The brightest $\gamma$-ray blazar 3C 454.3 "Crazy Diamond"

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Outline of the talk

- Blazar phenomenon
- 3C 454.3 (PKS 2251+158)
- Gamma-ray and multi-wavelength observations
- Perspectives and conclusions
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Blazar phenomenon

~5-10% of the AGNs

Harbor a SMBH $\sim10^8 - 10^9\,M_\odot$

Emission dominated by a relativistic jet of plasma aligned with the observer’s l.o.s.

Extremely variable almost at all frequencies

Double-humped SED: Synch. + SSC + EC

Urry & Padovani95
Blazar SEDs sequence

PKS 0528+134 - LSP

PKS 2135-304 - HSP

S5 0716+714 - ISP

Abdo+10
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3C 454.3

PKS 2251+158, z=0.859

- Detected at all frequencies, except TeV (too far!)
- Extremely variable
- Structured, highly relativistic jet
- Detected both the accretion disk and the BLR
Flux variations up to a factor of 5-6 in the radio band (4.8 - 14.5 GHz). Time-scale of about 40 yrs!

Larger flux variations (up to a factor of 10) in the mm band. Time-scale of about 10 yrs.
The *R*-band became more active since the beginning of 21st century, after the de-orbiting of CGRO. Time-scale ~40 yrs. The 8 GHz radio band seems to behave in the opposite way.
43GHz VLBA Imaging

A few jets components can be detected at 43 GHz.

We can track their motion by means of repeated snapshots at different epochs.
Disk signature

Little blue bump
Fell, MgII and Balmer continuum from the BLR

Big blue bump
Thermal emission from the accretion disk
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The EGRET era


$10^{-8}$ photons cm$^{-2}$ s$^{-1}$

Time [MJD]

48500  49000  49500  50000
May 2005: the missing one
May 2005: the missing one

During flaring states, the disk signatures are swamped by the dominant emission from the jet.

Villata+06

During flaring states, the disk signatures are swamped by the dominant emission from the jet.
During its science and performance verification phase, on 2007 July 24-30, AGILE detected a flare for 3C 454.3.

The 1-week flux was $F_{E>100\text{MeV}} = (2.8\pm0.4)\times10^{-6}$ ph cm$^{-2}$ s$^{-1}$.

No significant variability was detected during this period.
The 2005 event was quite unique, with an extremely intense emission in the optical and X-ray energy band.

The 2000 and 2007 gamma-ray flares are very similar in terms of SED parameters.
First AGILE MW campaign on this source.

Two $\gamma$-ray flares (P1 & P2) whose flux variations are almost simultaneous w.r.t. the optical ones.

Fit of the whole SED requires synch+SSC +EC(disk)+EC(BLR).

The $\gamma$-ray emitting region is within the BLR.
MAGIC observations in July and November 2007. No detections, only upper limits.

The SED modeling is consistent with EC(BLR).
An extremely fast optical flare (timescale ~ 3 hrs) occurred on 2007 Dec. 12, almost simultaneous with a \(\gamma\)-ray enhancement.

Both the SED synch. and IC peaks were monitored almost simultaneously by Spitzer and AGILE, respectively.
July 2008 - Fermi

First detection on 2008 July 10 of a $\gamma$-ray super-flare with a flux $F_{E>100\text{MeV}} \sim 1.2 \times 10^{-5}$ ph cm$^{-2}$ s$^{-1}$.

First direct observation of a break in the spectrum of a high-luminosity blazar above 100 MeV: $\alpha_{\text{pre}} = 2.27$, $\alpha_{\text{post}} = 3.5$, $E_{\text{break}} = 2-3$ GeV
Several flaring episodes superimposed to a slow, long-term dimming trend.

Towards January 2009, 3C 454.3 became barely detected, reaching a minimum at flux levels $F_{E>100 \text{ MeV}} \sim 5 \times 10^{-7} \text{ ph cm}^{-2} \text{ s}^{-1}$. 
18 months: radio data

It is not possible to correlate the radio peak with a single $\gamma$-ray or optical burst.

A multiple source activity in the optical and $\gamma$-ray bands is integrated in the radio emitting region in a single event.
18 months: jet properties

2007: the more pronounced fluxes and variability of the optical and $\gamma$-ray bands seem to favor the inner portion of the jet as the more beamed one.

2008: the optical & $\gamma$-ray dimming trend, the higher mm flux emission and its enhanced variability seem to indicate that the more extended region of the jet became more aligned w.r.t. the observer line of sight.
18 months: SED properties

Input Parameters for the Model of SED1, SED2, and SED3

<table>
<thead>
<tr>
<th>Parameter</th>
<th>SED1</th>
<th>SED2</th>
<th>SED3</th>
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<tr>
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<td>21.5</td>
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<td>$P_{\text{jet}}$</td>
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<td>3.7</td>
<td>2.5</td>
<td>$10^{46}$ erg s$^{-1}$</td>
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The $\gamma$-ray super-flare reached a flux $F_{E>100\text{MeV}} \sim 2.5 \times 10^{-5}$ ph cm$^{-2}$ s$^{-1}$. It was not accompanied by correspondingly intense emission at lower energy bands.

The SED of the flaring episodes cannot be modeled by a simple one-zone model and require an additional particle component.
Variability can be detected down to time-scale of about 3 hrs. This constraints the intrinsic size of the emitting region well below 0.1 pc, inside the BLR.
On 2010 November 20 3C 454.3 reached a peak flux level of $F_{E>100\text{MeV}} \sim 7 \times 10^{-5} \text{ ph cm}^{-2} \text{ s}^{-1}$. 
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Blazars in flare

Physical information derived from $\gamma$-ray flaring blazars

- Temporal evolution
- MW lags, $t_{var}$
- Spectral evolution
- Trends, SEDs
- High statistics

Example: 3C 454.3: SV+09, SV+10, Donnarumma+09
- Opt/$\gamma$ almost simultaneous
- $\gamma$-ray emitting region < 0.1 pc
- H.w.B $\rightarrow$ EC(BLR) $>$ EC(Disk) $\gamma$-rays
- Daily SEDs

Bonnoli+10
## Orders of magnitude

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<th>May '05</th>
<th>Dec '09</th>
<th>Nov '10</th>
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<td>$F_{[\text{R}]}$</td>
<td>48.5</td>
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<td>16.5</td>
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<tr>
<td>$F_{[1\text{mm}]}$</td>
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<td>50.0</td>
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<td>1.0</td>
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Vercellone et al., in prep.
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<td>$F_{[20-100 \text{keV}]}$ erg cm$^{-2}$s$^{-1}$</td>
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Vercellone et al., in prep.
The strong flares lessons

What do we learn from these fast flux variations?

We could have detected a change in the 3C 454.3 behavior

The source “ground level” seems to be shifted from a few tens, to a few hundreds up to several hundreds ($\times 10^{-8}$ ph cm$^{-2}$ s$^{-1}$).
Summary

3C 454.3, the Crazy Diamond, is by far the brightest and most variable $\gamma$-ray blazar in the sky.

The spinning (AGILE) and scanning ($Fermi$) observing modes were crucial to catch $\gamma$-ray flaring events at the Crab level and above.

These super-flares allow us to investigate in detail both the $\gamma$-ray emitting zone and the jet energetics.

Only a few blazars out of several hundreds display a behavior similar to 3C 454.3, and this is an enigma that is worth investigating in the near future.