GLAST and the future of High Energy Gamma-ray astrophysics
Why study $\gamma$’s?

- $\gamma$ rays offer a direct view into Nature’s largest accelerators.
- the Universe is mainly transparent to $\gamma$ rays with $< 20$ GeV that can probe cosmological volumes. Any opacity is energy-dependent for higher energy.
- Most particle relics of the early universe produce $\gamma$ rays when they annihiolate or decay.

Two GLAST instruments:
LAT: 20 MeV $\rightarrow$ 300 GeV
GBM: 10 keV $\rightarrow$ 30 MeV
Launch: December 2007
5-year mission (10-year goal)
LEO @ 550km, $\sim 26^\circ$
Overview of LAT

- **Precision Si-strip Tracker (TKR)** ~80 m² Si, 18 XY tracking planes. Single-sided silicon strip detectors (228 µm pitch)
  Measure the photon direction; gamma ID.

- **Hodoscopic CsI Calorimeter (CAL)**
  Array of 1536 CsI(Tl) crystals in 8 layers. Measure the photon energy; image the shower.

- **Segmented Anticoincidence Detector (ACD)**
  89 plastic scintillator tiles and 8 ribbons. Reject background of charged cosmic rays; segmentation removes self-veto effects at high energy.

- **Electronics System**
  Includes flexible, robust hardware trigger and software filters in flight software.

**Systems work together to identify and measure the flux of cosmic gamma rays with energy 20 MeV - >300 GeV.**
Gamma-Ray Large Area Space Telescope

GLAST Scheme
The GLAST Participating Institutions

American Institutions
- SU-HEPL Stanford University, Hanson Experimental Physics Laboratory
- SU-SLAC Stanford Linear Accelerator Center, Particle Astrophysics group
- GSFC-NASA-LHEA Goddard Space Flight Center, Laboratory for High Energy Astrophysics
- NRL - U. S. Naval Research Laboratory, E. O. Hulburt Center for Space Research, X-ray and gamma-ray branches
- UCSC- SCIPP University of California at Santa Cruz, Santa Cruz Institute of Particle Physics
- SSU- California State University at Sonoma, Department of Physics & Astronomy
- WUStL- Washington University, St. Louis
- UW- University of Washington
- TAMUK- Texas A&M University-Kingsville

Italian Institutions
- INFN - Istituto Nazionale di Fisica Nucleare and Univ. of Bari, Padova, Perugia, Pisa, Roma2, Trieste, Udine
- ASI - Italian Space Agency
- IASF- Milano, Roma

Japanese Institutions
- University of Tokyo
- ICRR - Institute for Cosmic-Ray Research
- ISAS- Institute for Space and Astronautical Science
- Hiroshima University

French Institutions
- CEA/DAPNIA Commissariat à l’Energie Atomique, Département d'Astrophysique, de physique des Particules, de physique Nuclaire et de l'Instrumentation Associée, CEA, Saclay
- IN2P3 Institut National de Physique Nucléaire et de Physique des Particules, IN2P3
- IN2P3/LPNHE-X Laboratoire de Physique Nucléaire des Hautes Energies de l'École Polytechnique
- IN2P3/PCC Laboratoire de Physique Corpusculaire et Cosmologie, Collège de France
- IN2P3/CENBG Centre d'études nucléaires de Bordeaux Gradignan
- IN2P3/LPTA Laboratoire de Physique Theorique et Astroparticules, Montpellier

Swedish Institutions
- KTHRoyal Institute of Technology
- Stockholms Universitet

Collaboration members: ~225
Members: 77
Affiliated Sci. ~80
Postdocs: 23
Graduate Students: 32

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12/16 Towers in the GRID on 7/10/05
16/16 Towers in the GRID on 20/10/05
The LAT Tracker numbers

11500 sensors
360 trays
~ 1M towers
83 m² Si surface
> 240K functional test recorded in DB
~ 30M strip tested
(30 test/strip on average)

> 60 physicist and engineers involved
in the italian teams from INFN (Trieste, Udine, Padova, Pisa, Perugia, Roma2, Bari) in partnership with ASI
Both the LAT and GBM were integrated to the Spacecraft at General Dynamics in Phoenix, Arizona.

the LAT and the NaI GBM modules mounted onto the spacecraft.
LAT MC Derived Performance

- Effective area/axis effective area vs. Inclination Angle (degrees)
- Angle for 68% containment vs. Energy (MeV)
- Area vs. Energy (MeV)
- Angle for 68% containment vs. Inclination Angle (degrees)

- thick+thin sections
- thick section
- thin section
Energy versus time for X and Gamma ray detectors

- WHIPPLE
- HEGRA
- CANGAROO
- MILAGRO
- HESS
- Cangaroo 3
- STACEE
- SolarTwo
- MAGIC
- VERITAS
- ARGO
- AMS
- GLAST
- AGILE
- GLAST GRB Monitor
- Constellation-X
- BeppoSAX
- HETE 2
- XMM
- Swift
- Super AGILE
- XEUS
- SIGMA
- RXTE
- ASCA
- ROSAT
- BATSE
- OSSE
- Chandra
- 1 TeV
- 100 GeV
- 10 GeV
- 1 GeV
- 100 MeV
- 10 MeV
- 1 MeV
- 100 KeV
- 10 KeV
- 1 KeV

Year

High galactic latitudes \( \Phi_b = 2 \times 10^{-5} \gamma \text{ cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1} (100 \text{ MeV/E}) \). 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.
GLAST LAT High Energy Capabilities

EGRET on CGRO firmly established the field of high-energy gamma-ray astrophysics and demonstrated the importance and potential of this energy band.

GLAST is the next great step beyond EGRET, providing a leap in capabilities:

- Very large Field of View (FOV) (~20% of sky), factor 4 greater than EGRET
- Broadband (4 decades in energy, including the essentially unexplored region E > 10 GeV)
- Unprecedented Point Spread function (PSF) for gamma rays (factor > 3 better than EGRET for E>1 GeV). On axis >10 GeV, 68% containment < 0.12 degrees (7.2 arc-minutes)
- Large effective area (factor > 5 better than EGRET)
- Results in factor > 30 improvement in sensitivity below < 10 GeV, and >100 at higher energies.
- Much smaller deadtime per event (27 µsec, factor ~4,000 better than EGRET - 0.1 s)
- No expendables ➔ long mission without degradation (5 year requirement, 10 year goal).
GLAST addresses a broad science menu of interest to both the High Energy Particle Physics and High Energy Astrophysics communities.

- Systems with (super-massive) black holes & relativistic jets
- Gamma-ray bursts (GRBs)
- Pulsars
- Origin of Cosmic Rays
- Probing the era of galaxy formation
- Discovery! Particle Dark Matter? Other relics from the Big Bang? Extra dimensions? New source classes?
Where should we look for WIMPs with GLAST?

- Galactic center
- Galactic satellites
- Galactic halo
- Extra-galactic
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EGRET data & Susy models

~2 degrees around the galactic center

Annihilation channel $W^+W^-$
$M_\chi = 80.3$ GeV

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

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

A.Morselli, A. Lionetto, A. Cesarini, F. Fucito, P. Ullio, astro-ph/0211327
Signal rate from Supersymmetry

gamma-ray flux from neutralino annihilation

\[ \phi(E, \Delta \Omega) \propto \left( \frac{\sigma v}{m_{\chi}^2} \right) \int_{l.o.s} \int_{\Delta \Omega} \rho^2(l) \, dl \, d\Omega \]

\[ J(\varphi) :\]

governed by supersymmetric parameters

governed by halo distribution
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GLAST
GLAST Expectation & Susy models

~2 degrees around the galactic center, 2 years data

Annihilation channel $W^+W^-$
$M_\chi = 80$ 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: $N_\chi = 3 \times 10^1$

EGRET, E $>$ 1GeV

Mayer-Hasselwander et al, 1998

Integral data
$2^0 \times 2^0$ field IBIS/ISGRI
20–40 keV
Point source location for GLAST ~ 5 arcmin

1 pixel ~ arcmin

2^0 x 2^0 field IBIS/ISGRI  20–40 keV
Point source location for GLAST ~ 5 arcmin

1 pixel ~ 5 arcmin

20° x 20° field IBIS/ISGRI 20–40 keV

20° x 20° field EGRET, E > 1 GeV

SLX 1744-299/300

A 1742-294

KS 1741-293

1E 1740.7-2942

GRS 1741.9-2853

Sgr A*
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 common mass of supersymmetric partners of gauge fields (gauginos)
- $m_0$ the common mass for scalar fermions at the GUT scale
- $\mu$ the higgs mixing parameters that appears in the neutralino and chargino mass matrices
- $A$ is the proportionality factor between the supersymmetry breaking trilinear couplings and the Yukawa couplings
- $\tan \beta = v_2 / v_1 = \langle H_2 \rangle / \langle H_1 \rangle$ the ratio between the two vacuum expectation values of the Higgs fields
Signal and Background are separated?

Signal and Background are separated?

tg(β) = 55, sign(µ) = +1
Signal and Background are separated?

- $\tan(\beta) = 55$, sign$(\mu) = +1$

- M$_{1/2}$ (GeV)

- $M_0$ (GeV)

- cMSSM

- no electroweak symmetry breaking
mSUGRA

Sensitivity plot for 5 years observation of mSUGRA for GLAST for $\tan(\beta)=55$.

GLAST $3\sigma$ sensitivity is shown at the blue line and below for truncated NFW halo profile.

GLAST limits

WMAP 3 $3\sigma$ allowed region

no electroweak symmetry breaking

$M_{1/2}$ (GeV)

$M_0$ (GeV)
Sensitivity plot for 5 years observation of mSUGRA for GLAST for $\tan(\beta) = 55$. GLAST $3\sigma$ sensitivity is shown at the blue line and below for truncated NFW halo profile.
SAFGRAL
Sensitivity plot for 5 years observation of mSUGRA for GLAST for $\tan(\beta)=55$ and for other experiments. GLAST $3\sigma$ sensitivity is shown at the blue line and below for truncated NFW halo profile.

accelerator limits @ $100 \text{ fb}^{-1}$ from H. Baer et al., hep-ph/0405210.
Sensitivity plot for observation of mSUGRA for a number of accelerator experiments and GLAST for $\tan(\beta)=10$. GLAST $3\sigma$ sensitivity is shown at the blue line and below a for truncated Navarro Frank and White (NFW) halo profile.
Sensitivity plot for observation of mSUGRA for GLAST for $\tan(\beta)=60$. GLAST $3\sigma$ sensitivity is shown at the blue line and below for a truncated NFW halo profile.

GLAST $3\sigma$ limits

WMAP $3\sigma$ allowed region

no electroweak symmetry breaking

5 years of data $\tan(\beta)=60$, sign($\mu$)=$+1$
Model independent results for the GC

- Assume a truncated NFW profile
- Assume a dominant annihilation channel (good assumption except for $\tau^+ \tau^-$)

Differential yield for each annihilation channel

WIMP mass=200GeV

Model independent results for the GC

5 years of operations, truncated NFW

\[ \left( \frac{dN}{dE} \right) \text{(eV cm}^{-2}\text{s}^{-1}) \]

above 3σ EGRET observation

detectable by GLAST
( conventional and optimized GALPROP models assumptions)

detectable by GLAST
( only for the conventional GALPROP model assumption)

Not detectable by GLAST

\[ a) \text{ channel } \bar{b}b \text{ at 3σ} \]

\[ m_{\text{wimp}} \text{ (GeV/c}^2) \]
Model independent results for the GC

5 years of operations, truncated NFW

\[ \langle v^2 \rangle (10^{-29} \text{ cm}^2 /\text{s}) \]

above 3 $\sigma$ EGRET observation

detectable by GLAST
(conventional and optimized GALPROP models assumptions)

Not detectable by the LAT

\[ m_{\text{wimp}} \text{ (GeV/c}^2\text{)} \]

a) channel $t \bar{t}$ at 3 $\sigma$, 5 years

b) channel $W^+W^-$ at 3 $\sigma$, 5 years

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Model independent results for the GC

5 years of operations, truncated NFW
Model independent results for the Sagittarius
GLAST Master Schedule

- August 2004
  Assembling of first tower completed

- Middle of October 2005
  Completion of the LAT - Environmental testing

- February 2006
  Delivery to NRL-

- 31 Jan. 2008
  Kennedy Space Flight Center

- June 2008
  Science operation begins!

more info: http://people.roma2.infn.it/glast/
Conclusion

GLAST launch is currently scheduled for May 16, 2008.

- Guest Investigator Program Proposals due September 9

http://glast.gsfc.nasa.gov/ssc/proposals/GI_Program_Background.html

SWIFT instrument launches on the same type rocket planned for GLAST
Through most of history, the cosmos has been viewed as eternally tranquil
During the 20th century the quest to broaden our view of the universe has shown us the vastness of the Universe and revealed violent cosmic phenomena and mysteries.
Exploring Nature’s Highest Energy Processes

- PAMELA
  June 2006
  Launched

- AGILE
  Apr. 2007
  Launched

- GLAST:
  May. 2008
  launch
Application to Mini-Spikes

Black Holes can be broadly classified in 3 categories, based on their mass:

- **Stellar Mass BHs**
  - Endpoint of stellar evolution
  - Indirectly observed
  - Robust evidence
  - Lower limits on mass from obs.

- **Intermediate Mass BHs**
  - Maybe form in Glob. clusters
  - Maybe observed as ULXs
  - Seed for SMBHs?
  - Likely to exist

- **Supermassive BHs**
  - Unknown origin
  - Ubiquitous!
  - Robust evidence
  - Mass correlated with host halo
IMBH mini-spikes observation prediction


Number of realizations

resolved sources

cutoff is observed

5 \sigma , 55 days

tenths of sources with no variability, no counter part and similar spectrum. Possible smoking gun?

159/200 simulated skymaps that do not violate EGRET limits
Conclusion

Discovery Potential for Supersymmetry

• GLAST will explore a good portion of the supersymmetric parameter space

• Search complementary to antimatter, LHC and Direct Search
add. slides
DM point sources in the sky for $m_\chi = 150$ GeV

for a 150 GeV mass we can estimate the mass of the DM particle with a precision of 25 GeV (10% @ 1TeV)


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GLAST sensitivity map for the detection of point sources of Dark Matter annihilation

minimum flux above 100 MeV, in units of [ph m\(^{-2}\) s\(^{-1}\) ]

DM particle with mass \(m_\chi = 150\) GeV annihilating into \(b\) bar, after a 2 months observation period


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GLAST sensitivity map for the identification of point sources of Dark Matter annihilation

minimum flux above 100 MeV, in units of \([\text{ph m}^{-2} \text{s}^{-1}]\)

DM particle with mass \(m_\chi = 150 \text{ GeV}\) annihilating into \(b\) bar, after a 2 months observation period


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how to discriminate a DM from a mere astrophysical origin of gamma-ray point sources?

• The GLAST LAT is expected to observe more than a hundred of Active Galactic Nuclei (AGNs) in ~ 2 months, some of which would, due to EBL attenuation, feature a spectral signature similar to that of DM annihilations. However, a population of DM sources would exhibit distinctive features that should allow to discriminate the from AGNs, such as the low energy spectral index of ~ 1.5 and the absence of variability.
Galactic Center

HESS Spectrum

Unbroken power-law.
- Hard spectrum $\Gamma = 2.2$.
- No evidence for variability on a variety of time scales.

Consistent with SGR A* to 6" and slightly extended.

Good agreement between HESS and MAGIC (large zenith angle observation).

astro-ph/0512469
it might still be that a DM component could be singled out, e.g. the EGRET source (?): a DM source can fit the EGRET data; GLAST would detect its spectral and angular signatures and identify without ambiguity such DM source!
**How the GLAST-LAT* telescope could help to disentangle the Dark Matter puzzle?**

<table>
<thead>
<tr>
<th>Search Technique</th>
<th>advantages</th>
<th>challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Galactic center</td>
<td>Good Statistics</td>
<td>Source confusion/Diffuse background</td>
</tr>
<tr>
<td>Satellites, Subhalos, Point Sources</td>
<td>Low background, Good source id</td>
<td>Low statistics</td>
</tr>
<tr>
<td>Milky Way halo</td>
<td>Large statistics</td>
<td>Galactic diffuse background</td>
</tr>
<tr>
<td>Extra-galactic</td>
<td>Large Statistics</td>
<td>Astrophysics, galactic diffuse background</td>
</tr>
<tr>
<td>Spectral lines</td>
<td>No astrophysical uncertainties, good source id</td>
<td>Low statistics</td>
</tr>
</tbody>
</table>

*See talk by J. McEnery and poster by J. Cohen-Tanugi*
Model independent results for the GC

Results for $\tau^+ \tau^-$ and $w^+ w^-$ dominant annihilation channel

Overproduce photons at 5$\sigma$ of EGRET data

Detectable by the LAT at 3$\sigma$ at least

Not detectable by the LAT at 3$\sigma$

Ambiguous DM signal seen by EGRET

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Model independent GLAST reach (5\(\sigma\))
NFW profile \(\pi^0\) background, bb annihilation channel

Overproduce photons at 5\(\sigma\) of EGRET data
Detectable by the LAT at 5\(\sigma\) at least
Not detectable by the LAT at 5\(\sigma\)
Ambiguous DM signal seen by EGRET