γ astronomia
con telescopi Cherenkov

Antonio Stamerra*
Università di Siena / INFN Pisa

- L'Universo non termico
- Problematiche in astroparticle
- Il cielo gamma
- Telescopi Cherenkov

* antonio.stamerra@pi.infn.it
MAGIC Collaboration
http://www.pi.infn.it/magic

L'Universo non termico

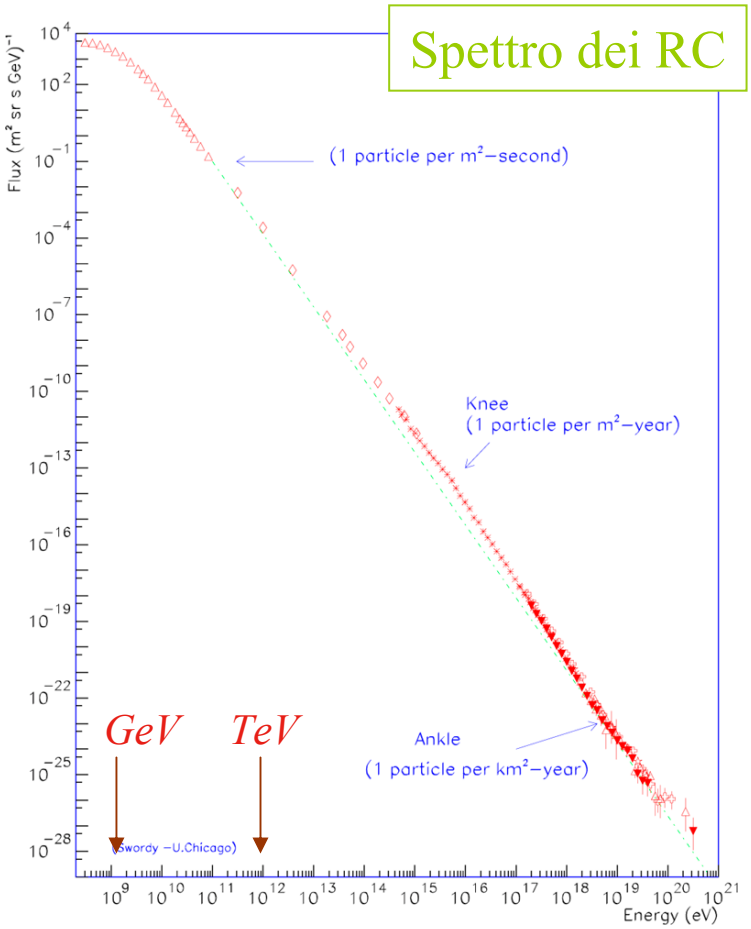
- **Emissione termica**
  Spettro di corpo nero

  Radio ⇔ UV

- **Emissione non termica**

  Accelerazione di particelle cariche

  X-ray ⇔ γ-ray (regione VHE)



Acceleratori cosmici

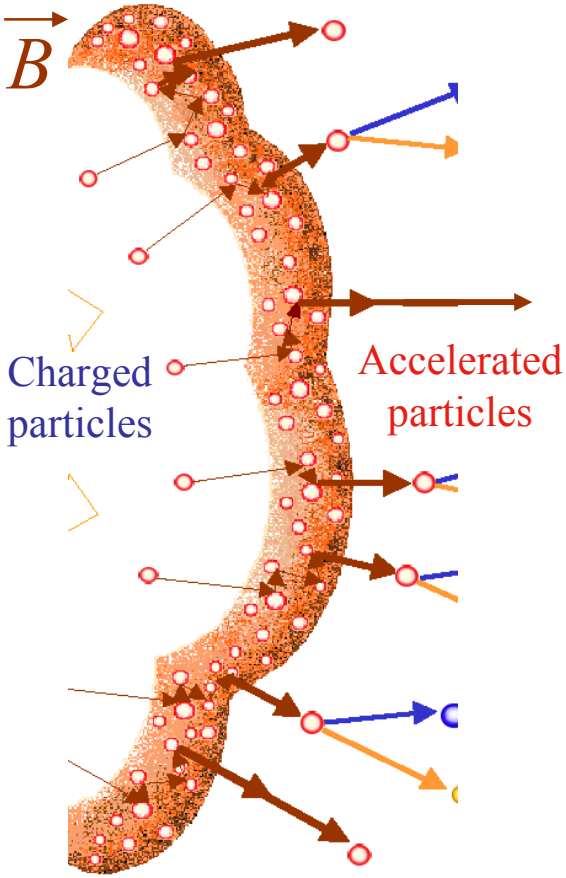
- Meccanismo di Fermi

  campi magnetici + particle injection +

  intrappolamento zona di acceleraz.

- Diffusione galattica/extragalattica

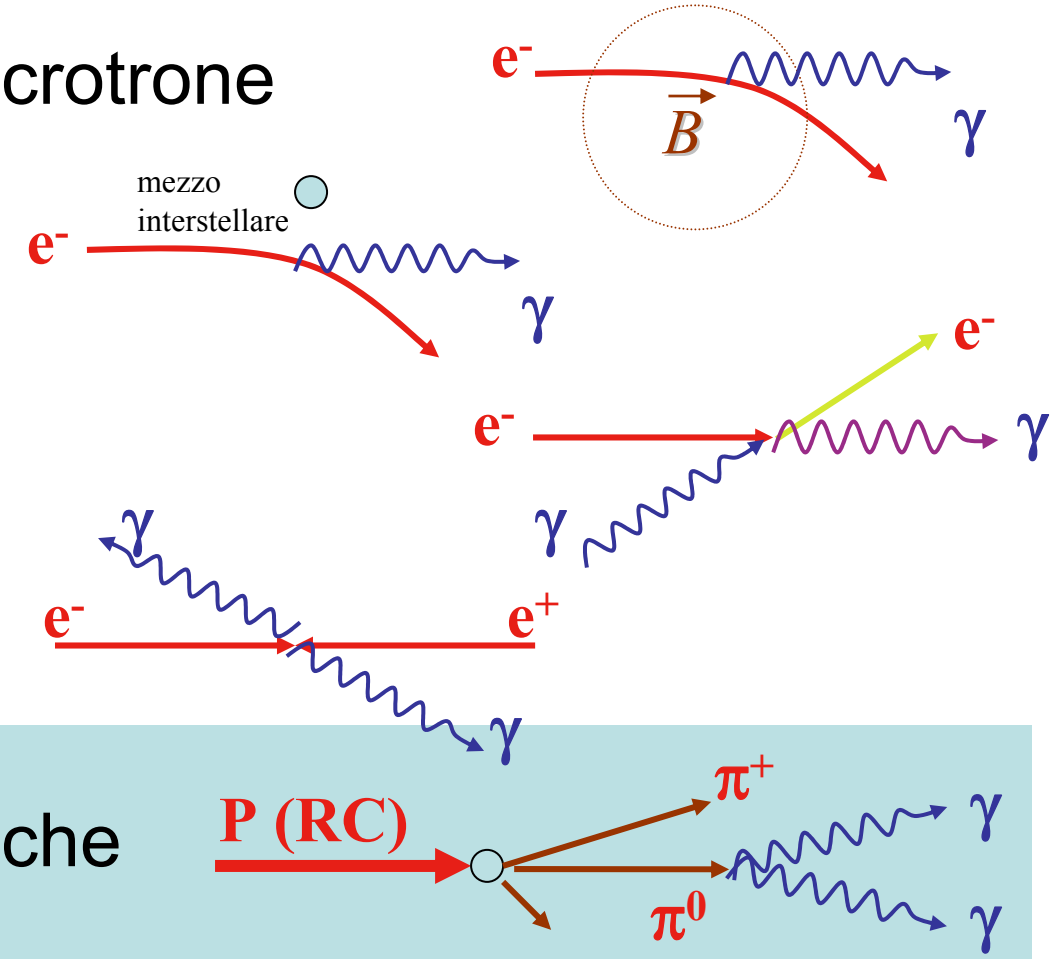
  Particelle deviate da campi magnetici: direzione di provenienza non coincide con sorgente di produzione



Raggi γ: tracciatori delle sorgenti di accelerazione

Produzione di raggi γ

- Radiazione di sincrotrone
- Bremstrahlung
- Compton inverso
- Annichilazione
- Collisioni energetiche



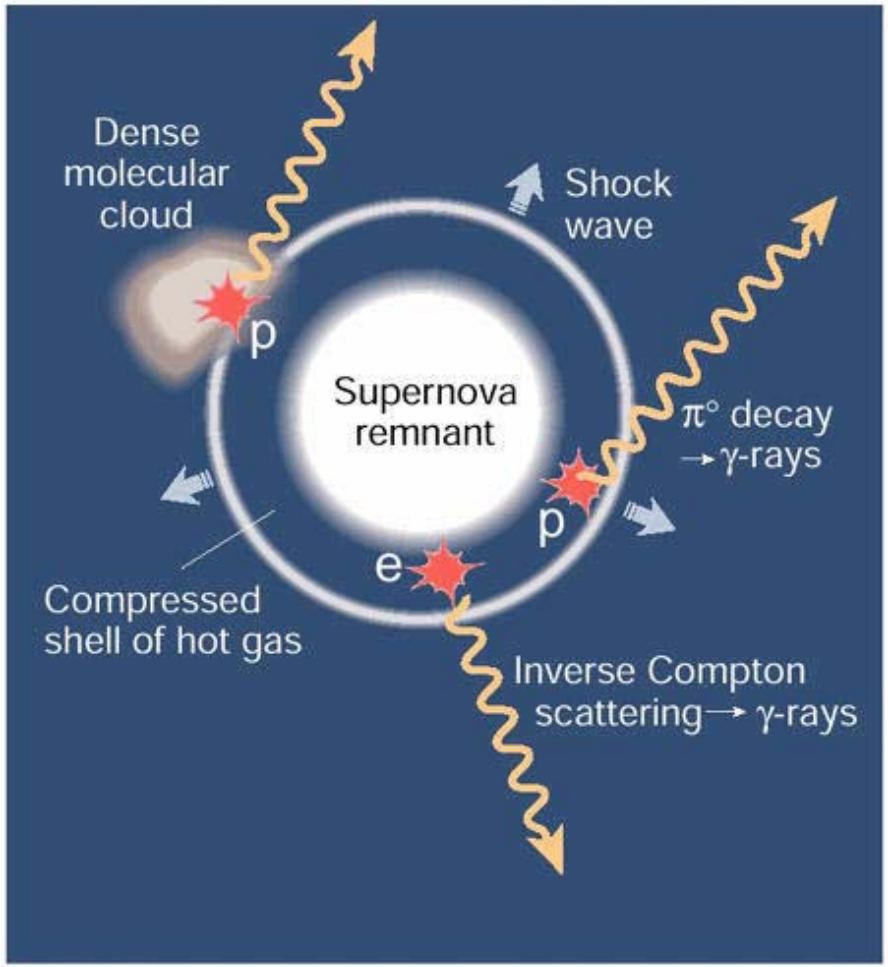
Problematiche in astroparticle

- Sorgenti di accelerazione dei RC
- Gamma-Ray-Horizon (GRH)
  - Parametri cosmologici
- Dark Matter (DM)
- Gamma-Ray-Burst (GRB)
- …

Sorgenti di RC

- Si ritiene che le SNR siano la sede di accelerazione dei RC fino a 10^{15} eV
- Emissione γ da decadimento π^0 e interazione *p* con nubi molecolari
- Identificabile da spettro di decadimento del π^0

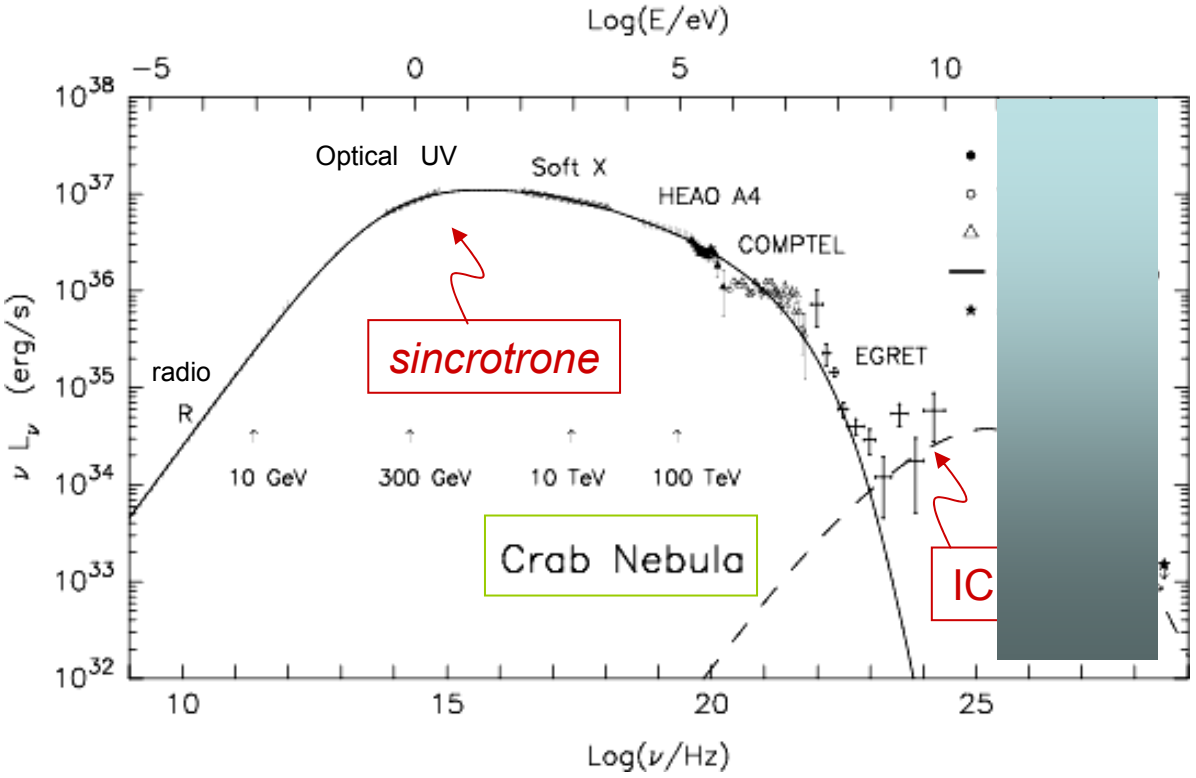
Non si hanno sorgenti γ con una chiara indicazione di decadimento da π^0

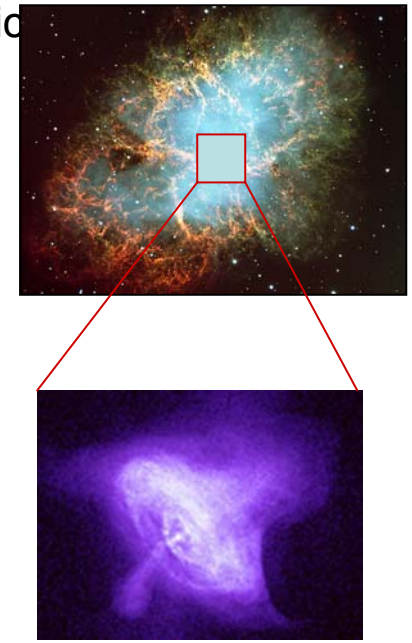


Dilemma e^-/had?

Spettri energia a due componenti (sincrotrone + IC)

giustificabile con l'emissione da parte degli elettroni relativistic

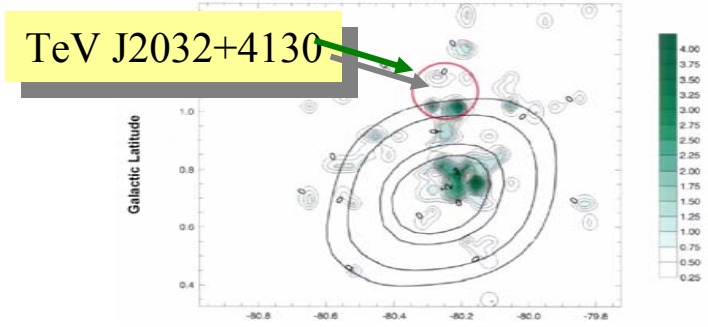




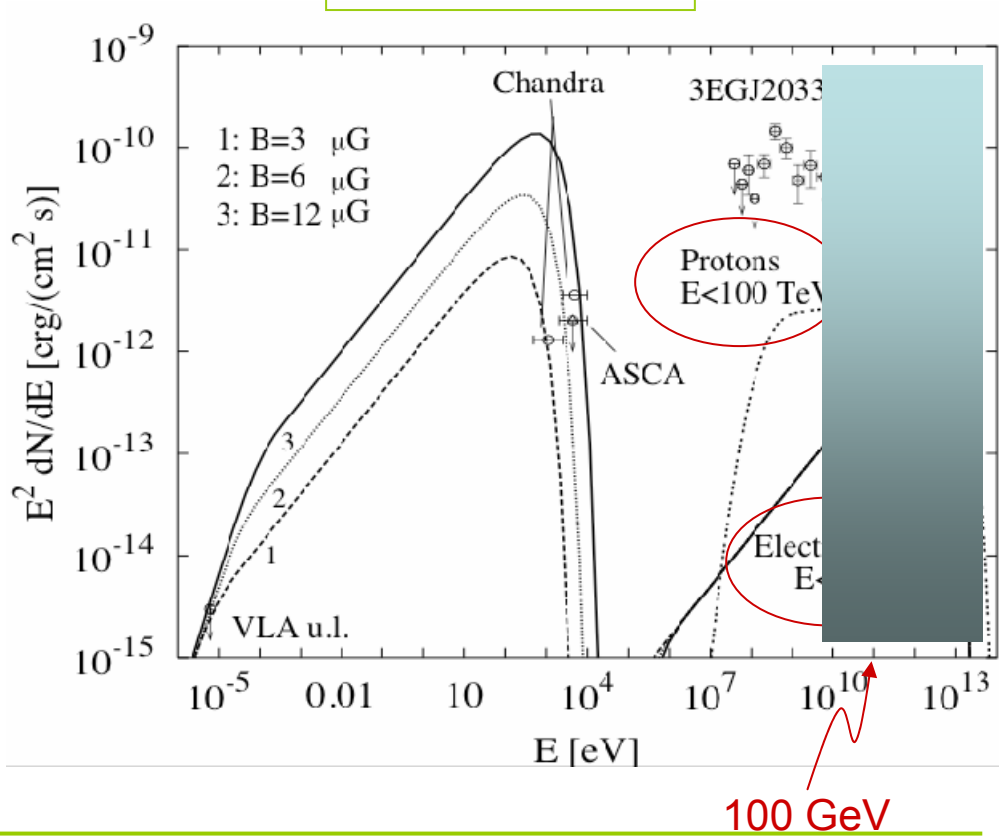
Dilemma e^-/had?

OB stellar associations

- Nuova popolazione di oggetti che possono accelerare protoni/nuclei e competere con le SNR nella produzione di RC
- Identificate nel TeV (TeV-J2032, TeV-J1013) ma non ad altre lunghezze d'onda…



TeV-J2032+4130

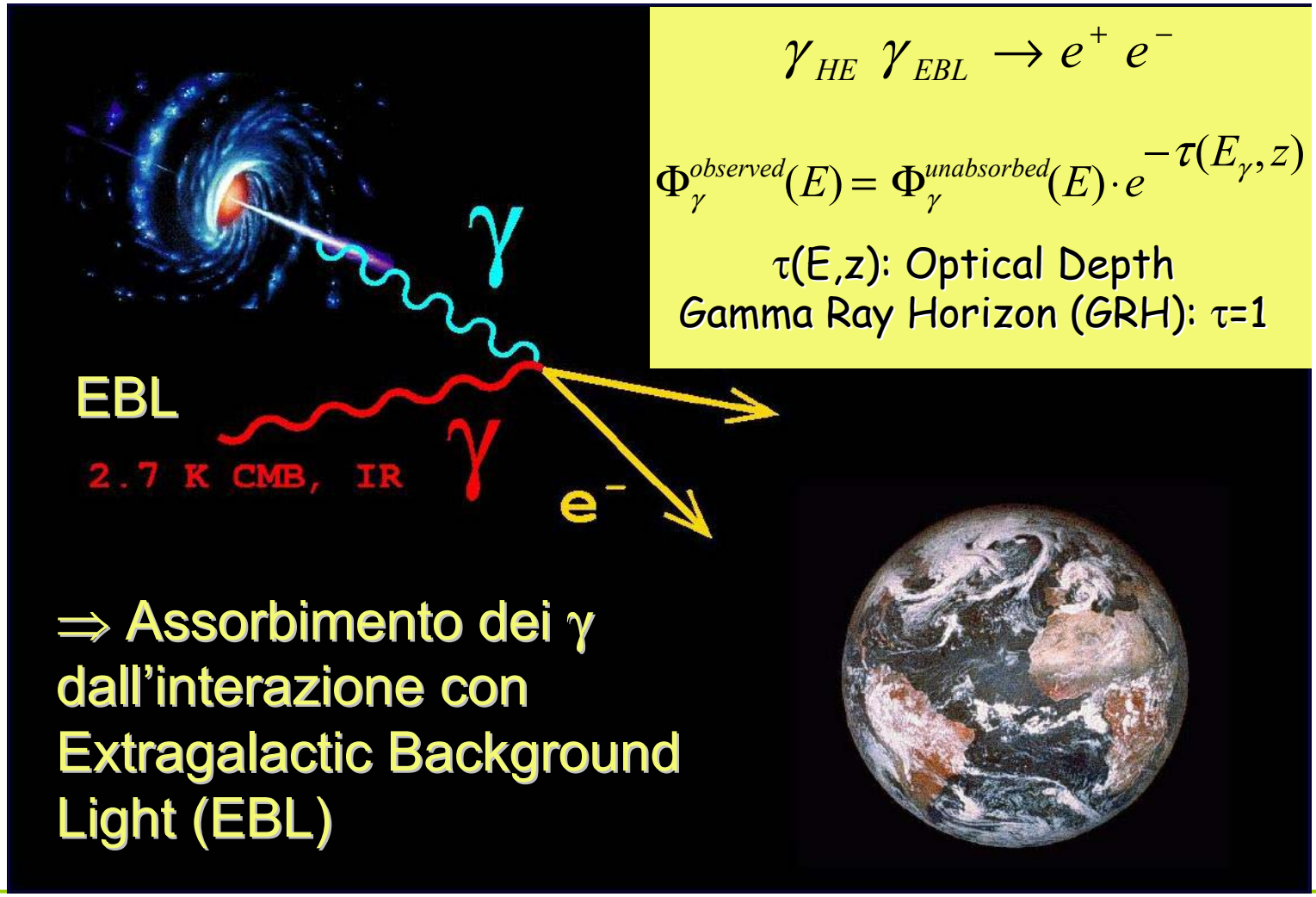


γ-Ray Horizon

$$\gamma_{HE}\ \gamma_{EBL} \rightarrow e^{+}\ e^{-}$$

$$\Phi_{\gamma}^{observed}(E) = \Phi_{\gamma}^{unabsorbed}(E) \cdot e^{-\tau(E_{\gamma},z)}$$

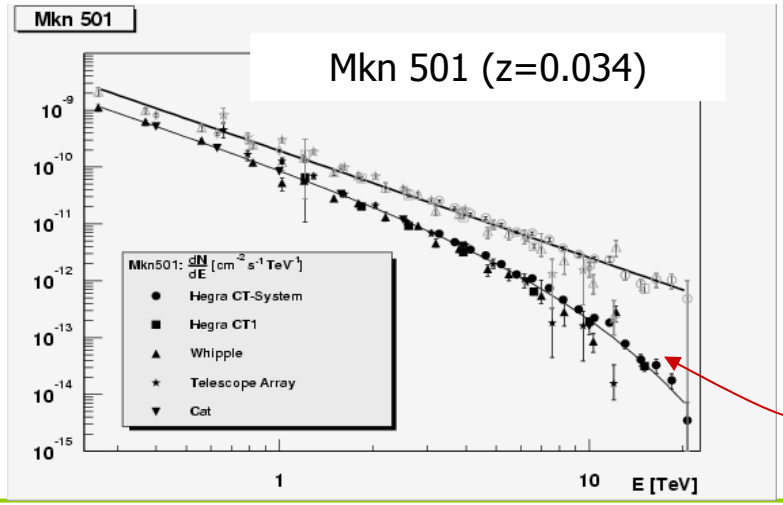
τ(E,z): Optical Depth
Gamma Ray Horizon (GRH): τ=1



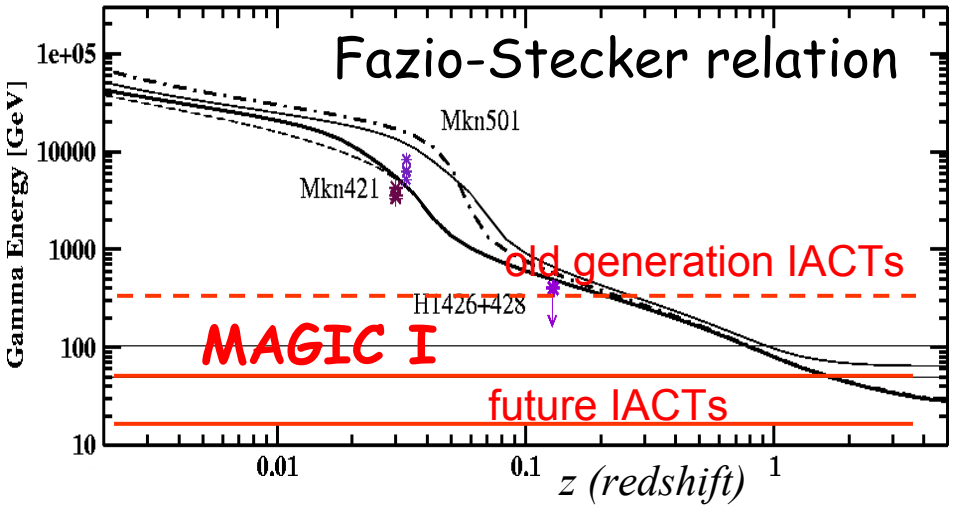
⇒ Assorbimento dei γ dall'interazione con Extragalactic Background Light (EBL)

γ-Ray Horizon

- L'assorbimento dipende dal redshift *z* e dall'energia dei γ *Fazio-Stecker relation*
- L'assorbimento determina un cutoff negli spettri degli AGN
- Misura dei cutoff di sorgenti a diversi *z* ⇒ misura dell'EBL.



Cut-off



Kneiske, Mannheim, Hartmann: Astron. Astrophys. 386 (2002)

Bassa energia di soglia

⇒ osservazione di sorgenti più distanti

Dark Matter search

- Observational cosmology: 25% of density of Universe consists of Cold Dark Matter (CDM)
- Stable weakly interacting massive particles (WIMPS) are attractive CDM candidates
- Direct searches (DAMA, CDMS, CRESST,...)
- Indirect searches: annihilation products (ν, γ,..)
- neutralino χ $\Rightarrow$ WIMP candidate

Neutralino
- *Lightest SUSY particle* $(100\ GeV \leq m_\chi \leq 1TeV)$
- *Stable (R-parity)*
- *Weakly interacting: mixture of neutral s-fermions (Higgsino, Gaugino)*

At one loop, neutralinos can annihilate to

$\chi\chi \rightarrow \bar{q}q$ $\quad \gamma\ continuum$

$\chi\chi \rightarrow \gamma\gamma$ $\quad \gamma\text{-}line\ \ E_\gamma = m_\chi$

$\chi\chi \rightarrow \gamma Z$ $\quad \gamma\text{-}line\ \ E_\gamma = m_\chi - m_Z^2 / m_\chi$

γ-flux predictions from χ annihilations

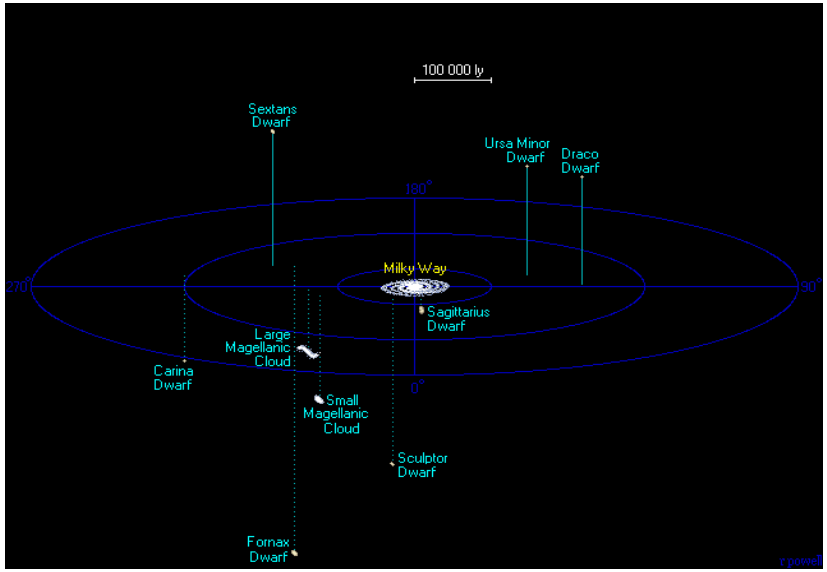
$$\Phi_\gamma(\Omega) = \frac{N_\gamma v\sigma}{4\pi \cdot M_\chi^2} \cdot \int \rho_{DM}{}^2(l)dl(\Omega)$$

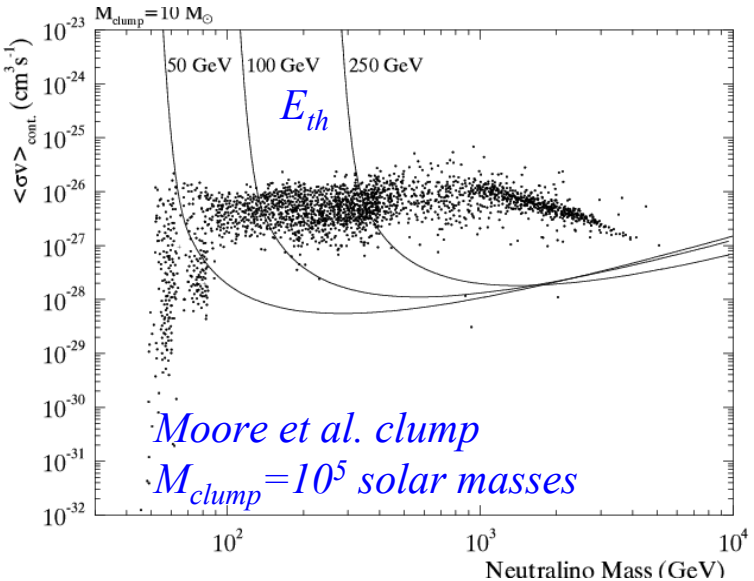
Cross section, χ mass

DM halo model

Dark Matter search

- Ricerca di addensamenti di DM per evidenziare il segnale γ
- Flusso γ continuum prevale sulle linee γ ...
- Centro galattico sfavorito (flusso di fondo gamma diffuso elevato)
- Ricerca di addensamenti di DM: ammassi globulari, galassie sferoidali…

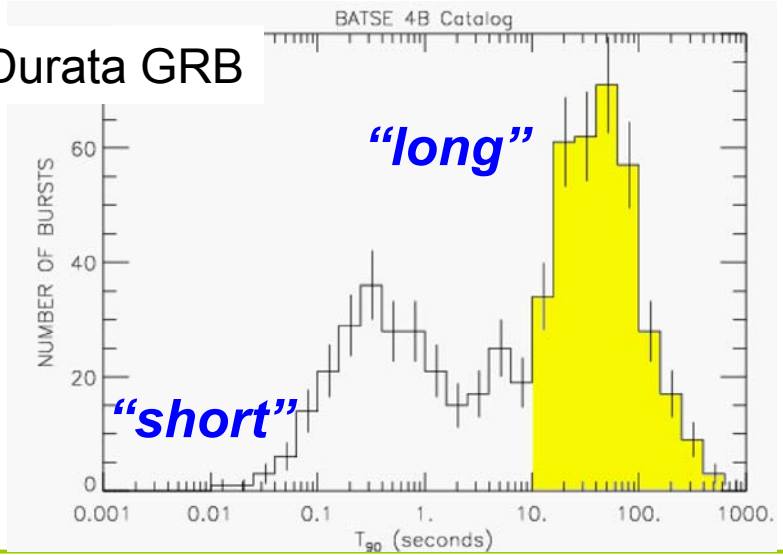




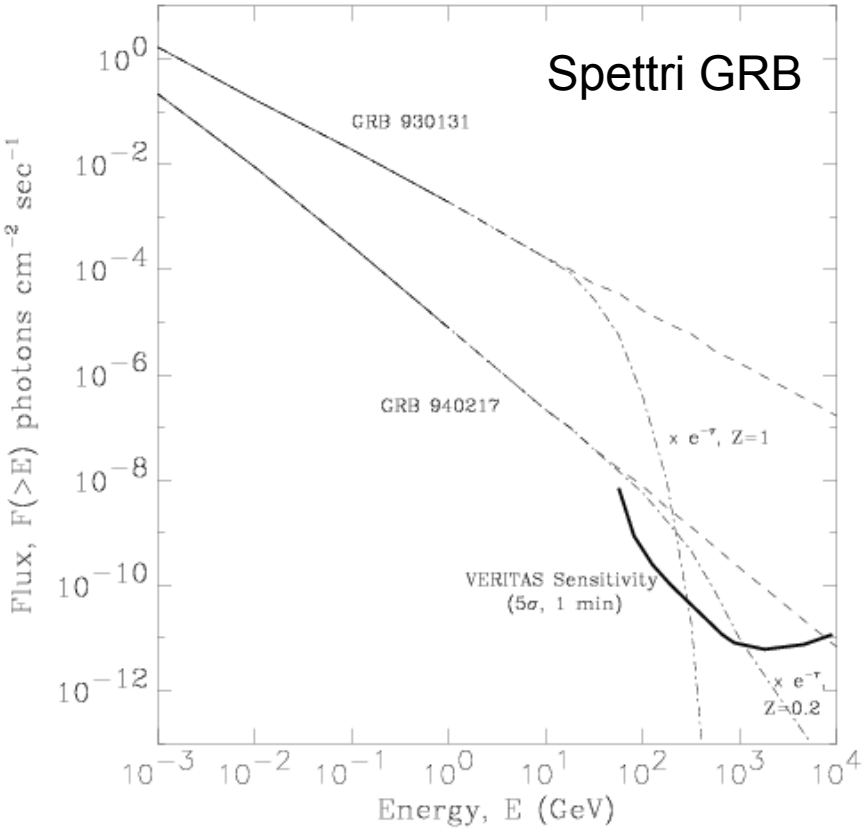
Gamma-Ray-Burst

- Osservazione della prompt emission nella regione VHE
- Estrapolazione spettri BATSE: flusso elevato
- Sistema di alert (GCN) e puntamento rapido

Durata GRB



Spettri GRB

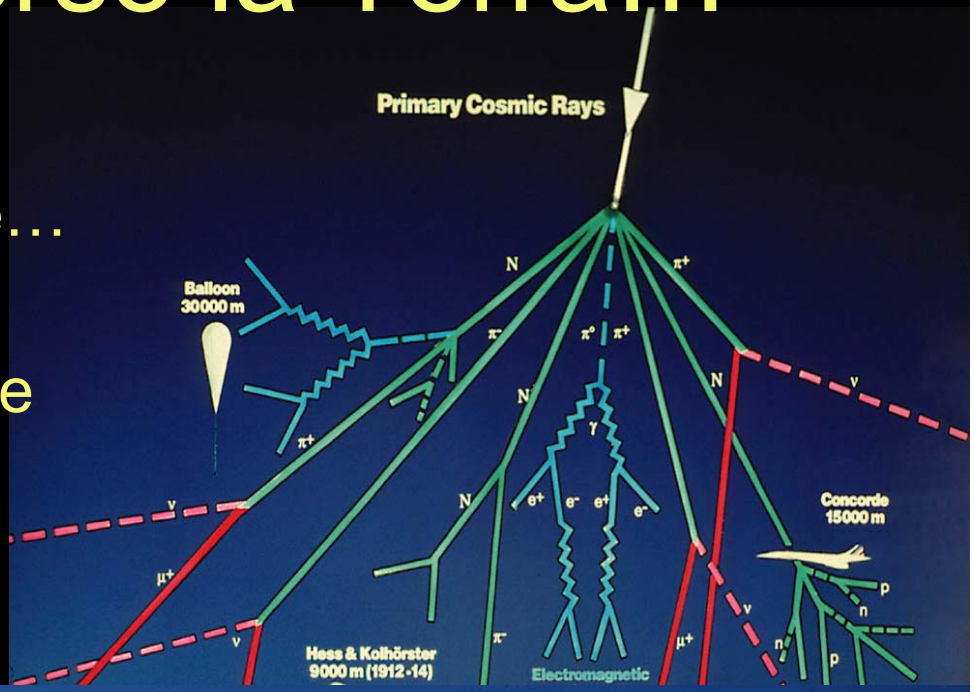


Viaggio verso la Terra…

La radiazione gamma VHE è bloccata dall'atmosfera terrestre…

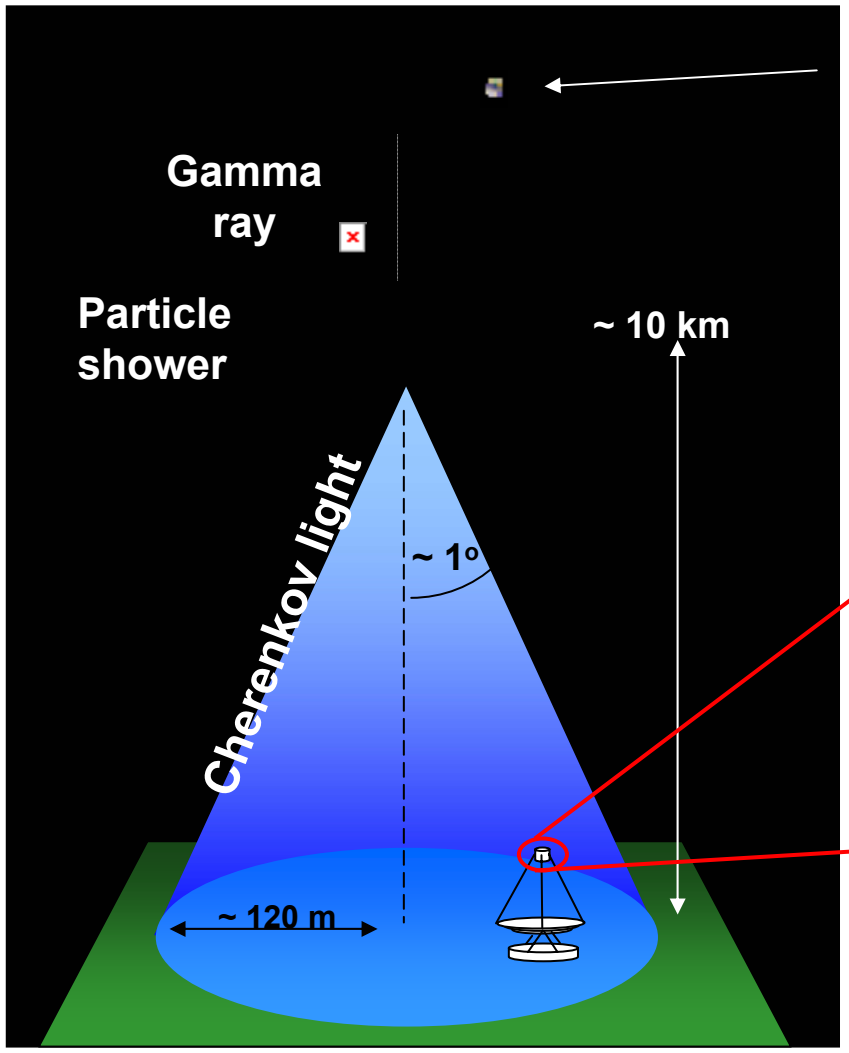
1054 g/cm^2 - 28X_0

- Osservazione diretta: satellite
- Osservazione indiretta: telescopi Cherenkov, EAS, underground detectors…



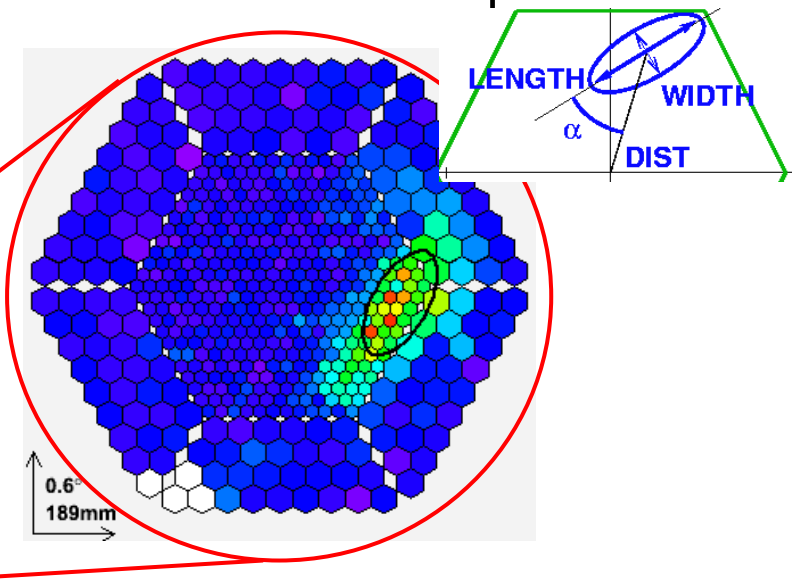
Imaging Air Cherenkov Telescopes

IACT



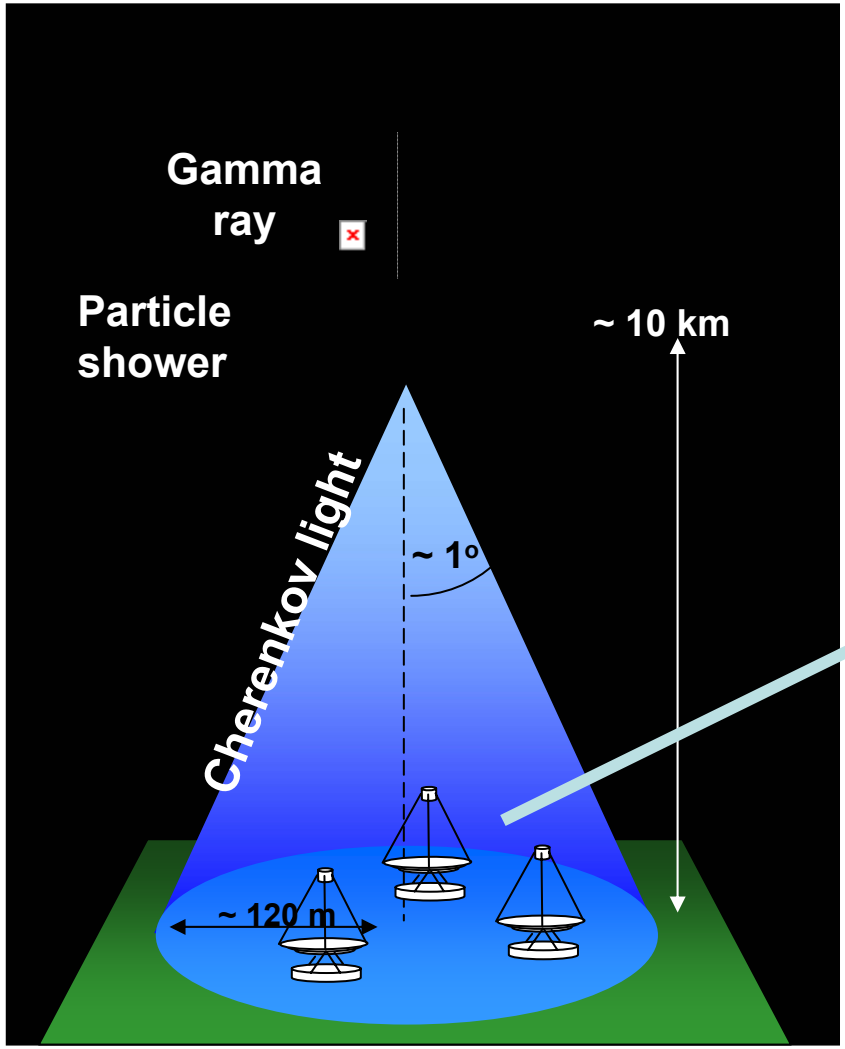
GLAST (ingrandito)

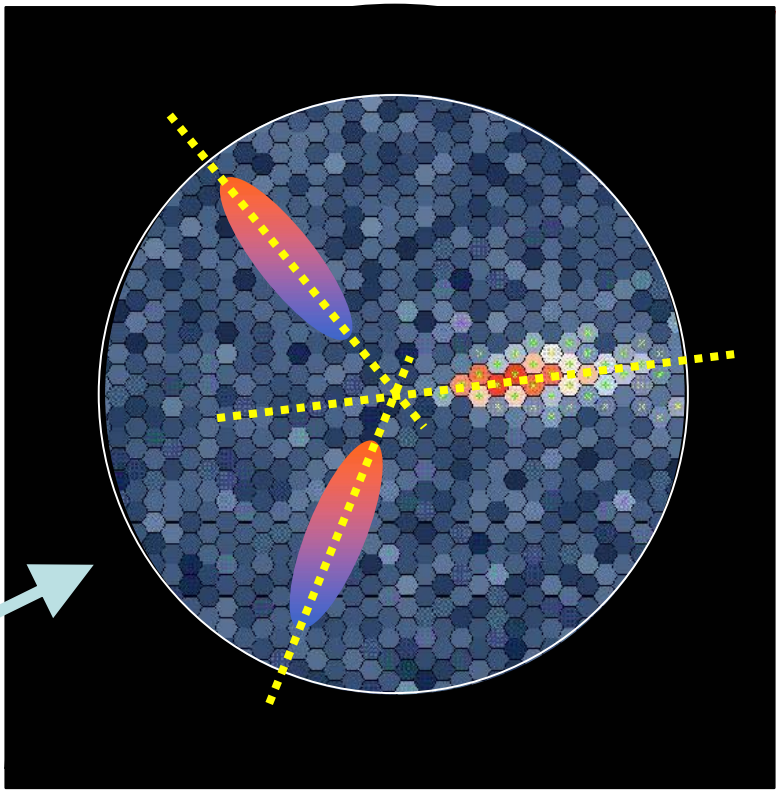
Immagine del flash Cherenkov sulla camera del telescopio



- Ricostruzione del primario
  - particle id: discriminazione dal fondo di adroni
  - direzione, energia…

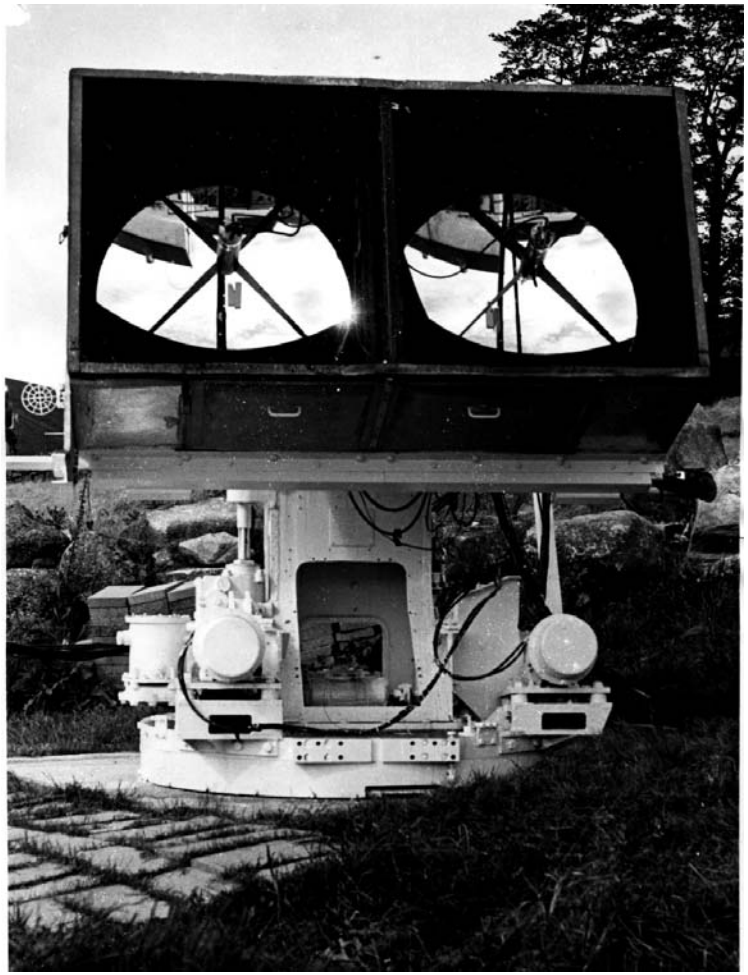
Imaging Air Cherenkov Telescopes





Utilizzando piu' immagini è possibile ricostruire la direzione di arrivo con maggiore precisione (visione stereo)

0th generation of Cherenkov telescopes



Glencullen, Ireland ~1962

Nessuna discriminazione dal fondo di raggi cosmici !

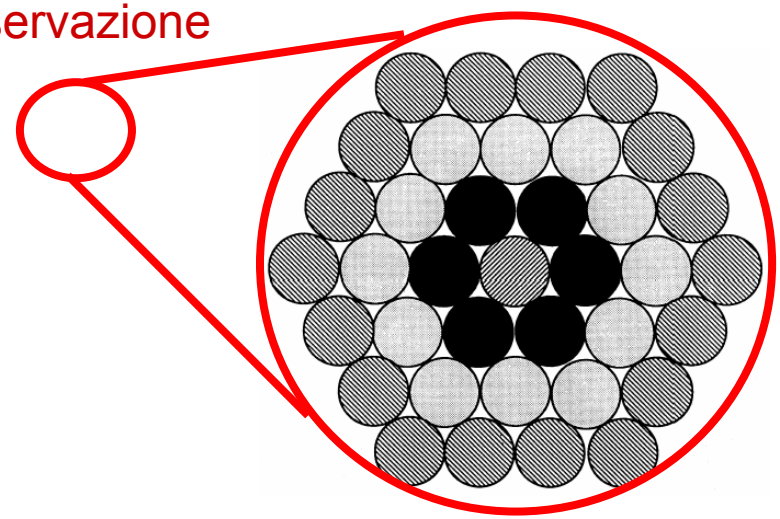
Whipple: singolo fototubo

1972: prima indicazione di TeV γ-rays dalla Crab Nebula (Fazio et al.)

- ON-OFF (direzione)
- 3σ in 3 anni di osservazione!

Imaging technique: 1st generation of IACT

- 1984: viene utilizzata la prima camera multi-PMTs da Whipple
- 1989: Emissione γ significativa identificata dalla Crab Nebula (Whipple '89)
  - E_{thr} = 700 GeV
  - 9σ in 50 h di osservazione



QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

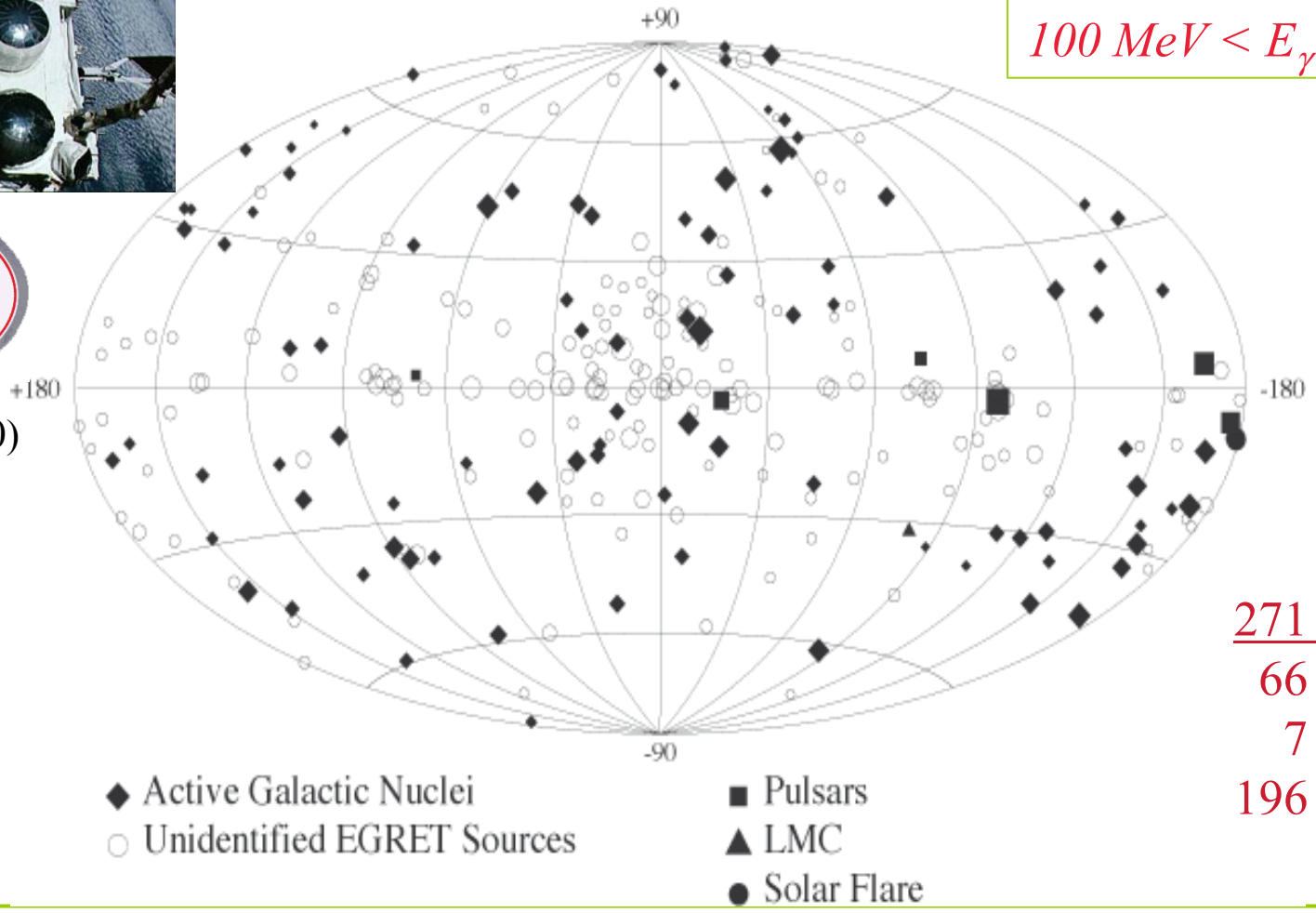
1995: HEGRA array di telescopi

Crab detection time: 15 min

Il cielo γ dal satellite…

(1991-2000)

$100\ MeV < E_\gamma < 10\ GeV$



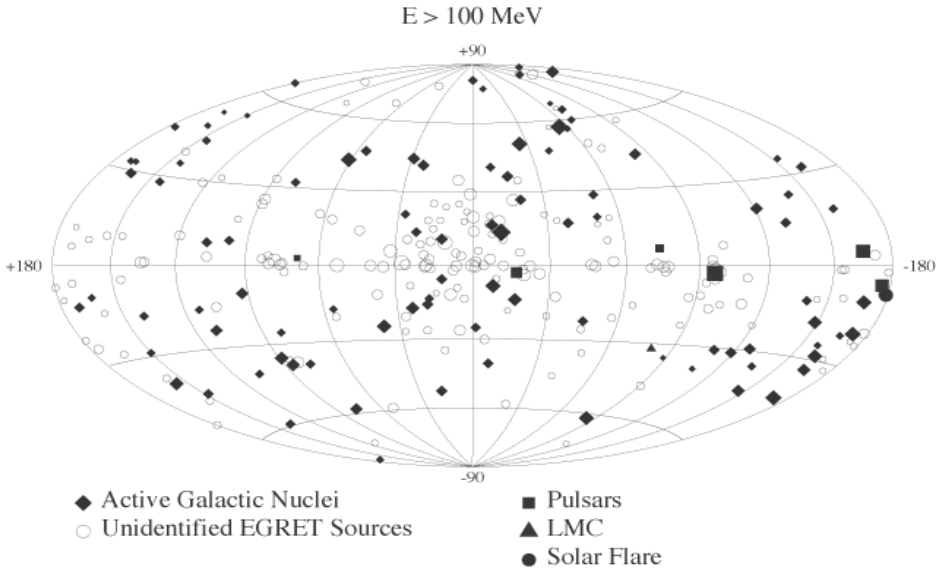
271 sources
66 AGNs
7 pulsars
196 UNID

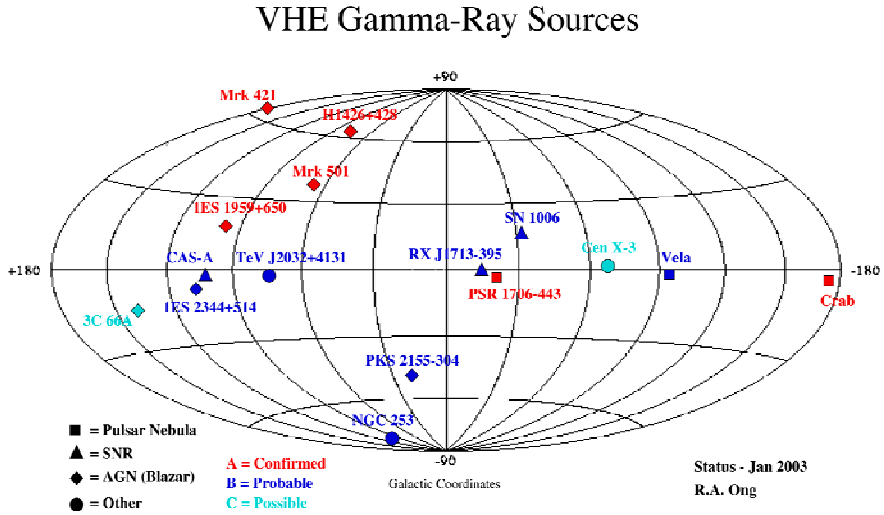
Satellites vs ground experiments

The energy gap

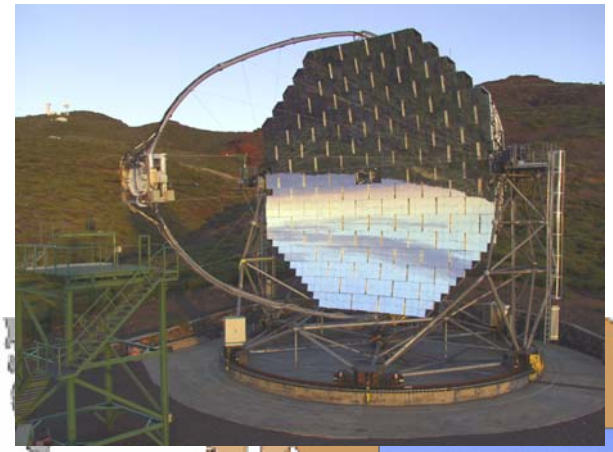
E < 10 GeV

E > 300 GeV





"Big four"



Crab detection time: 3 min

Crab detection time: 1 min

IACT: il presente

- **increased sensitivity** and better **angular resolution**:
  - improve and perfect stereo technique with highly pixelized camera (HESS, Cangaroo, Veritas)
- lower **energy threshold** (MAGIC)

Energy Threshold

$$E \propto \sqrt{\frac{\phi \Omega \tau}{A \epsilon}}$$

Ω - Pixel Solid Angle
τ - Integration time

A - Mirror Area
ε - Quantum Efficiency

MAGIC

17 m diameter reflecting surface (240 m^2)

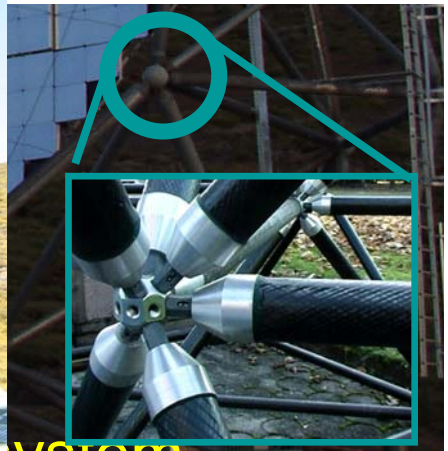
high reflective diamond milled aluminum mirrors

Active mirror control

3.5° FOV camera

577 high QE PMTs

Light weight **Carbon fiber** structure for fast repositioning



ystem

& 300 MHz FADC system

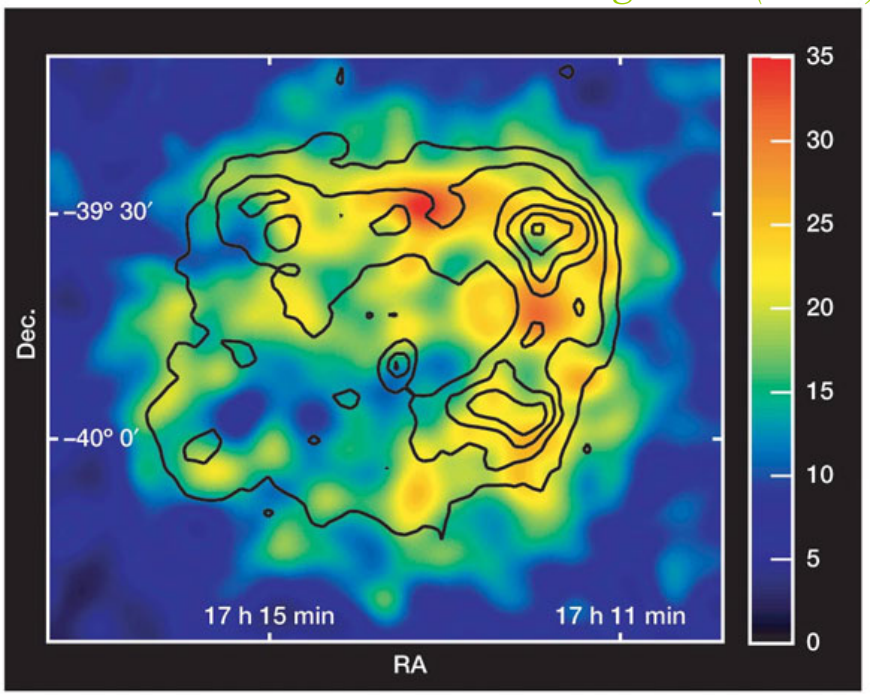
Sensitivity and resolution

- SNR RX J1713.7-3946
- HESS @ 800GeV; 26hrs obs time
  - Angular resolution: < 0.1 deg
  - SNR: Very important as possible CR accelerator!
  - Flux 0.66 Crab; Γ=2.2

gamma-imaging!

Aharonian et al.,
Nature, 4 nov 2004

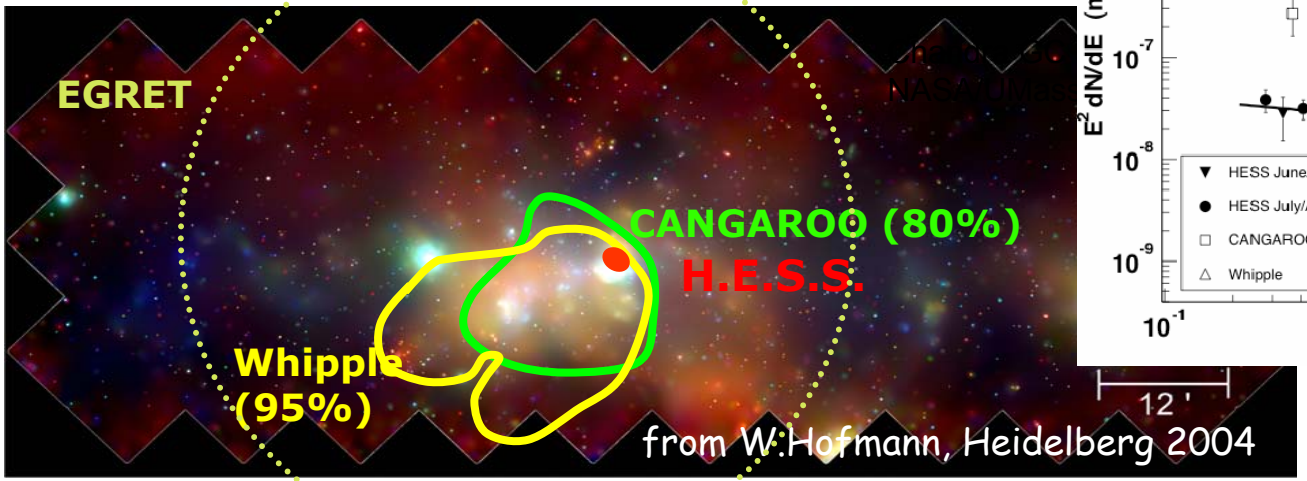
Contours of X-ray brightness (ASCA)

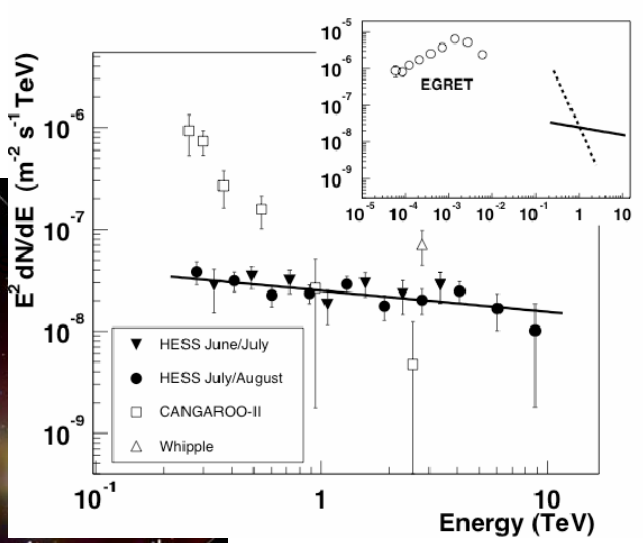


Sensitivity and resolution

- HESS - Galactic Center
  - Flux 5% Crab; Γ=2.2; size: 7' (7pc)
  - CANGAROO conflict…

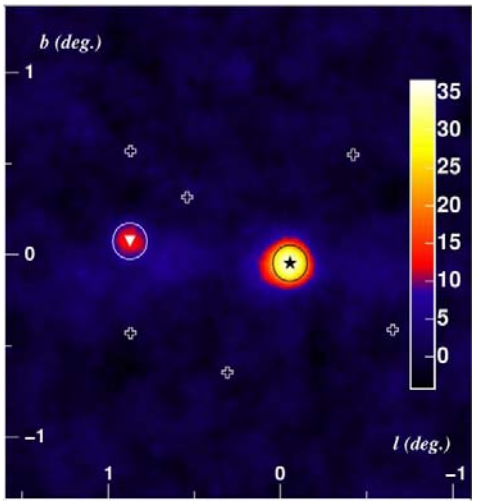
F. Aharonian et al. A&A 425 (2004) L13-L17



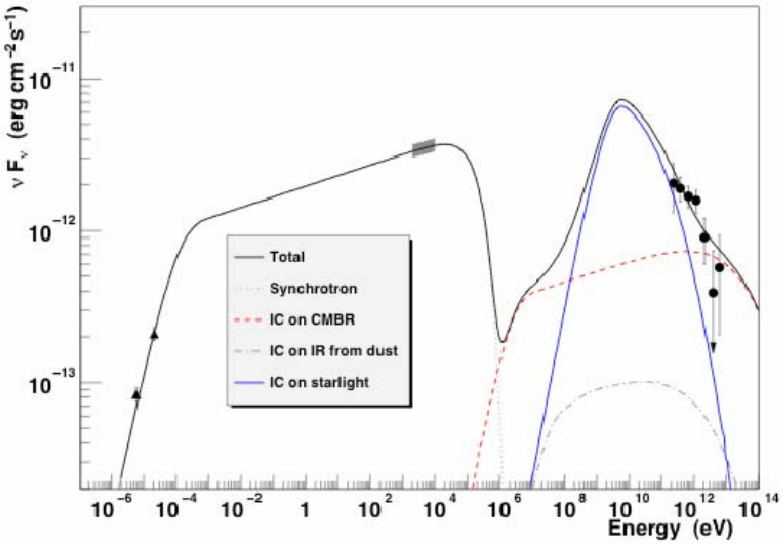


Sensitivity and resolution

- Un acceleratore di CR?
  - SNR G0.9+0.1 - Flusso: 2% Crab (!)
  - Scoperta casuale vicino il GC
  - spettro somma di piu' componenti



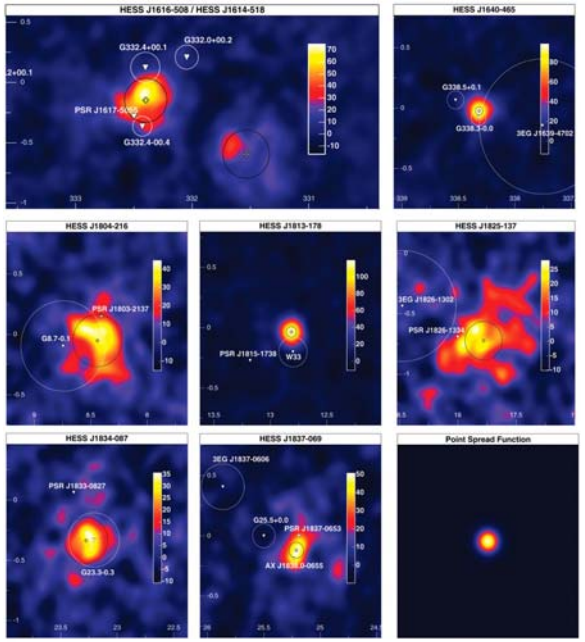
F. Aharonian et al. A&A 432 (2005) L25-L29

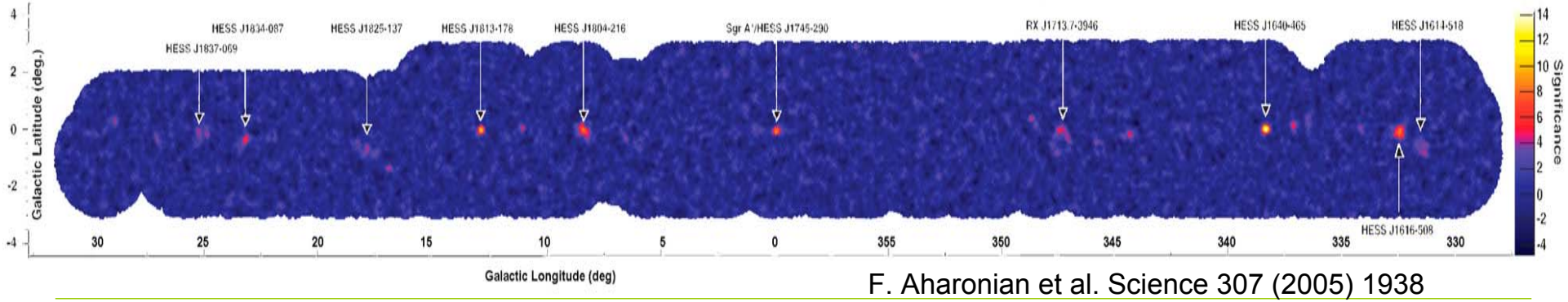


Sensitivity and resolution

HESS - Galactic plane survey

- flux > 3% Crab; E>200GeV; 110 hours total obs. time
- 8 new sources!
- possibly associated with SNR, PWN and OB associations…

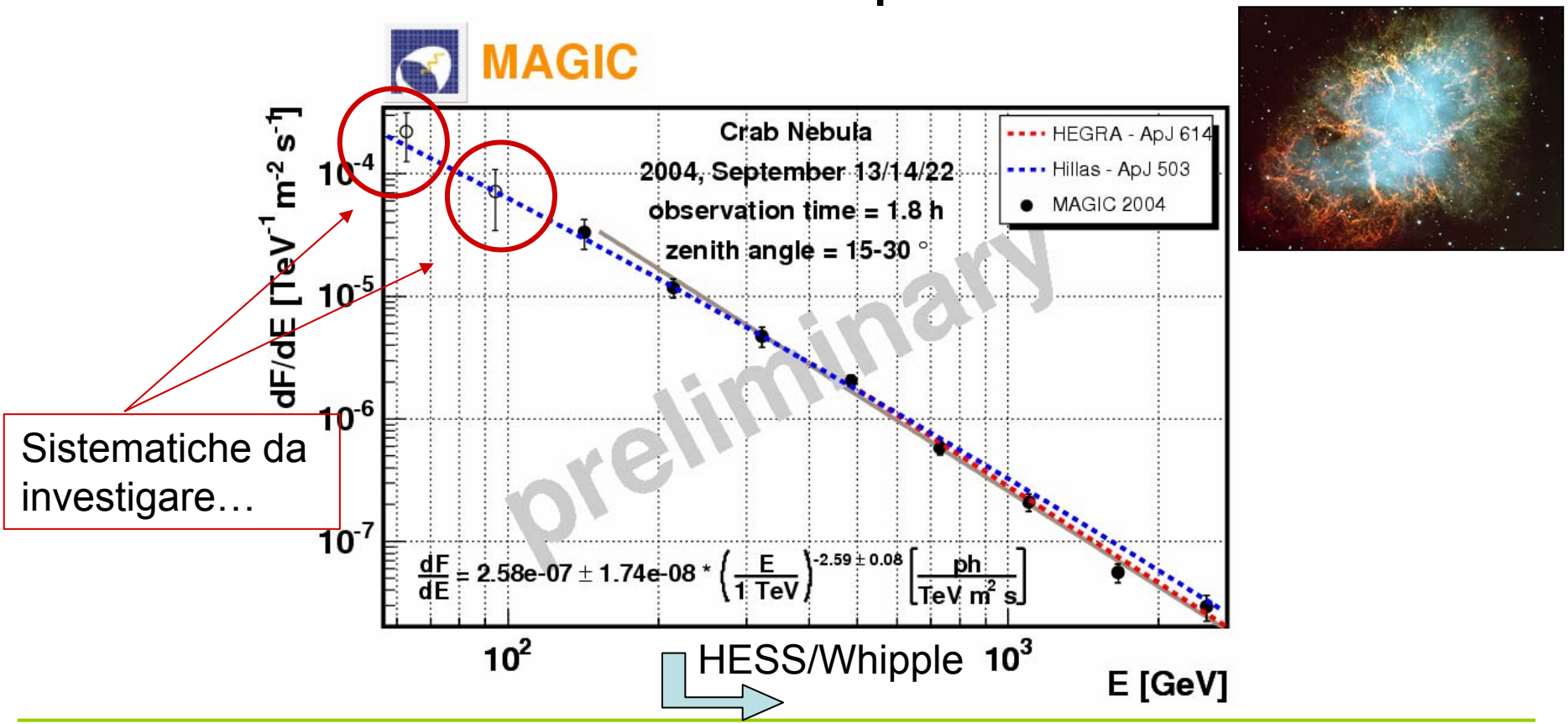




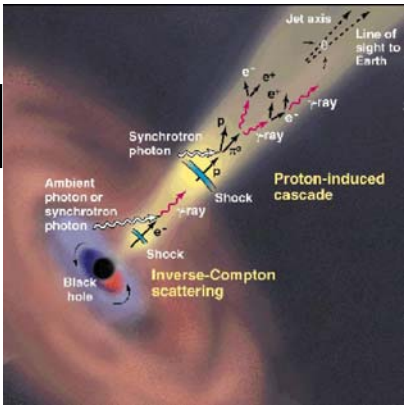
F. Aharonian et al. Science 307 (2005) 1938

Low Energy threshold

- Crab Nebula: verso il picco IC…

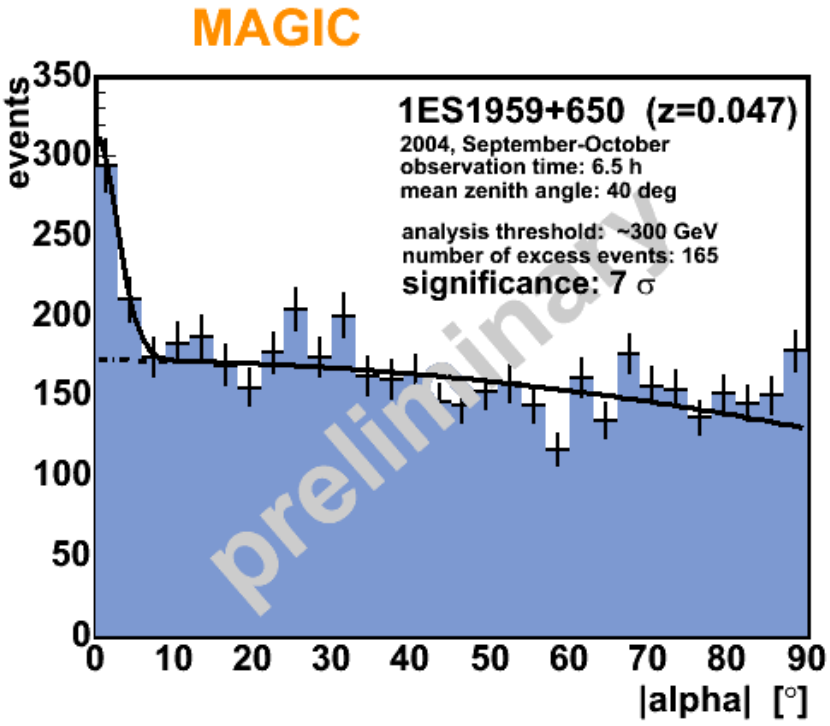


Low Energy threshold

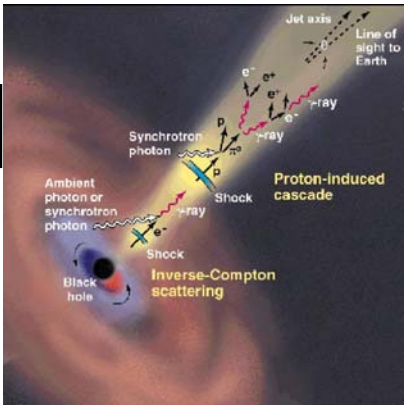


1ES1959+650

- AGN @ z=0.047 (intermediate)
- previously seen by Seven Telescope Array, Whipple, HEGRA (5.4σ in 94h!)
- 6.5 h observation by MAGIC in Sept - Oct 2004
- not flaring in X-ray (ASM)
- 7 σ detection
- ~ 10 % Crab level



Low Energy threshold



1ES1959 flux is about 40% the Crab

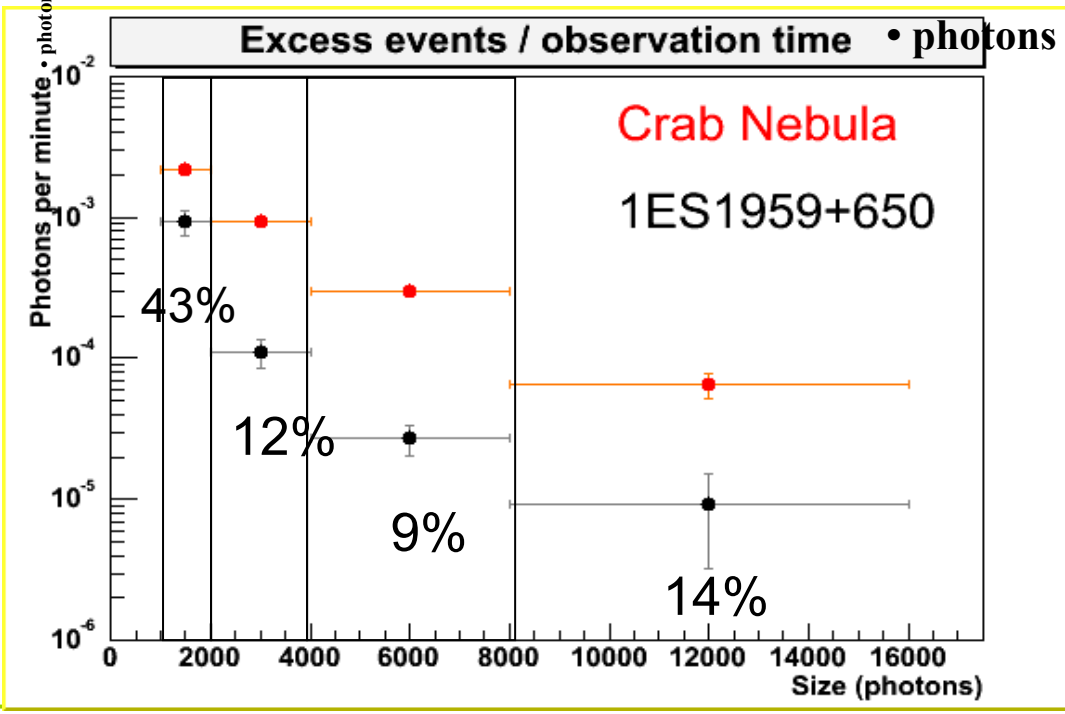
Spectrum softer than the Crab one.

"Consistent" with HEGRA flux measurements

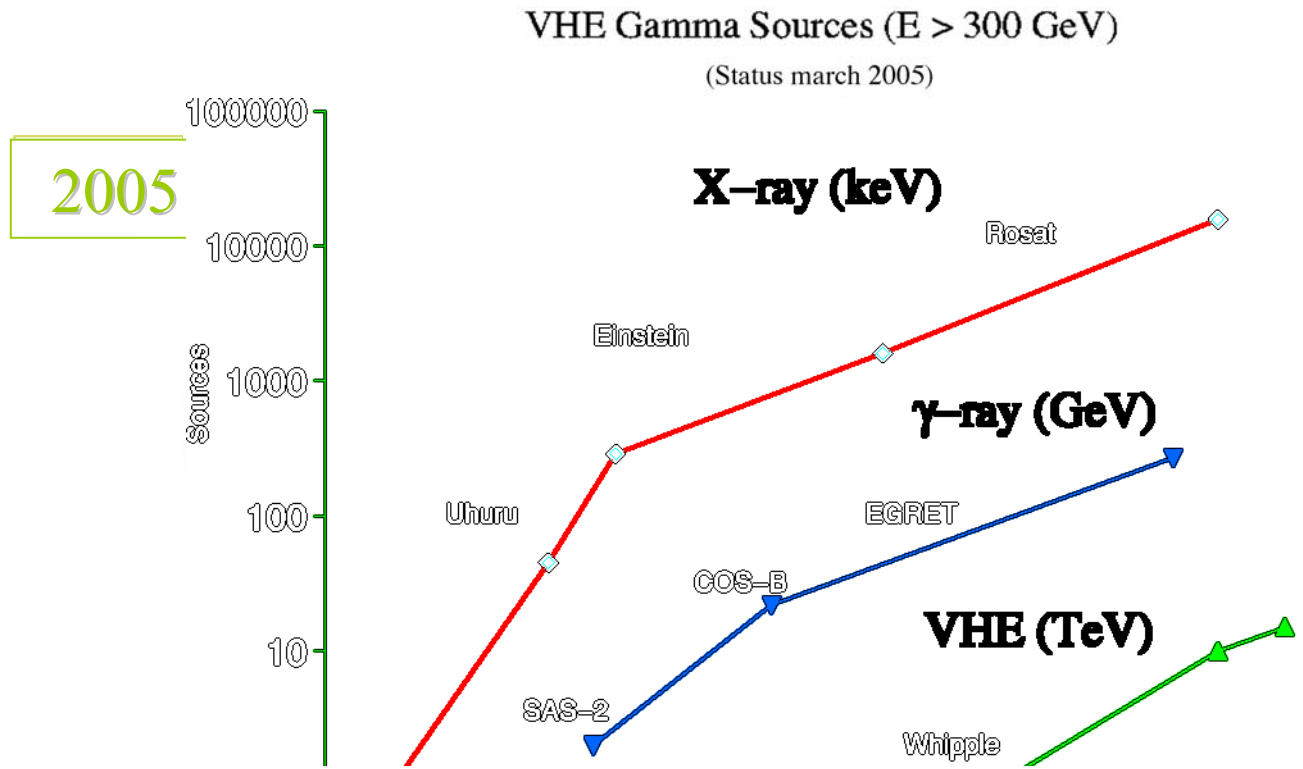
HEGRA System

Results (2000-2001):

- 94 h obs. Time.
- Energy threshold: 2TeV
- Significance 5.4 σ
- α= 3.3 ±0.7
- 8% Crab flux



Prospettive…



"Phase Transition: Number of VHE Sources getting Larger than Number of PhD Students"

W.Hofmann

Futuro (prossimo)

- MAGIC II
  - Clone “potenziato”
    - High QE HPD (SiPM…), 2GHz sampling, 1000 pixels…

Futuro (prossimo)

- HESS II
  - Clone “maggiorato”; test bed per 5@5
  - Sensitivitá a basse energie (50GeV)

Futuro…

- 5@5 (array 5 GeV - 5 km)
- ECO-1000 (1000 m^2, >5 GeV…)
- STAR (Small Telescope Array)

- Sulla carta…
  - costi ~ 100 M€
  - eventi Cherenkov bassa energia (< 50-100GeV) difficili da analizzare!!

Conclusioni

- L'astrofisica alle alte energie (VHE) è indispensabile alla comprensione dei fenomeni non termici
- I telescopi Cherenkov rappresentano una tecnica affidabile di indagine del cielo γ, complementare alle osservazioni da satellite (GLAST) e ν-telescopes (NEMO, ANTARES, ICECUBE)
- Il cielo gamma si sta popolando…