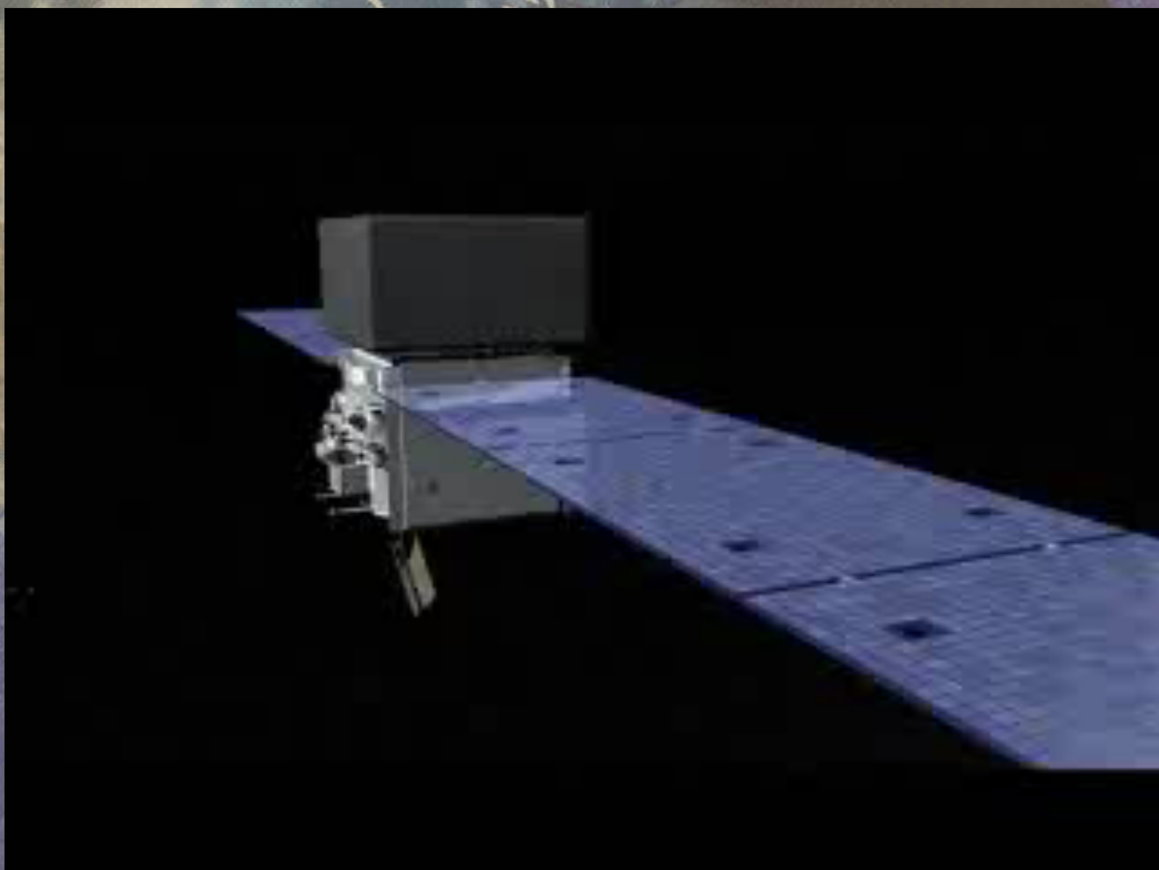
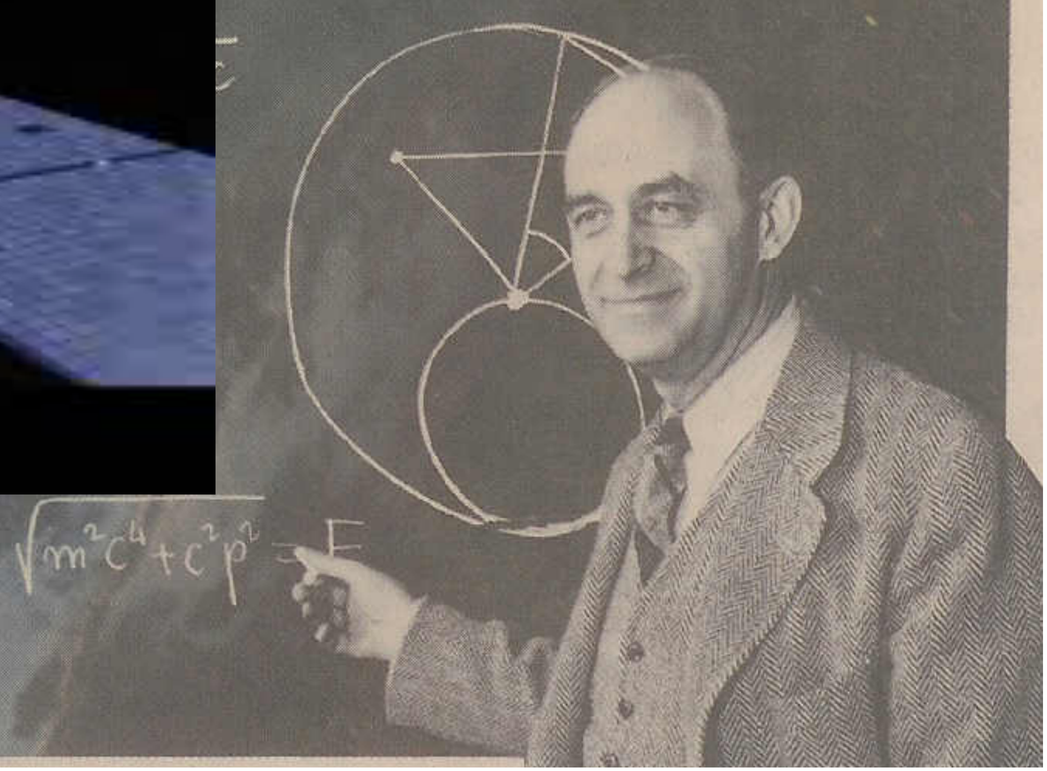
The Fermi pulsar revolution





Patrizia Caraveo

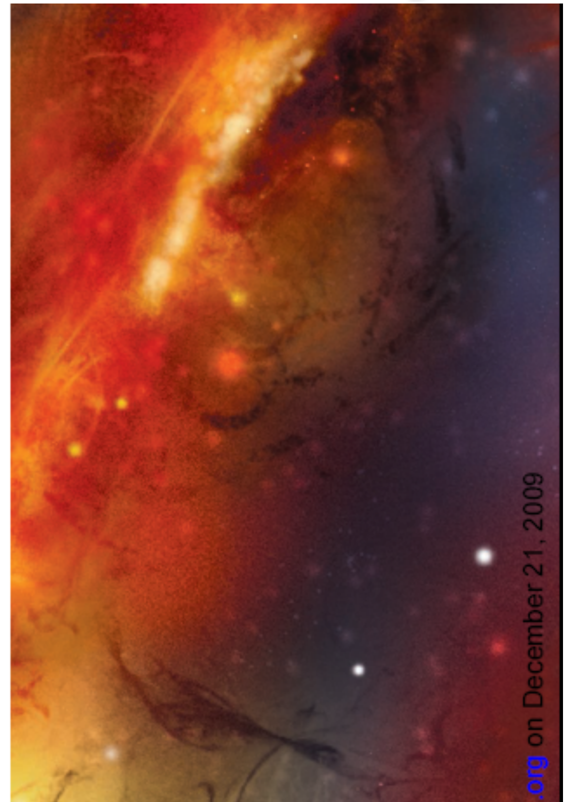
A Population of Gamma-Ray Millisecond Pulsars Seen with the Fermi LAT
Abdo, A. A. et al. 2009, Science, 325, 848

Detection of 16 Gamma-Ray Pulsars Through Blind Frequency Searches Using the Fermi LAT
Abdo, A. A. et al. 2009, Science, 325, 840

Discovery of high-energy gamma-ray emission from the globular cluster 47 Tucanae with Fermi
Abdo, A. A. et al. 2009, Science, 325, 845

2009 Breakthrough of the year

THE RUNNERS-UP >>



Opening Up the Gamma Ray Sky

LIKE A LIGHTHOUSE BLINKING IN THE NIGHT, A pulsar appears to flash periodically as it spins in space, sweeping a double cone of electromagnetic radiation across the sky. Since the discovery of the first pulsar 4 decades ago, astronomers have detected hundreds more of these enigmatic objects from the pulsing radio waves they emit. Now, astronomers have opened a new channel of discovery—the highly energetic gamma ray spectrum—to find pulsars that radio observations could not detect. The advance, part of a torrent of recent gamma ray observations, is giving researchers an improved understanding of how pulsars work, along with a rich haul of new pulsars that could help in the quest to detect gravitational waves.

The findings come from the Fermi Gamma-ray Space Telescope, which has been mapping the gamma ray universe since it was launched by NASA in June 2008. Combing through data the telescope collected in its first few months, an international team discovered 16 new pulsars; strong gamma ray pulsations from eight previously known pulsars with spin times of milliseconds, proving that these objects pulse brightly at gamma wavelengths as well as in the radio range; and high-energy gamma rays from the globular cluster 47 Tucanae indicating that the cluster harbors up to 60 millisecond pulsars.

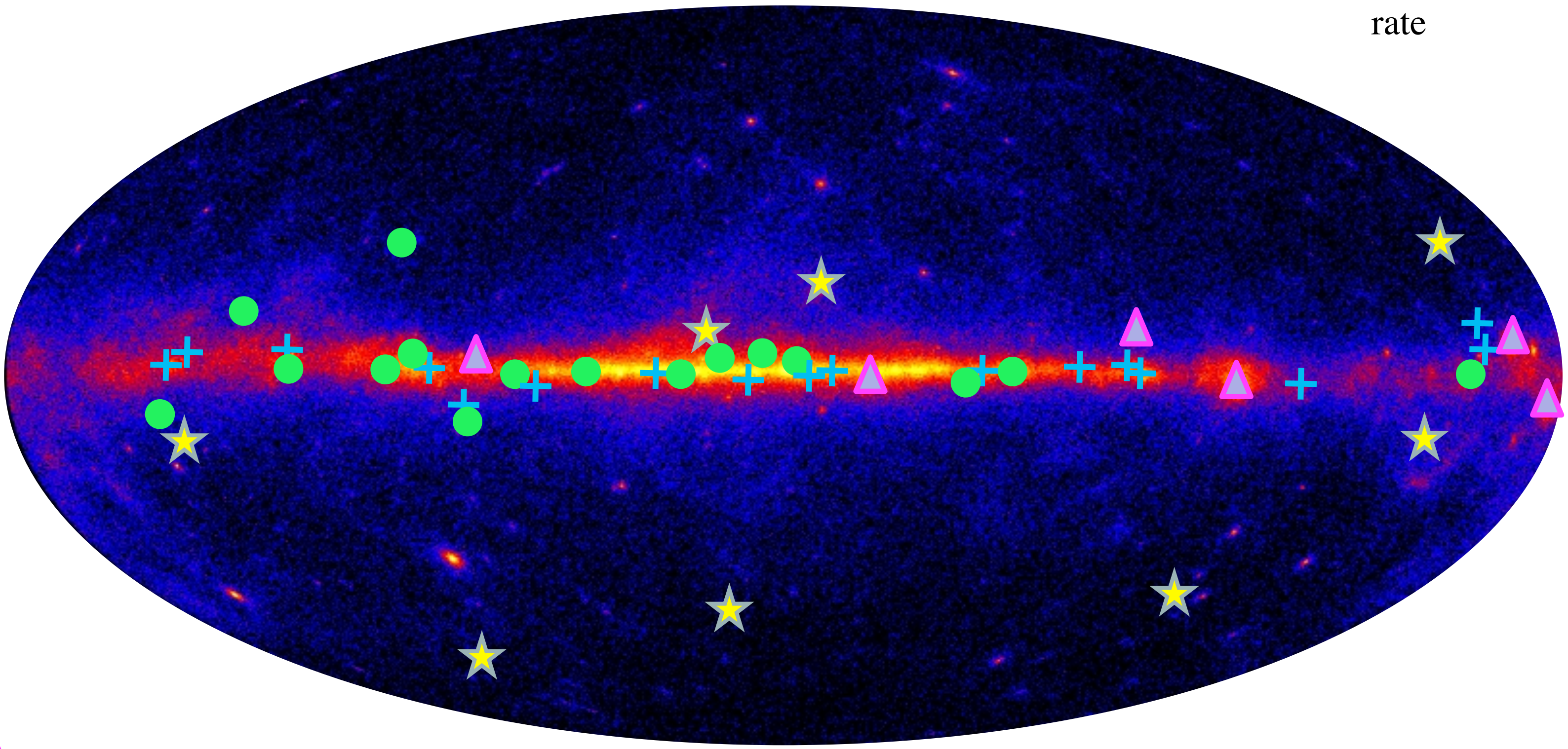
Those Fermi results might be just the beginning. Armed with their new knowledge of pulsar behavior, researchers are checking whether some of the unidentified gamma ray sources Fermi has detected might be pulsars. In November alone, teams of astronomers in the United States and France discovered five new millisecond pulsars by training ground-based radio telescopes on candidate objects Fermi had pointed out—a much more targeted search technique than scanning the sky blindly with ground-based radio telescopes.

Gamma ray beams of pulsars are believed to be wider than their radio beams, so in principle a space-based gamma ray telescope should be more likely to encounter and discern a pulsar's sweep than a radio telescope on Earth is. However, Fermi's forerunner—the Compton Gamma Ray Observatory, which flew from 1991 to 2000—did not have much luck finding these objects. What has made the difference is Fermi's high sensitivity, which enables it to detect pulsations that would have been too faint for Compton.

Already, the discoveries are shedding new light on the physics of pulsars. Researchers

Fermi Pulsars

Pulses at 1/10th real rate



EGRET pulsars

young pulsars discovered using radio ephemeris

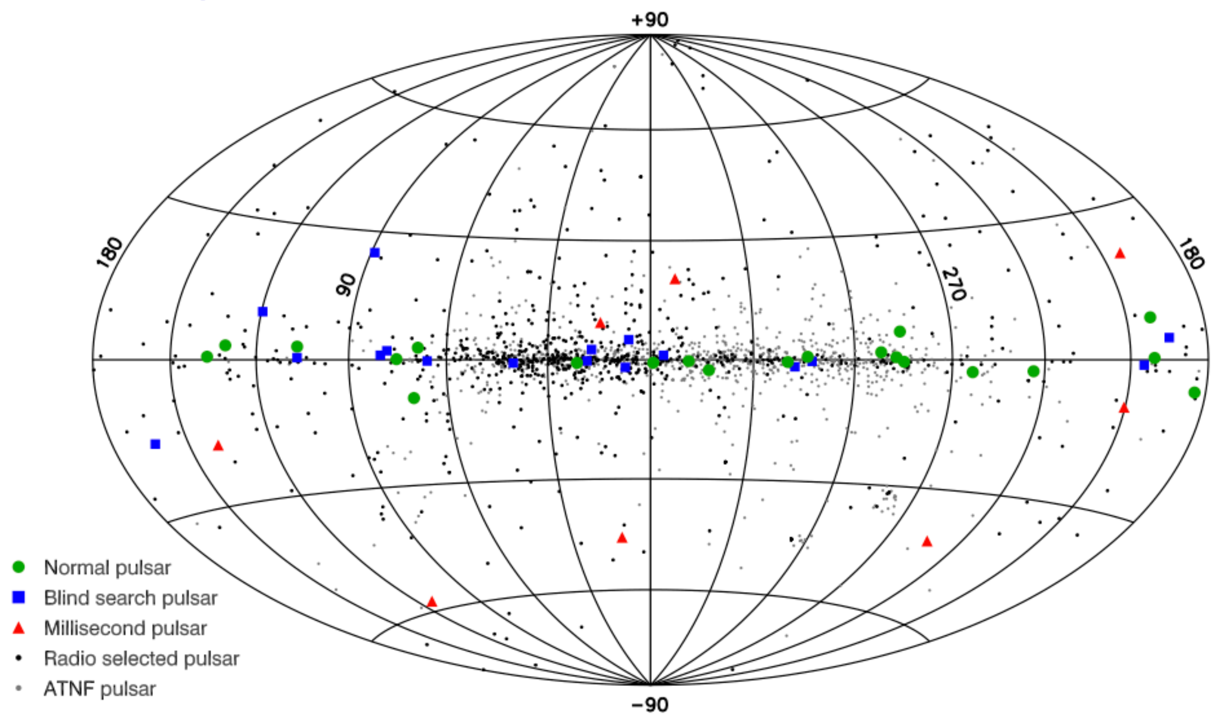
pulsars discovered in blind search

millisecond pulsars discovered using radio ephemeris

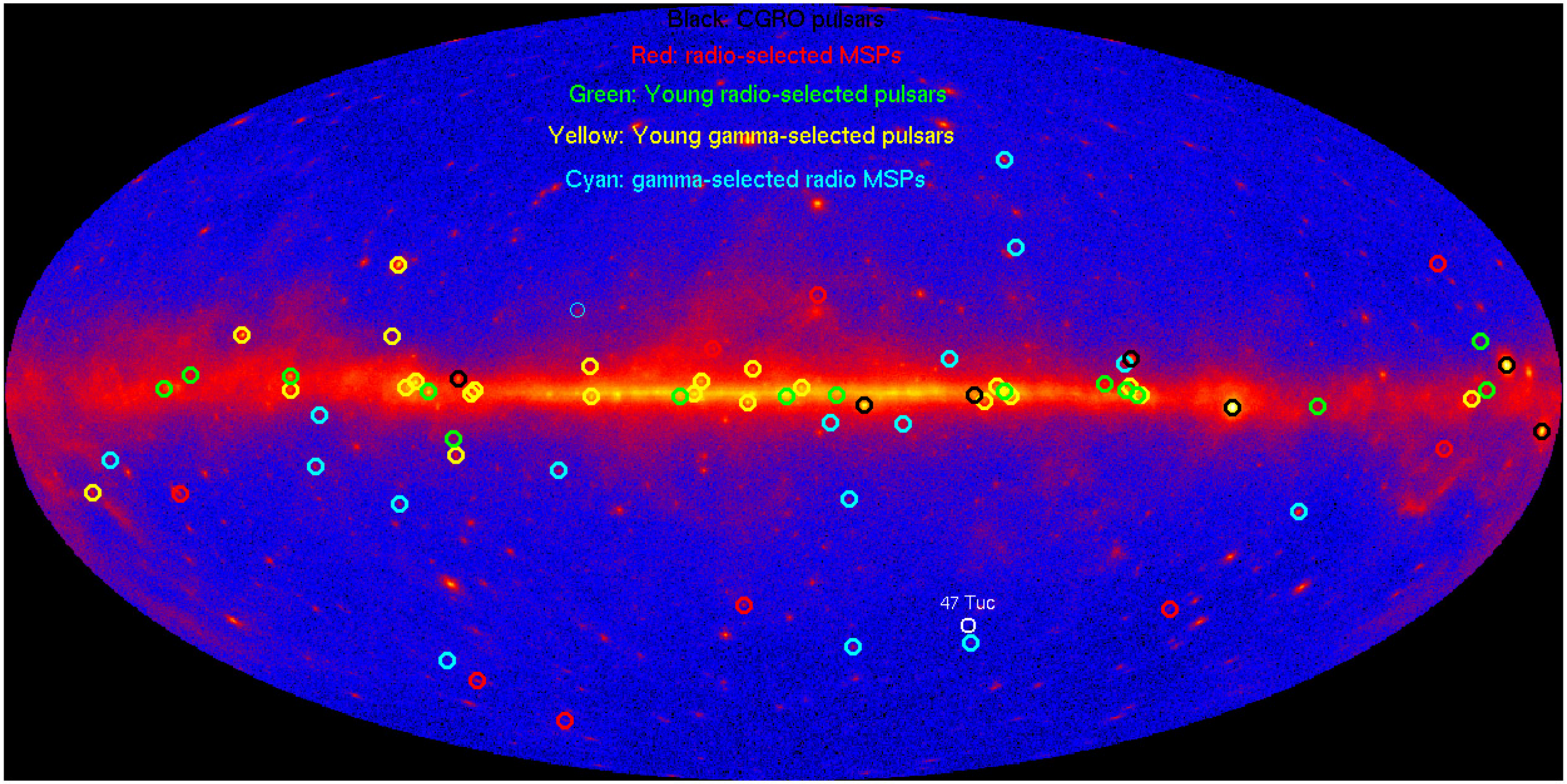
First Fermi LAT Pulsar Catalogue

- 46 pulsars detected by the LAT using the first 6 months of LAT data
- Of the 46, 16 resulted from blind searches, and 24 were discovered using ephemerides from radio monitoring*, including 8 MSPs

TOTAL
17 radio quiet
21 radio PSR
8 msec PSR



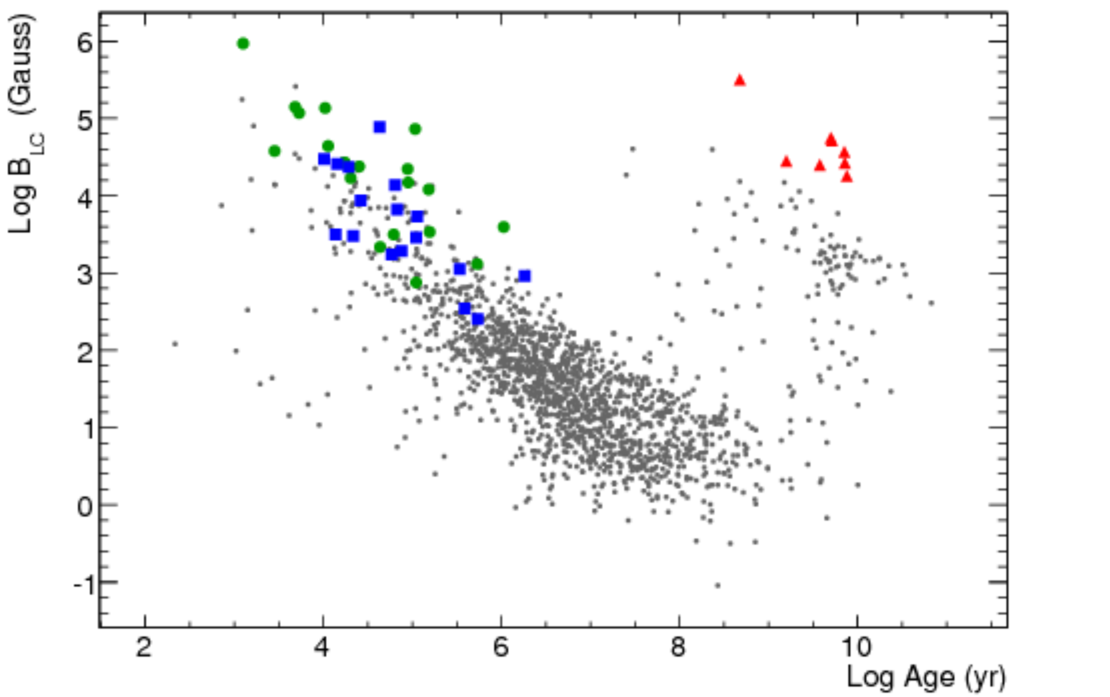
Recent update (D. Smith)

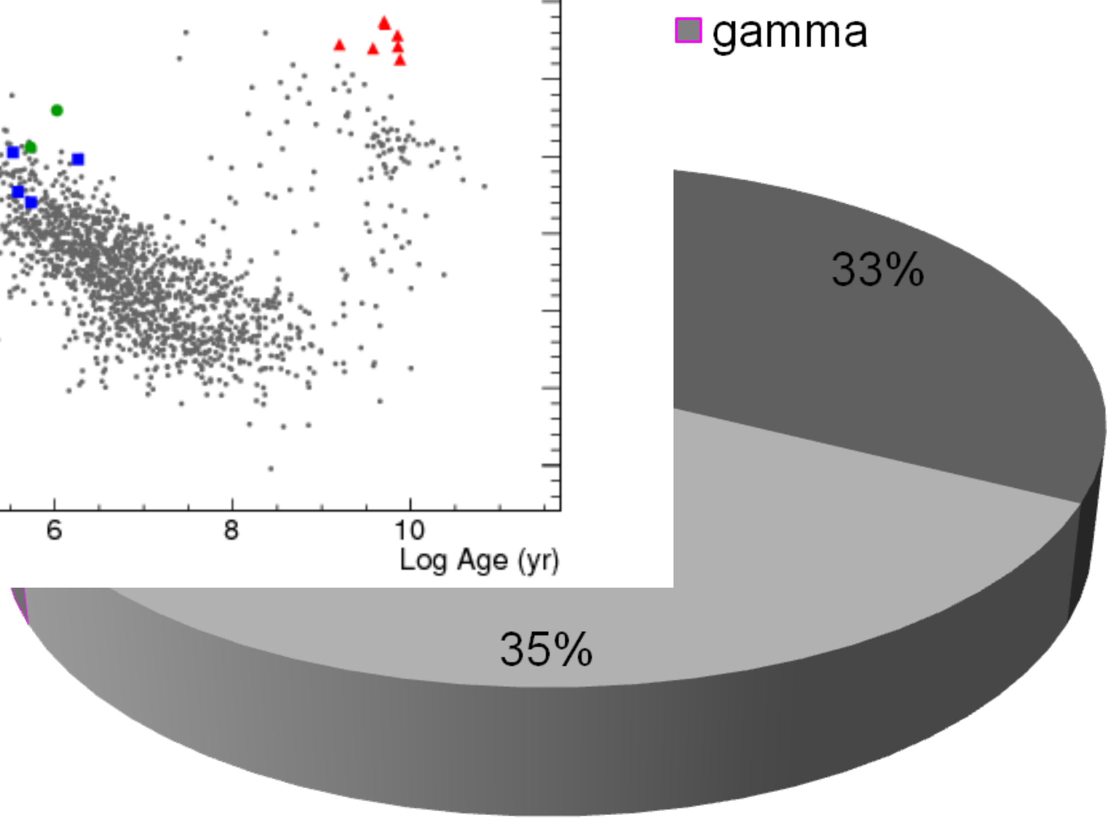


8 new gamma selected pulsar, several new radio PSRs, Several of the newly detected msec PSRs

Unexpected finding

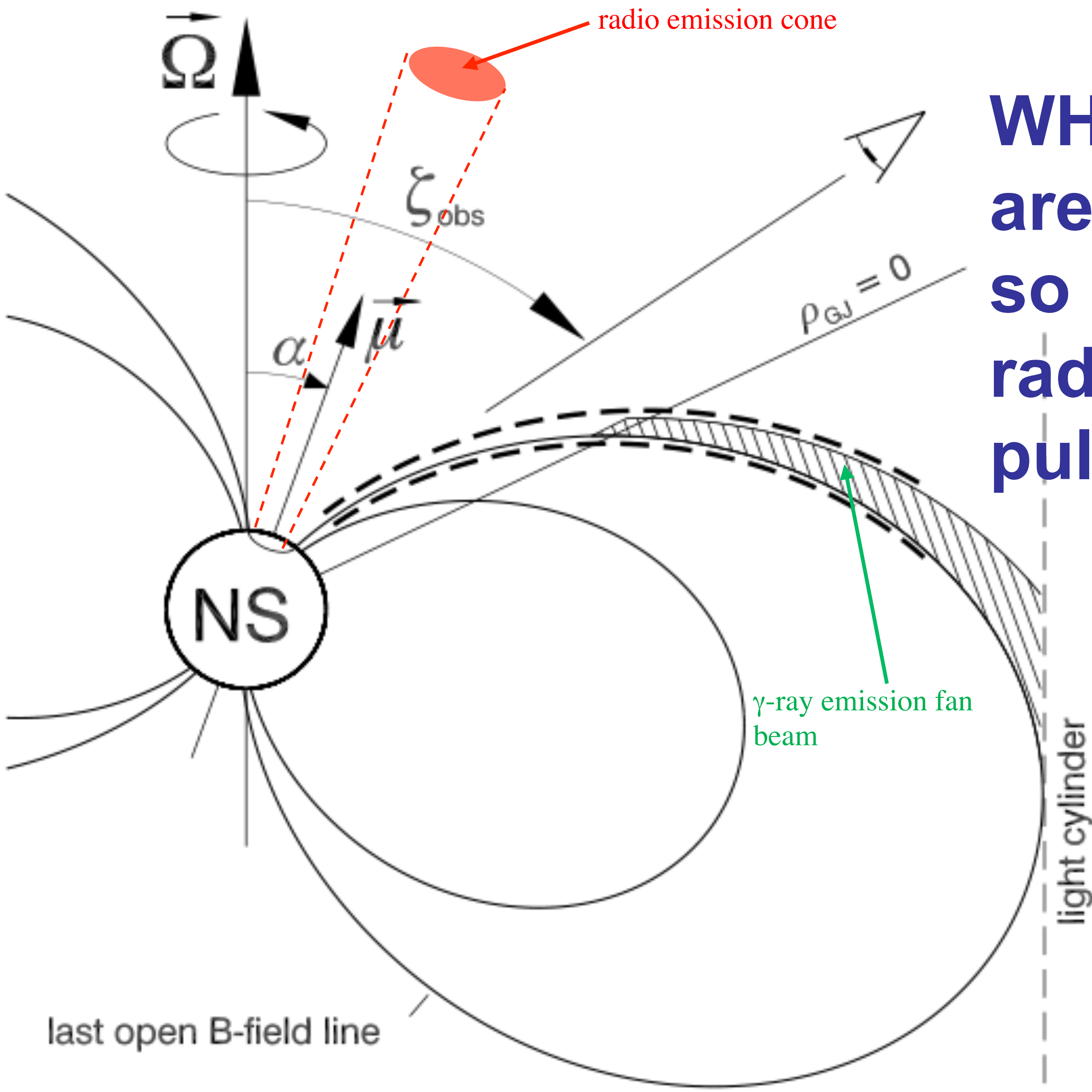
umerous as





Radio-loud versus Radio-quiet.

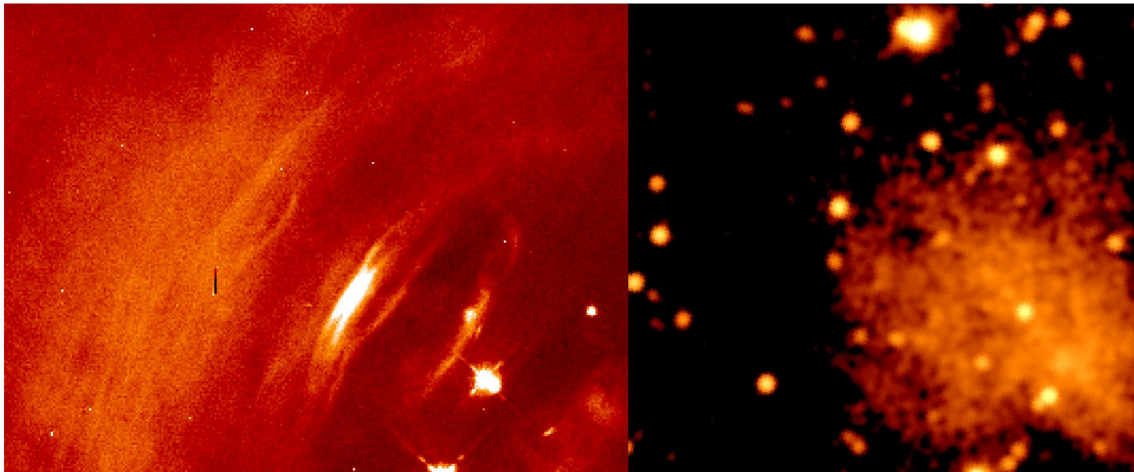
(Until Fermi, "*Geminga*" was the only gamma-loud, radio-quiet pulsar.)

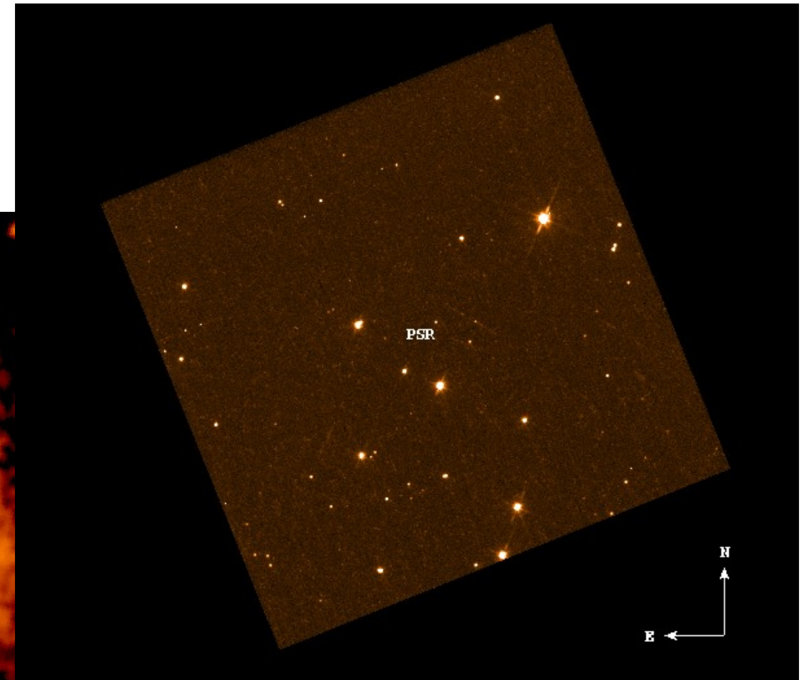


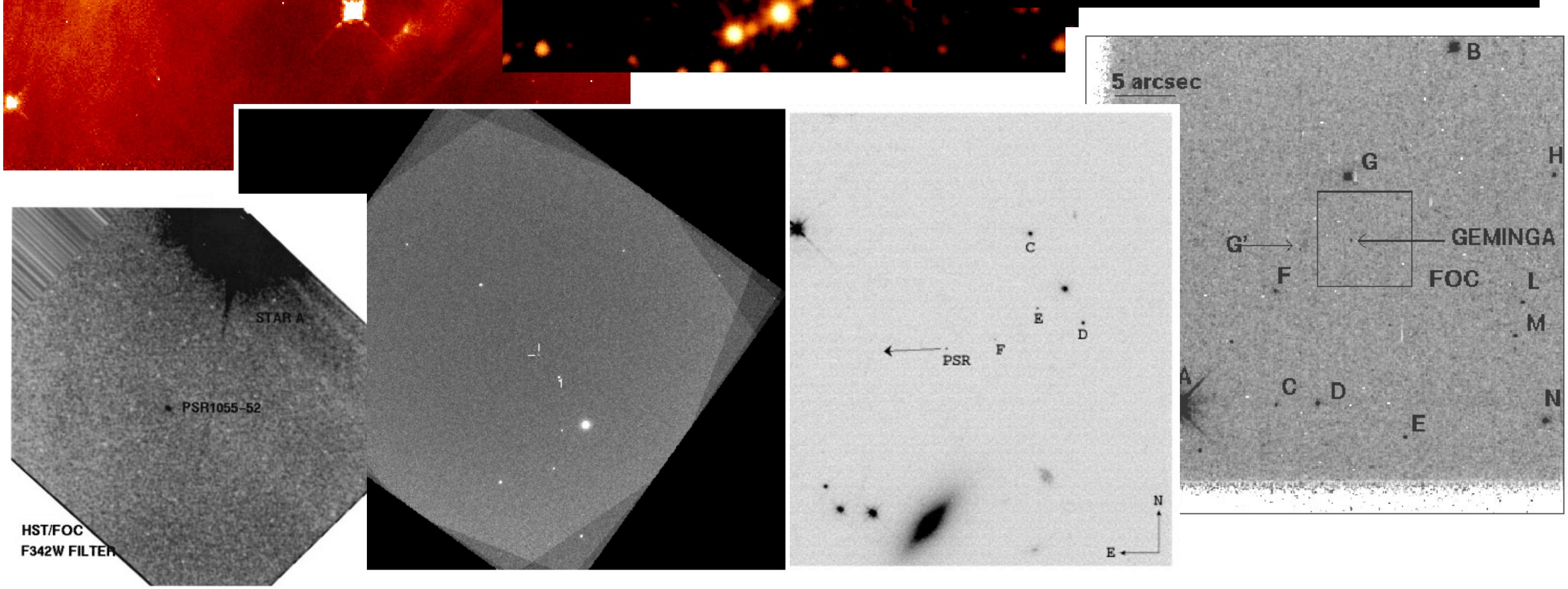
WHY are we seeing so many radio quiet pulsars

How can we study them ?

Forget optical emission

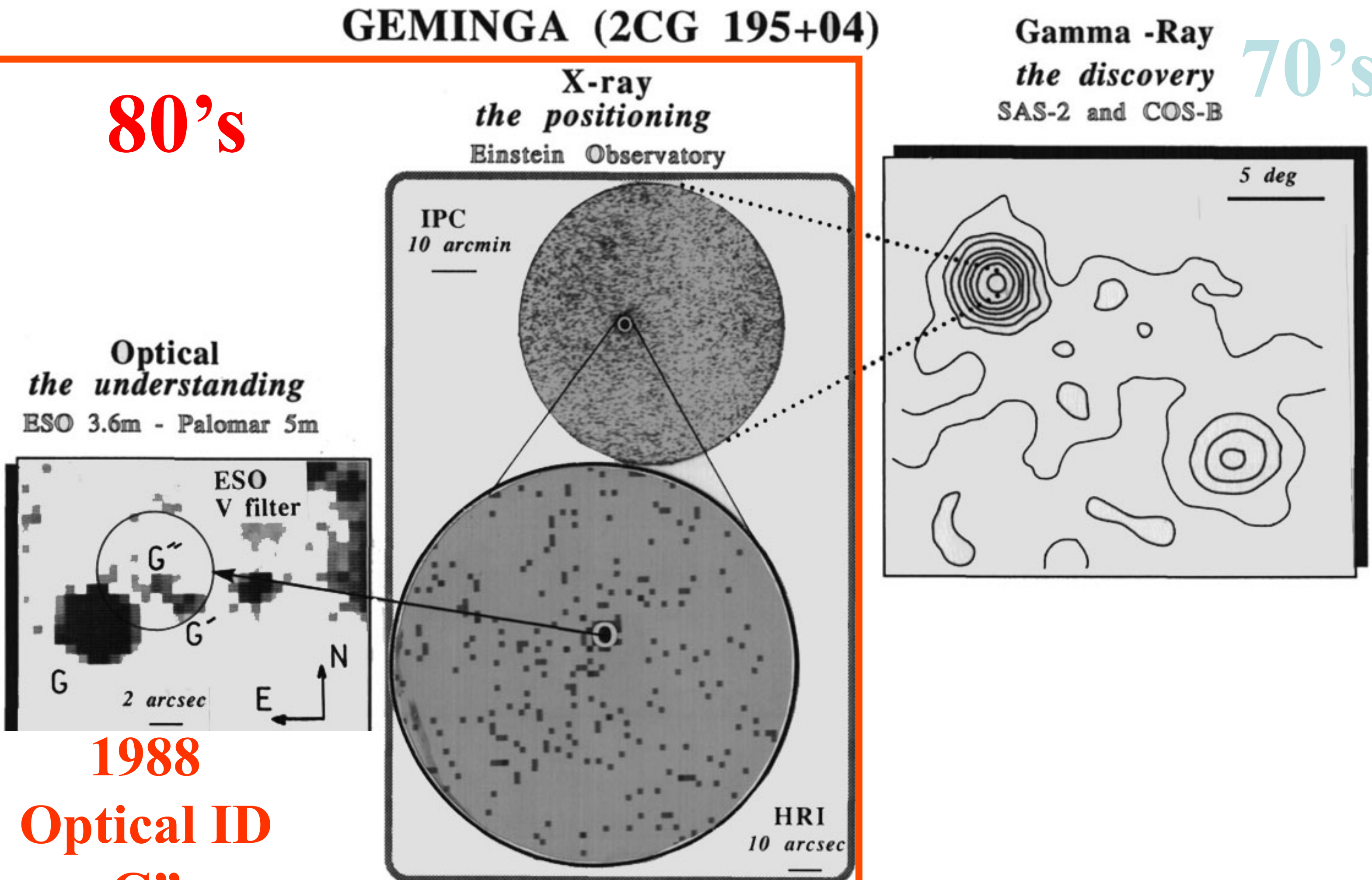






The power of X-ray Astronomy

80's



70's

1988
Optical ID
G"

1983
X-ray counterpart
1E0630+178

X-ray vs gamma emission from

- Classical (radio) NSs
- msec PSR
- Gamma-ray selected (Radio quiet) NSs

•Are radio loud and radio quiet NSs behaving in the same way?

Gamma vs X-ray behaviour

- Averaged fluxes
  Averaged spectra

- Light curves
- Phase-resolved spectra

Standard analysis is needed

In gamma-rays → LAT catalogue
In X-rays → a re-analysis of the entire data base
Martino Marelli PhD thesis

X-ray menu

- No observation
- Exploratory Obs.
- Good spectral analysis
- “ “ “ but PWN also detected
- Excellent spectral analysis

SWIFT

Chandra
XMM-Newton

X-ray menu

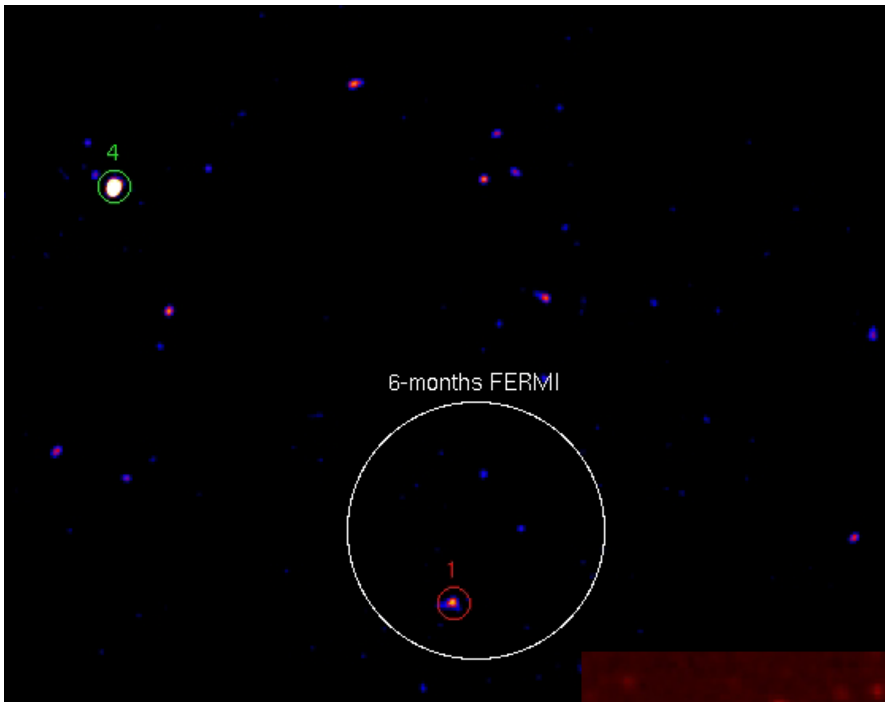
- No observation
- **Exploratory Obs.**
- Good spectral analysis
- “ “ “ but PWN also detected
- Excellent spectral analysis

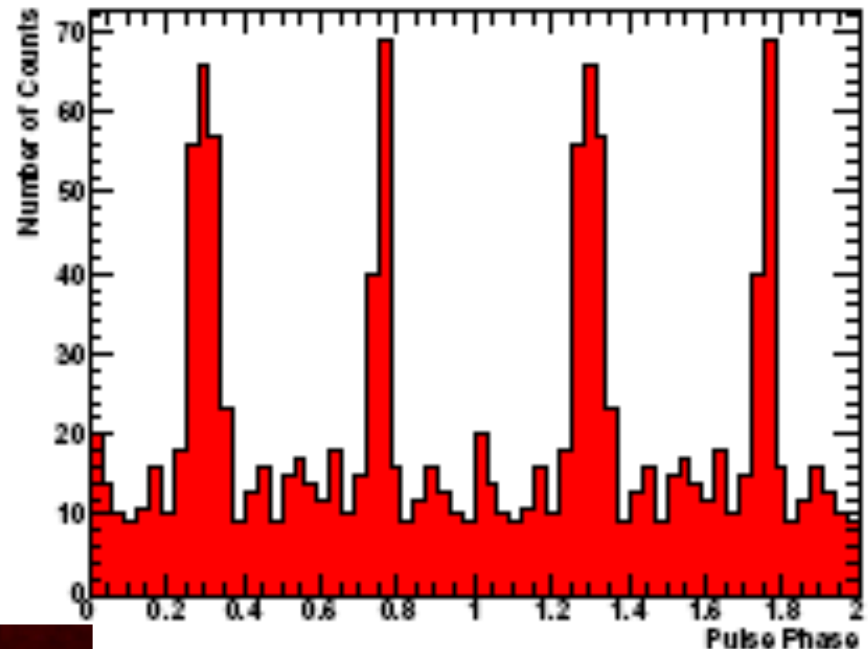
SWIFT

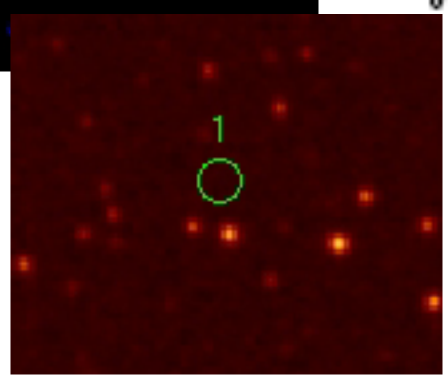
Chandra
XMM-Newton

XRT image of J0633

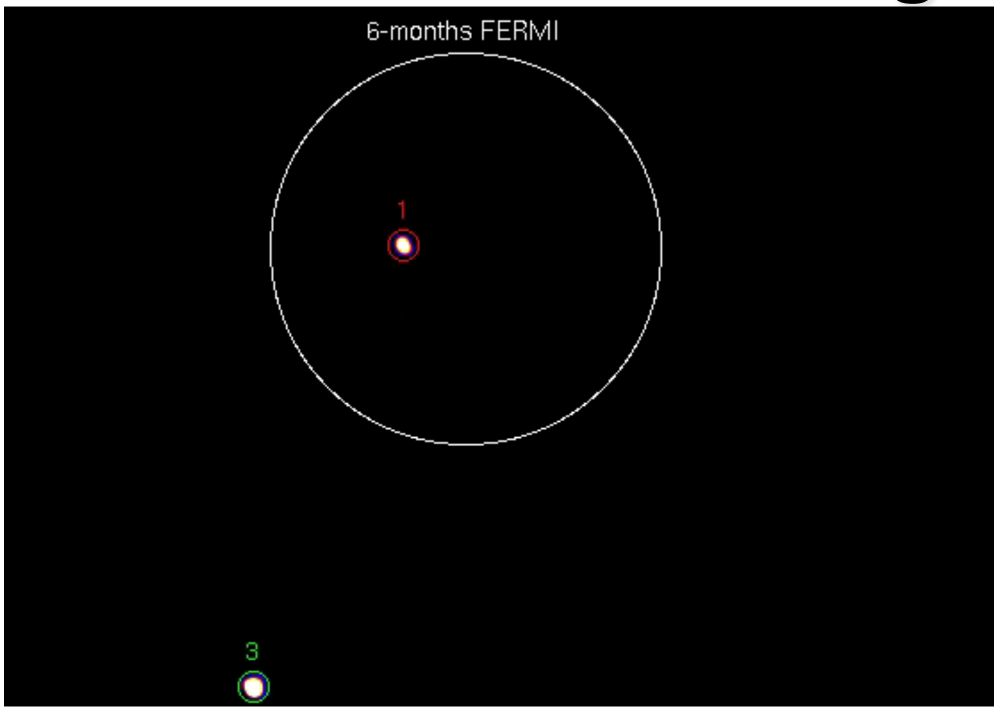
0633+0642R 98.4233 6.5708 .29739 77.7 0.0623 1.81 5.2E21 5.00E12 0.0531 3E-7 1.17

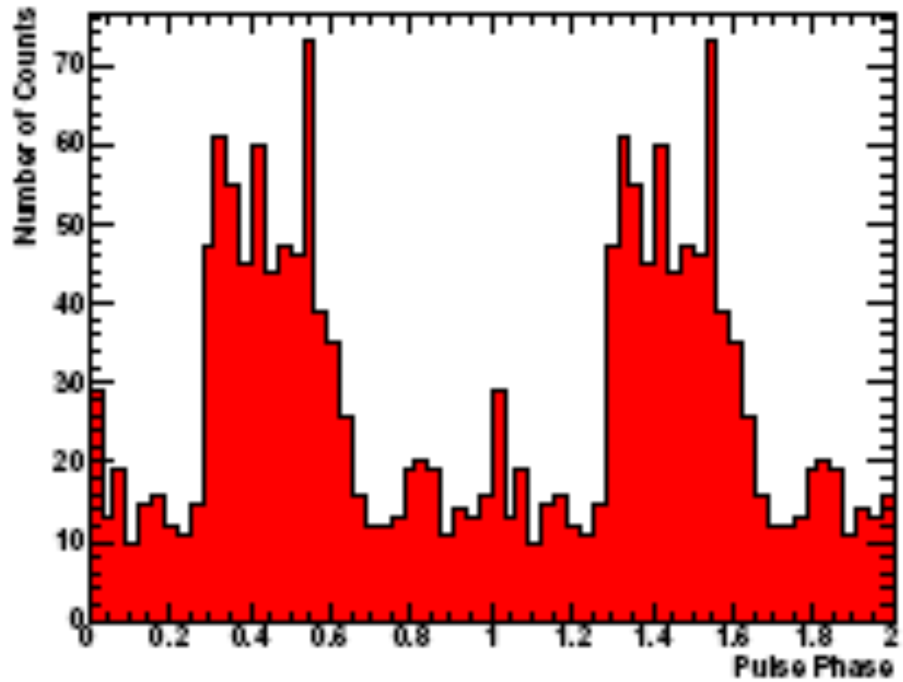




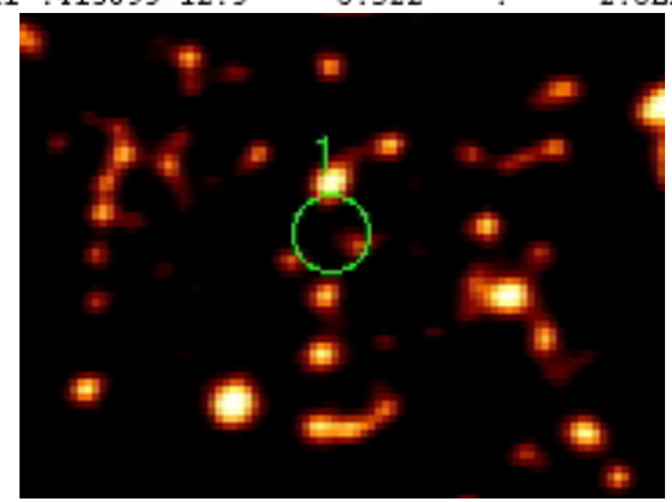


XRT image of J1741

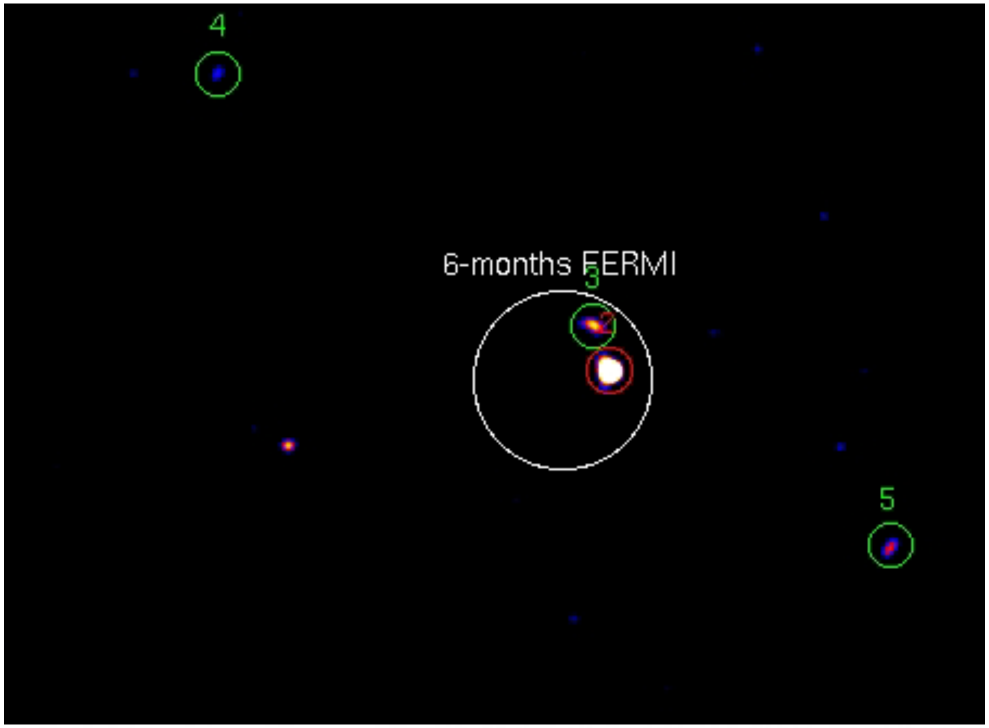


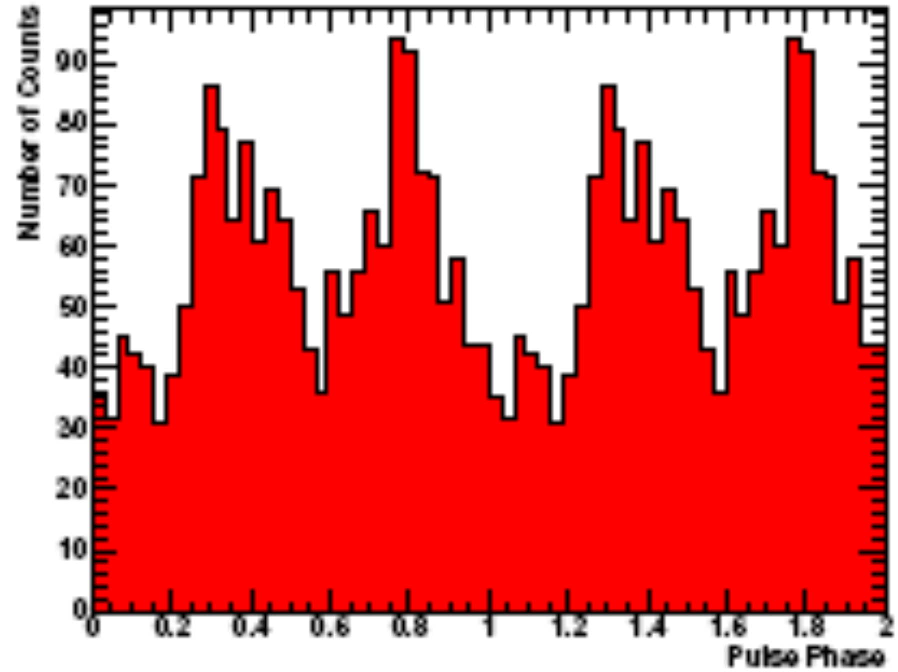


1741-2050 265.4656 -20.9041 .413699 12.9 0.522 ? 2.8E21 2.40E12 0.0715 3E-7 0.0719

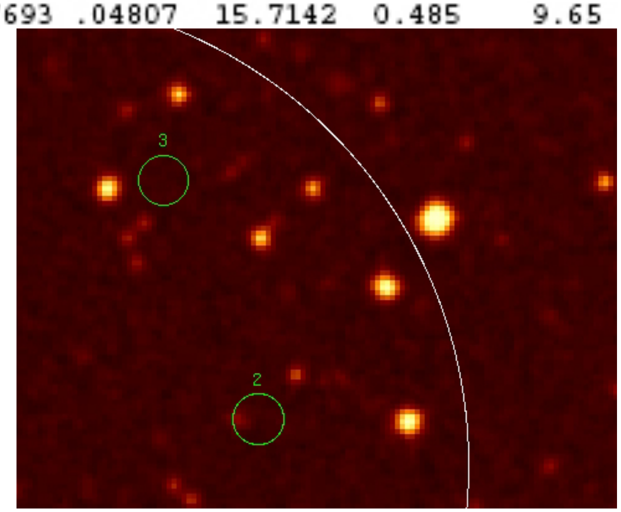


XRT image of J1813

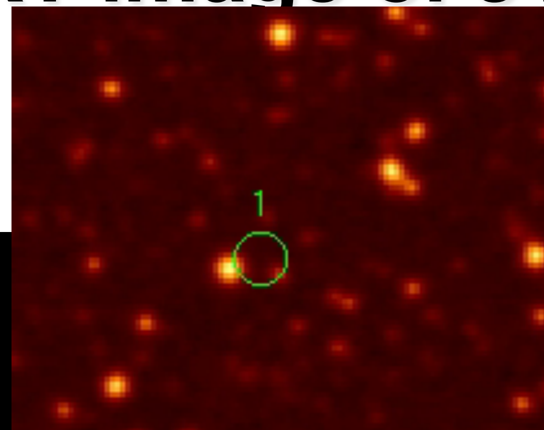


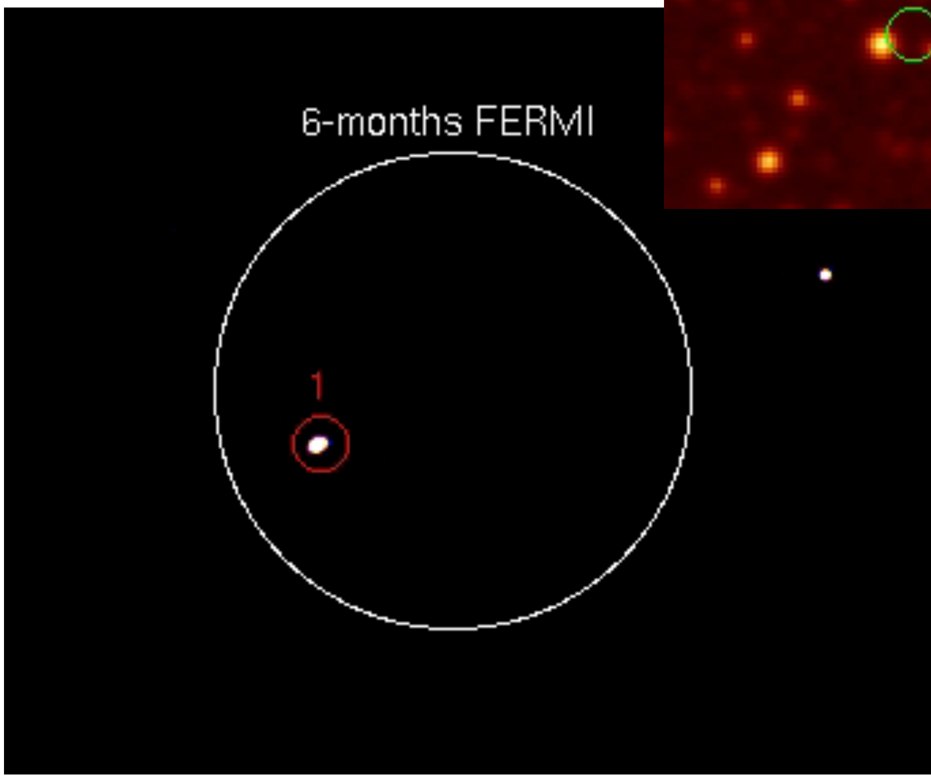


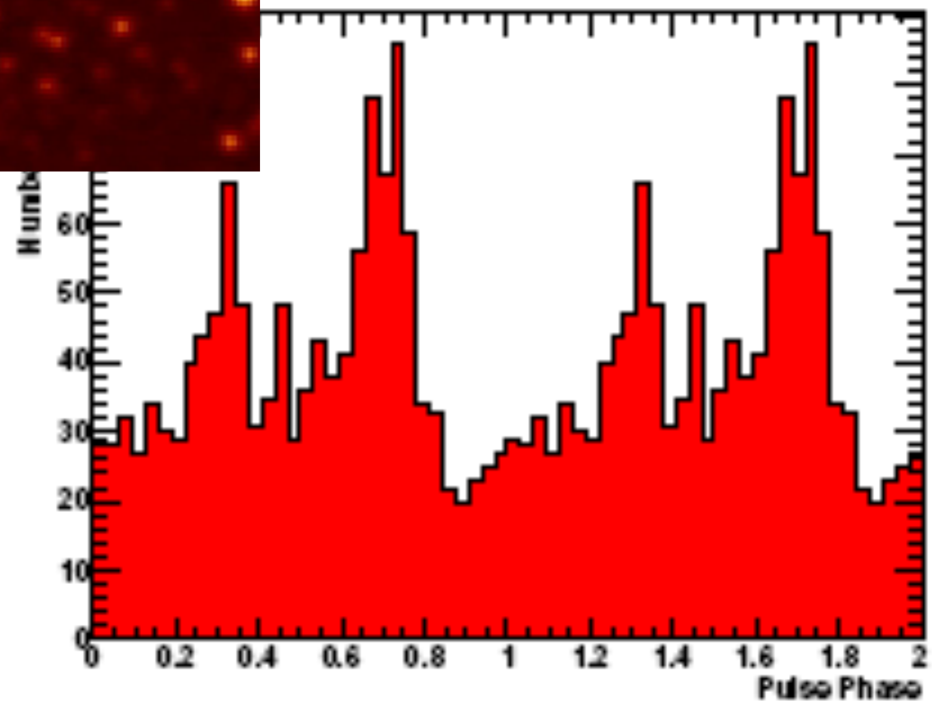
1813-12R 273.3622 -12.7693 .04807 15.7142 0.485 9.65 6.5E21 9.08E11 0.0266 6E-7 55.8



XRT image of J1958

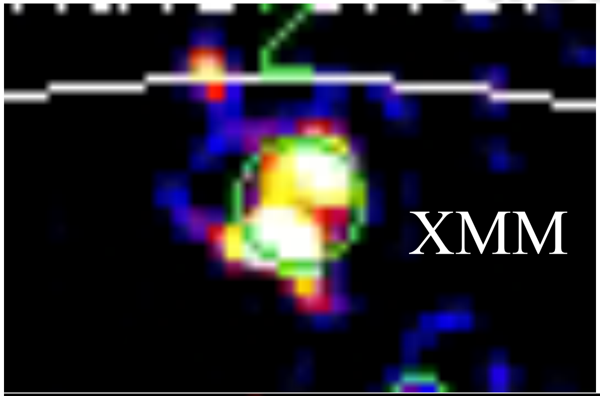


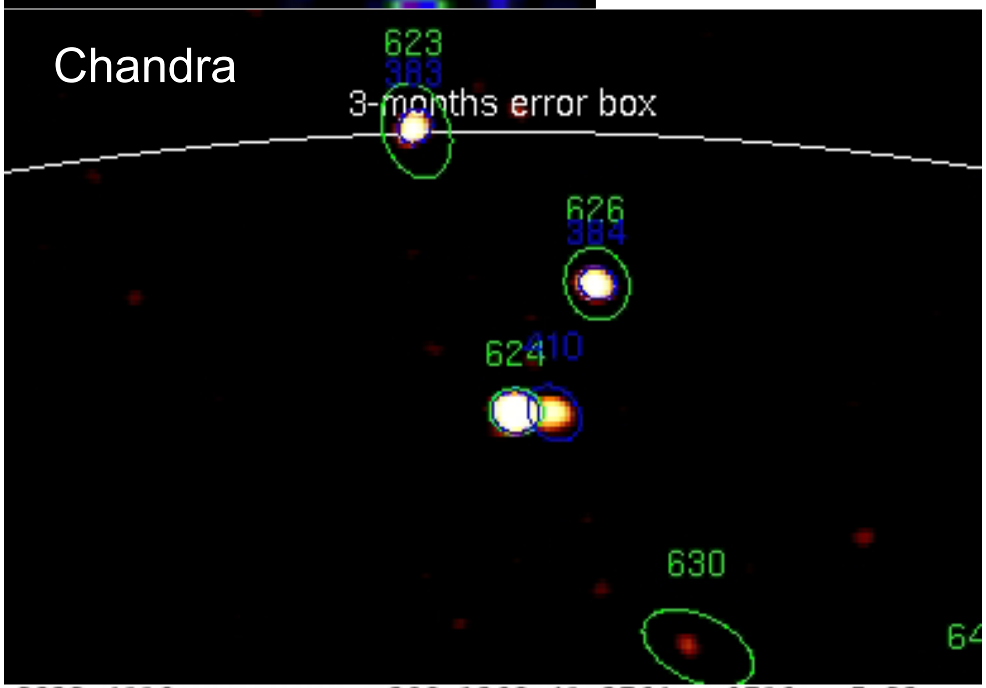


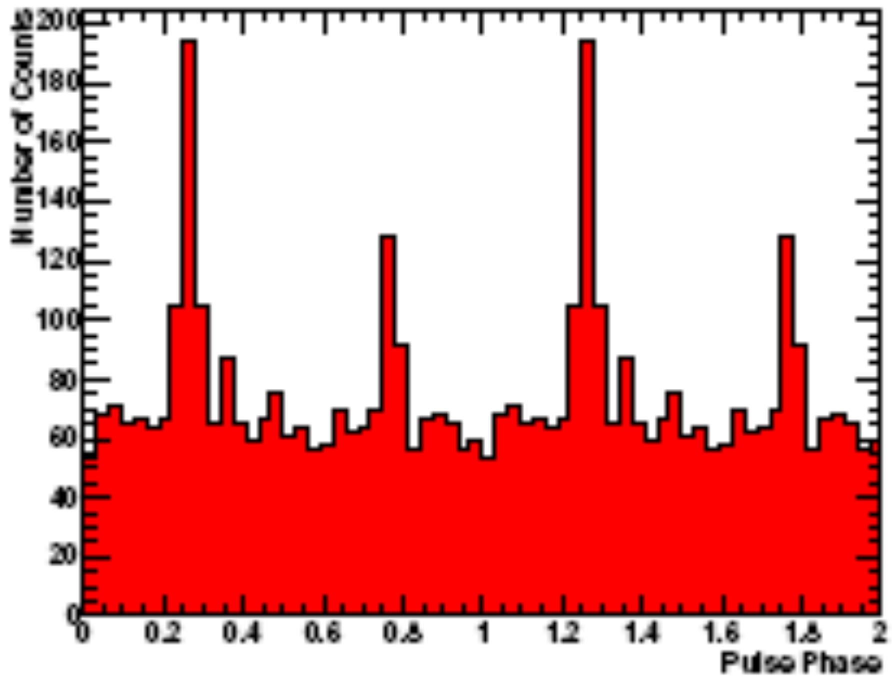


1958+2841R 299.6562 28.7801 .2904 208.83 0.0226 3.88 8.7E21 8.10E12 0.0572 1E-7 3.36

Archival searches: J2032







2032+4119 308.1388 41.3764 .0716 7.23 0.161 ? 1.2E22 7.48E11 0.0442 6E-7 7.77

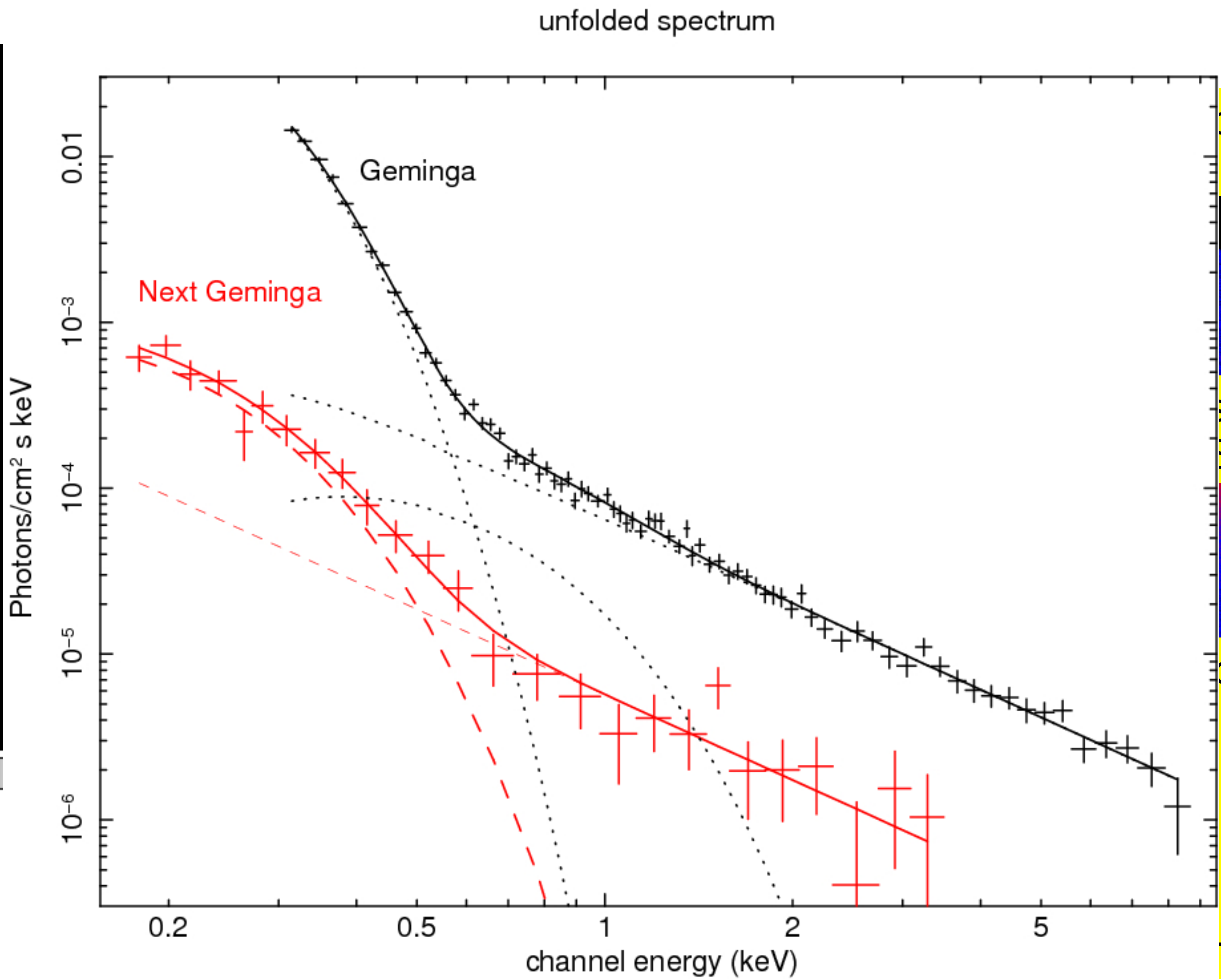
X-ray menu

- No observation
- Exploratory Obs.
- **Good spectral analysis**
- “ “ “ but PWN also detected
- Excellent spectral analysis

SWIFT

Chandra
XMM-Newton

3FG J1835+5918 a.k.a. “Next Geminga”



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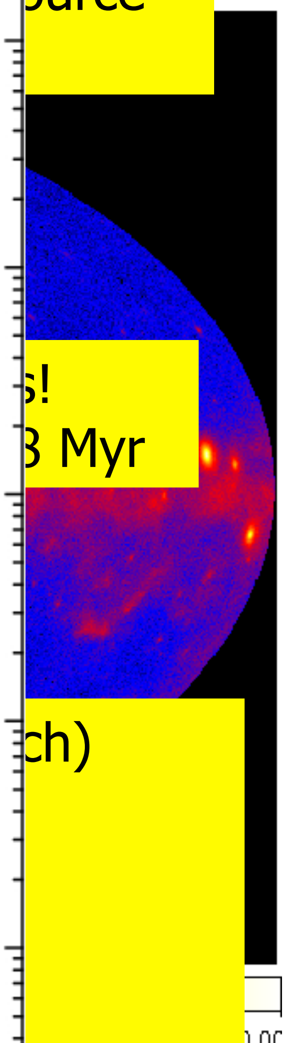
3 Myr



ch)

non-th)

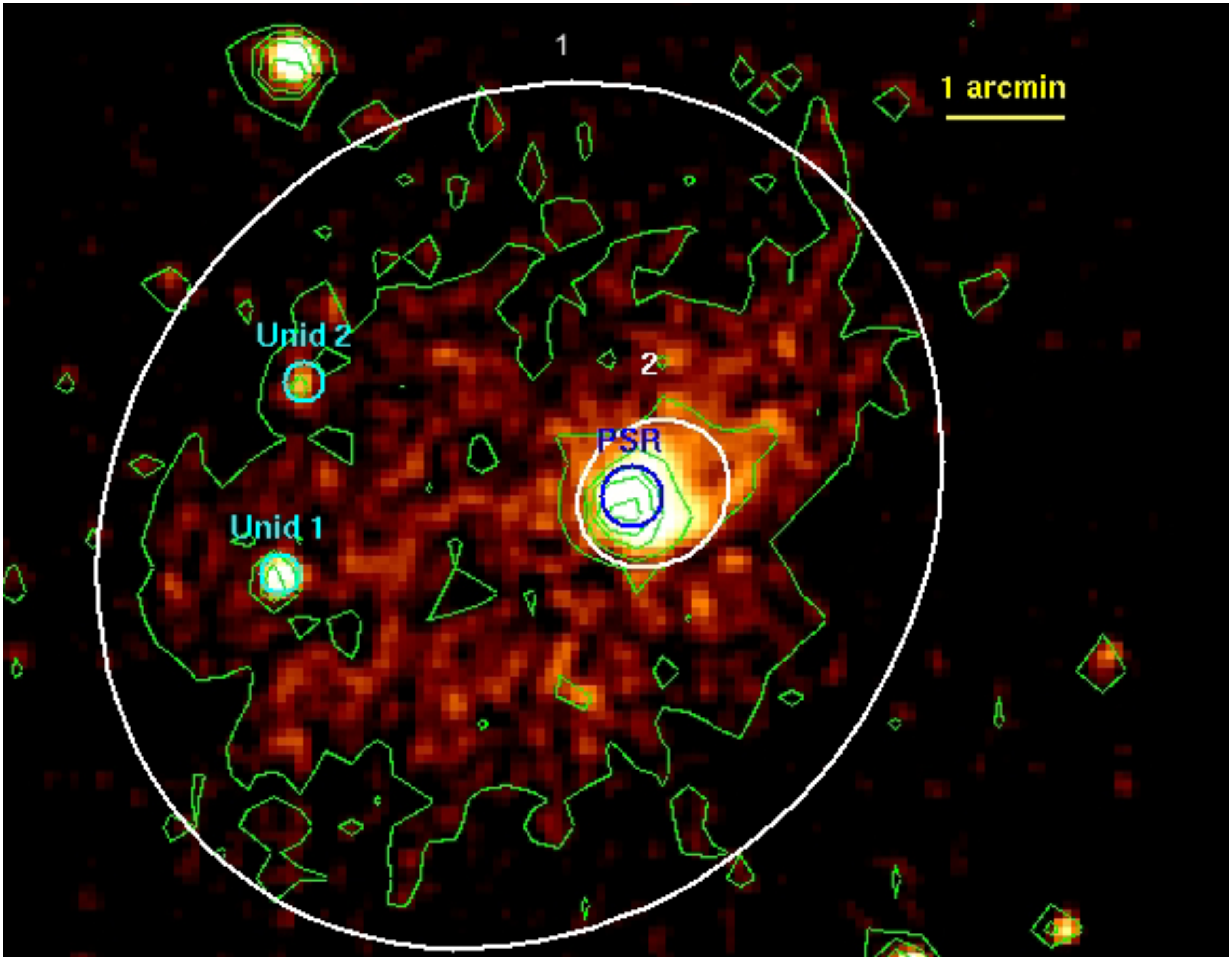
X-ray menu

- No observation
- Exploratory Obs.
- Good spectral analysis
- **“ “ “ but PWN also detected**
- Excellent spectral analysis

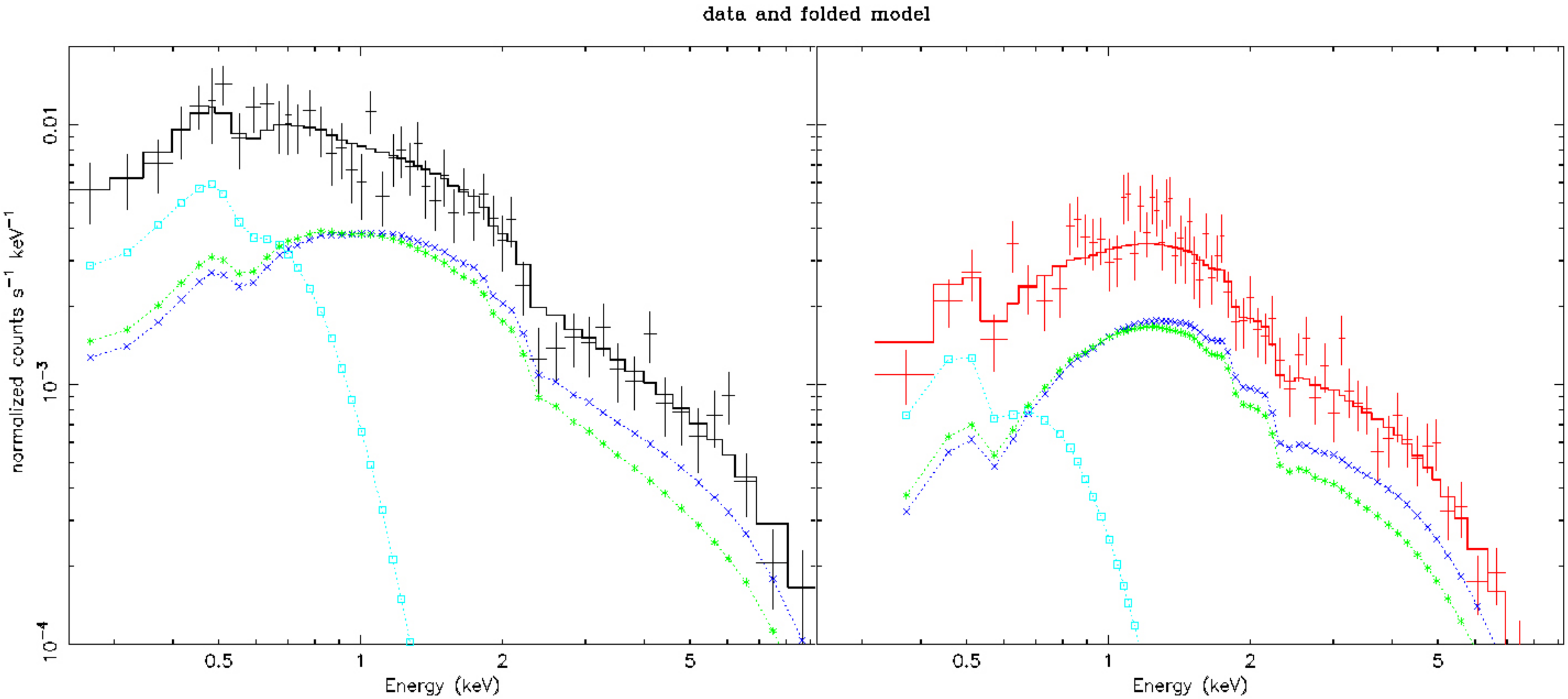
SWIFT

Chandra
XMM-Newton

CTA 1 XMM observation



CTA 1 NS spectum



pn

mos

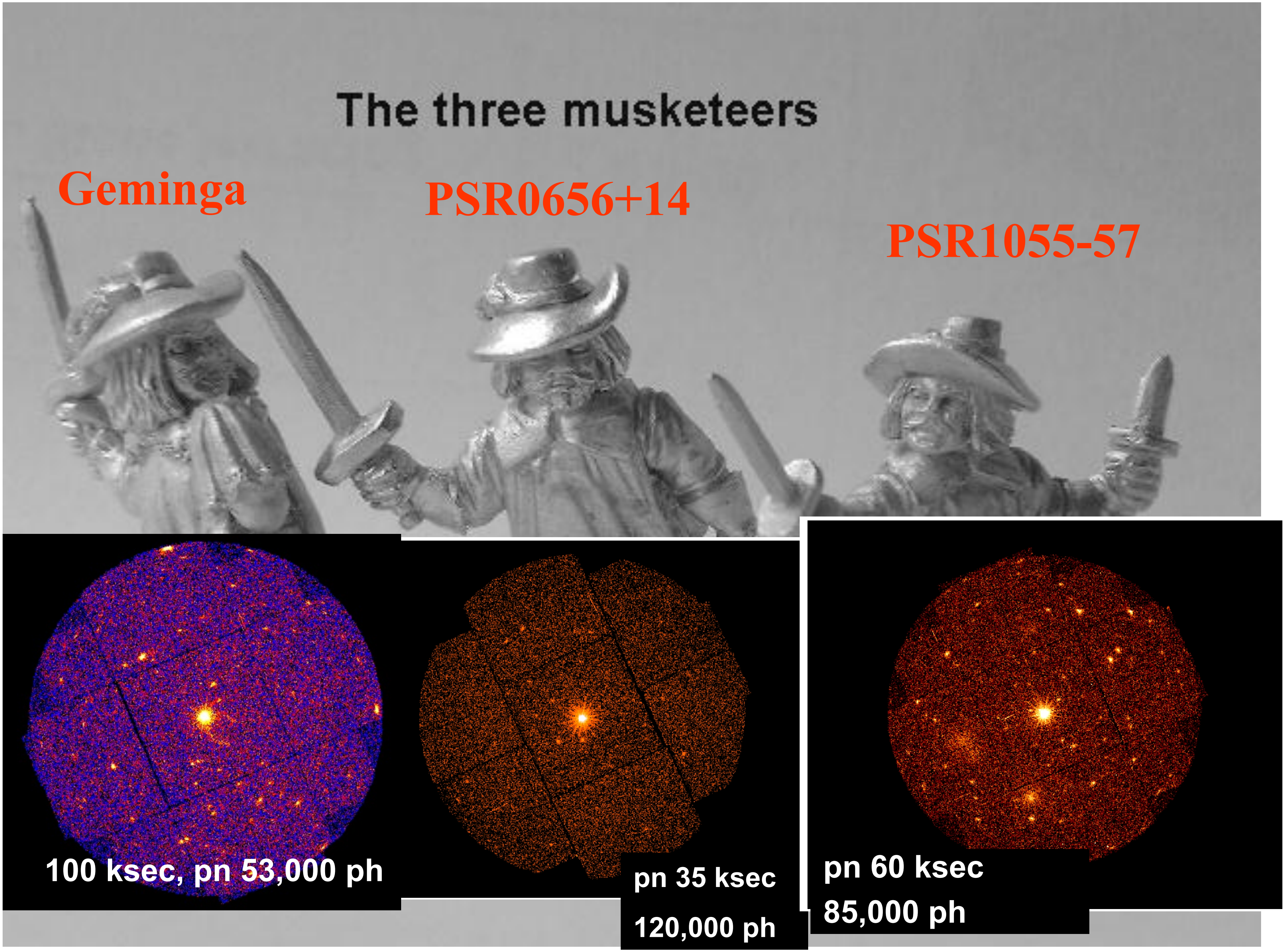
NS thermal + NS power law + PWN power law

X-ray menu

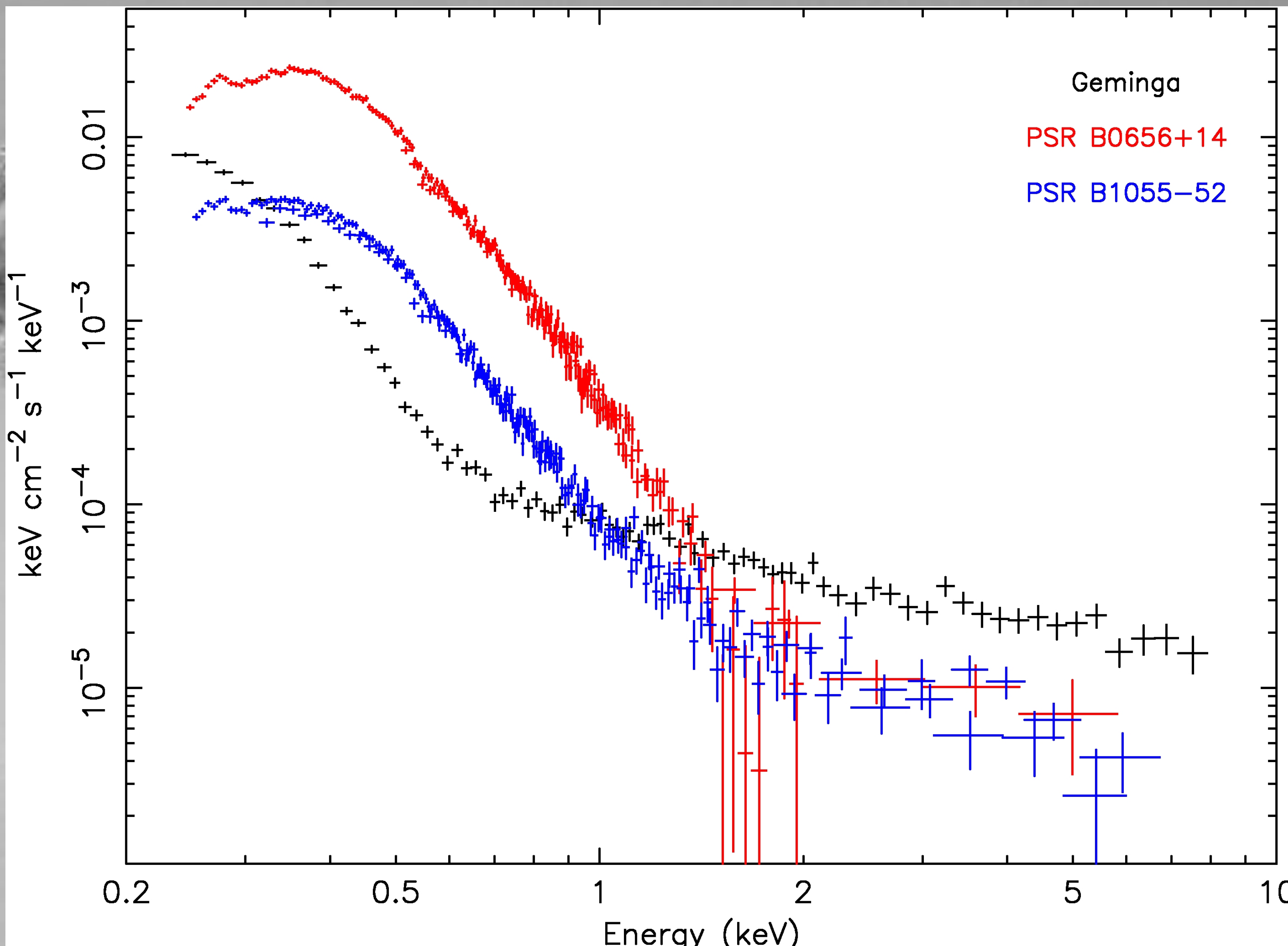
- No observation
- Exploratory Obs.
- Good spectral analysis
- " " " but PWN also detected
- **Excellent spectral analysis**

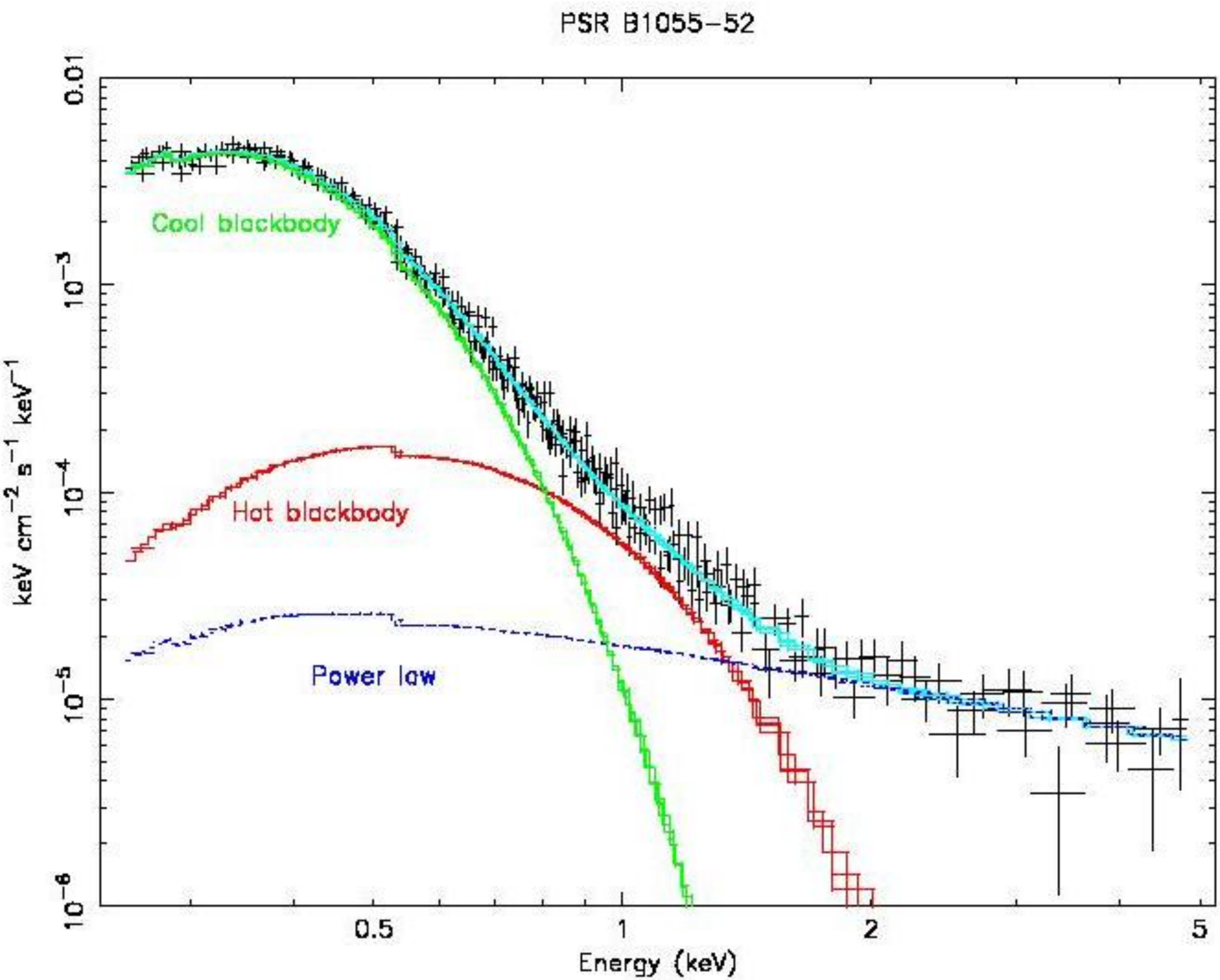
SWIFT

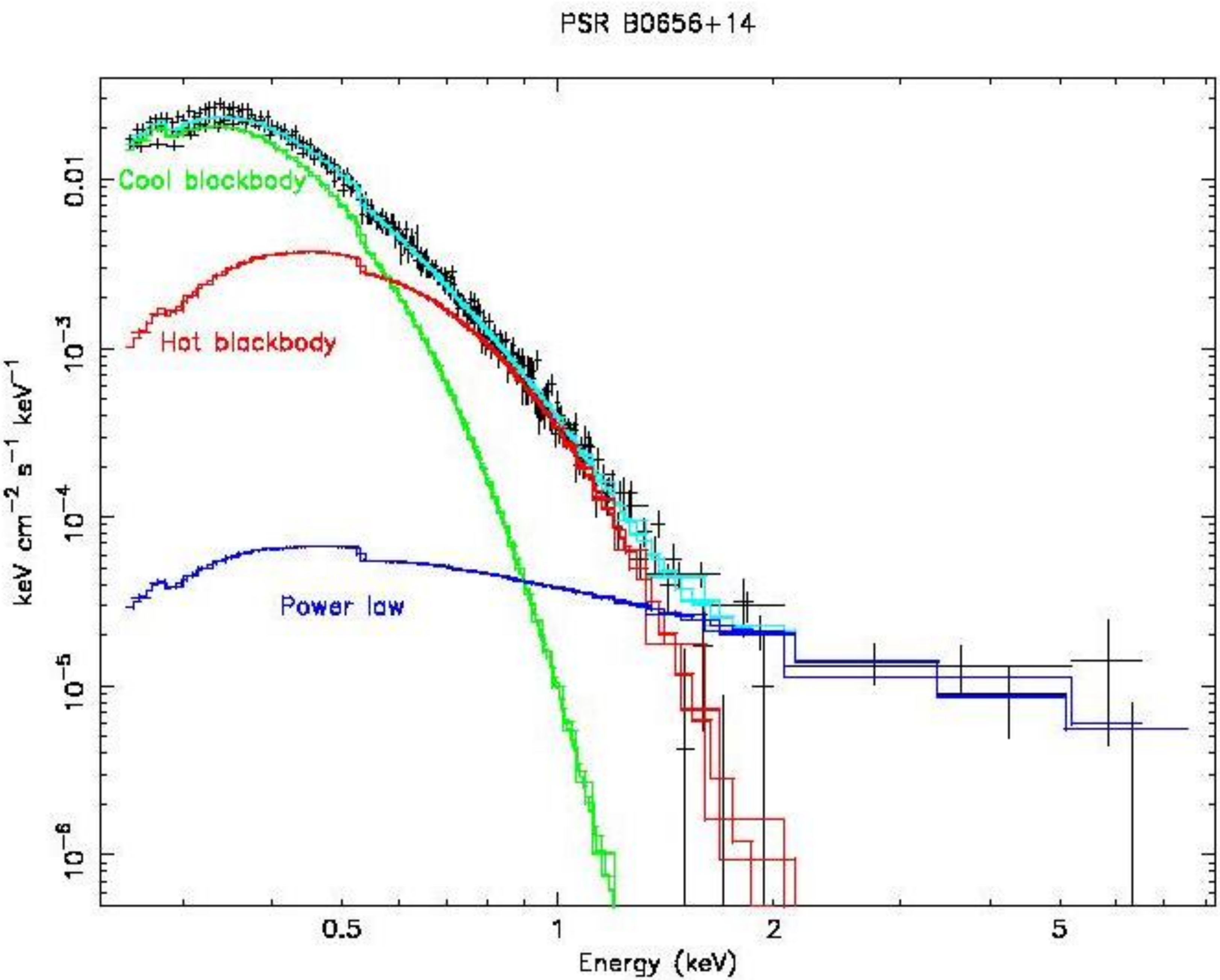
Chandra
XMM-Newton

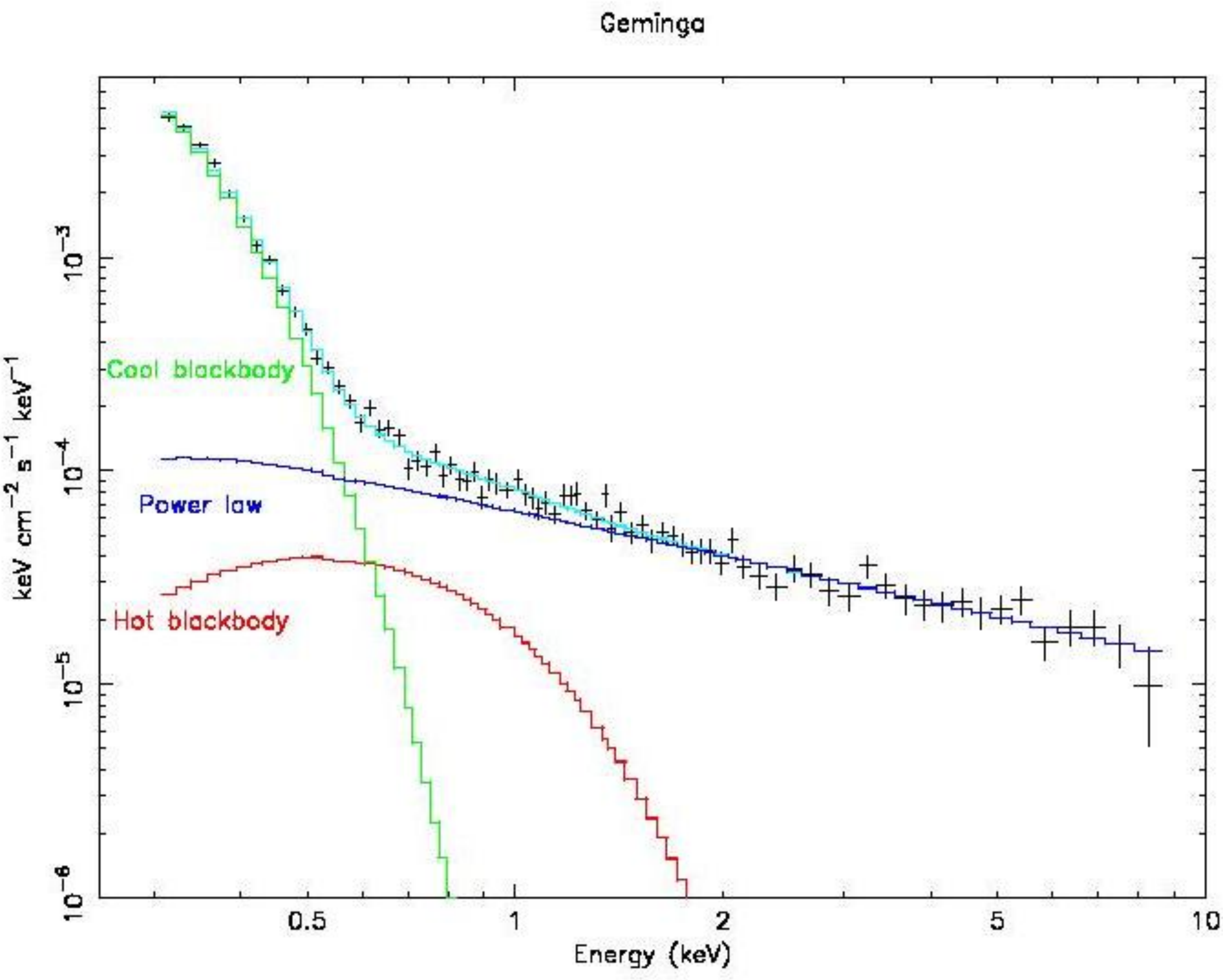

The three musketeers
Geminga
PSR0656+14
PSR1055-57
100 ksec, pn 53,000 ph
pn 35 ksec
120,000 ph
pn 60 ksec
85,000 ph

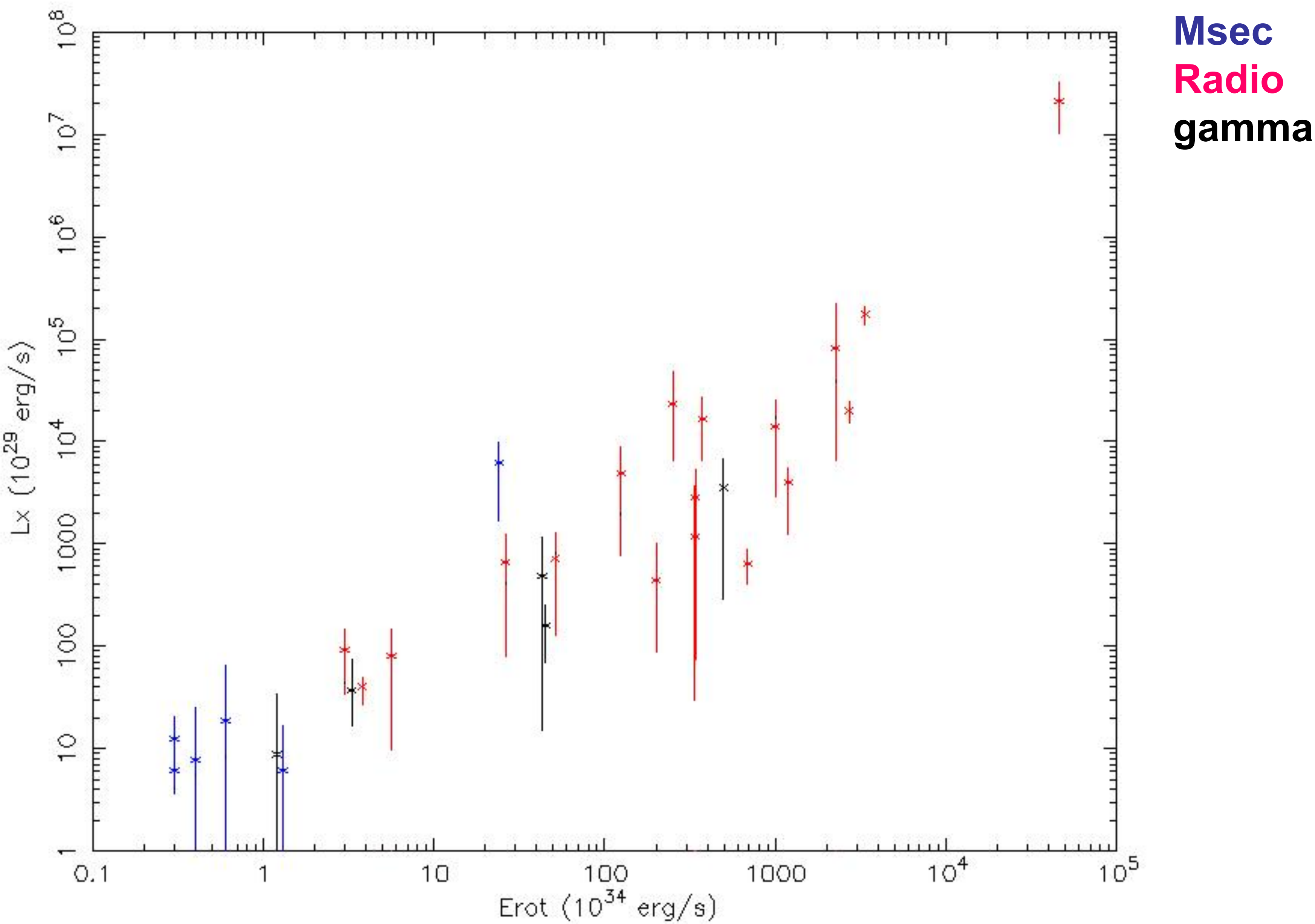
The three musketeers



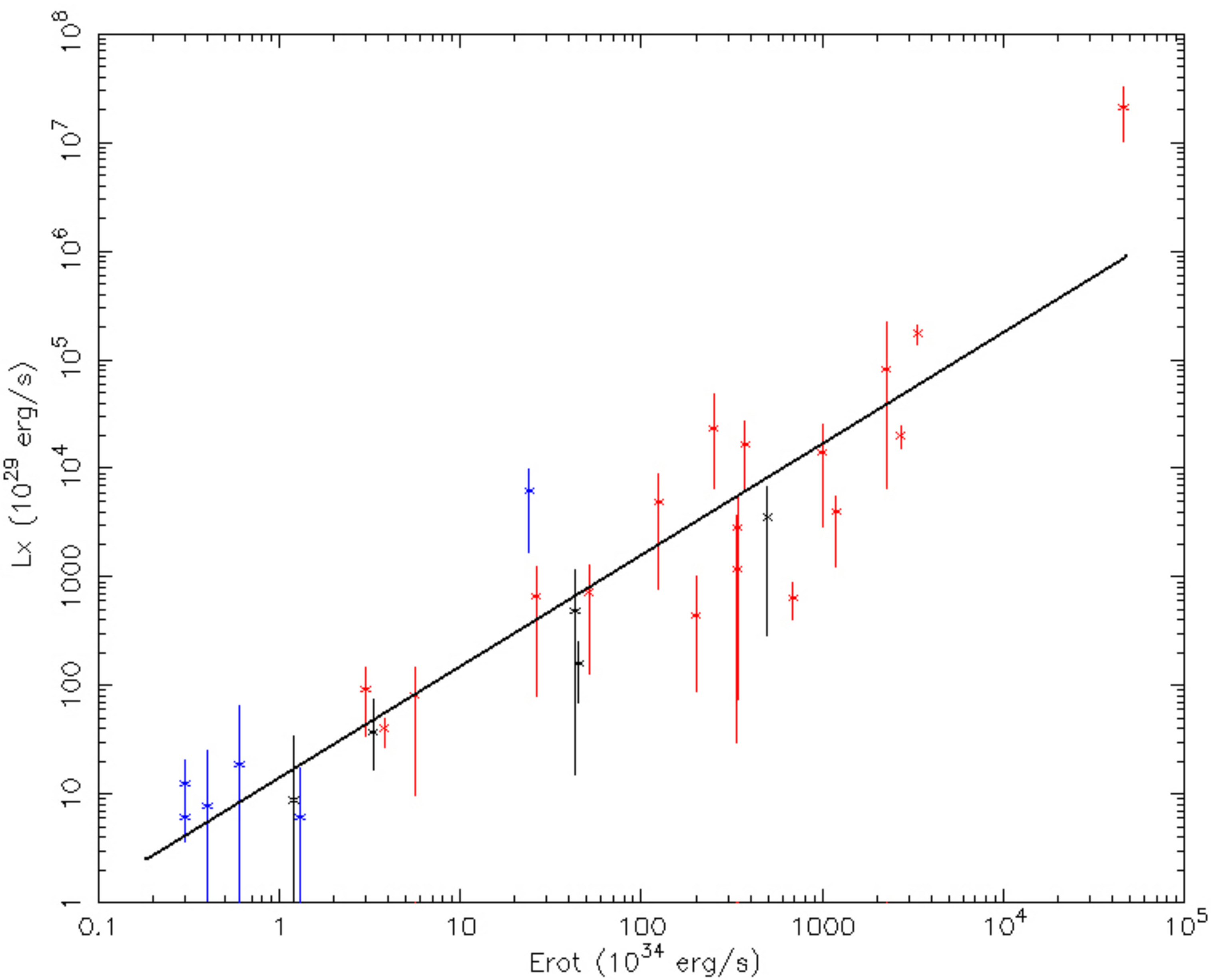

PSR B1055-52
Cool blackbody
Hot blackbody
Power law
keV cm^{-2} s^{-1} keV^{-1}
0.01
10^{-3}
10^{-4}
10^{-5}
10^{-6}
0.5
1
2
5
Energy (keV)


PSR B0656+14
Cool blackbody
Hot blackbody
Power law
keV cm^{-2} s^{-1} keV^{-1}
0.01
10^{-3}
10^{-4}
10^{-5}
10^{-6}
0.5
1
2
5
Energy (keV)

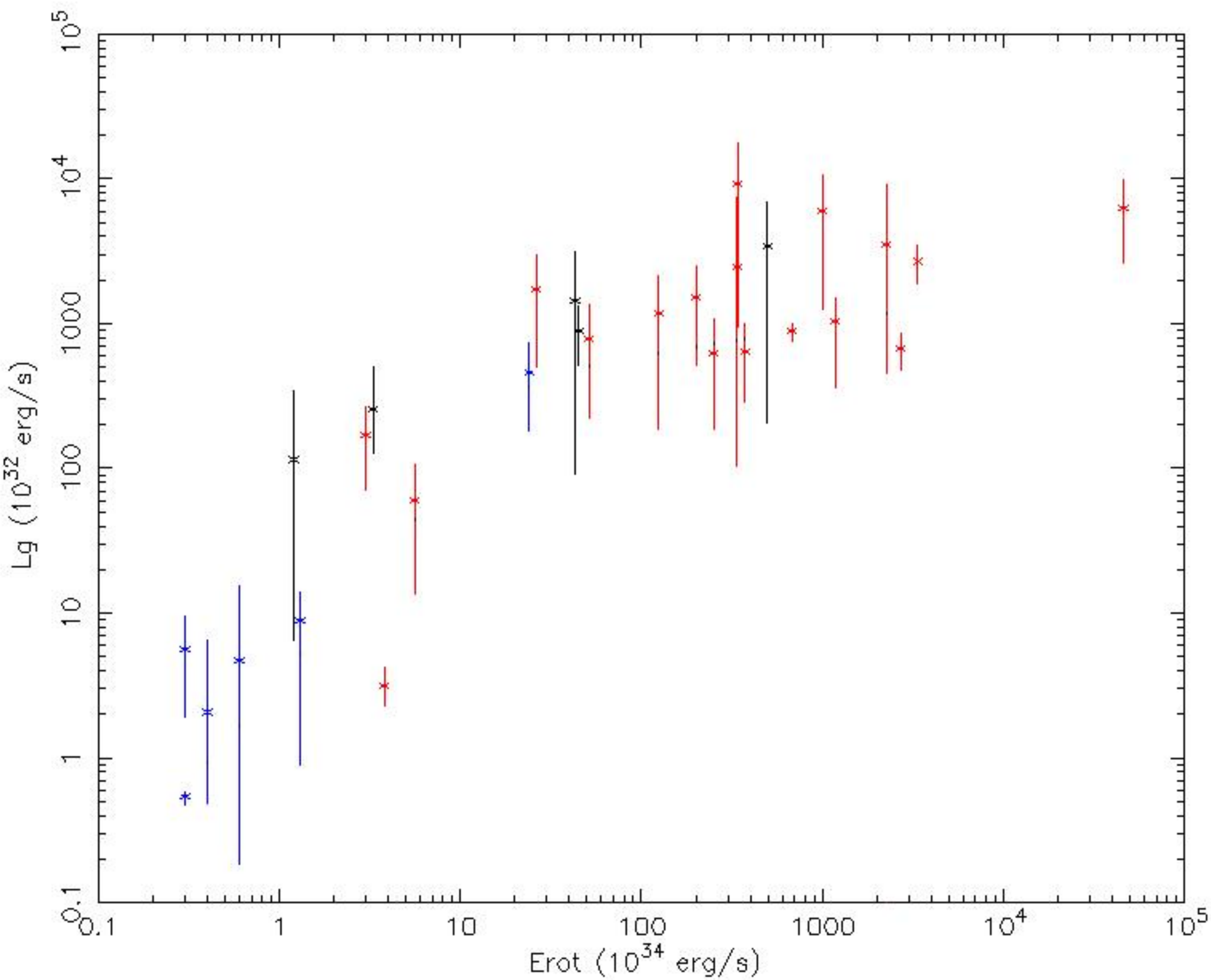

Geminga
Cool blackbody
Power law
Hot blackbody
keV cm^{-2} s^{-1} keV^{-1}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
0.5
1
2
5
10
Energy (keV)



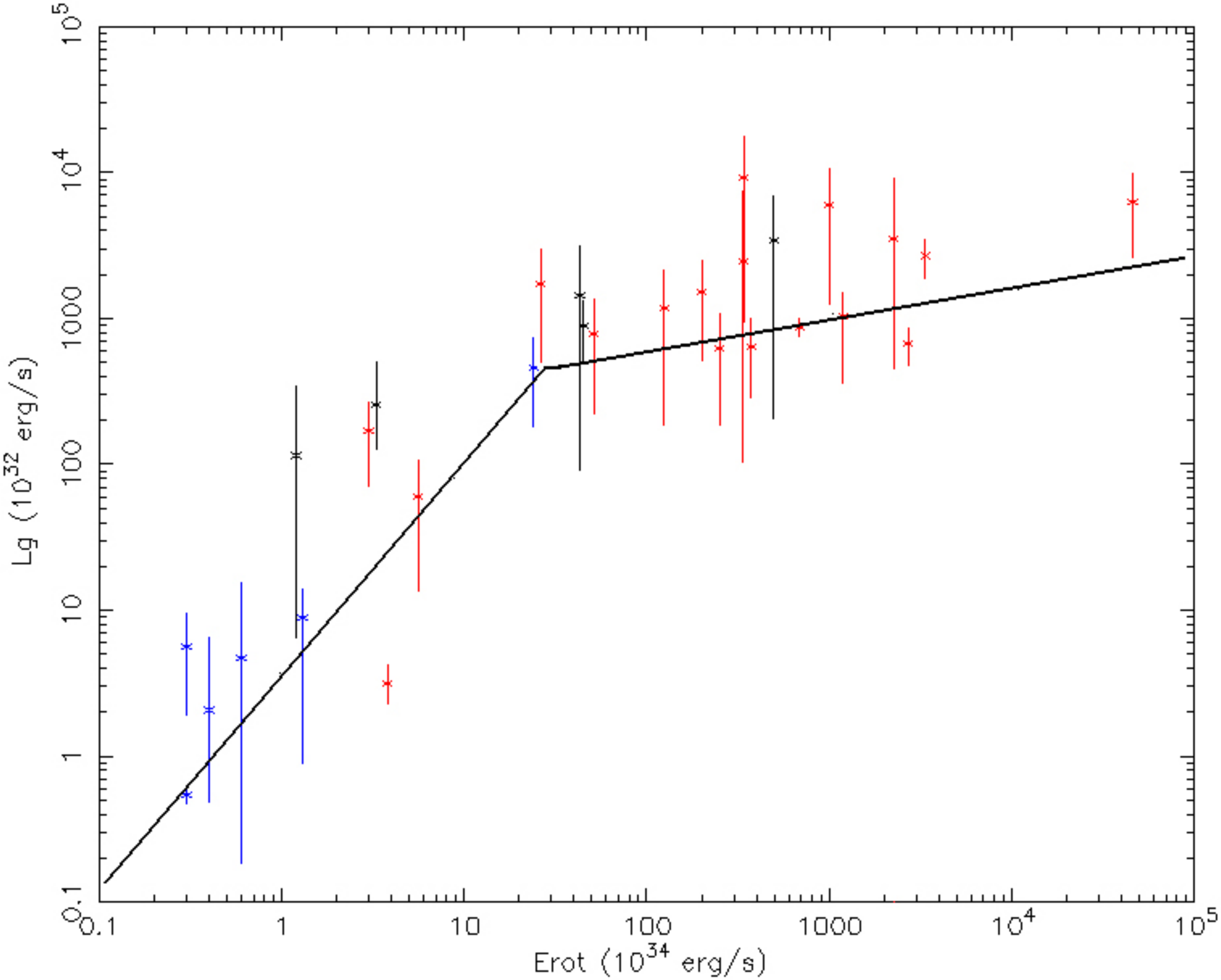
Lx (10^{29} erg/s)
Erot (10^{34} erg/s)
0.1
1
10
100
1000
10^4
10^5
1
10
100
1000
10^4
10^5
10^6
10^7
10^8
Msec
Radio
gamma



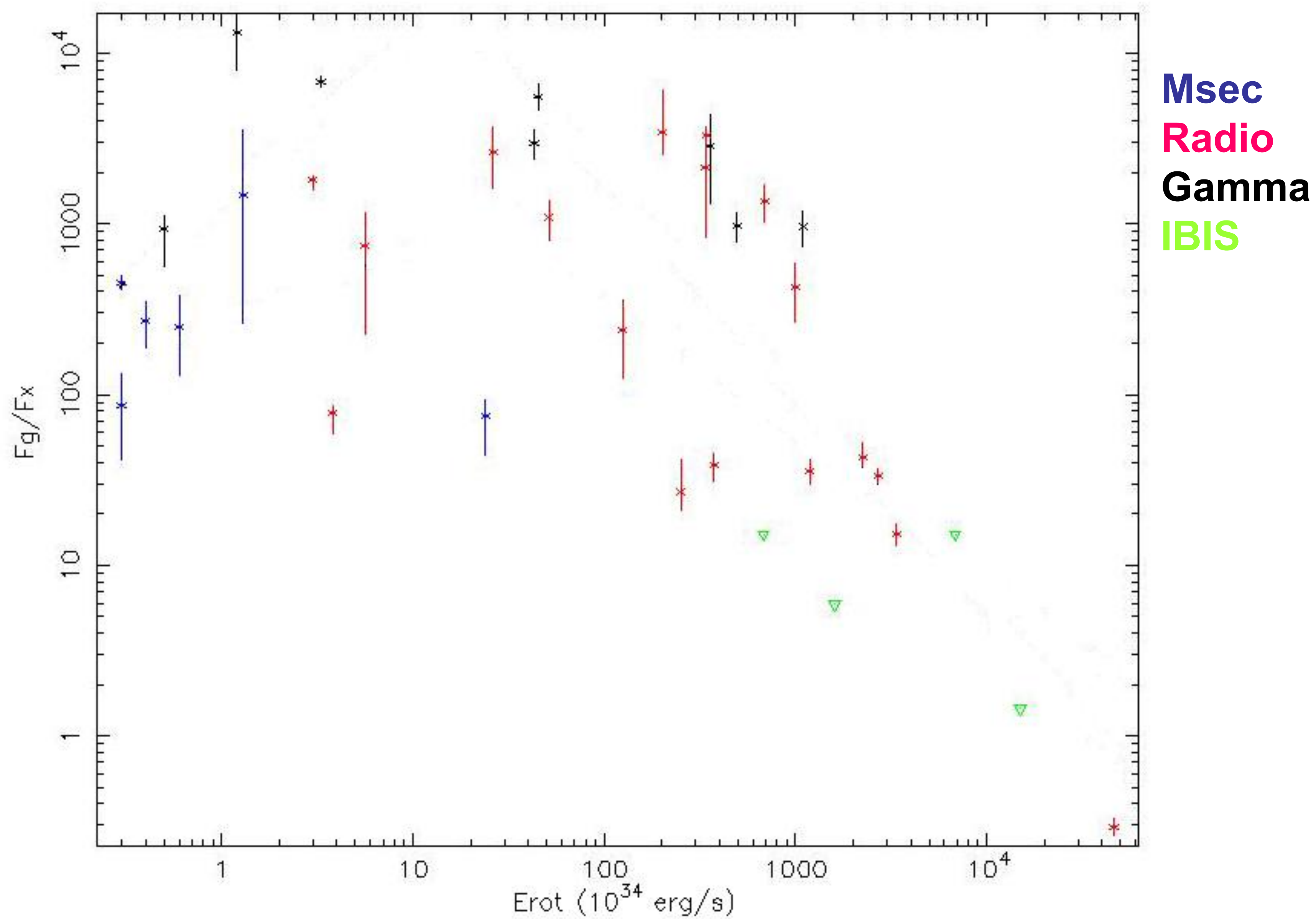
Lx (10^{29} erg/s)
Erot (10^{34} erg/s)
0.1
1
10
100
1000
10^4
10^5
1
10
100
1000
10^4
10^5
10^6
10^7
10^8



Msec
Radio
gamma



Lg (10^{32} erg/s)
Erot (10^{34} erg/s)
0.1
1
10
100
1000
10^4
10^5



Msec
Radio
Gamma
IBIS
Fg/Fx
Erot (10^34 erg/s)
1
10
100
1000
10^4

F_{gamma}/F_{x} vs E_{rot}

- Large scatter for NSs with similar Erot
  (note that the ratio does not depend on distance uncertainty)
- Radio loud pulsars seem to have lower ratio than radio quiet ones (i.e. radio quiet are underluminous in X-rays).
- Observational biases should also be considered
- More to come- stay tuned