The X-ray Universe 2014 – Dublin

Measuring the strongest magnetic fields in the Universe

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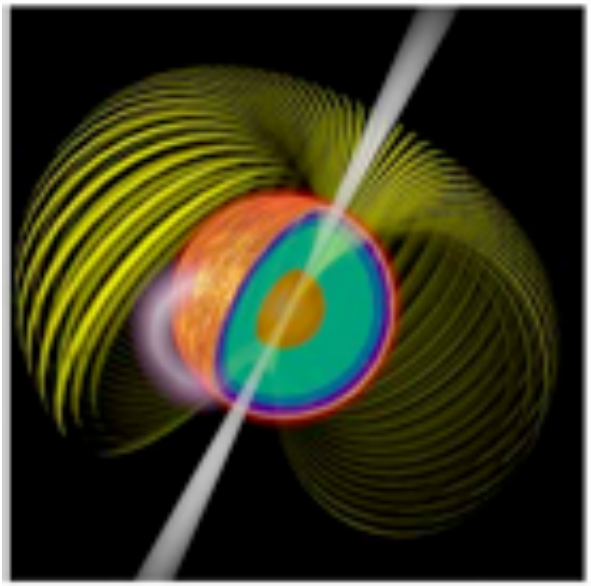
The *low B* magnetar SGR 0418+5729

- Two **BURSTS** detected on 2009 June 05, spin **PERIOD** of 9.1 s (*van der Horst et al. 2010*)
- Apparently all the 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** ($4X10^{-15}$ s s^{-1}, *Rea et al. 2013*)

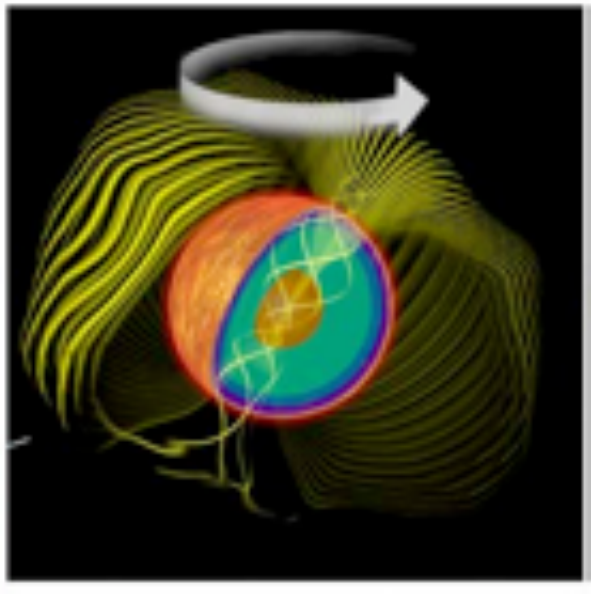
  $\Rightarrow$ $B_{dip} \approx 6x10^{12}$ G $\Rightarrow$ a **LOW MAGNETIC FIELD** magnetar?
- Consistent with magnetar model if born with higher B field and **INTERNAL** (crustal) B > 10^{14} G (*Rea et al. 2010; Turolla et al. 2011*)
- Strong **MULTIPOLAR** field components on the surface from spectral analysis with NS atmosphere model (*Güver et al. 2011*)

The importance of being twisted

High-*B* radio PSRs



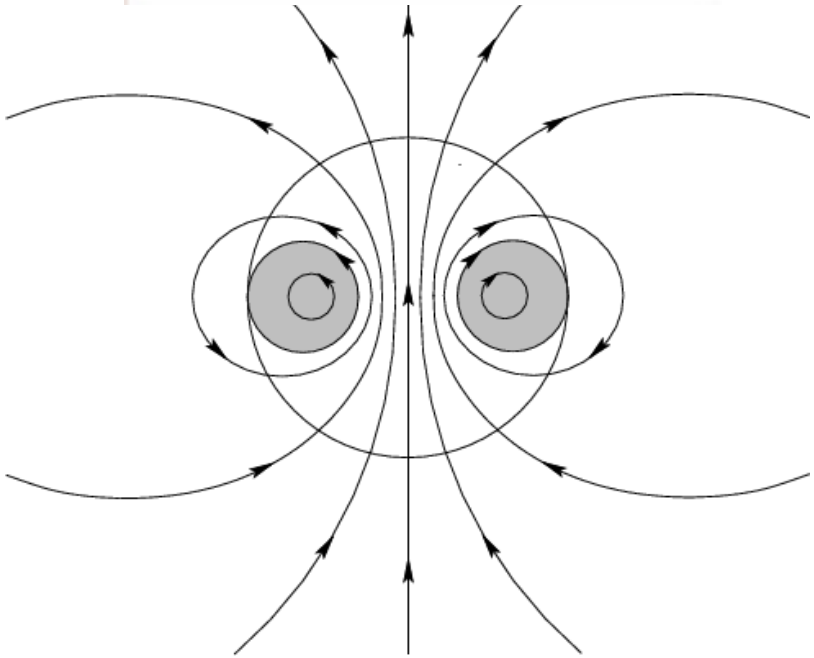
High-*B*



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)

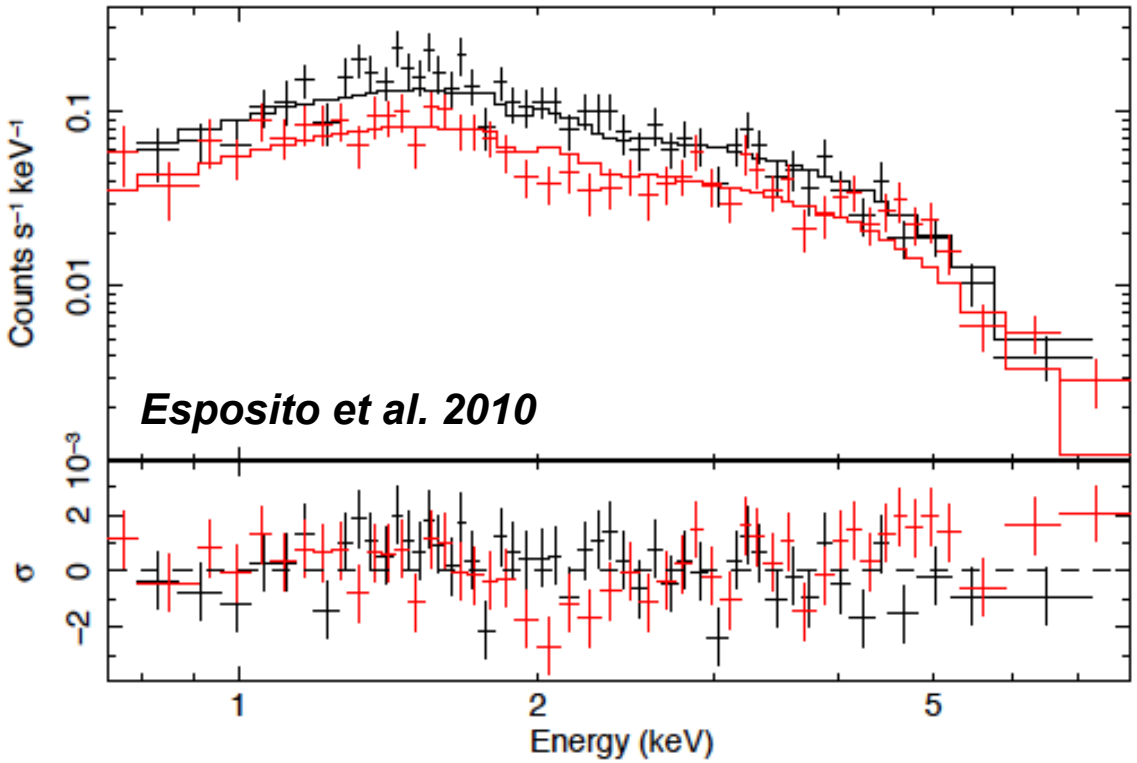


(Braithwaite & Spruit 2006)

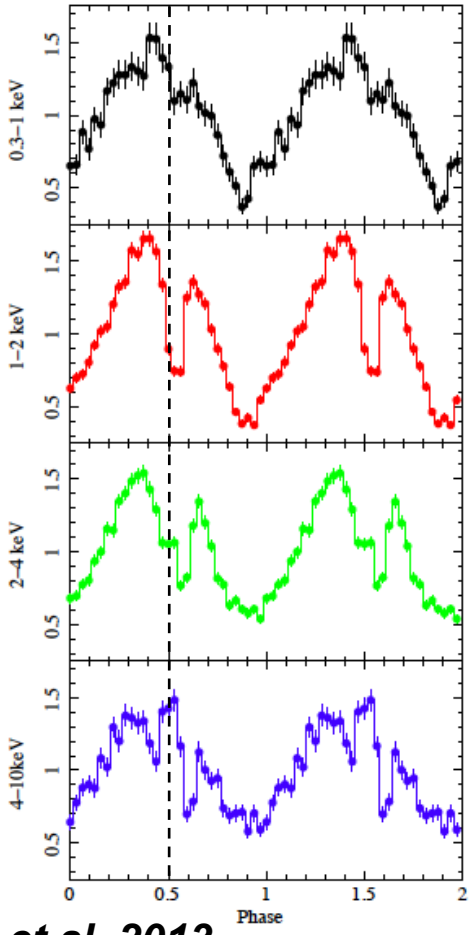
Another “anomaly” of SGR 0418+5729

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

Spectra from adjacent phase intervals:
absorption line at ~2 keV?



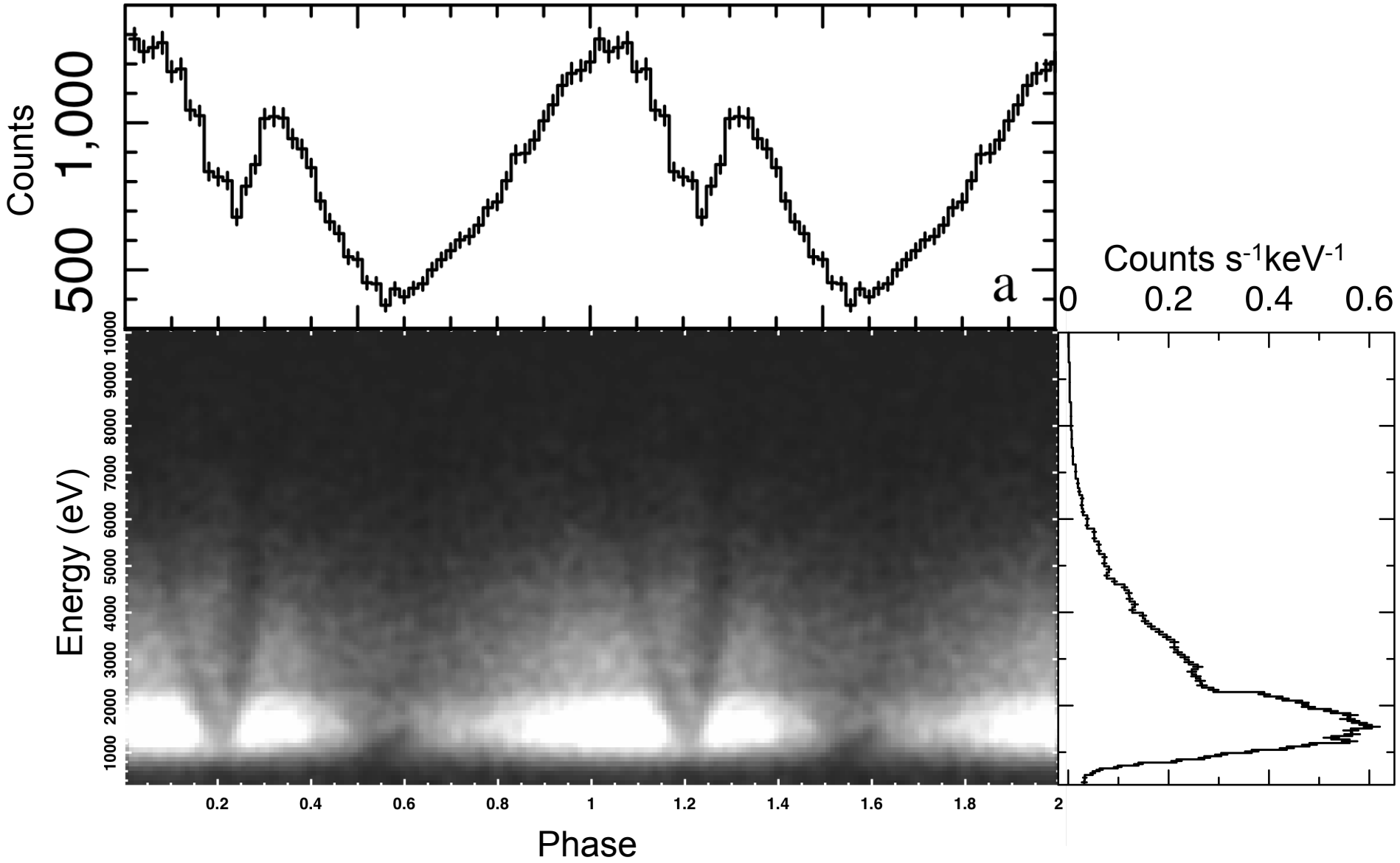
XMM-Newton/EPIC
2009 August 12



Rea et al. 2013

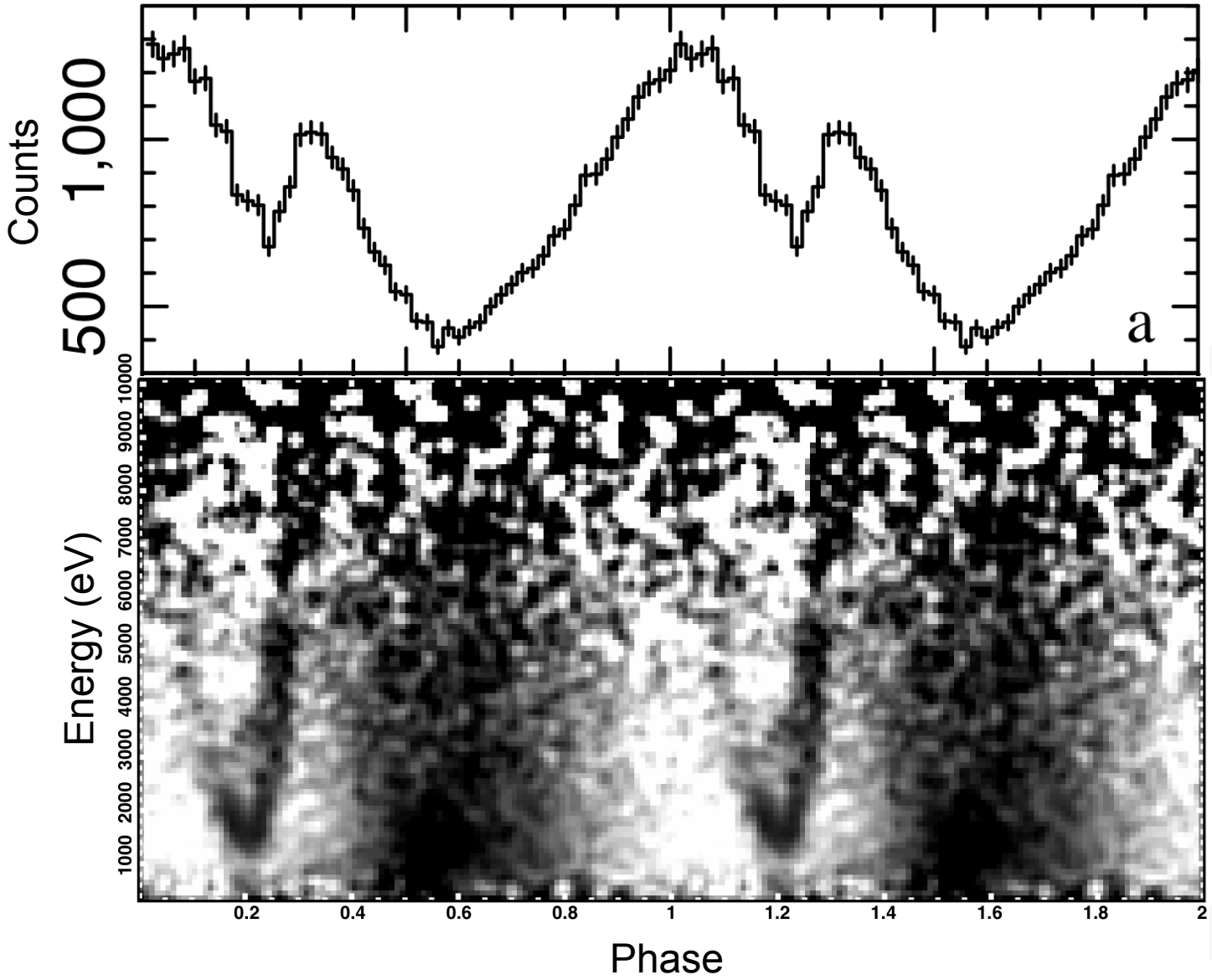
Indications for a PHASE-VARIABLE spectrum

XMM-Newton/EPIC phase-energy image



An ABSORPTION LINE at a phase-variable energy

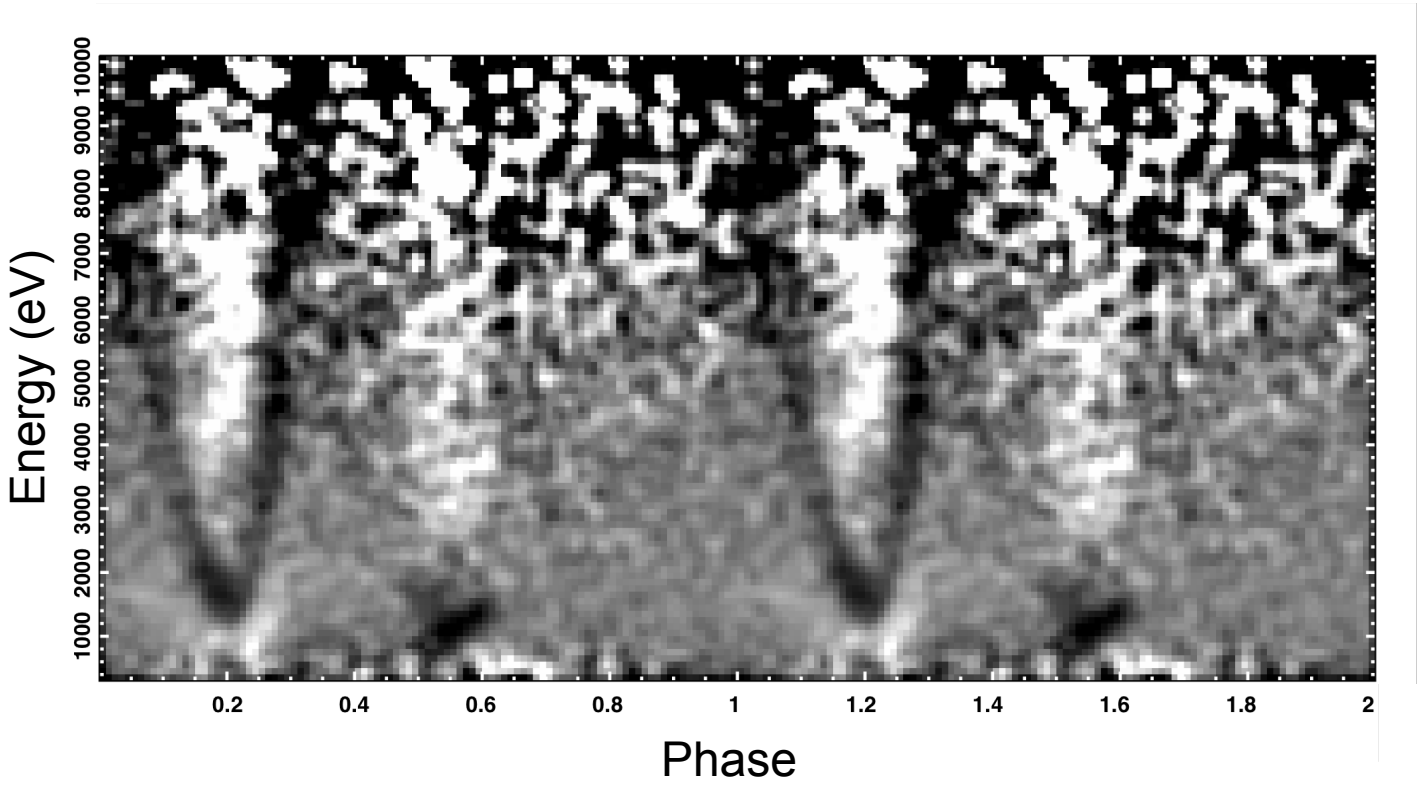
XMM-Newton/EPIC phase-energy image



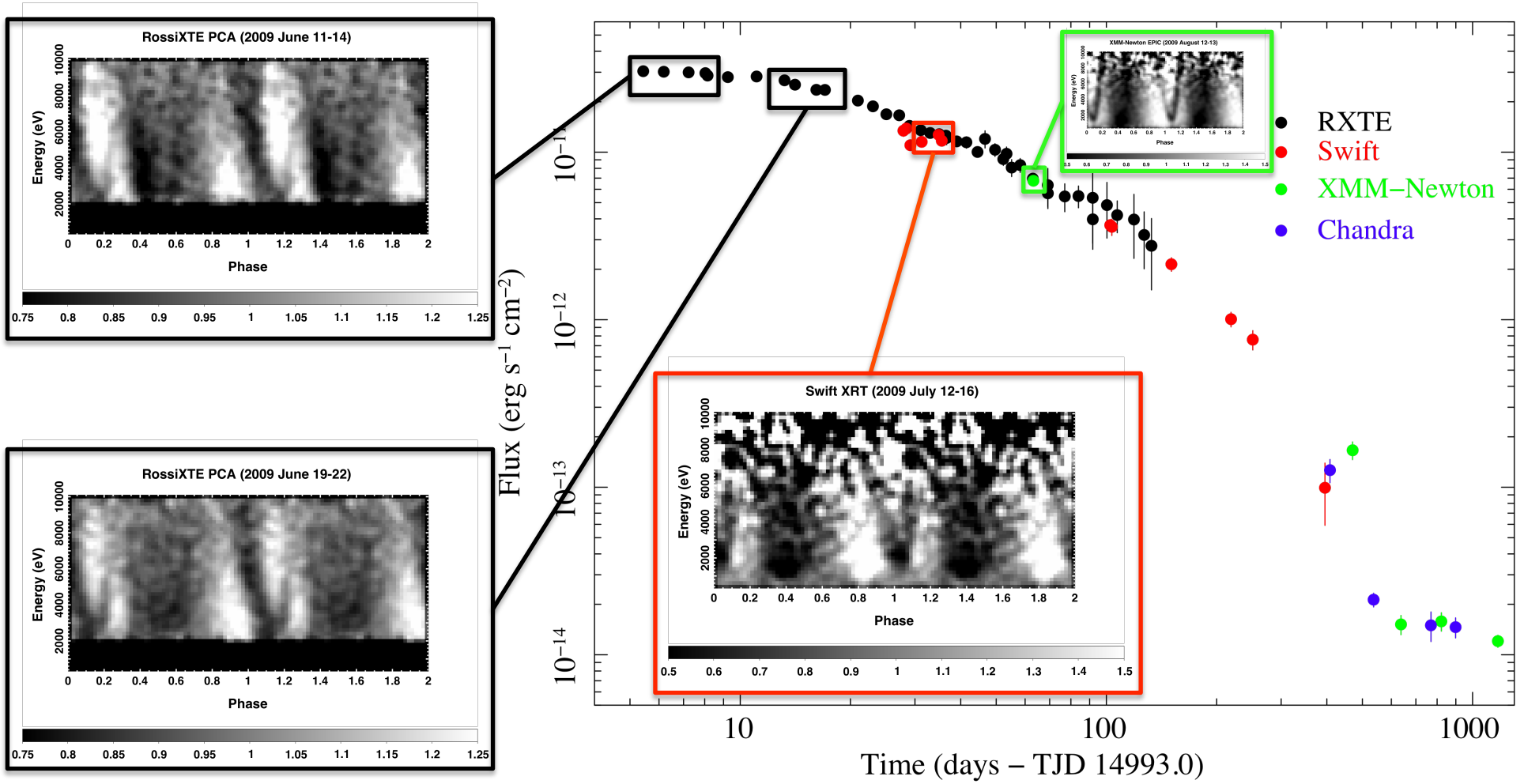
Normalized to the phase-averaged spectrum

XMM-Newton/EPIC phase-energy image

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



Detected in earlier RXTE and Swift data

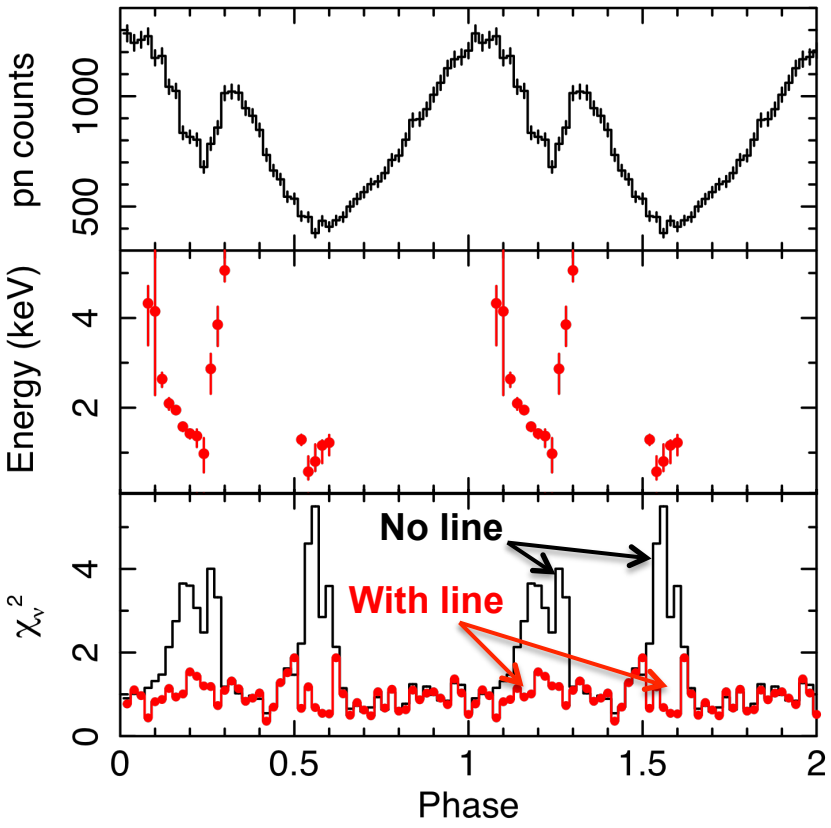


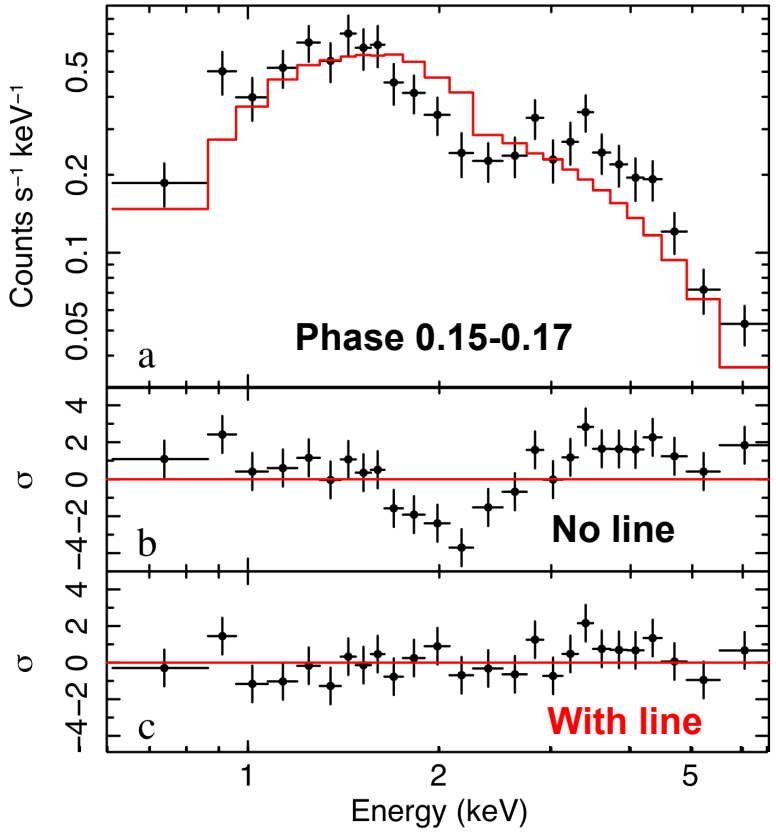
- Line is **NOT** due **INSTRUMENTAL** effects
- Line has been present since the **BEGINNING** of the outburst

Phase-resolved spectral analysis

50 PHASE RESOLVED EPIC PN SPECTRA

- **At most phases:** acceptable fits by **RESCALING** the model of the phase-averaged spectrum
- **At phases ~0.1-0.3 and ~0.5-0.6:** acceptable fits with the addition of an **ABSORPTION LINE**





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
- We need a **STRONGLY VARIABLE B**, that might vary:
  - along the **SURFACE** (small-scale multipolar B components)

  OR

  ✓along a **VERTICAL** plasma structure (coronal loop analogy; e.g., *Beloborodov & Thompson 2007; Masada et al. 2010*)

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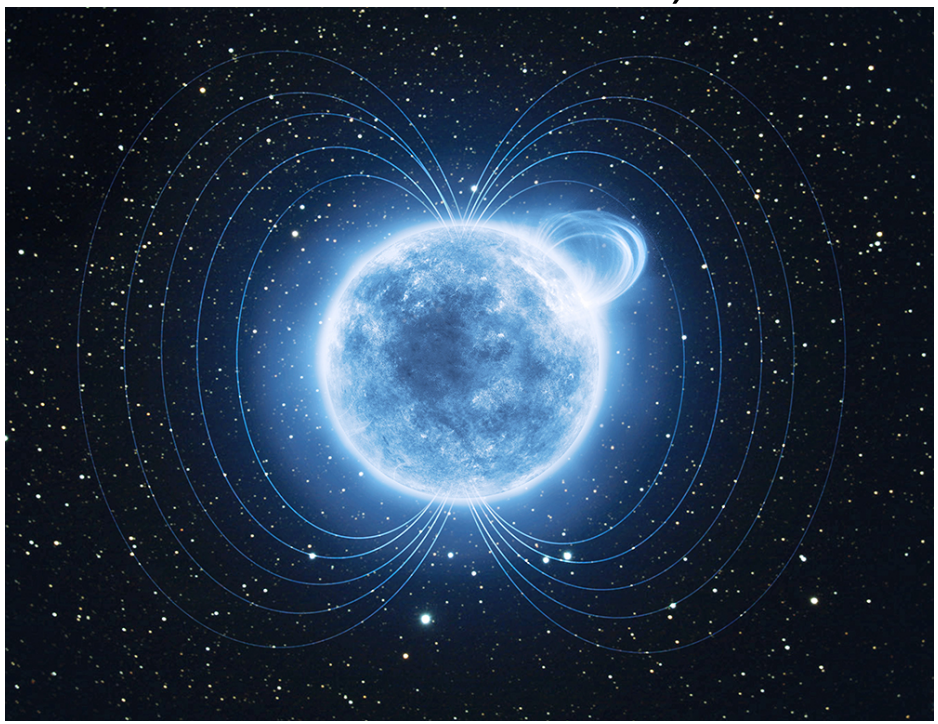

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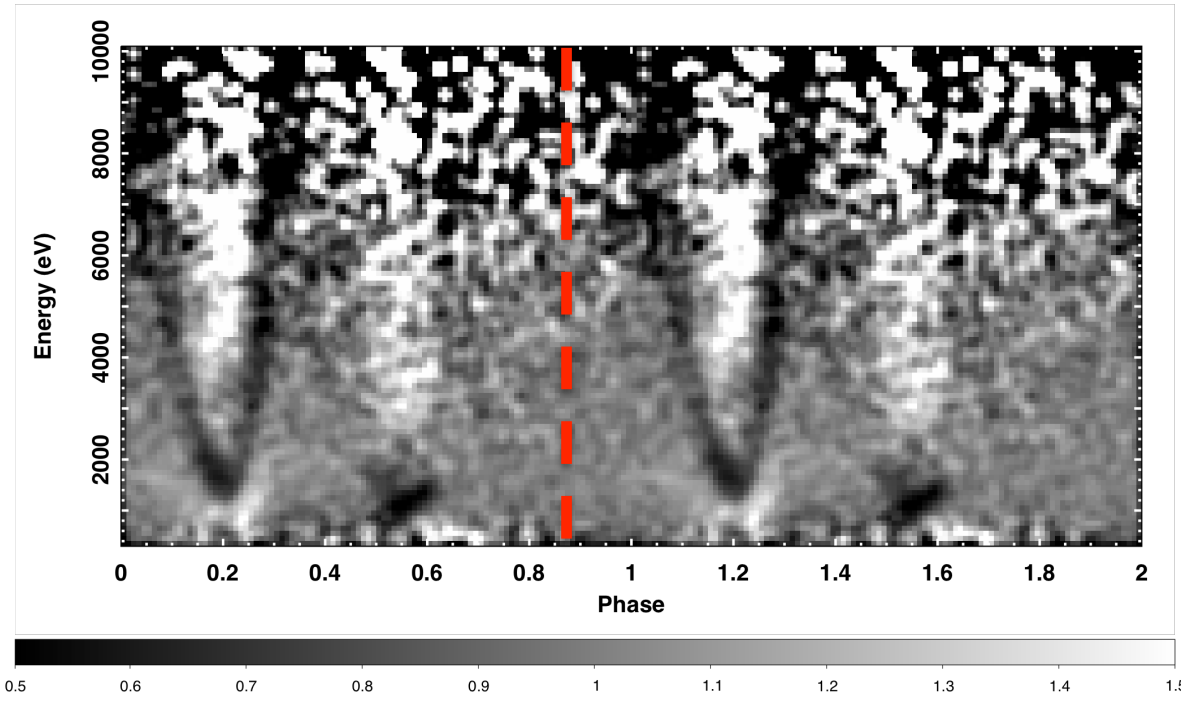

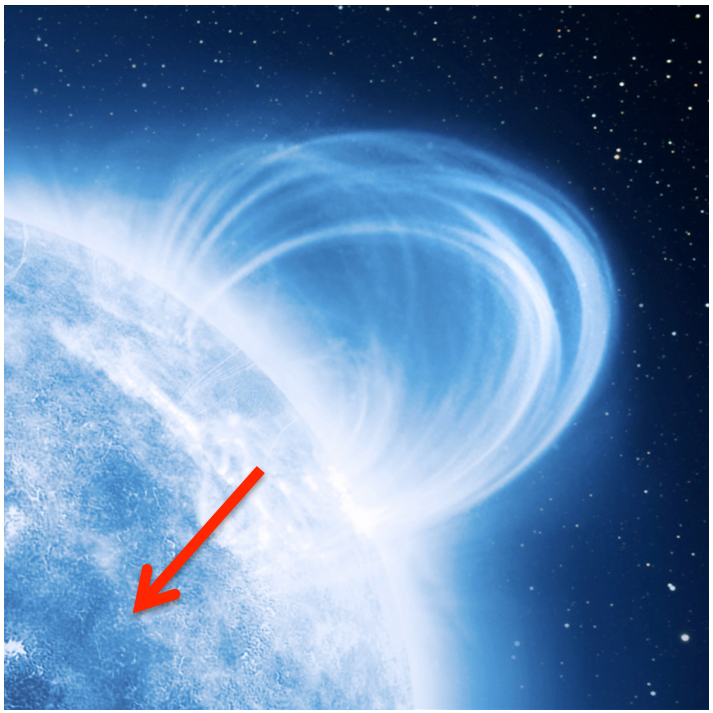

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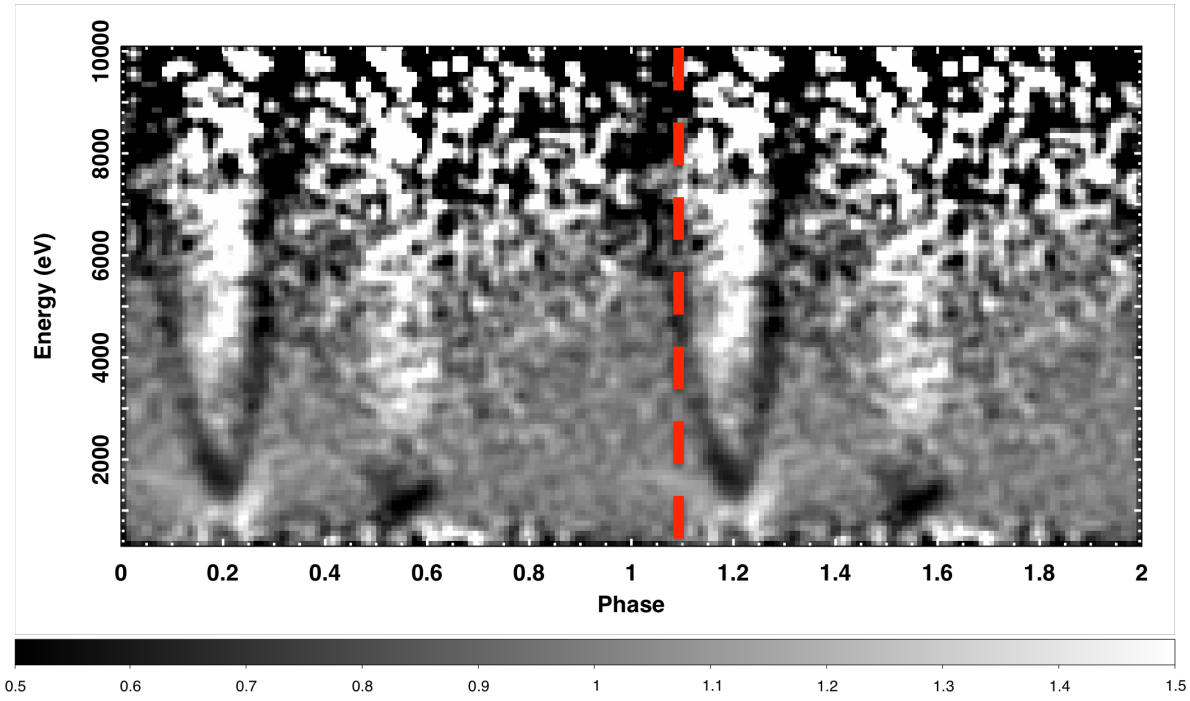

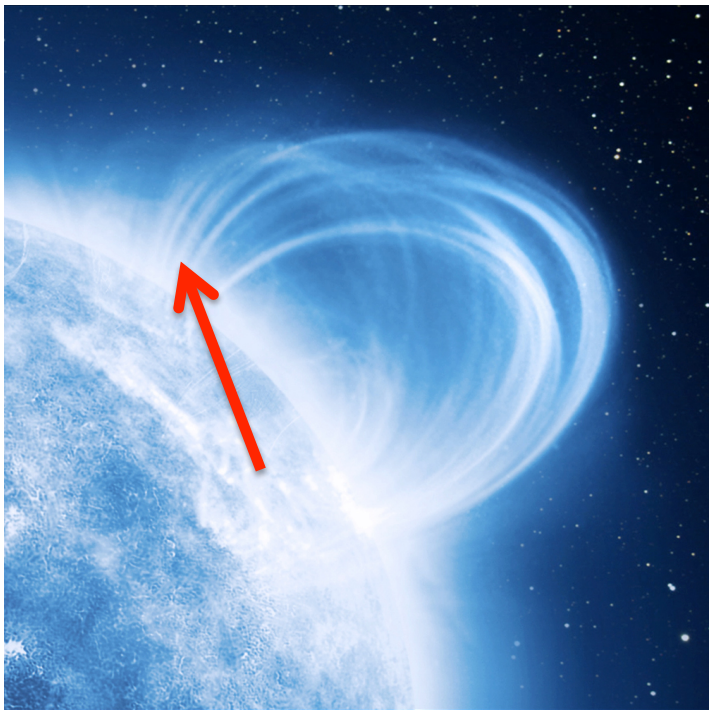

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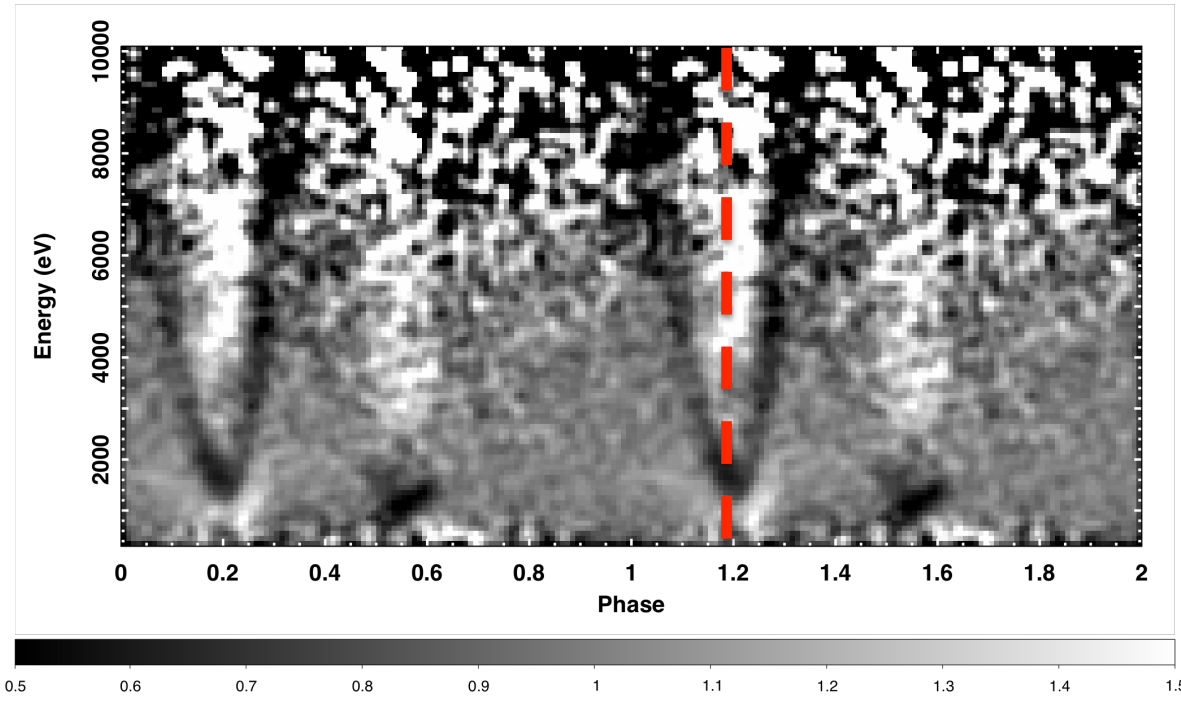

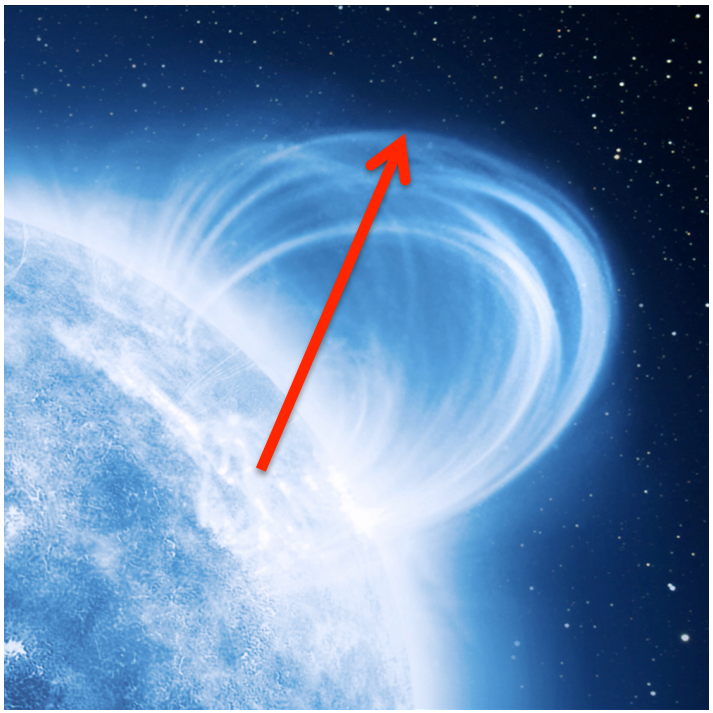

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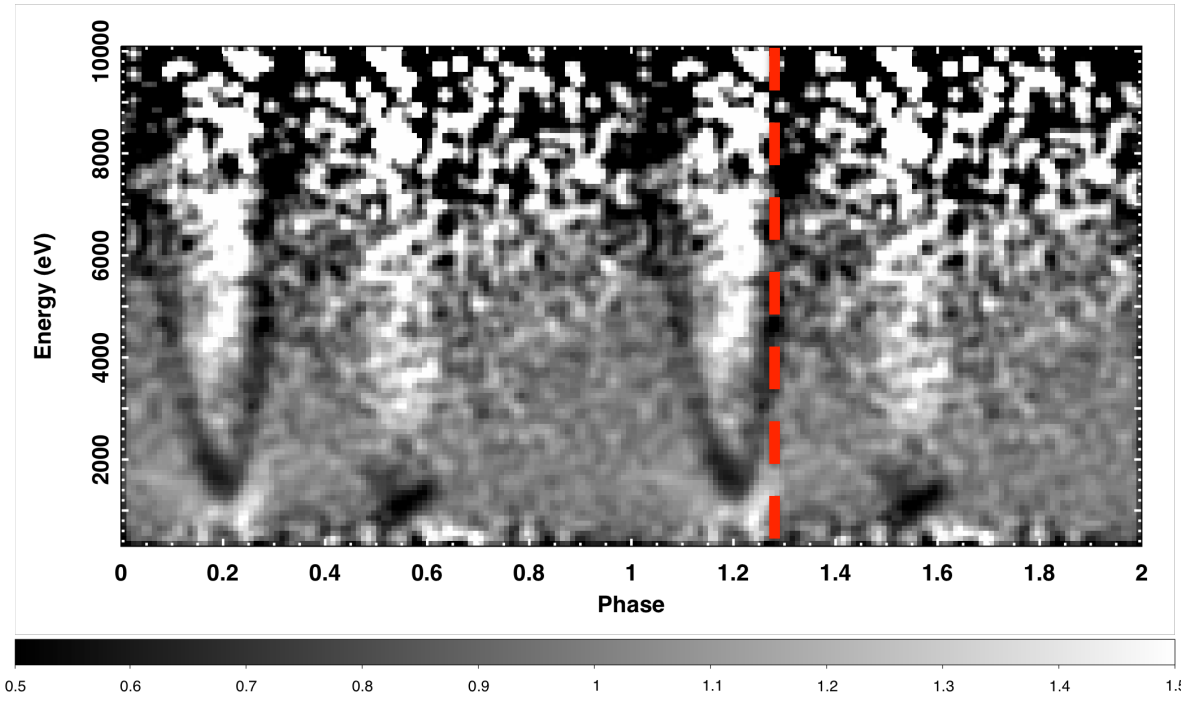
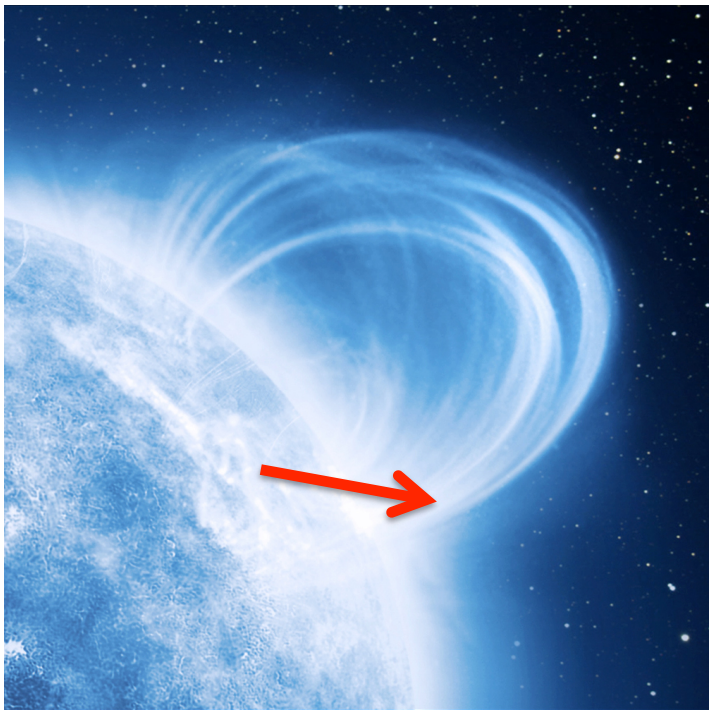
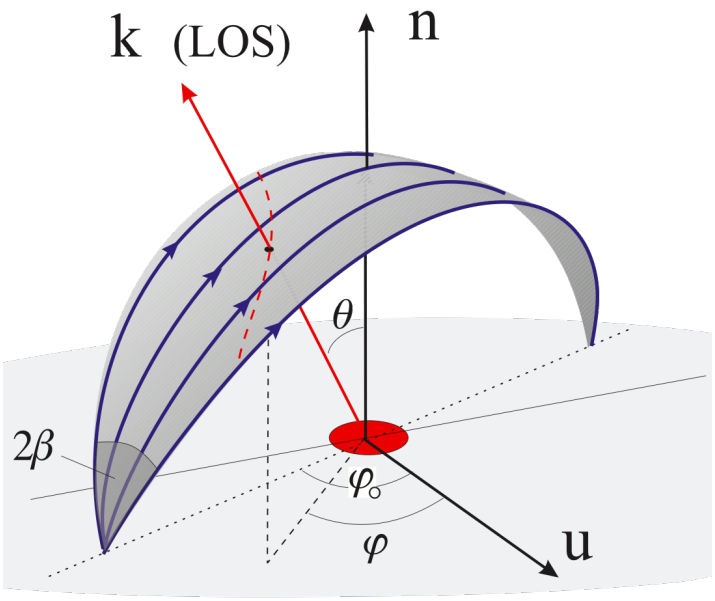
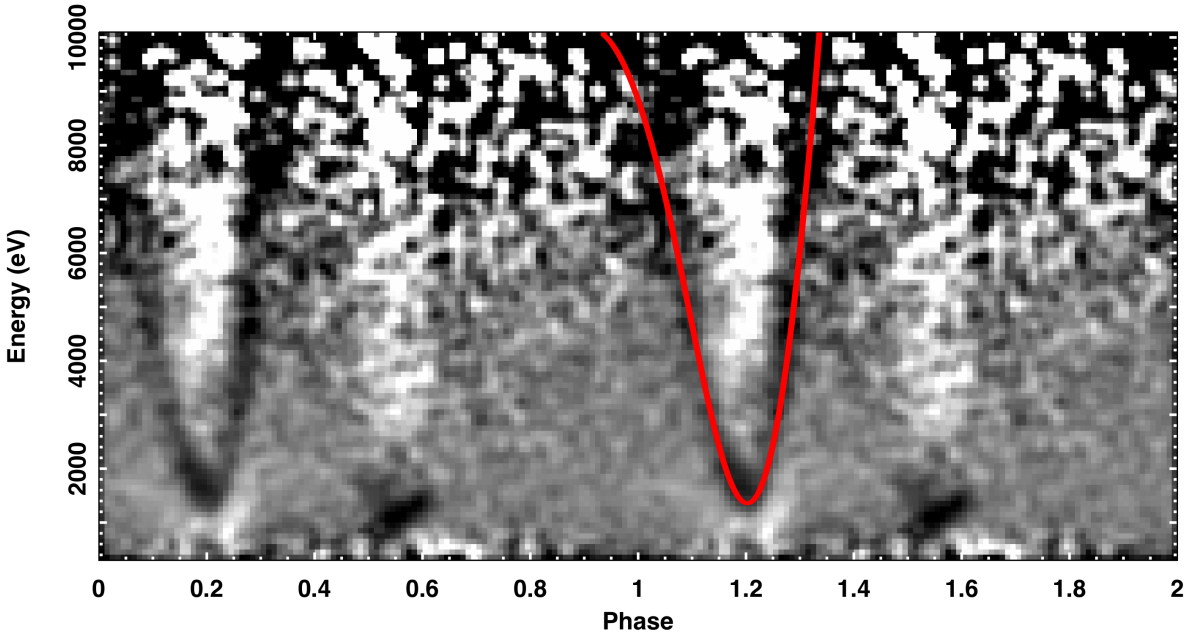




A simple proton cyclotron model





A **toy-model** with simple geometry and magnetic field intensity linearly decreasing with loop width can explain the line **variability** with phase

Other claims of lines in magnetars

Tentative **CYCLOTRON** lines in persistent and burst emission

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	RossiXTE/PCA	Burst, absorption
4U0142+614	4,8,14	-	RossiXTE/PCA	Bursts,emission
1E1048-5937	14;13	3.9;3.3	RossiXTE/PCA	Bursts,emission
XTE1810-197	12.6	4.5	RossiXTE/PCA	Burst,emission
1RXS1708-4009	8.1	2.95	BeppoSAX/MECS	PPS, absorption
SGR1900+14	6.4	3.7	RossiXTE/PCA	Burst, emission

NOT confirmed by XMM/Chandra, but ~13 keV emission line in 1E 1048-5937 burst tail with ***NuSTAR*** *(An et al., arXiv:1406.3377)*

Conclusions

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

- Discovery of **ABSORPTION LINE** with strong energy **VARIABILITY** with phase, **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. 2013)*

Work in progress and future prospects

- Similar analysis on archival data of **OTHER MAGNETARS** (mainly XMM-Newton, RXTE, NuSTAR data)

- More work on loop/arcade **MODELS**

- Better sensitivity to phase-variable lines in magnetars with **ATHENA**