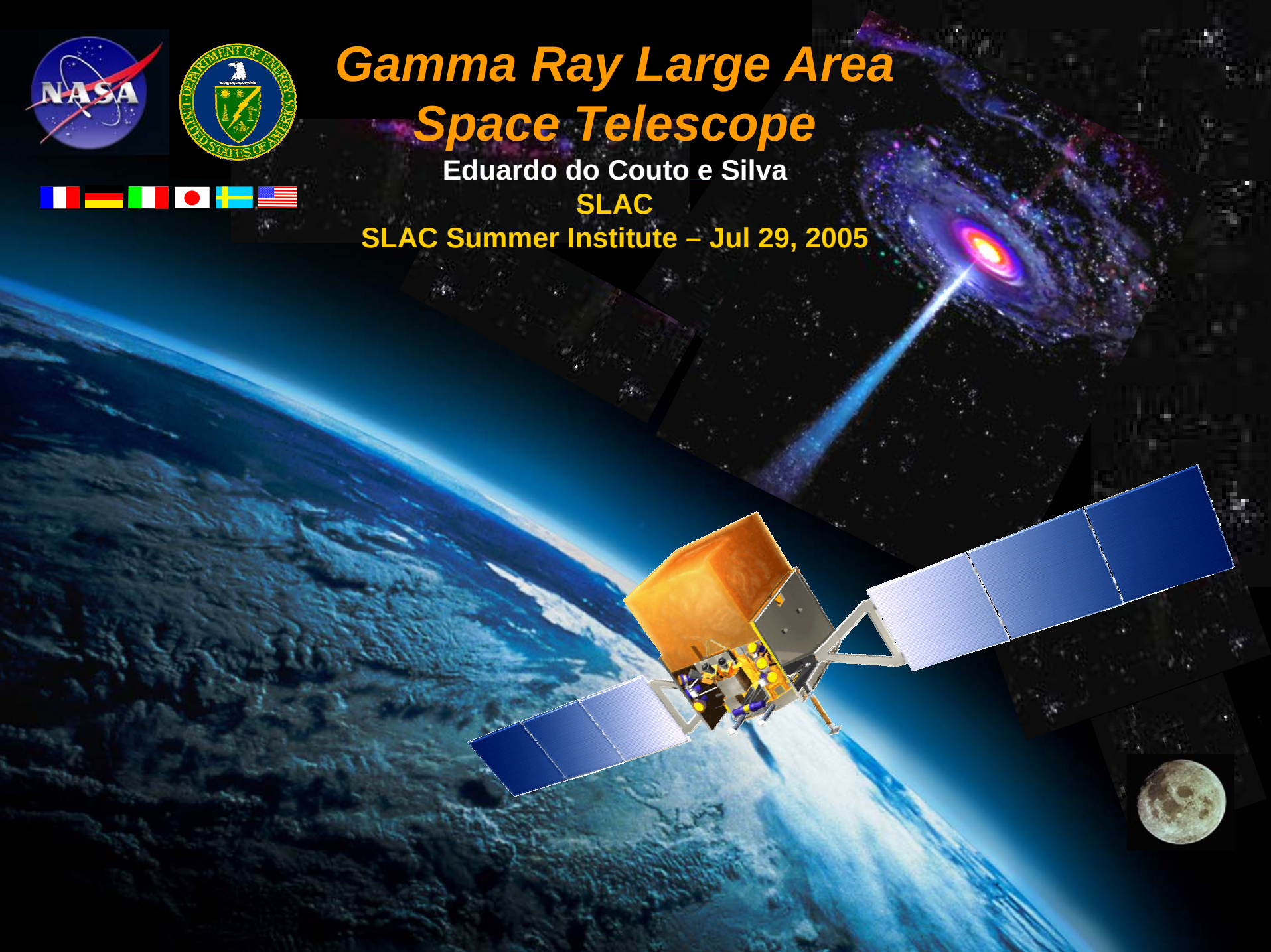
Gamma Ray Large Area Space Telescope

Eduardo do Couto e Silva
SLAC

SLAC Summer Institute – Jul 29, 2005



Outline

- Overview of the GLAST Observatory
  - Current status of two instruments (GBM and LAT)

- GLAST Science
  - Highlights of Instrument Capabilities
  - Selected Physics Topics
    - Particle Acceleration
      - » Active Galactic Nuclei
      - » Supernova Remnants
    - Diffuse γ Ray Emission
    - Dark Matter Searches and New Physics

- Timeline

GLAST Observatory : Overview

GLAST will measure the direction, energy and arrival time of celestial γ rays

Will follow on the measurements by its predecessor (EGRET) with unprecedented capabilities

Orbit
565 km, circular

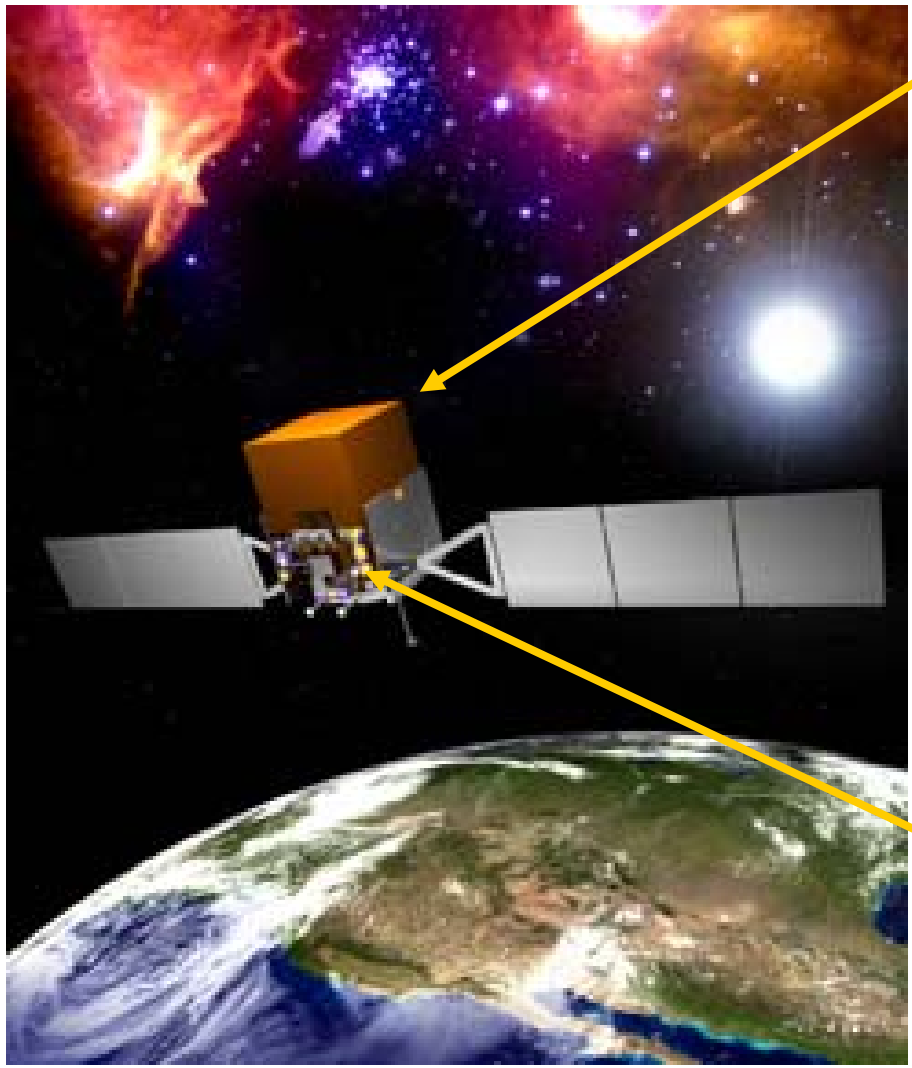
Inclination
28.5°

Lifetime
5 years (min)

Launch Date
Aug 2007

Launch Vehicle
Delta 2920H-10

Launch Site
Kennedy Space Center



LAT
will record gamma-rays in the energy range ~ 20 MeV to >300 GeV

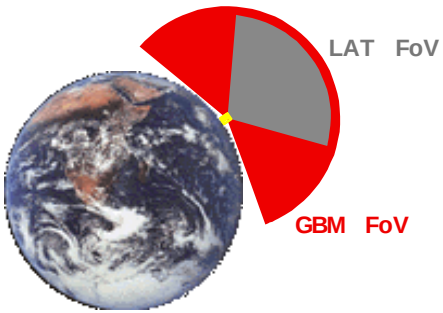
Observing modes
All sky survey
Pointed observations

Re-pointing Capabilities
Autonomous
Rapid slew speed
(75° in < 10 minutes)

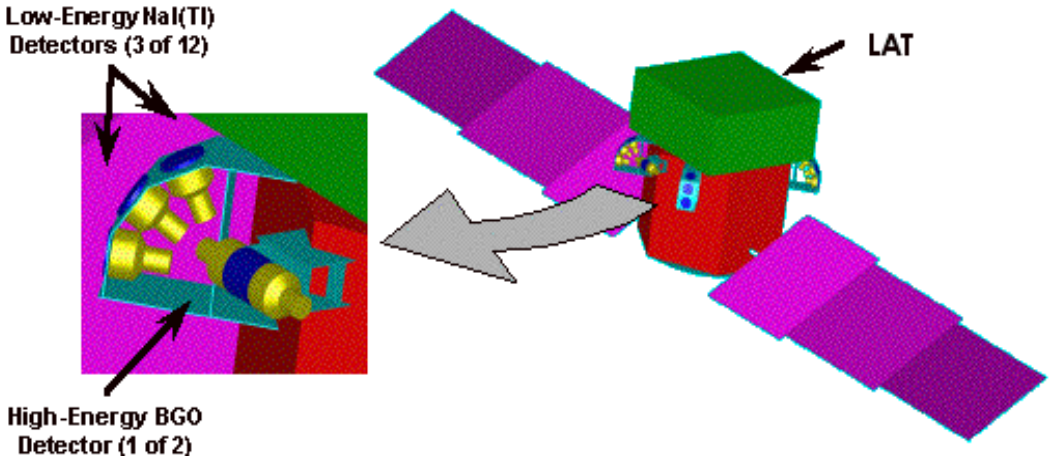
GBM
will provide correlative observations of transient events in the energy range ~10 keV – 25 MeV

GLAST Burst Monitor: Overview

NaI and BGO counters exposed to the entire sky



Principal Investigator: Charles Meegan



NaI crystals (12)

low-energy spectral coverage

~10 keV to ~1 MeV

rough burst locations

BGO crystals (2)

high-energy spectral coverage

~150 keV to ~30 MeV

GBM

10 keV to ~ 25 MeV

Correlative observations of transient phenomena

Spectral Measurements

measures spectra for bursts

connects with LAT measurements

Afterglows in Gamma Ray Bursts

Wide Sky Coverage (8 sr)

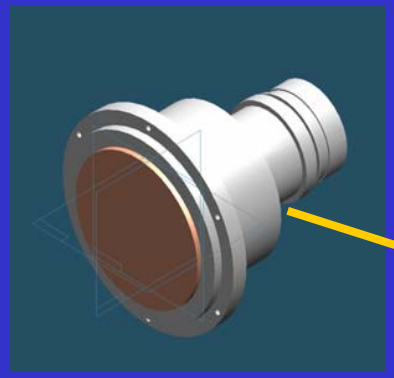
autonomous repoint for exceptionally bright bursts

that occur outside LAT field of view

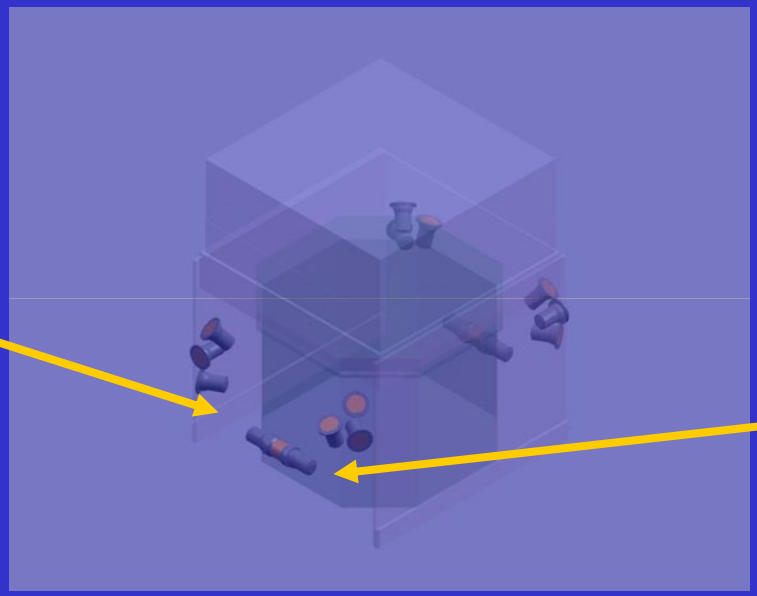
Connections to the Ground Network of Telescopes

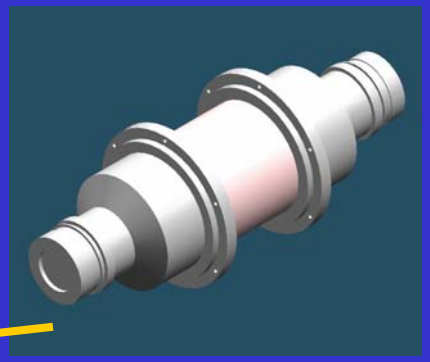
burst alerts to the LAT and ground telescopes within seconds

Current Status of GBM Assembly

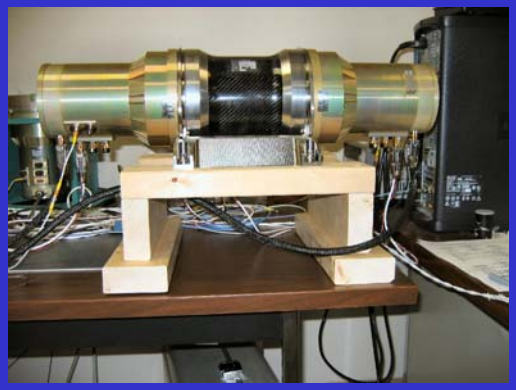


12 NaI modules





2 BGO modules



Environmental Tests
at Max Planck Institute

Large Area Telescope: Overview

Principal Investigator: Peter Michelson

The LAT is a pair-conversion telescope of 16 towers surrounded by plastic scintillators

Silicon Microstrip Tracker

~ 80 m² of silicon

8.8 x 10^5 readout channels

Strip pitch = 228 μm

xy layers interleaved with W converters

Total Rad length ~1.5 X^0

Calorimeter

Hodoscopic array

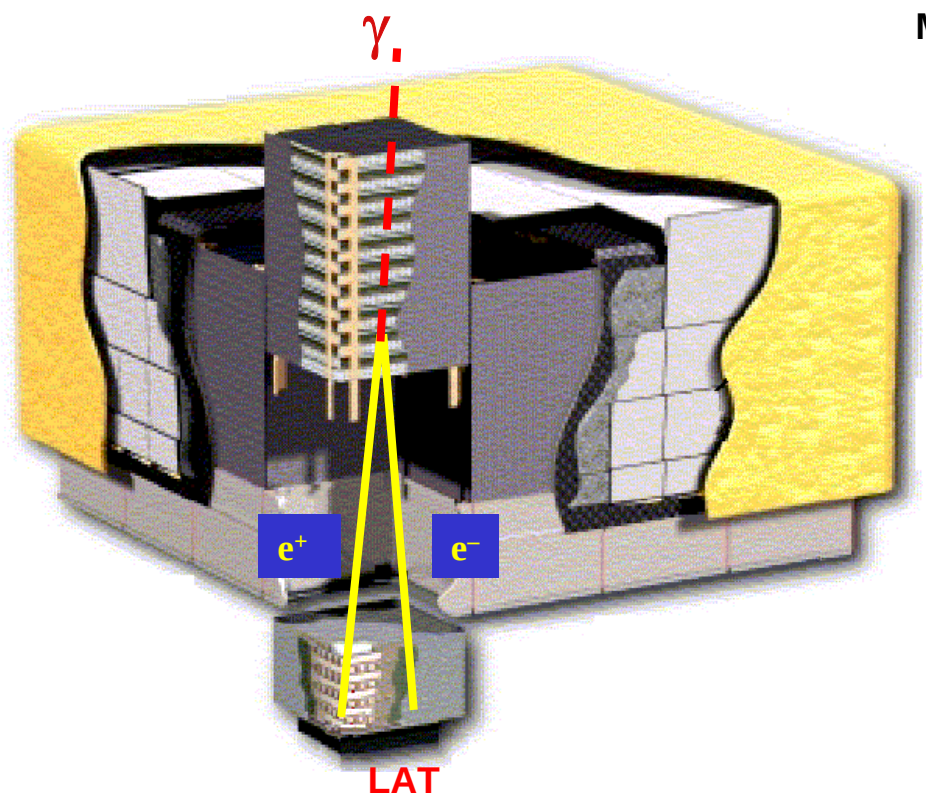
Array of 1536 CsI(Tl) crystals in 8 layers

Total Rad length ~8.5 X^0

Anti-Coincidence Detector

89 scintillator tiles

Segmented design



LAT

3000 kg, 650 W (allocation)

1.8 m × 1.8 m × 1.0 m

20 MeV – 300 GeV

Currently there is no other telescope covering this energy range

Silicon Microstrip Tracker

Measures γ direction

γ identification

Calorimeter

Measures γ energy

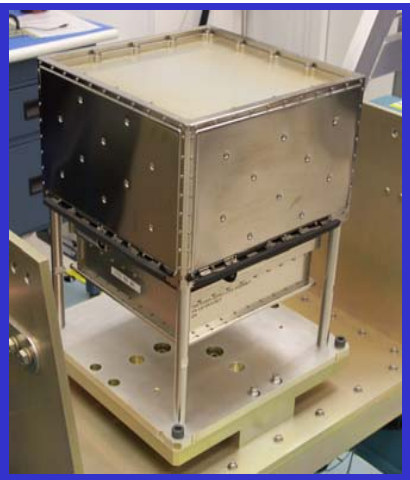
Shower imaging

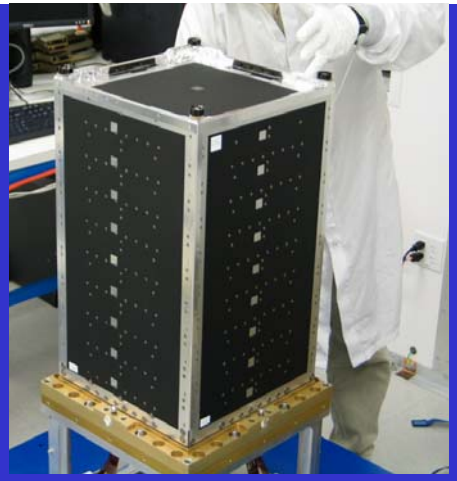
Anti-Coincidence Detector

Rejects background of charged cosmic rays

segmentation removes self-veto effects at high energy

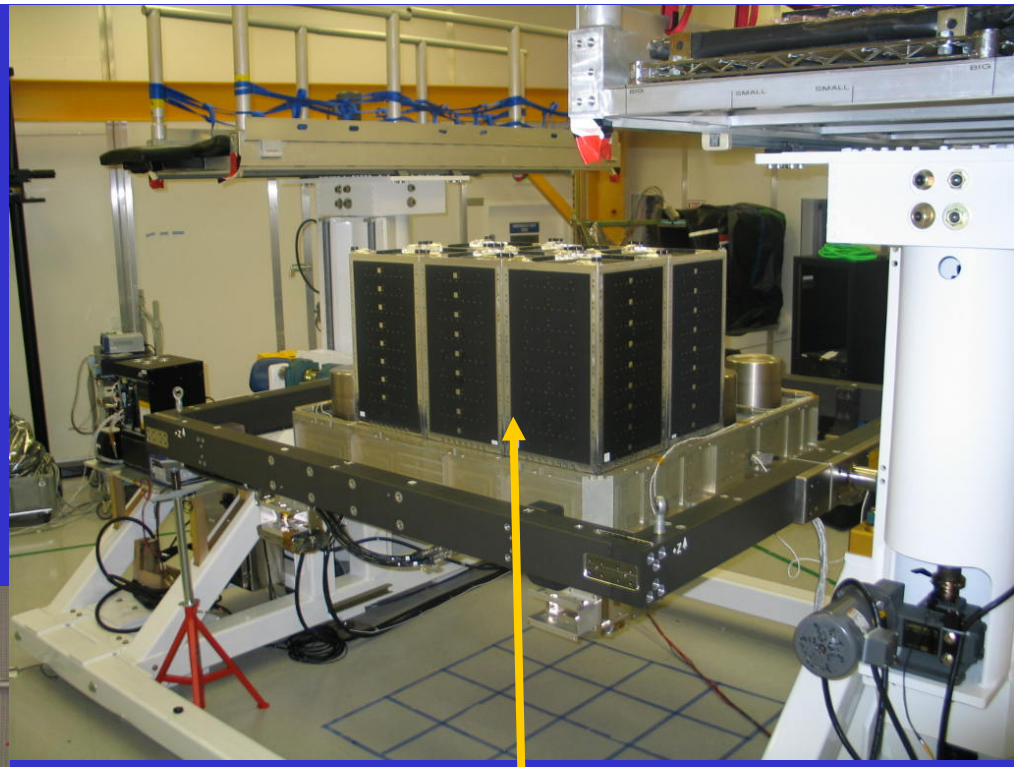
Current Status of LAT Assembly





18 CAL modules completed
16 CAL modules @ SLAC

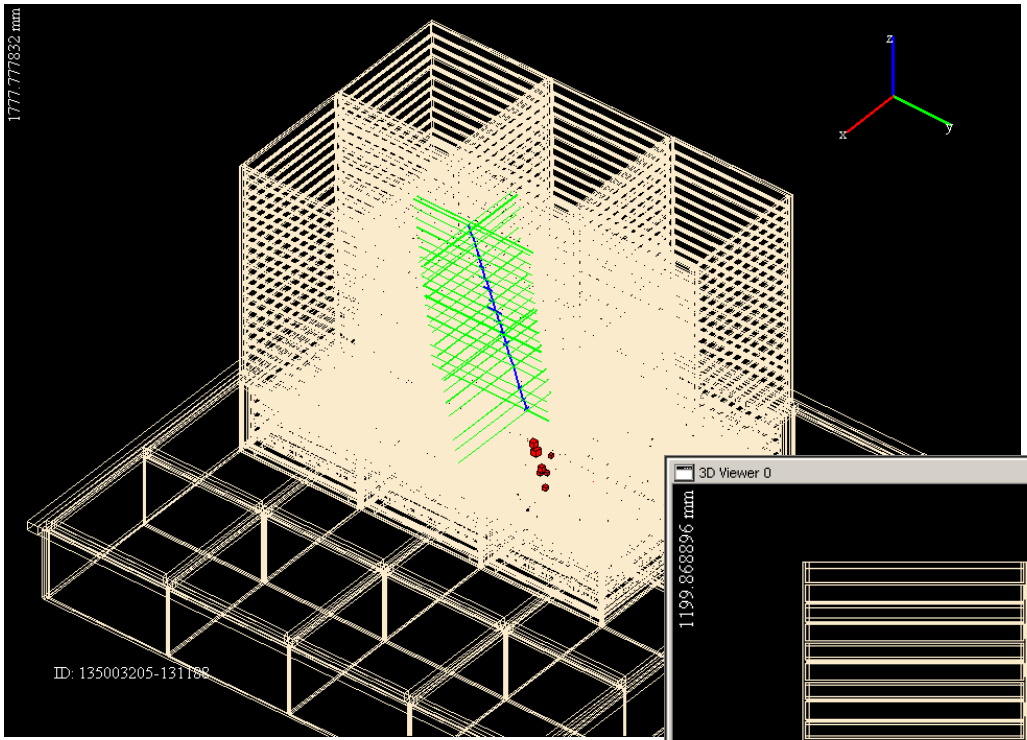
~80m^2 of silicon in hand.
8 TKR modules @ SLAC.



Six Towers in the flight grid

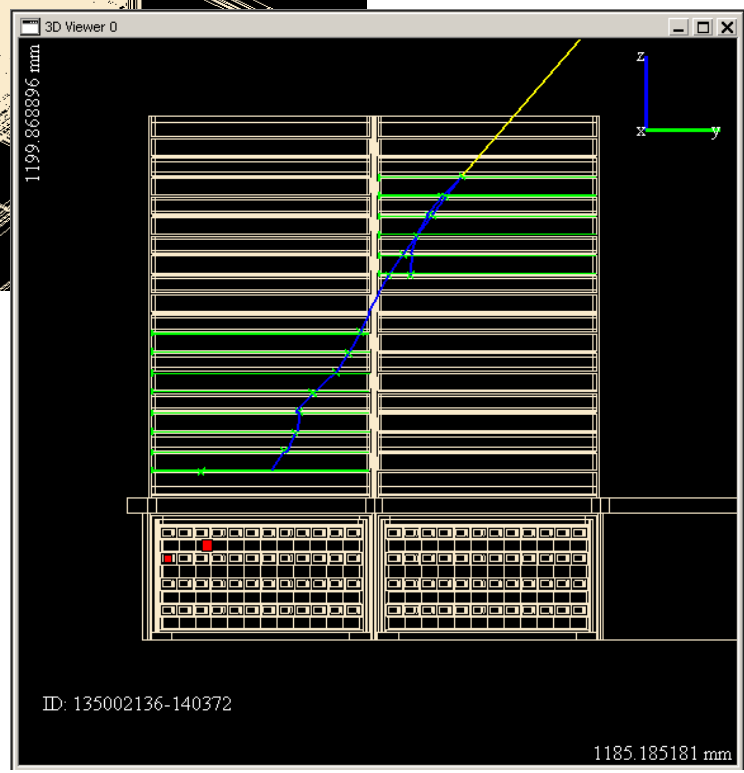
ACD completed and being tested at GSFC.
Delivery to SLAC scheduled for mid August

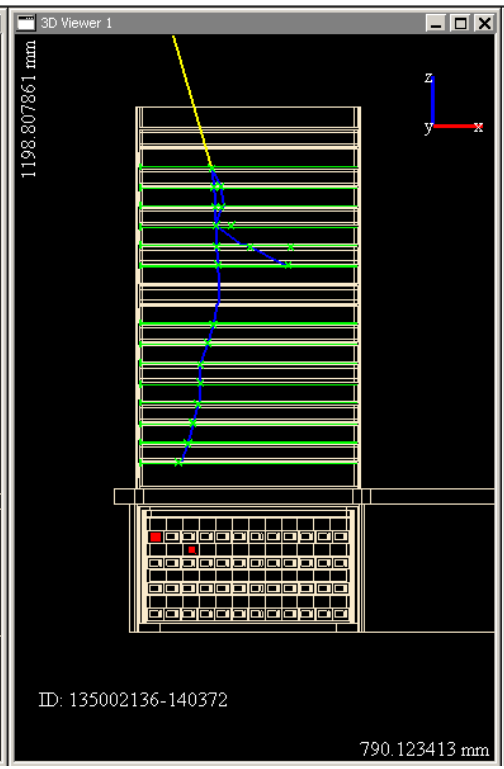
LAT Data from Tests at SLAC



Photon Candidates

10-20% of cosmic ray showers are not muons





Muon candidates

Most of the 200Hz of triggers recorded with 6 towers are muons

Science with GLAST

- High Energy Sky Survey :
  - Unidentified EGRET sources and GLAST Source Catalog
    - unresolved point sources
  - Population Studies
    - To avoid peculiarities of individual sources (AGN, Pulsars, SNR…)
  - Diffuse Gamma ray emission
    - Galactic and Extragalactic
  - Physics of particle acceleration
    - AGN jets
    - energy conversion
    - shocks in SNRs
    - role of hadrons in radiation processes

- High-energy behavior of transients :
  - Gamma Ray Bursts
  - Solar Flares

- Discovery Potential:
  - New classes of astrophysical objects
  - Origin of Extragalactic Background
  - Searches for Dark Matter and Extra Dimensions
  - Tests of Lorentz Invariance

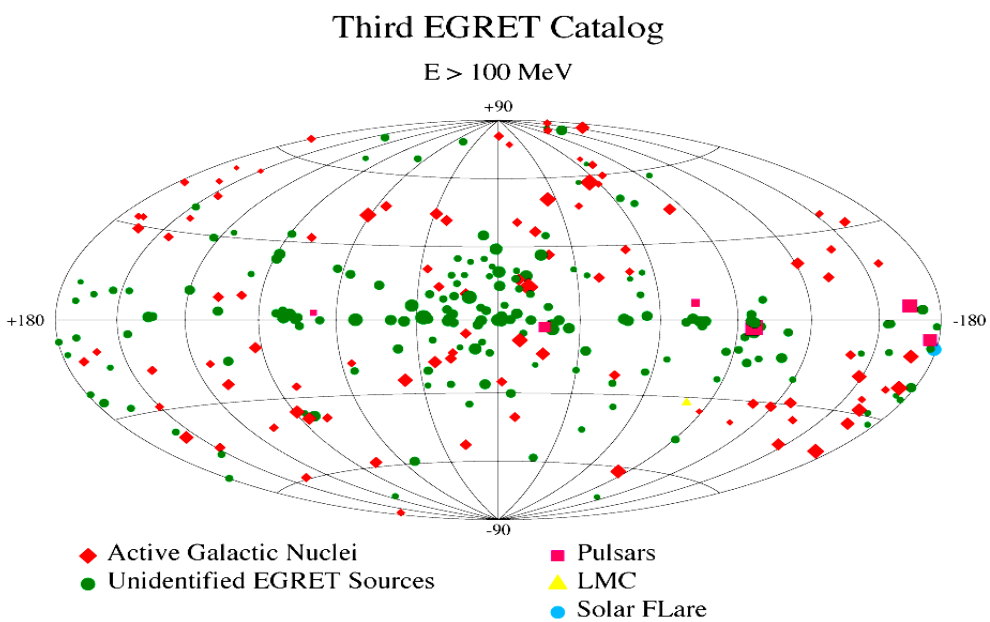
LAT strengths:

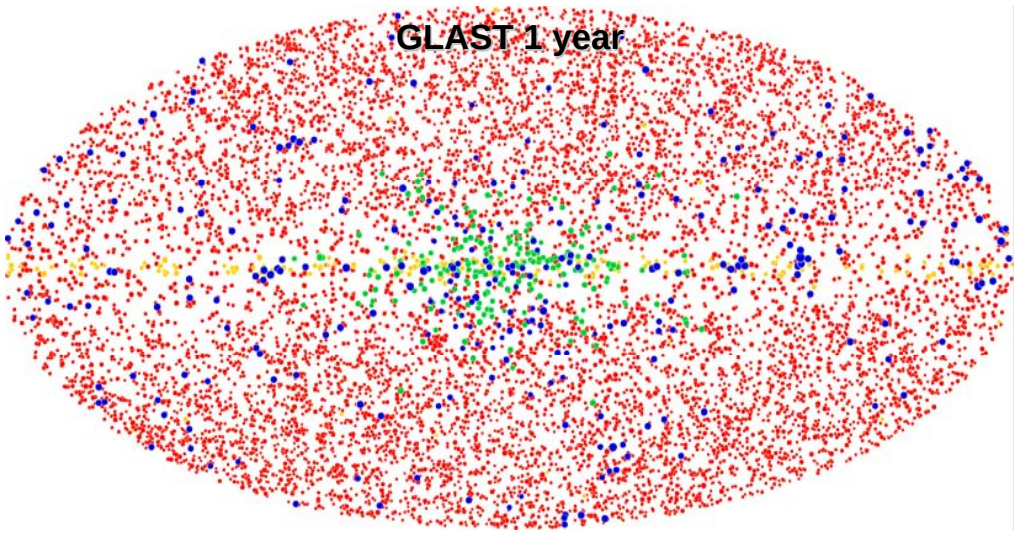
All-sky monitoring

Broad range of time scales

Energy range

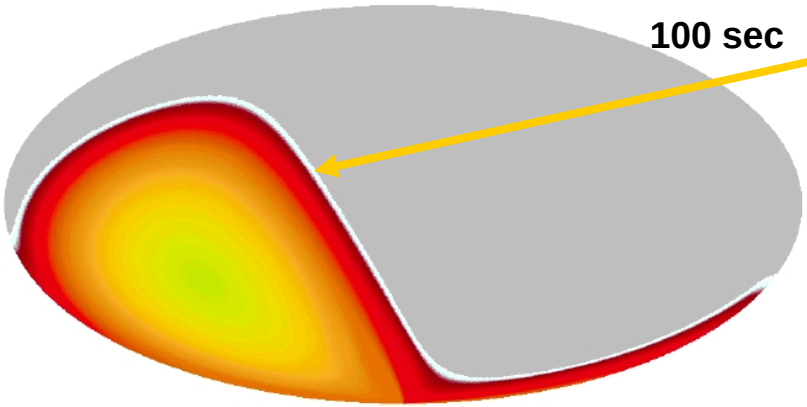
LAT will Rediscover the γ Ray Sky



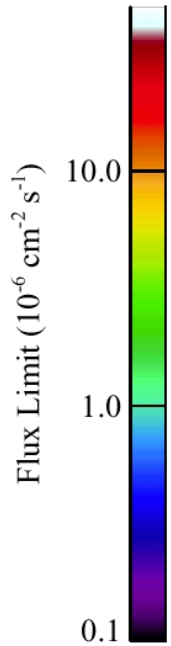


Source class	Seen by EGRET	Predicted with GLAST
Unidentified sources	170	?
Rotation powered pulsars	3-6	100-500
Blazars	50-80	>2000
Normal galaxies	2	4-5
Gamma ray bursts	5	>500
Supernova Remnants/plerions	1-5	>10
Radio galaxies	1-1	?
X ray binaries/microquasars	1-1	?
Starburst galaxies	0	?
Cluster of galaxies	0	?

All Sky Monitoring with Improved Sensitivity



Fraction of the γ ray sky observed within 2 min



EGRET Fluxes

- GRB940217 (100sec)
- PKS 1622-287 flare
- 3C279 flare
- Vela Pulsar

During the all-sky survey, GLAST will have sufficient sensitivity after O(1) day to detect (5σ) the weakest EGRET sources!!!

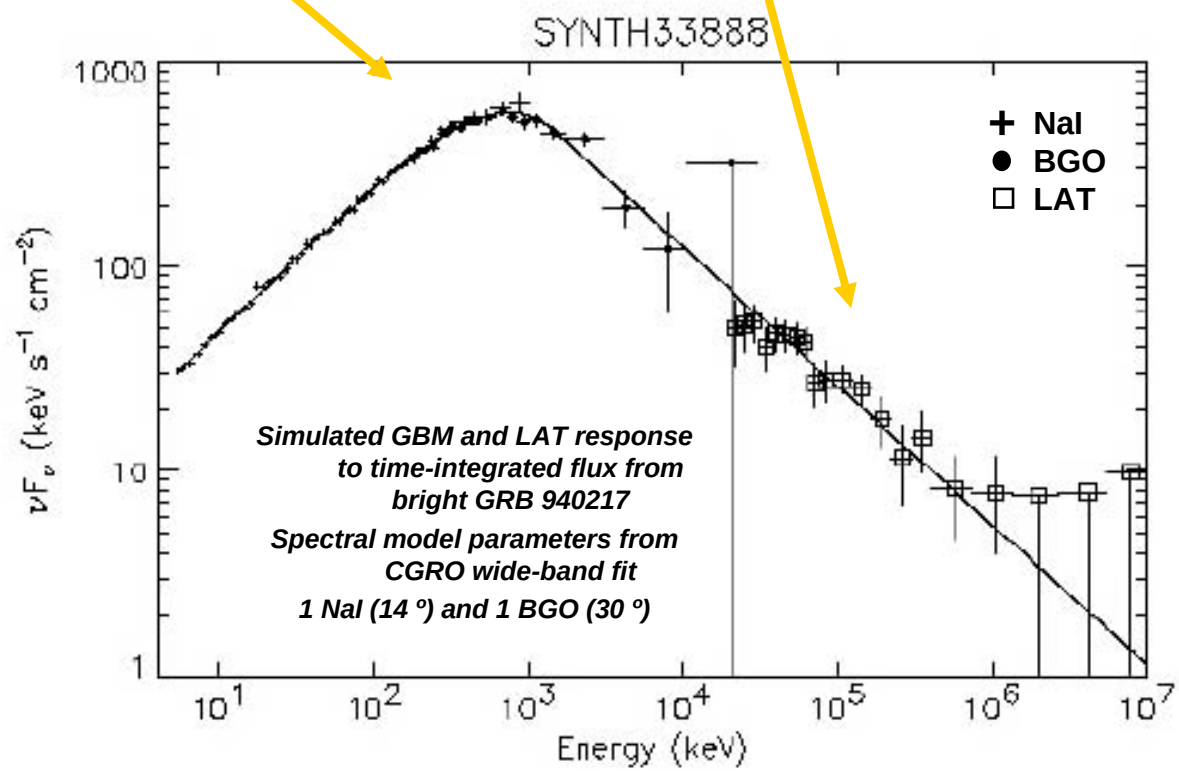
*zenith-pointed

Gamma Ray Bursts: GBM and LAT

- **GBM**
  - Huge field of view (8sr)
  - Measure spectra for bursts from 10 keV to 30 MeV
- **LAT**
  - Wide field of view (>2sr)
  - Extends spectral coverage to higher energies

GLAST

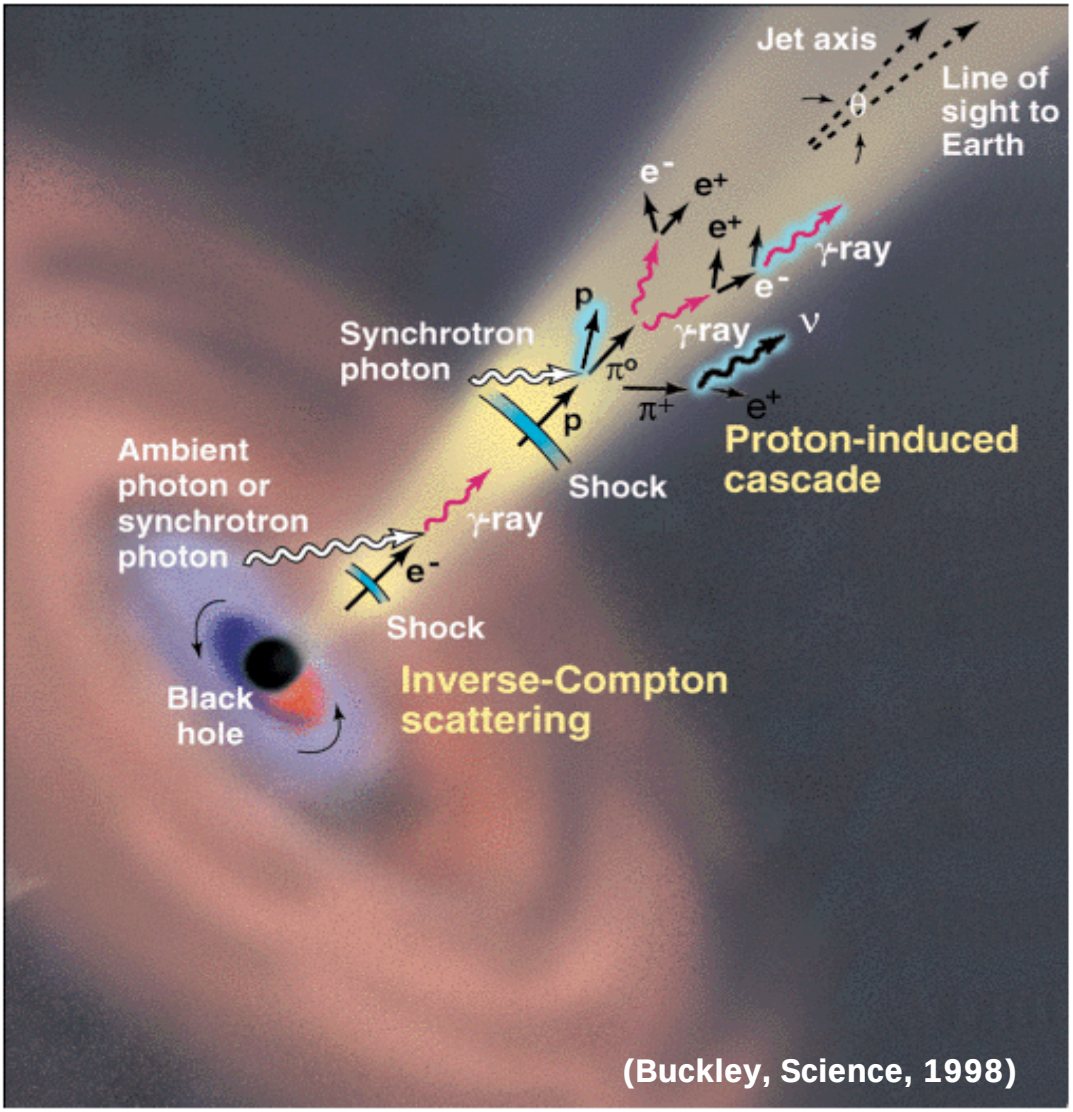
Can be re-pointed to catch exceptionally bright bursts that occur outside the LAT field of view



GLAST all-sky monitoring will be follow transient phenomena to a wide range of time scales from ~ 30 μs (GRB, solar flares) to hours or longer (AGN)

AGN (Blazars): Emission Mechanisms

Adapted from P. Coppi



(Buckley, Science, 1998)

Most of the EGRET AGNs were blazars

- **Variability: relativistic jets**
- **Jets point towards us !**

Radiation is produced by one or more of the following processes

- **Synchrotron Self Compton**
- **External Compton**
- **Proton Induced Cascades**
- **Proton Synchrotron**

Key issues to be addressed

- **Energetics of the source**
- **jet formation**
- **jet collimation**
- **nature of the plasma**
- **particle acceleration**

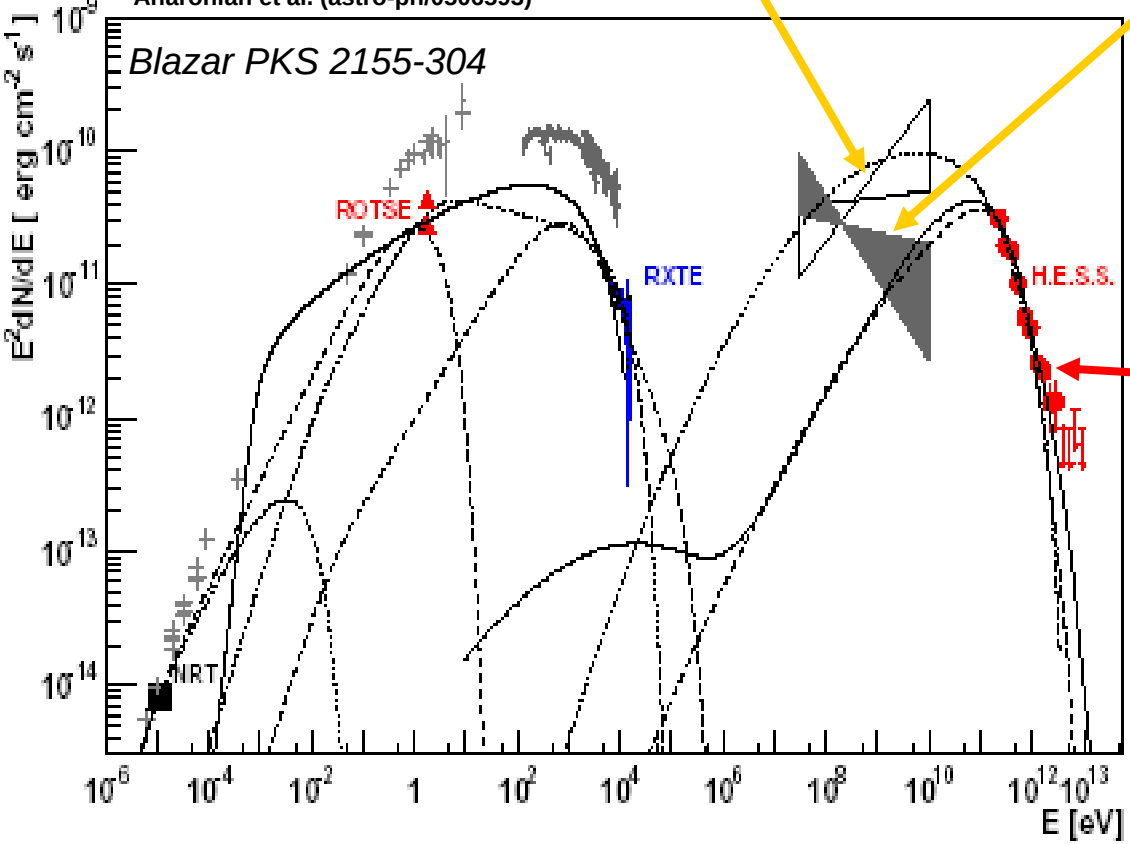
Multiwavelength Observations

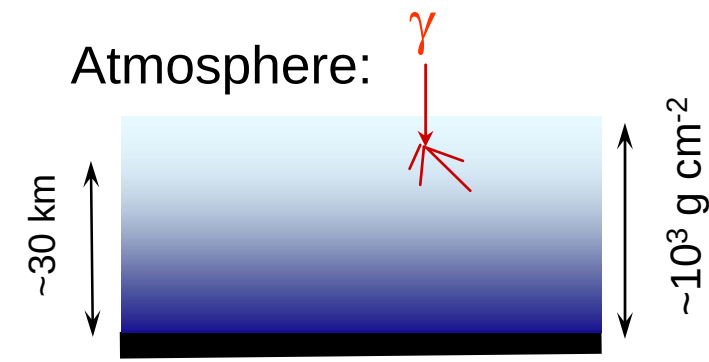
- Contemporaneous observations with other wavelengths
  - disentangle effects from state changes within individual sources
- GLAST will provide "continuous" baseline in GeV
  - helpful to ground based TeV γ–ray telescopes

3rd EGRET catalog

High γ-ray state (Verstrand et al. 1995)

Aharonian et al. (astro-ph/0506593)





For E_g > ~ O(100) GeV, must measure light emitted at the atmosphere (Cerenkov)

GeV-TeV campaigns will complement GLAST science!

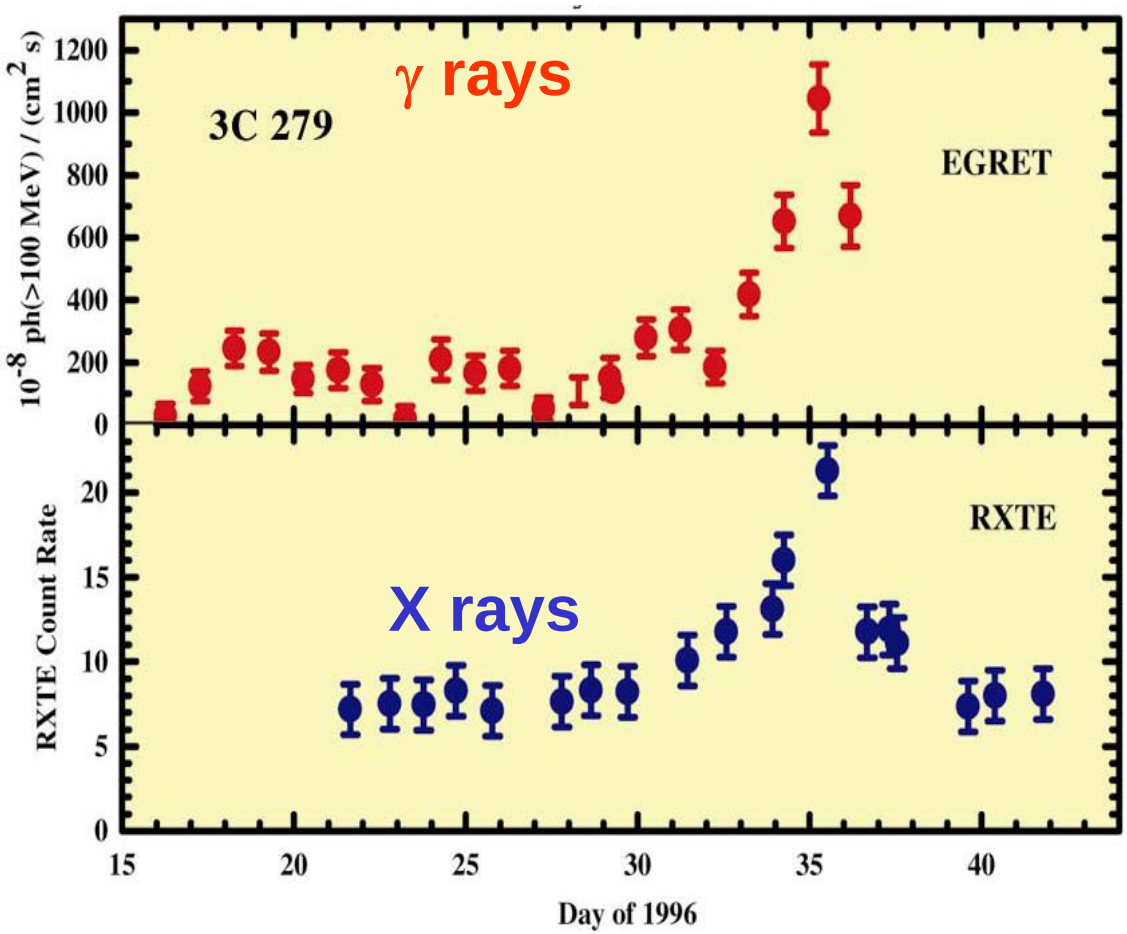
Multiwavelength planning in progress:

`http://glast.gsfc.nasa.gov/science/multi/`

Time lags: hadronic or leptonic model in AGNs?

- Leptonic processes are "preferred" by theorists
  - Hadronic models have nc yet been excluded!
- Time lags between AGN flare: may suggest dominance of hadronic processes

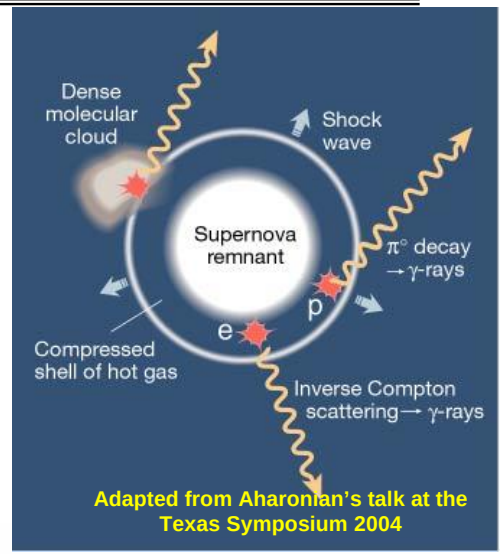
Credit: EGRET Team



Changes in Luminosity in a fraction of a day !
Variability constrains the size of the emitting source

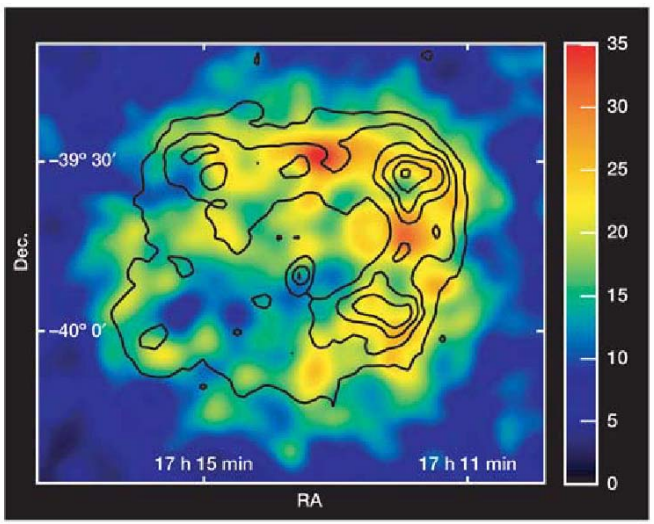
SNR: Sites of Hadronic Acceleration?

- Supernova Remnants: sites of galactic cosmic ray acceleration
  - Non-thermal emission (X-rays)
  - Signs of γ-ray activity
    - EGRET: GeV activity near SNR (3EG J1714-3837)
    - HESS: Recent detection of TeV γ-rays
- Question:
  - Do γ rays originate from hadronic or leptonic processes?
- Measurements in the range of 100MeV-100GeV
  - essential ingredient to resolve the origin (*p* vs *e+/-*)



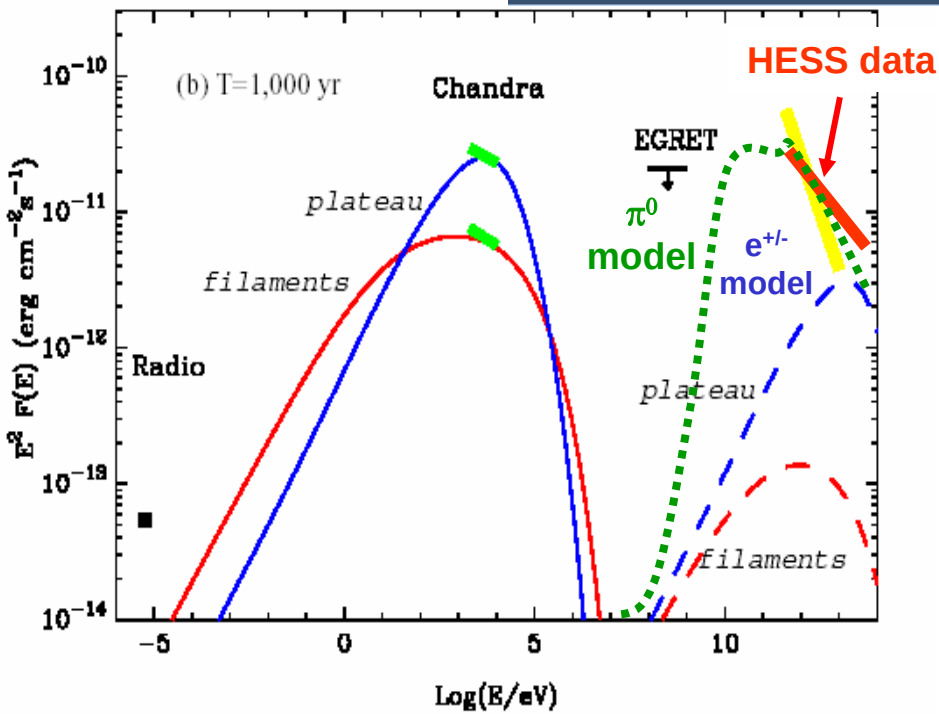
Adapted from Aharonian's talk at the Texas Symposium 2004

Supernova remnant RX J1713.7-3946
HESS 04 (color) + ASCA (contours)



E. do Couto e Silva

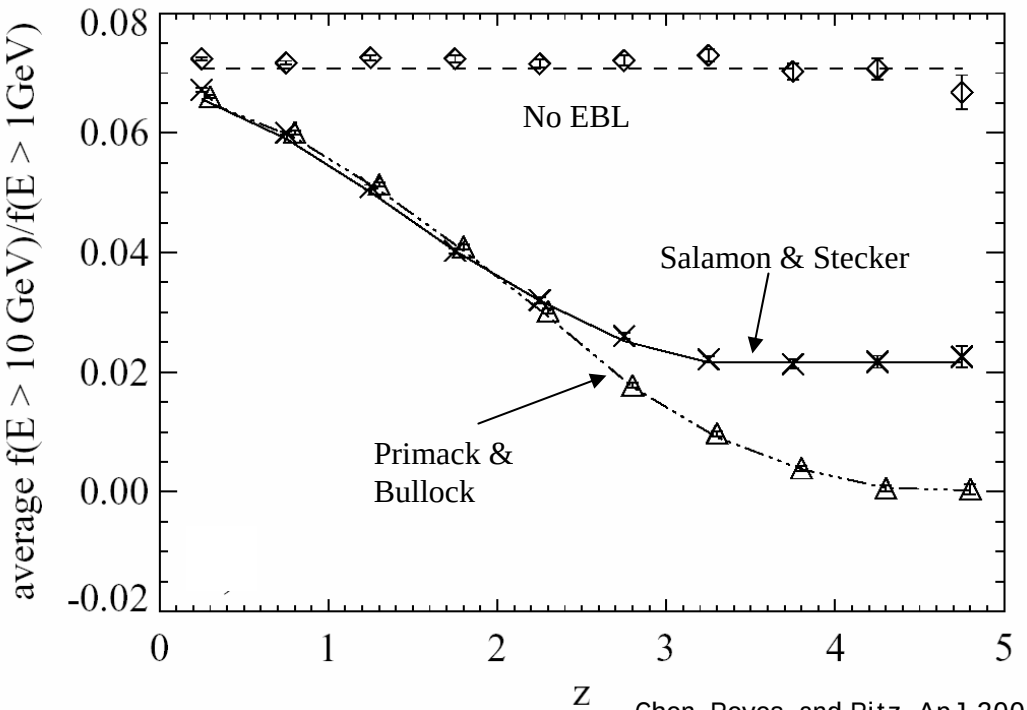
Uchiyama (2003)



AGN: Extragalactic Background Light

- High Energy photons (e.g. from AGN) can be absorbed via pair production
  - GeV (TeV) photons interact with intergalactic photons UV(IR)
  - strong dependence on the distance from the source (inferred from redshift)
- GLAST will see thousands of AGN
  - look for systematic effects vs redshift
  - key energy range for cosmological distances

effect is model-dependent (this is good):



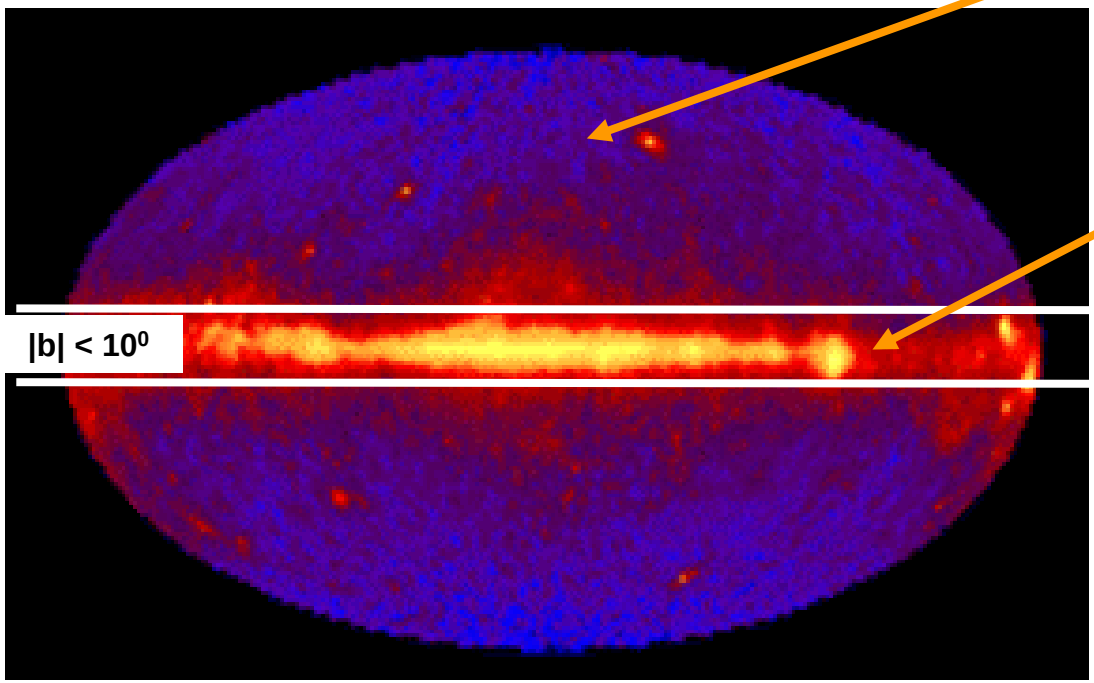
Chen, Reyes, and Ritz, ApJ 2004

A dominant factor in EBL models is the era of galaxy formation

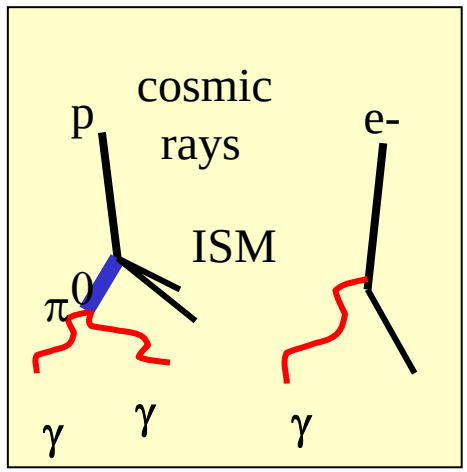
AGN roll-offs may help distinguish models of galaxy formation

Gamma Ray Background Radiation

EGRET Gamma Ray Emissions > 100 MeV



- **Extragalactic Emission**
  - **Higher latitudes**
    - **|b| > 10 ⁰**
- **Galactic Emission**
  - **falls rapidly at higher latitudes**
  - **gas density concentrated in the p**



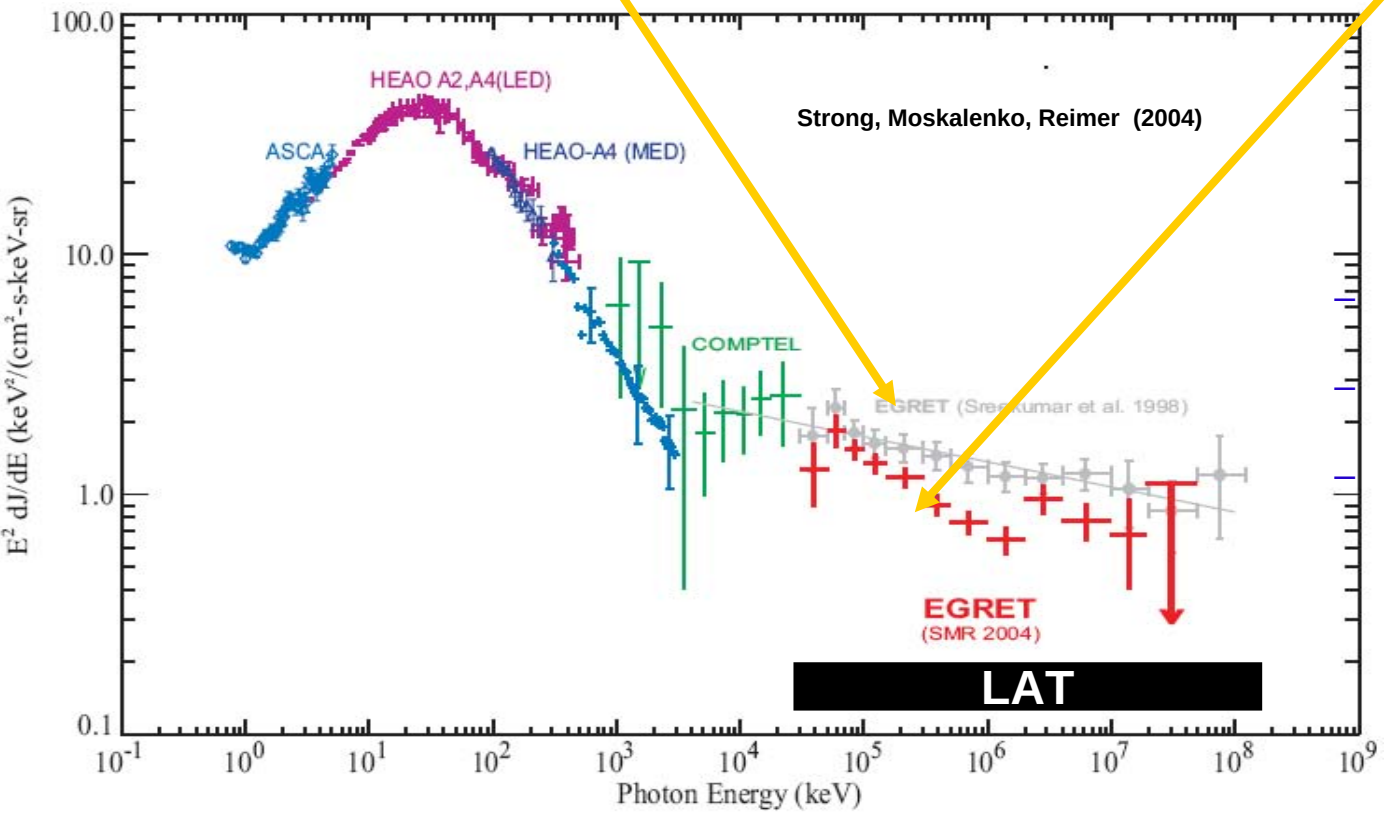
- **Galactic plane**
  - **Contains about 90% of the γ ray emission**
    - **Mostly high energy cosmic ray interactions with the interstellar medium (ISM)**

Origin of Extragalactic γ-Ray Background

- **GLAST can shed light in one of the long-standing problems in high energy astrophysics**
  - **The origin of the extragalactic background**

Galactic Diffuse γ ray is subtracted
Reanalysis using slightly modified e- spectrum with respect to the local injected spectrum

Original EGRET spectrum



What is it made of?

Blazars
- **we know…**

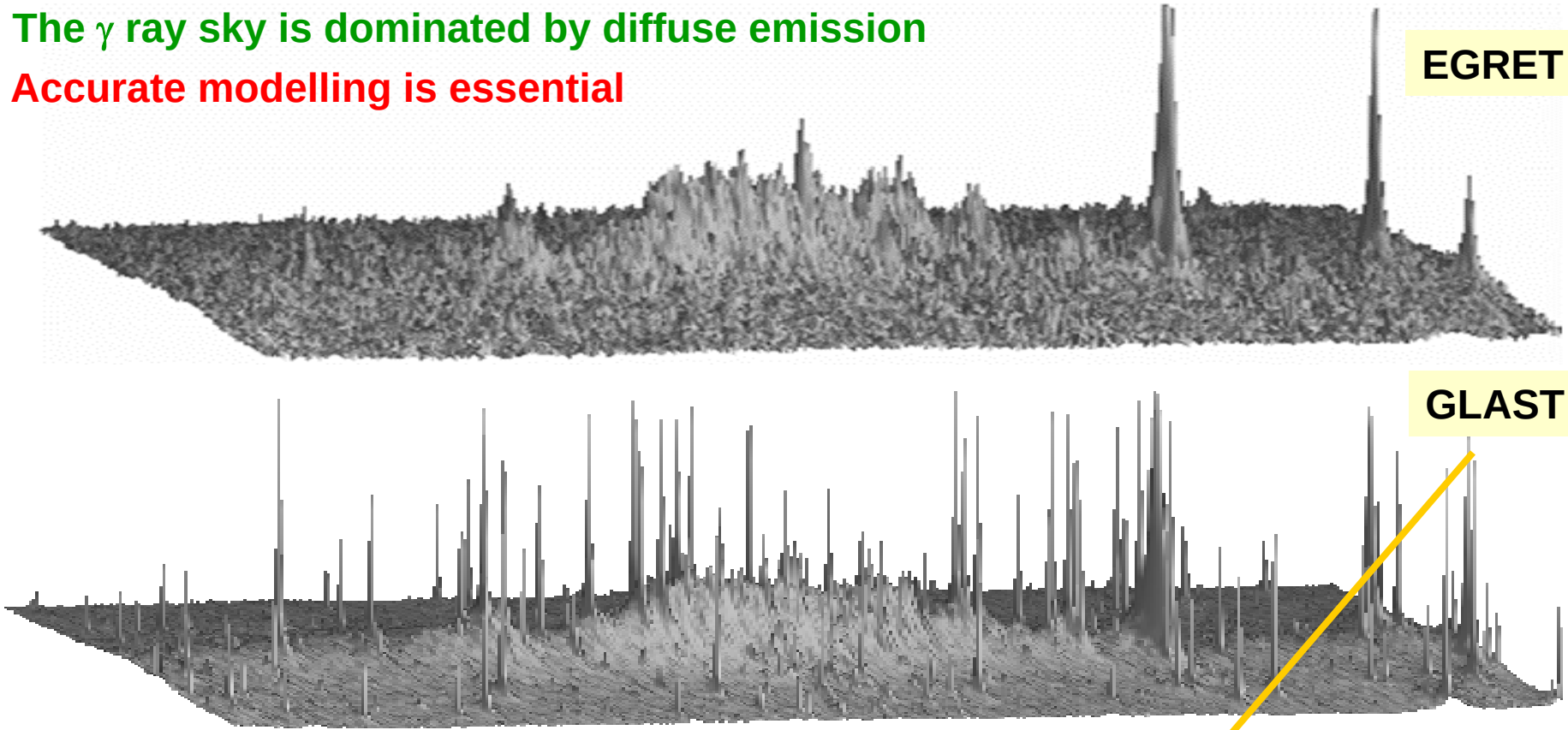
New physics
- **we can probe…**

Primordial diffuse
- **If else fails…**

Galactic Diffuse Gamma Ray Emission

The γ ray sky is dominated by diffuse emission

Accurate modelling is essential



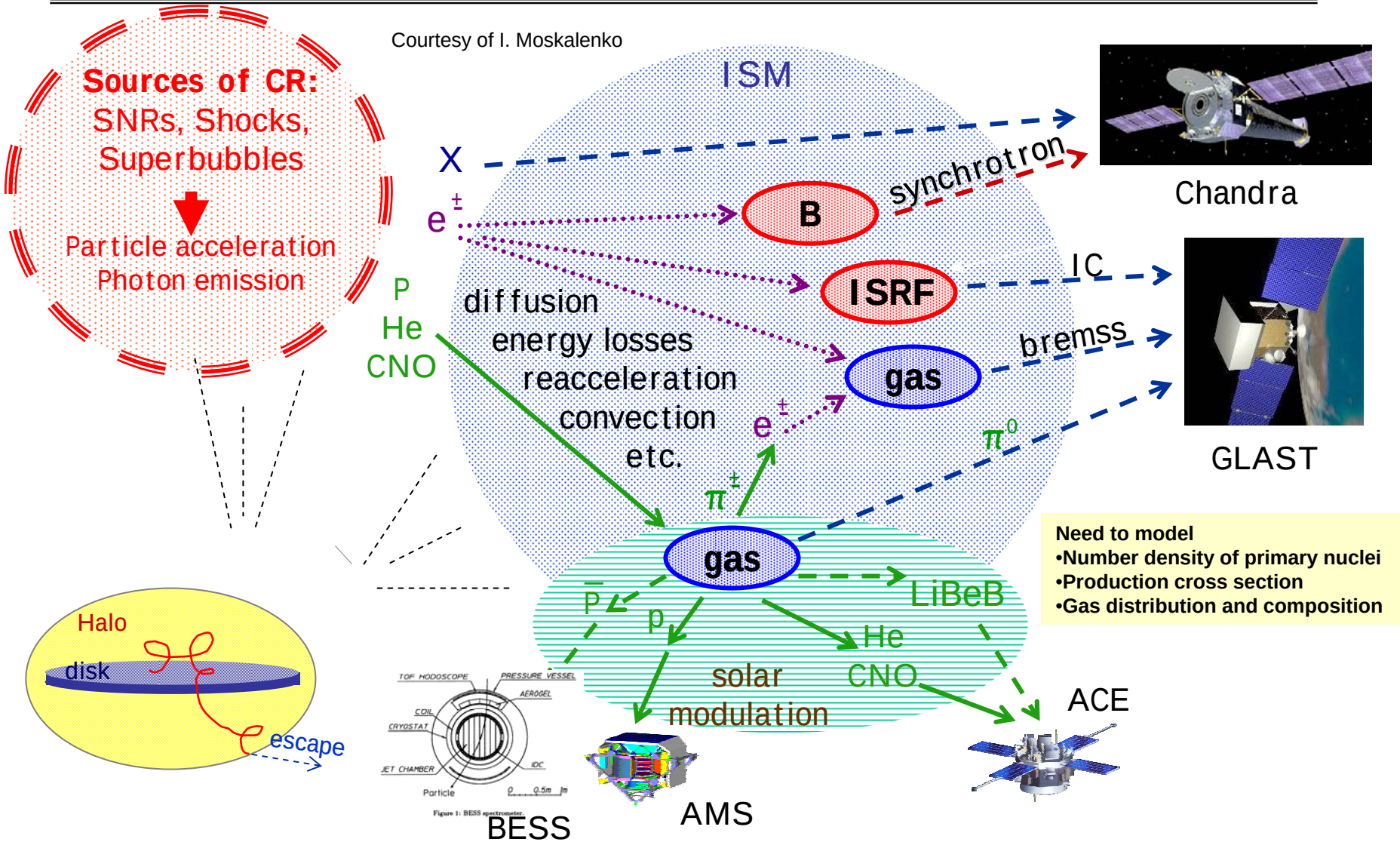
Many more point sources

Background determination for energy above 10 GeV

Sharper definition of the diffuse background

(smaller bins in the sky)

Complex Modeling of Particle Transport

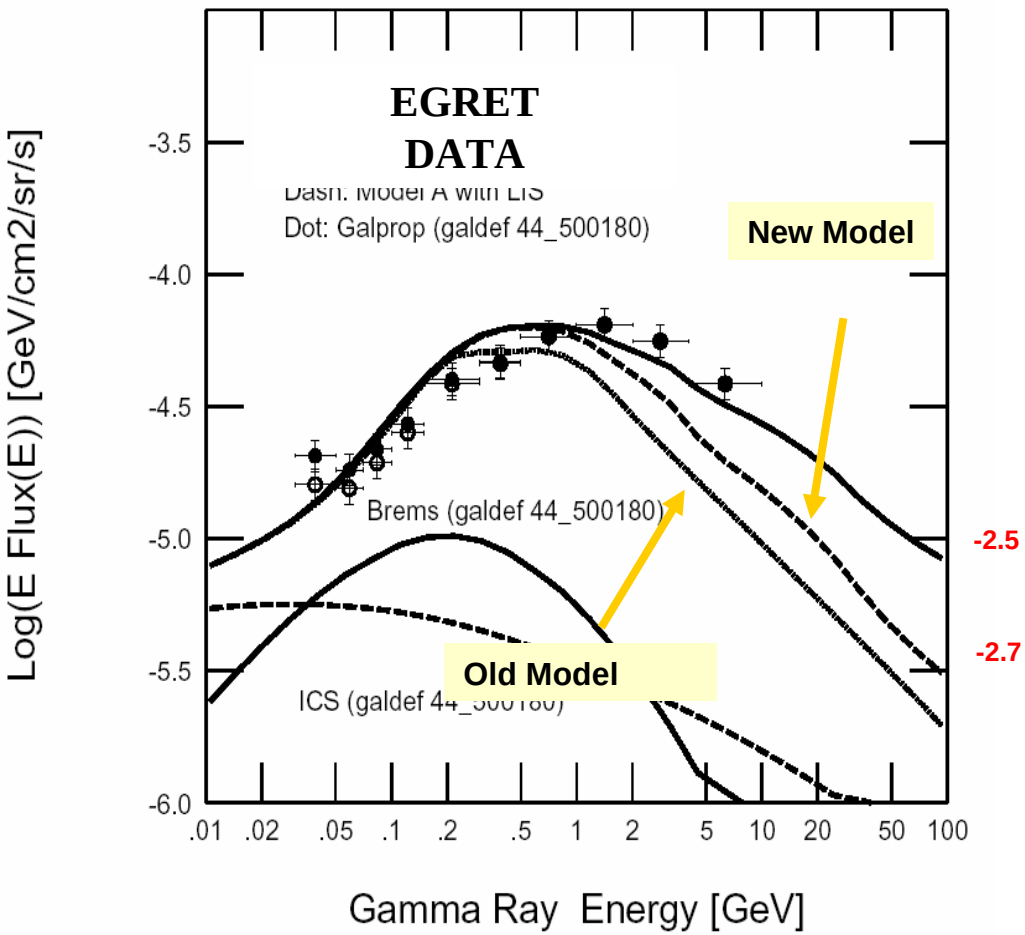


Need to model
- **Number density of primary nuclei**
- **Production cross section**
- **Gas distribution and composition**

Charged particle measurements will provide consistency checks for γ ray models

EGRET DATA: "γ-ray excess" is controversial

- After diffuse background subtraction there was an excess of γ in the EGRET Data
  - Revisited pp cross section: accounts for a fraction of the GeV excess



Old *pp* interaction models

- ❑ Constant inelastic cross-section
- ❑ Feynman scaling
- ❑ No diffraction dissociation

⇩

New *pp* interaction model

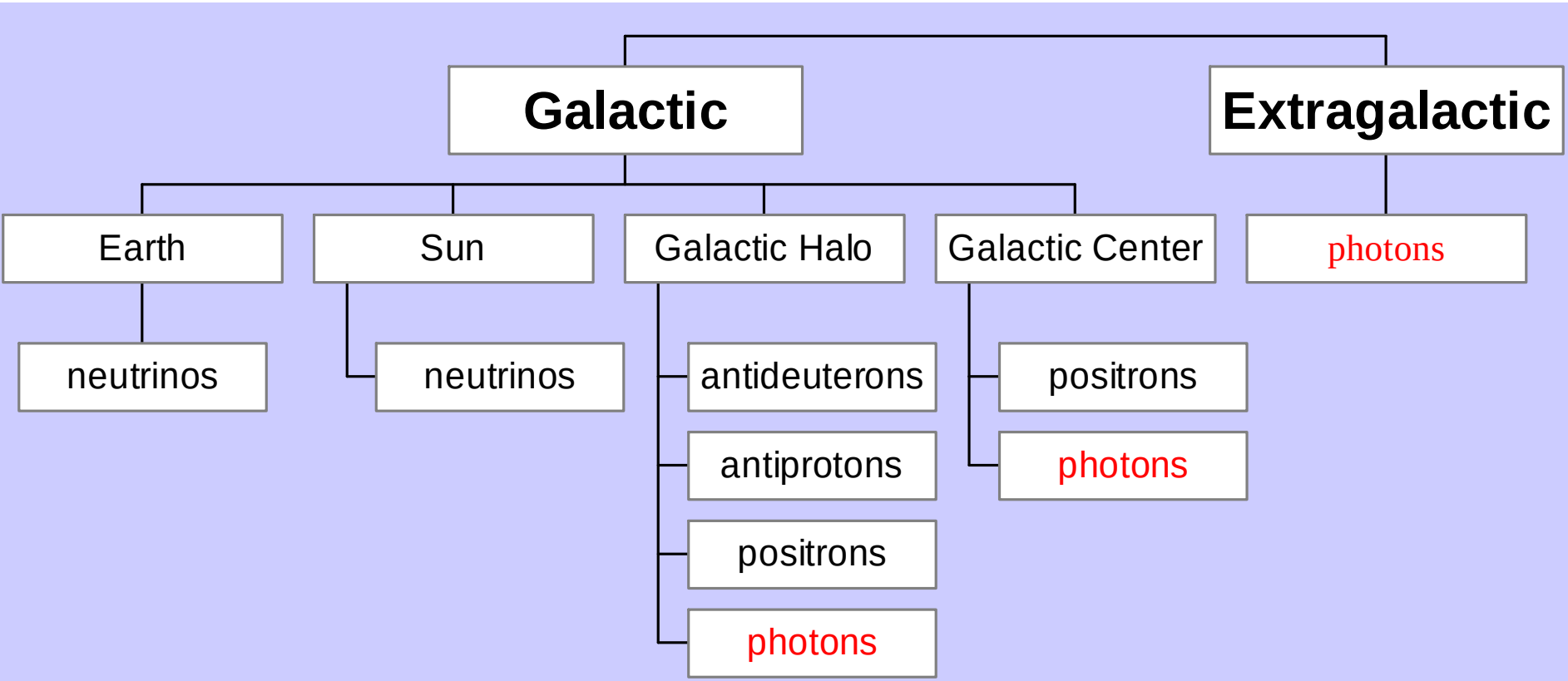
- ❑ Rising cross-sections
- ❑ Scaling violation
- ❑ Diffraction dissociation

Kamae et al. 05, Kamae, Karlsson, Mizuno et al. 05, Kamae, Karlsson, Cohen-Tanugi Mizuno et al.05

Can WIMPs be the source of Dark Matter?

Weakly Interacting Massive Particles (WIMP)

- **Direct searches:**
  - **scattering of WIMPS with nucleons in the detector**
    - **DAMA, CDMS, EDELWEISS, etc.**
- **Indirect Searches:**
  - **WIMP annihilations into other particles**
    - **GLAST, ICECUBE, ANTARES, GENIUS, HEAT, AMS, etc**

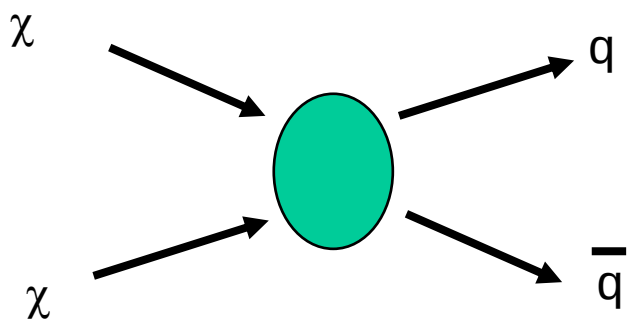


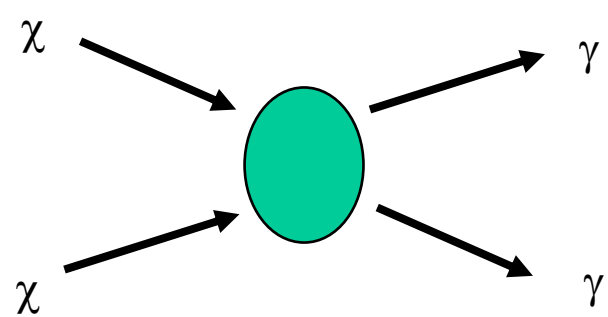
Dark Matter Candidate: Neutralino

If true, there may well be observable halo annihilations

$$\chi_1^0 = a_{11}\tilde{B} + a_{12}\tilde{W}^3 + a_{13}\tilde{H}_1^0 + a_{14}\tilde{H}_2^0$$

- **Good particle physics candidate for galactic halo dark matter**
  - **Lightest Supersymmetric Particle in R-parity conserving SUSY**



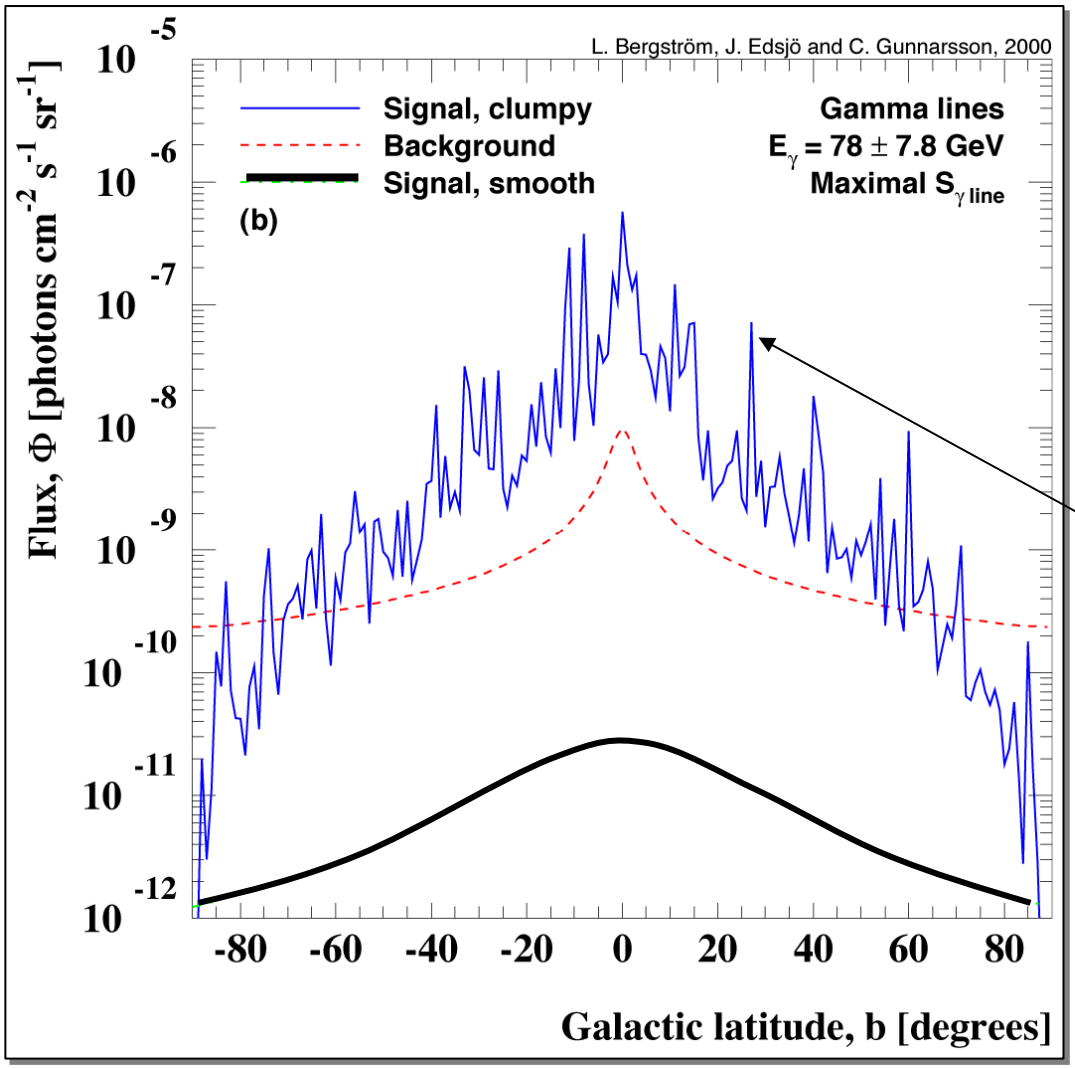


continuum energy spectrum
Higher statistics…
but higher background

Distinct signature
a "peak" in the energy spectrum !!
Lower background…
but lower statistics

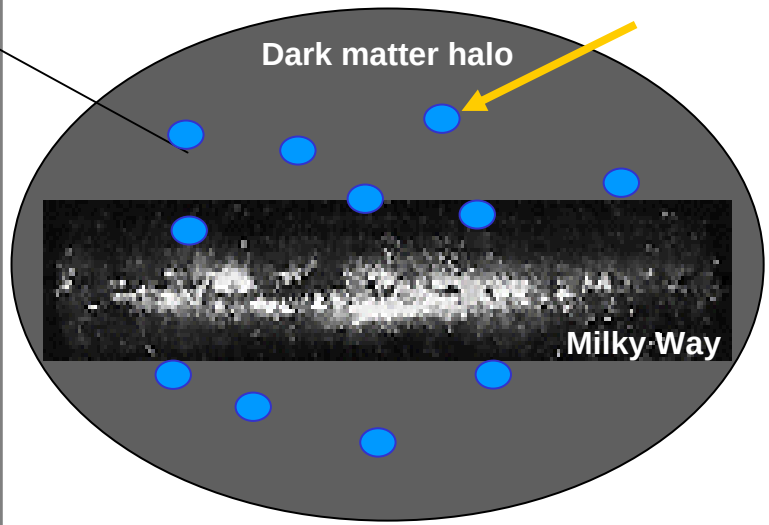
Dark Matter from SUSY: γ line and continuum

γ lines



Large uncertainties in the
Particle spectrum
Halo model
Background estimation

Detection rates can increase if halo is clumpy



N-body simulations from Calcáneo-Roldan and Moore, Phys. Rev. D62 (2000) 23005.

Halo Dark Matter Searches with GLAST

- **WIMP Annihilations in halo Clumps (b >|10| 0):**
  - **continuum γ from π^0 @ ~100 MeV**
  - **lines (2 γ, γZ)** (Bergstrom et al)
    - **Depends on models of clumps**
      - » **see previous slide**

- **IC from secondary electrons** (Baltz & Wai 04)
  - **>GeV IC from e + starlight**
    - **near galactic plane < 30^0 (trapping by B field)**

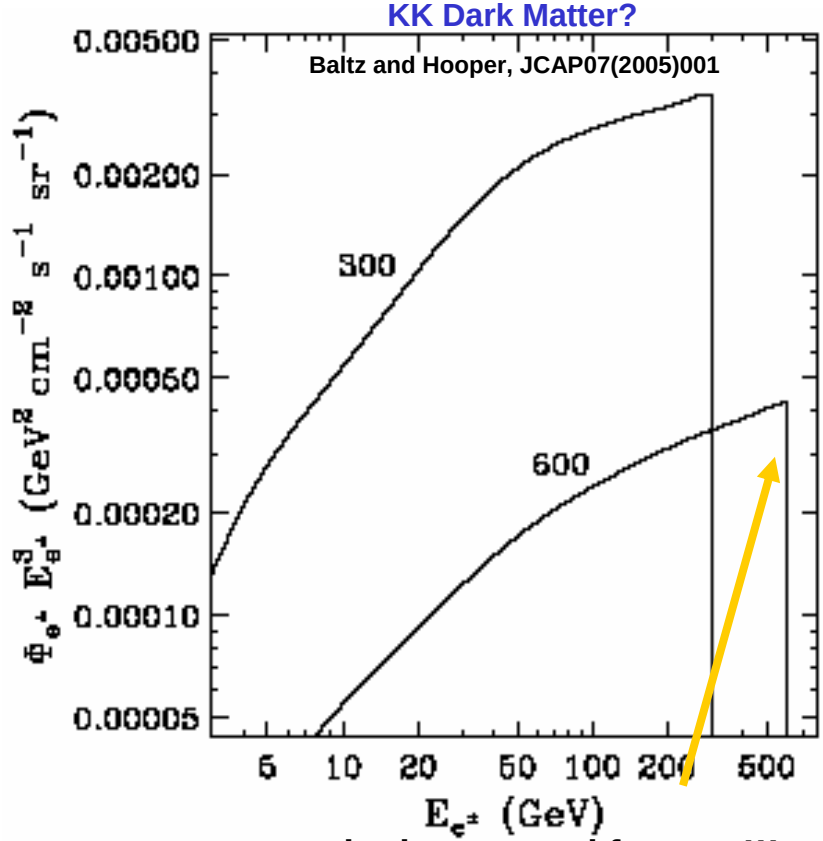
- **KK DM Scenario – electron "line" (20% Br) smeared into a sharp edge via mainly IC**
  - **>500 GeV: ~ 100 e± /year edge height**
    - **all-sky signature!**
      - » **see next slide**

Dark Matter: SUSY or Extra Dimensions?

- **SUSY**
  - **Lightest Supersymmetric Particle**
    - **Neutralino**
  - **Accelerator bounds**
    - **M χ^0 > tens of GeV**
  - **Search for photons**

- **Extra Dimensions**
  - **Lightest Kaluza-Klein Particle**
    - **B^1**
  - **Accelerator bounds**
    - **M_{B^1} > 300 GeV**
  - **Search for photons and leptons**
    - **Charged leptons are not helicity suppressed**
    - **59% charged leptons**
    - **35% quarks**

KK Dark Matter?



endpoint spectral feature !!!

Limited statistics with GLAST
hard to measure
but very interesting…!

Extra Dimensions: Possible GLAST Signatures?

Large Extra Dimensions

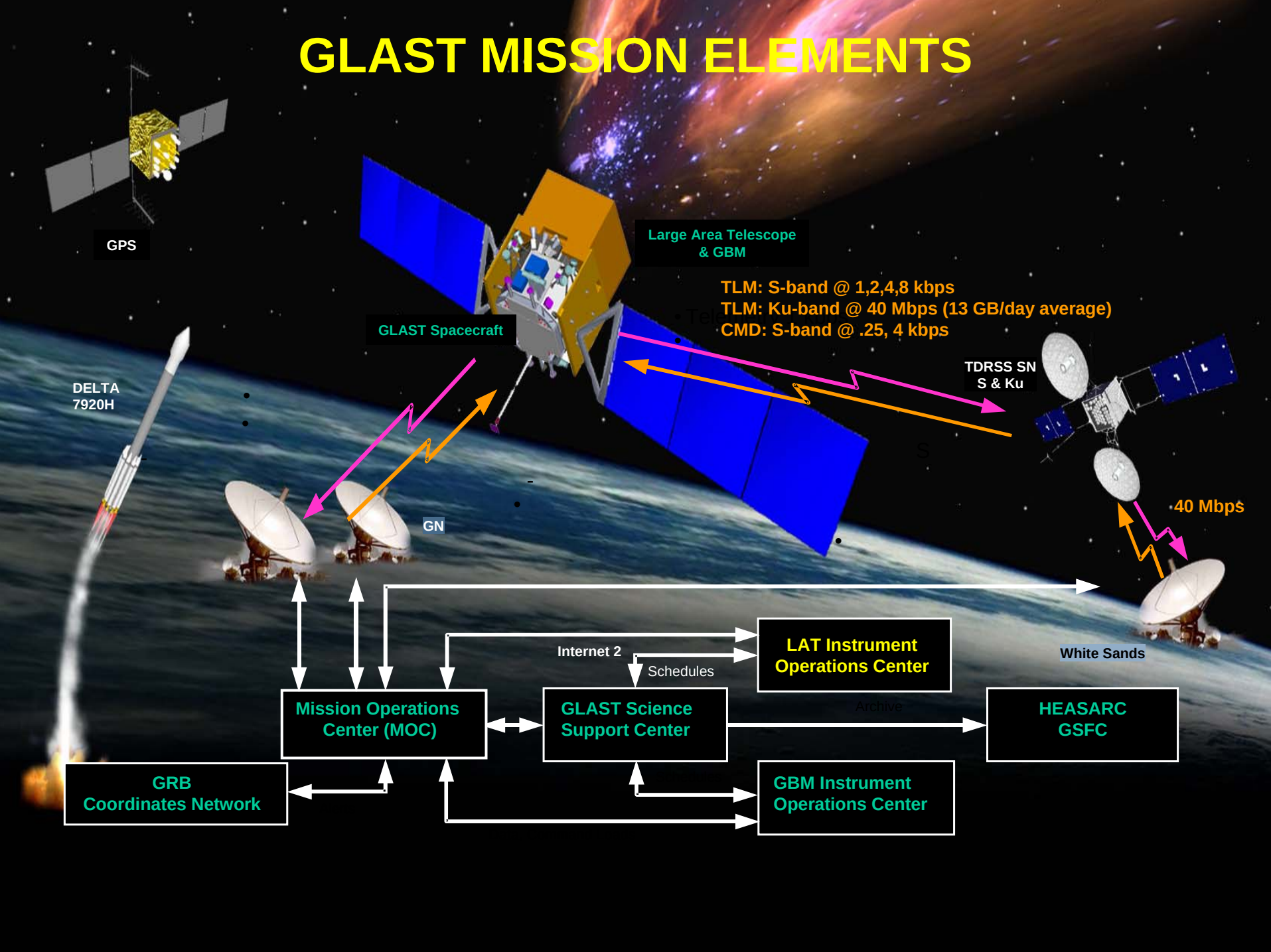
- Thermal graviton emission (how much energy went into the bulk without affecting cosmological evolution?) (Perez-Lorenzana 2005)
  - BBN (Hannestad 2004)
  - For n=2 there would be many KK Modes which would release too much energy into gravitons
- Gravitons emitted by stellar objects take away energy
  - SN (Hannestad 2003)
    - NS shines because gravitons are gravitationally trapped
- Massive Graviton decays into $\gamma\gamma$ continuously emitted by the Universe (less robust)
  - Excess in diffuse gamma ray emission around 30 MeV
  - Gamma ray emission from NS in the galactic bulge
  - Problem: heavy KK can decay into more lighter KK modes
    - not on SM particles only

Universal Extra Dimensions

- B^1B^1 annihilation in Galactic Center
  - Two photons via loop diagrams (Servant and Tait)
- B^1B^1 annihilation in Galactic Center
  - Charged lepton production is not helicity suppressed
    - 59% charged leptons
    - 35% quarks
    - 4% neutrinos
    - 1% charged gauge bosons
    - 0.5 % neutral gauge bosons
    - 0.5 % Higgs bosons
  - Primary gamma rays
    - Bremstrahlung of charged leptons
  - Secondary gamma rays
    - Photons from qq and synchroton

- High Energy Signal (hundreds of GeV)
  - Limited statistics and maybe $\Delta E/E$
- Low Energy Signal (< 100 MeV)
  - Uncertainties in the background
- Can theorists give us a signal between 10 and 100 GeV?
  - LZP (Agashe and Servant hep-ph 0403143)

GLAST MISSION ELEMENTS



Operation Phases

- First year of science operations
  - initial on-orbit checkout, verification, and calibrations, followed by an all-sky survey
    - detailed instrument characterization
    - refinement of the alignment
  - key projects needed by the community
    - source catalog, diffuse background models, etc.
  - Transients
    - data on transients will be released, with caveats.
    - repoints for bright bursts and burst alerts enabled.

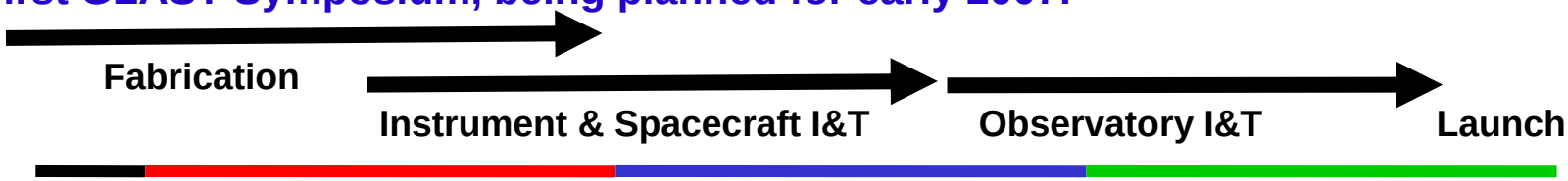
- First Year Guest Observer Program
  - limited first-year guest observer program
  - extraordinary Targets of Opportunities supported.
  - workshops for guest observers on science tools and mission characteristics for proposal preparation

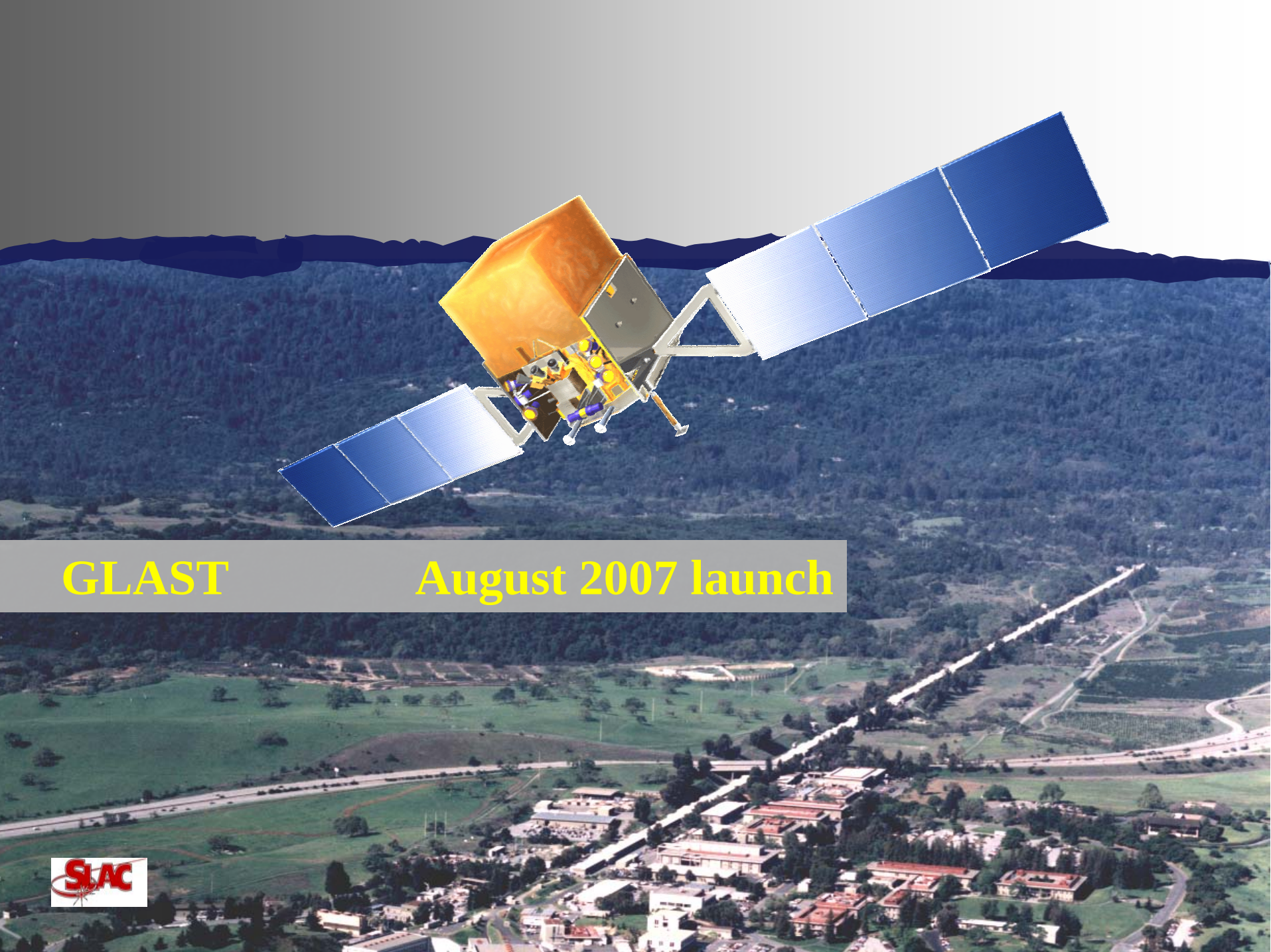
- Observing plan in subsequent years
  - driven by guest observer proposal selections by peer review.

- All data released through the GLAST Science Support Center (GSSC).

The Look Ahead

- The GLAST mission is
  - completing the fabrication phase and
  - is well into integration.
- LAT, GBM, and spacecraft assembly
  - complete by early 2006.
- Delivery of the LAT and GBM instruments
  - for observatory integration in spring 2006.
- Observatory integration and test
  - spring 2006 through summer CY07.
- Major scientific conference,
  - the First GLAST Symposium, being planned for early 2007.




GLAST
August 2007 launch
SLAC