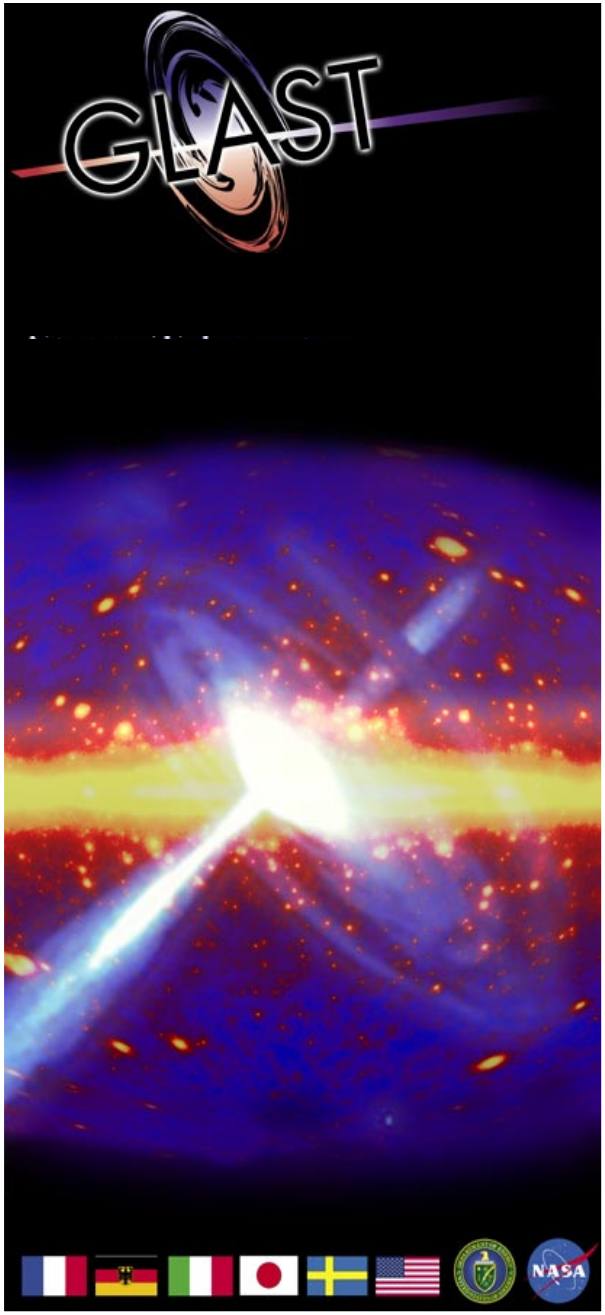
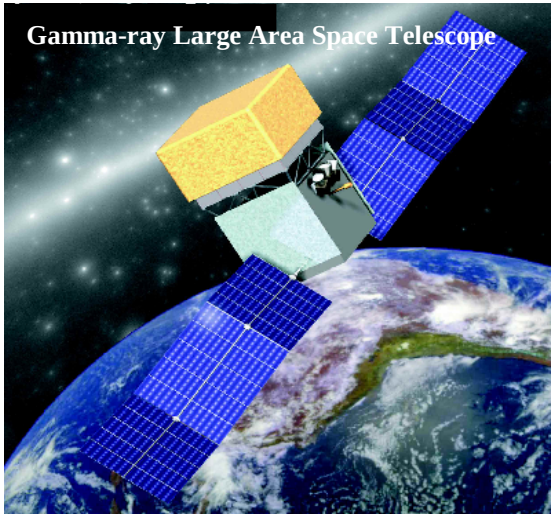



# GLAST Large Area Telescope

**- Daily Deep Survey of H.E. Universe -**

**Tuneyoshi Kamae**
**SLAC, GLAST Group**
**On behalf of the**
**GLAST-LAT Collaboration.**

- Gamma-ray astronomy VS. X-ray astronomy
- What makes GLAST-LAT unique
- Where we are now
- New way to study High Energy universe
- Gamma Ray Burst study with GLAST-GBM



# Gamma-ray astronomy VS. X-ray astronomy

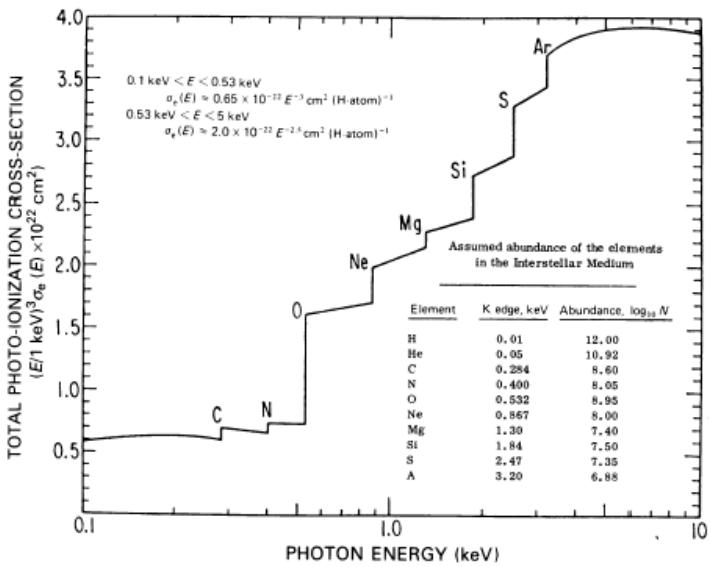
## - Transparency -

- **X-ray is absorbed by ISM**
- **VHE γ-ray by Extragal. Bkgnd Light**
- **GLAST will reach out to z>>10**

**Chance for serendipitous discoveries.**

***Total photoionization cross-section***

Total photo-ionization cross-section per hydrogen atom $[x(E/1\,\mathrm{keV})^3]$ in units $10^{-22}\,\mathrm{cm}^2$ as a function of incident photon energy for a gas having a cosmic elemental abundance. The elements responsible for the discontinuities due to their $K$ edges are shown. (Adapted from Brown, R. L. & Gould, R. J., *Physical Review*, **01**, 2252, No. 8, 1970.)



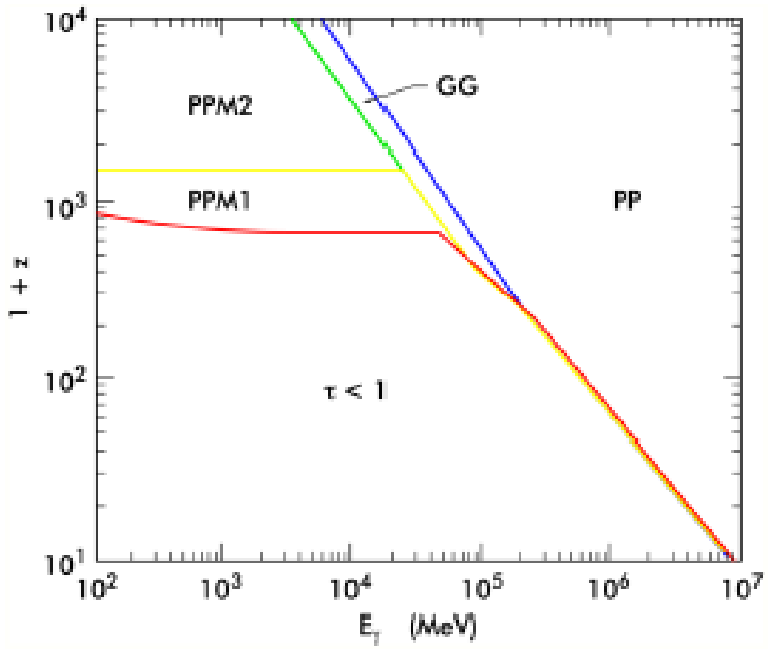
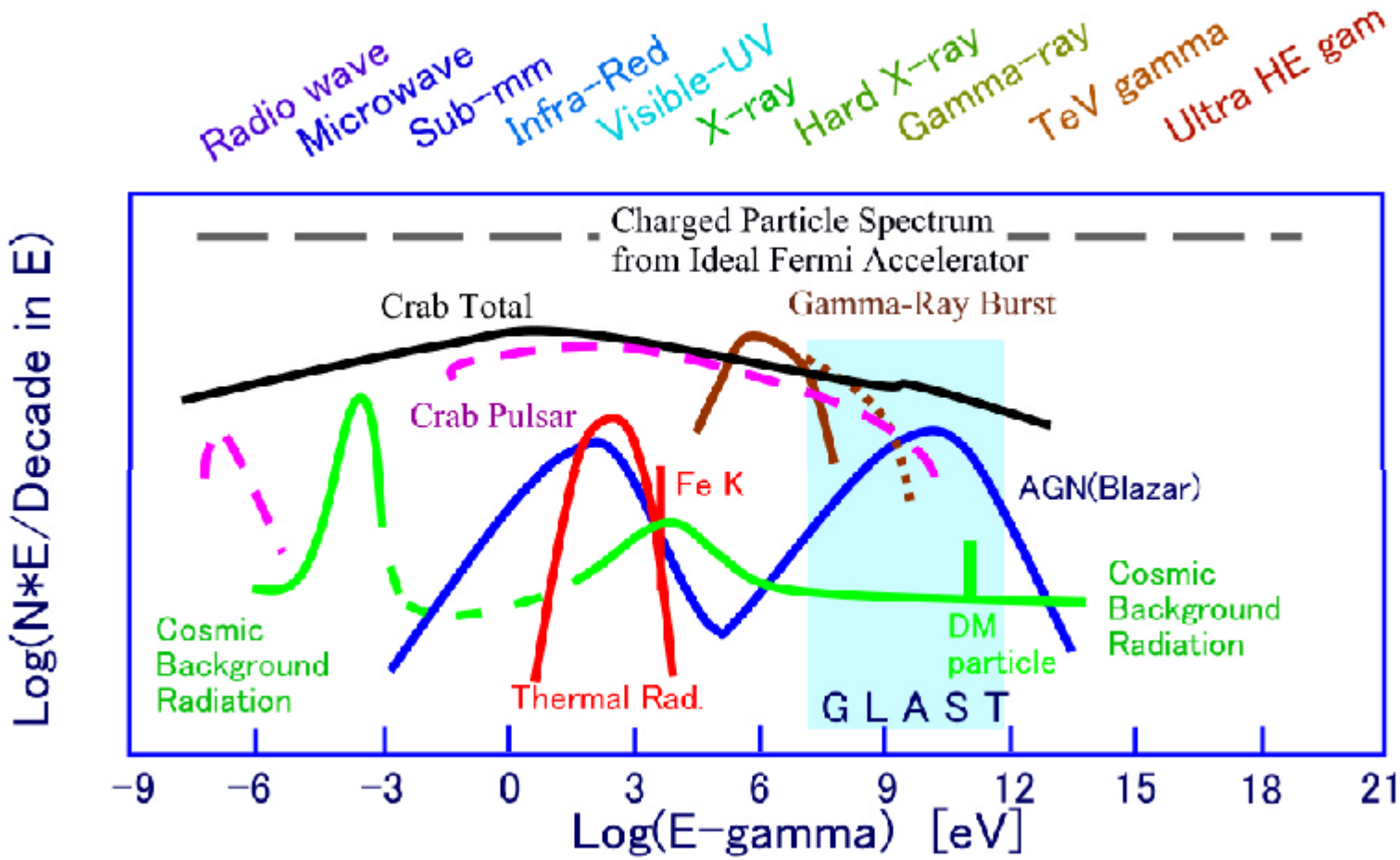




**Figure 5-2 Dominant scattering mechanisms for high-energy photons injected in the post-recombination era. The region below the red line has an optical depth τ < 1, thus no scattering occurs. The other regions are dominated by $e^+e^-$ pair production (PP), photon-photon scattering (GG), pair production in matter (PPM1) and pair production in ionized matter (PPM2) (Kribs & Rothstein 1997).**

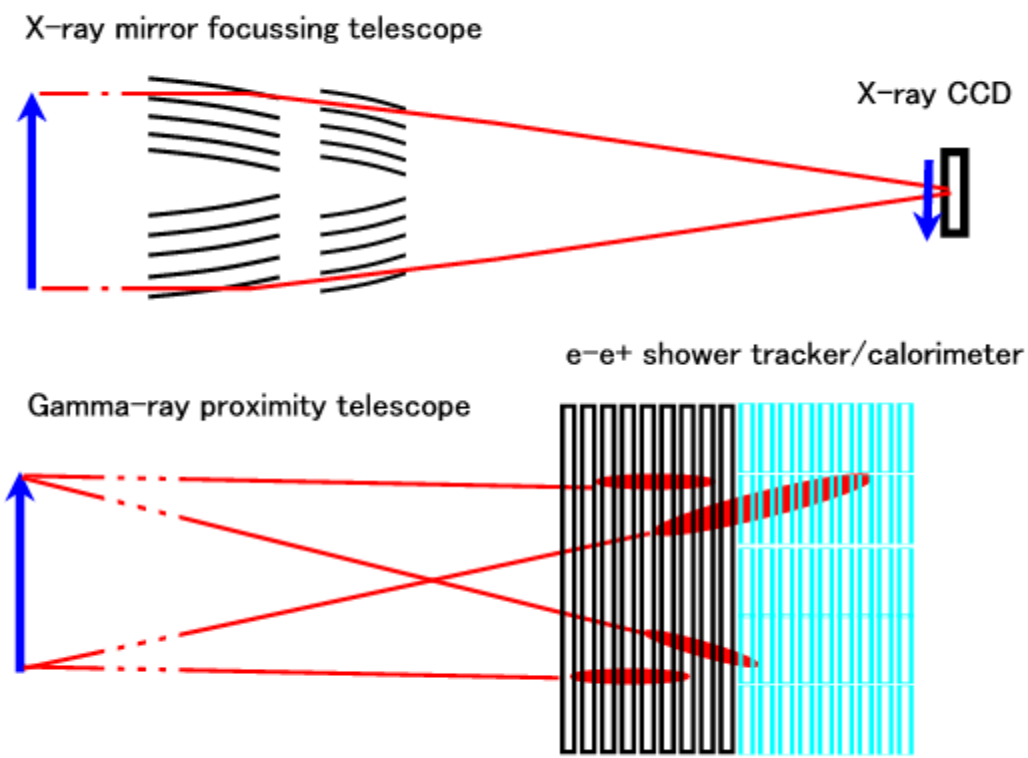
# Gamma-ray astronomy VS. X-ray astronomy

## - Cosmic sources emit gamma-rays -



# Gamma-ray astronomy VS. X-ray astronomy

## - Detector Technology -




**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**

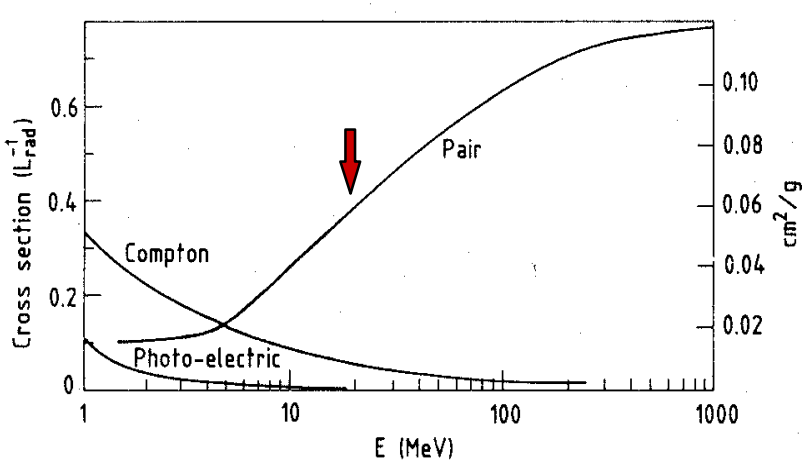
**Wide field of view**
**Limited effective area**
**Moderate energy resolution**
**High background**

# What makes GLAST unique

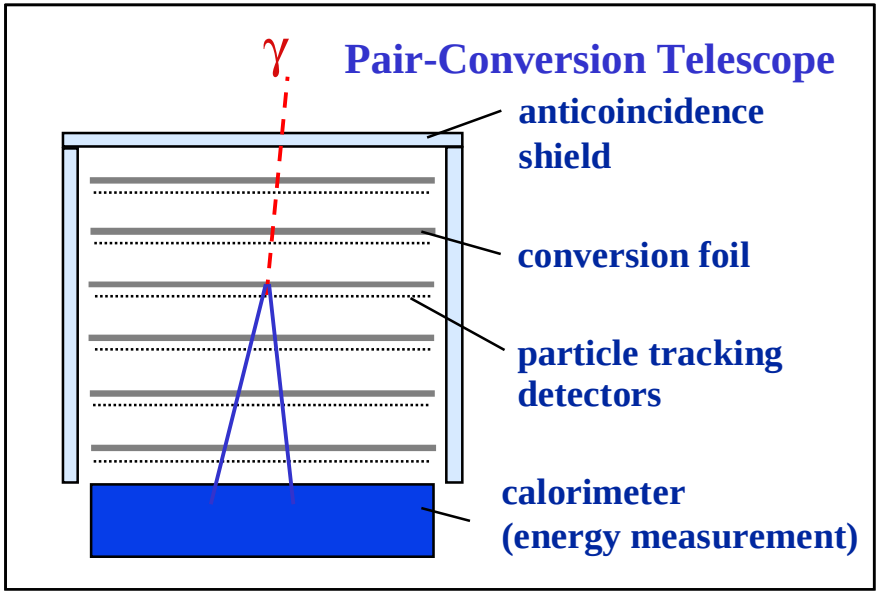
## - Tracking of e+e- pairs -

**Pair-conversion telescope**

**Measure θ,E, t of photons**




**Photon cross-section in lead**




**Limitations on energy coverage:**

**low E: low cross-section ➡ 20MeV**

**high E: shower leakage**

**Limitations on angular resolution (PSF):**

**low E: multiple scatt. ➡ many thin layers**

**high E: hit precision & lever arm**

# What makes GLAST unique

## - GLAST Large Area Telescope (LAT) Design (5) -

## Instrument

16 towers ⇒ modularity

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

## Tracker

Si-strip detectors: 236 mm pitch, total of $8.8 \times 10^5$ ch.

## Calorimeter

hodoscopic CsI crystal array

⇒ cosmic-ray rejection

⇒ shower leakage correction

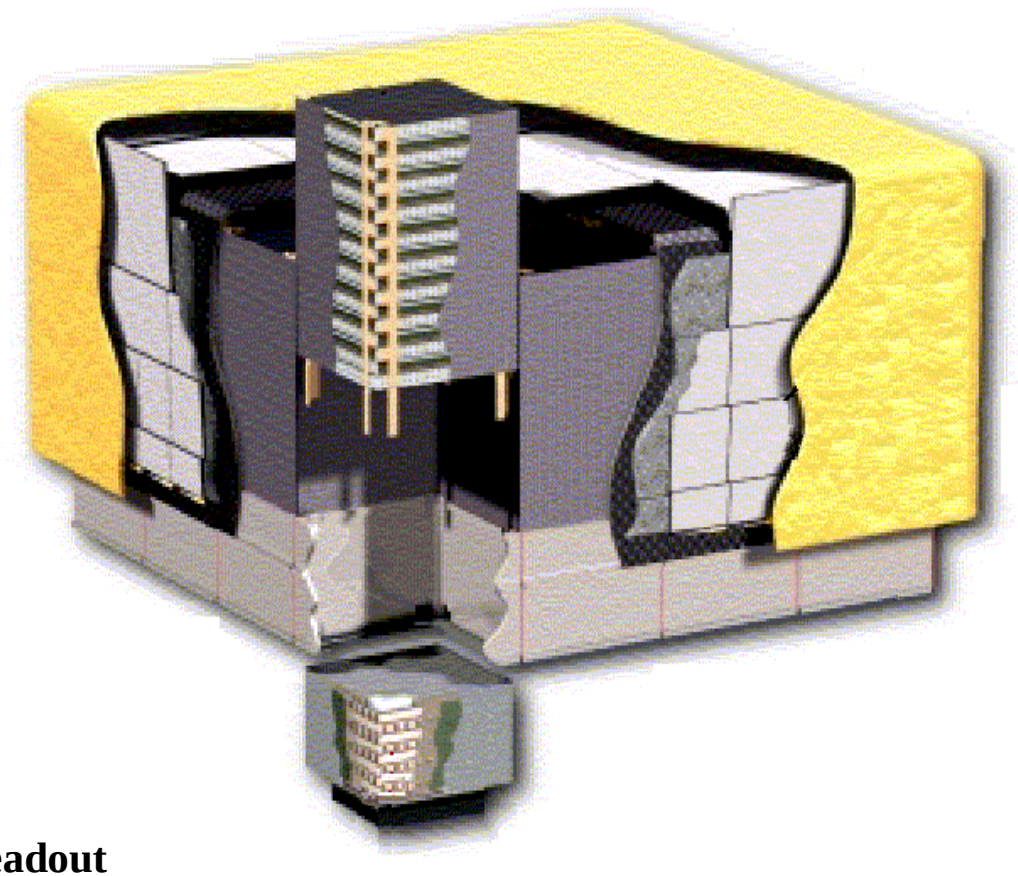
$X_{Tkr + Cal} = 10\ X_0$ ⇒ shower max contained < 100 GeV

## Anticoincidence Shield

segmented plastic scintillator

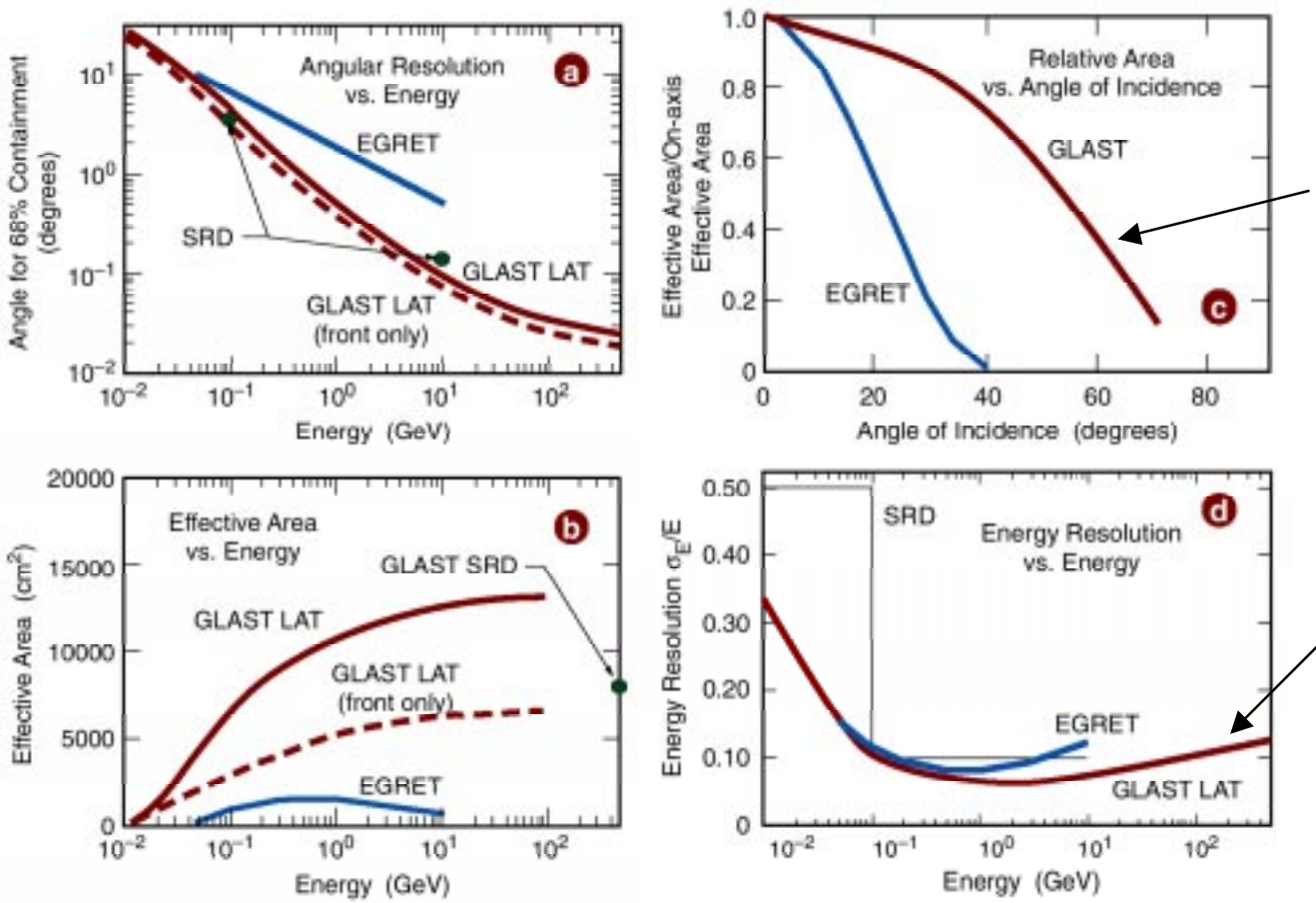
⇒ minimize self-veto

> 0.9997 efficiency & redundant readout



# What makes GLAST unique

## - GLAST LAT Performance -




FOV w/ energy measurement due to favorable aspect ratio

Effects of longitudinal shower profiling

# What makes GLAST unique

## - GLAST LAT Sensitivity -

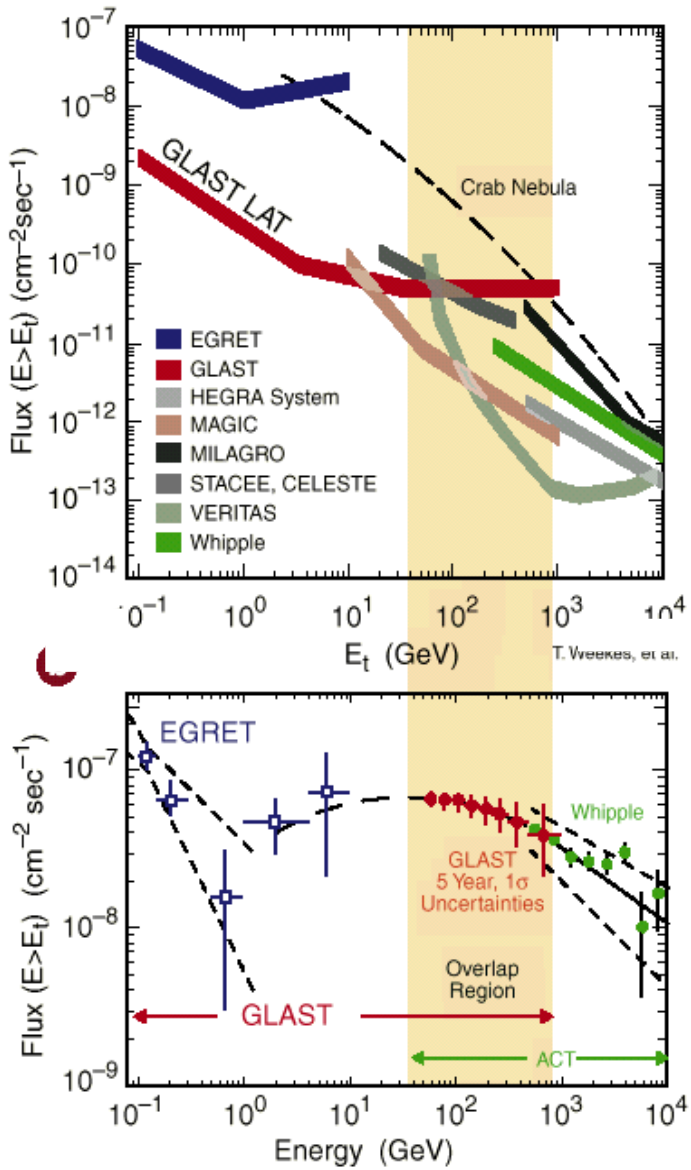
**More than 40 times the sensitivity of EGRET**

**Large Effective Area (20 MeV – 1 TeV)**

**Optimized Point Spread Function (0.35° @ 1 GeV)**

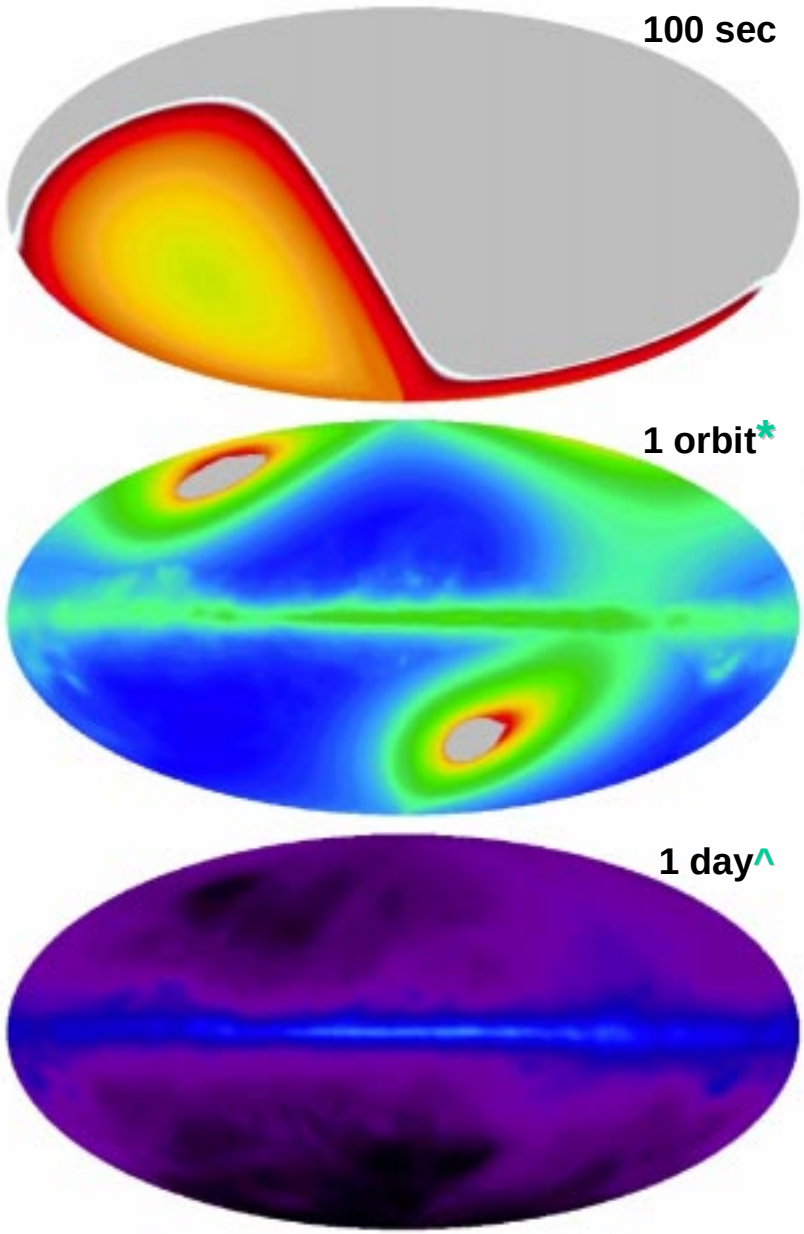
**Wide Field of View (2.4 sr)**

**Good Energy Resolution ($\Delta E/E$ ~ 10%)**



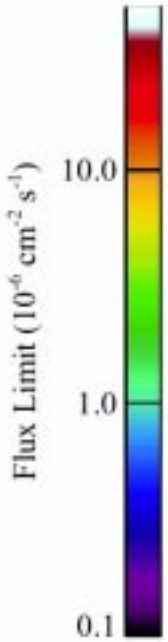
# What makes GLAST unique

## - EGRET's 3rd Catalog in 2 days -




**All 3EG sources + ~ 80 new in 2 days**

**Time Variability Monitoring:** **Flares (Blazars, AGNs, Coronas), Precessions and Glitches (Pulsars), Lensing (AGNs)**

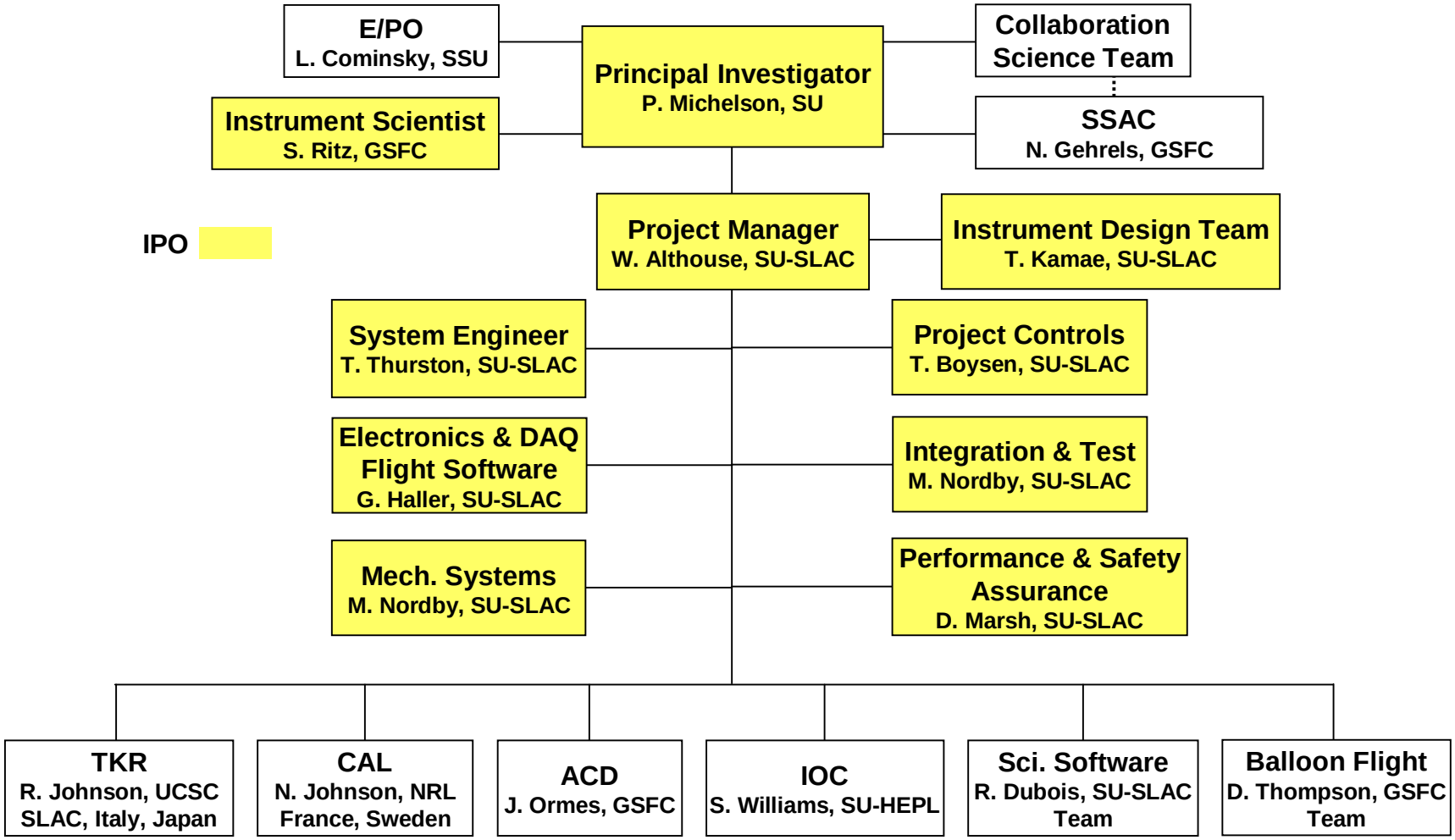



- GRB940217 (100sec)
- PKS 1622-287 flare
- 3C279 flare
- Vela Pulsar
- Crab Pulsar
- 3EG 2020+40 (SNR $\gamma$ Cygni?)
- 3EG 1835+59
- 3C279 lowest 5$\sigma$ detection
- 3EG 1911-2000 (AGN)
- Mrk 421
- Weakest 5$\sigma$ EGRET source

*zenith-pointed, ^"rocking" all-sky scan

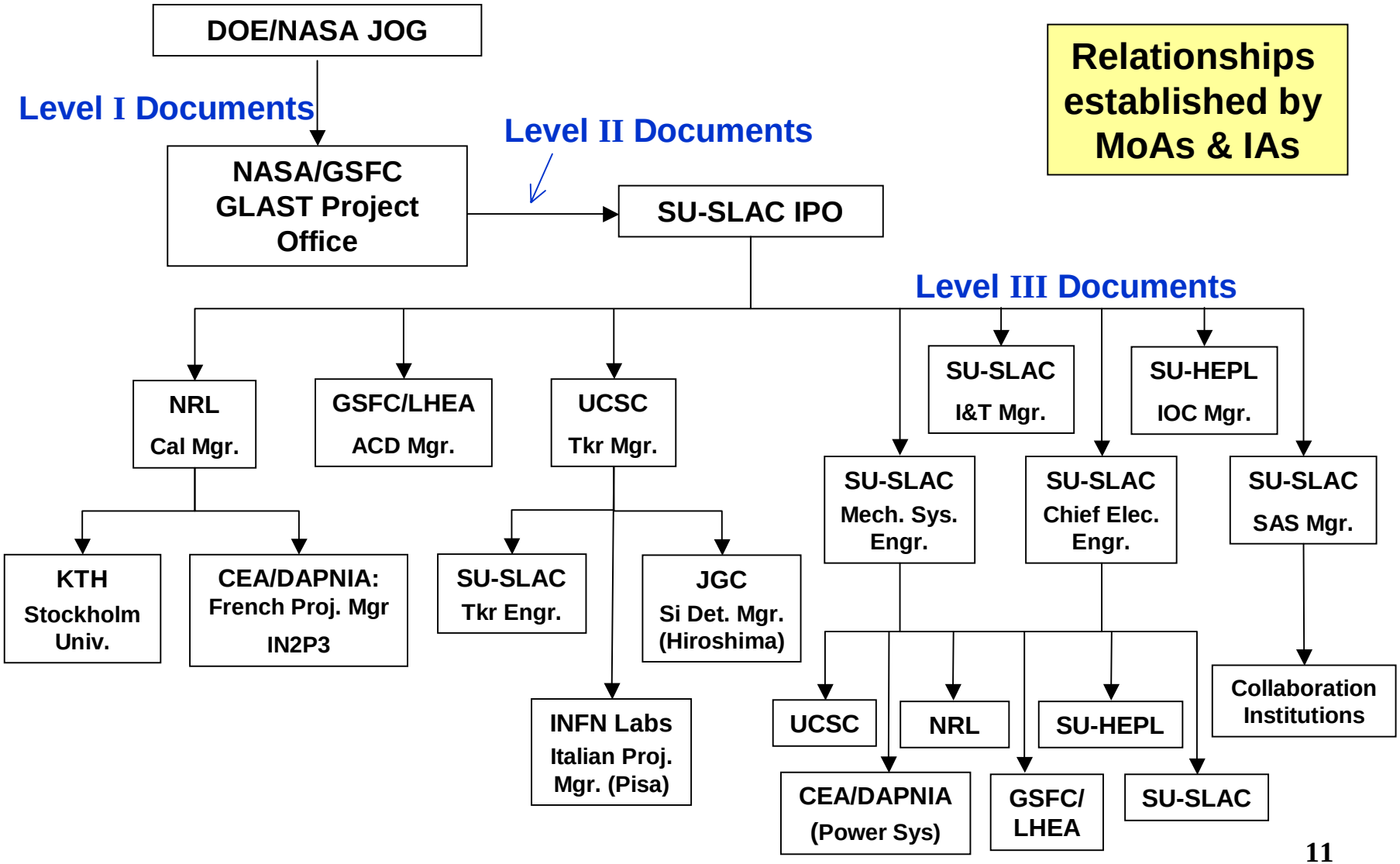
# Where we are now

## - GLAST LAT Organization -



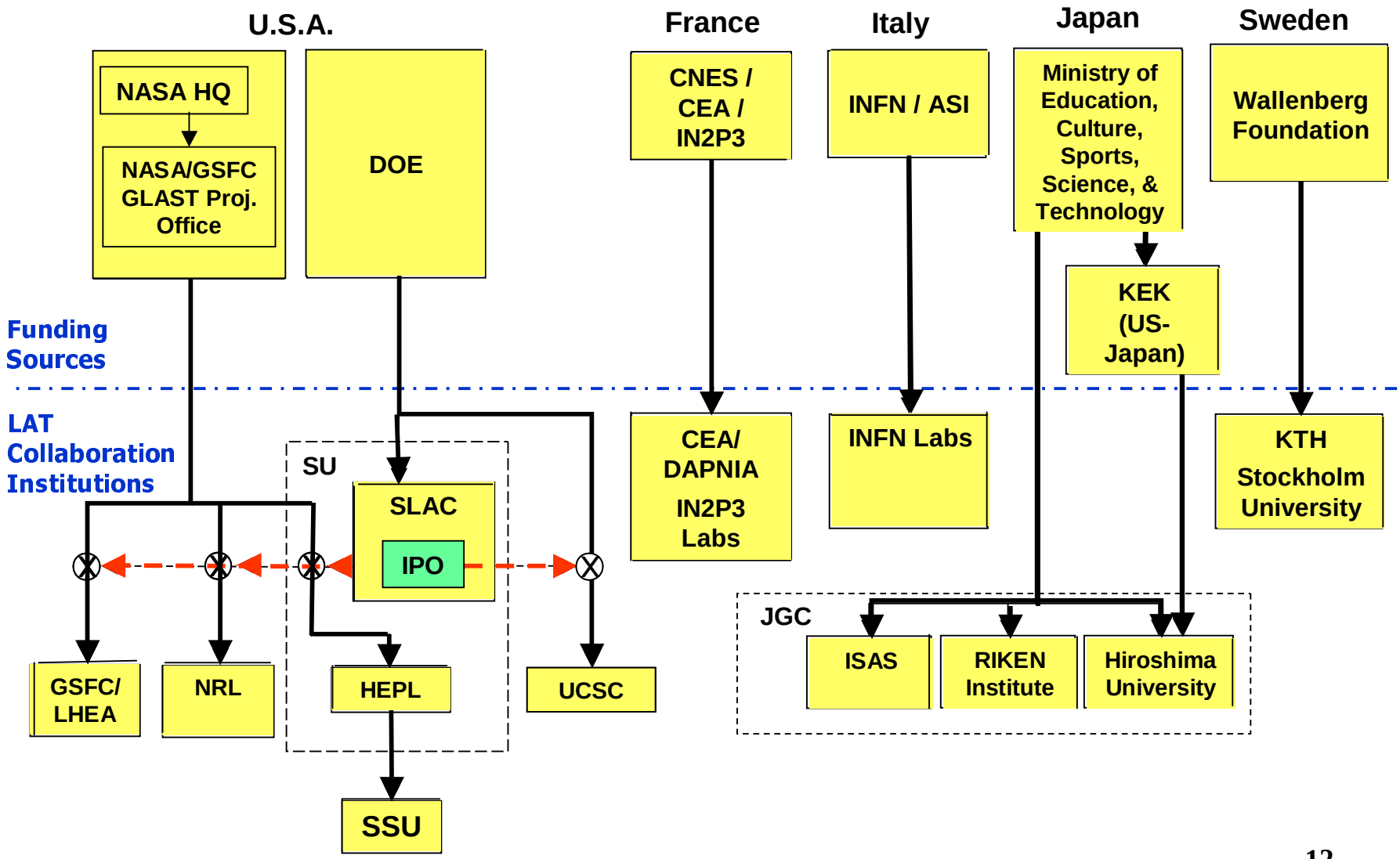
# Where we are now

## - Techinical Direction -



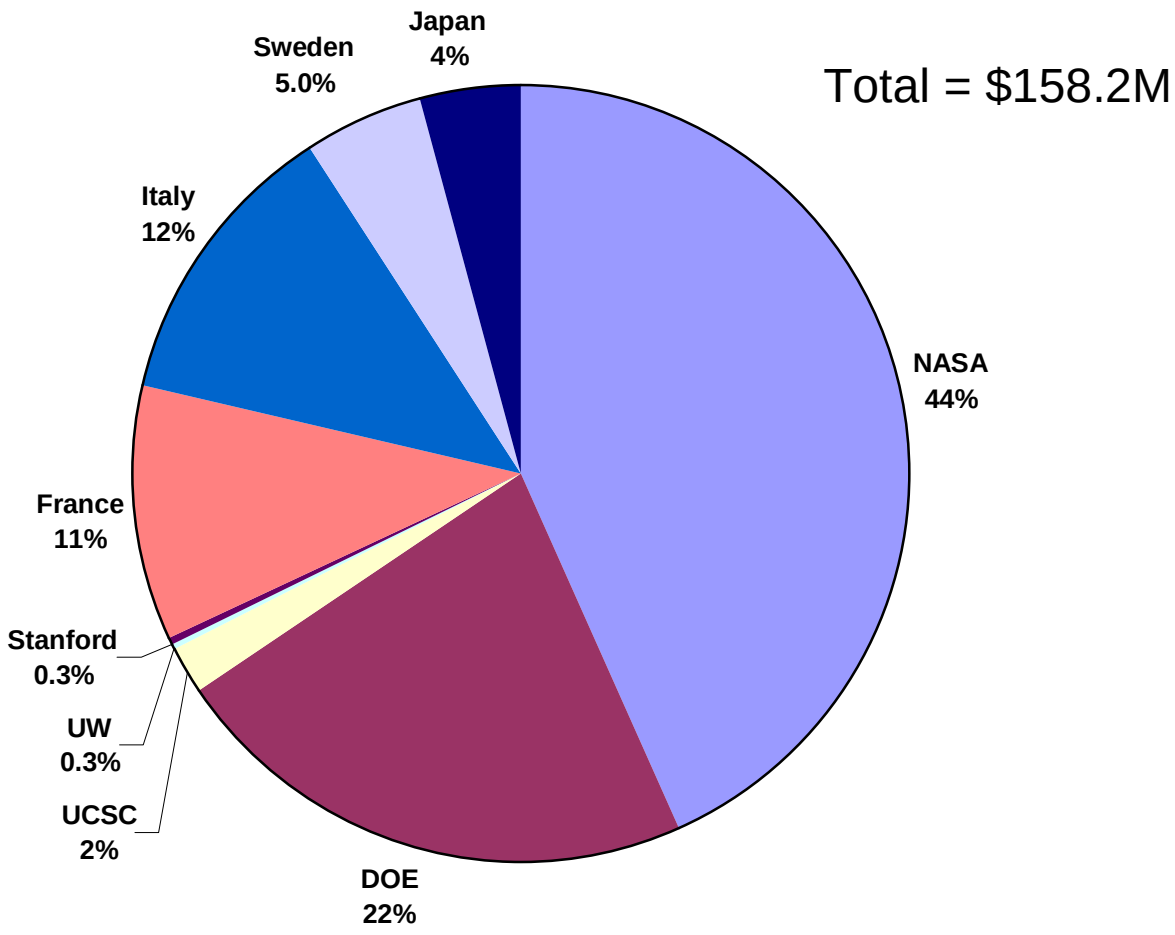
# Where we are now

## - Funding Flow -



# Where we are now

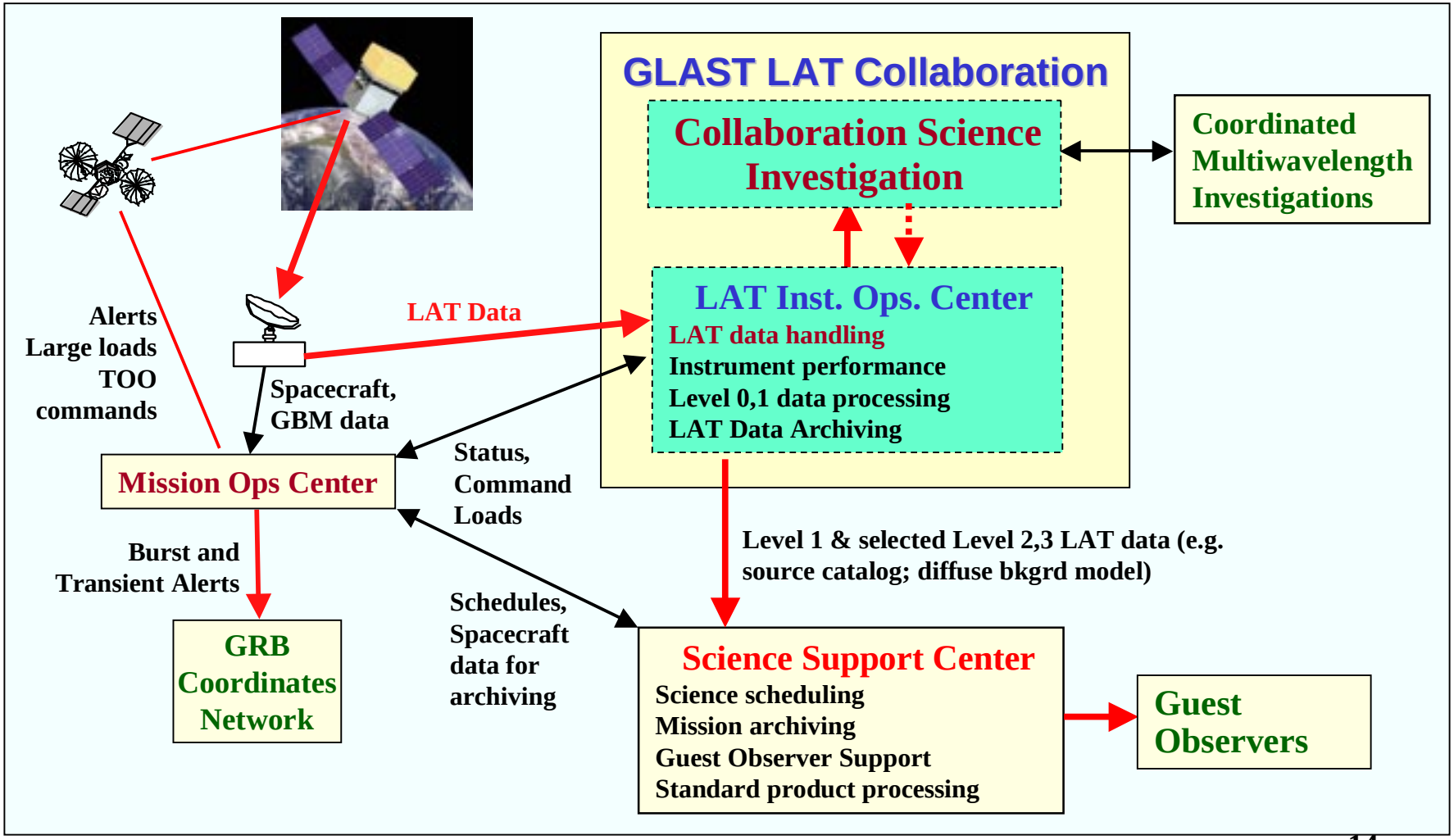
## - Funding -



# Where we are now

## - Data Management Plan -

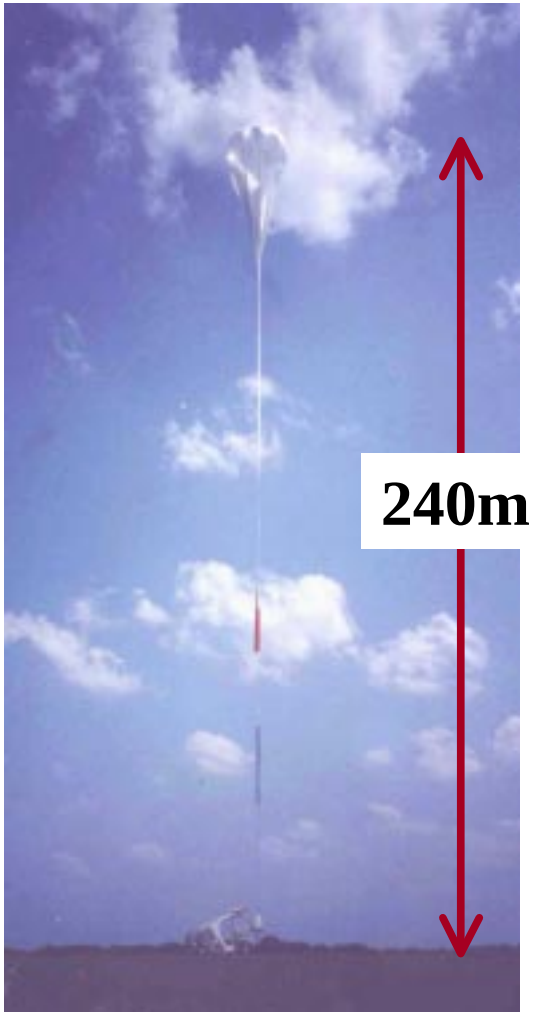
## LAT Data Flow



# Where we are now

## - Balloon Flight Engineering Model successfully flown -

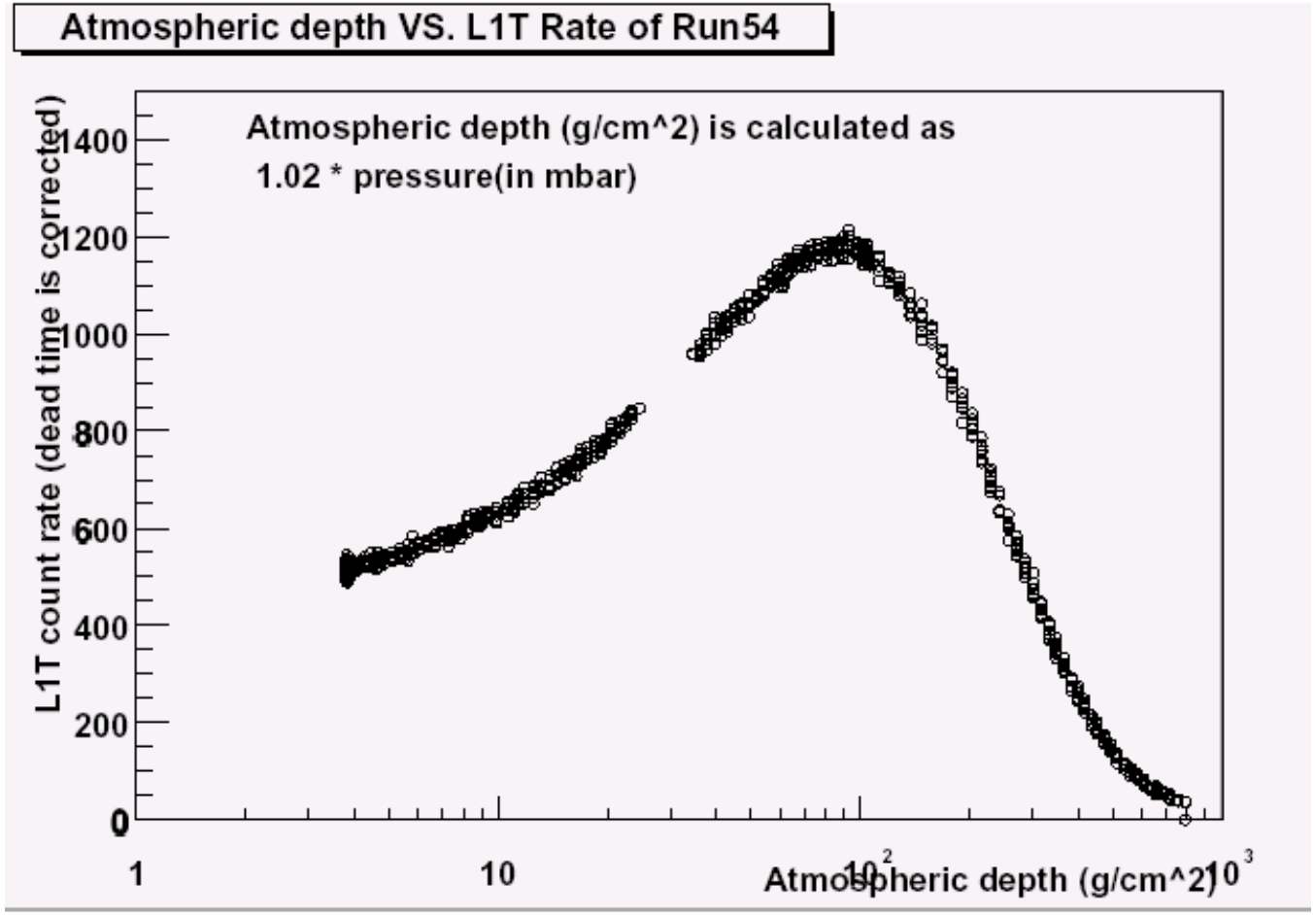
## Morning of August 4 (Saturday), 2001



# Where we are now

## - Three-in-a-row trigger worked quite well -

### L1T rate Vs Atmospheric depth



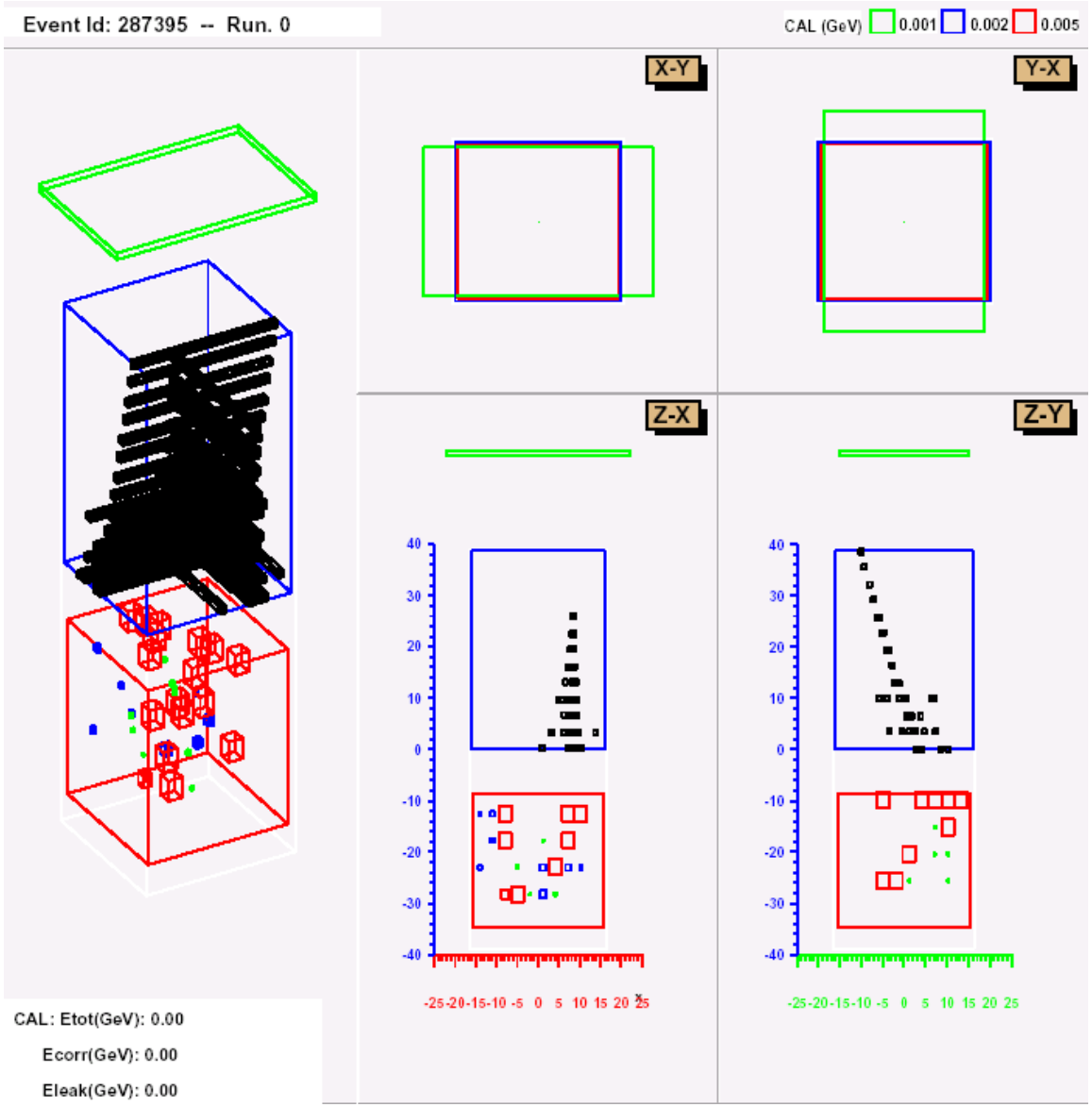
# Where we are now

## - Balloon event gallery No.1 -

**Ev #1: 2km above ground**
**Ev #250000: entering level flight**
**Ev #285594: 15 min. in level flight**

**ACD: PHA 250ch (a little > pedestal)**
**XGT: PHA 205ch (a little > pedestal)**
**Geometry not right.**
**Cal: No calibration done yet**

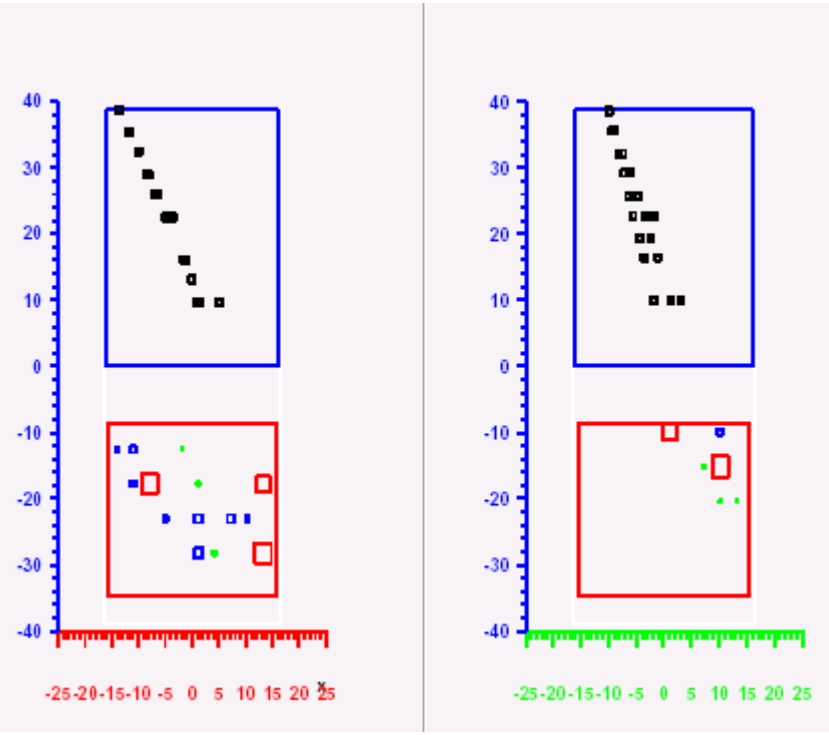
**A beautiful electron shower**



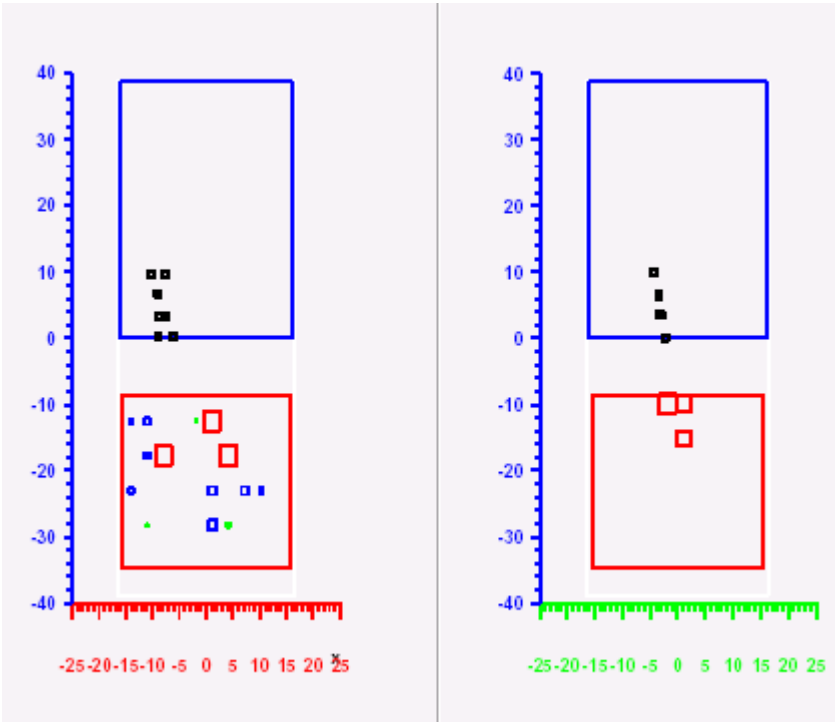
# Where we are now

## - Balloon event gallery No.2 -

### #16044: A beautiful gamma



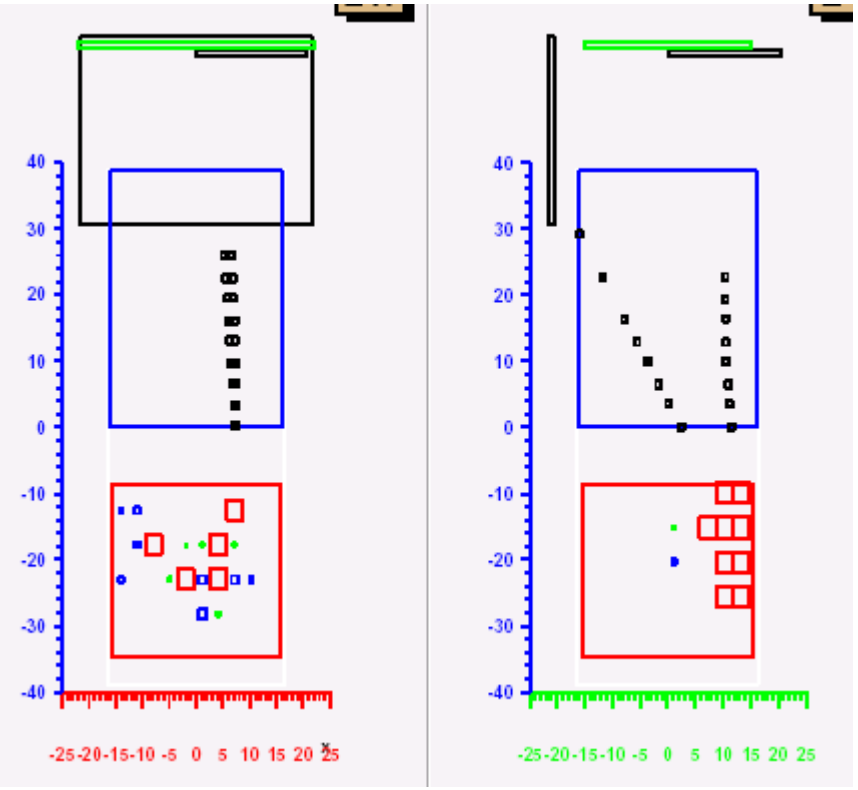

### #19060: A beautiful gamma



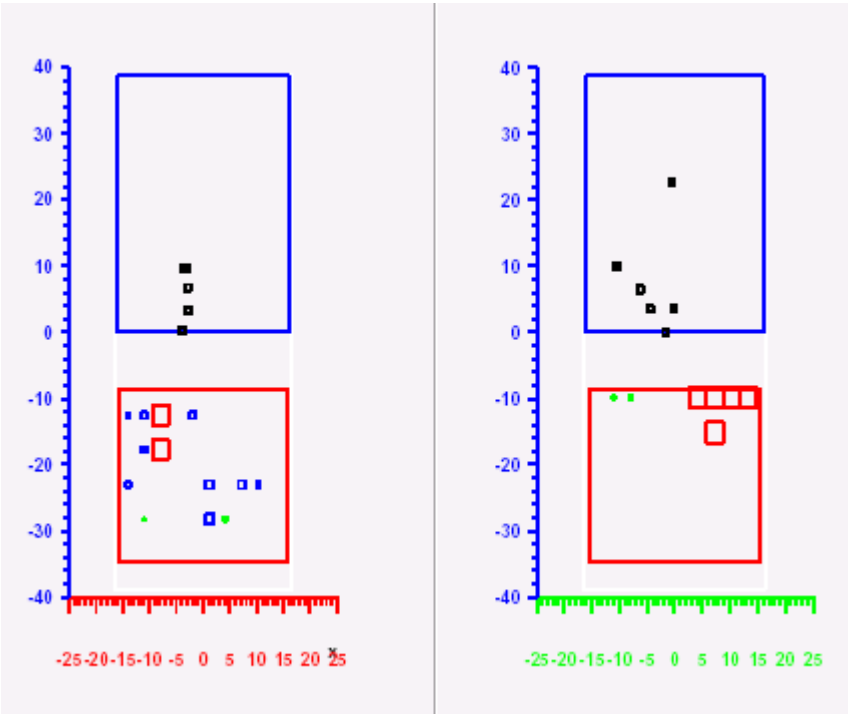
# Where we are now

## - Balloon event gallery No.3 -

### #276404: A beautiful upward V



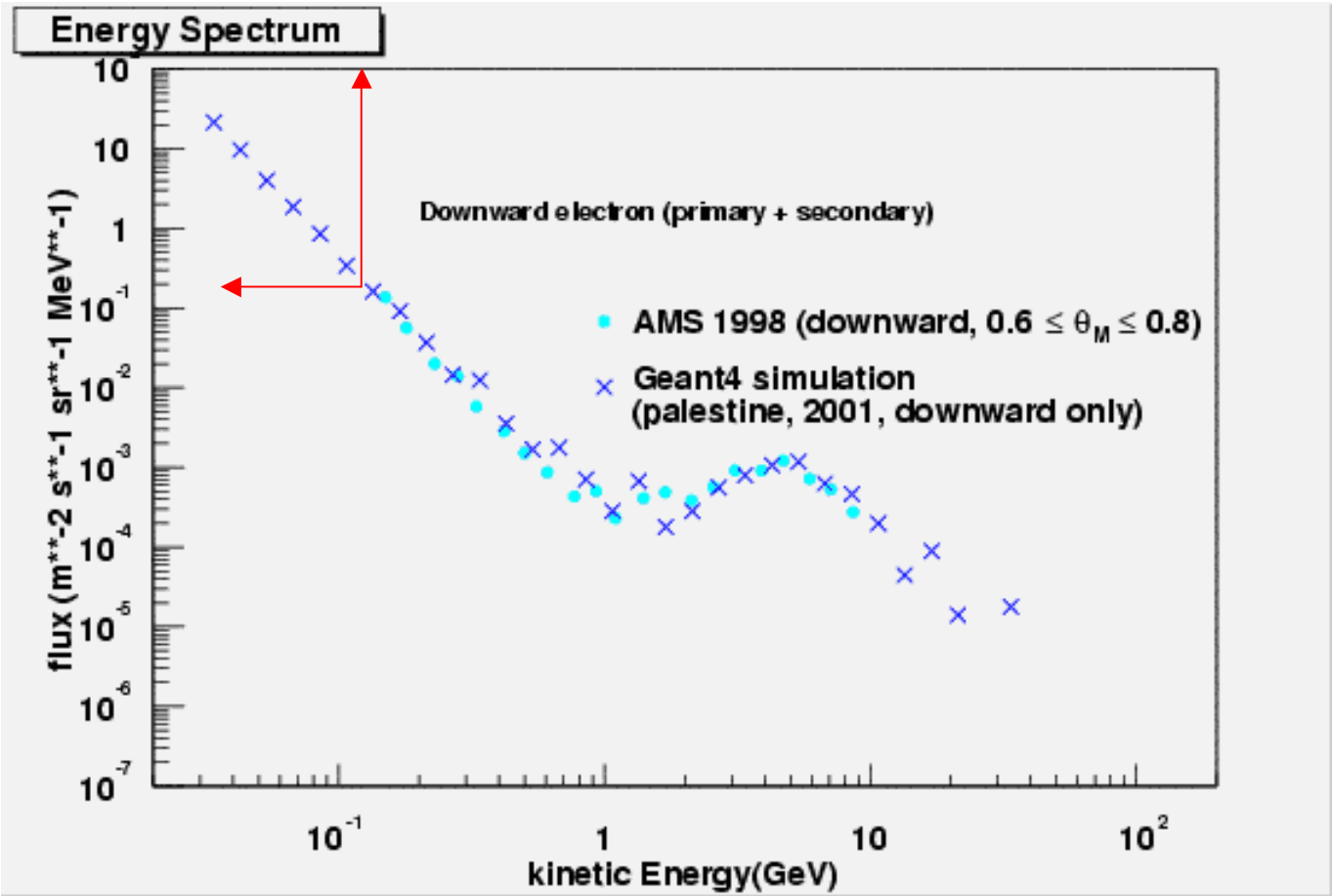

### #277127: Something entering sideway



# Where we are now

## - Understanding the data: Low energy $e^-/e^+/\gamma$ spectra -

- No reliable data below xtrapolate down to ~100 MeV
- We proceed being guided by Geant4 simulation



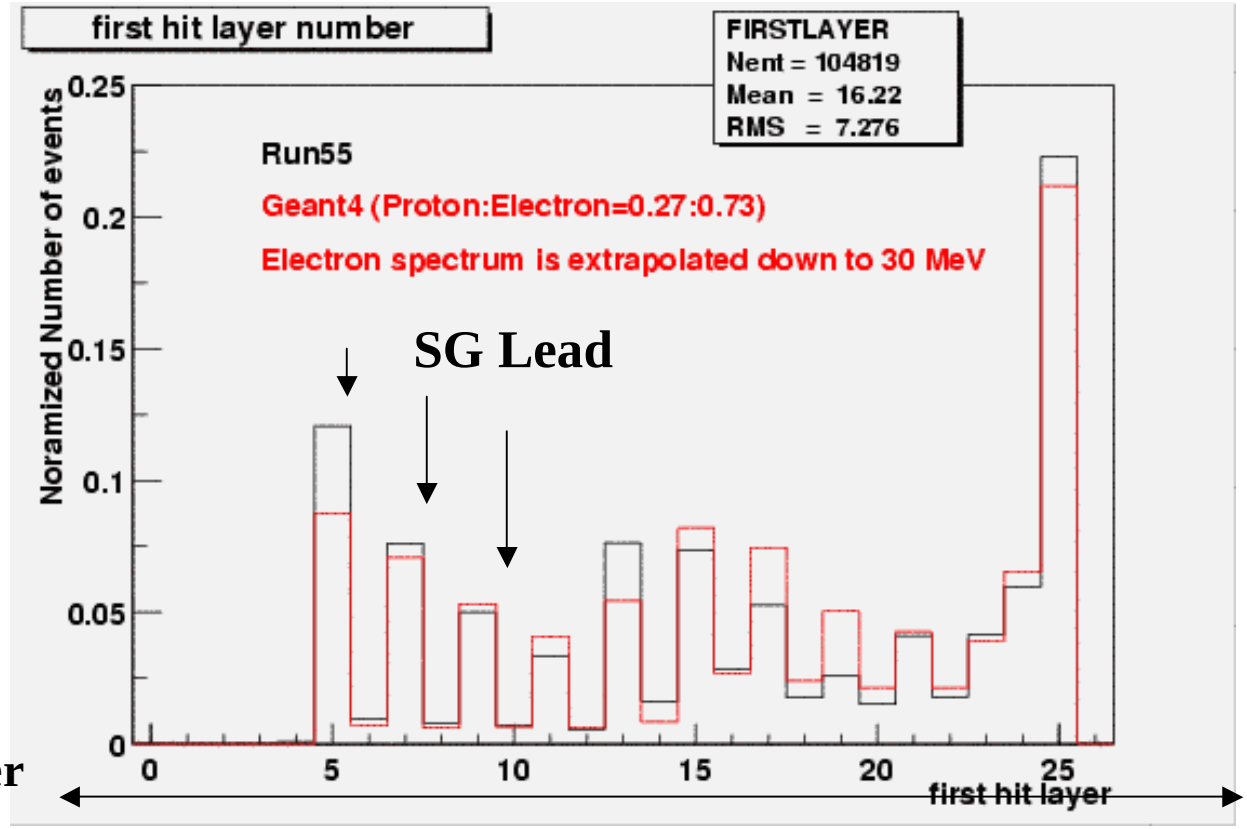
# Where we are now

## - BFEM data: Distr. of the top-most layer -

**BFEM data in level flight vs. Geant4 simulation with soft electrons**

Note: 1) The even/odd difference is due to the layer spacing

2) 25th is fully instrumented but next several layers are not

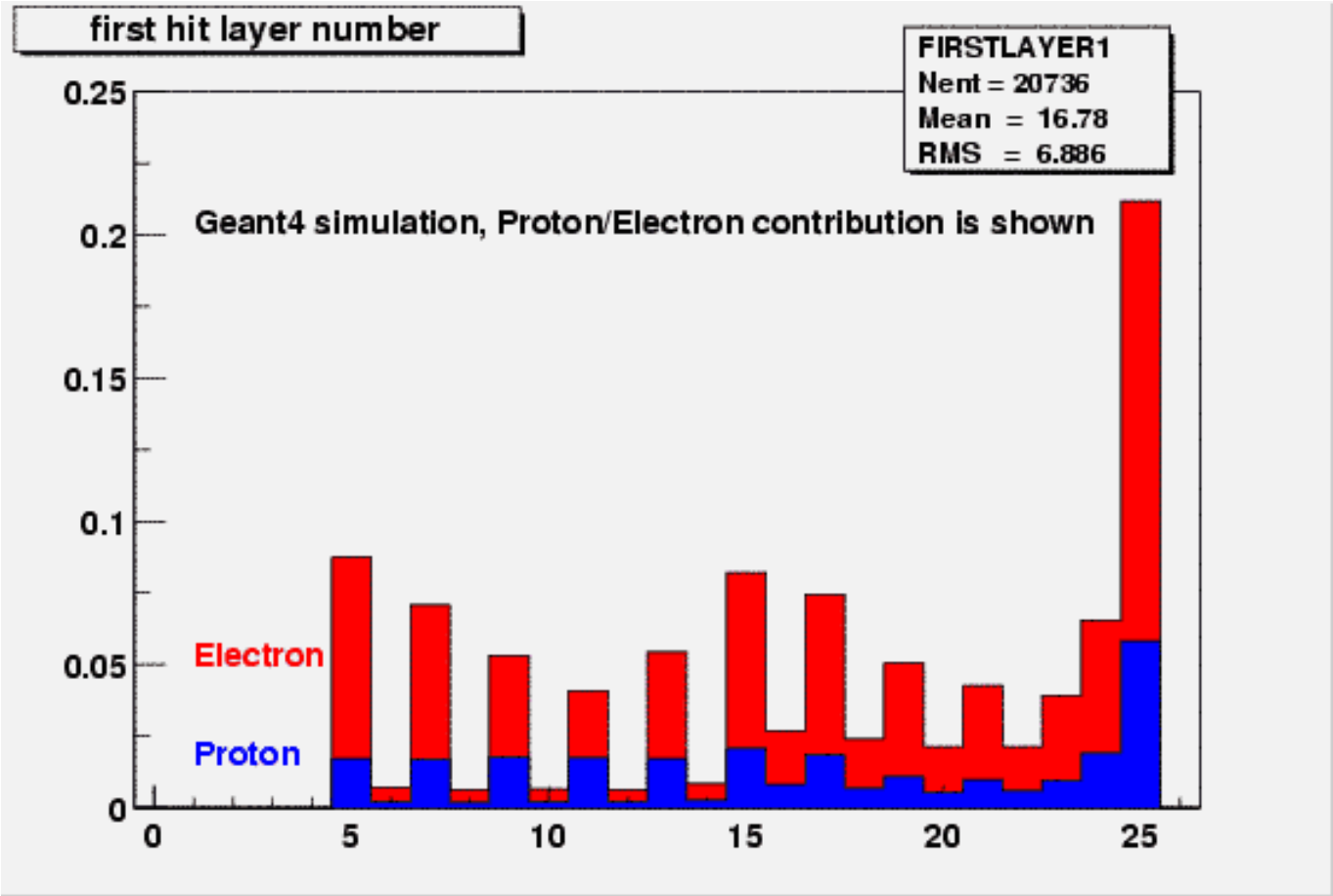



**Calorimeter** **Top**

# Where we are now

## - BFEM data: Distr. of the top-most layer: proton and electron -

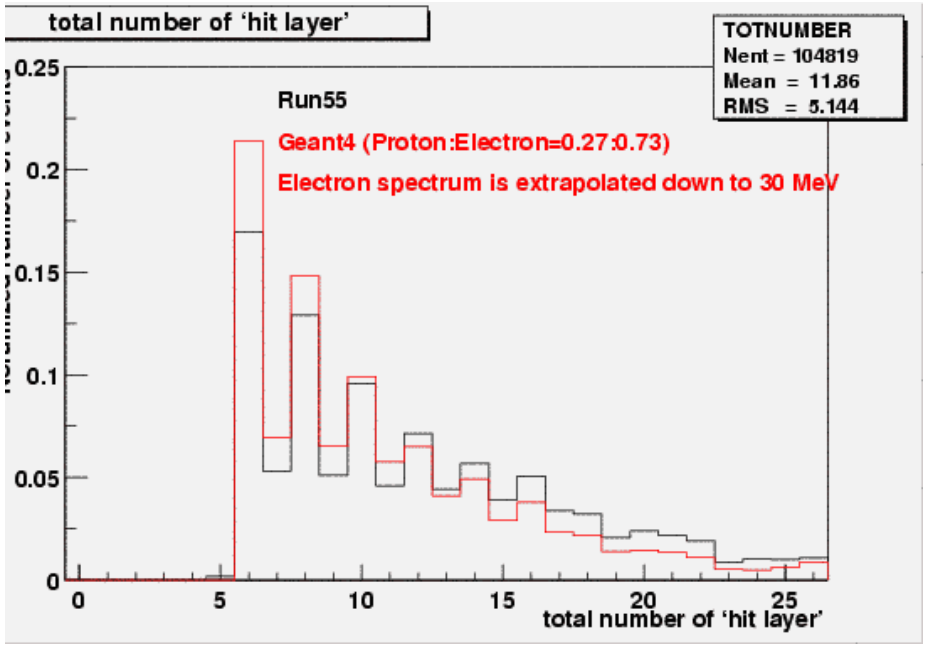
G4 simulation, proton/electron contribution



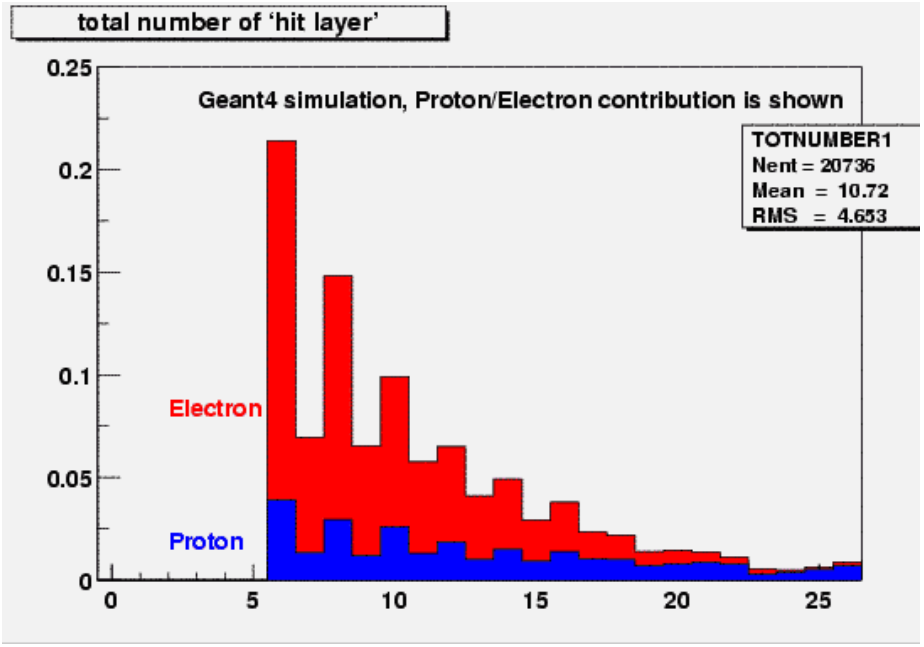
# Where we are now

## - BFEM data: Distr. of the total hit layers -

### BFEM data vs. G4 simulation

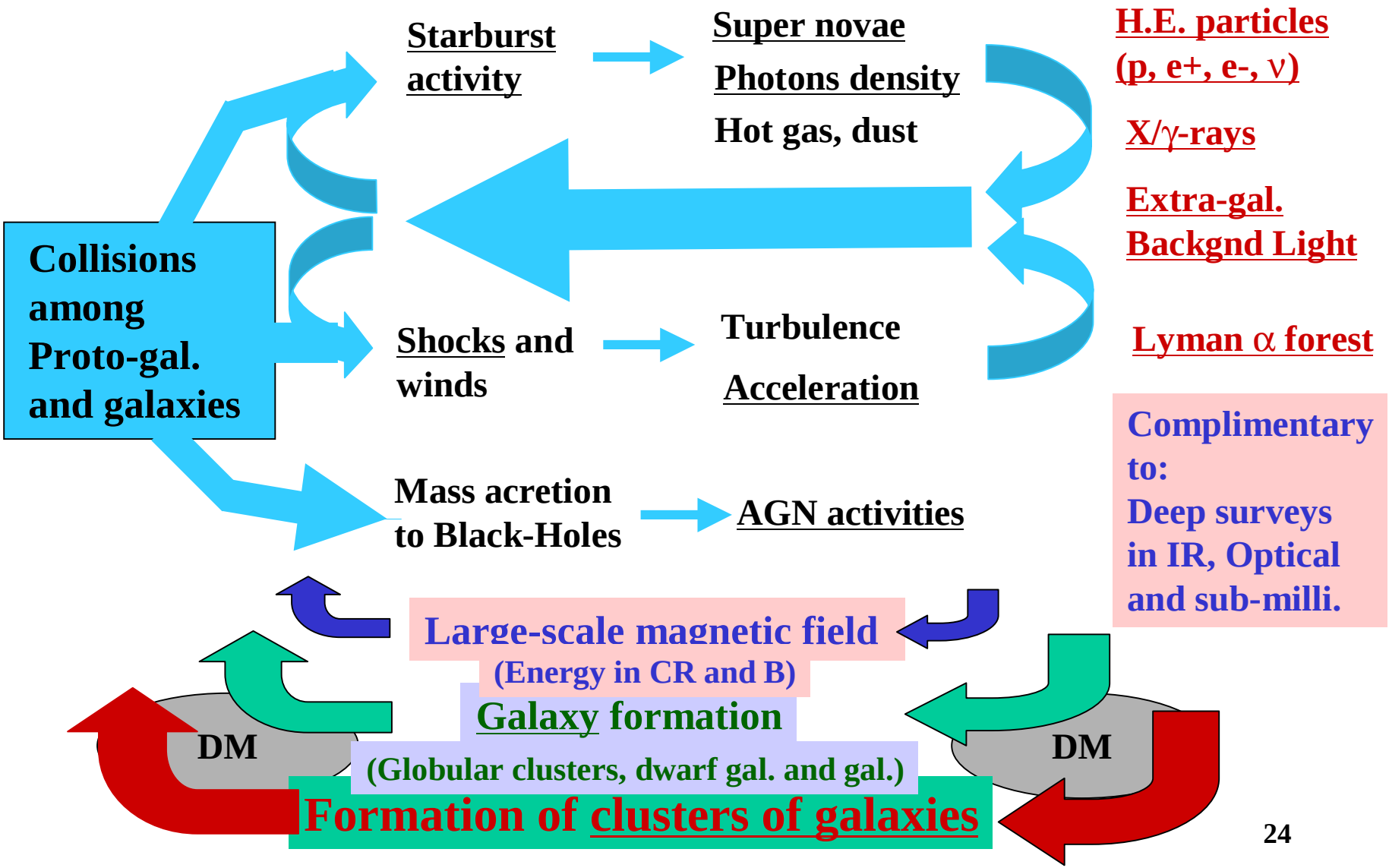



### Proton/electron contribution



# New Way to Study H. E. Universe

## - GLAST and study of the Early Universe -



# New Way to Study H. E. Universe

## - Merger of galaxies are very common in the Early Universe -

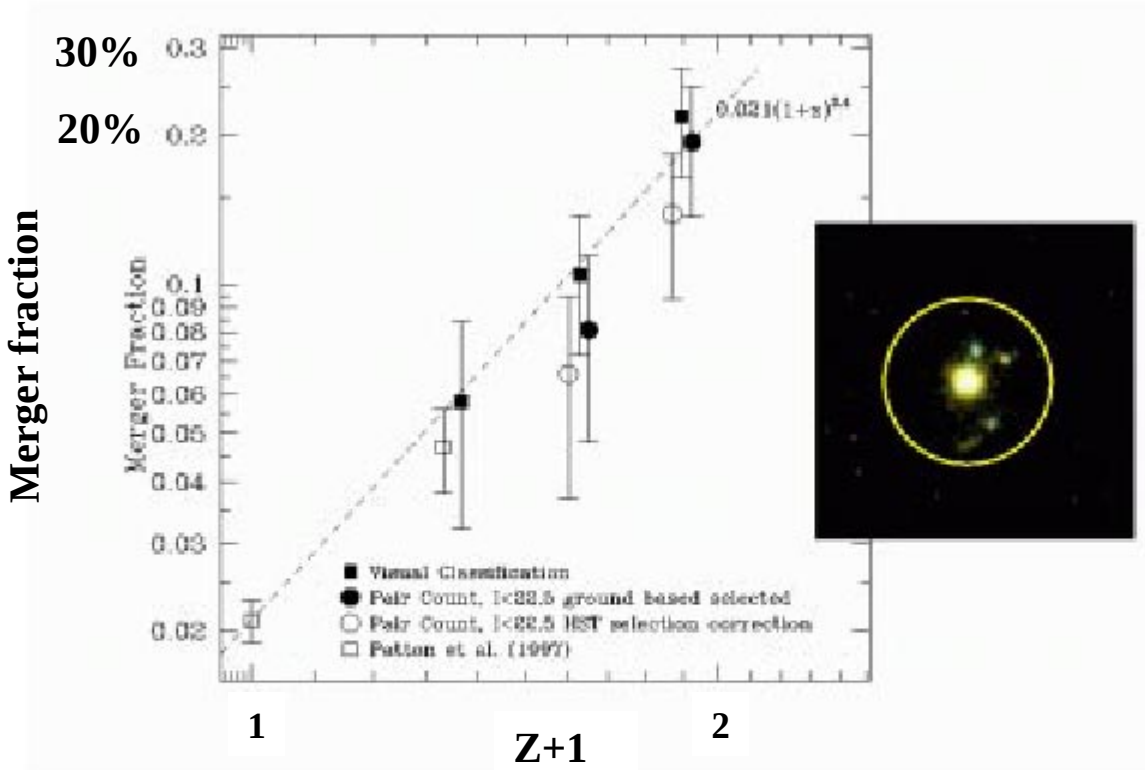



**Figure 16:** *An increase in the merger* fraction *as a function of redshift from the HST analysis of LeFevre et al (2000). Galaxies of known redshift were examined for satellites brighter than a fixed rest-frame luminosity within a projected radius of* $20h^{-1}$ *kpc and corrections made for unrelated line-of-sight contamination. This redshift-dependent merger* rate *was adopted by Brinchmann & Ellis (2000) in Figure 15.*

# New Way to Study H. E. Universe

## - Large structure formation in the Early Universe -

**z~1000** — **Decoupling between radiation and matter:**

Energy density of matter: ~ $a(t)^{-3}$

Energy density of radiation: ~ $a(t)^{-4}$

**Baryon Jeans mass ~ $10^6$ Solar Mass** ~ globular clusters?

**z~30** — **10kpc scale structure?** ~ inner part (bulge) of galaxies?

- Search for AGNs
- Search for GRBs
- Study for bulge

**z~4-6** — **Proto-galaxies and star formation** ~Quasars, AGNs, and their collisions

- Search for AGNs
- Absorption by EBL
- Search for GRBs

**z~1-2** — **Galaxies and star formation** Clusters of galaxies?

- Search for AGNs and star burst galaxies
- Search for GRBs
- Gammas from clusters and large scale shock fronts

# New Way to Study H. E. Universe

## - Absorption of H.E. photons by Extragal. Background Light -

$\gamma\gamma \longrightarrow e^+e^-$

**Target photons E=12eV** ⟷ **Probe photons E>~50GeV**

**Energy at detector for fixed photon energies (E) in the co-moving frame**

**Target photon density**

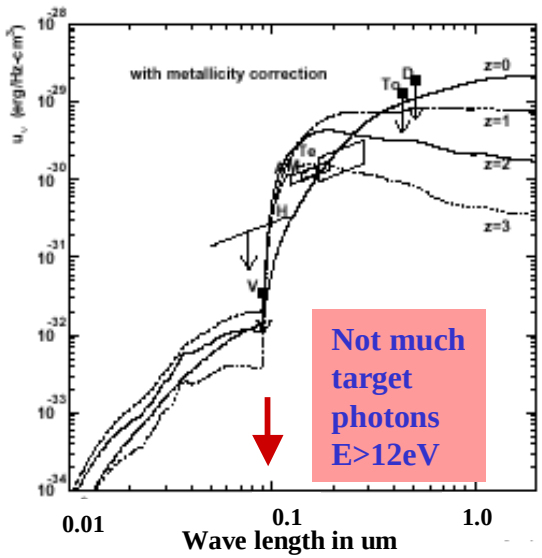



FIG. 4.—Intergalactic comoving radiation energy density from stars, calculated with the metallicity correction function $\mathscr{L}$ included, as a function of wavelength for redshifts $z = 0$ (*solid line*), $z = 1$ (*dashed line*), $z = 2$ (*dotted line*), and $z = 3$ (*dot-dashed line*), for a Hubble constant value of $h_0 = 0.5$. (The energy density scales as $h_0$; see eq. [7] and § 3.) QSO contributions to the UV energy density have a negligible effect on extragalactic gamma-ray absorption, and so are neglected in our calculations. Also shown in the figure are the high-latitude measurements of Anderson et al. 1979 ("A"), Tennyson et al. 1988 ("Te"), and Martin, Hurwitz, & Bowyer 1991 ("M"), and upper limits from Vogel et al. 1995 ("V"), Toller 1983 ("To"), Dube, Wickes, & Wilkinson 1979 ("D"), and Holberg 1986 ("H"). These data should be compared with only the $z = 0$ (*solid line*) curve.

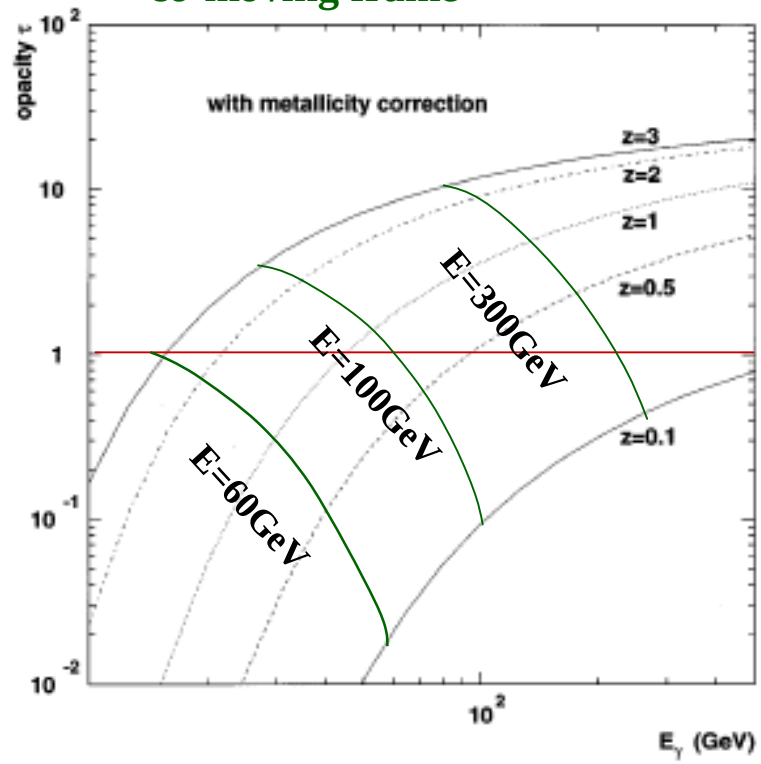



FIG. 6.—Opacity $\tau$ of the universal soft photon background to $\gamma$-rays as a function of $\gamma$-ray energy and source redshift. These curves are calculated with the metallicity correction function included in the expression for stellar emissivity. As discussed in the text, these results are independent of the value chosen for $h_0$.

# New Way to Study H. E. Universe

## - Several classes of γ-emitting AGN/QSO -

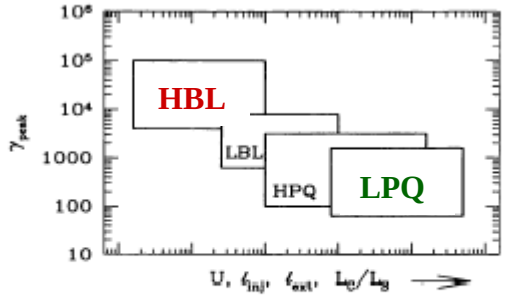



**Figure 7.** Schematic representation of the proposed unifying scheme: the sequence HBL, LBL, HPQ, LPQ corresponds to an increase in the external radiation field, the total energy density and the injected power. These in turn result in a decrease of $\gamma_{peak}$ and an increase in the Compton dominance.

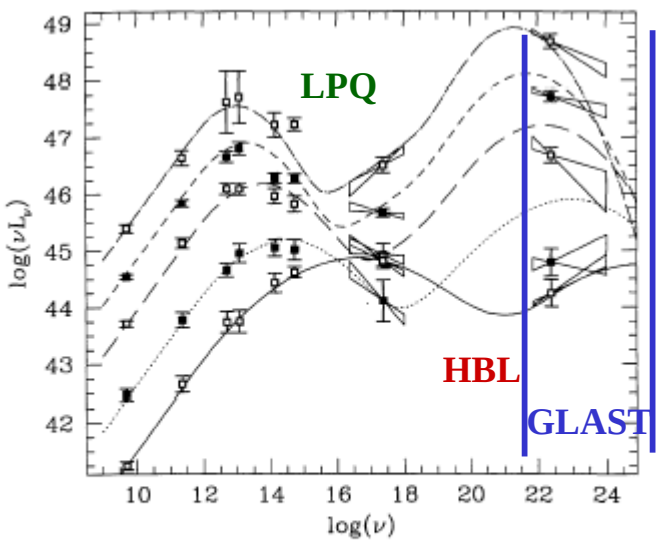



**Figure 12.** Average SEDs for the 'total blazar sample' binned according to radio luminosity irrespective of the original classification. The overlaid curves are analytic approximations obtained according to the one-parameter-family definition described in the text.

## Discovery by Beppo-SAX

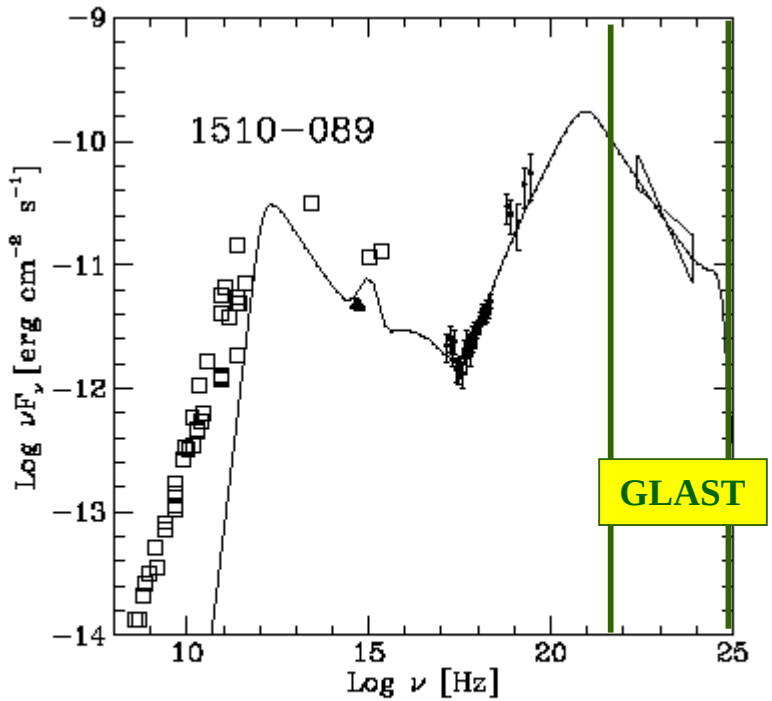
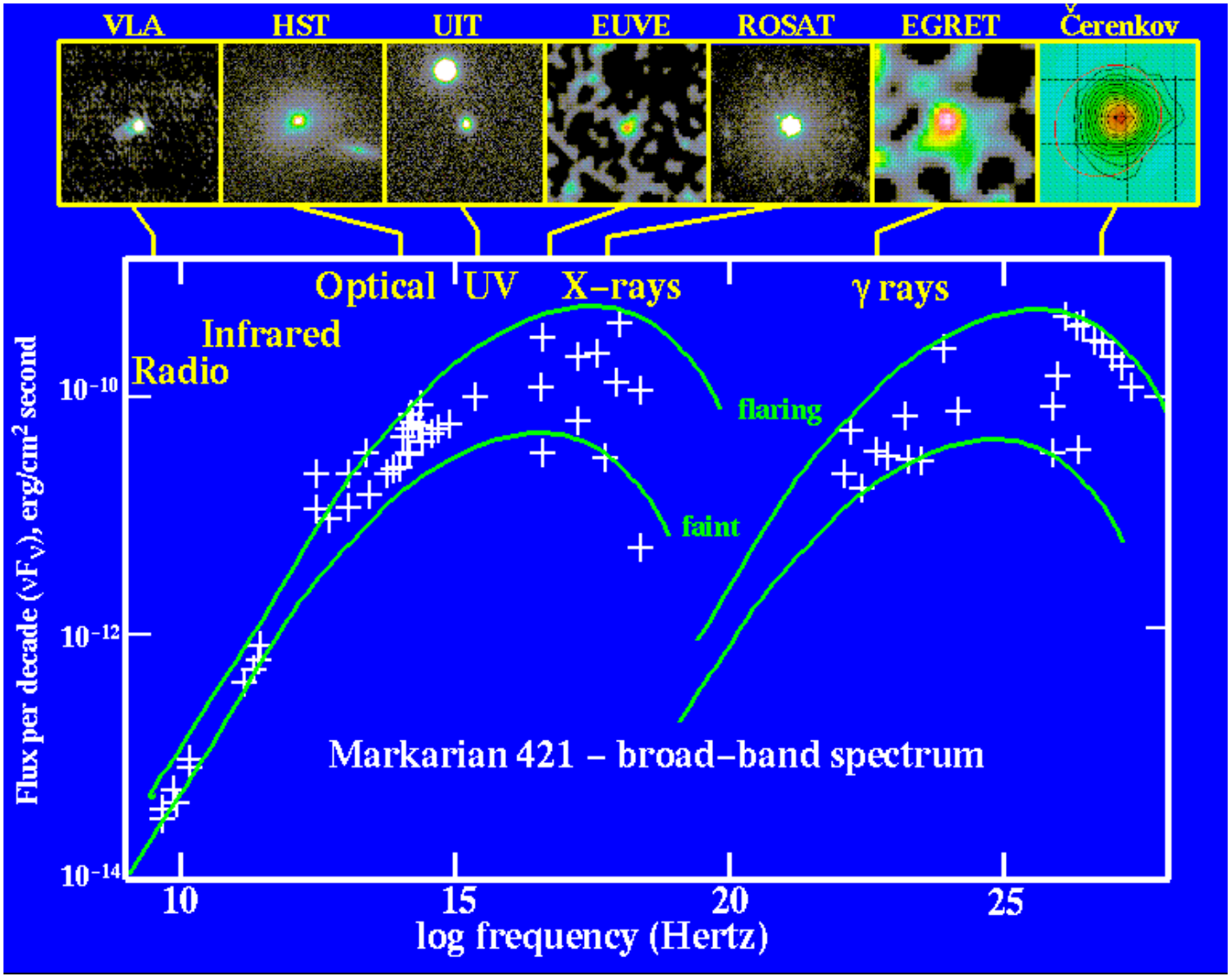



FIG. 8.—Overall SED of 1510−089 with the spectrum calculated using the homogeneous EC model (see text). Data are from Gear et al. (1994), Tornikoski et al. (1996), Landau et al. (1986; radio), Pian & Treves (1993; UV) and Hartman et al. (1999; EGRET). The bump around $10^{16}$–$10^{17}$ Hz is due to the SSC component.

**Many more γ-emitting objects (AGN, Quasar, BL Lac etc.)**

# New Way to Study H. E. Universe

## - Multiple wavelength campaign -



# VLBA 22 GHz Observations of 3C120

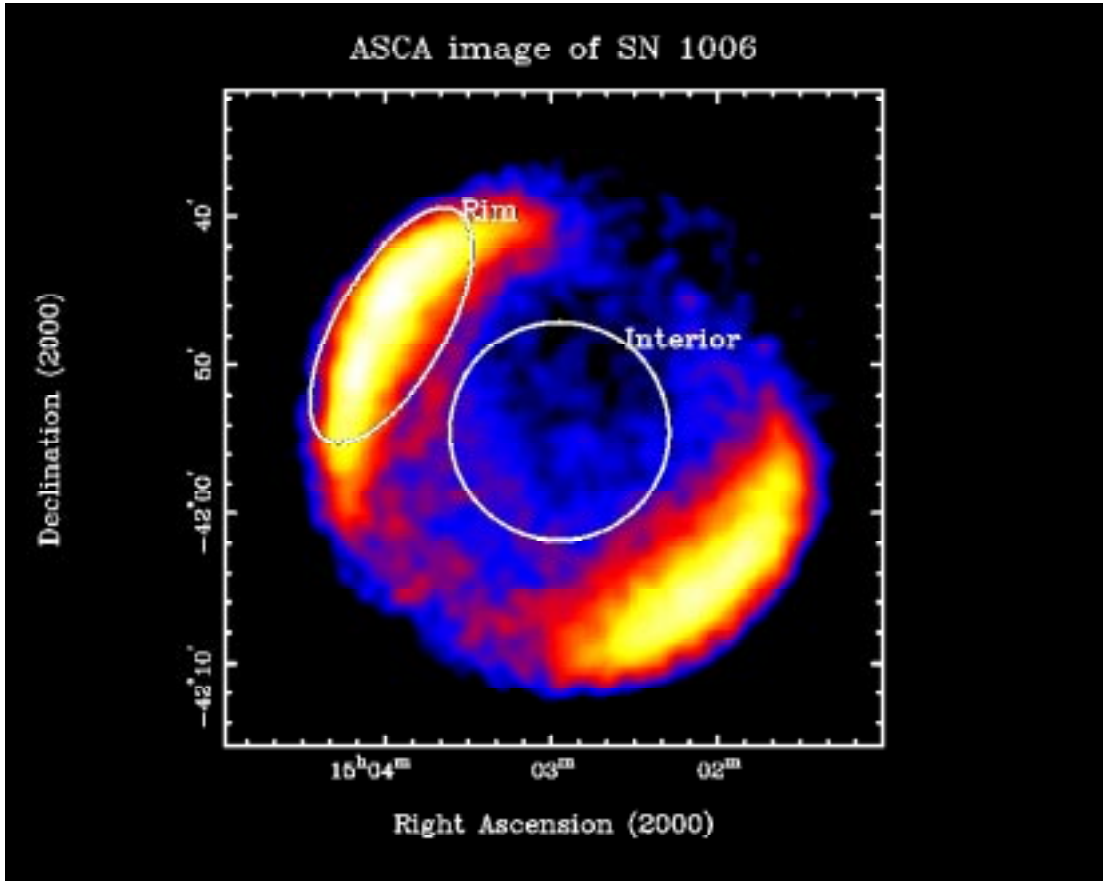

| | |
|---|---|
| José–Luis Gómez | IAA (Spain) |
| Alan P. Marscher | BU (USA) |
| Antonio Alberdi | IAA (Spain) |
| Svetlana Marchenko–Jorstad | BU (USA) |
| Cristina García–Miró | IAA (Spain) |

# New Way to Study H. E. Universe

## - Super Nova Remnants: Source of high energy particles -

**Super Nova Remnant 1006 seen by ASCA (X-ray band)**

**Image of synchrotron radiation by high energy (~200TeV) electrons in the accelerating shock front in SN1006**



# New Way to Study H. E. Universe

## - New classes of pulsars and evolution of known pulsars -

- **Synchrotron emission (X-ray) by high energy electrons (~100GeV) from the neutron star's magnetosphere (Magnetic induction: Pulsed)**
- **Synchrotron emission (X-ray) by high energy electrons (~100TeV) from the nebula around the neutron star's magnetosphere (Accelerating shock front: Unpulsed)**

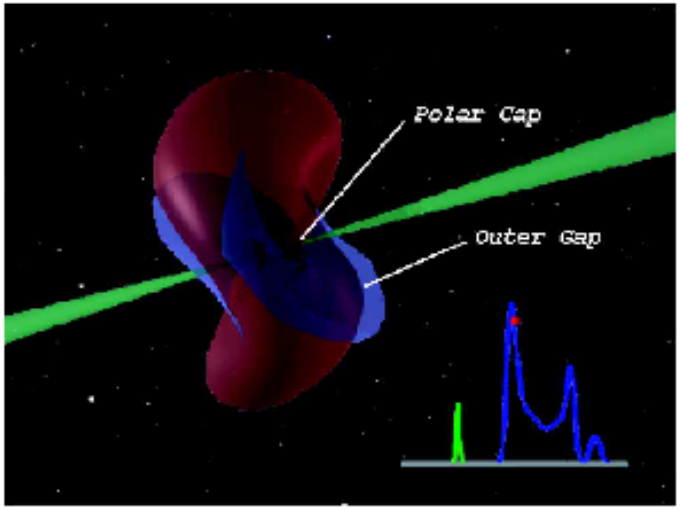
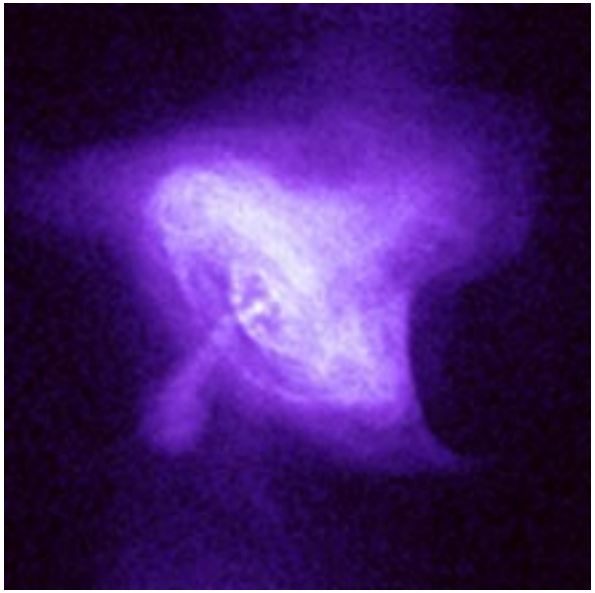



Figure 7-2 Three-dimensional simulation of the Vela pulsar. The spin axis is vertical. The red surface is the closed zone, the polar cap is at the base of the green (radio) beam, and the outer gap surface is in blue. The light curve, calculated for the Outer Gap model, has the same color coding.



**The bell-shaped synchrotron nebula around the Crab pulsar (the small dot at the center of the opening of the bell-shaped nebula). A string-like flow of electrons along its rotation axis is also visible.**

# New Way to Study H. E. Universe

## - New class of pulsars: Radio-quiet, gamma-ray loud pulsars -

- **Until recently, all pulsars have been discovered in Radio Band, with one exception of Geminga.**
- **In the past 5 years several pulsars have been discovered in X-ray. They are generally very weak in Radio Band. ⟶ Many radio-quiet pulsars to be discovered**
- **We now expect to find many radio-quiet pulsars. We can see throught the Galaxy with gamma-rays but not with radio wave. So we will study distribution of pulsars (ie. NS's) in the Galaxy. ⟶ History of star-formation activity in our Galaxy**

**Geminga's pulse profile by EGRET**

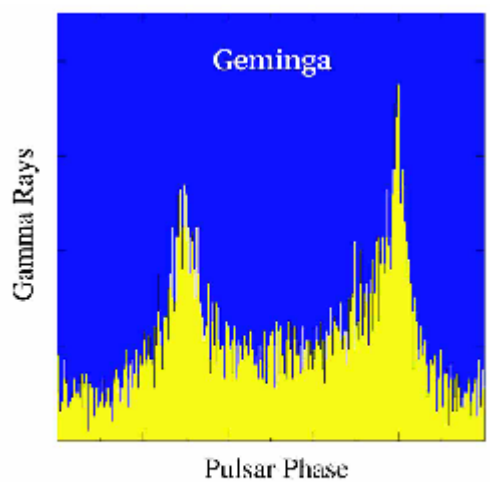
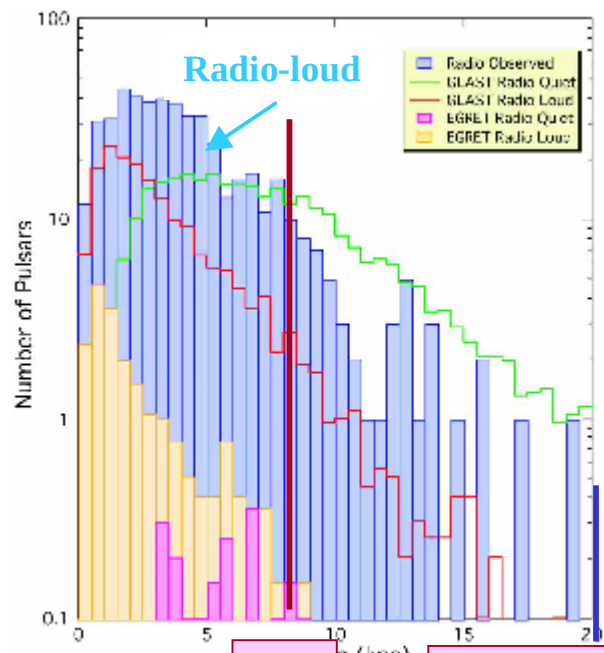



**Figure 7-1 Light curve of the Geminga pulsar (period 237 ms) observed by EGRET in gamma rays above 100 MeV.**



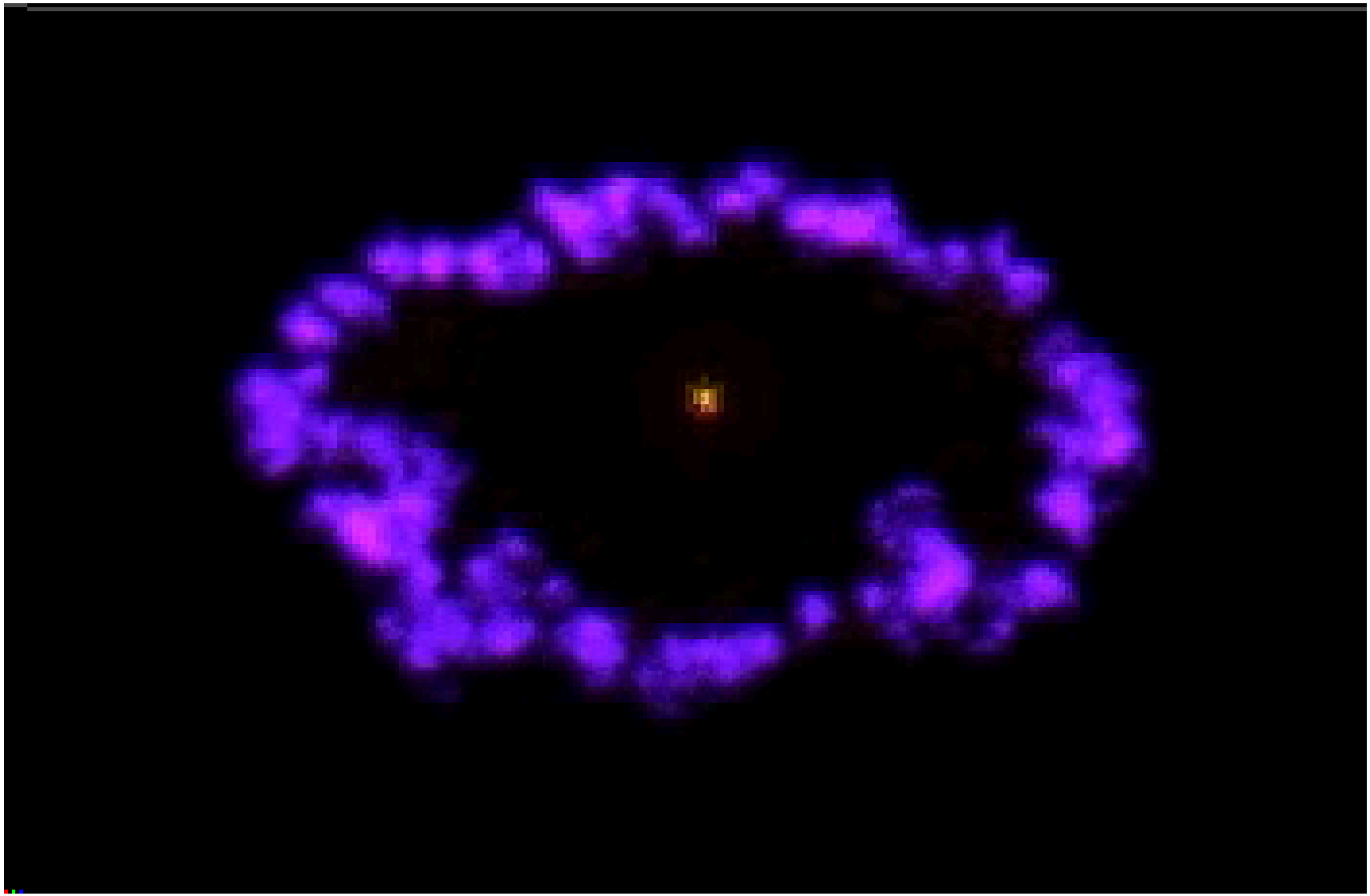

**GLAST's radio-quiet pulsar survey**

**GC**

**The other end of Galaxy**

# New Way to Study H. E. Universe

## - Interaction of shock fronts and ISM: SN1987A -



# New Way to Study H. E. Universe

## - Propagation of Cosmic protons and electrons -

**Gamma Cygni SNR: Pulsar, SNR, and cosmic-ray interaction with ISM**

↓

**Measurement on cosmic-ray proton and electron fluxes**

**Radio image of Molecular H line (21cm)**

**EGRET image**

**GLAST image (simulation)**

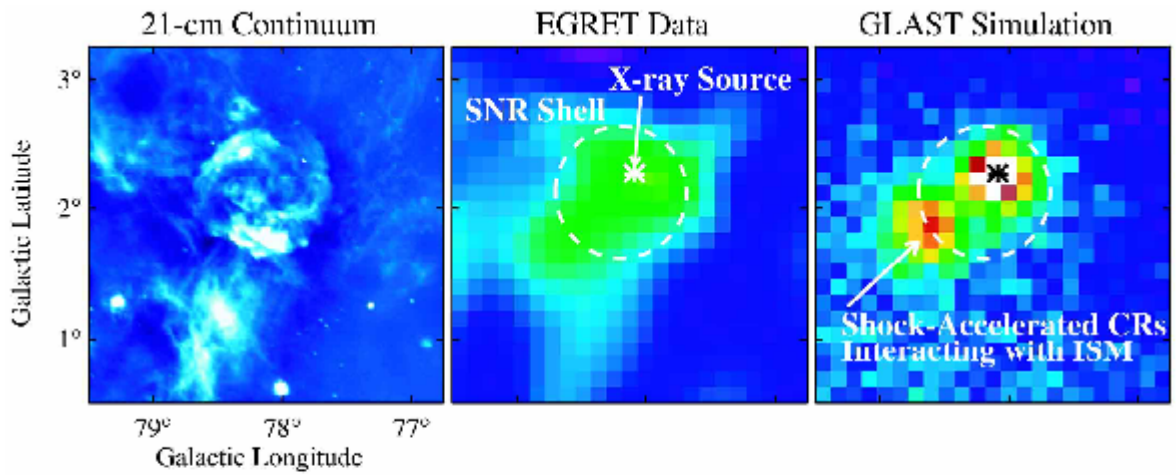


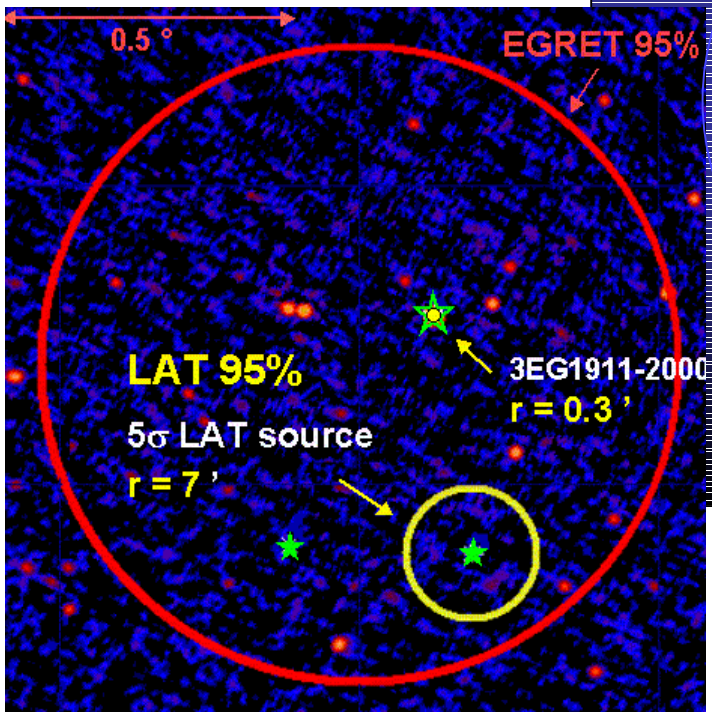

**Figure 8-2** Radio continuum emission of the Gamma Cygni SNR at 1.4 GHz from the (Canadian Galactic Plane Survey, English et al. 1998 compared with EGRET observed and GLAST simulated images > 1 GeV. The dashed circles indicate the location of the shell of the SNR (Higgs et al. 1977). An X-ray source suspected to be a gamma-ray pulsar (Brazier et al. 1996) is shown as an asterisk . In the GLAST model of data from a 1-year sky survey, the EGRET flux has been partitioned between the pulsar and a region at the perimeter of the shell where the CRs are interacting with an ambient interstellar cloud.

# New Way to Study H. E. Universe

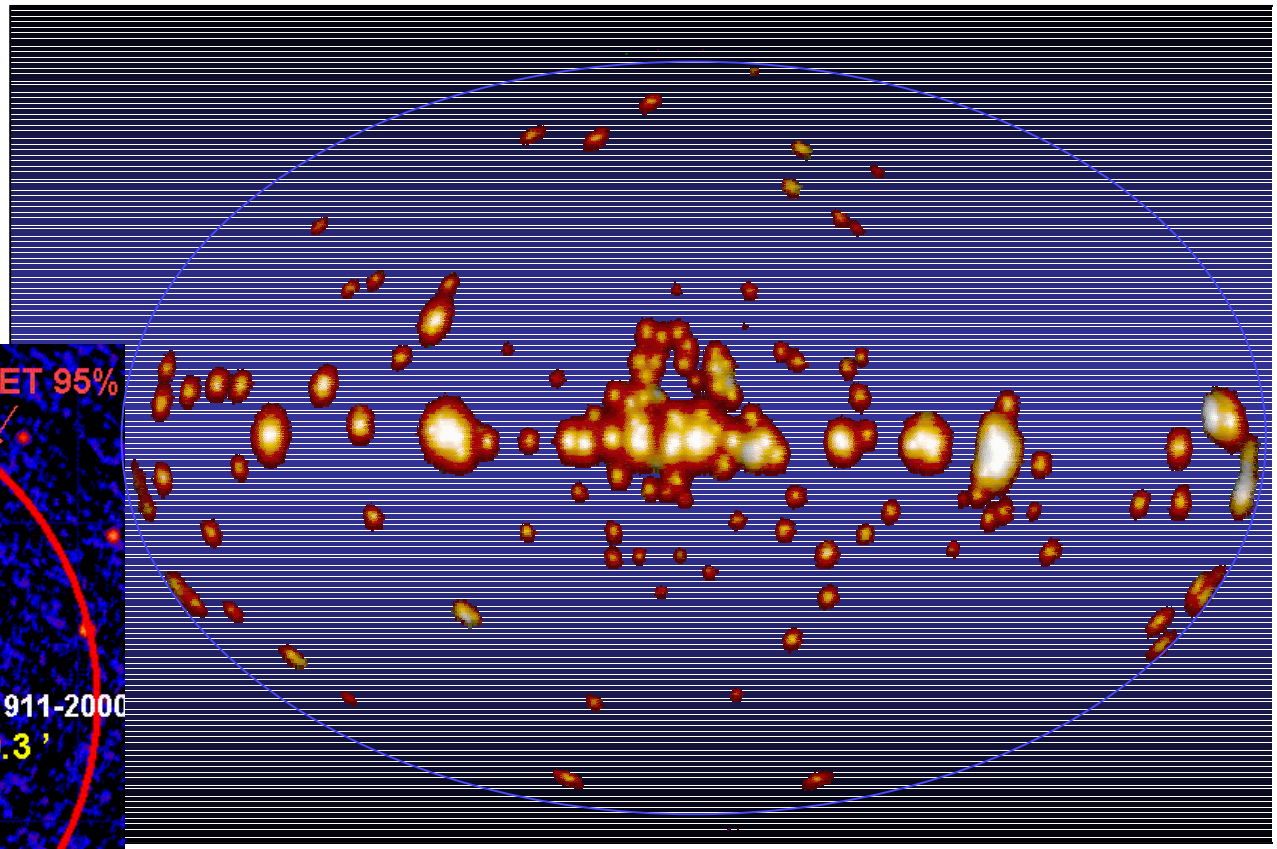
## - Propagation of cosmic ray particles -

**Source identification requires a multiwavelength approach**

- localization
- variability




### Unidentified EGRET Sources



**Evidence for at least 2 unidentified Galactic populations:**
- **variable Galactic halo population**
- **persistent Gould Belt population**

# New Way to Study H. E. Universe

## - Anatomy of our Galaxy: Basic structure and its origin -

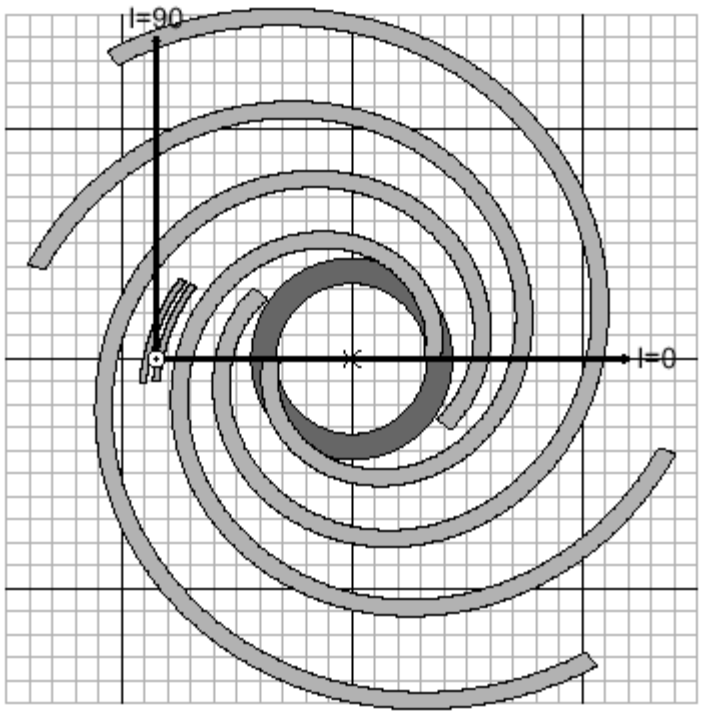



FIG. 1.—Pattern of spiral arms and the molecular ring in the star count model. Each little square is 1 kpc wide.

### Major components

- ◆Central bulge (nucleus, molecular ring)
- ◆Disk (spiral arms, thin disk, thick disk)
- ◆Halo

### Energy density

| | |
|---|---|
| ✧Starlight | ~$0.7\times10^{-12}$erg/cm$^2$ |
| ✧Turbulent gas | ~$0.5\times10^{-12}$erg/cm$^2$ |
| ✧Cosmic rays | ~$2\times10^{-12}$erg/cm$^2$ |
| ✧Magnetic field | ~$2\times10^{-12}$erg/cm$^2$ |
| ✧CMB | ~$0.4\times10^{-12}$erg/cm$^2$ |

### Luminosity

| | |
|---|---|
| ✧Radio | ~$3\times10^{38}$erg/s |
| ✧Infrared | ~$3\times10^{41}$erg/s |
| ✧Optical | ~$3\times10^{43}$erg/s |
| ✧X-ray | ~$10^{39-40}$erg/s |
| ✧$\gamma$-ray(>100MeV) | ~$5\times10^{38}$erg/s |

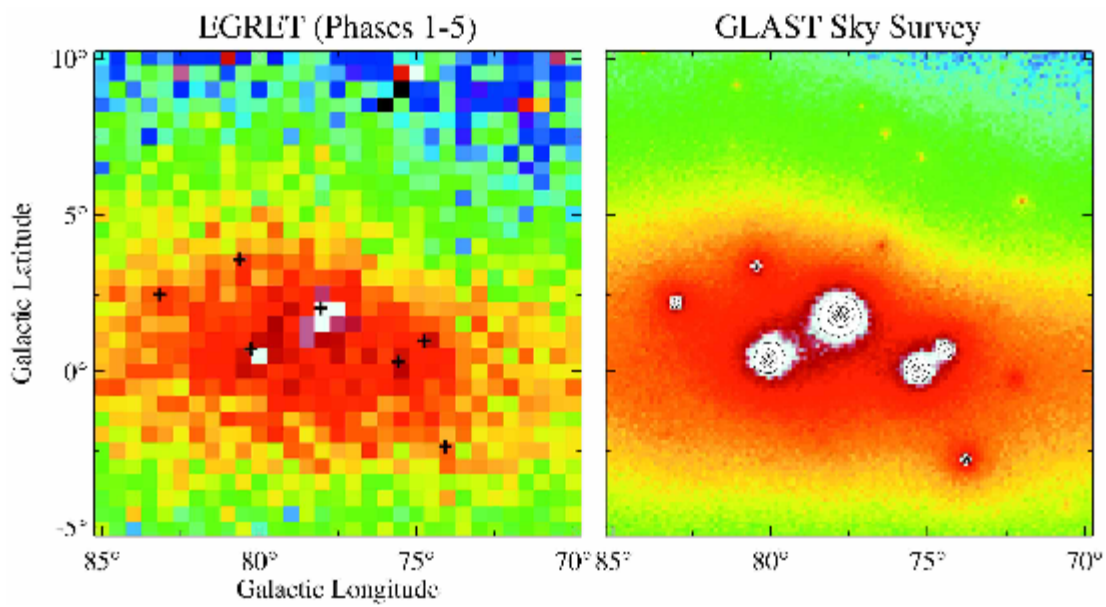
# New Way to Study H. E. Universe

## - Multi-Wave Analysis of Galactic Diffuse Emissions –

- **Galaxy Simulator Project**
  - Separate pi-zero and electron brems contributions
  - Determine total mass of nearby GMCs C/H ratio
  - Galactic electron distribution SNR association?
  - Galactic arm structure.... What are between arms?
  - Correlation with radio, X & hard-X observations
  - Galactic magnetic field: strength and large scale structure
  - Determine total amount of cold dark baryonic matter

**Giant Molecular Clouds in Cygns region (galactic arm structure?)**

**Pi-zero flux measurement by GLAST will determine the total mass in the GMCs and their C/H.**



# New Way to Study H. E. Universe

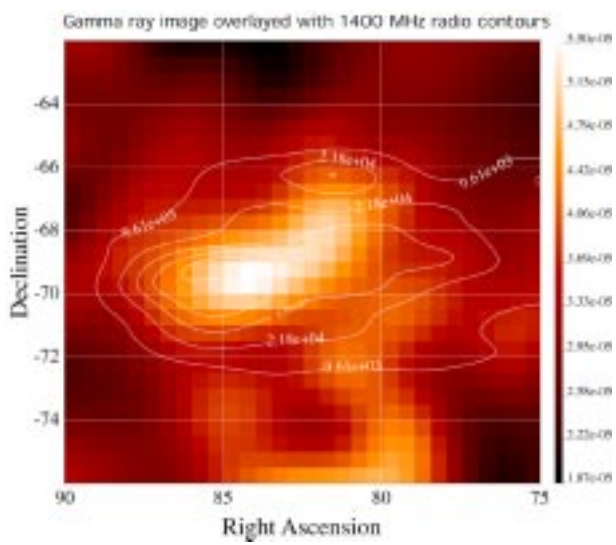
## - Cosmic Ray Contents in Nearby Galaxies -

**GLAST will measure cosmic electron and proton fluxes for LMC, SMC and M31**

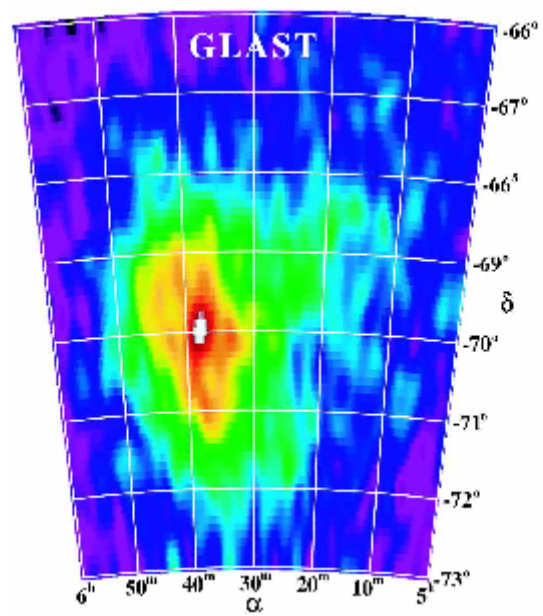
↓

**Past SN rate, past history of galaxies, stability of galaxies**

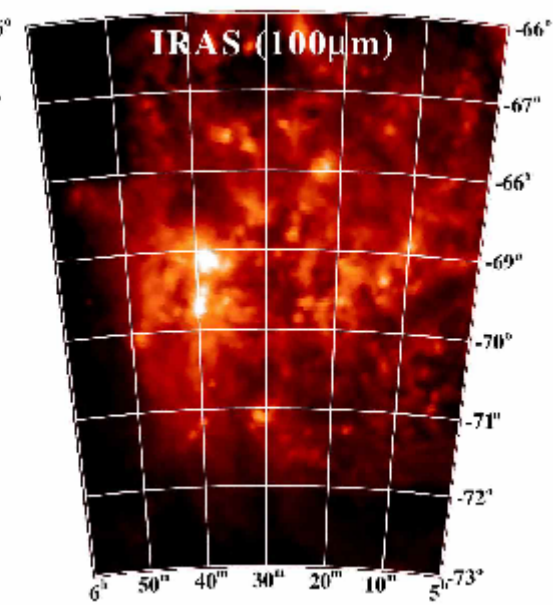
**LMC by EGRET**




**LMC by GLAST**
**(simulation)**

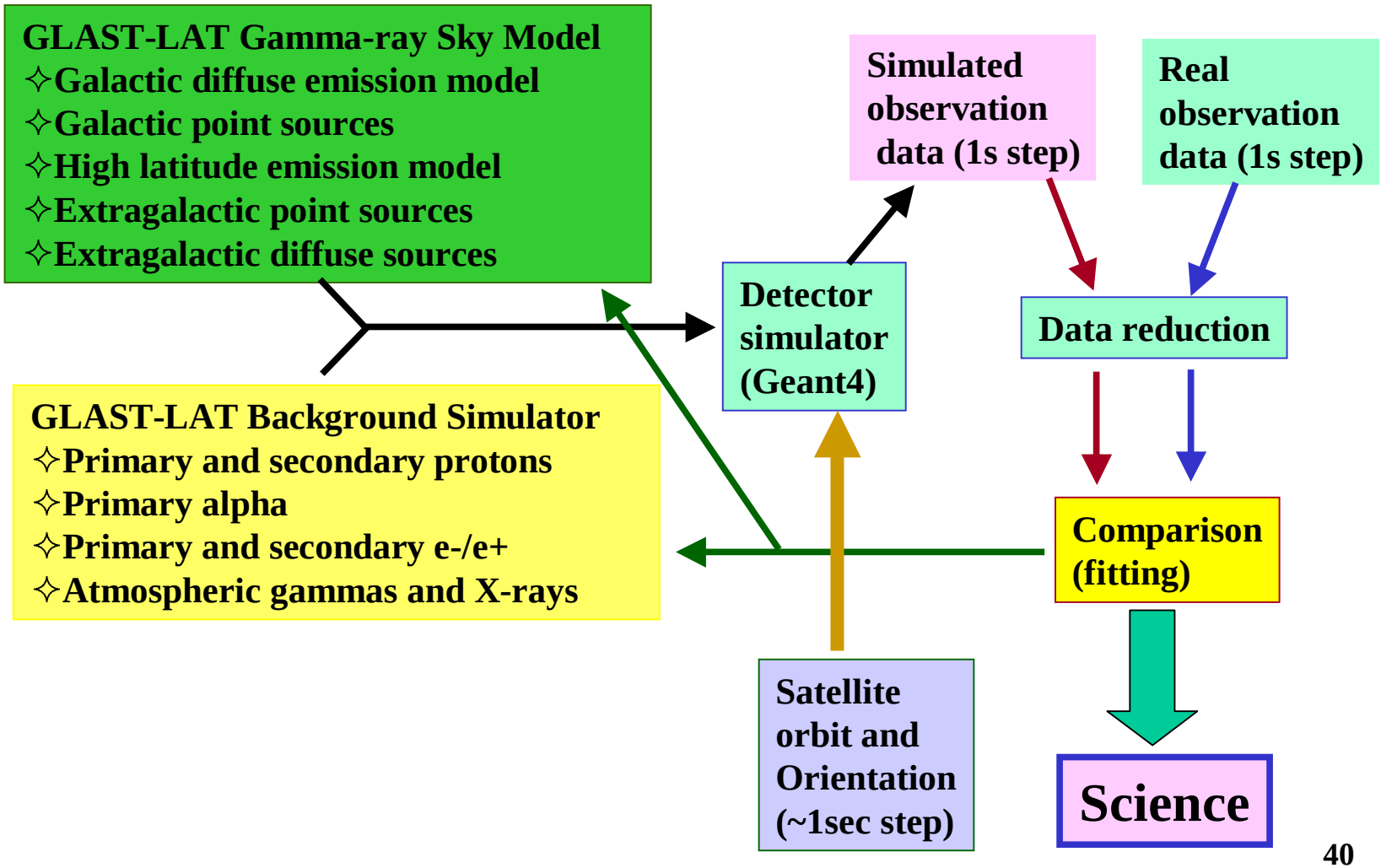



**LMC in IR (IRAS)**



# New Way to Study H. E. Universe

## - Thorough end-to-end simulations needed –



# Gamma Ray Burst study with GLAST-GBM

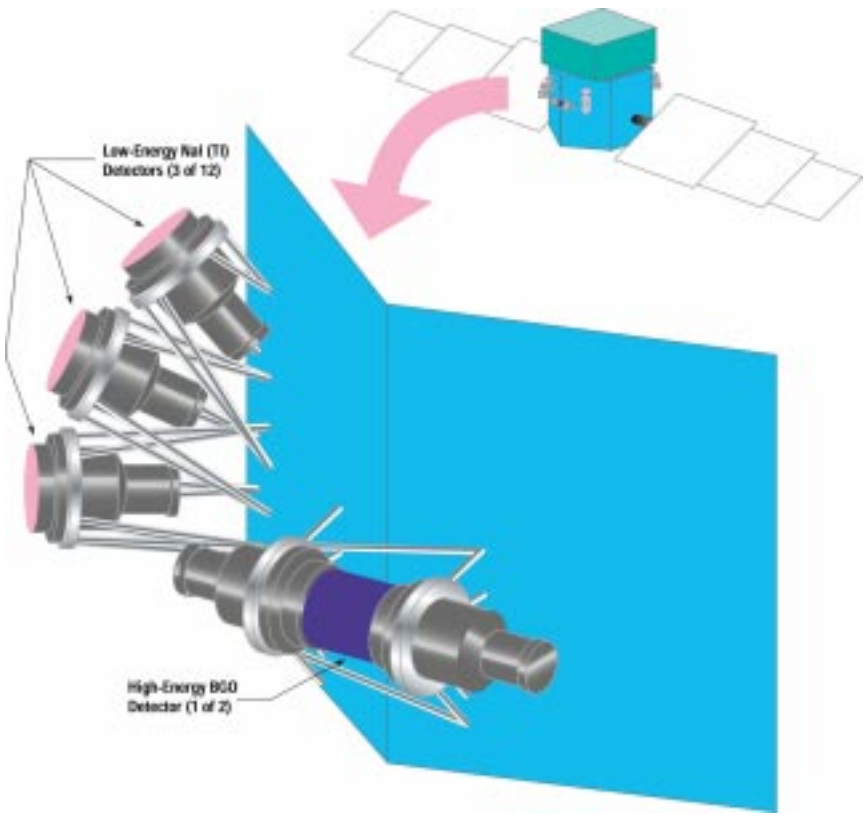
## - GLAST Gamma-ray Burst Monitor -

**LAT:**

- Capture > 25% of GRBs in LAT FOV (2 sr or more)
- Deadtime of < 100 msec per event
- Spectral resolution < 20%, especially at energies above 1 GeV

**GBM:**

- Monitor energy range: 10 keV - 20 MeV
- Monitor FOV of 8 sr (shall overlap that of the LAT)
- Notify observers world-wide:
  - Recognize bursts in realtime
  - Determine burst positions to few degree accuracy
  - Transmit (within seconds) GRB coordinates to the ground
  - Re-point the main instrument to GRB positions within 10 minutes

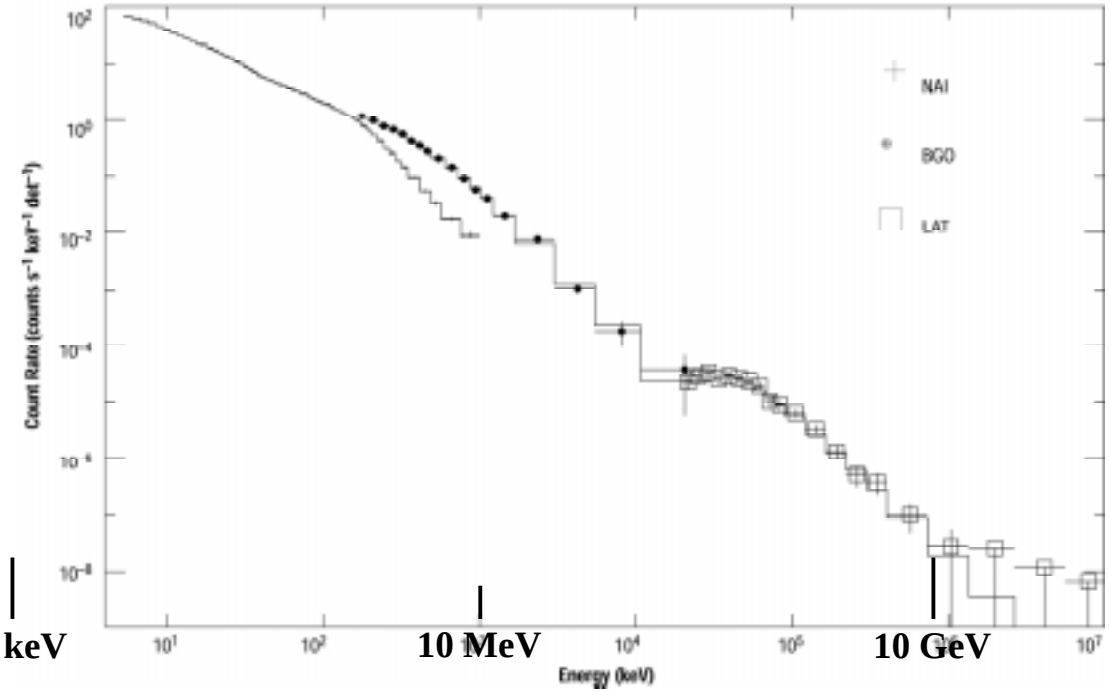


# Gamma Ray Burst study with GLAST-GBM

## - Monitor GRB with wide energy coverage -

- **Cover the classical gamma-ray band where most of the burst photons are emitted by GLAST Gamma-ray Burst Monitor (GBM)**
- **<u>Monitor all of the sky visible from Low-Earth Orbit ( 10keV-30MeV)</u>**
- **<u>Monitor 40% of the sky visible from LEO (20MeV-500GeV)</u>**
- **Identify when and where to re-point the spacecraft to optimize observations and notify other observers**

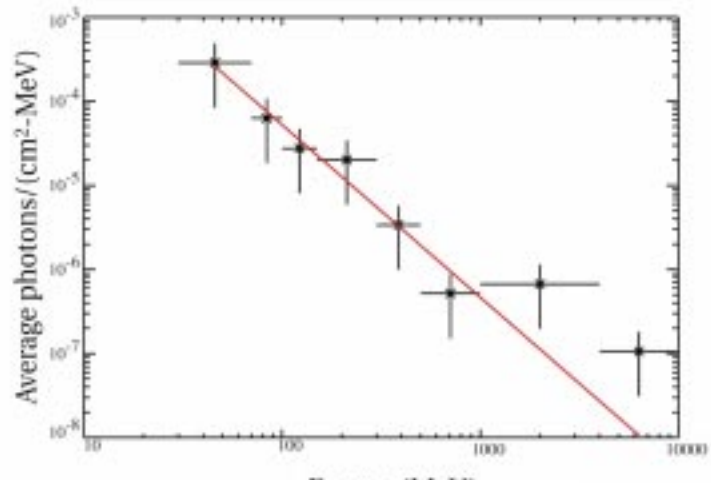
**Simulation: Spectrum of an intense GRB by GLAST**

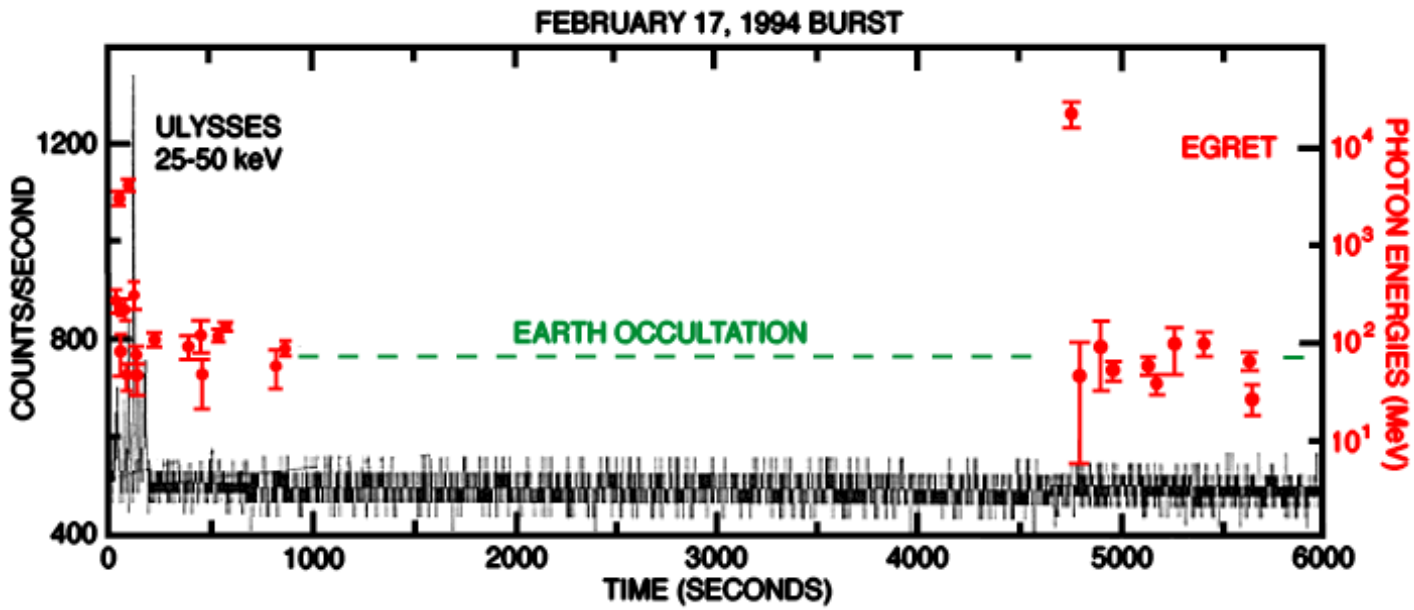


# Gamma Ray Burst study with GLAST-GBM

## - GRB afterglow in > 20 MeV ? -

- EGRET discovered high energy GRB afterglow
  - only one burst
  - dead time limited observations
- GLAST will observe many more high energy afterglows
  - strong constraint to GRB models



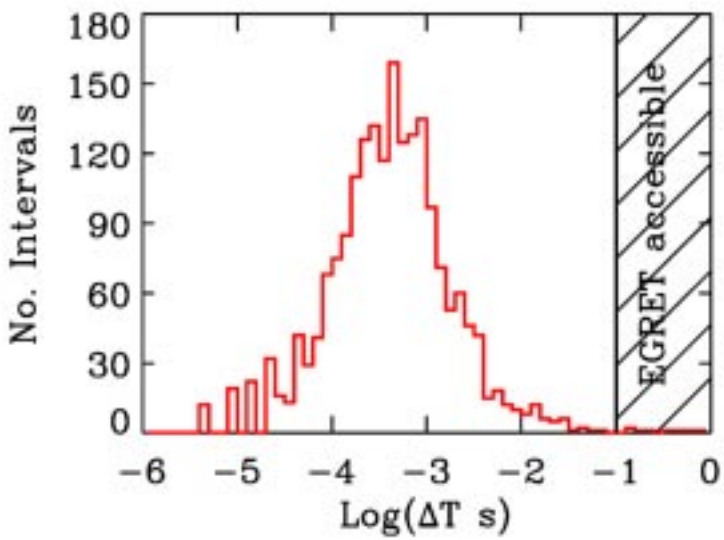



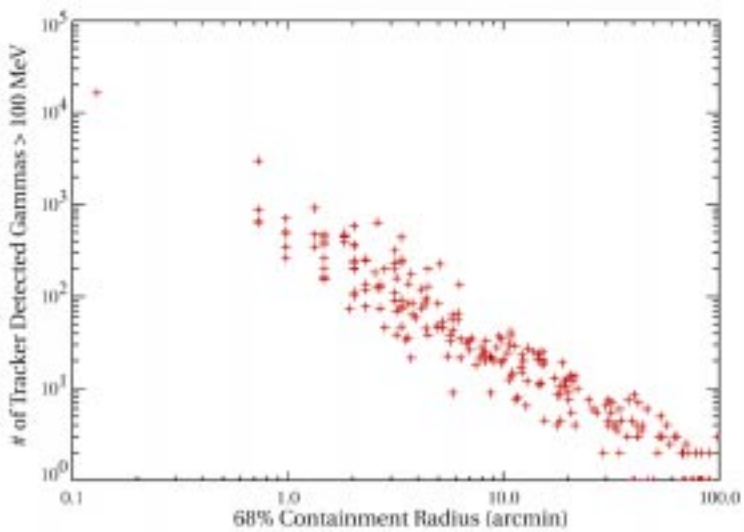
# Gamma Ray Burst study with GLAST-GBM

## - GRB flux for > 20 MeV ? -

**EGRET suffered severly from its dead time. GLAST can record far more photons**

**EGRET missed ~95% of photons for bright GRBs**
**GLAST will collect**
**x5(area)x10-100(deadtime)=x50-500 more photons**



# Gamma Ray Burst study with GLAST-GBM

## - Temporal correlation btwn X-ray and γ-ray -

**Standard wisdom about GRB is: the more energetic, the closer to the central energy source. GLAST measures both in X-ray/soft γ-ray (GBM) and high energy γ-ray (LAT), arrowing to study temporal correlation between them.**

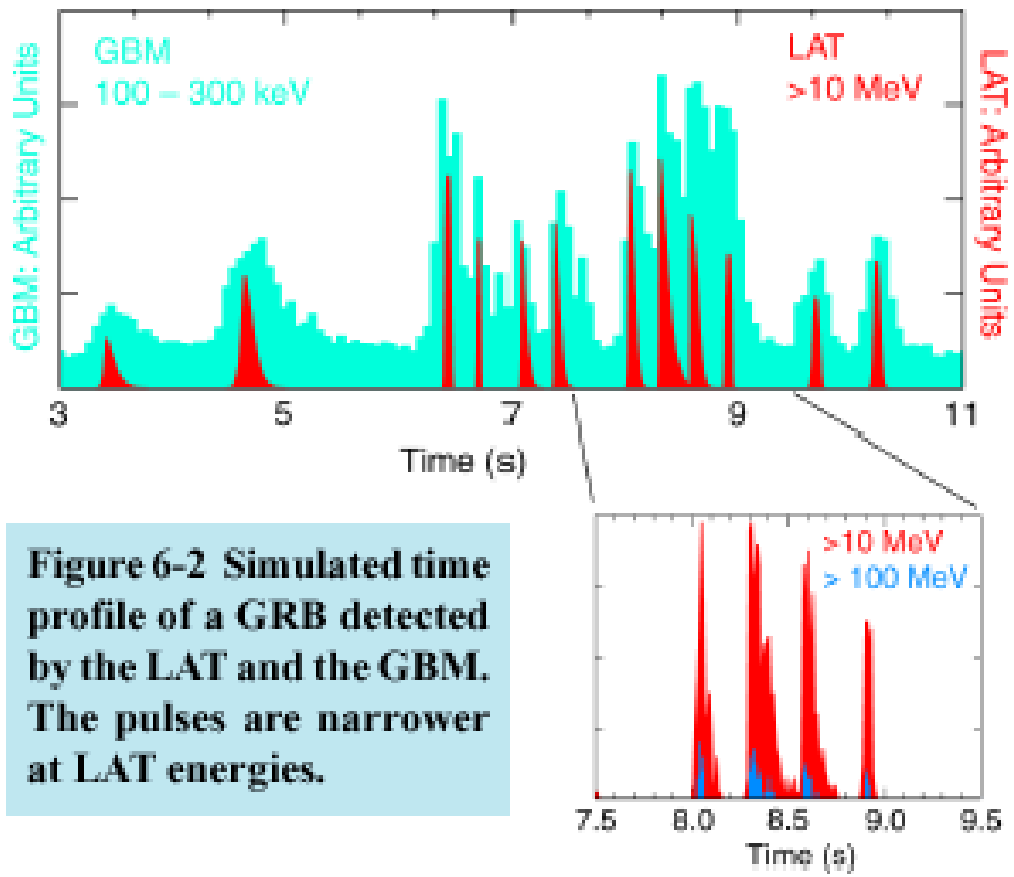
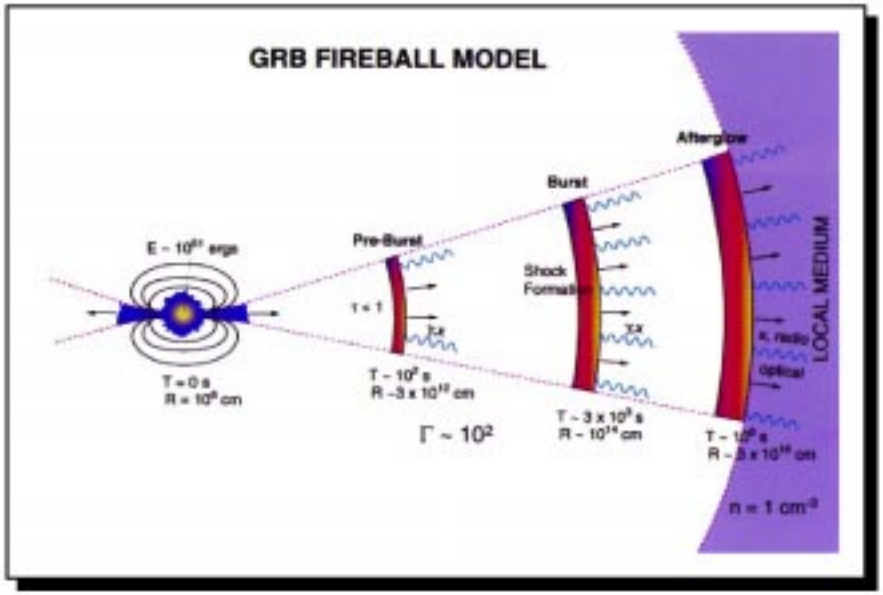


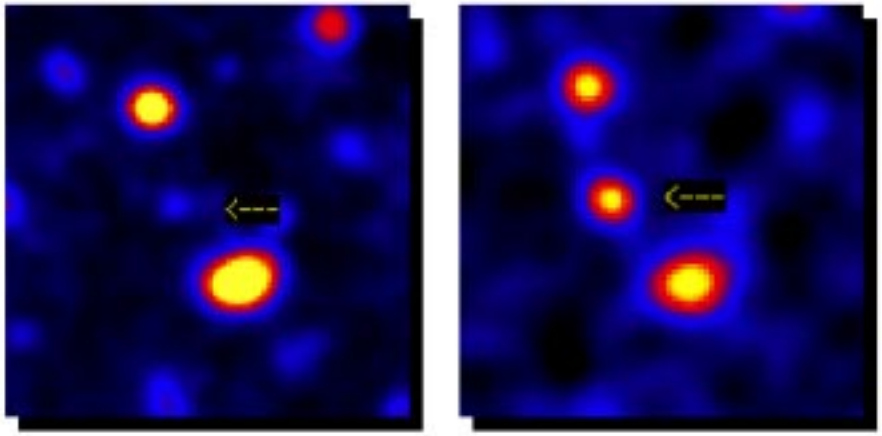

**Figure 6-2 Simulated time profile of a GRB detected by the LAT and the GBM. The pulses are narrower at LAT energies.**

# Gamma Ray Burst study with GLAST-GBM

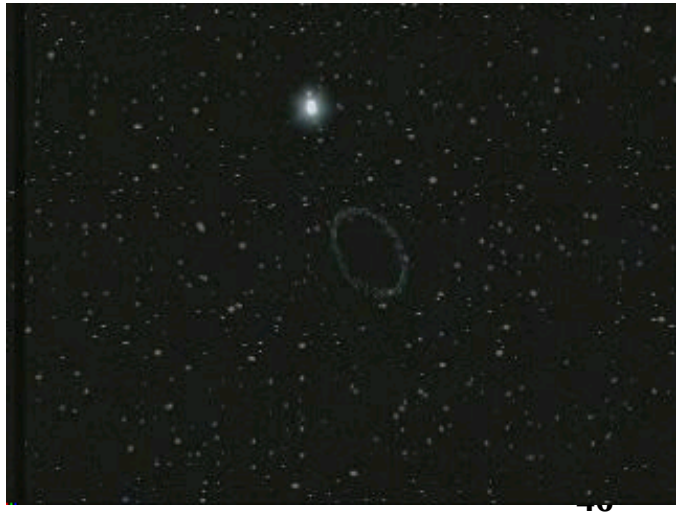
## - Two models of GRB: Hypernovae and mergers of compact objects -




Optical Afterglow



Hypernovae Explosion Model

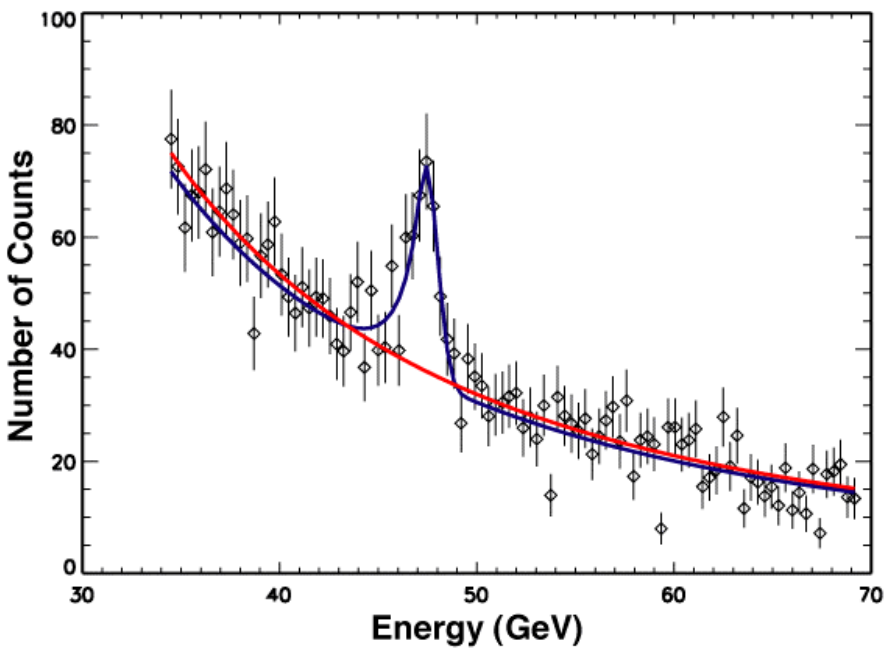


Binary Coalescence Model

# Biggest Bonus

## - Discovery of Dark Matter Particle -

- Identify relatively narrow spectral lines coming from two photon decay.
- For overall WIMP decays, the spectral feature will not be easy to detect.



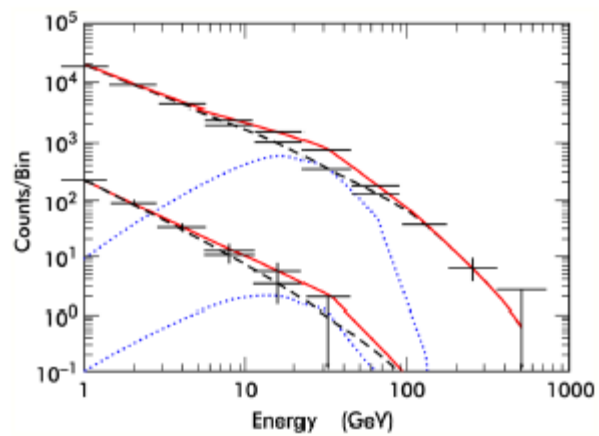
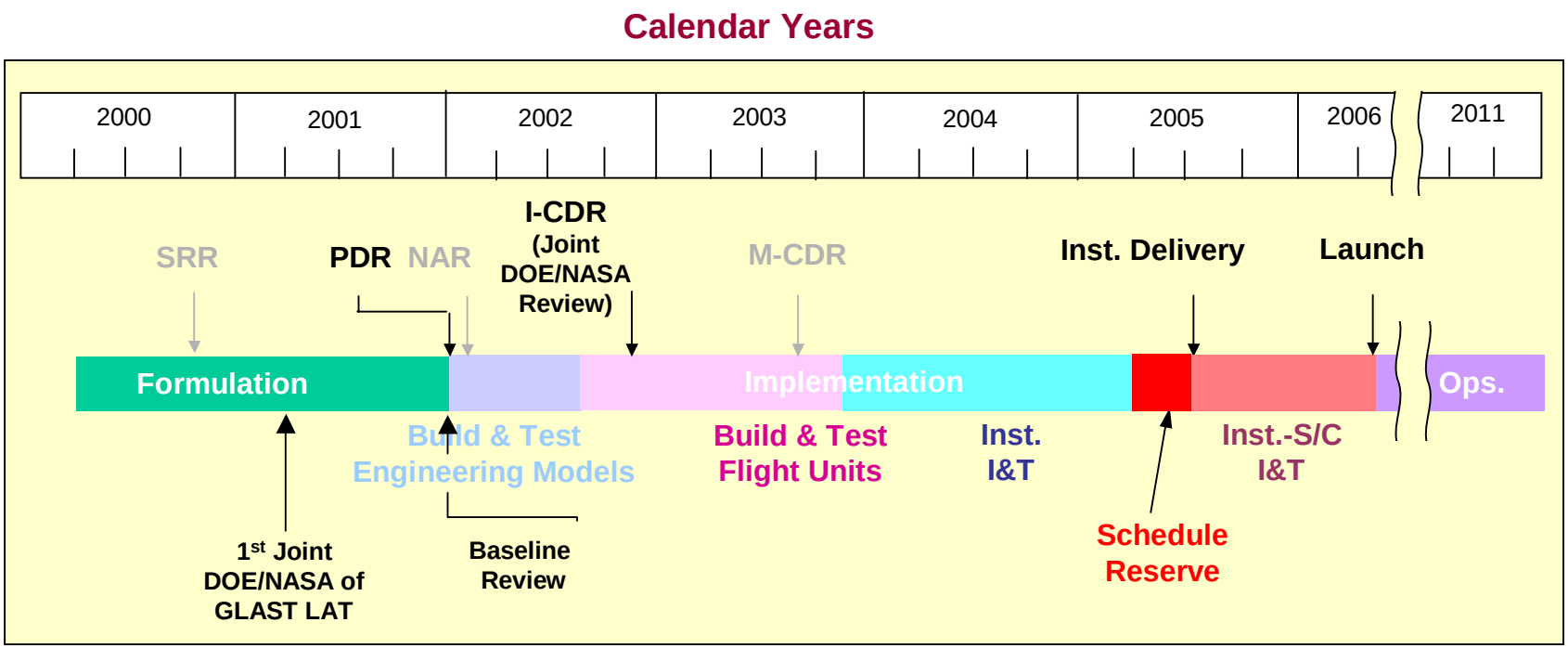




Figure 5-1 Simulated diffuse extragalactic gamma-ray flux measurements for GLAST (upper points) and EGRET (lower points). The dashed lines show the flux from unresolved AGNs, the dotted lines the contributions from WIMP decays in the early universe, and the solid line shows the total (Willis 1996).

# Schedule

## - Overall Schedule as of March 2001 -




**NASA-PDR and DOE-Baseline Review Rescheduled for Jan. 8,2001**

**NASA announced a new launch date of March 2006**