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 γ-ray/optical polarization angle event in 3C 279

PMN J0948+0022 & Narrow-line Seyfert 1 galaxies

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

Introduction

- *Fermi*/LAT: powerful "all-sky-monitor"
- first time: detailed studies of AGN properties at γ-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

Participating MW facilities:

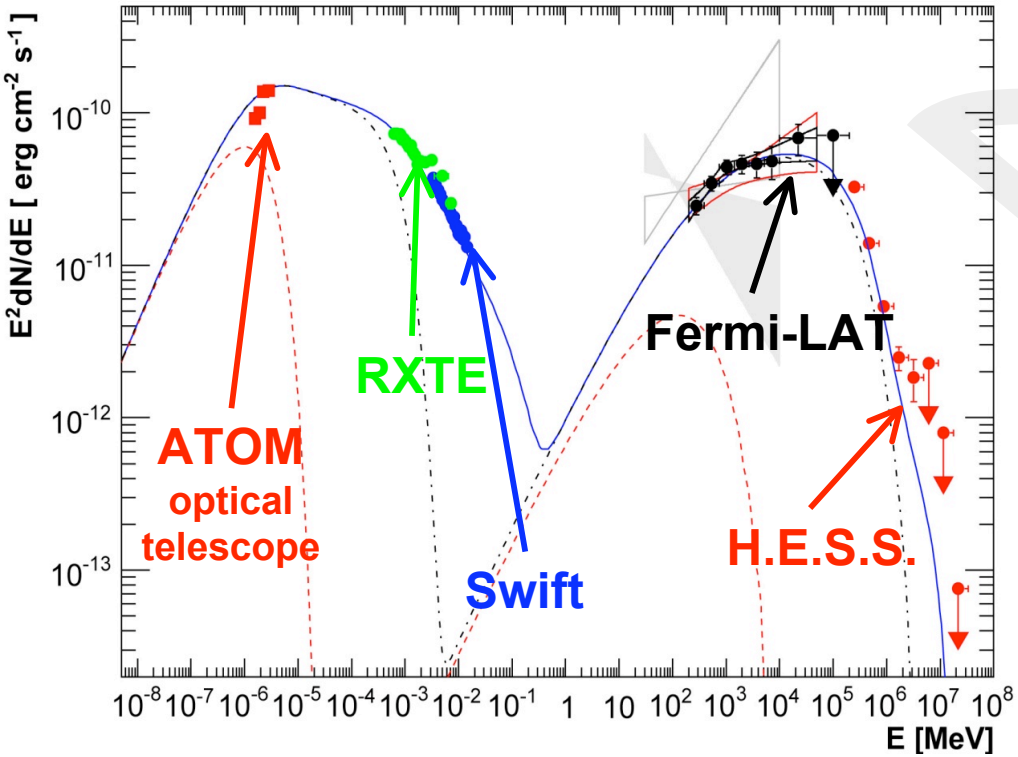
Radio:
OVRO 40-m program
F-GAMMA cm/mm/sub-mm program: EFF, IRAM PV, APEX
GASP/WEBT collaboration radio: UMRAO, Metsähovi, SMA, Medicina, Noto
RATAN-600, ATCA
VLBI: MOJAVE, TANAMI, Boston 43 GHz, VLBA multi-λ ToO program, EVN/LBA
IR/optical: GASP/WEBT collaboration (many telescopes), Kanata, ATOM, SMARTS,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

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

Fermi/LAT MW campaign publications

Source	Reference
RGB J0710+591	Acciari, V. A., et al. 2010, ApJ, 715, L49
5 FSRQs	Abdo, A. A., et al. 2010, ApJ, 716, 835
PKS 1424+240	Acciari, V. A., et al. 2010, ApJ, 708, L100
3C 279	Abdo, A. A., et al. 2010, Nature, 463, 919
PKS 1502+106	Abdo, A. A., et al. 2010, ApJ, 710, 810
NGC 1275	Acciari, V. A., et al. 2009, ApJ, 706, L275,
	Abdo, A. A., et al. 2009, ApJ, 699, 31
3C 454.3	Abdo, A. A., et al. 2009, ApJ, 699, 817
PKS 2155-304	Aharonian, F., et al. 2009, ApJ, 696, L150
PMN J0948+0022	Abdo, A. A., et al. 2009, ApJ, 707, 727,
	Abdo, A. A., et al. 2009, ApJ, 699, 976
PKS 1454-354	Abdo, A. A., et al. 2009, ApJ, 697, 934



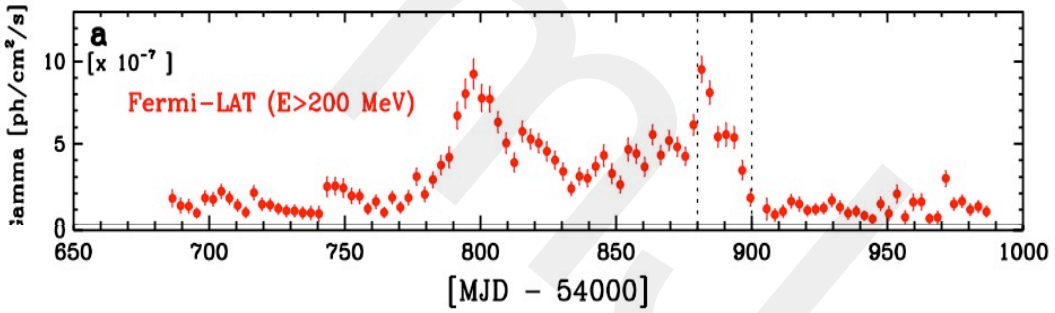
Many in the pipeline, e.g.:

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

Insights into structure of quasar jets from γ-ray and optical polarimetric observations

Abdo et al. 2010, Nature, 463, 919



- 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

Observatory	Detector/Telescope (diam.)	Band
	Gamma-ray	
Fermi	LAT (survey mode)	> 200 MeV
	X-ray	
RXTE	PCA	3-10 keV
Swift	XRT	0.6 - 7 keV
	Ultra-Violet, Optical, Near-infrared	
Abastumani, Georgia	(70 cm)	*R*
Calar Alto		*R*
Campo Imperatore, Italy	(110cm)	*J*, *H*, *K*
Crimean, Ukraine	ST-7 (70 cm)	*R*
Crimean, Ukraiine	ST-7, pol.(70cm)	*R*
Hiroshima, Japan	KANATA (150 cm)	*V*, *J*, *Ks*, polarization (*V*)
Kitt Peak, Arizona, USA	MDM (130 cm)	*R*
La Silla, Chile	GROND (220 cm)	*g*, *r*, *i*, *z*, *J*, *H*, *K*
L'Ampolla		*R*
Lowell (Perkins)	Perkins	*R*
Lulin, Taiwan	SLT (40 cm)	*R*
Roque, Canary Islands	KVA (35 cm)	*R*, polarization (no filter)
Roque, Canary Islands	LT (200 cm)	*R*, *H*
San Pedro Martir	(84 cm)	*R*
St. Petersburg, Russia	(40 cm)	*R*
Swift	UVOT (30 cm)	*W2*, *M1*, *W1*, *U*, *B*, *V*
	Radio	
Effelsburg	(100 m)	3, 5, 8, 10, 15, 23, 32 GHz
Mauna Kea USA	SMA(8 × 6 m)	230 GHz, 345 GHz
Medicina, Italy	(32 m)	5, 8, 22 GHz
Metsahovi, Finland	KURP-GIX (14m)	37 GHz
Noto, Italy	(32 m)	43 GHz
Owens Valley, USA	OVRO (40 m)	15 GHz
UMRAO, USA	(26 m)	5, 8, 14 GHz

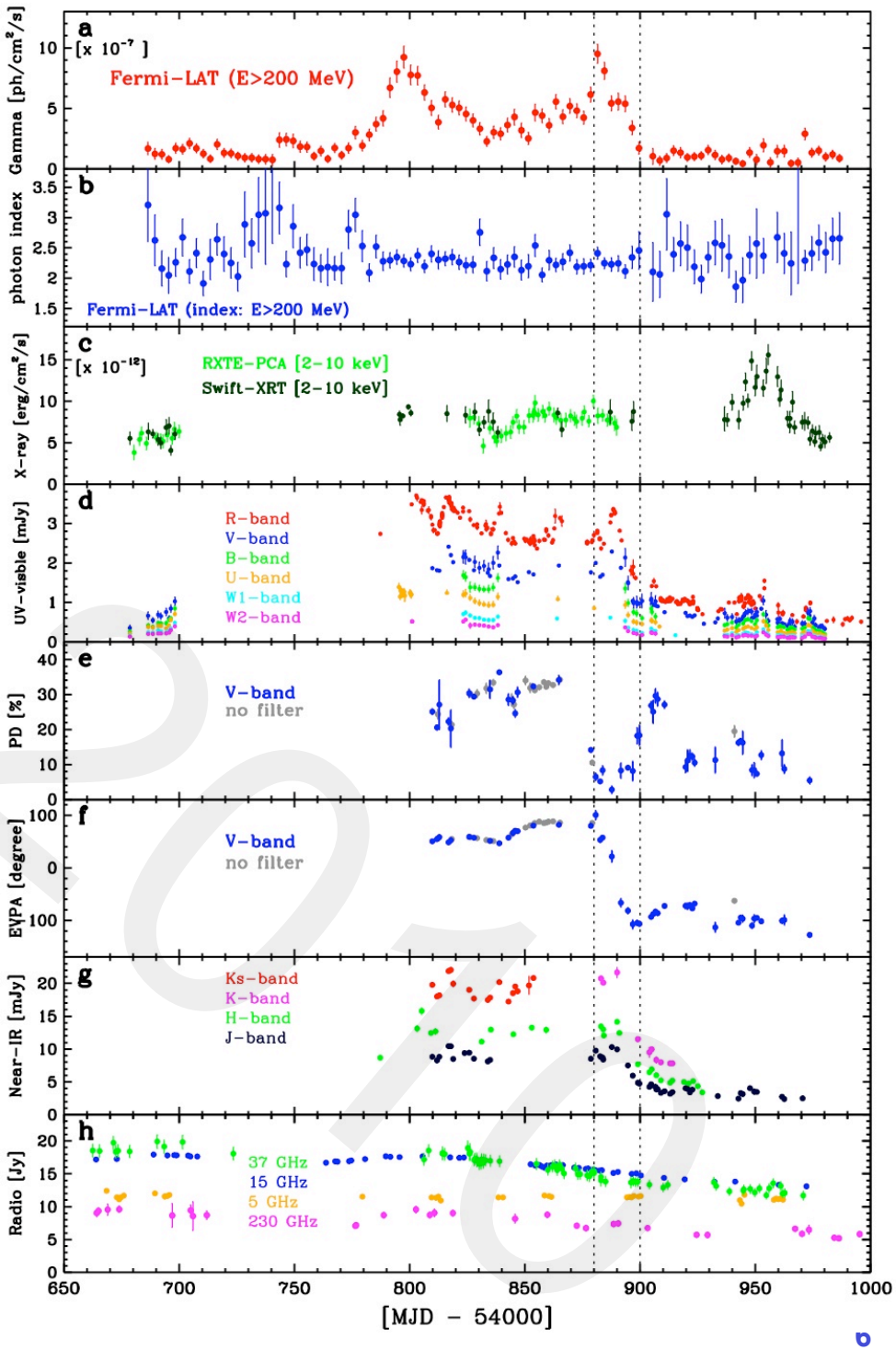
Contact authors:
M. Hayashida & G. Madejski

The γ-ray/optical pol. angle event in 3C 279

- photon index about constant
- striking ~ 20 day event during second γ-ray flare around MJD 54880:

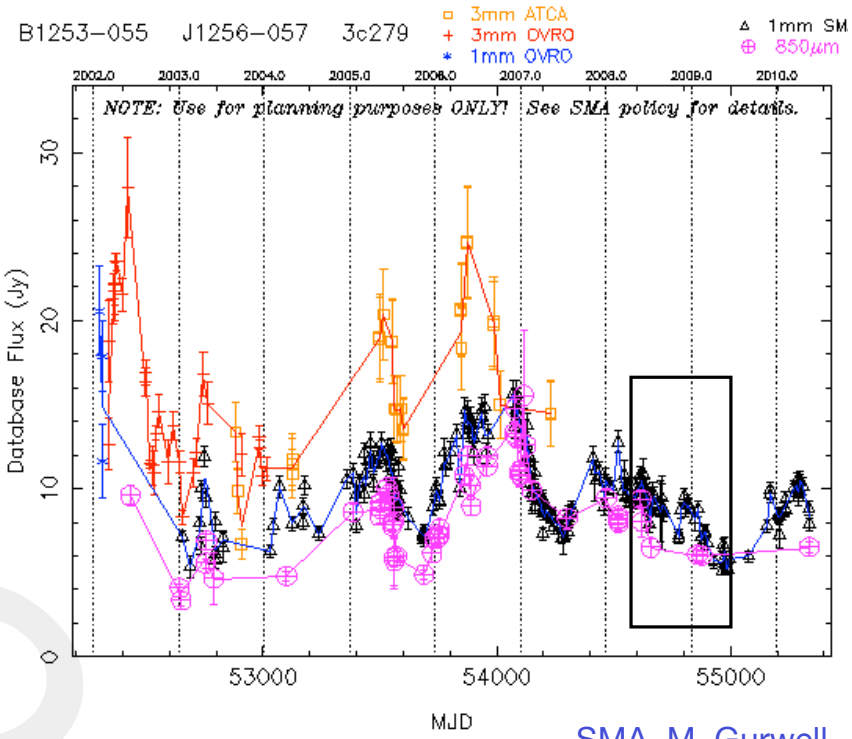
- associated with drop in optical polarization
- plus: dramatic change in optical EVPA by 208° (12°/day), before: ~ 50° (VLBI jet)
- γ-ray event produced in a single, coherent event, co-spacial with optical
- highly ordered magnetic fields

- single X-ray flare around MJD 54950 on similar time scales



The γ-ray/optical polarization angle event in 3C 279

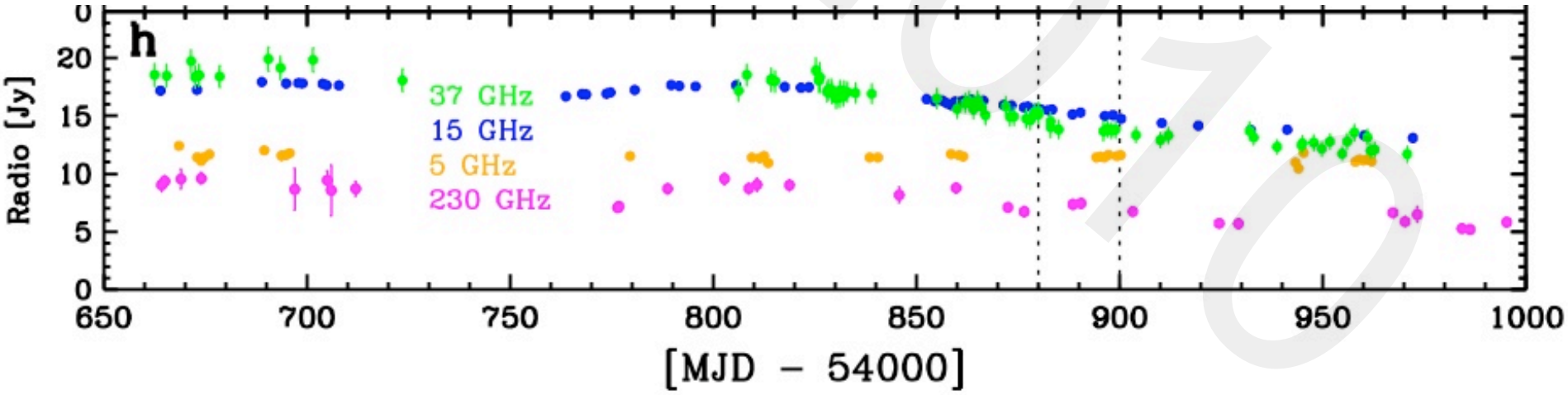
- radio bands:
  - cm/mm bands less strong variable
  - no obvious strong, associated event
  - but, also overall higher flux state
  - sub-structure at mm-bands



SMA, M. Gurwell

- synchrotron self-absorption:

  size of emission zone: < 5 x 10^{16} cm, in agreement with shortest γ-ray variability



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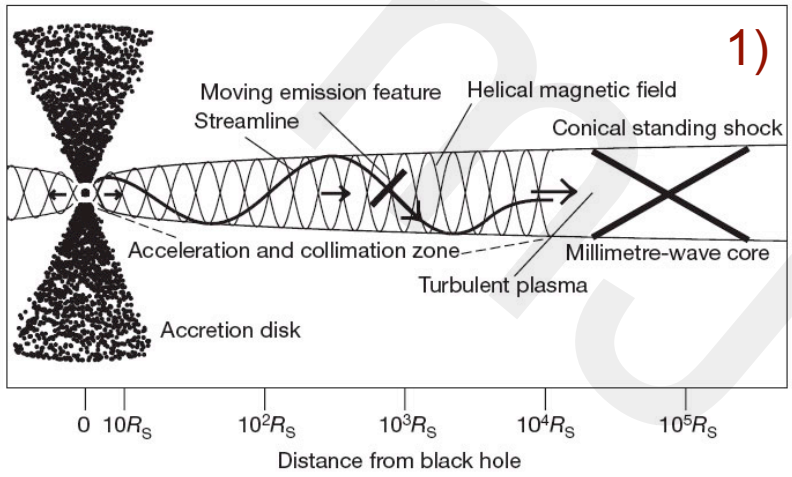
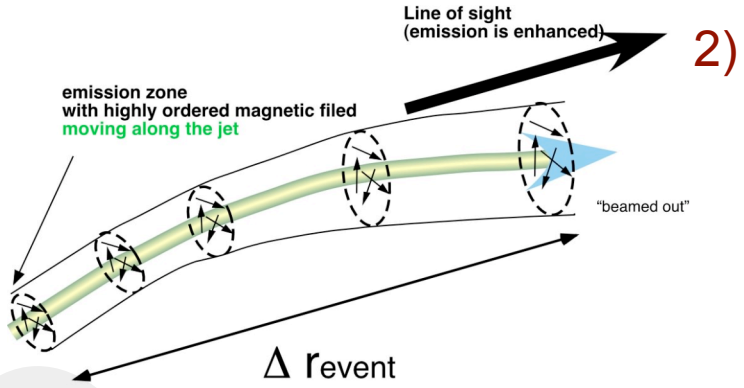
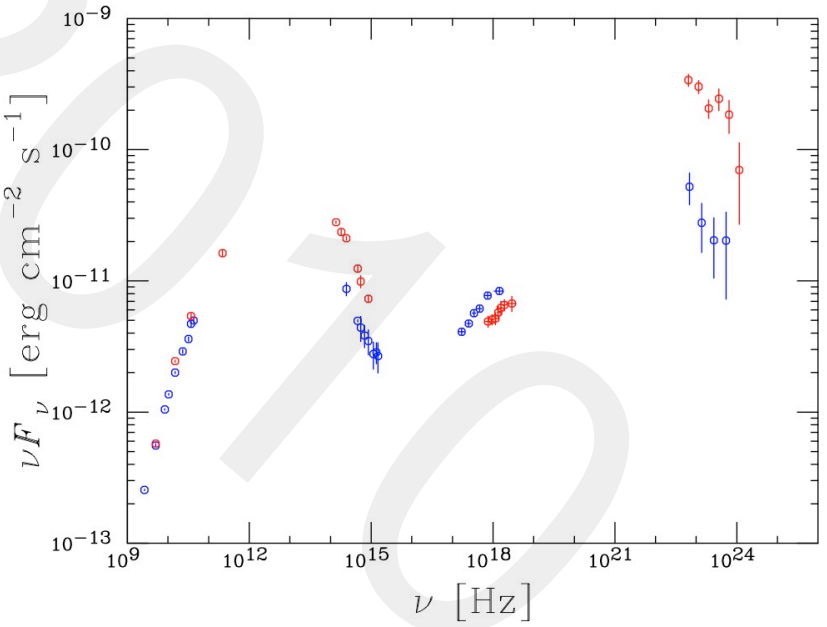


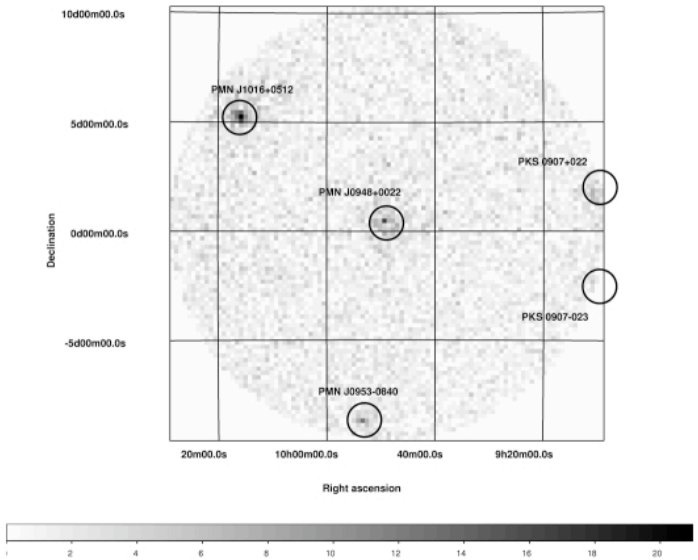


- gradual rotation of EVPA requires non-axissymetric trajectory
- basically two models for outward propagation of the emission region
- both constrain distance from BH: ~ 5 orders of magnitude > than grav. radius
- at parsec scales, IC likely through torus IR or jet synchrotron photons
- isolated X-ray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



PMN J0948+0022 & Narrow-line Seyfert 1 galaxies

Fermi/LAT discovery of gamma-ray emission from a relativistic jet in the Narrow-Line Quasar PMN J0948+0022
Abdo et al. 2009, ApJ, 699, 976



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

BUT:

first *Fermi*/LAT detection of a γ-ray emitting Narrow-line Seyfert 1 (NLS1)

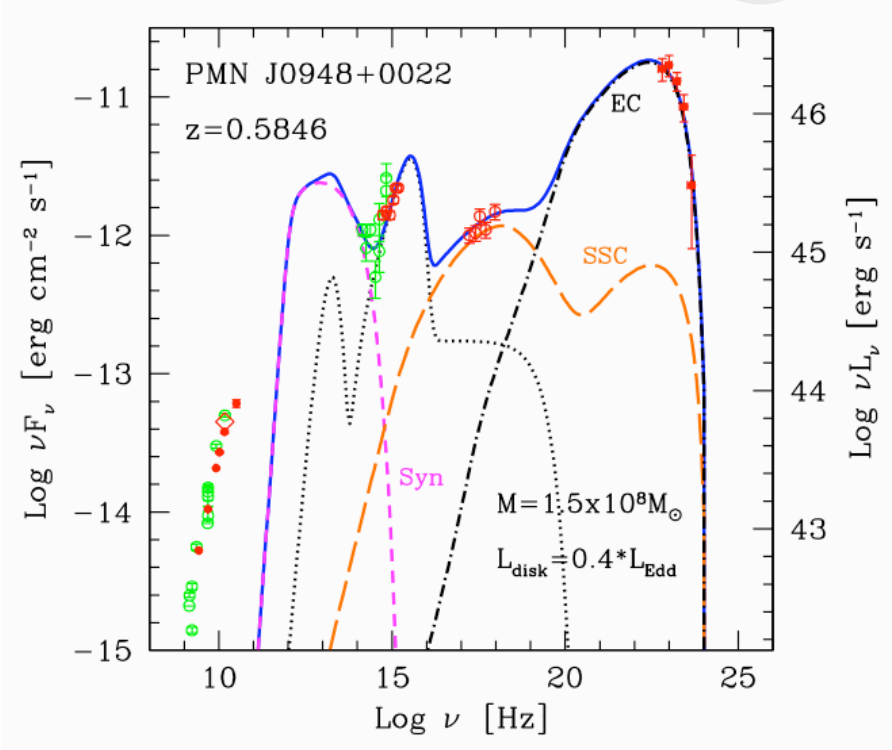
in 2008: PMN J0948+0022 (contact author: L. Foschini)

- NLS1:
  - Seyfert-like AGN, spiral host galaxies
  - e.g. permitted optical lines from BLR much narrower than in Seyfert 1 or blazars (FWHM(Hβ) < 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

- answer promptly:
  early MW follow-up and a triggered MW campaign (Abdo et al. 2009a, 2009b, Foschini et al. 2009)
- many MW facilities involved
- first averaged SED similar to ordinary blazars

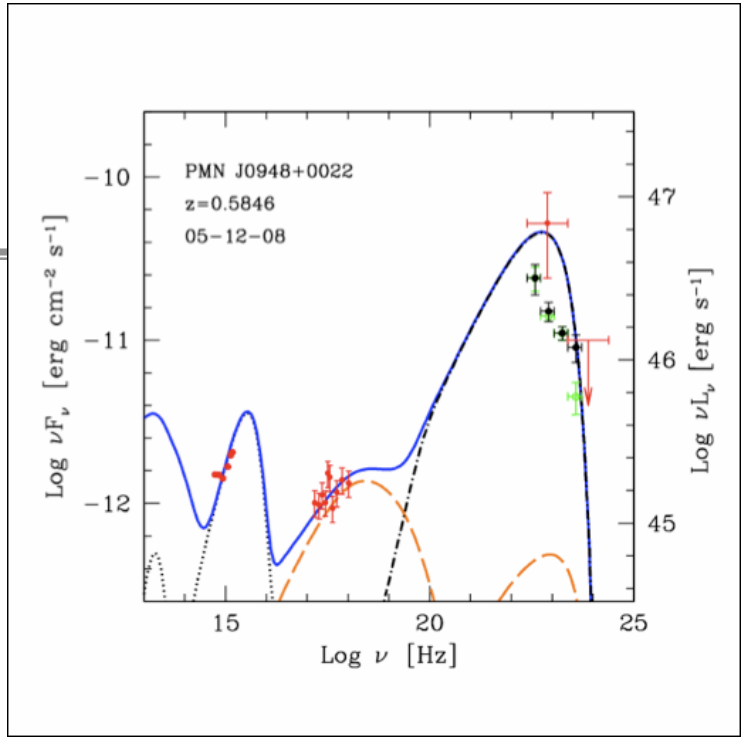
Domain	Energy band/Filter /Frequency	Facility
Gamma-rays	0.1-10 GeV	Fermi/LAT
Hard X-rays	20-100 keV	Swift/BAT
X-rays	0.2-10 keV	Swift/XRT
Optical/UV	V,B,U,UVW1,UVM2,UVW2	Swift/UVOT
Optical	B, R	ATOM
Optical/NIR	B, R, J	SMARTS/Yale
NIR	J, H, Ks	INAOEP
NIR	J, K	WIRO
Radio	15 GHz	OVRO
Radio	cm/mm, Polarization	Effelsberg
Radio	1-22 GHz	RATAN-600
Radio	15 GHz, Polarization	MOJAVE
Radio	1.66, 22.2 GHz	e-VLBI
Radio	37 GHz	Metsahovi

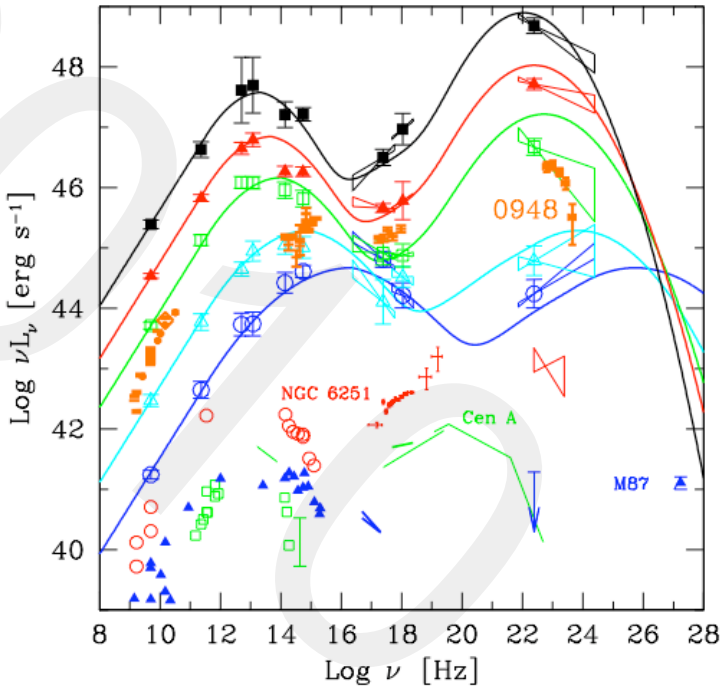


- double-humped SED with disk component in UV band
- m_{BH} upper limit: 1.5 x 10^8 M_{solar}

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)

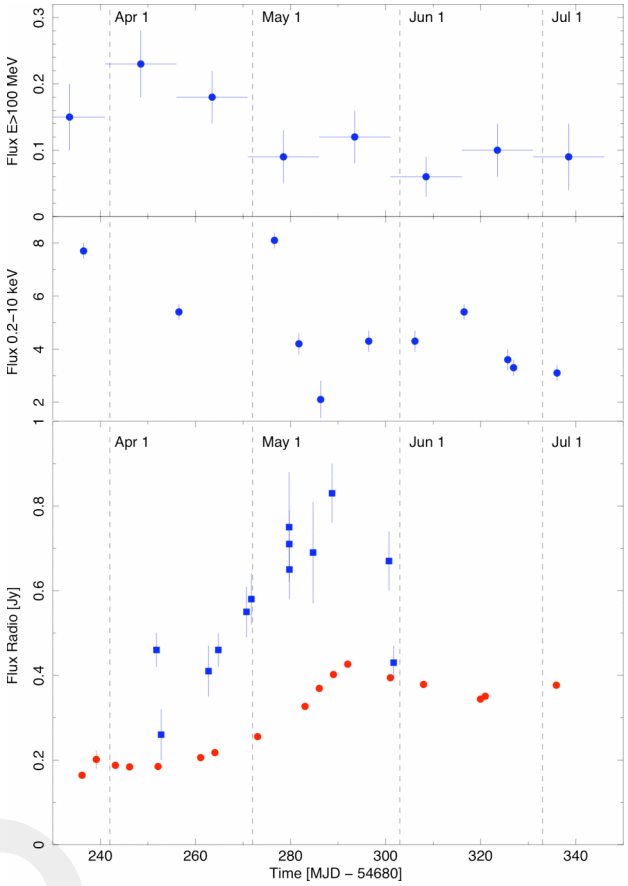


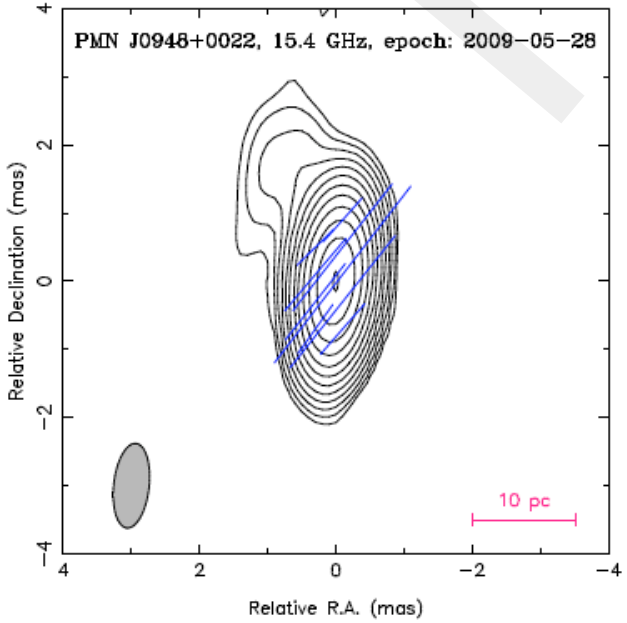


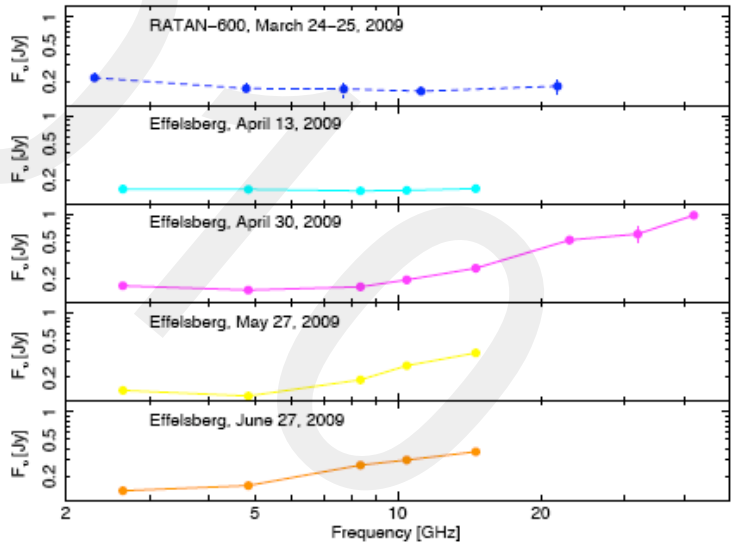
PMN J0948+0022 & Narrow-line Seyfert 1 galaxies

- 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, $T_b = 1.0 \times 10^{12}$ K
  - VLBI core fractional linear polarization of 0.7%

→ Typical signature of a relativistic jet







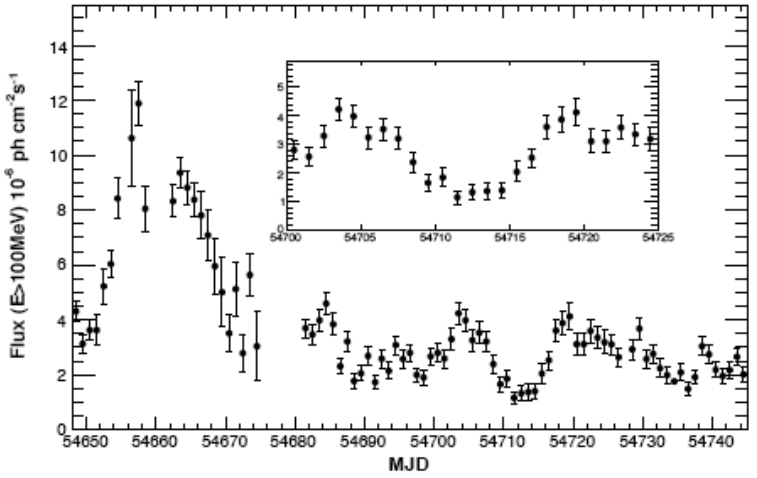
PMN J0948+0022 & Narrow-line Seyfert 1 galaxies

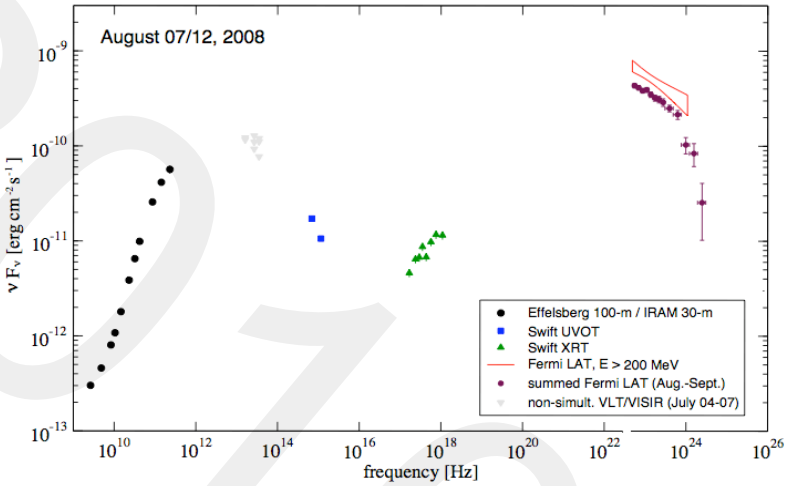
- In summary:
  - Fermi/LAT + MW observations: NLS1 new class of γ-ray AGN hosting a relativistic jet
  - further detections (now 4): emerging population of RL-NLS1 (Abdo et al. 2009)
  - SEDs similar to blazars
  - but, small BH masses ($10^{6.7}$-$10^{8.2}$ $M_{\odot}$); very high accretion rates (up to 90% Eddington)
  - optical: general different physical conditions - spiral hosts
  - challenges the view that relativistic jets are typically hosted in elliptical galaxies

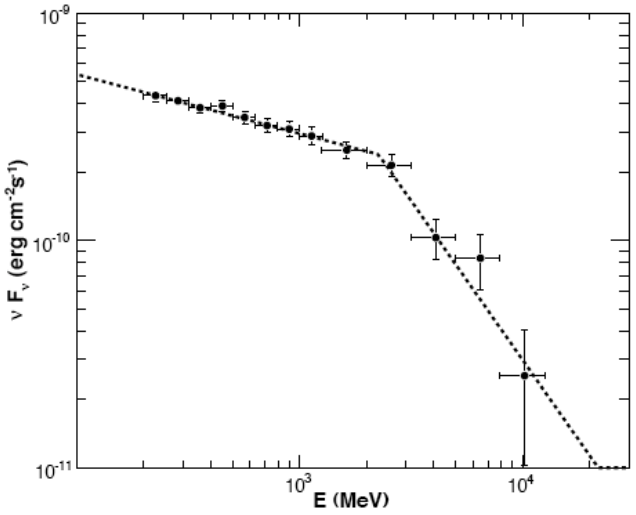
The early γ-ray flare of 3C 454.3 during 2008

Early Fermi Gamma-ray Space Telescope Observations of the Quasar 3C 454.3
Abdo et al. 2009, ApJ, 699, 817

- 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 ~ 3 days
- flare triggered a large multi-wavelength campaign







Not a simple power law:
broken power law with a break,
Γ_1 ~ 2.3 to Γ_2 ~3.5
at E_{br} ~ 2-2.5 GeV

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

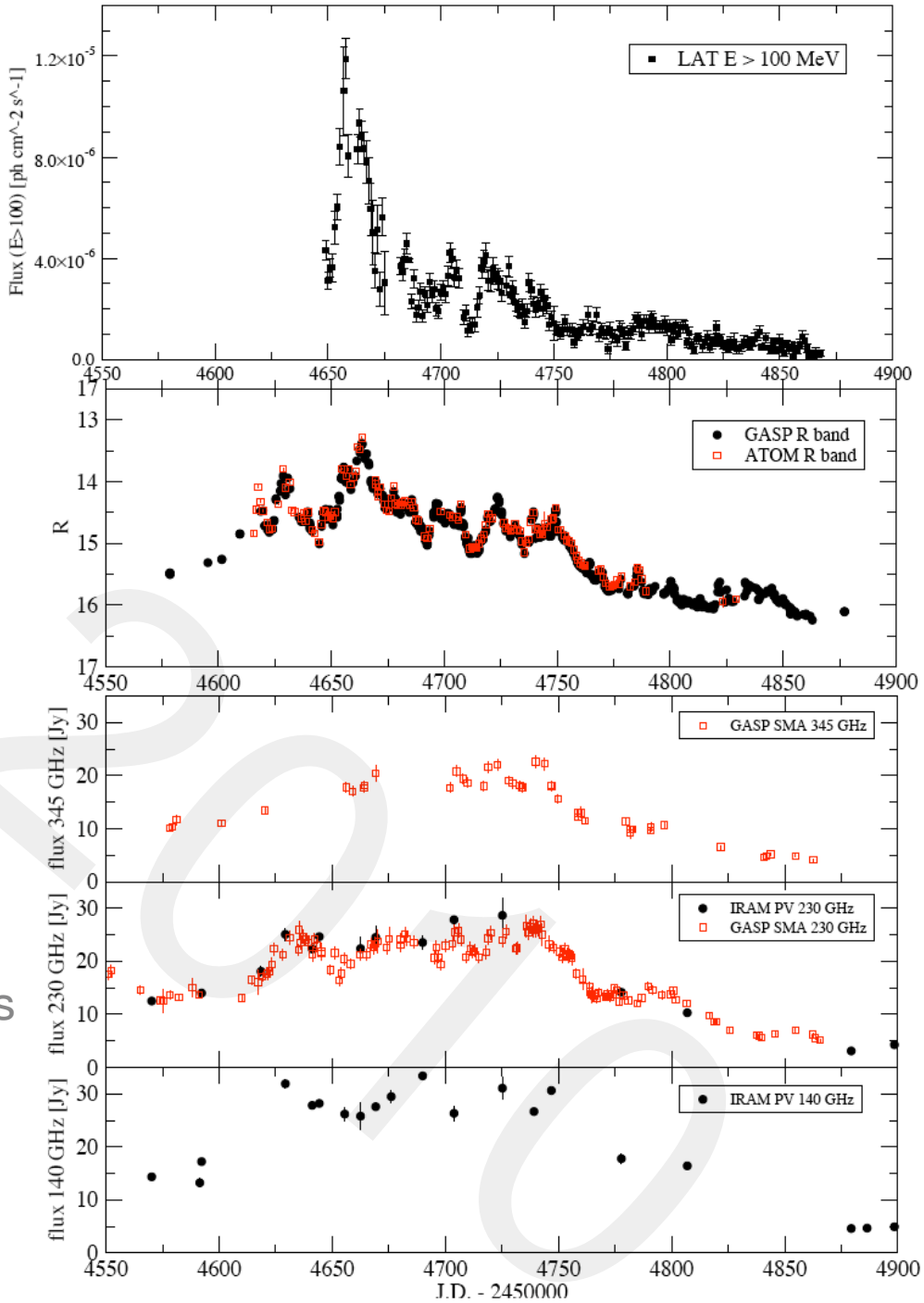
intrinsic break in the energy distribution of the radiating particles?
γγ-absorption? two IC-scattered component?

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

- extremely good frequency coverage

Band	Observatory	sampling
X-ray	Swift (XRT)	daily
IR/Optical/ UV	Spitzer,GASP/WEBT, ATOM, Palomar, Pomona, Kanata, UVOT	daily to ~ weekly/ monthly
Radio (cm/mm/ sub-mm)	Effelsberg, OVRO, UMRAO,Medicina, Noto, Metsähovi, IRAM 30m, APEX, SMA, VLBA	daily to ~ weekly/ monthly

- no spectral changes at γ-ray and X-rays
- no strong optical polarization/EVPA changes

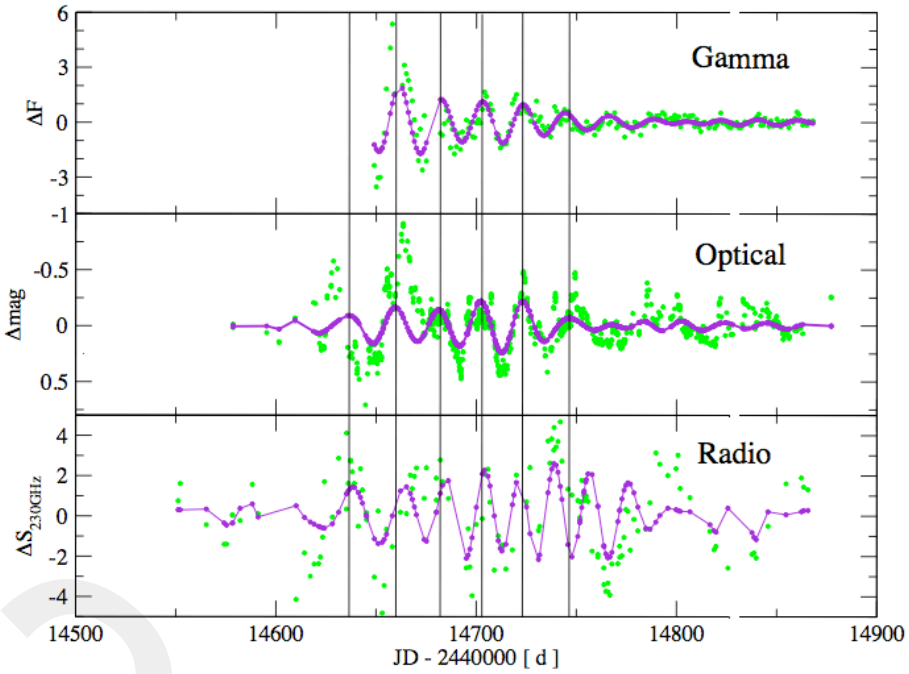


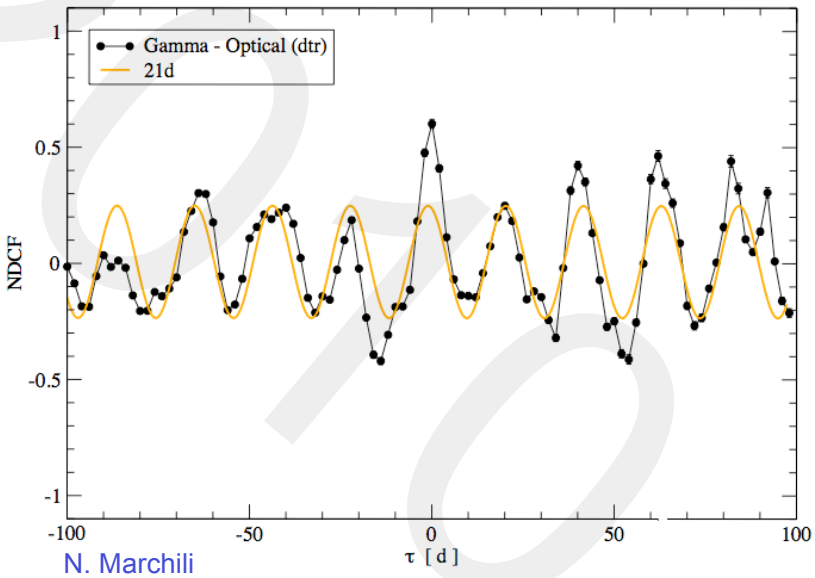
Fermi/LAT and multi-wavelength observations of quasar 3C 454.3 during the 2008 outburst
Abdo et al. in prep.

The early γ-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 γ-ray/opt.
- fast „modulation“ seen also at mm, but more prominent: 60d (also optical)
- CCF:
  - γ-ray/optical: strong correlation (~ 0 lag)
  - Opt./mm less strong correlation (60d comp.)
- hints of a connection between features seen even down to mm-bands





N. Marchili

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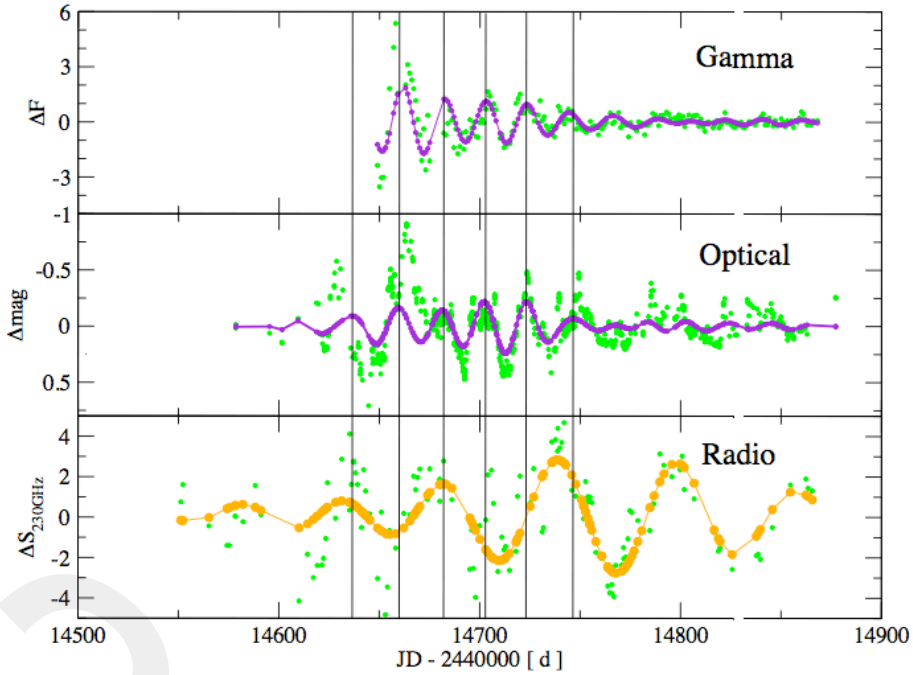
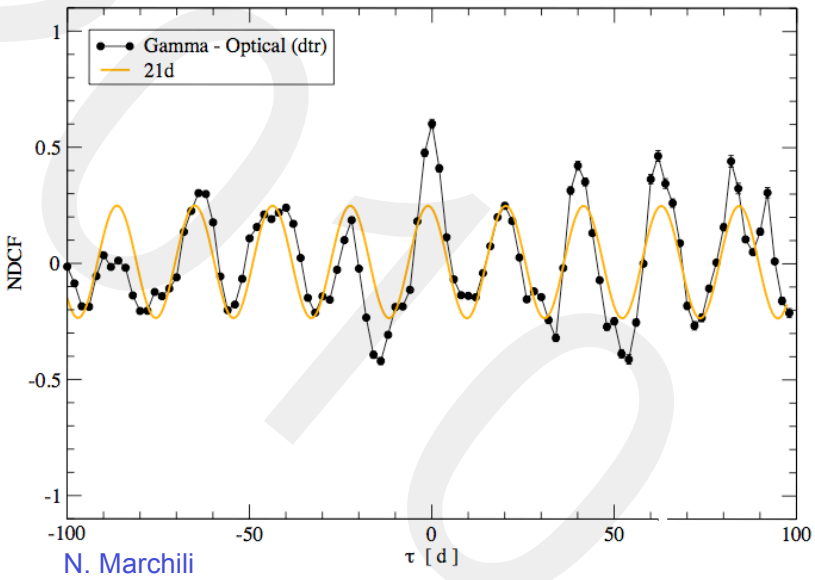
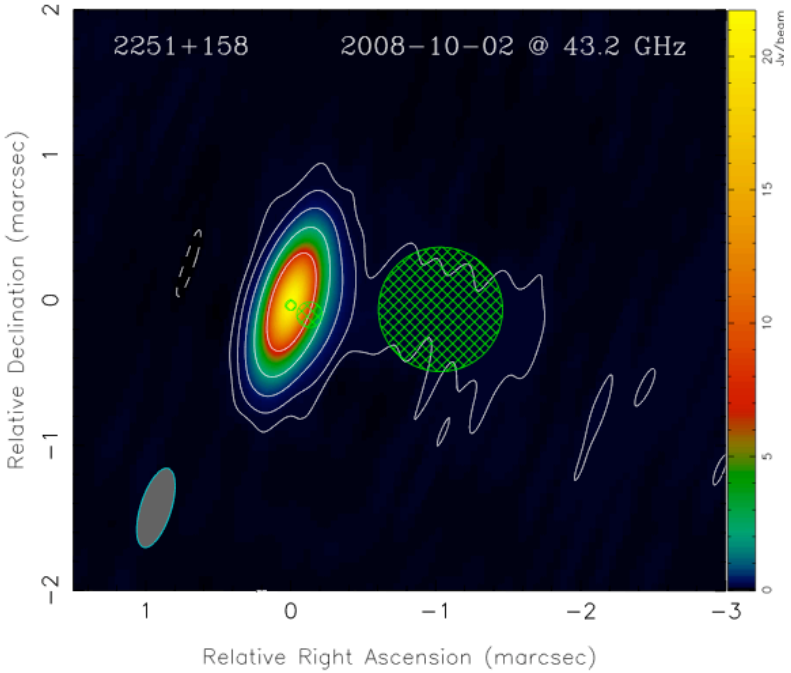


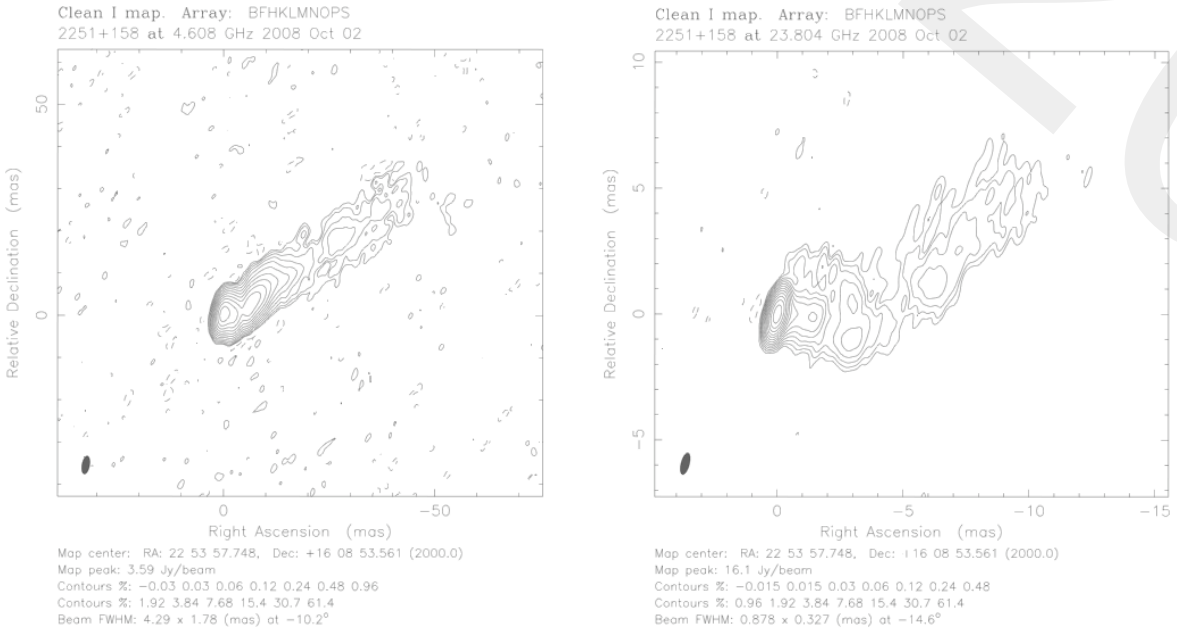


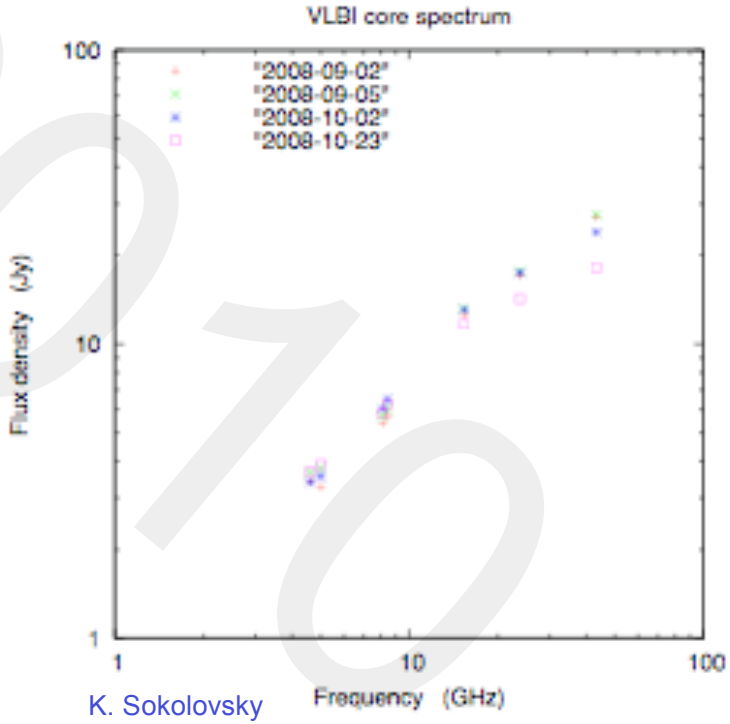
N. Marchili

The early γ-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



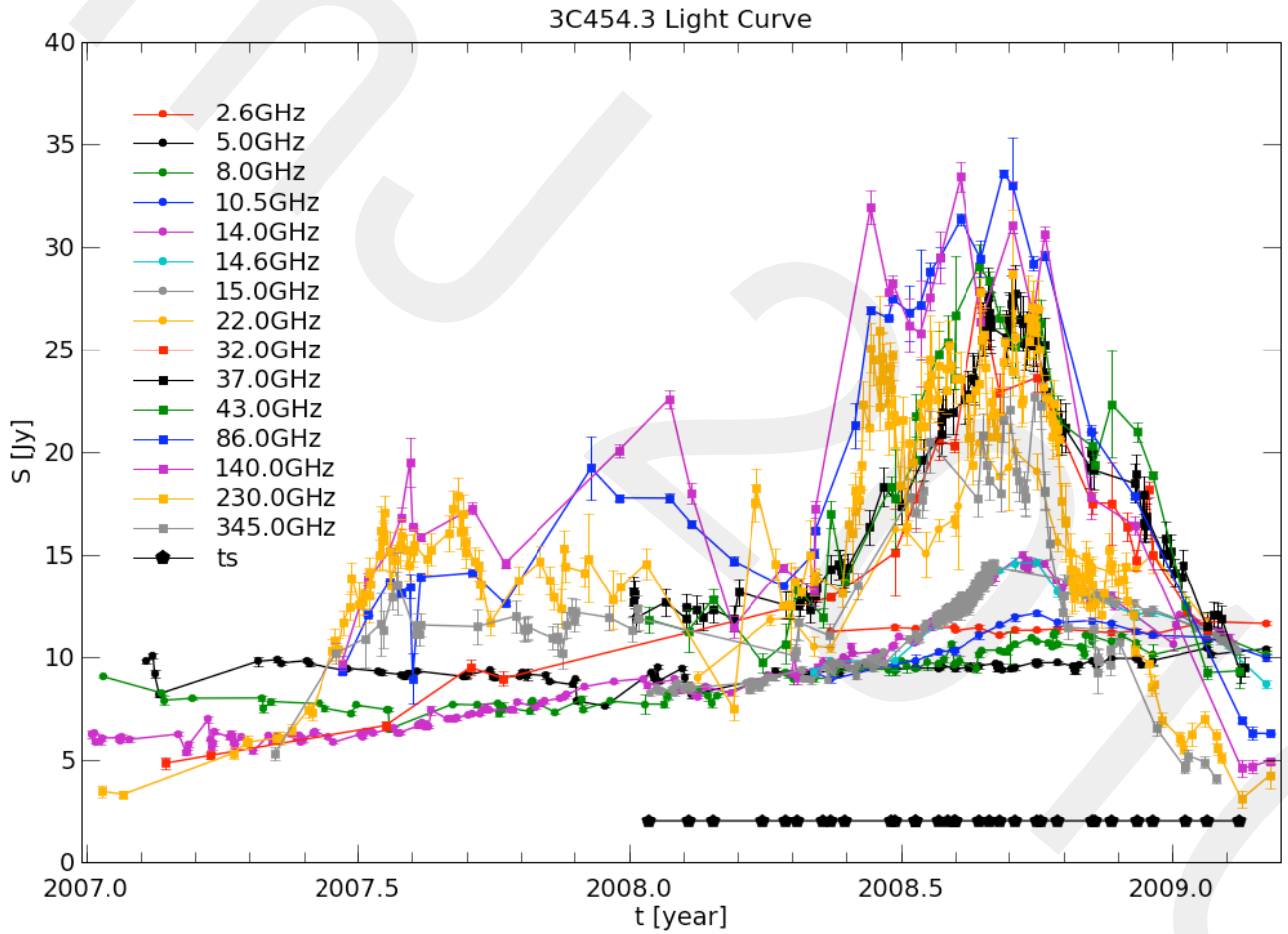




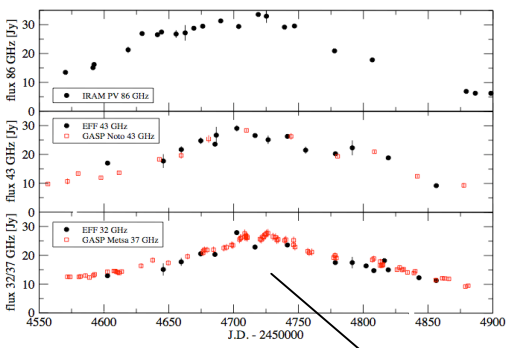
K. Sokolovsky

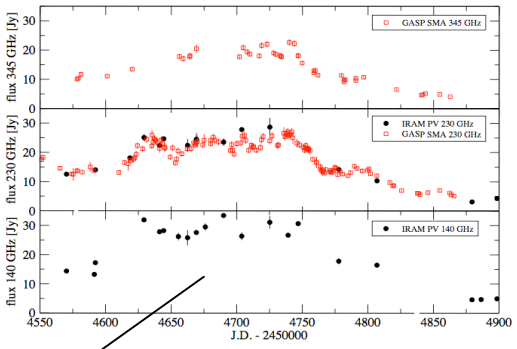
The early γ-ray flare of 3C 454.3 during 2008

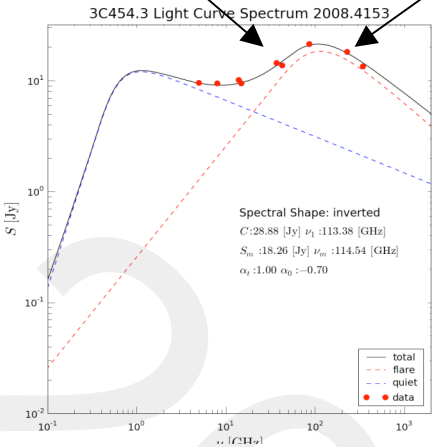
- radio single-dish coverage

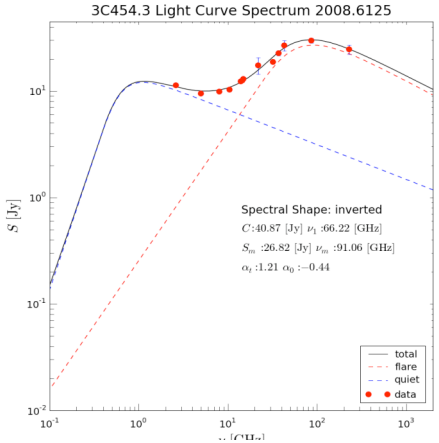


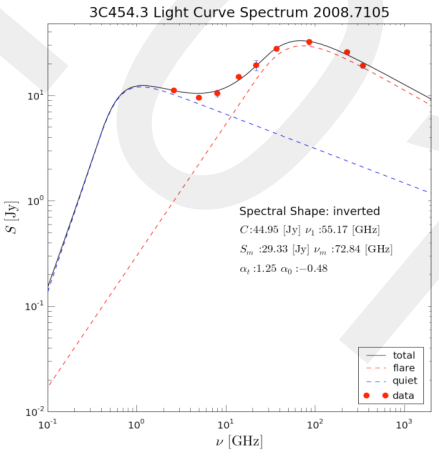
- detailed spectral evolution
- shock-in-jet model (Marscher & Gear 1985)
- synchrotron and adiabatic phase ~ ok! Compton phase? additional Doppler component or previous flare?

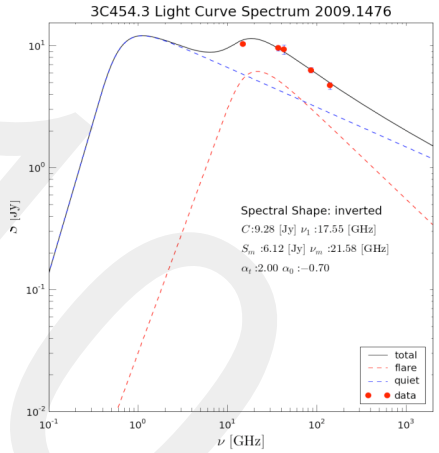


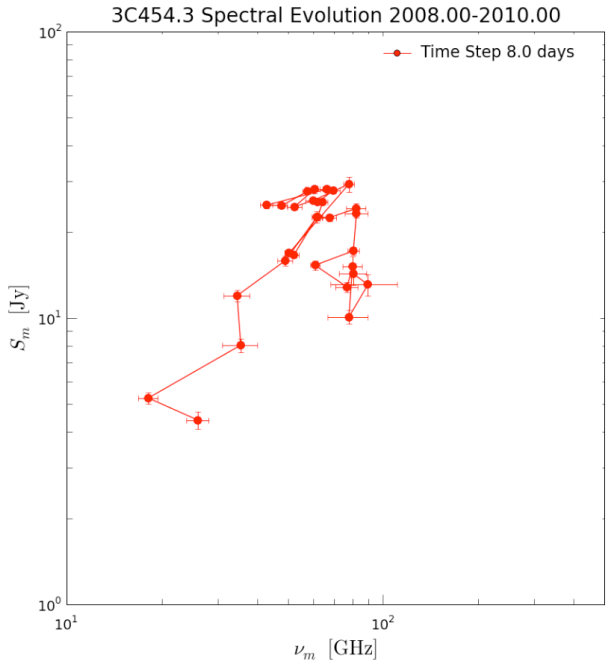












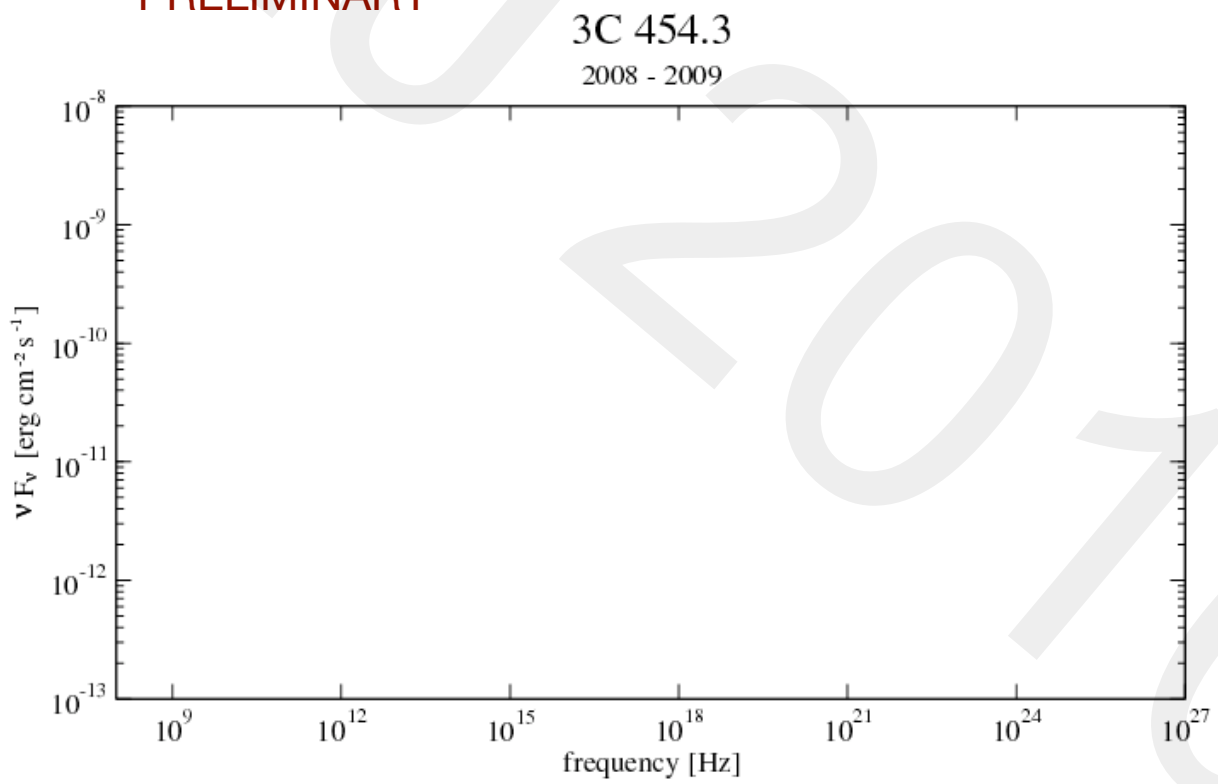
C. Fromm

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

- Doppler factors: D_{var}: ~ 3 - 9, D from B_{SA} and B_{eq} : ~ 3 - 4, Dγ > ~ 8

- Simultaneous SEDs at high, medium & low states

PRELIMINARY



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