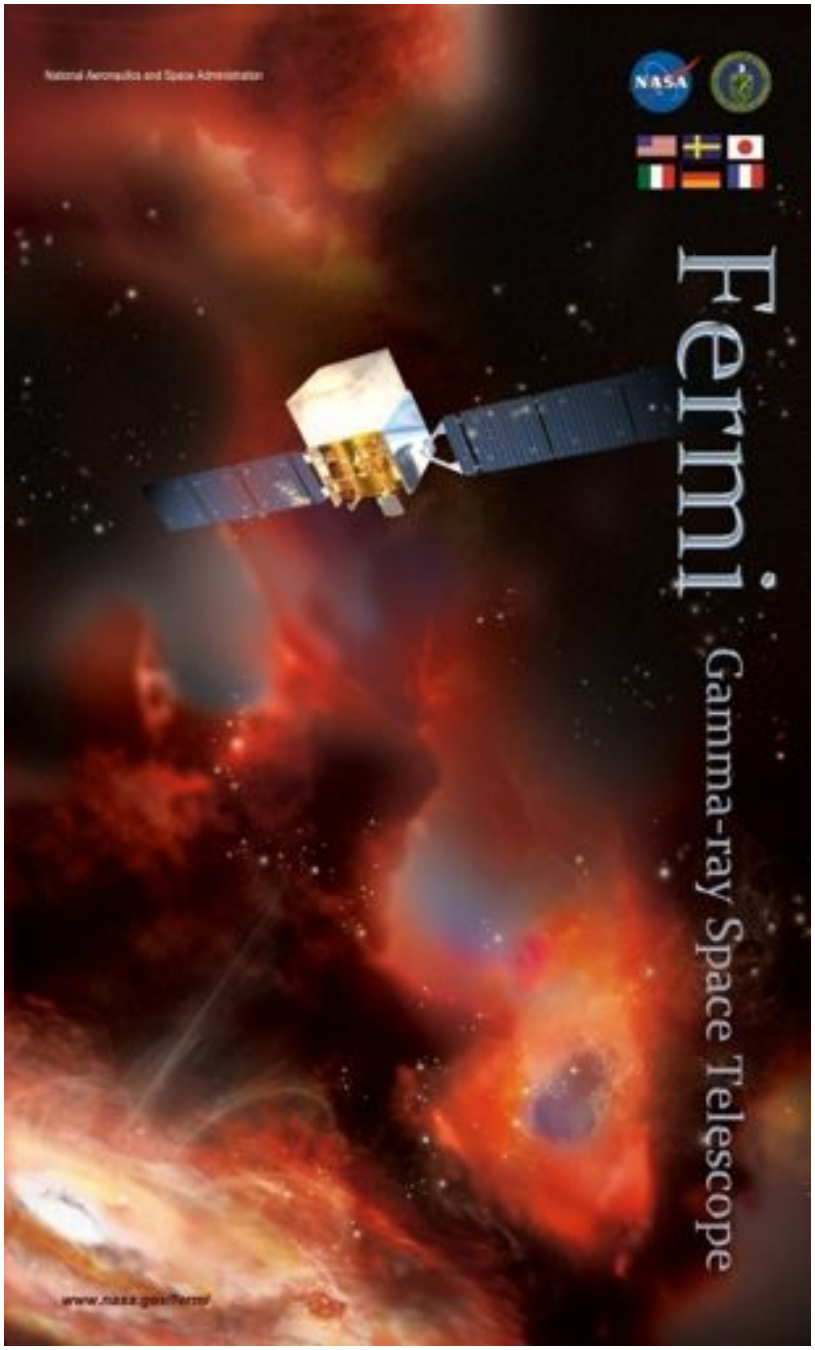


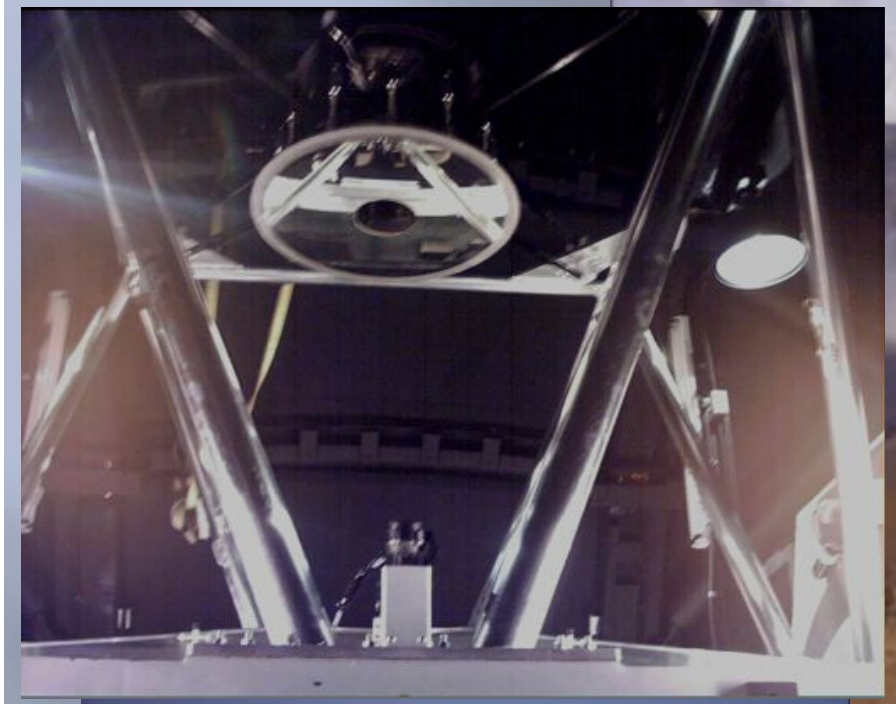
The Pan-STARRS Sky Survey and *Fermi*

K. S. Wood

Naval Research Lab

Fermi Symposium
Monterey
October 30, 2012

What is Pan-STARRS? (PS1)



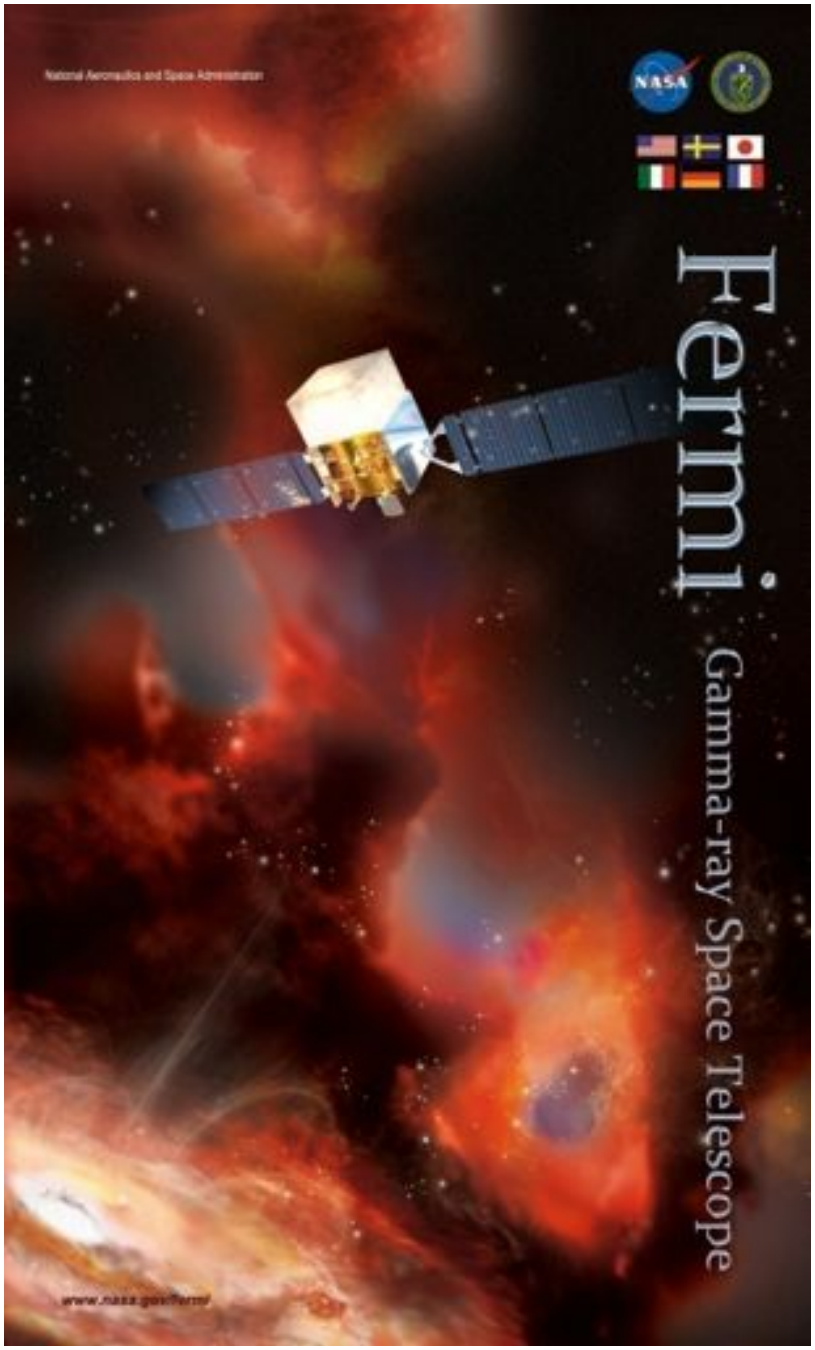
New telescope:

Wide-field, sensitive, visible-to-near-IR coverage, with temporal information

What can be done using PS1 with *Fermi* ?

PS1 became operational in *Fermi* era

***Fermi* and Pan-STARRS have a collaborative agreement, established 2009**



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Fermi-LAT Collaboration

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D. Finkbeiner
Harvard

Outline

- ***Perspective -- not a "results" talk***
- ***Quantify capabilities that support work with Fermi***

- I. Characteristics of Pan-STARRS
  - Telescope
  - PS1 Survey
  - Data pipeline stages, IPP and PSPS
  - Status

- II. Pan-STARRS and *Fermi*
  - Important characteristics for using them together
  - Implementation, status
  - Specific scientific benefits

- ***Neither levies requirements on other – "best effort" suffices***

Part I: Characteristics of Pan-STARRS

PS1 Telescope

- 1.8m telescope at Haleakala, Maui, developed by Institute for Astronomy, U. of Hawaii.
- PS1 uses *first* telescope, to be followed by PS2 and hopefully PS4
- Image fields have ~3 deg length and width
  - overall, 8 sq. deg. (not perfectly square)
- 1.4 Gigapixel camera
- Five filters, g, r, i, z, and y, collectively covering wavelengths 405 to 1020 nm.
- **Single exposures reach mag ~22 in r**
- Telescope captures **~500-600 images nightly**
  - ~ 1 Tbyte / night
- Operated by Pan-STARRS Project and PS1 Science Consortium

PS1 Survey

- **PS1 Survey is optimized to science plan, which is divided by Key Projects -- solar system to cosmology**
- In normal conditions nightly observations occur in an optimized sequencing of the five filters (g, r, i, z, y)
- **3π steradians** surveyed, systematically …
- … that's 100% coverage, north of Dec. = -30 deg.
- *Also* ten smaller fields (called "Medium Deep" fields) totaling ~ 80 sq deg and viewed more frequently. *Additional special surveys:* M31, stellar transits, solar system objects. **Collectively the special fields use slightly less than half the observing time**
- Uniqueness of 3π
  - Complete coverage, all filters, deep
  - Good cadence, for Fermi purposes

Pan-STARRS Data Pipeline

- **IPP: takes camera images, does flat fielding, fits features, outputs images and fit results; also does stack images to reach fainter magnitudes (24 to 25); also does fits and forced photometry to stacks**

- **PSPS: takes IPP fitted results and arranges for distribution; flexible support to queries**

  - **Not all IPP output has yet made it to PSPS**
  - Recent "Grand Reprocessing" is in RA Hrs 19-23
  - Older processing exists elsewhere (less uniform)
  - Detection quality still being upgraded, leading to more reprocessing

Status, end-to-end

- Telescope: operational since Feb 2010 (+ some from earlier)
- Survey: has observed 3π in all filters, multiple times; NSF now funding PS1 survey to end of FY 13. Data release will come FY14, with archive to be hosted at STScI.
- IPP: has processed throughout 3π. Detection quality greatly improved during 2012, particularly in photometry
- Publications are appearing, many results coming from Medium Deep fields
- PSPS: presently holds data from R.A. hours 19-23; this region is being used for *Fermi* – PS1 pilot studies
- IPP re-processing will lead to PSPS re-load soon, giving access to additional hours of R.A. with detection quality superior to that now available in hours 19-23

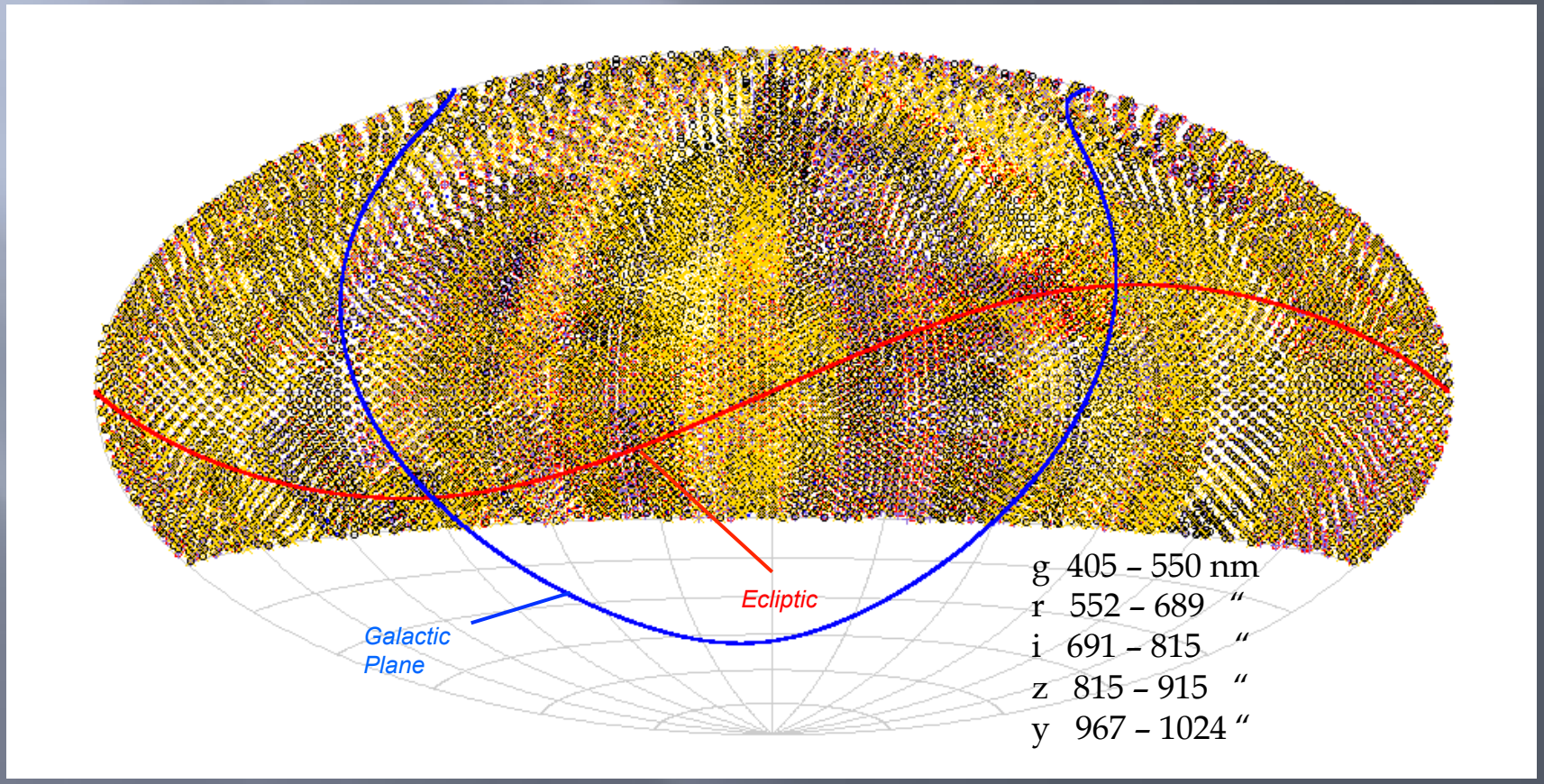
PS1 3π survey

coverage in five bands

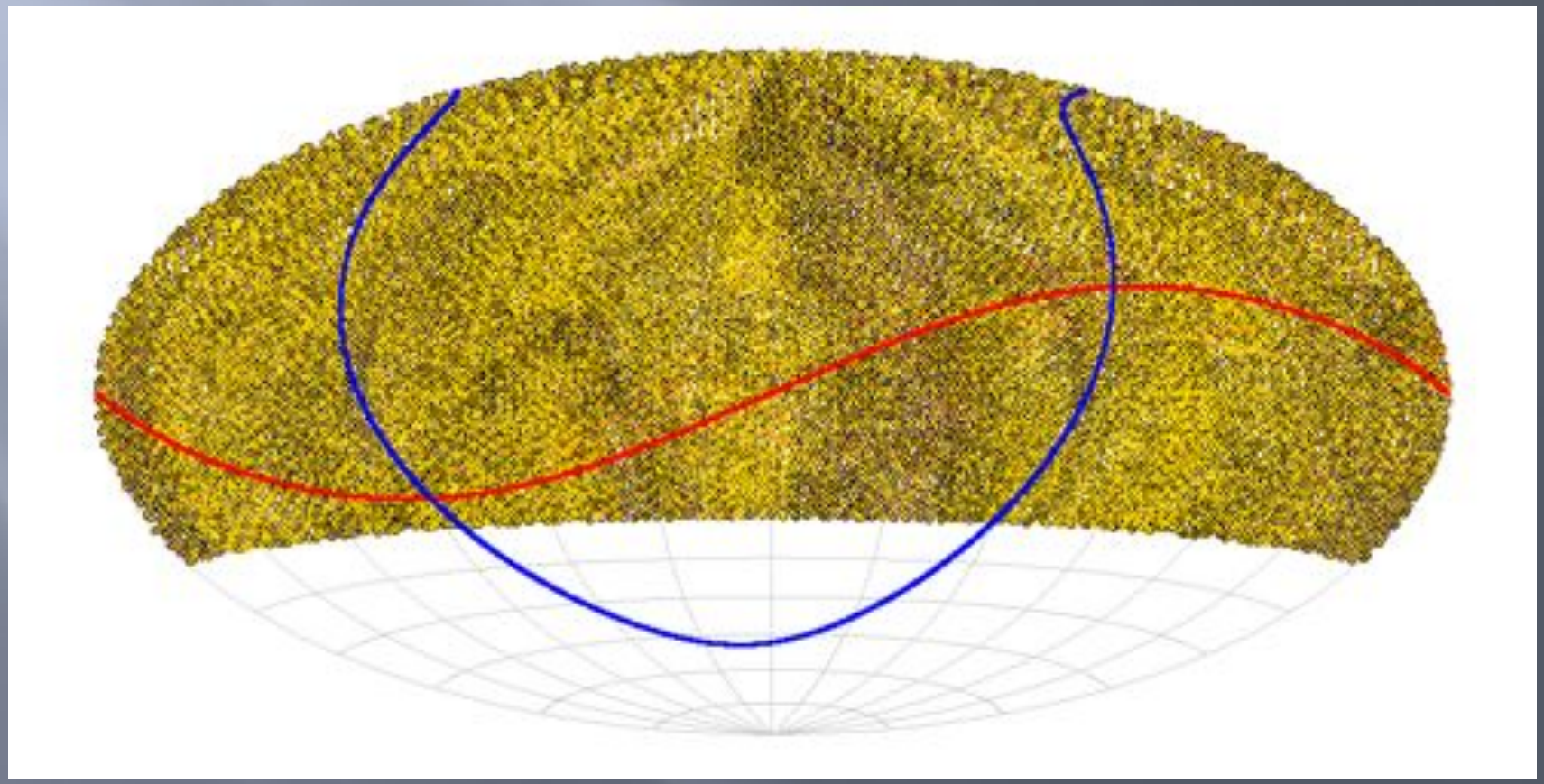
Display is in R.A. and Dec

RA hr 0 at right, RA hr 12 in middle and hr 24 at left

Dec > -30 degrees



PS1 3π survey



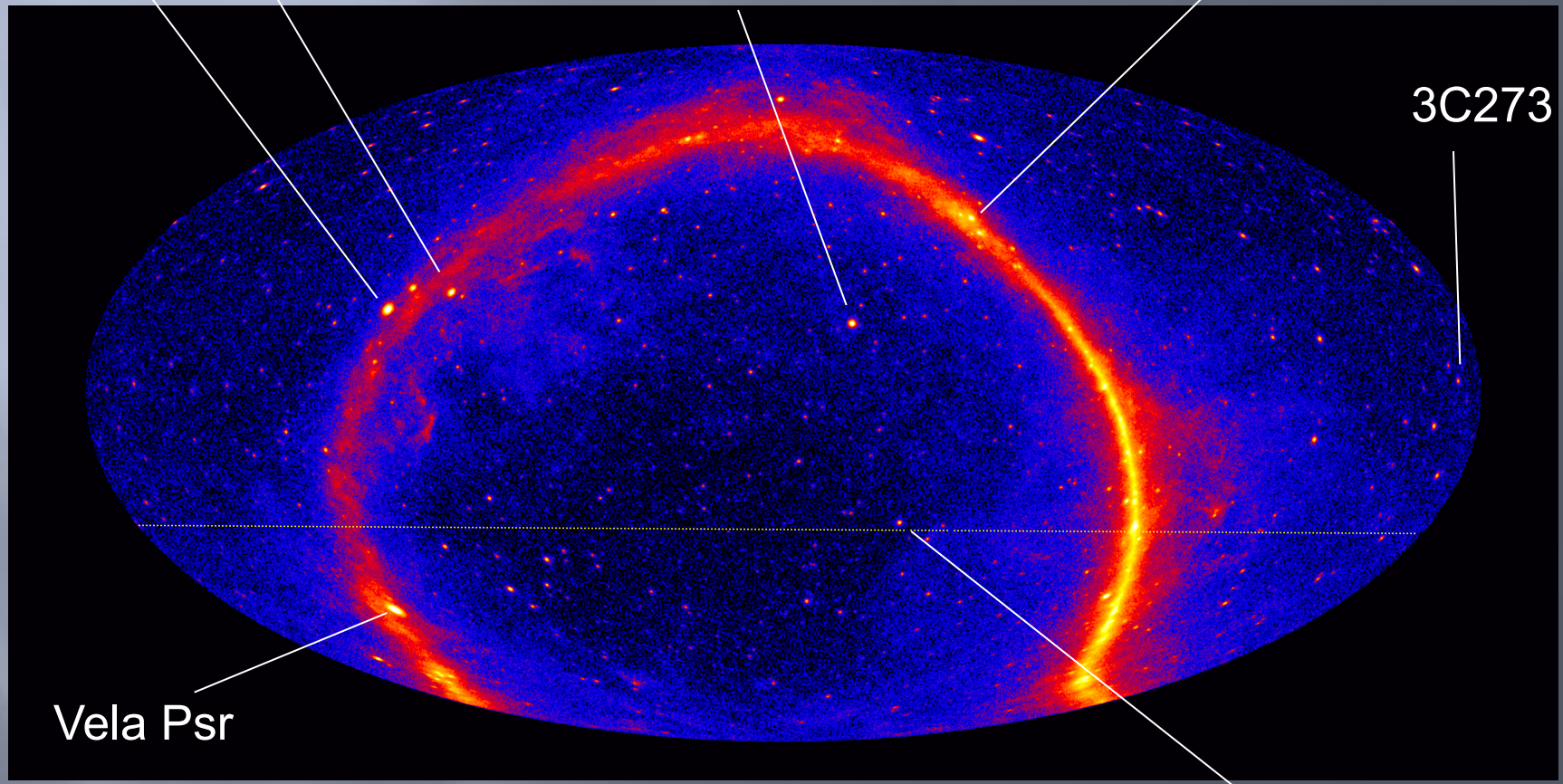
Part II: Pan-STARRS and *Fermi*

What matters for use with *Fermi* ?

- 75 % sky coverage comes closest to Fermi's 100%
- Contemporaneous, i.e., Non- contemporaneous wide coverage (SDSS, LSST) much less useful
- Magnitude limit -- "Requirement" from Fermi source SEDs
  - PS1 meets it for AGN; AGN associations mostly m< 19.5
  - SEDs of some transients also favorable, but transient must occur in window of PS1 yearly/daily coverage
  - However PS1 would not meet requirement for all Fermi classes, e.g., isolated (non-binary) pulsars
- Cadence is quite well matched for important classes
- Pipeline merger (practical consideration)
  - 3π is most useful PS1 coverage when starting from *Fermi*
  - Objects monitored in PS1 MD fields can be followed in *Fermi*

Fermi Sky Map

(Equatorial Coordinates)



Gold Standard of Identification in 2FGL = Correlated Variability

- **Galactic:** Pulsars; V 407 Cyg, Binaries, etc…
- **Only these AGN:** see table in 2FGL Catalog

All the gold :

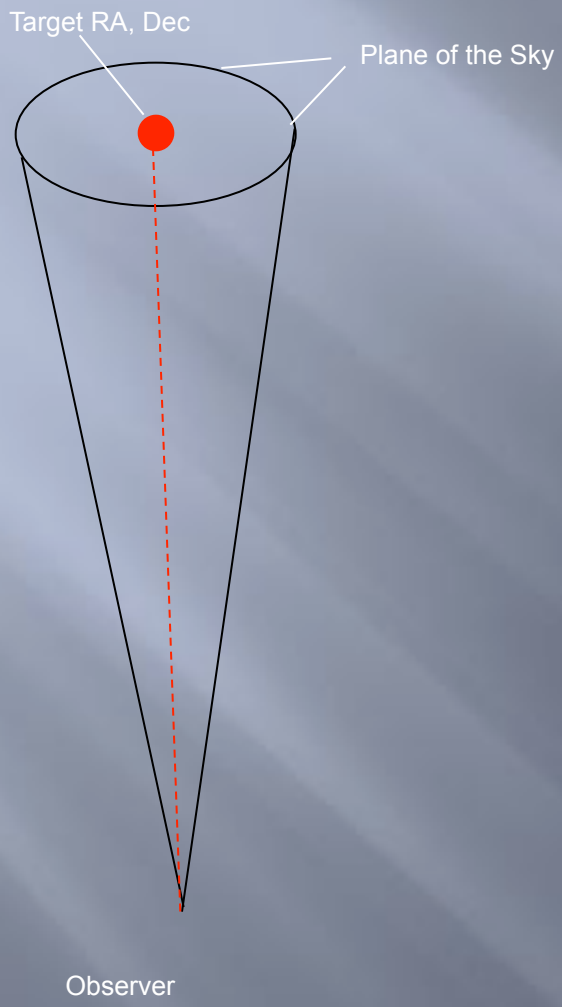
3C66A, AO 0235+164, PKS0420-01, PKS0521-36, PKS 0537-441, 4C+14.23, OJ 287, PMN J0948+0022, S4 1030-61, SBS 1150+487, 4C21.35, 3C273, 3C279, PKS 1424-418, PKS 1454-354, PKS 1502+106, PKS 1510-089, PKS B1622-297, NRAO 512, 3C 345, Mkn 501, CGRaBS J1848+3219, PKS 2005-489, PKS 2233-148, 3C 454.3, PMN J2345-1555

Most at least involve optical; many *solely* based on optical

Extending this table is ongoing project using PS1

PS1-Fermi Data Merger

Finding ~3k *Fermi* sources amid ~5B PS1 objects



- **PS1-Fermi Pipeline:** extracts by "cone search" near lists of Fermi locations of interest.
- - small cone, for association with ~ arcsec position
- - larger cone, to search fields such as 2FGL error circles without association
- Retrieved detections then arranged by PS1 source ID, passed to further processing stages

Photometry and Astrometry

Uniformly high quality detections are needed for variability and spectral studies; false positive rejection is another metric

Photometry:

By 2011, IPP photometry was sufficient for AGN variability work.

"Ubercalibration" (developed by E. Schlafly, D. Finkbeiner) has resulted in system that delivers 8-10 milli-magnitude accuracy (see Schafly et al, Ap. J, 2011); being applied to full 3π

Astrometry:

Locally, astrometry is 10-20 mas

Globally, qso positions match to accuracy < 100 mas

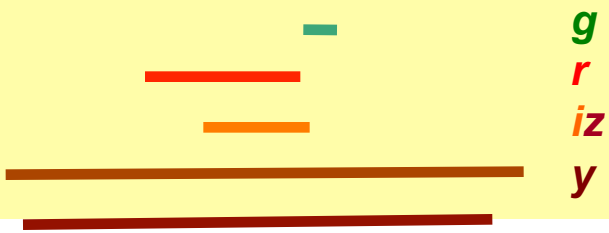
PS1 positions for 2FGL associations are confirmed to be highly accurate in current 3π PSPS, comparing with best radio positions

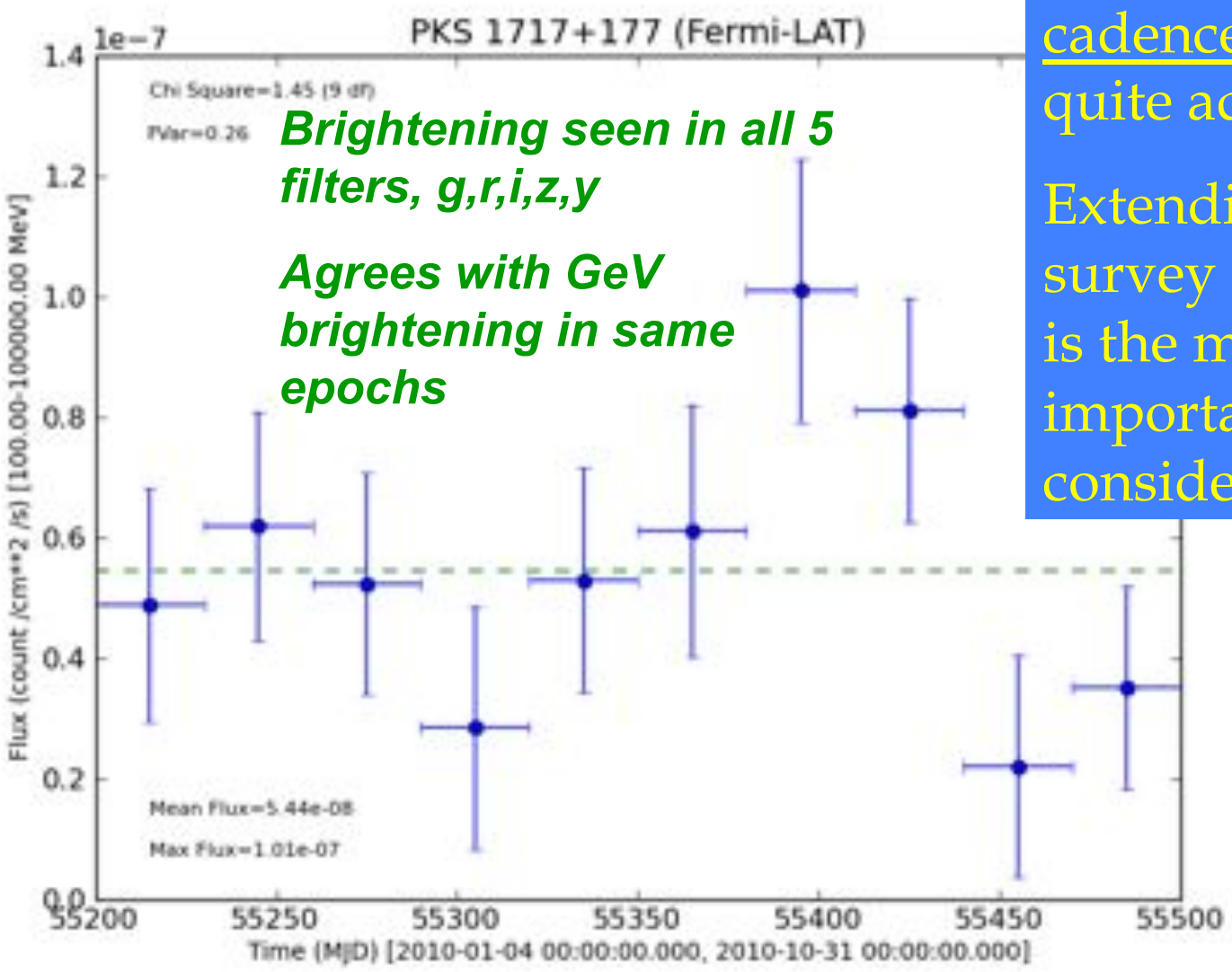
Typically better than 100 mas – possibility of further improvement but good enough right now -- it is like working Pass 7 while awaiting Pass 8

Yield

- Right now, best place for tests is RA 19h-23h.
- Other hours of RA to become available late 2012
- Essentially all searches that start from a good AGN (blazar or BL Lac) position for a proposed 2FGL association are successful – source is found with multiple detections at various epochs spread over 2009-2011, usually detections in all filters
- **Not accidental – Fermi detection plus SED typical of AGN virtually *assures* detection. (Good prospects for Fermi sources of *other* classes with *similar* SEDs)**
- At this point it is still possible to hit holes in the data base, from incomplete processing

Line start/end are earliest, last dates for that filter





Brightening seen in all 5 filters, g,r,i,z,y

Agrees with GeV brightening in same epochs

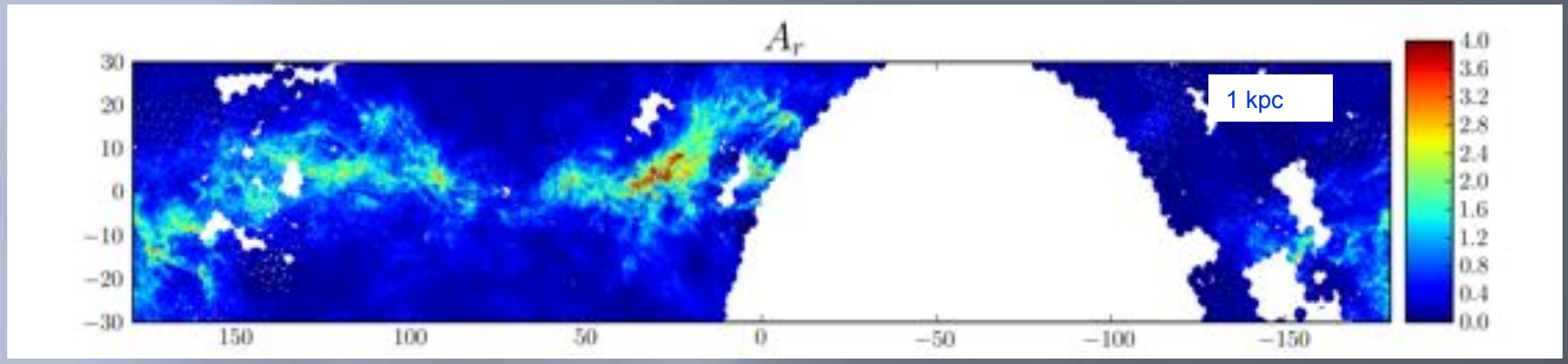
For Fermi AGN, PS1 cadence is quite adequate.

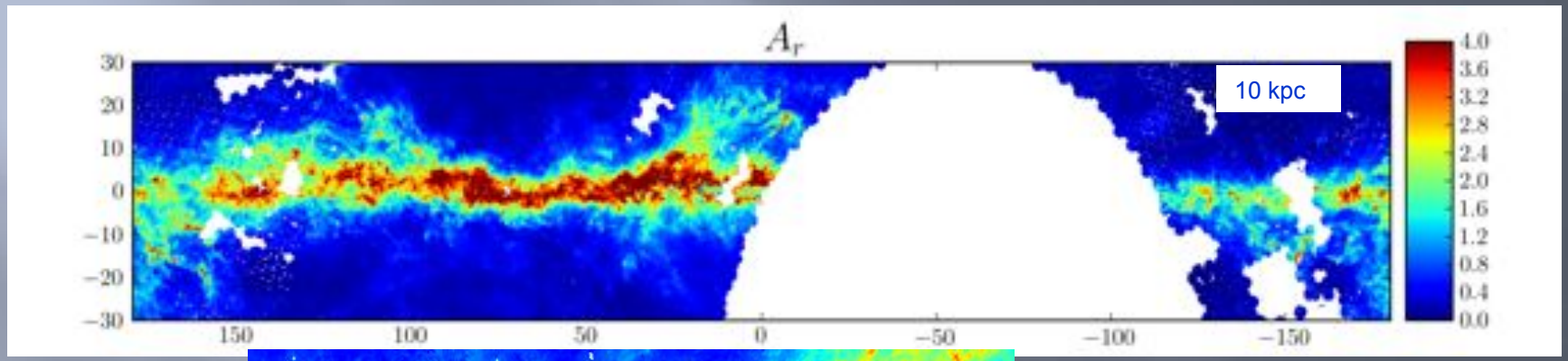
Extending PS1 survey timeline is the most important consideration.

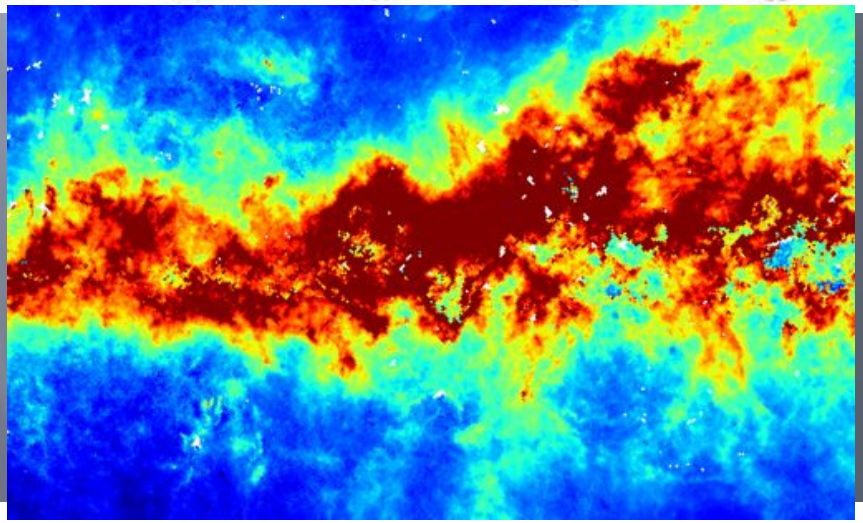
Scientific Uses with Fermi

- **Confirming 2FGL associations attempting to make them full *identifications, by*** correlating variability
- PS1 astrometry then gives **precise position** for source component that is variability-correlated with γ-rays; **filter photometry contributes to SED**
- **New candidate associations,** by colors in Pan-STARRS, training on established sample. Identify *Fermi* UnIDs, going fainter and to higher z.
- **Galactic transients** (such as Nova V407 Cyg 2010)
- **Binary systems,** e.g. "Black Widow" millisecond pulsars from *Fermi,* optical modulation at orbital period.
- Searching **precursors** of GRB or transients -- Pan-STARRS sometimes observes at transient position shortly *before* outburst, by chance. (No other automated way to do this to high sensitivity.)
- Maps of absorption at low Galactic latitudes -- **dust maps**
- Also the reverse: **looking for Pan-STARRS transients in *Fermi***

Dust Maps







Thanks to D. Finkebeiner

Conclusion

- Fermi and Pan-STARRS are both deep sky monitors -- cover multiple steradians of sky (4π, 3π), and reach low flux levels in their respective bands. Both cover substantial range in photon wavelength/energy.
- Cadence of PS1 and epoch (2010 - end FY13) are good match to Fermi. It isn't necessary to alert PS1 to cover a piece of sky in response to a Fermi transient – it will have covered it before and afterward
- AGN, BWPs, GRBs, and transients are among source classes to which they are applicable. Galactic dust can also be mapped effectively in Pan-STARRS