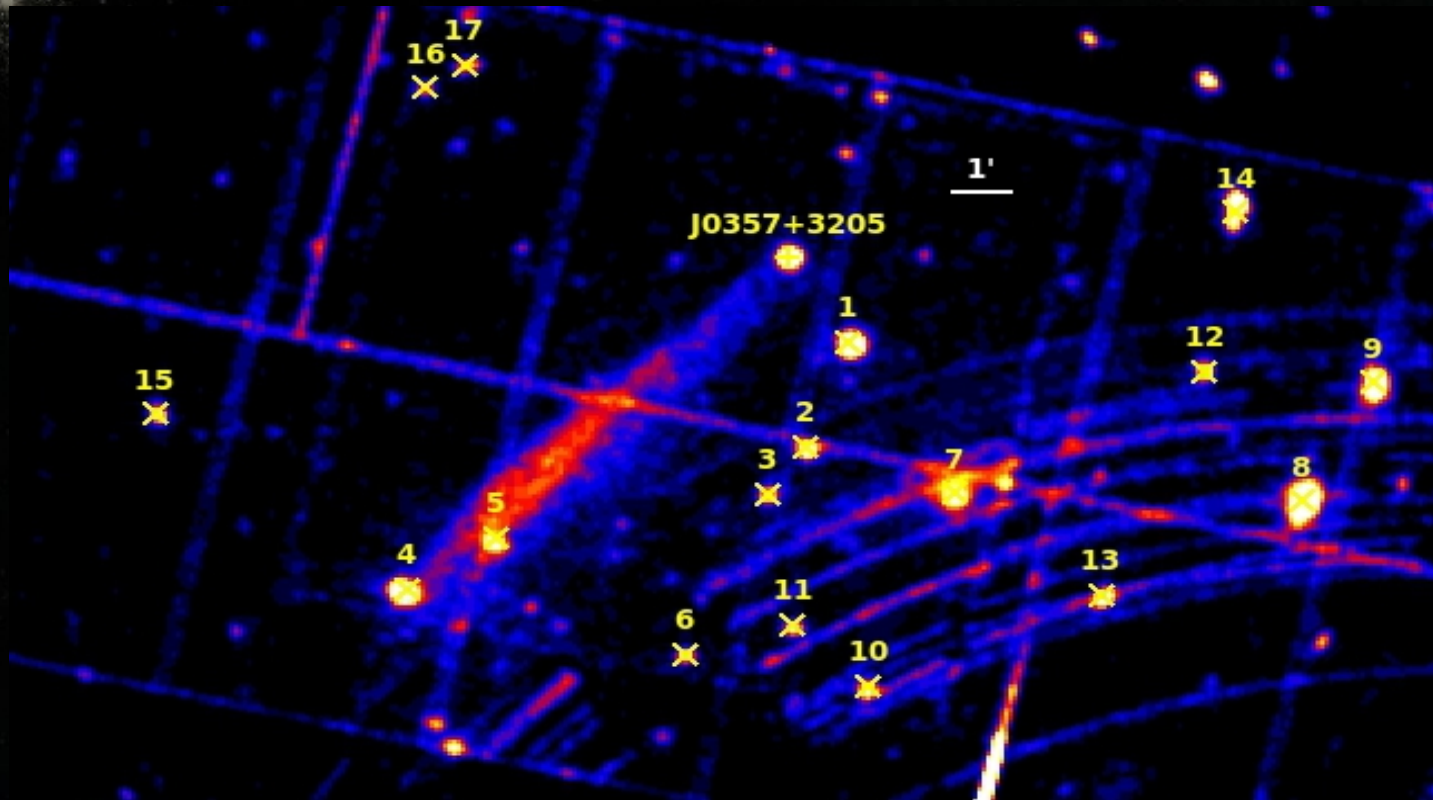


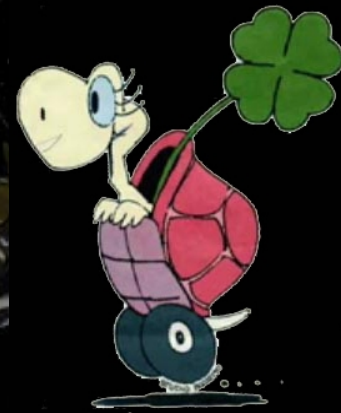
MORLA, THE FAST TURTLE-PULSAR

Milano, 2012 September 27th

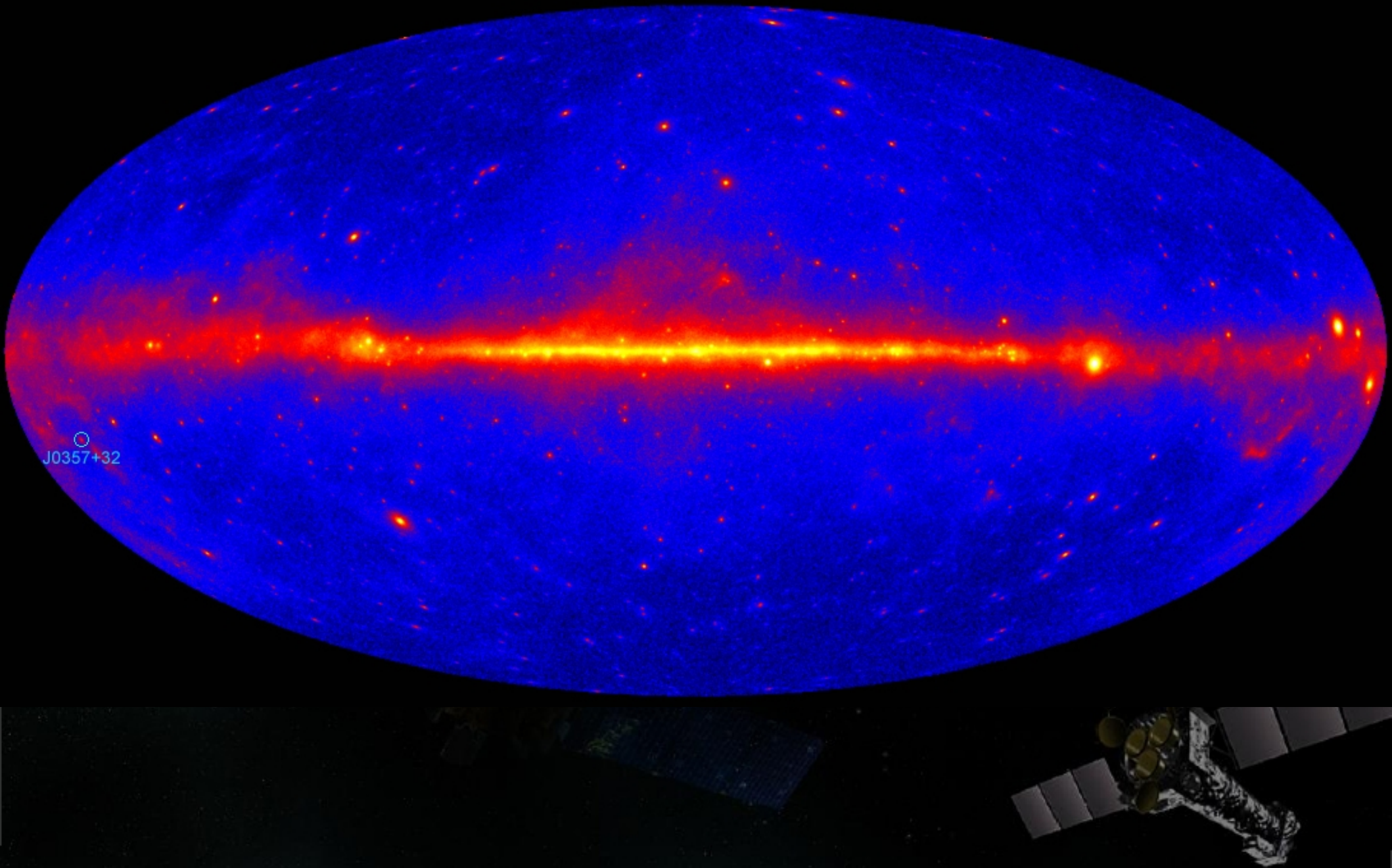


Starring : M. Marelli, A. De Luca, D. Salvetti, N. Sartore, A. Sartori, P. Caraveo, F. Pizzolato

De Luca et al. 2011, ApJ 733, 104
Marelli et al. 2012 submitted to ApJ
De Luca et al. 2012, Science, in preparation



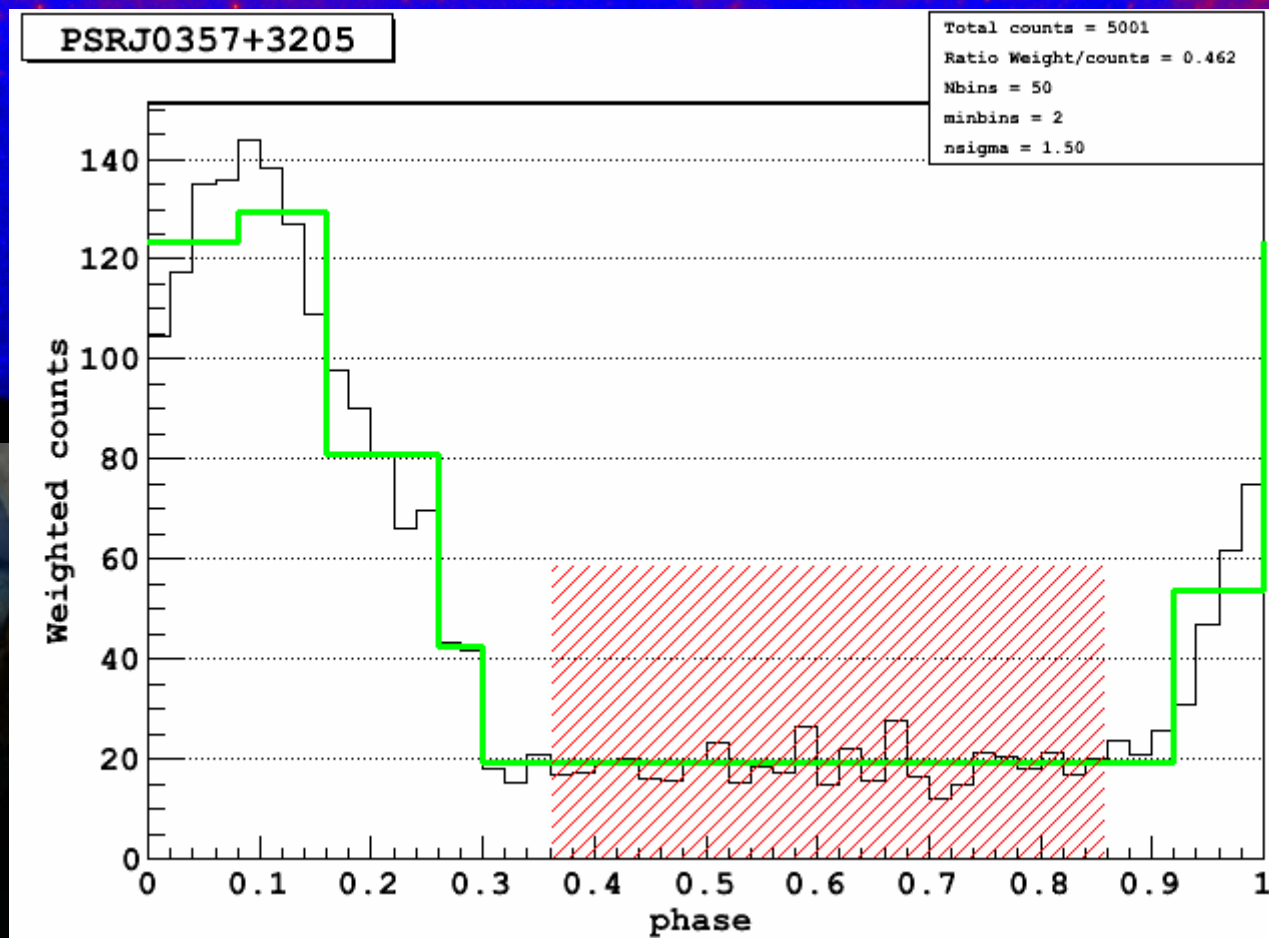
Seen by Fermi from the early observations, it is an off-plane bright source in the γ -ray sky (1/100 of Vela flux) (Abdo, A.A. et al. 2009, ApJ, 700, 597)



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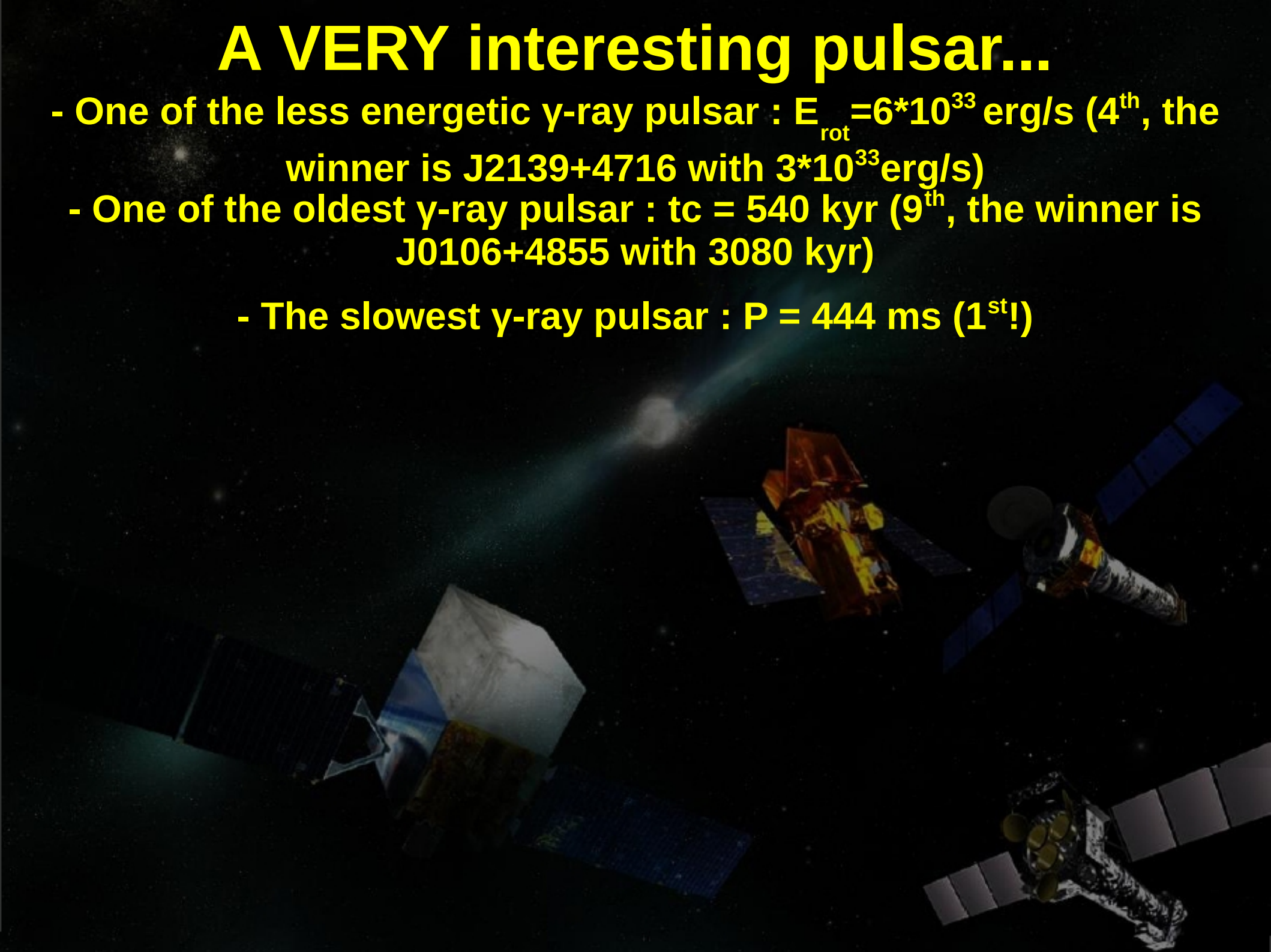
J0357+32

After 3 months: it pulses!
It's one of the first radio-quiet pulsar detected (Abdo, A.A. Et al. 2009, Sci, 325, 840)



A VERY interesting pulsar...

- One of the less energetic γ -ray pulsar : $E_{\text{rot}} = 6 \cdot 10^{33}$ erg/s (4th, the winner is J2139+4716 with $3 \cdot 10^{33}$ erg/s)
- One of the oldest γ -ray pulsar : $t_c = 540$ kyr (9th, the winner is J0106+4855 with 3080 kyr)
- The slowest γ -ray pulsar : $P = 444$ ms (1st!)



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Bright, low energetics, off-plane => Near?

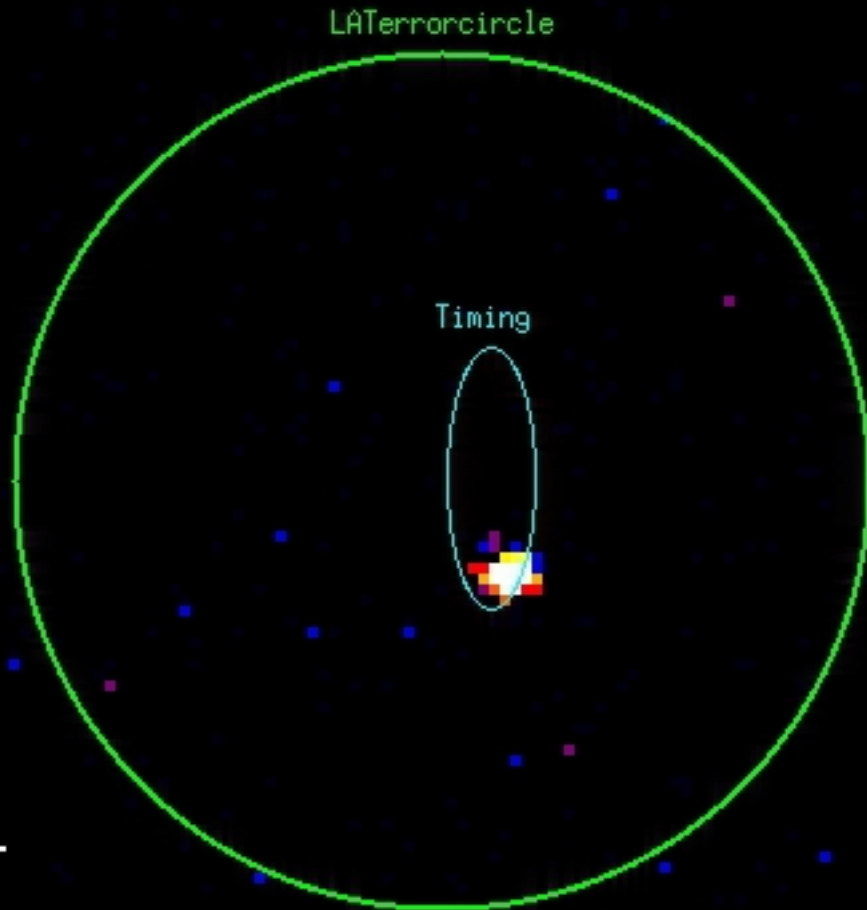


Morla, the Ancient One

75 ks Chandra ACIS-S observation (u.l. 10^{-15} erg/cm²s)

+

Deep Optical/IR imaging (u.l._v 26.8 , u.l._k 21.4)



X counterpart detected!

~ 530 counts

Flux sim $5 \cdot 10^{-14}$ erg/cm²s

$F_x / F_v > 520$

$F_y / F_x \sim 1000$

Powerlaw spectrum

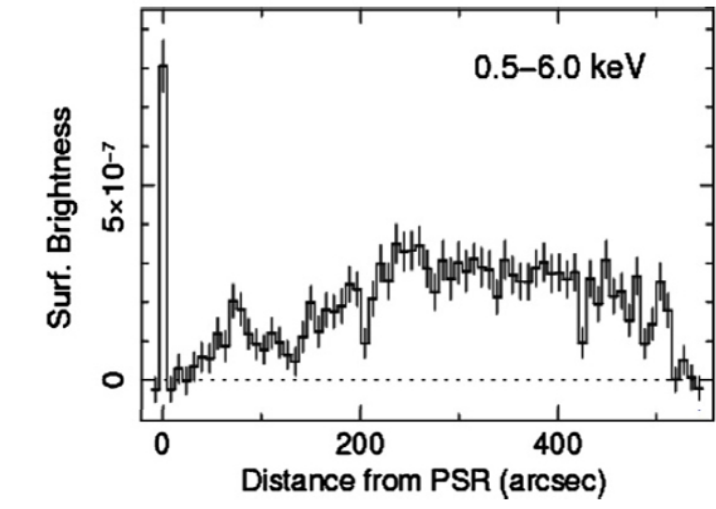
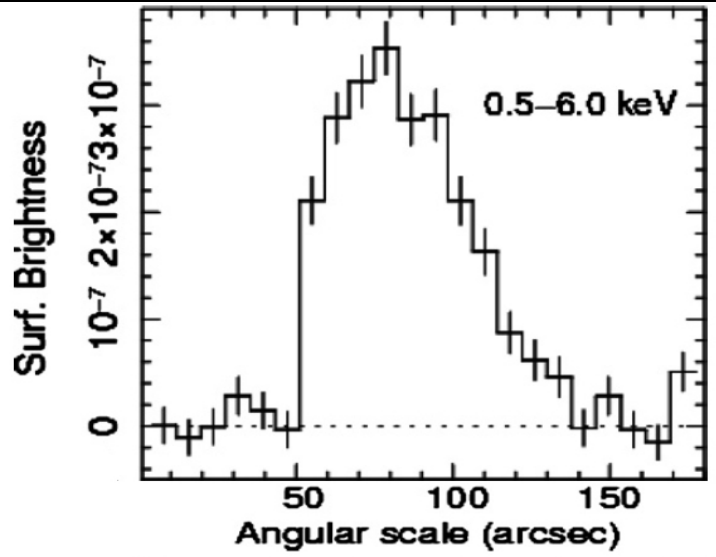
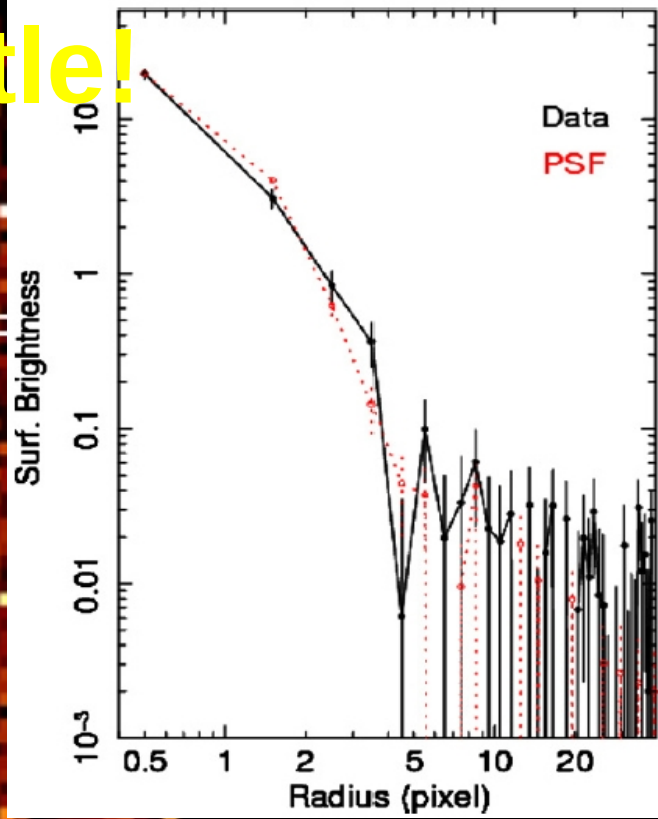
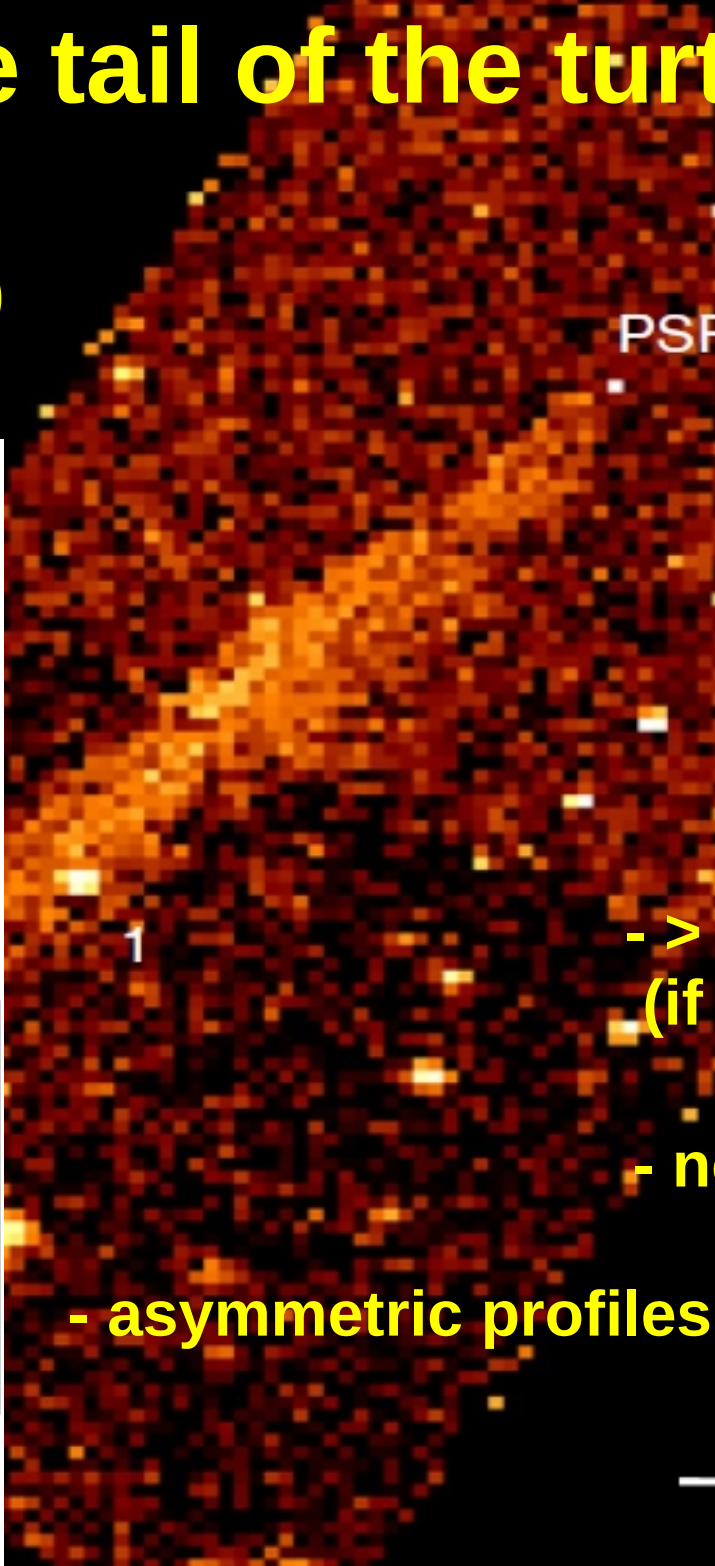
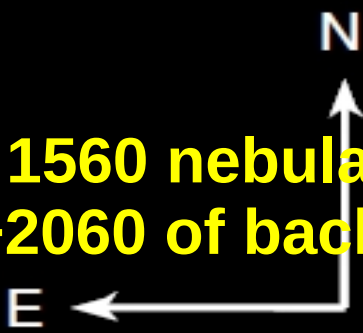
$n_H \sim 10^{21}$ cm⁻²

p.i. ~ 2.5

But, on a larger scale...

The tail of the turtle!

~ 1560 nebular counts
(+2060 of background)



- > 9' in length => 1.3 pc
(if $d = 500$ pc and $i = 0$)
- $\text{flux}_{\text{tail}} \sim 5 \cdot \text{flux}_{\text{psr}}$
- no tail detection < 50''
from pulsar

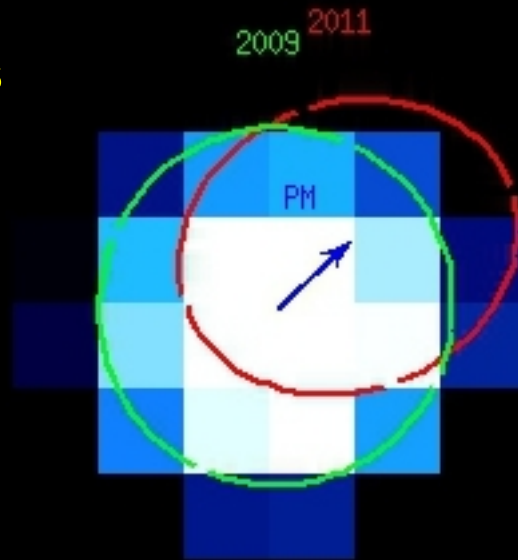
- asymmetric profiles, with maximum at 4'

5 arcmin

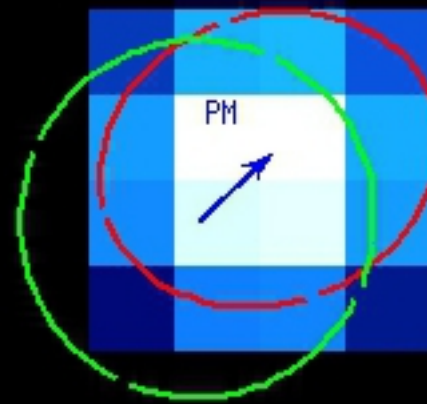
New Chandra campaign: detect the PM!

2 new 30 ks Chandra observations each 2 years.
First observation done!

530 counts



2009 2011



180 counts

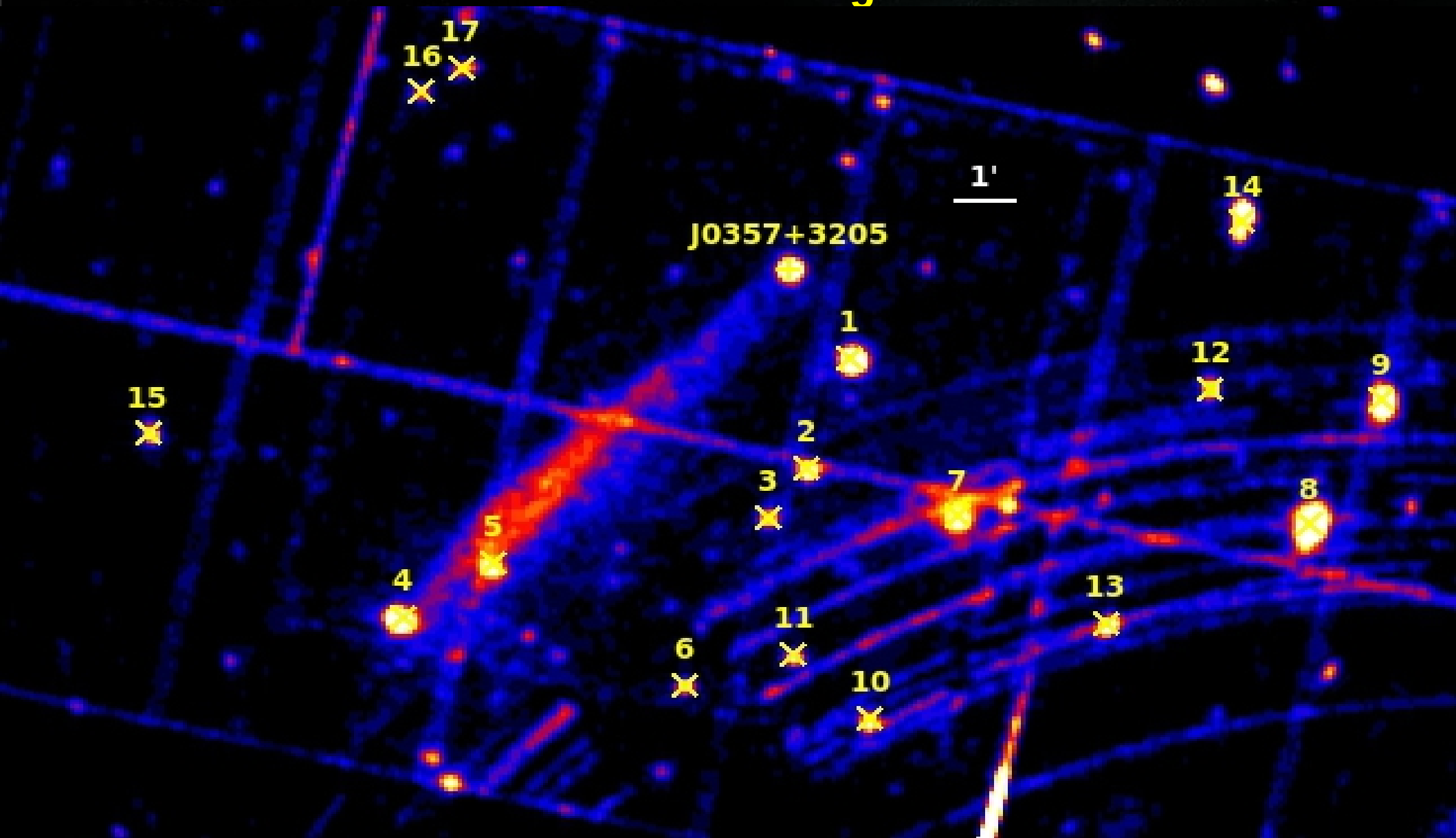
Detected (5sigma)!

165 ± 30 mas/yr \Rightarrow 400 km/s at 500 pc and $i=0$
direction : opposite the tail, parallel to the galactic plane

This makes the turtle quite fast... (more than the rabbit)

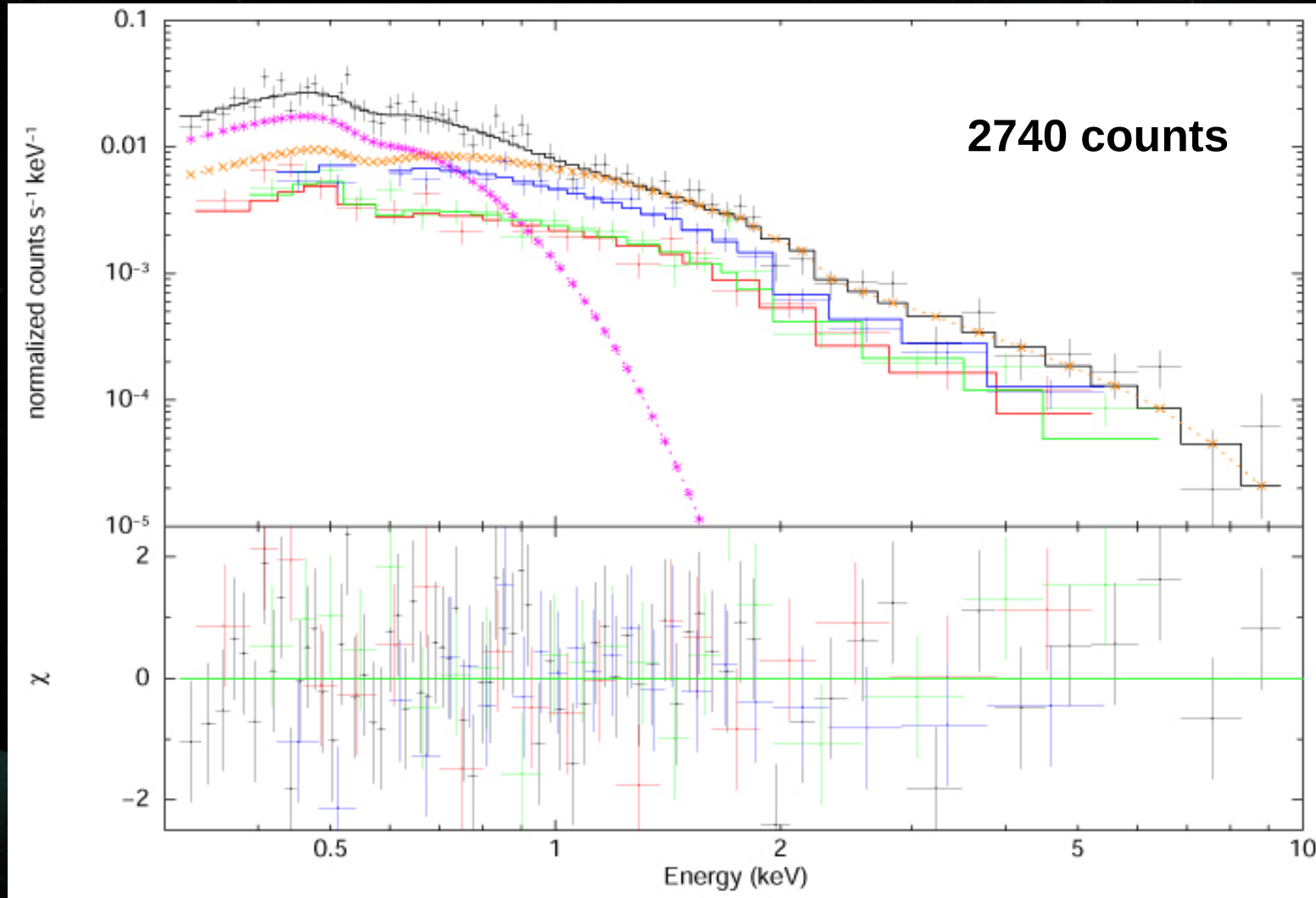
Contemporaneous XMM campaign: detect the pulsation/study the tail!

110 ks XMM-Newton Large Window

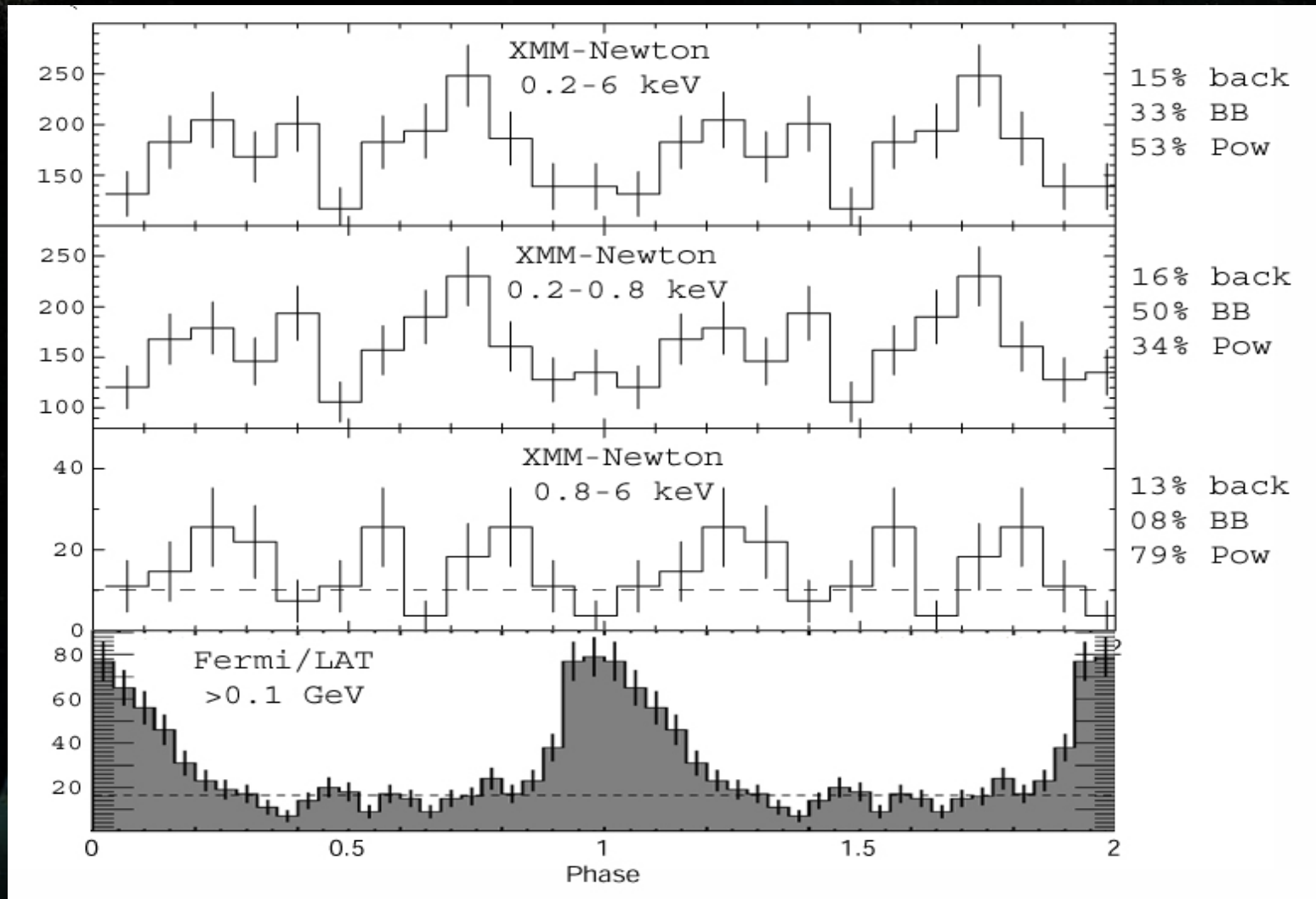


The pulsar

- Thermal component found: $T \sim 10^6$ K , $R \sim 450$ m
 $T_{\text{sup}} < 4 \cdot 10^5$ K (very cold!)



The pulsar

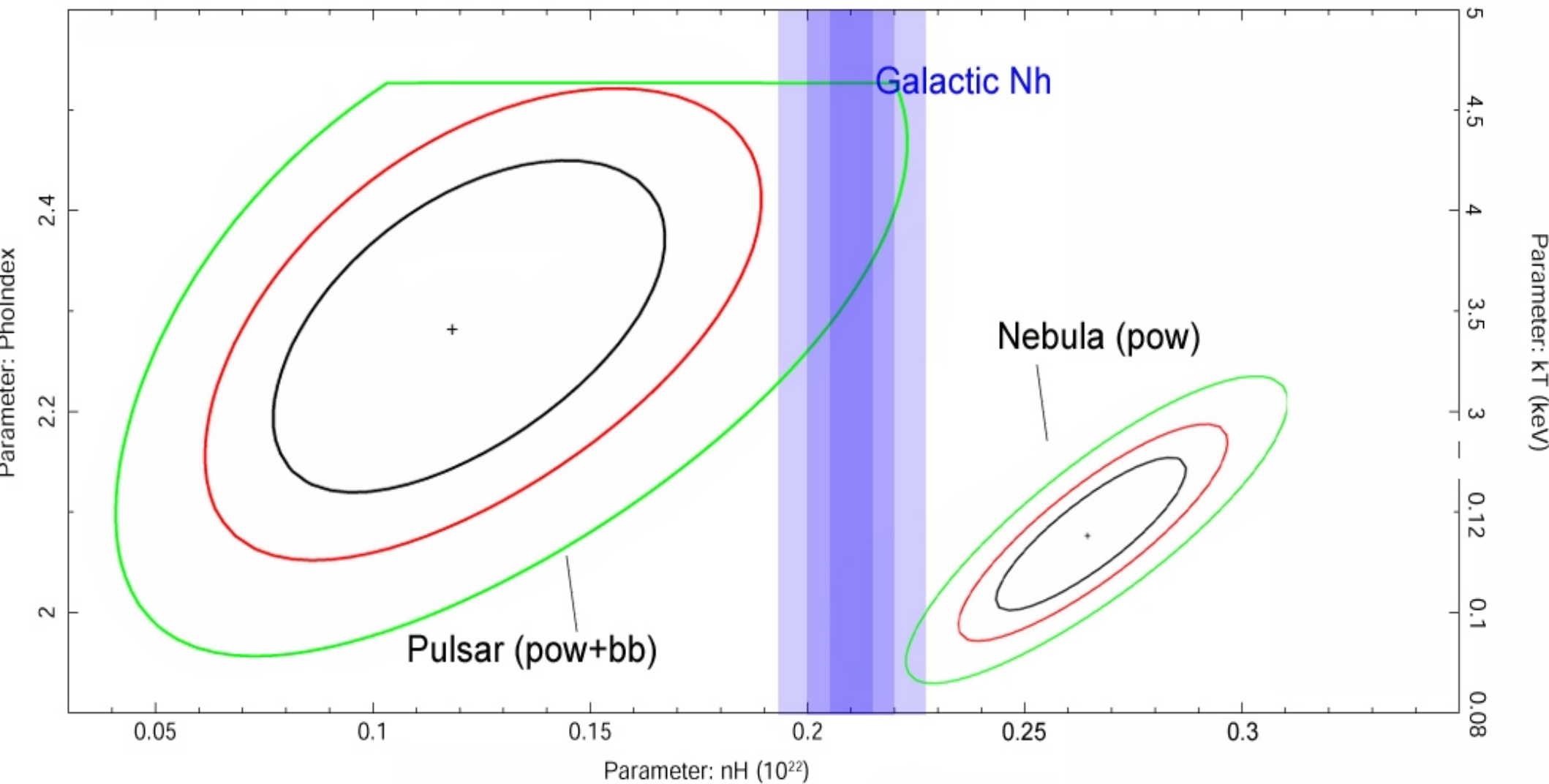


And... pulsations!
By folding at the Fermi ephemerides, with a chance probability of $3 \cdot 10^{-6}$

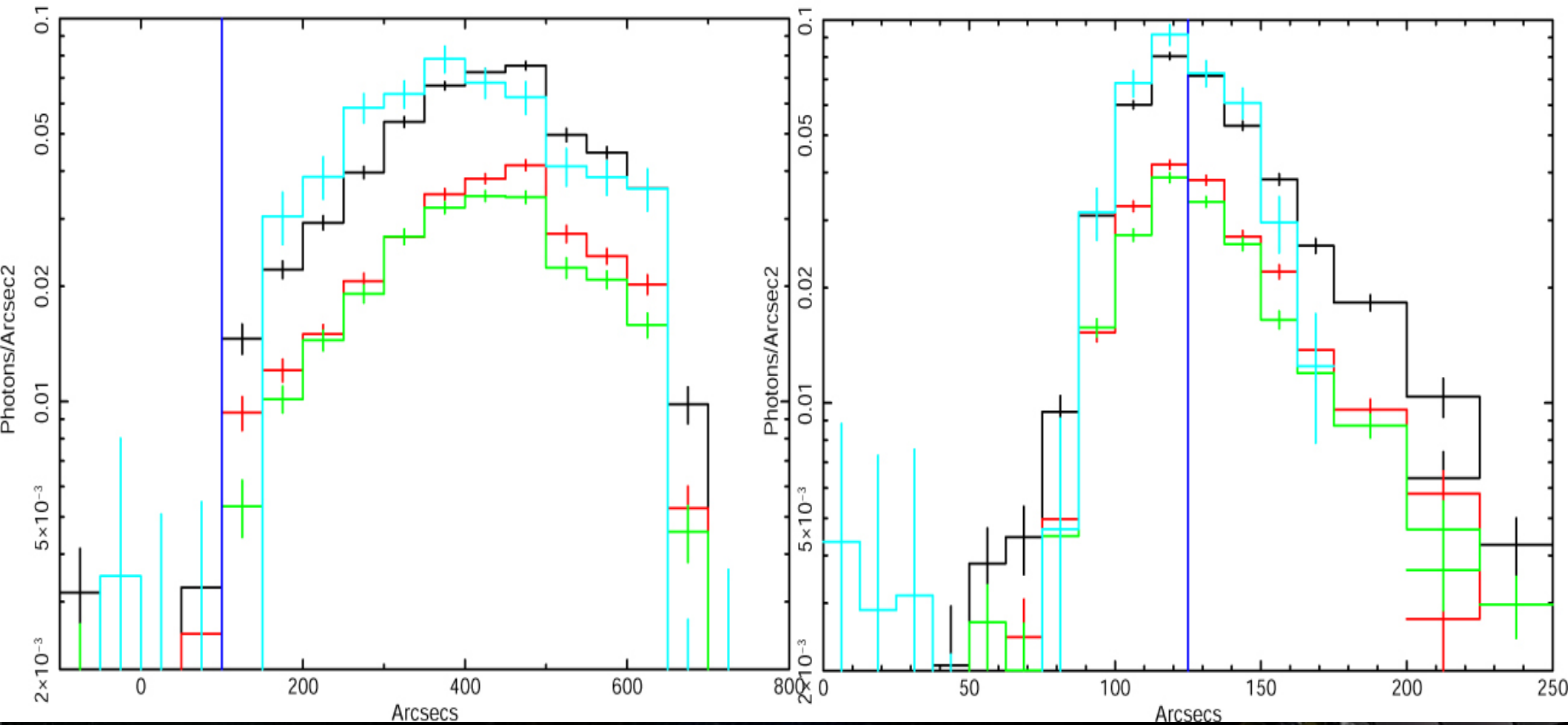
The tail

A powerlaw well fits the total spectrum

BUT... the pulsar, nebular and galactic n_H doesn't match!



No variations between Chandra and XMM data (tail's features confirmed)



No spatial/spectral variations down to 0.2 in the p.i.

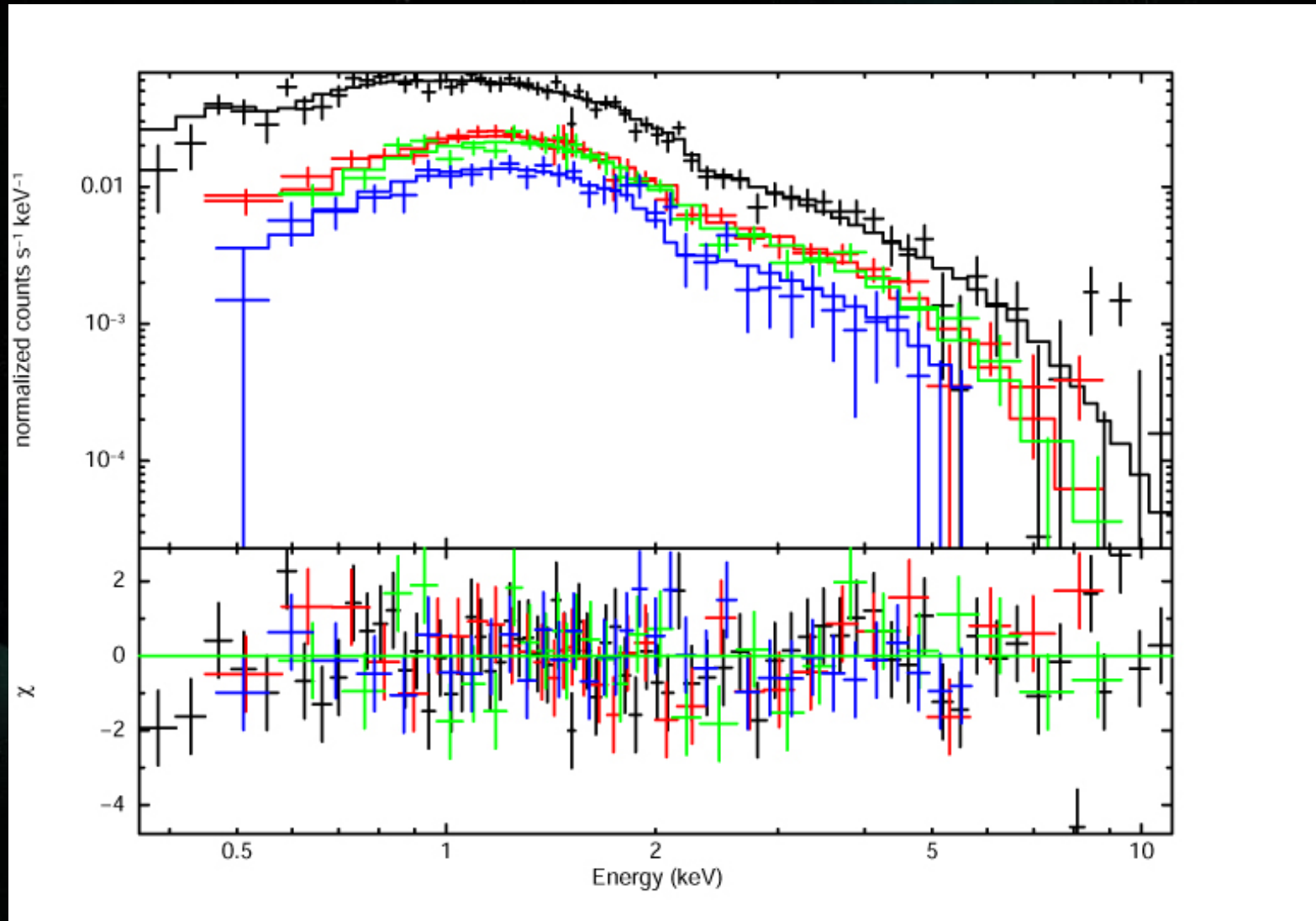
Synchrotron Nebula : X-rays are due to synchrotron emission from the wind particles accelerated at the termination shock

- low pulsar E_{rot} : maximum post-shock wind electron energy sim 5 TeV. Assuming the local magnetic field to be of order 10 μG , no synchrotron radiation at $E > 50$ eV would be expected.
- lack of wind termination shock : unresolved if $n_{\text{ISM}} = n * 100$ atoms/cm³ or $v_{\text{PSR}} = n * 1000$ km/s; ok it $i > 70^\circ$ (\Rightarrow longer tail)
- lack of emission around the pulsar, where acceleration of the wind particles is maximum
- asymmetric brightness profile: synchrotron nebula emission only marginally dependent to n_{ISM}
- the low synchrotron cooling time would imply a spatial/spectral variation of the nebula
- disagreement between fitted galactic, pulsar and nebular n_{H}

Model Rejected!

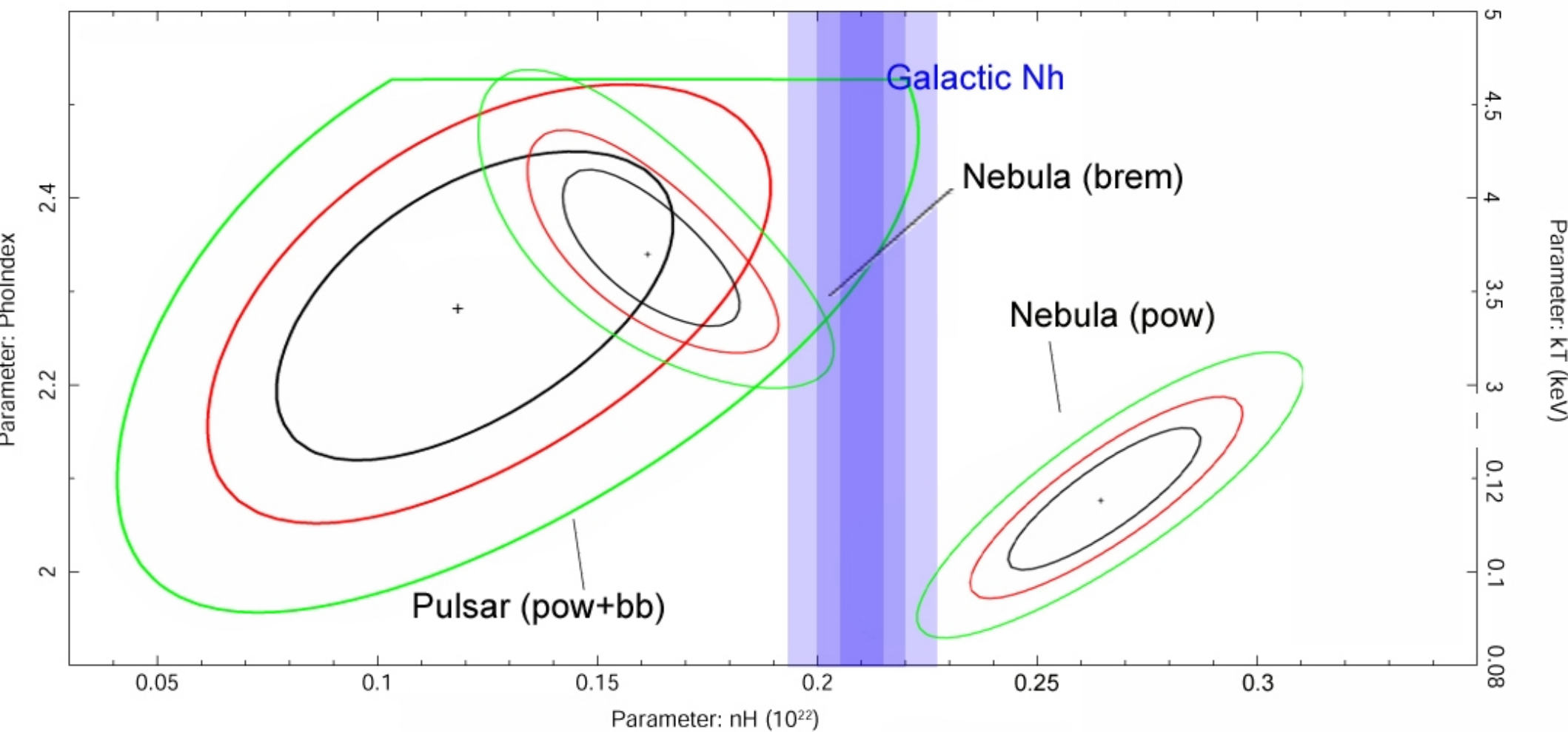
Bremsstrahlung Nebula : X-rays come from the shocked ISM material heated up to X-ray temperature

- nebula well fitted ($\chi^2_{\text{red}} = 1.06$) by a bremsstrahlung model, with n_{H} in agreement with the pulsar one and lower than the galactic one; similar models bring to a low metallicity of ISM



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- energetically acceptable if $v_{\text{PSR}} \sim 1900$ km/s: ok if $i > 75^\circ$ (this makes Morla the fastest pulsar known!). Required $n_{\text{ISM}} \sim 1$ atoms/cm³ and $T_{\text{ISM}} = n * 10^5$ K (ok if “local bubble”); problem : low fitted metallicity of ISM

- volume emissivity proportional to n_{ISM}^2 so that a variation of ~ 2 in the density can explain the asymmetric profiles

- $t_{\text{cool}} \sim 10^7$ yr : it fully explain the lack of spatial/spectral variation.

The “low age” of the tail ($\sim 3 * 10^3$ yr) can be explained with a variation of ~ 3 in the n_{ISM}

- lack of diffuse emission surrounding the pulsar: kinetic energy mainly transferred to ions; electrons must be heated by the ions. $t_{\text{transfer}} \sim 200$ yr:

ok

Model Plausible!

We also find $300\text{pc} < d_{\text{PSR}} < 2\text{kpc}$!

Conclusions

- We have studied one of the most extreme Fermi pulsar : very slow, old and with a low energetics
- We have found the X counterpart
- We have fitted its spectrum: non-thermal emission, hot spot thermal emission and we placed upper limit on the surface temperature (cold!)
- We have found an hint of pulsations (the 3rd RQ pulsar!)
- We have found the pulsar proper motion (maybe the fastest known pulsar!)
- We have found a big X-ray trail not consistent with the classical synchrotron model
- We have developed a new model for the trail based on bremsstrahlung emission (turtle-tail nebulae)

17
16 X
X

MORLA (and its nebula) Thanks for your attention!

11
14

J0357+3205

