Understanding neutron stars through multi-wavelength observations of pulsars

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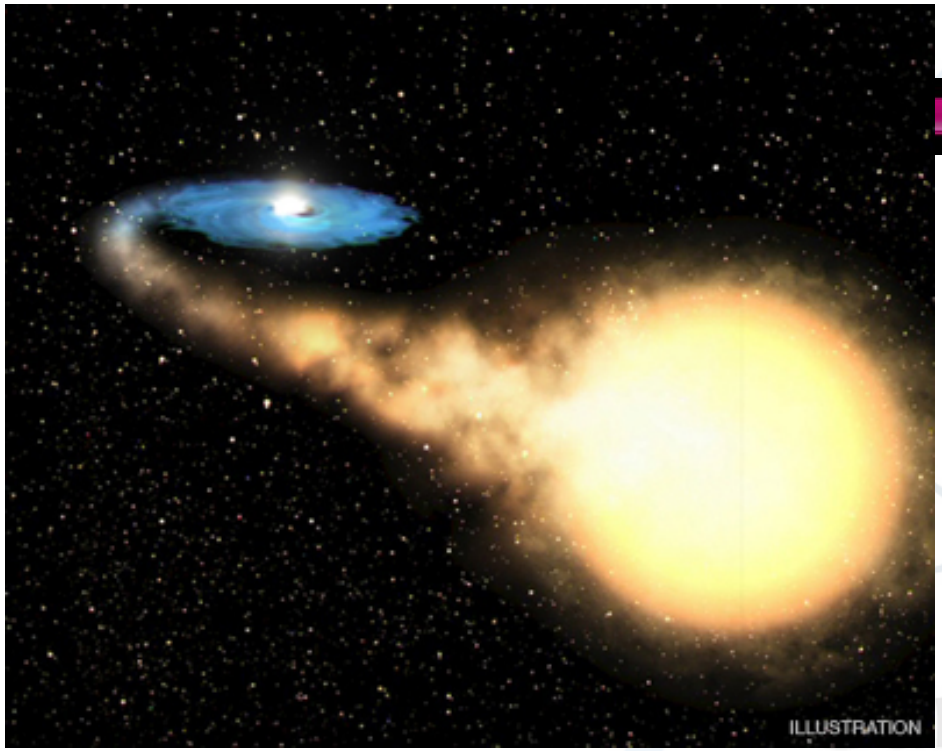
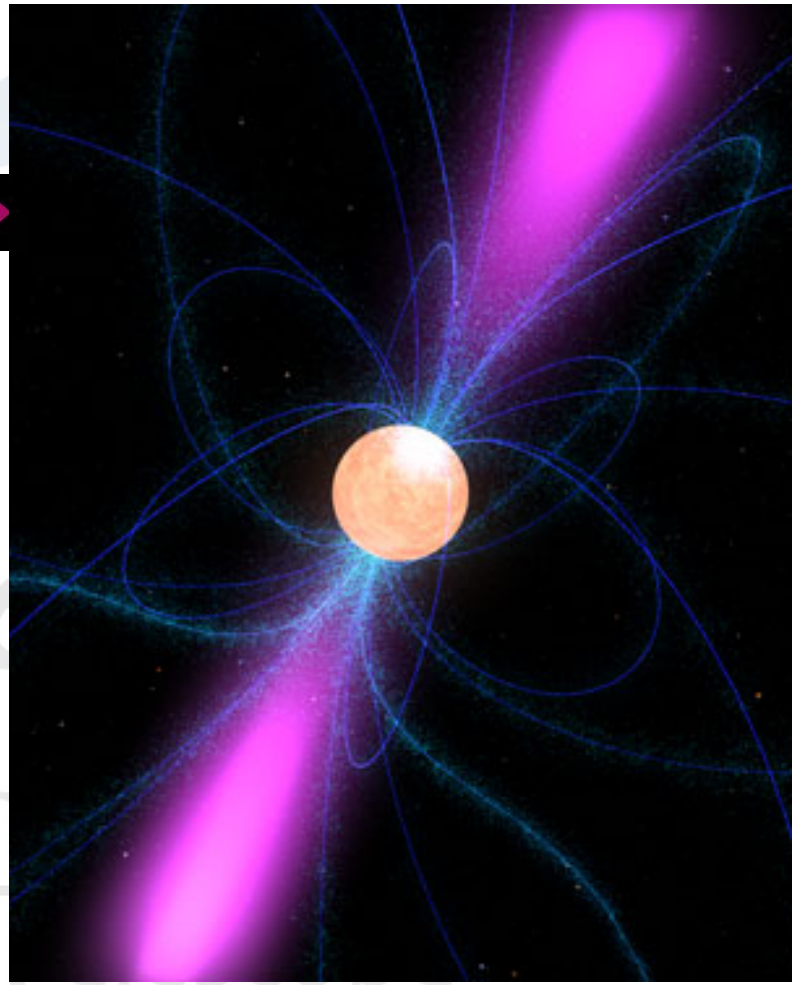
and the Fermi LAT collaboration

The X-ray Universe 2011, Berlin

Compact binaries:



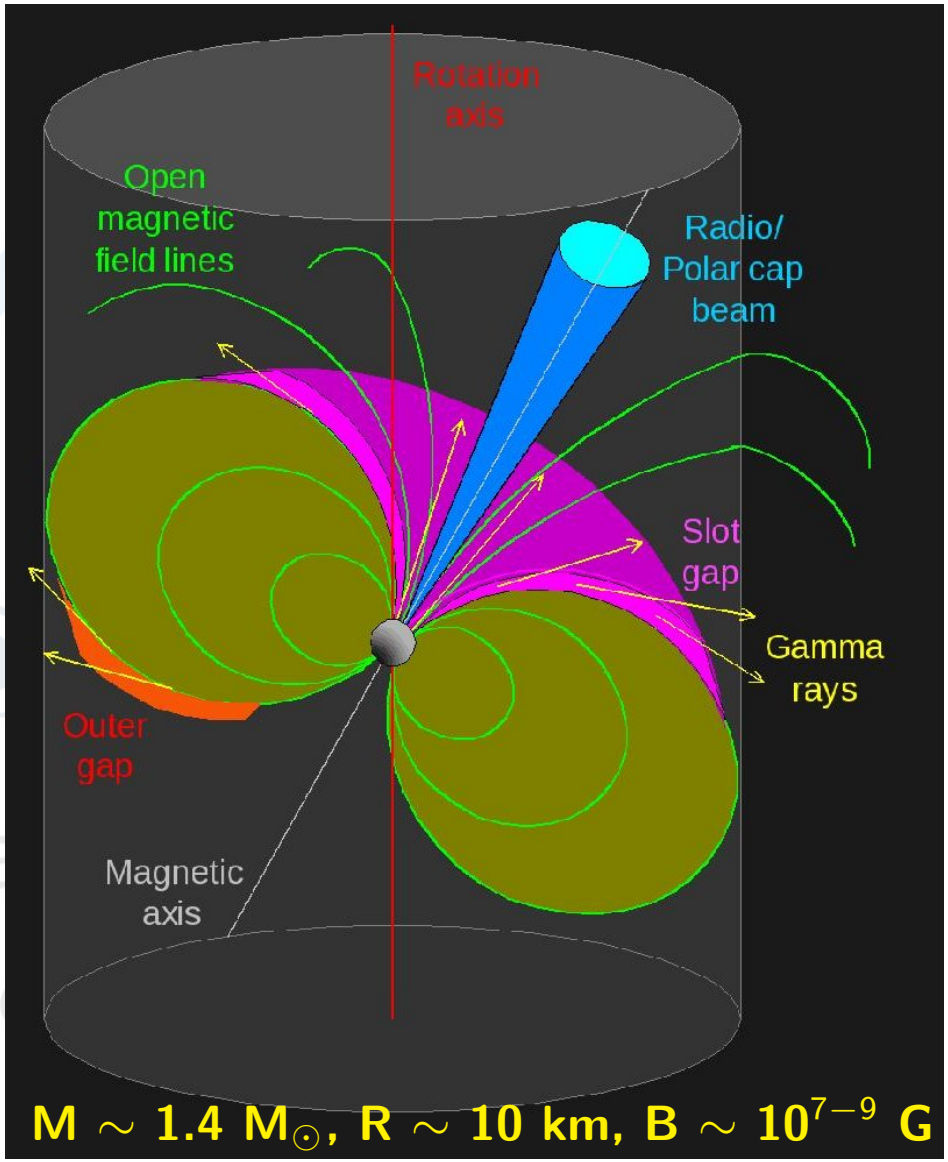
Artist's impression of an X-ray binary (Credits: ESA, NASA and Felix Mirabel)



Artist's impression of a pulsar (Credit: NASA)

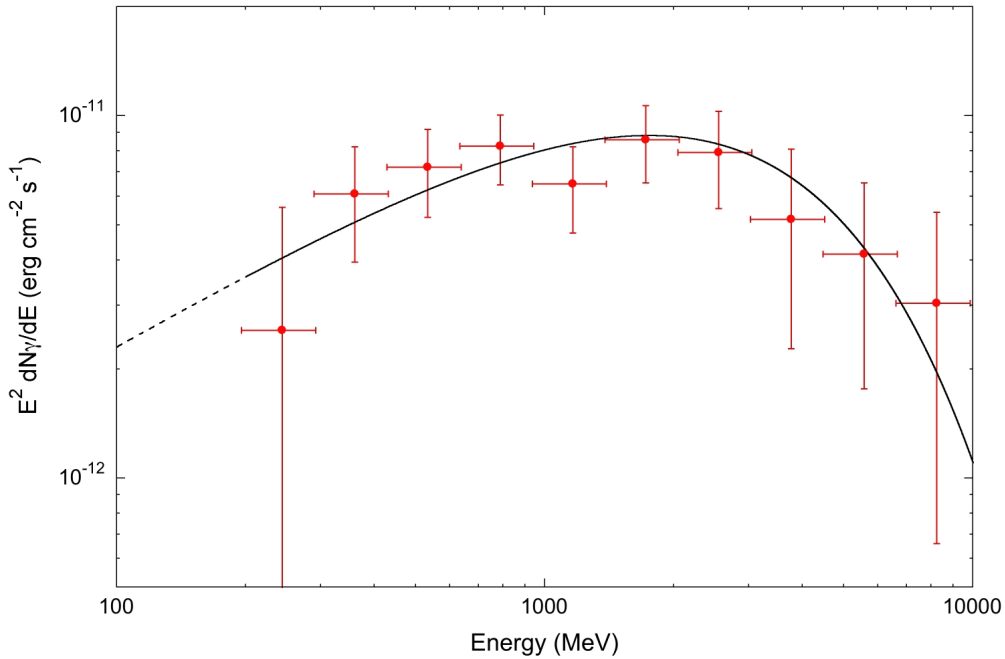
High energy emission from pulsars

- **Three models:**
  - **polar cap**
  - **outer gap**
  - **slot gap**
- **Inverse Compton scattering/ curvature radiation $\longrightarrow$ γ-rays**
- **Discovery of γ-ray emission from MSPs (Abdo et al. 2009a,b)**



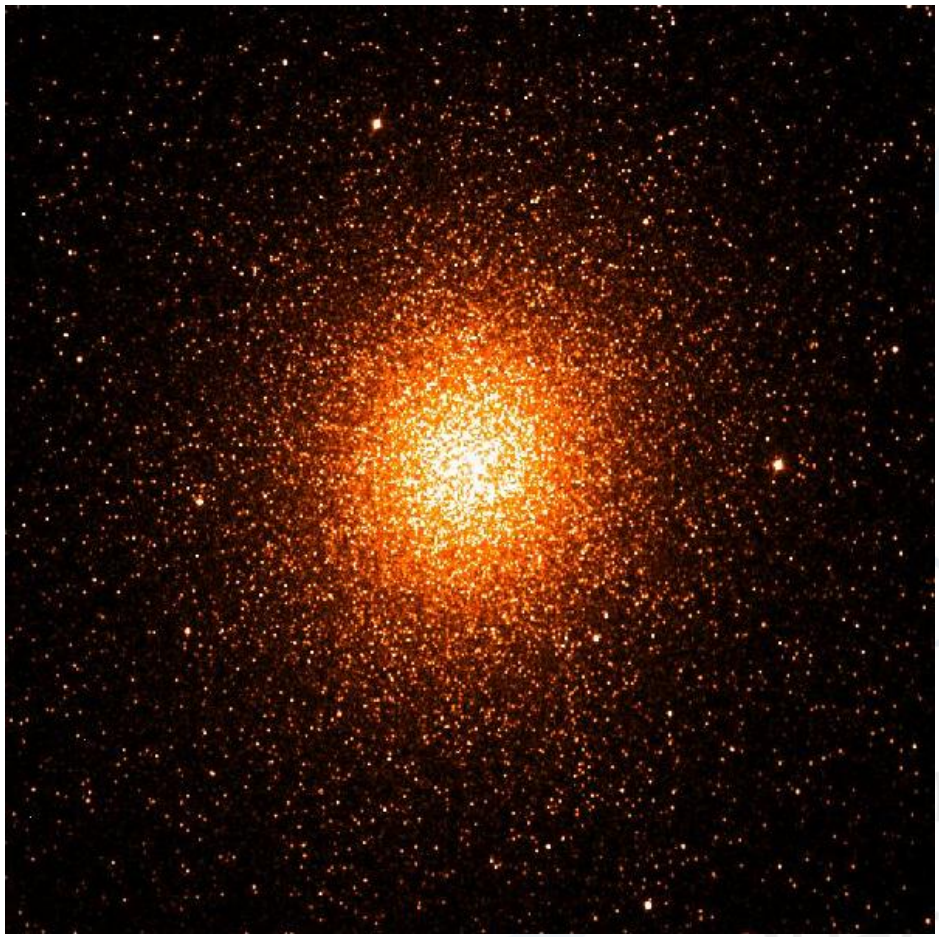
Three years of Fermi LAT

- Observations in the ∼100 MeV - >300 GeV
- Full sky scan every 3 hours
- Previous EGRET observations detected 6(+1) pulsars
- Fermi LAT has discovered >85 pulsars
- Timing of many pulsars at Green Bank, Parkes, Arecibo, Nançay, Jodrell
- Many of the unidentified sources are being revealed to be pulsars e.g. Ransom et al. (2011)



Typical Fermi pulsar spectrum
Power law spectrum, $\Gamma < 2$
$E_{cut-off}$ = 1 - 3 GeV

Galactic globular clusters



Omega Cen

- **Dense groups of old stars (10^{5-6} stars)**
- **Stable on dynamical timescales ($\sim 10^6$ yr)**
- **Unstable on thermal timescales ($\sim 10^9$ yr)**

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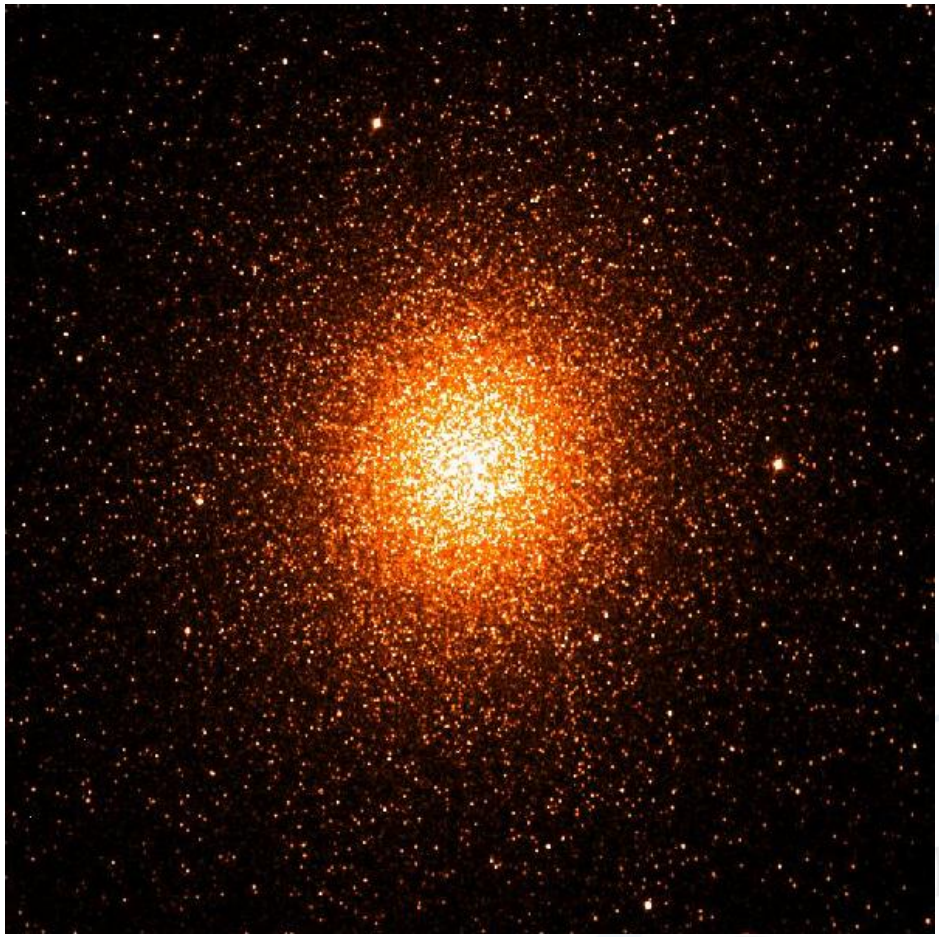

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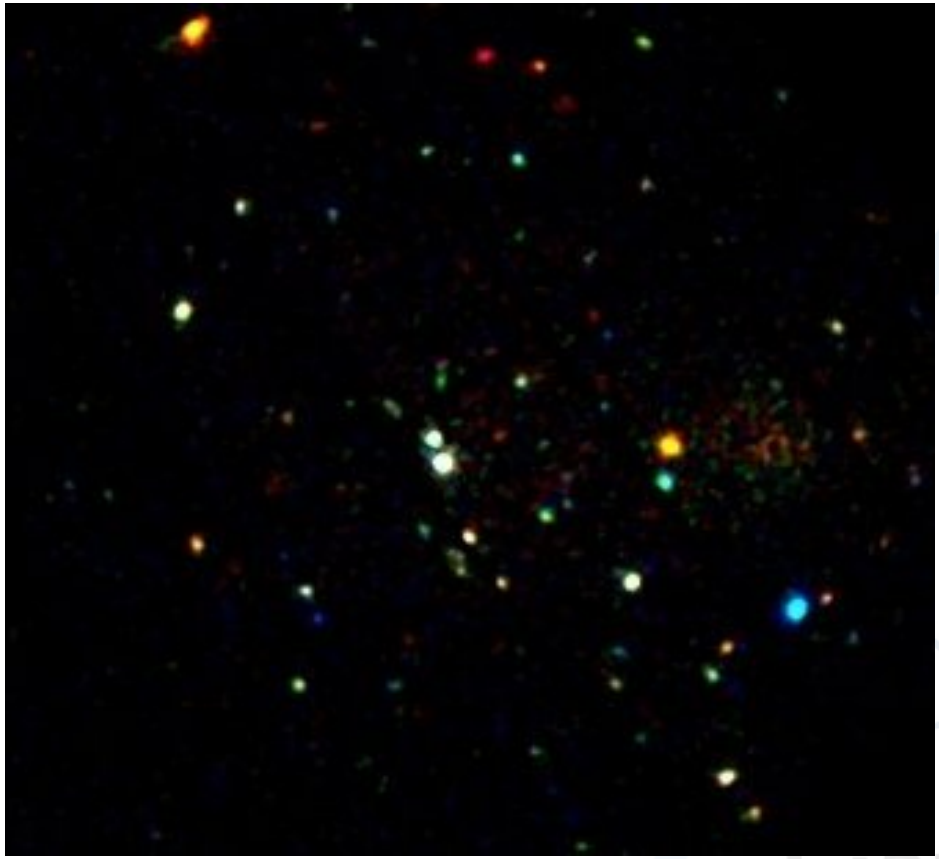

Omega Cen - XMM-Newton, 0.5-1.0, 1.0-2.0, 2.0-4.5

Adapted from Gendre, Barret & Webb (2003a)

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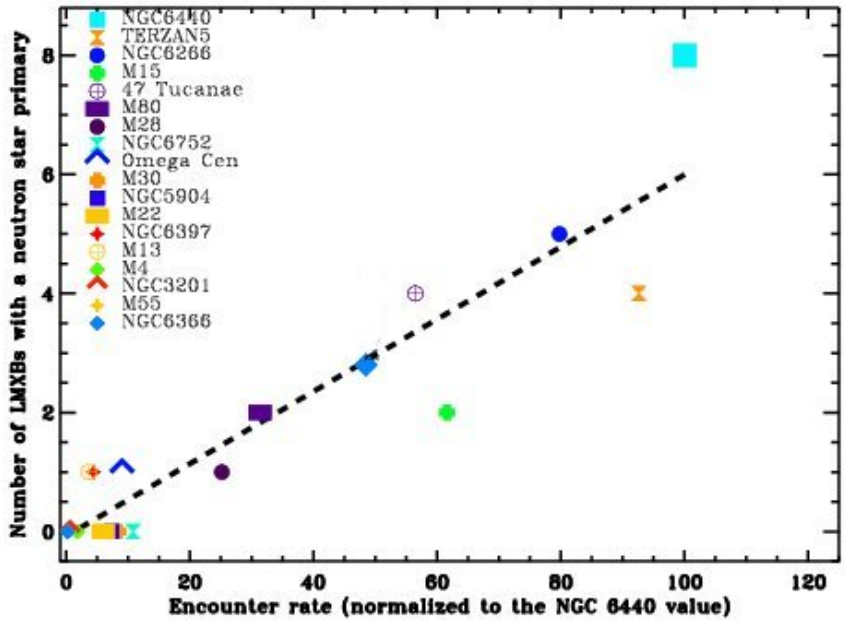

Adapted from Gendre, Barret & Webb (2003b)

Millisecond pulsars in globular clusters

- **γ-rays not affected by interstellar absorption**
- **Possibly wider γ-ray beams**
- **Spin down energy, $\dot{E} \propto I\, \omega\, \dot{\omega}$**
- **$n_{MSP} = L_\gamma / (\langle \dot{E} \rangle \langle \eta_\gamma \rangle)$**
- **Using GGC $\langle \dot{E} \rangle$ and local $\eta_\gamma \rightarrow n_{MSP}$**

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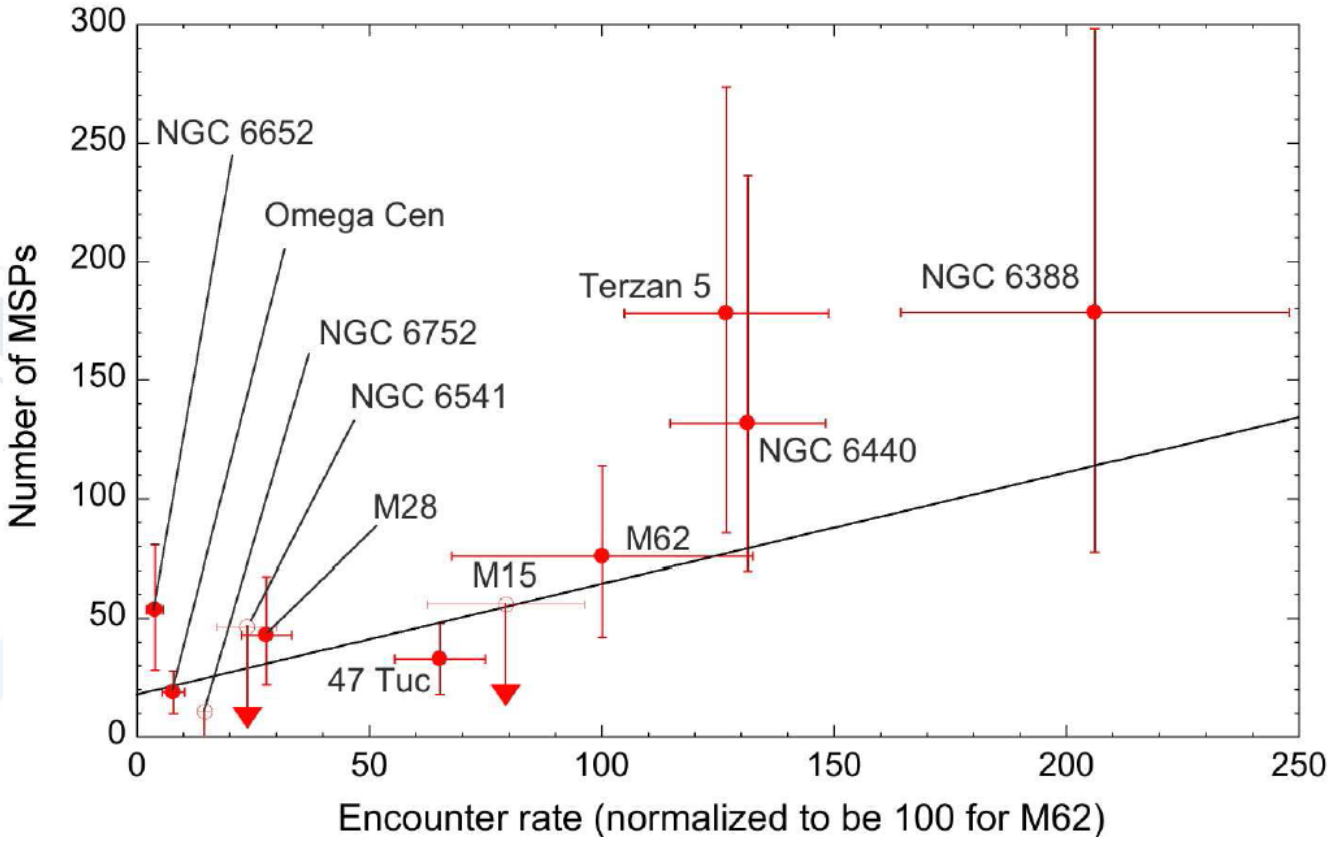

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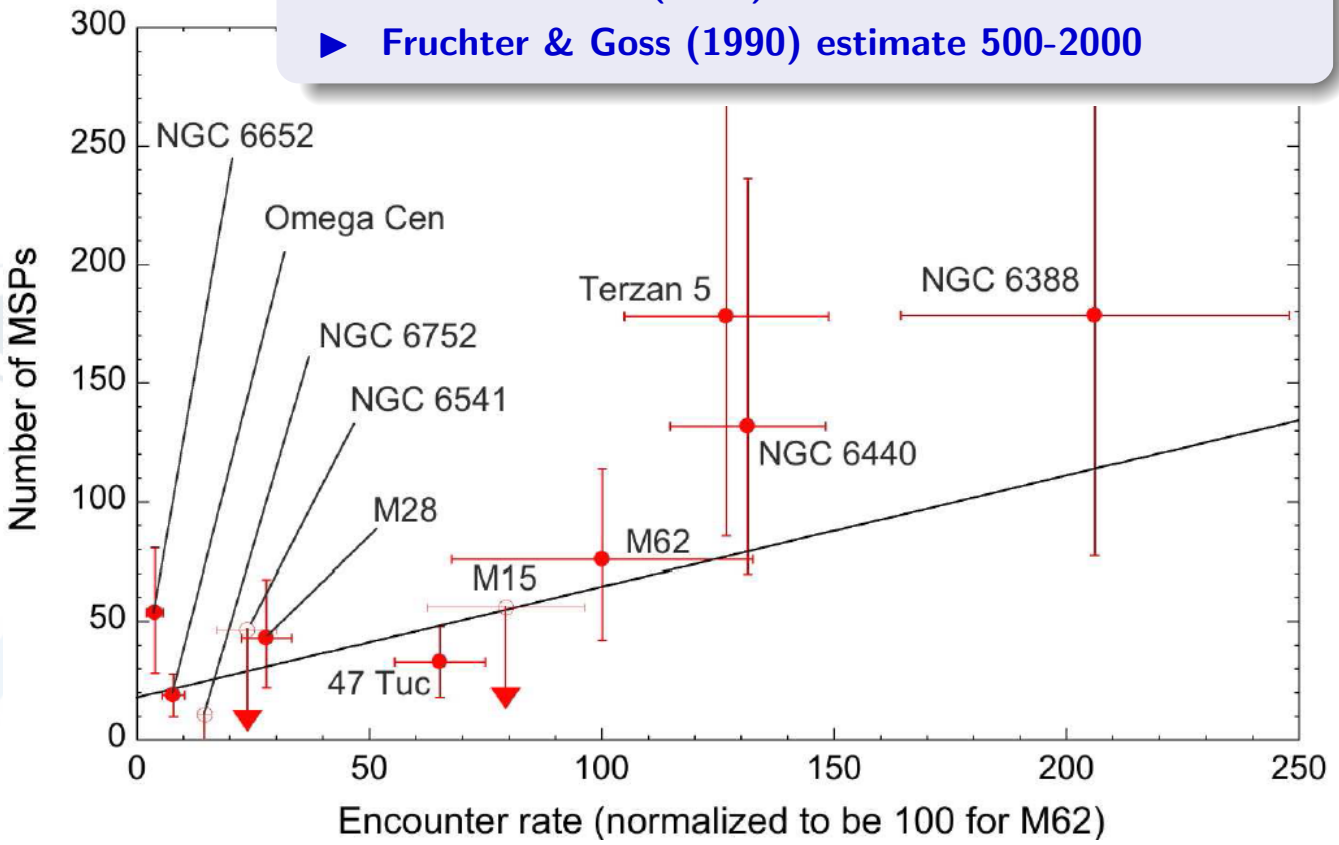
$L_\gamma = (5.5 \pm 1.9) \times 10^{32} \times \Gamma_e + (2.6 \pm 0.7) \times 10^{34}$ erg s^{-1}

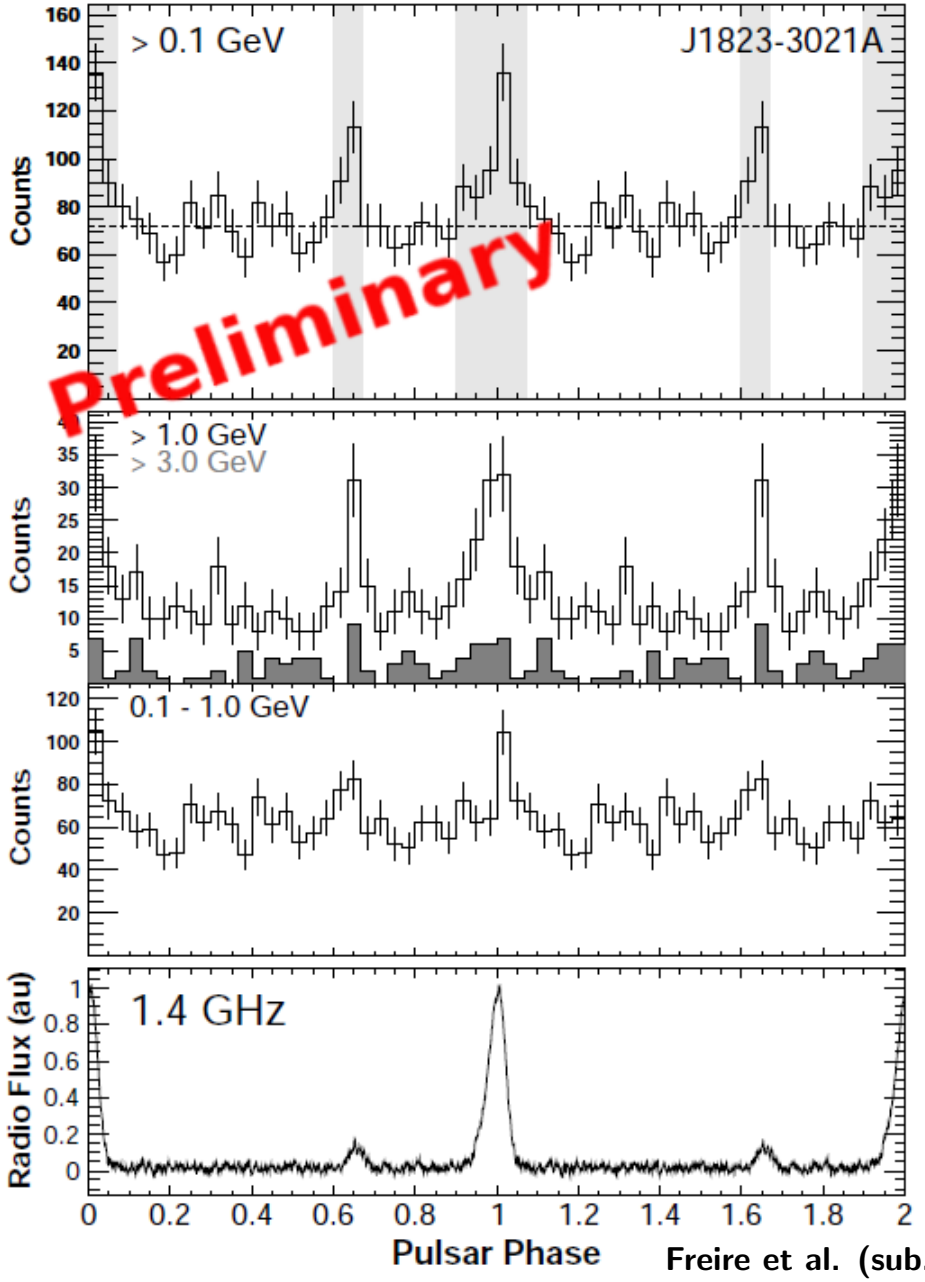
- $\Rightarrow$ 2600-4700 MSPs in GGCs
- Kulkarni et al. (1990) estimate $\sim$10000
- Fruchter & Goss (1990) estimate 500-2000



Abdo et al. (2010)

γ-RAY PULSATIONS OF GLOBULAR CLUSTER MSPs

- Good ephemerides for only 15 of 143 GGC MSPs
- PSR 1823-3021A in NGC 6624 (core collapsed)
- P=5.4 ms, $\dot{P}$=3.4$\times 10^{-18}$ s s^{-1}
- 6.8 σ (>100 MeV) detection
- No off-pulse emission $\Rightarrow$ <32 GC MSPs
- Large $\dot{P}$ may imply
  - accel. by other GC member(s)
  - if $P_{init} \propto B_0 M R \dot{M}$, then $\Rightarrow$ high mass ($\sim$2 $M_\odot$) or
  - possible accretion induced collapse formation



Phase aligned multi-λ observations of MSPs

- **Determine origin of the different emission**

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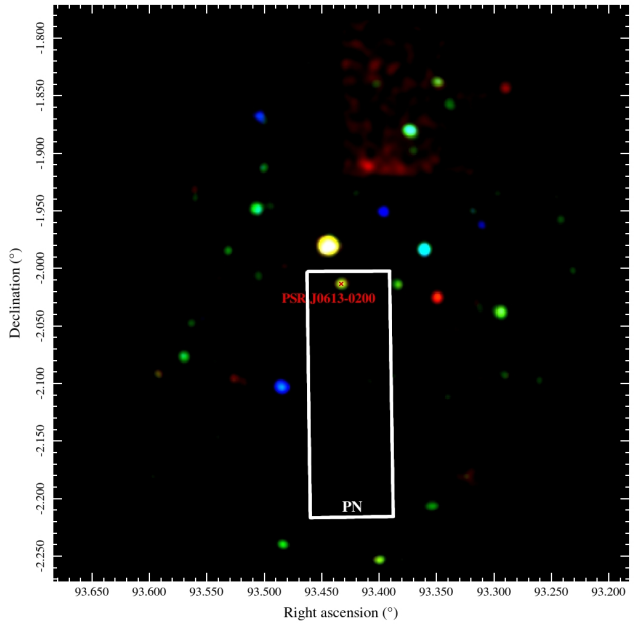

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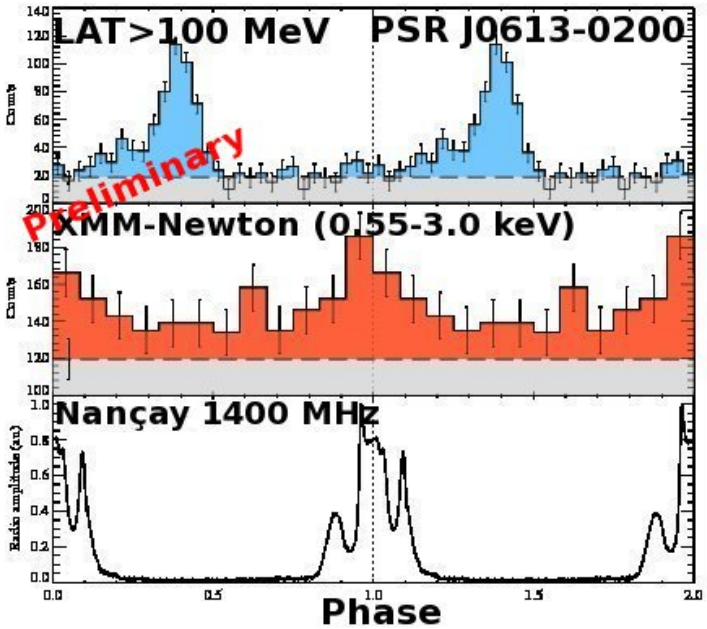

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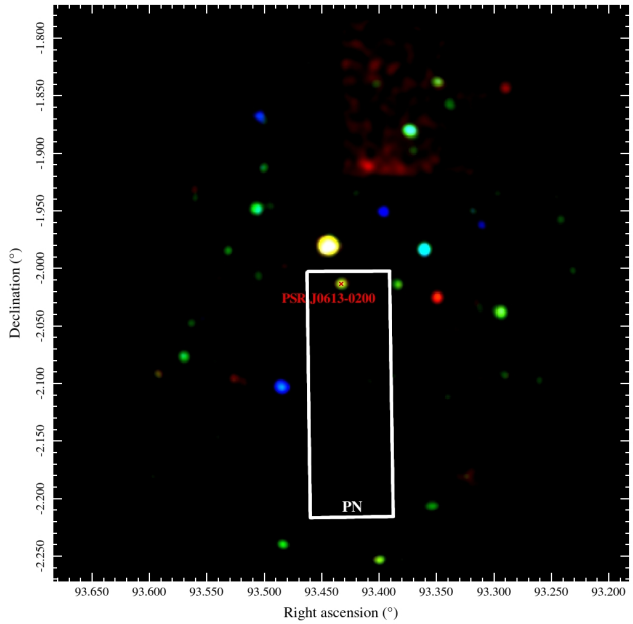

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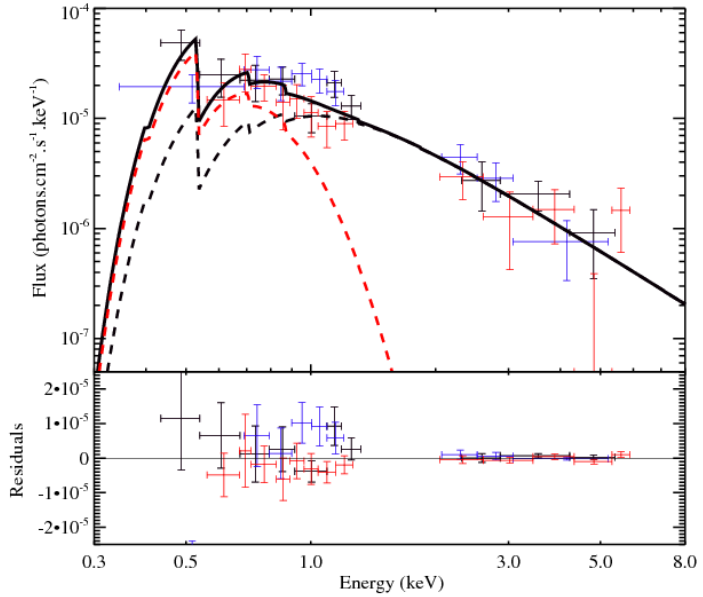
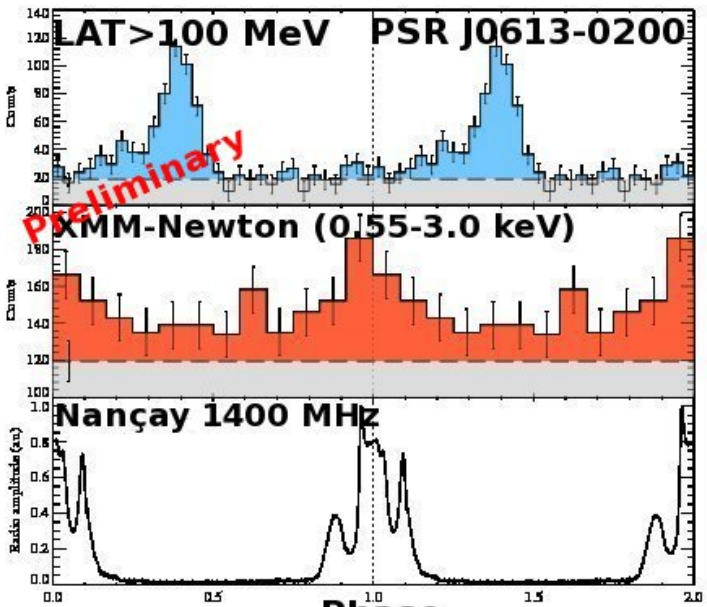
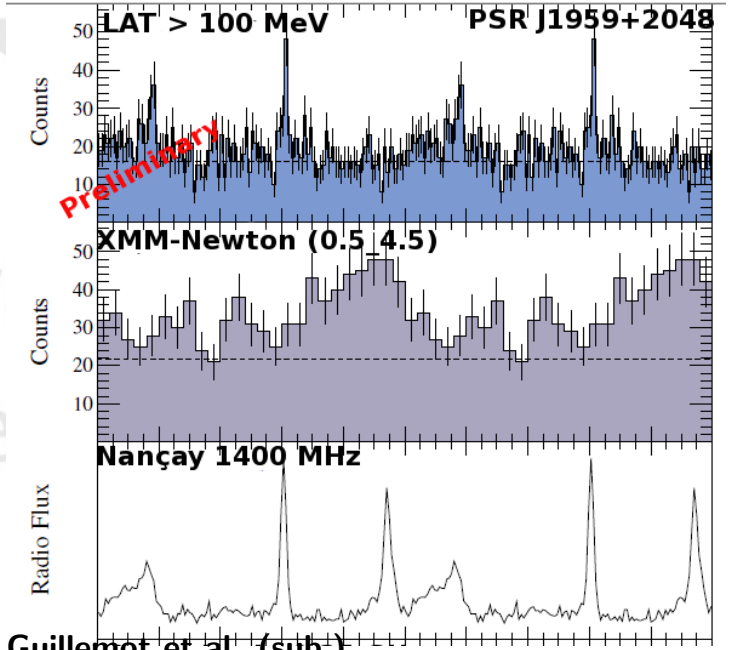




Pancrazi et al. (sub.)



Guillemot et al. (sub.)

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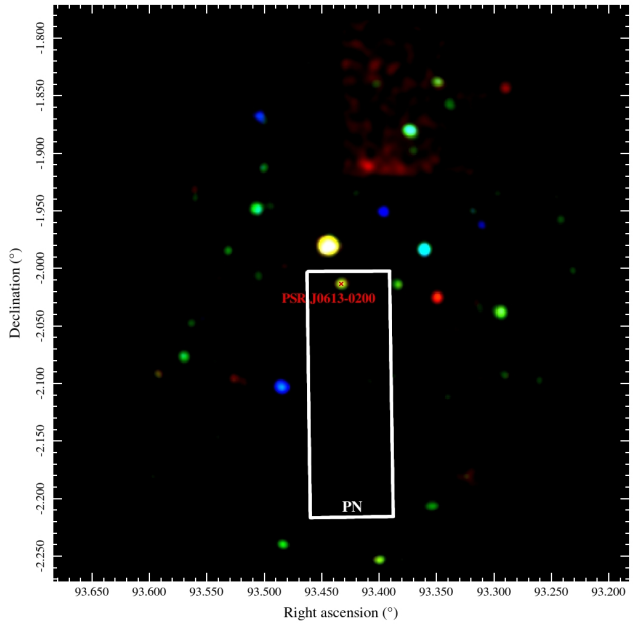
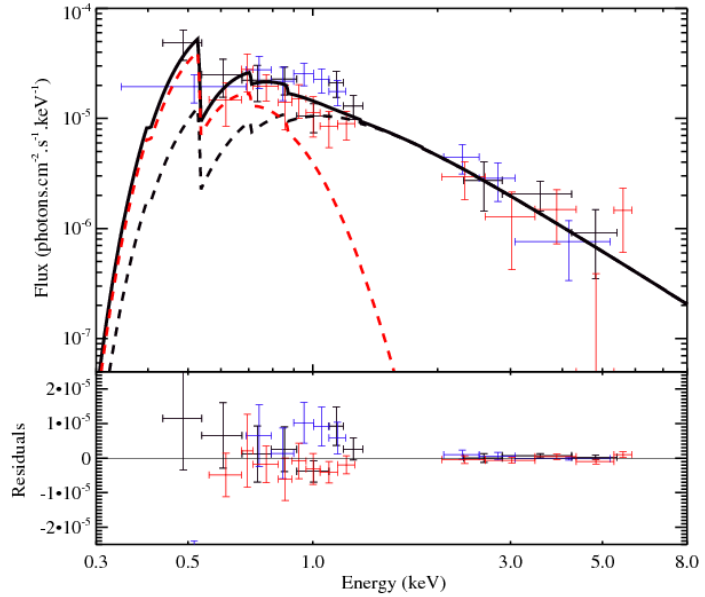
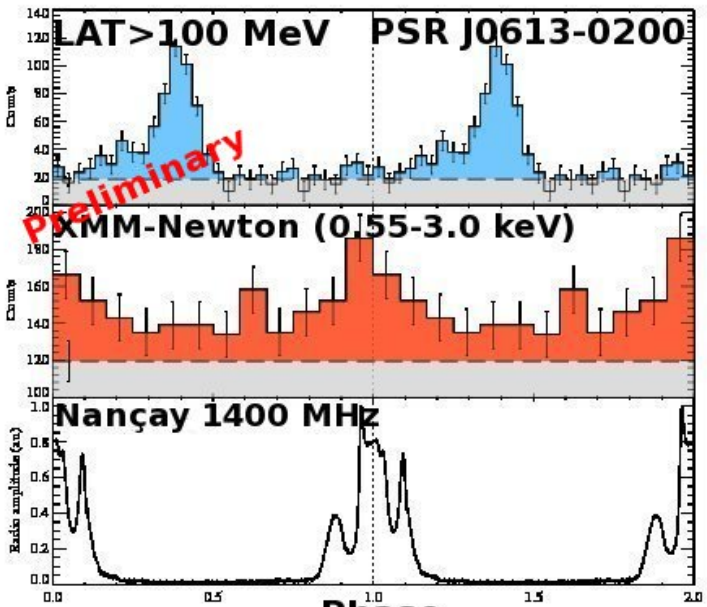


- Determine origin of different emission
- Aligned radio & γ-ray peaks indicate radio caustic emission
- Offset polar caps $\Rightarrow$ pair production in MSPs
- Some thermal X-ray emission from heated polar cap





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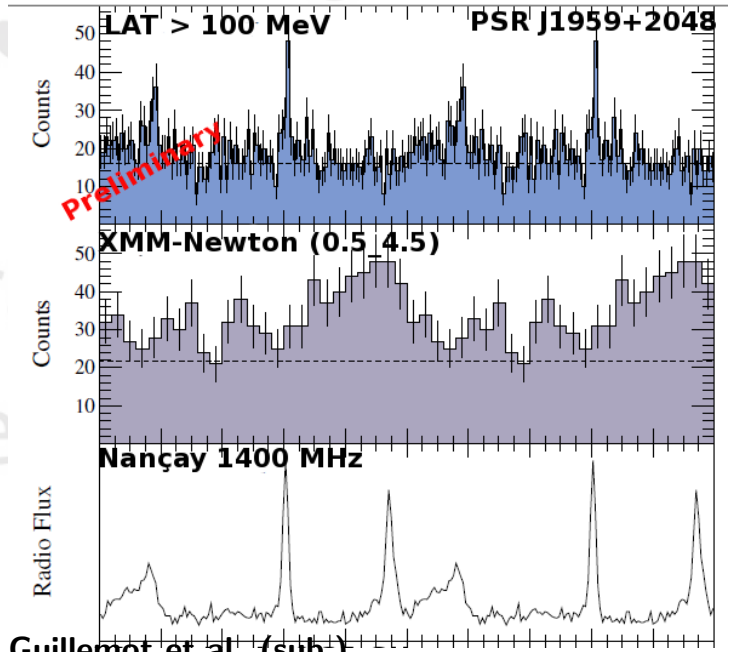

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Constraining the equation of state

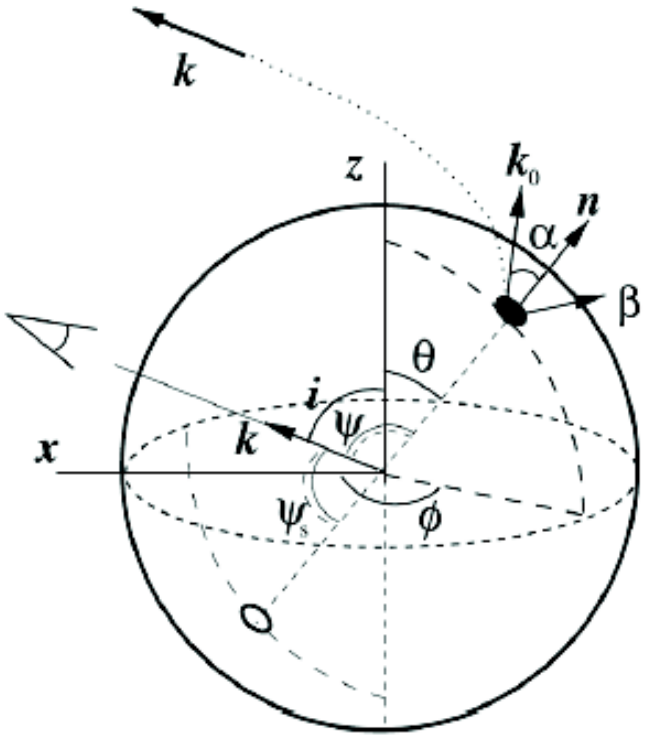
Thermal emission coming from a heated PC on a weakly magnetised NS covered by an H atmosphere (*Bogdanov et al. 2007*).

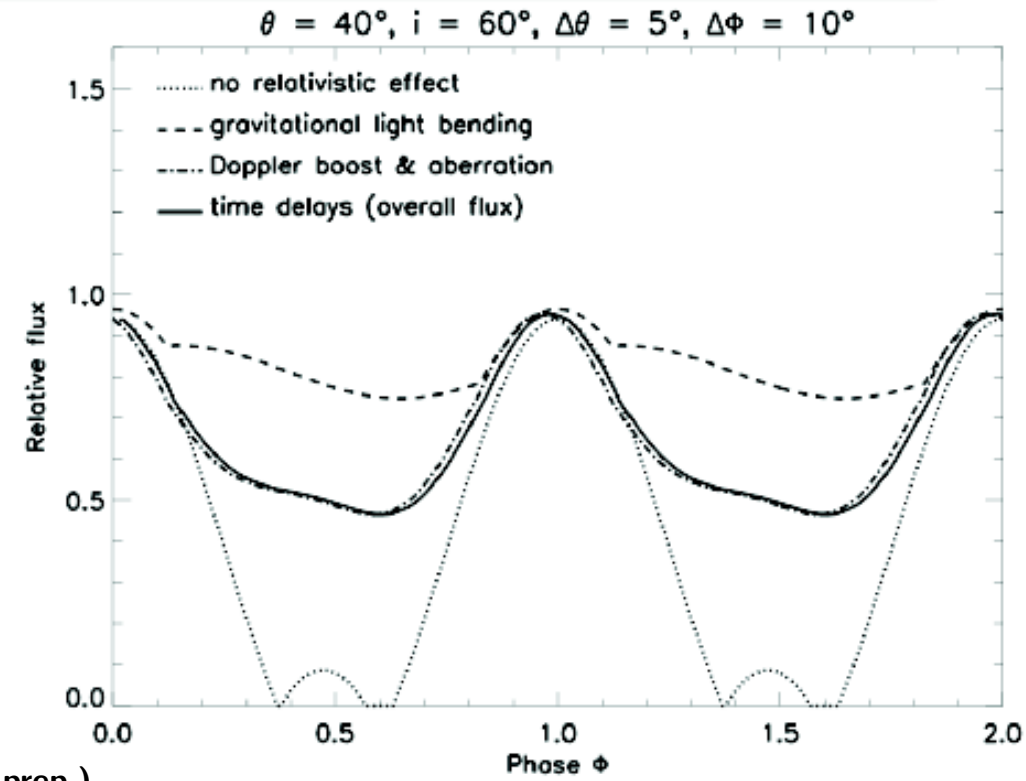
- Relativistic effects (light bending, aberration, Doppler boosting, time delays).
- Many parameters : M, R, freq, i, θ ...

$\Rightarrow$ Reduce the number of free parameters (*Venter et al. 2009*).

$\Rightarrow$ Account for the oblateness of the NS (*Morsink et al. 2007*).

$\Rightarrow$ **Tighter constraints on M/R.**





Pancrazi et al. (in prep.)

Summary

- **Thanks to Fermi we have discovered high energy emission from many (new) pulsars**
- **Higher conversion of spin down energy into γ-rays than X-rays**
- **Millisecond pulsar populations observed in globular clusters big enough to slow cluster core collapse**
- **Constraints made on the emission regions and mechanisms**
- **New pulsars in conjunction with γ- and X-ray modelling should help constrain neutron star equation of state**