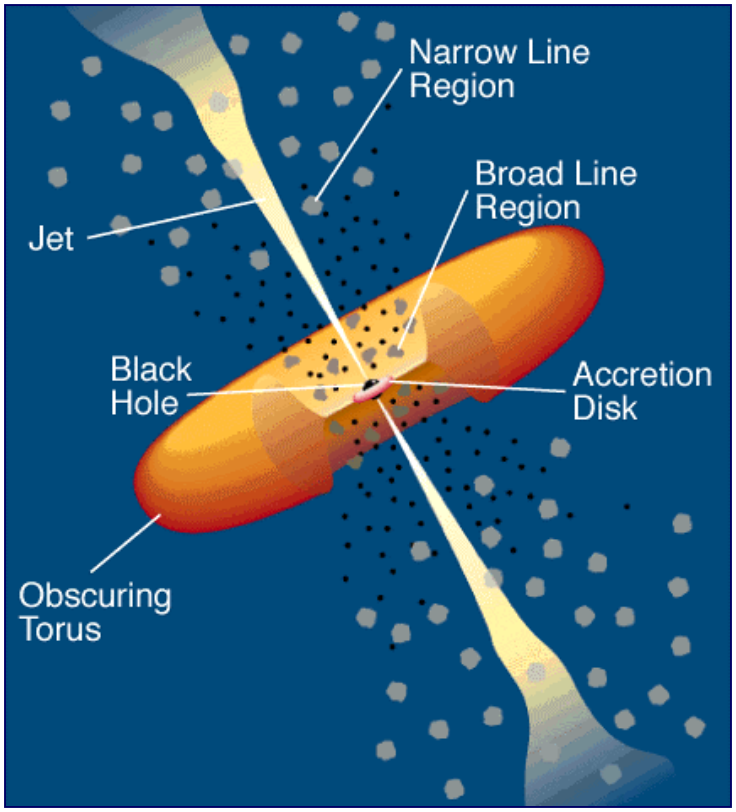
Extreme high-energy variability of Markarian 421

- Mrk 421 – an extreme blazar
- Previous observations – outstanding science issues
- 2001 Observations by VERITAS/Whipple 10 m
- 2001 Light Curve
- Energy spectrum – is there an IR cutoff?
- Conclusions

astro-ph/0107113 – ApJ 560, L45, 2001

Blazar Properties

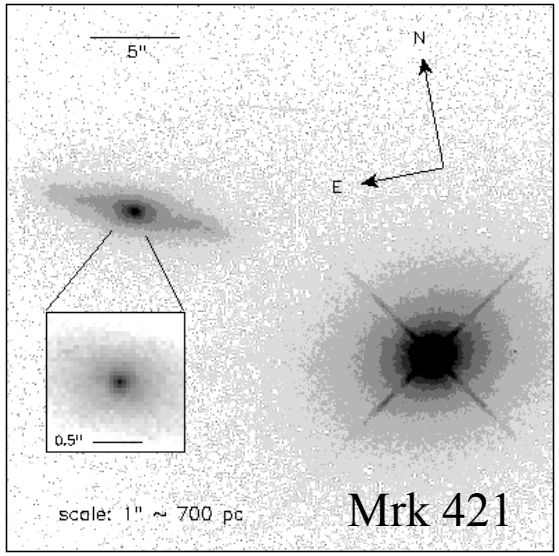
- Luminous, radio-loud AGN
- Polarized, highly variable (< 1 hr)
- Superluminal motion
- Broad, double-peaked SED: most energy in X-ray, γ-ray bands



→ Compact sources, BH powered

→ Relativistic beaming in jets

Markarian 421



QSO 1101+384
Gorham et al.
HST archival

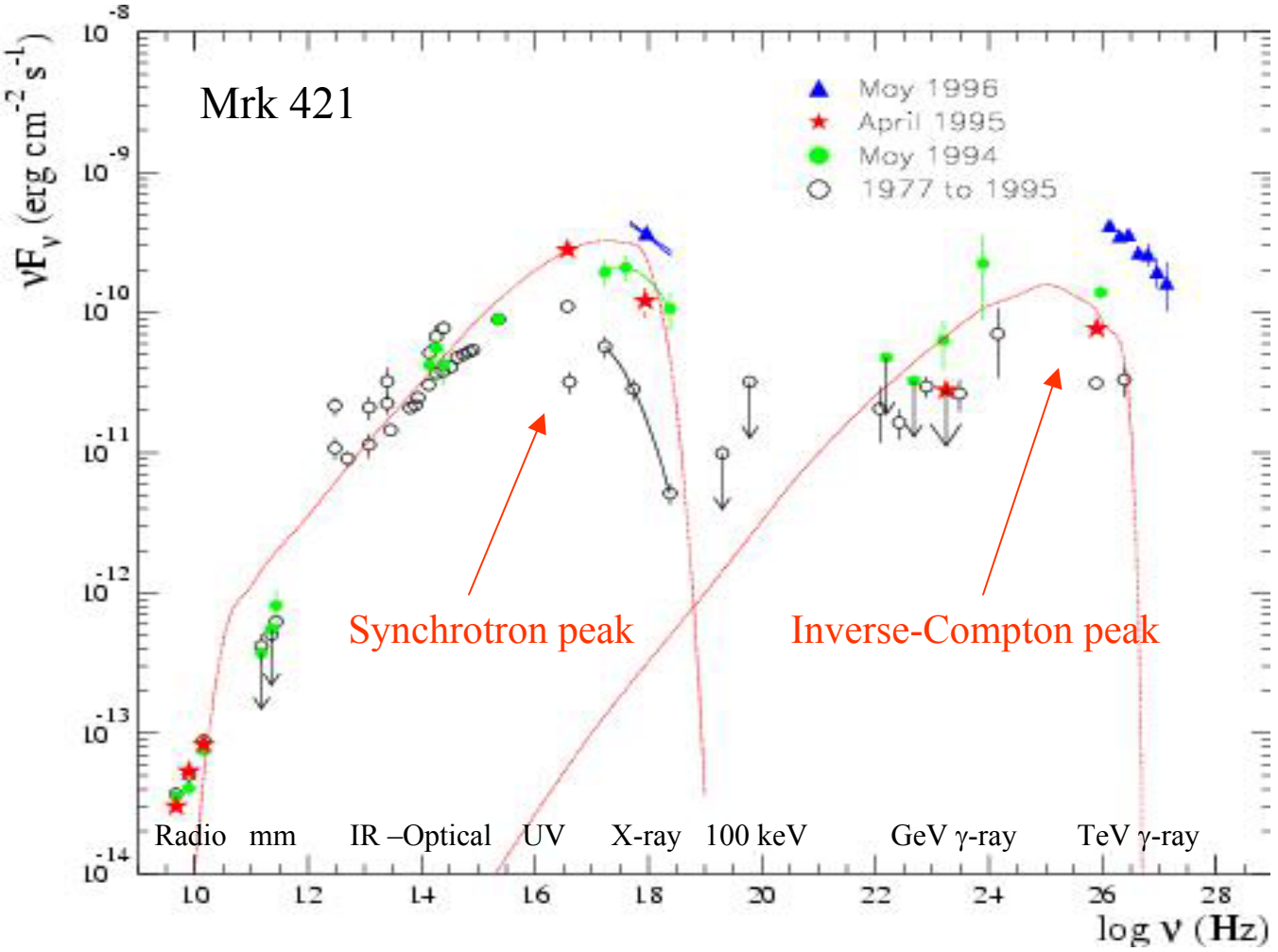
- Giant elliptical galaxy
- Closest BL-Lac (z = 0.030)
- Weak absorption lines

$1 \text{ TeV} = 10^{12} \text{ eV}$

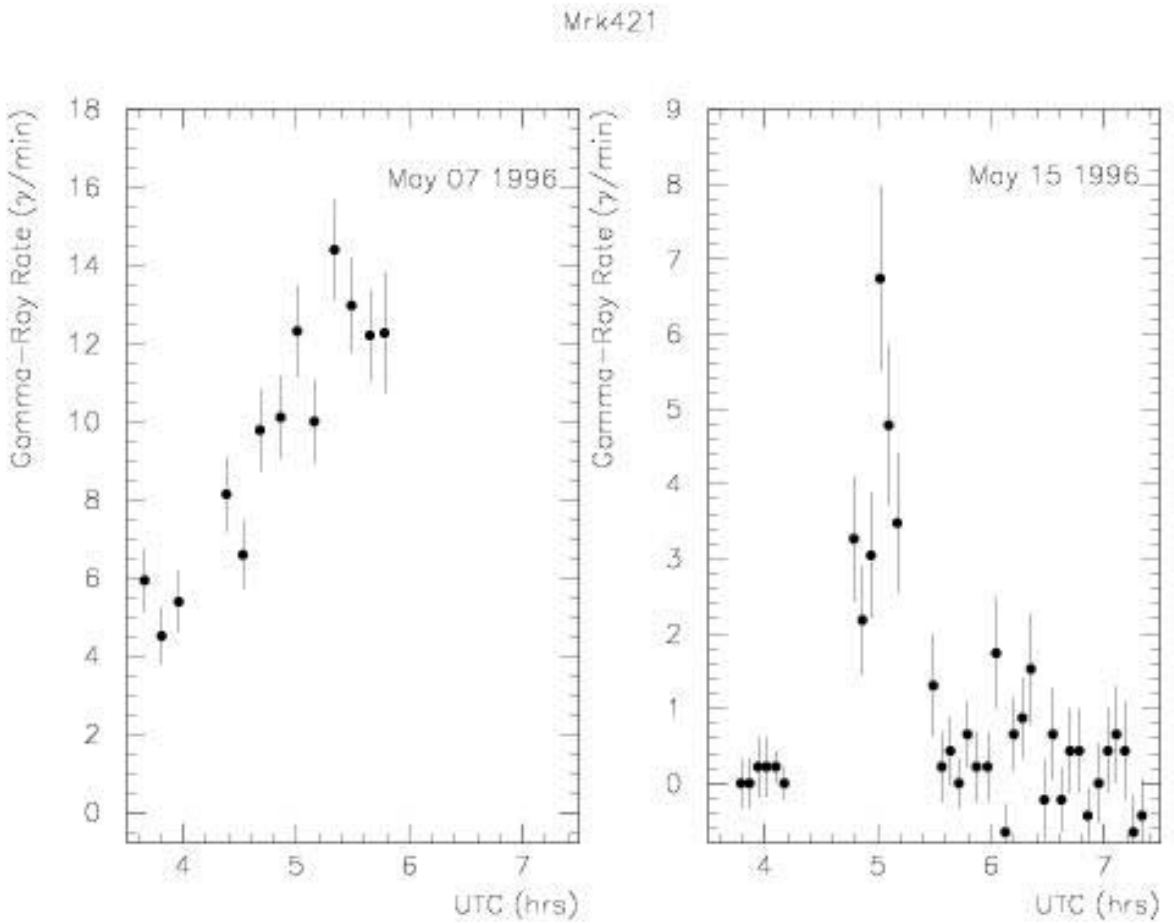
- 1992: Detected in TeV γ-rays (Whipple)

  First extragalactic TeV source
- 1994-6: Large flares observed
- 2001: Dramatic and continual flaring

Spectral Energy Distribution

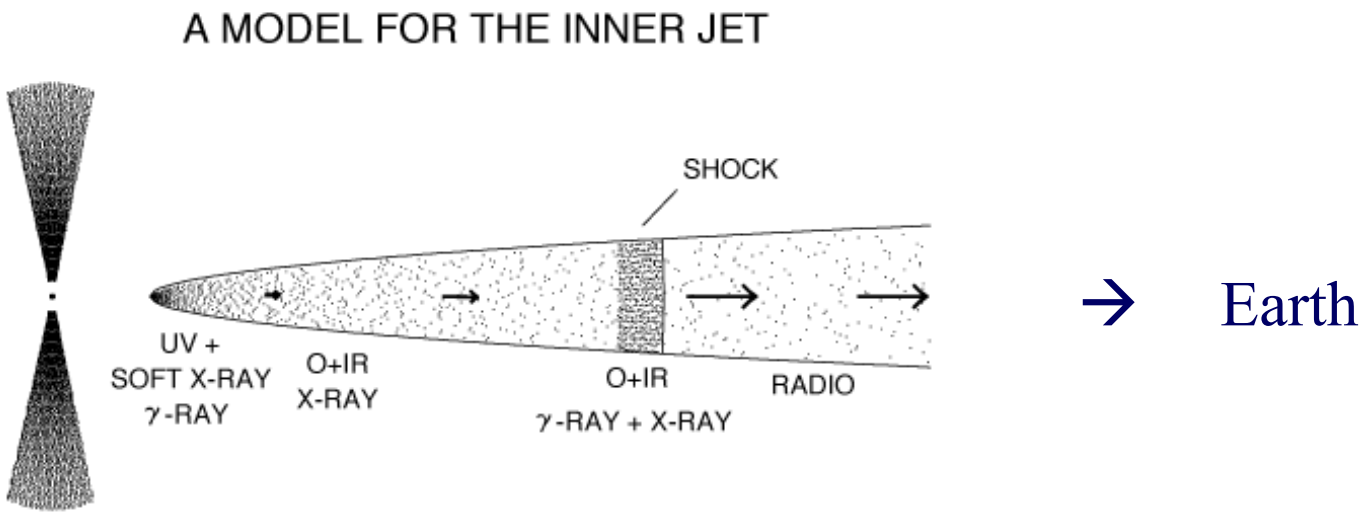


1996 Variability



- Variability < 20 min
- Constrains emission
  $R \times \delta < 10^{15}$ cm
- $\Gamma \sim 10$ required
- Limits on parameters of central engine

Key Science Issues



Source mechanisms:

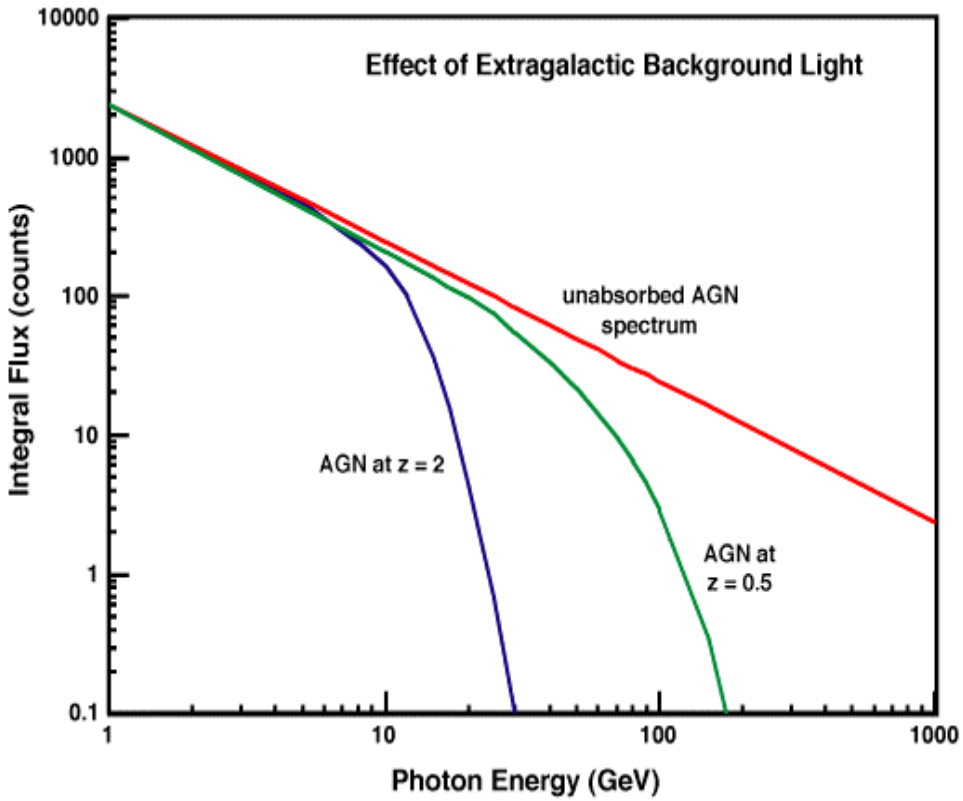
- Nature of beams
- Accleration processes
- Emission zones
- Rad. & mag. environ.

Absorption:

- Intrinsic- source opacity
- Intergalactic

$\gamma\,\gamma \rightarrow e^{+}\,e^{-}$, probes CIBR

For Mrk 421, expect this effect at $E_{\gamma} > $ few TeV

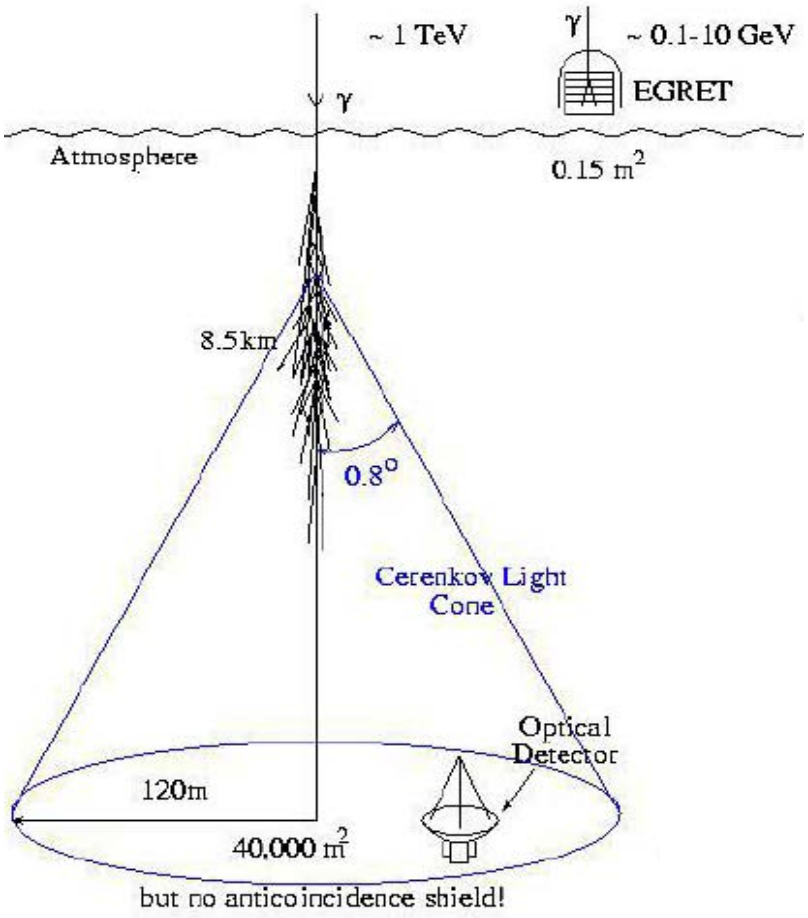


Experimental Technique

Cherenkov Telescopes:

- Relativistic air shower
- Short bursts of light ~ 5 ns
- Coherent over ~ 250m

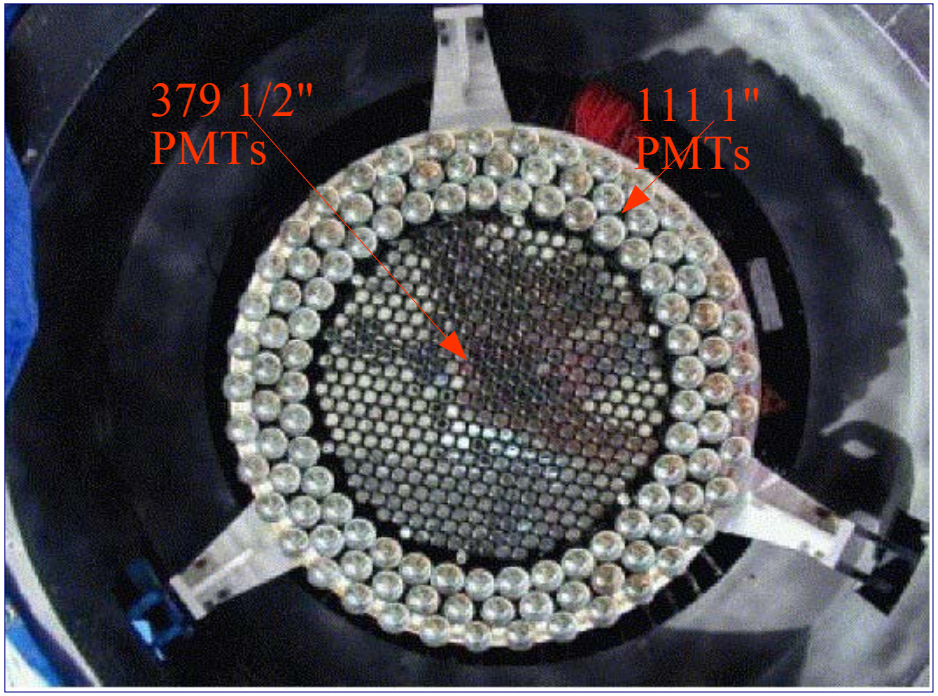
- Huge collection area > 10^8 cm^2
- Angular resolution ~ 10'
- Wide dynamic range



Whipple γ-ray Telescope

10m optical reflector

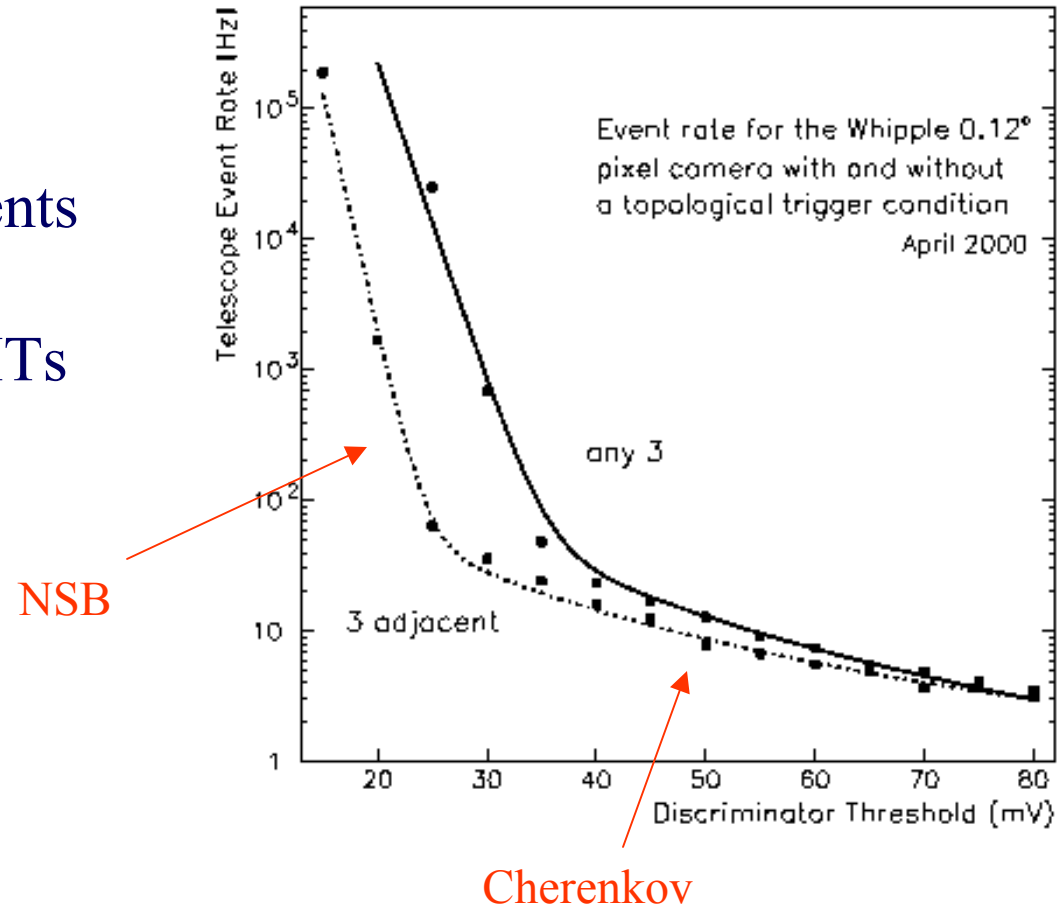
480 PMT camera



Operation

Trigger selects Cherenkov events

3 adjacent PMTs



Performance

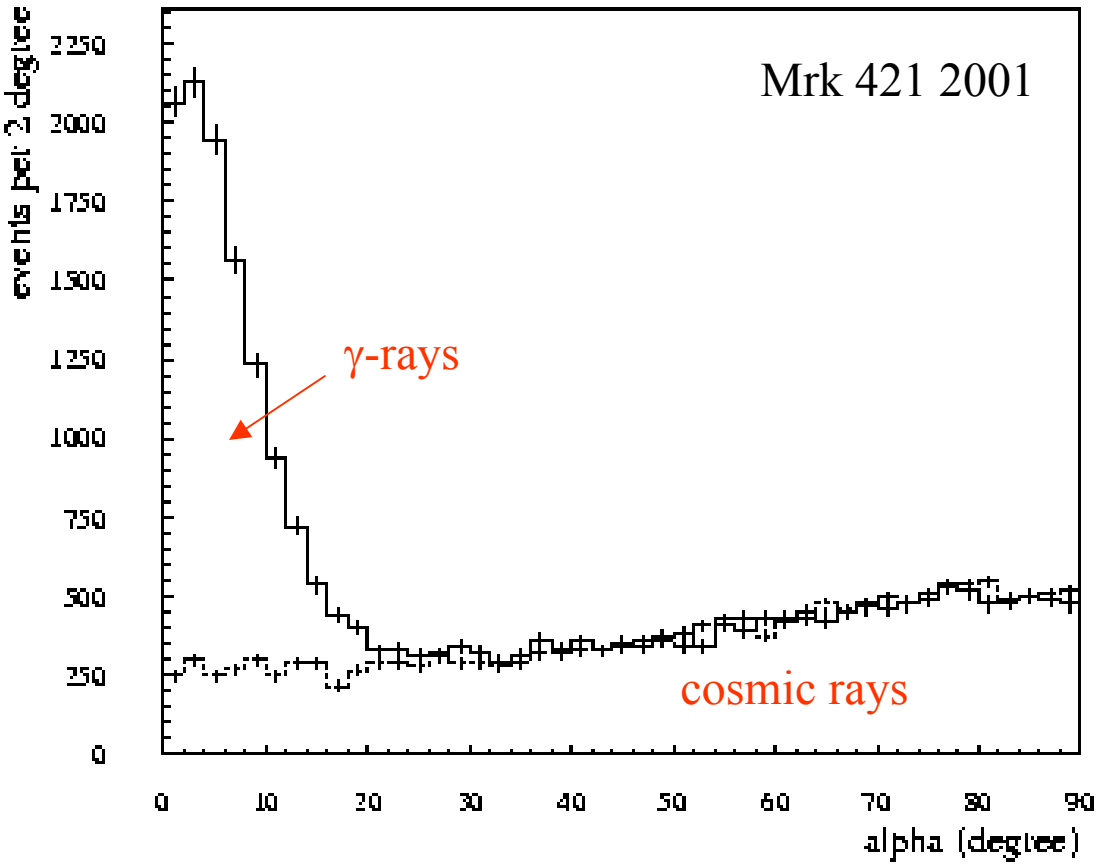


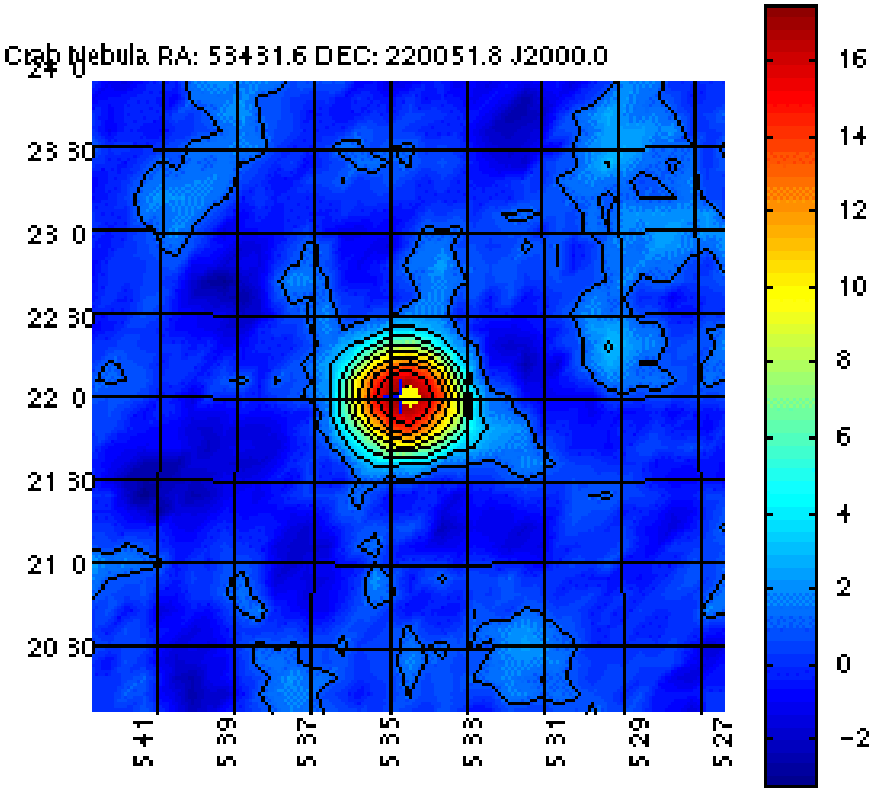
Image orientation

Excellent statistics

~ 100 σ detection

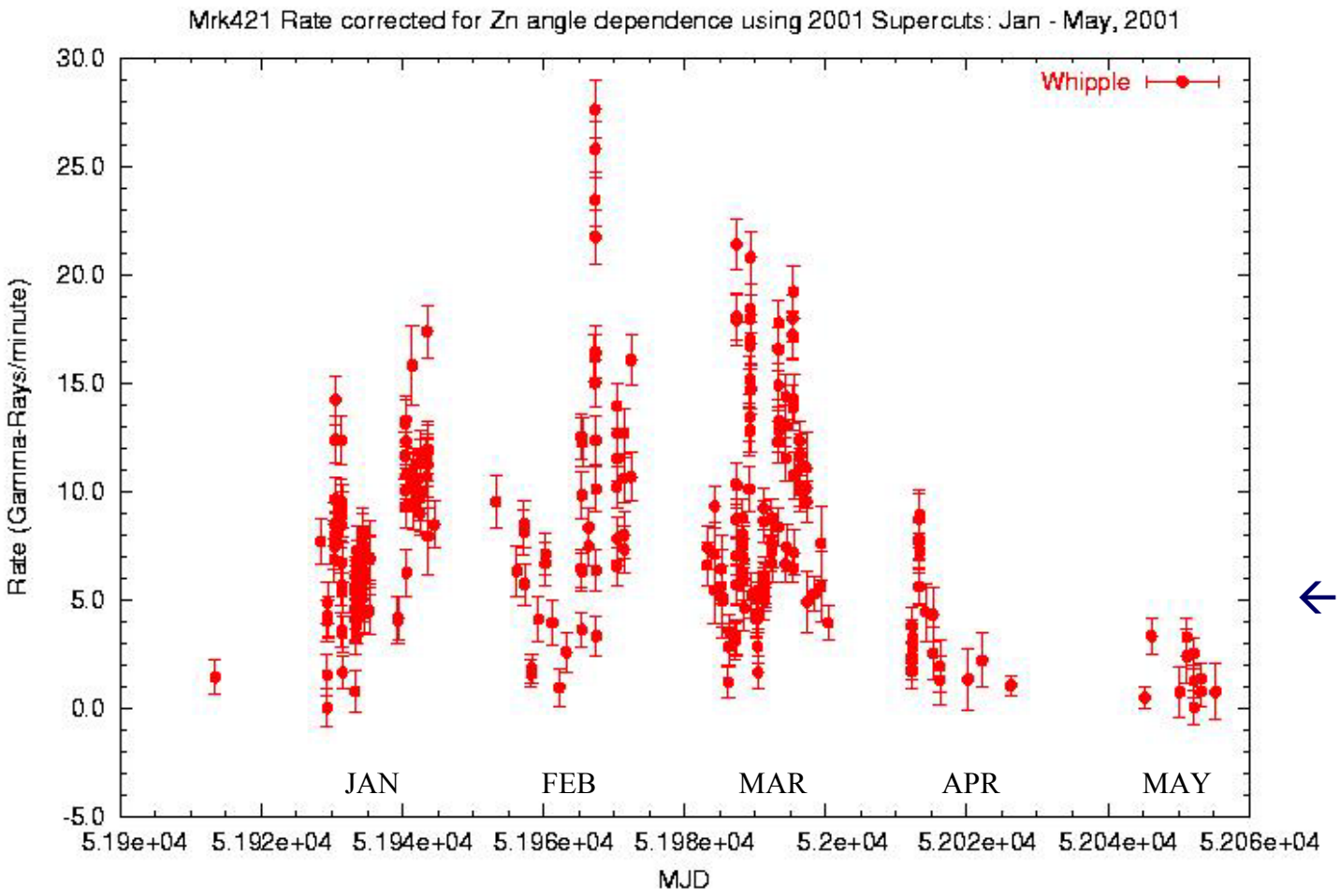
Performance

Source location accuracy ~ 3’



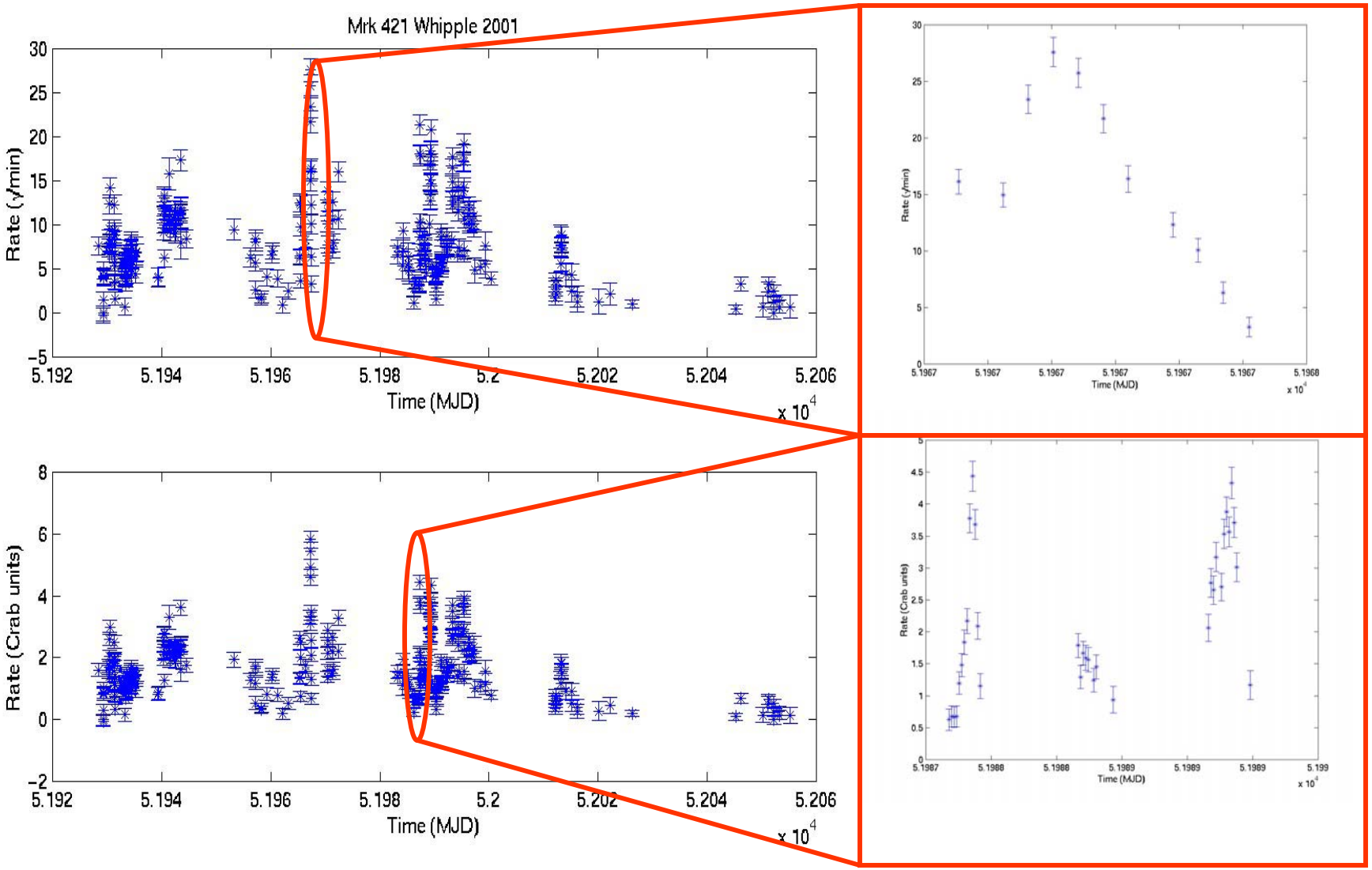
Crab Nebula

Light Curve



←1 Crab

Mrk 421 2001


Mrk 421 Whipple 2001
Rate (γ/min)
Time (MJD)
x 10^4
Rate (Crab units)
Time (MJD)
x 10^4

~ 75,000 γ–ray photons detected

→ ~ 8 x 10^4 erg

Compare with Keck (Visible):

- Same photon yield ~ 60 msec on 13.3 mag AGN
- Same energy yield ~ 500 yr

Compare with EGRET (MeV γ-rays):

- Whipple rates ~ 10 γ's /min
- EGRET ~ 1 γ / 2.5 hr

Analysis

- Select 9 nights of high flaring activity – 30.8 hr
- ~ 23,000 γ-rays
- Estimate energy from fit to Cherenkov intensity

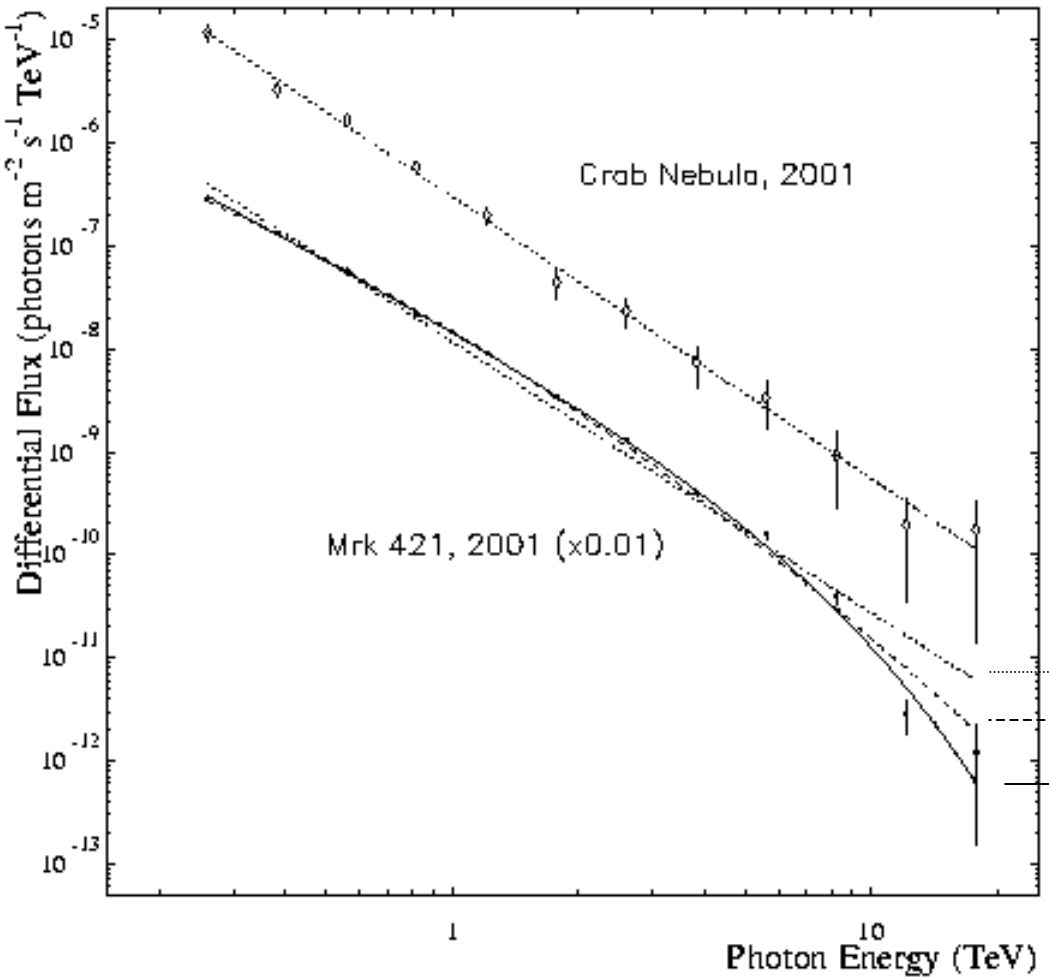
  energy resolution ~ 35% statistical

  ~ 20% systematic
- Spectrum not well fit by simple power law

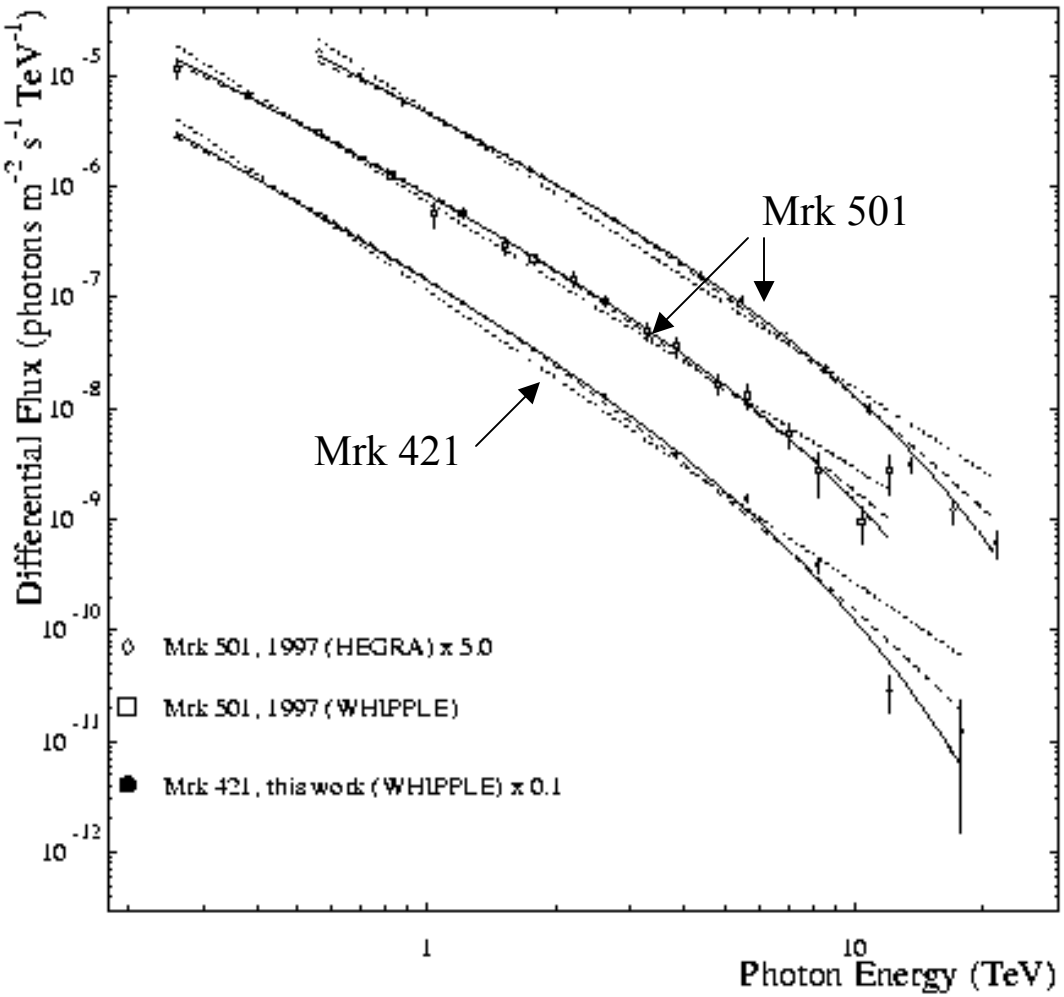
  much better described by power law + exp. cutoff

$$E_c = 4.3 \pm 0.3 \pm 1.5 \text{ TeV}$$

Spectrum

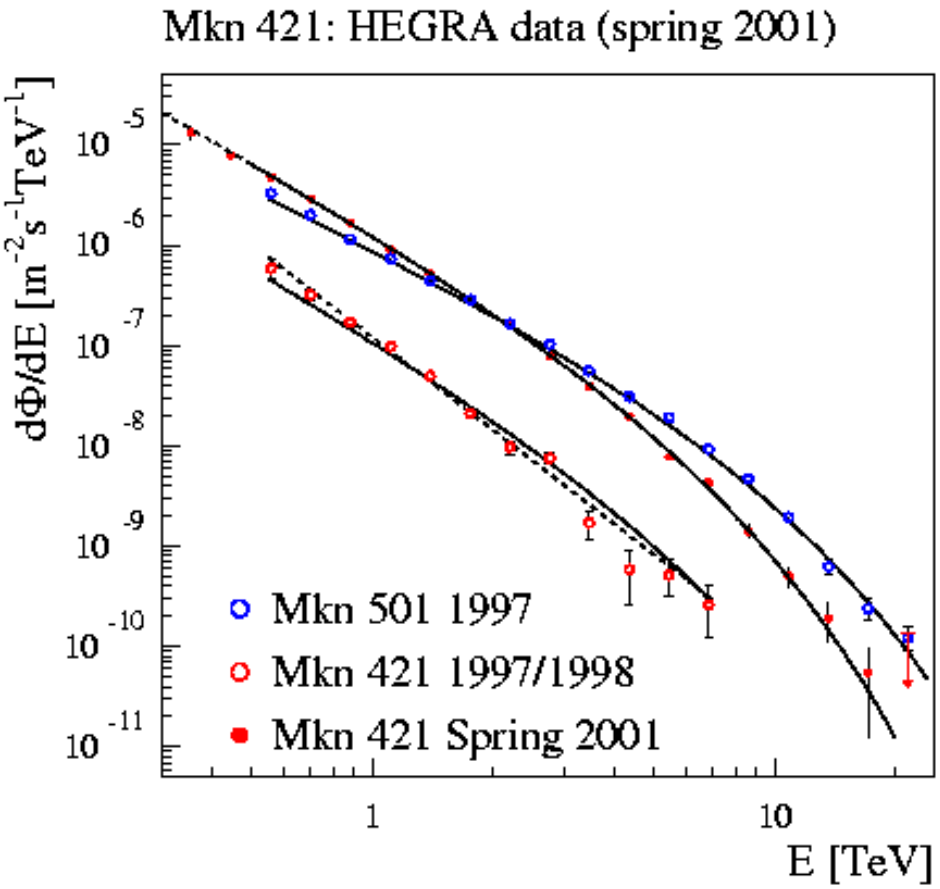

Crab Nebula, 2001
Mrk 421, 2001 (x0.01)
Differential Flux (photons m^{-2} s^{-1} TeV^{-1})
Photon Energy (TeV)
1
10
power law
parabolic
Power + exp. cutoff

Comparison with Mrk 501



Universal feature?

A different view



Function fit to data:

$$dN/dE \propto E^{-\alpha}\exp(-E/E_{cut})$$

Data-set	α	E_{cut}	χ^2/d.o.f. (d.o.f.)
Mkn421 (2001)	2.23±0.04	4.0 ± 0.4	0.8(13)
Mkn421 (1997/8)	2.23 (fixed)	4.0 (fixed)	4.3(11)
Mkn501 (1997)	1.92±0.03	6.2 ± 0.4	

stat. error only

Intrinsic feature?

Conclusions

- Rich data set – multi λ studies to follow
- Energy spectrum – first clear evidence for cutoff $E_c \sim 4$ TeV
- Consistent with CIBR absorption, not conclusive
- Difficult measurement over five decades in flux, requires:

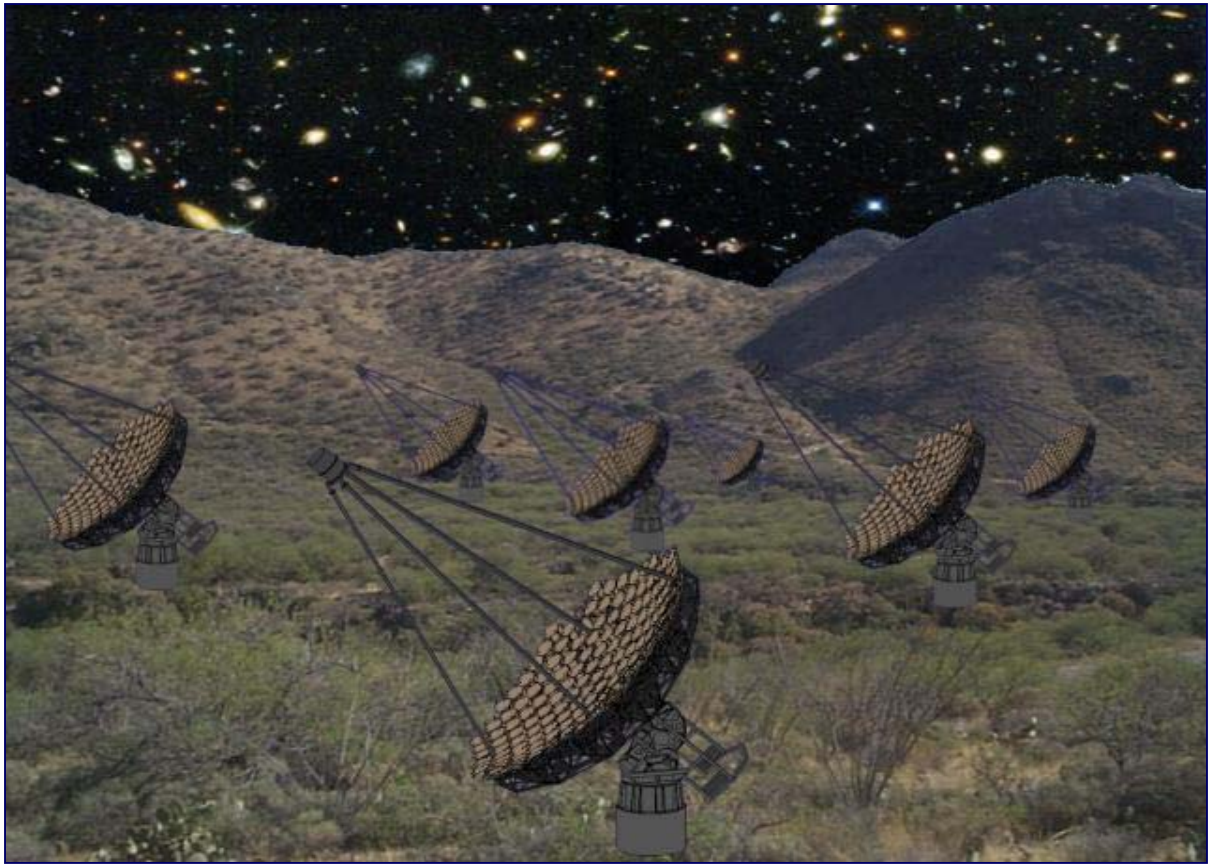
  high statistical sample

  excellent energy resolution – control of systematics

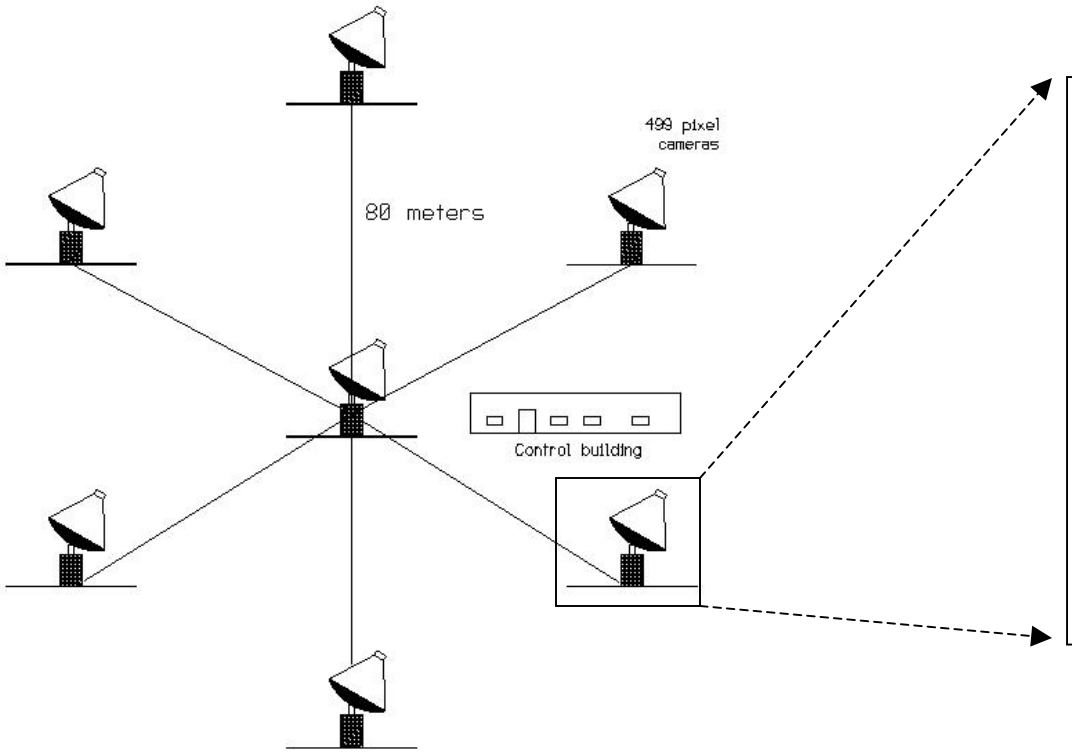
- Much better done by future instruments - **VERITAS**

Very Energetic Radiation Imaging Telescope Array System

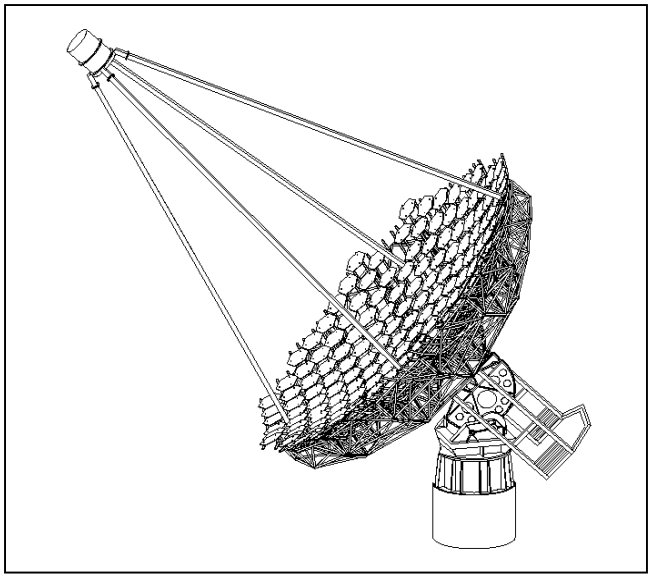
(VERITAS)



VERITAS

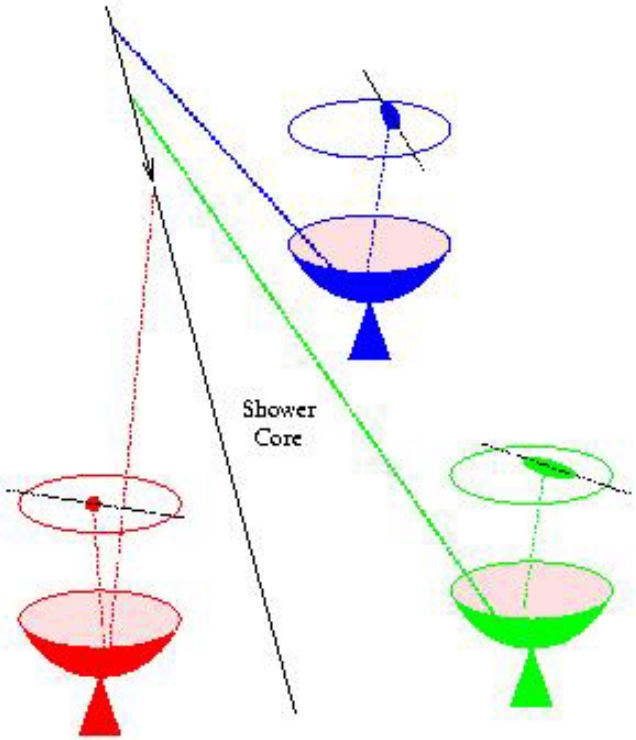


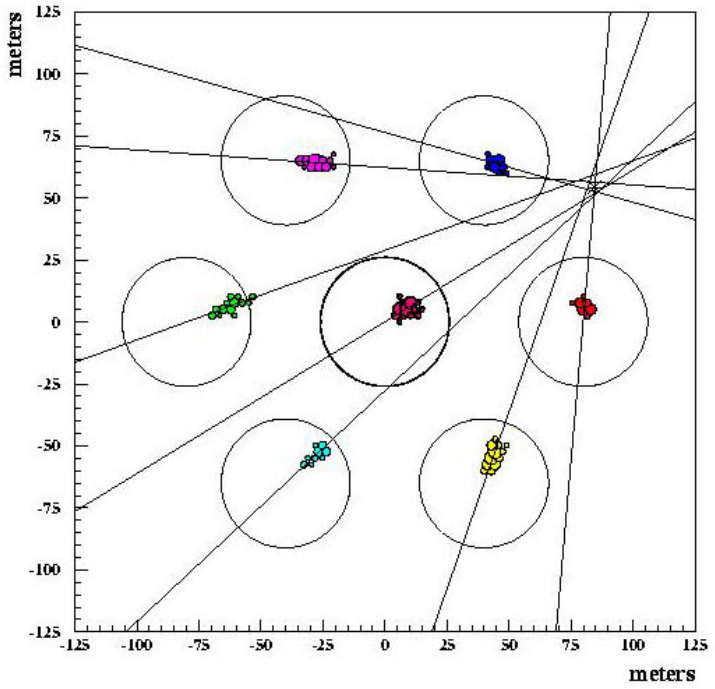
Telescope Array



Updated design f 1.2

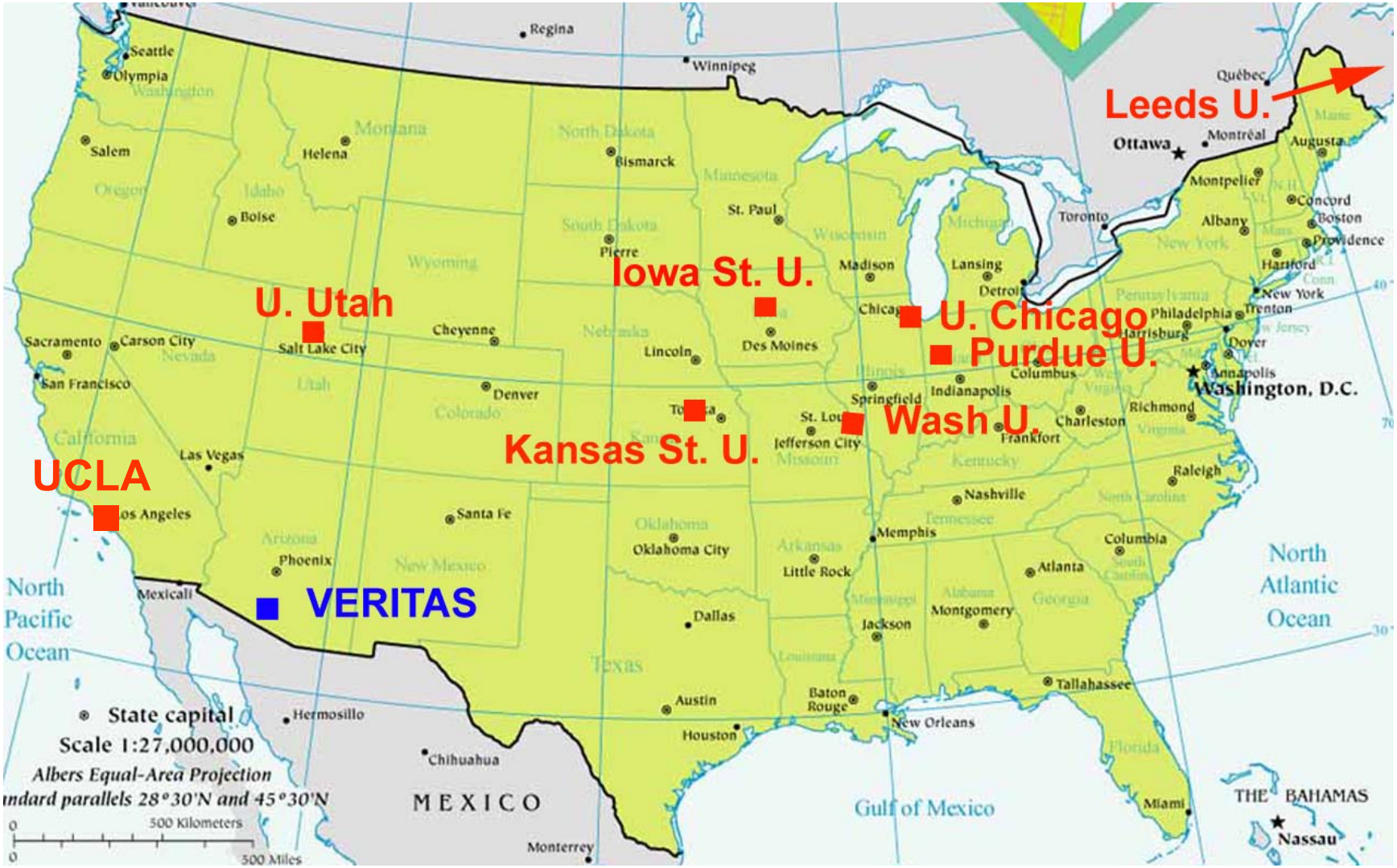
VERITAS





Reconstruct showers fully in 3-dimensions

VERITAS Detector Hardware groups



VERITAS

Advanced hardware

Multi-level trigger
500 MHz FADCs
High speed DAQ