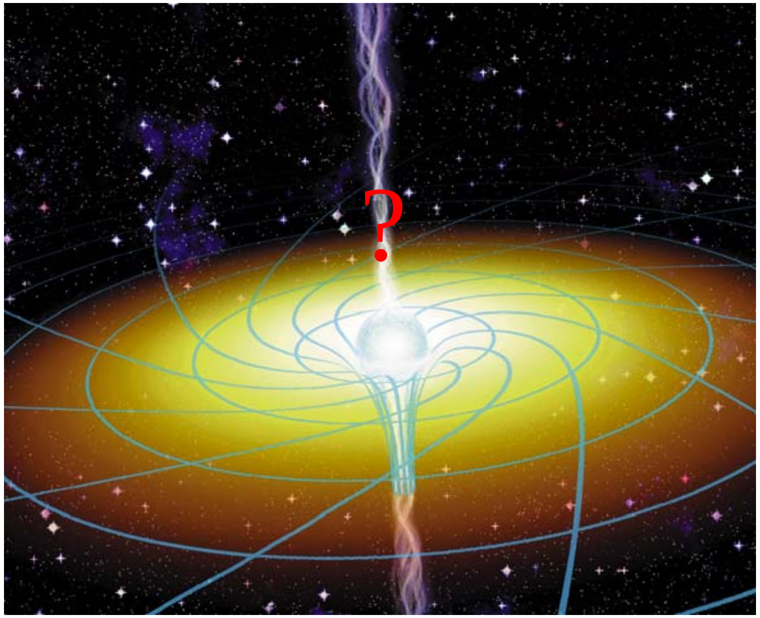
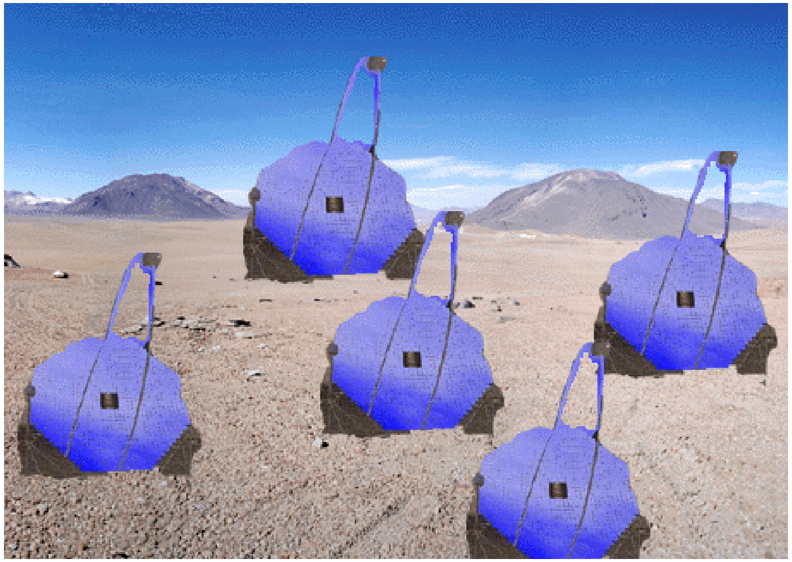
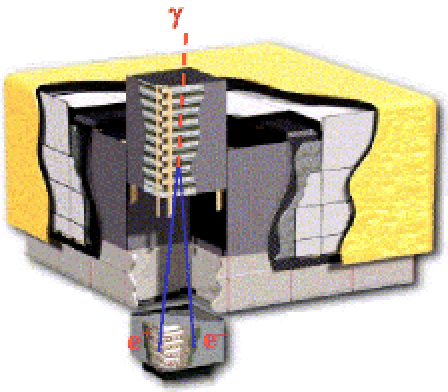
Blazar Physics in the GLAST Era: Eduardo’s Talk Continued…

P. Coppi,
Yale







?

General comments: the astrophysics-particle physics connection

Astronomical observations + detailed understanding of astronomical objects and processes provides access to physical conditions and length scales not accessible in the laboratory.

E.g., supernovas + CMB + galaxy and cluster surveys
    => dark energy, #1 problem for many
  helioseismology + solar model + neutrino observatory
    => neutrino oscillations
  galaxy rotation curves + cluster X-rays/gravitational lensing
    => dark matter
  MeV-GeV gamma-ray background + WMAP + BBN
    => measure baryon asymmetry
      + no significant antimatter domains w/in our horizon
      + baryogenesis at T> MeV (BBN scale)
      + probably not via GUT scale relicts that decay late
  in "old days," cosmic rays
    => new particles

Pendulum has swung back and forth between accelerator and non-accelerator science.
In US, at least, DOE non-accelerator science has grown dramatically in last 5-10 years.
Until LHC and we get out of the desert, will probably continue to do so.

Probing the high-energy Universe: pick your messenger particle!

- Photons - Radio: mainly non-thermal, relatively good at penetrating intervening matter [currently highest spatial resolution, .g., VLBA,]

  Infrared: see energy absorbed and re-emitted by dust [Spitzer, ALMA]

  Optical/UV: characteristic (z=0) stellar energy, worst in terms of obscuration, but do see lots of useful atomic features

  Soft X-Ray: hot gas, atomic features still available but not completely understood, still easily obscured

  ◇ ◇ hard X-ray (>10 keV): very little gas/stellar contamination, very penetrating, lose atomic features, hard to focus

  ◇ Soft Gamma-Ray (>500 keV): pair annihilation line, nuclear lines, but start being subject to obscuration again due to photon-photon pair production, even harder to stop in detector and image, lots of background

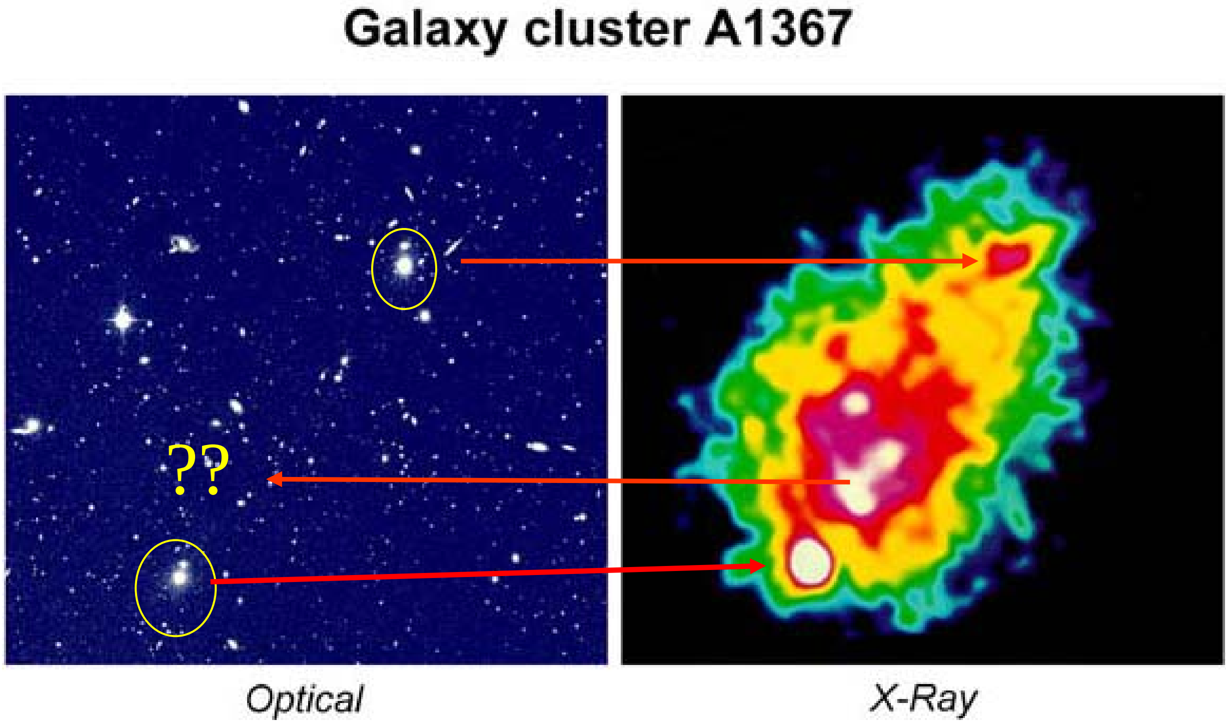
  ◇ ◇ Gamma-Ray (>GeV): obscuration in source and during propagation big worry, but clearly indicates presence of very energetic particles and “extreme” processes

All, straight line propagation from source!

Messenger particle II.

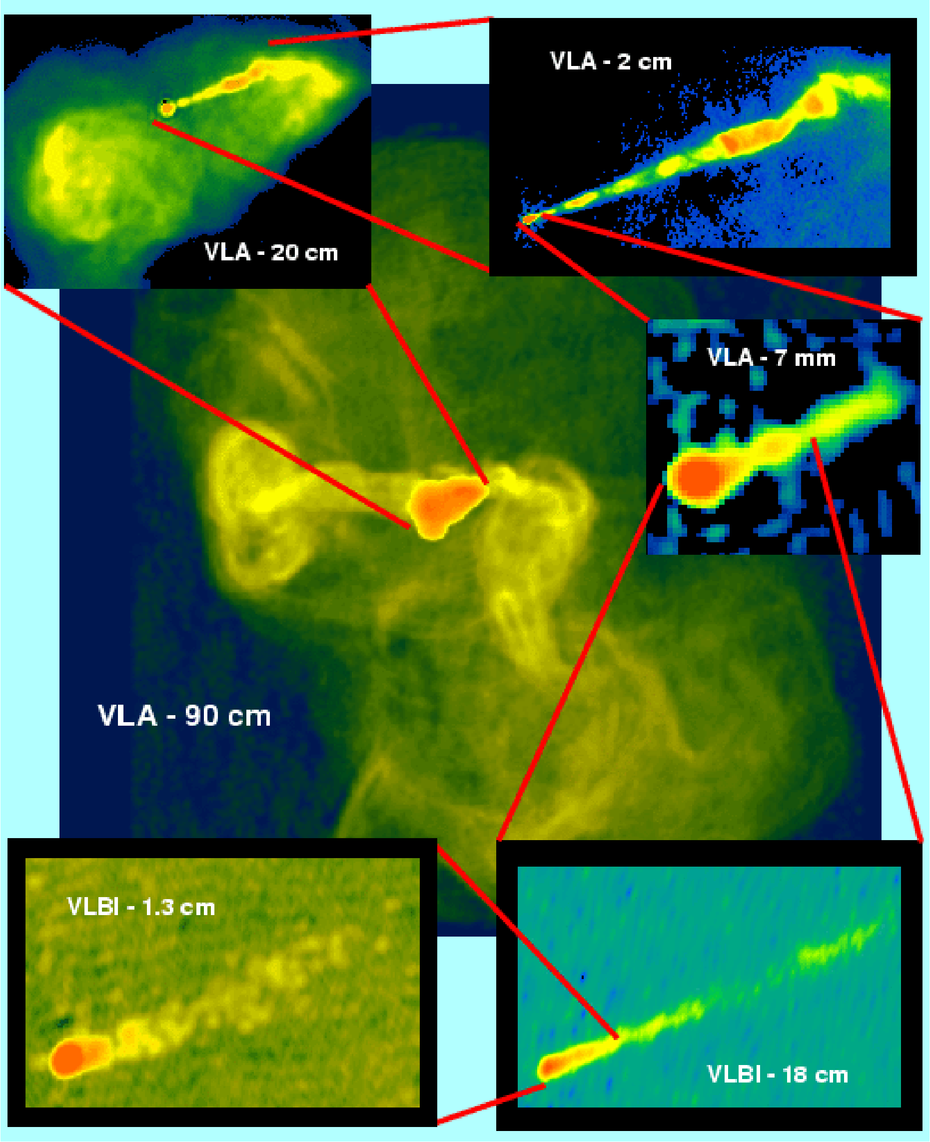
- proton, electron (cosmic rays): subject to energy losses, deflection by magnetic field
- neutrino: straight line propagation, usually impossible to stop in source, smoking gun probe for hadronic processes, but almost equally impossible to detect ☺ [e.g., ICECUBE, right sensitivity level to finally start seeing something besides nearby supernova]
- gravity waves: straight line propagation, need only to detect strain (amplitude not power) => can see to high redshift, but expected strains miniscule, no convincing detections yet [LIGO, LISA]

When you look in new ways …

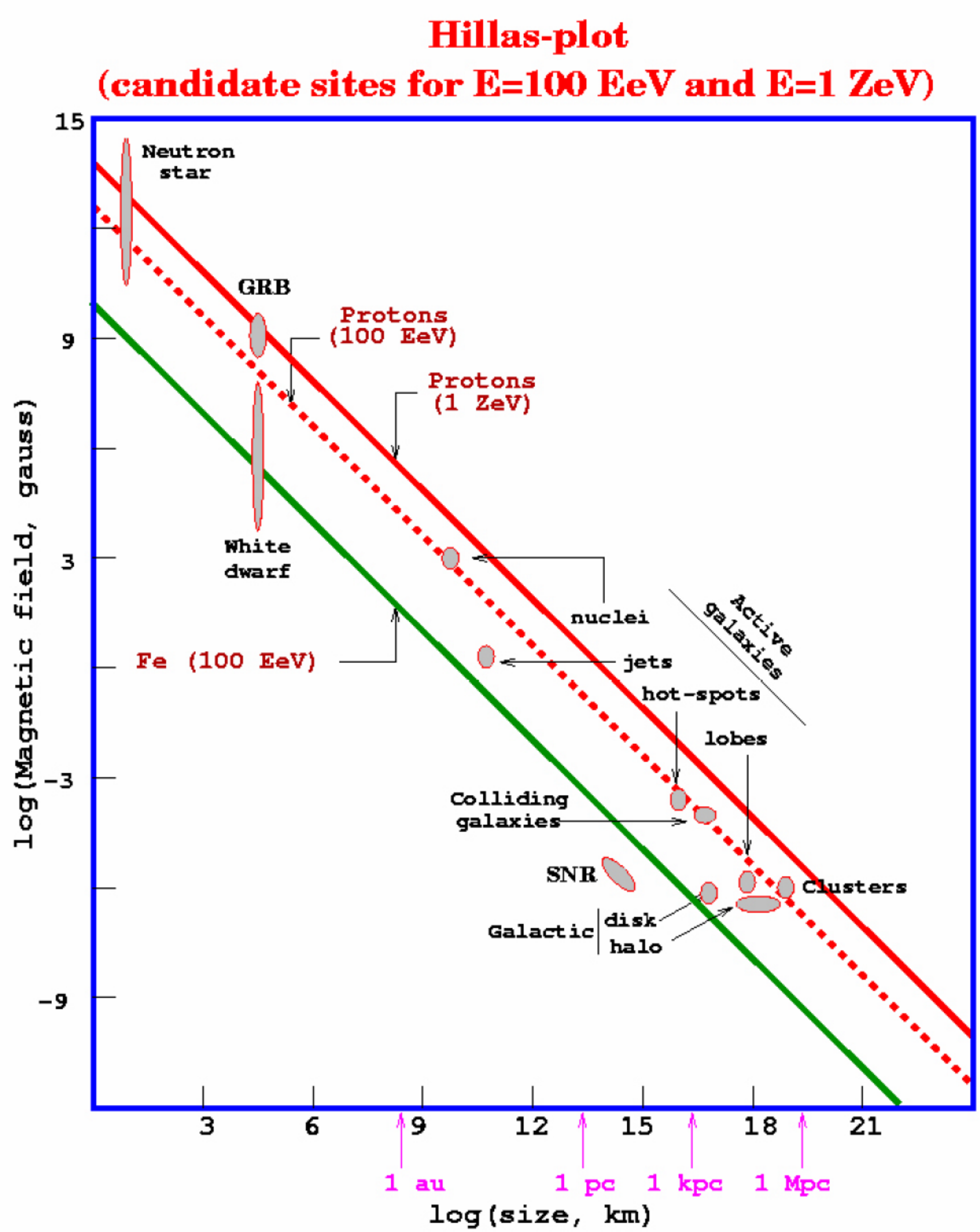


A “boring” object in the sky: the nearby elliptical galaxy M87

Optical



Radio



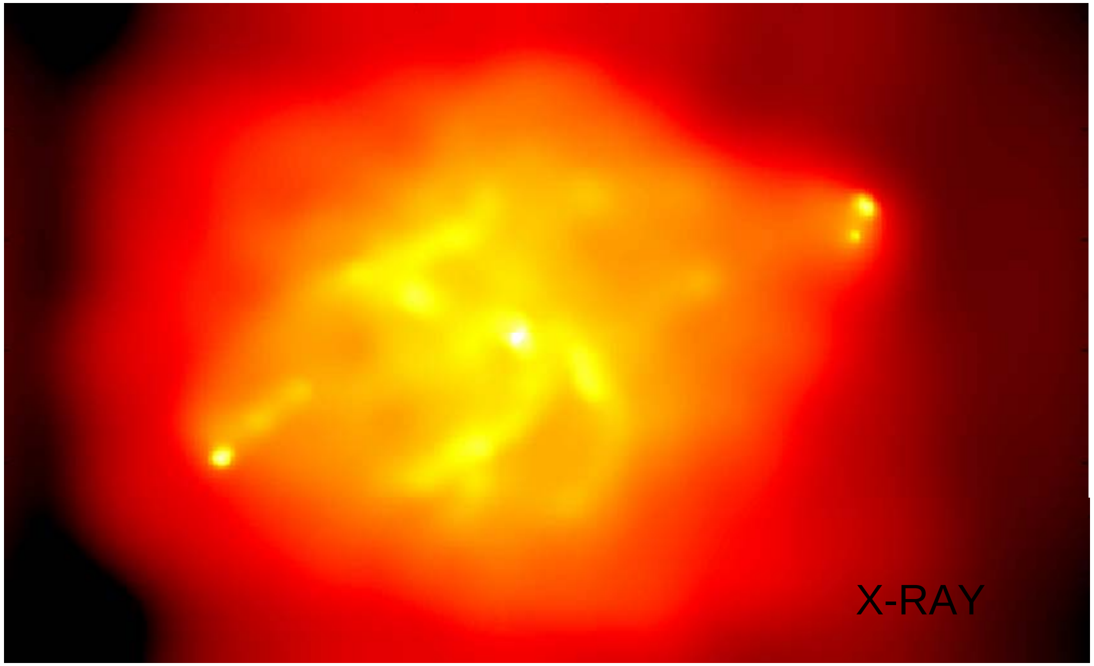
Black holes one of most extreme environments can imagine --- strong gravity, spinning black hole can extract up to ~0.4 of the rest mass energy of infalling matter

⇒huge power outputs, and densities:

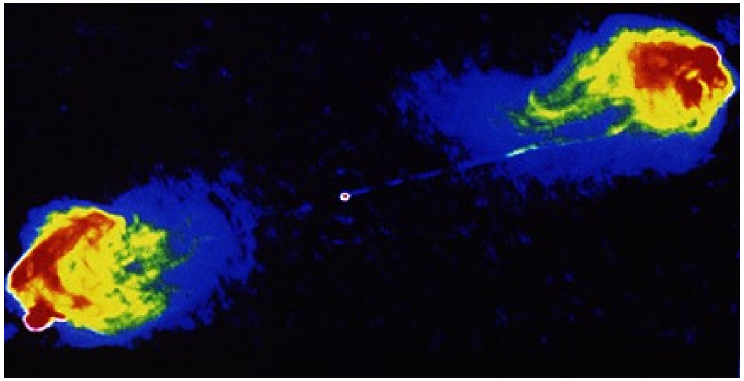
- Black hole environments probe *extreme physics*!
- Because they are often so bright, accreting black holes very useful as *cosmological probes* (can see them to very high redshifts).
- *Background/noise for exotic particle astro. sources, e.g.,* probably dominate GeV gamma-ray background and may produce UHECR.

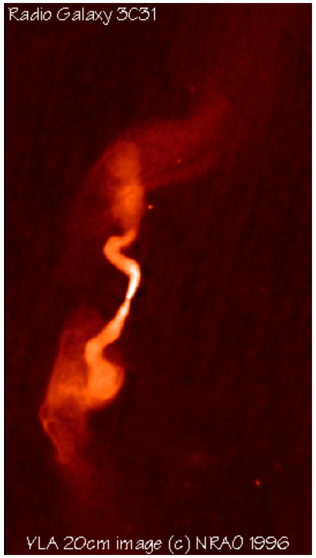
Better understand them and what they can do!

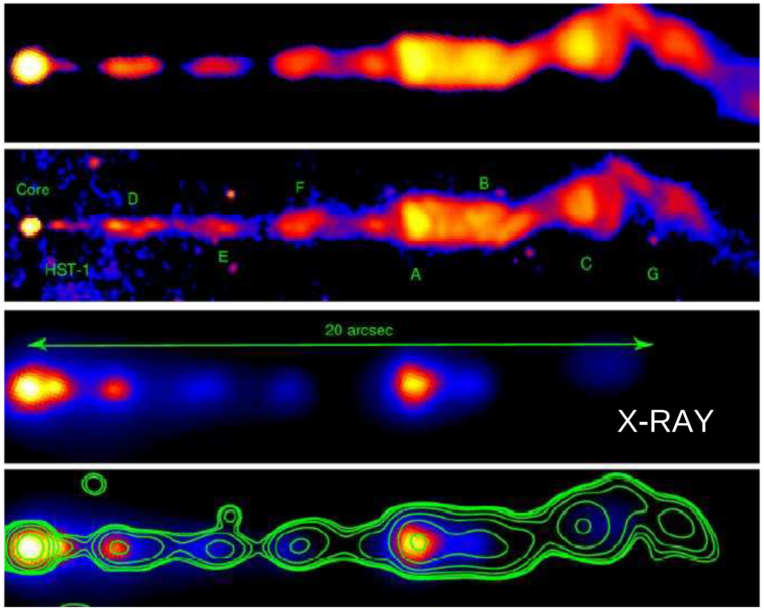
Extended X-Ray Emission from Jets!! – Potential GeV/TeV Sources!



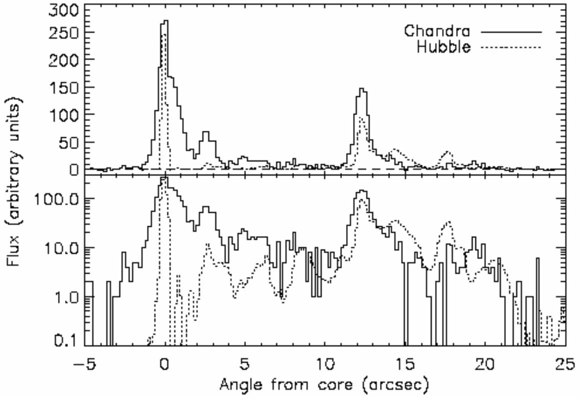
Cygnus A - FRII (powerful jet?)



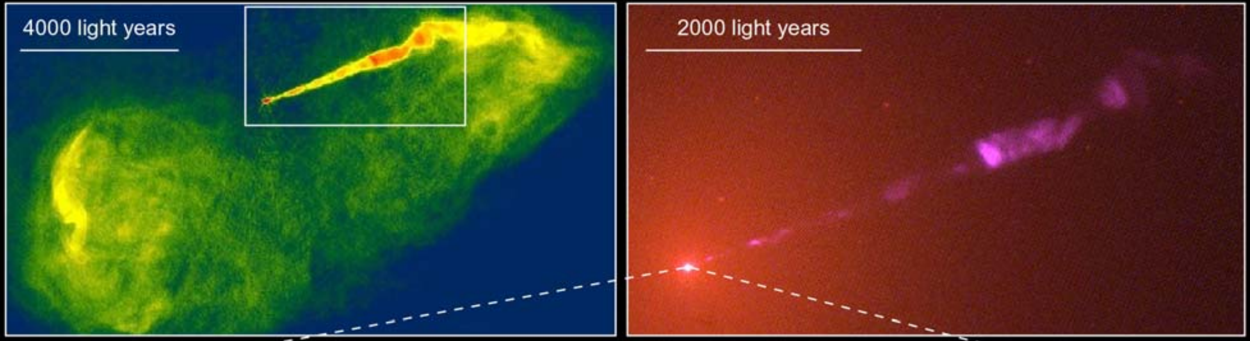




M87 – FRI (weak jet)

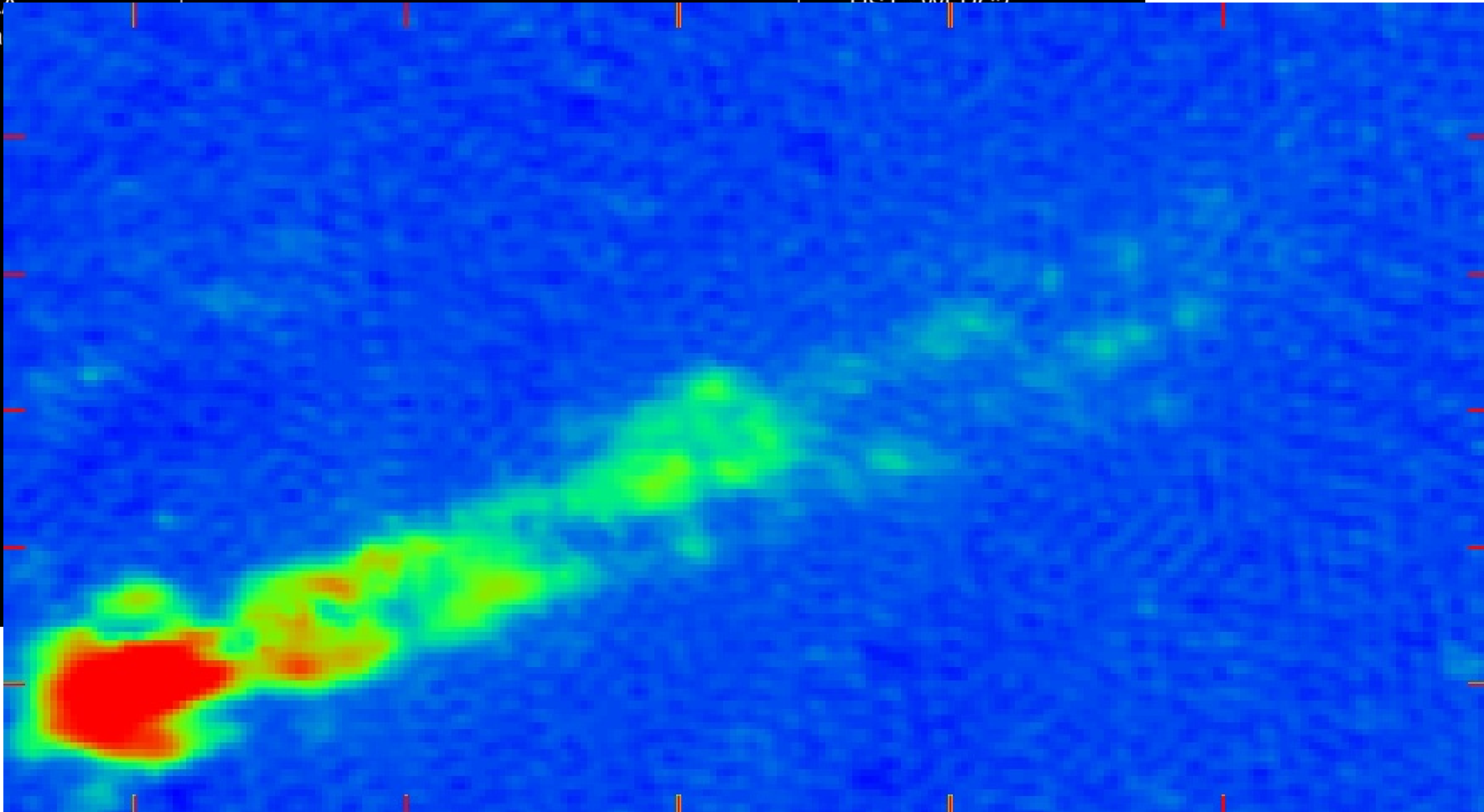


Galaxy M87



VL
Ra

HST - WFPC2



HST M87 Superluminal Motion

X-ray variability seen in HST-1 knot too!!

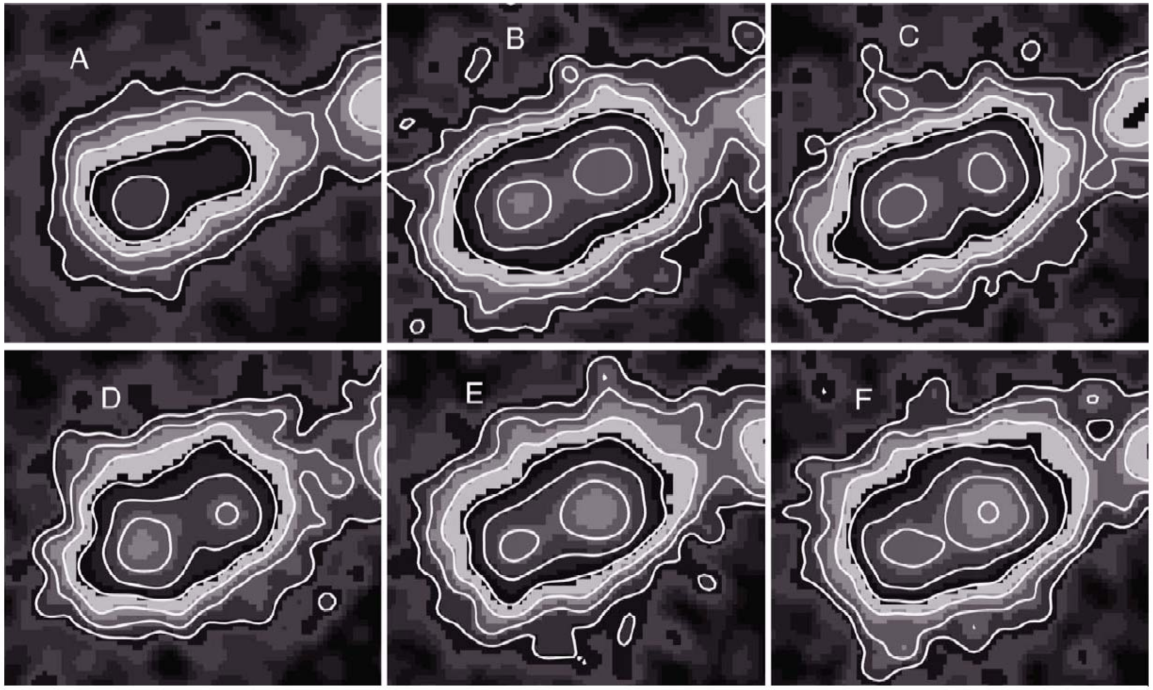


Fig. 1. The core and HST-1: (A) is the archival observation of 2000Jul and our five monitoring observations of 2002 follow. The contours increase by factors of two with the lowest contour level being 2×10^{-16} erg cm^{-2} s^{-1} per pixel in the 0.2 to 6 keV band. The data were regridded to a pixel size of 0.0492″; and a Gaussian smoothing function of FWHM = 0.25″ was applied.

M87 jet is not wimpy!!!

D. Harris,2003

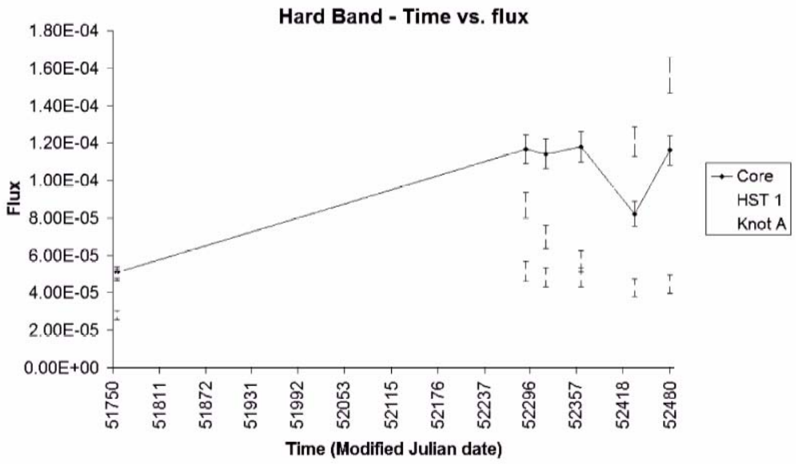
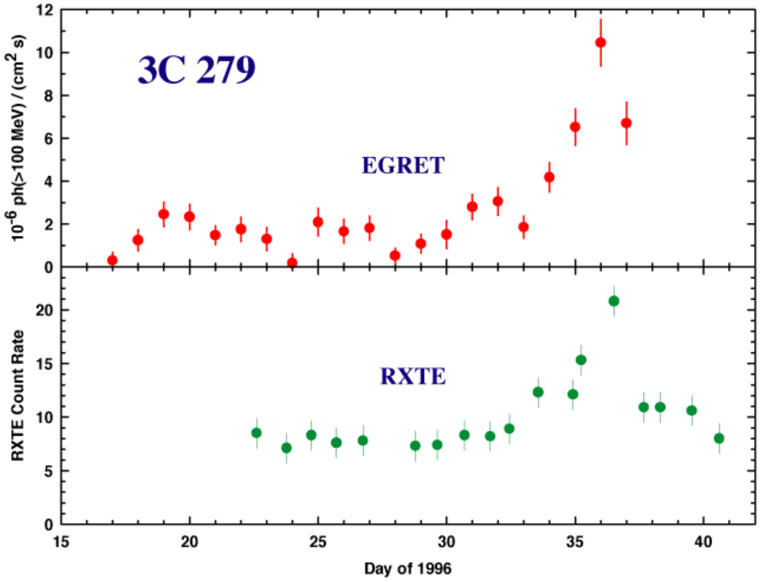
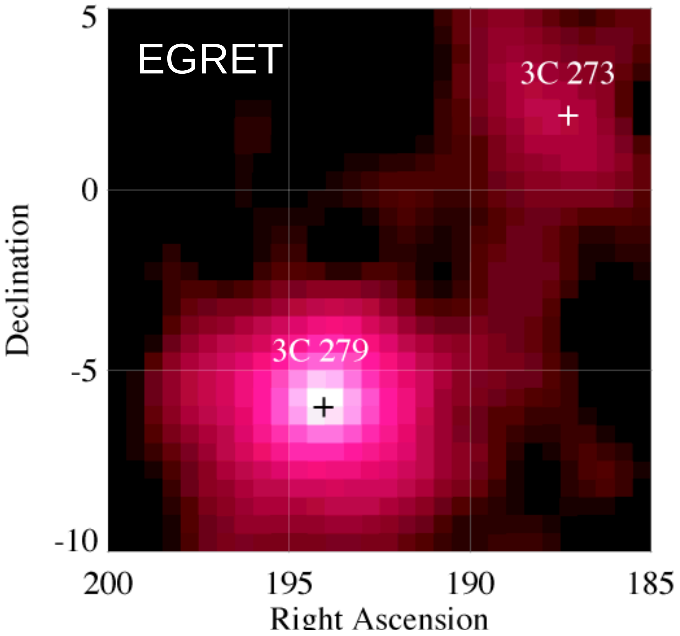


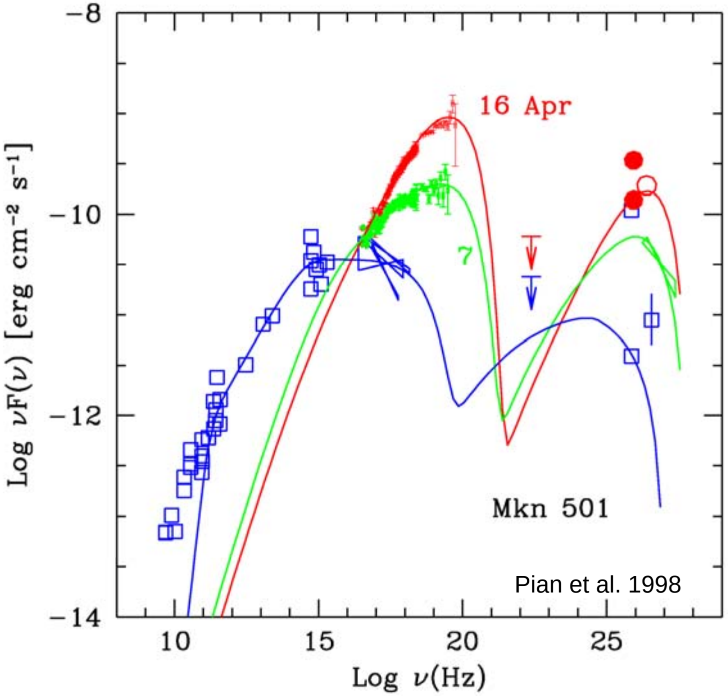
Fig. 2. Hard band lightcurves for the M87 core, HST-1, and knot A. The observation at the left is from 2000 July; those to the right from the 2002 season. Error bars are SQRT(N) type, based on total counts in the measuring apertures prior to background subtraction. The energy band is 2 to 6 keV.

GeV Blazars…

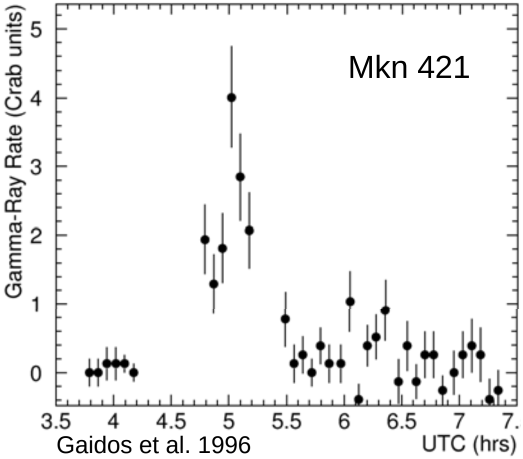




TeV Blazars…

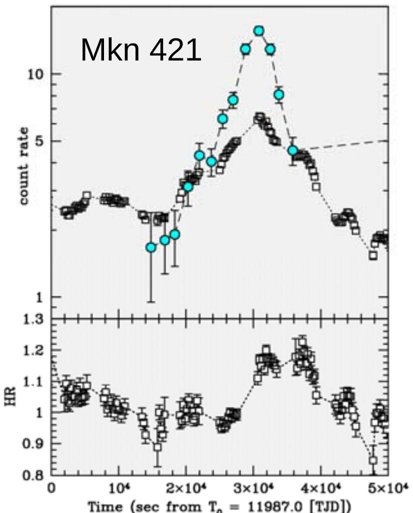


Pian et al. 1998



Gaidos et al. 1996

Fossati et al. 2002



Rapid spectral variability!

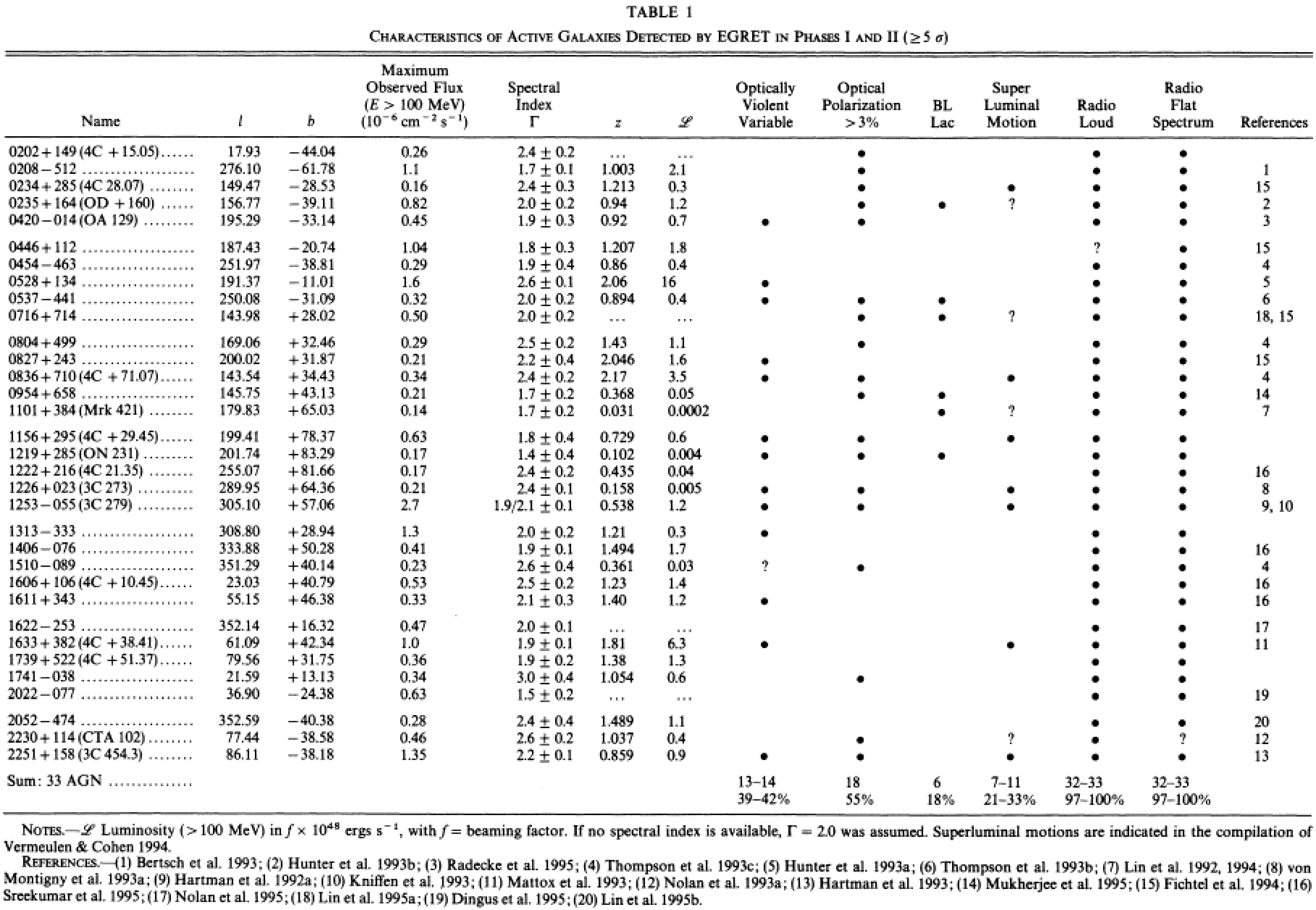


TABLE 1

CHARACTERISTICS OF ACTIVE GALAXIES DETECTED BY EGRET IN PHASES I AND II ($\geq 5\ \sigma$)

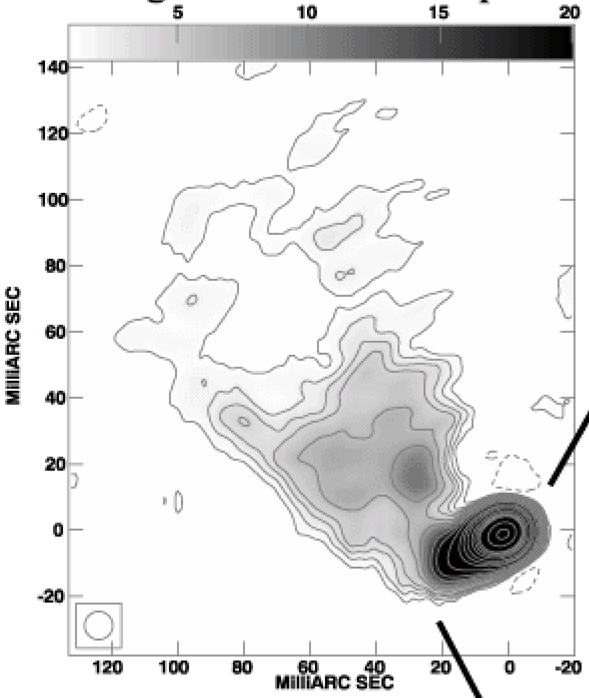
Name	l	b	Maximum Observed Flux ($E > 100$ MeV) (10^{-6} cm^{-2} s^{-1})	Spectral Index Γ	z	$\mathscr{L}$	Optically Violent Variable	Optical Polarization > 3%	BL Lac	Super Luminal Motion	Radio Loud	Radio Flat Spectrum	References
0202+149 (4C +15.05)	17.93	−44.04	0.26	2.4 ± 0.2	...	...		●			●	●	
0208−512	276.10	−61.78	1.1	1.7 ± 0.1	1.003	2.1		●			●	●	1
0234+285 (4C 28.07)	149.47	−28.53	0.16	2.4 ± 0.3	1.213	0.3		●		●	●	●	15
0235+164 (OD +160)	156.77	−39.11	0.82	2.0 ± 0.2	0.94	1.2		●	●	?	●	●	2
0420−014 (OA 129)	195.29	−33.14	0.45	1.9 ± 0.3	0.92	0.7	●	●			●	●	3
0446+112	187.43	−20.74	1.04	1.8 ± 0.3	1.207	1.8					?	●	15
0454−463	251.97	−38.81	0.29	1.9 ± 0.4	0.86	0.4					●	●	4
0528+134	191.37	−11.01	1.6	2.6 ± 0.1	2.06	16	●				●	●	5
0537−441	250.08	−31.09	0.32	2.0 ± 0.2	0.894	0.4	●	●	●		●	●	6
0716+714	143.98	+28.02	0.50	2.0 ± 0.2	...	...		●	●	?	●	●	18, 15
0804+499	169.06	+32.46	0.29	2.5 ± 0.2	1.43	1.1		●			●	●	4
0827+243	200.02	+31.87	0.21	2.2 ± 0.4	2.046	1.6	●				●	●	15
0836+710 (4C +71.07)	143.54	+34.43	0.34	2.4 ± 0.2	2.17	3.5	●	●		●	●	●	4
0954+658	145.75	+43.13	0.21	1.7 ± 0.2	0.368	0.05		●	●		●	●	14
1101+384 (Mrk 421)	179.83	+65.03	0.14	1.7 ± 0.2	0.031	0.0002			●	?	●	●	7
1156+295 (4C +29.45)	199.41	+78.37	0.63	1.8 ± 0.4	0.729	0.6	●	●		●	●	●	
1219+285 (ON 231)	201.74	+83.29	0.17	1.4 ± 0.4	0.102	0.004	●	●	●		●	●	
1222+216 (4C 21.35)	255.07	+81.66	0.17	2.4 ± 0.2	0.435	0.04					●	●	16
1226+023 (3C 273)	289.95	+64.36	0.21	2.4 ± 0.1	0.158	0.005	●	●		●	●	●	8
1253−055 (3C 279)	305.10	+57.06	2.7	1.9/2.1 ± 0.1	0.538	1.2	●	●		●	●	●	9, 10
1313−333	308.80	+28.94	1.3	2.0 ± 0.2	1.21	0.3	●				●	●	
1406−076	333.88	+50.28	0.41	1.9 ± 0.1	1.494	1.7					●	●	16
1510−089	351.29	+40.14	0.23	2.6 ± 0.4	0.361	0.03	?	●			●	●	4
1606+106 (4C +10.45)	23.03	+40.79	0.53	2.5 ± 0.2	1.23	1.4					●	●	16
1611+343	55.15	+46.38	0.33	2.1 ± 0.3	1.40	1.2	●				●	●	16
1622−253	352.14	+16.32	0.47	2.0 ± 0.1	...	...					●	●	17
1633+382 (4C +38.41)	61.09	+42.34	1.0	1.9 ± 0.1	1.81	6.3	●			●	●	●	11
1739+522 (4C +51.37)	79.56	+31.75	0.36	1.9 ± 0.2	1.38	1.3					●	●	
1741−038	21.59	+13.13	0.34	3.0 ± 0.4	1.054	0.6		●			●	●	
2022−077	36.90	−24.38	0.63	1.5 ± 0.2	...	...					●	●	19
2052−474	352.59	−40.38	0.28	2.4 ± 0.4	1.489	1.1					●	●	20
2230+114 (CTA 102)	77.44	−38.58	0.46	2.6 ± 0.2	1.037	0.4		●		?	●	?	12
2251+158 (3C 454.3)	86.11	−38.18	1.35	2.2 ± 0.1	0.859	0.9	●	●		●	●	●	13
Sum: 33 AGN							13–14 39–42%	18 55%	6 18%	7–11 21–33%	32–33 97–100%	32–33 97–100%	

NOTES.—$\mathscr{L}$ Luminosity (>100 MeV) in $f \times 10^{48}$ ergs s^{-1}, with f = beaming factor. If no spectral index is available, $\Gamma = 2.0$ was assumed. Superluminal motions are indicated in the compilation of Vermeulen & Cohen 1994.

REFERENCES.—(1) Bertsch et al. 1993; (2) Hunter et al. 1993b; (3) Radecke et al. 1995; (4) Thompson et al. 1993c; (5) Hunter et al. 1993a; (6) Thompson et al. 1993b; (7) Lin et al. 1992, 1994; (8) von Montigny et al. 1993a; (9) Hartman et al. 1992a; (10) Kniffen et al. 1993; (11) Mattox et al. 1993; (12) Nolan et al. 1993a; (13) Hartman et al. 1993; (14) Mukherjee et al. 1995; (15) Fichtel et al. 1994; (16) Sreekumar et al. 1995; (17) Nolan et al. 1995; (18) Lin et al. 1995a; (19) Dingus et al. 1995; (20) Lin et al. 1995b.

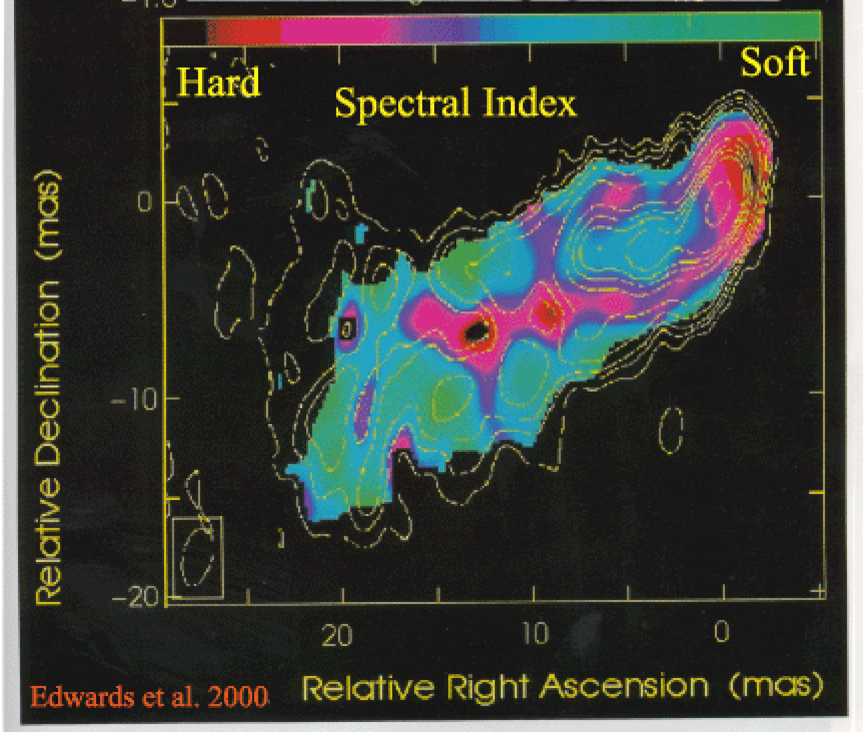
C. von Montigny 1995

Larger Scale Radio Map



Giovannini et al. 1998

Aaron 1999



Edwards et al. 2000

Mkn 501

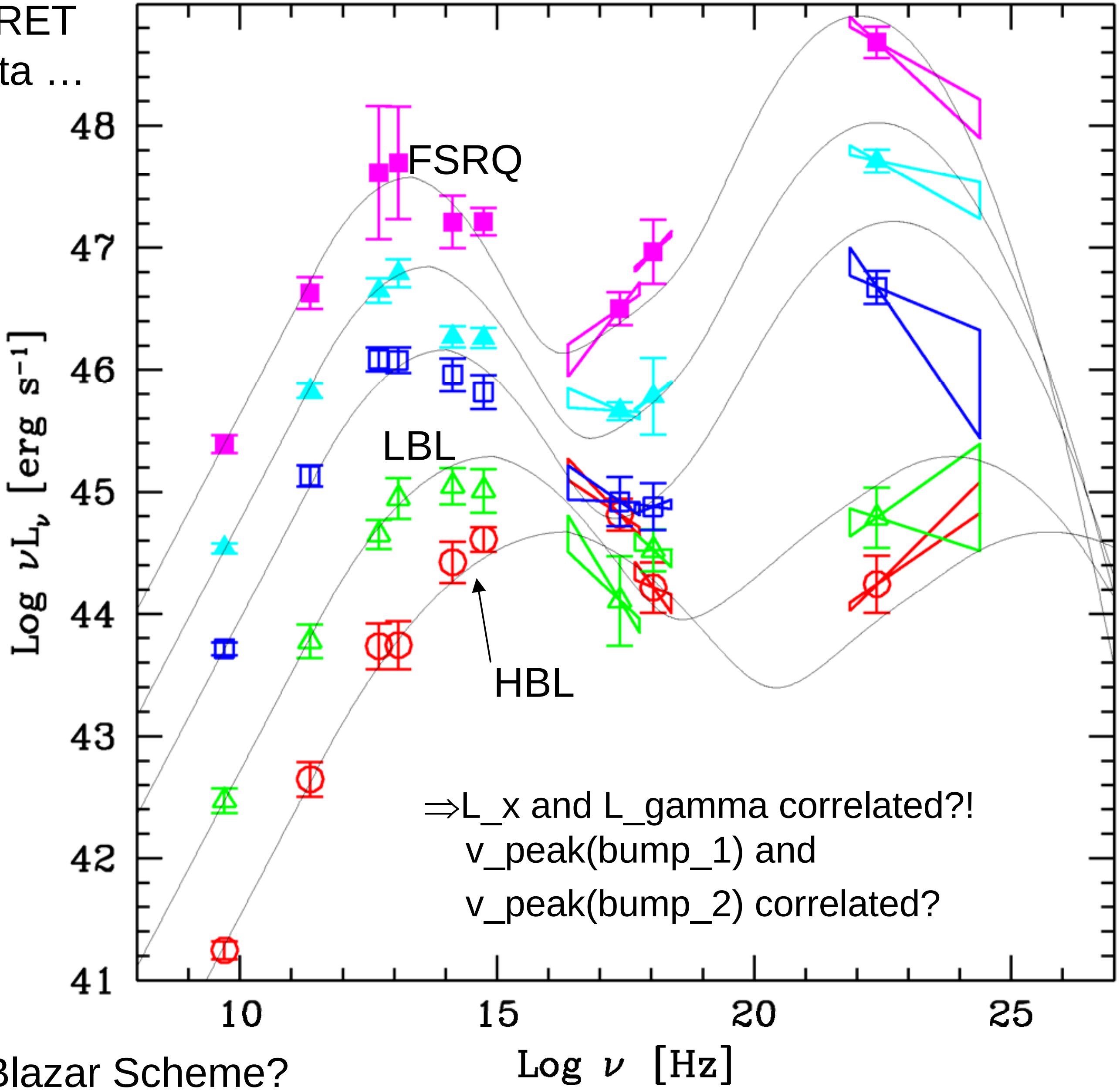
High Resolution (mas.)

Space VLBI (VSOP)

Radio Images

=> "fast spine" structure?

Summary of EGRET
Gamma-Ray Data …



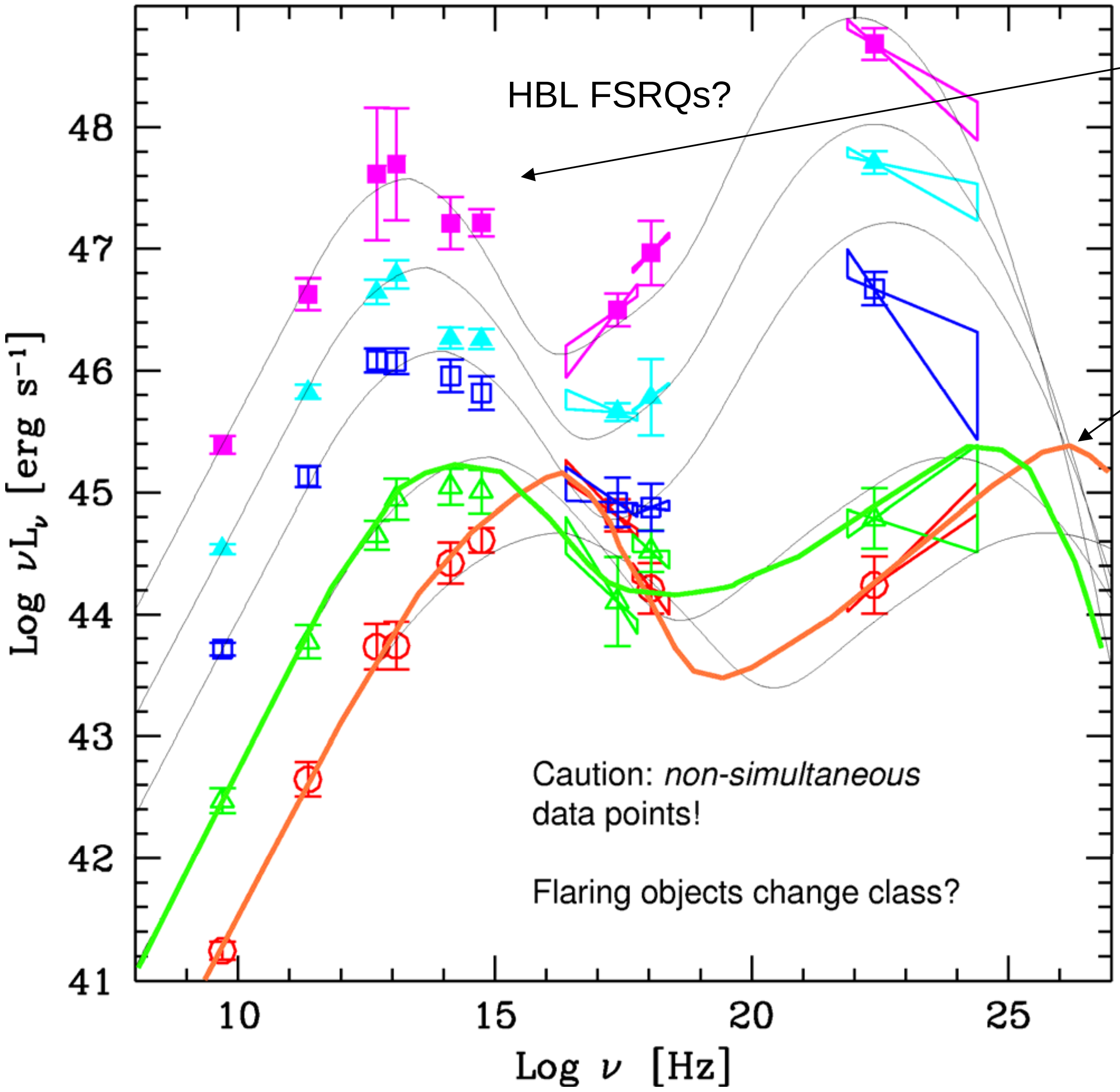
⇒L_x and L_gamma correlated?!
v_peak(bump_1) and
v_peak(bump_2) correlated?

Grand Unified Blazar Scheme?

(synchrotron & Compton from SAME e+/e-?; $\gamma_{peak} \propto Lum^{-1}$?)

Donati et al. 2001
(cf. Fossati el. 1998)

Caution…..



HBL FSRQs?

Caution: *non-simultaneous* data points!

Flaring objects change class?

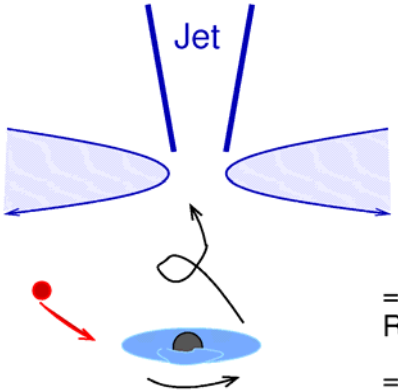
When one looks at *non*-gamma ray selected objects, there seem to be objects here too….

Don’t forget absorption by infrared/optical background!

TeV blazars don’t show any superluminal Motion?

Jet Origin

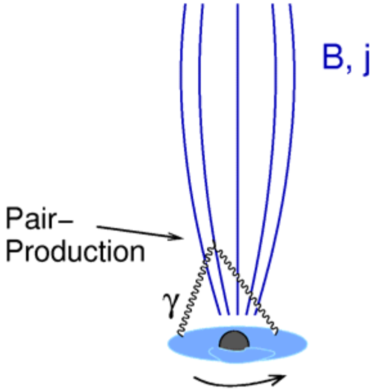
1.) Mass Accretion onto Black Hole



=> Extraction of up to 42.6% of
Rest Mass Energy of Infalling Material

=> Accretion Disk =>
Jet Matter

2.) Extraction of Rotational Energy of Black Hole



=> Extraction of up to 29% of
Rest Mass Energy of Black Hole

=> Electron/Positron Jet

=> Different Jet Matter
Different AGN Life Time

Main Observational Facts and Implications

Large Luminosity ⇨ -- efficient power source, e.g., accretion onto black hole?
black hole spin?

L_gamma>L_Edd?
Compactness Problem!
⇨ Relativistic Bulk Motion

Rapid Variability ⇨ -- small source
-- source close to black hole?
-- rapid particle acceleration/creation and cooling/escape

↳ ~~hadronic~~ models, unless push source parameters

Double Peaked SED +
Good X-Ray/Gamma-Ray Correlation ⇨ -- same emission region for X-rays/gamma-rays?
-- same particle population responsible for emission
at both energies (Occam's razor)?

↳ two peaks = (e+/e-) synchrotron + I.C.?

-- ***close analogy with galactic SNR!***
(similar GeV to TeV peaked sequence,
similar modeling issues and "discussions")

Optical/Radio ID = FSRQ, blazar ⇨ -- emission from relativistic **jet**
(like GRB: Doppler boosting, internal vs.
external shocks, etc.)

Many EGRET blazars show broad emission lines

⇨ strong ambient radiation field; messy systems; zone of avoidance

Theoretical Considerations [Complications]

Several excellent reviews already – e.g., see Sikora (astro-ph)

Global Energetics

$L_{rad} \lesssim L_{kinetic}$ at radio lobe (at least for FR II sources)

$\Rightarrow$ something dramatic happens to jet, but jet is not disrupted/stopped

$\Rightarrow$ Compton ~~drag/bulk Comptonization~~ of initially highly relativistic ($\Gamma \gg 1$) jet

Process(es) directly responsible for observed X-ray/γ-ray emission?

- Compton scattering $(e\gamma \to e\gamma)$
- synchrotron radiation $(eB \to eB\gamma)$

lowest order, most “efficient”

- Bremsstrahlung $(ee \to ee\gamma, pe \to pe\gamma)$
- π^0 decay $(\pi^0 \to \gamma\gamma)$

almost always accompanied by $\pi^{\pm} \to ...e^{\pm}$

- proton synchrotron $(pB \to pB\gamma)$

⇩

This theoreticians prejudice: $e^{\pm}$ probably involved (i.e., synchrotron/Compton)

Theoretical Considerations [Complications] II.

O.K. Where do we get required GeV/TeV electrons/pairs?

- Acceleration (bottom-up)

Direct acceleration by $\vec{E}$ (e.g., pulsar)

Stochastic shock/wave acceleration (e.g. 1^{st} / 2^{nd} order Fermi process)

"leptonic" models

- Creation at desired energies (top-down)

usually involves cascade (e.g., P.I.C.) with ultrarelativistic protons + photons

$$\left\{\begin{array}{l} p\gamma \rightarrow pe^{+}e^{-} \\ (p/n)\gamma \rightarrow (n/p)\pi^{\pm} \\ \gamma\gamma \rightarrow e^{+}e^{-} \\ \gamma e \rightarrow ee^{+}e^{-} \end{array}\right. \quad \square \quad ..e^{\pm}, \nu$$

don't need to be ultrarelativistic, e.g., SNR

or $pp \rightarrow pp\pi$

but need large target matter densities

"hadronic" models

Neutrinos: "smoking gun" for hadronic models

Big advantage of hadronic models: protons easier to accelerate to very high energies
Big disadvantage … : protons harder to extract energy from

Theoretical Considerations [Complications]   III.

If electrons/pairs are primary particles, what is acceleration energy spectrum?

$$\frac{dN}{dE} \propto E^{-\alpha}\ ?$$

$$E_{\max}\ ?$$

$$E_{\min} / E_{peak}\ ?$$

(or just t_{cool} vs. $t_{\text{escape/expansion}}$)

If they are instead secondary particles, similar considerations for primary protons ….
(relativistic e/p behave in same way for given energy)

Good questions!!

Relativistic shock theory $\Rightarrow \alpha$ □ 2, but $\exists$ range (1.7-2.4),
depends on details like pitch angle diffusion ... (messy).

$$E_{\max} = f(B, R_{shock}, t_{cool})$$

e.g., if particle too energetic, $r_g > R_{shock}$ and particle escapes

often before get to this, though,

$$t_{accel} \sim r_g / c \sim t_{cool} \propto E^2 B^2 \text{(synch. radn.)}$$

□ (Bohm limit, $r_g = eB/mc$)

Maybe α reaches asymptotic value during strong flare, but would not be surprising to see $E_{\max}$ vary as source region varies....

Theoretical Considerations [Complications] IV.

Is the observed high energy cutoff in some objects intrinsic or simply due to photon-photon pair production (inside source or intergalactic)?

Depends on ambient radiation field, but for 3C279

γ-sphere: $\mathrm{r}_{\mathrm{emission}} \lesssim 100\, R_g$ $(\sim 10^{15}\,\mathrm{cm})$, $\tau_{\gamma\gamma} > 1$ for $\mathrm{E} \gtrsim 10$ MeV

$\mathrm{r}_{\mathrm{emission}} \lesssim 10^{17}$ cm (BLR), $\tau_{\gamma\gamma} > 1$ for $\mathrm{E} \gtrsim 50$ GeV

$\mathrm{r}_{\mathrm{emission}} \lesssim$ parsecs (dust torus), $\tau_{\gamma\gamma} > 1$ for $\mathrm{E} \gtrsim 1$ TeV

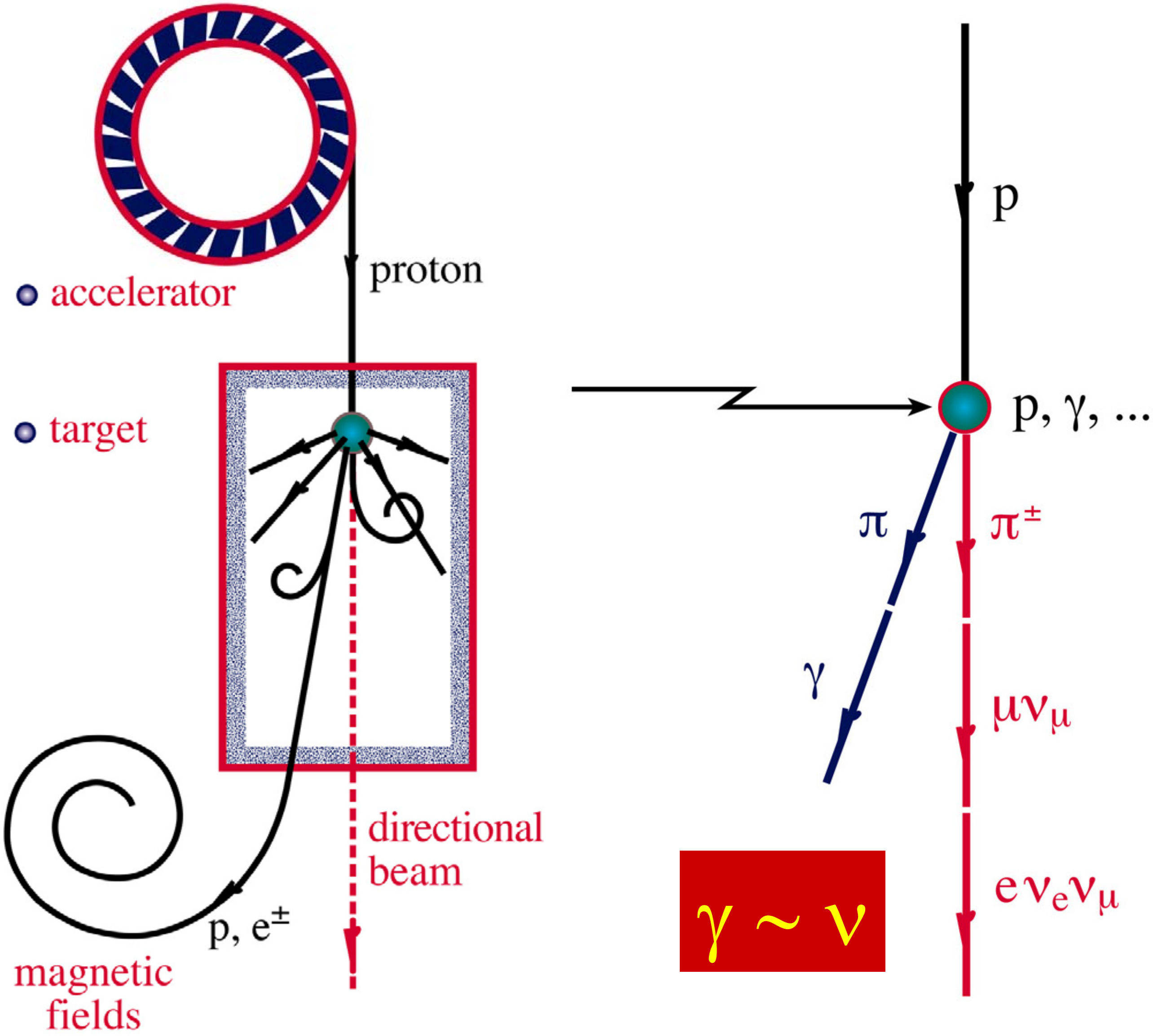
[N.B. Estimates don't apply to Mrk 421/501 -- BL Lacs appear to have weak central radiation fields. Accretion disk underluminous for black hole mass]

What is the origin of the spectral breaks seen in X-rays/gamma-rays?

- Superposition of different emission components?
- Transition from efficient to "inefficient" cooling (particles escape before cooling)?
- Acceleration process: E_max or E_min?
- *Klein-Nishina effects?*

What else will happen….

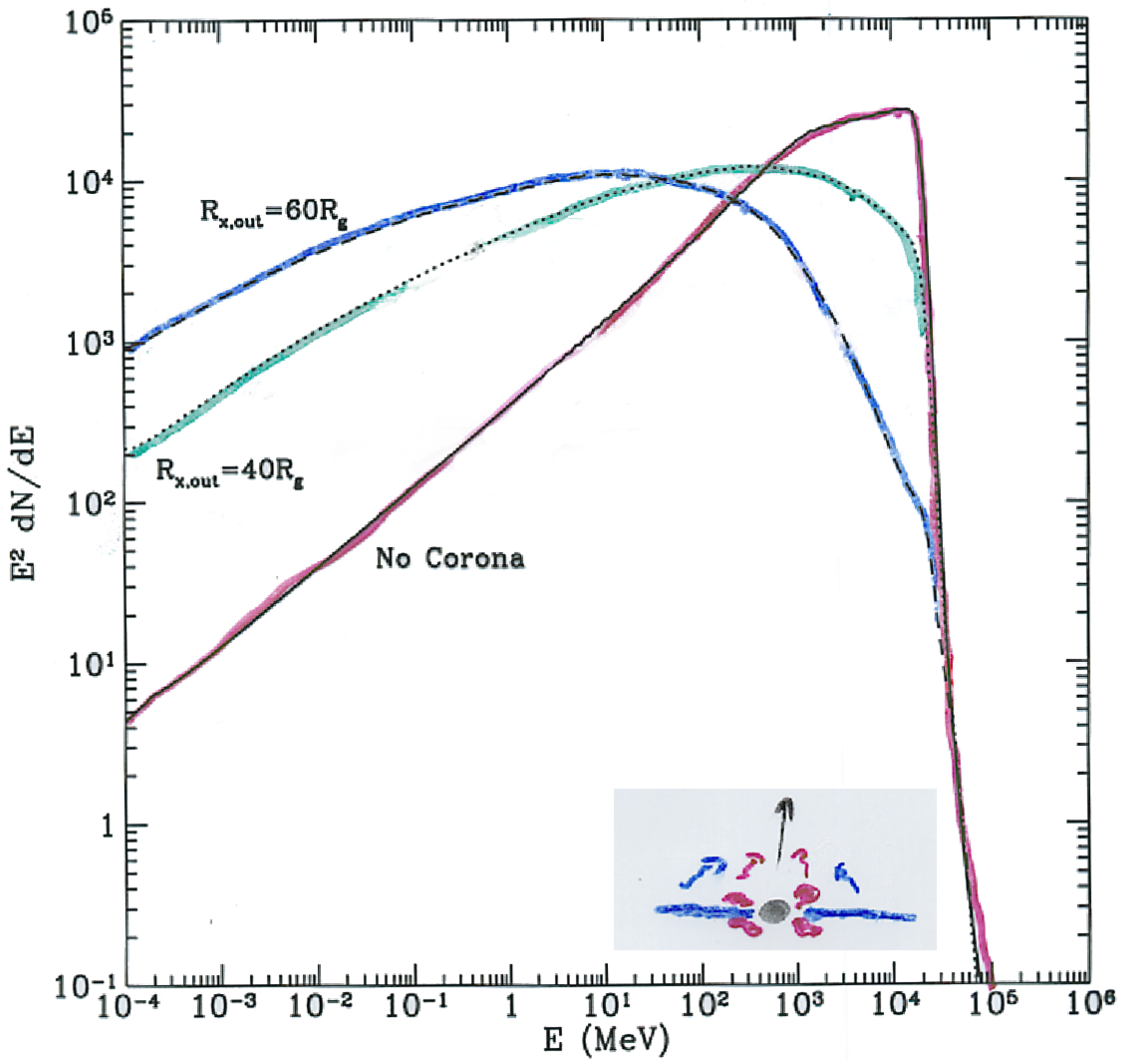
Neutrino Beams: Heaven & Earth



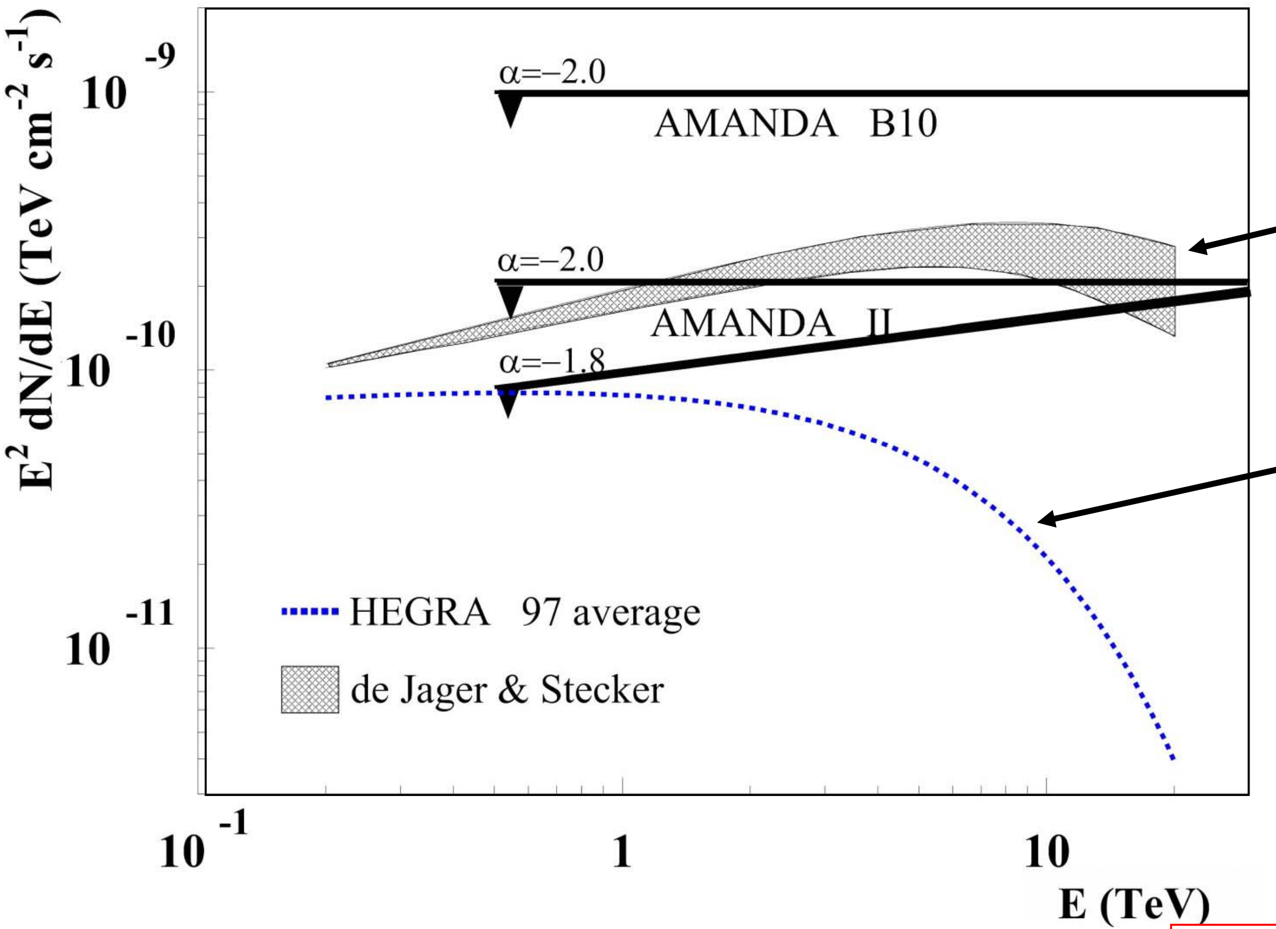
$\gamma \sim \nu$

F. Halzen, 2004 lecture

Proton-Initiated Cascade in Accretion Disk + X-Ray Corona Radiation Field



Coppi, Kartje, & Konigl 1993



Intrinsic source γ spectrum (corrected for IR absorption)

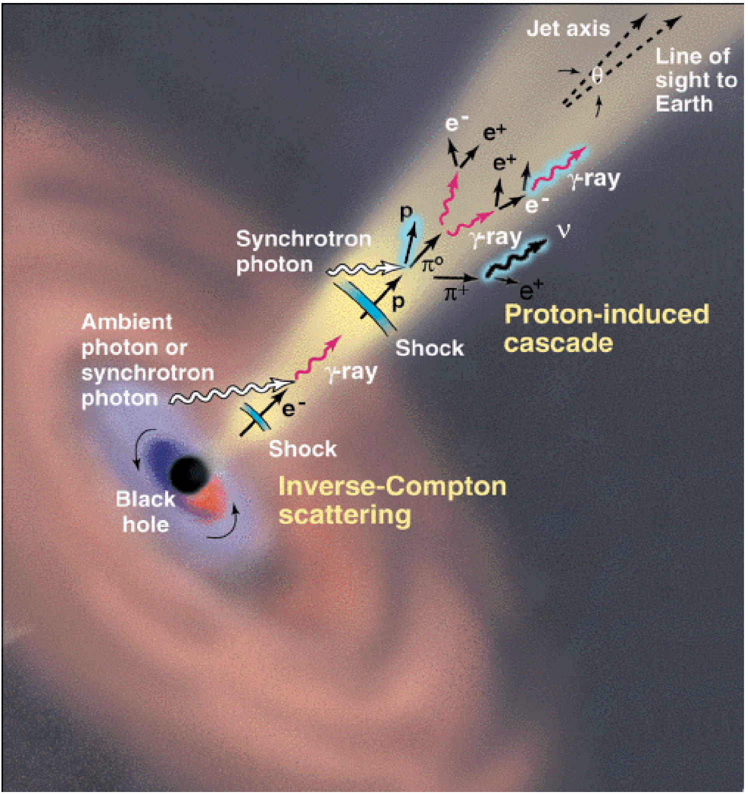
Measured γ spectrum

Hadronic models dying…!

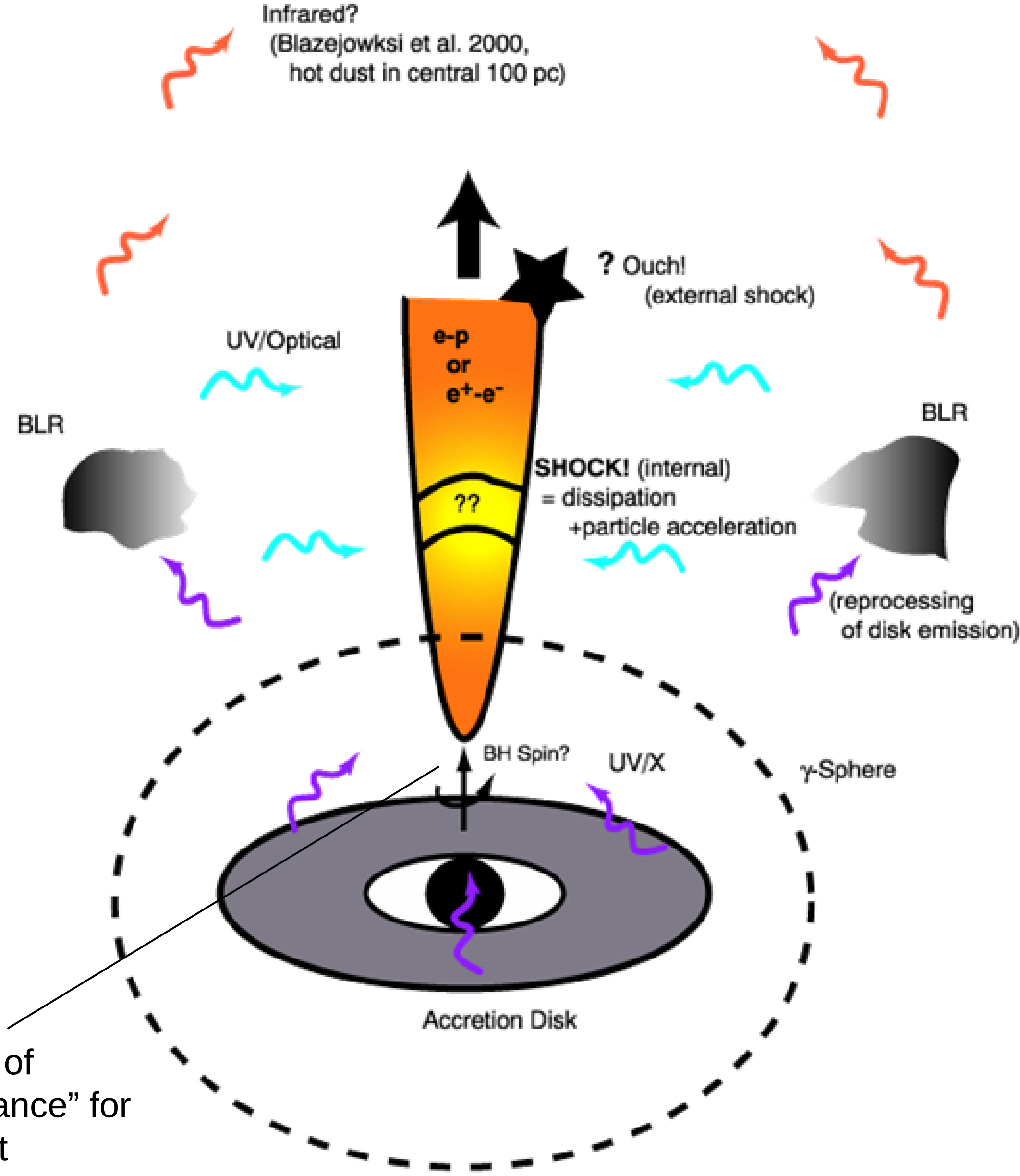
AMANDA average flux limit for two assumed spectral indices α, compared to the average gamma flux of **Markarian 501** as observed in 1997 by HEGRA.

AMANDA-II has reached the sensitivity needed to search from neutrino fluxes from TeV gamma sources of similar strength to the instrinsic gamma flux. This Plot 2000 data only!

Blazar Emission Mechanisms: Idealized vs. Real Life



(Buckley, Science, 1998)



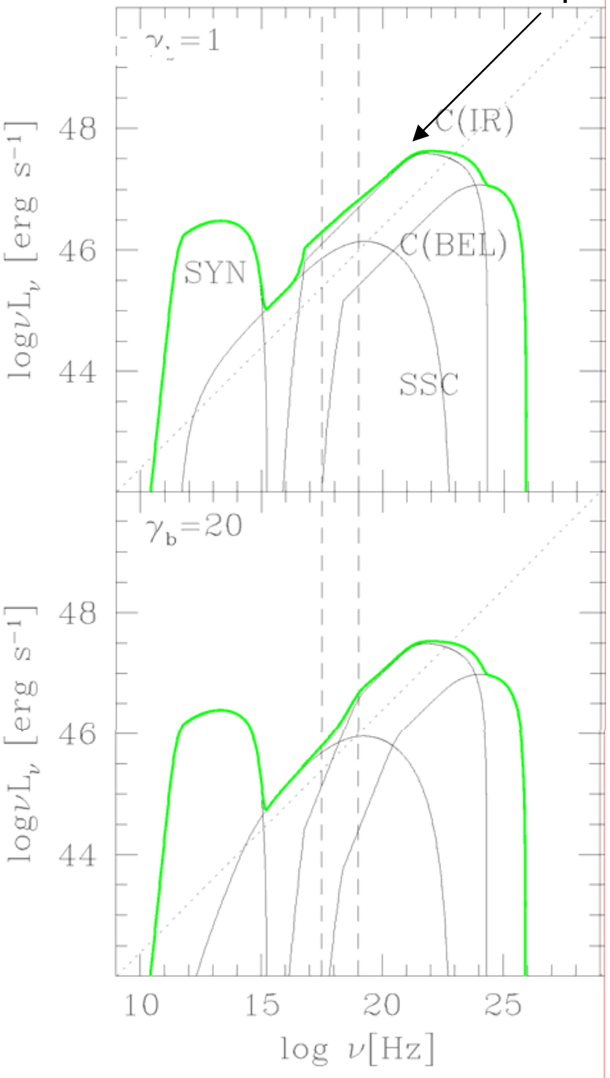
"Zone of Avoidance" for pair jet

The central engine of a generic gamma-ray blazar is a MESSY place!

Which photon field(s) does jet interact with???

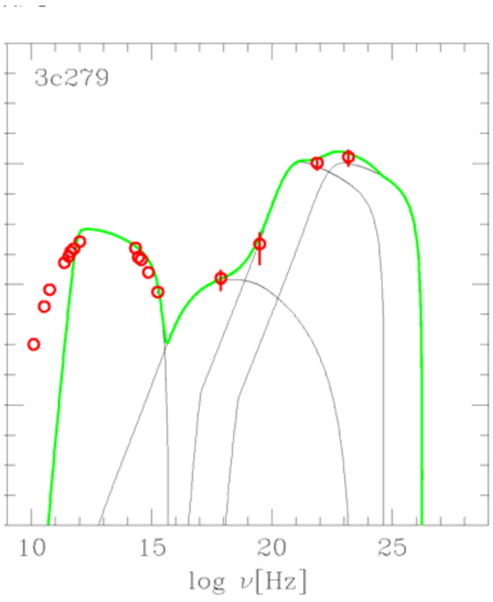
Boettcher et al. 2001

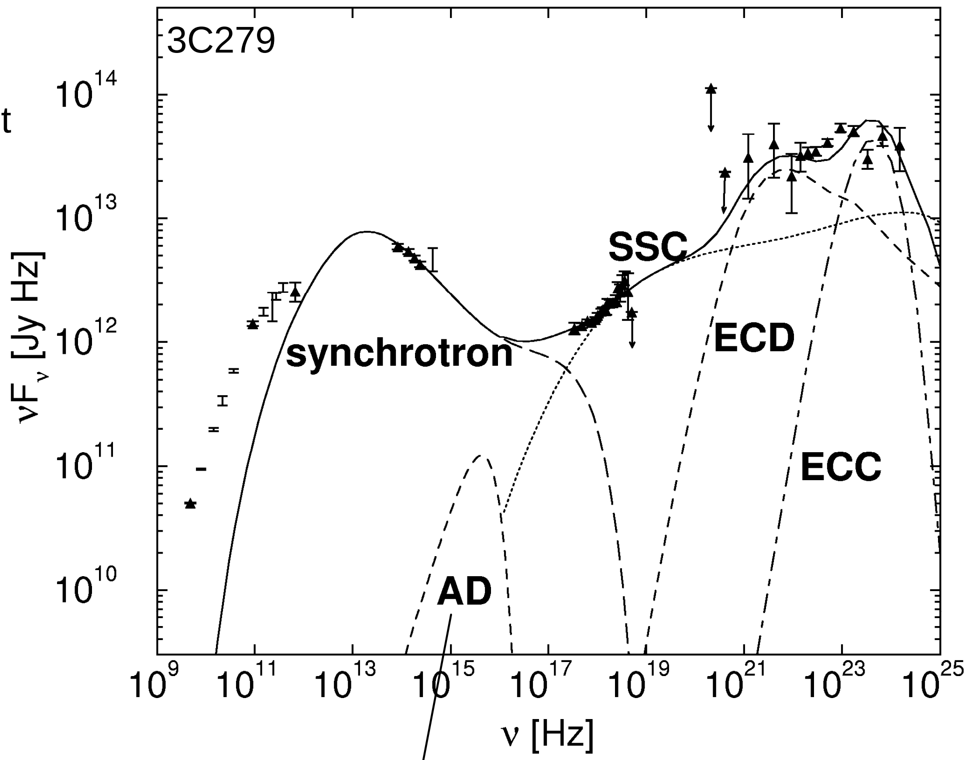
Seed photons: IR from dust

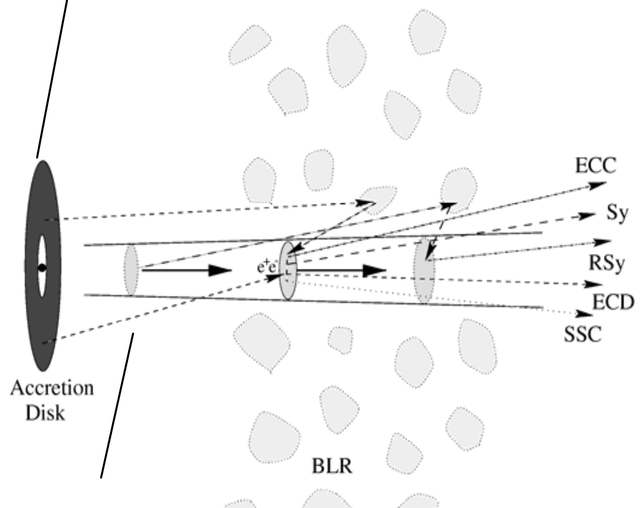


Blazejowski et al. 2000

vs.

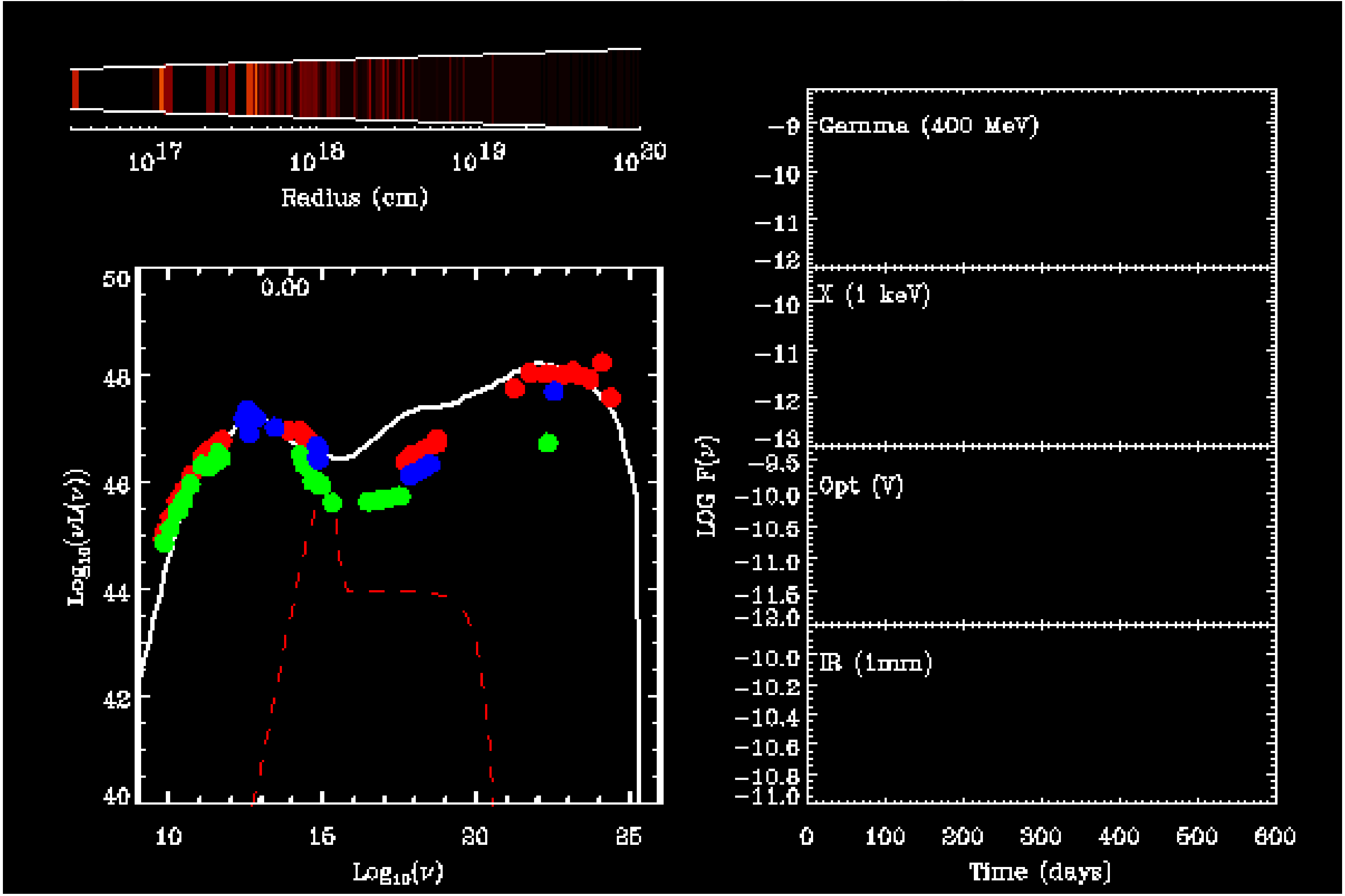


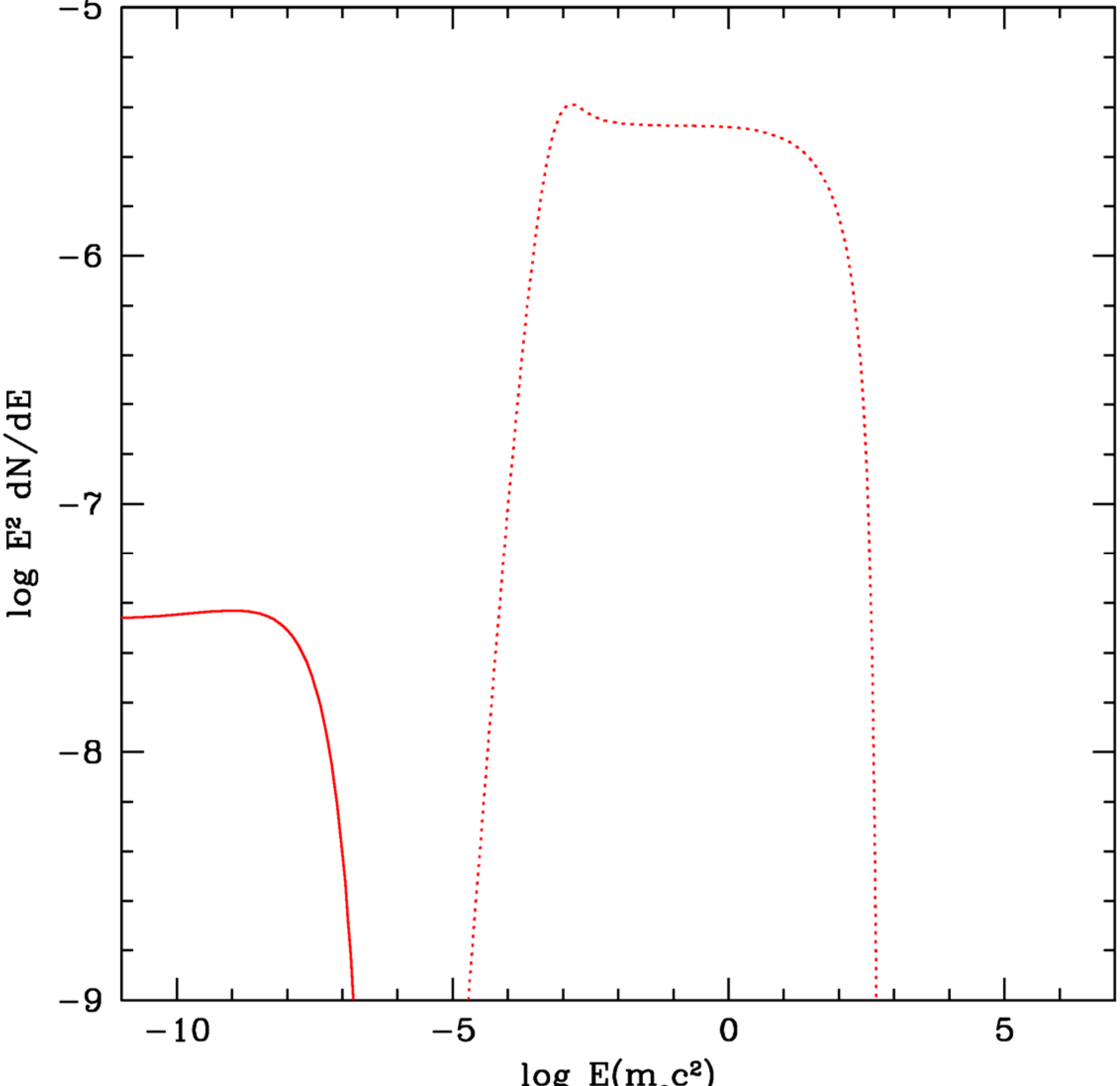




Beamed from behind, reduced efficiency?

Numerical simulations for 3C 279. Spada et al. 2001

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−6
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log E² dN/dE
−10
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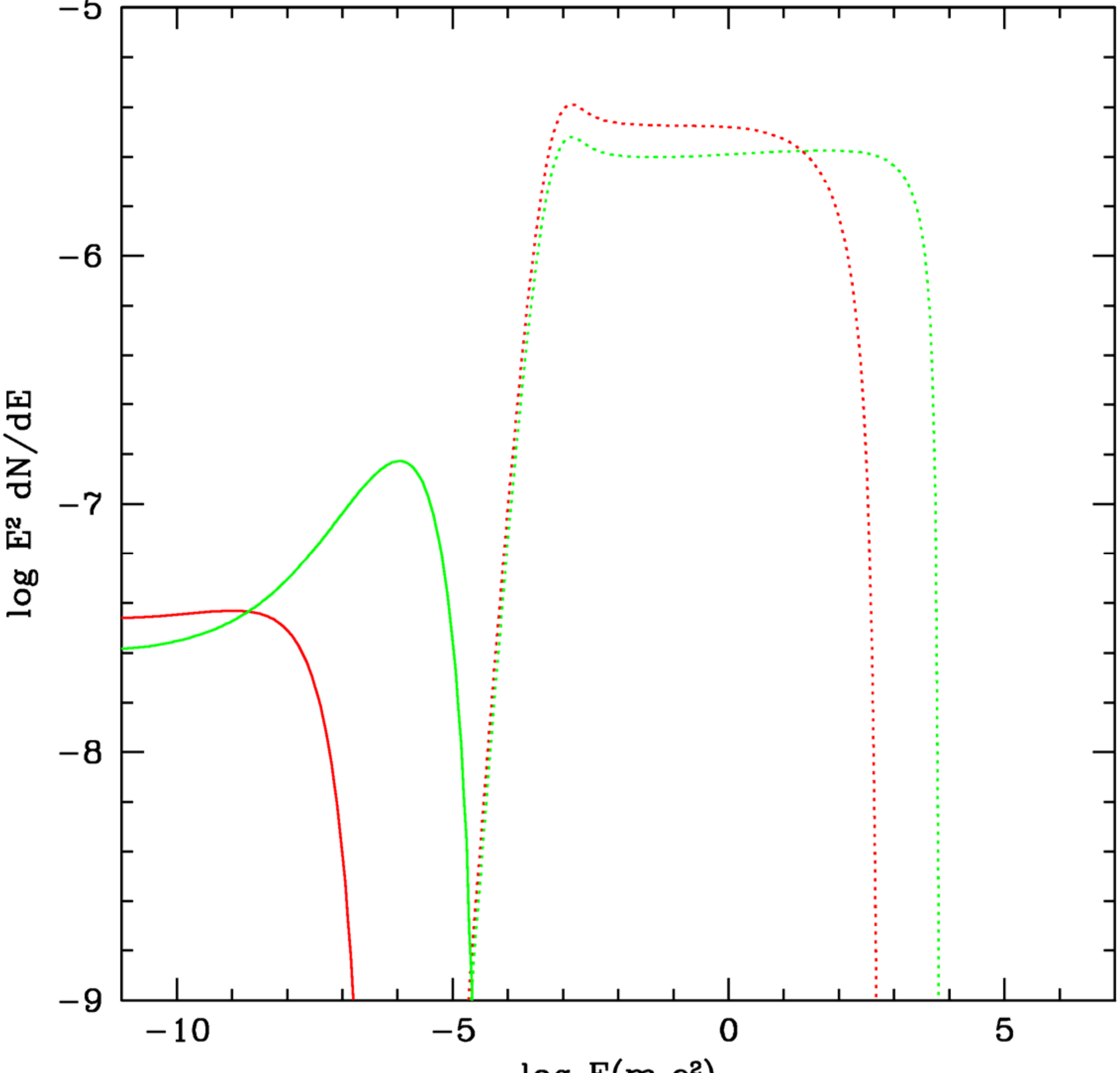
log E(m_e c²)



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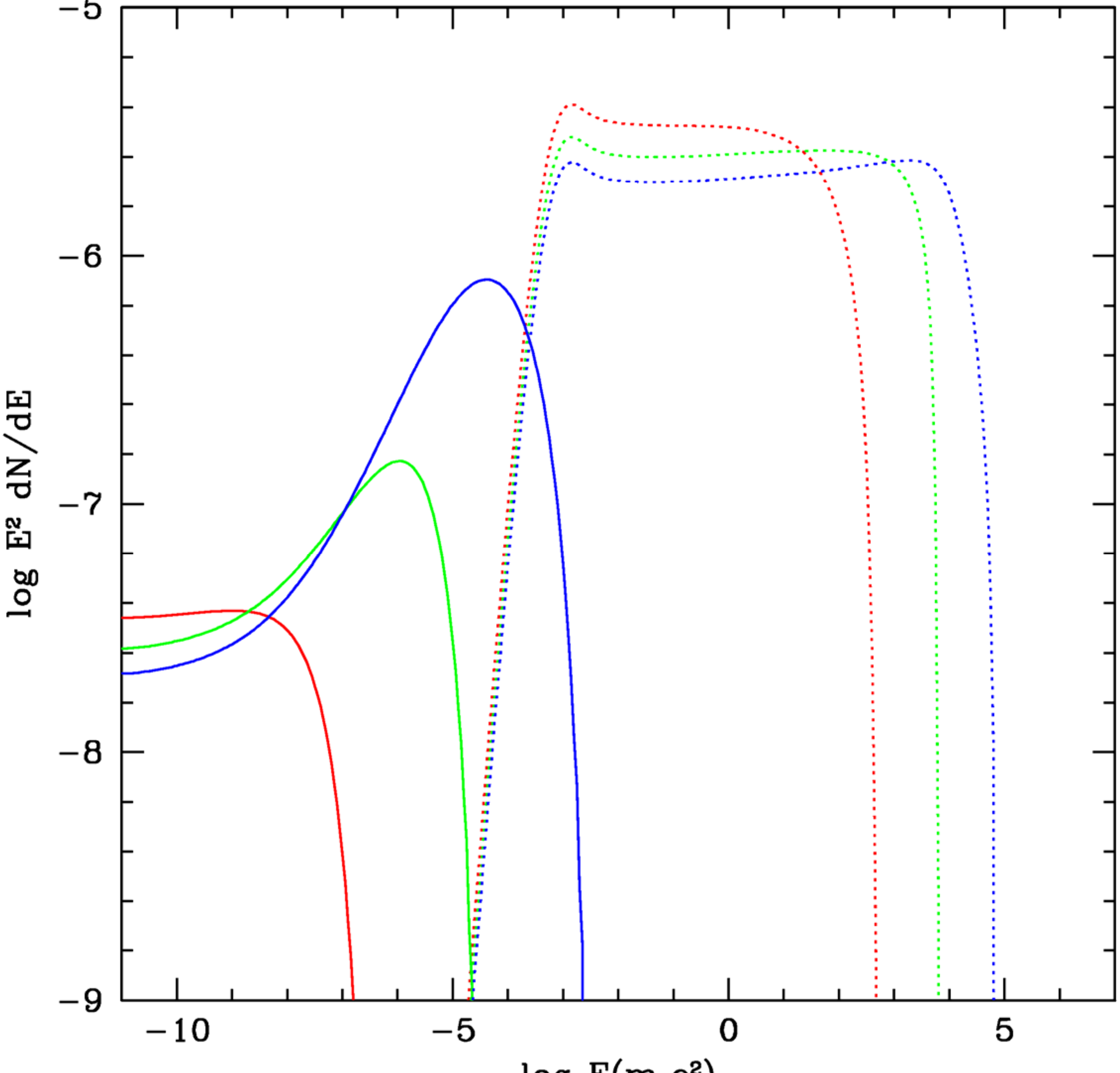
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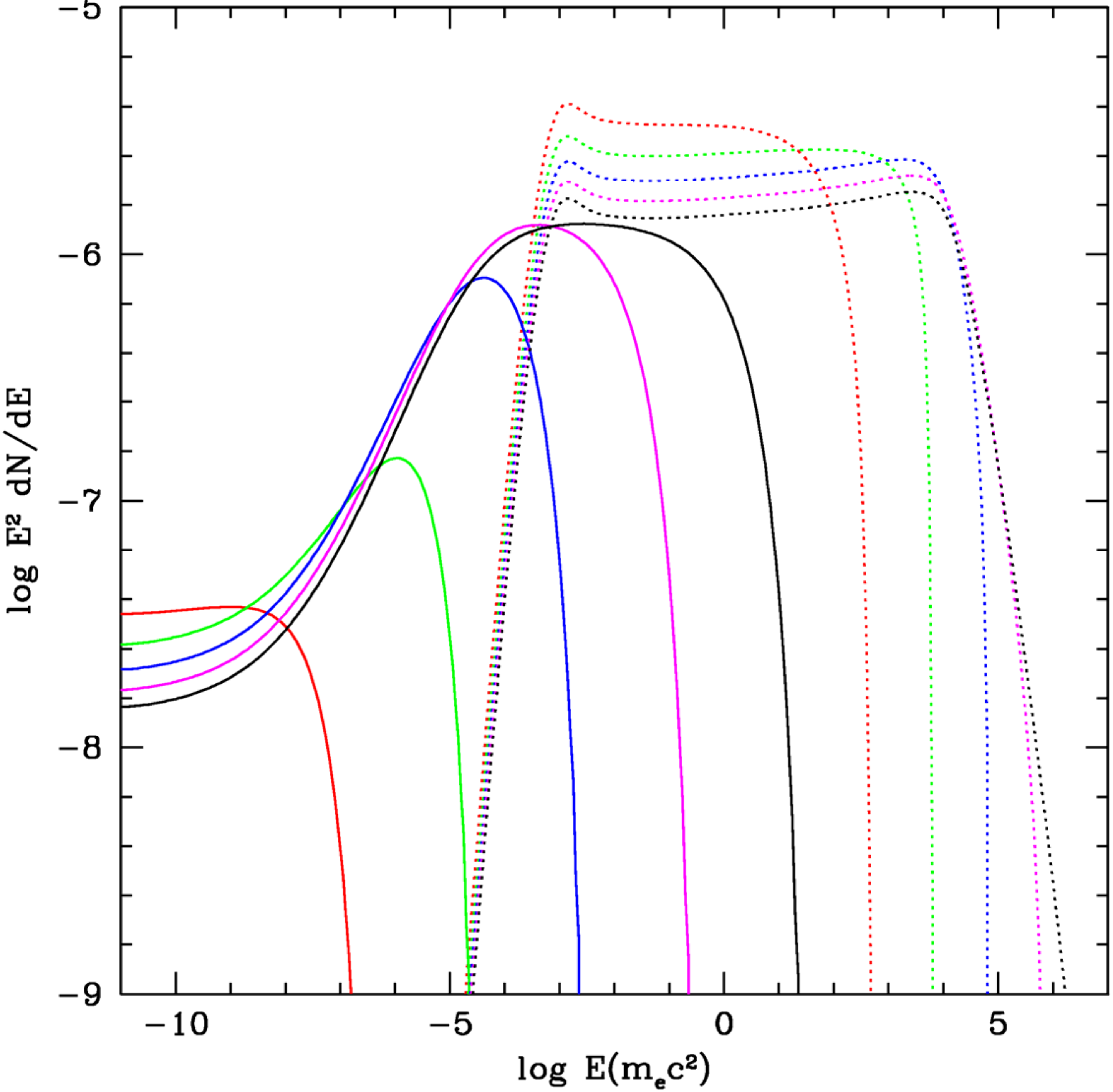
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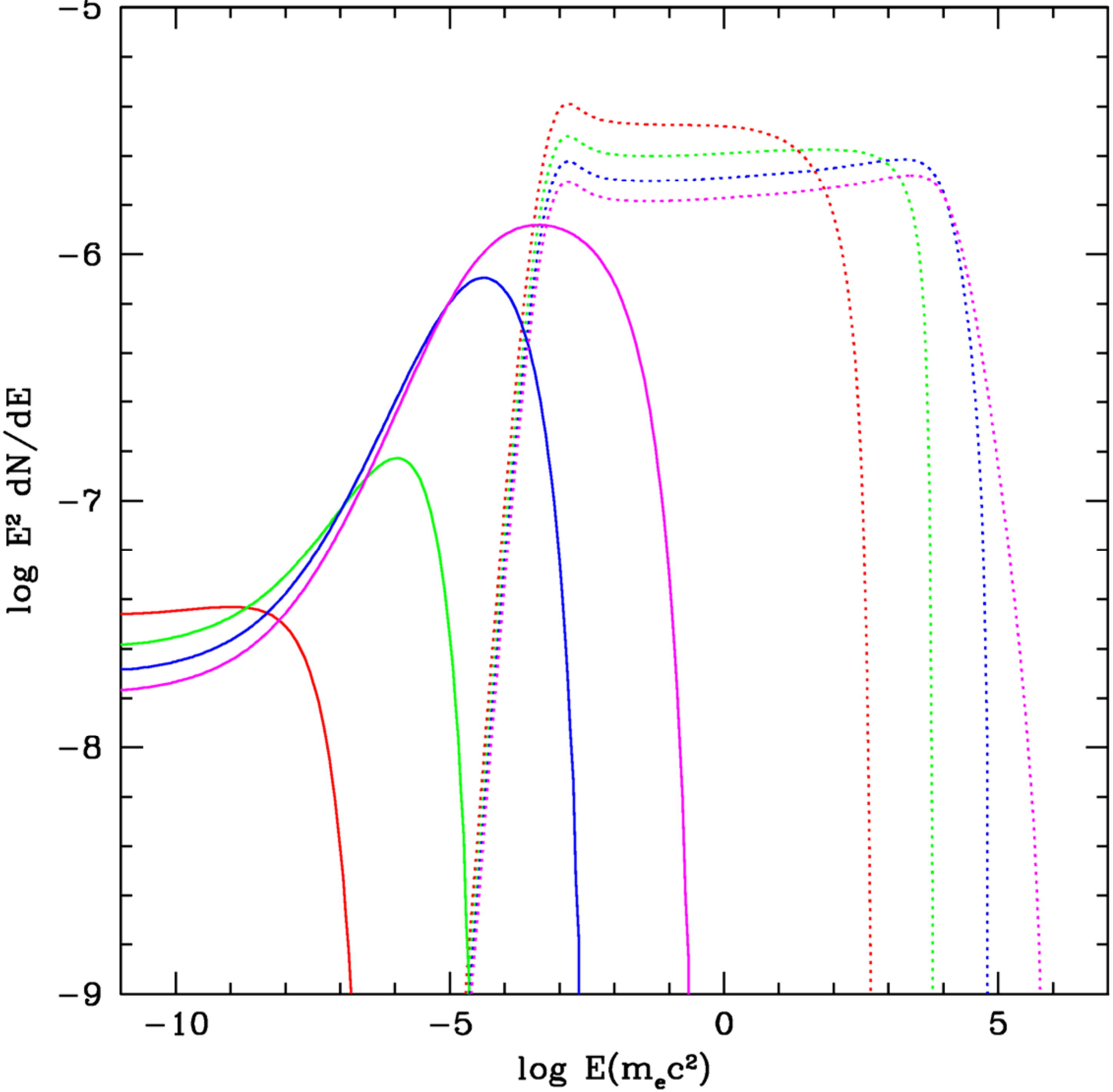

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log E² dN/dE
−10
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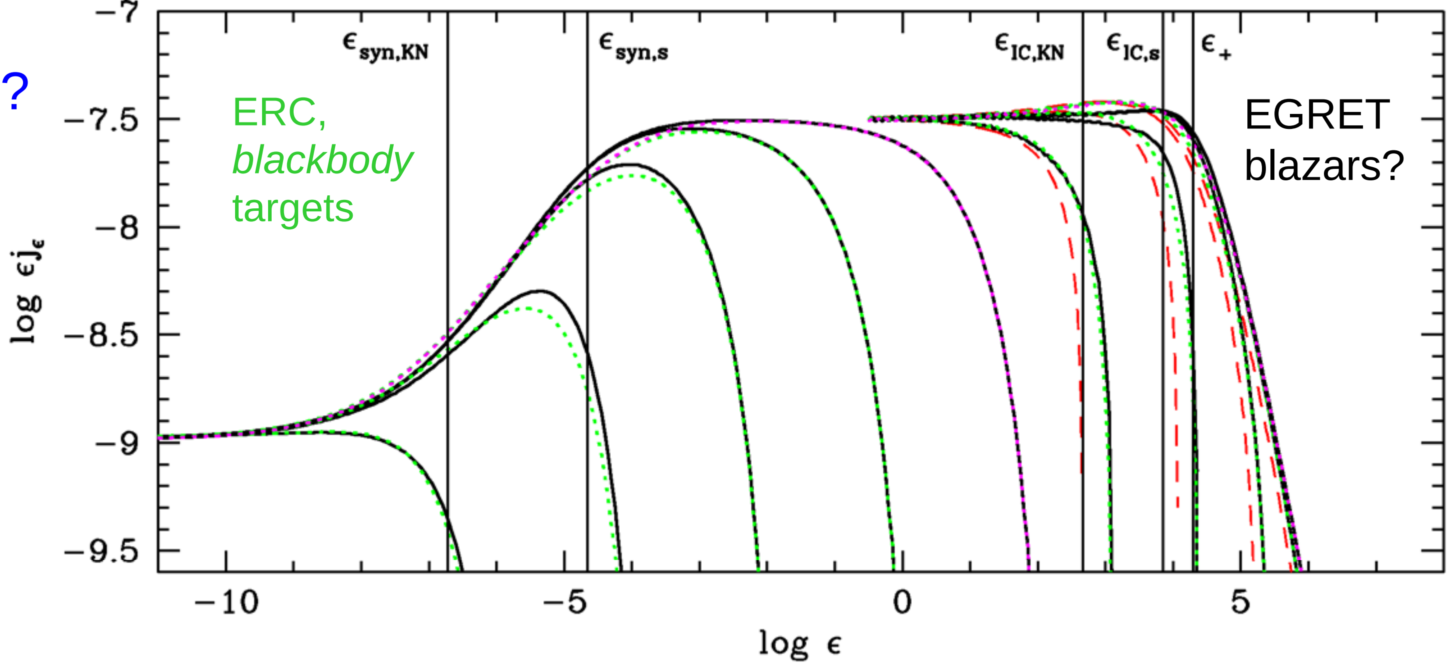
0
5
log E(m_e c²)

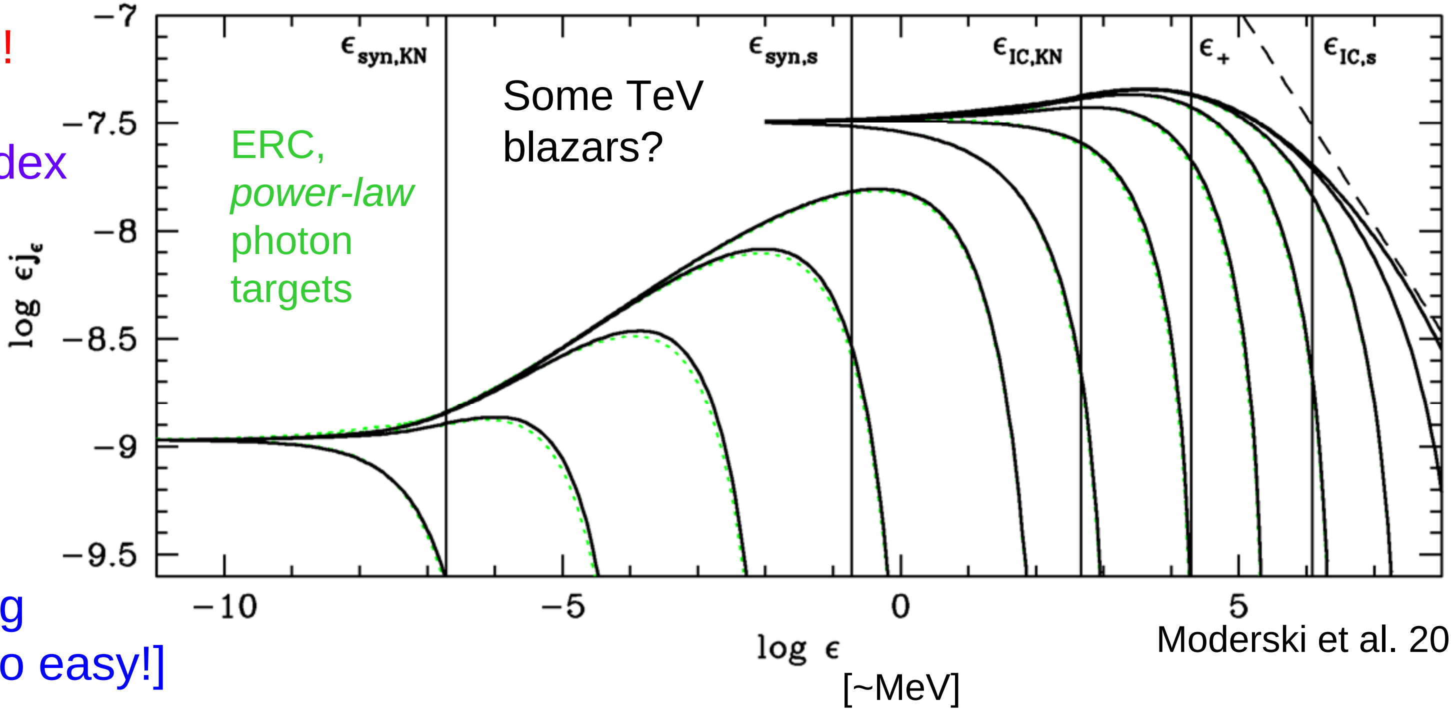
Klein-Nishina effects important?



ERC, *blackbody* targets

EGRET blazars?

Be careful in interpreting origin of spectral features such as “bumps” and break energies!



ERC, *power-law* photon targets

Some TeV blazars?

Can get spectral index *harder* than 0.5!

Moderski et al. 2005

[N.B.: Getting strong TeV emission not so easy!]

Theoretical Considerations [Complications] V.

Assume simplest scenario:
e- directly accelerated, no protons, no photon-photon pair production.

⇒UV/X-ray = synchrotron
⇒GeV/TeV = Compton

What are seed photons for Compton upscattering??

• Synchrotron Photons	(SSC)
• Accretion Disk Photons	(ERC)
• BLR Photons (reprocessed accretion disk photons)	..
• IR photons from hot dust in central region	..
• [Microwave background, probably not relevant, but always there]	..

All possible => **different** gamma-ray spectra for **same** e- distribution!

∴ Lots of uncertainty for generic blazar!!

If you think you can *a priori* predict a gamma-ray spectrum, I have a deal for you…

Modeler HEALTH WARNING

With better data, even factors 2-3 will matter in the future!

Don’t ignore Klein-Nishina effects:
-- use correct cross-sections/solve full kinetic equations.
-- in TeV blazars, factor 10 in gamma-rays corresponds to factor 100 in X-rays!

Use self-consistent models:
-- even if accelerated particle distributions are power laws(?), cooled distributions (and emitted photon spectra) are usually not!
-- often seem to be in “moderate” Klein-Nishina regime => asymptotic approximations poor.
-- don’t assume synchrotron and Compton spectral indices match.
=> do not use phenomenological “power law” models or constraints derived from such models (e.g., Tavecchio et al. 1998).
=> no more “eyeball” theorist fits…

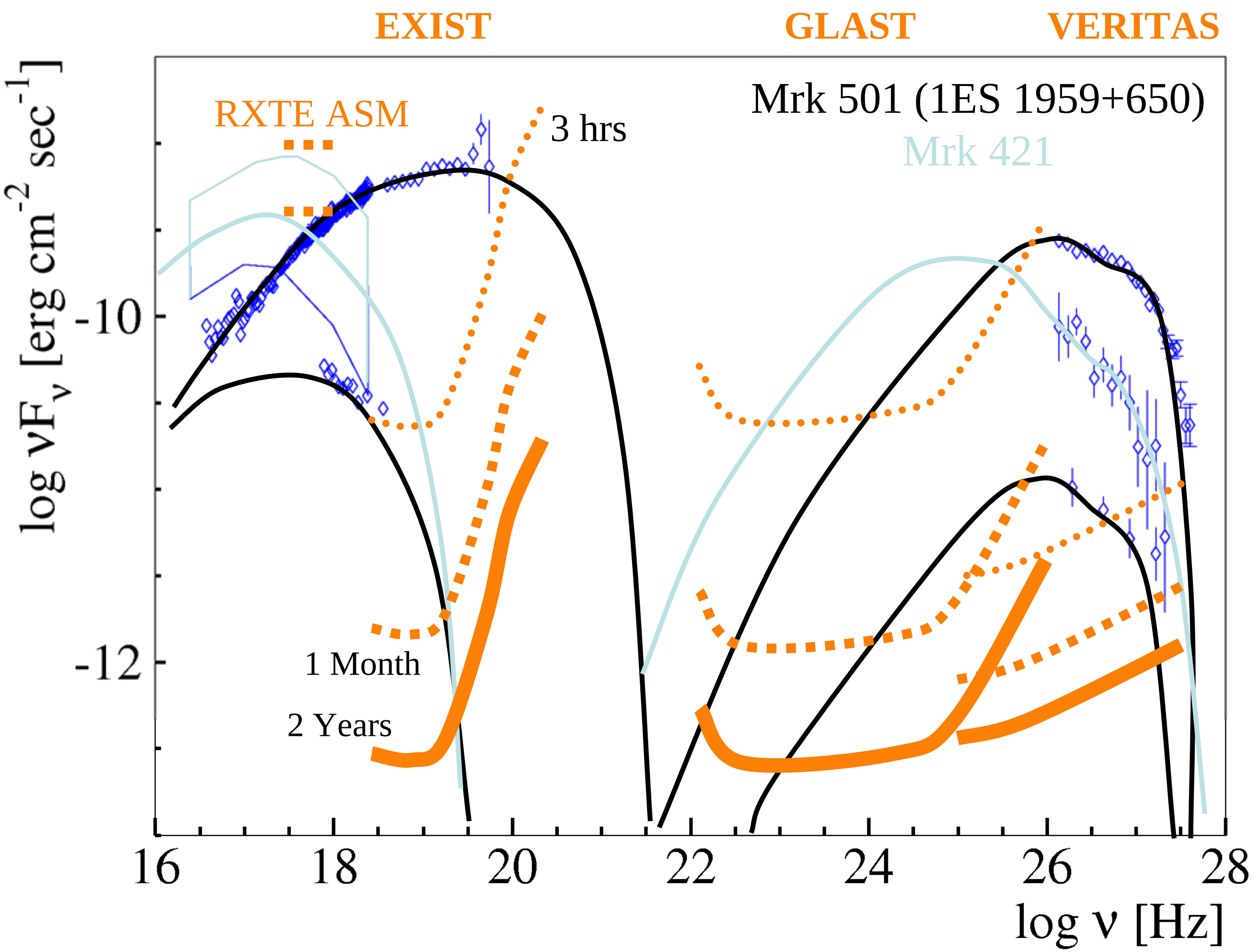
In estimating source parameters, don’t ignore absorption by infrared/optical background!
(B,R, L_kin can change by factor 10!)

Don’t forget time dependence of problem/finite cooling times of particles.

Several emission regions may be active at any given time => confusion, especially at low (keV) energies => watch for big flares, focus on hard X-rays.

If you don’t have sensitivity/energy coverage to track curvature/peak in both X-ray/gamma-ray spectra as well as emission from *same* electrons, don’t bother…

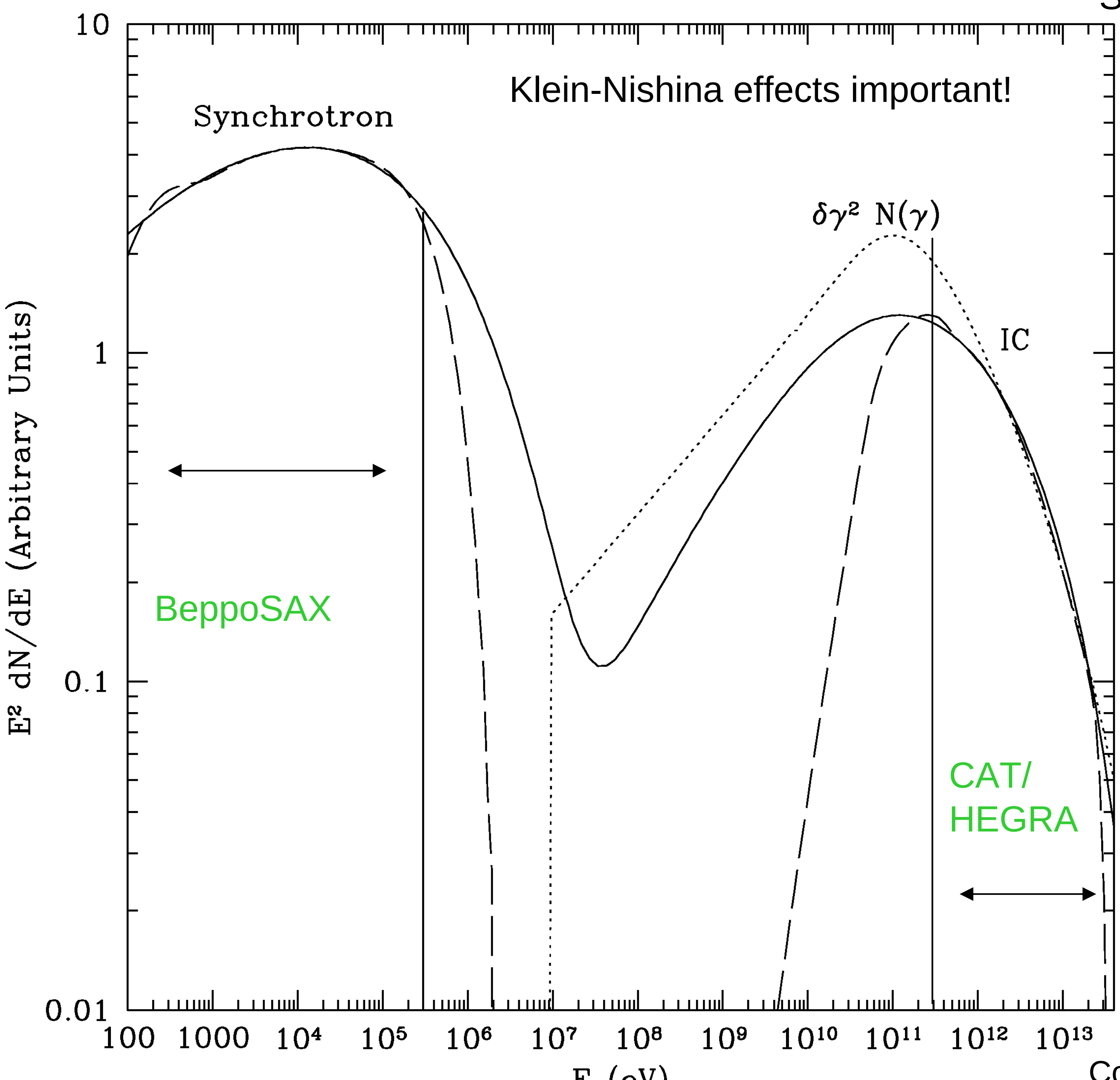
Telescope Sensitivities For TeV Blazars



- EXIST: Synchrotron Emission from “Blue” TeV Blazars

The potential advantage of TeV blazars… they are much simpler?

SSC model



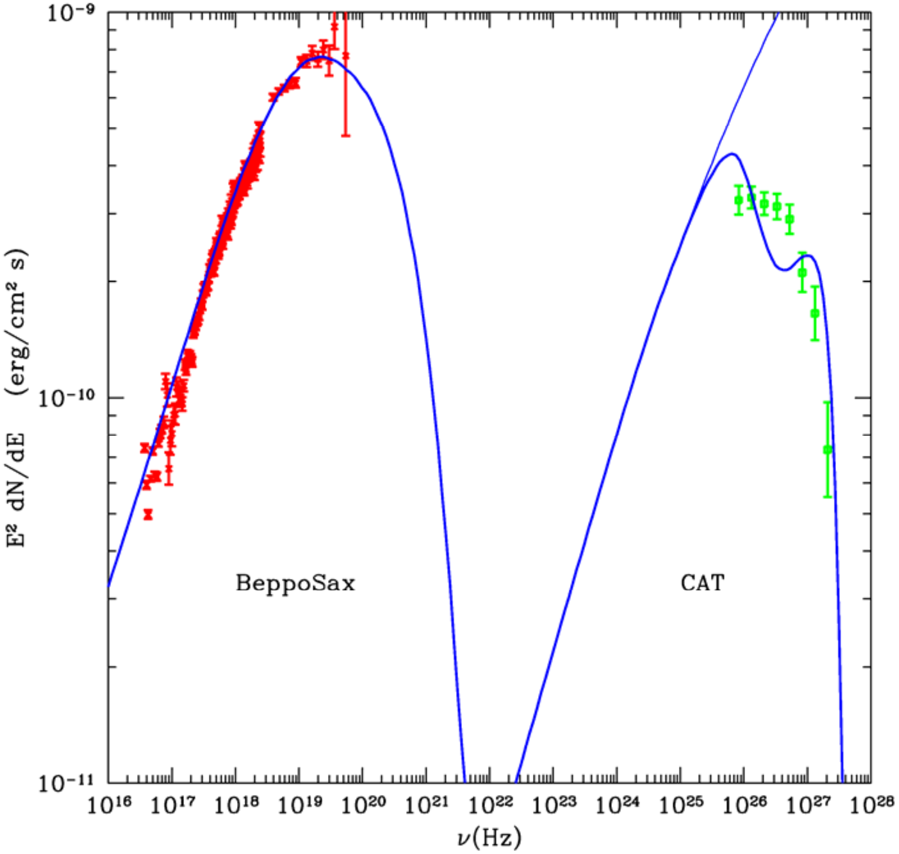
Internal, self-consistently generated photon field…

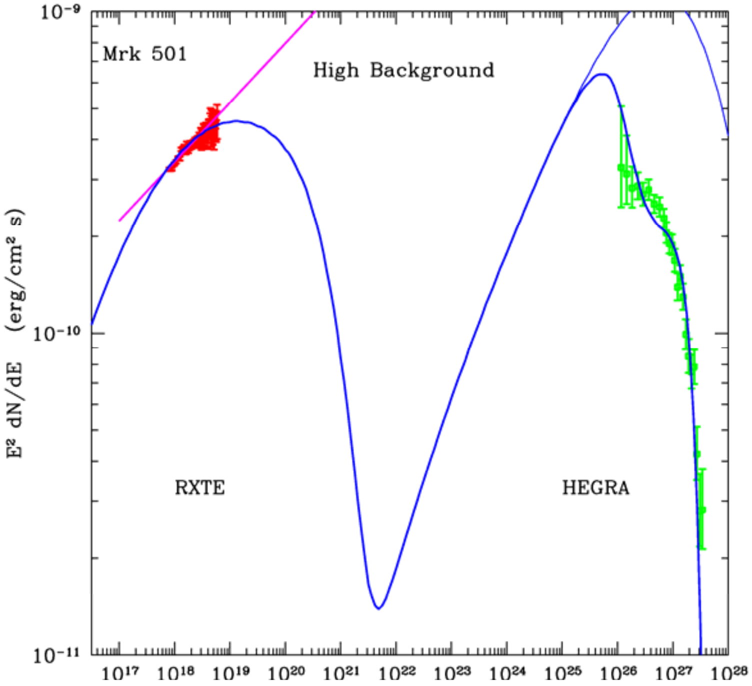
Testable Predictions!

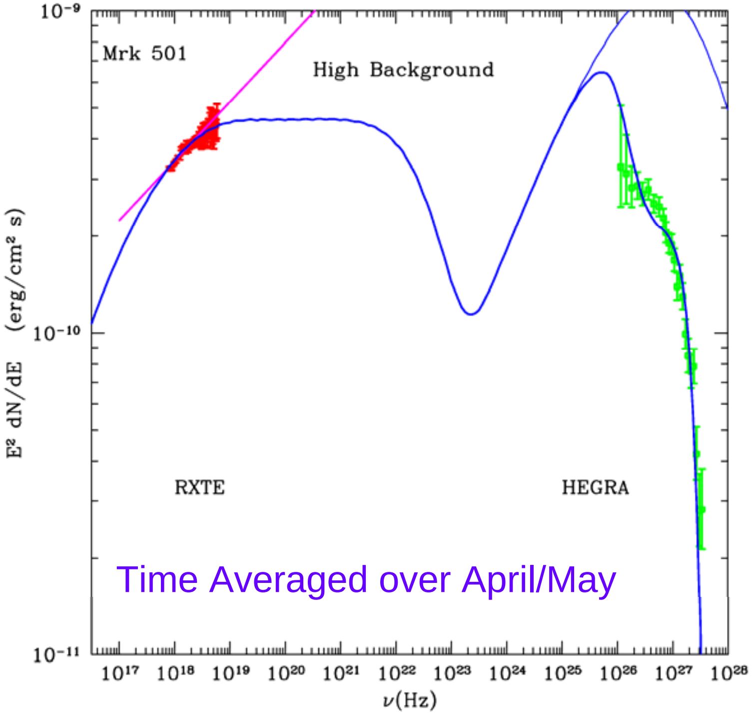
Coppi & Aharonian 1999

SSC fits (e- distribution obtained by “inverting” X-rays) to quasi-simultaneous (< 6hr difference) data for Mrk 501 April-May flare.

April 16, 1997



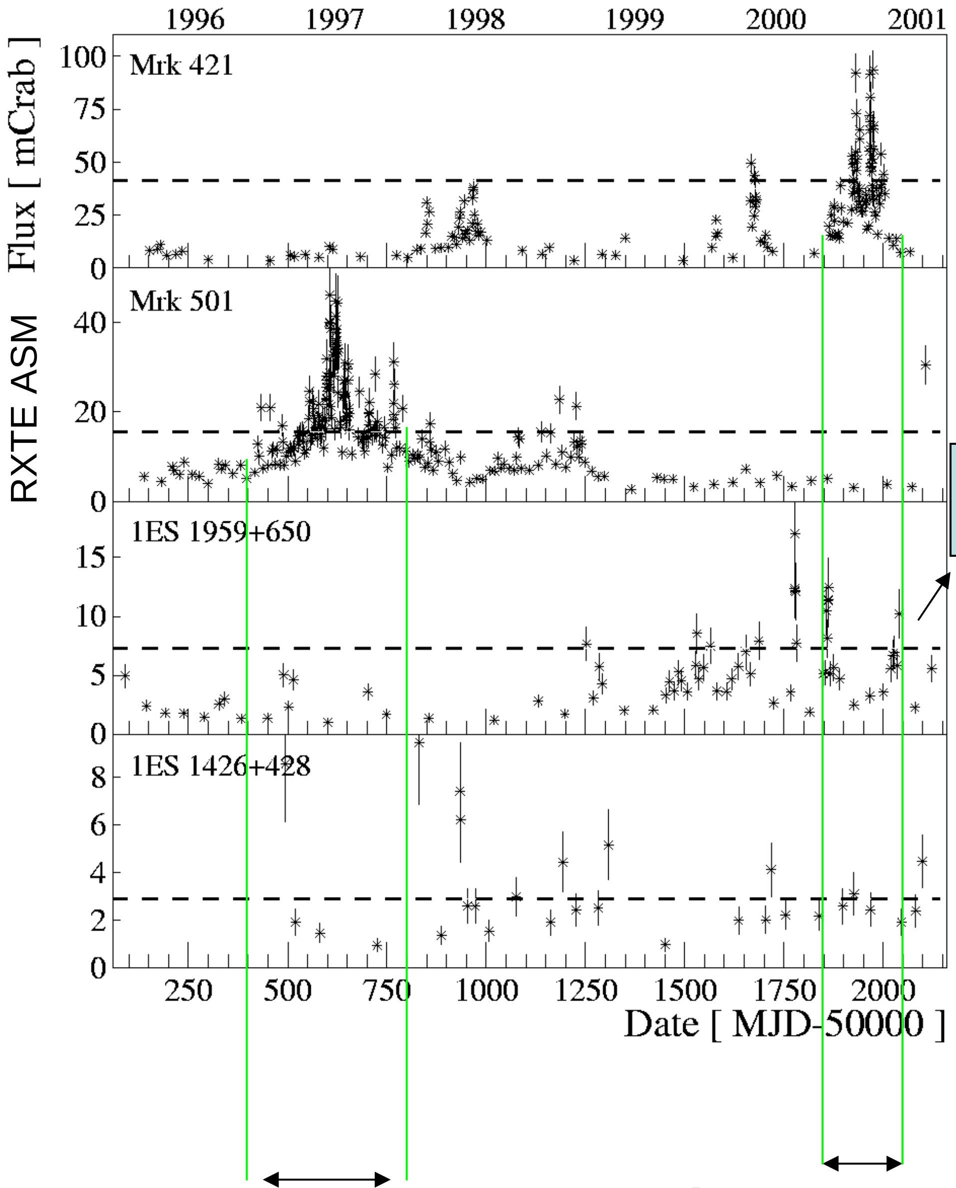




Time Averaged over April/May

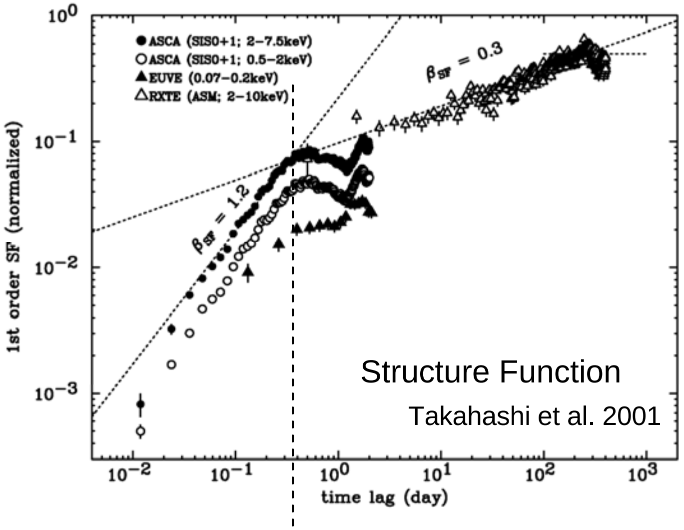
Variability:

TeV (and GeV) blazars appear to have discrete “flare” states…



$\Delta t \sim$ months??

vs.



Structure Function

Takahashi et al. 2001

6 hr rapid variability timescale in Mrk 421??

May-June 2002

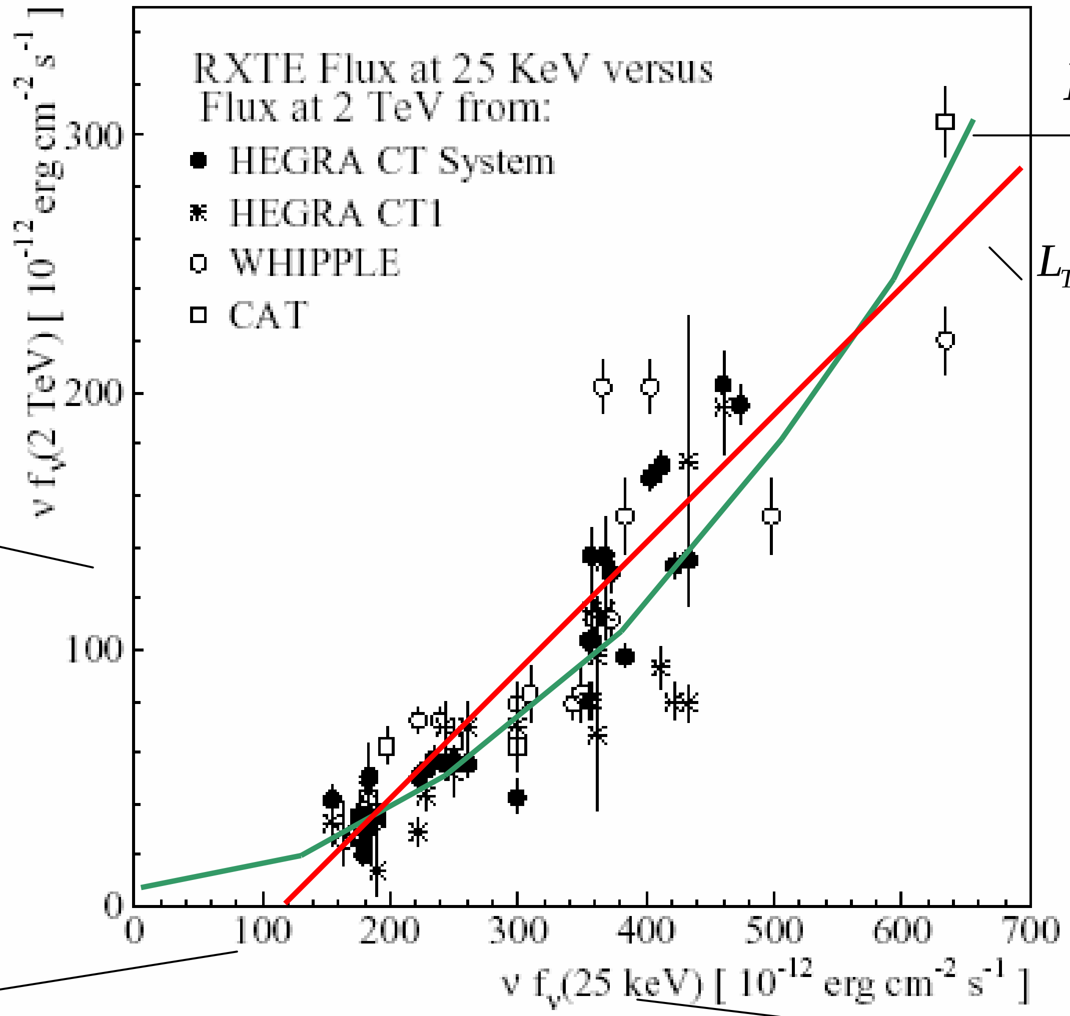
1959 flares!
(RXTE TOO)

Problem: In "standard model," single blob would be at

$R \sim \delta^2 c\Delta t \sim 5\times10^{19}\,\delta_{25}^{2}\,\Delta t_{\rm month}\,$cm!

Unlikely....

The stability problem…



$L_{TeV} \propto L_x^2$ (naive SSC)

$L_{TeV} \propto L_x$

(ERC, SSC,

hadronic model)

Linear
Axes!

Steady X-Ray
Component??

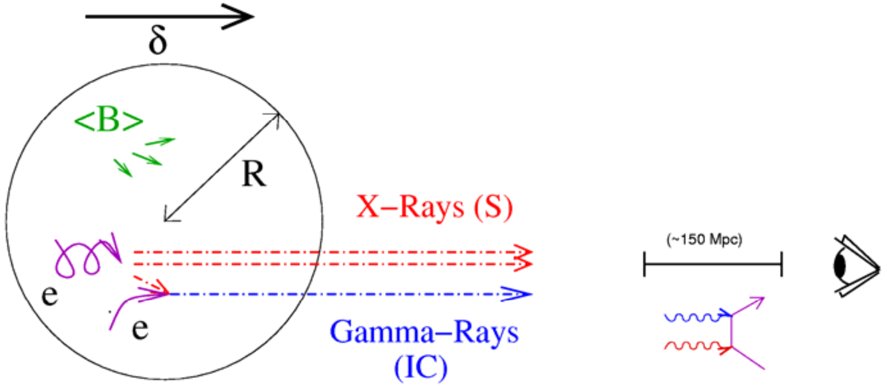
Figure 1. Correlation between X-ray (RXTE) and TeV Gamma-ray fluxes. The Gamma-ray fluxes are from CAT (squares), HEGRA CT System (solid points), HEGRA CT 1 (asterisks), and Whipple (open circles). Only observation pairs with less than 6 hrs time delay have been used.

Key – 3 keV flux
tracks TeV flux
relatively poorly

N.B. June 1997 data (after main flaring) included!

O.K. So you can explain individual spectrum, but what about the variability data?

Mkn 501 – Synchrotron Self–Compton Models



Model parameters:

- δ Doppler Factor
- R Size
- <B> Magnetic field
- e Electron Distribution:
  - – Intensity
  - – Acceleration Spectrum

Model Constraints:

$\Delta t < 1$ day
=> Small Radius ($\delta 10^{15}$ cm)

Cooling Times: B>0.025

SSC Photons =>
Accounts already for
TeV Flux ($\delta = 25$)

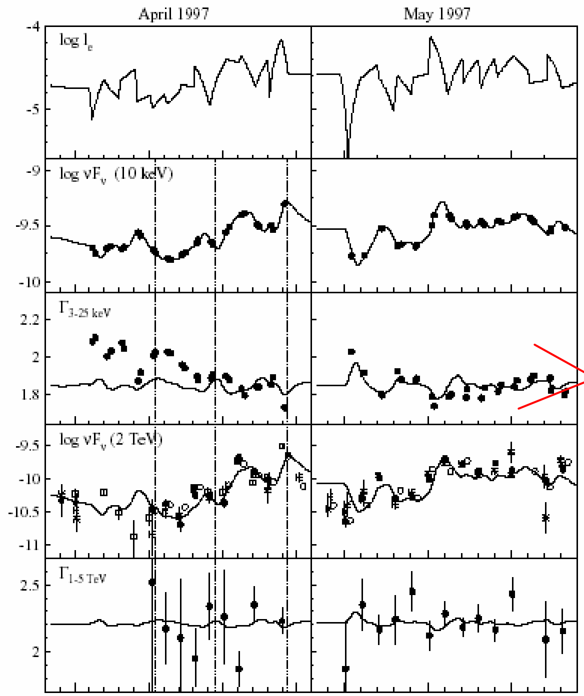
Optically Thin: Doppler Factor >15

Approaches:

– Reconstruct e–Spectrum from X–Ray Spectrum

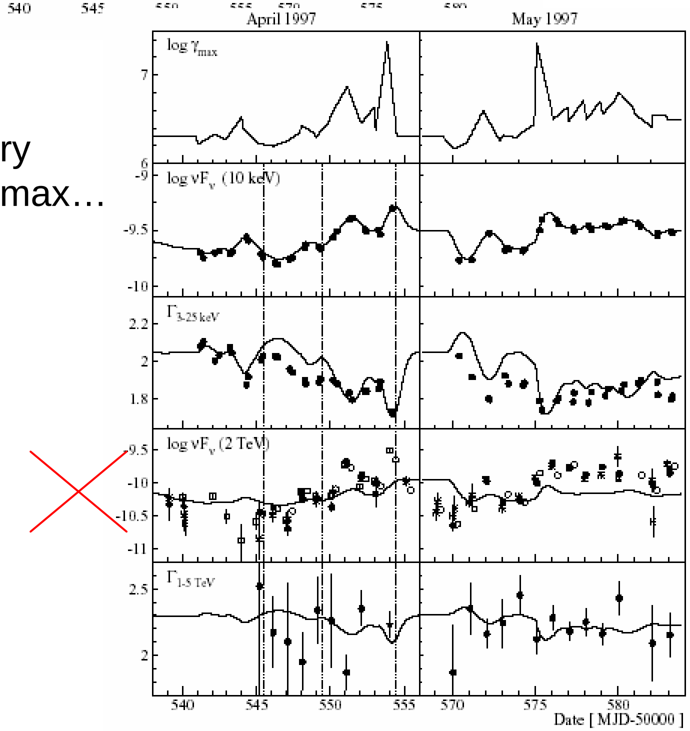
– Time Dependent Model of X–Ray and TeV Gamma–Ray Emission

Krawczynski, Coppi, & Aharonian 2002

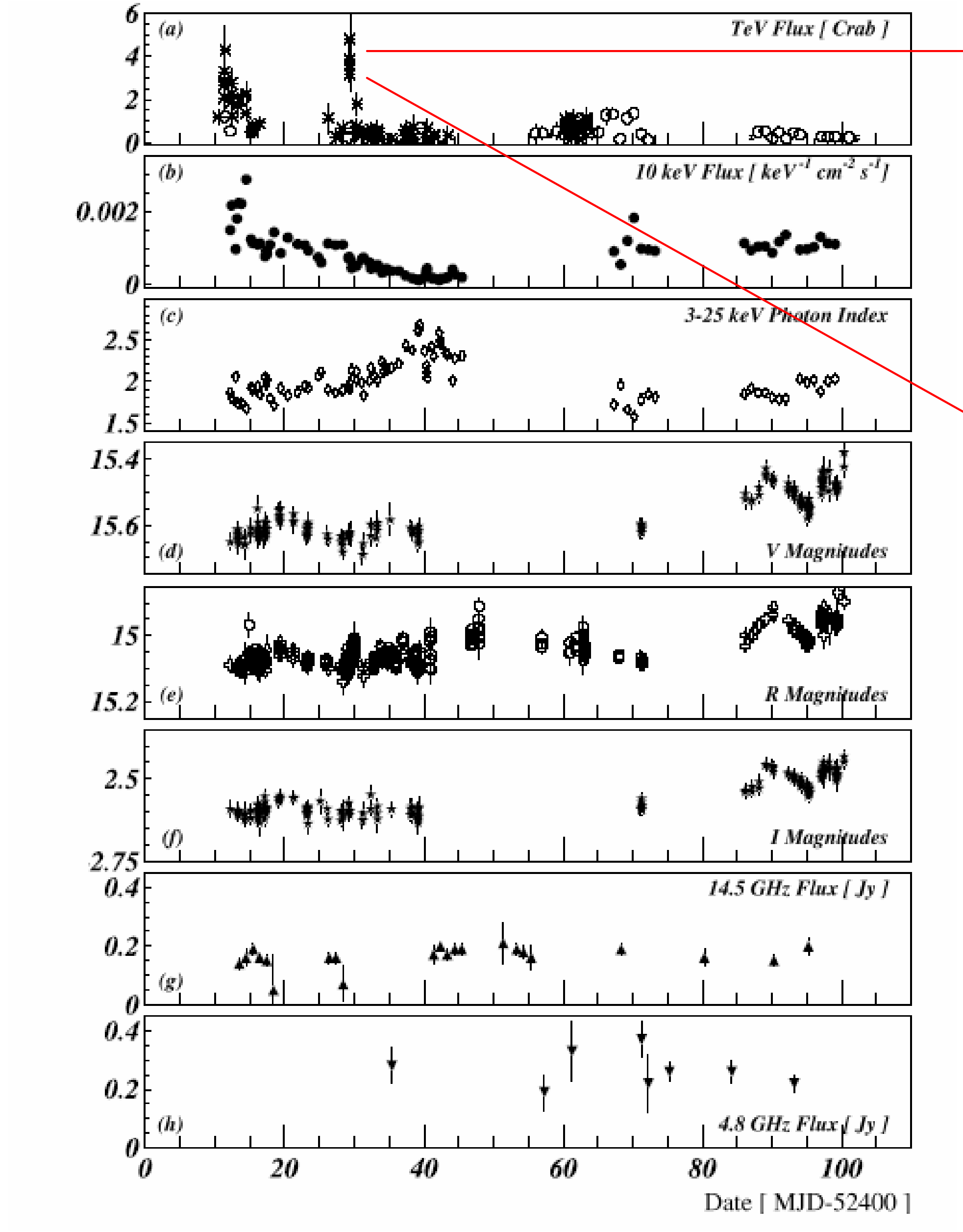


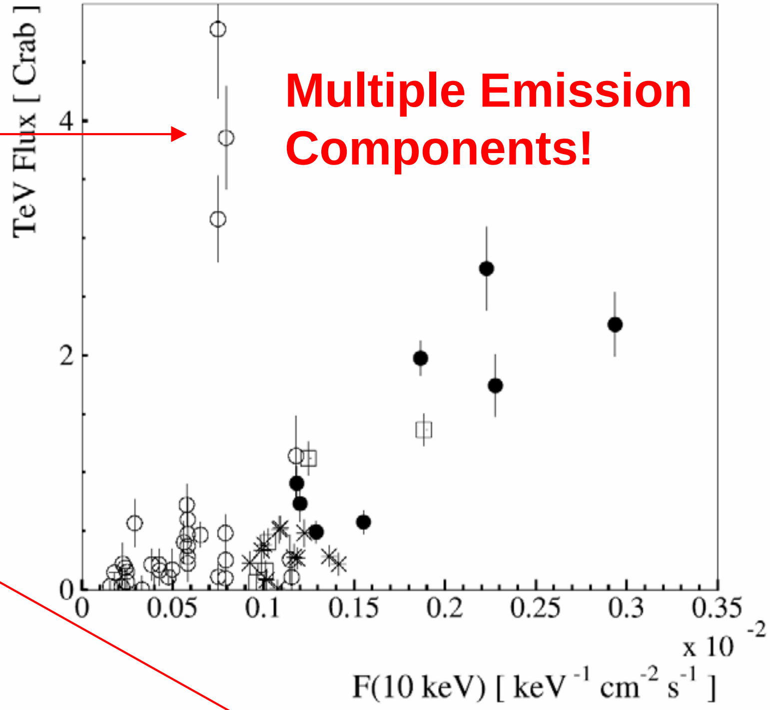
Vary source luminosity

Vary E_max…

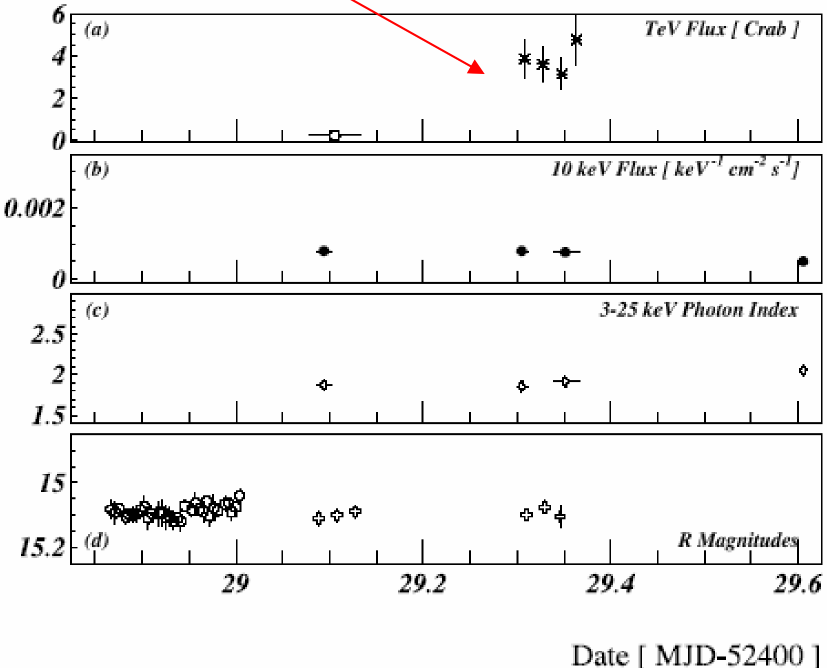


Oops!! -- 1ES1959 May-Aug 2002





Multiple Emission Components!

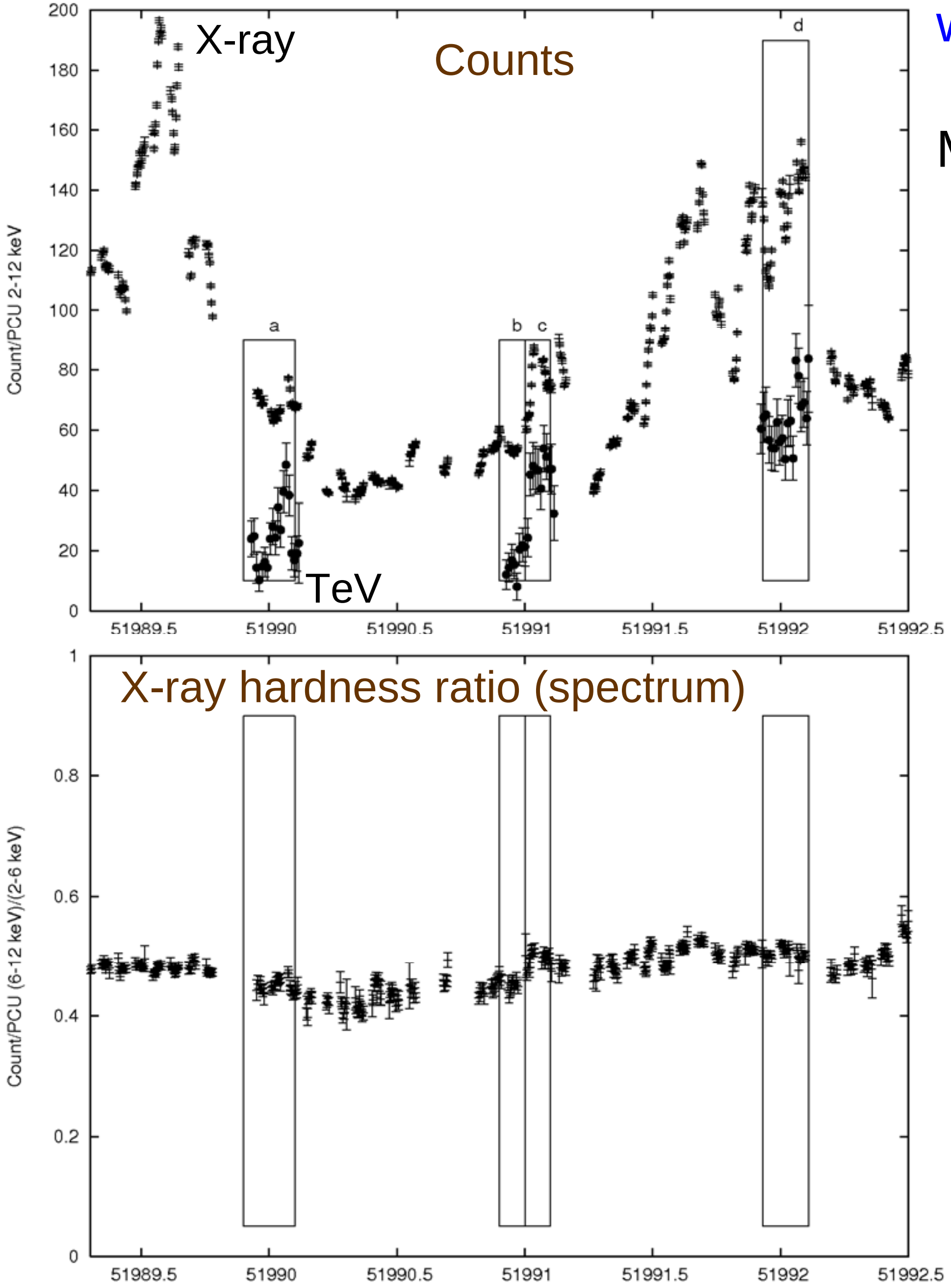


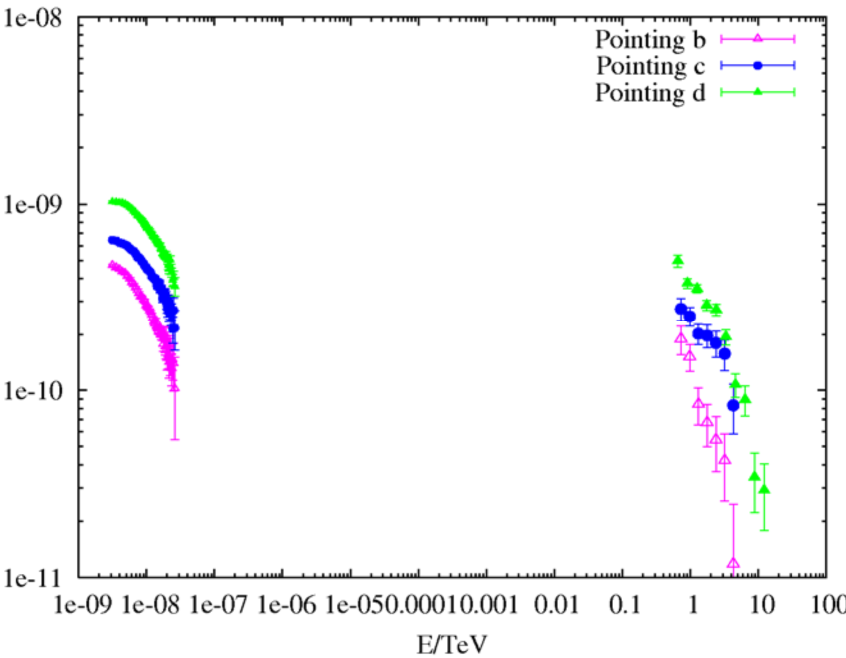
Krawczynski et al. 2004

In case you still thought things were simple…

Mkn 421 2002 X-ray/TeV campaign

(Dieter Horns, preliminary)



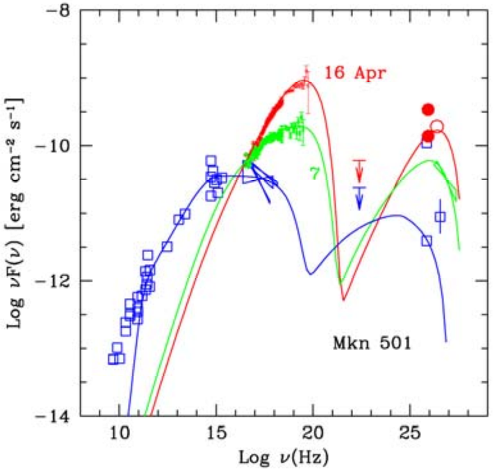


Theorist’s Wish List

Rule of thumb: give a theorist a spectrum consistent with a power law (e.g., due to insufficient statistics) and he can fit any model/EBL you like.

⇩

Need to detect curvature! Ideally measure both sides of low and high energy peaks, simultaneously w/good (< hour-month) time-sampling: UV-MeV, 100 MeV-TeV coverage. ☺ [Also very good to get below IR/O absorption threshold.]



+

There will always be some special objects, e.g., Mkn 501, not accessible from.

+

Want good population statistics ….

⇨ One “super” telescope not enough – want tightly coordinated space *and* ground-based telescopes.

The Big Payoff: Remove spurious sources and…

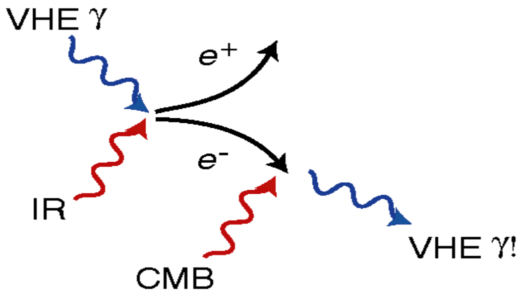
An accurate measurement (upper limits) on
the GeV-TeV *extragalactic* diffuse background.

Why so interesting?

GeV-TeV+ gamma-rays only produced in extreme environments or by “exotic” processes: e.g., black hole jets, supernova blast waves, cosmic strings, relict particle decays, or matter-antimatter annihilation.

Background is sum of all nearby GeV-TeV activity in the Universe + **all** > GeV activity at z > 1.

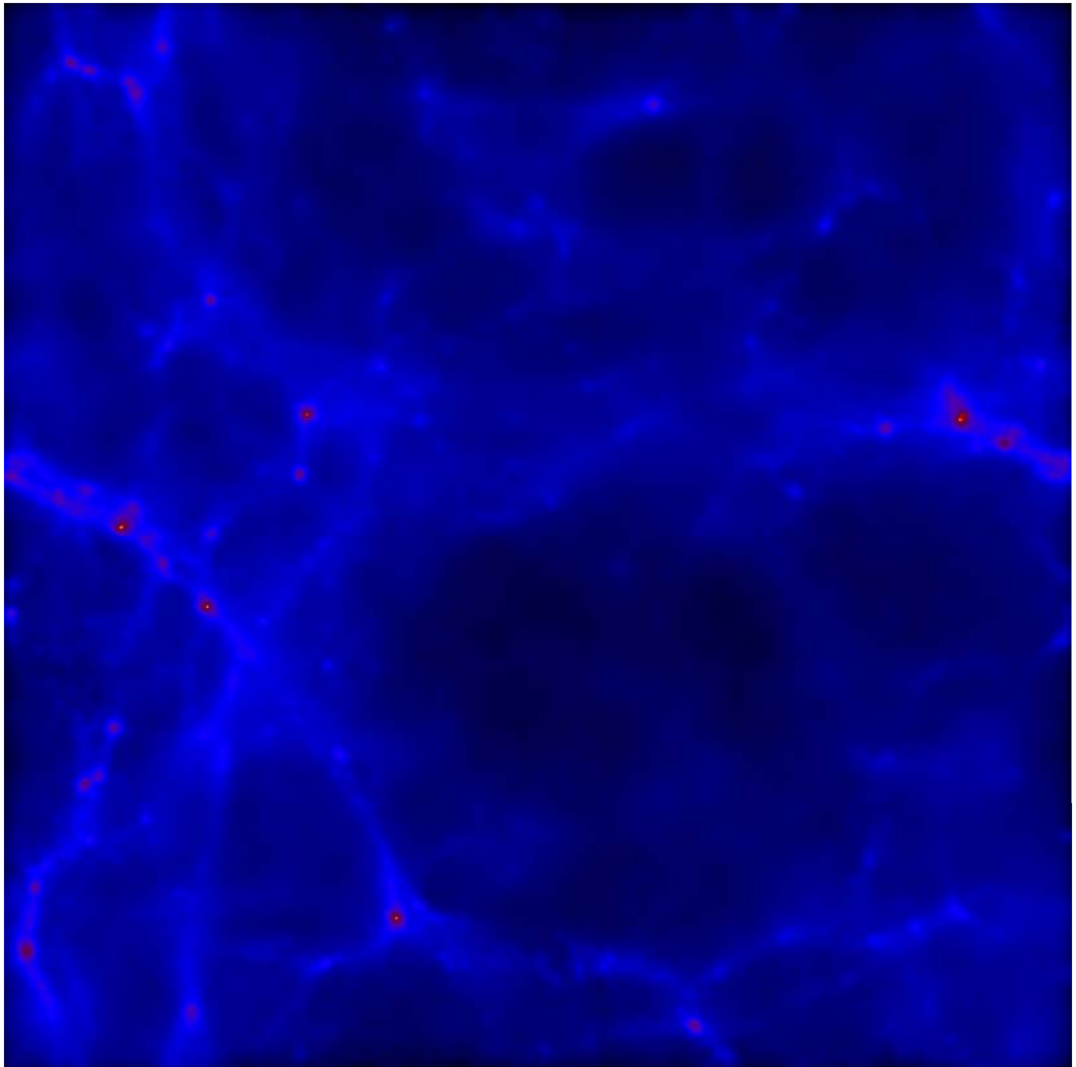
[Gamma-ray pair production and
cascading on intergalactic photon fields



**GLAST = calorimeter for
VHE-EHE Universe!**

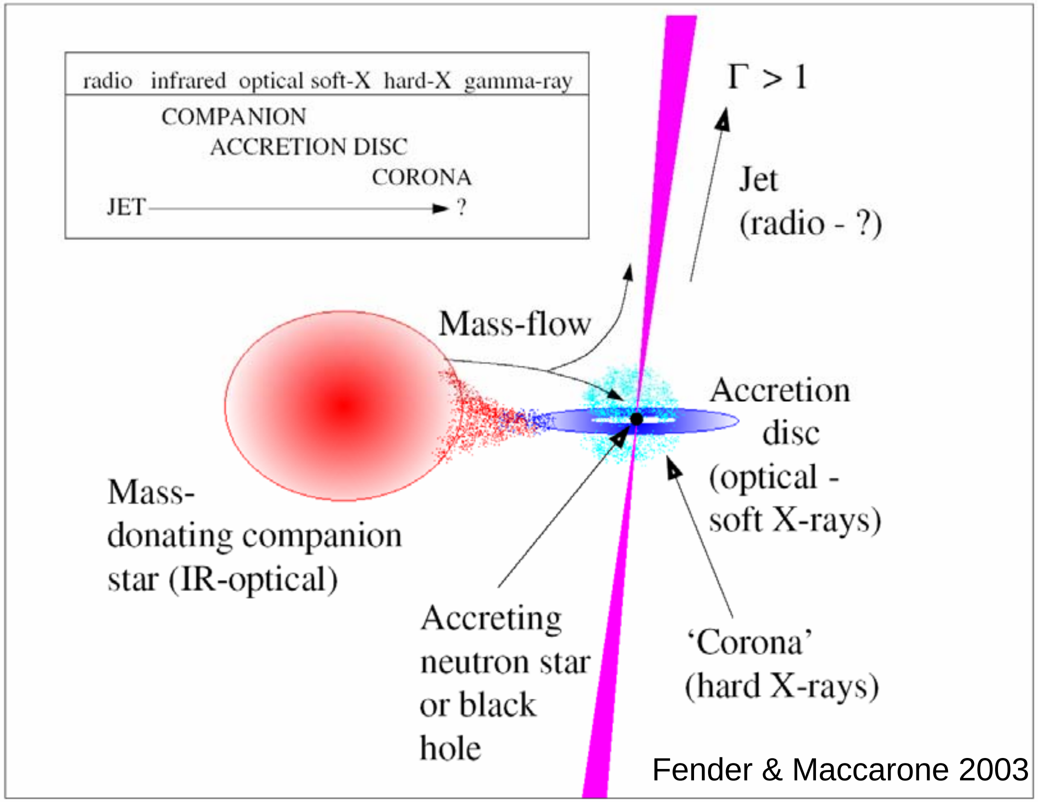
(best limits on BAU/matter-antimatter
domains from gamma-rays)]

Most sources can think of, even decaying/annihilating CDM particles, trace large scale structure… look for *clustering* signal!

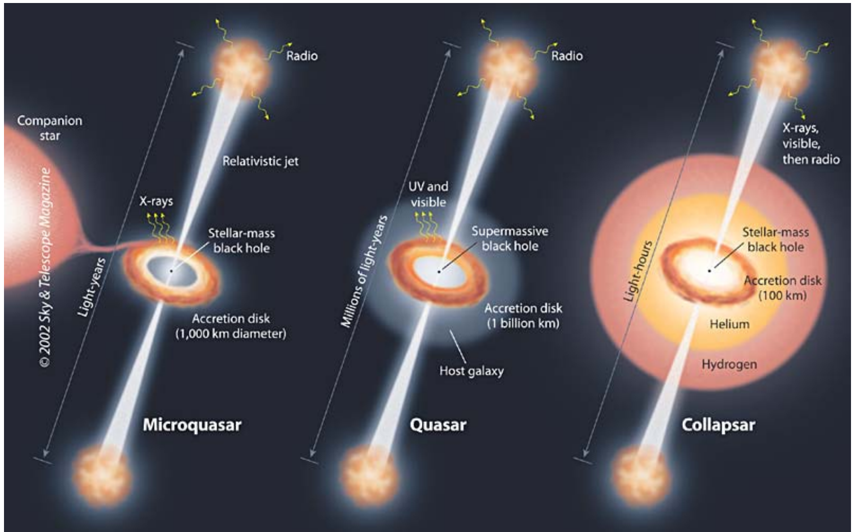


Bromm et al. 2003

Relativistic jets everywhere! Galactic "micro" blazars?

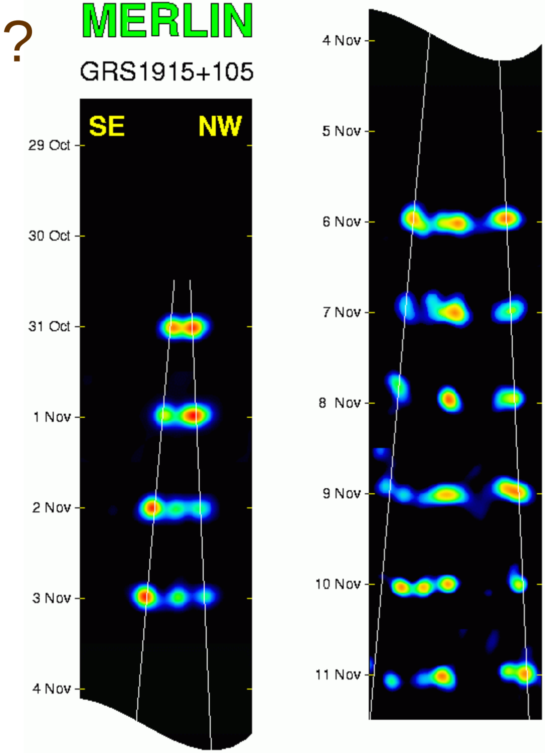


Fender & Maccarone 2003

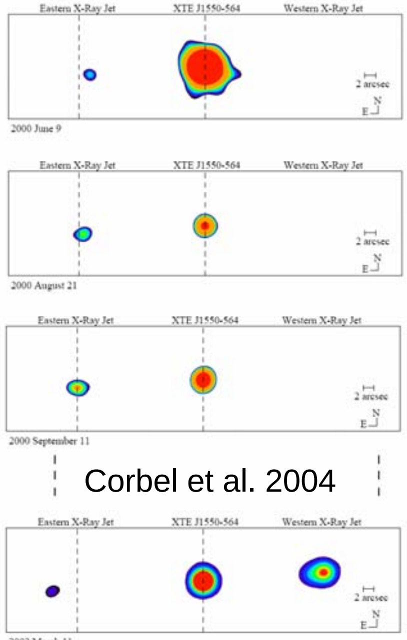


Mirabel & Rodriguez 2002

Radio



X-ray



Corbel et al. 2004

GeV+ gamma-rays from afterglow … not common, but it happens … something for GLAST/HESS to see…!

GRB very promising class of sources to study. May be able to see out to very high redshift (10+). SWIFT GRB satellite just successfully launched…

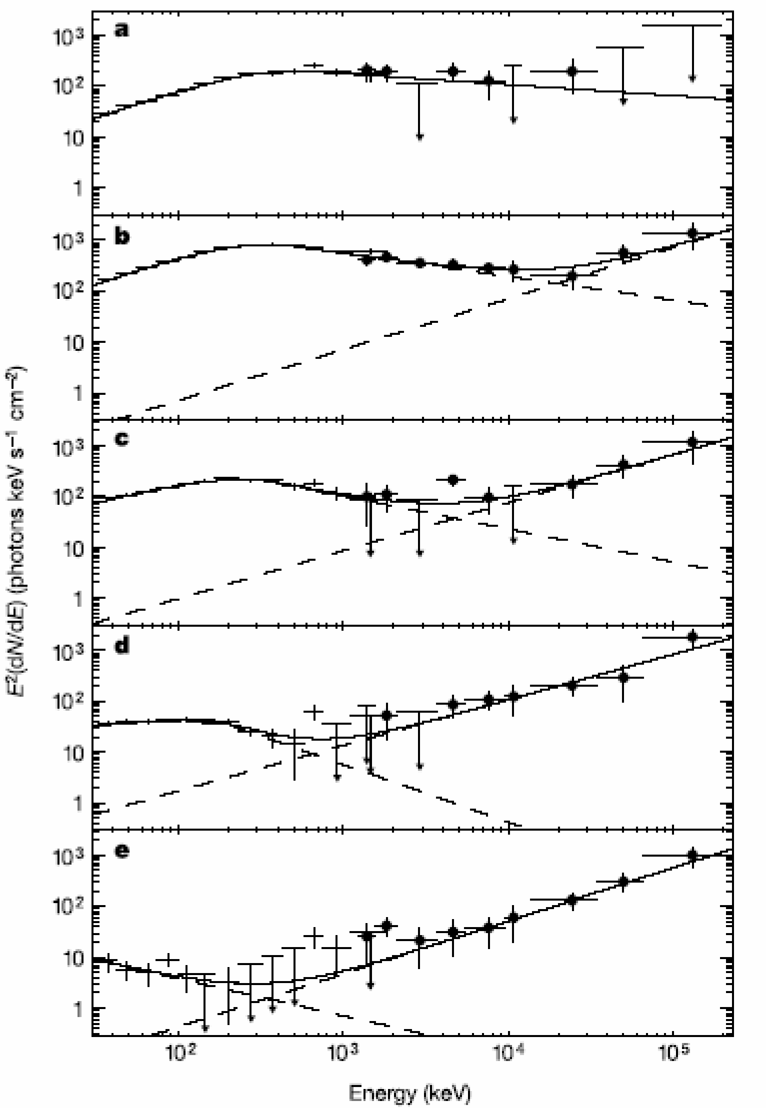


Figure 2 Energy fluxes from GRB941017. **a–e**, Data were obtained with LAD (crosses) and TASC (filled circles) during five time intervals shown in Table 1 (with **a** and **e** being the

Gonsalez et al. 2003

The X-ray/Radio correlation

Microquasars – e.g., GX339 - Corbel et al. 2004

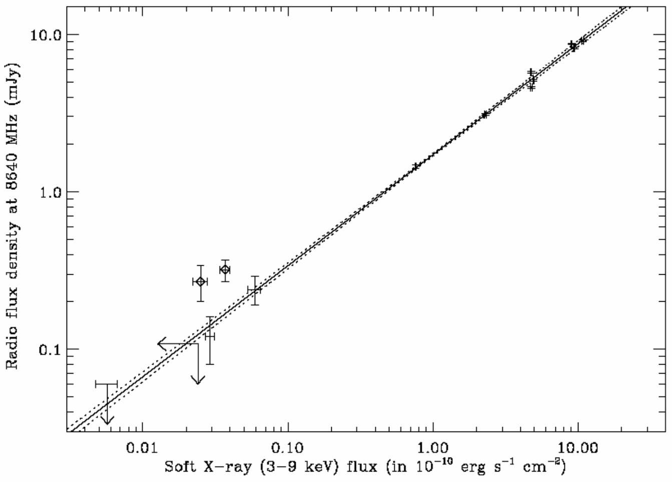


Fig. 1. The radio flux density at 8.6 GHz is plotted versus the X-ray flux in the 3-9 keV energy band. The continuous line denotes the fit to the data with the function described in the body of the paper and with the parameters estimated in Table 3, the dotted line represents the one-sigma deviation to those parameters. Upper limits are plotted at the three sigma level. The diamond points are those points that are not strictly simultaneous (1999.08.17) or maybe affected by a small reflare observed in hard X-rays (1999.09.01, see Figure 15 in Corbel et al. 2000).

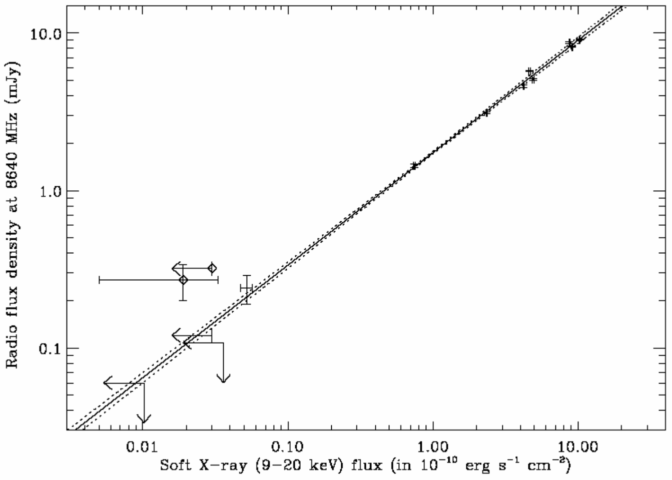


Fig. 2. Same as Fig. 1, but for the X-ray flux in the 9-20 keV energy band.

AGN !? - Maccarone et al. 2003

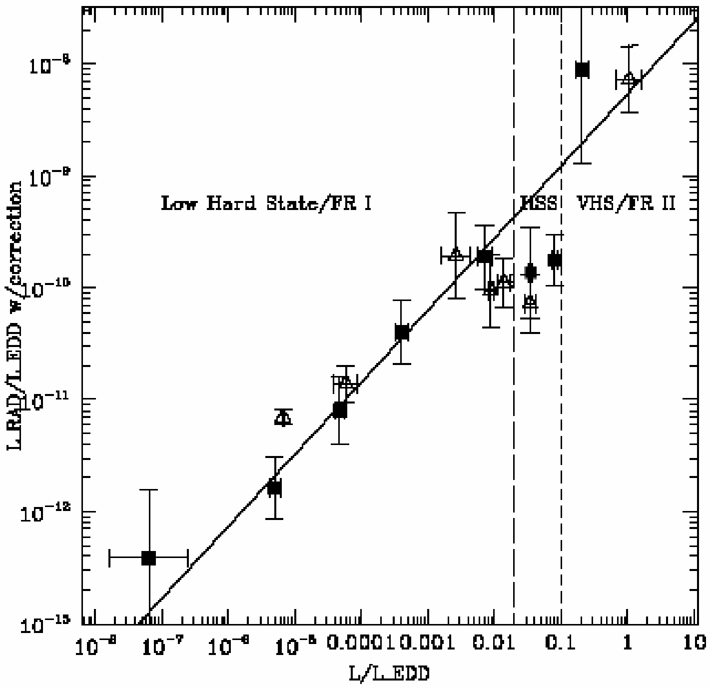
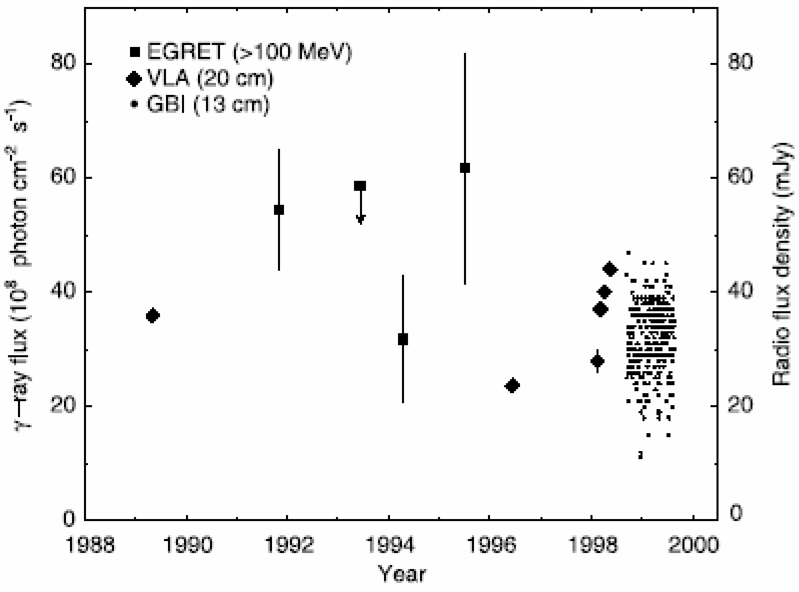


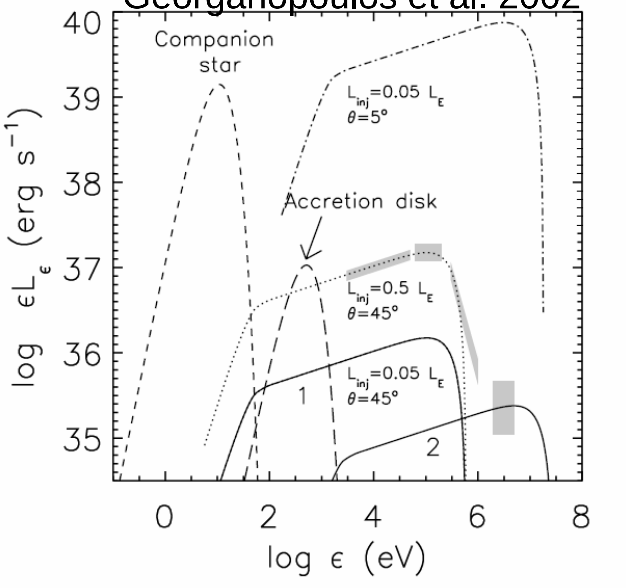
Figure 2. The same as Fig. 1b, with the X-ray binaries included. The open triangles represent the X-ray binaries. The long-dashed vertical line indicates the transition luminosity between the high/soft state (HSS) and the low/hard state as measured in Maccarone (2003) and also is very close to the transition luminosity between FR I & II galaxies as determined by Ghisellini & Celotti (2001). The short-dashed vertical line indicates the estimated state transition luminosity between the high/soft state and the very high state (VHS). The fit to the data is the same as that presented in Figure 1.

Microquasar/Microblazars potential gamma-ray sources!

Fig. 3. Radio and γ-ray light curves of LS 5039 and 3EG J1824-1514, which we propose originate in the same object. Both LS 5039 and 3EG J1824-1514 are consistent with a persistent level of emission over the last decade. The fluxes plotted here are taken from the literature and archive data (*3, 4, 19, 21*). Error bars for GBI (±4 mJy) are not shown for clarity, whereas those of the VLA are usually smaller than the symbol size.



Georganopoulos et al. 2002



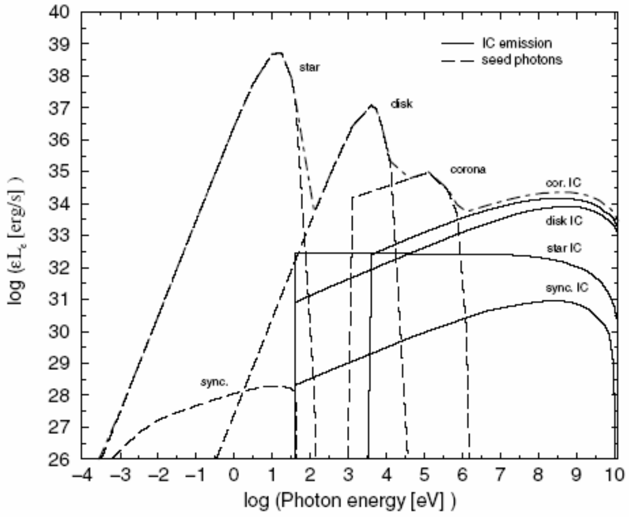


Fig. 6. Complete SED for a model with $q_e = 10^{-4}$, $B(z_0) = 10$ G, $L_{cor} = 10^{35}$ erg s^{-1}, $\gamma_{emax}(z_0) = 10^4$, $\Gamma_{jet} = 2.5$, and a viewing angle of 10°. This is the representative case.

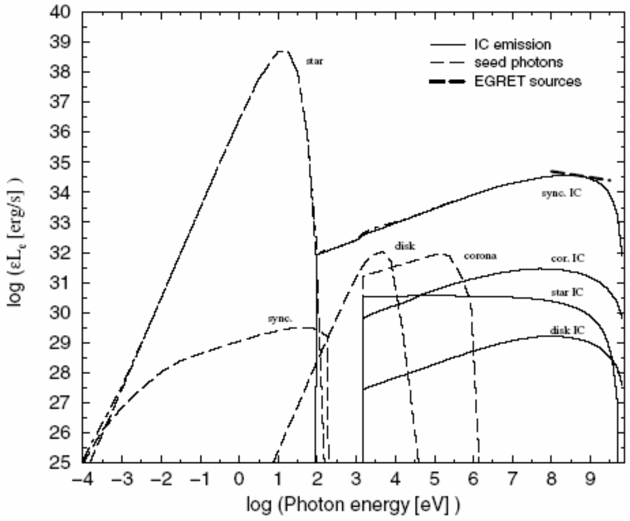


Fig. 8. SED for a model with $q_e = 10^{-3}$, $B(z_0) = 200$ G, $L_{cor} = 3 \times 10^{32}$ erg s^{-1}, $\gamma_{emax}(z_0) = 10^4$, $\Gamma_{jet} = 1.1$, and a viewing angle of 10°. This is the "realistic" case.

Ramon-Bosch et al. 2005

N.B. Parameter regime different from AGN ones! (e.g., B^2 goes as M_{BH}^{-1}; n_{ISM}~1 cm^{-3} vs. n_{ICM}~10^{-3} $cm^{-3.}$)

Summary

Gamma-ray emission from blazars still not well-understood.

Leptonic models “preferred,” but hadronic models not ruled out (need more work though! especially temporal variability signatures) – flys in the ointment: TeV/X corr? multiple emission components!?.

Complex environment in GeV blazars may hinder progress in understanding them, even with arrival of GLAST. When detailed modeling required, e.g., for IR background constraints, focus on TeV blazars: simpler (?) and better matched to detectors (GLAST area small).

TeV blazars may not be as boring as we once thought.

High Doppler boost factor (>20?) => multi-component jet structure? [relativistic spine?]

(Too) large jet kinetic energy? K_e,p order unity? Jet very inefficient radiator? Interaction with local environment, e.g., recollimation shock, may be important.

External photon fields may still be important in TeV blazars (in Mrk 501, can significantly lower energetics). Radical hypothesis: main difference with GeV blazars is higher electron energies and importance of Klein-Nishina effects??

Fossati et al. unification/classification scheme may not be quite right – new classes of objects? Don’t bias your surveys.

With good broad band, time-resolved X-ray AND gamma-ray data, detailed modeling possible =>interesting constraints. Activity just starting … lots of data already in hand (e.g., Mrk 421 2000 flare) and some starting to becoming public ☺.

Better data coming soon – one simultaneous observation of an April 16 Mrk 501-type flare by HESS/VERITAS and ASTROE-2 has potential to measure 1-80 micron IR background (but may first cause headaches for modelers – data too good!).

Converging flows in merging/accreting clusters
=> clusters should be gamma-ray sources …

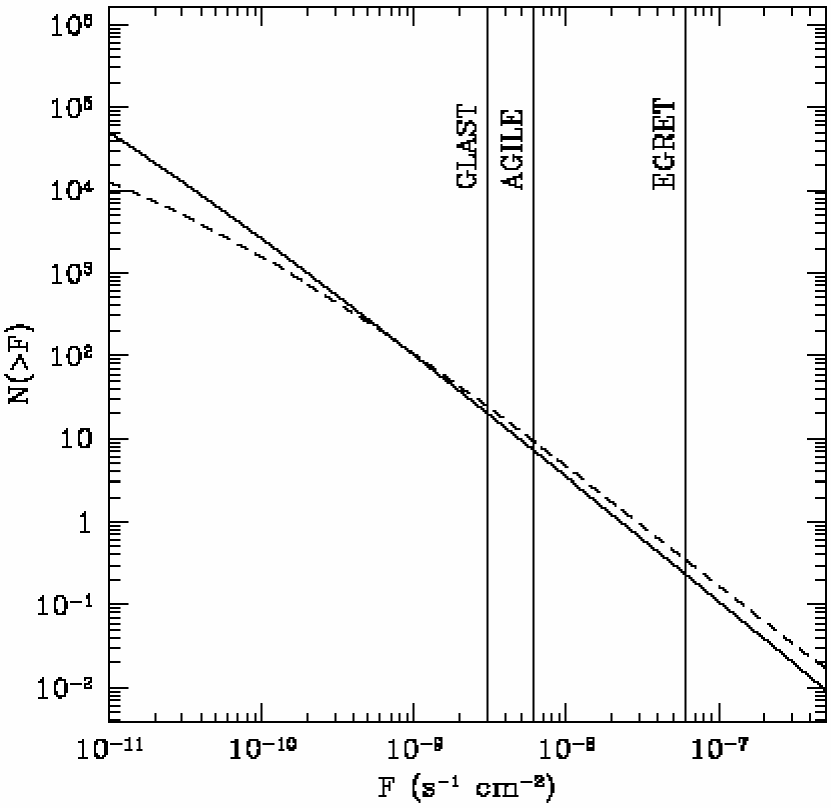


Fig. 2. Number of accreting (solid line) and merging (dashed line) clusters with gamma ray flux greater than *F*. The vertical lines represent the GLAST, AGILE and EGRET sensitivity for point sources.

Gabici & Blasi 2003

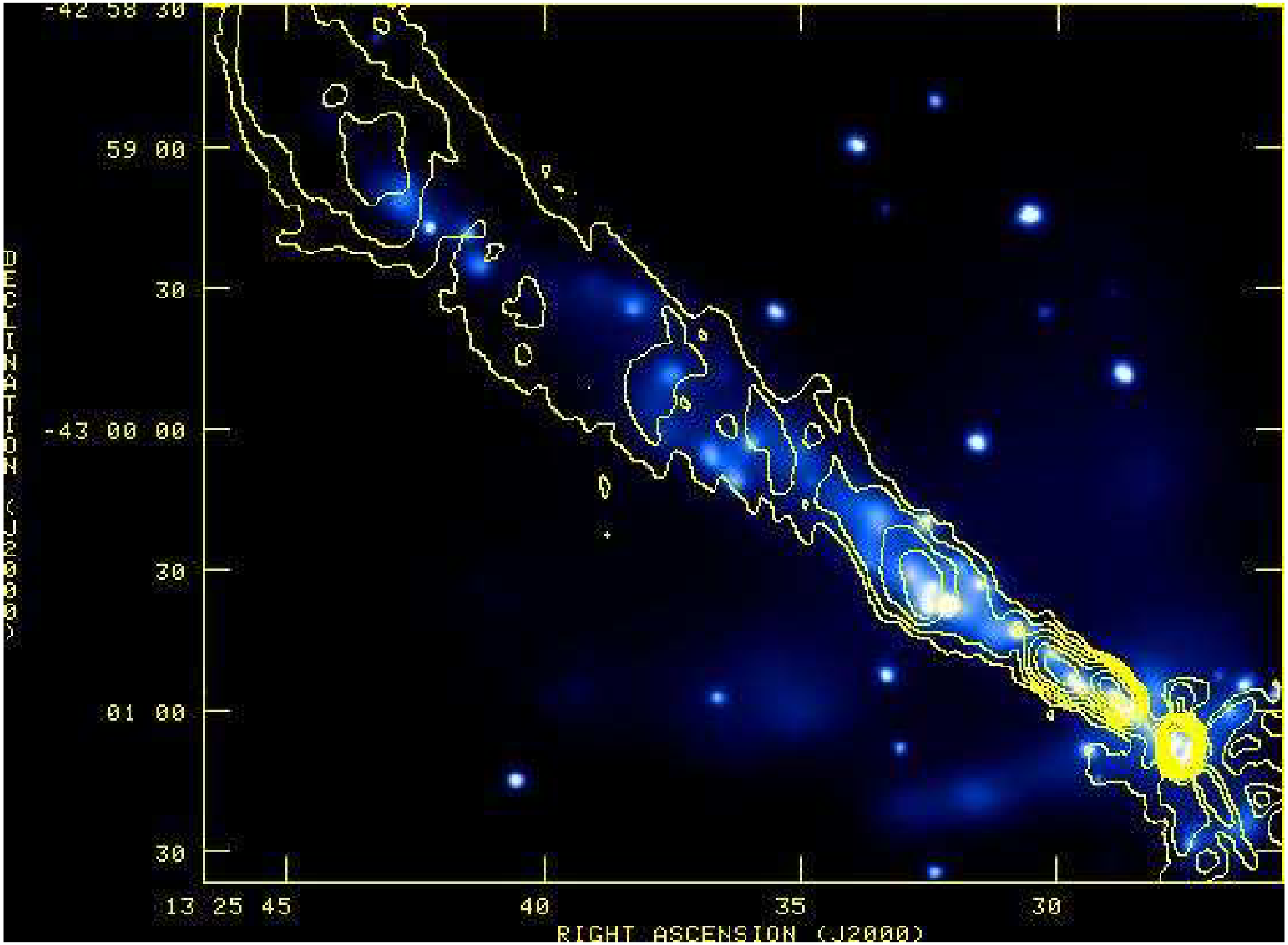
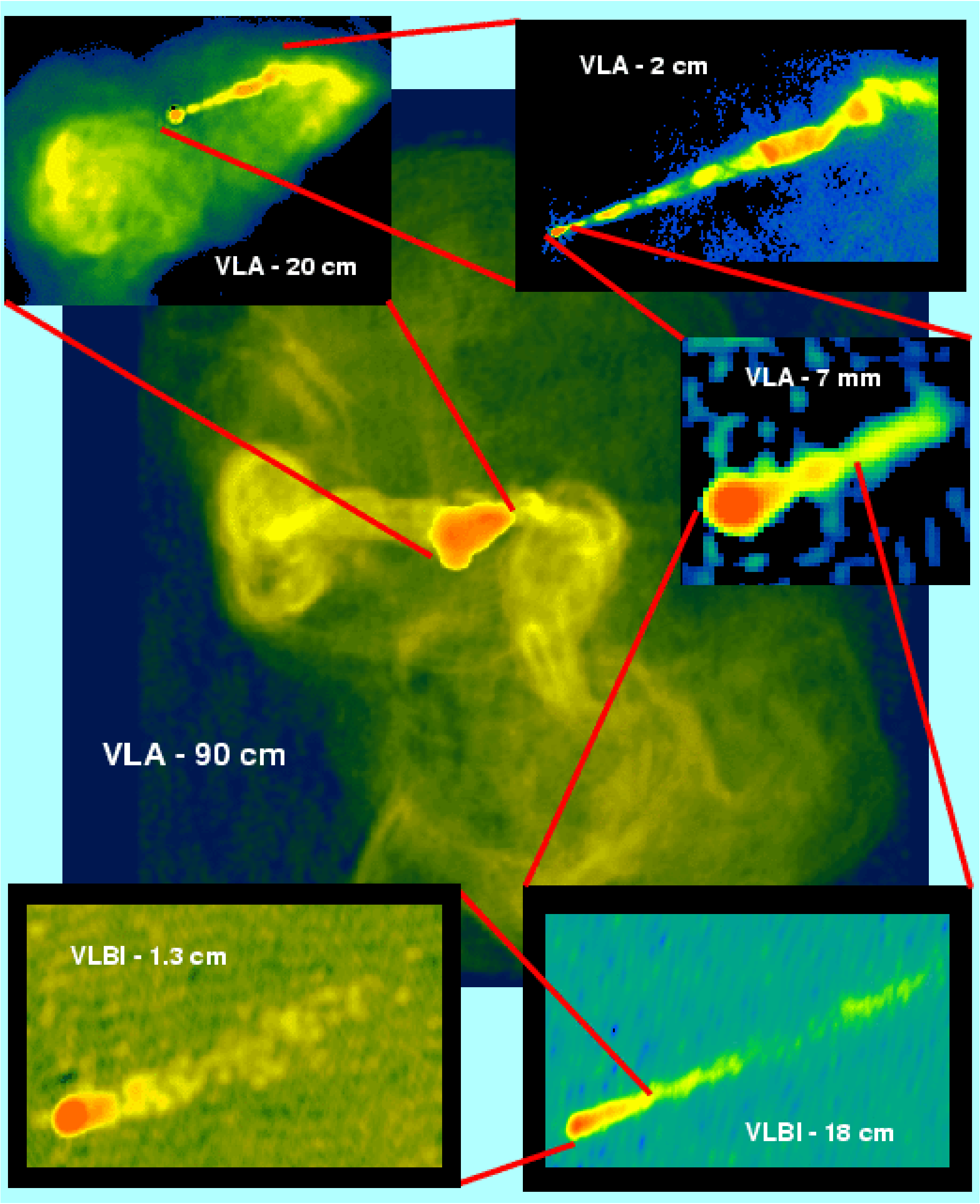
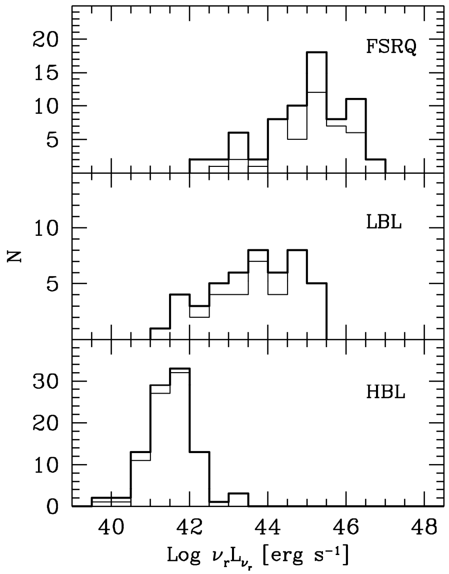


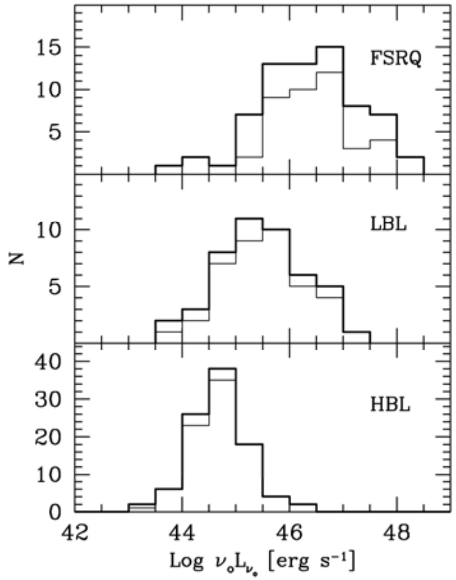
Fig. 10.— Adaptively smoothed, coadded X-ray image in the 0.4-2.5 keV bandpass of the jet in Centaurus A with 3.6 cm radio contours overlaid. North is up and east is to the left. The radio beam is 3.39″ (RA) × 4.70″(DEC).


VLA - 20 cm
VLA - 2 cm
VLA - 7 mm
VLA - 90 cm
VLBI - 1.3 cm
VLBI - 18 cm

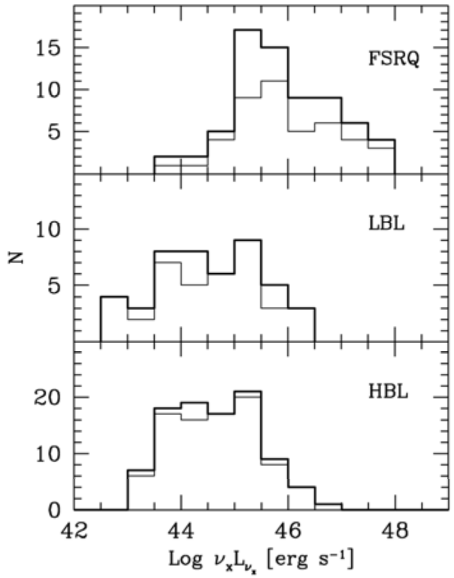
Radio Luminosity



Optical Luminosity



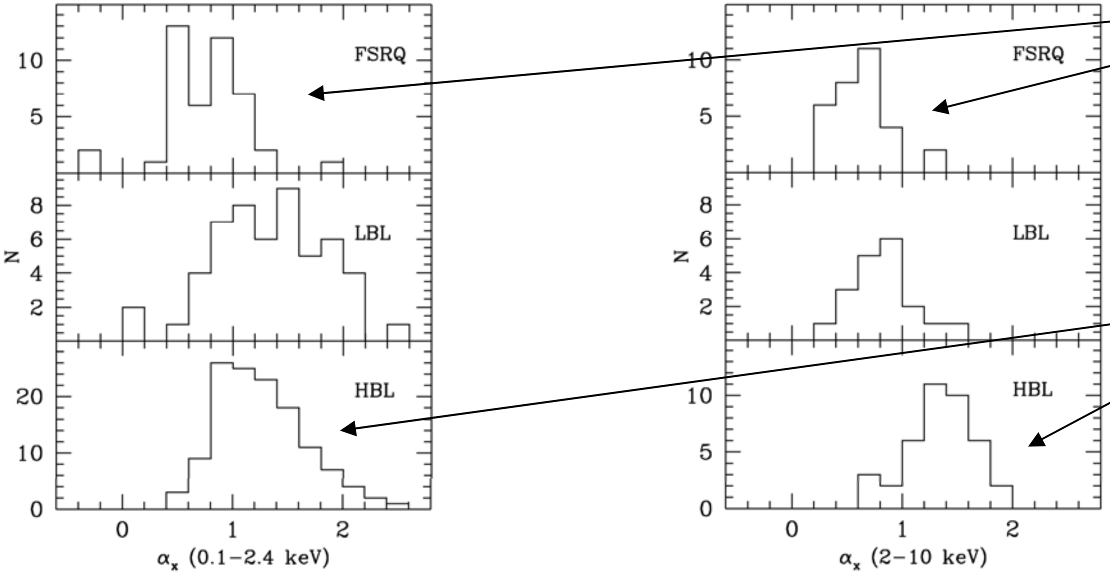
X-Ray Luminosity??



strong

↑

weak



Hard inverse Compton
component dominates
X-rays

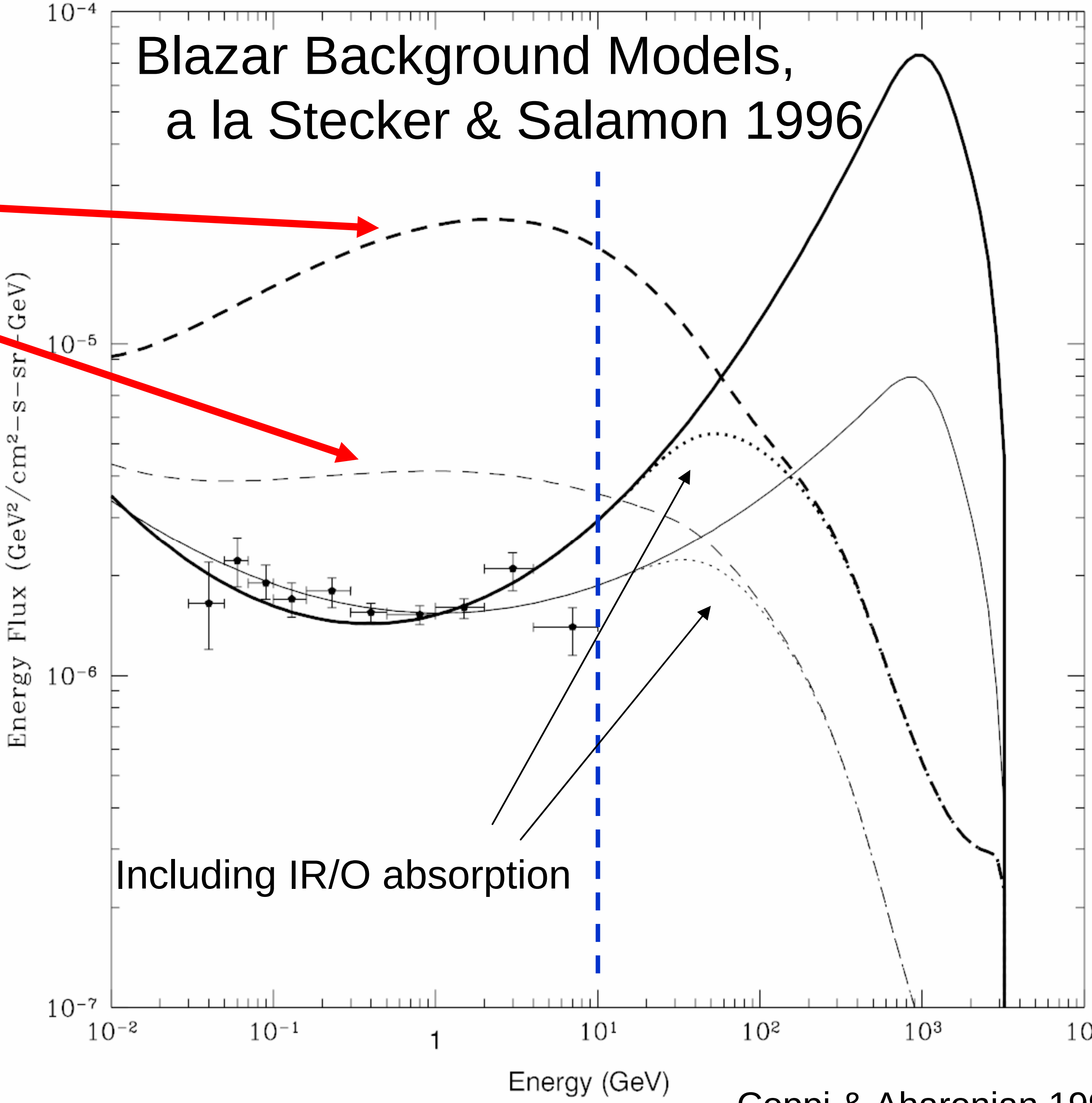
↓

Steep tail of synchrotron
Component dominates
X-rays

X-Ray Spectral Index

Donati et al. 2001

Blazar Background Models, a la Stecker & Salamon 1996



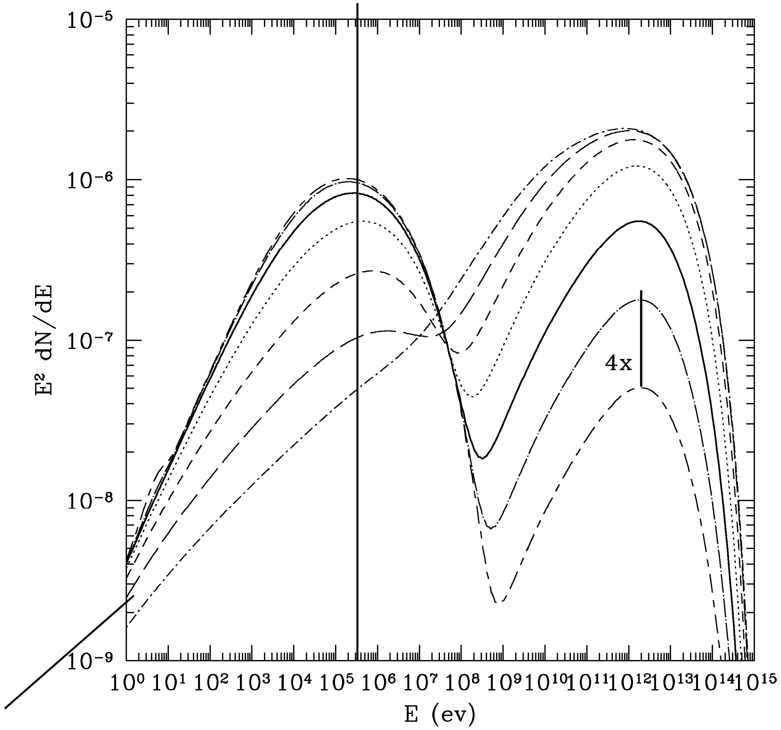
Don’t forget cascades!

Including IR/O absorption

Coppi & Aharonian 1997

TeV Blazars: Self-Consistent Modeling & Klein-Nishina Correction to Thomson Cross-Section Important!

E_p determined by t_cool=t_esc

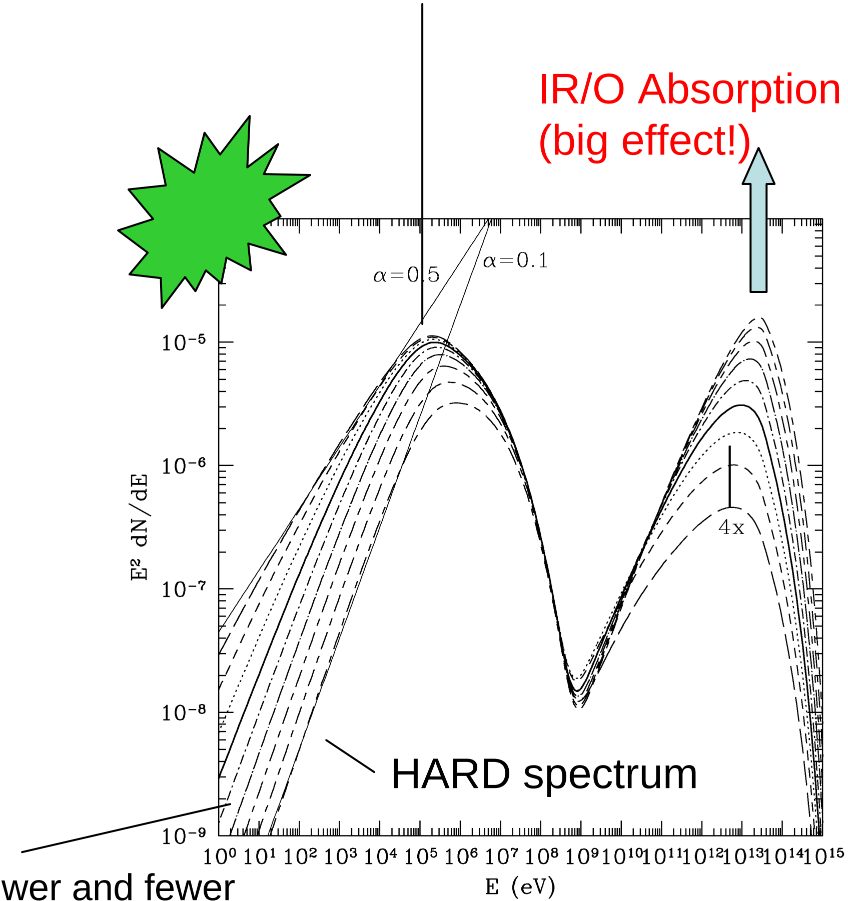


Lots of soft target photons

Response to variations in electron acceleration luminosity.

E_p determined by E_min (t_esc=infinity)

IR/O Absorption (big effect!)



HARD spectrum

Fewer and fewer soft photons

Fits BeppoSAX < 2 keV X-ray Better!!

Solid line models: Both fit April 16th Mrk 501 CAT gamma-ray and BeppoSax data above 2 keV equally well…

Using Mrk 501 April 1997 data can start to constrain DEBRA models – *if* SSC hypothesis is correct.

Key which allows this is simultaneous, broadband X-ray and TeV data.

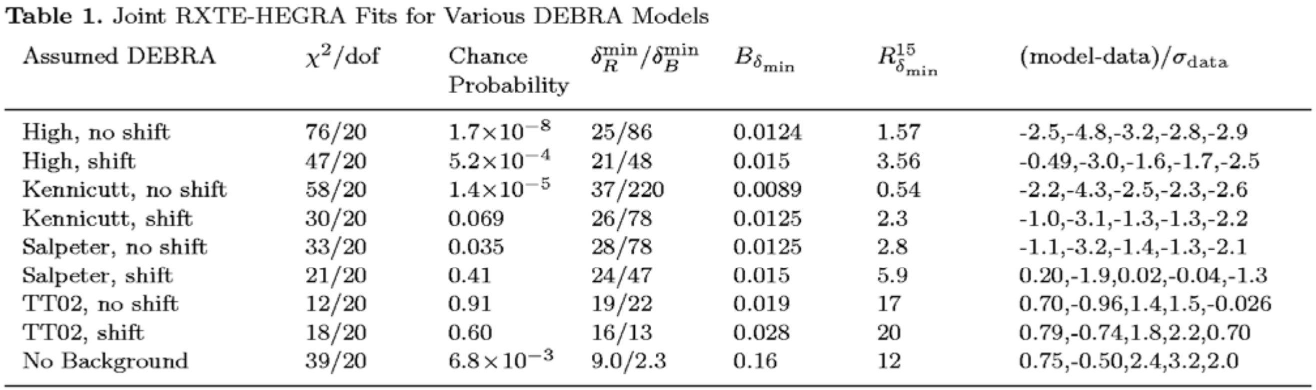


Table 1. Joint RXTE-HEGRA Fits for Various DEBRA Models

Assumed DEBRA	χ^2/dof	Chance Probability	$\delta_R^{\rm min}/\delta_B^{\rm min}$	$B_{\delta_{\rm min}}$	$R^{15}_{\delta_{\rm min}}$	(model-data)/$\sigma_{\rm data}$
High, no shift	76/20	1.7×10^{-8}	25/86	0.0124	1.57	-2.5,-4.8,-3.2,-2.8,-2.9
High, shift	47/20	5.2×10^{-4}	21/48	0.015	3.56	-0.49,-3.0,-1.6,-1.7,-2.5
Kennicutt, no shift	58/20	1.4×10^{-5}	37/220	0.0089	0.54	-2.2,-4.3,-2.5,-2.3,-2.6
Kennicutt, shift	30/20	0.069	26/78	0.0125	2.3	-1.0,-3.1,-1.3,-1.3,-2.2
Salpeter, no shift	33/20	0.035	28/78	0.0125	2.8	-1.1,-3.2,-1.4,-1.3,-2.1
Salpeter, shift	21/20	0.41	24/47	0.015	5.9	0.20,-1.9,0.02,-0.04,-1.3
TT02, no shift	12/20	0.91	19/22	0.019	17	0.70,-0.96,1.4,1.5,-0.026
TT02, shift	18/20	0.60	16/13	0.028	20	0.79,-0.74,1.8,2.2,0.70
No Background	39/20	6.8×10^{-3}	9.0/2.3	0.16	12	0.75,-0.50,2.4,3.2,2.0

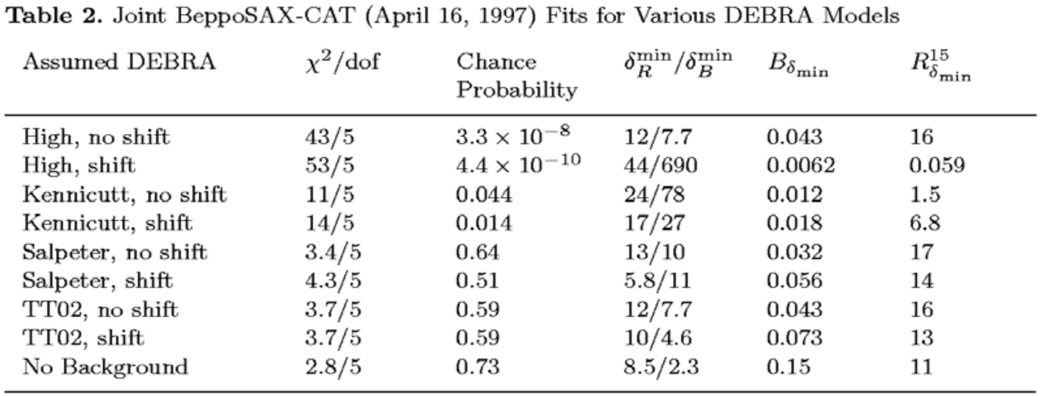
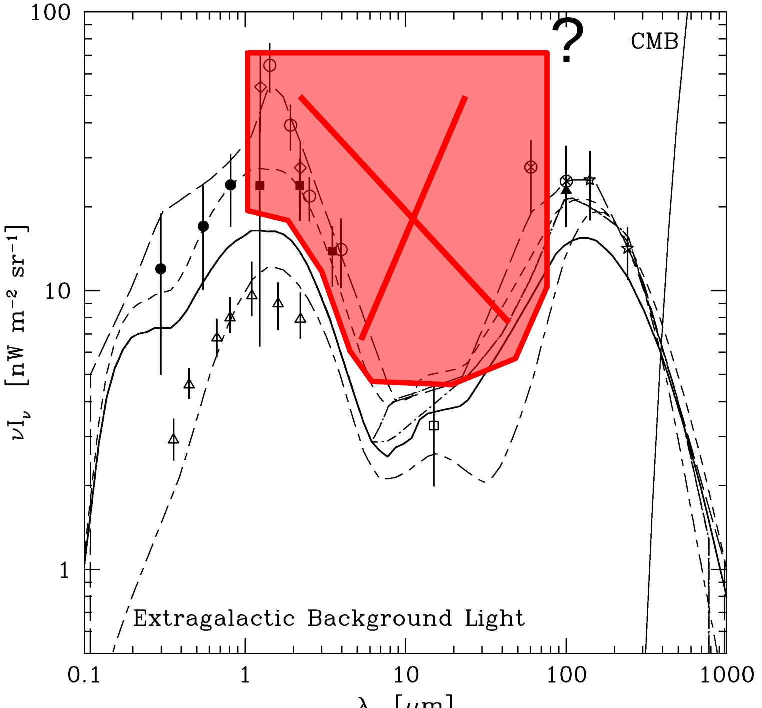


Table 2. Joint BeppoSAX-CAT (April 16, 1997) Fits for Various DEBRA Models

Assumed DEBRA	χ^2/dof	Chance Probability	$\delta_R^{\rm min}/\delta_B^{\rm min}$	$B_{\delta_{\rm min}}$	$R^{15}_{\delta_{\rm min}}$
High, no shift	43/5	3.3×10^{-8}	12/7.7	0.043	16
High, shift	53/5	4.4×10^{-10}	44/690	0.0062	0.059
Kennicutt, no shift	11/5	0.044	24/78	0.012	1.5
Kennicutt, shift	14/5	0.014	17/27	0.018	6.8
Salpeter, no shift	3.4/5	0.64	13/10	0.032	17
Salpeter, shift	4.3/5	0.51	5.8/11	0.056	14
TT02, no shift	3.7/5	0.59	12/7.7	0.043	16
TT02, shift	3.7/5	0.59	10/4.6	0.073	13
No Background	2.8/5	0.73	8.5/2.3	0.15	11



Coppi, Krawczynski, & Aharonian 2002