Fermi and Wide Field Data Bases: From Optical to Gamma-rays

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Sixth Fermi Symposium
Washington DC
Nov 9, 2015

Assignment:

Review *Fermi* LAT in relation to wide field data bases

Big topic: (opt, XR) * (static sky, time-domain) = ∞

LAT *use of wide field data bases is increasing over time*

Two basic points:

Fermi needs multi-wavelength support in optical, X-rays

Optical, X-ray, γ-ray differ as to mix of static sky / time-domain

Not new results

… review assets, methods , principles; status, outlook

Fermi **itself** is a precious asset to astronomy

Grand All-sky monitor + deep mapper of static sky

Time-Domain Astronomy vs Static Sky goes differently in each waveband

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Aristotle: **Ancient concept of *completely* static sky**

"We have already discussed ***the first heaven and its parts,*** ***the moving stars within it,*** *the matter of which these are composed and their bodily constitution, and we have also shown that they are* ***ungenerated and indestructible…."*** **(*De Caelo*, c. 350 ±30 BCE)**

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F. Dyson: **High-energy astronomy *terminated* all that**

*The newly discovered X-ray sources gave an **entirely fresh picture of the universe**, dominated by violent events, explosions, shocks, rapidly varying dynamical processes. The X-ray observations finally **demolished the ancient Aristotelian view** of the celestial sphere as a serene region populated by perfect objects moving in eternal peace and quietness.* ***(Dyson, 1986)***

Aristotle's static sky remains relevant

Optical (eV) Sky: ***Aristotelian: "serene" steady point sources.*** *Variability elusive. Have to fit all the point sources to find the variability.*

X-ray (keV) Sky: *No steady point sources; everything extended or variable. Variable sources predominantly driven by inflows, gravitational energy release.* ***Clusters of galaxies, however, are reasonably Aristotelian – a significant component.***

Gamma-ray (GeV) Sky: *Again, everything extended or variable. Variable sources associated with outflows.* ***A Dark Matter signature would be almost perfectly Aristotelian.*** *(Unravel physics of the Galaxy to find it.)*

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So what?

- X-ray: monitors are easy. Whole sky variable. Start bright, work down

- Gamma-rays: monitors are feasible; Fermi shows how it is done

- But optical: monitors are a struggle,

against Sun, Earth, Moon, weather, … and Aristotle's static sky

Sky Monitoring in X-rays

Simpler than optical, done from space
Straightforward data access
4π access, with useful cadence, sensitivity

Surveys, from Uhuru to *Rosat*:

Mainly "static" sky, i.e., cadence limited, from revisits.

Archives maintained for long-term work

True All-Sky Monitors started with Ariel V ASM (1974.)

Later, better monitors:

RXTE-ASM Active 1996 to 2011; overlaps early *Fermi*

MAXI, on ISS: active 2009 to now: covers most of *Fermi*

Better ones are now being proposed

Meanwhile, there are other assets:

SWIFT, INTEGRAL, etc. deeper coverage, variable cadence, $<4\pi$

Convenient websites, easy access

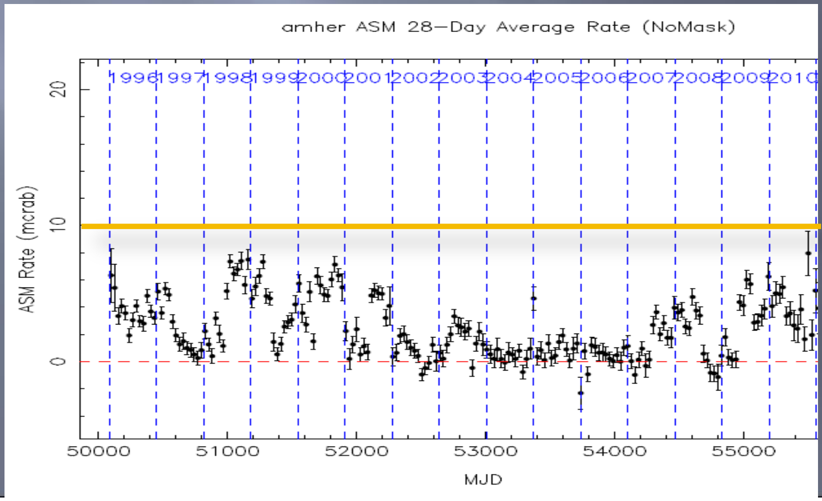
RXTE-ASM (1996-2012)

long time line; reasonably stable over the long timeline

- Generally good to ~10 mCrab, but can integrate, go lower
- Instrument saw all sky, but analysis limited to set of positions

Faint sources are generally available (if in list of fitted positions) except for suffering contamination when they come within about 45° of the Sun.

- ASM has maintained websites; can download detections and customize



MAXI (2009-now)

overlaps RXTE, then continues to present epoch;

can fit at arbitrary positions

- Flux limit is lower
- but it too has solar avoidance

Website: maxi.riken.jp

Wide-field optical has limitations

Wide-field optical monitors cannot hope to provide spectral resolution, with cadence for time resolved spectroscopy, over whole sky, *e.g.*, to track Hα at periastron in PSR B1259-63

If wide-field approaches can't do everything, what do they do well?

Wide-field monitors can provide context when:

source is bright enough for the monitor, monitoring cadence matches source timescales, source falls in sky region monitored, high spectral resolution not required

Some Uses:

Surveys, e.g., SED variability; correlations; finding/following transients; going back in time to sky locations *later* found to be important

Before Optical Resources Survey (2nd of 2)

Exclusion: Targeted Optical Monitoring Programs

Monitoring campaigns have been a mainstay of *Fermi*:

take likely *Fermi* counterparts, monitor those

This talk is essentially about automating or roboticizing that kind of coverage, without prejudice as to sources chosen

Three Further Categories Excluded (for lack of time):

(1) surveys with limited cadence, even if covering multiple steradians (SDSS, WISE). Some already proven invaluable for Fermi.

(2) surveys with coverage of limited sky even if depth and cadence reasonable (Kepler, SN surveys, NEO surveys, DES). There might be a way to "federate," but it is out of scope for this talk

(3) assets with interesting coverage and cadence, but not reaching down to magnitudes of interest for Fermi (CONCAM)

Seek assets that approximate X-ray/ Fermi all-sky monitoring, at useful sensitivity with useful cadence :

AAVSO, CRTS, PTF, DASCH, PS1, SkyMapper, GAIA, LSST

Survey of Optical Resources

Start at the Bright End

AAVSO (American Association of Variable Star Observers)

plus other federated amateur observers (e.g. ARAS)

– **Significant existing resource, already important for Fermi**

Bright objects, recognized as variable – "complete" in that sense

- **Take advantage of their enthusiasm to get good coverage; worldwide organization facilitates it. Result sometimes the best available.**

Look at an example (V407 Cyg)

Amateurs found effect in visible (V and R) before *Fermi*.

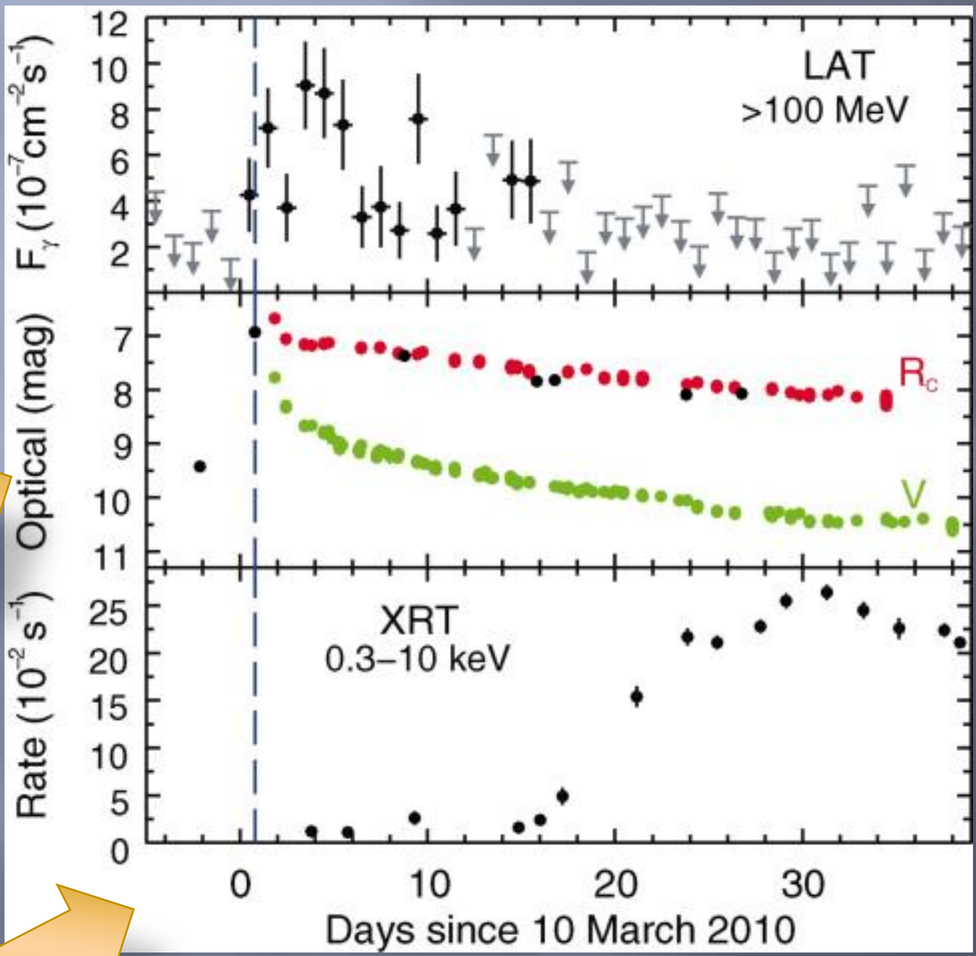
AAVSO monitors source-by-source; cannot be used retroactively to search an arbitrary location at an arbitrary epoch; depends on source pre-selection

Begin to lose it at magnitude ~ 15. But monitoring for variable objects with m <15 is extensive

https://www.aavso.org

"

Nova V 407 Cyg 2010
a perfect optical / X-ray / γ-ray case



Symbiotic Nova in Cygnus, in 2010

First of a new Fermi class of sources/events

First detection came from amateur observers

R and V light curves from those sources provided the needed optical monitoring and context for the *Fermi* flux history

Magnitude range was <11;

Source was close to horizon at time of outburst (i.e., Cygnus in March)

Had optical spectra from amateurs (ARAS)

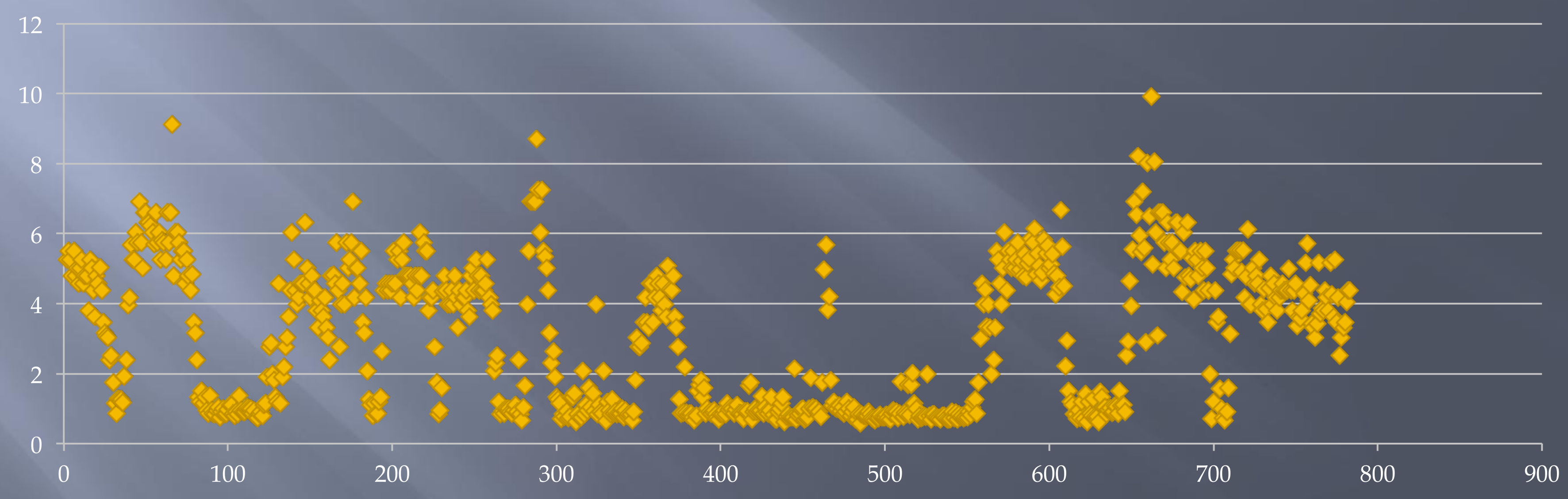
www.astrosurf.com/aras

Nightly broad band provided much of needed context; dedicated spectroscopy (not shown) complemented it.

AM Her optical light curve

Beautiful AAVSO light curve runs for years with no gaps in coverage.

In this plot each data point is one week and it runs for about 15 years.



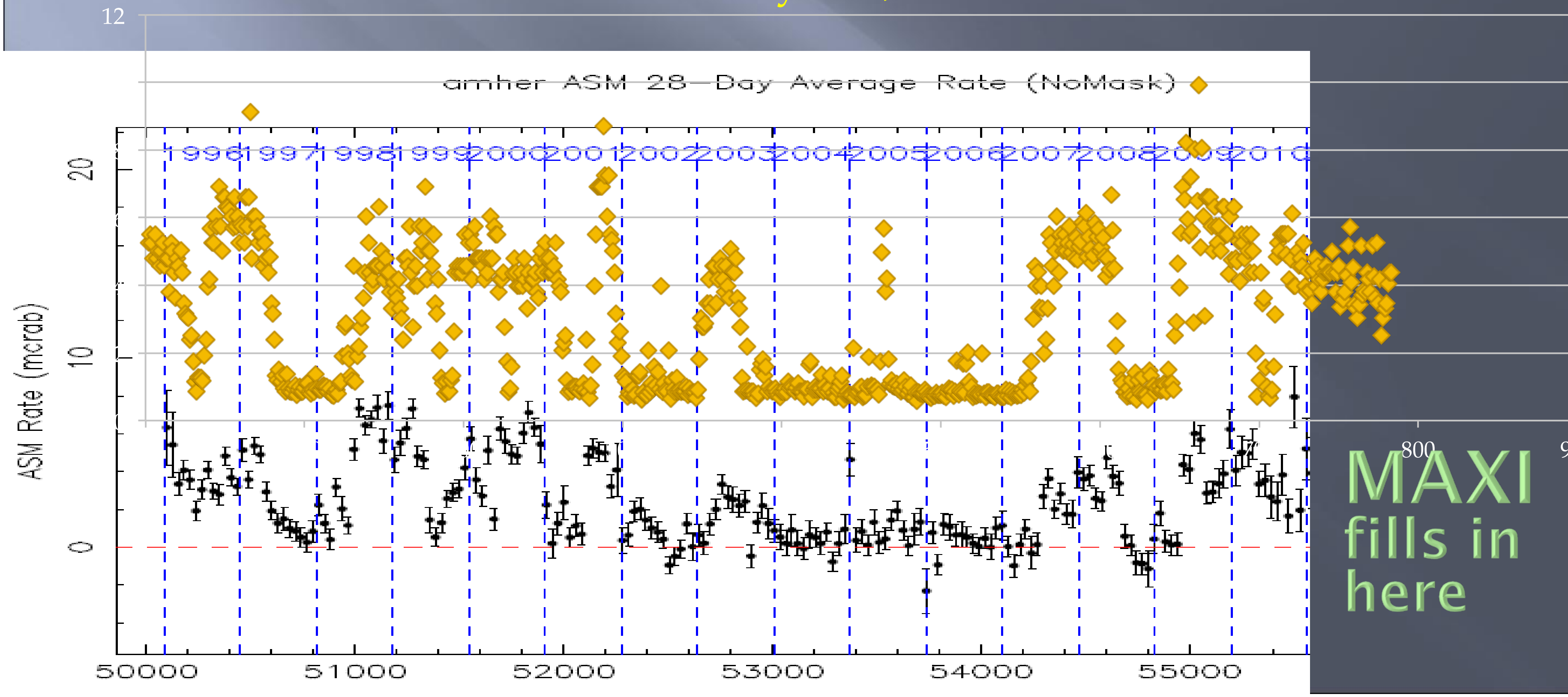
AM Her optical, X-ray light curves

- **AM Herculis in X-rays and optical for 1996-2012**

Coverage Perfect. No gaps! Shows What's Possible

- Optical and X-ray emission mechanisms distinct, but derive from same mass accretion rate

Fermi covers final 5 years, but does not see source



Challenge: Continuity of Sky Access in Optical Band

Constraints: Sun moves through 360°on Ecliptic; Scatters copious photons through all steradians observed in daylight. Wipes out pretty much same stars for whole earth on any one day.

Distribution in longitude only buys time coverage for stars away from Sun

Effect on light curves: **leads to unavoidable gaps for most sources.** Gaps are *typical*… repeatedly at same weeks, each year, because of unavoidable spherical trigonometry relationships

What it takes to *avoid* gaps, using ground-based optical telescopes:

High |Ecliptic Latitude| for source is needed. (|β| > 45°, or more)

High |Declination| for source also helps

Array of telescopes variously sited in latitude

Mobility, replication are trades against *depth*

AM Herculis is a star where gaps are avoidable, a comparatively rare example (might hope to improve from orbit)

Pursuing 4π coverage with high cadence

CRTS (Catalina Real-Time Transient Survey)

2007-present ; to mag ~18; >3π; crts.caltech.edu

PTF (Palomar Transient Factory)

2009-present; ptf.caltech.edu

CRTS :

monitors ~ 280 bright Fermi blazars. Used for PKS 1502+036 (2013)

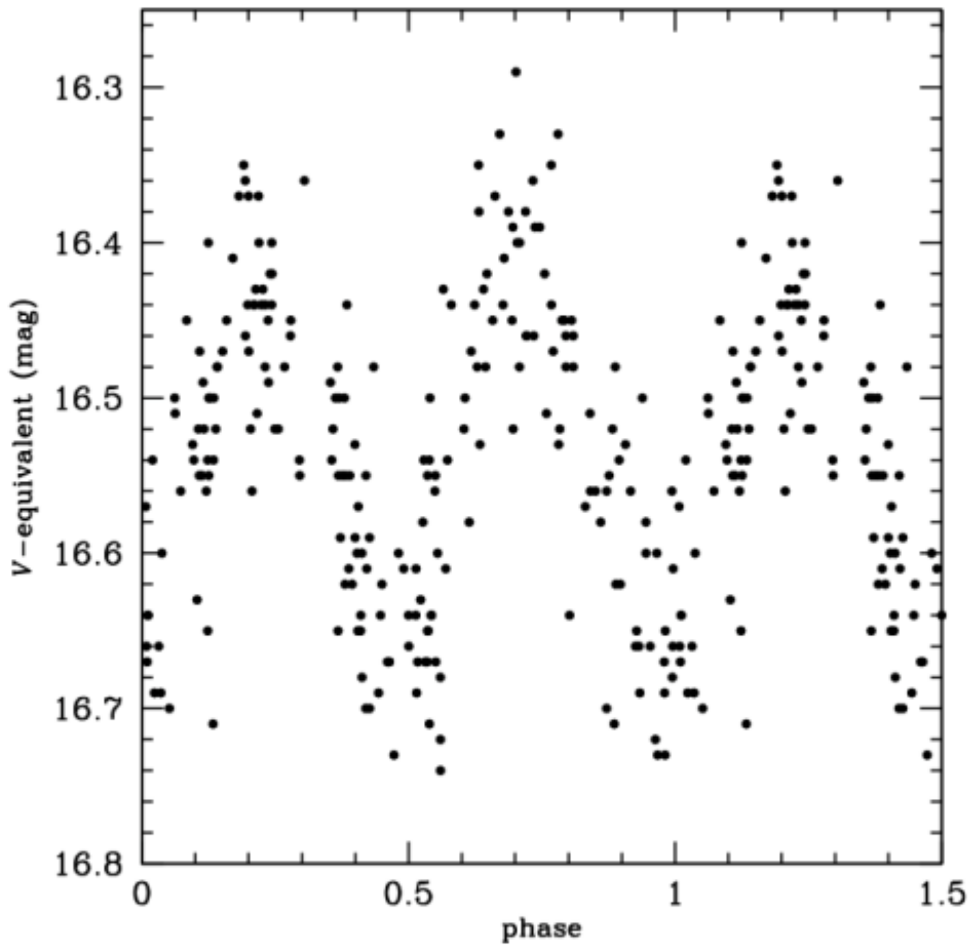
Used for identification of counterparts for Fermi binaries

1FGL J0523.5-2529 (at right) was first example (2014)

TIMELINE:

1st data 2007

1st LAT uses 2011, 2013, 2014



DASCH= (4π) Digital Access to a Sky Century @ Harvard

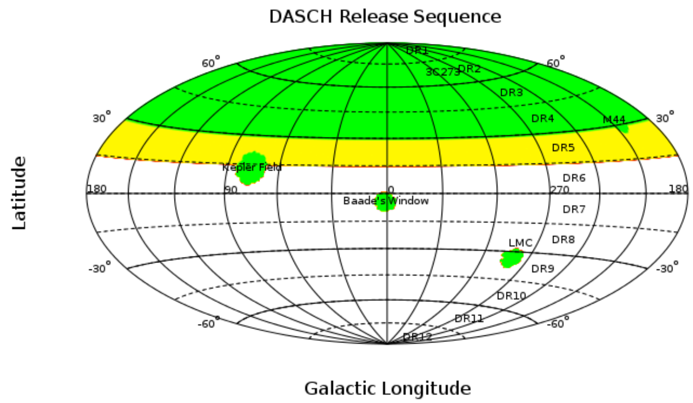
- Complementary way to get depth *cadence, <u>spanning a long range of epochs, sampling over that range</u>
- HCO plates uniquely provide the look-back in time, but must be digitized. This is DASCH, a work in progress, starting at N Galactic Pole and moving south.

Website hosting releases:
http://dasch.rc.fas.harvard.edu/project.php

To mag ~12 before 1935, mag ~14 after. Even if a Fermi source is below threshold now, DASCH supports asking whether it was brighter in the past century. For accretion-driven objects this can be relevant

Example: PG1553+113.

It is there, with large errors, major gaps



Why Go to Fainter Magnitudes?

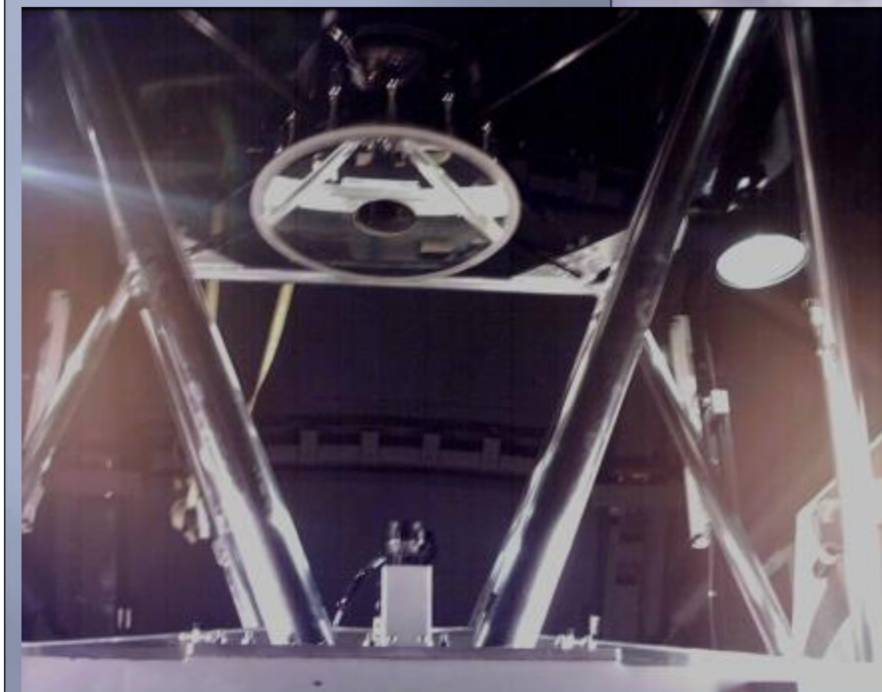
Have now considered the bright time domain, but *Fermi* has valid needs that call for going deeper.

AGN: ~19^{th} to 20^{th} magnitude; unbroken 4π coverage; colors
Full sky searches for dwarf spheroidal galaxies
Resources for unraveling the Galactic plane (dust, extinction)

Redbacks: typically 19^{th} to 20^{th} for faintest phase; unbroken coverage; colors;
White dwarf MSP binaries -- much fainter
Novae: unbroken coverage needed.
New class searches: coverage, magnitude, colors
Greater accuracy in photometry, sensitivity to modulation

Pan-STARRS and SkyMapper go deeper, with colors and cadence
Going fainter encounters difficulties; entails compromises.

Pan-STARRS (PS1)



Telescope operational 2009-present

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

1.8m telescope at Haleakala, Maui, developed by IfA, U of HI.

Image fields have ~3 deg length and width (overall, 8 sq. deg.)

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 can capture ~500 images nightly (~ 1 Tbyte / night)

Operated by Pan-STARRS Project and PS1 Science Consortium

Has Static Sky, but also Time Domain with both Depth and Cadence – and contemporaneous with *Fermi*

Cadence is good for sources with sustained variability, months or longer; less suitable for transients, days or less

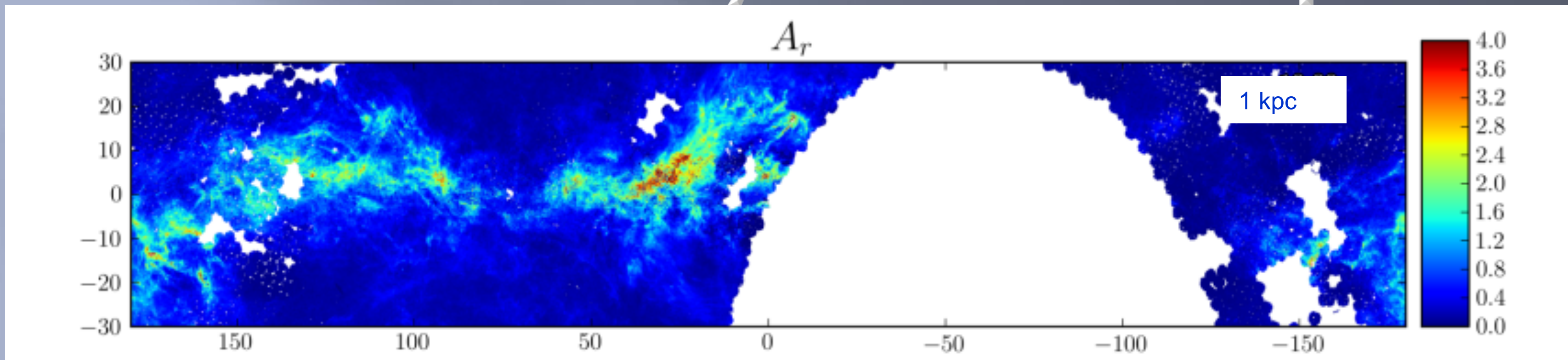
Pan-STARRS has made 3 passes (processing versions) on its image data base, designated PV1,PV2, PV3, improving photometry and astrometry

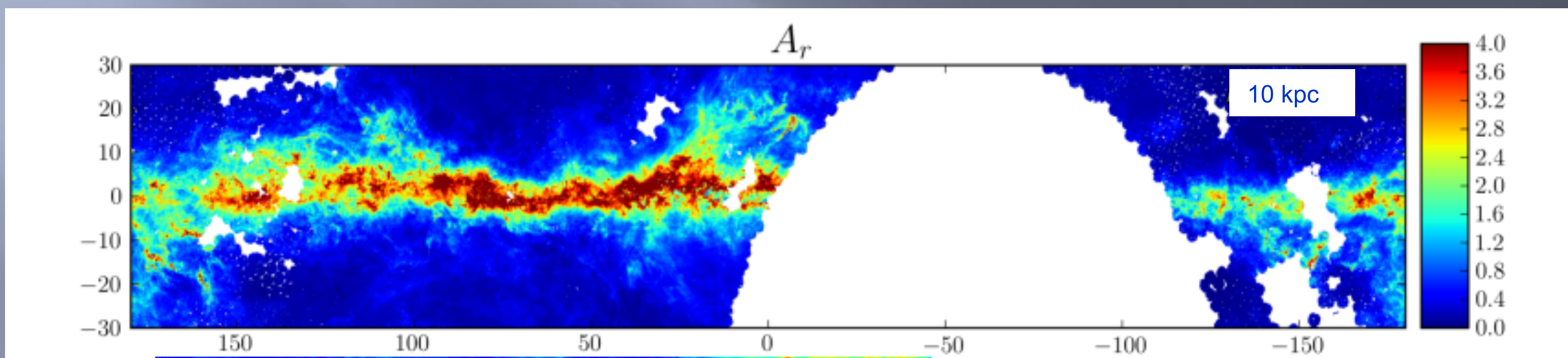
Processed data are being delivered to STScI

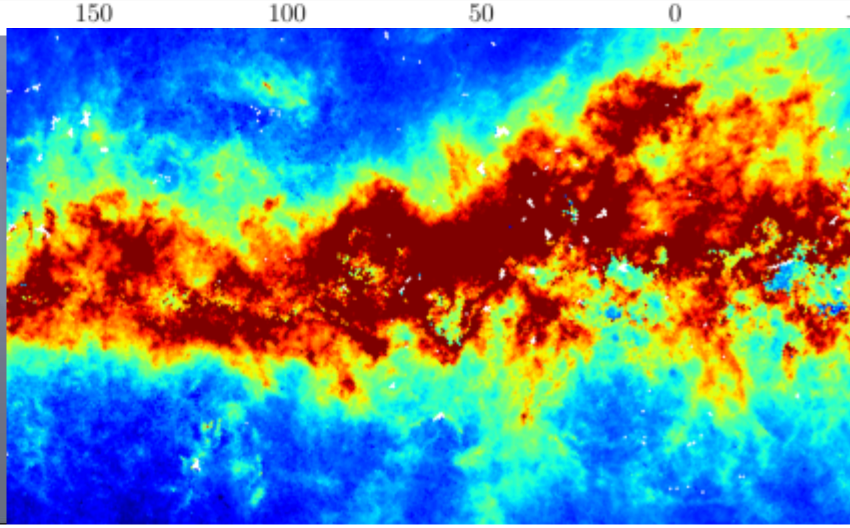
STScI will handle public distribution

Pan-STARRS results now appearing on many topics, ranging from NEOs and comets to the Hubble Diagram and Type Ic supernovae

Static Sky: Dust Maps







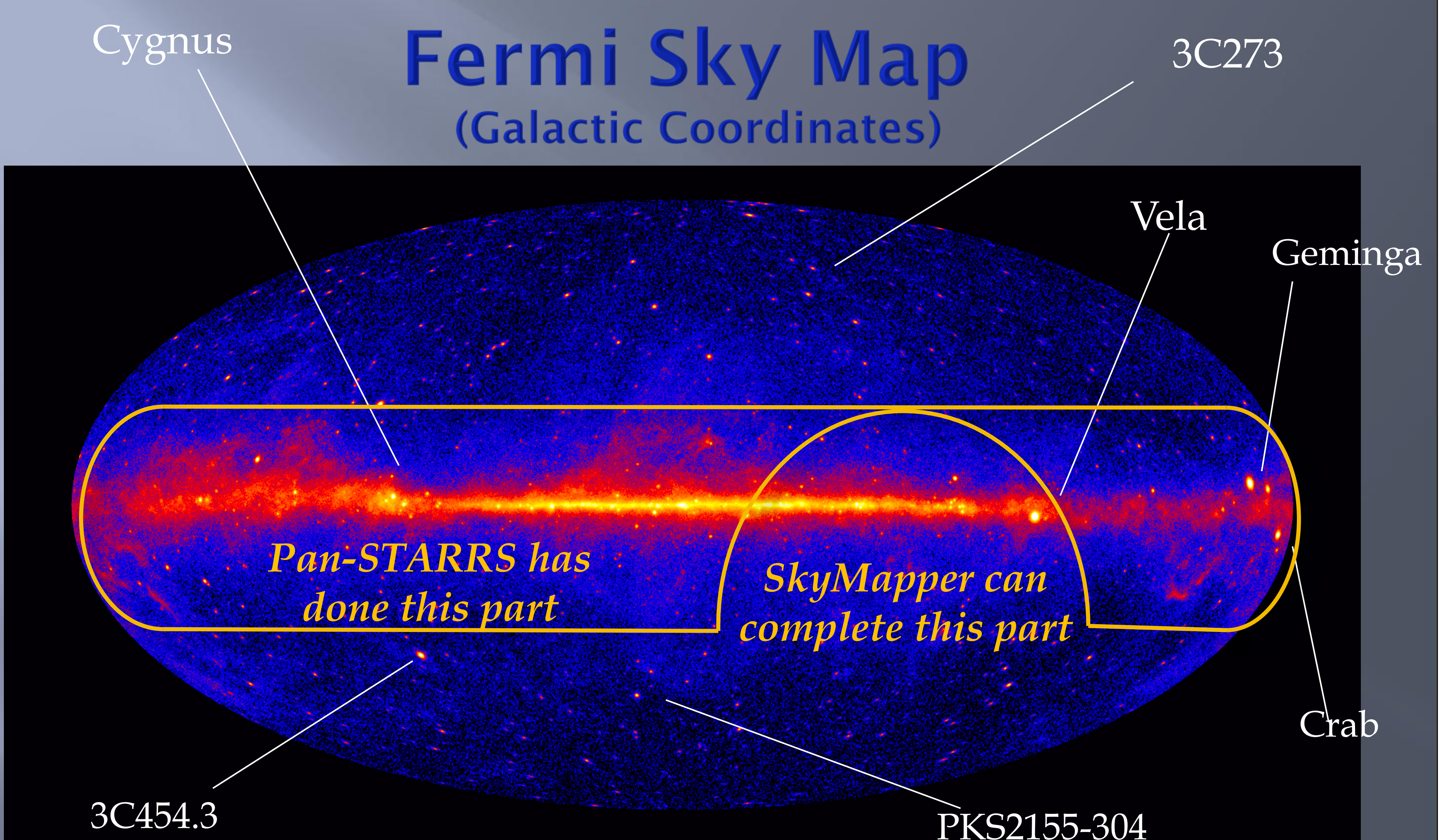
Fine-resolution extinction maps

(Schlafly et al., 2014)

Correlate with LAT static sky

For Galaxy

Fermi Sky Map
(Galactic Coordinates)



Skymapper is done from Australia. Limited access release in 2015. Wider access in 2016.

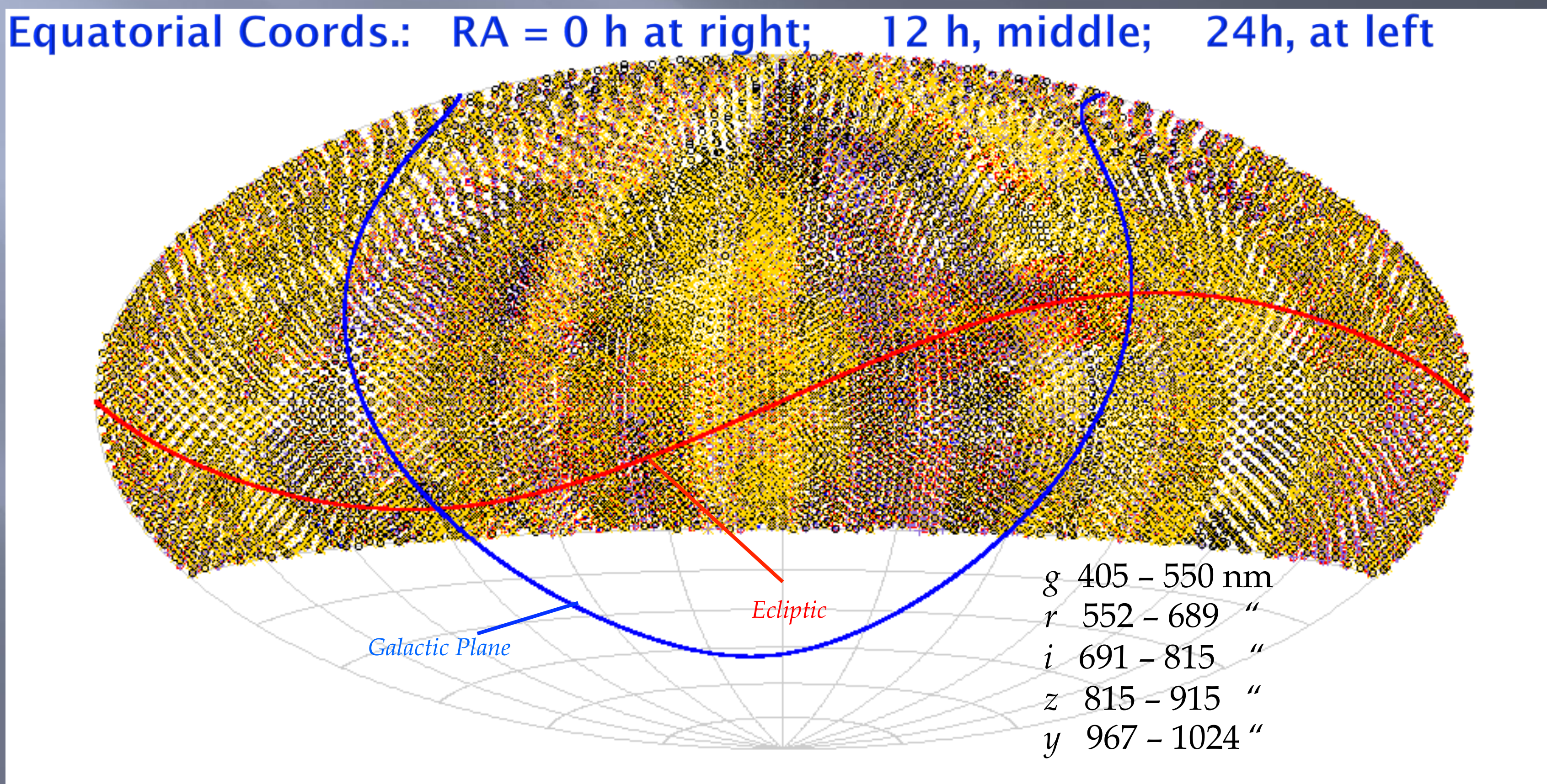
Covers southern half of sky. SkyMapper + PS1 = 5π sr. Filters: *u,v,g,r,i,z*

PS1 3π survey

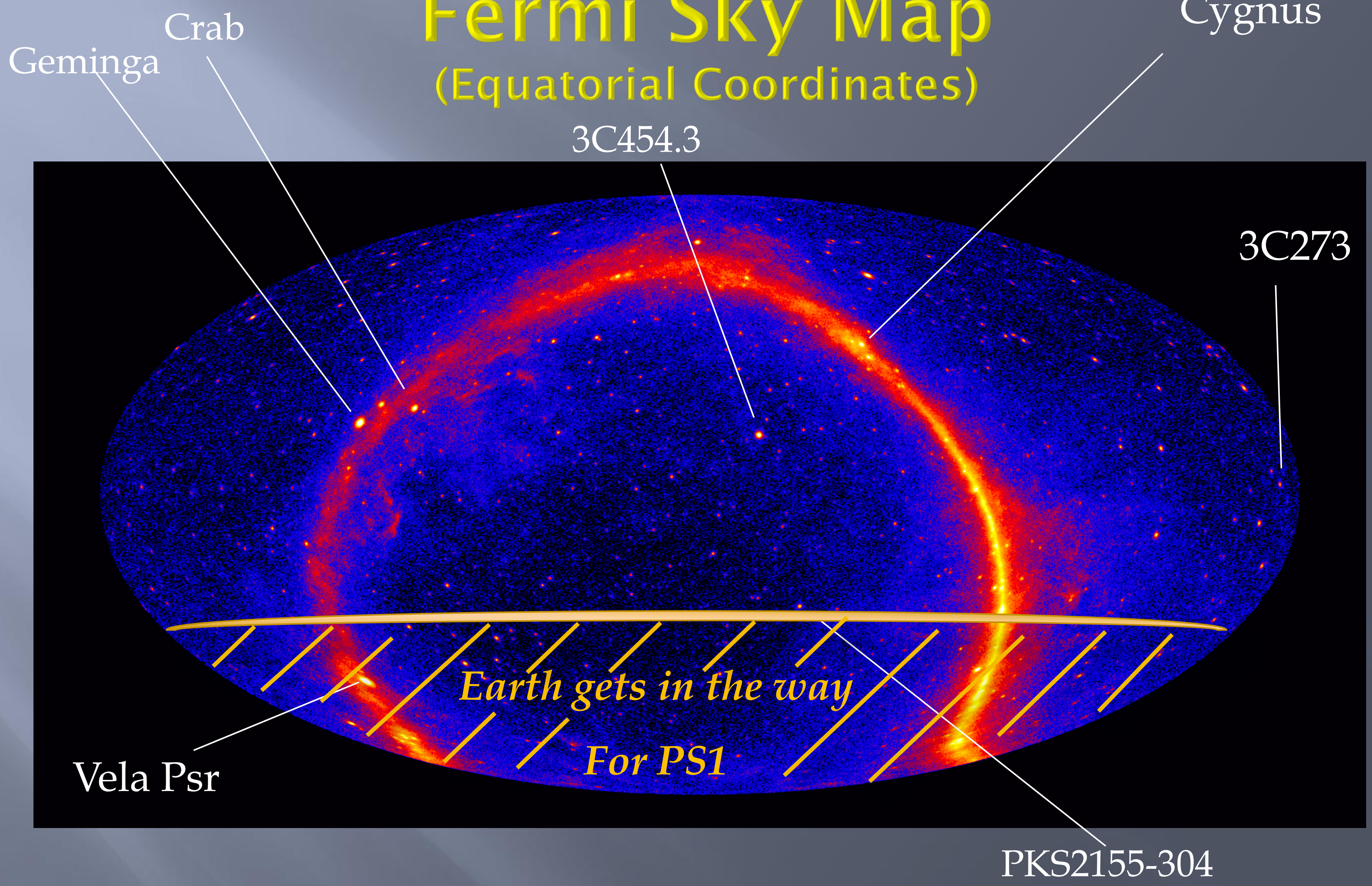
coverage in five bands over 2010-15

Dec > -30 degrees

Cadence well-matched to many Fermi applications
Faint, aperiodic LAT sources → integrate weeks, months
Periodic LAT sources (binaries) → can fold detections

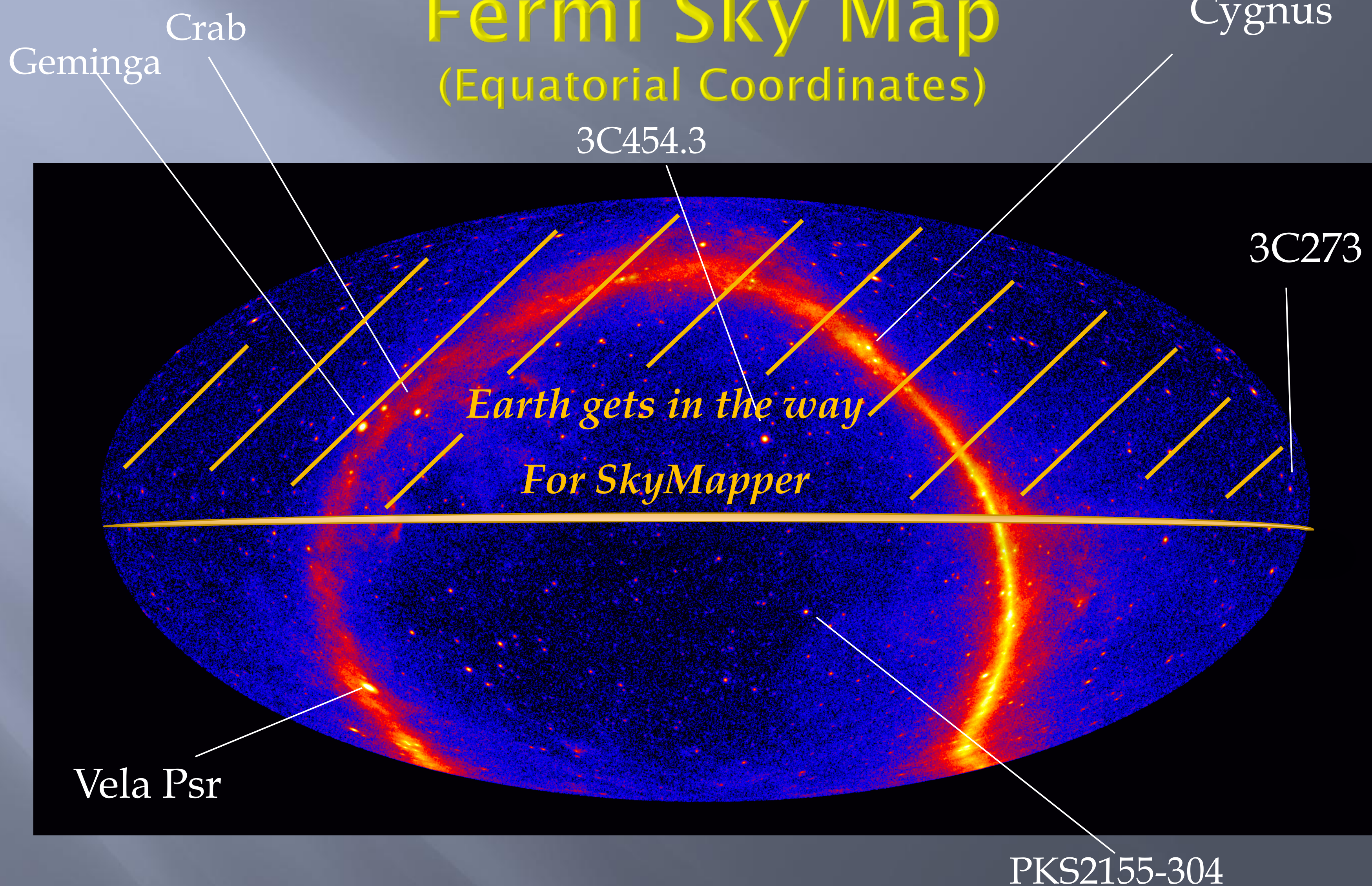


Fermi Sky Map
(Equatorial Coordinates)



Hour 0 is at center; RA increases to left out to Hr 12, then picks up on right at 12 and runs back to center at 23.
Pan STARRS displays 0 at left, 12 in middle and 23 at right. So, for comparison rotate this in180° to left!

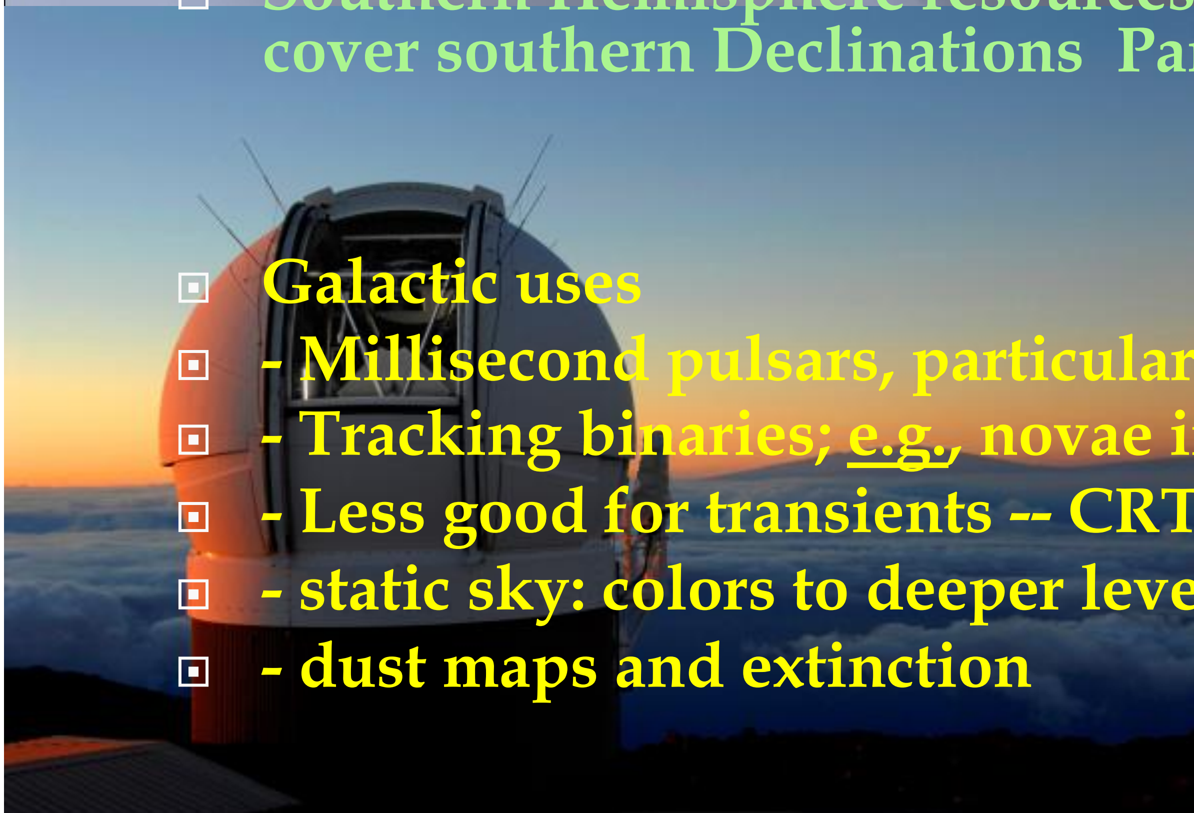
Fermi Sky Map
(Equatorial Coordinates)



SkyMapper + PS1 = 5π sr. **Filters:** ***u,v,g,r,i,z***

Deep Data Base Impacts

- Not practical to monitor all Fermi AGN in dedicated programs. When new AGN identified, cannot collect optical data retroactively, but AGN north of Dec = -30° will have been tracked as single exposure detections in the Pan-STARRS data base, during Fermi epochs.
- Static sky: could find more dwarf spheroidal galaxies
- Southern Hemisphere resources (SkyMapper, DES) cover southern Declinations Pan-STARRS cannot reach



- Galactic uses
- - Millisecond pulsars, particularly redback MSPs
- - Tracking binaries; <u>e.g.</u>, novae in quiescence
- - Less good for transients -- CRTS, PTS, AAVSO cover
- - static sky: colors to deeper level than the detections
- - dust maps and extinction

Redback MSPs

Important binary systems, transitioning between LMXBs and MSPs

Several have used Catalina (CRTS) or PTF

Pan-STARRS now coming into play

Possible periodic signatures

(phase=0 when NS cross sky plane outbound)

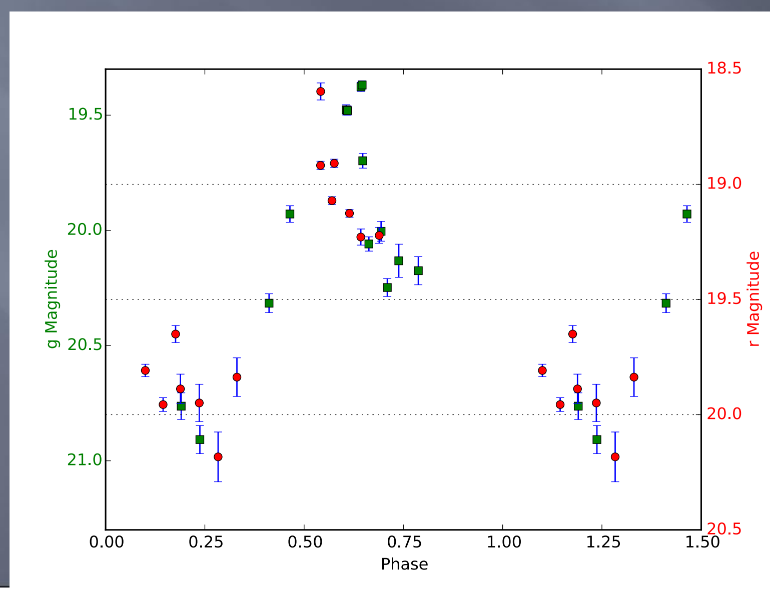
- ellipsoidal variation (two peaks per orbit, at 0.0, 0.5)
- irradiation (one peak per orbit; max at 0.75, min at 0.25)
- or, something else

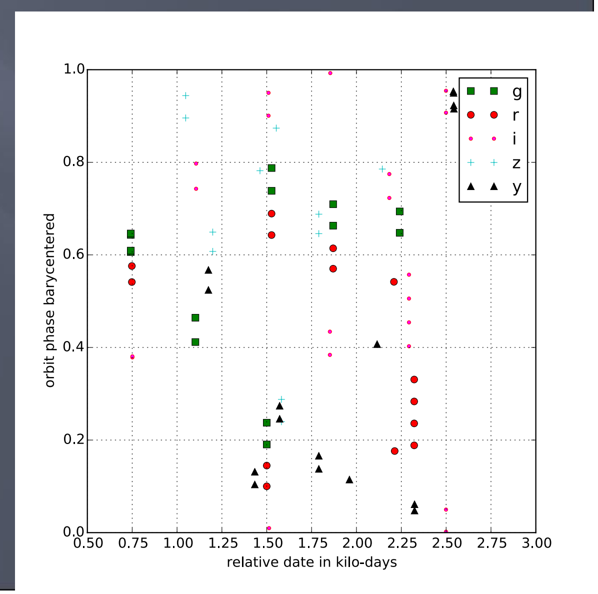
Folded *g* and *r* detections, from PS1

Left: magnitude *vs* phase

Right: phase *vs* epoch

See talk by J. Deneva, this Symposium, for discussion of the source





GAIA

New Standard for Astrometry --

precise positions, PM, down to magnitude 20

200 μas at mag = 20;   20 μas at mag= 15

Will give best optical positions for AGN, redbacks, etc

Already launched -- First data releases expected in 2016

How do precise positions help *Fermi* science?

Example 1:

Find Fermi source, spectrum indicates possible pulsar

Use search in Swift to refine position, and/or

Search in optical wide field data bases to refine position

Still would like a definitive position to use to search pulsations

GAIA positions could assist at precisely this point, facilitate search

Example 2:

Take Fermi source, identify AGN candidate

Use optical light curves (from wide-field or monitoring); establish ID

Then, optical position = gamma-ray position

GAIA position is then best determination of optical-to-gamma position

After that, can compare with precise radio position

LSST

Large Synoptic Space Telescope

Will go significantly fainter (several magnitudes) than Pan-STARRS, SkyMapper

There would be many ways to use with *Fermi*

Example: could monitor white dwarf counterparts to MSPs

Aperture: 8 m
Magnitude reach > 23.5 in single exposures
Covers Dec < +10°
Cadence set by time-domain astrophysics

But it is expected on-line *circa* 2023.
The challenge for *Fermi* community is to keep *Fermi* going that long.

Closure: Thoughts for Future:

Can regard foregoing as upcoming opportunities for research – how will wide-field resources help my next paper?

But it is also a community issue:
Emerging suite of wide-field resources will gradually change how Fermi is utilized and increase its impact on astrophysics

One more reason to continue Fermi as long as possible, grounded mainly in astrophysics of source populations.

Some are already in use (CRTS, PTF, Pan-STARRS)
improved access brings increased utilization

Major improvements expected 2016:
Pan-STARRS, SkyMapper, Gaia

P.S. What About High Cadence from Orbit?

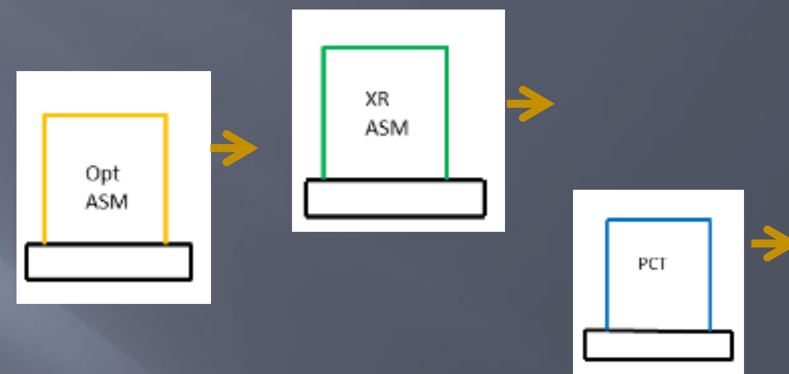
Facts:

Orbit required for X-ray and Gamma-ray; Optical ASM in orbit is conceivable

Optical could benefit from no-weather + tactics for Sun-avoidance + 24-hr day

- *Remember AM Her in AAVSO? Try to do that deeper, for more of 4π, in orbit*
- *Could consider two or three separate s/c for this purpose*

Constraint: **would like to have them on same side of Earth so as to have simultaneity and not just contemporaneity**



Notional Implementation

- **#1: *Fermi* is already flying; keep it flying and add to it**
- **#2: There *will* come a better X-ray monitor. Launch it into roughly *Fermi's* orbit. This is feasible. Keep it nearby with trim maneuvers. But what about the optical?**
- **Optical can, for now, be covered by suite of ground facilities, but contemplate an orbital ASM.**

Conclusion:

Fermi **LAT has much to give to astrophysics**

Grand All-sky monitor for gamma rays,

while also covering static sky.

Providing a new portrait of our own Galaxy

Fermi needs multi-wavelength support in optical, X-rays

Optical, X-ray, γ-ray differ as to mix of static sky / time-domain

Optical and X-ray analogs do exist. They are getting better

Improving in time for extended Fermi mission:

Keep it going