An accretion model for the quiescent X-ray emission of AXPs and SGRs

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-- Fall-Back Disk Model
-- Accretion Geometry, Spectral Formation & Beaming
-- Comparison with X-ray pulsars
-- Summary & Conclusions

NS 2011
Saint Petersburg

Difficulties of the classical magnetar model with explaining the quiescent emission

-- discovery of SGR 0418+5729 with P = 9.1 s and a (vacuum)
dipole field < 1.5 x 10^{13} G (Rea et al. 2010).

-- the long term stability of pulse shapes over ~15 years requires that the same crustal plate is torqued every few years (den Hartog et al. 2008)

-- no explanation for the beaming/pulse profiles of the hard tail component

-- Vick Kaspi (this session): high B radio pulsar showing no magnetar properties (no X-rays)

History of accretion from a fall-back disk

1995 van Paradijs et al. AXPs are single neutron stars accreting from a residual disk

- remnants from the common-envelope evolution of an HXMB

2000 Chatterjee et al.
2001 Alpar → AXPs accrete from a supernova fall-back disk

followed by a series of papers of the Istanbul group 2003 – 2011 on the disk physics,
disk-magnetosphere interaction neutron star fields 10 – 10 G

2006 Wang et al. discovery of IR/optical radiation from 4U 0142+61
2009 Kaplan et al. and from 1E 2259+586

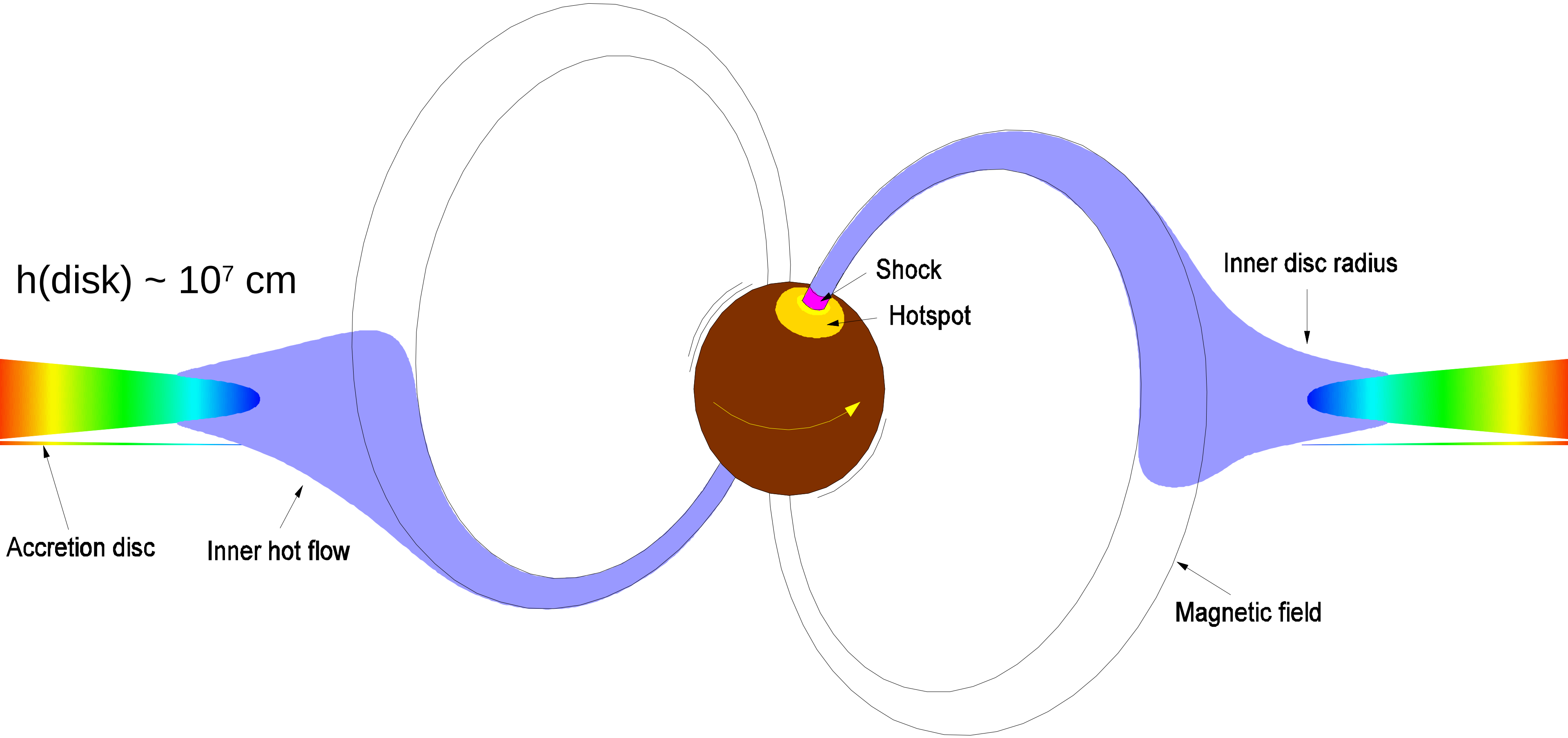
2011 Ertan poster after this session: „Evolution of SGR 0418+5729“

2010 Truemper et al. model for the emission from the accretion

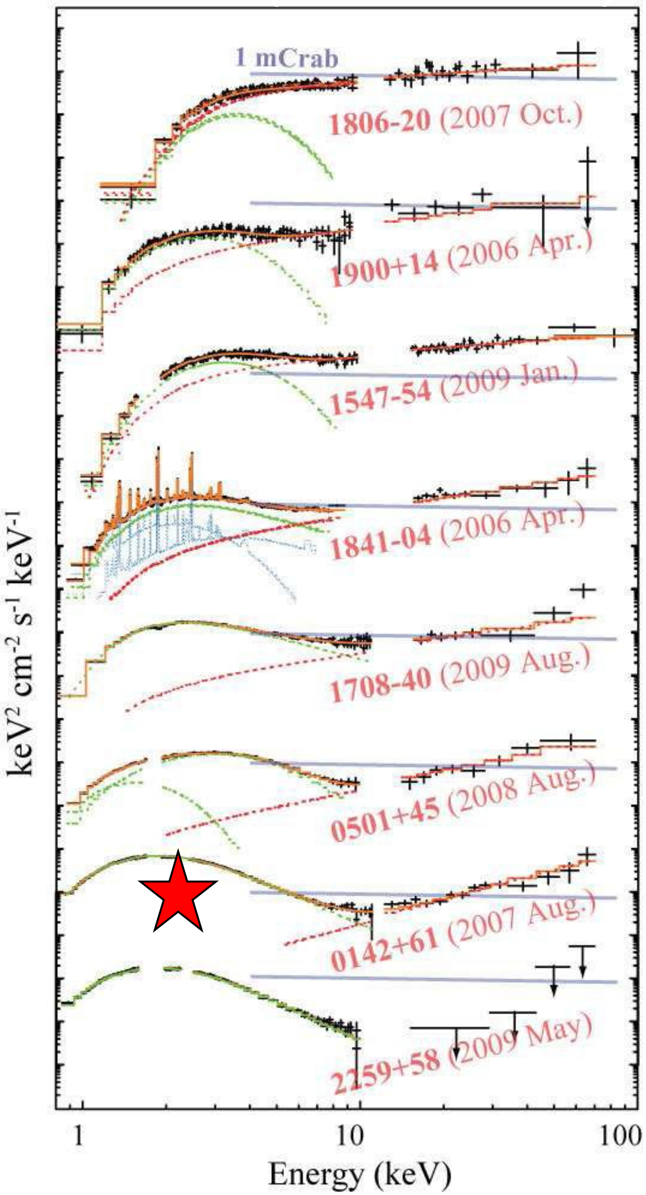
The persistent emission is produced by accretion from a fall-back disk

4U 0142 +61:

h(disk) ~ 10^7 cm



AXPs/SGRs spectra have two components



Suzaku spectra
(Enoto et al. 2010)

Two spectral components

Lhard/Lsoft ≈ 1 ± factor 3

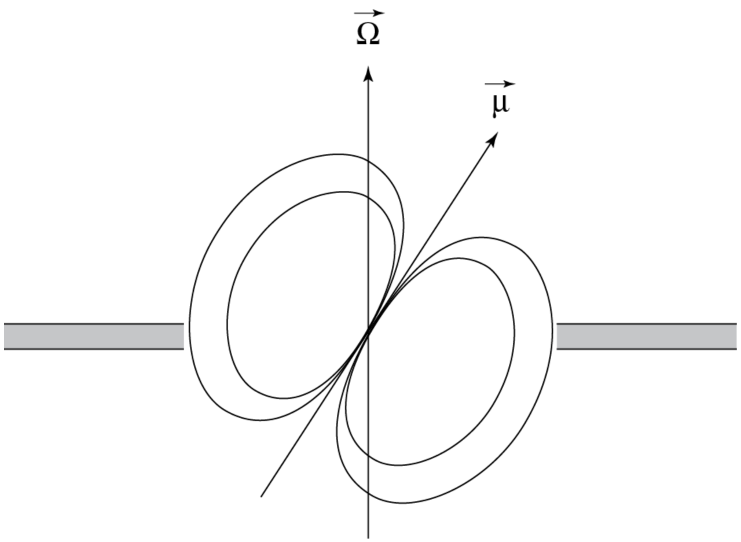
soft emission from the polar cap

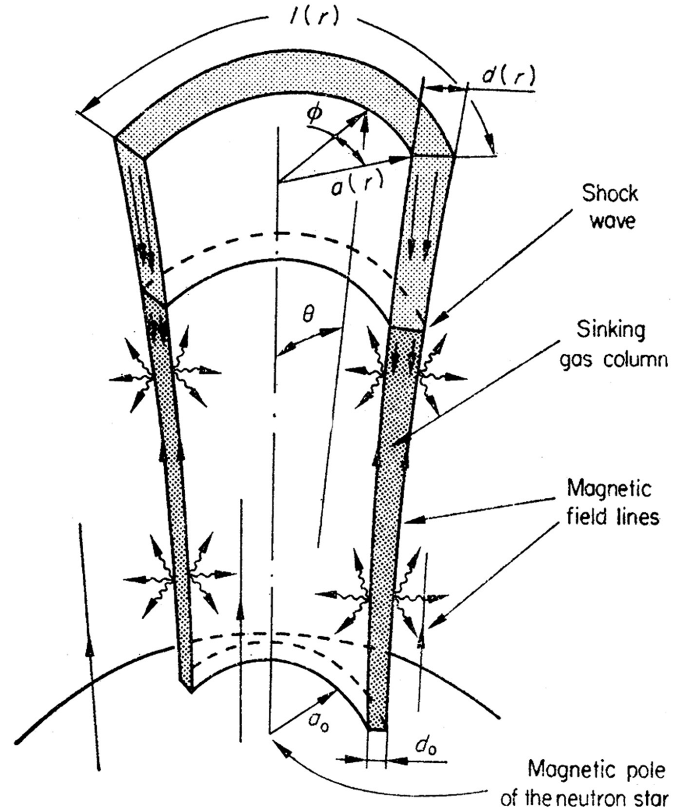
origin of the hard tail?

4U 0142+61

Geometry of the accretion column

For an inclined dipole the Alfven surface is not circular in the plane of the accretion disk. The matter enters the magnetosphere not along the whole of the inner disk edge but in two opposite regions (Basko & Sunyaev 1976, supported qualitatevily by MHD simulations of Romanova et al. 2008, for much smaller magnetosphers.



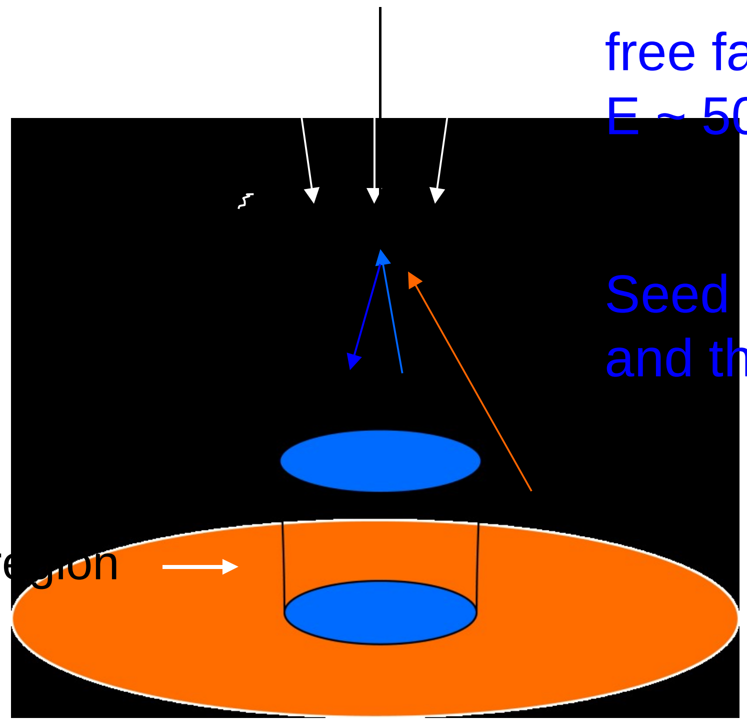


- This means there is an azimuthal modulation of the column width!

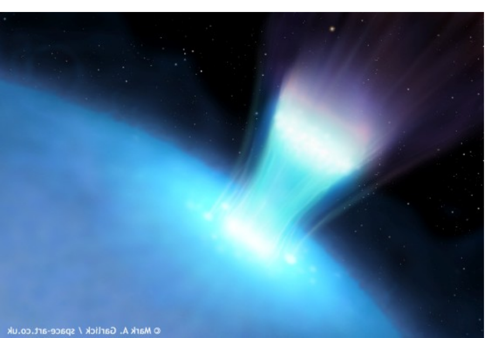
How to produce a hard X-ray tail ?

Bulk motion comptonization (BMC)

e.g. Titarchuk, Mastichiadis & Kylafis 1997 (70 equations!)



In addition thermal comptonization (TC)
takes place in the shock region



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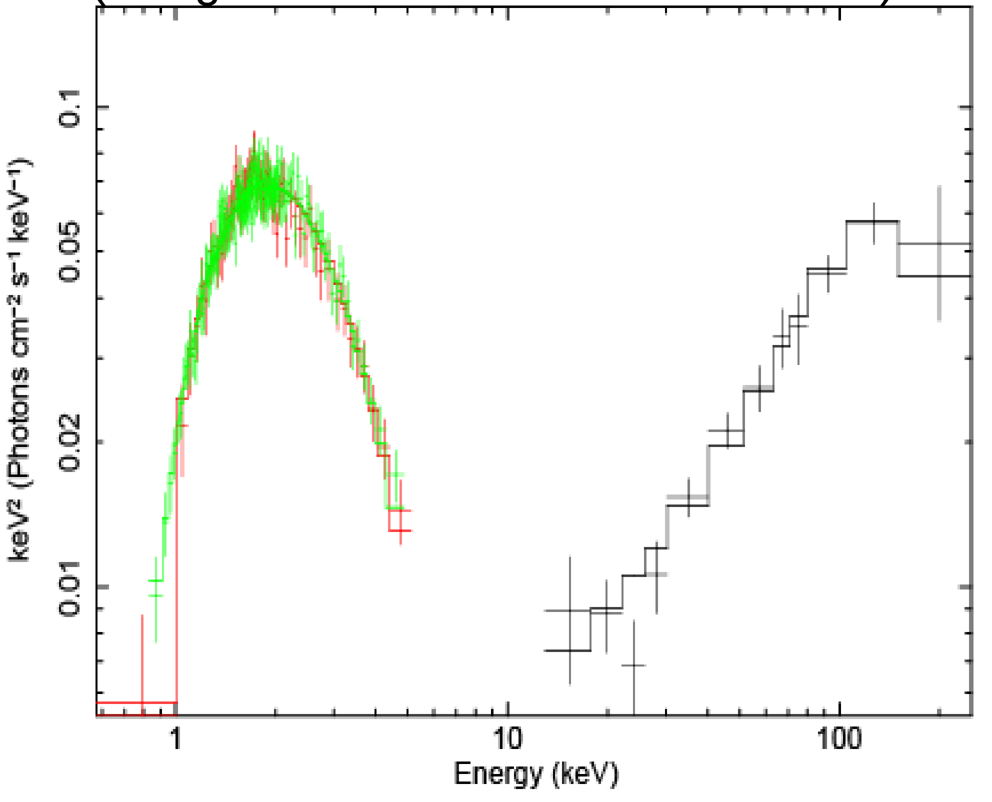
BMC/TC fit to the spectrum of AXP 4U 0142+61

(using the S/W of Farinelli et al. 2008)



The best fit BMC & TC model fitted to Chandra HEG & Integral ISGRI spectra

< 10 keV: photospheric spectrum: blackbody-like
+ TC power law (thermal comptonization)

> 10 keV: BMC power law (bulk motion comptonization)

(Trümper, Zezas, Ertan & Kylafis A&A 2010)

Modeling the
energy dependent pulse profiles
phase dependent spectra

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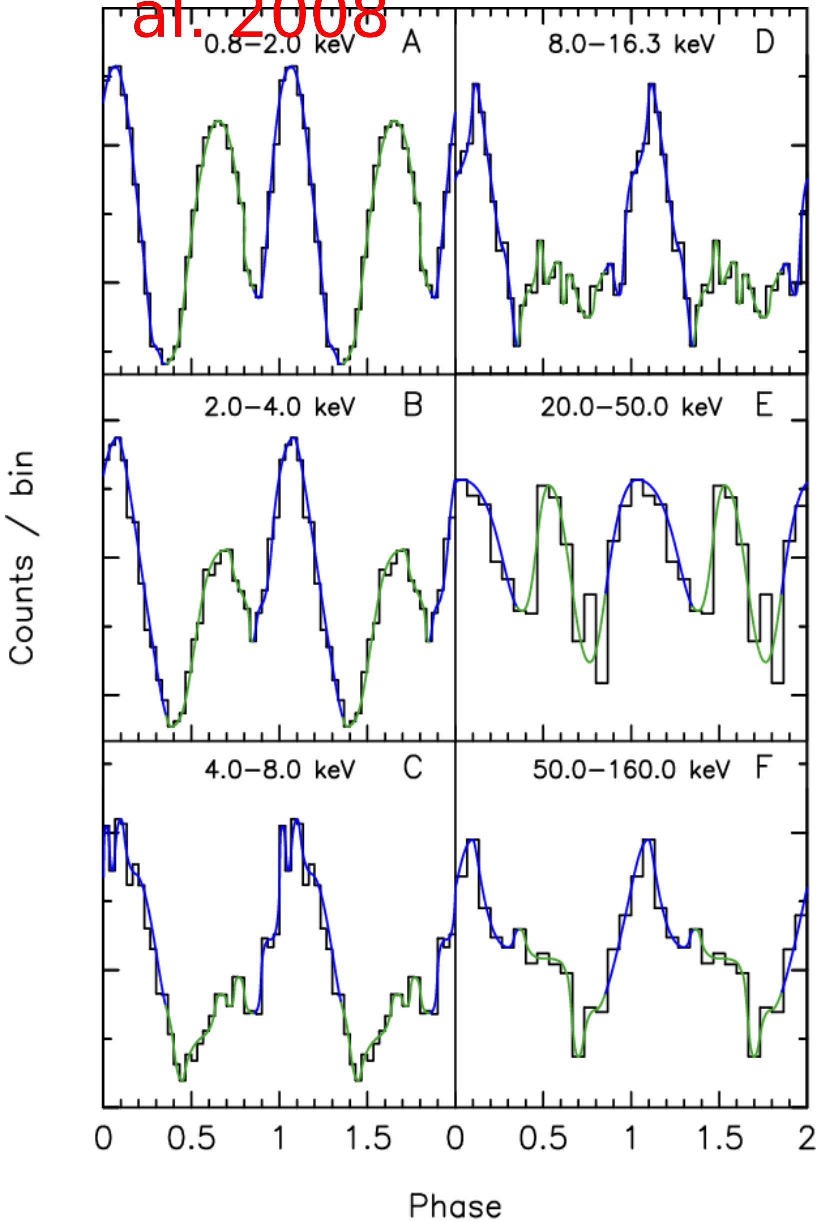
Pulse profiles of 4U 0142+61 from den Hartog et al. 2008

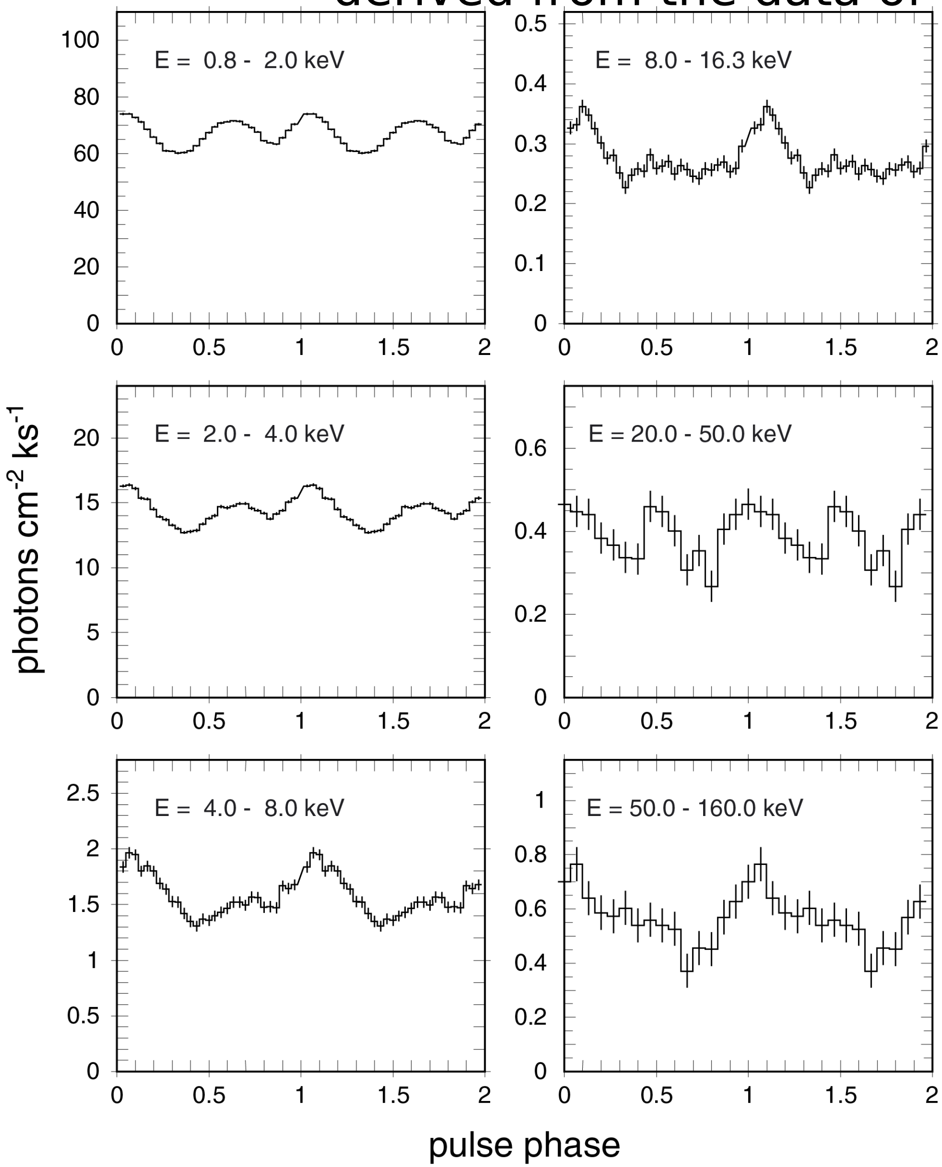


We identify the main pulse (marked in blue) extending up to 160 keV with the BMC component escaping from the column as a fan beam,

and the secondary pulse (marked in green)
with the polar beam from the hot polar cap. This consists of the photospheric
emission (≤ 2keV) and „reflected“ fan beam photons.

The full pulse profiles (including the dc component) of 4U 0142+61

derived from the data of den Hartog 2008 by Dennerl and Trür



main pulse (0.8 – 160 keV)
peaking at phase 1.1
„fan beam“

secondary pulse (0.8 – 80 keV)
peaking at phase 0.6
„polar beam“

The energy and angle dependent emission from an accretion column

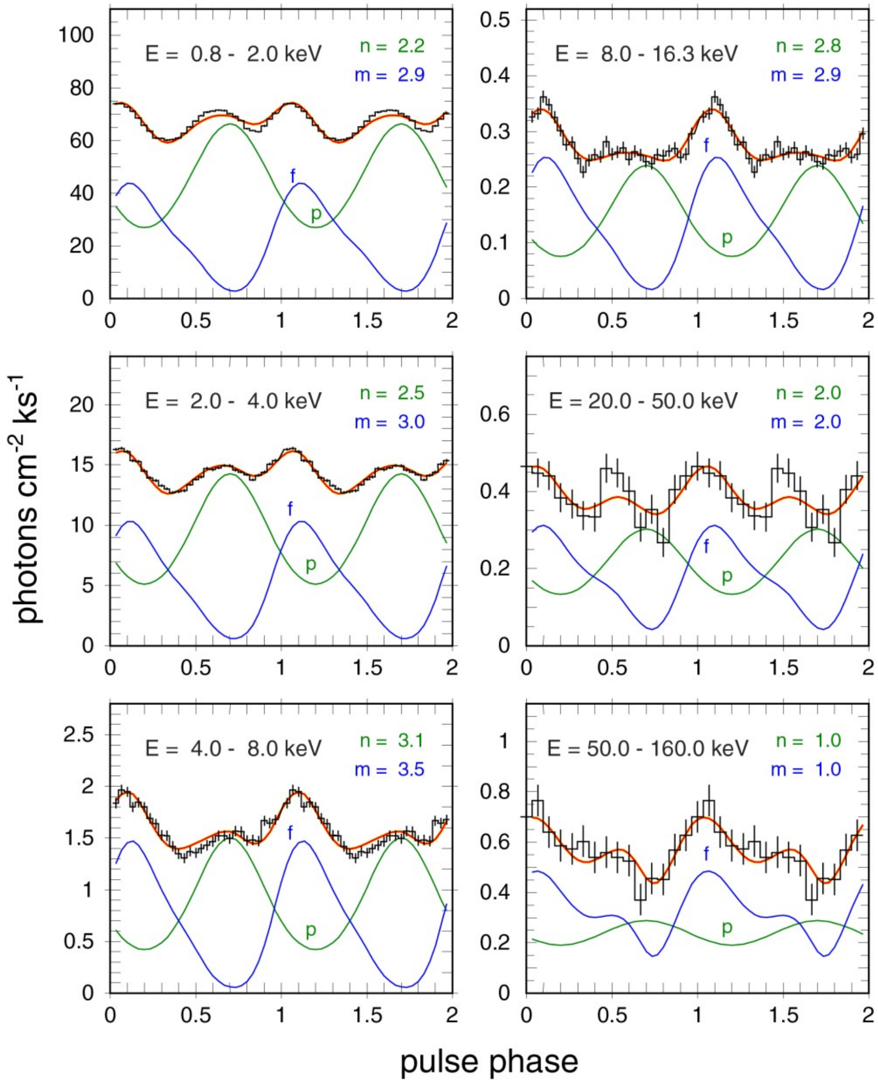
In superstrong magnetic fields the scattering and absorption cross sections
depend strongly on the energy (cyclotron resonance) and direction of the photon
with respect to the magnetic field

- for the photospheric emission reasonable models exist (e.g. Pavlov & Zavlin,...)
- for the emission from the accretion column only crude models exist

  Becker & Wolff 2007 use energy averaged cross sections

  Meszaros & Nagel 1985 use realistic cross sections, but assume that the density and temperature in the column is constant. In reality the temperature must drop towards the surface.

Best fitting energy dependent pulse profiles



p = polar beam

f = fan beam

inlination spin axis i = 35.3 ± 0.5 , angle dipole/rotation axis $\alpha = 16.2 + 0.9$

ratio column width q = 3.8 ± 0.4 (from the asymmetry of the pulse profiles)

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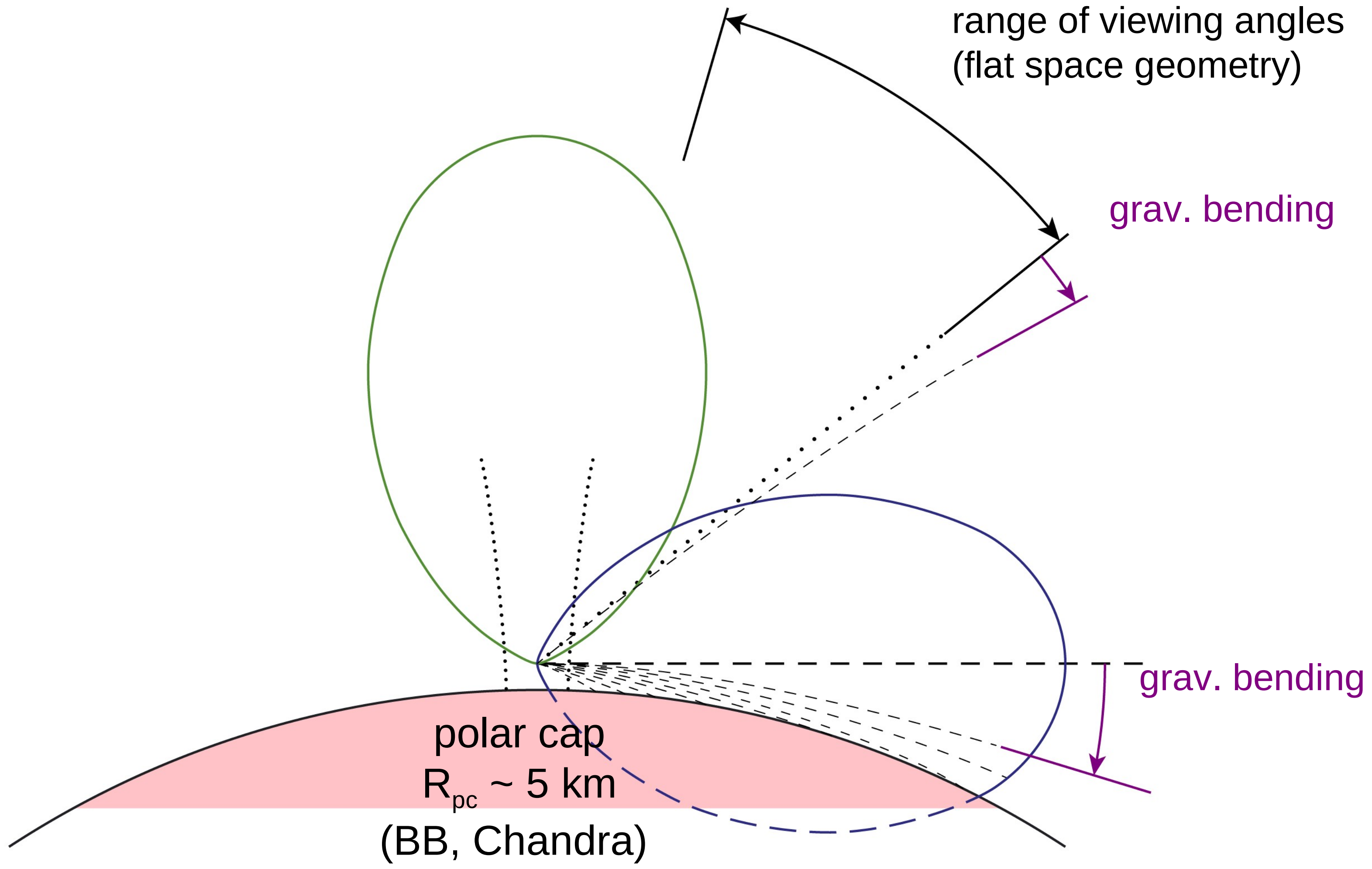
The beaming geometry (for m = n = 3)



gravitational bending (asssumed M = 1.4 solar masses, R = 14 km)

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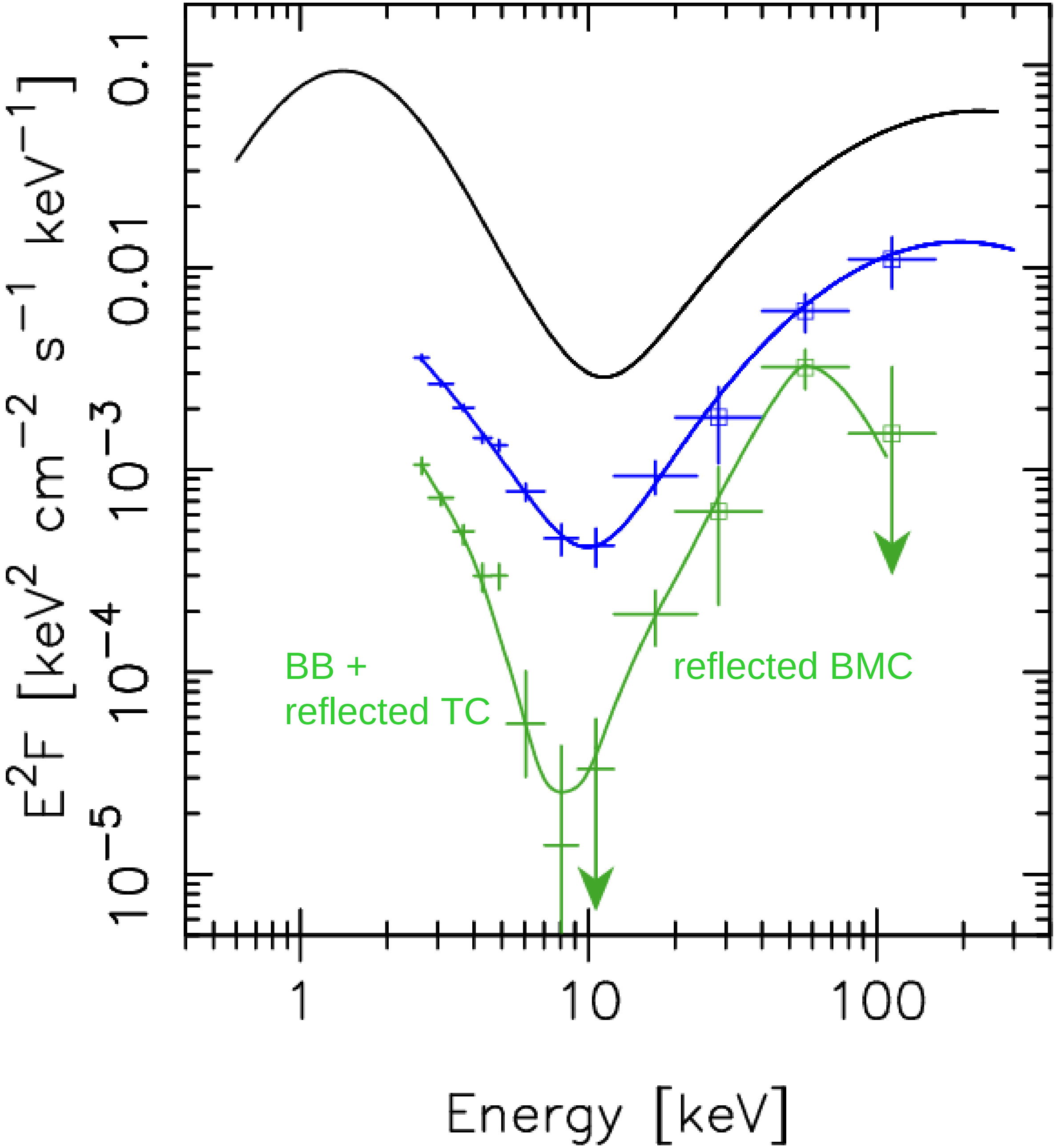
Phase dependent spectra of 4U 0142+61 (JT et al. 2010)



(from den Hartog et al 2008)

total emission

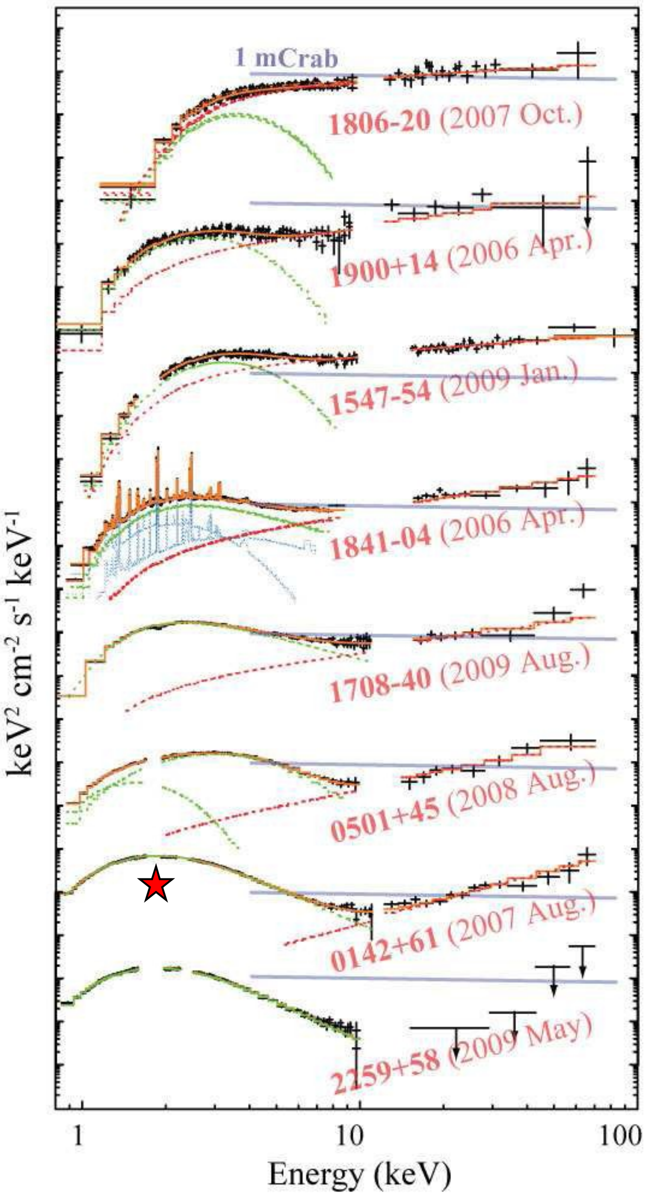
fan beam
BMC/TC photons

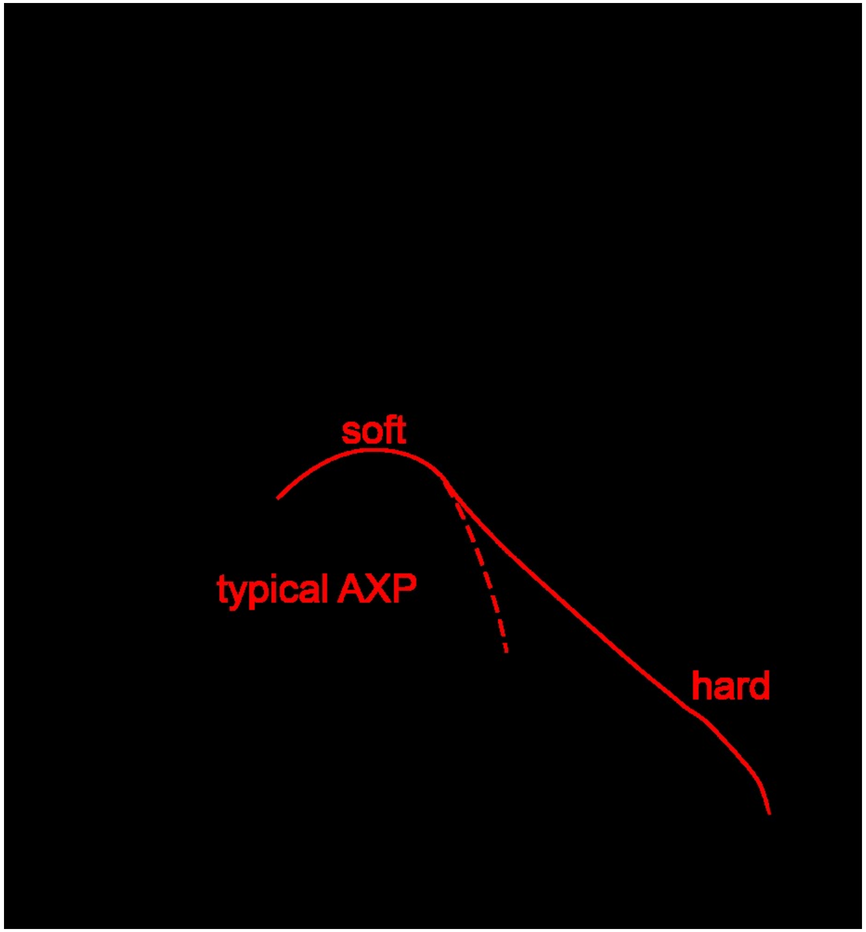
polar beam
BB + reflected photons

peak at 60 keV
(2.5σ)
enhanced scattering
at the cyclotron
resonance

B ~ 5 x 10 (1+z) G

Why do SGR/AXPs have hard X-ray tails in contrast to binary X-ray pulsars having similar magnetic fields?





AXPs are less luminous by a factor of 100!

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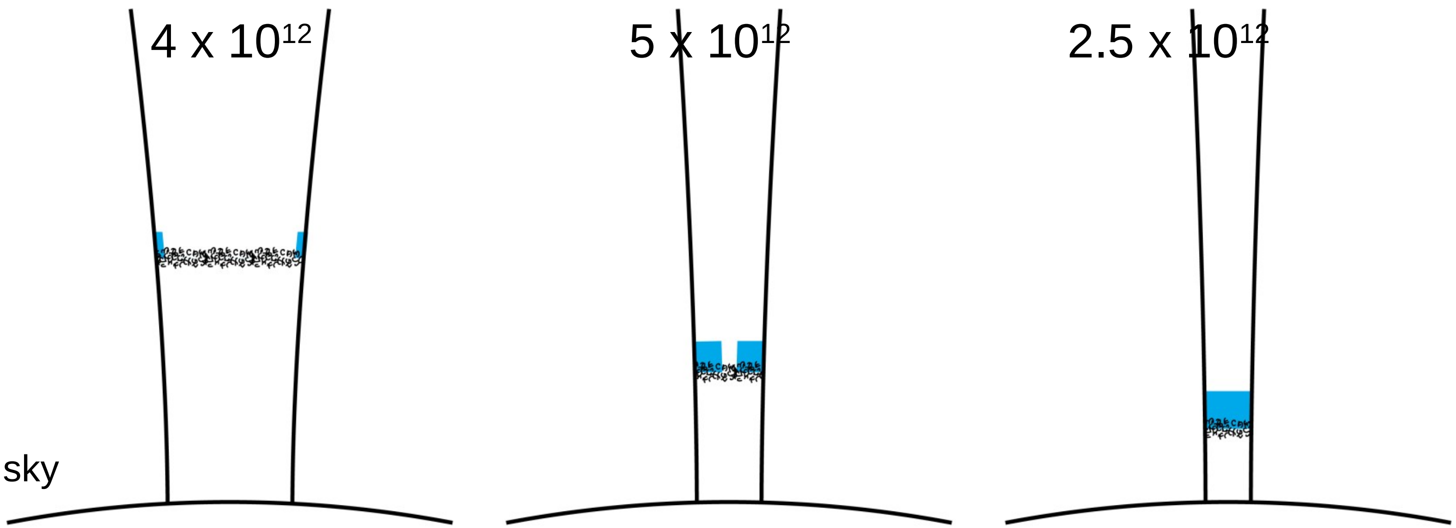
Comparison with Accreting X-ray Pulsars (schematic)

	Her X-1	AXP 4U 0142+61	X - Persei
L_x (erg/s)	3×10^{37}	3×10^{35}	2.4×10^{34}
B_d (G)	4×10^{12}	5×10^{12}	2.5×10^{12}



D ~ L   B

(Shapiro & Teukolsky 1983)

Hard/soft   very low   ~ 1/1
> 1

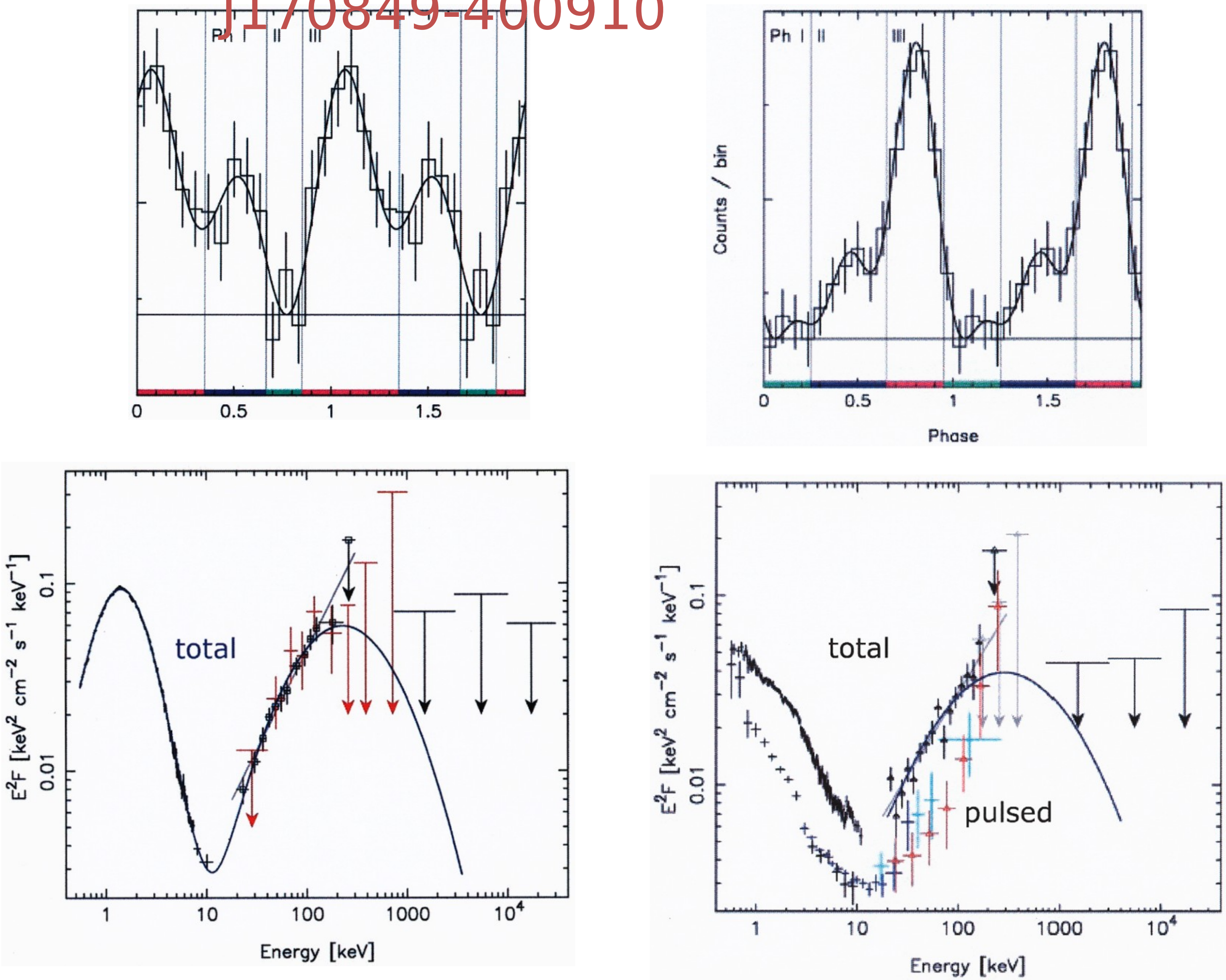
Cut-off (keV)   > 100   > 100
65

-- BMC producing the hard tail takes place over the whole cross section

-- Th[illegible] hard X-ray photons escape as a fan beam from an optical depths τe

-- optimum condition for the production of a hard tail: τe ≈ τT (transv. opt. depth)

4U 0142+61 1RXS J170849-400910



The same analysis can be applied to 1RXS J1709-40 and other AXPs/ SGRs

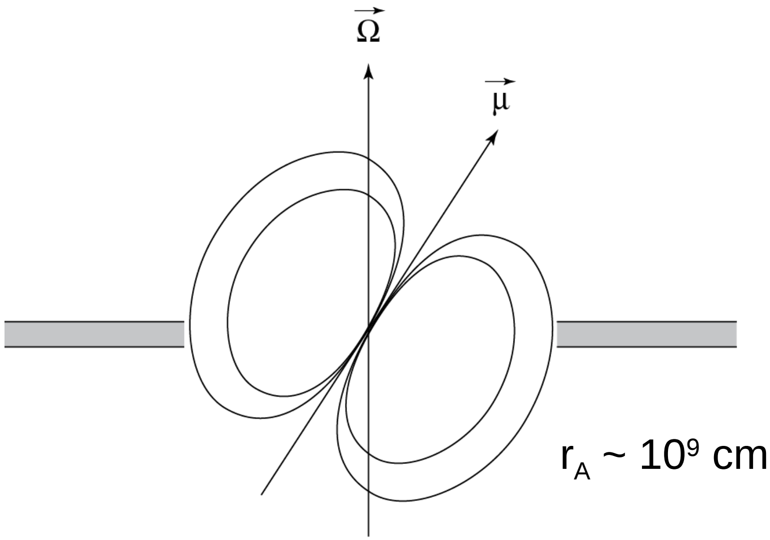
The radio emission of AXPs

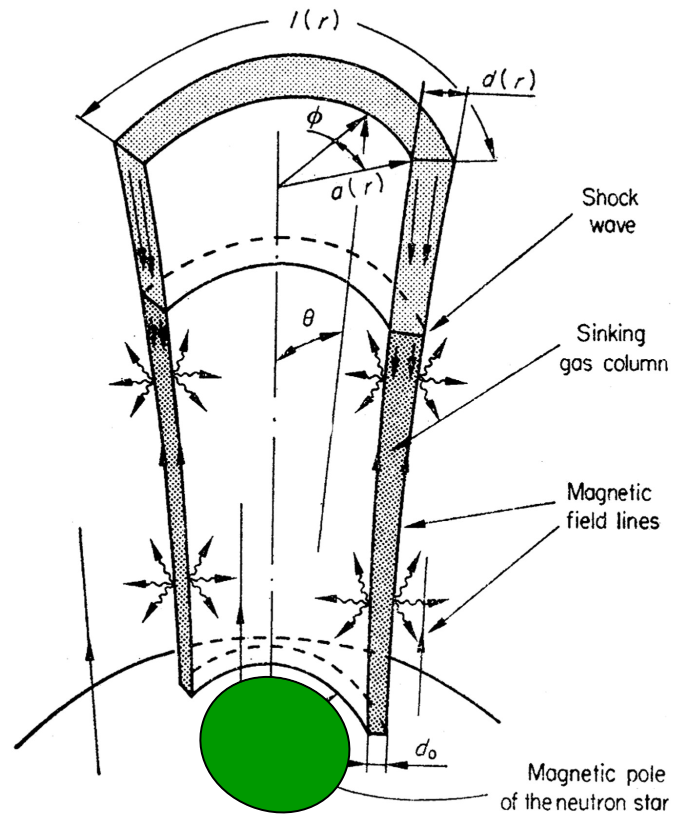
Three of AXPs/SGRs have shown radio emission:

--1E 1547-54 , P = 2.07 s (Camilo et al 2006)
-- XTE J1810-197, P = 5.54 s (Halpern et al. 2005)
-- PSR J1622-4950 P = 4.33 s (Levin et al. 2010)

For normal accreting neutron stars the radio emission is quenched.
But for the AXPs/SGRs the situation may be different due to the low accretion rate and the long period:

Geometry of the radio and X-ray emission region





The radio polar cap is small due to the long pulse period and may be separated from the accretion region allowing the co-existence of radio emission and accretion

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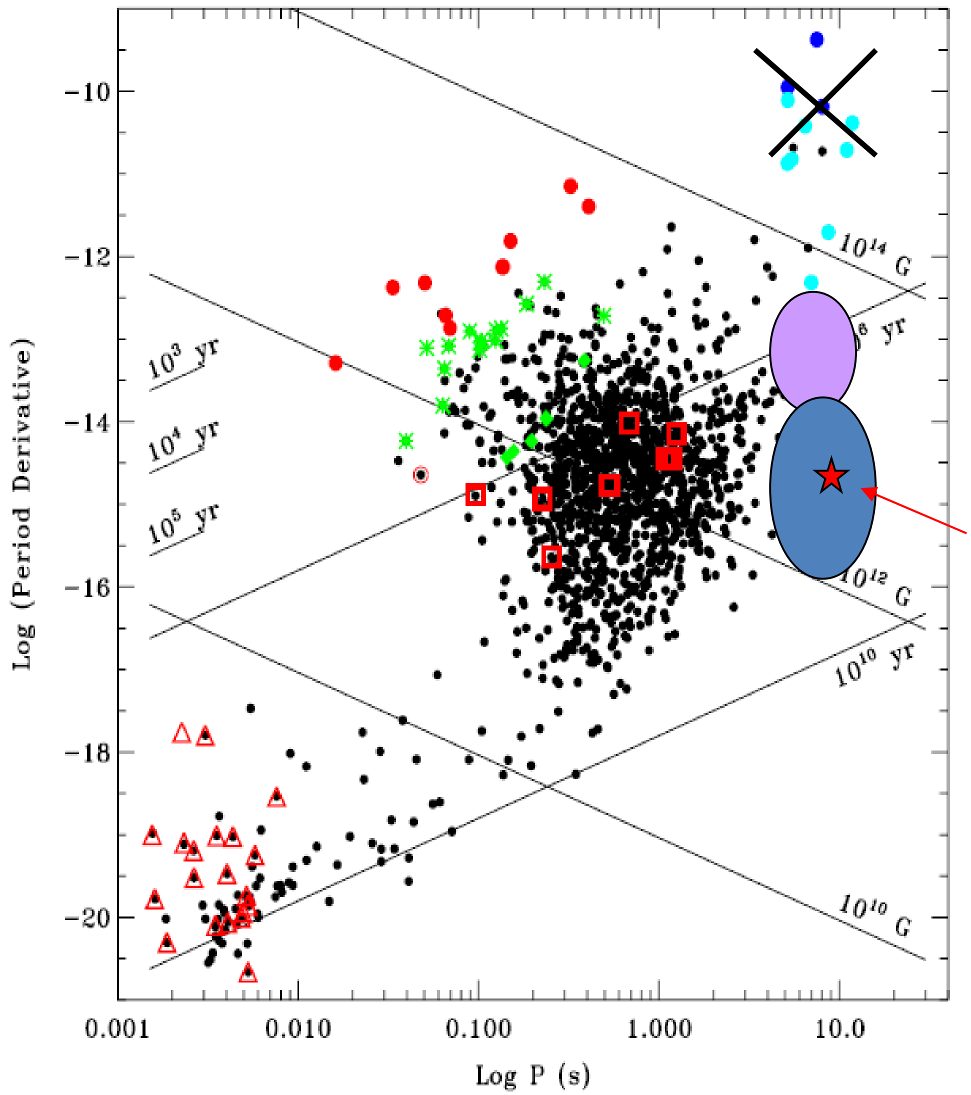
Magnetic Dipole Fields of AXPs & SGRs - Fallback disk model

The XDINSs („Magnificent Seven“) have ages

→



Magnetar model:
SGR‘s
AXP‘s

7 XDINS

Fall back disk model:
10 -10 G

4U 0142+61

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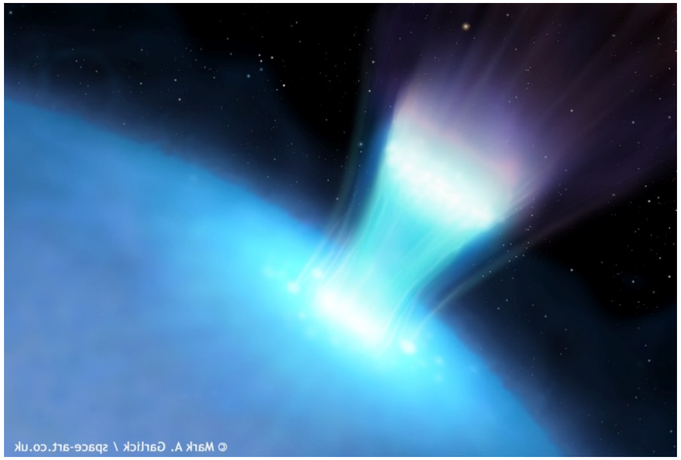
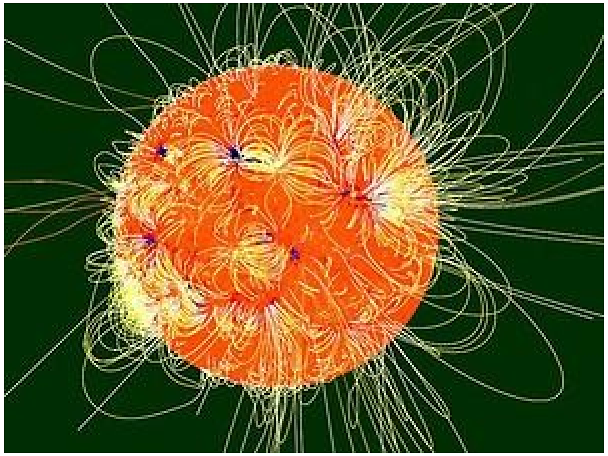
Summary and Conclusions

-- the „quiescent“ X-ray emission of SGRs and AXPs is powered by accretion





Thank you !

Jenam talk 19 slides
two backup slides follow (there may be a few more)

NS 2011 talk will be reduced by a few slides, e.g. on the radio emission

Magnetar models (Duncan & Thompson 1995….)

Assumption: AXPs and RGRs are isolated neutron stars

secular spindown P, Pdot → B ~ 10^{14} …. 2 x 10^{15} G

L_x >> spin down power → magnetic field decay

principal models

for the large and giant bursts

energy liberation by crustal shifts

formation of a relativistic e^+e^- plasma

magnetic reconnection

for the quiescent emission

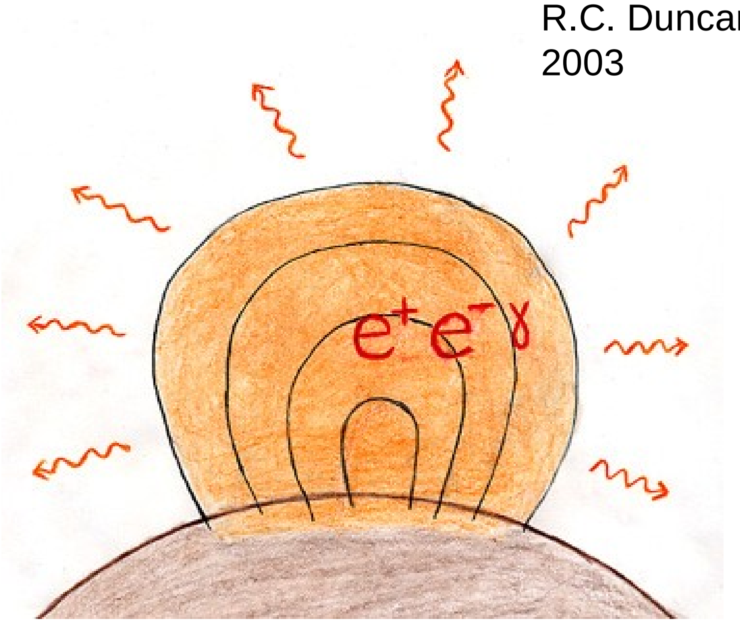
magnetic twist by crustal motion

induced current (electrons + protons)

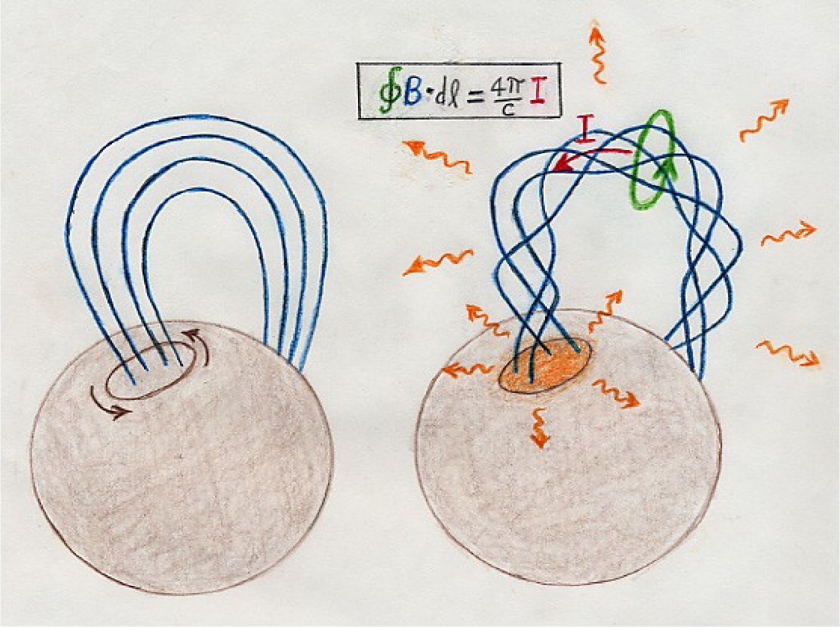
protons heat the polar cap → soft X-rays

electrons upscatter soft X-rays → hard X-rays

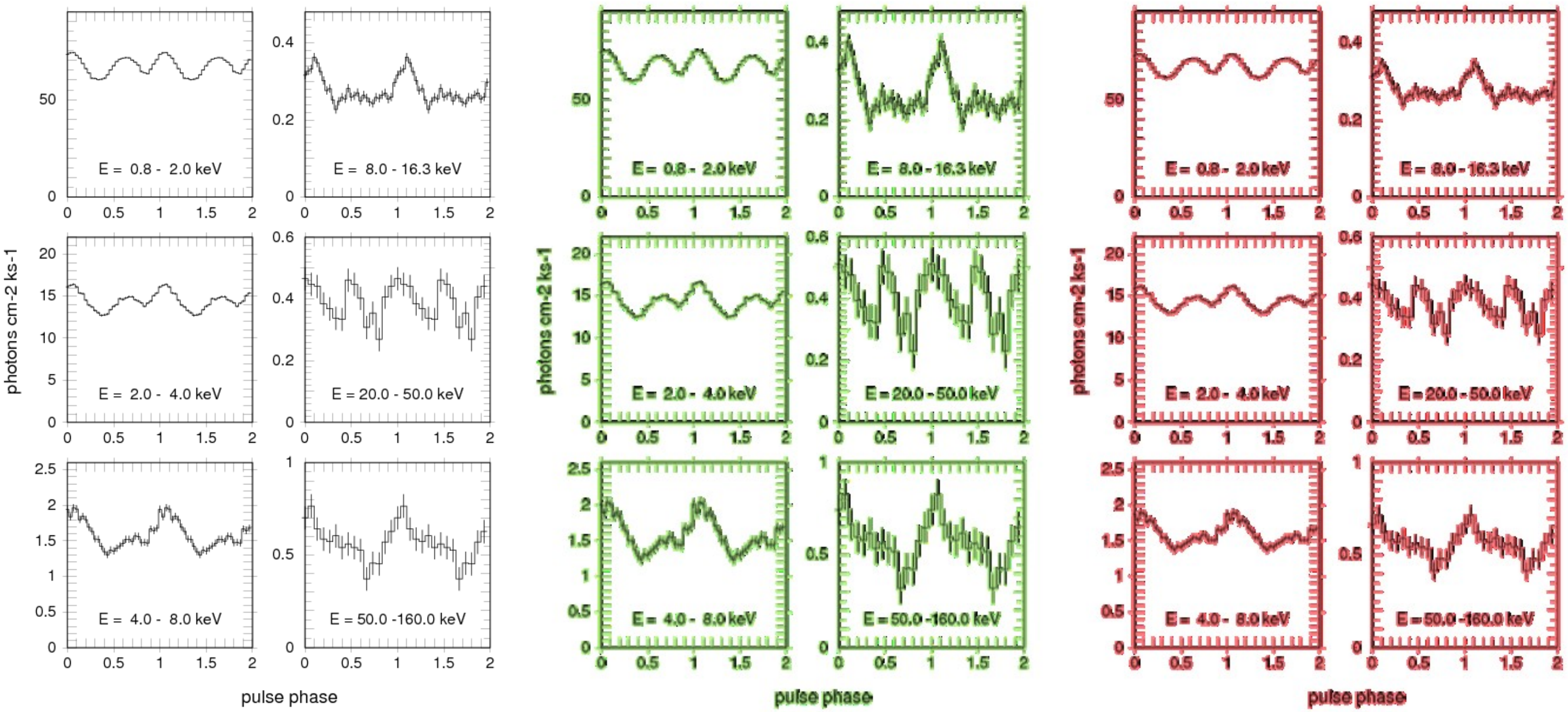
R.C. Duncan 2003



A trapped fireball (orange zone) on the surface of a neutron star



A magnetic twist gives rise to the quiescent X-ray emission of a magnetar.



photons cm-2 ks-1
pulse phase
E = 0.8 - 2.0 keV
E = 8.0 - 16.3 keV
E = 2.0 - 4.0 keV
E = 20.0 - 50.0 keV
E = 4.0 - 8.0 keV
E = 50.0 -160.0 keV