Particle Physics with Space Detectors

Aldo Morselli

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

Corso di Astroparticelle
Anno 2003-2004

Roma, 18 Marzo 2004
Cosa si vuole studiare?

• Cielo nei raggi gamma
• Antimateria nell'Universo
• Brillamenti e tempeste solari
• ........

Come?
Gamma ray attenuation

Rockets & Satellites

Balloons

Airplanes

Mountain-top Observatories

Sea level

Radio  Microwave  Infrared  UV  X-rays  Gamma-rays

Visible Light
Gamma ray attenuation (2)

Relation between the temperature of a black body and the frequency at which most of the energy is emitted.

Transparency of the atmosphere for radiation of different wavelengths. The solid line shows the height above sea-level at which the atmosphere becomes transparent.
COMPTON OBSERVATORY INSTRUMENTS

- COMPTEL
- EGRET
- BATSE
- OSSE

TWO OF EIGHT
EGRET: the detector

Energy range: 20 MeV - 30 GeV
Weight: 1820 Kg
Power: 160 W
Field of view: 0.5 sr
Dead Time: 100 ms
Effective Area (@1GeV) 1200 cm$^2$
Angular resolution 5.8° (@100MeV)

Sensitivity for point sources
0.1 GeV 5x10$^{-8}$
1 GeV 1x10$^{-8}$
10 GeV 2x10$^{-8}$
(ph cm$^{-2}$ s$^{-1}$)*

Aldo Morselli INFN, Se
A $\gamma$-ray which enters the top of the EGRET instrument will pass undetected through the large anticoincidence scintillator surrounding the spark chamber and has a probability 33% of converting into an electron-positron pair in one of the thin tantalum (Ta) sheets interleaved between the 28 closely spaced spark chambers in the upper portion of the instrument. Below the conversion stack are two 4 x 4 arrays of plastic scintillation detector tiles spaced 60 cm apart which register the passage of charged particles. If the time_of_flight delay indicates a downward moving particle which passed through a valid combination of upper and lower scintillator tiles, and the anticoincidence system has not been triggered by a charged particle, the track information is recorded digitally. In this manner, a three dimensional picture of the path of the electron-positron pair is measured. The energy deposition in the NaI(Tl) Total absorption Shower Counter (TASC) located directly below the lower array of plastic scintillators is used to estimate the photon energy.
Elements of a pair-conversion telescope

- photons materialize into matter-antimatter pairs: \( E_\gamma \rightarrow m_e c^2 + m_e c^2 \)

- electron and positron carry information about the direction, energy and polarization of the \( \gamma \)-ray
Interaction of electrons and photons with matter

Fractional energy loss for $e^+$ and $e^-$ in lead

\[ \frac{dE}{dx} \text{ Brems} = - \frac{E}{X_0} \quad \Rightarrow \quad E(x) = e^{-\frac{x}{X_0}} \]

Photon total cross sections

\[ \text{Prob. of Int.} = 1 - \exp\left(-\frac{7}{9} \frac{x}{X_0}\right) \]
\[
\theta_0 = \theta_{rms}^{plane} = \frac{1}{\sqrt{2}} \theta_{rms}^{space}
\]

\[
\theta_0 = \frac{13.6 \, MeV}{\beta c p} z \sqrt{x/X_0} \left[ 1 + 0.038 \ln \left( \frac{x}{X_0} \right) \right]
\]
The Deep Sky
EGRET All Sky Map (>100 MeV)

Cygnus Region

3C279

Vela

Geminga

Crab

LMC

PKS 0528+13

4

PSR B1706-44

PKS 0208-512

Cosmic Ray Interactions With ISM
Third EGRET Catalog

E > 100 MeV

- Active Galactic Nuclei
- Unidentified EGRET Sources
- Pulsars
- LMC
- Solar FLare
Binary system formed by a black hole and a companion star
a rotating black hole in an accretion disk
Models for High Energy Emission: A cartoon
2512 BATSE Gamma-Ray Bursts

Fluence, 50-300 keV (ergs cm$^{-2}$)
Astroparticelle:

Usare la fisica delle particelle per capire la struttura ed evoluzione dell'Universo (e/o viceversa)
What is the Universe made of?

M33 rotation curve

<table>
<thead>
<tr>
<th>R(kpc)</th>
<th>v (km/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>100</td>
</tr>
<tr>
<td>10</td>
<td>50</td>
</tr>
</tbody>
</table>

observed
expected from luminous disk
What is the Universe made of?

We know that there is dark matter, which is needed to explain the dynamics of stars in Galaxies and of galaxies in clusters. This dark matter does not interact with light, and we do not know which particles is made of.

- The peripheral stars of the galaxy M63 rotate around the center so fast that they would fly away in space without the presence of additional mass inside the galaxy. This is indirect evidence for the presence of dark matter.
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 $\Omega = \rho / \rho_{\text{crit}}$ is:

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

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

$$\Omega_{\text{halo}} \geq 0.1$$

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

$$\Omega_{\text{halo}} \approx 0.2 \div 0.3$$

from structure formation theories and analyses of the CMB:

$$\Omega_{\text{halo}} \geq 0.3$$

but from big bang nucleosynthesis and analyses of the CMB the Barionic matter cannot be more then:

$$0.03 \leq \Omega_{\text{B}} \leq 0.05$$

(astro-ph/0106035)

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.
What is the Universe made of?

Bright stars: 0.5%
Baryons (total): 4.4% ± 0.4%
Matter: 27% ± 4%
Cold Dark Matter: 22.6% ± 4%
Neutrinos: < 0.15%
Dark Energy: 73% ± 6%
h = 0.71 + 0.04 - 0.03
Candidates for Galactic Dark Matter

• Massive Compact Halo Objects (MACHOs)
  • Low (sub- solar) mass stars. Standard baryonic composition.
  • Use gravity microlensing to study.
  • Could possibly account for 25% to 50% of Galactic Dark Matter.

• Neutrinos
  • Small contribution if atmospheric neutrino results are correct, since $m_\nu < 1$eV.
  • Large scale galactic structure hard to reconcile with neutrino dominated dark matter

• Weakly Interacting Massive Particles (WIMPs)
  • Non- Standard Model particles, ie: supersymmetric neutralinos
  • Heavy (> 10GeV) neutrinos from extended gauge theories.
Supersymmetry

Particle $\leftrightarrow$ Sparticle

For unbroken supersymmetry they should be degenerate in mass

Sparticle have not be found at accelerators so far

Supersymmetry is broken

Supersymmetry breaking schemes:
1) gravity-mediated scenarios
2) Gauge mediated scenarios
3) Anomaly mediated scenarios
Andamento delle Costanti di Accoppiamento

Andamento delle costanti di accoppiamento in funzione dell'energia per il modello Standard delle particelle elementari e per il Minimo Modello Supersimmetrico Minimale
Neutralino WIMPs

Assume $\chi$ present in the galactic halo

- $\chi$ is its own antiparticle $\Rightarrow$ can annihilate in galactic halo producing gamma-rays, antiprotons, positrons….
- Antimatter not produced in large quantities through standard processes (secondary production through $p + p \rightarrow p + X$)
- So, any extra contribution from exotic sources ($\chi \chi$ annihilation) is an interesting signature
- ie: $\chi \chi \rightarrow p + X$
- Produced from (e. g.) $\chi \chi \rightarrow q / g /$ gauge boson / Higgs boson and subsequent decay and/ or hadronisation.
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 5 parameters are fixed:

- $M_{1/2}$ the mass parameter of supersymmetric partners of gauge fields (gauginos)
- $\mu$ the higgs mixing parameters that appears in the neutralino and chargino mass matrices
- $m_0$ the common mass for scalar fermions at the GUT scale
- $A$ the trilinear coupling in the Higgs sector
- $\tan \beta = \frac{v_2}{v_1} = \frac{<H_2>}{<H_1>}$ the ratio between the two vacuum expectation values of the Higgs fields
Limits on Supersymmetry already established

**LEP**
Experimental lower limit on the mass of the lightest neutralino assuming MSSM

(Minimal Standard Supersymmetric Model)

$M_\chi > 50$ GeV

\[ a) \mu < 0 \]
SuperSymmetric Dark Matter

Possible signature: 
Gamma Ray 
from Neutralino 
Annihilation

Annihilation at rest: 
bump around Neutralino mass

\( \phi_\gamma \)

Diffuse background

10 GeV 100 GeV

A= pseudoscalar 
\( \chi^\pm = \text{chargino} \) 
\( \chi^0 = \text{neutralino} \) 
H= Higgs boson
Total photon spectrum from the galactic center from $\chi\chi$ \textit{ann.} (6s)

Neutralino continuum gamma ray flux towards galactic centre - NFW model, $\Delta\Omega=10^{-3}$ sr

$\gamma$ lines

- Two-year scanning mode
- Infinite energy resolution
- With finite energy resolution

---

*Graph*:

- Background, $E^{-2.7}$
- 300 GeV neutralino added
- 50 GeV neutralino added

*Axes*:

- Photon energy [GeV]
- Number of Counts
- Energy (GeV)
HALO SUBSTRUCTURE


Milky Way

600 kpc
Contours of photons intensity in units of $10^{-5}$ ph cm$^{-2}$ sec$^{-1}$ sr$^{-1}$ for $E_\gamma>1$GeV, after subtraction of “best estimate of Galactic Diffuse model. Data indicates presence of a galactic halo (Dixon et al. 1998).
Search for the Nature of Dark Matter

- The EGRET team (Mayer-Hasselwander et al, 1998) have seen a convincing signal for a strong excess of emission from the galactic center, with \( I(E) \times E^2 \) peaking at \( \sim 2 \) GeV, and in an error circle of 0.2 degree radius including the position \( l = 0^\circ \) and \( b = 0^\circ \). In their paper it was speculated that among other possible causes, this excess could be due to the continuum \( \gamma \)-ray spectrum from Wimp annihilation. With the dramatically improved angular resolution and effective area of GLAST, this effect should become both more localized and pronounced if it is a Galactic Center phenomenon.

EGRET Map of Galactic Center Region
EGRET data & Susy models

Annihilation channel $b$-$b\bar{b}$
$M_\chi = 50$ GeV

$N_b = 1.82 \times 10^{21}$
$N_\chi = 8.51 \times 10^4$

Typical $N_\chi$ values:
- NFW: $N_\chi = 10^4$
- Moore: $N_\chi = 9 \times 10^6$
- Isotermal: $N_\chi = 3 \times 10^1$

~2 degrees around the galactic center
GLAST Expectation & Susy models

\[ N_b = 1.82 \times 10^{31} \]
\[ N_x = 8.51 \times 10^4 \]

\(~2\) degrees around the galactic center, 2 years data

Annihilation channel $W^+W^-$
\[ m_x = 80.3 \text{ GeV} \]

- Background (Galprop)
- WIMP annihilation (one example from DarkSusy)
- Total contribution
Differential yield
for each annihilation channel

WIMP mass=200GeV
Differential yield for $b\bar{b}$
Estimated reaches with GLAST

Minimal Supersymmetric Standard Model with: \( A_0 = 0, \mu > 0, m_+ = 174 \text{ GeV} \)

region where 
\[ 0.13 < \Omega_{\text{CDM}} h^2 < 1 \]

region where 
\[ 0.09 < \Omega_{\text{CDM}} h^2 < 0.13 \]

GLAST sensitivity (5 \( \sigma \)) for a neutralino density \( N_\chi \) of \( 10^4 \) in a \( \Delta \Omega = 10^{-5} \text{ sr} \) region around the galactic center.

Typical \( N_\chi \) values for \( \Delta \Omega = 10^{-5} \text{ sr} \):
- NFW: \( N_\chi = 10^4 \)
- Moore: \( N_\chi = 9 \times 10^6 \)
- Isotermal: \( N_\chi = 3 \times 10^4 \)

A.Cesarini, F.Fucito, A.Lionetto, A.Morselli, P.Ullio, astro-ph/0305075 v.2
Estimated reaches with GLAST

**Minimal Supersymmetric Standard Model with:**

- $A_0 = 0$, $\mu > 0$, $m_\tau = 174$ GeV

**region where**

$0.13 < \Omega_{CDM} h^2 < 1$

**region where**

$0.09 < \Omega_{CDM} h^2 < 0.13$

**GLAST sensitivity (5 $\sigma$) for a neutralino density $N_\chi$ of $10^4$ in a $\Delta\Omega = 10^{-5}$ sr region around the galactic center**

**Typical $N_\chi$ values for $\Delta\Omega = 10^{-5}$ sr:**

- NFW: $N_\chi = 10^4$
- Moore: $N_\chi = 9 \times 10^6$
- Isotermal: $N_\chi = 3 \times 10^1$

if GLAST do not see Supersymmetry

this region is excluded for a NFW halo

$\tan(\beta) = 55$, $\text{sign}(\mu) = +1$

$m_{h0} < 114.3$ GeV

Positron Ratio

- Background from normal secondary production
- Signal from ~ 300 GeV neutralino annihilations

- Caprice98 data from
  XXVI ICRC, OG.1.1.21, 1999
- Caprice94 data from
PAMELA POSITRONS expectation

Secondary production
'Leaky box model'
Secondary production
'Moskalenko + Strong model' without reacceleration

Primary production from $\chi\chi$ annihilation
$(m(\chi) = 336 \text{ GeV})$

Charge ratio $(e^+/e^+e^-)$ vs Energy (GeV)

- CAPRICE98
- AMS
- CAPRICE94
- HEAT94+95
- Clem et al. 1996
- TS93
- MASS89
- Golden et al. 1987
- Muller & Tang 1987
- Daugherty 1975
- Fansenlow 1969

PAMELA expectation for 3 years of operation

Primary production

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

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.

Background from normal secondary production

Signal from 964 GeV neutralino annihilations (astro-ph 9904086)

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

Data sources:
- Mass91 data from XXVI ICRC, OG.1.1.21, 1999
- AMS data : preliminary (astro-ph 9904086)
PAMELA: Cosmic-Ray Antiparticle Measurements: Antiprotons

Secondary production (upper and lower limits)
Simon et al.

Primary production from $\chi \chi$ annihilation ($m(\chi) = 964$ GeV)

Secondary production (CAPRICE94-based)
Bergström et al.
RaggiCosmici

Come?
MASS  Matter Antimatter Space Spectrometer
The TS93 and CAPRICE silicon-tungsten imaging calorimeter.
CAPRICE 94
Proton energy spectrum at the top of atmosphere
The helium energy spectrum at the top of atmosphere
SilEye on MIR Space Station
wizard.roma2.infn.it
The NINA instrument

A silicon wafer 6x6 cm², 380 µm thick with 16 strips, 3.6 mm wide in two orthogonal views X-Y

NINA 2 on MITA

Launch of NINA 1: 10/8/1998
Launch of NINA 2: 15/7/2000

More info: http://wizard.roma2.infn.it

Aldo Morselli INFN, Sezione di Roma 2 & Università di Roma Tor Vergata
PAMELA

Physics Objectives
♦ AntiProton spectrum : 80 MeV - 180 GeV
♦ Positron spectrum : 50 MeV - 200 GeV
♦ Search for Antinuclei
♦ $e^+ + e^-$ up to 1 TeV
♦ Multi TeV electrons
♦ Solar and Trapped Cosmic Rays
♦ Solar Energetic Particles
♦ Long Term Solar Modulation
♦ Radiation Belts Transient Phenomena

Bare Mass: 450 Kg
Total Mass: ~750 Kg
Power: 350 W
GF: 21 cm$^2$sr
MDR: 740 GV/c

RESURS-DK1 Satellite
Mass: 10500 Kg
Elliptical Orbit 70.4° incl.
300-600 Km altitude
Launch: December 2002
Mission Life > 3 Yr.
Launcher : Soyuz-TM
Pamela

Separating \( p \) from \( e^- \)

antiproton

positron

TOF : Time of Flight (S1)

TRD : Transition Radiation Detector

TOF : Time of Flight (S2)

Magnetic Spectrometer

TOF : Time of Flight (S2)

Silicon Calorimeter

S4 and Neutron detectors

Tracker(s)

Silicon Strip Detectors

1 m
Pamela

- **Protoni** 80 MeV - 700 GeV
- **Antiprotoni** 80 MeV - 190 GeV
- **Elettroni** 50 MeV - 2 TeV
- **Positroni** 50 MeV - 270 GeV
- **Nuclei** < 700 GeV/n
- **Limite per Antinuclei** 10^{-8}

- **Massa del rivelatore** 440 Kg
- **Potenza** 355 W
- **MDR** - 770 GV
**TRD**
- Threshold detector.
- 9 radiator planes (carbon fiber) and straws tubes (4mm diameter) filled with Xe-CO₂ mixture.
- e/p separation (E > 1 GeV/c) at level of 10⁻².

**Anticoincidence system**
- Defines tracker acceptance
- off-line or on-line veto
- Plastic scintillators + PMTs

**Si-W Calorimeter**
- Imaging Calorimeter: reconstructs shower profile.
- Si-X / W / Si-Y structure
- 22 W planes 16.3 X₀ / 0.6 l₀
- rejection power e⁺/p and p/e⁻ at level of 10⁻⁴ ~ 10⁻⁵
- Energy Resolution for e⁺ ΔE/E_{measured} < 5% (20-200 GeV)
- selftriggering
- G.F. ~ 470 cm² sr
- Electrons up to 2 TeV

**Time-of-flight**
- Level 1 trigger
- Albedo discrimination
- dE/dx (Z)
- particle identification (up to 1 GeV/c)
- Plastic scintillators + PMTs
- Time Resolution ~ 110 ps

**Si Tracker + magnet**
- Permanent magnet B=0.4T
- 6 planes double sided Si strips 300 µm thick
- Spatial resolution ~3µm
- MDR = 740 GV/c

**S4 and Neutron detectors**
- Extend the energy range for primary protons and electrons up to 10 TeV
- Plastic Scintillator. Trigger for neutron detector
- 36 ³He counters in a polyetilen moderator

**PAMELA DETECTOR**
- **TOF**
- **TRD**
- **TRK**
- **ANT**
- **CALO**
- **S4**
- **ND**
New Detector Technology

- **Silicon strip detector**

  Strip-shaped PN diode

  300-500 micron thick

  50-500 micron wide

  VLSI amplifier

  **Stable particle tracker that allows micron-level tracking of gamma-rays**

Well known technology in Particle Physics experiments. Used by our collaboration in balloon experiments (MASS, TS93, CAPRICE), on MIR Space Station (SilEye) and on satellite (NINA)
Silicon Strip Detector Principle

VLSI
Low-noise, Low-power Amplifier/Discriminator (S/N typically > 20)

- VLSI design for low noise and low power
- Amplifier/Discriminator with high signal-to-noise ratio

Diagram highlights:
- p⁺ Implant Strips at Ground
- Holes
- Al Strip Electrodes
- Electrons
- n⁺ Implant
- Al Backplane at ~+90V
- Depletion region: Charged particle produces ~32,000 electron/hole pairs.
- Coupling Cap
- 200 μm
- 400 μm

Aldo Morselli  INFN, Sezione di Roma 2 &  Università di Roma Tor Vergata
Detecting $\bar{p}$ with Pamela

10 GeV $e^-$

10 GeV $\bar{p}$
Calorimeter Response

10 GeV $\bar{p}$

10 GeV $e^-$
PAMELA Launch

The Resurs-DK1 satellite
Carrier rocket: SOYUZ

Expected Date of launch: end of 2004
Collisions of High Energy Cosmic Rays With the Interstellar Gas

Cosmic Rays Leaking Out of Antimatter Galaxies

Annihilation of Exotic Particles

Evaporation of Primordial Black Holes

PAMELA

ANTIPROTON
AMS-02 on Space Station
A TeV Detector in Space

Lancio: 2007
Durata: 3 anni

- Protoni fino ad alcuni TeV
- Antiprotoni fino a 200 GeV
- Elettroni fino al TeV
- Positroni fino a 200 GeV
- Nuclei fino ad alcuni TeV
- AntiNuclei fino al TeV
- $\gamma$ fino a 100 GeV
- Isotopi leggeri fino a 20 GeV

Based on

\[ \gamma + N \rightarrow (\rho, \omega, \phi) \rightarrow e^+e^- + N, \]
\[ p + N \rightarrow J (\rightarrow e^-e^+) + .... \]

\[ \frac{e^+e^-}{h^+h^-} < 10^{10} \]
\[ \frac{\Delta M}{M} = 2 \cdot 10^{-3} \]
Altezza: 320-390 Km
Inclinazione 51.7°
**AGILE**

**Super Agile Mask**

**Super Agile Silicon plane**

**AntiCoincidence**

Photomultipliers
Top: 0.5cm plastic scintillator
Lateral: 12 panels 0.6 cm

**Tracker**, 14 X/Y planes
W 0.07 X₀
X/Y plane, 121 mm pitch
distance between planes 1.6cm

**Calorimeter**

1.5 X₀ CsI Calorimeter
1.4*2*40 cm³ bars
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 X₀

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

1.5 X₀ CsI Calorimeter
1.4*2*40 cm³ bars

14 cm
25 cm
40 cm
**Aldo Morselli**

INFN,
Sezione di Roma 2
University of Rome Tor Vergata

74

SAS-2
11/1972-7/1973

Anti-Coincidence Dome
Spark Chamber
Trigger Telescope
Cerenkov Counter
Energy Calorimeter

**Cos-B**
8/1975-4/1982

**EGRET**

**AGILE**
2002-

ANTI-COINCIDENCE SCINTILLATION DOME
CLOSERLY SPACED SPARK CHAMBERS
WIDELY SPACED SPARK CHAMBERS
TIME OF FLIGHT COINCIDENCE SYSTEM
PRESSURE VESSEL
NaI (TI) ENERGY MEASUREMENT COUNTER
ELECTRONICS
GAS REPLENISHMENT SYSTEM
AGILE Silicon Tracker prototype ladder

5 8x8 cm**2 CANBERRA silicon detectors with 195um strip pitch. The detectors are mechanical samples. The mechanical assembly and bonding has been done by Mipot SPA. The procedure is as follows:
-> the detectors are aligned one at a time and glued head on with non conductive expoxy glue which is made to polimerize with an infrared lamp for 20 minutes.
AGILE Silicon Tracker prototype

Silicon wafer

TA1
AGILE Silicon Tracker beam test prototype
Three dimensional PSF as a function of photon energy for AGILE and EGRET.
GRB studies with AGILE

- Study of the initial impulsive phase: $\Delta t < 1$ ms
- Expected detection rate (above 50 MeV): 5-10 yr$^{-1}$

- Expected detection rate (above 50 MeV): 5-10 yr$^{-1}$
- Broad band spectral information: $\sim 200$ keV - 30 GeV
- Rapid communication of GRB quicklook results
More information on AGILE:

please visit us:

http://www.ifctr.mi.cnr.it/agile/
http://www.roma2.infn.it/infn/agile/
Gamma-Ray Large Area Space Telescope
Aldo Morselli  INFN, Sezione di Roma 2 & Università di Roma Tor Vergata

Gamma-Ray Large Area Space Telescope

4×4 array of towers

84 cm

1.68 m

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

Anticoincidence Shield
GLAST Instrument Description

- **General Characteristics:** imaging, wide field-of-view, pair-conversion telescope, backed by EM calorimetry using modern HEP technology:

  - energy range: 10 MeV to 300 GeV
  - energy resolution: 10%
  - effective area: > 8,000 cm\(^2\) (above 1 GeV)
  - field-of-view: ~2\(\pi\) sr
  - point source sensitivity: 2 \(\times\) \(10^{-9}\) ph cm\(^{-2}\) s\(^{-1}\) (@ 100 MeV)  
    \(10^{-10}\) ph cm\(^{-2}\) s\(^{-1}\) ( > 1 GeV)
  - source location determination: 30 arcsec - 5 arcmin
  - cosmic ray/\(\gamma\) rejection > 10\(^5\) to 1
EGRET (Spark Chamber) VS. GLAST (Silicon Strip Detector)

EGRET on Compton GRO (1991-2000)

GLAST Large Area Telescope (2006-2015)
Detector Technology: X-ray vs. Gamma-ray

**X-ray (0.5 - 10keV)**
- Focusing possible
- Large effective area
- Excellent energy resolution
- Very low background
- Narrow view

**Gamma-ray (0.1-500GeV)**
- No focusing possible
- Wide field of view
- Limited effective area
- Moderate energy resolution
- High background
GLAST Large Area Telescope (LAT) Design

**Instrument**

Pair-conversion telescope

16 towers ⇒ modularity

height/width = 0.4 ⇒ large field-of-view

**Tracker Modules**

Si-strip detectors: fine pitch: 236 µm, high efficiency

12 **front** tracking planes (x,y): 0.45 $X_o$

reduce multiple scattering

4 **back** tracking planes (x,y): 1.0 $X_o$

increase sensitivity > 1 GeV

One of 18 Tracker trays (detectors top & bottom)
GLAST Large Area Telescope (LAT) Design

**Instrument**

Pair-conversion telescope
16 towers ⇒ modularity
height/width = 0.4 ⇒ large field-of-view

**Calorimeter Modules**

Hodoscopic Imaging Array of CsI crystals:
~ 8.5 rl depth
PIN photodiode readout from both ends:
2 ch/xtal x 80 xtals/mod = 2,560 ch

segmentation allows pattern recognition ("imaging") and leakage correction
GLAST Large Area Telescope (LAT) Design

**Instrument**

Pair-conversion telescope  
16 towers \(\Rightarrow\) modularity  
height/width = 0.4 \(\Rightarrow\) large field-of-view

**Anticoincidence Shield**

Segmented, plastic scintillator tile array:  
high efficiency, low-noise, hermetic;  
segment ACD sufficiently and  
only veto event if a track  
points to hit tile

ACD tile readout  
with Wavelength Shifting Fiber
GLAST Performance

Angular Resolution vs. Energy

Effective Area vs. Energy

Relative Area vs. Angle of Incidence

Energy Resolution vs. Energy
200 $\gamma$ bursts per year
$\Rightarrow$ prompt emission sampled to $>20$ $\mu$s

AGN flares $>2$ mn
$\Rightarrow$ time profile + $\Delta E/E$
$\Rightarrow$ physics of jets and acceleration

$\gamma$ bursts delayed emission
GLAST LAT Strength
- Continuous All-sky Monitoring -

EGRET Fluxes
- GRB940217 (100 sec)
- Solar Flare
- GRB940217 (1 orbit delayed)
- PKS 1622-297 Flare
- 3C279 Flare
- Vela Pulsar
- Crab Pulsar
- 3EG 2020+40 (SNR γ Cygni?)
- 3EG 1835+59

Flux Limit (cm$^{-2}$ s$^{-1}$)

1 orbit
GLAST LAT Strength
- New EGRET Catalog Every 2 days -

In scanning mode, the LAT will achieve after one day sensitivity sufficient to detect ($5\sigma$) the weakest EGRET sources

All 3EG sources + ~ 80 new in 2 days

⇒ periodicity searches (pulsars, X-ray binaries)
⇒ pulsar beam, emission vs. luminosity, age, B
One year All-Sky Survey Simulation, \( E_\gamma > 100 \) 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.
Active Galactic Nuclei (AGN) $\gamma$-ray emission:

Unanswered questions

• What are the “primary particle in the $\gamma$-ray emitting beam?
• How are particles accelerated
  ….. And where ?
• What is the highest energy the particles are accelerated to ?
  ( TeV - $10^7$ - $10^8$ TeV ?? )
• What causes AGN $\gamma$-ray flares?
Flux absorption due to the interaction with the infrared and microwave background

\[ \sqrt{2\omega_1 \omega_2 (1 - \cos \theta)} \geq 2m_e \]

if the center of mass energy is:

- photons interactions produce electron positron pairs

\[ \gamma \text{ ray source} \]

Microwave and infrared background

Earth

\[ \gamma \]

\[ e^+ \]

\[ e^- \]
Flux absorption due to the interaction with the infrared and microwave background \( (2) \)

The cross section of the process \( \gamma\gamma \rightarrow e^+e^- \) is:

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

where \( r_e \) is the classical radius of the electron and:

\[
\nu = \sqrt{1 - \frac{4m_e^2}{2\omega_1\omega_2(1 - \cos \vartheta)}}
\]

\( \omega_1 \) 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 \(3\)

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

\[
\frac{I(L)}{I_0} = \exp(-k_{\gamma} L)
\]

where \(k_{\gamma}\) is the absorption coefficient:

\[
k_{\gamma} = \frac{1}{2} \int_0^\infty \int_0^{\pi} \frac{d n_{\gamma}}{d \omega_1} \sigma_{\gamma\gamma} \sin \theta \, d\theta \, d\omega_1
\]

that contains the cross section and the low energy photon distribution.

For the microwave spectrum:

\[
\frac{d n_{\gamma}}{d \omega_1} = \frac{1}{\hbar^3 c^3 \pi^2} \frac{\omega_1^2}{\exp(\omega_1/kT) - 1}
\]
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.
Transparency of the Universe

Super Cluster
Virgo Cluster  60mly, 18mpc
Andromeda
(700 kpc, 2.9Mly)
LMC
(50 kpc, 179kly)
Our galaxy

Distance (mpc)

10^0
10^1
10^2
10^3
10^4
10^5

100 GeV
10 TeV

E(eV)

10^{10}
10^{12}
10^{14}
10^{16}
10^{18}
10^{20}
10^{22}
10^{24}

2.7 k

IR

radio

pγ → e^+ e^-
pγ → π^+ π^-

γγ → e^+ e^-

Z~0.03 ~2 × 10^{26} cm (Mrk521)
Z~0.53, 2C279
Z~1 ~ 2 × 10^{28} cm

Andromeda (700 kpc, 2.9Mly)
LMC (50 kpc, 179kly)
Our galaxy

Virgo Cluster 60mly, 18mpc
Flux absorption due to the interaction with the infrared and microwave background

an example on 3C279:
- fixed background
- different values of the Hubble constant
GRB studies with GLAST

EGRET observed delayed GeV emission from the GRB of February 17, 1994, including a 20 GeV photon that arrived 80 minutes after the burst began. GLAST will make the definitive measurements of the high-energy behaviour of GRBs and GRB afterglows.
GRB studies with GLAST (2)

- Study of the initial impulsive phase: Δt < 1 ms
- Expected detection rate (above 50 MeV): 50-100 yr⁻¹

- Broad band spectral information: ~ 200 keV - 30 GeV
- Rapid (few seconds) communication of GRB quicklook results
- Single γ angular resolution ~10 arcmin at high energies for good source localization.
Gamma -ray mission deadtime

Aldo Morselli  INFN, Sezione di Roma 2 & Università di Roma Tor Vergata
Test of Quantum Gravity

Candidate effect:

\[ c^2 P^2 = E^2 \left( 1 + f\left( \frac{E}{E_{QG}} \right) \right) \]

\( E = \) photon energy \hspace{1cm} \( E_{QG} = \) 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

\[ c^2 P^2 = E^2 \left( 1 + \alpha \left( \frac{E}{E_{QG}} \right) + O\left( \frac{E}{E_{QG}} \right)^2 \right) \]

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

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

(analogous to propagation through an electromagnetic plasma)

Medium fluctuation at a scale of the order of \( L_p \sim 10^{-33} \text{ cm} \)

\[ \Delta t = \sim \alpha \frac{E}{E_{QG}} \frac{D}{c} \]
Test of Quantum Gravity (2)

\[ \Delta t = \sim \alpha \frac{E}{E_{QG}} D/c \]

\[ \Delta t \sim 60 \Delta E(\text{GeV}) \]

\[ D \sim 2 \times 10^{28} \text{ cm} \quad E_{QG} \sim 10^{19} \text{ GeV} \quad c \sim 3 \times 10^{10} \text{ cm} \]

even at pulsars distance: \[ D \sim 6 \times 10^{21} \text{ cm} \quad \Delta t(\mu s) \sim 100 \quad E_{QG} \sim 10^{14} \text{ GeV} \]
Cerenkov and Extensive air shower (EAS) gamma ray telescope concepts

Cerenkov shower ~8.5km ~ 40,000 m², but no anticoincidence shield!

EAS

Optical detector

Particle detectors
Development of vertical 1-TeV proton and $\gamma$-ray shower

Proton $\gamma$-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 $\gamma$-ray shower

Proton shower
Whipple

10 m telescopes

E = >350 GeV

Location: Mt.Hopkins

in operation
“Solar Farm” Cerenkov gamma ray telescope concept

CELESTE
Location: Thémis, France

STACCEE
Location: Albuquerque

~40 m² mirror area
E = 20 GeV - 200 GeV
Schedule: in test
MAGIC
220 m² mirror area
E = 10 GeV - 300 GeV
Location: La Palma
(Canary Islands)
Scheduled June 2004
Veritas

7 Whipple like 10 m telescopes
$E = 50 \text{ GeV} - 50 \text{TeV}$
Location: southern Arizona
Scheduled 2005?
HESS Phase 2

four 110m² telescopes
Field of view 5 deg
Detection capability at E > 40 GeV
Spectroscopy at E > 100 GeV
Location: Namibia
Scheduled 2004

Night-sky background light

(artistic composition) (not yet real ! )
MILAGRO

Area 5000 m$^2$
Field of view $\sim$ 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 $\sim$ 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
Test Carpet in Tibet

ARGO Test Carpet in Tibet

The detector structure

Resistive electrode plates

Pick-up X strips

High voltage 8 kV

PVC Spacers

Pick-up Y strips

GRD

2 mm

GAS
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

\[ \rho = \rho_0 \cdot h_0 \cdot e^{-h/h_0} \]

\[ h_0 \sim 6.4 \text{ Km} \]

\[ \rho_0 \sim 161 \text{ g/(cm}^2 \text{ Km)} \]

16 X₀ Yanbajiging
Sky coverage of “all sky“ and Cerenkov telescopes in 2002
High galactic latitudes ($\Phi_b = 2 \times 10^{-5} \frac{\gamma}{cm^2 s \ sr} (100 \ MeV/E)$). 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, AMS) are for 1 year of observation.
X and Gamma-ray detectors

- WHIPPLE, HEGRA, CAT, CANGAROO
- MILAGRO, ARGO, MAGIC
- HESS, CANGAROO
- CELESTE, STACCE, Solar Two
- VERITAS, GLAST
- AGILE
- GLAST GRB Monitor
- INTEGRAL
- Super AGILE
- Constellation-X
- XEUS

Energy
- 100 keV
- 10 MeV
- 1 GeV
- 10 GeV
- 100 MeV
- 100 GeV
- 1 TeV

Year
- 1992
- 1994
- 1996
- 1998
- 2000
- 2002
- 2004
- 2006
- 2008
- 2010
- 2012

INFN ground based
INFN-ASI Space borne
Gamma-Ray Astronomy Long Term Plan

Ultimate Objective: To image the particle accelerator near the event

GLAST

<table>
<thead>
<tr>
<th>Year</th>
<th>Energy resolution</th>
<th>Angular resolution</th>
<th>Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>$10^{-10}$ cm$^{-2}$ s$^{-1}$</td>
<td>5 arc min</td>
<td>5 %</td>
</tr>
<tr>
<td>2015</td>
<td>$10^{-12}$ cm$^{-2}$ s$^{-1}$</td>
<td>10 arc sec</td>
<td>1%</td>
</tr>
<tr>
<td>2025</td>
<td>$10^{-14}$ cm$^{-2}$ s$^{-1}$</td>
<td>0.03 arc sec</td>
<td>?</td>
</tr>
</tbody>
</table>

Aldo Morselli  INFN, Sezione di Roma 2 & Università di Roma Tor Vergata
Cosmic rays: about 10 Myears in the Galaxy (6-7 g/cm²)

Atmosphere
40 km
23 Xo

High Montain Detectors
Cherencov Detectors
Particle Accelerators

Space experiments ~ 400 km
Balloons ~ 40 km
~3 g/cm² residual atmosphere
Extensive Air Shower Detectors

Particle Astrophysics Experiments
Underground, Under-ice, Underwater

Source
{ creation acceleration injection

Further acceleration?

Propagation

Modulation

Particle Astrophysics Experiments
L’immagine seguente è stata usata per studiare i livelli di stress al CNR.
Guarda i due delfini che saltano fuori dall’acqua. I due delfini sono identici. I ricercatori che hanno condotto lo studio sono giunti alla conclusione che una persona è ad un livello di stress troppo elevato se trova che i due delfini sono differenti. Il livello di stress è proporzionale alla quantità di differenze trovate, per cui più i due delfini sembrano differenti, più è elevato il livello di stress. Se vedete molte differenze tra i due delfini, siete consigliati di smettere subito di studiare e fare immediatamente qualcosa di piacevole.