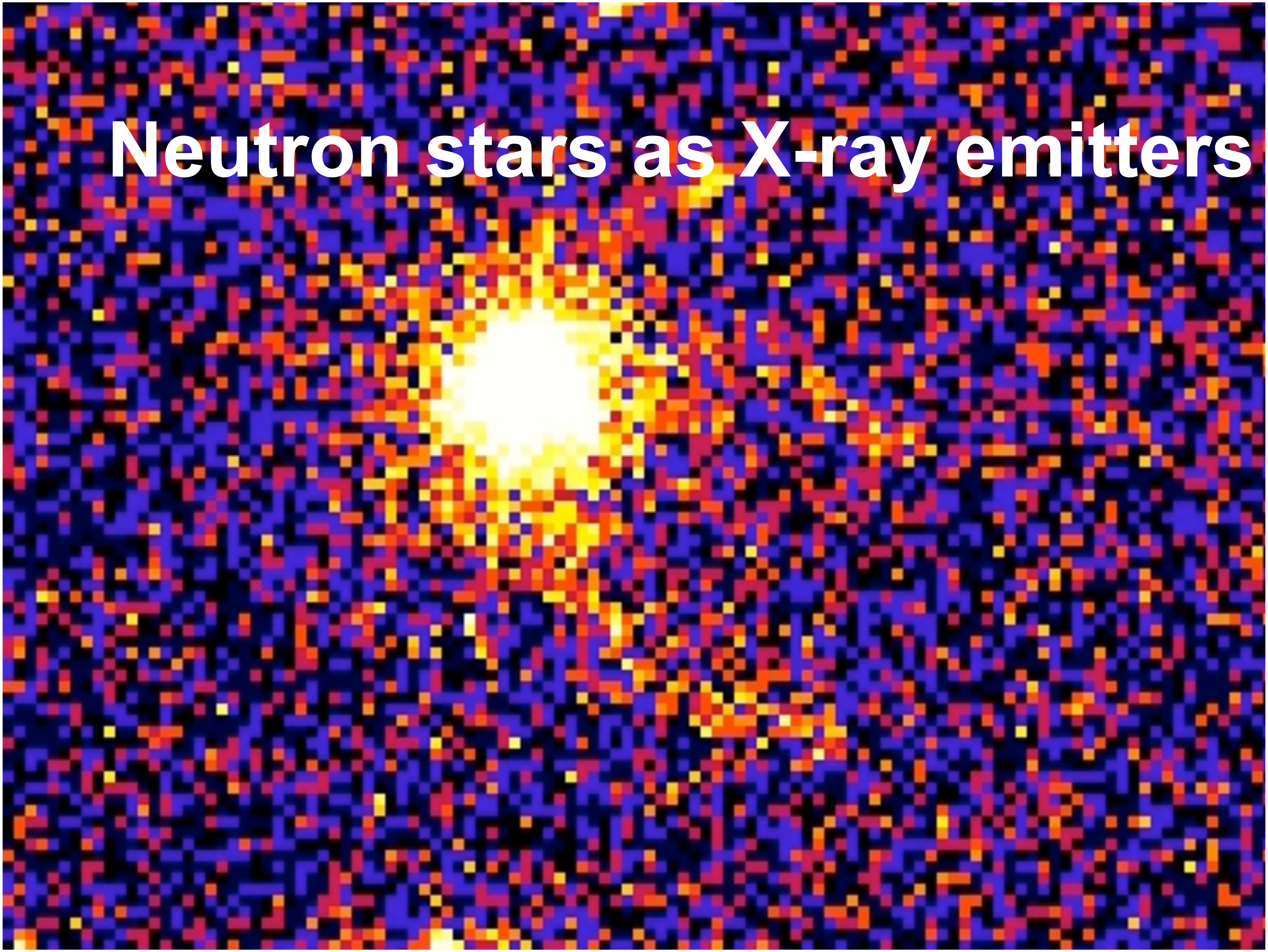
Neutron stars as X-ray emitters



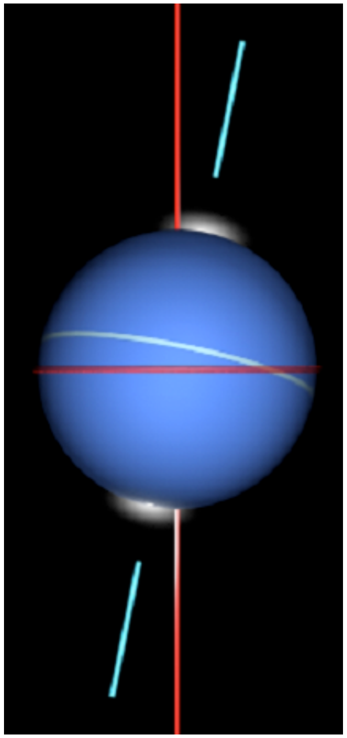
X-ray behaviour of

- **Classical NSs (radio,opt, X-rays,γ-rays)**
- **INSs (opt., X-rays)**
- **CCOs (X-rays)**

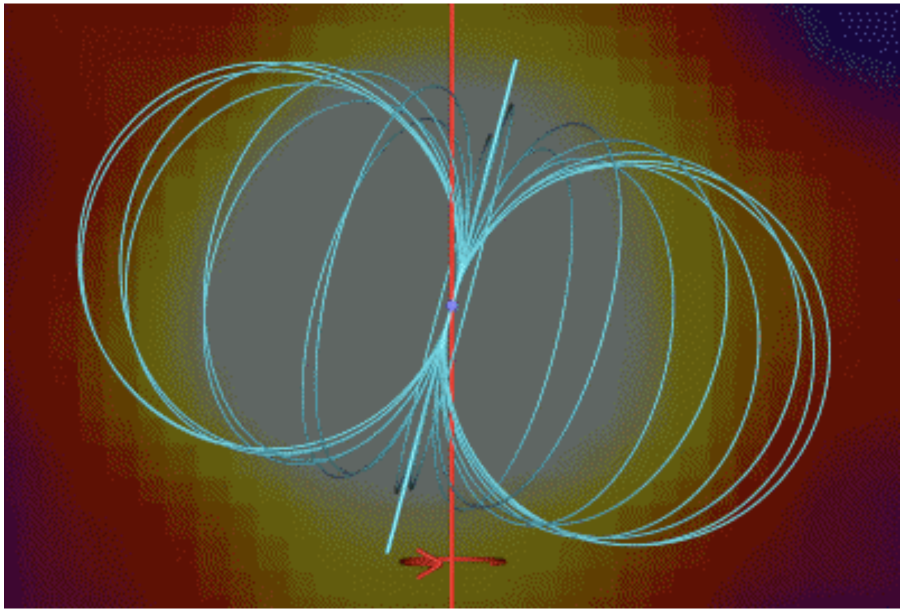
- **plus a look on their surroundings (radio,opt.,X-rays)**

•NO msec, RRAT, AXP, SGR

Anatomy of NSs' emission



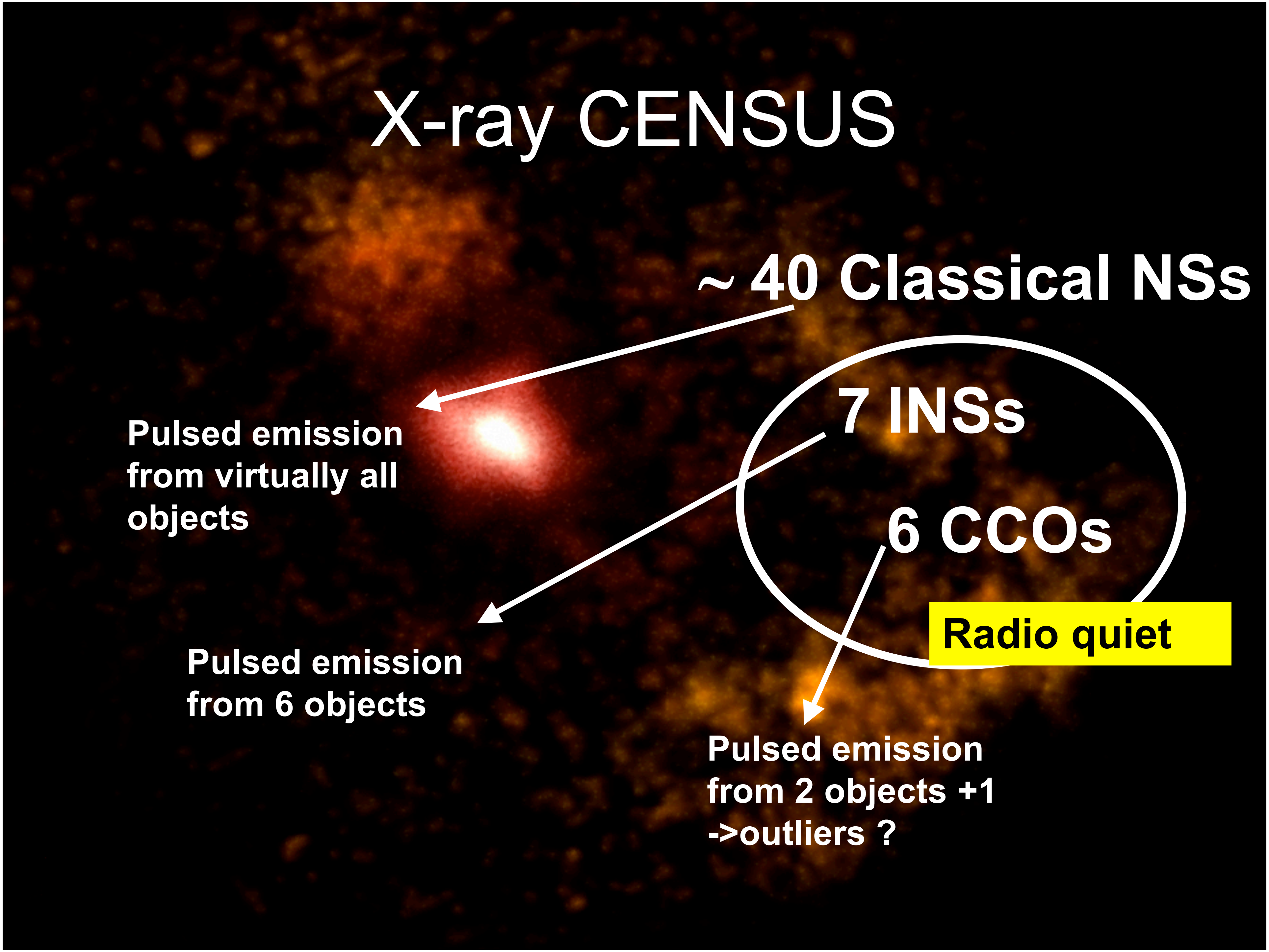
- (rotating) surface emission
  primeval heat, particle re-heating
- (rotating) magnetospheric emission
  particle acceleration- rot. energy loss



- NS surroundings
  relativistic wind,
  interaction with ISM

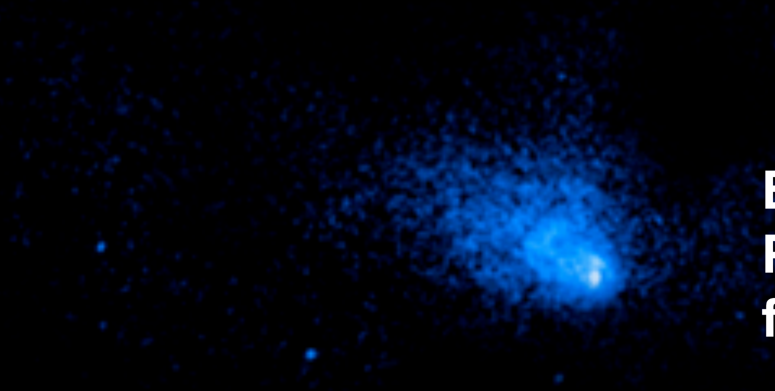
Phenomenological approach

- (rotating) surface emission
  thermal, generally (not always) pulsed
- (rotating) magnetospheric emission
  non thermal, STRONGLY pulsed
- NS surroundings- variable but not pulsed
  non thermal PWNe, non thermal Tails,
  non thermal Bow shocks (ISM interaction)


X-ray CENSUS
~ 40 Classical NSs
7 INSs
6 CCOs
Radio quiet
Pulsed emission from virtually all objects
Pulsed emission from 6 objects
Pulsed emission from 2 objects +1 ->outliers ?

Diffuse feature CENSUS

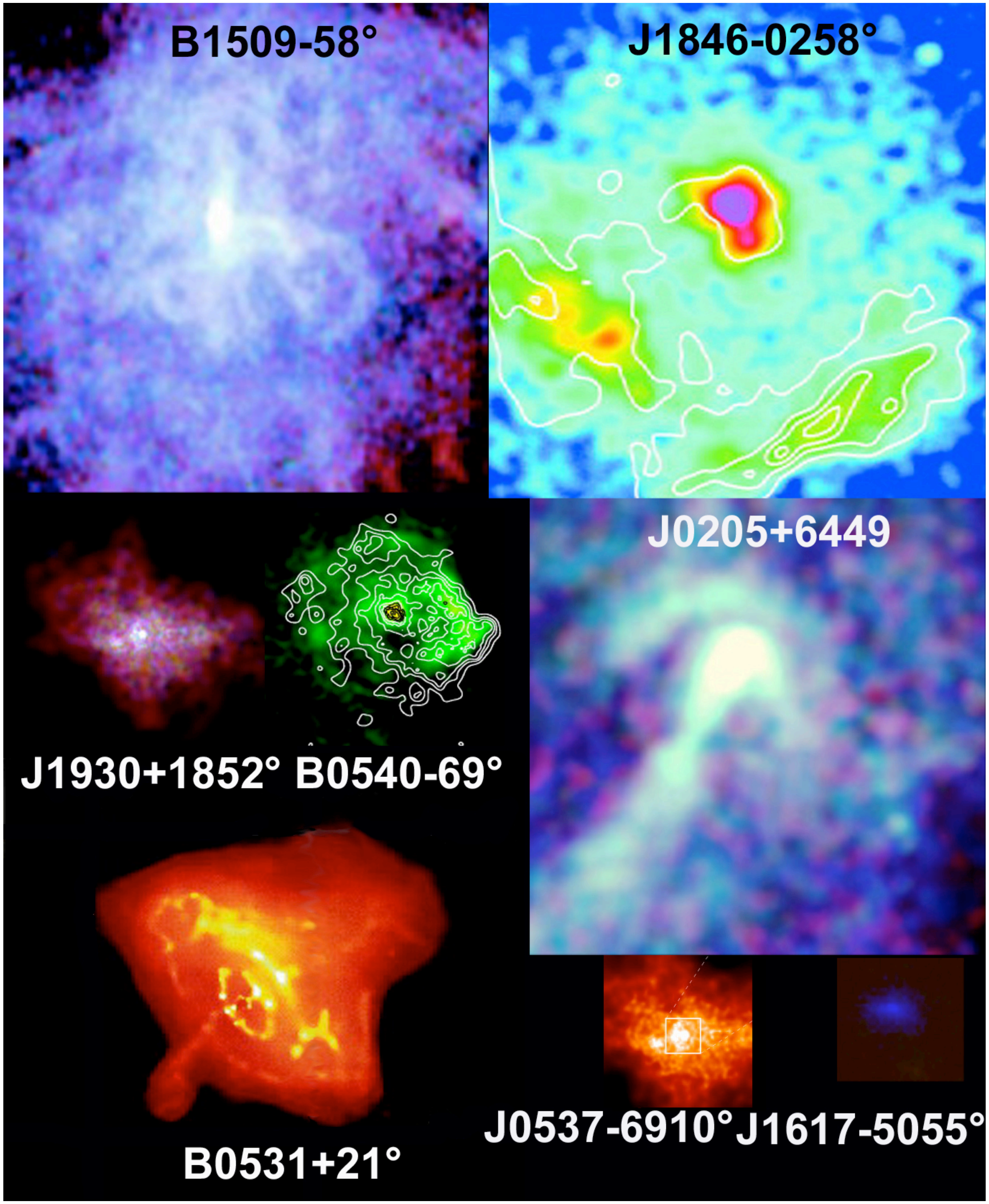
NSs with X-ray PWNe (and more) 20



Energetic objects
PWNe are not detected
for NSs with Edot <10^{36}

NSs with tails/jets 10

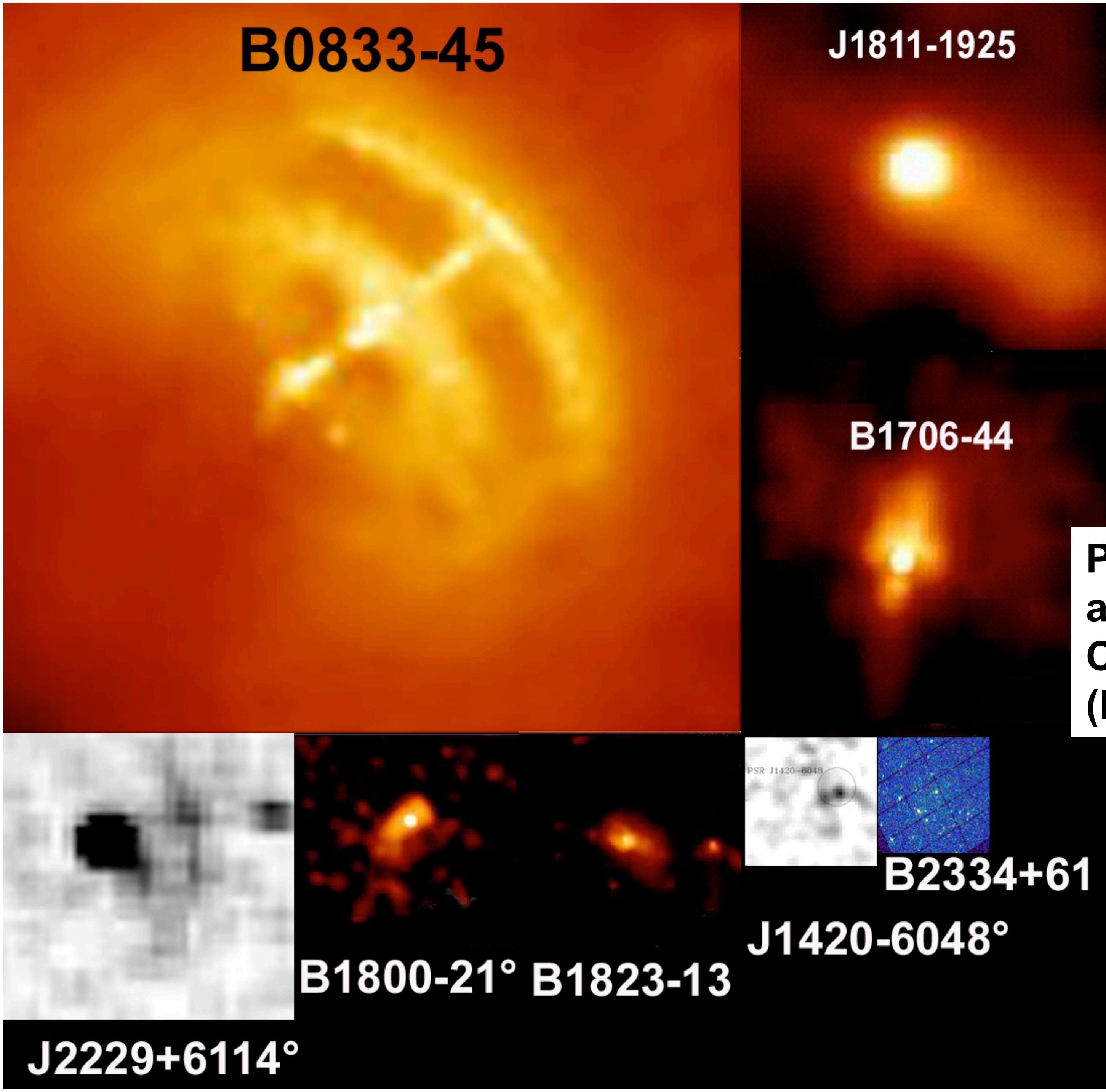
Diffuse structures with no pulsar detected (as yet) 24



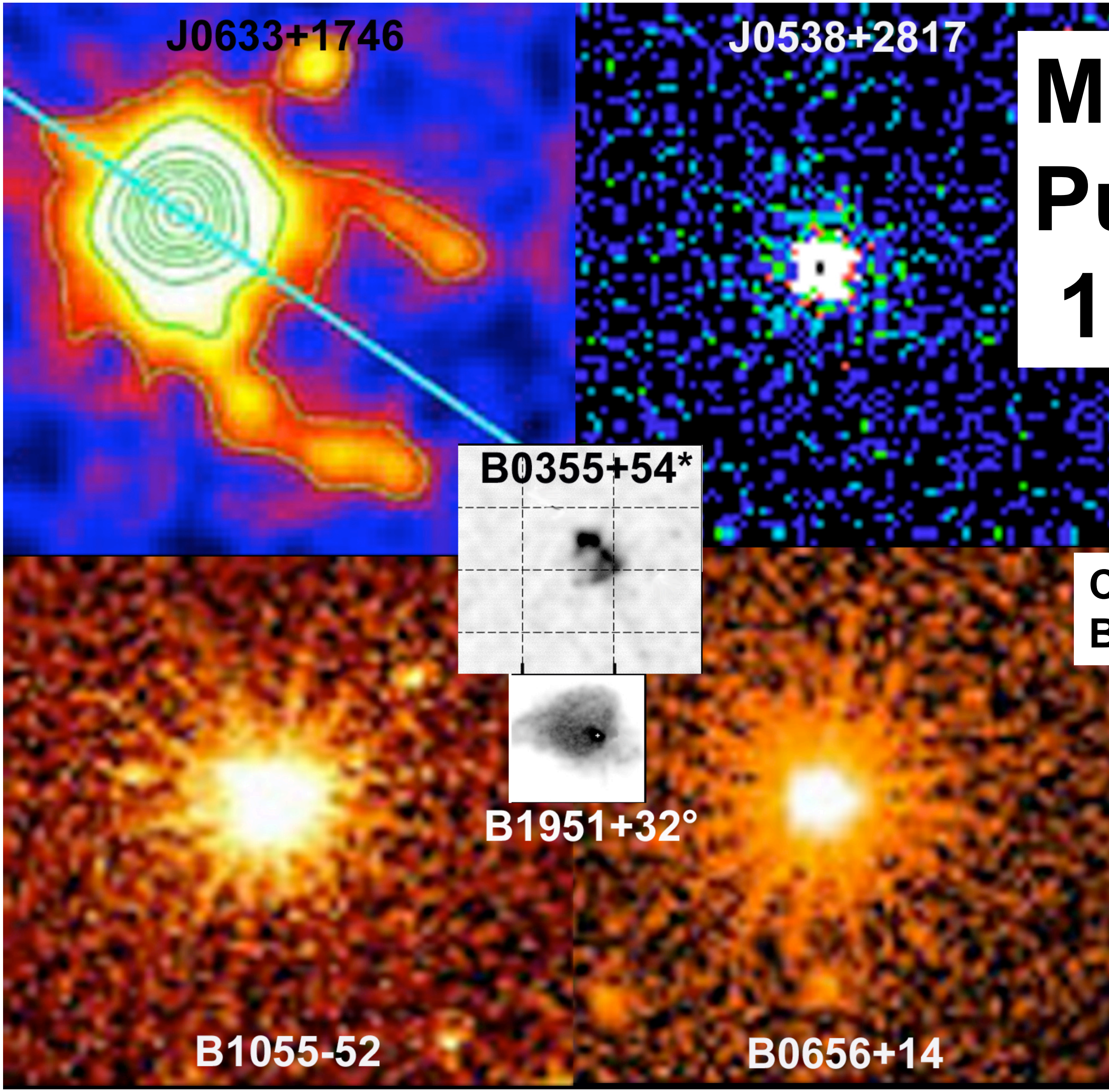
Young Pulsars (< 10,000 y)

PI sectra
Pulsed emission

Adult Pulsars 10^4- 10^5

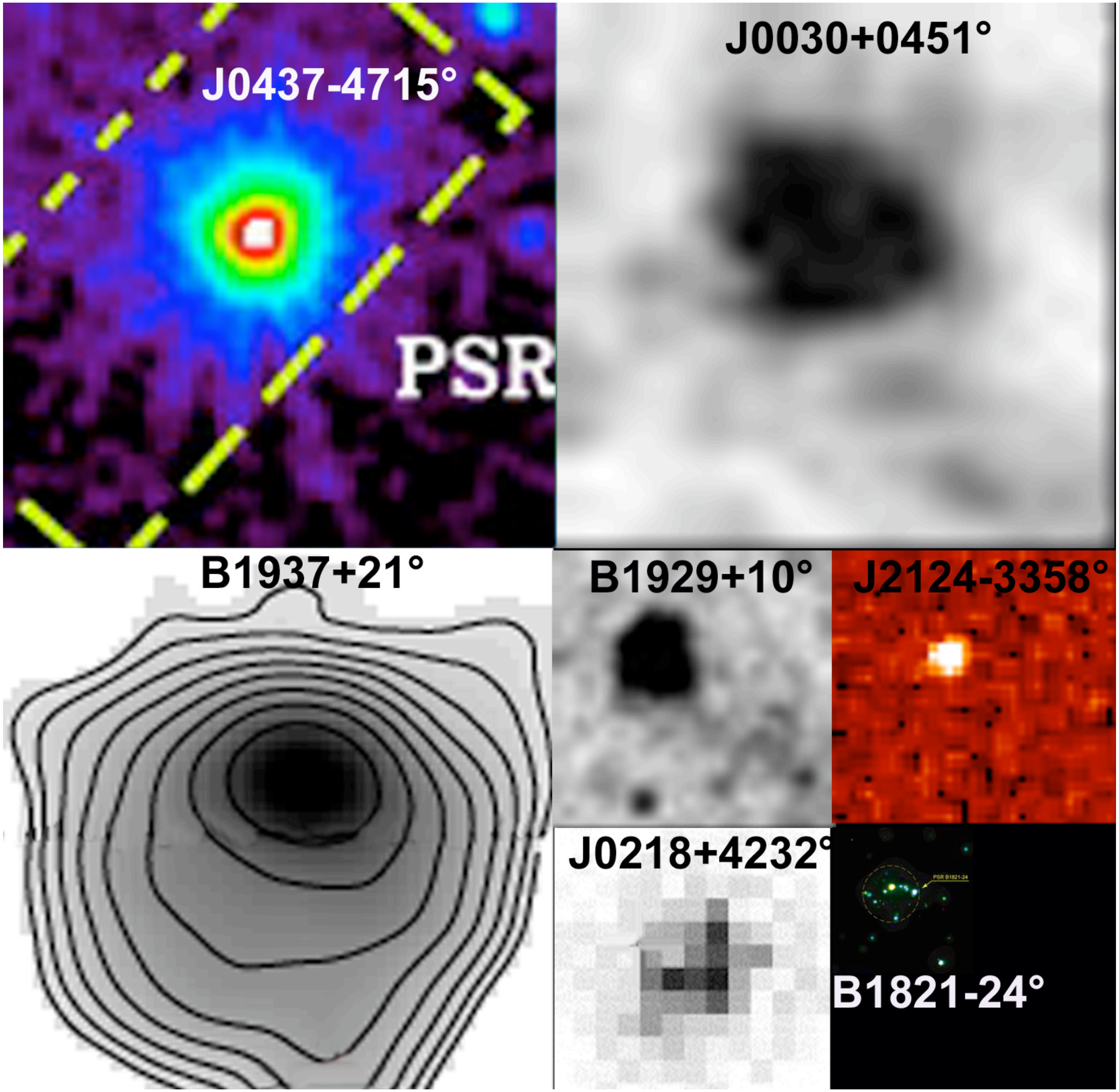


PL spectra
and
Composite spectra
(BB+ PL)



Mature Pulsars 10^5- 10^6 y

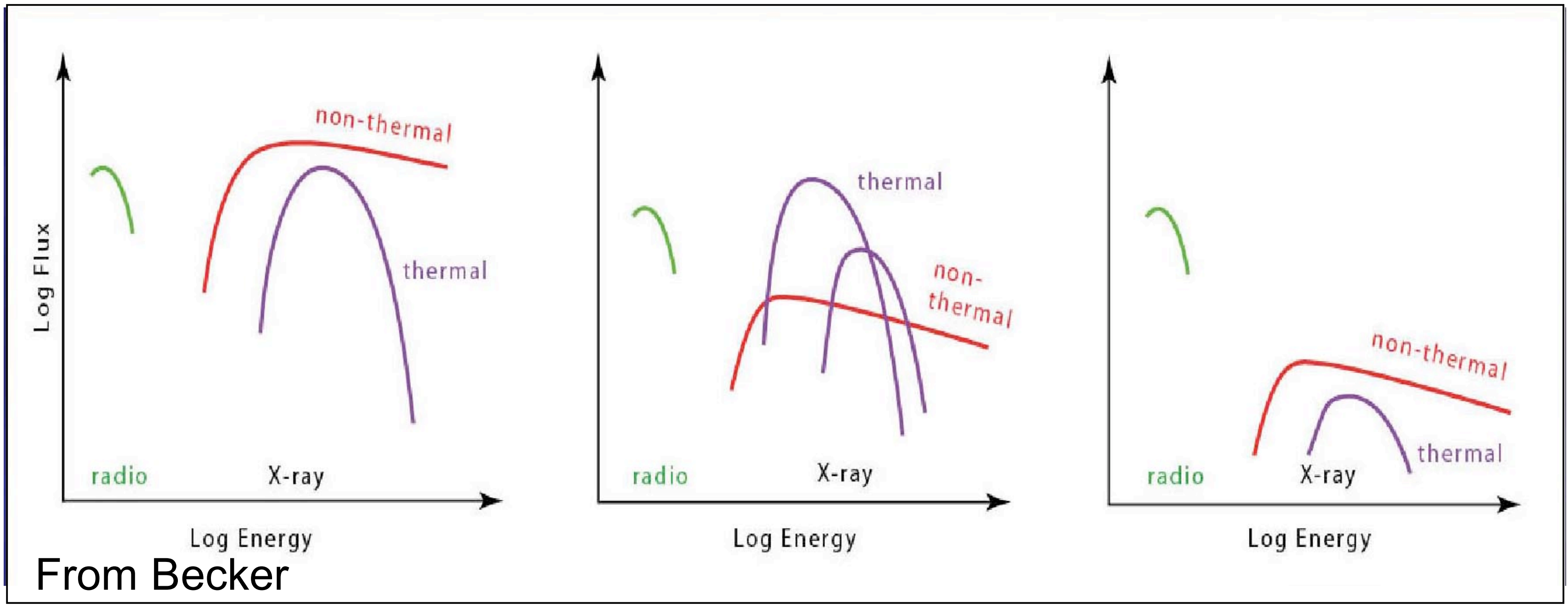
Composite spectra
BB+ PL



Old Pulsars $> 10^6$ y

PL spectra

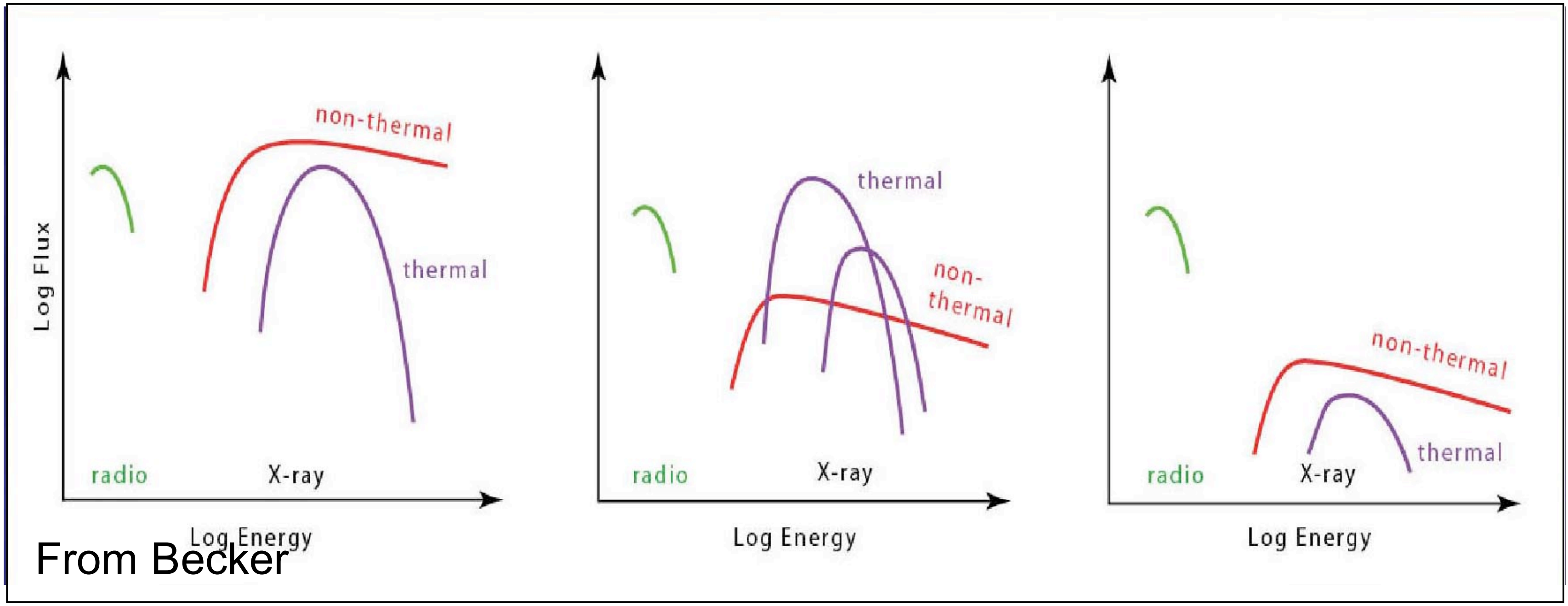
NSs' X-ray emission vs. age



young 10^3 y **Middle-aged 10^4-10^5** **Old >10^6 y**

Pulsed fraction is maximum for young objects
Thermal emission produces shallow light curve, lower PF

NSs' X-ray emission vs. age

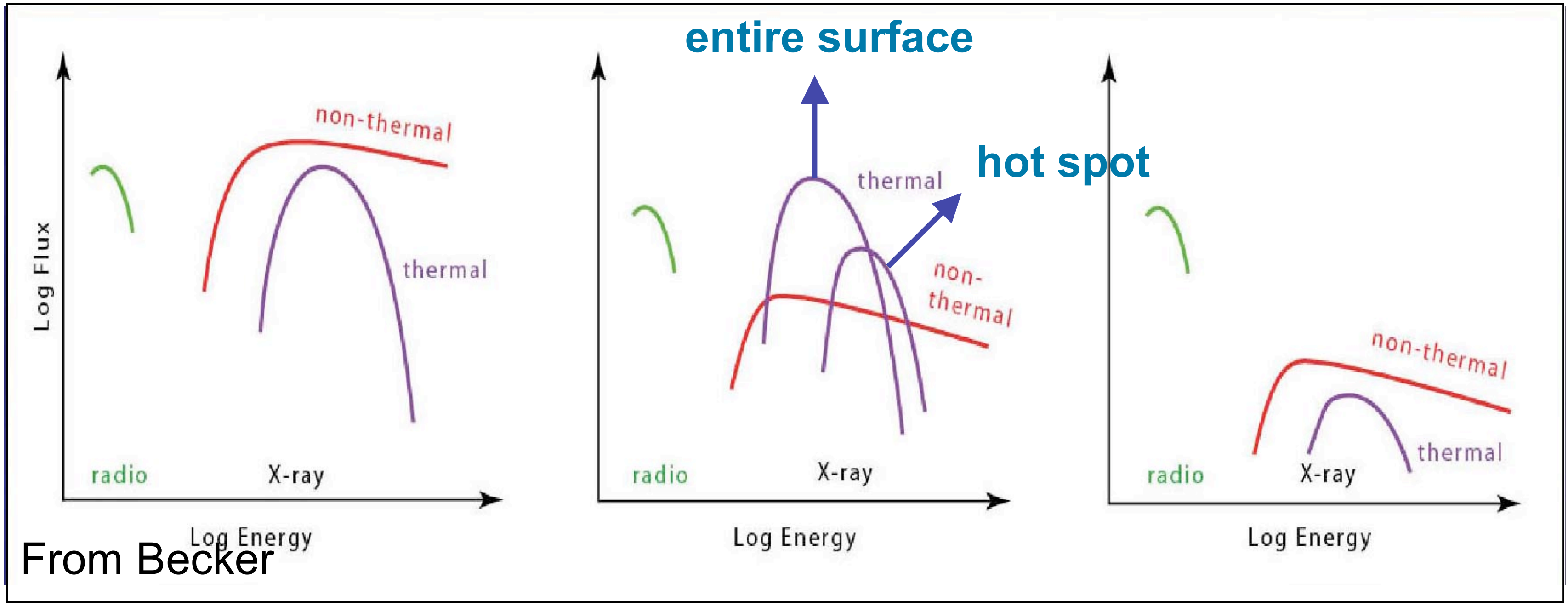


From Becker

young 10^3 y **Middle-aged 10^4-10^5** **Old >10^6 y**

Exception J1119-6127, 1,700 y, thermal emission high pulsed fraction (74%), high T 2.4 10^6 °K, R=3.4km

NSs’ X-ray emission vs. age



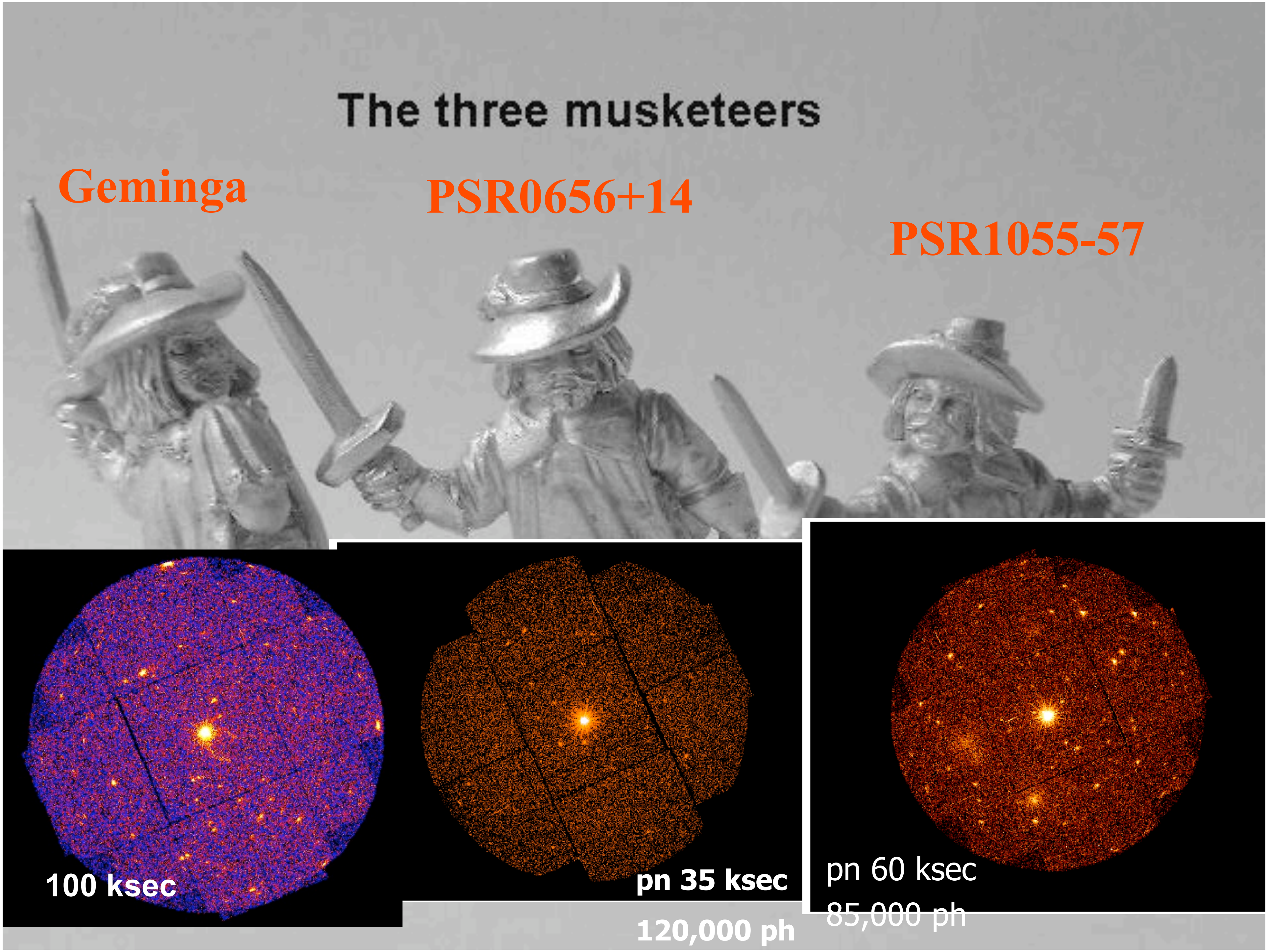
young 10^3 y **Middle-aged 10^4-10^5** **Old $>10^6$ y**

L_{NT} @ 5 10^{-4} – 5 10^{-5} Edot

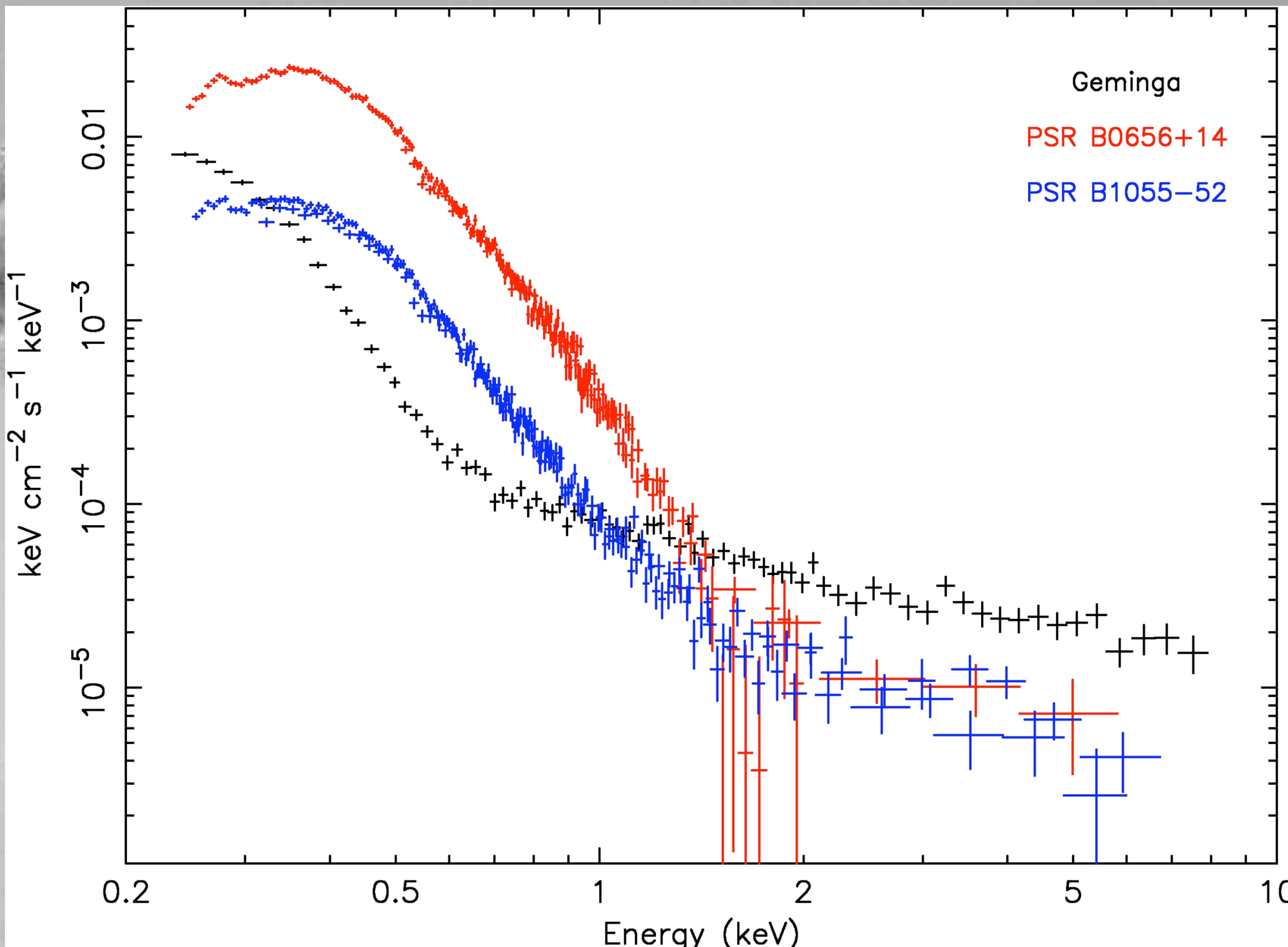
Exception PSR0628-28 overluminous
P=1.24s t=2.8 10^6y

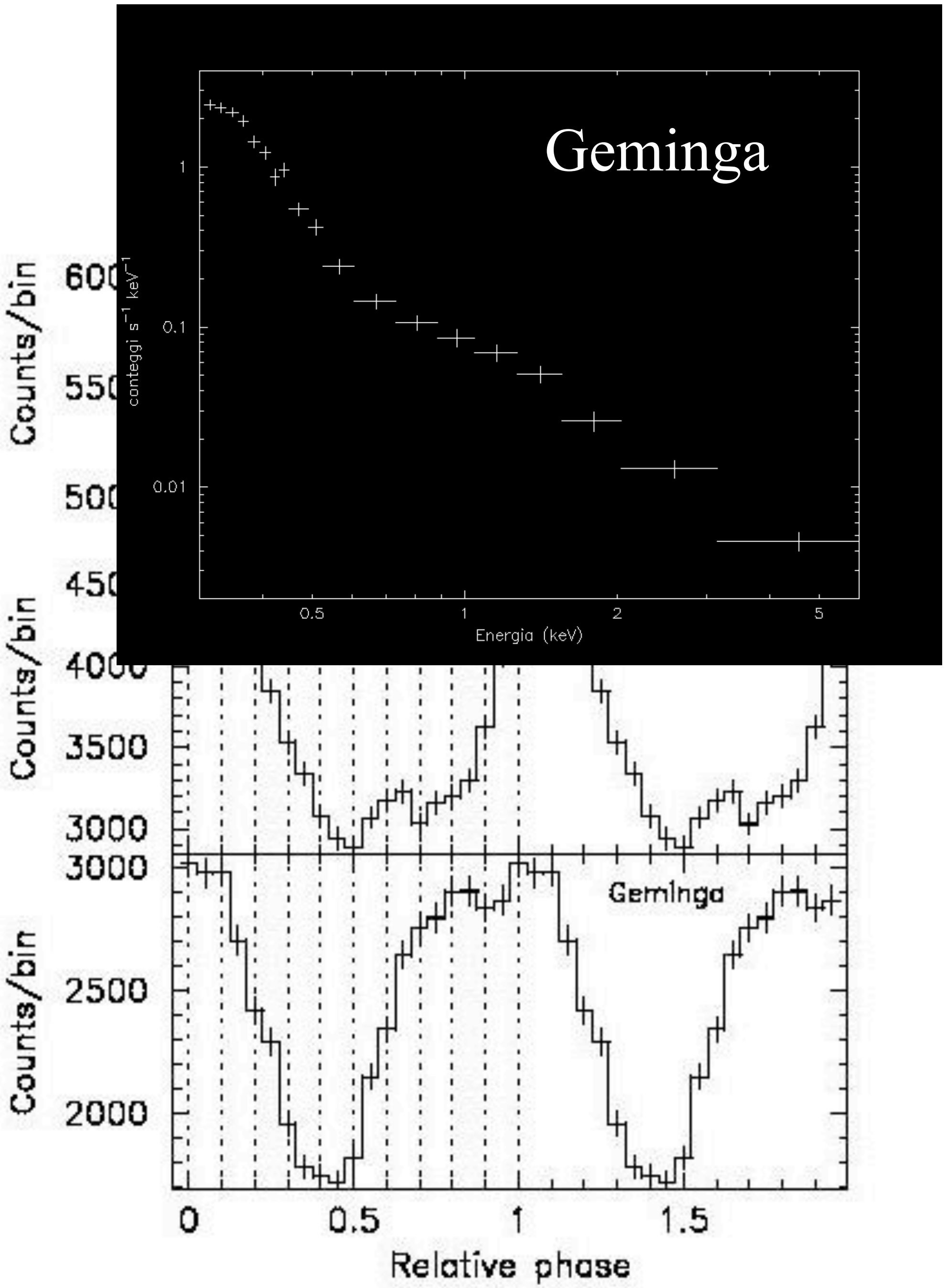
T → cooling,
Emitting surface

if D known →EOS

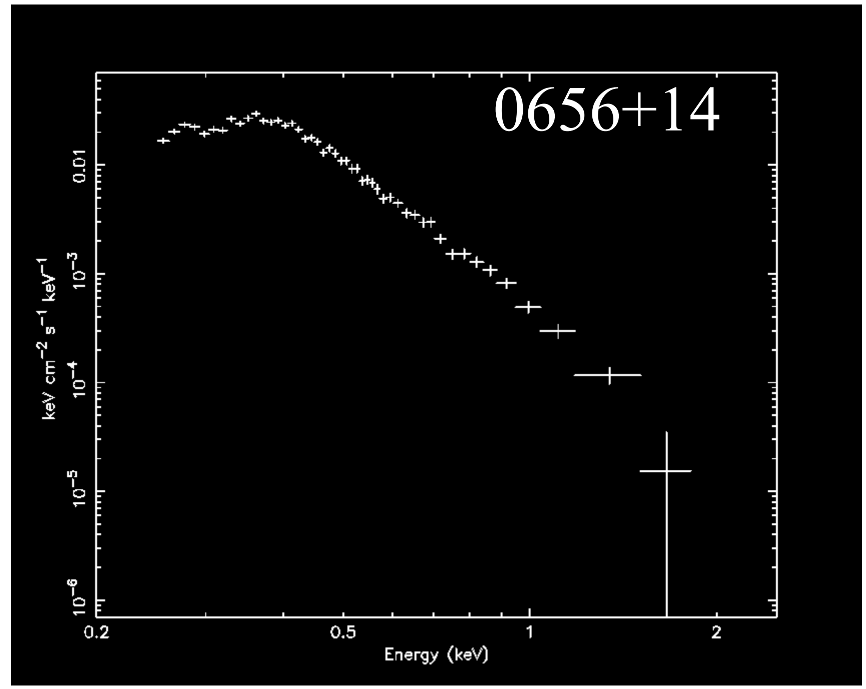

The three musketeers
Geminga
PSR0656+14
PSR1055-57
100 ksec
pn 35 ksec
120,000 ph
pn 60 ksec
85,000 ph

The three musketeers

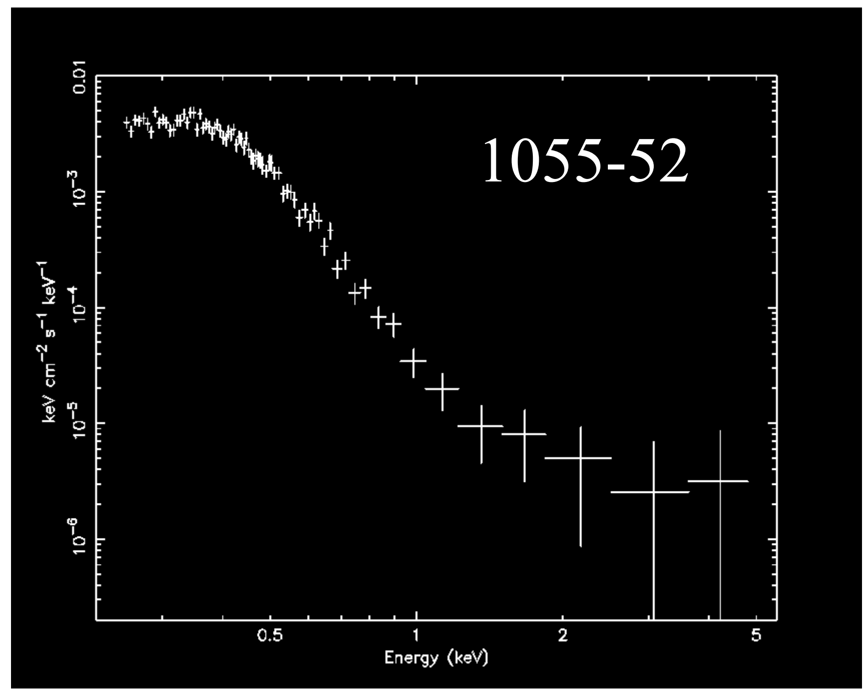




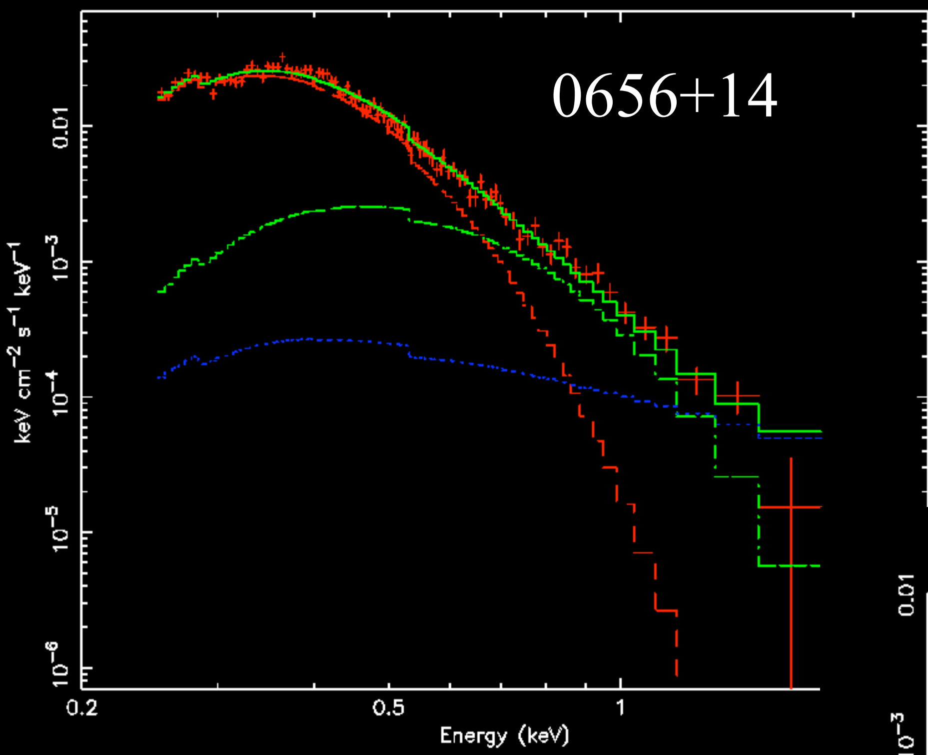
Geminga
conteggi s^{-1} keV^{-1}
Energia (keV)
Counts/bin
Relative phase
Geminga

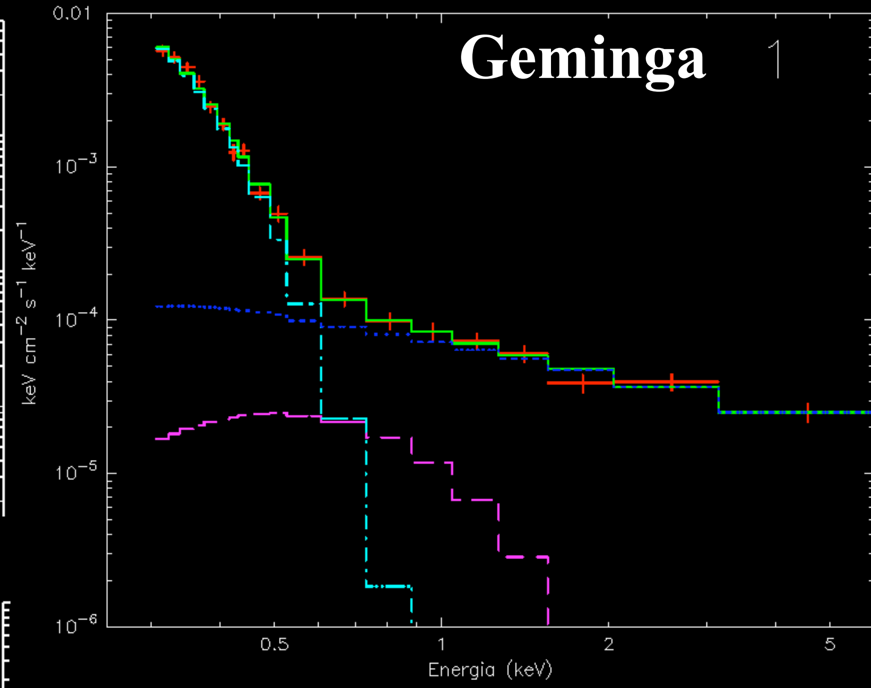


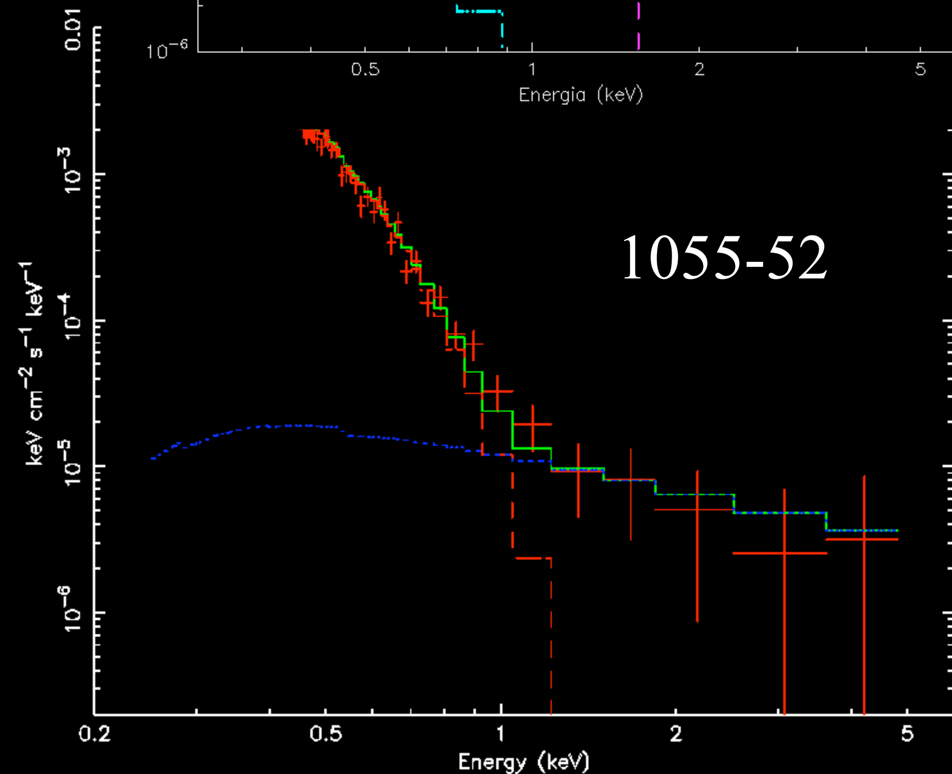
0656+14
keV cm^{-2} s^{-1} keV^{-1}
Energy (keV)

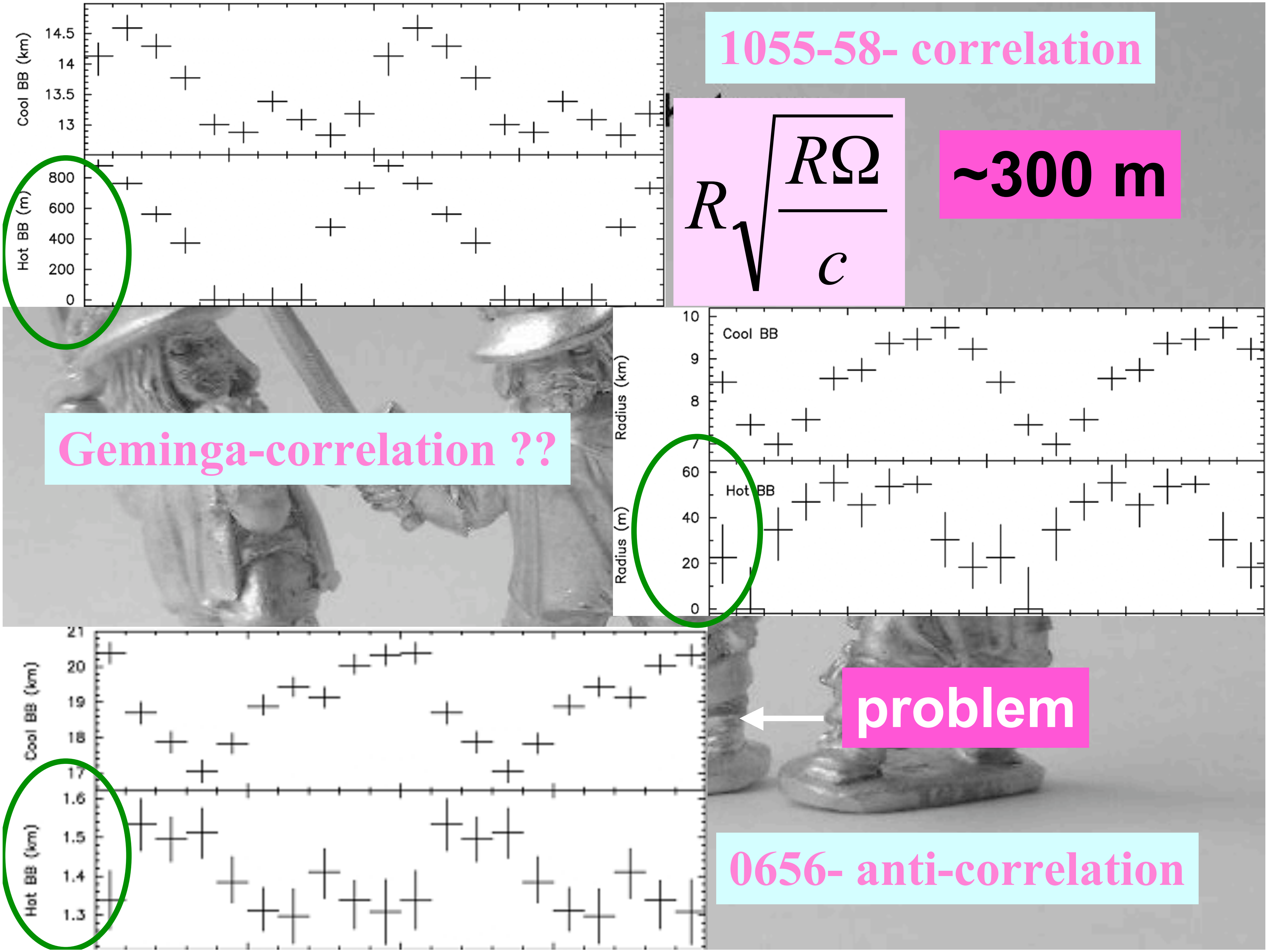


1055-52
keV cm^{-2} s^{-1} keV^{-1}
Energy (keV)

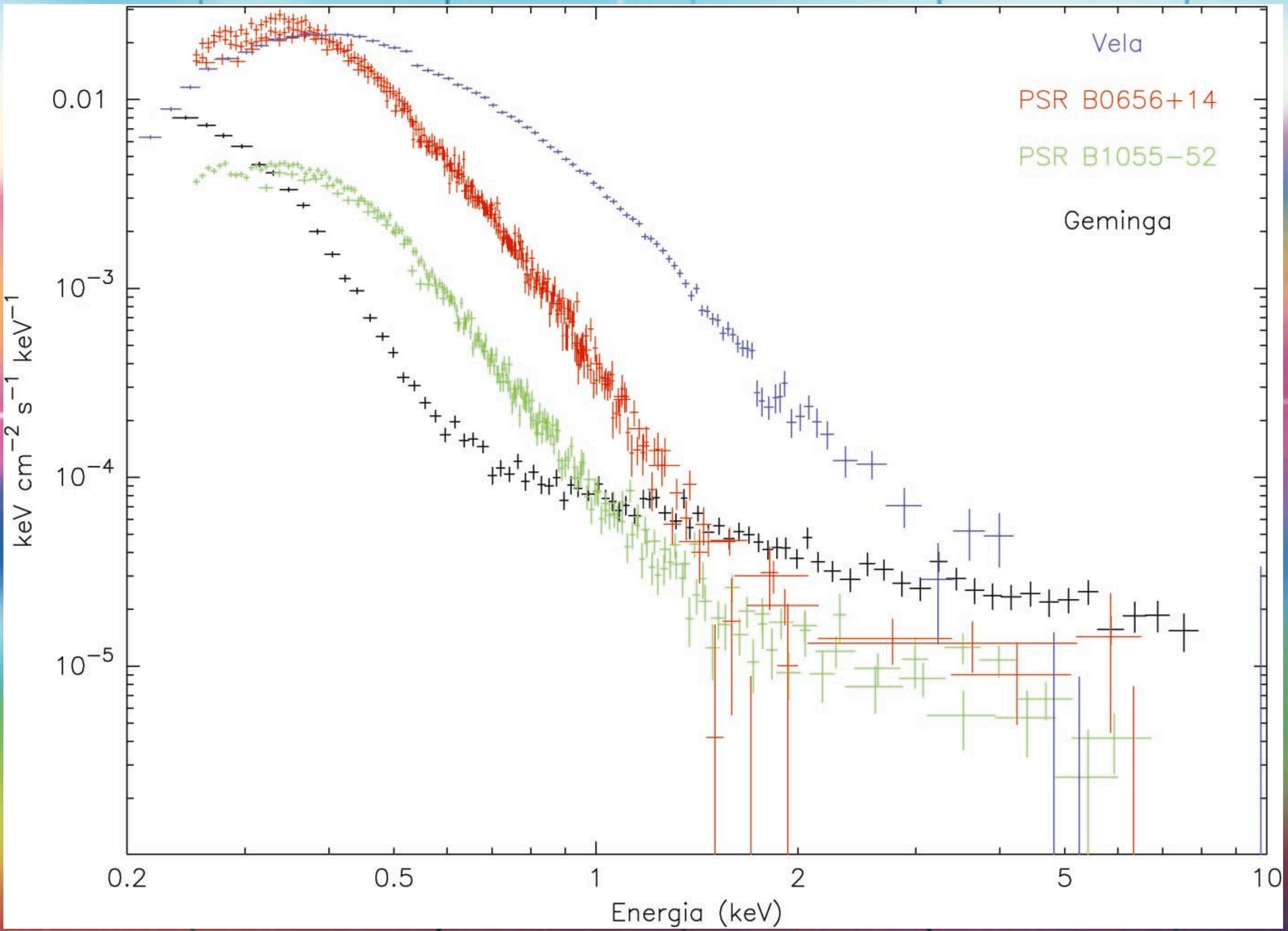

0656+14
keV cm^{-2} s^{-1} keV^{-1}
0.01
10^{-3}
10^{-4}
10^{-5}
10^{-6}
0.2
0.5
1
Energy (keV)


Geminga
keV cm^{-2} s^{-1} keV^{-1}
0.01
10^{-3}
10^{-4}
10^{-5}
10^{-6}
0.5
1
2
5
Energia (keV)


1055-52
keV cm^{-2} s^{-1} keV^{-1}
0.01
10^{-3}
10^{-4}
10^{-5}
10^{-6}
0.2
0.5
1
2
5
Energy (keV)

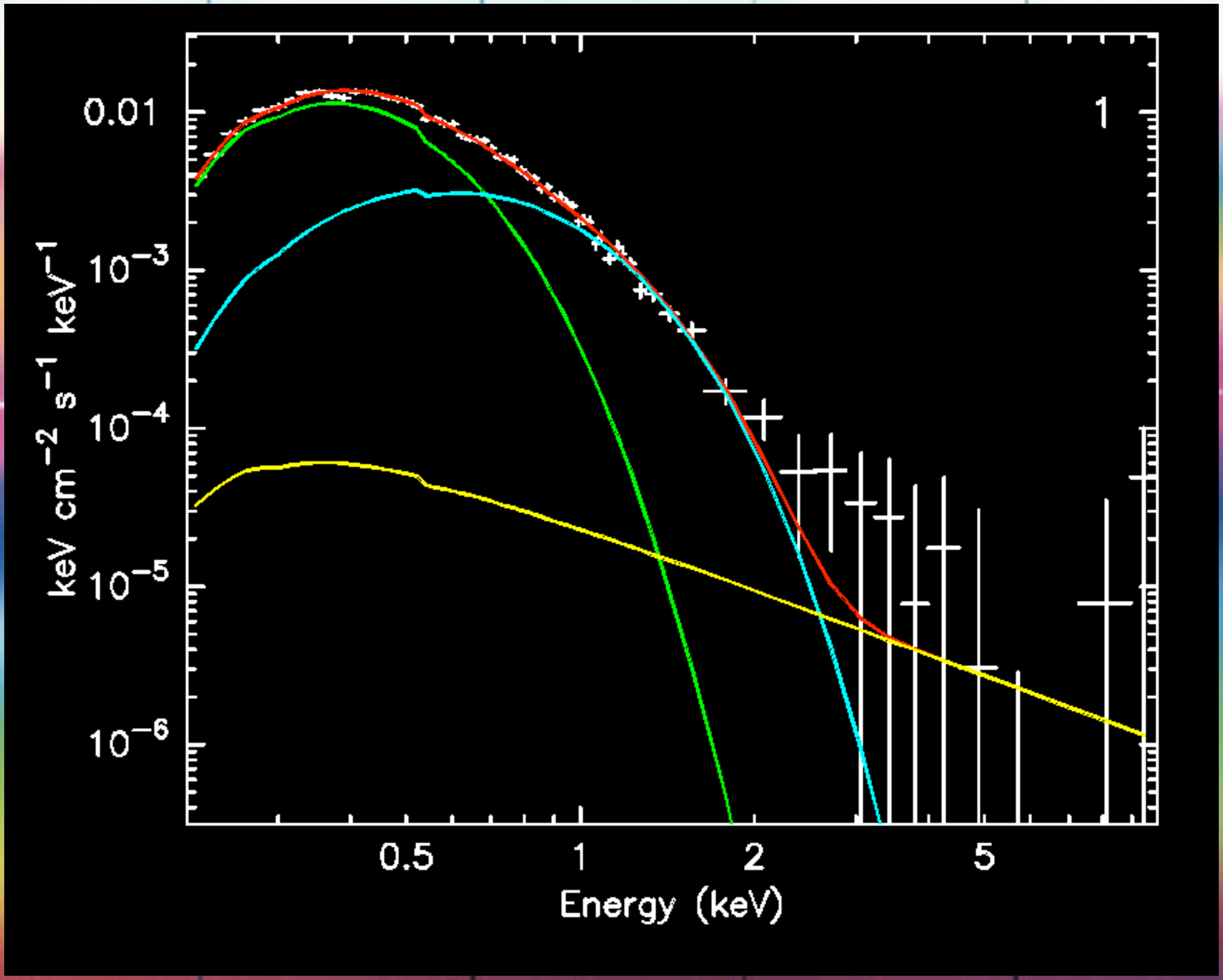

1055-58- correlation
R √(RΩ/c)
~300 m
Geminga-correlation ??
problem
0656- anti-correlation
Cool BB (km)
Hot BB (m)
Cool BB
Hot BB
Radius (km)
Radius (m)
Cool BB (km)
Hot BB (km)

and Vela

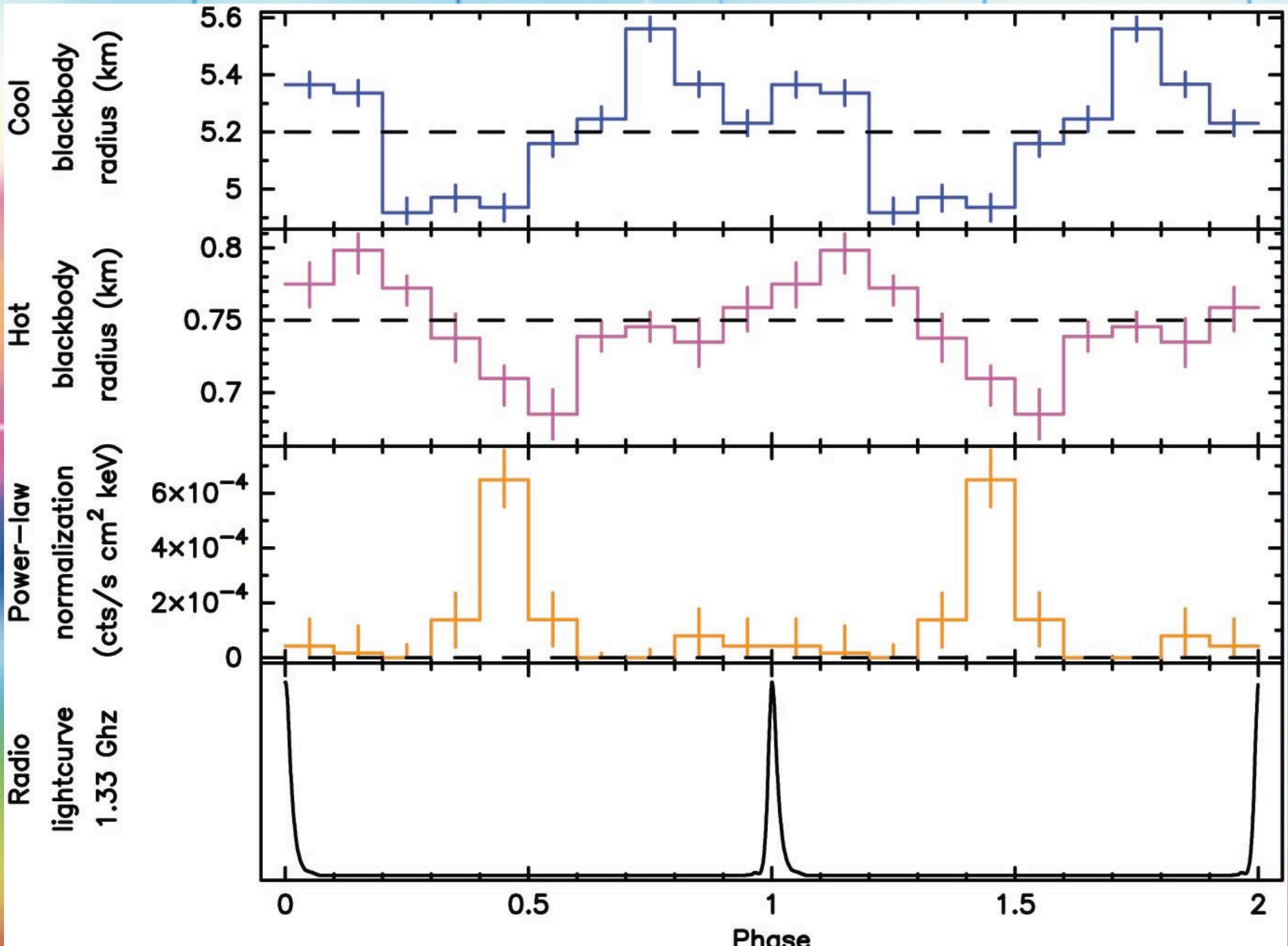


Vela
PSR B0656+14
PSR B1055−52
Geminga
0.01
10−3
10−4
10−5
keV cm−2 s−1 keV−1
0.2
0.5
1
2
5
10
Energia (keV)

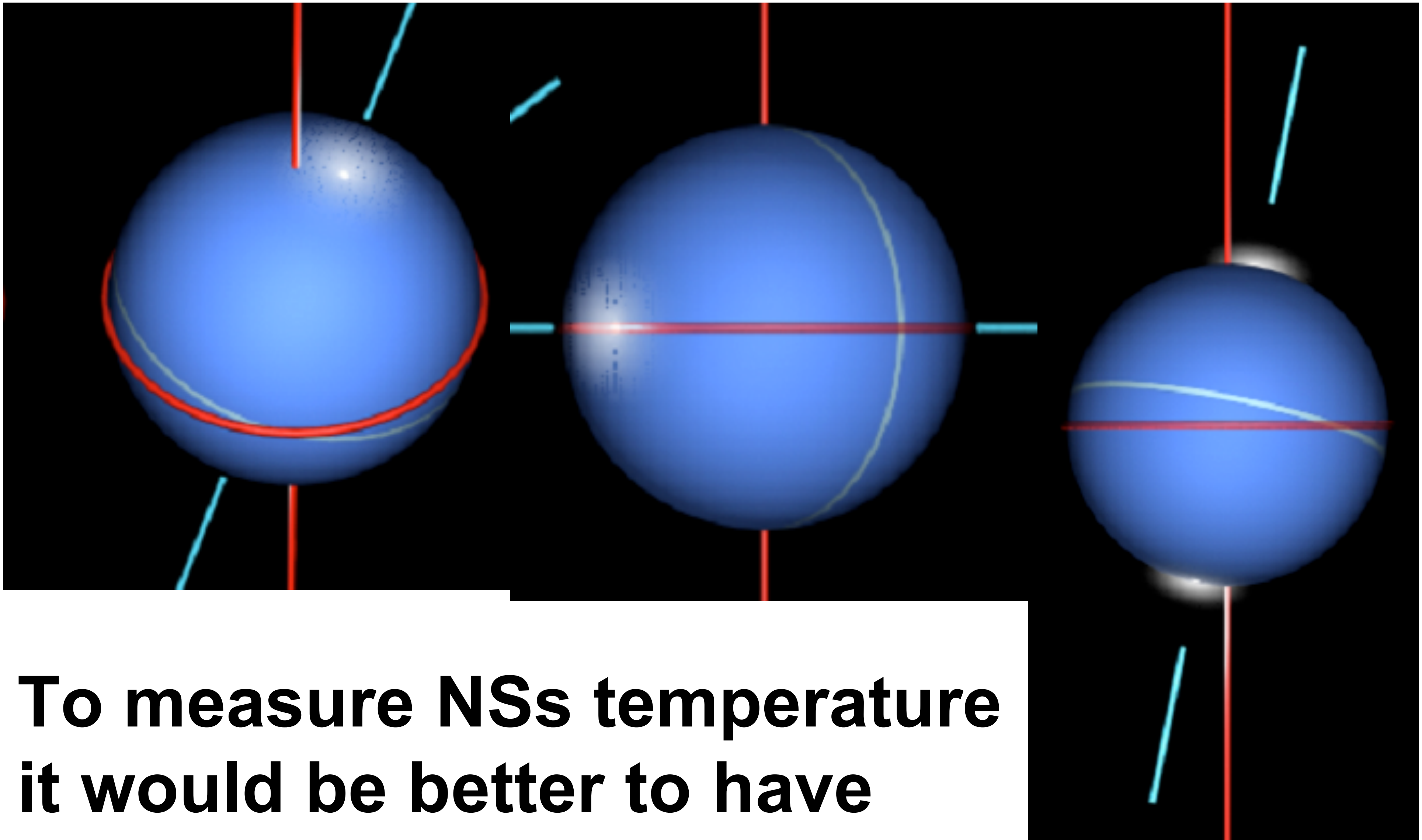
and Vela



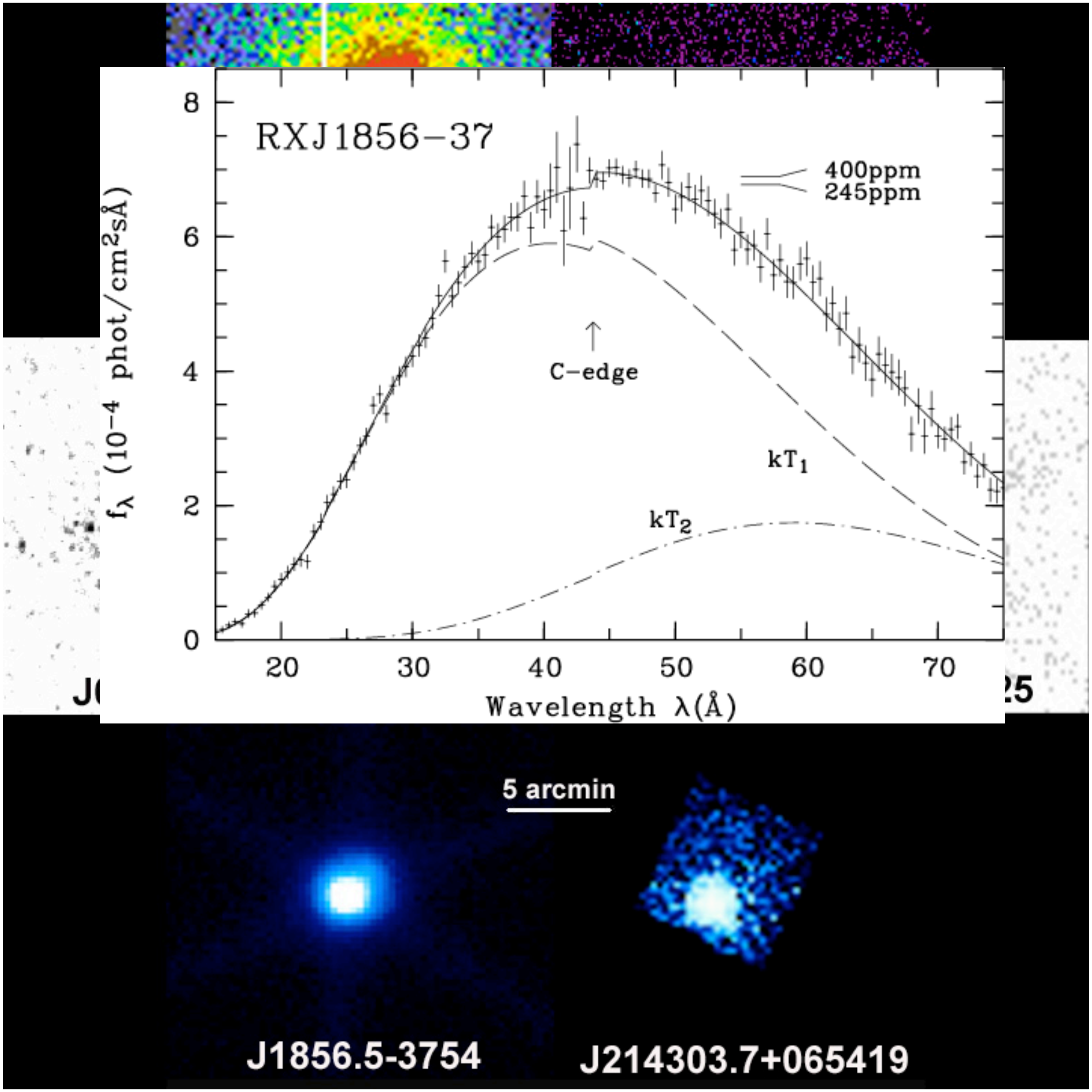
and Vela



Cool blackbody radius (km)
5.6
5.4
5.2
5
Hot blackbody radius (km)
0.8
0.75
0.7
Power−law normalization (cts/s cm^2 keV)
6×10^{-4}
4×10^{-4}
2×10^{-4}
0
Radio lightcurve 1.33 Ghz
0
0.5
1
1.5
2
Phase



To measure NSs temperature it would be better to have a neutron star without "hot spots".



INSs

No radio em.

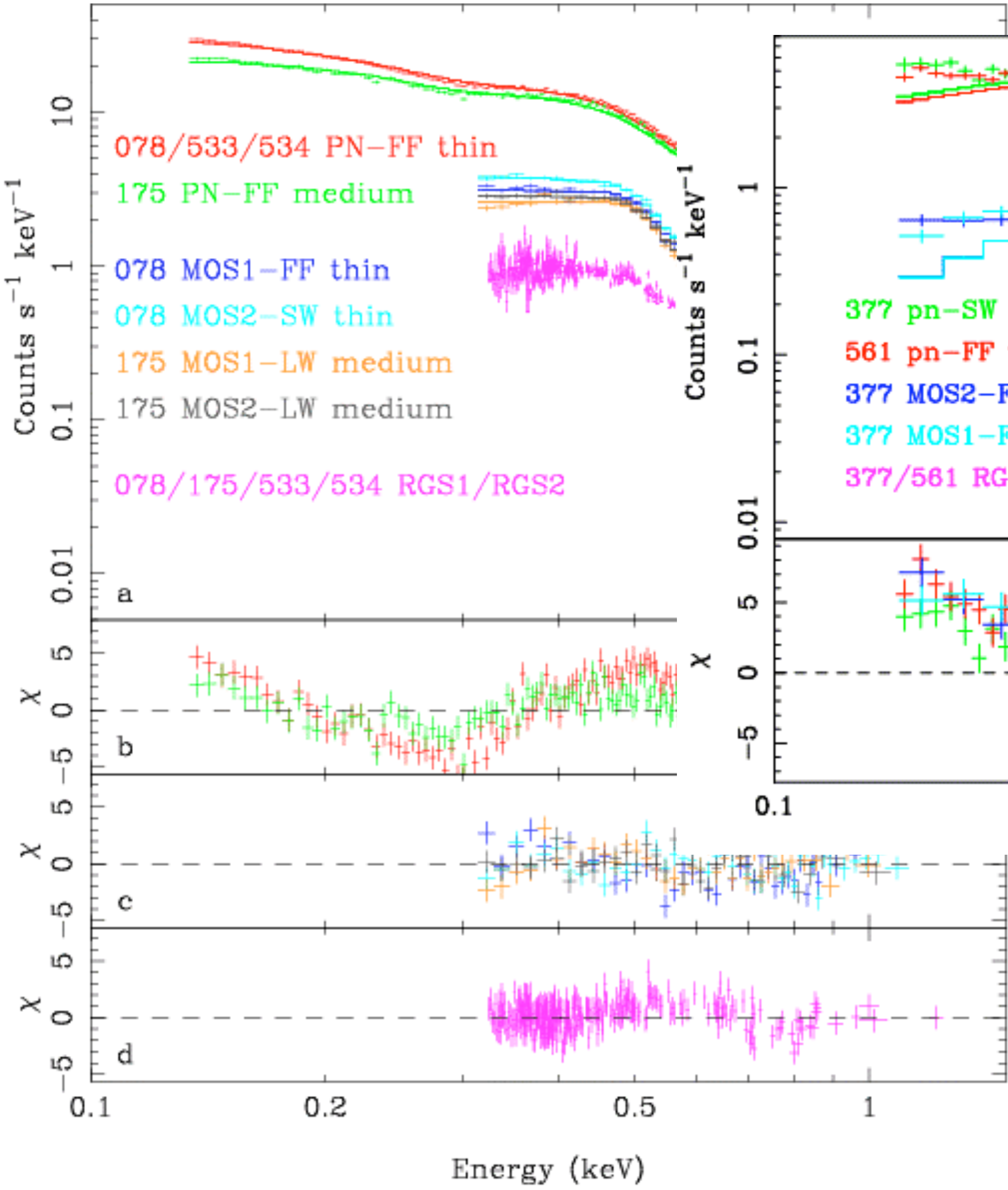
Faint optical em.

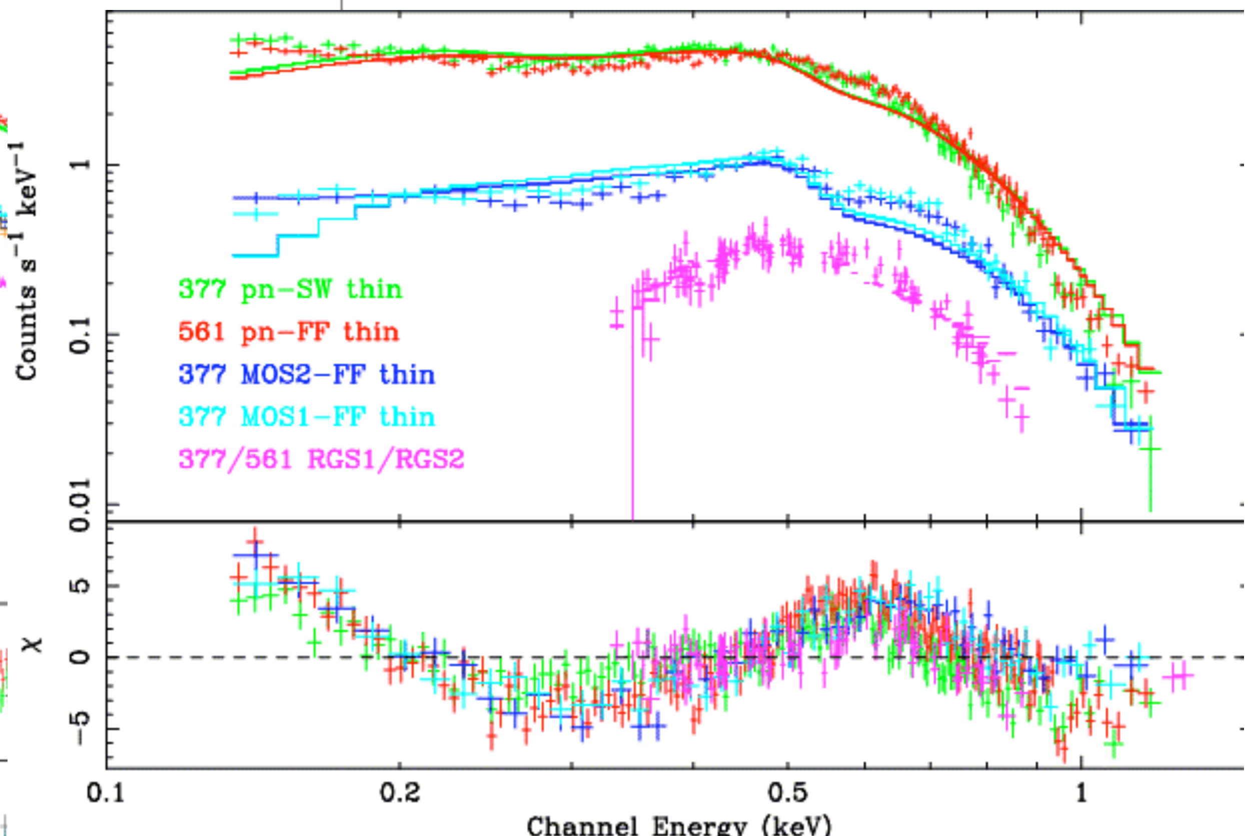
Thermal spectra
Low T
Whole surface

Shallow puls.
Long Periods

Spectral features?

B~ 2-6 10^{13} G

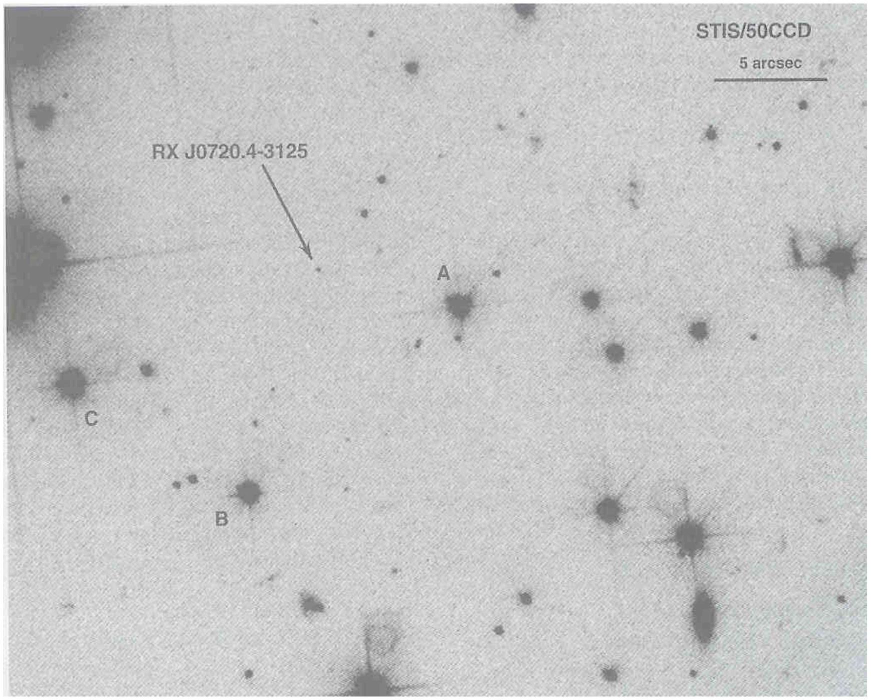




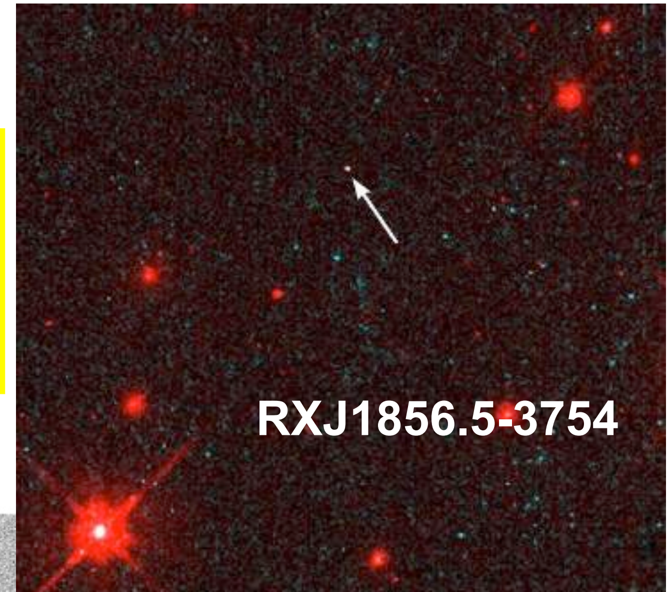
RBS1223

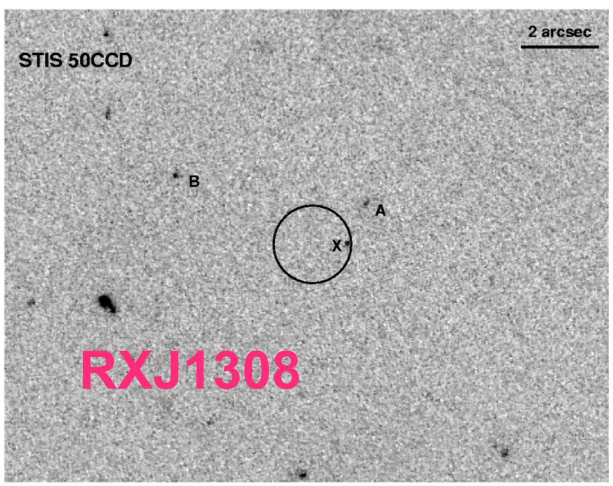
RXJ 0720.4-3125

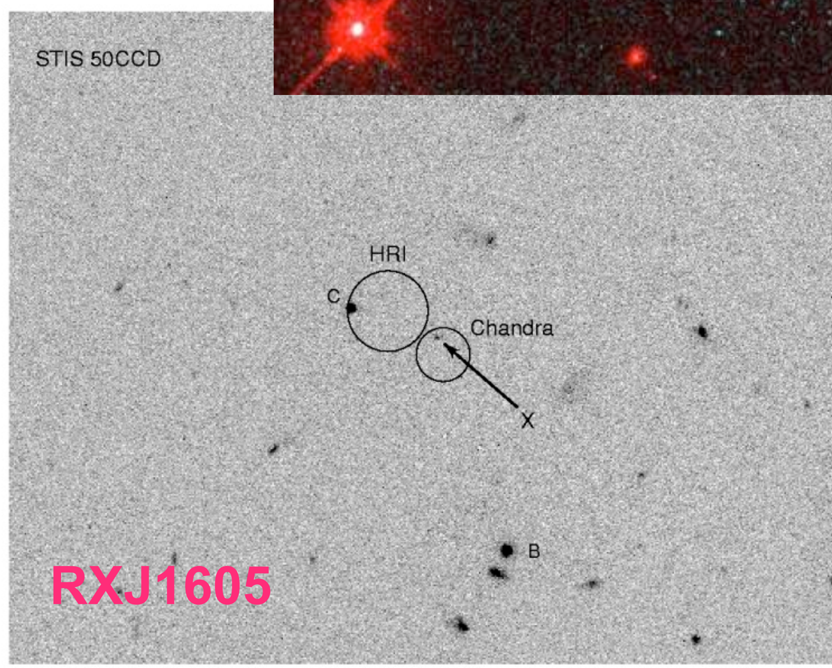
Isolated Neutron Stars seen by HST



PM
← →
Parallax







From position to physics
INS's EOS: the ambitious goal

- RX J1856.5-3754 : perfect BB, PF=1.2 %

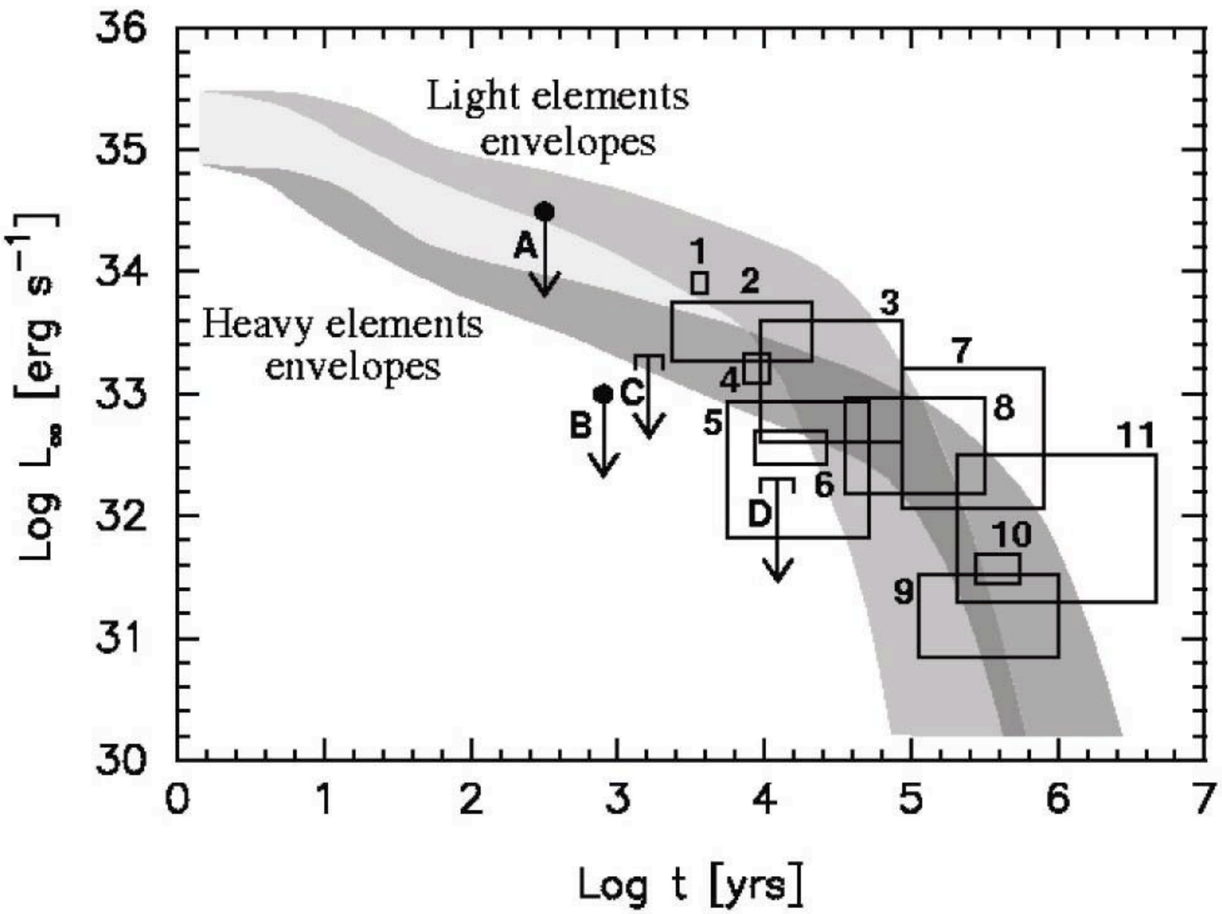
  knowing the distance one could **measure the star radius >>>> thus EOS**

  at parallactic distance (117 pc (± 12)
  R=4.3km (or 7.2 at revised distance of 175).
  Optical emission is above BB extrapolation

- RX J0720.5-3754 : B=26.6 mag

  d =360 pc (+170-90)

Comparison with Data



Mag H fits:

1) RX J0822-4247 (in Puppis A)

2) 1E 1207.4-5209 (in PKS 1209-52)

3) PSR 0538+2817

4) RX J0002+6246 (in CTB 1)

5) PSR 1706-44

6) PSR 0933-45 (in Vela)

BB fits:

7) PSR 1055-52

8) PSR 0656+14

9) PSR 0633+1748 "Geminga"

10) RX J1856.5-3754

11) RX J0720.4-3125

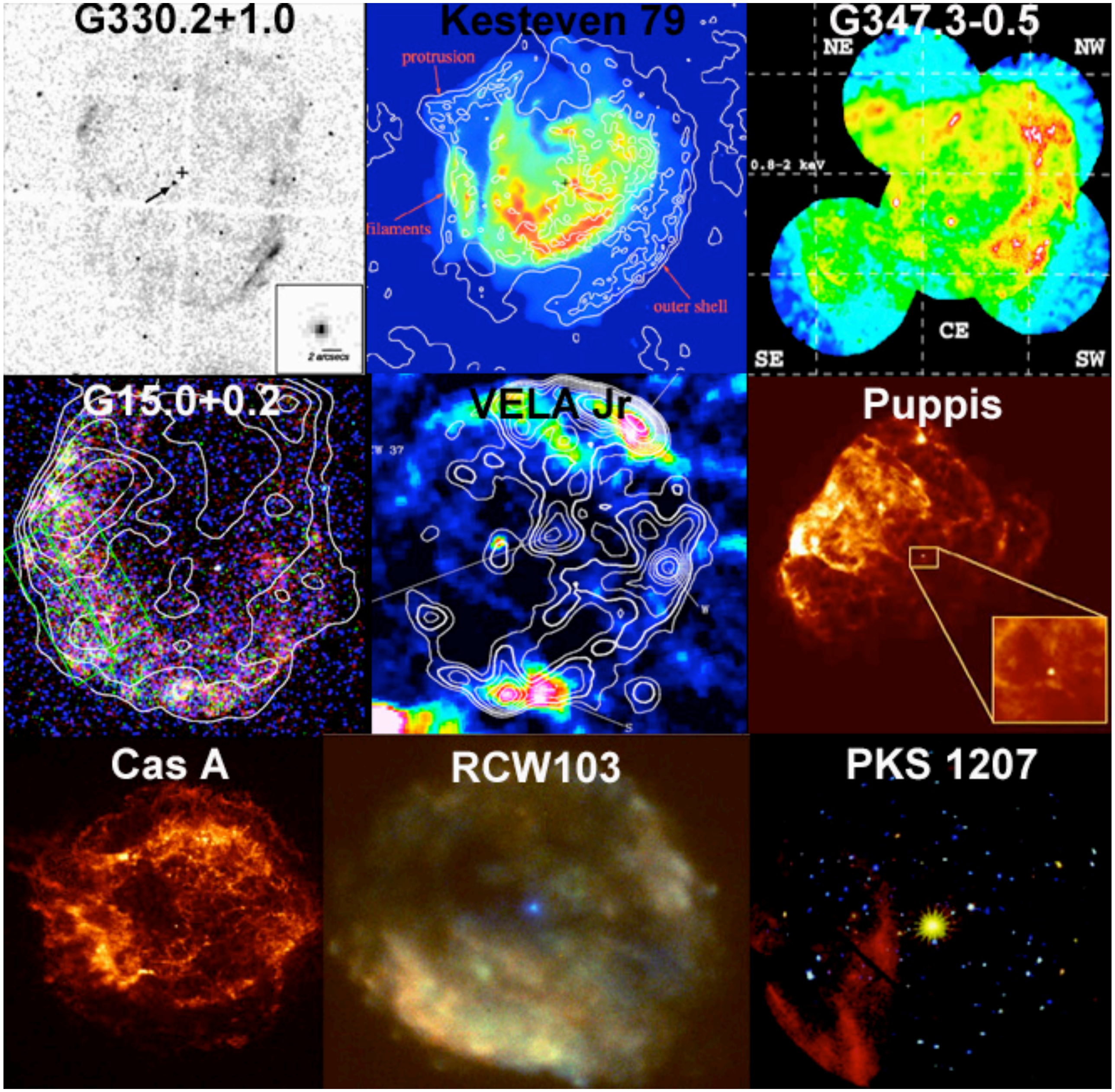
Upper limits:

A) CXO J232327.8+584842 (in Cas A)

B) PSR J0205+6449 (in 3C58)

C) PSR J1124-5916 (in G292.0+1.8)

D) RX J0007.0+7302 (in CTA 1)



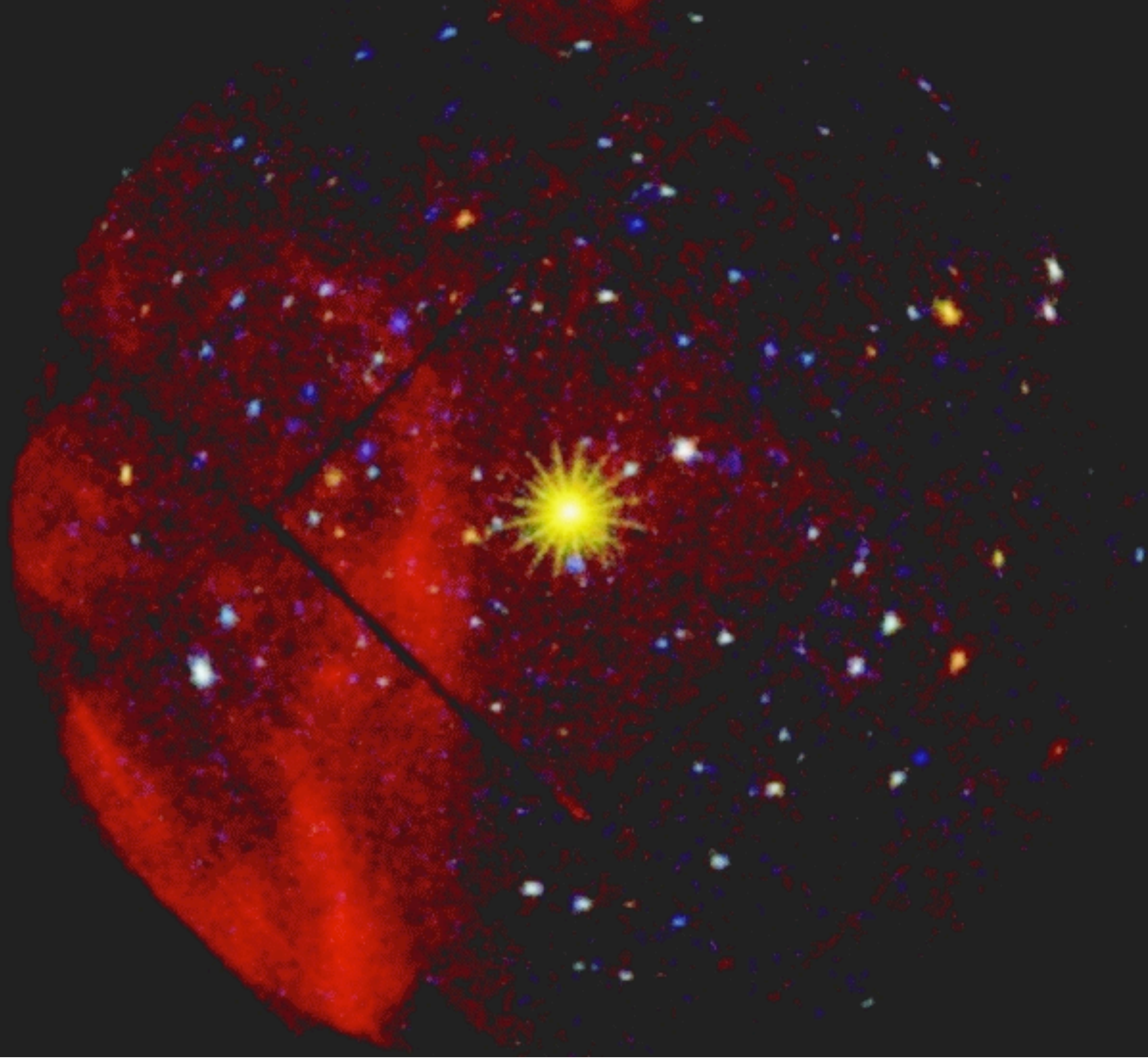
CCOs

No radio emission
No optical emission

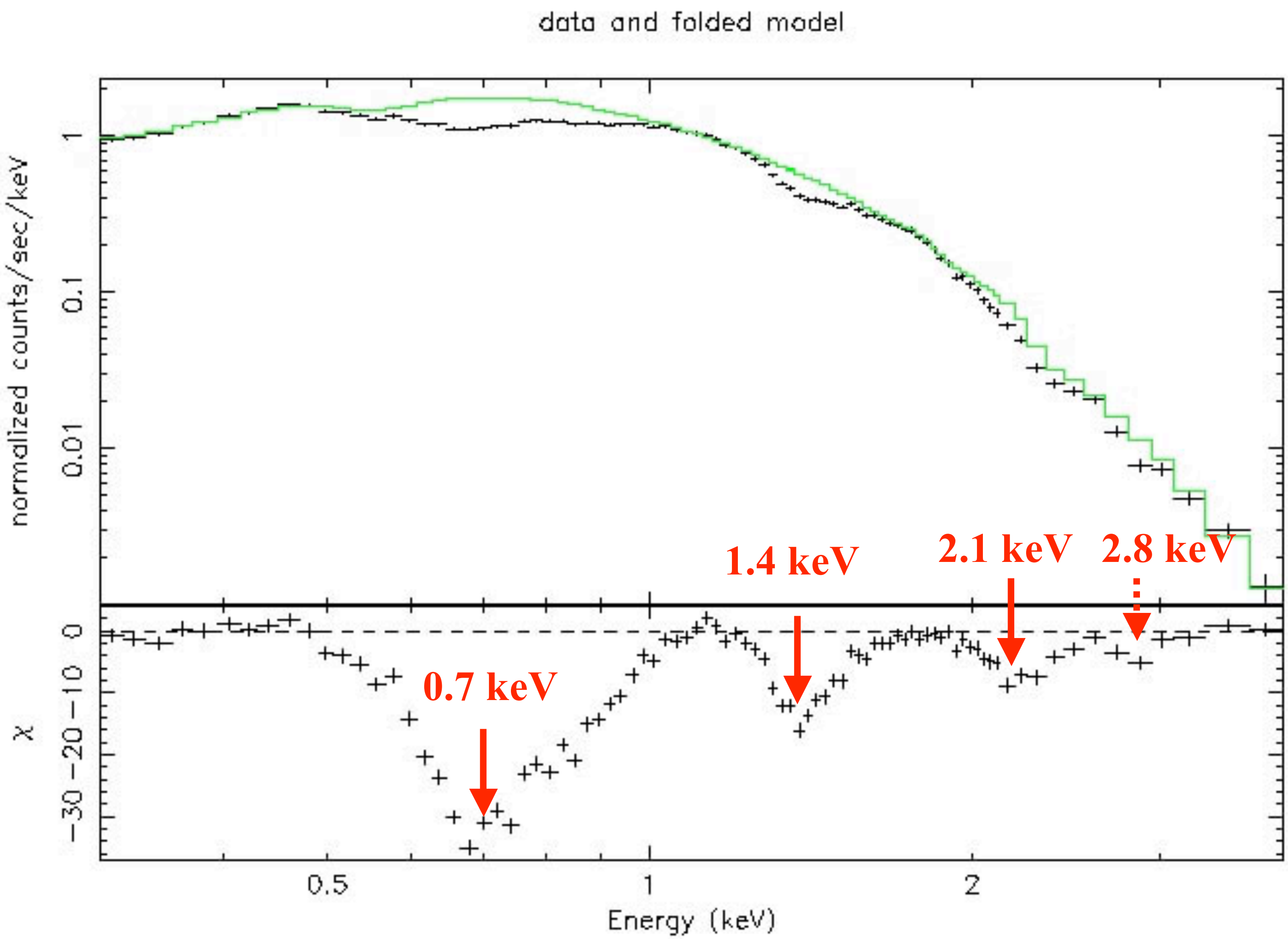
Thermal spectra
Small R, high T

3/6 have periodicity
PKS 424 msec
Kes 79 105 msec
RCW103 6.67 h

EPIC view of 1E1207.4-5209 : 260 ksec

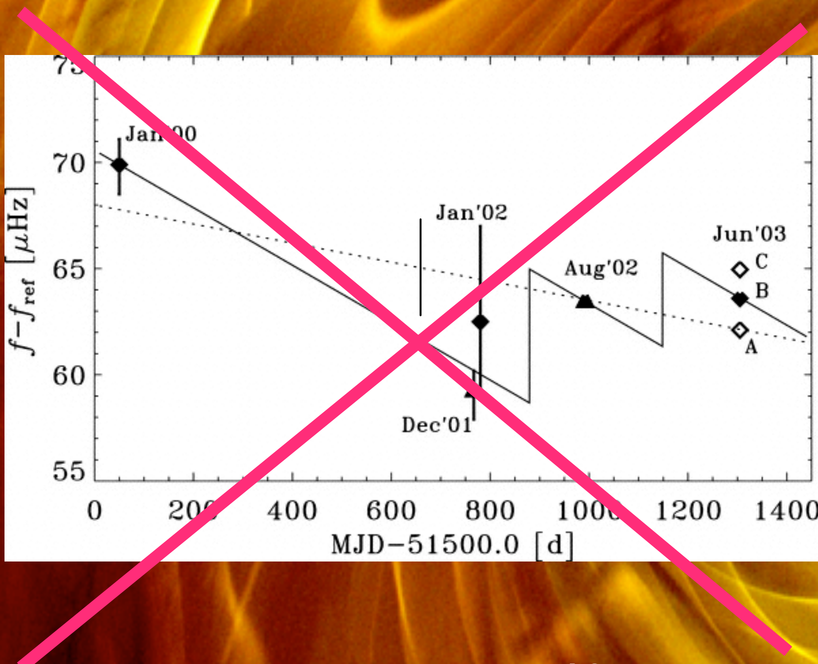


Pn data 208,000 photons



IF electron cyclotron: <B> 8 10^{10}
IF proton <B> 1.6 10^{14}

P irregularities hampered a classical B derivation



Pdot < 2.8 10^{-16} s/s

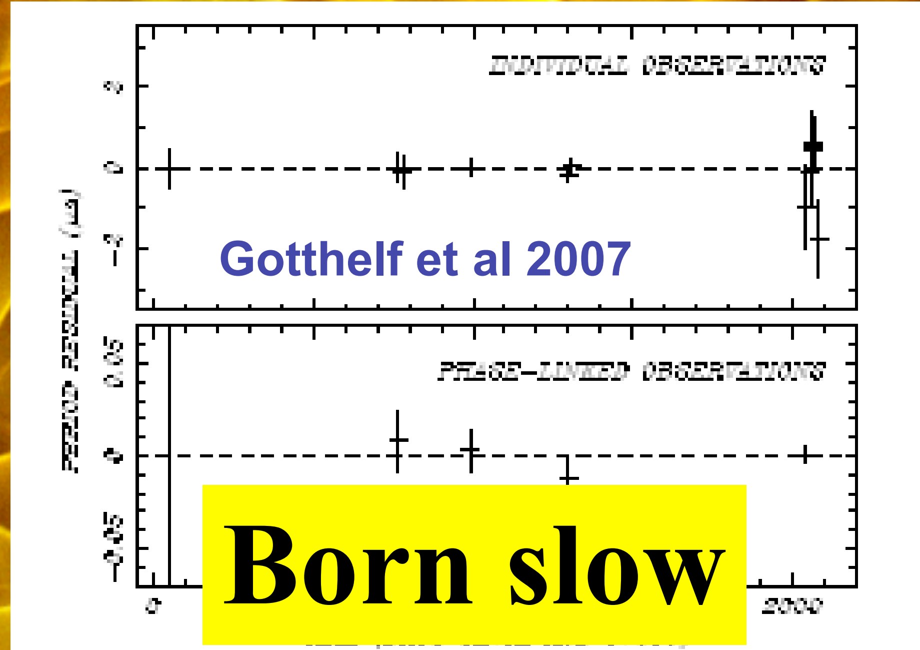


FIG. 1.— Period residuals after fitting a linear solution to individual observations (*top panel*) and grouped data sets (*bottom panel*) from Table 1. The error bar for the first individual observation is used, and continues off-scale, in the bottom panel.

Thus, $B < 3.5\ 10^{11}$

$\dot{E} < 1.5\ 10^{32} \rightarrow L_x = 2\ 10^{33}$

Fallback accretion???

Electron Cyclotron is the natural explanation

Similar situation for Kes 79

$B < 1.5\ 10^{11}$ G

Born slow

Edot < 7 10^{33} → $L_x = 3\ 10^{33}$

R_{bb} 0.8 km, kT .46 keV, PF 80%

Fallback accretion???

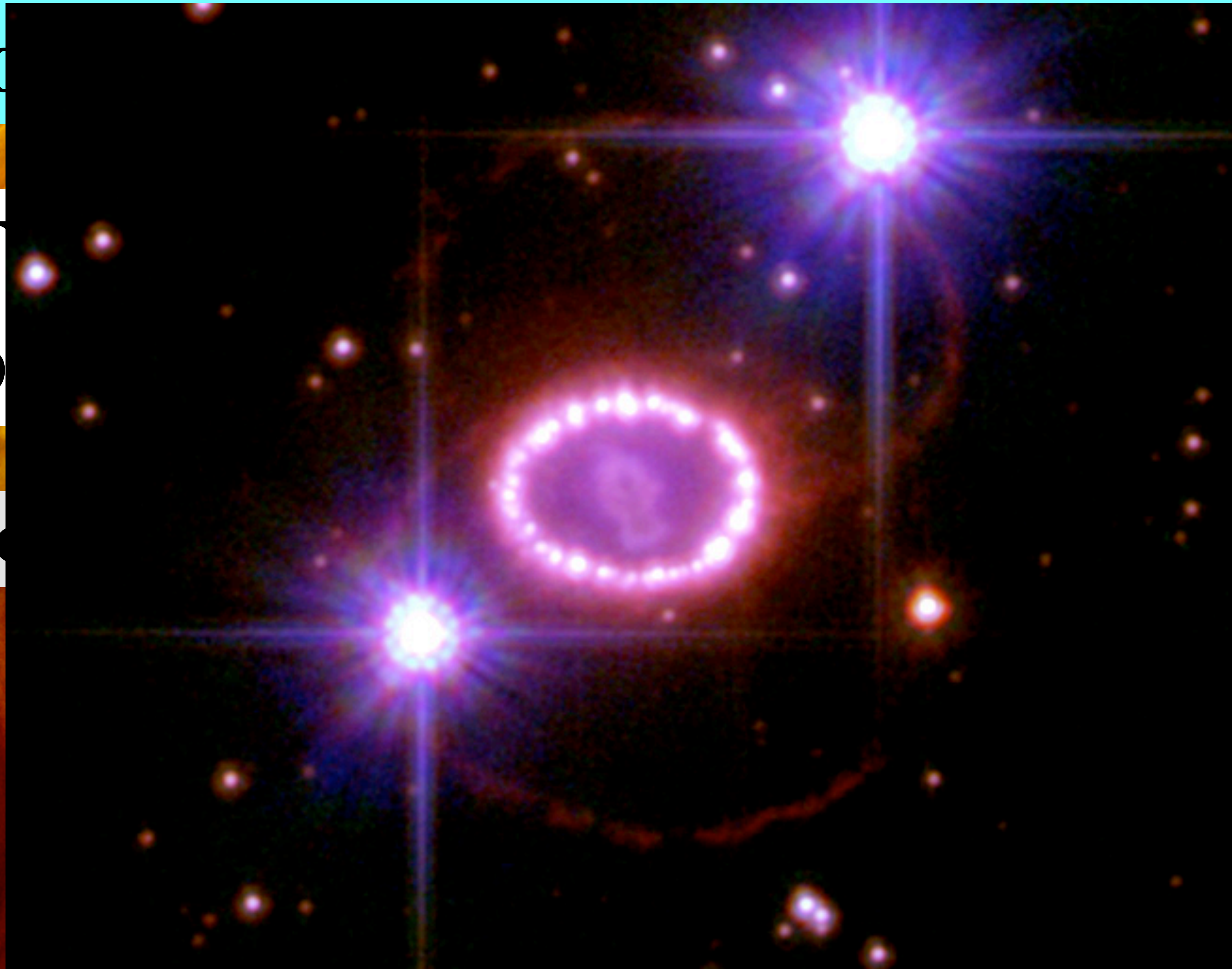
CCOs as a class:

sl … s?

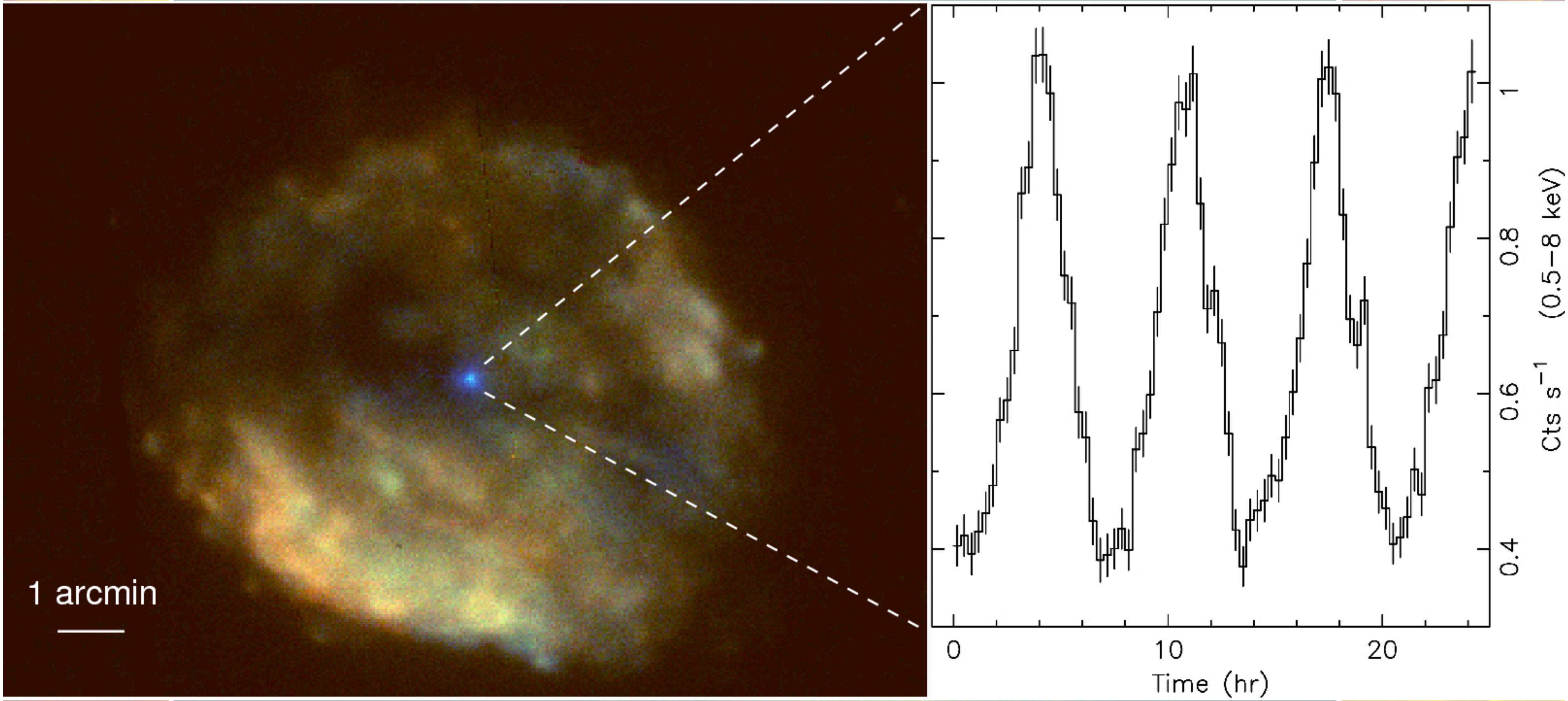
F … m.

b …

C …



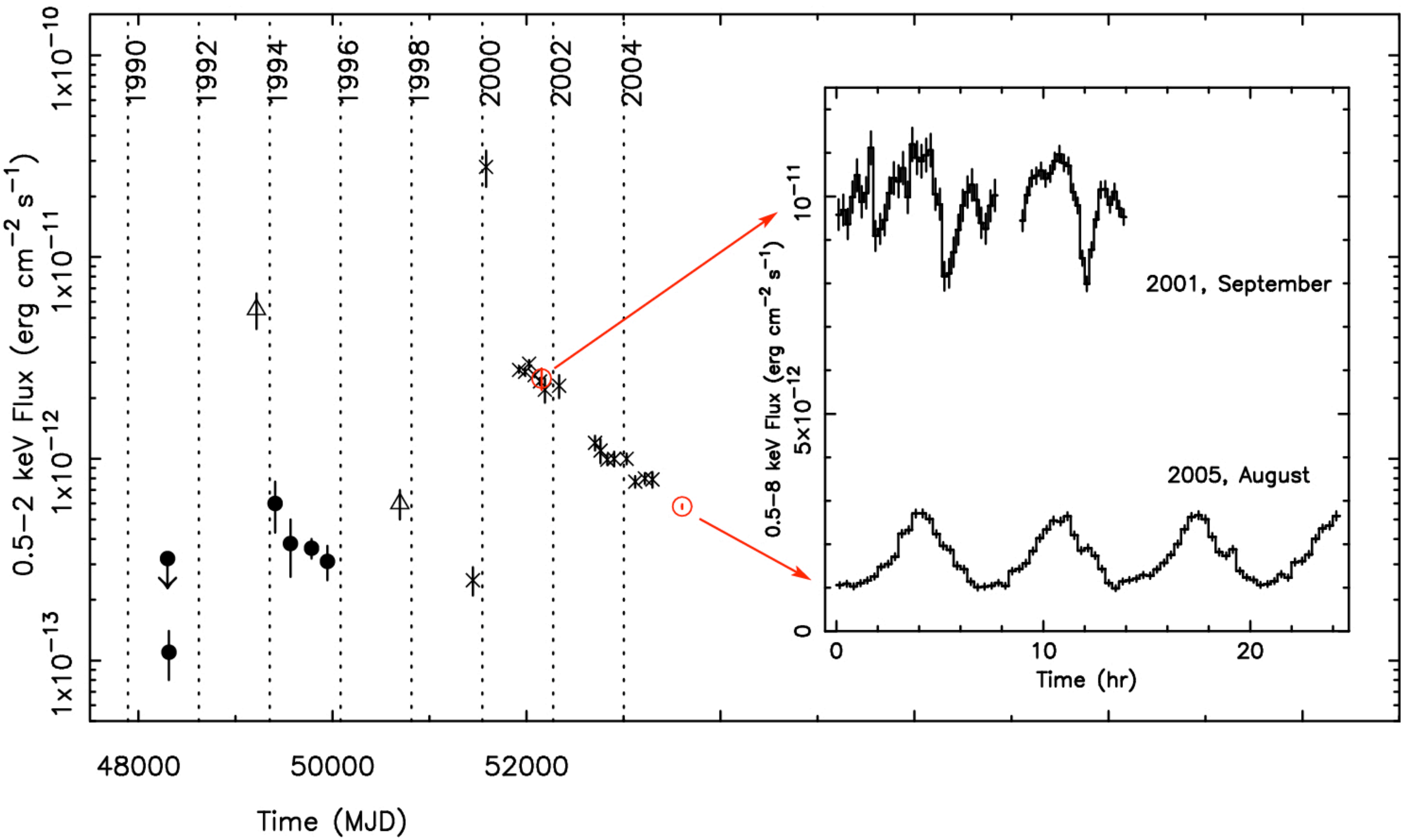
1E 161348-5055



2,000 y old

Cleopatra object

1E 161348-5055



What could 1E be?

- Need to explain long period and violent variability
- NS precession could explain periodicity but not long term variability
- Super magnetar?
- Normal magnetar with fossil disk?
- A baby binary system?
  - Second example of a binary systems in a SNR after SS433

- Classical NSs
- INSs
- CCOs

Same stellar structure
different behaviour driven by
Different period at birth
Different B field

?

Different
types
of compact stars
Neutron stars
Strange stars

The future

More promising PSRs ? unlikely

More radio INSs/CCOs ? certainly

AGILE and GLAST will certainly discover more Geminga-like NSs

and the chase will start again