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Review on magnetar observations

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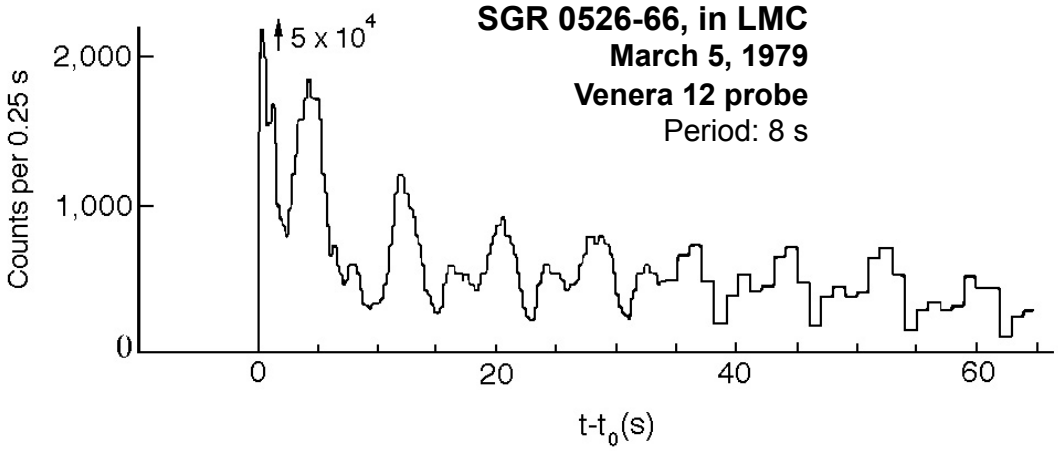
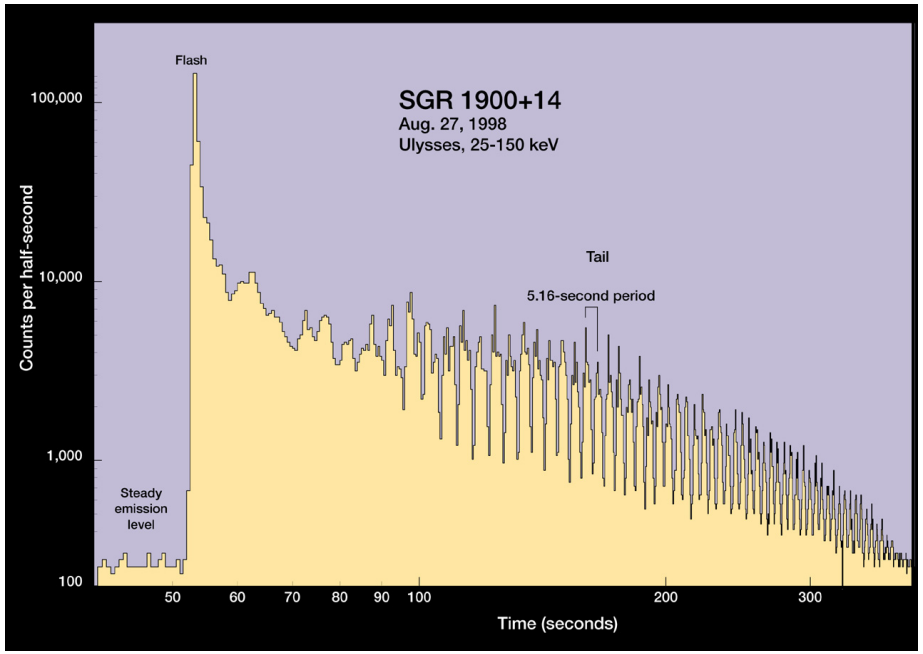
Outline

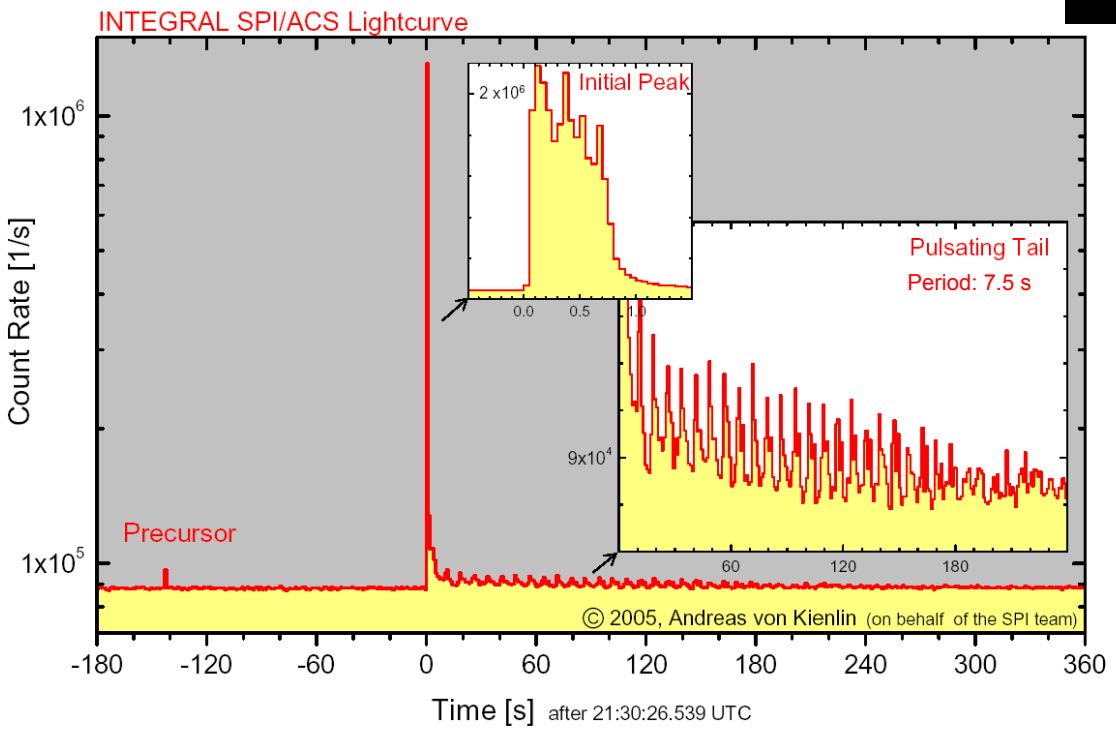
- **OBSERVATIONAL PROPERTIES** distinguishing Anomalous X-ray Pulsars (**AXPs**) and Soft Gamma-ray Repeaters (**SGRs**) from **ALL** the other astrophysical objects:
  - Giant Flares;
  - bursts;
  - peculiar absorption features
- What **KEY OBSERVATIONS** might better clarify **MAGNETAR** origin, properties and evolution?

SGR Giant Flares



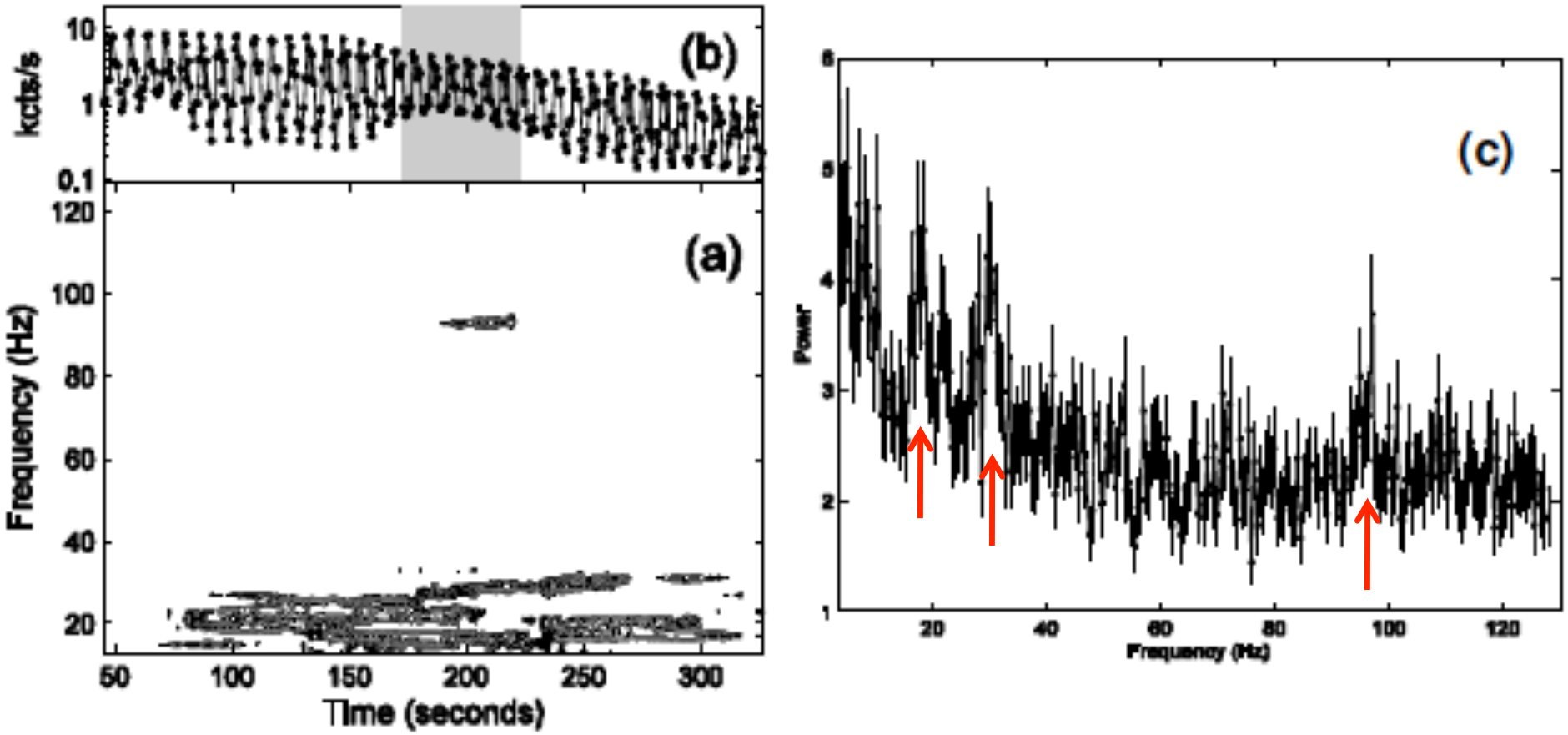


SGR 1806-20 Outburst on December 27, 2004



Bright ($E>10^{44}$-10^{46} erg) and short ($\Delta t<0.5$ s) **BURST** followed by **PULSATING TAIL** ($P\sim5$-8 s; $\Delta t\sim5$ min; $E\sim10^{44}$ erg)

QPOs in SGR Giant Flare tails

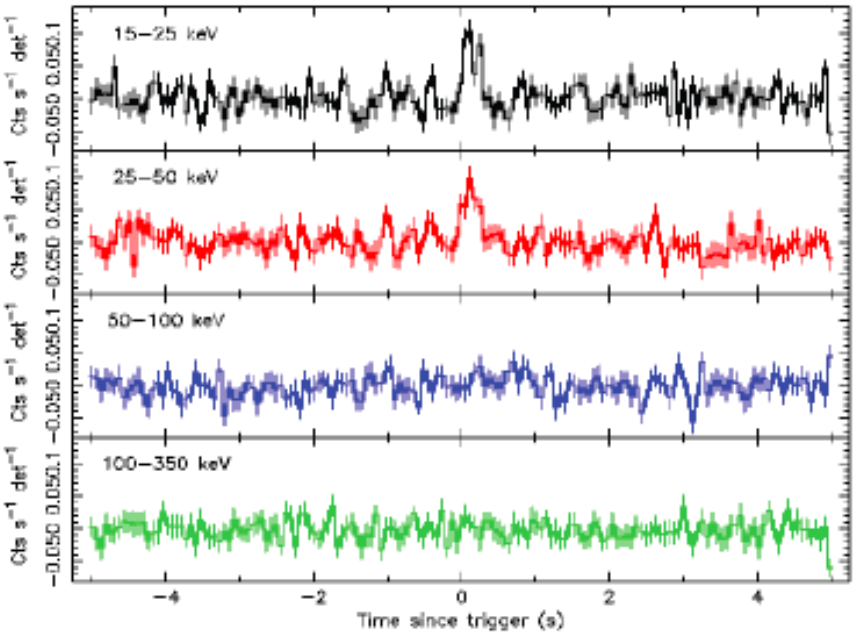


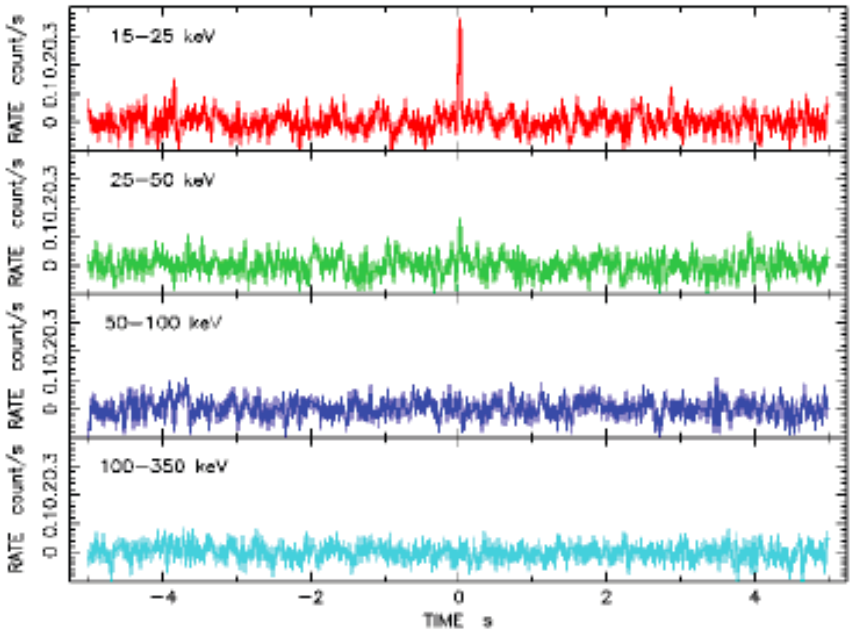
- Quasi-Periodic Oscillations (**QPOs**) in pulsating tails ⇒ seismic neutron star oscillations *(Israel et al. 2005; Strohmayer & Watts 2005, 2006)*
- Now detected also in normal bursts *(Huppenkothen et al. 2014; 2015)*

SGR bursts

Detected only in SGRs and AXPs, with only few **EXCEPTIONS**:

- 2 bursts detected by Swift/BAT in X-ray binary **LS I +61° 303**





(Torres et al. 2012, P. Esposito)

2008 Sep 10

T_{90} = 0.24 s; kT = 8 keV

$L_{(15–50\ keV)} = 2.4 \times 10^{37}$ erg s^{-1}

2012 Feb 05

T_{90} = 0.04 s; kT = 6 keV

$L_{(15–50\ keV)} = 8.1 \times 10^{37}$ erg s^{-1}

Peculiar object (variable from radio to TeV): **Be** star +

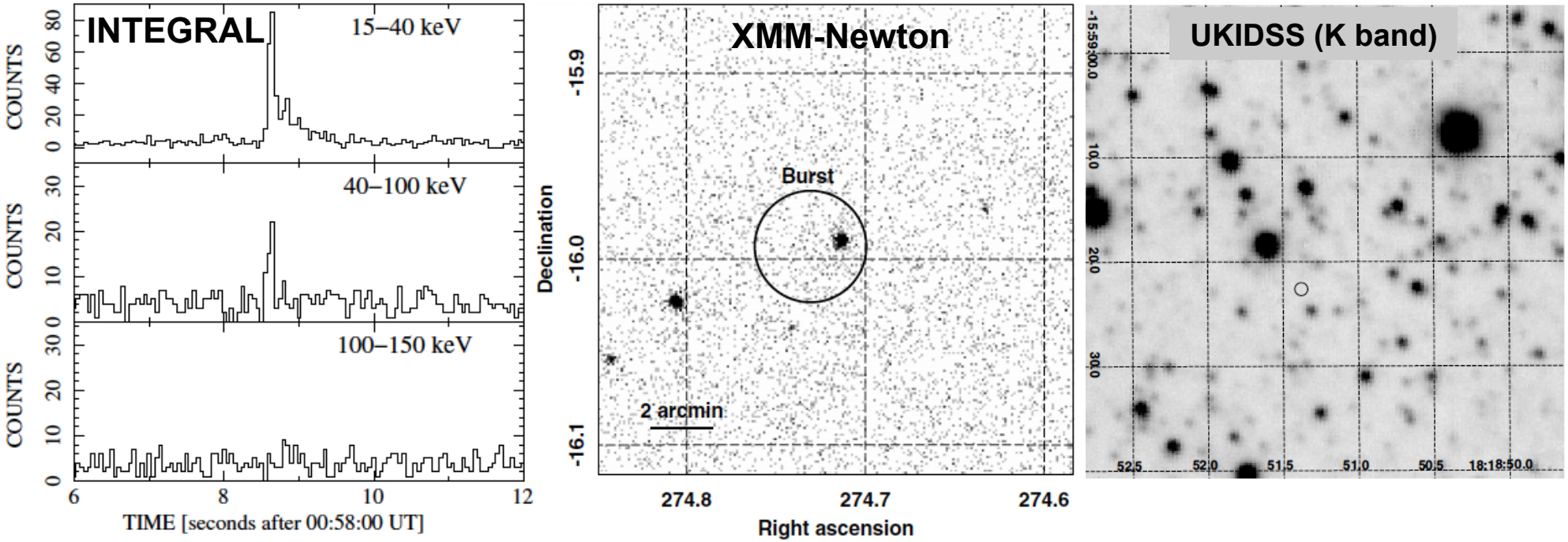
BH (μquasar) OR **NS** (**MAGNETAR?**)

SGR bursts

Detected only in SGRs and AXPs, with only few **EXCEPTIONS**:

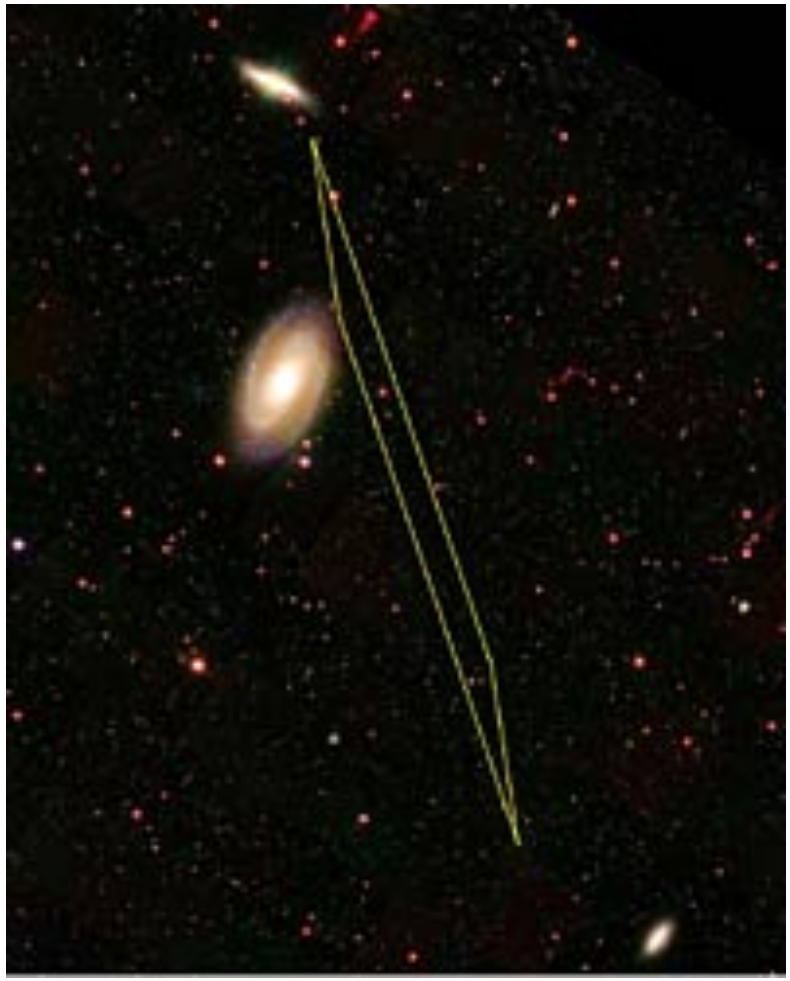
- Galactic bursts with **NO** clear AXP-like **COUNTERPART**

EXAMPLE: AX J1818.8−1559 *(Mereghetti et al. 2012)*

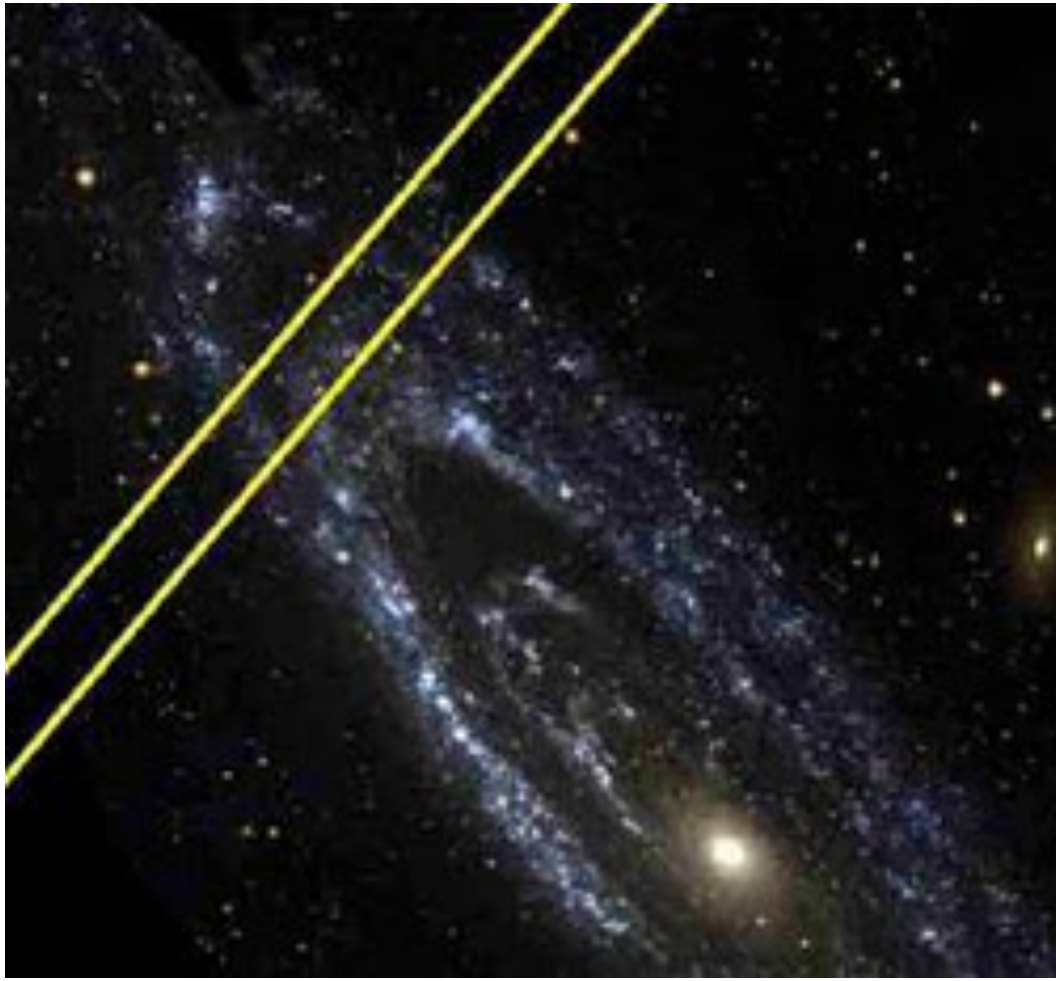


No pulsations, but X-ray source consistent with **AXP/SGR**

Extra-galactic Giant Flares?



GRB 051103 in M81 or M82
(Frederiks et al. 2007)



GRB 070201 in M31
(Ofek et al. 2008)

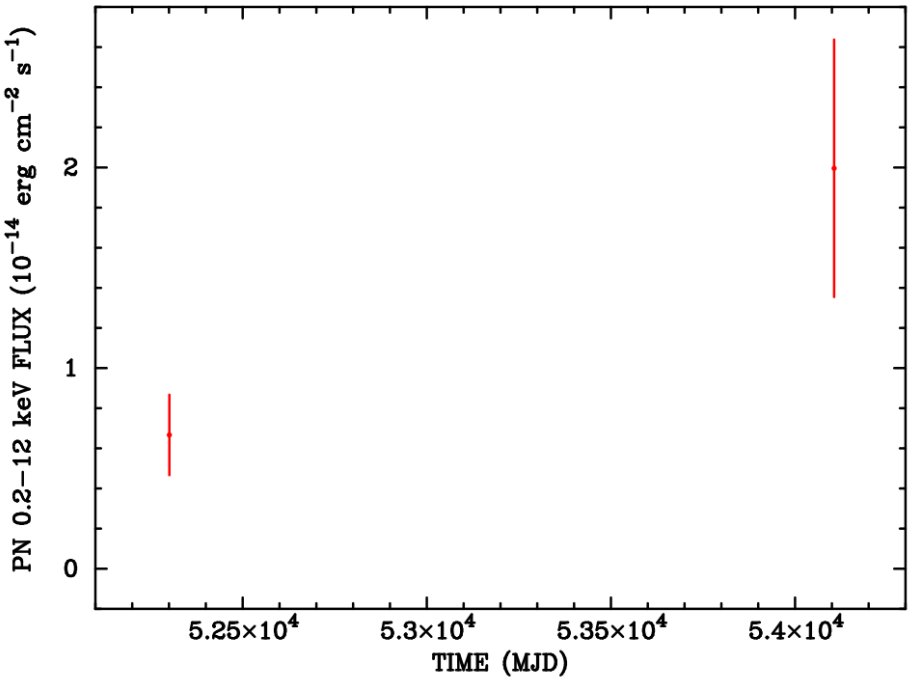
Extra-galactic Giant Flares: ~1–15% of **SHORT GRBs** *(Hurley 2011)*

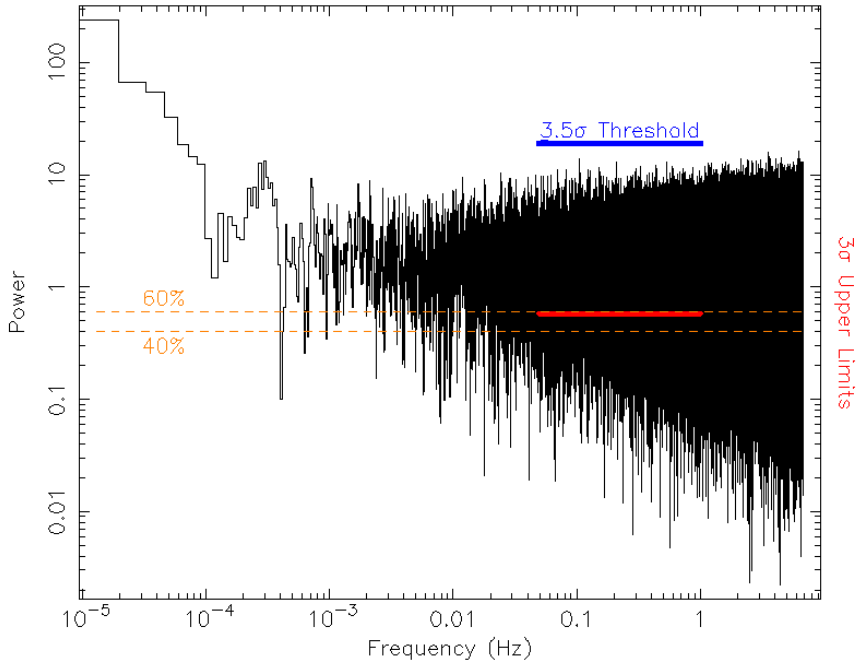
A magnetar in M31?

- **GRB 150301C**: ~15 s burst detected by Swift/BAT from **M31** disk
- Swift/**XRT** source brighter than in **XMM** archival data *(GCN 17536)*

Possibly the first **MAGNETAR** in M31: intermediate **FLARE** (10^{43} erg)
+ persistent emission (6×10^{35} erg/s)

GCN 17548/ATel #7181



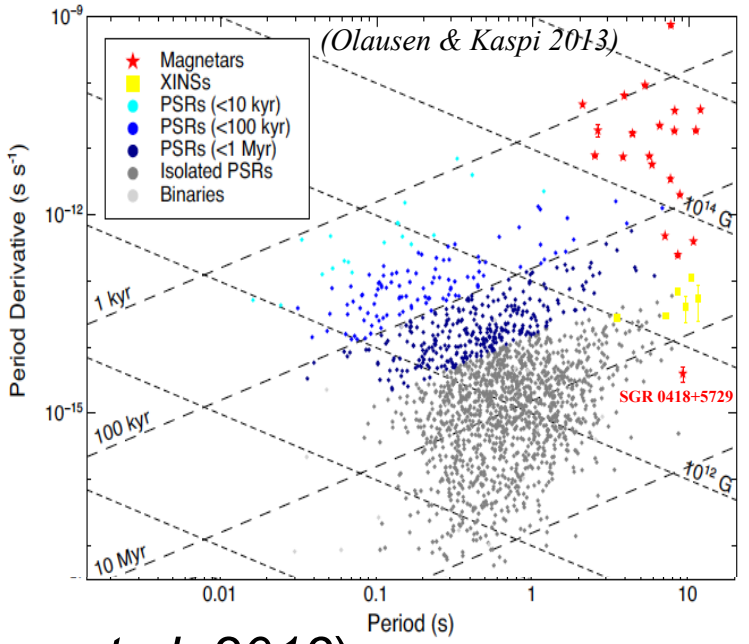


EXTraS project (PI: De Luca): http://www.extras-fp7.eu

The "*low B*" magnetar SGR 0418+5729

- Two **BURSTS** detected on 2009 June 05, spin **PERIOD** of 9.1 s (*van der Horst et al. 2010*)

- Typical features of a (transient) **SGR**
  - Large flux increase and decay
  - Emission of bursts
  - Period in the SGR/AXP range (2–12 s)



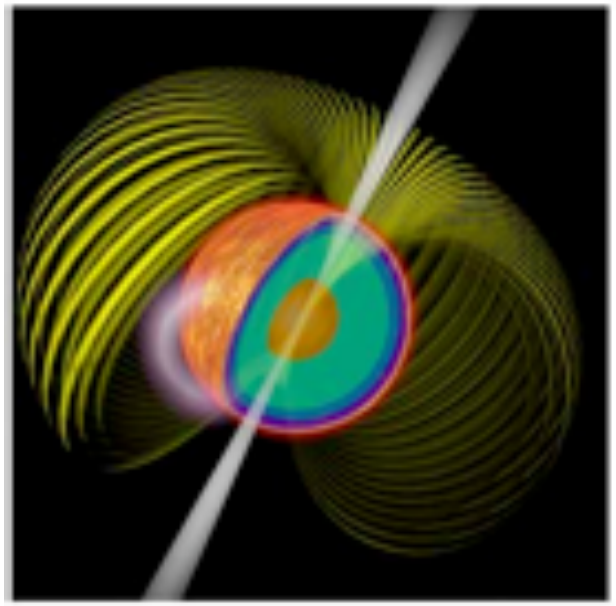
- Small **PERIOD DERIVATIVE** (4×10^{-15} s s^{-1}, *Rea et al. 2013*)

  $\Rightarrow$ $B_{dip} \approx 6 \times 10^{12}$ G $\Rightarrow$ a **LOW MAGNETIC FIELD** magnetar?

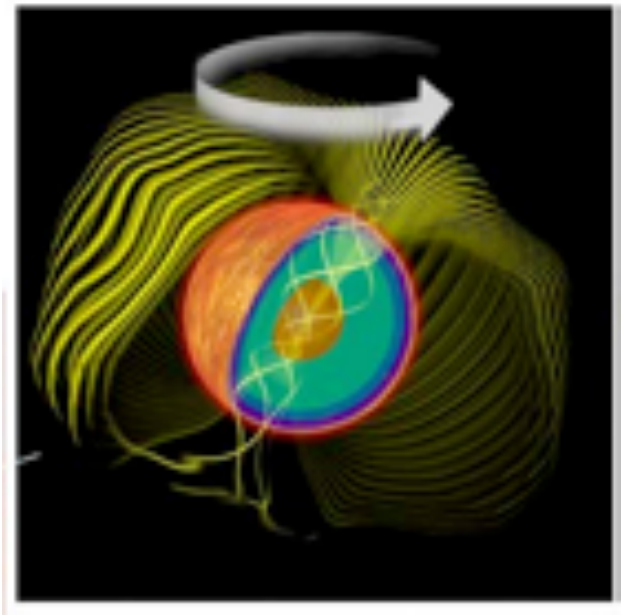
- Consistent with magnetar model if born with higher B field and **INTERNAL** (crustal) B > 10^{14} G (*Rea et al. 2010; Turolla et al. 2011*)

The importance of being twisted

High-*B* radio PSRs



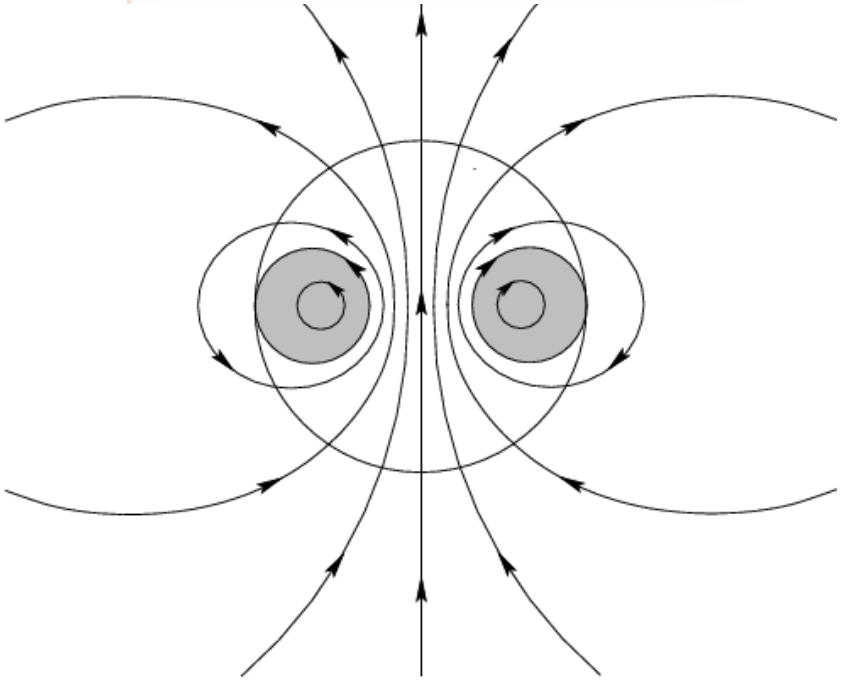
High-*B*



Magnetars

The internal **TOROIDAL** *B* produces the crustal displacements responsible for the bursting/outbursting episodes in AXPs/SGRs

(Thompson & Duncan 1995; Thompson et al 2002; Beloborodov 2009)



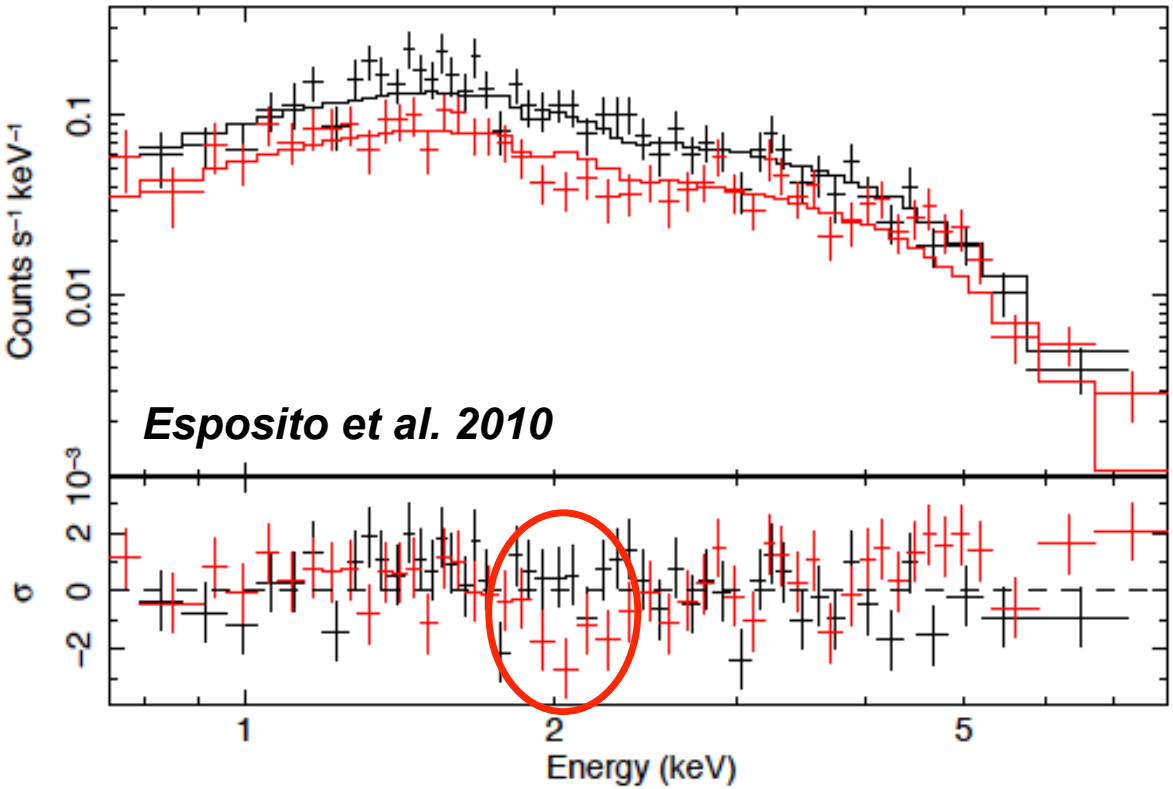
(Braithwaite & Spruit 2006)

Another “anomaly” of SGR 0418+5729

Swift/XRT (WT mode)
2009 July 12-16

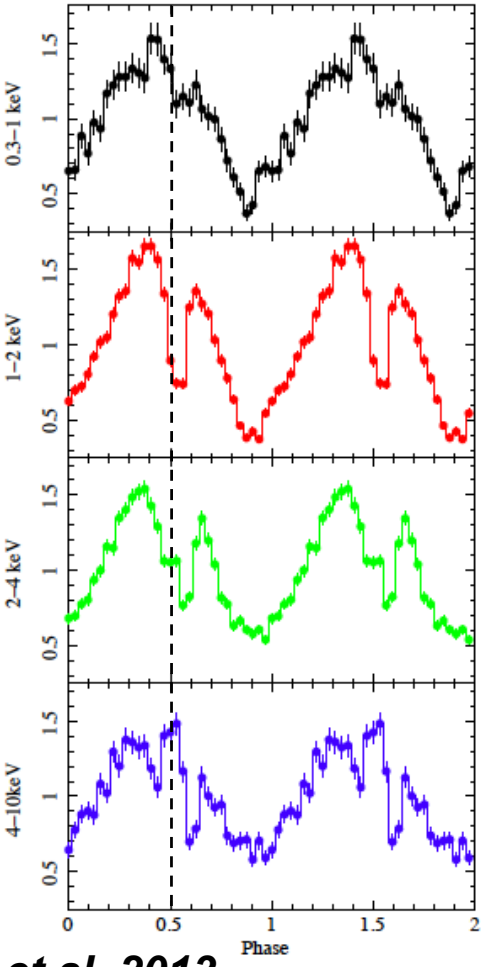
Spectra from adjacent phase intervals:

ABSORPTION LINE at ~2 keV?



Esposito et al. 2010

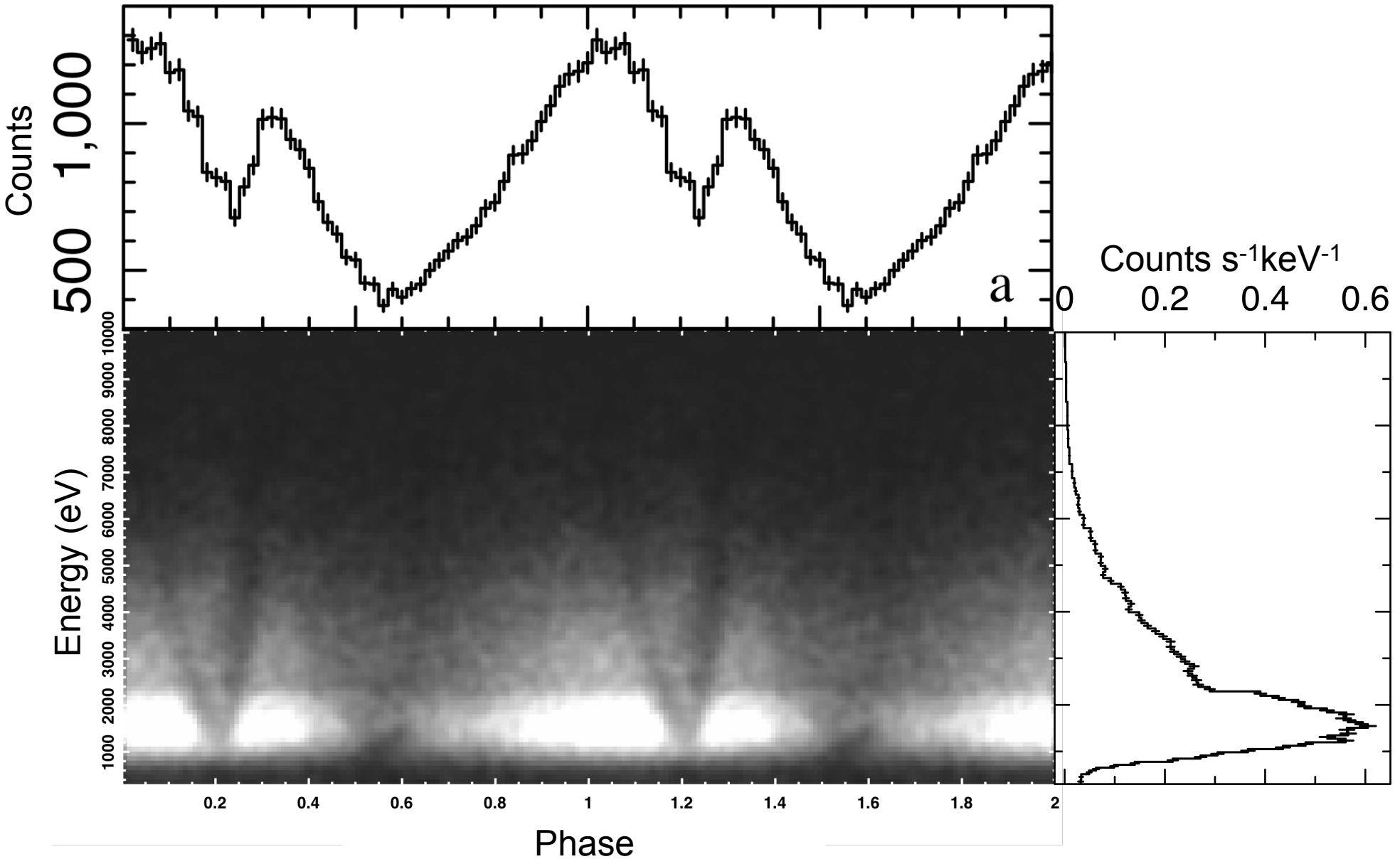
XMM-Newton/EPIC
2009 August 12



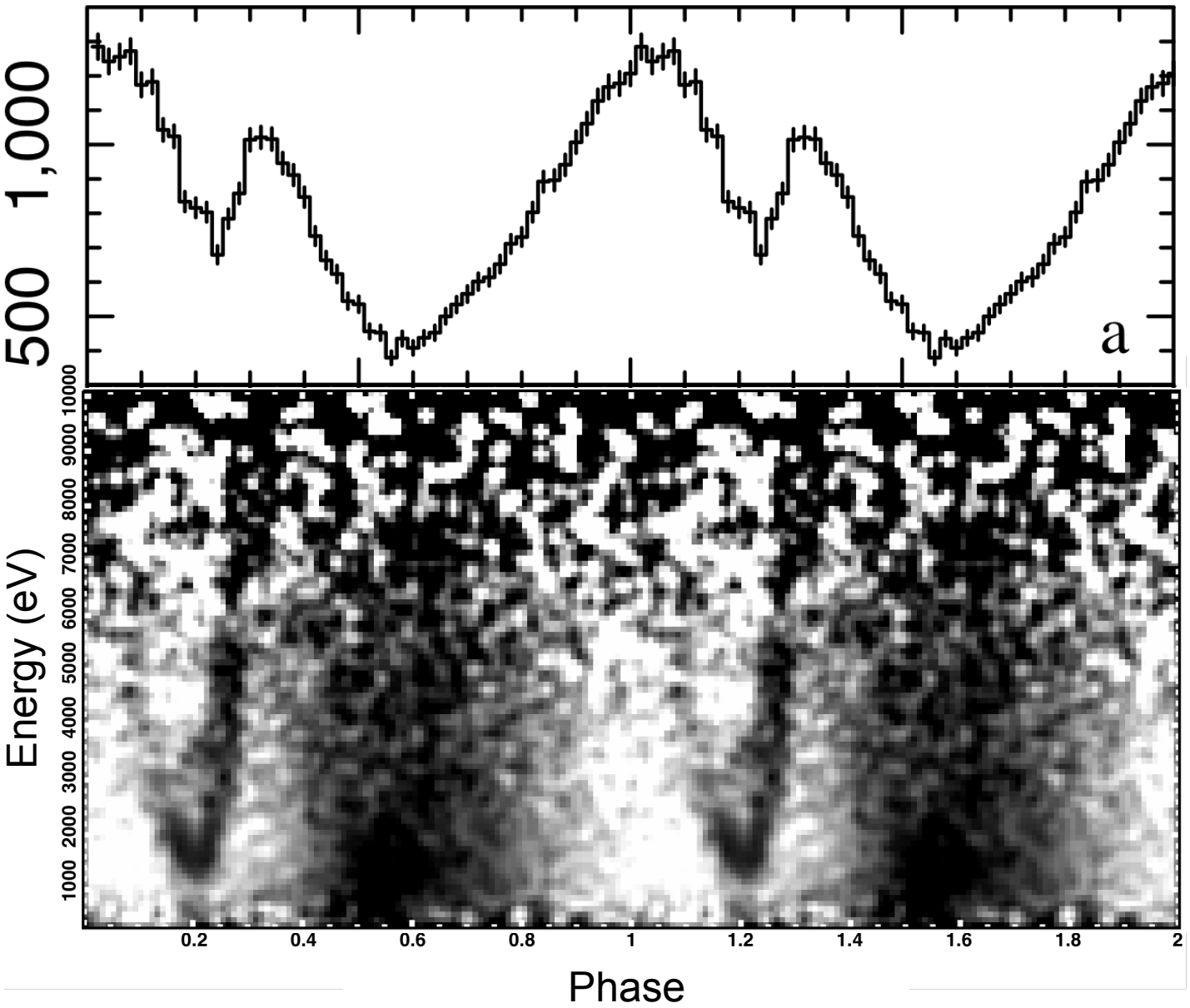
Rea et al. 2013

Indications for a PHASE-VARIABLE spectrum

XMM-Newton/EPIC phase-energy image



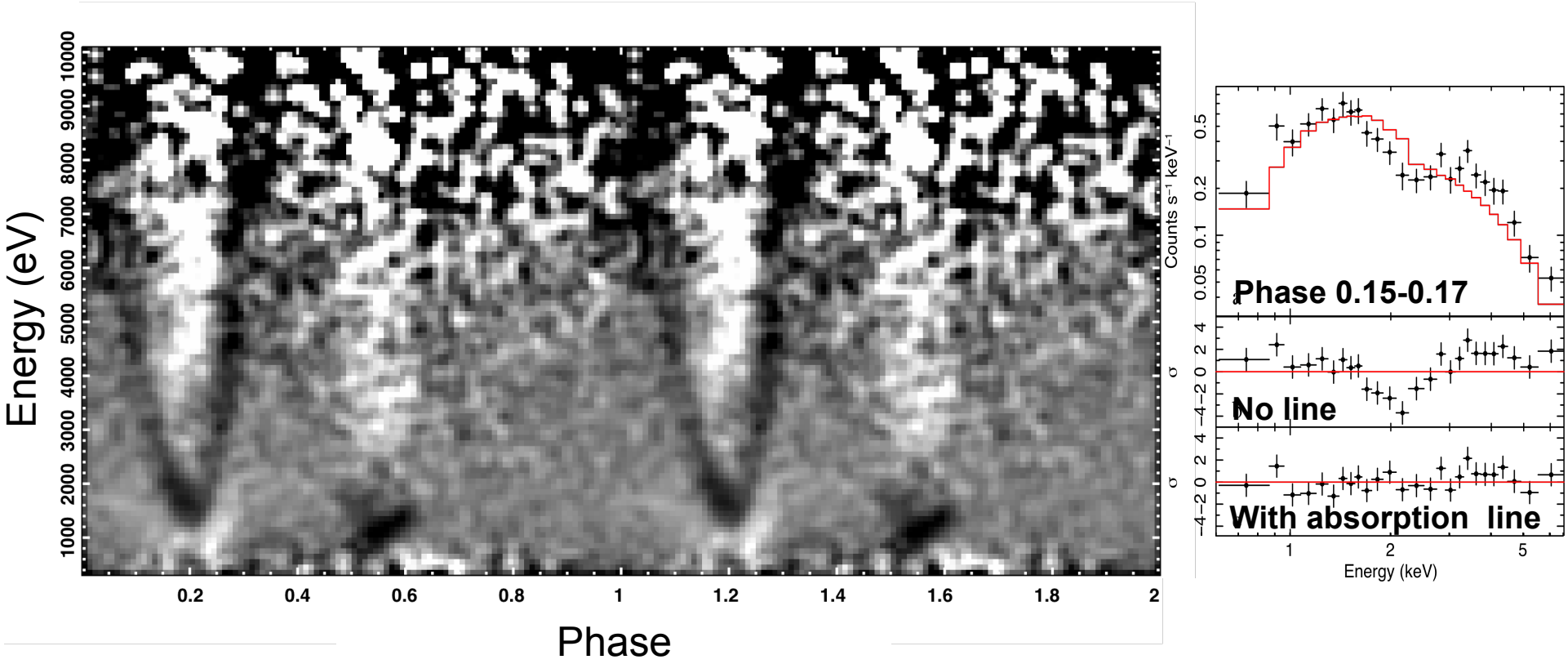
XMM-Newton/EPIC phase-energy image



Normalized to the phase-averaged spectrum

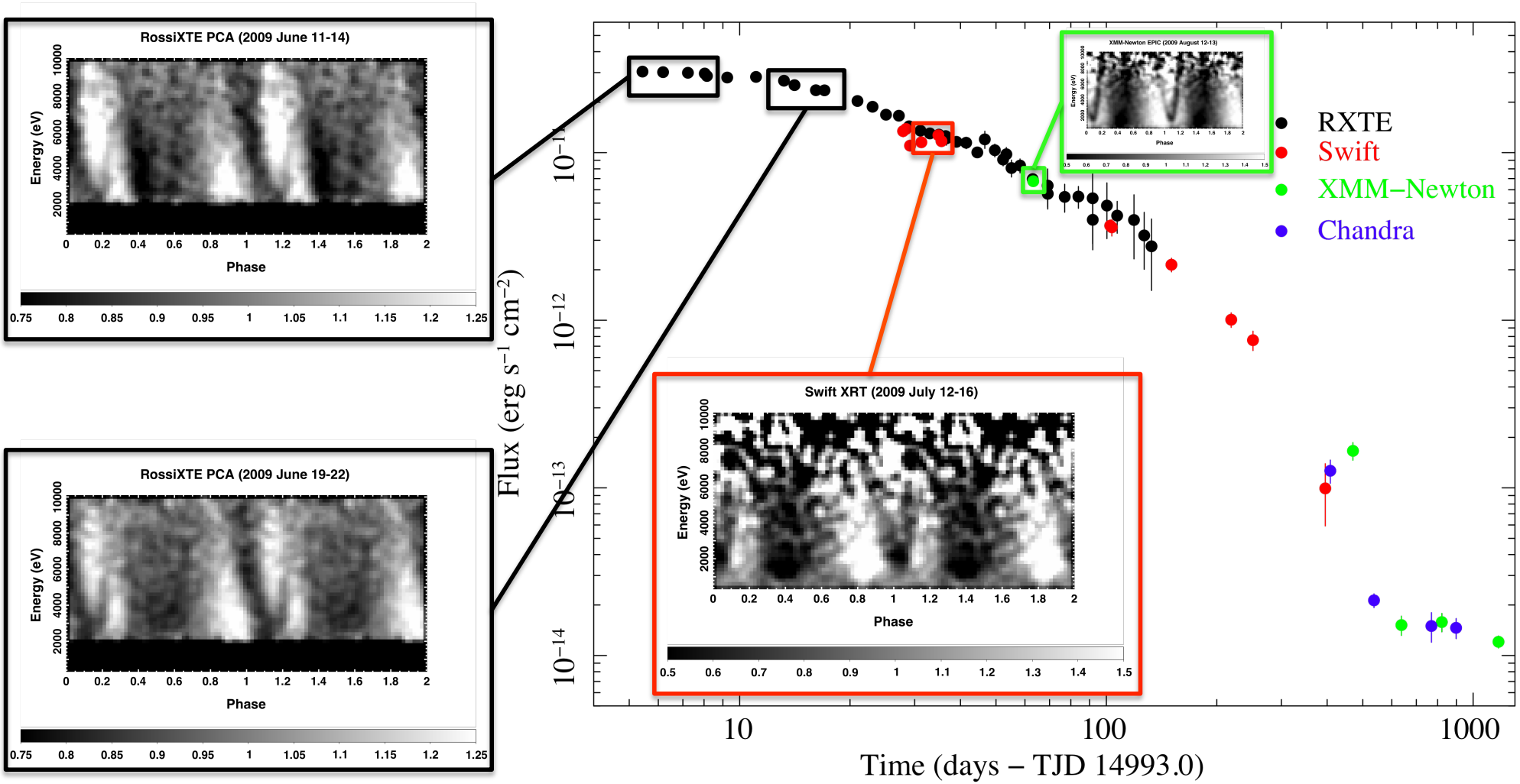
XMM-Newton/EPIC phase-energy image

Normalized to the phase-averaged spectrum AND the energy-integrated pulse profile



An ABSORPTION LINE at a phase-variable energy

Detected in earlier RXTE and Swift data



- Line is **NOT** due to **INSTRUMENTAL** effects
- Line detected since the **BEGINNING** of the outburst

Past claims of lines in magnetars

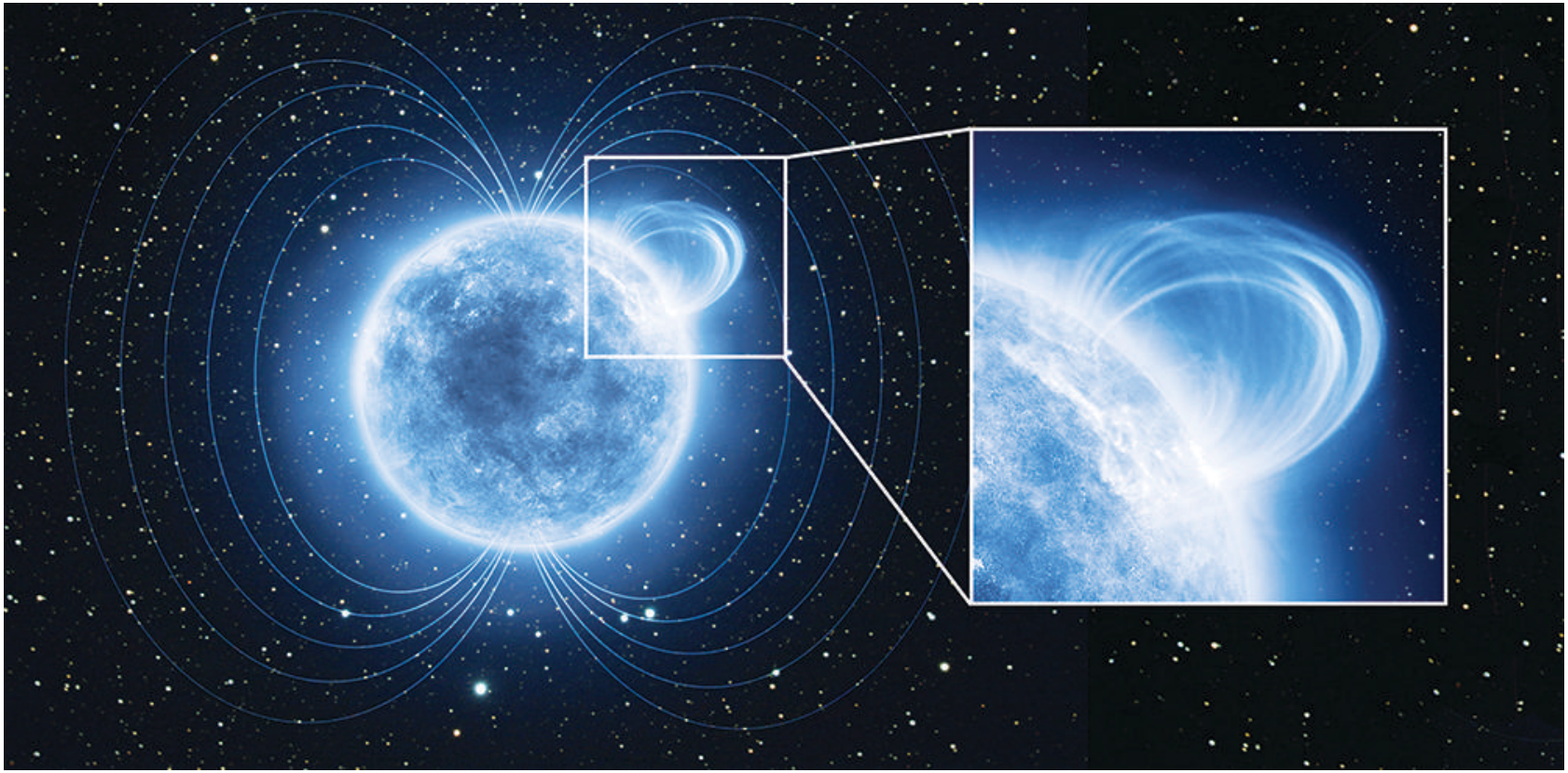
AXP/SGR	Line energy (keV)	Significance (σ)	Satellite/ Instrument	Notes
1E2259+586	5,10	-	GINGA/LAC	PPS, absorption
SGR1806-20	5,7.5,11.2,17.5	3.3	RXTE/PCA	Burst, absorption
4U0142+614	4,8,14	-	RXTE/PCA	Bursts,emission
1E1048-5937	14;13	3.9;3.3	RXTE/PCA	Bursts,emission
XTE1810-197	12.6	4.5	RXTE/PCA	Burst,emission
1RXS1708-4009	8.1	2.95	SAX/MECS	PPS, absorption
SGR1900+14	6.4	3.7	RXTE/PCA	Burst, emission

NOT confirmed by XMM/Chandra, but ~13 keV emission line in 1E 1048-5937 burst tail with ***NuSTAR*** *(An et al. 2014)*

Interpretation within magnetar model

PROTON CYCLOTRON ABSORPTION FEATURE:

- $E_{cycl,p} = 0.6\ B_{14}$ keV ⇒ **B ~ (2-20) x 10^{14} G** ⇒ **MAGNETAR** field
- **STRONGLY VARIABLE B** along a **VERTICAL** plasma structure (coronal loop analogy; *Beloborodov & Thompson 2007; Masada et al. 2010*)



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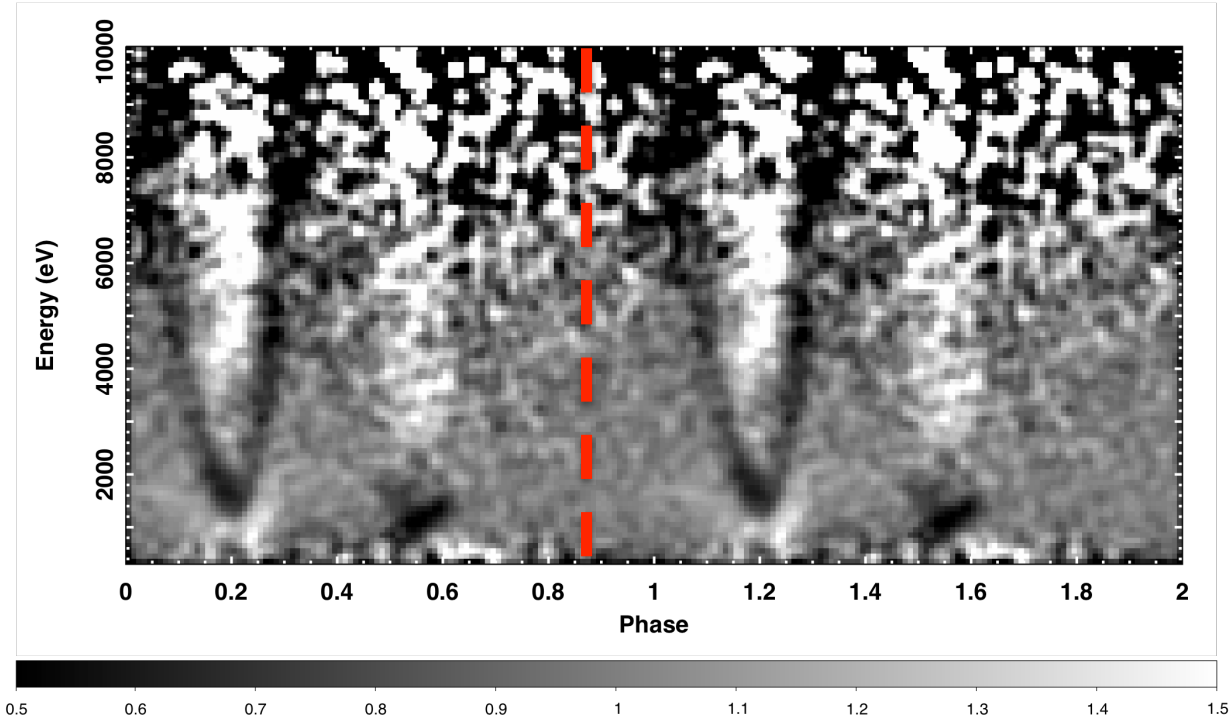

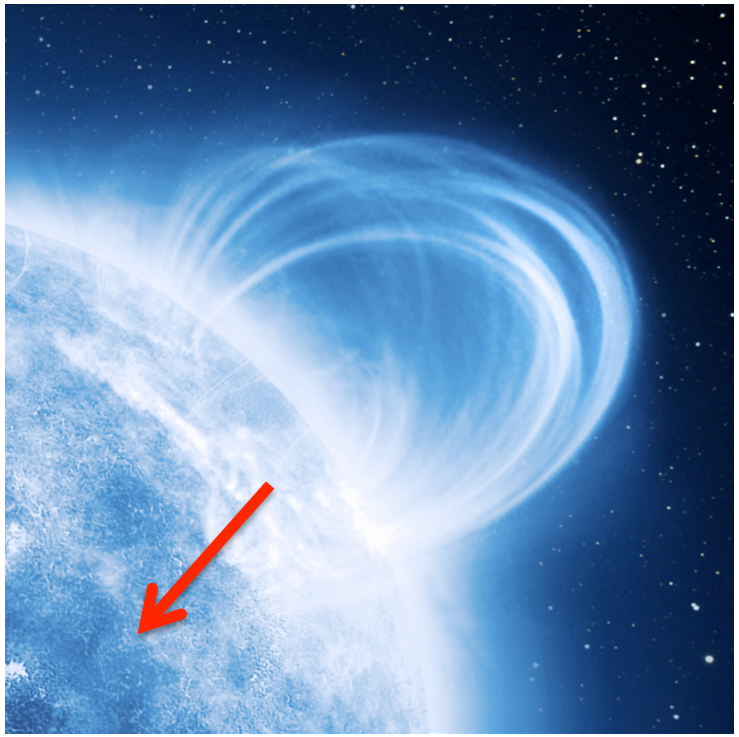

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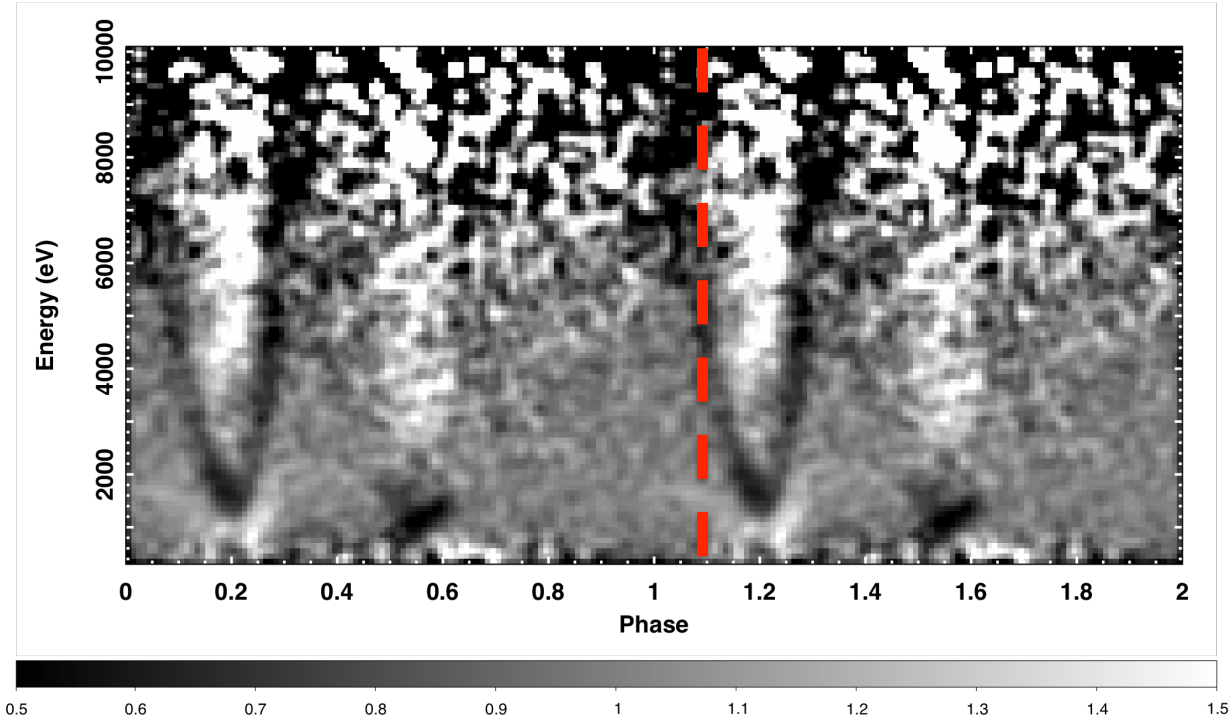

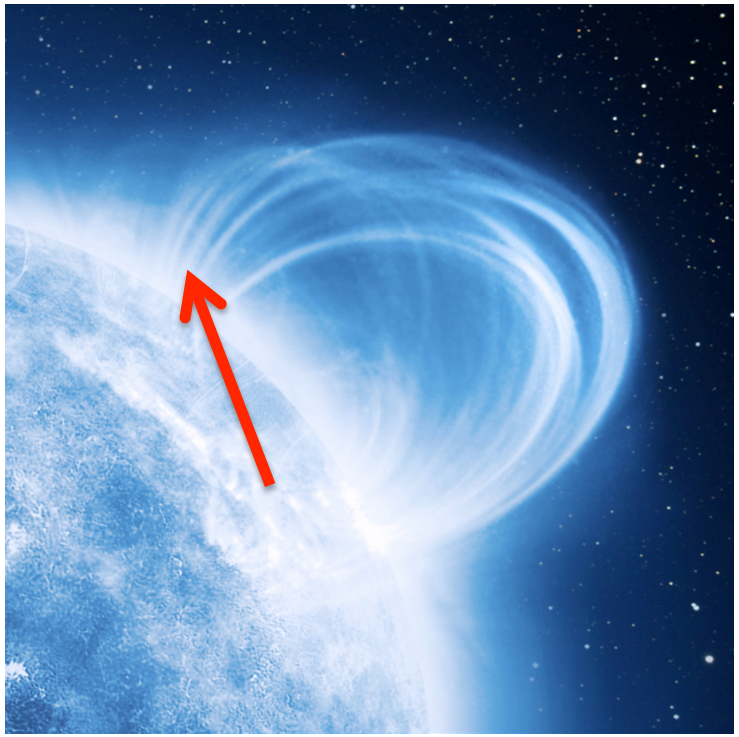

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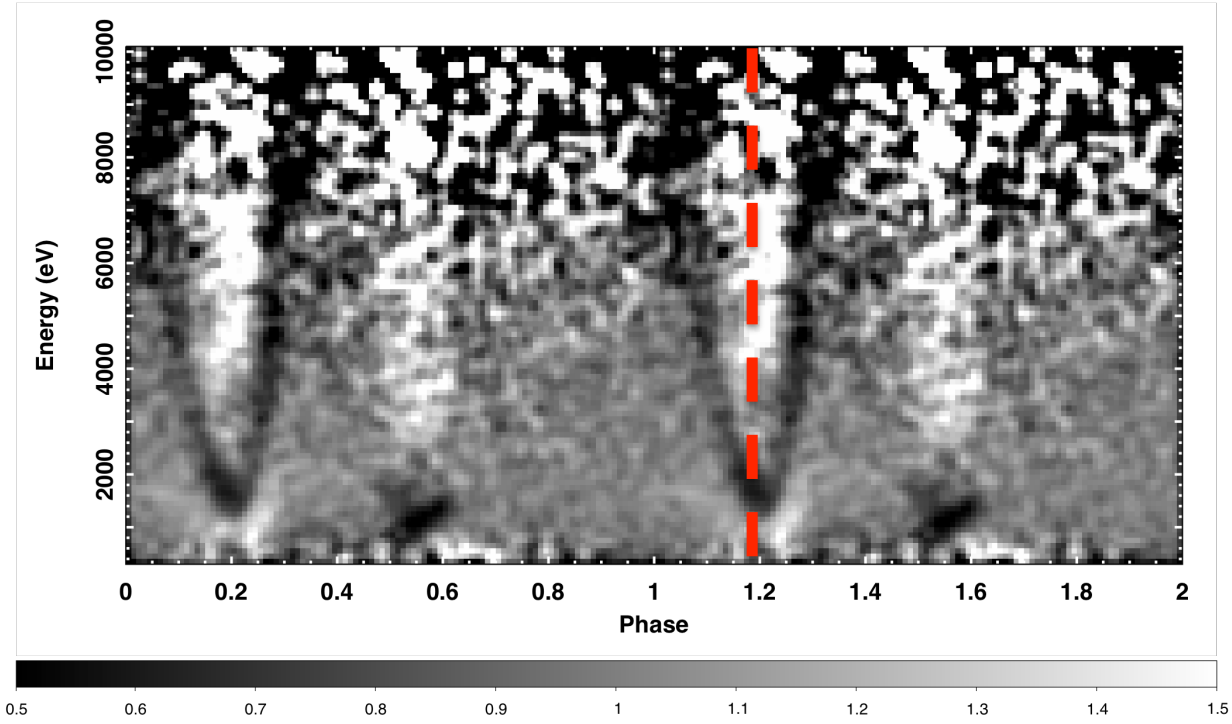

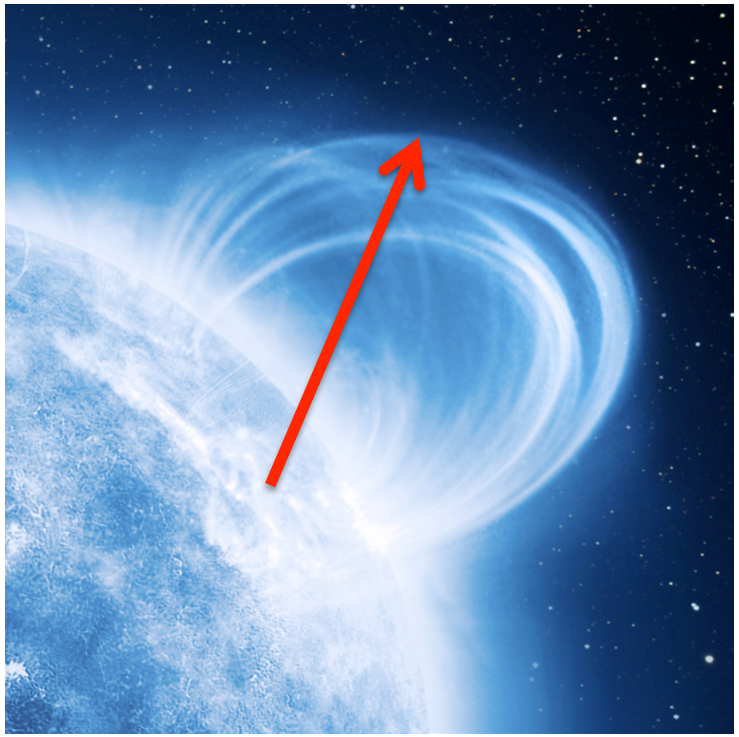

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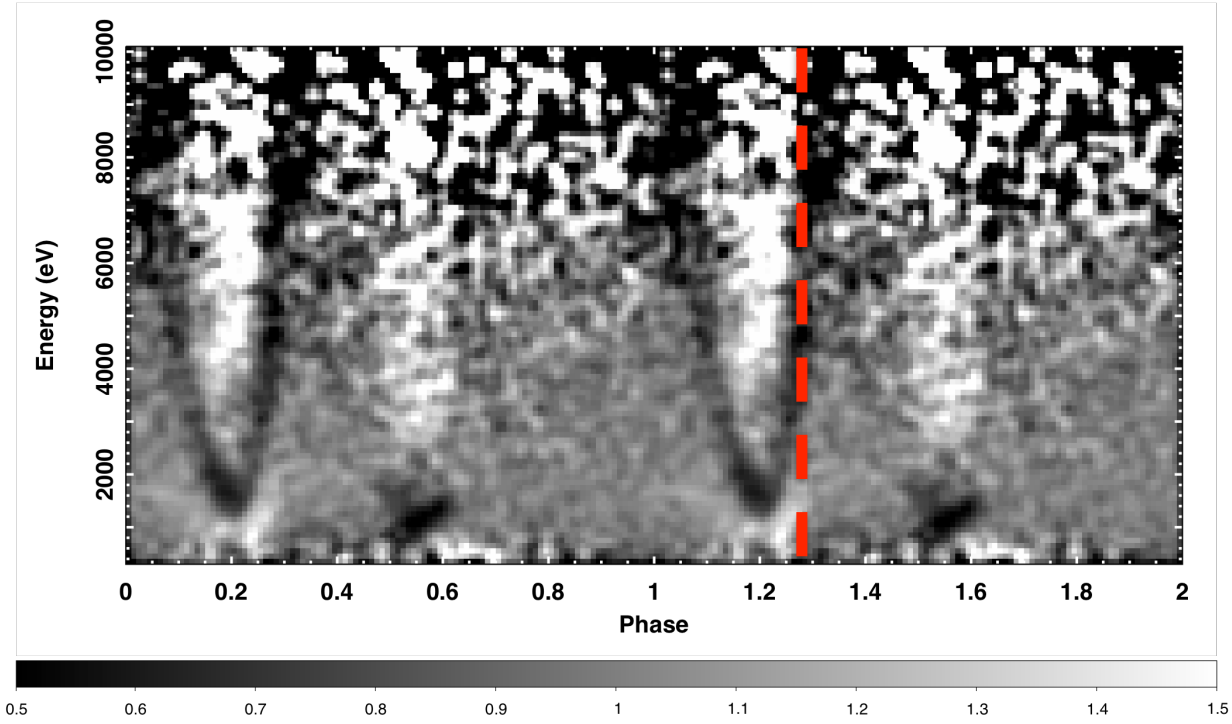
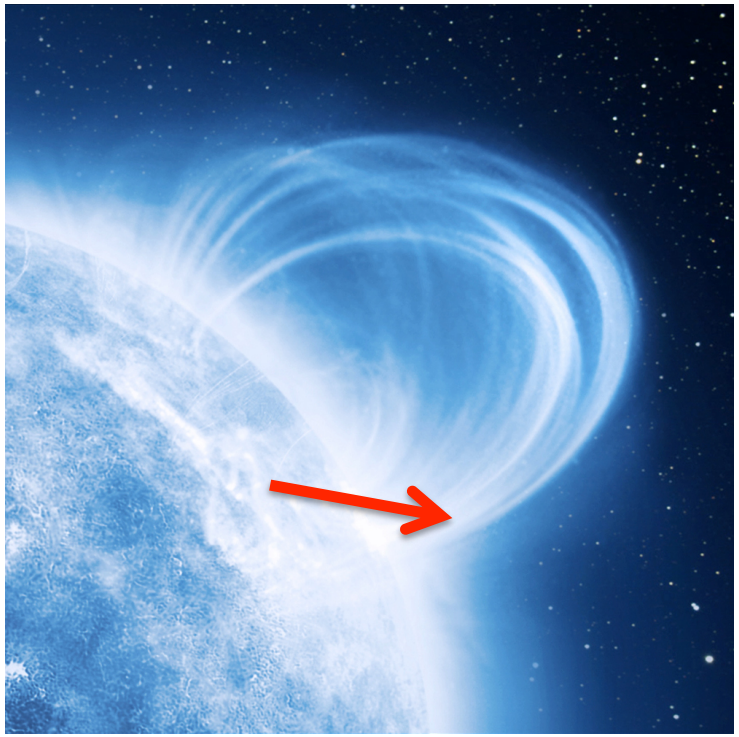




Why is it important?

(Tiengo et al. 2013, Nature 500, 312)

- The strong energy **VARIABILITY** with phase of the SGR 0418+5729 line is **UNPRECEDENTED** among neutron stars (including accreting pulsars)

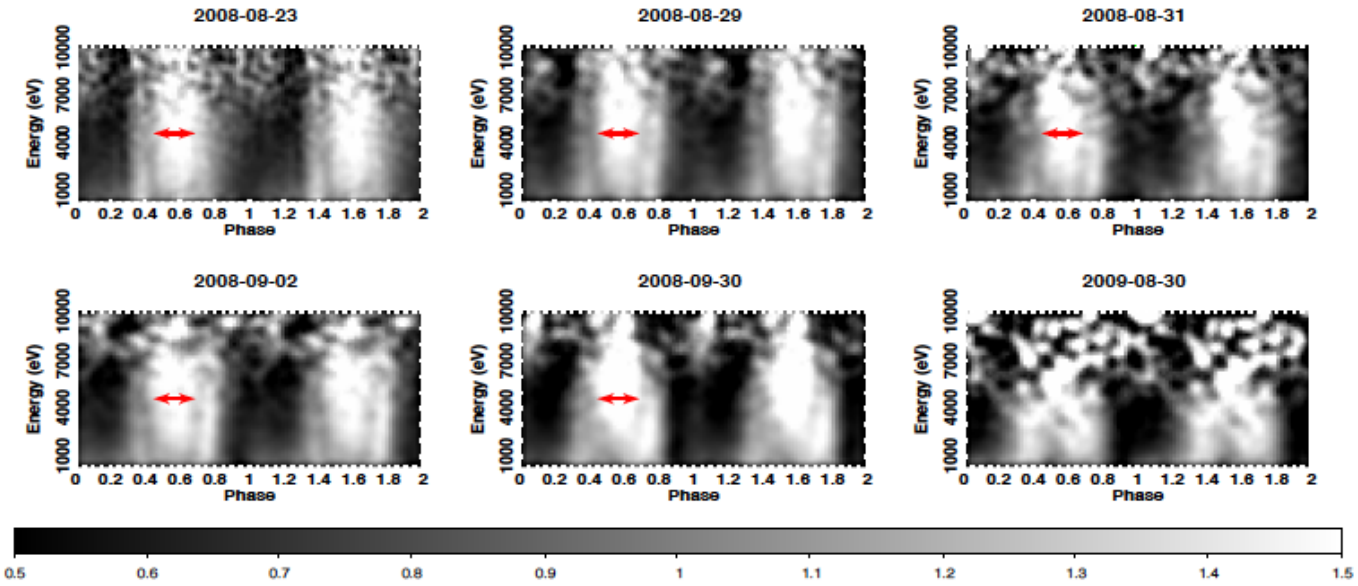
- If **PROTON CYCLOTRON** line ⇒ $B > 2 \times 10^{14}$ G ⇒ additional confirmation of magnetar nature of SGR 0418+5729 and of the overall **MAGNETAR MODEL**

- Low dipolar component of B from low spin-down rate and line phase variability ⇒ strong **MULTIPOLAR** magnetic field components ⇒ impact on **GWs** emission from magnetars *(Mastrano et al. 2015)*

Variable lines in other magnetars?

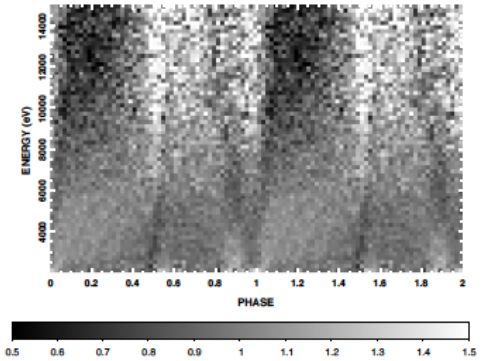
SGR0501+4516

(Camero et al. 2014)

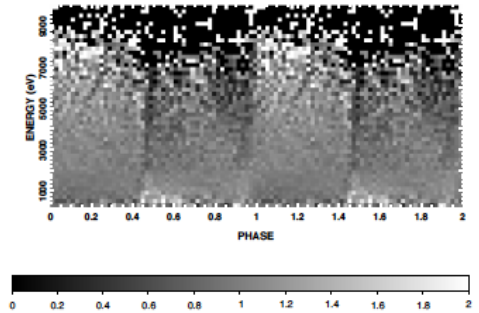


Swift J1822.3-1606

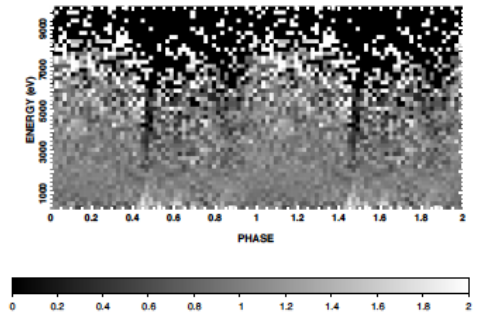
RXTE/PCA



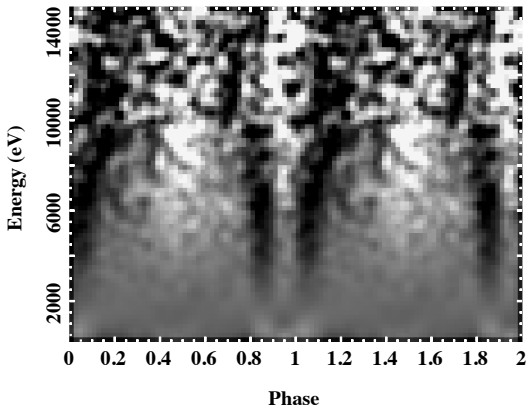
Chandra/ACIS



XMM/PN



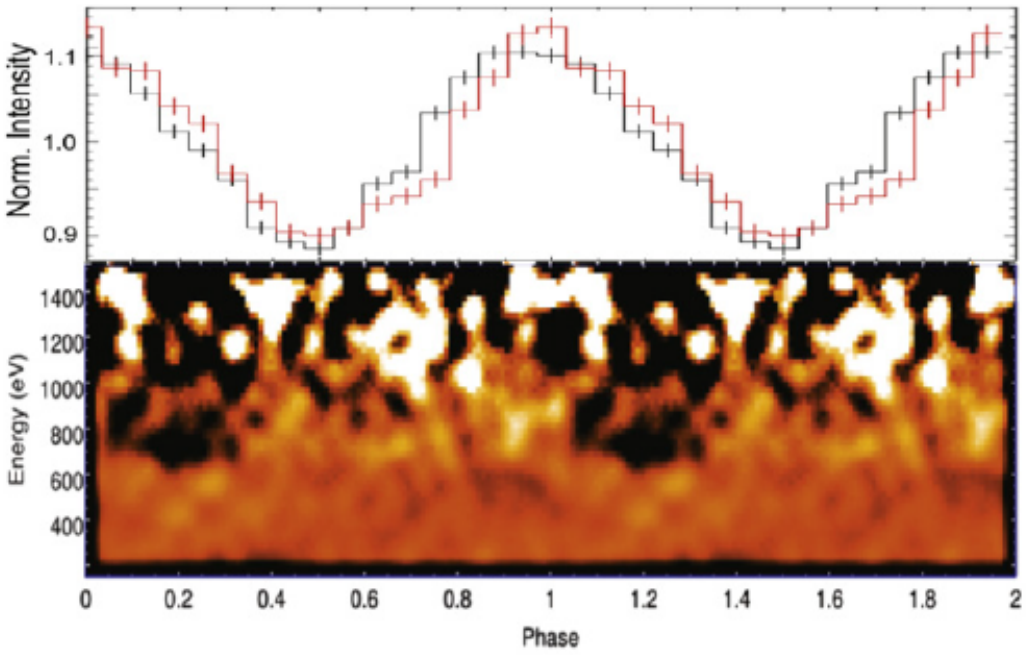
1E 2259+586

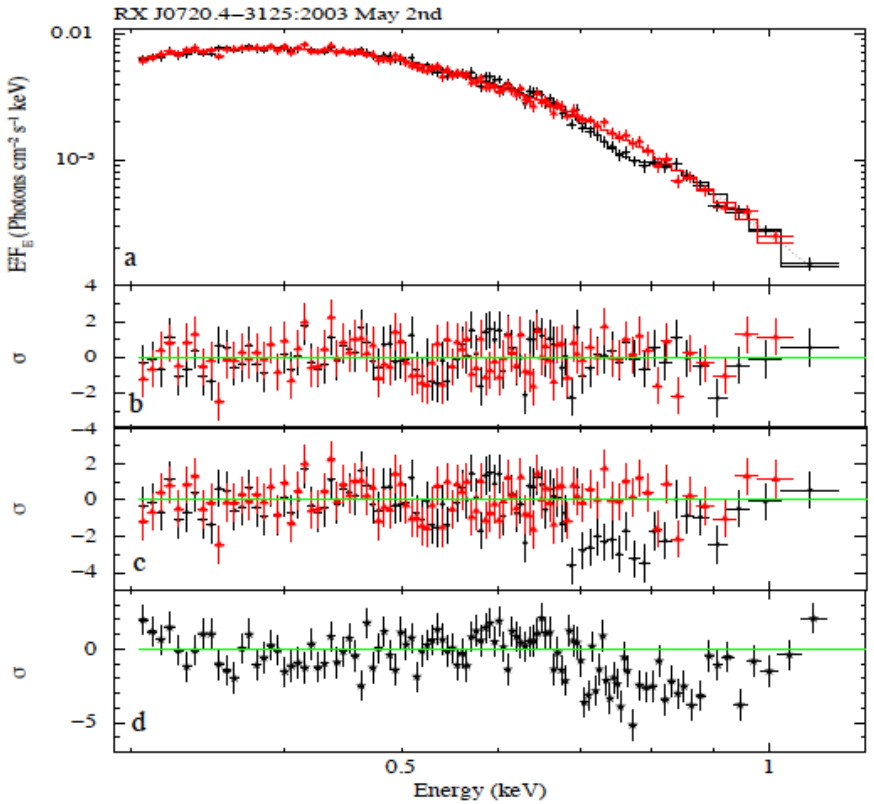


Nothing as convincing as in SGR0418

Proton cyclotron lines in other NSs?

RX J0720.4–3125 is the second brightest of the Magnificent Seven (aka XDINSs)





Absorption line at 0.7 keV only in short phase interval, in multiple XMM observations *(Borghese et a. 2015)*

Future: key observations (I)

- **GIANT FLARES**:
  - **GALACTIC** (3 in 25 years, last one in 2004...): better multi-wavelength coverage;
  - **EXTRA-GALACTIC**: better localization (Swift/BAT) and X-ray pulsating tail (Swift/XRT)

- **BURSTS**:
  - **QPOS**: detected in very few cases with Fermi/GBM or RXTE/PCA, more cases with better statistics would be needed (LOFT-like mission or long ToOs during bursting phases)
  - **SPECTRA**: confirmation of spectral features, from different sources and at different energies (NuSTAR, ASTRO-H)

Future: key observations (II)

- **PERSISTENT X-RAY EMISSION**:
  - **SPECTRAL FEATURES**: systematic search for variable X-ray lines (deep XMM observations; ATHENA);
  - **HARD X-RAY TAILS**: evolution of broad-band spectrum during outbursts (XMM+NuSTAR; ASTRO-H)

- **POPULATION** (now 23+5 candidates):
  - **RADIO PULSATIONS**: only 1 discovered from pulsar surveys;
  - **X-RAY PULSATIONS**: EXTraS search in XMM archive;
  - **BURSTS**: Swift/BAT and Fermi/GBM very prolific, but also EXTraS might discover faint bursts or extra-galactic flares