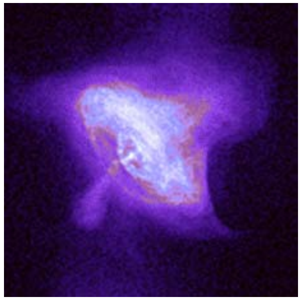
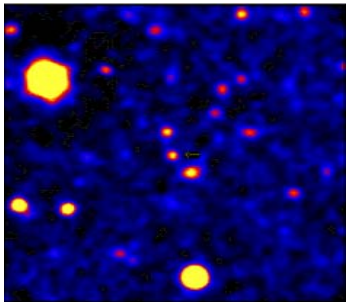
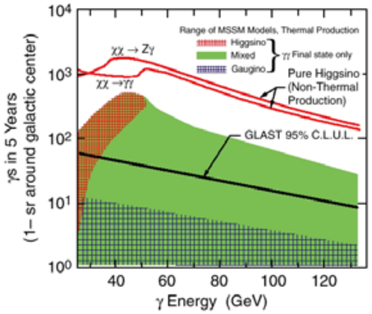
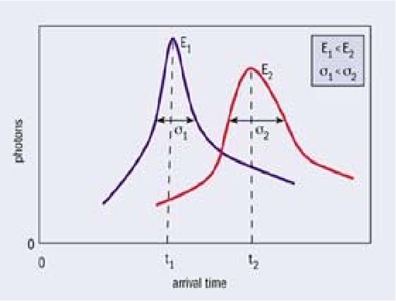
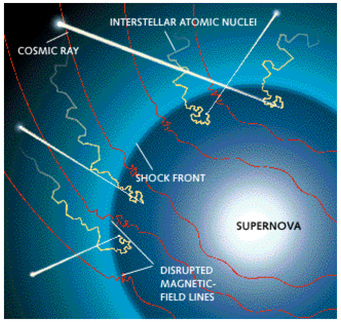
STATUS OF VHE ASTRONOMY

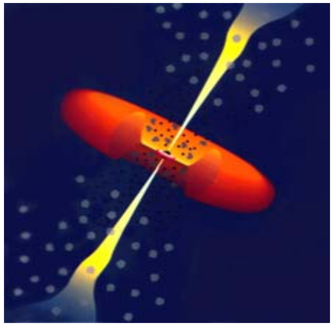












Rene A. Ong
UCLA

GSFC LHEA Seminar
24 October 2003

OUTLINE

- Introduction – science goals
- Technique & history
- Current source catalog
- Science highlights:
  - **AGN**
  - **Galactic sources: SNR's & other**
- Future – new telescopes (VERITAS)

Definition

γ-rays

HE = E > 30 MeV (satellite)

VHE = E > 100 GeV (ground-based)

Distinction becoming more and more arbitrary.

Broad Science Goals

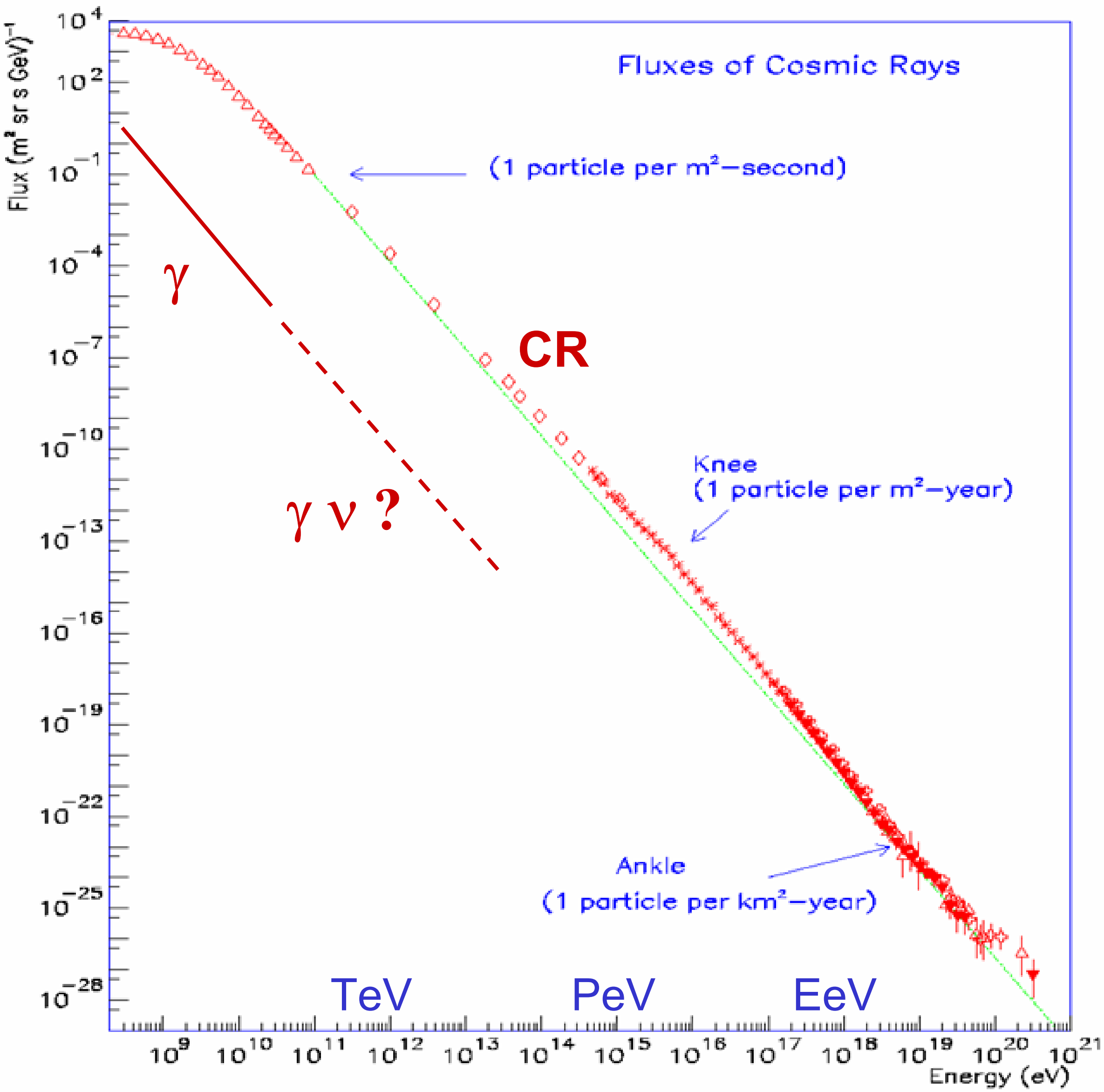
What are the origins of cosmic and γ-radiation?

- Studying particle acceleration in extreme astrophysical environments.
- Looking beyond standard models:
  - → particles from higher mass scale
  - → relics from early Universe
  - → particle interactions at VHE

Using γ-rays to probe intergalactic space.

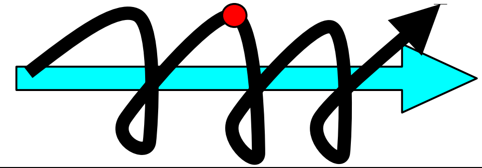
- Diffuse radiation fields, fabric of space-time.

Cosmic Ray Energy Spectrum



- Total,diffuse spectrum individual species not resolved.
- Power-law spectrum E^{-3} differential.
- E > 10^{20} eV.
- Energy density ~ 1 eV / cm^3.
- Diffuse ν not (yet) seen.

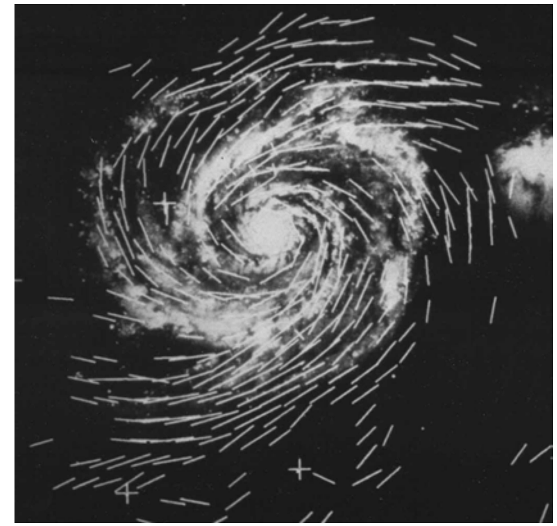
Magnetic Fields



1. Galaxies have magnetic fields.
   - Protons and nuclei will be deflected by the B ~ 5 μG galactic field.

     Larmor radius r = R/cB

R	r	
10^{15} eV	0.3 pc	
10^{20} eV	30 kpc	← size of galaxy

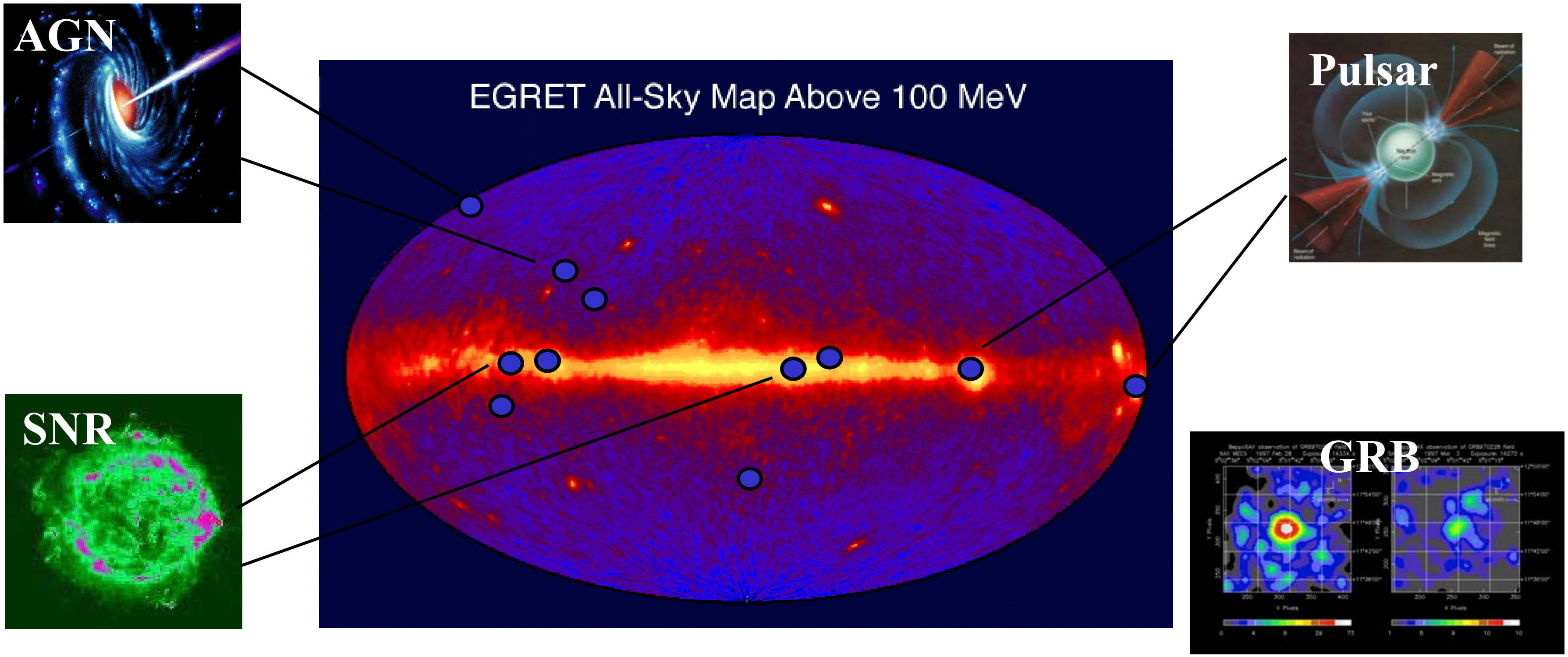


M51

2. Intergalactic fields may also be significant
   - Clusters (e.g. Coma) have field strengths B ~ 0.1 – 2 μG, perhaps extending out along sheets and filaments.

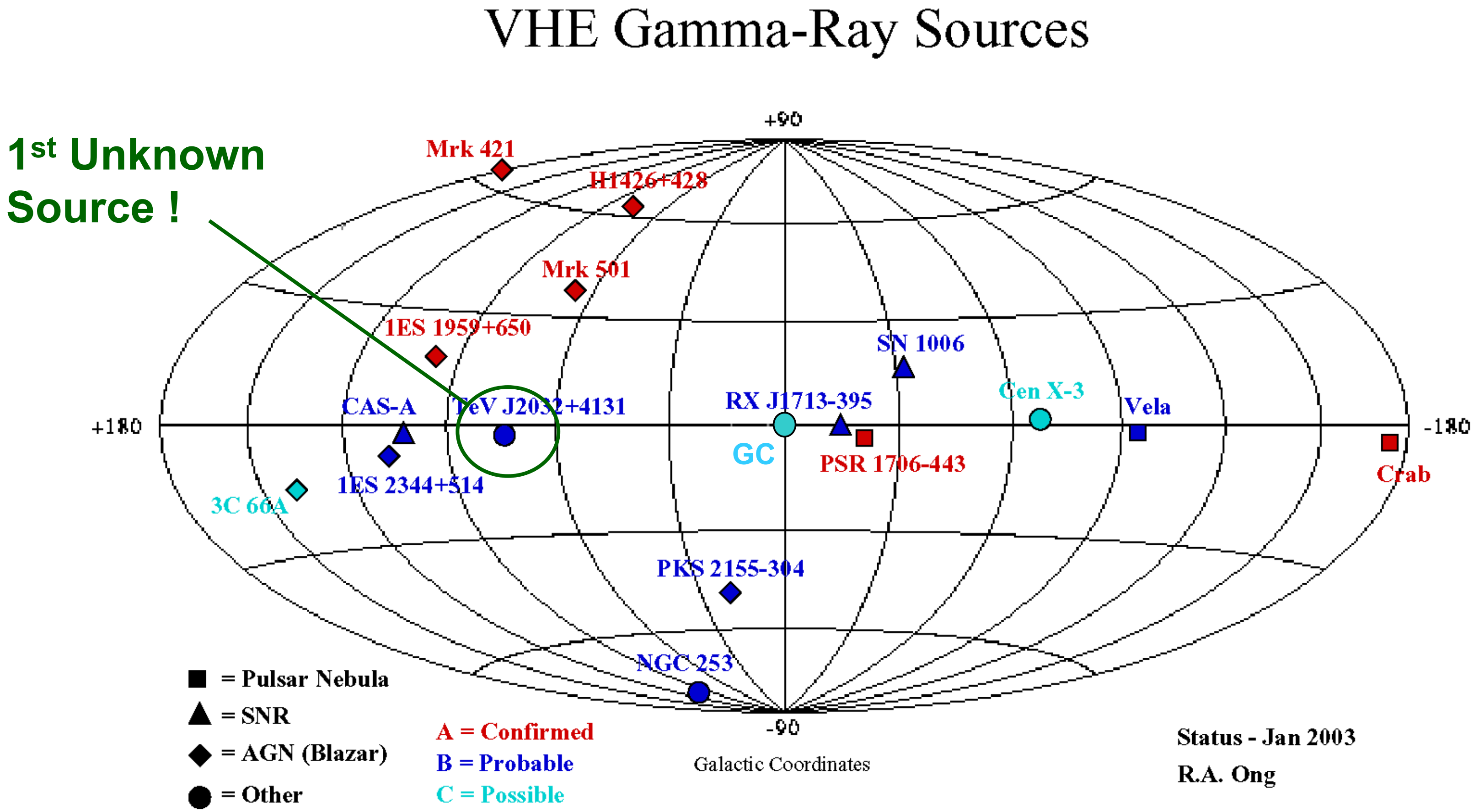
Charged CR directions will be scrambled by B fields.
Gamma-rays and neutrinos will be undeflected.

HE γ-ray Sky



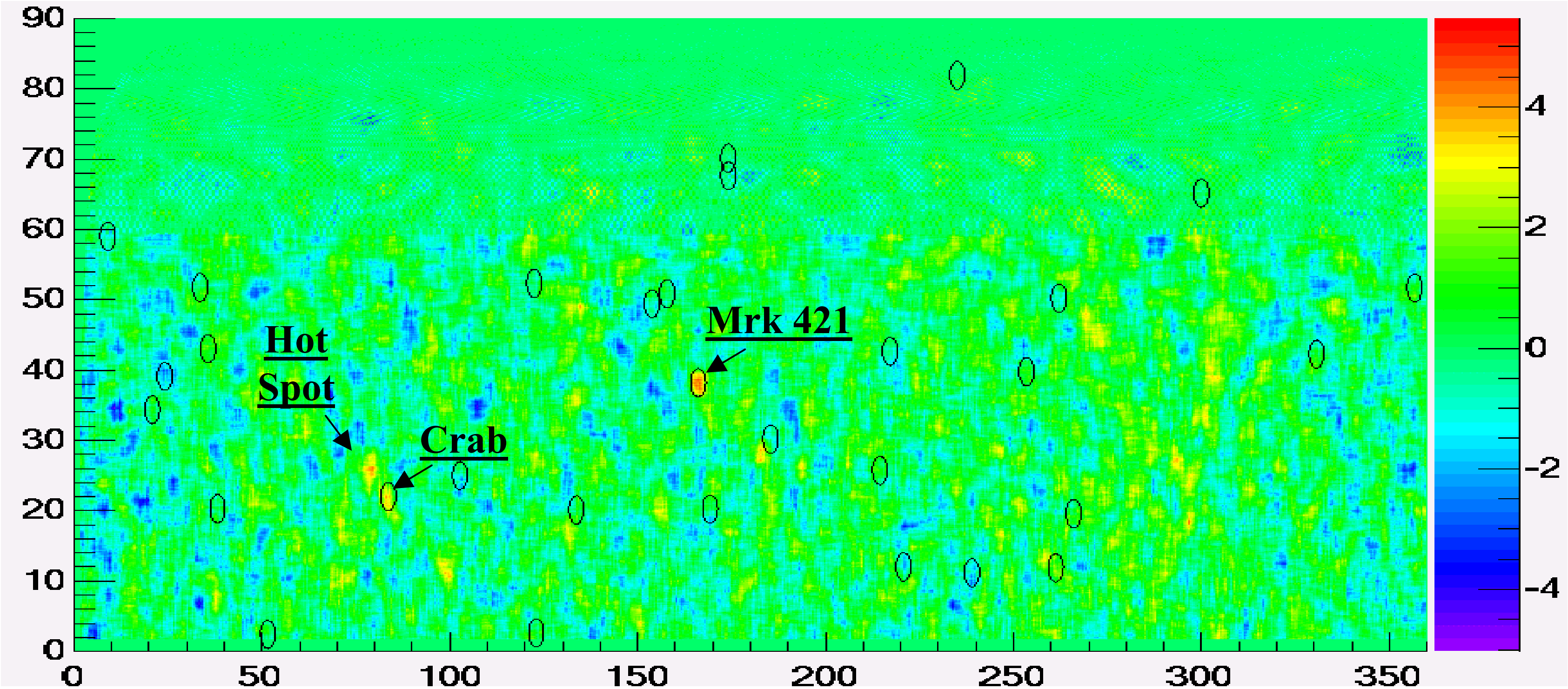
- ~ 250 HE point sources, the majority unidentified.

VHE γ-ray Sky



- 16 putative sources – various confidence levels.
- All discovered by Cherenkov telescopes – few % sky.

TeV Sky Survey

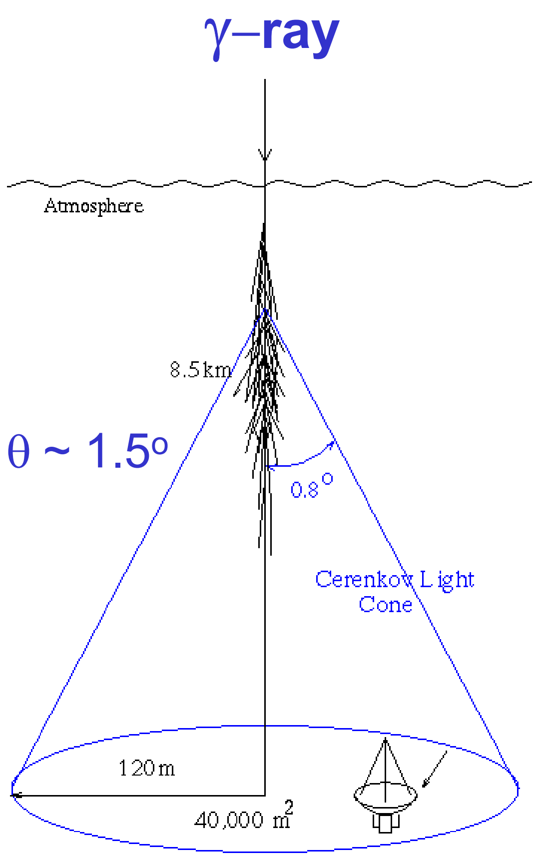


- Milagro: Very few sources comparable to Crab @ 1 TeV.

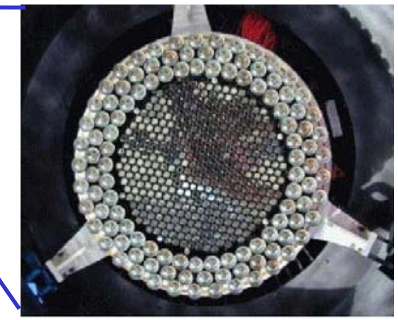
Technique
&
History

Experimental Techniques

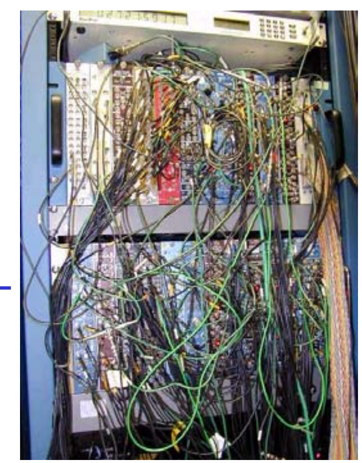
Cherenkov Telescopes (Imaging)



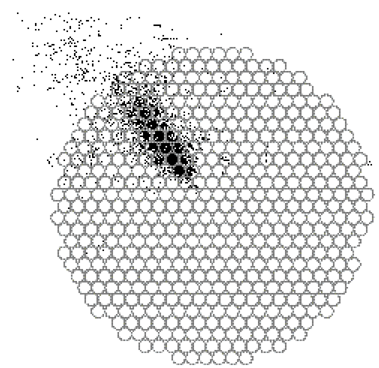
Whipple 10m (Arizona)



PMT camera



ns electronics

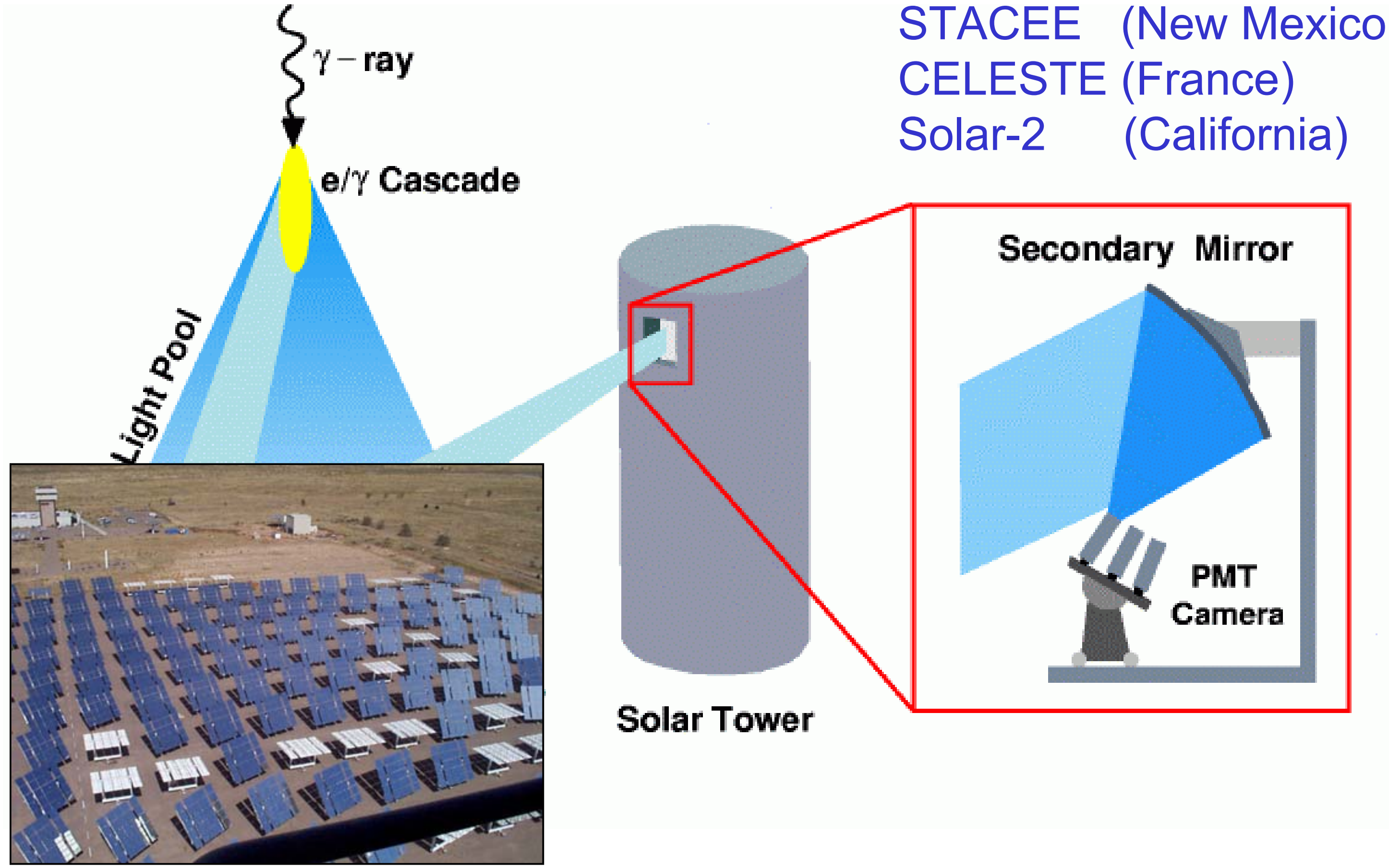


Cherenkov image

Area = $10^4 - 10^5$ m^2

~60 optical photons/m^2/TeV

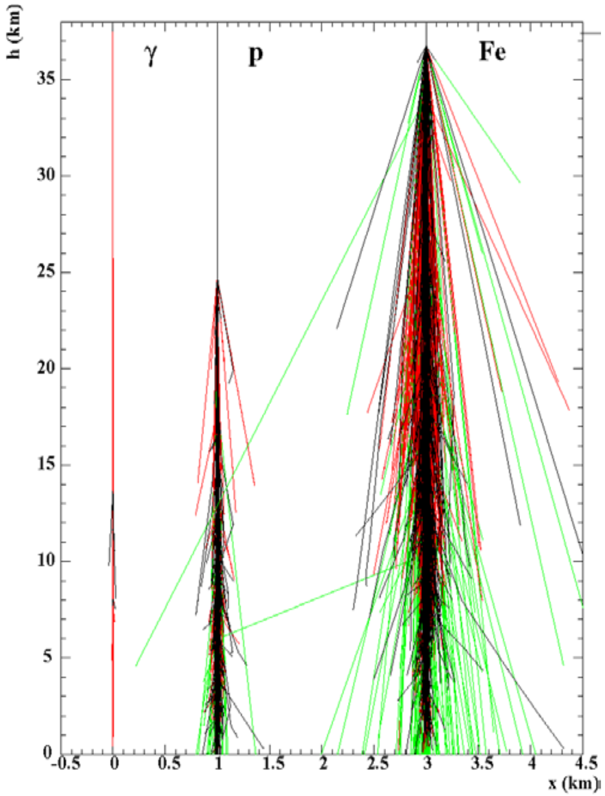
Cherenkov Telescopes (Wavefront)



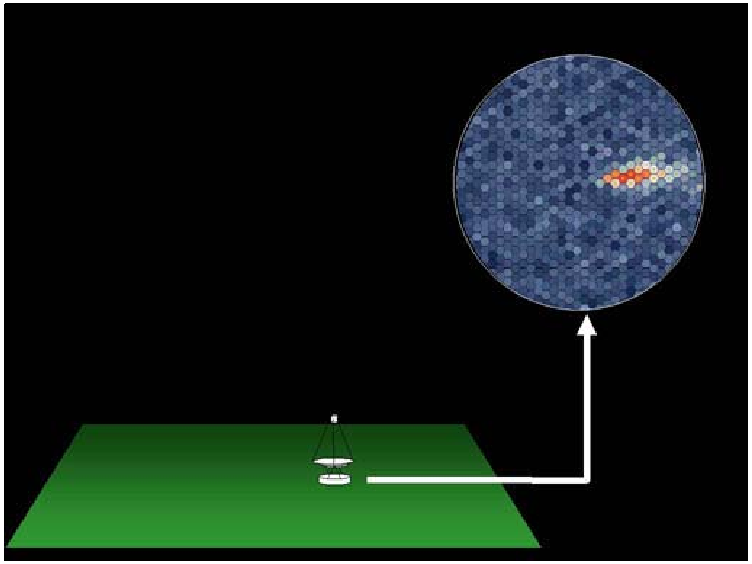
STACEE (New Mexico)
CELESTE (France)
Solar-2 (California)

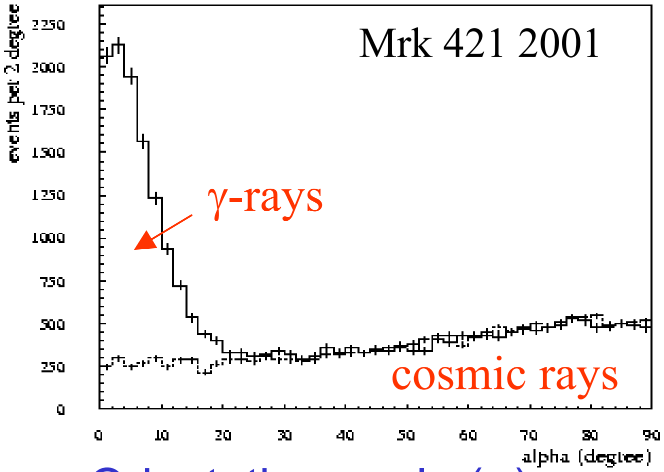
- **Go to low threshold energy (E ~ 50 GeV)**
- **Wavefront information → Direction, energy, γ/had**

Isolating γ-rays



Shower profile
in atmosphere





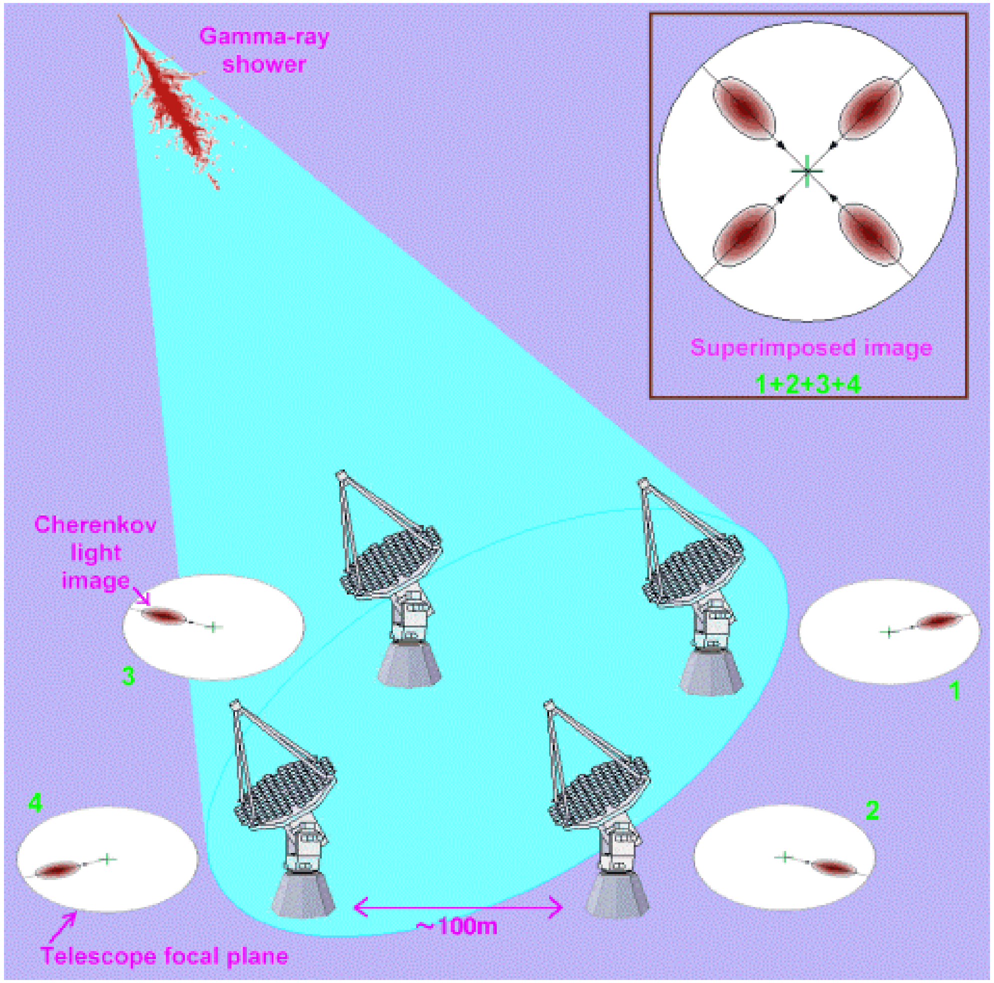
Orientation angle (α)

Rejection
Factor ~ 300
(single tel)

Telescope Characteristics

Parameter	Wavefront (STACEE)	Sing. Imager (Whipple)
Mirror Area	64 x 37m^2	1 x 80 m^2
E (peak)	75 GeV	350 GeV
FOV	0.75^o	3.5^o
P rejection	~ 50	~ 300
Energy Res.	~ 40%	~ 25%
Ang. Res.	0.25^o	0.20^o
Crab rate (γ/min)	~ 5	~ 2

Array of Cherenkov Telescopes



HEGRA
(La Palma, decomissioned)

Rejection Factor ~ 5,000

HISTORY


Crimea (1960's)

- 1970's: First Experiments
- 1980's: X-ray binary period

1989: Detection of Crab Nebula (Whipple)
1992: Detection of Markarian 421 (Whipple)
1997: Flares from Markarian 501
1998: Detection of SN1006 (CANGAROO)
2002: Detection of Unid TeV (HEGRA)

- 2004+: New generation of Telescopes

AGN Science

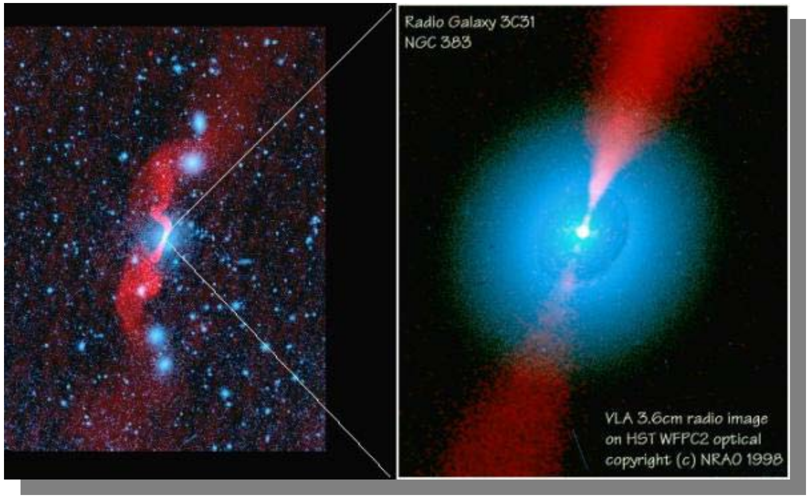
- Source list (6).
- Light curves.
- Spectra: SED’s and correlations with X-ray.
- Interpretation.
- (EBL absorption).

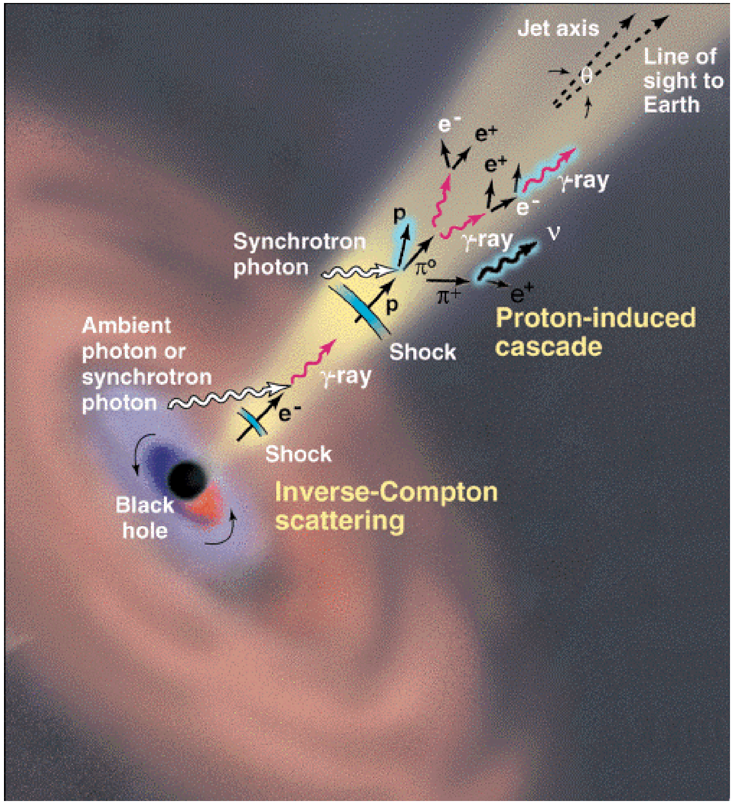
Detected AGN

Source	Type	Z	Confirmed?	Comments
Mrk 421	BL Lac	0.031	Yes	flaring, X-ray, IR abs.? spectral variability
Mrk 501	BL Lac	0.034	Yes	flaring, X-ray, IR abs.?
1ES 2344+514	BL Lac	0.044	No	
1ES 1959+650	BL Lac	0.048	Yes	flaring, IR abs.?
PKS 2155-304	BL Lac	0.116	Yes	
1ES 1426+428	BL Lac	0.129	Yes	weak source

Blazars → AGN Jets

- Giant elliptical galaxies
- SM black hole, accretion power
- Relativistic jets



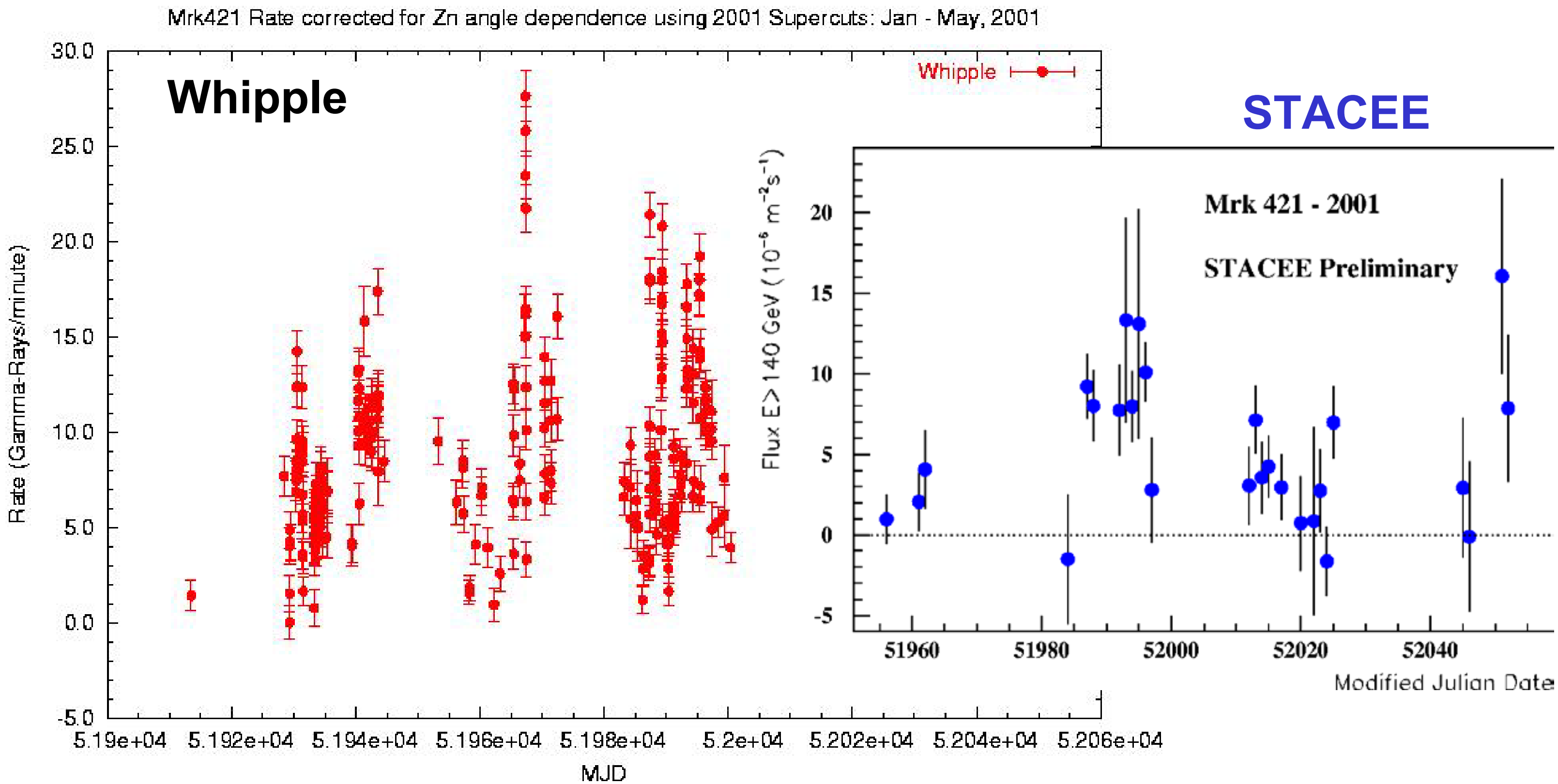


Current paradigm:

- Synchrotron self Compton
- External Compton
- Proton induced cascades
- Proton synchrotron

Energetics, formation & collimation of jet, nature of plasma, acceleration mechanisms, & magnetic fields are all poorly understood.

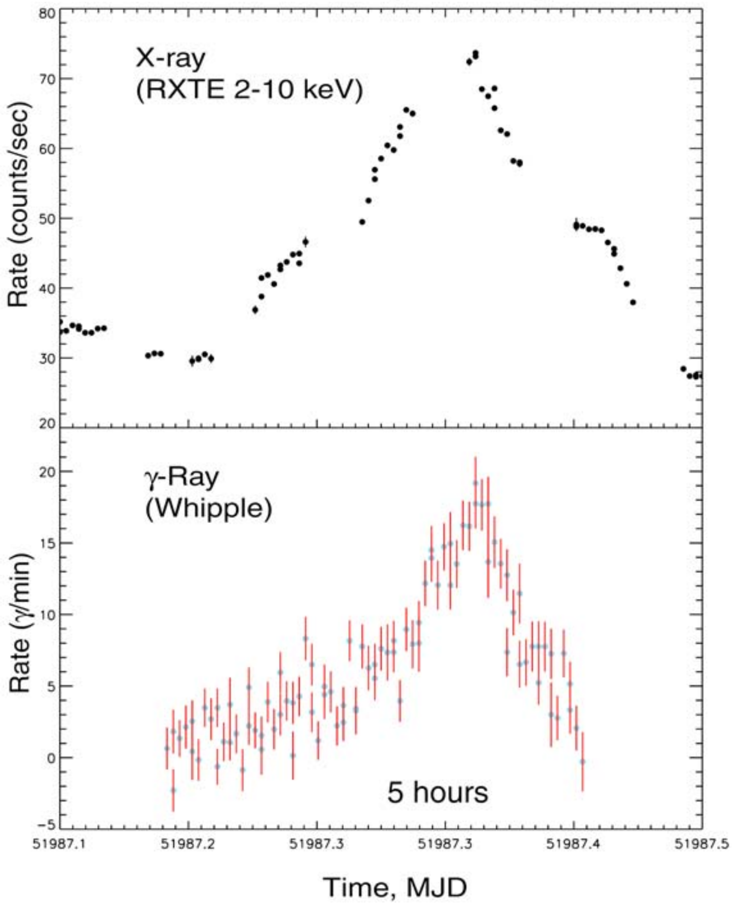
Light Curves

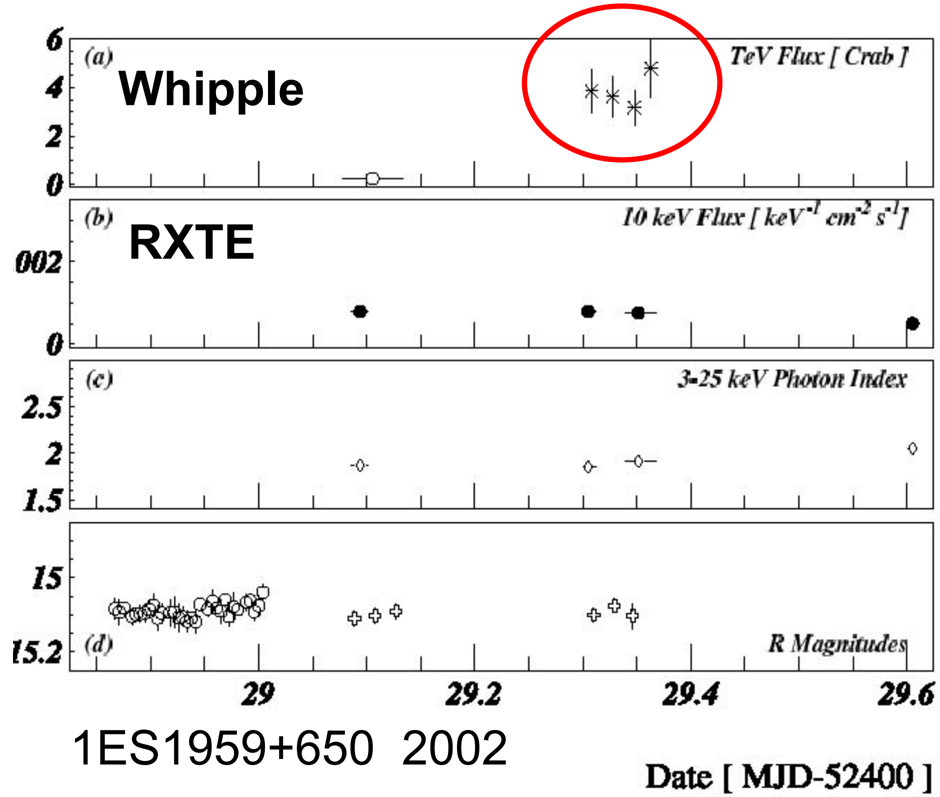


- Mrk 421, 2001 – “best case”.
- Highly statistically significant.

Correlation with X-rays

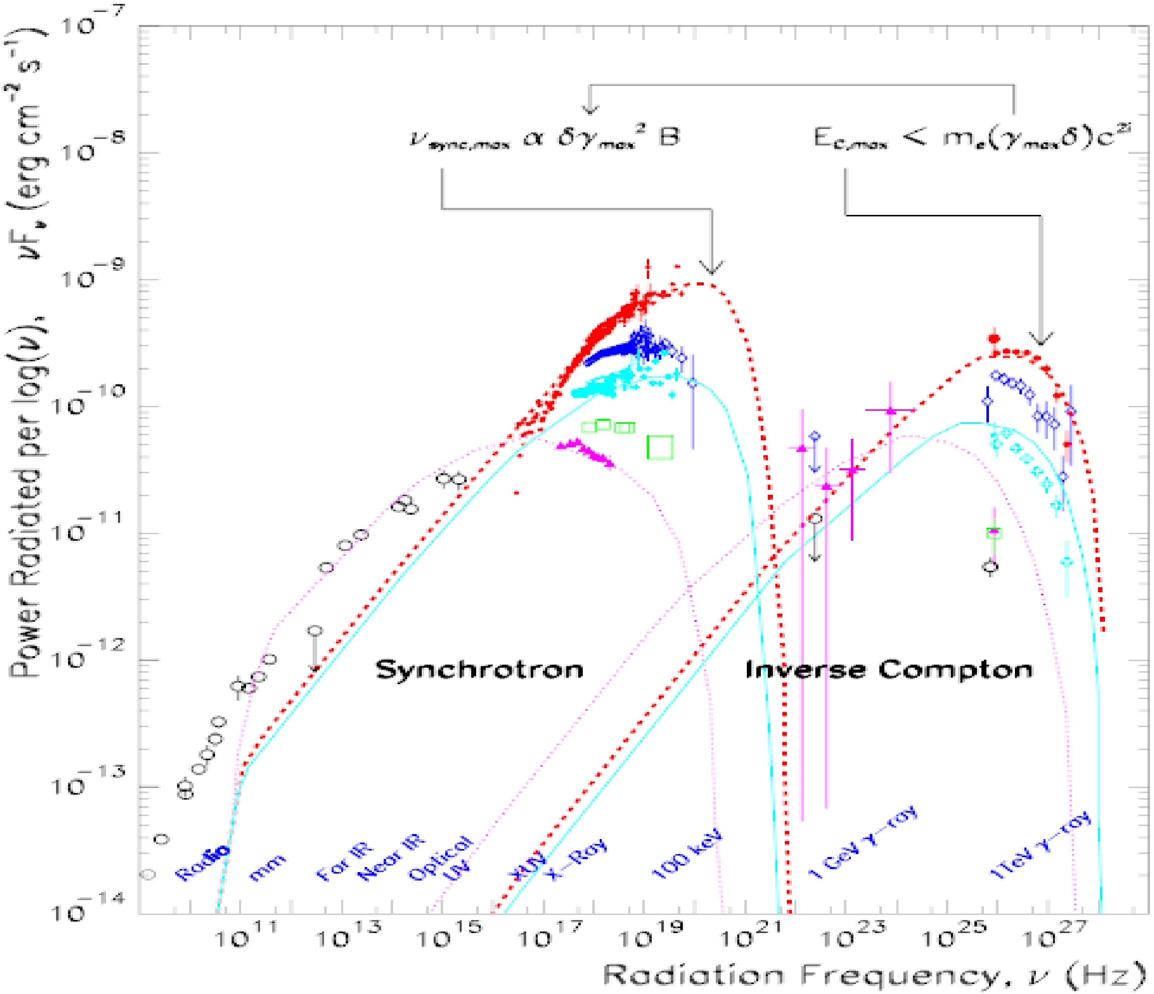
Markarian 421 Flare, March 19, 2001





- VHE Flares are generally well correlated with X-ray flares.
- But not in this case !

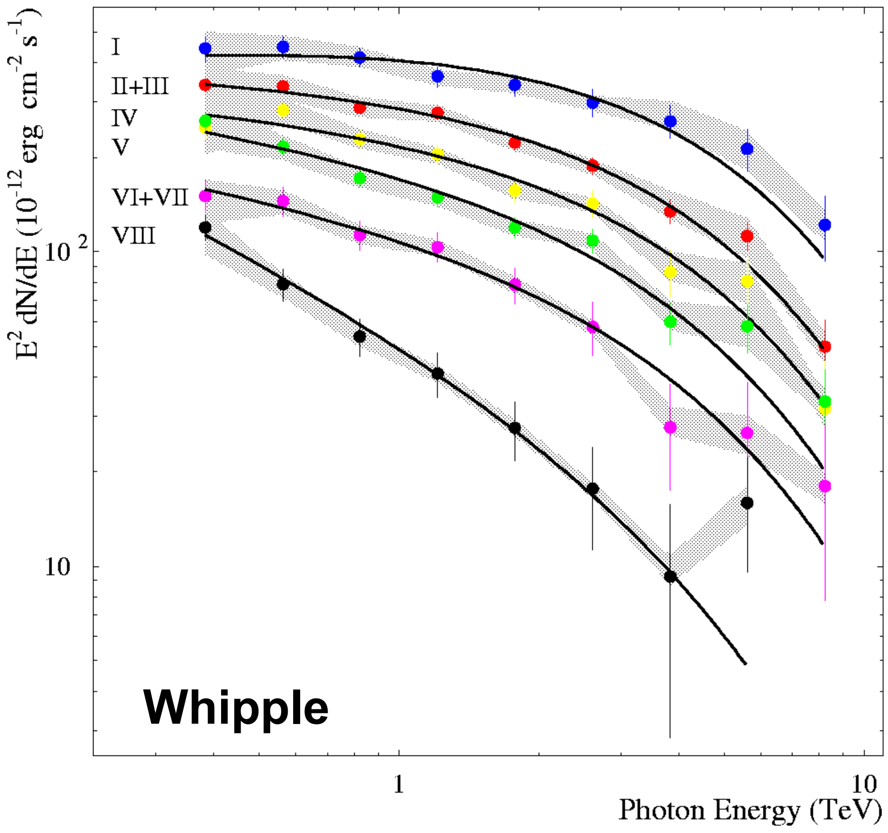
SED's – Mrk 501

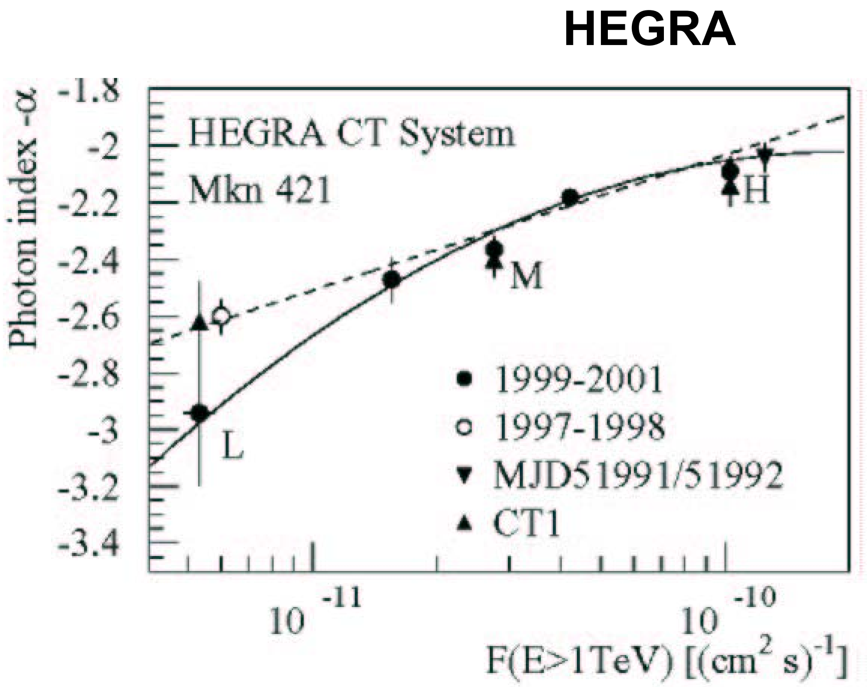


Correlation in γ-ray and X-ray variability is most easily explained in IC scenarios.
→ Same e^- population.

Additional constraints on electron energies, time scales, etc.

Spectral Variability

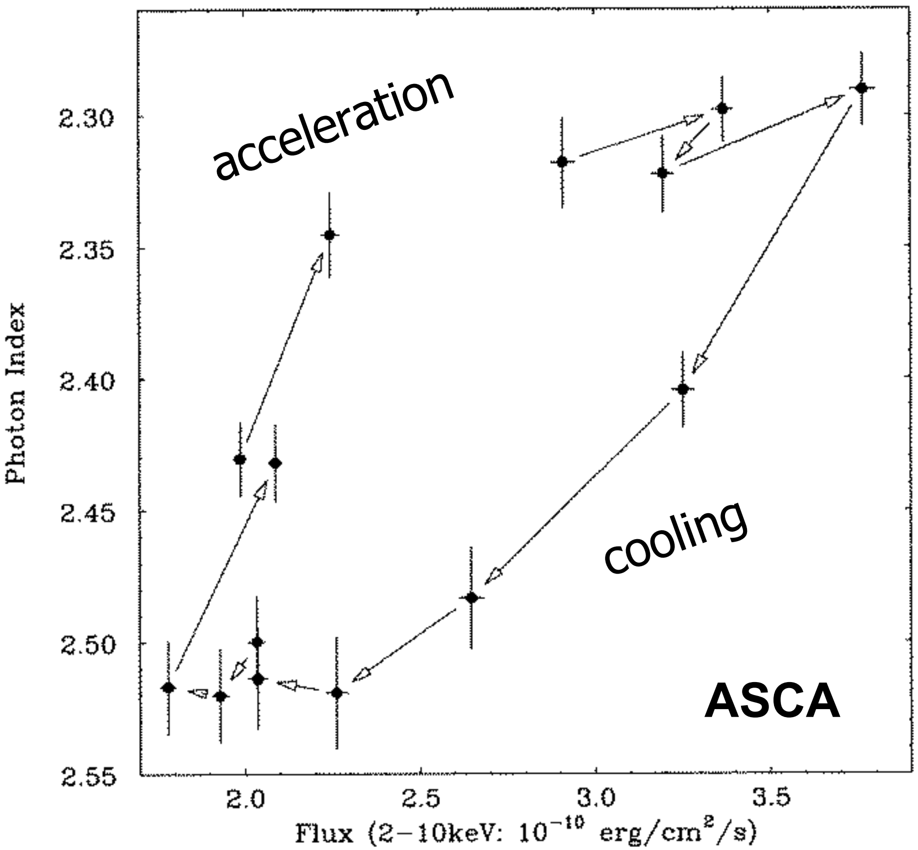




- Spectral variability now clearly detected!

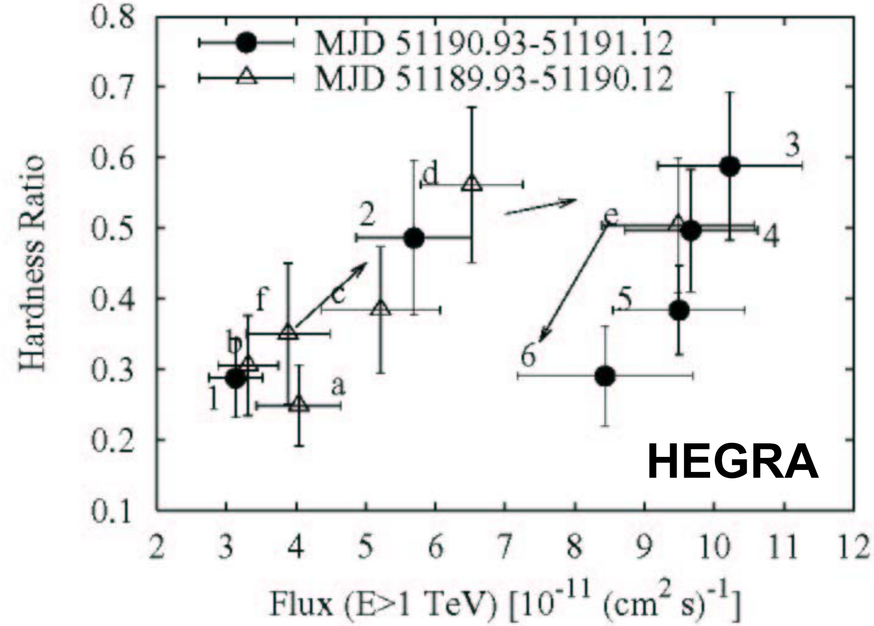
Spectral Evolution

X-ray Mrk 421



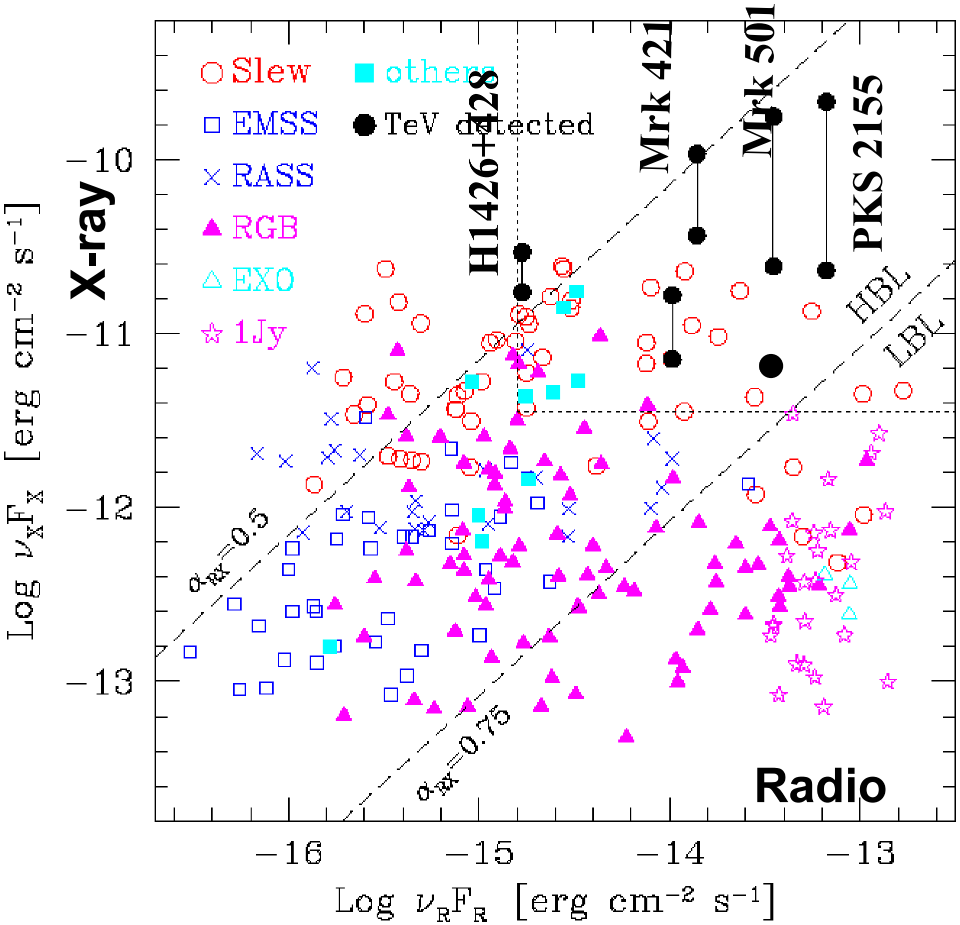
(Takahashi et al. 1996, ApJ 470 L89)

VHE γ-ray Mrk 421

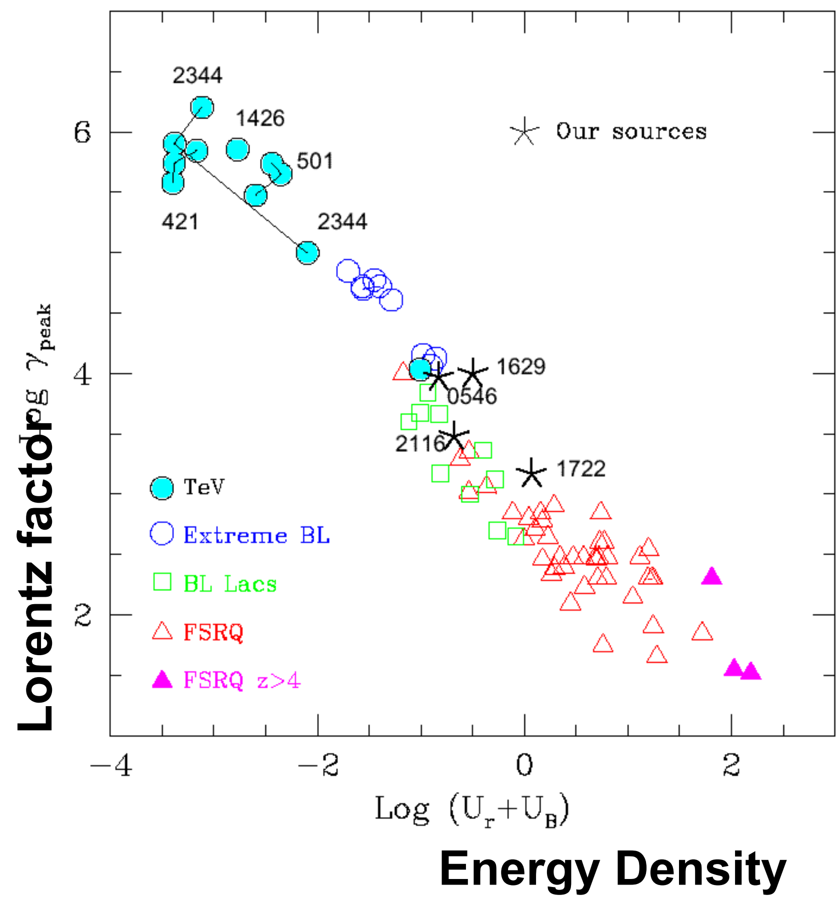


Rise and fall of flares help determine timescales: acceleration, cooling, emission size.

Understanding VHE Blazars

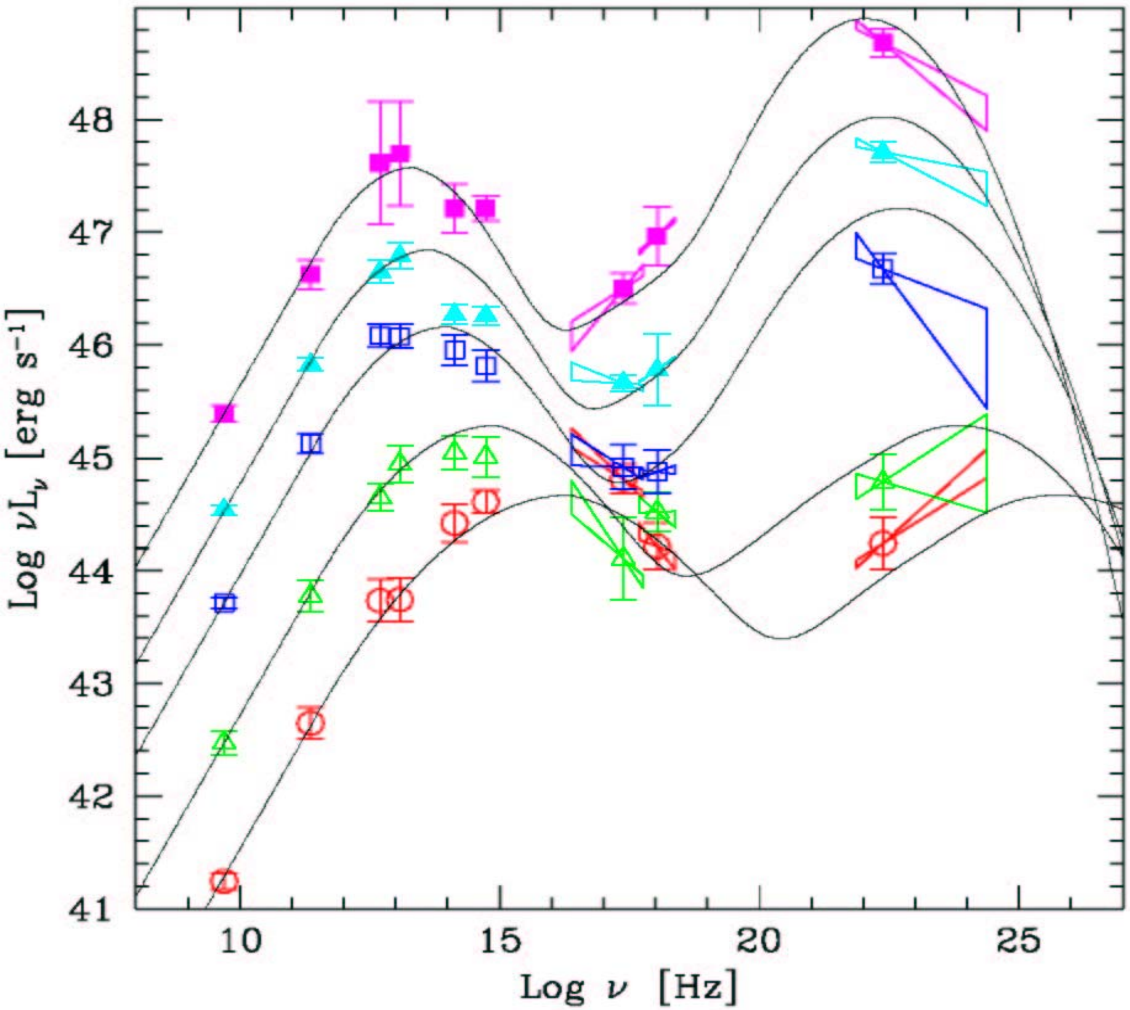


Costamante. & Ghisellini 2001, A&A, 384, 56



- Selection effects.
- Source continuum.

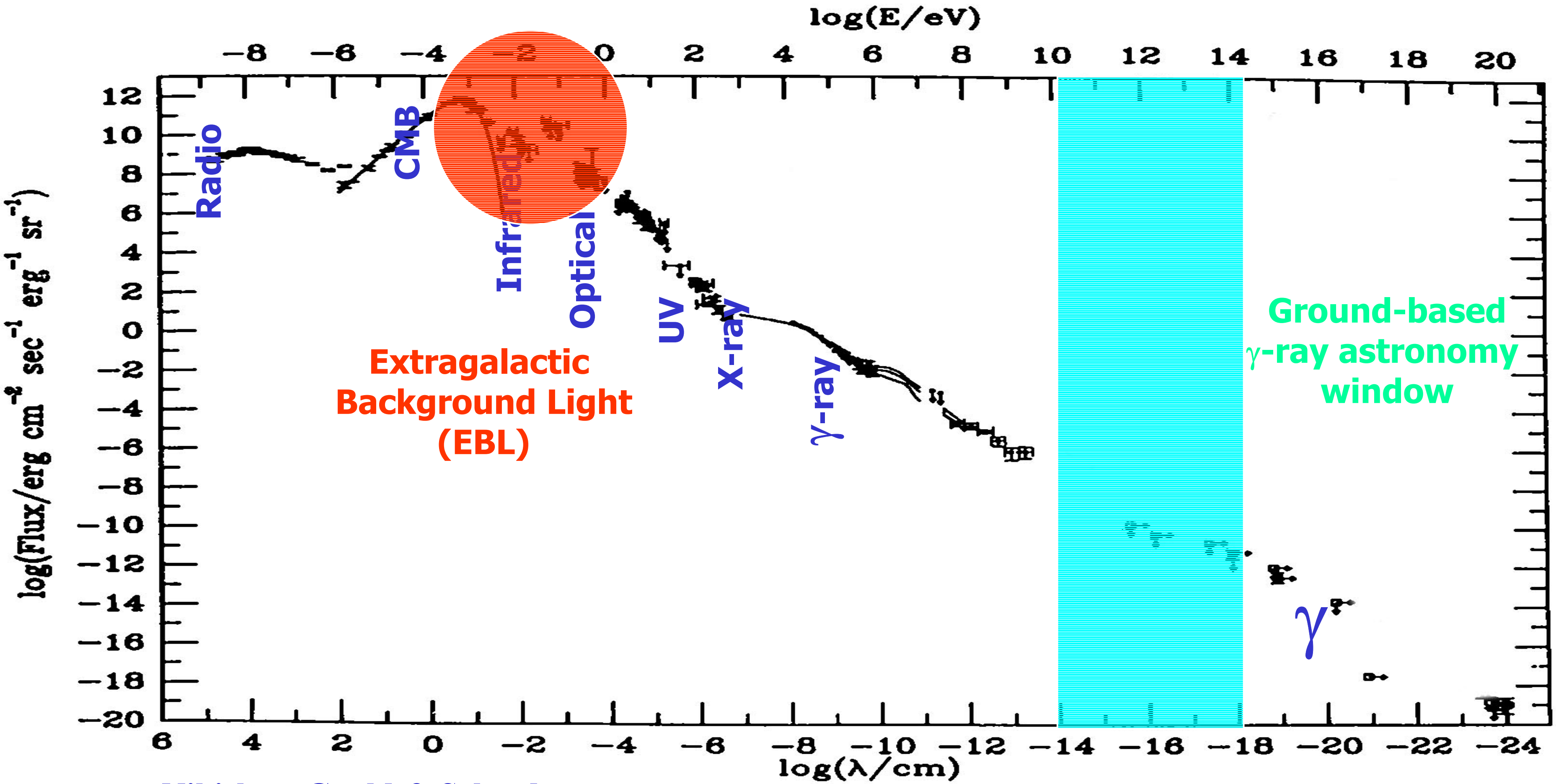
Understanding II



Fossati et al.:

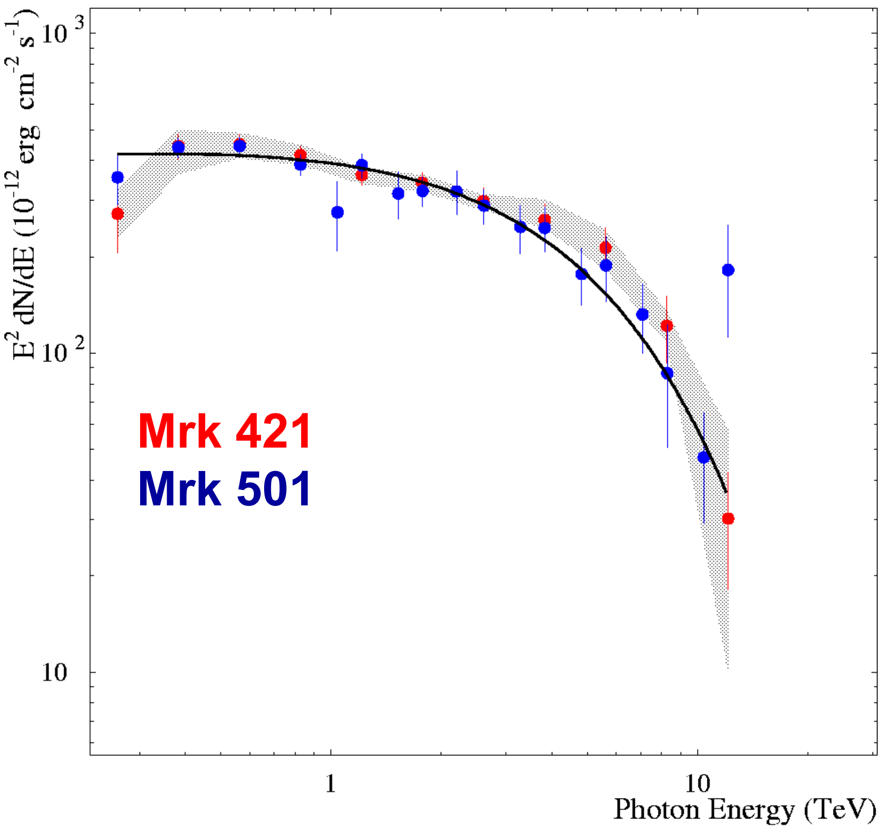
- Source families are characterized by bolometric luminosity.
- Relative components of Synch. and IC determine VHE emission or not.

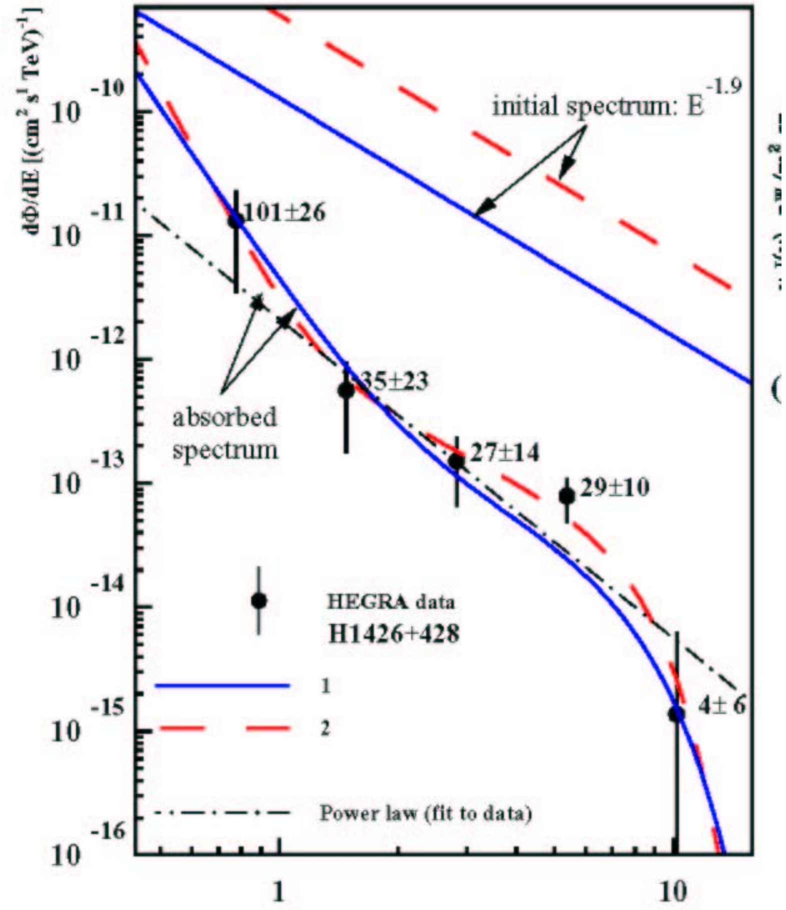
VHE Cosmology



Nikishov, Gould & Schreder
Stecker, de Jager, & Salamon

EBL Absorption ?





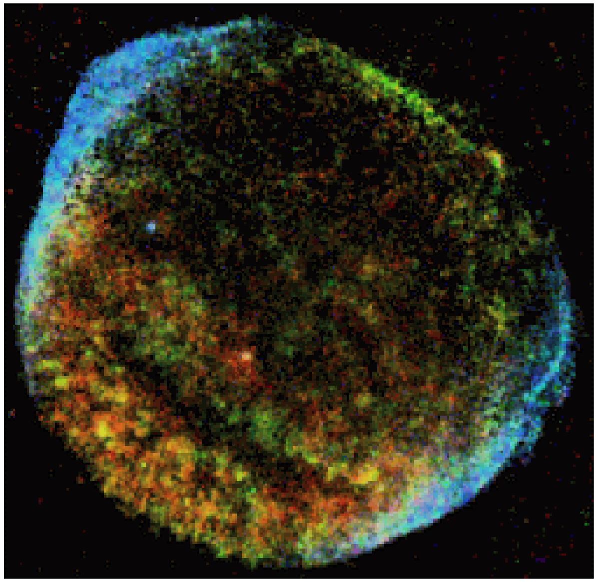
- Whipple data show similar cutoff values for two sources.
- HEGRA 1426 data. Very large uncertainties at present time.

SNR's & Other

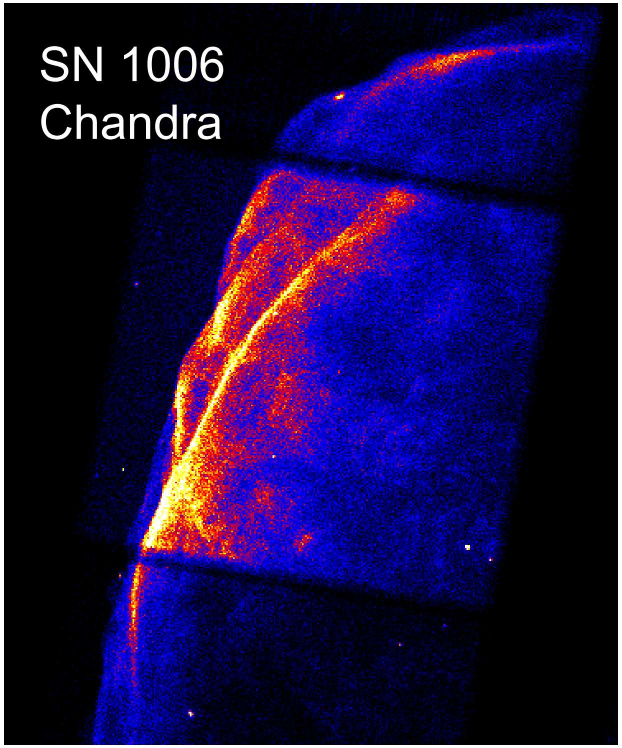
- Origin of cosmic rays.
- Detected SNR's:
  SN1006, RX J1713-3946 (CANGAROO)
  Cas-A (HEGRA, but very weak).
- Newest results – contradiction ?
- NGC 253 – Starburst galaxy
- A Galactic center detection ?

Cosmic-Ray Origin

SNR 1006

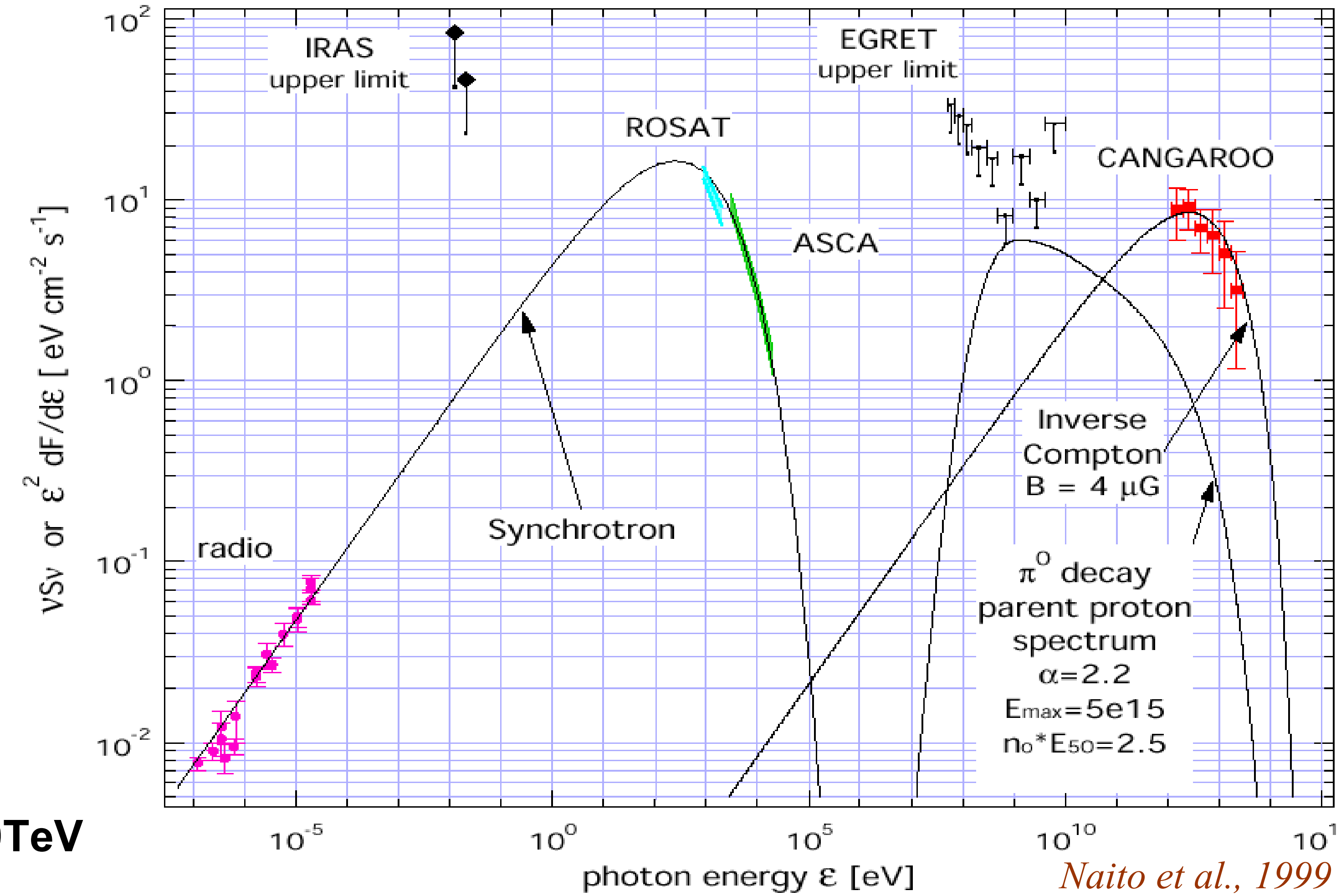


- Collapse of massive star.
- Outer layers ejected
  $v \sim 1\text{-}2 \times 10^4$ km/s.
- Shock front forms as it sweeps up material from ISM.
- CR's accelerated to $z \times 10^{14}$ eV.



- Spectrum of limb dominated by non-thermal emission
- X-ray observations show distinct shock structure in shell.
- Same region as VHE γ-rays

SN 1006 Electrons?



Naito et al., 1999

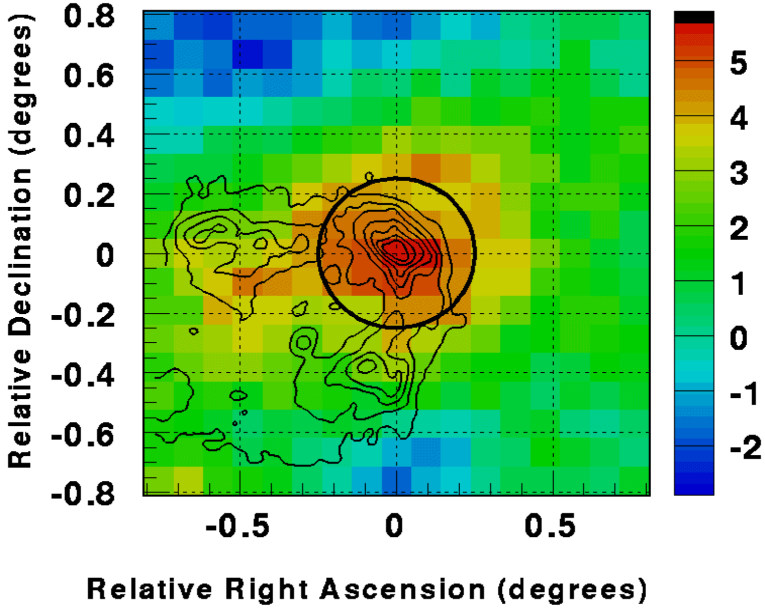
S = -2.2

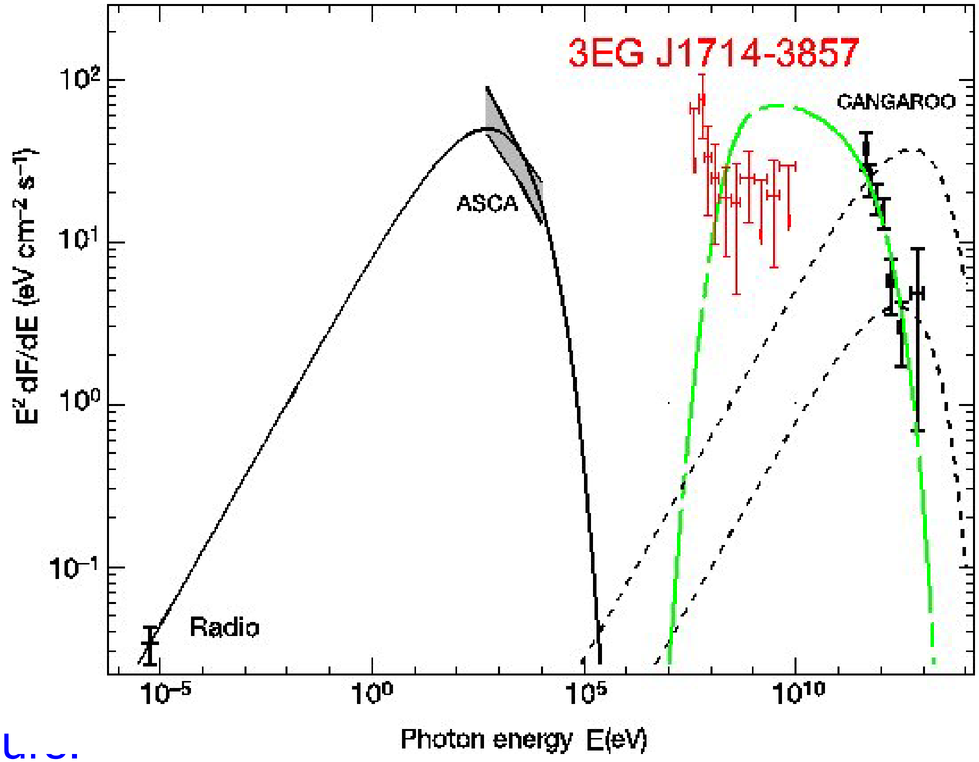
B ~ 4 μG

E_{max} ~ 50TeV

IC Modeling works! Consistent with relativistic e^-.

RX J1713-3946   Protons?





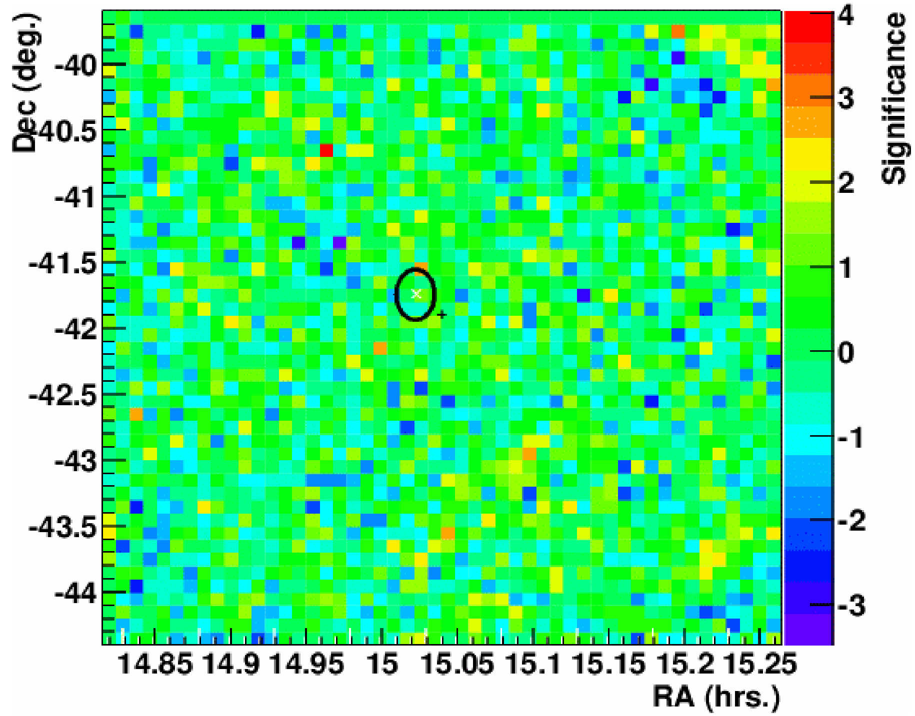
- CANGAROO image, SNR contou...
- SED claimed inconsistent with IC.

- Pohl & Reimer argue that proton model violates EGRET flux.

Source is still mysterious and far from settled.

SN 1006 – New HESS Data

HESS (Namibia)
Coming on line.

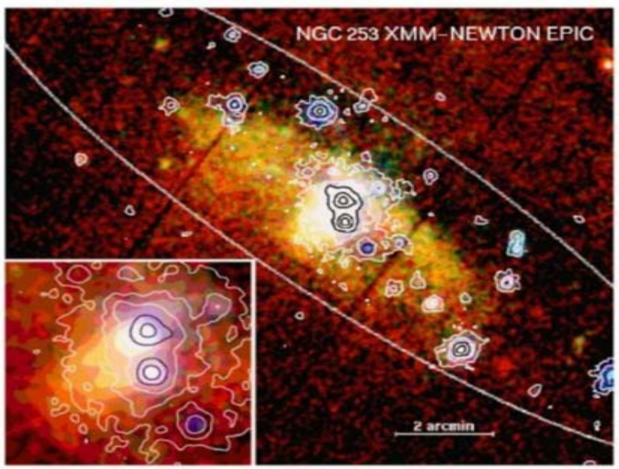


Should have easily detected with CANGAROO flux.

CT2 + CT3
~7 h on source
No γ-ray evidence

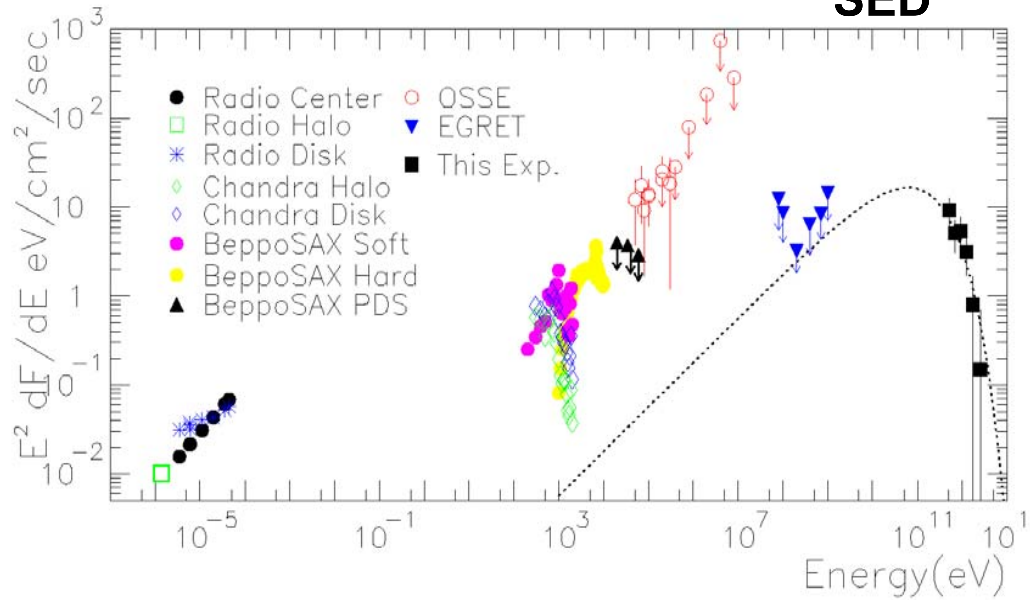
Other New CANGAROO Sources

NGC 253
Starburst Galaxy



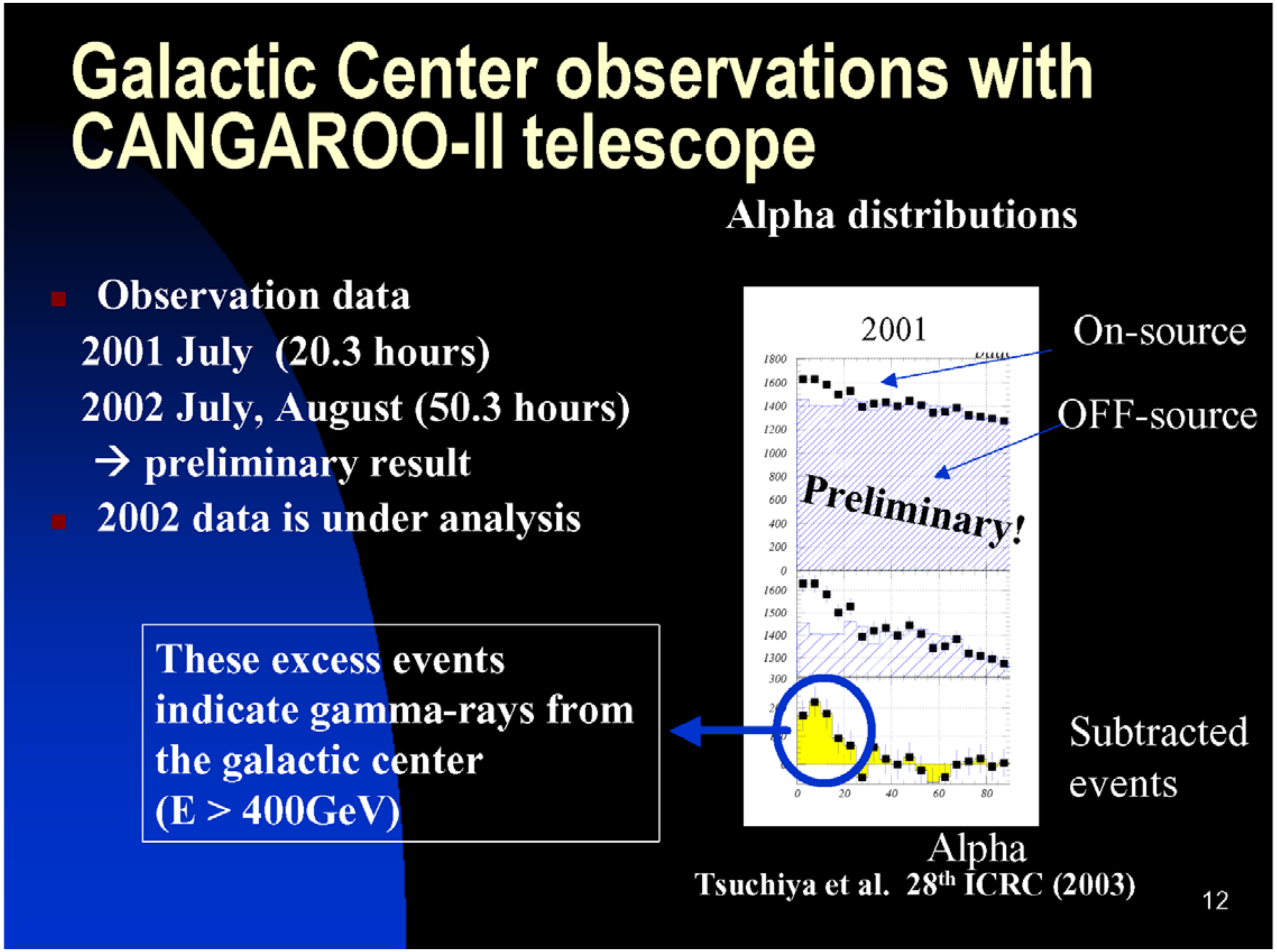
X-ray

SED



- Nearby starburst – EGRET UL.
- Enhanced SFR, 0.2-0.3 SN/yr corresponding higher CR production.
- Testing universal model of CR’s.

Galactic Center



Quo Vadis ?

What can we say regarding the various CANGAROO sources: SNR's, starburst galaxy, GC

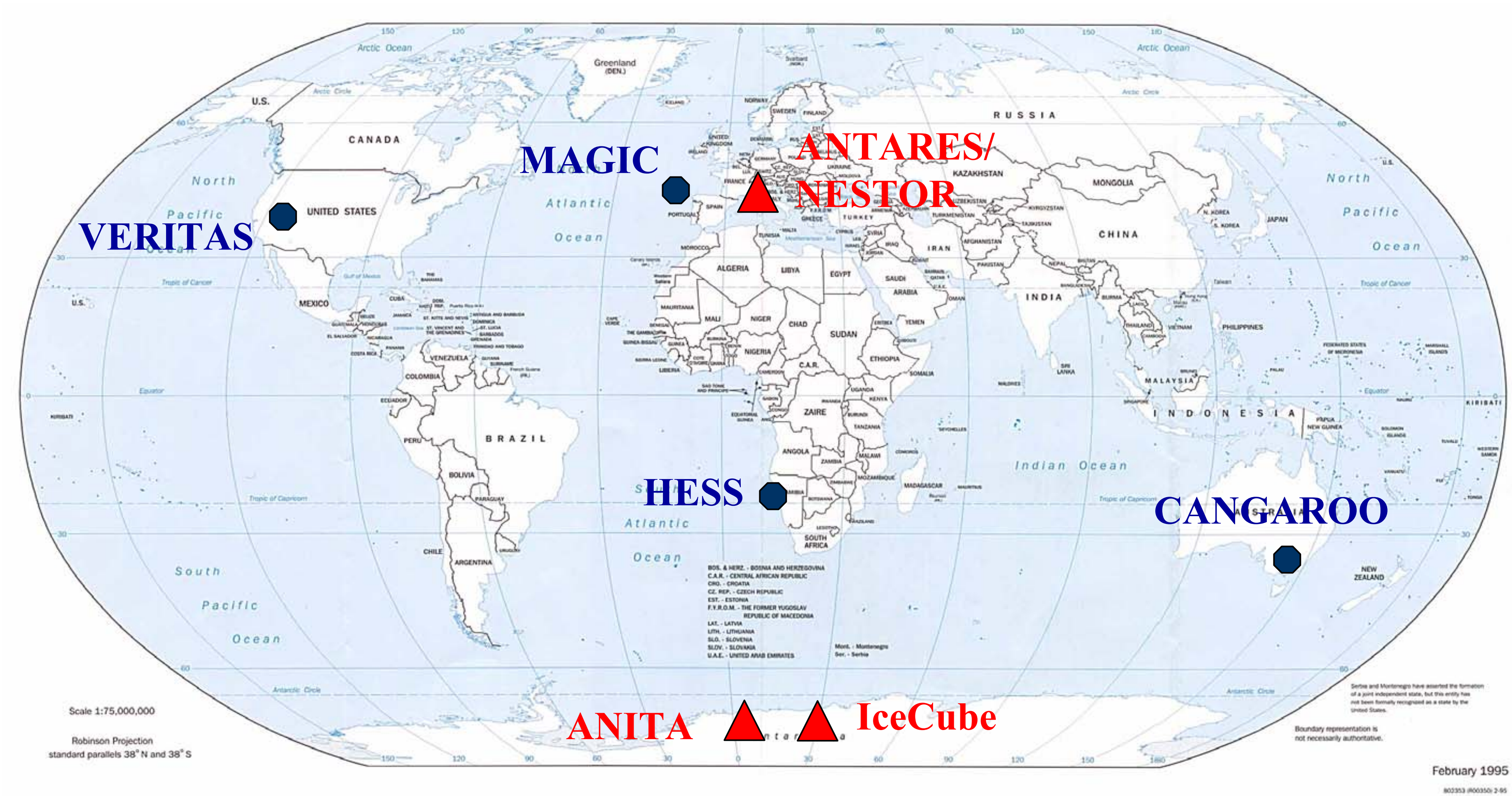
? ?

Not much.

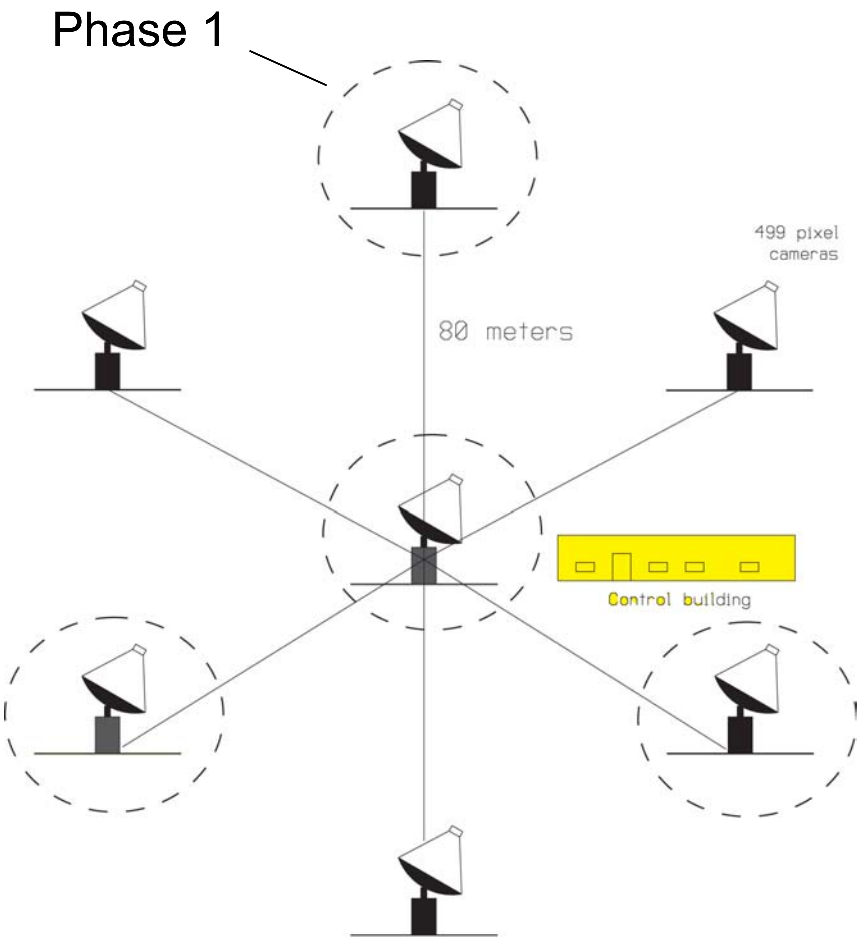
Future HE Telescopes

In space | GLAST

γ-ray telescopes
Neutrino telescopes



VERITAS



Collaboration: 50 scientists from U.S, Canada, U.K., Ireland

Detector Design:

- Seven 12m telescopes
- 500 pixel cameras (3.5°)
- Site in southern Az (1700m)
- Phase 1 operational in 2006.

Some characteristics:

- Energy threshold ~ 100 GeV
- Ang. Resolution ~ 4 arc-min
- Crab rate ~ 35 γ/min (45s detection!)

VERITAS History

1995: Concept study

1998: SAO/DOE proposal, SAGENAP review

2000: Decadal Survey (VERITAS in 10 mid-sized)

2001: Ritz Review – ready to go.

2002: SI & site difficulties. Descope to Phase 1. Blandford Review.

2003: Site issue settled (Horseshoe Canyon, Kitt Peak) Construction funds start.

2006: Phase 1 operations begins (4 Telescopes).

VERITAS – Well Underway

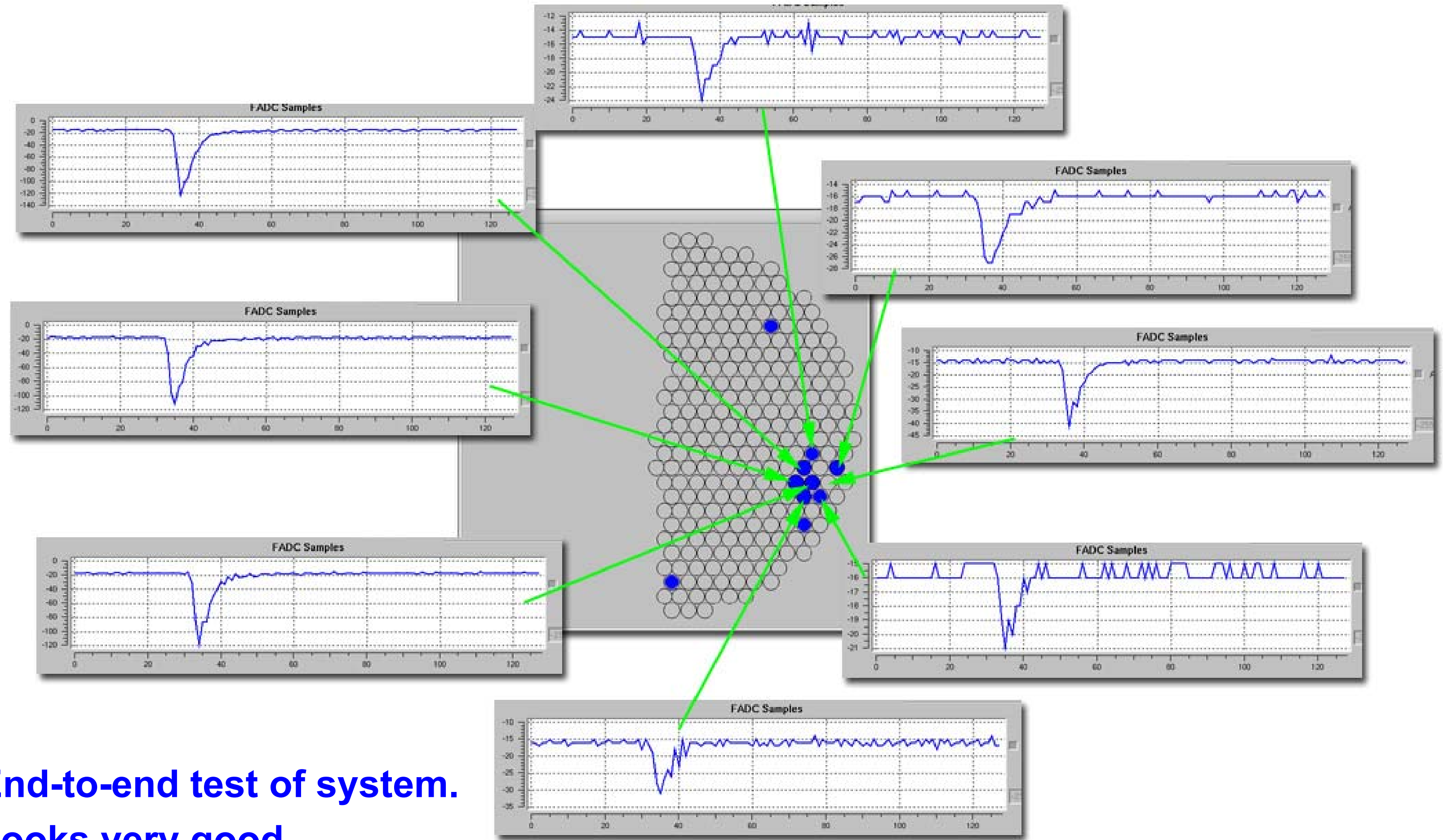
Electronics trailer

500 MHz FADC

Telescope 1:

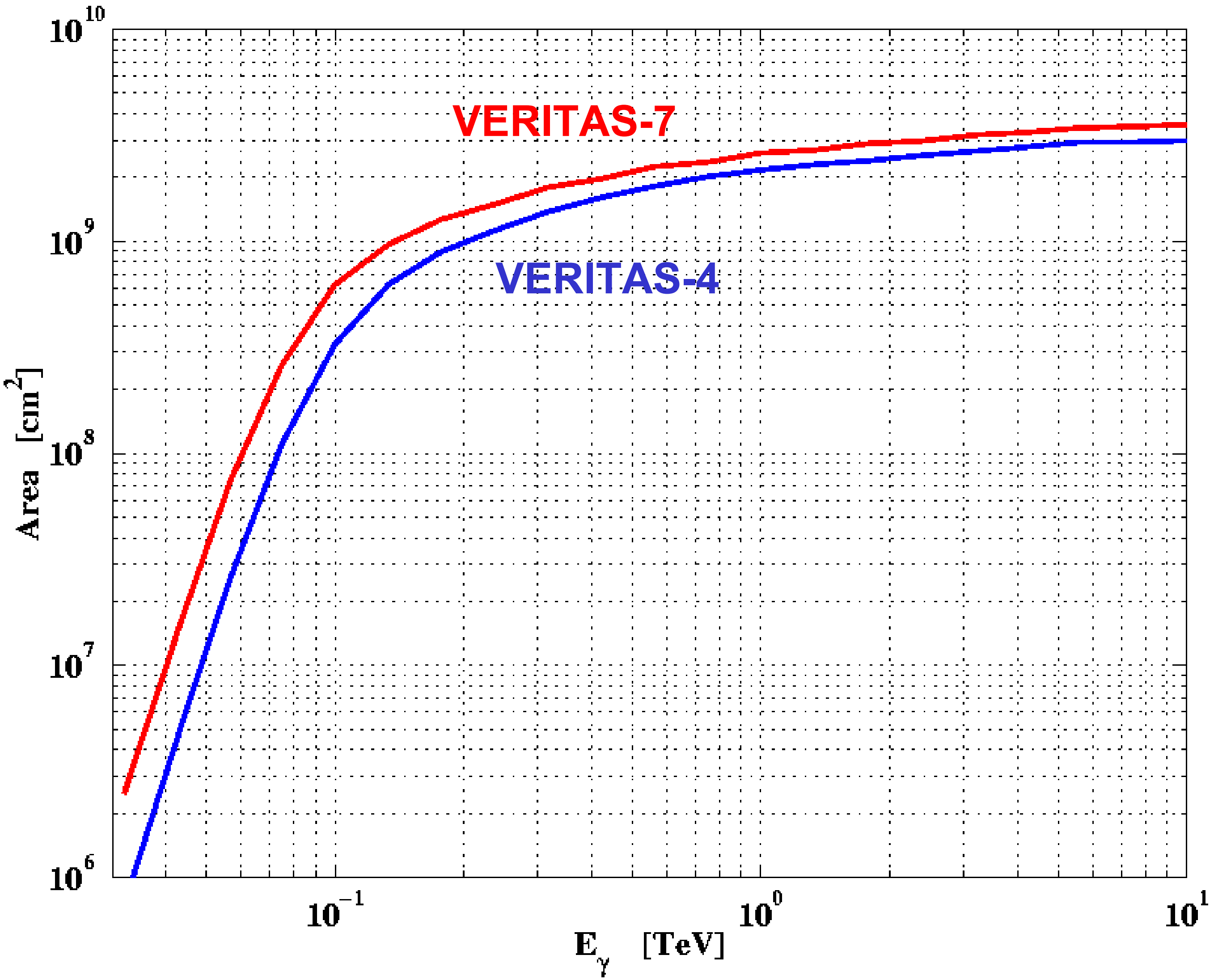
- All systems tested.
- Operational in spring 2004.

VERITAS – 1st Cherenkov Images



- End-to-end test of system.
- Looks very good.

VERITAS Effective Area



VERITAS-4:

100 GeV - 3.3×10^8 cm^2
1 TeV - 2.2×10^9 cm^2
10 TeV - 3.0×10^9 cm^2

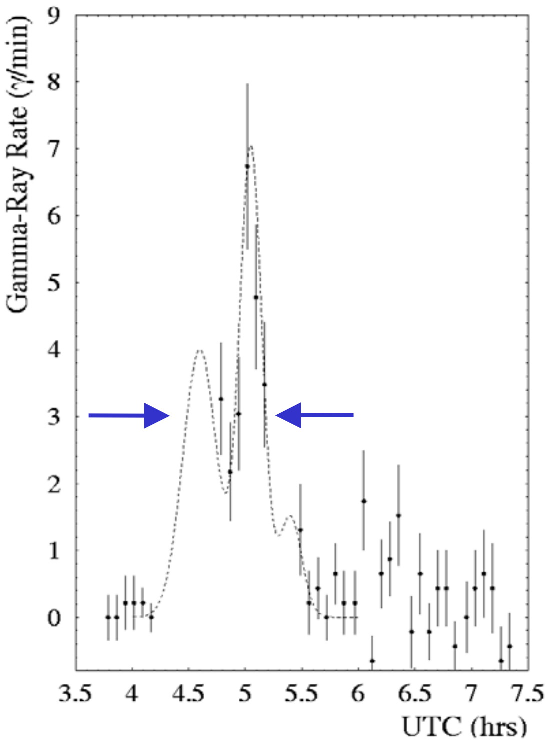
Trigger:
3 out of 4 telescopes
Pixel threshold– 5.6 pe

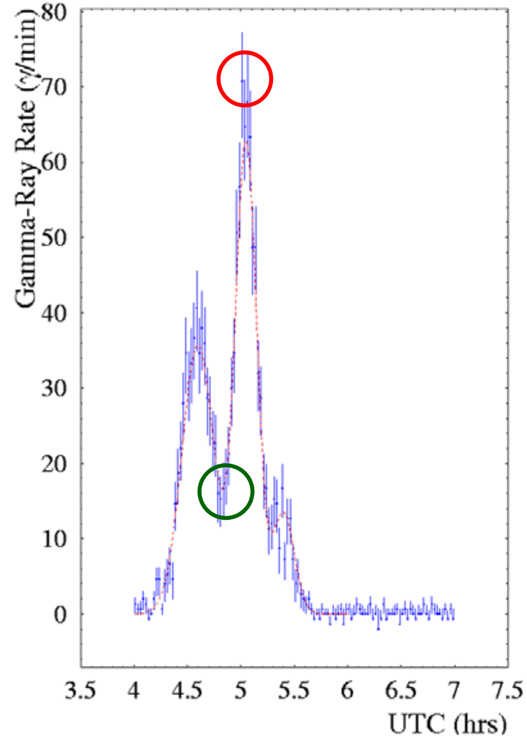
Main impact of seven telescopes Is in flexibility.

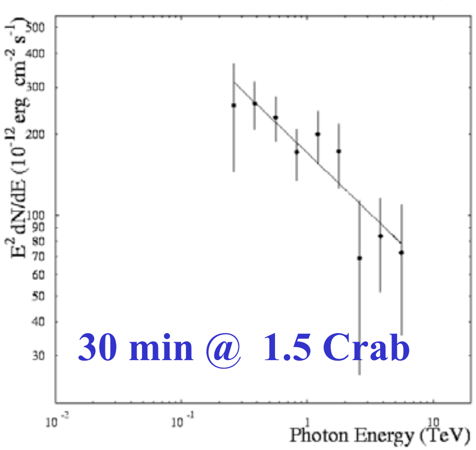
Telescope Characteristics

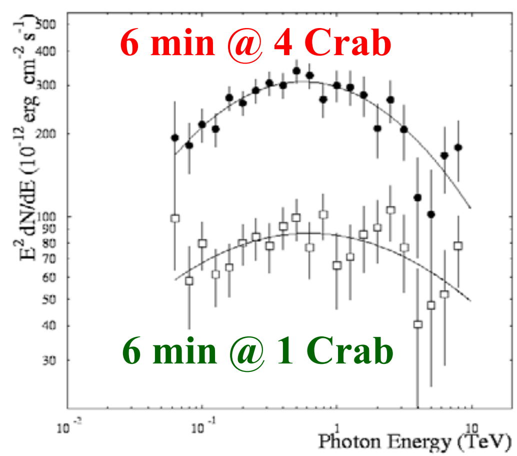
Parameter	Wavefront (STACEE)	Sing. Imager (Whipple)	Array Imager (VERITAS-4)
Mirror Area	64 x 37m^2	1 x 80 m^2	4 x 110 m^2
E (peak)	75 GeV	350 GeV	110 GeV
FOV	0.75^o	3.5^o	3.5^o
P rejection	~ 50	~ 300	~ 5,000
Energy Res.	~ 40%	~ 25%	~10%
Ang. Res.	0.25^o	0.20^o	0.07^o
Crab rate (γ/min)	~ 5	~ 2	~ 35

Variability Performance







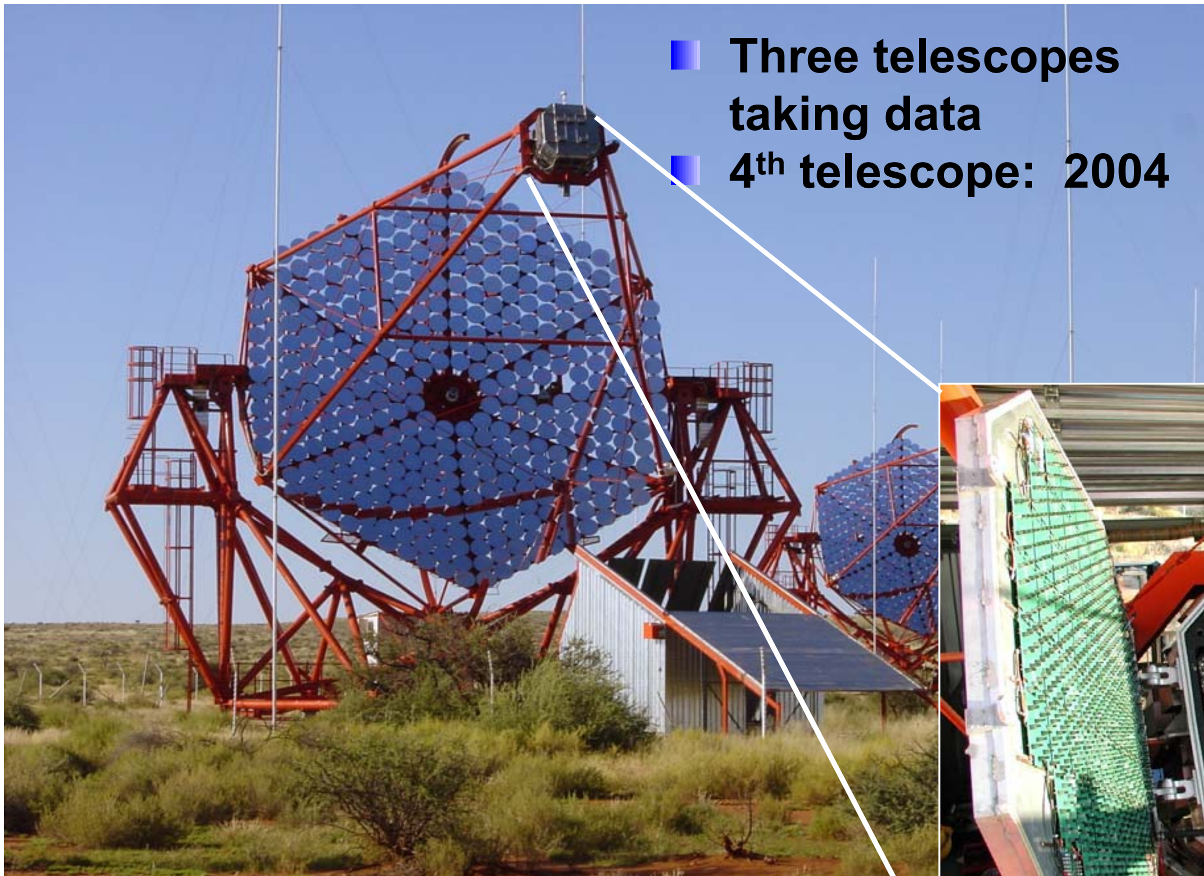


VERITAS:

- has hour-scale sensitivity for time-resolved spectral measurements.
- can probe intrinsic variability timescales; distinguish between
  - external absorption
  - intrinsic curvature
    - (variable)

HESS Telescope

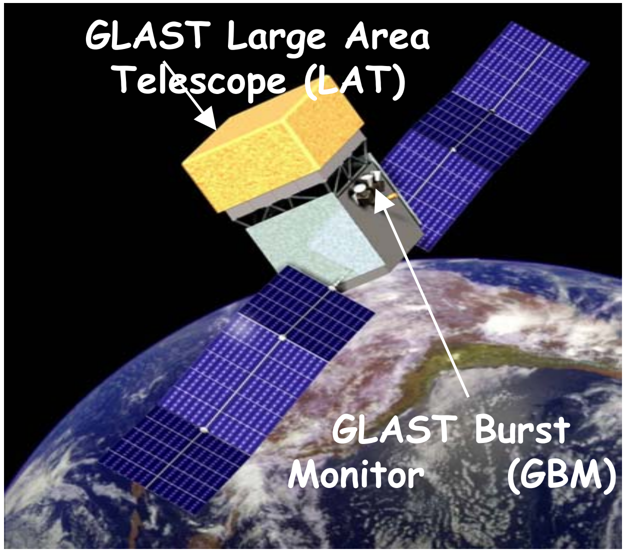
- **Three telescopes taking data**
- **4th telescope: 2004**



H.E.S.S. Phase I
4 Telescopes
107 m^2 mirrors

Namibia Site

GLAST & VERITAS Synergy



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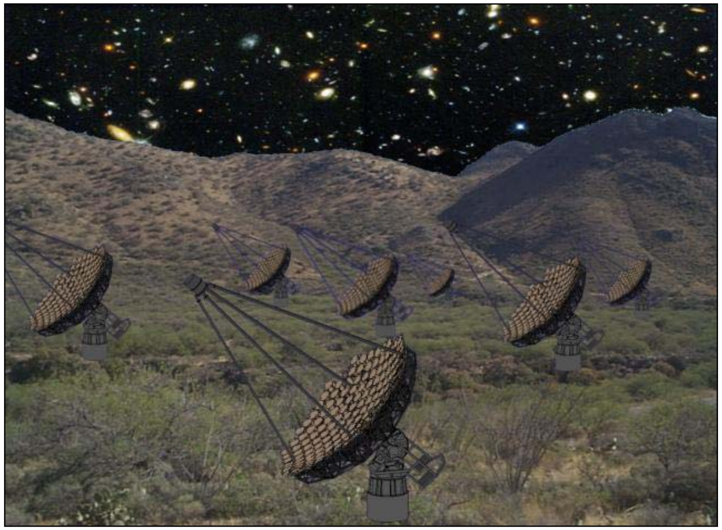

GLAST:
- Sensitive & wide FOV
- 100% duty cycle
- Broad energy range

Some sleepless nights.

VERITAS:
- Very sensitive
- Very large collection area
- Coverage to 50 TeV

<u>Many</u> sleepless nights.

SUMMARY

- VHE γ-ray astronomy is developing rapidly.
- We have made detailed studies on selected sources. AGN, SNR's, pulsar nebulae.
  (few % of sky surveyed with high sensitivity).
- Next generation telescopes will be much more sensitive and versatile.
  (40-50 new sources/hemisphere).
- Connection to GLAST is very important.