# Particle Physics with Space Detectors

*Aldo Morselli*

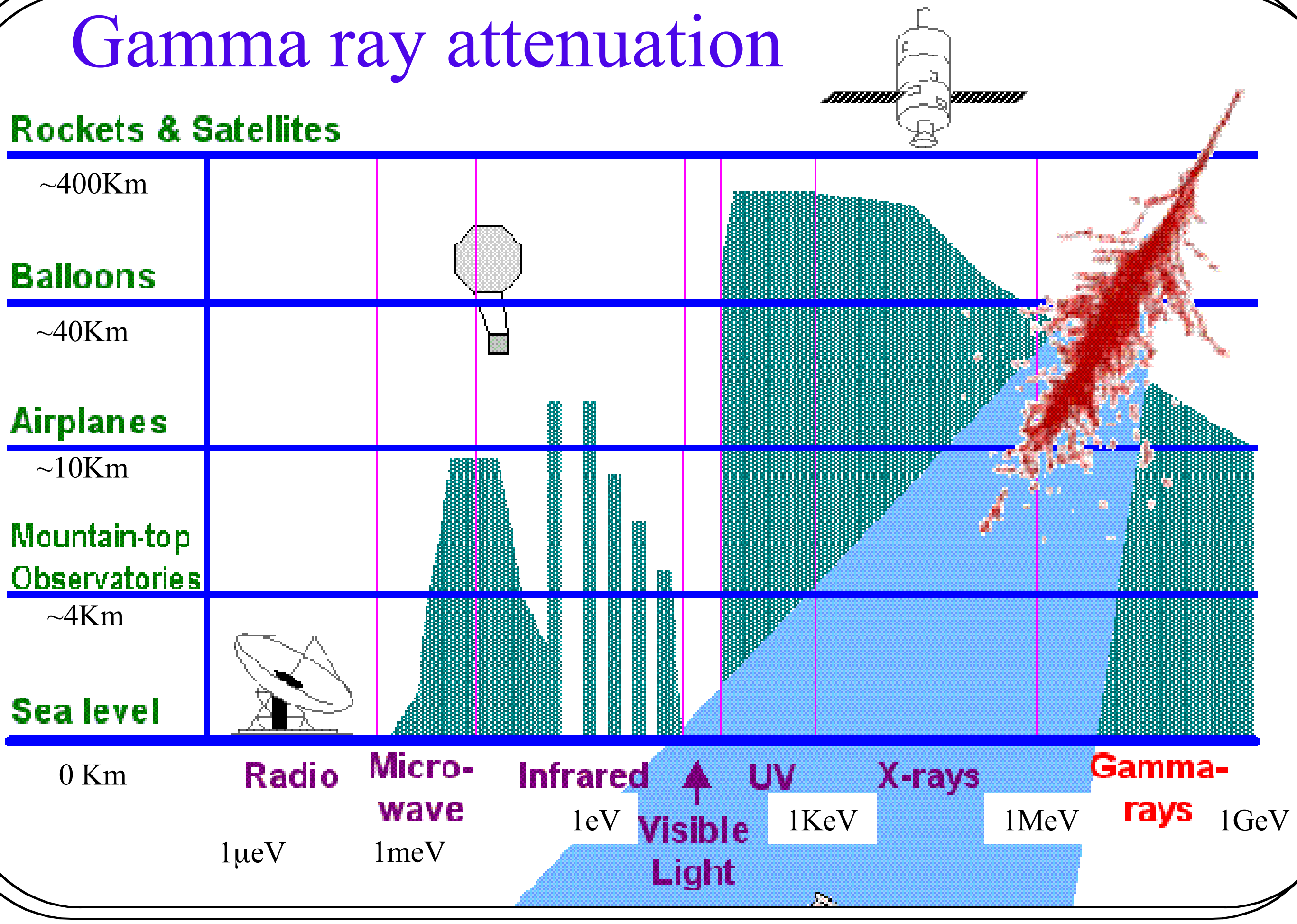
***INFN, Sezione di Roma 2 &***
***Università di Roma Tor Vergata***

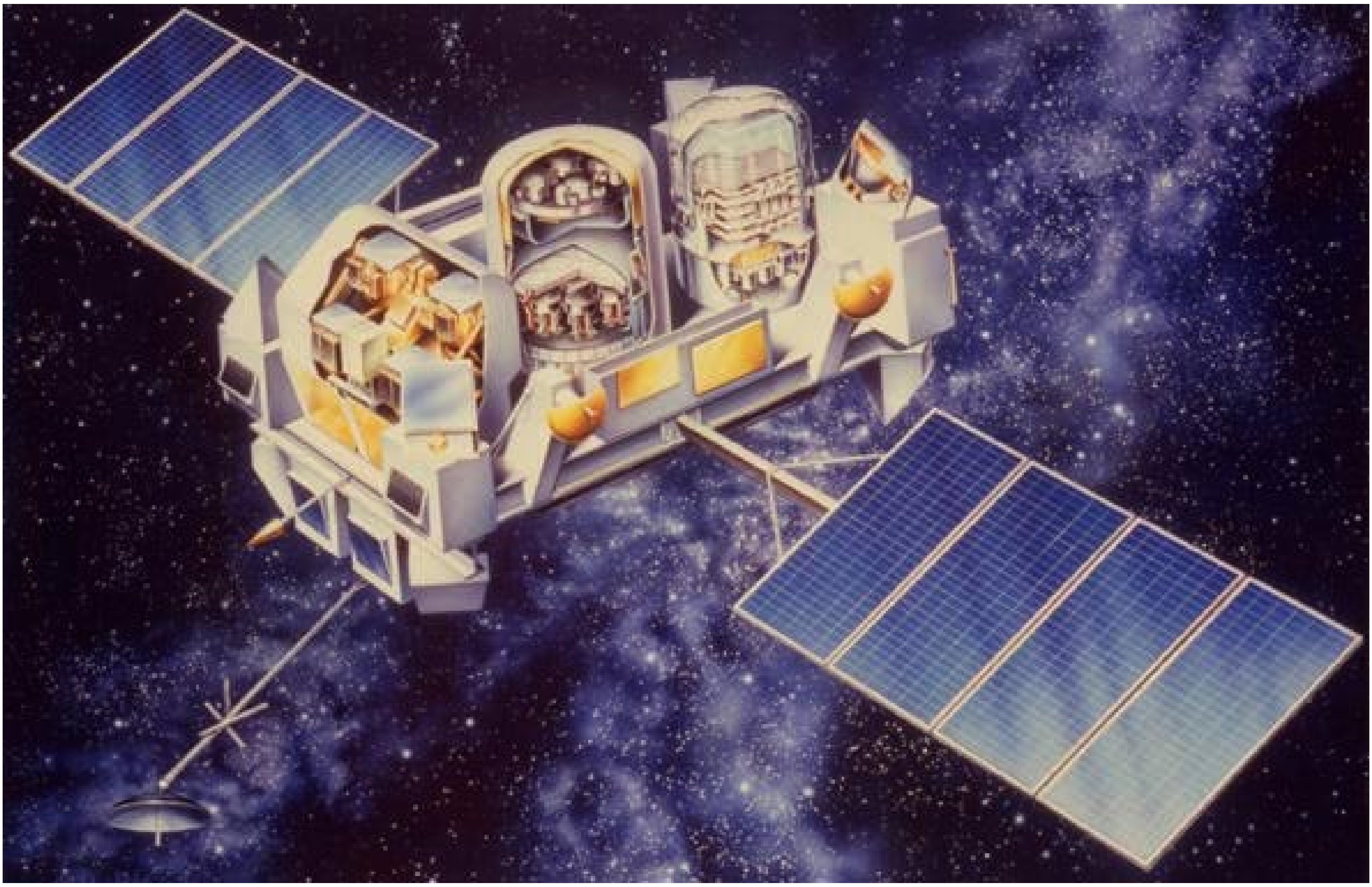
Tecniche Sperimentali della Fisica Nucleare e Subnucleare, A.A.99-00

**Roma, April 19 - 2000**

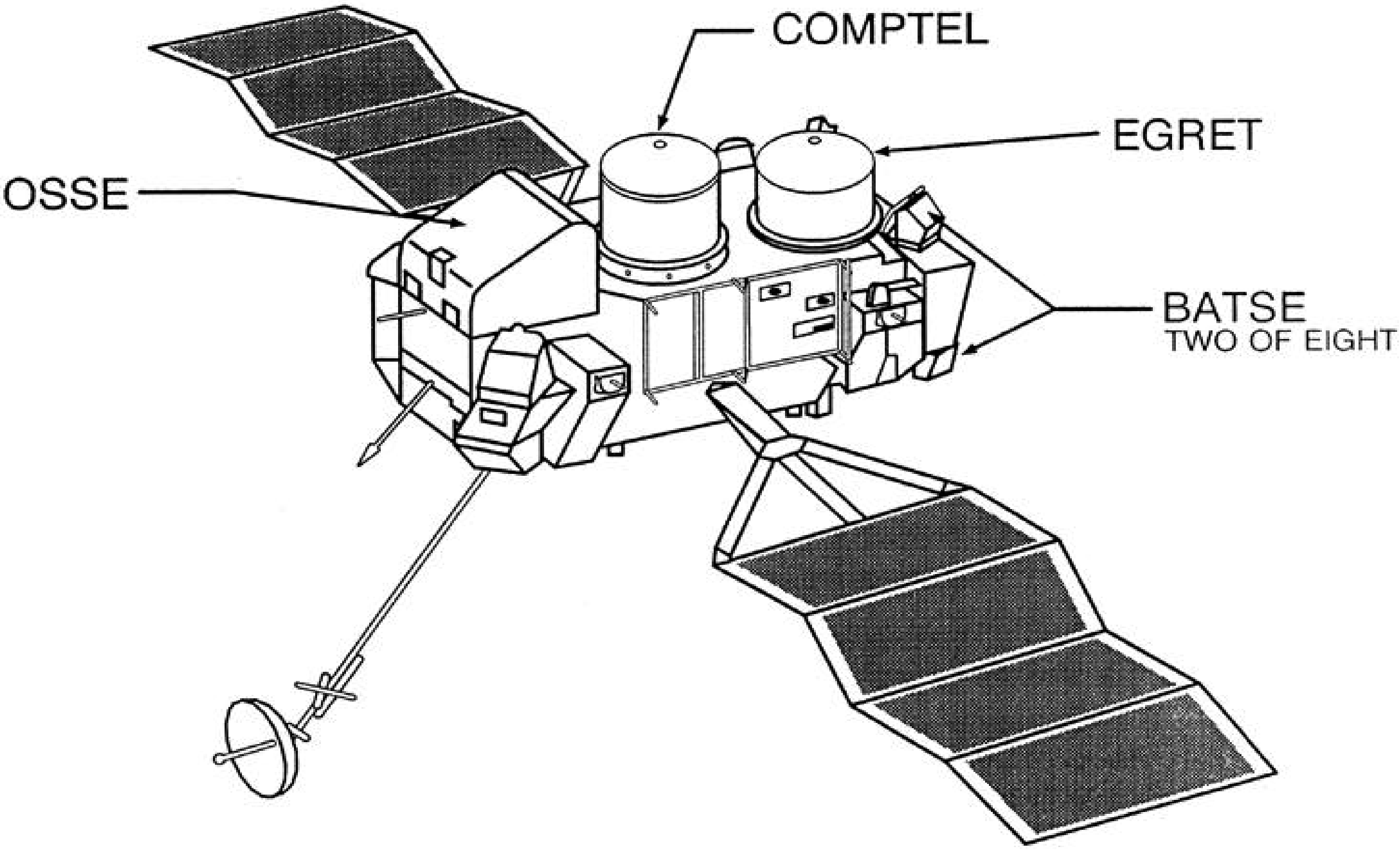
---

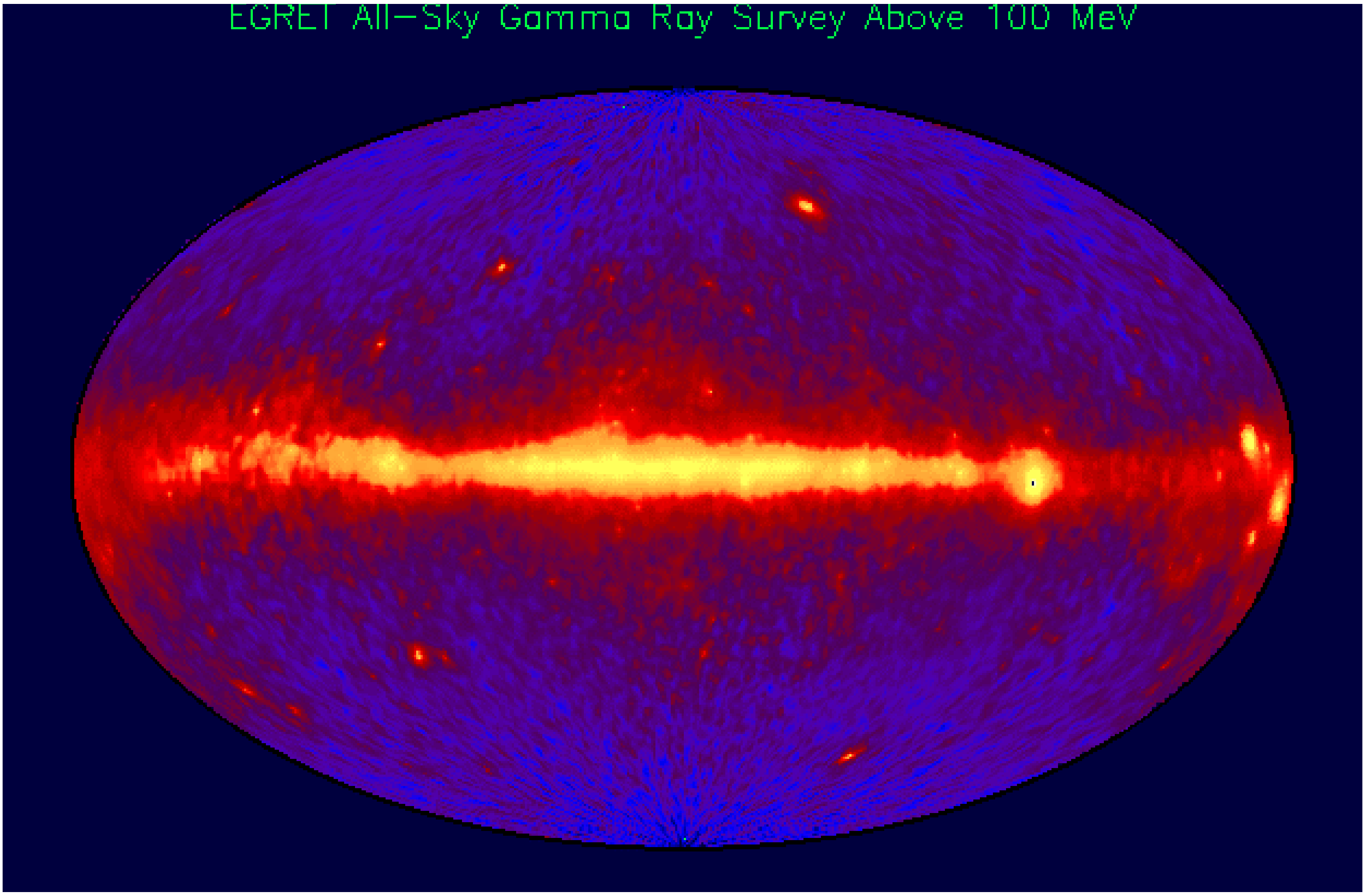
# Gamma ray attenuation





# COMPTON OBSERVATORY INSTRUMENTS

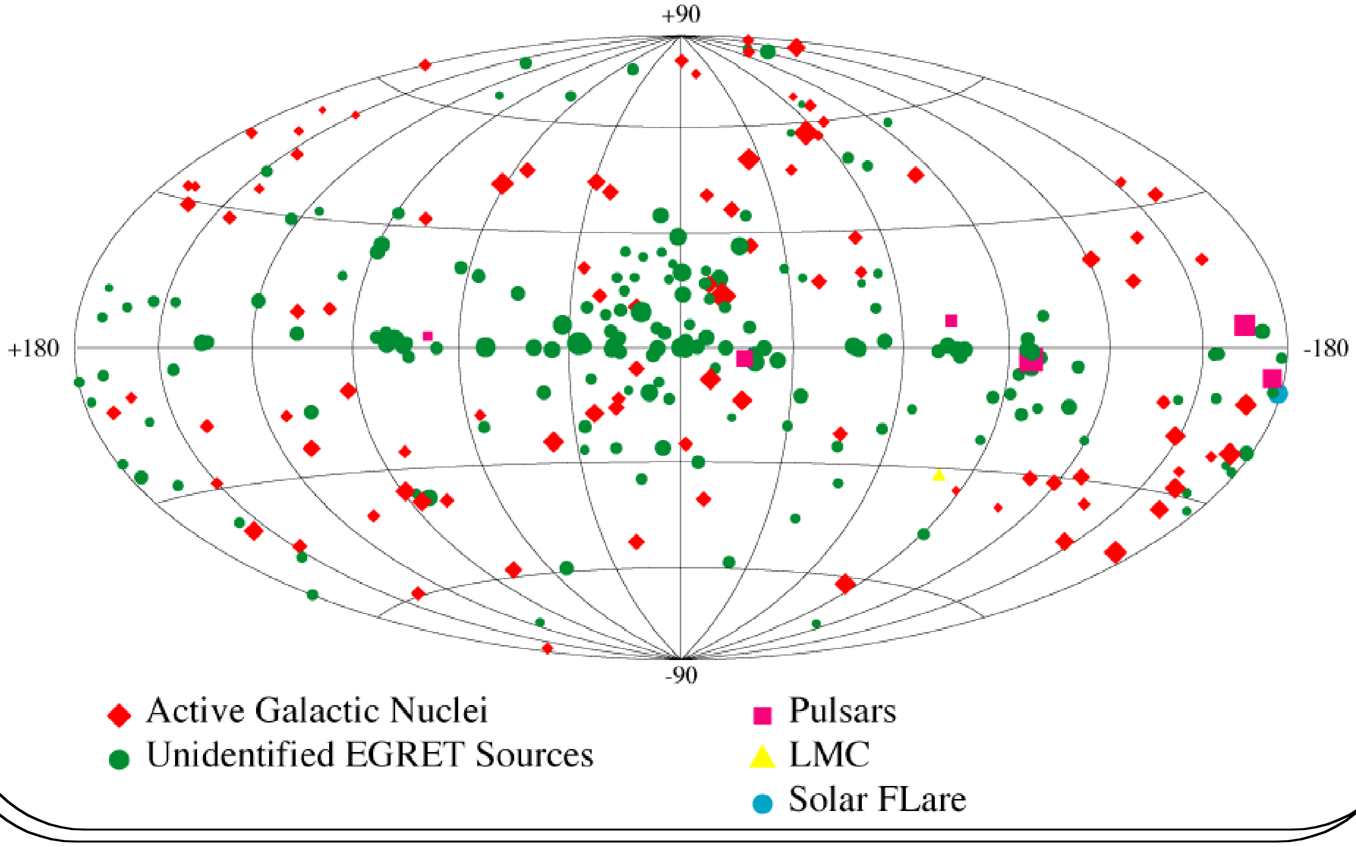




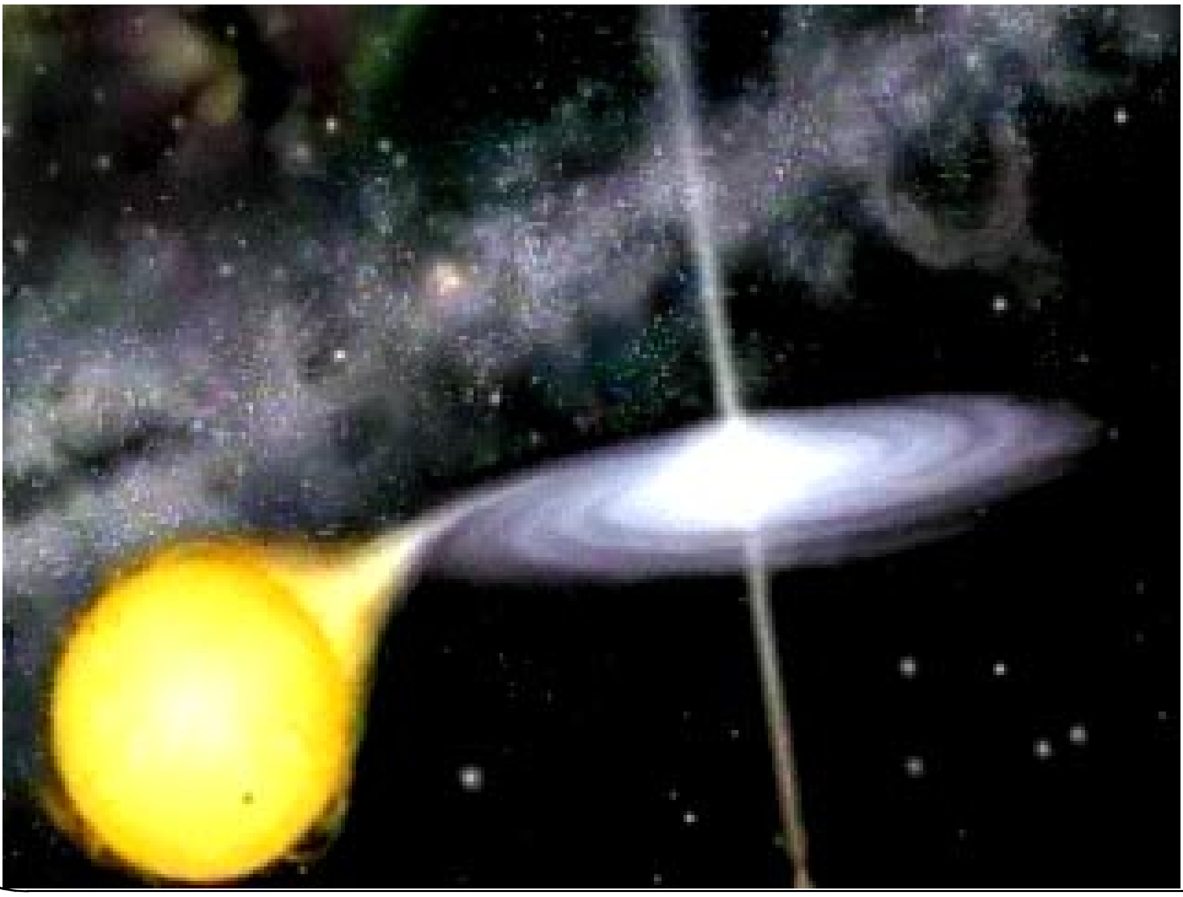
---

# Third EGRET Catalog

E > 100 MeV

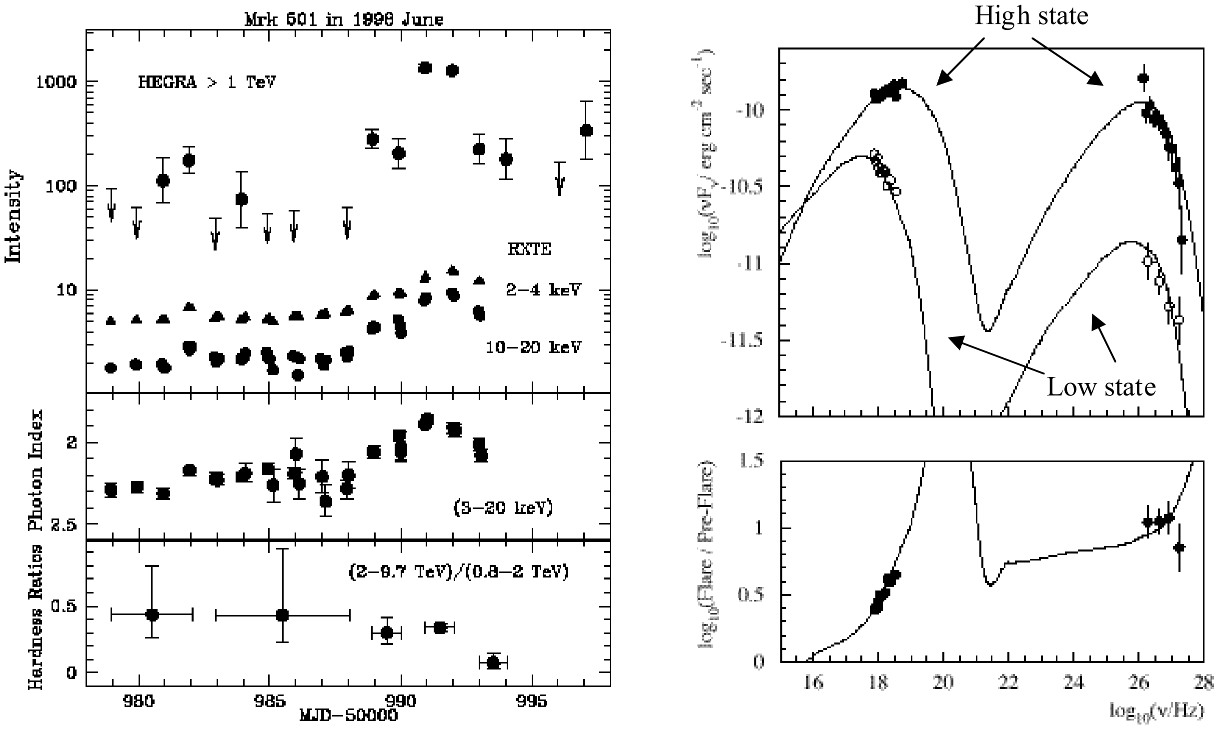


## Binary system formed by a black hole and a companion star



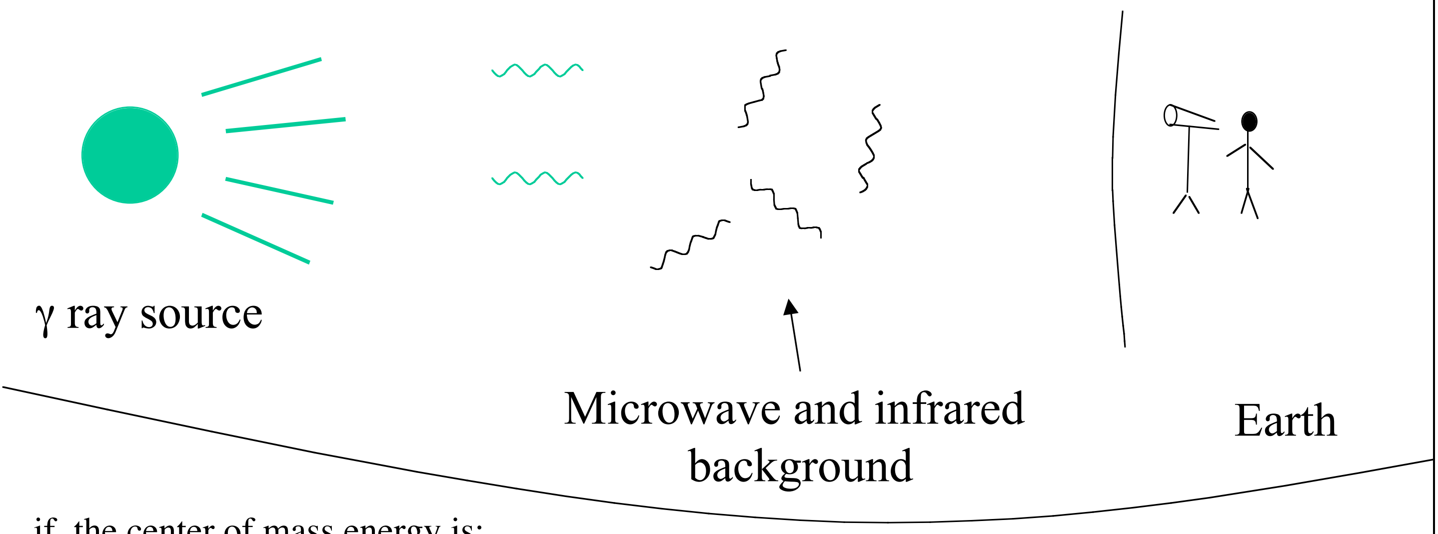
---

## Multiwavelenght observation of Mrk 501 in June 98



R. Sambruna et al., RXTE and Hegra, astro-ph 0002215

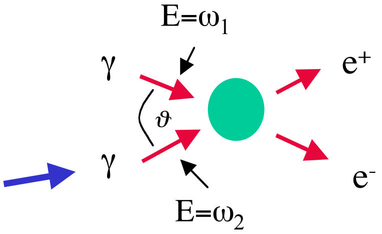
## Flux absorption due to the interaction with the infrared and microwave background



if the center of mass energy is:

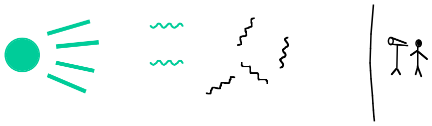
$$\sqrt{2\omega_1\omega_2(1-\cos\vartheta)} \geq 2m_e$$

photons interactions produce electron positron pairs



---

## Flux absorption due to the interaction with the infrared and microwave background



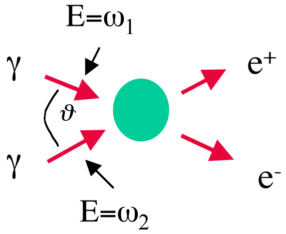
The cross section of the process $\gamma\gamma \to e^+e^-$ is:

$$\sigma_{\gamma\gamma} = \frac{\pi r_e^2}{2}(1-v^2)\left\{(3-v^4)\ln\left(\frac{1+v}{1-v}\right) - 2v(2-v^2)\right\}$$

where $r_e$ is the classical radius of the electron and:

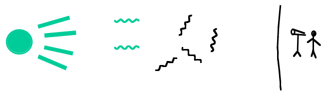
$$v = \sqrt{1 - \frac{4m_e^2}{2\omega_1\omega_2(1-\cos\vartheta)}}$$

$\omega_1$ and $\omega_1$ are respectively the energies of the low and the high energies gamma ray and $\vartheta$ is their angle of incidence.



# Flux absorption due to the interaction with the infrared and microwave background

the ratio between the flux I(L) at a distance L from the source and the initial flux I can be written as:



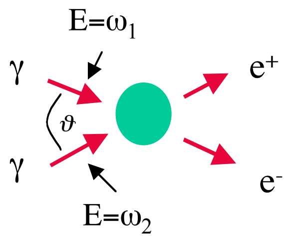
$$I(L)/I_o = \exp(-k_\gamma L)$$

where $k_\gamma$ is the absorption coefficient:

$$k_\gamma = \frac{1}{2}\int_0^\infty \int_{\vartheta^*}^{\pi} \frac{dn_\gamma}{d\omega_1}\sigma_{\gamma\gamma}\sin\vartheta\, d\vartheta\, d\omega_1$$

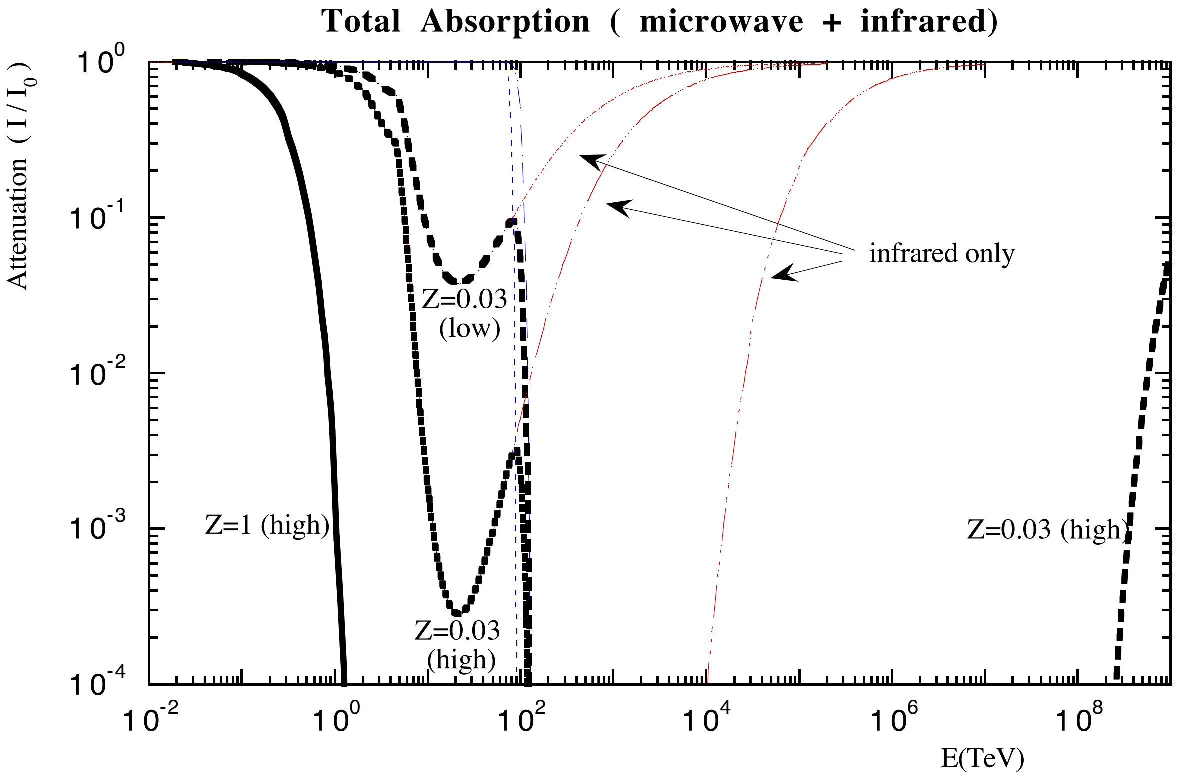
that contains the cross section and the low energy photon distribution.
For the microwave spectrum:

$$dn_\gamma/d\omega_1 = \frac{1}{\hbar^3\ c^3\ \pi^2}\frac{\omega_1^2}{\exp(\omega_1/kT)-1}$$



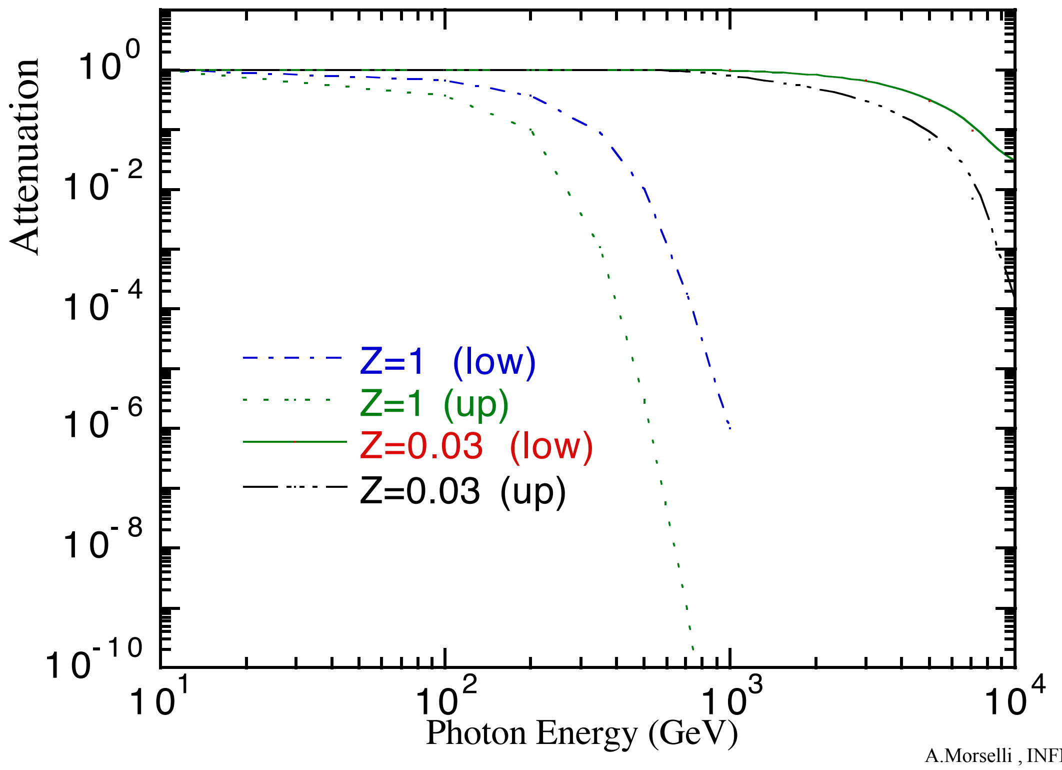
---

# Ratio between surviving flux and initial flux versus photon energies for two different distances due to the sum of the infrared and black-body background



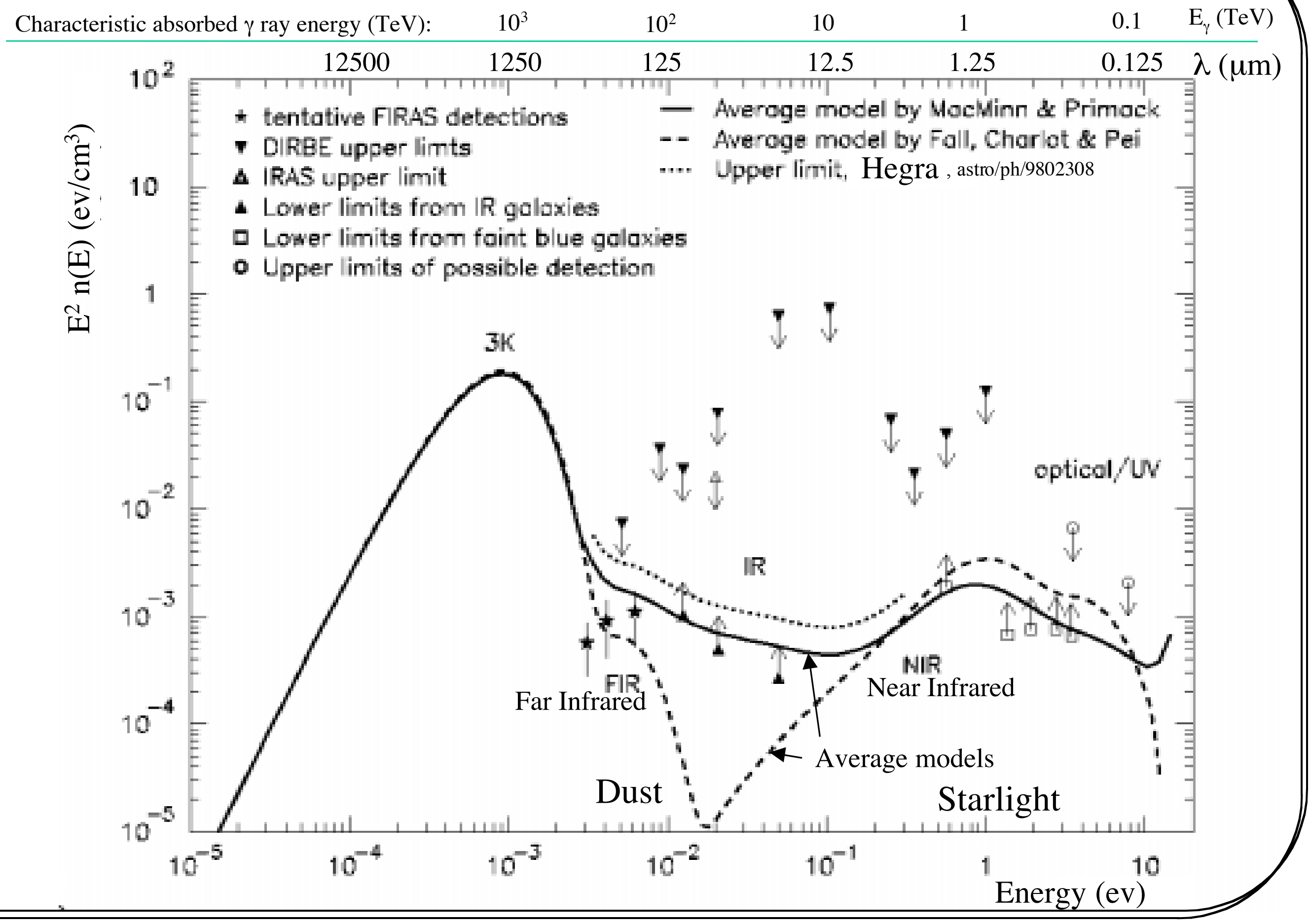
A.Morselli , INFN/AE-94/22

## Ratio between surviving flux and initial flux versus photon energies for two different distances (blow up)

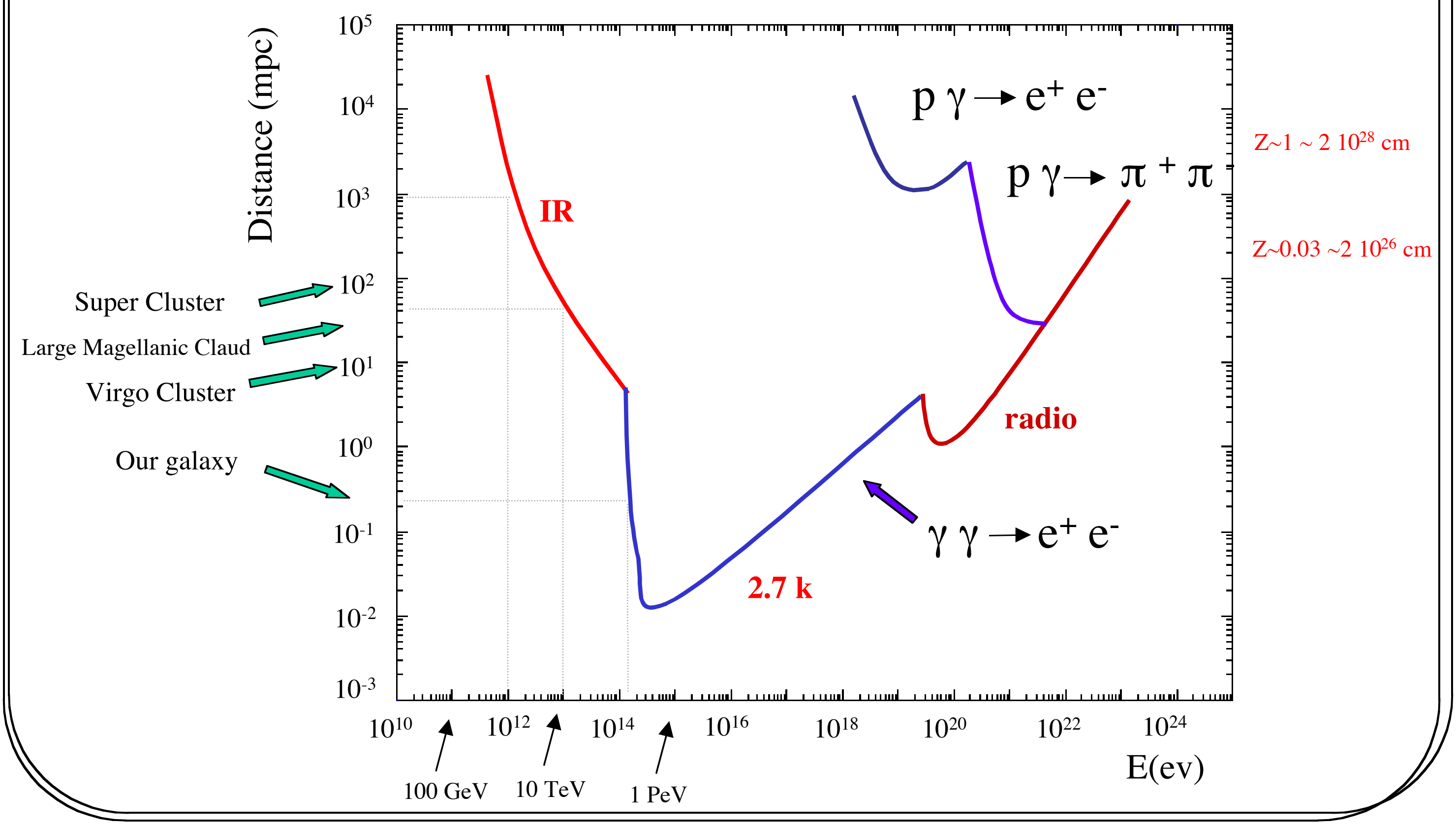


A.Morselli , INFN/AE-94/22

## Energy density of the extragalactic diffuse background radiation

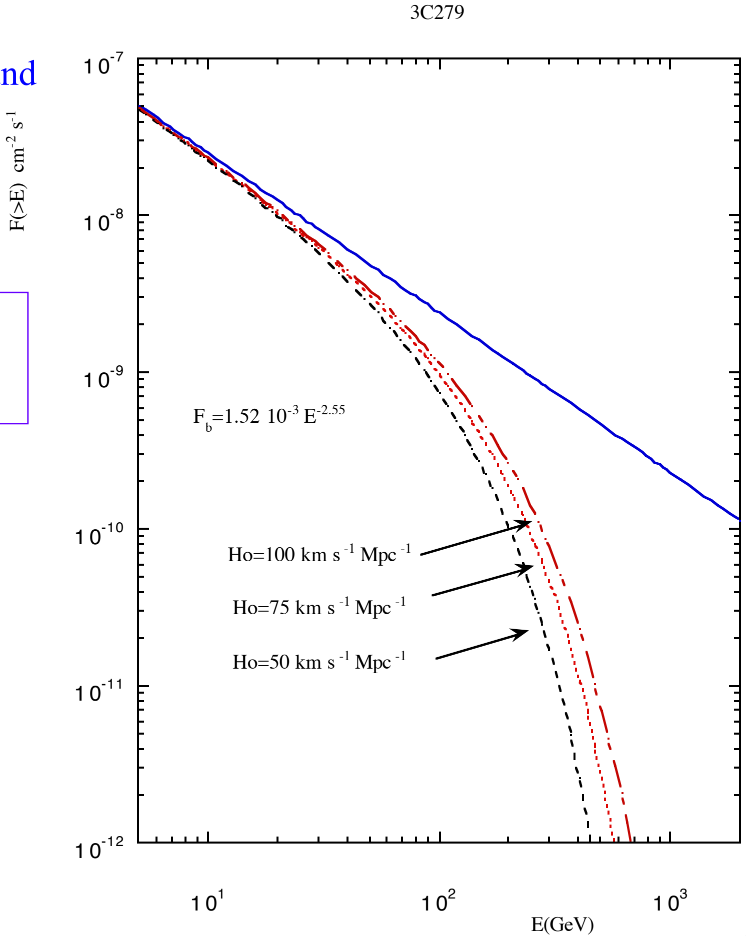


# Transparency of the Universe

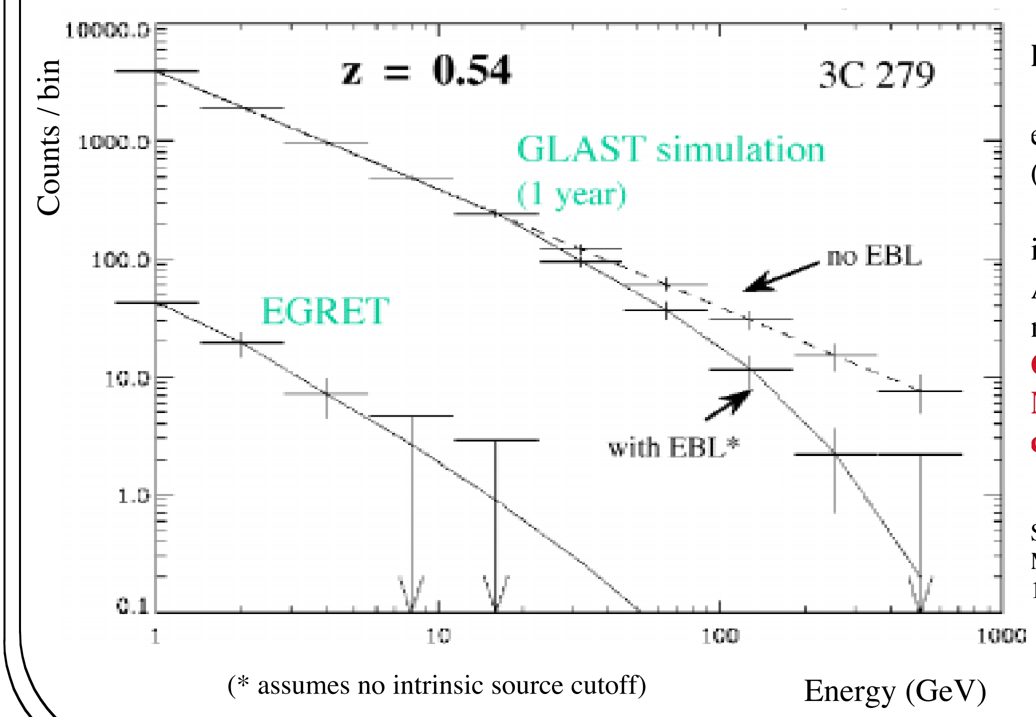


## Flux absorption due to the interaction with the infrared and microwave background

an example on 3C279:
- fixed background
- different values of the Hubble constant



# Probing the era of Galaxy Formation
# Uncover the nature of Dark Matter

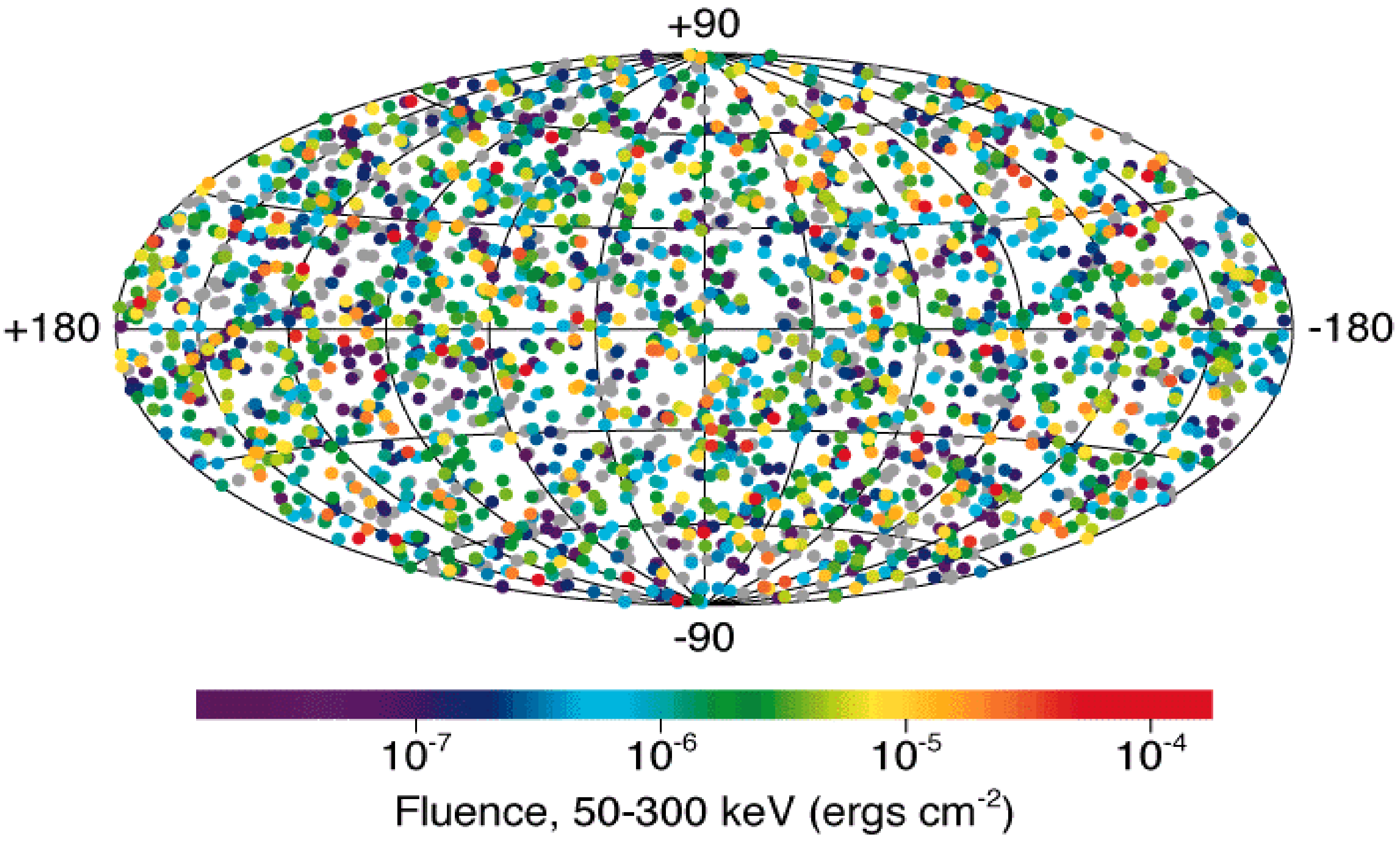


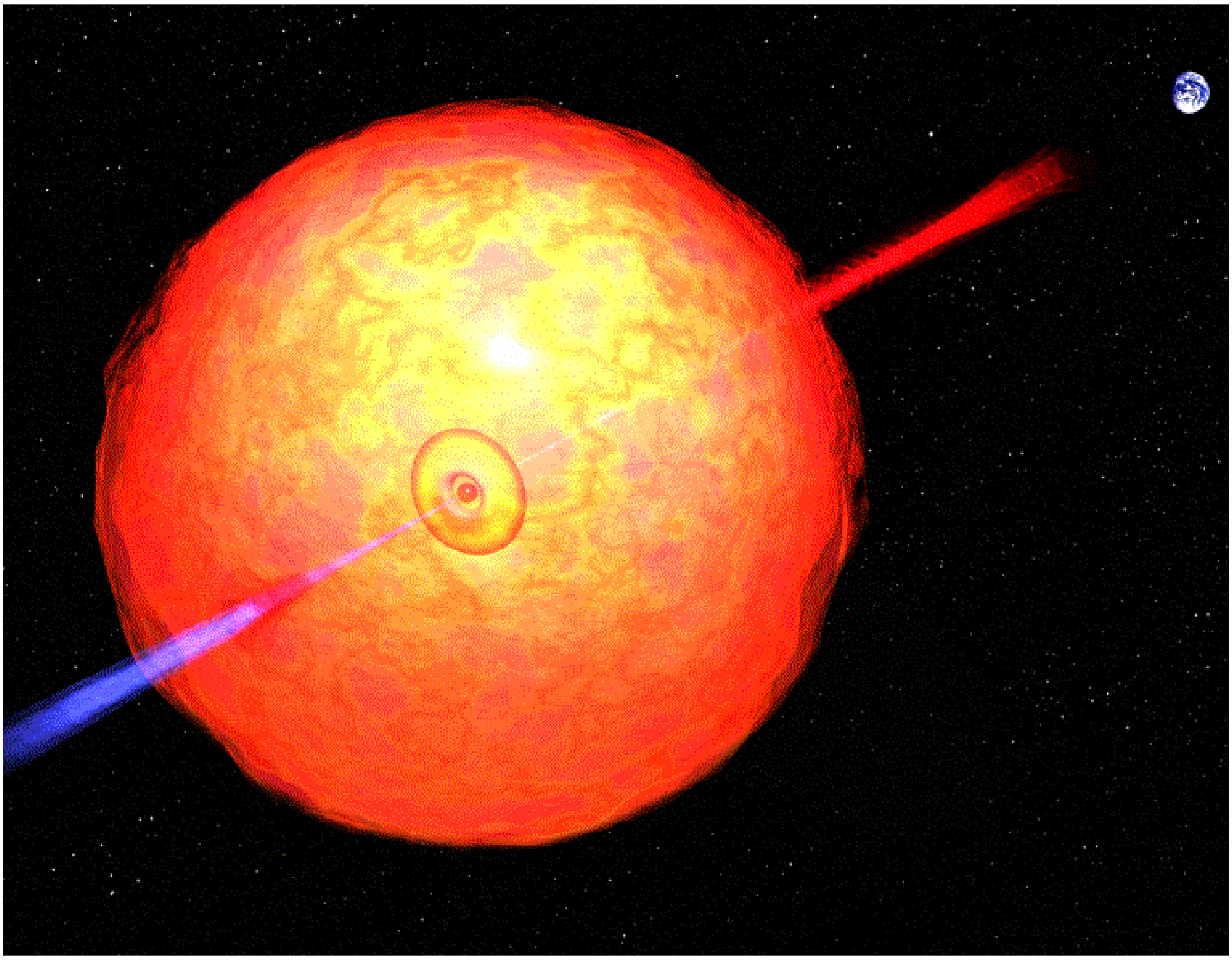
(* assumes no intrinsic source cutoff)

Roll- offs in the γ -ray spectra from AGN at large z probe the extra-galactic background light (EBL) over cosmological distances. A dominant factor in EBL models is the era of galaxy formation: AGN roll- offs may help distinguish models of galaxy formation, e. g., **Cold Dark Matter vs. Hot Dark Matter-- 5 eV neutrino contributions, etc.**

See for example
Macminn, D., and J. R. Primack, 1995, astro- ph/ 9504032.

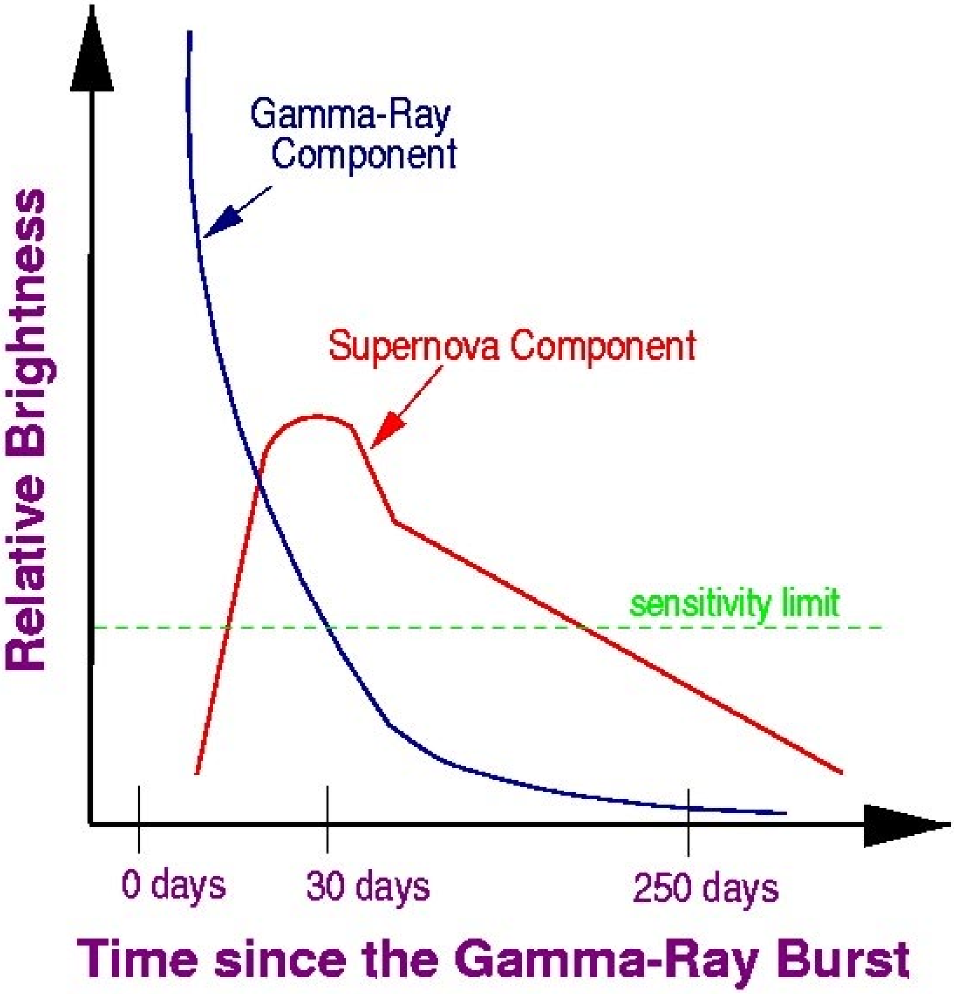
# 2512 BATSE Gamma-Ray Bursts





A model of Gamma Ray Burst

A model of
Gamma Ray
Burst



First observation of a Gamma Ray Burst ?

## Test of Quantum Gravity

Candidate effect:

$$c^2 P^2 = E^2 \left( 1 + f(E/E_{QG}) \right)$$

$E$=photon energy $E_{QG}$ =effective quantum gravity energy scale

Deformed dispersion relation with function $f$ model dependent function of $E/E_{QG}$

if $E \ll E_{QG}$ series expansion is applicable

$$c^2 P^2 = E^2 \left( 1 + \alpha(E/E_{QG}) + O(E/E_{QG})^2 \right)$$

➡ $$v = \delta E/\delta P \sim c \left( 1 + \alpha(E/E_{QG}) \right)$$

*vacuum as quantum-gravitational medium which respond differently to the propagation of particle of different energies.*

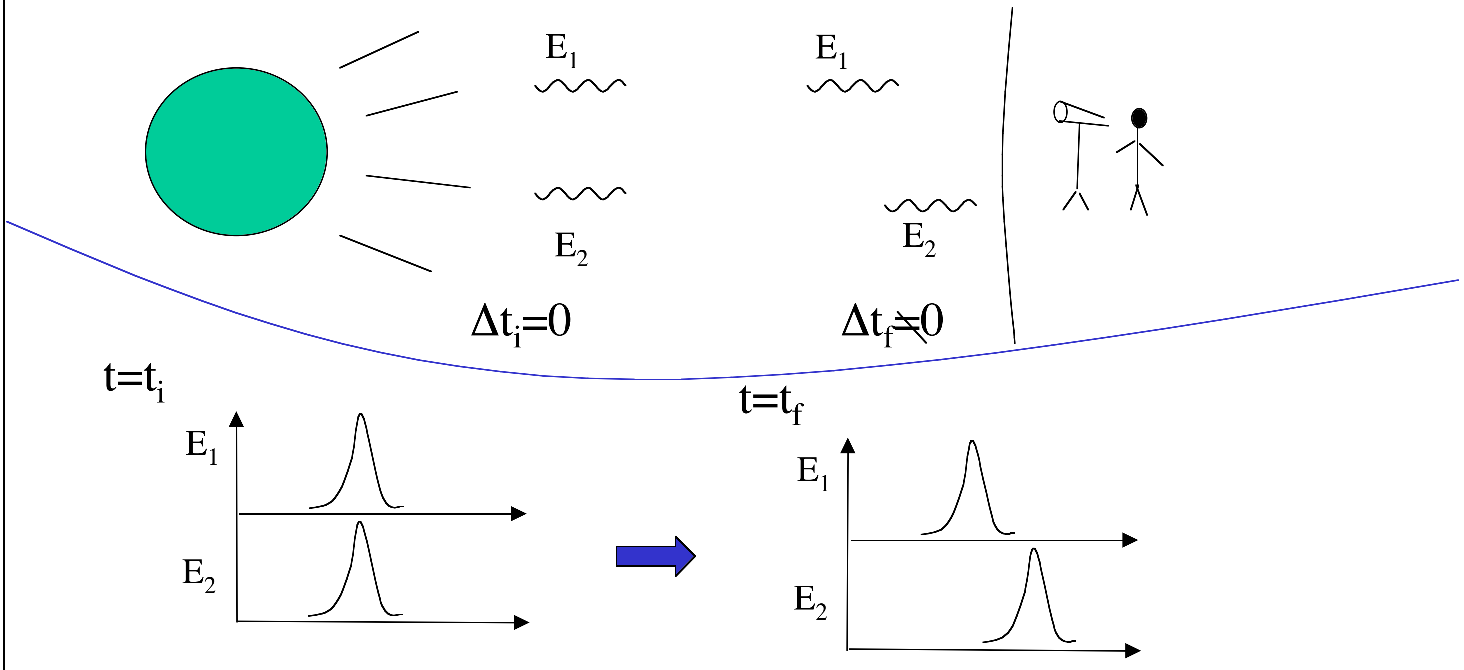
*(analogous to propagation though an electromagnetic plasma)*

*Medium fluctuation at a scale of the order of* $L_p \sim 10^{-33}$ *cm*

➡ $$\Delta t = \sim \alpha \, E/E_{QG} \, D/c$$

# Test of Quantum Gravity

$\Delta t = \sim \alpha\, E/E_{QG}\, D/c$



D ~ 2 $10^{28}$ cm $E_{QG}$ ~$10^{19}$ GeV c~3 $10^{10}$ cm ➡ Δt(ms) ~ 60 ΔE(GeV)

even at pulsars distance: D ~ 6 $10^{21}$ cm Δt(μs) ~ 100 ➡ $E_{QG}$ ~$10^{14}$ GeV

---

# Why Supersymmetry ?

The standard electroweak model is very successful but nevertheless has some problems:

- the unitarity of electroweak interaction breaks down at energy Scales < 1 TeV in the absence of a mechanism to account for electroweak symmetry breaking
- it leaves many fundamental parameters unexplained (like $\sin^2 \vartheta_W$ )
- moreover the gauge structure in the standard model suggest the existence of a Grand Unified theory of electroweak and strong interaction at an energy around $10^{16}$ GeV
- … and at energies around the Plank mass $10^{19}$ GeV there is the need of a theory that includes the Gravitational force because the quantum gravitational effects cannot be neglected.

The Supersymmetry seems to be the most promising field of research to solve these problems. If Supersymmetry is true there is the prediction of the existence of a whole class of new particles that are the supersymmetric partners of the known particles.

In particular the Lightest Supersymmetric Particle (LSP) must be stable by R-parity conservation and can escape detection due to its weakly interacting nature.

# Dark matter problem

The LSP can be a good candidate also for the solution of the Dark Matter Problem.

Experimentally in spiral galaxies the ratio between the matter density and the Critical density Ω is :

$$\Omega_{\text{lum}} \leq \mathbf{0.01}$$

but from rotation curves must exist a galactic dark halo of mass at least:

$$\Omega_{\text{halo}} \geq \mathbf{0.03 \div 0.1}$$

from gravitational behavior of the galaxies in clusters the Universal mass density is :

$$\Omega_{\text{halo}} \cong \mathbf{0.1 \div 0.3}$$

from structure formation theories:

$$\Omega_{\text{halo}} \geq \mathbf{0.\ 3}$$

**but** from big bang nucleosinthesis the Barionic matter cannot be more then:

$$\Omega_{B} \leq \mathbf{0.\ 1}$$

So the best candidate seems to be a Weakly Interacting Massive Particles (WIMP), but neutrinos with mass less then 30 eV do not reproduce well the observed structure of the Universe, so the LSP is a good candidate to solve the Dark matter problem.

---

# Supersymmetry introduces free parameters:

In the MSSM, with Grand Unification assumptions the masses and couplings of the SUSY particles as well as their production cross sections, are entirely described once five parameters are fixed:

- M2 the mass parameter of supersymmetric partners of gauge fields (gauginos)
- the higgs mixing parameters μ that appears in the neutralino and chargino mass matrices
- m0, the common mass for scalar fermions at the GUT scale
- A, the trilinear coupling in the Higgs sector
- the ratio between the two vacuum expectation values of the Higgs fields defined as:

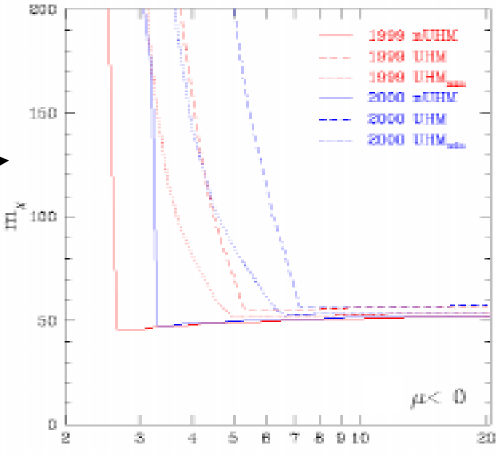
$$\text{tang}\,\beta = v_2 / v_1 = \langle H_2 \rangle / \langle H_1 \rangle$$

## Experimental lower limit on the mass of the lightest neutralino assuming MSSM

(Minimal Standard Supersymmetric Model)

Lep , $\sqrt{s}$ = 189 GeV

**UHM** : universal soft supersymmetry-breaking scalar masses for Higgs
**nUHM:** non-universal
**1999** : available LEP data
**2000** : assessment of the likely sensitivity of data to be taken in 2000.
( the μ<0 plot is similar)

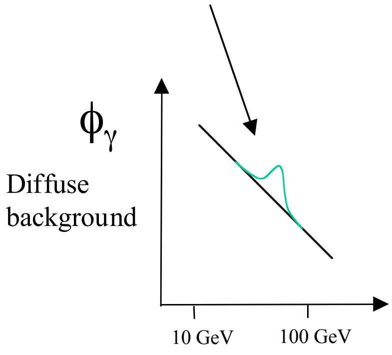


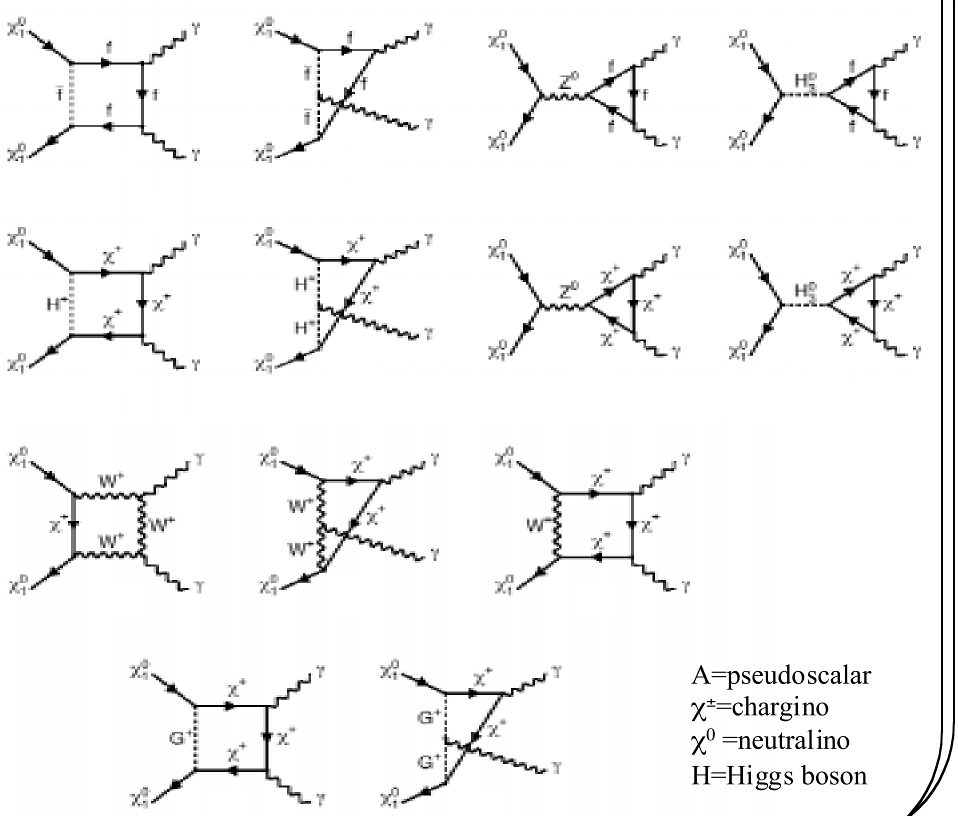
*hep-ph/*0004169

# SuperSymmetric Dark Matter

*Possible signature:*
Gamma Ray
from Neutralino Annihilation

Annihilation at rest:
bump around Neutralino mass





A=pseudoscalar
$\chi^\pm$=chargino
$\chi^0$ =neutralino
H=Higgs boson

---

# Signal rate from Supersymmetry

The signal rate is :

$$\Phi_\gamma \sim 2\cdot 10^{-11}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}(\rho_\chi^{0.4})^2 f_{halo}\left(\frac{\sigma_{\chi\chi\to\gamma\gamma}\cdot v\ /10^{-30}\ \mathrm{cm}^3\ \mathrm{s}^{-1}}{(m_\chi/10\ GeV)^2}\right)\Delta\Omega/sr$$

where:

$\rho_\chi^{0.4}$ is the local halo neutralino density in units of 0.4 GeV/cm$^3$

$f_{halo}$ is a factor that can vary between 0.3 and 2 due to the uncertainty in modeling the galactic halo.

Sensitivity of GLAST up to 300 GeV ~ $10^{-10}$ cm$^{-2}$ s$^{-1}$

with $f_{halo}$ ~1, $\rho_\chi^{0.4}$ ~ 3 , $\phi_b = 2\ 10^{-5}$ ( 100 MeV / E(MeV) ) $^{-1.1}$ photon cm$^{-2}$ s$^{-1}$ sr$^{-1}$

$$\Phi_{min} \geq 5\left(\frac{\Phi_B\ \Delta\Omega}{S\ \eta\ T}\right)^{\frac{1}{2}}$$

In two years, full eff. $\Delta E/E$ ~5% $\phi_{min} \geq 4\ 10^{-10}$ ph cm$^{-2}$ s$^{-1}$ sr$^{-1}$
$\Delta E/E$ ~10% $\phi_{min} \geq 6\ 10^{-10}$ ph cm$^{-2}$ s$^{-1}$ sr$^{-1}$

GLAST has the possibility to explore a good portion of the possible values of this parameters space

(5b$_S$)

# Signal rate from Supersymmetry (2)

But in more general form we have:

$$\frac{d\Phi_\gamma}{d\Omega} = \frac{\sigma_{\chi\chi\to\gamma\gamma} v}{4\pi m_\chi^2} \int_0^\infty \rho^2(r)\, dr(\psi) \simeq$$

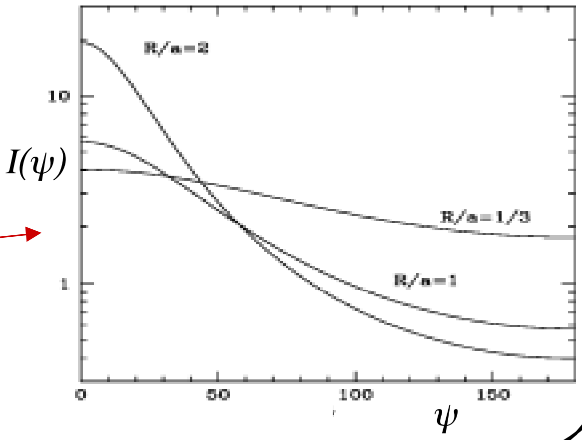
$$\simeq (2\cdot 10^{-12}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}\ \mathrm{sr}^{-1})(\rho_\chi^{0.4})^2 \frac{(\sigma_{\chi\chi\to\gamma\gamma}\cdot v/10^{-30}\,\mathrm{cm}^3\,\mathrm{sec}^{-1})}{(m_\chi/\,10\,\mathrm{GeV})^2}\, I(\psi)$$

where:

$\psi$ is the angle between the line of sight and the Galactic center,
r($\psi$) is the distance along that line of sight

I($\psi$) is the angular dependence of the gamma-ray flux.

The galactic dark matter density distribution can have the form $\rho(r) \sim r^{-\alpha}$ with $\alpha \sim 1.8$ and the predicted photon flux can be $10^4$ brigther from certain directions!
(the sources can appear nearly pointlike)

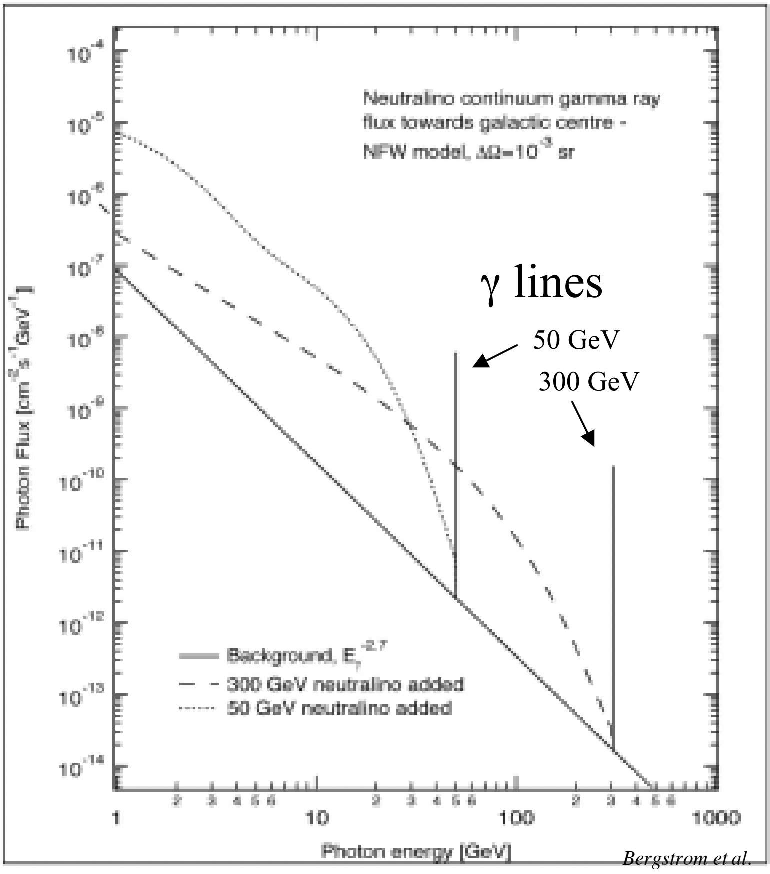


R ~ 8.5 kpc

---

(6$_S$)

# Total photon spectrum from the galactic center from $\chi\chi$ ann.

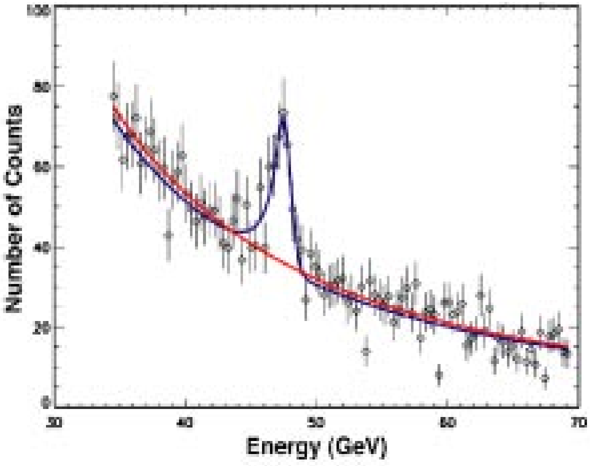


*Bergstrom et al.*

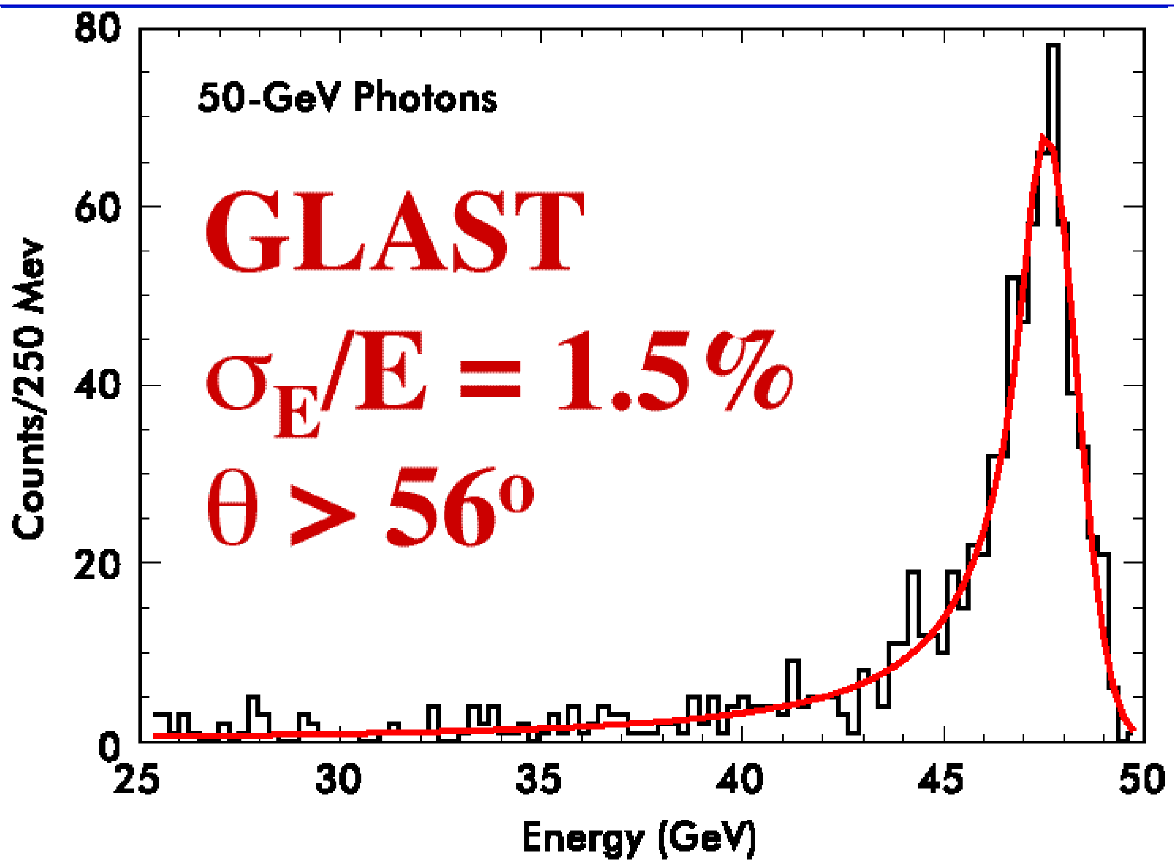
- Two-year scanning mode

Infinite energy resolution

With finite energy resolution

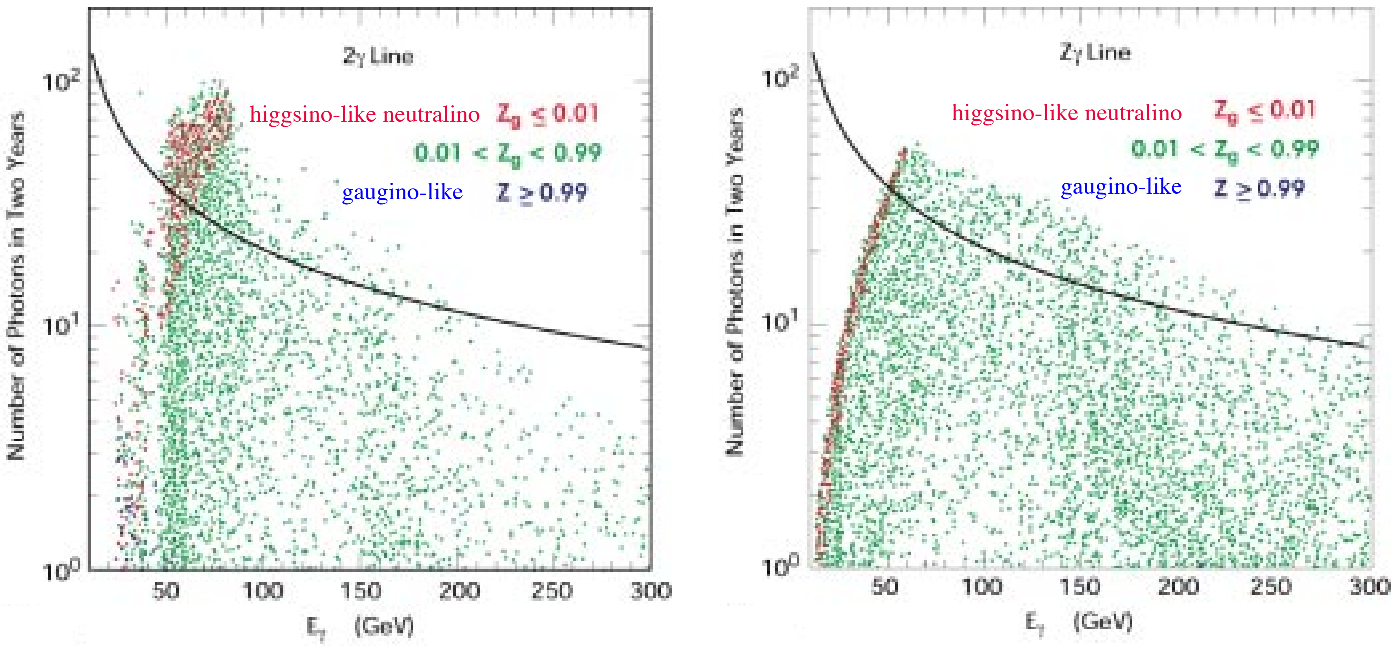


# GLAST Performance : Energy resolution for lateral photons



---

## Number of photons expected in GLAST for χχ -> γγ from a 1-sr cone near the galactic center



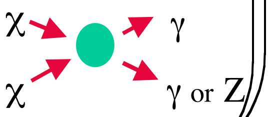
*Bergstrom et al. astro-ph/ 9712318*

Two-year scanning mode exposure.

**Each point is a different set of Minimal SuperSymmetric Standard Model parameters**

The galaxy dark matter halo profile giving the maximal flux has been assumed.

The solid line shows the number of events needed to obtain a five-sigma detection over the galactic diffuse gamma-ray background as estimated from EGRET data.

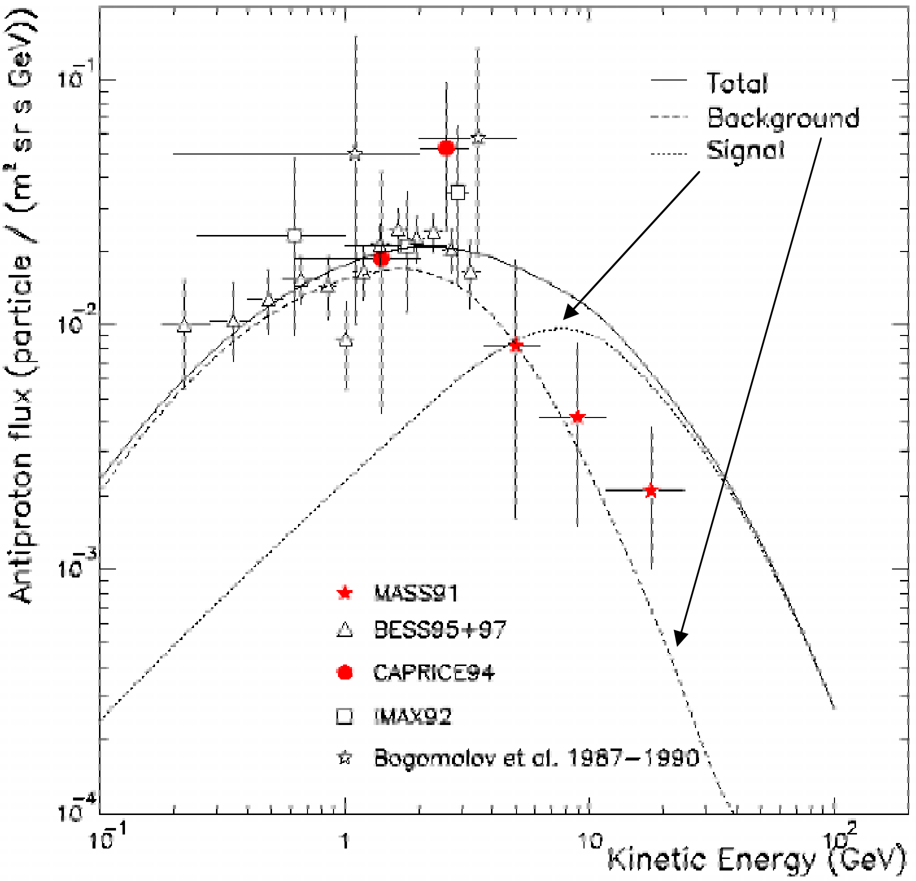


## Distortion on the secondary antiproton flux induced by a signal from a heavy Higgsino-like neutralino.

- Background from normal secondary production
- Signal from very heavy (~ 1 TeV) neutralino annihilations

  ( astro-ph 9904086)
- Mass91 data from XXVI ICRC, OG.1.1.21 , 1999
- Caprice94 data from ApJ , 487, 415, 1997

Particles and photons are sensitive to different neutralinos.
Gaugino-like particles are more likely to produce an observable flux of antiprotons whereas Higgsino-like annihilations are more likely to produce an observable gamma-ray signature

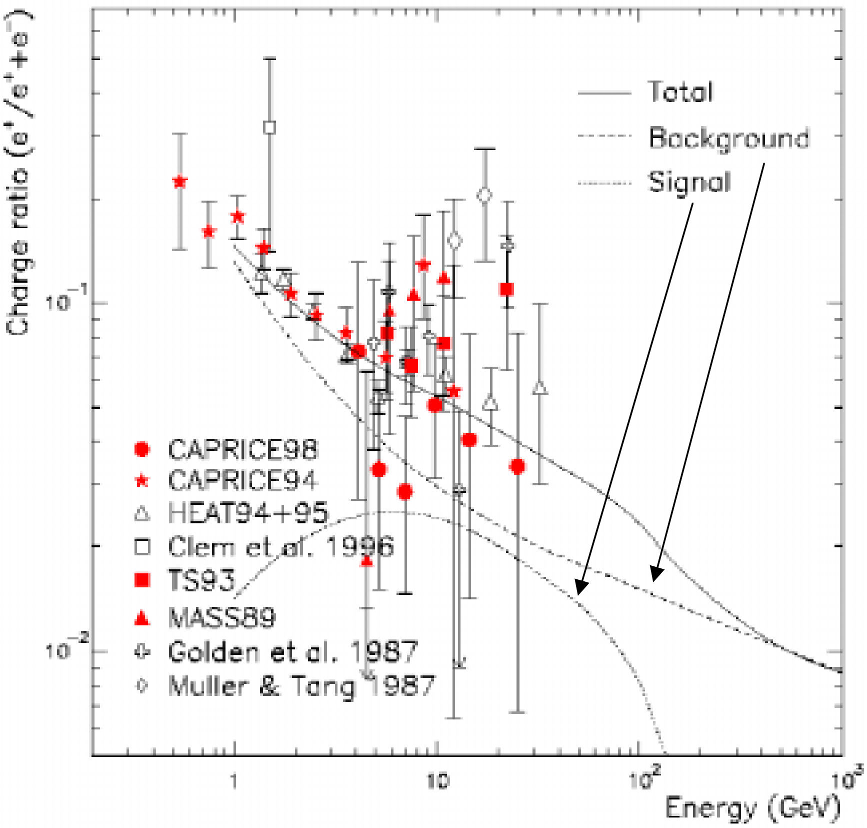


## Distortion on the secondary positron fraction induced by a signal from a heavy neutralino.

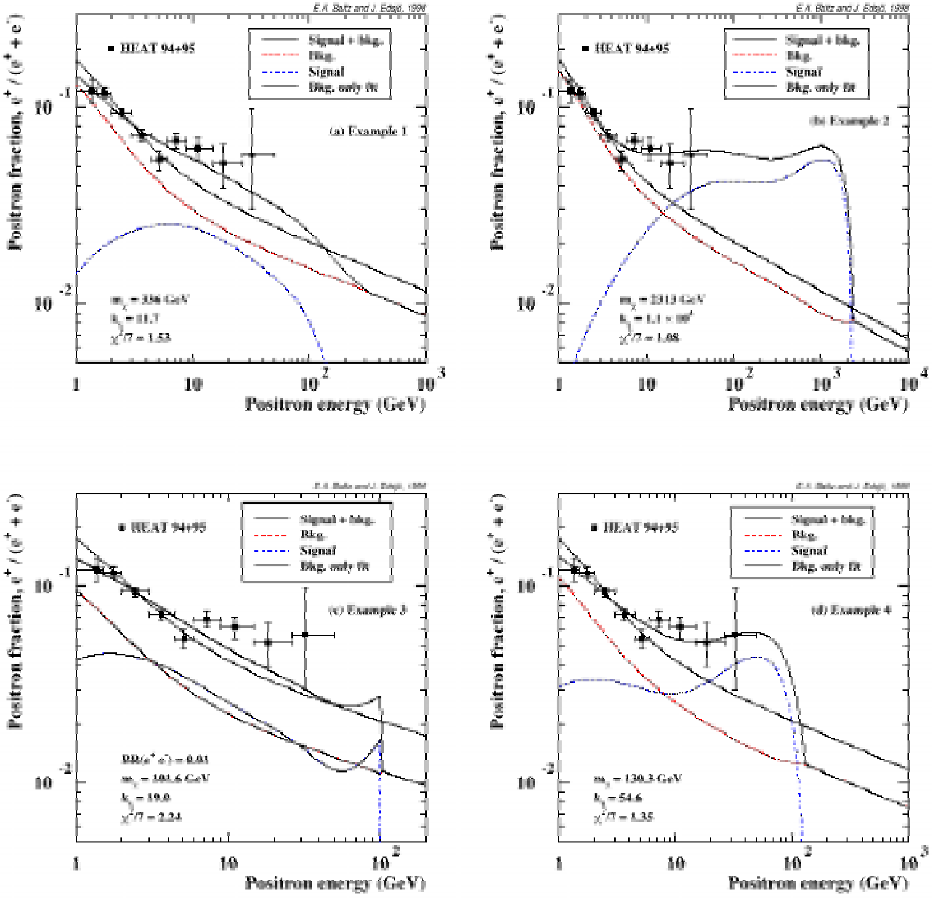
- Background from normal secondary production

  (ApJ 493, 694, 1998)
- Signal from ~ 300 GeV neutralino annihilations

  (Phys.Rev. D59 (1999) astro-ph 98008243)
- Caprice98 data from XXVI ICRC, OG.1.1.21, 1999
- Caprice94 data from ApJ , 532, 653, 2000



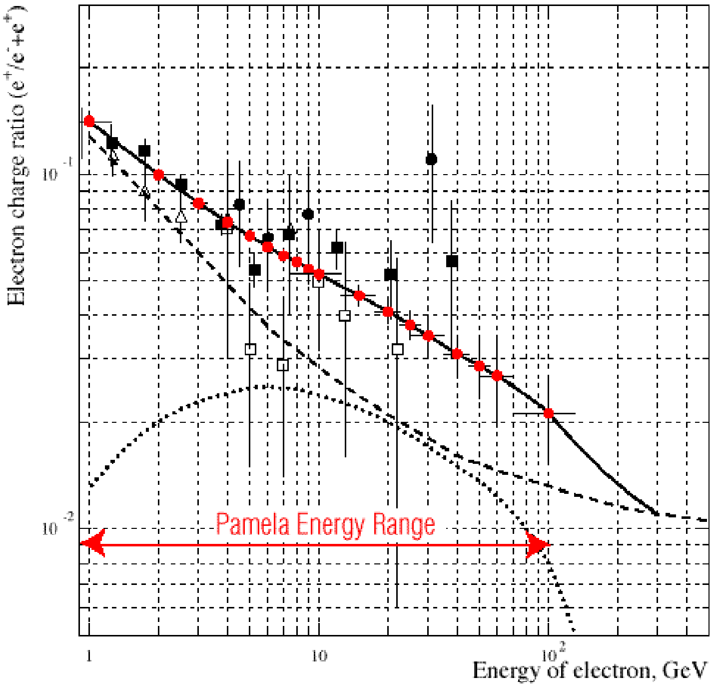
## Distortion on the secondary positron fraction induced by a signal from a heavy neutralino.



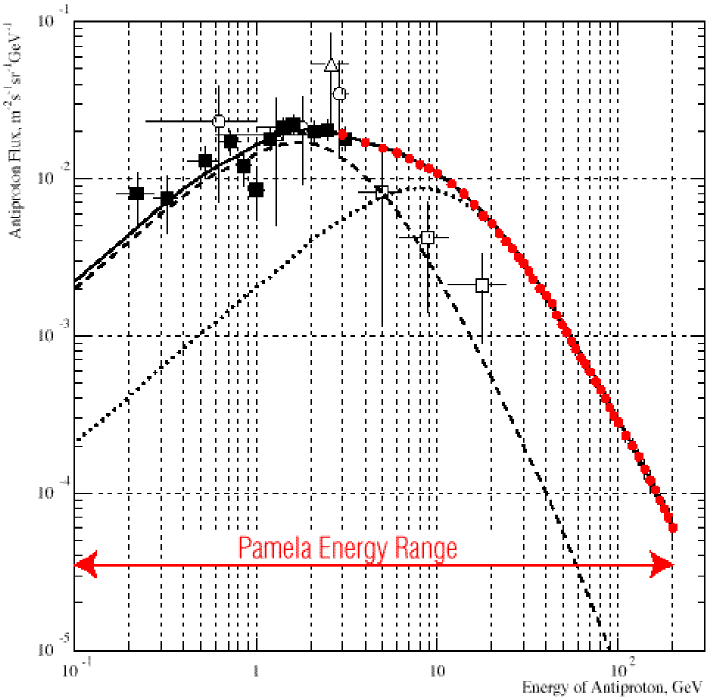
Phys.Rev. D59 (1999)
astro-ph 98008243

---

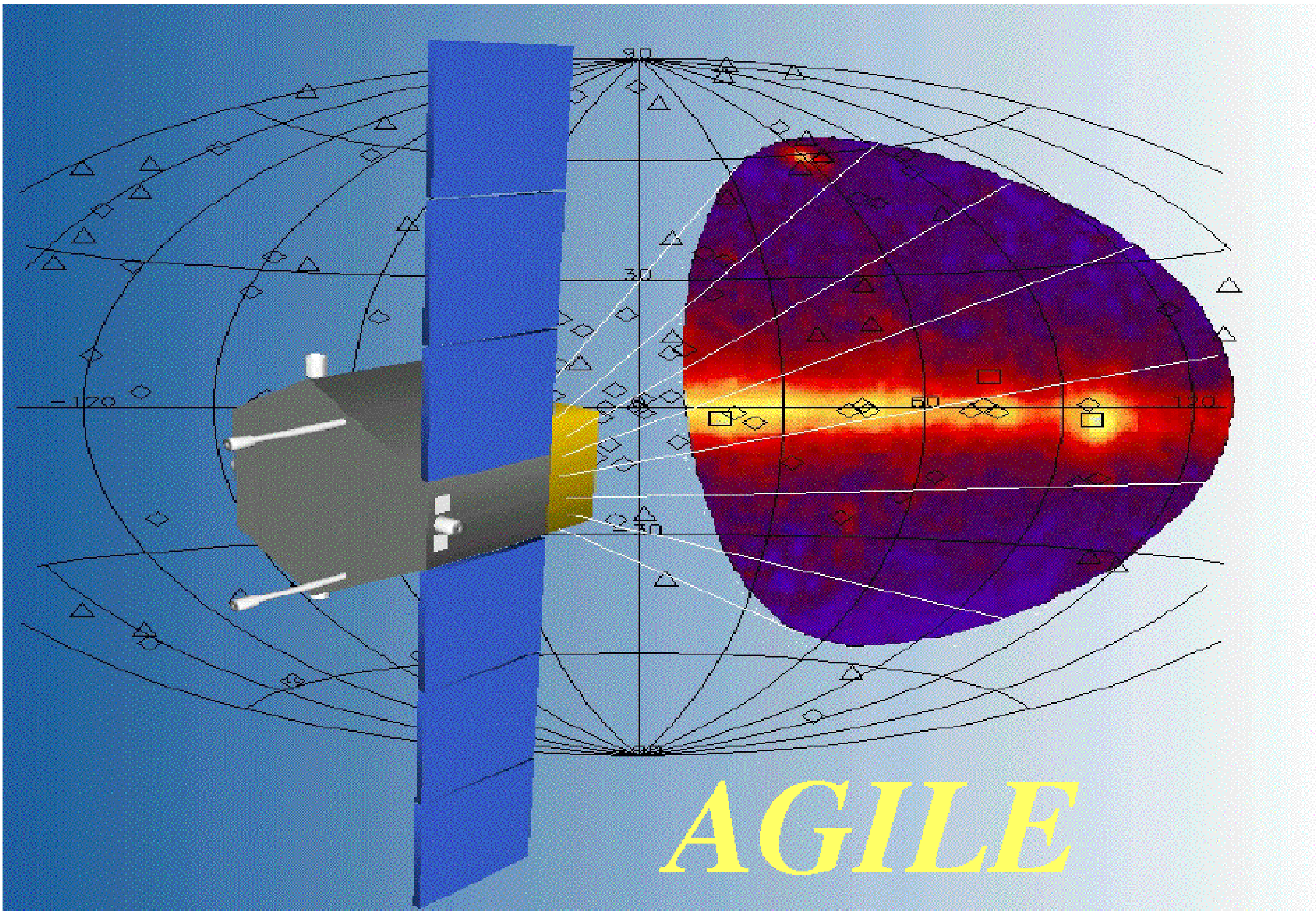
### Distortion on the secondary positron fraction induced by a signal from a heavy neutralino.



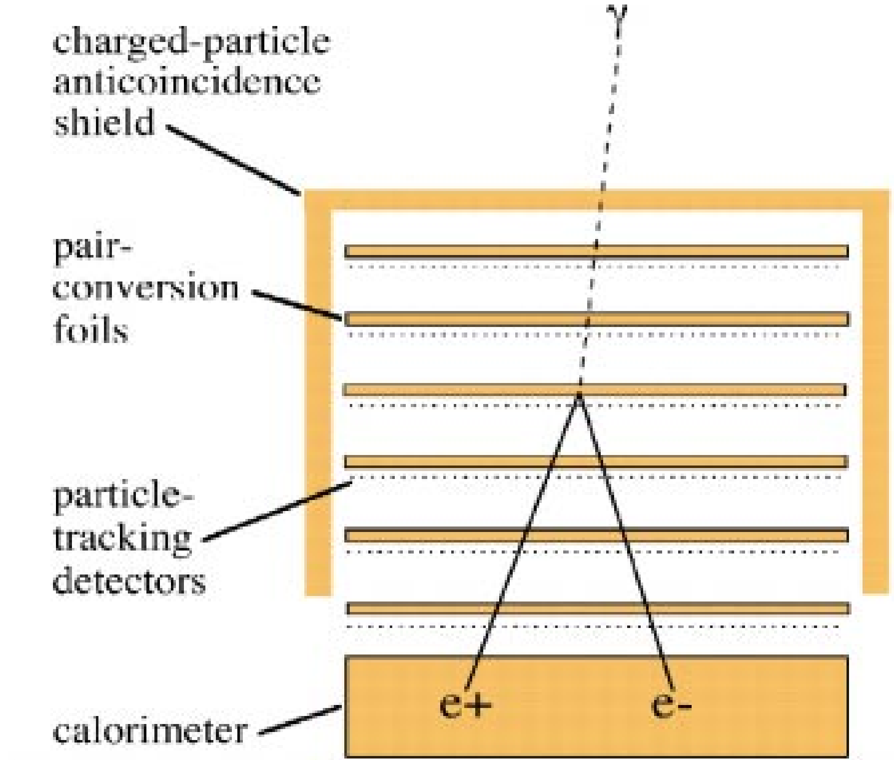
### Distortion on the secondary antiproton flux induced by a signal from a heavy Higgsino-like neutralino.



Expected data from Pamela for one year of operation are shown in red.



# Elements of a pair-conversion telescope

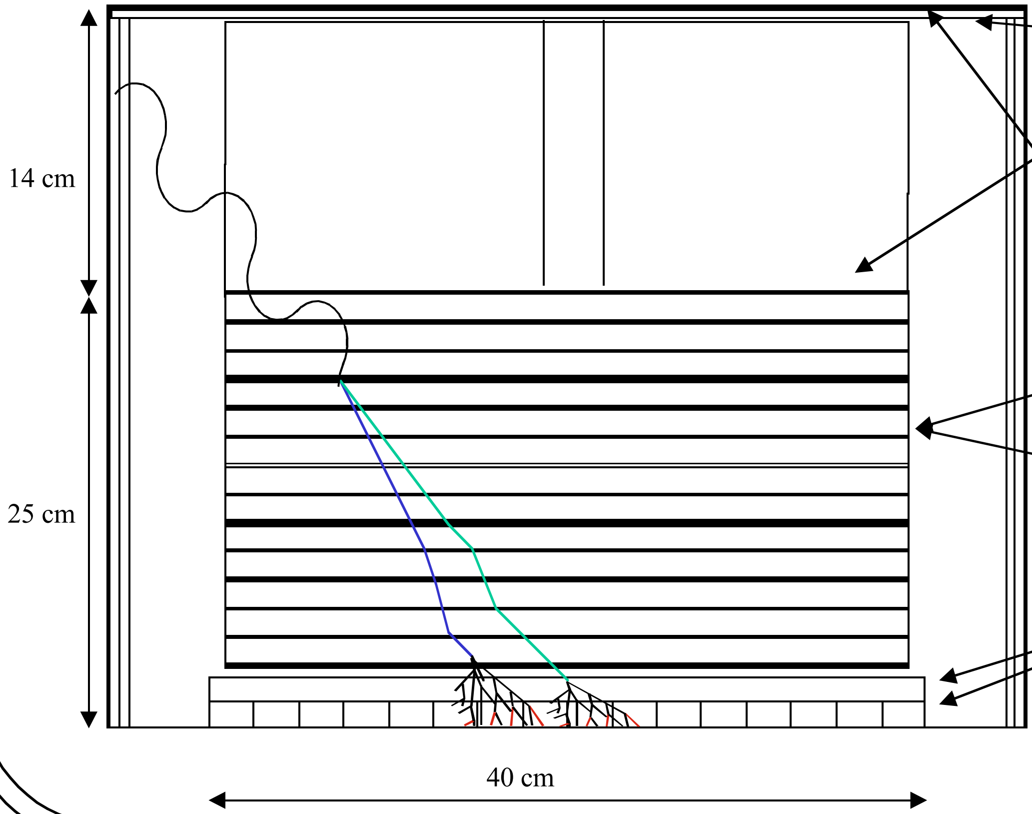


(energy measurement)

- photons materialize into matter-antimatter pairs: $E_{\gamma}$ --> $m_{e+}c^2 + m_{e-}c^2$

- electron and positron carry information about the direction, energy and polarization of the γ-ray

# AGILE



**Super Agile Mask**

**Super Agile Silicon plane**

**AntiCoincidence**
**Top: 0.5cm plastic scintillator**
**Lateral: 12 panels 0.6 cm**

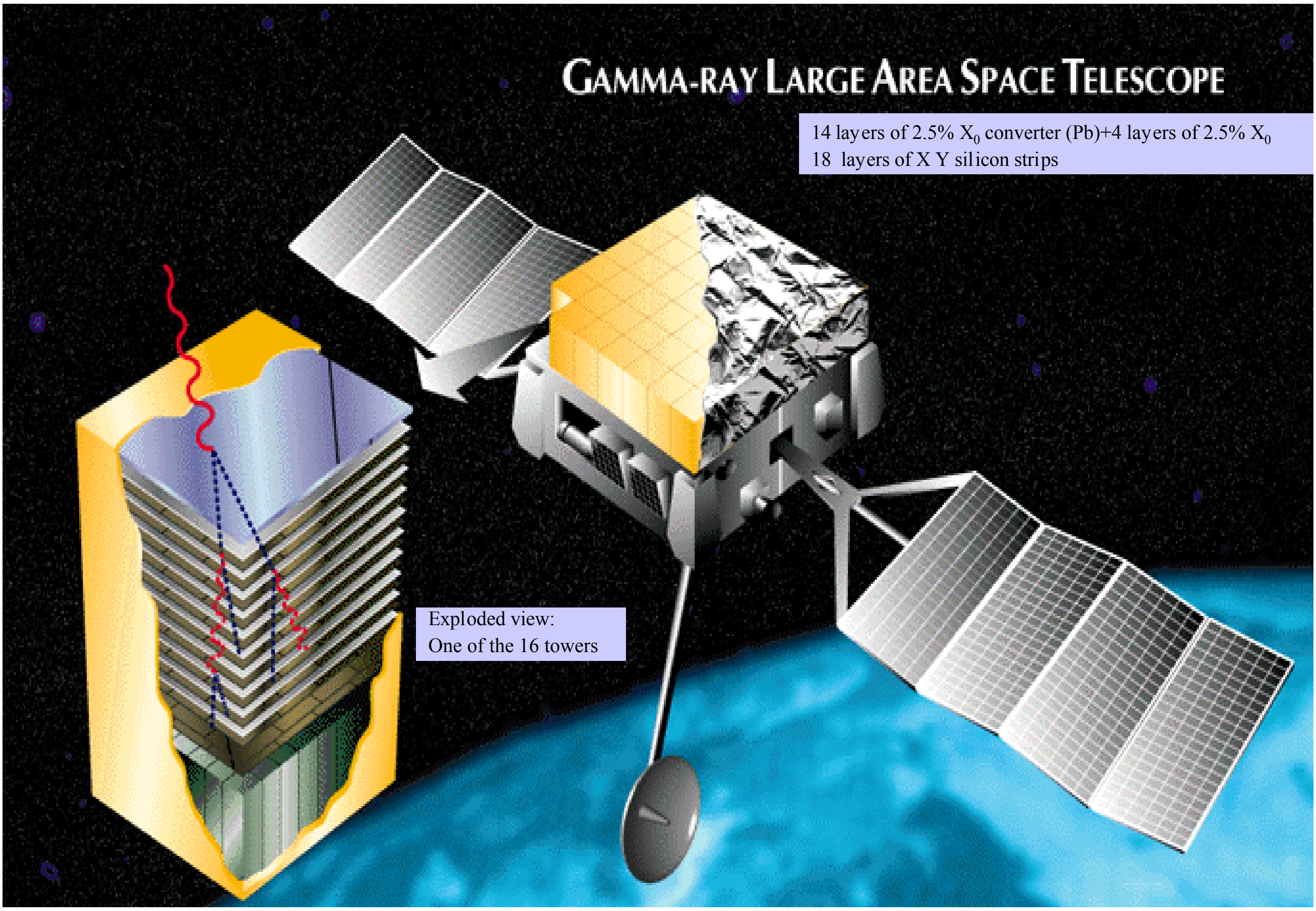
Tracker , 14 X/Y planes

**W 0.07 $X_0$**

**X/Y plane, 121 μm pitch**
distance between planes 1.6cm

**1.5 $X_0$ CsI Calorimeter**
$1.4*2*40$ cm$^3$ bars

---

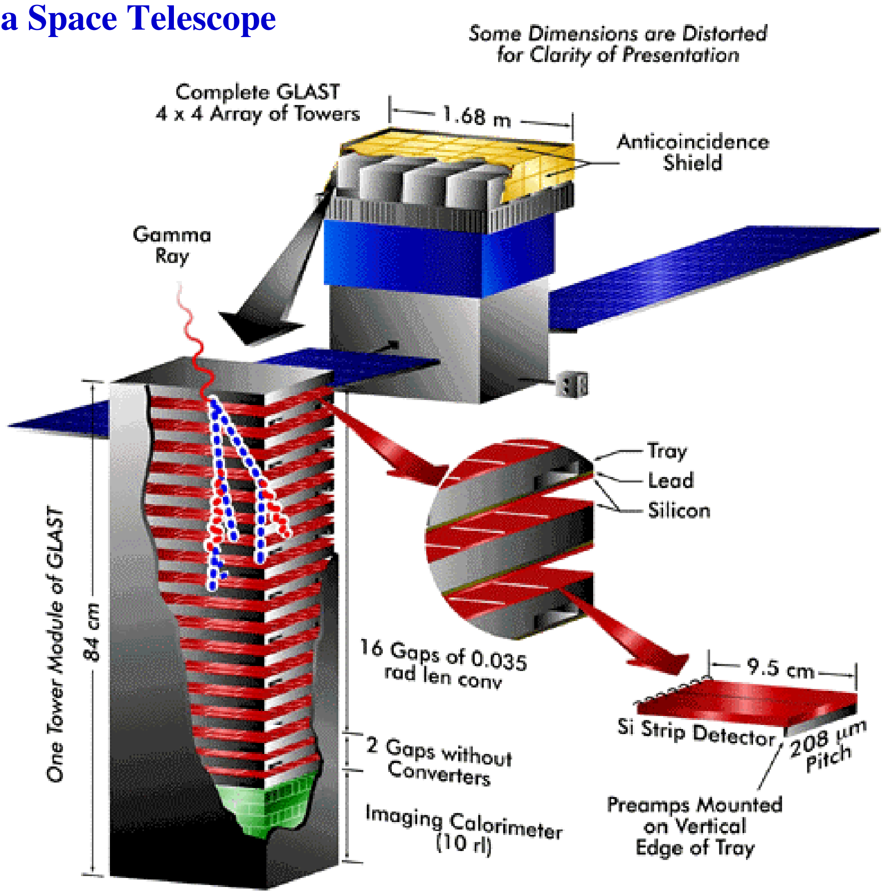


## GAMMA-RAY LARGE AREA SPACE TELESCOPE

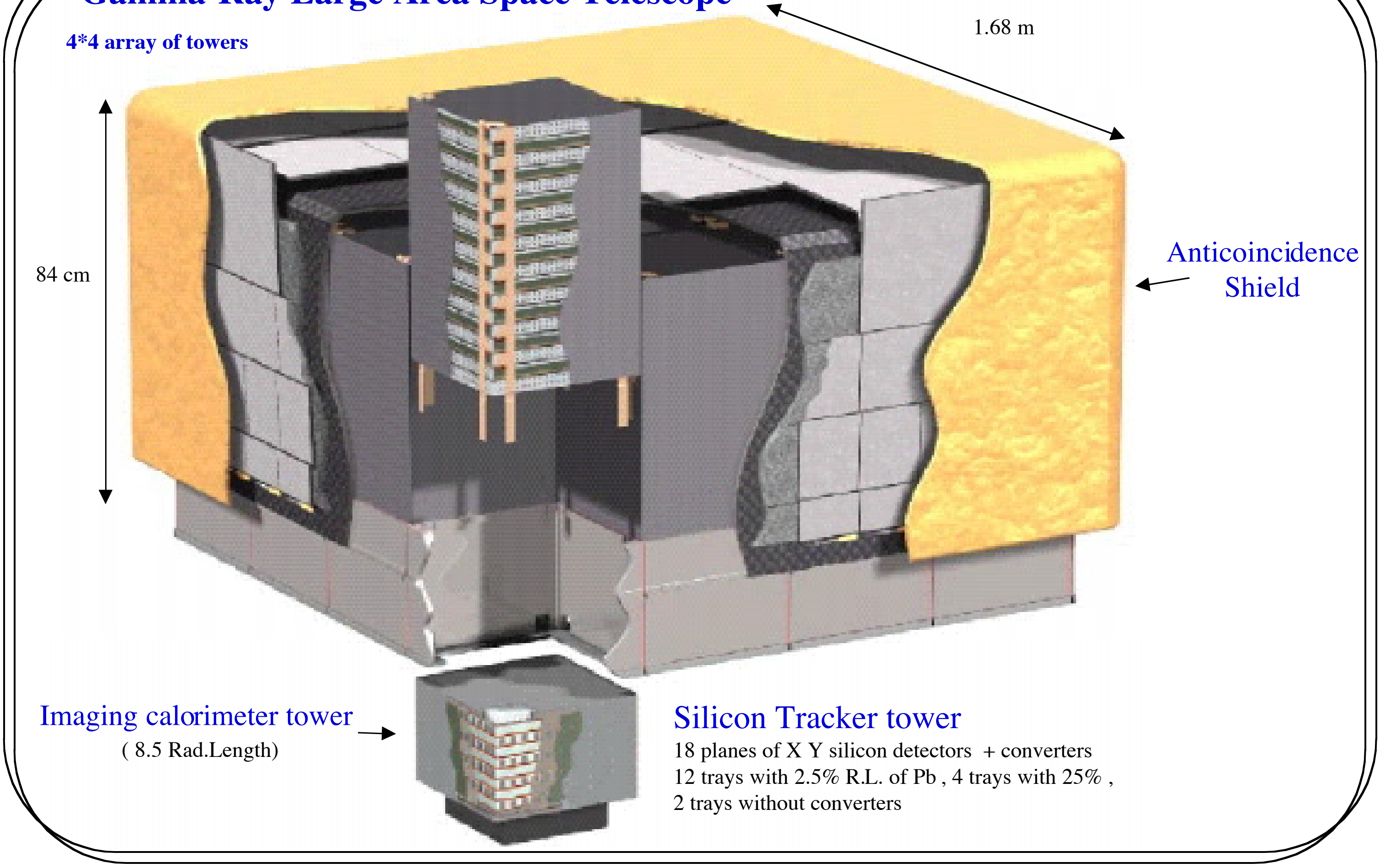
14 layers of 2.5% $X_0$ converter (Pb)+4 layers of 2.5% $X_0$
18 layers of X Y silicon strips

Exploded view:
One of the 16 towers

# Gamma-Ray Large Area Space Telescope



# Gamma-Ray Large Area Space Telescope



**4*4 array of towers**

1.68 m

84 cm

Anticoincidence Shield

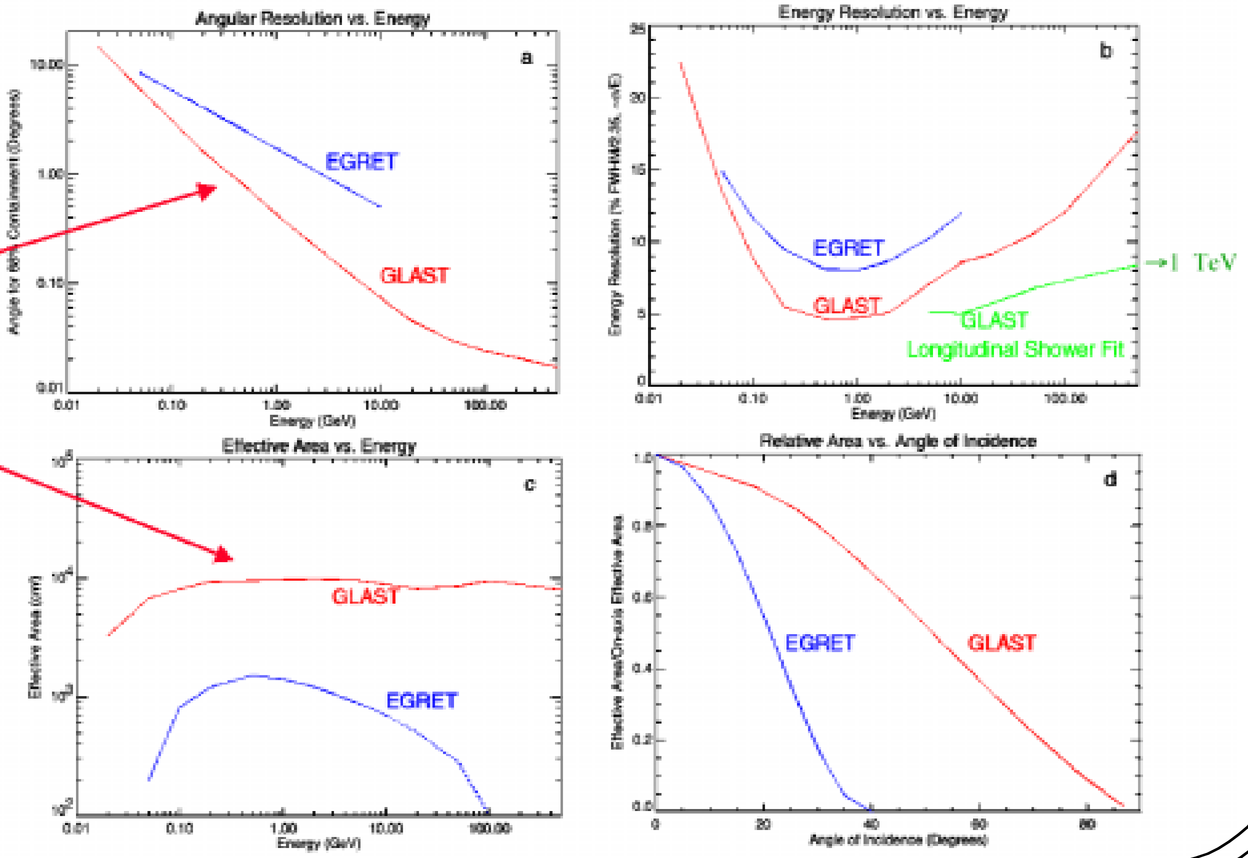
Imaging calorimeter tower

( 8.5 Rad.Length)

Silicon Tracker tower

18 planes of X Y silicon detectors + converters
12 trays with 2.5% R.L. of Pb , 4 trays with 25% ,
2 trays without converters

# GLAST Performance

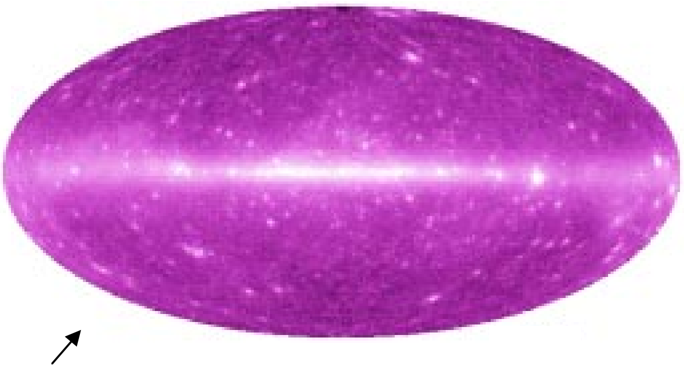


This PSF is with this Effective Area (after all bkgd. cuts and full reconstr., normal incidence)

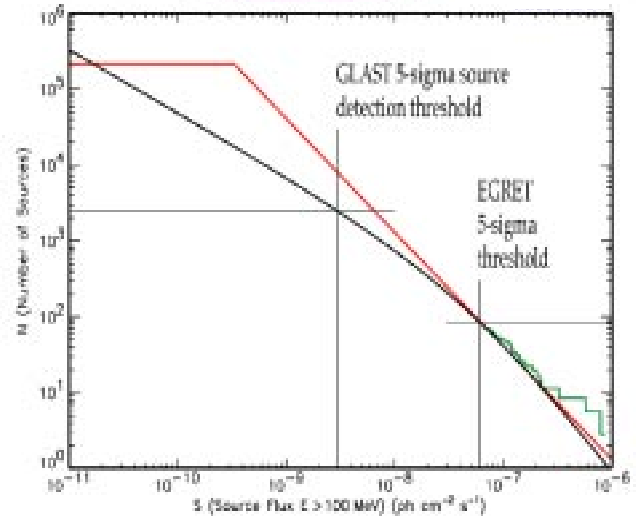
---

# One year All-Sky Survey Simulation, Eγ > 100 MeV

All-sky intensity map based on five years EGRET data.



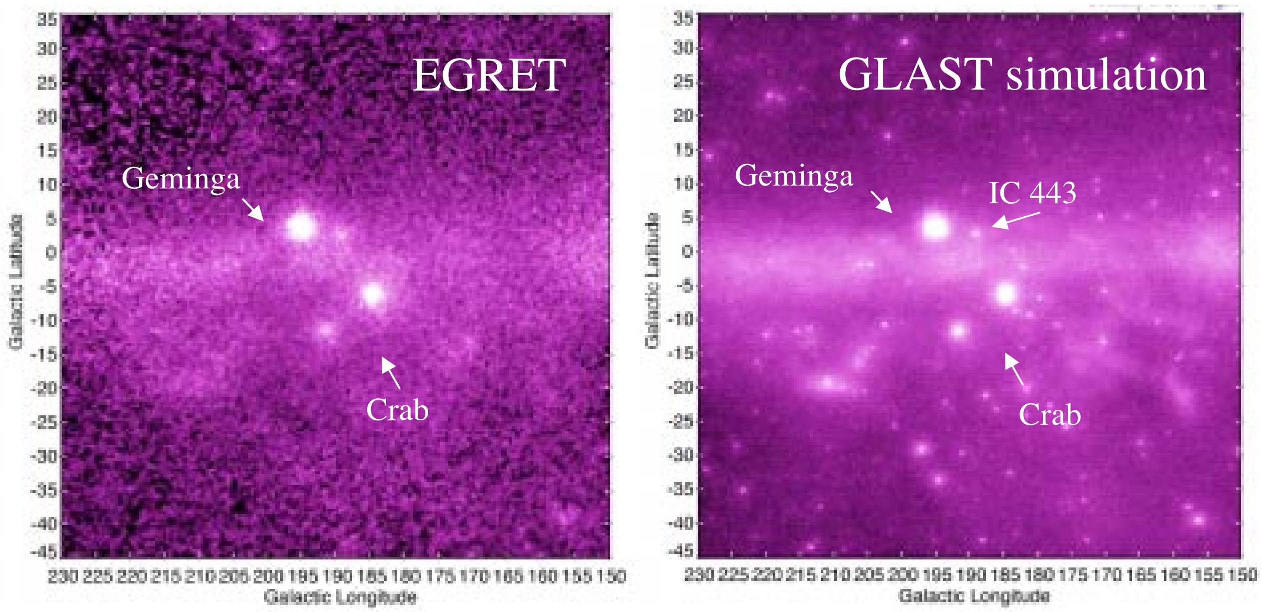
All-sky intensity map from a GLAST one year survey, based on the extrapolation of the number of sources versus sensitivity of EGRET



# Acceleration of Cosmic Rays

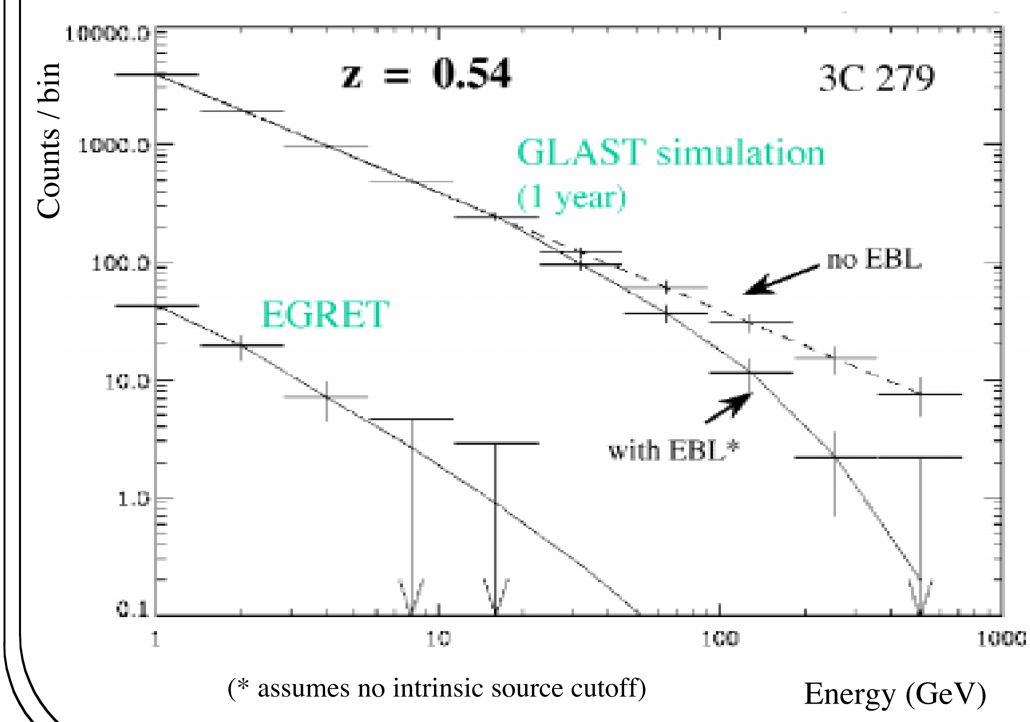
If cosmic rays are accelerated in supernova remnants, then the high-energy gamma-ray spectral index in supernova remnants will be equal to the cosmic-ray spectral index at the source. GLAST will have enough angular resolution to resolve the remnant IC443 and enough sensitivity to measure its spectral index.

Galactic anticenter at Eγ > 100 MeV. EGRET data and GLAST one-year all-sky survey



---

# Probing the era of Galaxy Formation Uncover the nature of Dark Matter

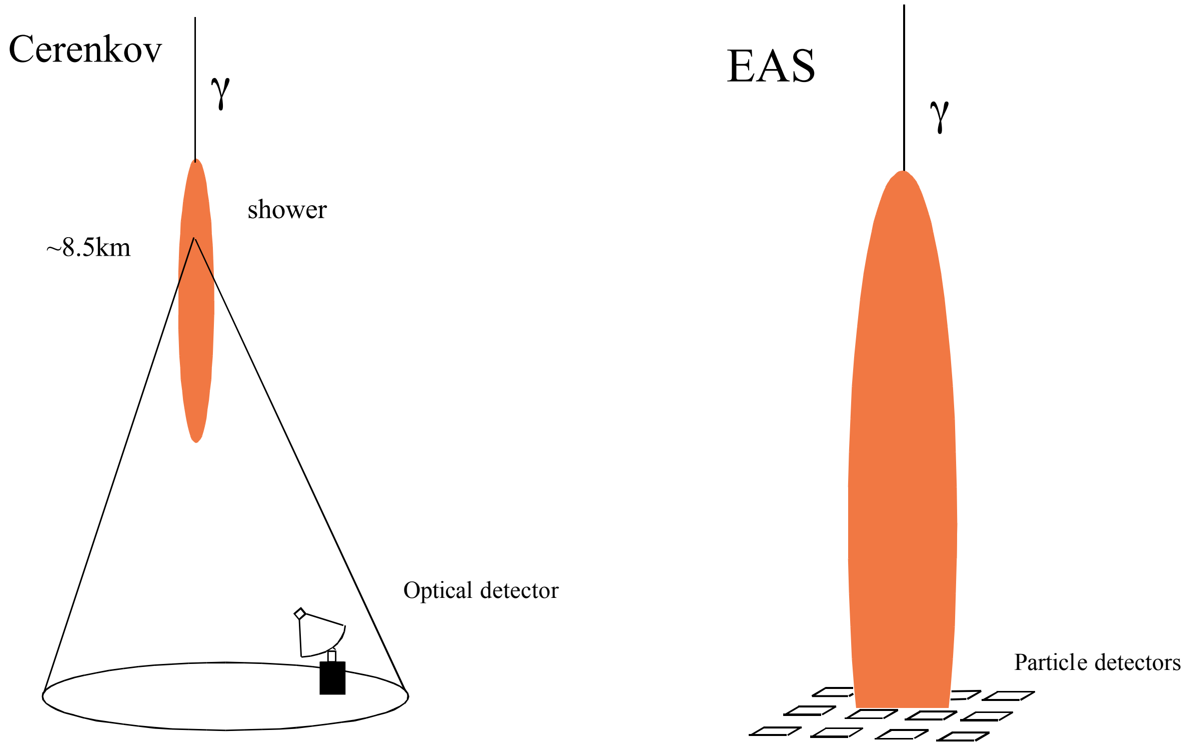


(* assumes no intrinsic source cutoff)

Roll- offs in the γ -ray spectra from AGN at large z probe the extra-galactic background light (EBL) over cosmological distances. A dominant factor in EBL models is the era of galaxy formation: AGN roll- offs may help distinguish models of galaxy formation, e. g., **Cold Dark Matter vs. Hot Dark Matter-- 5 eV neutrino contributions, etc.**

See for example
Macminn, D., and J. R. Primack, 1995, astro- ph/ 9504032.

# Cerenkov and Extensive air shower (EAS) gamma ray telescope concepts



Cerenkov

γ

shower

~8.5km

Optical detector

EAS

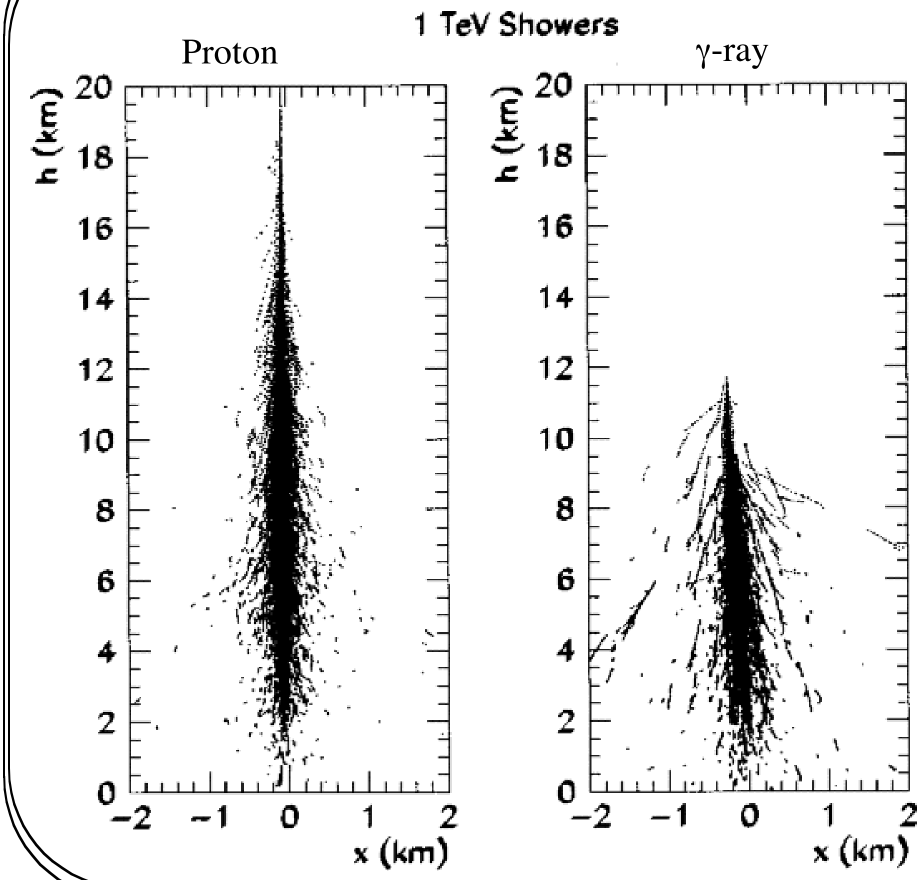
γ

Particle detectors

~ 40.000 m^2 , but no anticoincidence shield !

---

# Development of vertical 1-TeV proton and γ-ray shower

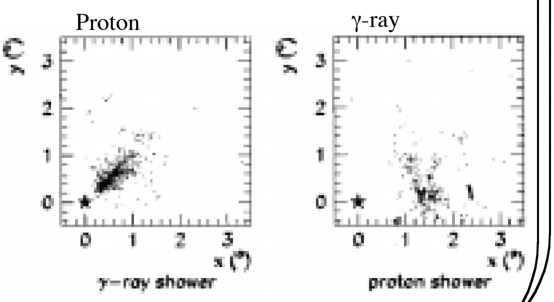


Proton

γ-ray

Positions in the atmosphere of all shower electrons above the Cerenkov threshold

Resulting Cerenkov images in the focal plane of a 10-m reflecting mirror .

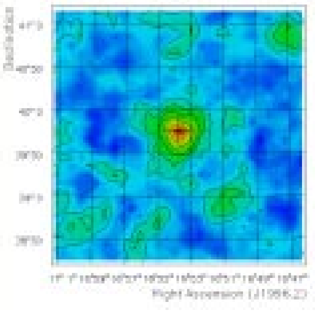


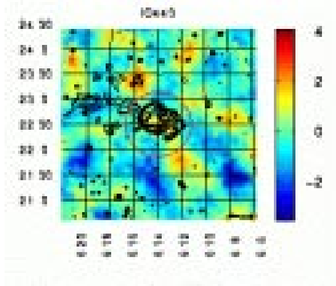
Proton

γ-ray

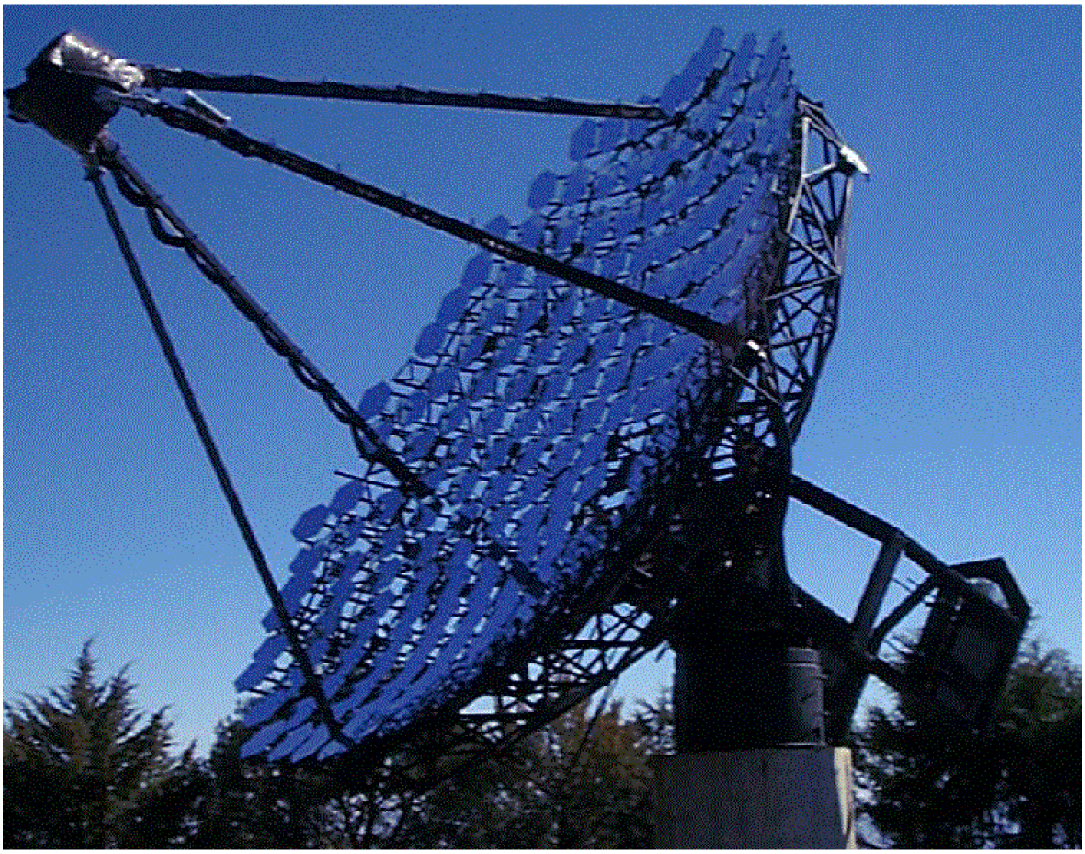
## Whipple

10 m^2 telescopes
E = >350 GeV
Location: Mt.Hopkins
in operation


MHK501



Supernova remnants



---

## "Solar Farm" Cerenkov gamma ray telescope concept

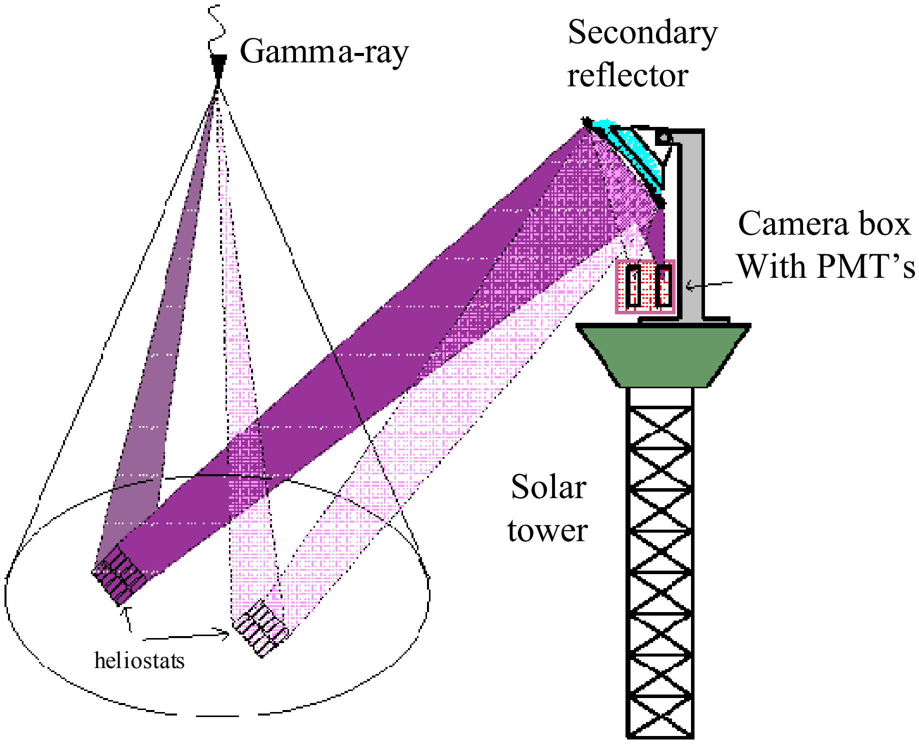
## CELESTE

Location: Thémis , France

## STACEE

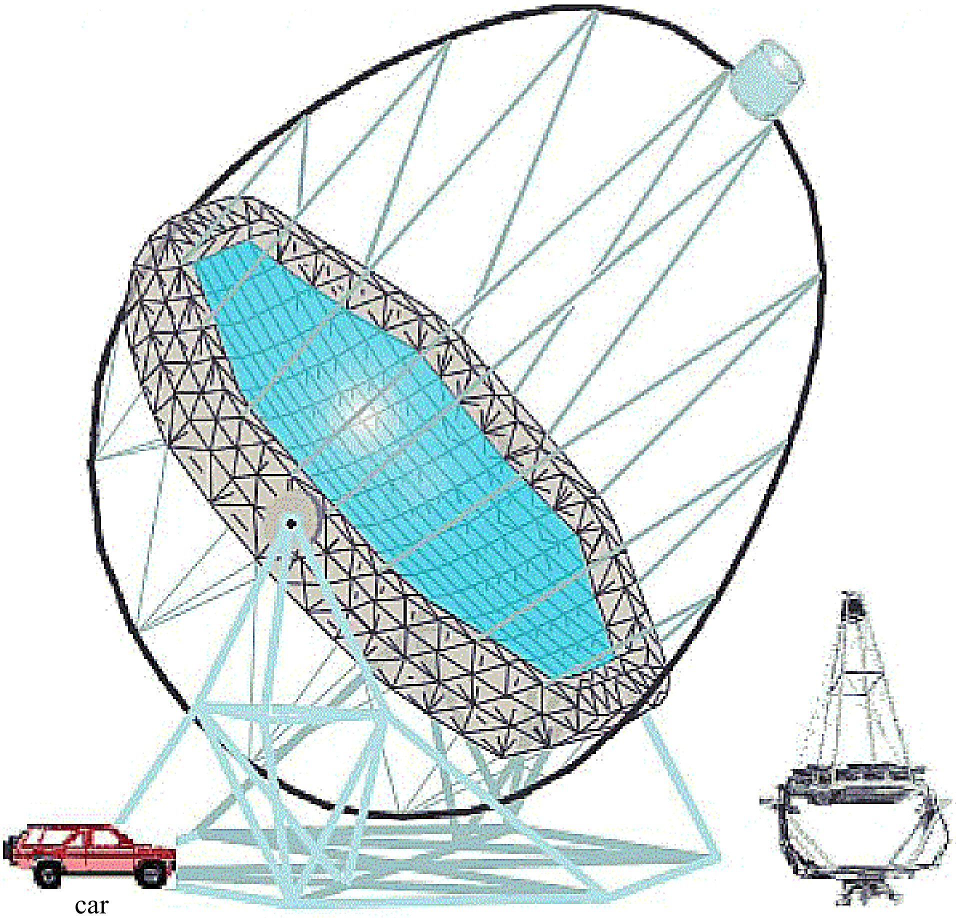
Location: Albuquerque

~40 m$^2$ mirror area
E =20 GeV - 200 GeV
Schedule: in test



# MAGIC

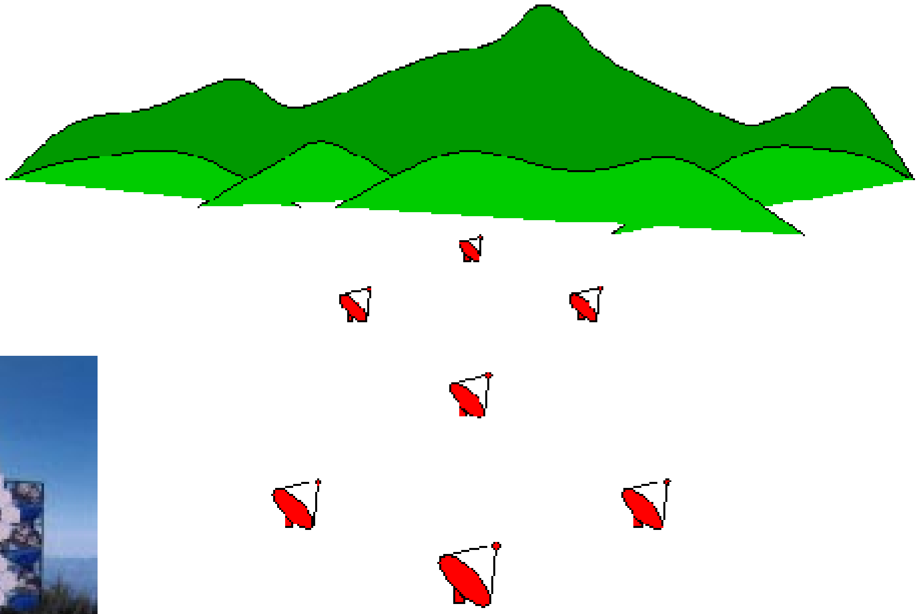
220 m$^2$ mirror area
E =10 GeV - 300 GeV
Location: La Palma
(Canary Islands)
Scheduled June 2001

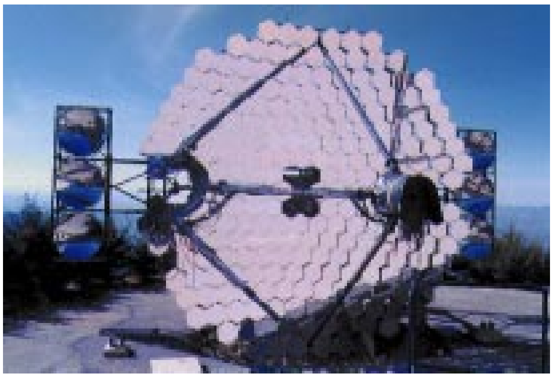


---

# Veritas

7 Whipple like 10 m^2 telescopes
E = 50 GeV -50TeV
Location: southern Arizona
Scheduled 2005

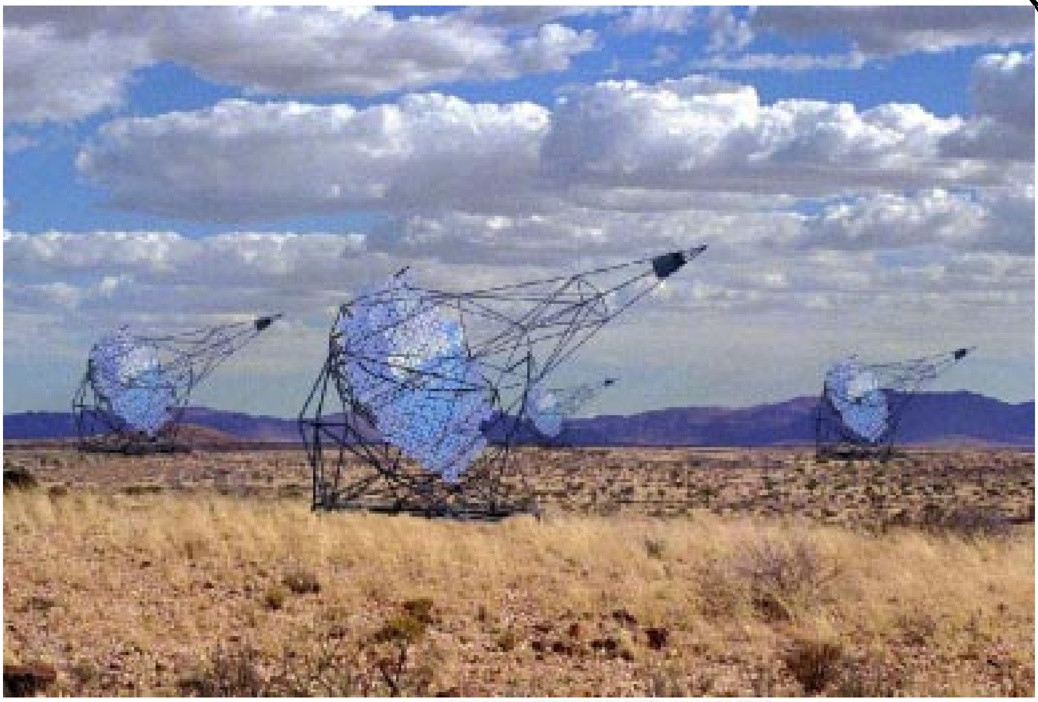




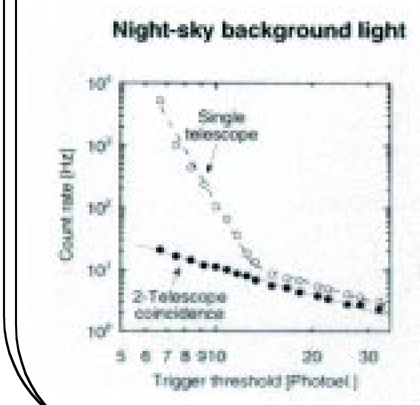
Whipple

# HESS Phase 2

four 110m^2 telescopes
Field of view 5 deg
Detection capability at E > 40 GeV
Spectroscopy at E > 100 GeV
Location: Namibia
Scheduled 2002



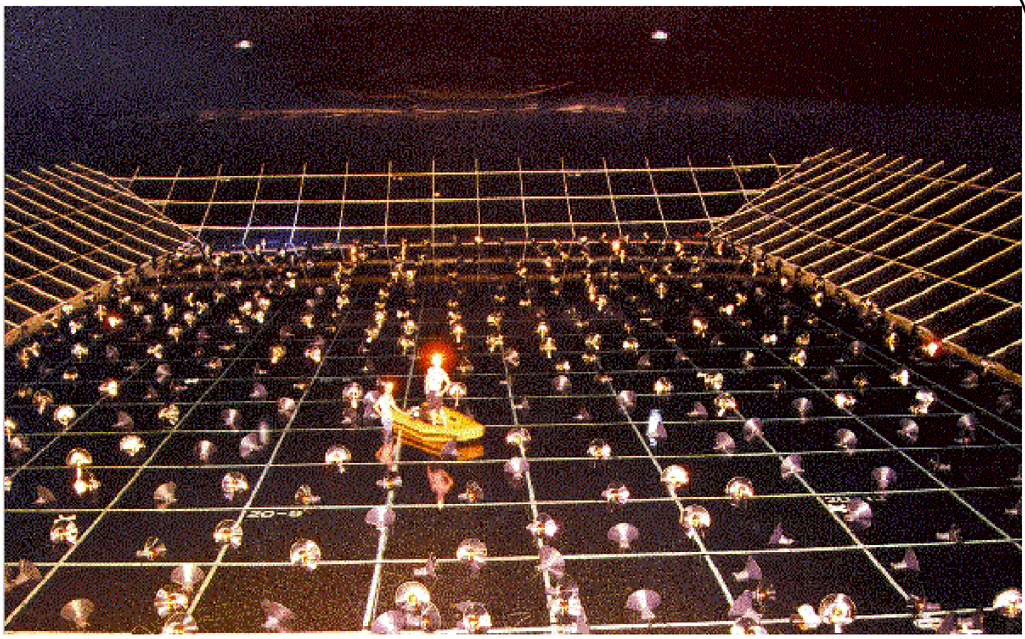
(artistic composition)
(not yet real ! )

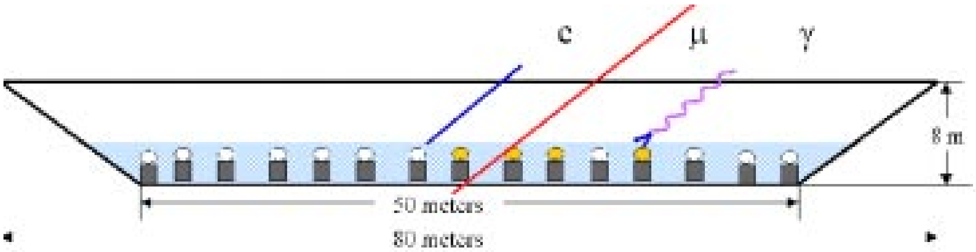


---

# MILAGRO

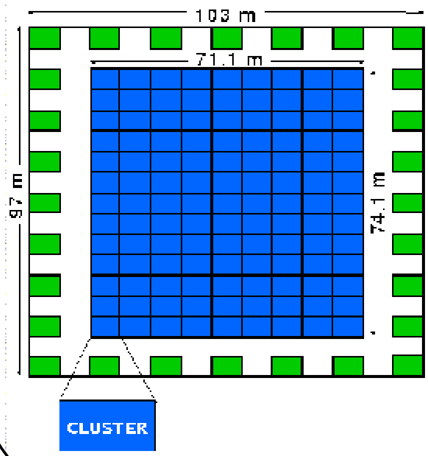
Area 5000 m^2
Field of view ~ 1 sr
E = 250 GeV - 50 TeV
Location: New Mexico 2600m alt.
Started June '99

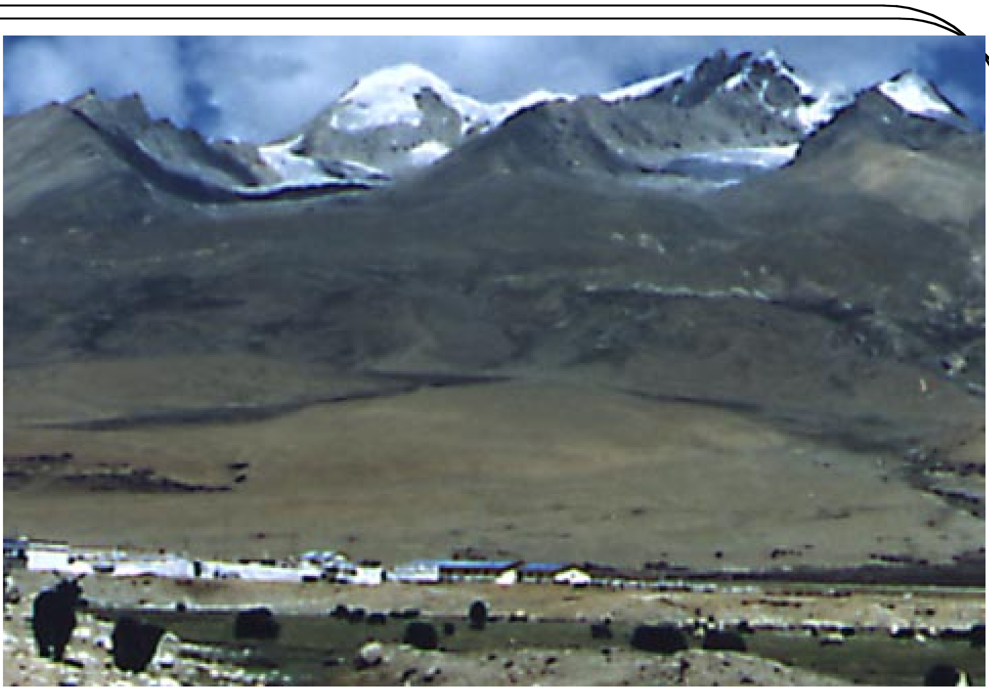




# ARGO

Area 5.200 m$^2$ (full coverage)
(10.000 m$^2$ with guard ring)
Field of view ~ 1 sr
E = 50 GeV - 50 TeV
Location: Tibet 4300m alt.
Scheduled 2002 (final conf.)



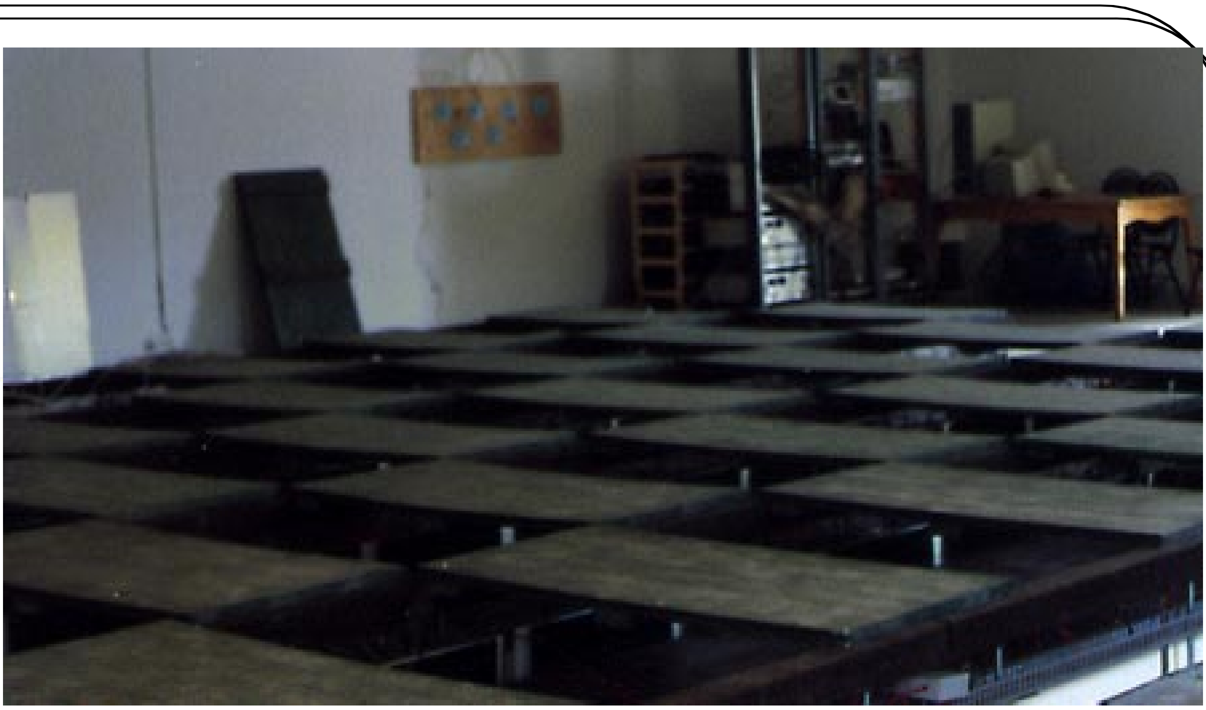


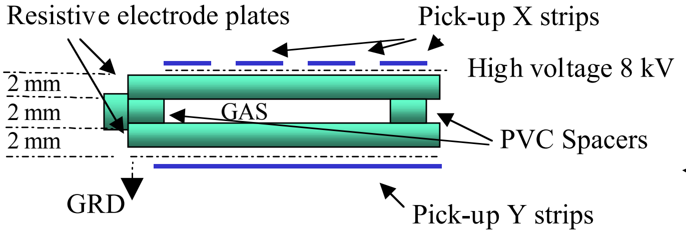
17400 Pads 56 by 60 cm$^2$ each of Resistive Plate Chamber (RPC).
Each pad subdivided in pick-up strips 6 cm wide for the space pattern inside the pad.
The CLUSTER is made of 12 RPCs Pads

---

# ARGO

## Test Carpet in Tibet

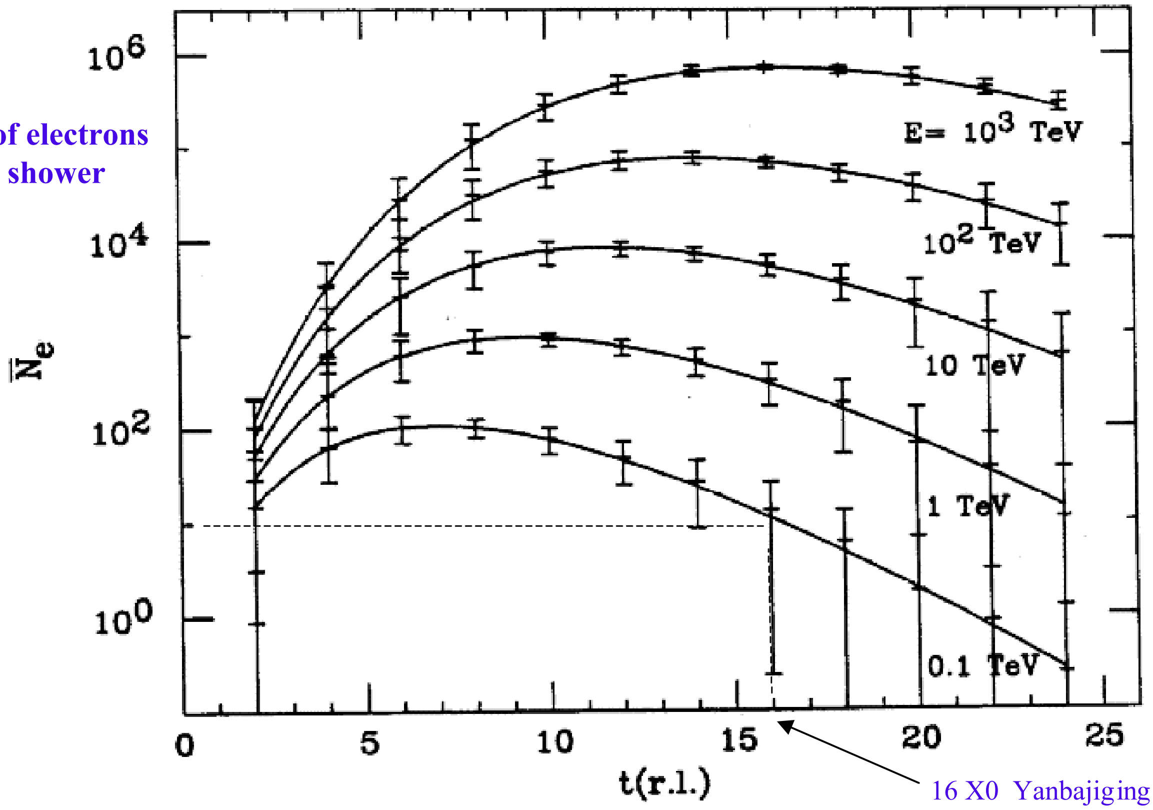




The detector structure

## Longitudinal development of the electron component of photon initiated shower

( with electron threshold energy of 5 MeV and fluctuations superimposed )

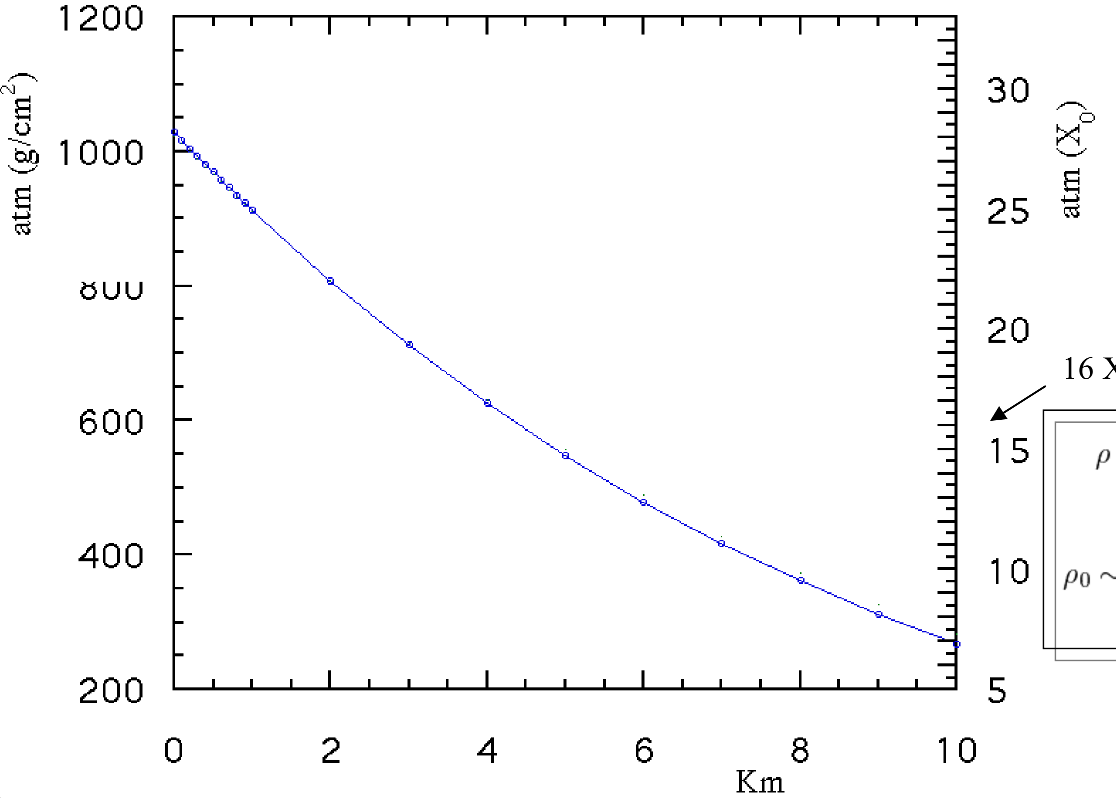


Number of electrons in the shower

16 X0 Yanbajiging

---

## Relation between altitude, number of Radiation Length and g/cm² traversed



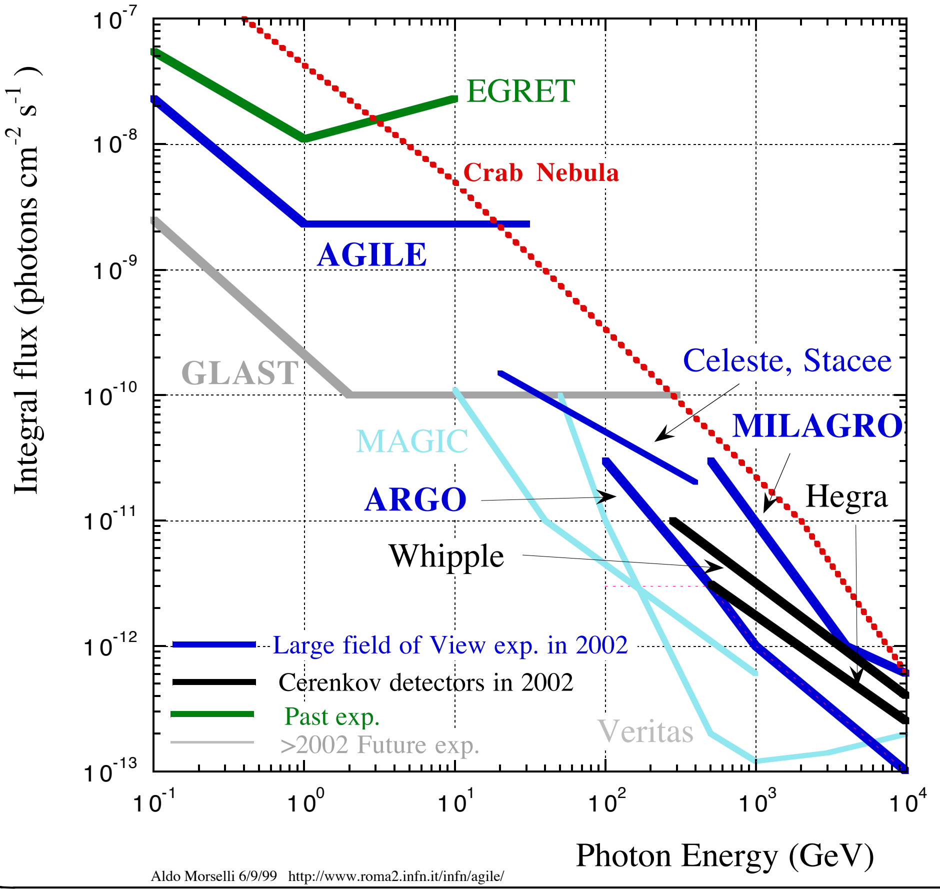
16 $X_0$ Yanbajiging

$$\rho = \rho_0 \; h_0 \; e^{-h/h_0}$$

$$h_0 \sim 6.4 \; Km$$

$$\rho_0 \sim 161 \; g/(cm^2 Km)$$

# Sensitivity of γ-ray detectors in 2002



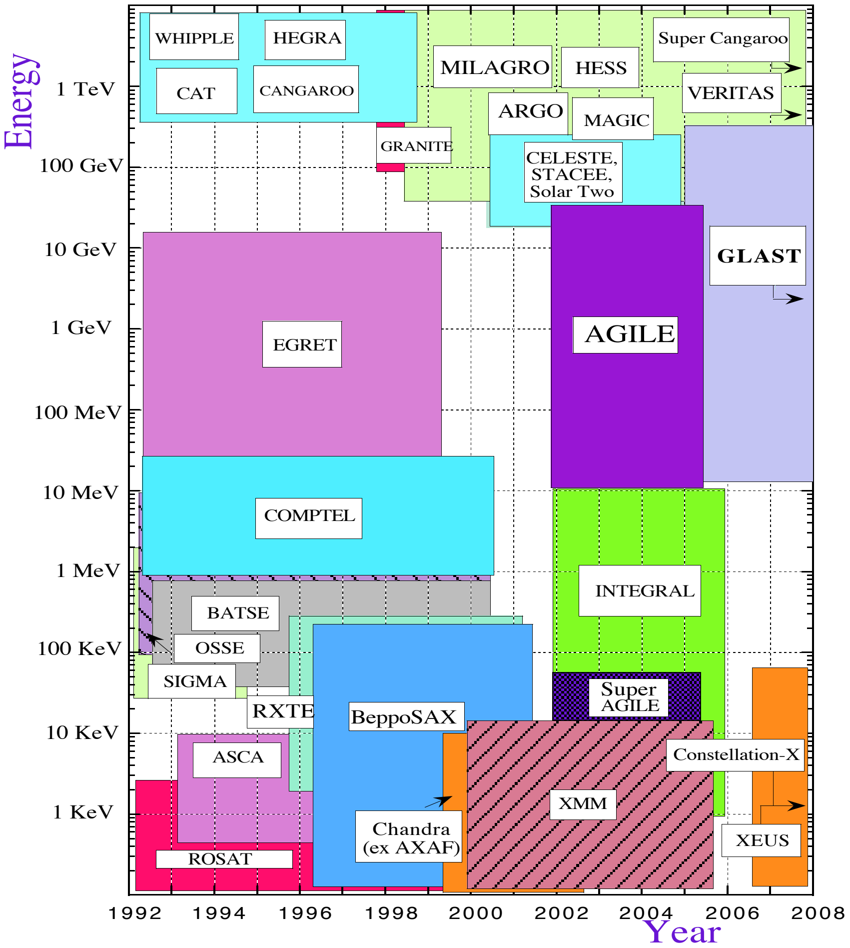
Aldo Morselli 6/9/99 http://www.roma2.infn.it/infn/agile/

All sensitivities are at 5σ.
Cerenkov telescopes sensitivities
(Veritas, MAGIC, Whipple, Hess, Celeste, Stacee, Hegra)
are for 50 hours of observations.
Large field of view detectors sensitivities
(AGILE, GLAST, Milagro,ARGO
are for 1 year of observation.

MAGIC sensitivity based on the availability of high efficiency PMT's

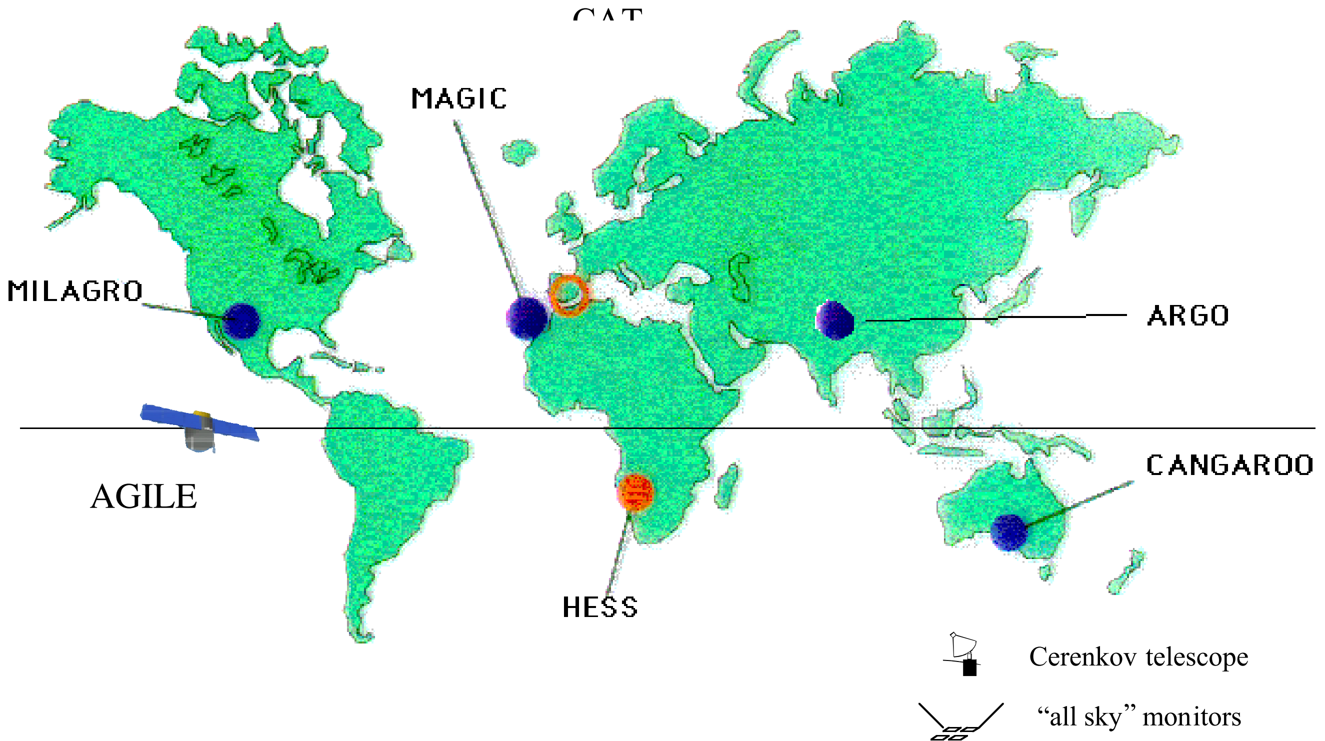
---

# Energy versus time For X and Gamma ray detectors



Aldo Morselli 6/9/99 http://www.roma2.infn.it/infn/agile/

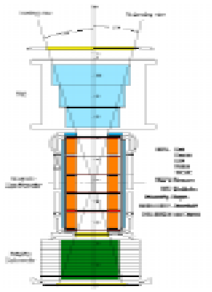
# Sky coverage of “all sky “ and Cerenkov telescopes in 2001



---

# Cosmic Ray Physics with charged particles:

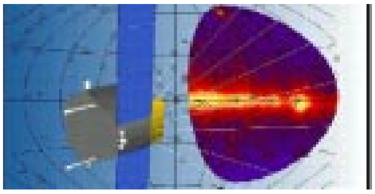
- Study of the origin and propagation of cosmic rays using sample of galactic and extragalactic material.
- Test of cosmological models
- Search for dark matter and supersymmetry



# Cosmic Ray Physics with photons:

- Study of the origin of cosmic rays by looking one by one the sources of cosmic rays
- Test of cosmological models
- Test of galaxies formation models
- Search for dark matter and supersymmetry
- Complementary with gravitational waves detectors

# Conclusion:



- AGILE will provide transient quicklook alert for all the Cerenkov telescope that will operate from 2002: MAGIC, Whipple, Hess, Celeste, Stacee, Hegra...
- AGILE will make simultaneous observations together with the ground “all-sky monitors” like MILAGRO and ARGO.
- for the first time there will be the possibility to “fill the gap” between space and ground !