Absorption of γ-rays

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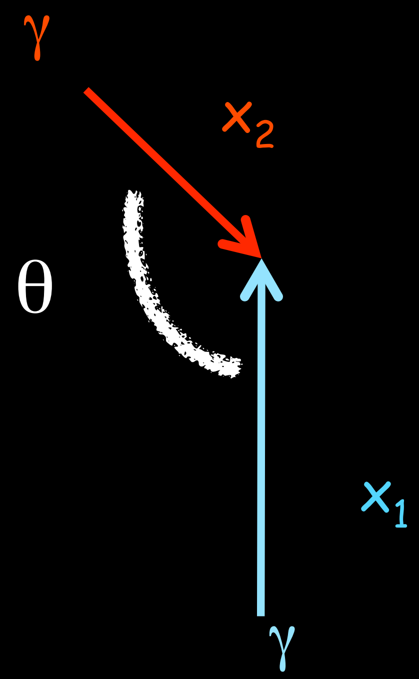
Mera-TeV

Absorption of gamma rays

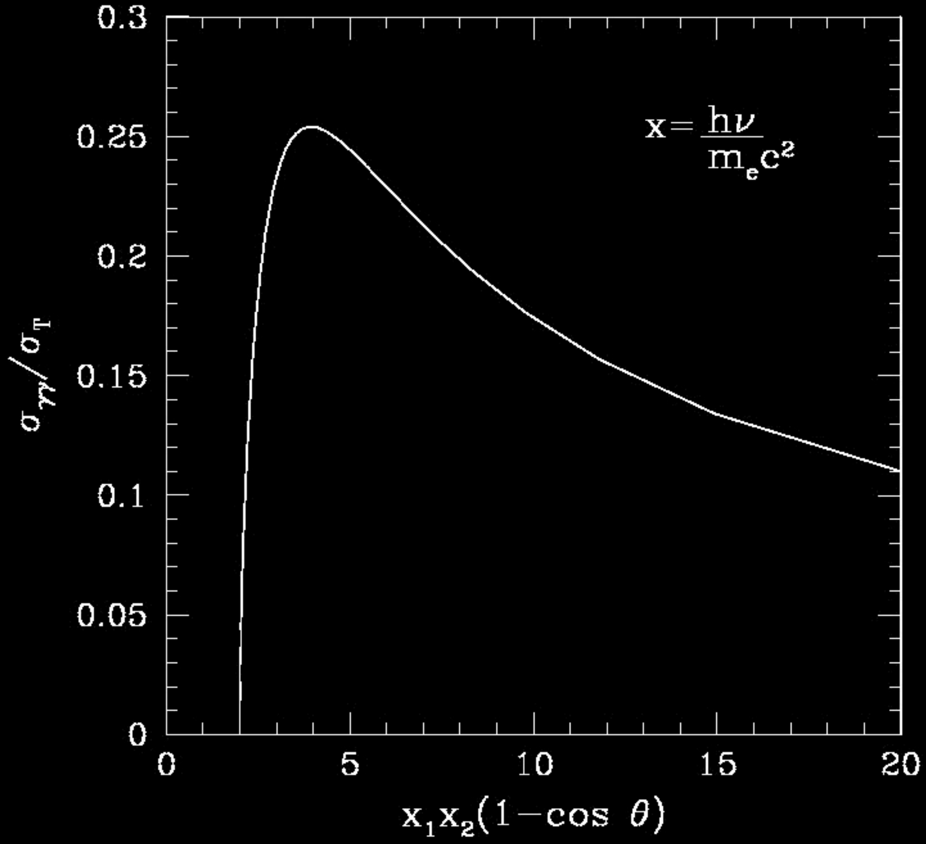
$\gamma + \gamma \rightarrow e^{+} + e^{-}$

In the center of mass the total energy must exceed $2m_ec^2$

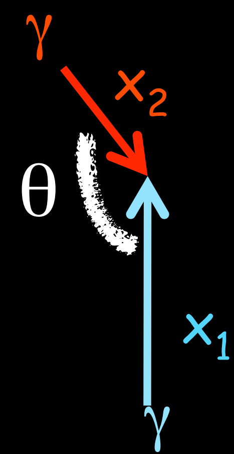
$$E_1E_2(1-\mu) > 2(mc^2)^2$$



Absorption of gamma rays



$\gamma + \gamma$ -> e+ + e-



$$\sigma(s) = \frac{3}{16}\sigma_T(1-s^2)\left[(3-s^4)\ln\frac{1+s}{1-s} - 2s(2-s^2)\right]$$

$$s = \left[1 - \frac{2}{x_1 x_2 (1-\mu)}\right]^{1/2}$$

$$\nu = 2\times 10^{15}\left(\frac{E}{100\,\mathrm{GeV}}\right)^{-1} \; Hz$$

Internal opacity: limit on δ - 1

Observations of gamma rays provide interesting limits on the minimum value of the Doppler factor

E_γ=10-100 GeV $h\nu$=5-50 eV   (UV photons)

Internal opacity: limit on $\delta - 1$

Observations of gamma rays provide
interesting limits on the minimum value
of the Doppler factor

E_γ=10-100 GeV $h\nu$=5-50 eV (UV photons)

Without any correction:

$\tau(x) = \sigma_{\gamma\gamma} R\, n(1/x)\, 1/x \sim (1/x)^{-\alpha} \sim x^{\alpha}$ increasing with E ($x = E/mc^2$)

where $n(1/x)\, 1/x \sim L(1/x) / R^2$

τ(100 GeV)>>1 gamma-rays cannot escape!!

Internal opacity: limit on δ - 2

e.g. Ghisellini & Dondi 1996

Taking into account relativistic motion:

1) Intrinsic energy of gamma-ray is lower: decreasing number density of target photons

2) Density of target soft photons also strongly decreases (lower luminosity, larger radius)

One finds: $\tau'(x) = \tau(x)/\delta^{4+2\alpha}$

$$\delta > \tau(x)^{1/(4+2\alpha)}$$

Typically $\delta > 5$

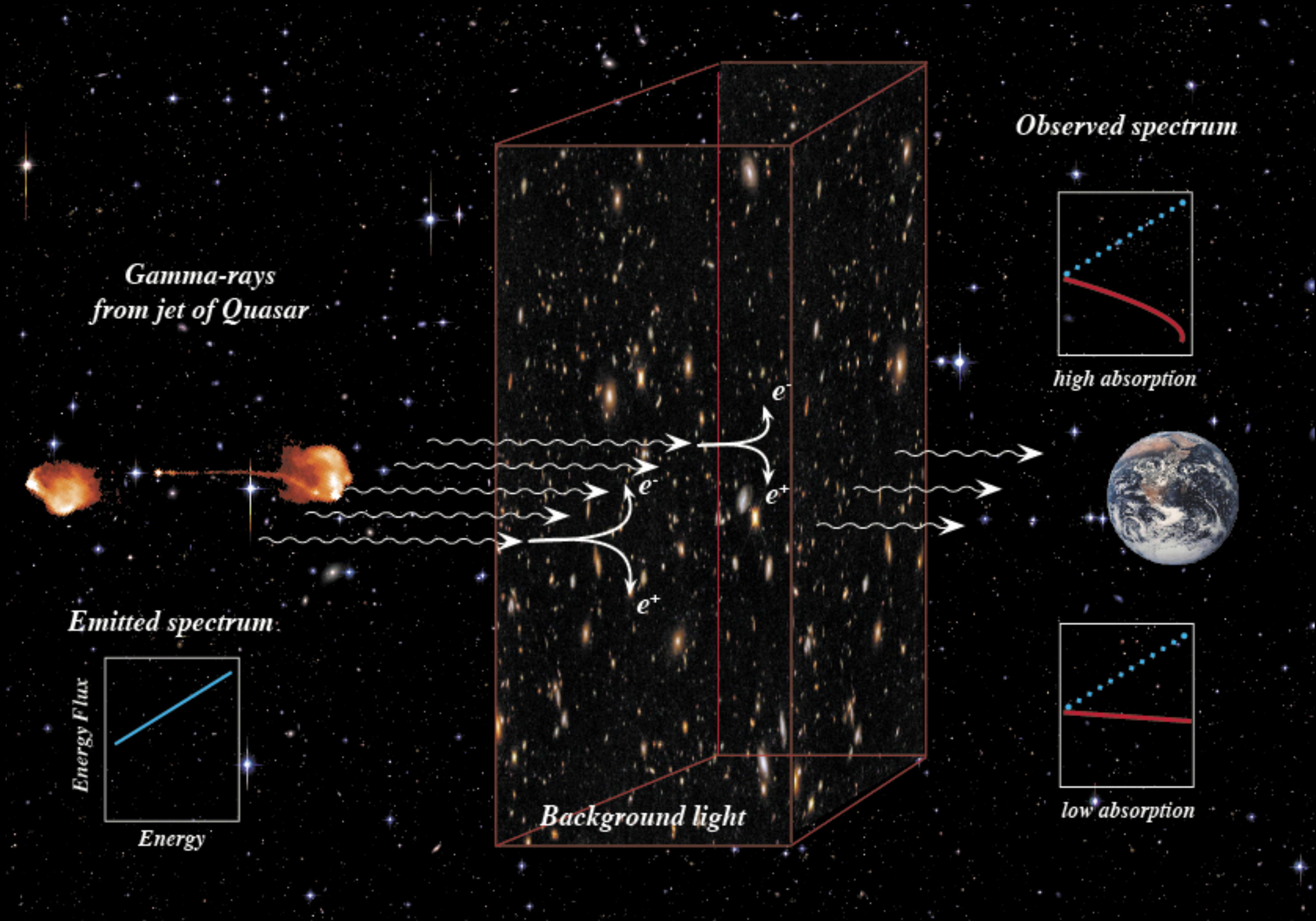
Blazars as cosmic beacons

Blazars illuminate the Universe with gamma rays

Gamma rays interact with the IR-O-UV bkg producing pairs
(e.g. Stecker 1966, Nikishov 1966)

Spectral distortions useful to probe the poorly known
Extragalactic Background Light (EBL)

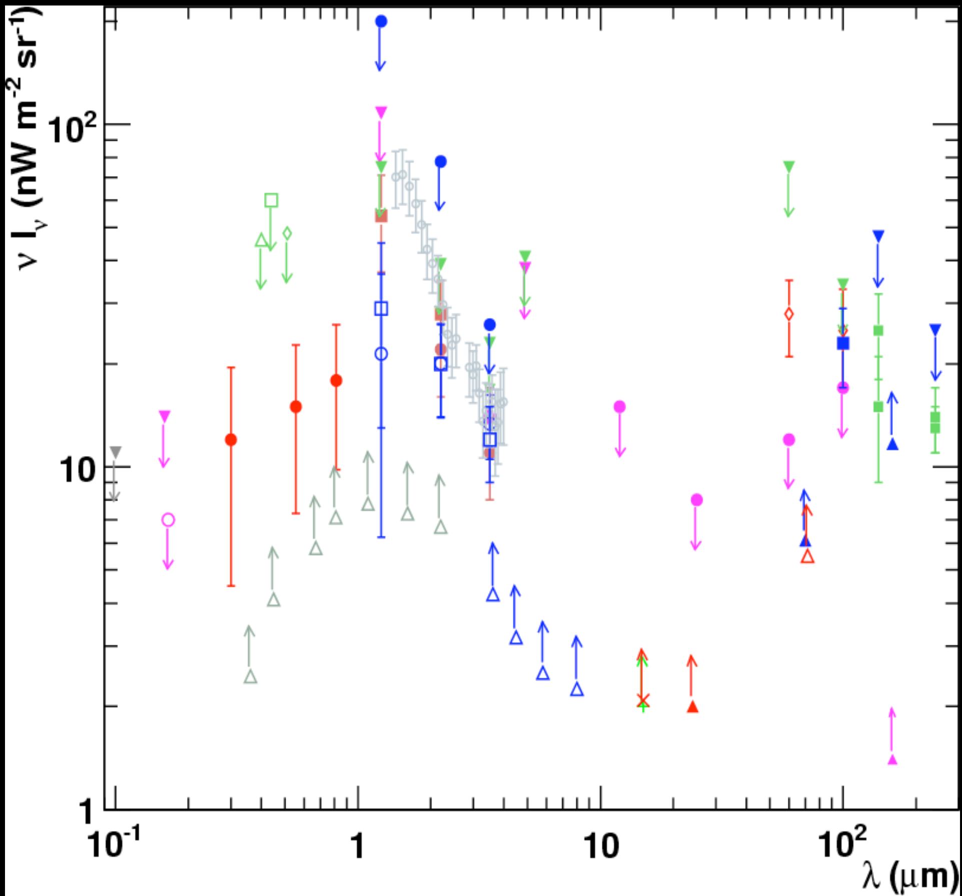
Pairs re-emit through IC with CMB.
Trajectories and fluxes depends on intergalactic magnetic fields

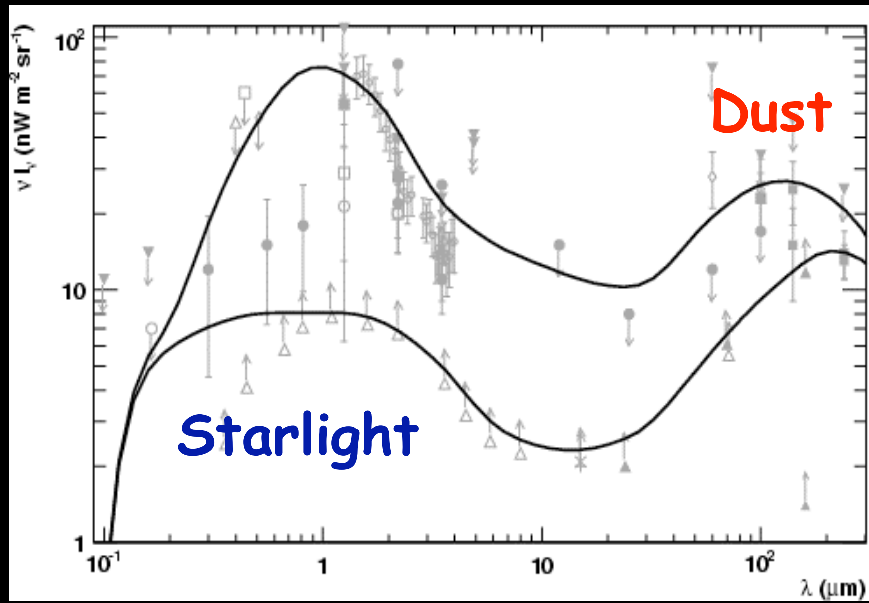


Cosmic beacons

Extragalactic background light

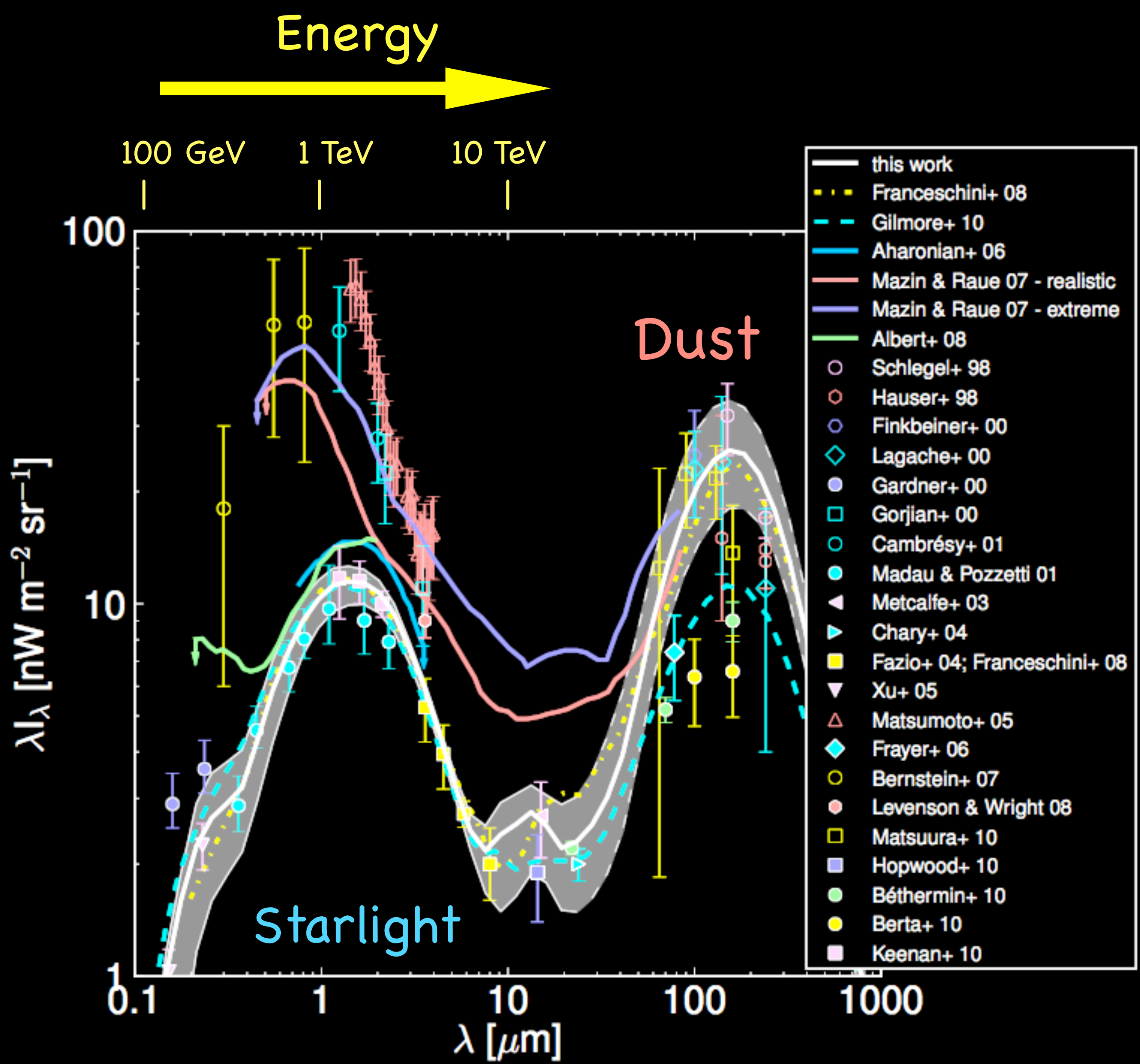
EBL measurements





Mazin & Raue 2007

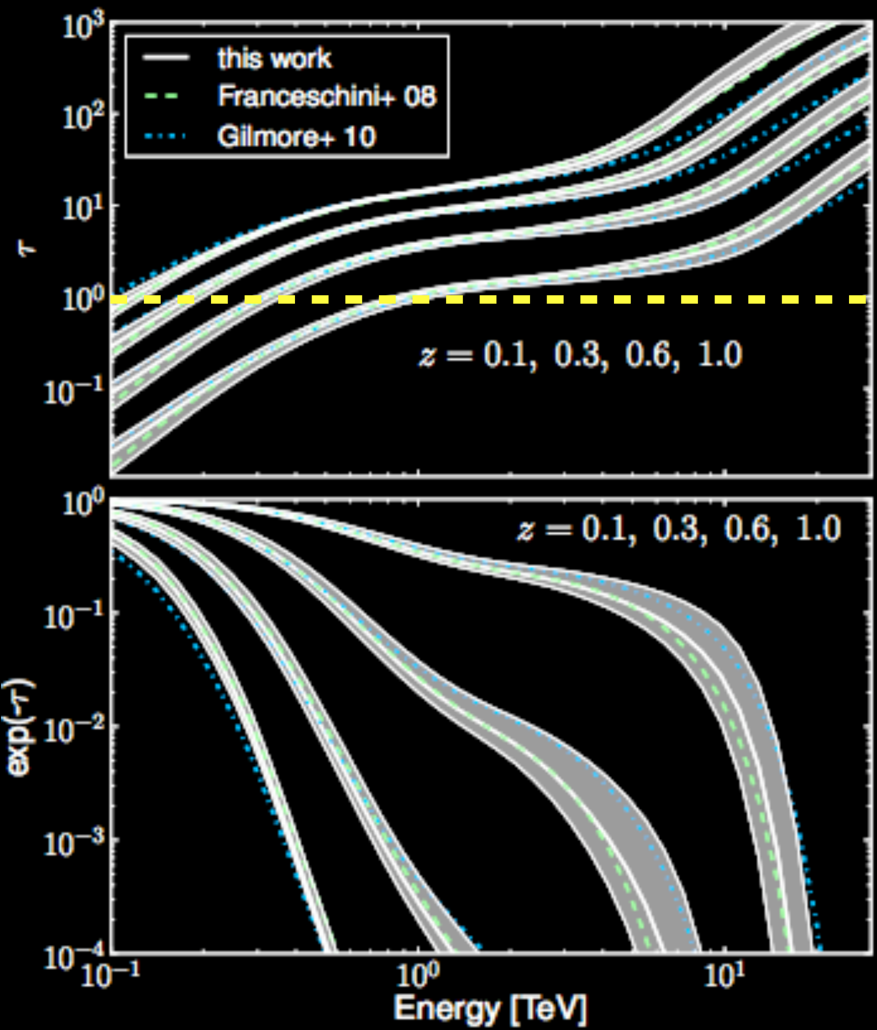
Modeling EBL



Dominguez-Diaz et al. 2010

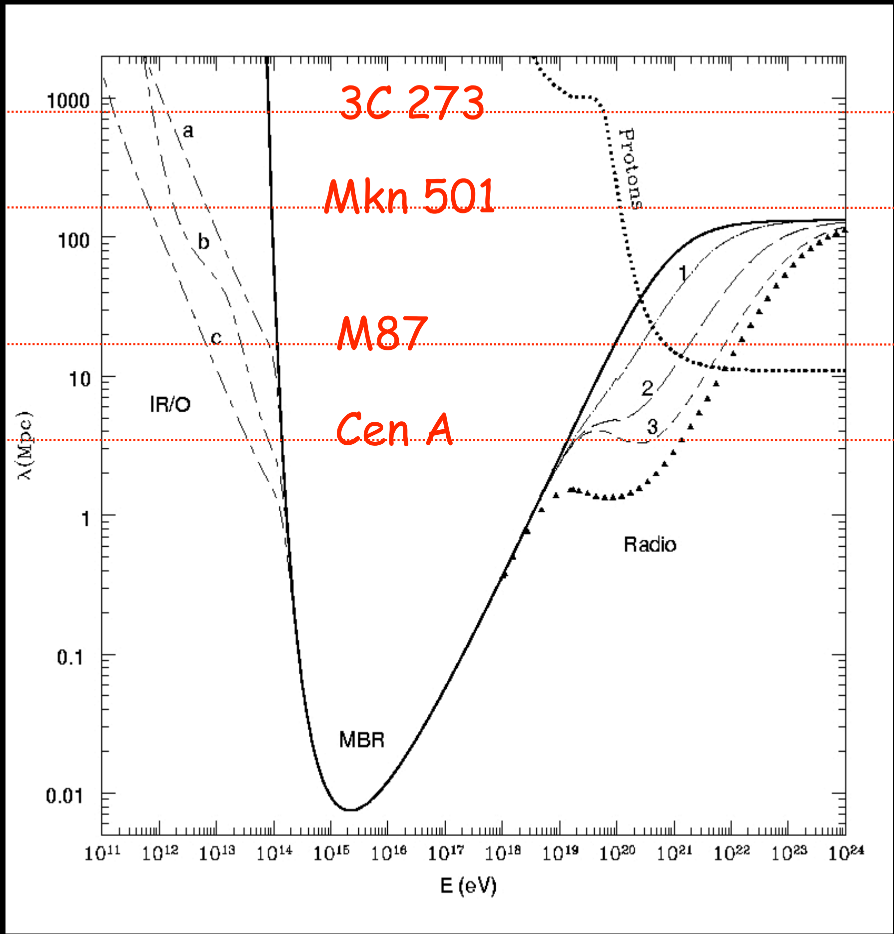
Modeling EBL

$$\tau_{\gamma\gamma}(E,z) = c\int_0^z \int_0^2 \int_\epsilon^\infty \sigma_{\gamma\gamma}(E,\epsilon,\mu,z')\frac{dn_{EBL}}{d\epsilon dz'}\frac{\mu}{2}\frac{dr}{dz'}d\epsilon d\mu dz'$$



Dominguez-Diaz et al. 2010

The "gamma-ray horizon"

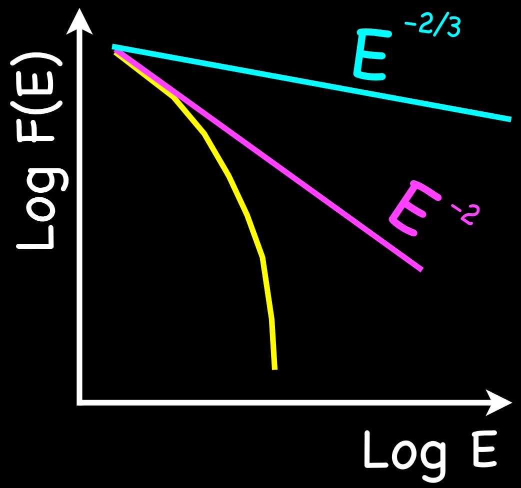


Mean free path

$\tau=1$

Coppi & Aharonian 1997

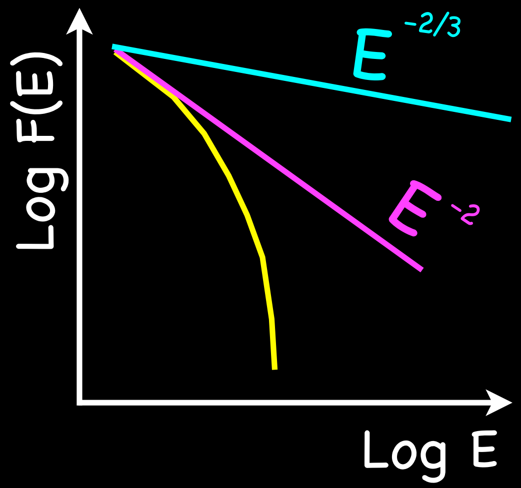
Constraining EBL with VHE spectra of blazars



Shock acceleration

SSC, large E_{min}

Constraining EBL with VHE spectra of blazars



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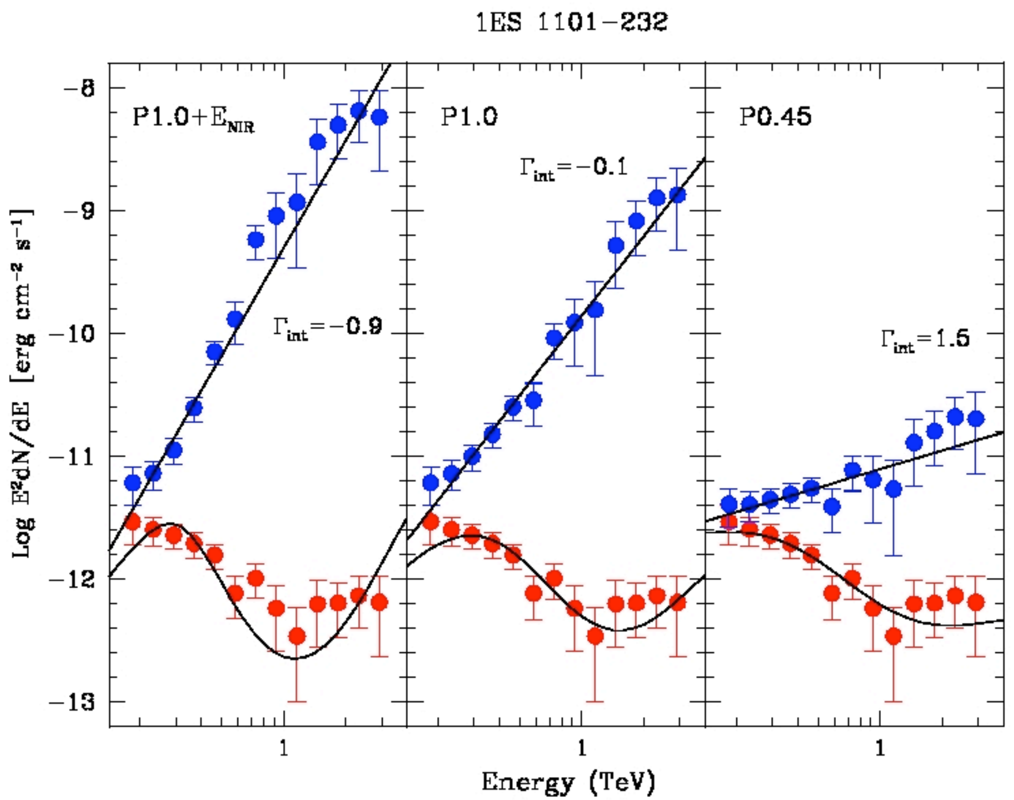
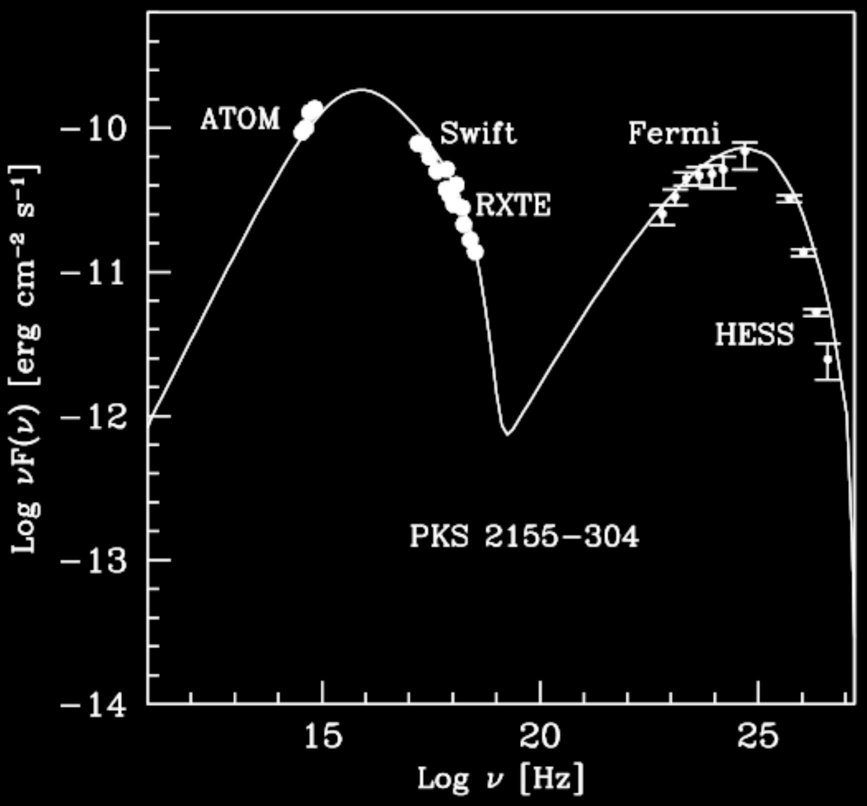
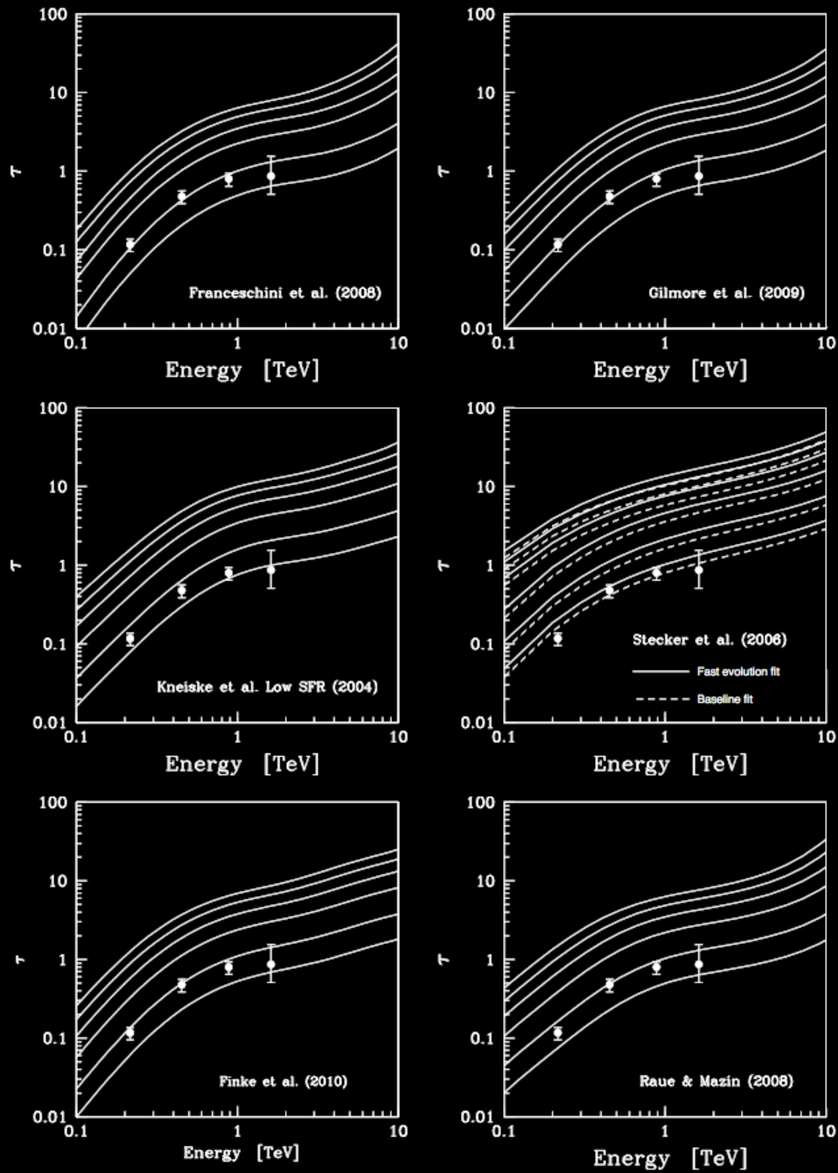


Aharonian et al. 2006

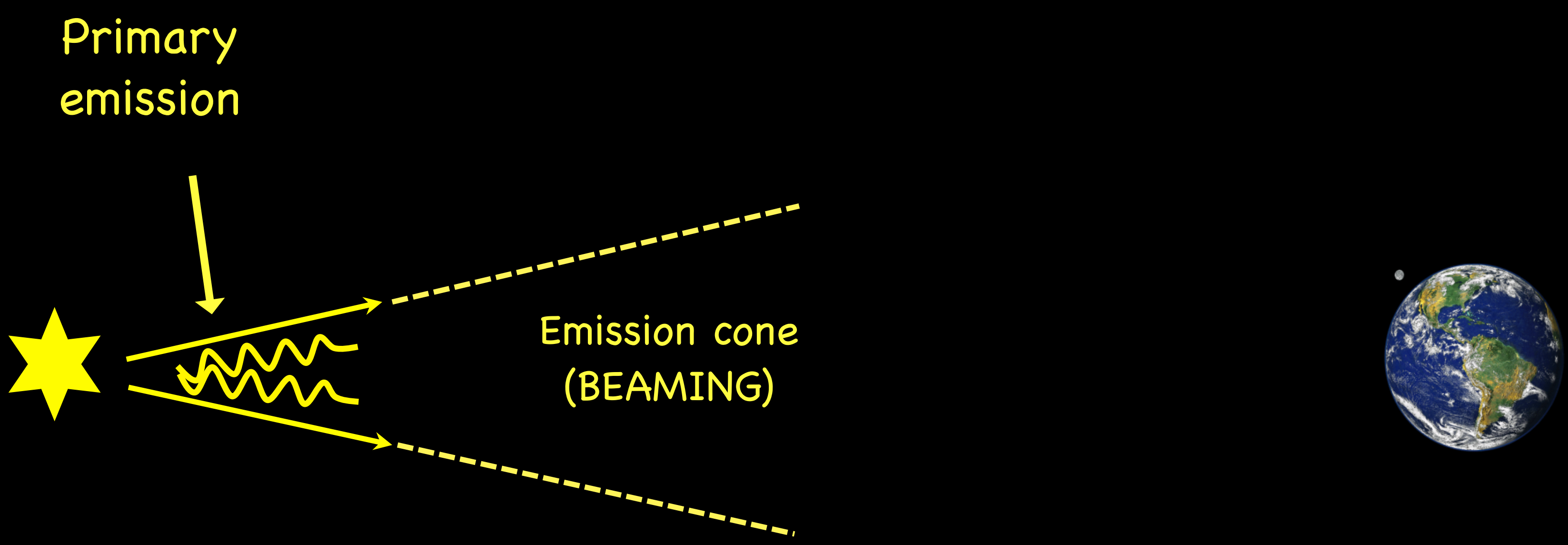
Modelled spectra



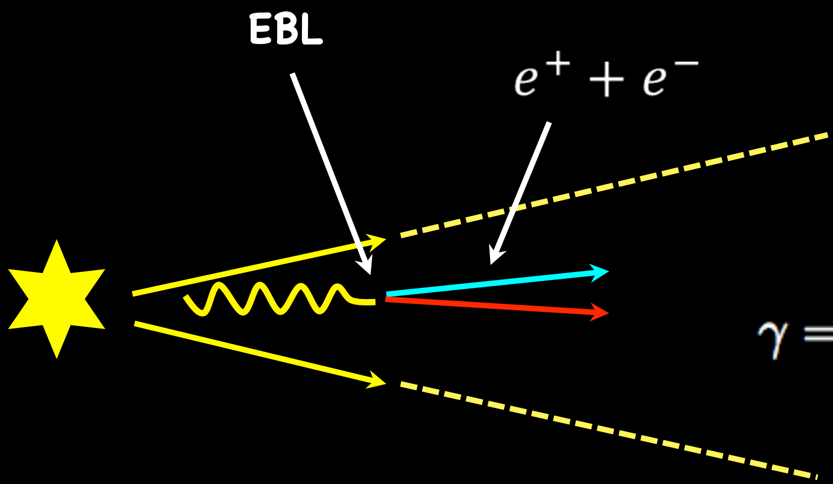


Mankuzhiyil, Persic & FT 2010

Effect of IGMF



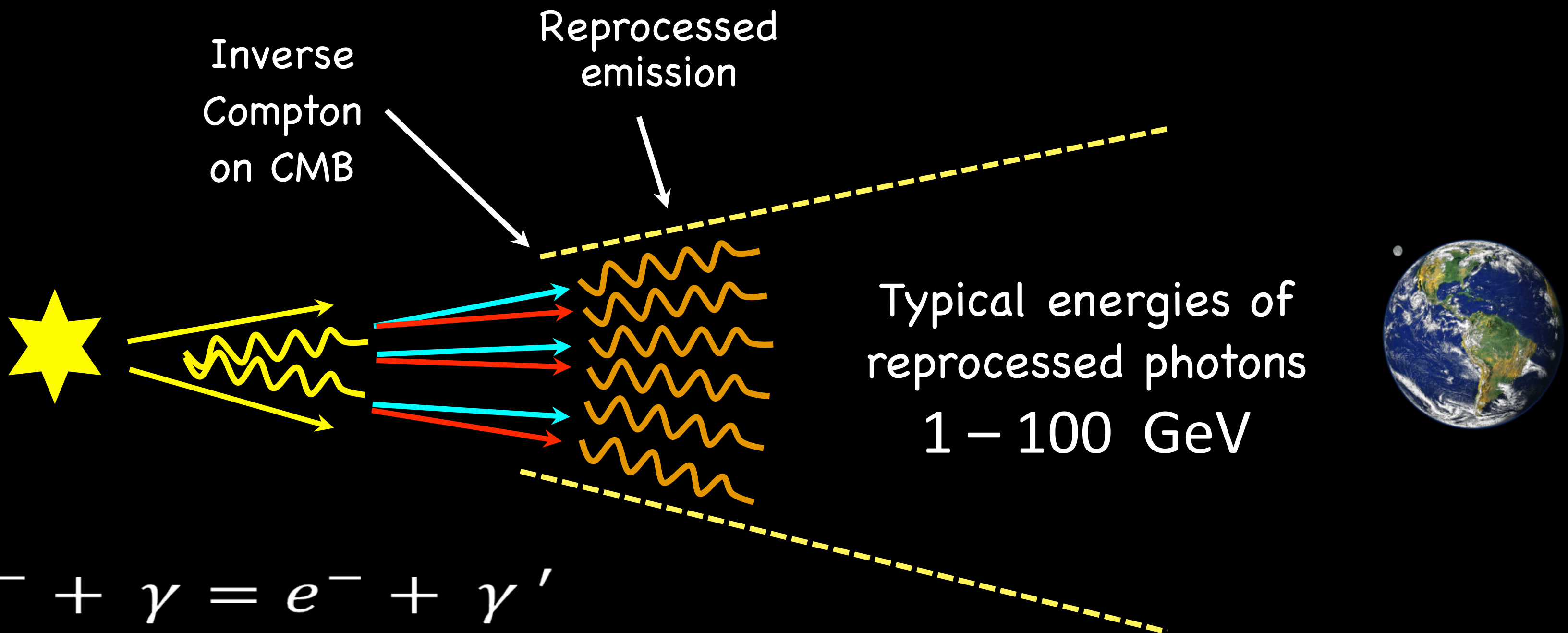
Effect of IGMF



$$\gamma = \frac{E}{2m_e c^2} \simeq 10^6 E_{\rm TeV}$$

$$\gamma_1 + \gamma_2 = e^- + e^+$$

Effect of IGMF



$$e^- + \gamma = e^- + \gamma\,'$$

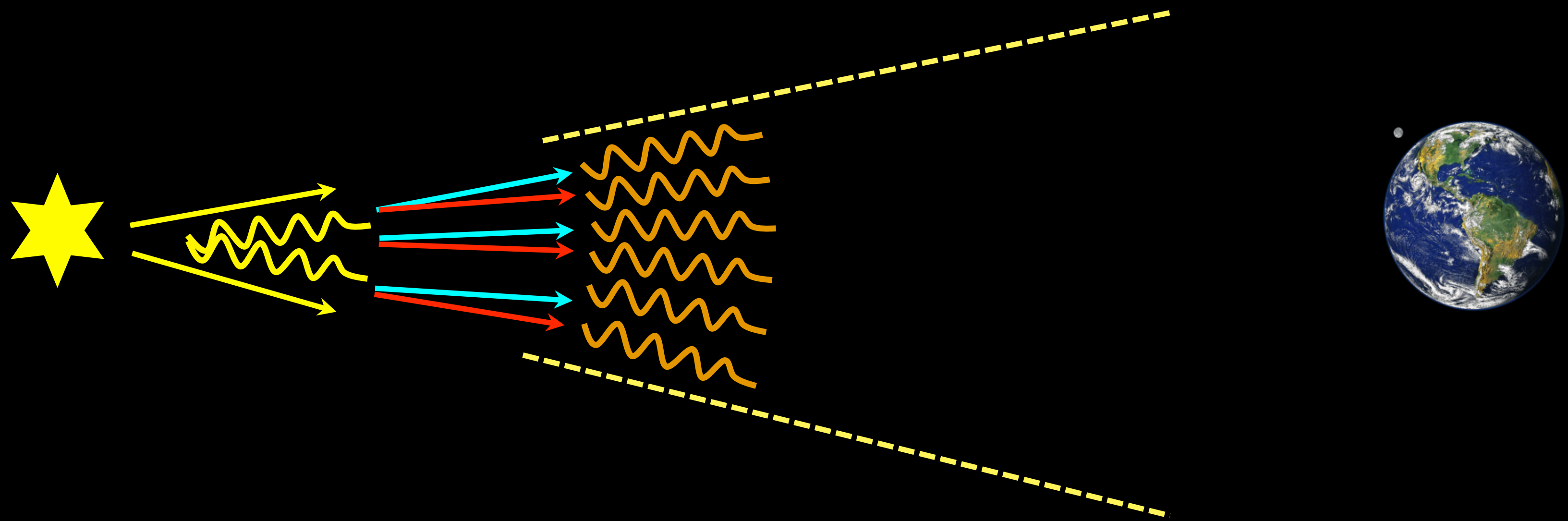
$$\epsilon = \gamma^2 h\nu_{\rm CMB} \simeq 2.8\,kT_{\rm CMB}\,\gamma^2 = 0.63\,E_{\rm TeV}^2\ {\rm GeV}$$

$$ct_{\rm cool} = \frac{3m_e c^2}{4\gamma U_{\rm CMB,0}(1+z_r)^4} \simeq 2\times 10^{24}\gamma_6^{-1}(1+z_r)^{-4}\ {\rm cm}$$

$$N(\gamma) = k\gamma^{-2}$$

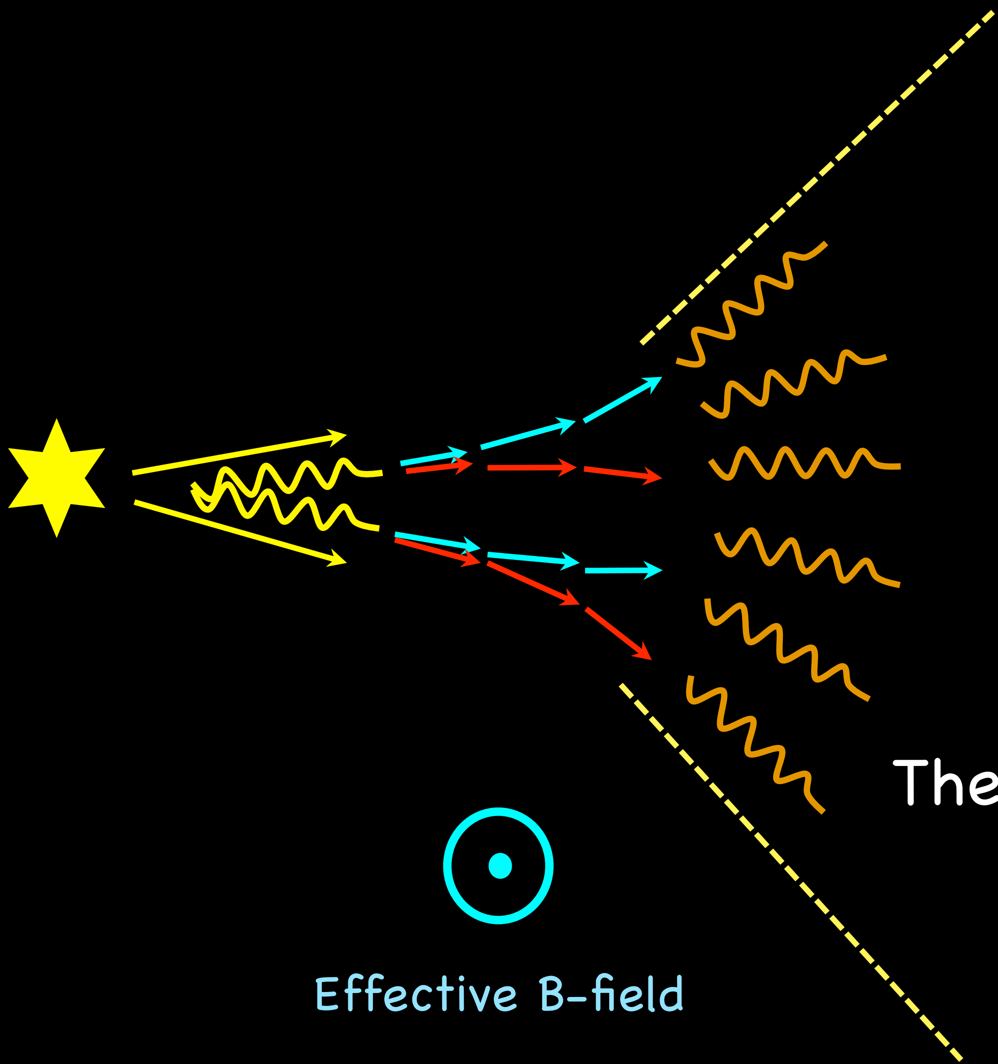
"cooled " distribution

B=0



The reprocessed emission is contained within the primary beaming cone

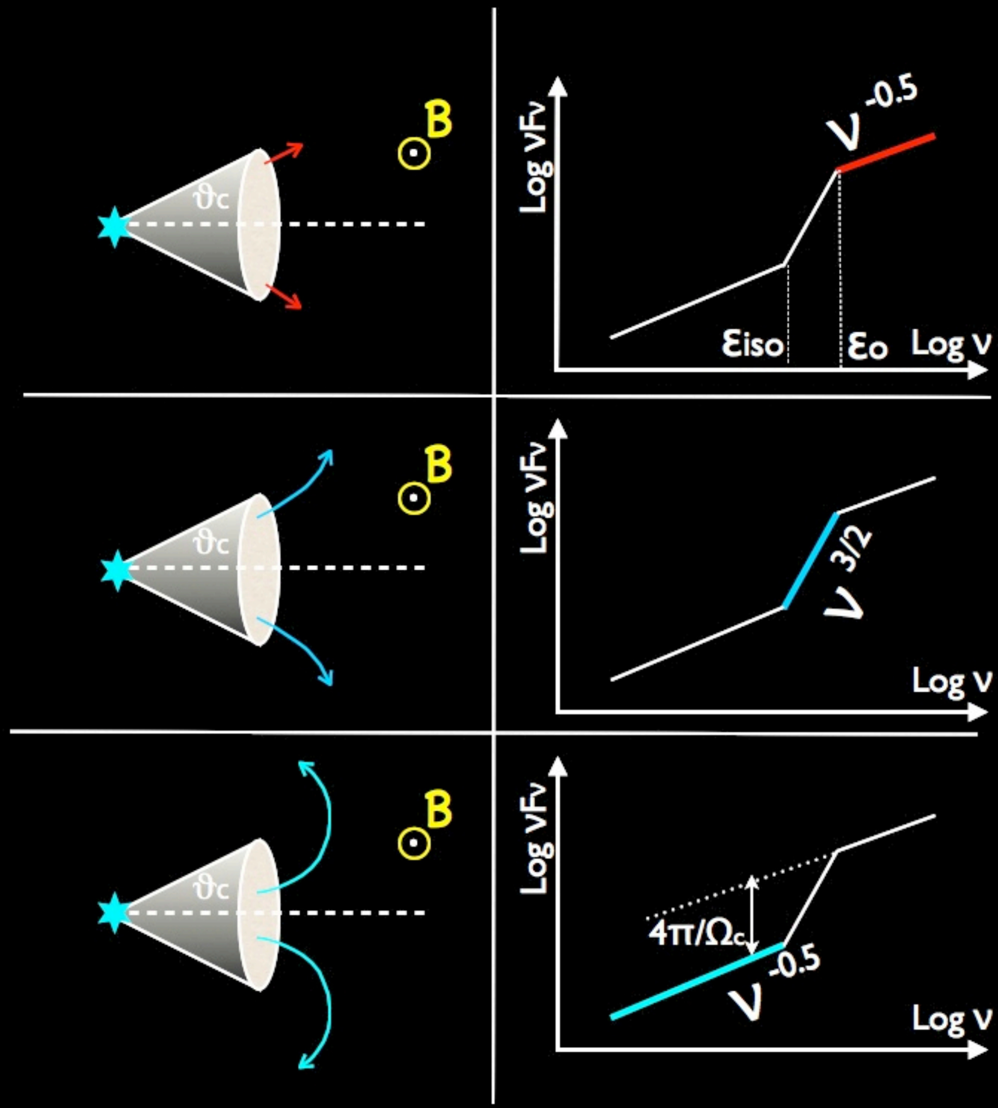
B>0



$$\theta_\gamma = \frac{ct_{\rm cool}}{r_{\rm L}} = 1.17\, B_{-15}\, \gamma_6^{-2}\ {\rm rad}$$

The reprocessed flux is diluted within a larger solid angle

A simplified model for the spectrum



Stationary VHE flux!

$$F(\epsilon) = k\epsilon^{-0.5}\frac{1}{\Omega_c+\Omega_\gamma}$$

$$\Omega_\gamma = 2\pi(1-\cos\theta_\gamma) \sim \pi\theta_\gamma^2$$

$$\Omega_c = 2\pi(1-\cos\theta_c) \sim \frac{\pi}{\Gamma^2}$$

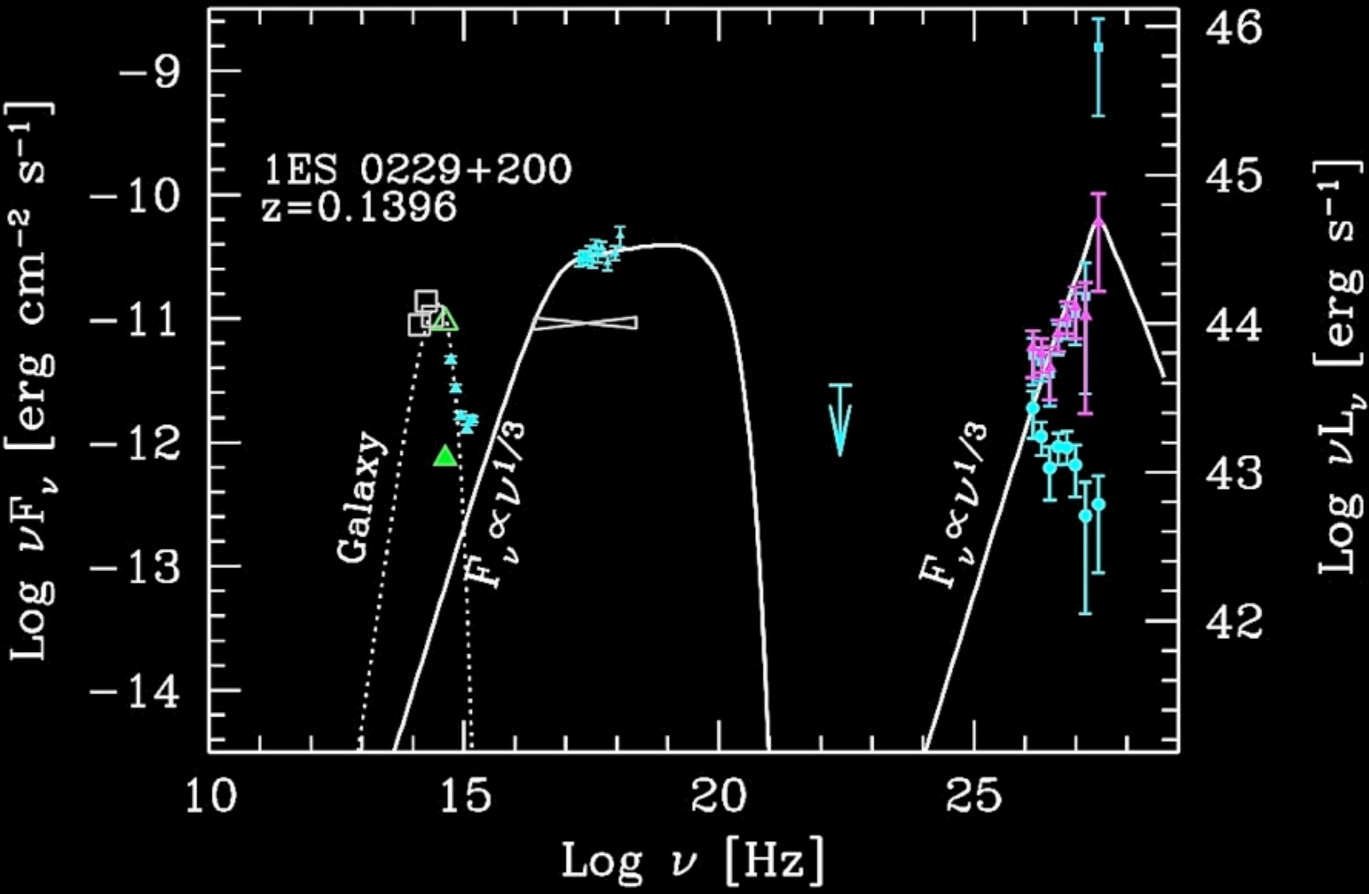
FT et al. 2010

Basic requirements

- ✓ *Hard and powerful TeV spectrum*
- ✓ *Large distance (high absorption)*
- ✓ *Low intrinsic GeV flux*

1ES 0229+200: the source of desires

FT et al. 2009



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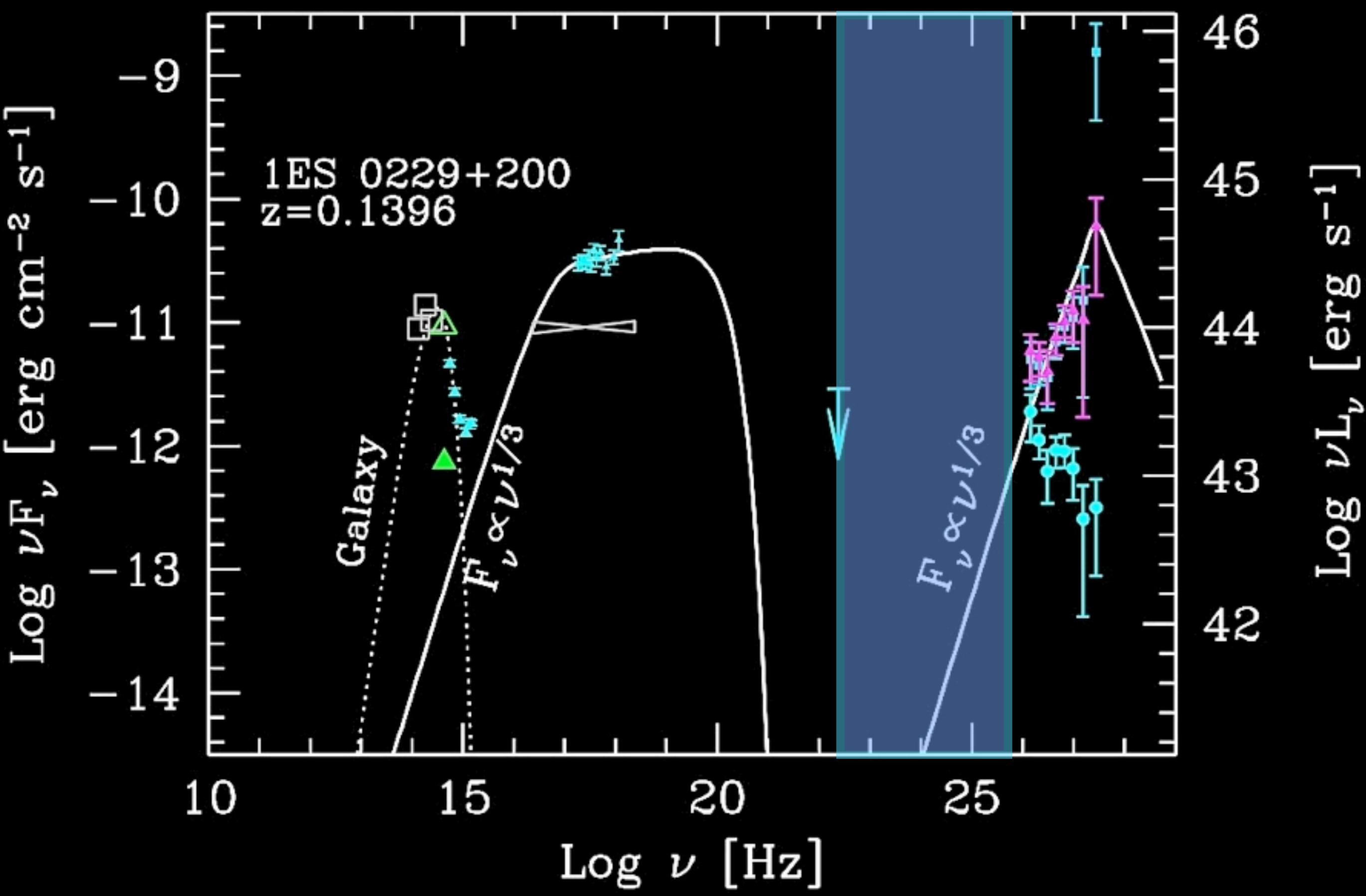
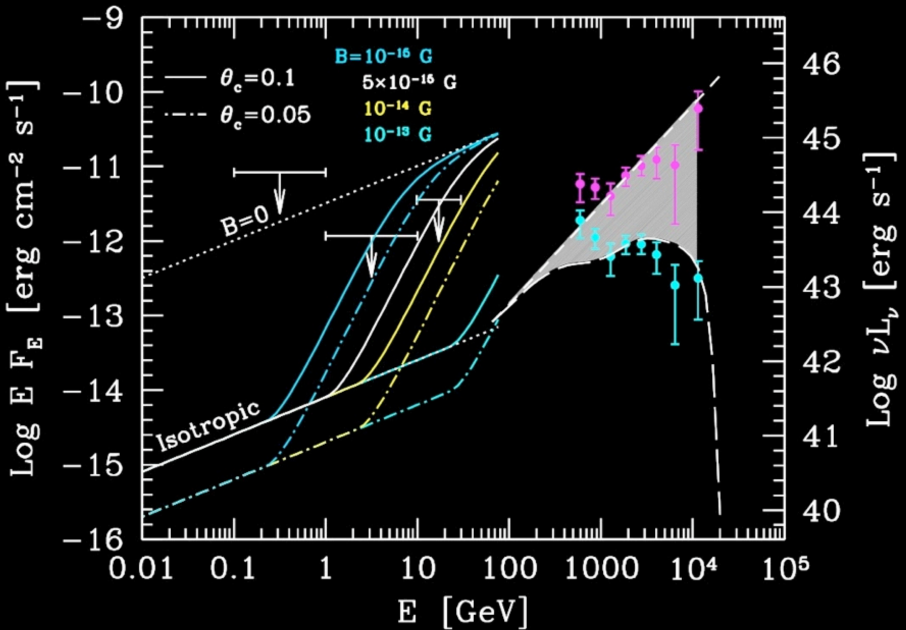
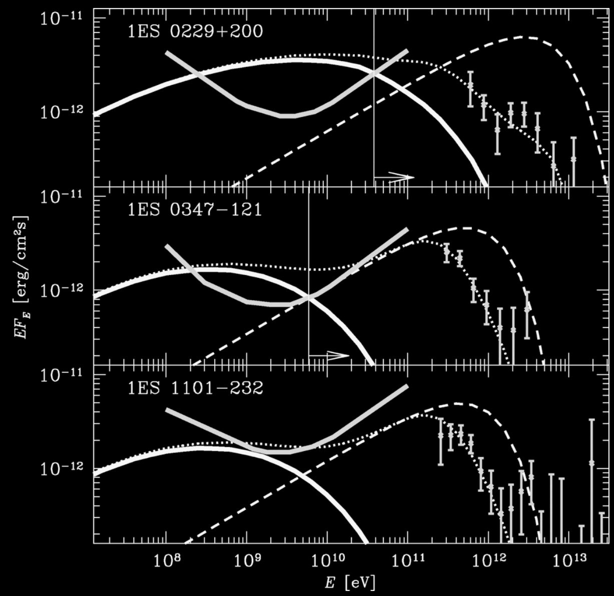


B>0!

FT et al. 2010

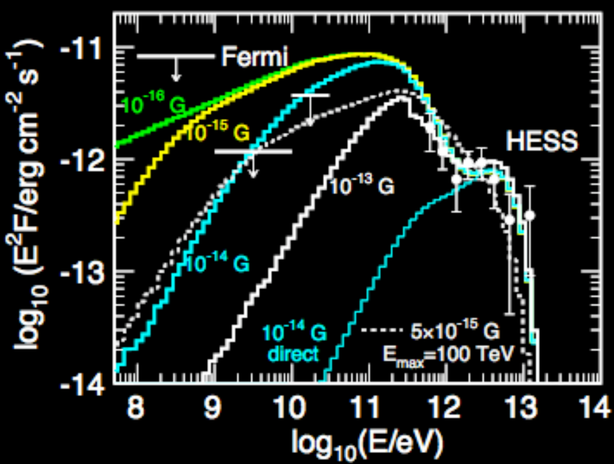


Neronov & Vovk 2010



Stationary VHE flux!

Dolag et al. 2011

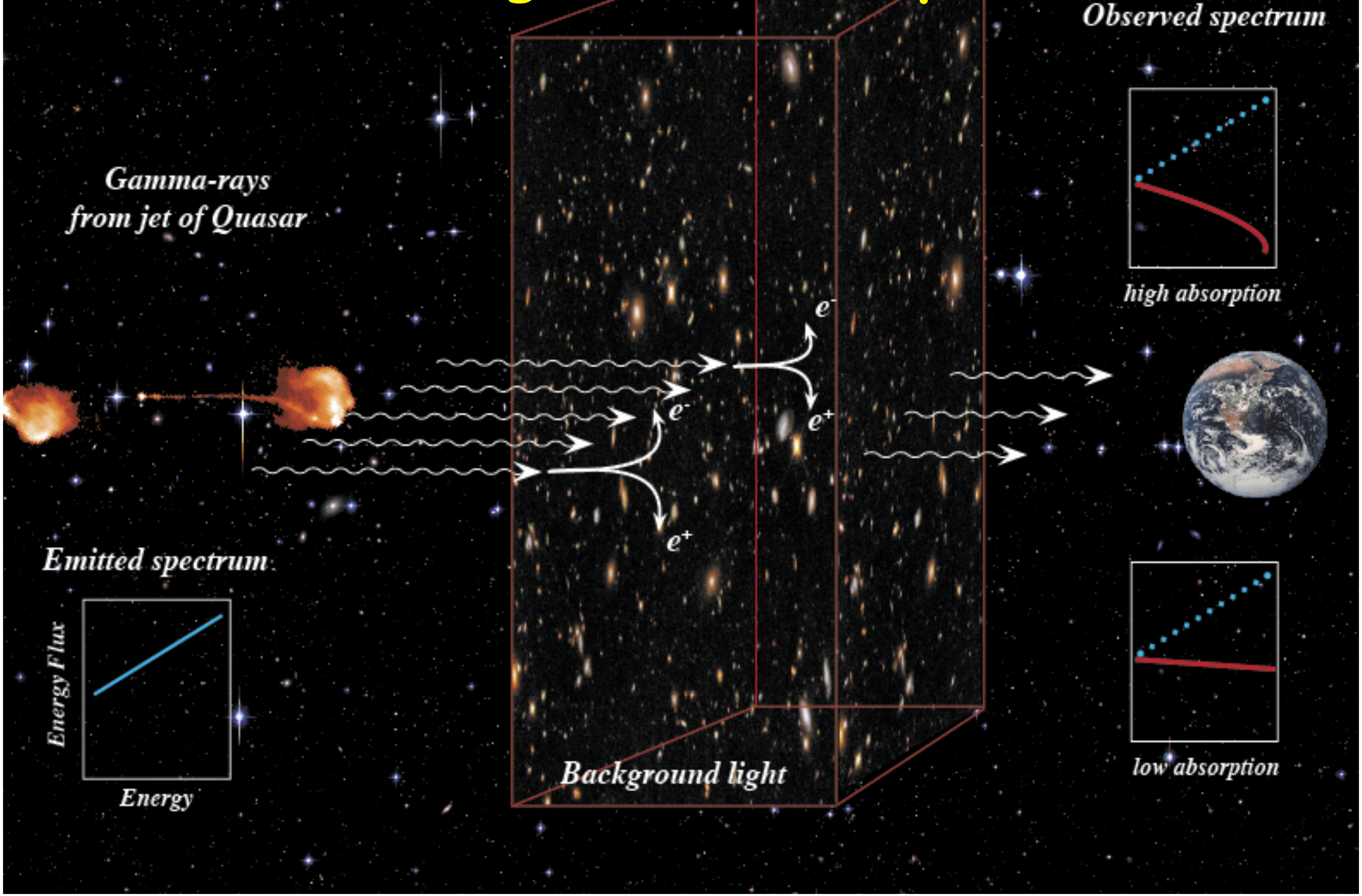


$B=10^{-16}-10^{-15}$ G

See also:
Taylor et al. 2011
Huan et al. 2011

Adesso .... pappa!

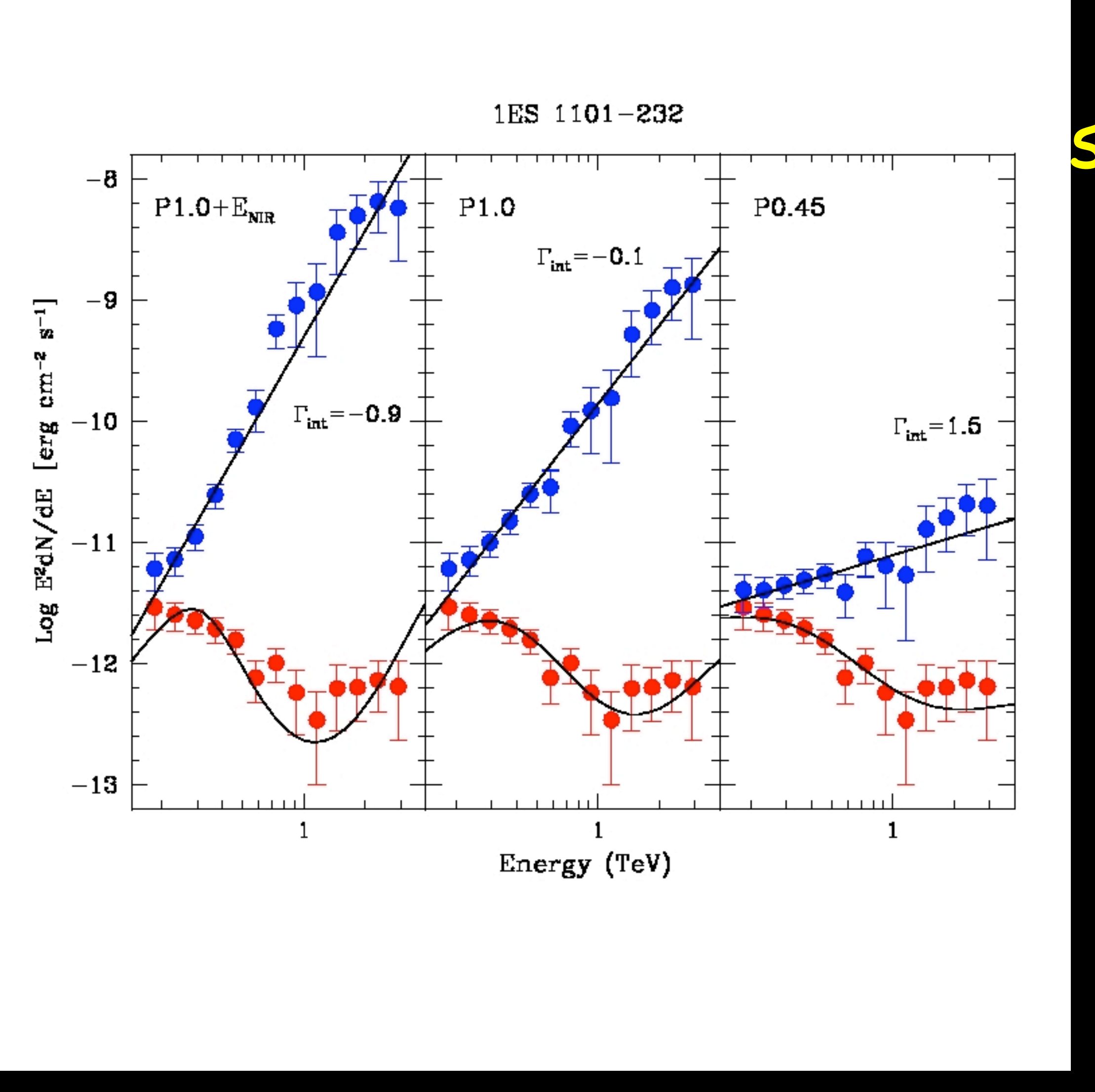
Intergalactic absorption



BL Lac 1101-232 (z=0.186) found that, even assuming the lowest

level of the IR background (estimated through

counts) ... s very



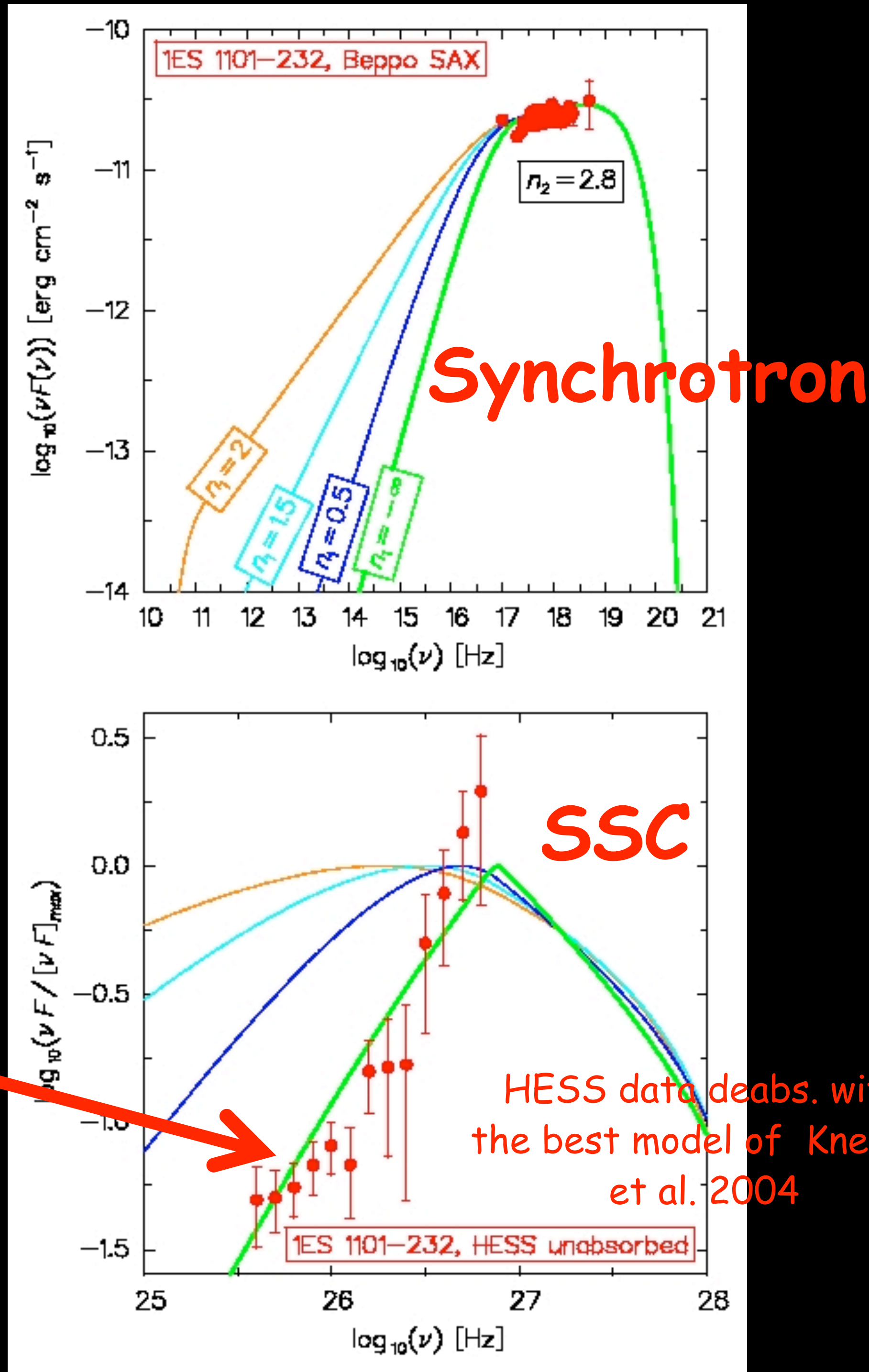
can be obtained assuming a power law electron distribution with a relatively large lower limit γ_{min}

Below the corresponding freq. synchrotron and SSC spectra are very hard!

The absolute limit is:

$F_\nu \sim \nu^{1/3}$

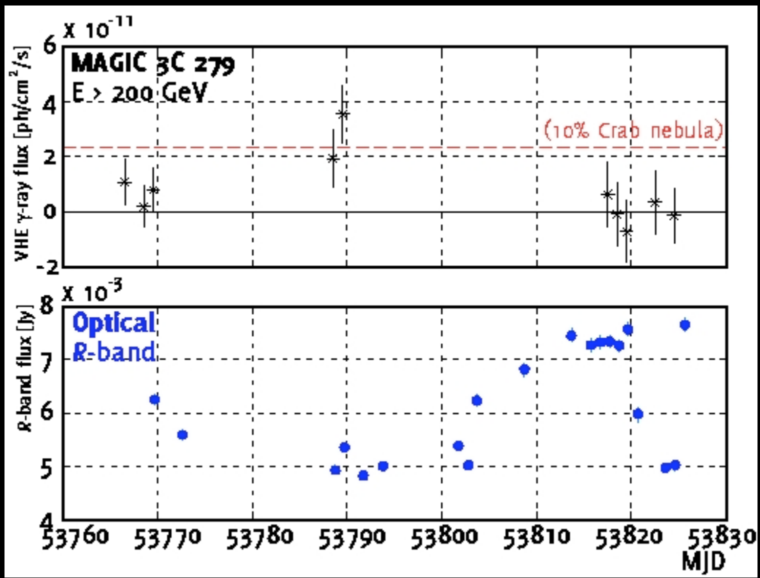
Katarzinski et al. 2006



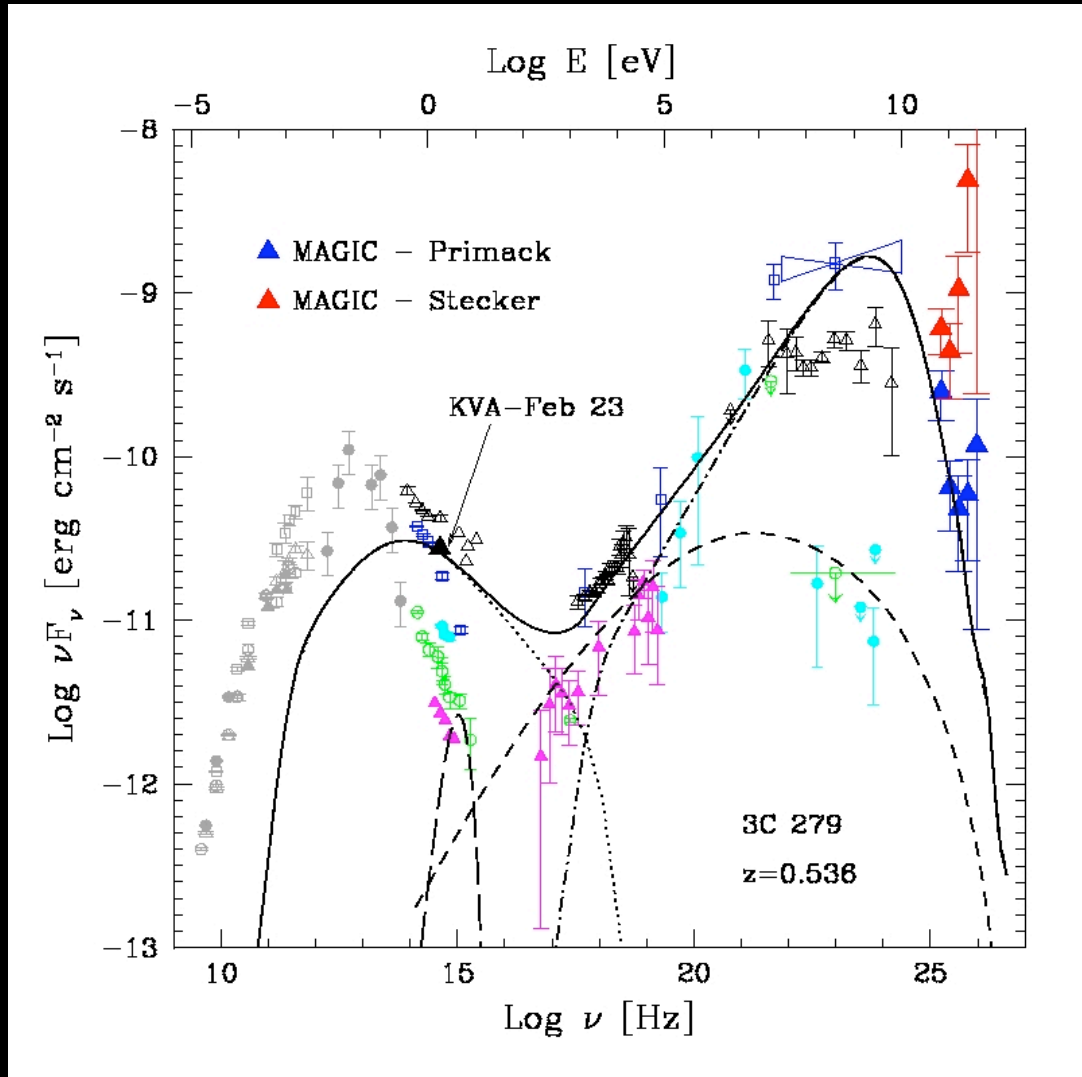
HESS data deabs. with the best model of Kneiske et al. 2004

VHE emission of FSRQs

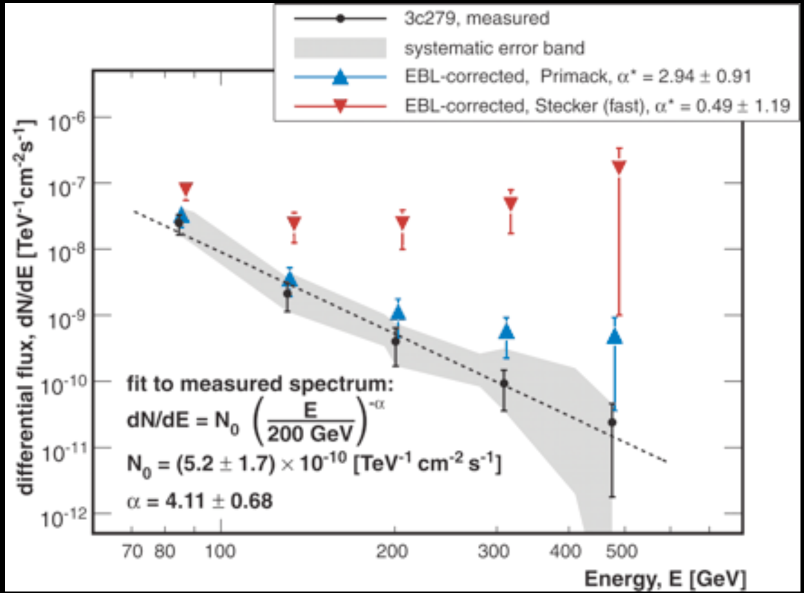
3C 279, z=0.536

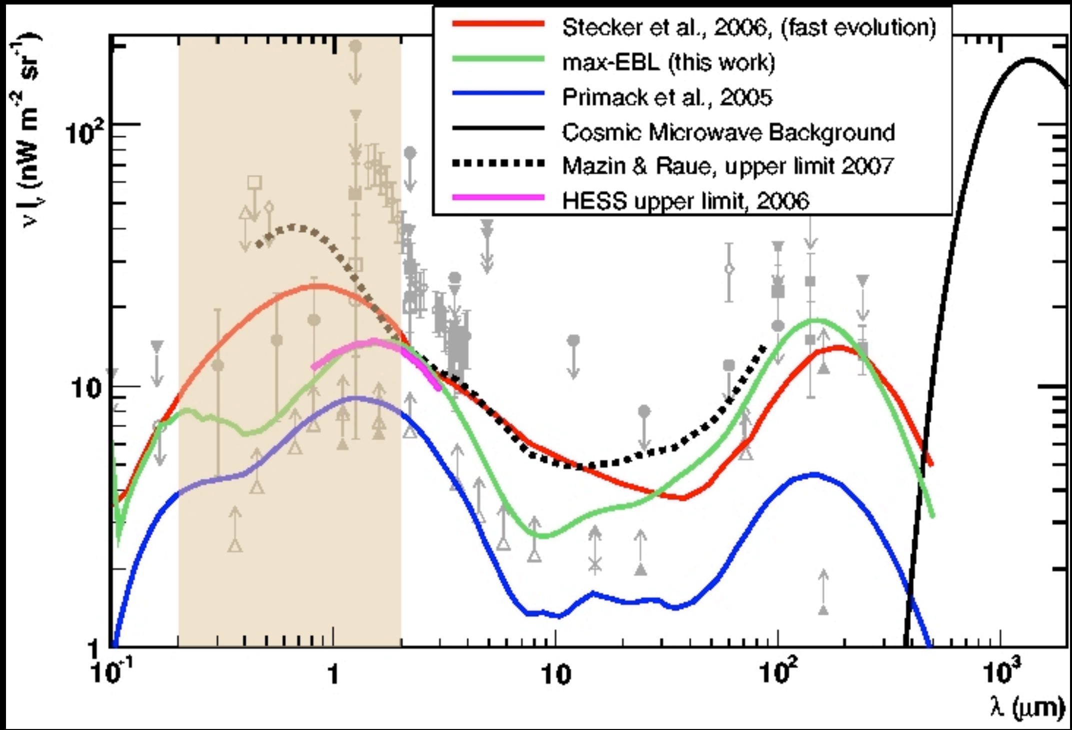


Albert at al.
2008



Constraints from 3C279





Albert at al. 2008

γ-ray emission from non-blazar AGNs

Only one non-blazar AGNs is known at VHE band:

the radiogalaxy M87

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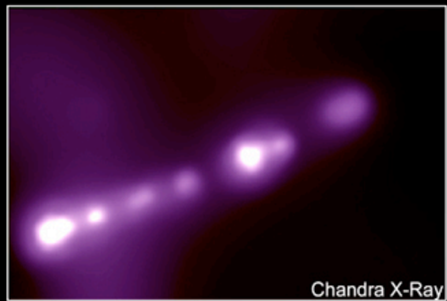
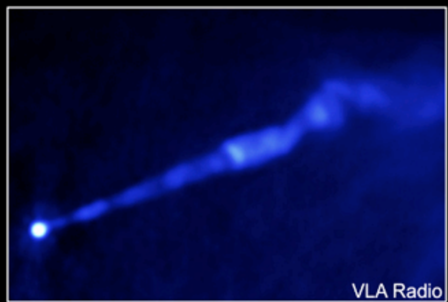
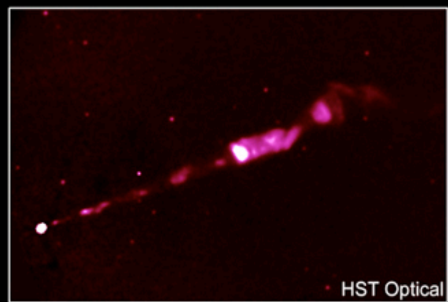
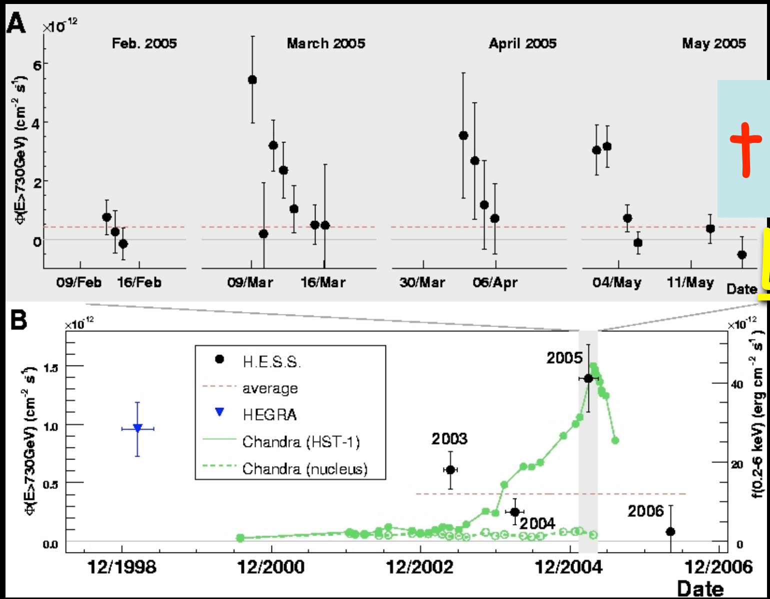
the radiogalaxy M87





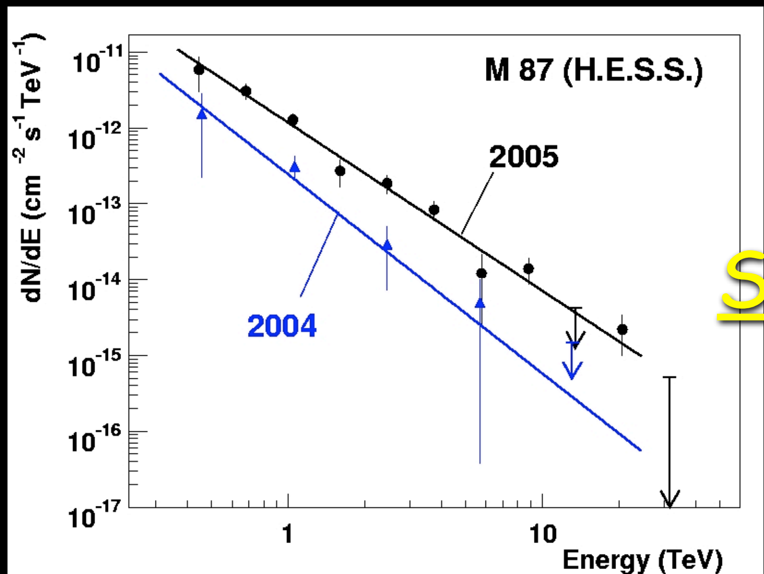


VHE emission of M87



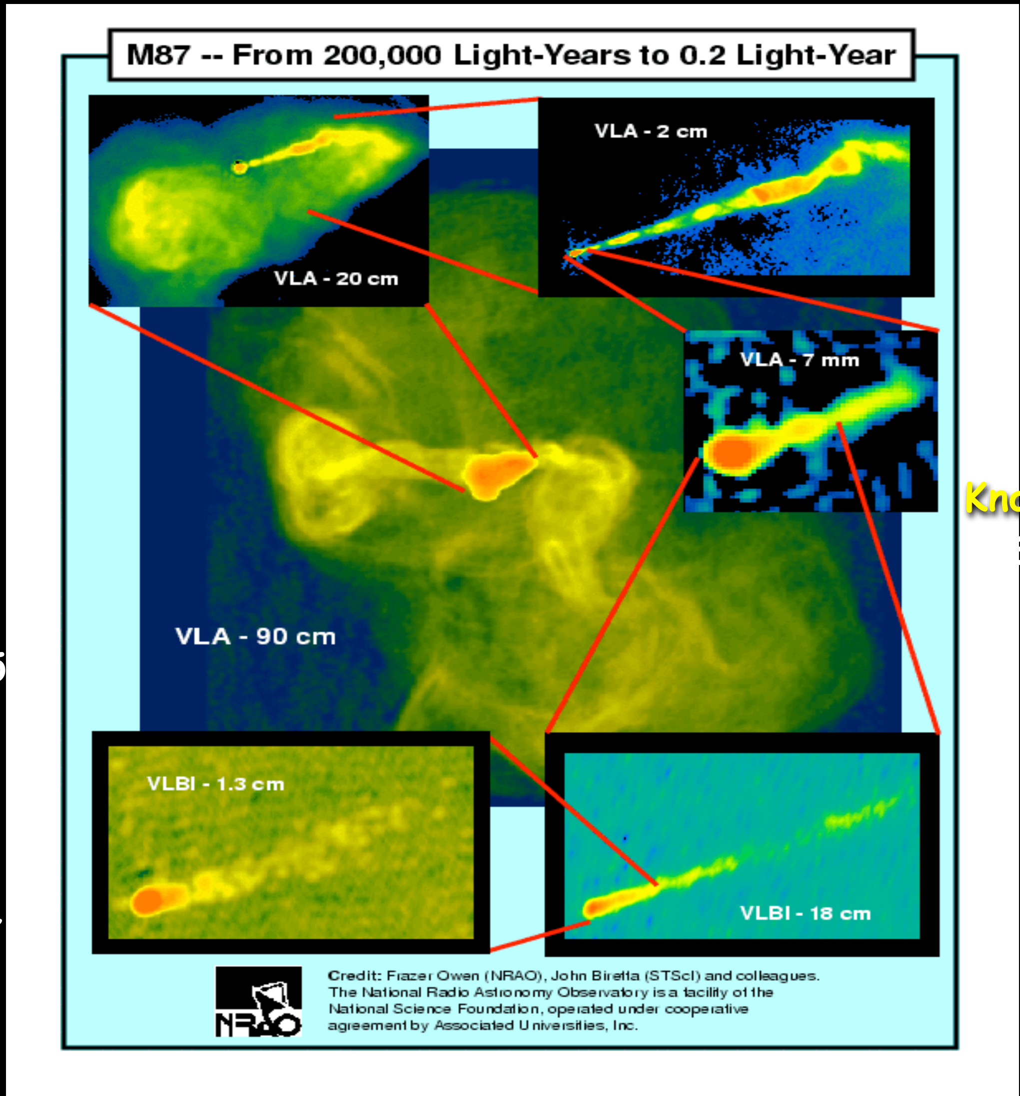
$t_{var} \sim 2$ days !

Light curve



Spectrum

Emission region?



Large scale jet
Stawarz et al. 2003

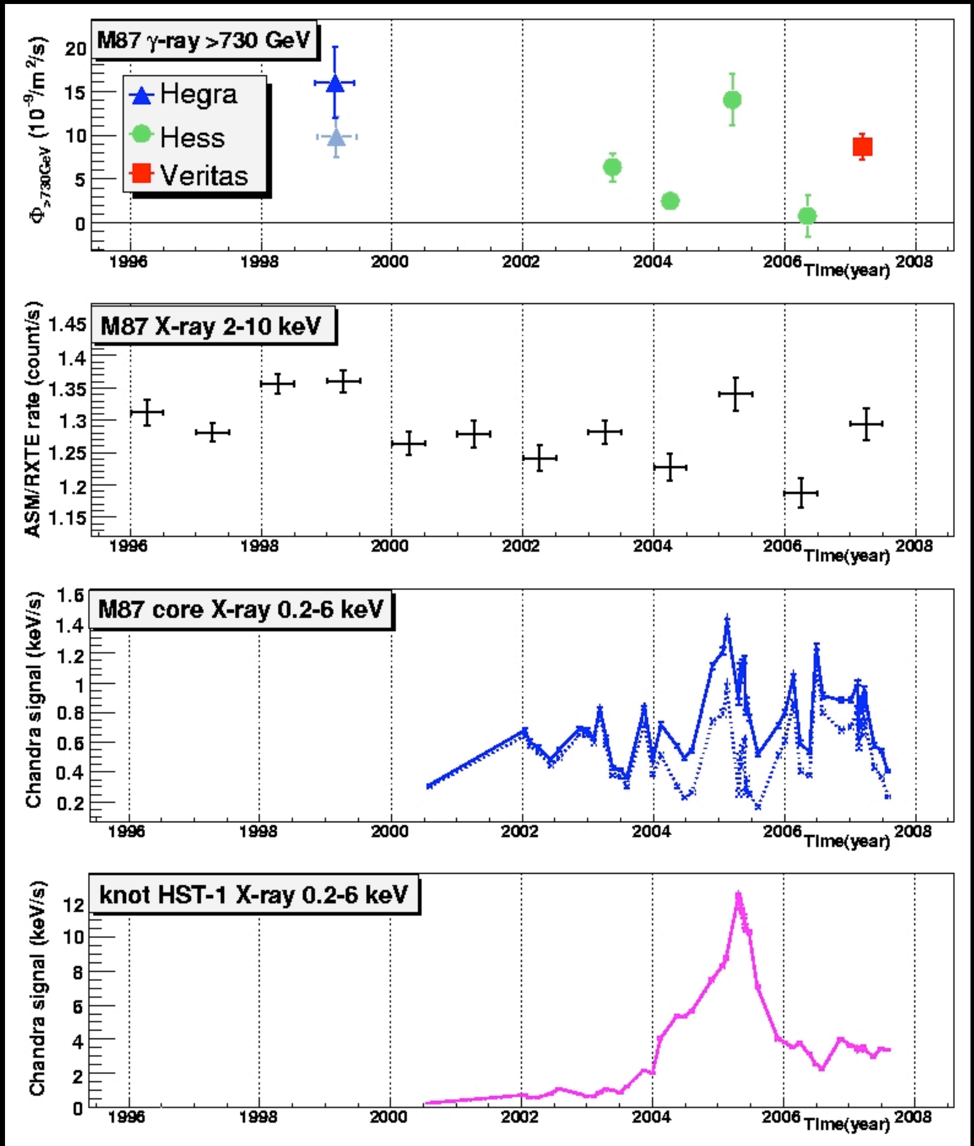
Knot HST-1 (60 pc proj.)
Stawarz et al. 2006
Cheung et al. 2007

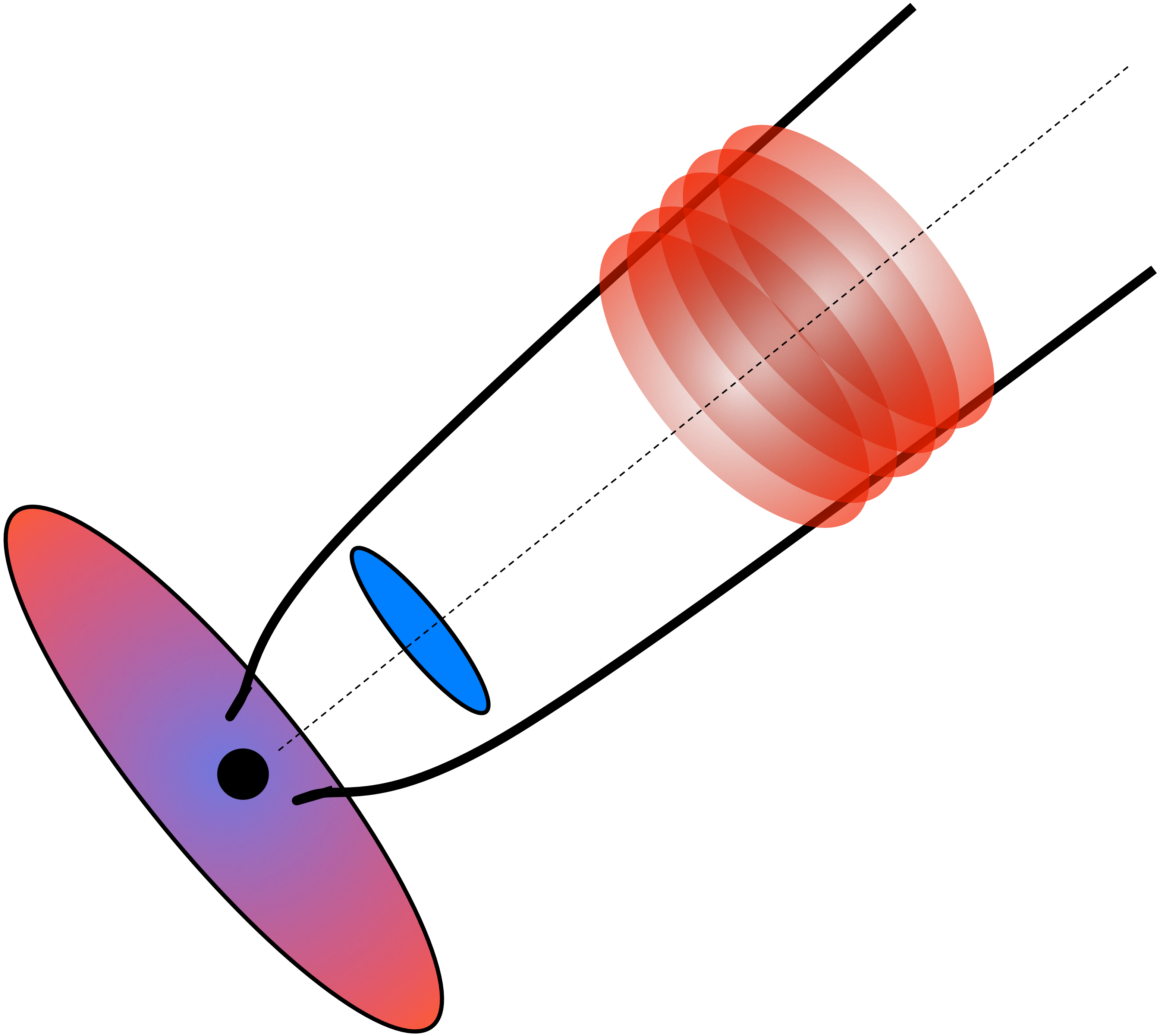
Misaligned (20 deg) blazar
Georganopoulos et al. 2005
Lenain et al. 2007
FT and GG 2008

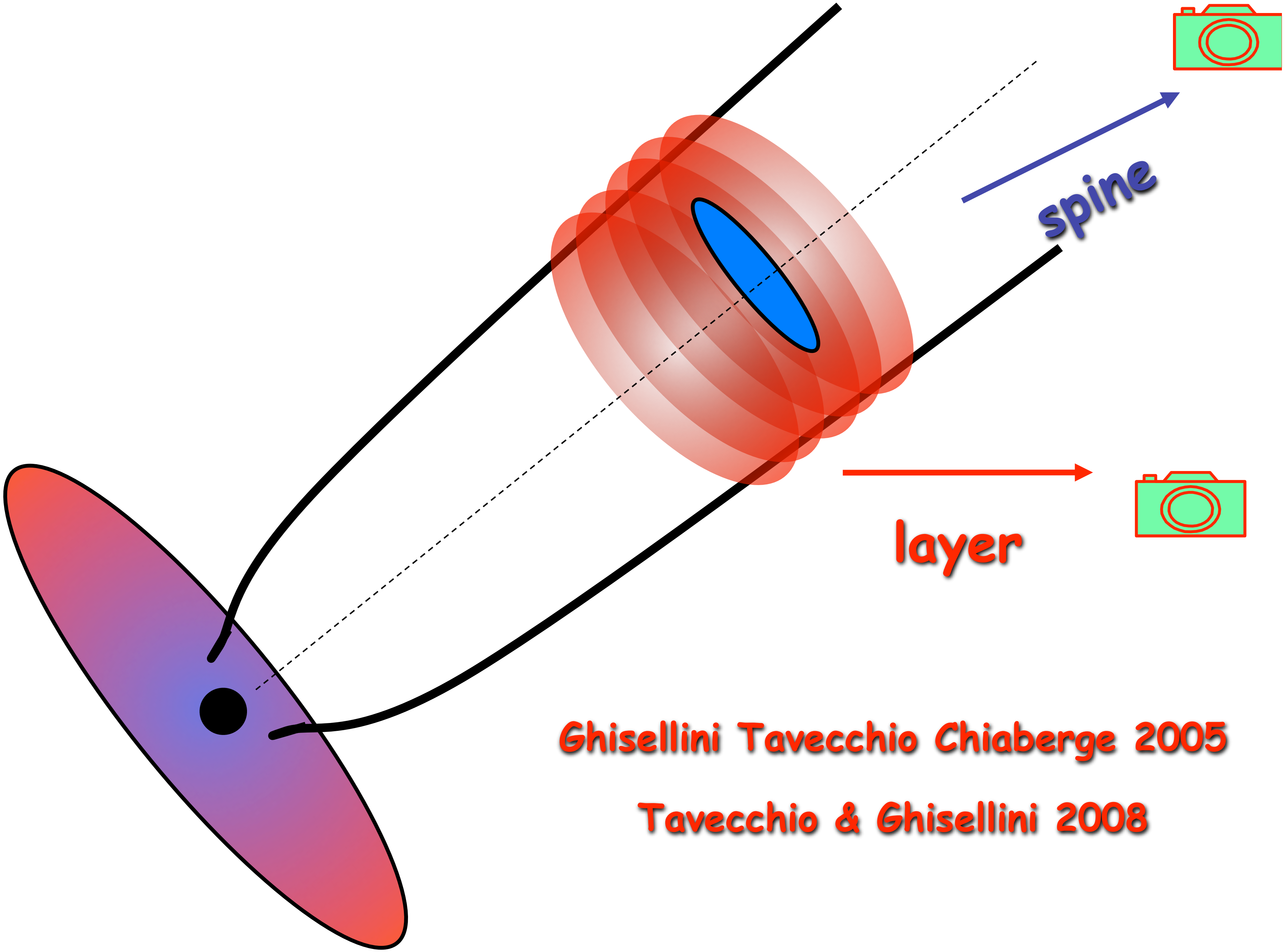
BH horizon
Neronov & Aharonian 2007
Rieger & Aharonian 2008

Core?

Acciari et al. 2008





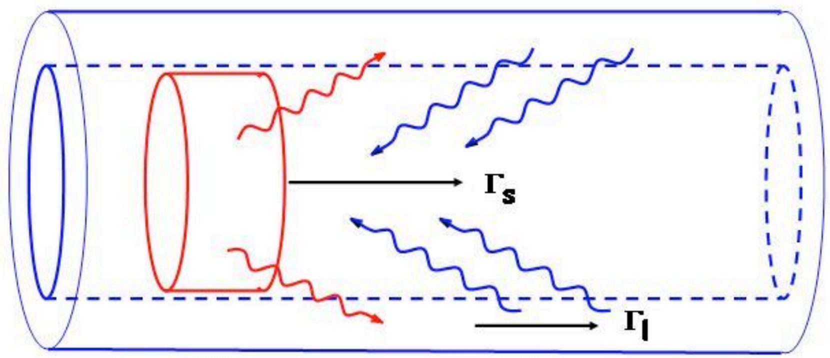

spine
layer
Ghisellini Tavecchio Chiaberge 2005
Tavecchio & Ghisellini 2008

- $\Gamma_{rel} = \Gamma_{layer}\Gamma_{spine}(1-\beta_{layer}\beta_{spine})$

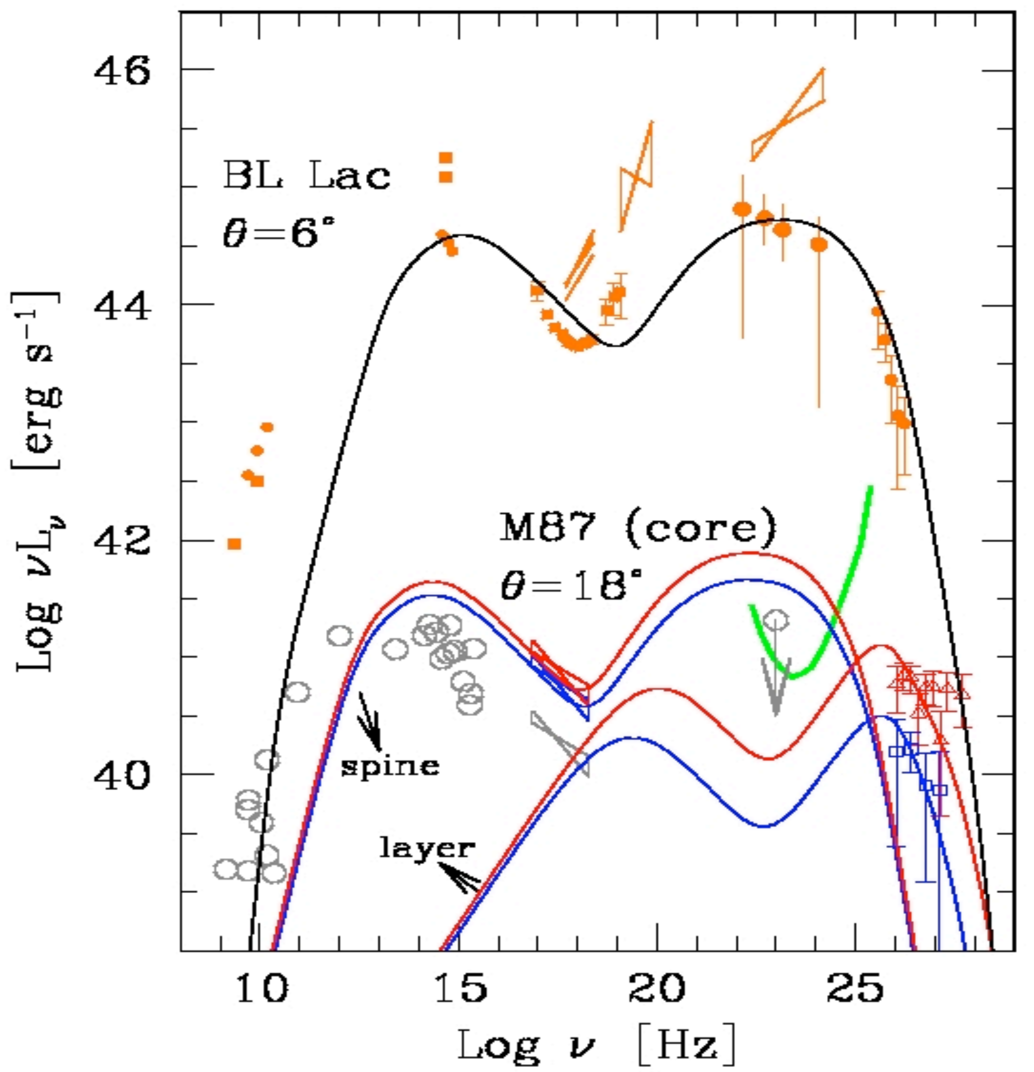
- The spine sees an enhanced U_{rad} coming from the layer

- Also the layer sees an

  from the spine



Misaligned structured blazar jet

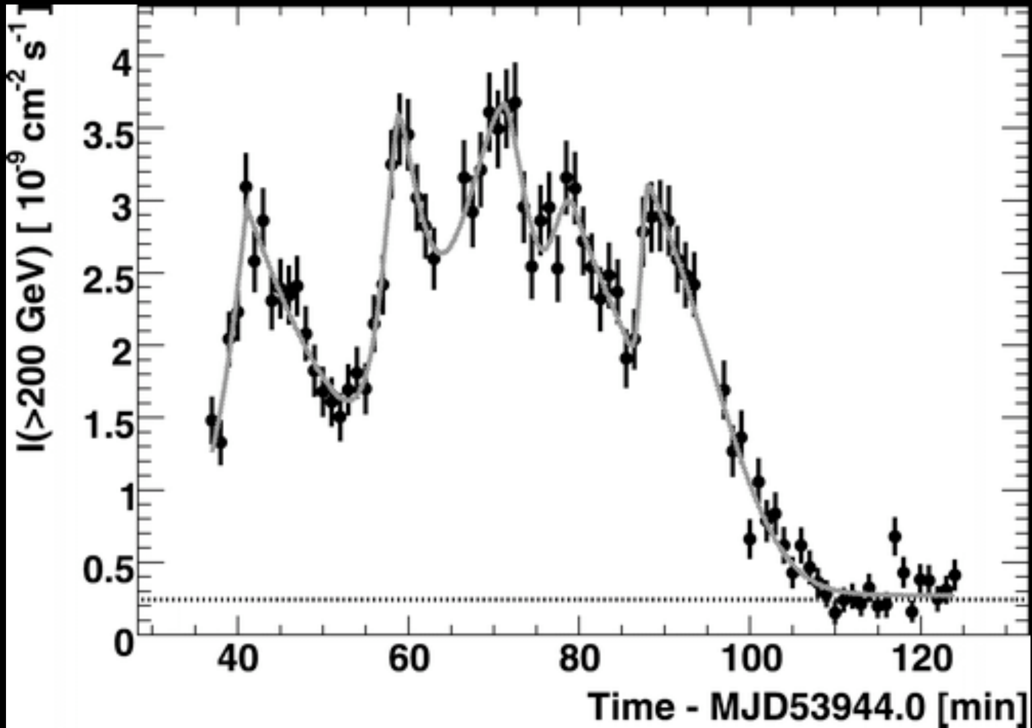


FT and GG 2008

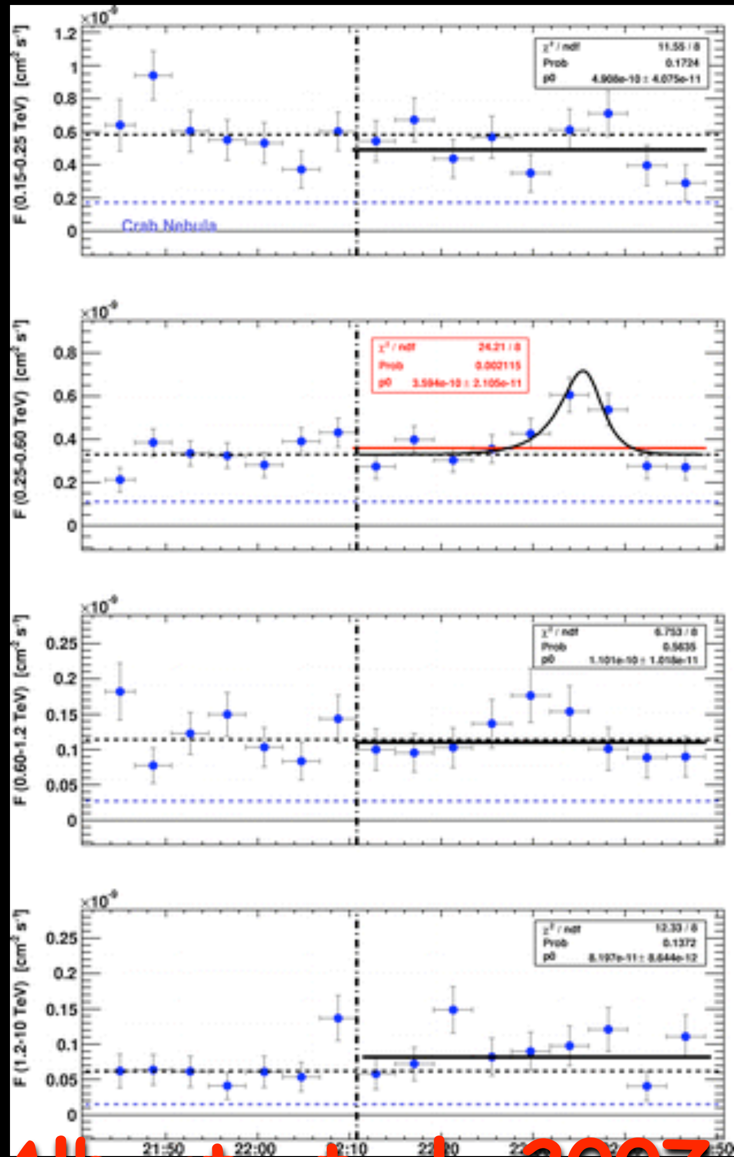
New problems: Ultra-rapid variability

Mkn 501

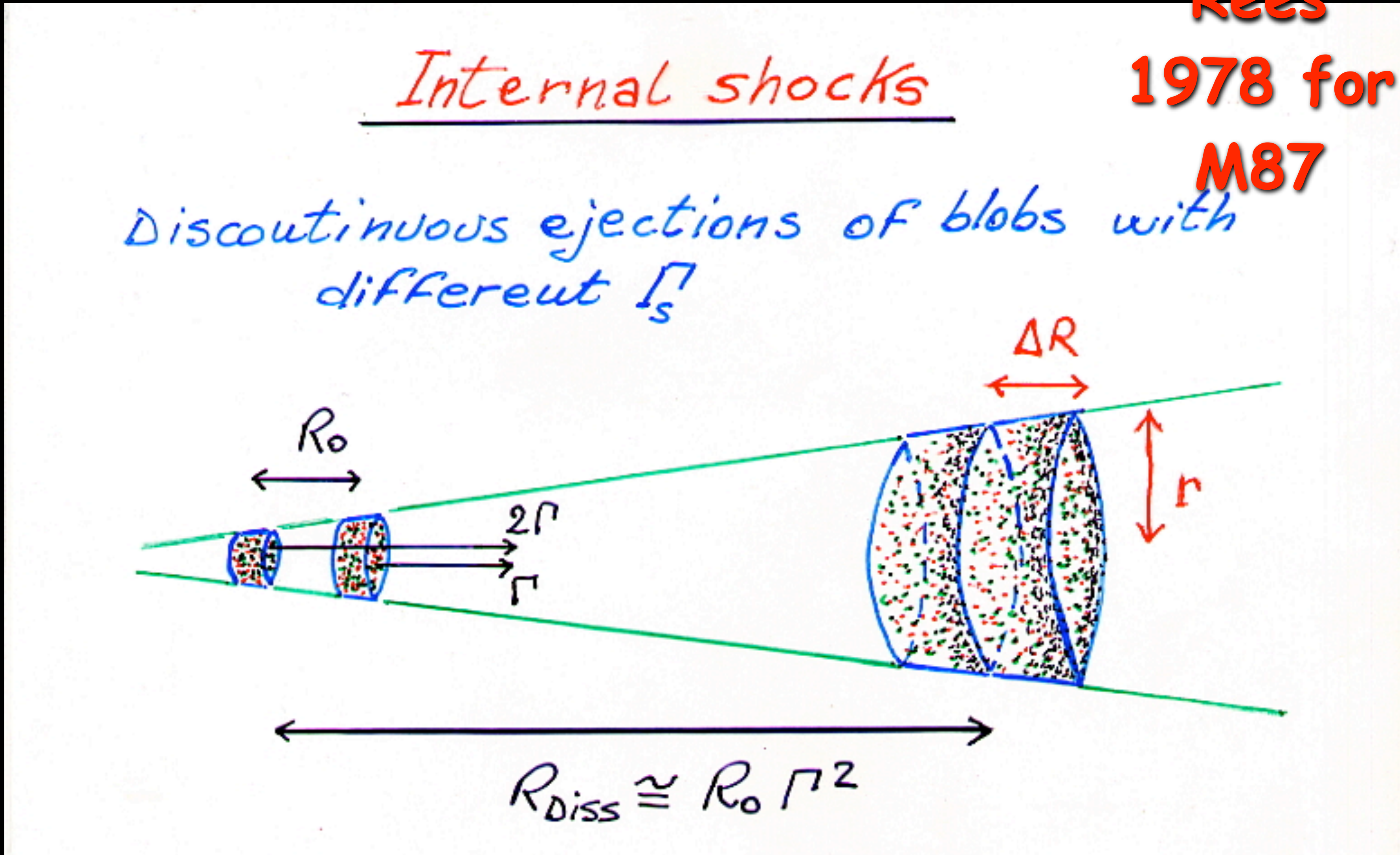
PKS 2155-304



Aharonian et al. 2007 - H.E.S.S.



Albert et al. 2007 - MAGIC



Rees 1978 for M87

Observed time: $(R_0/c)\Gamma^2(1-\beta\cos\theta) \sim R_0/c$!

t_{var} =200 s →

In the standard scenario $t_{var} > r_g /c = 1.4\ M_9$ h !

Conclusion:
only a small portion of the jet (and/or BH horizon) is involved in the emission

(e.g. Begelman, Fabian & Rees 2008)

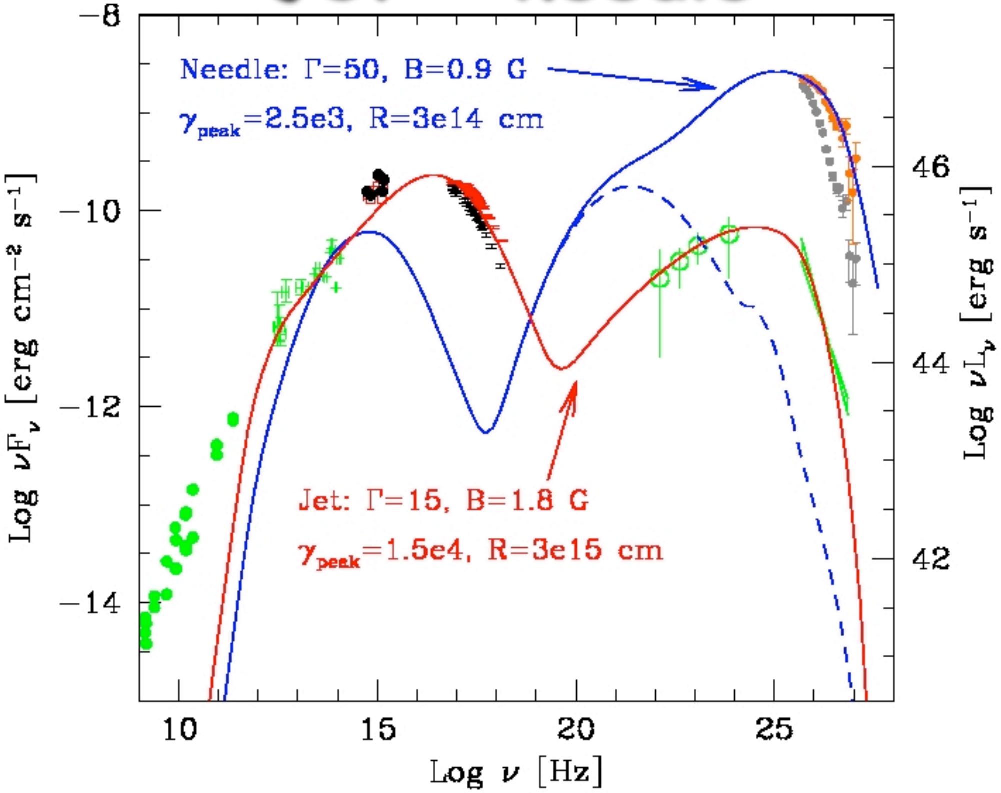
Possible alternative: VHE emission from a fast, transient "needle"

(Ghisellini & Tavecchio 2008)

VHE emission dominated by IC from the needle (spine) scattering the radiation of the jet (layer)

A different "flavour" of the spine-layer scenario

Jet - needle

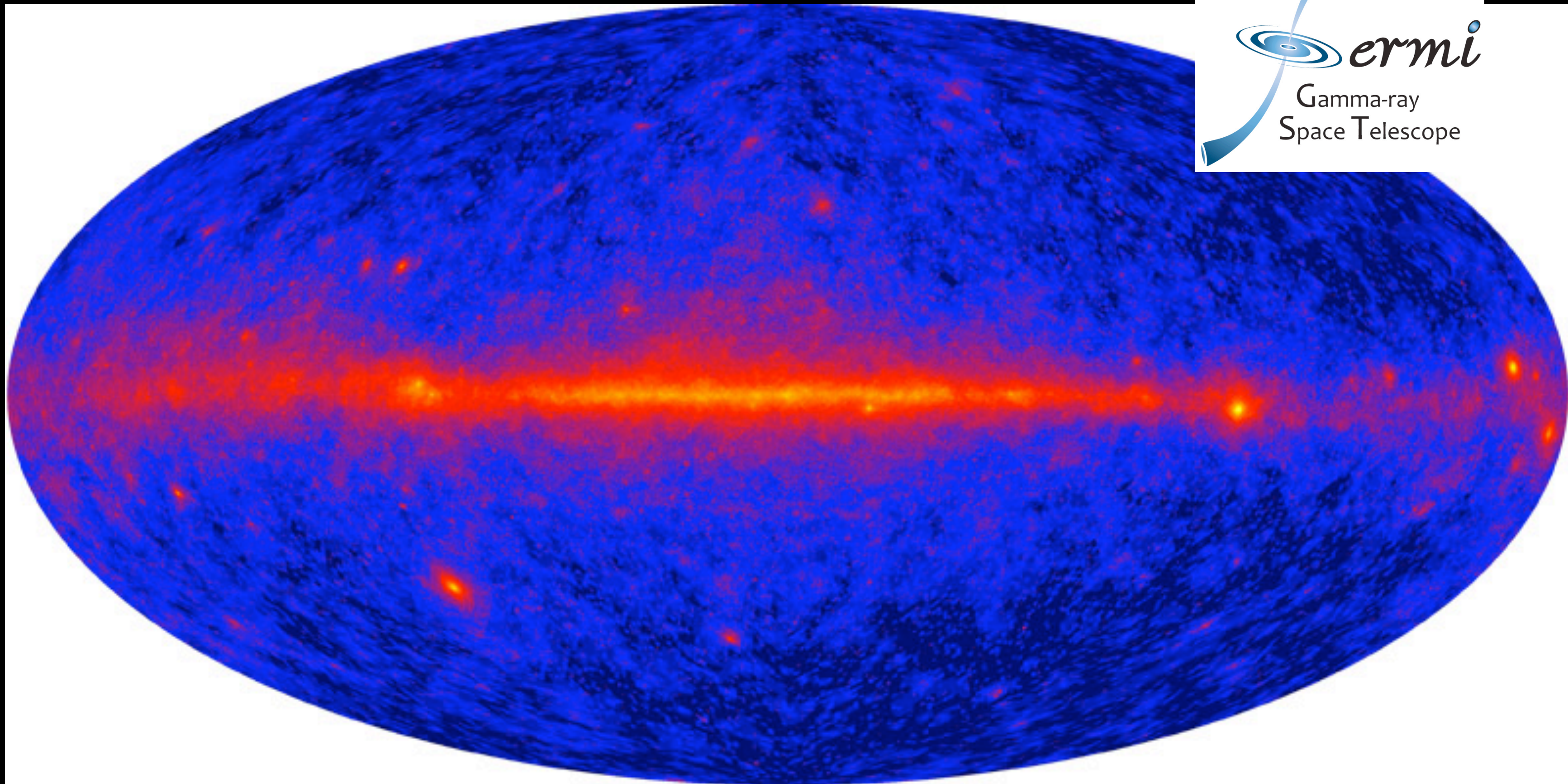


GG & FT 2008

The future -1

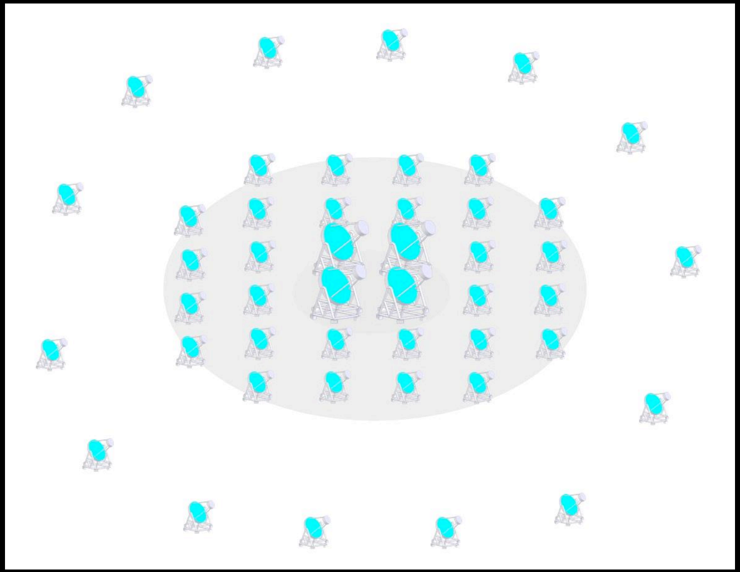
Fermi (former GLAST) !

First light, 96 hrs of integration



The future -2

New Cherenkov Telescope Arrays:



CTA, Europe

?

AGIS, USA

Krolik, "AGNs", 1999, Princeton Univ. Press

Suggested readings

Beaming: Ghisellini 1999, astro-ph/9905181

Unification schemes: Urry & Padovani 1995, PASP, 107, 803

Emission Mechanisms: Rybicki & Lightman, 1979, Wiley & Son

Jets: Begelman, Blandford & Rees, 1984, Rev. Mod. Physics, 56, 255

de Young, The physics of extragal. radio sources, 2002, Univ. Chicago Press