Recent multi-wavelength monitoring campaigns in the Fermi-GST era

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on behalf of the Fermi-LAT collaboration and many multi-wavelength collaborators!
Outline

- overview

- three examples:

  The $\gamma$-ray/optical polarization angle event in 3C 279

  PMN J0948+0022 & Narrow-line Seyfert 1 galaxies

  The early $\gamma$-ray flare of 3C 454.3 during 2008
Introduction

- **Fermi/LAT**: powerful “all-sky-monitor”
- first time: detailed studies of AGN properties at $\gamma$-ray energies
- **Fermi/LAT**’s full capability: in combination with complementary ground+space-based, (quasi-) simultaneous Multi-Wavelength (MW) observations
- large collection of different MW data required (“single-dish”, VLBI, polarization, spectral information) across cm/mm/sub-mm, IR/optical/UV, X-ray, TeV

- in combination: fundamental questions can be effectively addressed

- **Fermi** AGN group: ad-hoc & planned intensive MW campaigns since 2008 including MANY MW facilities

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**Participating MW facilities:**

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<th>Radio:</th>
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<tr>
<td>OVRO 40-m program</td>
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<td>F-GAMMA cm/mm/sub-mm program: EFF, IRAM PV, APEX</td>
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<td>GASP/WEBT collaboration radio: UMRAO, Metsähovi, SMA, Medicina, Noto</td>
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<td>RATAN-600, ATCA</td>
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<td>VLBI: MOJAVE, TANAMI, Boston 43 GHz, VLBA multi-$\lambda$ ToO program, EVN/LBA</td>
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<tr>
<td>IR/optical: GASP/WEBT collaboration (many telescopes), Kanata, ATOM, SMARTS, Stewart Observatory, MDM, WIRO, KVA, INAOEP, VLT/VISIR, Palomar, Pomona, Spitzer</td>
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<td>X-ray: Swift, Suzaku, RXTE, Chandra</td>
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<td>TeV: HESS, VERITAS</td>
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Introduction

- since 2008: many sources target of MW campaigns
- often triggered due to flaring states
- first joined campaigns with TeV facilities such as HESS and VERITAS

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<thead>
<tr>
<th>Source</th>
<th>Reference</th>
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Many in the pipeline, e.g.:

- J0109+6134 (Abdo et al. 2010d)
- 3C 66a
- PKS 1510-089
- Mrk 501
- Mrk 421
- AO 0235+164
- 3C 454.3
The γ-ray/optical polarization angle event in 3C 279

- after ~ 100 days of Fermi/LAT operations: FSRQ 3C 279 turned into active phase at γ-rays
- Fermi AGN team triggered MW campaign
- many telescopes involved
- into high state at ~ MJD 54780 for about 120 days
- double-peak structure with factor ~ 10 variations
- doubling time scales as short as 1 day

Contact authors:
M. Hayashida & G. Madejski
The $\gamma$-ray/optical pol. angle event in 3C 279

- photon index about constant
- striking $\sim 20$ day event during second $\gamma$-ray flare around MJD 54880:
  - associated with drop in optical polarization
  - plus: dramatic change in optical EVPA by 208° (12°/day), before: $\sim 50°$ (VLBI jet)
- $\gamma$-ray event produced in a single, coherent event, co-spacial with optical
- highly ordered magnetic fields
- single X-ray flare around MJD 54950 on similar time scales
The $\gamma$-ray/optical polarization angle event in 3C 279

- **radio bands:**
  - cm/mm bands less strong variable
  - no obvious strong, associated event
  - but, also overall higher flux state
  - sub-structure at mm-bands

- **synchrotron self-absorption:**
  - size of emission zone: $< 5 \times 10^{16}$ cm, in agreement with shortest $\gamma$-ray variability

SMA, M. Gurwell
The γ-ray/optical polarization angle event in 3C 279

- gradual rotation of EVPA requires non-axisymmetric trajectory
- basically two models for outward propagation of the emission region
- both constrain distance from BH: ~ 5 orders of magnitude > than grav. radius
- at parsec scales, IC likely through torus IR or jet synchrotron photons
- isolated X-ray flare: one-zone emission models too simple
PMN J0948+0022 & Narrow-line Seyfert 1 galaxies

- before *Fermi/LAT*: $\gamma$-ray emitting AGN are blazars and radio galaxies
- *Fermi/LAT*: LBAS confirmed extragalactic $\gamma$-ray sky dominated by those!

**BUT:**
first *Fermi/LAT* detection of a $\gamma$-ray emitting Narrow-line Seyfert 1 (NLS1) in 2008: PMN J0948+0022 (contact author: L. Foschini)

**NLS1:**
- Seyfert-like AGN, spiral host galaxies
- e.g. permitted optical lines from BLR much narrower than in Seyfert 1 or blazars (FWHM(H$\beta$) < 2000 km s$^{-1}$); no intrinsic obscuring matter
- large fraction radio-quiet (only ~ 7% radio-loud, Komossa et al. 2006)
- radio jets in NLS1?
PMN J0948+0022 & Narrow-line Seyfert 1 galaxies

- many MW facilities involved
- first averaged SED similar to ordinary blazars

- double-humped SED with disk component in UV band
- $m_{\text{BH}}$ upper limit: $1.5 \times 10^8 \, M_{\odot}$
PMN J0948+0022 & Narrow-line Seyfert 1 galaxies

- variability & SED modeling (averaged plus time-resolved) using Ghisellini & Tavecchio (2009)
- Synchro/SSC component plus EC component
- physical parameters: typically blazar-like
- jet power similar to those of blazars (intermediate between FSRQs and BL Lacs)
PMN J0948+0022 & Narrow-line Seyfert 1 galaxies

- presence of a relativistic jet from radio bands:
  - flux density & spectral variability/flare
  - equipartition Doppler factors of ~7
  - highly compact, unresolved 15 GHz core on pc-scales with size < 60 μas, $T_b = 1.0 \times 10^{12} \text{ K}$
  - VLBI core fractional linear polarization of 0.7%

Typical signature of a relativistic jet
PMN J0948+0022 & Narrow-line Seyfert 1 galaxies

- In summary:

  - Fermi/LAT + MW observations: NLS1 new class of $\gamma$-ray AGN hosting a relativistic jet
  - further detections (now 4): emerging population of RL-NLS1 (Abdo et al. 2009)

  - SEDs similar to blazars
  - but, small BH masses ($10^{6.7}-10^{8.2} M_\odot$); very high accretion rates (up to 90% Eddington)
  - optical: general different physical conditions - spiral hosts

  - challenges the view that relativistic jets are typically hosted in elliptical galaxies
The early $\gamma$-ray flare of 3C 454.3 during 2008

- well-known radio source, identified with an OVV quasar at $z = 0.859$
- detected by EGRET, AGILE
- very active (bright, rapidly variable) since 2000
- outburst detected in the early Fermi/LAT data, showing rapid flares with rise-times of $\sim 3$ days
- flare triggered a large multi-wavelength campaign

Not a simple power law: broken power law with a break, $\Gamma_1 \sim 2.3$ to $\Gamma_2 \sim 3.5$ at $E_{br} \sim 2-2.5$ GeV

First observation of a spectral break in the spectrum of a high luminosity blazar above 100 MeV

intrinsic break in the energy distribution of the radiating particles? $\gamma\gamma$-absorption? two IC-scattered component?
The early $\gamma$-ray flare of 3C 454.3 during 2008

- extremely good frequency coverage

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<tr>
<th>Band</th>
<th>Observatory</th>
<th>sampling</th>
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<tr>
<td>X-ray</td>
<td>Swift (XRT)</td>
<td>daily</td>
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<tr>
<td>IR/Optical/UV</td>
<td>Spitzer, GASP/WEBT, ATOM, Palomar, Pomona, Kanata, UVOT</td>
<td>daily to ~ weekly/ monthly</td>
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<td>Radio (cm/mm/sub-mm)</td>
<td>Effelsberg, OVRO, UMRAO, Medicina, Noto, Metsähovi, IRAM 30m, APEX, SMA, VLBA</td>
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- no spectral changes at $\gamma$-ray and X-rays
- no strong optical polarization/EVPA changes

Fermi/LAT and multi-wavelength observations of quasar 3C 454.3 during the 2008 outburst
Abdo et al. in prep.
The early $\gamma$-ray flare of 3C 454.3 during 2008

- similar variability pattern
- detailed time scale and cross-band analysis (SF, CCF, WL, PD)
- quasi-periodic pattern at all 3 bands with very similar start & stop times
- fast component (21d) at $\gamma$-ray/opt.
- fast "modulation" seen also at mm, but more prominent: 60d (also optical)
- CCF:
  - $\gamma$-ray/optical: strong correlation ($\sim 0$ lag)
  - Opt./mm less strong correlation (60d comp.)
- hints of a connection between features seen even down to mm-bands
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The early $\gamma$-ray flare of 3C 454.3 during 2008

- **VLBA:** 3 epochs (Sept. 08 - Oct. 08) ToO multi-frequency observations (5, 8, 15, 23, 43 GHz):
  - 2 inner bright components (core + first jet comp.)
  - variability from core region
  - inverted core spectrum resembles total single dish spectrum and provides quiescent spectrum

K. Sokolovsky
The early γ-ray flare of 3C 454.3 during 2008

- radio single-dish coverage
• detailed spectral evolution
• shock-in-jet model (Marscher & Gear 1985)
• synchrotron and adiabatic phase ~ ok! Compton phase? additional Doppler component or previous flare?
The early $\gamma$-ray flare of 3C 454.3 during 2008

- Doppler factors: $D_{\text{var}} \approx 3 - 9$, $D_{\text{BSA}}$ and $D_{\text{B_{eq}}} \approx 3 - 4$, $D_{\gamma} > \approx 8$

- Simultaneous SEDs at high, medium & low states
Conclusions

• *Fermi/LAT*: powerful “all-sky-monitor”

• in combination with MW observations: powerful tool to study and attack “the important questions” in detail

• first MW studies/campaigns already provided deeper insights

• many ongoing/upcoming MW campaigns

• **in the future**: from detailed “MW single source studies” + (statistical) studies of large samples to

  a more general picture