X-ray and optical emission from

- **Classical NSs**
- **INSs**
- **CCOs**

- **plus a look on their surroundings**

•NO msec, AXP, SGR

X-ray CENSUS

~ 40 Classical NSs

Pulsed emission from virtually all objects

7 INSs

Pulsed emission from 5 objects

6 CCOs

Pulsed emission from 2 objects +1 ->outliers ?

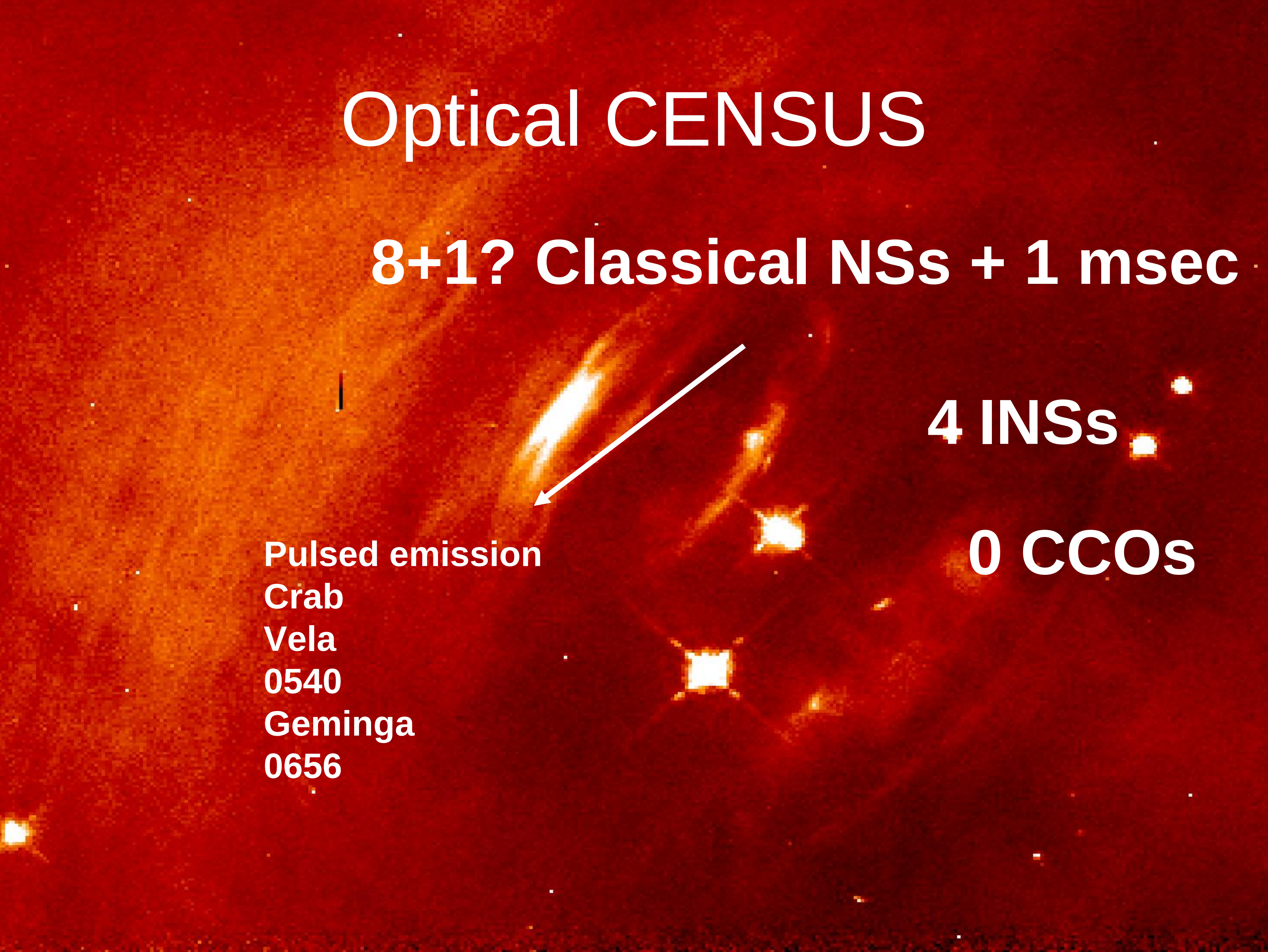
Optical CENSUS

8+1? Classical NSs + 1 msec

4 INSs

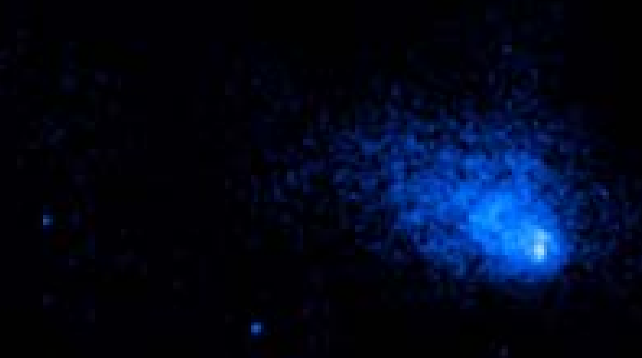
0 CCOs

Pulsed emission
Crab
Vela
0540
Geminga
0656



Diffuse feature CENSUS

NSs with X-ray PWNe (and more) 20

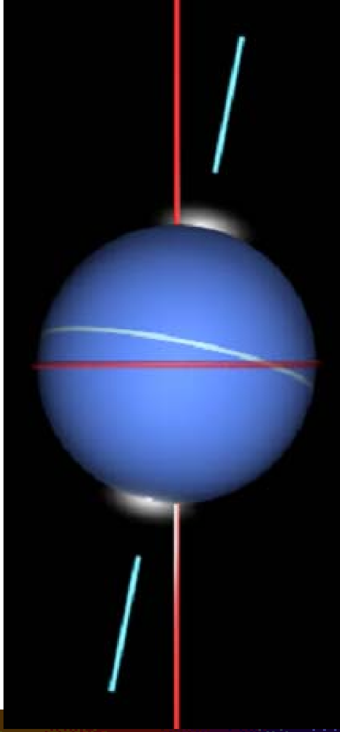


Energetic objects
PWNe are not detected
for NSs with Edot $< 5\ 10^{36}$

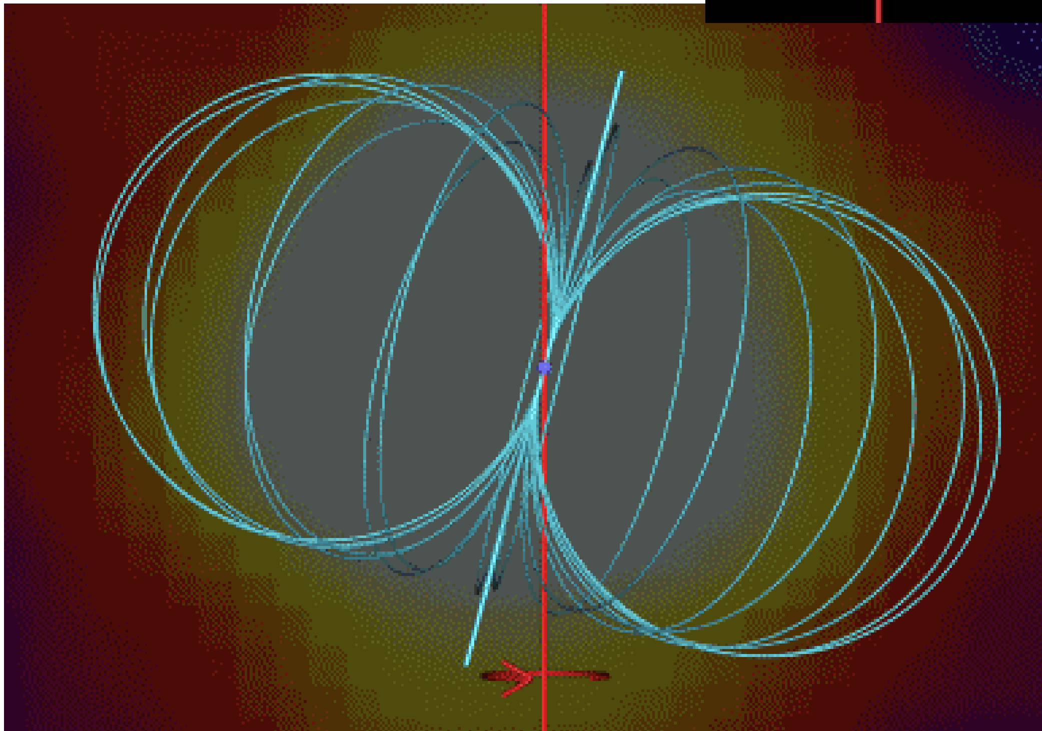
NSs with tails/jets 10

Diffuse structures with no pulsar detected (as yet) 24

Geographical approach



- **(rotating) surface emission**
- **(rotating) magnetospheric emission**



- **NS surroundings**

Phenomenological approach

- **(rotating) surface emission**
  thermal, generally (not always) pulsed

- **(rotating) magnetospheric emission**
  non thermal, pulsed

- **NS surroundings- variable but not pulsed**
  non thermal PWNe, non thermal Tails,
  non thermal Bow shocks (ISM interaction)
  fossil disk emission (thermal) ?

Physical approach

- **(rotating) surface emission**
  primeval heat, particle heating

- **(rotating) magnetospheric emission**
  particle acceleration- rot. energy loss

- **NS surroundings-**
  relativistic wind, interaction with ISM

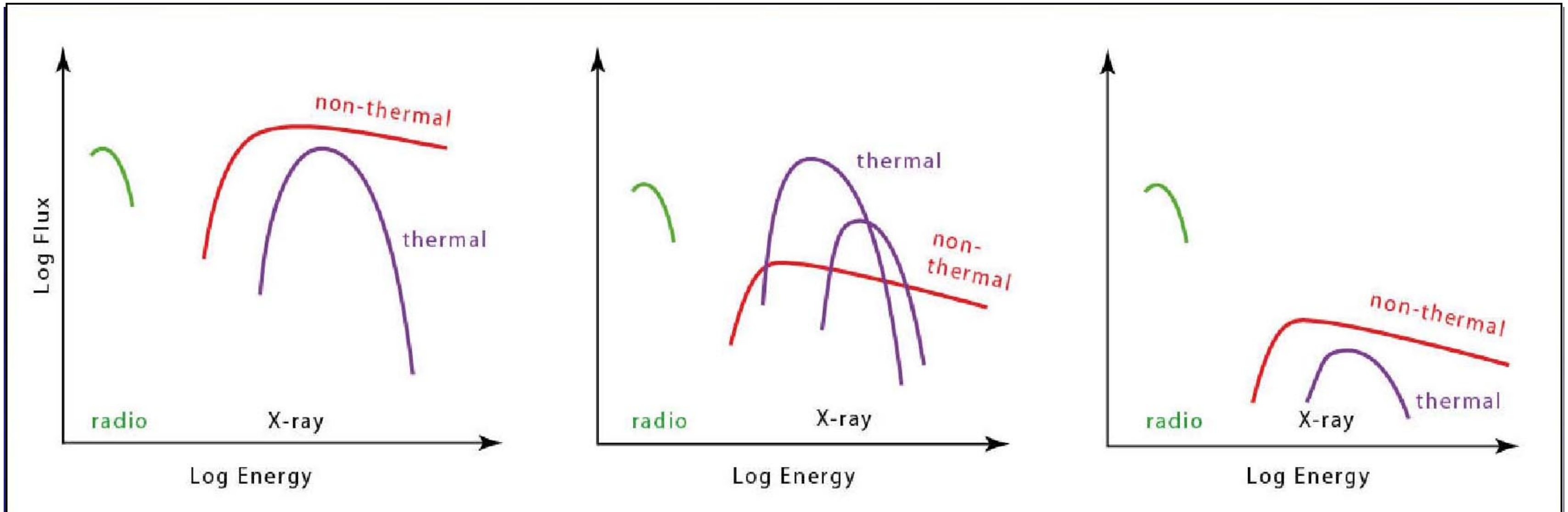
Multiwavelength approach

- **(rotating) surface emission generally PULSED**
  optical/UV, soft X-rays

- **(rotating) magnetospheric emission PULSED**
  radio, optical, X-ray, γ-ray

- **NS surroundings- NON PULSED**
  PWNe and tails: X-rays, radio, few in optical
  ISM-interaction bow shocks: optical, X-rays
  fossil disks: IR

NSs' X-ray emission vs. age



From W.Becker, talk presented at the 363rd Heraeus Seminar, cf. http://www.mpe.mpg.de/363-Heraeus-Seminar

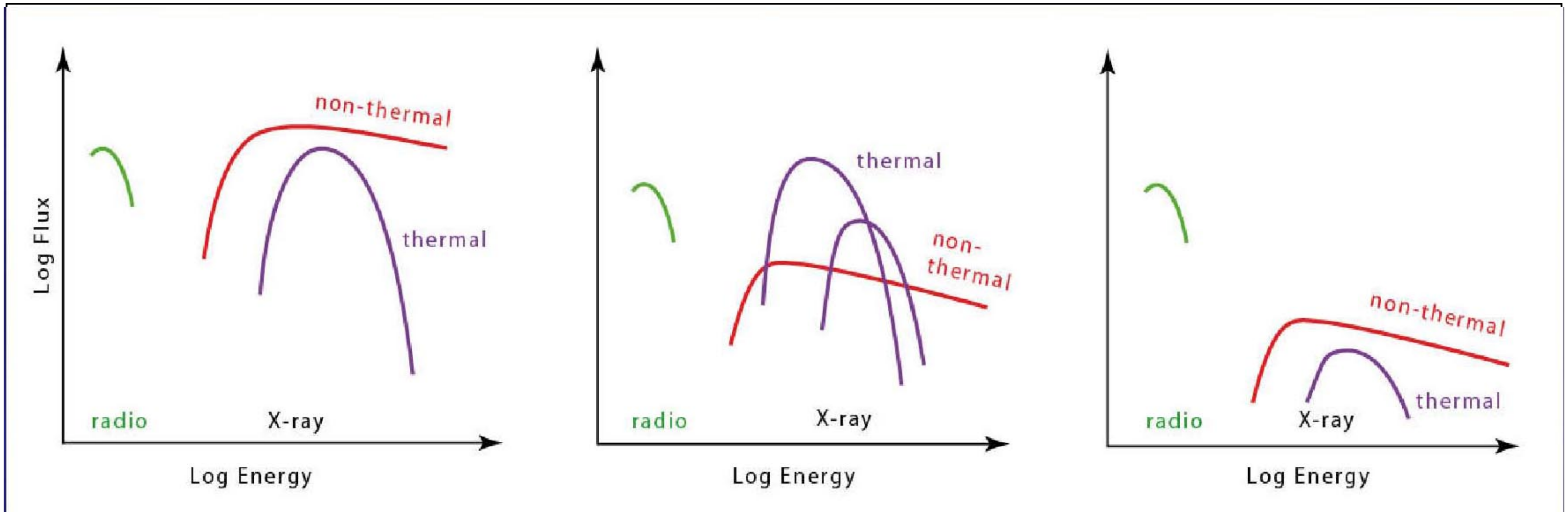
young 10^3 y **Middle-aged 10^4-10^5** **Old >10^6 y**

L_{NT} @ 5 10^{-4} – 5 10^{-5} Edot

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

T ⟶ cooling, EOS
Emitting surface

NSs' X-ray emission vs. age

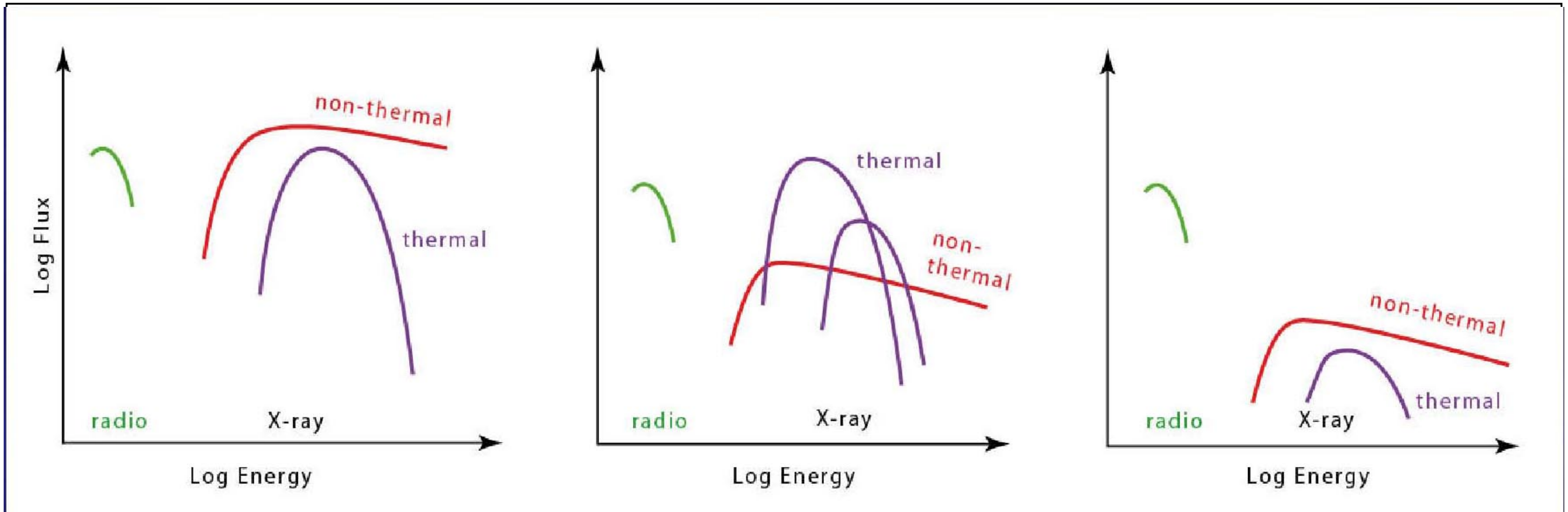


From W.Becker, talk presented at the 363rd Heraeus Seminar, cf. http://www.mpe.mpg.de/363-Heraeus-Seminar

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

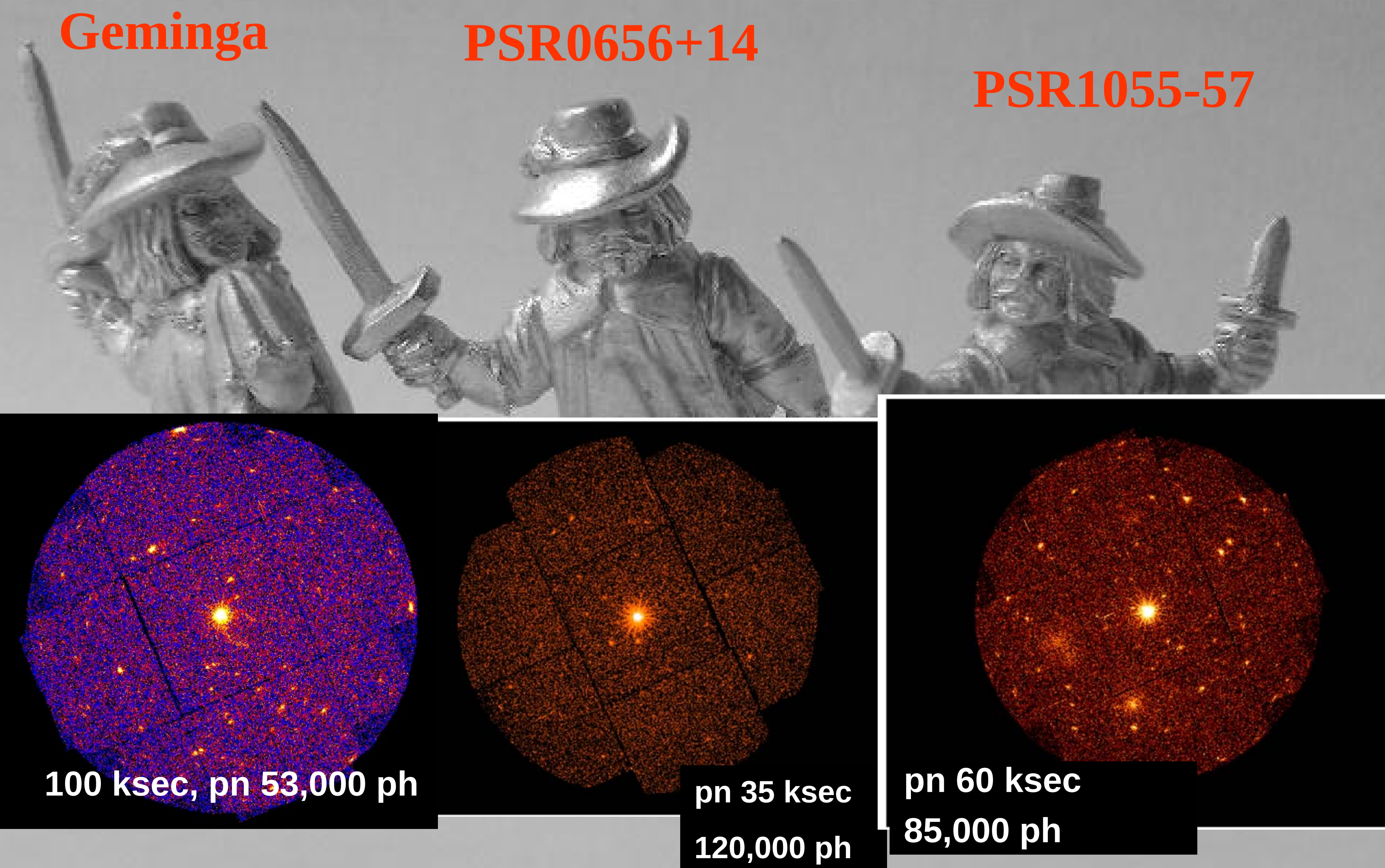


From W.Becker, talk presented at the 363rd Heraeus Seminar, cf. http://www.mpe.mpg.de/363-Heraeus-Seminar

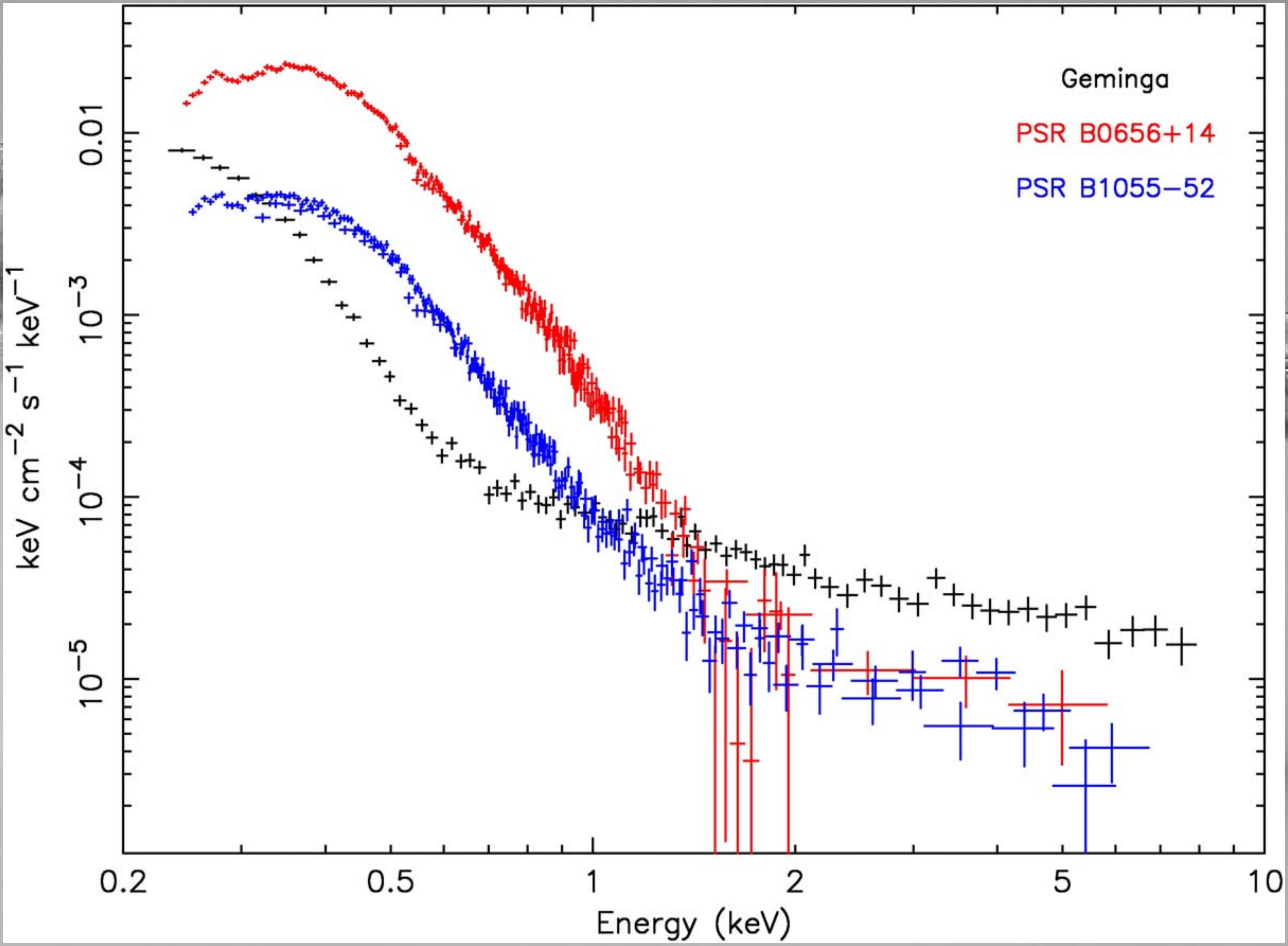
young 10^3 y **Middle-aged 10^4-10^5** **Old >10^6 y**

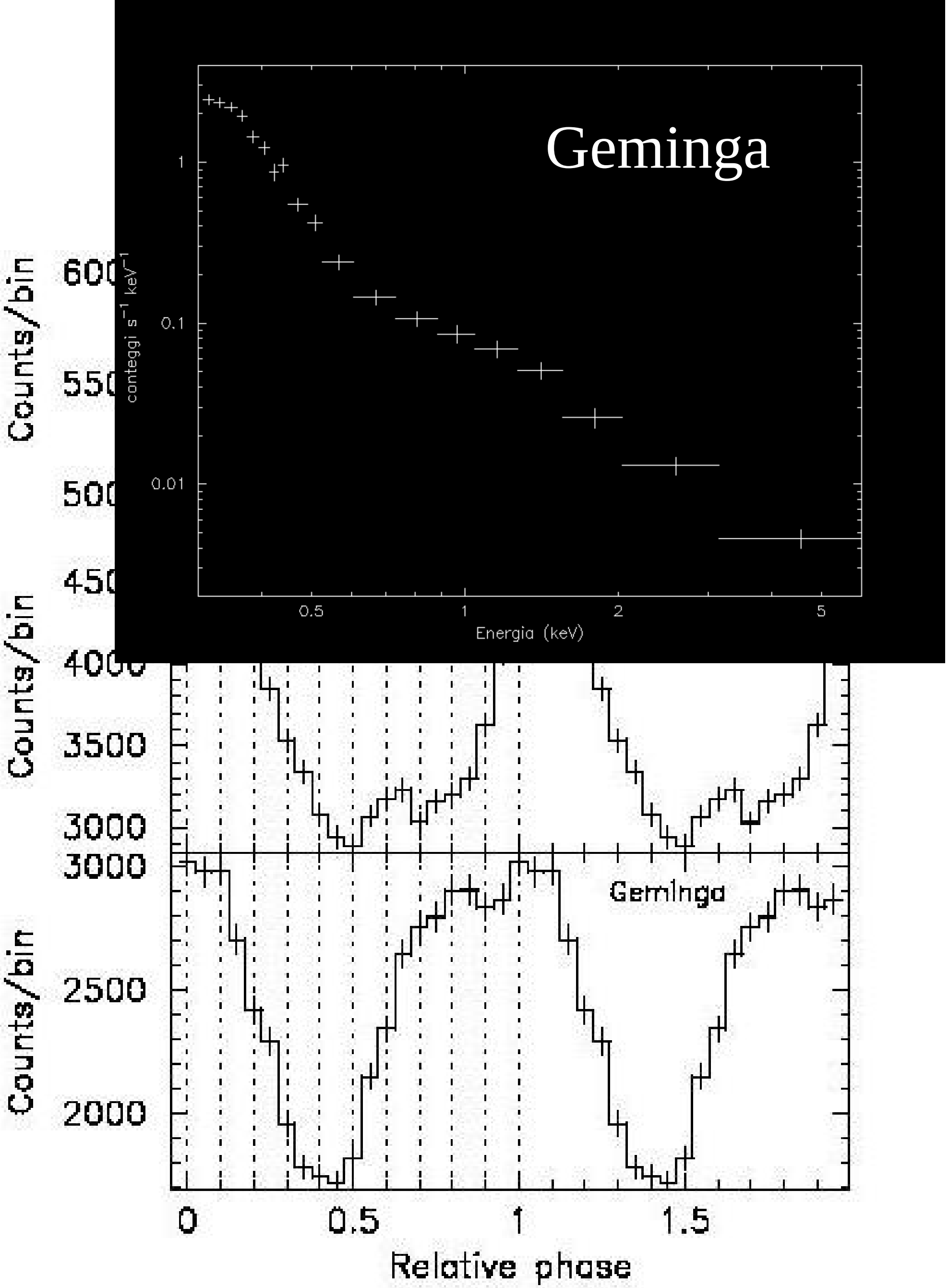
Exception J1119-6127, 1,700 y, thermal emission high pulsed fraction (74%), high T 2.4 10^6 °K, R=3.4km

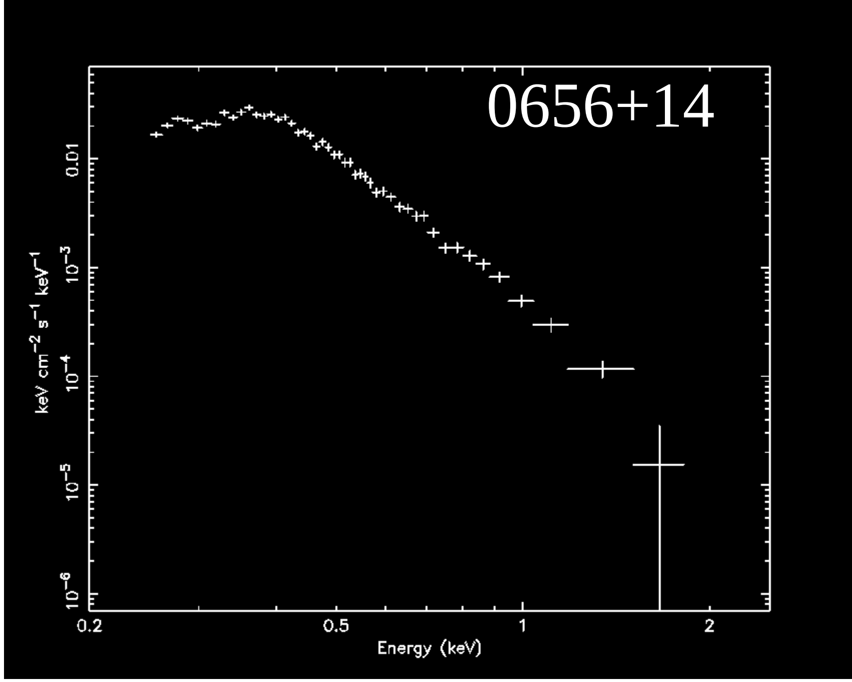
The three musketeers

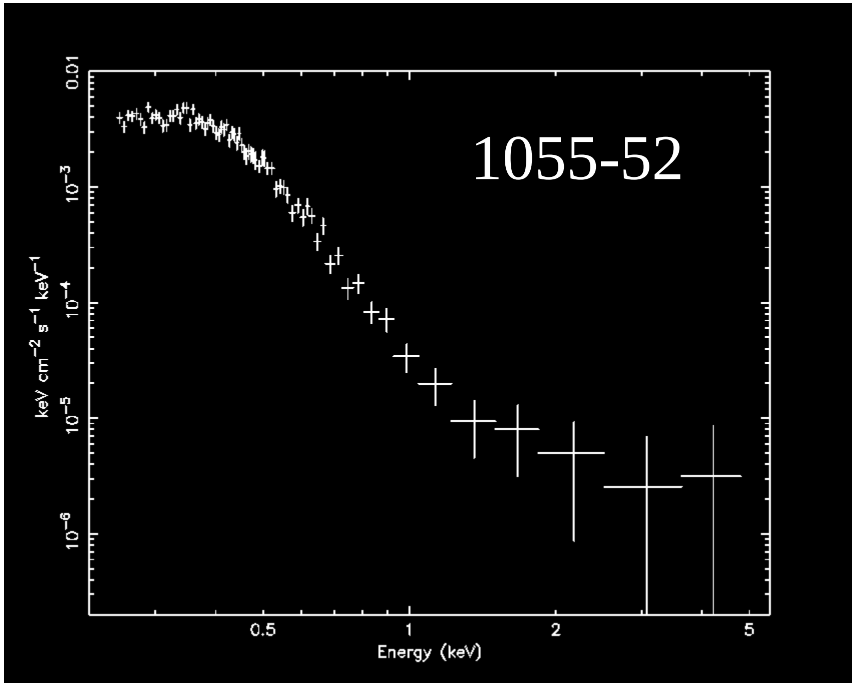


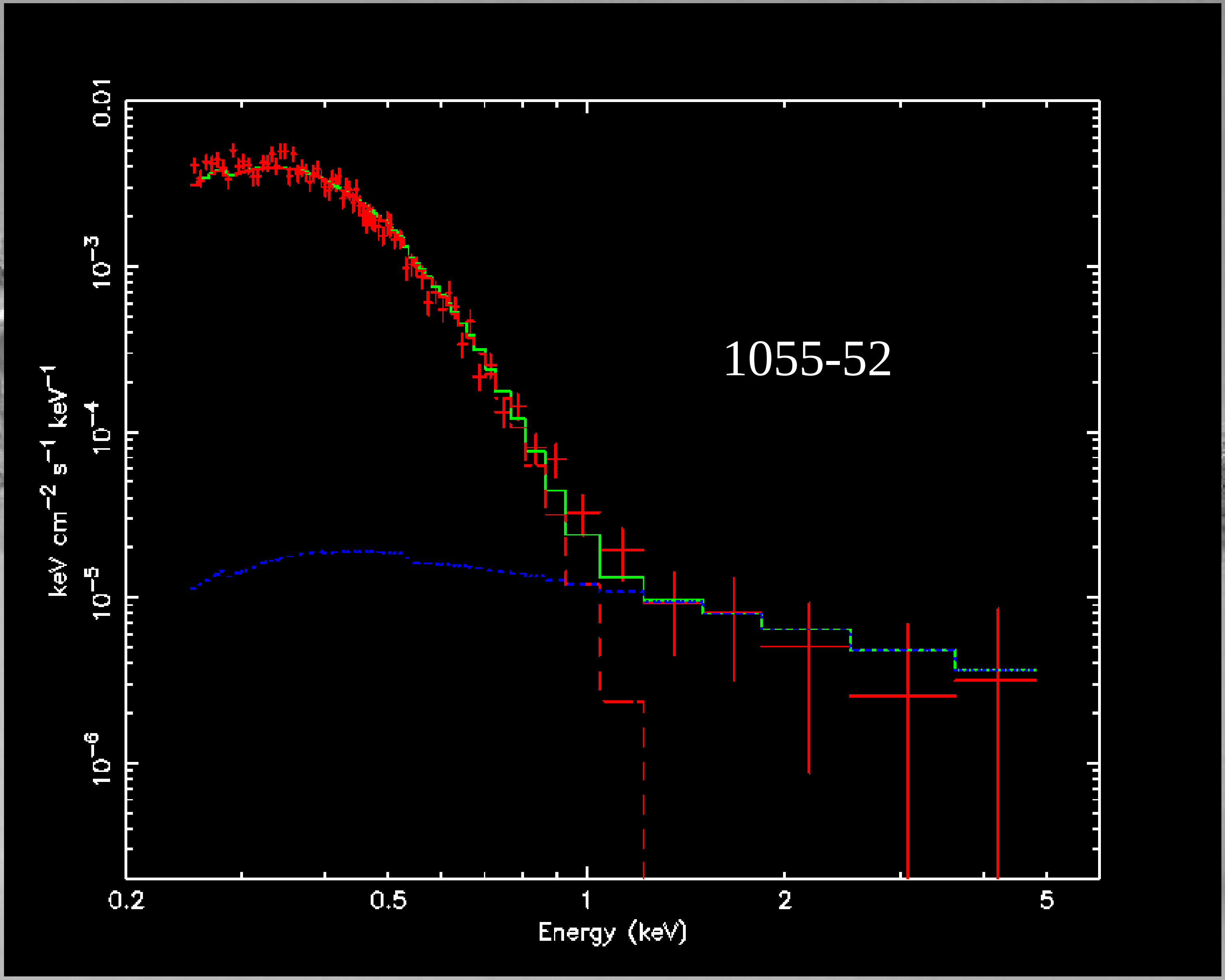
The three musketeers




Geminga
conteggi s^{-1} keV^{-1}
1
0.1
0.01
0.5
1
2
5
Energia (keV)
Counts/bin
450
4000
3500
3000
2500
2000
Geminga
0
0.5
1
1.5
Relative phase

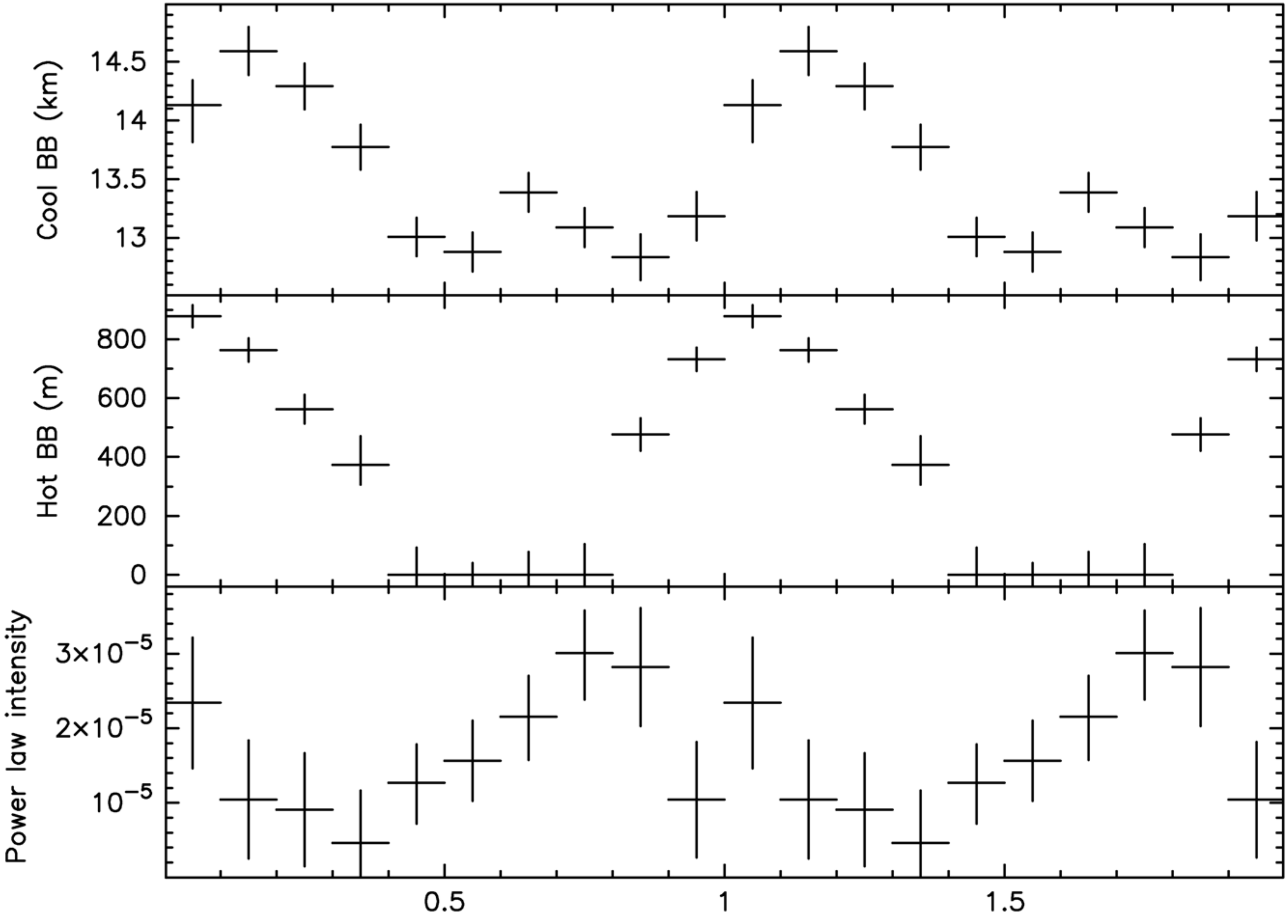

0656+14
keV cm^{-2} s^{-1} keV^{-1}
0.01
10^{-3}
10^{-4}
10^{-5}
10^{-6}
0.2
0.5
1
2
Energy (keV)

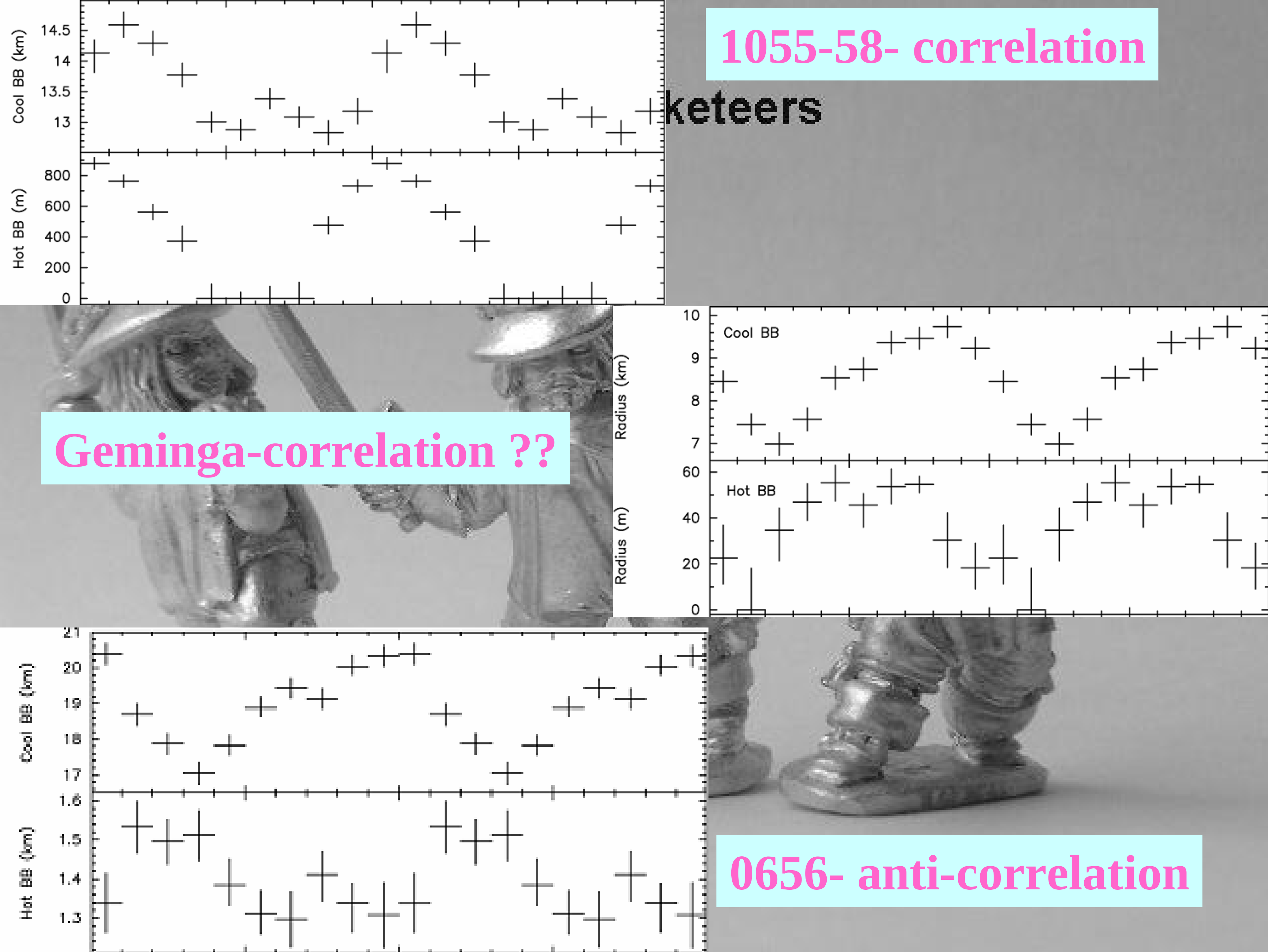

1055-52
keV cm^{-2} s^{-1} keV^{-1}
0.01
10^{-3}
10^{-4}
10^{-5}
10^{-6}
0.5
1
2
5
Energy (keV)



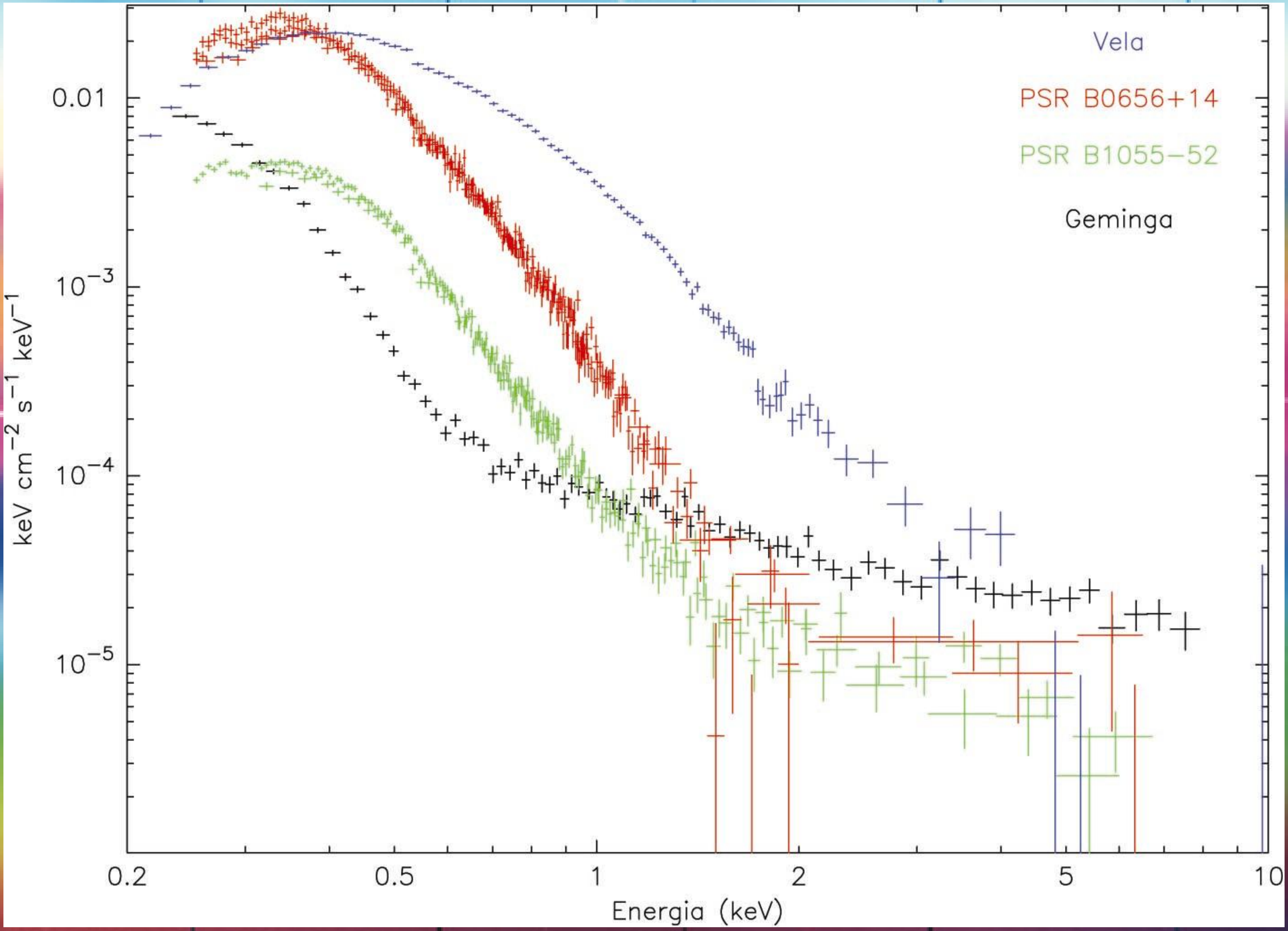
1055-52
keV cm^{-2} s^{-1} keV^{-1}
0.01
10^{-3}
10^{-4}
10^{-5}
10^{-6}
0.2
0.5
1
2
5
Energy (keV)

Phase-resolved spectroscopy – PSR1055



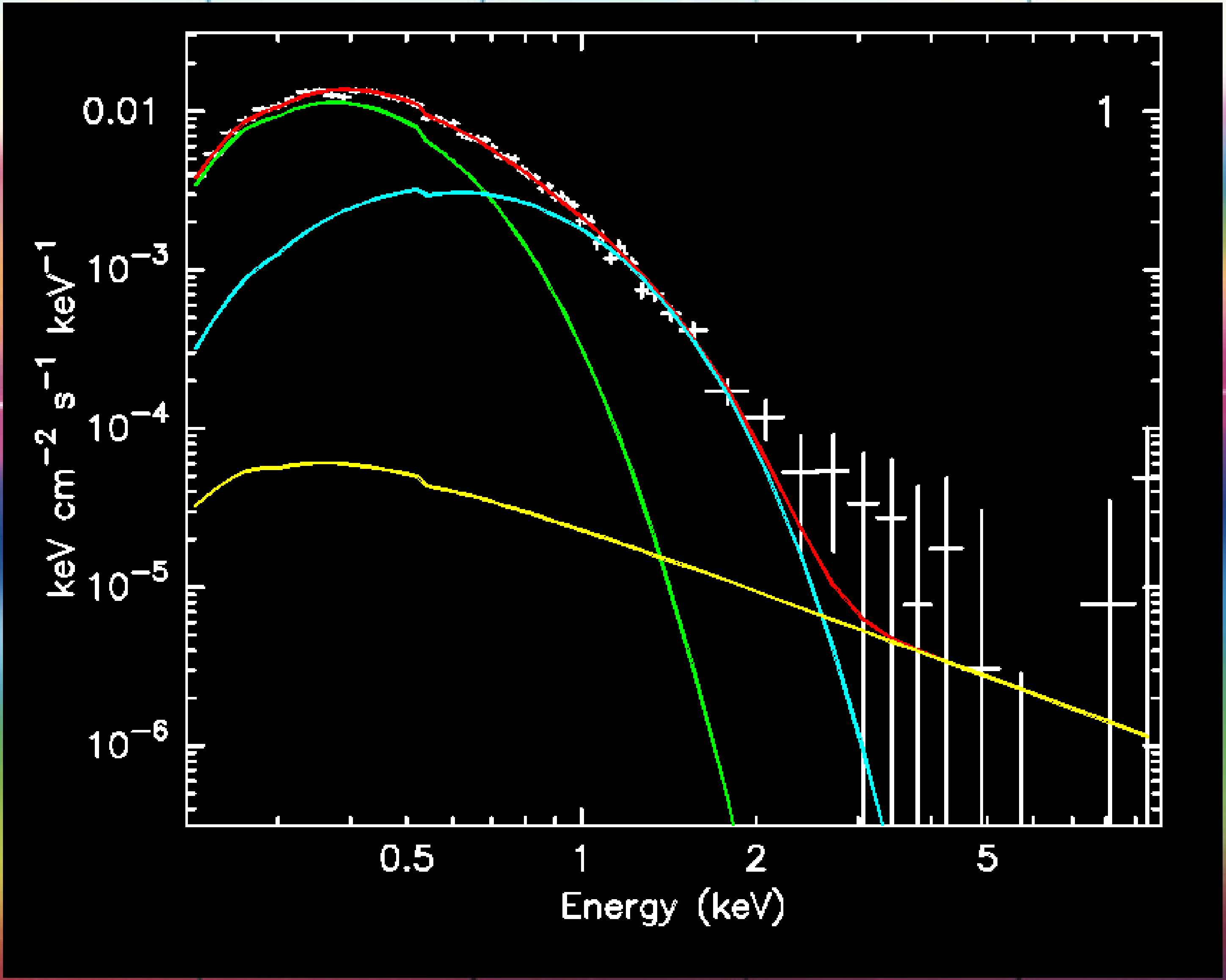

1055-58- correlation
keteers
Cool BB (km)
Hot BB (m)
Geminga-correlation ??
Cool BB
Hot BB
Radius (km)
Radius (m)
0656- anti-correlation
Cool BB (km)
Hot BB (km)

and Vela

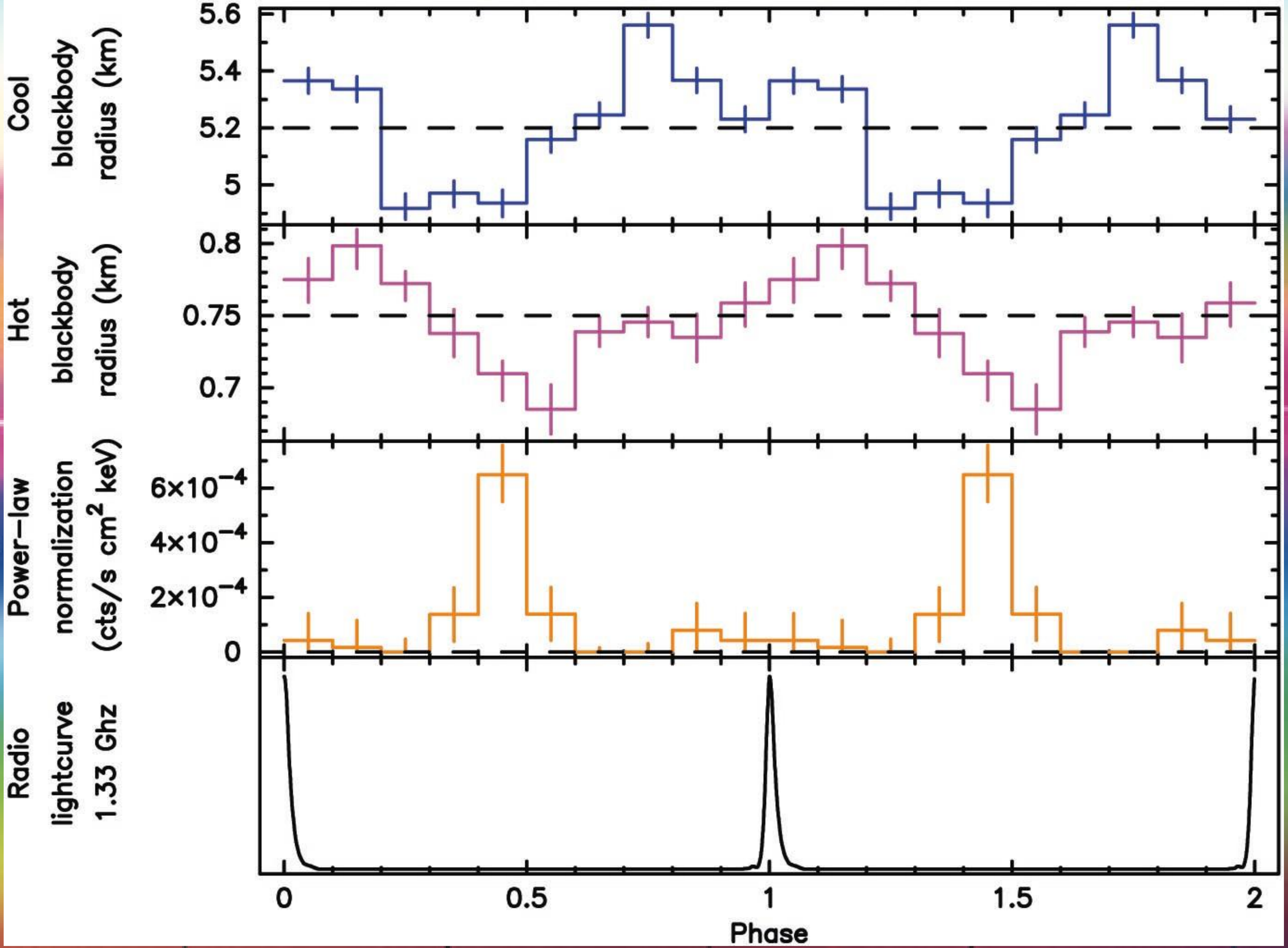


Vela
PSR B0656+14
PSR B1055−52
Geminga
0.01
10−3
10−4
10−5
keV cm−2 s−1 keV−1
0.2
0.5
1
2
5
10
Energia (keV)

and Vela

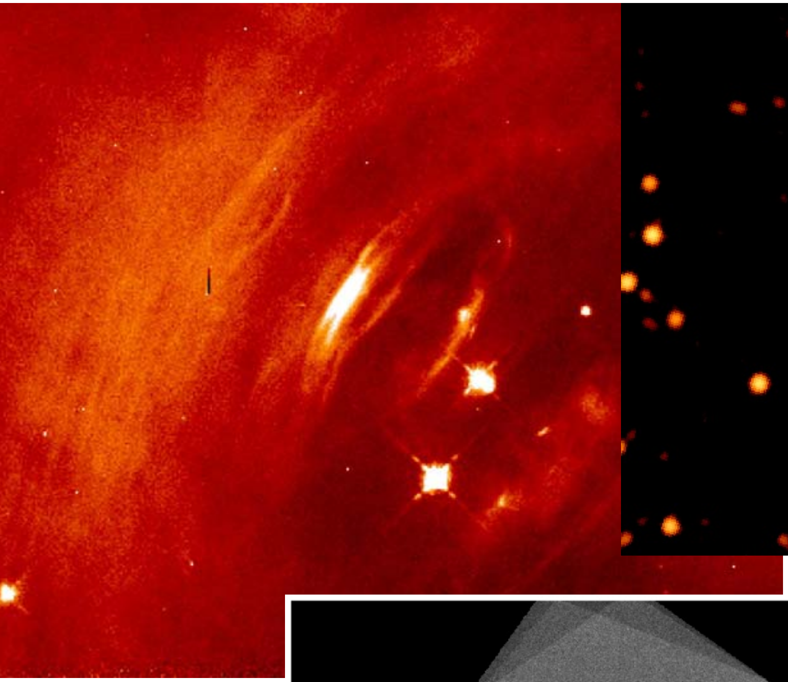


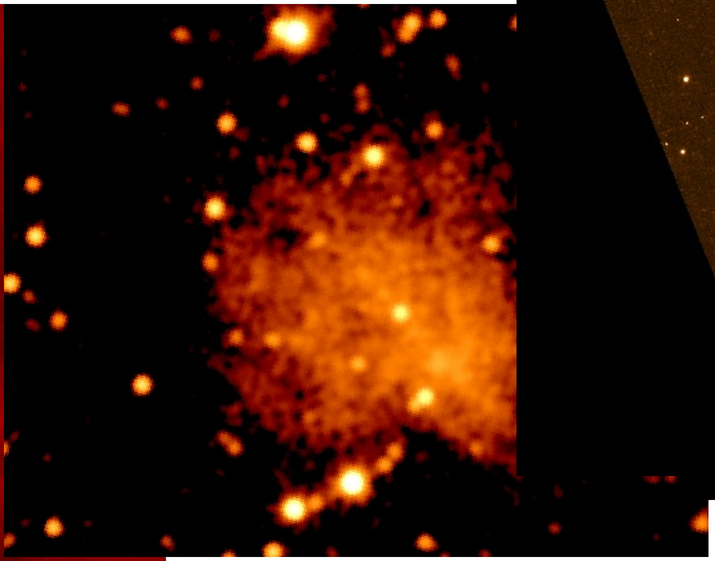
and Vela

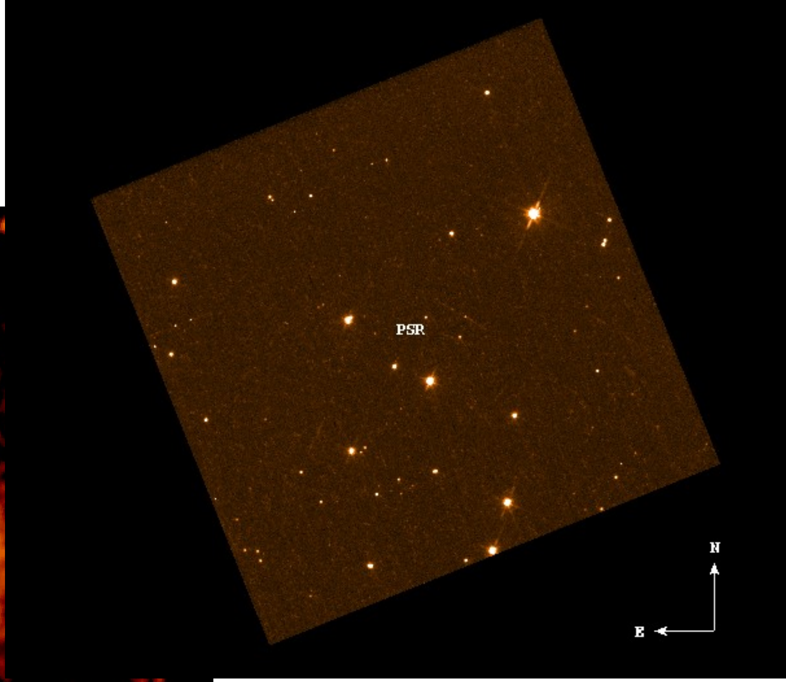


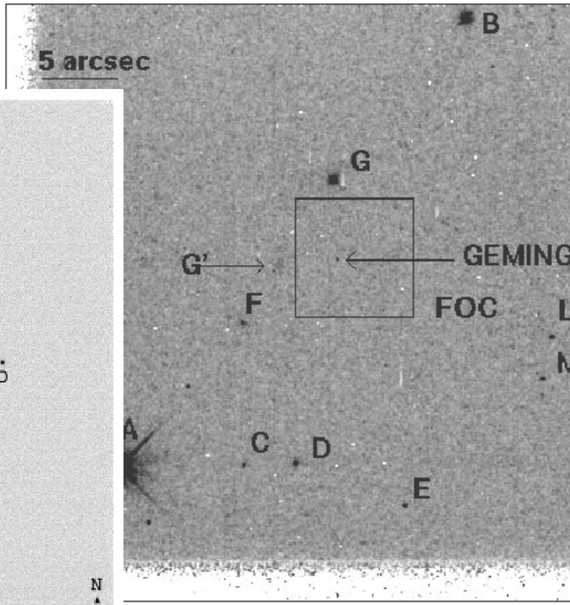
Cool blackbody radius (km)
5.6
5.4
5.2
5
Hot blackbody radius (km)
0.8
0.75
0.7
Power–law normalization (cts/s cm^2 keV)
6×10^{-4}
4×10^{-4}
2×10^{-4}
0
Radio lightcurve 1.33 Ghz
0
0.5
1
1.5
2
Phase

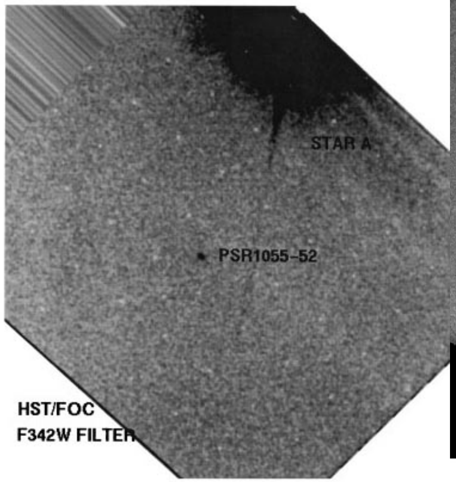
Optical gallery

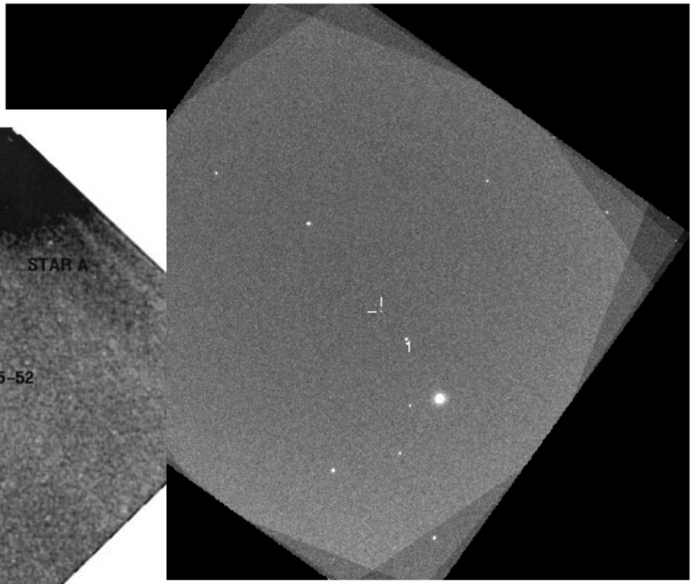


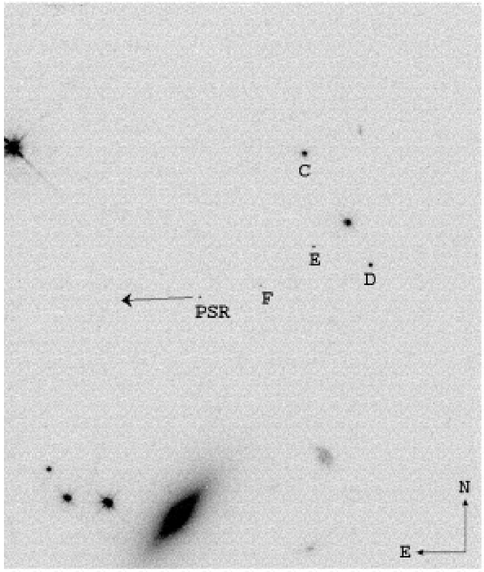












Optical evolution

- young NSs are dominated by non-thermal emission (Pacini law P^{-10} for the three brightest)
- Middle-aged NSs are fainter, broadly on the extrapolation of the soft X-ray BB, but with additional component(s)
- Old NSs (2) have steep PL spectra

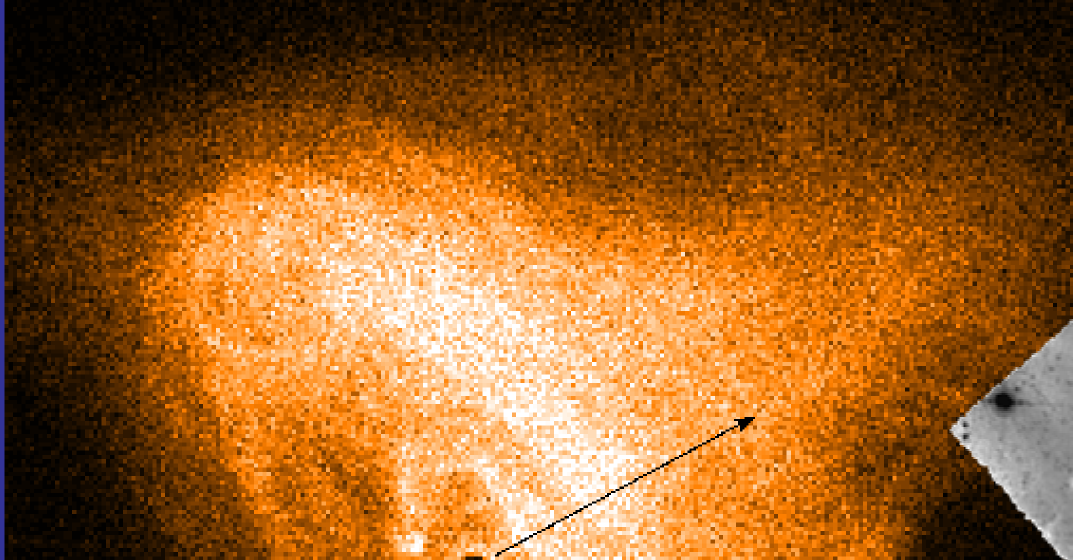
An optical aside

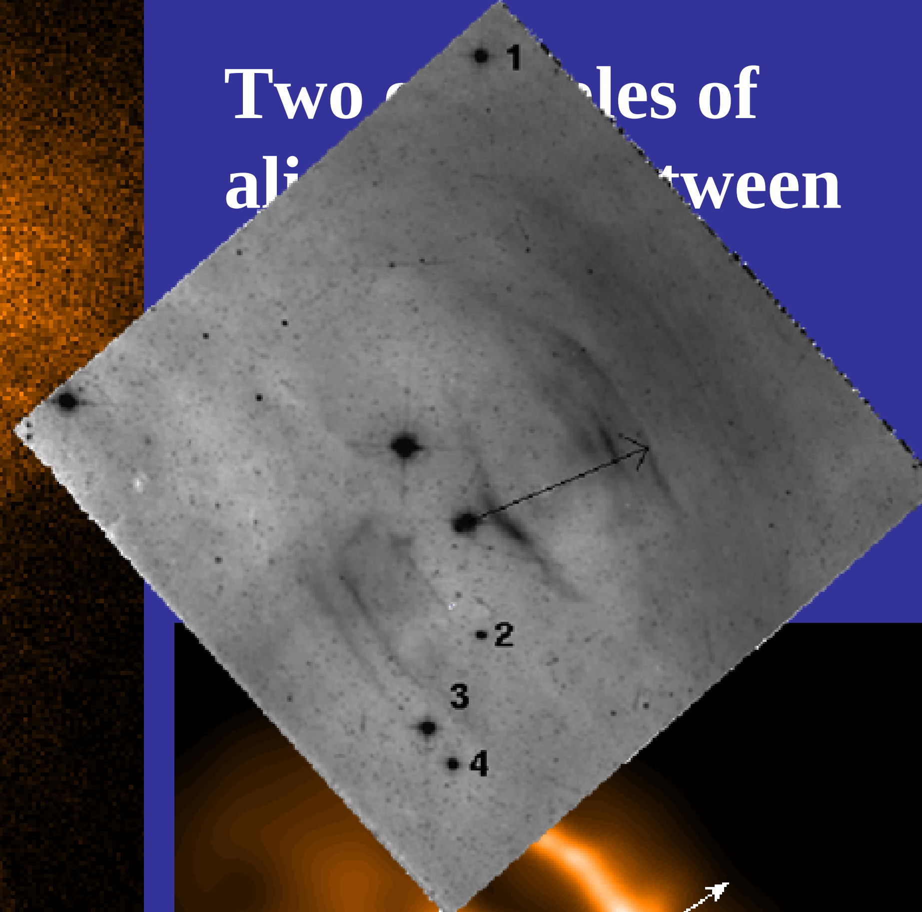
- **Optical counterparts mean accurate positioning, thus allowing p.m. and parallax measurements**

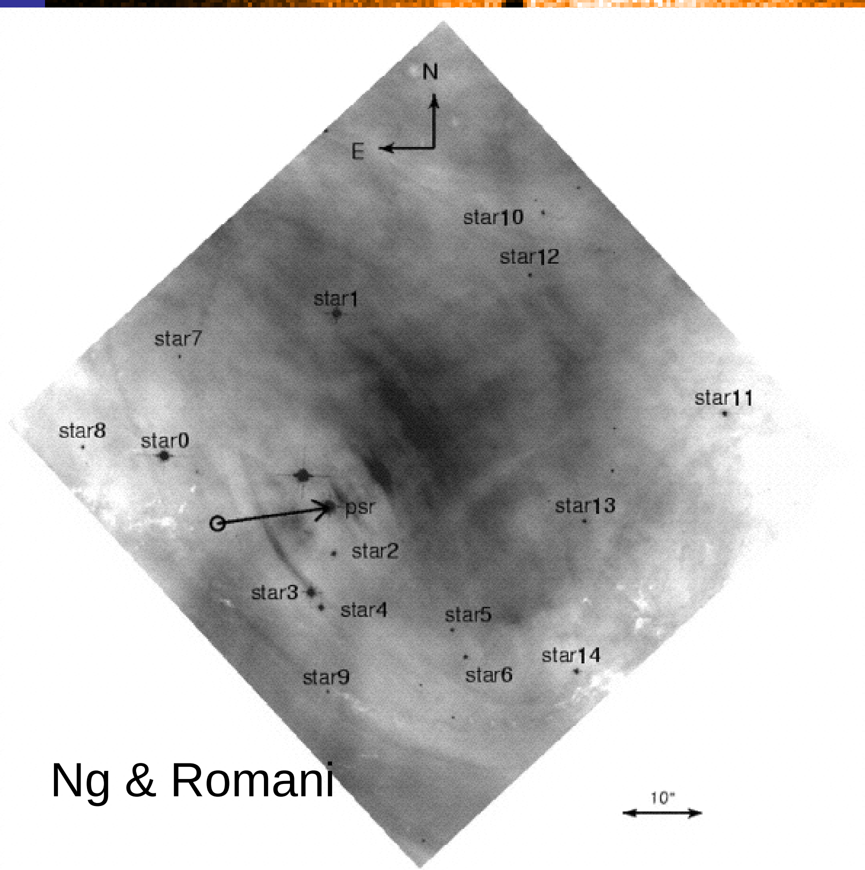
- **Useful for classical NSs**
  -p.m. alignment with PWNe structures
  - clinch the identification, e.g Geminga, PSR 0656, PSR1929

- **Instrumental for INSs (the only way to gather info on their velocities and distances)**

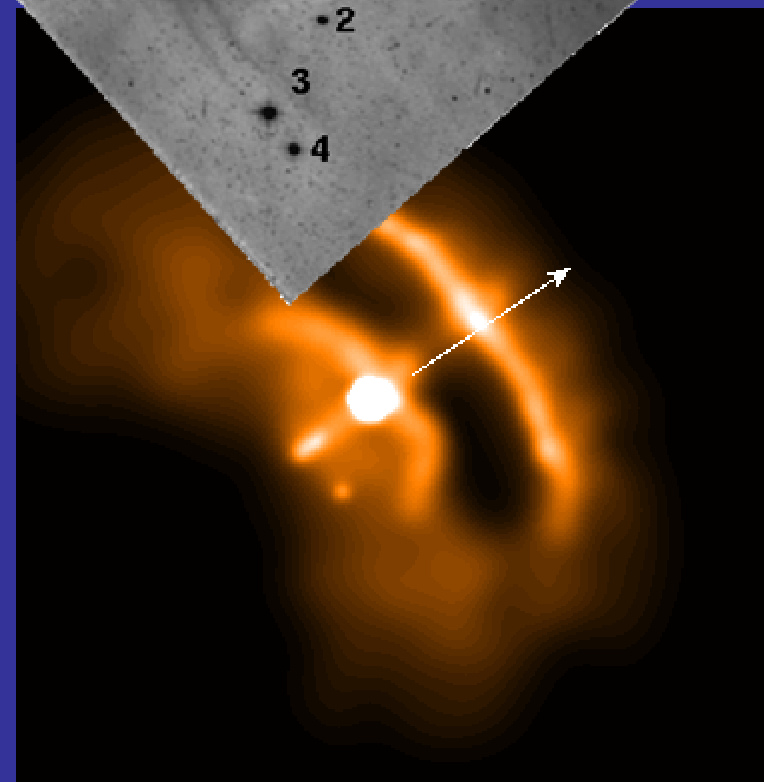
Two … les of ali… tween … data



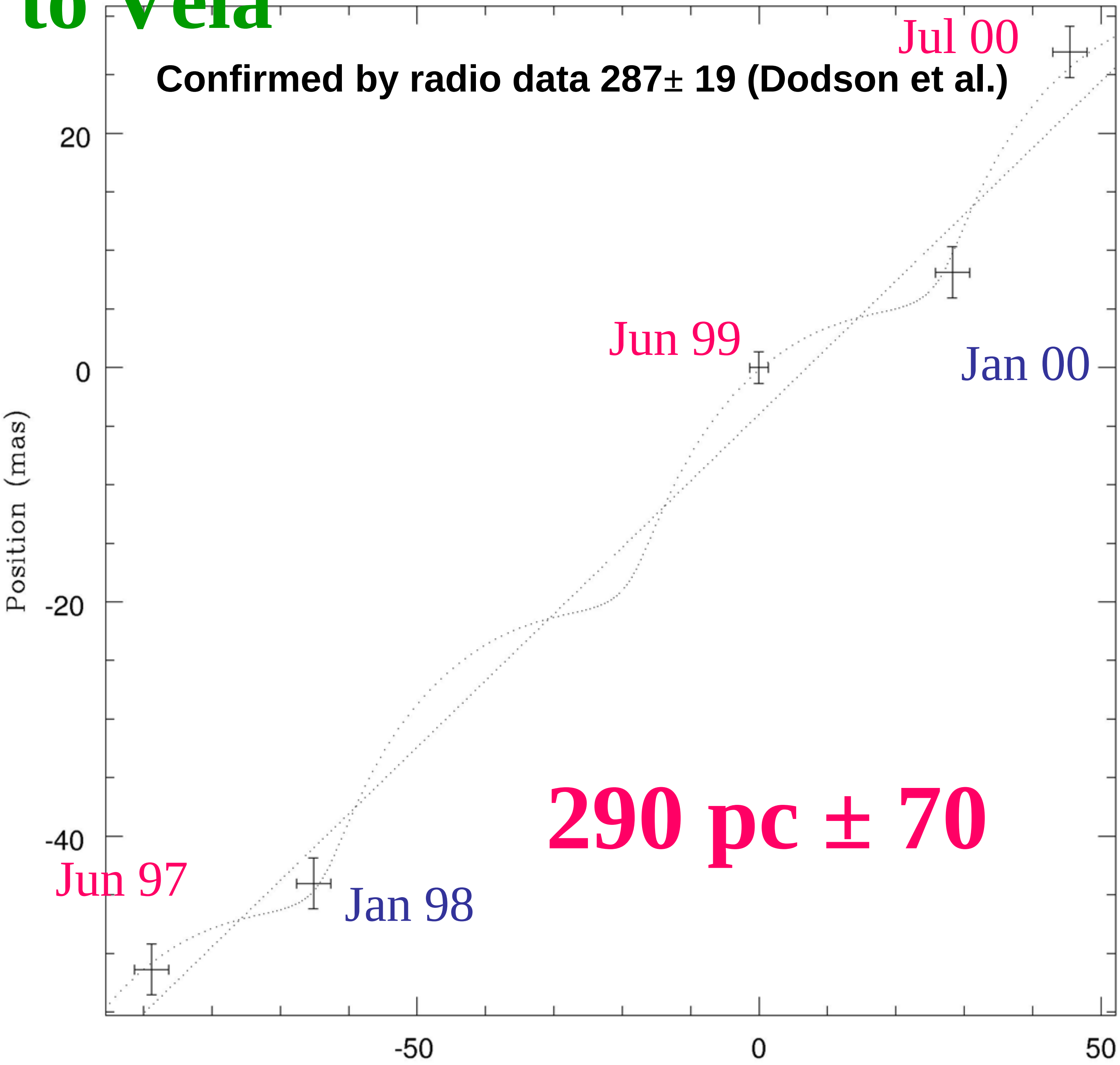




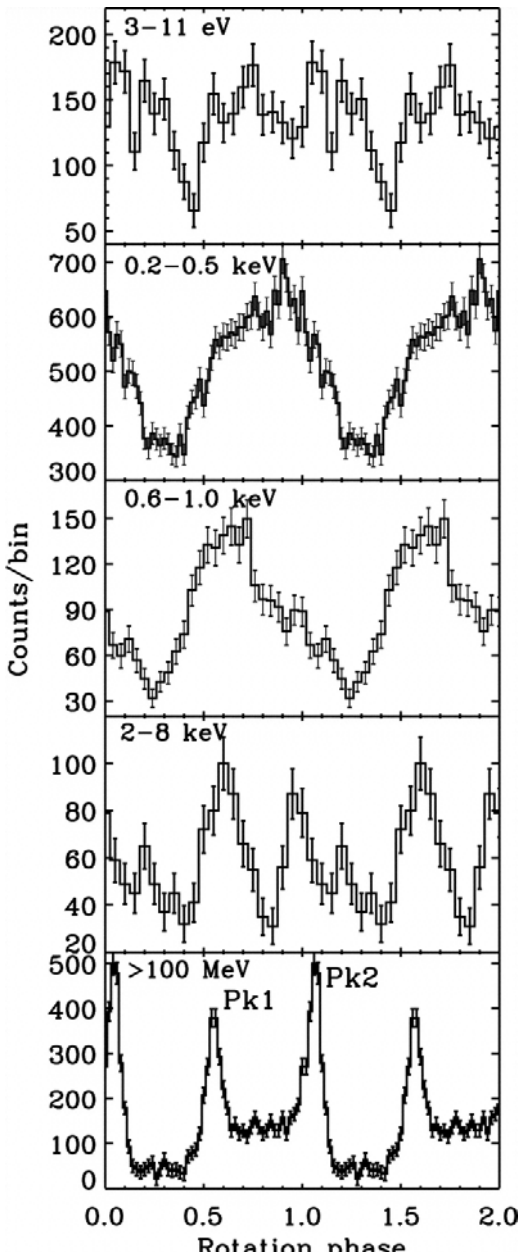
Ng & Romani

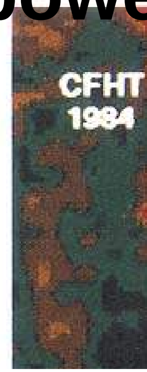


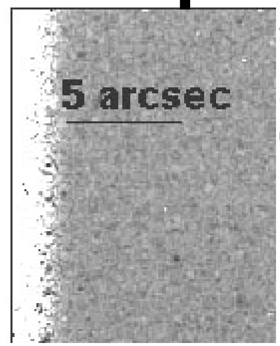
Distance to Vela

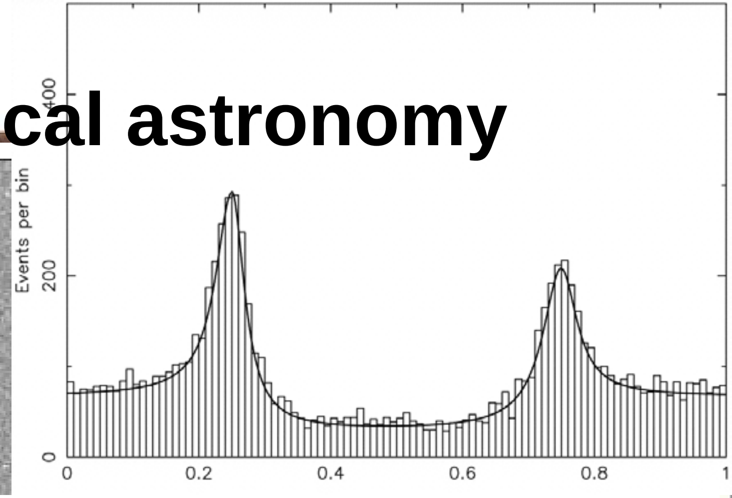


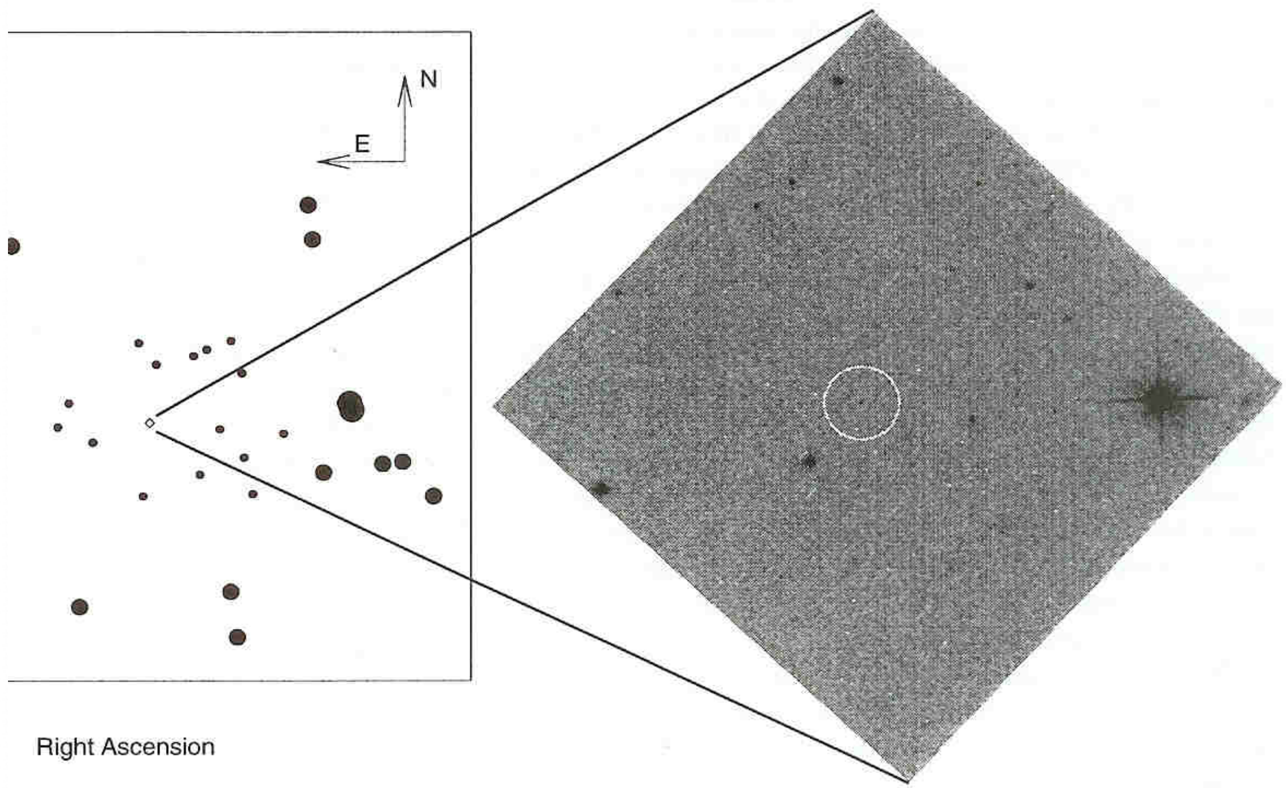
Geminga, or the power of optical astronomy











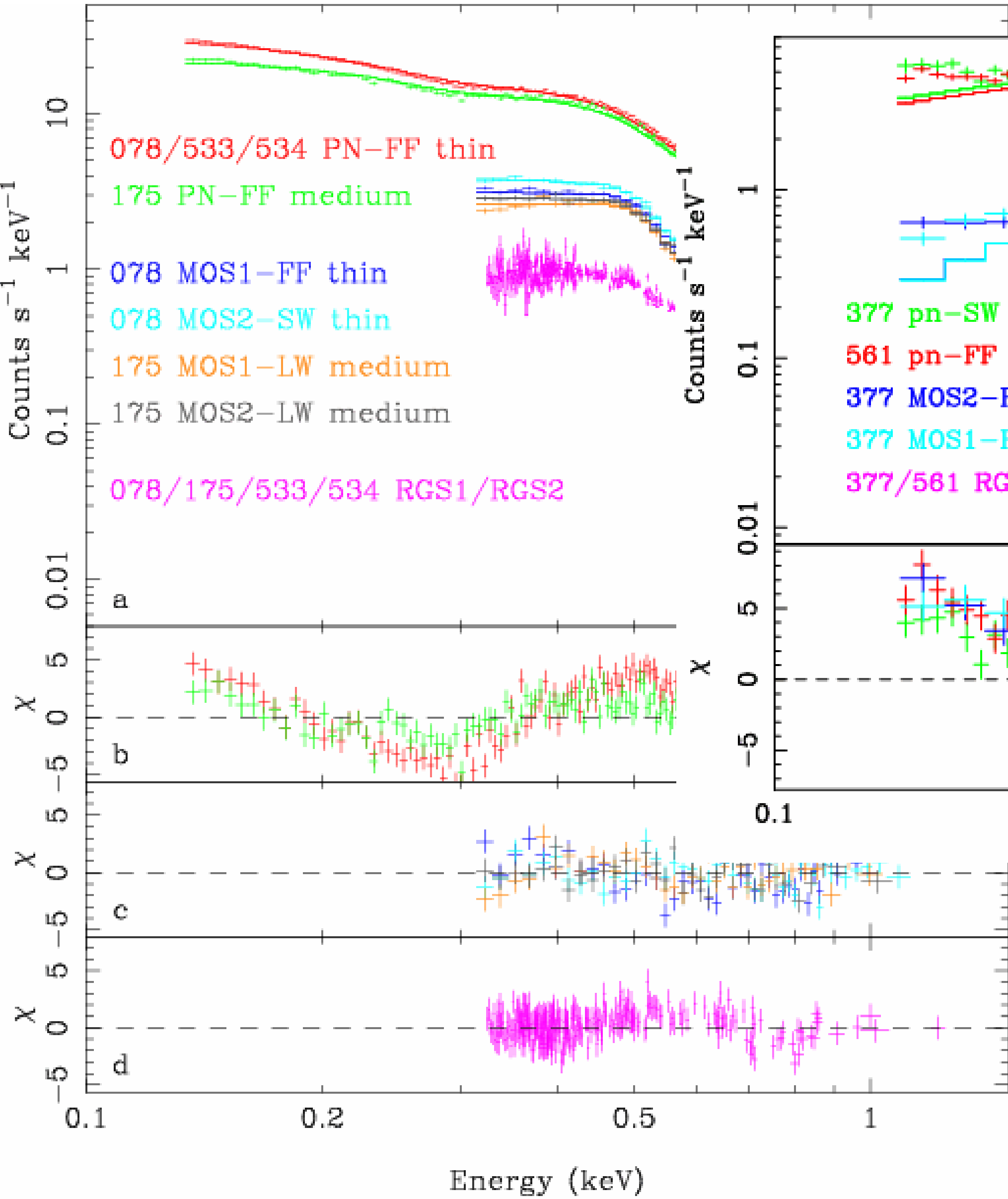
2005 optical pulsations (Kagaltsev et al)

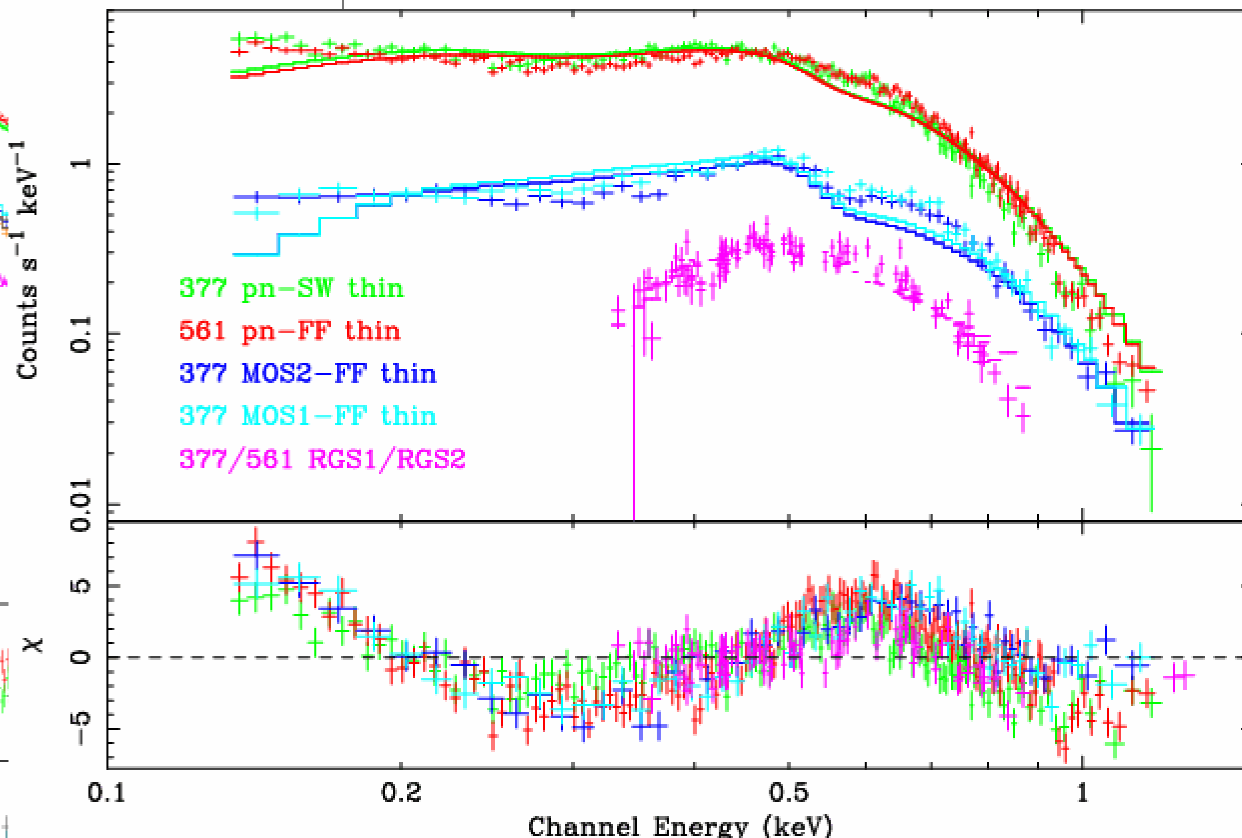
INSs (7)

- 5 out of 7 INSs have rather long Ps
- RX J0720.4-3125 changes PF over several years: precession?
- RX J1856.5-3754: perfect BB PF <1% possibility to measure R? at parallactic distance (117 pc) R=4.3km (or 7.2 at revised distance of 175). Optical emission is above BB extrapolation

Spectral features?

B~ 2-6 10^{13} G





RBS1223

RXJ 0720.4-3125

CCOs (6)

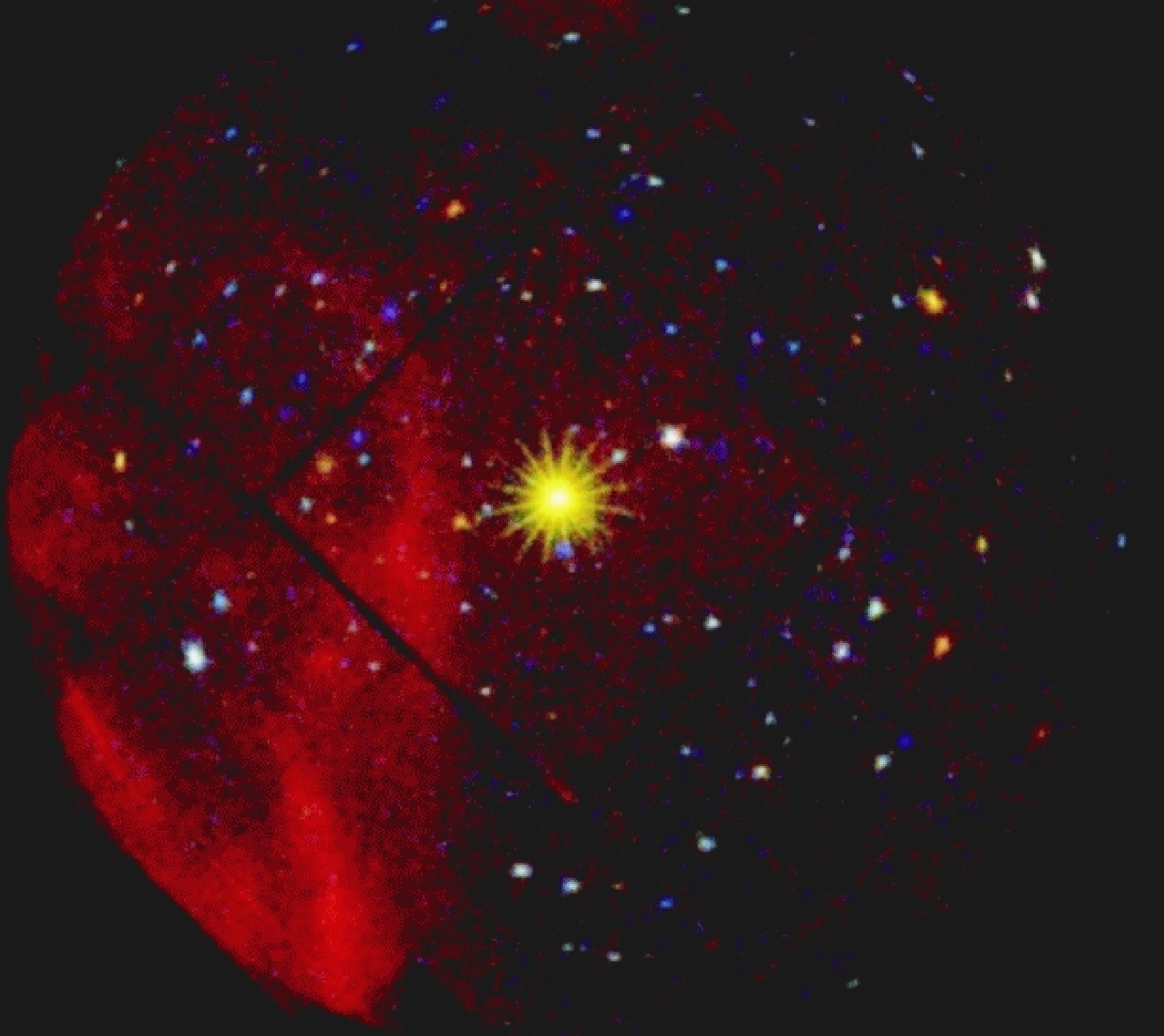
- Presumibly young, in the center of SNRs
- No radio emission
- No optical counterpart
- Thermal X-ray emission, small R, high T
- 3/6 show periodicity

  CXOU 1852.. (Kes79) 105 msec

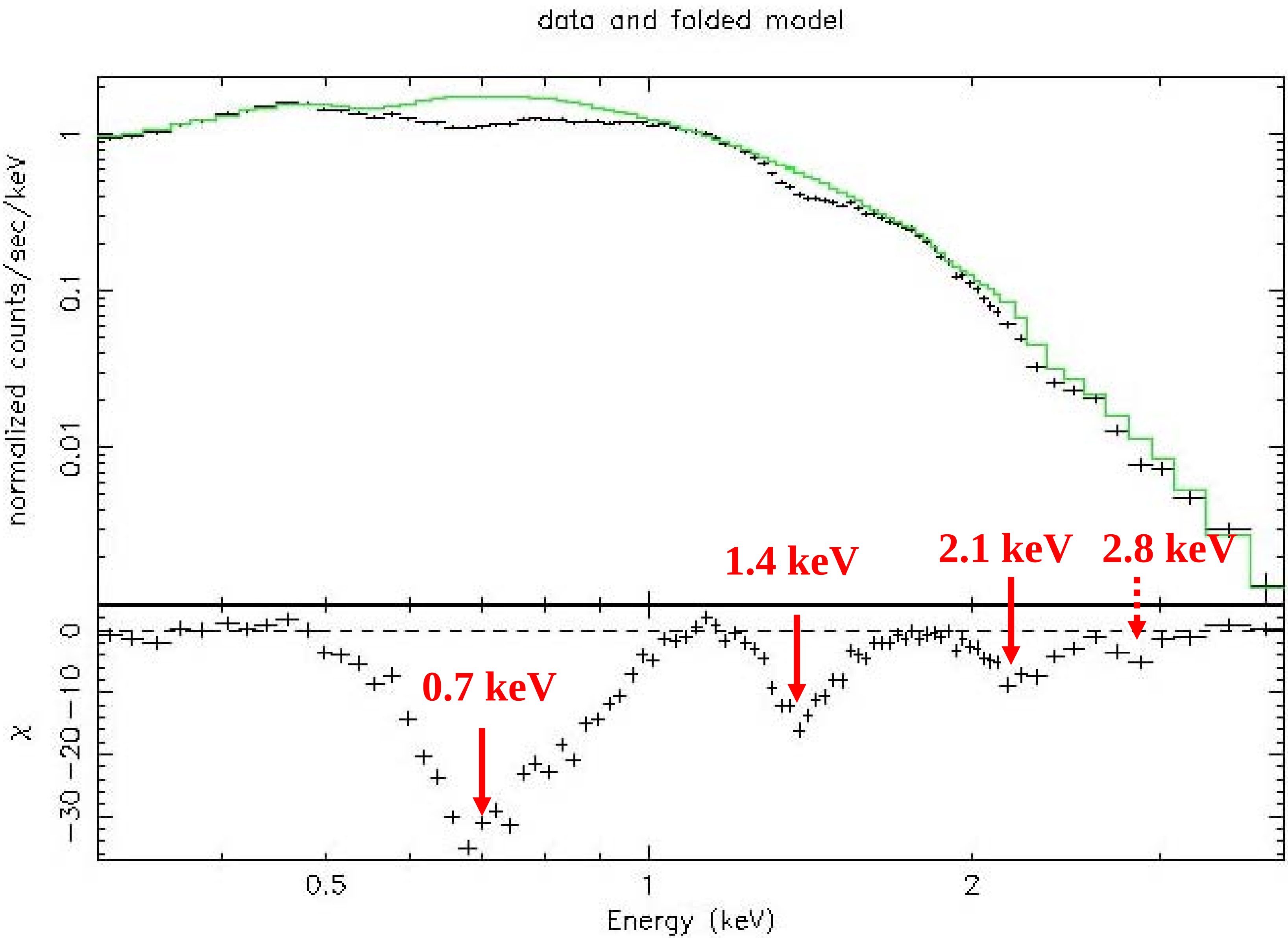
  1E 1207-52 (G296.5+10.0) 424 msec

  1E 161348 (RCW103) new

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



Pn data 208,000 photons



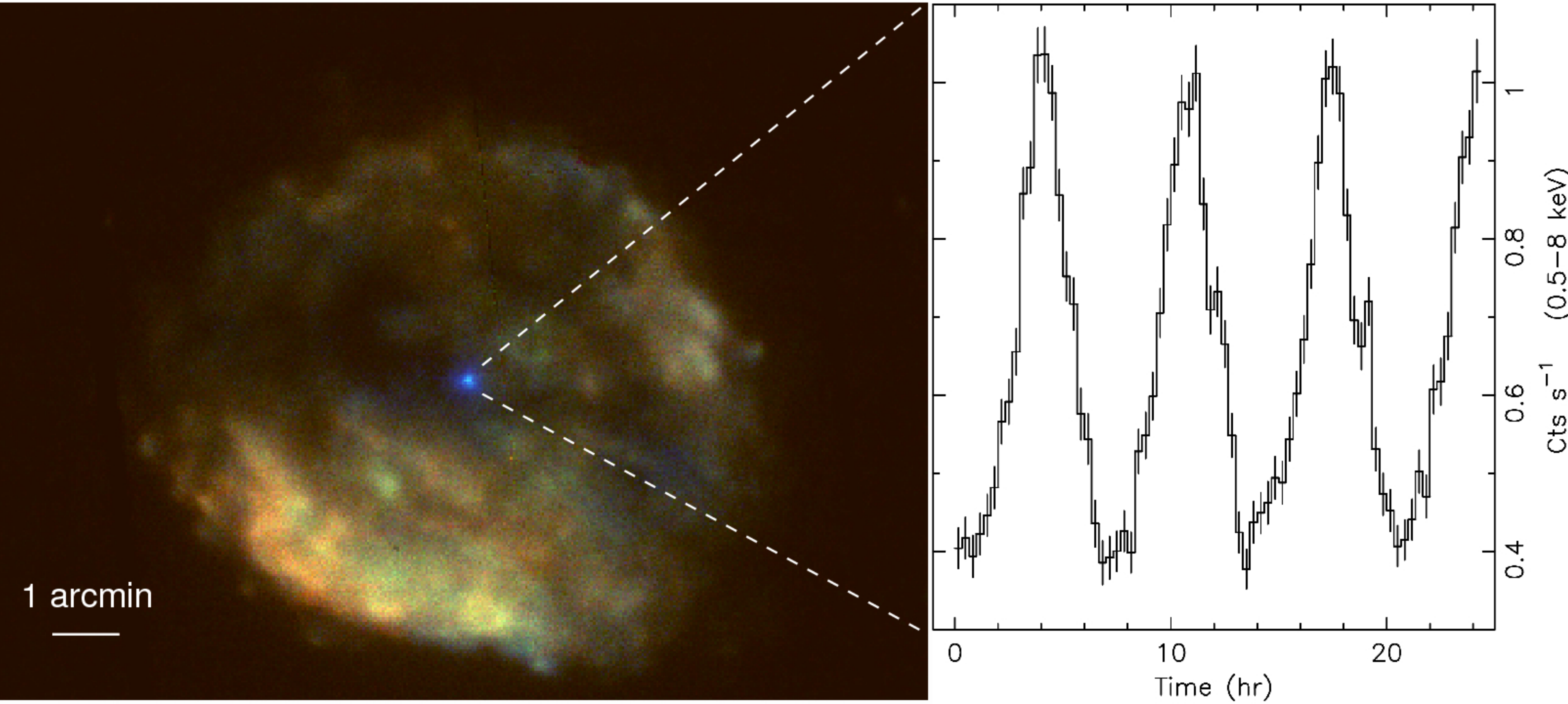
IF electron cyclotron: <B> $8\ 10^{10}$

IF proton <B> $1.6\ 10^{14}$

Classical B derivation from timing parameters is very difficult owing to P irregularities

Why is it a unique object ?

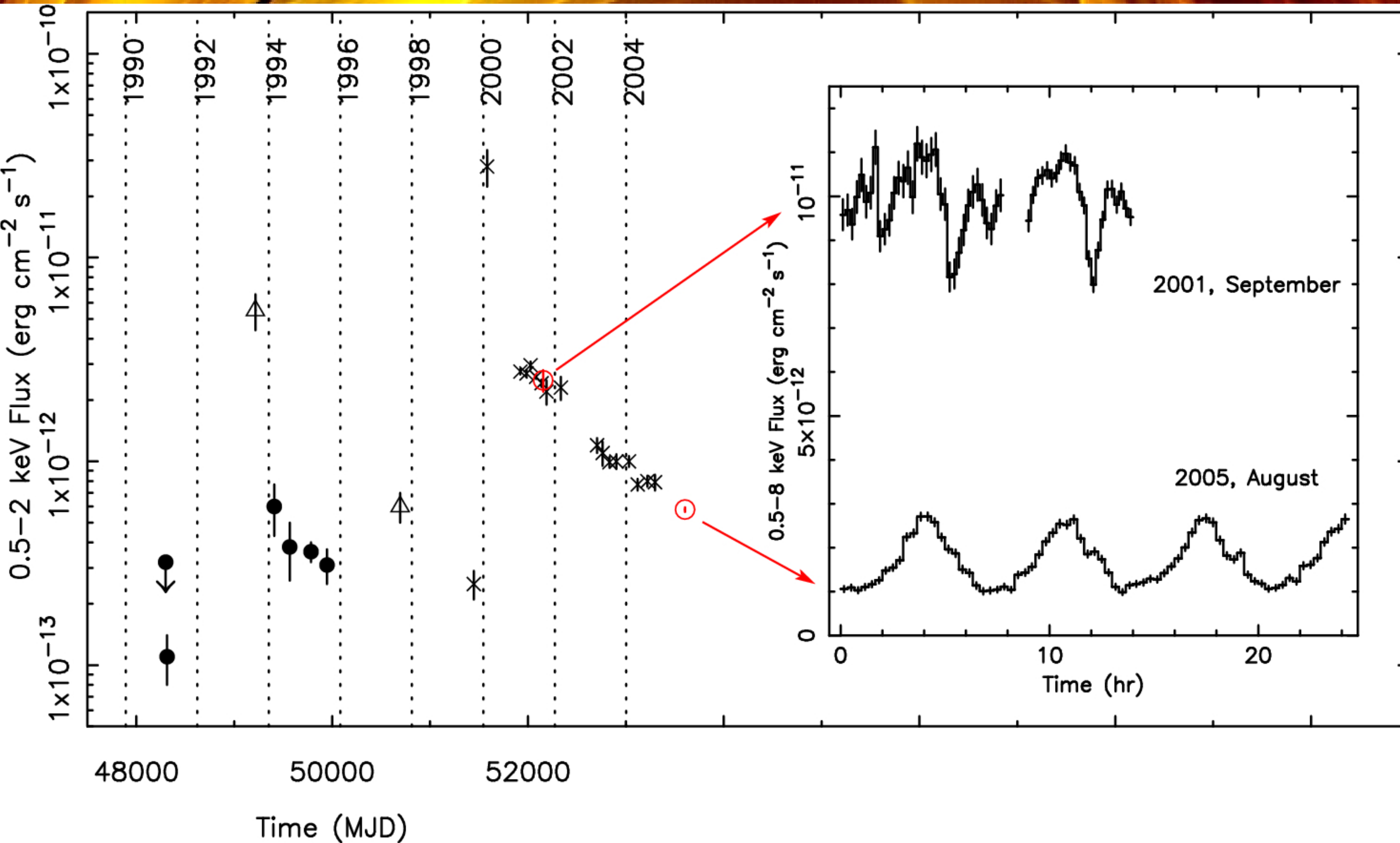
1E 161348-5055



2,000 y old

Cleopatra object

1E 161348-5055



What could Cleopatra be?

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