Magnetar High-Energy Emission

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Magnetars are magnetically powered neutron stars

- ~16 are discovered to date – two recently (2008-2009) – only 2 extragalactic sources
- Discovered in X-rays; radio, optical and IR observations
- $P = [2\text{-}12]$ s, $\dot{P} \sim [10^{-11}\text{-} 10^{-13}]$ s/s
- $\tau_{spindown}(P/2\dot{P})$ = 2-220 kyrs *(characteristic age)*
- B~[1-10]x10^{14} G (mean surface dipole field: $3.2\times10^{19}\sqrt{P\dot{P}}$)
- Bright X-ray sources, $L_X \sim 10^{34-36}$ erg/s , >> rotational E-loss $\dot{E}$
- Very soft X-ray spectra E<10 keV: kT~0.5 keV + Γ~3-4
- No evidence for a companion
- ~ 4 SNR associations

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Magnetars: Soft Gamma-ray Repeaters SGRs and
Anomalous X-ray Pulsars AXPs

Reasons for including this lecture in this Fermi workshop:

- The Fermi Gamma-Ray Burst Monitor (GBM) triggered over the first 17 month of operations on 4 SGRs, of which two are new
- The last one, (candidate) SGR 0418+5729, was discovered by the GBM (van der Horst et al. 2009, 2010)

→ The GB Monitor is also a good SGR Monitor

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Magnetars: Soft Gamma-ray Repeaters SGRs and Anomalous X-ray Pulsars AXPs

Reasons for including this lecture in this Fermi workshop:

- INTEGRAL discovery of luminous non-thermal (pulsed) persistent hard X-ray emission from AXPs up to at least 200 keV
- INTEGRAL discovery of weak persistent hard X-ray emission from SGRs

→ The GBM will reveal the extension of the AXP high-energy spectra above 200 keV, but, till what energy?

→ Will the LAT detect high-energy gamma rays from magnetars?

→ Why is this interesting?

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Outline

- Comparison magnetars v.s. rotation-powered pulsars
- Short history and characteristics of SGRs
- Short history and characteristics of AXPs
- Non-thermal persistent emission from AXPs

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Rotation-powered pulsars: parameters, assuming magnetic dipole braking

- Period P
- Period derivative $\dot{P}$
- Rotational energy loss $\dot{E} = I\Omega\dot{\Omega}$

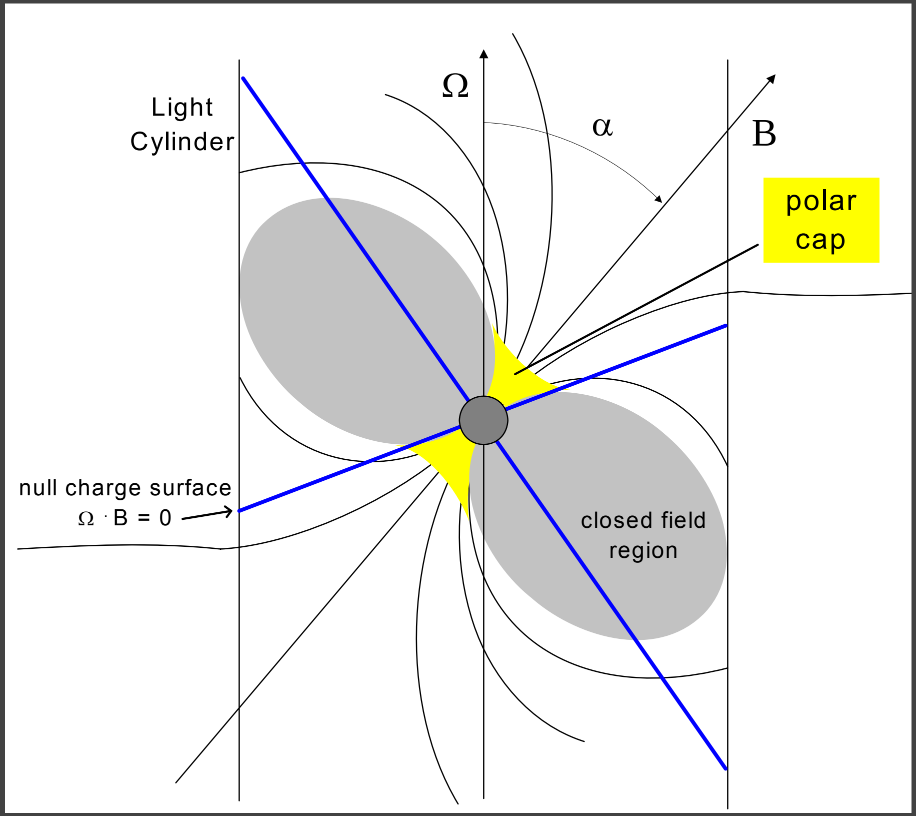
  I moment of inertia, $\boldsymbol{\Omega = 2\pi/P}$
- Characteristic age $\tau_c = P/2\dot{P}$
- Magnetic field strength,

  1) over neutron star surface

  $B_S = 3.2 \times 10^{19} (P\dot{P})^{1/2}$

  2) at pole

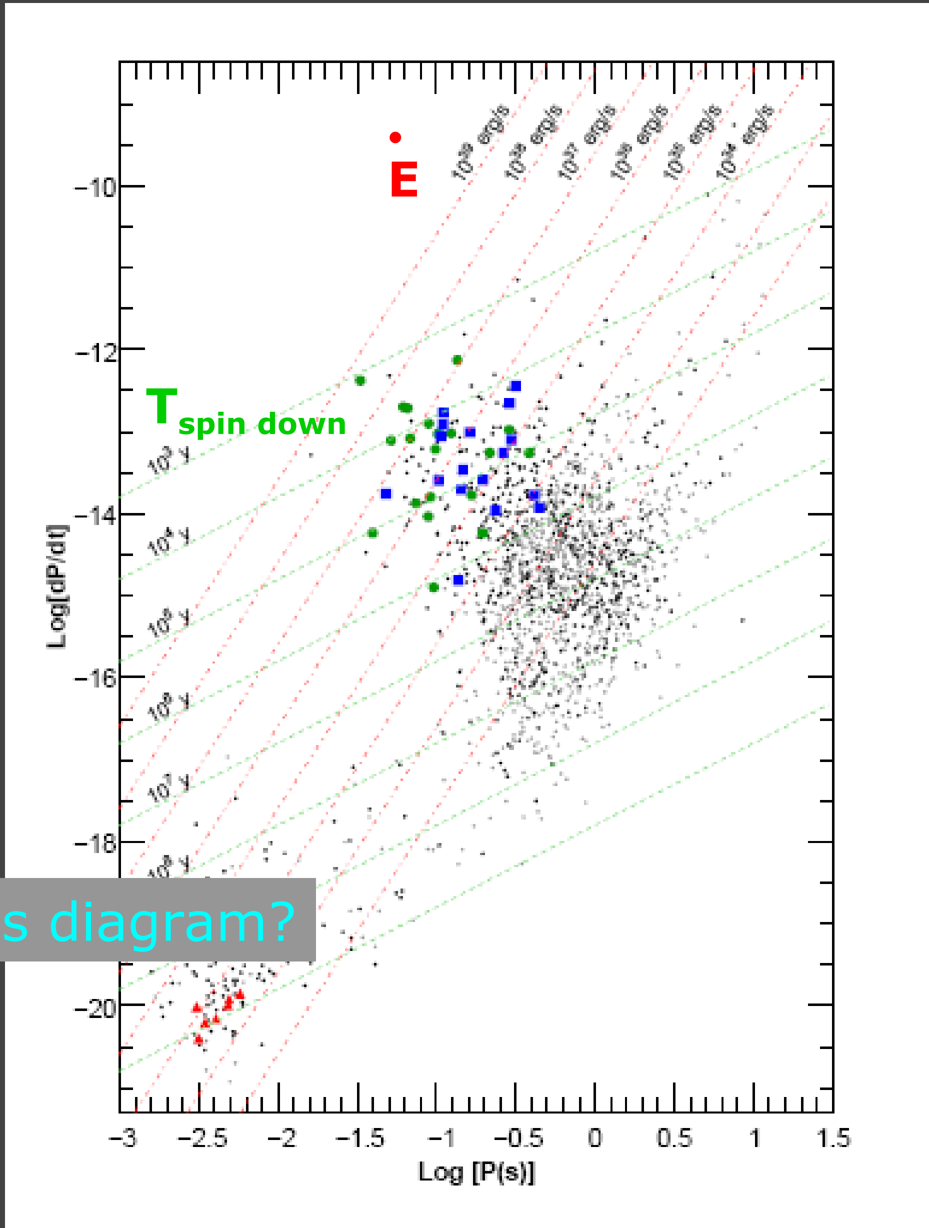
  $B_0 = 6.4 \times 10^{19} (P\dot{P})^{1/2}$



1st Fermi LAT catalog of Gamma-ray Pulsars, rotation-powered pulsars

Abdo et al. (2009)

Colored symbols represent pulsars detected by Fermi / LAT



Where do magnetars fit into this diagram?

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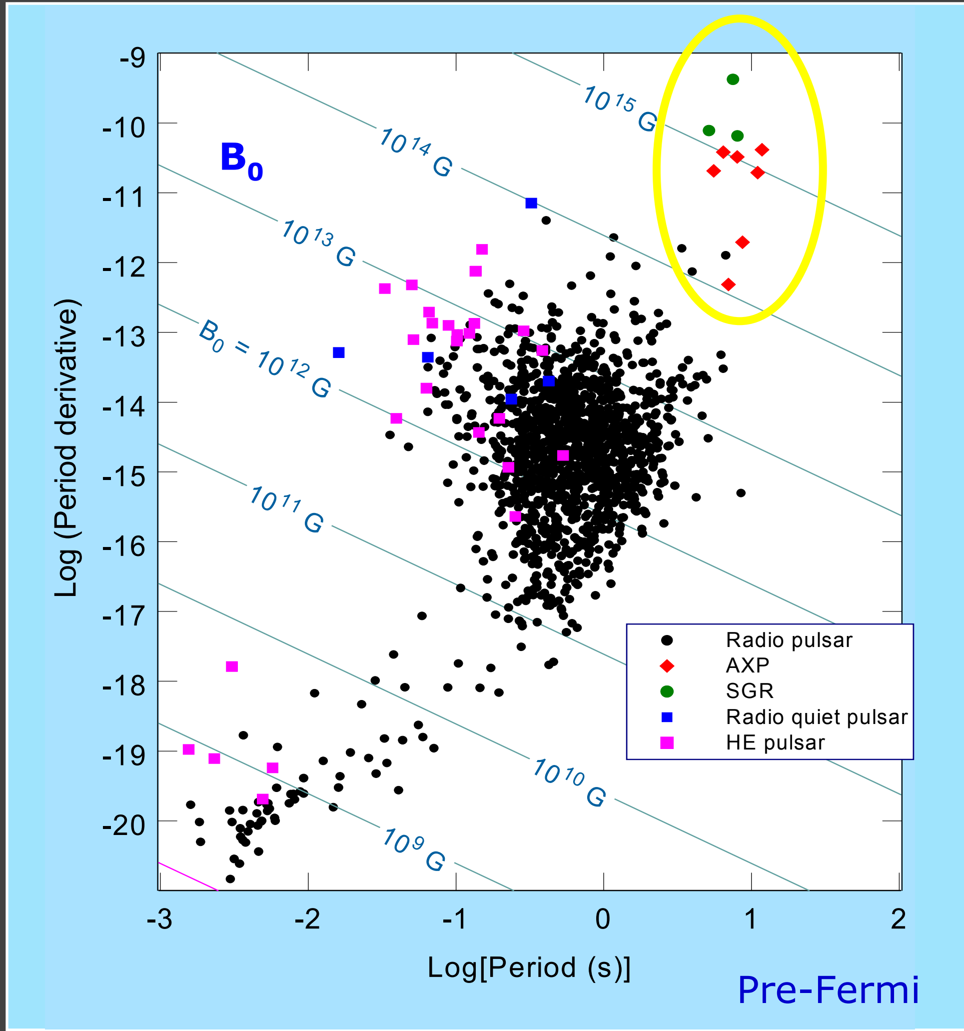
Rotation-Powered Pulsars and Magnetars:

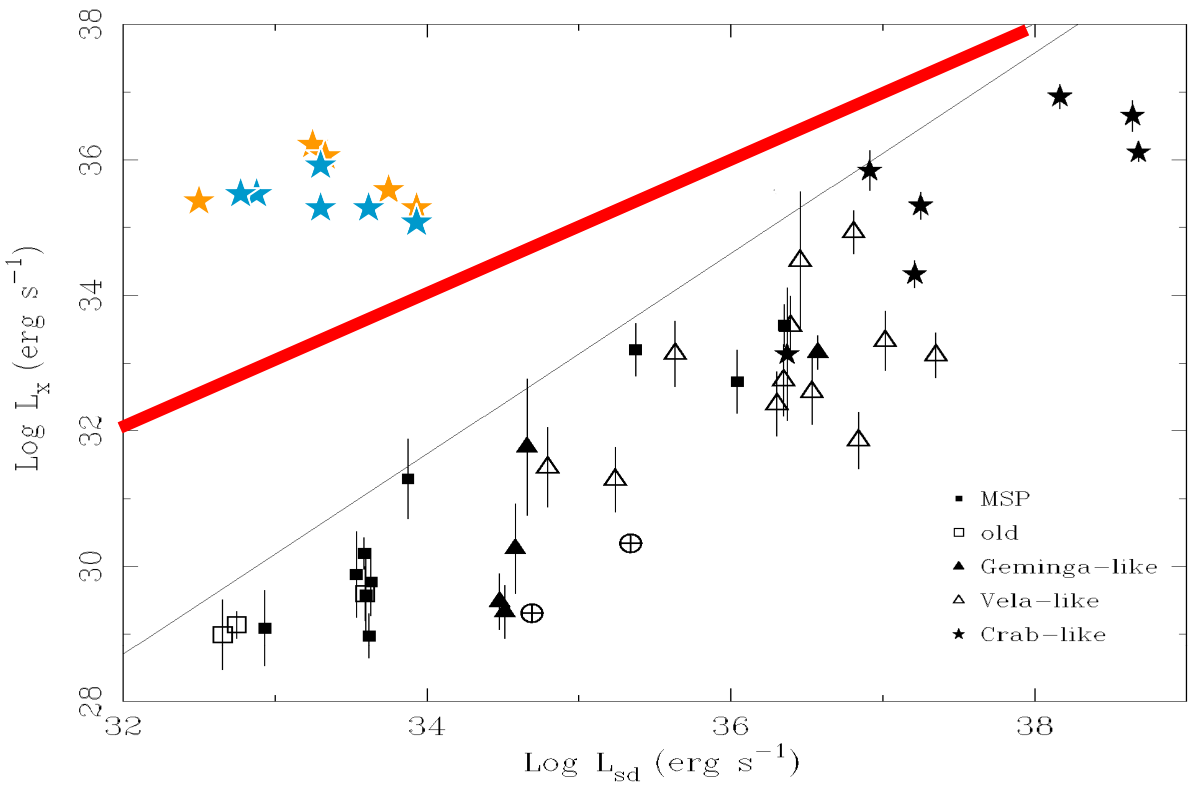
- ~ 40 X-ray and γ-ray rotation-powered pulsars (pre-Fermi)
- Magnetars: AXPs + SGRs



Extreme B fields:

- AXPs & SGRs $10^{14} – 10^{15}$ G (young)
- Millisecond pulsars $10^{8} – 10^{10}$ G (old "recycled" pulsars)

Persistent X-ray emission SGRs and AXPs: $L_x >> L_{spindown}$

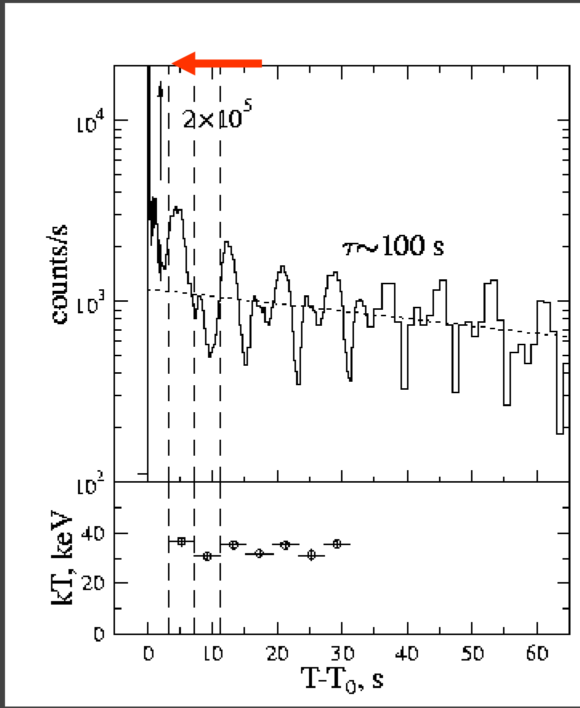


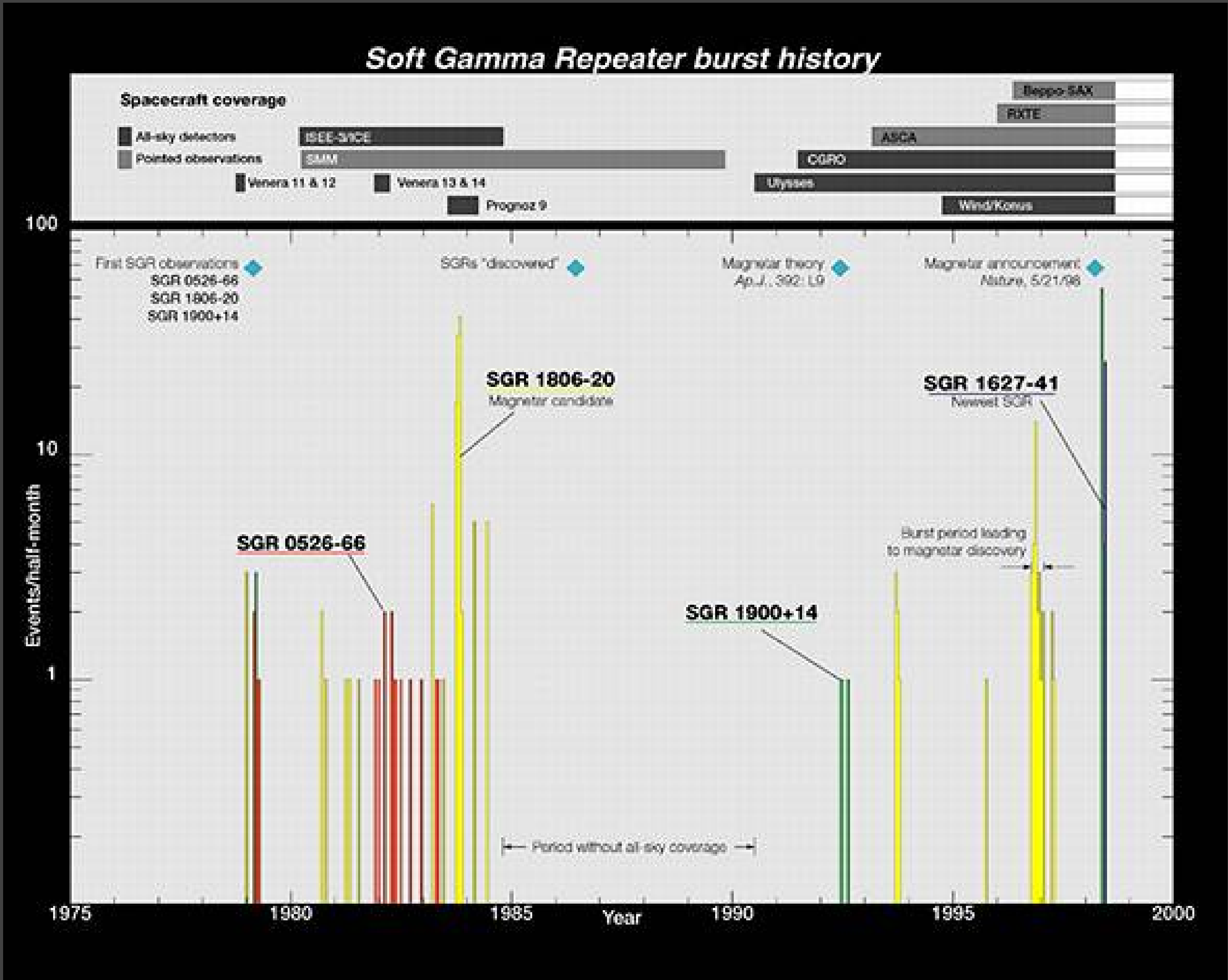
(Possenti^{+} 2002)

Short history Soft Gamma-Ray Repeaters

- First SGR detected with the "**March-5-1979** event", announced as a Gamma-Ray Burst
- Detected by several space craft: triangulation pointed to position in LMC
- Discovery of pulses in tail, plus additional burst from same direction: SGR 0526-66

Mazets et al. 1979




Soft Gamma Repeater burst history
Spacecraft coverage
All-sky detectors
Pointed observations
ISEE-3/ICE
SMM
Venera 11 & 12
Venera 13 & 14
Prognoz 9
Beppo SAX
RXTE
ASCA
CGRO
Ulysses
Wind/Konus
First SGR observations
SGR 0526-66
SGR 1806-20
SGR 1900+14
SGRs "discovered"
Magnetar theory
Ap.J., 392: L9
Magnetar announcement
Nature, 5/21/98
SGR 1806-20
Magnetar candidate
SGR 1627-41
Newest SGR
SGR 0526-66
Burst period leading
to magnetar discovery
SGR 1900+14
Period without all-sky coverage
Events/half-month
100
10
1
1975
1980
1985
Year
1990
1995
2000

Short history Soft Gamma-Ray Repeaters, cntd

- 1985-1986 : Bursts appear to come from the plane of the Milky Way
- 1992: Magnetar theory (Duncan & Thompson) ←
- 1998: 7.8-s period reported in persistent emission of SGR 1806-20 with p-dot in RXTE data by Kouviliotou et al.:

  Nature paper : SGRs are magnetars

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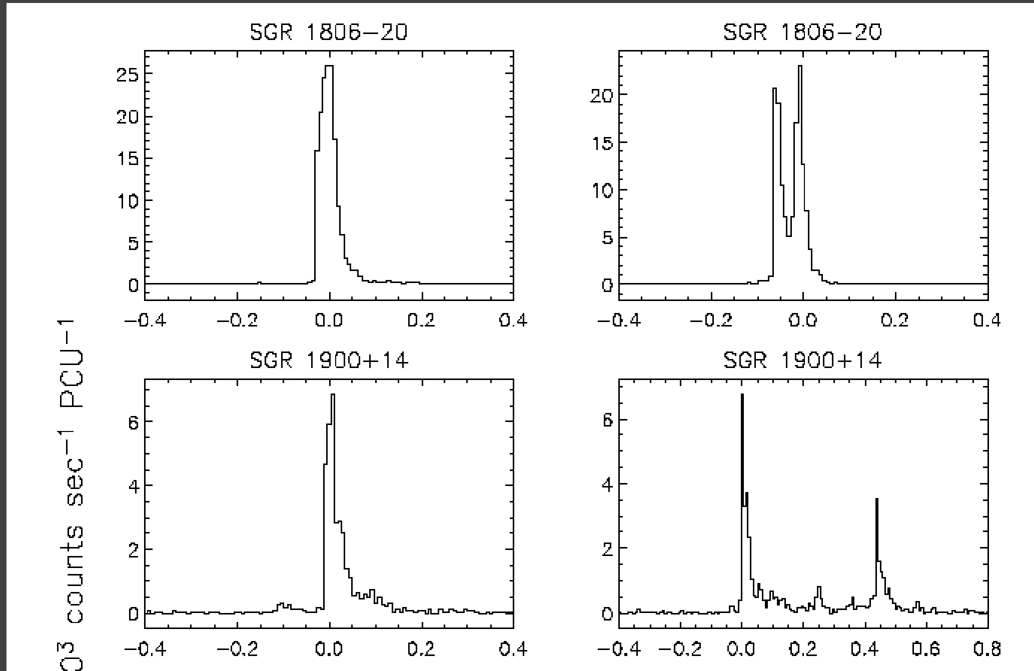
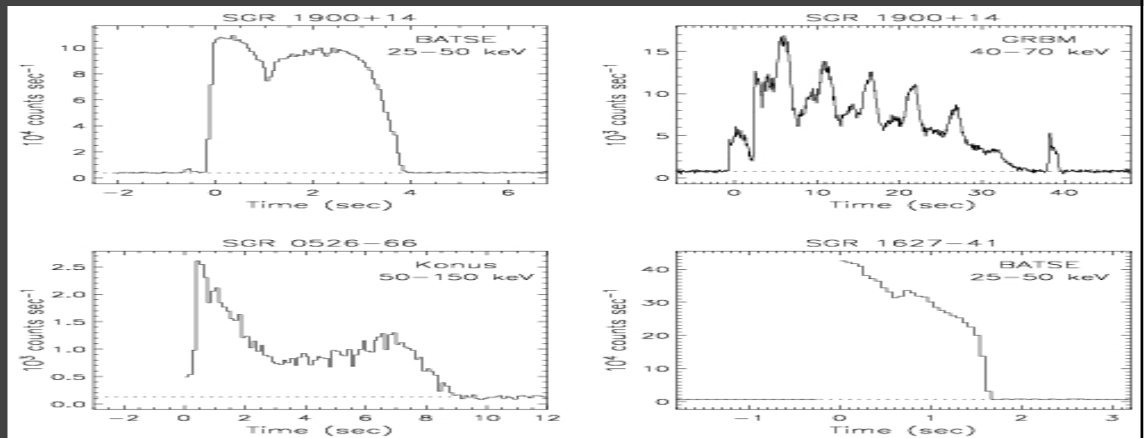
SGR bursts

(for a review see Woods & Thompson 2004)



Short bursts

- the most common
- they last ~0.1s
- peak ~10^{41} ergs/s
- soft γ-rays thermal spectra



Intermediate bursts

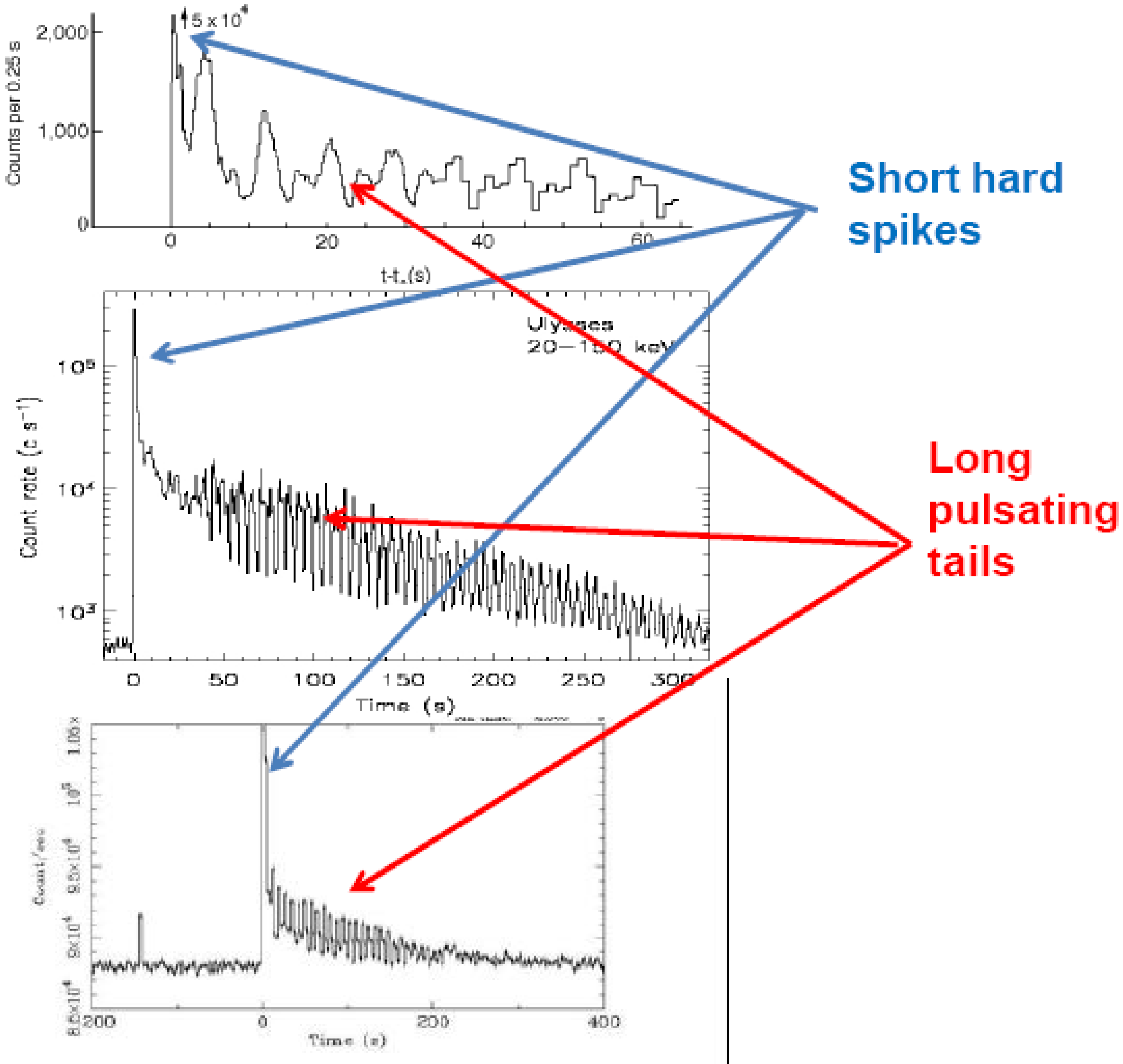
- they last 1-40 s
- peak ~10^{41}-10^{43} ergs/s
- abrupt on-set
- usually soft γ-rays thermal spectra

The three famous Giant Flares from SGRs:

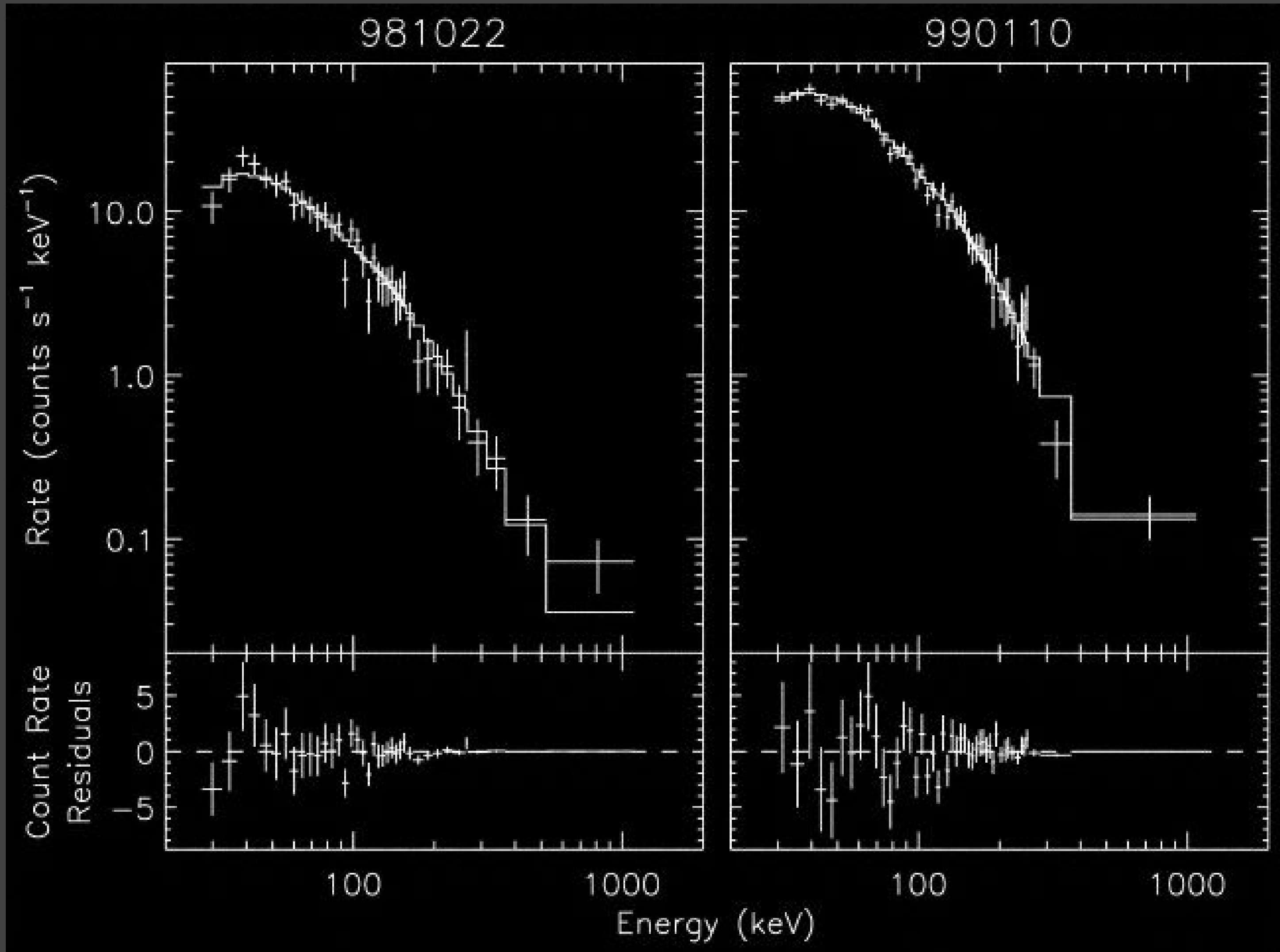
1979 March 5
SGR 0526-66
L_{peak} ~ 4 10^{44} erg/s
E_{TOT} ~ 5 10^{44} erg
(Mazets et al. 1979)

1998 August 27
SGR 1900+14
L_{peak} > 8 10^{44} erg/s
E_{TOT} > 3 10^{44} erg
(Hurley et al. 1999)

2004 December 27
SGR 1806-20
L_{peak} ~ 2-5 10^{47} erg/s
E_{TOT} ~ 2-5 10^{46} erg
(Palmer et al. 2005)



SGR Spectra for burst emission

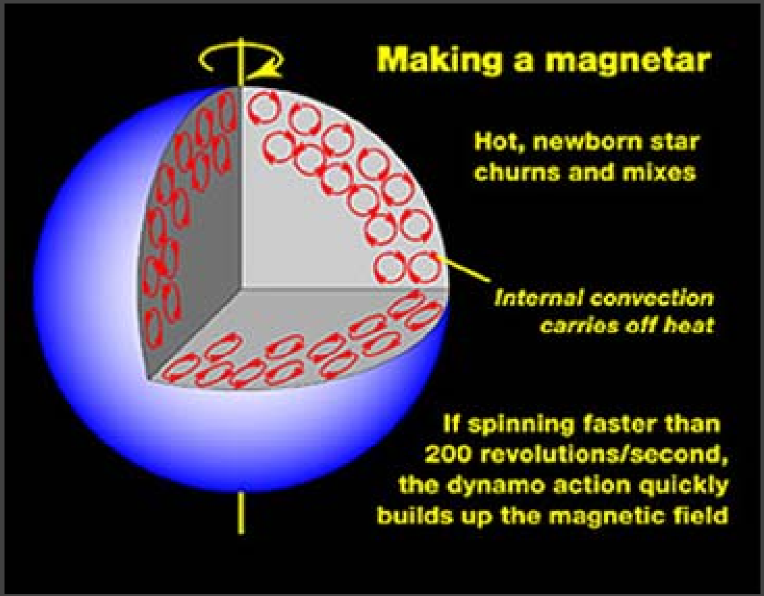


Soft spectra with e.g. Bremstrahlung spectrum ~30 keV

Magnetar model, Duncan & Thompson 1992; Thompson & Duncan 1995

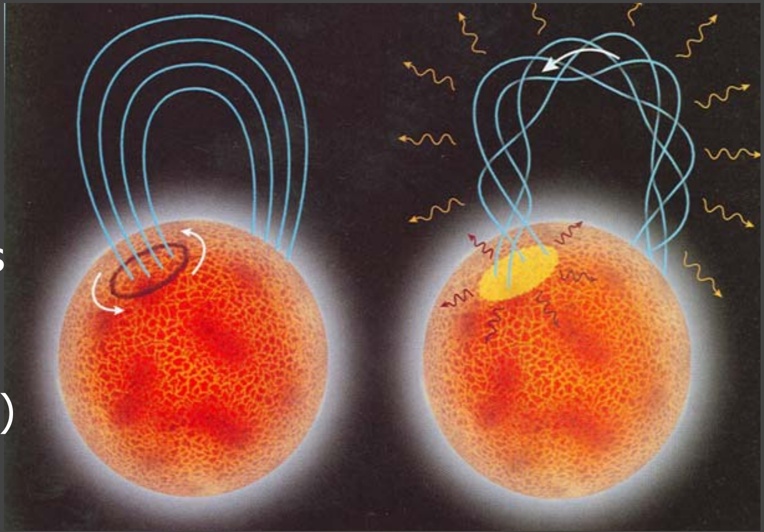
- If a newborn neutron star spins fast enough (P ~few ms) violent convection can amplify the magnetic field efficiently (dynamo action) up to 10^{16-17} Gauss during the first 10-30 s.

  (10% of kinetic energy transferred to B-field of 10^{12-13} Gauss → 10^{15-16} Gauss)



- Huge internal field evolves diffusively over lifetimes of ~10,000 y, thereby

  a) heating the core and deep crust (keep magnetars hot)
  b) elastical stresses in the crust too large, and the lattice responds in an irreversible manner: crust fractures; magnetically driven star quakes "glitches", outbursts
  c) strong toroidal internal magnetic field causes twist of external poloidal field (footpoint motion)



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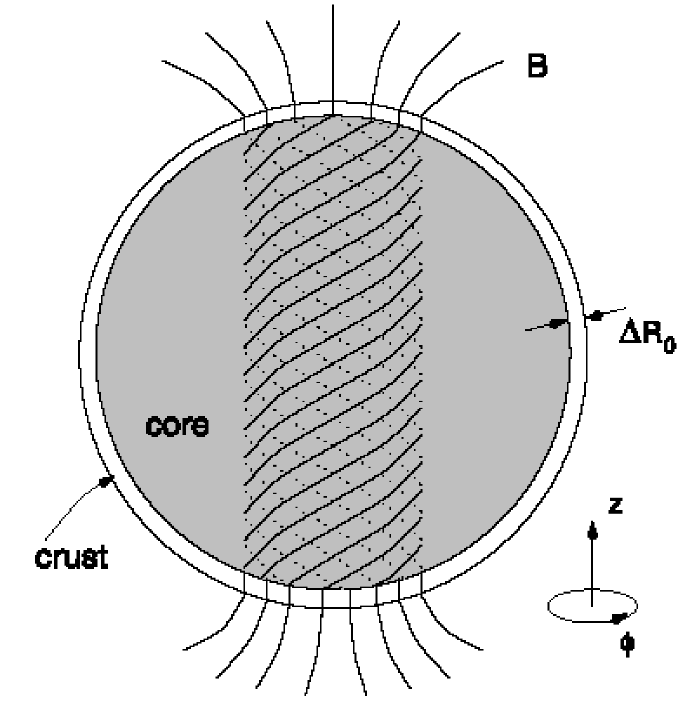
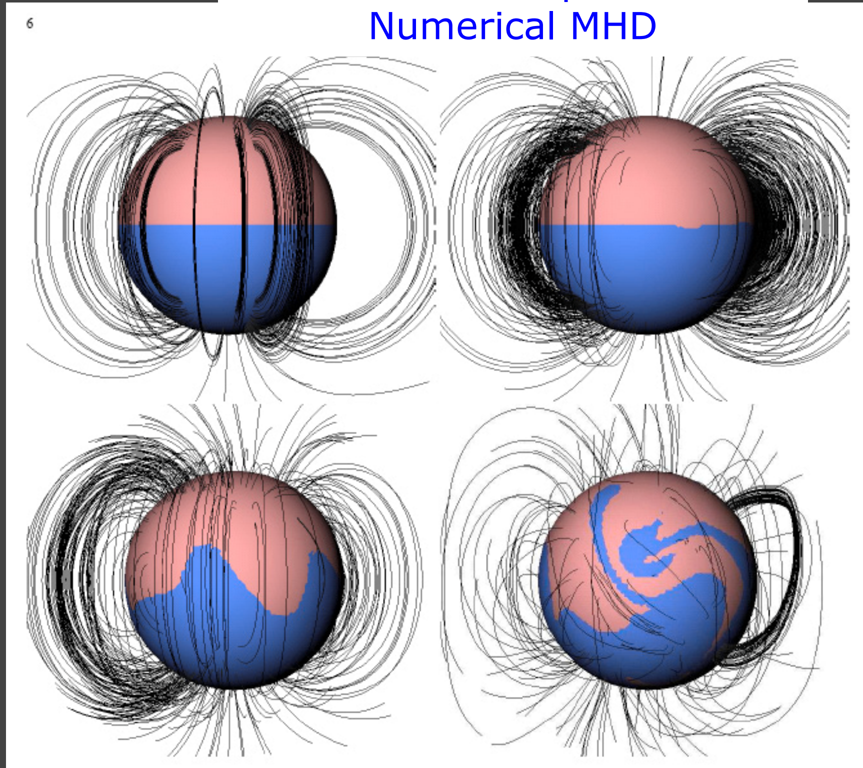
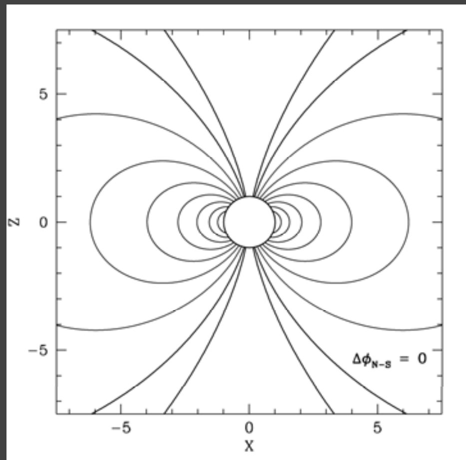


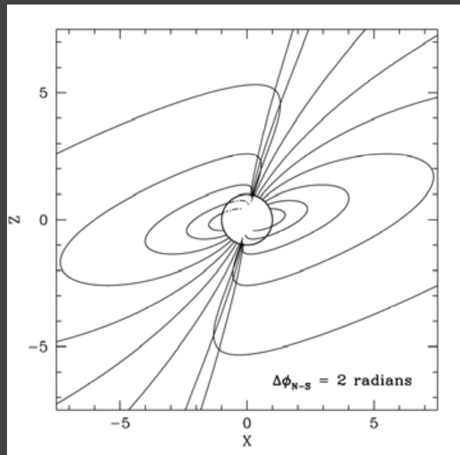
Braithwaite & Spruit 2006
Numerical MHD



Thompson & Duncan 1995, 1996

Thompson, Lyutikov & Kulkarni 2002





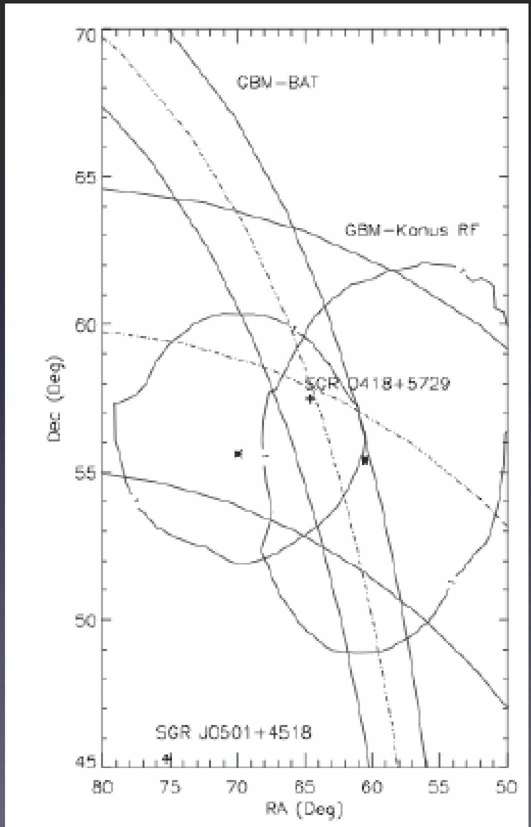
At larger distances from ns the magnetic field structure bagain dipolar. Close to the ns it is twisted of looks more like spaghetti.

GBM-FERMI detection of 2 bursts from SGR 0418+5729

DISCOVERY OF A NEW SOFT GAMMA REPEATER: SGR J0418 + 5729

A. J. van der Horst[1], V. Connaughton[2], C. Kouveliotou[3], E. Göğüş[4], Y. Kaneko[4], S. Wachter[5], M. S. Briggs[2], J. Granot[6], E. Ramirez-Ruiz[7], P. M. Woods[8], R. L. Aptekar[9], S. D. Barthelmy[10], J. R. Cummings[10], M. H. Finger[11], D. D. Frederiks[9], N. Gehrels[10], C. R. Gelino[12], D. M. Gelino[13], S. Golenetskii[9], K. Hurley[14], H. A. Krimm[10], E. P. Mazets[9], J. E. McEnery[10], C. A. Meegan[11], P. P. Oleynik[9], D. M. Palmer[15], V. D. Pal'shin[9], A. Pe'er[16], D. Svinkin[9], M. V. Ulanov[9], M. van der Klis[17], A. von Kienlin[18], A. L. Watts[17] C. A. Wilson-Hodge[3]

Draft version January 6, 2010



2 GBM bursts… inconsistent with known SGRs but seem to have a common origin => one seen also with Konus and Swift BAT.

Follow-up observations with Chandra reveal a source with a spin period of ~ 9 s.

But not yet a Ṗ!!!; Is this an SGR??

"SGR 0418+5729" spectra of the 2 bursts detected by the GBM

Power-law with exponential cut-off? Black-body? Optically-thin thermal Bremsstrahlung (OTTB)?

Van der Horst et al. 2010:

Best spectral fit over energy range ~ 10-100 keV is with an Optically-thin Thermal Bremsstrahlung spectrum

- Burst 1: 33.5 keV
- Burst 2: 20 keV
- Indication for cooling?
  Bursts 21 minutes apart: 2 unrelated events?

Studying timing and spectral properties of burst events is crucial for understanding burst mechanisms of these exotic magnetars

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Short history Anomalous X-ray pulsars

- The first AXPs were discovered with the UHURU satellite (SAS-A) early 1970s as relatively strong X-ray sources
- They were found to have periods of several seconds
- What type of X-ray pulsars are we dealing with?
- Discussions on the likely identification went on for 30-35 years!

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Anomalous X-ray pulsars (AXPs) (status end 2004)

- **No** rotation powered pulsar — $L_X >> L_{spin\ down}$
- **No** X-ray pulsar in LMXB/HMXB (**no** accretion-powered pulsar) — steady spin-down; no apparent optical counterpart; no periodic Doppler delay in X-ray timing

Characteristics:

◇ Pulse periods: — 5 -12 s

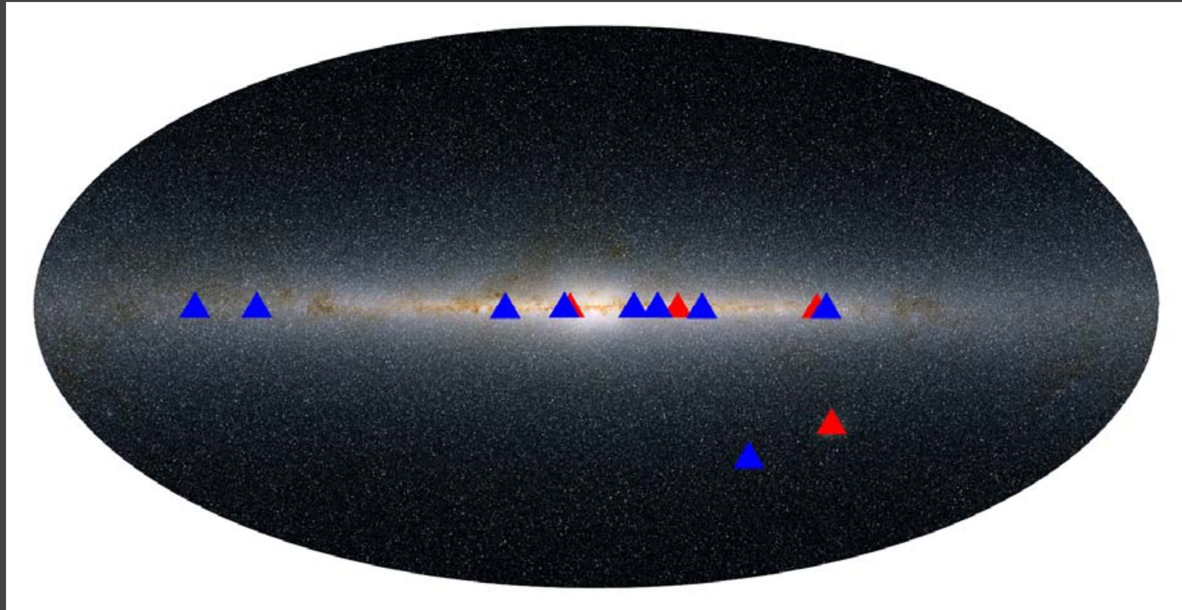
◇ "Steady" spin-down like rotation powered pulsars (glitches observed also) — typically 10^{-11} s s^{-1}

◇ X-ray luminosities: — 10^{34-36} erg/s (steady, but outbursts also detected; transient AXPs)

◇ (very) soft X-ray (0.5-10 keV) spectra: — BB (0.35 – 0.6 keV) + PL with $\Gamma \sim 2 - 4$ ($F \propto E^{-\Gamma}$)

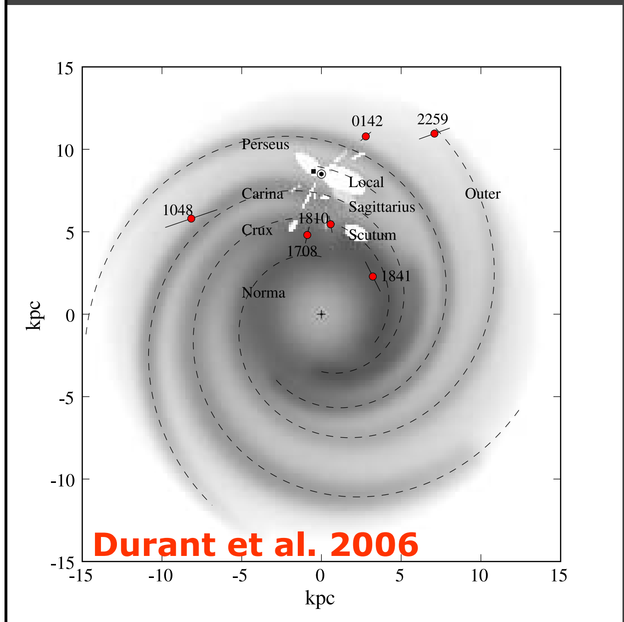
◇ Similar to Soft Gamma-Ray Repeaters (glitches; (out)bursts) ➡ **Magnetars**

◇ Young population concentrated along galactic plane



SGR's

AXP's



Durant et al. 2006

AXP	Discovery	P[s]	B[10^{14} G]
Persistent			
1E2259+586 (SNR)	1981	6.98	0.6
1E1048.1-594	1985	6.45	5.0
4U 0142+61	1993	8.69	1.3
1RXS J1708-4009	1997	11.00	4.6
1E1841-045 (SNR)	1997	11.77	7.1
CXOU J0110-721 (SMC)	2002	8.02	3.9
CXOU J164710.2-455216 (Westerlund 1)	2005	10.61	< 3.0
1E1547.0-5408 (SNR)	2007	2.07	2.2
Transient			
AX J1845-026 (?)	1998	6.97	?
XTE J1810-197	2003	5.54	2.6

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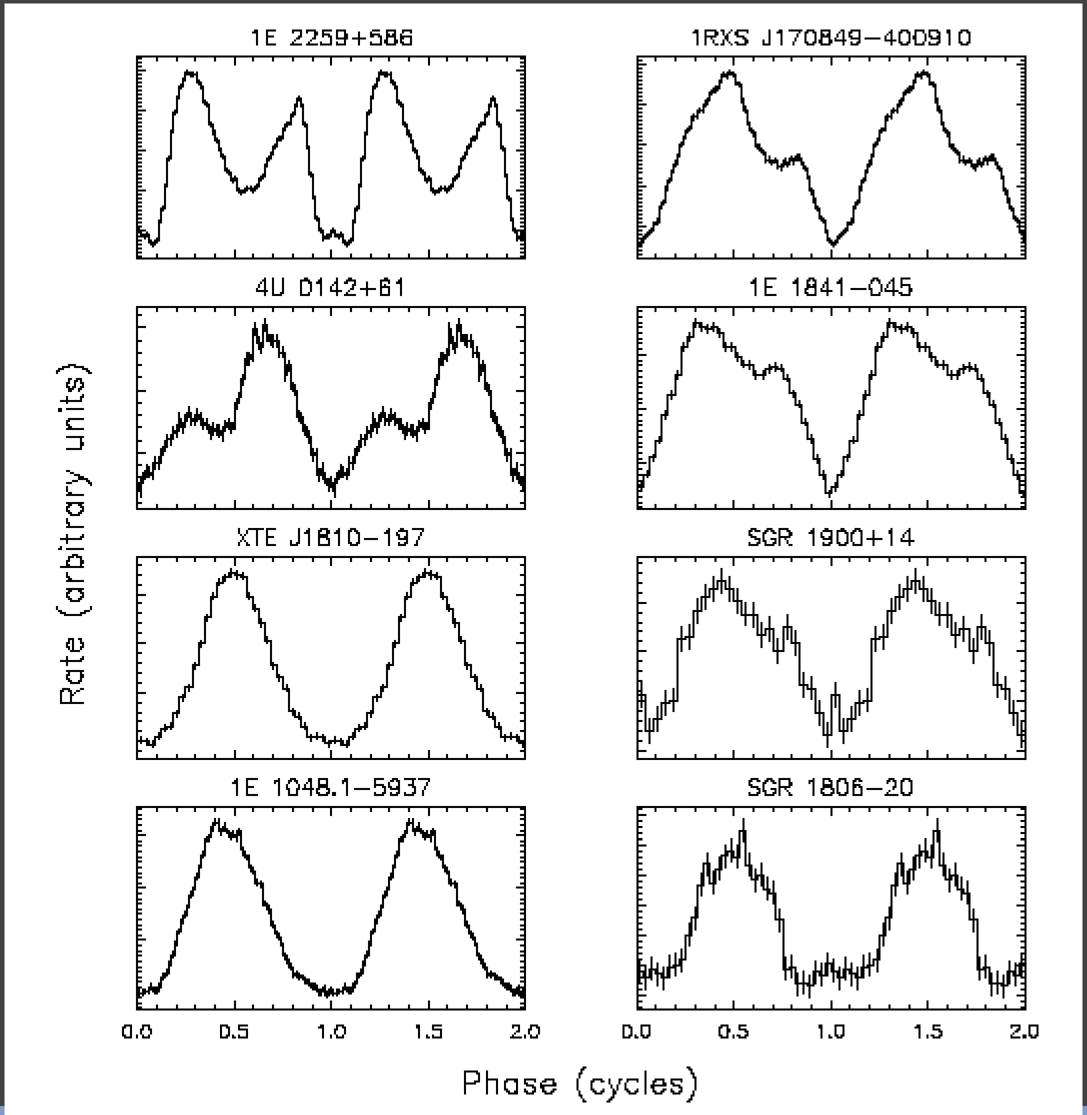
Quiescent emission pulse profiles of AXPs and SGRs E<10keV

Profiles of AXPs and SGRs persistent emission looks very similar

Woods & Thompson 2004

$L_Q \sim 10^{35}$ erg $s^{-1} >> L_{SD} \sim 10^{33}$ erg s^{-1}

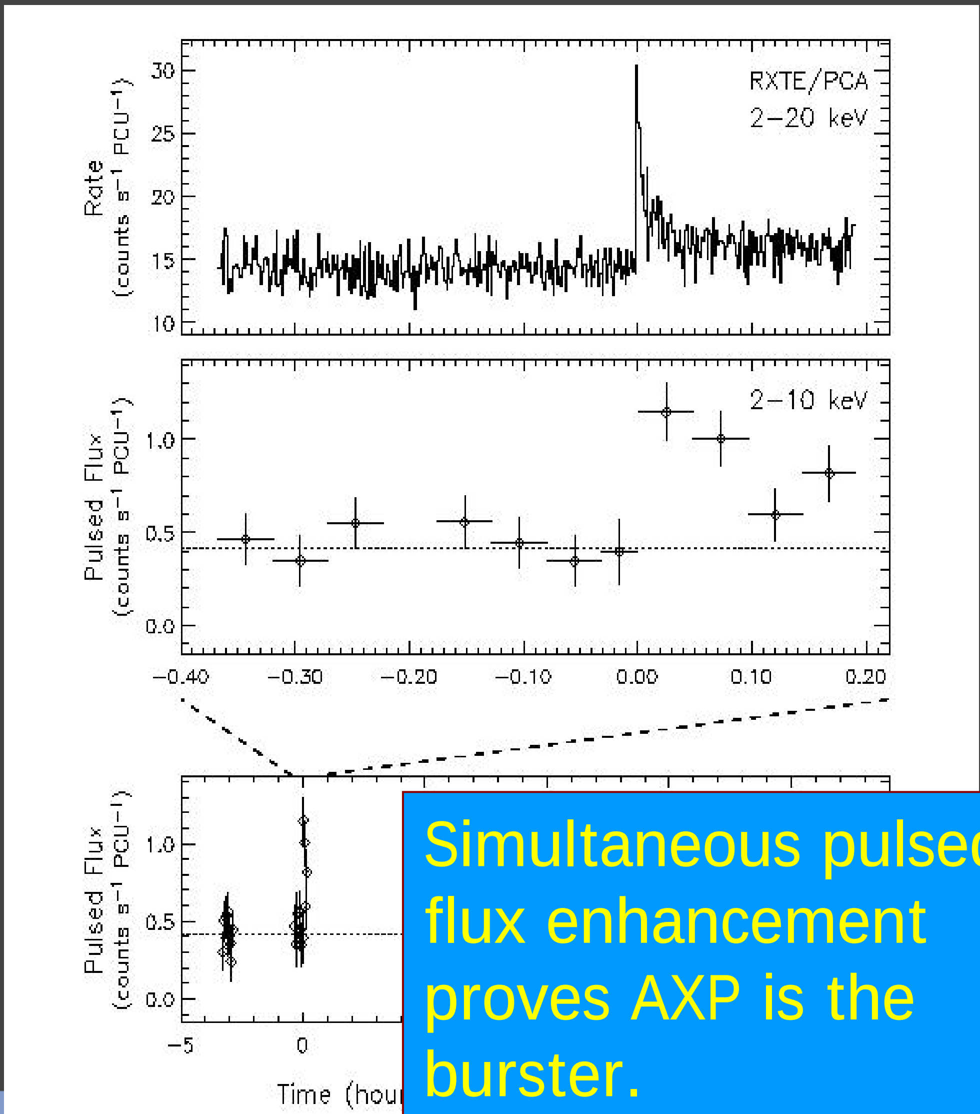


Bursts from AXPs!

Note: SGR 0526-66 (Kulkarni et al. 2003)

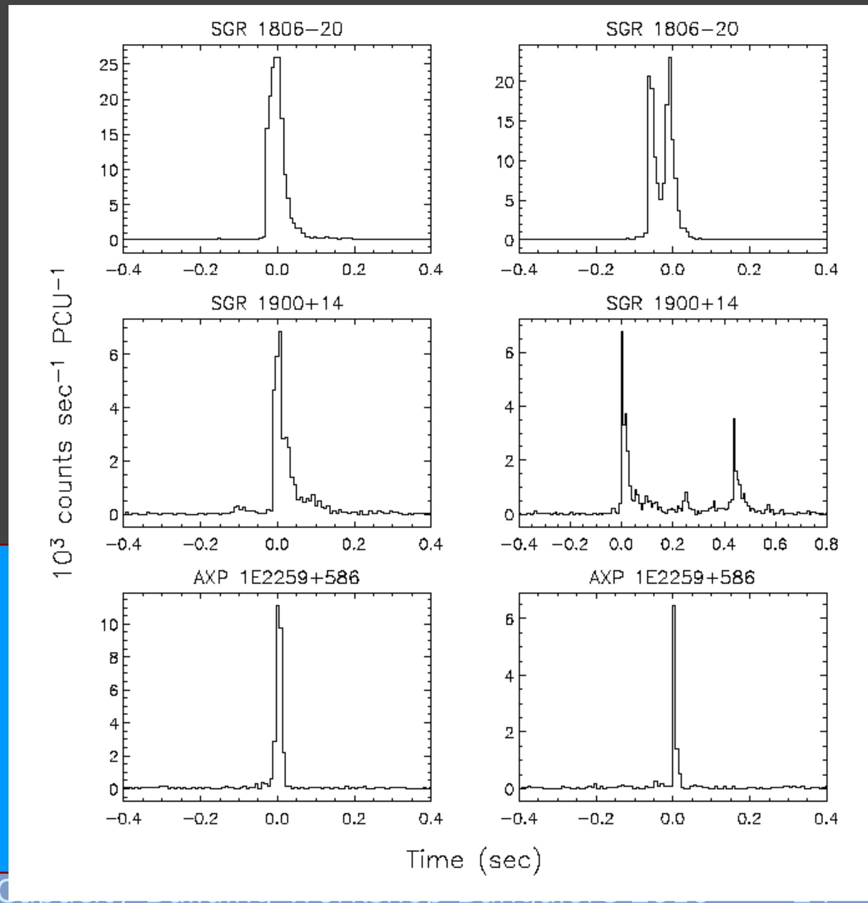
June 2004 Burst from 1E 1048-5937

Gavriil, Kaspi & Woods 2005

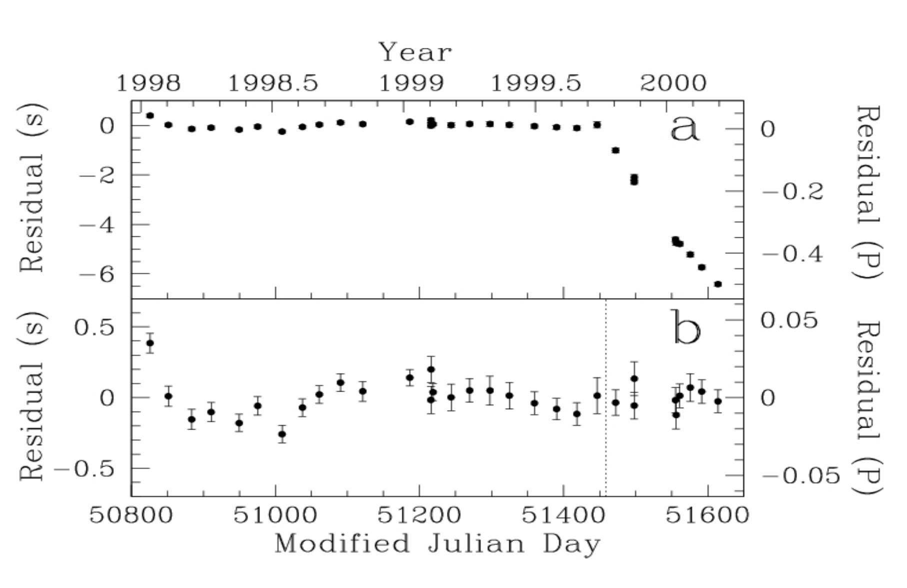


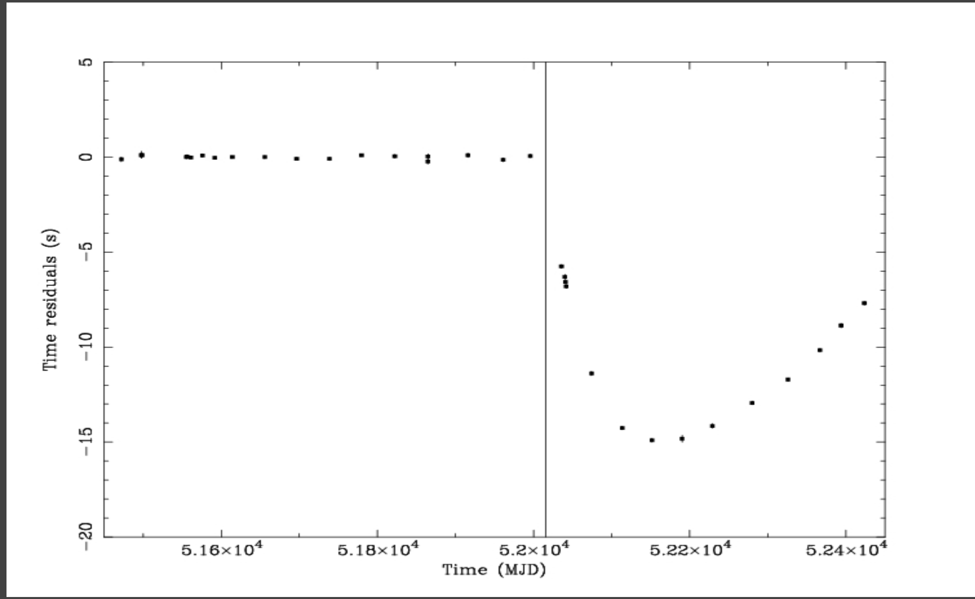
Simultaneous pulsed flux enhancement proves AXP is the burster.

Bursts from AXPs predicted by magnetar model of Thompson & Duncan (1996)



The glitch phenomenon for AXP 1E 2259+586

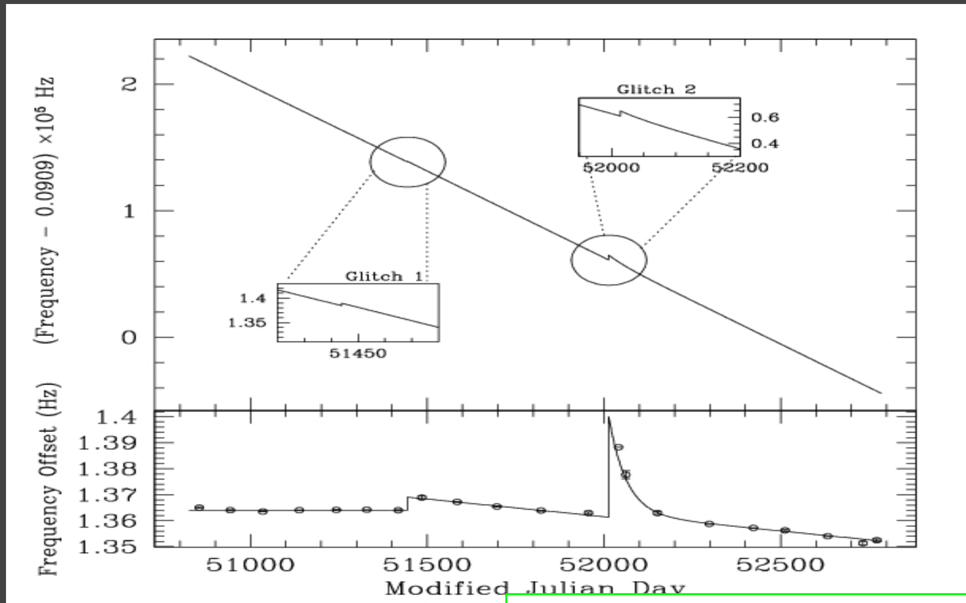




$\Delta\omega/\omega = 6.5 \times 10^{-7}$

$\Delta\dot{\omega}/\dot{\omega} = 1.7 \times 10^{-2}$

Vela-like glitch



$\Delta\omega/\omega = 3.9 \times 10^{-6}$

$\Delta\dot{\omega}/\dot{\omega} = 9 \times 10^{-3}$

Crab-like glitch

(Kaspi et al. 2001; Dall'Osso et al. 2003; Kaspi & Gavriil 2003)

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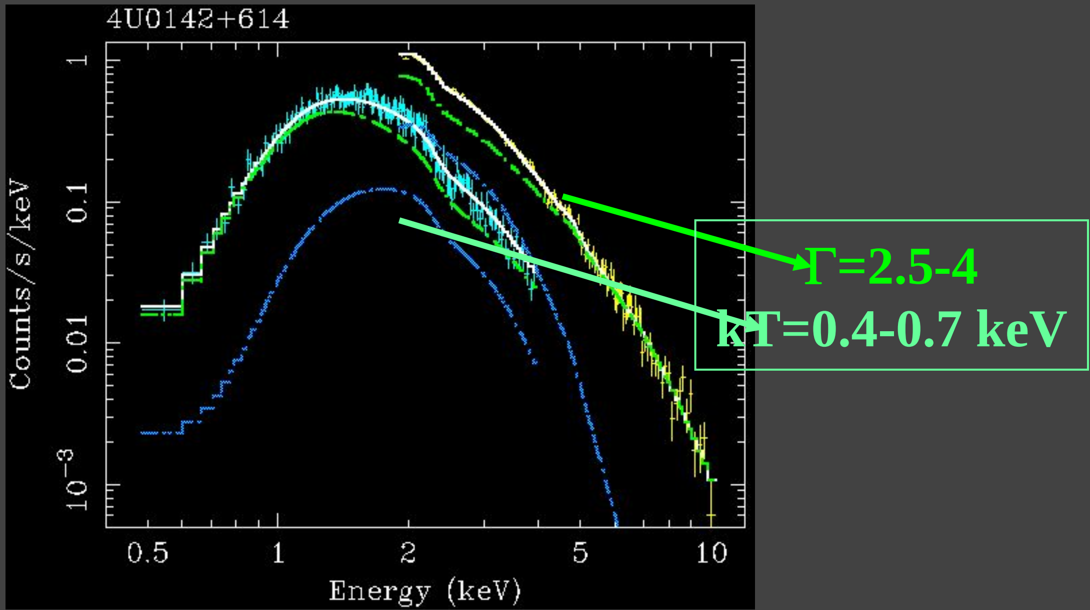
Soft spectra of AXPs: 4U 0142+614

Soft spectra below 10 keV can be described with a BB + soft power law



Also, variable X-ray fluxes below 10 keV (Rea et al. 2004, 2005)

AXP / SGR	Hosts	P (s)	B (10^{14} G)	L(10^{33} erg/s) (0.2-10 keV)	comments
4U 0142+61		8.7	1.3	7.2	hard X-rays
RXS J1708-4009		11	4.7	80-190	hard X-rays
1E 1841-045	Kes 73	11.8	7.1	110	hard X-rays
1E 2259+586	CTB 109	7.0	0.6	17-159	~transient/hard X-rays
CXO J0100-72	in SMC	8.0	3.9	200	
1E 1048-5937		6.4	3.9	5.3-250	~transient
1E 1547-5408		2.0	2.2	2.6-170	transient/radio/hard X-rays
XTE 1810-197		5.5	2.9	5-260	transient/radio
CXO 1647-4552	in Wes 1	10.6	1.5	1-130	transient
AX J1845-0258	G29.6+0.1	7.0	-	5-120	transient
SGR 1900+14	OB	5.2	5.7	200-350	GF/hard X-rays spectr. index 3.1
SGR 1806-20	OB	7.5	7.8	320-540	GF/hard X-rays?/outburst
SGR 0526-66	in LMC	8.0	7.4	260	GF
SGR 1627-41		2.6	2	4-100	outburst
SGR 0501+4516		5.75	1.7		outburst/transient hard-X
SGR 0418+5729		9.1	-		outburst

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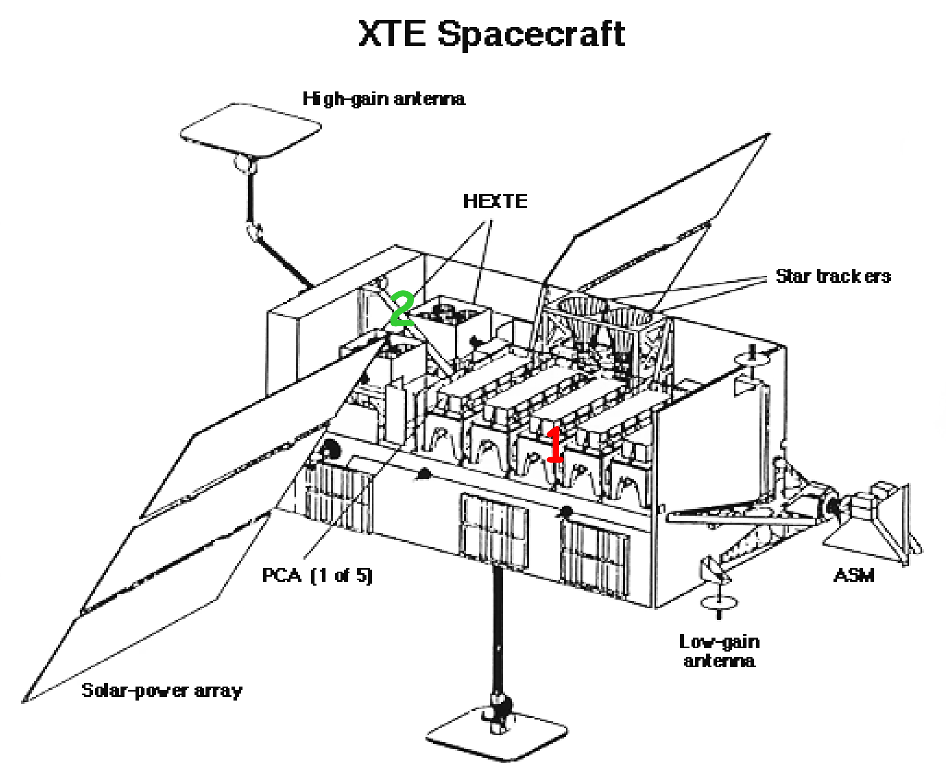
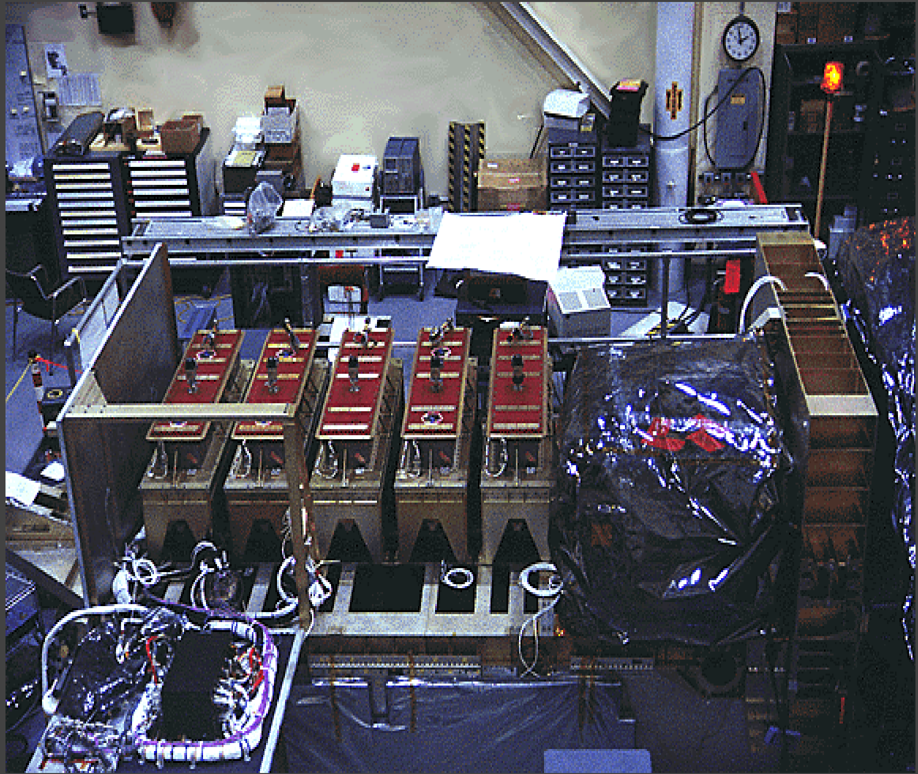
Rossi X-ray Timing Explorer (RXTE) (30-12-1995 - .....)



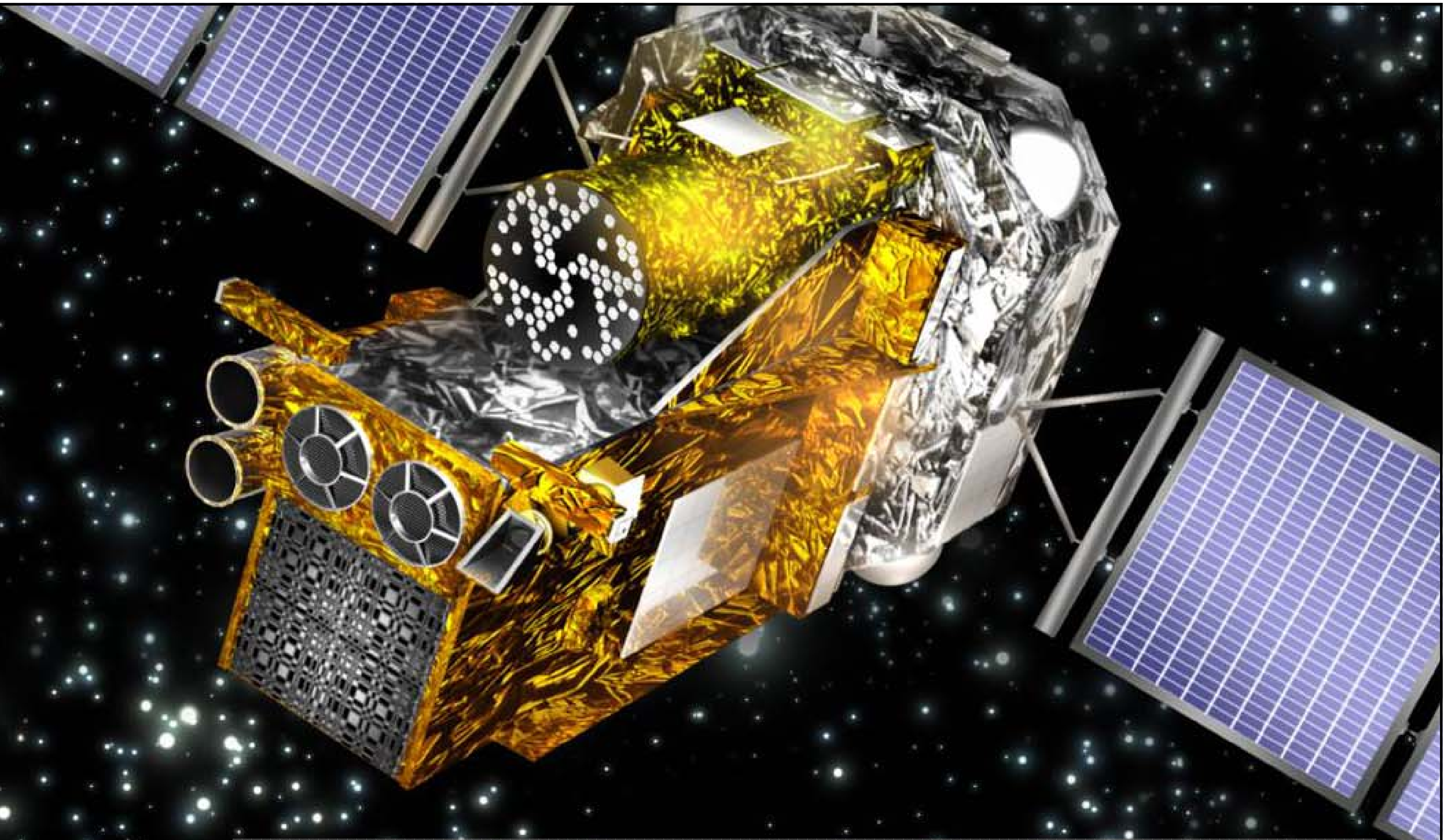


Prime instruments (both NON-IMAGING)

1 Proportional Counter Array (PCA): 2-60 keV
2 High-Energy X-ray Timing Experiment (HEXTE): 15-250 keV

INTEGRAL IBIS-ISGRI

Imager onboard INTEGRAL Spacecraft



Energy range:	20 keV - ~300 keV
Field of view:	9º x 9º (fully coded)
	29º x 29º (partially coded)
Angular resolution:	12′ (FWHM)
Point-source location accuracy:	30″ – 3′

Magnetars (AXPs/SGRs): discovery of persistent emission > 10 keV

Original discovery: Total emission by INTEGRAL ISGRI
Pulsed emission by RXTE-PCA-HEXTE

- 1E 1841-045 * (Molkov et al. 2004, Kuiper et al. 2004)
- 1RXS J170849-400910 * (Revnivtsev et al. 2004, Kuiper et al. 2006, den Hartog et al. 2008)
- 4U 0142+61 * (den Hartog et al. 2006, Kuiper et al. 2006, den Hartog et al. 2008)
- 1E 2259+586 (Kuiper et al. 2006)
- SGR 1806-20 (Mereghetti et al. 2005, Molkov et al. 2005)
- SGR 1900+14 (Götz et al. 2006; Esposito et al. 2006)

* best studied, and will be shortly presented

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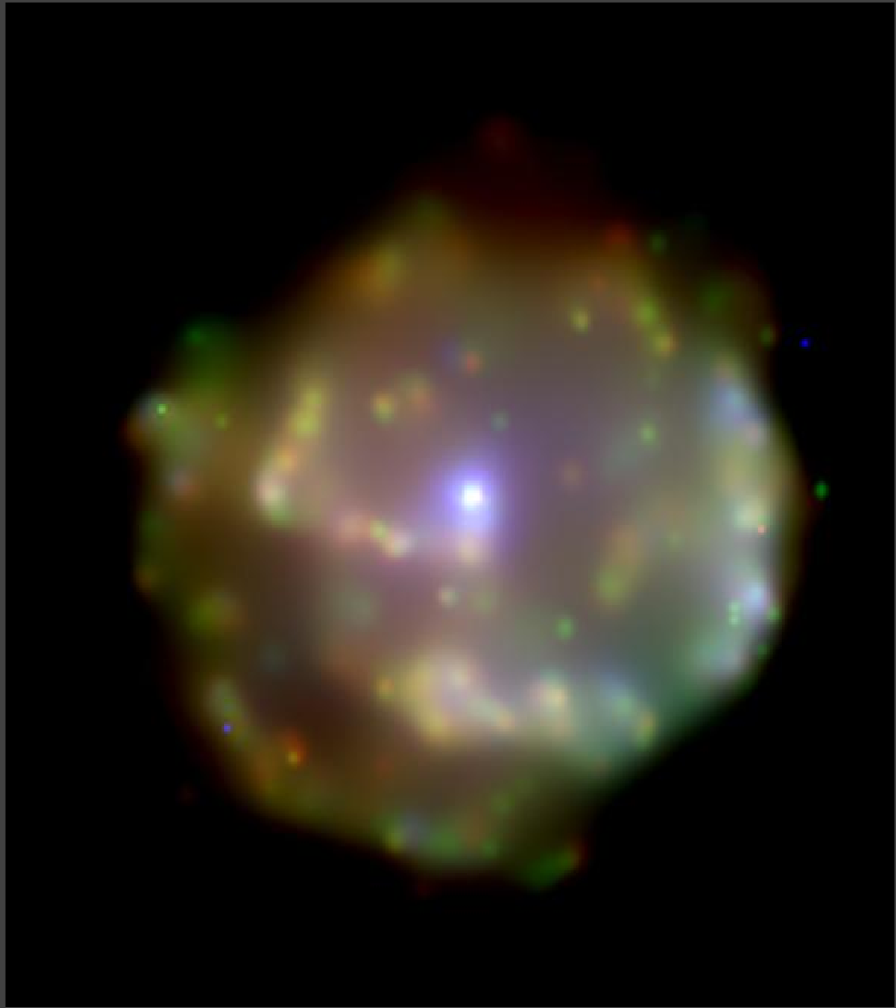
AXP 1E1841-045 in SNR Kes 73 (G27.4+0.0)

- 11.8^s X-ray pulsations discovered in ASCA data (Vasisht & Gotthelf 1997) Double peaked profile
- Resolved from surrounding SNR in *Chandra* data: BB+PL spectrum (Morii et al. 2003)
- Molkov et al. (2004) discovered soft γ-rays from Kes 73 position with INTEGRAL



Chandra ACIS 0.5-7 keV image

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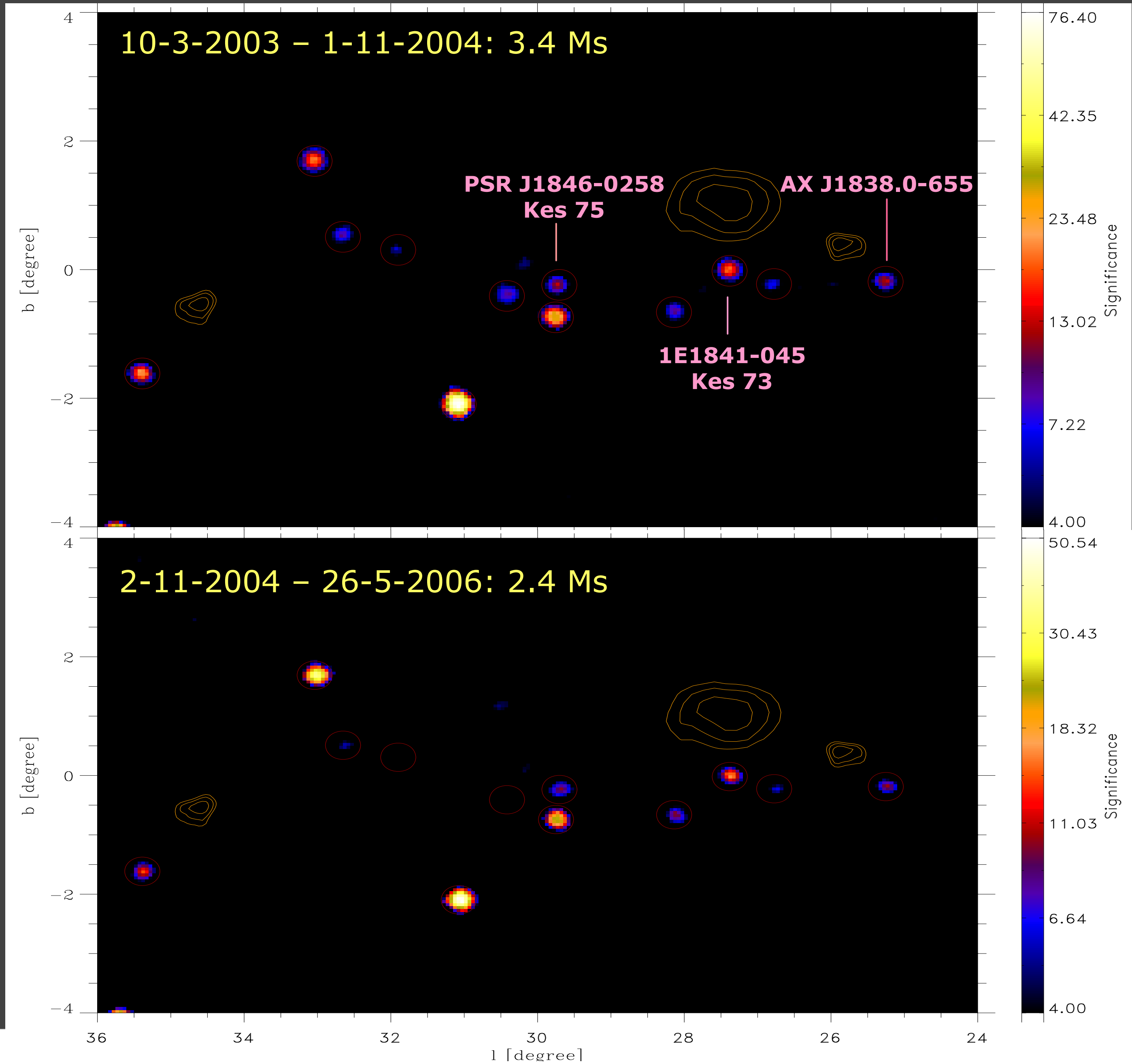
High-energy view by IBIS-ISGRI of Scutum region, 20-70 keV



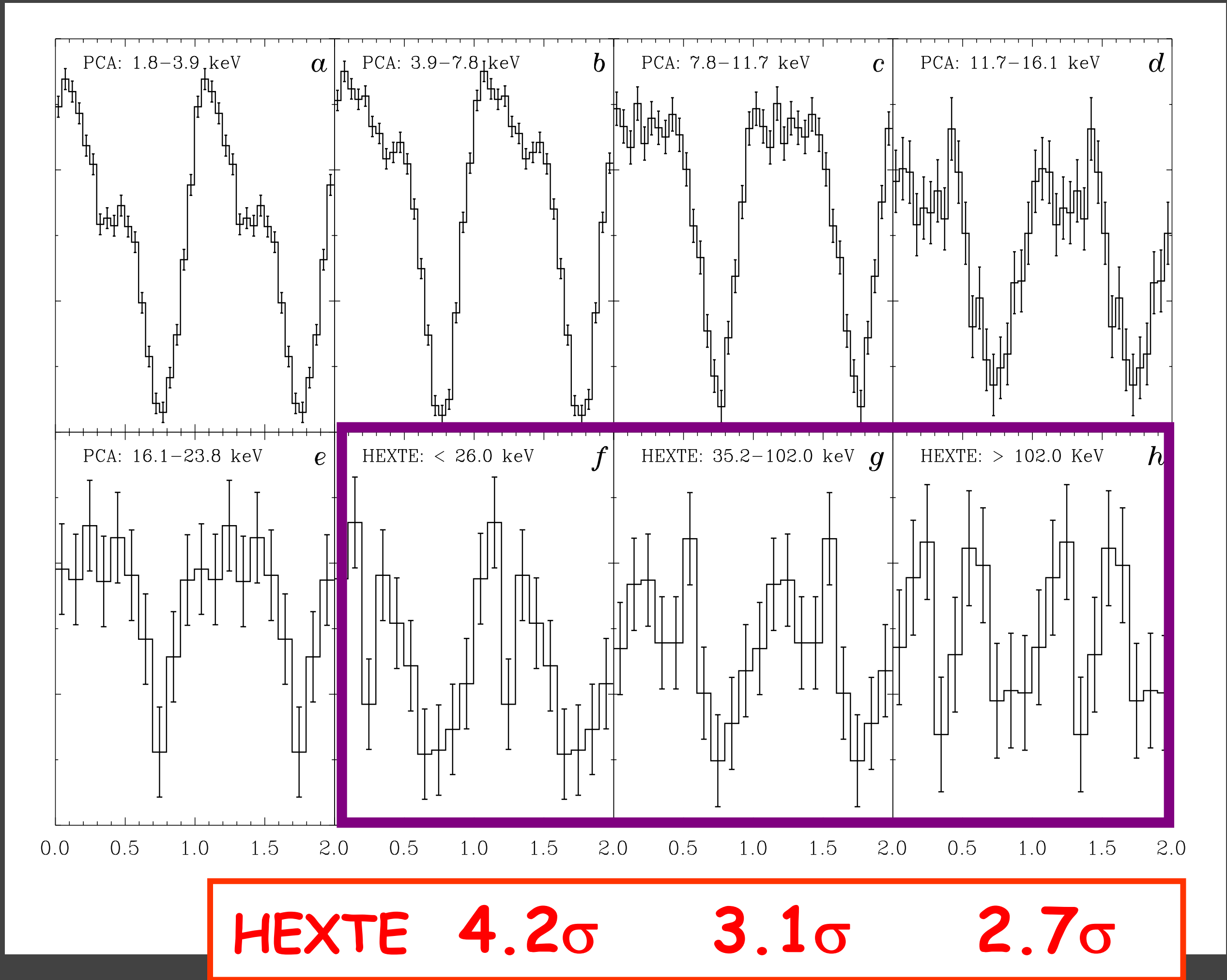
Archival RXTE PCA/HEXTE data

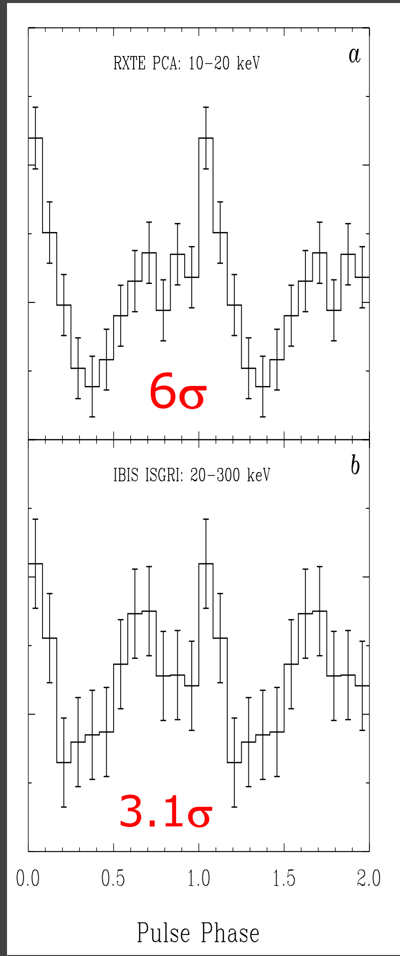
Kuiper, Hermsen & Mendez 2004, ApJ 613, 1173

RXTE/INTEGRAL Contemporaneous

Kuiper, Hermsen, den Hartog, Collmar 2006, ApJ 645

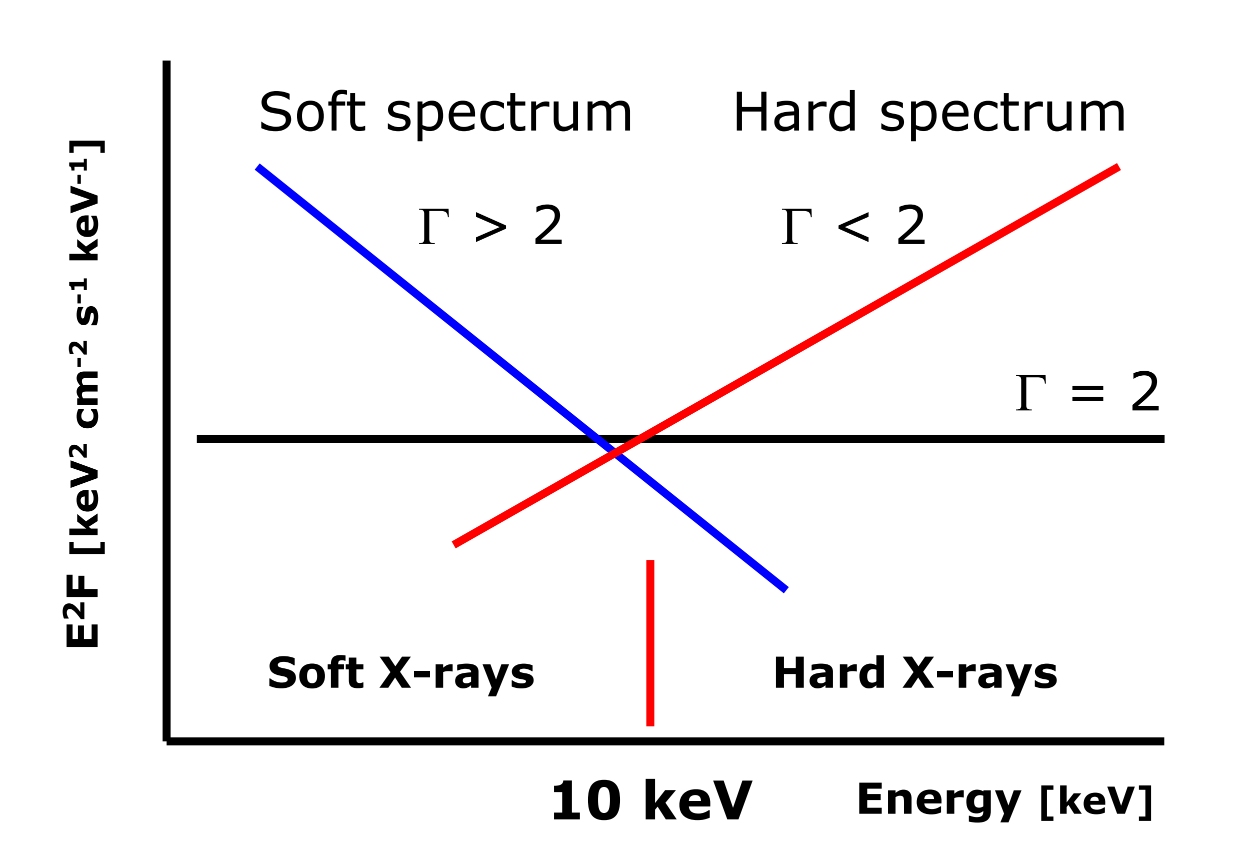
1E 1841-045





SRON

X-ray Spectrum; SED

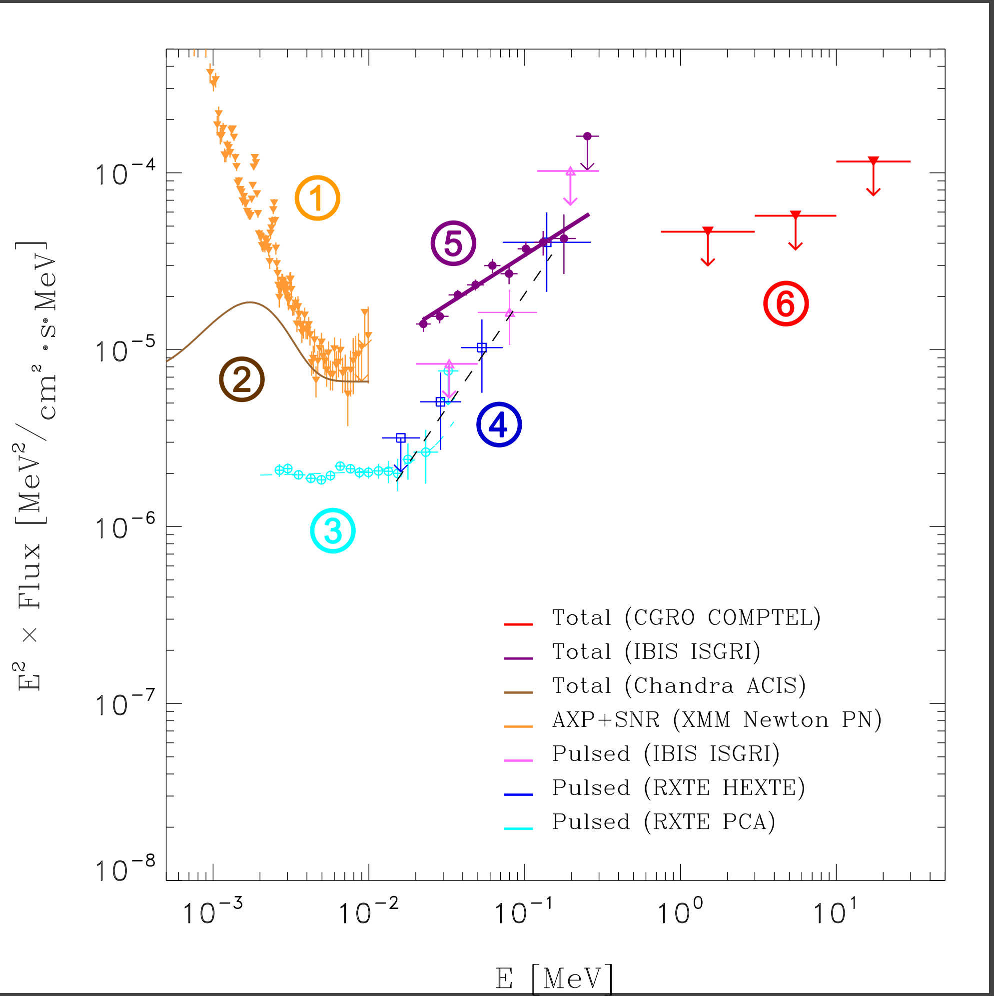


High-energy spectra: Kes 73 and AXP 1E 1841-045

① Kes 73 +
1E 1841-045;
XMM-Newton

② Total
1E 1841-045;
Chandra
(Morii et al. 2003)

③ Pulsed
1E 1841-045;
RXTE-PCA



④ Pulsed
1E 1841-045;
RXTE-HEXTE
$\gamma = 0.94 \pm 0.16$

⑤ Kes 73 (?)
+
1E 1841-045;
IBIS ISGRI
$\gamma = 1.39 \pm 0.05$

⑥ Kes 73 (?) +
1E 1841-045;
CGRO COMPTEL

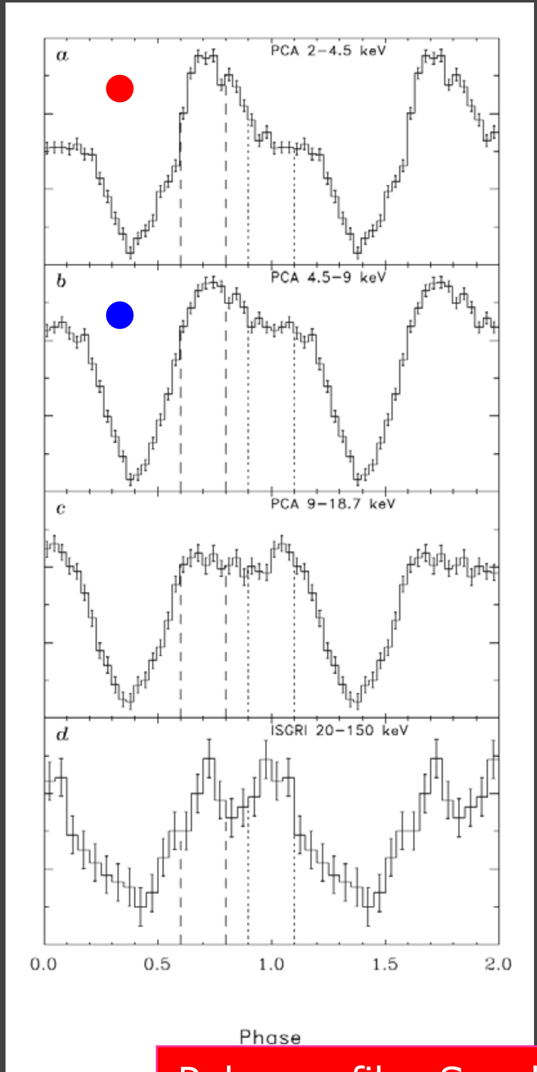
SRON

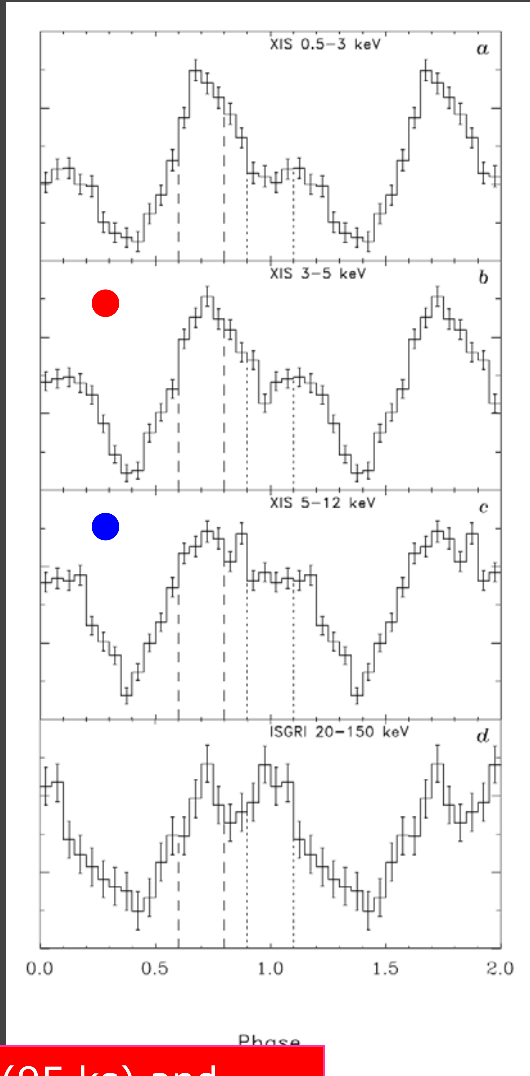
1E1841-045 in SNR Kes 73 (G27.4+0.0)

RXTE-PCA
(2-18.7 keV)

Time average
over many years

INTEGRAL-
ISGRI
(20-150 keV)





Suzaku-XIS
(0.5-12 keV)

Exp. 95.3 ks

INTEGRAL-
ISGRI
(20-150 keV)

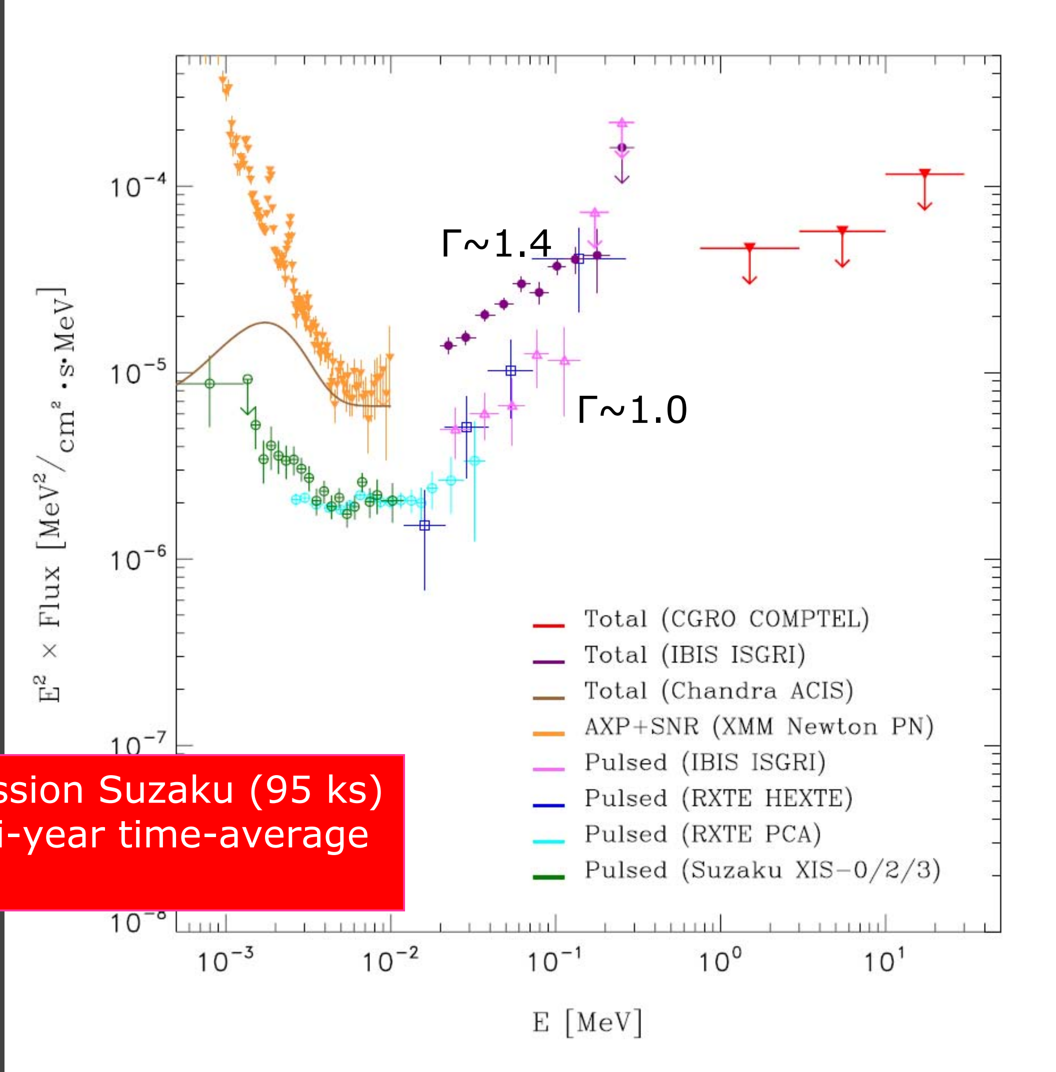
Pulse profiles Suzaku (95 ks) and
RXTE PCA (multi-year time-average)
are fully consistent

SRON

1E1841-045 in SNR Kes 73 (G27.4+0.0): Total and pulsed emission spectra

Power-law fit **total** spectrum above 20 keV : Γ= 1.39 ± 0.05 (INTEGRAL/ISGRI)

DC spectrum AXP above 20 keV much softer !

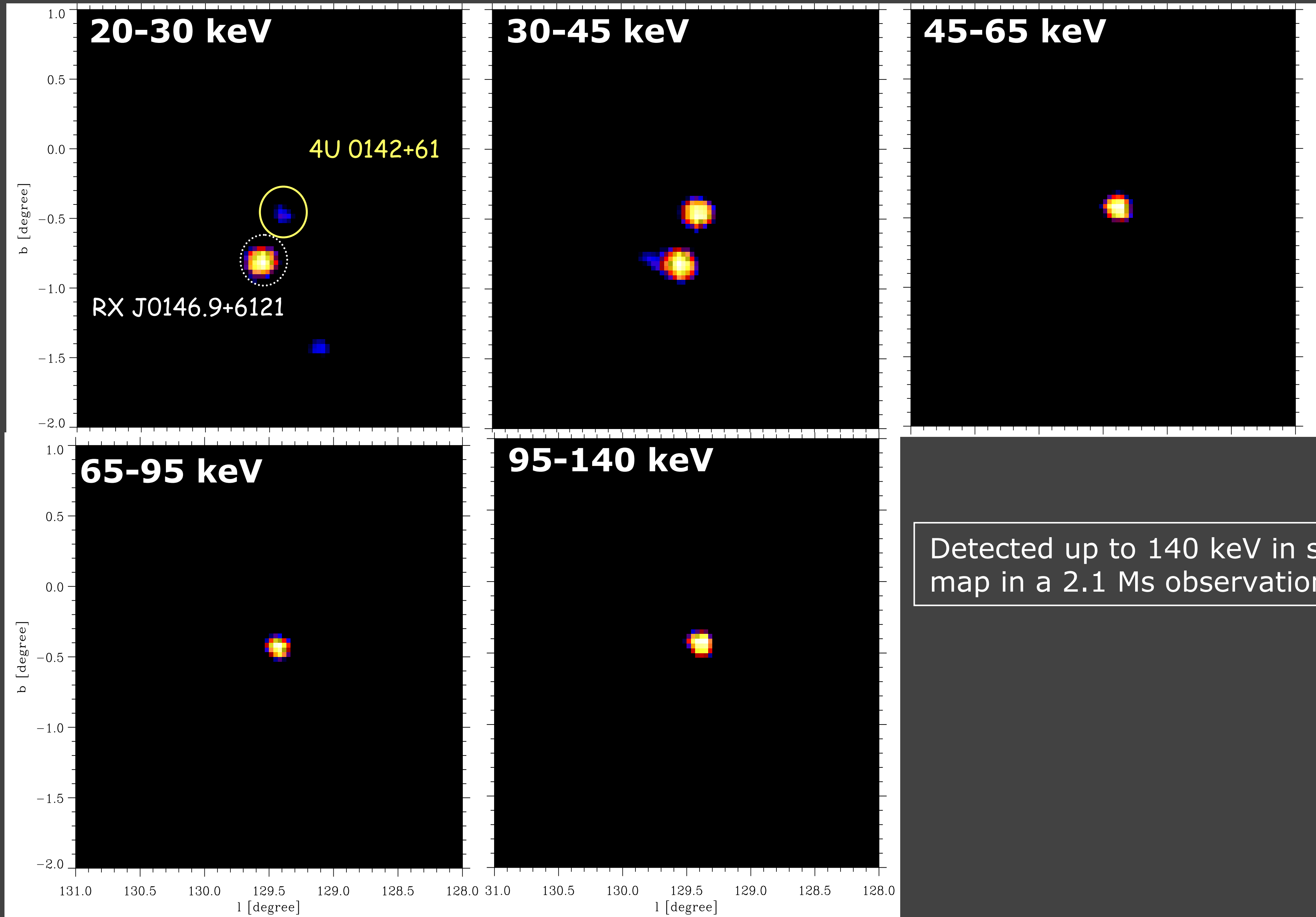


Power-law fit **pulsed** spectrum above 20 keV 14.3 – 300 keV : Γ= 1.01 ± 0.12 (RXTE/PCA + INTEGRAL/ISGRI)

Spectra pulsed emission Suzaku (95 ks) and RXTE PCA multi-year time-average are fully consistent

4U 0142+61; IBIS ISGRI 2.1 Ms

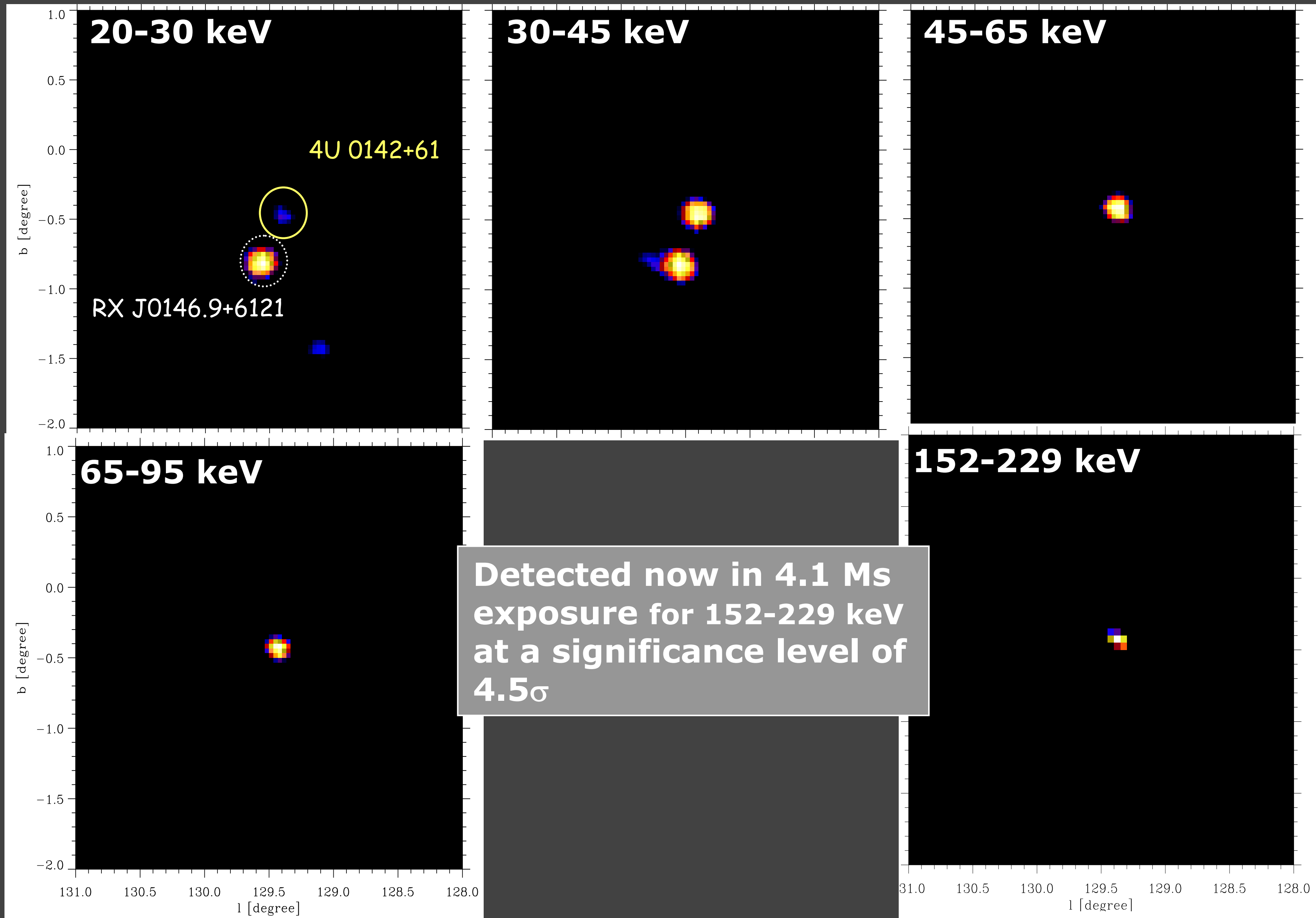
den Hartog, Kuiper, Hermsen 2004



Detected up to 140 keV in sky map in a 2.1 Ms observation

4U 0142+61; IBIS ISGRI 2.1 Ms

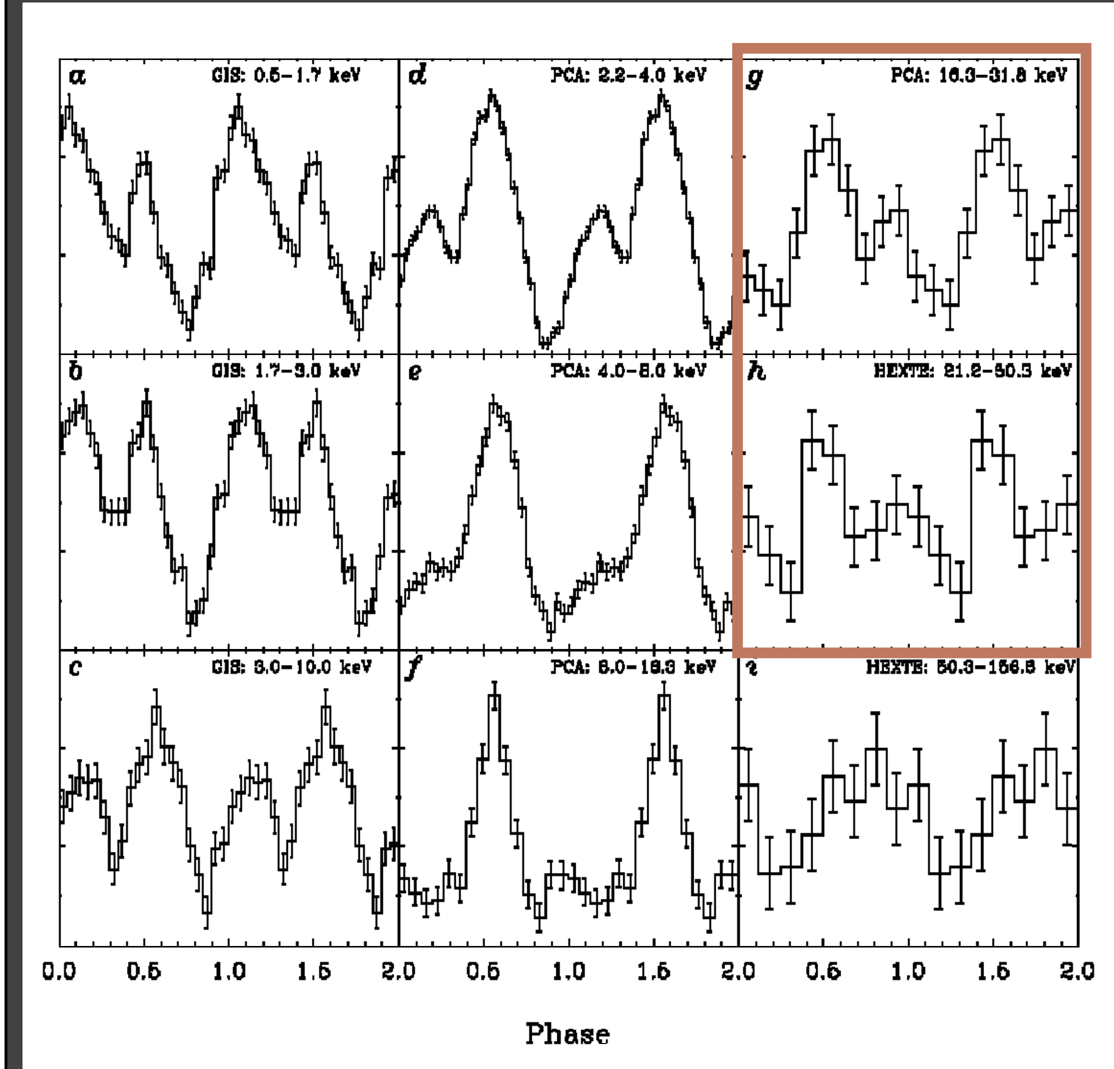
den Hartog, Kuiper, Hermsen 2004



Detected now in 4.1 Ms exposure for 152-229 keV at a significance level of 4.5σ

4U 0142+61; RXTE PCA/HEXTE

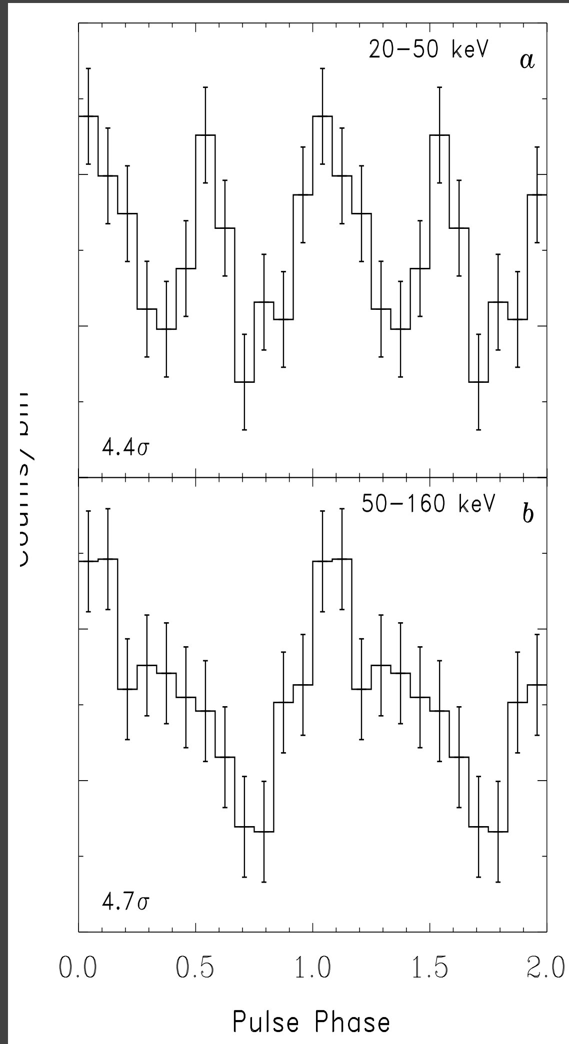
IBIS ISGRI 4.1 Ms



5.7σ

3.4σ

2.1σ



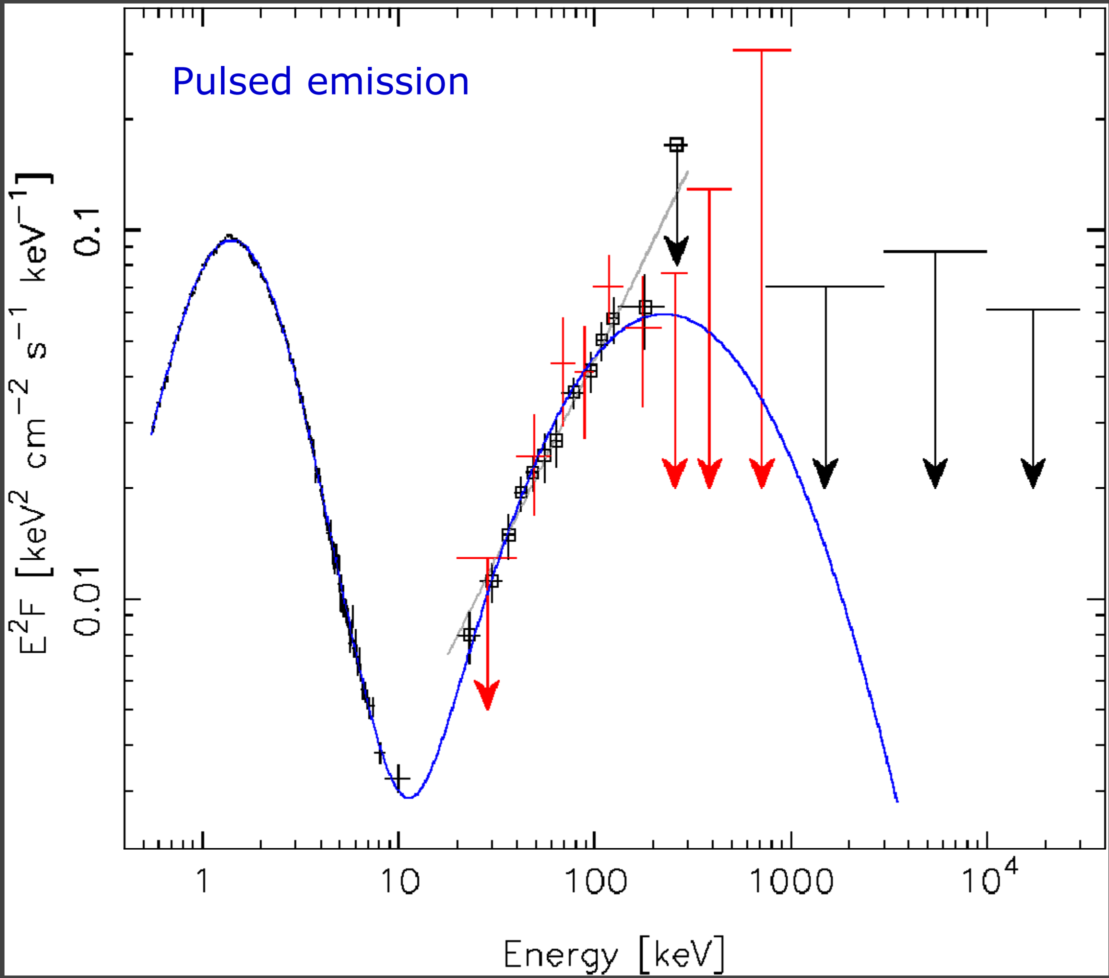
a) Significant pulsed emission up to ~160 keV
b) Morphology change with time not significant, with energy it is!

4U 0142+61: Total HE-emission spectrum (0.5 keV – 30 MeV), not in SNR

(den Hartog et al. 2008)

$L_X >> L_{\text{spin down}}$

XMM-Newton

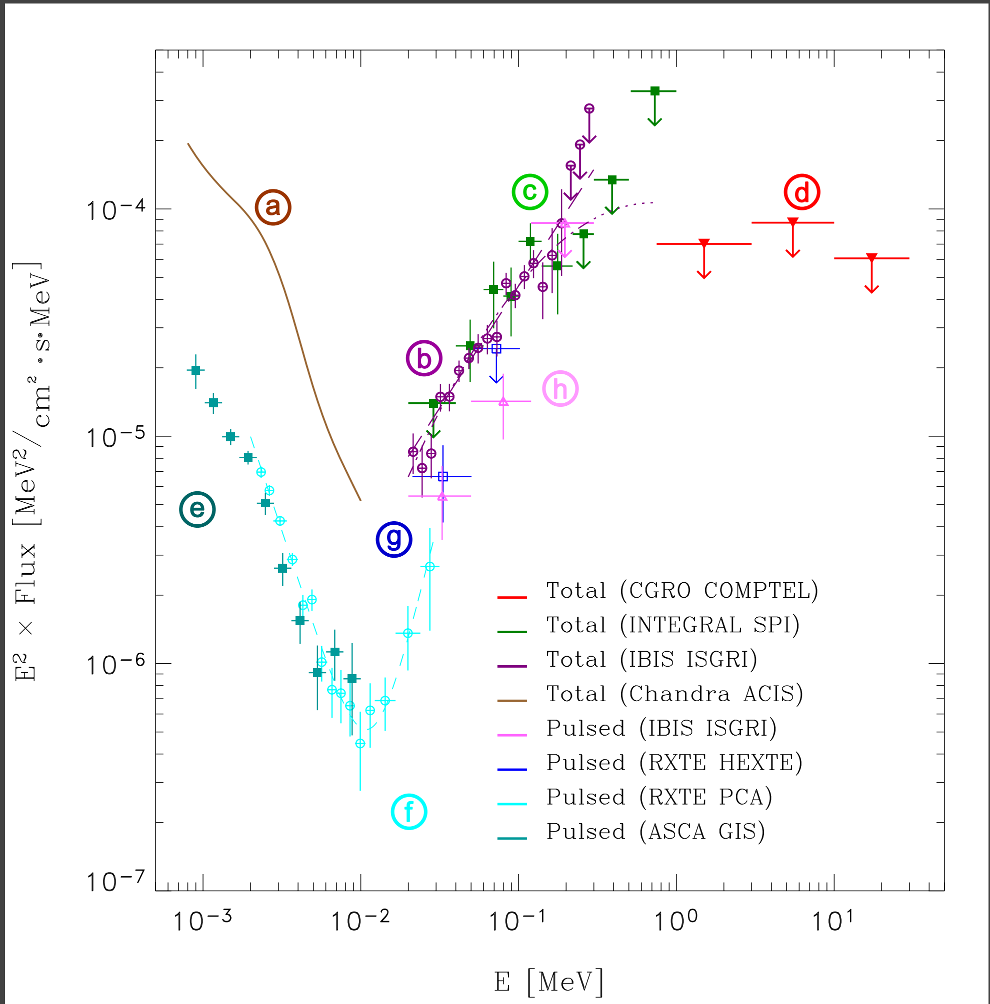


$L_\gamma >> L_{\text{spin down}}$

INTEGRAL
IBIS + SPI

Emission up to ~220 keV, but then break

4U 0142+61



Total

(a) Chandra ACIS

(b) IBIS ISGRI (den Hartog et al., 2008 A&A)

(c) INTEGRAL SPI (den Hartog et al., 2008 A&A)

(d) CGRO COMPTEL

Pulsed

(e) ASCA GIS (Kuiper et al. 2006)

(f) RXTE PCA (Kuiper et al. 2006)

(g) RXTE HEXTE (Kuiper et al. 2006)

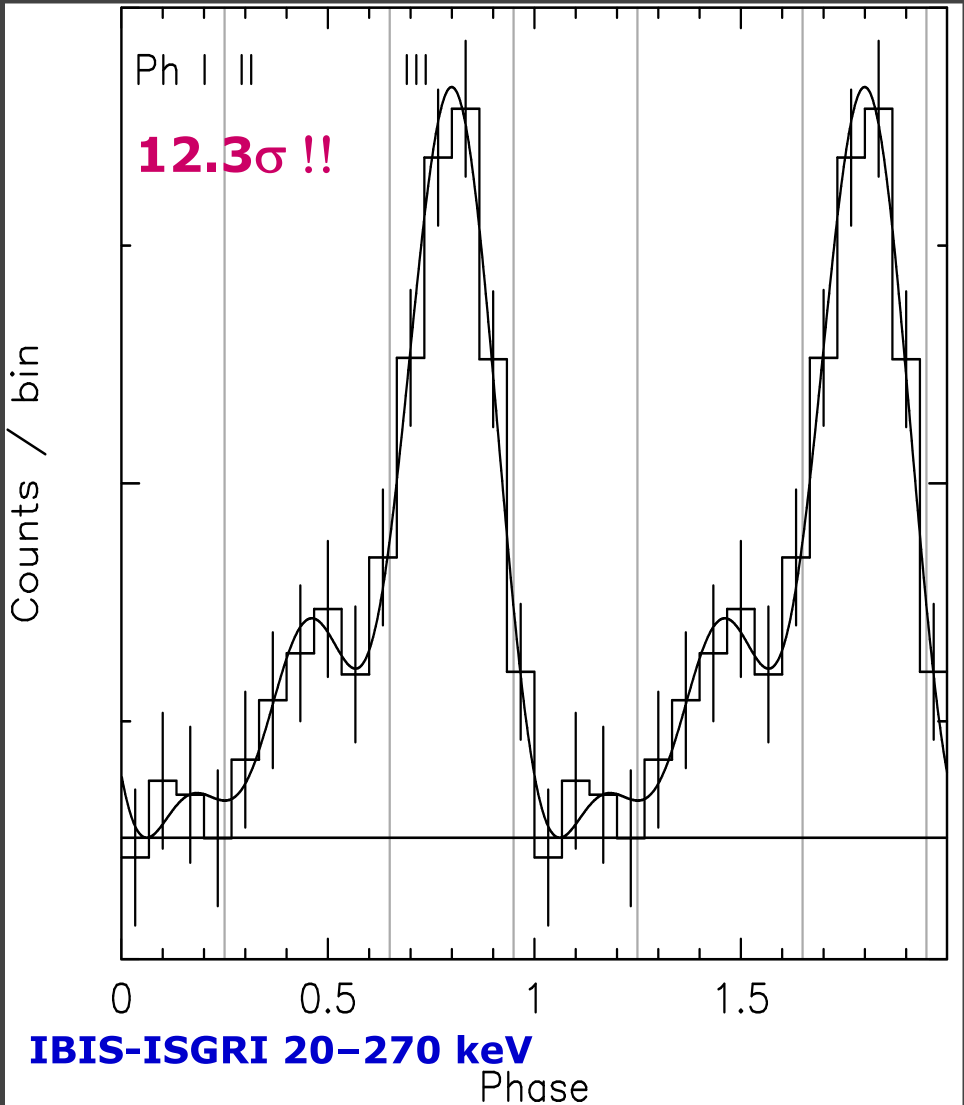
(h) IBIS ISGRI (den Hartog et al., 2008 A&A)

Emission up to 220 keV!

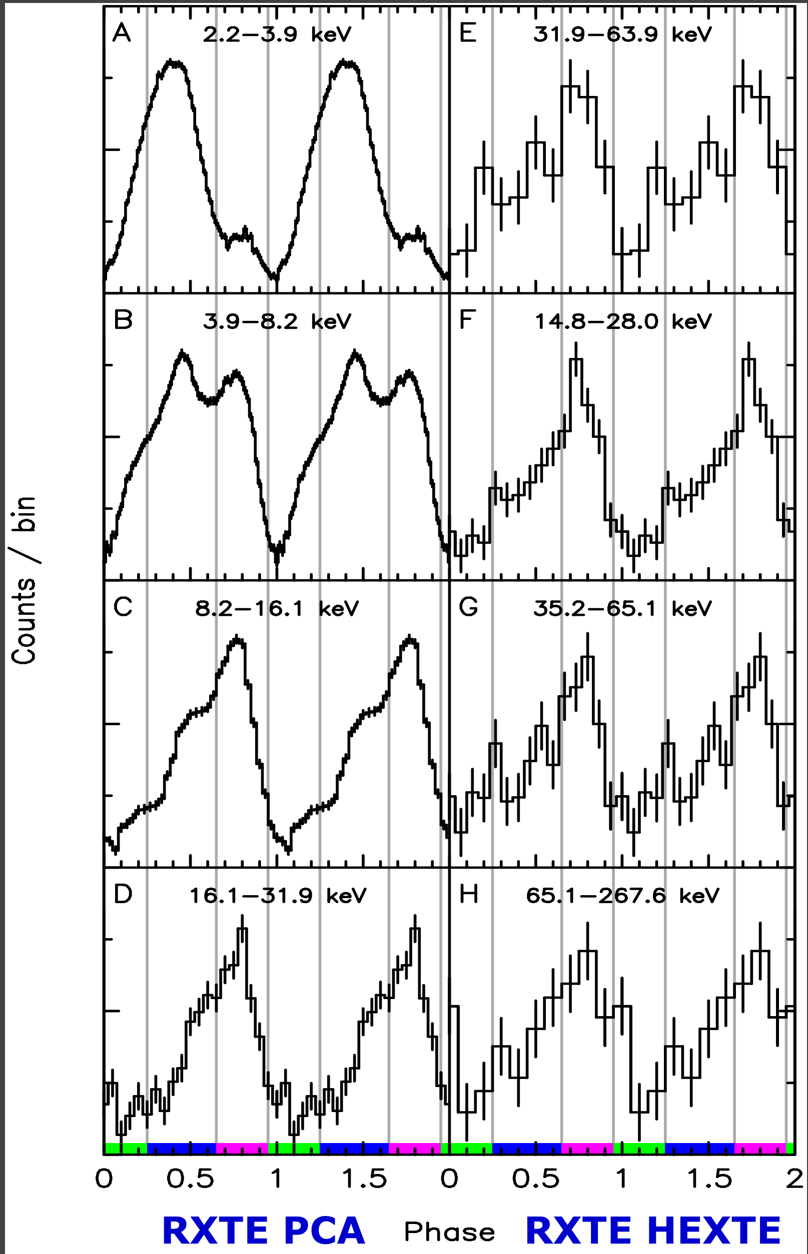
Above 10 keV: Pulsed fraction → 100%

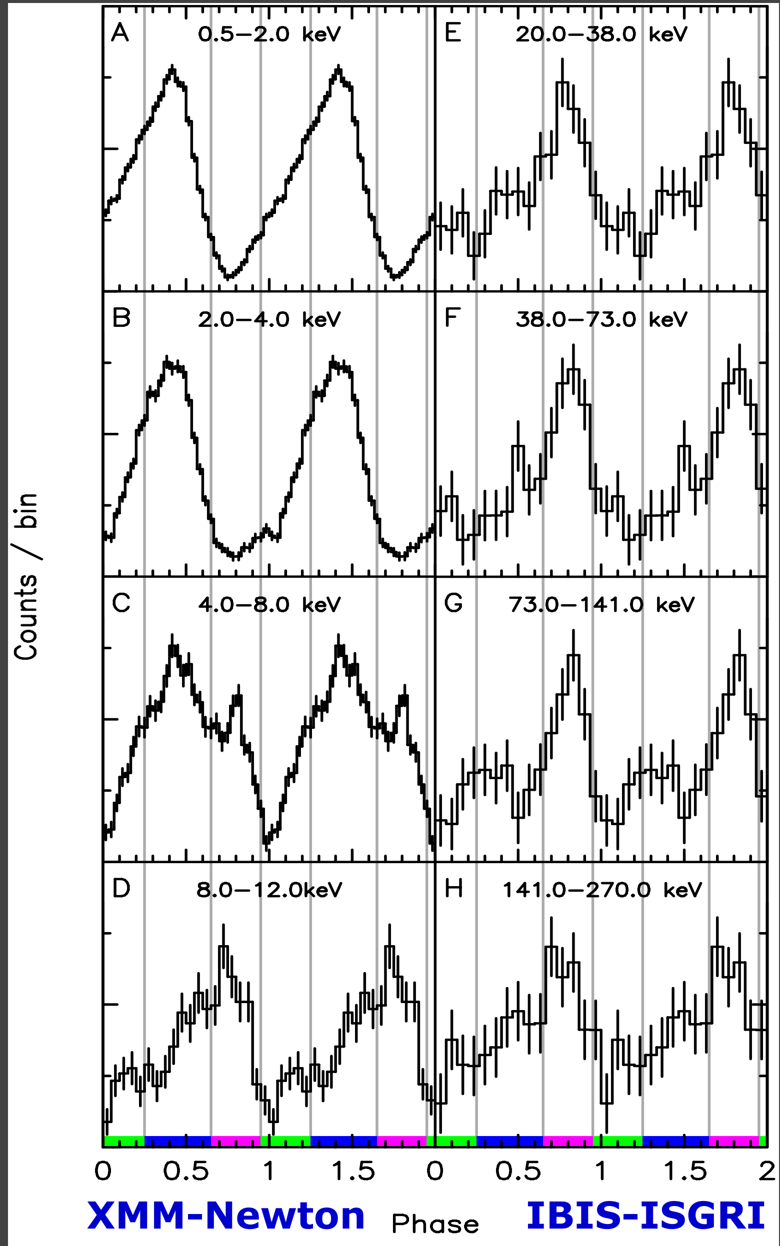
SRON

1RXS J170849.0-400910



very significant profile obtained for this AXP with relatively narrow pulse / duty cycle.





Phase resolved spectral analysis performed over 0.5-300 keV

Drastic changes in pulse morphology with energy!

1RXS J170849-400910: XMM, RXTE, INTEGRAL

XMM-Newton

0.5-4.0 keV

RXTE-PCA

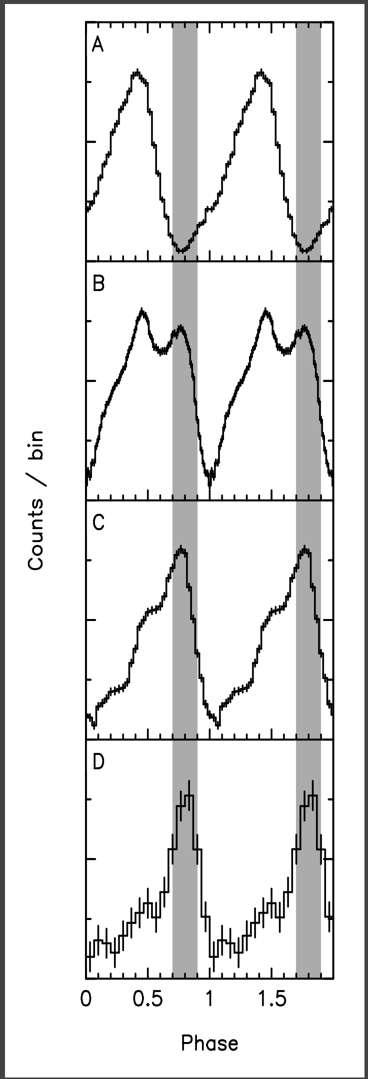
3.8-8.2 keV

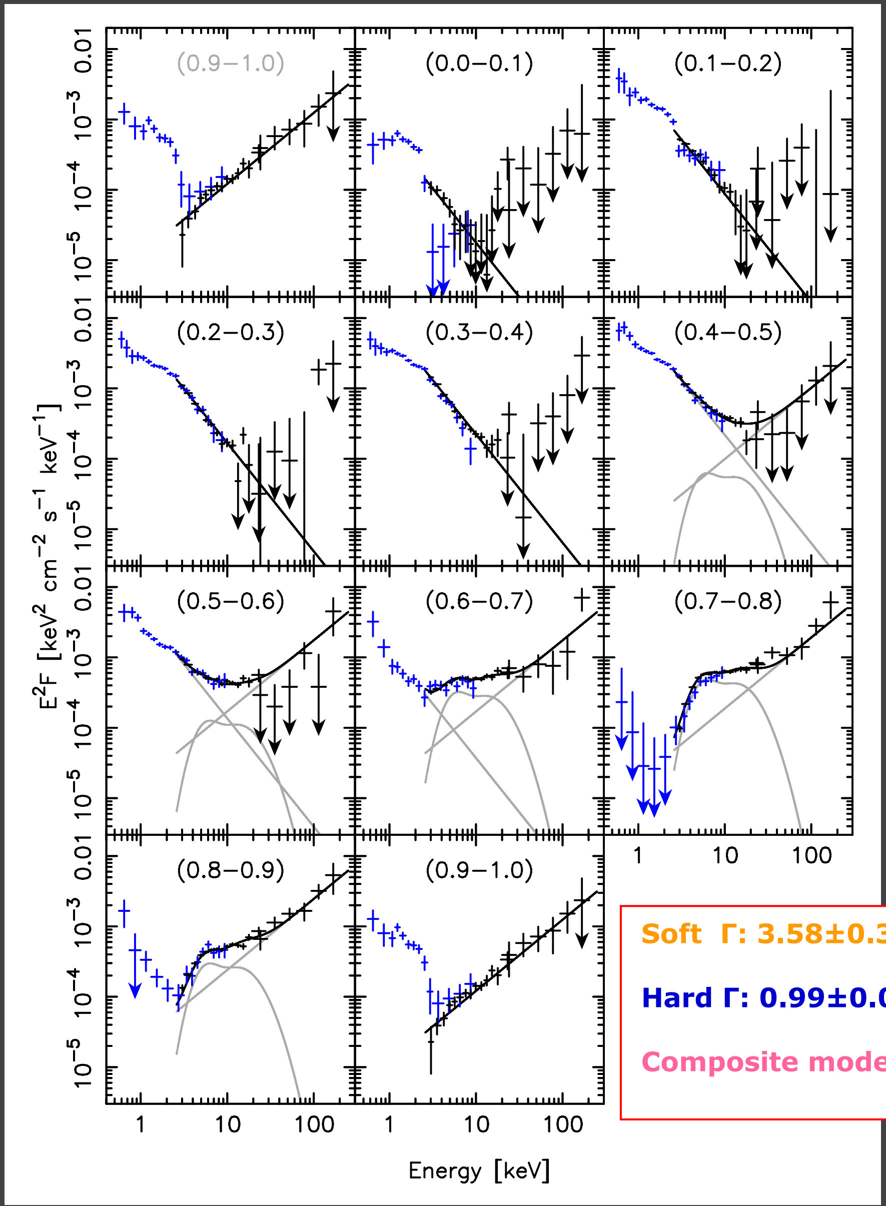
RXTE-PCA

8.2-16.1 keV

INTEGRAL-ISGRI

20-270 keV





Soft Γ: 3.58±0.34

Hard Γ: 0.99±0.05

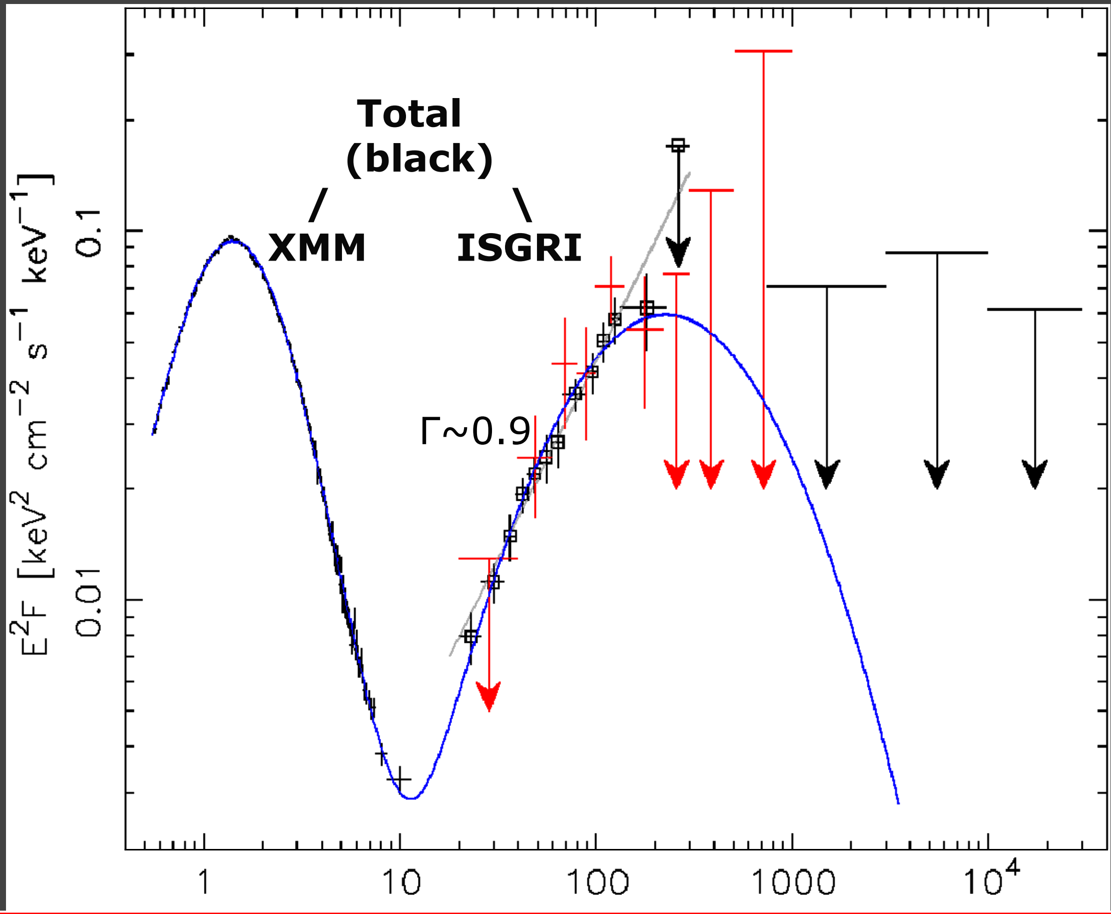
Composite model

Different components with different spectral shapes contribute to total pulsed emission

4U 0142+61: Total Pulsed HE-emission spectrum (0.5 keV – 30 MeV)

(den Hartog et al. 2008)

$L_X >> L_{spin\ down}$



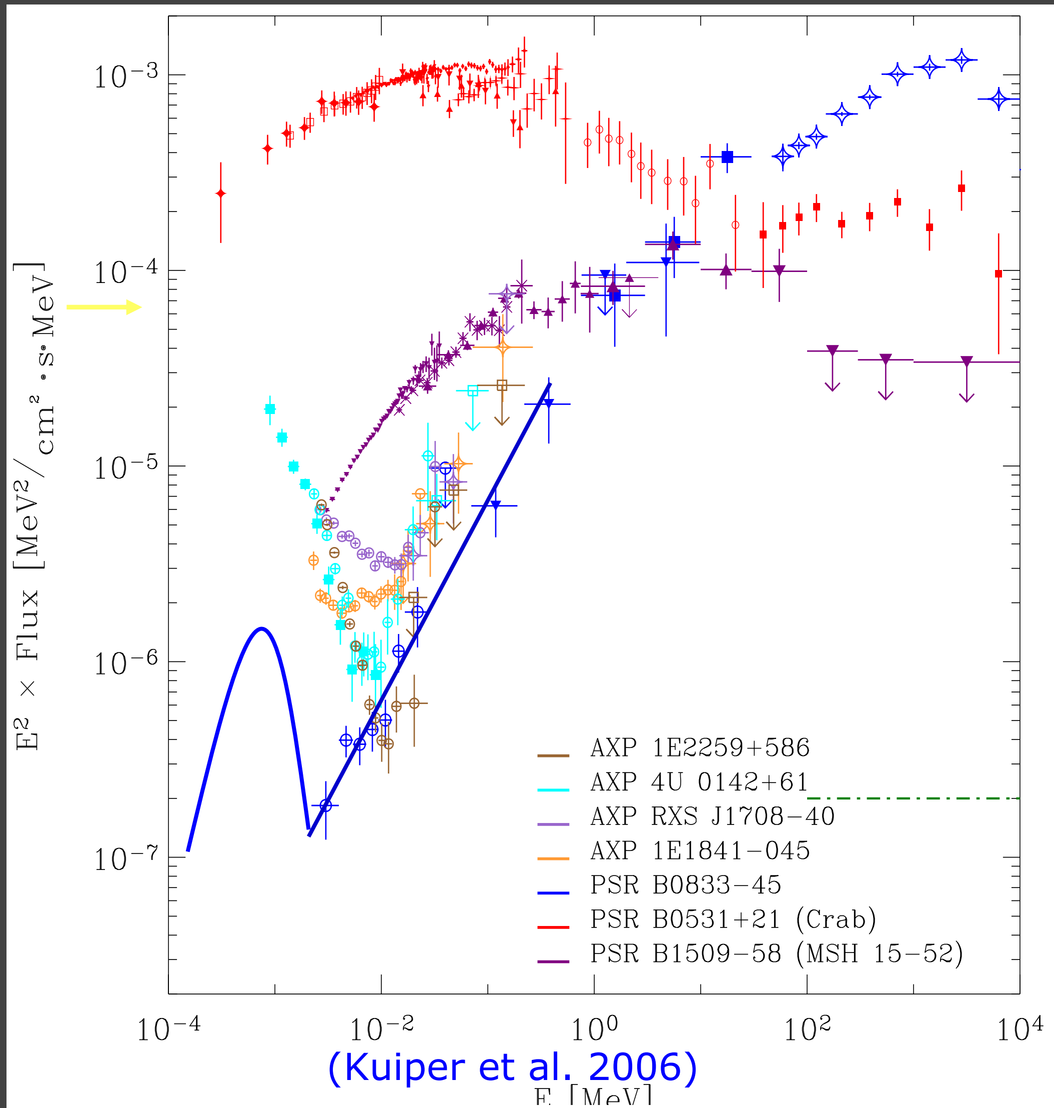
$L_\gamma >> L_{spin\ down}$

Several model fits, e.g. $BB+BB+PL_h$; $BB+PL_l+PL_h$; BB+PL+TB, or
E < 10 keV BB+resonant cyclotron scattering (Thompson et al. 2002; Lyutikov & Gavriil 2006; Fernandez & Thompson 2007; Guver et al 2007; Nobili, Turolla & Zane 2008; Rea et al. 2008, Zane et al. 2009)

All these papers just take an empirical PL to fit the hard X-rays!

Anomalous X-ray Pulsars are hard X-ray sources!!!

Comparison of the high-energy SED of the persistent emission from 3 AXPs with those from 3 young pulsars, Crab, PSR B1509-58 and Vela



(Kuiper et al. 2006)

Anomalous X-ray Pulsars are hard X-ray sources!!!

- **Pulsed emission > 10 keV exceptional hard: Γ -1 to 1**
- **Total emission: Γ 0.9 to 1.4**
- **Pulsed fraction → approaches 100% near 100 keV**
- **$L_x^{1-10} \sim L_x^{20-100} >> L_{spin\text{-}down}$**
- **Spectral breaks/bends above ~280 keV**
- **Persistent emission above 10 keV stable in flux and spectral index within statistics (15-20 %)**
- **Different components with different spectra contribute to total emission**
- **Pulse profiles stable over years**

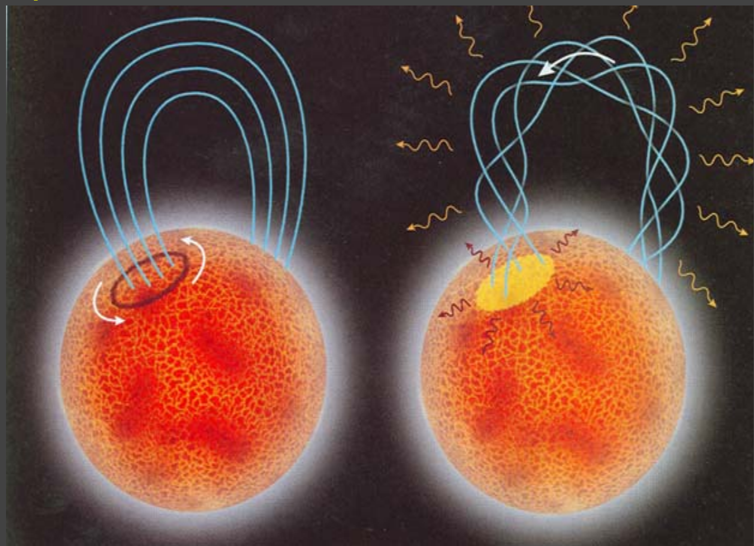
Production scenarios for persistent hard X-rays above 10 keV

1) Bremstrahlung photons produced in thin layer close to neutron star. Cutoff energy at ~100 keV (Beloborodov & Thompson 2007)

2) Magnetic Compton up-scattering of soft X-ray photons by non-thermal population of highly relativistic electrons (Baring & Harding 2007)

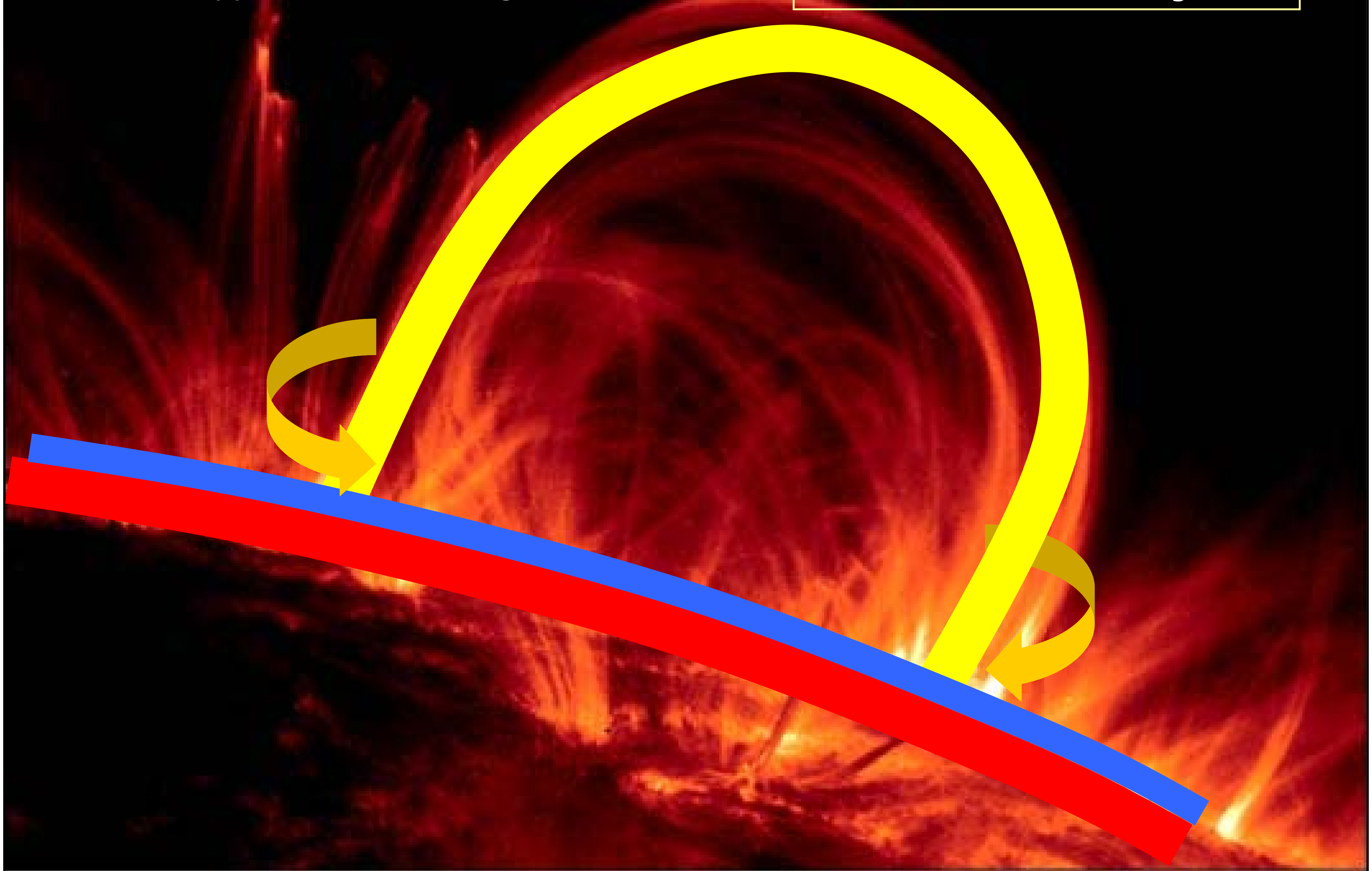
3) Secondary pairs in the closed-field-line region producing synchrotron radiation at a distance of ~100 km from the star (Thompson & Beloborodov 2005)

4) A quantum electrodynamical model involving magnetohydrodynamic fast-mode breakdown forming electron-positron pairs which can produce non-thermal emission far from the star (Heyl & Hernquist 2005)



Theoretical approach within magnetar model

Hot coronae around magnetars



(Beloborodov & Thompson 2006)

- **Magnetosphere is twisted and filled with a plasma corona (footpoint motions twist magnetic field anchored to surface)**
- **Plasma and electric field in the corona are self-organized**
- **The corona is made mostly of relativistic e+/- pairs**
- **Voltage eΦ ~1 GeV implies dissipation rate L= I Φ ~10^{36}** erg/s. **(twisted field is source of energy)**
- **Hard X-rays likely originated from transition region between corona and thermal photosphere: Bremsstrahlung spectrum expected Γ ~ 1 below cutoff (too hard for SGRs)**
- **The corona lives 1-10 yr unless new star quakes happen: variability?**

SRON

Production scenarios for persistent hard X-rays above 10 keV

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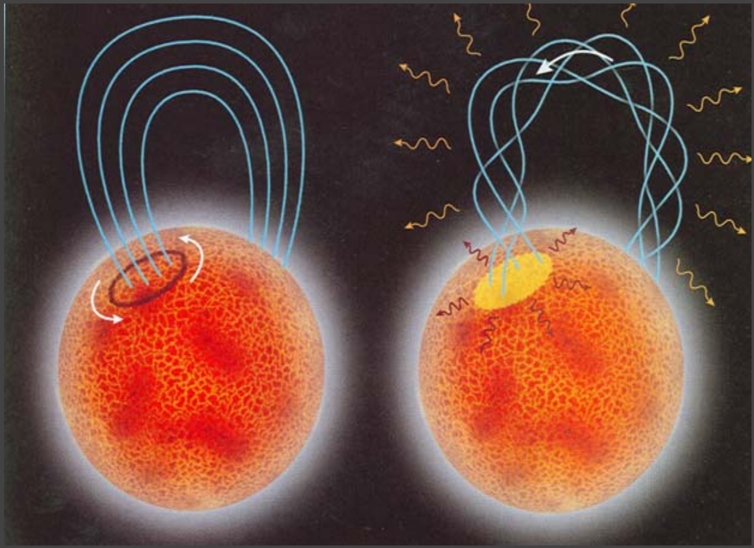


None of these models explain all observed characteristics

Anomalous X-ray Pulsars are hard X-ray sources

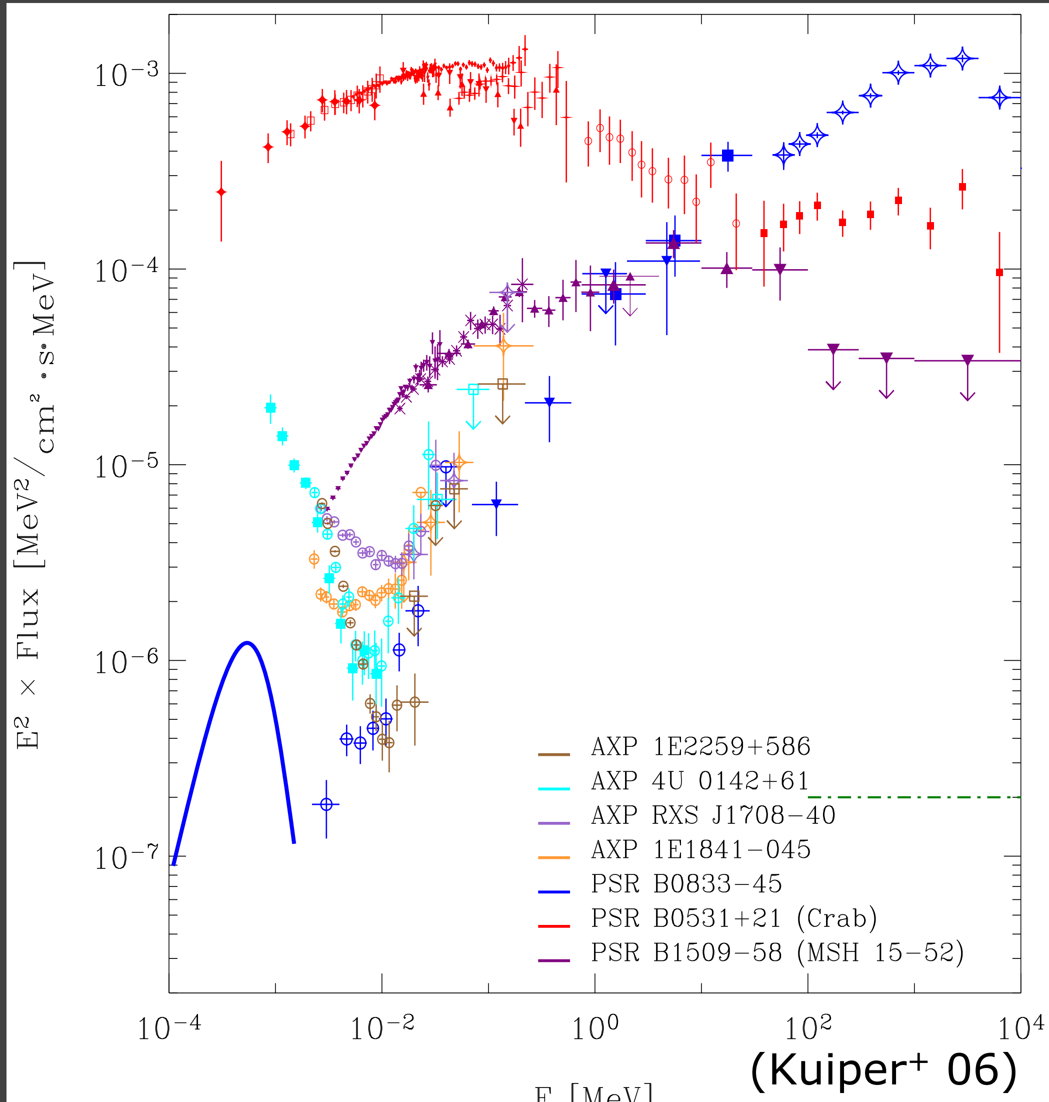
Three young pulsars, Crab, PSR B1509-58 and Vela compared with three AXPs

The GBM wil be able to extend the spectra to the MeV range?

Wil the LAT see emission from magnetars?

Production of non-thermal emission high in the magnetosphere?

Near light cylinder?



(Kuiper+ 06)

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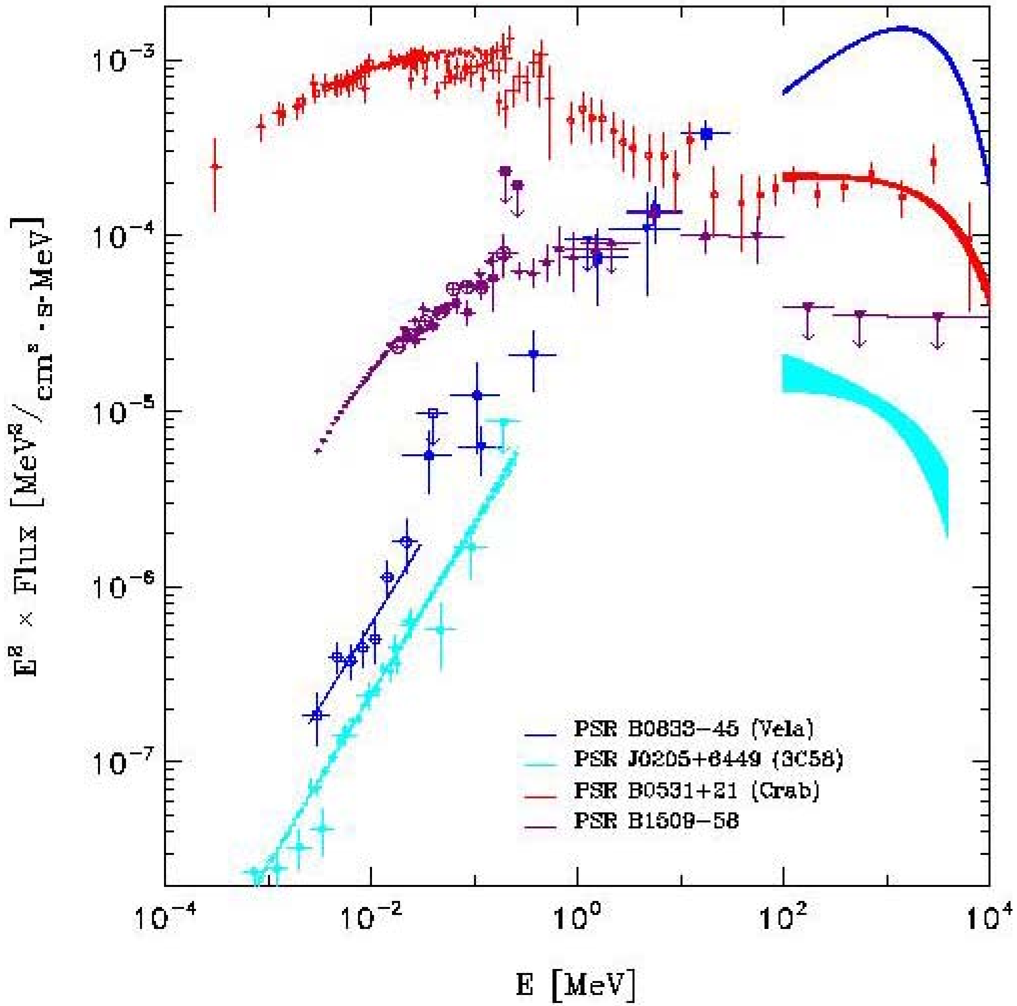
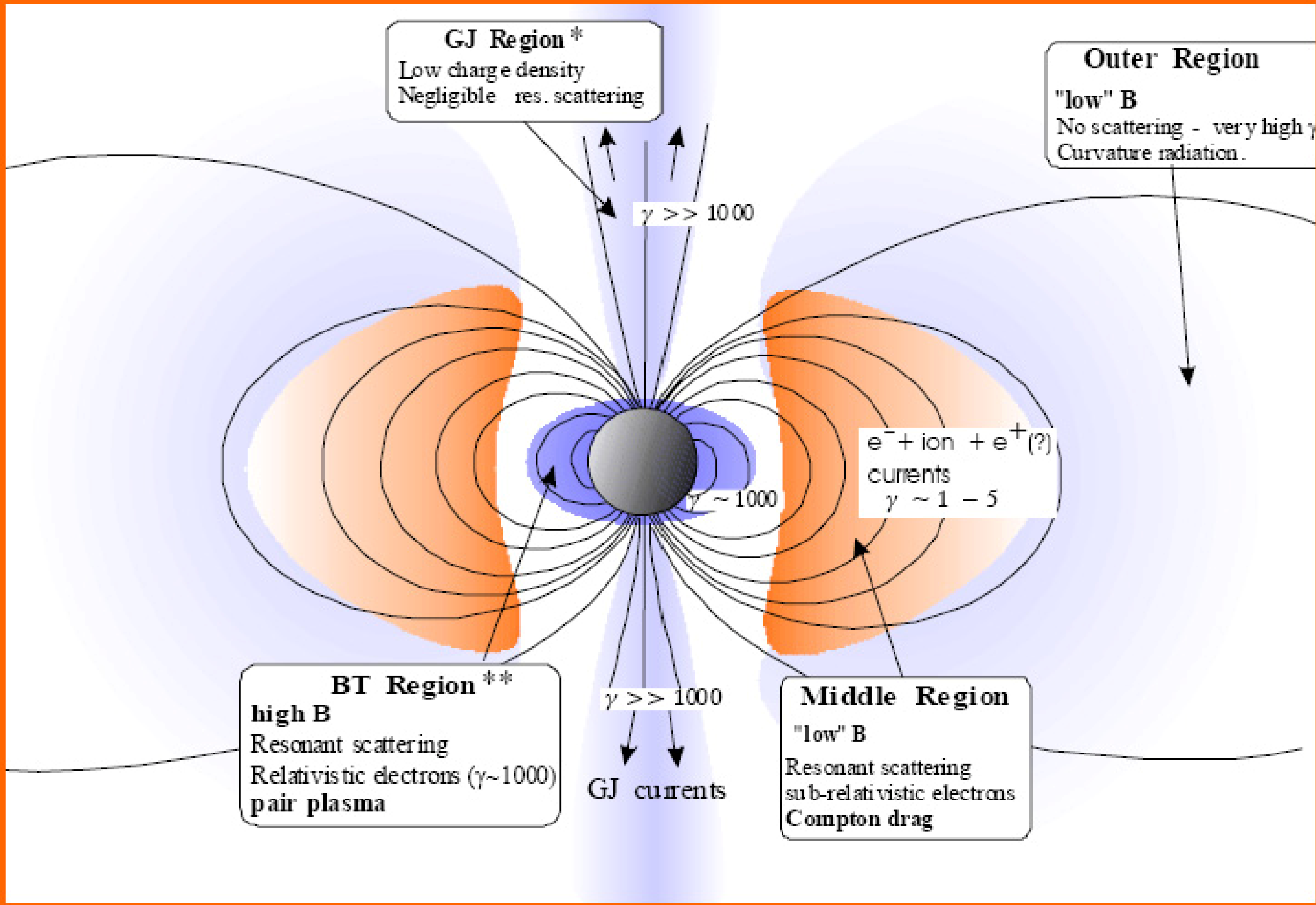
Young pulsar PSR J0205+6449 is at 20 keV order of magnitude weaker than AXPs, but is detected by FERMI



SRON

a big onion



* Goldreich & Julian 1969
** Beloborodov & Thompson 2007

(Nobili 2009)

(not in scale)

Current-carrying bundle of field lines at the pole ("j-bundle"); Beloborodov, 2009

SRON

- In conclusion, there is yet no agreed model that explains the measured characteristics of the luminous, non-thermal persistent hard X-ray emission measured from AXPs.

- The cartoon drawn by Nobili might give indications for emission or acceleration sites at higher altitudes in the magnetosphere in more stable regions for the production of this component.