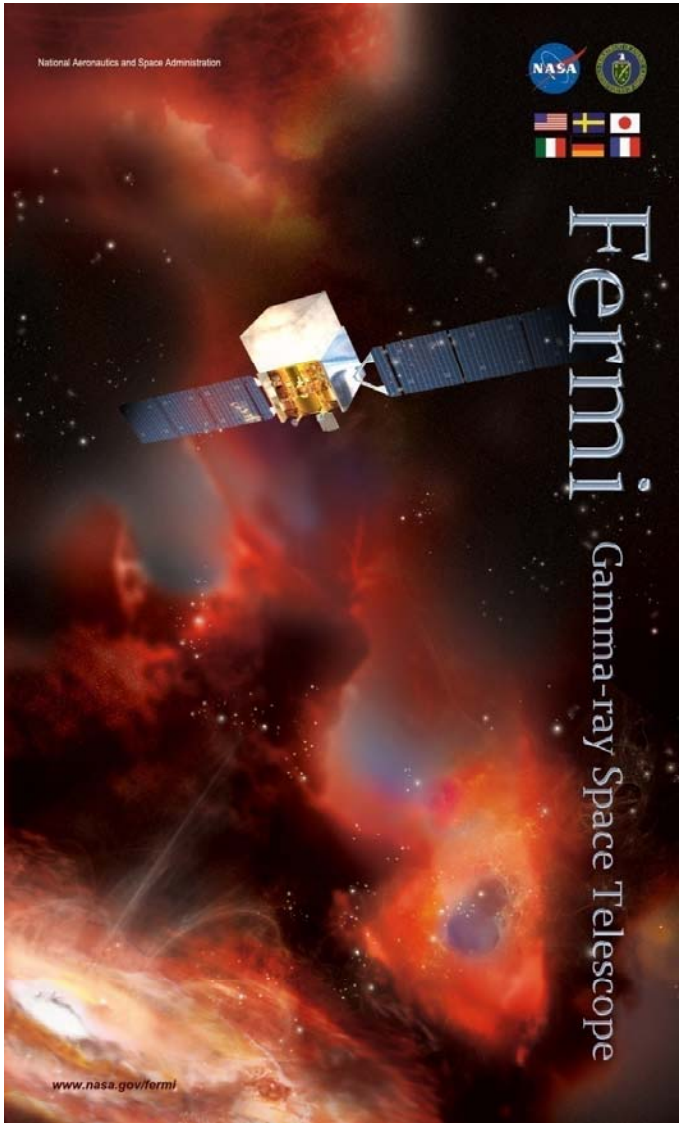


Flaring Active Galactic Nuclei: the view from Fermi-LAT

Filippo D'Ammando

INAF-IASF Palermo

On behalf of the

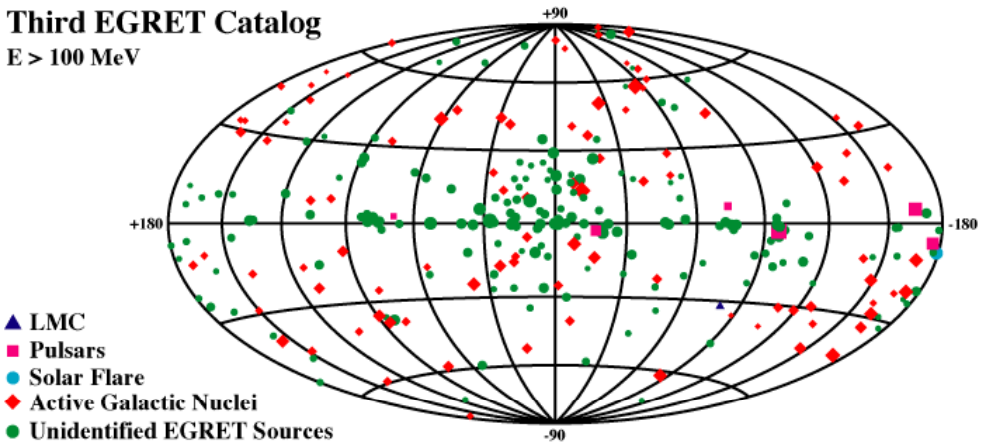
Fermi-LAT Collaboration

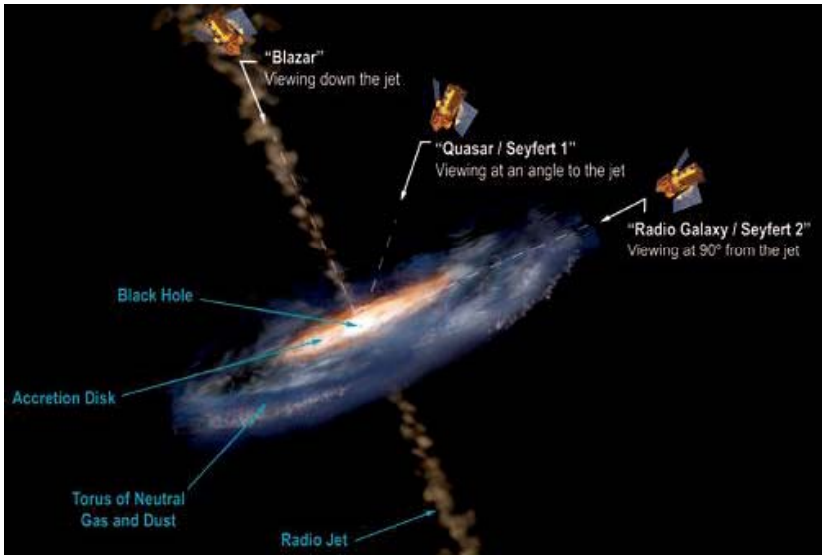
and many multi-wavelength collaborators

The EGRET Era

AGN dominate the extragalactic high-energy sky

- 67 Blazars (3rd Catalog, Hartman et al. 1999; >100 Sowards-Emmerd et al. 2003,2004)
- marginally detection of a couple of radio-galaxies

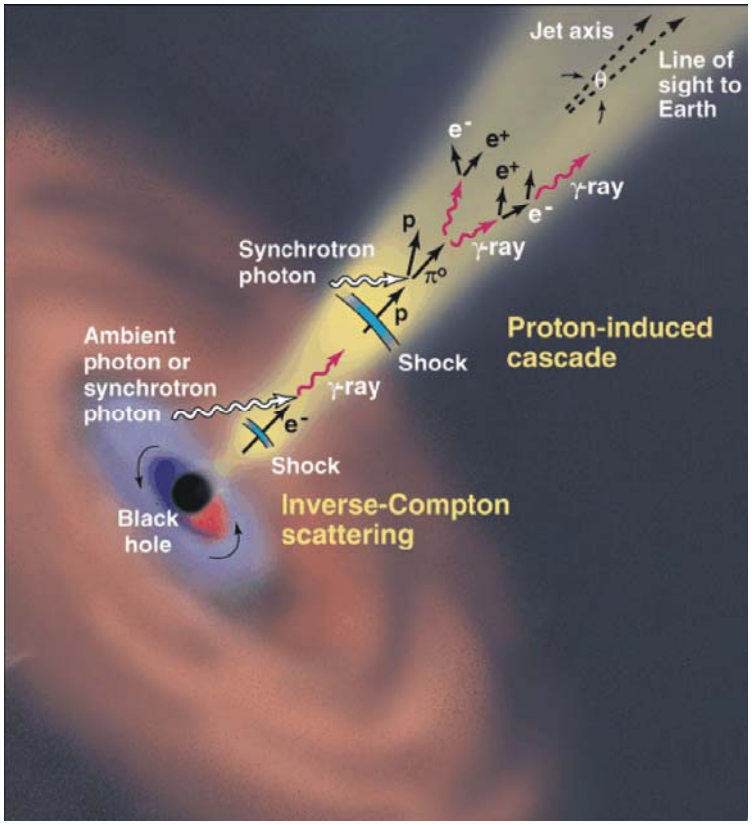




The discovery of emission in the gamma-ray domain from many AGNs by EGRET and the Cherenkov Telescopes was one of the most breakthrough of high energy astrophysics in the last 20 years, but many open questions remain...

Key Questions for Blazars

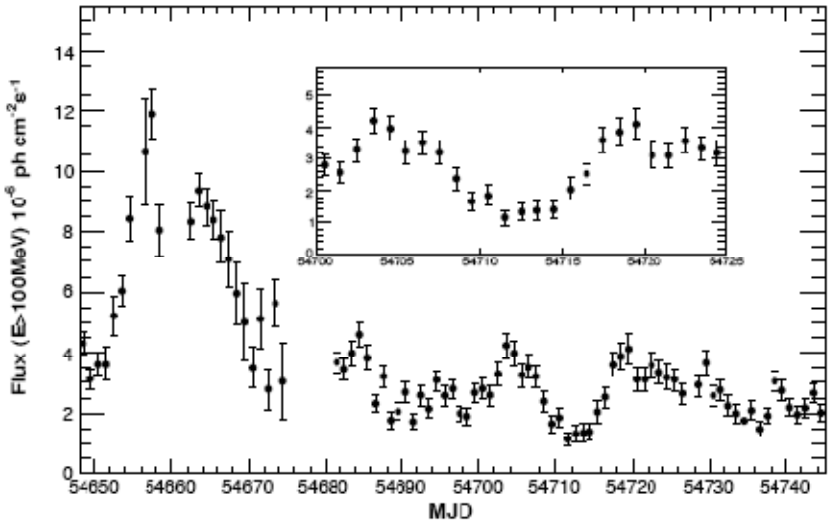
- **Emission mechanisms (especially for high energy component)**
  - **Leptonic (IC of synchrotron or external photons) vs hadronic ($\pi_0 \rightarrow \gamma\gamma$, proton synchrotron)**
- **Emission location**
  - **Single zone for all wavebands (completely constraining for simplest leptonic models)**
  - **Opacity effects and energy-dependent photospheres**
- **Particle acceleration mechanisms**
  - **Shocks, Blandford-Znajek**
- **Jet composition**
  - **Poynting flux, leptonic, ions**
- **Jet confinement**
  - **External pressure, magnetic stresses**
- **Accretion disk-black hole-jet connection**
- **Blazars as probes of the extragalactic background light (EBL)**
- **Effect of blazar emission on host galaxies and galaxy clusters**

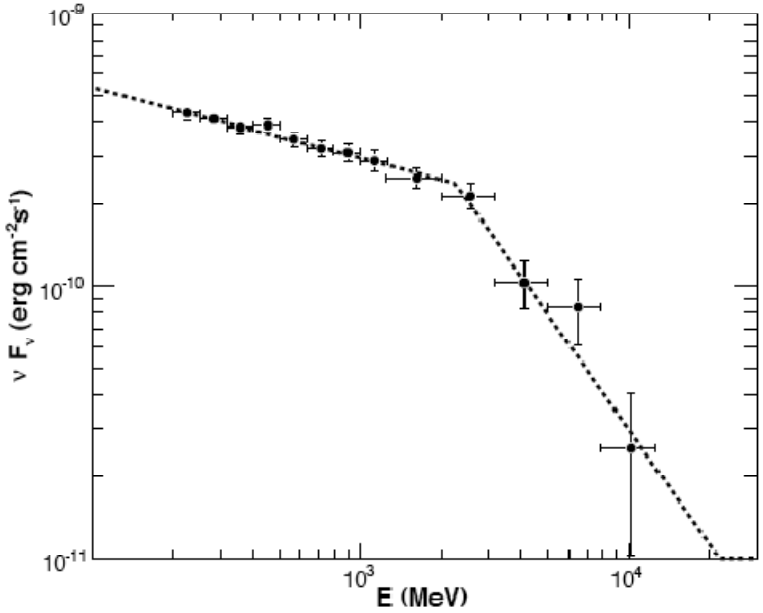


The early γ-ray flare of 3C 454.3 during 2008

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

- **well-known OVV quasar very active (bright, rapidly variable) since 2000**
- **outburst detected in the early *Fermi*/LAT data, showing rapid flares with rise-times of ~ 3 days**



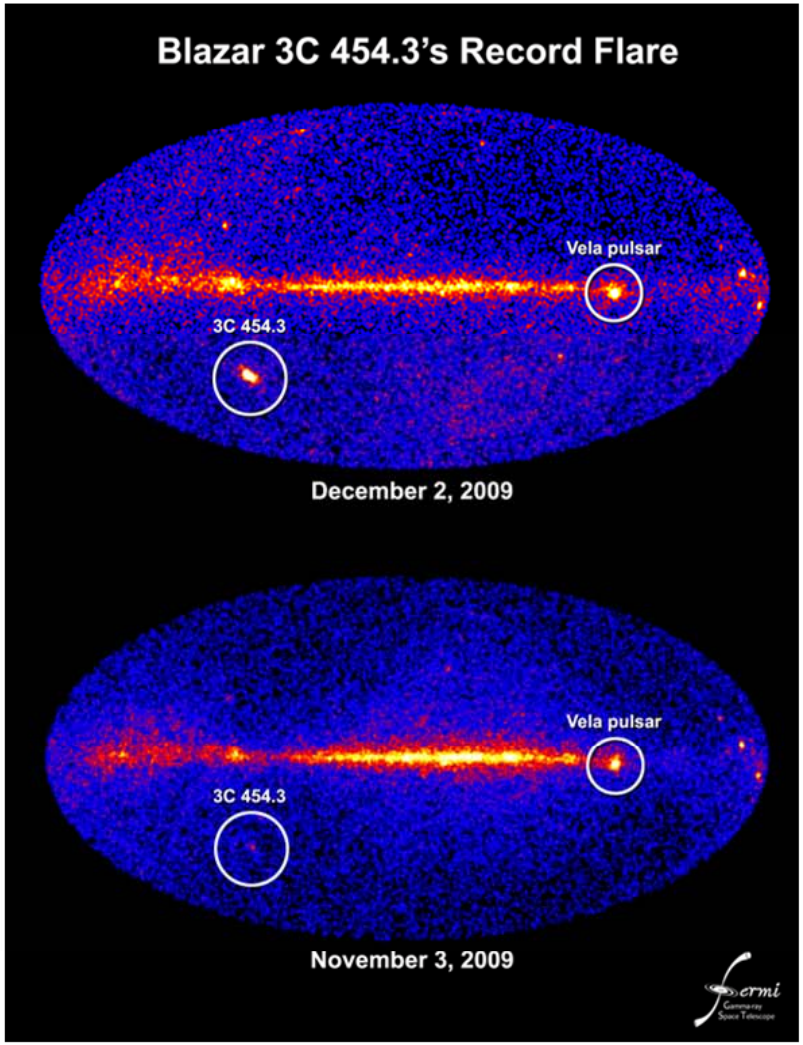


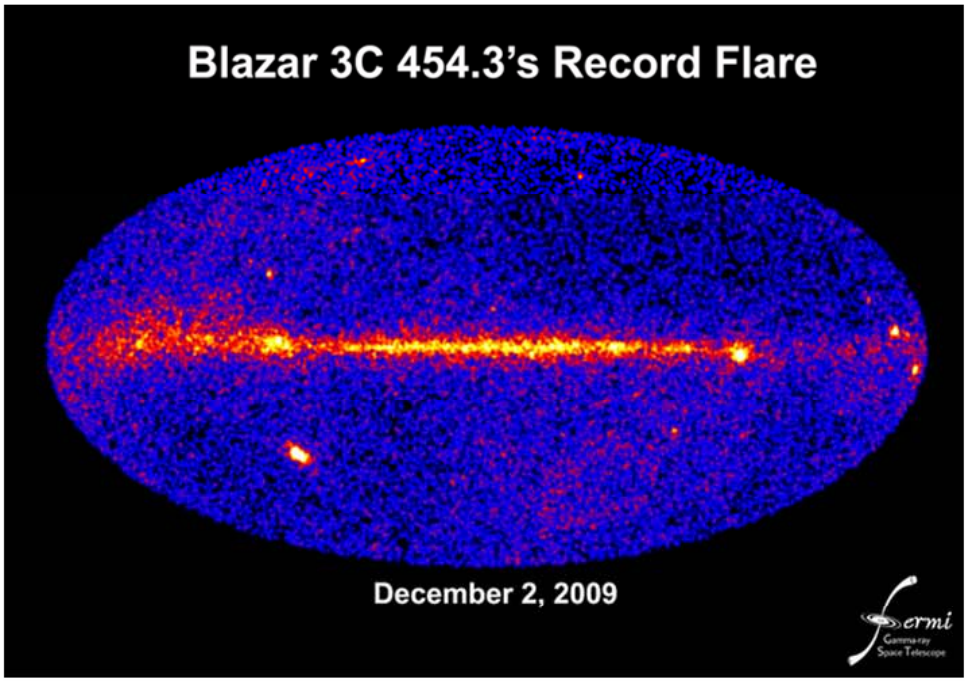
Not a simple power law: broken power law with a break, Γ_1 ~ 2.3 to Γ_2 ~3.5 at E_{br} ~ 2-2.5 GeV

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?

3C 454.3 Brightest Flare - Dec. 2009





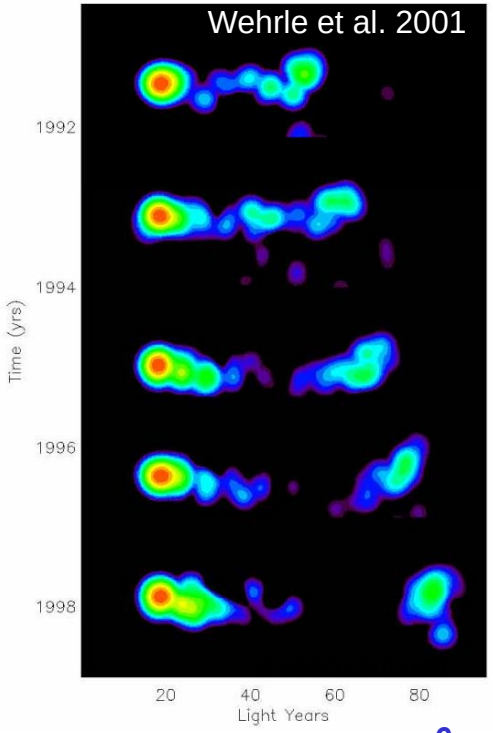
See Lise Escande's talk

Daily photon count maps

FSRQ 3C 279 (z = 0.536)

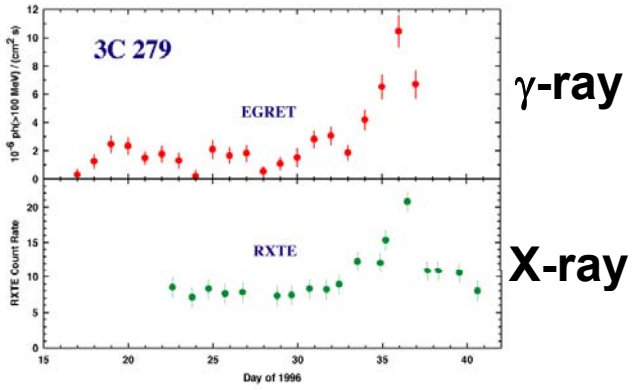
- **One of the EGRET brightest AGN**
  - Apparent luminosity: as high as 10^{48} erg/s
  - Can vary in γ-ray flux by roughly two orders of magnitude
  - > 100 GeV emission detected by MAGIC
  - Mass: ~ $6 \times 10^8 M_\odot$

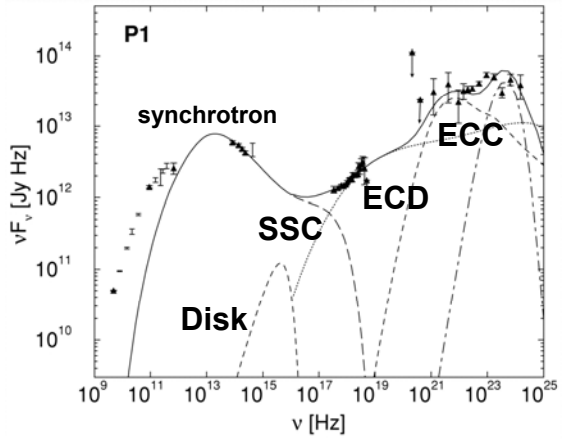
- radio VLBI image (super-luminal motion)
  - Γ_{jet} ~ 15
  - jet angle to our line of sight ~ 2°



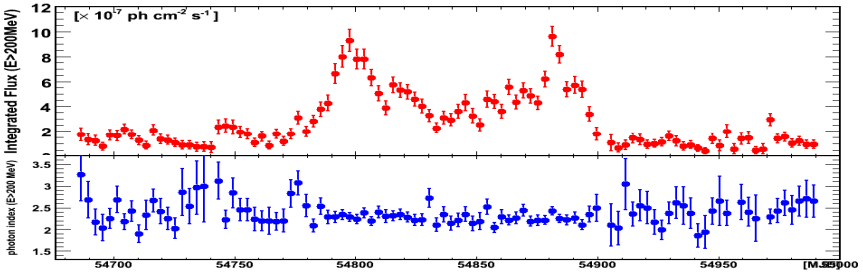
<emission model> (Hartman et al. 2001)
- radio- optical : synchrotron
- X-ray : SSC
- Gamma-ray : EC (ECD+ECC)

1996 flare





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**

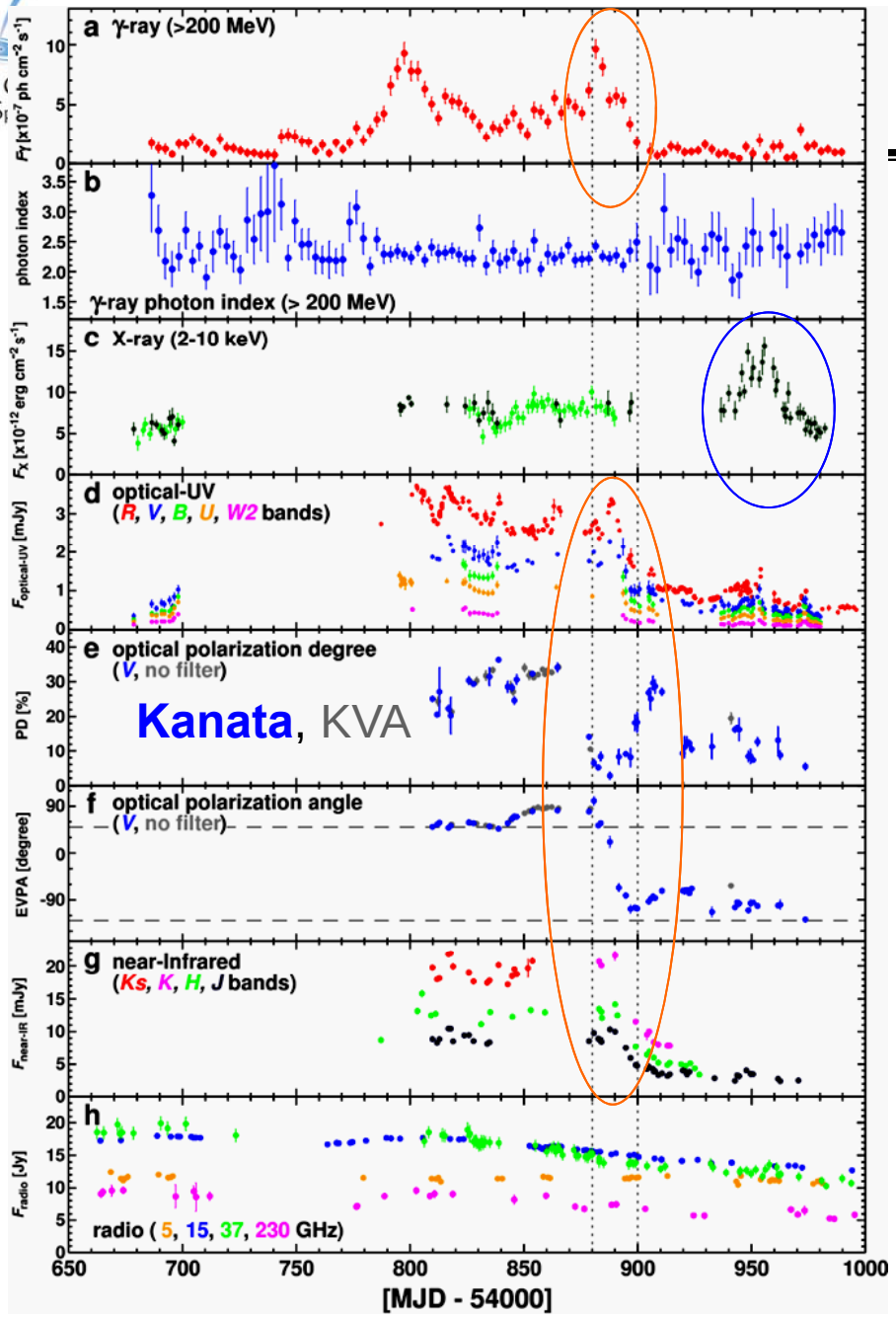
Observatory	Detector/Telescope (diam.)	Band
	Gamma-ray	
Fermi	LAT (survey mode)	> 200 MeV
	X-ray	
RXTE	PCA	3-10 keV
Swift	XRT	0.6 - 7 keV
	Ultra-Violet, Optical, Near-infrared	
Abastumani, Georgia	(70 cm)	*R*
Calar Alto		*R*
Campo Imperatore, Italy	(110cm)	*J*, *H*, *K*
Crimean, Ukraine	ST-7 (70 cm)	*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

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

Abdo et al. 2009, Nature, 463,919

Contact authors:

M. Hayashida & G. Madejski



γ-ray (LAT)

γ-ray photon index (LAT)

X-ray

optical-UV

optical polarization degree (PD)

optical polarization angle (EVPA)

Near-Infrared

Radio

Synchrotron self-absorption -> the ***size*** of the γ/optical emission region :
$R_b < 5 \times 10^{16}$ cm

Gamma-ray flare with polarization change

The event lasts for ~ 20 days

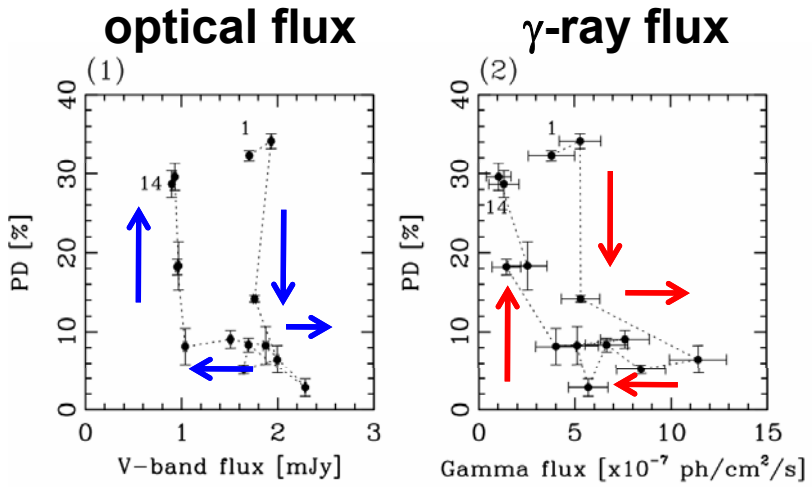
- **flux vs polarization degree (PD)**
  - flares coincide with the drop of PD
  - fluxes decrease, followed by a temporary recovery of PD

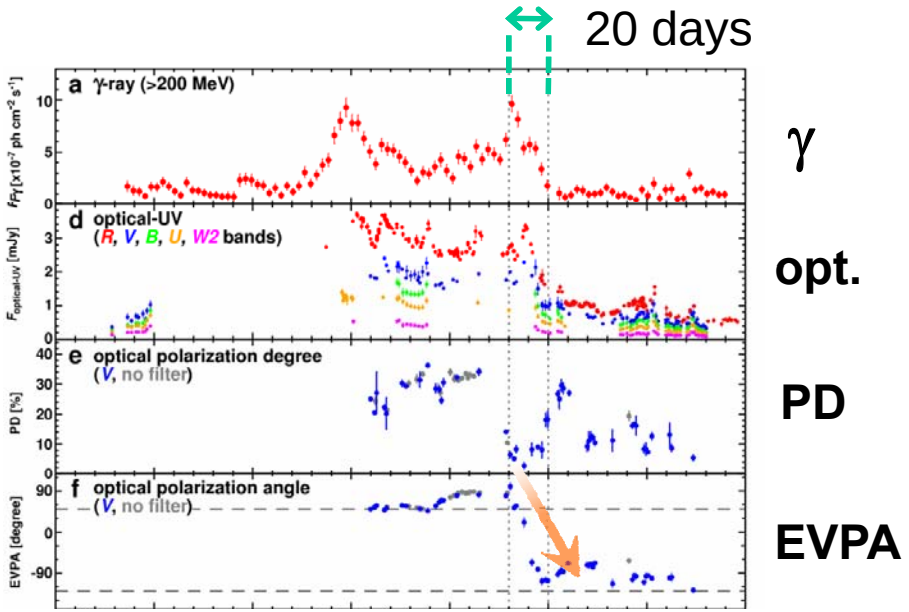
clear correlation !!

-> a highly ordered magnetic field

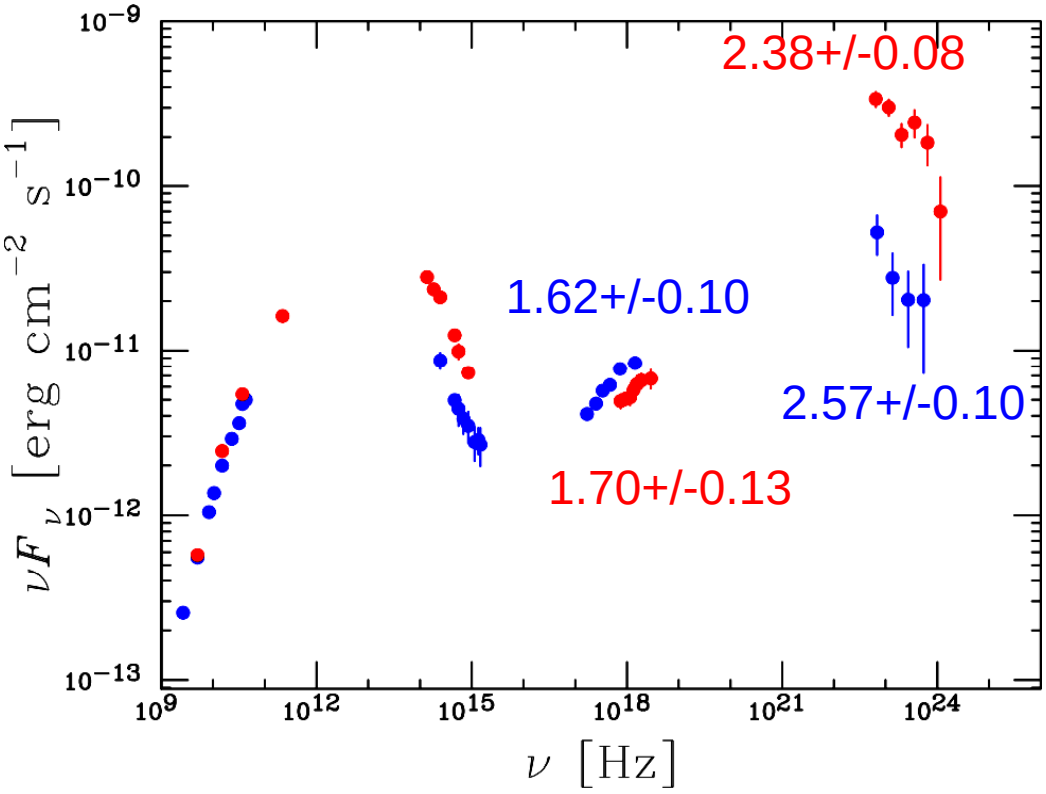
- **polarization angle (PA or EVPA)**
  - during the low PD, it gradually decreases by 208 deg (~12 deg/day)

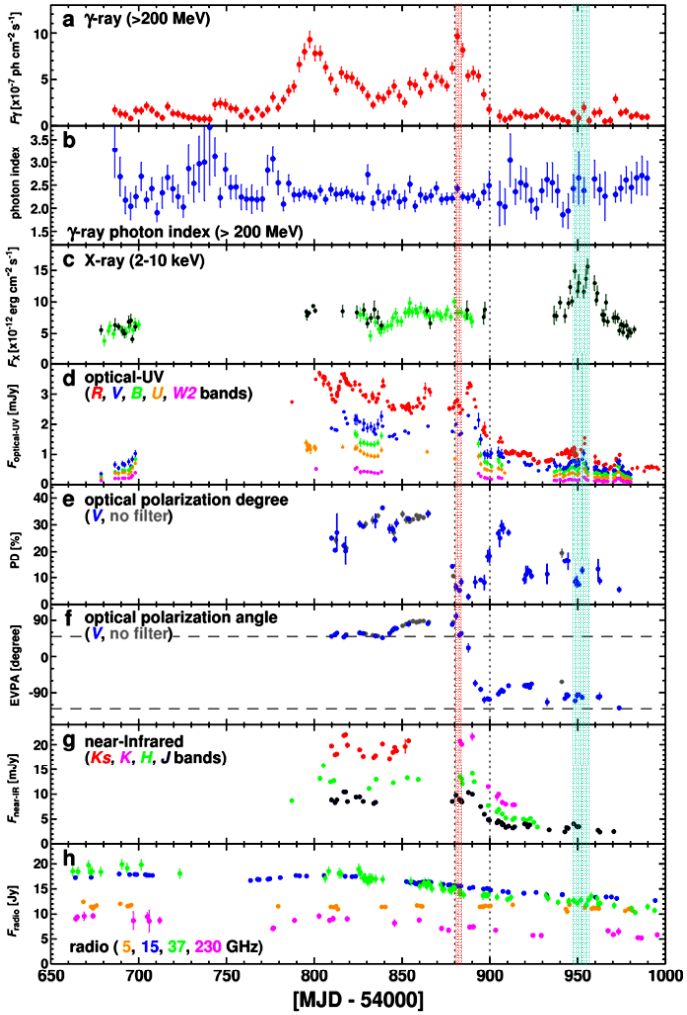
-> non-axisymmetric structure of jet





Spectral Energy Distribution

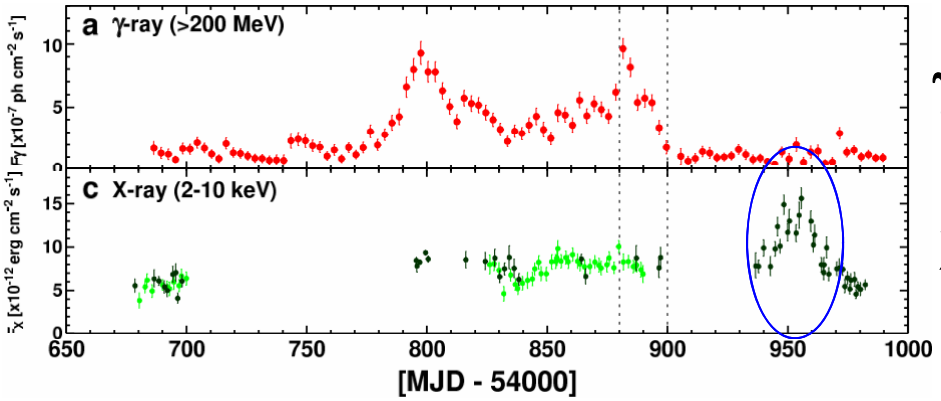




- **gamma-ray emission is:**
  - ***dominant and most variable***
- **several x 10^{47} erg/s at the peak**
- **comparable photon indices between two states**

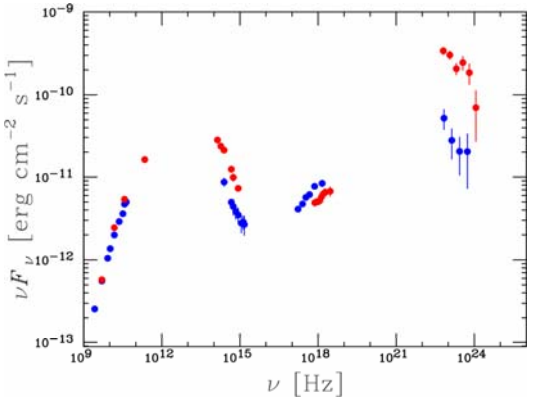
Red Blue

Isolated X-ray flare



γ-ray

X-ray



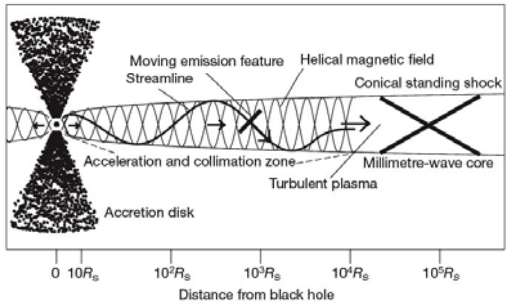
- a significant, symmetrical flare at 54950 MJD (~60 days after the γ-ray flare)
  - the optical and γ-ray bands show lower states
  - the X-ray spectrum is much harder than the optical spectrum
    - likely to be generated by IC scattering of low energy electrons
  - duration ~ 20 days; similar profile to the γ-ray flare
    - X-ray flare cannot be a simple delayed version of the γ-ray flare (due to, e.g, particle cooling)
  - Still, the γ-ray emission is dominant; 5 times the energy flux even during the isolated X-ray flare event

challenge to the simple, one-zone emission models!!

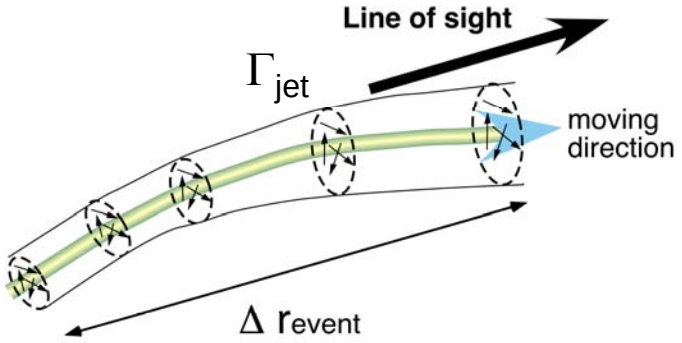
Jet structure (I)

a γ-ray flare with polarization change : duration ~ 20 days
-> constrains on the *location* of the γ/optical emission region

1. helical magnetic field model (Marscher et al. 2008)



2. bend jet model



***location* of the emission region :**

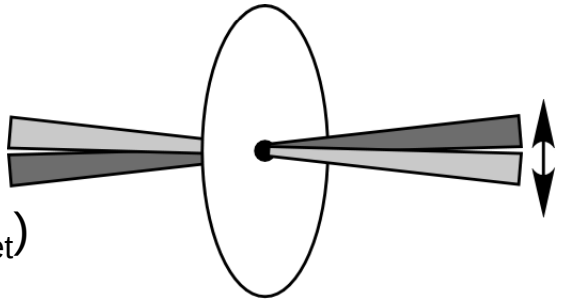
$$\Delta r_{\rm event} \sim 10^{19}\,(\Delta t_{\rm event}/20\,{\rm days})\,(\Gamma_{\rm jet}/15)^2\,{\rm cm}\,.$$

~ 10^5 gravitational radii

3. "flow-through" (jet wobbling) scenario

(emission pattern may move much slower than the bulk speed of the jet)

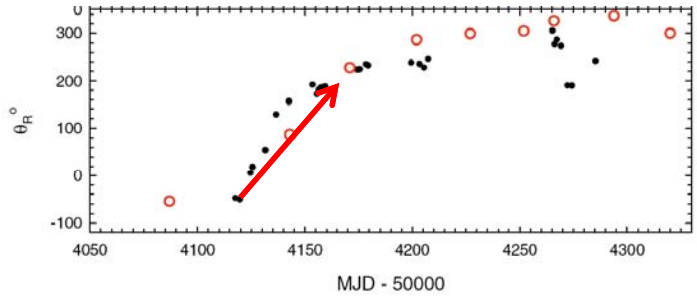
emission region can be located closer (by a factor of Γ^2_{jet}) to BH : $r_{event} \sim c\Delta t_{event} \sim 10^3$ **gravitational radii**



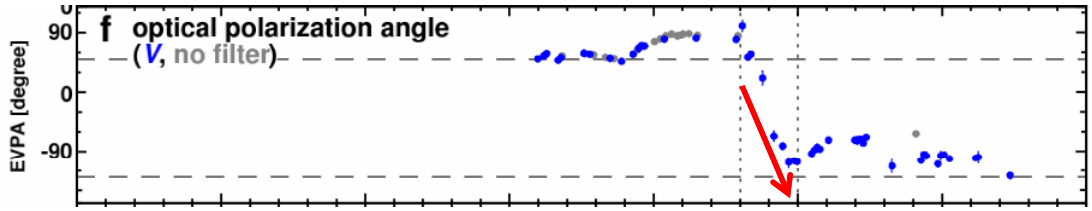
Jet structure (II)

- Comparison to previous EVPA observations

(Larionov et al. 2008)

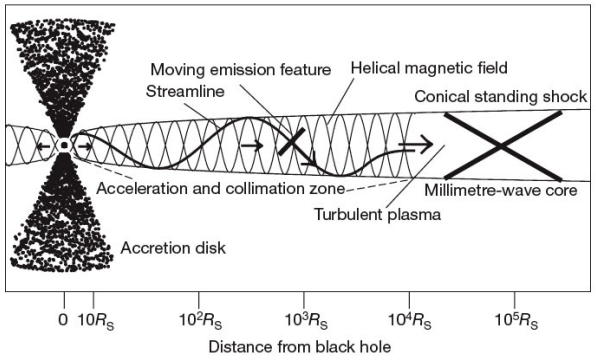


(our results)

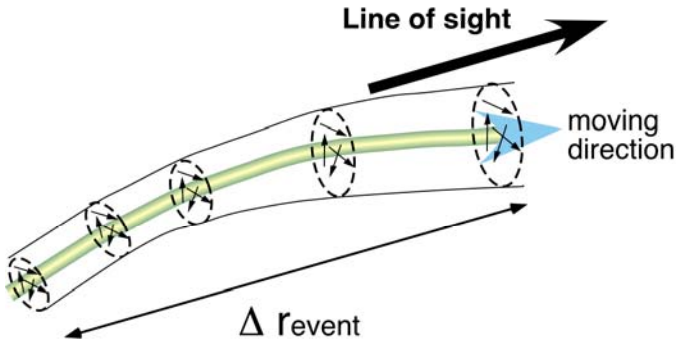


Scenarios 1 and 3 imply the rotation of EVPA should be always following the same direction
-> But, not in the observations: needs further confirmation

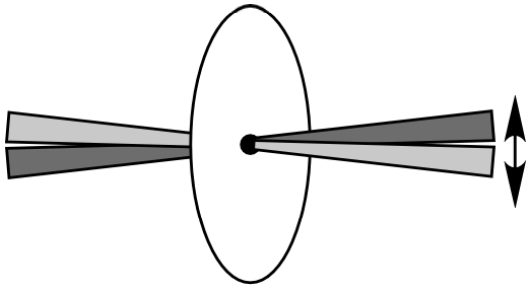
1. helical magnetic field



2. bend jet model

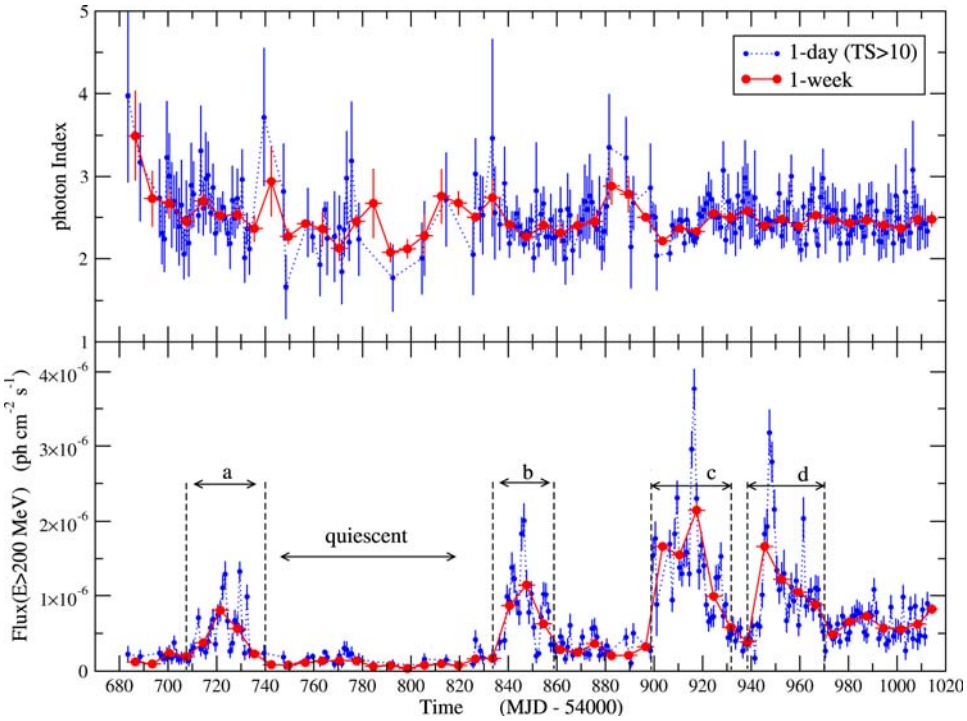


3. flow-through



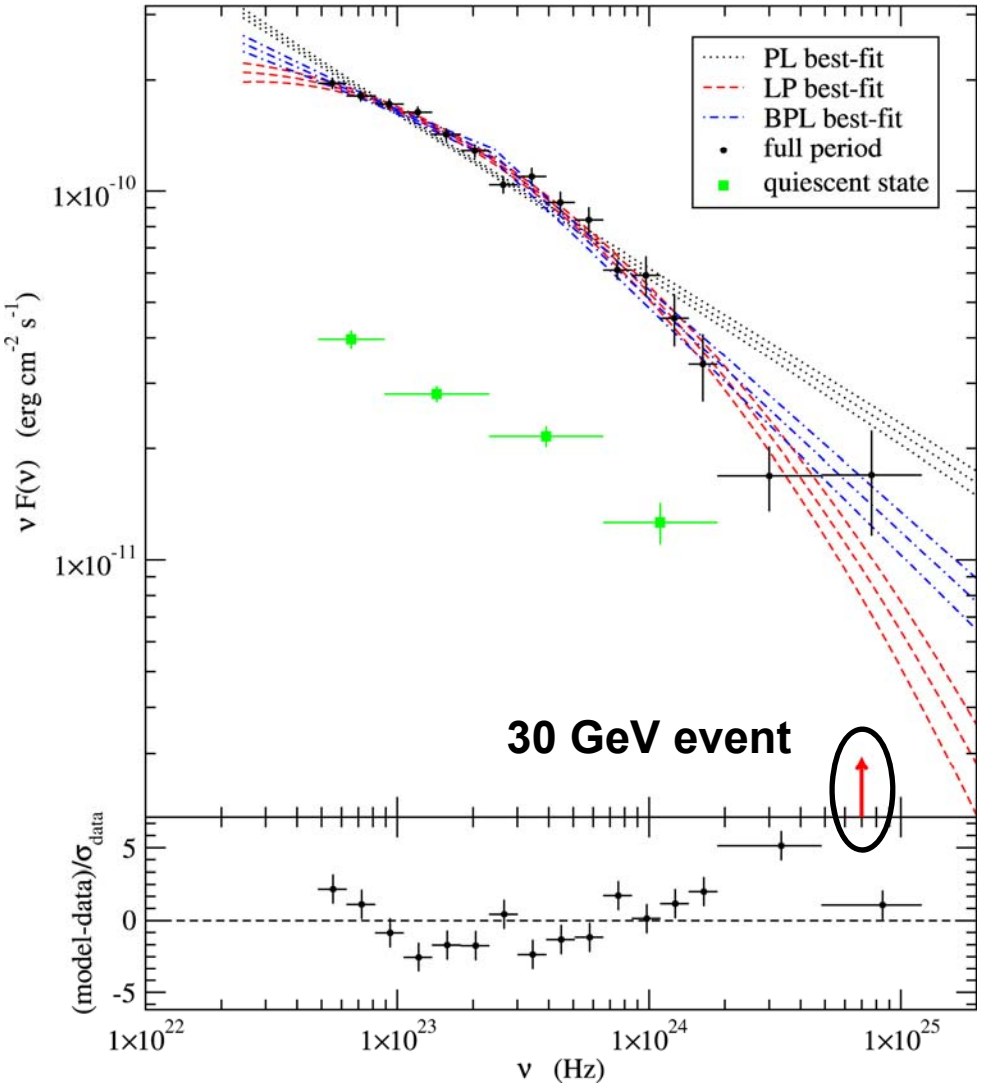
PKS 1510-089

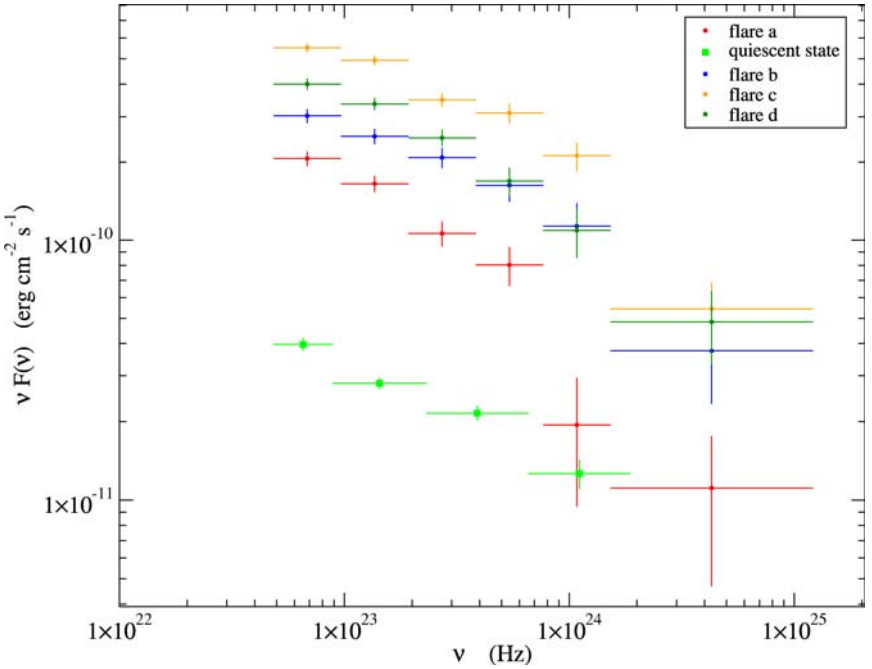
- **FSRQs detected in MeV - GeV by EGRET and AGILE**
- **Extensively studied also in X-ray from ROSAT to *Suzaku***
- **Redshift z = 0.361, θ ~ 3°**
- **Apparent velocities of $v_{app} \geq 10c$ observed in multiepoch VLBA observations**
- **The synchrotron emission peaks around IR, but with a pronounced UV bump likely due to the thermal emission from the accretion disk**



- **4 major flaring episodes observed by *Fermi*/LAT between August 2008 and September 2009**
- **~weekly trends**
- **smaller sub-flares on shorter timescales**
- **temporal resolution limited by the minimum integration time**

γ-ray spectra



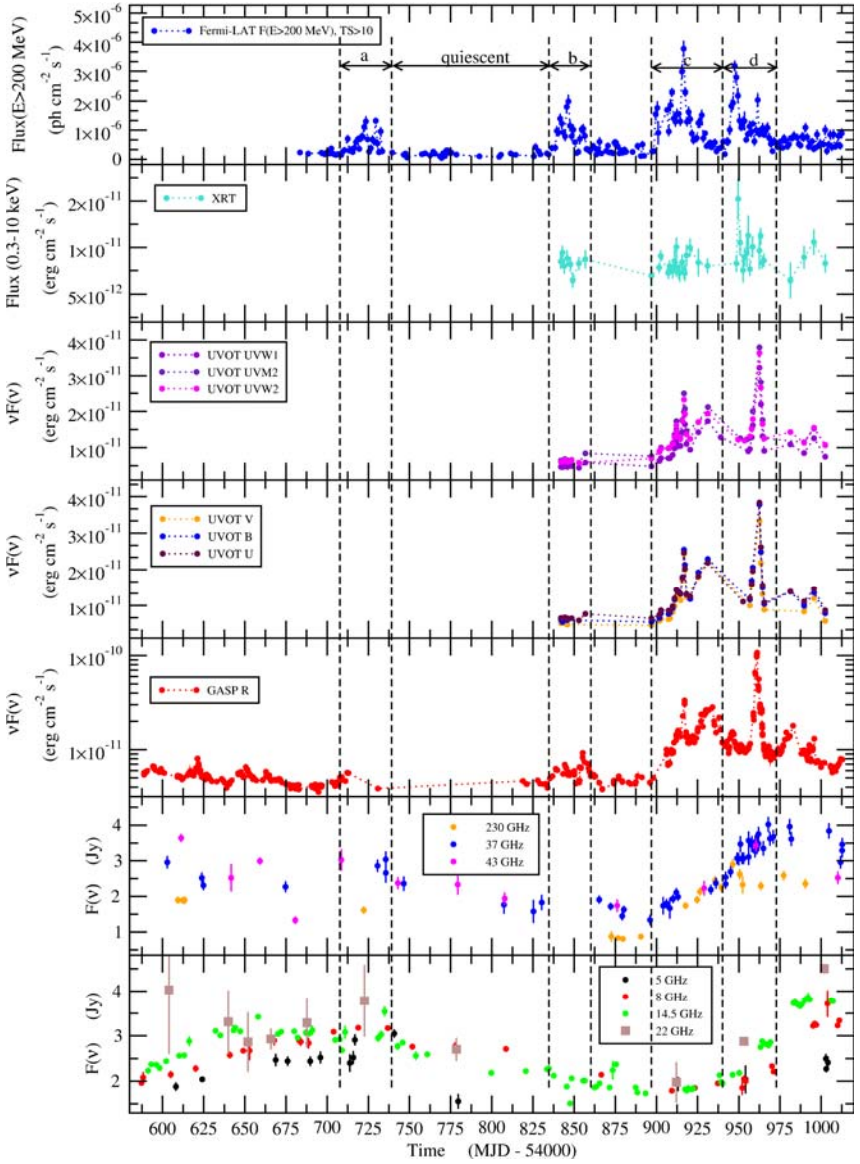


Flaring and full period spectra are well described by a LogParabola with a curvature ~0.1

$dN/dE \propto E/E_0^{-\alpha-\beta \log(E/E\_0)}$

Typical full range photon index ~ [2.3-2.5]

Multifrequency Observations



Fermi Large Area Telescope and multi-wavelength observations of the flaring activity of PKS 1510-089 between 2008 September and 2009 June

Abdo et al. 2010, Apj accepted, arXiv:1007.1237

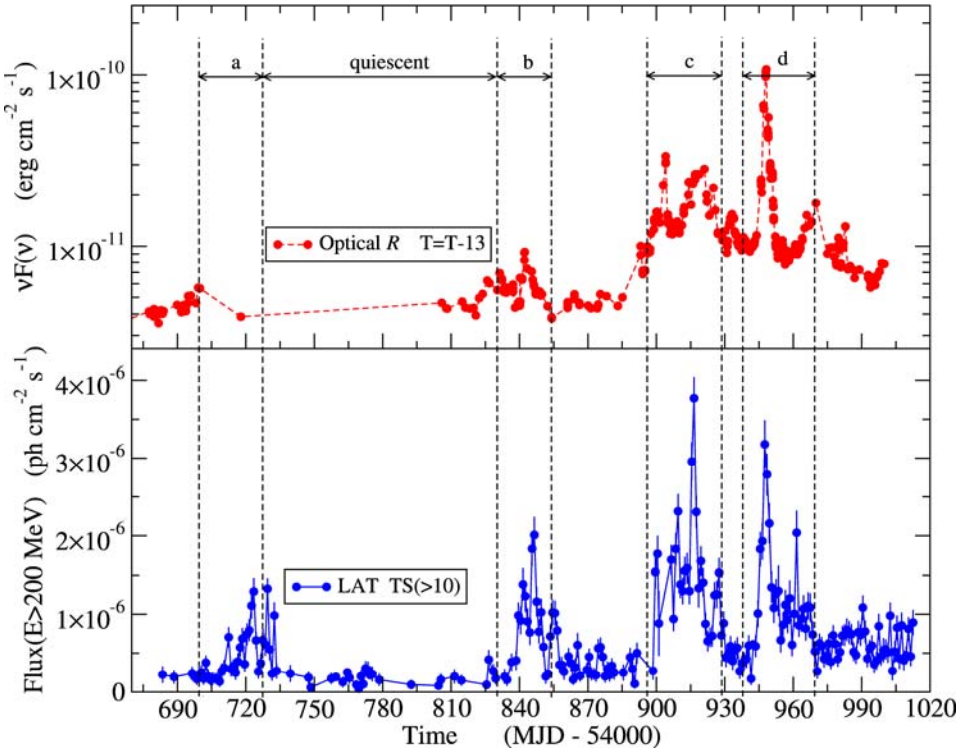
- **complex MW variability**
- **X-ray less variable and not correlated with optical and gamma-ray activity**
- **Optical/UV seems to follow the γ, but....**
- **Increasing trend of the radio emission at higher frequencies after March 2009**

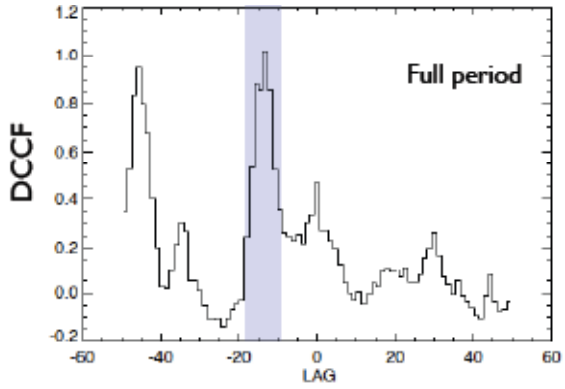
Contact authors:

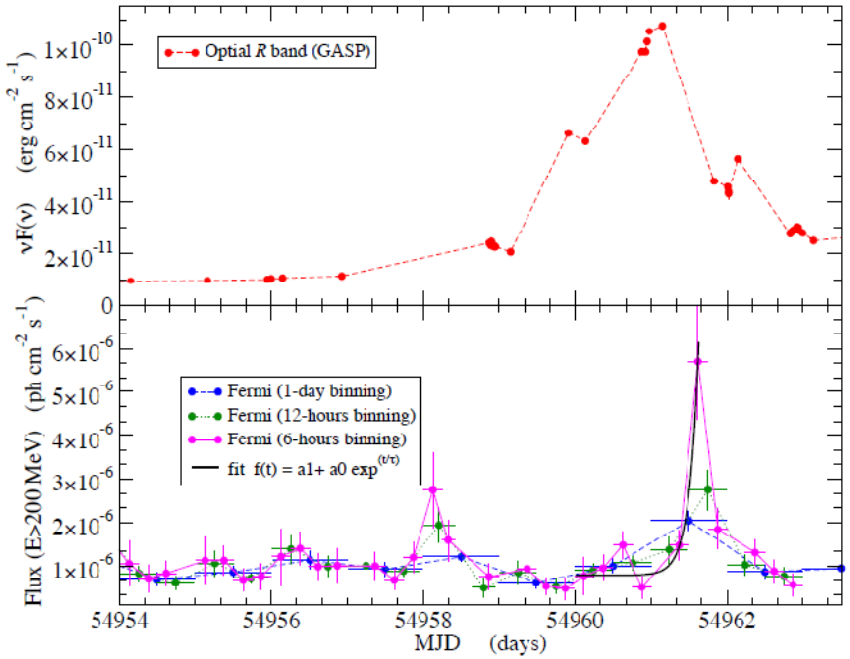
A. Tramacere & E. Massaro

Optical/γ-ray correlation

The general trend seems to be that gamma leading the optical ~ 13 days...



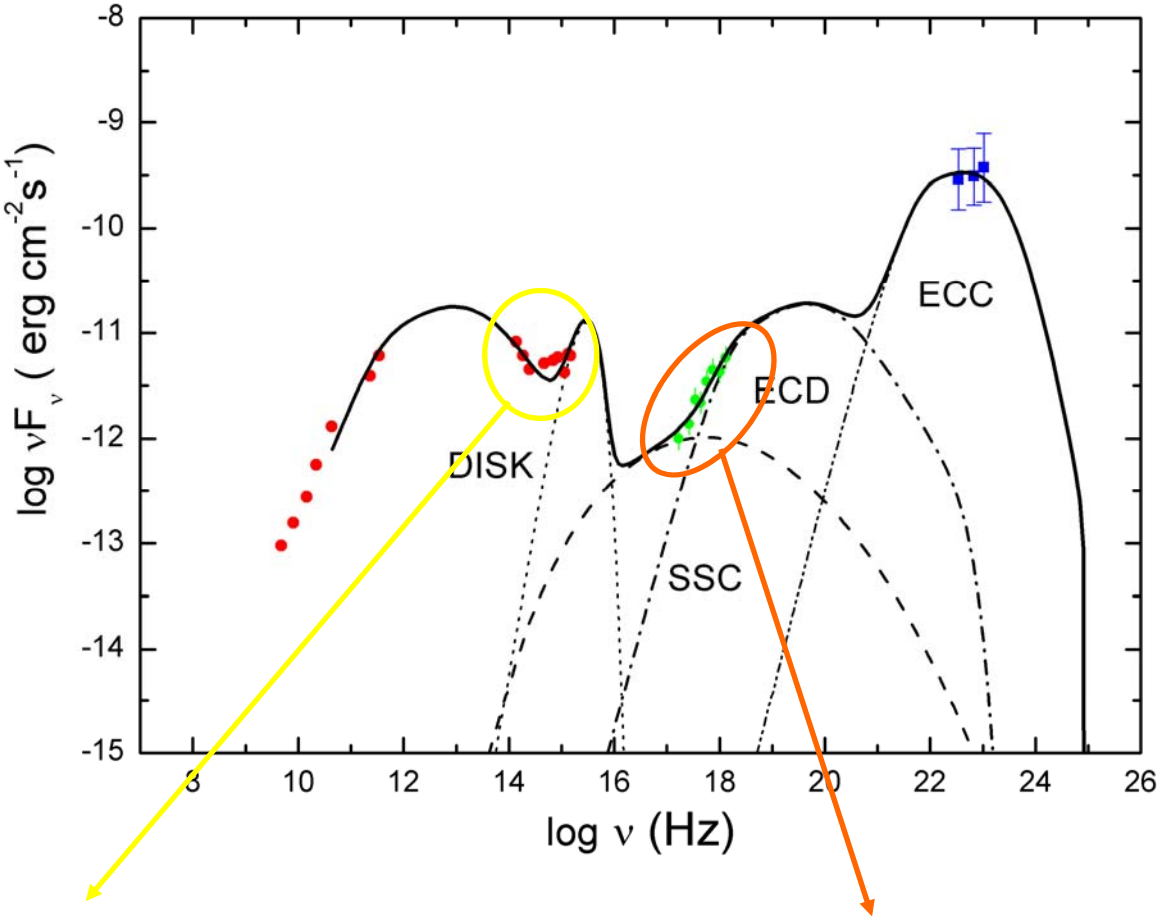




...but a sharp gamma-ray flare (6hr) coincident with the historical optical flare was observed

SED of PKS 1510-089 during March 2008

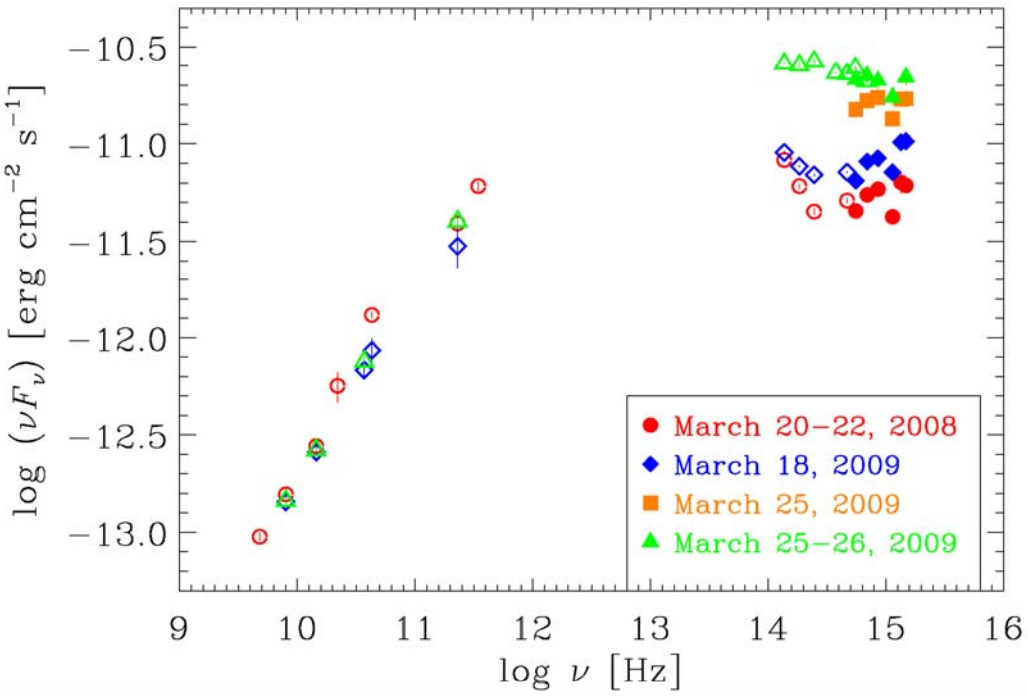
D'Ammando et al. 2009



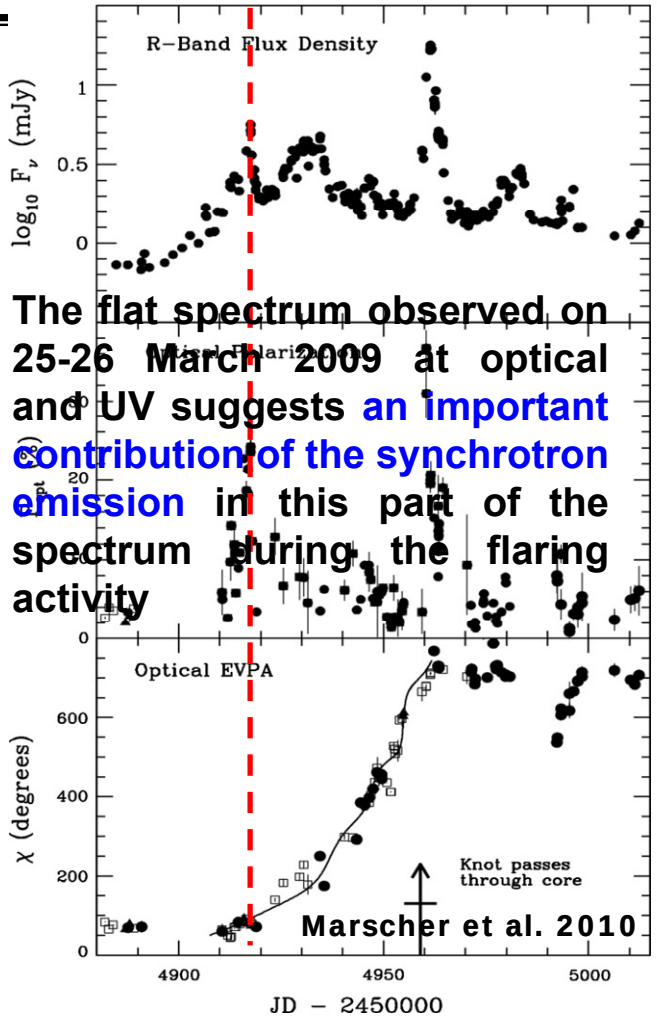
Signatures of the little and big blue bumps

Very hard X-ray photon index (Γ = 1.16 ± 0.16)

SED radio-to-UV during 2008-2009



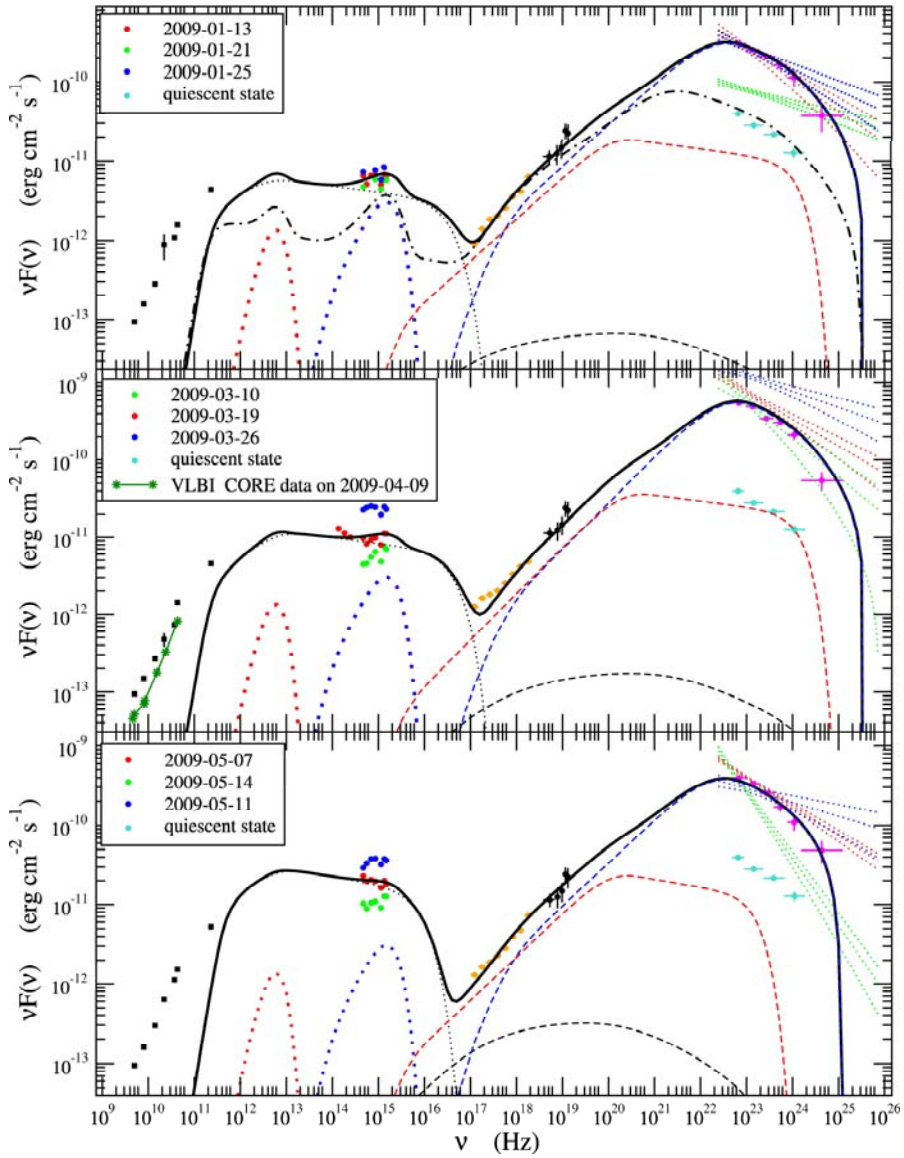
D'Ammando et al., 2010



The flat spectrum observed on 25-26 March 2009 at optical and UV suggests an important contribution of the synchrotron emission in this part of the spectrum during the flaring activity

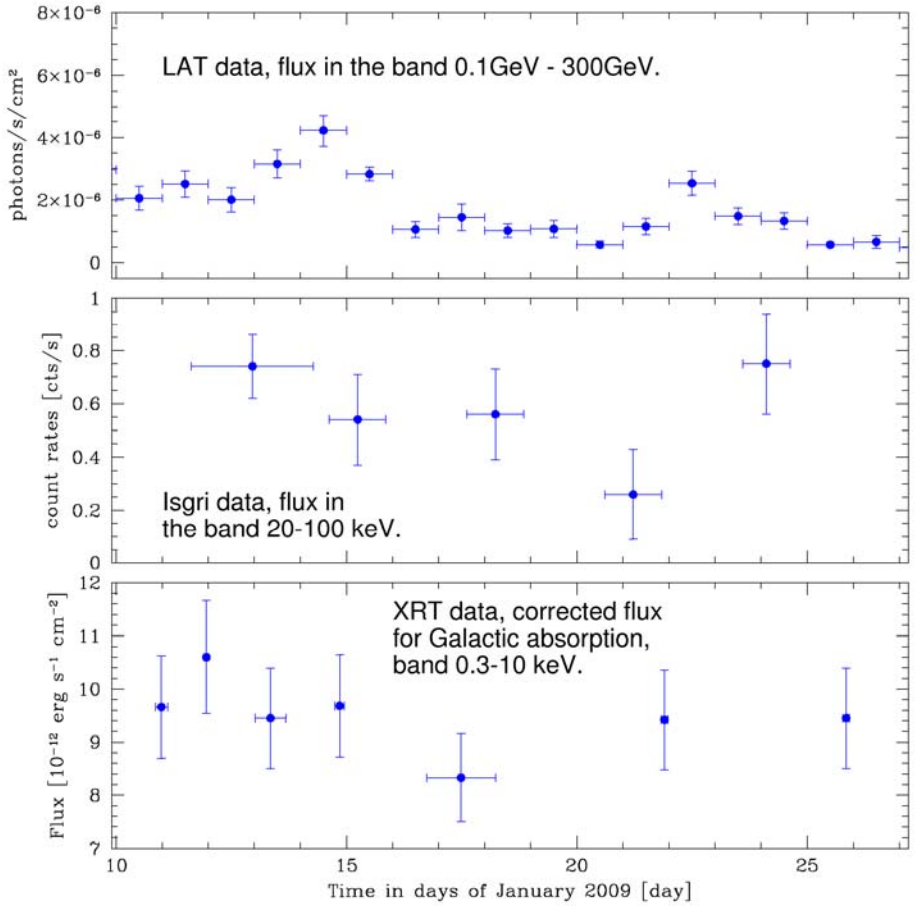
Considering that the synchrotron peak is usually observed in the infrared band in PKS 1510-089, this is an indication of a significative shift of the synchrotron peak during very high activity of the source at the end of March 2009

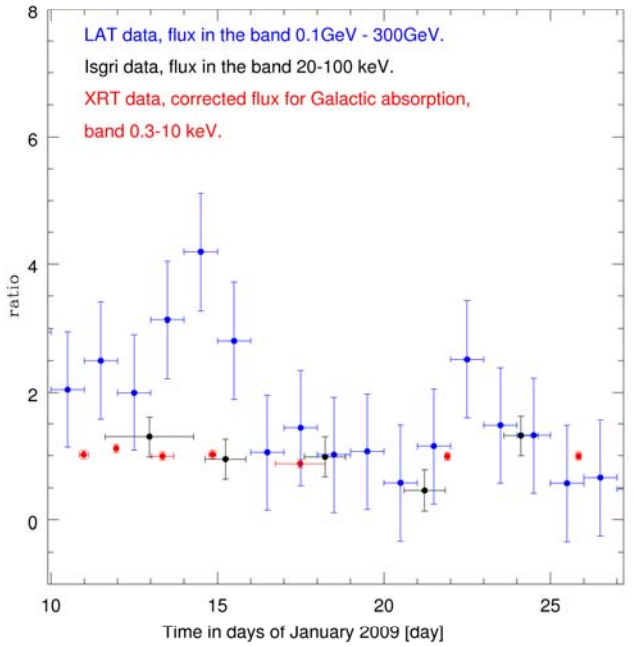
SED model (BKN + EC/BLR)



- δ form VLBI data ~ 21 consistent with previous estimates and with the $\tau_{\gamma\gamma}$ transparency argument using X-ray and γ-ray data
- Compton dominance = L_{IC}/L_S > 10 during flares
- No strong evolution in the peak of the IC component among different flare-averaged SEDs
- strong BBB also during the huge optical flare (but not always)
- the absence of X-ray/γ-ray correlation hints that the ERC flux variations relies on a change in the high energy spectral index of the electron distribution, or in a change of the external radiation field
- γ-ray curvature ~0.1 compatible with data due to KN

Fermi & INTEGRAL observations (I)

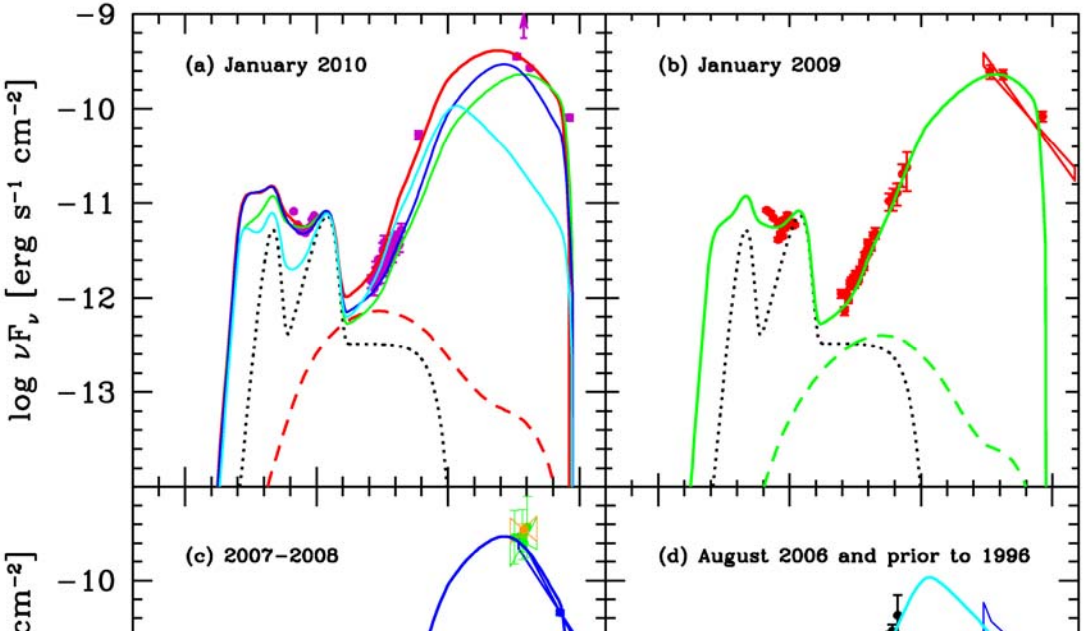




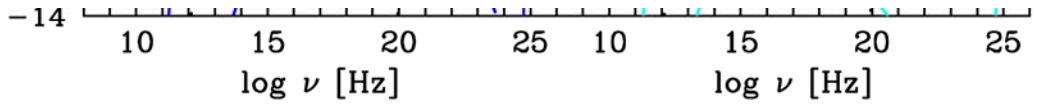
Pian et al., in prep.

INTEGRAL observations confirm no high activity in X-rays (hard and soft) during gamma-ray flares nor strong correlation between X-ray and gamma-ray

Fermi & INTEGRAL observations (II)



panel	$R_{\rm diss}$ [1]	$P'_{\rm j}$ [3]	B [4]	Γ [5]	$\gamma_{\rm b}$ [6]	$\gamma_{\rm max}$ [7]	s_1 [8]	s_2 [9]	$\log P_{\rm r}$ [10]	$\log P_{\rm B}$ [11]	$\log P_{\rm e}$ [12]	$\log P_{\rm p}$ [13]
a	90 (1000)	0.012	2.5	16	200	3e3	1.3	2.6	45.47	44.68	44.92	47.35
b	81 (900)	7e-3	2.2	15	1e3	4e3	1	3.0	45.15	44.44	44.41	46.72
c	86 (950)	8e-3	2.9	16	300	4e3	1	3.1	45.26	44.77	44.58	46.84
d	72 (800)	8e-3	3.8	13	10	4e3	1	2.7	44.68	44.68	44.70	47.20

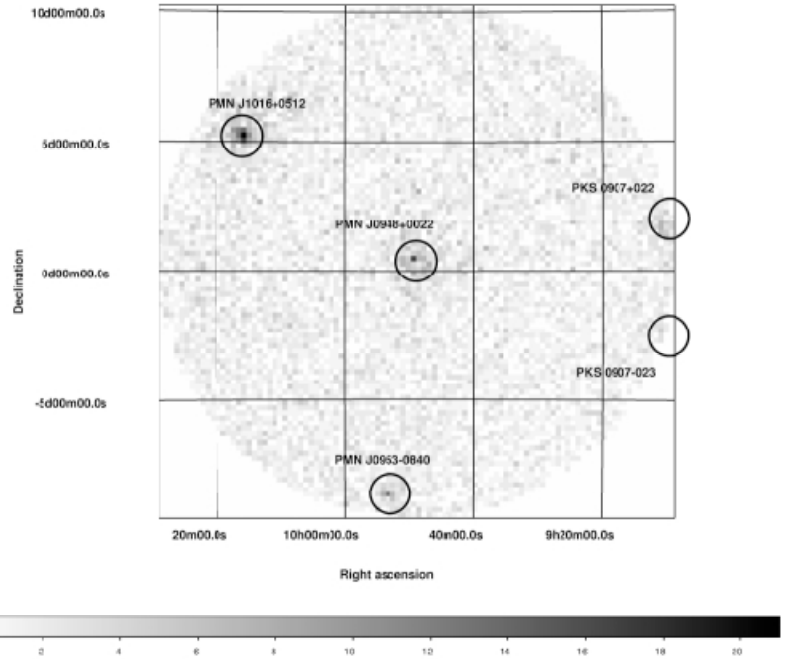


Pian et al., in prep.

PMN J0948+0022 & Narrow-line Seyfert 1 galaxies

- **Before *Fermi*/LAT: γ-ray emitting AGN are only blazars and radio galaxies**
- ***Fermi*/LAT: 1FGL catalogue confirmed extragalactic γ-ray sky dominated by those two classes!**

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

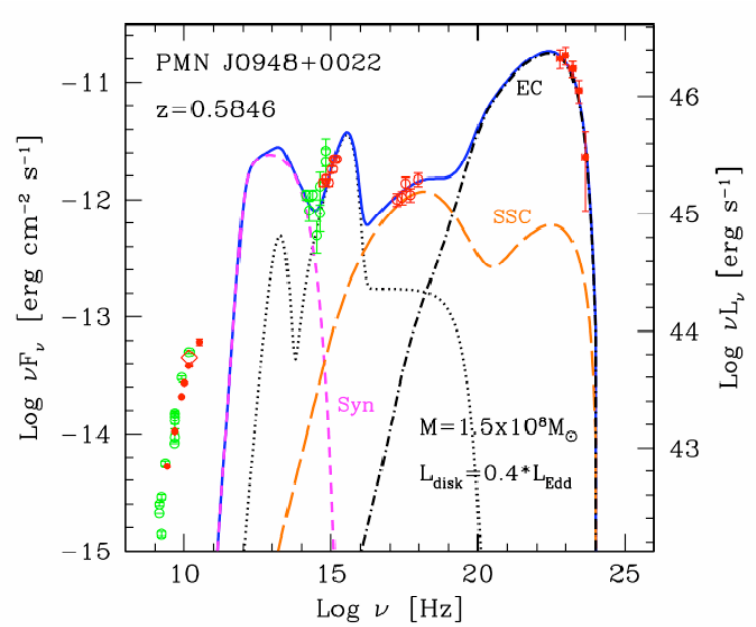


Fermi/LAT discovery of gamma-ray emission from a relativistic jet in the Narrow-Line Quasar PMN J0948+0022 Abdo et al. 2009, ApJ, 699, 976

- **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

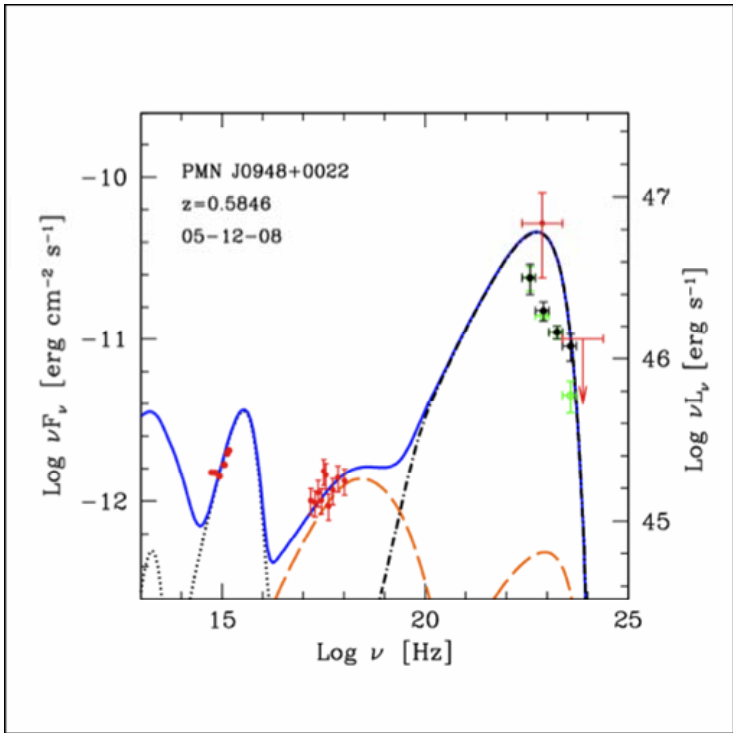
- **answer promptly: early MW follow-up and a triggered MW campaign (Abdo et al. 2009a, 2009b)**
- **Follow-up multiwavelength campaign showed correlated variability with lower energies**
- **first averaged SED similar to FSRQs, but at lower luminosity**



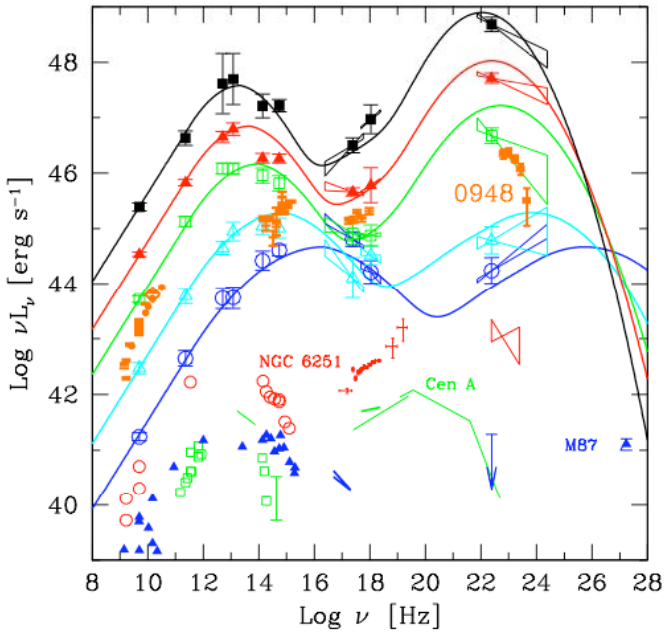
Domain	Energy band/Filter /Frequency	Facility
Gamma-rays	0.1-10 GeV	Fermi/LAT
Hard X-rays	20-100 keV	Swift/BAT
X-rays	0.2-10 keV	Swift/XRT
Optical/UV	V,B,U,UVW1,UVM2,UVW2	Swift/UVOT
Optical	B, R	ATOM
Optical/NIR	B, R, J	SMARTS/Yale
NIR	J, H, Ks	INAOEP
NIR	J, K	WIRO
Radio	15 GHz	OVRO
Radio	cm/mm, Polarization	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 $M_\odot$**

PMN J0948+0022 & Narrow-line Seyfert 1 galaxies



- **NLS1 have lower mass BHs and high accretion rates → Eddington ratio is a key determinant of SED characteristics**
- **It is not like a RG, both for high-power (with respect to RG) and radio structure (compact vs extended)**
- **Host is likely to be spiral, instead of elliptical, like blazars and radiogalaxies**

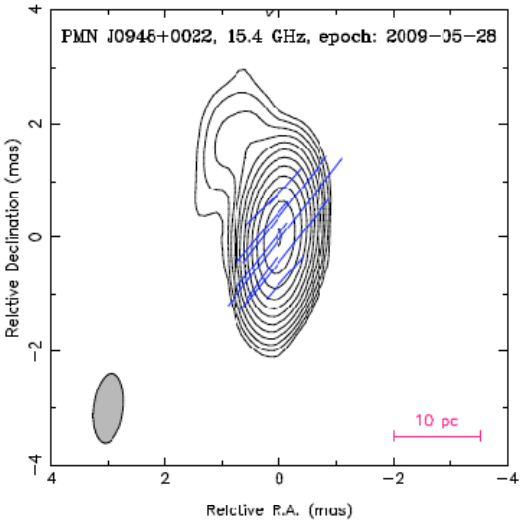


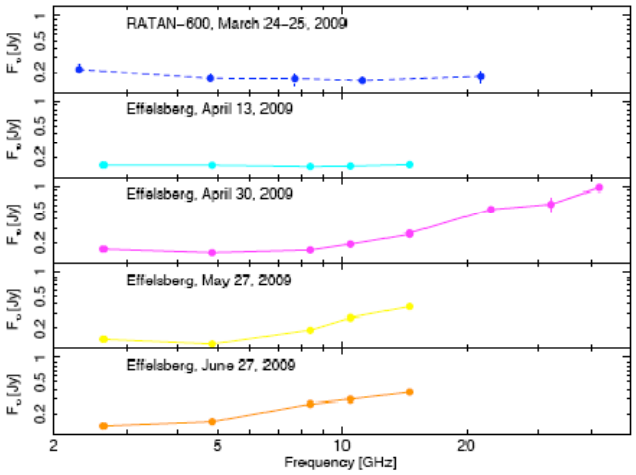
- **SSC component plus EC component**
- **physical parameters: typically blazar-like**
- **jet power similar to those of blazars (intermediate between FSRQs and BL Lacs)**

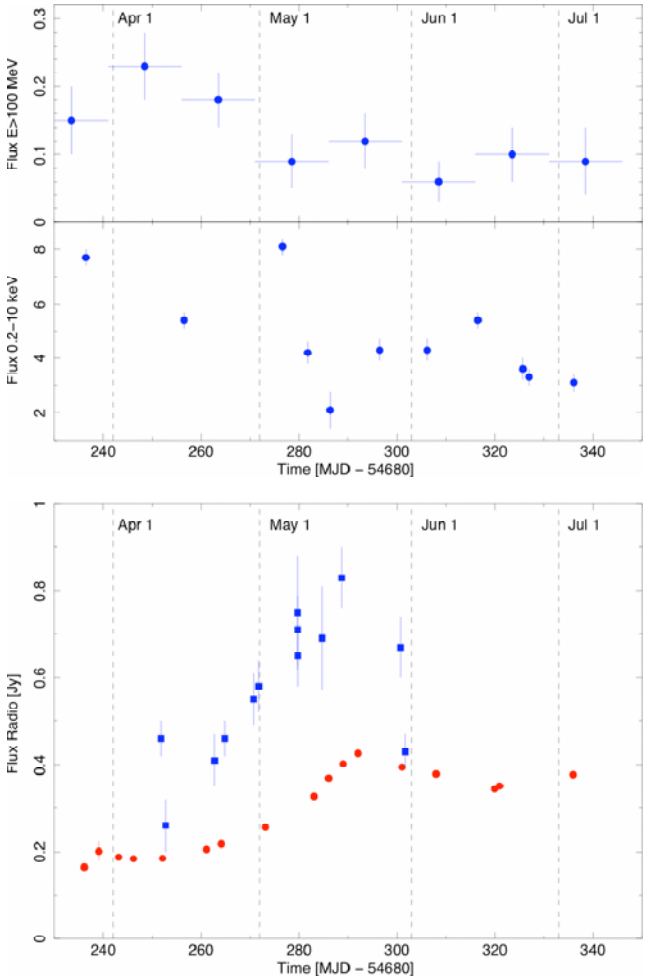
PMN J0948+0022 & Narrow-line Seyfert 1 galaxies

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 x 10^{12} K
– VLBI core fractional linear polarization of 0.7%







Typical signature of a relativistic jet

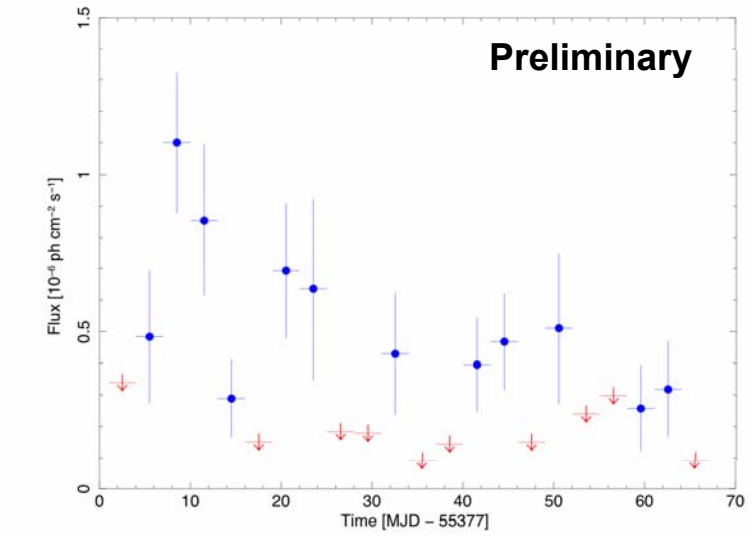
PMN J0948+0022 & Narrow-line Seyfert 1 galaxies

PMN J0948+0022 is not the only NLS1 detected in gamma-rays by *Fermi*-LAT (4 objects in the 1FGL): emerging population of RL-NLS1 (Abdo et al. 2009)

- **SED similar to blazars but...**
- **small BH masses ($10^{6.7}$-$10^{8.2}$ $M_\odot$) and very high accretion rates (up to 90% Eddington)**
- **spiral hosts, challenge the view that relativistic jets are typically hosted in elliptical galaxies**

A key question was about the power released by the jets of NLS1s

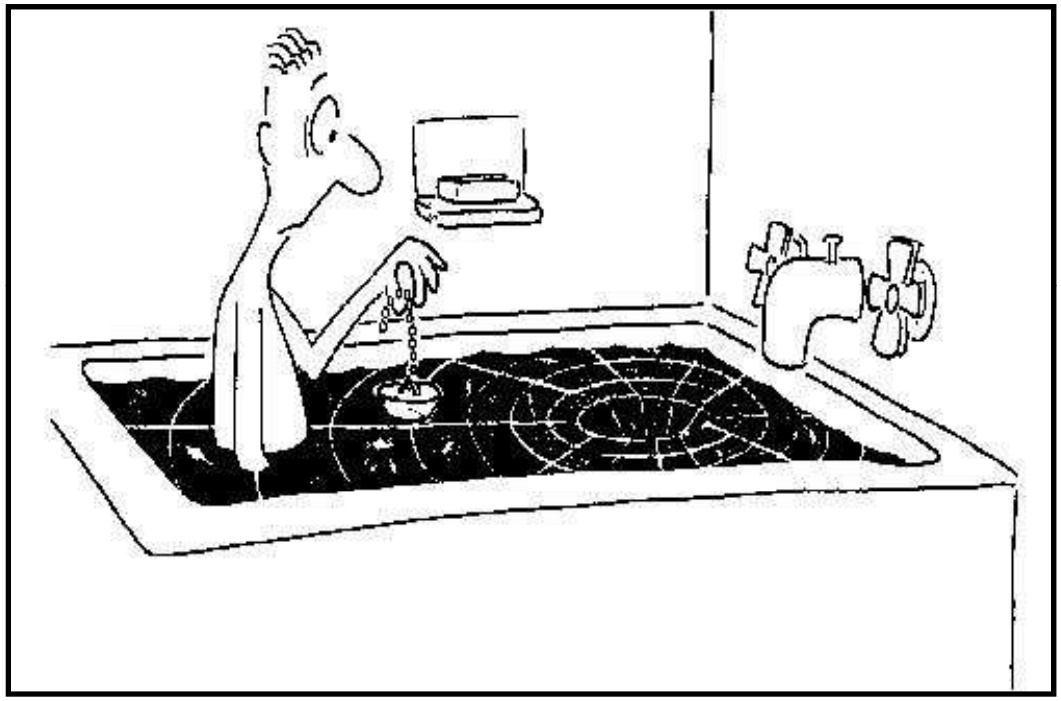
Flaring gamma-ray activity from PMN J0948+0022 was observed in July 2010 by Fermi-LAT (Donato 2010; Foschini 2010), with a luminosity of ~10^{48} erg s^{-1}



Foschini et al., in prep. (see arXiv:1009.1055)

Concluding Remarks

- **With the advent of the *Fermi* satellites a new window on the observations of AGNs is now opened, not only for observations in gamma-rays but also for further coordinated investigations over the whole electromagnetic spectrum**
- **We have investigated in detail the emission mechanisms of some blazars through multiwavelength studies, uncovering in many cases a more complex behaviour with respect to the standard emission models**
- **Moreover a new class of gamma-ray emitters was detected by *Fermi*: the NLS1, and gamma-ray flaring episodes seem to be observed also for these objects**
- **Notwithstanding 20 yrs of observation and the increasing knowledge about individual and collective properties of these objects, some questions on the emission mechanisms of blazars are still open…**
- **…and multiwavelength studies from radio to gamma-rays will be the key to understanding the structure of the inner jet, the origin of the seed photons for the IC process and the physical processes taking place in these intriguing sources**



Thanks for your attention!!!