CBPF

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AGNs seen with gamma-rays

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29.05.2017

FAPESP High-Energy
CTA Advanced School

IAG/USP

RAIOS GAMA CÓSMICOS

De onde vem essa misteriosa radiação ultraenergética?

O filósofo jesuíta e cientista Pierre Teilhard de Chardin (1881-1955) descreveu, certa vez, o itinerário das ciências naturais como “o desenvolvimento de olhos cada vez mais perfeitos em um mundo onde existe sempre algo a mais para se ver”. De fato, em seu trabalho cotidiano, o cientista tem a impressão de estar sempre diante de um horizonte inesgotável e experimenta que suas descobertas prestam-se não tanto à conclusão de um caminho, mas a abrir novas vias pelas quais se aprofundar em investigações futuras. Tais palavras serviriam para descrever as motivações de um novo projeto científico – do qual o Brasil faz parte – que pretende entrar em funcionamento em poucos anos, formado por uma gigantesca rede de telescópios espalhados por dois sítios complementares, nos hemisférios Sul e Norte. Objetivo desses novos ‘olhos’: encontrar no céu fontes de raios gama, a radiação mais energética do universo. E, se possível, fazer descobertas inesperadas.

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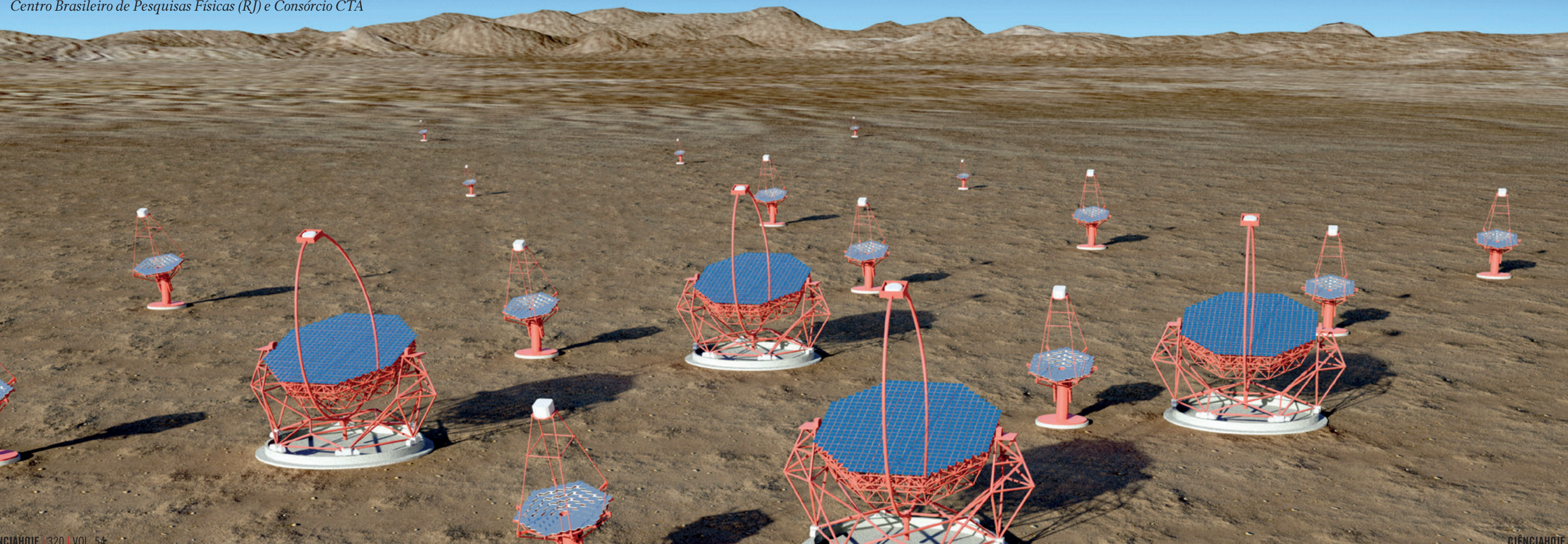
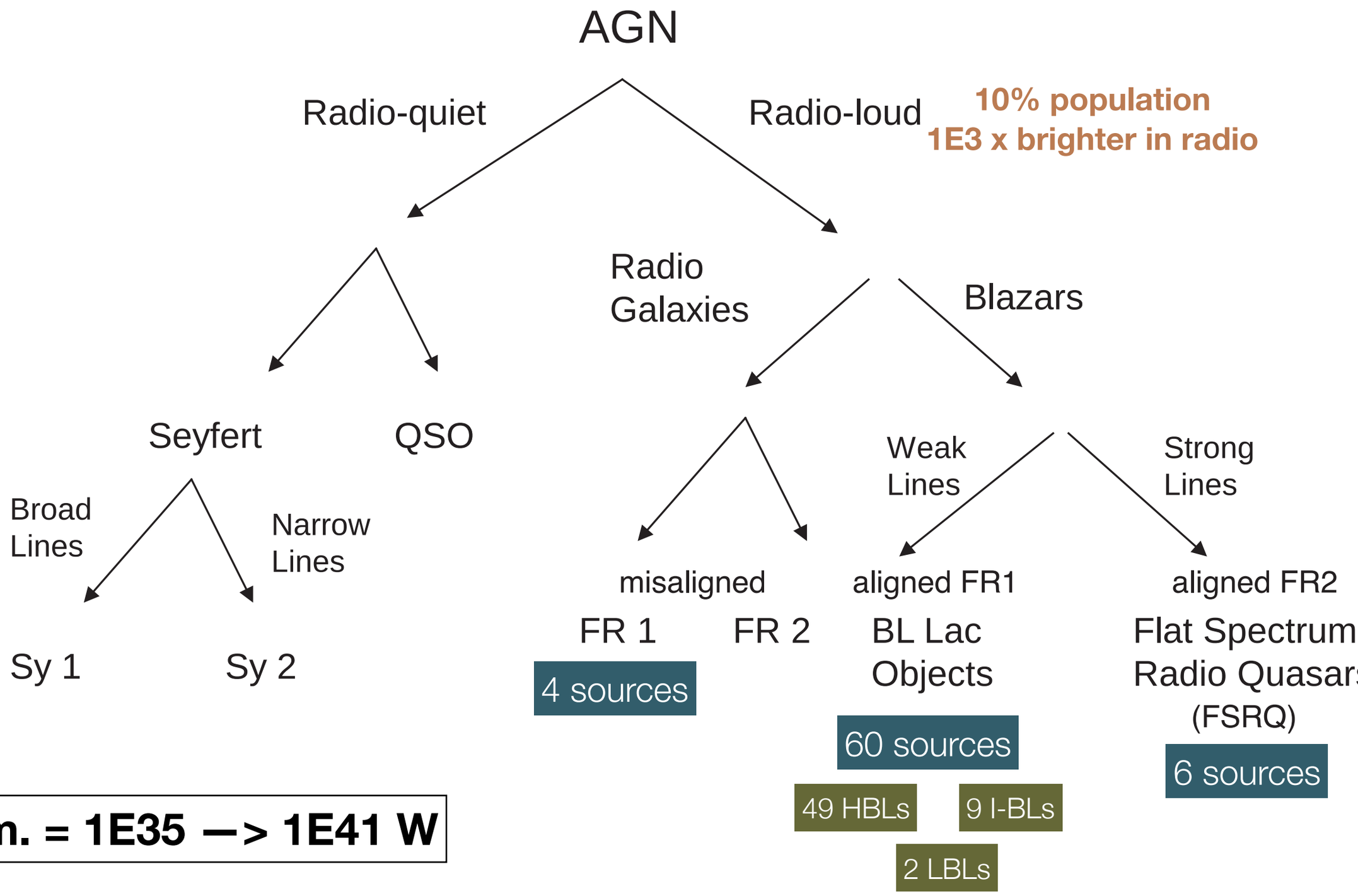
Sempre que o homem elevou seu olhar para os céus com a ajuda de instrumentos de observação novos ou mais potentes, uma nova realidade – não totalmente previsível a partir daquilo que já se conhecia – foi revelada. O século passado, com os grandes saltos tecnológicos que o caracterizaram, assistiu a uma sucessão particularmente intensa de novas técnicas que foram adicionando-se umas às outras, ampliando e alterando, de maneira singular na história, a concepção que o ser humano tem do cosmo.

Se o céu observado a olho nu é dominado por aquilo que os antigos chamaram “estrelas fixas” e identificaram com o imutável e o eterno, o decorrer das descobertas do século passado pouco a pouco nos levou a entender o céu como palco de uma dinâmica natural muito mais dramática até do que a terrestre.

Em particular, com a observação do céu nas chamadas altas energias (raios X e raios gama), o cosmo se mostrou dominado por processos violentos e extremos, cujos atores são explosões estelares, buracos negros ou colisões de plasma (‘nuvem’ quentíssima de núcleos atômicos e elétrons).

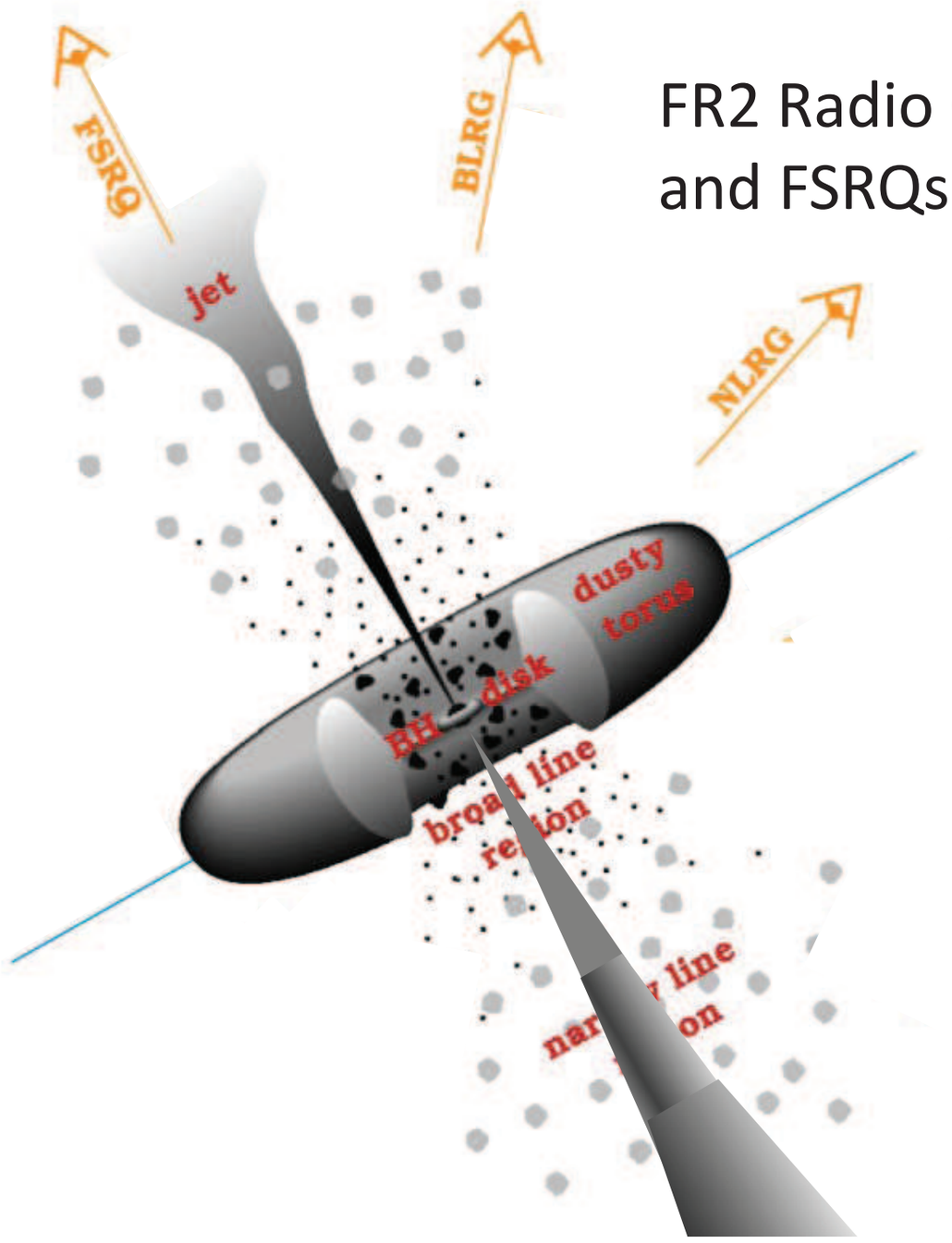
Concepção artística da rede de telescópios do CTA





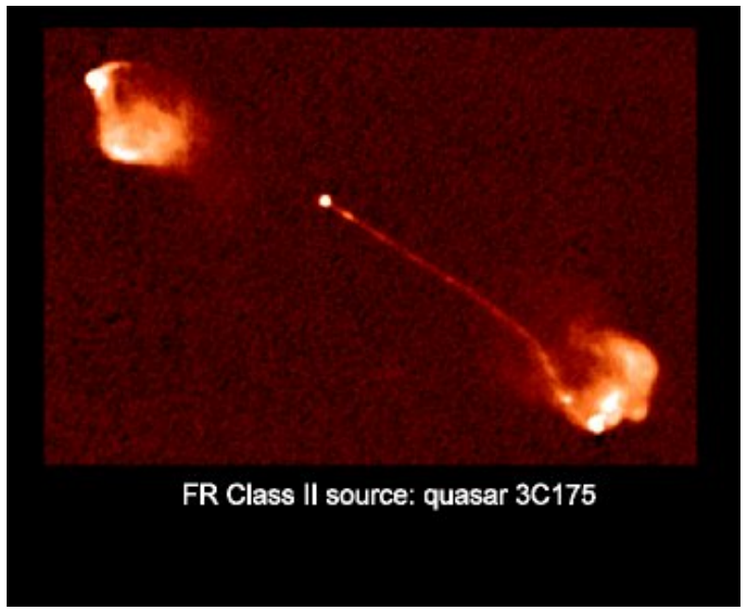
The zoo of active galaxies

Source statistics at VHE
according to www.tevcat.uchicago.edu



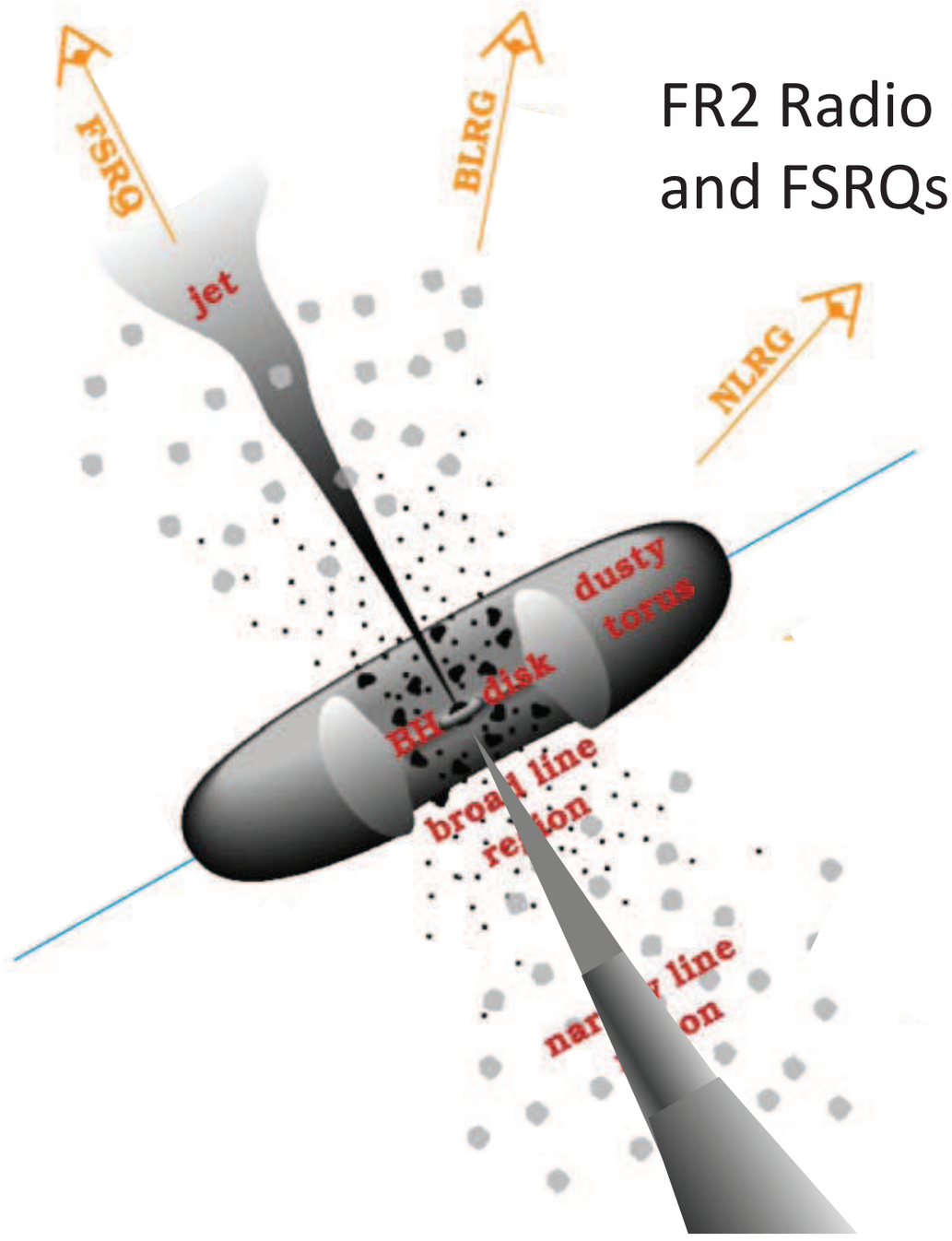
FR2 Radio Galaxies and FSRQs

$$\delta = \frac{1}{\gamma_{\text{bulk}}(1 - \beta \cos\theta)}$$

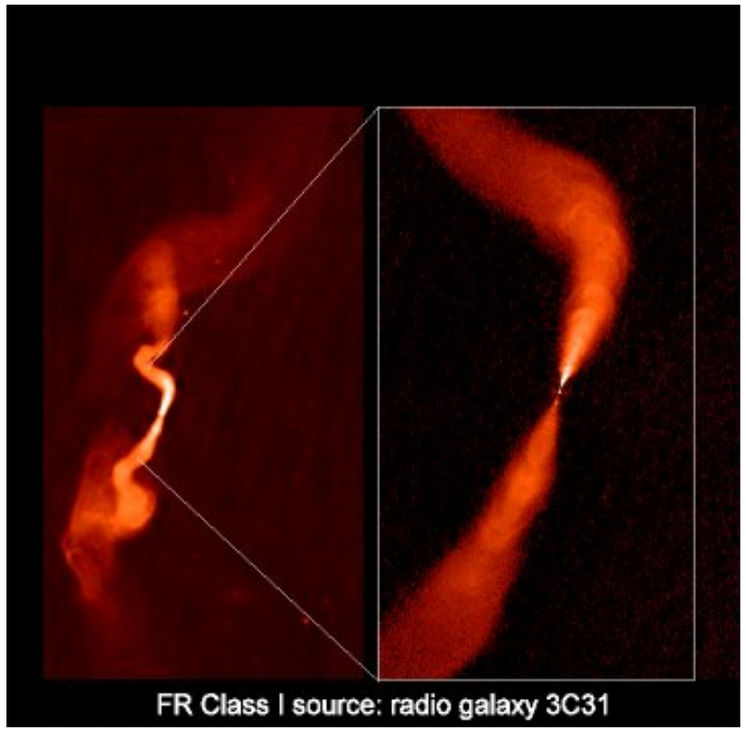


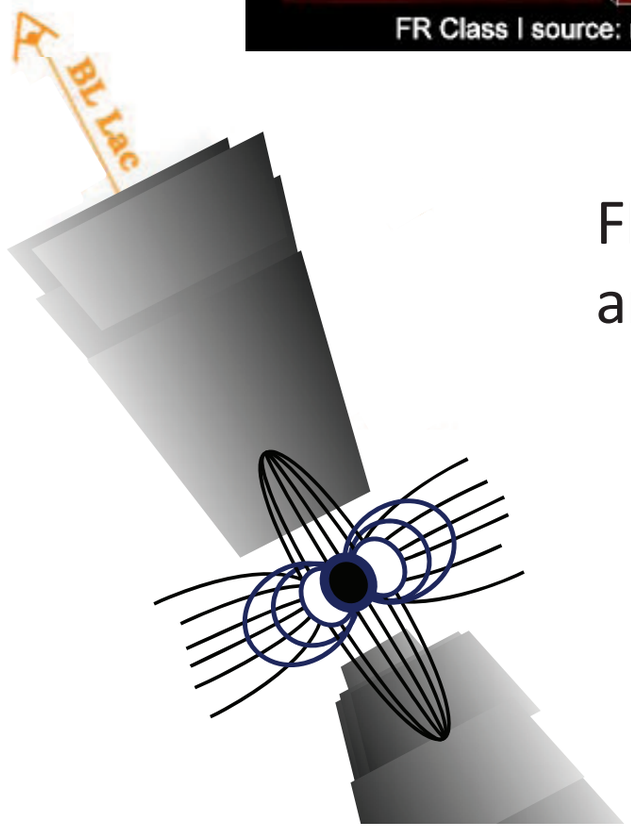
The unification scheme for radio louds

see Dermer & Giebels 2016 and Urry & Padovani 1995



FR2 Radio Galaxies
and FSRQs


FR Class I source: radio galaxy 3C31



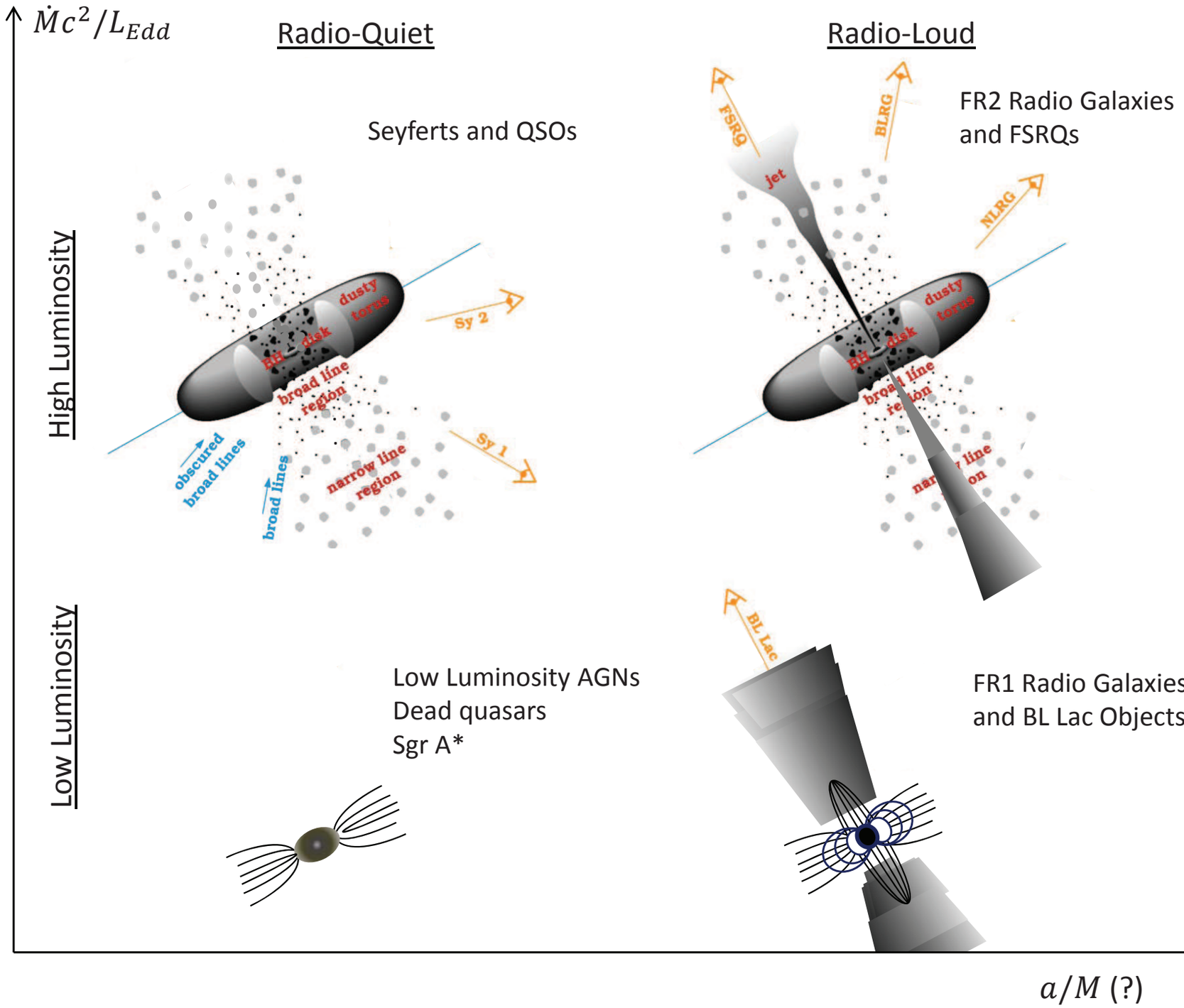
FR1 Radio Galaxies
and BL Lac Objects

The unification scheme for radio louds

The FRI / FR II dichotomy

$$L_{\mathrm{Edd}} = 4GMm_pc \,/\, \sigma_T$$

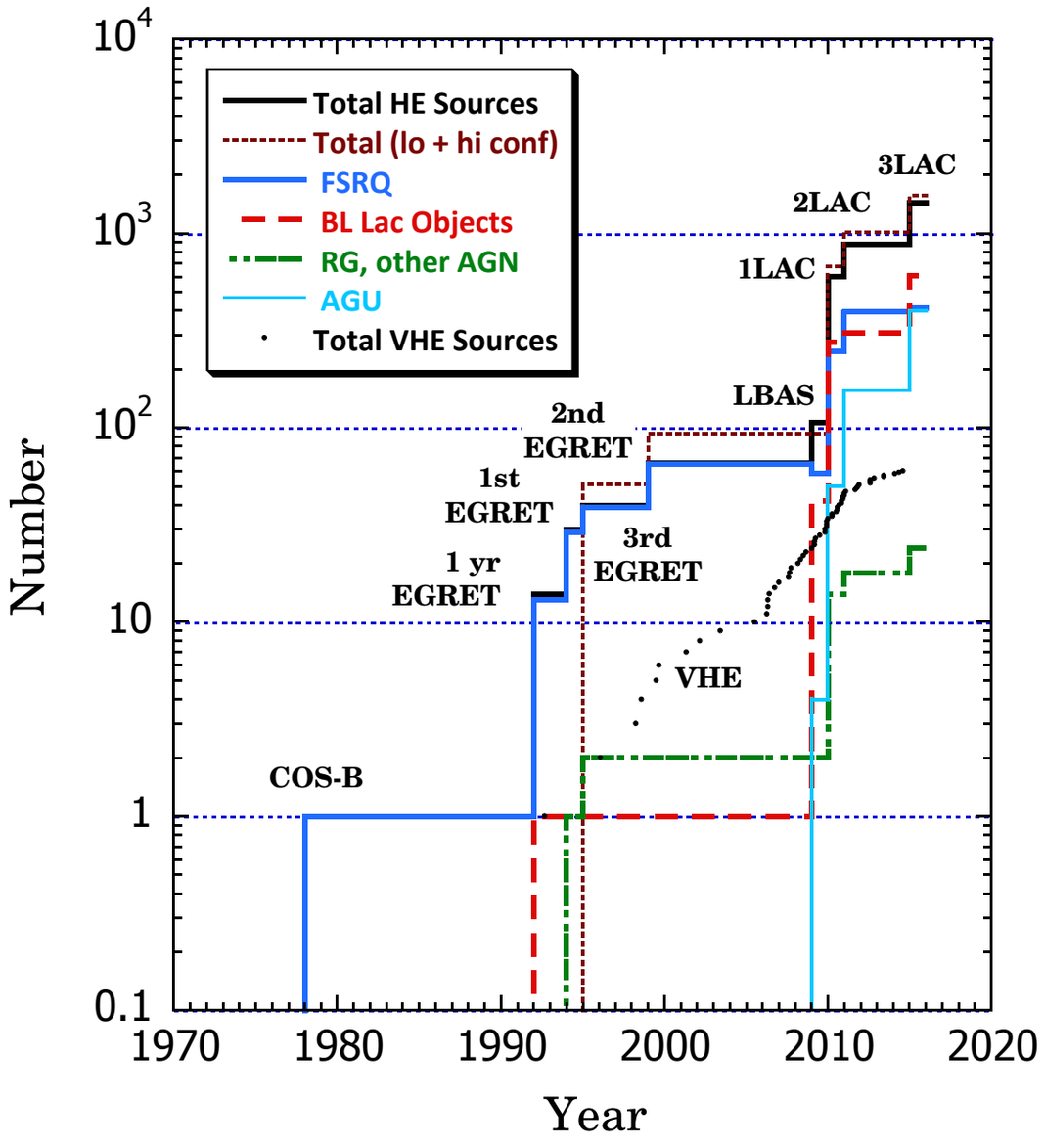
$$L_{\mathrm{Edd}} = 30{,}000\ (M \,/\, M_\odot)\ L_\odot$$

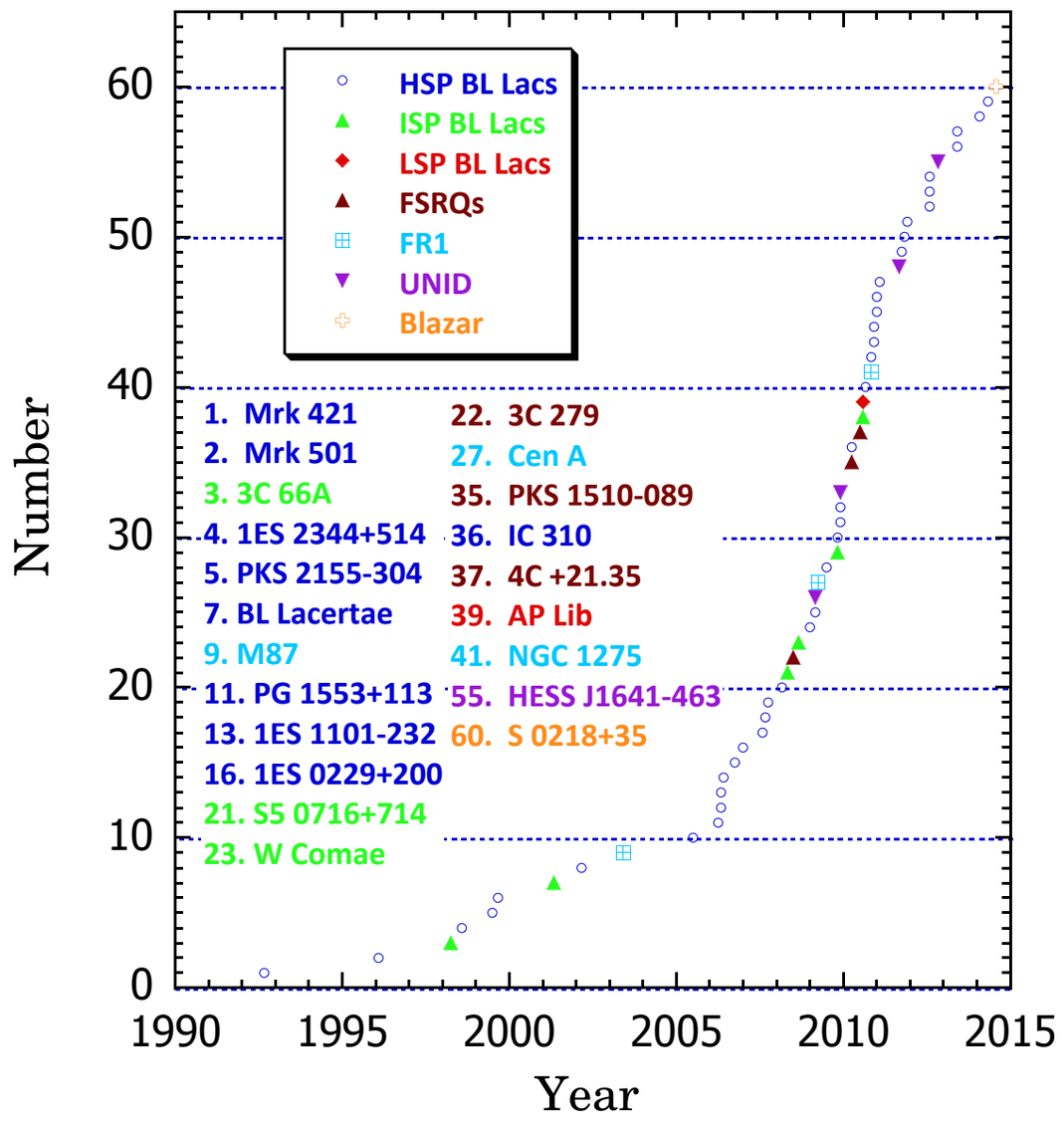


The unification scheme: physical links

The role of Black Hole spin?

Sy luminosity : The role of accretion power

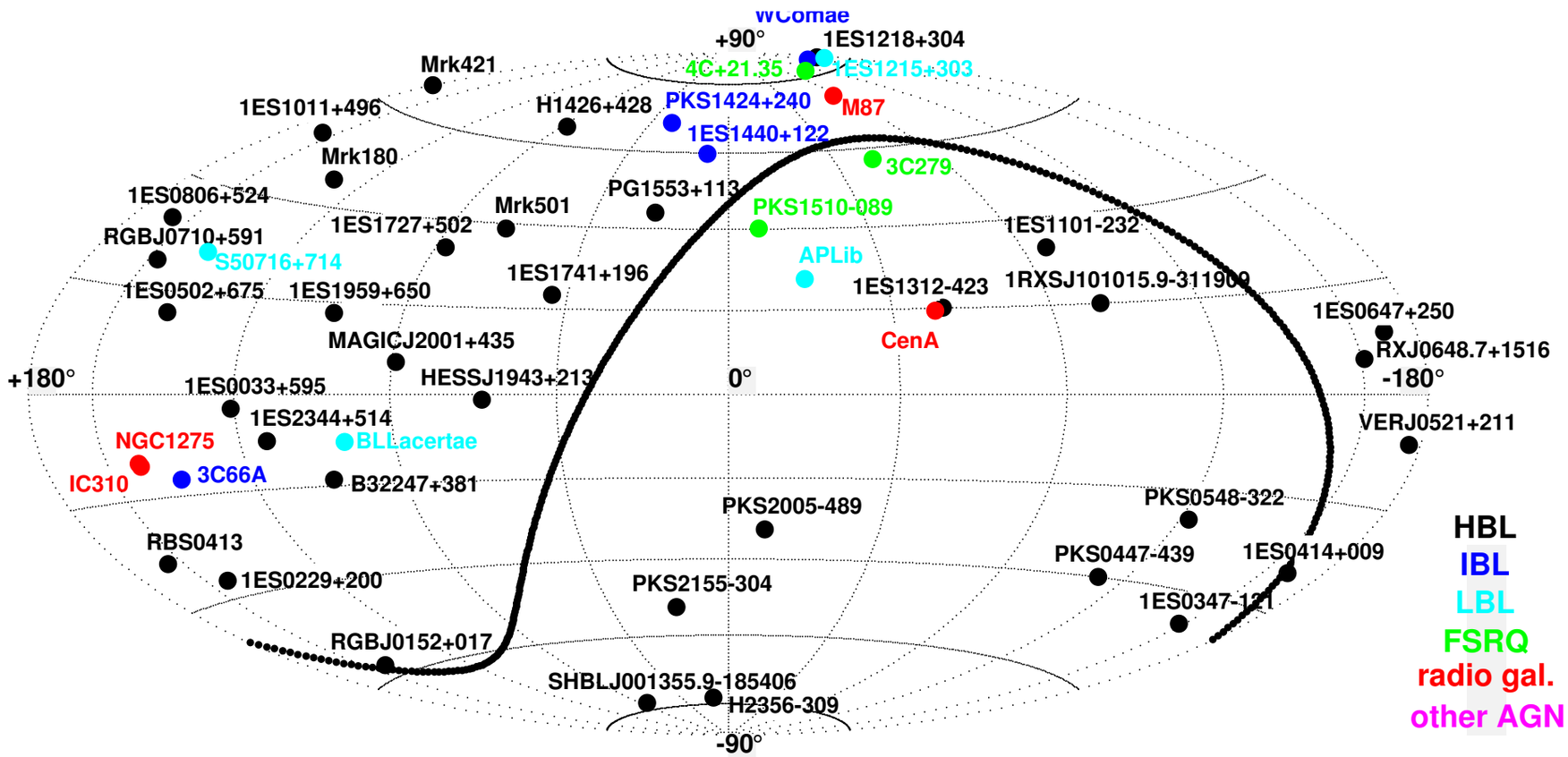


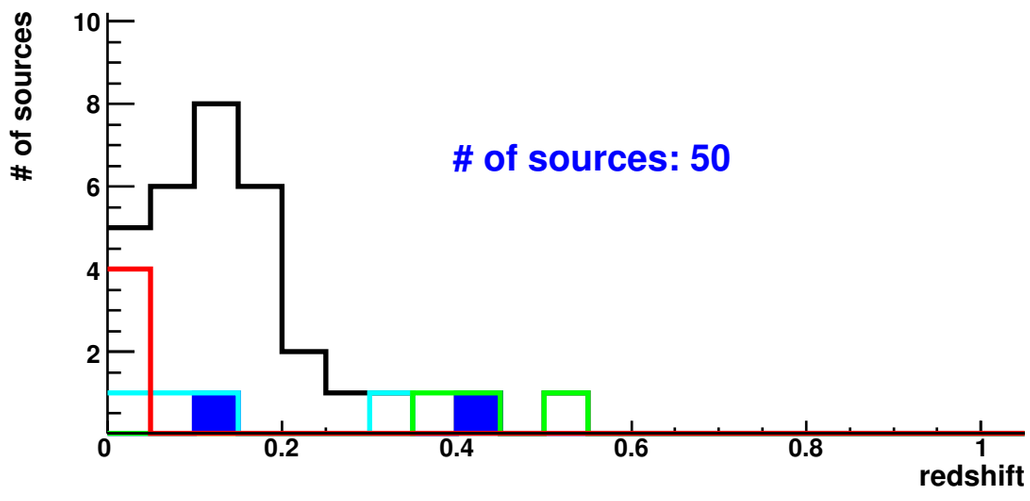


Source Statistics

Left : MeV-GeV gamma-rays

Right : VHE sources

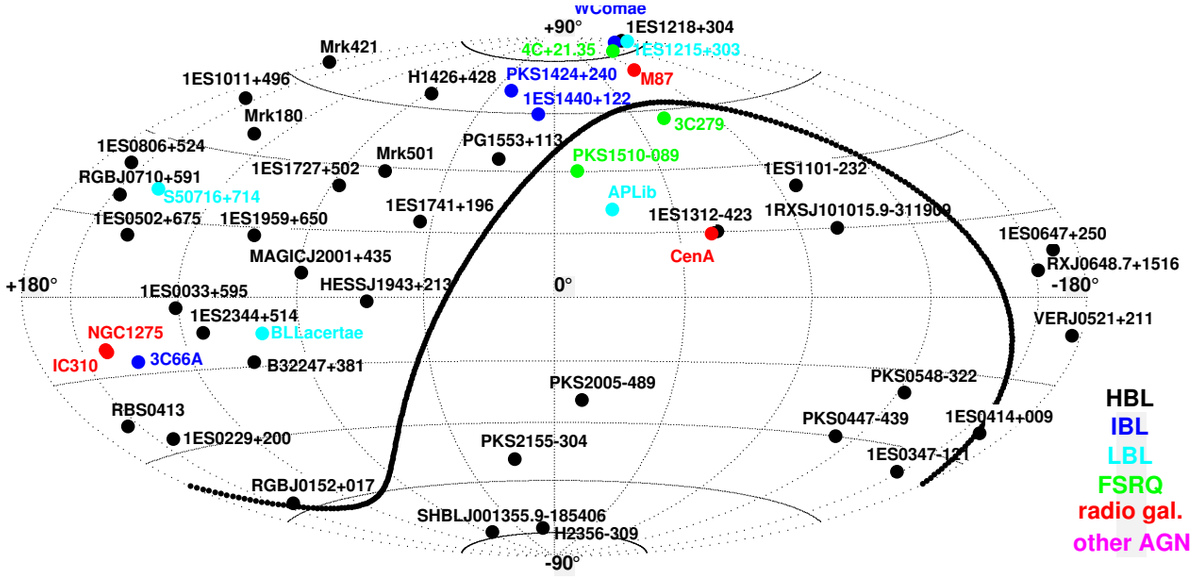


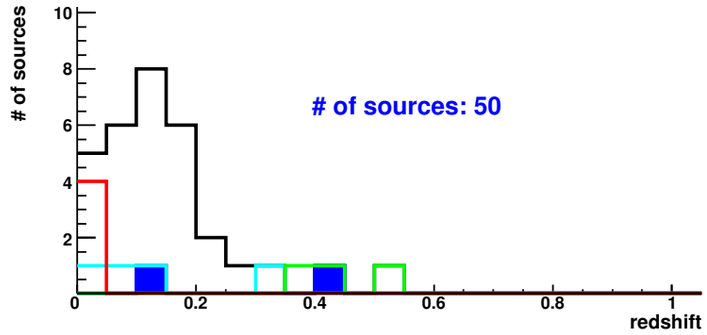


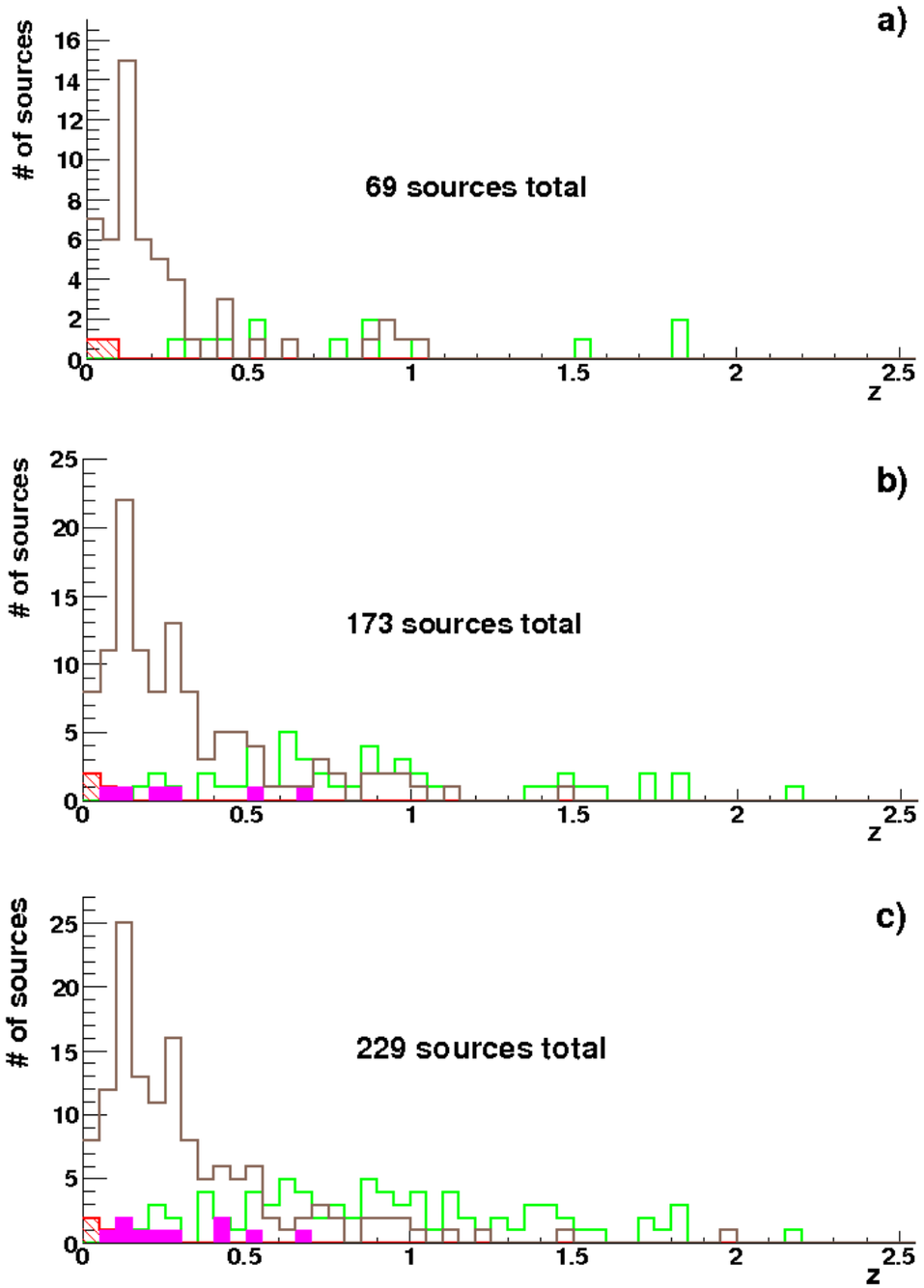
Sol et al. 2013

VHE Source Population

The redshift distribution, 5 years ago…







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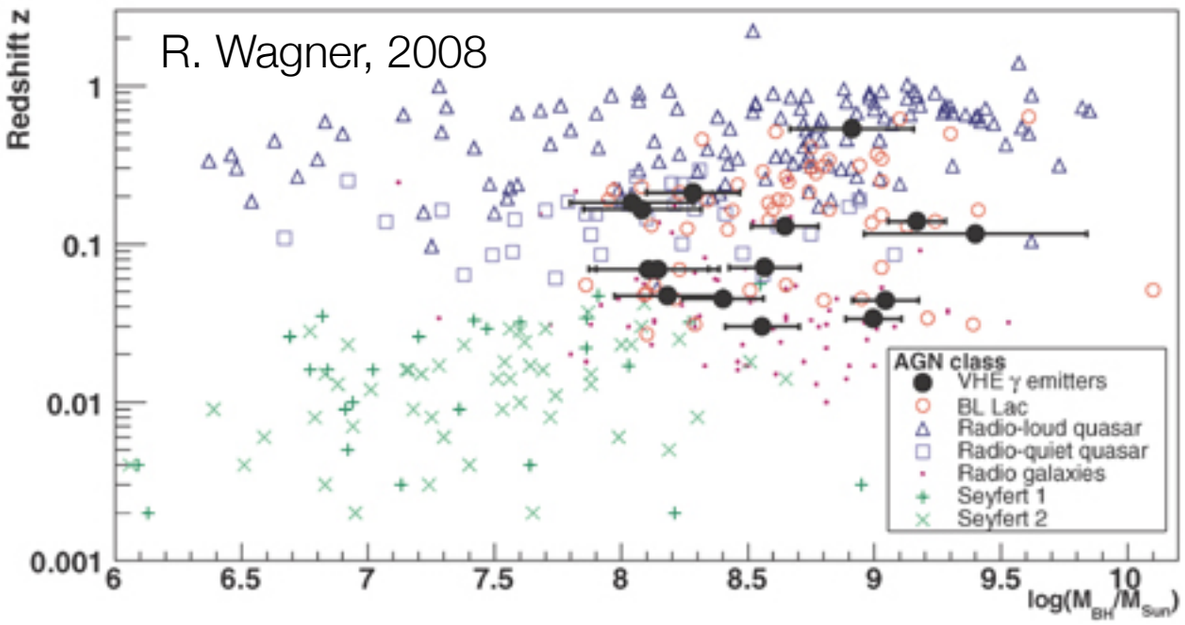
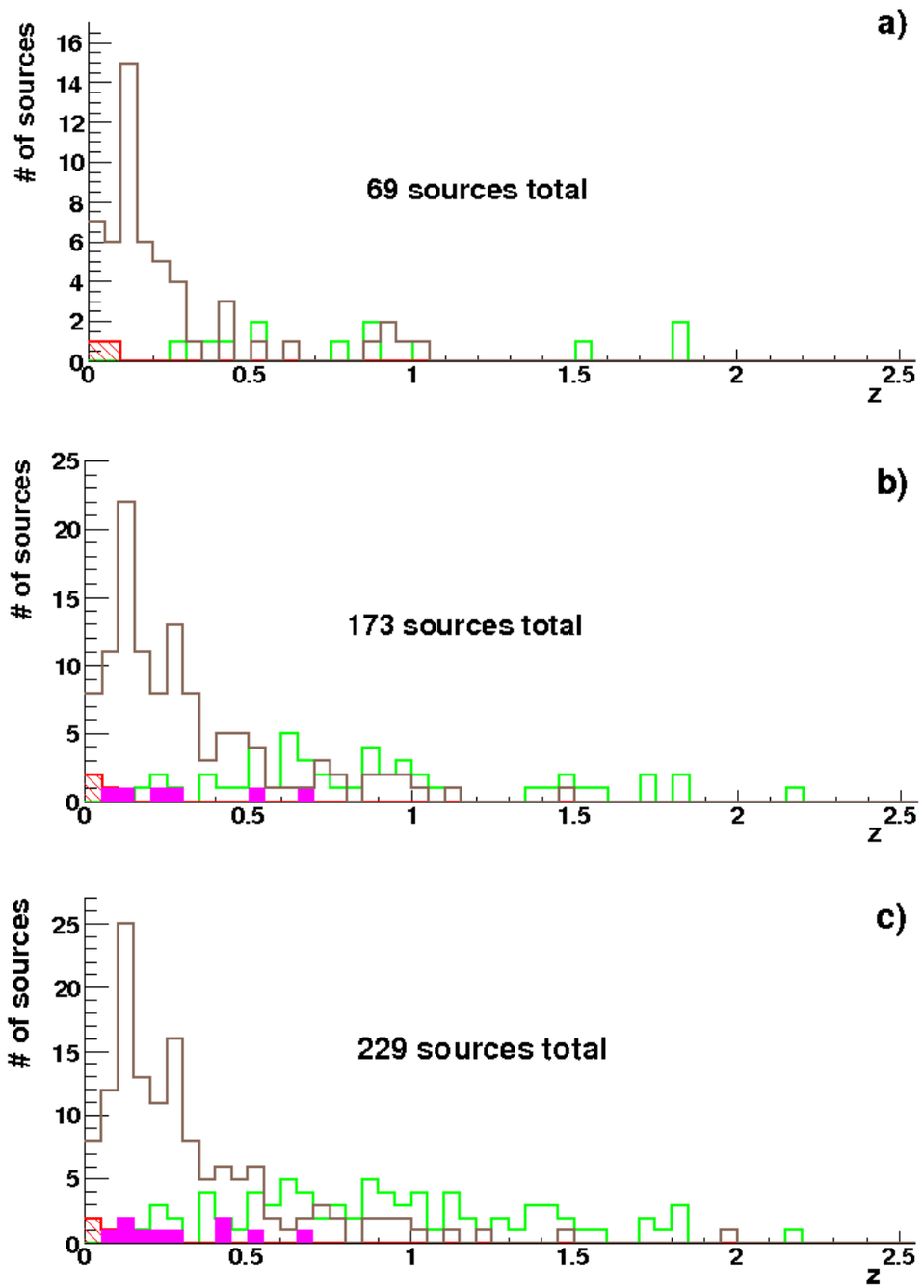


Trace the high-BH mass blazar population, but with a redshift limit.

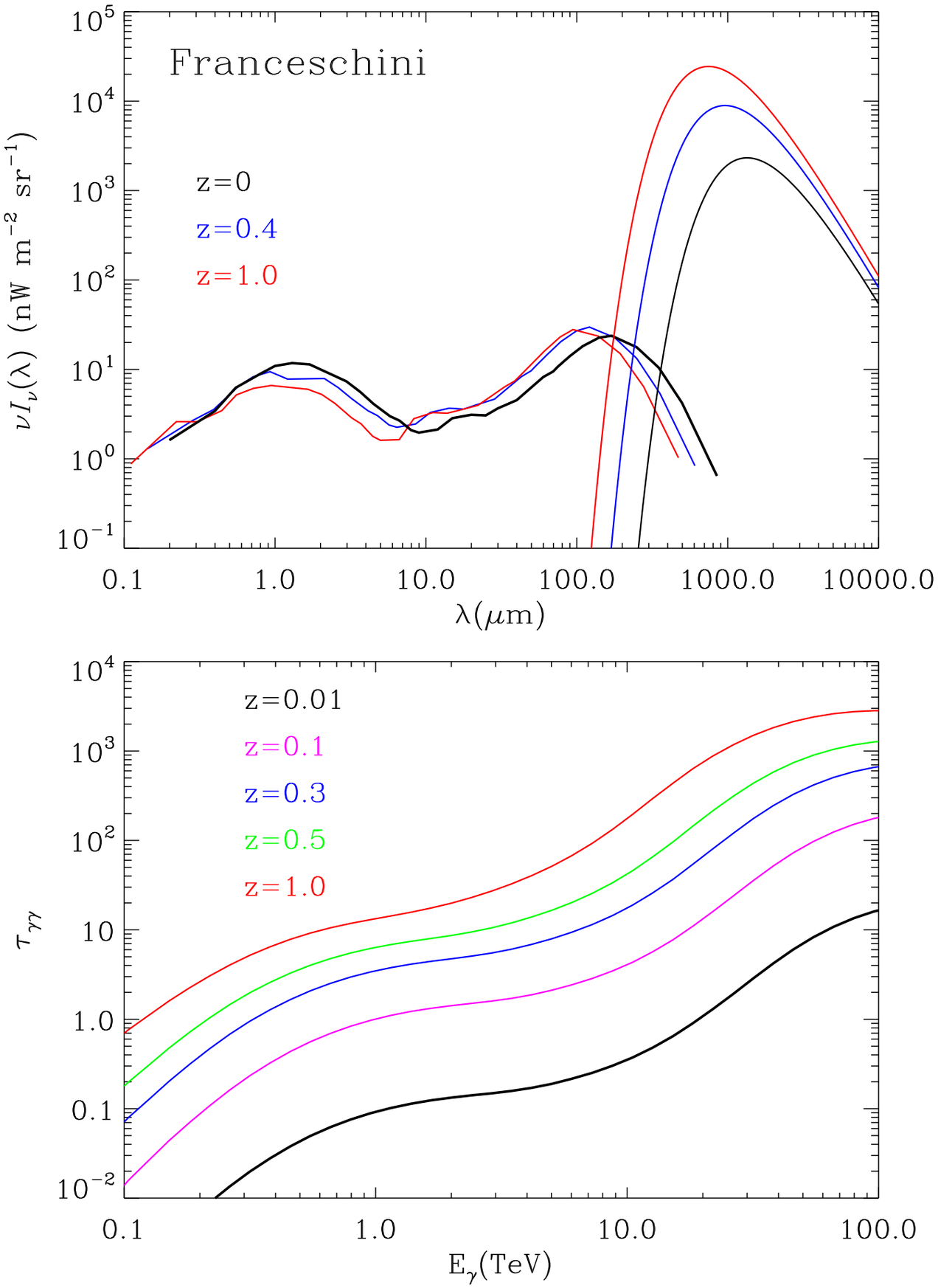
Sol et al. 2013



VHE Source Population

Expectations with CTA for (a) 5hrs (b) 50 hrs and (c) 150 hrs. Extrapolation from 2 FGL.

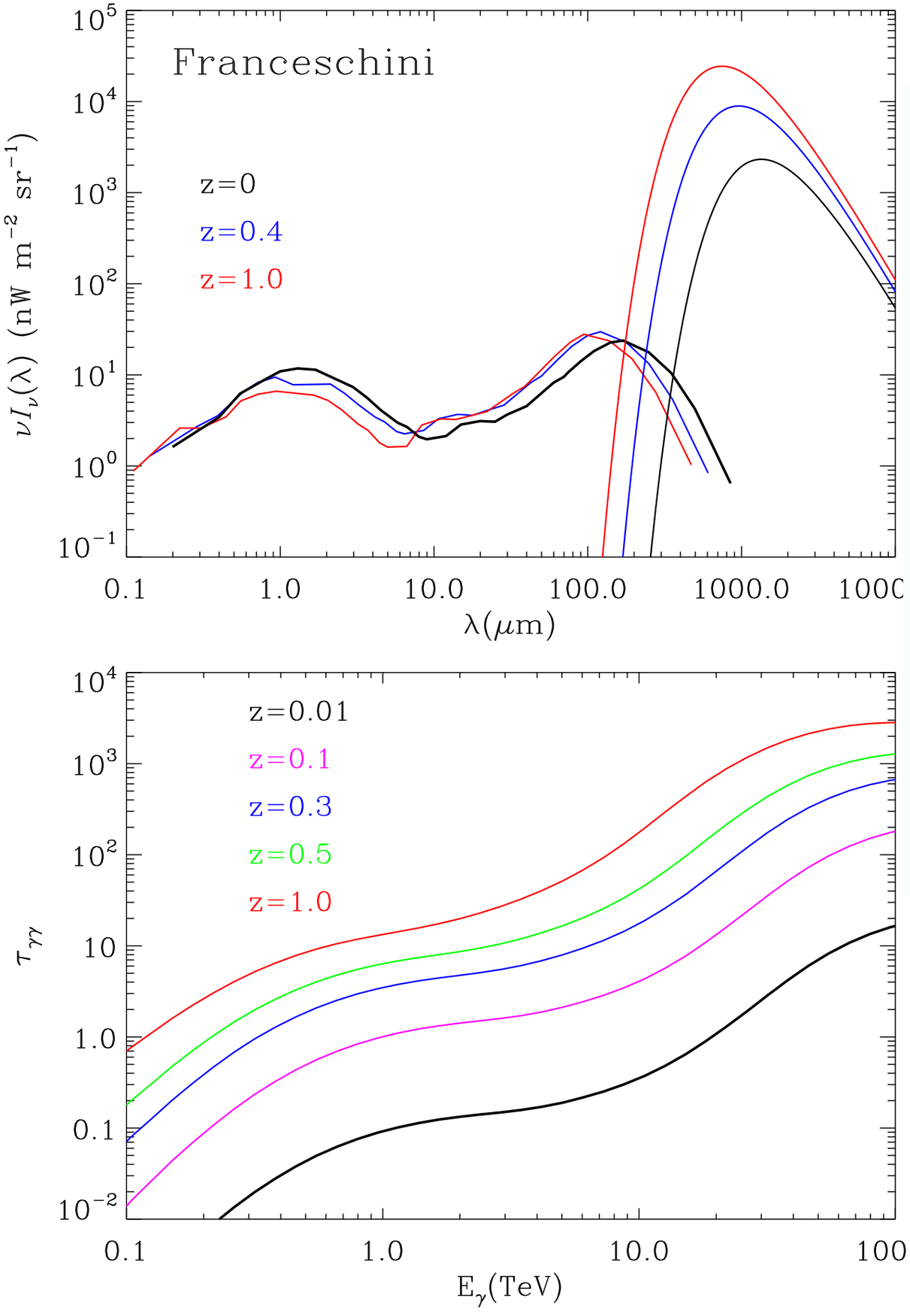
Aharonian et al. 2008, Rep. Prog. Phys.



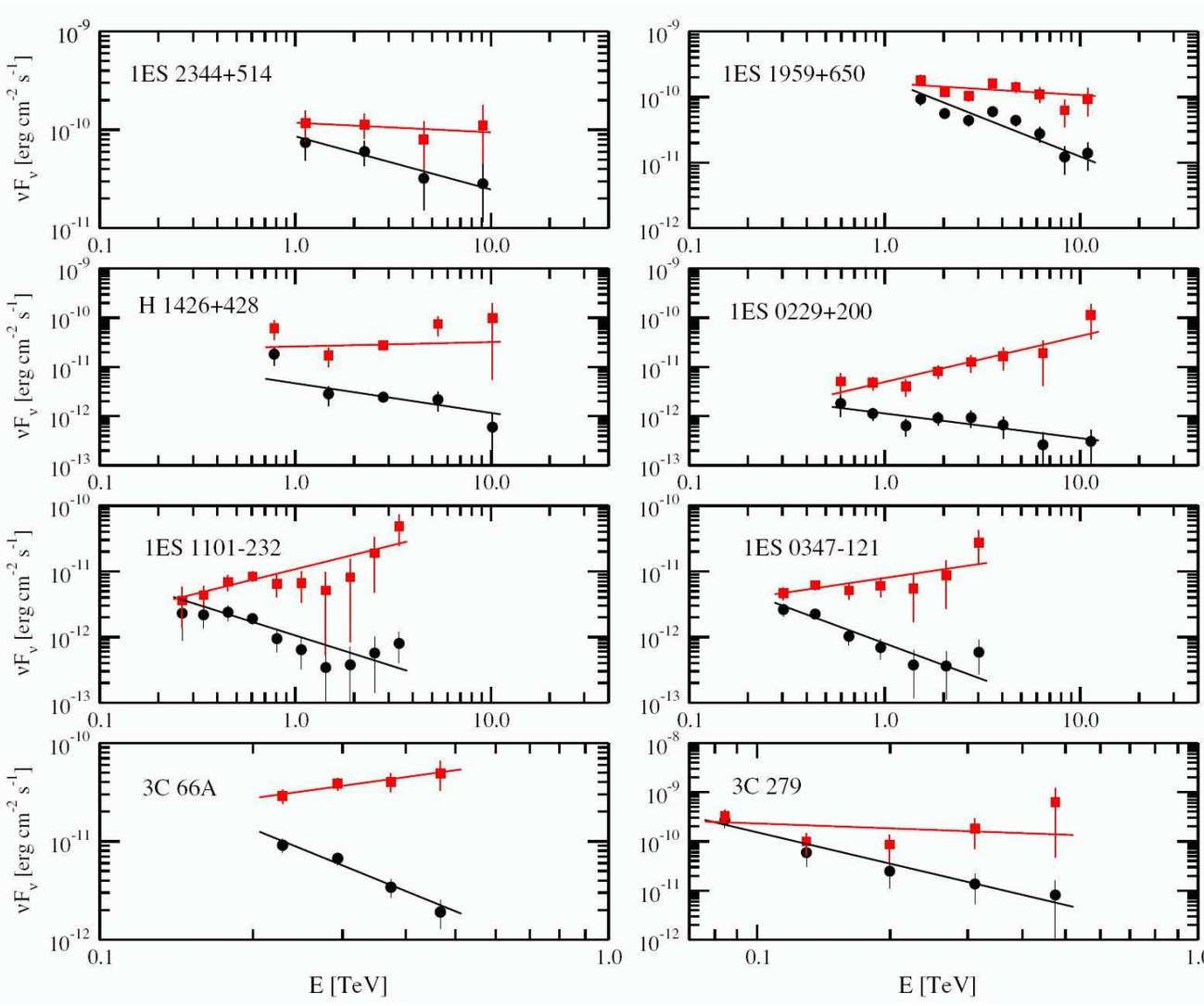
EBL absorption

Top: EBL density and opacity.

Bottom: EBL opacity (optical depth).



Aharonian et al. 2008, Rep. Prog. Phys.



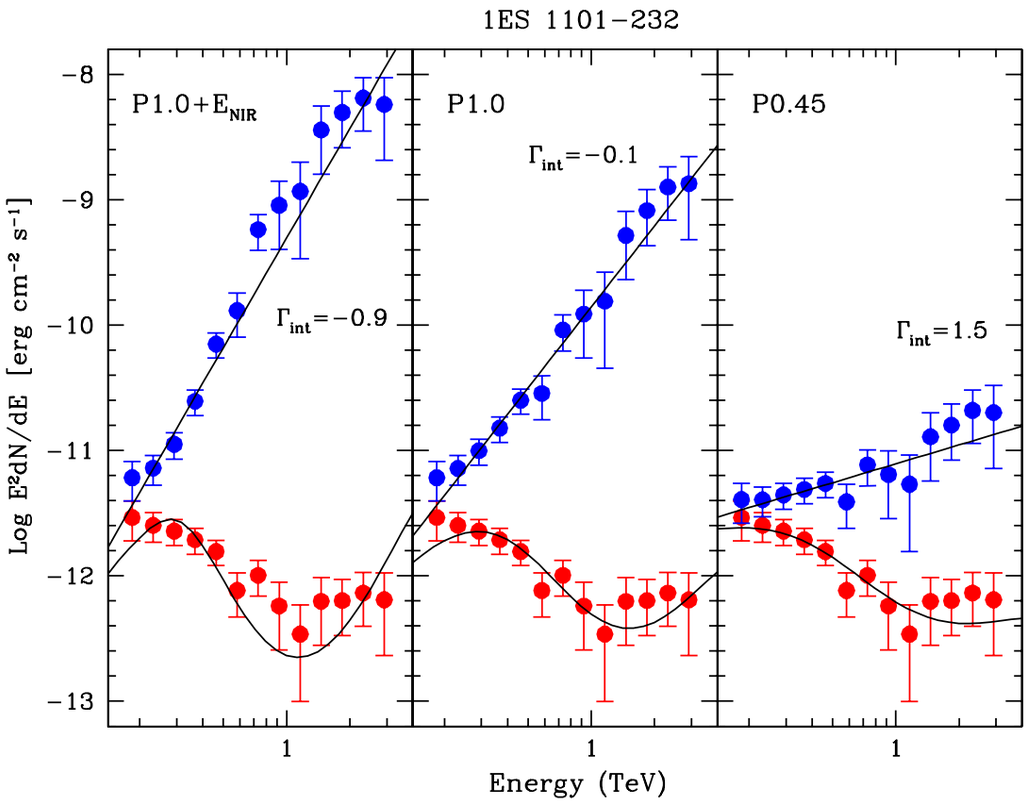
EBL absorption

EBL spectral corrections for blazars at different redshifts.

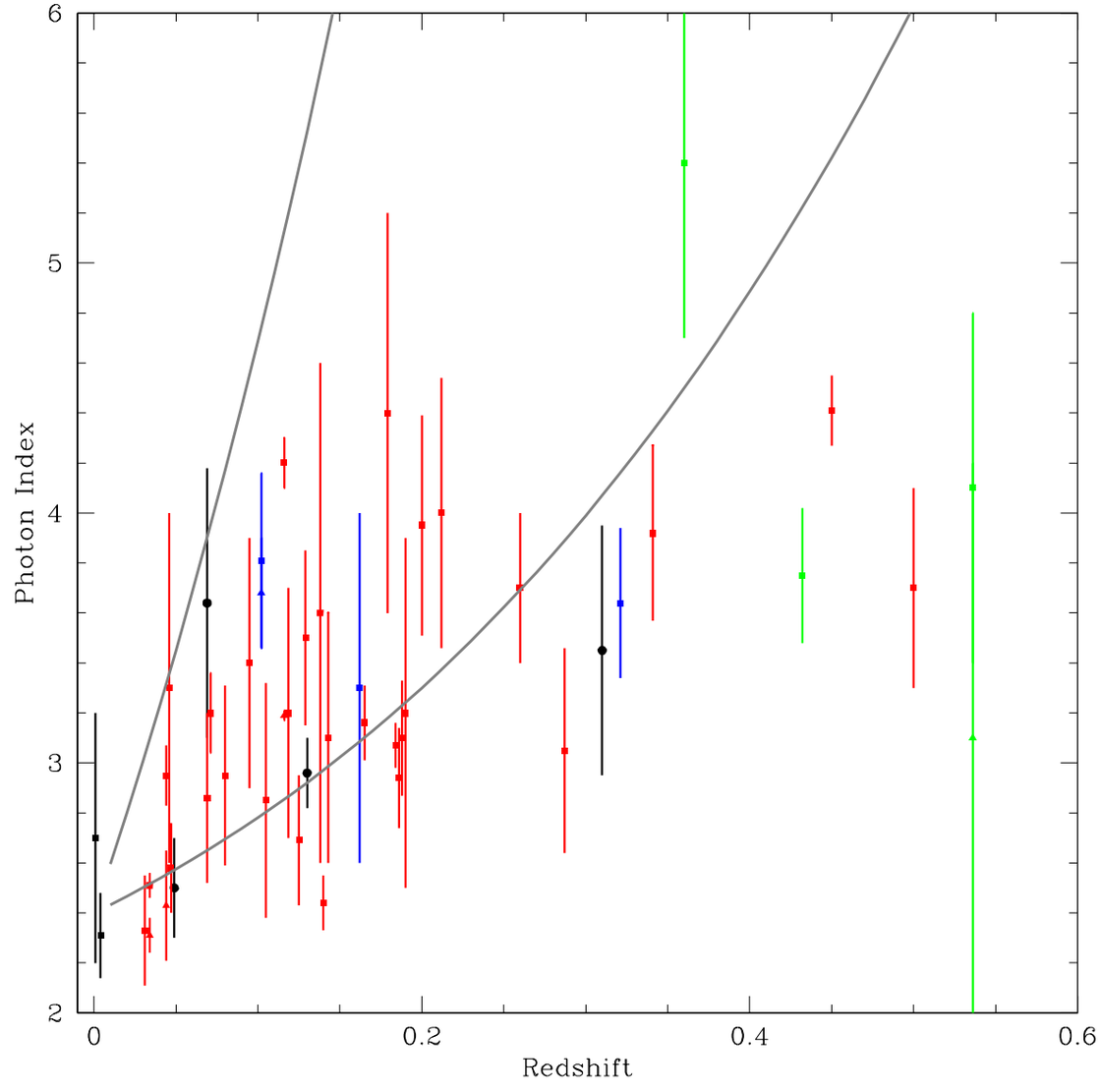
$$\gamma_{\mathrm{EBL}}\gamma_{\mathrm{VHE}} \rightarrow e^{+}e^{-}$$

$$h\nu_{\mathrm{EBL}} \times h\nu_{\mathrm{VHE}} > (m_{\mathrm{e}}c^{2})^{2}$$

$$\Phi_{\mathrm{obs}}(E,z) = e^{-\tau_{\gamma}(E,z)}\Phi_{\mathrm{em}}$$



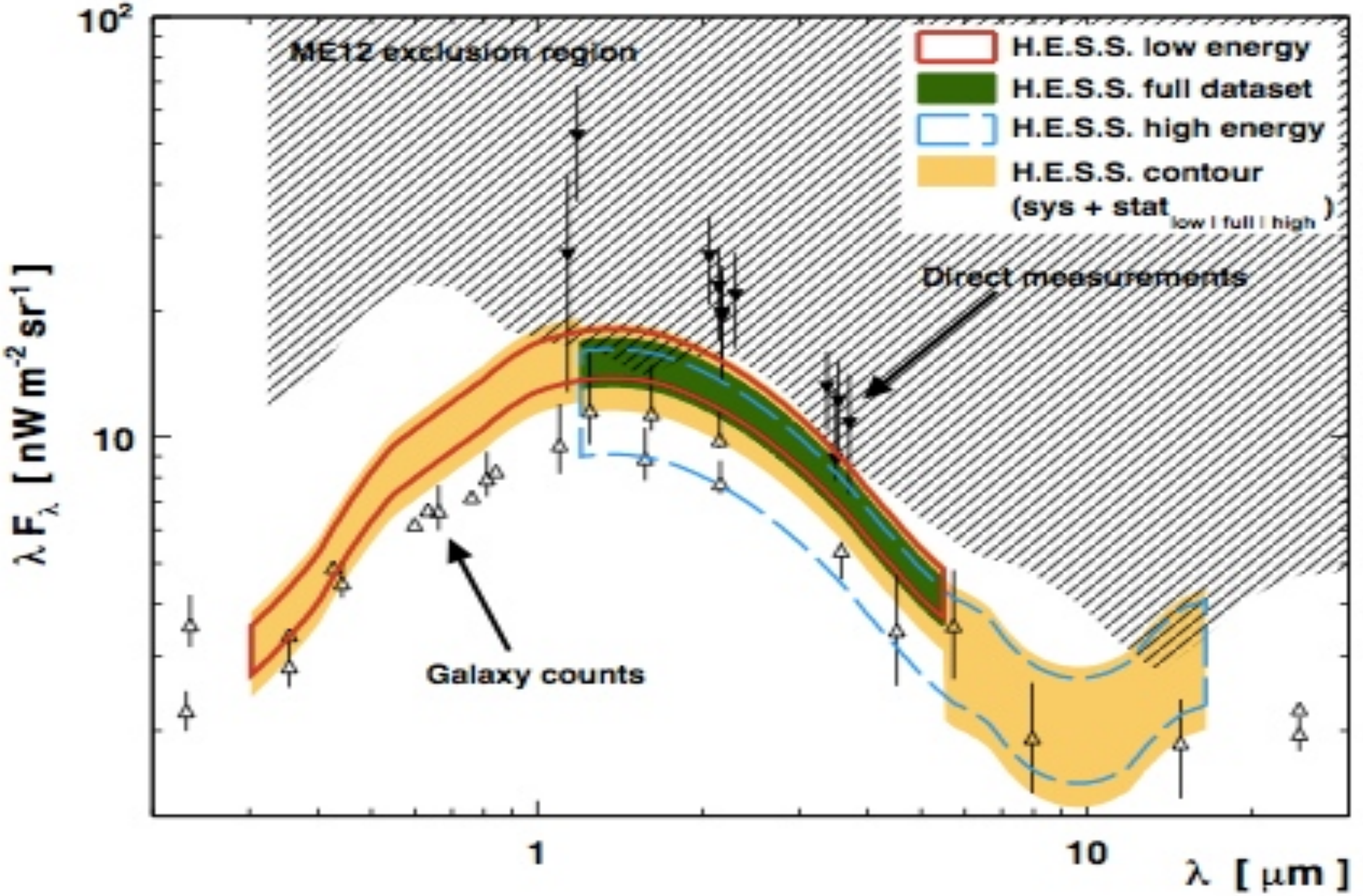
$$\Gamma_{\mathrm{obs}}(z) \sim \Gamma_{\mathrm{em}} + \Delta\Gamma(z)$$



Which is the correct intrinsic spectrum?

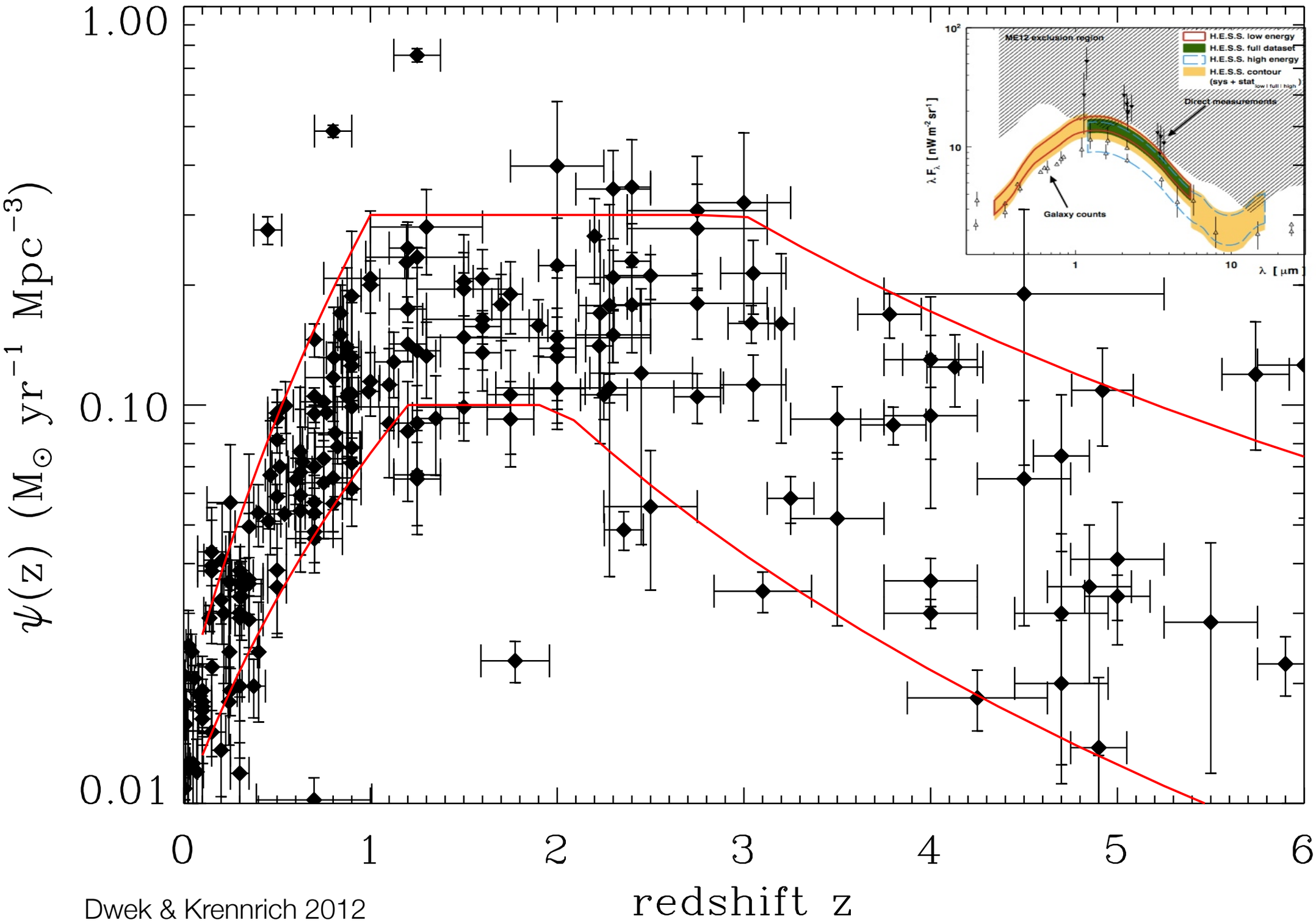
EBL absorption

Right: The effect of EBL absorption assuming intrinsic index of 2.3 (De Angelis 2009)



EBL absorption

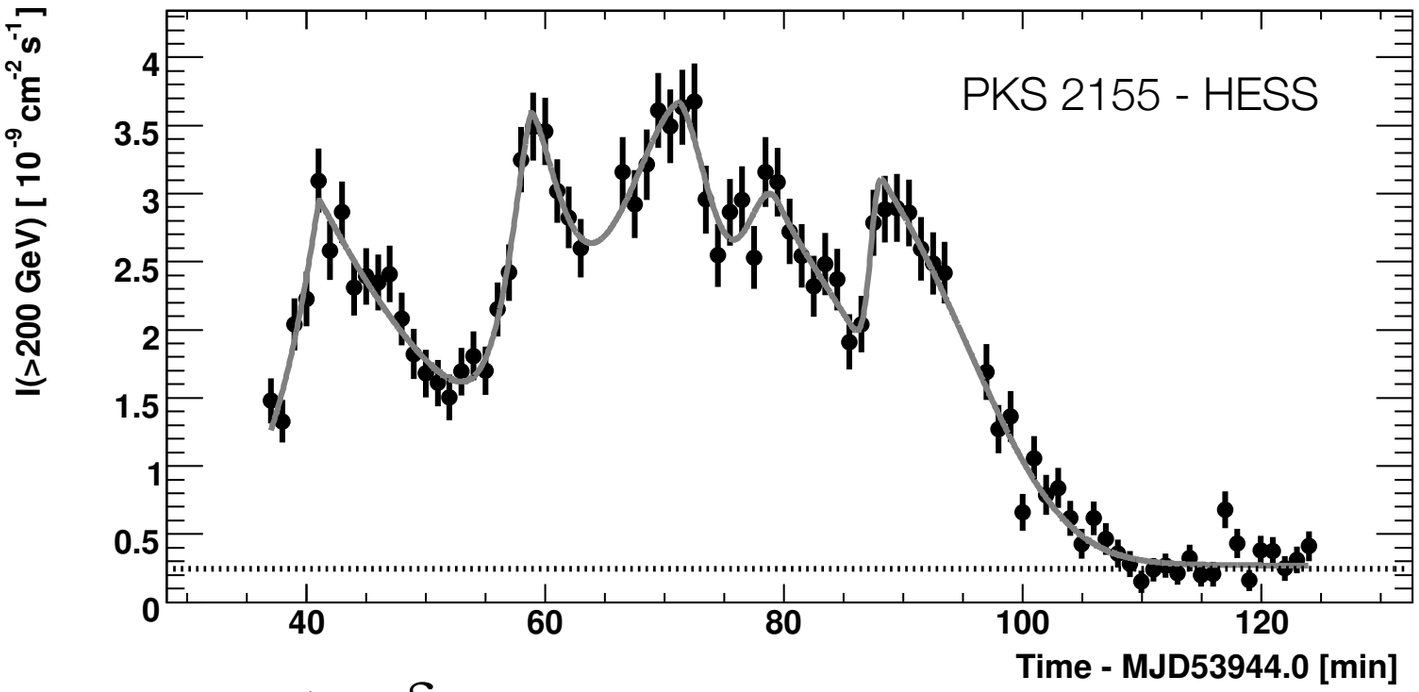
Complementary measurements allow for constraining the EBL level, with implications to cosmology.



Dwek & Krennrich 2012

EBL absorption

Comoving star formation rate



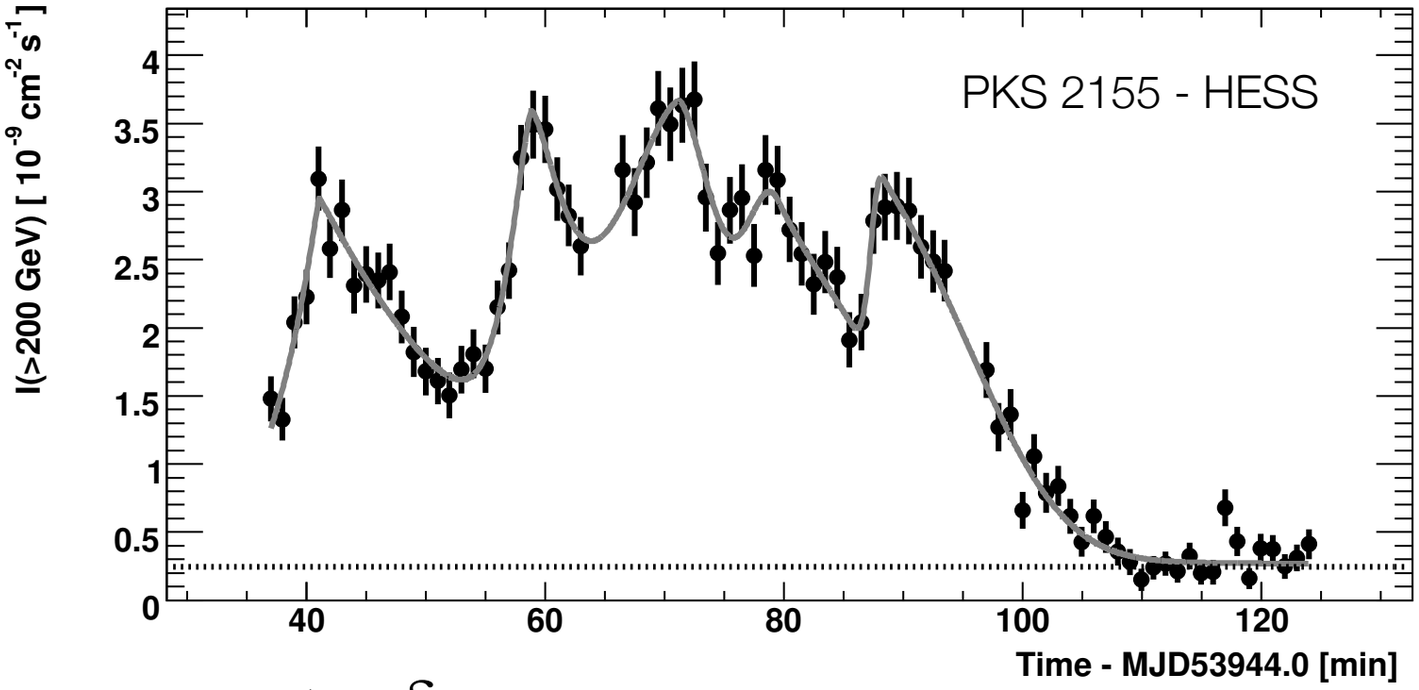
$$R' \leq \frac{ct_{\mathrm{var}}\delta}{1+z} \qquad R' \sim 10^{14} \text{ to } \sim 10^{17} \text{ cm}$$

Here is observed doubling timescales of ~ 2 min, and peak flux observed implied variations of an order of magnitude in flux in as little as 15 min.

This is equivalent to having the luminosity of the source changing by an amount equivalent to the Milky Way star light luminosity in a matter of minutes.

Flux Variability

Dramatic variability is observed in the emission from AGNs at the VHEs.



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Gamma-gamma escape condition:

$$R = c\,\Delta t_{var}\,\delta_j = 10^{14}\delta_{10} \text{ cm}$$

$$\Gamma > 100$$

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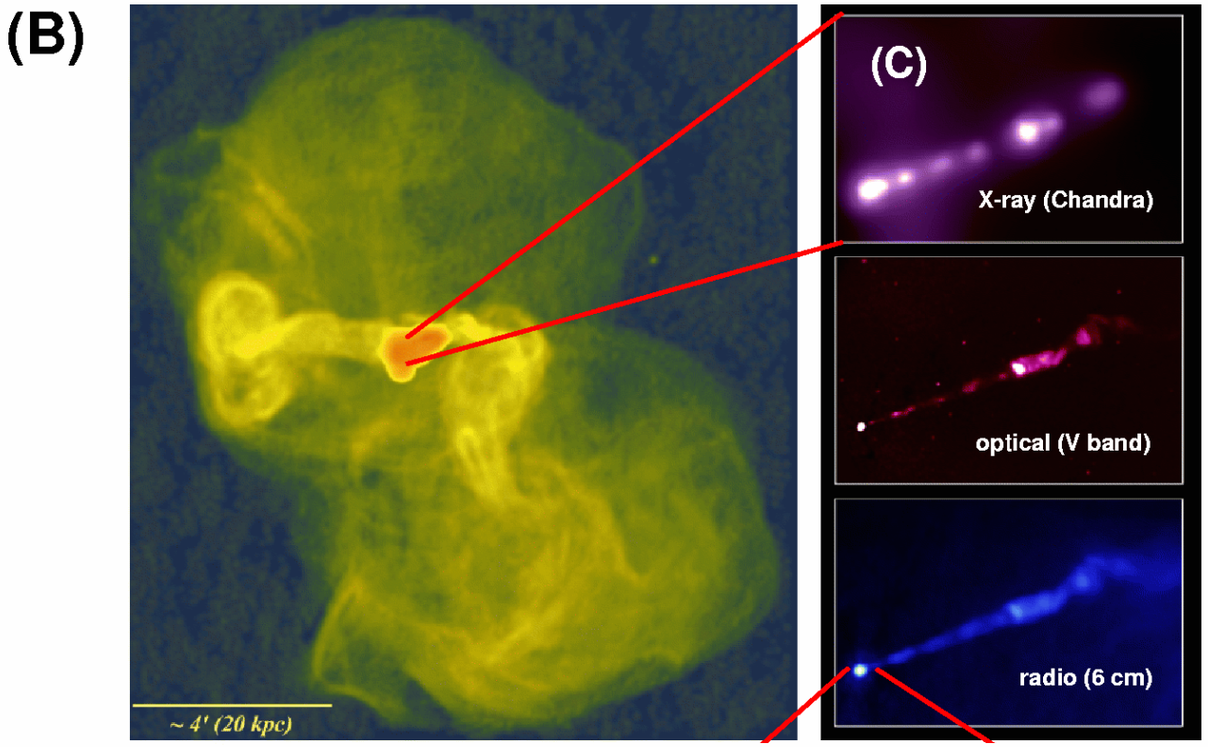
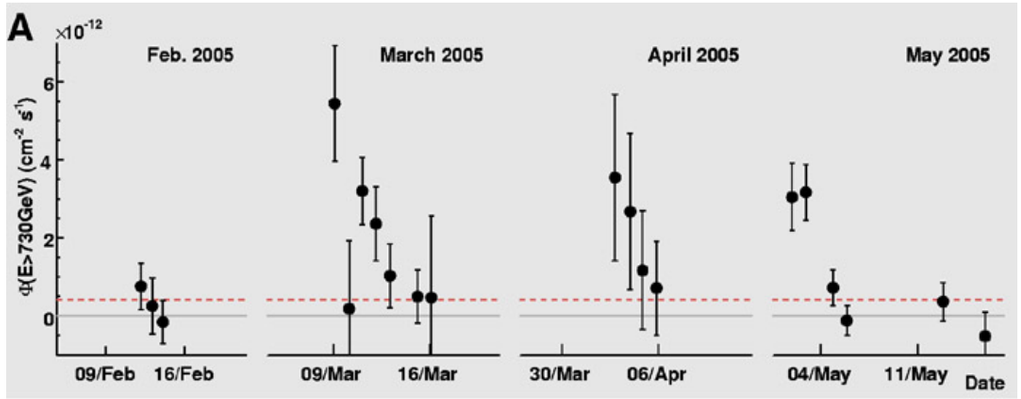
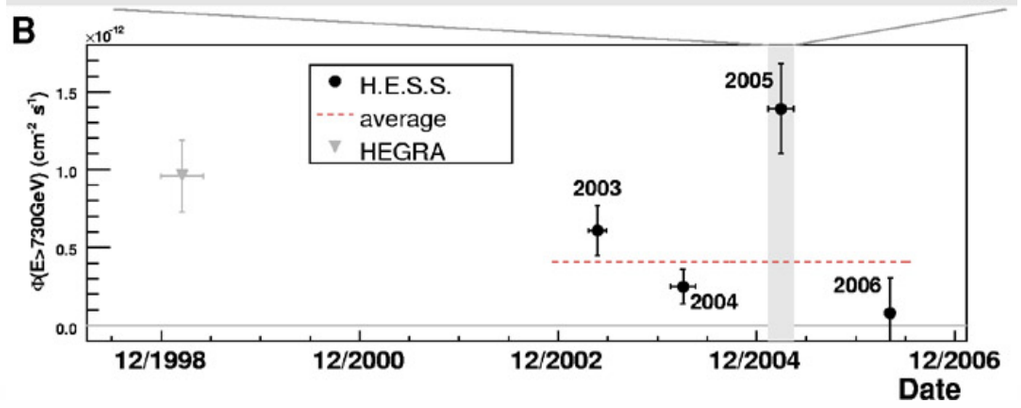
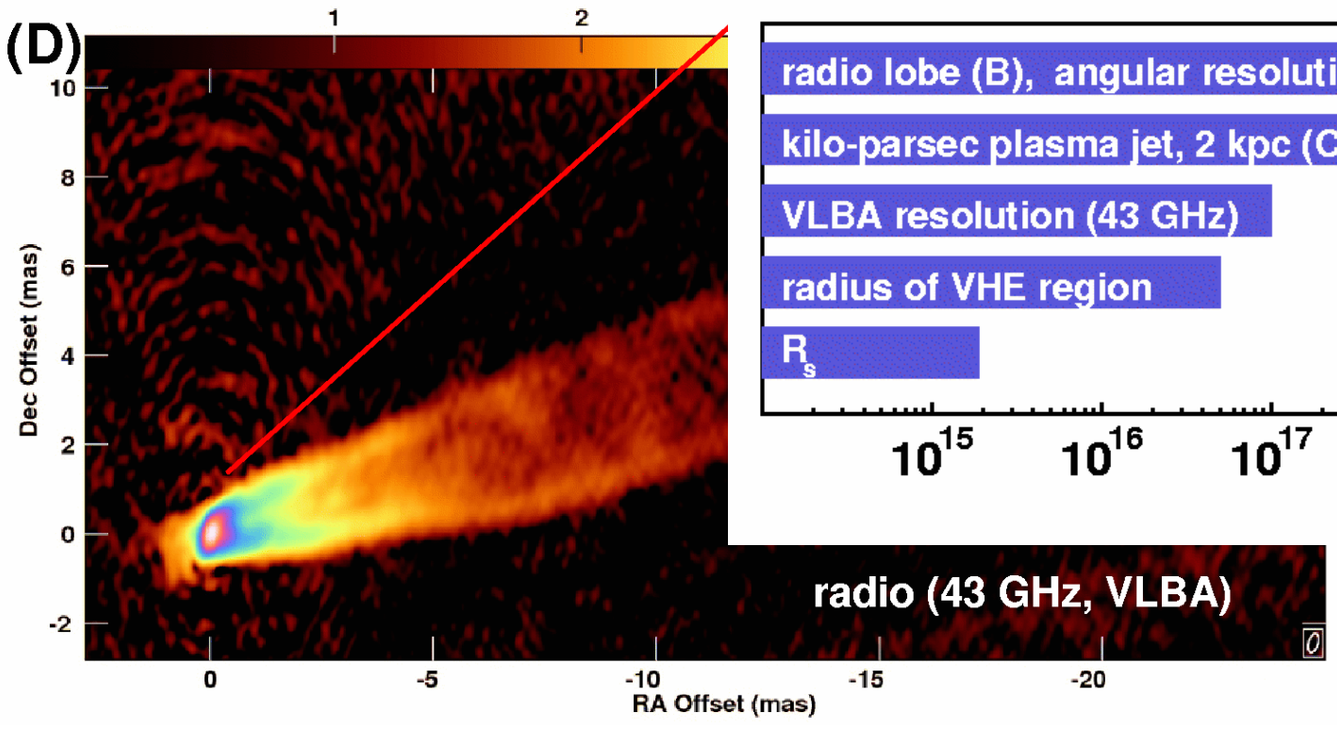
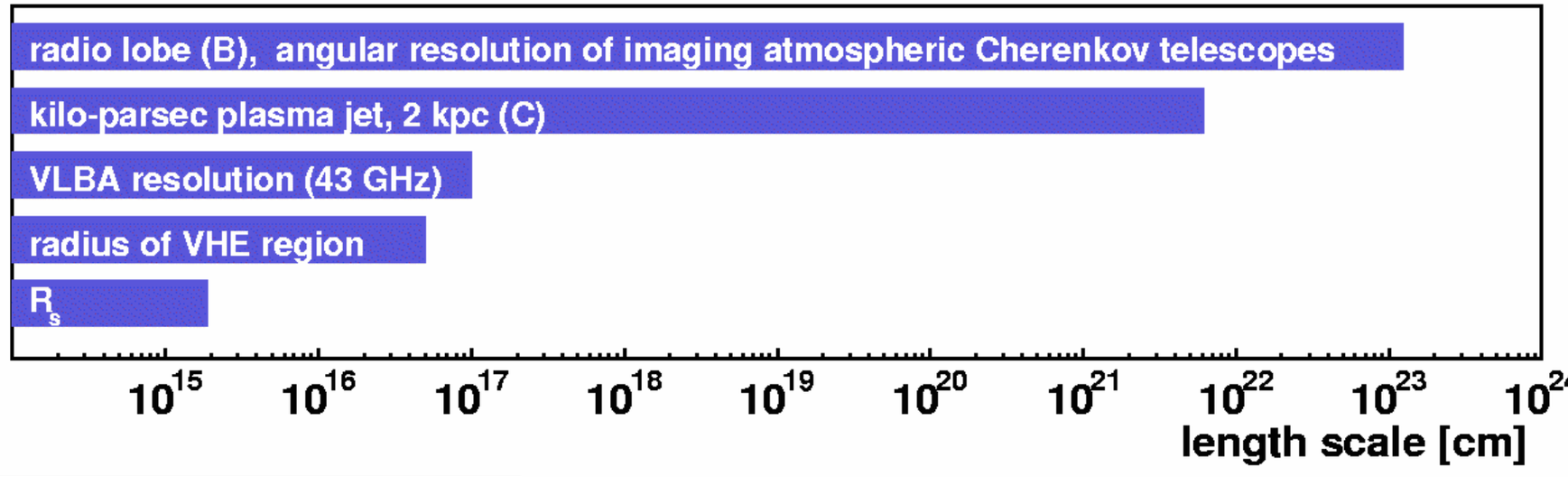




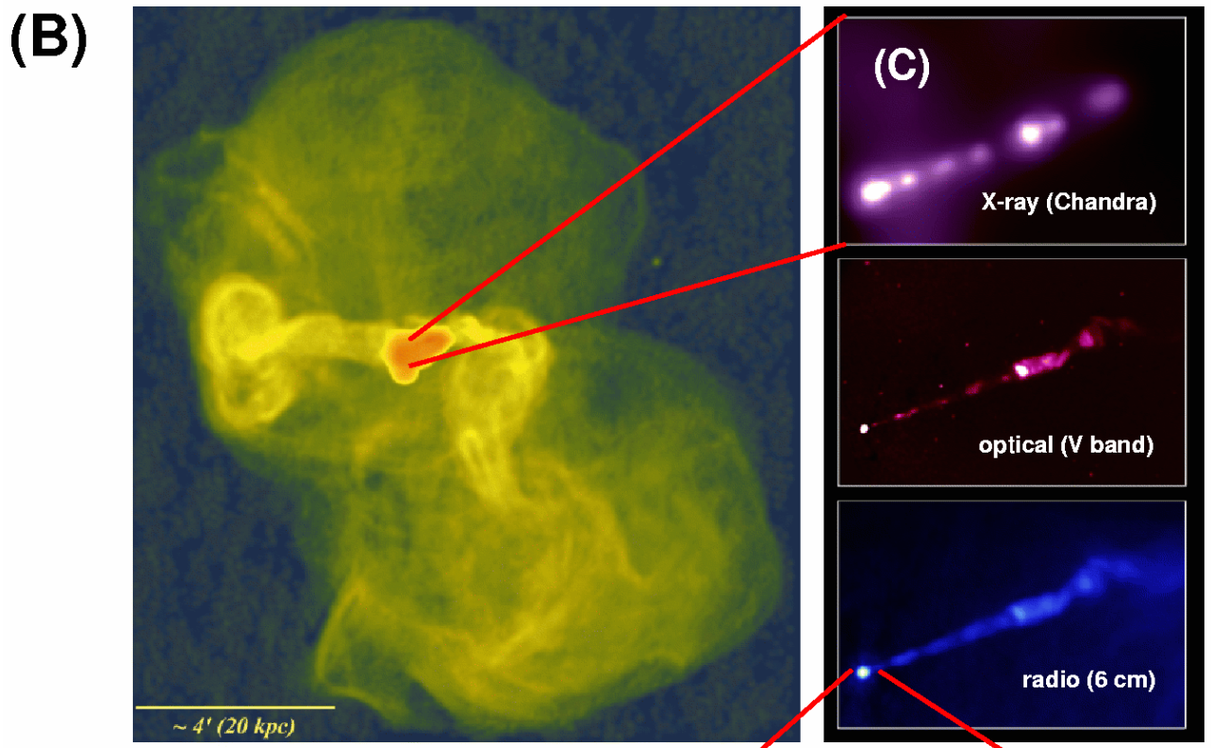


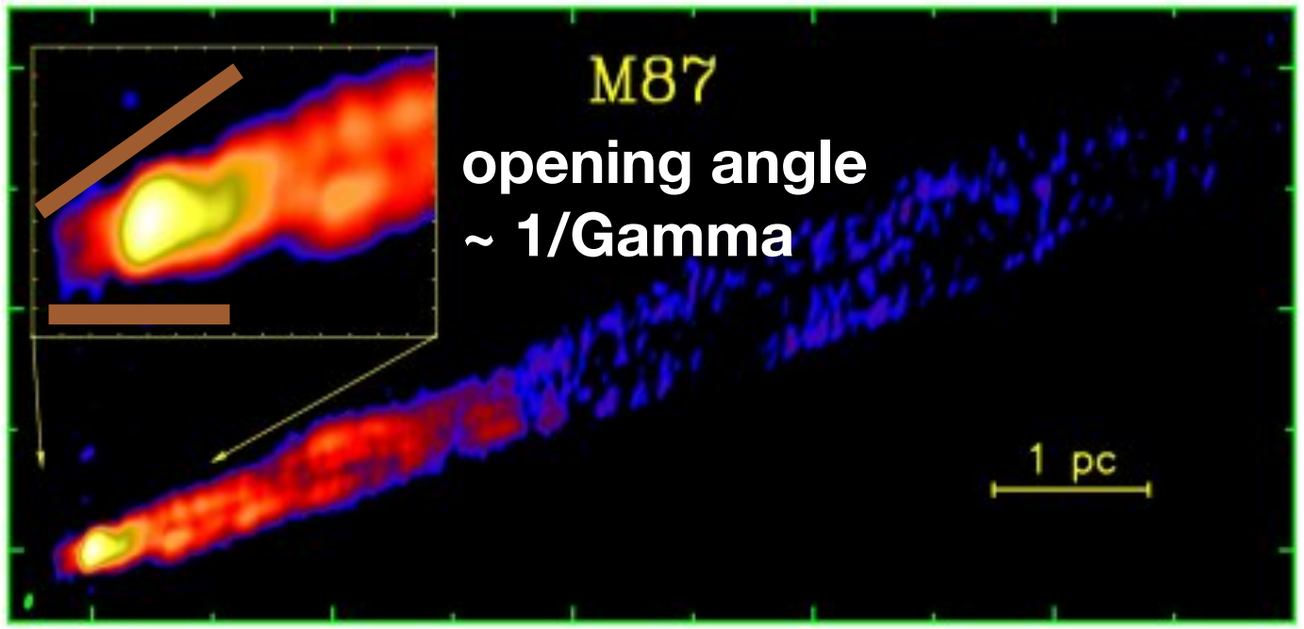


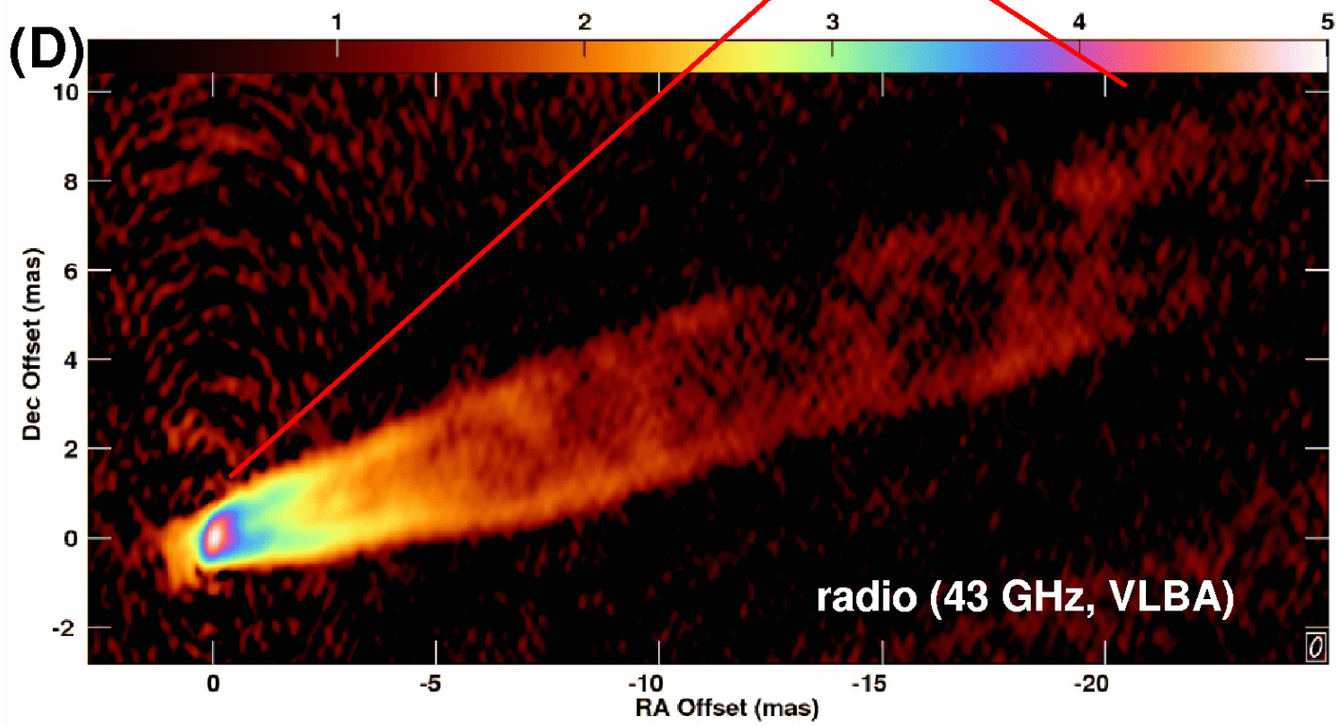


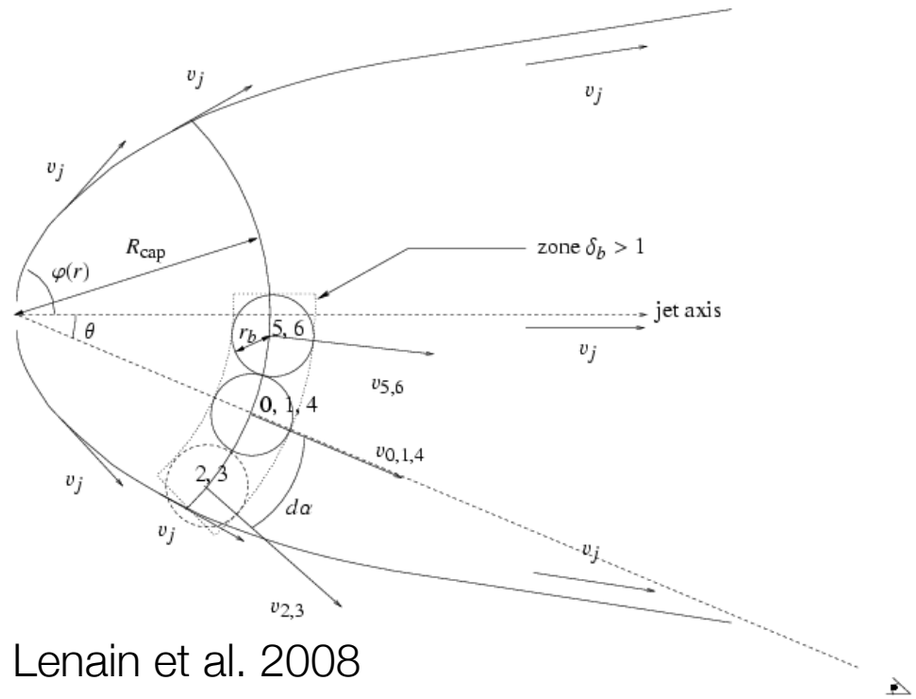
The jet of powerful AGNs

Images are for the M 87 jet - the closest, best studied powerful jet, emitting at VHEs.





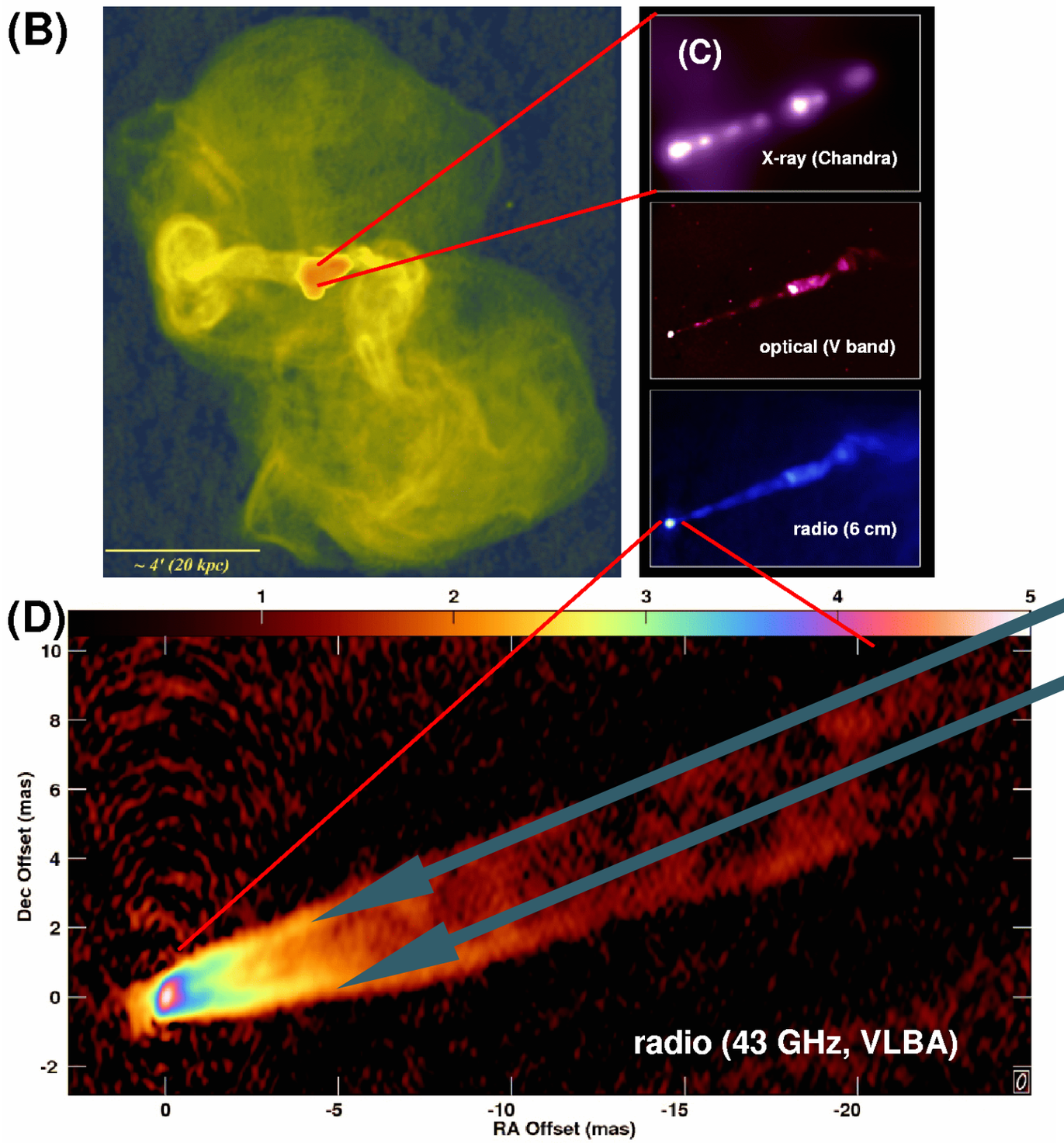


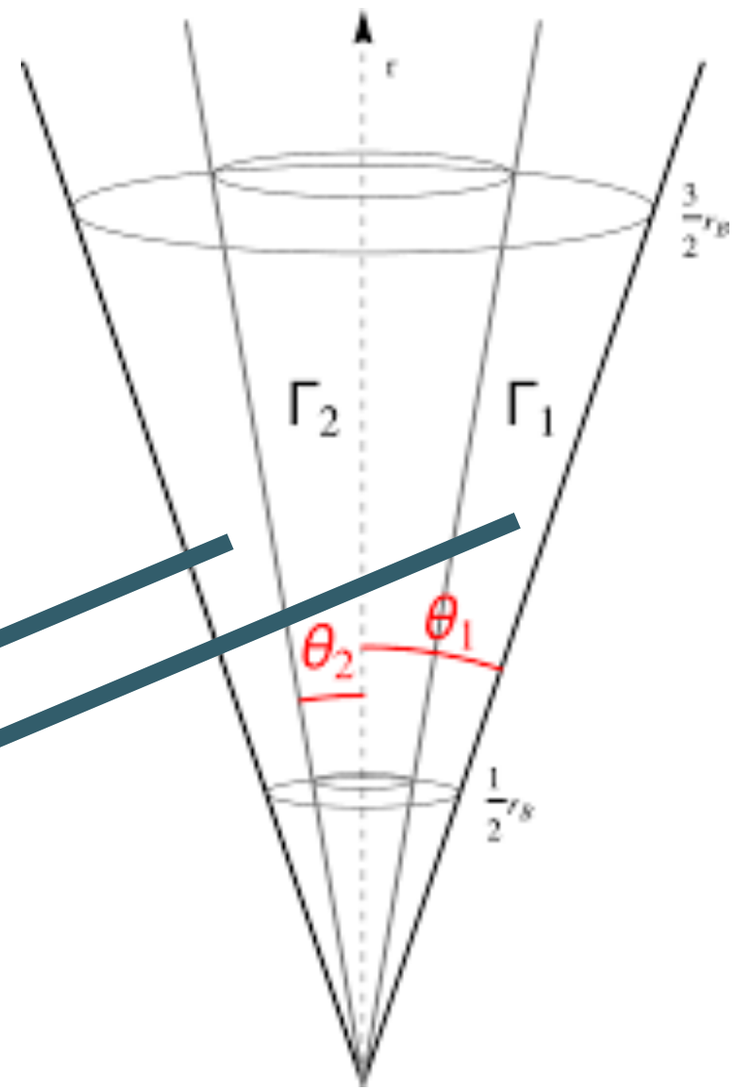


Lenain et al. 2008

Multi-zone emission models

Multi-blob models and interaction multi-zone models are a means to explain mis-aligned VHE source emission.





Sikora et al. 2011 - Spine - Sheath model

Multi-zone emission models

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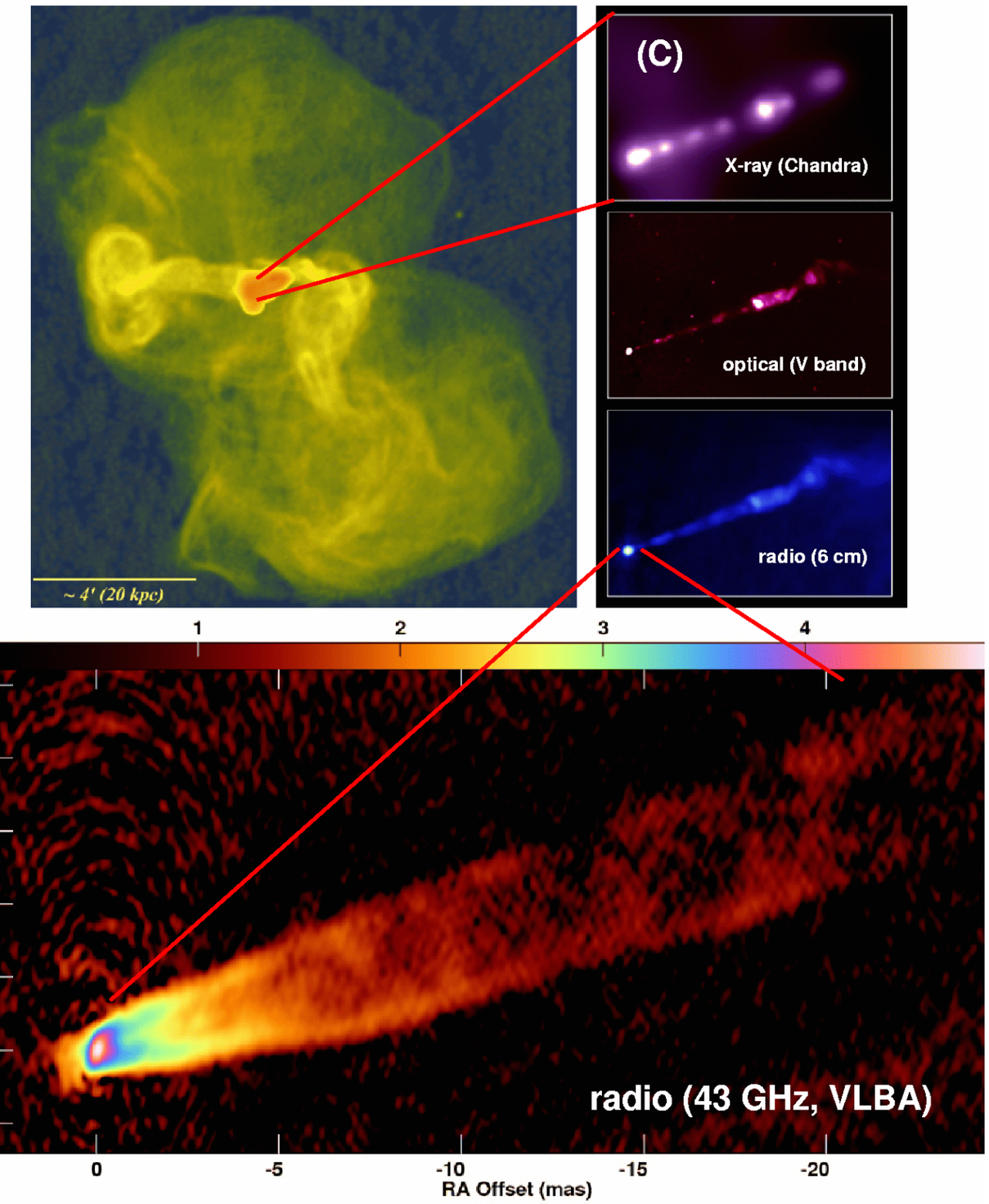
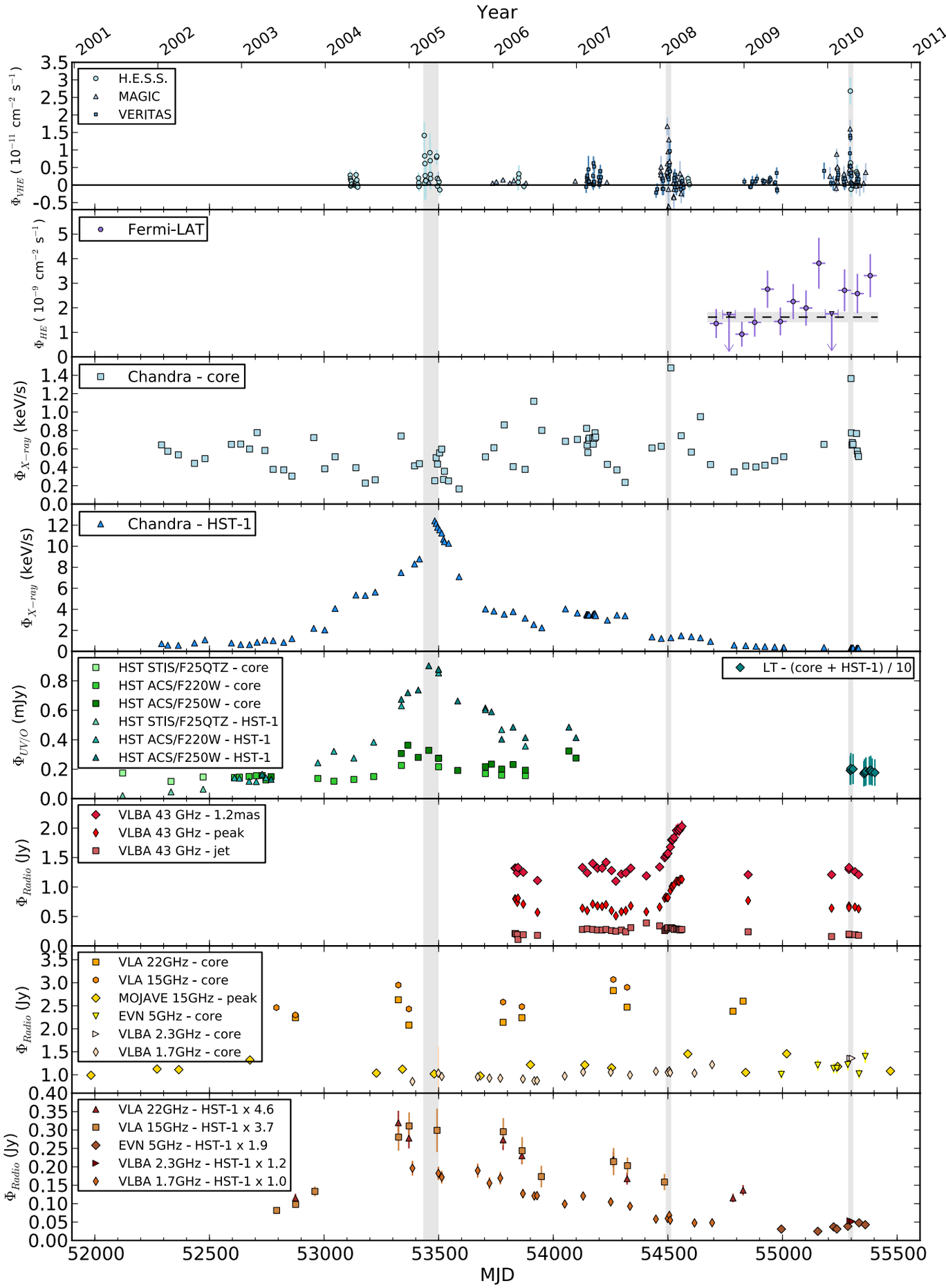
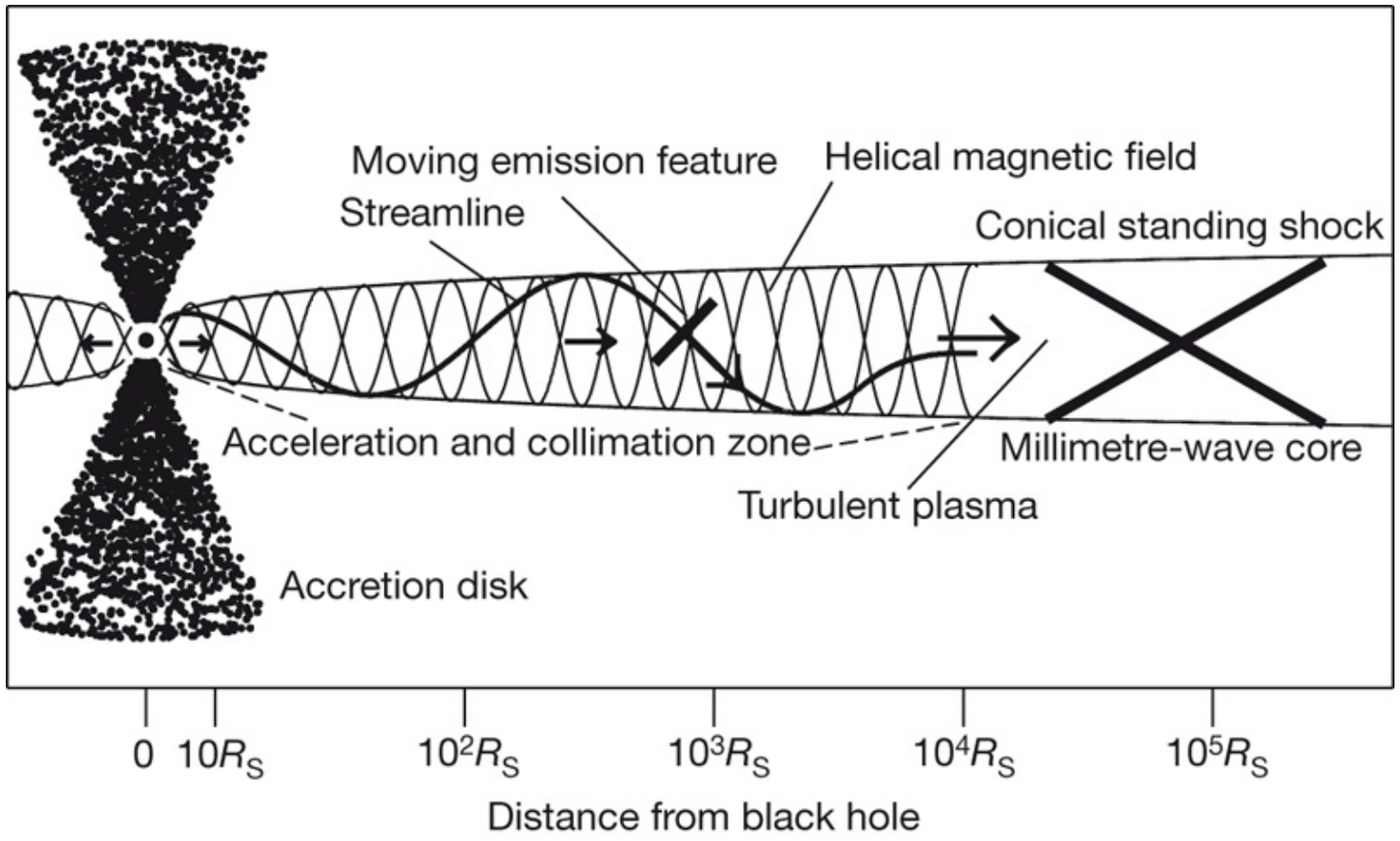
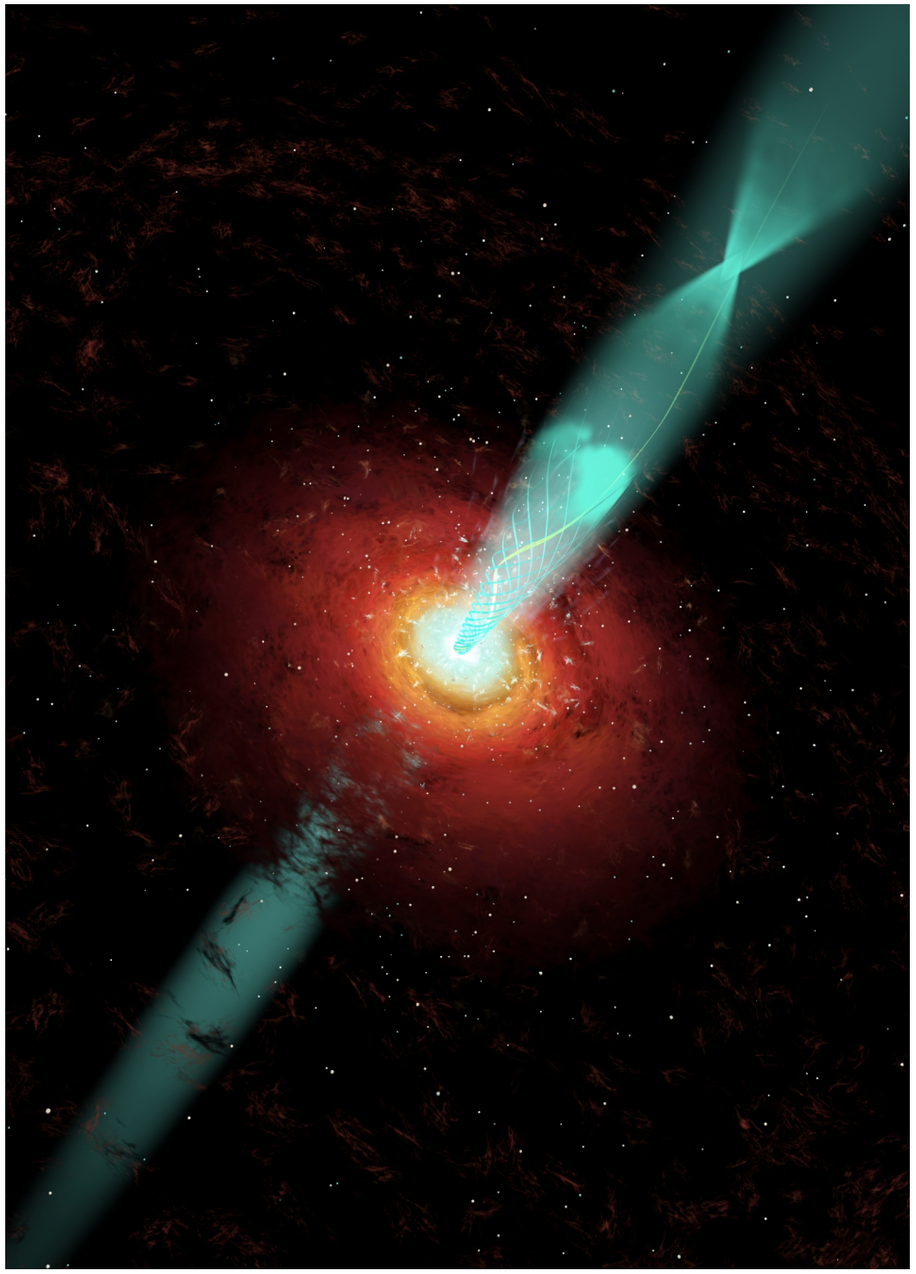
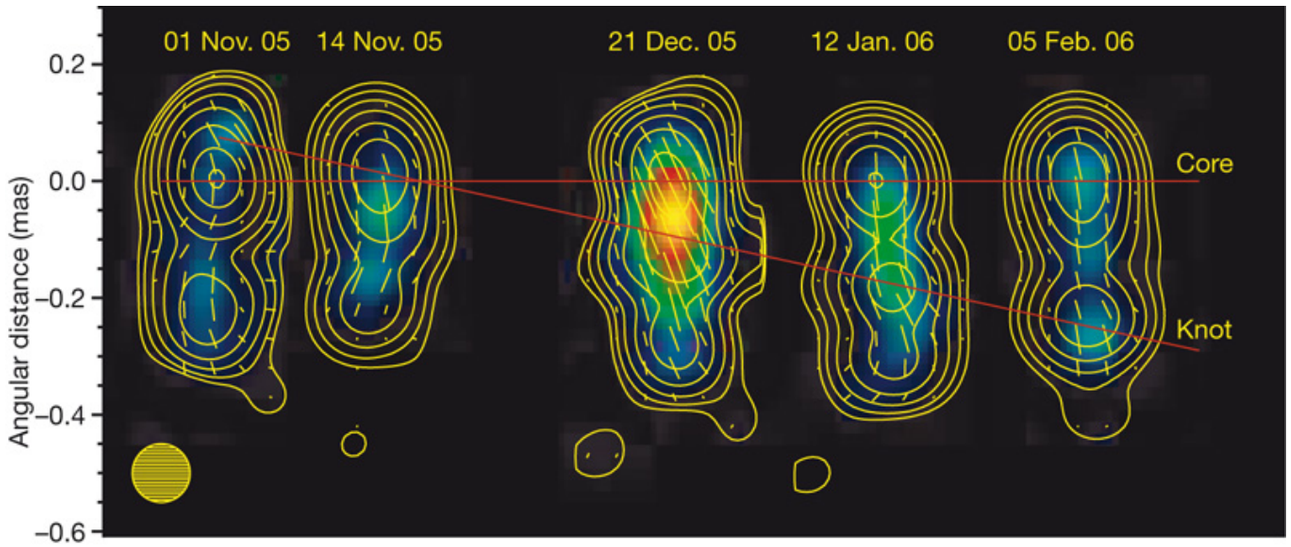


Multi-wavelength picture



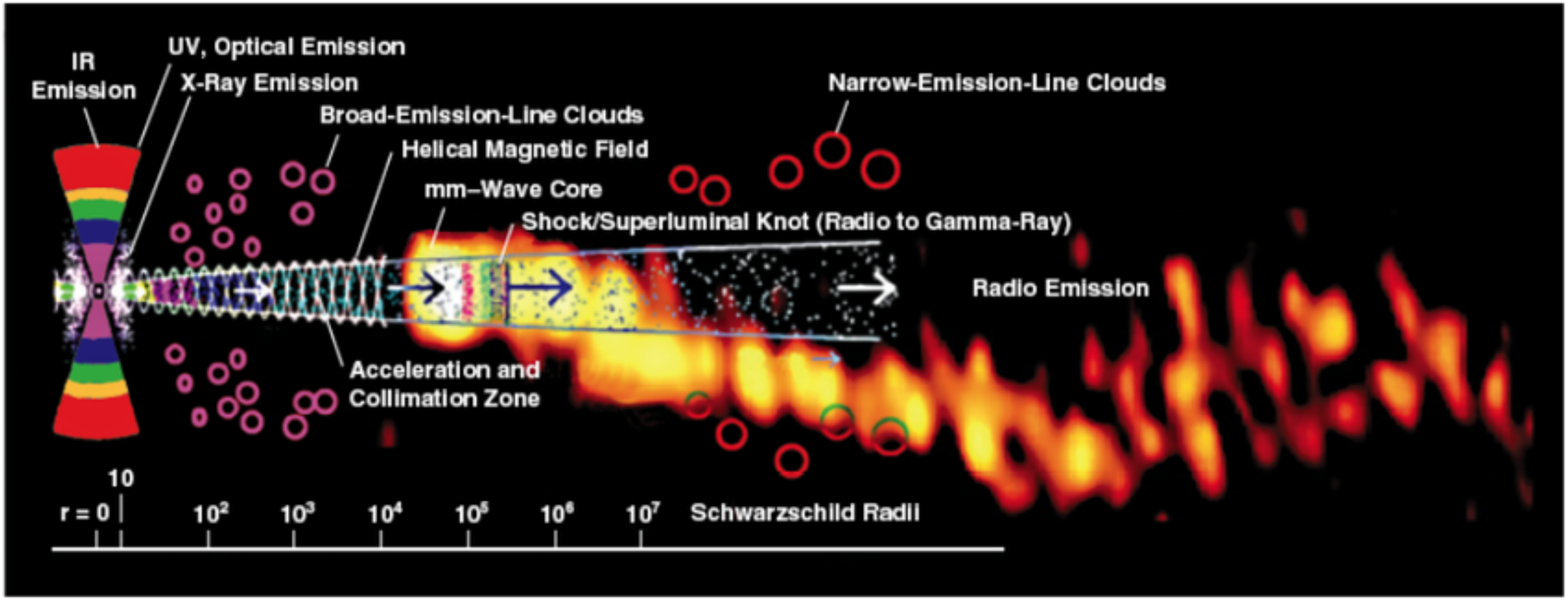


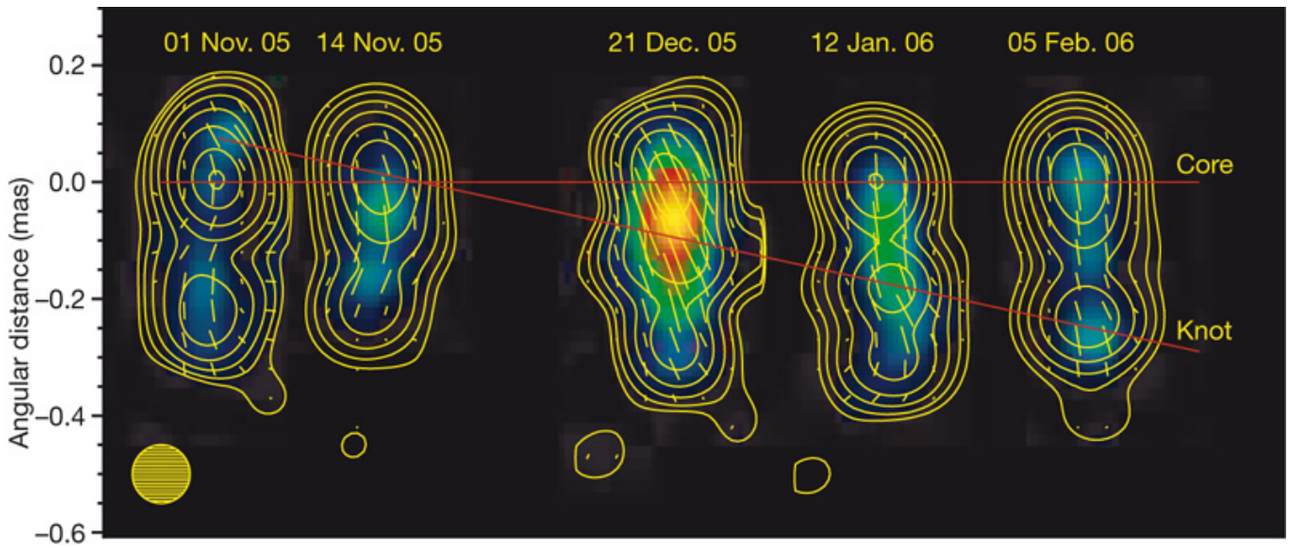




The jets of AGNs as revealed by high-E observations

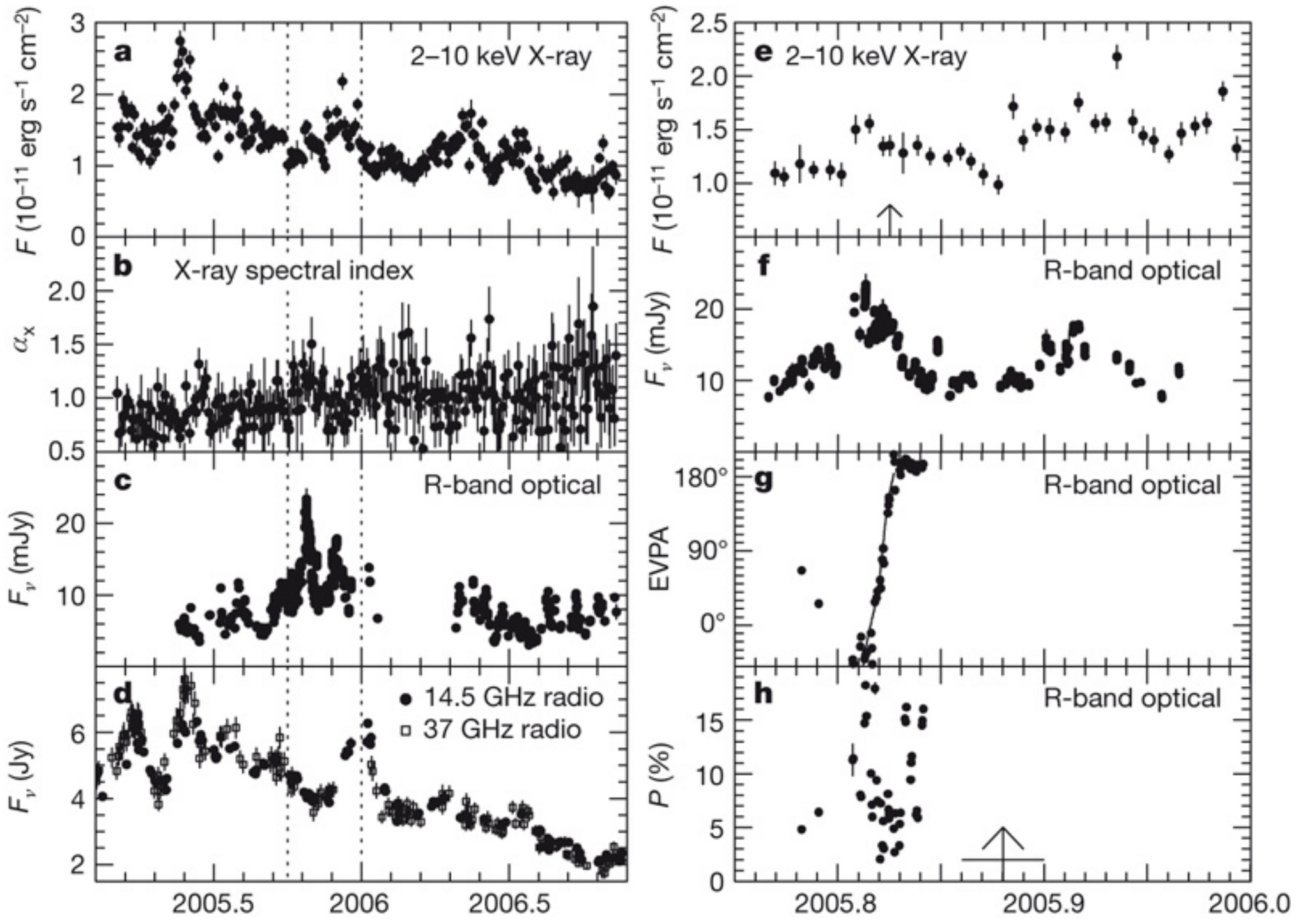
The famous case of BL Lac - Marscher et al. 2008, Nature





The location of the gamma-ray emission?

The famous case of BL Lac - Marscher et al. 2008, Nature



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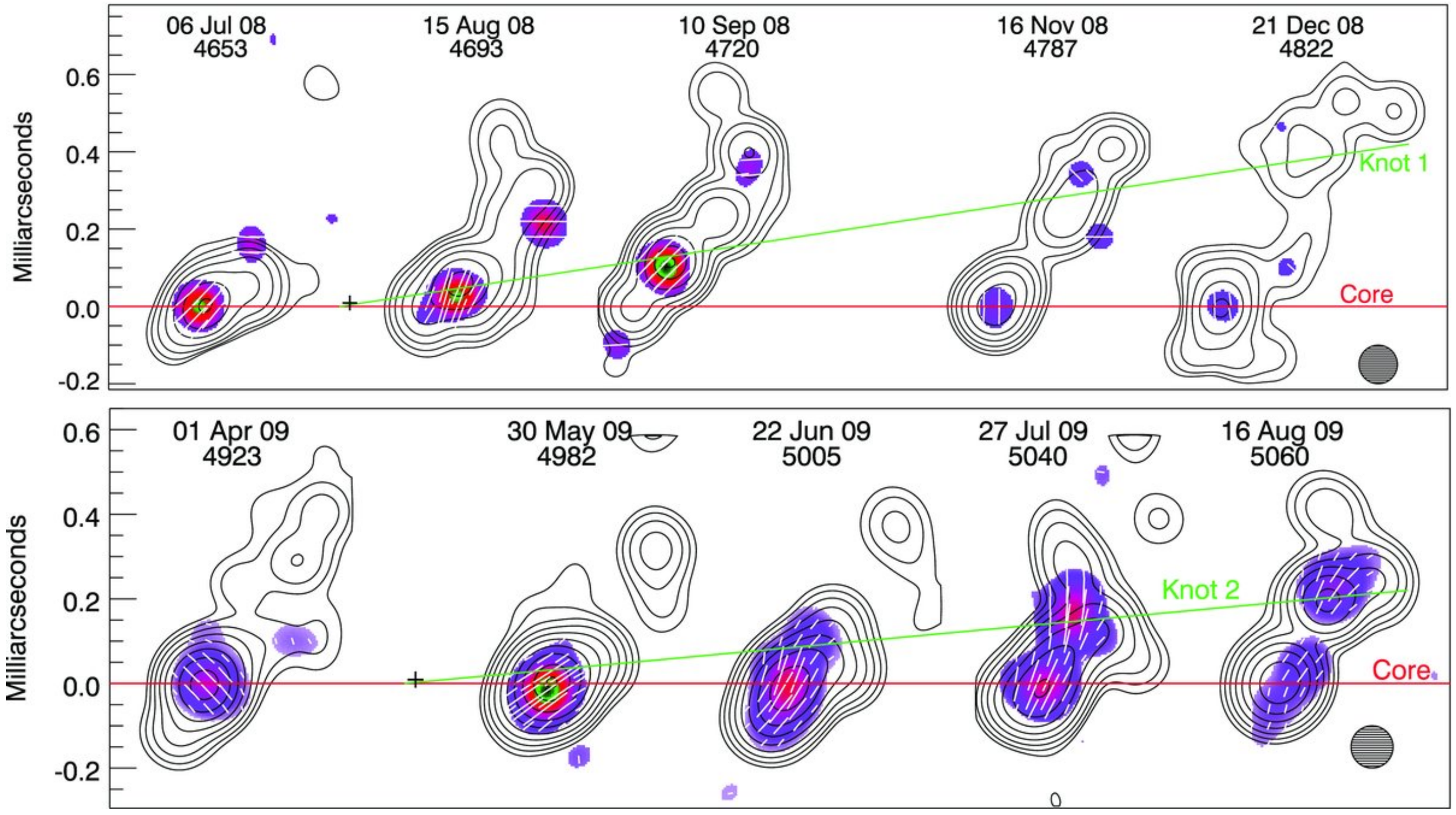
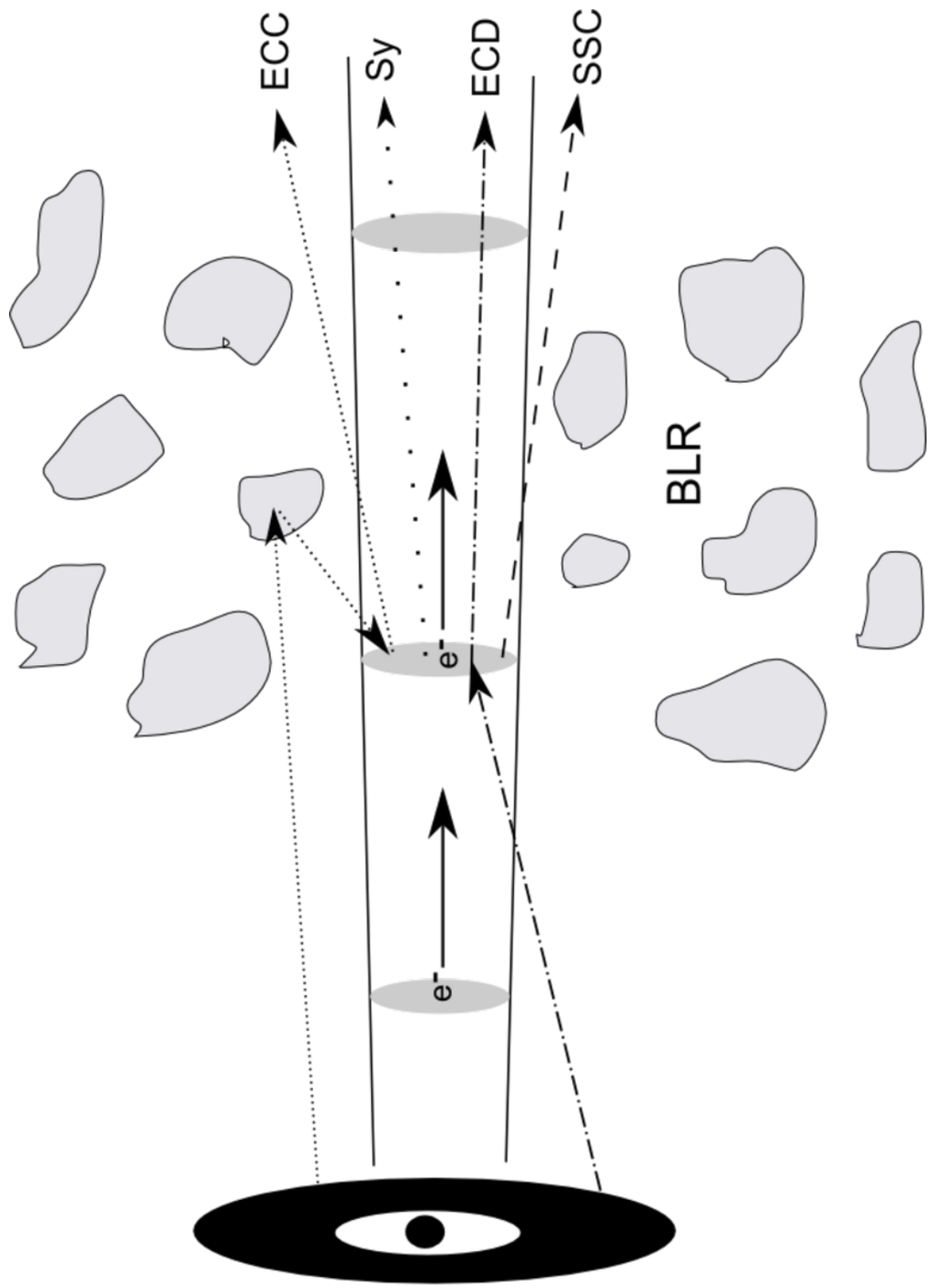


The location of the gamma-ray emission?

PKS 1510-089.

The moment of a gamma-ray flare can be traced to the emission of a radio blob.



Gamma-gamma opacity:

$$\tau_{\gamma\gamma} = n\,\sigma_{\gamma\gamma} R \approx n\,\sigma_T R$$

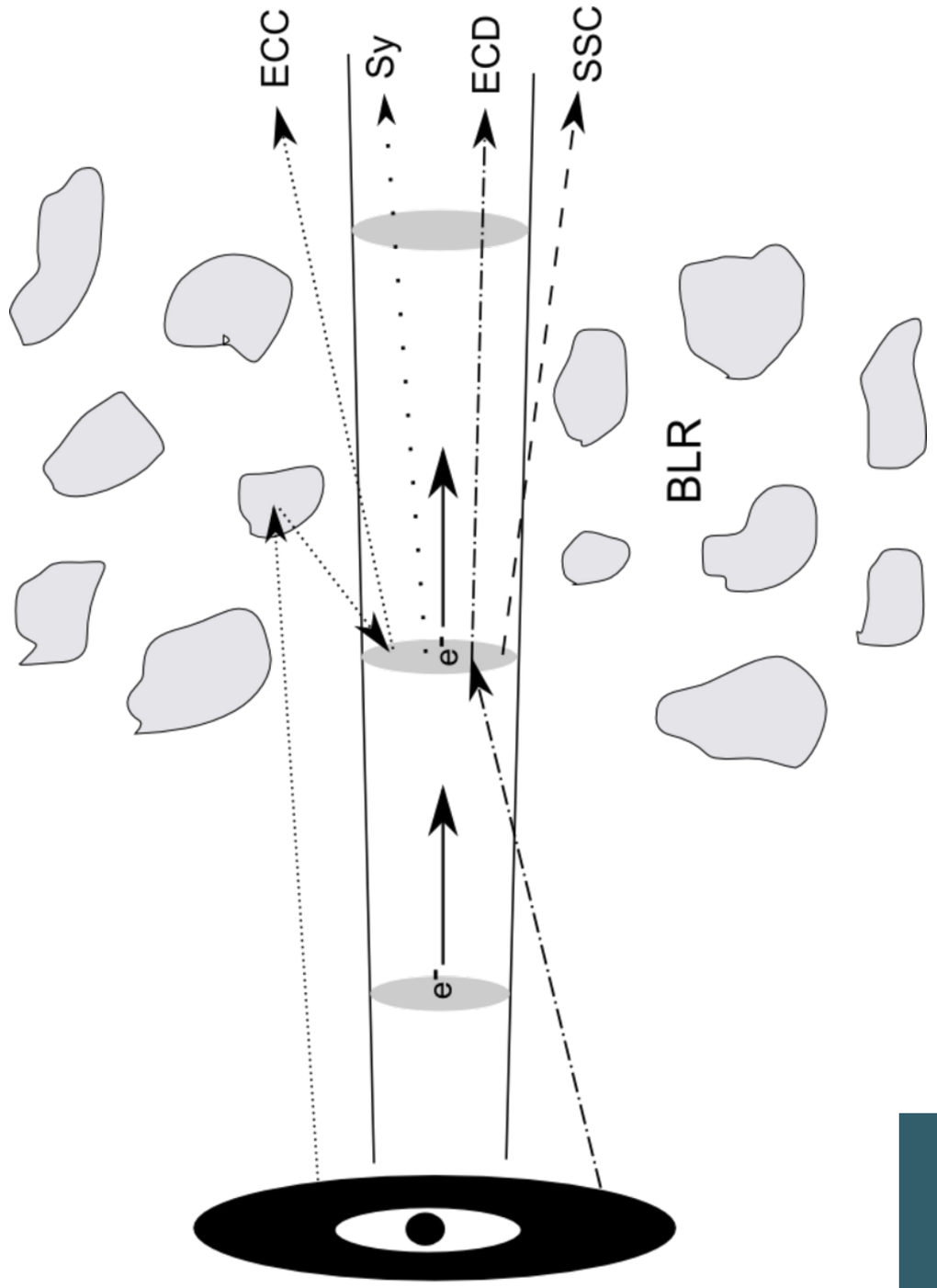
$$\tau_{\gamma\gamma} \approx \sigma_T L / (4\pi c^2 E T_{var})$$

Solution is a high beaming D:
[Rees 1966]

$$L \approx D^4 \cdot L' \approx 4\pi c^3 D^6 \cdot u' \cdot T^2_{var}$$

The location of the gamma-ray emission?

A caveat: intrinsic gamma-gamma absorption opacity and the necessity for Doppler boosting



Gamma-gamma opacity:

$$\tau_{\gamma\gamma} = n\,\sigma_{\gamma\gamma} R \approx n\,\sigma_T R$$

$$\tau_{\gamma\gamma} \approx \sigma_T L / (4\pi c^2 E T_{var})$$

Solution is a high beaming D:
[Rees 1966]

$$L \approx D^4 \cdot L' \approx 4\pi c^3 D^6 \cdot u' \cdot T^2_{var}$$

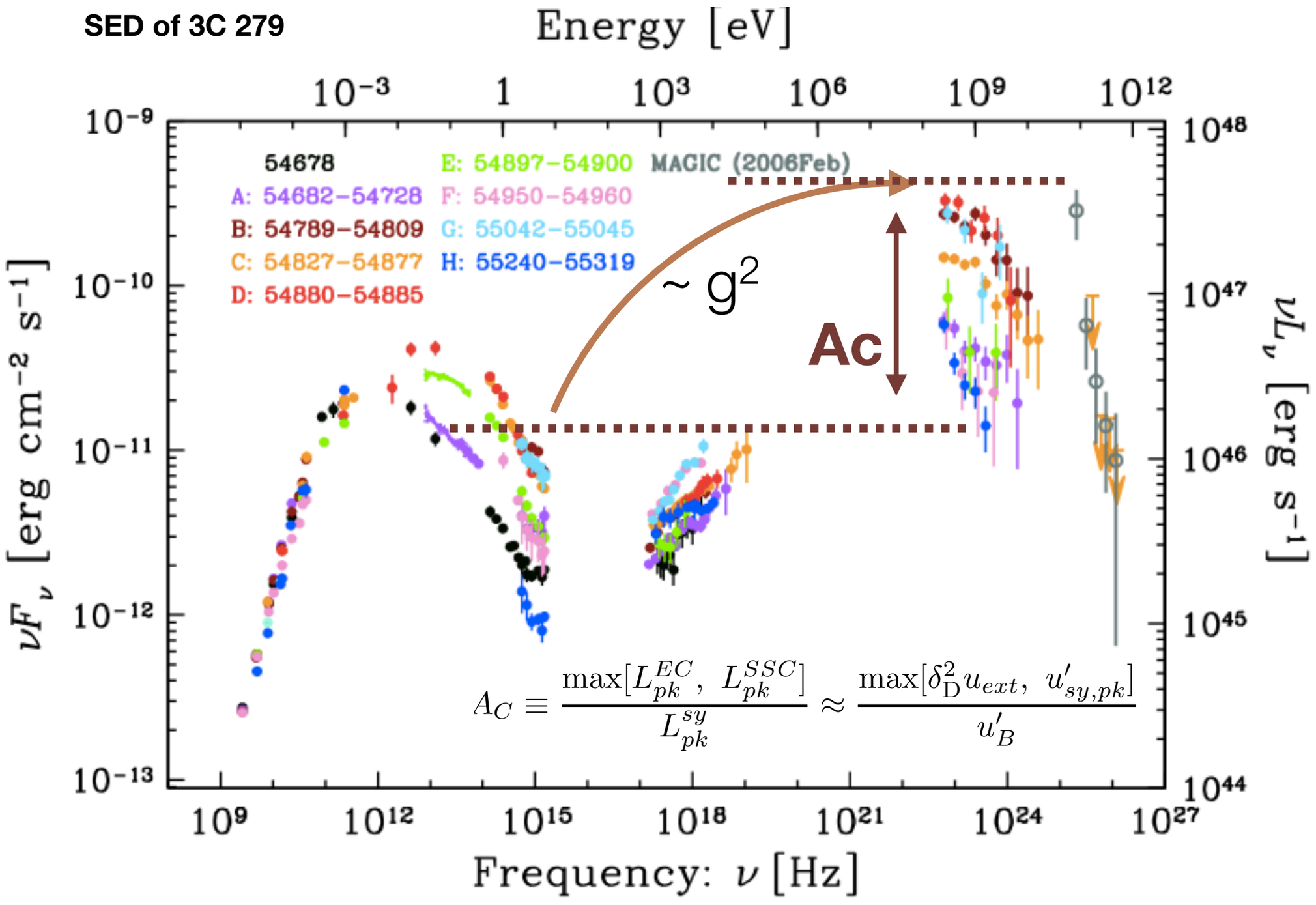
Doppler Crisis?

Inferred vs. VLBI observed "D"

The location of the gamma-ray emission?

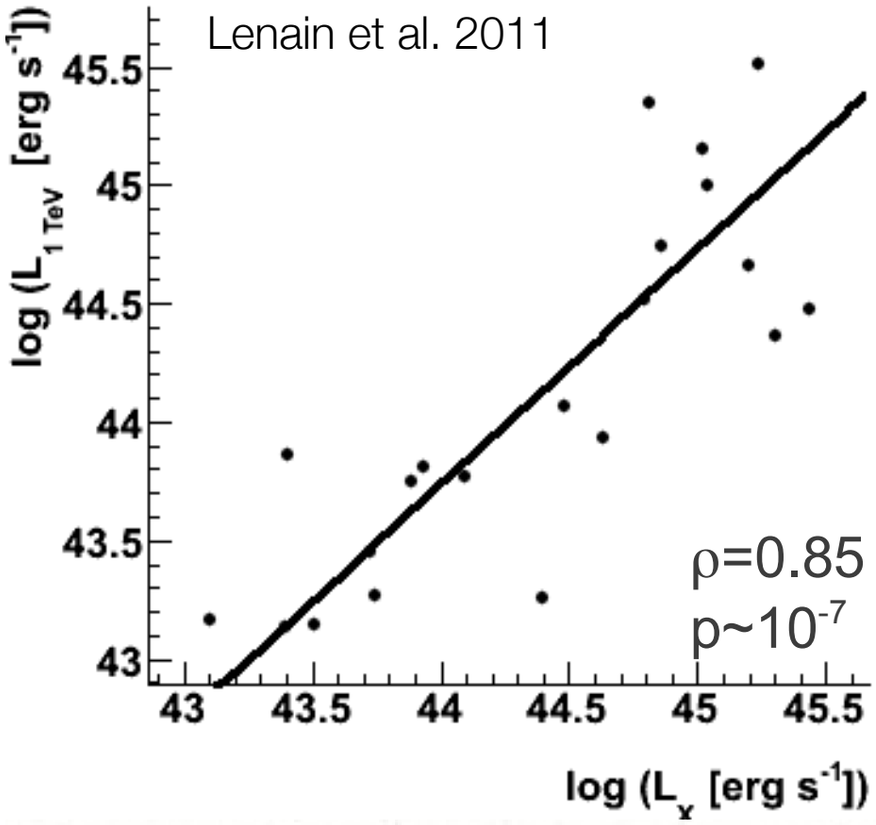
A caveat: intrinsic gamma-gamma absorption opacity and the necessity for Doppler boosting

SED of 3C 279



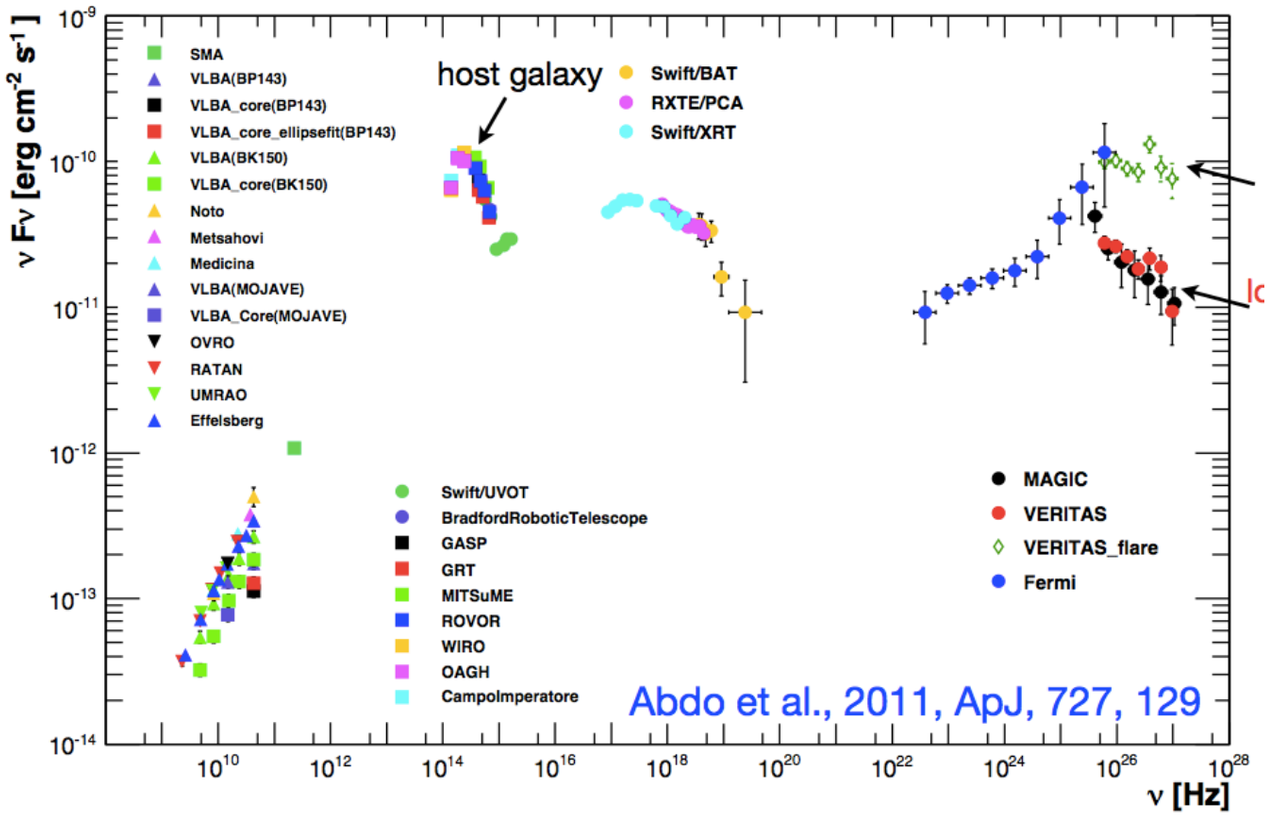
The origin of the correlated variability

The SED of blazars is formed by two broad bumps of Sy and IC emission, from a same particle population.



Correlation with X-ray Sy luminosity
(energetic particle pops)

The archetypical Blazar Mkn 501



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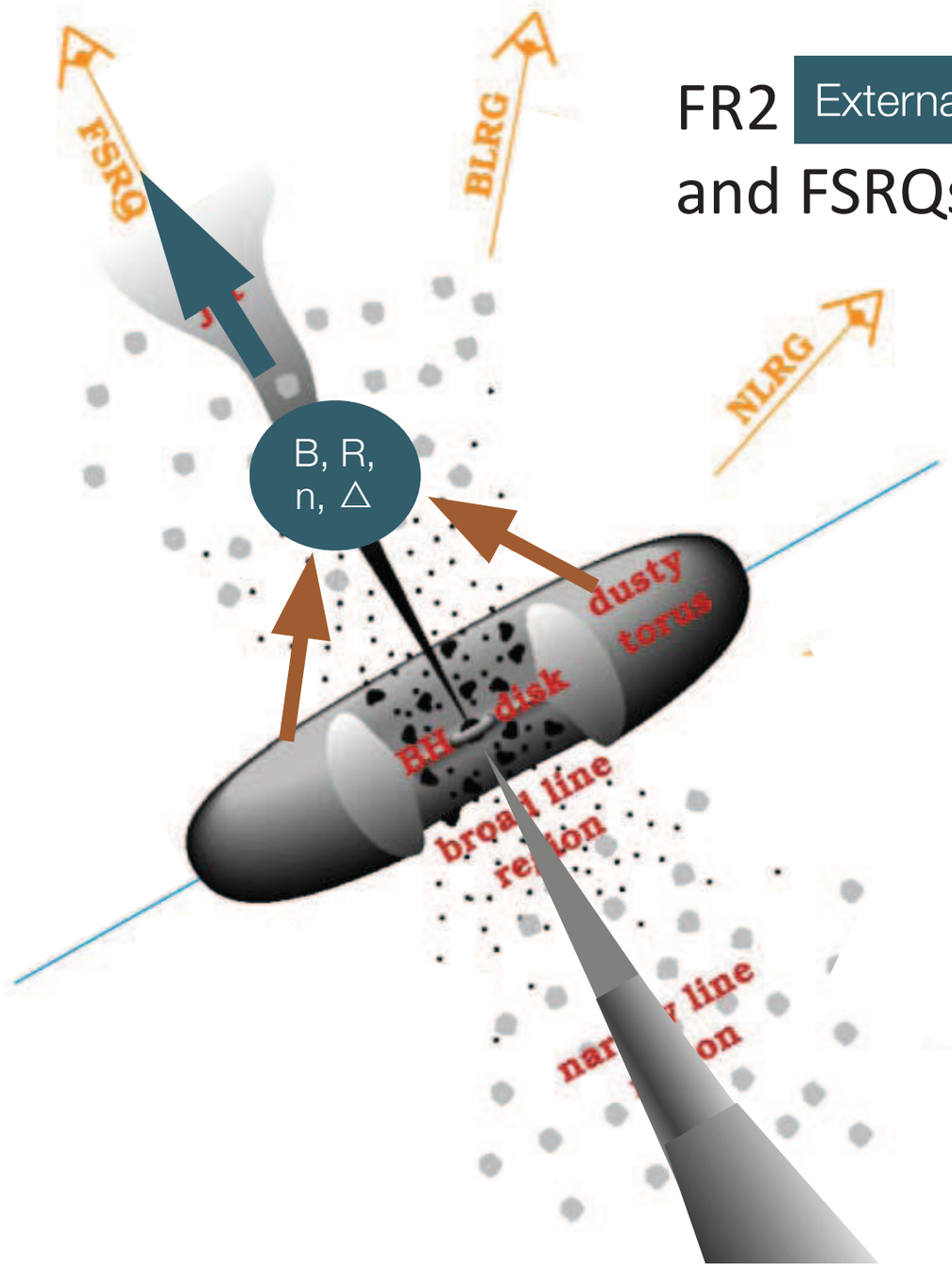
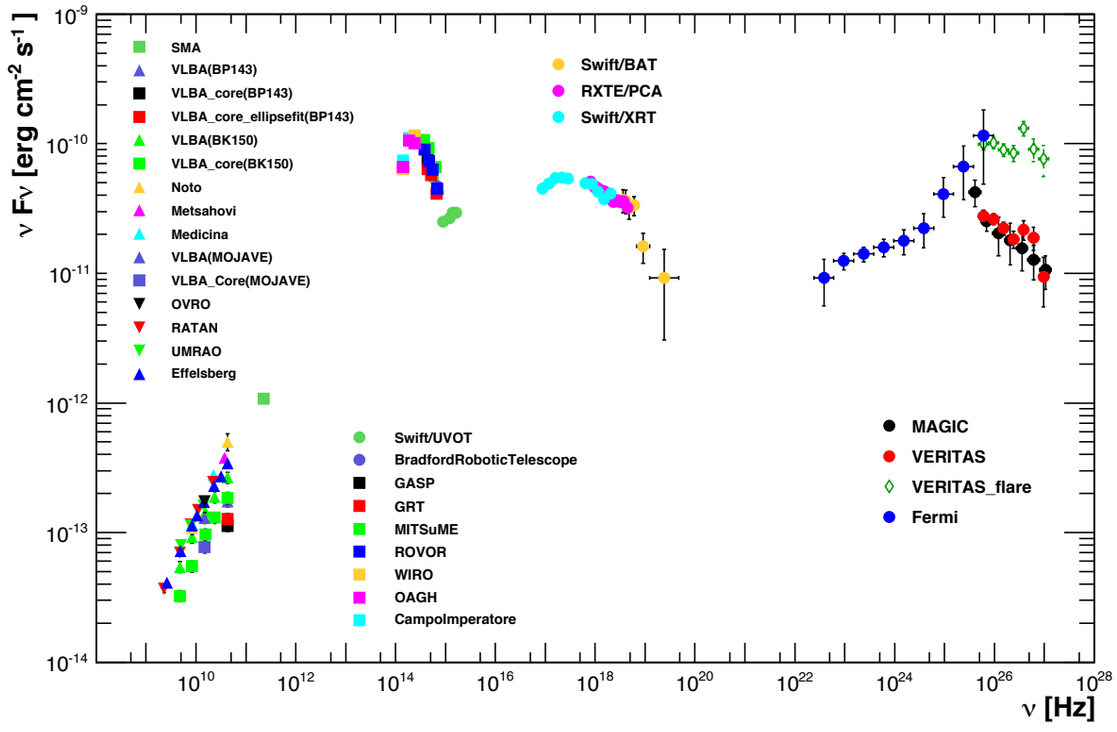
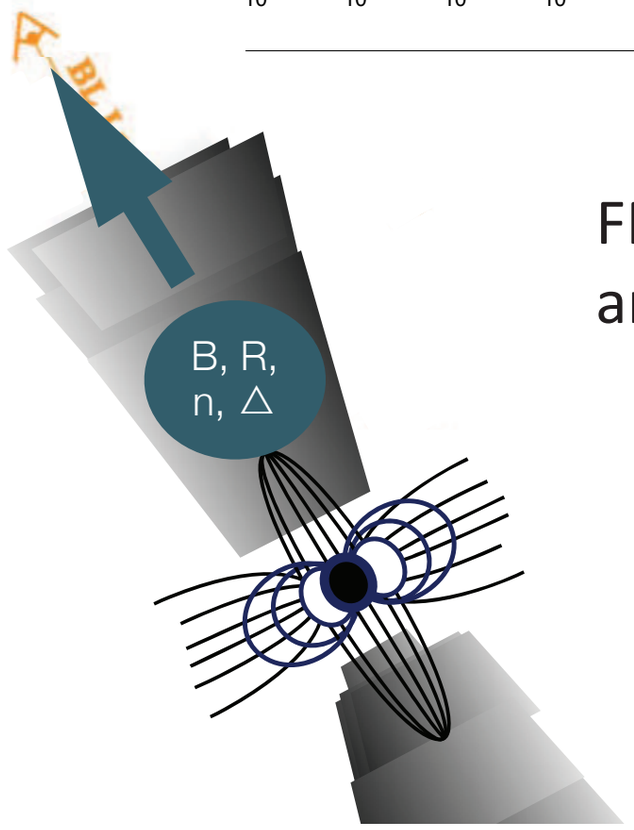


FR2 External Compton?
and FSRQs

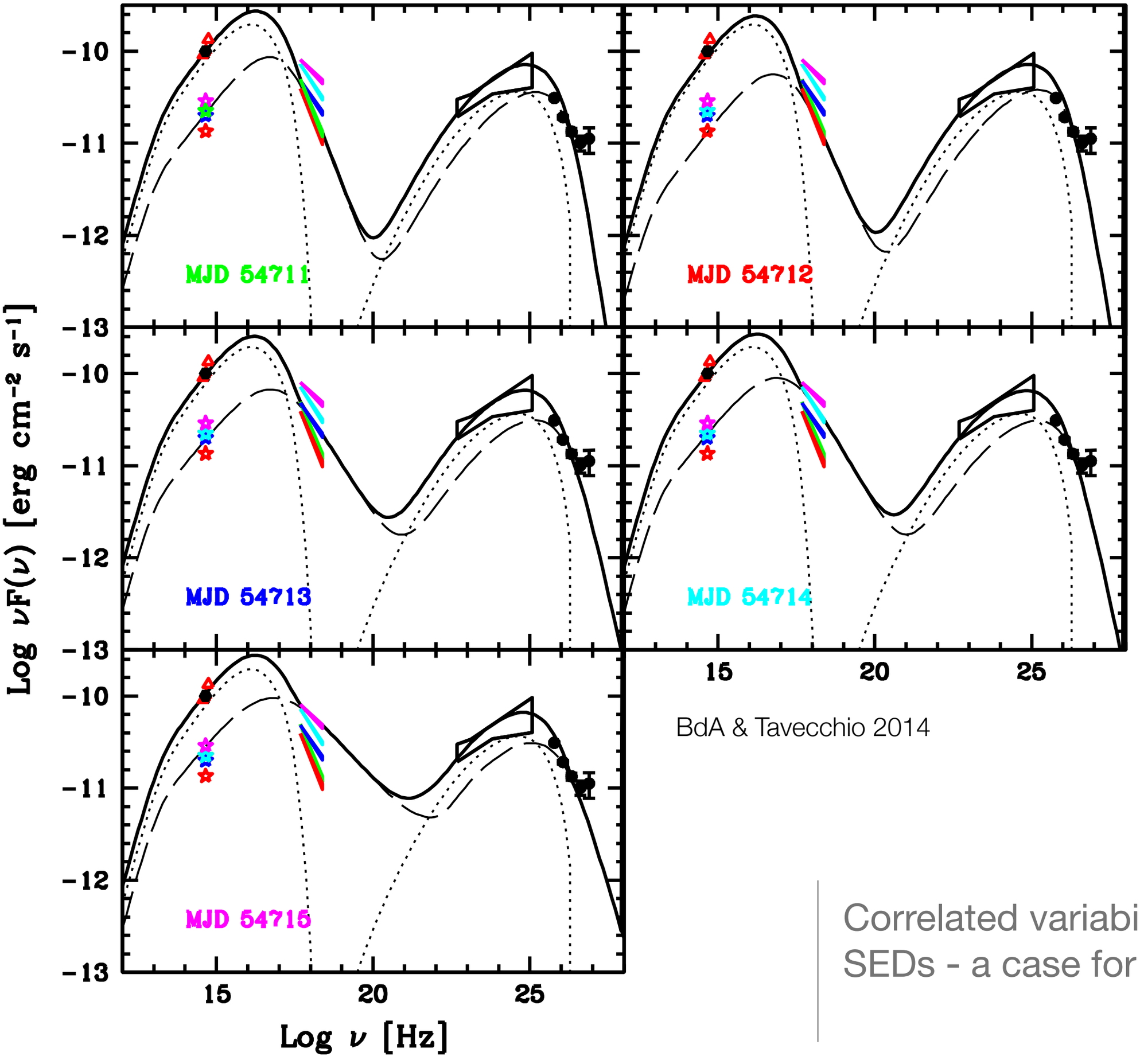




FR1 Sy Self-Compton?
and BL Lac Objects

Which leptonic mechanism?

Dependence on the environment radiation density will constrain location and dominant of SSC or EC in leptonic models.



BdA & Tavecchio 2014

Correlated variability in AGN SEDs - a case for PKS 2155-304.

- **proton-matter interaction:**

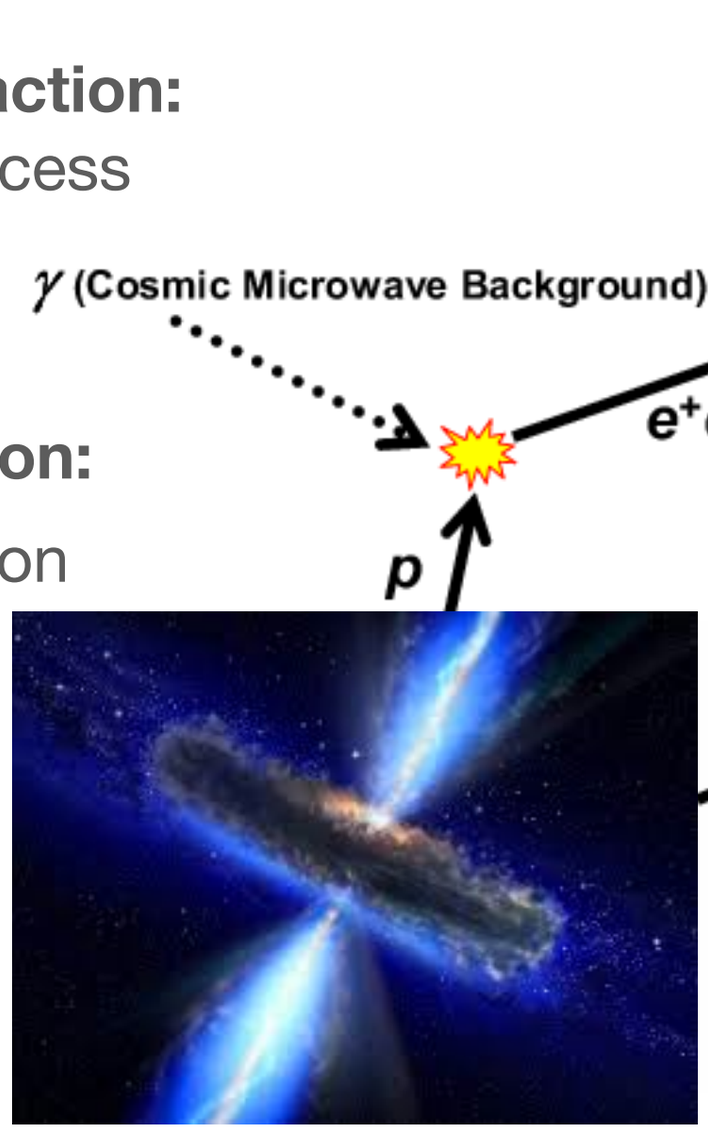
very slow inefficient process

neutrinos

- **photo-pion production:**

severe gamma absorption

neutrinos



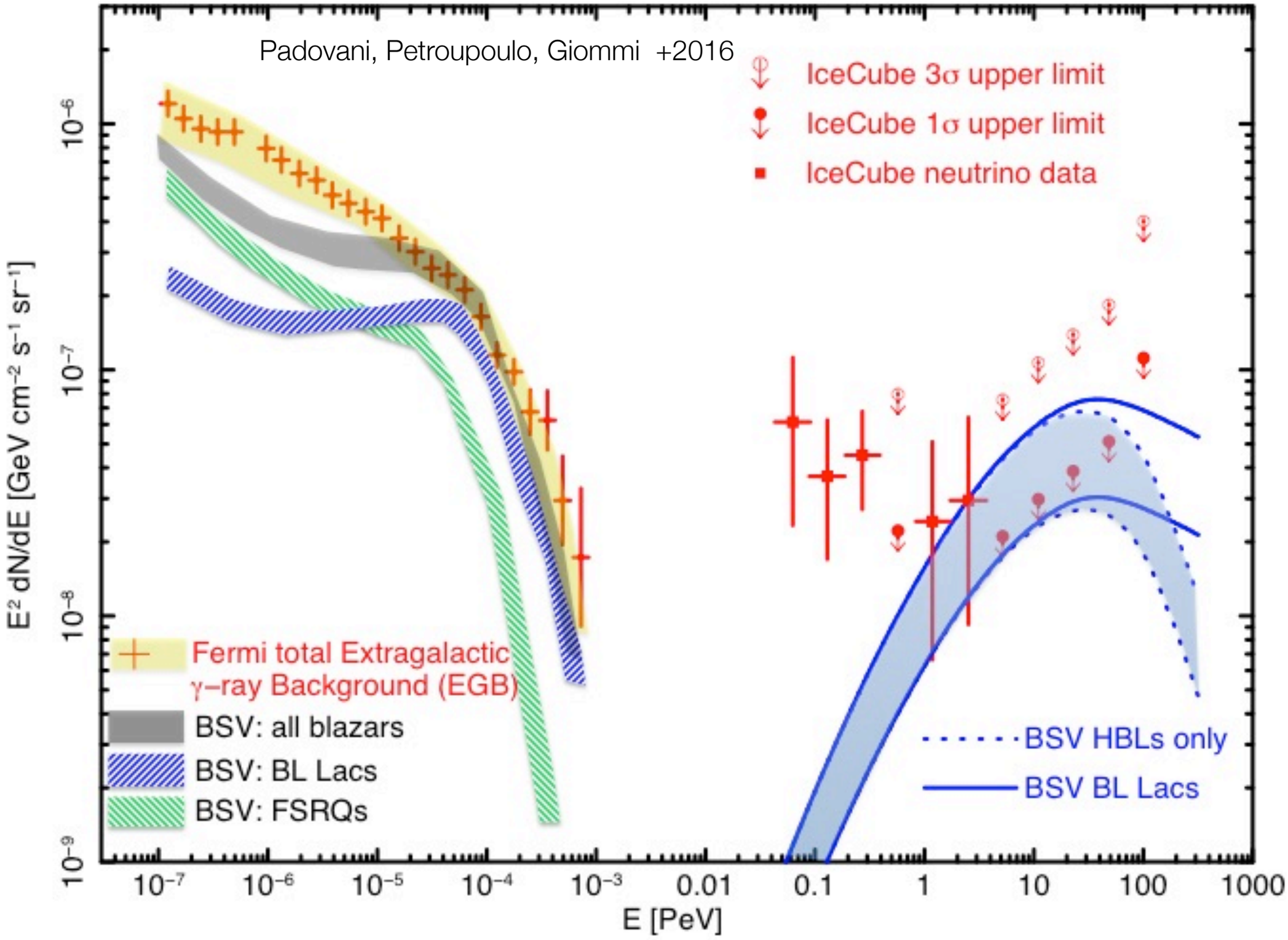
- **proton-synchrotron:**

extremely large B > 100 G required!

Hadronic Models?

Are possible, but not unambiguously detected yet in AGNs…

Padovani, Petroupoulo, Giommi +2016

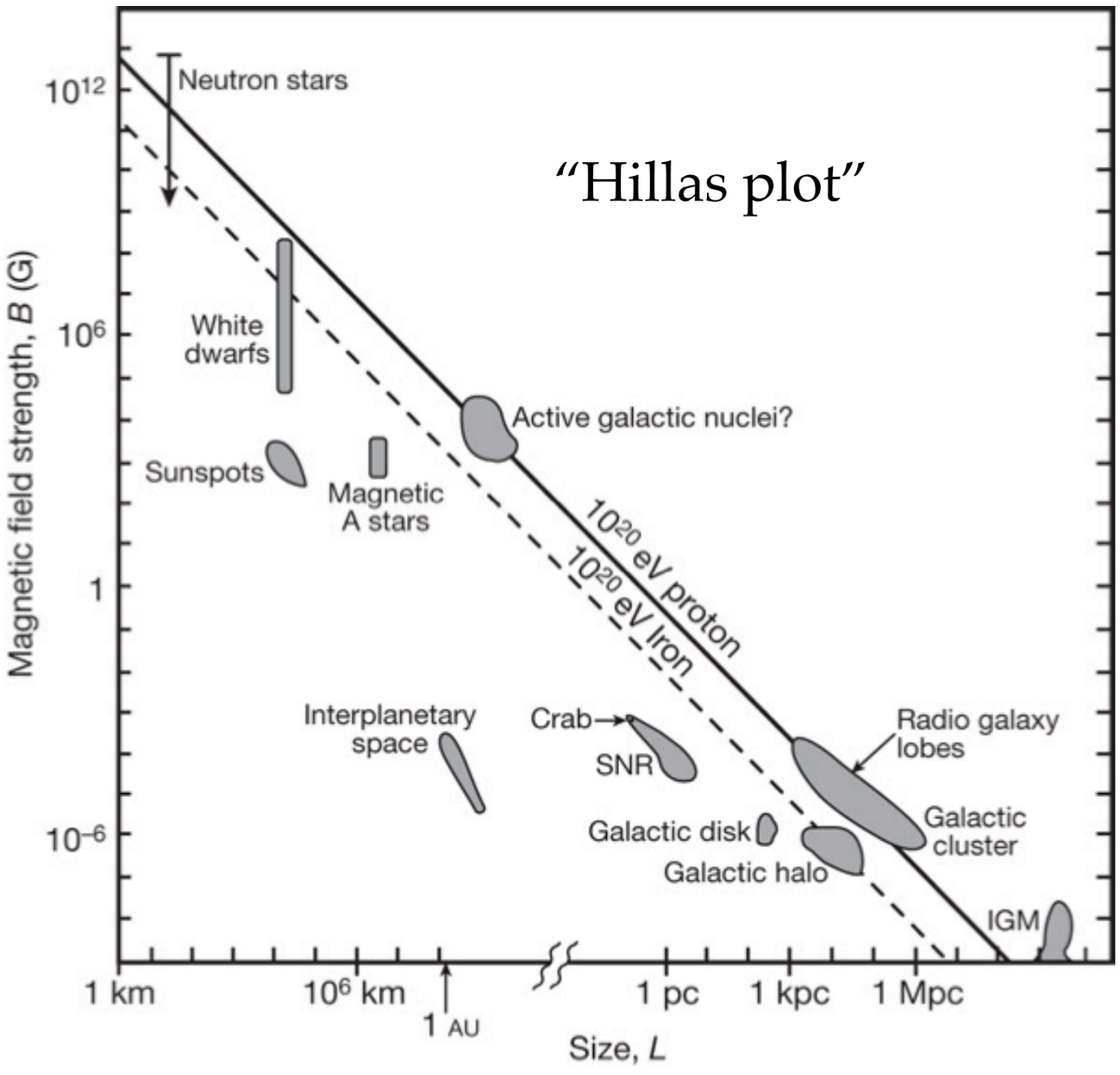


Hadronic Models?

Are possible, but not unambiguously detected yet in AGNs.

The dawn of a multi-messenger approach.

$$(R/1pc)(B/1G) > 0.1\ (E/10^{20}eV)$$



PM Bauleo & JR Martino Nature 458, 847-851 (2009

Fundamental conditions:

a) source size > Larmour radius

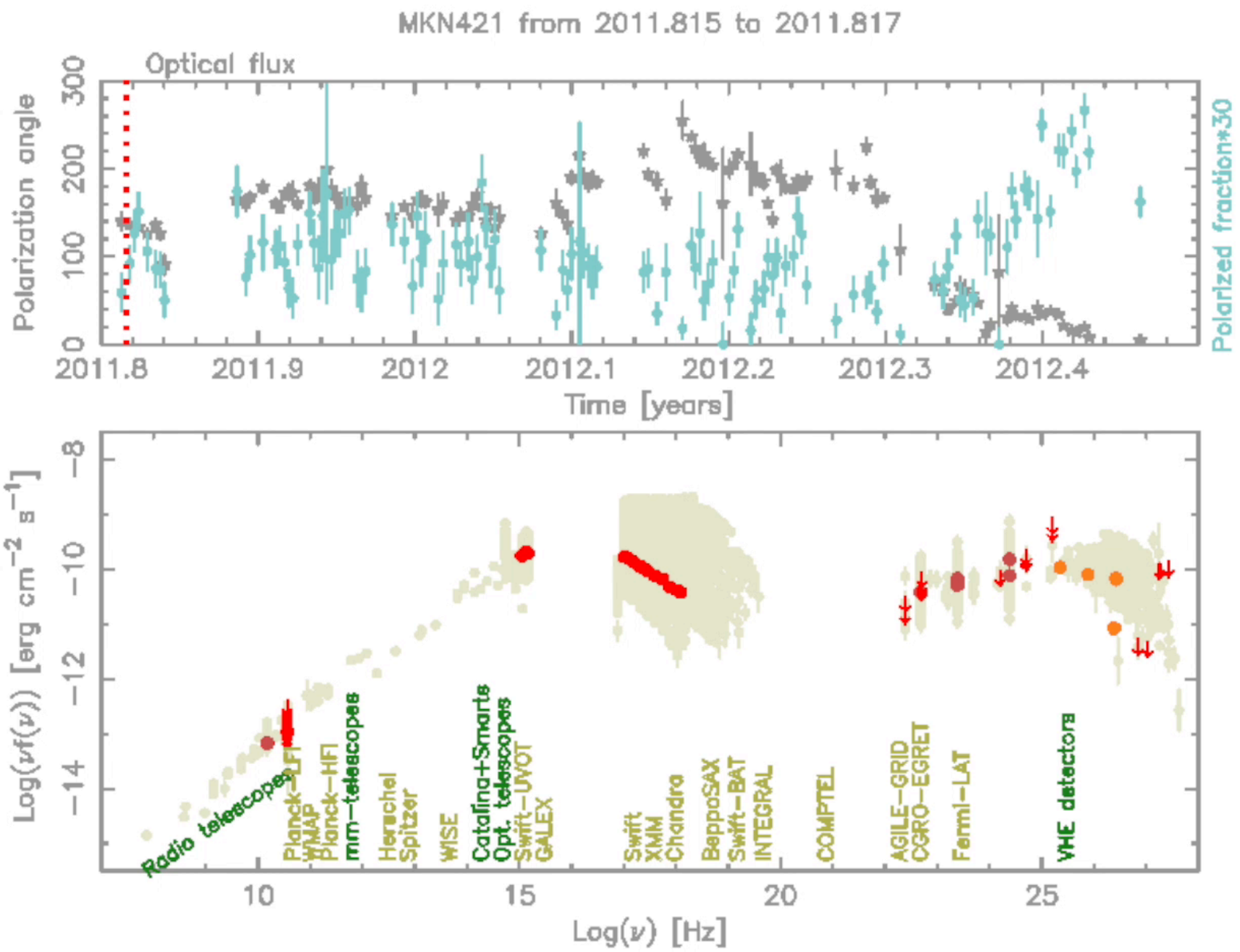
b) tacc < time confined in the source ~ 1/B

$$t_{acc}=R_L/c=E/eBc$$

excluding radiative energy dissipation conditions…

Hadronic Models?

An important UHE CR link…



An AGN in action!

Film made with data from ASDC and the BSDC (BdA, Fraga+ in prep.)