Origin of Gamma Radiation from Active Galactic Nuclei

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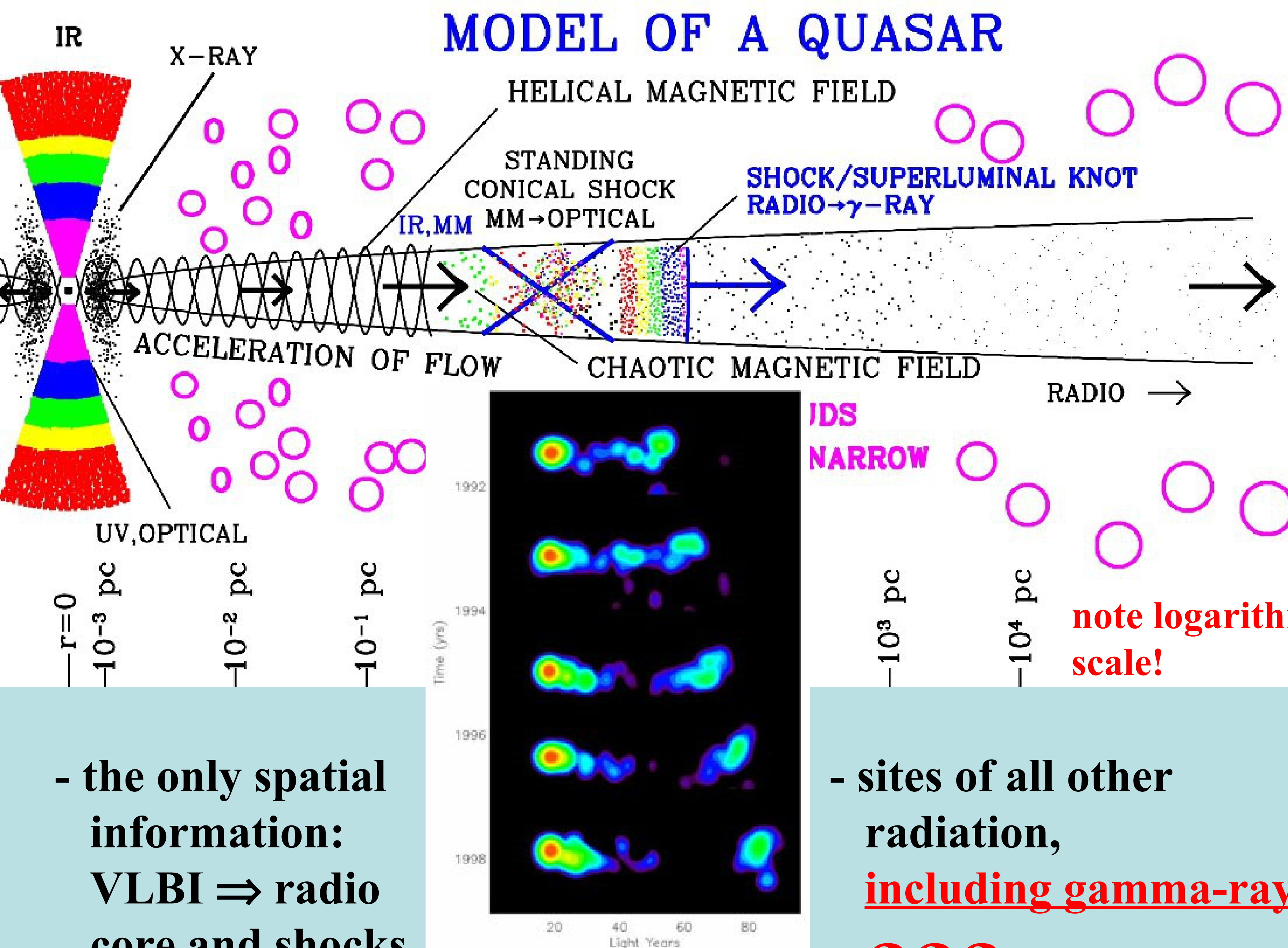


note logarithmic scale!

- the only spatial information: VLBI ⇒ radio core and shocks downstream in the jet

- sites of all other radiation, <u>including gamma-rays</u>

???

EGRET 1991-

What determines the gamma-ray brightness?

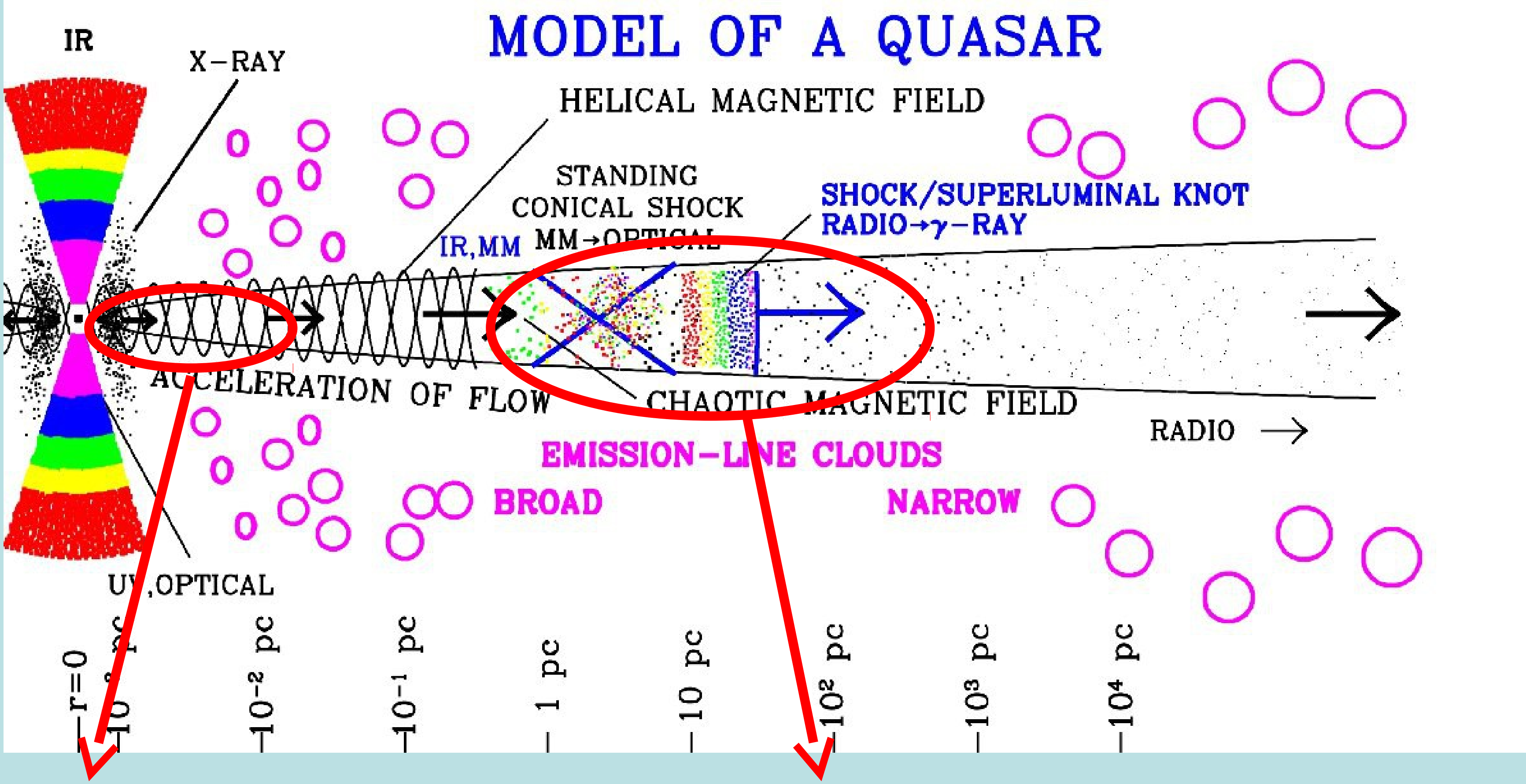
- must have **relativistic jets** (i.e., radio bright)

What mechanisms are responsible?

- inverse Compton ⇒ **relativistic electrons** + **seed photons**

Where in the source do gamma-rays originate?

- **close** to the BH/accretion disk (plenty of photons – but electrons?)
- **distant,** around/downstream of the radio core (plenty of electrons – but photons?)



CLOSE to BH/accretion disk (inside BLR):

-gamma-rays *precede* radio variations (VLBI zero epoch, beginning of a millimeter flare)

-*little or no correlation* with radio variations

DISTANT, at or downstream of the radio core (outside the BLR):

- gamma-rays *simultaneous, or after,* the beginning of radio variations
- *correlation* with radio variations

SPECTRA AND MODELS FOR 3C 279

Hartman et al. 2001

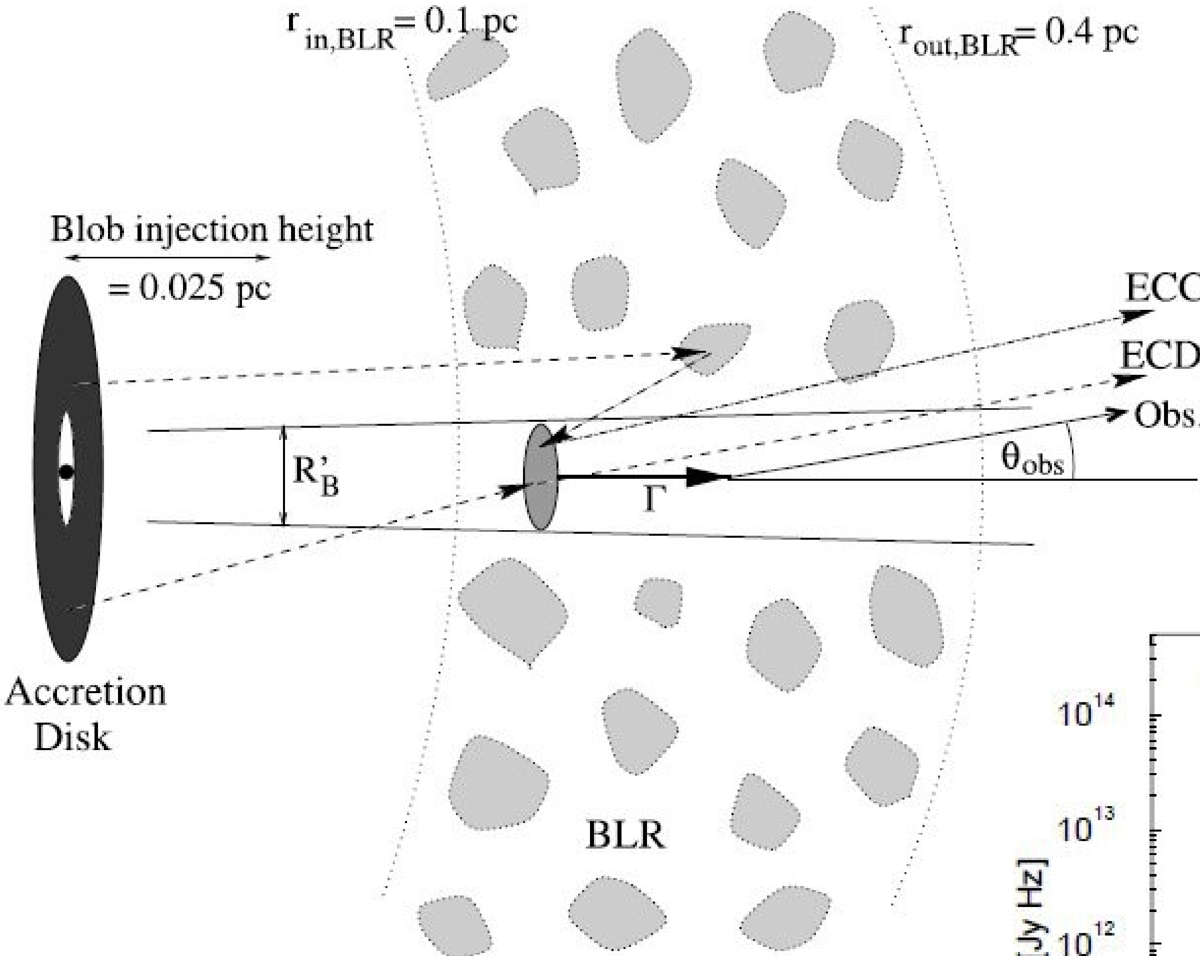
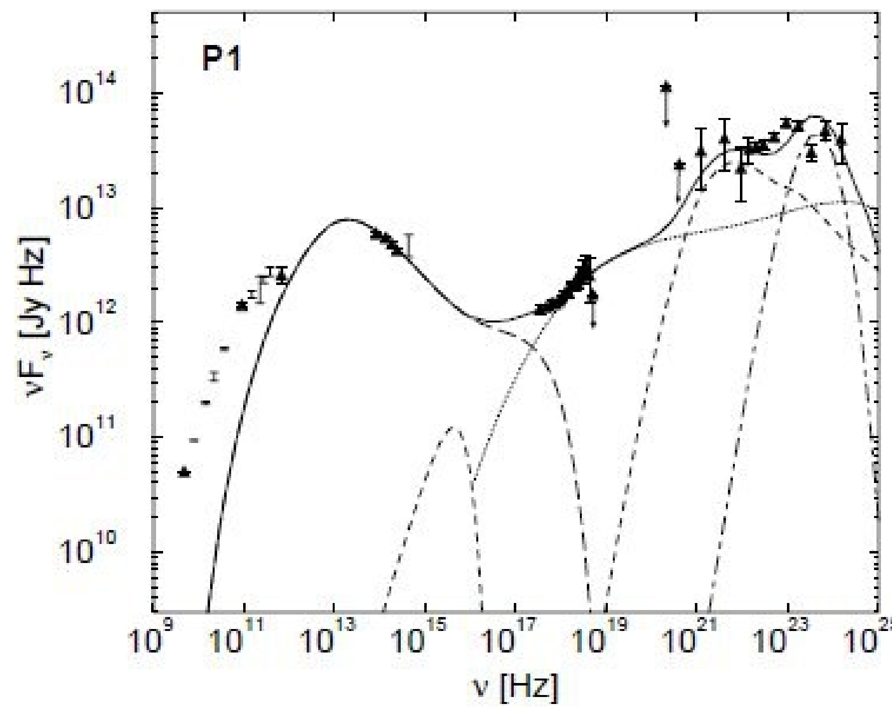


FIG. 3.—Schematic showing the geometric properties of the model

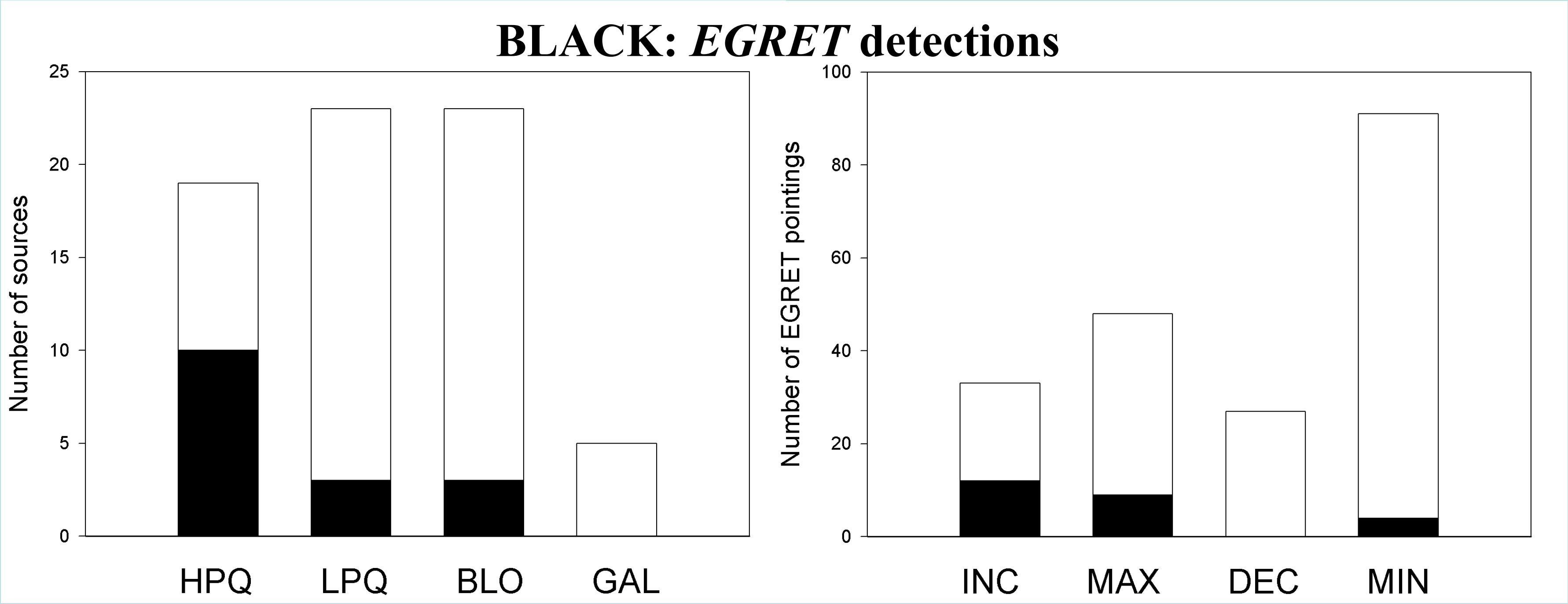


CLOSE!

EGRET: *Valtaoja and Teräsranta 1995, 1996*

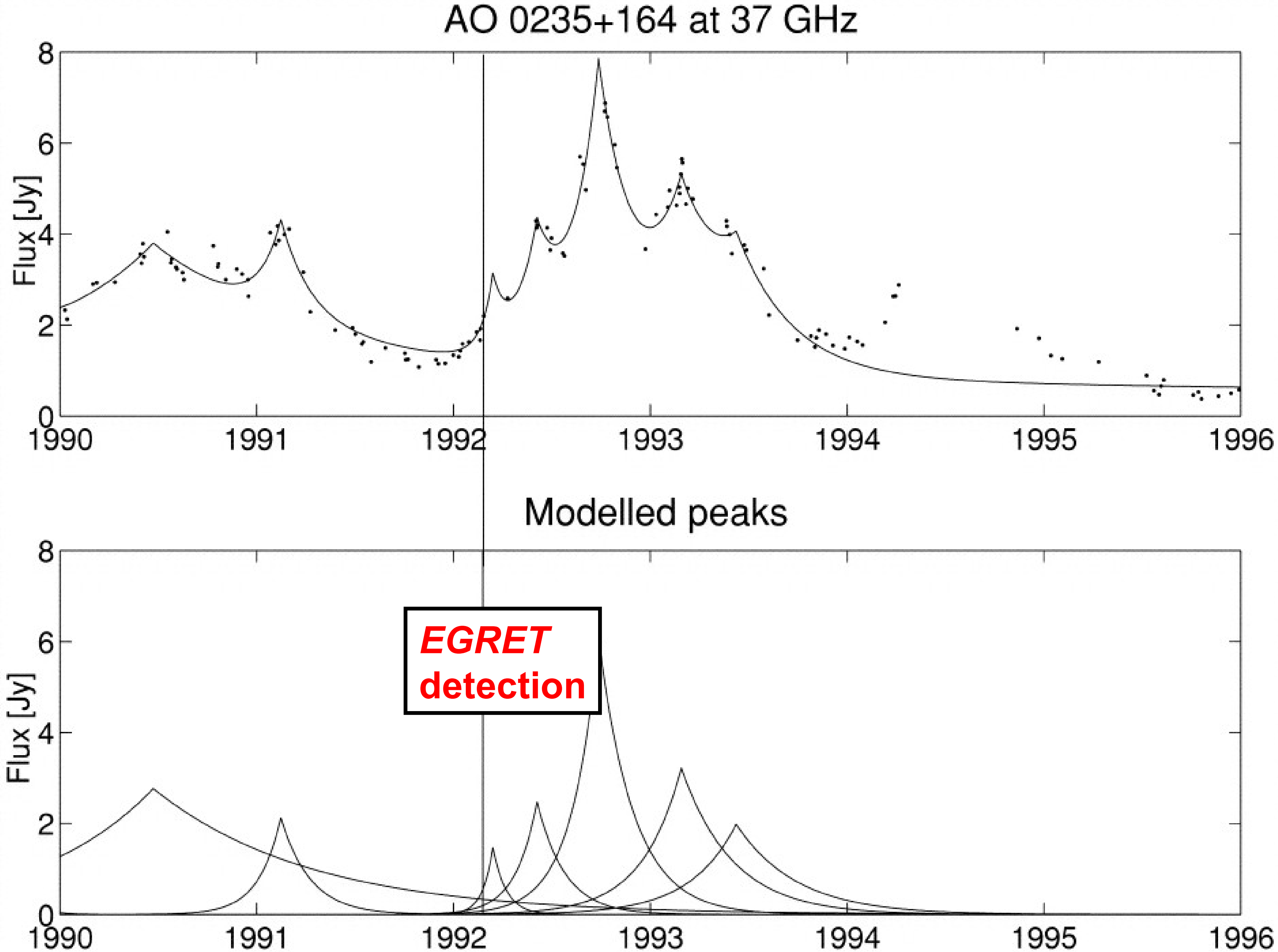
(EGRET Phase 1 all-sky survey, Metsähovi radio sample)

DISTANT!



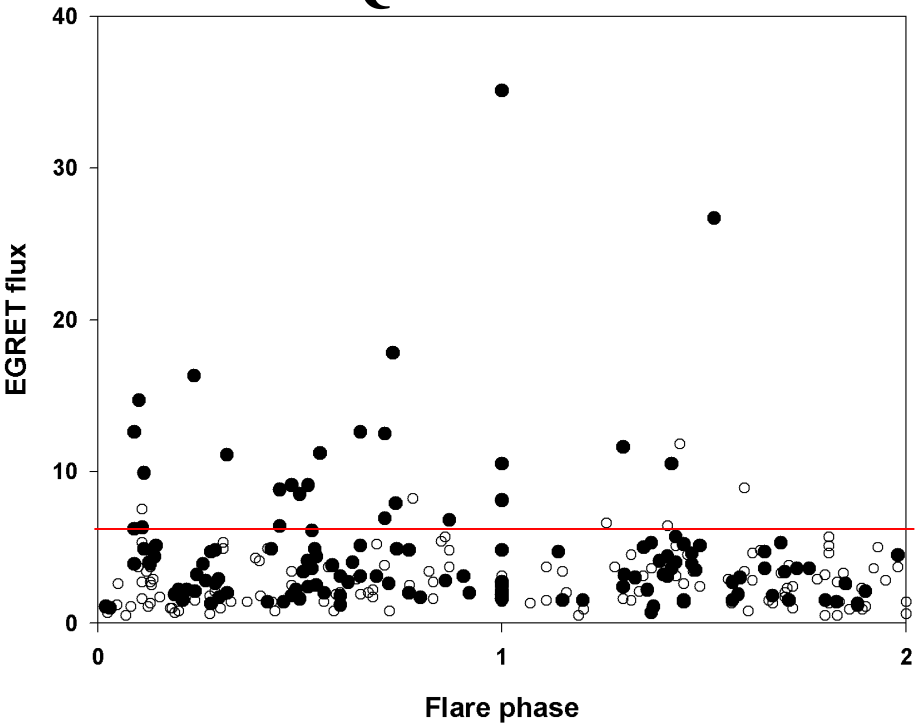
HIGHLY POLARIZED QUASARS ARE STRONGEST GAMMA-RAY EMITTERS

STRONGEST GAMMA-RAYS DURING RISING OR PEAKING MM-FLARES ⇒ FROM SHOCKS

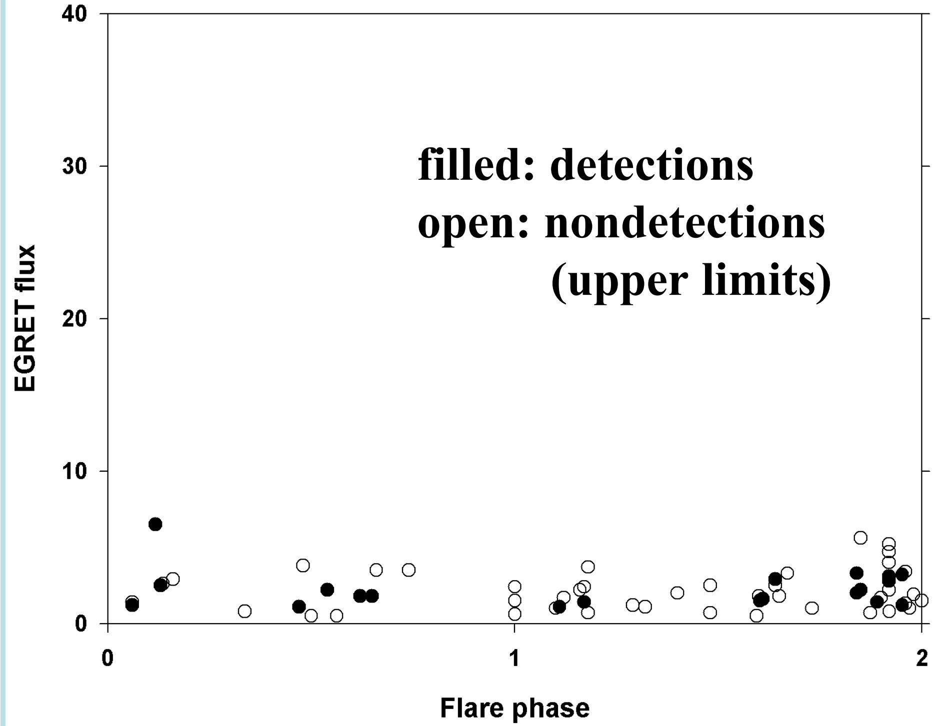

AO 0235+164 at 37 GHz
Flux [Jy]
Modelled peaks
EGRET detection
1990
1991
1992
1993
1994
1995
1996
0
2
4
6
8

EGRET: Lähteenmäki and Valtaoja 2003
(all *EGRET* data, Metsähovi sample)

Quasars



BL Lacs



- STRONGEST GAMMA-RAY EMISSION DURING FLARE RISE/PEAK ⇒ <u>SHOCKS</u>
- BL LACS MUCH WEAKER GAMMA-RAY EMITTERS
- STRONG/WEAK EMISSION (HPQ/BLLAC?) TWO DIFFERENT MECHANISMS?

average: gamma 2 months after the beginning of the radio flare = Jorstad et al. (VLBI) 2001

Lindfors et al. (2005, 2006)

3C 279

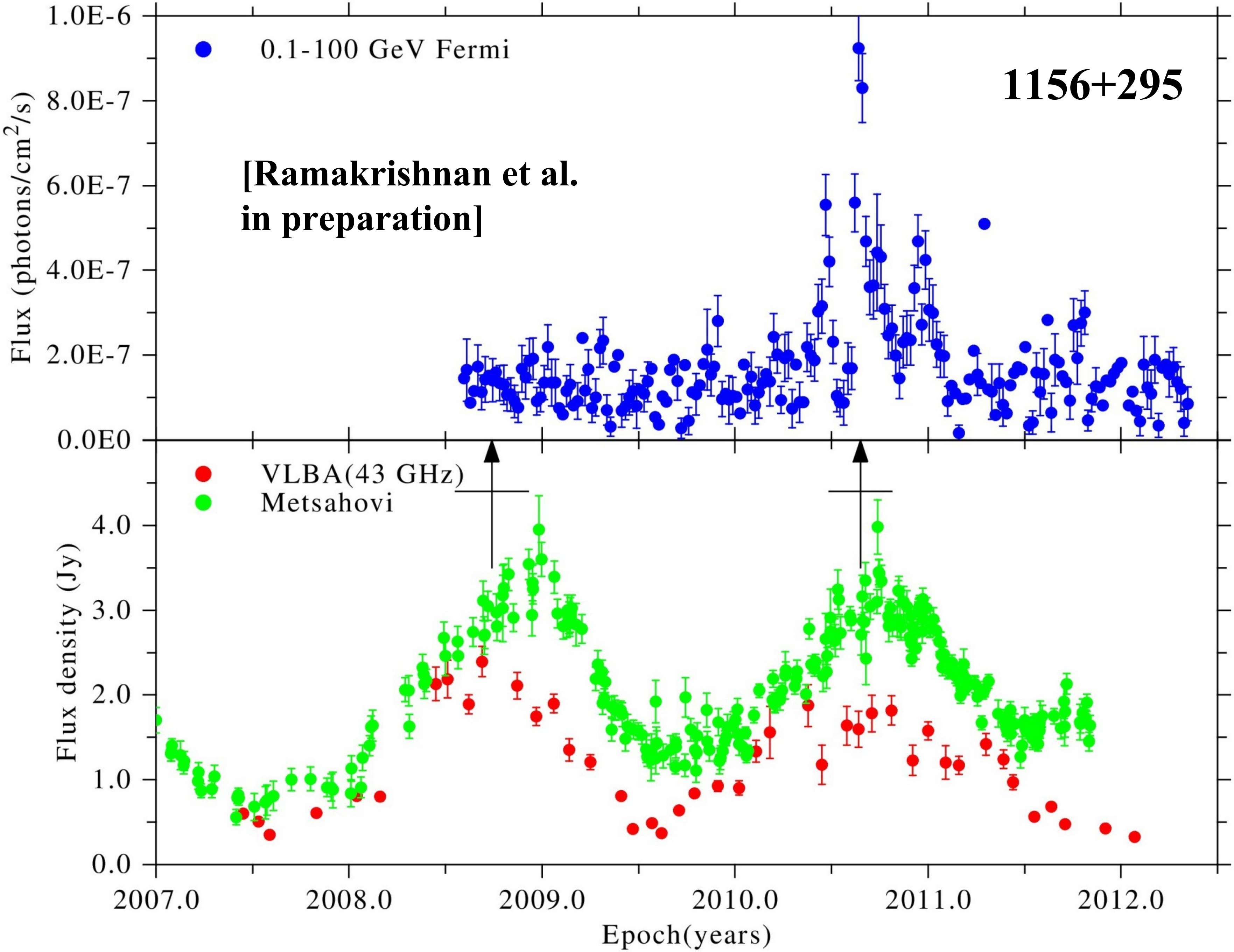
The longer the interval from the onset of the radio flare to the gamma-ray flare (=the distance from the radio core to the site of γ emission downstream), the weaker the gamma

Table 3: The EGRET epochs ordered by increasing Δt_{obs} [years], the time interval since the start of the last outburst as derived here. This order is compared to the gamma-ray state adopted from Hartman et al. (2001). Also an estimate of the distance, L, of these shock components from the apex of the jet is given (see text).

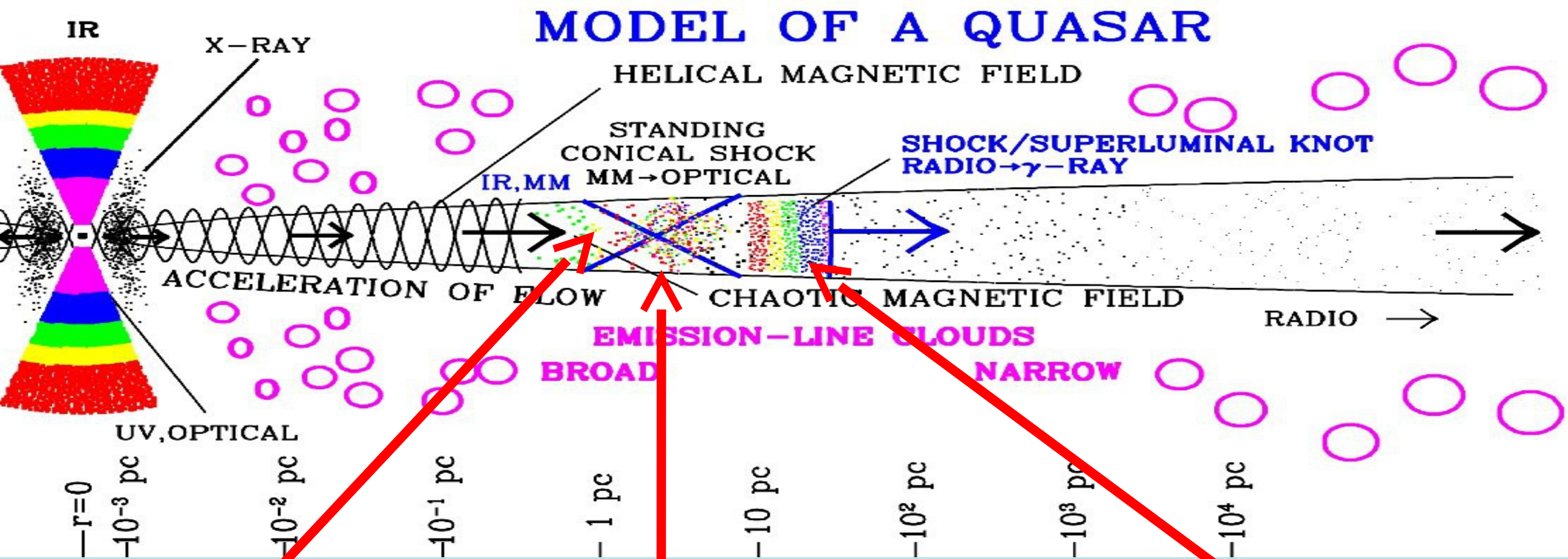
Epoch	Shock No.	Δt_{obs}	gamma-ray state	L [pc]
P5b (1996.092)	10	0.006	very large flare	0.12
P8 (1999.070)	15	0.195	high	3.88
P5a (1996.063)	9	0.206	high	4.10
P1 (1991.47)	3	0.225	high	4.48
P3a (1993.858)	6	0.288	moderate	5.74
P6b (1997.470)	12	0.328	moderate	6.53
P3b (1993.979)	6	0.409	moderate	8.15
P2 (1993.004)	4	0.49	low	9.76
P6a (1997.010)	10	0.924	low	18.41
P4 (1994.970)	7	0.99	low	19.72

2008-

- *Fermi*: wealth of γ-ray data, monitoring
- case for "distant" γ origin is much stronger
  - no direct observational evidence for "close" origin
  - all observations point towards "distant" origin:
    radio-gamma correlations, delays from radio to γ
- case for several "distant" γ sites is strong
  - gamma-rays from upstream, at, and downstream
    of the radio core as a disturbance propagates
    along the jet



0.1-100 GeV Fermi
1156+295
[Ramakrishnan et al.
in preparation]
Flux (photons/cm^2/s)
1.0E-6
8.0E-7
6.0E-7
4.0E-7
2.0E-7
0.0E0
VLBA(43 GHz)
Metsahovi
Flux density (Jy)
4.0
3.0
2.0
1.0
0.0
2007.0
2008.0
2009.0
2010.0
2011.0
2012.0
Epoch(years)



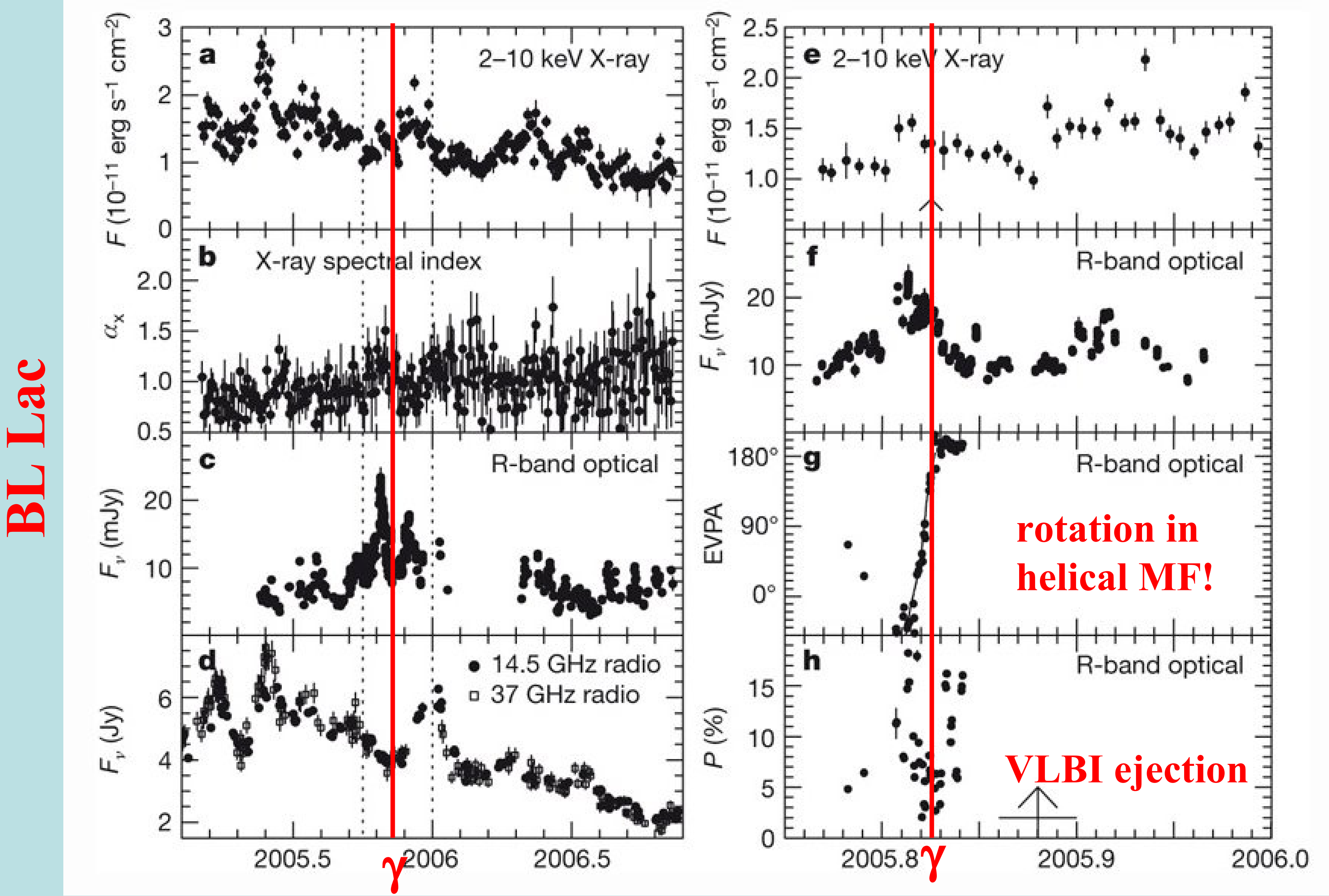
BL Lac: slightly upstream of the radio core (Marscher et al. 2008)

1510-089: similar case (Marscher et al. 2010)

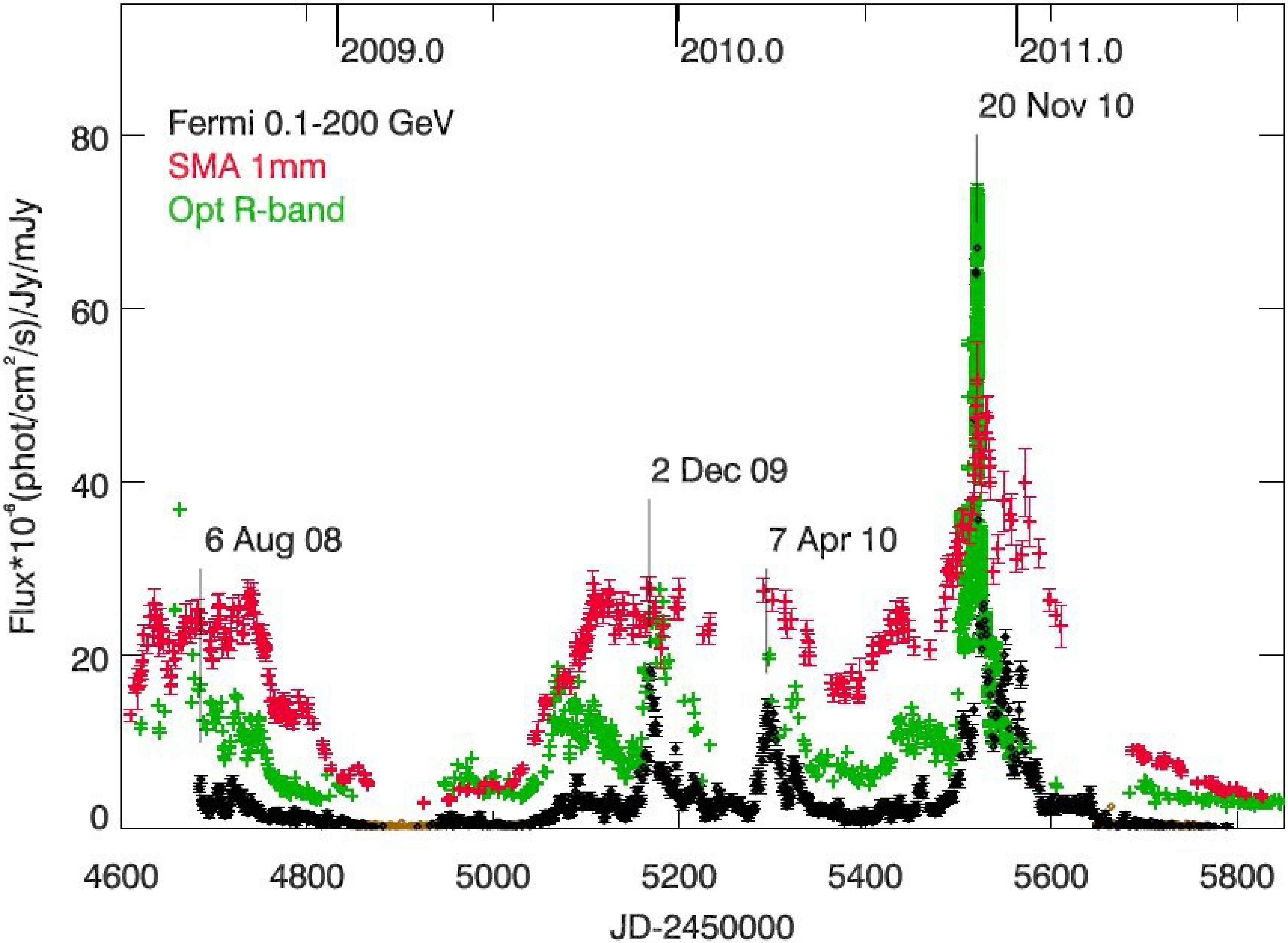
around the RC:
- **in 2/3 of 34 γ-AGN (Marscher et al. 2012)**
- **3C345 (Jorstad et al. 2012)**
- **3C454.3 (Jorstad et al. 2010)**
- **AO 0235+164 (Agudo et al. 2011)**
- **3C279 (Abdo et al. 2010)**
- **etc...**

OJ 287: 14 pc downstream the RC (Agudo et al. 2011)

3C 345: up to 40 pc down-stream (Schinzel et al. 2010)

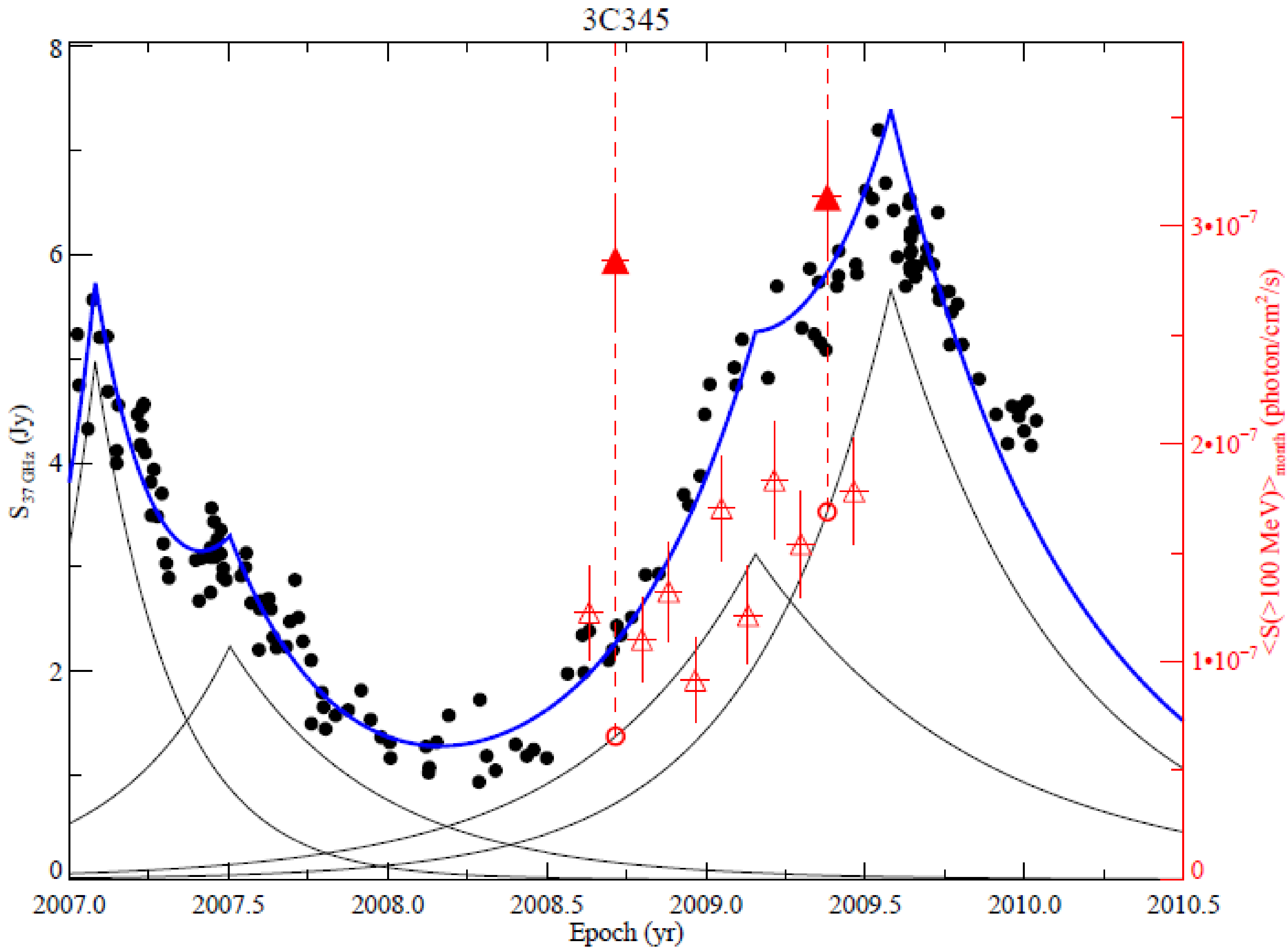


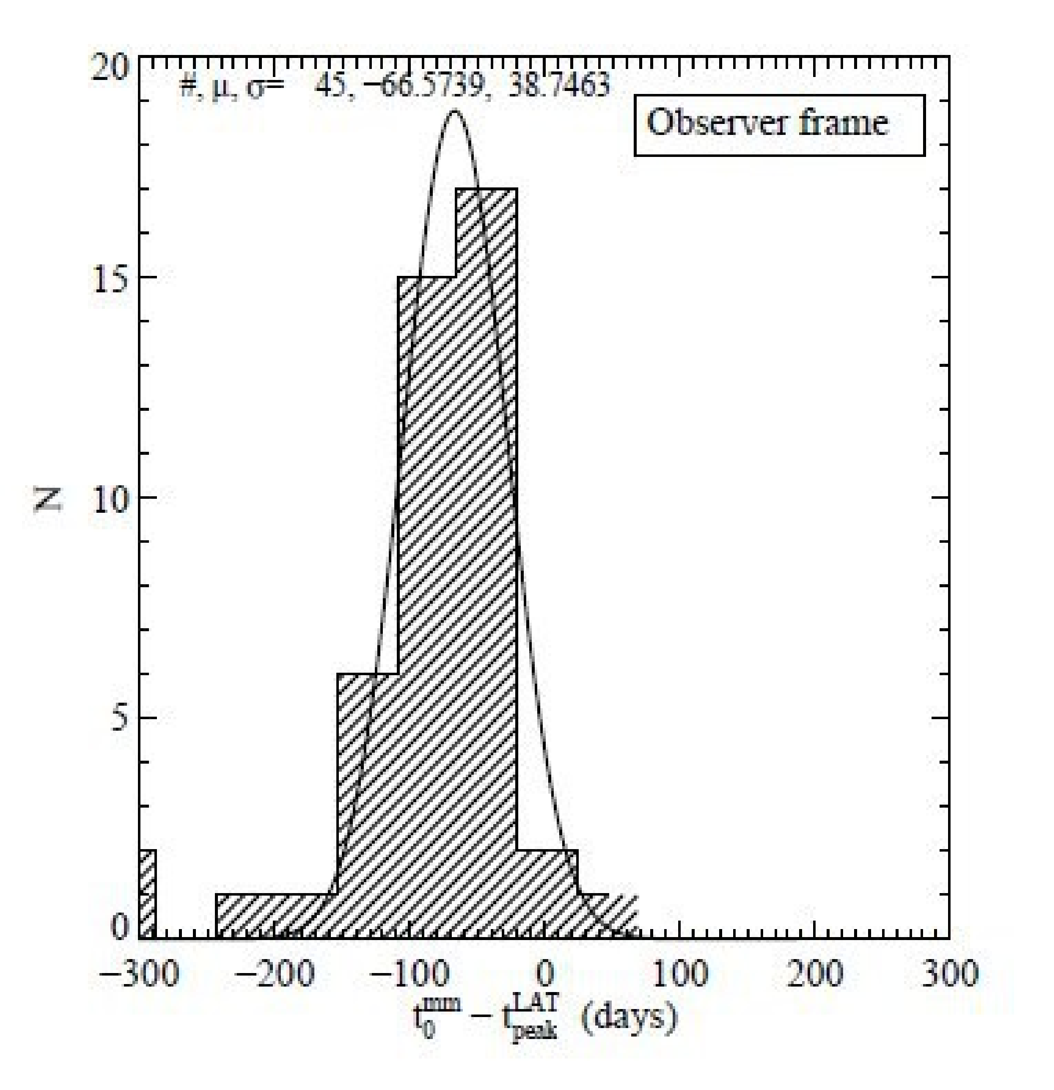
Marscher at al. 2008: gamma flare at the end of an optical rotation ⇒ beginning of mm-flare, VLBI ejection epoch



Jorstad et al 2012: optical, 1 mm, gamma peak within one day from each other

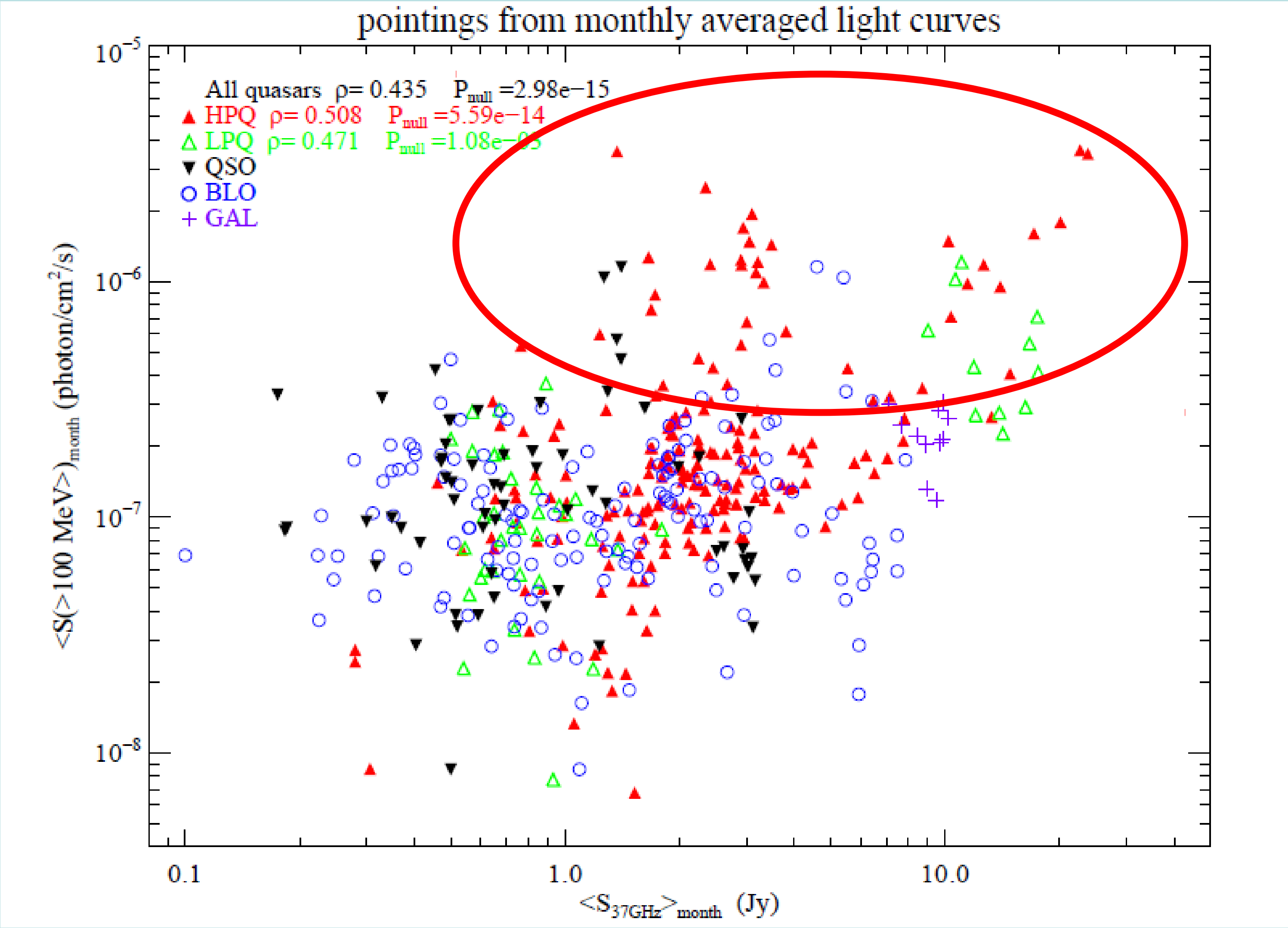
Léon-Tavares et al. (2011): monthly γ vs. radio flares





Léon-Tavares et al. 2011: average delay from the onset of a mm-flare to γ-flare peak ~ 70 days (= Lähteenmäki & Valtaoja 2003; Jorstad 2001)

QUASARS: CORRELATION FOR MONTHLY AVERAGES (Léon-Tavares et al. 2011)



The strongest γ flares from HPQ, BL Lacs weaker, no r/γ correlation?

<u>Marscher 2012</u>: ”The evidence is therefore clear that most (but not all) of γ-ray flares occur near or in the mm-wave core. The challenge is then to create a model within this context that is capable of reproducing the observed characteristics of the multi-band variability of blazars”

<u>WE</u>

- **wait for the final *Planck* data to model the syncrotron and IC SEDs with unprecedented accuracy (and four epochs)**
- **cross-correlate all *Fermi* data with Metsähovi + other radio/gamma analysis**
- **develop new, realistic multicomponent models which reproduce MF variations, SEDs and VLBI data**

One possible scenario (Agudo et al. 2012)

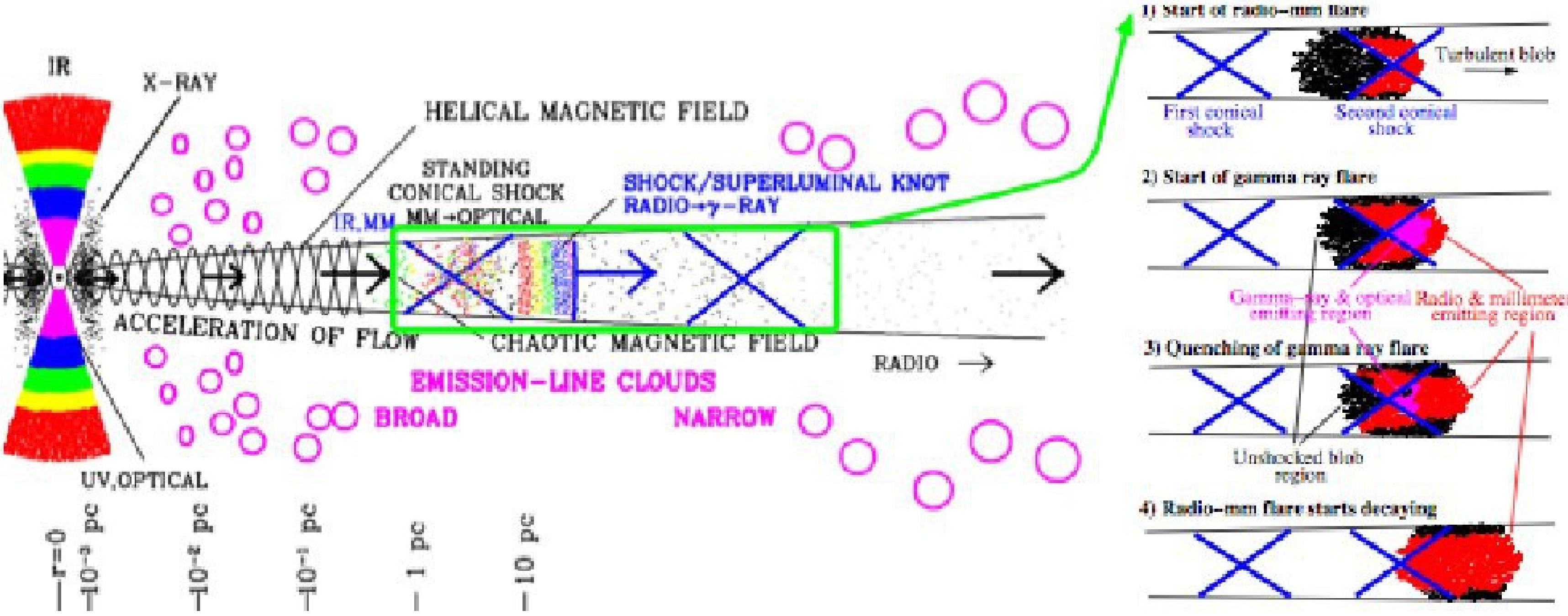


Figure 4. Illustration of the proposed scenario for the multi-spectral-range behavior of OJ287.

<u>Some open questions / challenges</u>:

-difference between quasars and BL Lacs / different γ mechanisms, sites?
-origin of seed photons: SSC, Mach disk, dust torus, "dragged" BLR, ...?
-rapid variability – turbulent multizone models?
-signatures of absorption (e.g. Poutanen)?
-nature of the upstream flow
-jets starting close to the black hole (M87)?