MAGIC observations of variable VHE γ-ray emission from PKS1510-089 during May 2015 outburst


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PKS 1510-089

- One of only a few FSRQs detected in VHE gamma rays
- Moderately distant (z=0.36)
- Highly variable in optical and GeV gamma rays
- One of the highest apparent speeds of superluminal motion, up to 46c
- Large swings (up to 720°) of optical polarization vector

http://fermi.gsfc.nasa.gov/ssc/data/access/lat/msl_lc/

Marscher et al. 2010
All other FSRQs known in VHE gamma-ray range have been detected first in short flares (from tens of min to a few days)

The odd one out in VHE FSRQ family

3C 279
Albert et al 2008

PKS1222+21
Aleksić et al 2011

S4 0954
(possible FSRQ)
Pedaletti et al
Texas Symp. 2015

PKS1441+25
Ahnen et al 2015

B0218+357
Ahnen et al 2016
PKS1510-089 in VHE gamma rays

- Detected by H.E.S.S. during high optical and GeV state in 2009
- Confirmed by MAGIC during another high state in 2012
- Neither short-term nor long-term variability has been observed at VHE until 2015

Abramowski et al. 2013
Aleksić et al. 2014
PKS1510-089 monitoring with MAGIC

- MAGIC performs monitoring of PKS1510-089 since its first detection in 2012
- Two flares were observed so far: May 2015 and May 2016

See the talk by M. Zacharias
May 2015 flare

- The source showed a high optical and GeV state in May 2015
- MAGIC detected elevated VHE emission during two nights (constant fit prob. of $1.6 \times 10^{-6}$)
- X-rays: slow drop of the flux starting from one of the gamma-ray flares
- A smooth rotation of EVPA by $\sim 100^\circ$ was detected throughout May 2015
- In optical and IR slow raise and fall of the flux, no obvious correlation with other wavelengths

Emission of a new radio component

- Follow-up radio observations show a new jet component, moving in unusual direction.
- The zero separation epoch is roughly consistent with the May 2015 high state (however with large uncertainty and additional *Fermi*-LAT flares).
- Similar situation to that of 2012 (VHE gamma rays + EVPA rotation + new radio component).

Ahnen et al 2017
Comparison with previous measurements

- During the May 2015 flare, the source was ~4 times brighter in VHE gamma rays than in 2009 and 2012, however the spectral shape stayed similar (intrinsic slope of 3.2±0.8)
- Four nights later, the VHE flux was measured to be similar to that reported for previous years

Ahnen et al 2017
GeV variability in *Fermi*-LAT data

- PDS level is similar for the 2015 flare and the complete *Fermi* data set – the 2015 flares in *Fermi* were not “exceptional”
- PDS index of about -1 (pink noise)

Power Density Spectrum (normalized to variance per frequency unit)

Ahnen et al 2017
VHE gamma-ray emission region in FSRQ

- It is not clear where does the gamma-ray emission in FSRQ originate, classically we consider:
  - Within BLR
  - In the radiation field of dust torus
  - Near the radio core
- The closer to BH the easier to explain variability and luminosity, but the more problematic the absorption of sub-TeV gamma rays
A possible scenario of emission

- EC scenario on BLR and dust torus photons
- Emission region placed just outside BLR
- Variability due to changes in $B$ field and electron distribution flowing through the emission region

Ahnen et al 2017
Scenarios with farther emission region

- VHE variability puts constraints on the size of the emission region and thus on its location: \(d = 2.7(t/3 \text{ days})(\delta/25)(\theta/1^{\circ})^{-1} \text{ pc}\)
- For a \(\theta \sim 1/\Gamma\) emission region cannot fill the whole cross-section of the jet at the location of the radio core (~6.5pc)
- Alternatively the emission region might be smaller than the cross-section of the jet: e.g. spine-sheath or ring-of-fire class of models

MacDonald et al. 2015
Conclusions

- May 2015 flare is the first example of VHE gamma-ray variability in PKS 1510-089
- No spectral hardening in VHE emission was seen during the flare
- After the flare the high energy emission returned to a “typical high state”
- SED consistent with EC scenario just outside of BLR
- Similarly to 2012, the flare was accompanied by EVPA rotation and ejection of a new radio component (note the multiple Fermi flares however – need a larger statistics of flares to draw firm conclusion)
How does the new radio component fit in the picture? (if it is connected with VHE)

- For a narrow jet (or a narrow spine) the VHE emission can be produced close to the radio core.
- If the emission is produced upstream of the radio core, just beyond the BLR the electrons (after a lot of cooling and adiabatic energy losses) will reach the radio core after:
  \[
  (1+z)d_{\text{core}}/(c\delta\Gamma) = 21(d_{\text{core}}/6.5\text{pc})(\delta/25)^{-1}(\Gamma/20)^{-1} \text{ days}
  \]
  still consistent (even more) with the timescale we saw.
The MAGIC telescopes

- Two 17m diameter Imaging Atmospheric Cherenkov Telescopes located in La Palma, Canary Islands

- Observing gamma rays between 50 GeV and a few tens of TeV
- FoV: ~3.5°
- Angular resolution: ~0.1°
- Energy resolution: ~15-23%
- Sensitivity: 10% of Crab in 1h above 100 GeV
Active Galactic Nuclei

- AGN are bright cores of some galaxies hosting supermassive black holes
- Strongly variable non-thermal emission from radio up to TeV energies
- They exhibit relativistic jets
- FSRQs are one of the AGN classes:
  - Observed along the jet
  - Very luminous, but energy spectra shifted to lower energies (w.r.t. BL Lacs)
  - Direct evidences of accretion disk and broad line region
Intranight LC during the flare

Ahnen et al 2017
How does the optical polarization rotation fit in the picture? (if it is connected with VHE)

- Emission region following a spiral path in mainly toroidal magnetic field (Marscher et al. 2010) – large swings of polarization are possible.

- Alternatively light travel effects of axisymmetric emission region pervaded by helical magnetic field (Zhang et al. 2015) – swing of 90 deg is possible (sufficient for 2015 flare).