Finding (or not) New Gamma-Ray Pulsars with GLAST

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Credit: P. Sreekumar (NASA/GSFC)
Why pulsars with GLAST?

• **EGRET** saw pulsed emission from 7+ pulsars
• All but one (**Geminga**) are radio pulsars
• Usually **young and energetic**
• Pulsars are used as **tools:**
  – Strong-field gravitation tests
  – Equation of state of matter at supra-nuclear densities
  – Plasma astrophysics
• Yet we **still don't understand the emission mechanism(s)!**
Gamma-ray Pulsar Properties

- Non-variable
- Flat-ish spectra (power-law indices <2)
- Spectral breaks above 1 GeV
- Complex pulse profiles
- All found without using EGRET!
- Likely many more

See review by David Thompson (astro-ph/0312272)
High Energy PSR Search Basics

• Several techniques:
  – Sinusoidal: Fourier techniques are optimal
  – Complex profiles:
    • Fourier techniques with harmonic summing
    • Epoch folding with significance test
• For **optimal sensitivity**, collect source events and maintain **phase coherence** for as long as possible -- this is **hard**
• Can use **incoherent techniques** with a loss of sensitivity
Phase Coherent Techniques

- Discussed by many groups. Good published discussion for EGRET data by Chandler et al., 2001, ApJ, 556, 59

- Highly sensitive, but many problems:
  - Low count rates demand long integrations
  - Long integrations mean searching over f-dot
  - Young pulsars have timing noise and glitches
  - As integration times increase, so do the computations and the numbers of trials

- Crab, Vela, and Geminga (at least) can be identified blindly in EGRET data
Scaling Relations

- $N_b, N_s, N_t =$ background, source, and total events
- $T_{\text{view}} =$ time from first event to last
- $\alpha =$ shape factor (0.4-0.9 for known PSRs)

"Power":

$$P \sim 1 + \alpha \frac{N_s^2}{N_t}$$

- # of Trials:

$$N_{\text{trials}} \sim f_{\text{max}} |\dot{f}_{\text{max}}| T^3$$

- Significance:

$$\propto e^{-P} N_{\text{trials}}$$
Frequency Derivatives

Coherent searches with $T_{\text{view}} > 1$ day will need to account for $\dot{f}$

Note: 1 "bin" is $1/T_{\text{view}}$ in Hz
Frequency Derivatives

Position errors can cause a Doppler-induced fdot

(Chandler et al. 2001)

\[ \delta \dot{f} \sim 2 \times 10^{-13} \left( \frac{\epsilon}{10^{-3} \text{rad}} \right) \left( \frac{f}{10 \text{ Hz}} \right) \cos \theta \ \text{Hz s}^{-1} \]
Coherent searches with $T_{\text{view}} > 1-2$ months will need to account for freq 2nd derivs.
Frequency

2\textsuperscript{nd} Derivs

Position errors can cause Doppler-induced freq 2\textsuperscript{nd} derivs

(Chandler et al., 2001)

\[ \delta f \sim 4 \times 10^{-20} \left( \frac{\epsilon}{10^{-3}\text{rad}} \right) \left( \frac{f}{10\text{Hz}} \right) \sin \theta \text{ Hz s}^{-2} \]
Sinusoidal Pulse

Most conservative
Valid for any $T_{\text{view}}$
All calculations are at 95% confidence-limit
Does not account for trials!

Exact DFT, Sinusoidal Profile

$>15$-sigma detection

10-sigma
5-sigma

non-detection

Number of Background Events
Sinusoidal Pulse

$T_{\text{view}} = 20 \text{ days}$

Majority of pulsars are unaffected by 2$^{\text{nd}}$ freq deriv or position error

$\sim 10^{12}$ trials!

This would be a reasonable request for a GLAST pointing
Sinusoidal Pulse

$T_{\text{view}} = 20$ days

Majority of pulsars are unaffected by 2\textsuperscript{nd} freq deriv or position error

$\sim 10^{12}$ trials!

This would be a reasonable request for a GLAST pointing
15% FWHM Gaussian

Probably a bit optimistic

Valid for any $T_{\text{view}}$

All calculations are at 95% confidence-limit

Does not account for trials!
15% FWHM Gaussian

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Incoherent Search Techniques

- Break $T_{\text{view}}$ into segments of duration $T_{\text{win}}$
- Optimally:
  - $T_{\text{win}}$ is as large as possible for sensitivity
  - $T_{\text{win}}$ is small enough to remove $\dot{f}_{\text{dot}}$ effects
- Perform a coherent analysis on each segment, then add the segments
- Computations faster, sensitivity suffers
- New “time-differencing technique” by Atwood, Ziegler, Johnson, & Baughman 2006, ApJ, 652, L49 is promising
Time-Difference Method

(Atwood et al '06)

FWHM = 15% Gaussian

$T_{\text{view}} = 1 \text{ yr}$

$T_{\text{win}} = 1 \text{ day}$

$\sim 10^{10}$ trials

Note: very preliminary MC!
Summary

- GLAST will likely find several to 10s of new gamma-ray pulsars via blind searches:
  
  - **Coherent searches:**
    
    - Useful when $T_{\text{view}} < 1\text{-}2 \text{ months}$
    - Sensitivity: $4 \times 10^{-8}$ to $4 \times 10^{-7}$ phot/cm$^2$/s ($>100\text{MeV}$)
    - Significantly improved sensitivity when pointing instead of slewing $\sim 2 \times 10^{-8}$ phot/cm$^2$/s ($>100\text{MeV}$)
  
  - **Incoherent searches:**
    
    - Allow analyses on workstation-size computers
    - Atwood et al method will allow (at some level) analysis of events over long durations (1+ years)
    - Sensitivities maybe as low as $\sim 1\text{-}2 \times 10^{-8}$ phot/cm$^2$/s