# GLAST LAT Multiwavelength Studies Needs and Resources

## Report of the Ad Hoc Multiwavelength Observation Planning Group

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# Outline

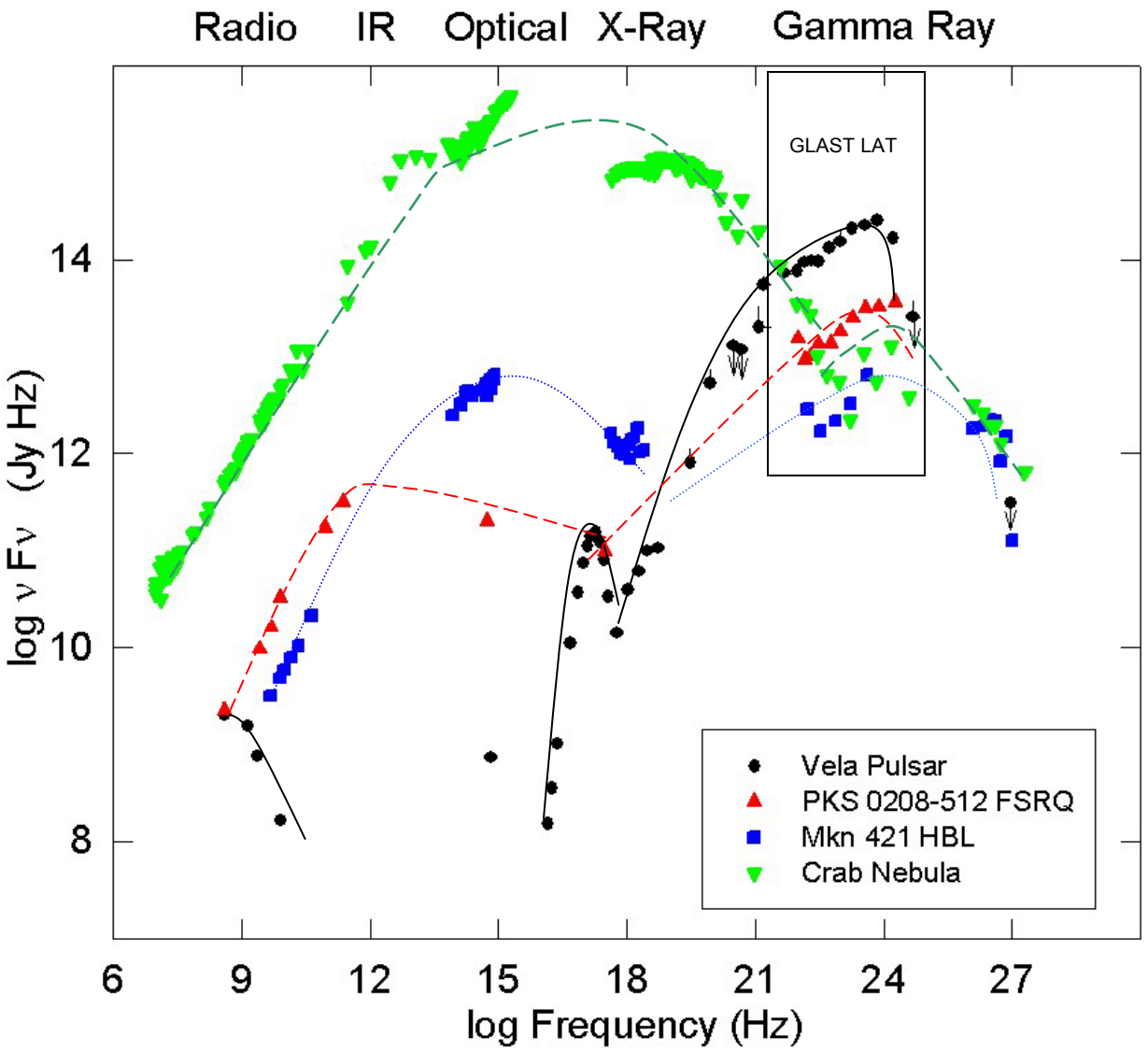
- **MOTIVATION: Why gamma-ray sources should be multiwavelength (MW) objects**
- **IDENTIFICATION :Finding the blazars and pulsars.**
- **DISCOVERY: New science; counterpart searches.**
- **EXPLORING: MW blazar monitoring and campaigns.**
  **MW pulsar studies**
- **CONCLUSION: Some issues.**

# Gamma-ray Sources: Inherently Multiwavelength

**In the MeV range and above, sources are non-thermal**
**$\Rightarrow$ produced by interactions of energetic particles**

- Nature rarely produces monoenergetic particle beams. Broad range of particle energies leads to a broad range of photon energies.
  - Example: $\pi^o$ 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

# Multiwavelength Gamma-ray Sources



# MW Approaches for LAT

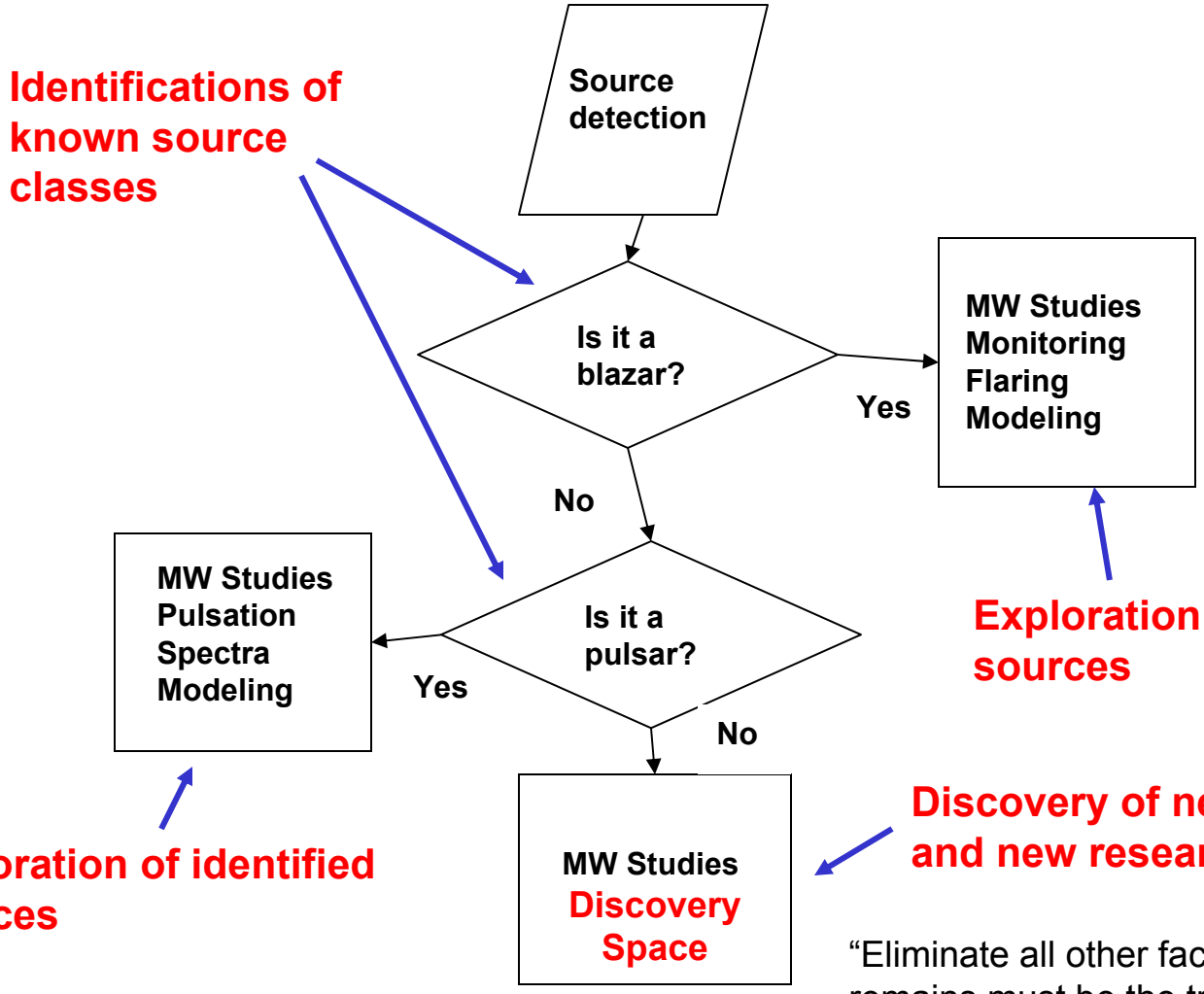
| Source Class | Number seen by EGRET | Number anticipated with LAT |
|---|---|---|
| Blazars | 80 definite<br>50 possible | >2000 |
| Rotation-powered pulsars | 6 definite<br>3 possible | 100-500 |
| Normal galaxies | 2 | 4-5 |
| Gamma-ray bursts | 5 | >500 |
| Unidentified sources | 170 | ? |
| Supernova remnants/plerions | 1 likely<br>~5 possible | >10 |
| Radio galaxies | 1 likely<br>1 possible | ? |
| X-ray binaries/microquasars | 1 likely<br>1 possible | ? |
| Starburst galaxies | 0 | ? |
| Clusters of galaxies | 0 | ? |

## Two broad areas:

1. Identification for known source classes; discovery of new classes. "What are they?"
2. Exploration of identified sources. "What can we learn from them?"

Note: GRB needs are being studied by the GLAST Burst Committee.

# MW Approaches for LAT

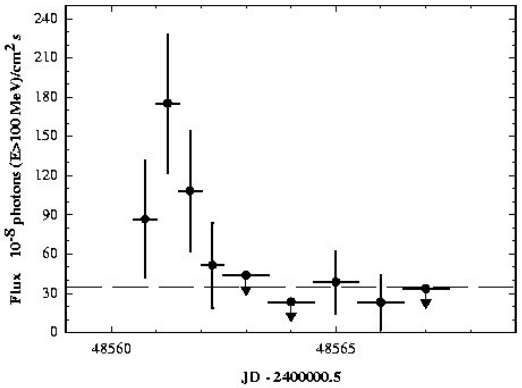



"Eliminate all other factors, and the one which remains must be the truth." Sherlock Holmes

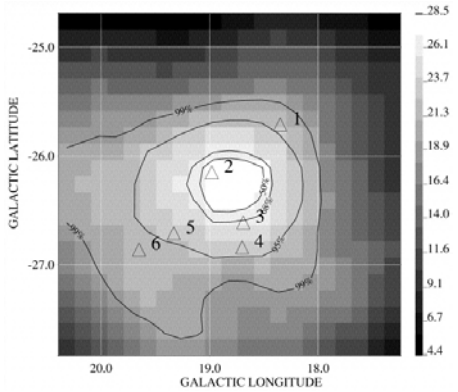
# IDENTIFICATION AND DISCOVERY

# Blazar Identification Example: 3EG J2006-2321

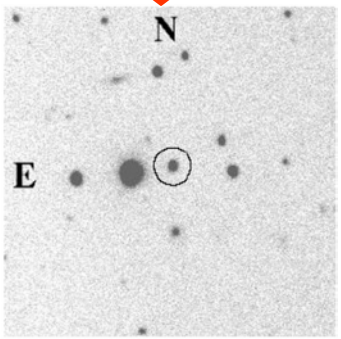
**First Clue: Gamma-ray variability**




**Radio sources in the error box**



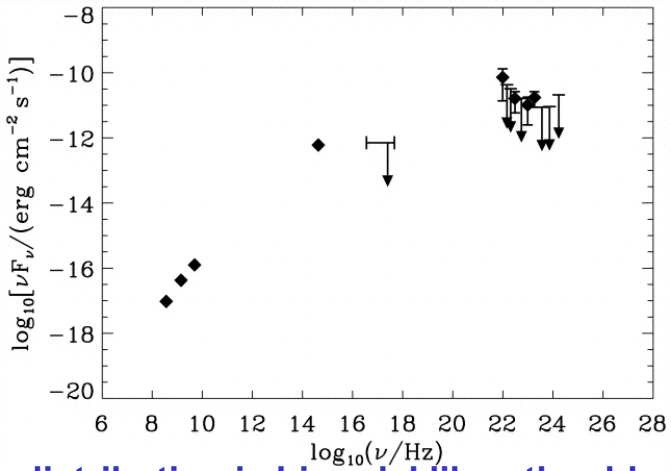

One flat-spectrum radio source, 260 mJy at 5 GHz; one marginally-flat source, 49 mJy; other sources are much weaker




**Optical observations:**

The 49 mJy source is a normal galaxy;

The 260 mJy source has an optical counterpart with a redshift z=0.83




Variable optical polarization is seen.

Only an X-ray upper limit found.

Spectral energy distribution is bimodal like other blazars

**Conclusion: a flat spectrum radio quasar (FSRQ)**

# Identifying Blazars

**Problem: the exhaustive, one-at-a-time approach just described is impractical for the thousand or more blazars expected with LAT.**

**LAT needs an efficient blazar identification scheme, basically an expanded catalog of blazars. BEFORE LAUNCH.**

**Three examples of pilot projects to accomplish this goal:**

1. **The Deep X-Ray Radio Blazar Survey (DXRBS) compares X-ray sources with flat-spectrum radio sources. Landt et al. X-ray selected blazars are not necessarily gamma-ray blazars.**
2. **Sowards-Emmerd, Romani, and Michelson have shown that compact, flat-spectrum radio sources, with optical follow-up, are a good identifier of blazars. Their analysis has found a substantial number of new blazars in the EGRET source catalog.**
3. **The ASI (Italian Space Agency) Data Center Blazar Candidate sample uses cross-correlation between NVSS and ROSAT All Sky Survey (RASS) radio and X-ray surveys, plus optical magnitudes in the blazar range from the Guide Star Catalog 2 (GSC2), producing over 7400 candidates.**

# MW Needs for Identifying Blazars

Strong correlation of blazars with flat-spectrum, compact radio sources.

In Northern Hemisphere, CLASS 8.4GHz + NVSS/FIRST

In Southern Hemisphere, need new observations. ATCA 20 GHz survey may help.

Recommendation: complete a Southern Hemisphere survey out to at least 8.4 GHz and down to at least 100 mJy, preferably to 30 mJy.

Optical identifications and redshift measurements are important to establish extragalactic origin and rule out unlikely candidates.

Recommendation: complete a program of optical identifications and redshift measurements for all known flat-spectrum radio sources brighter than 100 mJy at 8 GHz.

# MW Resources for Identifying Blazars

**Other blazar identifiers**

- **Core-dominated radio**
- **Radio polarization**
- **Radio variability**
- **Optical polarization**
- **Optical variability**

| Measurement | Facility - Examples |
|---|---|
| Radio spectrum<br>Radio mapping<br>Radio variability | VLA/VLBA |
| Radio spectrum | Metsahovi |
| Radio variability | Green Bank |
| Radio spectrum<br>Radio mapping<br>Radio variability | Parkes, Australian Telescope Compact Array |
| Redshift | Keck, Hobby-Eberly, ESO, 4 m telescopes, others |
| Radio polarization | |
| Optical polarization | |

# MW Needs for Identifying Gamma-ray Pulsars

Although some pulsars may be detectable in LAT data with blind searches, the deepest searches for pulsed emission will require timing information from other wavelengths, primarily radio.

Timing observations need to be contemporaneous, because young pulsars typically have significant timing noise.

Radio astronomers, coordinated by Steve Thorsett, are prepared to support LAT observations, but the number of pulsars to be monitored will have to be limited.

Recommendation: Use pulsar models to develop a prioritized list of radio pulsars to be monitored.

BEFORE LAUNCH AND DURING THE FULL MISSION

# MW Resources for Identifying Pulsars

| Measurement | Facility |
|---|---|
| Radio timing/search | Parkes |
| Radio timing/search | Arecibo |
| Radio timing/search | Allen Array |
| Radio timing/search | Green Bank |
| Radio timing/search | Jodrell |
| Radio timing/search | VLA |

# MW Needs for Discovery Space

If neither a blazar nor a radio pulsar identification is possible, then the challenge is one of discovery, covering a wide range of exciting possibilities.

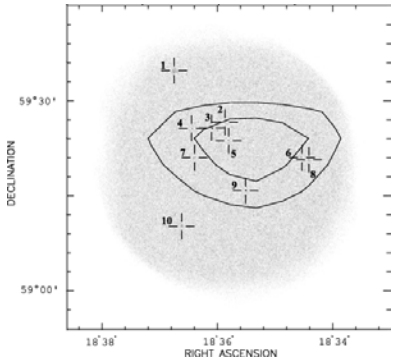
Although some specific source characteristics may motivate particular searches (e.g. non-variable, extended gamma-ray emission could be a molecular cloud, a supernova remnant, a galaxy, or a cluster of galaxies), we suggest that a generic approach is to work from X-rays downward in energy (as was done with Geminga, the classic example).

Note that gamma-ray source identification in general, but in particular for sources near the Galactic Plane, is strongly dependent on development of a good model of the diffuse emission, a responsibility of the LAT team.

Recommendation: support detailed CO observations for specific directions needed to augment models of the diffuse emission.

# Nearby/High-Latitude Discovery Approach Example

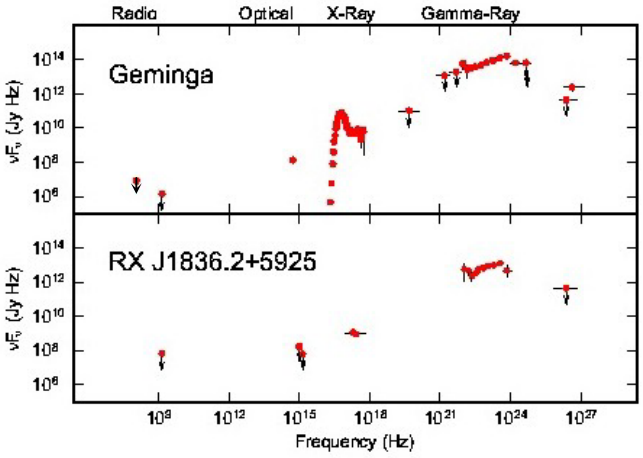
**Parallel effort by two groups, headed by Mirabal/Halpern and Reimer/Carramiñana – used the same approach and reached the same conclusion for 3EG J1835+5918**



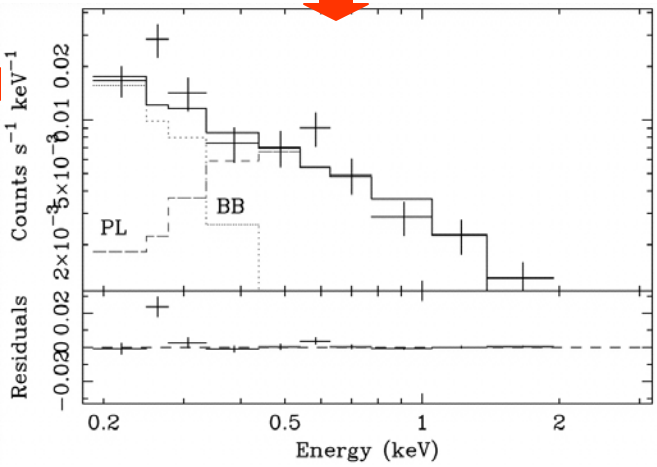

**Start with deep ROSAT image (soft X-rays)**

**Take deep optical images to try to identify all the X-ray sources. Most turn out to be stars or QSOs, unlikely gamma-ray sources. One candidate has no obvious optical counterpart: RX J1836.2+5925.**

**Use radio search to look for possible radio pulsar. None found.**



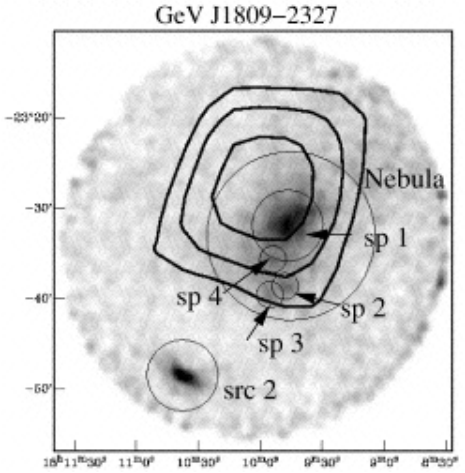

**Construct MW spectrum. It resembles that of Geminga, a spin-powered pulsar. No pulsations have yet been found for 3EG J1835+5918.**



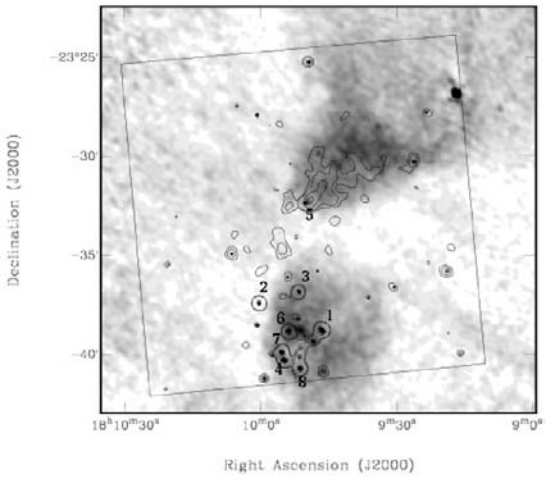

**Use Chandra to obtain X-ray spectrum of the candidate: two components, one thermal, one power law.**

# Distant/Low-Latitude Discovery Approach Example

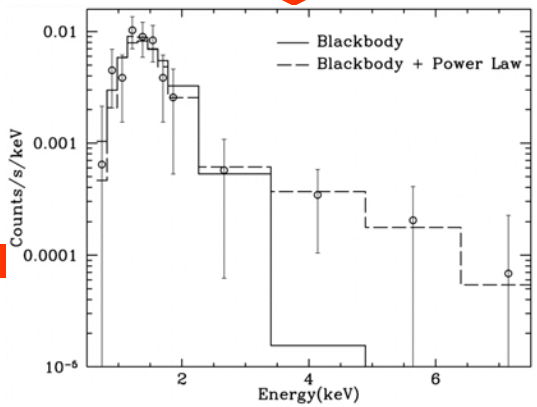
**For low latitudes or distant sources, use hard X-rays and radio to minimize absorption effects.**




**Start with ASCA hard X-ray image, which suggests extended emission.**

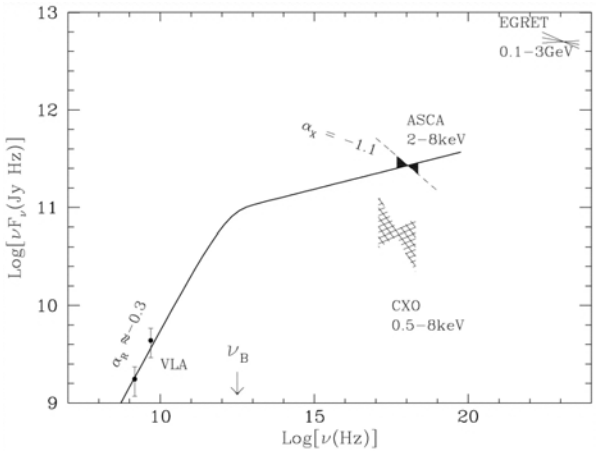



**More detailed Chandra X-ray contors overlaid on VLA 21 cm radio map (nonthermal). Source 5 is the candidate, after elimination of others as unlikely gamma-ray sources from optical observations.**




**Use Chandra to obtain X-ray spectrum of the candidate: two components, one thermal, one power law.**

**Construct MW spectrum. It is consistent with that of a pulsar wind nebula, but with an extra component for the gamma rays. The variability of the gamma-ray source suggests that it is not a pulsar.**




**M. Roberts and colleagues**

# MW Needs for Discovery Space

Catalogs of existing objects, plus search tools such as NED and Simbad, provide tools for population studies, which are important but do not necessarily identify individual sources.

The most useful X-ray observations for discovering gamma-ray counterparts are likely to be those with good angular resolution and sensitivity above 2 keV, where absorption effects are minimized.

Recommendation: Plan campaigns with Chandra, XMM, Astro E2, and (if selected) NuSTAR or DUO for high-energy X-ray studies of unidentified gamma-ray source error boxes, supplemented by radio mapping.

DURING EARLY PART OF MISSION IN PARTICULAR

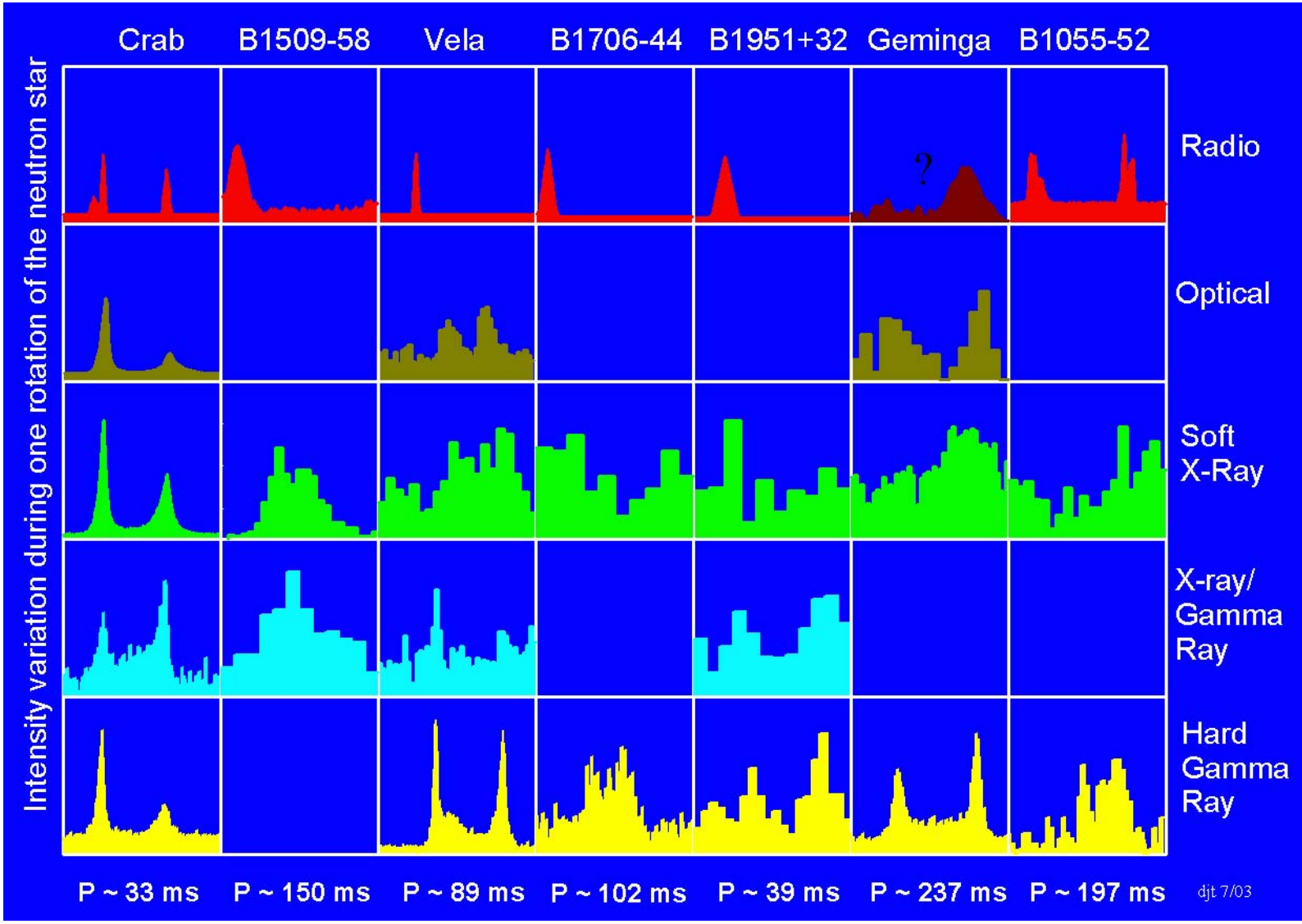
# EXPLORATION OF IDENTIFIED SOURCES

## Pulsars and Blazars as examples

# The Seven Highest-Confidence Gamma-ray Pulsars

**Pulsars are seen across the spectrum, and the pulses seen at different wavelengths are not generally in phase.**

**Pulsars are typically faint in optical and weak in X-rays.**



# MW Needs/Resources for Pulsar Exploration

In order to study phase relationships of pulses and to add data over long time intervals, we need absolute phase information. This requires continued timing of pulsars, along with occasional collection of Dispersion Measure (DM) information from radio measurements.

Recommendation: Work with radio pulsar astronomers to collect radio timing information regularly over the life of GLAST, for some set of pulsars.

Deep radio, optical and X-ray exposures, with timing, will be needed in order to develop true MW information about pulsars, both young and millisecond.

Recommendation: Plan proposals for follow-on pulsar observations with X-ray, optical, and radio telescopes.

DURING THE MISSION

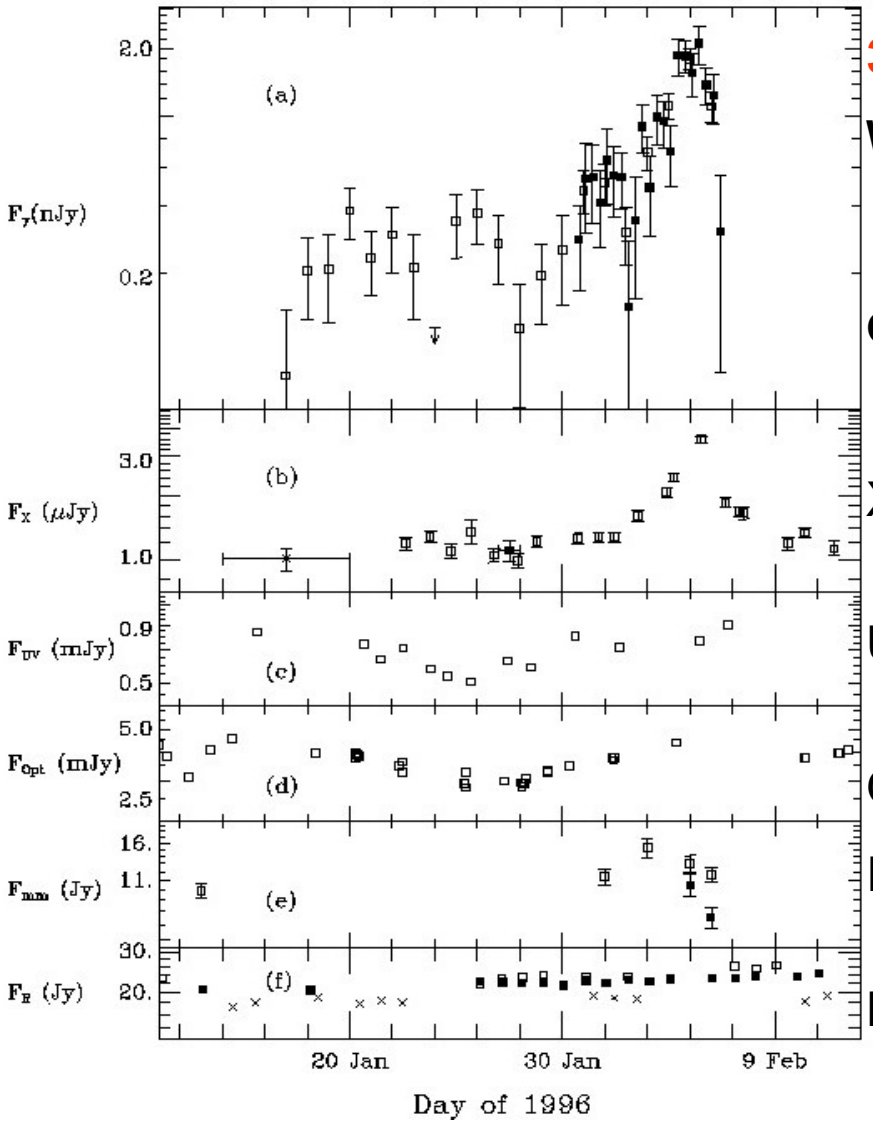
# MW Needs for Blazar Exploration

**Blazars are characterized by both short-term and long-term variability at essentially all wavelengths. The relationship between changes at different wavelengths is a powerful tool for studying the jets in these sources.**

**Two general aspects to exploration of blazar variability:**

1. **Monitoring to know what the long-term behavior is and to identify short-term flares.**
2. **Campaigns for intensive study, particular during flares.**

**DURING THE MISSION**



# MW Resources for Blazar Monitoring

**LAT itself will be an excellent monitor for blazar activity, particularly in scanning mode.**

**There are a number of existing blazar monitoring programs at other wavelengths.**

**Recommendation: We should be sure to participate with existing programs.**

| Measurement | Facility - Examples |
|---|---|
| Radio monitoring | Metsahovi |
| Radio monitoring | Michigan |
| Radio monitoring | VLA/VLBA |
| Optical monitoring | ESO |
| Optical monitoring | WYBT |
| Optical monitoring | GTN |
| Optical monitoring | Perugia |
| Optical monitoring | Crimea |
| X-ray monitoring | RXTE |
| X-ray monitoring | Swift |
| TeV monitoring | VERITAS |
| TeV monitoring | Magic |
| TeV monitoring | HESS |
| TeV monitoring | CANGAROO |

# MW Resources for Blazar Campaigns

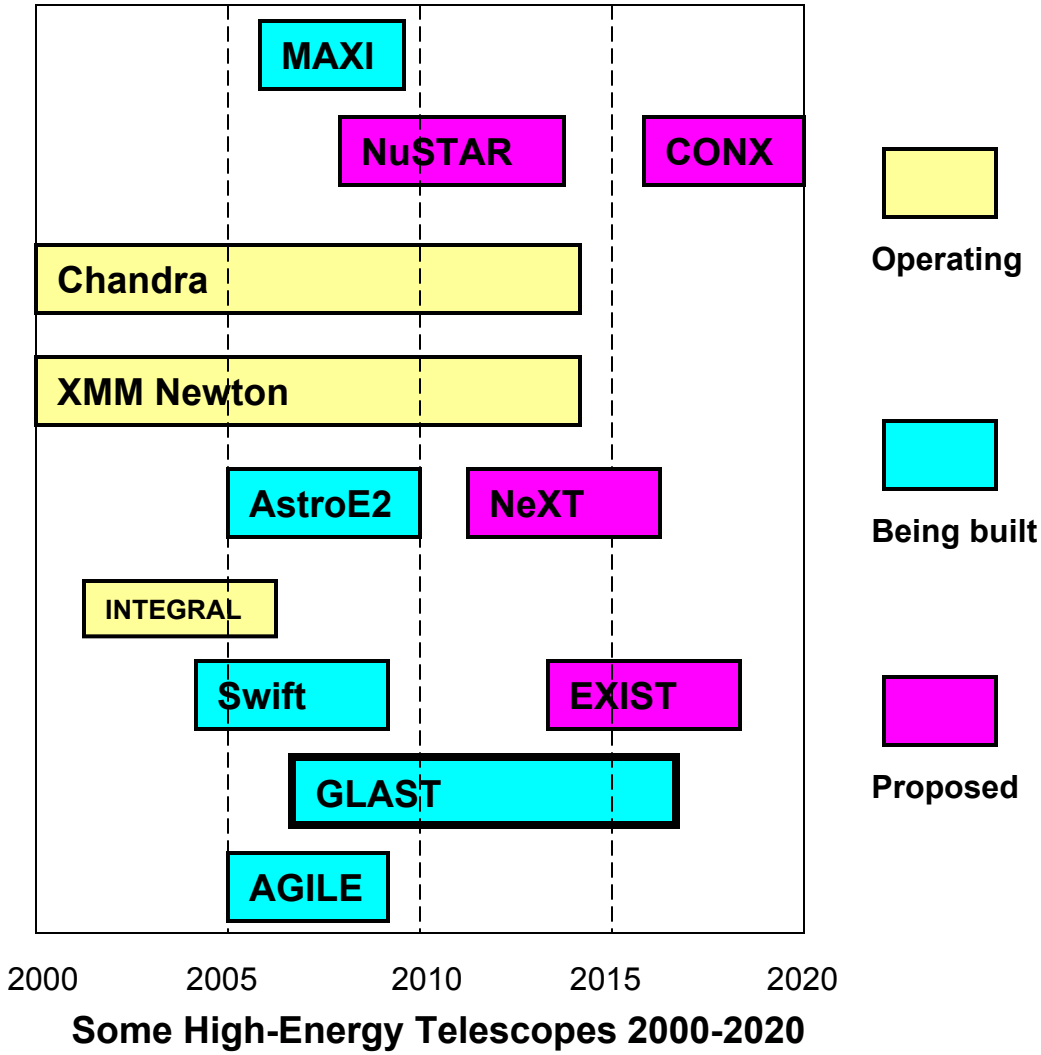
- Planned MW campaigns require substantial effort to organize but can produce broader coverage.
- Target of Opportunity campaigns are easier to manage, but the coverage is less likely to be complete.
- Recommendation: We should participate in both types of MW blazar campaigns and work to obtain 24 hr. coverage around the world for ground-based telescopes.

| Measurement | Facility - Examples |
|---|---|
| Radio | Metsahovi |
| Radio | VLA |
| Radio | VLBI |
| Radio | Green Bank |
| Radio | Parkes |
| Radio | Michigan |
| Radio | VLBA |
| Sub-mm | SEST |
| IR | Spitzer |
| Optical | ESO/ENIGMA |
| Optical | WEBT |
| Optical | GTN |
| Optical | Perugia |
| Optical | Crimea |
| X-ray | Chandra |
| X-ray | XMM |
| X-ray | RXTE |
| X-ray | Swift |
| X-ray | Astro E2 |
| X-ray | NuSTAR or DUO |
| TeV | VERITAS |
| TeV | Magic |
| TeV | HESS |
| TeV | CANGAROO |

# SOME ISSUES

In reviewing resources, we note two possible "choke points" in planning:

1. Far-IR (satellite) observations (the peak of some FSRQ synchrotron components) are only possible with Spitzer Space Telescope (SIRTF), but it is heavily oversubscribed and will lose cooling early in the GLAST mission.
2. The amount of X-ray telescope time needed for both identification and exploration is substantial, probably more than will be readily available through the few X-ray telescopes that will be operating in the GLAST era.




Some High-Energy Telescopes 2000-2020

# IMPLEMENTATION ISSUES

- How do we maintain the MW effort after the first year, when all the data become public?
- How do we prioritize our MW efforts, especially the trade between discovery efforts and exploration efforts?
- How do we balance the desire for competitive, peer-reviewed science opportunities with the rights of the existing LAT team?
- How should new, major contributors to the MW campaign be incorporated into the LAT team?
- How do we persuade NASA to invest in a "Legacy" or "Treasury" program that will largely involve the support of MW observations before and during the LAT mission.

# SUMMARY

- **GLAST science will be maximized by MW studies carried out cooperatively between the instrument teams and the user community.**

- **BEFORE LAUNCH – expand the catalog of known blazars; start radio timing program for pulsars**
- **EARLY IN THE MISSION – carry out radio and X-ray observations, in particular, to help identify gamma-ray sources.**
- **THROUGHOUT THE MISSION – collaborate in monitoring and coordinated MW campaigns for flaring sources, regular timing for pulsars**