Multiwavelength observations of Blazars

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Abstract

Blazars exhibit very broad spectral energy distributions, extending over up to 20 orders of magnitude in photon energy. Blazars also very on a wide range of time scales with power density spectra that have been measured over as many as 9 orders of magnitude in time for the best studied objects. Given these characteristics, coordinated multiwavelength observations are required to understand the physical processes in Blazars. Apart from detailed studies of a very small number of prominent targets, statistical investigations of homogenous observations are important, but difficult to assemble due to technical constraints. The current status of multiwavelength investigations will be reviewed with a special emphasis on future opportunities.

Multiwavelength observations of Blazars

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HESS collaboration

Multiwavelength observations

Broadband studies of Blazars are monitoring studies: 3 reasons
Scale-free spatial and temporal structures
Localizing emitting regions
Clues on Lorentz factors, Uncertainties in Doppler corrections

Special emphasis:
"Astrophysics with All-Sky X-Ray Observations"

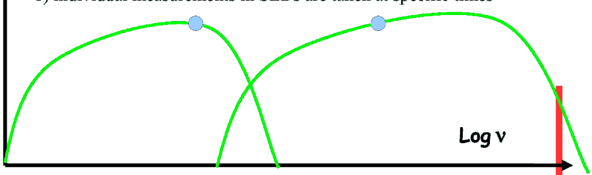
All-Sky >> many sources >> populations (parameter studies)
>> alerts for pointed studies
>> long-term studies >> flux/sensitivity is 'only' bias
(window function well understood)
>> avoid coincidences

From examples to samples: avoiding biases, enabling parameter studies

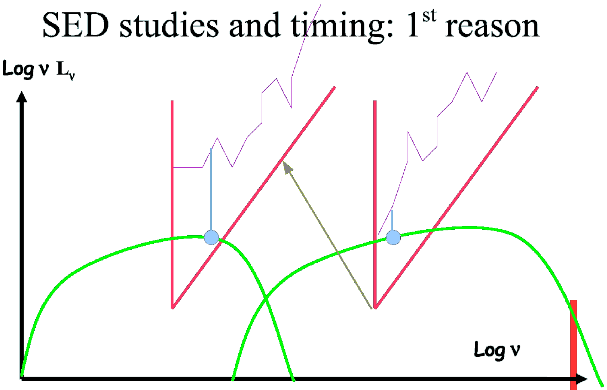
SED studies and timing: 1st reason

Multiwavelength Studies: Compiling SEDs,
aiming for an understanding mechanisms and measure parameters.

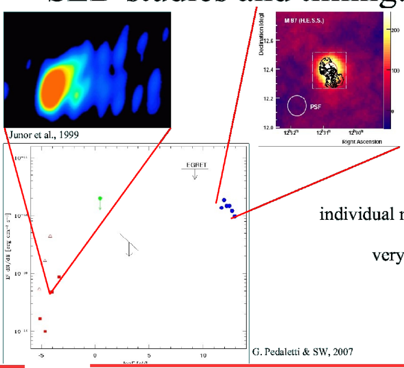
however,
1) individual measurements in SEDs are taken at specific times



SED studies and timing: 1st reason

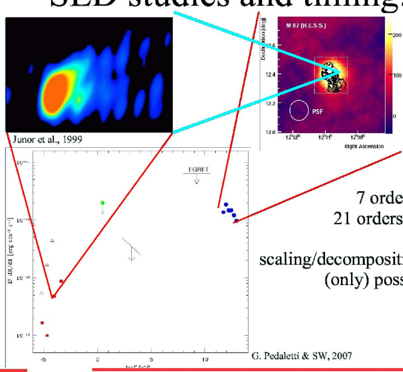


SED studies and timing: 2nd reason



individual measurements in SEDs
are integrated over
very different spatial scales

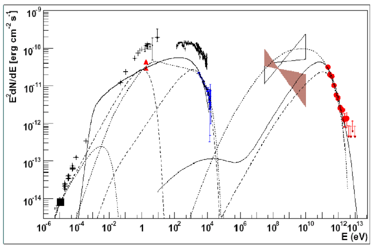
SED studies and timing: 2nd reason



7 orders of magnitude (linear)
21 orders of magnitude (volume)

scaling/decomposition/cross-identification
(only) possible through variability

SED studies and timing: 3rd reason



Aharonian et al. (HESS collaboration, 2006)

simultaneous (single epoch) SEDs do not provide a unique constraint for models of acceleration and radiative processes.
(It has not been demonstrated, but there is hope that time-resolved multifrequency studies will provide unique constraints.)

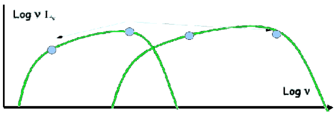
General motivation

Seaking correlations to identify sources
(when known coincidences are insufficient)

1960s finding radio sources: "3C273B = ... "
1970s finding X-ray sources: "Ariel ... = PKS 2155-304"
1990 finding Gamma-ray sources: 3C66A, PKS 1406-076
2000s finding TeV sources (see Elina Lindfors)

Finding sources in the sky;
localizing subvolumes in the sources (in space and time);
localizing subvolumes in parameter space (B, n, γ);
identify and understand processes (qualitative relations between bands)

Review:



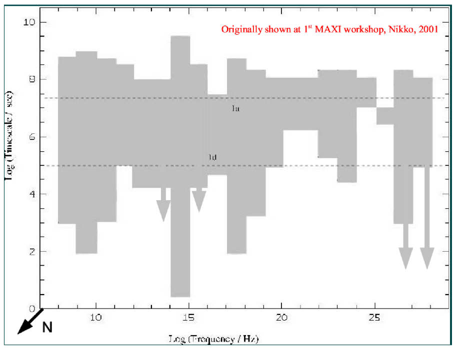
Within synchrotron band: Radio-Optical Correlations
Lunar Occultations (e.g. Dent)
Flares (e.g. van der Laan)
Outburst and VLBI components (Babadzhanyants)
Polarisation characteristics (Kikuchi)
but: IDV (SW and Quirrenbach)
relation to X-ray bands (e.g. Urry; Brinkmann; Courvoisier; Edelson)

Within HE bump: 3C279 (Wehrle)

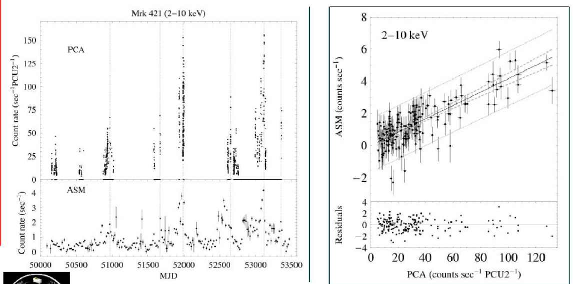
Synchrotron – HE bump: several in 1980s (without mentioning)
involving gamma-rays (1406-076; Mkn 421: Takahashi & SW)

but several counter-examples ("orphan" events); poor coverage in energy

Parameter Space



Long, continuous light-curves

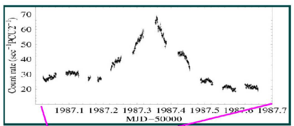


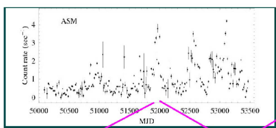
uninterrupted, unbiased, but coarse binning, few sources

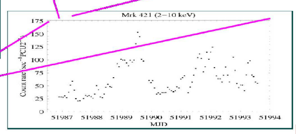
D. Emmanoulopoulos & SW (2008)

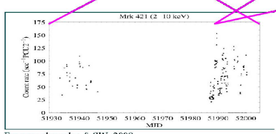
Self-similar structures?

Mrk 421, XTE (2-10 keV)









factors of 30: 3000d to 3h

D. Emmanoulopoulos & SW, 2008

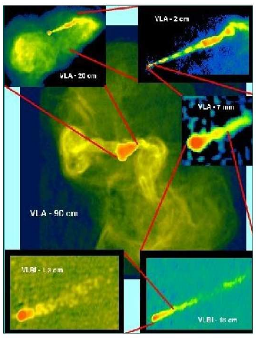
Spatial and temporal scales

Temporal scales:
Mrk 421, X-rays: 100 s - 10 Msec
3C345, optical: 300 s - 1 Gsec

Spatial scales:
M87, radio (GHz): 10 mpc - 100 kpc

self-similar structures

self-similar flares
(power-law PDS)



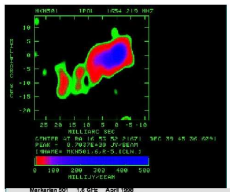
Small scales

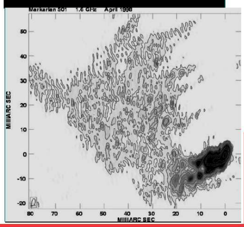
Variability as a tool to small spatial scales
Fast flares extend resolution to very compapct regions.
Strongly structured jets
(Single blobs in VLBI resulting from limited dynamic range).

Mrk 501 shows many small clouds.

If the self-similarity extends to smaller spatial scales, small clouds might refer to fast flares.

Extreme examples from IDV and VHE.

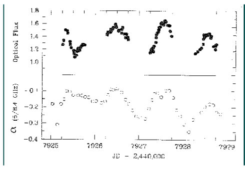




Giovannini et al., 2000

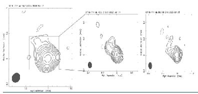
Small scales: Intraday Variability

Intraday variability (IDV)
S5 0716+714 (z~0.3)
Radio (5, 8.4 GHz) and optical (650 nm)
variations on timescales ~ 100 ksec



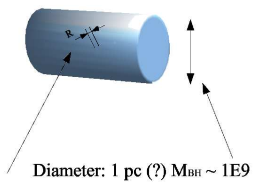
Wagner et al., 1994

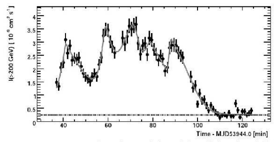
implied linear dimensions:
500 times smaller than (resolved) vlbi knots,
100 times smaller than unresolved vlbi core
(assumed to be self-absorbed).
Variable subvolume one million times smaller
than any resolved structures
(radiation density 100 000 times larger)



Krichbaum et al., 2001

Just how small can they be?





Aharonian et al. (H.E.S.S. collaboration, 2007)

PKS 2155-304 (flare in 2006)
time-scale 60 sec ... 300 sec
linear scale from causality

Diameter: 1 pc (?) M_{BH} ~ 1E9
Emitting volume: $R\mathcal{D}$ < 4.6E12 cm
Cross-section of emitting volume: $\mathcal{D}^2$ E-11 A (A= cross-section of jet)

[Inferences in both cases: $\mathcal{D}$ might be as high as 100]

Filling factors and duty cycles

Subvolumes producing 0.1 to 10 times the quiescent flux with individual filling factors E-10...E-15 should result in large numbers of such subvolumes blending the integrated light curves.

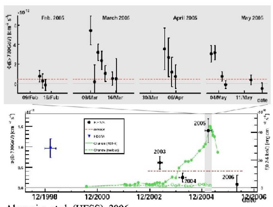
The contrast to observations implies one of three possibilities:

1) Duty cycle is very low
2) Zone of variations extends over small radial range only
3) Distribution function in some crucial parameter very steep (highly nonliner system)

(1) is essential a special case of (3)

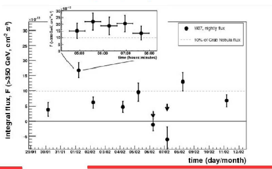
consider (2): Where do Blazars produce their emission?

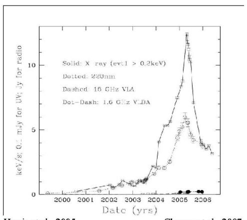
Emission site in M 87



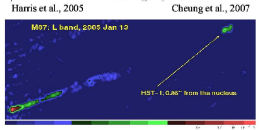
Aharonian et al. (HESS), 2006

Albert et al. (MAGIC), 2008, astro-ph/0806.0988



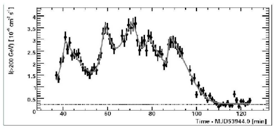


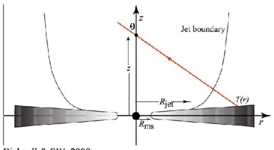
Harris et al., 2005 Cheung et al., 2007



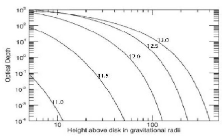
Locating site of PKS 2155-304

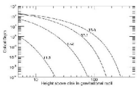
Evidence from spectral monitoring: Non-detection of spectral changes during bright VHE flare (Costamante et al., 2008) implies minimum distance > 100 Rg





Bicknell & SW, 2008

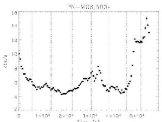


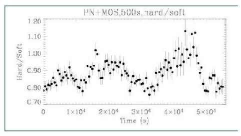


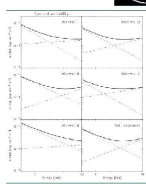
simple worries γ_{min}, γ_{max}, Γ

Almost all SED "fits" of Blazars invoke high γ min.
There are other observations/problems that suggest that this is required.
(e.g. Blundell et al., 2004, Tsang & Kirk, 2007, SW, 1997)
There are very few (no?) acceleration mechanisms achieving this.

Optical and Xray observations can derive those:



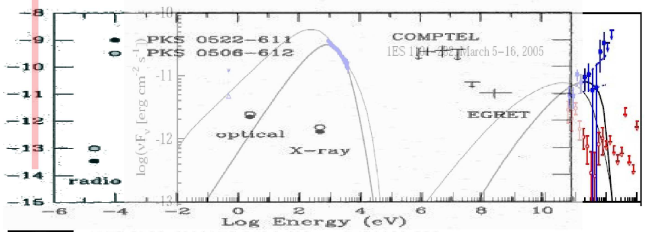




Optical/XMM studies og 0716+714 (Ferrero et al., 2006)

simple worries γ_{min}, γ_{max}, Γ

MeV Blazars (Bloemen et al., 1995), GeV Blazars, TeV Blazars
E(max) in Synchrotron/IC changes by <3/>7 orders of magnitude



PKS 0522-611/PKS 0506-612 vs. 1ES1101-232 (Aharonian et al., HESS, 2007)

simple worries γ_{min}, γ_{max}, Γ

observed SED needs to be corrected for
various excesses (host galaxies, extended emission),
various absorptions (SSA, E, n_H, pair absorption),
redshift, and ... Doppler factor(s).

Notoriously difficult: VLBI vs. variability (IDV, VHE) $\mathcal{D}\sim1...100$
large values possible in exceptional sources (IDV of various kinds)
but difficult for large classes (TeV Blazars). [Remember M87]
... if TeV Blazars they are: PKS 2155-304 200 GeV – ($\mathcal{D}\sim$ 100) > 2 GeV

Radial or lateral stratification, divergent trajectories?
Different parts of the jets (different subvolumes, flares, wavelengths)
may be subject to different Doppler corrections.

Summary

Simultaneous multifrequency monitoring required to compare
oranges (or the right season) to oranges and (hopefully)
break the degeneracy of different acceleration/radiation mechanisms.

Variability across the EM spectrum occurs on a wide range of timescales.
Individual components/flares relate to regions of very different
sizes (but they are not very different otherwise).

Very small filling factors of emissivity. Stratified media.
Single-zone models ought to be self-consistent

Multifrequency observations may also provide localisations

Range of Lorentz factors may be constrained with Maxi observations.

Doppler factors might be diverse and provide the biggest challenge.

The End

Thank you for your attention