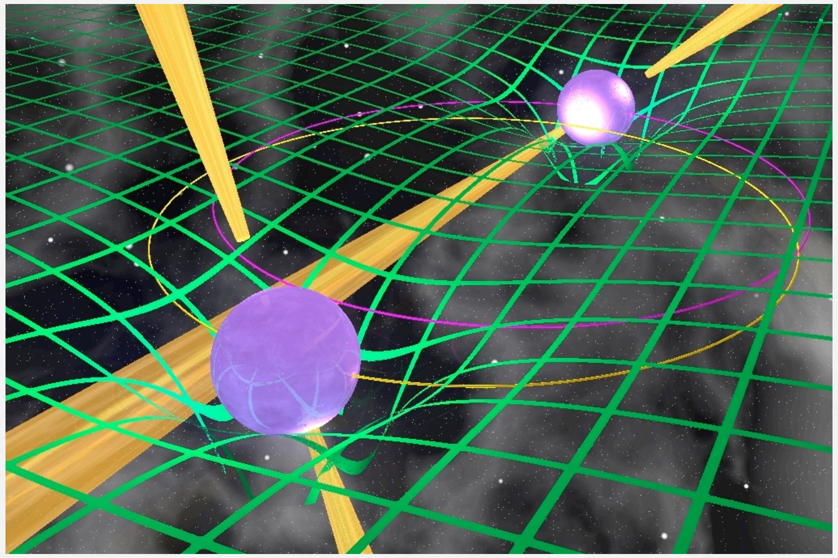
Spectral Analysis of the Double Pulsar PSR J0737-3039 with XMM-Newton



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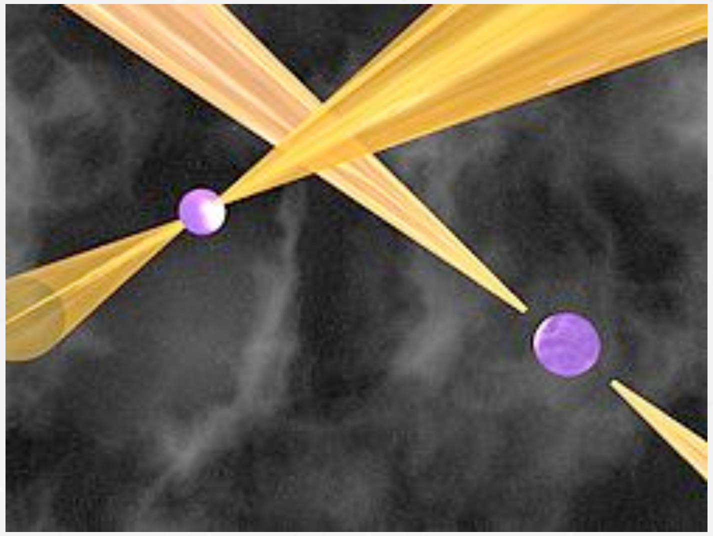
The X-ray Universe 2014, Dublin

A fantastic system!

- Binary neutron star systems are rare... less than 10 systems
- PSR J0737-3039 is amazing since both neutron stars are radio pulsars



- High orbital velocities : 1 million km/h !!!

  => the most relativistic system ever found

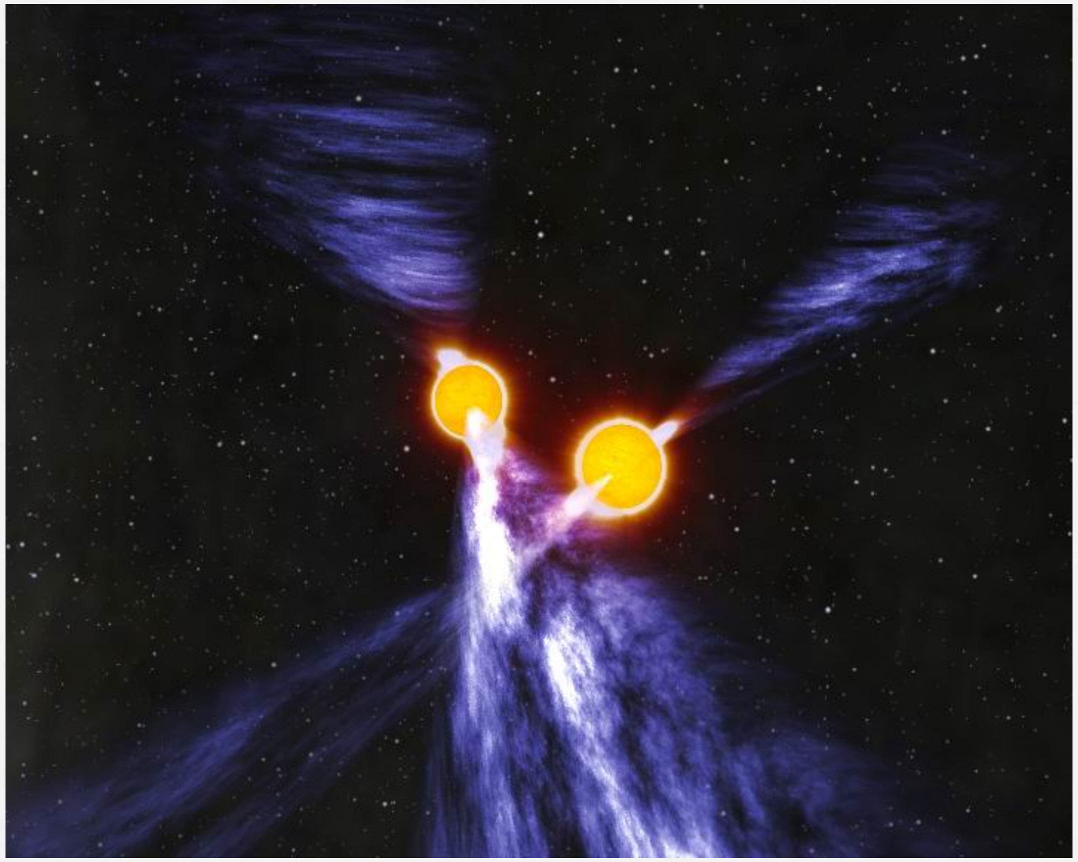
The double-radio pulsar

- Discovered 10 years ago (Burgay et al. 2003, Lyne et al. 2004)

PSR A

Fast, mildly recycled, old pulsar

$P = 22.7$ ms
$M = 1.3381(7)\ M_{sol}$
$B = 6.3 * 10^{9}$ G
$\dot{E}_{rot} = 5.9 * 10^{33}$ erg/s
Age = 210 Myr



PSR B

Slower, young, «lazy» pulsar

$P = 2.77$ s
$M = 1.2489(7)\ M_{sol}$
$B = 1.2 * 10^{12}$ G
$\dot{E}_{rot} = 1.7 * 10^{30}$ erg/s
Age = 50 Myr

A unique laboratory

- **Best timing test for GR in strong field regime** (Kramer et al. 2006)
- **Observed pulse arrival times modified by relativistic effects**

=> 5 post-Keplerian parameters very well-determined

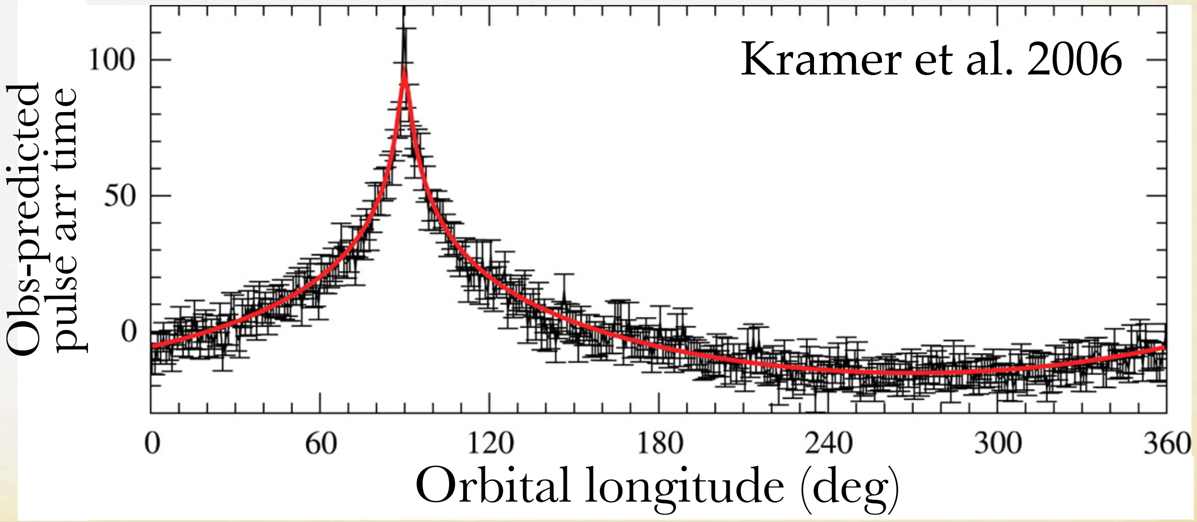
- Advance of periastron: **$\dot{\omega}$ = 17°/yr**

- Orbital shrinking: **7 mm/day**

System expected to merge in **85 Myr** (Burgay et al. 2003)

- Shapiro delay: pulses demonstrate the **curvature of space-time**

Confirmation of prediction of GR within 0.05% !!!



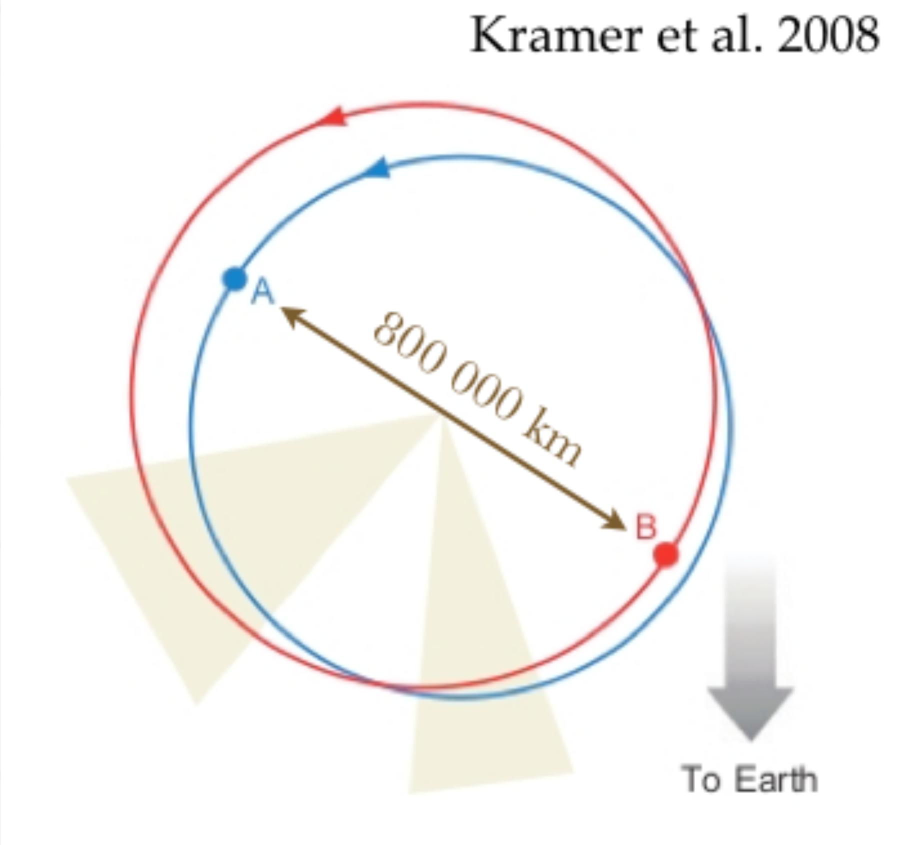
Observational properties

- **Surprising parameters :**

  - Low orbital period : 2.4 hours

  - Eccentricity : e = 0.088

  - Pulsars' separation : 3 light-sec



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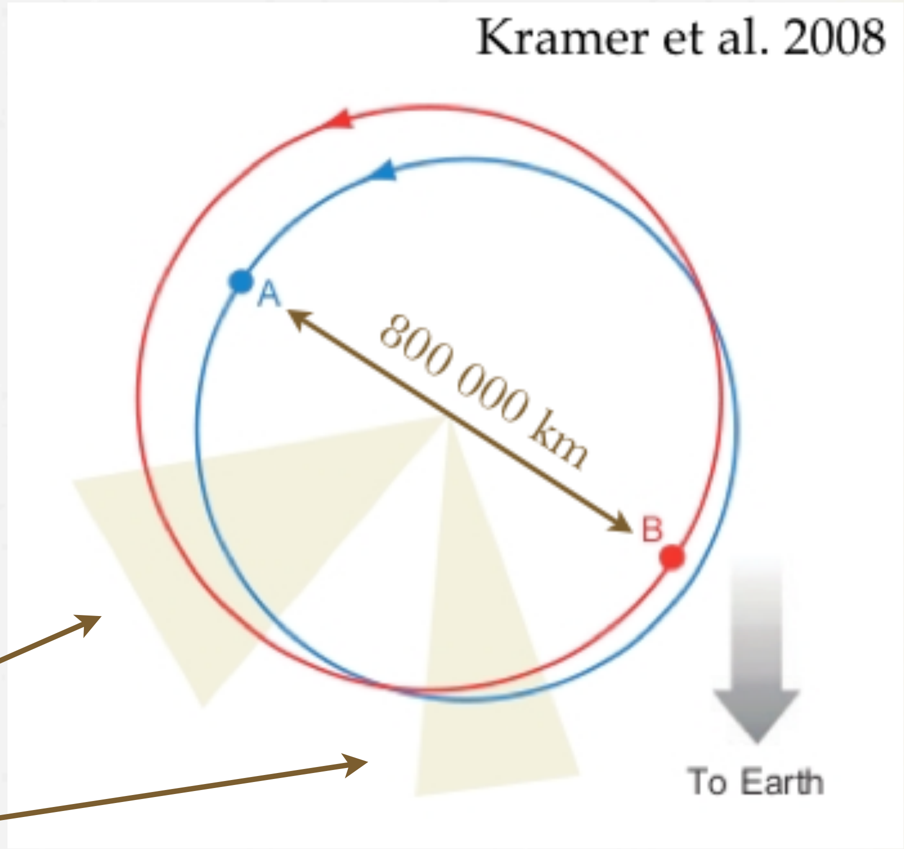


Orbital phases where PSR B was strongly detected

Observational properties

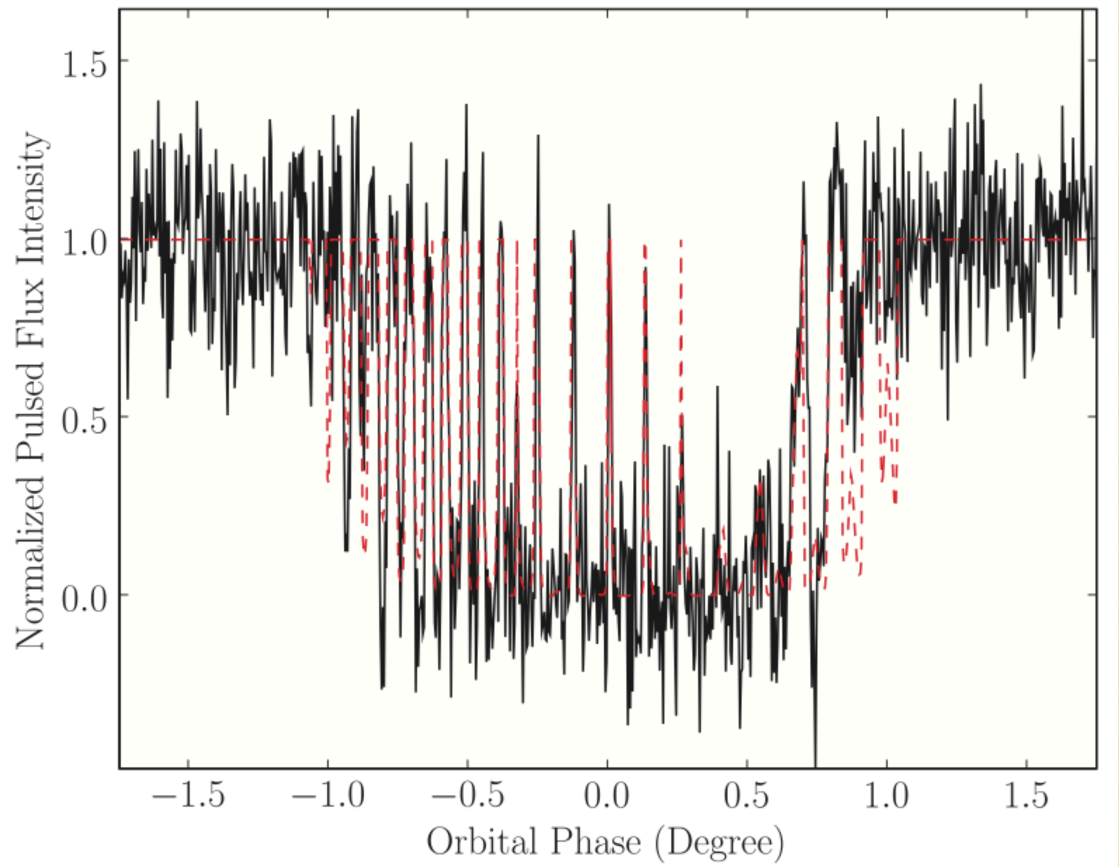
- **Surprising parameters :**

  - Low orbital period : 2.4 hours
  - Eccentricity : e = 0.088
  - Pulsars' separation : 3 light-sec
  - Inclination : **nearly edge-on**

Radio eclipses

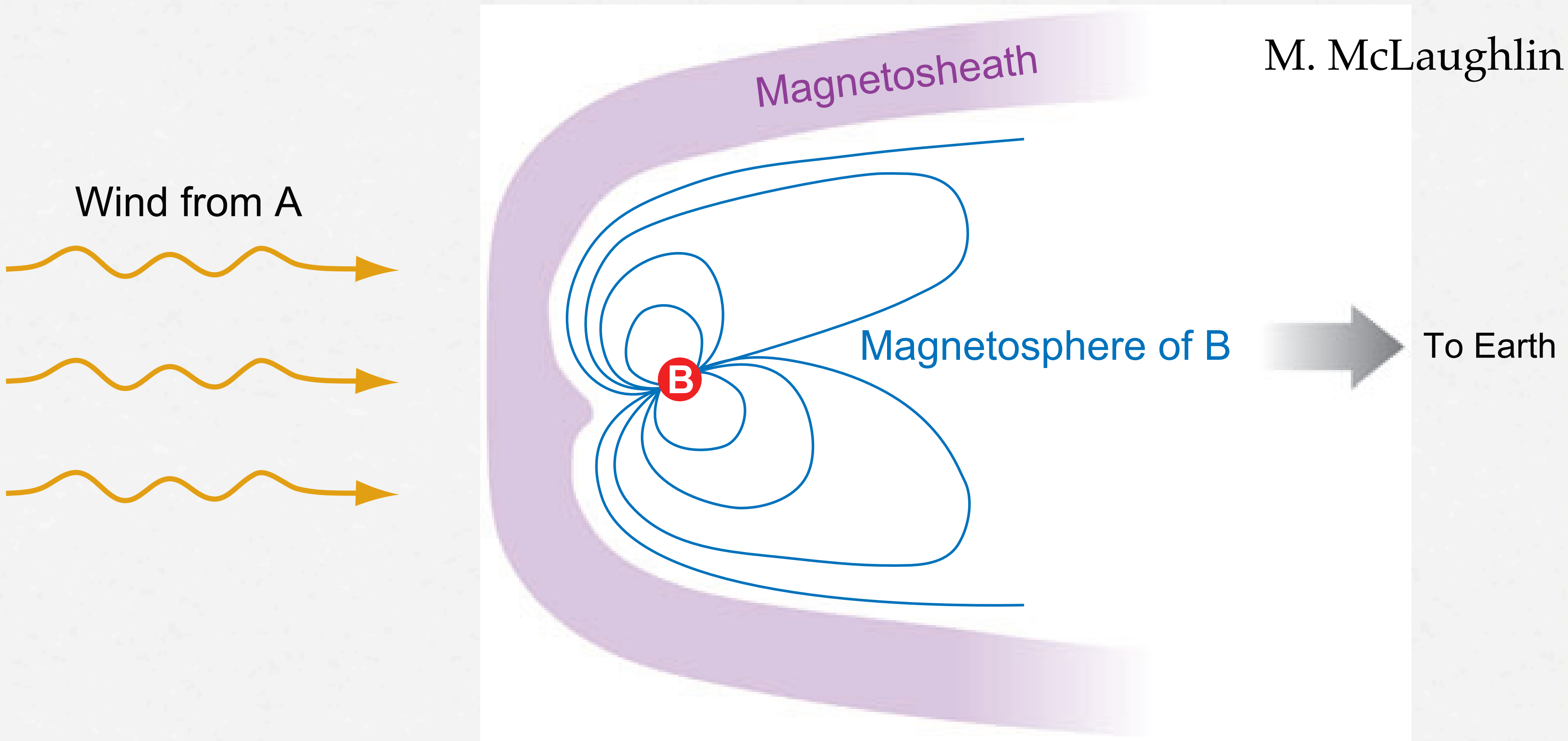
=> Unusual magnetospheric interactions between the 2 pulsars

Breton et al. 2008



X-rays

- To understand the physics of the magnetospheric emissions and their interactions



M. McLaughlin

- Deformation of the magnetosphere of PSR B caused by the wind of PSR A

X-ray observations

- **Chandra** : first X-ray observation, 10 ks, **80 photons**

 => $L_X = 2*10^{30}$ erg/s, about 10^{-4} E_{rotA} (assuming d=0.5 kpc)

 => spectrum poorly constrained, quite soft (McLaughlin et al. 2004)

- **XMM-Newton** : 50 ks, **800 photons**

 (Pellizzoni et al. 2004, Campana et al. 2004)

 => confirmation soft spectrum

 => single component : PHABS*PL or PHABS*BB

- **Chandra** : 90 ks + 80ks, **400 + 500 photons**

 (Chatterjee et al. 2007, Possenti et al. 2008)

 => double-peaked pulses at the PSR A period, similar to radio pulses

Two large programs with XMM-Newton

- **2006 : 26 revolutions** of the binary system (120 ks + 115 ks) **=> 235 ks**

  (Pellizzoni et al. 2008)

- **2011 : 41 revolutions** (130 ks + 130 ks + 107 ks) **=> 367 ks**

- **Cameras'characteristics**

	Mode	Time res
PN	small window	5.67 ms
MOS	small window	0.3 s

=> timing + spectral analysis of the Double Pulsar

(Pellizzoni et al. 2008, Iacolina et al. 2014, Iacolina et al. in prep, Egron et al. in prep)

Molels tested

- **PL + BB :** magnetospheric emission from Pulsar A (synchrotron/ICS), thermal emission from Pulsar A or B (polar cap?) / shock?
- **BB + BB :** thermal emissions from Pulsars A and B
- **PL + BB +BB :** thermal emissions from Pulsars A and/or B / shock?

=> Applied on 2011 data, then comparison with 2006 data

=> Results perfectly in agreement

Results: 2 large programs

- **PL + BB :** Soft photon index: 3.2 +/- 0.2
  => no shock!
  kT_{bb} = 160 +/- 15 eV;
  Chi2/dof = 533/520 (=1.02)

- **BB + BB :** N_H not constrained
  kT_{bb1} = 105 +/- 5 eV; kT_{bb2} = 270 +/- 15 eV
  Chi2/dof = 551/520 (=1.06)

- **PL + BB +BB :** N_H not constrained
  Photon index = 2.4 +/- 0.6
  => shock ?
  kT_{bb1} = 110 +/- 20 eV; kT_{bb2} = 230 +/- 30 eV
  Chi2/dof = 525/518 (=1.01)

=> Low error bars on the parameters

Where do X-rays originate?

PSR A: non-thermal

PSR A: thermal

PSR B

shock?

- Black-body emission radii consistent with polar cap radii?
- Luminosity of each component => % $\dot{E}$rotA, $\dot{E}$rotB

Assuming d = 1.2 kpc (Deller et al. 2009)

Where do X-rays originate?

- **PL + BB :** no shock, 85% emission from the PL => Pulsar A's magnetosphere

  R_{BB} compatible with the polar cap radius of Pulsar B (100m)

- **BB + BB :** R_{BB} compatible with the polar cap radii of Pulsar A (1km) and Pulsar B

  Hot BB: Pulsar B, and Cold BB: Pulsar A

- **PL + BB +BB :** possible shock, large error bars on the black-body radii...

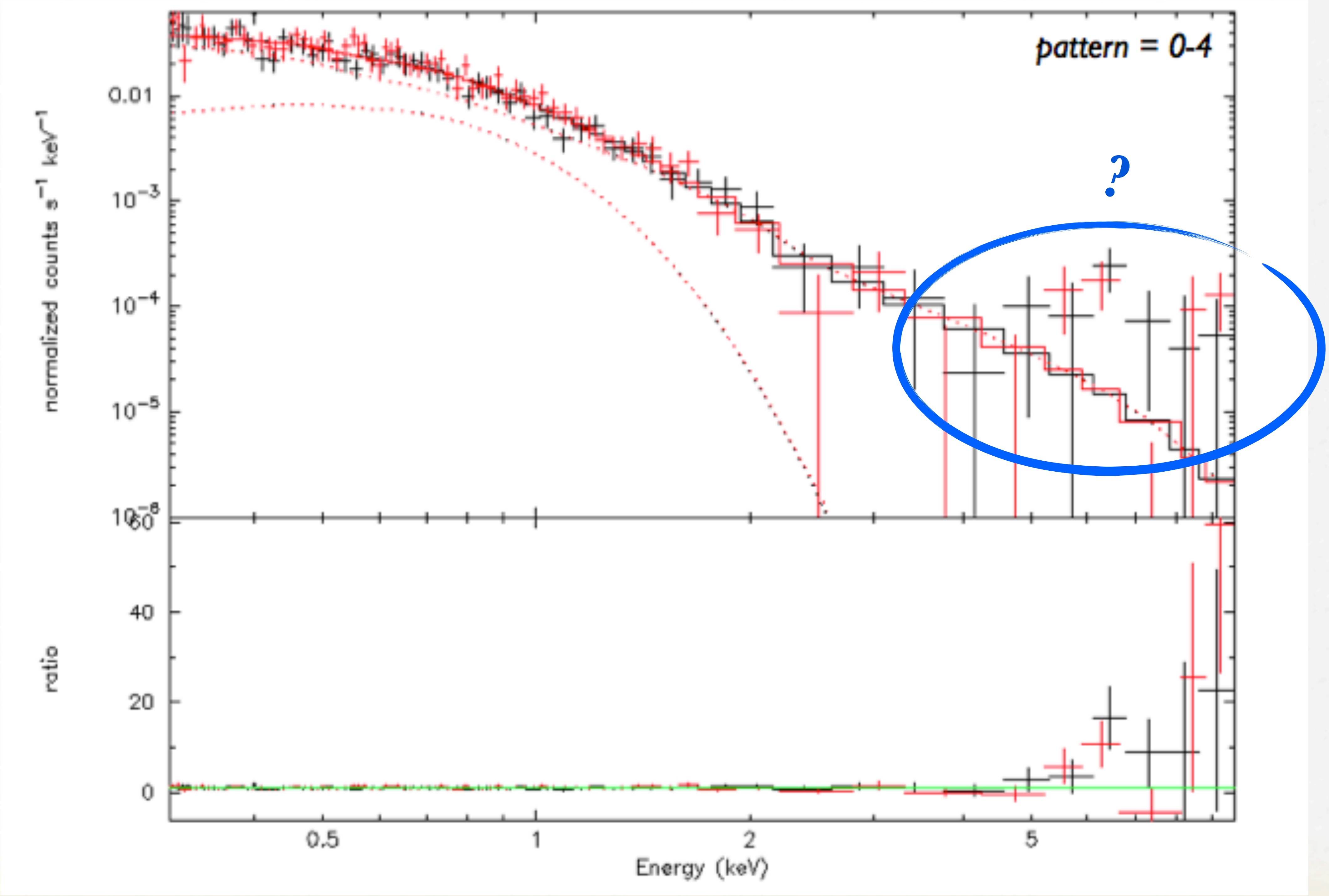
=> Pulsar B powered by Pulsar A's spin-down energy

=> Timing analysis confirms X-ray pulsations from Pulsar B

(Pellizzoni et al. 2008; Iacolina et al. 2014)

Last but not least...

An intringuing feature in the 2006 data



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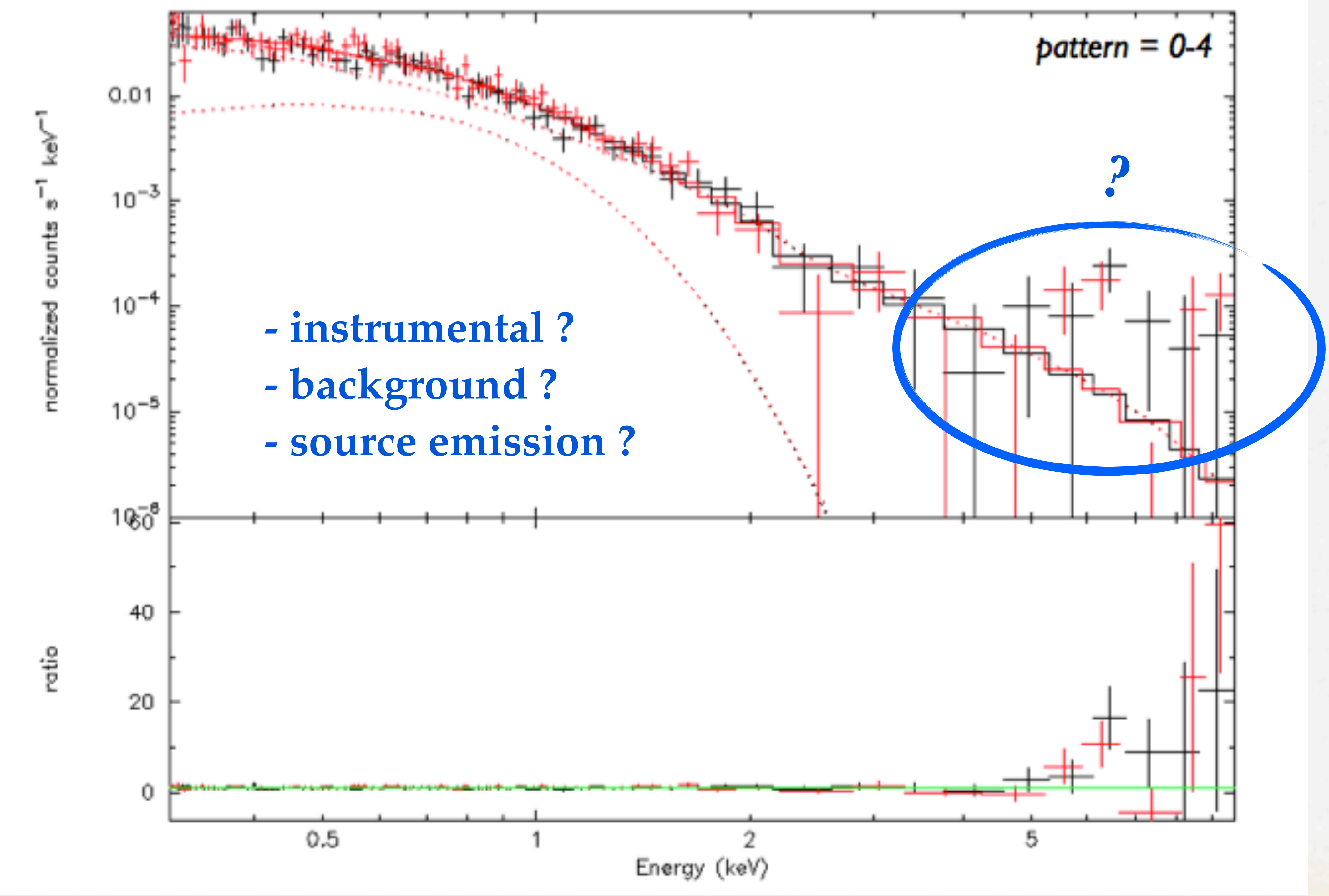


Emission from the Double Pulsar ?

- **Spatial model (4 < E < 8 keV) applied by A. Pollock**

  * Combined likelihood detection statistic : lnL = 15.04

  * 157 photons detected in about 400 ks

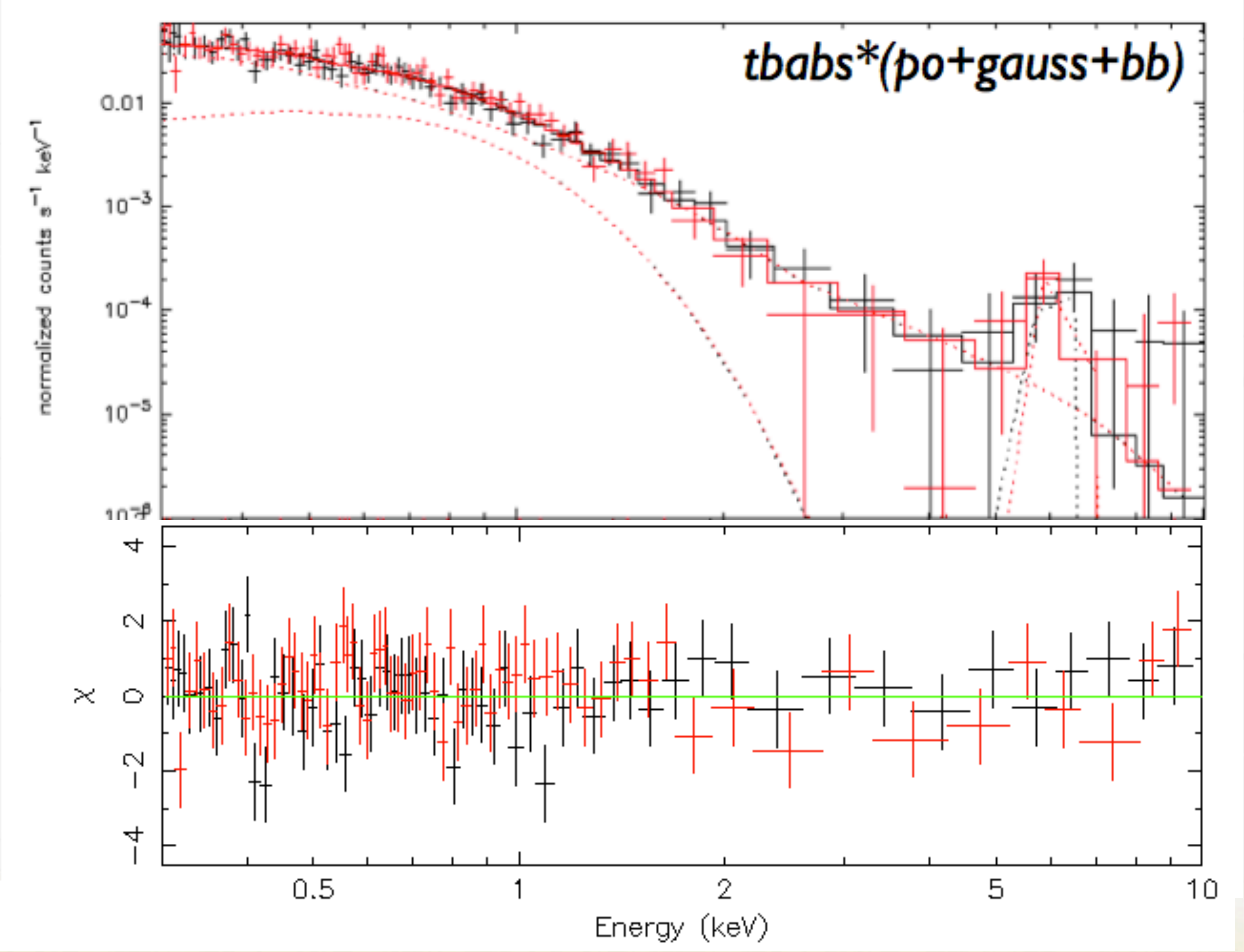
  * 1 high-energy photon every 44 minutes

- **Confirmation that the detection at high energy comes from the source !!!**

- **Above 8 keV: background dominates**

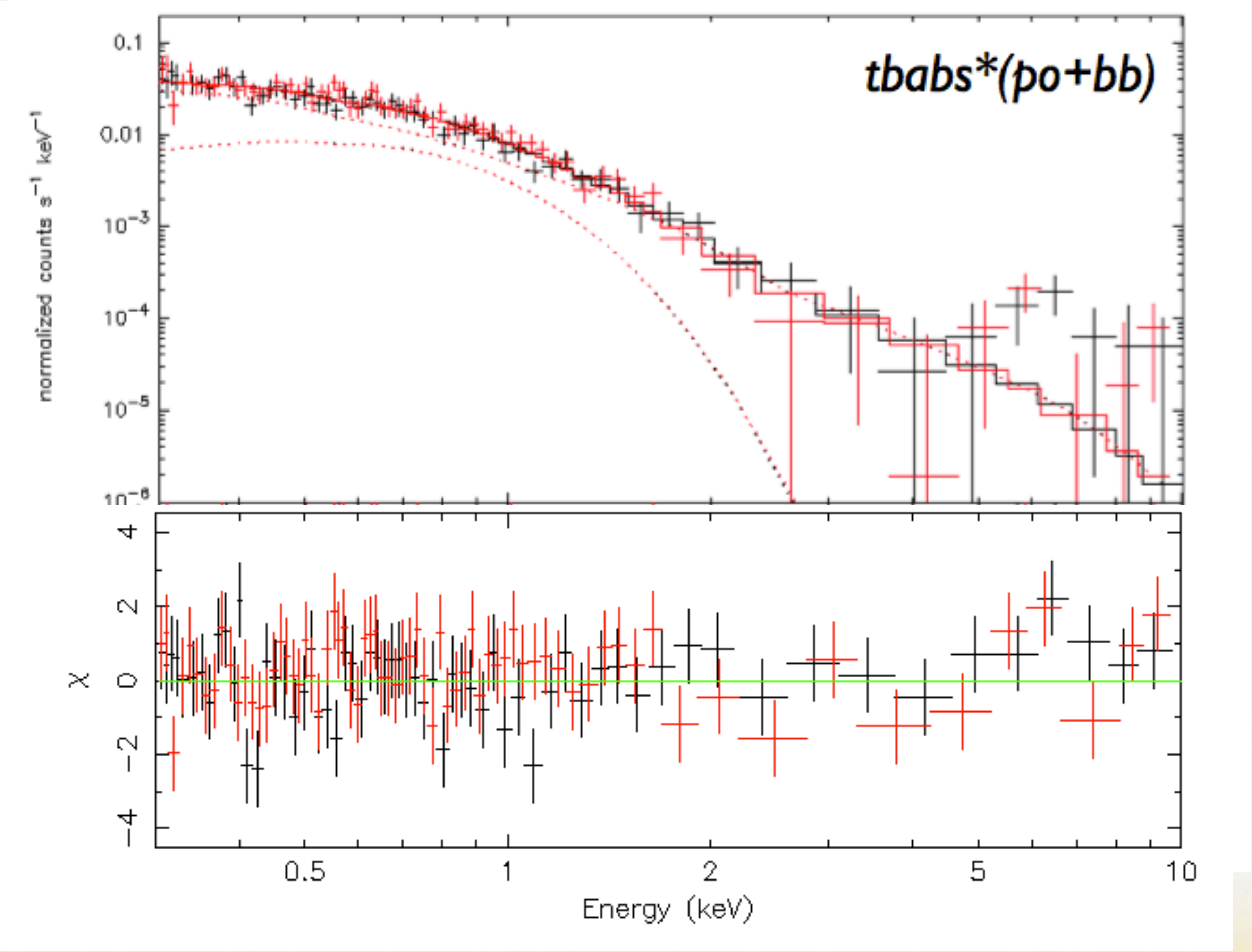
2006 data

- Addition of a Gaussian at 6.2 +/- 0.2 keV



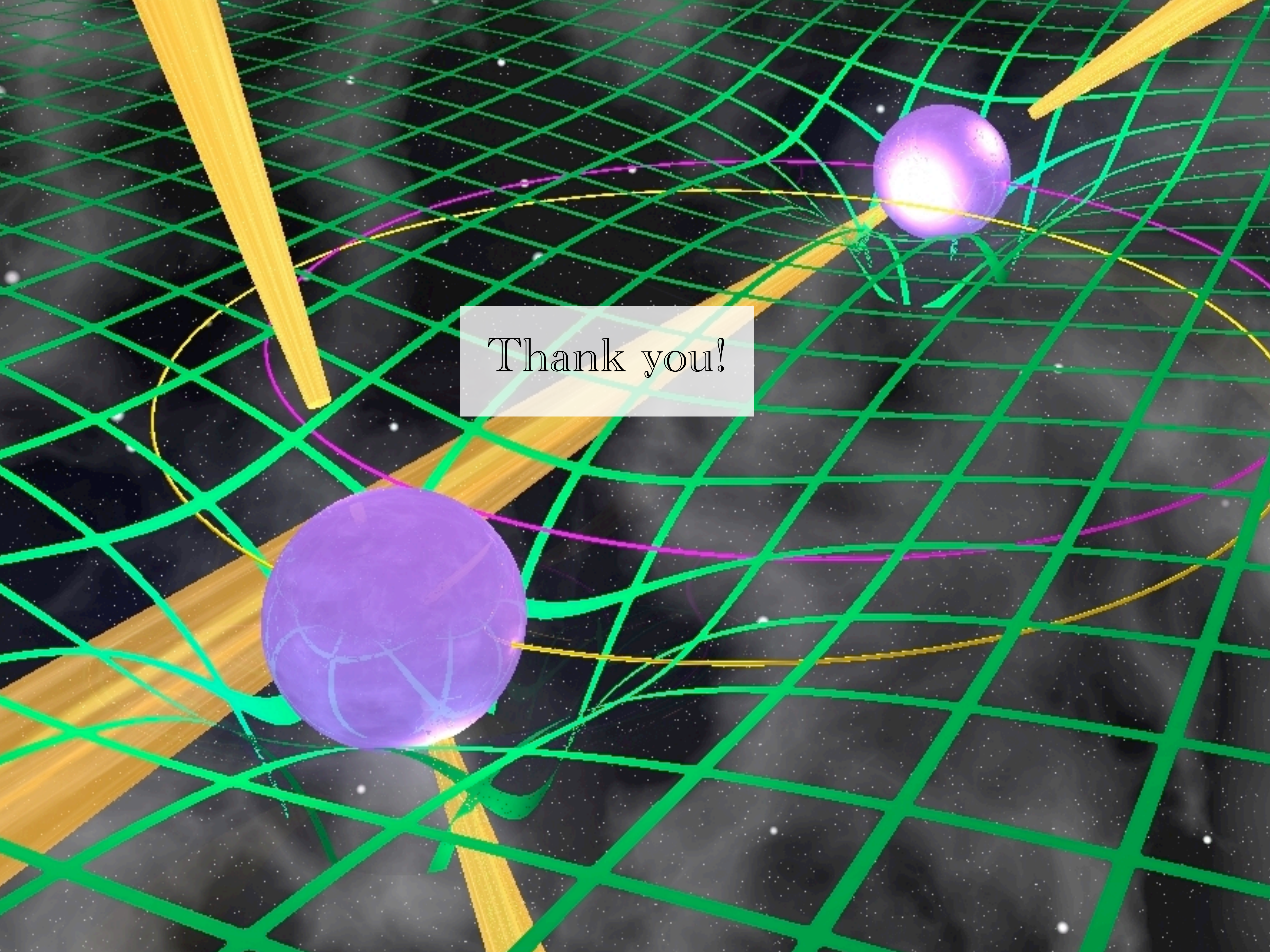
2006 data

- Without the Gaussian at 6.2 +/- 0.2 keV



Conclusion

- **Double Pulsar : amazing but very complex system**
- **Most of the X-ray emission : PSR A**
- **Thermal emission of PSR B’s : powered by PSR A’s spin-down energy**
  => confirmation of the timing analysis
- **No evidence of a bow shock** as suggested by Lyutikov et al. 2004, Arons et al. 2005
- **Evidence of high-energy photons above 4 keV**
- **2006 data : Fe line? Not visible in 2011...**
- **Work in progress :** pulse phase resolved spectra...



Thank you!