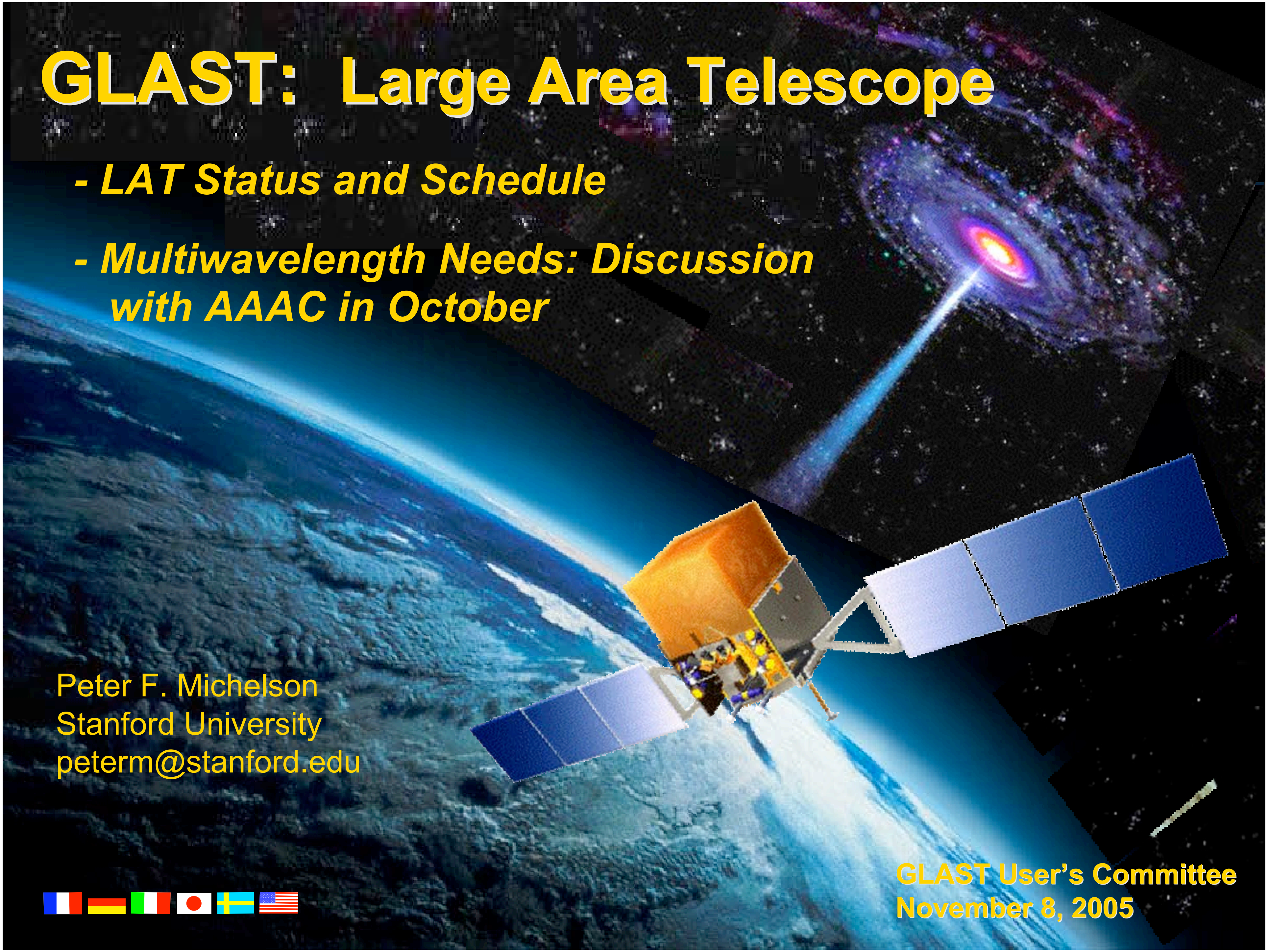
# GLAST: Large Area Telescope

*- LAT Status and Schedule*

*- Multiwavelength Needs: Discussion with AAAC in October*



Peter F. Michelson
Stanford University
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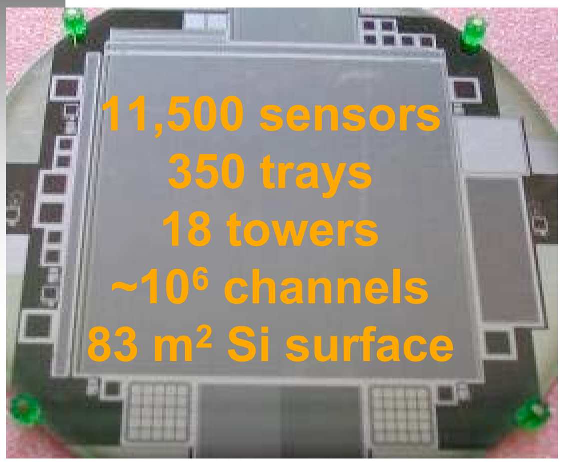
**GLAST User's Committee**
**November 8, 2005**

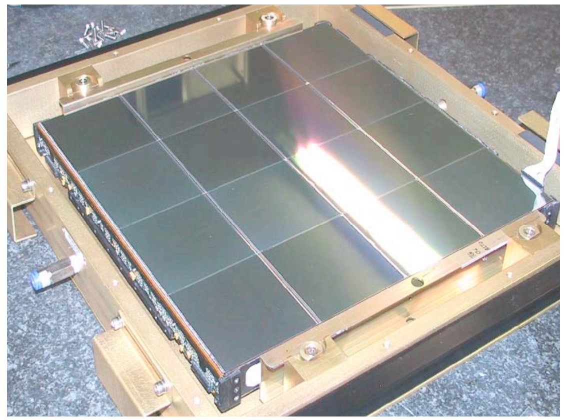
# LAT development status

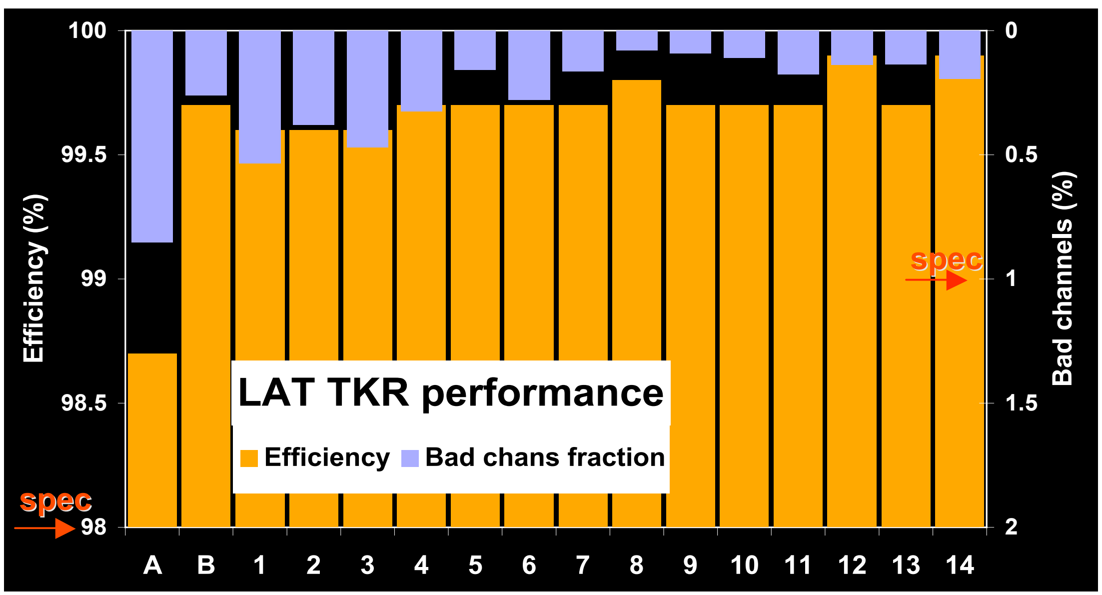
General

# LAT Silicon Tracker

***team effort involving ~70 physicists and engineers from Italy (INFN & ASI), the United States, and Japan***

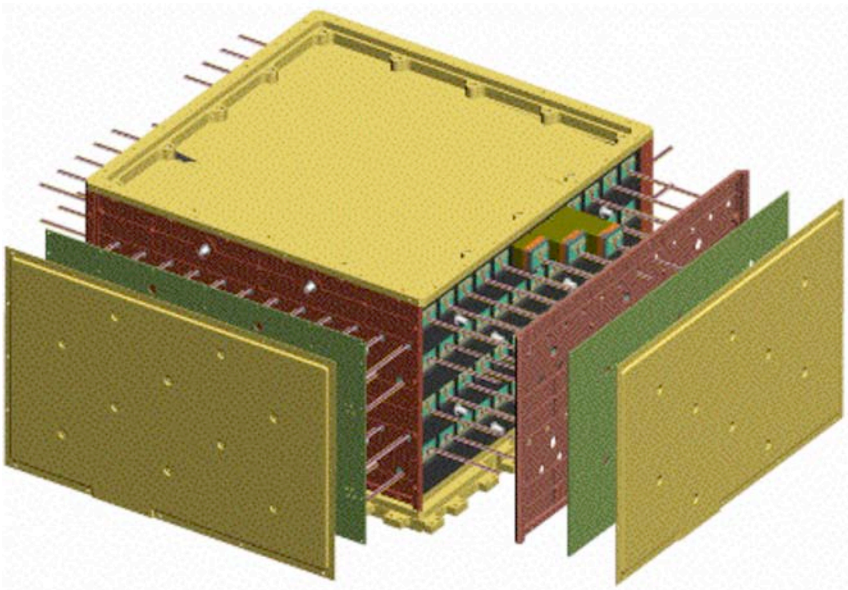


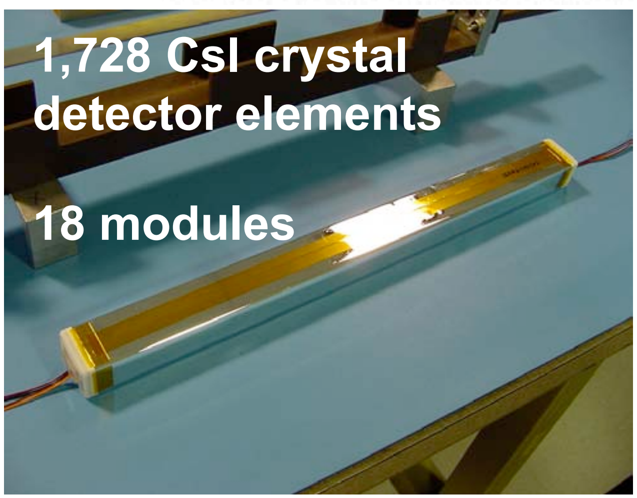



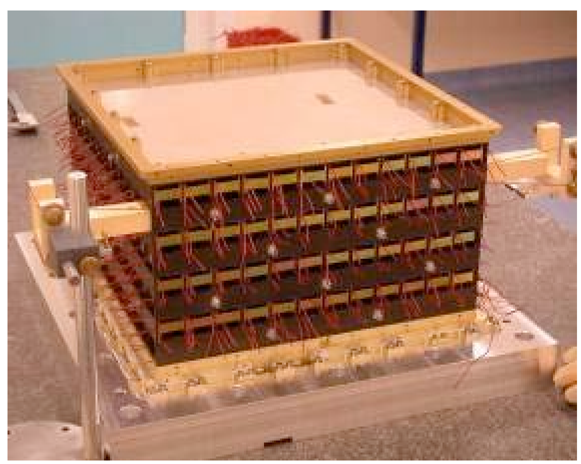



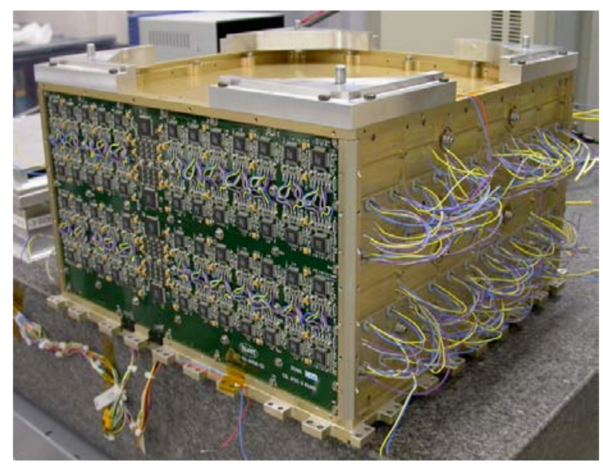
# LAT Calorimeter

***team effort involving physicists and engineers from the United States, France (IN2P3 & CEA), and Sweden***



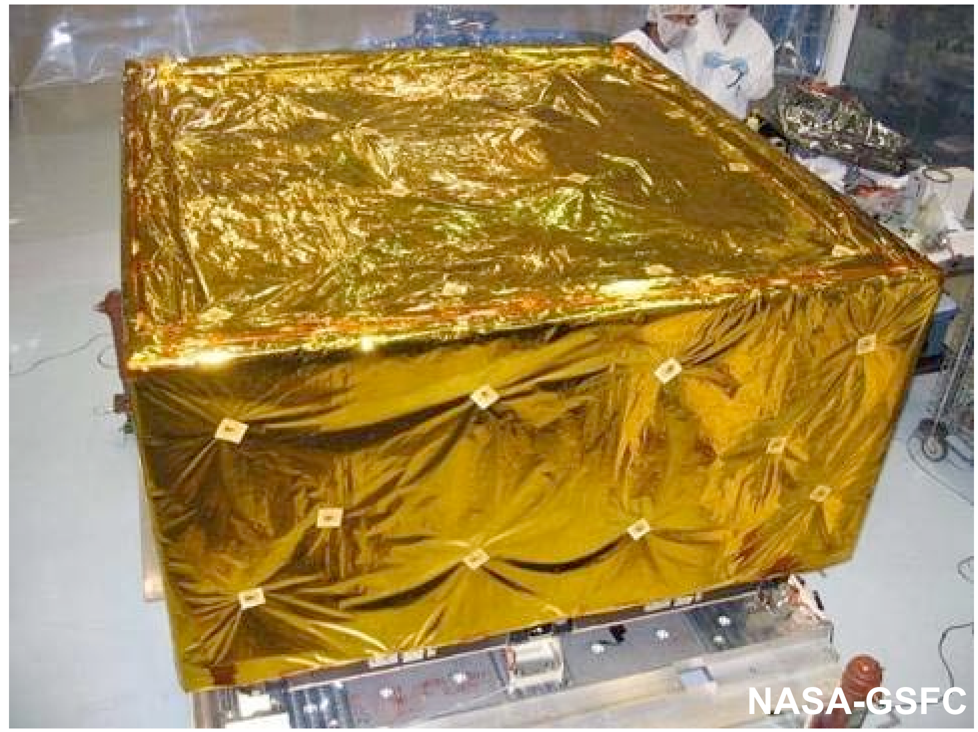





# LAT Anti-Coincidence Detector

***team effort involving physicists and engineers from Goddard Space Flight Center, SLAC, and Fermi Lab***

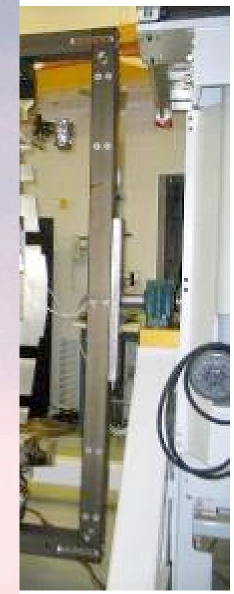


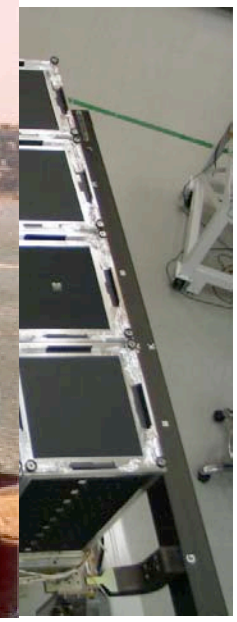

ACD before installation of Micrometeoroid Shield

ACD with Micrometeoroid Shield and Multi-Layer Insulation (but without Germanium Kapton outer layer)

# LAT integration and test status

- LAT proceedir
  2006 RFI to ob
- LAT collabora
  Japan, and Sw
  key contributo

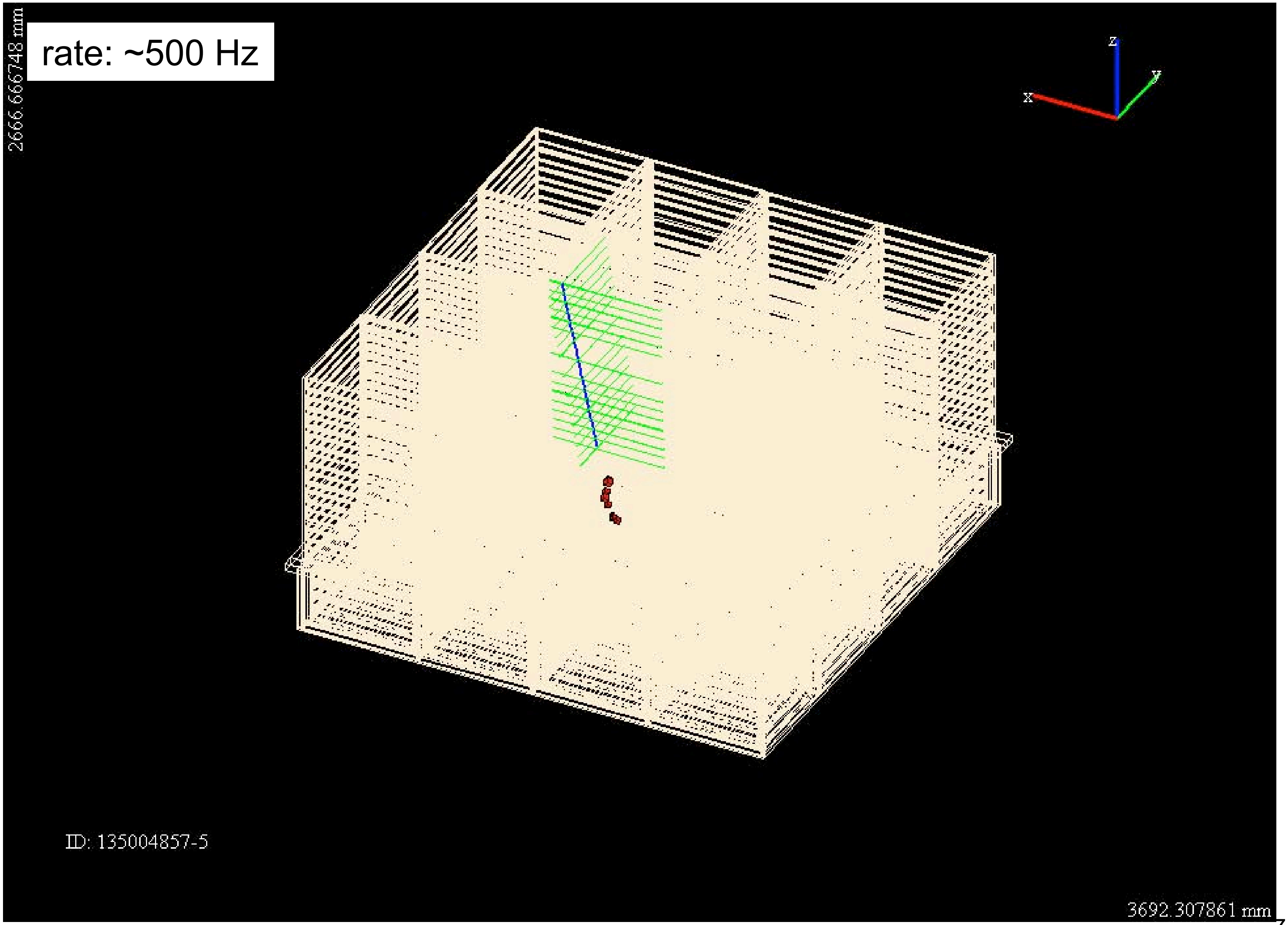


LAT is possible because of partnership between

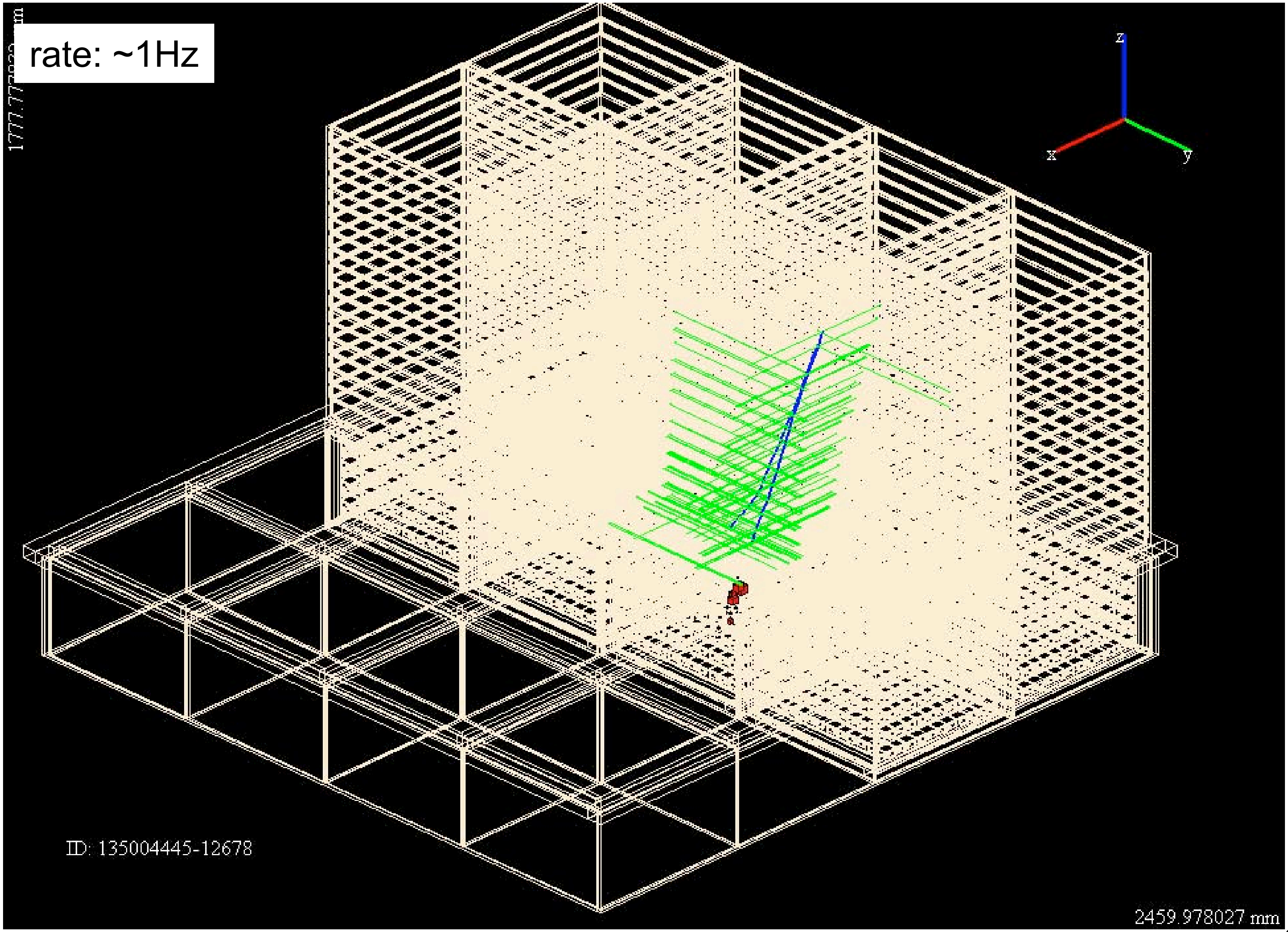
- particle physicists & astrophysicists,
- SLAC & GSFC,
- DOE & NASA

I&T facility

# 16-tower movie



# 8-tower movie – photon events



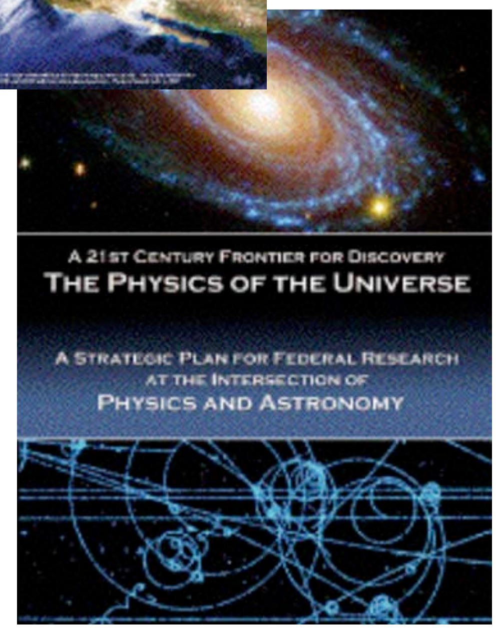
# Discussion with AAAC

- *presentation to AAAC in October 2005*
  - ***GLAST status report***
  - ***summary of multiwavelength needs and need for recognizing agency interdependencies***
  - ***informed AAAC that LAT Collaboration is developing a multiwavelength implementation plan to address critical needs***

- *GLAST also highlighted in presentations by Anne Kinney (NASA) and Robin Staffin (DOE)*

# GLAST: Multiwavelength needs

- ***Some key science objectives:***
  - *understand particle acceleration and high-energy emission in neutron stars and black holes*
  - *determine origin(s) of $\gamma$-ray extragalactic diffuse background*
  - *measure extragalactic background starlight*
  - *search for dark matter*



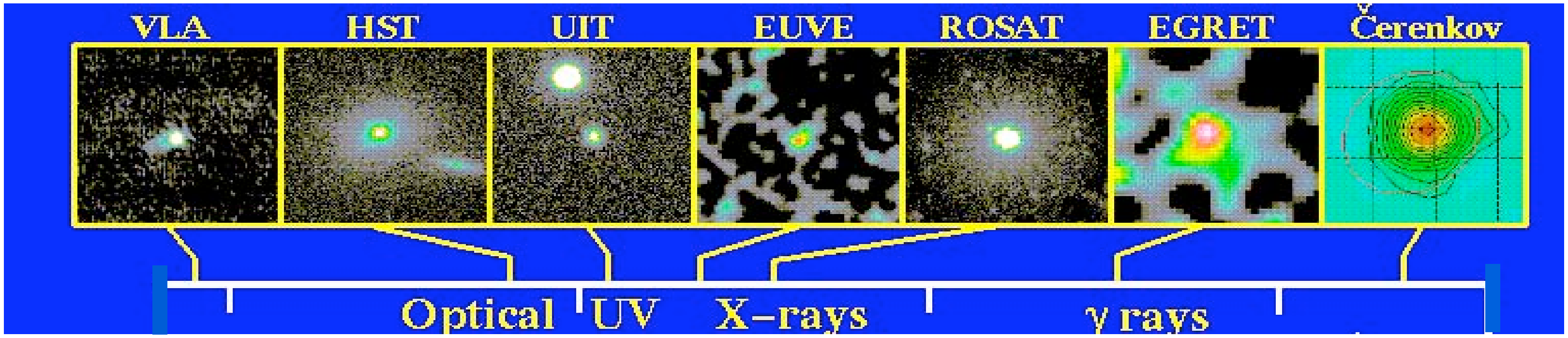

multiwavelength observations important to several science objectives

*".. GLAST will focus on the most energetic objects and phenomena in the universe…"*

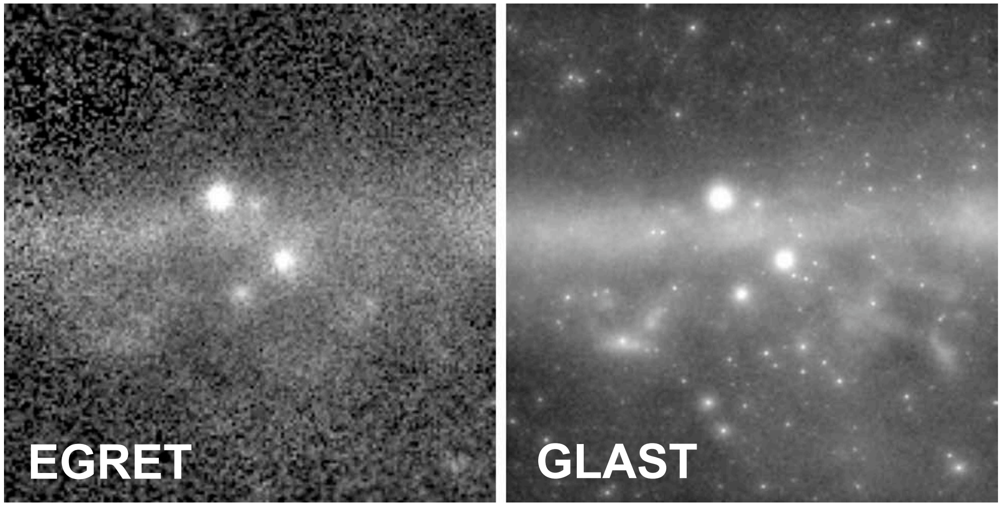
# Multiwavelength observations are important for GLAST

- ***Multiwavelength observations needed for***
  - *understanding the high-energy diffuse emission of the Milky Way*
  - *source identification and population studies*
  - *intensive exploration of the brightest and most variable sources that will allow deep study of the source physics*
  - *rapid follow-up on transients (e.g. GRBs, blazar flares)*
    - *GLAST mission designed to support rapid notification for follow-up*

***example: Markarian 421***



# Science opportunities




$\gamma$-ray sky (>100 MeV)

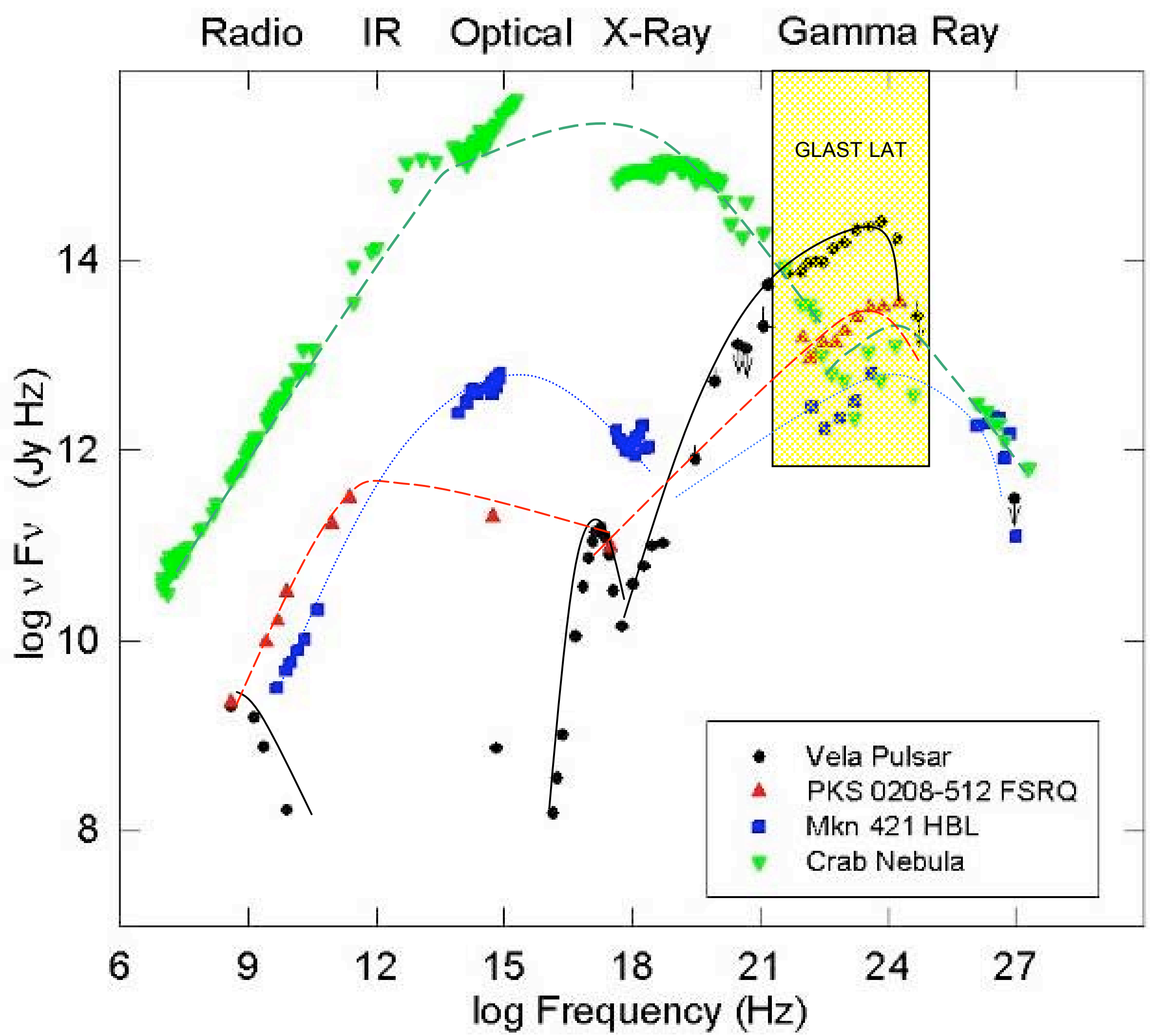
- 85% galactic diffuse emission
- ~5% isotropic emission
- 10% point sources

***Many opportunities for exciting discoveries:***

- *origin(s) of the high-energy extragalactic diffuse background*
- *extragalactic background starlight to $z > 3$*
- *new physics & the unknown! (e.g. dark matter, extra dimensions, big bang relics)*
- *$\gamma$-ray emission from clusters of galaxies; cosmic-ray acceleration and confinement on large scales*
- *$\gamma$-rays from Ultra-Luminous Infrared Galaxies; cosmic ray acceleration efficiency and star formation rate*
- *high-latitude Galactic Inverse-Compton emission and thereby measure TeV-scale CR electrons in the Galaxy*
- *high-energy emission from Galactic pulsars and their birth places*

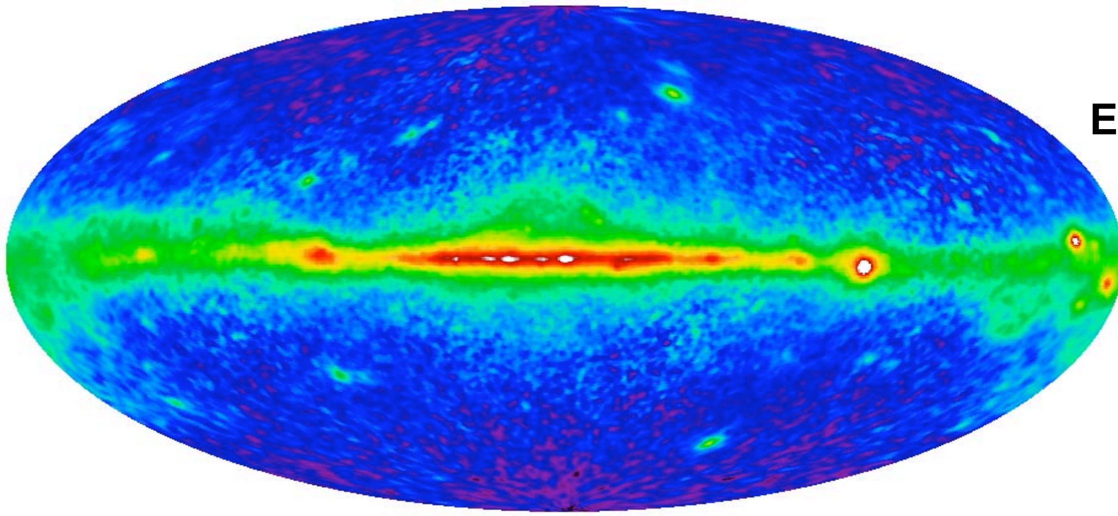
# $\gamma$-ray Sources: Multiwavelength observations are important

Sources are non-thermal: produced by interactions of energetic particles




- *Nature rarely produces mono-energetic particle beams. Broad range of particle energies leads to broad range of photon energies.*
  - *example: $\pi^0$ production*
- *Charged particles rarely interact by only one process. Different processes radiate in different energy bands.*
  - *example: synchrotron-Compton processes*
- *High-energy particles needed to produce gamma rays can radiate in lower-energy bands as they lose energy.*
  - *example: gamma-ray burst afterglows*

# Science opportunities & multiwavelength needs



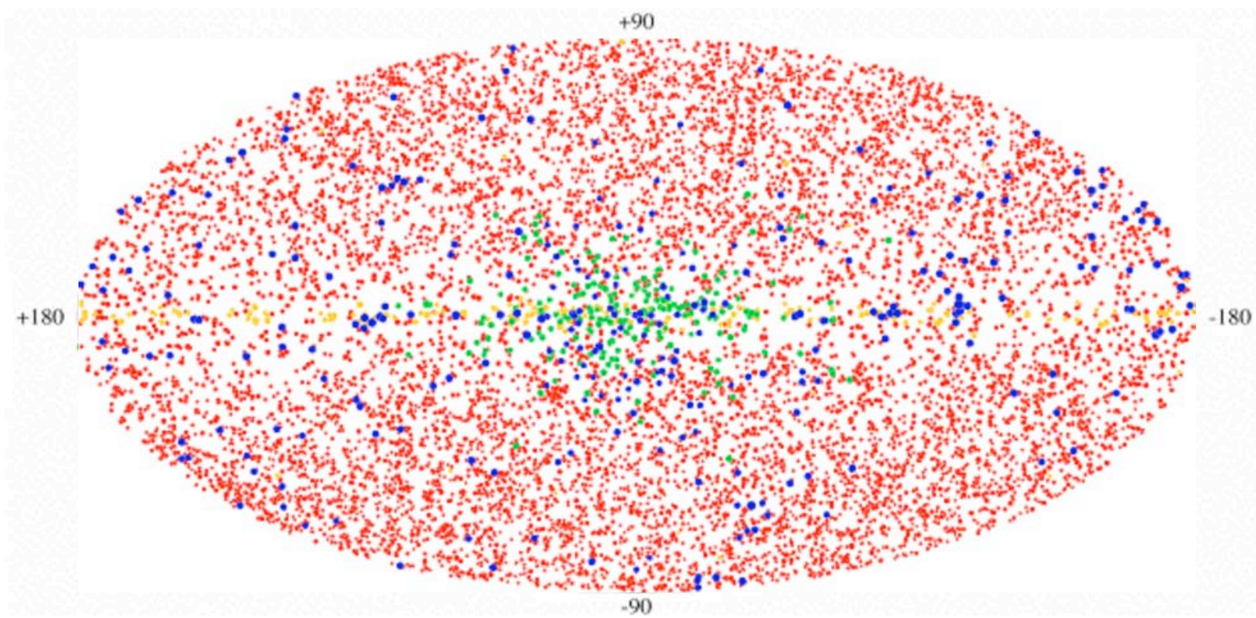
**EGRET (>100 MeV)**

**85% galactic diffuse emission**

**~5% isotropic emission**

**10% point sources**

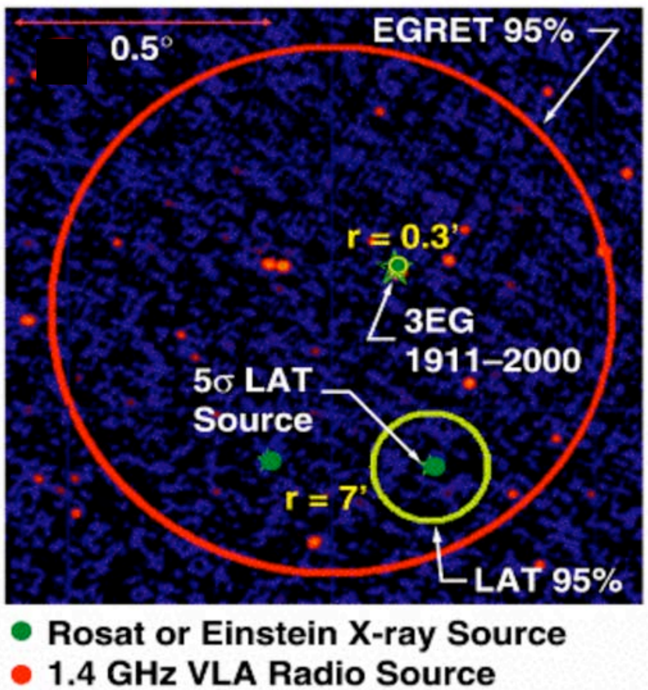
**GLAST all-sky survey**
**(~$10^4$ sources)**

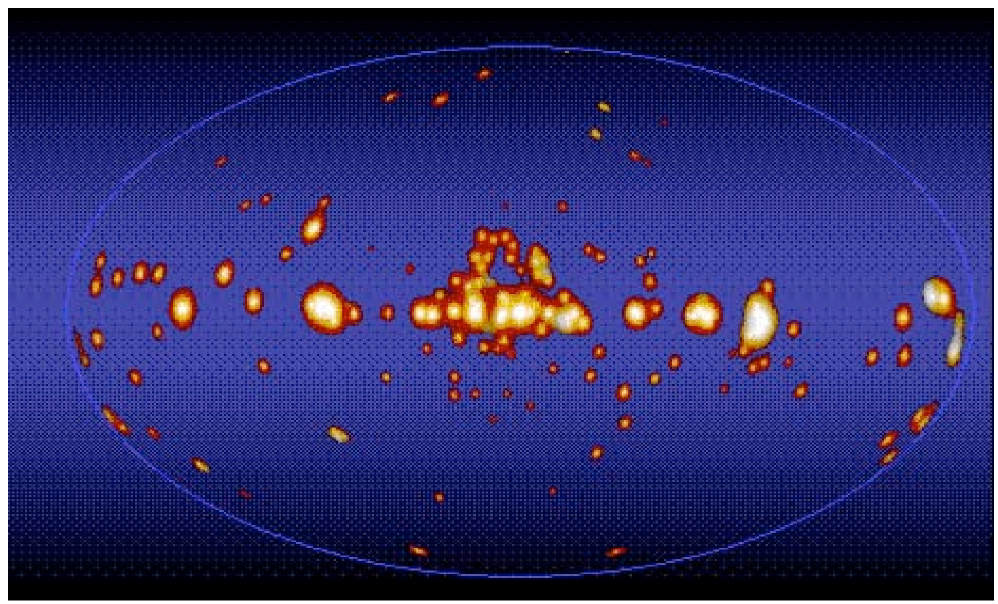


# γ-ray source localization

**multi-wavelength approach to γ-ray source identification:**
- **localization**
- **variability**

***source localization (68% radius)***
- *γ-ray bursts: 1 to tens arcminutes*
- *unid EGRET sources: 0.3’ – 1’*



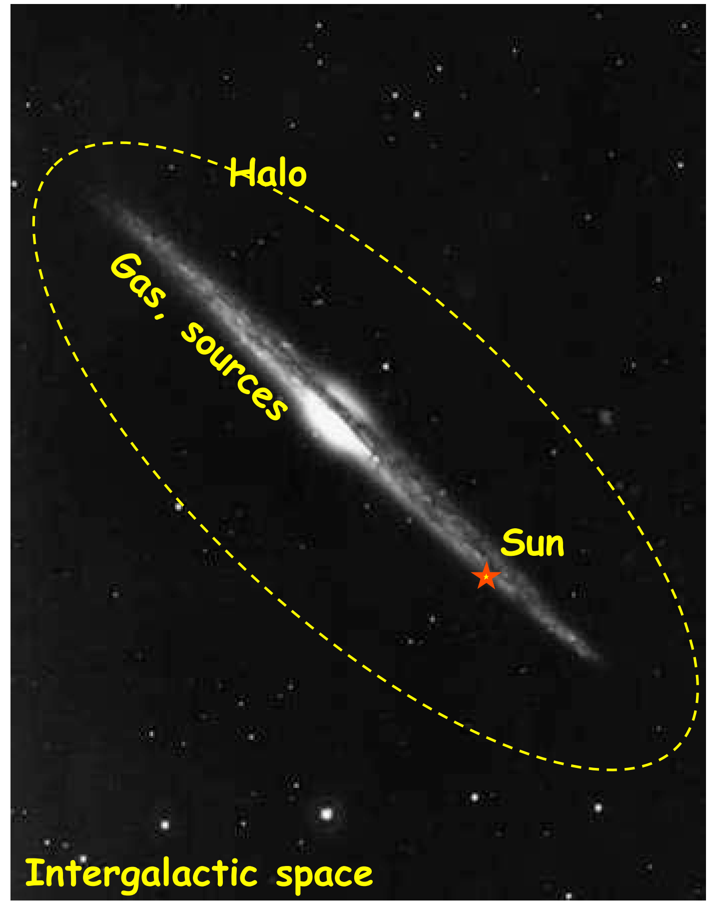



**Unidentified EGRET sources**

# Diffuse γ-ray emission from the Milky Way

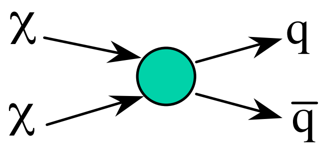
*85% of the celestial gamma-ray emission*

- *This foreground needs to be well characterized for analysis of LAT data, much more so than for EGRET, owing to vastly better statistics and better angular resolution*
- *The origin is cosmic-ray interactions with interstellar gas and the interstellar radiation field*
- *Fundamental questions remain from EGRET with results limited by knowledge of the diffuse emission; e.g.*
  - *particle dark matter;*
  - *the isotropic γ-ray background*



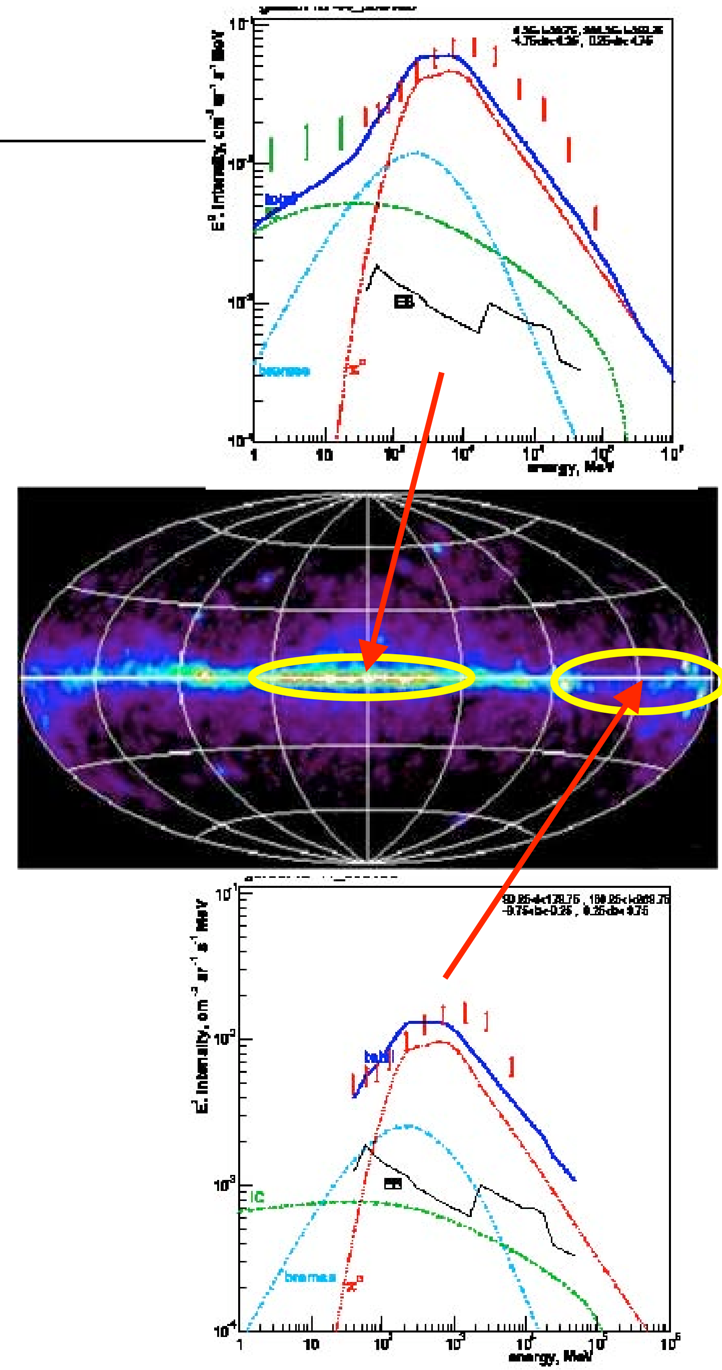
# particle dark matter

- *The lightest supersymmetric particle is a plausible dark matter candidate, most likely with mass > ~50 GeV*
- *Annihilation channels produce $\gamma$-ray lines and continuum, and secondary electrons that in turn can produce $\gamma$-rays*



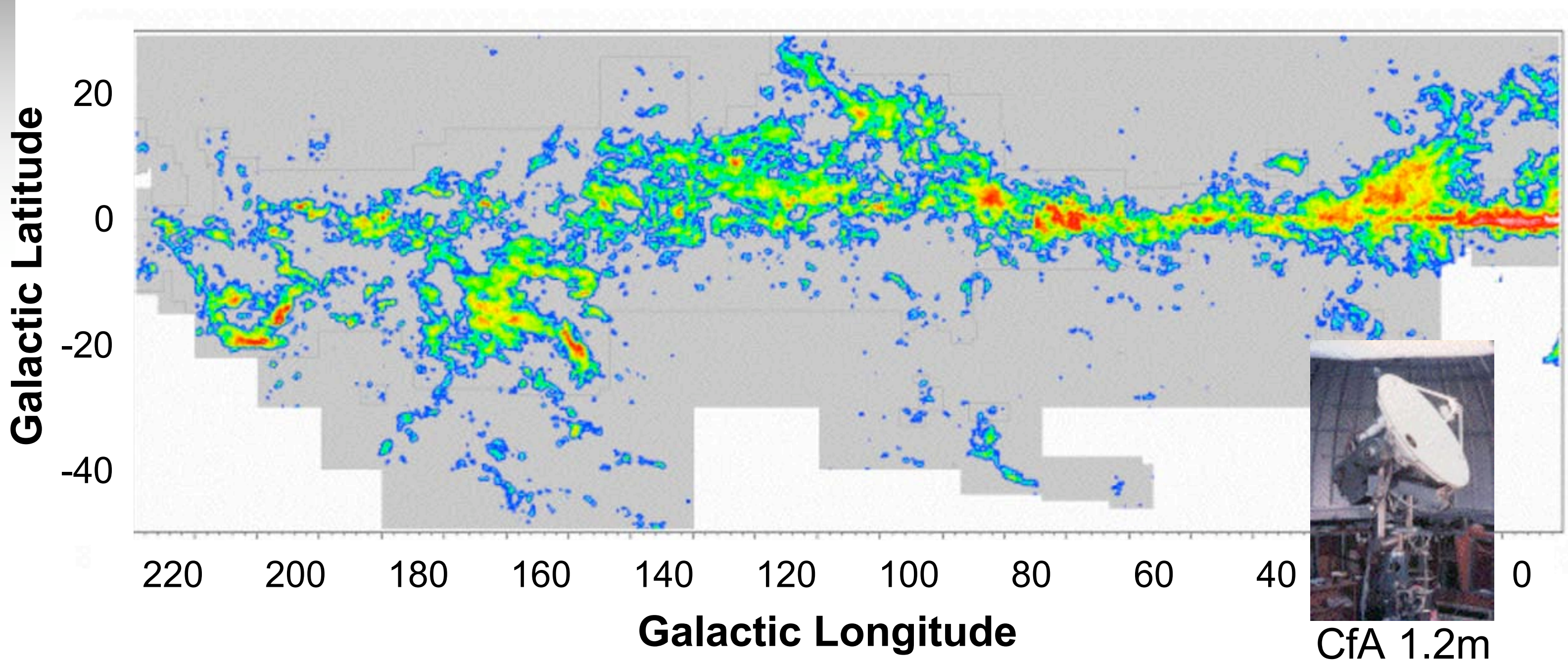

inclusive flux,
or γγ or Zγ "lines"?

- *WIMPs would be distributed in a Galactic halo, with a central density enhancement of uncertain cuspiness,*
  - *most likely the halo will have significant substructure, which is important as the annihilation rate ~$\rho^2$*
- *we need to improve the precision of the galactic diffuse emission model*



# Modeling diffuse emission: need for new data

- ***Extend CO surveys to high latitudes***
  - *newly-found small molecular clouds will otherwise be interpreted as unidentified sources, and clearly limit dark matter studies*




CfA 1.2m

Dame, Hartmann, & Thaddeus (2001)
Dame & Thaddeus (2004)

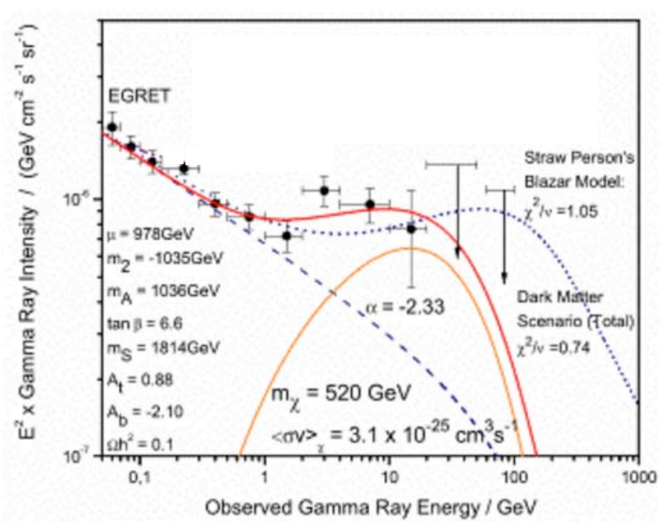
- **$C^{18}O$ *observations (optically thin tracer) of special directions (e.g. Galactic center, arm tangents)***
  - *assess whether velocity crowding is affecting calculations of molecular column density, and for carefully pinning down the diffuse emission*

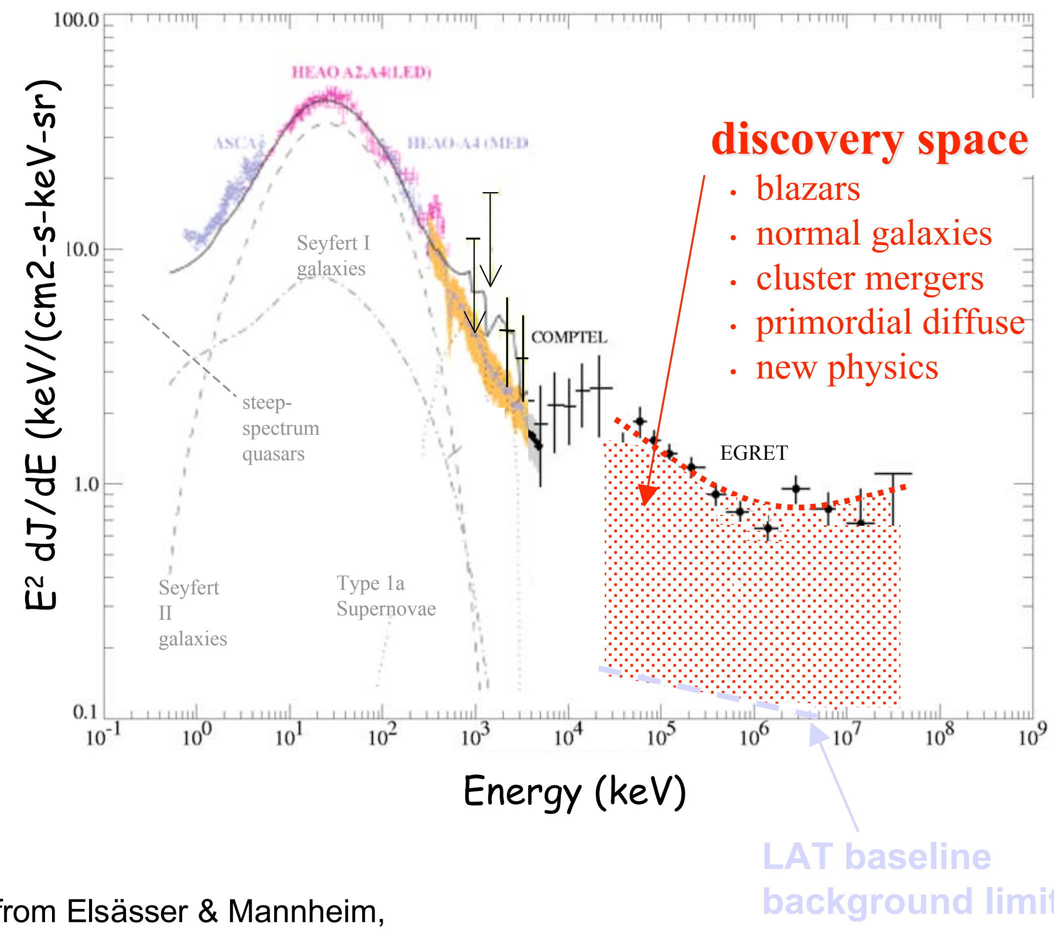
# Extragalactic $\gamma$-ray background

– ***origin is a mystery; either sources there for GLAST to resolve (and study!) OR there is a truly diffuse flux from the early Universe***

*EGRET constrains blazars to be > 25% of diffuse;*

*annihilation of cosmological neutralinos has, in principle, a distinctive spectral signature*

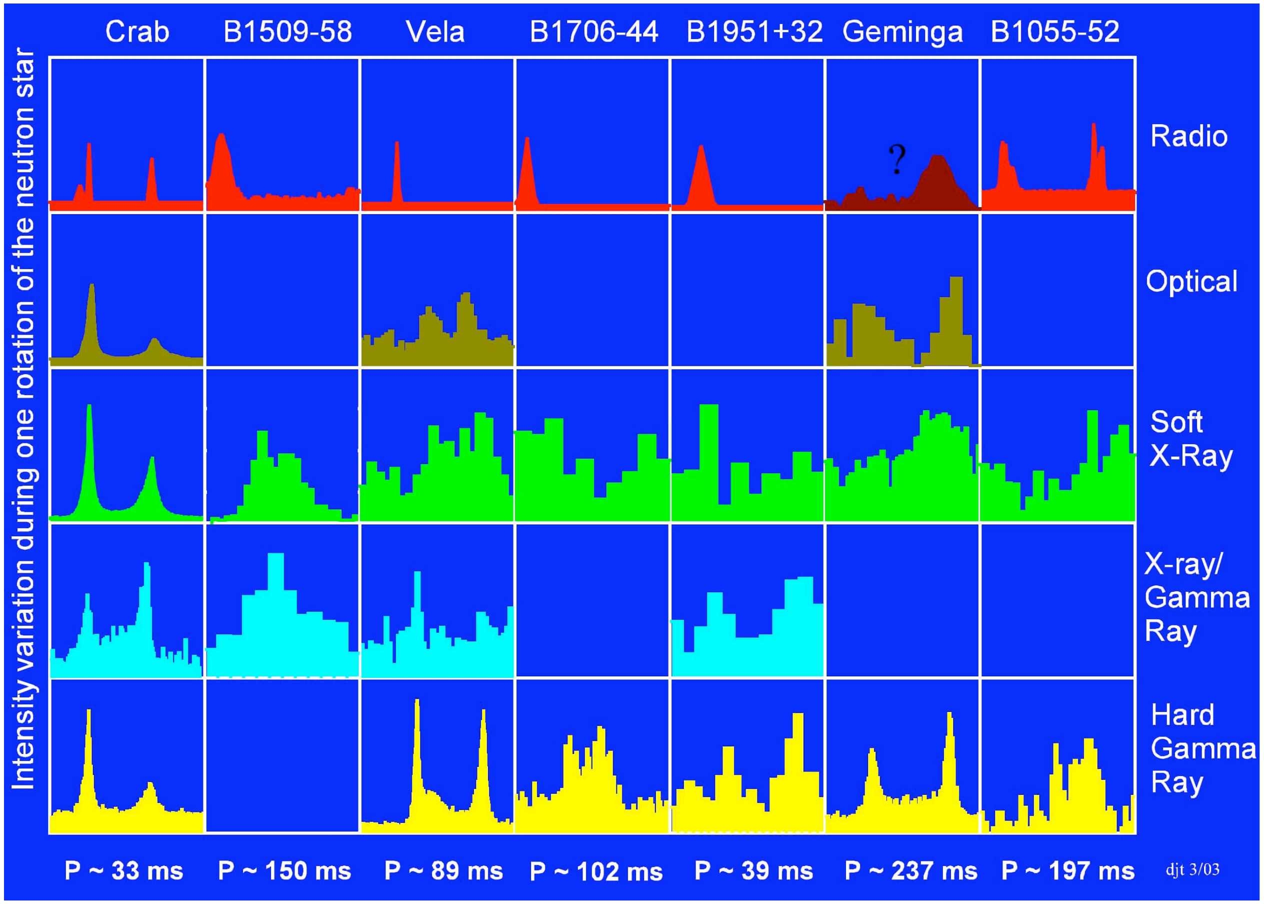



from Elsässer & Mannheim, Phys. Rev. Lett. (2005)

# Physics in the Extreme Environments of Pulsars

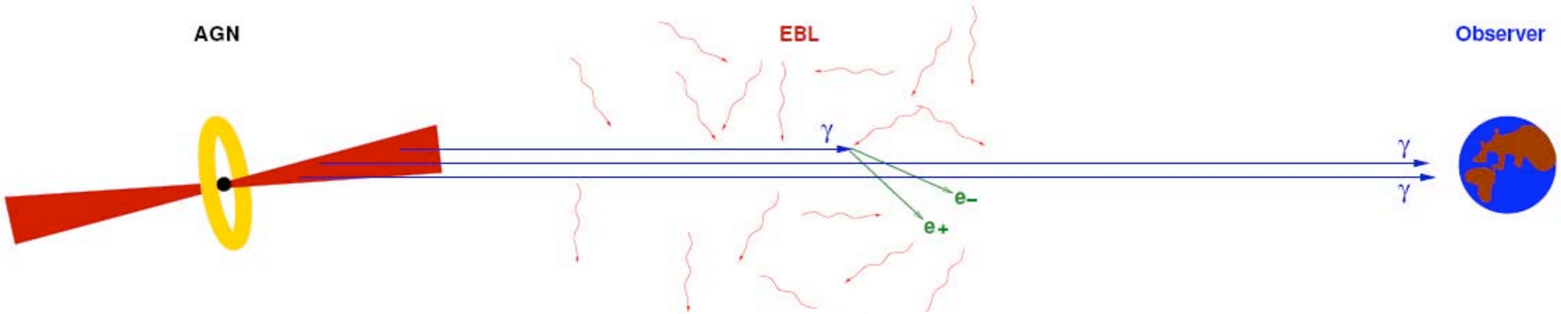
- ***sites of interactions in extreme gravitational, electric, and magnetic fields.***
- ***key to deciphering these extreme conditions is having accurate, absolute timing data for many pulsars.***
- ***with the exception of a few X-ray pulsars, radio band provides the needed timing information. A sizeable radio timing program is beyond the scope of routine radio pulsar programs.***




***Multiwavelength light curves of gamma-ray pulsars***

***- their diversity shows the need for a larger sample with better detail, including phase-resolved spectra at all wavelengths.***

# Probing Extragalactic Background StarLight with Blazars



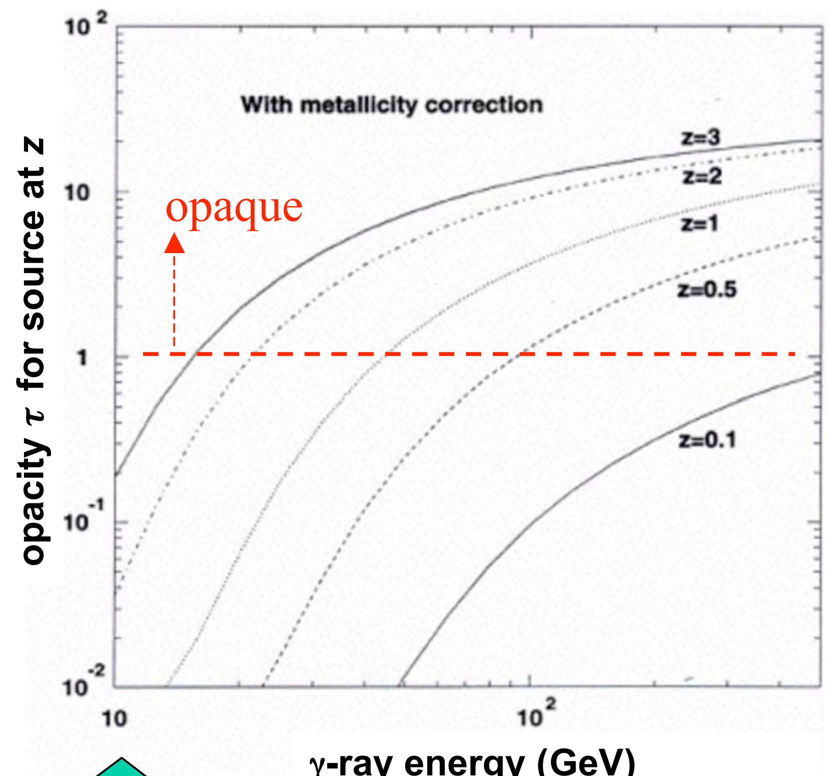

- *diffuse EBL contains unique information about the epochs of formation and the evolution of galaxies*

- *direct EBL measurements require accurate model-based subtraction of bright foregrounds (e.g., zodiacal light)*

- *alternative approach: extract imprint of EBL absorption, as function of redshift, from high-energy spectra of extragalactic sources*

$\gamma\gamma \to e^+e^-$, *maximum when*

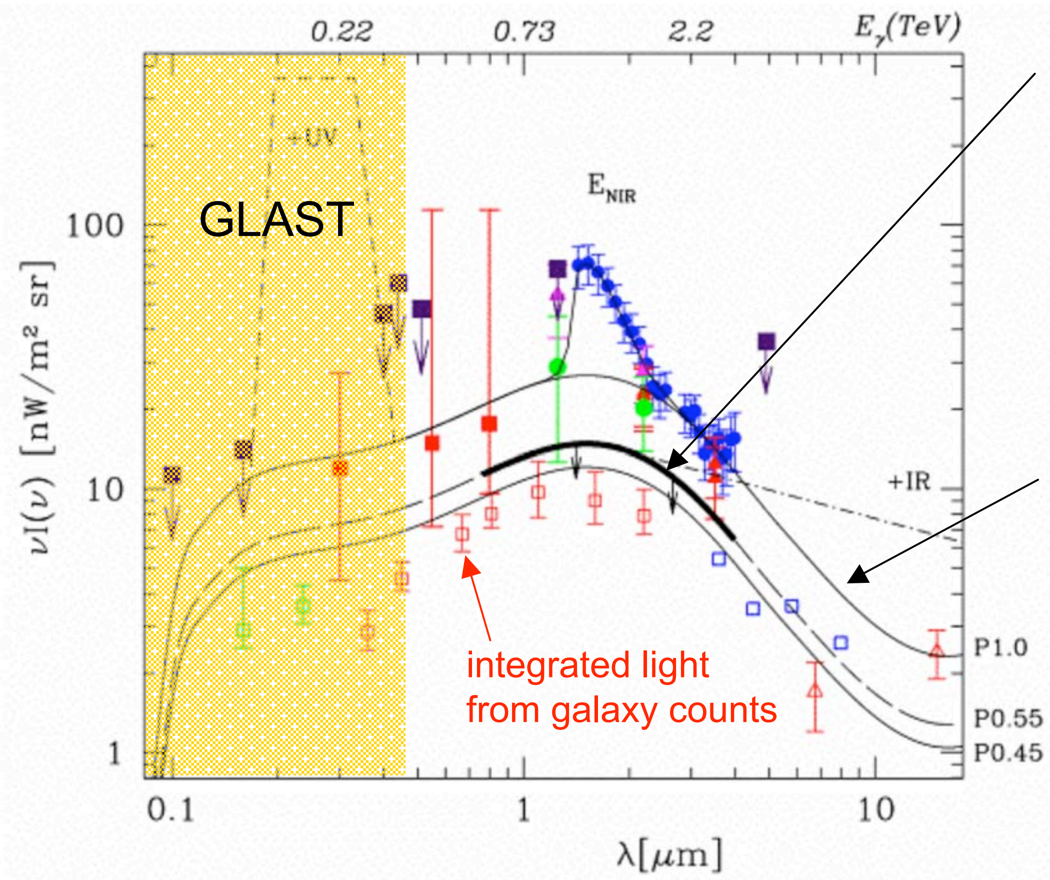
$\varepsilon_{EBL} \sim$ _ (1000 GeV / $E_\gamma$) eV




No significant attenuation below 10 GeV

# TeV (HESS) blazar constraints on EBL

***EBL spectral energy distribution***




**HESS upper limit derived from observed hard spectra of blazars at z = 0.165 and 0.186**

reference EBL SED, matches direct measurements at 2.2 and 3.5 $\mu$m.

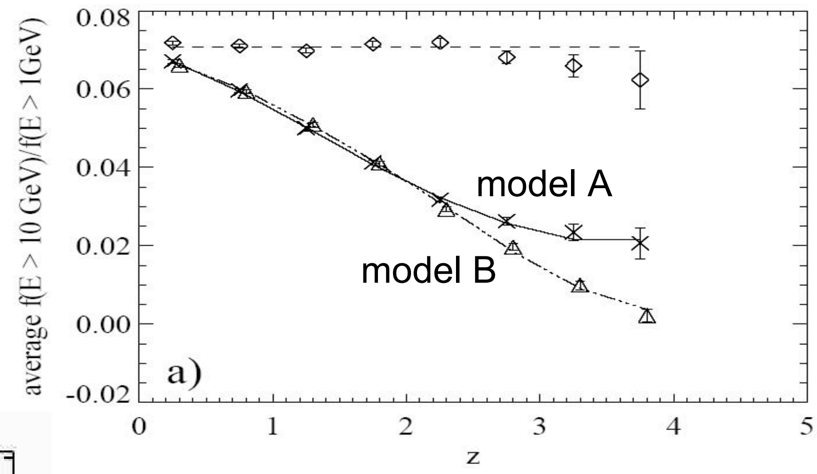
- *lower limits on HST galaxy counts combined with HESS upper limit on EBL imply that any unresolved component is no more than ~1/3 of the total.*

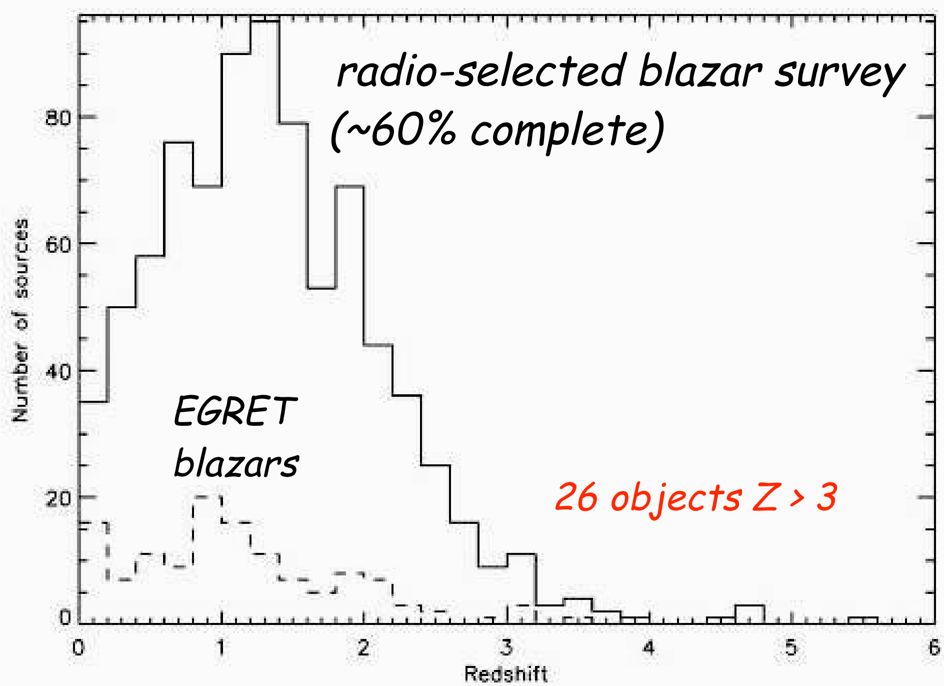
# Probing Extragalactic Background StarLight with Blazars

***GLAST science objective:***
*measure the redshift dependence of the attenuation of flux above 10 GeV for a sample of high-redshift blazars*

***sensitive to optical-UV EBL***

***measure flux E>10 GeV/flux E>1 GeV***




*70% of EGRET sources (|b|>10°) are blazars*

*4.8 GHz radio survey; chose bright flat-spectrum sources*

*95% of radio-selected sources are blazars*

# Summary of Critical Multiwavelength Needs

| Science Objective | GLAST provides | multi-$\lambda$ requirements |
|---|---|---|
| Differential measurement (vs $Z$) of extragalactic background light to $Z$ ~5.5 | Measurement of blazar spectra in band where cutoffs are expected from $\gamma + \gamma_{ebl} \rightarrow e^{+} + e^{-}$ | Broadband contemporaneous / simultaneous spectral measurements (radio, optical, X-ray, TeV) of blazar spectra, particularly around the synchrotron peak; |
| Resolve origin of particle acceleration and emission mechanisms in systems with relativistic jets, supermassive black holes | All-sky monitoring coverage of blazar flares and GRBs | radio and optical surveys of flat-spectrum radio sources to extend blazar catalogs |
| Reliable model of Milky Way diffuse emission required for accurate source localization and to facilitate search for dark matter | Mapping of cosmic ray interactions with all forms of interstellar matter. | Extend CO surveys to high galactic latitude; survey special directions (eg. spiral arms, galactic center) with optically thin tracer ($C^{18}O$) |
| Understand particle acceleration and emission mechanisms in extreme environment (gravity, electric and magnetic fields) of rotating neutron stars | Spectra and light curves resulting from primary interactions of the most energetic particles. | Contemporaneous radio and X-ray pulsar timing observations |

# Importance of national facilities

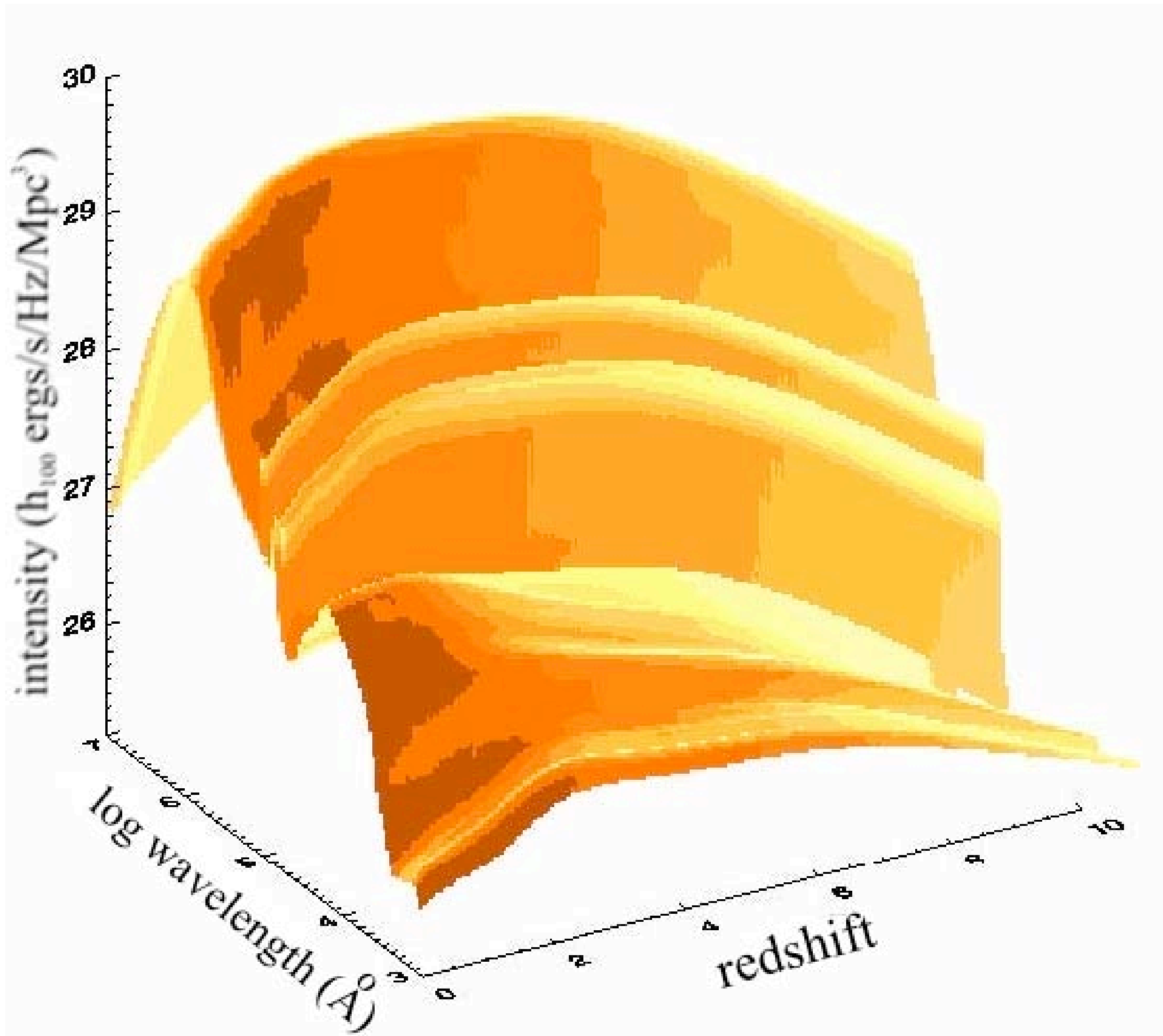
- ***GLAST operations depend on NASA and DOE facilities:***
  - **NASA** / GSFC: *mission operations, science support center*
    / MSFC*: GBM instrument operations*
  - **DOE** / SLAC: *LAT instrument operations; level-1 data processing pipeline*

- ***science is connected across facilities and agencies***
  - *GLAST is scientifically connected to, for example,*
    - *NRAO (VLA, VLBA, Greenbank)* **- NSF**
    - *NOAO* **- NSF**
    - *VERITAS* **- NSF/DOE**

- ***actions by one agency on one project can affect science; important for agencies to recognize interdependencies***

# Summary

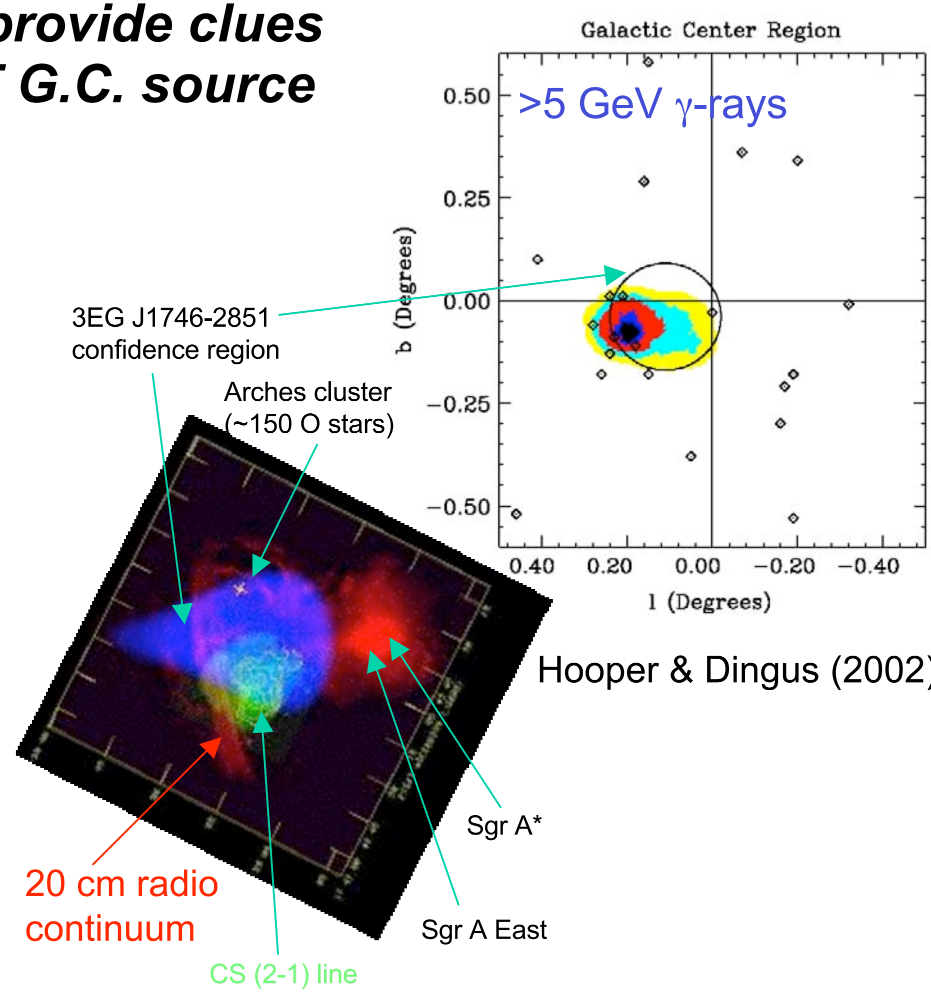
- ***Integration & test of all GLAST components underway.***
  - *LAT expected to be ready for observatory integration: June 2006*
  - *GLAST launch:  August 31, 2007*
  - ***DOE–NASA partnership on the Large Area Telescope is a success !!***
- ***GLAST will provide a major new capability for addressing important science questions.***
  - *optimal use will require extensive coordinated and, in some cases, simultaneous observations from radio to TeV energies*


intensity ($h_{100}$ ergs/s/s/Hz/Mpc$^3$)
30
29
28
27
26
log wavelength (Å)
redshift
0
2
4
6
8
10

Backup slides

# DM signal from Galactic center ?

- ***Spectrum, position, variability, and potentially angular extent provide clues about nature of the EGRET G.C. source***
  - *all of these depend on the model for diffuse emission*
- *Recent re-analyses of EGRET data suggest*
  - *source not coincident with the Galactic center itself*
  - *variable, too, although systematics are significant (Nolan et al. 2003)*
- *Many complications affect modeling the diffuse emission of this region & therefore the current results*




Hooper & Dingus (2002)

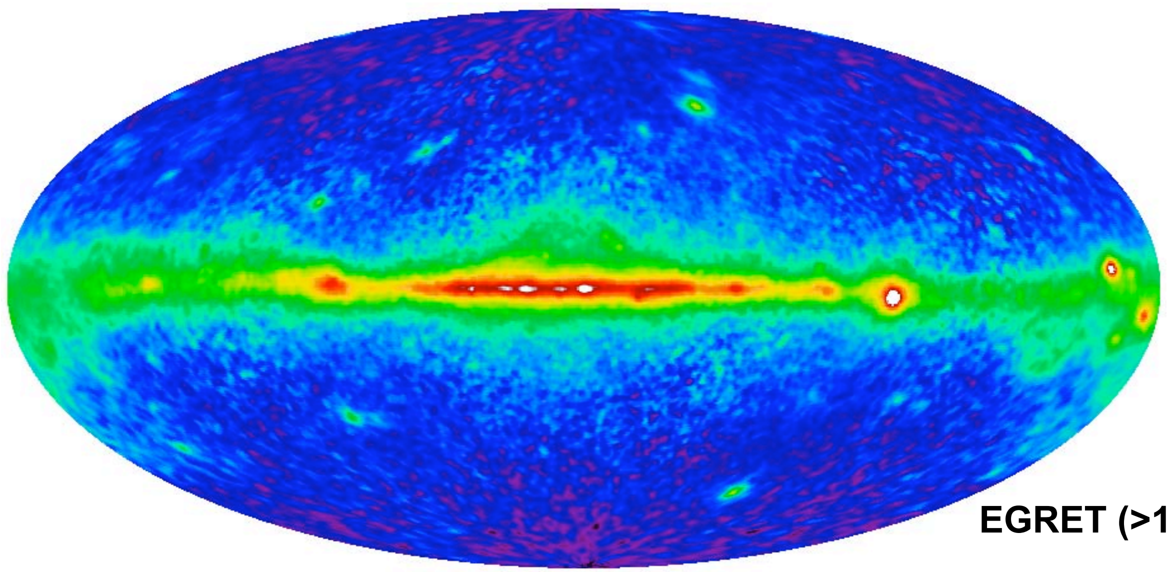
Yusef-Zadeh (2002)

# Modeling diffuse emission of the Milky Way

- ***Nature has given us some breaks***
  - *Radiative transfer is simple – once γ-rays are produced, they propagate without scattering or absorption*
  - *CRs tend to be much more smoothly distributed than the interstellar gas*
  - *Good tracers of the gas exist for most regions, with Doppler shift measurements obviating to a large extent the disadvantage of our in-plane perspective*

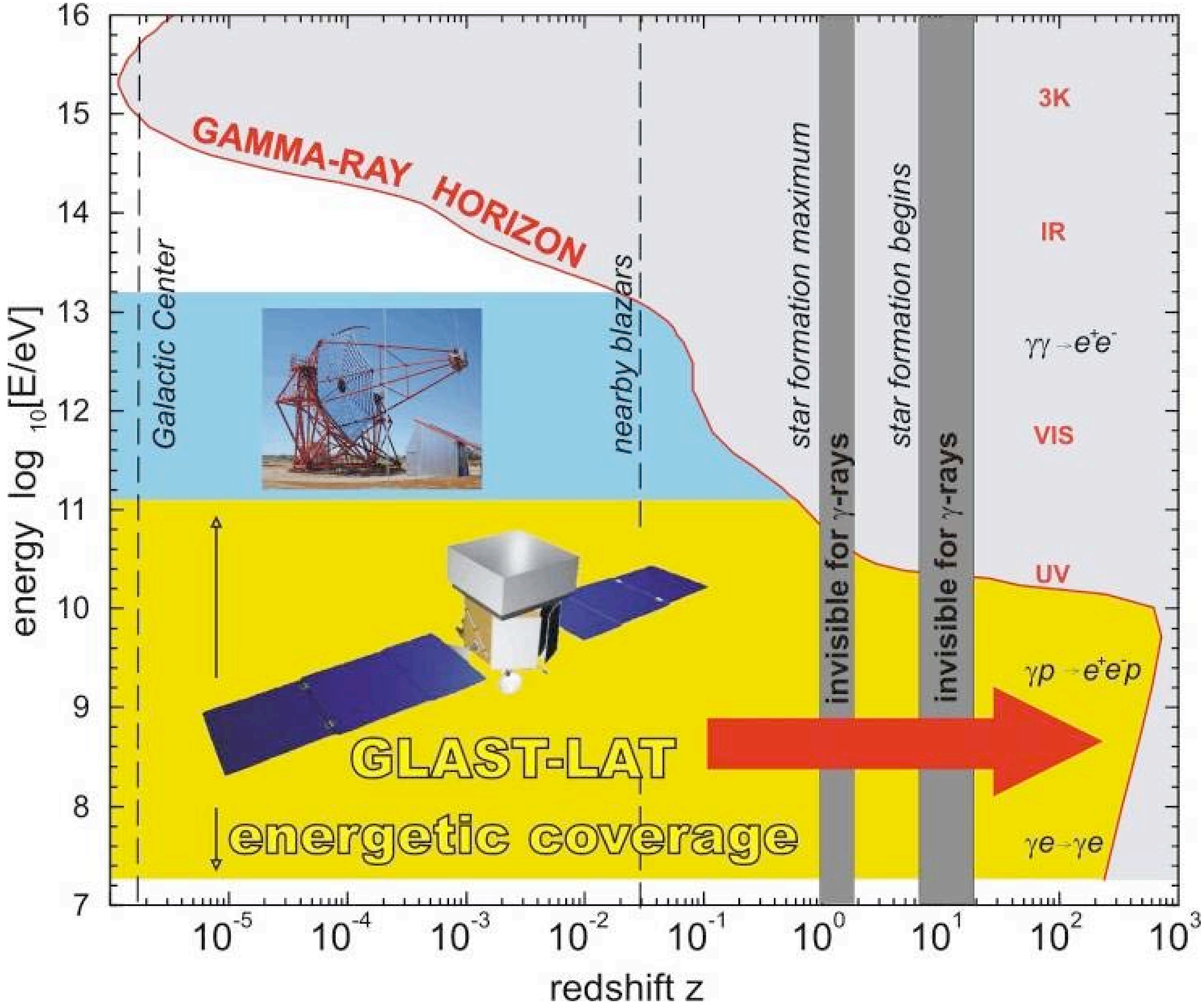
# Diffuse γ-ray emission from the Milky Way

- ***Milky Way: bright celestial background in high-energy γ-rays (approx. 85% of EGRET γ-rays)***



**EGRET (>100 MeV)**

- ***GLAST LAT science goals require a model for the Milky Way background that is reliable:***
  - *on large scales (absolute intensities of extended sources),*
  - *on small scales (positions and fluxes of sources)*



GAMMA-RAY HORIZON
Galactic Center
nearby blazars
star formation maximum
star formation begins
invisible for γ-rays
invisible for γ-rays
3K
IR
γγ → e+e-
VIS
UV
γp → e+e-p
γe → γe
GLAST-LAT
energetic coverage
energy log 10[E/eV]
16
15
14
13
12
11
10
9
8
7
10-5
10-4
10-3
10-2
10-1
100
101
102
103
redshift z

# Growing Science Community Involvement

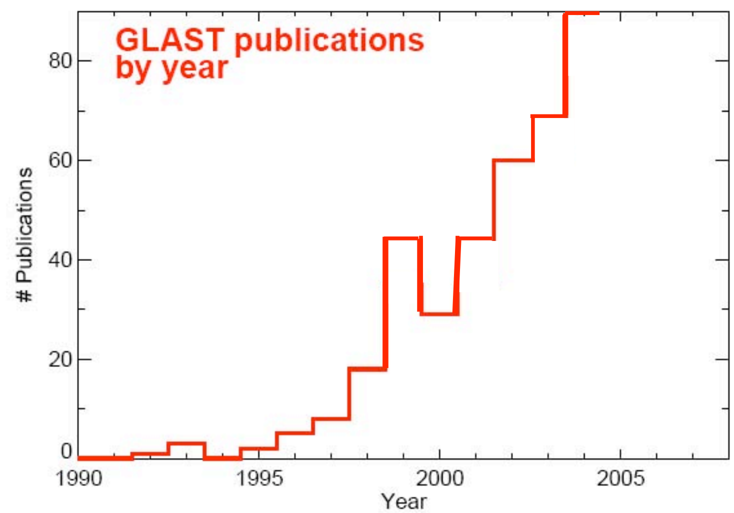
- ***At all mission levels: Science Working Group, User's Committee, Conferences, Workshops.***

- ***Multiwavelength survey initiatives underway***
  - *VLA monitoring for a large sample of flat-spectrum, compact sources (Ulvestad, et al.)*
  - *VLBA Imaging and Polarimetry Survey proposed to obtain a set of reference images for 1000 potential LAT sources in advance of GLAST launch (Taylor, Ulvestad, Readhead, Blandford, et al.).*
  - *Northern and Southern hemisphere radio pulsar timing campaigns in support of GLAST mission (Thorsett, et al. ; Manchester, et al.)*
  - *optical monitoring of LAT AGN*

- ***Broad and growing interest***

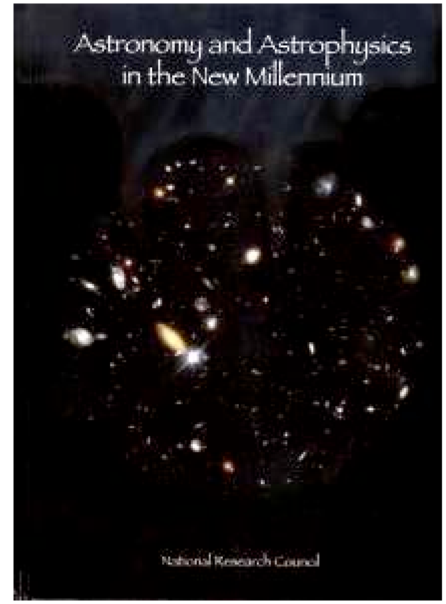
**Publications & Conference Proceedings**

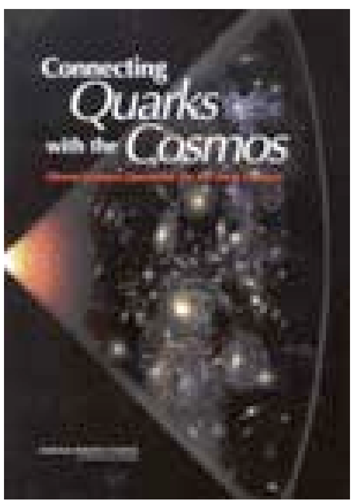
| | | pre-launch | total |
|---|---|---|---|
| ***COS-B*** | ***1975-1982*** | ***11*** | ***481*** |
| ***EGRET*** | ***1991-2000*** | ***53*** | ***1212*** |
| ***GLAST*** | ***2007-*** | ***404*** | ***???*** |

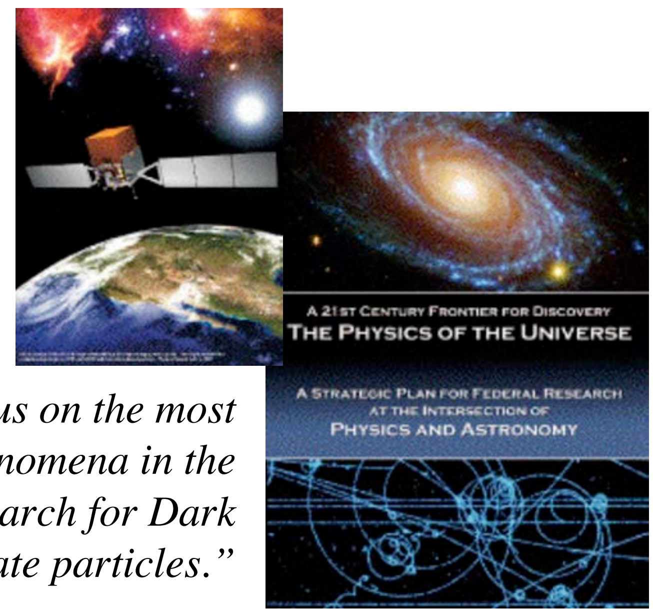


# GLAST: Exploring the High-Energy Universe

- ***gamma rays provide a direct view into Nature's largest accelerators***
- ***the Universe is mainly transparent to $\gamma$ rays: can probe cosmological volumes. Any opacity is energy-dependent.***
- ***huge leap in key capabilities, including a largely unexplored energy range; great potential for*** **Discovery**
  - *recognized by the National Academy of Sciences 2000 Decadal Survey (Taylor-McKee): GLAST is* ***top-ranked*** *mission in its category*
- ***also featured in NAS Connecting Quarks with the Cosmos and the Physics of the Universe 2004 Strategic plan:***




*"…GLAST will focus on the most energetic objects and phenomena in the universe…it will also search for Dark Matter candidate particles."*