An X-ray view to pulsars

Martino Marelli

Astro-siesta 15/01/2015
Overview

- Emission from rotation-powered pulsars
- X-ray pulsar emission: J1741 & J1813
- Future prospects & a new XMM-Newton tool
Rotation-powered, “classical” pulsars
Rotation-powered emission

- PSRs as rotating, magnetized NSs radiating at expense of rotational energy
- $E_{\text{rot}} \sim 10^{28}-10^{38}$ erg/s
- Efficiency $\eta_i = L_i/E_{\text{rot}}$
- $\eta_{\text{radio}} \sim 10^{-6}$
- $\eta_x \sim 10^{-3}$
- $\eta_y \sim 10^{-1}$
- Pulsar engine not yet understood
Radio and γ-ray bands

Radio pulsars:
- >2100 since Hewish+68, listed in ATNF PSRs database
- Thousands of articles spanning 50 years
- Synchrotron radiation from the inner magnetosphere (polar cap?)

γ pulsars:
- >160 since Campbell+73, listed in 2PC
- Only seven psrs before Fermi(2008); tens of articles since then
- Curvature radiation from the outer magnetosphere (outer gap, slot gap, ...
Spectral Energy Distribution
Spectral Energy Distribution

Radio-loud
Radio-quiet
X-loud
X-quiet
\(\gamma\)-loud
\(\gamma\)-quiet

Radiation Type  |  Radio  |  Microwave  |  Infrared  |  Visible  |  Ultraviolet  |  X-ray  |  Gamma ray
---|---|---|---|---|---|---|---
Wavelength (m)  | 10^3  | 10^-2  | 10^-5  | 0.5x10^-6  | 10^-8  | 10^-10  | 10^-12
Frequency (Hz)  | 10^4  | 10^8  | 10^12  | 10^15  | 10^16  | 10^18  | 10^20

Temperature of objects at which this radiation is the most intense wavelength emitted

- 1 K  | 1 K
- 100 K  | -272 °C
- 10,000 K  | 9,727 °C
- 10,000,000 K  | ~10,000,000 °C
Multiwavelength emission

Crab

Vela

J1057

J0659

J1420

J2229

Abdo+13
Radio and γ-ray simulations

Bai & Spitkovski
Radio and γ-ray simulations

10
Radio and y-ray simulations

In particular, the best results came from simultaneous radio-y-ray simulations.

Pierbattista+14 tested different emission models and “found” the geometry of ~120 Fermi pulsars.
X-ray band - 1

- Lack of X-ray surveys, few telescopes with adequate time/spectral resolution result in dishomogeneous observations (0s to 1Ms)
- Few, incomplete catalogs in literature: Becker09 (45 psrs), Marelli+11&2PC (49 psrs)
- Many observational papers but few theoretical paper focussed on X-ray emission
- (Thermal, non-thermal, nebular emissions mixed)
- Synchrotron radiation from particles in outer magnetosphere is thought to produce a broad spectrum of emission from infrared to up to 10 MeV... but it works only for the Crab (no phase lag!)
Overview

- Emission from rotation-powered pulsars
- X-ray pulsar emission: J1741 & J1813
- Future prospects & a new XMM-Newton tool
J1741-2054

- Bright γ-ray source located 5° from the plane, at a distance of about 400 pc (DM)
- Parkes detected it as a radio-faint pulsar – flux density (1400MHz) = 0.16 mJy (Camilo+09)
- Slow&Low energetic – P = 413 ms, $\dot{E} = 9 \times 10^{33}$ erg s$^{-1}$

Marelli+14
J1741 – X-ray light curve

- BB and PL ~40% pulsed
- Thermal and non-thermal peaks in phase

- X, radio, γ-ray peaks out of phase
- No γ-ray spectral variation with phase
- X-ray spectral variation with phase
J1741 – X-ray phase-resolved

Phase-resolved model parameters

Counts

Pl

NormPow

NormBB

Phases
J1813-1246

- Located 2.5° from the plane, > 2.5 kpc
- Bright in γ-rays & radio quiet
- 2\textsuperscript{nd} most energetic radio-quiet pulsar (\(\dot{E} = 6.3 \times 10^{36} \text{ erg s}^{-1}\)) and the fastest one (\(P = 48.1\text{ms}\))
J1813 – X-ray light curve

- VERY pulsed
  \( PF = (96 \pm 3) \% \)
- Two asymmetric peaks
  phase lag \( 0.496\pm0.001 \)
- Off-pulse emission
  \( (17\sigma) \)

- No spectral variation
  with phase down to
  \( 0.08 \) in \( \Gamma \) \( (3\sigma) \)
J1813 – γ-ray light curve

- Two asymmetric peaks phase lag 0.485±0.003
- No off-pulse emission
- Very significant (>>10σ) spectral variation with phase, mainly due to Γ, with softening during peaks

>0.1 GeV

$\Gamma$,
J1813 – new geometrical model

- magnetic inclination angle of 60°
  - a) simulated γ-ray emission for a separatrix layer model from outer magnetosphere
  - b) simulated cone beam X-ray emission from the polar caps for an emission altitude 0.2 R_{LC}
  - c) Model γ-ray and X-ray light curves for a viewing angle of 90°
Overview

- Emission from rotation-powered pulsars
- X-ray pulsar emission: J1741 & J1813
- Future prospects & a new XMM-Newton tool
### X-ray band - 2

<table>
<thead>
<tr>
<th>87 X-ray psrs</th>
</tr>
</thead>
<tbody>
<tr>
<td>43 puls.</td>
</tr>
<tr>
<td>45 not puls.</td>
</tr>
<tr>
<td>22 pow</td>
</tr>
<tr>
<td>17 pow+bb</td>
</tr>
<tr>
<td>2 bb</td>
</tr>
<tr>
<td>2 ?</td>
</tr>
<tr>
<td>33 pow</td>
</tr>
<tr>
<td>7 pow+bb</td>
</tr>
<tr>
<td>3 bb</td>
</tr>
<tr>
<td>2 ?</td>
</tr>
</tbody>
</table>

| 14 X-ray psrs with “good” non-thermal light curve and spectrum |

A comprehensive, multiwavelength study of the spectra and light-curves of these pulsars is necessary to build a model!

— MY FUTURE WORK —
A new tool for X-ray band

In γ-rays, photon weighting based on position and spectrum resulted to be a winning method to minimize source contamination, coming from high positional uncertainties. This increases the sensitivity to pulsars by more than 50% under a wide range of conditions (Kerr+11).

In X-rays, positional uncertainties are ~10 lower, but...

We have much more point-like and extended sources and we have a possibly high background, so that...

We should test a similar method
XMM-Newton photon weighting

I am developing a python program that evaluates for each photon the probability of coming from one of the sources in an input list

Input: event file, sources positions, sources spectra, sources spatial extension and shape

Output: probability columns in event file, different band simulated & subtracted images

Tests on the first versions revealed an improvement ranging from 1.1 to 2 of the H-value in a pulsation search of six known X-ray pulsars
An example...

Observed

Simulated

Subtracted

Marelli+ in prep
There are some frequencies we were never meant to find.

(Thank you for the attention!)