The Fermi LAT in relation to All-sky Monitors: a New Approach to Multi-Wavelength Correlations

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Introduction: Multi-wavelength All-sky Monitor Coverage

We are entering an age of grand all-sky monitors:

All-sky monitor (ASM) =

full or near-full sky coverage with high revisit frequency

Although the term "ASM" has been associated historically with X-ray instruments particularly the ASM on *RXTE*, it will be used here in this generic sense

New ASMs coming on line reach *high levels of sensitivity* for their respective EM bands – examples will be considered

Supplements or provides alternative to multi-wavelength campaigns

Fermi needs this, because sources seen in Fermi tend to be very broad band, from radio to GeV or TeV, and often variable.

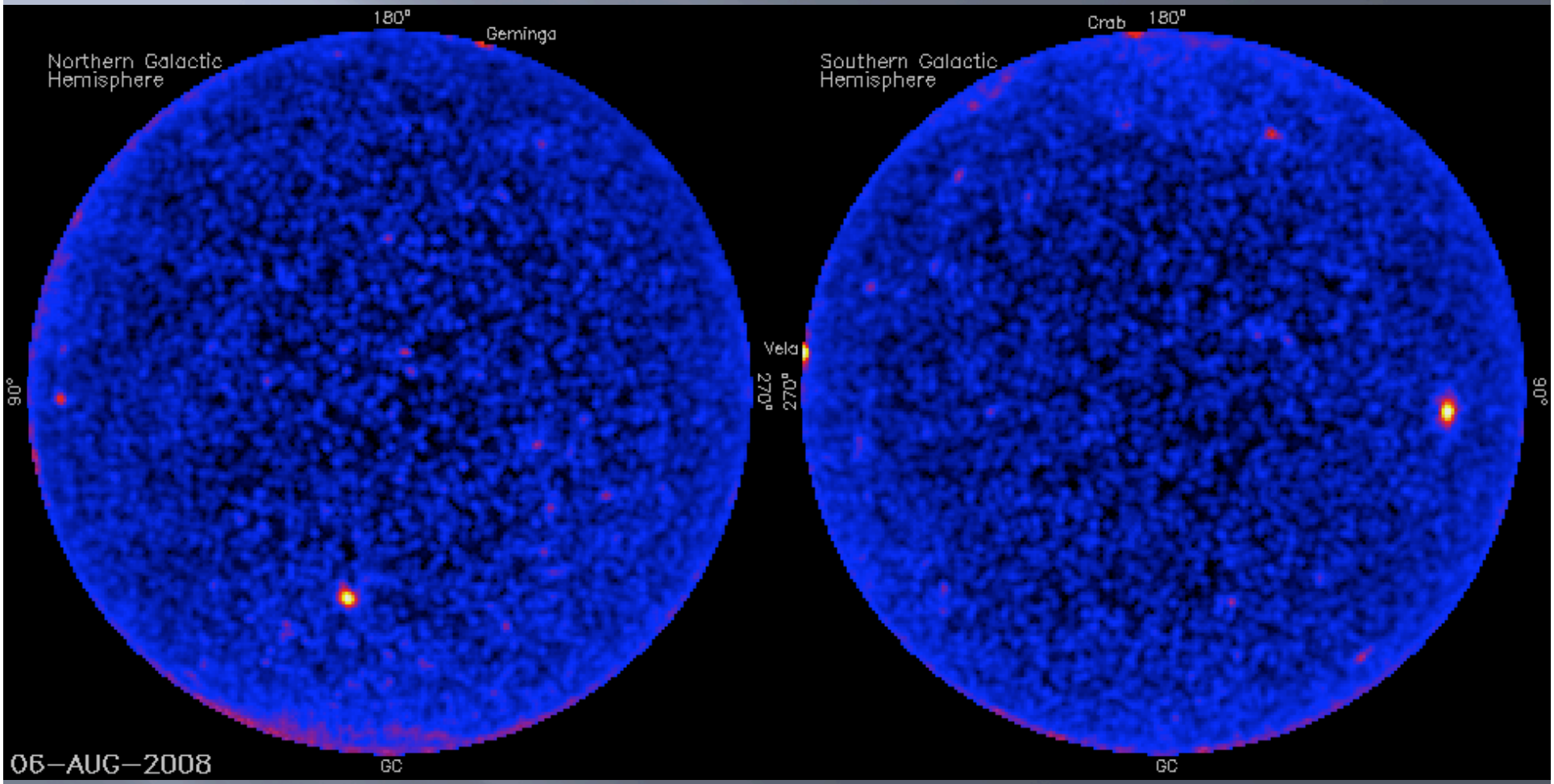
Fermi LAT as an ASM

- **Fermi LAT is first true ASM for E>20 MeV**
  - **Imaging, timing, high sensitivity, 4π**
  - **Also have GBM for energies < 20 MeV**

- **Fermi multi-wavelength work currently combines several approaches to achieve needed coverage (these are mainly photometric examples)**
  - **Dedicated campaigns on prominent sources**
  - **Scheduled re-visits. on source lists**
  - **GI targeted-science proposals, collaborations**
  - **Some use of existing ASMs, e.g., RXTE ASM**

- **ASM approach (idealized):**
  - **Observe all wavebands, full sky, all the time**
  - **When one channel triggers, look forward and backward in other channels; mine the data**
  - **Global data base available for sanity checks**
  - **Effective for flares, transients**
  - **Eventually gives long data sets for FFTs, correlations**

Three months of Fermi, the movie



Pan-STARRS 1: first optical ASM?

PanSTARRS (3π survey) qualifies as an optical ASM for Fermi purposes. (As with Fermi, they have other objectives; they would regard this one as secondary to their main goals.)

Properties of PanSTARRS

Coverage: **Sees 3/4 of sky**

Cadence: **Surveys accessible sky twice per lunation**

Sensitivity: **Single image limit can reach m >22**

Spectral: **5 filters (g,r,i,z,y)**

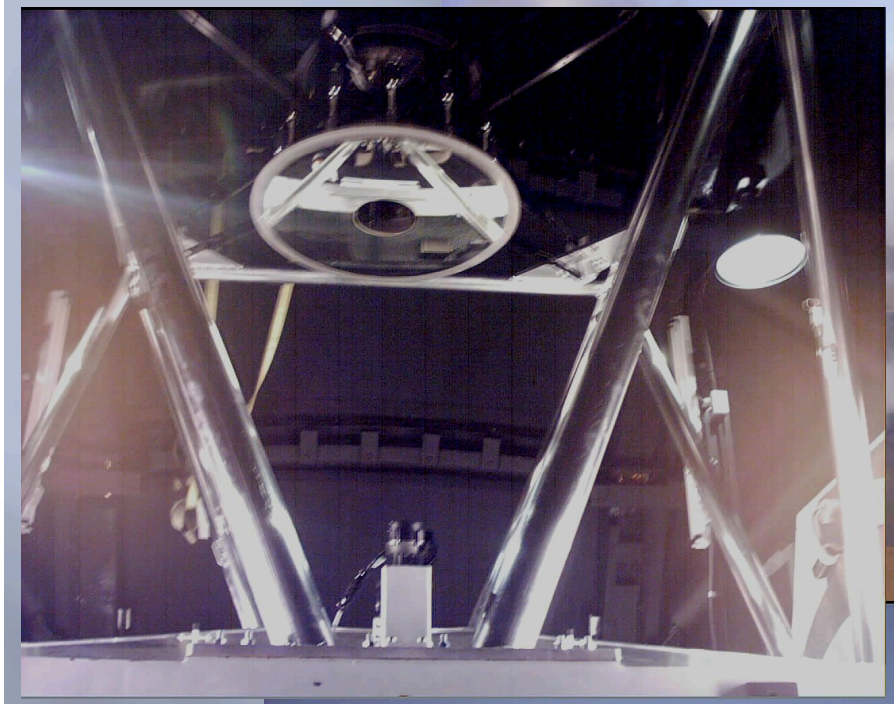
- g 405 – 550 nm >24
- r 552 – 689 " >24
- i 691 – 815 " >24
- z 815 – 915 " >24
- y 967 – 1024 " >22

Pan-STARRS 1 (PS1)

- 4 @ 1.8 meter telescopes for PS4;
- *One* of these four telescopes constitutes PS1, assembled now at IfA site at Haleakala (Maui)
- Telescope system: Richey Chretien; 8 m focal length;
  - FOV 3 deg by 3 deg
- 1.4 Gigapixel camera (focal plane CCD); pixels sub-arcsecond
- ~1 Tbyte per night; Tflops of processing
- >22nd magnitude possible in one exposure, about 100 s.
- Approximately "3π" of sky in 5 filters
- Stacking images may reach ~ 25th magnitude
  - However cannot do variability that way
- Several thousand sq deg/night
- Available sky done 2 times per lunation at nominal efficiency
- Consortium finances operations and controls data

Website: *http:// pan-starrs.ifa.hawaii.edu*

Pan-STARRS



Publications out of June- July 2009 observing:

10 new asteroids published

New supernovae discovered (one published)

Pan-STARRS 1: status

- The telescope is a new design for coverage of a large sky area with frequent revisits. It includes the GPX1 large format CCD camera.
- The system has been integrated and tested and there have been initial survey activities starting summer 2009.
- More than 5000 square degrees have been monitored in the initial surveys.
- The software pipeline is designed and the essential elements are being used to handle the data from the surveys.

How Can LAT and PS1 be Used Together?

Starting from LAT :

- Upgrading LAT Catalog associations to identifications by finding correlated variability
- Searching UNID LAT catalog error regions for optically variable sources with correlated variability
  - UNIDs at high Galactic latitude have mean radii of order 10 arcmin
  - Scan multiple times, get variability in g,r,i,z,y
- Study flaring and variability, (if identification established)
- Spectral Energy Distributions (SEDs), as functions of time
- Photometric data for use in identifying Galactic UNIDs by variability
- Optical follow up to LAT transients and GRB
  - PS1 can look for any activity *before* the GRB

Reversing Roles

PS1 is finding optical transients and variable sources

Many of these will be candidates for Fermi LAT follow up (AGN, GRB, accreting Galactic compact objects, perhaps stellar coronae or other new classes)

PS1 discoveries can be used to interrogate Fermi data base

Example: PS1 Medium Deep Survey fields already yielding SNe with light curves (e.g., ATel #2249). Can derive RA, Dec and estimate of time of SN onset. Then use that to search Fermi LAT at position and time of interest.

Pan-STARRS 1 Scientific Consortium (PS1SC) manages science for PS1

Organized into Key Projects in various areas including cosmic variability and explosive transients and AGN

Memorandum of Understanding between LAT Collaboration and PS1SC

21 May 2009

Establishes basis for collaborating by merging information from LAT and PS1 data bases.

Everything is best-effort on both sides – neither levies requirements on the other; each side follows its own rules and procedures

21 May. 2009

Memorandum of Understanding between the Fermi Large Area Telescope (LAT) Collaboration and the Pan-STARRS Telescope # 1 Science Consortium (PS1SC)

1. This memo delineates an agreement for collaboration between the Fermi Gamma-ray Space Telescope Large Area Telescope Collaboration (hereafter LAT) and Pan-STARRS 1 Science Consortium (hereafter PS1SC). Its goal is to enhance science output of both projects through science utilizing data from both instruments, in a manner consistent with policies of both projects.

2. The LAT team and the PS1SC will make a best effort to share information about transient detections made by either instrument, including those with flux below the public release threshold. The intention is to merge these in a LAT-PS1 software module within the PS1SC Transient Server.

3. The LAT team will make a best effort to transmit transient and unidentified gamma-ray detections to the PS1SC Transient Server. The PS1SC Transient Server will search for optical transients and/or variable sources, and possibly for other unusual objects, within the LAT error ellipse and report them to both teams.

4. The PS1 team, through scientists from the relevant PS1 key projects, will make a best effort to filter relevant transient optical detections with the LAT-PS1 module to send to the LAT Routine Science Processing system to search for gamma-ray emission and return a detection and its statistical significance or an upper limit on the possible gamma-ray flux.

5. It is not expected that either LAT or PS1 will alter its observing priorities. The intention is to use the existing datasets to maximum advantage.

6. Any shared information that is not public (from either group) will be treated in confidence by both collaborations. The data shared should be used only for the purposes intended in this collaboration. Group members will be cautioned not to share these results outside the collaborations in any form, including publications, Web sites, e-mail, ATELs, or seminars. This agreement does not prevent either collaboration from publishing its own data.

7. If scientific results would be enhanced by a joint publication, then authorship will potentially be open to all members of both collaborations. LAT will take the leadership role when gamma-ray detections initiate the joint effort, and PS1SC will take the leadership role when optical detections initiate the effort. Any conflicts will be resolved by the LAT PI and the Chair of the PS1SC Board. Publications undertaken jointly will follow the rules of authorship of each entity.

8. Procedures for multi-wavelength collaborations with the LAT are outlined by https://confluence.slac.stanford.edu/display/GLAMCOG/Fermi+LAT+Multiwavelength+Coordinating+Group, in particular at the link "Information for Multiwavelength Observers about Working with the LAT Team." Policies for PS1SC are in the PS1SC Policies Document. NRL will lead for the LAT Team in developing the merger software but other institutions in the LAT collaboration may contribute.

Date / Prof. Peter Michelson
PI of the LAT collaboration

Date / Hans-Walter Rix
Chair of the Board of the PS1SC

Software, Algorithms

NRL and NASA-Ames have started building software for correlation

- Fermi aperture photometry, any source
- tools to merge and correlate with multi-wavelength data
- generalized cross- correlation/wavelet spectra/structure functions

Using RXTE ASM (X-ray) as proxy for PS1

- LAT aperture photometry at selectable timescales
- RXTE fluxes *cleaned, then* summed to selectable timescales
- Fainter sources need longer integrations – same principle for PS1, other ASMs

Software to merge with PS1 still in work

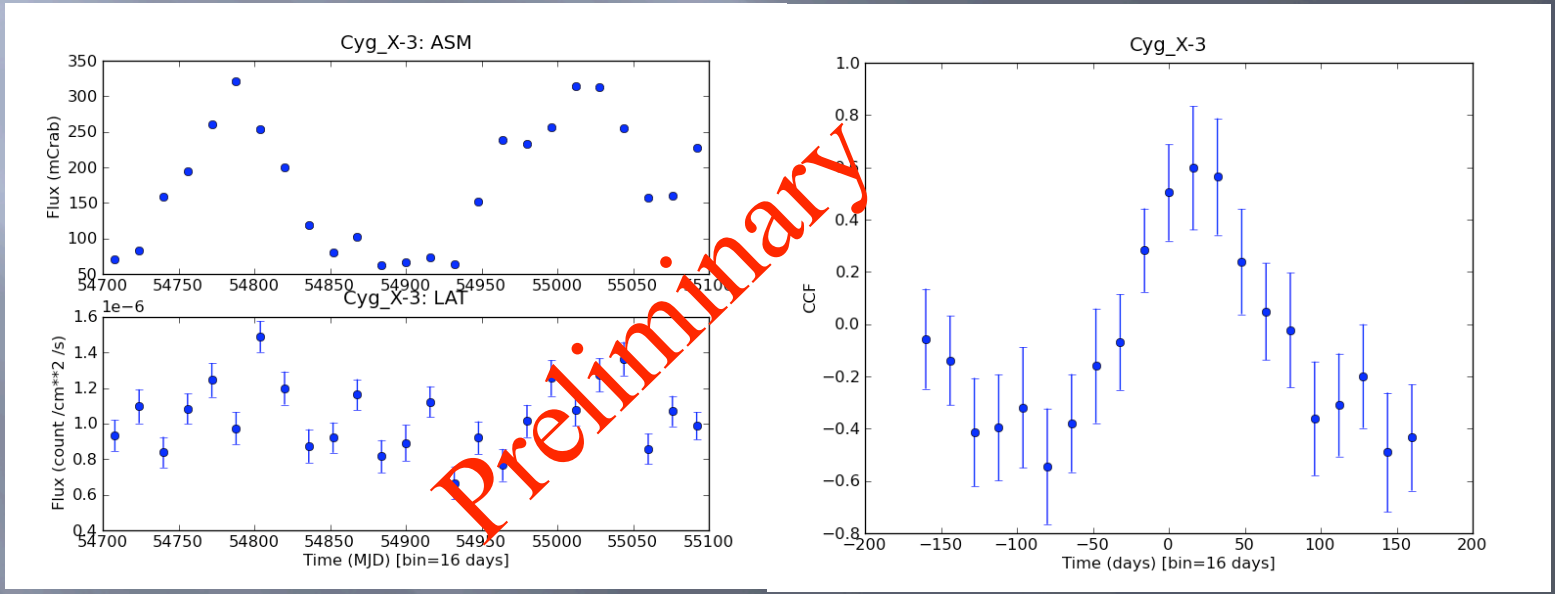
Approach is general enough to cover further mergers of information with other ASM or grand ASM capabilities coming online.

- MAXI is an example of interest: X-ray all-sky monitor launched 2009

Full utilization of ASM-to-ASM approaches to multi-wavelength involves new algorithmic approaches to cross-correlation.

Fermi – ASM: Cyg X-3

- Edelson & Krolik cross correlation routine for unevenly sampled data
  - ASM must be "cleaned" of solar contamination
  - 16-day binned light curves



- Edelson - Krolik being extended, *e.g.,* to correlate other data sources with LAT event data without binning.

Many standard and novel time series analysis tools can be done without binning in time or energy.

	Correlation Function	Fourier Power	Wavelet Power	Structure Function
Auto	✔	✔	✔	✔
Cross	✔	✔	✔	✔

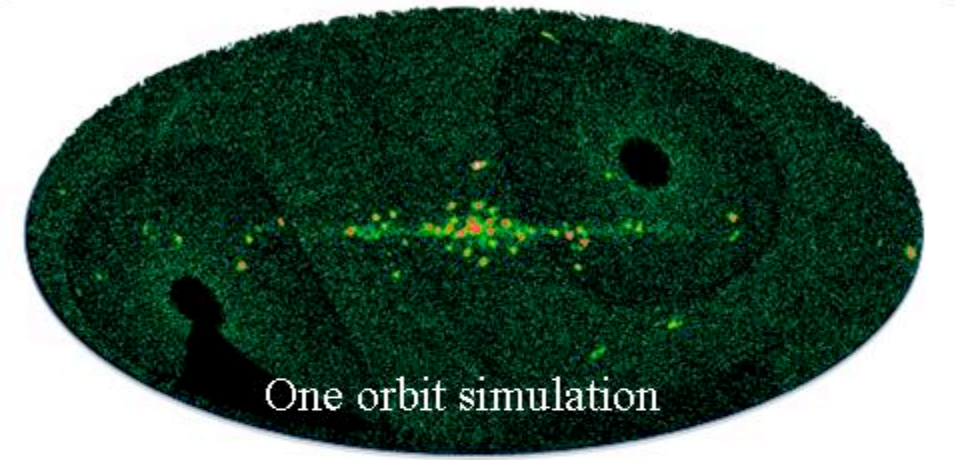
MAXI (GSC: Gas Slit Camera)

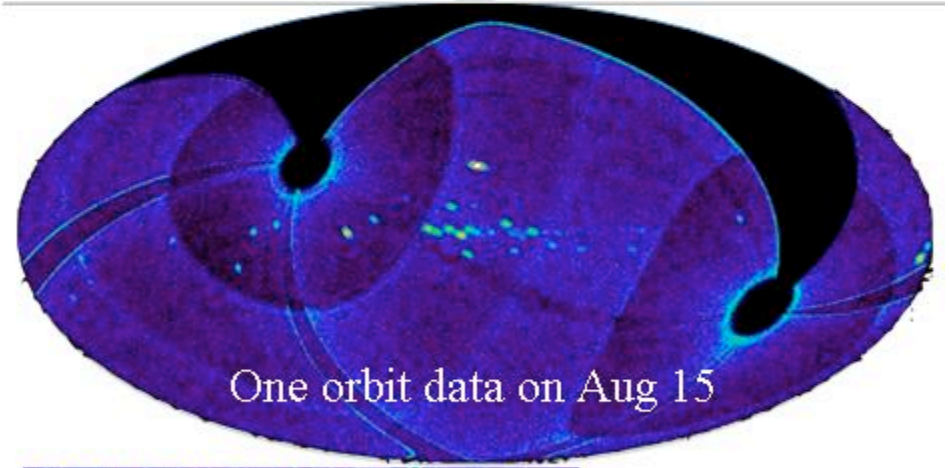
- Installed in July 2009, STS-127
- Full units operating since August 14
- 12 Xe-filled PSPC (2-30 keV)
- >x10 RXTE/ASM detector area
- 90% of sky scanned in 94 min
- PSF 1.5 deg, localization ~0.1 deg
- current systematic error ~1 deg
- expected sensitivity …

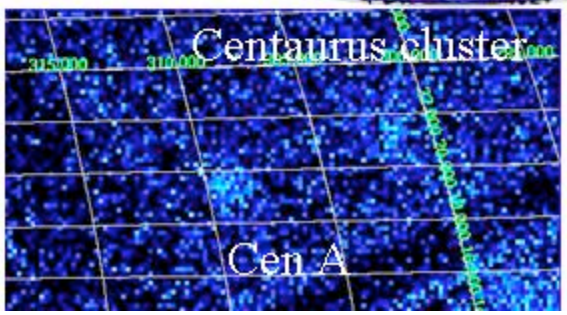
1 orbit	20 mCrab
1 day	5 mCrab
1 week	2 mCrab (100 AGN)
1 month	1 mCrab
0.5 years	0.4 mCrab (1300 AGN)

(3σ Detection Limit)

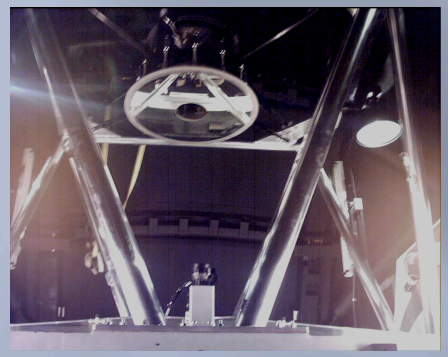
*need good background handling







zooming in near
Cen A
1-day exposure



Summary

The age of ASMs has arrived

Multi-wavelength work can be done ASM-to-ASM

PS1 is a major milestone for optical

LAT and PS1 have memo, work is starting

…two grand ASMs, phased to each other in epoch

Other ASMs appearing: MAXI, Skymapper, anticipated radio facilities (ASKAP: see Cameron *et al.*, P5.208)