Fermi
Gamma-ray
Space Telescope

Precise Pulsar Timing and Radio Follow-Up of Pulsars Discovered in LAT Blind Periodicity Searches

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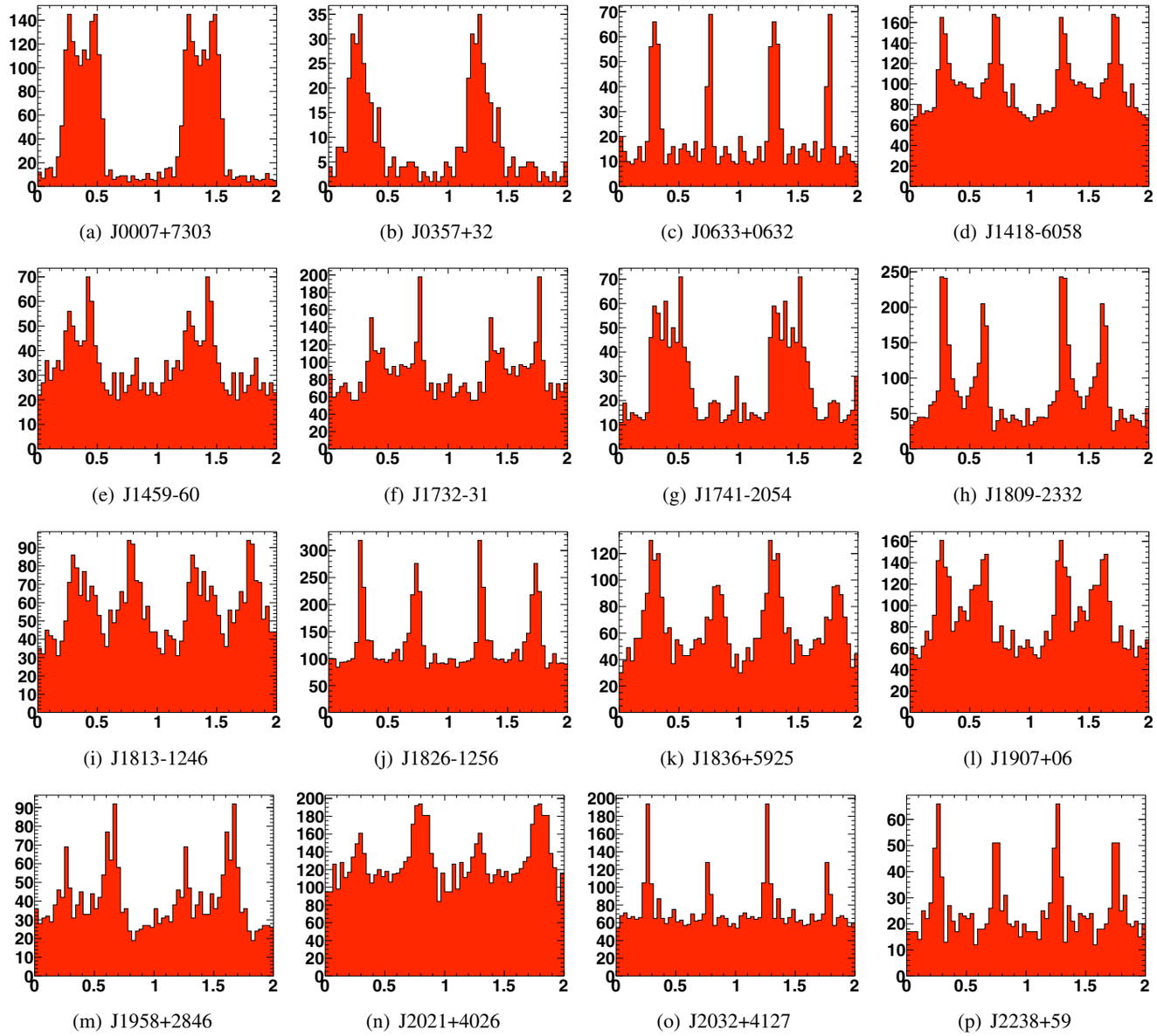
on behalf of the LAT Collaboration
and the
Fermi Pulsar Search Consortium (PSC)

Blind Search Pulsars

- Before Fermi, Geminga was the only "gamma-ray only" pulsar
- 16 discovered in first 6 months (see Abdo et al. 2009, Science, **325**, 840)!
- 8 new discoveries since then! (see Saz Parkinson and Dormody talks on Wednesday)
- Questions:
  - What is their timing behavior?
  - These are "gamma-ray selected" pulsars, but are they also radio quiet?
  - Are there counterparts at other wavelengths?

➡ Need precise positions!



LAT Pulsar Timing

- Survey mode observing and large FOV and area make for excellent long term timing of pulsars discovered
- Developed Maximum Likelihood method for measuring TOAs from small numbers of photons (typically ~100 photons per 2-week TOA). Achieves sub-ms residuals on most pulsars
- All 24 blind search pulsars timed, plus several others where the LAT is better than any alternative (Geminga, PSR J1124–5916, Vela)

METHOD

- Convert photon times to the Geocenter
- Assign phases using a preliminary timing model
- Construct analytical model of pulse profile
- Divide data set into segments
- Using ML, fit for phase offset between profile and data in each segment

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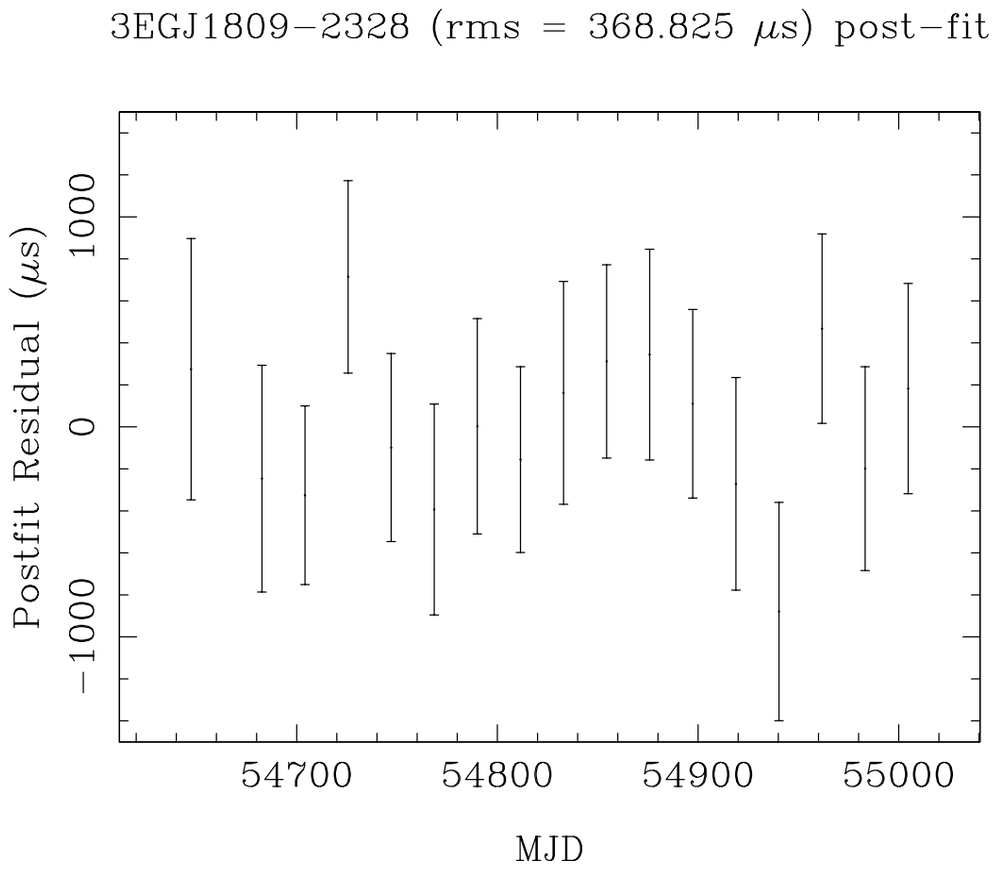
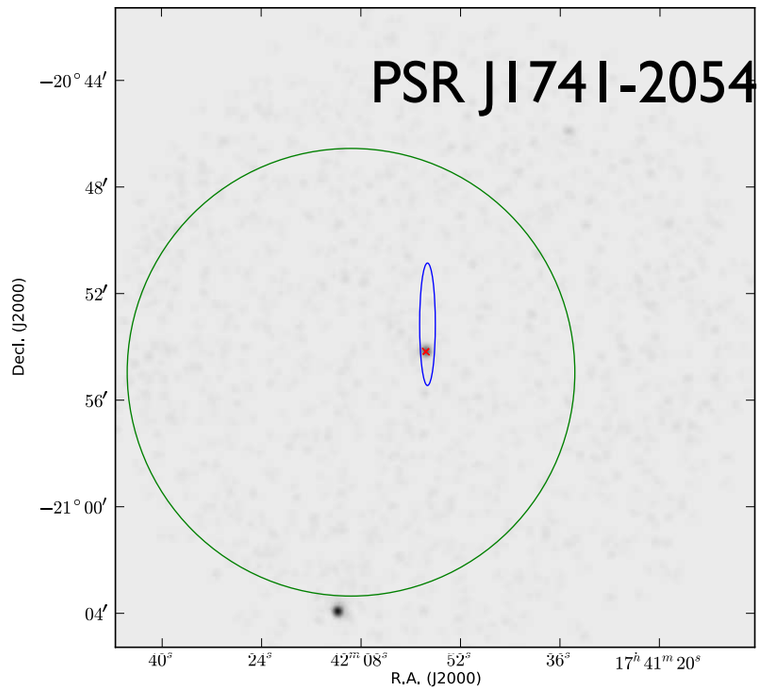
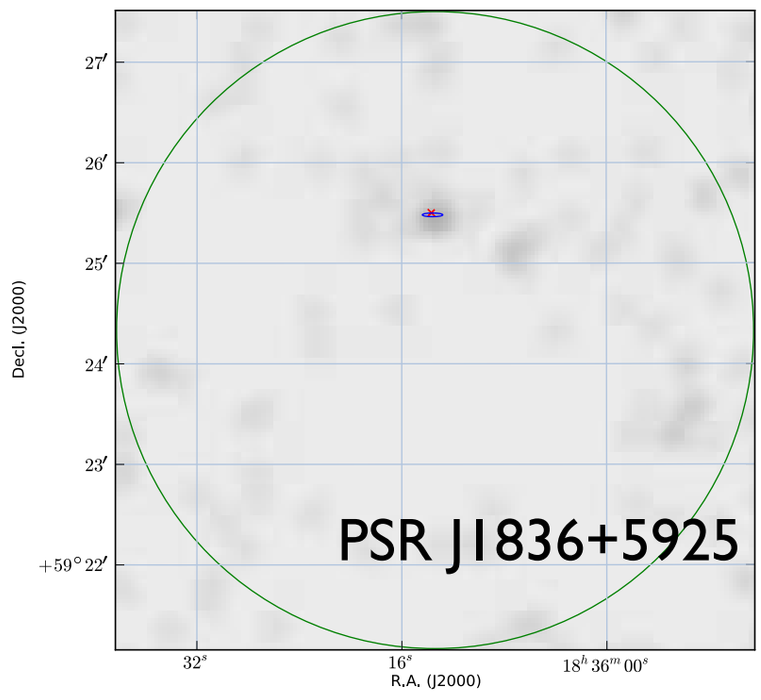


The Power of Timing

- Improved rotational parameters
- Study timing noise and glitches (free from any radio propagation effects)
  - Glitch detected in CTA1 pulsar on 2009 May 1
- **Precise positions**, which enable multiwavelength follow up!
  - Sub-ms residuals lead to arcsec position accuracy

Ray et al. 2009, in preparation





LAT Pulsar Search Consortium (Radio)

- All these new pulsars are **gamma-ray selected** (discovered in blind periodicity searches of LAT data), but are they **radio quiet**?
- Some (CTA1, 3EG J1835+5918) already have stringent radio limits
- For the others, we recruited pulsar observers with expertise at key observatories (Parkes, Arecibo, GBT, Effelsberg, Nançay)
- Radio detection yields
  - Distance from Dispersion Measure (DM)
  - Information on emission region from radio to gamma-ray offset
  - Geometry from polarization studies
  - Population studies of radio quiet vs. radio loud, which constrain models

Fermi PSC

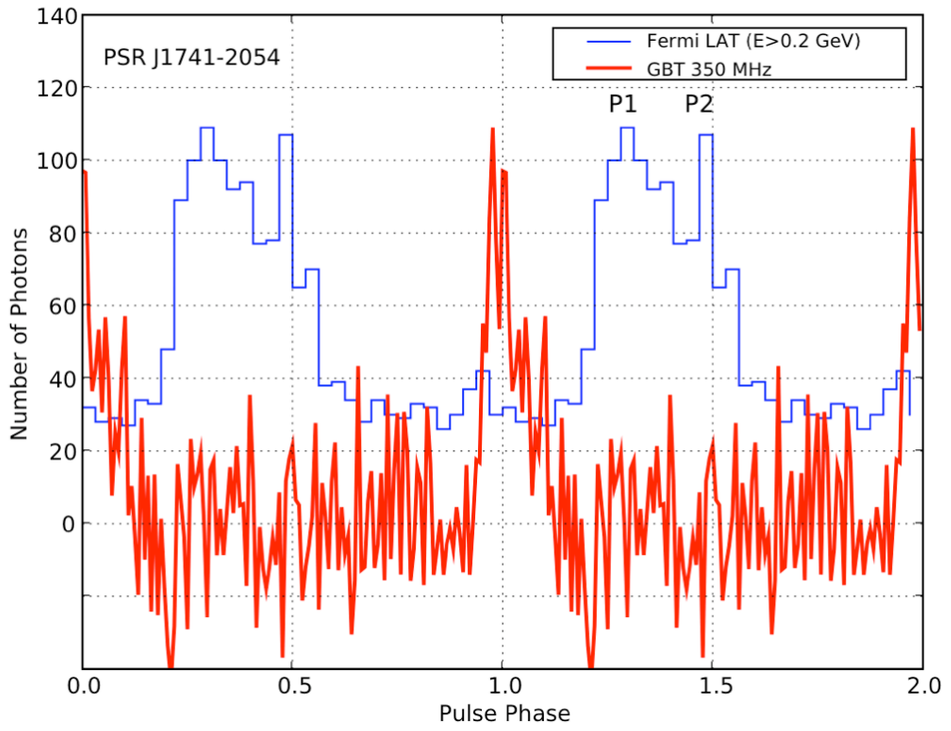
- Purpose: To organize deep radio searches of the blind search pulsars and unidentified LAT sources (see following talk by Ransom)
- Fermi LAT members:
  - Ray, Smith, Harding, Thompson, Saz Parkinson, Ziegler, Abdo, Wood, Romani, Kramer (Effelsberg), Johnston (Parkes), Theureau, Cognard (Nançay)
- External members on MOU:
  - **GBT**: Camilo, Ransom, Roberts
  - **Arecibo**: Freire
  - **Jodrell Bank**: Stappers
  - **Parkes**: Keith, Weltevrede

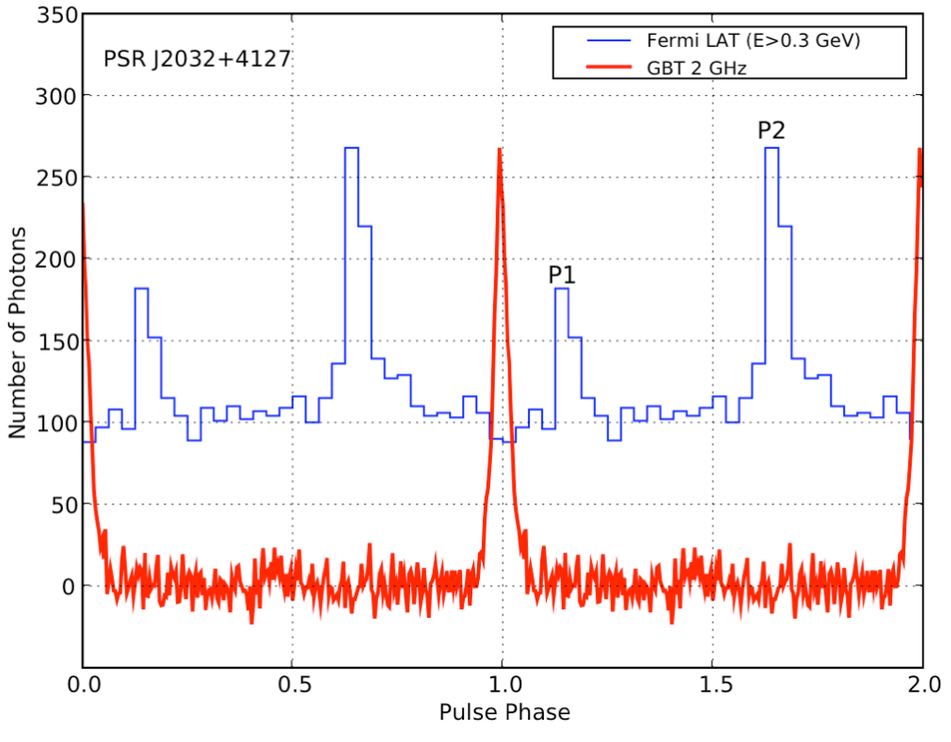
PSC Observations

- Parkes: 4 of the most southern sources + a dozen UNID sources
- Arecibo: 5 pulsars + 10 UNID sources
- GBT: 5 pulsars + 27 UNID sources from the BSL + 50 fainter UNID sources
- Jodrell observes when needed
- Effelsberg just started observing with new filterbank
- Nançay also contributing

First Two Radio Detections

- **PSR J1741-2054**
  - Radio pulsar found in archival Parkes multibeam data
  - Extremely low DM (4.7 pc cm^{-3}), implies D=400pc
  - May be lowest luminosity of any young radio pulsar (L~0.025 mJy kpc^2)
- **PSR J2032+4127**
  - Pulsations discovered at GBT
  - DM=115 implies D=3.6 kpc, but may be at half that distance (possibly associated with Cyg OB2)

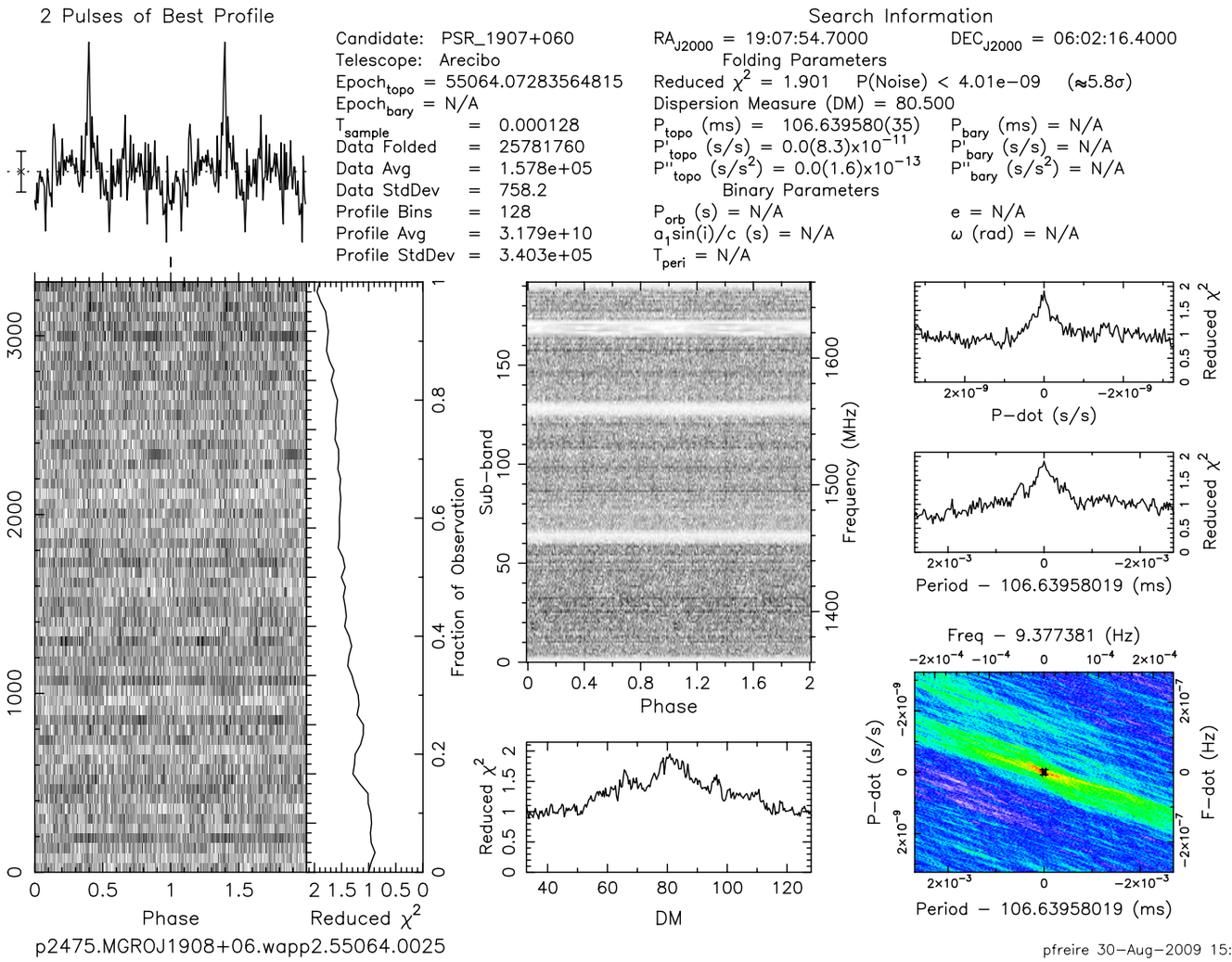




Camilo, Ray, et al. 2009, ApJ, **705**, 1

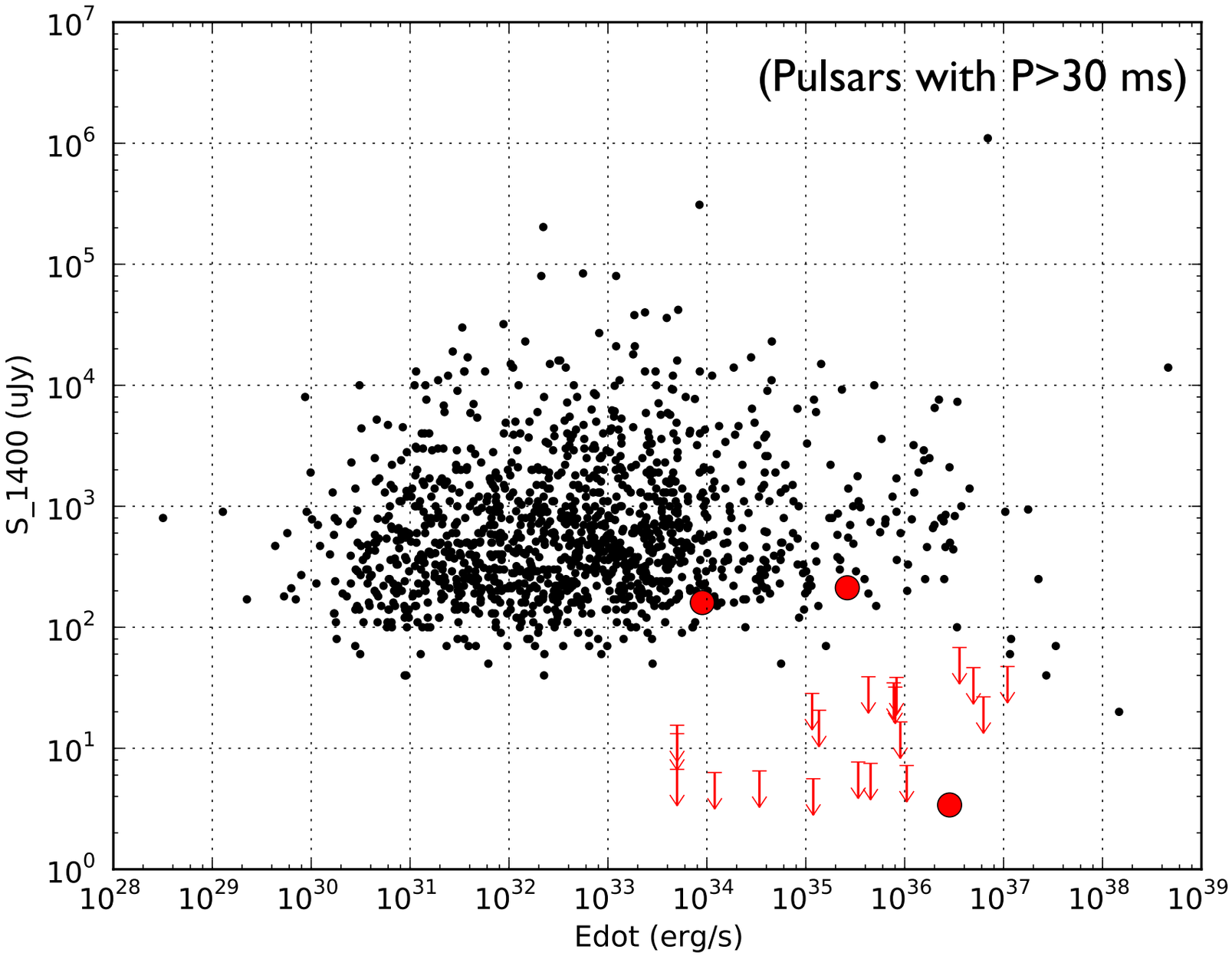
New Detection: J1907+06!

- **Very** faint radio pulsations (~3.5 μJy) detected at Arecibo!
- DM 80 pc cm^{-3} gives distance of 3.1 kpc
- Another very low luminosity pulsar
- See talk by Abdo on Wed.



Abdo et al. 2009, ApJ, submitted

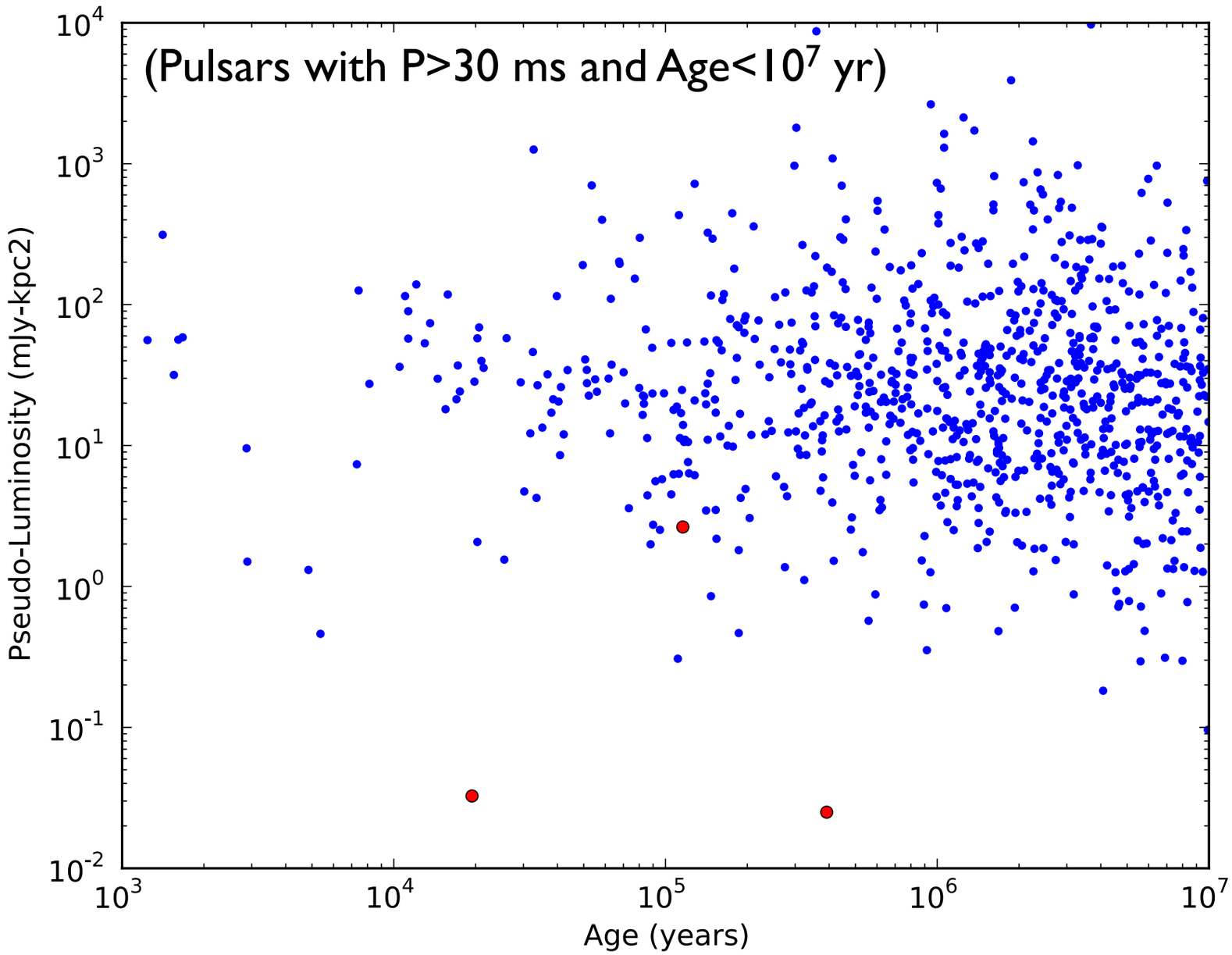
Radio Upper Limits



- 25 gamma-ray selected pulsars

➡ 3 detected, 21 upper limits (all <70 μJy), 1 left to observe

What is "Radio Quiet"?



- The new radio detections are very low luminosity!

Summary

- The LAT has given us an abundance of gamma-ray selected pulsars
- Pulse timing with the LAT yields arcsec accuracy positions and the spindown behavior of these pulsars
- The PSC has made radio observations of all but one
  - 3 detected in radio, others have deep upper limits
  - Detections immediately give distance measurement!
- When combined with LAT upper limits on gamma-ray pulsations from radio pulsars population studies will provide interesting constraints on models