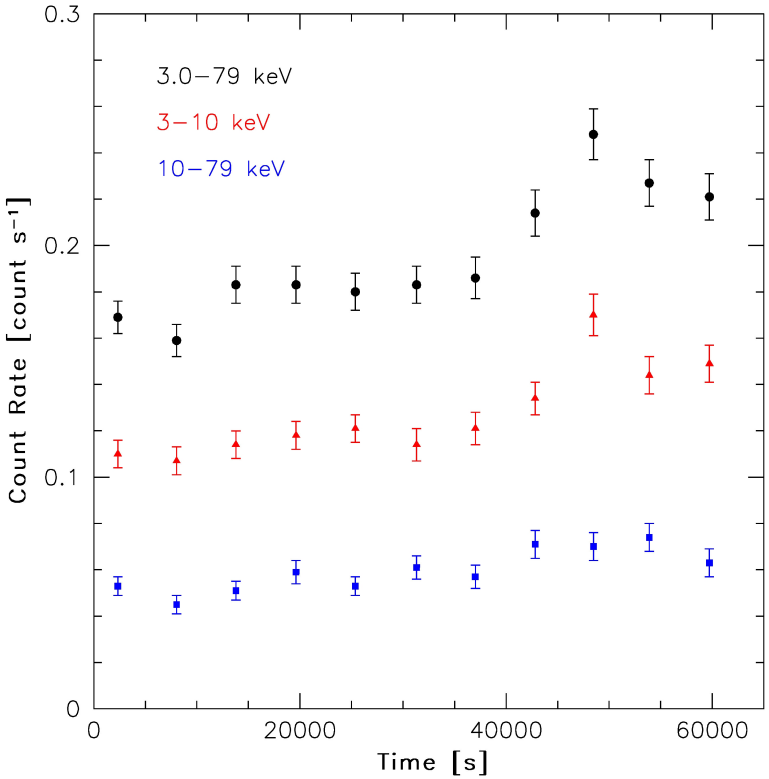
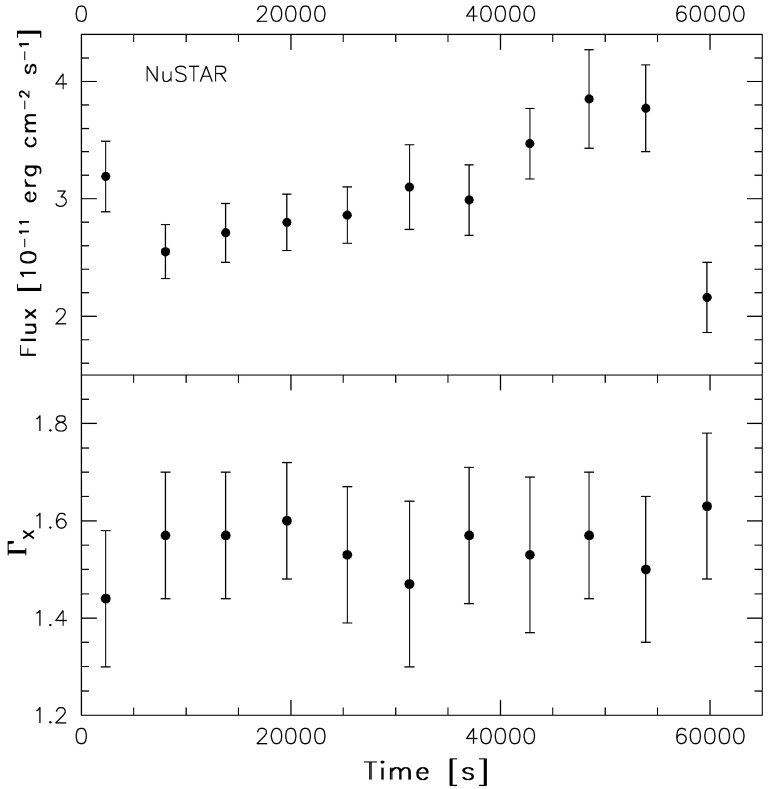
NuSTAR observations of BL Lacertae

The NuSTAR observation extended over 11 satellite orbits during 2020 October 11-12





- The photon index ranges orbit by orbit between 1.44 and 1.63, with an average value of 1.54 and no significant variability within the uncertainties

- The 3-79 keV flux ranges between 2.55 and 3.85×10^{-11} erg cm^{-2} s^{-1}, with an average value of 3.04×10^{-11} erg cm^{-2} s^{-1} and an increase of the flux up to 50 per cent

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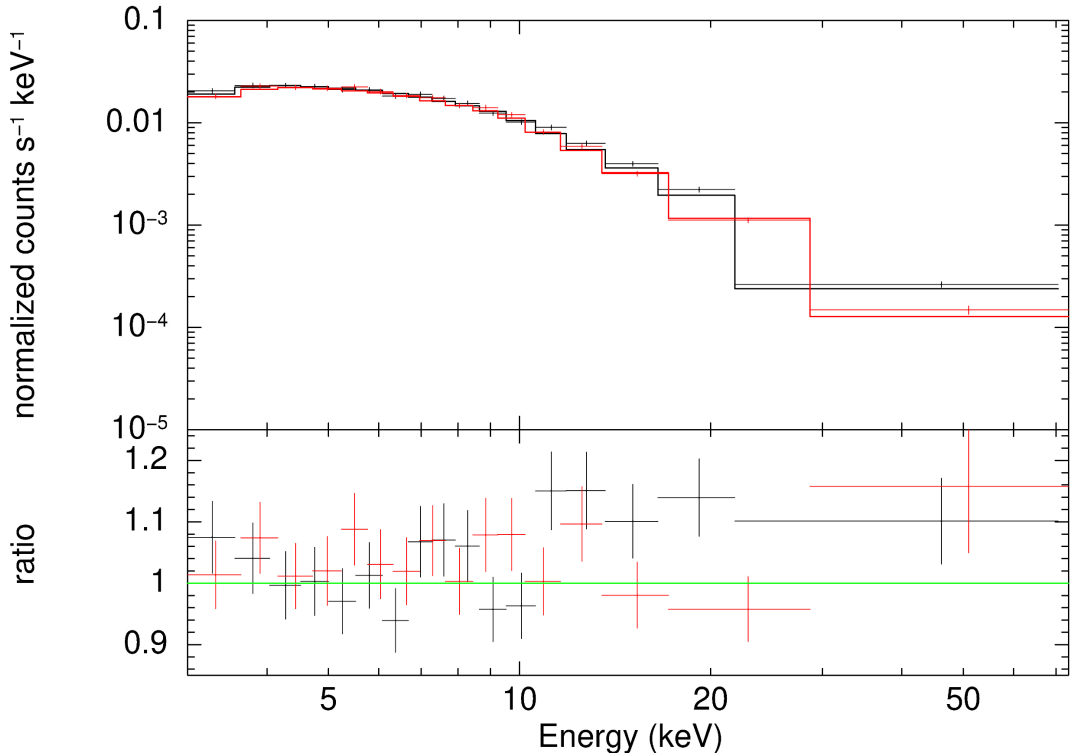
NuSTAR observations of BL Lacertae



- A simple absorbed *power-law* with a **photon index of 1.59±0.03** and N_H fixed to 2.7×10^{21} cm^{-2} provides an acceptable fit (χ^2/dof = 452.85/458)
- A comparable quality of fit has been obtained by using a *log-parabola* model, with a slope α = 1.59±0.04 and a negligible curvature parameter β = 0.003±0.010 (χ^2/dof = 452.84/457)

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Galactic total absorption toward BL Lac

- The Galactic atomic hydrogen column density toward BL Lacertae is 1.75×10^{21} cm $^{-2}$ (HI 4 PI survey) and 1.73×10^{21} cm $^{-2}$ (LAB survey)

- Observations of local interstellar CO have shown the presence of a molecular cloud toward BL Lacertae (e.g., Bania+91, Liszt+97), therefore the total hydrogen column density toward BL Lac should be composed by the atomic hydrogen column density and the molecular column density

- The value of N_{H_2} changes significantly depending on the X-ray study from 0.5×10^{21} cm^{-2} using ASCA data (Madjeski+99) to 1.7×10^{21} cm^{-2} using XMM-Newton data (Raiteri+09)

- According to Liszt+97, the ^{13}CO column density is $(8.48 \pm 0.78) \times 10^{14}$ cm^{-2}. Assuming that the molecular hydrogen column density is usually $1\text{-}2 \times 10^{6}$ times the ^{13}CO one (Liszt+07), the estimation of hydrogen column density varies between 7.7×10^{20} and 18.6×10^{21} cm^{-2} to the molecular cloud. This results in a total hydrogen column density towards BL Lacertae of $(2.52\text{-}3.61) \times 10^{21}$ cm $^{-2}$. **A broad band X-ray spectrum is important for determining in detail the Galactic total absorption toward BL Lacertae**

NICER and NuSTAR joint fit

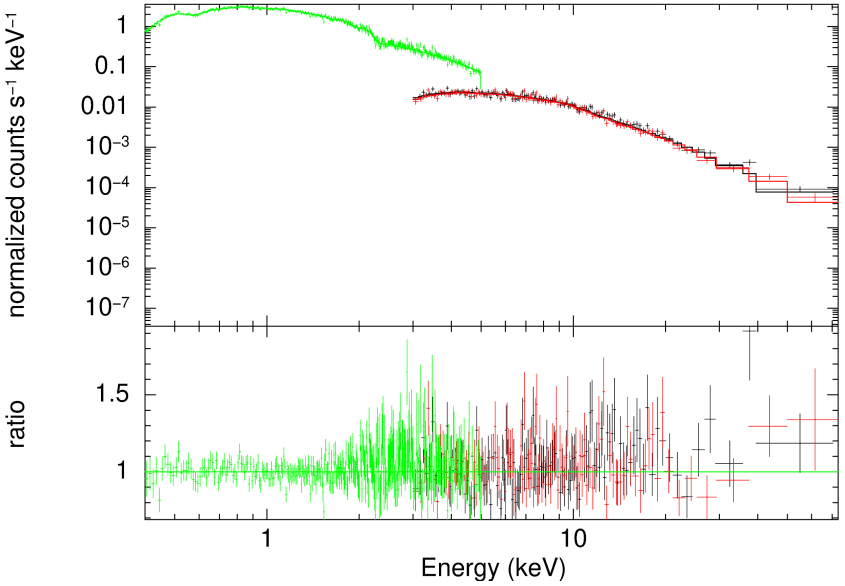

Table 2. Summary of fits to the 0.4–79 keV *NICER* and *NuSTAR* joint spectrum of BL Lacertae. Flux and E_{break} are given in units of erg cm^{-2} s^{-1} and keV, respectively.

Model	Parameter	Value
Power law	Γ	1.98 ± 0.01
	Cross-calibration normalization FPMA/FPMB	1.06 ± 0.03
	Cross-calibration normalization FPMA/NICER	0.76 ± 0.02
	χ^2/dof	1453.19/916
Log parabola	α	2.11 ± 0.02
	β	-0.25 ± 0.02
	Cross-calibration normalization FPMA/FPMB	1.05 ± 0.03
	Cross-calibration normalization FPMA/NICER	0.89 ± 0.03
	χ^2/dof	972.44/915
Broken Power-law	Γ_1	2.10 ± 0.02
	E_{break}	$2.67^{+0.29}_{-0.17}$
	Γ_2	$1.60^{+0.03}_{-0.03}$
	Cross-calibration normalization FPMA/FPMB	1.05 ± 0.03
	Cross-calibration normalization FPMA/NICER	0.97 ± 0.04
	χ^2/dof	954.69/914

- There is a significant difference of the photon index estimated in the NICER and NuSTAR spectra alone, in agreement with the results obtained for the joint spectrum applying a broken power-law model
- Leaving the N_H value free to vary we found $N_H = (2.58 \pm 0.09) \times 10^{21}$ cm^{-2}, $\Gamma_1 = 2.04 \pm 0.04$, $\Gamma_2 = 1.60 \pm 0.07$ and $E_{break} = 3.01$ (+0.41, -0.45) keV
- Fixing the spectral parameters of the broken power-law model (Γ_1, Γ_2, E_{break}) and leaving the N_H value free to vary we found $N_H = (2.69 \pm 0.04) \times 10^{21}$ cm^{-2}

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A new flaring activity in 2021 Jan

Fermi-LAT gamma-ray flare in BL Lacertae contemporaneous with optical flaring activity

ATel #14330; ***Sara Cutini (INFN Perugia) on behalf of the Fermi-LAT collaboration***
*on **18 Jan 2021; 19:35 UT***
Credential Certification: Dario Gasparrini (dario.gasparrini@asdc.asi.it)

Subjects: Gamma Ray, >GeV, Request for Observations, AGN, Blazar

Referred to by ATel #: 14342, 14350, 14583

Tweet

The Large Area Telescope (LAT), one of the two instruments on the Fermi Gamma-ray Space Telescope, has observed high gamma-ray activity from BL Lacertae (4FGL J2202.7+4216; The Fermi-LAT Collaboration 2020, ApJS, 247, 33).

This activity coincides with optical brightening reported recently in ATel #14318.

On 2021 January 17 Fermi-LAT detected strong enhancement, with a flux = (4.2 +/-0.3) x 10^-6 photons cm^-2 s^-1 (E > 100 MeV) on a daily time scale, and (5.1 +/- 1.0) x 10^-6 photons cm^-2 s^-1 on the six-hour time scale (statistical uncertainties only). This flux is comparable to the 2020 October 6 (ATel #14072) maximum observed flux of BL Lacertae since the beginning of Fermi-LAT operations in Aug 2008 with a flux of (5+/-1) x 10^-6 photons cm^-2 s^-1 in the daily time scale.

The corresponding photon index was 1.8 +/- 0.1 which is smaller than the photon index of 2.23 +/- 0.01 reported in the 4FGL catalog, indicating a spectral hardening accompanying the flux increase.

Swift follow-up observations of BL Lacertae during a new flaring activity

ATel #14350; ***Filippo D'Ammando (INAF-IRA Bologna)***
*on **26 Jan 2021; 17:38 UT***
Credential Certification: Filippo D'Ammando (dammando@ira.inaf.it)

Subjects: Optical, Ultra-Violet, X-ray, AGN, Black Hole, Blazar, Quasar

Referred to by ATel #: 14467

Tweet

After the recent optical and gamma-ray flaring activity of the blazar BL Lacertae (ATel #14318, #14328, #14330, #14334), significant variability in brightness has been observed in X-rays by NICER during 2021 January 18-22 (ATel #14342). Following this activity, Swift target of opportunity observations were performed on 2021 January 25.

Swift-XRT data were taken in Photon Counting mode for a net exposure of about 1.0 ksec. Preliminary analysis has been performed fitting the 0.3-10 keV X-ray spectra with an absorbed power-law with a photon index of 2.25 +/- 0.11 and the Galactic absorption corresponding to a hydrogen column density of n_H = 2.7 x 10^21 cm^-2, in agreement with the value obtained by the analysis of the joint NICER and NuSTAR spectrum obtained on 2020 October 11-12 (ATel #14096). The X-ray (0.3-10 keV) flux observed (i.e. not corrected for Galactic extinction) is (1.4+/-0.1) x10^-10 erg cm^-2 s^-1, a factor of 2.5 lower than the historical maximum observed in X-rays on 2020 October 6 (ATel #14069) but higher than all other fluxes observed for this source so far (ATel #14065).

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NICER observations in 2021 Jan

NICER follow-up observations of the flaring blazar BL Lacertae

ATel #14342; ***Filippo D'Ammando (INAF-IRA Bologna)***
*on **22 Jan 2021; 17:52 UT***
Credential Certification: Filippo D'Ammando (dammando@ira.inaf.it)

Subjects: X-ray, AGN, Black Hole, Blazar, Quasar

Referred to by ATel #: 14350

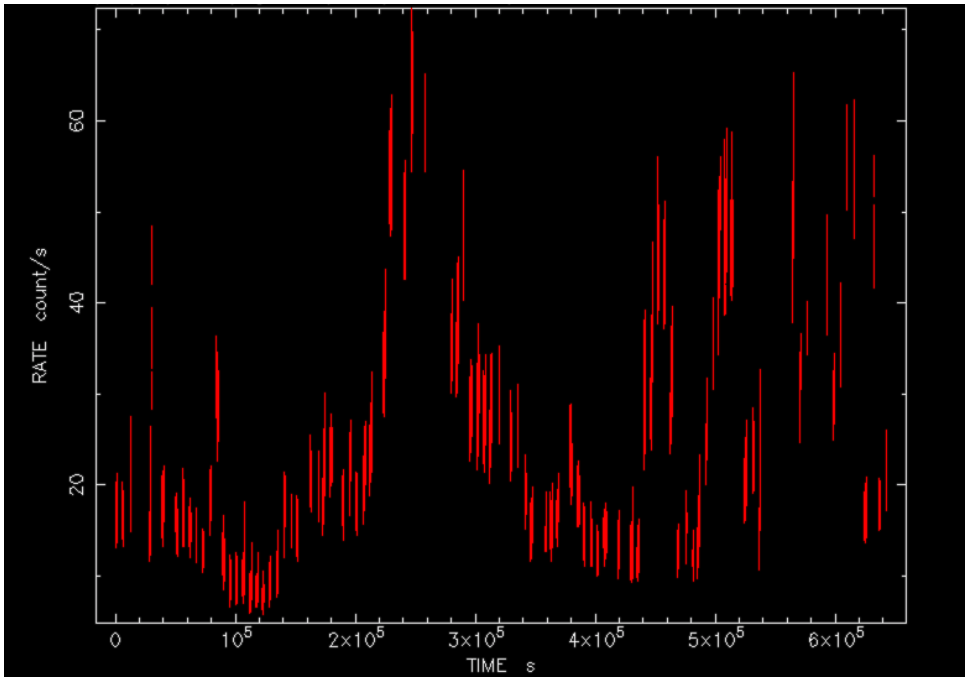
Tweet

Following the recent optical and gamma-ray flaring activity of the blazar BL Lacertae (ATel #14318, #14328, #14330, #14334), the source has been observed by NICER for a DDT request (PI: D'Ammando) between 2021 January 18 20:22 UTC and January 22 11:13 UTC for an effective time of 61.9 ks.

The source is detected above the background across the energy interval 0.3-5.0 keV in the quick look data, with an average count rate of 22.2 counts/s, a factor of 6 higher than the average count rate observed by NICER on 2020 October 11-12 during a previous flaring activity of BL Lacertae (ATel #14096). Variations of the count rate up to a factor of 7 has been observed across the observation, with possible short flares.

Preliminary analysis shows that the NICER spectrum collected over the entire period in the 0.3-5 keV energy range is described by a power-law with a photon index of 2.56 +/- 0.01.

Further NICER observations are planned in the next days and multi-wavelength observations are encouraged.



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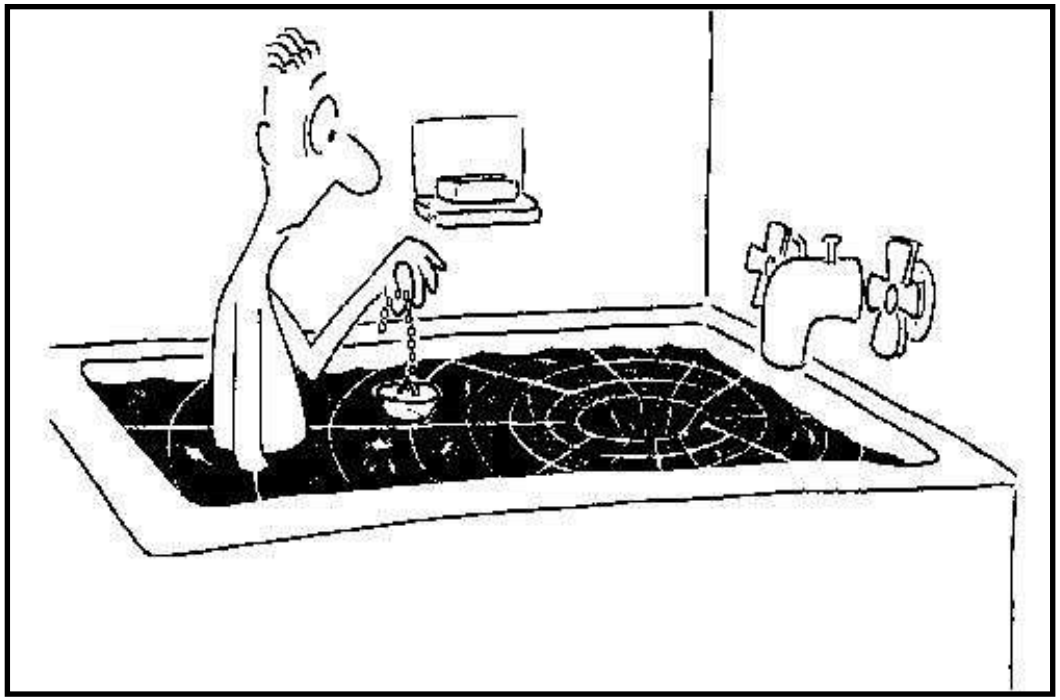
Summary

- A strong γ-ray flaring activity from BL Lacertae has been observed by Fermi-LAT and MAGIC during 2020 August-October
- The historical maximum X-ray flux has been detected by Swift-XRT on 2020 October 6, then follow-up observations have been carried out by NICER and NuSTAR on 2020 October 11-12
- Rapid variability in soft X-rays has been observed with both the Swift-XRT and NICER observations on 60 to 240 s time-scales, suggesting a very compact emitting region
- The joint NICER and NuSTAR spectra are well fitted by a broken power-law with a significant difference of the photon index below and above an energy break at 2.5-3.0 keV, indicating the presence of two different emission components (synchrotron and IC) in the broad band X-ray spectrum
- A Galactic total absorption of $N_H = (2.58 \pm 0.09) \times 10^{21}$ cm^{-2} has been estimated using the joint NICER and NuSTAR observations
- A new γ-ray flaring activity has been observed in 2021 January, with a larger variability in soft X-rays observed by NICER with respect to the 2020 observations
- ***NICER observations of blazars, in particular simultaneously to NuSTAR observations, are important for characterizing the broad band X-ray spectrum of these sources and their variability on short time-scales***



Thanks for your attention