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X-ray Emission & Properties of Double Neutron Star Binaries

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Credits: NASA

Double Neutron Star Binaries

Double neutron star binaries (DNSBs) represent a rare class of systems in which two neutron stars interact in a tight orbit. The formation and evolution of these extreme cases depend on the inital star masses, the supernova kick velocity imparted to the NSs at birth and binary orbital parameters.

Despite extensive searches, only a few DNSBs are currently confirmed (based on mass measurements). High-energy observations represent a crucial aspect for these studies, in particular for what concerns the physics of the magnetosferic emission and dissipative shocks in the close environment of the two neutron stars.

Properties of DNSBs

- a rare population: 5 firmly confirmed, 10 very likely candidates
- detection by pulsar radio survey
- eccentricity evolves on short timescales
- orbital period of the order of a few hours
- emission of gravitational waves (orbital decay)
- coalescence rate related to the initial kick velocity at birth of the NSs

What is at the origin of the X-ray emission?

- emission in the magnetosphere or heated polar caps?
- interaction of the pulsar's wind with the NS companion?

The **Double Pulsar** and **PSR J1537+1155** are the only DNSBs detected in X-rays with the current generation of X-ray telescopes.

	J0737-3039	**J1537+1155**	J1756-2251	J1915+1606	J2130+1210C
$E_{rot}(10^{33} ergs\ s^{-1})$	5.8	**1.8**	1.7	1.6	6.8
d (kpc)	1.1[(a)]	**1.0**	2.5	7.0	10
P (ms)	22.7(PSR A)	**37.9**	28.5	59.0	30.5
$\dot{P}$ (10^{-18})	1.74	**2.42**	1.01	8.60	4.99
E_{rot}/d^2 $(10^{-10}$ erg cm^{-2} s$^{-1})$	5.1	**1.9**	0.28	0.03	0.07
$F^{(b)}_{0.2-3keV}$ $(10^{-15}$ erg cm^{-2} s$^{-1})$	40	**2.4**	2.3 ?[(c)]	0.3 ?[(c)]	0.7 ?[(c)]
P_{orb} (days)	0.102	**0.421**	0.32	0.3	0.3
e	0.0877	**0.274**	0.18	0.62	0.68

[a] Distance updated according to a recent VLBI paral. observation (Deller et al., 2009, Science, 323, 1327).
[b] X–ray flux in the 0.2-3 keV range.
[c] Extimated X–ray flux assuming $L_X = 10^{-3} E_{rot}$.

The Double Pulsar

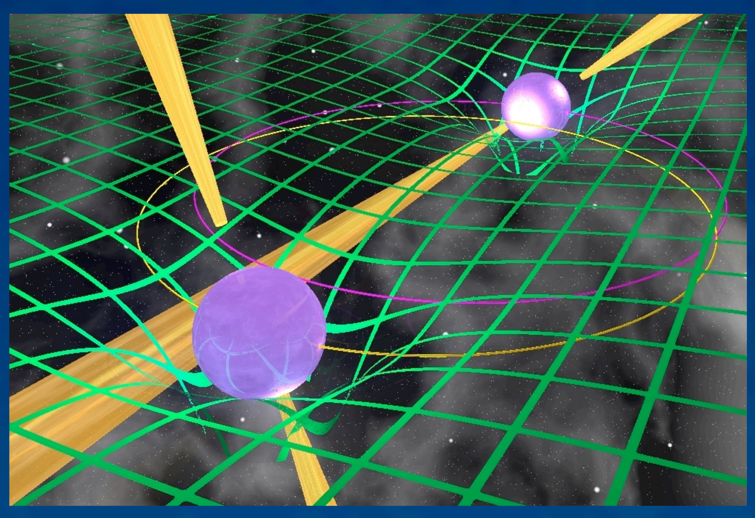
XMM-Newton observations of this unique system

Two «Large Programs» were performed with XMM-Newton in 2006 (235 ks) and 2011 (370 ks) to better understand the X-ray emission from the pulsars (PSR A and PSR B) and their interaction.

Different spectral scenarios (up to 3 model components) can fit the data (Pellizzoni et al. 2008, Egron et al. in prep).

Most of the emission (>75%) is produced by synchrotron and/or inverse Compton in PSR A's magnetosphere.

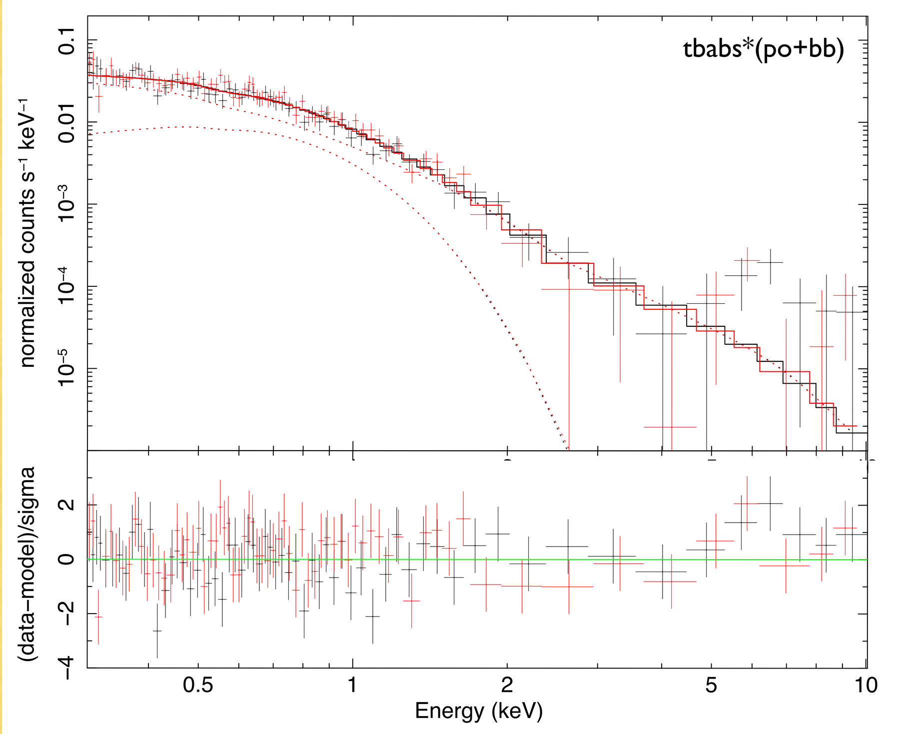
There is no evidence for a spectral signature of a bow shock between the relativistic wind of PSR A and the magnetosphere of PSR B.



Credits: Michel Kramer

See M.N Iacolina's talk for the timing analysis of the Double Pulsar: PSR J0737-3039

An intriguing feature at high energy



Spatial models between 4 an 8 keV confirm that the detection at high energy does not come from the background.

A Gaussian at 6.5 keV fits correctly the data

Fig. 1 Epic-pn data obtained in 2006 (Egron et al. in prep)

PSR J1537+1155

Its higher **eccentricity** represents a unique opportunity for the identification and study of NS interaction signatures.

Two observations were performed by *Chandra*:
36ks (2005) and 38ks (2009): detection of 33 photons

=> **deficit of photons at the apastron**
=> X-ray emission when the companion star crosses the equatorial pulsar wind of the recycled pulsar

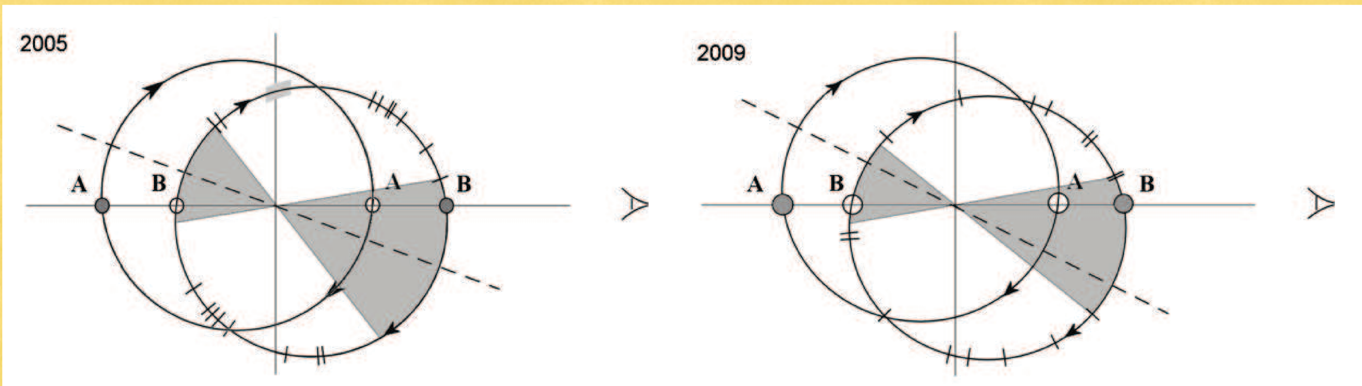


Fig. 2 Location of the detected photons (thickmarks). Durant et al. 2011.

A new observation was performed by *XMM-Newton* on February 2015 for a total exposure time of 125 ks (Epic-PN in small window mode).

Aims:

- Constrain the orbital flux modulation suggested by Chandra
- Spectral analysis with reasonable counts statistics to confirm the very soft X-ray spectrum
- Timing analysis at the known radio ephemeris to measure the pulsed flux
- Compare the properties of the X-ray emission of J1537+1155 with those of PSR J0737-3039 to better understand the X-ray emission (mechanisms, nature, origin) of DNSBs.

DNSBs represent a rare and very interesting class of objects. Multi-wavelength observations are necessary to better understand the physics and properties of such systems. Strong interactions between the two neutron stars are expected to produce an emission at high energy. The X-ray observations of the Double Pulsar and PSR J1537+1155 indicate a very soft spectrum (photon index of the power-law at about 3), with no spectral evidence of a shock between the wind of the pulsar and the magnetosphere of the other neutron star. However, a feature at about 6.5 keV is visible in the data of the Double Pulsar, and a deficit of photons seems to be revealed at the apastron of PSR J1537+1155. The recent observation with XMM-Newton will certainly help to better understand this system.

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