Gamma-Ray Astronomy with VERITAS

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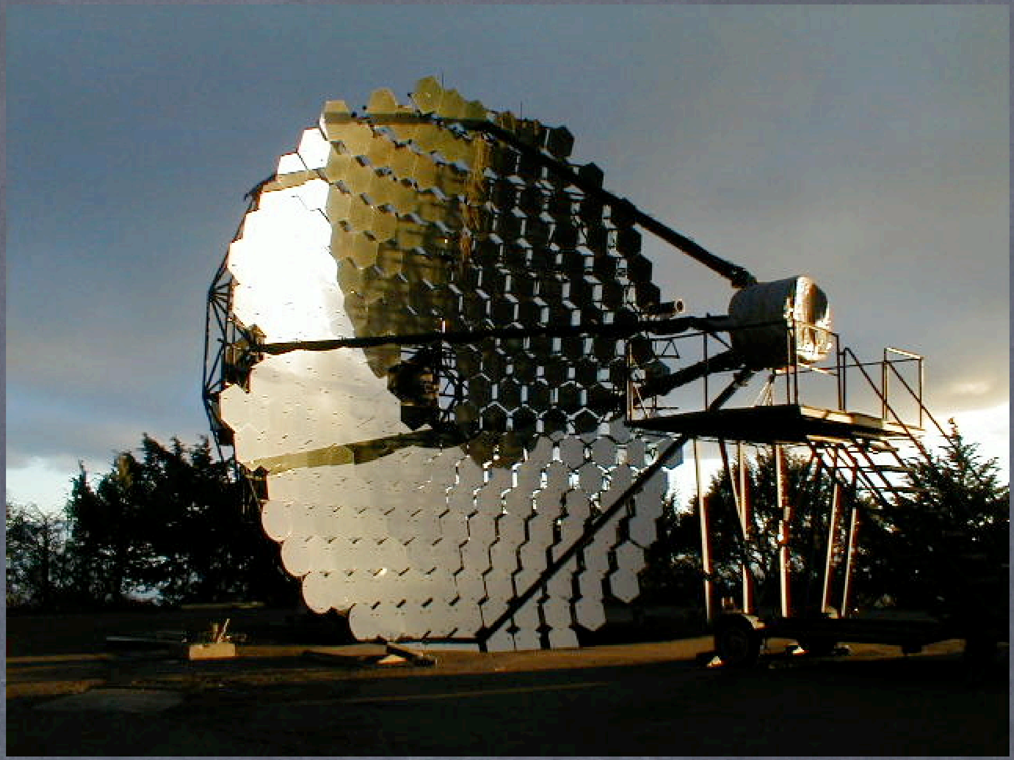
for the VERITAS Collaboration

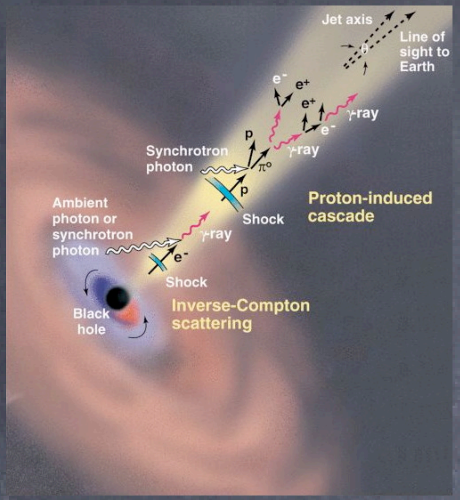
Workshop on UHE cosmic rays, photons and neutrinos
KITP, May 17, 2005

Outline

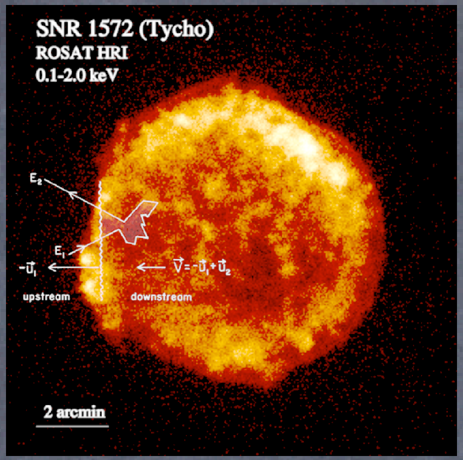
- Results from Whipple
- VERITAS construction status
- Science with VERITAS.
- Beyond VERITAS



Sources of TeV Gammas

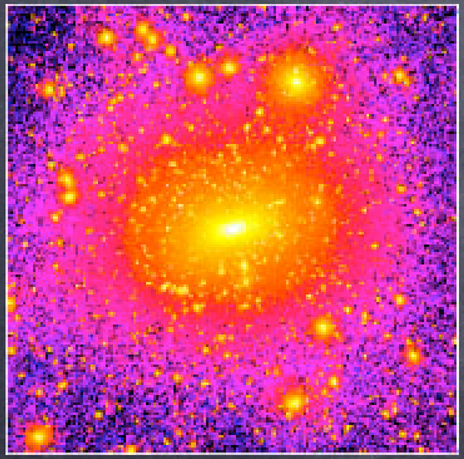


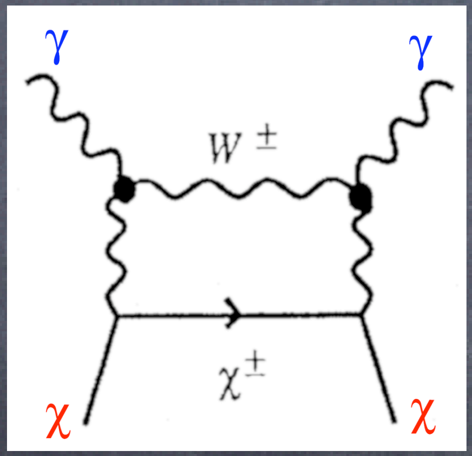
AGNs, Blazars and other SMBH accretion sources



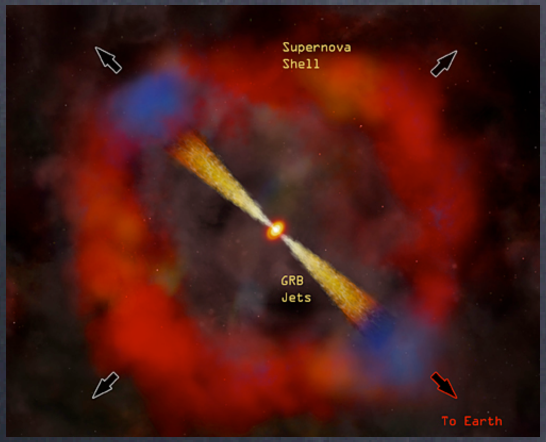
Shell-type SNR, Plerions, Pulsars, origin of cosmic rays

I wouldn't dare discuss this after Felix's talk!





Dark matter - Galactic center, galactic IMBHs, clusters

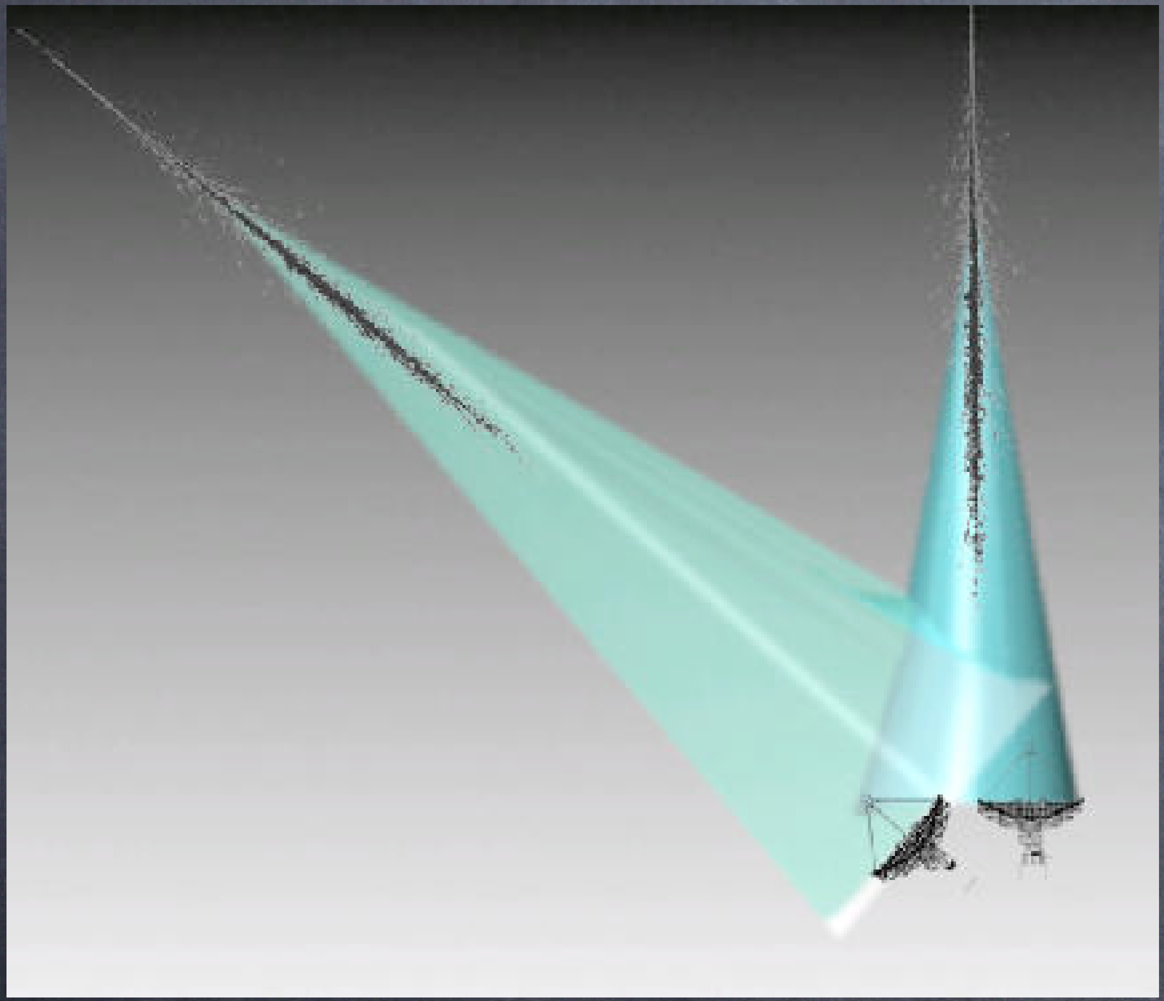


GRBs

I. Blazars

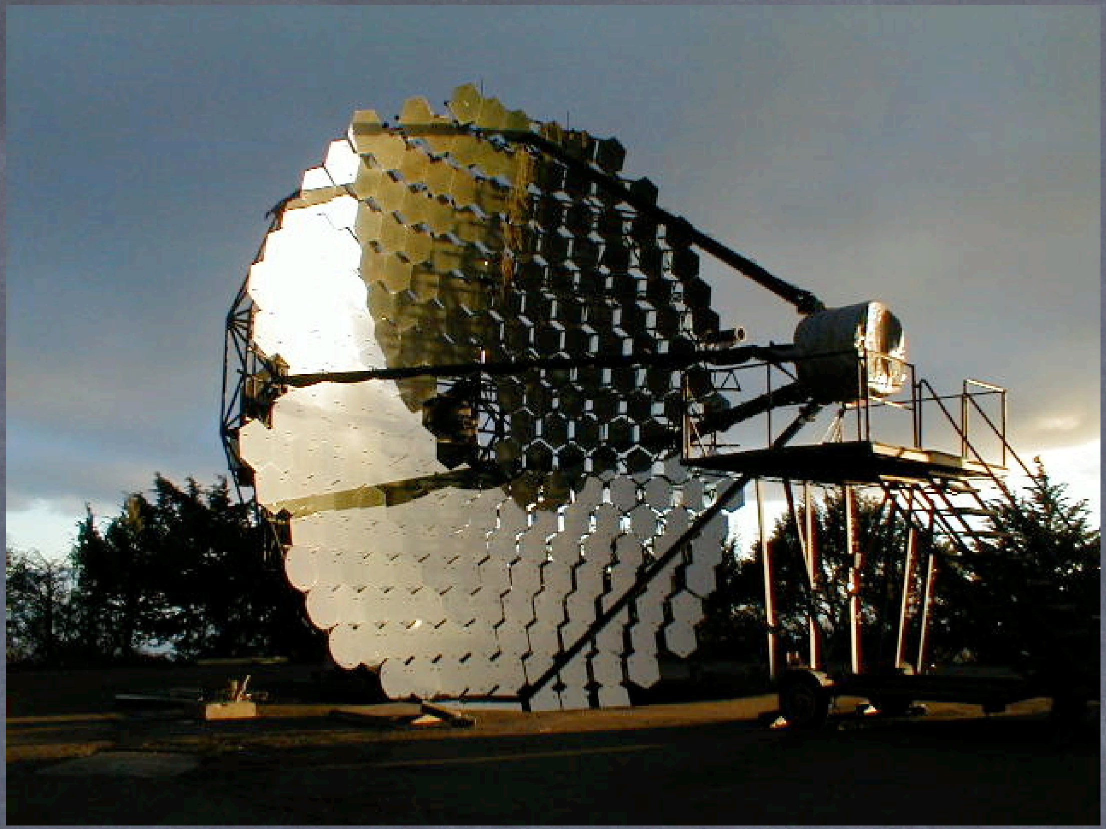
Lessons from Whipple, Expectations for VERITAS

Atm. Cherenkov Tech.

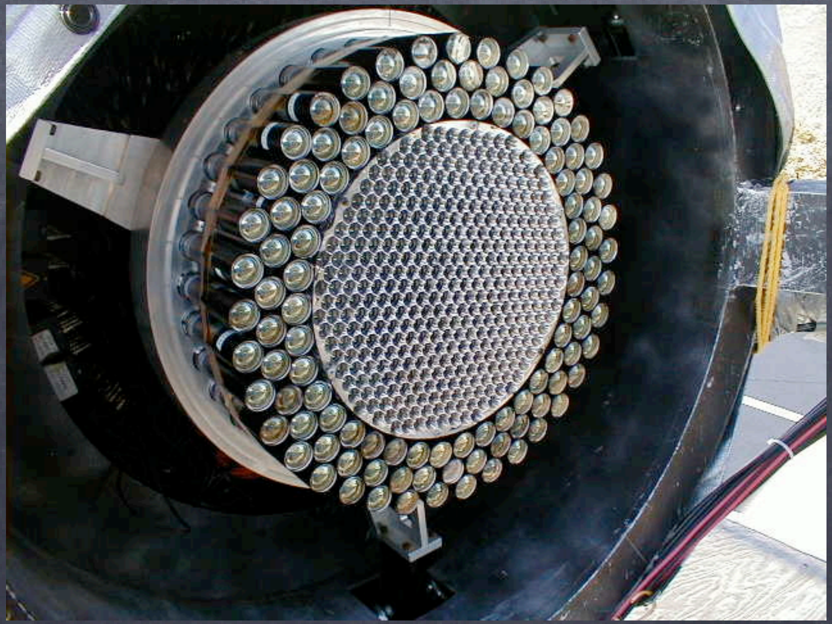


- Gamma-rays interact in atmosphere to give E/M showers
- Cherenkov light pool spreads out over ~10^5 m^2 ogiving a huge effective area compared with space-based gamma-ray experiments or ground-based neutrino experiments
  - Note that Large Zenith Angles -> Larger A_{eff} but higher E_{thr}
- IACT provides excellent sensitivity to short transients

Whipple 10m IACT

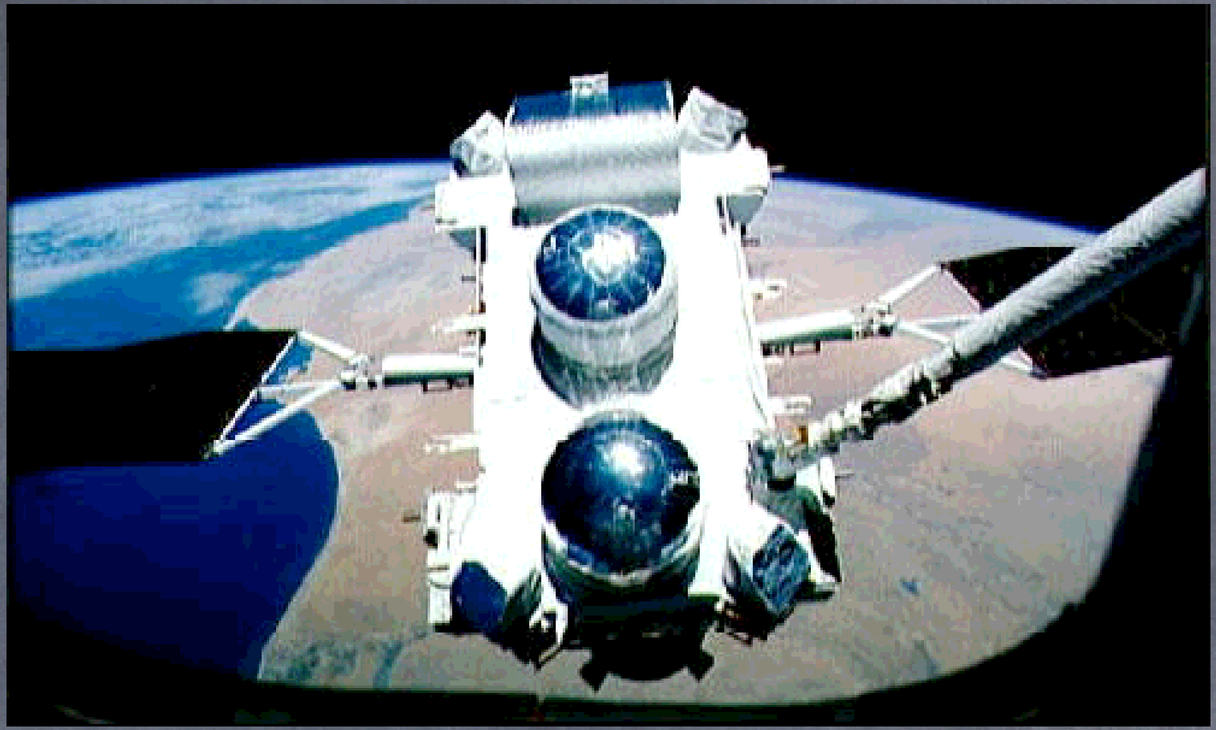


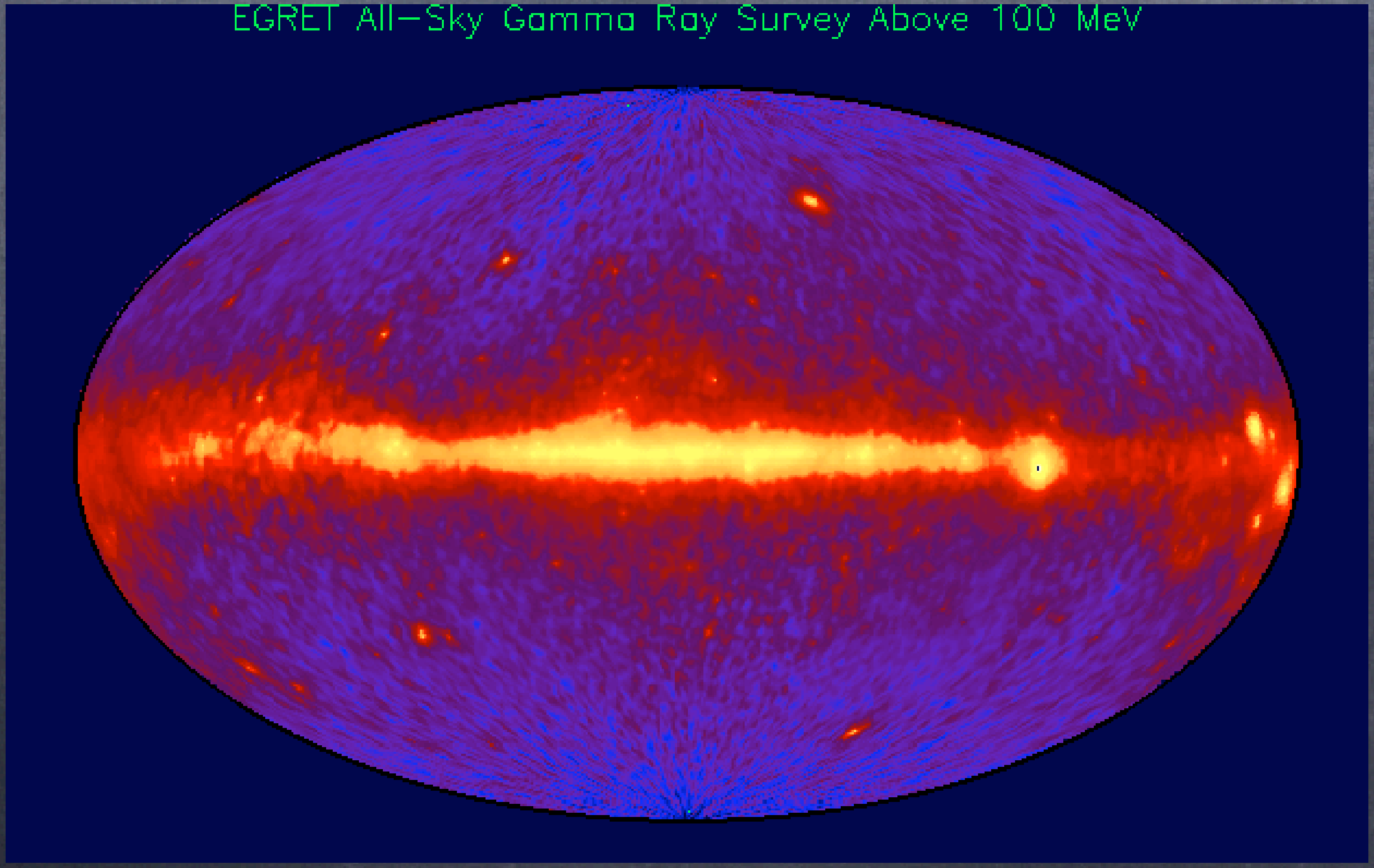
Whipple 10m Reflector



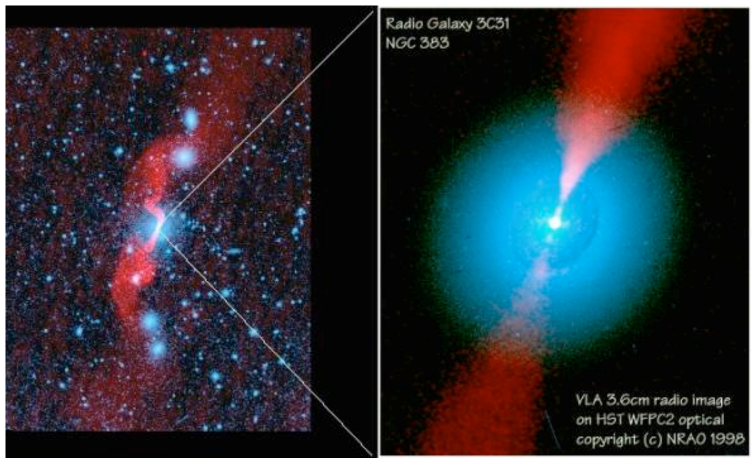
Photomultiplier Tube Camera

High Energy Gammas



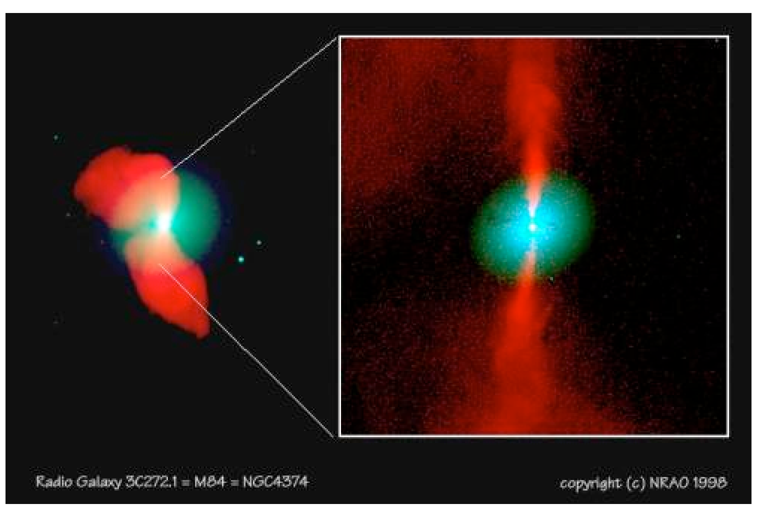


Active Galaxies



3c31 in radio and optical, courtesy of NRAO/AUI

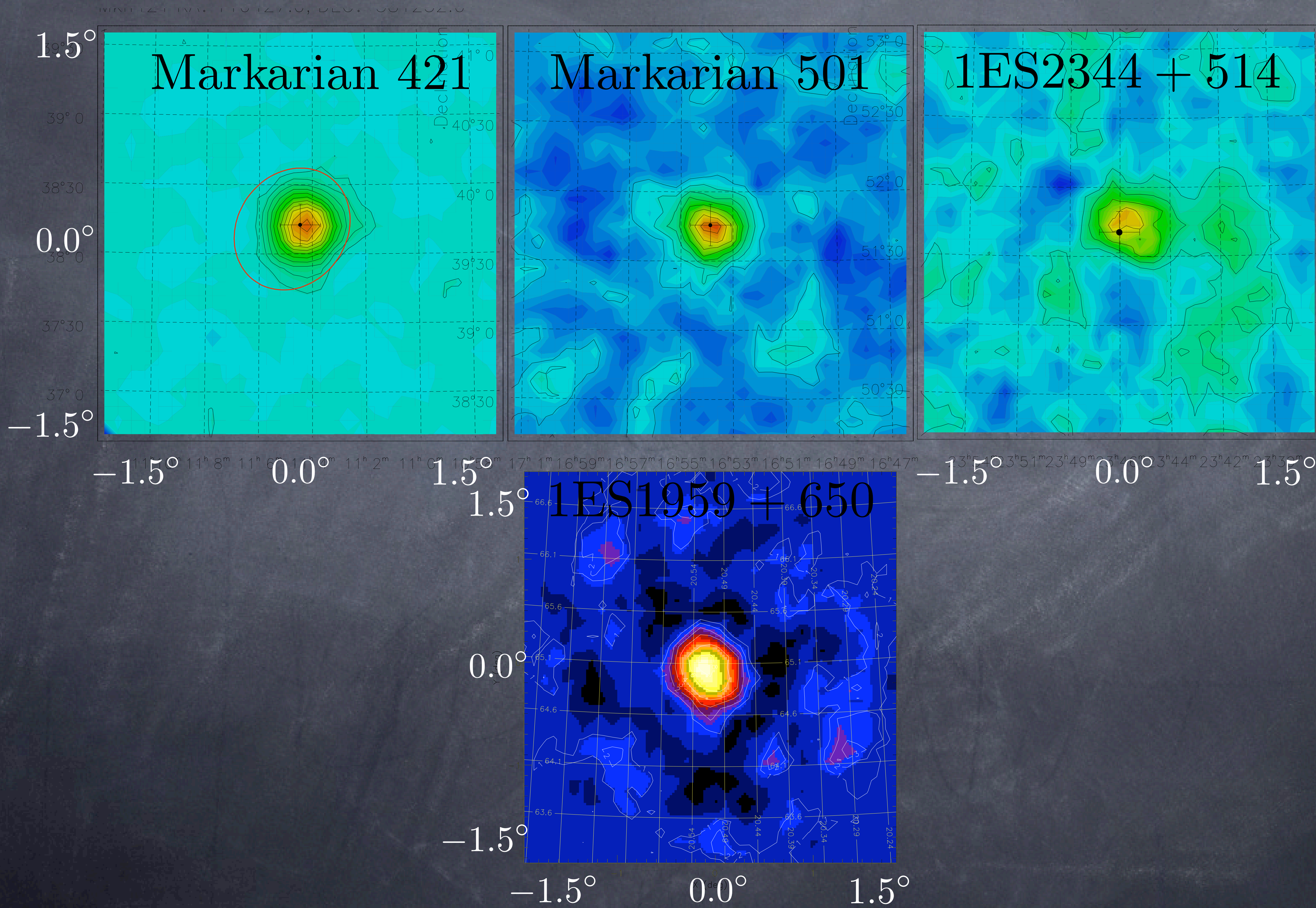
Radio emission comes from relativistic streams of high energy particles generated by the AGN. The well collimated jets have bulk velocities with $\Gamma \rightarrow 10$ eventually balloon into massive radio lobes.



M84 in radio and optical, courtesy of NRAO/AUI

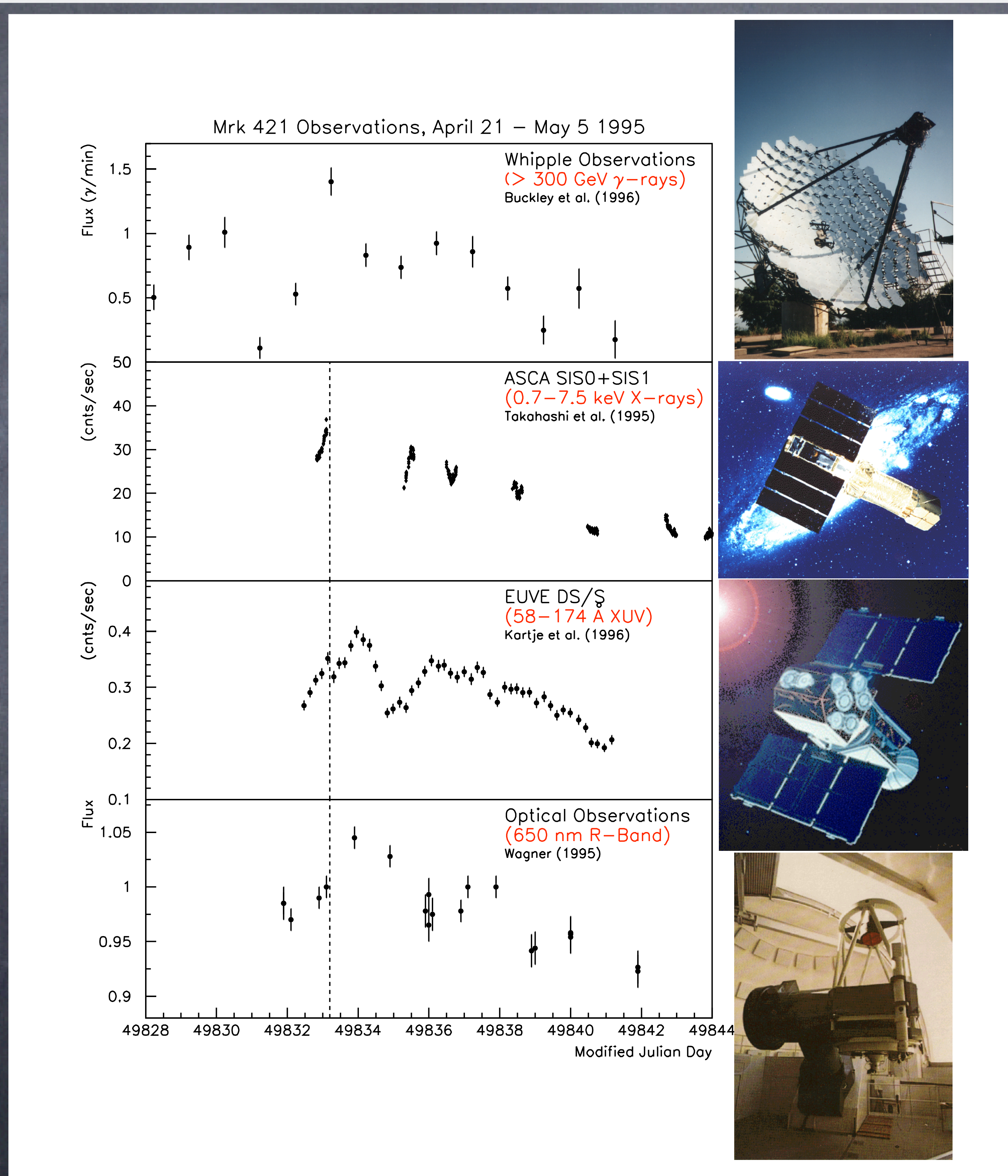
No ordinary galaxies,
Rather Giant Elliptical Galaxies - perhaps 100 times more mass, often at centers of galaxy clusters, likely disrupted by mergers

TeV Blazars

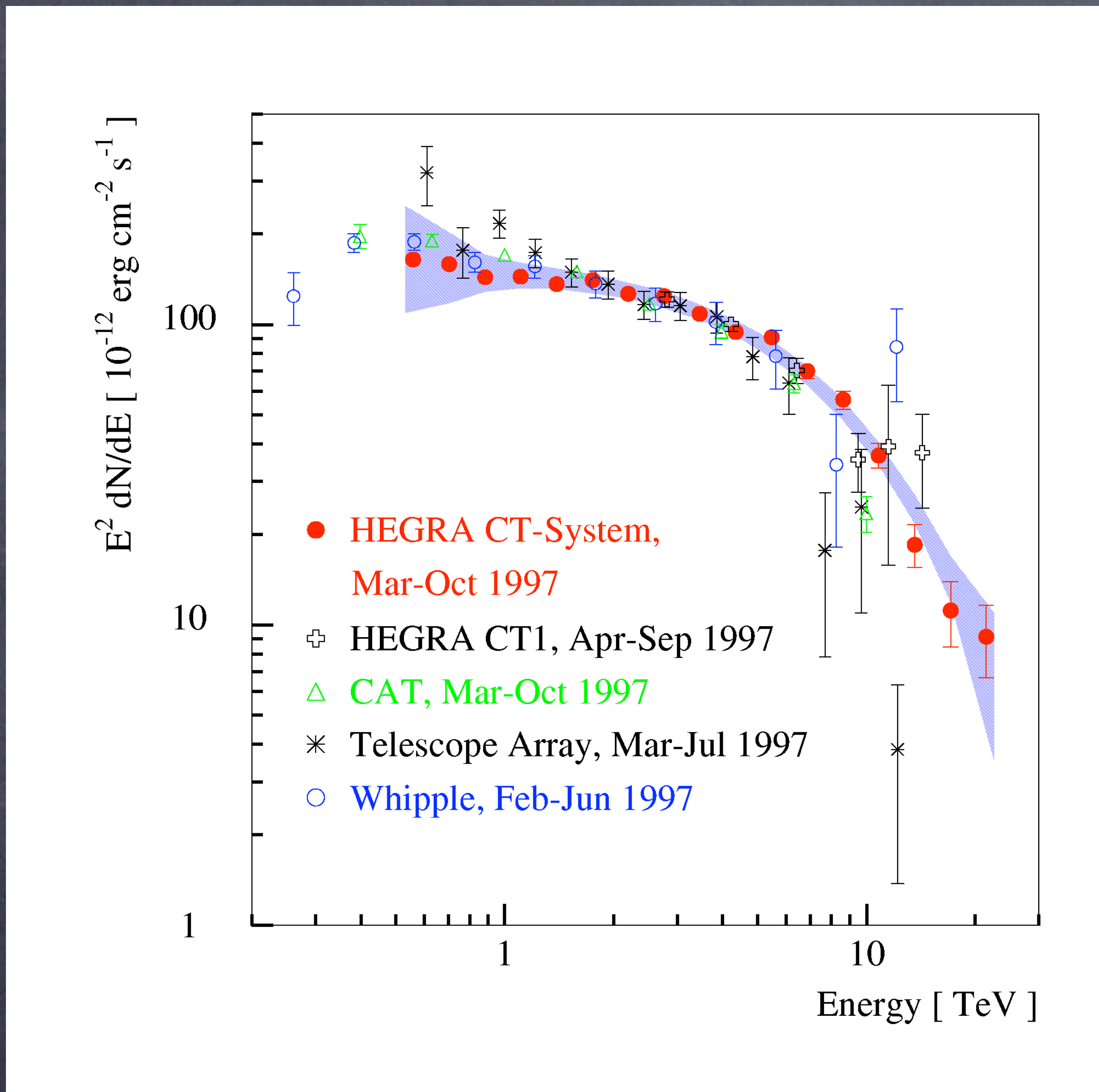


Markarian 421
Markarian 501
1ES2344 + 514
1ES1959 + 650
1.5°
0.0°
−1.5°

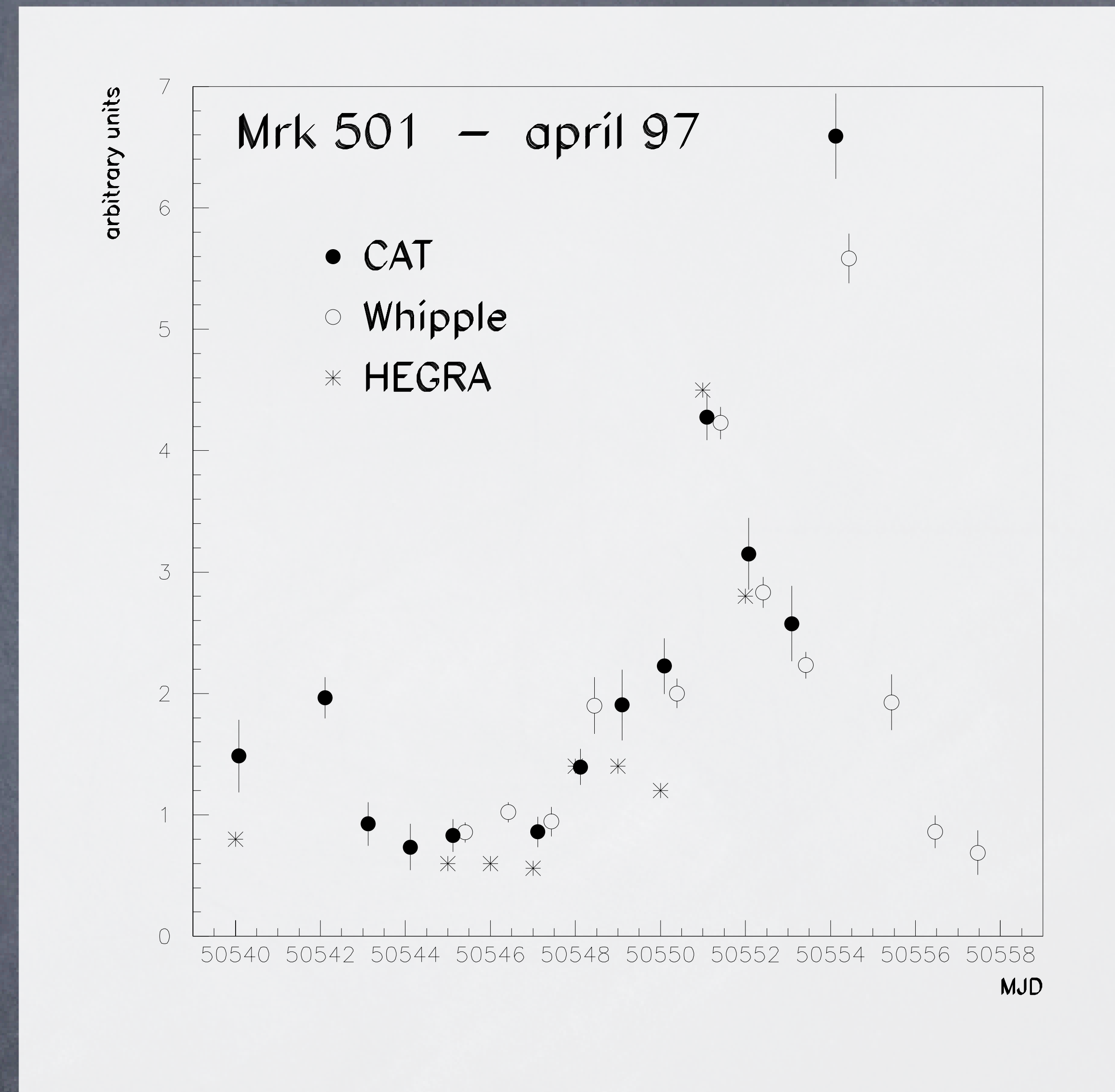
Multiwavelength Obs.



TeV Astronomy Matures



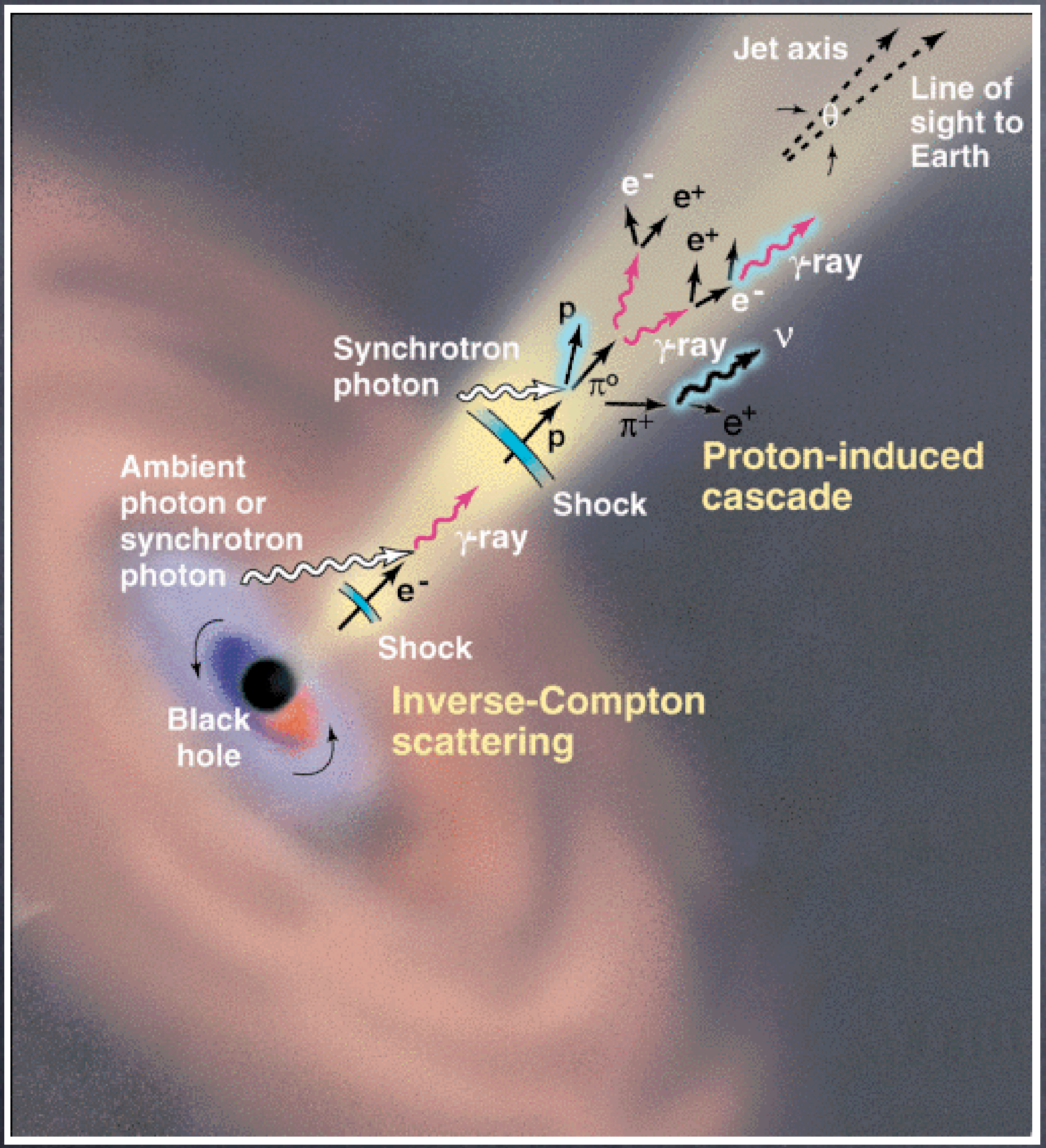
Mrk501 Spectra (Aharonian et al.)



Mrk501 Lightcurve (Fleury)

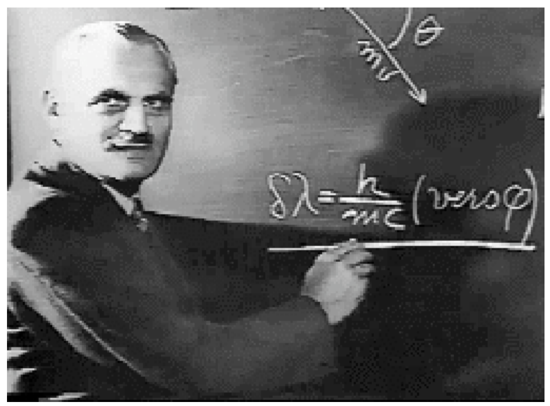
- Excellent agreement between different experiments.

Blazar Emission Mechanisms

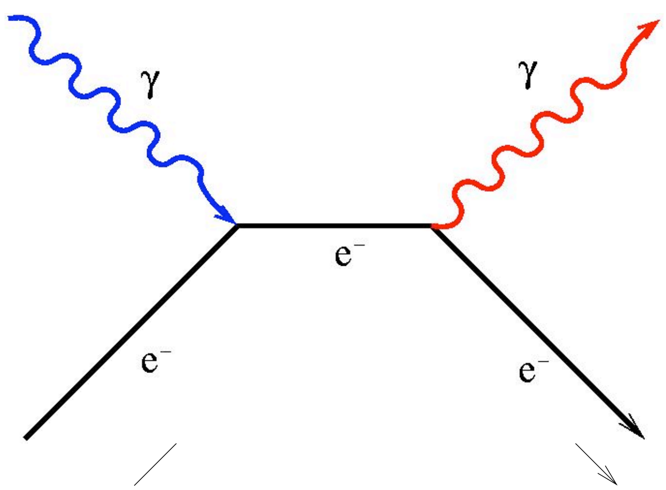


- Current paradigm
  - BL Lacs and OVVs (Blazars) rapid time variability, featureless continuum => relativistic jets seen end-on (e.g., Blandford & Konigl 1979)
  - Synchrotron Self Compton (SSC)
  - External Compton (EC) (e.g., Sikora, Begelman and Rees 1994; Dermer & Schlickeiser 1993)
  - Proton Synchrotron (Aharonian), photopion production (Mannheim)
- Open Questions
  - Energetics of jet
  - Origin of flares
  - Particle acceleration
  - Jet plasma composition
  - Location of emission region and onnection with central engine

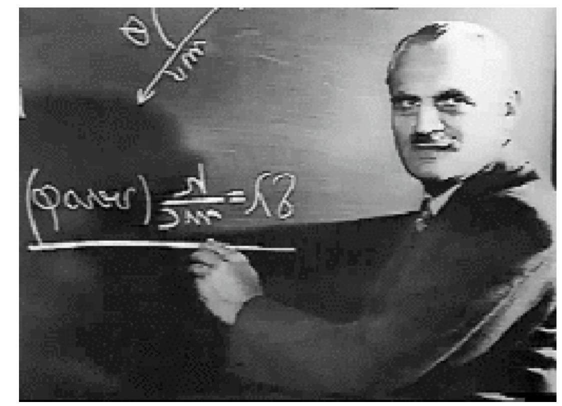
Gamma-ray Production



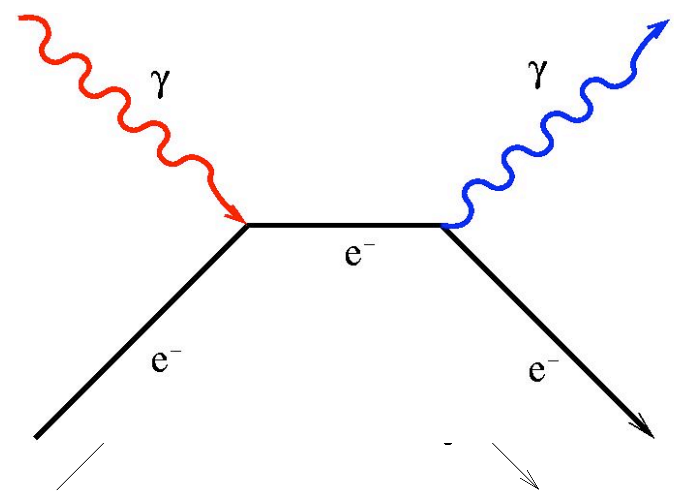
Compton deriving Compton scattering



Feynman diagram for Compton scattering

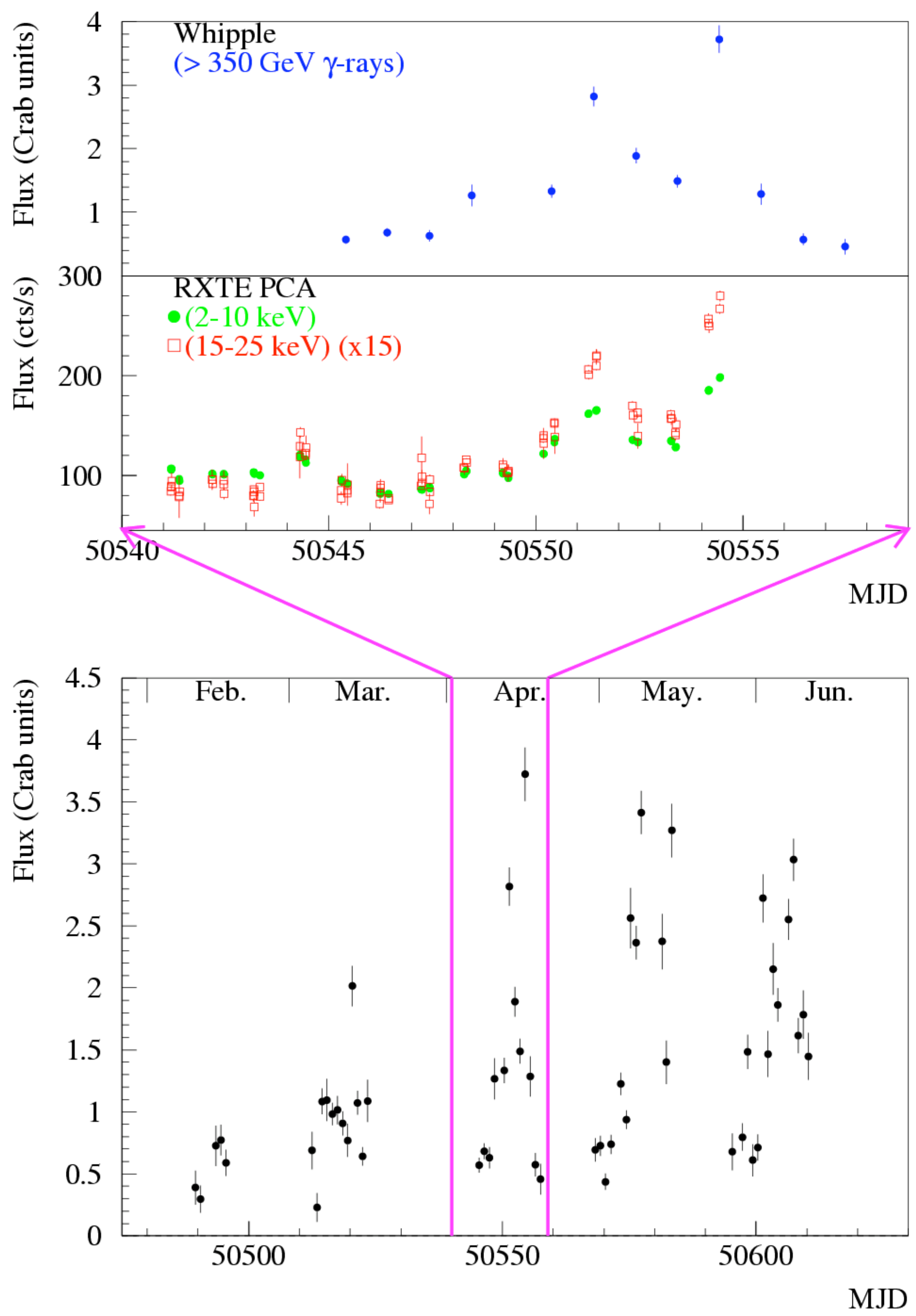


deriving Inverse-Compton scattering

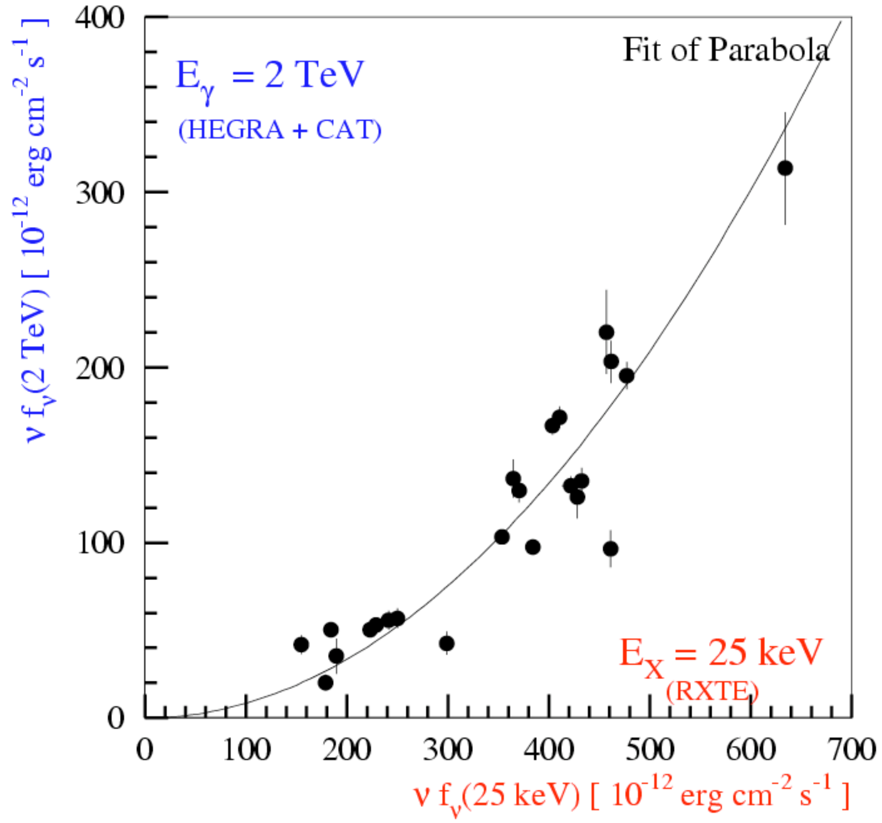


for Inverse-Compton scattering

Correlated Variability



Multiwavelength data adapted from Catanese et al. (1997) show strong evidence for correlated variability in the X-ray and γ-ray wavebands.



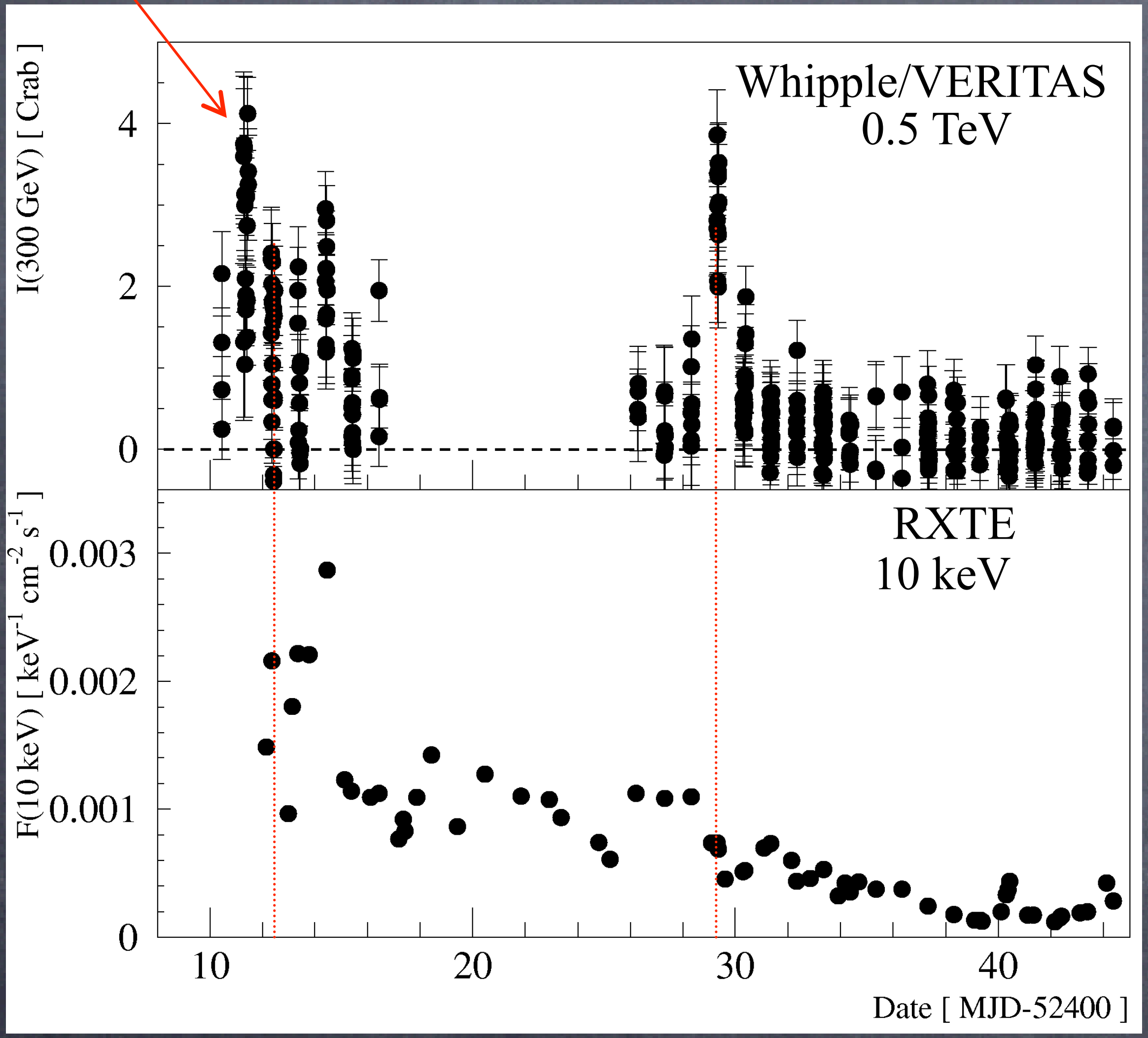
$$L_{\rm sync} \propto n_e,\ L_{ssc} \propto n_e^2$$

- Mrk 501, and sometimes, Mrk 421 show correlated variability in gamma-rays and X-rays - but not always so simple

Orphan Flare?!

1ES 1959+650 In May And June 2002

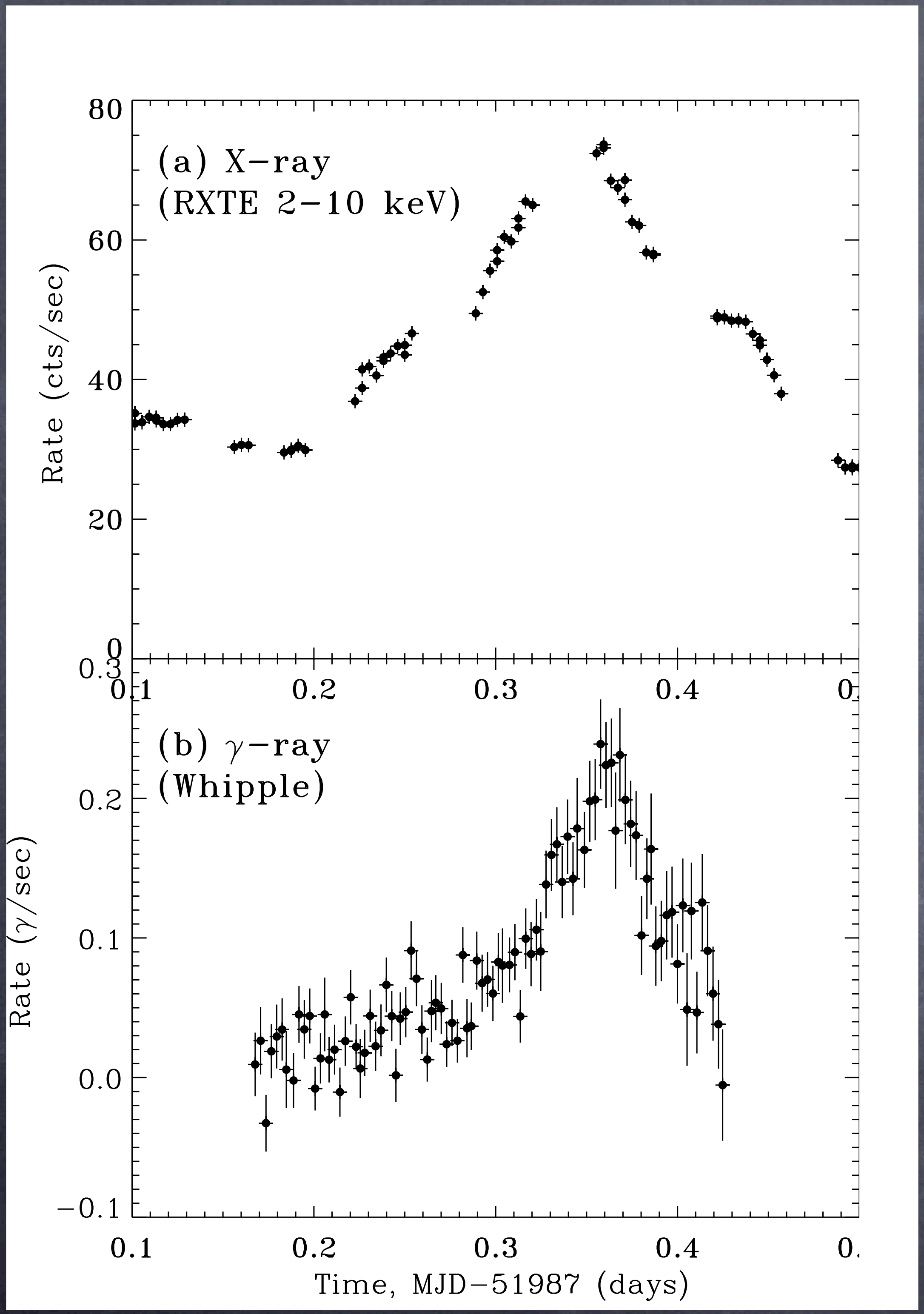
Detection



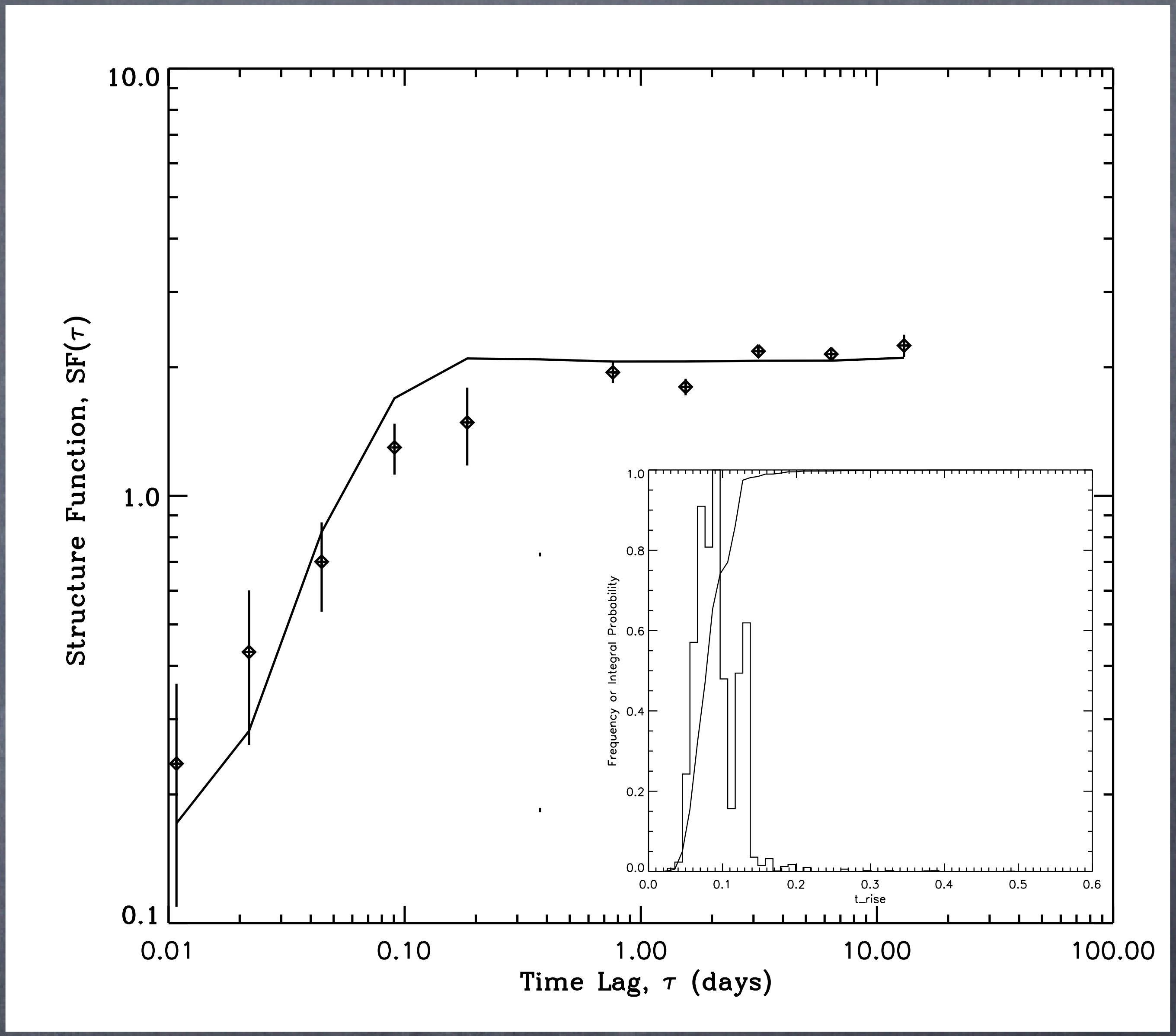
1ES 1959+650 (z=0.048)

- Third Strong TeV Blazar
  - Energy Spectra Up To 10 TeV
  - Flux Variability ~min
- Slower Than Mrk 421:
  t_{dble} > 12 hrs
- TeV Flares Without
  X-Ray Counterpart

AGN Variability



Buckley et al., 2005

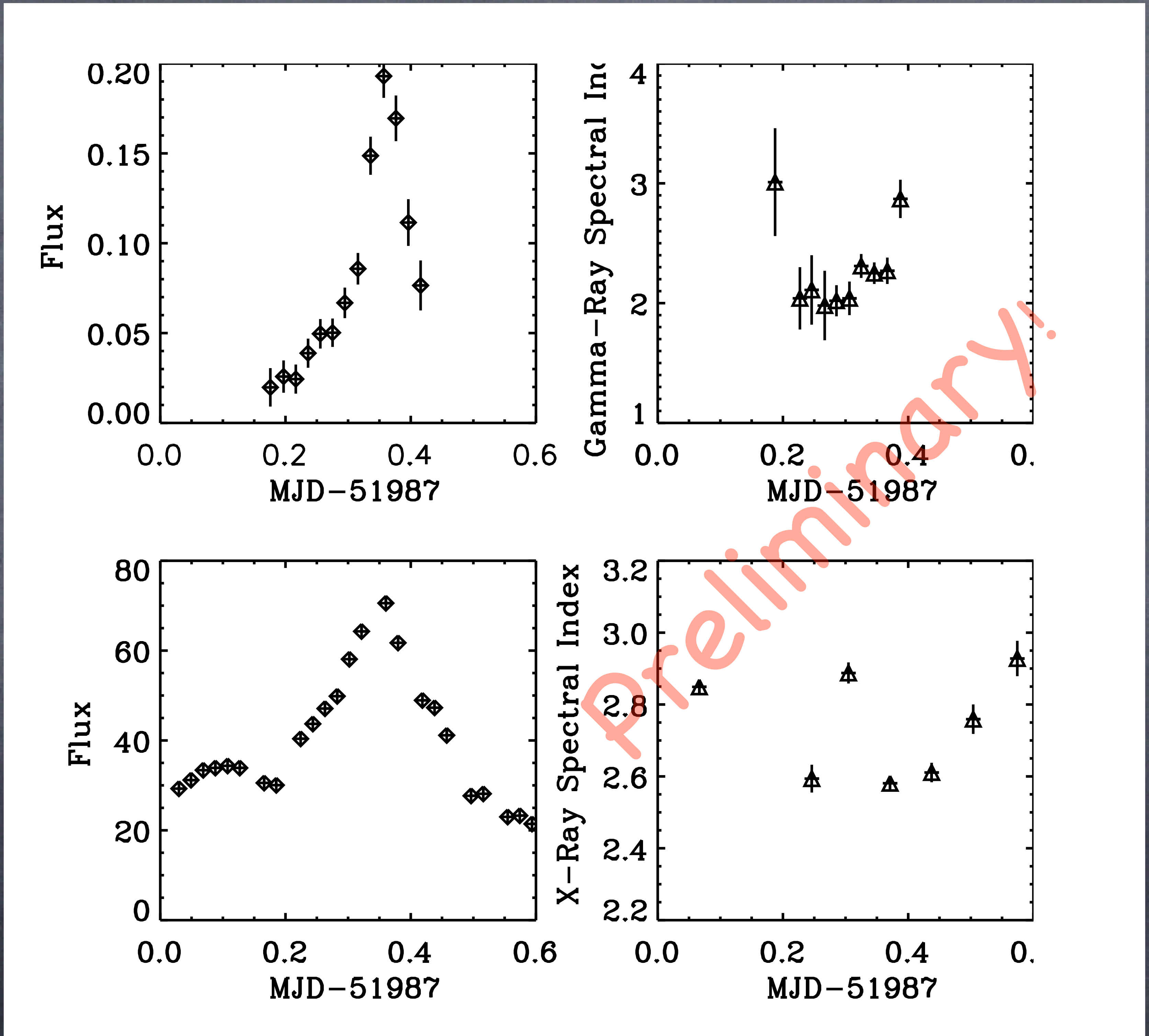


$$t_{\gamma,\text{rise}} = 1.9 + 0.84, -0.58 \text{ hr}$$

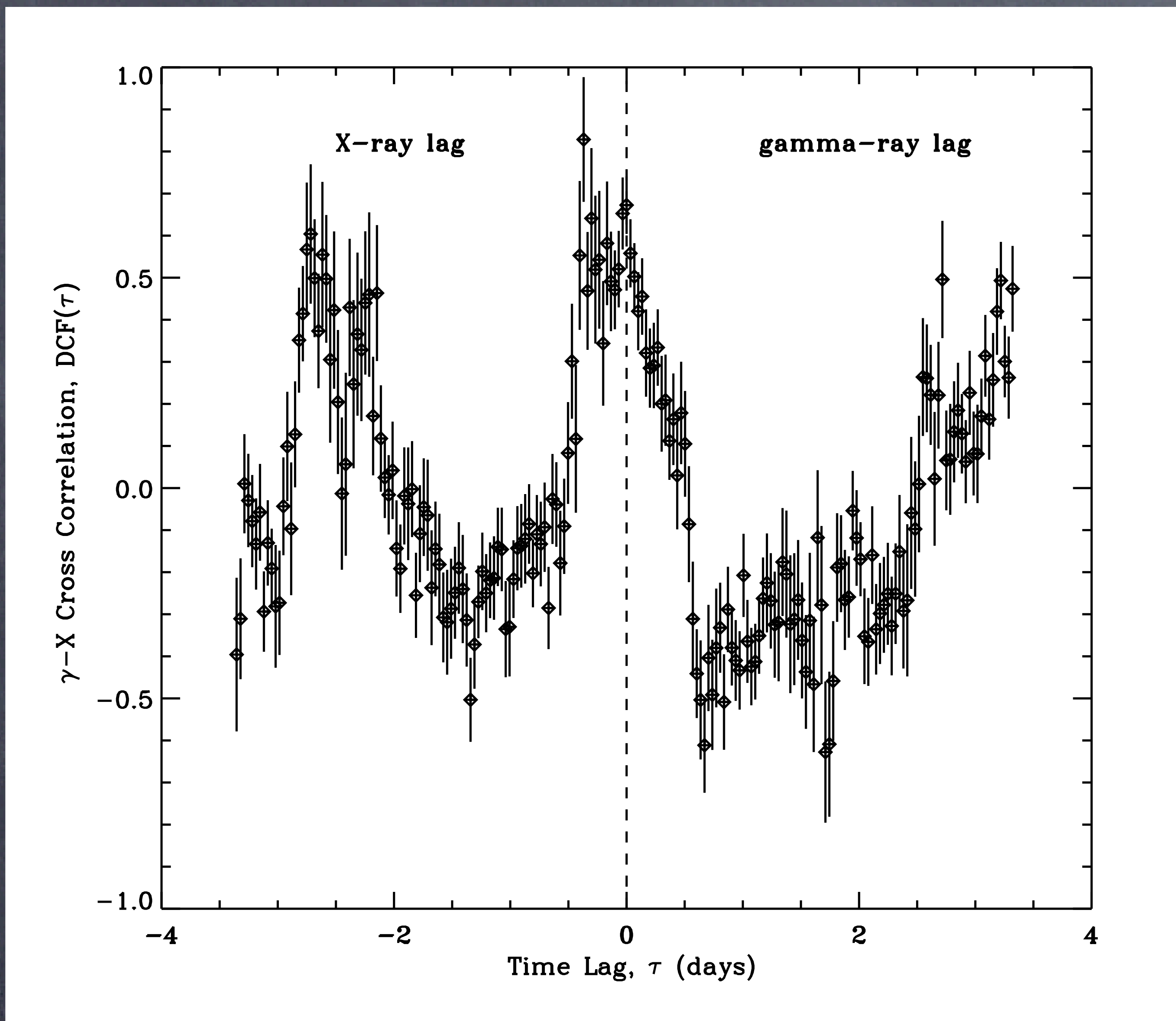
$$t_{x,\text{rise}} = 4.8 + 0.58, -0.72 \text{ hr}$$

Duty cycle approximately 10 flares/day

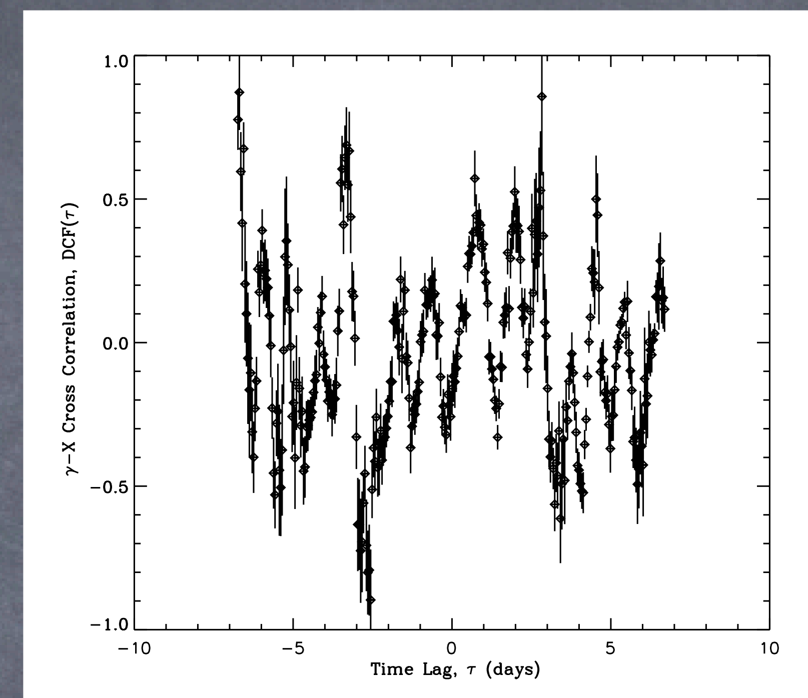
Mrk421 Spectral Variability

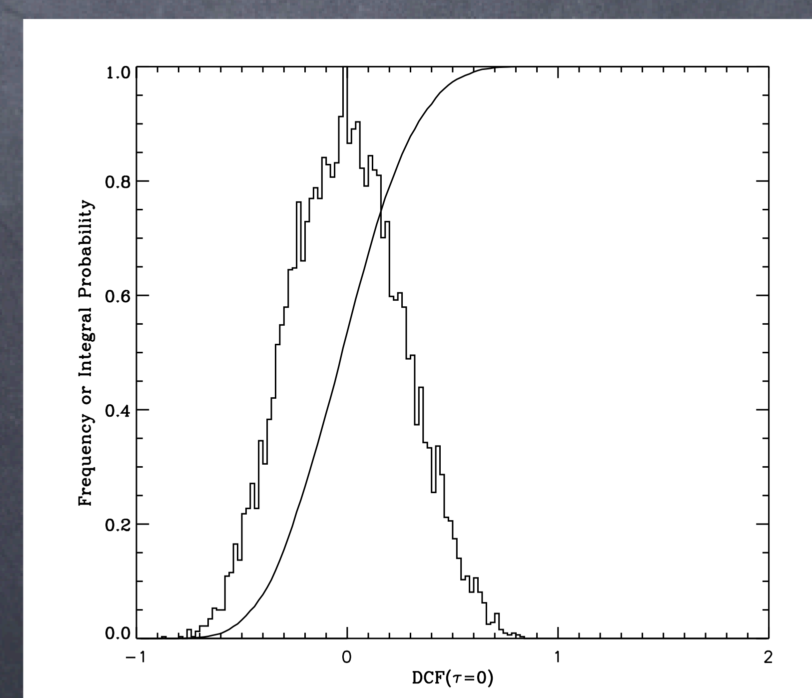


Correlation



Simulate X-ray lightcurves with same windowing, errors, and structure function (symmetric shots), calculate DCF...

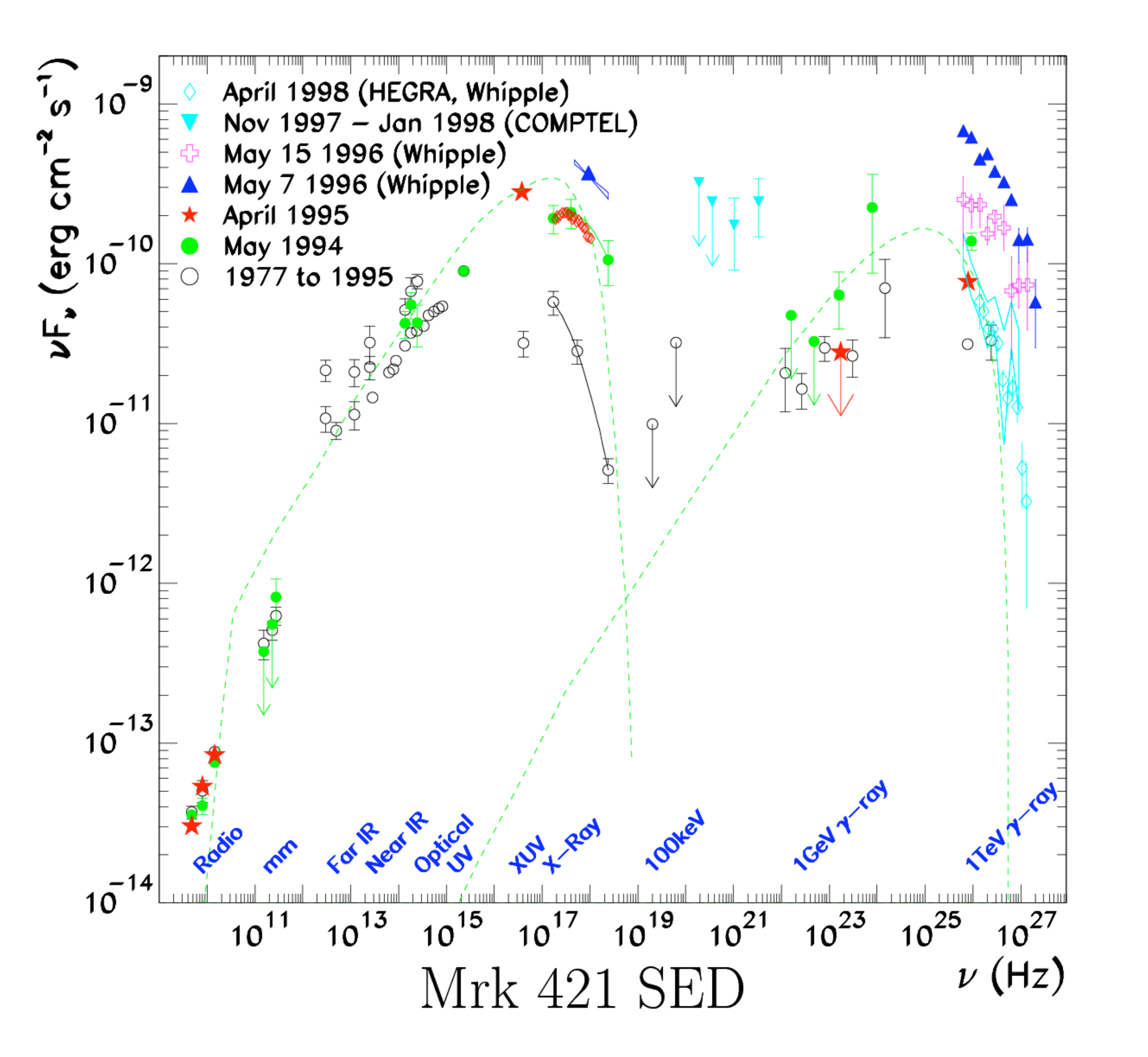




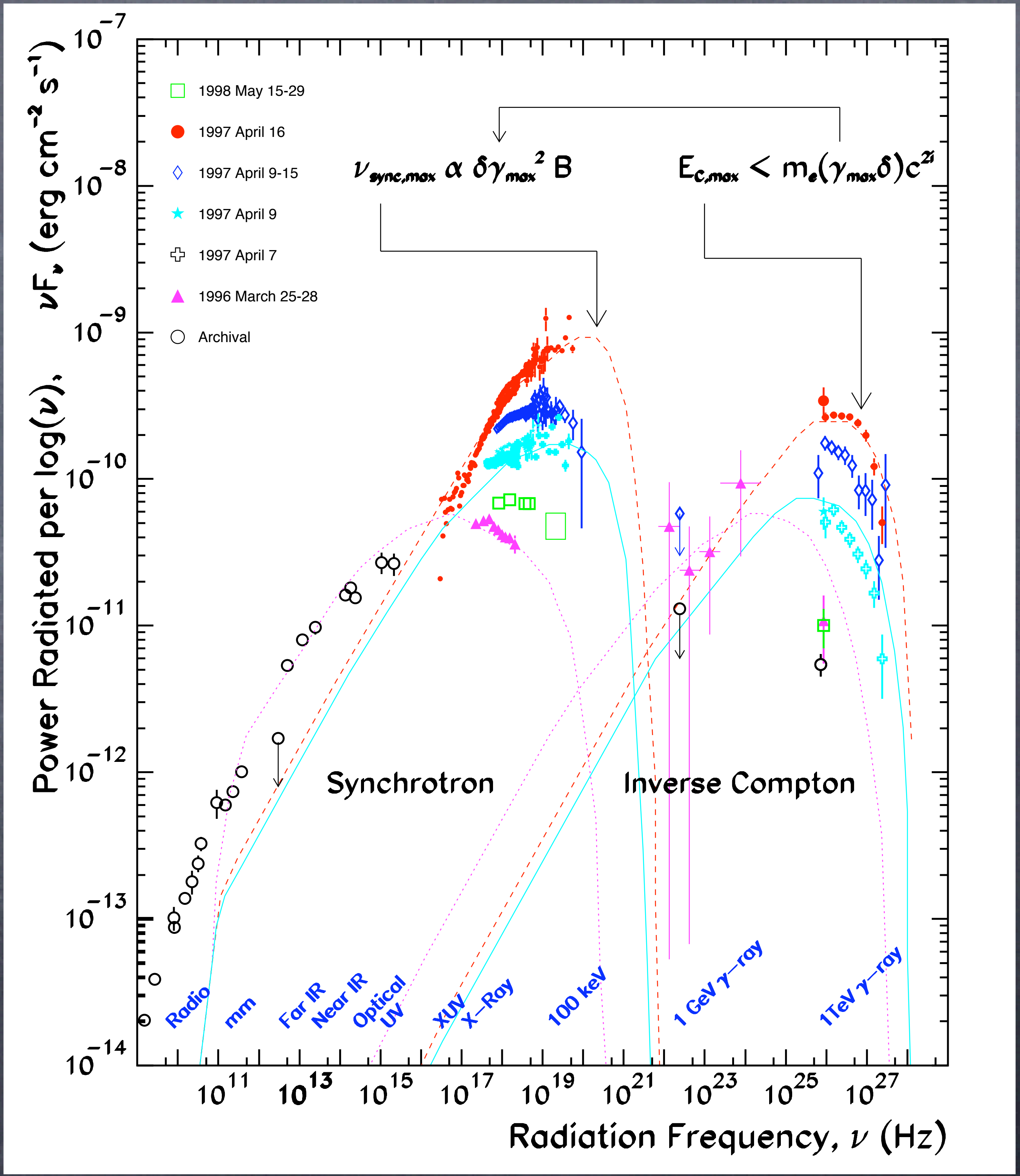
The Monte-Carlo calculated probability for a chance correlation is finite, 0.89%

Multiwavelength Spectra

Mrk 421 Multiwavelength Spectrum

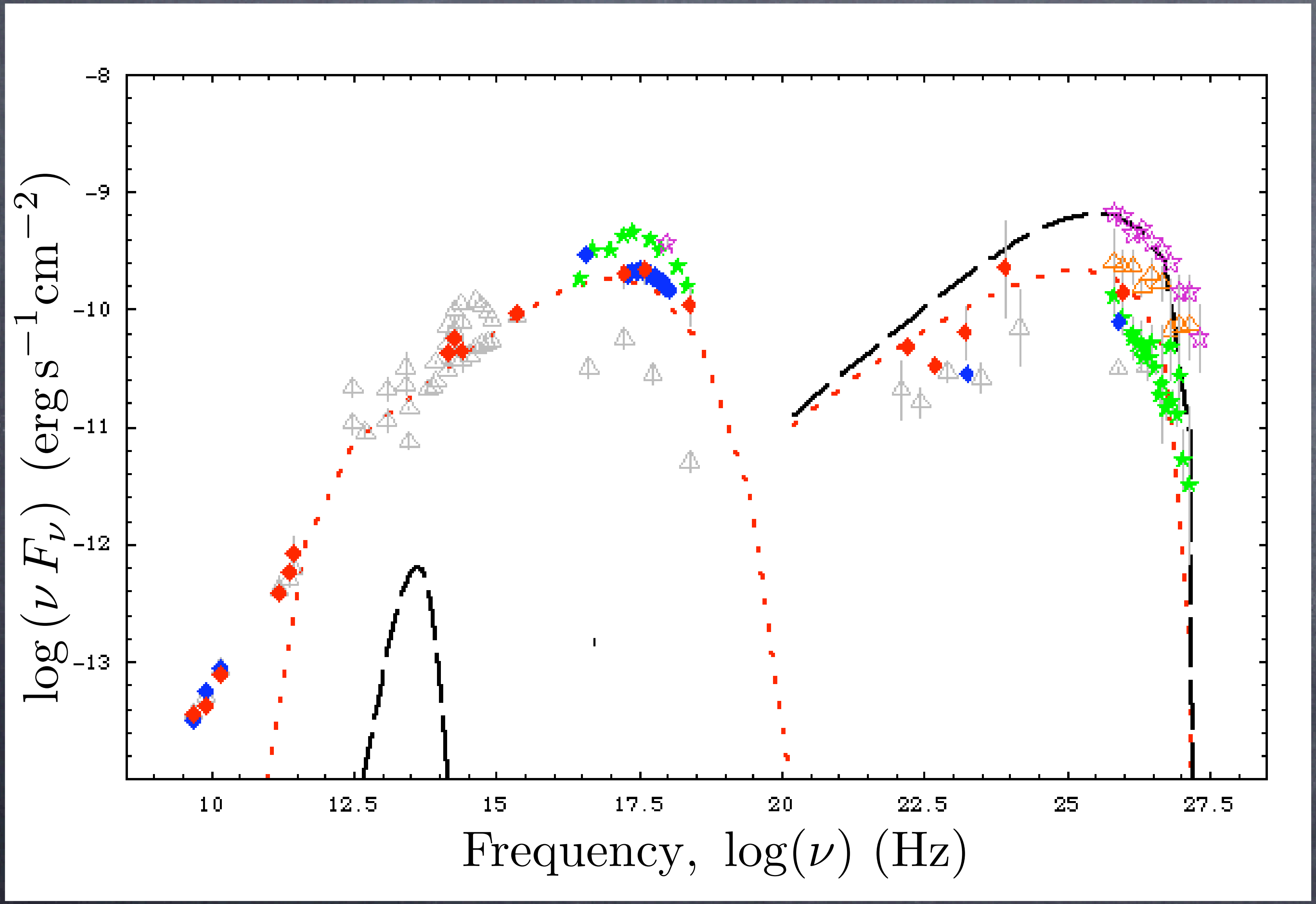


Mrk 501 Multiwavelength Spectrum



Detailed Spectral Fits

- Self-consistent model of particle accel., synchrotron, SSC, EIC (e.g., Inoue and Takahara, me, lots of other people...)



$B = 0.08\,\mathrm{G}$

$\delta_{\rm jet} = 100$

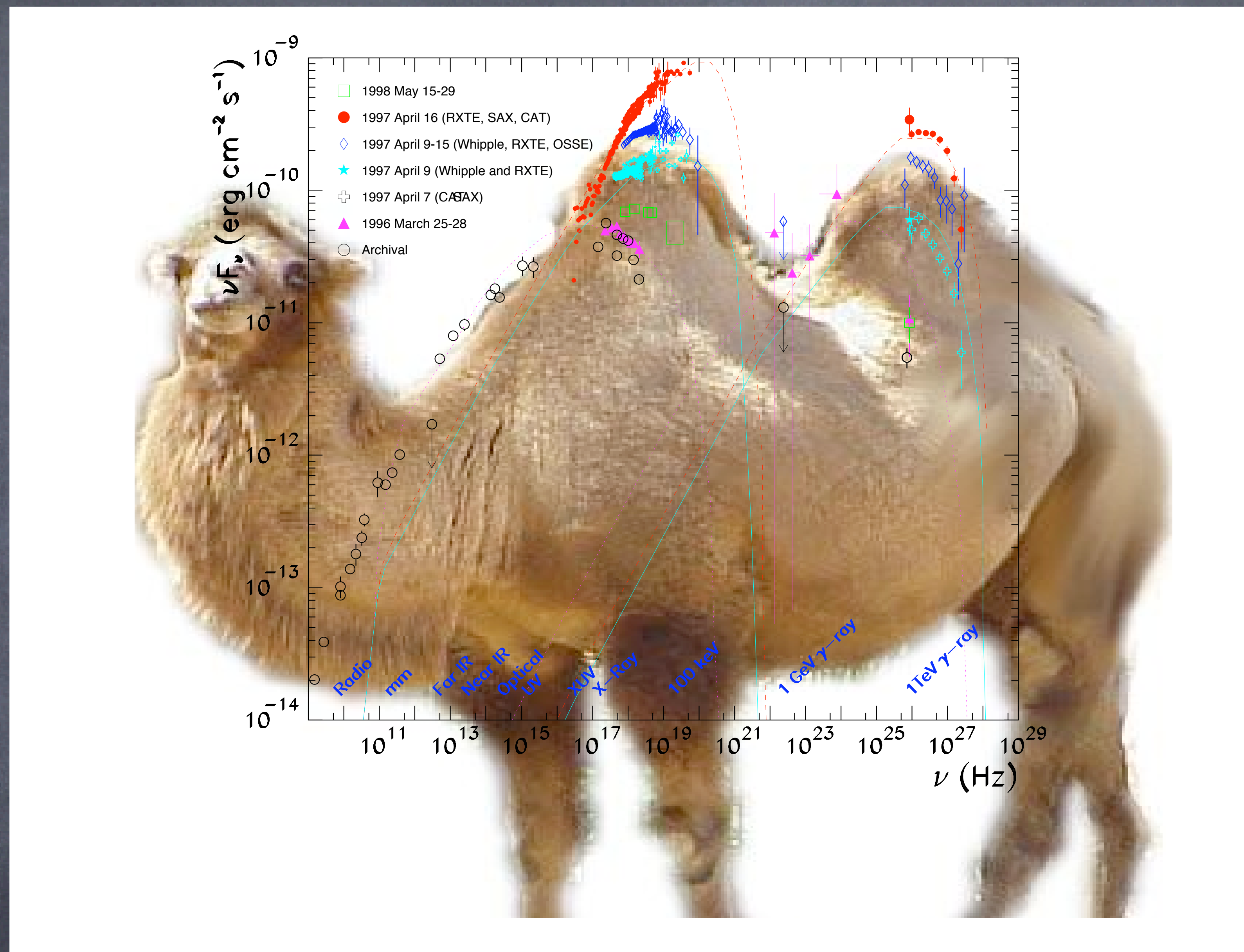
$R = 4.4 \times 10^{14}\mathrm{cm} = 30\,R_S$

$\gamma_{\rm max} = 1.2 \times 10^5$

$\tau_{\rm cool} = 4.9\mathrm{min}$

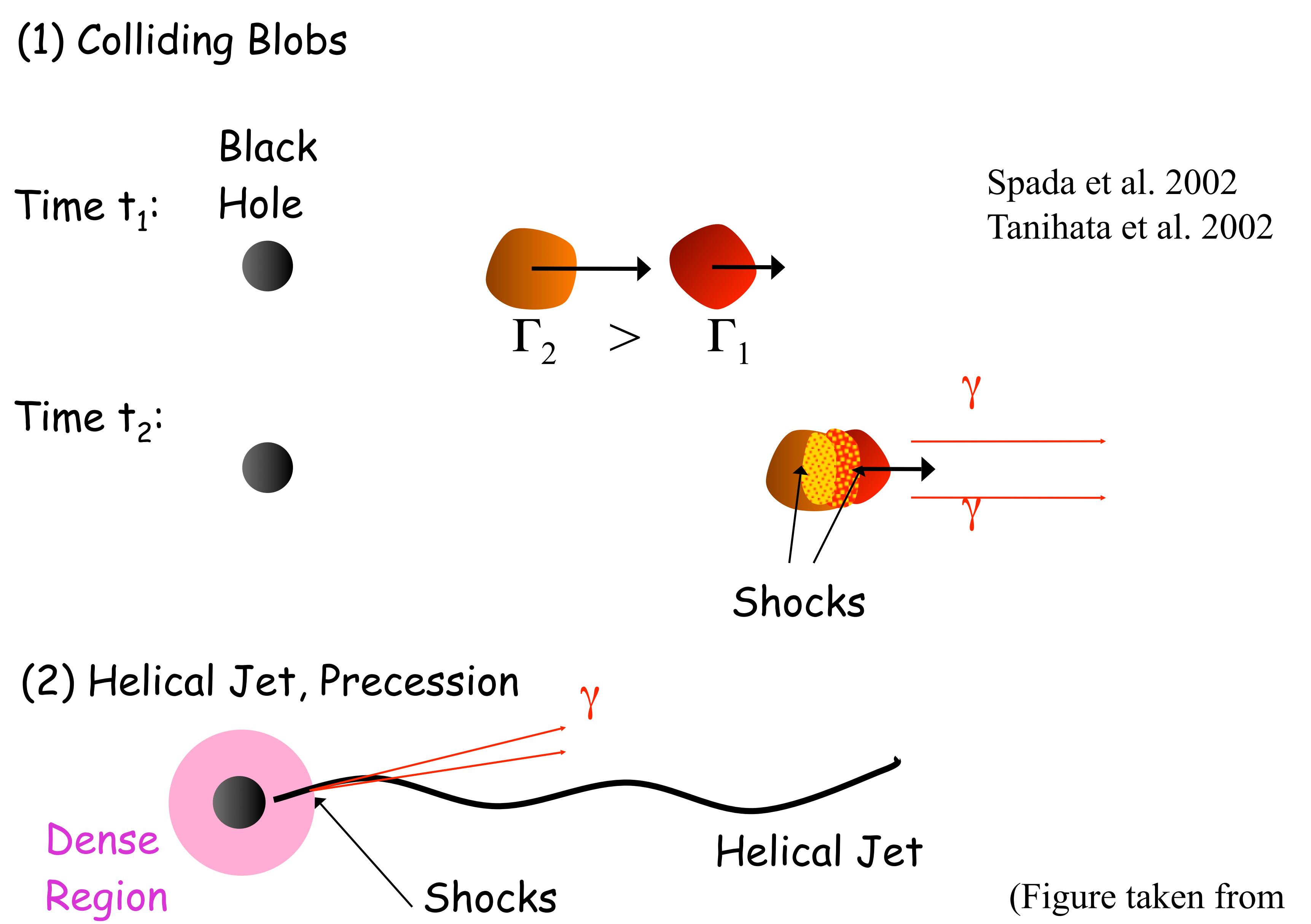
$\tau_{\rm light\ crossing} = 2.5\mathrm{min}$

Free Parameters



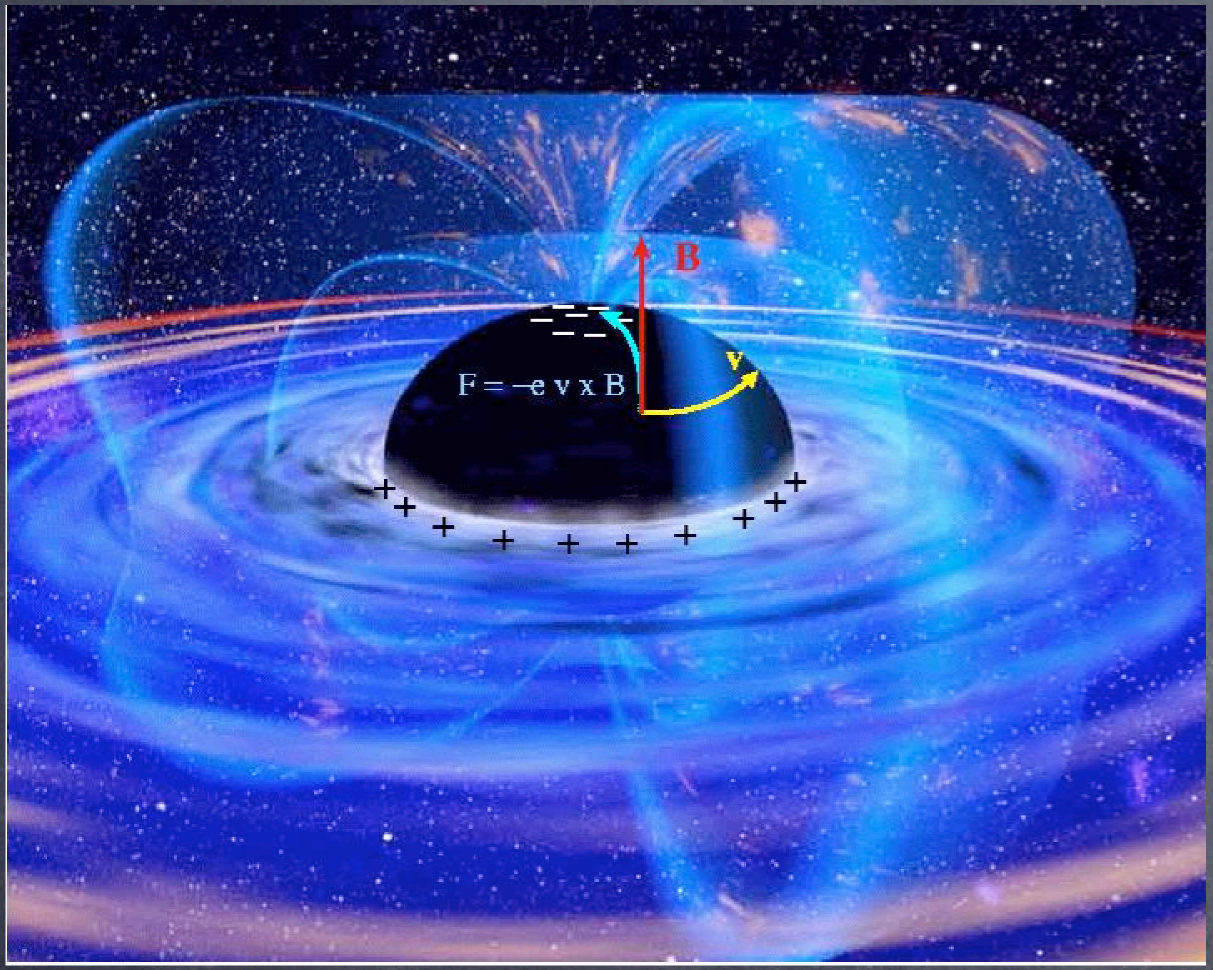
- Bactrian camel gives good fit, Dromedary excluded at the 99.5% confidence level

Origin of Flares?



(Figure taken from Krawczynski 2004)

Central Engine



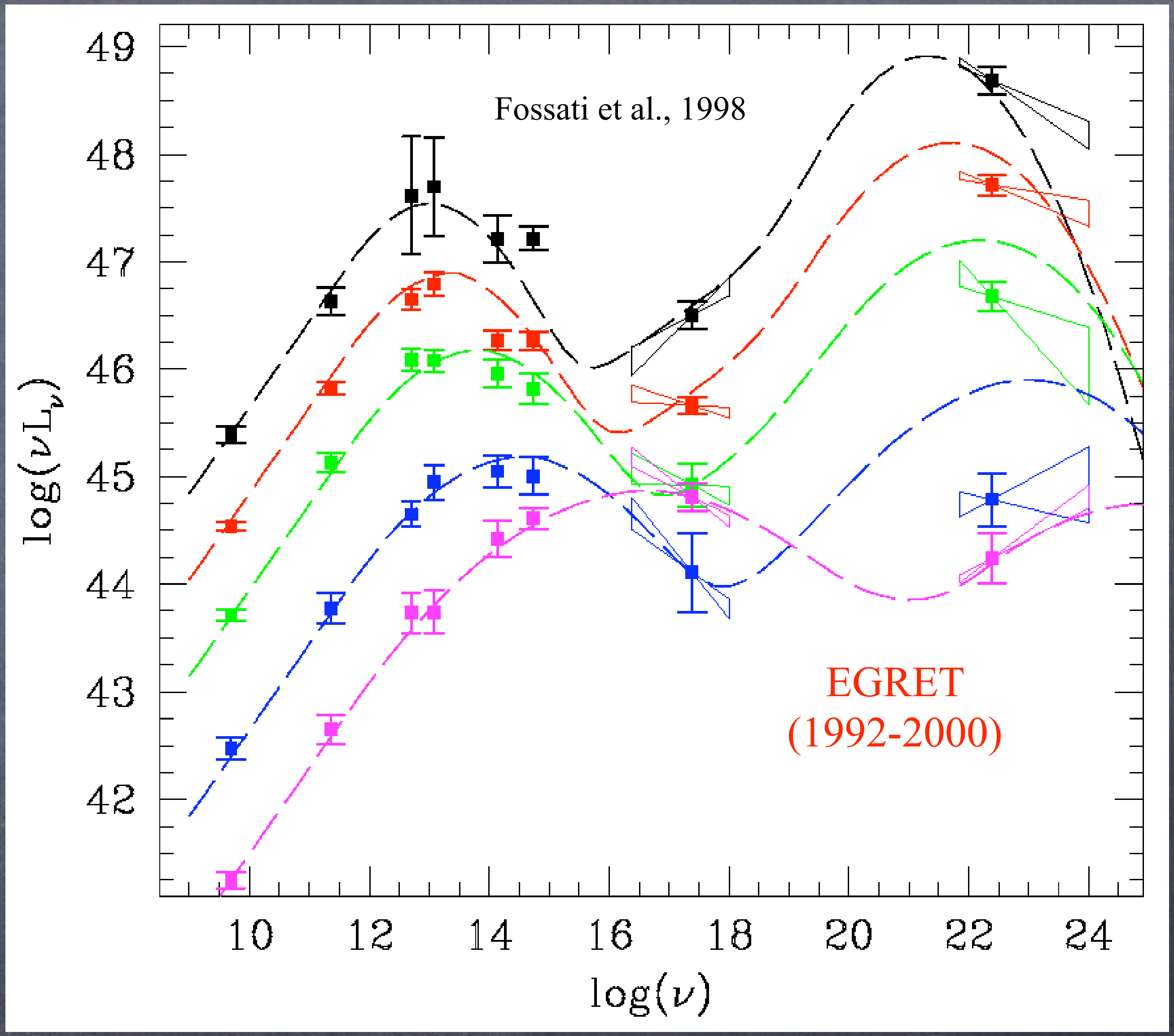
- Would like more than phenomenology of radiative processes, probe the central engine
  - Can multiwavelength observations map the inner jet and disk? (e.g., reverberation mapping as proposed by Bottcher and Dermer)?
  - Can VHE g-rays probe strong gravity?
  - Fundamental mechanism (e.g., Blandford and Lovelace, Blandford & Zjanek)
  - Are properties correlated with black hole mass

II. Blazars

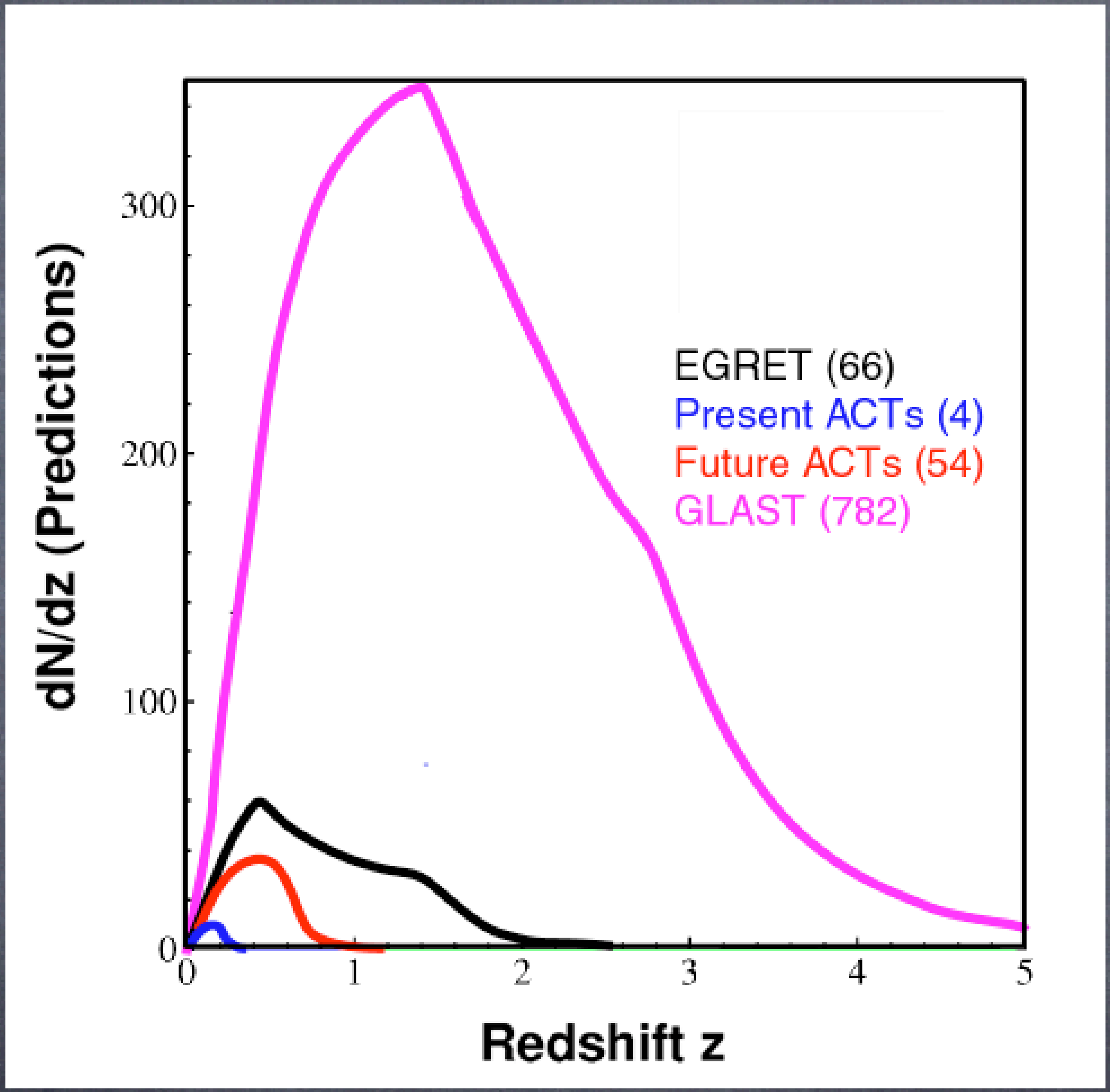
Expectations for VERITAS

AGN Unification

- Most useful classification: LBLs (sync. peaks at low energies) HBLs (sync. peaks at high energies, accretion luminosity is organizing parameter (Padovani & Giommi 1995; Fossati & Ghisellini 1998, 1999)
- 3 objects, Mrk 501, 1ES2344+514 and H1426+428 have X-rays that extend to 100 keV (BeppoSAX observations: Pian et al. 1998; Giommi, Padovani & Perlman 2000; Costamante et al. 2000, 2001)
- Costamante et al. *predicted* H1426+428 as a TeV emitter



AGN Detections



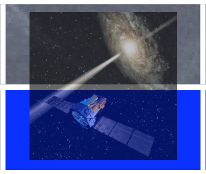
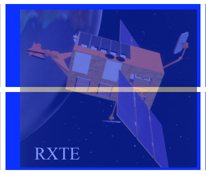
- VERITAS, HESS, MAGIC and CANGAROO could collectively detect about 50 AGNs

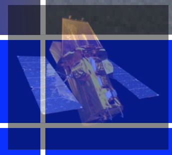
VERITAS Target List?

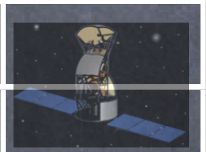
Mrk 421	HBL	
Mrk 501	VHBL	
1ES1959+650	HBL	
PKS2155-304	HBL	LZA with HESS
H1426+428	VHBL	
BL Lac	XBL	with optical
3C273	RBL	GLAST overlap
W-Comae	XBL	GLAST overlap
Mrk 180	XBL	z=0.046
1ES0033+595	XBL	z=0.086
RGB J0214+517	XBL	z=0.049
1ES 0229+200	XBL	z=0.139
1ES 0323+02.2	XBL	z=0.147
1ES 0806+524	XBL	z=0.138
J111706.2+201407	XBL	z=0.139
BWE 1133+6753	XBL	z=0.135
BL 1722+119	XBL	z=0.018
1ES 1727+50.2	XBL	z=0.055
1ES 1741+196	XBL	z=0.084
1ES 2200+420	XBL	z=0.069

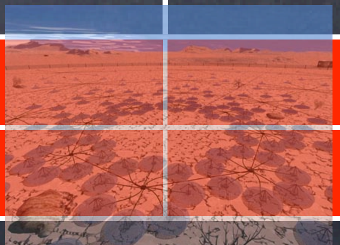
Instrument Timelines

Waveband	Instrument	2004	2005	2006	2007	2008	2009	2010	2011	2012
0.1-20 TeV	VERITAS									
0.1-40 GeV	GLAST									
1-100 MeV	ACT?									
10-300 keV	EXIST?									
5-600 keV	Integral									
keV	RXTE ASM									
2-10 keV	RXTE PCA									
0.3-150 keV	SWIFT	11/04?								
0.2-10 keV	XMM									
keV	ASTRO-E2		2/05?							
0.3-80keV	ASTROSTAT				6/07?					
100-300nm	ASTROSTAT				6/07?					
UV-Vis	SWIFT UVOT	11/04?								
UVBRIJK	Optical									
FIR	Spitzer									
mm	Alma???									
mm	SMT???									
GHz	VLA/VLBA									
30-240MHz	LOFAR									

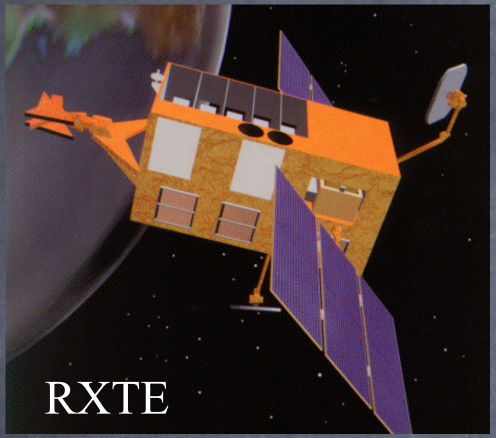




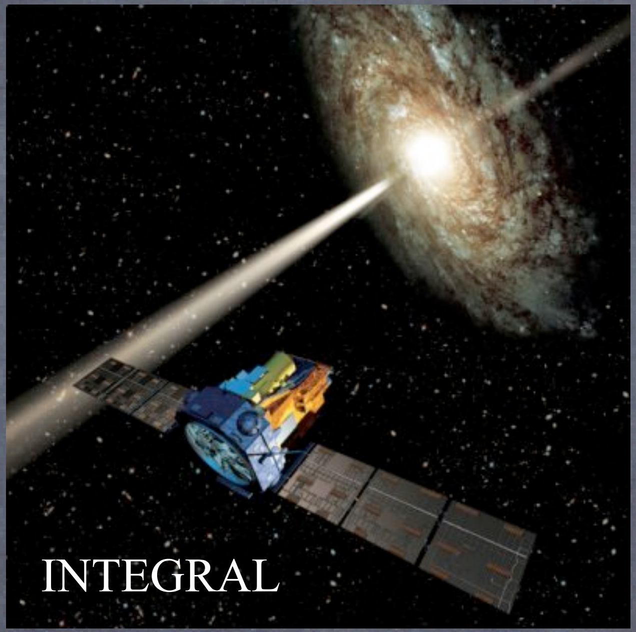


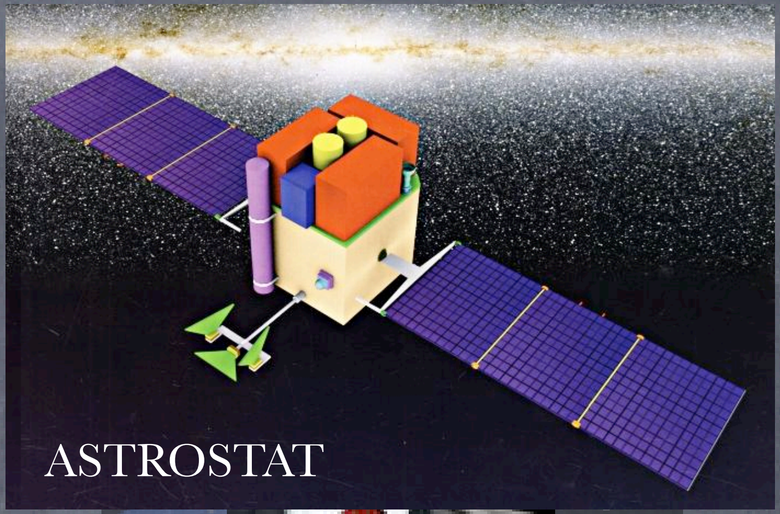



X-Ray Instruments

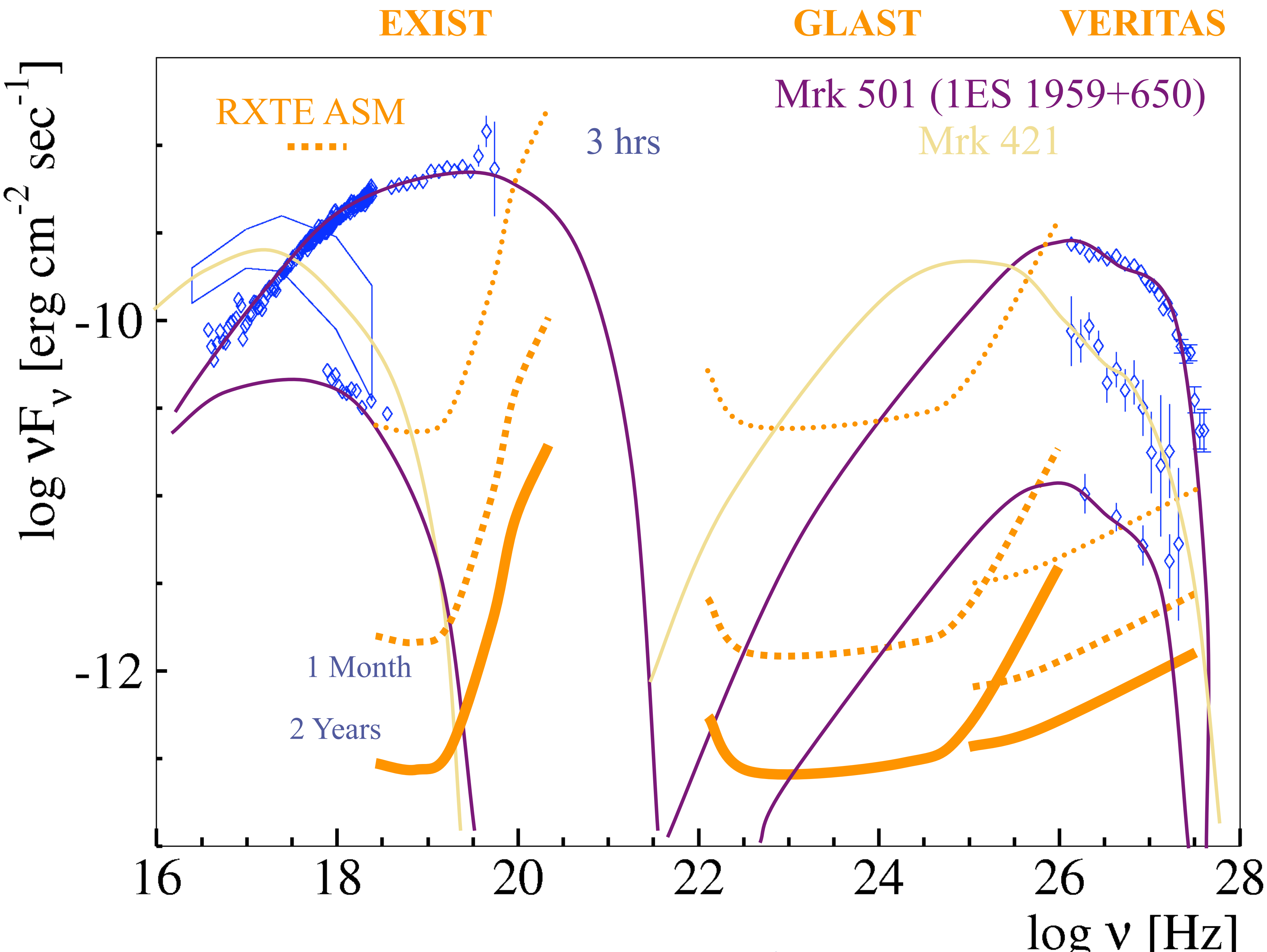






Outsourcing?

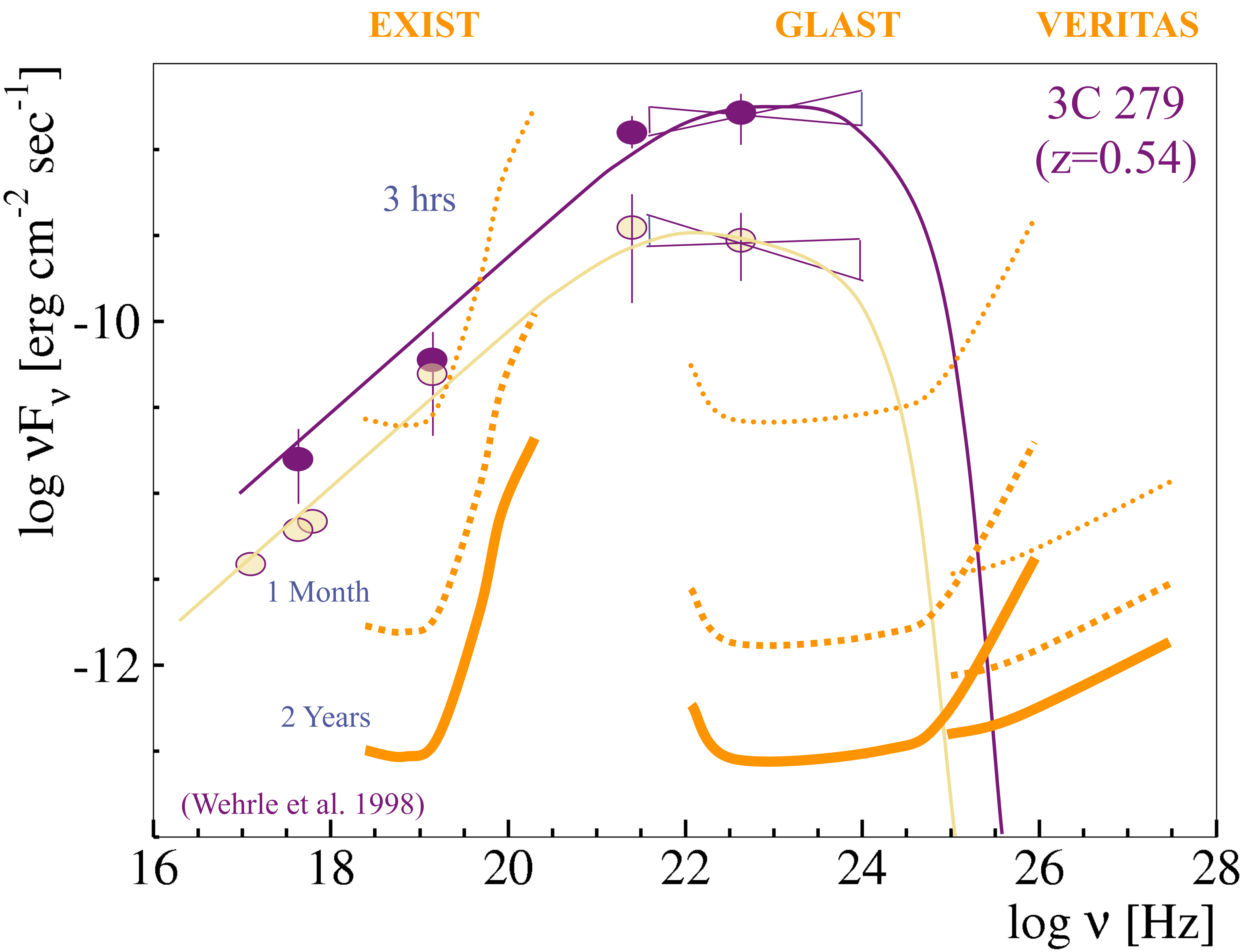
Sensitivities For TeV Blazars



- 2006- : GLAST +CTs, MeV-GeV Blazars
- 2010- : EXIST + CTs, GeV and TeV Blazars

(Krawczynski 2003)

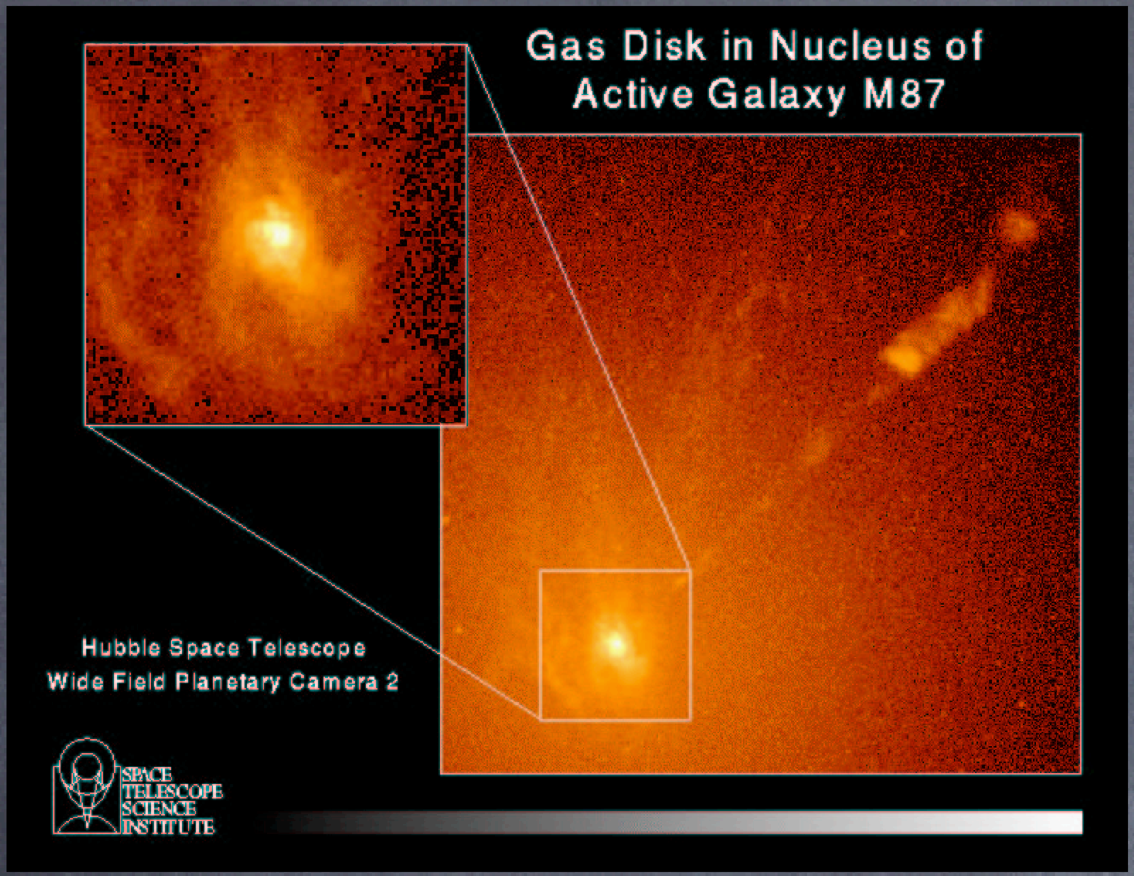
Sensitivities for MeV/GeV Blazars

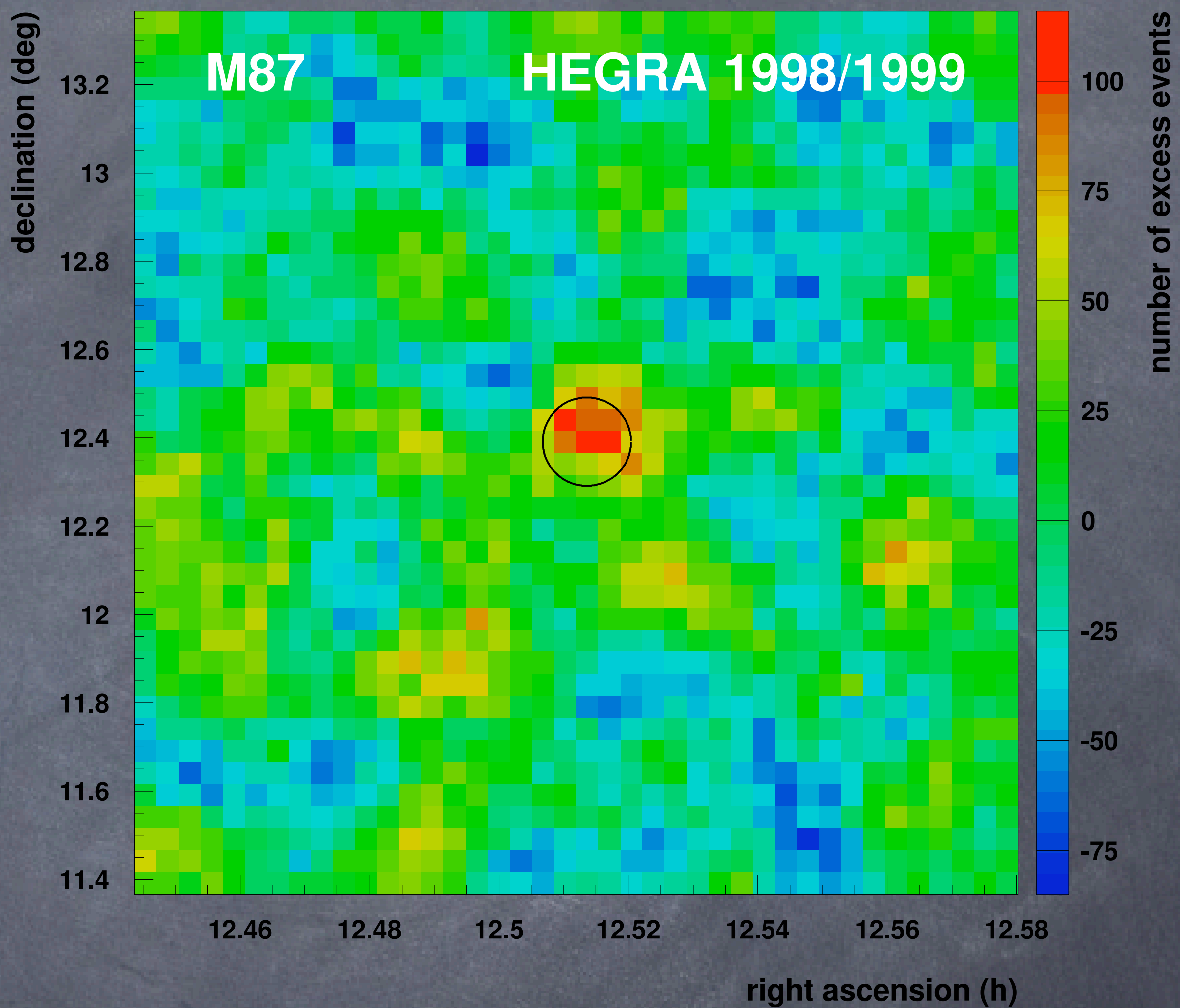


- EXIST + GLAST: Large FoV + High Sensitivity

(Krawczynski 2003)

M87!



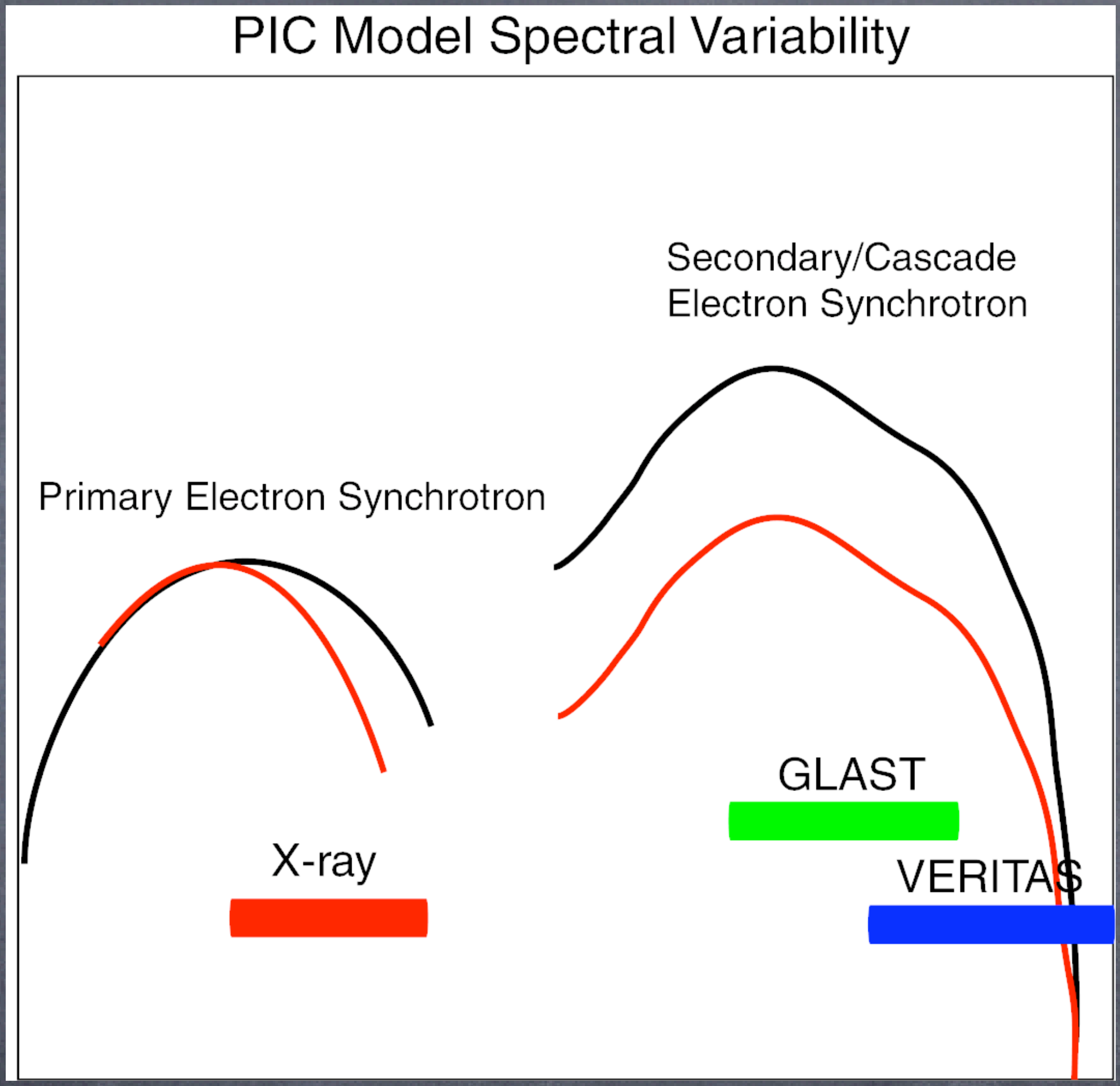


Matthias.Beilicke@desy.de, 2nd VERITAS Symp. on TeV Astroph. of Extragal. Sources, (Chicago - April, 24-26, 2003)

- supermassive black hole: $M_{\rm BH} \approx (2.4 \pm 0.7) \cdot 10^9 M_\odot$
- jet angle to observer: $30^\circ - 35^\circ$
- distance: $\approx$ 16 Mpc (much closer than e.g. Mkn-501)

- 77 h of M87 observations with HEGRA (1998/99)
  - $\Rightarrow$ steady excess on the $4\,\sigma$ level
  - $\Rightarrow$ 3.3 % of the Crab nebula flux ($E > 730$ GeV)
  - $\Rightarrow$ new source type

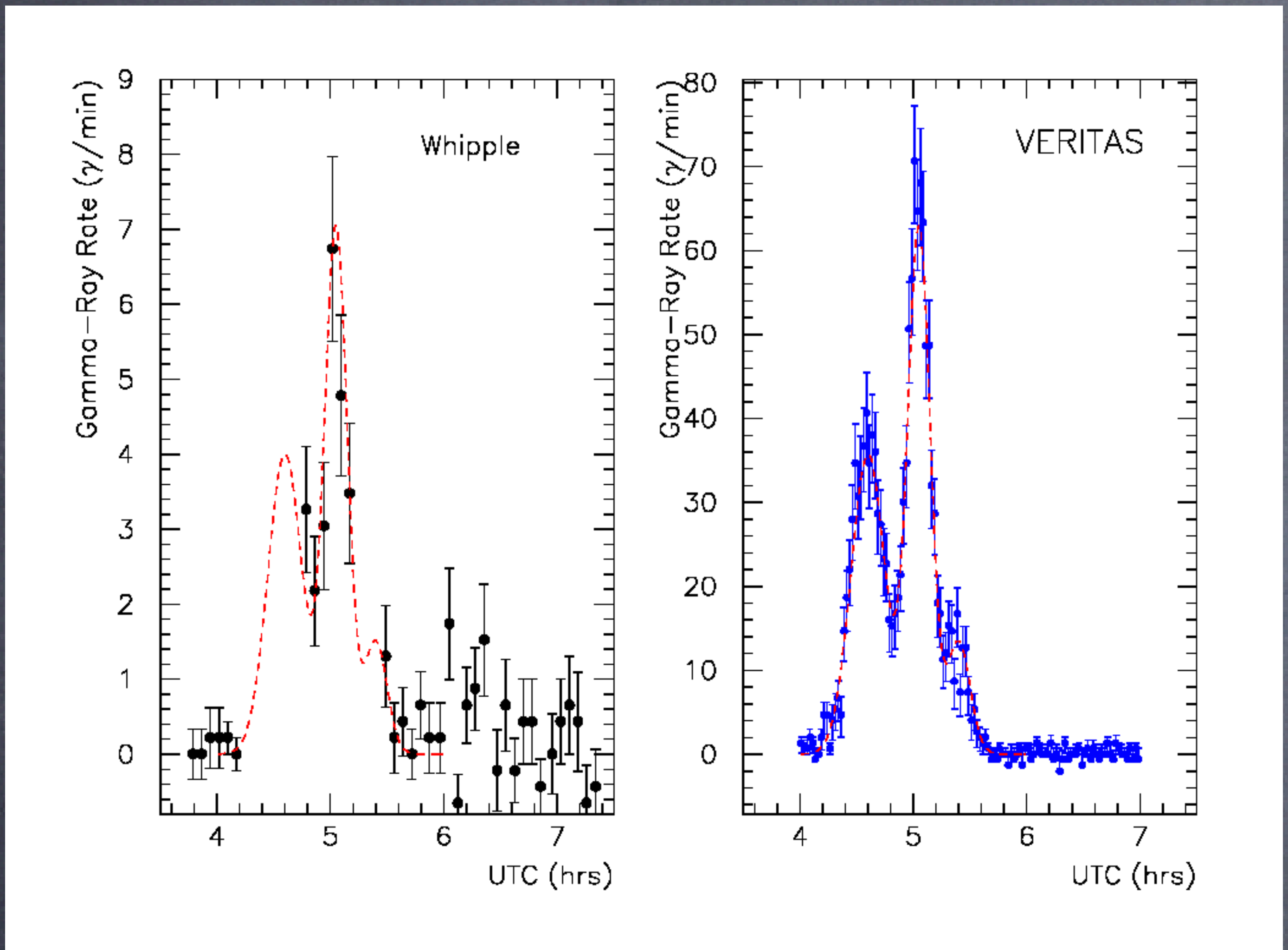
Protons vs. Electrons

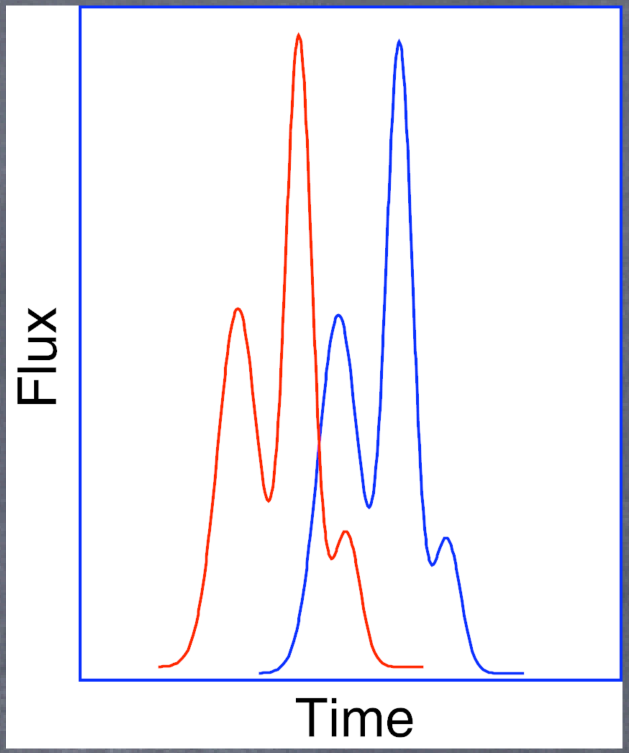


- Radio-X-ray from primary e- synchrotron
- γ-Ray from VHE cascade electrons rapidly cooling in large field (~40 Gauss)
- Signature: GLAST (100 MeV) and VERITAS (TeV) measurements will show almost simultaneous variation (Hillas 1996)

AGN Variability

Gaidos et al., 1996





$t_{\rm rise} \approx t_{\rm fall} \approx 15{\rm min} - 1{\rm hr}$

by causality $R < ct\delta \approx 10^{-4}{\rm pc}$

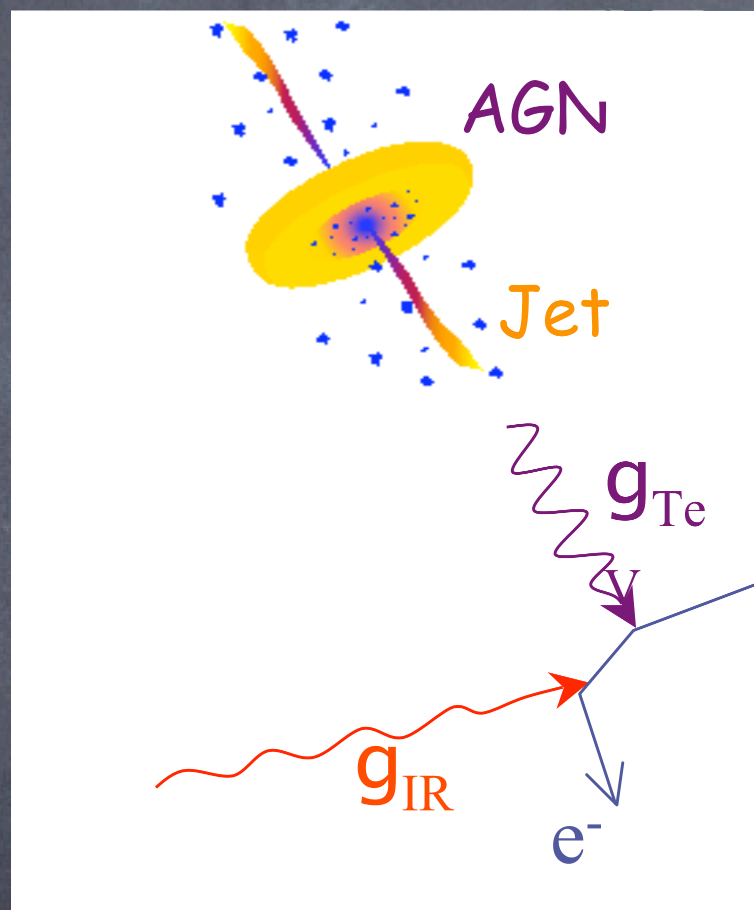
for $M = 10^8 M_\odot \quad R_S = 2GM/c^2 \approx 10^{-5}{\rm pc}$

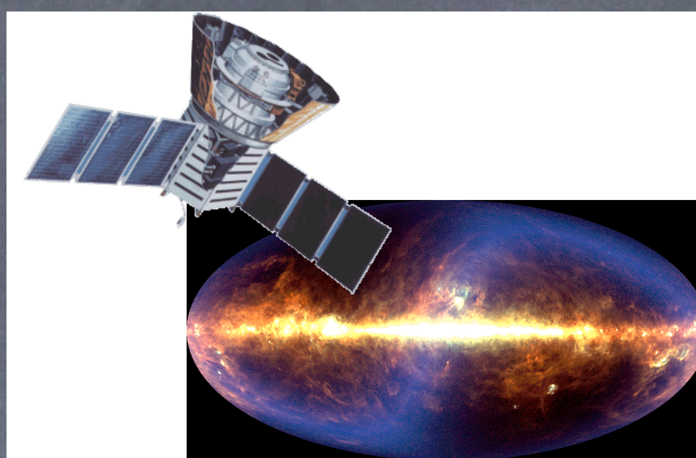
- Probe refractive index of vacuum giving rise to energy dependence in velocity of light
  - Quantum Gravity
  - Large extra dimensions
  - TeV to Planck scale physics
  - Lorentz violation?!
  - One of best limits to date from Whipple flare (Biller et al., Phys Rev Letters 1999)

Gamma-Ray Tomography

- Some may say that absorption of gamma-rays by pair-production off of low energy photons is a bad thing
- But just like absorption of X-rays gives an image of what lies beneath the surface, absorption of gamma-rays reveals the structure of the absorbing target either in the source, or filling intergalactic space

Probing the EBL





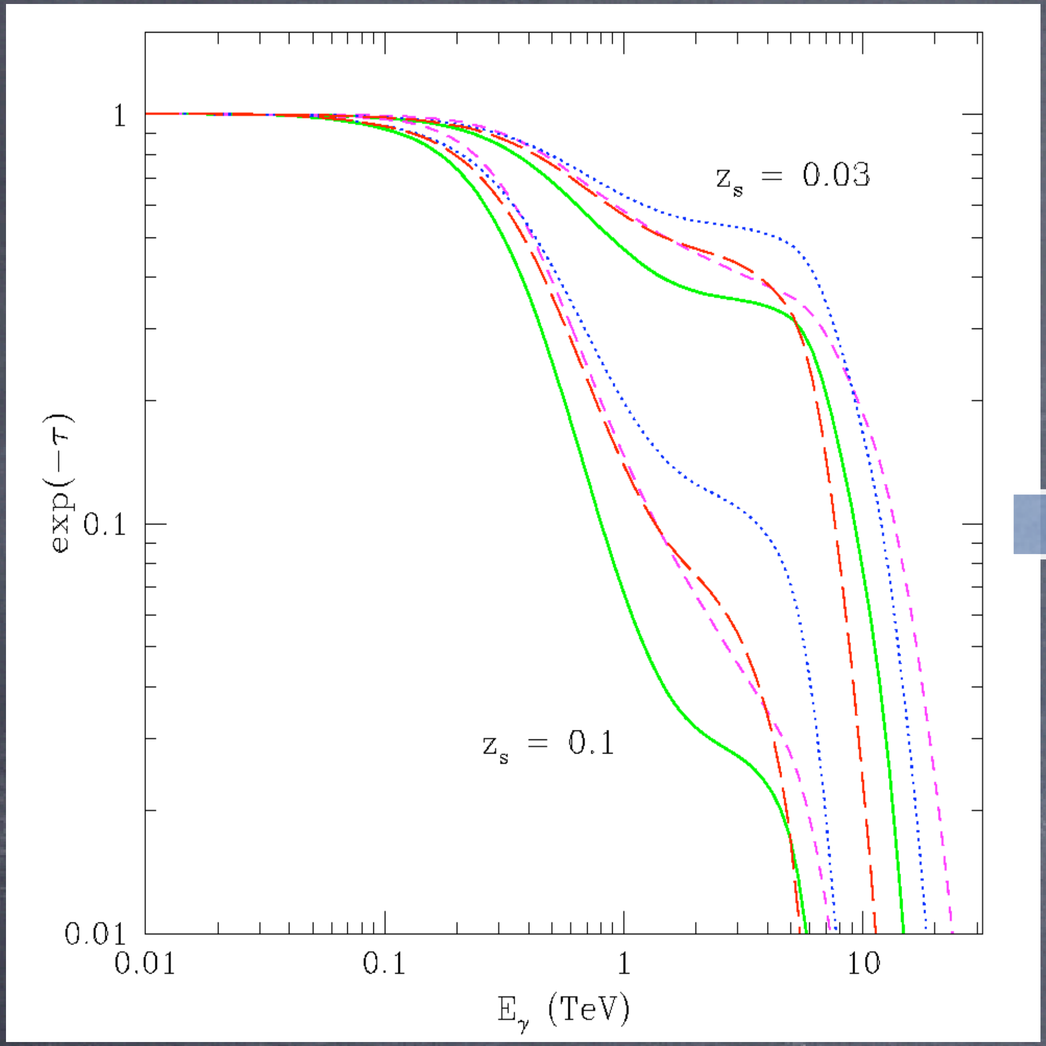
Hauser et al., 1998, ApJ, 508, 25

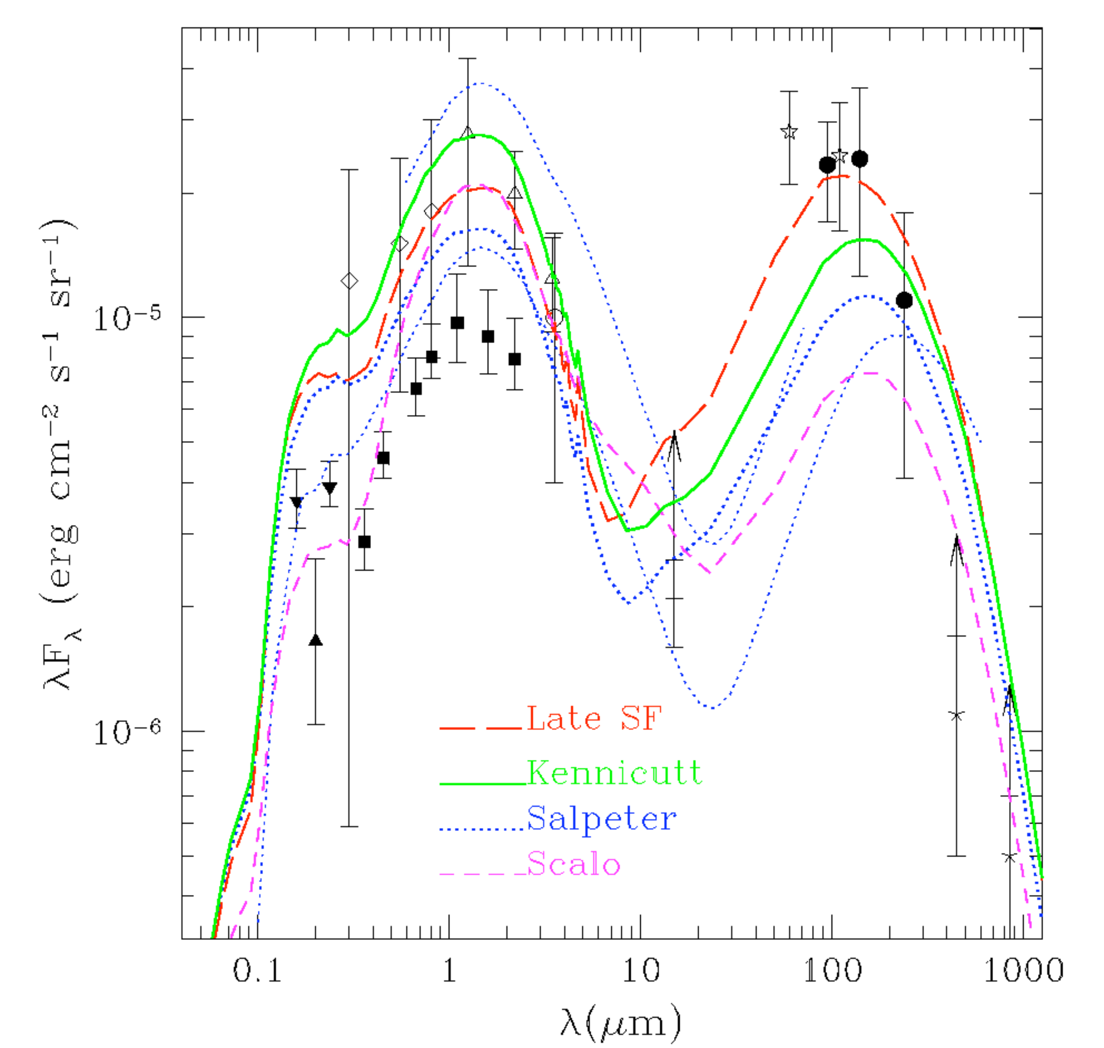
The DIRBE team has reported detection of EBL at 140 and 240 mm, and has set only

upper limits to its brightness at eight other wavelengths-

1.25, 2.2, 3.5, 4.9, 12, 25, 60 and 100 mm.

Probing the EBL

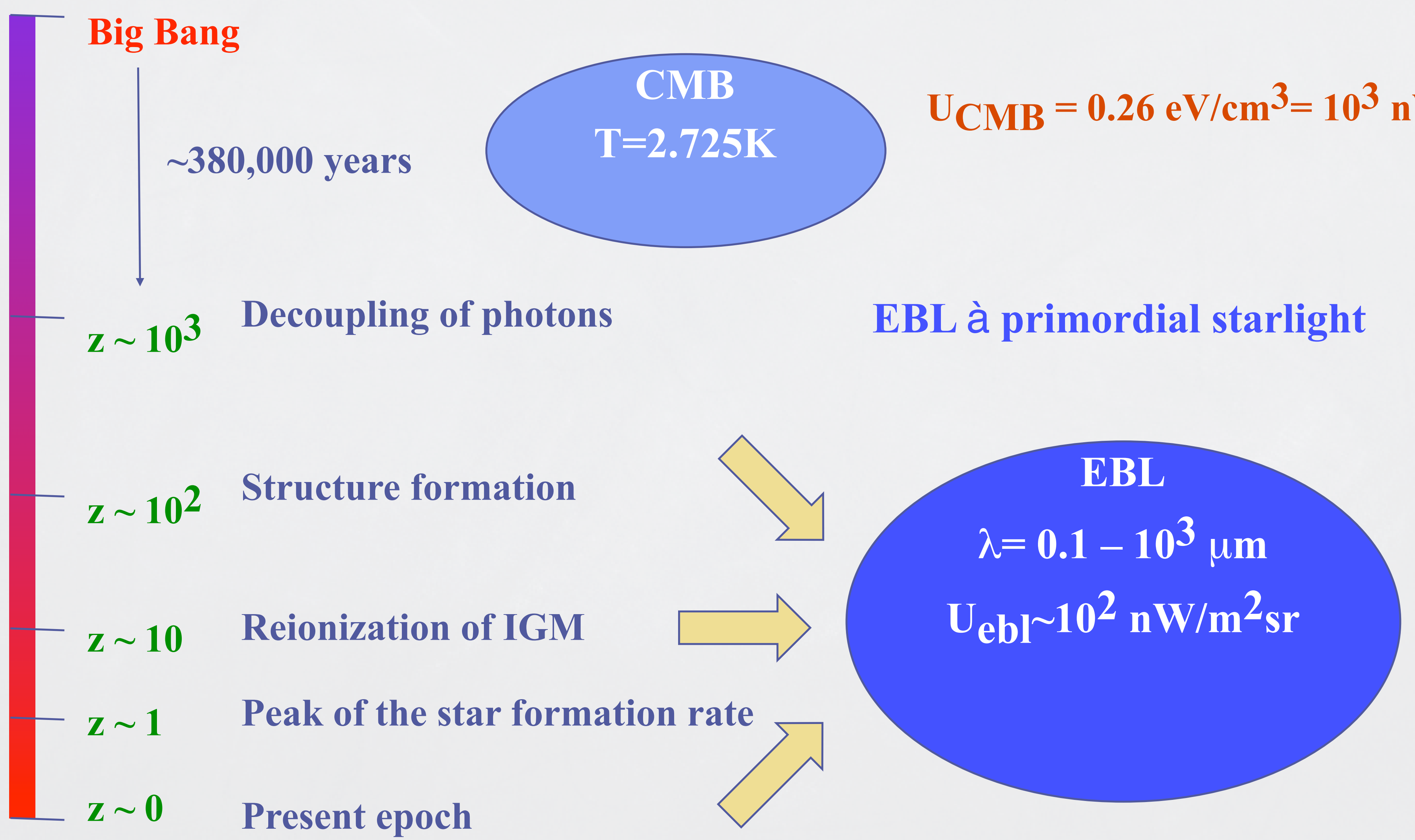




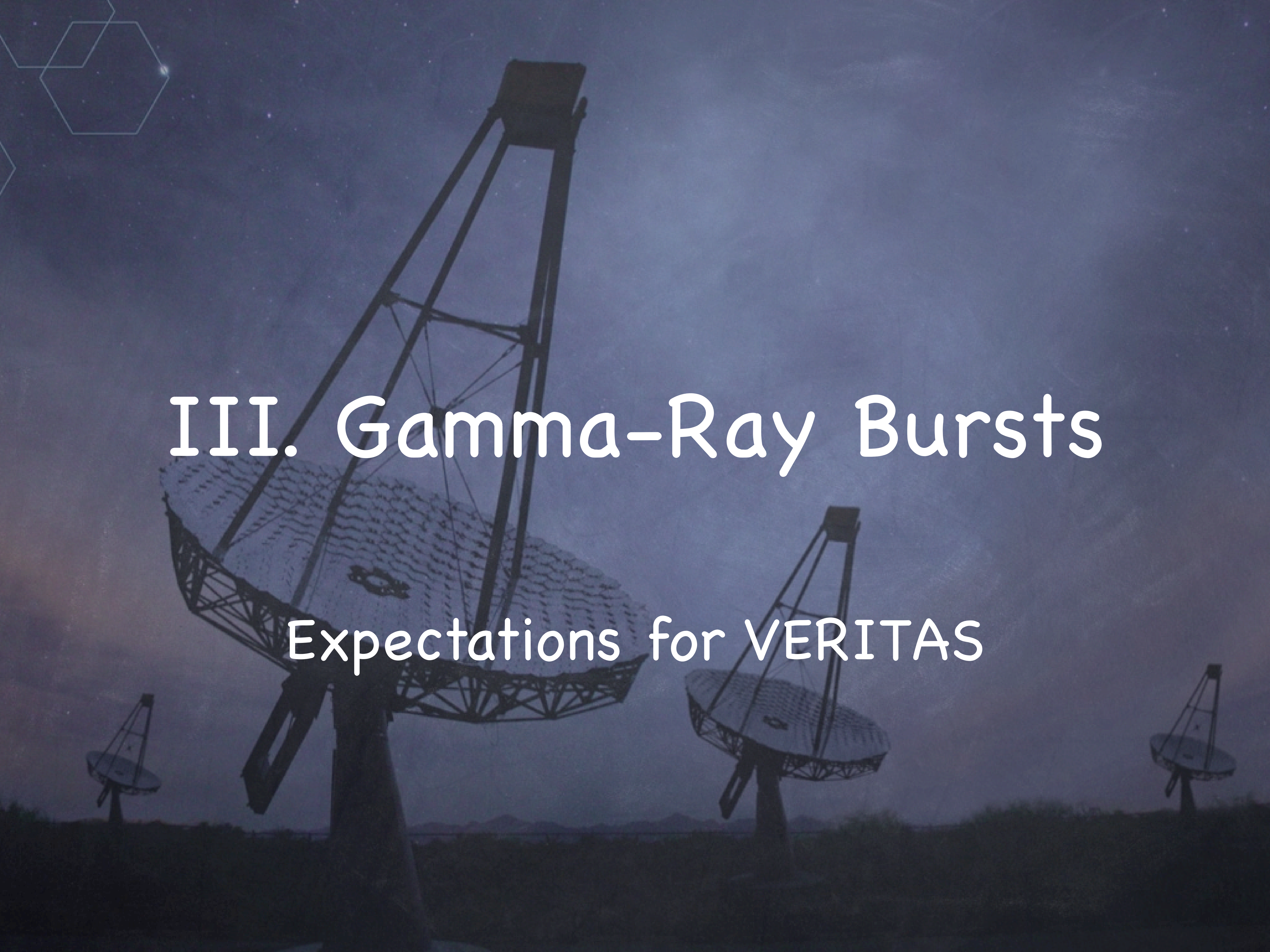
- Absorbing target for pair production resulting in distortions of high energy end of TeV spectrum
- If one detects enough sources, and can constrain the source spectrum it is possible to invert and measure the spectrum of the EBL in the visible to IR band
- Provides calorimetric information about electromagnetic energy production in the Universe
- Provides information about the epoch of star formation and structure formation

Extragal. Background Light

EBL place in cosmology



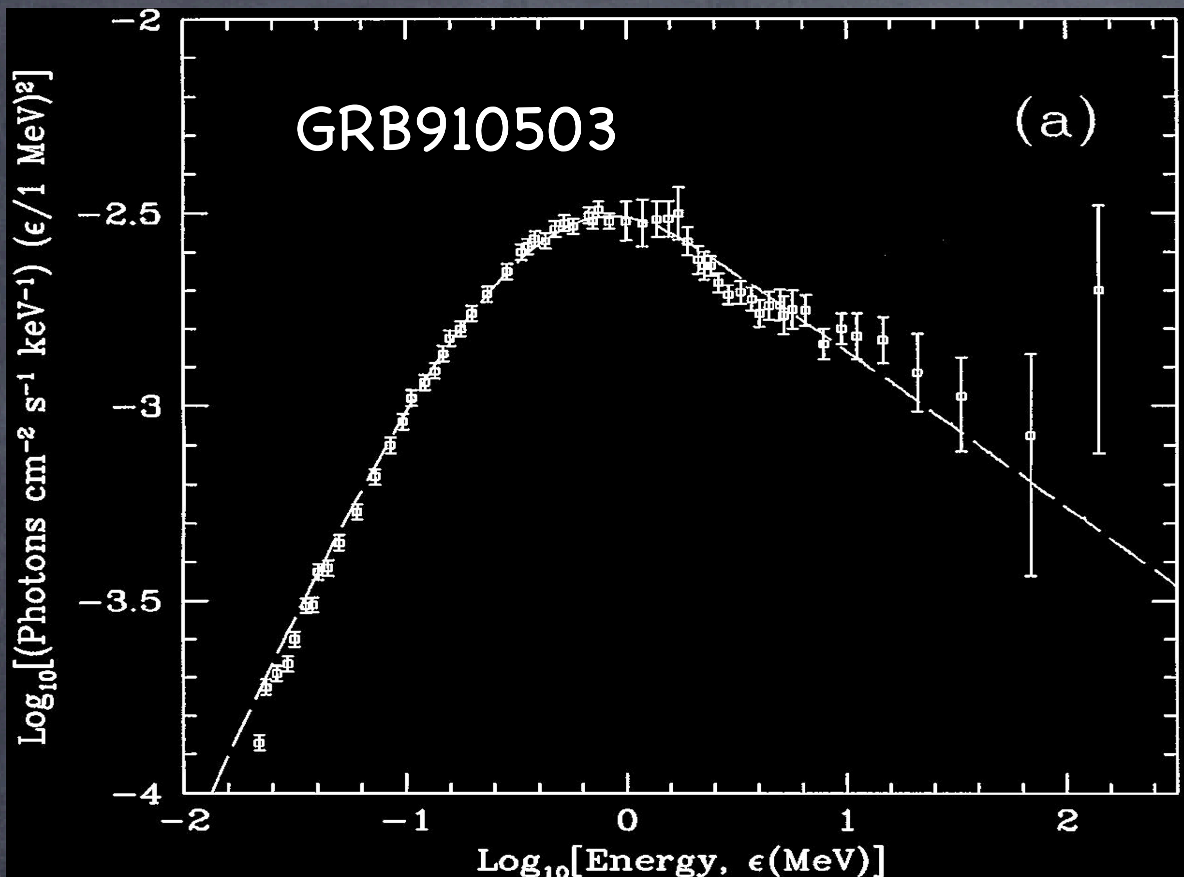
(from Vladimir Vassiliev)



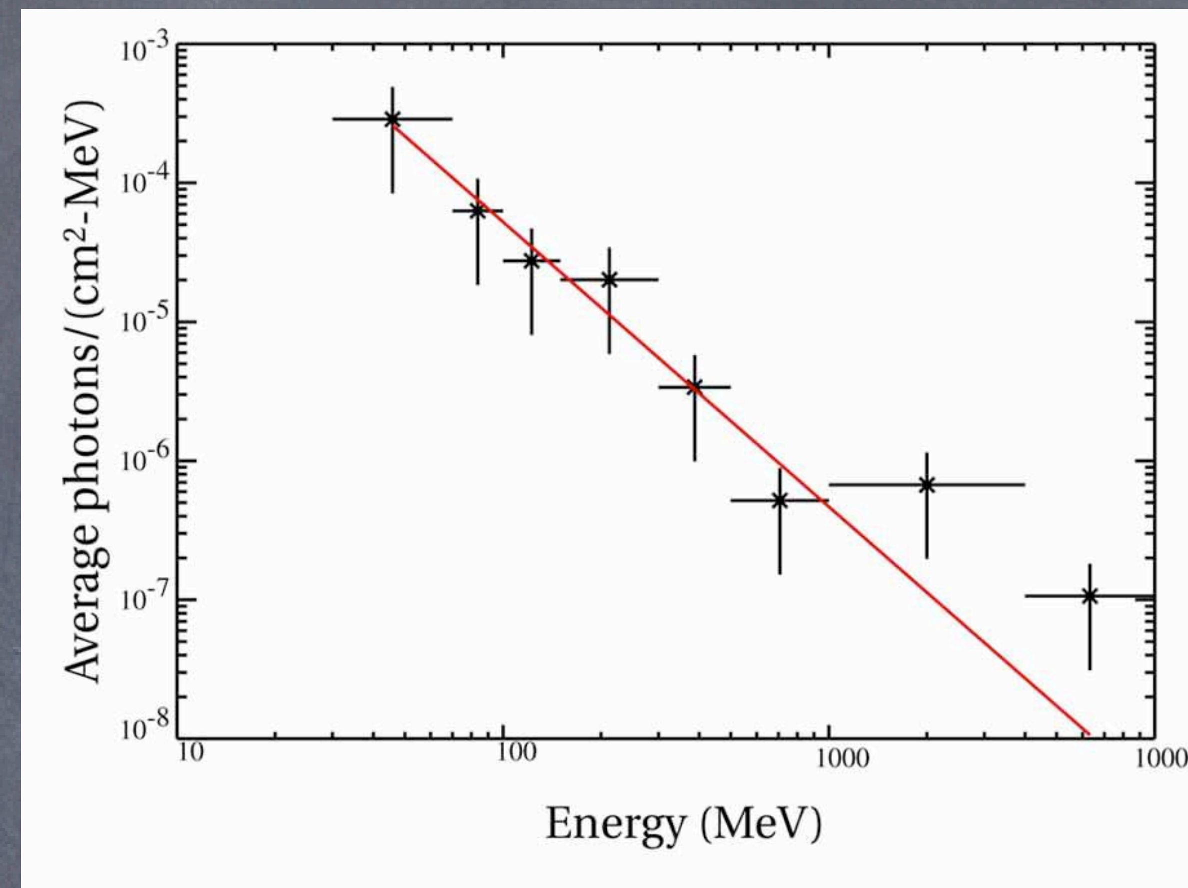
III. Gamma-Ray Bursts

Expectations for VERITAS

VHE Gammas from GRBs



(Tavani M. 1996, PRL 76, 3478)

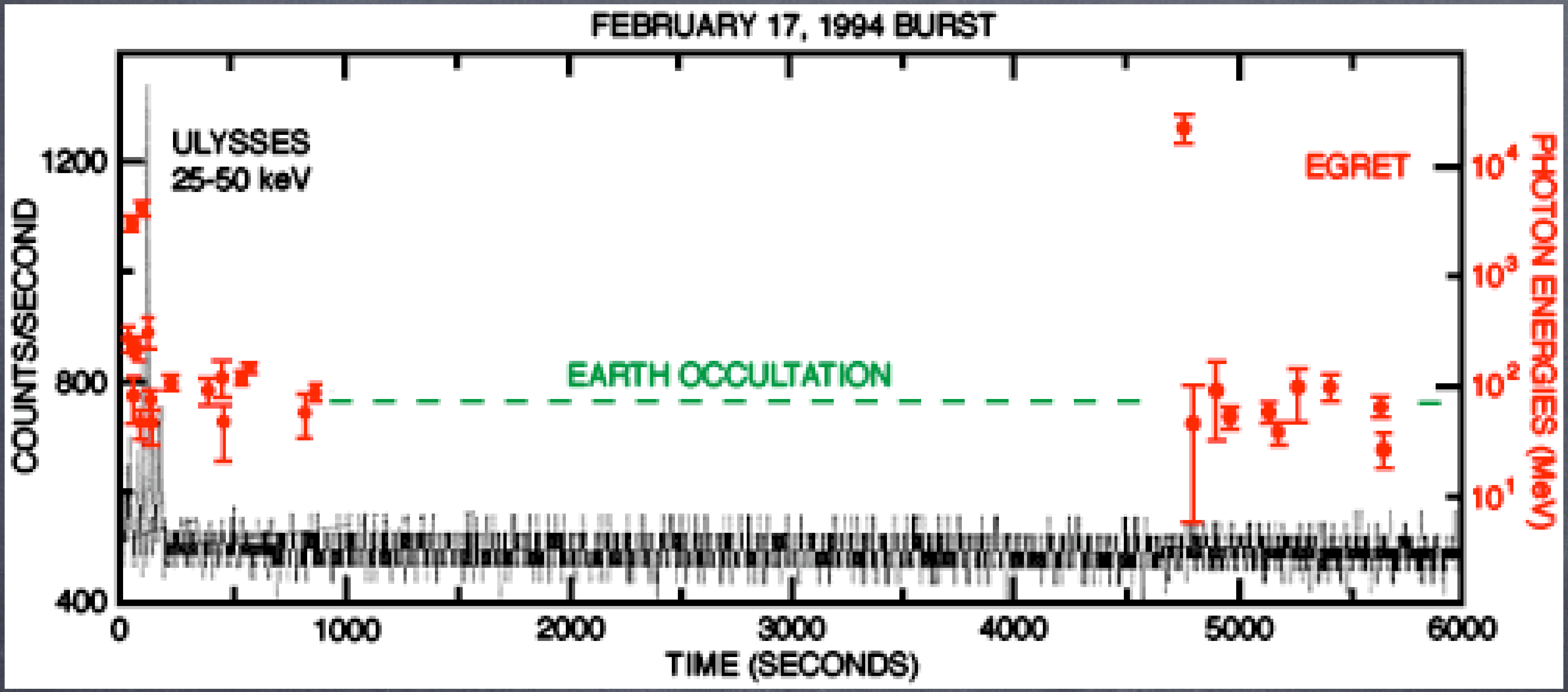


(http://glast.gsfs.nasa.gov/resources/brochures/gsd)

Spectrum Peaks around 1.5 MeV

Averaged EGRET spectrum shows no evidence for a cutoff to 10 GeV

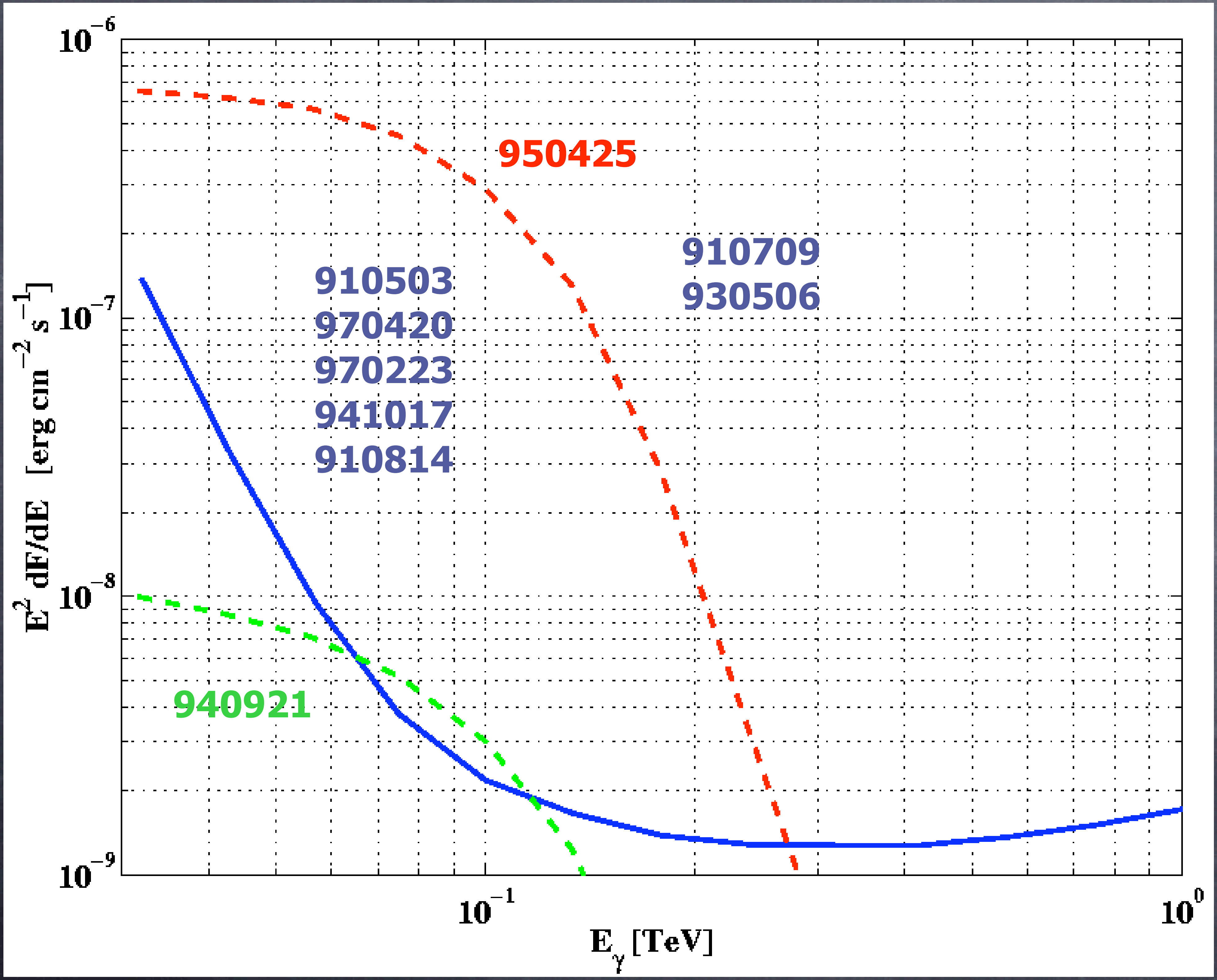
GRB940217



(Hurley et al. 1994, Nature 372, 652)

Delayed VHE Component?

VERITAS GRB sensitivity



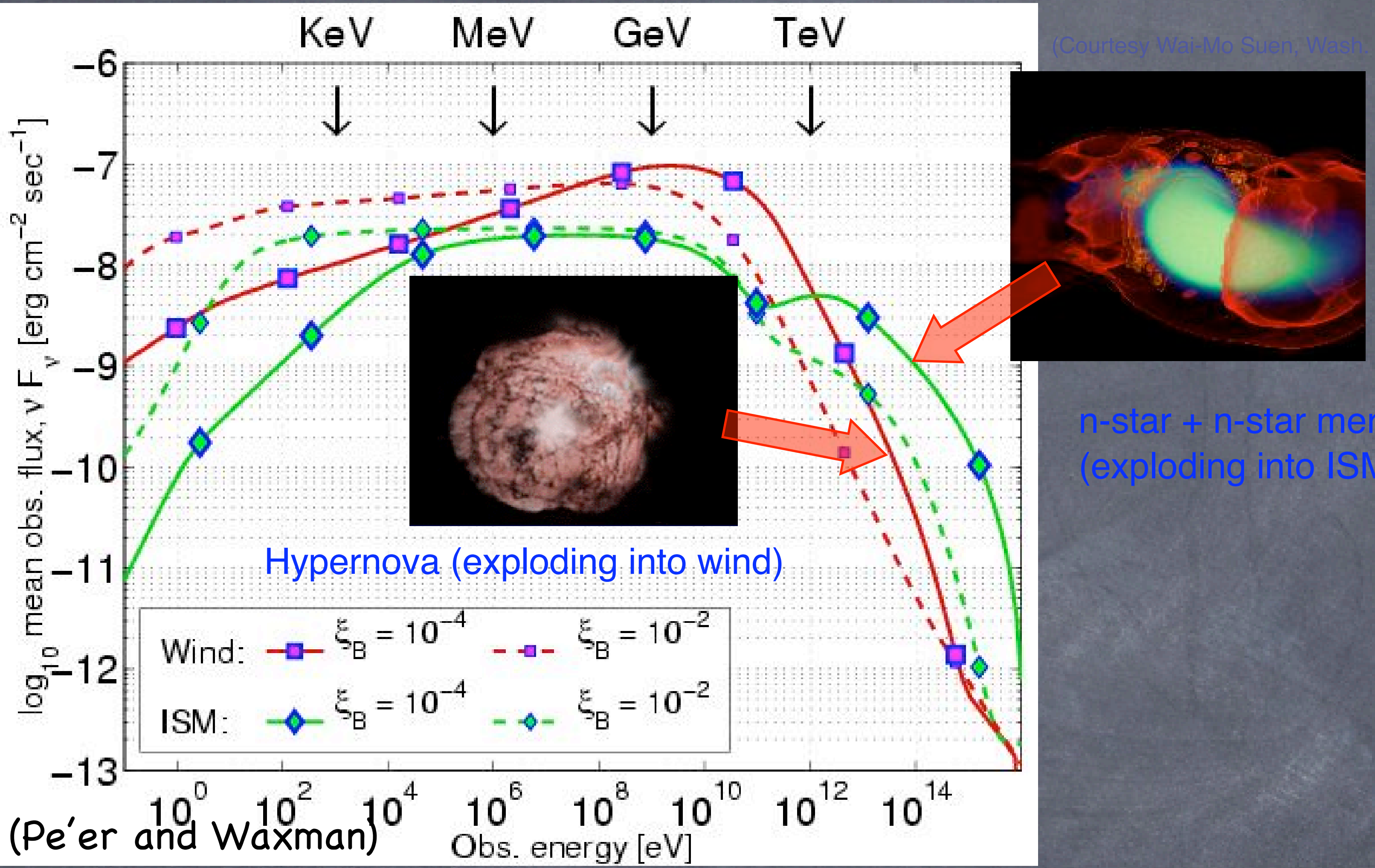
Hypothetical duration:
1 minute

Hypothetical distance:
Z=1.0

EBL absorption:
Primack et al.

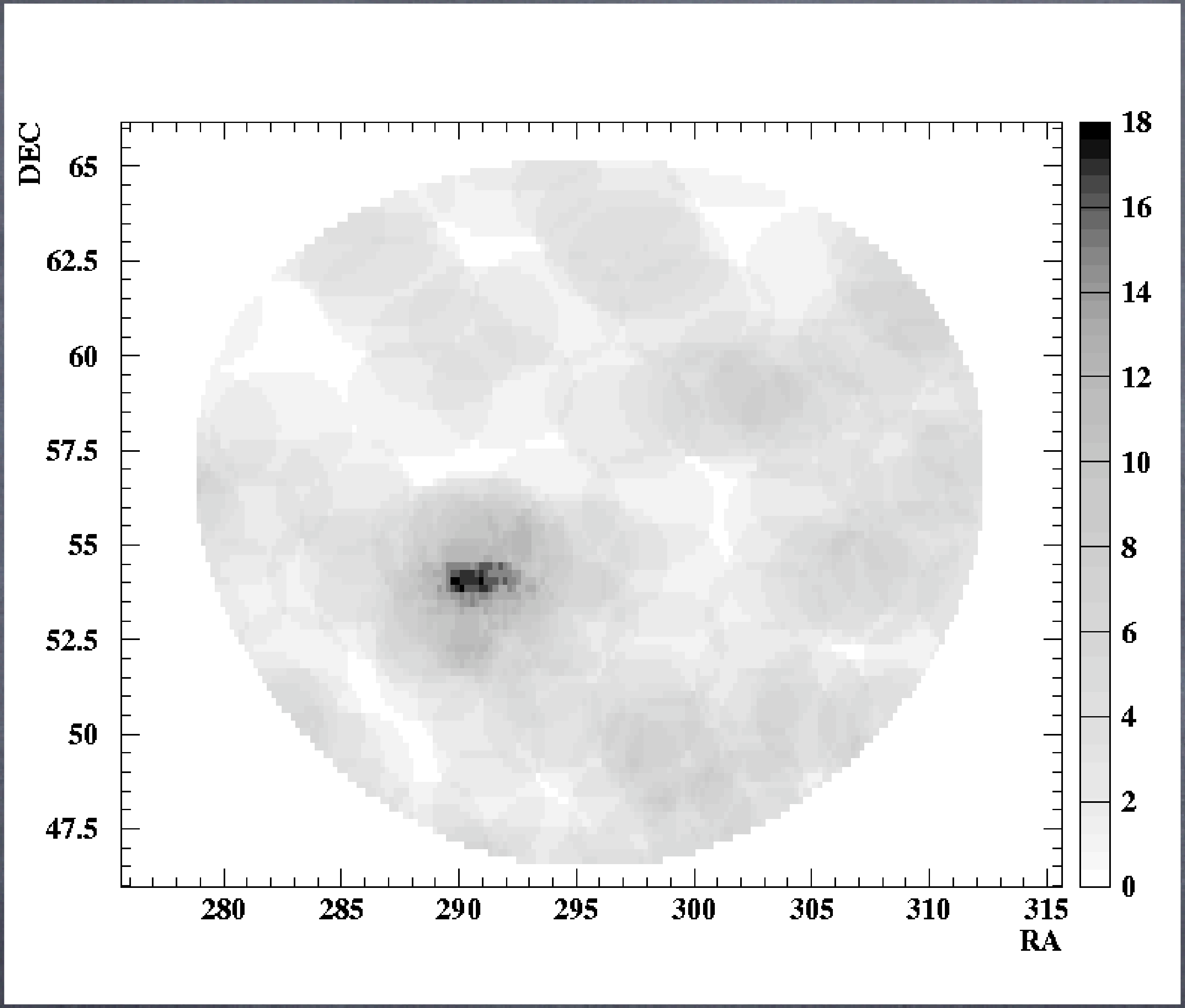
SFR:
Scalo IMF

Prospects for VERITAS



- Observations of the IC component would provide new constraints on the physical conditions in the environment of the GRB.
- EGRET observations indicate 10-20 GeV emission - it is not a large extrapolation to 100 GeV
- With very large Γ~800, internal shocks can give prompt GeV-TeV emission and delayed UHE cascades (e.g., Razzaque, Meszaros and Zhang, 2004)
- External shocks could give delayed VHE emission (e.g. Dermer, Pe'er and Waxman).

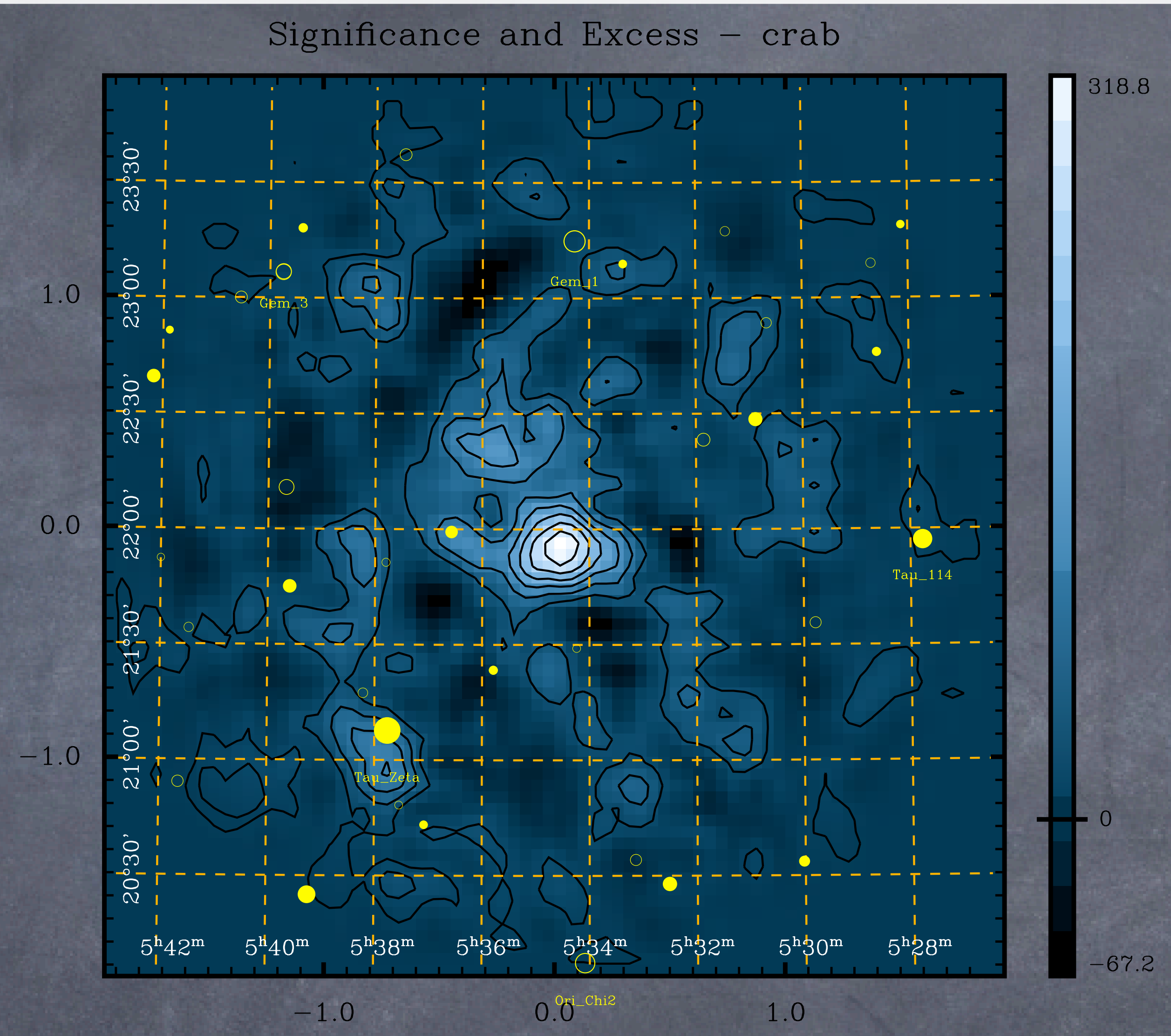
MILAGRO Detection?



- MILAGRITO analysis of 50 BATSE triggers discovered one possible coincidence (~3 sigma) (Dingus, McEnery)

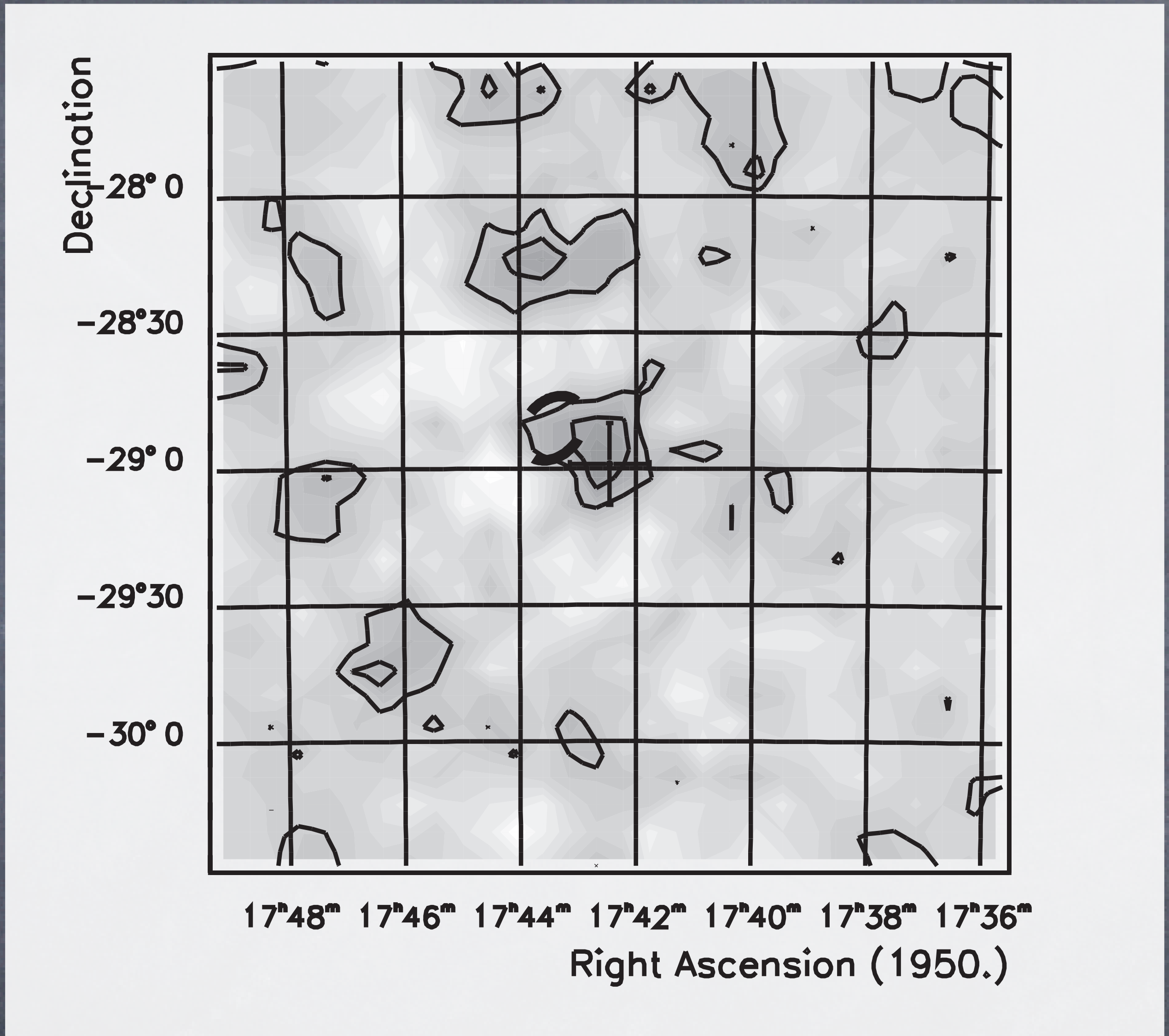
V. Galactic Center

Crab as Standard Candle



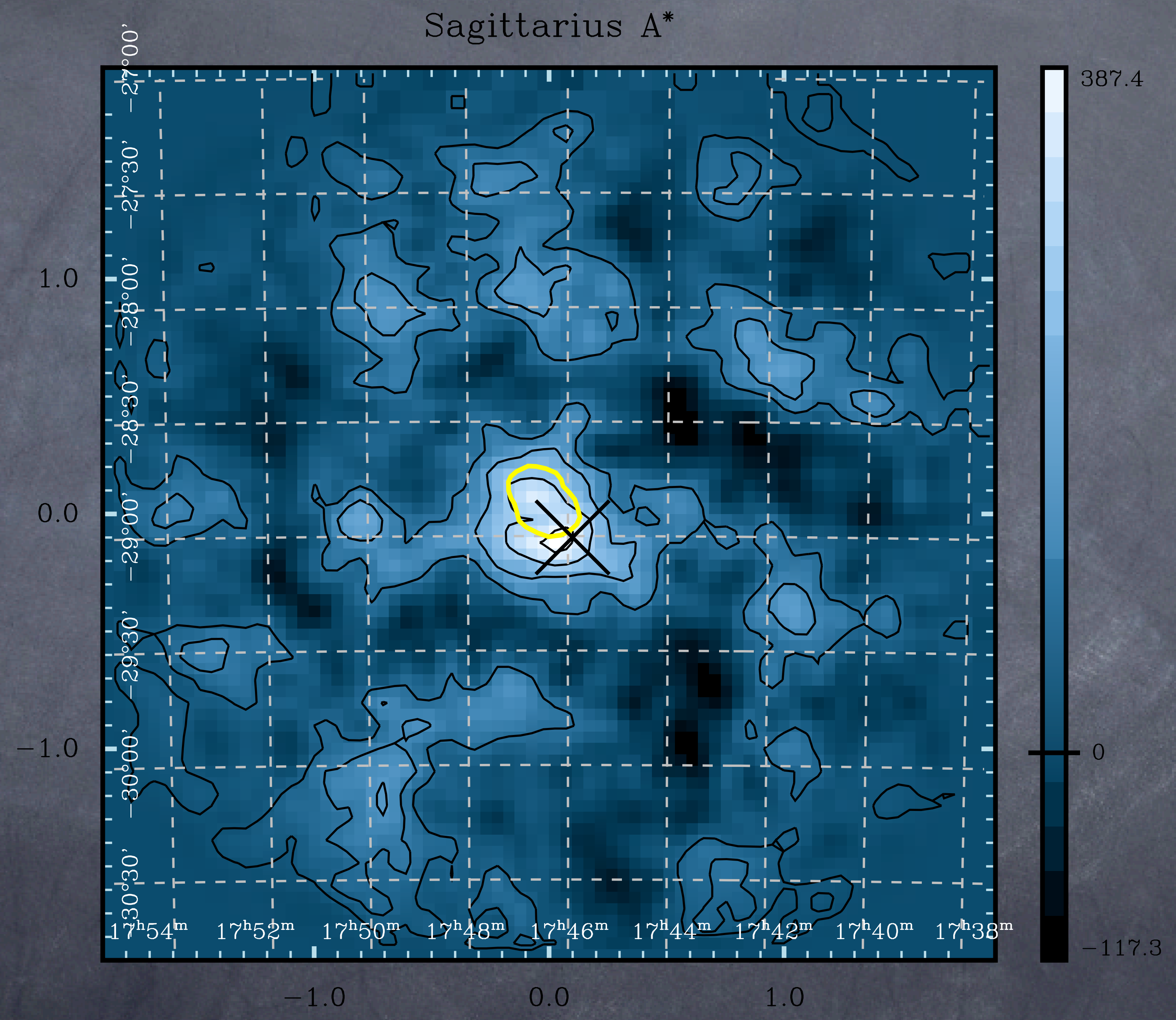
- Optimize analysis on simulations
- Refine cuts on data from Crab Nebula (standard candle)
- Calibrate cuts on independent LZA Crab data set (also at 60deg zenith; not optimization set)
- Normalize results to the Crab to cancel systematic errors in absolute flux normalization

1995 Whipple Data



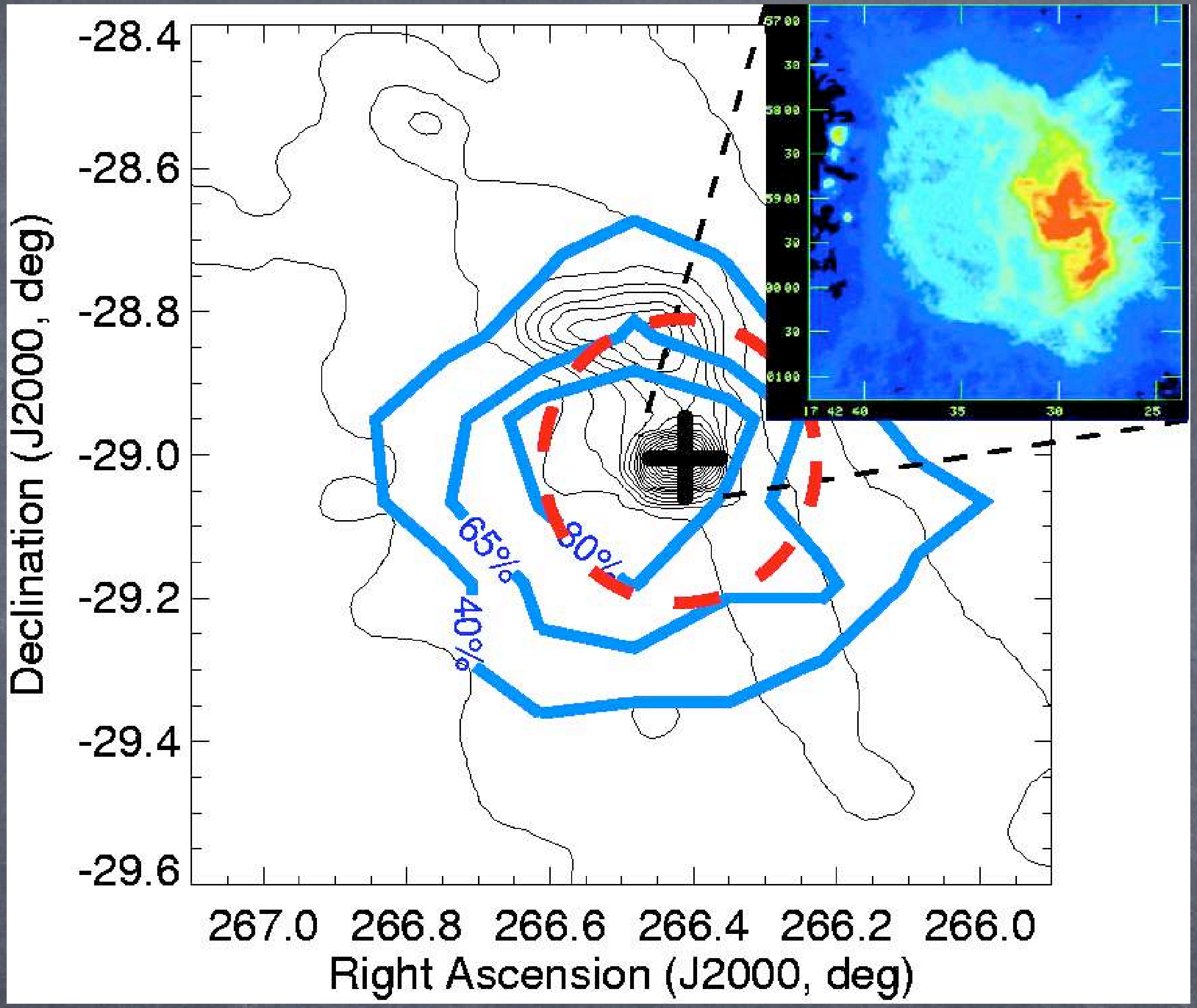
- Upper-limit but 2.4 sigma excess (Buckley et al., 1997, Proc. 25th ICRC (Durban) 3, 237)
- Took data in spring every year for 10 years to improve upper limit...

Whipple GC Results



- Kosack et al. (astro-ph 0403422; 2004, ApJ, 608, L97)
- 26 hr at LZA, 3.7 sigma, 2.8 TeV

Cangaroo Results



- Tsuchiya et al., (astro-ph 0403592; 2004, ApJ, 606, L115)
- 67 hours, with 10m telescope, July 2001 and July/August 2002
- 250 GeV threshold, F(E) ~ $E^{-4.6+-0.05}$

HESS Results

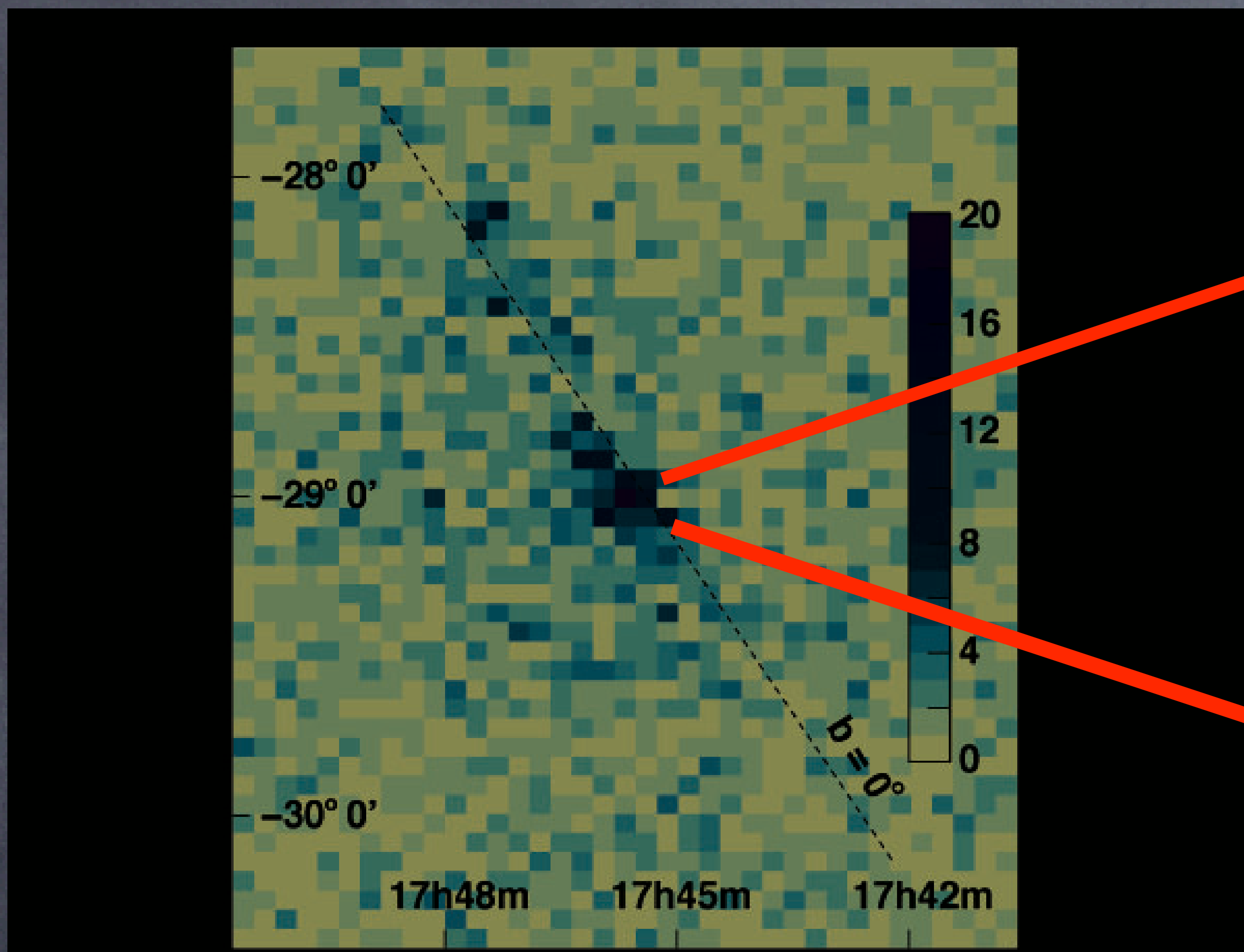
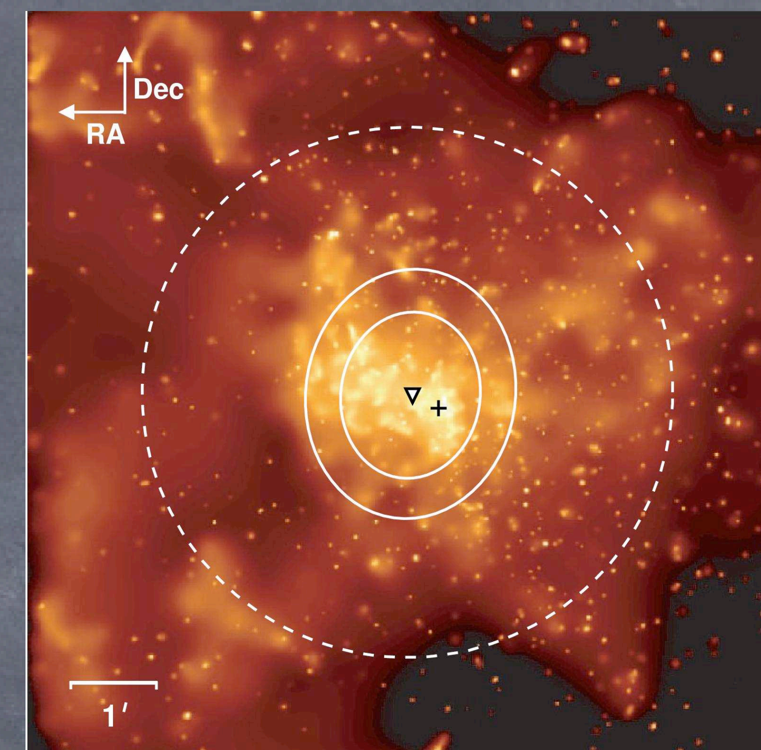
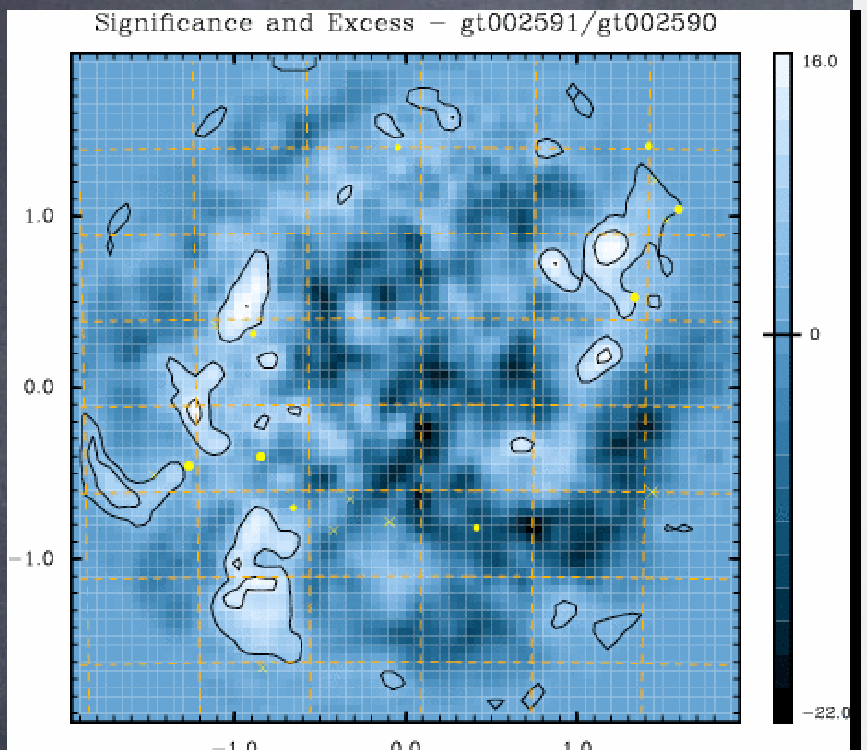


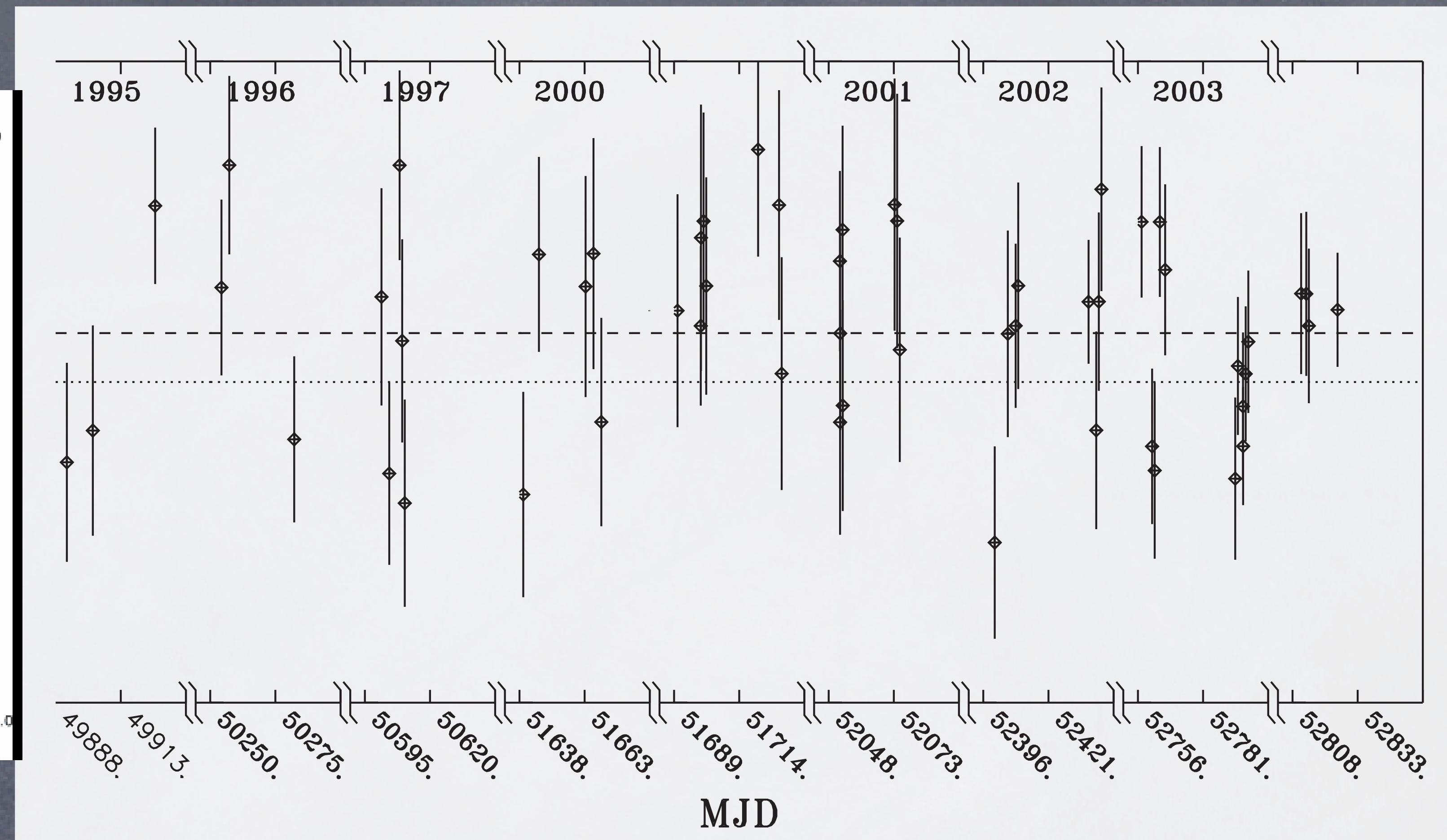
Fig. 1. Angular distribution of γ-ray candidates for a 3° field of view centred on Sgr A*. Both data sets ('June July' and 'July August') are combined, employing tight cuts to reduce the level of background. The significance of the feature extending along the Galactic Plane is under investigation.



- Aharonian et al. (astro-ph 0408145; 2004, A&A, 425, 13)
- 2 telescopes, 4.7 hr June 2003, 225 GeV, 6.1 sigma; 11.8 hr July/August 2003, 165 GeV 9.2 sigma
- Within ~1 arcmin of SgrA*

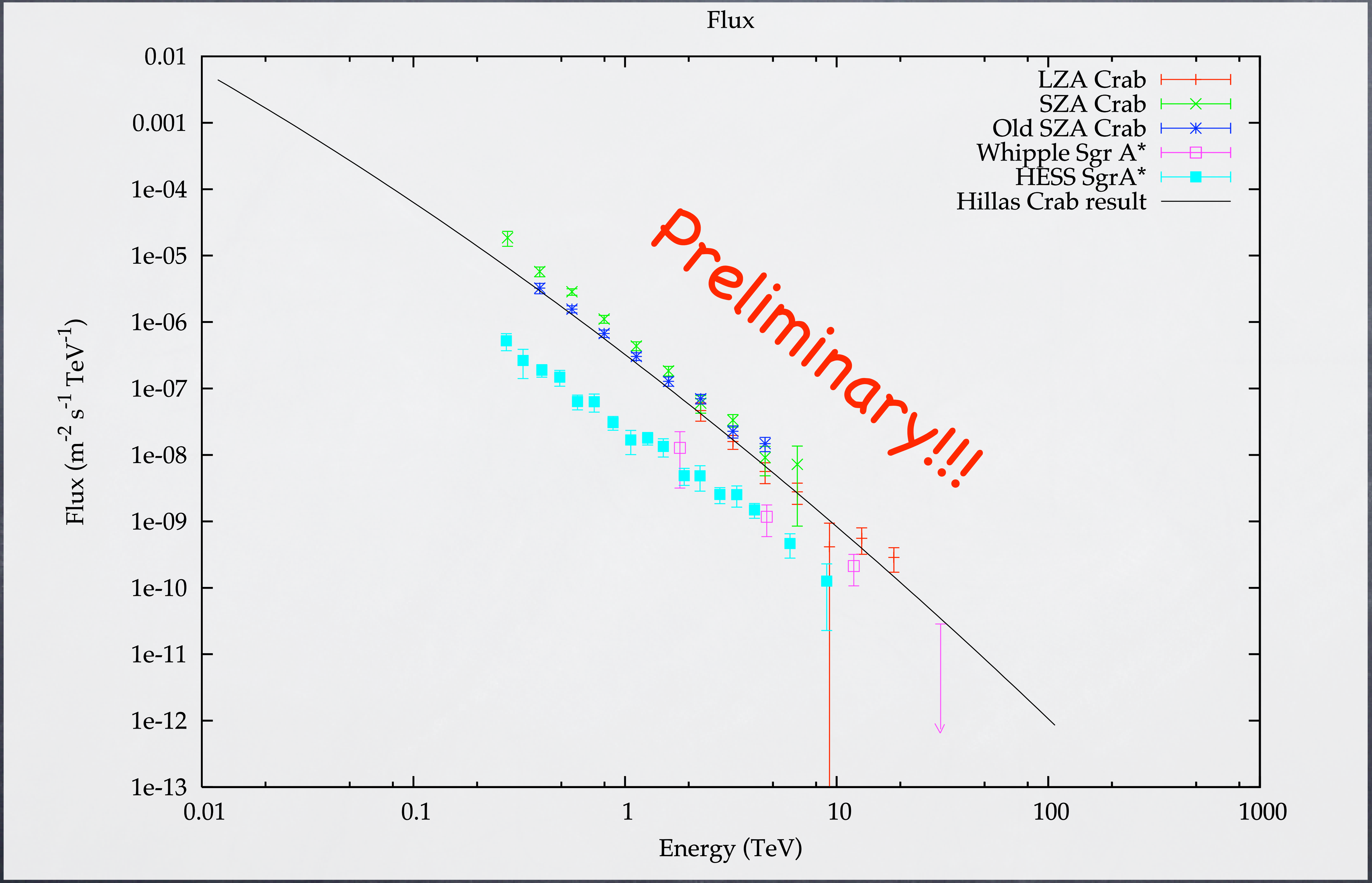
Time Variability?





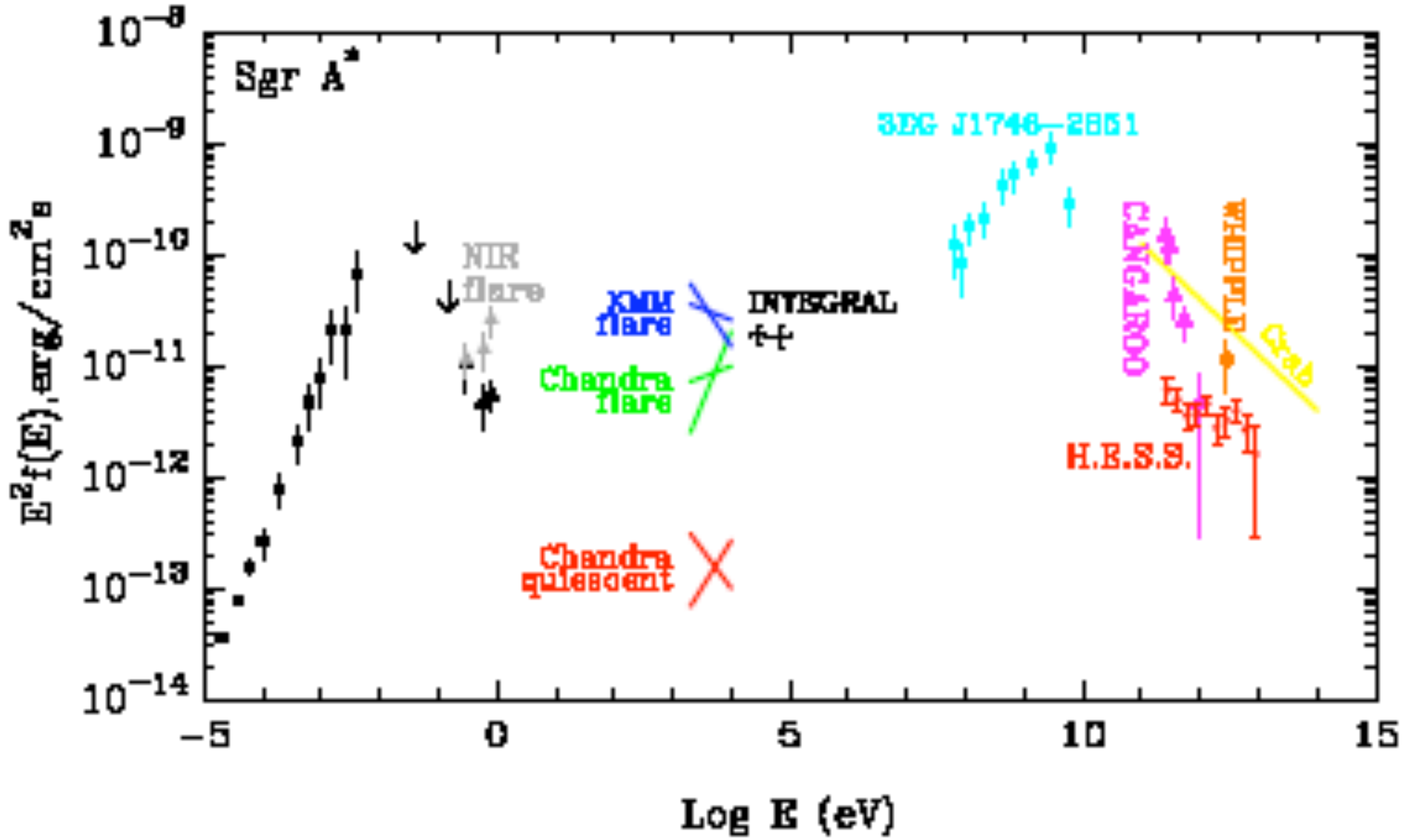
- Low significance, but Whipple data over 10 years doesn't show strong variability (like Mrk421)
- All groups see steady emission within own data sets
- HESS image may show extended structure
- Cangaroo data, taken at face value, would imply variability

New Results



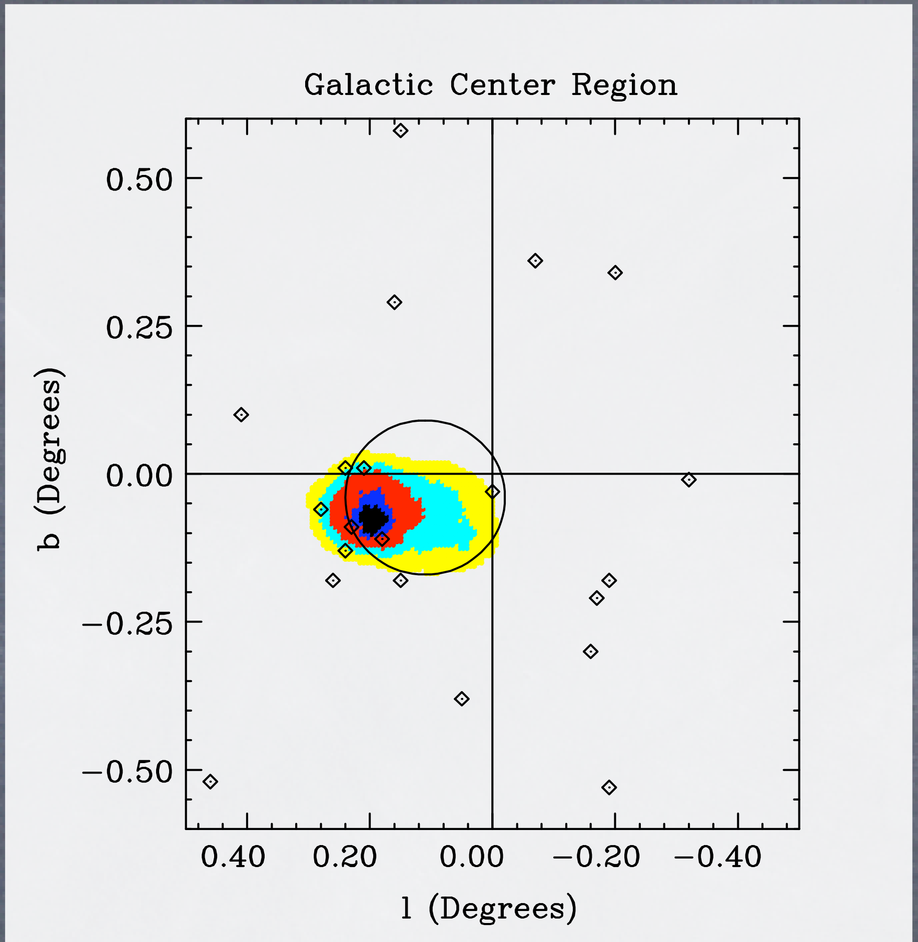
- More Sgr A* data
- Detailed spectral analysis

GC Spectrum!



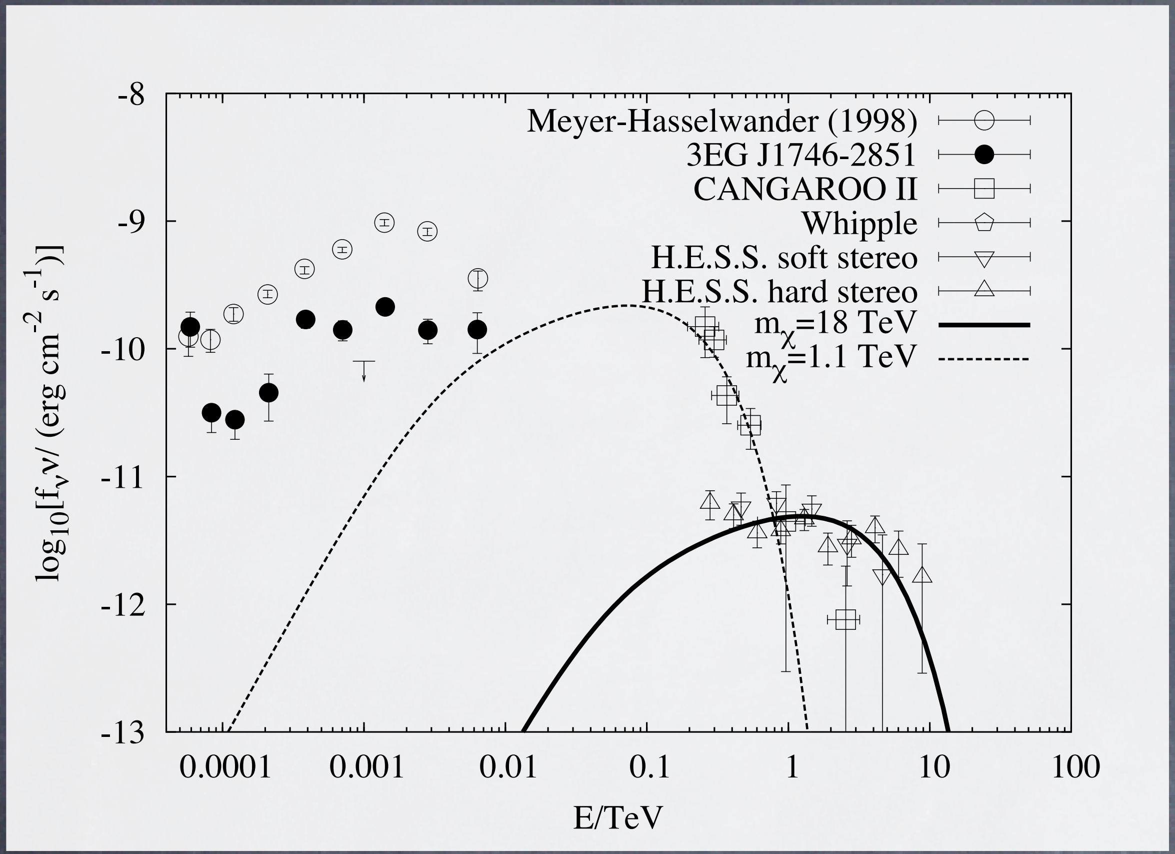
Aharonian & Neronov (2004)

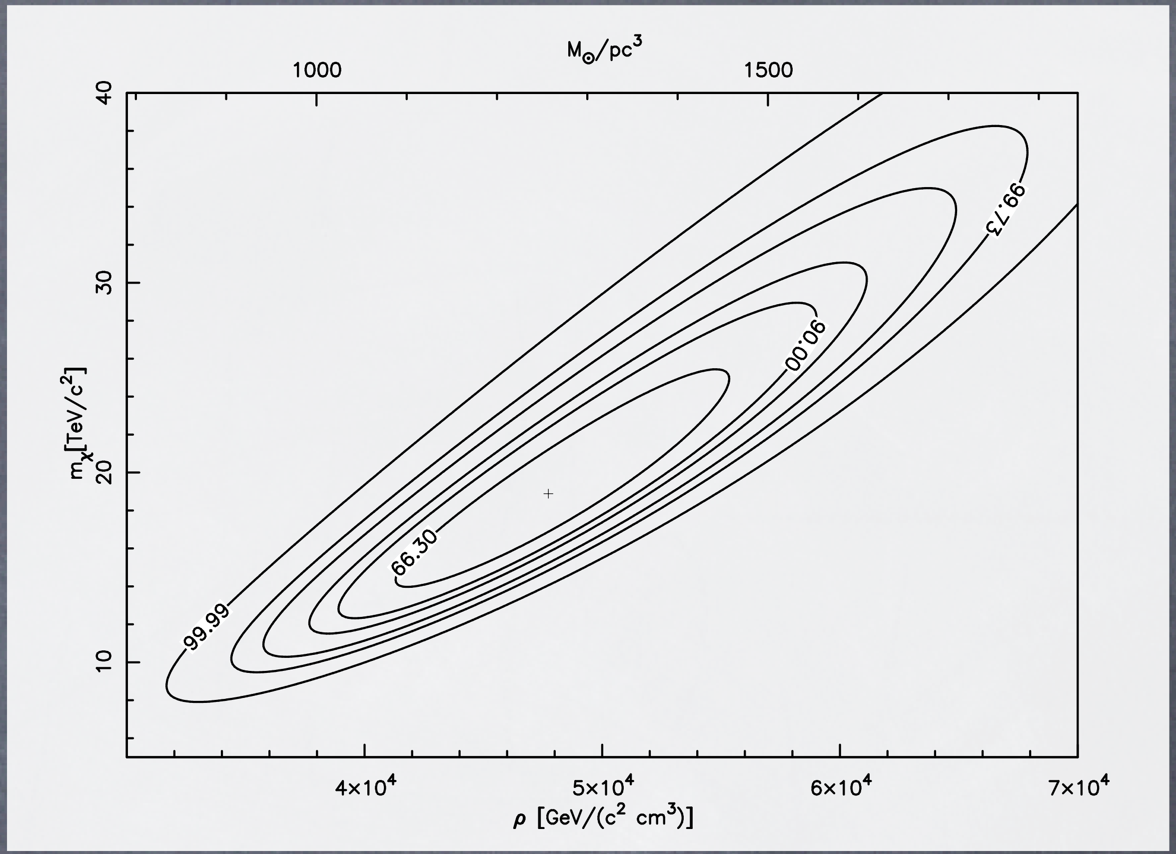
EGRET Observations



- Hooper and Dingus, astro-ph/0212509 and Pohl (2004) reanalyzed EGRET data and found Sgr A* excluded at > 95% conf. level
- My interpretation: Not one source, but 3 unidentified sources:
  - Whipple/HESS (Sgr A* ?)
  - EGRET source
  - CANGAROO source

Neutralino Constraints

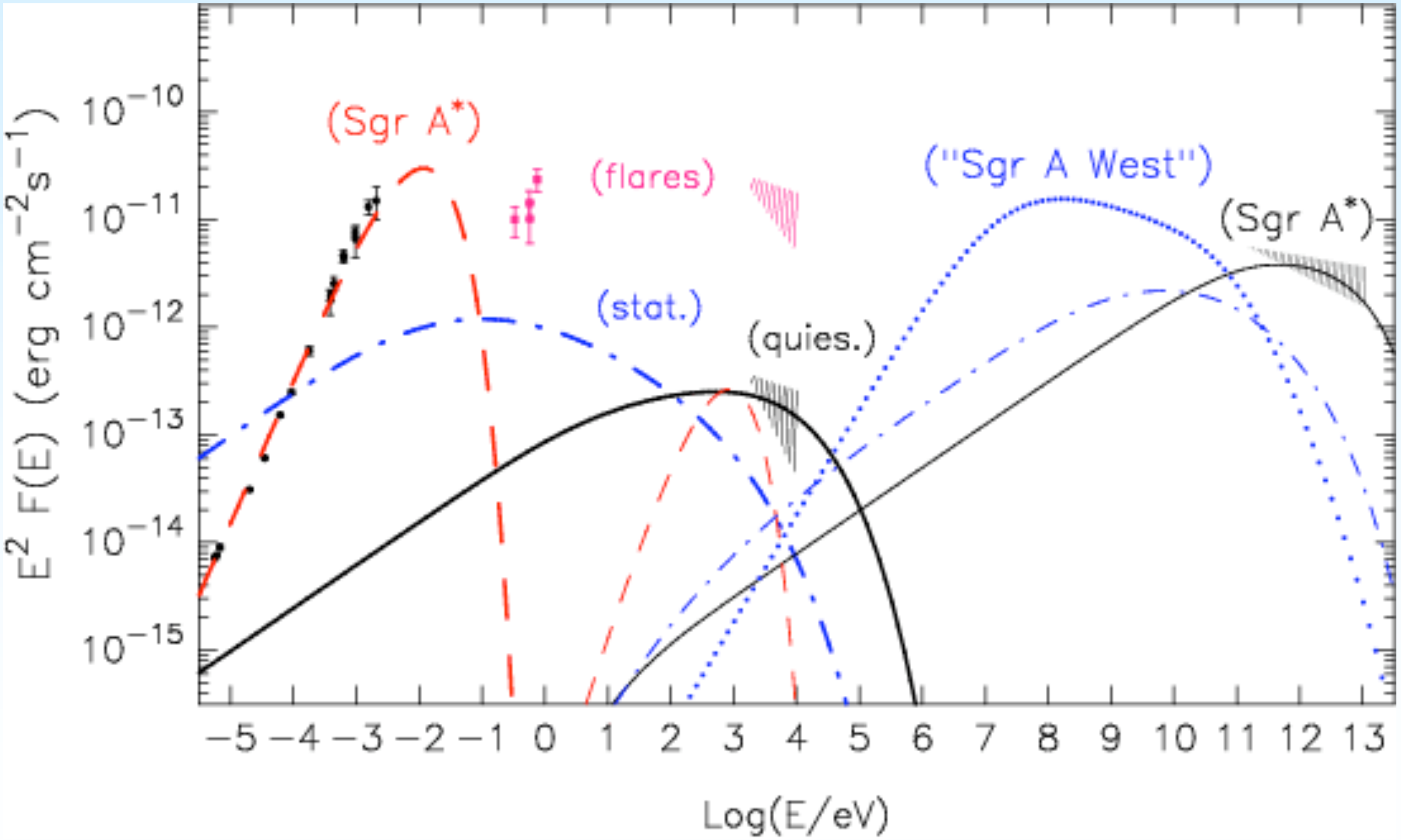




- Dieter Horns (asto-ph/0408192)
- High masses are unlikely -> pure Higgsino-like solutions, resonances in decoupling cross-sections, need lots of fine-tuning
- One good flare would rule this out!

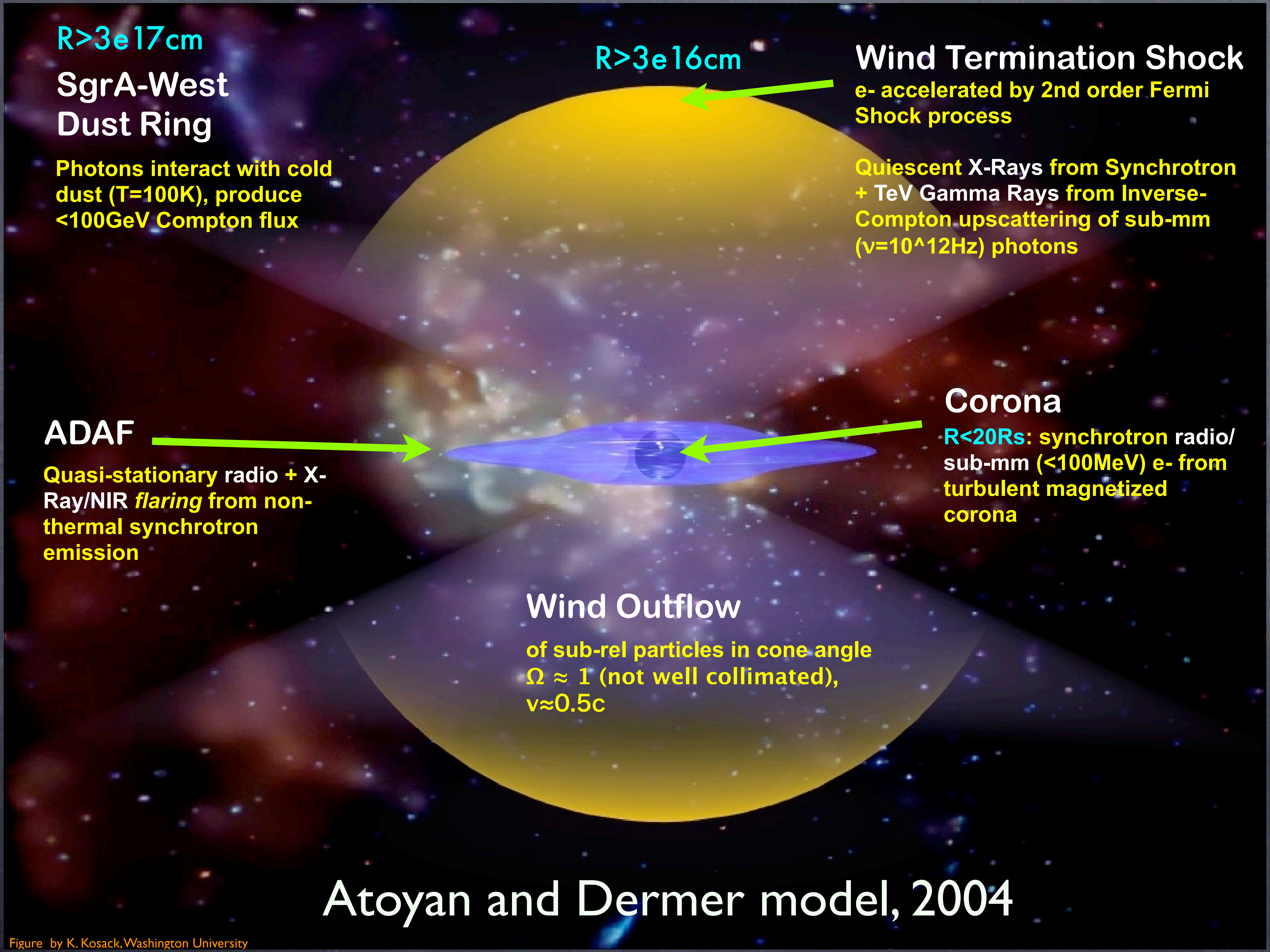
Modeling the GC Region

Sgr A: ADAF+Black Hole Plerion + Sgr A West



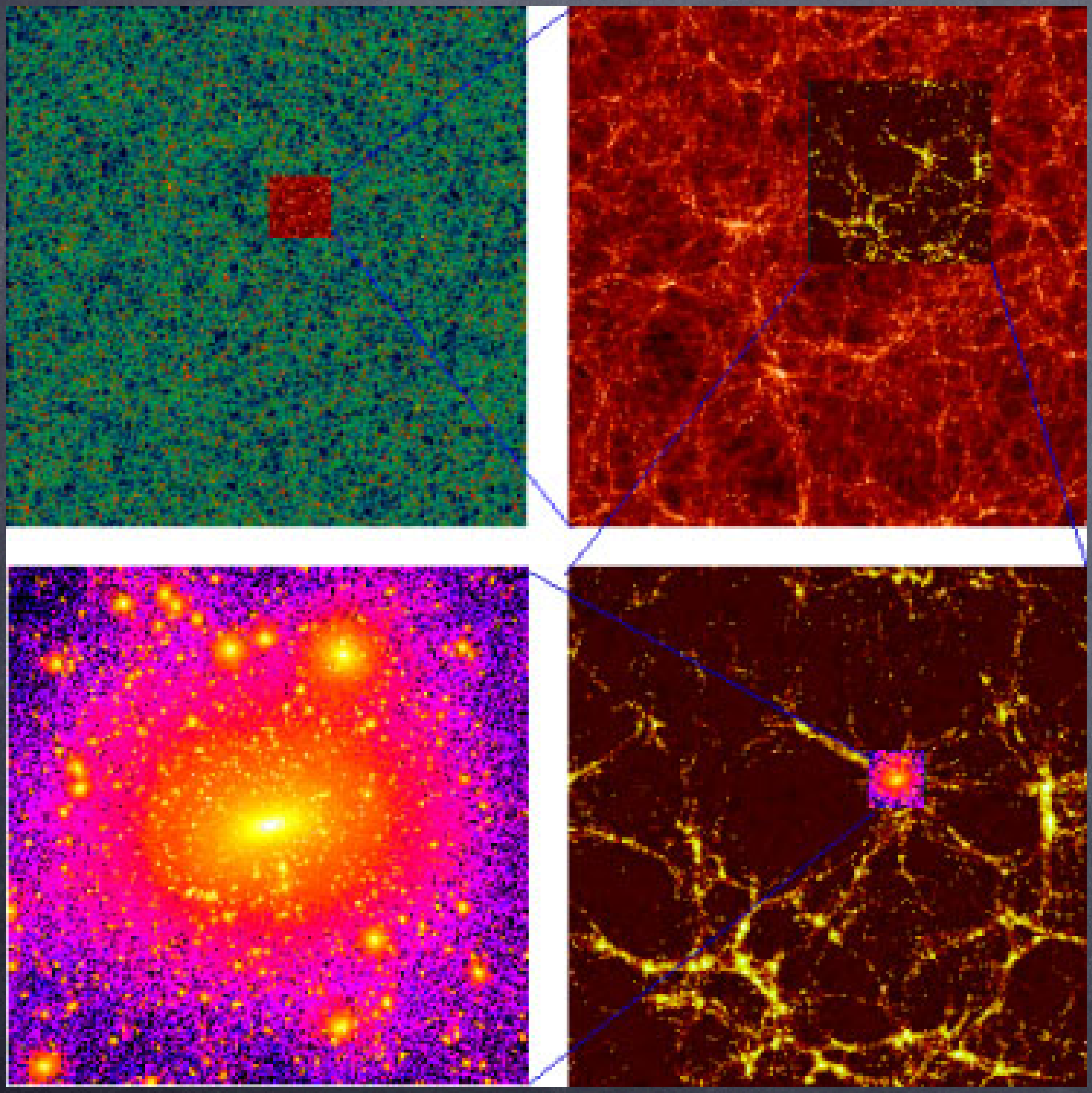
Atoyan & Dermer (2004)

Black-Hole Plerion




VI. Dark Matter

CDM Structure Formation



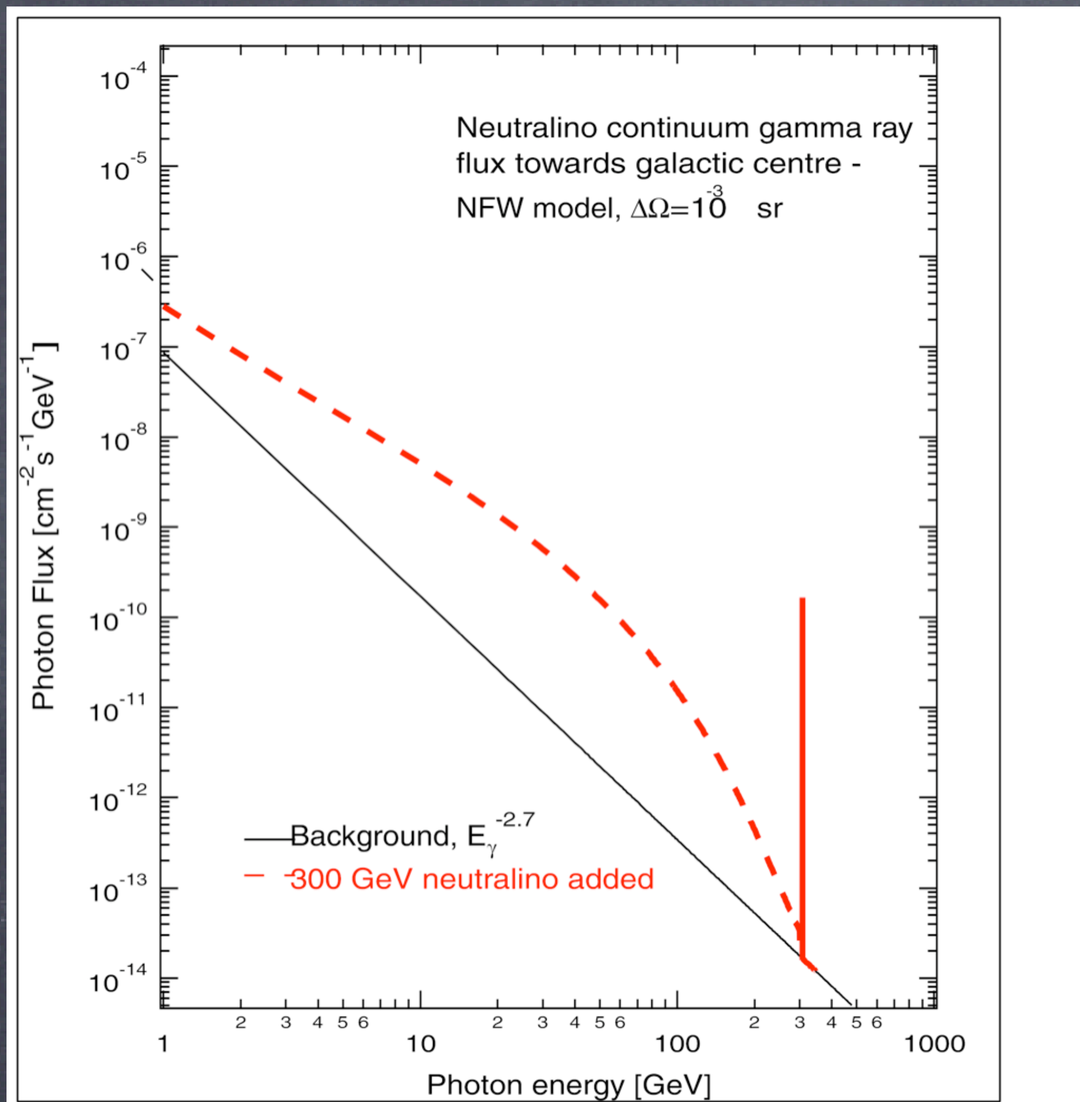
- Start with clumps of dark matter
- Collapse of dark matter provides gravitational potential wells into which ordinary matter falls
- Navarro, Frenck and White (and others) find similar structure on all scales

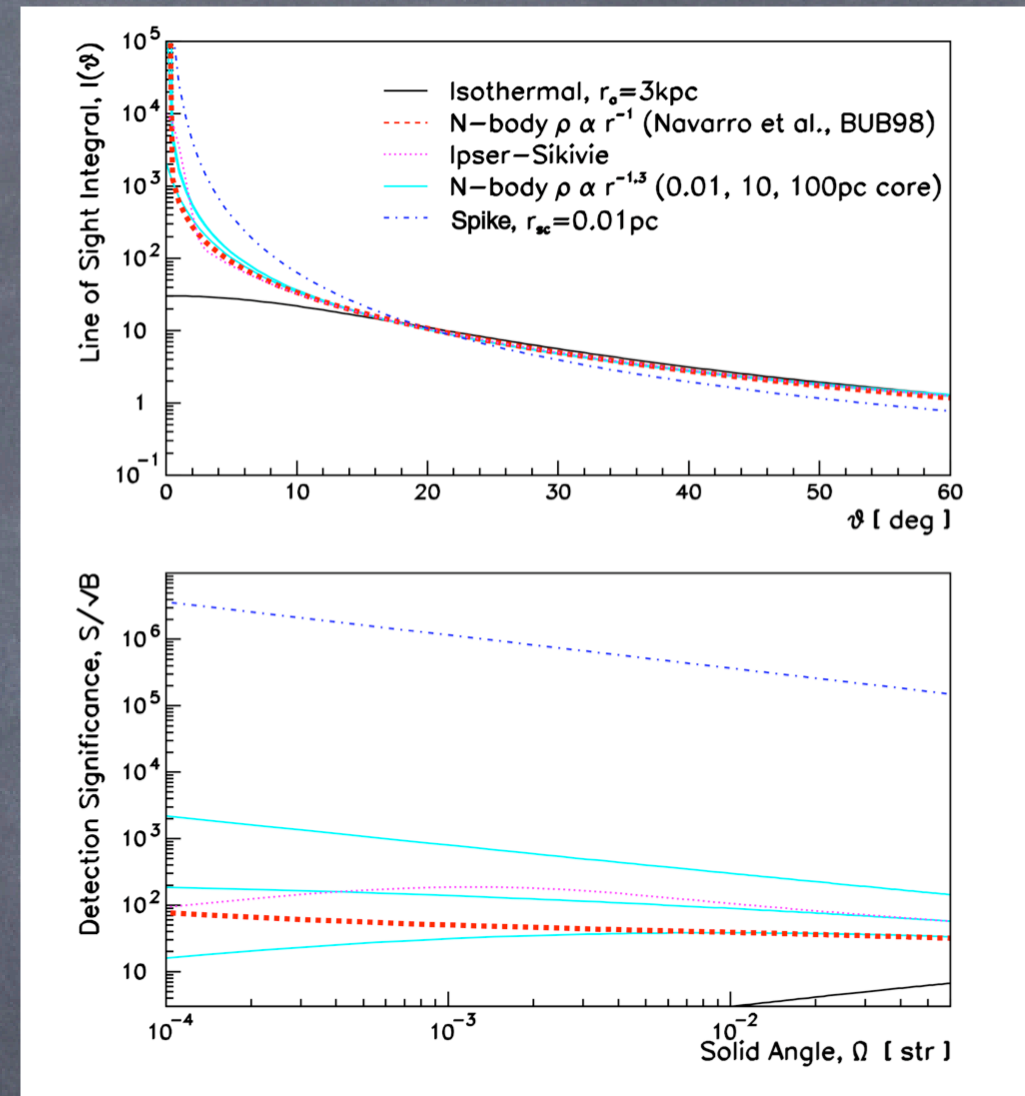
$$\rho(r) \propto \frac{1}{r(r+b)^2}$$

- Massive black holes steepen density profiles (Gondolo and Silk, Gnedin and Primack, Merritt), resulting in

$$\rho(r) \sim r^{-1.5}$$

Neutralino Annihilation

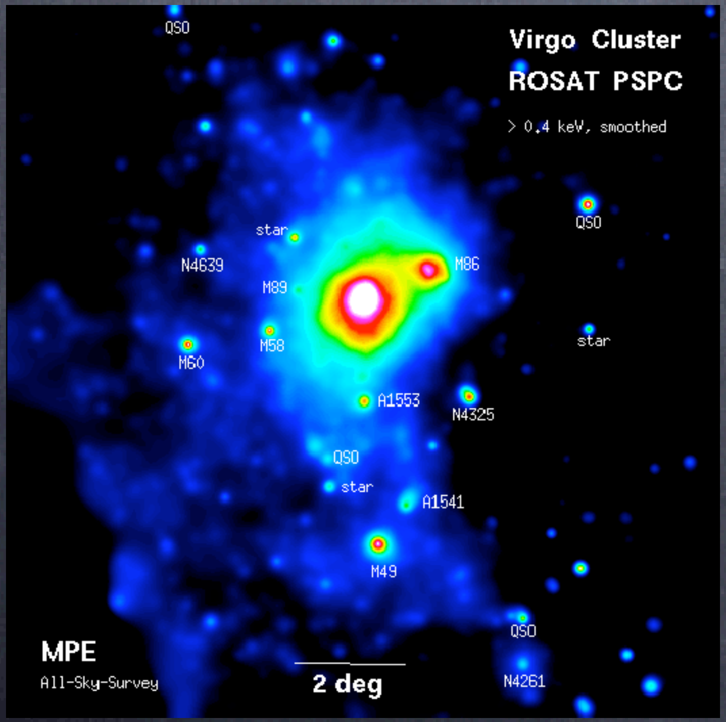




- Neutralino annihilation line + continuum gamma-ray signature (e.g., Jungman, Kamionskowski and Griest, Phys. Rep. 1996, 267, 195)
- Calculate expected line flux for N-body (NFW) halo distributions (e.g., Buckley and Jungman 1995; Bergstrom, Ullio, Buckley 1998, APh, 9, 137)
- A line would only be observable for very steep cusp -> point source near the GC

Dark Matter - Where Next

Andromeda Galaxy



Virgo Galaxy Cluster (X-ray)

Perseus Galaxy Cluster (optical)

Halo Gamma Signal

$$\rho(r) \propto \left[(r/r_s)(1+r/r_s)^2\right]^{-1}$$

Object	Mass (10^{11} M_{sun})	Distance (Mpc)	Virial Radius of Halo (kpc)	Angular Diameter of Source	Best SNR	Optimum Aperture (deg)	Signal
Dwarf (Ursa or Draco)	0.001	0.075	0.600	0.5	0.140	0.054	4.5×10^{-14}
GC	1.0	0.0085	9.6	N/A	65.6	1.92	9.7×10^{-11}
Andromeda	1.0	0.730	9.6	0.75	0.70	0.033	2.3×10^{-13}
Virgo Cluster/ M87	1000	17	188	12	0.54	0.026	1.3×10^{-13}
Coma Cluster	7000	139	354	1.0	0.168	0.013	1.1×10^{-14}

IMBHs?

- Zhao and Silk (Phys. Rev. Letters, in press) make interesting suggestion that Early stars form IMBHs which will cary with them spiked dark matter halos
- While accretion luminosity will be very low, IMBH halos might provide a detectible annihilation signal in our galaxy

VII. VERITAS Status

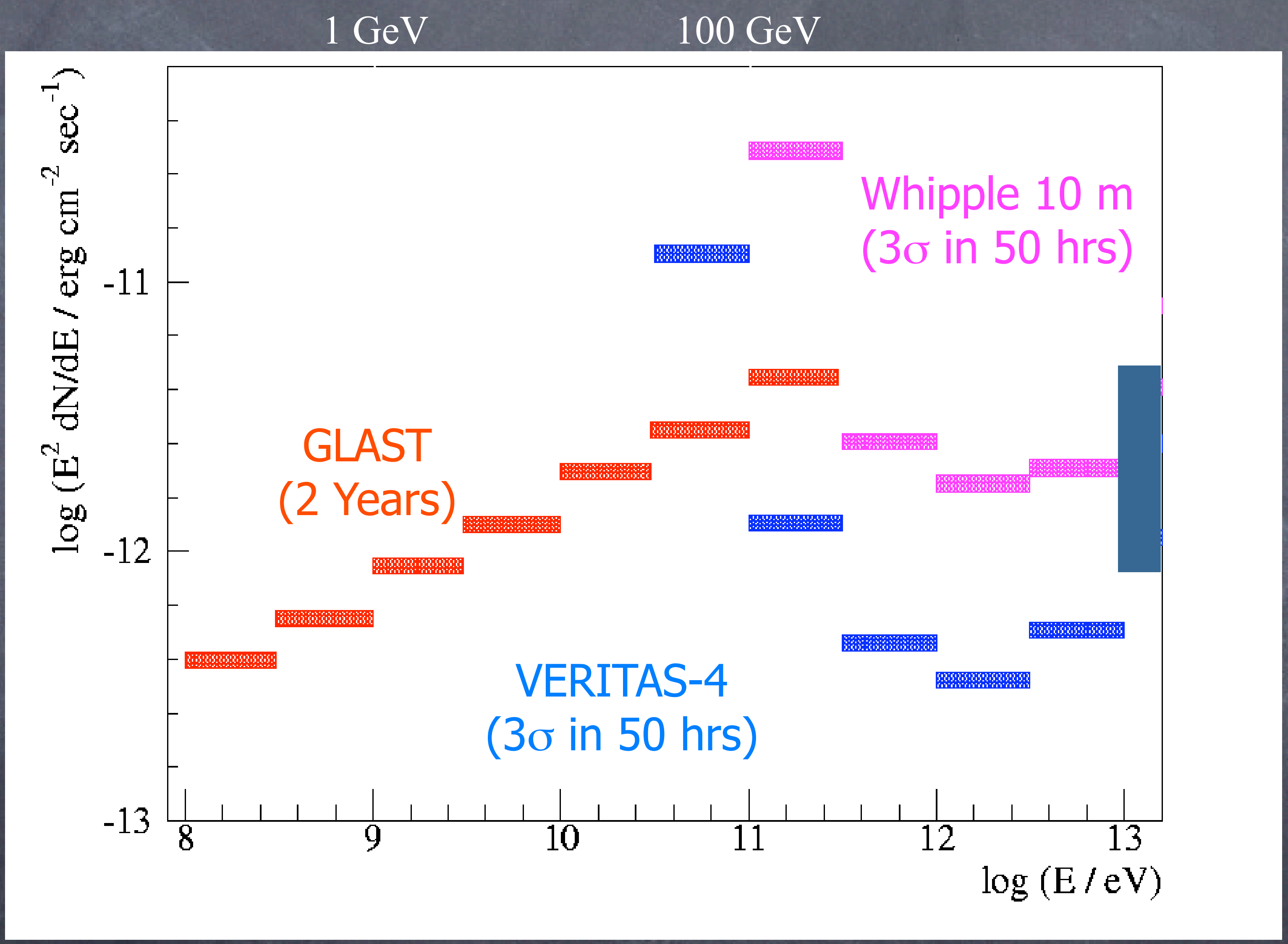
VERITAS Collaboration

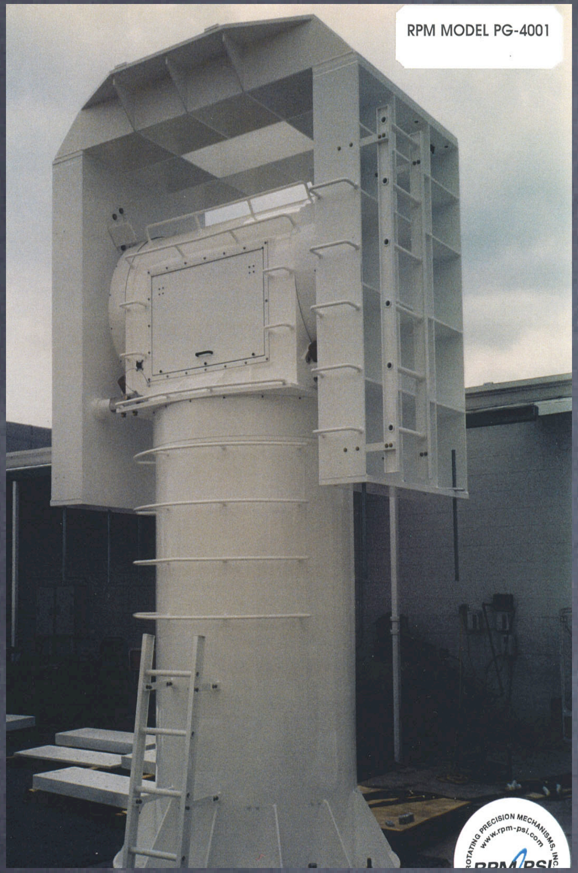
Member Institutes	Collaborators
Iowa State University Planetarium	Adler
Leeds University College	Barnard
McGill University University	DePauw
National University of Ireland, Dublin College	Grinnell
Purdue University	U.C. Santa Cruz
Smithsonian Astrophysical Observatory	U. Mass.
University of California, Los Angeles	N.U.I., Galway
University of Chicago	Cork I.T.
University of Utah I.T.	Galway-Mayo
Washington University, Saint Louis	

Project Office: Whipple Observatory, SAO

Funding from NSF/DOE/Smithsonian/PPARC/SFI/NSERC

Differential Sensitivity

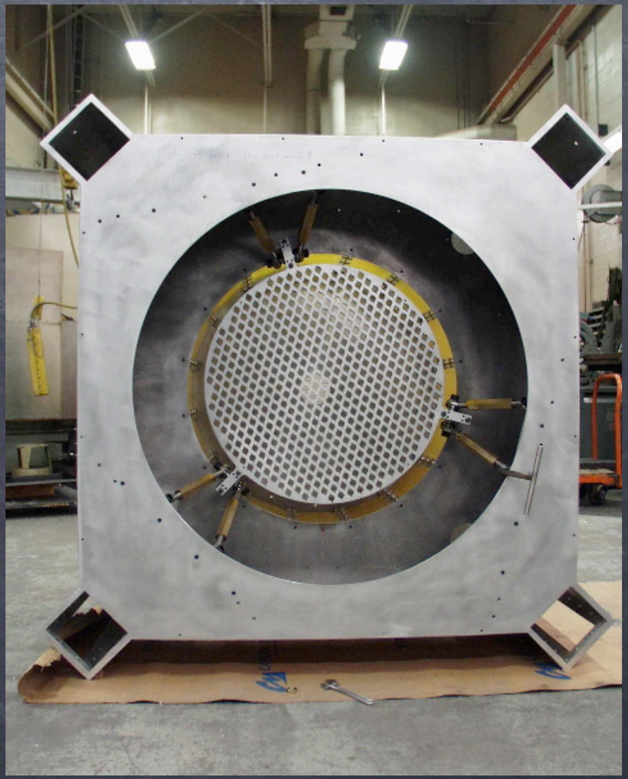




Optical Support Structure
Amber Steel, Chandler, AZ

Positioner
R.P.M.,
Northridge, CA

Focus Box
Aluminium
University of
Arizona



VERITAS Camera

499 pixels; 0.15 degree diameter
3.5 degree FoV

Photo Gallery

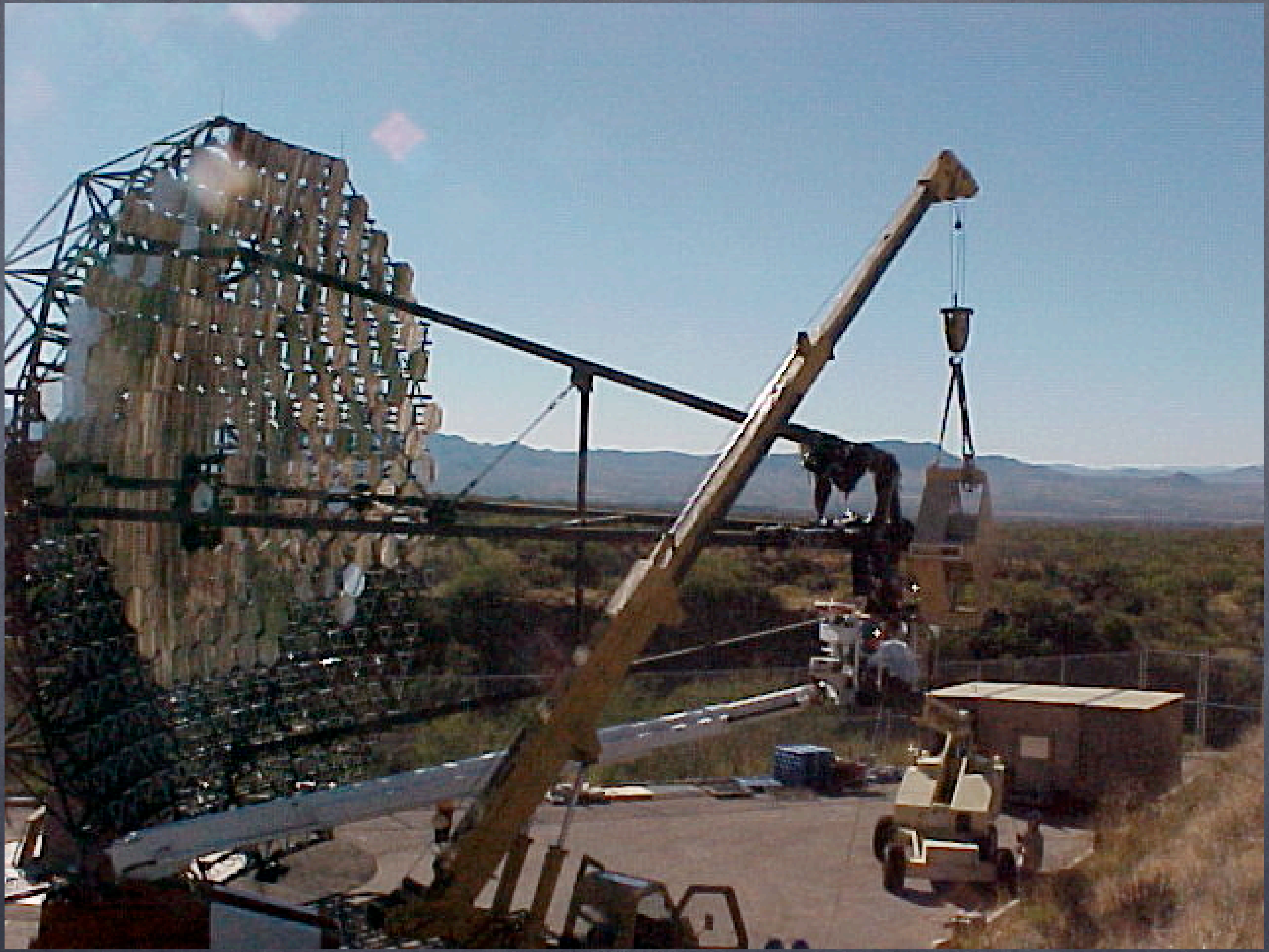


Photo Gallery

VERITAS Telescope-1 completed and operating at temporary site.
First Light on February 1, 2005 (Crab detection, Mrk 421 detection)

VERITAS Progress

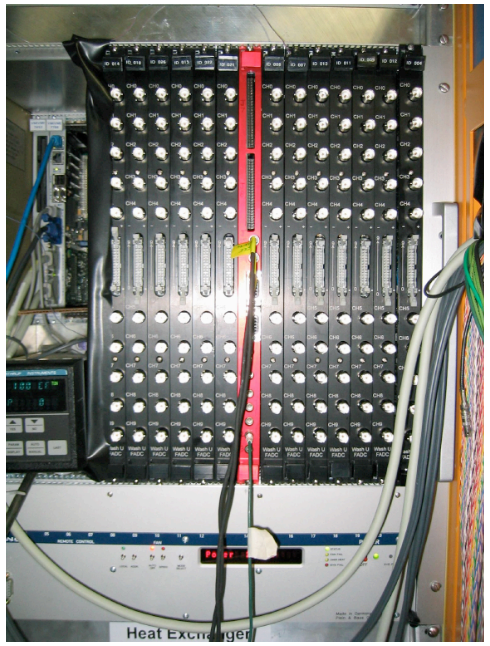
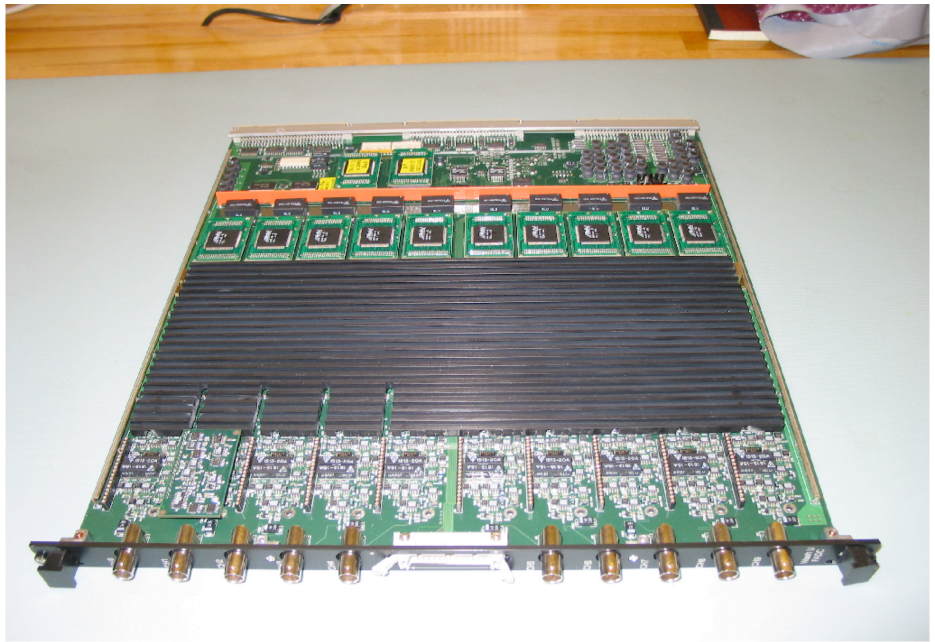
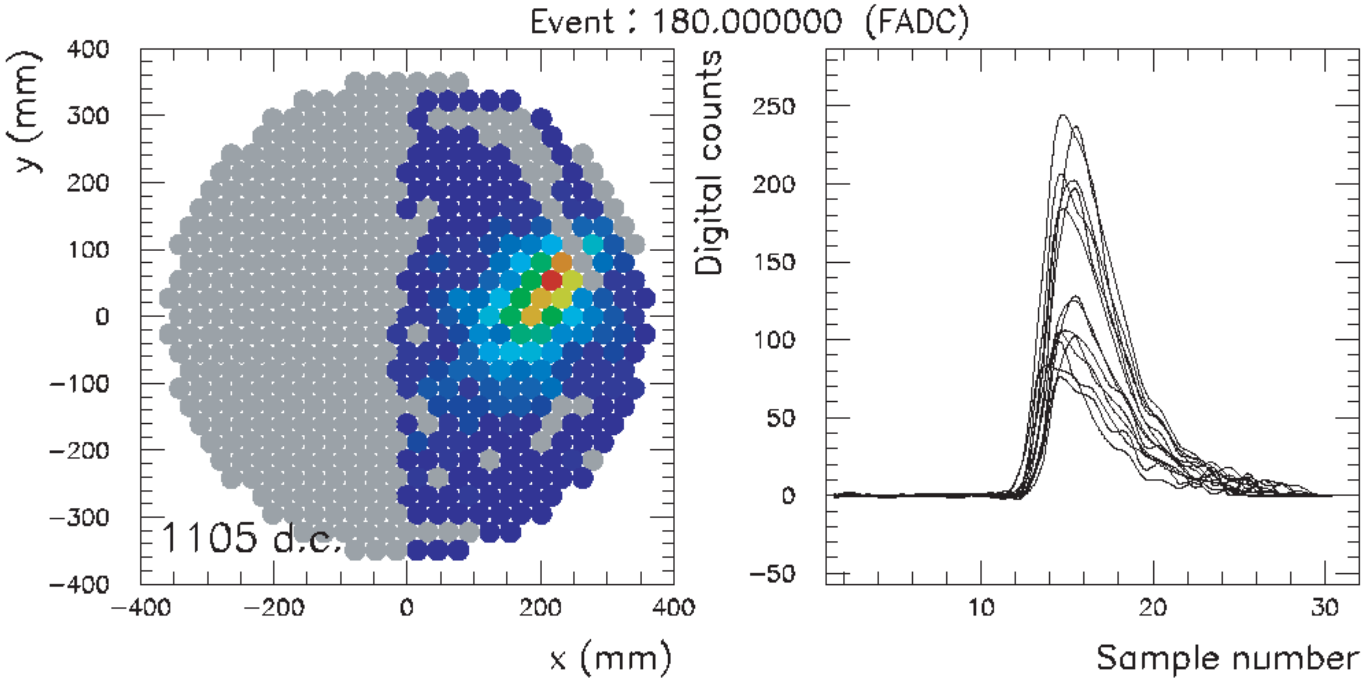



Figure 3: *Left:* One FADC VME crate populated with 130 channels of 500 MHz FADCs. *Right:* Close-up of one of our custom 10-channel FADC boards, designed and favricated entirely by the Washington University group.

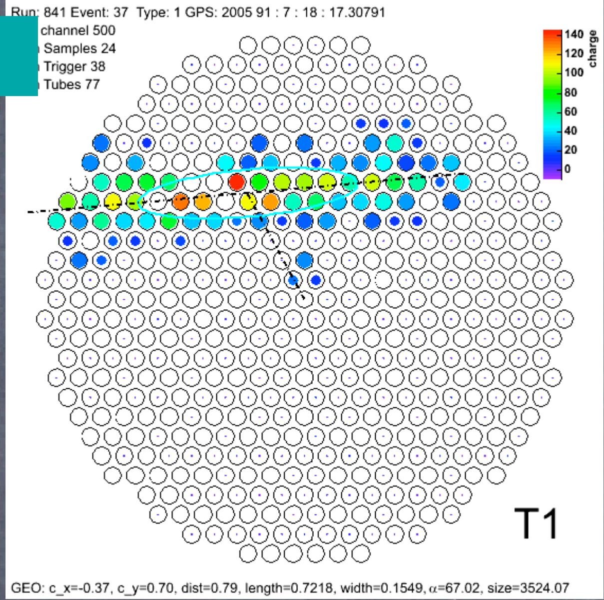


A sample cosmic ray event from the prototype telescope. The waveforms in the individual photomultiplier tubes are shown to the right [18].

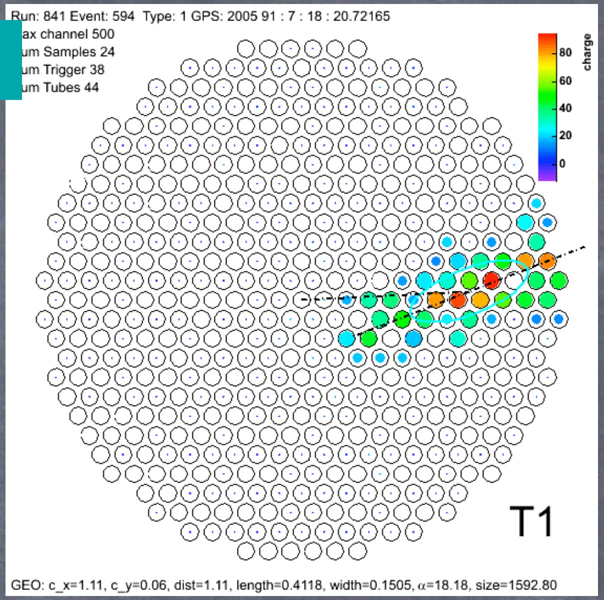
First Light

Shower Images from Telescope-1

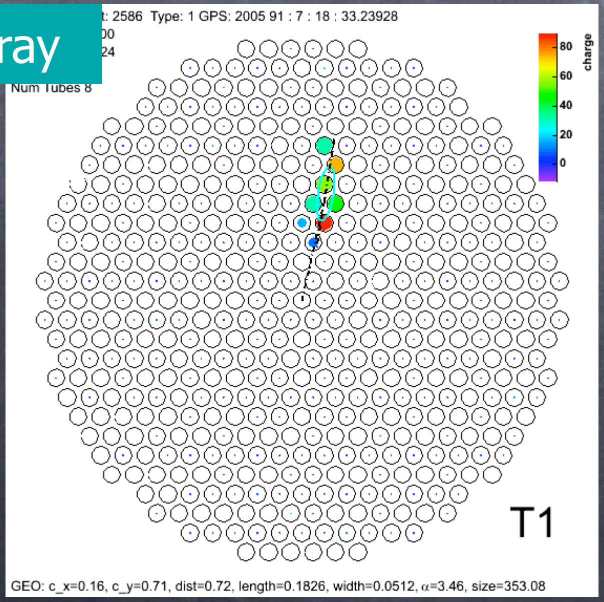
Hadron



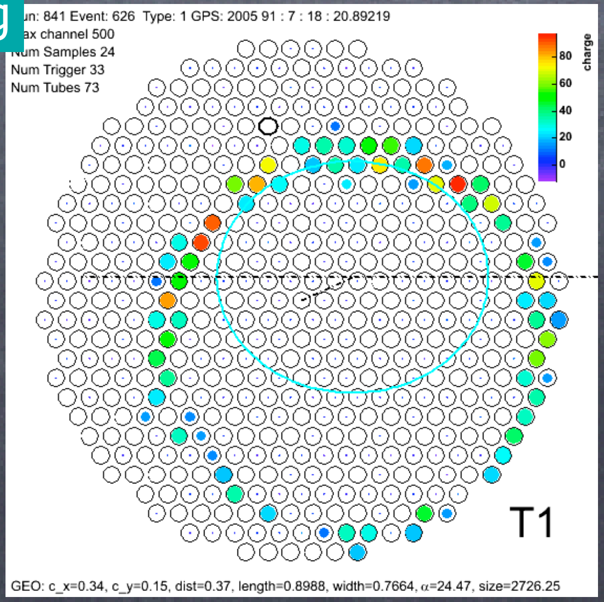
Hadron



Gamma ray



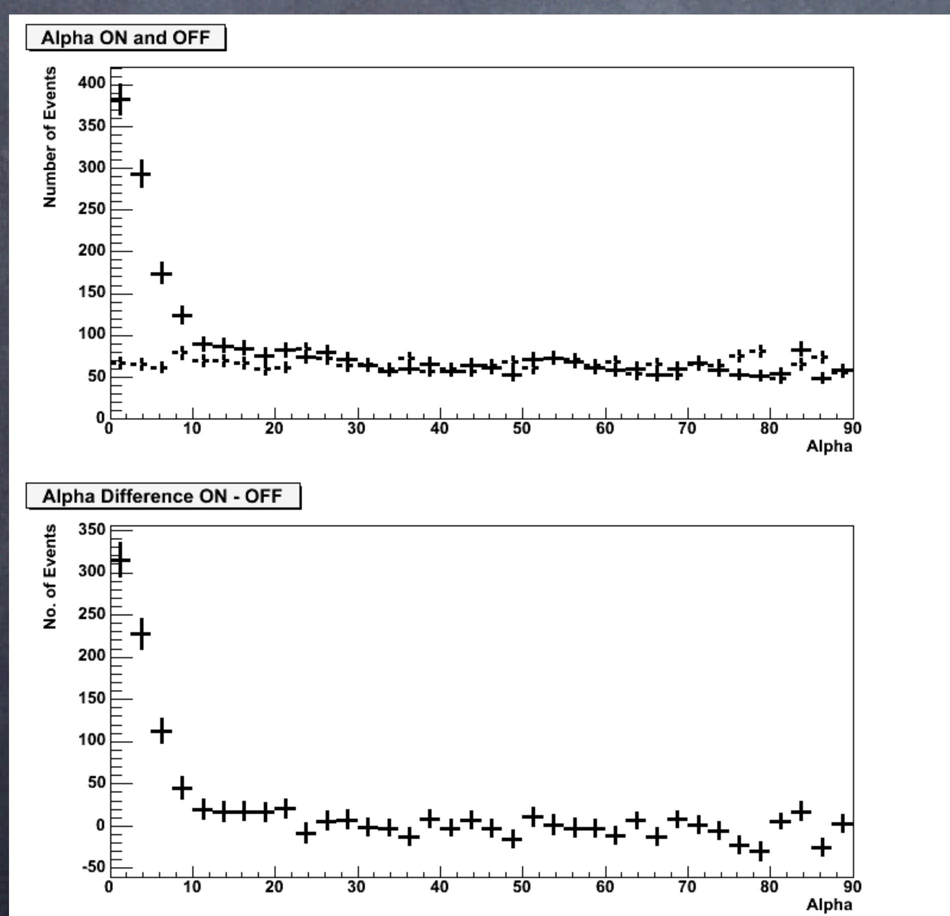
Muon Ring

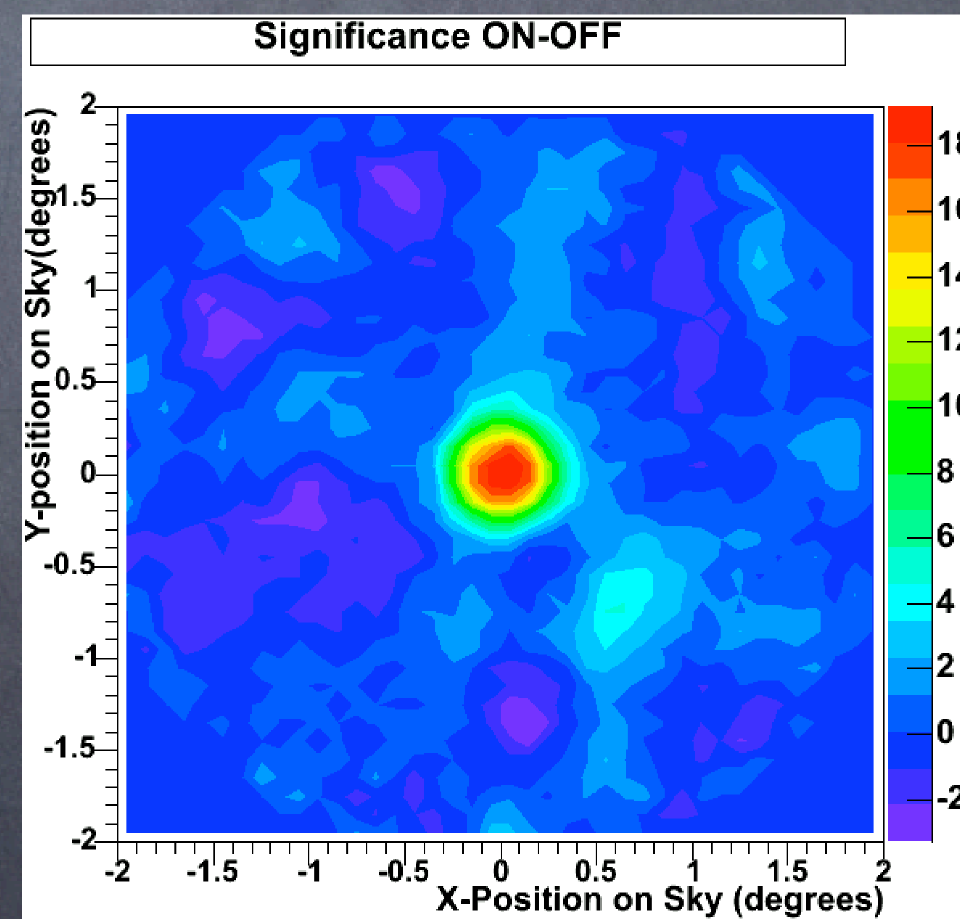


First Light

Crab Nebula

4.37 hours ON; +21.1 sigma
2.56 gammas/minute
10.1 sigma/sqrt(time in hours)

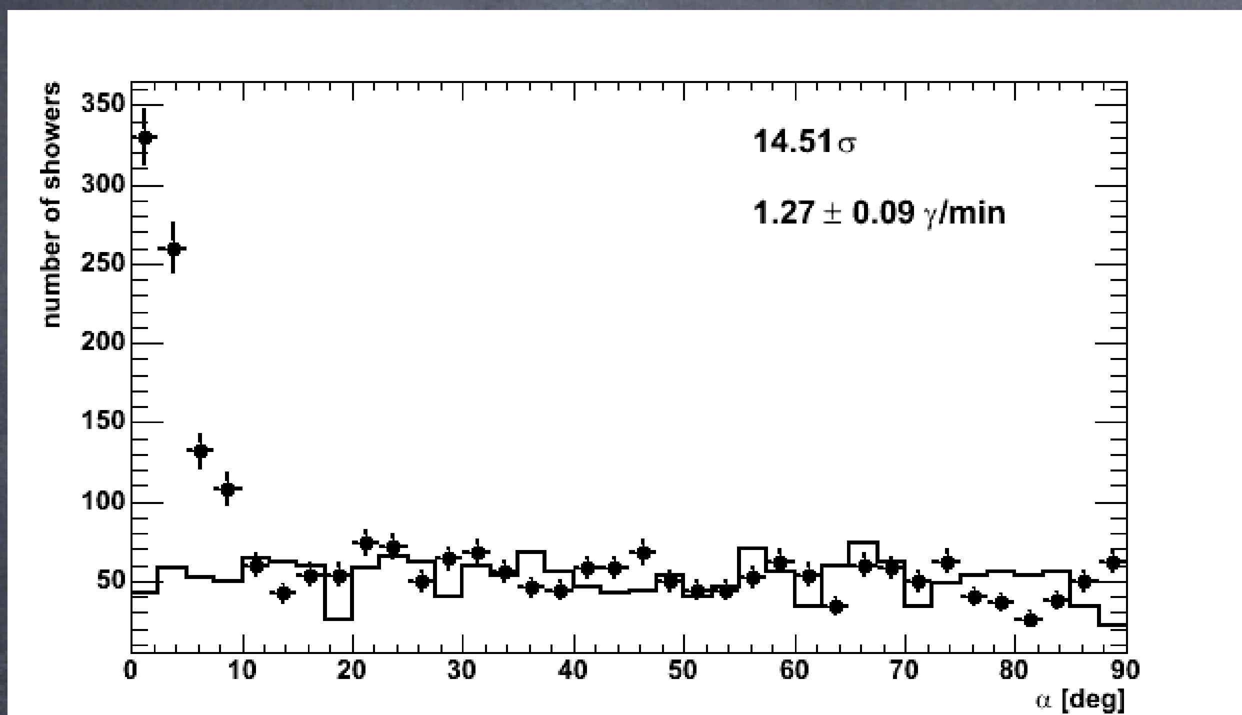




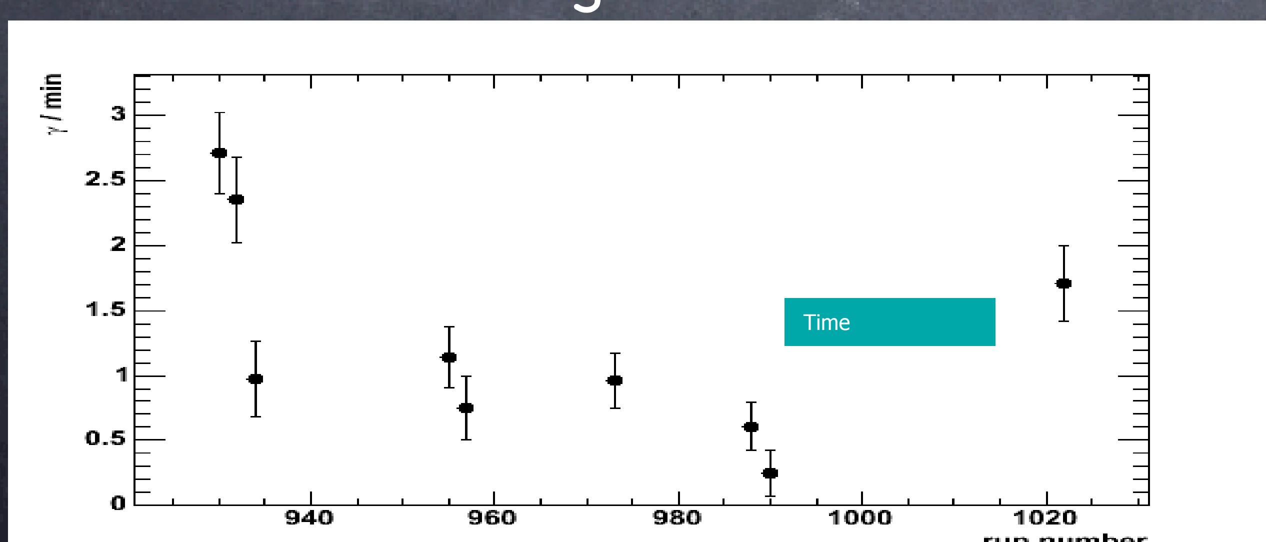
First Light

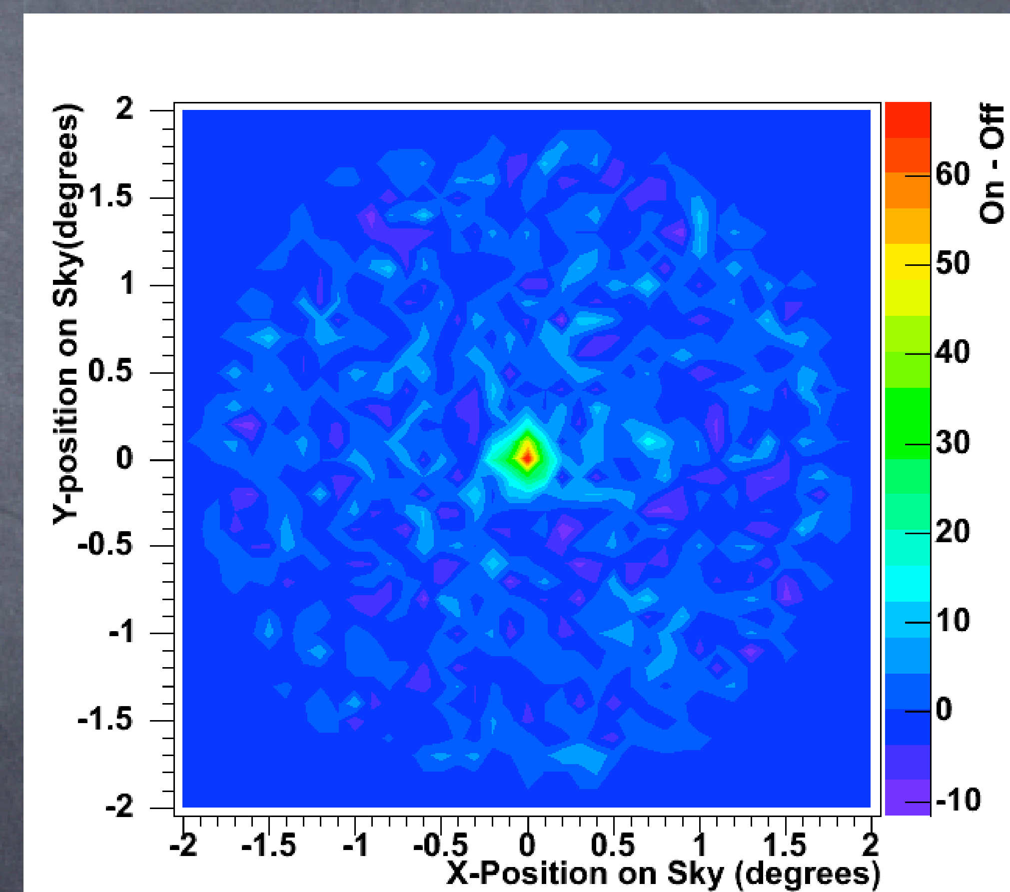
Markarian 421

5.6 hours ON   +14.51 sigma



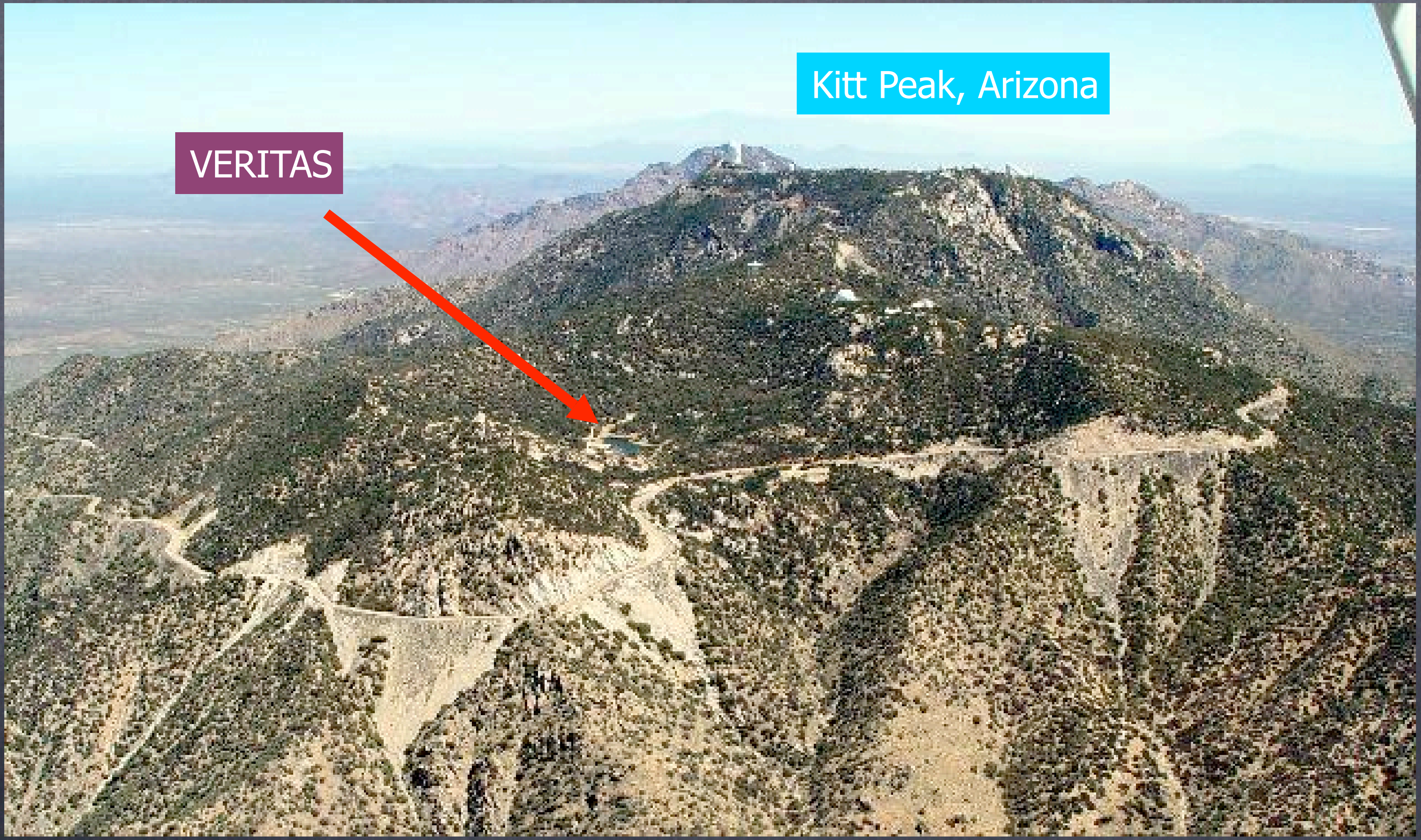
Light Curve





VERITAS Site

Horseshoe Canyon, Kitt Peak



VERITAS Site

The odyssey continues

- National Science Foundation issued Stop Work order for VERITAS activity on Kitt Peak on

  April 7, 2005

- NSF has leased Kitt Peak mountain as site for national optical observatory since 1958 when lease was signed with Indian Nation;

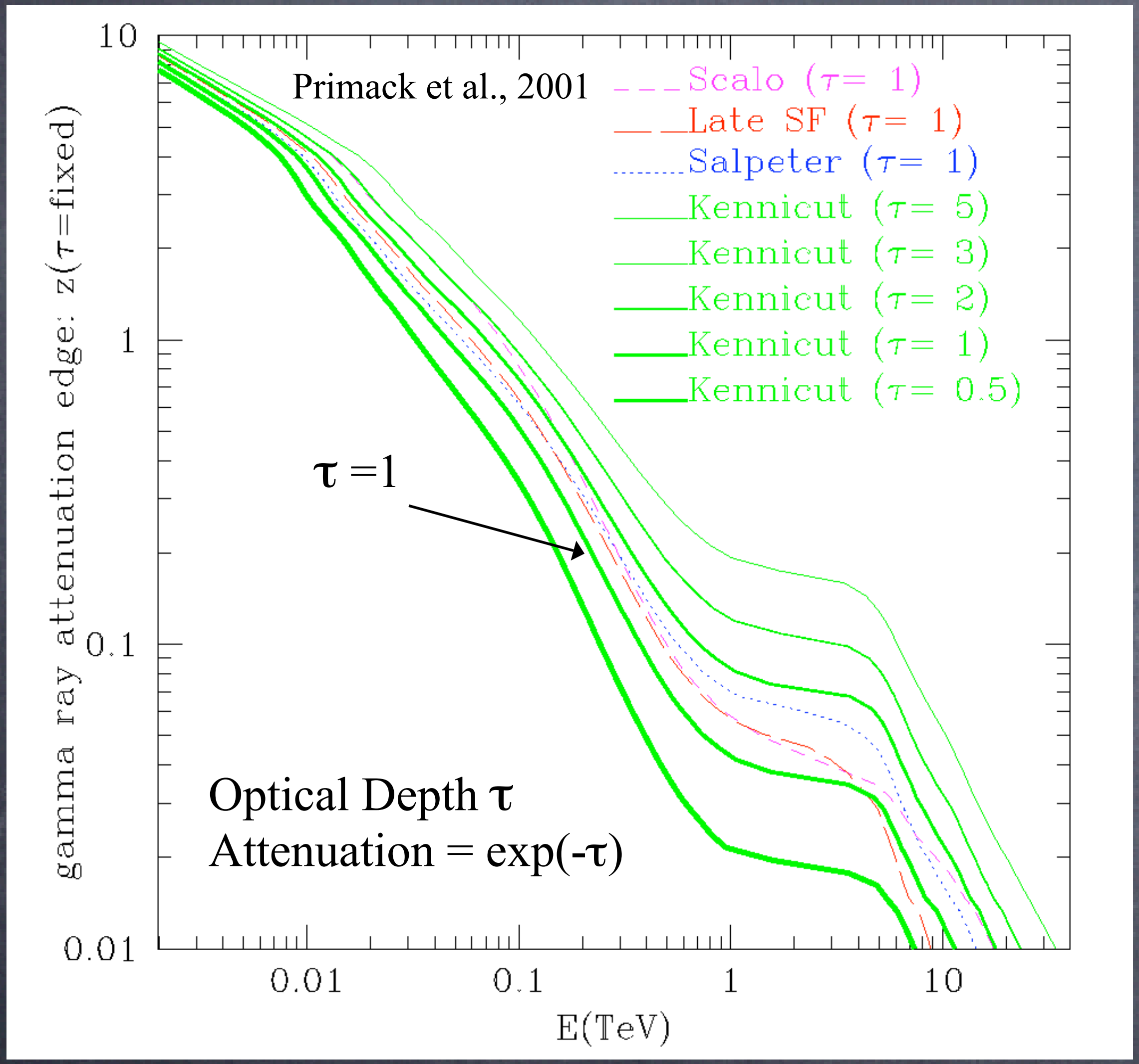
  VERITAS sub-leases site from NSF

- Complaint lodged by Tohono O'Odham Nation; court hearing scheduled for June 16, 2005

- New Environmental Assessment required;

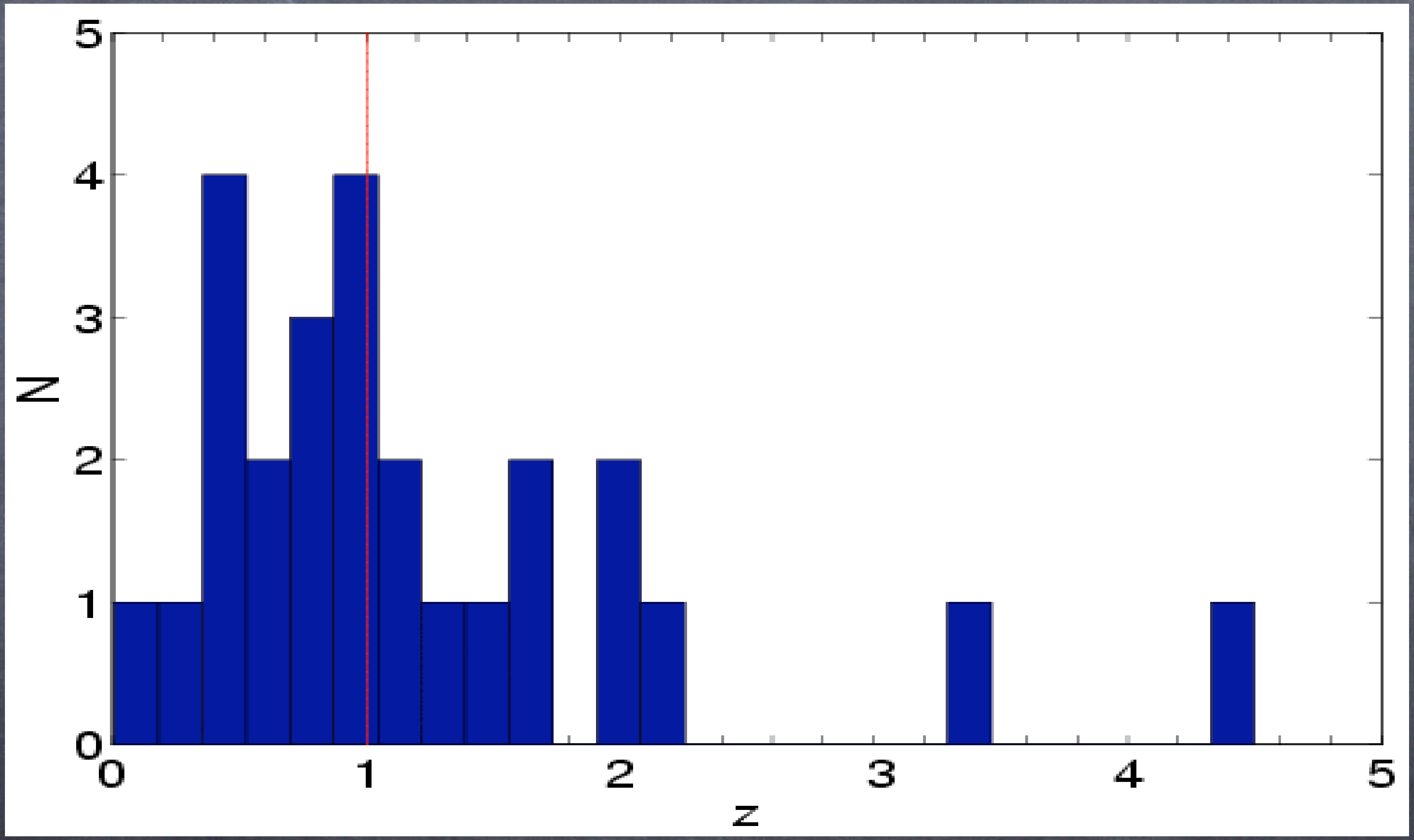
VIII. Beyond VERITAS

Looking over the Horizon



- One needs to get down to 10s of GeV to see out to cosmological (z>2) distances.
- Relatively fast slewing is needed to see GRBs, but low threshold and good instantaneous sensitivity is also important

GRB Redshift Dist.



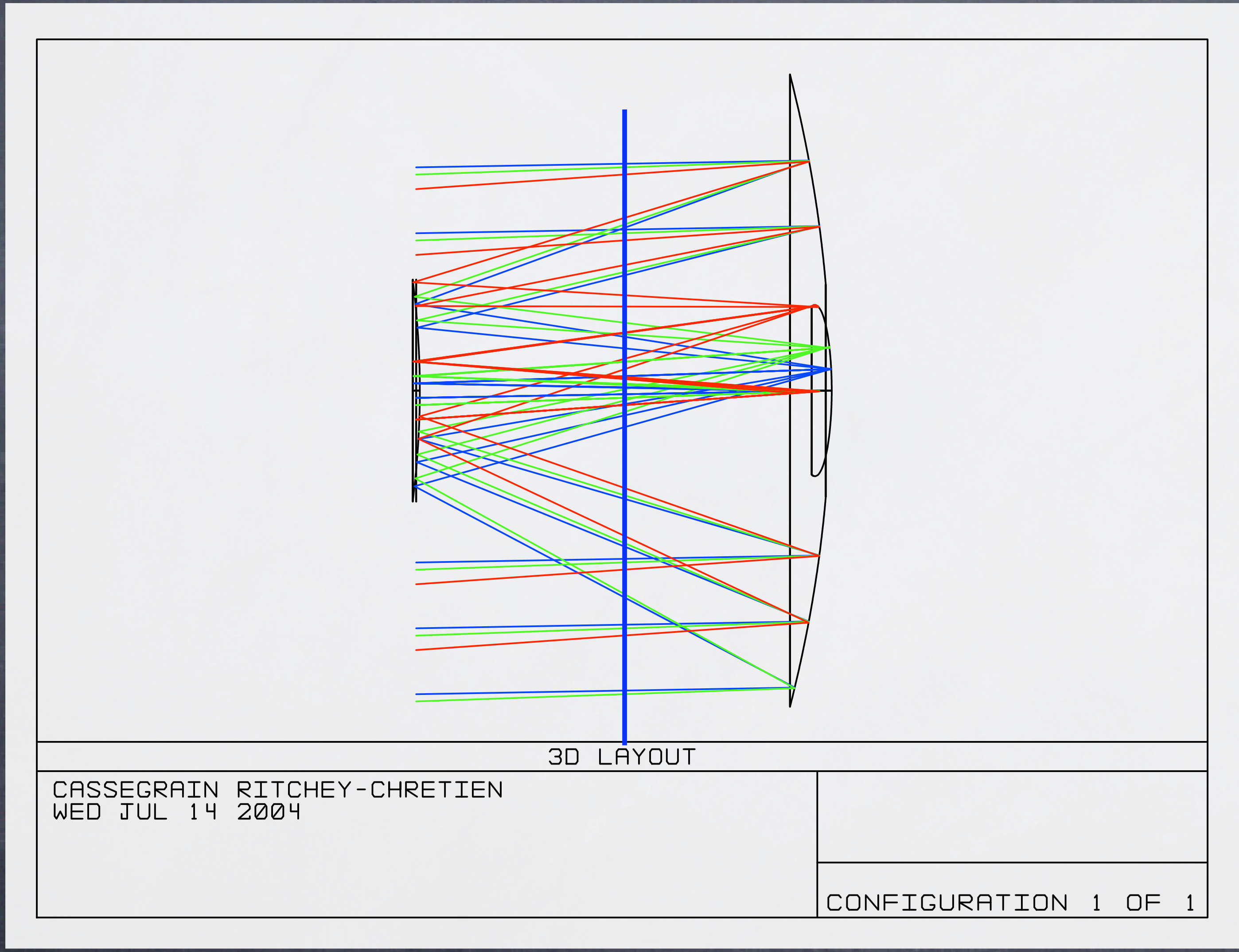
Science

- Next generation instruments should:
  - Extend horizon to cosmological distances!
  - Cover the whole sky with high temporal density
  - Provide all-sky coverage on AGN timescales (< 1hr), and provide AGN ToOs for other instruments
  - Respond to AGN ToOs in minutes
  - Respond to GRB ToOs in < 1 minute

Optical Design

Ritchey – Chretien with curved focal plane

Primary and secondary OSS have optimized conic constants



$D_{\text{primary}} = 25\,\text{m}$

$D_{\text{secondary}} = 10\,\text{m}$

$f/\# = 2.1$

$f = 50\text{m}$

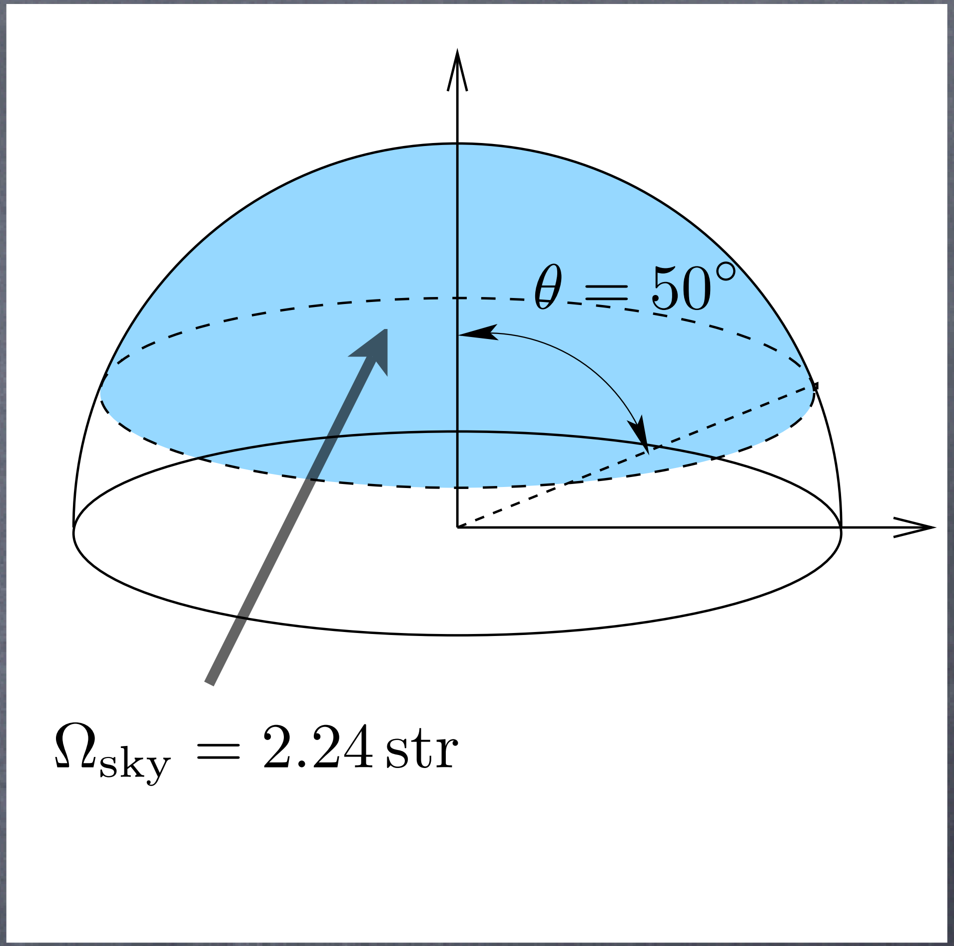
$D_{\text{eff}} = \sqrt{25^2 - 10^2} = 23\,\text{m}$

$0.15^\circ \leftrightarrow 13\,\text{cm} = 5\,\text{in}$ PMTs!

- 2800 PMTs for 8°, 4400 PMTs for 10°
- Large f/# allows large concentration, baffling of light outside secondary
- PMTs and electronics over mount, no cables

VLACT Observing Mode

- Assume telescope slews continuously to cover sky to $\theta = 50^\circ$ zenith angle every hour
- Assume sensitivity of $\dfrac{1\,\mathrm{Crab}}{\sqrt{t/30\,\mathrm{sec}}}\left(\dfrac{E_\mathrm{thr}}{100\,\mathrm{GeV}}\right)^{0.65}$
- For an 8° fov, $\Omega_\mathrm{fov} = 0.0153\,\mathrm{str}$
- Out to 50° zenith angle, $\Omega_\mathrm{sky} = 2.24\,\mathrm{str}$

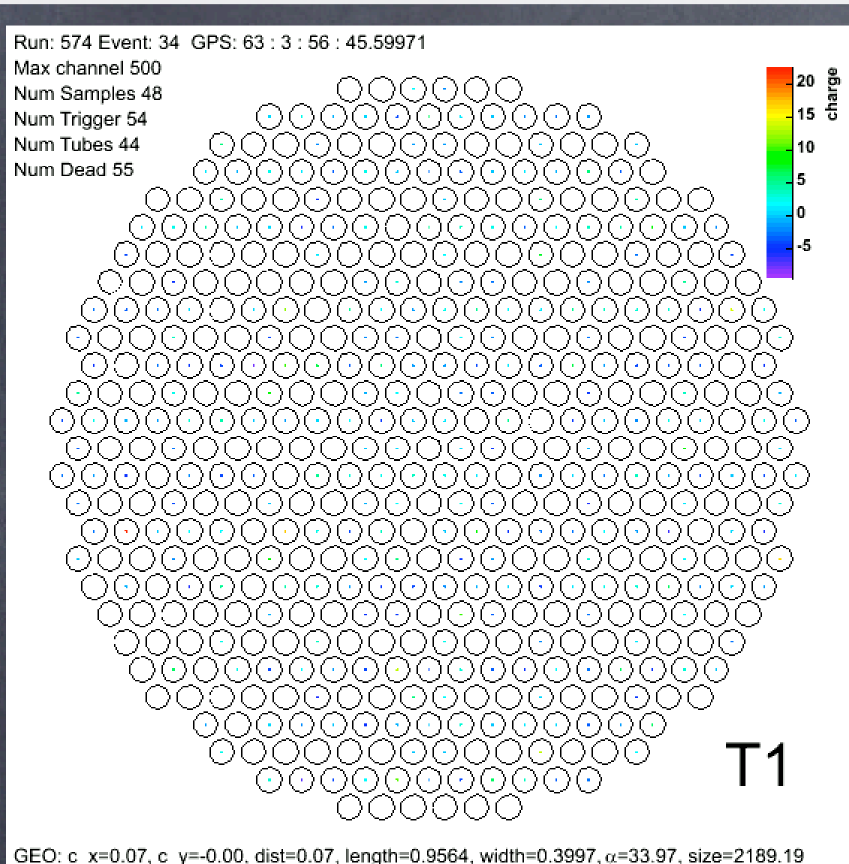


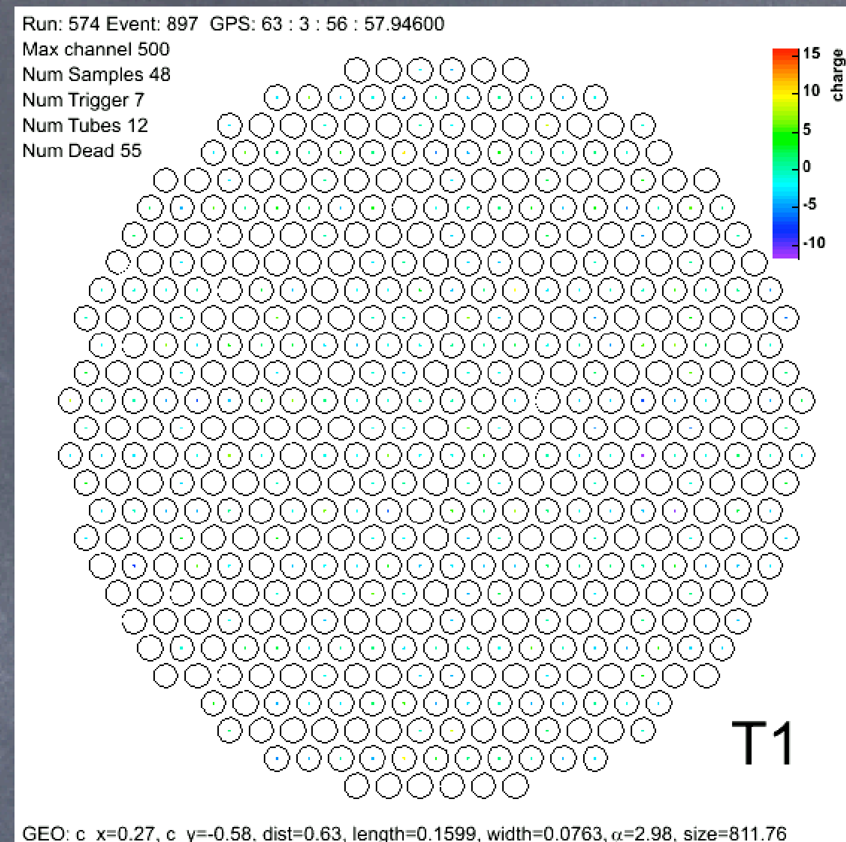
- Sensitivity in one hour $S_\mathrm{hr} = \left(\dfrac{40\,\mathrm{GeV}}{100\,\mathrm{GeV}}\right)^{0.65}\left[\left(\dfrac{\Omega_\mathrm{fov}}{\Omega_\mathrm{sky}}\right)1\,\mathrm{hr}/30\,\mathrm{sec}\right]^{-1/2} = 0.61\,\mathrm{Crab}/\sqrt{\mathrm{hr}}$
- Sensitivity in 1 yr $S_\mathrm{yr} = \left(\dfrac{40\,\mathrm{GeV}}{100\,\mathrm{GeV}}\right)^{0.65}\left[\left(\dfrac{\Omega_\mathrm{sky}}{4\pi}\right)\left(\dfrac{\Omega_\mathrm{fov}}{\Omega_\mathrm{sky}}\right)\dfrac{0.1\cdot 1\,\mathrm{yr}}{30\,\mathrm{sec}}\right]^{-1/2} = 50\,\mathrm{mCrab}/\sqrt{\mathrm{yr}}$

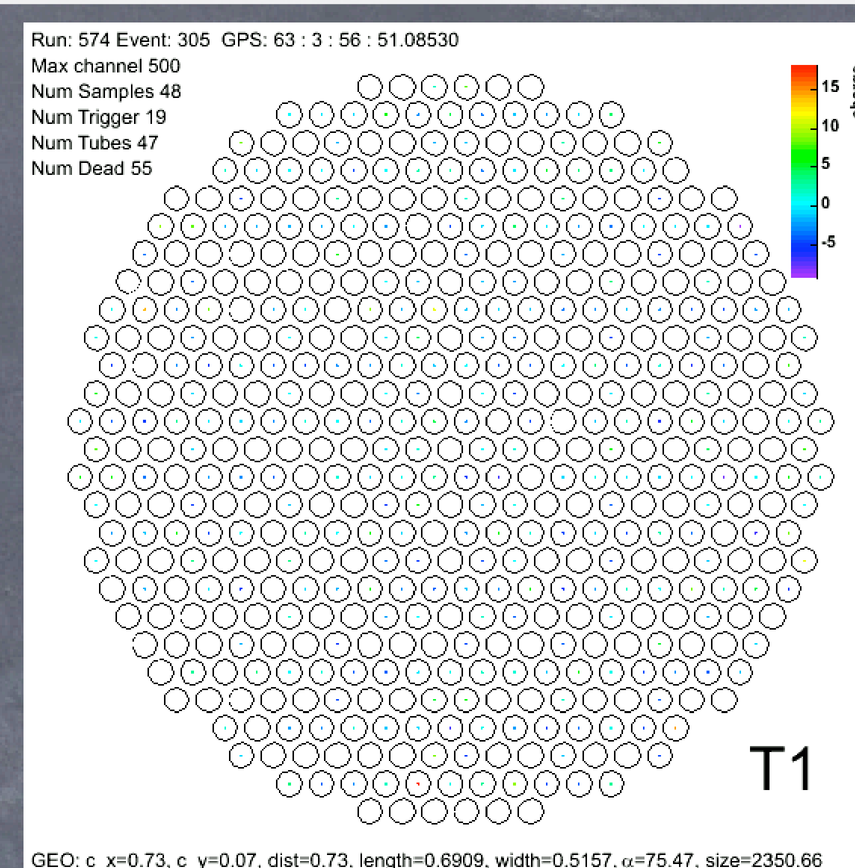
Conclusions

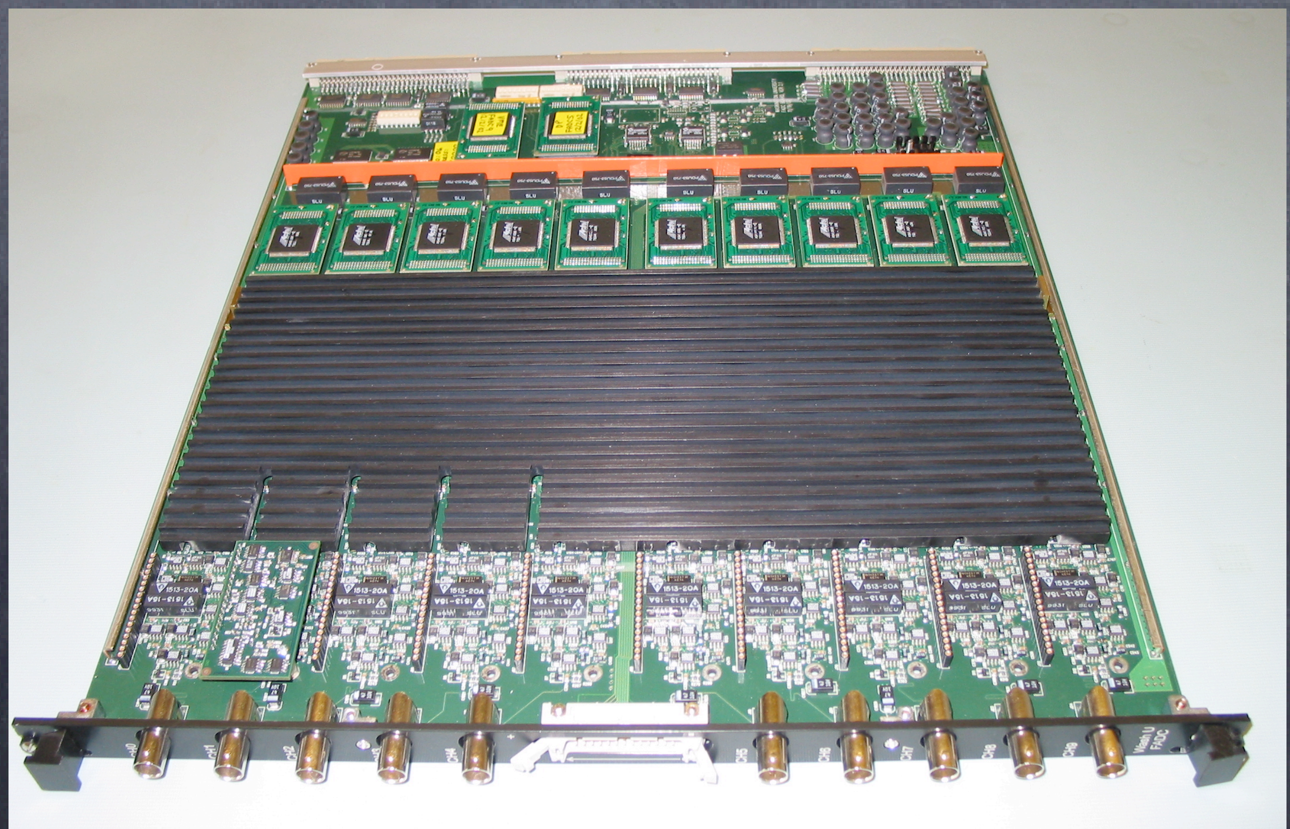
- HESS has made a number of wonderful discoveries of galactic sources, but extragalactic science is yet to come
- VERITAS will make important new measurements of time-resolved spectral variability of the strong TeV blazars
- VERITAS should make spectral measurements on enough AGNs to begin to measure the EBL (GLAST will be important for normalization to the LE spectrum)
- Many interesting galactic sources in the northern hemisphere (Cas-A, Tycho, IC443, W44, etc.) and one unique extragalactic source (M87).
- All of the current instruments (CANGAROO, MAGIC, HESS and VERITAS) are narrow field instruments, and there are more than enough targets to keep all of these busy

Flash ADCs


Run: 574 Event: 34 GPS: 63 : 3 : 56 : 45.59971
Max channel 500
Num Samples 48
Num Trigger 54
Num Tubes 44
Num Dead 55
charge
T1
GEO: c_x=0.07, c_y=-0.00, dist=0.07, length=0.9564, width=0.3997, α=33.97, size=2189.19


Run: 574 Event: 897 GPS: 63 : 3 : 56 : 57.94600
Max channel 500
Num Samples 48
Num Trigger 7
Num Tubes 12
Num Dead 55
charge
T1
GEO: c_x=0.27, c_y=-0.58, dist=0.63, length=0.1599, width=0.0763, α=2.98, size=811.76


Run: 574 Event: 305 GPS: 63 : 3 : 56 : 51.08530
Max channel 500
Num Samples 48
Num Trigger 19
Num Tubes 47
Num Dead 55
charge
T1
GEO: c_x=0.73, c_y=0.07, dist=0.73, length=0.6909, width=0.5157, α=75.47, size=2350.66



Robotic Telescopes

Optical Monitoring of Gamma-Ray Transients

Antipodal Transient Observatory