High-Energy Emission of PSR B1937+21

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Abstract:

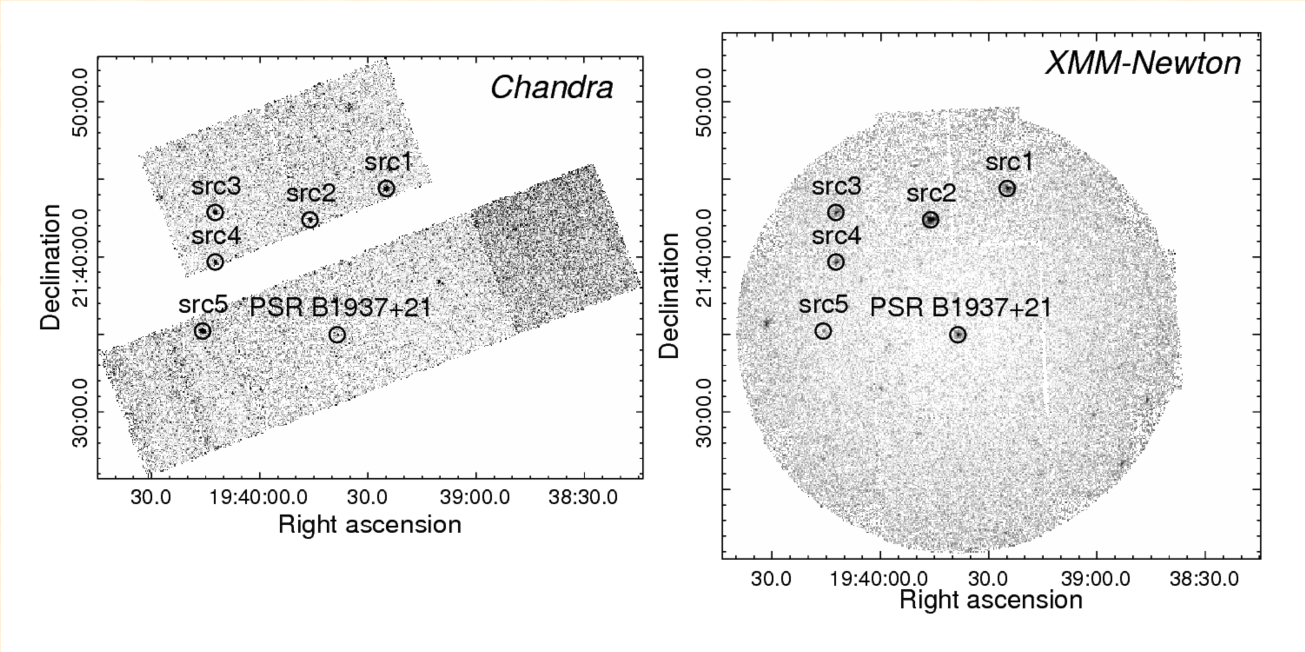
PSR B1937+21 is the first millisecond pulsar (MSP) detected and it is representative of an emerging class of MSPs that shows aligned pulse profiles in different energy bands (Guillemot et al. 2012). We report on a study of the high-energy emission of the pulsar using archival *Chandra*, *XMM-Newton*, and *Fermi* LAT observations. Our results indicate that the pulsar X-ray emission is ~100% pulsed and has a purely non-thermal spectrum with a hard photon index of 0.9±0.1. Using 5.5 yr of *Fermi* survey data, we obtained much improved constraints on the pulsar's gamma-ray timing and spectral properties. The pulsed spectrum is adequately fitted by a simple power-law with a photon index of 2.38±0.07, and an exponential cutoff power-law model is not significantly better. Both the gamma-ray and X-ray pulse profiles exhibit similar two-peak structure and generally align with the radio peaks.

A comparison with other MSPs suggest that the aligned profiles and the hard spectrum in X-rays could be common properties among MSPs with high magnetic fields at the light cylinder. We discuss a simple model in which the non-thermal X-rays are contributed by IC scattering between radio waves and primary particles in the outer magnetosphere and by synchrotron radiation from secondary particles. As shown in the SED below, this toy model is capable to qualitatively reproduce the observed spectral energy distribution in X-rays and gamma-rays.

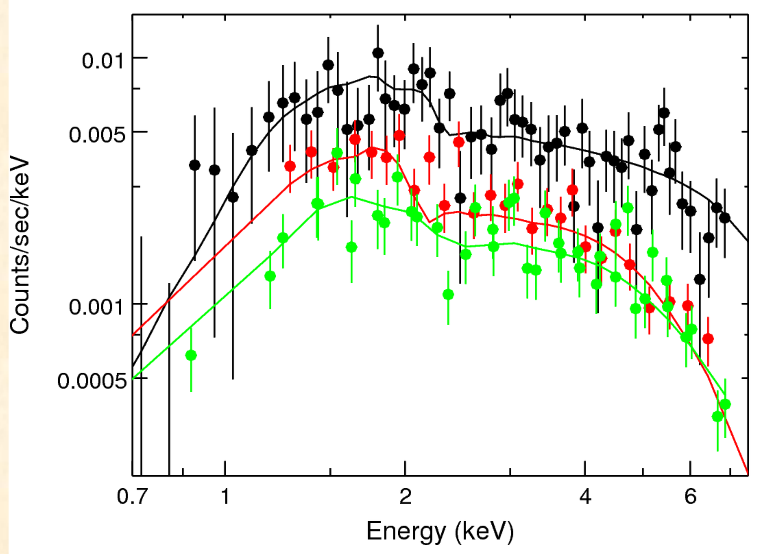
Observations:

Telescope / Instrument	Date	Exposure
Chandra / ACIS-S	2005 Jun 28	49.5ks
XMM-Newton / MOS1, MOS2, PN	2010 Mar 29	40.4ks, 47.5ks, 40.4ks
Fermi / LAT	2008 Aug – 2014 Jan	5.5yr

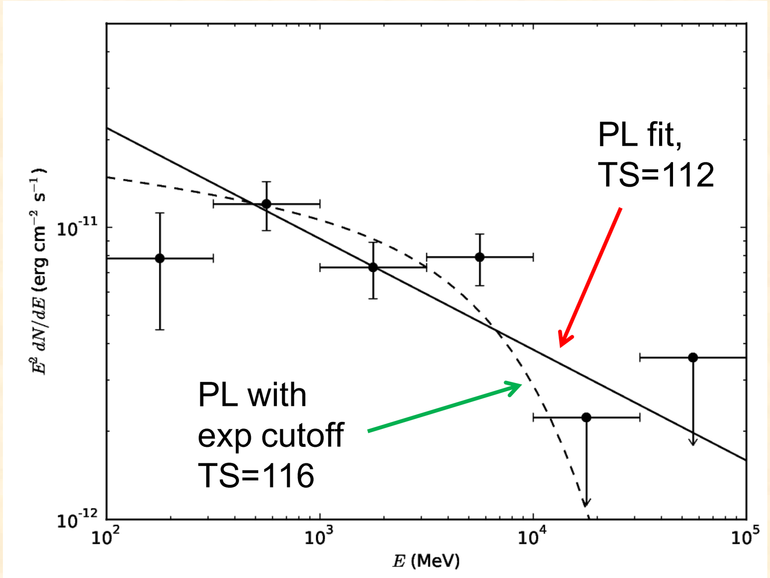
X-ray images of the field of PSR B1937+21

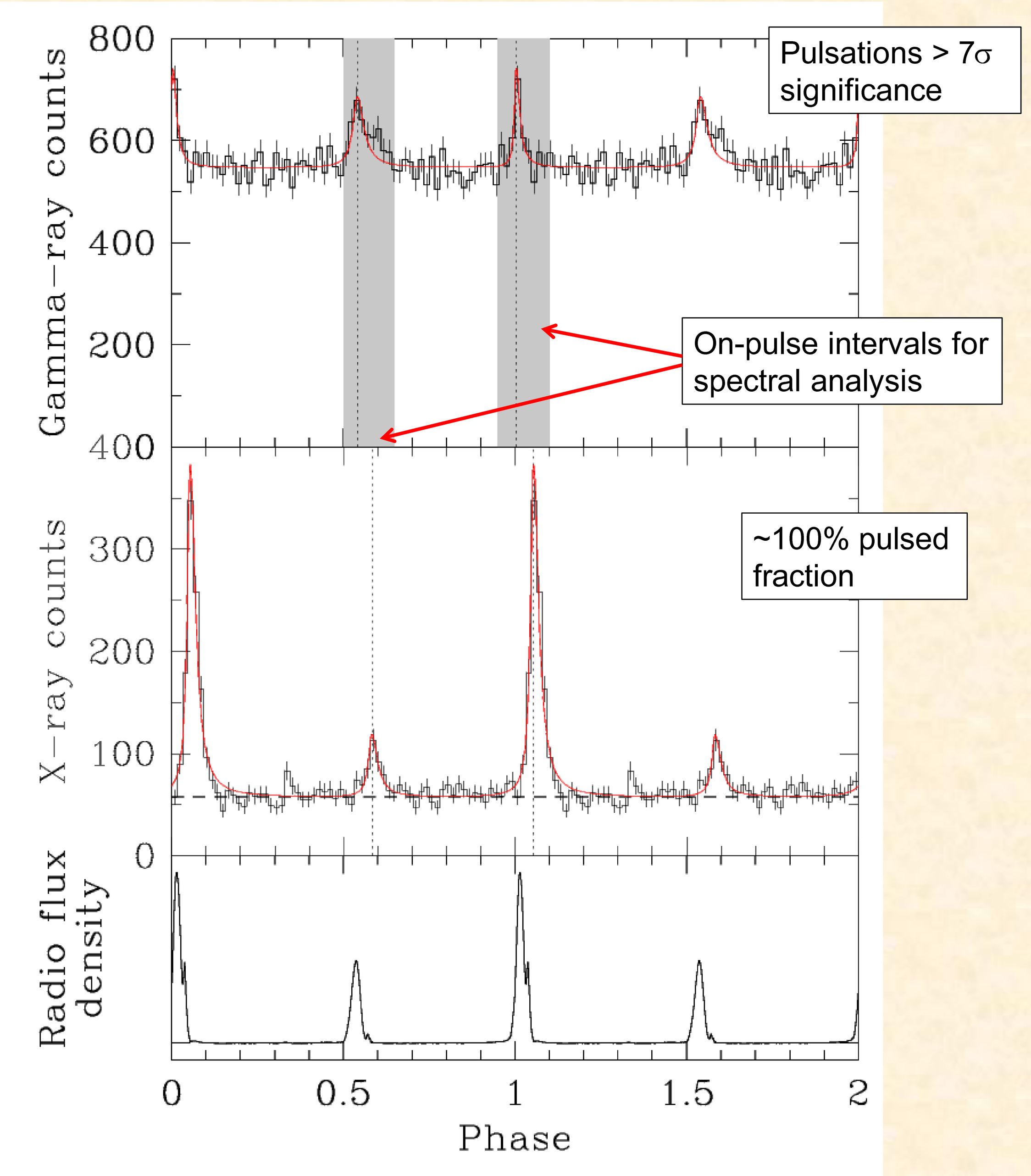


Best-fit PL X-ray spectrum



Gamma-ray spectrum





Best-fit Timing and Spectral Parameters of PSR B1937+21

Parameter	X-ray	Gamma-ray
Timing		
First peak		
Position, Φ_1	0.054 ± 0.001	$0.003^{+0.001}_{-0.003}$
Width parameter, σ_1^-	$0.010^{+0.001}_{-0.002}$	$0.006^{+0.001}_{-0.004}$
Width parameter, σ_1^+	$0.019^{+0.001}_{-0.003}$	$0.012^{+0.001}_{-0.005}$
$\mathrm{FWHM}_1 = \sigma_1^- + \sigma_1^+$	$0.029^{+0.001}_{-0.003}$	$0.019^{+0.002}_{-0.006}$
Radio lag, δ_1	0.068 ± 0.001	$-0.011^{+0.001}_{-0.004}$
Second peak		
Position, Φ_2	0.583 ± 0.005	$0.540^{+0.006}_{-0.005}$
Width parameter, σ_2^-	$0.012^{+0.003}_{-0.007}$	$0.015^{+0.001}_{-0.007}$
Width parameter, σ_2^+	$0.020^{+0.001}_{-0.009}$	$0.023^{+0.001}_{-0.010}$
$\mathrm{FWHM}_2 = \sigma_2^- + \sigma_2^+$	$0.032^{+0.003}_{-0.012}$	$0.018^{+0.002}_{-0.012}$
Radio lag, δ_2	$0.032^{+0.006}_{-0.005}$	$0.003^{+0.006}_{-0.005}$
Spectroscopy		
Column density, N_H (10^{22} cm^{-2})	1.2 ± 0.2	...
Photon index, Γ	0.9 ± 0.1	2.38 ± 0.07
Statistic	$\chi^2_\nu = 0.86$	TS-value=112
Unabsorbed energy flux[a] (10^{-12} erg cm^{-2} s^{-1})	$0.23^{+0.04}_{-0.03}$	16 ± 2
Luminosity[a] (10^{33} erg s^{-1})	0.7	49
Efficiency[a], η	6×10^{-4}	0.044

High-$\dot{E}$ MSPs and Their X-ray Properties.

Name	P (ms)	$\dot{E}$ (10^{35} erg s^{-1})	B_s (10^8 G)	B_{lc} (10^5 G)	Dist. (kpc)	Γ_X	L_X (10^{32} erg s^{-1})	PF (%)
B1821−24	3.1	22	23	7.3	5.1	1.23 ± 0.03	14	82.5 ± 4
B1937+21	1.6	11	4.1	10	5.0	0.9 ± 0.1	6.8	~ 100
B1820−30A	5.4	8.3[a]	43[a]	2.5[a]	7.9	...	...	...
J1701−3006F	2.3	7.3[a]	7.2[a]	5.5[a]	6.9	...	...	...
J1701−3006E	3.2	3.6[a]	10[a]	2.7[a]	6.9	...	...	...
J0218+4232	2.3	2.4	4.3	3.1	2.7	1.10 ± 0.06	3.3	64 ± 6
B1957+20	1.6	1.1	1.4	3.0	2.5	~ 2[b]	~ 0.5[b]	...
J1750−3703D	5.1	1.4[a]	16[a]	1.1[a]	12	< 50	...	...
B0021−72F	2.6	1.4	4.1	2.1	4.0	...	0.055[c]	...
J1740−5340A	3.7	1.4[a]	7.9[a]	1.5[a]	3.4	1.73 ± 0.08[b]	0.22[b]	...
J1701−3006D	3.4	1.2[a]	6.6[a]	1.5[a]	6.9	...	...	...

High-$\dot{E}$, high-B_{lc} MSPs:

- Aligned radio, X-ray, and gamma-ray profiles
- Large pulsed fraction
- Hard power-law spectrum in X-rays
- Giant radio pulses

Aligned profiles => same emission zone

- Gamma-rays: curvature radiation from primary particles
- X-rays: inverse-Compton between primary particles and radio waves? + Synchrotron
- Radio: coherent emission from plasma instability?

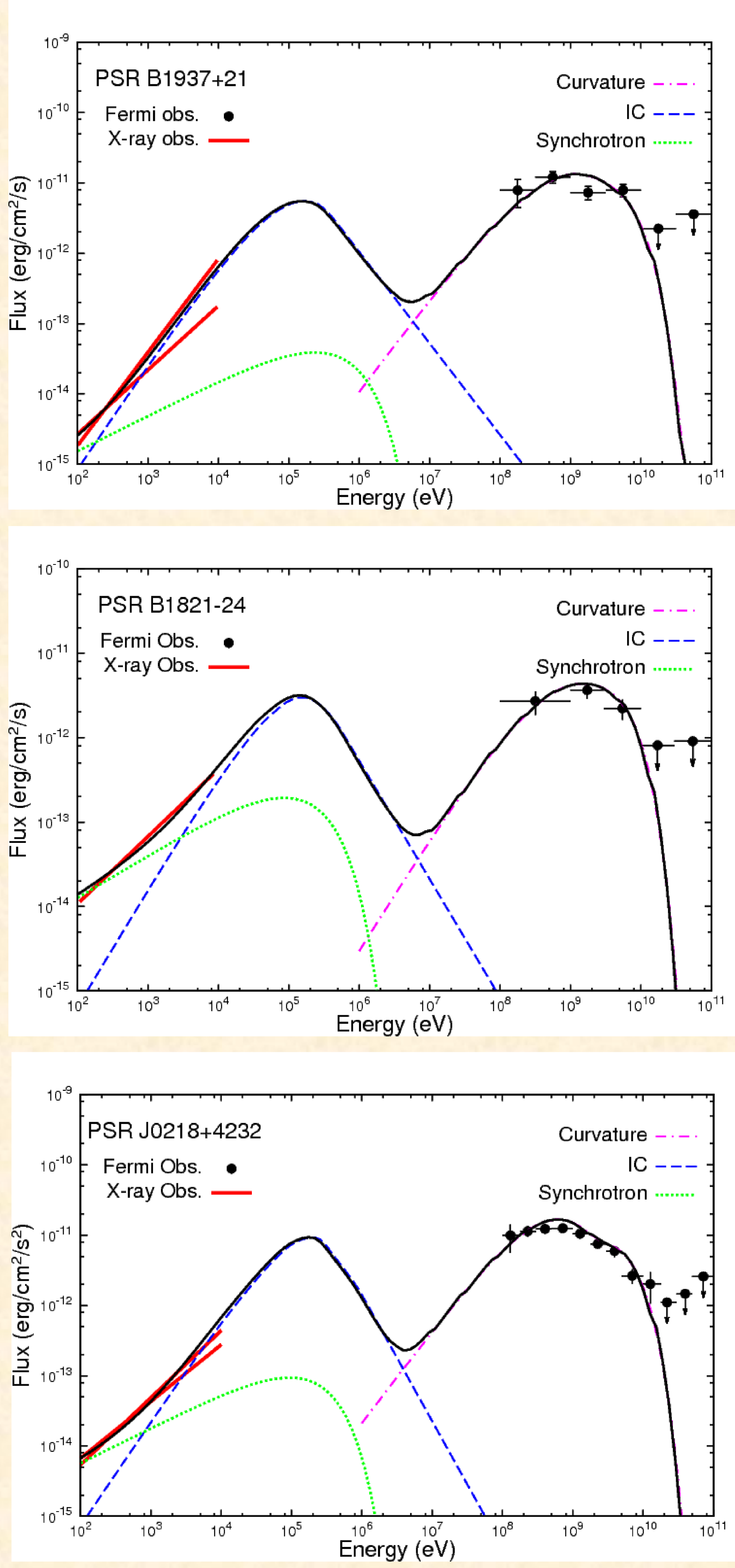
- Fit the X-ray to gamma-ray spectrum: assuming a broken power-law radio spectrum with turnover at 10MHz:

$$F_{\rm rad}(\nu) = A \begin{cases} \left(\frac{\nu}{100\,\rm MHz}\right)^{\beta_1} & \text{for } \nu \geq 10\,\rm MHz \\ \left(\frac{10\,\rm MHz}{100\,\rm MHz}\right)^{\beta_1} \left(\frac{\nu}{10\,\rm MHz}\right)^{\beta_2} & \text{for } \nu < 10\,\rm MHz \end{cases}$$

β_1 from observed flux density between 400MHz and 1.4GHz, β_2 taken to be 0.5.

- Future radio observations LOFAR and hard X-ray observations with *NuSTAR* or *Astro-H* would be useful.

Modeling the X-ray and gamma-ray spectrum of high-$\dot{E}$, high-B_{lc} MSPs



Reference:

Ng, C.-Y., Takata, J., Leung, G. C. K., Cheng, K. S., & Philippopoulos, P. 2014, ApJ, 787, 167

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