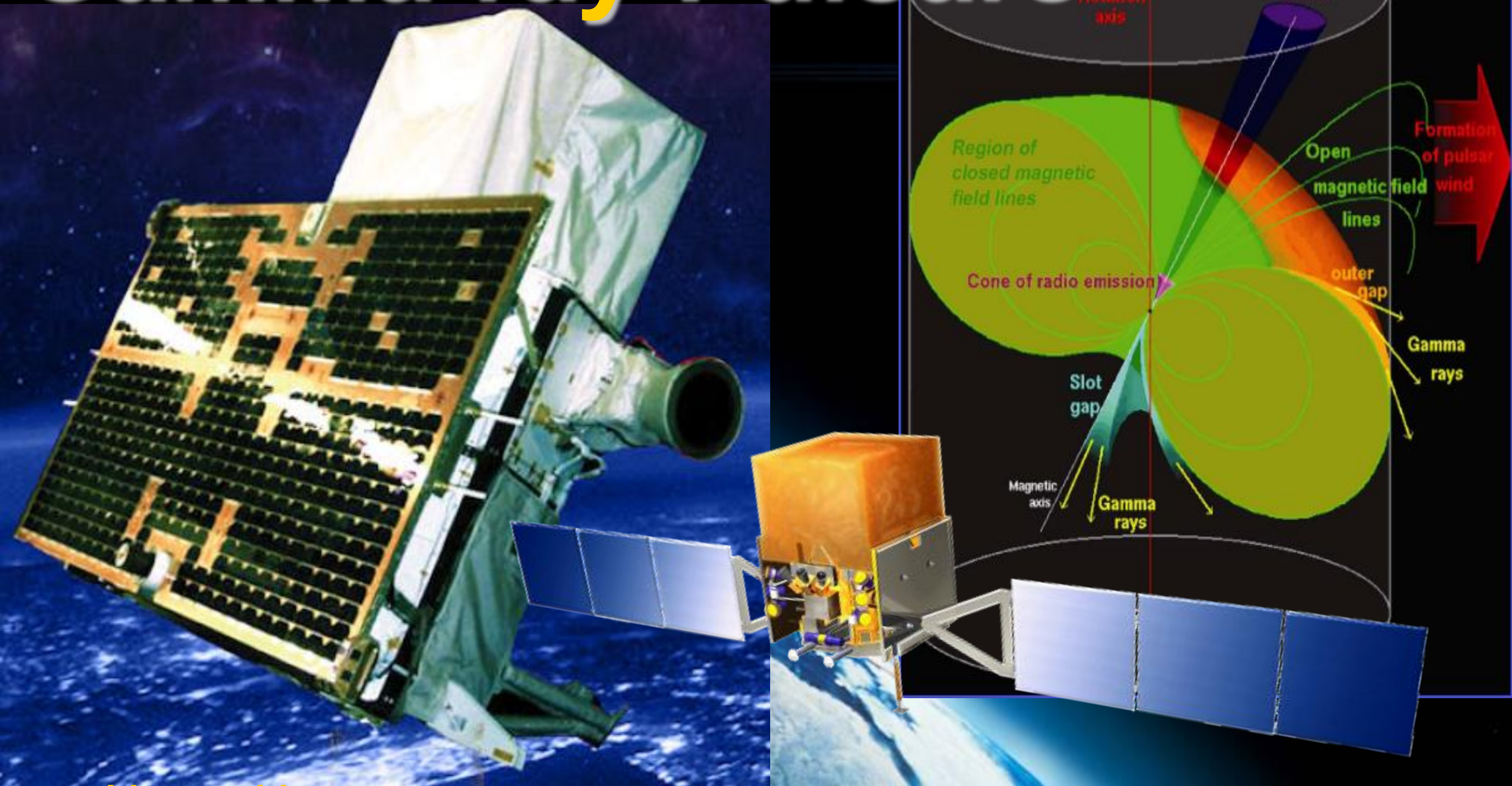
Gamma-ray Pulsars

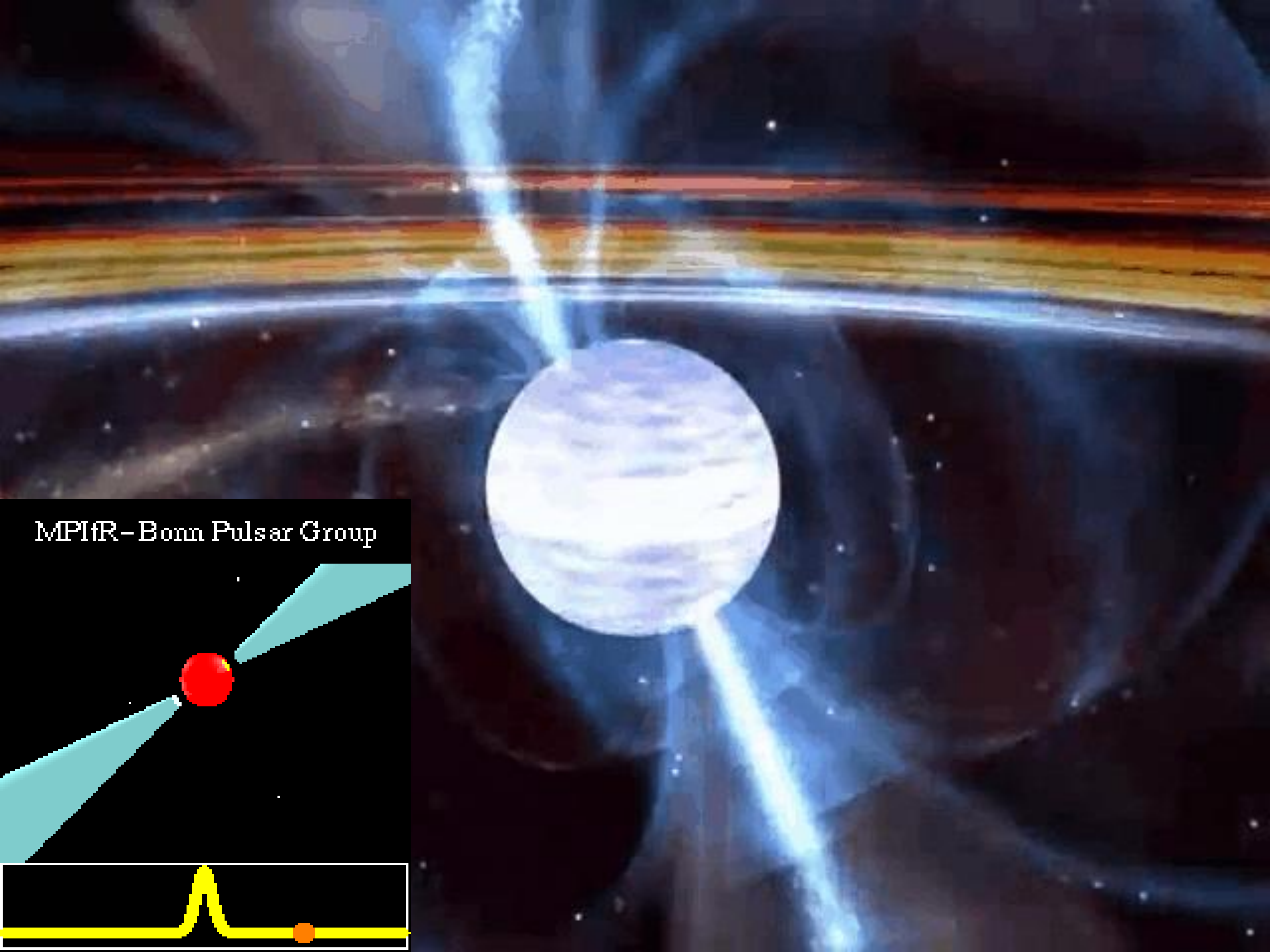


David A. Smith, for the *Fermi* LAT collaboration and pulsar consortia
Centre d'Études Nucléaires de Bordeaux-Gradignan
CENBG (CNRS)
smith@cenbg.in2p3.fr

A DECADE OF AGILE
Rome, December 11-13, 2017
Accademia dei Lincei and ASI

This talk:

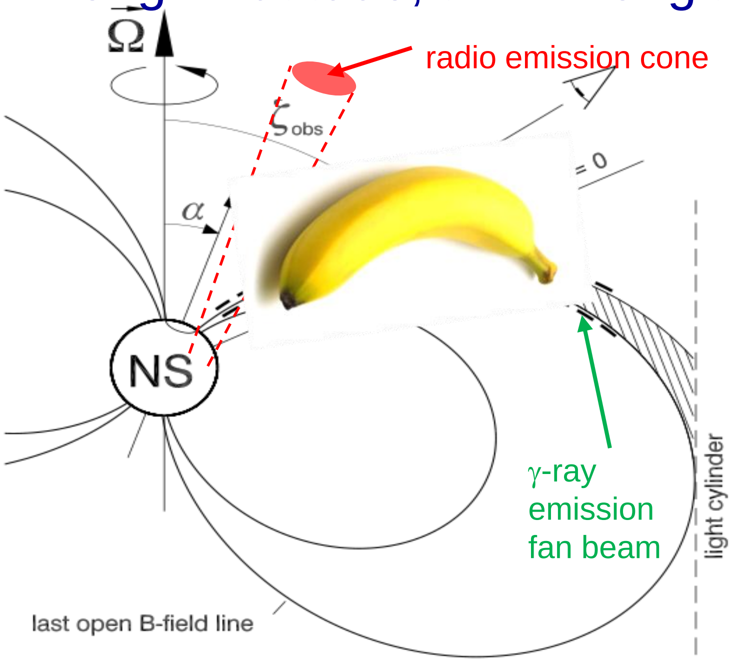
- An overview of gamma-ray pulsars so far
- Fast Weighting to Search 1000 Pulsars
  - *>4σ single-trial false positives don't happen.*
  - *The gamma-ray deathline near $\dot{E}$ = E33 erg/s* ***is real****.*
  - *Subluminous & unresolved pulsars.*

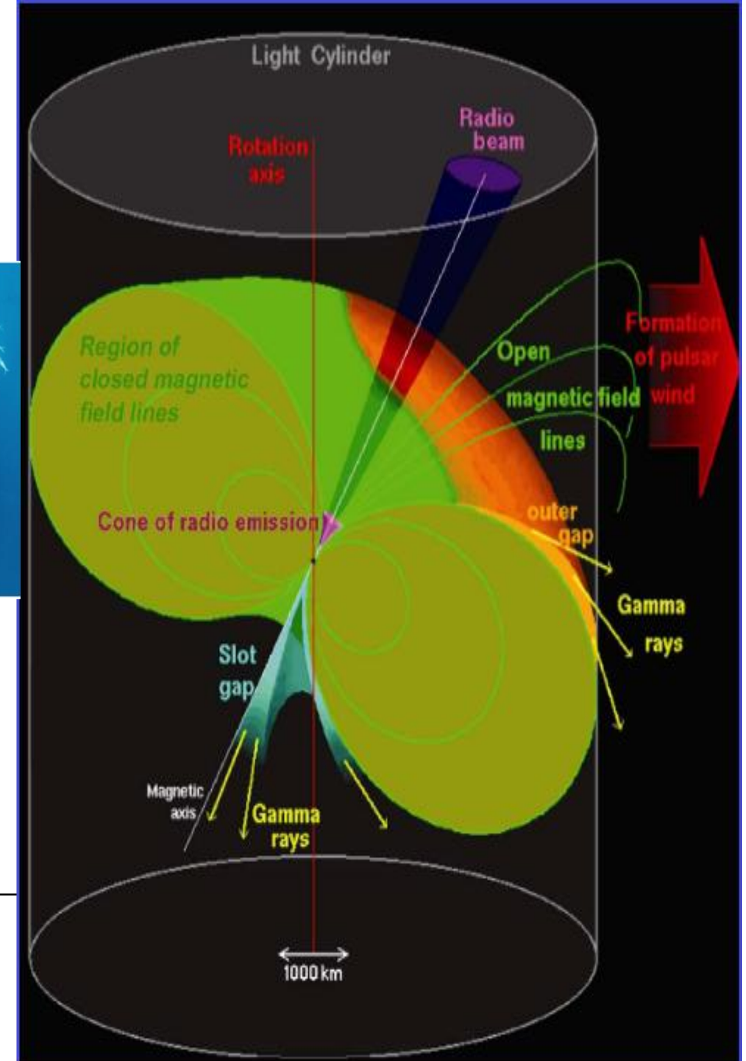

MPIfR–Bonn Pulsar Group

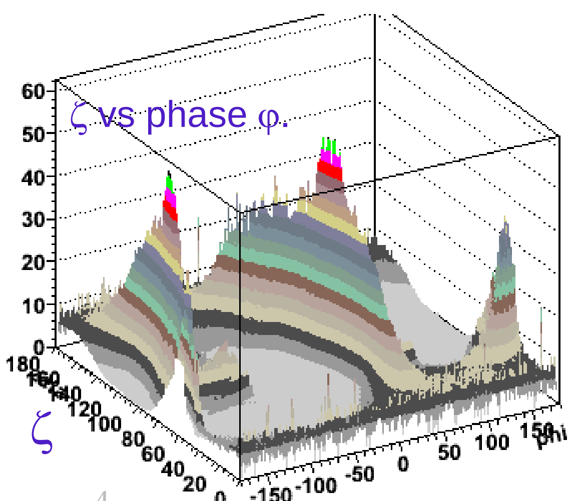
Gamma-ray beam:

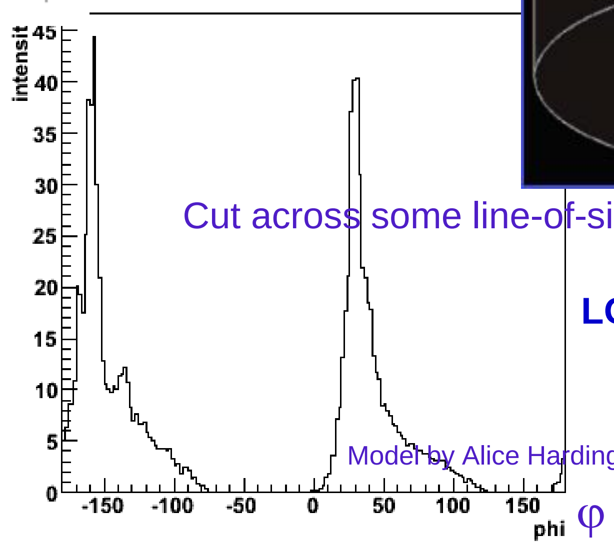
Curvature radiation in '*gaps*'.

Long in latitude, thin in longitude (*caustics*).









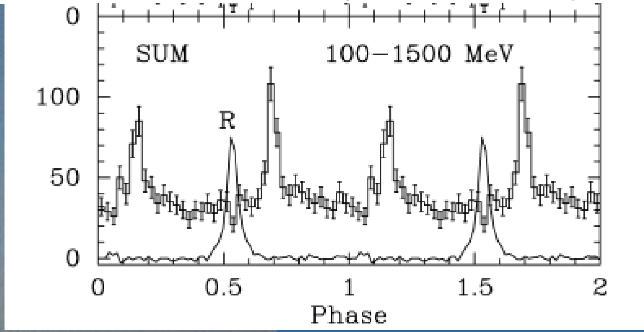
LOBs = Luminous Orbiting Bananas

AGILE launch, 23 April 2007

1st new gamma pulsar after Compton GRO ApJ (2008)

DISCOVERY OF HIGH-ENERGY GAMMA-RAY PULSATIONS FROM PSR J2021+3651 WITH *AGILE*

J. P. Halpern,[1] F. Camilo,[1] A. Giuliani,[2] E. V. Gotthelf,[1] M. A. McLaughlin,[3] R. Mukherjee,[4] A. Pellizzoni,[2] S. M. Ransom,[5] M. S. E. Roberts,[6] and M. Tavani[7,8]



Followed quickly by 3+1=4 more ApJ (2009)

DISCOVERY OF NEW GAMMA-RAY PULSARS WITH *AGILE*

A. Pellizzoni[1], M. Pilia[1,2,3], A. Possenti[1], A. Chen[2,4], A. Giuliani[2], A. Trois[5], P. Caraveo[2], E. Del Monte[5], F. Fornari[2], F. Fuschino[6], S. Mereghetti[2], M. Tavani[5,7], A. Argan[5], M. Burgay[1], I. Cognard[8], A. Corongiu[8], E. Costa[5], N. D'Amico[1],

+52 others.

Searched 35 pulsars with high $\sqrt{\dot{E}}/d^2$ and good timing.

B1509-58; B1821-24,
in the globular cluster M28;
J2229+6114; J2043+2740.


11 June 2008
In our 10th year!
Fermi
Gamma-ray
Space Telescope
Formerly "GLAST"

First observations of Pulsars with the DArk Matter Particle Explorer *ICRC 2017, 709*

DAMPE launch, 17 December 2015

Maria Muñoz Salinas*
University Geneva
E-mail: maria.munoz@unige.ch

Xin Wu, Stephan Zimmer
University of Geneva

Fabio Gargano
INFN Bari

Zhaoqiang Shen
Purple Mountain Observatory

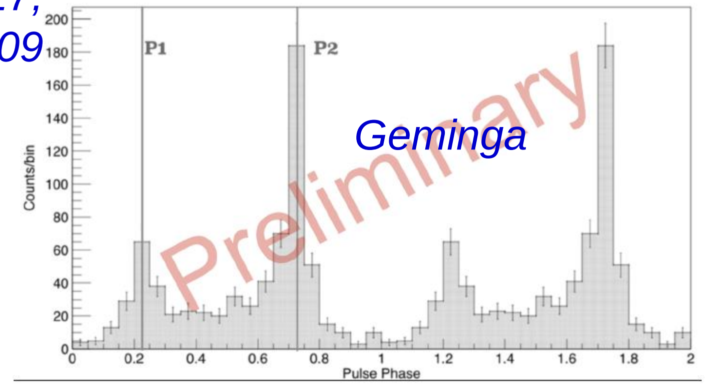


Figure 3: Geminga light curve for energies above 1 GeV. Two pulse phase periods are presented with a precision of 20 bins per period.

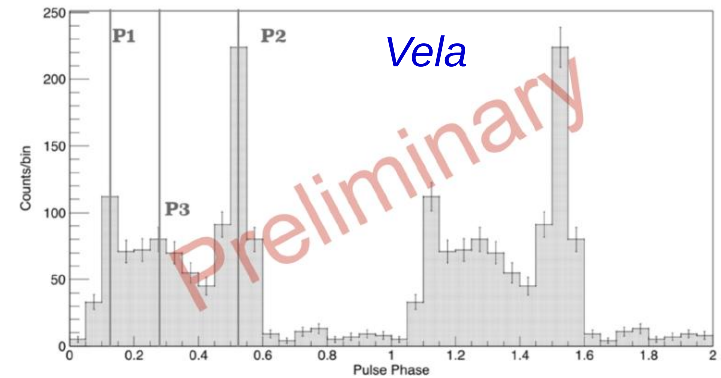


Figure 4: Vela light curve for energies above 1 GeV. Two pulse phase periods are presented with a precision

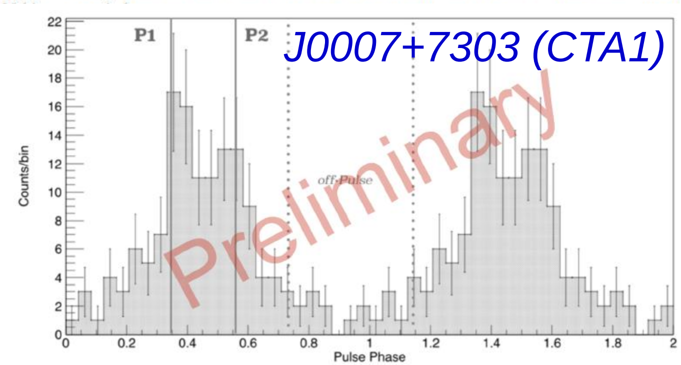


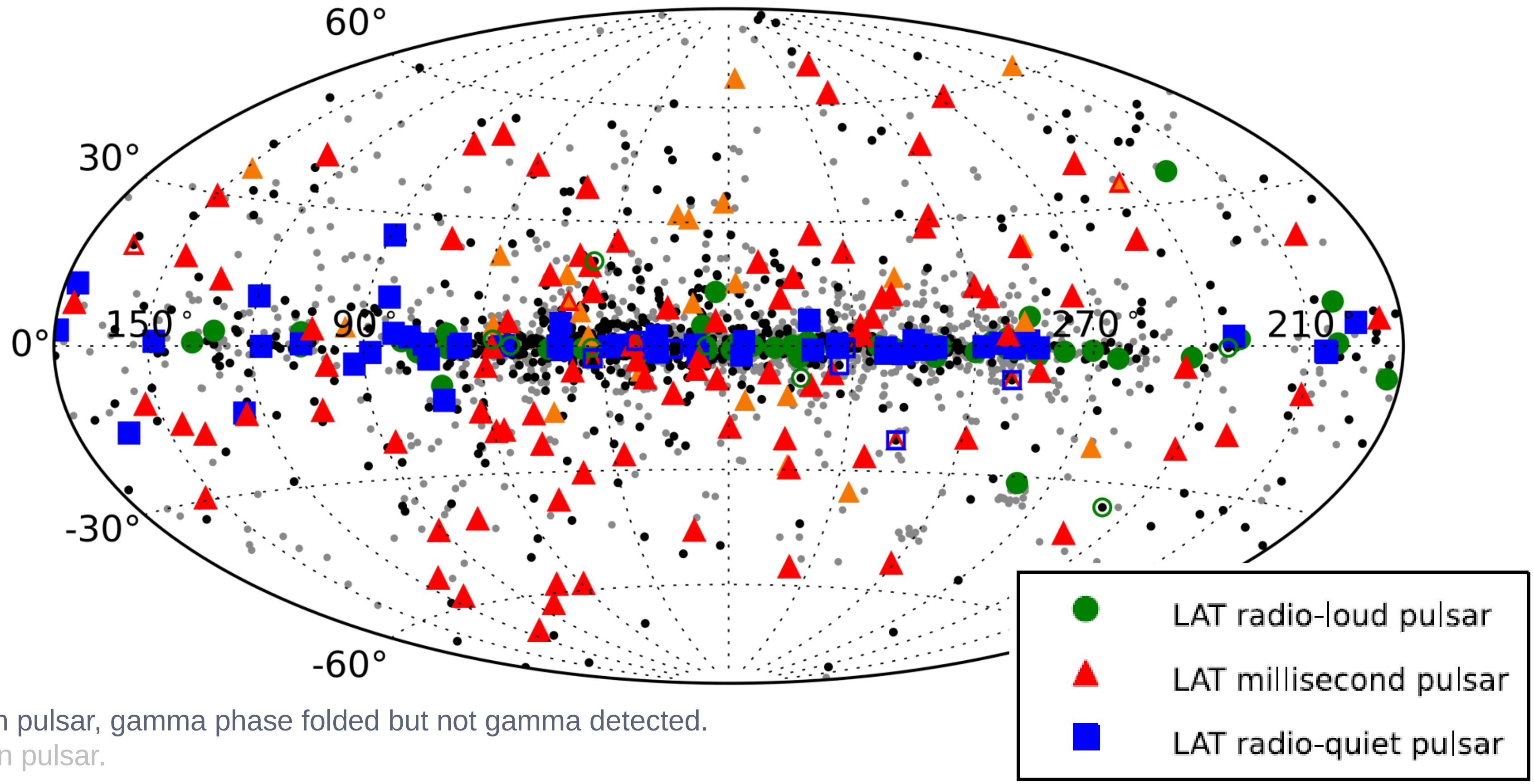
Figure 5: J0007+7303 light curve for energies above 1 GeV. Two pulse phase periods are presented with a precision of 24 bins per period.

Before *Fermi*: 10 pulsars seen with CGRO (all confirmed), and PSR J2021+3651 discovered by AGILE.

Now over 231 *Fermi* LAT pulsars.

Update of Fig 2 from **2PC** = *2nd Pulsar Catalog*: ApJ Suppl. 208 17 (2013)

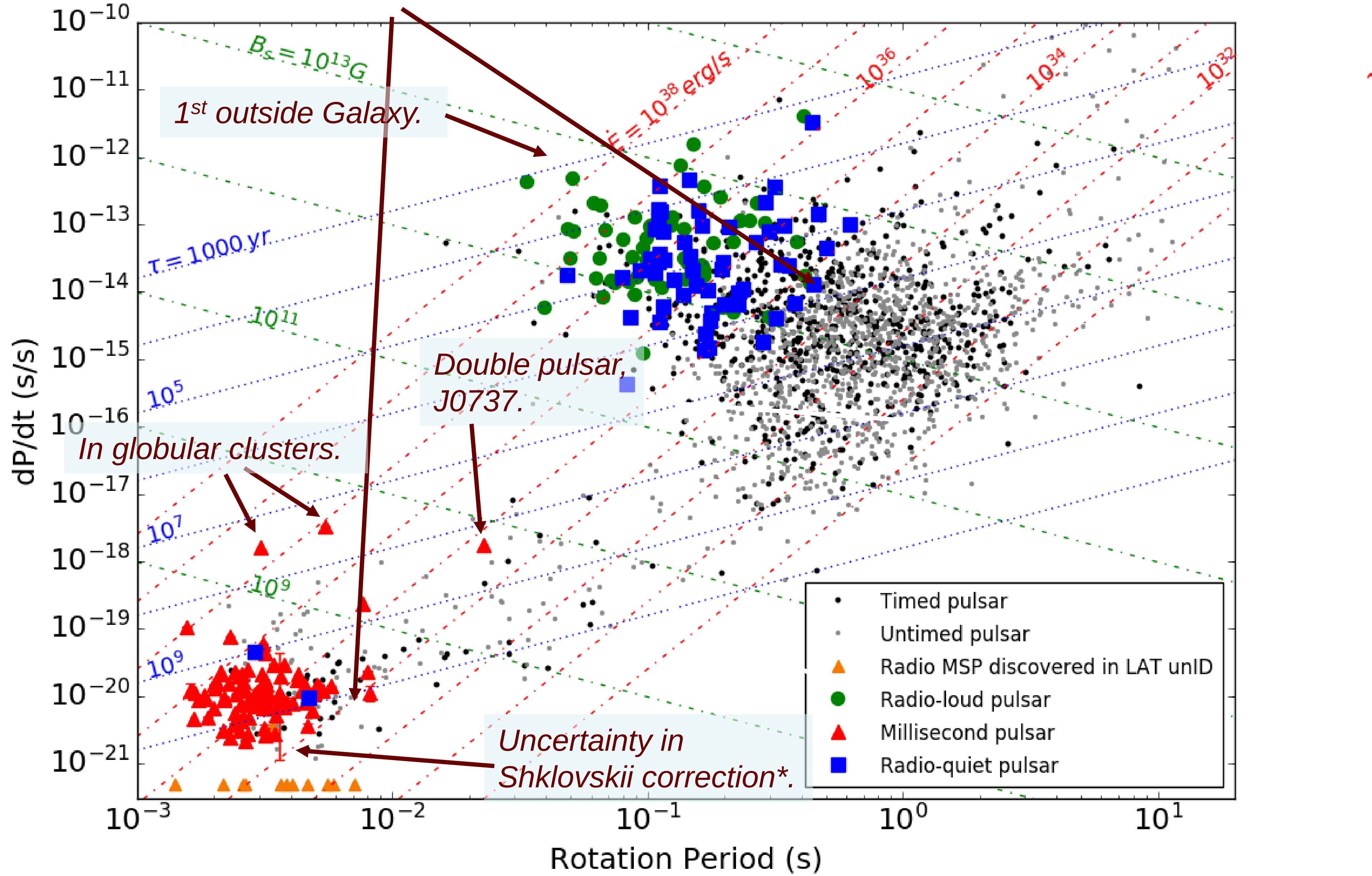
3PC in preparation for Summer 2018.



- known pulsar, gamma phase folded but not gamma detected.
- known pulsar.

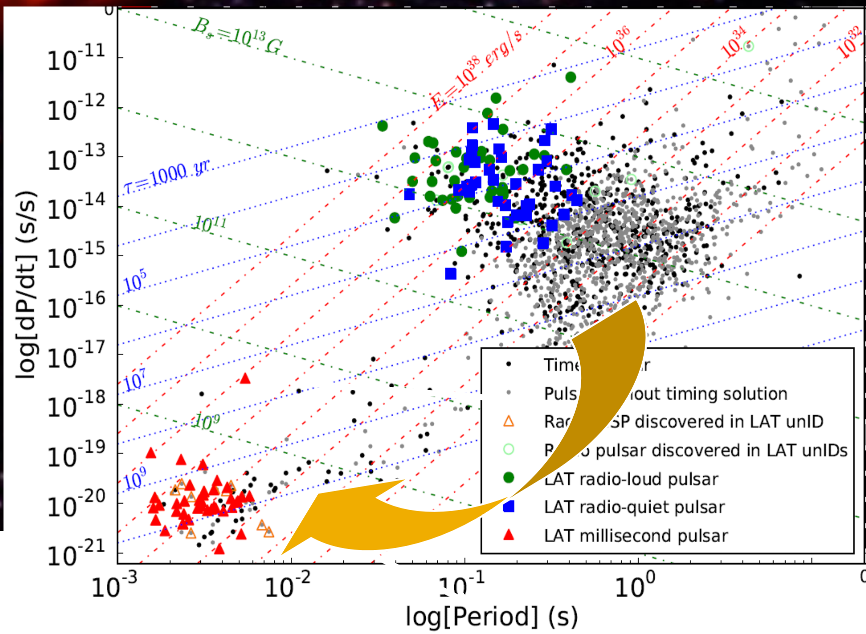
Gamma-ray deathline near spin-down power $\dot{E} = 4I\pi^2 \dot{P} / P^3$ of ~3E33 erg/s. (I ≡ 1E45 gm cm² depends on EoS.)

Update of 2PC Fig 1.



*See e.g. *γ MSP Deathline, revisited*, Guillemot et al. A&A (2016) "recycled" = millisecond pulsars = MSPs *(life after death!)*

Fermi-led discoveries of many "*spiders*" (companion star ablated by pulsar wind) provide tests of binary evolution theory.



3 ways to discover gamma-ray pulsars

1. Phase-fold gammas using ***known*** rotation parameters.

*Weight using spectrum ⊗ point-spread-function** ➔ *𝒪(1) trials, highest sensitivity.*

~1000 ephemerides provided by radio astronomers (x-rays too) Smith et al, A&A (2008)

2. Deep radio searches at positions of pulsar-like unidentified gamma sources.

85 MSPs found. e.g. Cromartie et al ApJ (2016)

• Rotation ephemeris ➔ phase-fold as above. 58 gamma MSPs so far.

LOFAR found fastest (707 Hz) field MSP in a *Fermi* source Bassa et al, ApJ Lett (2017)

Looking forward to Meerkat and SKA

3. Blind period search in gamma-rays at those same positions.

58 young PSRs e.g. Clark et al ApJ (2017), 5 MSPs.

~4 radio detections.

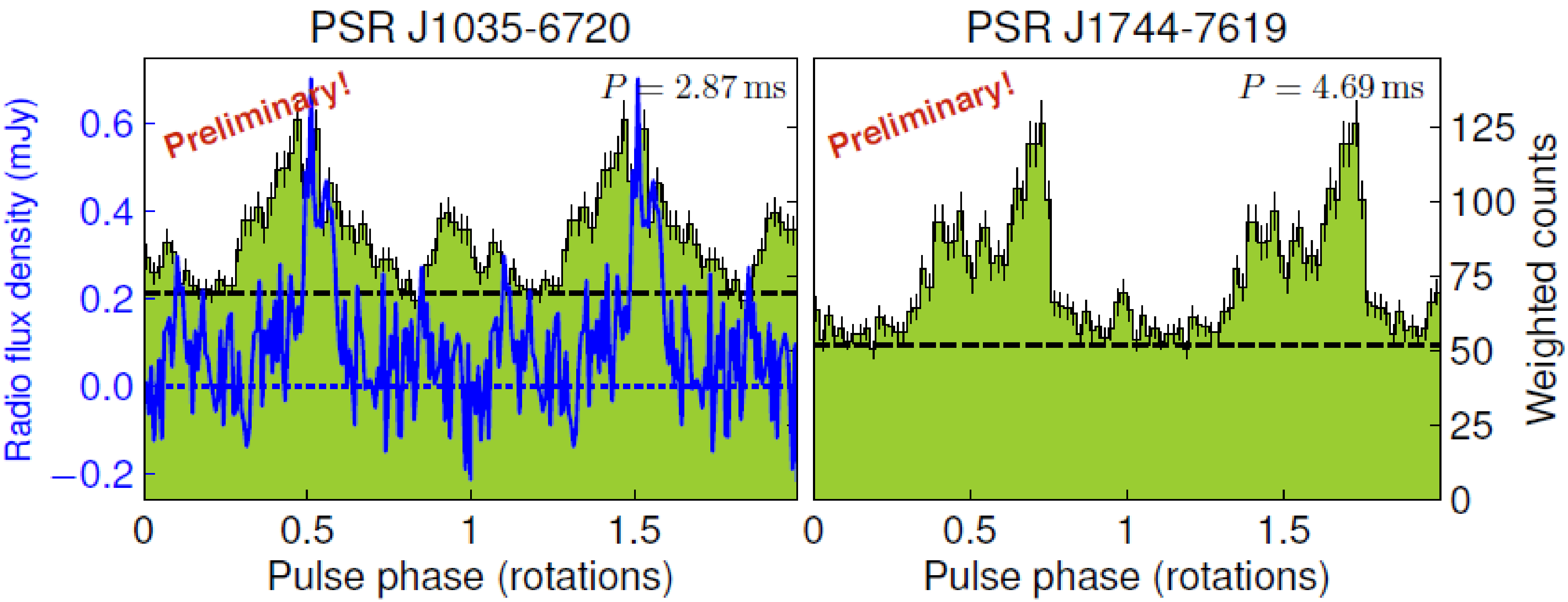
Einstein@Home searches very successful.

1st radio quiet MSP discovered! Clark et al, *Science* (submitted)

*M. Kerr, ApJ (2011)

Einstein@Home Blind-search MSPs

10,000 years of CPU on thousands of volunteers' PCs.
'*citizen science*' at work



- Two isolated MSPs found in completely blind gamma-ray searches
- 2 out of 3 most significant unassociated 3FGL sources

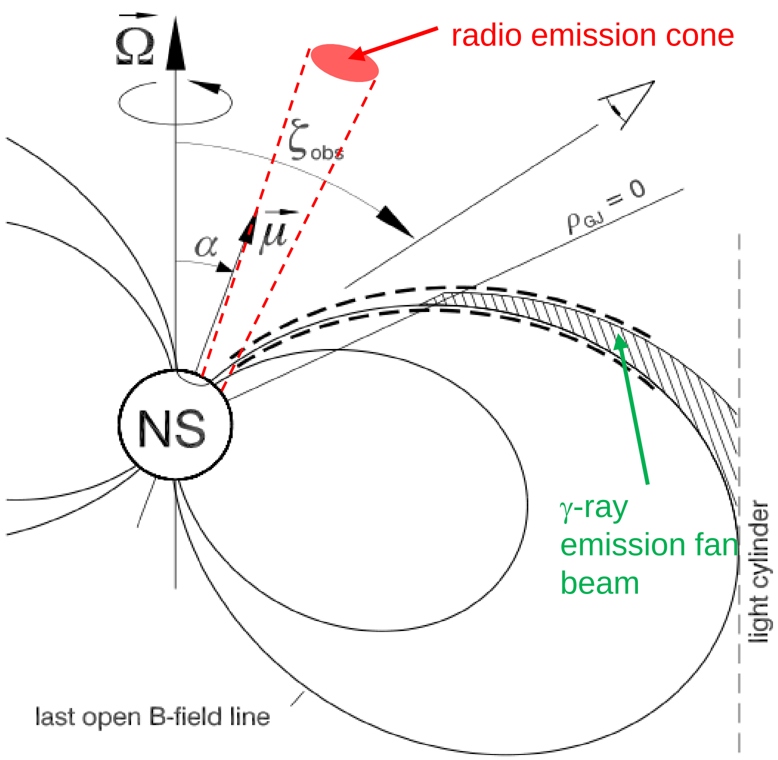
Profile example: PSR J2240+5832

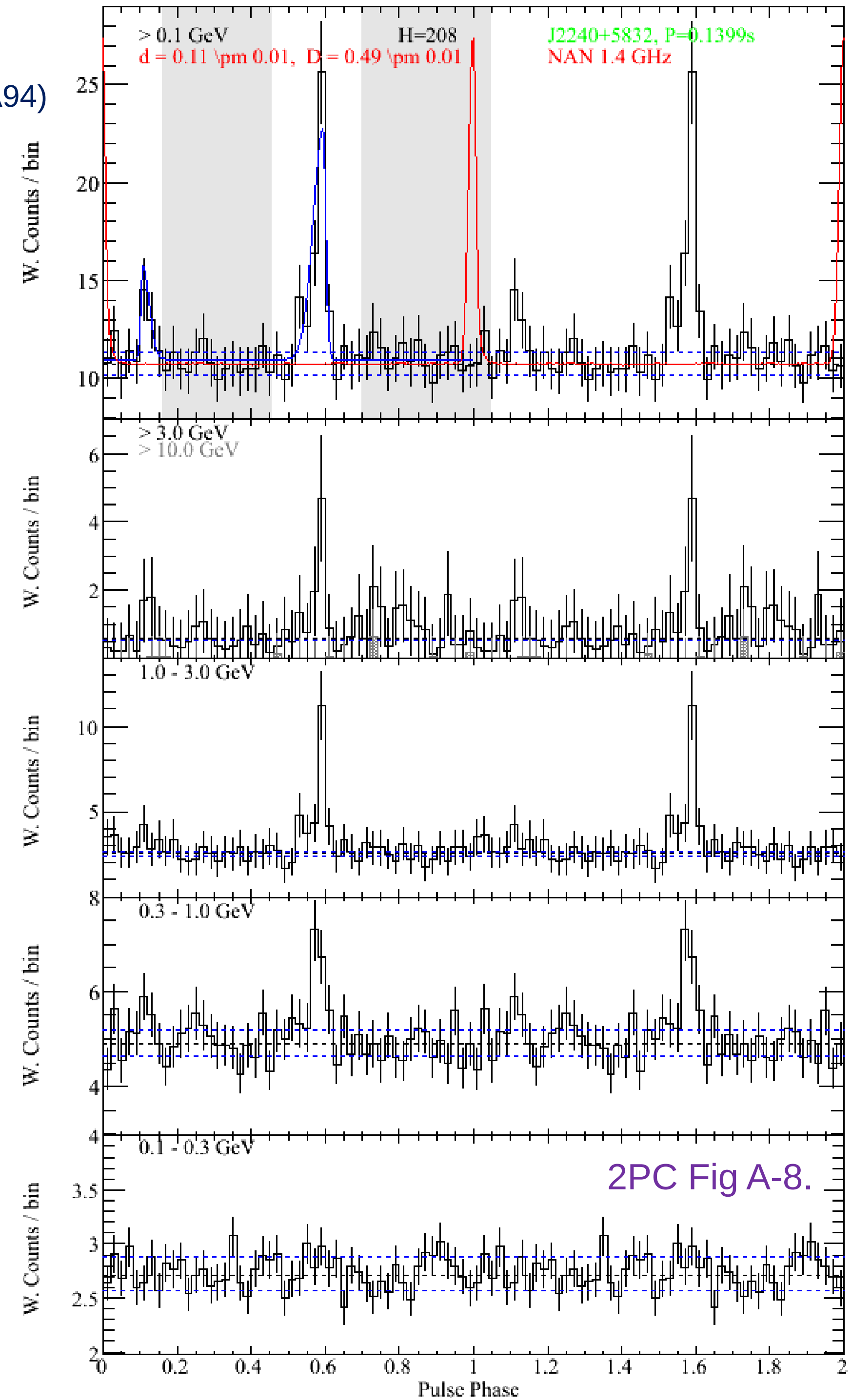
(see also Theureau et al. 2011, A&A, 525, A94)

- Black – weighted gamma-ray profiles. Blue – fit
- Red – phase-aligned radio profile.
- Gray – ‘off-peak’ phase range

Horizontal dash – local gamma-ray b’grd

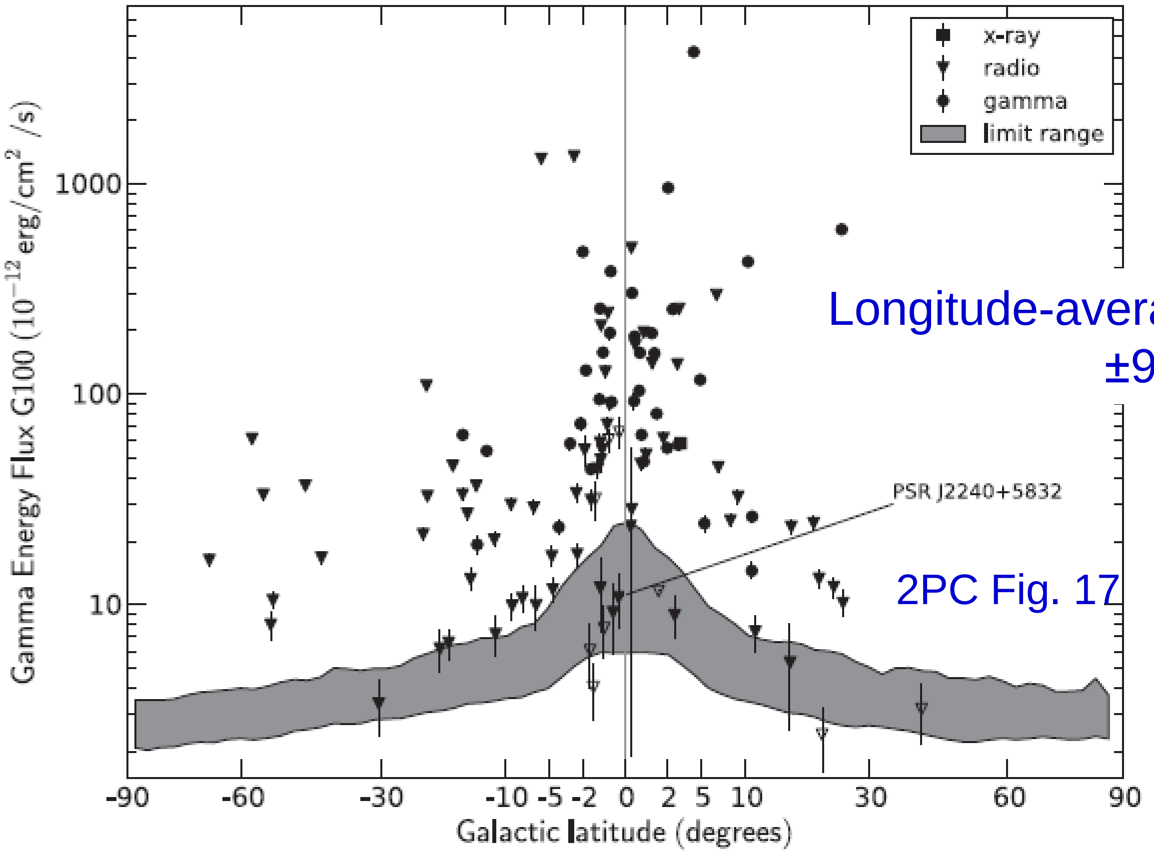
- d = δ = ‘radio lag’
- D = Δ = ‘peak separation’
- **H-test pulse significance** (Kerr ApJ 2011, and refs therein)





PSR J2240+5832:

narrow γ peaks ➔ below average sensitivity threshold.



Longitude-averaged sensitivity,
±95% percentiles.

2PC Fig. 17

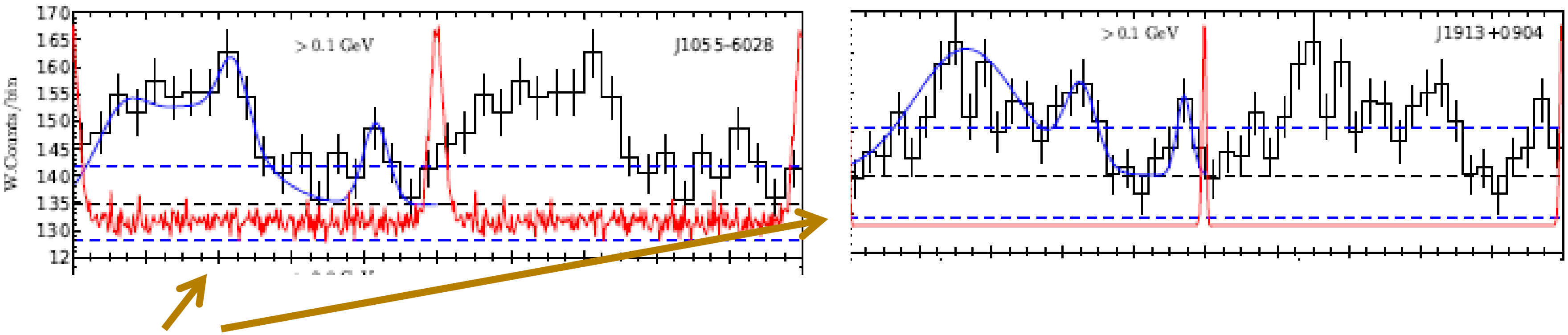
Avoid bias! Search also for broad peaks.
Fat γ peaks ➔ above average sensitivity.

Six faint gamma-ray pulsars seen with the *Fermi* Large Area Telescope

A&A 570, A44 (2014)

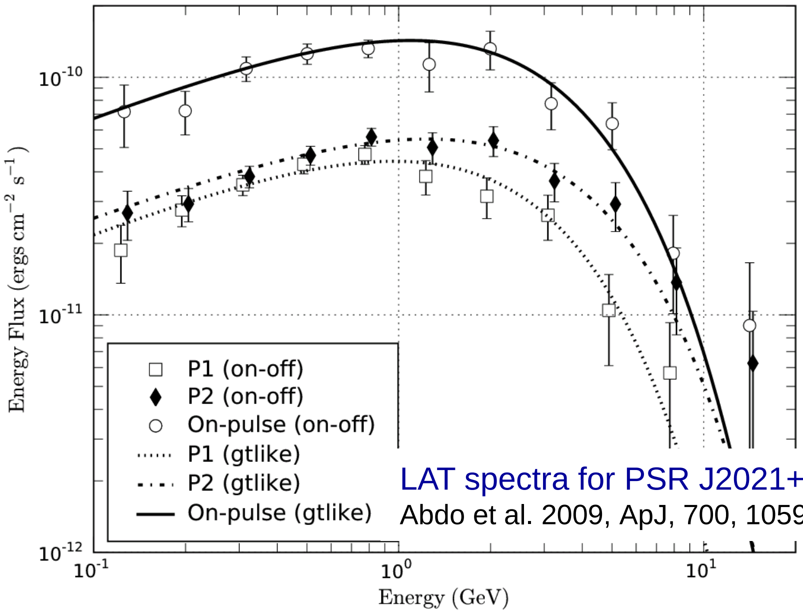
Towards a sample blending into the background

X. Hou (侯賢)[1], D. A. Smith[1], L. Guillemot[2,10], C. C. Cheung[3], I. Cognard[2,10], H. A. Craig[4], C. M. Espinoza[5], S. Johnston[6], M. Kramer[7,8], O. Reimer[9,4], T. Reposeur[1], R. Shannon[6], B. W. Stappers[7], and P. Weltevrede[7]



60% duty cycles! Need sensitive pulse searches.

2PC includes searches for magnetospheric emission in the “off” pulse.



LAT spectra for PSR J2021+3651
Abdo et al. 2009, ApJ, 700, 1059

$$\frac{dN}{dE} = N_0 E^{-\Gamma} \exp\left(-\frac{E}{E_0}\right)^{b} \mathrm{cm^{-2}s^{-1}GeV^{-1}}$$

➔ b=1 ➔ high altitude curvature radiation*.

(strong magnetic fields near the neutron star surface "absorb" gammas.)

Pulsar spectral '<u>signature</u>'

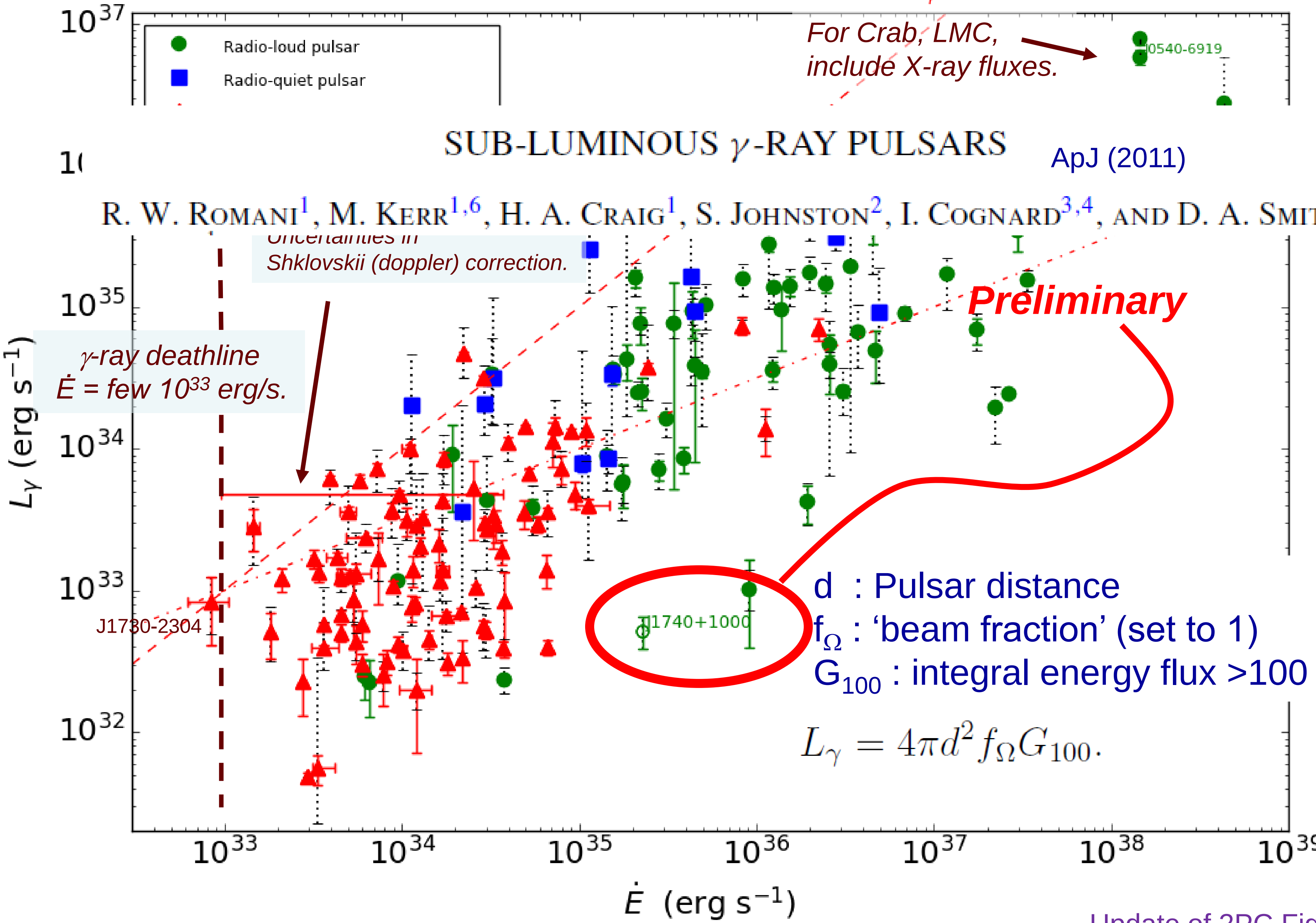
Most gamma spectra (=blazars) extend to high energy. Blazars flare, pulsars mostly don't.

Gamma-ray luminosity: $$L_\gamma = 4\pi d^2 f_\Omega G_{100}.$$

d : Pulsar distance
f_Ω : 'beam fraction' (set to 1)
G_{100} : integral energy flux >100 MeV

* Synchroton? See Cerrutti, Philippov & Spitovsky.

Gamma-ray luminosity versus spindown power



SUB-LUMINOUS γ-RAY PULSARS

ApJ (2011)

R. W. Romani[1], M. Kerr[1,6], H. A. Craig[1], S. Johnston[2], I. Cognard[3,4], and D. A. Smith[5]

d : Pulsar distance

f_Ω : 'beam fraction' (set to 1)

G_{100} : integral energy flux >100 MeV

$$L_\gamma = 4\pi d^2 f_\Omega G_{100}.$$

Update of 2PC Fig 9.

Currently, 210 gamma-ray pulsars listed at
https://confluence.slac.stanford.edu/display/GLAMCOG/Public+List+of+LAT-Detected+Gamma-Ray+Pulsars

½ are young, ½ are MSPs.

Of the young: ½ radio loud, ½ radio quiet.

⅓ already known. ⅔ found from *Fermi* data (½ radio MSPs, ½ young gamma).

¼ of all known MSPs are gamma MSPs.

For spindown power $\dot{E}$>5E33 erg/s is >¾ (!)

This part of the population is called GEMINGA-LIKE
One of Nanni & Patrizia's legacies

My main point today:

The ongoing hunt for <u>faint</u> pulsars.

FUN FACT: Lowest flux 2PC pulsars average 3.5 photons per month.

A fast, simple weighting method

Phase-fold 1000 pulsars

>4σ single-trial false positives don't happen.

*The gamma-ray deathline near $\dot{E}$ ≈1.E33 erg/s **is real**.*

Another reason to care about *faint* γ pulsars:

Dark Matter *versus* Pulsars

~10% more diffuse GeV emission towards the Galactic center than naïvely expected.

Spectrum as for neutralino annihilation (and pulsars). *Abundant literature…*

A key : Extrapolate log N-log S to estimate the contribution of unresolved pulsars.

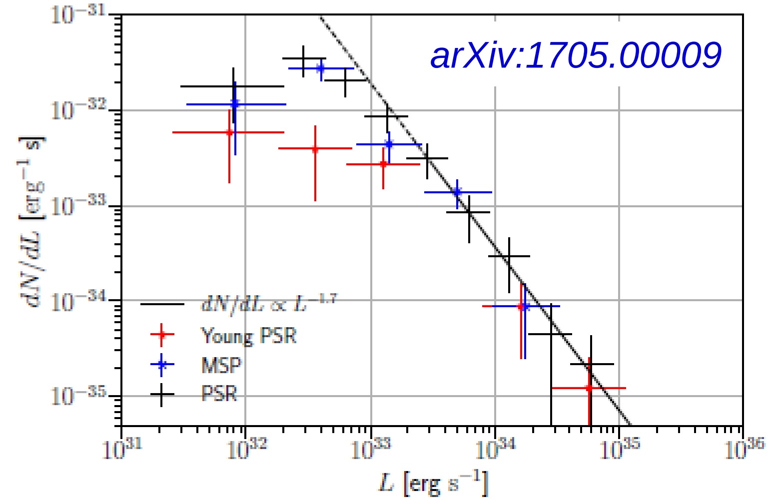


Figure 9. Observed luminosities for young PSRs (red data), MSPs (blue data) and the whole population of PSRs with $d < 1.5$ kpc (black data). The best fit to the luminosity distribution for $L > 3 \times 10^{33}$ erg s^{-1} is also reported (black line). The luminosity is integrated over the energy range [0.3, 500] GeV.

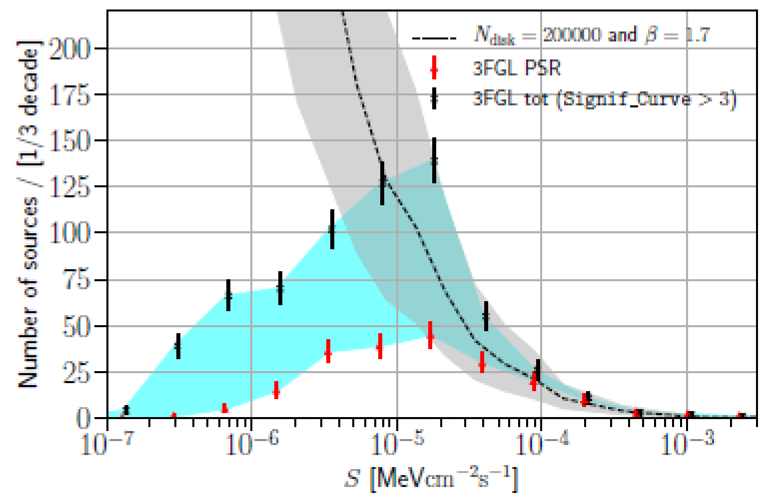
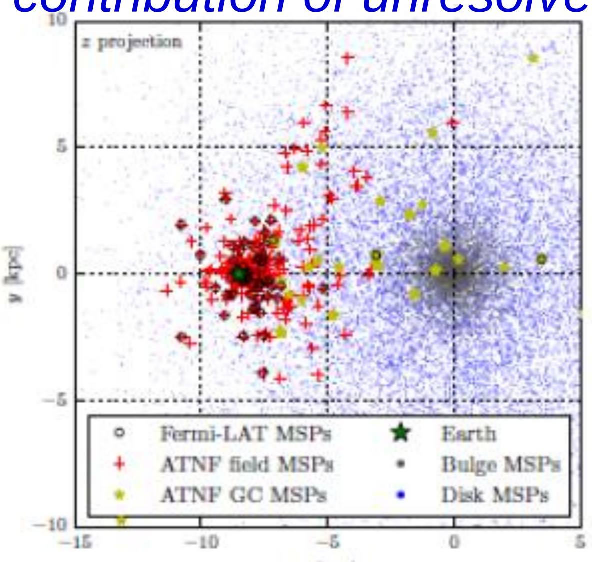


Figure 10. Flux histogram of 3FGL PSRs alone (red triangles) or added to the flux distribution of unassociated 3FGL sources with curvature `Signif_Curve` > 3 (black points). The cyan band represents the region between the lower limit (already detected PSRs) and upper limit (3FGL PSRs plus unassociated 3FGL sources with detected spectral curvature). Finally the black curve (gray band) represents the benchmark (band between the minimum and maximum) number of disk PSRs. The flux is integrated over the energy range [0.3, 500] GeV.



Calore, F., et al., 2016, ApJ, 827, 143

Gamma-ray photon weighting

• gtlike *source_model* allows gtsrcprob to calculate

Weight = rate(pulsar) / rate(all sources)

for all source directions near pulsar direction.

M. Kerr, ApJ (2011)

• gtlike difficult or impossible for faint sources

Simulations revealed simplifying assumptions and approximations that gave a one-parameter equation that works amazingly well.

Ph. Bruel, in prep

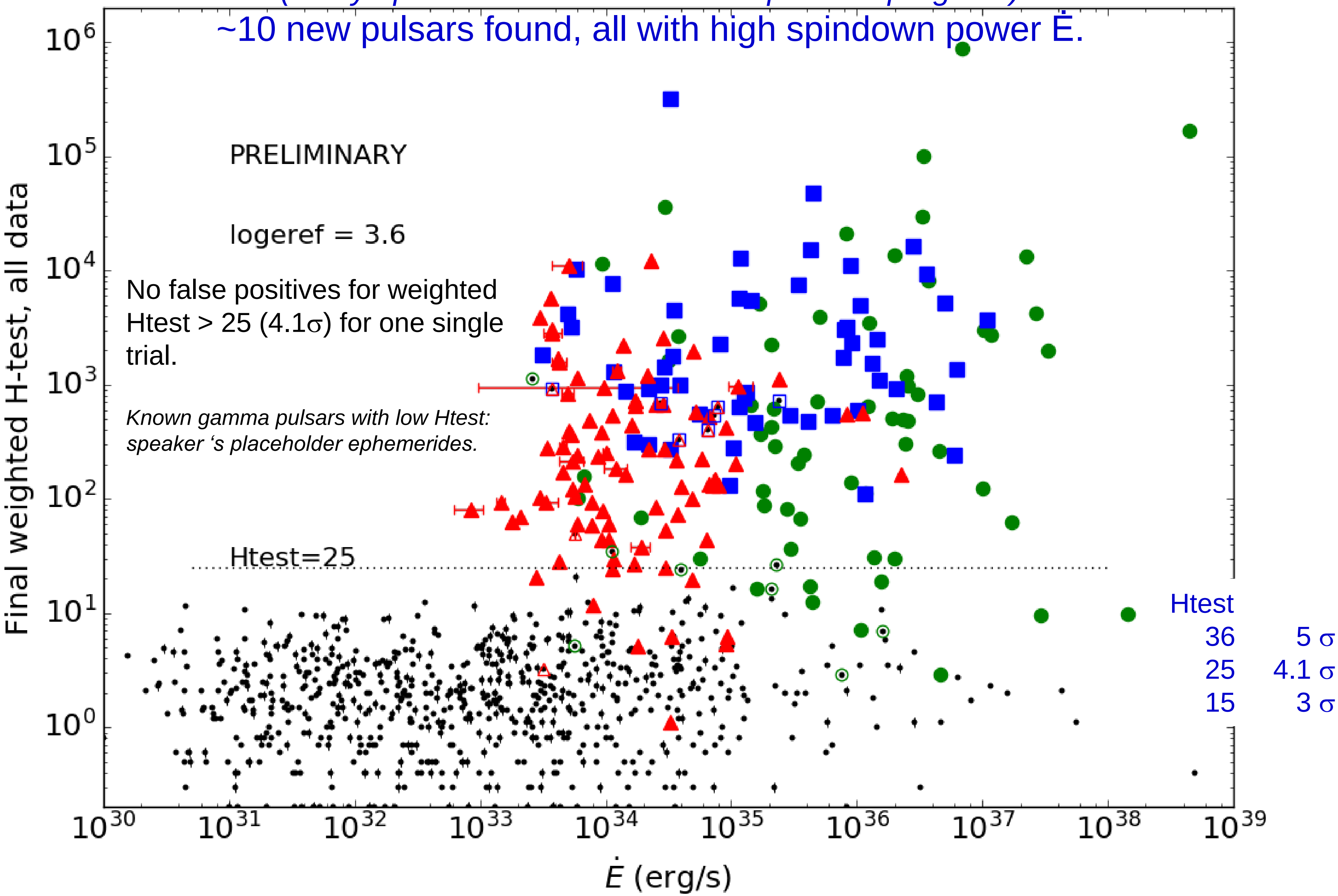
Weights = $w(E_\gamma, \Delta\Theta)$ calculated on-the-fly.

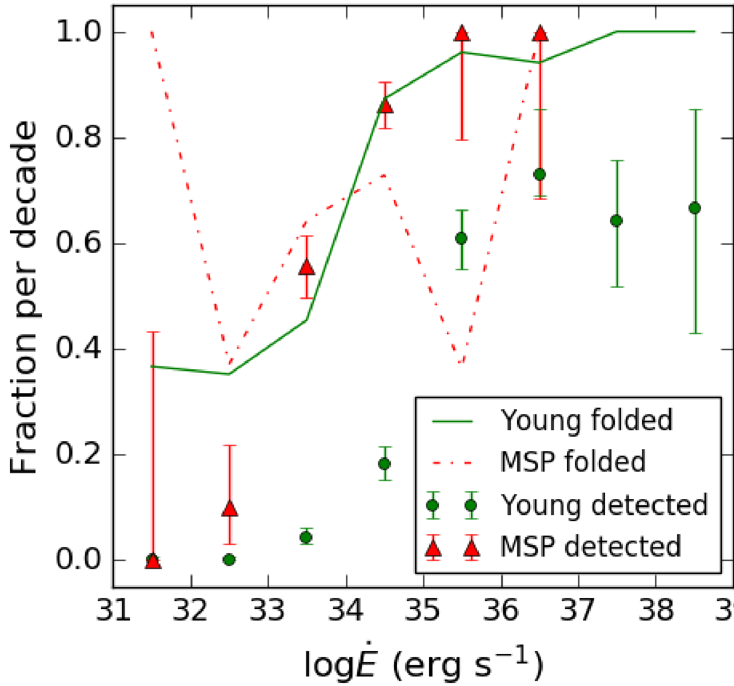
$\Delta\Theta$ = | PSR direction – photon direction |

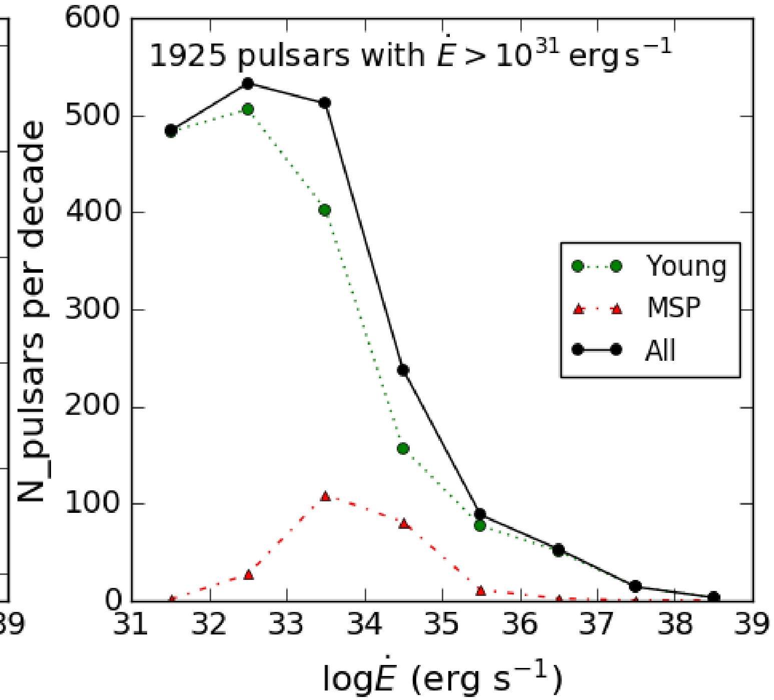
Allows weighted phase-folding for 1000 pulsars, ≤3 trials (for weighting param).

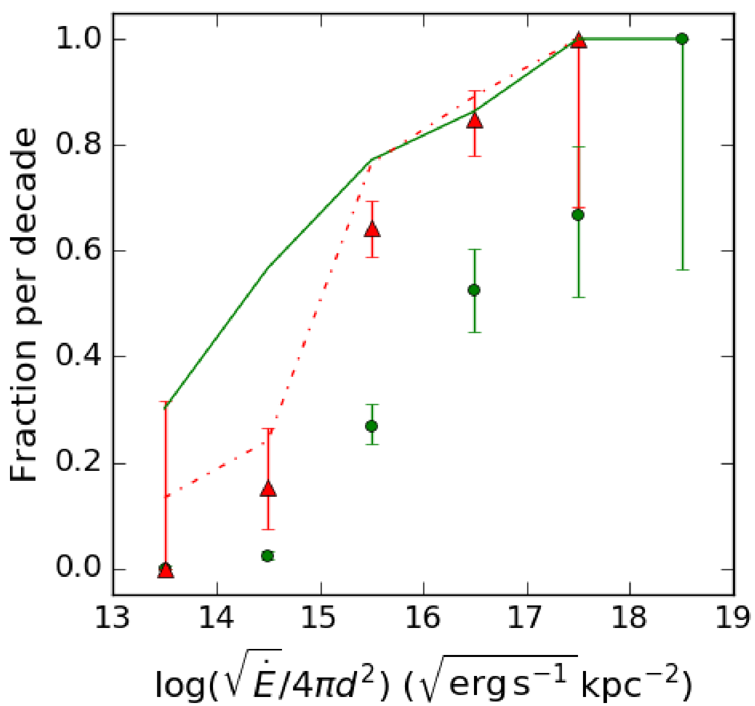
Black dots: ~800 radio pulsars folded with >9 years of Pass 8 data.

(Many ephemerides out of date – update in progress)







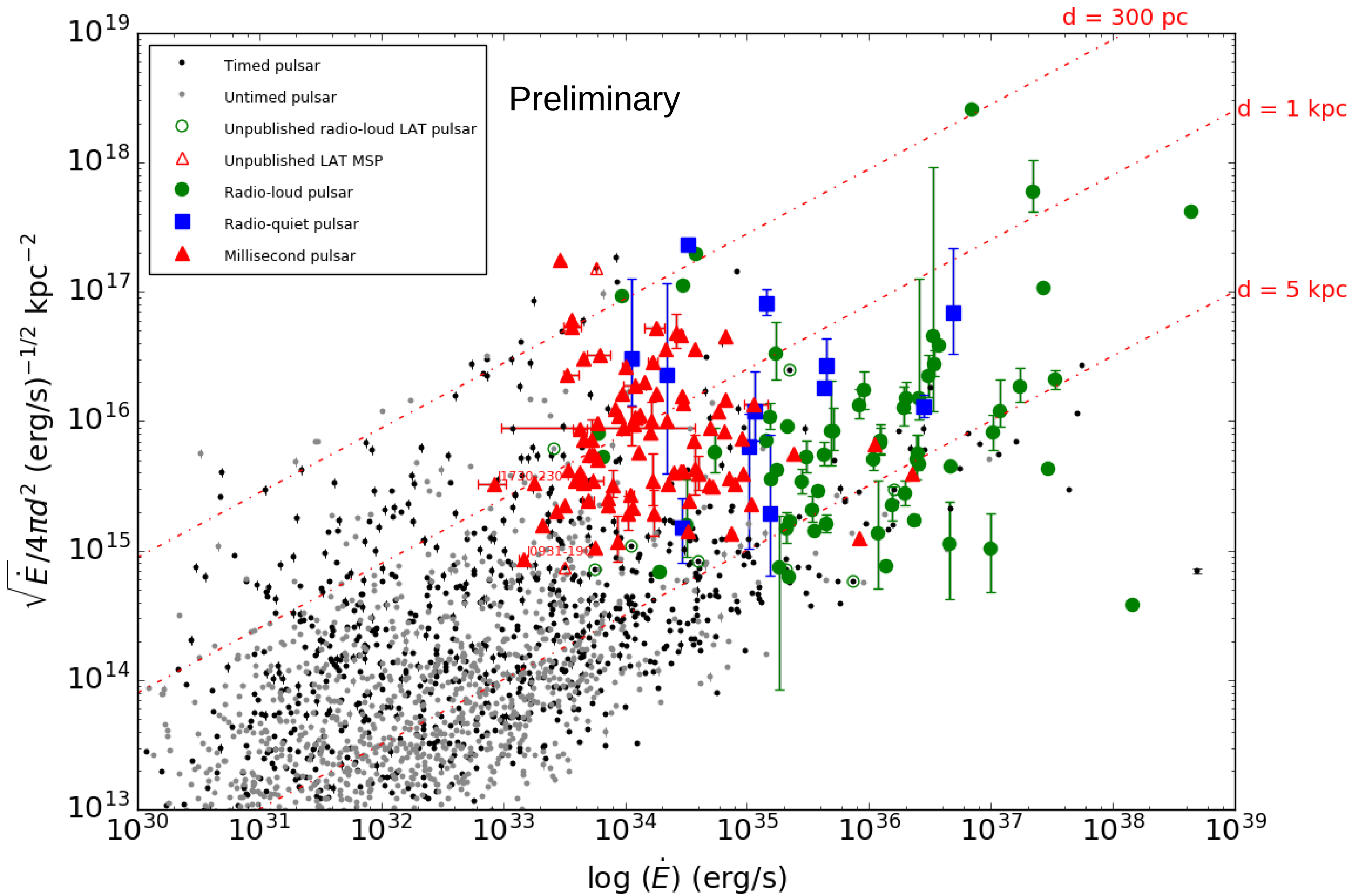


Pulsar numbers from ATNF database (Manchester et al).

Pulsars folded using ephemerides provided mainly by Parkes (Johnston & Kerr), Jodrell Bank (Stappers, Lyne, Weltevrede, Espinoza) and Nançay (Cognard & Guillemot) radio observatories.

Update of figure in Laffon, Smith, & Guillemot, 5th Fermi Symposium, arXiv:1502.03251

The observed deathline: _not_ due to distance selection.



Few pulsar models predict a spindown power* cut-off for gamma emission.

The Astrophysical Journal, 736:127 (8pp), 2011 August 1

DEATH LINE OF GAMMA-RAY PULSARS WITH OUTER GAPS

Ren-Bo Wang[1,3] and Kouichi Hirotani[2,4]

Here: we confirmed a minimum for MSPs near $\dot{E}$=1.E33 erg/s

A&A 587, A109 (2016)
DOI: 10.1051/0004-6361/201527847

Astronomy & Astrophysics

The gamma-ray millisecond pulsar deathline, revisited

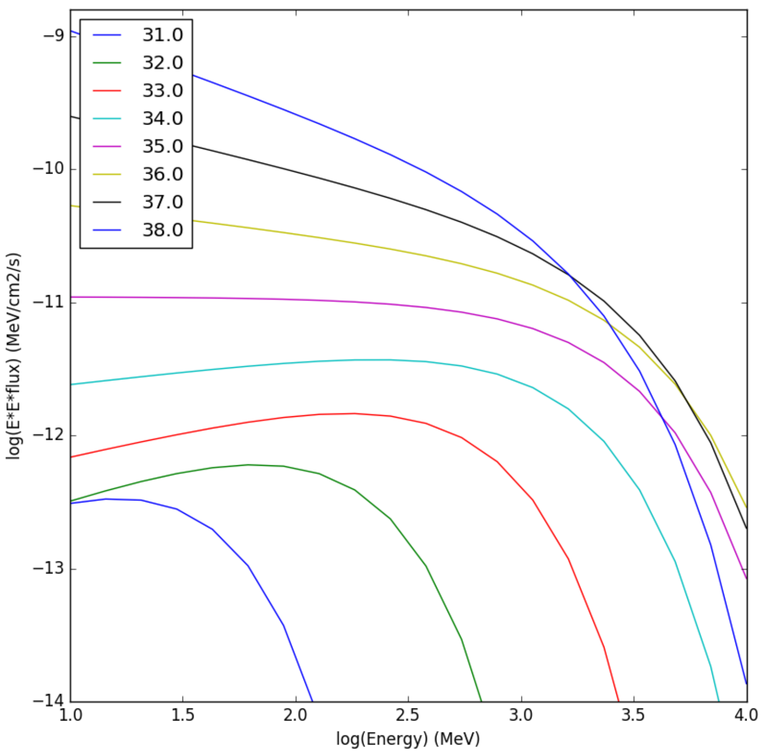
New velocity and distance measurements

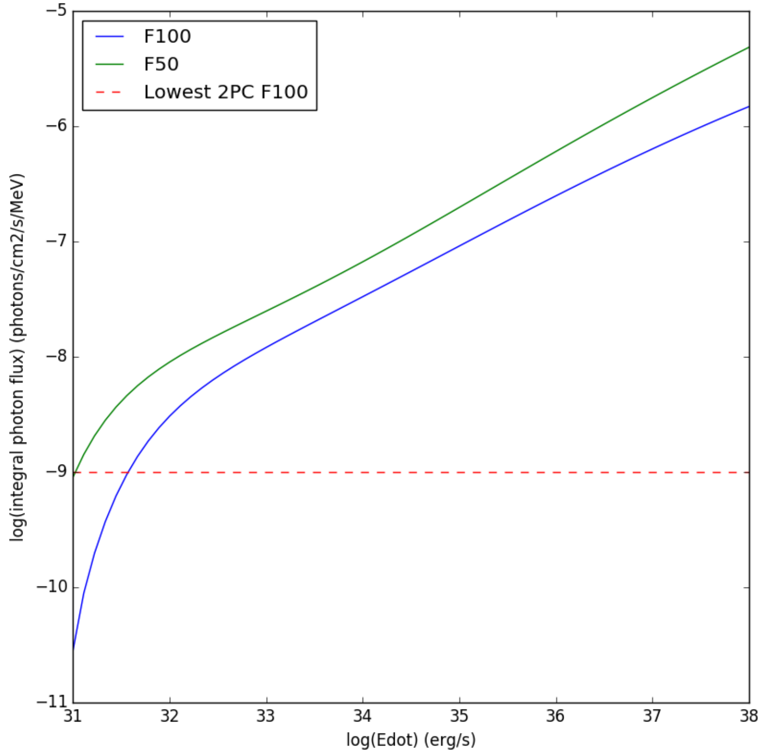
L. Guillemot[1,2], D. A. Smith[3], H. Laffon[3], G. H. Janssen[4], I. Cognard[1,2], G. Theureau[1,2], G. Desvignes[5], E. C. Ferrara[6], and P. S. Ray[7]

*or other combination of $P^{\alpha}\dot{P}^{\beta}$.

Some theorists:

emission would shift from GeV to MeV range with decreasing Ė.





Left:

SEDs vs spindown power Ė, taking 2PC Γ, E_{cut}, $\mathcal{L}$ at face value.

(ooops! $\mathcal{L}$ > Ė below 10^{33} erg/s.)

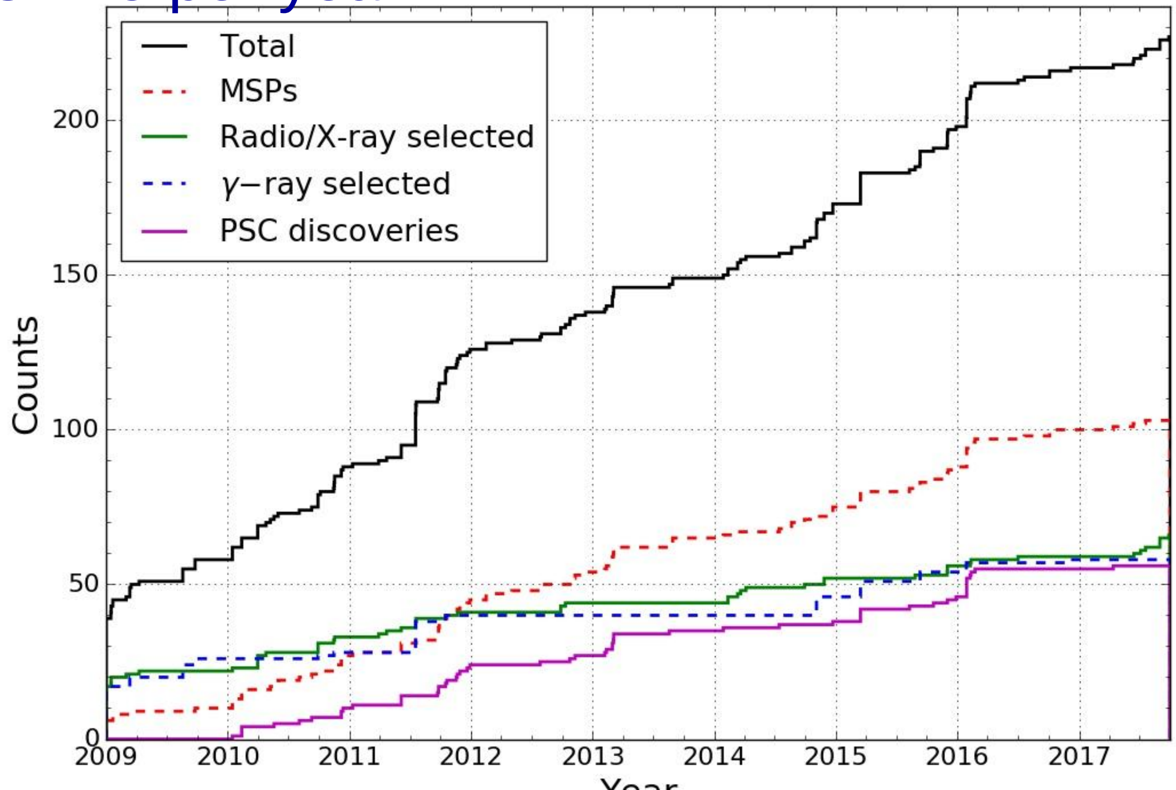
Right:

Integral photon flux for those SEDs.

Conclusions

- A broad variety of high-power gamma-ray pulsars, with central roles in a range of topics.
- *Fermi* LAT still detects ~25 per year.

3PC
coming Summer 2018



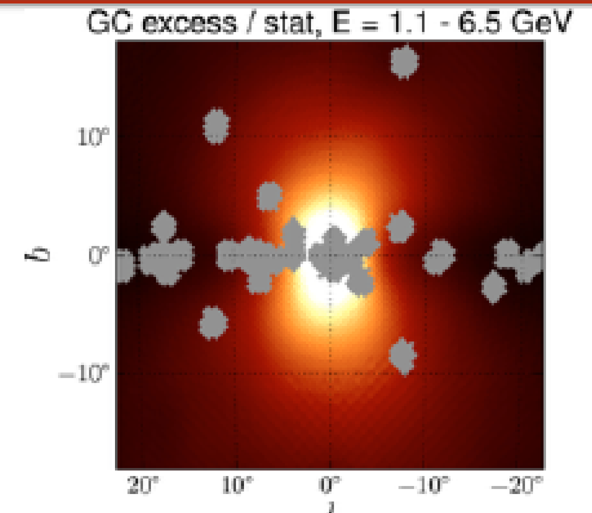
Some excellent reviews:

γ-ray Pulsar Revolution, P. Caraveo, Annual Review of Astronomy and Astrophysics 52, 2014.
γ-ray Pulsars: a Gold Mine, I. Grenier & A.K. Harding, Compte rendus Physique 16, 2015
The Soft γ-ray Pulsar Population: a High-Energy Overview, L. Kuiper & W. Hermsen, MNRAS 449, 2015
γ-ray Pulsars with *Fermi*, D.A. Smith et al., arXiv:1706.03592

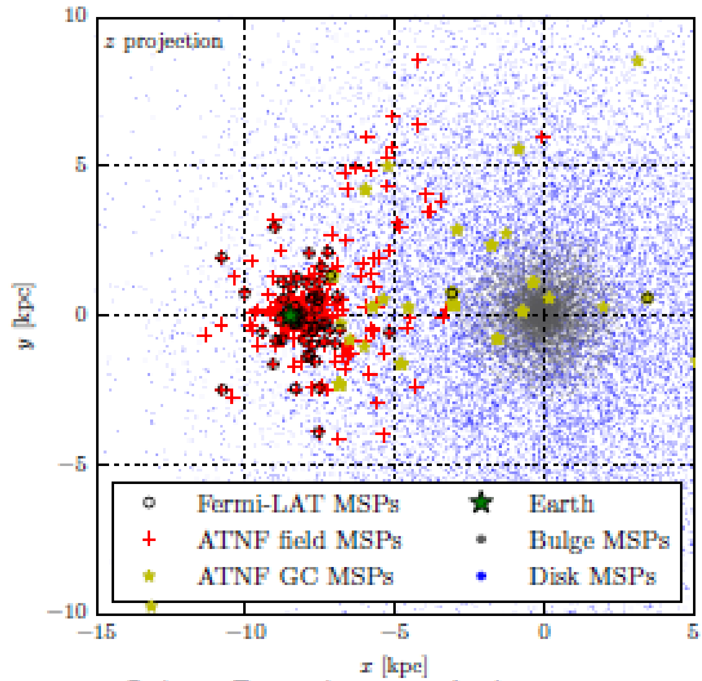
Backups

MSPs in the Inner Galaxy

- GeV excess towards the Galactic Centre consistent with a population of point sources — MSPs?
- Comparing GC gamma-ray luminosity to stacked globular clusters suggests a bulge population with 1000s of radio-loud MSPs
  Calore, F., et al., 2016, ApJ, 827, 143
- Detected gamma-ray point sources towards GC have pulsar-like spectra and luminosity function
  The Fermi-LAT Collaboration, 2017, ApJ, submitted
- Current L-band surveys only scratching the surface, MeerKAT and SKA may find hundreds of bulge MSPs



Ackermann, M., et al., 2017 ApJ, 840, 43



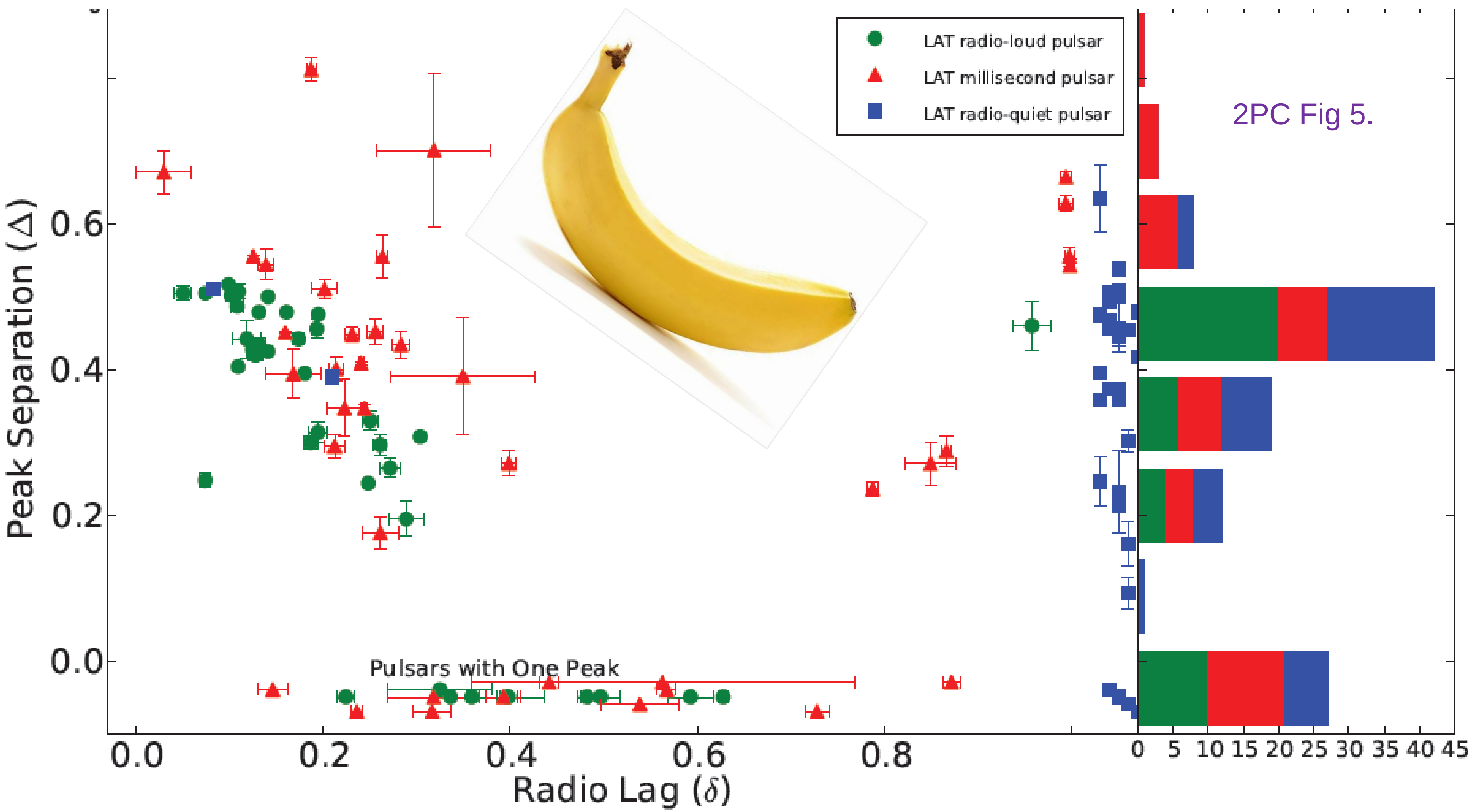
Calore, F., et al., 2016, ApJ, 827, 143

Radio-loud γ pulsars: closer peaks ➔ bigger offset from radio.

Insight into banana *shape* & *location*.

Current trend in pulsar models:

Gamma-ray emission may come from beyond the light cylinder.

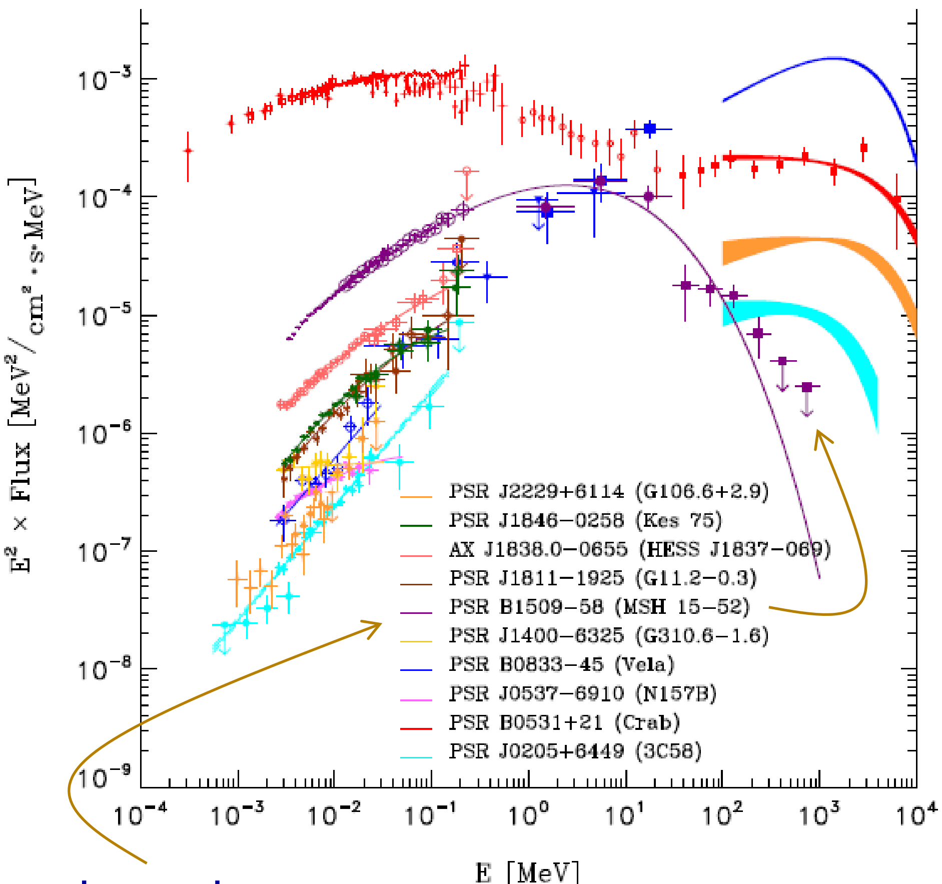


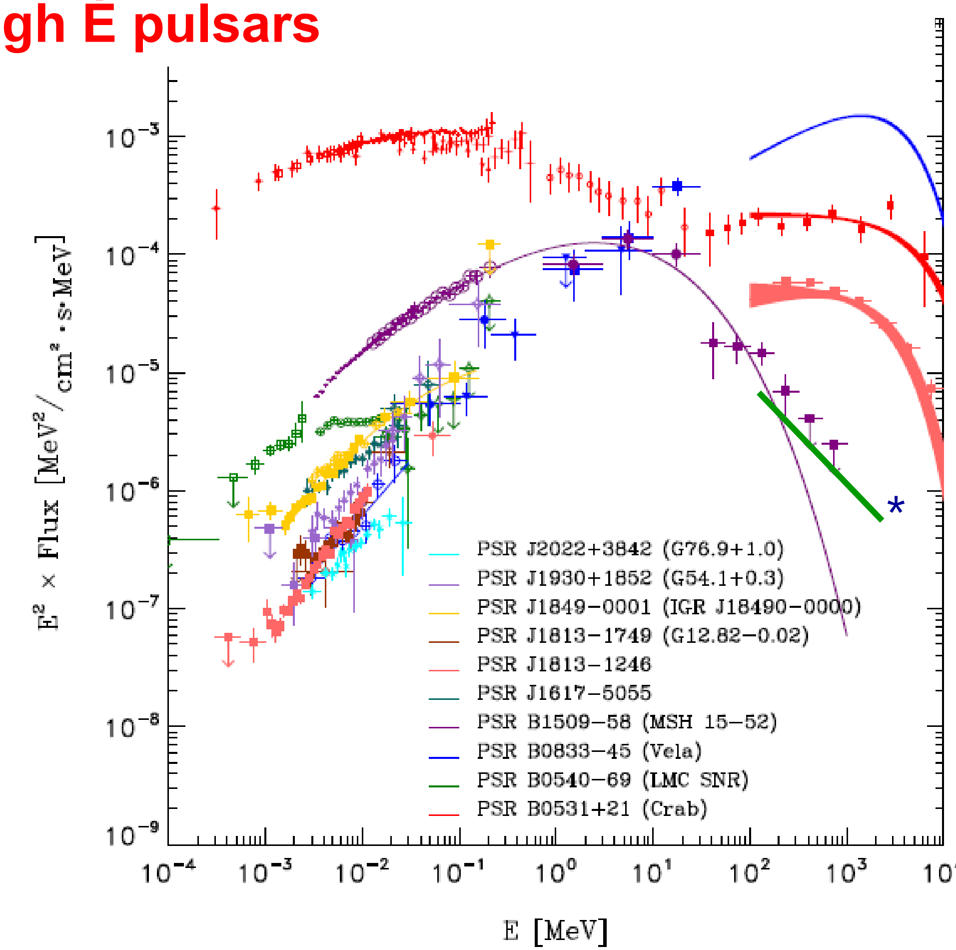
18 pulsars seen at 20 keV < E_γ < 30 MeV

only half are seen in Fermi LAT

due in part to the spectral peak in the MeV range

These are high Ė pulsars





the archetype
low cutoff γ pulsar

The soft γ-ray pulsar population: a high-energy overview

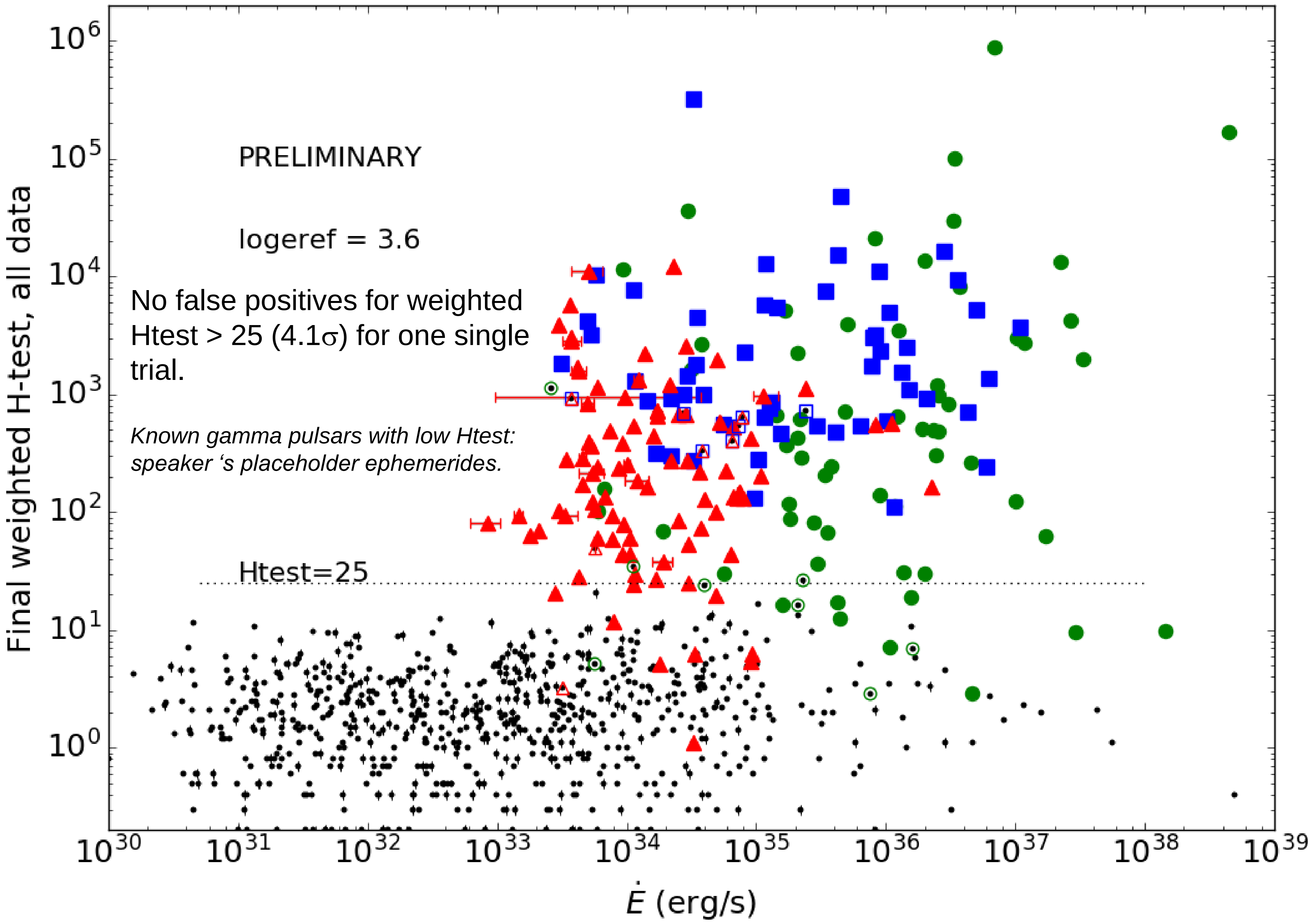
MNRAS **449**, 3827–3866 (2015)

L. Kuiper[1★] and W. Hermsen[1,2]

* B0540-69, Ackermann et al, *Science* 2015

Htest > 25 (4 σ) never happens (if Ntrials ≤ 3).

This has yielded ~10 new gamma-faint radio pulsars.



Nota bene #1:

The EM radiation of frequency F0≡ $\Omega/2\pi$ (thus, <1kHz) transfers its power to the electrons in the magnetosphere ("*pulsar wind*") within a few wavelengths, i.e. before the light cylinder.

The MHz and GHz radio signals are emitted by the electrons.

Nota bene #2:

From this contradiction, *we conclude that a rotating magnetic neutron star cannot be surrounded by a vacuum.*

Goldreich & Julien, ApJ (1969)

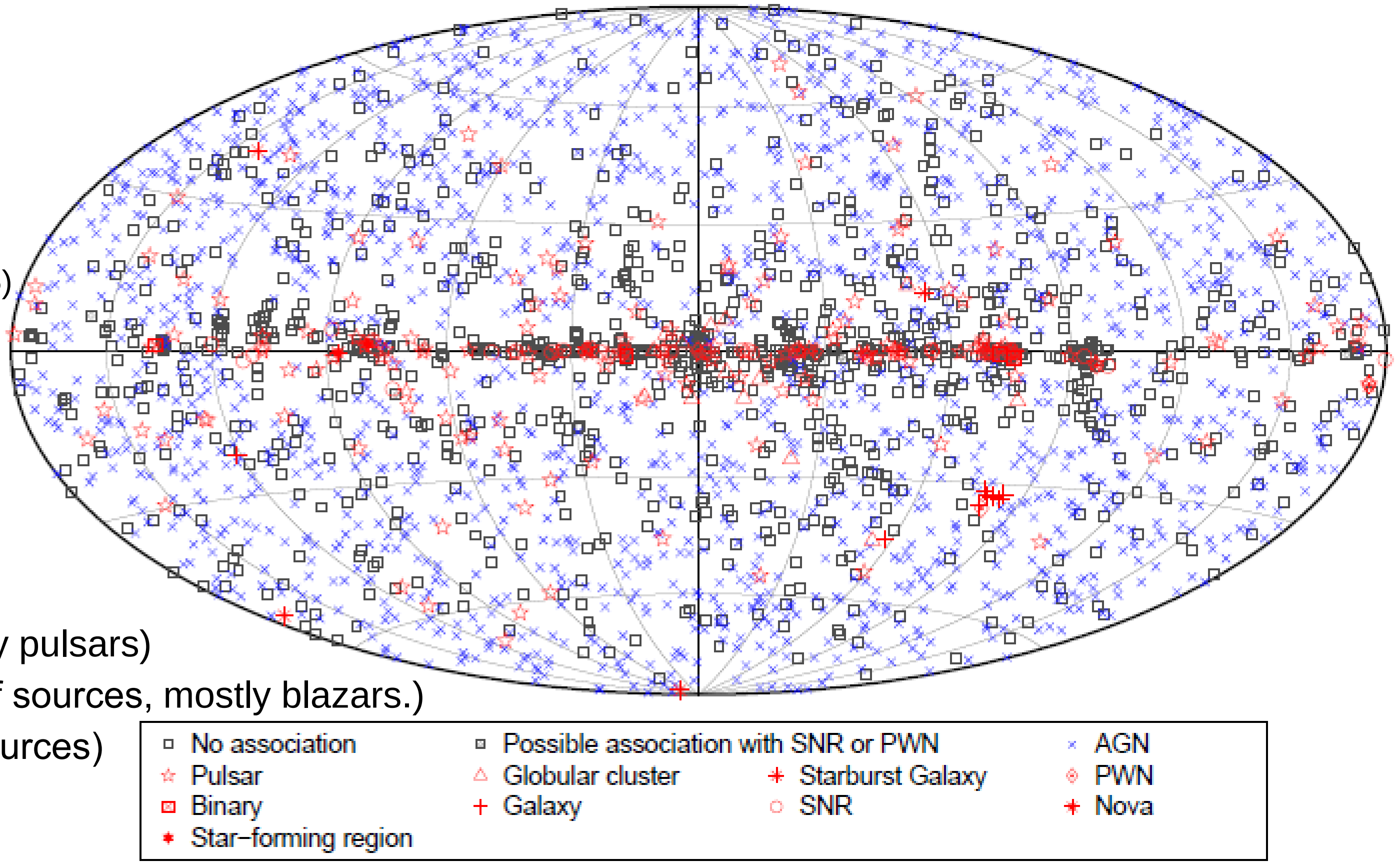
The huge electric fields suck electrons out of the neutron star's iron crust.

3FGL

3rd LAT source catalog

Acero et al. ApJS 218, 23 (2015)

http://arxiv.org/abs/1501.02003



3033 total sources (>4σ)

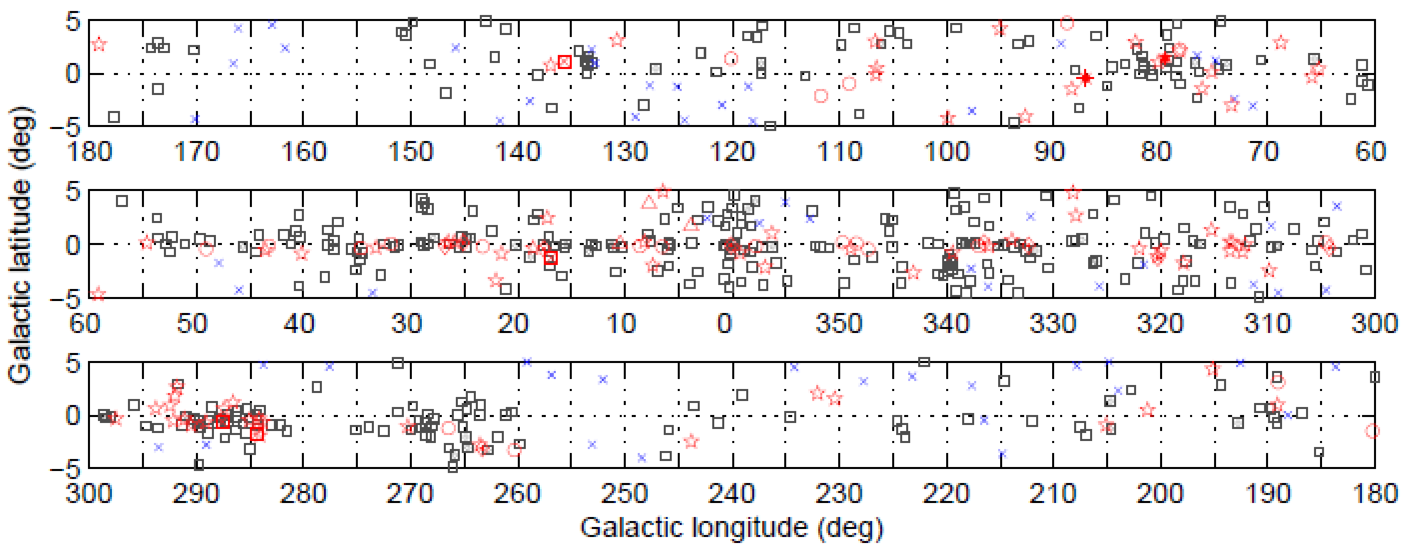
Red: Firm I.D. (232, mostly pulsars)

Blue: 'Association' (> ⅓ of sources, mostly blazars.)

Black: No I.D. (< ~⅓ of sources)

Un Id's == *Gold* mine!

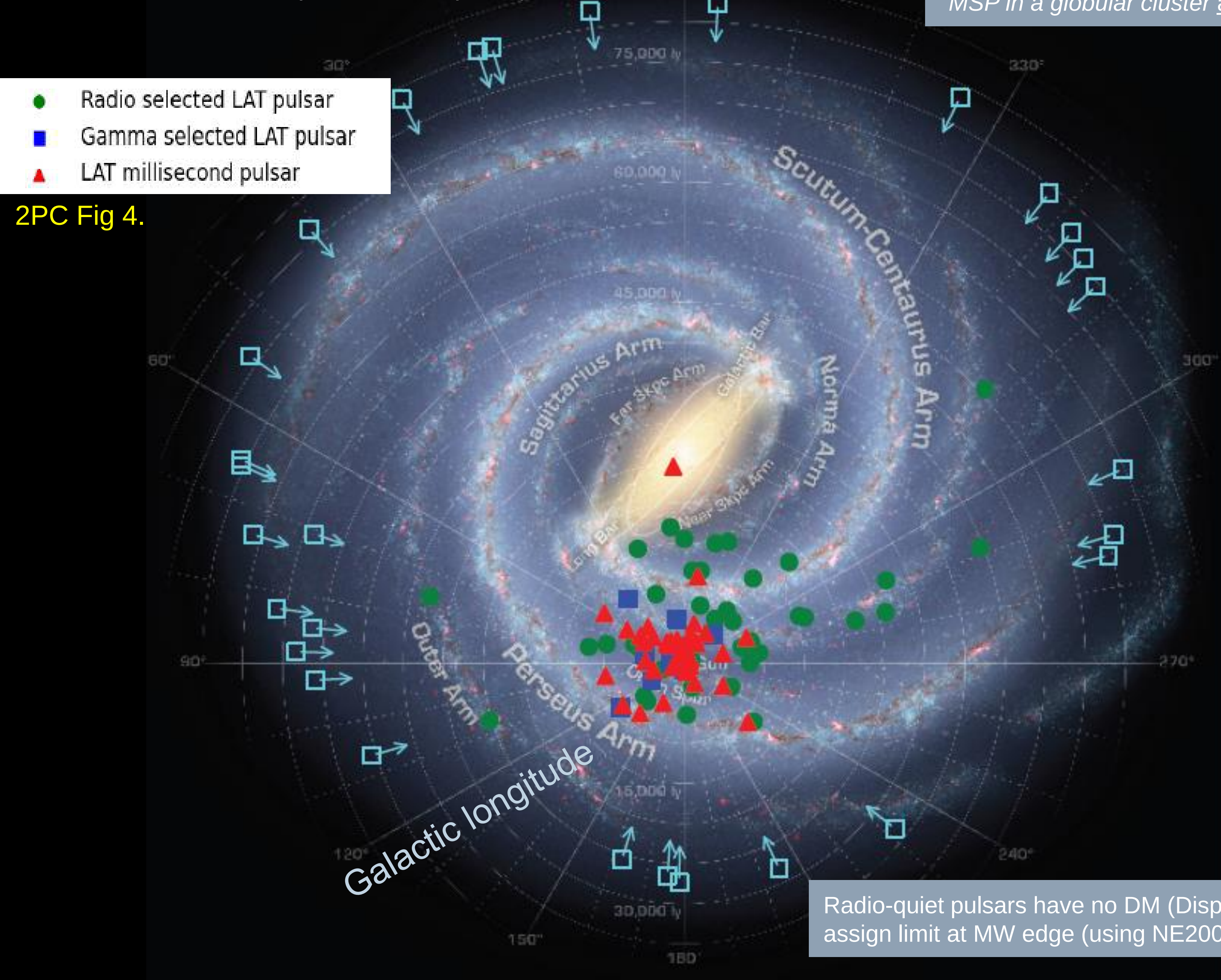
4FGL next year.
>5000 sources.



``Anatomically correct'' Milky Way.

Reid et al, ApJ 700, 137 (2009)

<u>Not</u> an MSP in the Galactic center.
MSP in a globular cluster <u>above</u> the center.



2PC Fig 4.

Radio-quiet pulsars have no DM (Dispersion Measure): assign limit at MW edge (using NE2001).

The rest of this talk:

Some recent discoveries

- State changes in gamma-ray pulsars
  - ➢ PSR J2021+4026 in Cygnus: sudden decrease in γ flux and spindown rate.

    Allafort et al ApJ (2013)
  - ➢ MSP J1023+0038: sudden γ flux increase when radio signal vanished.
  - ➢ e.g. 3FGL J1544.6-1125 should also be a transitional MSP

    ‘ tMSPs’ -- See yesterday’s talks by A. Patruno & A. Jaodand
  - ➢PSR J1119-6127 turns magnetar-like

    Archibald et al, ApJ Lett (2016)
    Göğüş et al, ApJ Lett (2016)

    See next talk by E. Göğüş
  - ➢ PSR B0540-69 in the LMC is intermittent, with a tiny braking index

    Marshall et al, ApJ Lett (2016)
- Einstein@Home finds many radio-quiet pulsars

  Clark et al, ApJ resubmitted
- Radio eclipses in presumably gamma MSPs

  Cromartie et al, ApJ (2016)
  Deneva et al, ApJ (2016)

The most luminous γ-ray pulsar
is
extragalactic, intermittent, and has a tiny braking index

Its breaking index went from n=2.13 to 0.031

- *Not* a linear combination of wind & dipole.

- Infall disk? Magnetic torque? Propellor?
  - Yes, you can find values of $\dot{M}$ etc that give ¾ of your observables, but no, not *naturally*…

Chen & Li, MNRAS 2015, arXiv:1511.03111
Menou, Perna, & Hernquist (2001)

- Simplest (?) explanation:

The neutron star B-field is 'unburying' itself. Since a jump in late 2011, the B-field is emerging more quickly.

3859 year time scale switched to 831 years,
as per time derivative of dipole braking in Lyne et al (2015).

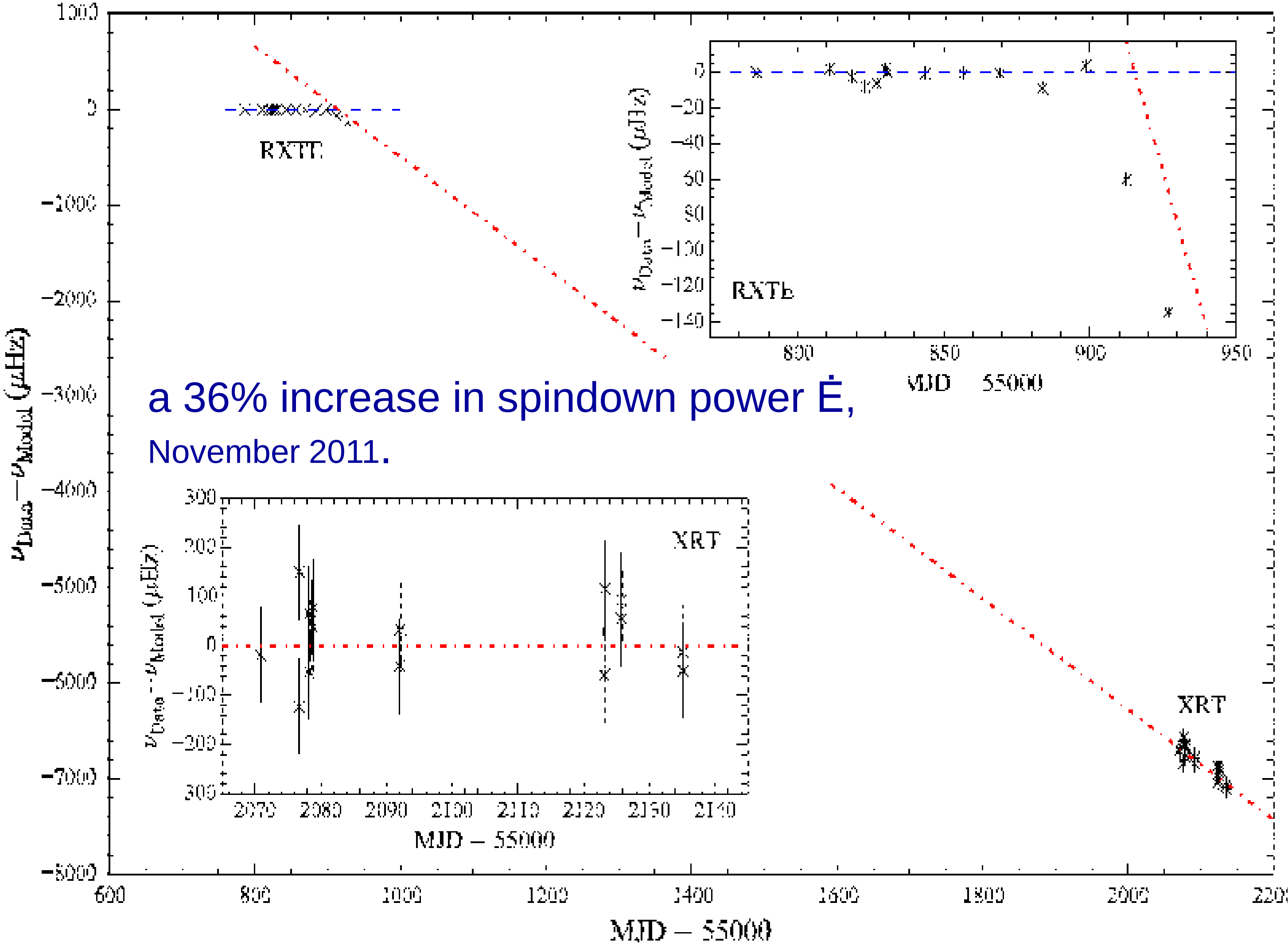
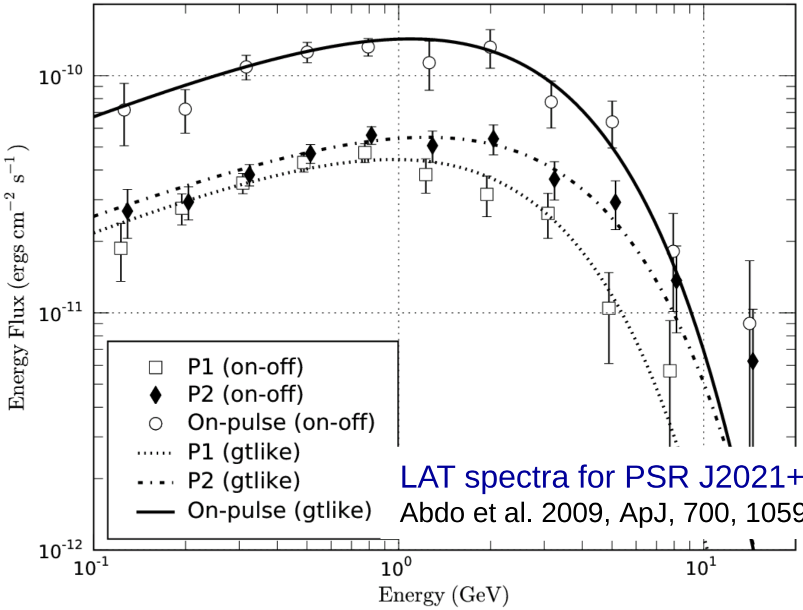


Figure 1. The frequency residuals for the *RXTE* and *XRT* observations relative to the ephemeris model (the dark blue dashed line) determined with the *RXTE* observations before the state transition. The dashed–dotted red line shows the best-fit ephemeris for the *XRT* data. 1σ uncertainties are shown, but they are smaller than the symbols for the *RXTE* data.

Of the ~5700 sources in a current pre-4FGL list, pick
stable, cut-off unidentified targets.

e.g. *Ranking LAT sources with Machine Learning*, Saz Parkinson et al, ApJ 820:8 (2016)



LAT spectra for PSR J2021+3651
Abdo et al. 2009, ApJ, 700, 1059

$$\frac{dN}{dE} = N_0 E^{-\Gamma} \exp\left(-\frac{E}{E_0}\right)^b \mathrm{cm}^{-2}\mathrm{s}^{-1}\mathrm{GeV}^{-1}$$

➔ b=1 ➔ high altitude curvature radiation.

(strong magnetic fields near surface "absorb" gammas.)

Pulsar spectral 'signature'

Most gamma spectra (=blazars) extend to high energy. And blazars flare, pulsars mostly don't.

New – Match UnId gamma sources to UnId steep spectrum radio sources.

Pulsar candidates towards *Fermi* unassociated sources
MNRAS 461, 1062 (2016)

KNOWN PULSARS IDENTIFIED IN THE GMRT 150 MHz ALL-SKY SURVEY
ApJ 829:119 (2016)

D. A. Frail[1], P. Jagannathan[1,2], K. P. Mooley[3,5], and H. T. Intema[1,4]

Next problem: computation time

The young pulsars have large timing noise ➔ many parameters.

Isolated millisecond pulsars require very small parameter steps.

Tight binary MSPs need both many steps and many parameters.

Solutions:

- Re-purpose gravity wave search methodology for period searches.
- Enlist the computers of citizen scientists.

OPTIMIZED BLIND GAMMA-RAY PULSAR SEARCHES AT FIXED COMPUTING BUDGET

HOLGER J. PLETSCH[1,2] AND COLIN J. CLARK[1,2]   ApJ 795:75 (2014)

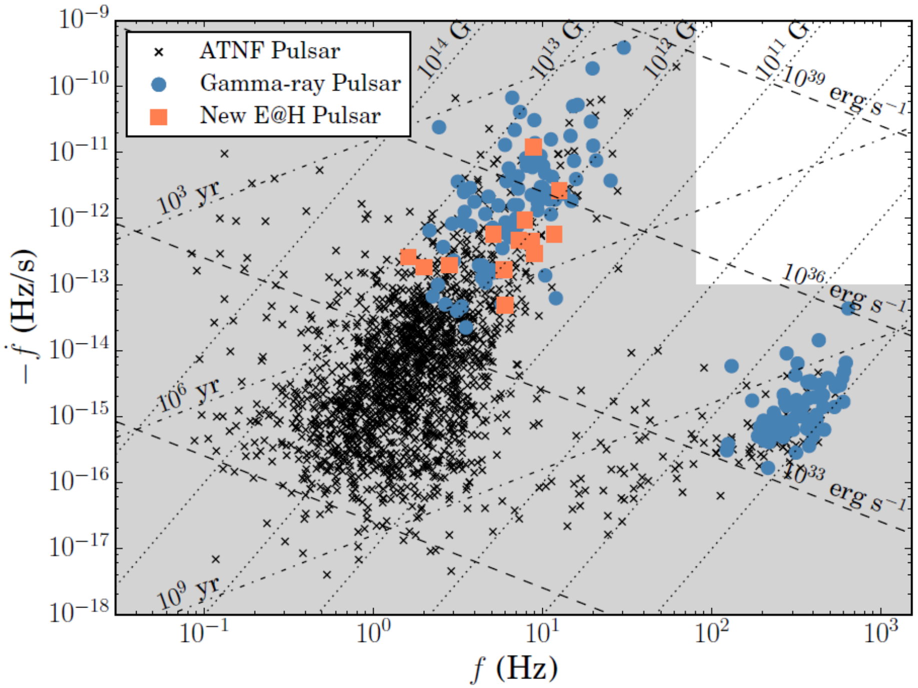
THE EINSTEIN@HOME GAMMA-RAY PULSAR SURVEY I:
SEARCH METHODS, SENSITIVITY AND DISCOVERY OF NEW YOUNG GAMMA-RAY PULSARS

Clark et al, ApJ (in press)

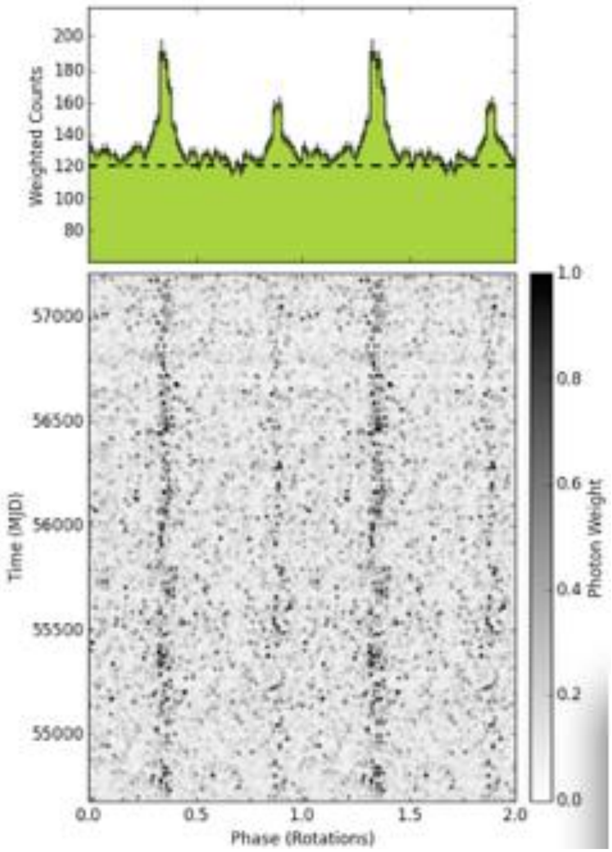
E@H = Einstein @ Home

~10,000 CPU years!
17 detections (so far) in 118 targets.

One (PSR J1208-6238) has the 2nd highest known surface B-field, with an accurate braking index (n=2.598).

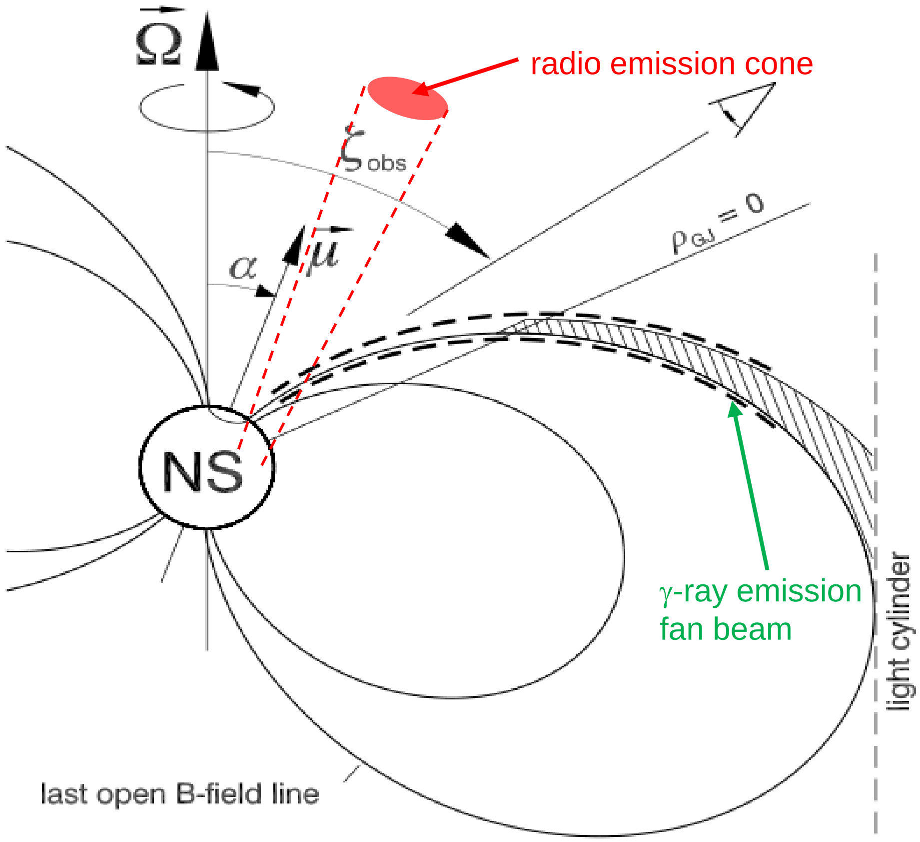


Clark et al, in prep



Currently:
Binary MSP search in progress,
using orbital constraints from optical companions.

Are they really radio-quiet?



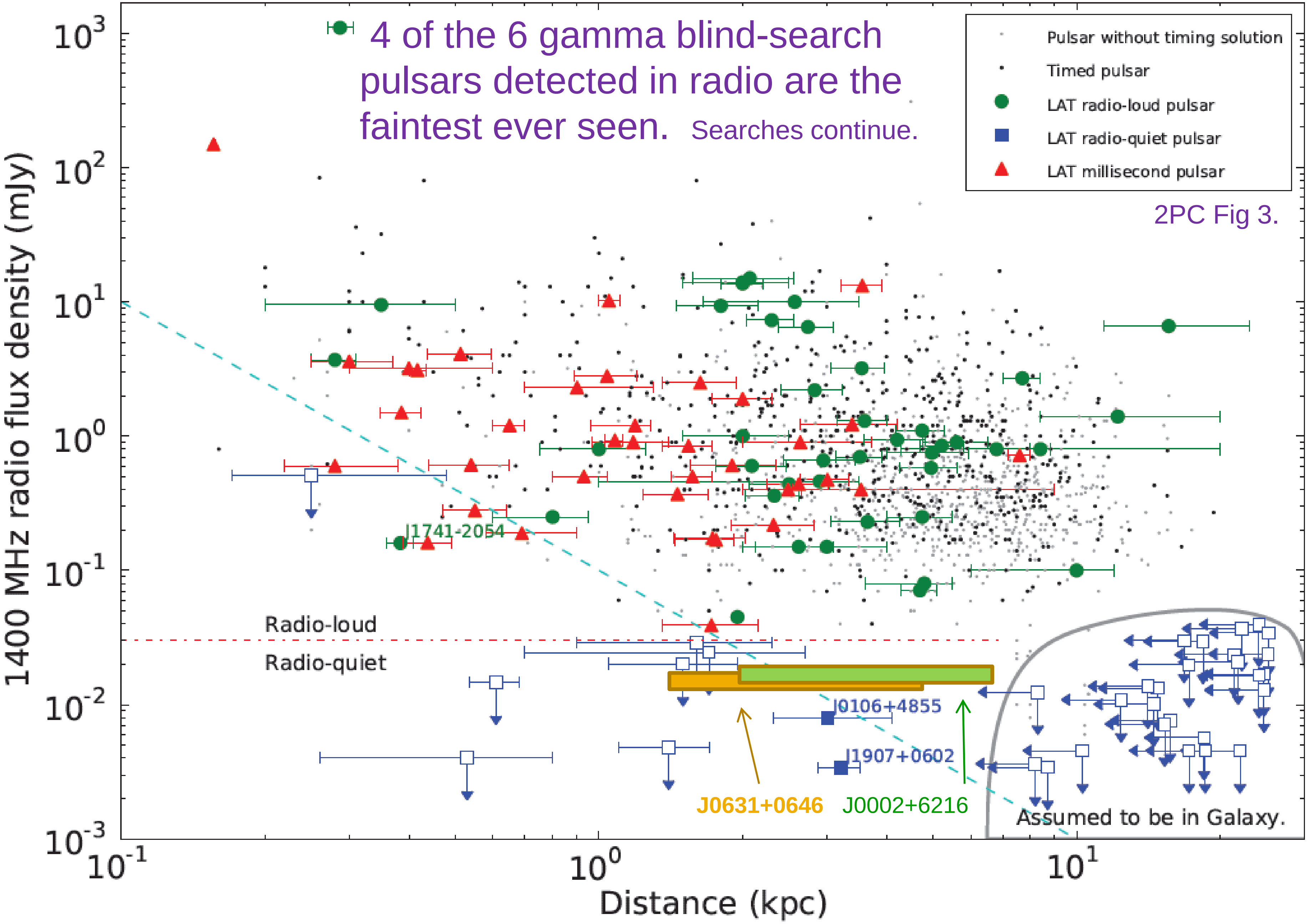
Radio pulsars have a limited range of magnetic (α) and overall (ζ) inclinations: the radio beam must sweep the Earth.

LAT shows, γ-ray beams are mostly *wide*: Many young, **radio-quiet** pulsars.

MSPs have a smaller light-cylinder. The magnetic field lines are cut close in, making broader radio beams.

No radio-quiet MSPs yet. Expect few or none.

Before *Fermi*, 'Geminga' was the only radio-quiet pulsar.



Diagonal : 100 µJy-kpc² pseudo-luminosity.

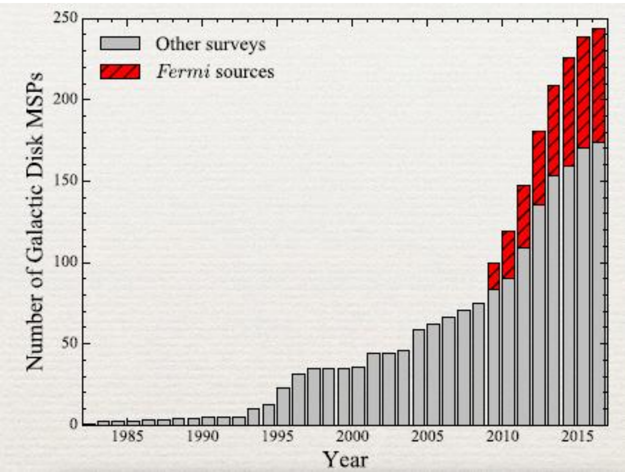
Similar problem: targets for deep radio searches

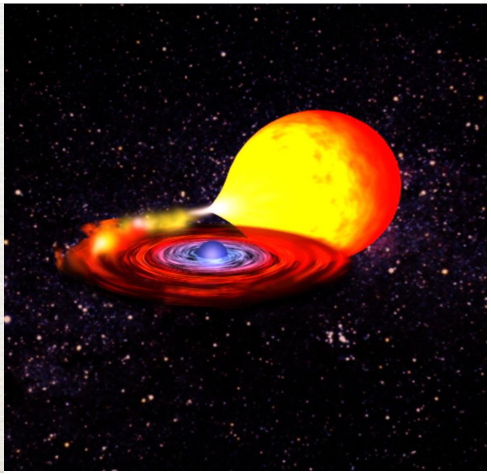
- Of 75 pulsars found near gamma UnId positions, 70 are MSPs.
- *Different* from MSPs found in radio surveys:
  - faster
  - the pulsar wind often ablating (eating) the companion star

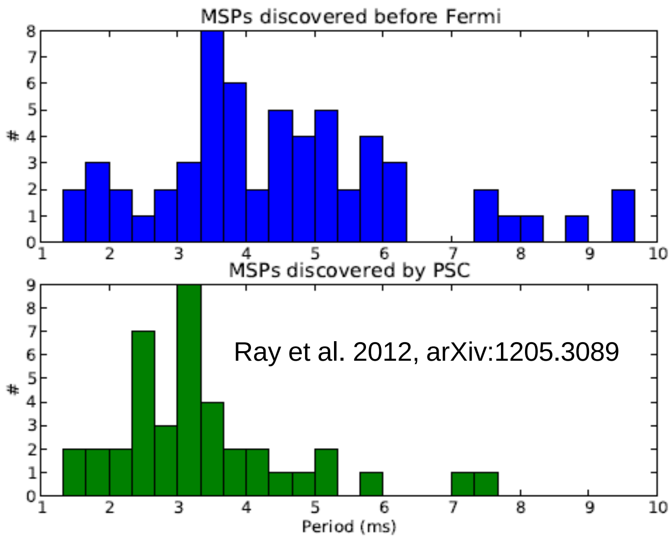
Black-widow and redback "spiders".

Most pre-Fermi spiders in globulars .

Now 24 BWs, 12 RBs outside globulars.







Recent radio MSP discoveries in Fermi sources

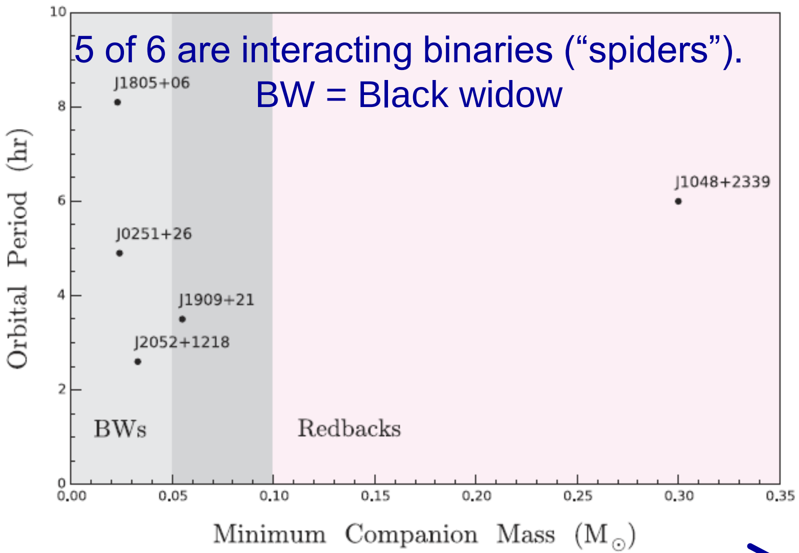
SIX NEW MILLISECOND PULSARS FROM ARECIBO SEARCHES OF *FERMI* GAMMA-RAY SOURCES

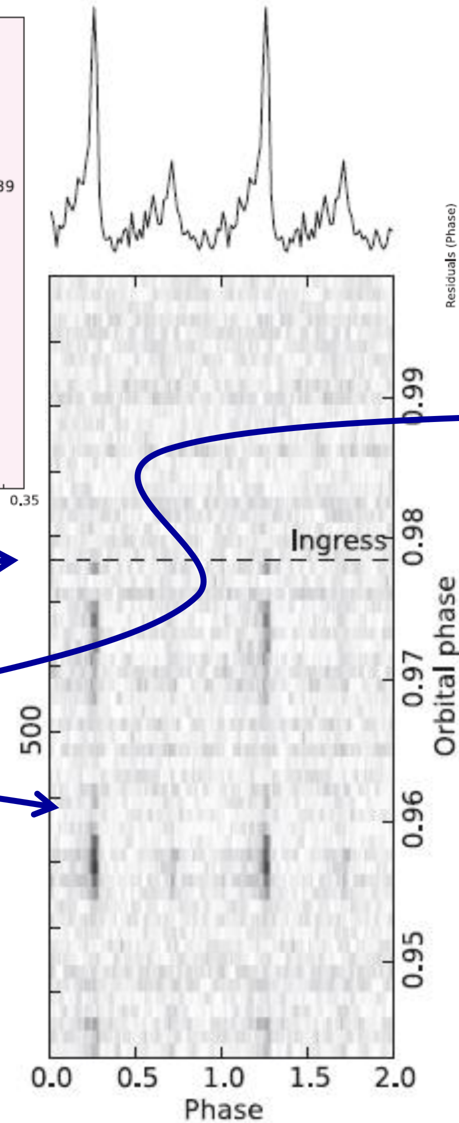
Cromartie et al ApJ (2016)

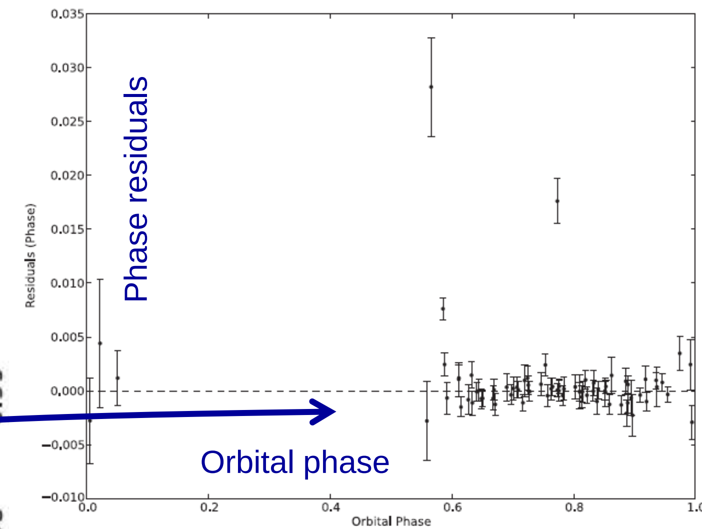
MULTIWAVELENGTH OBSERVATIONS OF THE REDBACK MILLISECOND PULSAR J1048+2339

Deneva et al ApJ (2016)

5 of 6 are interacting binaries (“spiders”).
BW = Black widow







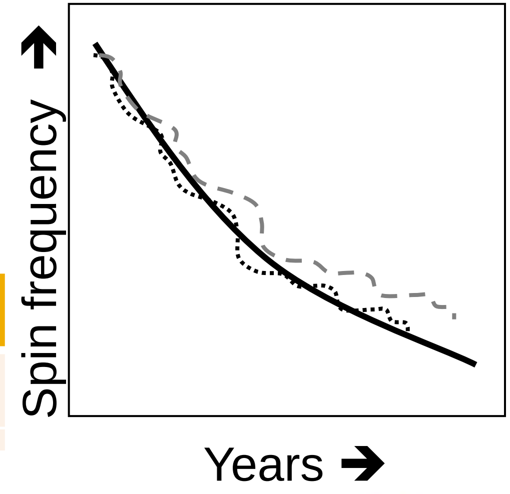
J1048+2339:
Spectacular radio, optical eclipses.

(*scintillation*)

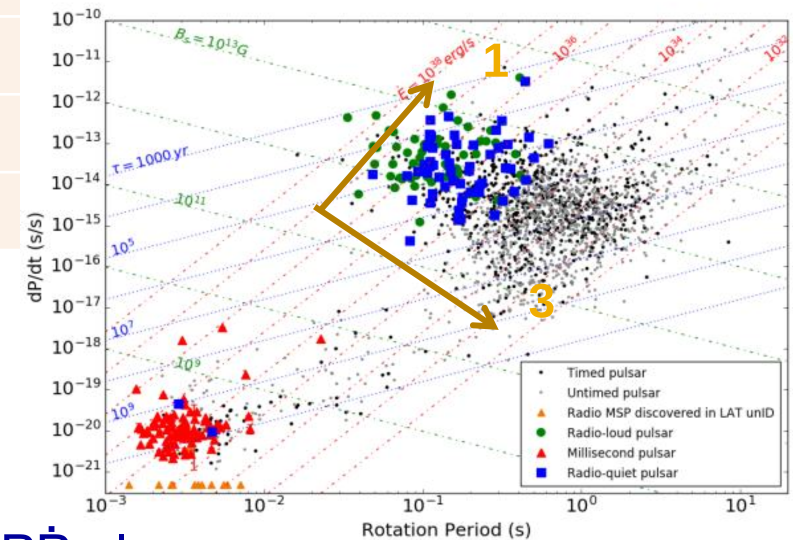
Dispersion Measure (DM) probes the wind .

Pulsar Braking Indices

Torque τ = I Ωdot = kΩ^n ➔ $n = \ddot{\nu}\nu\dot{\nu}^{-2}$



Mechanism	n
Gravitational quadropole	5
Magnetic dipole	3
Wind	1 Michel & Tucker 1975
Infall disk propeller	0
Infall disk magnetic torque	-1



- Measured n ~never 3 (mostly 1's & 2's).
- Linear combinations ?
- Slowly changing B, α, I ?

(Blandford & Romani 1988, Lyne et al 2015)

- (2-n) slope is evolution direction in the P$\dot{\text{P}}$ plane.

n<3 means characteristic age decreases, "B" increases.

(See Espinoza et al 2011)

$$\dot{\Omega} = \frac{\dot{J}}{I} = -\frac{|\Phi|^2 \sin^2\theta \, a^2 \, \Omega^3}{6\pi^2 I c^3}$$

Dipole radiation, Gunn & Ostriker (1969)

PSR B0540-69 in the Large Magellanic Cloud

$\dot{E}$=1.5e38 erg/s (3rd highest known) @ 50 kpc

1. Science 350, 801 (2015) **An extremely bright gamma-ray pulsar in the Large Magellanic Cloud**

   The Fermi LAT Collaboration*†

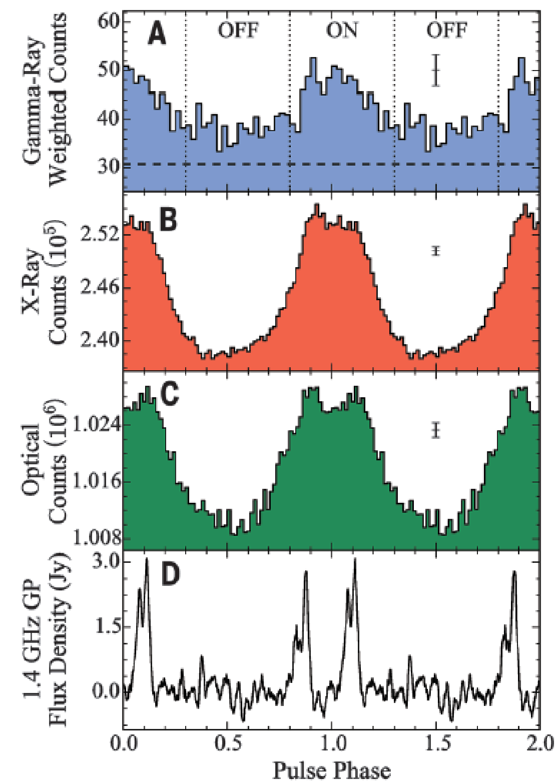


Fig. 2. Pulse profiles for PSR J0540–6919.

2. A&A 568, 71 (2016)

   A deep view of the Large Magellanic Cloud with 6 years of *Fermi*-LAT observations

3. Ap J Lett 807, 27 (2015)

   Sudden 36% increase in $\dot{E}$

   DISCOVERY OF A SPIN-DOWN STATE CHANGE IN THE LMC PULSAR B0540-69

   F. E. MARSHALL[1], L. GUILLEMOT[2,3], A. K. HARDING[1], P. MARTIN[4], AND D. A. SMITH[5]

The most luminous γ-ray pulsar is extragalactic, intermittent, and has a tiny braking index

Ap J Letters 827, 39 (2016)
arXiv:1608.01901

A NEW, LOW BRAKING INDEX FOR THE LMC PULSAR B0540−69

F. E. Marshall[1], L. Guillemot[2,3], A. K. Harding[1], P. Martin[4], D. A. Smith[5],

Draft version August 1, 2016

ABSTRACT

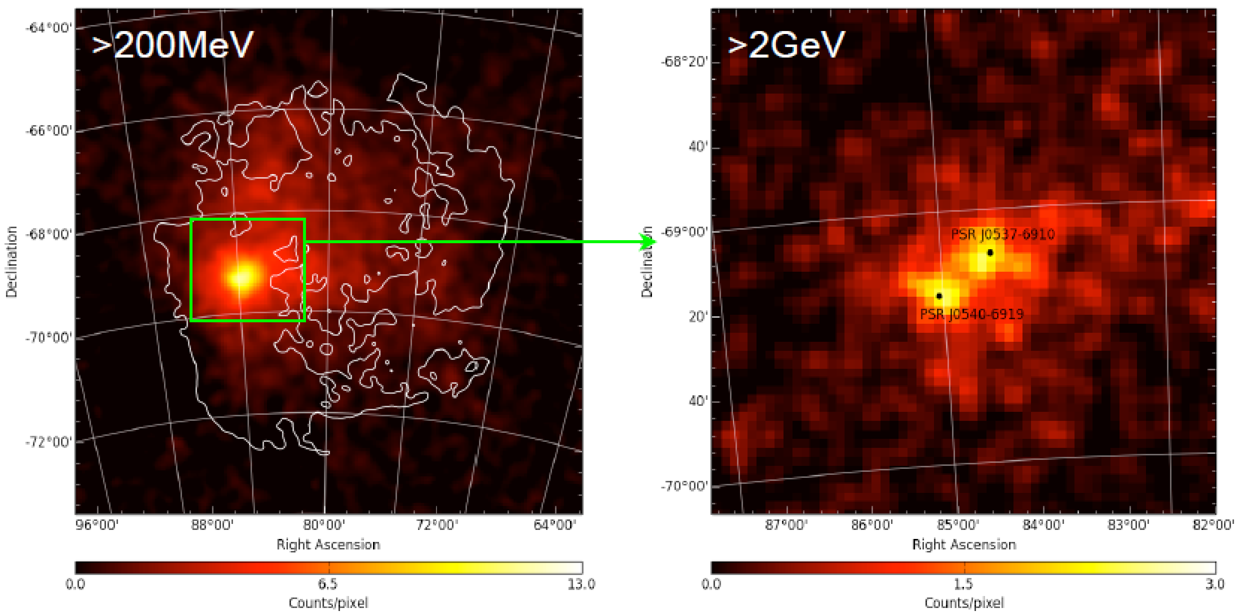
We report the results of a 16-month monitoring campaign using the *Swift* satellite of PSR B0540−69, a young pulsar in the Large Magellanic Cloud. Phase connection was maintained throughout the campaign so that a reliable ephemeris could be determined, and the length of the campaign is adequate to accurately determine the spin frequency ν and its first and second derivatives. The braking index n is 0.031 ± 0.013 (90% confidence), a value much lower than previously reported for B0540−69 and almost all other young pulsars. We use data from the extensive monitoring campaign with *RXTE* to show that timing noise is unlikely to significantly affect the measurement. This is the first measurement of the braking index in the pulsar's recently discovered high spin-down state. We discuss possible mechanisms for producing the low braking index.

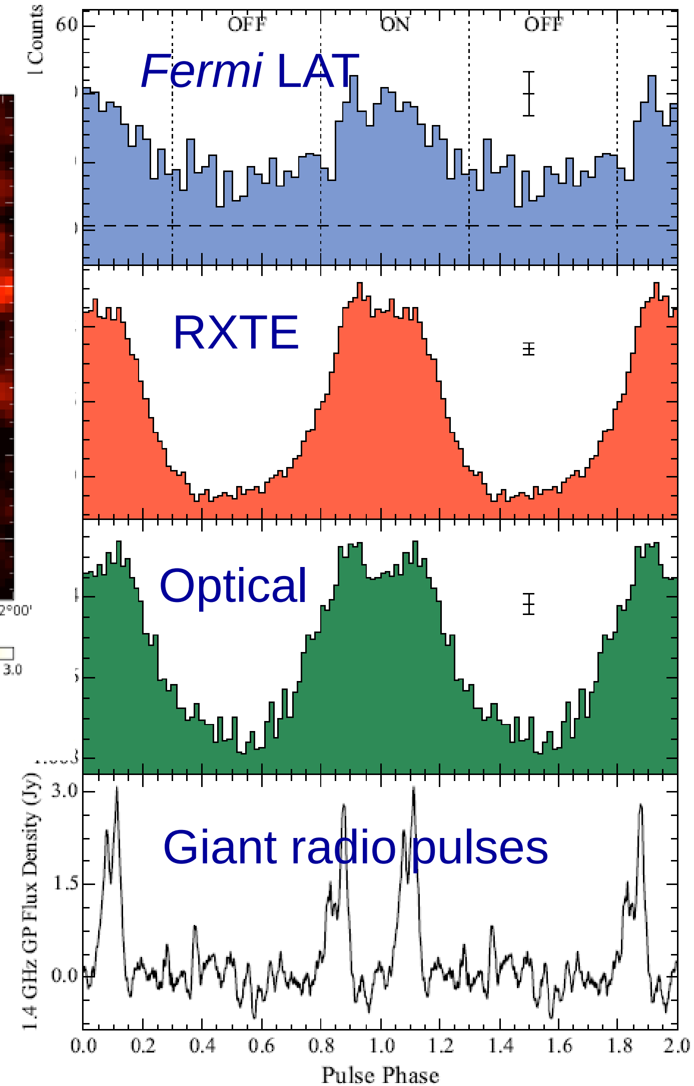
Subject headings: pulsars: individual (PSR B0540−69)

Repeat the early LAT spatial/spectral analysis of 30 Dor in the Large Magellanic Cloud, to study diffuse emission.

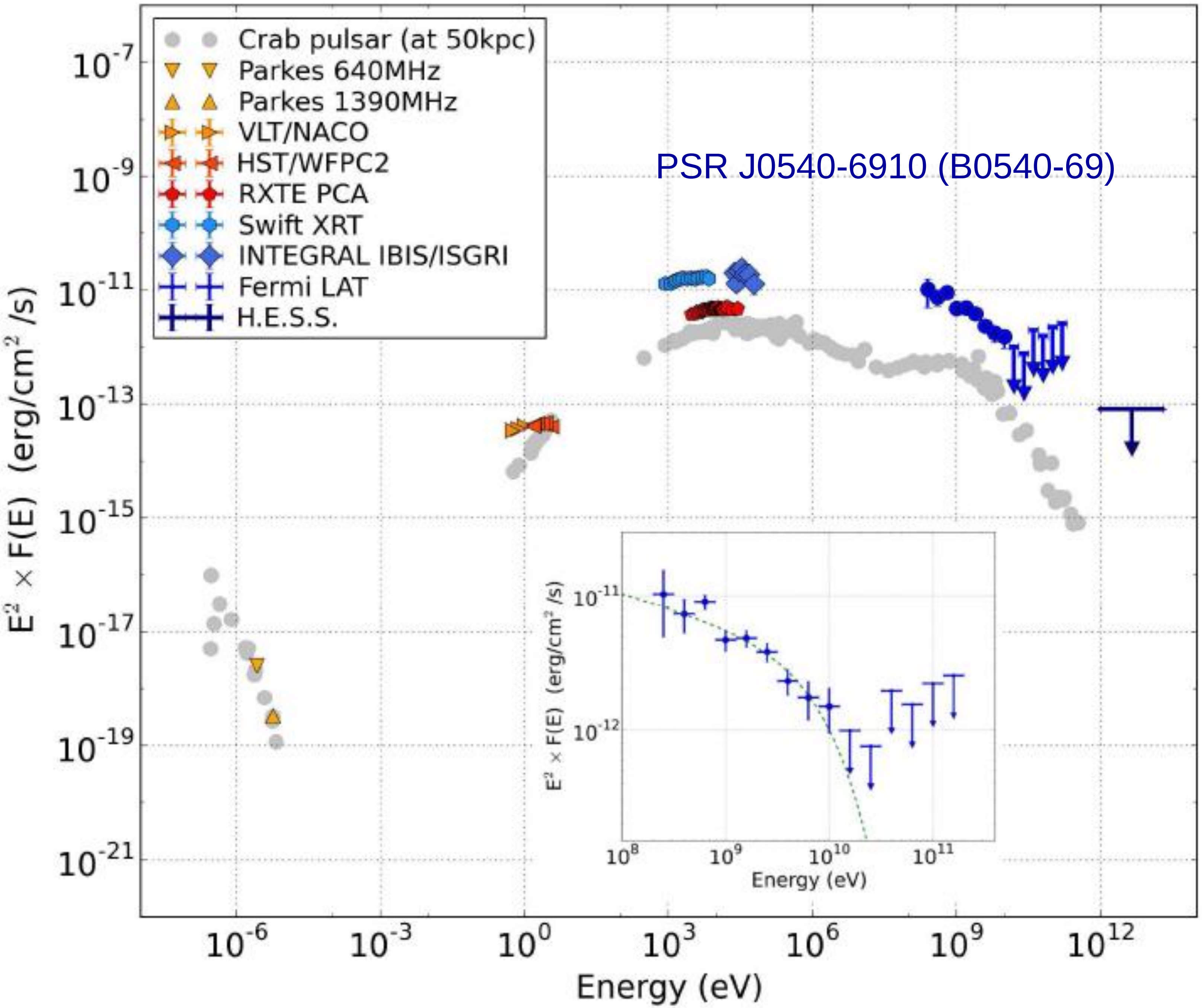
Pierrick Martin et al, A&A in prep.

Spectral model allowed weighted gamma folding of LMC's two Ė>1E38 erg/s pulsars.





The brightest gamma-ray pulsar seen in the LMC



Crab pulsar (at 50kpc)
Parkes 640MHz
Parkes 1390MHz
VLT/NACO
HST/WFPC2
RXTE PCA
Swift XRT
INTEGRAL IBIS/ISGRI
Fermi LAT
H.E.S.S.
PSR J0540-6910 (B0540-69)
E² × F(E) (erg/cm² /s)
Energy (eV)

Ap J Letters, in press
arXiv:1608.01901

The timing model fits the data without ambiguity.

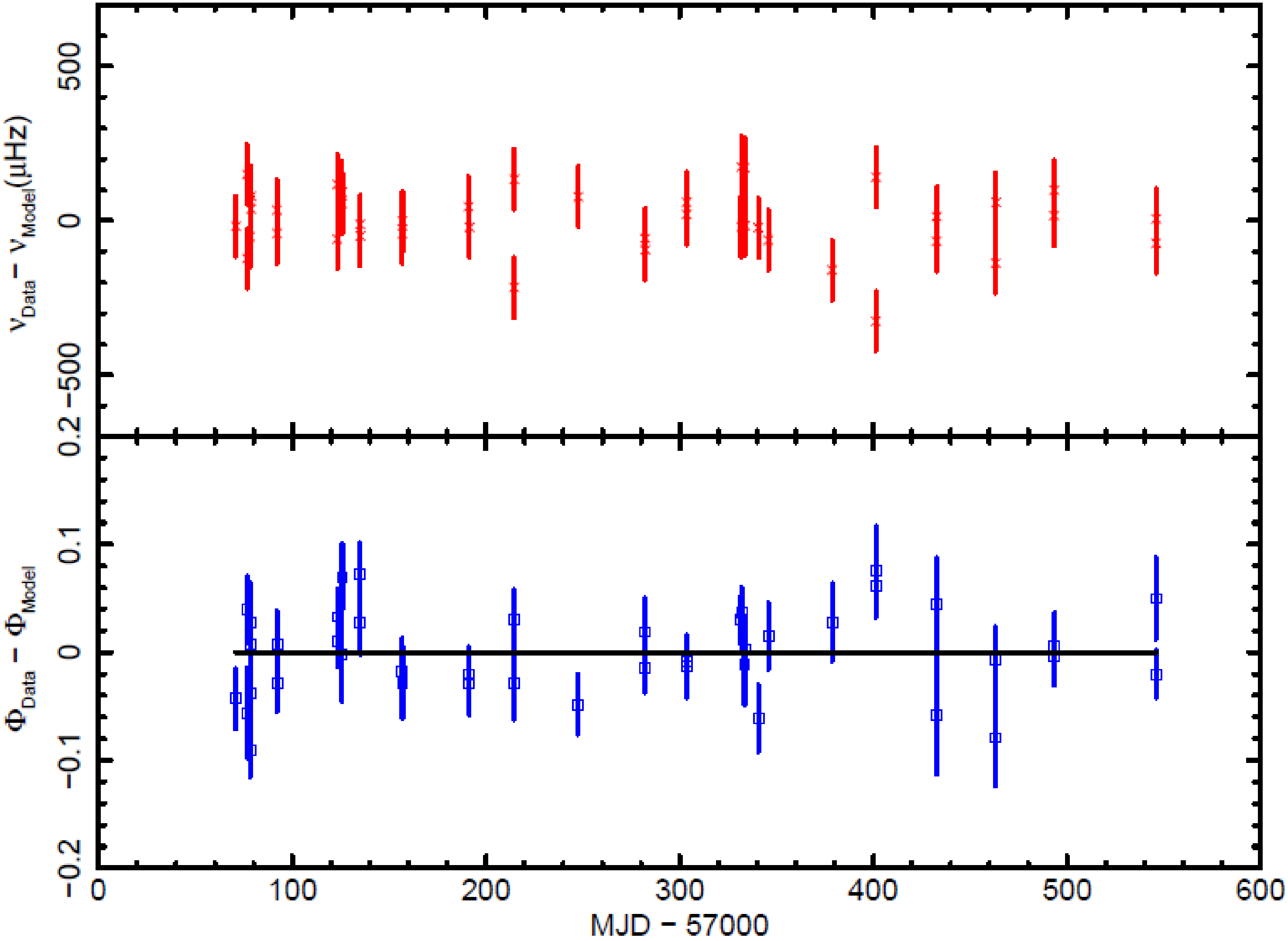
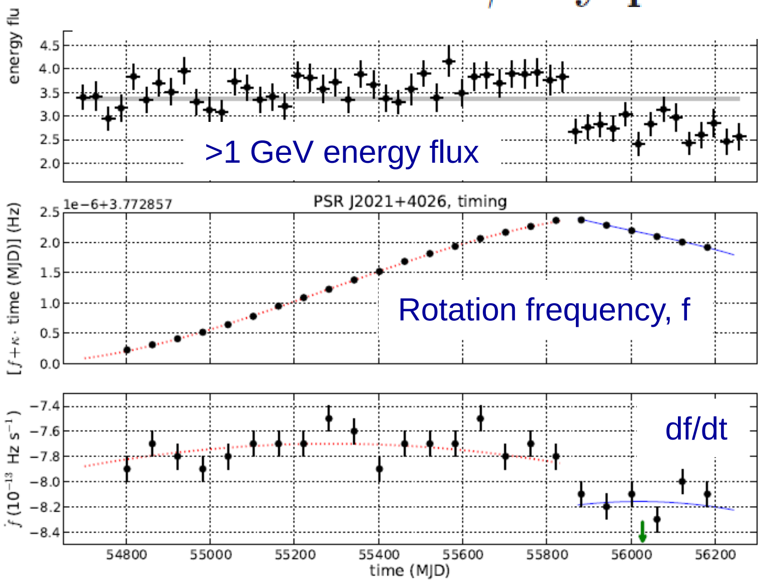


FIG. 1.— The phase and frequency residuals for the XRT observations relative to the ephemeris model in Table 2. The estimated one-σ uncertainties are shown. The solid line shows a residual of 0.0 for the phase.

PSR J2021+4026 in the Gamma Cygni region: the first variable γ-ray pulsar seen by the *Fermi* LAT



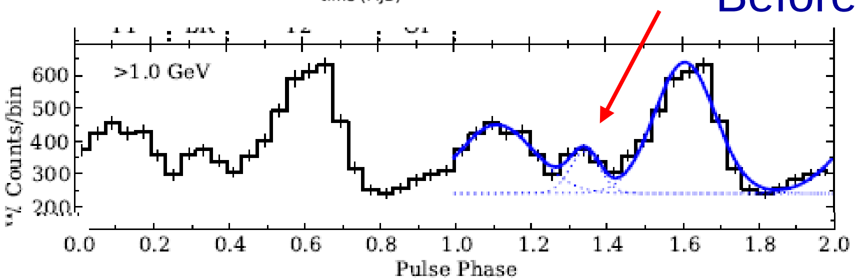
http://adsabs.harvard.edu/abs/2013ApJ...777L...2A

PSR B0540-69 in the LMC is a gamma pulsar
Ackermann et al. 2015, Science, 350, 801

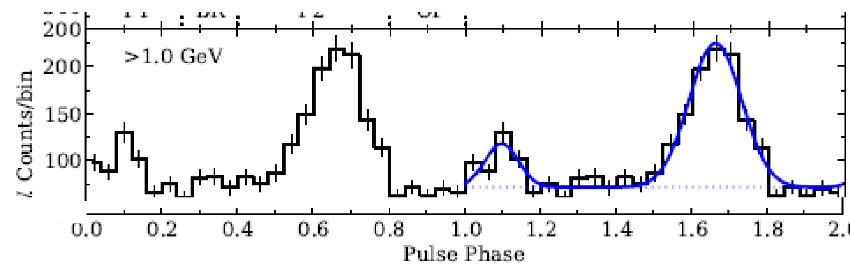
and appears to be an “intermittent” pulsar,
Marshall et al. 2015, Ap J Lett, 807, 27

like PSRs B1931+24, J1832+0029, J1841-0500,
a bit like gamma pulsar J2021+4026.

Before



After



A minor shift in how the magnetic field lines enter the neutron star crust can shift the complex ‘aurora borealis’ beam pattern.

For a fixed line of sight, intensity and profile change.

Magnetic field shift ➔ slight change in spindown rate.

(The Crab flare was the nebula, not the pulsar.)

25-Year Period Pulsar Binary

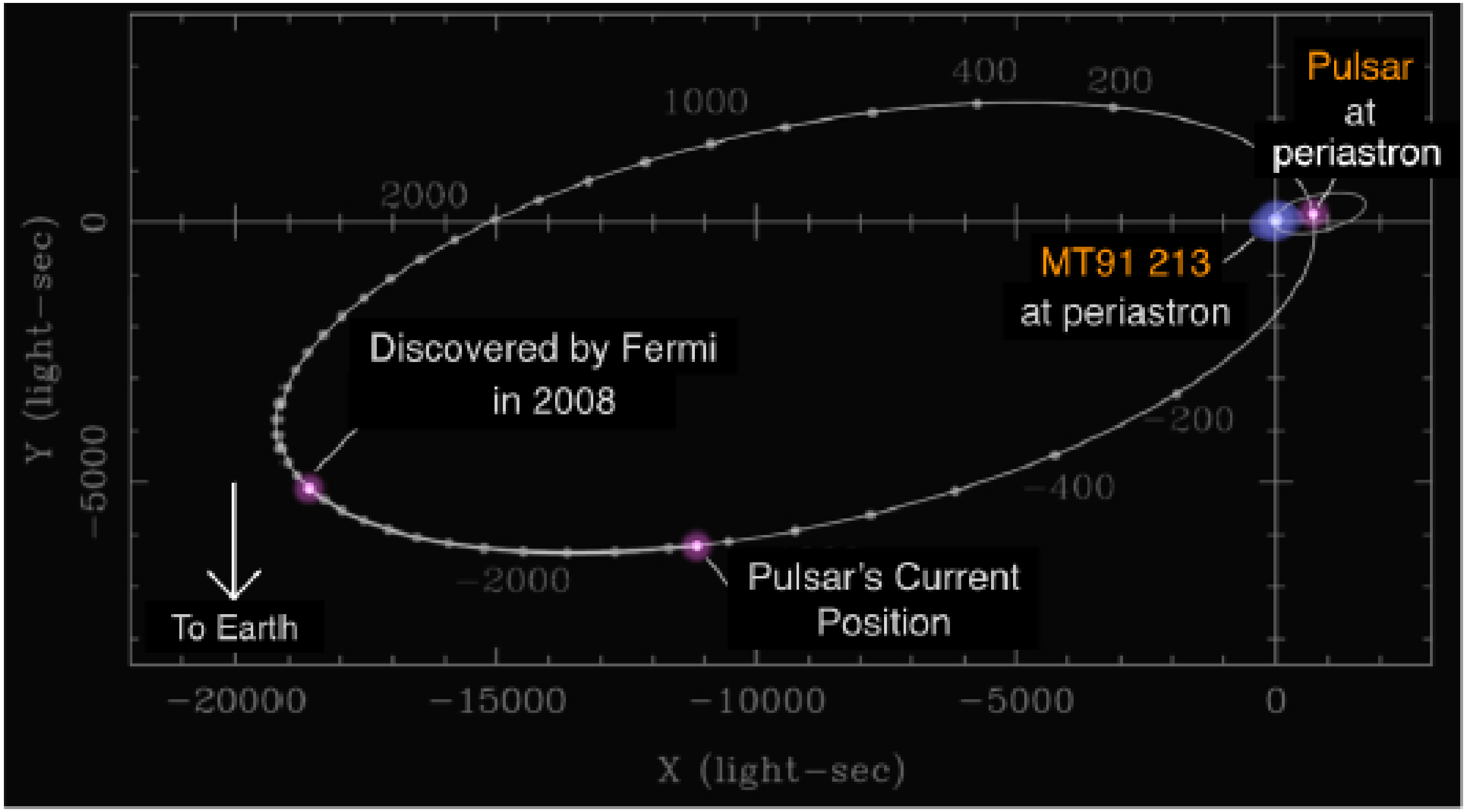


Figure 6: In 2018 *Fermi* will provide critical observations of the periastron passage of the 25-year binary system MT91 213/PSR J2032+4127 [31].

[31] Lyne, A. G. et al. *MNRAS* 451, 581, 2015

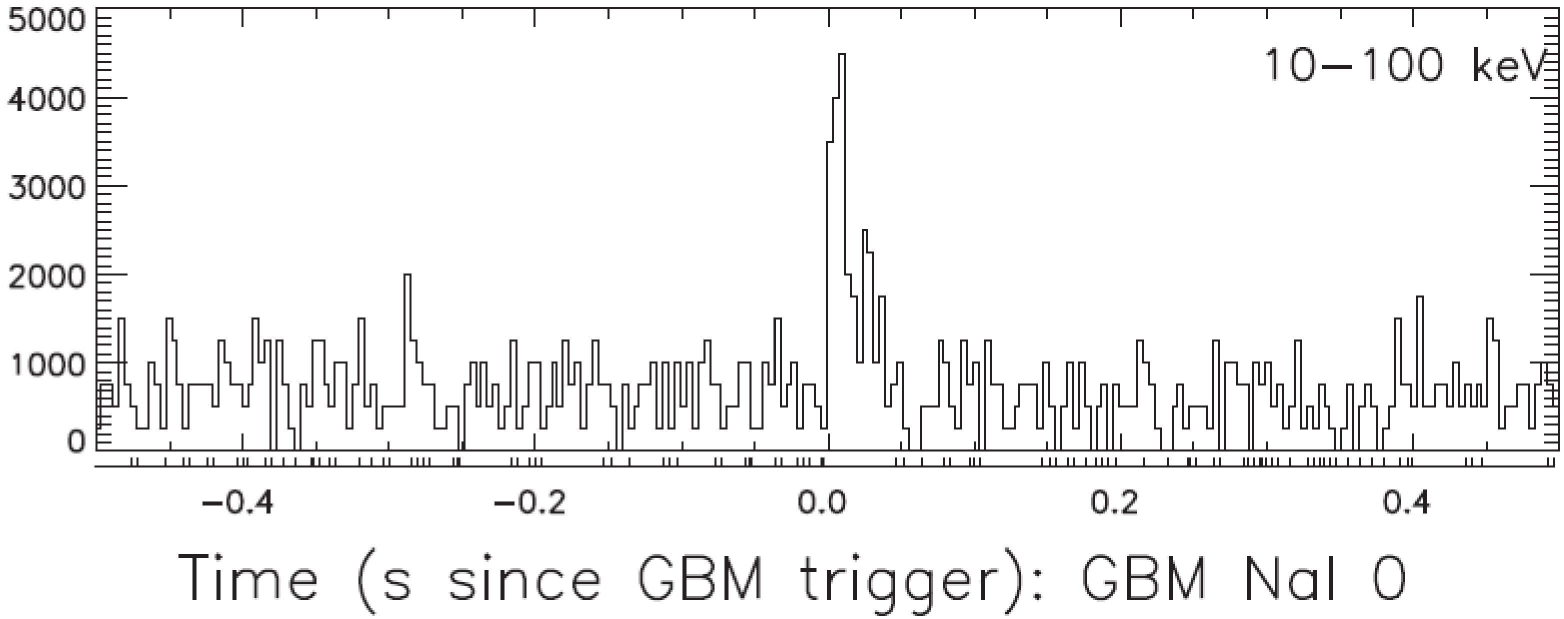
PSR J1119-6127: RPP or magnetar?

RPP = Rotation Powered Pulsar

• Parent et al ApJ (2011) – one of highest B-field pulsars seen with the LAT. Others *not* seen, e.g. PSR J1846-0258 ➔ see L. Kuiper's talk today.

• **New**: Upper limits on 20 magnetars Li et al, ApJ accepted (2016) arXiv:1607.03778

But then, 2016 July 27… *A soft-gamma flare from the pulsar.*

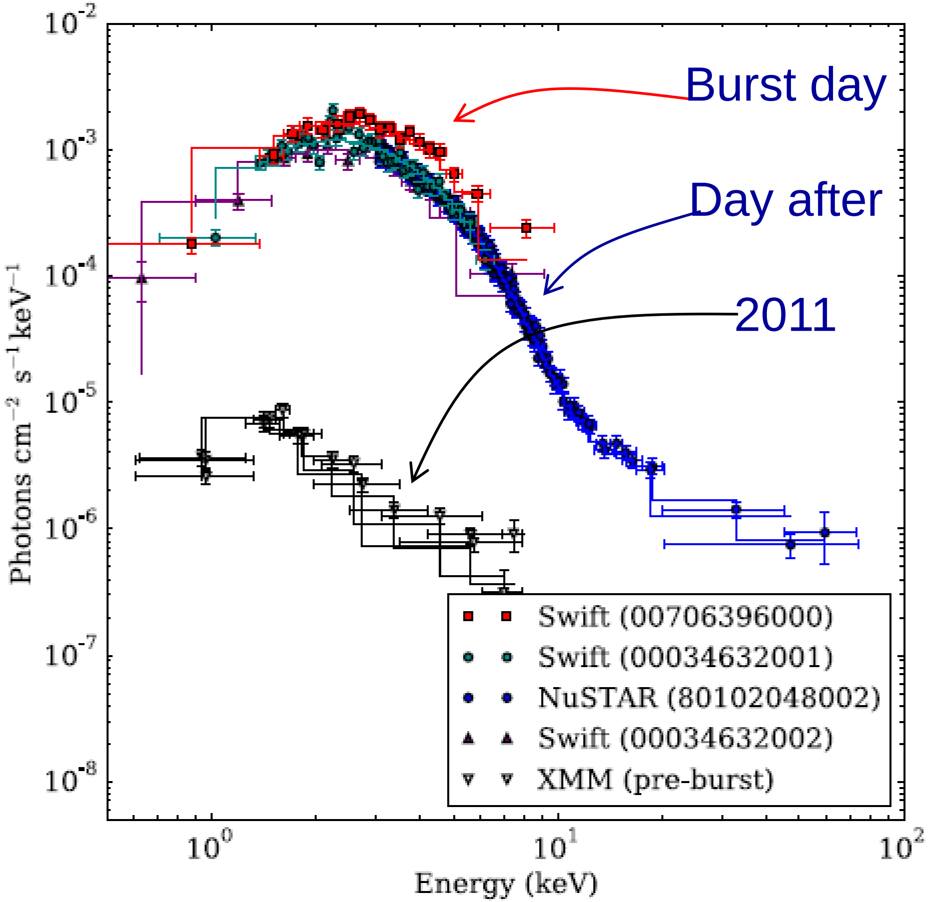


Next speaker! ➔ Göğüş et al, ApJ Lett (2016)

PSR J1119-6127: *an RPP goes magnetar*

Dramatic X-ray hardening, up to soft γ-rays.
LAT timing ➔ big $\Delta\nu/\nu$ = 5.7e-6 glitch.

Archibald et al, ApJ Lett (2016)



Radio signal vanished! Re-appeared!
Burgay et al ATELs 9286, 9366.

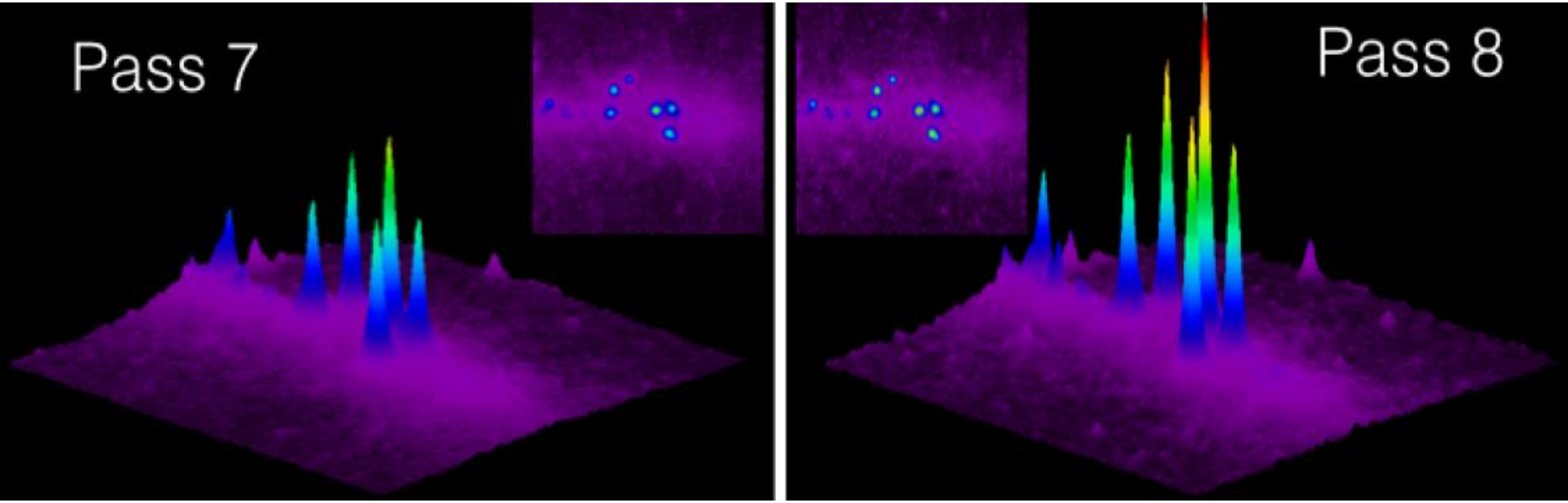
Fermi one-week ToO:
No detection yet –
normal for this weak pulsar.

To be continued!

Pass 8: Toward the Full Realization of the Fermi-LAT Scientific Potential

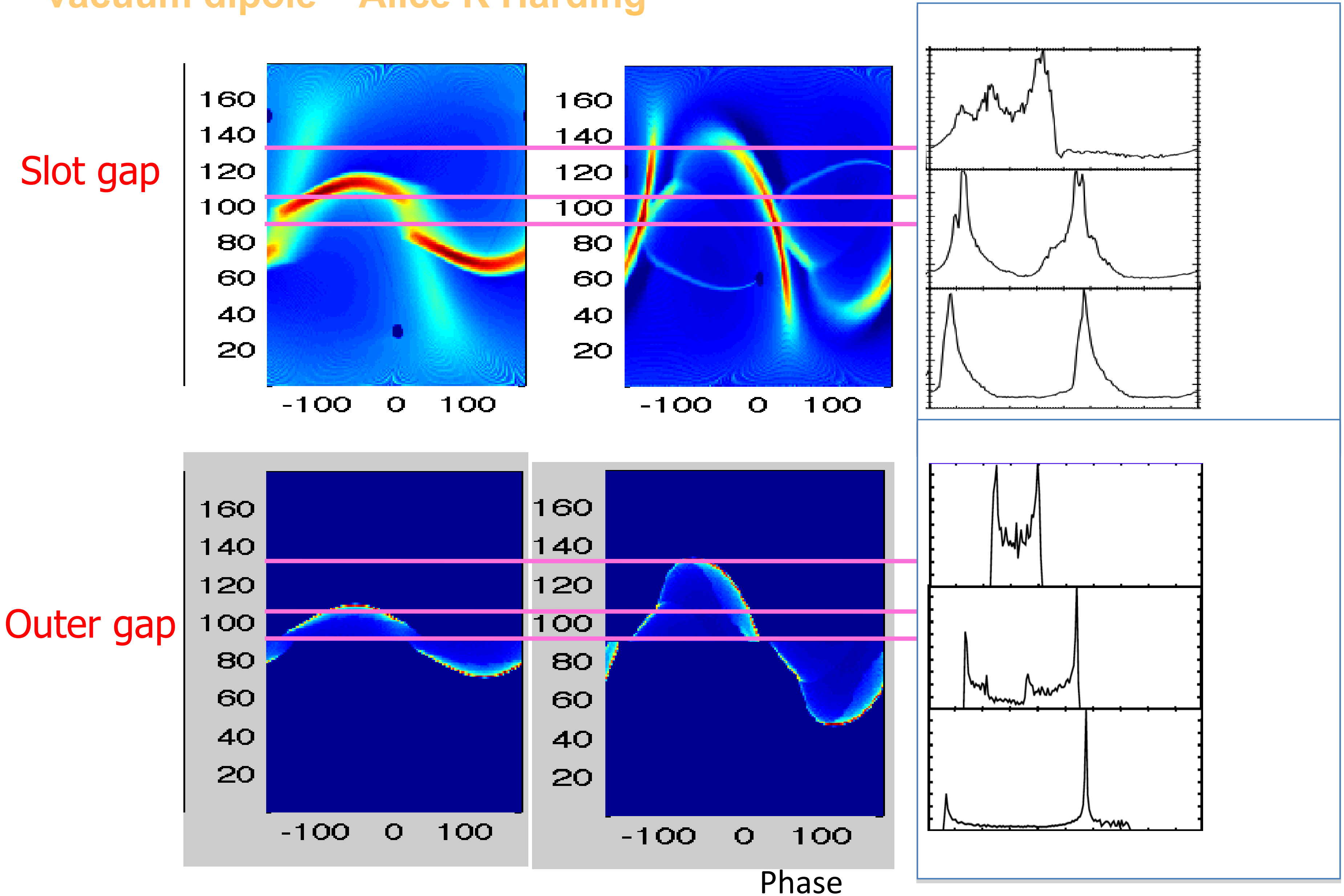
- Event reconstruction re-thought, re-coded from bottom to top.
- Performs significantly better.
- Data public since 2015.
- More pulsars popped into view.

Figure from 2016 NASA Senior Review.

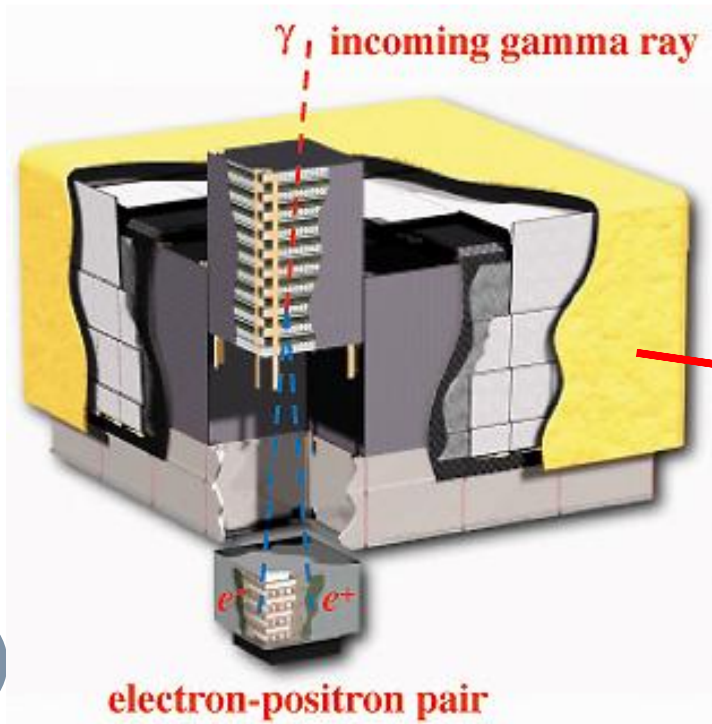


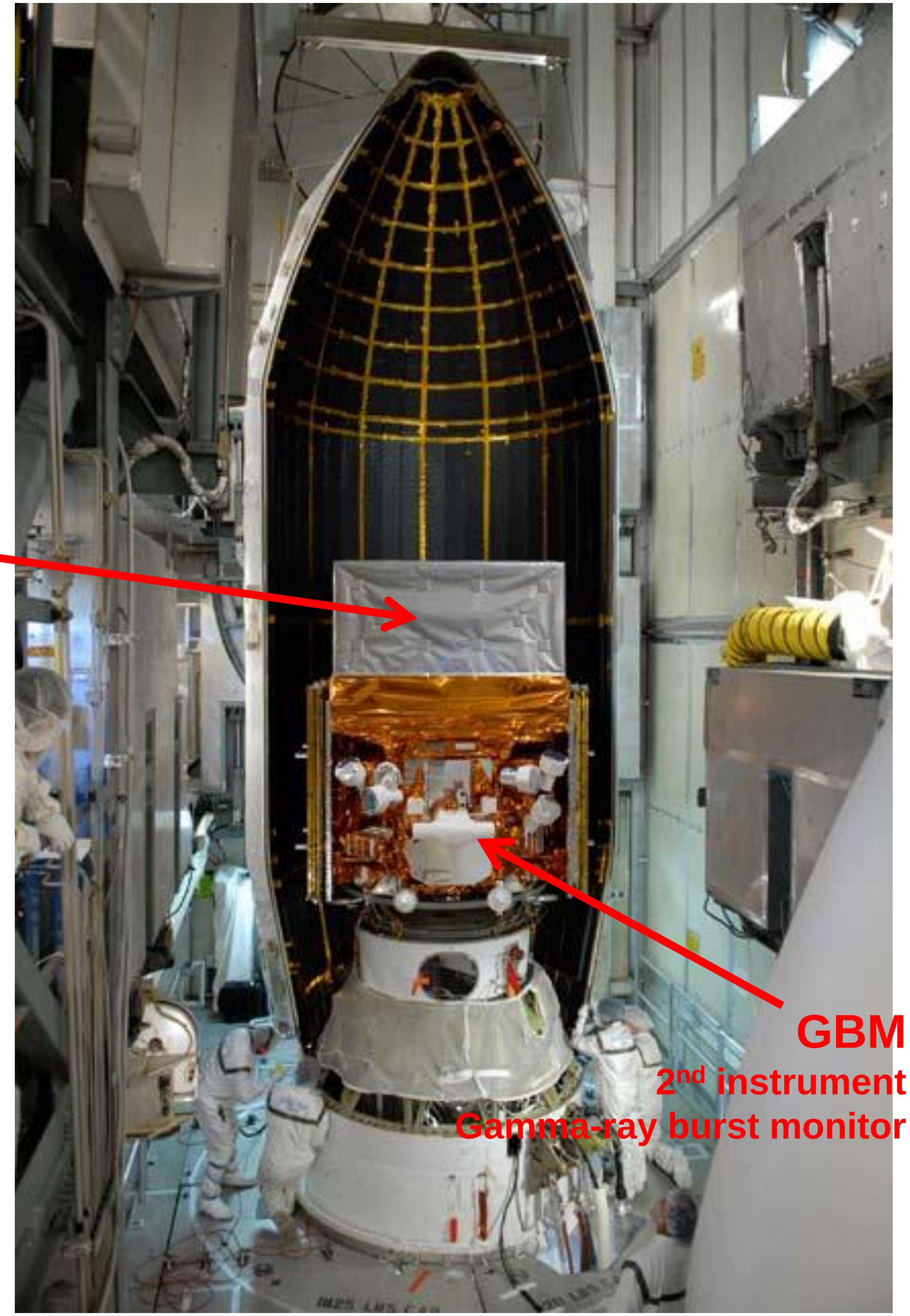
Sky distribution of intensity

vacuum dipole – Alice K Harding



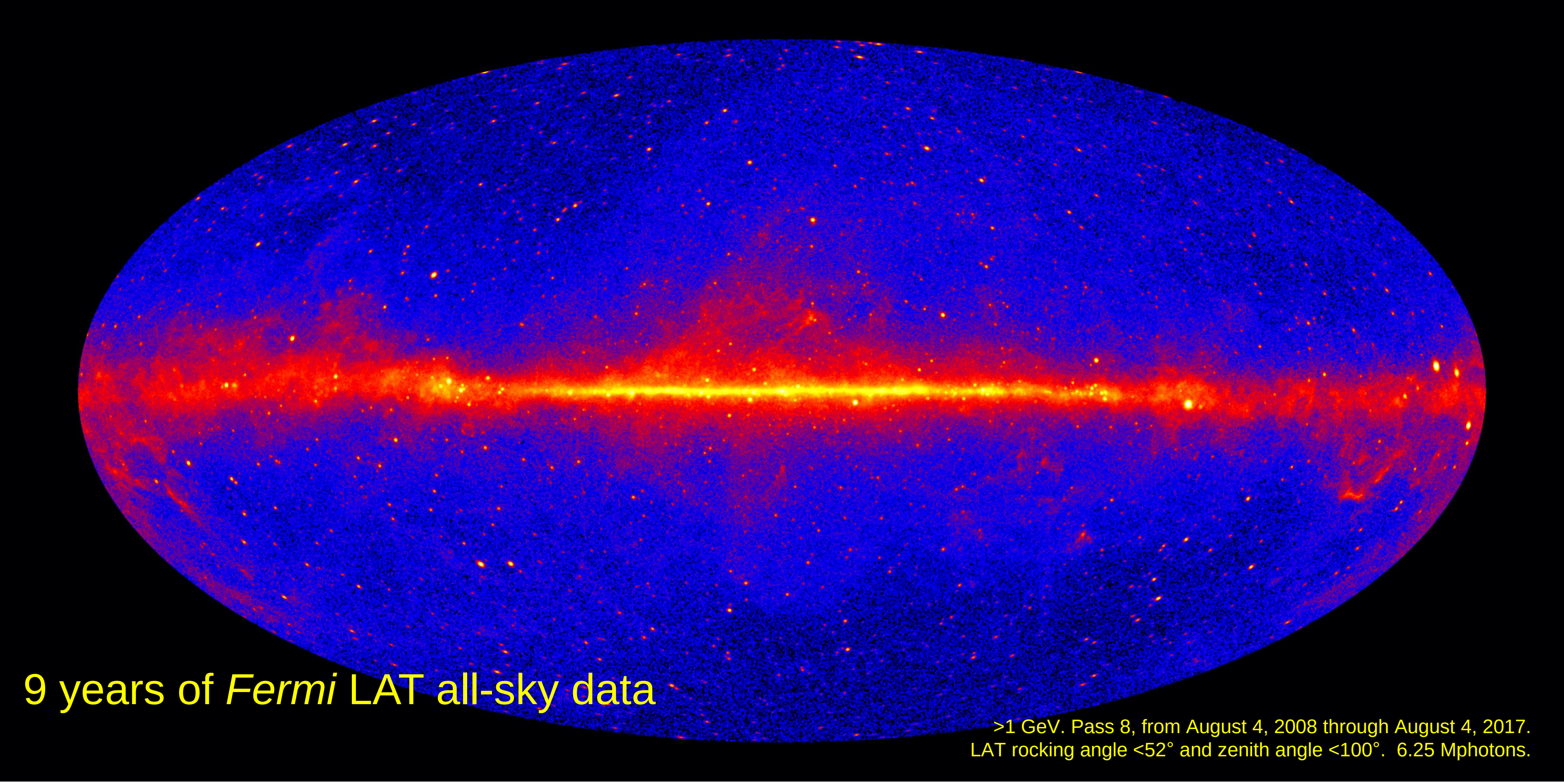
Large Area Telescope
30 MeV to 300 GeV





The whole sky, 8 times per day:

- Known and unknown sources.
- Good localization.



Milky Way in gammas: cosmic ray protons → gas & dust → pions,
then $\pi^\circ \rightarrow \gamma\gamma$ and $\pi^\pm \rightarrow \mu^\pm\nu \rightarrow e^\pm\nu\nu$, $e^\pm \rightarrow \gamma$'s.

Point sources in the plane are mostly pulsars.
Off the plane, mostly blazars (and some millisecond pulsars)