Leptonic jet models for VHE AGN

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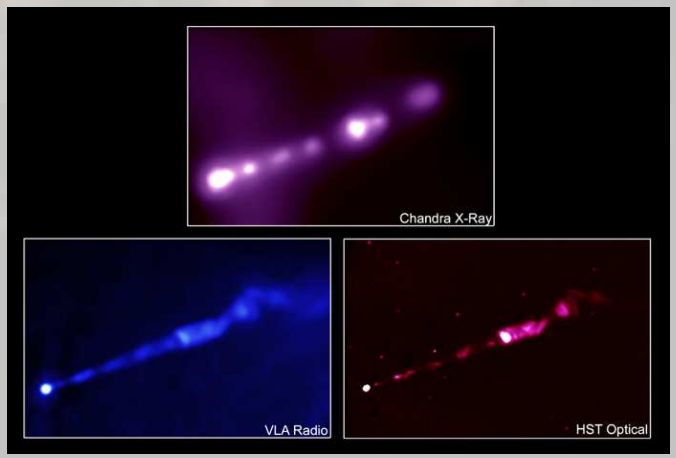
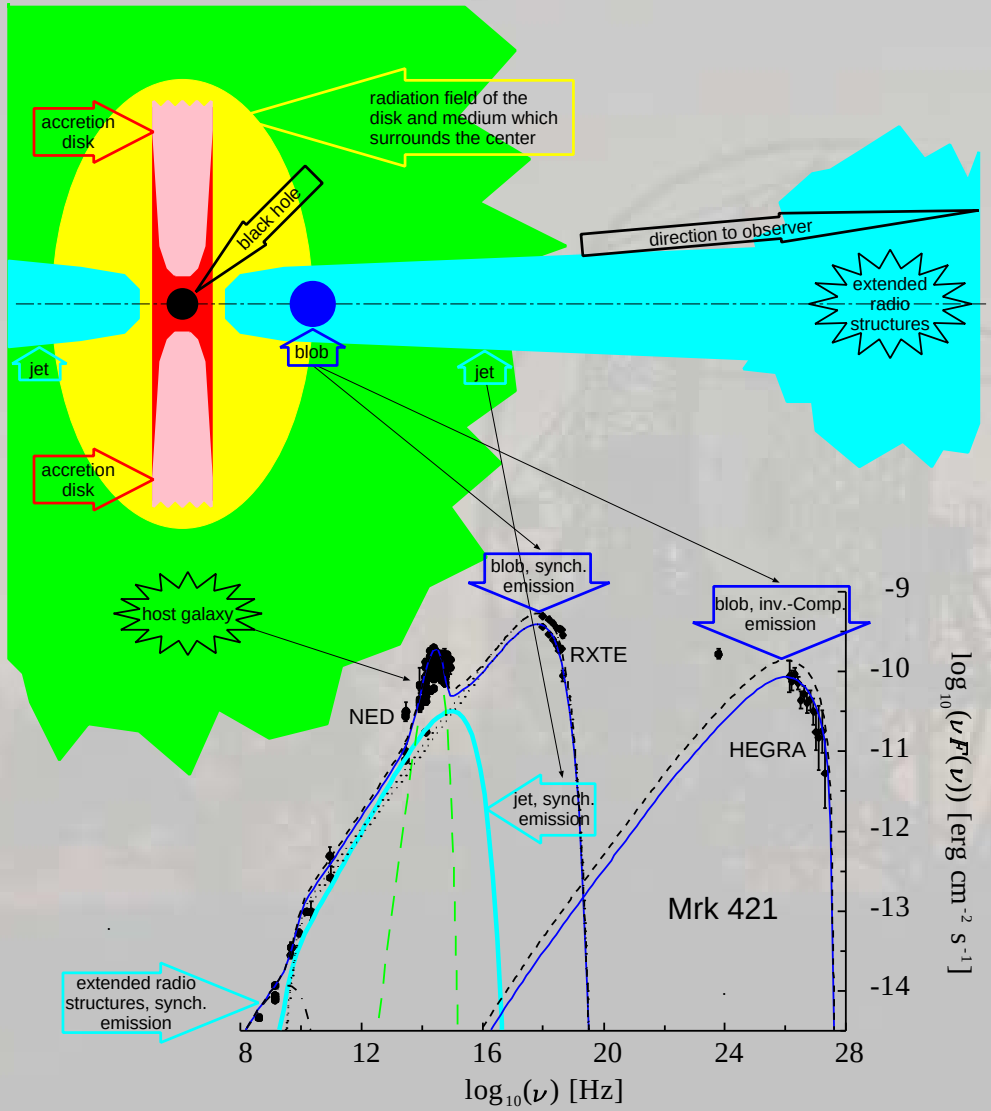


9 December 2008

Outline

1. Some examples of leptonic models
2. A multi-blob SSC model for misaligned blazar-like AGN
3. PKS 2155–304 and dynamic SSC modelling
4. Some short news from the VHE sky

Blazar structure



Caveat:

Different instruments @ different wavelengths, with different angular resolutions

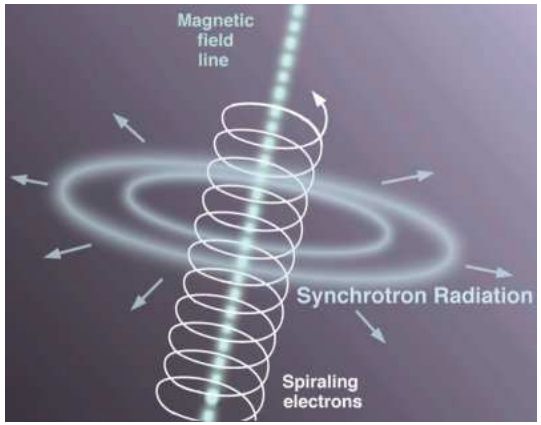
⇒ Broadband SED probe different scales of the central engine !!

Outline

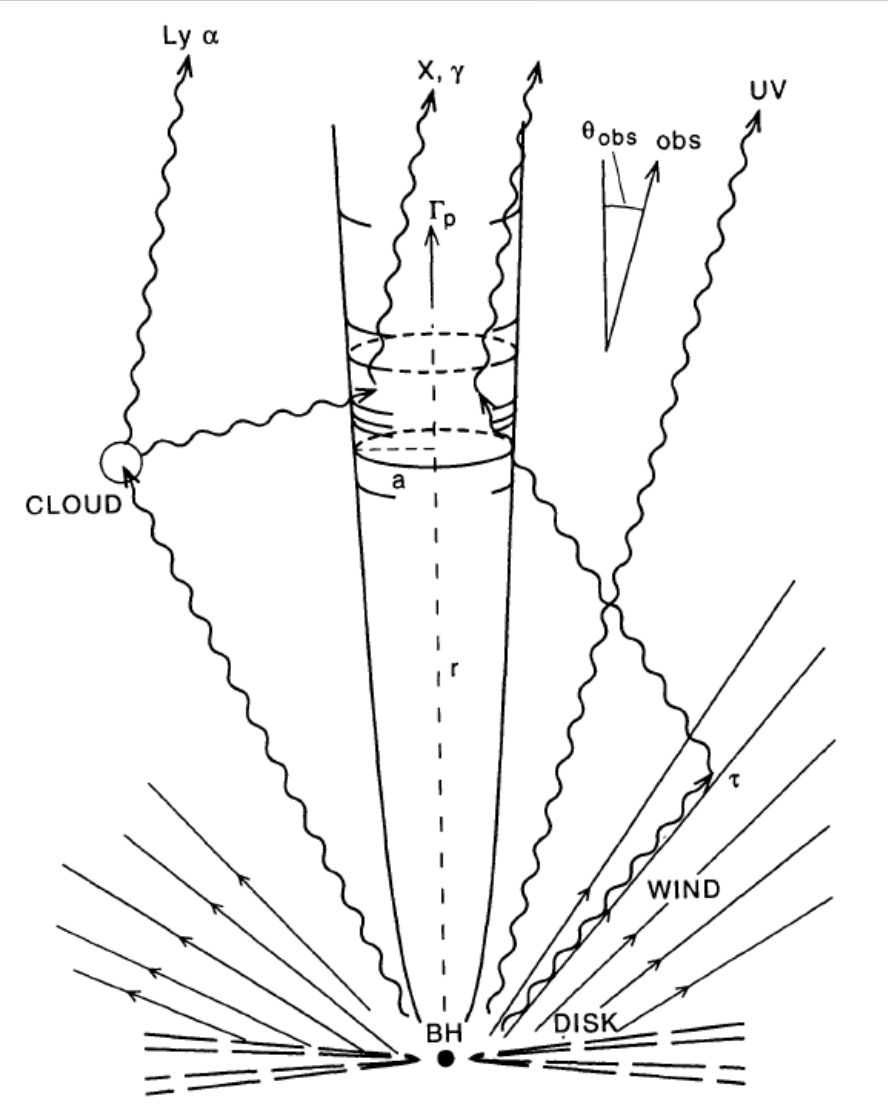
Radiative leptonic models

Different possible processes:

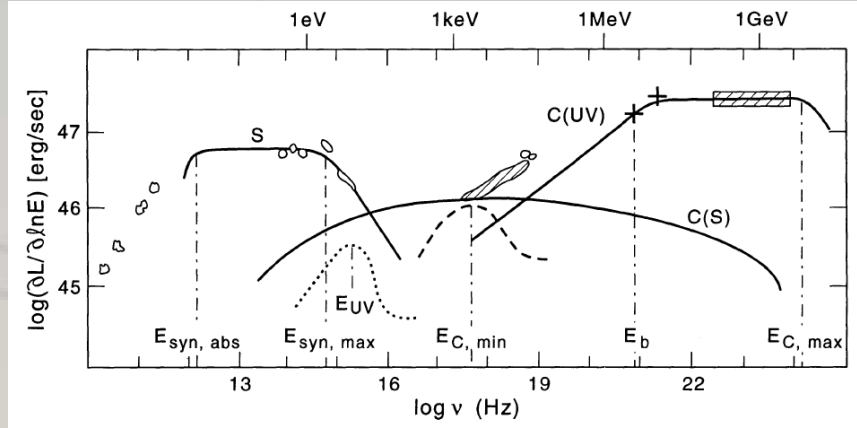
- Synchrotron self-Compton
- External Inverse Compton, on:
  - radiation field from the corona
  - on the star light
  - direct emission from accretion disk
  - accretion disk photons scattering off the BLR
  - CMB
  - ...



EIC models: EIC on BLR scattered photons



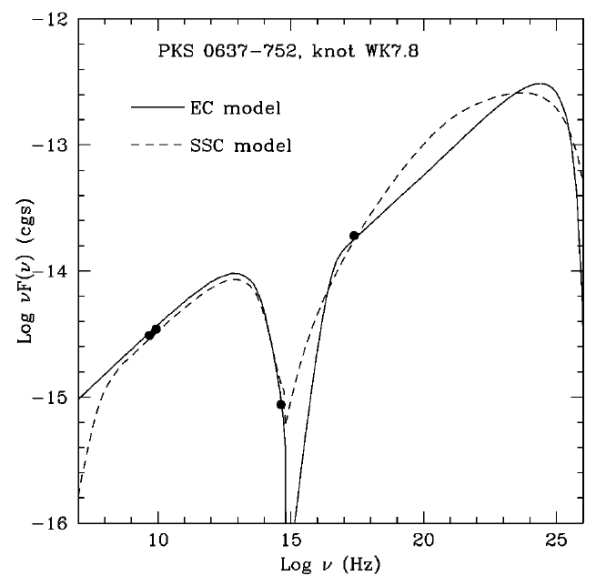
Sikora et al., 1994



Application to 3C 279:

- $\Gamma \sim 20$
- $B \sim 0.5$–1 G
- Distance BLR-source: $r \sim 10^{18}$ cm
- Size of the radiating region: $a \sim 5 \times 10^{16}$ cm

EIC models: EIC on CMB



Tavecchio et al., 2000

Parameters:

EIC in X-ray and γ-rays.

- $\delta \sim 10$
- $R \sim 10^{22}$ cm
- $B \sim 10^{-5}$ G

EIC/CMB preferred over SSC from equipartition (between radiating particles and magnetic field) argument, but very poor observational constraints on 2$^{\text{nd}}$ bump.

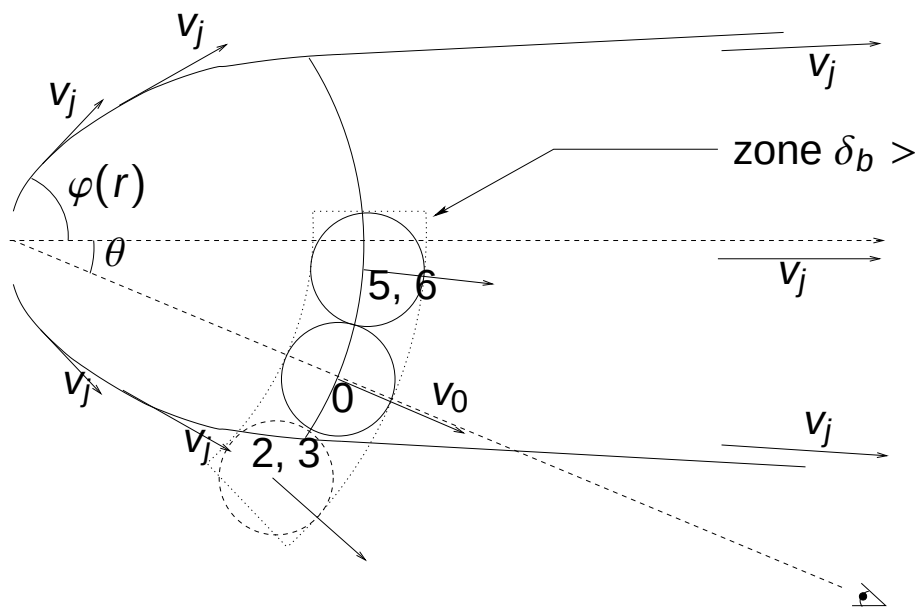
Outline

A multi-blob SSC model for misaligned blazar-like AGN

- "Blazar-like" effect before collimation of the jet.
- 7 blobs on a 3D cap (blob size may be $< r_S$).
- Blobs at $\sim 100 r_g$ (i.e. at $\sim 2.2 \times 10^{-4}$ pc for Cen A) of the SMBH (beyond the Alfvén surface).
- Same electron distribution as for blazars:

$$N_e(\gamma) = \begin{cases} K_1 \gamma^{-n_1} & \gamma_{min} \leqslant \gamma \leqslant \gamma_b \\ K_2 \gamma^{-n_2} & \gamma_b \leqslant \gamma \leqslant \gamma_c \end{cases}$$

- Synchrotron self-Compton process.
- Differential Doppler boosting.

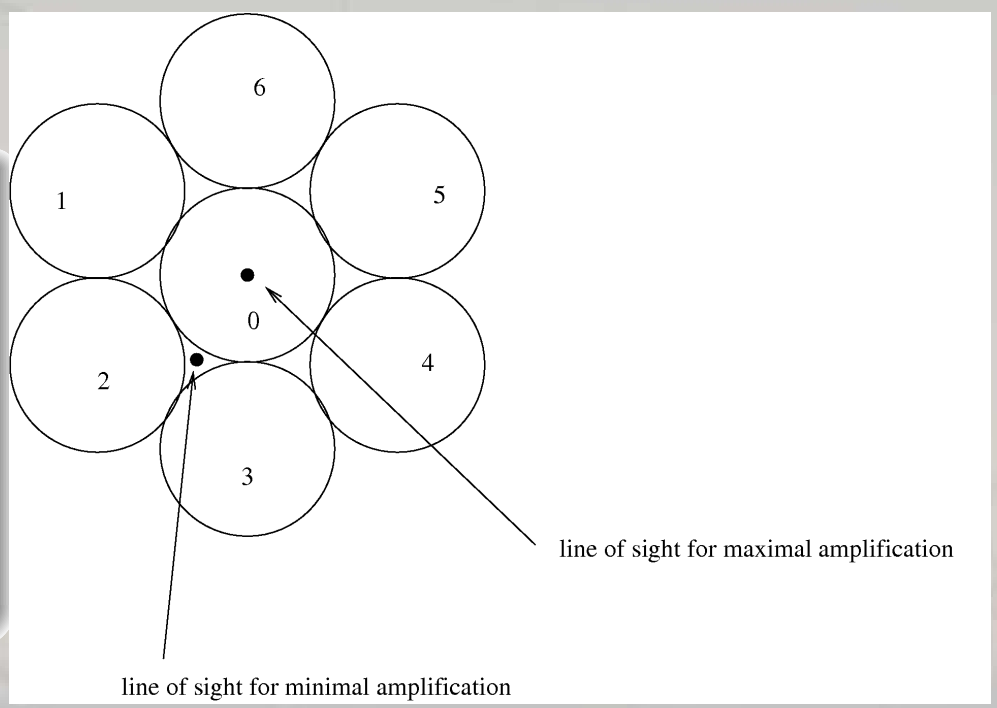


Lenain, Boisson, Sol, Katarzyński, 2008, A&A, 478, 111

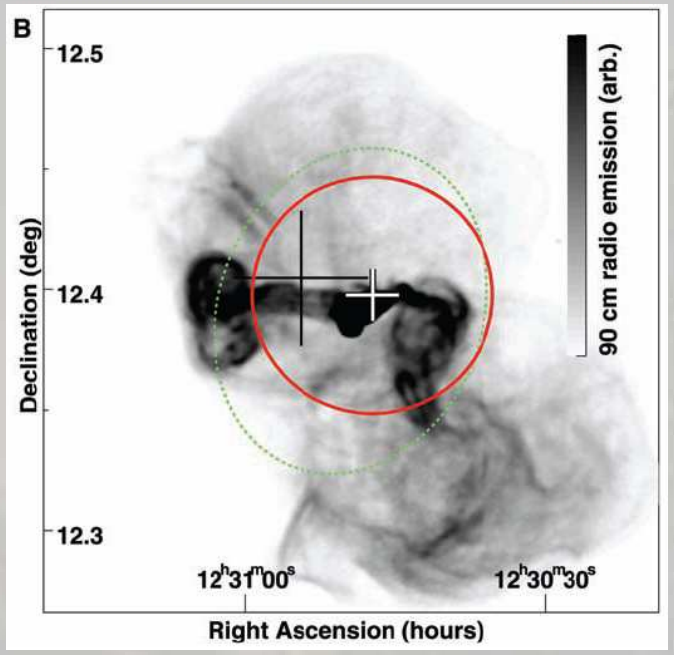
The multi-blob SSC model

2 extreme geometric cases:

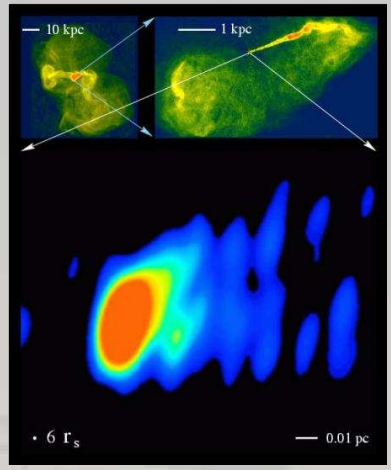
- "Inter-blob": line of sight exactly through the gap between 3 blobs → minimal amplification.
- "On-blob": line of sight exactly aligned with velocity vector of the central blob → maximal amplification.



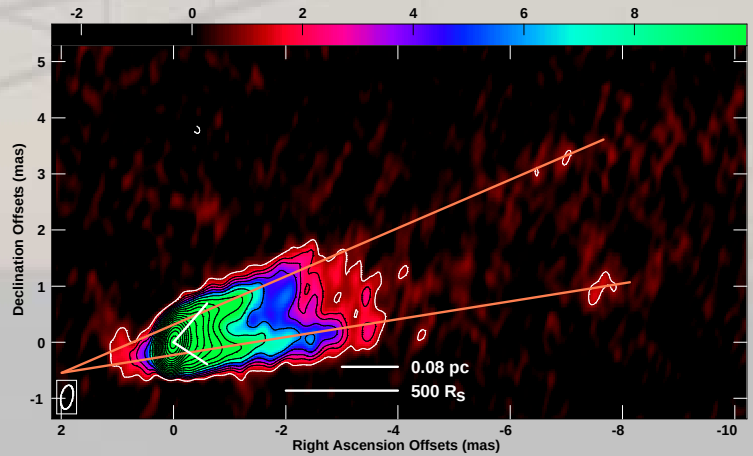
M 87 as a misaligned blazar ?



Aharonian et al., Science, 2006, 314, 1424



Junor et al., Nature, 1999, 401, 891



Ly et al., ApJ, 2007, 660, 200

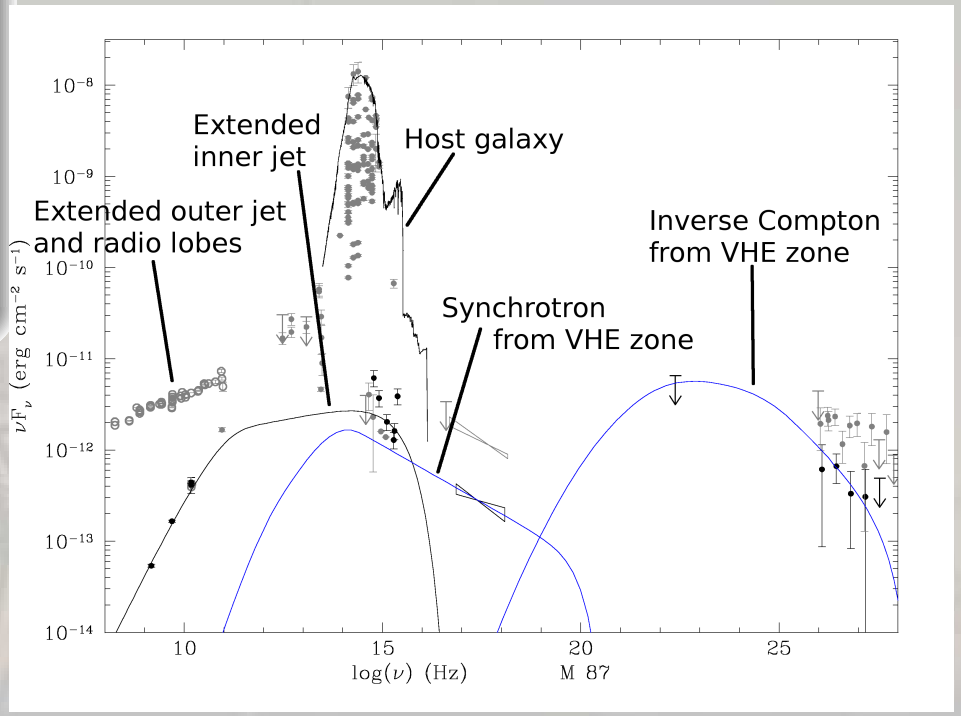
- Between 2003 and 2006: 89hr, 13σ.
- VLBI: broadened jet formation zone, predicted by MHD jet formation models.

Inner jet VLBI observations

Application of the multi-blob SSC model to M 87

- Assumptions:
  - VHE emission comes from the inner jet;
  - both *Chandra* (2000) and H.E.S.S. (2004) are in low state.
- Model: $\Gamma_b \sim 10$ enough $\rightarrow$ in favor of a misaligned blazar object.

Γ_b	10.0
θ	15°
$R_{\rm cap}$	100 r_g
B	0.01 G
r_b	2.8×10^{14} cm
K_1	1.8×10^4 cm^{-3}
n_1	1.5
n_2	3.5
$\gamma_{\rm min}$	10^3
γ_b	10^4
γ_c	10^7

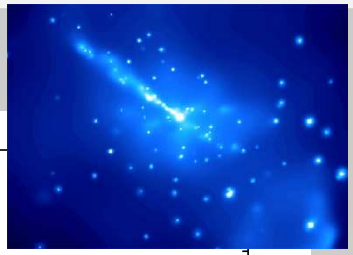


Lenain, Boisson, Sol, Katarzyński, 2008, A&A, 478, 111

Prediction on the nuclear flux expected from Cen A with the multi-blob SSC model

X/soft γ = inverse Compton

Γ_b	8.14
θ	25°
$R_{\rm cap}$	100 r_g
B	2 G
r_b	10^{14} cm
K_1	9×10^7 cm^{-3}
n_1	2.0
n_2	3.0
$\gamma_{\rm min}$	3×10^2
γ_b	5×10^2
γ_c	4×10^3

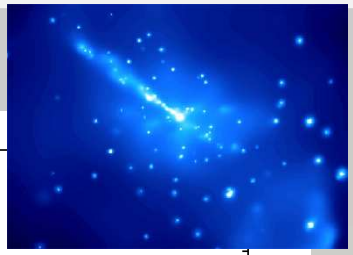


Lenain, Boisson, Sol, Katarzyński, 2008, A&A, 478, 111

Prediction on the nuclear flux expected from Cen A with the multi-blob SSC model

X/soft γ = synchrotron

Γ_b	20.0
θ	25°
$R_{\rm cap}$	100 r_g
B	10 G
r_b	8×10^{13} cm
K_1	4×10^4 cm^{-3}
n_1	2.0
n_2	3.5
$\gamma_{\rm min}$	10^3
γ_b	3.5×10^5
γ_c	6×10^6



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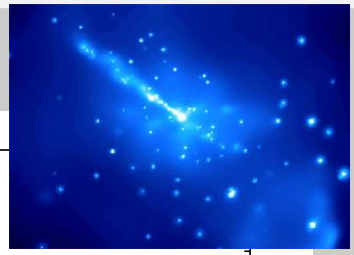
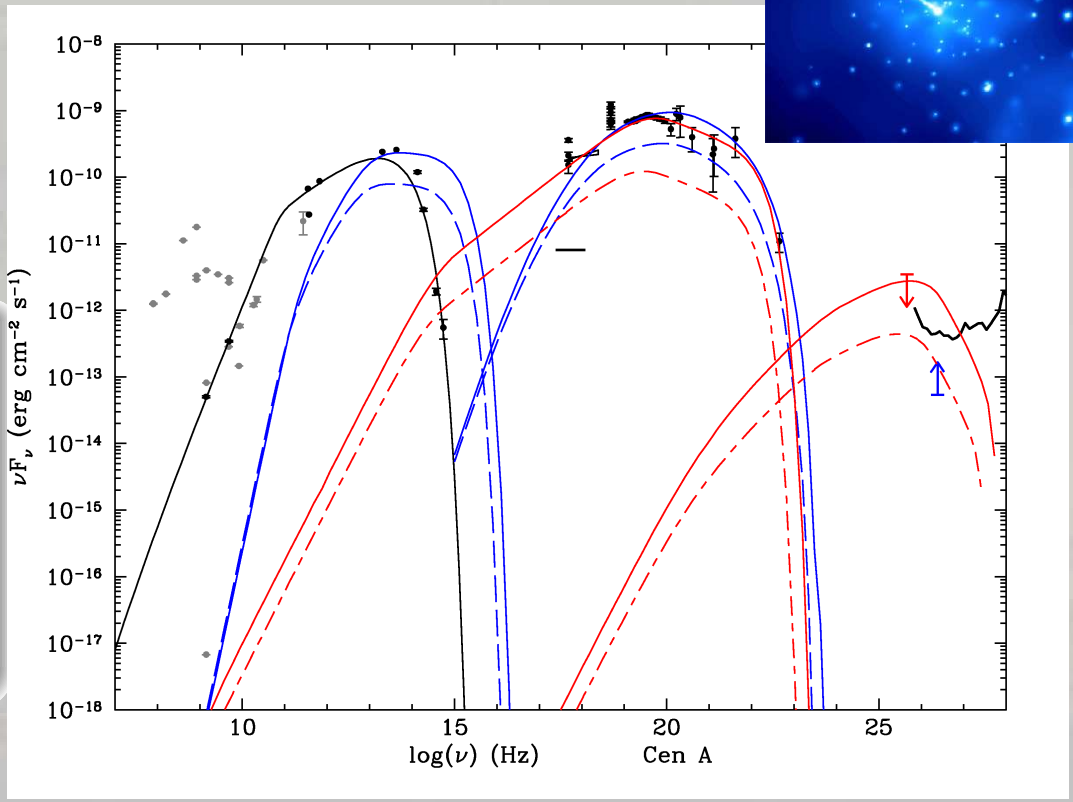
Prediction on the nuclear flux expected from Cen A with the multi-blob SSC model



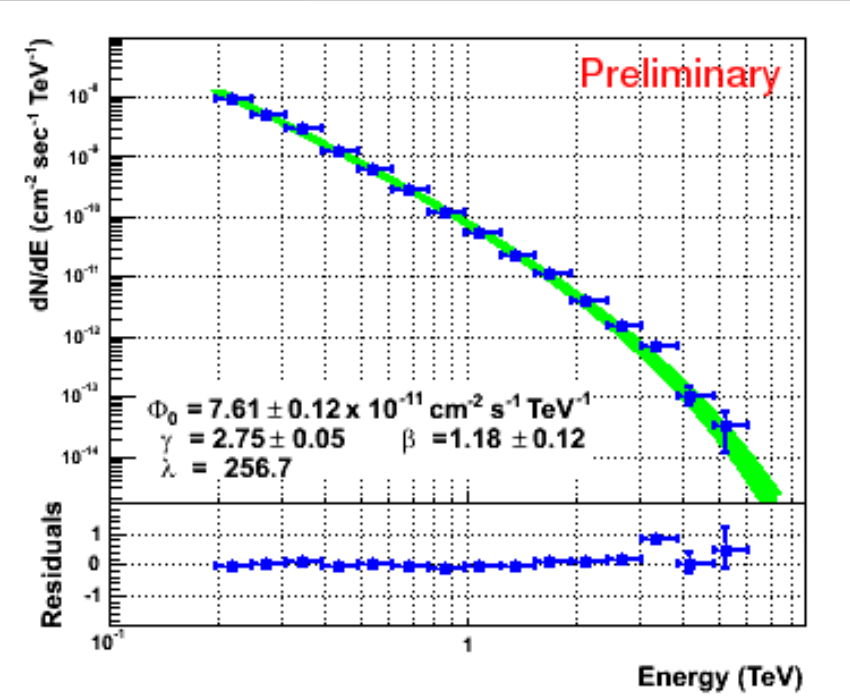
- Nature of the X/soft γ emission not yet clear:
  synchrotron or inverse Compton ?
- If X=synchrotron (cf. Bai & Lee, 2001) then Cen A should be detectable by the current Čerenkov facilities at 5σ within 50 h.

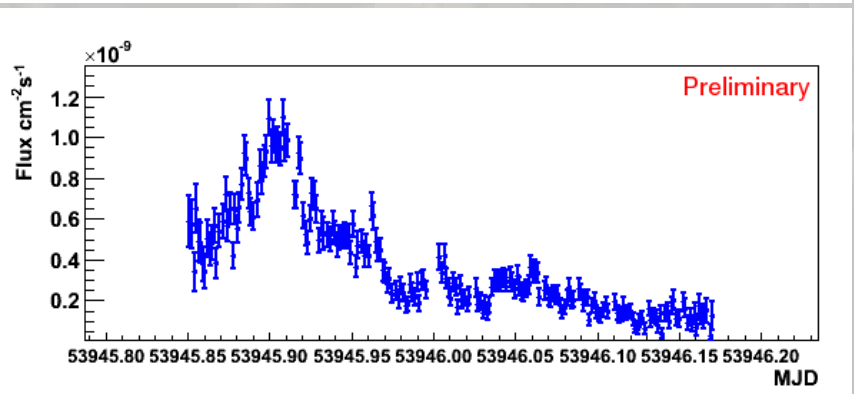


Lenain, Boisson, Sol, Katarzyński, 2008, A&A, 478, 111

Outline

PKS 2155−304 in July 2006: dynamic SSC modelling





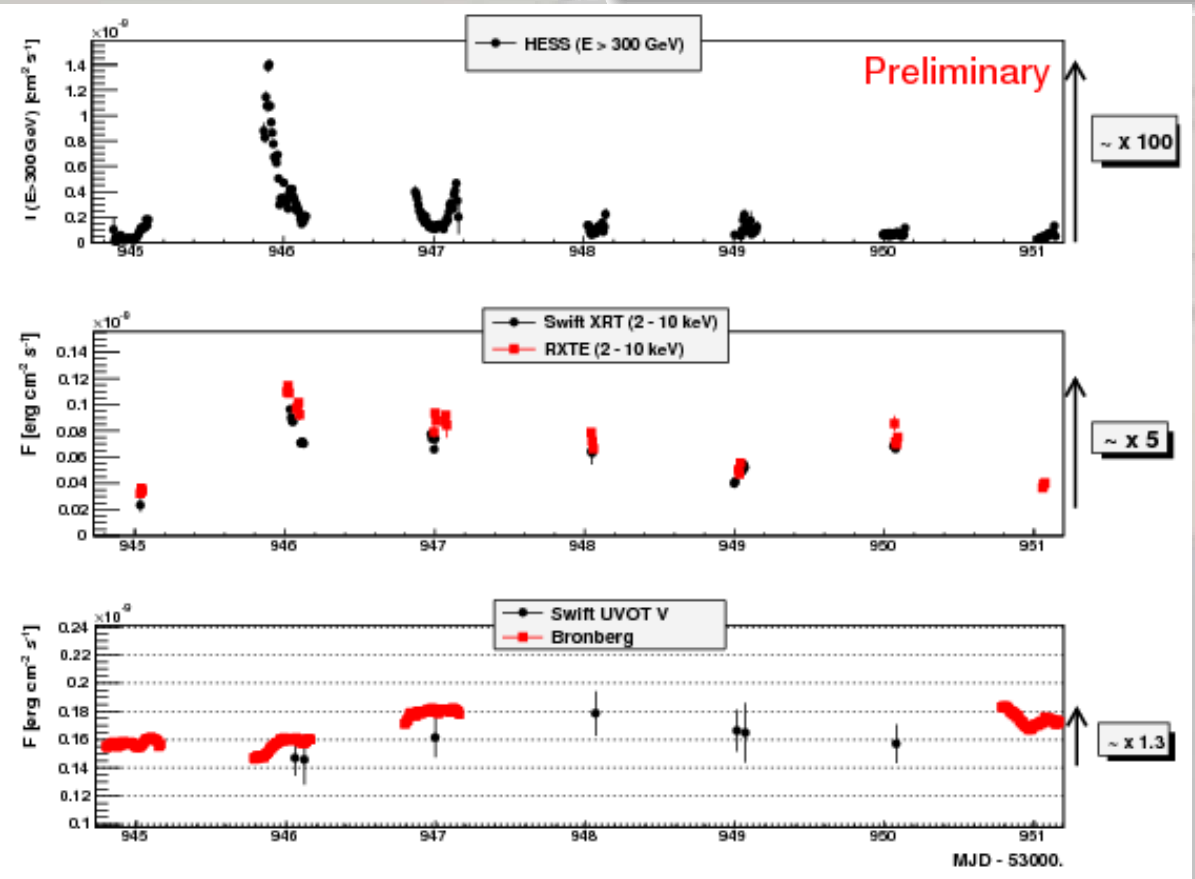
H.E.S.S. observations:

- MJD 53945–53946 (29–30/07/2006).
- 32073 γ-like events, in 1 single night (more than EGRET in 8 years !!).
- 252σ !!
- Curved-shaped spectrum.

PKS 2155−304 in July 2006: dynamic SSC modelling

MWL observations:

- Greater flux variations in VHE than in X-ray.
- Second flare night: $F_{\rm VHE}$ vs F_X more than quadratic.



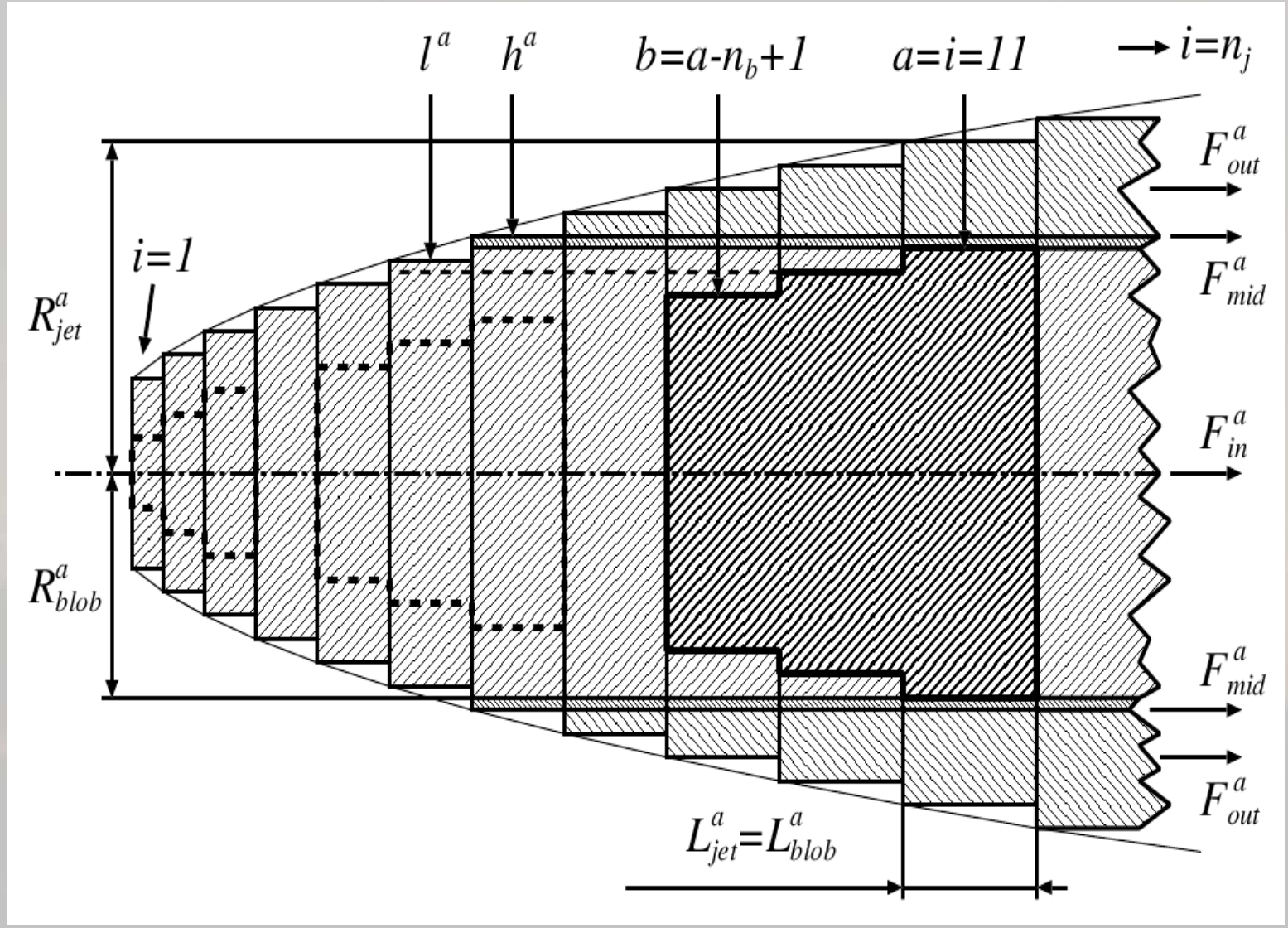
Time-dependent SSC “blob-in-jet” model

Based on Katarzyński, Sol & Kus 2003, *A&A*, 410, 101.

- Dynamic leptonic Synchrotron Self-Compton model.
- Inhomogeneous jet.
- Compact component (blob) travelling through the jet.
- Homogeneous blob.

- Acceleration/injection term.
- Adiabatic losses + escape of particles.
- Radiative cooling: Synchrotron self-Compton.

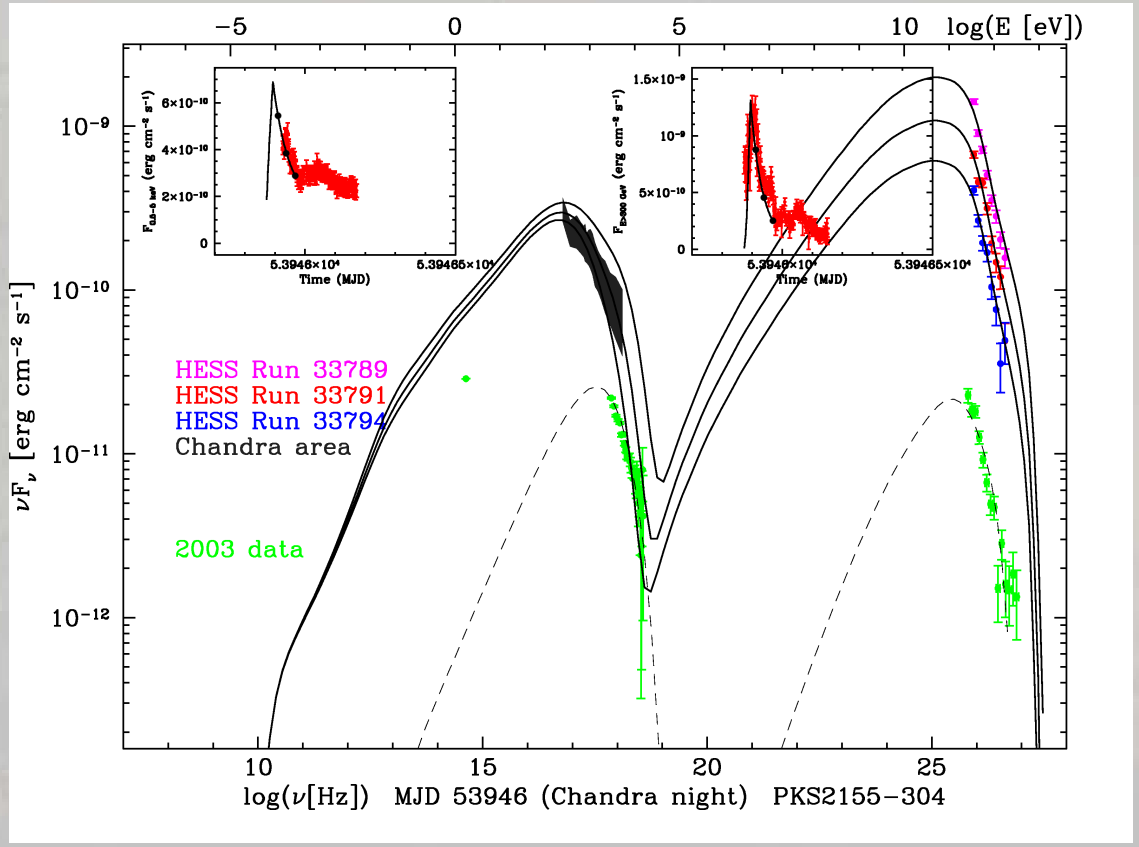
Geometry of the jet



PKS 2155−304 in July 2006: dynamic SSC modelling

$\delta = 50$
$B_{\rm blob} \sim 30\,{\rm mG}$
$B_{\rm blob}/B_{\rm jet} \sim 3$
$K_{\rm blob} \sim 10^7\,{\rm cm}^{-3}$
$K_{\rm blob}/K_{\rm jet} \sim 4\times10^3$
$n_{\rm blob} = 2.45$, $\gamma^{\rm min}_{\rm blob} = 10^3$,
$\gamma^{\rm max}_{\rm blob} = 7.4\times10^5$

Launch dynamic spectrum
(click)

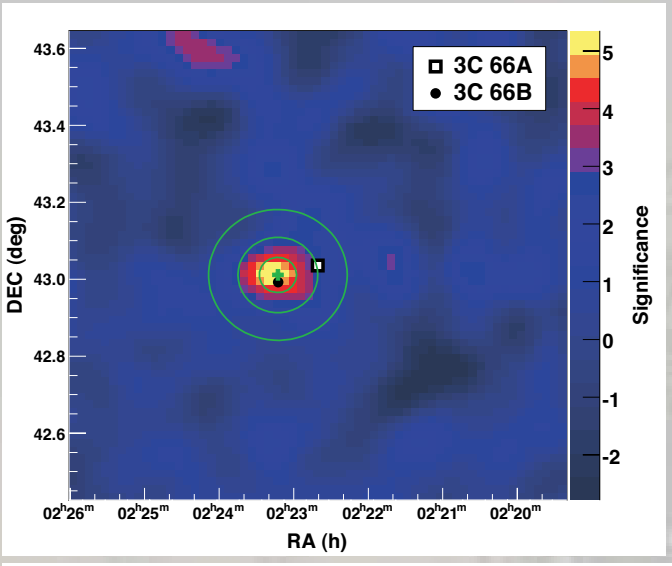


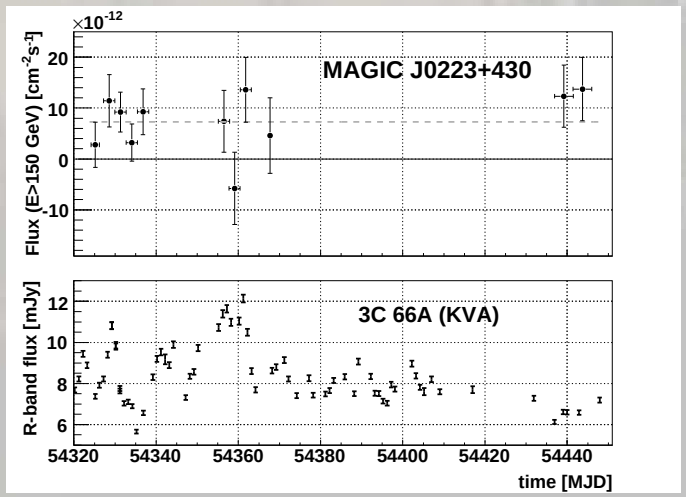
Snapshots of the dynamic MWL SED.

Outline

3C 66A/B: VHE detection

A short story ! 28 Oct. 2008





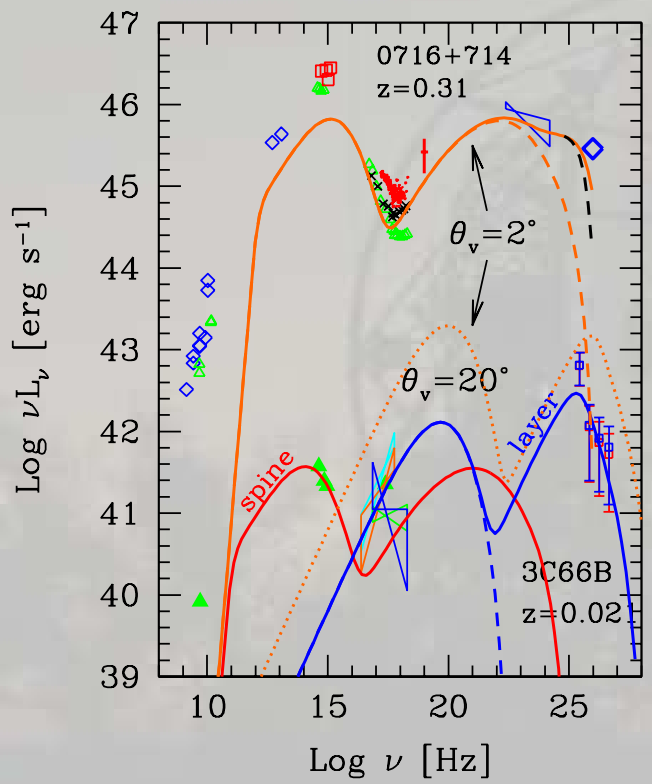
MAGIC collaboration, arXiv:0810.4712, 2008

MAGIC detection:

- VERITAS detection of 3C 66A reported on 1st Oct. 2008: *Astronomer's Telegram, 1753*.
- MAGIC Observations: August-December 2007.
- Detection of a VHE γ-ray source @ 5.4σ (post-trial) in the 3C 66A/B region.
- Skymap: Offset from 3C 66A, consistent with 3C 66B, @ $\sim 2\sigma$ (but observation during mirror alignment calibration...).
- 3C 66B ($z = 0.0215$) much closer than 3C 66A ($z \sim 0.4$, uncertain)
  $+$ $\sim$ hard VHE spectrum:
  $\Gamma = -3.10 \pm 0.3_{\rm stat} \pm 0.6_{\rm syst}$
  $+$ no variability observed in the VHE signal.
  $\Rightarrow$ VHE emission more likely from 3C 66B.

3C 66A/B: 2-zone SSC stationary modelling

A short story ! 12 Nov. 2008



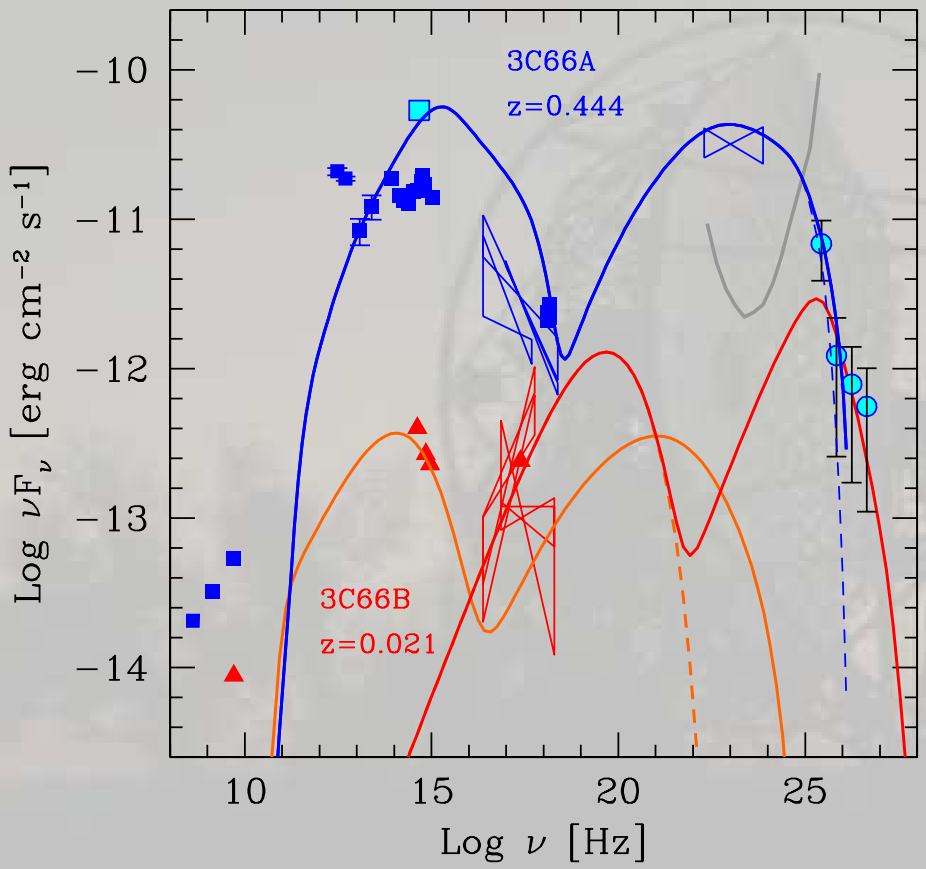
Spine & Layer modelling:

- 3C 66B: layer dominating at high energy, spine dominating at low energy.
- Beaming $\theta = 20° \rightarrow 2° \Rightarrow$ SED very similar to blazar S5 0716+714.

Tavecchio & Ghisellini, arXiv:0811.1883, 2008

3C 66A/B: 2-zone SSC stationary modelling

A short story ! 12 Nov. 2008



Spine & Layer modelling:

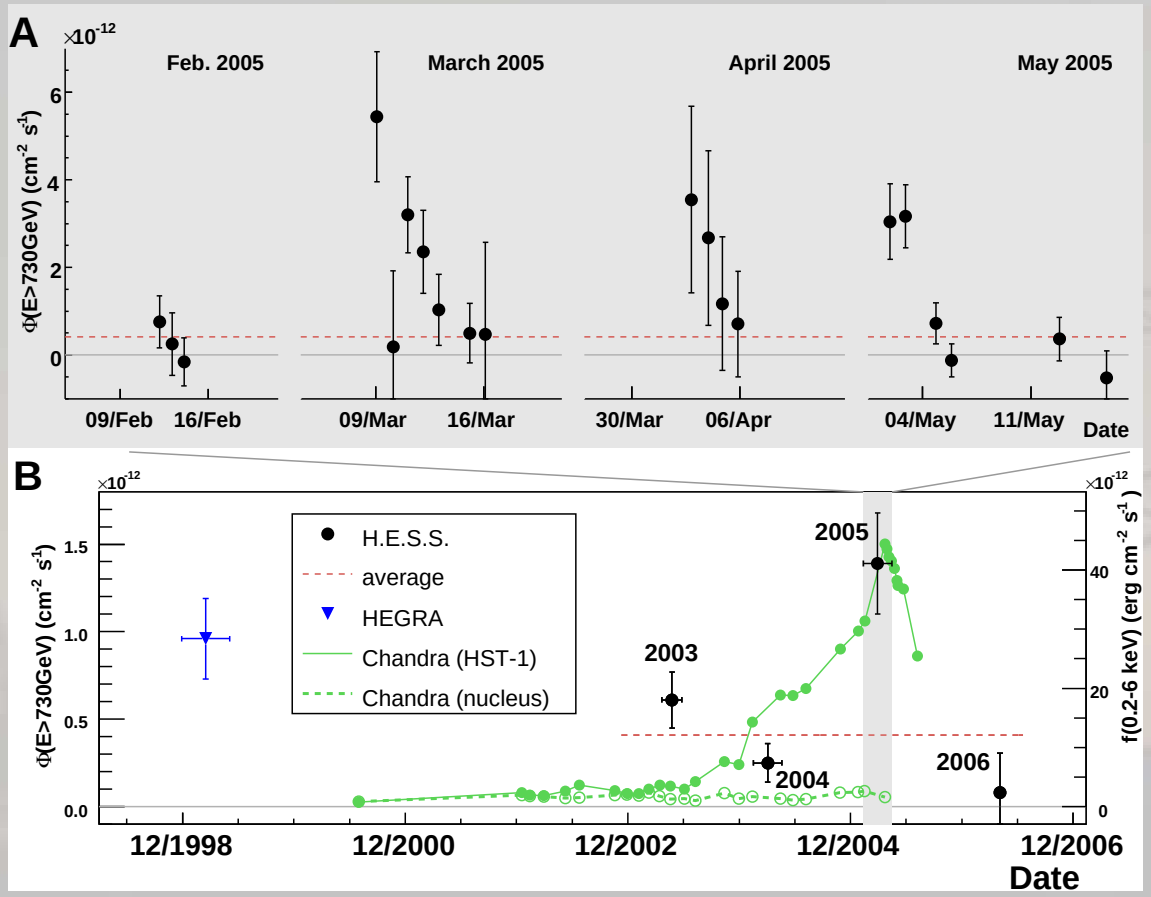
- 3C 66B: layer dominating at high energy, spine dominating at low energy.
- Beaming $\theta = 20^\circ \rightarrow 2^\circ \Rightarrow$ SED very similar to blazar S5 0716+714.
- Possible contamination of 3C 66A in the lowest bins in VHE, spine dominating the whole SED.

Tavecchio & Ghisellini, arXiv:0811.1883, 2008

Thanks !

Backup

Fast variability



Aharonian et al., 2006, Science, 314, 1424

- No spectral variability.
- H.E.S.S. VHE observations: Fast variability ($\sim$ 2 days)
  $\Rightarrow r_b \leqslant \frac{c\delta}{1+z}\Delta t_{\rm obs} \Rightarrow r_b \lesssim 5\times10^{15}\delta$ cm.
- Exclude e.g. extended kiloparsec jet or radio lobes.
- Emitting zone: nucleus or HST-1?