Accreting Magnetars: spectral formation in the accretion shock

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Question

- Let me ask a provocative question:

- Are Magnetars really Magnetars?

- In other words, are super-strong magnetic fields **needed** to explain the observations?

Answer

- It depends!
- If one addresses the observed **giant** or **big bursts**, then it is unavoidable that super-strong, magnetar-type magnetic fields are needed to explain them.
- Accretion cannot provide such super-Eddington luminosities, if they are isotropic.
- However, as I will show, for the **persistent** or the **transient luminosity** of magnetars, normal magnetic fields and accretion can explain the observations.

Proposal

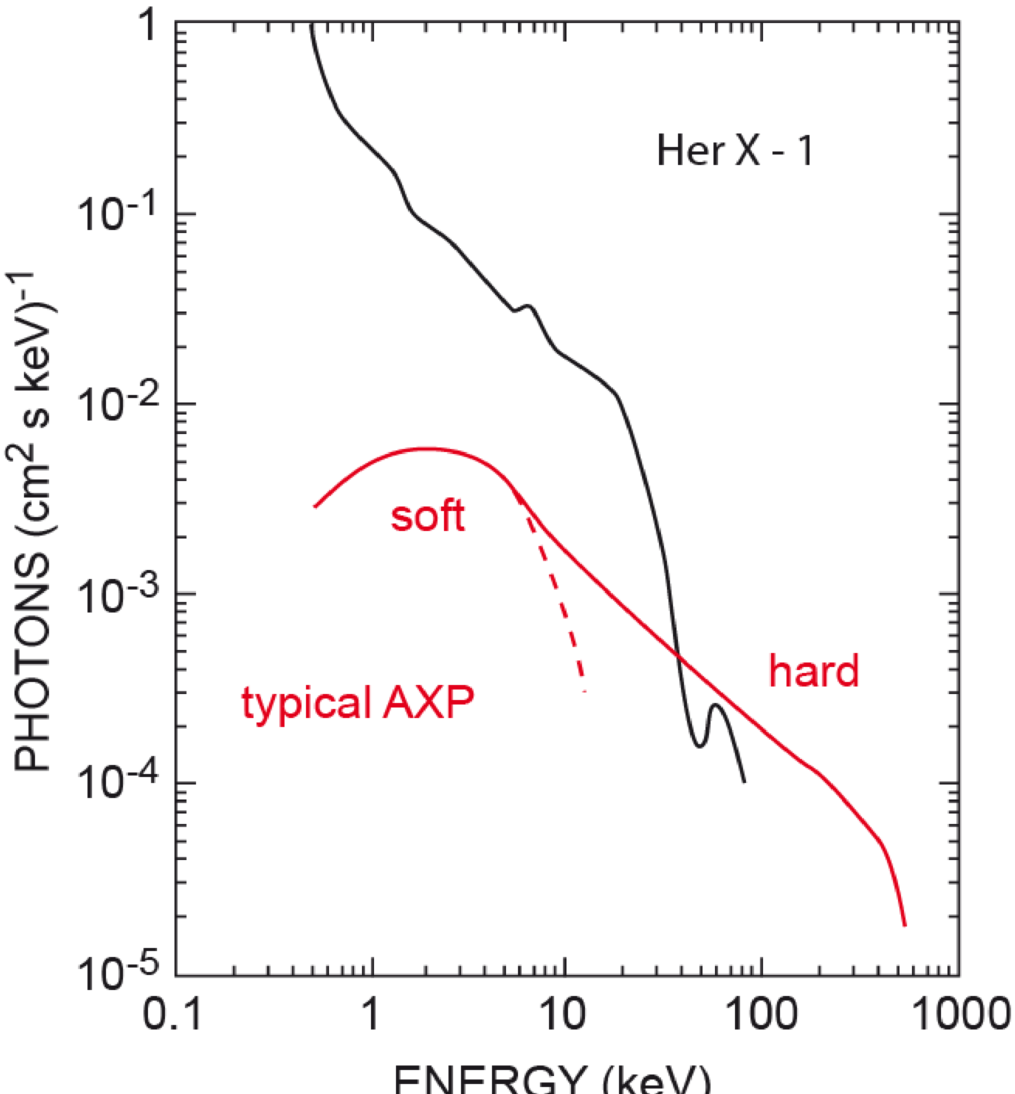
- I hope to convince you that **magnetar-type magnetic fields and accretion can coexist**!

- The basic picture that we propose is that **magnetar**-type magnetic fields are in **multipole** components, and it is these components that produce the **bursts**.

- The **dipole component** can be two orders of magnitude weaker and still dominate at large distances.

- Thus, accretion occurs along dipole field lines, **very much like in X-ray pulsars**.

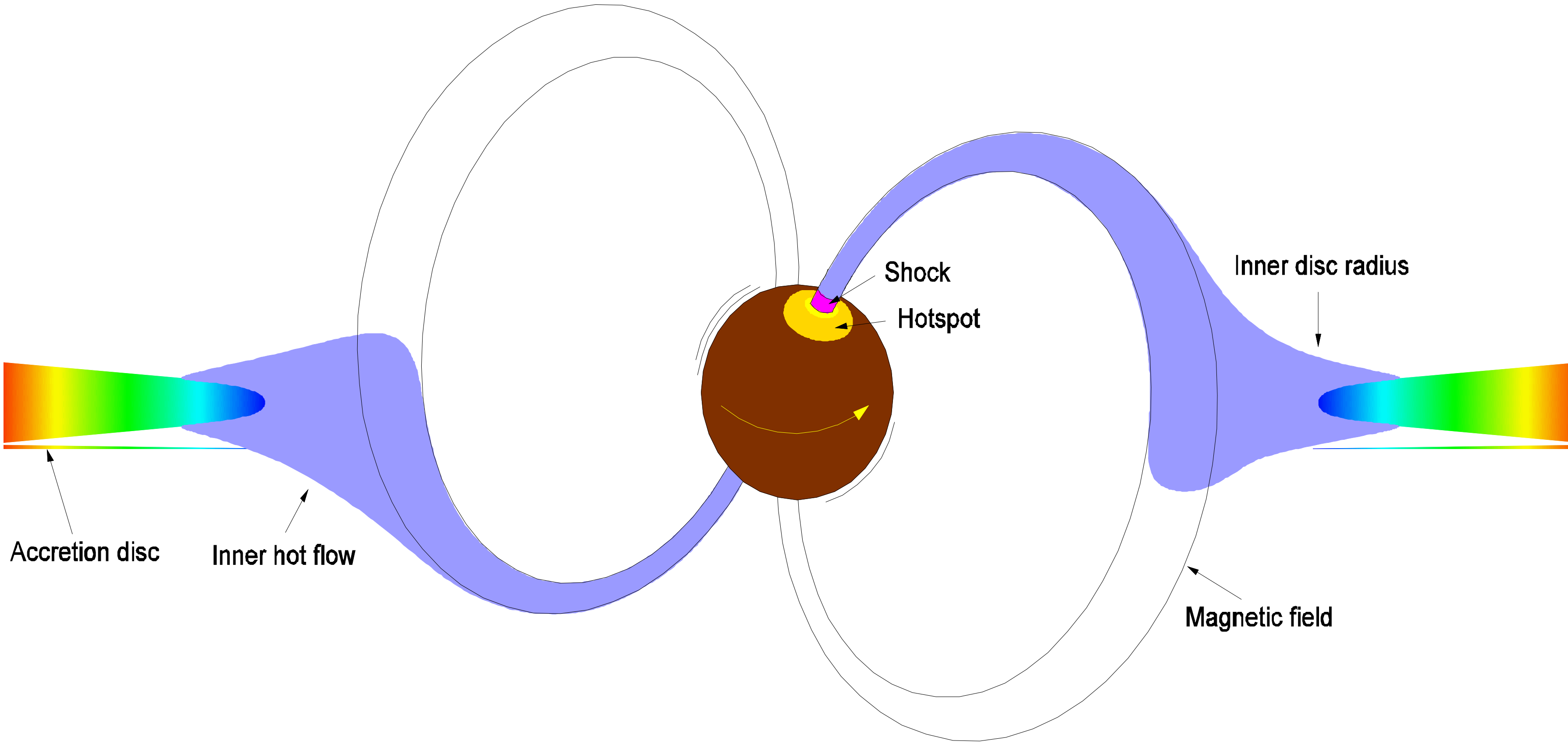
Comparison of spectra from X-ray pulsars and magnetars



Accretion

- The X-ray luminosity of AXPs and SGRs is two to three orders of magnitude **lower** than that of normal X-ray pulsars, like Her X-1.
- Thus, two to three orders of magnitude **less** mass-accretion rate is needed to power the persistent luminosity of AXPs and SGRs.
- Such a mass-accretion rate can be provided by a disk left over from the formation of the neutron star.
- Such disks are called **fallback** disks.

Schematic of accretion flow



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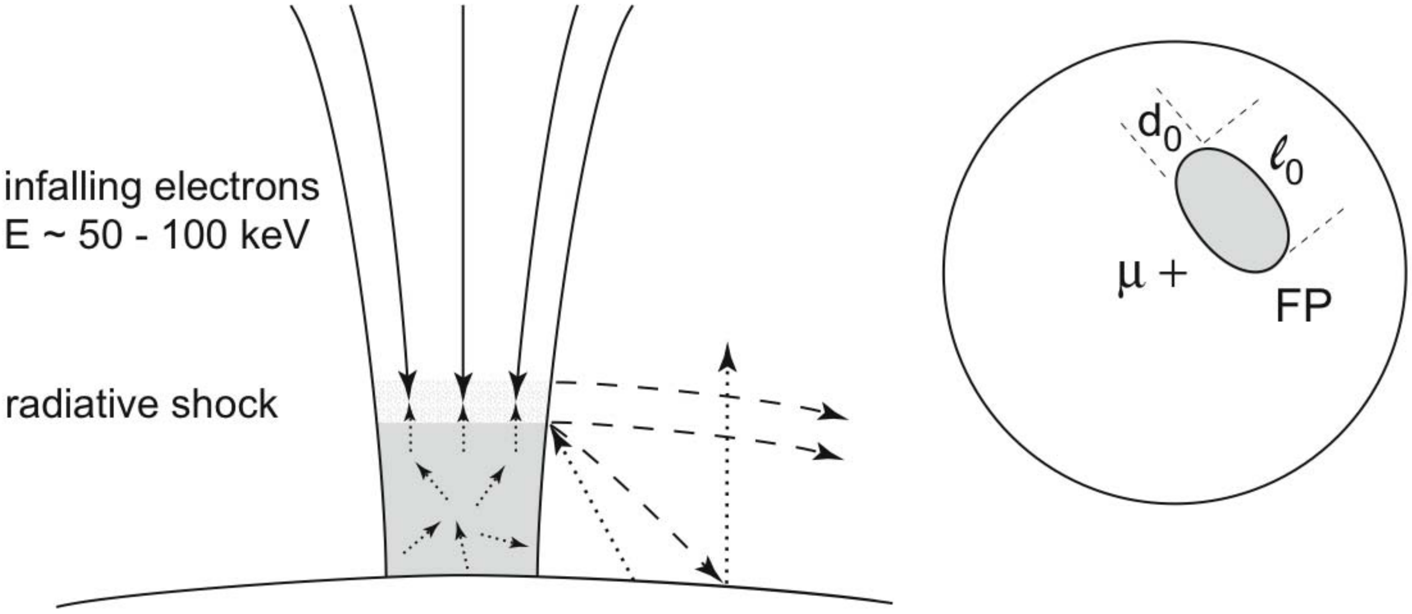
Bulk-motion Comptonization (BMC) and Thermal Comptonization (TC)

- We claim that Bulk-Motion Comptonization (BMC) and Thermal Comptonization (TC) at the radiative shock in the accretion column can naturally explain the observed hard X-ray spectra from AXPs and SGRs.

- I will present detailed calculations of X-ray spectra (soft and hard) at the end.

Schematic of accretion column



Size ~ 100 m

Optical depths to Thomson scattering

$$\tau_{\perp} = n_0 \sigma_T a_0 = \frac{\dot{M}}{m_p u_{ff} \pi a_0^2} \sigma_T a_0 \approx 1.7 \left(\frac{10^4\, cm}{a_0} \right)$$

$$\tau_{||} = \frac{2}{3} \tau_{\perp} \frac{R}{a_0} \approx 110 \left(\frac{10^4\, cm}{a_0} \right)^2$$

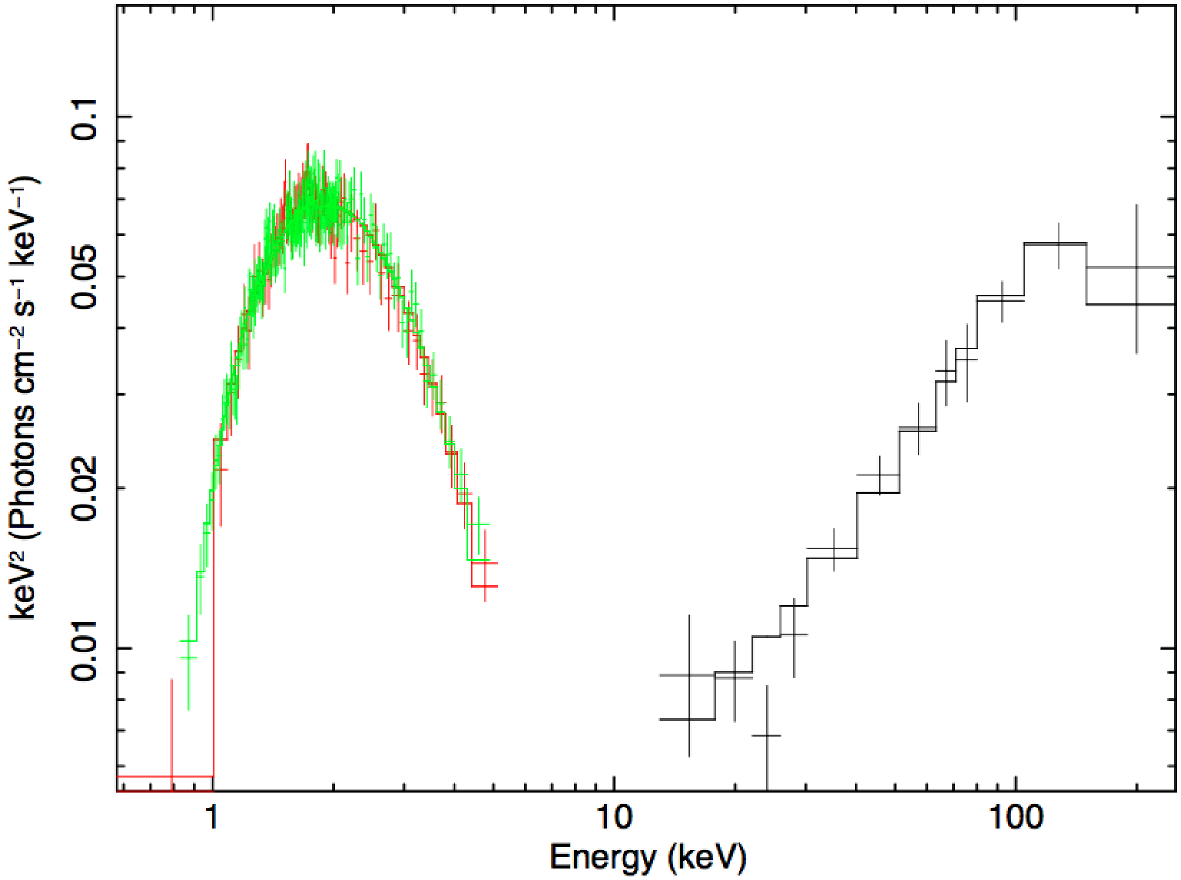
$$for \quad \dot{M} = 2 \times 10^{15}\, g/s, \quad i.e., \; L_x = 4 \times 10^{35}\, erg/s$$

- Thus, soft photons that go upwards may criss-cross the shock several times and have their energy significantly increased (first order Fermi energization).

Truemper et al. (2010)

- As a test case, we fitted the X-ray spectrum of 4U 0142+61, which is a typical AXP.
- We used the bulk-motion and thermal Comptonization software that exists in XSPEC (Farinelli et al. 2008).
- Result:

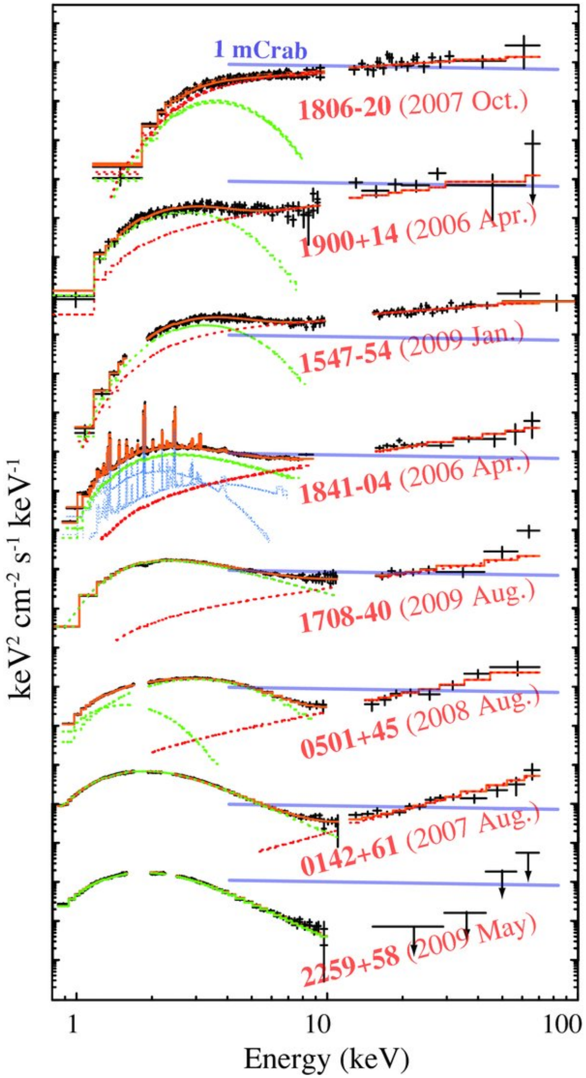
Trumper et al. (2010)



Other constraints

- The result is rather impressive, but (given enough freedom) other models can probably have equally good fits.
- It is remarkable however, that the magnetar model **has not** reproduced this spectrum or the high-energy spectrum of any other AXP/SGR.
- Since the spectrum alone cannot usually distinguish among models, we must look at other constraints.
- Nevertheless, the similarity of the spectra of all the AXPs and SGRs observed (next slide) guarantees that our accretion model, which works well for one AXP, **works well for all of them** (Zezas et al. in preparation).

Energy spectra of 8 AXPs and SGRs (Enoto et al. 2010)

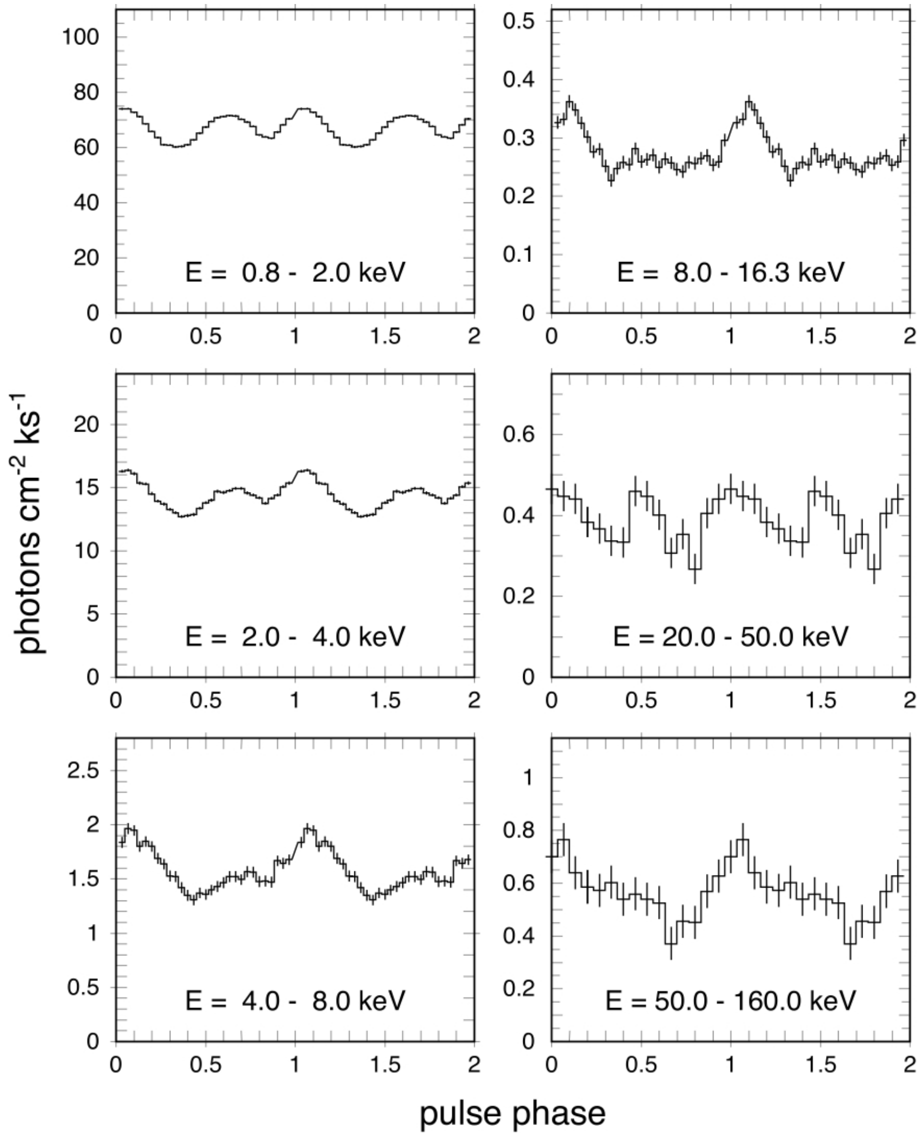


X-ray pulsations

- Three AXPs and one SGR exhibit X-ray pulsations with period the rotational period of the neutron star.
- The average pulse shape of 4U 0142+61 (den Hartog et al. 2008) is shown in the next slide.

Pulse profiles in various energy bands

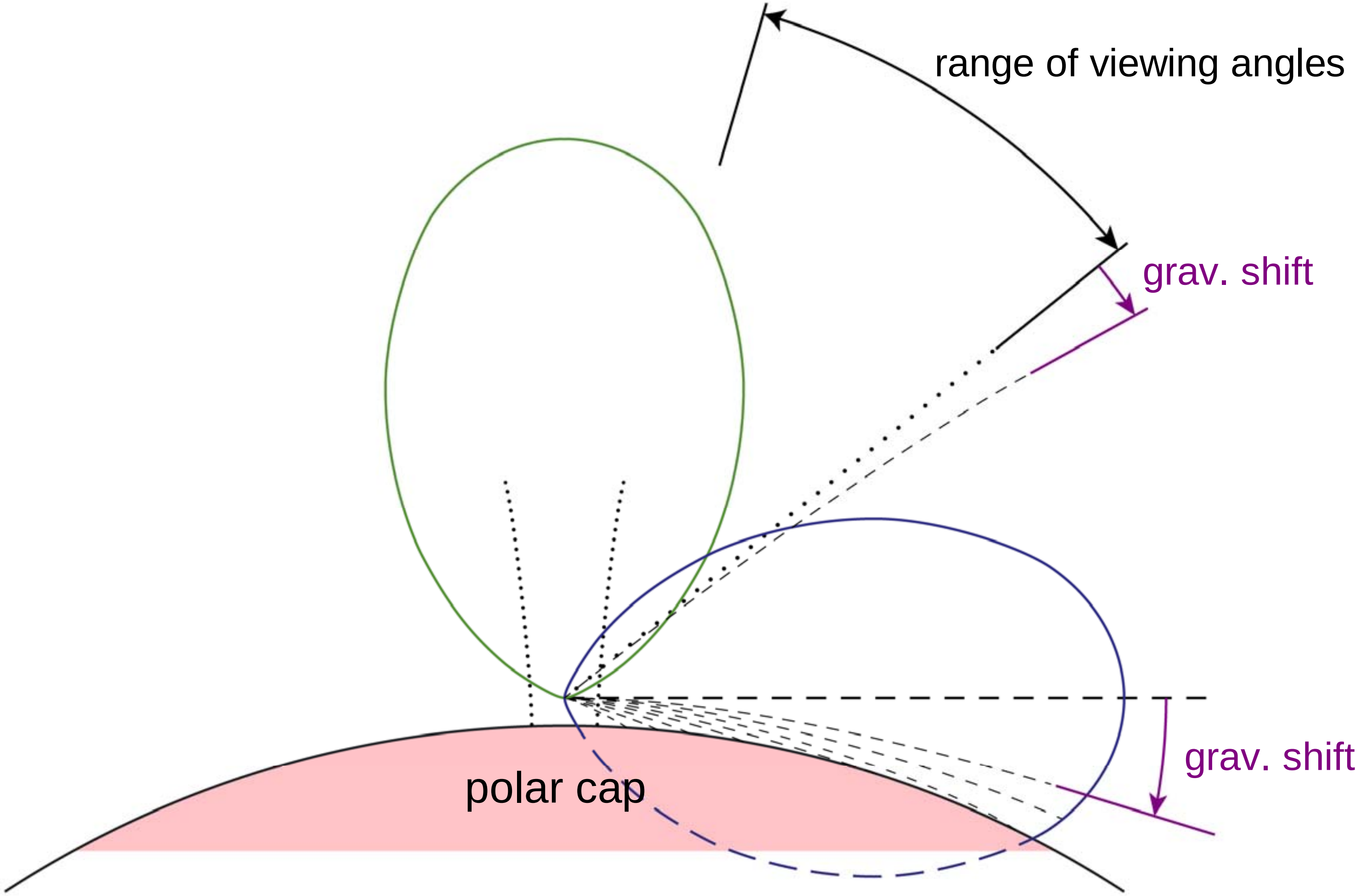
(Truemper et al. 2013, using data from den Hartog et al. 2008)



Trumper et al. (2013)

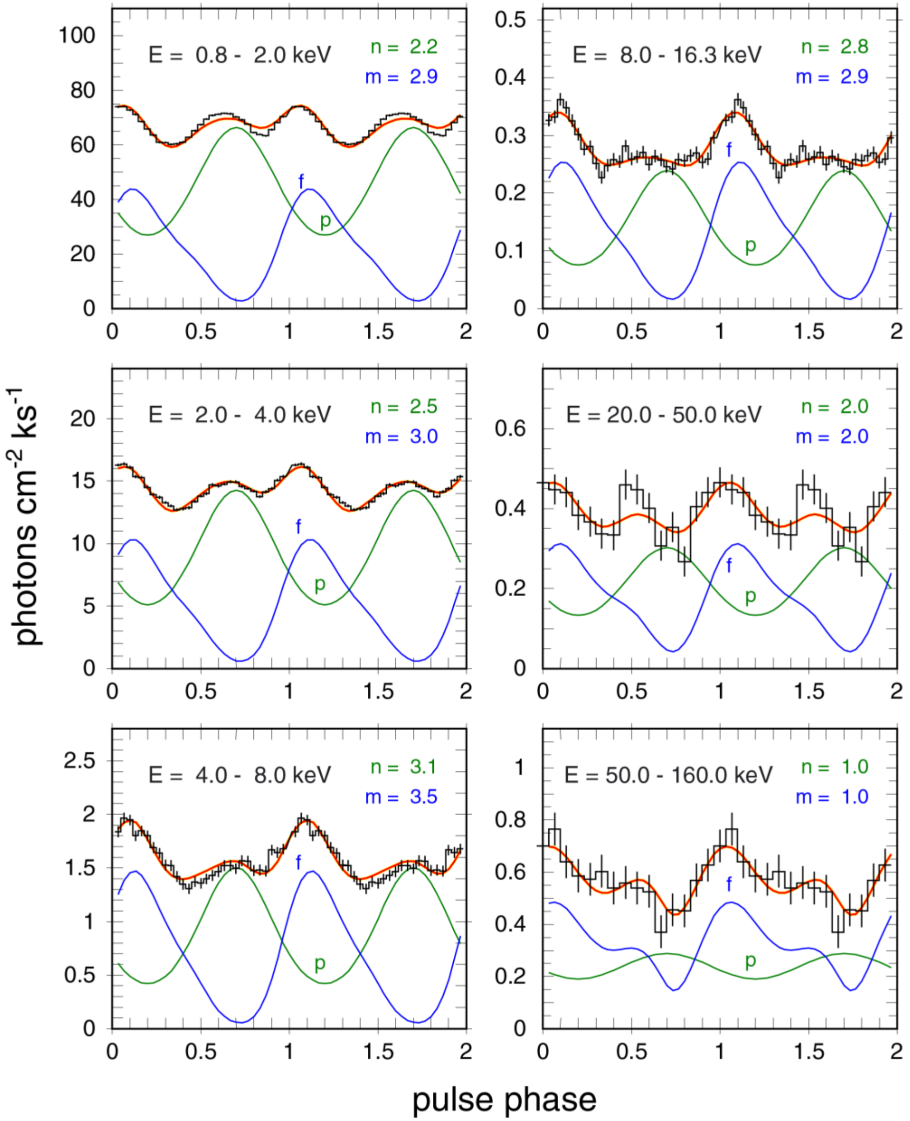
- Our model explains in a natural way the pulse profiles.
- **Main pulse**: It is produced by the **fan beam** emitted perpendicular to the magnetic field (next slide).
- **Secondary pulse**: It is produced by the **polar beam** (emitted and reflected photons from the neutron-star surface).

Schematic of the two beams that make the pulse



Fit to pulse profiles in various energy bands

(Truemper et al. 2013)



p = polar beam

f = fan beam

Bursts

- Before addressing the bursts, let's think of the Sun.
- The Sun has a dipole magnetic field of ~100 G. It also has **multipole** magnetic fields more than two orders of magnitude larger!!!
- All the bursts in the Sun are due to these **multipole** fields, not due to the dipole field.

Bursts

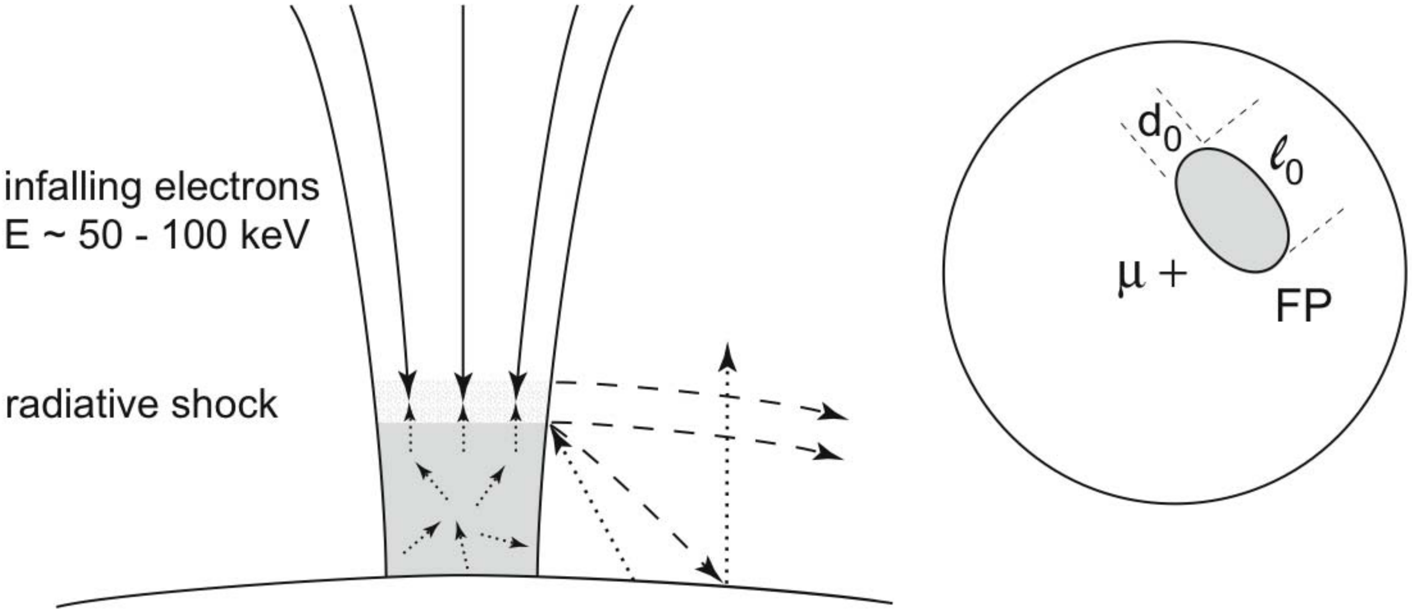
- It is then not crazy to think that AXPs and SGRs have "**normal**" **dipole** magnetic fields and "**magnetar-type**" **multipole** fields.

- The persistent and transient X-ray luminosity of AXPs and SGRs is due to accretion along **dipole** field lines, but all the bursting activity is due to **multipole** fields.

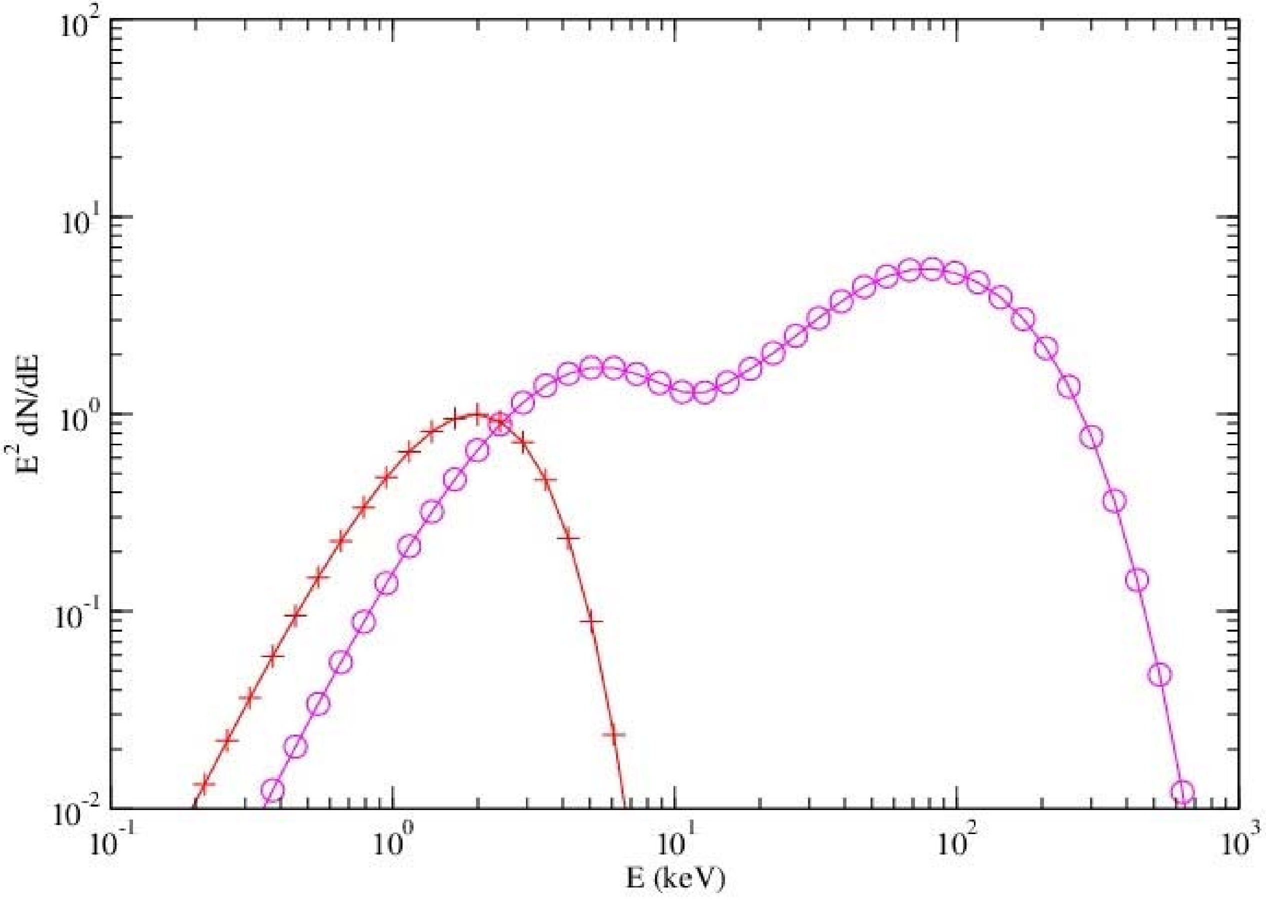
Spectral formation in radiative shocks

- We performed Monte Carlo calculations of radiative transfer across a radiative shock.
- The input photons are either BB from the photosphere surrounding the accretion column or bremsstrahlung from below the shock.
- We used magnetic scattering cross section with Klein-Nishina correction.

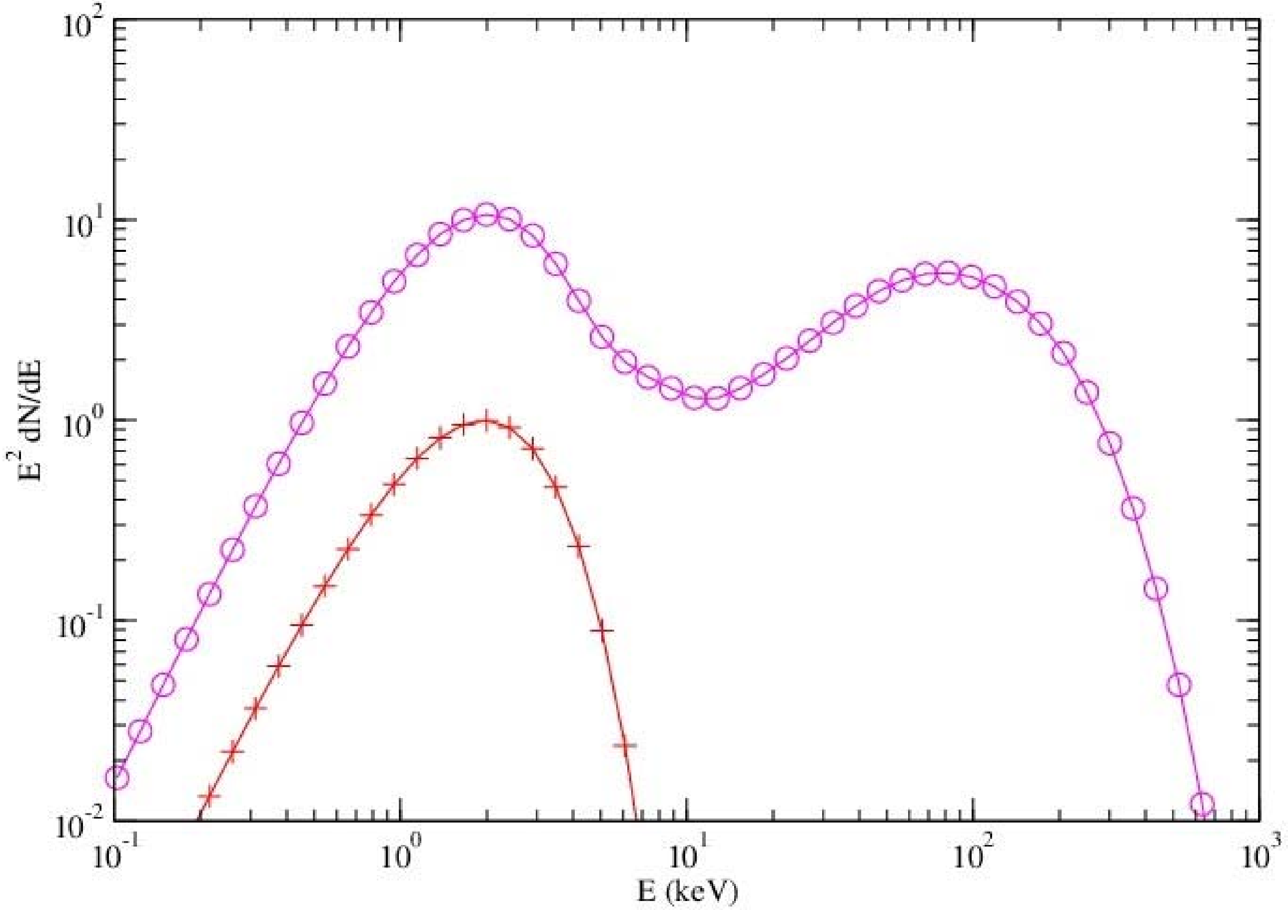
Schematic of accretion column



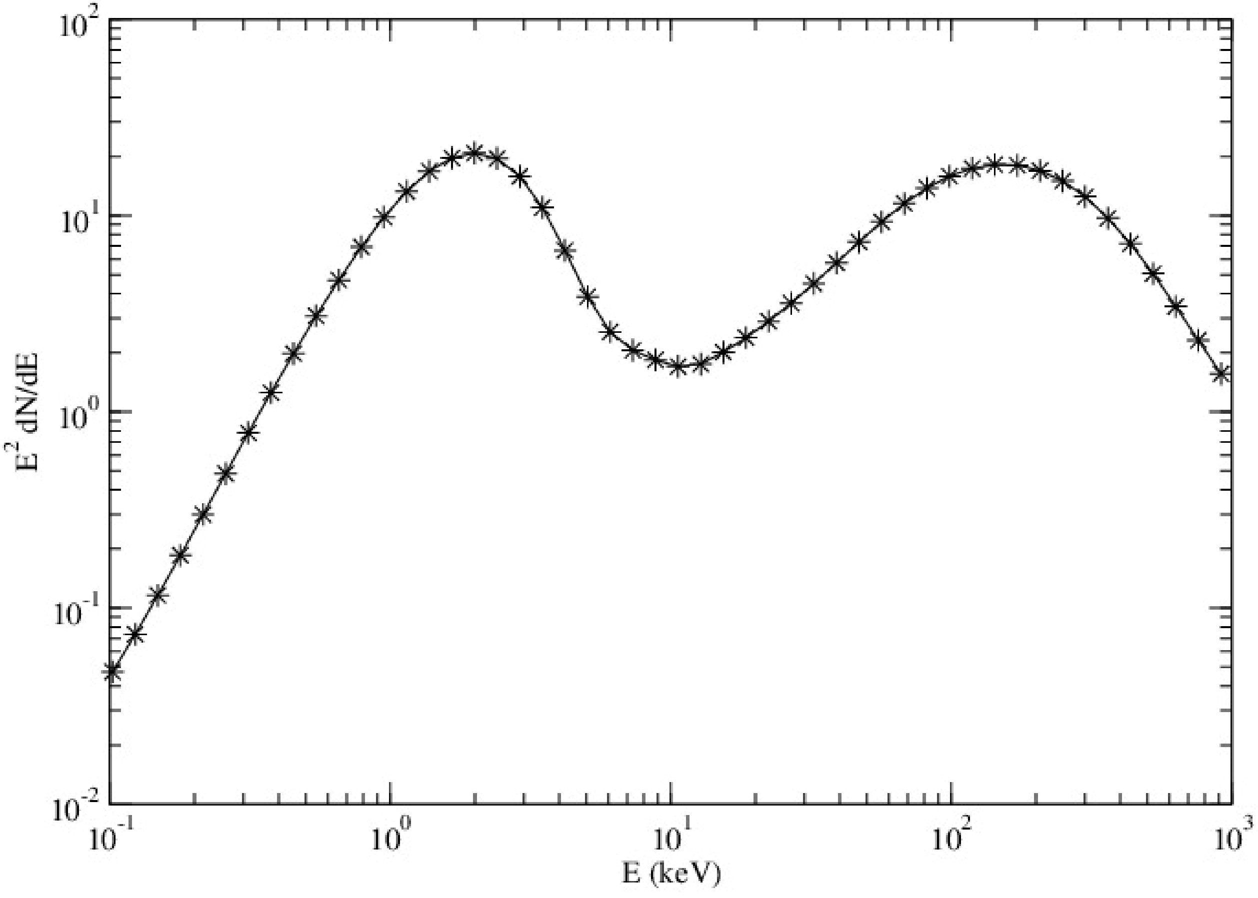
BB input, T_e=50 keV
tau=7, B=1E12 G



BB input, T_e=50 keV
tau=7, B=1E12 G



Bremss. + BB input, T_e=100 keV tau=5, B=1E12 G



Remark

- If our picture is correct, then low-luminosity X-ray pulsars should have high-energy spectra similar to those of AXPs/SGRs.
- They do!!! (else I would not make the remark ☺)
- 4U 0352+309 (X Per) and 4U 2206+54 show high-energy power-law tails similar to those of AXPs/SGRs.

Conclusions

- It will take some time before it is decided which of the two pictures is correct.
- Our accretion picture is the easiest to be proven wrong, because **it is well defined**.
- We **predict** that no AXP/SGR will be found with a high-energy peak above 400 keV.
- **THANKS**

Woods et al. (2001). SGR 1900+14