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The TeV Blazar 1ES 1959+650 -A Short Review

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1ES 1959+ 650 is one of the X-ray bright blazars and a frequent target of various space missions and ground-based telescopes. In the framework of our intensive studies, the source has shown an 0.3–10 keV flux variability on diverse timescales from a few months down to the fluctuations over several hundred seconds. Since 2015 August, it is exhibiting a period of enhanced X-ray activity. Being regularly monitored with different Cherenkov-type telescopes, 1ES 1959+ 650 has been frequently detected at very high-energy frequencies and exhibited an uncorrelated X-ray – TeV variability several times. In this paper, we give a short review of the results of multiwavelength studies of this object performed by various authors to date.

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1. Introduction

1ES 1959+650 is a high-energy peaked BL Lacertae source (HBL: a BL Lac object with a synchrotron peak in the UV-X-ray part of the spectrum [1]) with z=0.048 [2]. Generally, BL Lacs are prominent by (see [3])

- quasi-featureless spectrum
- high and variable optical and radio polarization
- compact radio-morphology
- strong flux variability in most spectral bands
- broad continuum extending radio to very high energy (VHE, E >100 GeV) γ-rays
- spectral energy distribution (SED) with two broad components
  - lower-energy one from radio to X-ray frequencies, explained via the synchrotron radiation emitted by relativistic electrons in the jet
  - higher-energy component from MeV to TeV frequencies, possibly produced by ([4])
    - inverse Compton (IC) scattering of lower-energy photons of the local origin by their "parent" electrons (so–called synchrotron self-Compton mechanism, SSC)
    - hadronic processes (proton–synchrotron or synchrotron radiation from a second electron population produced by a cascade induced by the interaction of high-energy protons with ambient photons)

In this paper, we produce a short review of multiwavelength observational results of 1ES 1959+650 obtained by means of various instruments to date, and give their plausible interpretations.

2. Multiwavelength Studies

- 1ES 1959+650 was originally detected as an X-ray source in the framework of *Eistein Slew Survey* [5] and optically identified as a BL Lac source by [6].
- Giebels et al. [7] reported the presence of X-ray flaring activity of the source during the observations performed by the Proportional Counter Array (PCA) onboard the *Rossi X-Ray Timing Explorer (RXTE)* and the *Advanced Research and Global Observation Satellite(ARGOS)* in the 1–16 KeV energy band during 2000 July - November, accompanied by a significant spectral variability.
- Tagliaferri et al. [8] found the source in the high X-ray state in the case of the two *BeppoSAX* pointings of 2011 September 25–29 along with the optical observations using the 50-cm Newtonian reflector of the Astronomical Station of Vallinfreda (Rome).

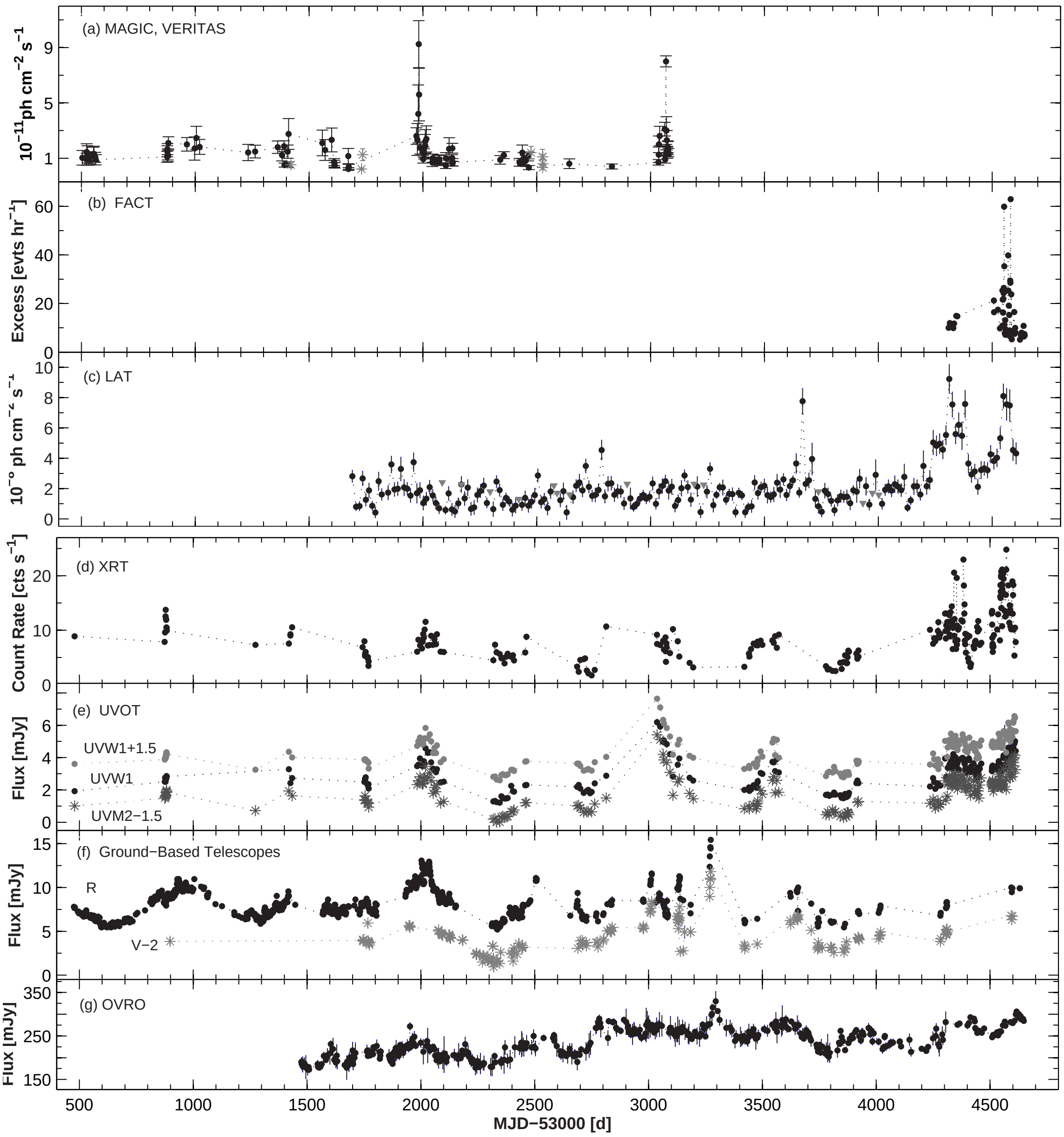

Figure 1: X-ray images of 1ES 1959+650 from the *Swift*-XRT observations performed in the photon counting (PC; left) and windowed timing (WT; right) regimes.

- Krawczynski et al. [4] revealed several strong flares from the contemporaneous observations of Whipple, HEGRA and *RXTE*-PCA. Although the X-ray and γ-ray fluxes were correlated in general, an “orphan”gamma-ray flare, not being accompanied by an increasing activity in other spectral bands, was also detected.

- In 2003 April–May, the source showed an increased level of X-ray activity: the 10 keV flux varied by a factor of 3.4 (the *RXTE*-PCA observations). However, the Whipple campaign did not reveal any TeV flare [9].

- Albert et al. [10] reported the detection of a VHE emission during the MAGIC 2004 September–

October observations, at the time of a low activity in both the optical and X-ray bands.

- Tramacere et al. [11] presented the results of the X-ray and optical–UV observations performed with the *Swift*-XRT and *Swift*-UVOT, respectively, on 2005 April 19.

- Tagliaferri et al. [12] found 1ES 1959+650 in one of the lowest historical VHE states (the MAGIC observations) during the 2006 May multiwavelength campaign while the source exhibited a relatively high state in X-ray.

- The simultaneous VERITAS, *Fermi*-LAT, *Swift*-XRT *RXTE*-PCA observations of 2007–2011 revealed the X-ray flux to vary by an order of magnitude, while other energy regimes exhibited less variable emission [13].

- Aliu et al. [14] reported contemporaneous broadband observations of 1ES 1959+650 performed between 2012 April 17 and 2012 June 1, including 0.7 ks of strictly simultaneous Swift and VERITAS observations occurring during a period of elevated VHE flux. Along with a strong VHE variability, the source was less variable in other spectral bands and showed a lack of inter-band cross-correlation.

- Kapanadze et al. [15] presented the results based on the monitoring of 1ES 1959+650 with XRT and UVOT during 2005–2014, along with the other publically available multiwavelength data. X-ray flux and spectral variability was studied on various timescales, and the inter-band cross-correlation was checked. Similar to 2002 June, the source sometimes showed an uncorrelated X-ray–TeV variability.

- Kapanadze et al. [16] reported a strong X-ray flaring activity of 1ES 1959+650 in 2015 AugustŰ2016 January, which was the most powerful and prolonged during the 10.75 yr period since the start of its monitoring with *Swift*-XRT. The source also showed a simultaneous flaring activity in the optical–UV and 0.3–100 GeV bands.

- During 2016 January–August, the source showed another very strong X-ray flaring activity, revealed with the densely-sampled Swift-XRT observation. It was active also in other spectral bands, and, similar to the previous years, it sometimes showed a lack of a correlated X-ray–TeV variability [17].

2.1 TeV-band Variability

The TeV-detection of 1ES 1959+650 occurred in 1998 [18] using the Utah Seven Telescope Array detector. Consequently, 1ES 1959+650 became one of the frequent targets of different Cherenkov-type telescopes. After the tentative detection of the source by the HEGRA Cerenkov telescopes in 2000 and 2001, a spectacular TeV flaring activity by a factor more than 5 was observed with Whipple and HEGRA during 2002 May–June [4]. Following Mrk 421 and Mrk 501, 1ES 1959+650 became the third TeV-detected blazar with a high-state flux much stronger than that from the Crab Nebula, allowing to construct VHE light curves with a binning of a couple of minutes and to take energy spectra with good photon statistics on a nightly basis. During the 20-d multiwavelengh campaign, the source showed several strong TeV flares, followed by a seven-fold decline. The TeV and X-ray fluxes mainly were correlated to each other, with the notable exception of an "orphan" TeV flare on June 4: while the TeV flux increased by a factor of 15 within 5 hr, the X-ray flux, X-ray photon index, and optical brightness remained approximately constant. Other intaday TeV events incorporated an e-folding time of 10 hr and the fastest variability timescales of 7 hr [19]. The time-averaged VHE spectrum from the flaring period was fitted with a power-law model, giving a photon index of 2.8 over the energy range from 316 GeV to 10 TeV [20].

Analyzing the entire TeV data set obtained with Whipple during 2003 May 2 and June 29, the significance of the γ-ray signal over the 2 month observation was 3.3σ without evident flaring activity [9].

MAGIC observed 1ES 1959+650 during 6 hr in 2004 September–October. The source was detected with $\sim$8σ significance, and the light curve, sampled over 7 d, showed no significant variations.

1ES1959+650 was observed with the MAGIC telescope for 7 nights during 2006 May 21–27 with the total effective observation time of 14.3 hr. The daily-binned VHE light curve did not exhibit a strong variability [12].

VERITAS observations of 1ES 1959+650 were carried out between 2007 November 13 and 2011 October 28 as part of a routine blazar program monitoring for enhanced emission. The source never met the threshold criteria for target of opportunity (ToO) observations during enhanced VHE emission, so only minimal monitoring data were taken. The variability amplitude with respect to the average was of order $\sim$2. Whipple observed 1ES 1959+650 between 2007 October 9 and 2008 June 13 and again between 2010 October 8 and 2011 May 7. On 2010 December 2, the VHE flux was greater than average by a factor of 2 [13].

The source showed relatively high VHE state during the VERITAS observations during 2012 April 17 and 2012 June 1. The nightly-averaged integral flux above 315 GeV showed an overall variability by a factor of 8 during the whole period. On May 20, the VHE flux showed a rise by a factor of in less than 30 min, followed by a decline by $\sim$40% within the next 1-hr interval [14].

Analyzing the archival MAGIC observations, Kapanadze et al. [15] reported the occurrence of significant TeV flares in 2009 May (by a factor of 4 in 8 d) and 2012 May (by a factor of 9 in 3 d) not accompanied by those in the synchrotron part of the spectrum, similar to the prominent "orphan" TeV event in 2002.

1ES 1959+650 was observed for more than 300 hr during 2012 December–2016 August with First G-APD Cherenkov Telescope (FACT). The daily-binned data showed a detection with at least 3σ significance 53 times (falling within the period 2015 October–2015 August), exhibiting three strong flares by a factor of 5.55–9.50 during 2016 June–August. While the VHE peaks on June 6, 13, and July 1 were observed in the epoch of increasing X-ray activity, a strong TeV flare by a factor 9.4 occurred around MJD 57581 when the source showed a decreasing X-ray brightness. Furthermore, the source exhibited a low TeV state during some X-ray flares [17].

2.2 High-energy Variability

As a HBL source, the source generally is relatively faint in the Fermi-LAT band (20 MeV–300 GeV) compared to nearby low-energy peaked BL Lacs (LBLs), and shows a weaker variability than in the X-ray and VHE bands. Namely, the 0.3–10 GeV flux did not show strong long-term flares, and the photon flux, derived from 2-weeks binned data, rarely exceeded 4×10^{-8} photons cm^{-2} s^{-1} ([13],[14],[15]), the source mostly was above this threshold during 2015 August – 2016 August with two strong, long-term HE flares ([16],[17]). In the latter period, the source generally was detectable from 3-d binned data, while this happened very seldomly during 2008 August – 2015 July.

2.3 X-ray Variability

The *ARGOS*–USA and *RXTE*-PCA observations of 1ES 1959+65 conducted from 2000 July through November showed that the source was in a high state and variable in the X-ray band for at least 4 months, with the X-ray spectrum significantly harder than observed during the periods of lower brightness [7]. Namely, the source underwent an X-ray flare with a doubling time of 2.5 d during the last quarter of 2000 reaching the 12 mCrab level in the 1–16 keV band on November 14. A variability of a factor of $\sim$6 was detected within 20 days and a factor of $\sim$3 within 7 days. the source does not appear to vary significantly on timescales shorter than a day. The PCA archival data obtained 2 months prior to the USA observations show 65% flux changes in 3.5 d. The highest observed flux F(2–10 keV)=1.4×10^{-10}erg cm^{-2} s^{-1}, but the peak value is unknown, since the observed maxima are at the endpoints of the observed period, when the source was falling or rising. The flux did not change more than a few percent on timescales shorter than a day in the PCA data. The 2–10 keV spectra were fitted with a simple power-law $SE)$=$KE^{-\Gamma}$ where the photon index throughout the spectral range Γ=2.37–2.68.

In the case of the 7 ks *BeppoSAX* observation on 2001 September 25, the source did not show a variability. During the second pointing of 50 ks duration on September 25–26, the source was by 20% brighter than in the first observation and did not show a significant variability also in that case. The spectra fitted well with the log-parabolic (LP) model $S(E)=K(E/E_1)^{-(a+b\,\log(E/E_1)}$ with the photon index at 1 keV a=1.83–1.93, the curvature parameter b=0.40–0.47, the 0.3–10 keV flux of $(0.83-1.06)\times10^{-10}$ erg cm^{-2} s^{-1} [8].

During the *RXTE*-PCA observations in 2002 May 16 – August 14, the 10 keV X-ray flux was strongest on May 18–20. It slowly decreased by a factor of 18.7 from the maximum on May 20 to a minimum on June 17. From July 17 until the end of the campaign, the X-ray flux stayed at a consistently high level: a factor of 1.7 below the maximum flux observed at the beginning of the campaign and a factor of 11.5 above the minimum flux measured on June 17. The fastest flux increase had an e-folding time of 5.9 hr. The 3–25 keV photon index from the power-law fit varied between 1.6 and 2.4. The X-ray photon index and the X-ray flux were clearly correlated, higher flux corresponding to harder energy spectrum [4].

Thee three *XMM-Newton* observations of 2002 November – 2003 February: the 2–10 keV flux varied in the range of (6.9–29.6)$\times10^{-11}$ erg cm^{-2} s^{-1} [26].

During the *RXTE*-PCA observations in 2003 May 2–June 7, the 10 keV X-ray flux varied by a factor of 3.4 [9]. The X-ray flux was to be correlated with the 4–15 keV photon index in the sense that higher fluxes are accompanied by harder energy spectra. The spectra were fitted with the LP model yielding a=1.93(0.17)–2.16(0.12), b=0.11(0.05)–0.38(0.10), the position of he synchrotron SED peak $E_{\rm p}$=0.51(0.27)–20.4(13.9).

Tagliaferri et al.[12] reported a flux increase by a factor of 2, *Swift*-XRT and *Suzaku* observations. The extended *Suzaku* observation (lasting more than 2 d) exhibited a low-amplitude flare by 10% with the timescale of 20–30 ks, and the flare in the 2–10 keV band was faster than in

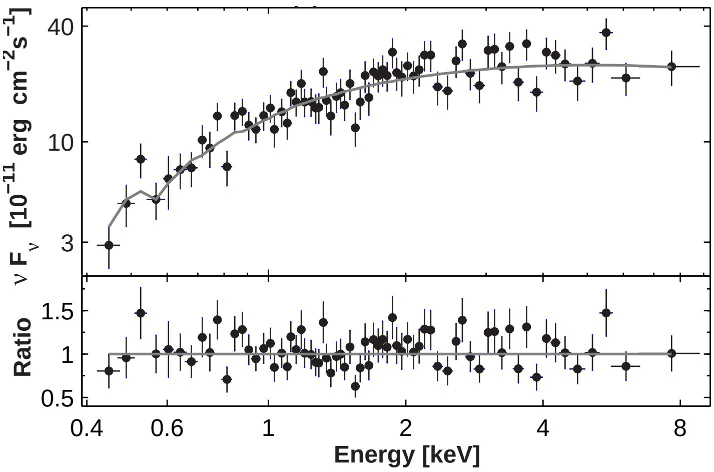

Figure 2: One of the hardest 0.3–10 keV 1ES 1959+65 extracted from the first 240 s segment of the XRT observation performed on 2016 June 30. The logparabolic fit yields the photon index at 1 keV a=1.50±0.06 [17].

the 0.3–2 keV band [15]. A LP fit of the 0.3–10 keV spectra yielded a=1.89(0.02)–2.15(0.02), b=0.22(0.03)–0.36(0.04).

The *Swift*-XRT and *RXTE*-PCA observations performed in 2007–2011: the 2–10 keV flux varied by an order of magnitude within (3.5–1.7)$\times10^{-11}$ erg cm^{-2} s^{-1} [13].

During 2012 April 17 – 2012 June 1, the 2–10 keV flux ranged between 4.2$\times10^{-11}$ erg cm^{-2} s^{-1} and 1.29$\times10^{-10}$ erg cm^{-2} s^{-1} derived via the power-law fit with the photon index Γ=2.5–3.1 (XRT observations; [14]].

The source was highly variable on longer (weeks-to-months) time-scales with the 0.3–10 keV flux ranging by a factor of 8 during the XRT observations in 2005–2014 [15]. It sometimes showed a significant intra-day variability in the course of 1 ks, detected mainly in the epochs of higher brightness states. The X-ray spectra were mainly curved with broad ranges of photon index (a=1.76–2.37), curvature parameter (b=0.18–0.67, hardness ratio (HR=0.317–0.918), synchrotron SED peak position ($E_{\rm p}$=0.12–1.84 keV) which exhibited a significant variability with the flux on various timescales, mostly following a mainly a “harder-when-brighter” spectral evolution. The synchrotron SED location mainly shifted towards higher energies with a flux increase, and vice versa.

In the course of the strong, prolonged X-ray flaring activity in 2015 August – 2016 January, a new highest historical 0.3–10 keV count rate from 1ES 1959+650 was recorded three times, making this object the third BL Lac source exceeding the level of 20 cts s^{-1}. A Along with the overall variability by a factor of 5.7, this epoch was characterized by fast X-ray flares by a factor of 2.0–3.1, accompanied by an extreme spectral variability with a=1.45–2.09, b=0.28–098, $E_{\rm p}$=0.39–3.70 keV, HR=0.396 – 1.064 [16].

A long-term high X-ray state was superimposed by shorter-term flares by a factor of 1.9–4.7 in 2016 June–August. Moreover, 35 instances of intra-day 0.3–10 keV flux variability were found which showed very fast flux changes by 14–21 per cent occurring within 1 ks and a decline by a factor 2.3 in 17.2 ks. 84.4% of the 0.3–10 keV spectra were fitted well with the PL model yielding a=1.50(0.06)–2.03(0.03), b=0.12(0.05)–0.77(0.14), $E_{\rm p}$=0.74–12.80 keV (see Fig. 2 for the hardest spectrum). 82% of the curved spectra were harder than a=2 and the source was a hard X-ray peaking BLL during the majority of XRT observations. Other spectra did not show a significant curvature and were fitted well with a simple power-law with Γ=1.72(0.03)–2.22(0.04). During the whole 2005–2016 Period, the 2–10 keV flux showed a range (1.90–55.6)$\times 10^{-10}$ erg cm^{-2} s^{-1}. The source showed an unabsorbed 0.3–10 keV flux larger than 10^{-9} erg cm^{-2} s^{-1} for the first time since the start of *Swift* observations [17].

2.4 Optical–UV Flux Variability

The *Hubble Space Telescope* observations showed the presence of a bright elliptical host galaxy with an unusual dust lane [22].

Using the data from the log-term optical campaigns carried out at the Rome and Perugia (Italy) observatories, Tagliaferri et al. [8] obtained the V and R-band fluxes of 4.77–5.23 mJy and 4.78–5.52 mJy, respectively. No periodical variability was detected.

The *V*-, *R*-, and *I*-band optical data (the Johnson-Cousins photometric system), derived from the observations performed at Boltwood (Stittsville, Canada) and Abastumani (Georgia) observatories, showed flux variations by about 0.1 mag on typical timescales of about 10 d during 2002 May–August. No optical intra-day flux variability was detected even from very densely-sampled observations lasting up to 7 hr per night. During the whole period, Overall variability amounted 0.32 mag and 0.29 mag in the *V*- and *R*-bands, respectively. Within the statistical errors, the *V-R* and *V-I* colors remained constant throughout the full campaign [4].

The *V*-band observations performed with the Bordeaux optical telescope during 2003 June 7 – October 18, showed a variability between 14.89 mag and 15.67 mag [9].

The UVOT observation of 2005 April 19 yielded the UV fluxes of 1.9–2.5 mJy in the *UVW1*-, *UVM2*-, *UVW2*-bands and 3.1–4.9 mJy in the optical *V*-, *B*-, *U*-bands [11].

The source showed four consecutive long-term flares in the *R*-band with flux increases by a factor of 1.5–2 during the observations with the 70-cm Meniscus Telescope of Abastumani Observatory in 2002–2007. The *R*-band flux, corrected on the Galactic absorption and host contribution, ranged between 2.78 mJy and 6.27 mJy [23].

During 2005–2016, the Swift-UVOT observations showed an overall variability by 8.02–9.46 mJy in the V–U bands and by 5.0–5.4 mJy in the UVW1–UVW2 bands. In contrast to the X-Ray –TeV energy range, the source did not show strong flares since 2015 August and the highest optical–UV states were observed in the beginning of 2012. A significantly densely sampled *R*-band light curve, constructed using the data obtained at different observatories, showed a slow long-term variability with the host-subtracted flux range of 5.05–15.90 mJy. Optical fluxes showed few correlation with the 0.3–10 keV one, and sometimes underwent a decline along with X-ray flare [15],[16],[17]).

The *R*-band monitoring of 1ES 1959+650 with the Perugia and Kungliga Vetenskapsakademi (KVA; La Palma, Spain) telescopes yielded the range of the host-subtracted flux of 2.70–7.25 mJy. During the more intense monitoring of 2006 May–June, centered around the multiwavelength campaign, the source showed an optical flux variability by 0.1–0.2 mag around a mean value of 14.40 mag (including the host galaxy). In particular, in the period May 25 – June 1, the *R*-band flux increased by 40%, at odds with the 2–10 keV flux that instead showed a decrease in the period May 25–29 [12].

Using the optical observations with the 1.56-m telescope at Shanghai Observatory (China) during 2006 June 11 to 2014 July 31, Yuan et al. [24] derived the ranges 1.74 mag, 0.97 mag and 1.15 mag in the V, R, and I bands, respectively. Although these authors reported extreme intra-night variability (e.g., ΔV=0.40 mag within 27 min, ΔR=0.21 in 23 min and ΔI=0.53 mag within 45 min), each event could be related to instrumental effects or variable seeing conditions [24].

Sorcia et al. [25] reported a long-term optical *R*-band flux and polarization variability by 1.12 mag and 10.7%, respectively, using the observations of the 0.84-m telescope at Observatorio Astronomico Nacional of San Pedro Martir (Baja California, Mexico) performed in 2007 October 18 – 2011 May 5.

1ES 1959+650 exhibited a long-term optical variability by 0.85–1.23 mag in the *B*-, *V*-, *R*-, *I*-bands during the observations performed with the 50-cm – 2-m telescopes of different observatories in 2009 July – 2010 November. No intranight flux variability was detected from the densely sampled light curves obtained during 24 nights [26].

Zhang & Li [27] reported the results of optical monitoring of 1ES 1959+650, performed with the 80-cm telescope at Xinglong observatory (China) during 2010–2016. Over 19 nights of intense photometric observations, the object did not show an intra-night variability. During the whole period of our monitoring, the source showed maximum changes of about 1.2 and 1.4 magnitudes at the *R*- and *B*-bands, respectively. The larger variability at the blue band than at the red one is demonstrated by the variability trend of bluer-when-brighter.

3. Radio Variability

The source was observed with Very Large Array at the wavelength of 6 cm in 1992 January, yielding a radio flux of 251 mJy [6]. The Very Large Baseline Interferometry observation on 1997 May 17 (4.964 GHz) showed a typical core-dominated radio-structure with a diffuse jet characterized by a wide opening angle (>60deg; [28]).

Within statistical errors, the 14.5 GHz and 4.8 GHz radio fluxes measured with the 26-m telescope of University of Michigan Radio Astronomy Observatory (UMRAO) stayed at constant levels of 174 mJy and 254 mJy, respectively, throughout the period 2002 May–August [4].

The 14.5 and 4.8 GHz radio observations at UMRAO in 2003 June–October did not show significant evidence for flux variability, and the observed values are consistent with those measured earlier [9].

The 15 GHz data data obtained with the OVRO 40-m telescope during 2008 August – 2016 August showed a slow variability between 173 mJy and 330 mJy. The highest historical radio state of 1ES 1959+650 was recorded at the end of 2012, and it nearly coincided with that recorded in the *V* and *R* bands (with a delay by about 2 weeks). In 2016 June–August, the source showed a long-term brightening by 22 per cent, and the radio light curve exhibited its maximum with $\sim$1 week delay with respect to the optical-UV maxima [17].

4. Plausible Particle Acceleration and Emission Processes

A lack of a correlated X-ray–TeV variability and "orphan" TeV flares pose a challenging to one zone SSC emission model which predicts a close correlation between the X-ray and TeV fluxes. To explain such multiwavelength behaviour of the source, different models were proposed (see [4]):

- Multiple-component SSC models: high-density electron population confined to a small emission volume can account for an “orphan” γ-ray flare.
- External Compton models: the γ-ray flux originates from the IC processes of high-energy electrons with radiation external to the jet. Variations of the external photon intensity in the jet frame can cause γ-ray flares without lower energy counterparts.
- Magnetic field aligned along jet axis: if the magnetic field in the emission region of the orphan flare is aligned with the jet axis and thus with the line of sight, the observer would not see the synchrotron flare. The electrons, however, would scatter SSC γ-rays in our direction, and we would thus be able to see the IC flare.
- Proton models: the low-energy radiation is produced by a population of nonthermal electrons and high-energy radiation by accelerated protons, either directly as synchrotron radiation or via a proton-induced cascade.
- hadronic mirror model: the orphan flare originated from relativistic protons (with the Lorentz factor $\gamma_p \sim 10^3$–10^4) in $p\gamma \rightarrow \Delta^0 \rightarrow p\pi_0$ and $\pi_0 \rightarrow \gamma\gamma$ processes inside the jet as the protons interacted with jet photons back-scattered into the jet by a cloud several parsecs from the central engine [29].

However, each of these models need a very fine tuning: several assumptions should be hold simultaneously (very low probability in the real astrophysical circumstances) and yield extreme values of some parameters (e.g. very high values of the Doppler factor) to yield a satisfactory fit with the observed broadband SEDs. Moreover, different studies show that the external Compton model can not implement the observed energy budget in HBL source (see, e.g. [30]).

The source showed a positive correlation between the 0.3–10 keV and 0.3–100 GeV fluxes while the latter was not correlated with the UVOT-band fluxes during 2015 August – 2016 August. This result leads us to the suggestion that the upscatter of X-ray photons to the MeV/GeV energies in the Klein–Nishina regime possibly was more efficient during the flares in this period than the upscatter of UV photons to these energies in the Thomson regime [17].

Proposed models for the origin of the spectral curvature - related to the LP spectral distribution of the emitting electrons with energy [31]:

- Energy-dependent acceleration probability process - a first-order Fermi Acceleration, to be at work at the front of the relativistic shock wave propagating through the BL Lac jet. However, a positive correlation is expected between the parameters a and b, not being detected in any period for our target [15,16,17].
- stochastic acceleration of charged particles, to be related to the magnetic turbulence close to a shock front [32], “operating” along with the first-order Fermi process. In that case, an anticorrelation between the parameters b and $E_{\rm p}$ is expected, along with relatively small values of the spectral curvature ($b \sim 0.3$; [3]). These features was shown by our target in 2005–2014 and 2016 June–August periods ([15],[17]). However, the first strong flare in 2015

August – 2016 January was in contrast to the flares observed in other periods: significantly larger curvature and absence of the expected b–E_p anticorrelation, hinting at the possibly less efficient stochastic acceleration during this event [16].

The source often showed very hard X-ray spectra during strong X-ray flares in 2016–2017 and the 0.3–300 GeV photon index was also very hard in the same epochs [k17]. Note that the hard γ-ray spectrum can be obtained much more easily within hadronic scenarios, whereas achieving a hard spectrum from leptonic models is more demanding [33]. For example, the proton blazar model, introduced by Mannheim [34], predicts the generation of X-ray spectra with photon index of 1.5–1.7, and an uncorrelated X-Ray–TeV variability, which is familiar to our target, can be explained more easily by means of hadronic models.

5. Summary and Conclusions

- 1ES1959+650:
  - One of the brightest blazars in X-rays sky and at TeV energies
  - In both bands, strong flaring activity on diverse time scales
  - Less strong flares in GeV-band
  - Even more weaker and slow variability in the radio, optical and UV bands
- 2015 August – 2016 August
  - Unprecedented high and prolonged brightness in X-rays
  - A new highest historical 0.3−10 keV count rate recorded several times, making 1ES1959+650 the third BLL exceeding the level of 20 cts s^{-1}
  - Large variability on day-to-day timescales
  - Fast X-ray variability on intra-day timescales
  - Extremely hard spectra
  - Large curvature, narrow synchrotron SEDs during 2016 August – 2017 January: predicted in the case of less efficient stochastic acceleration
- 1ES1959+650 − one of the most extreme BLLs:
  - Complex, unpredictable X-ray flux/spectral variability
  - Orphan γ-ray flares
  - Evidences of a hadronic emission component
- More densely sampled multiwavelength observations of 1ES1959+650 would be useful for our understanding of the blazar phenomenon

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DISCUSSION

FRANCO GIOVANNELLI: Have you found correlations between the emissions in the optical, UV, soft X-ray, hard X-ray, γ-ray bands? I would expect a delay between the low-energy and high-energy flares.

BIDZINA KAPANADZE: 1ES 1959+650 is the most prominent BL Lac source challenging one-zone SSC scenario. Along with “orphan” TeV flares, it sometimes shows X-ray flares without “counterparts” in other spectral bands. However, it also has undergone a correlated X-ray–HE–VHE flares many times. As for the emission in the radio–UV part of the spectrum, it generally shows a lack of the correlation with higher-energy one: no enhanced activity or a decline in the course of some X- and γ-ray flares, or there are large shifts between the lower- and higher-energy flares that is very difficult to reconcile with one-zone SSC models.