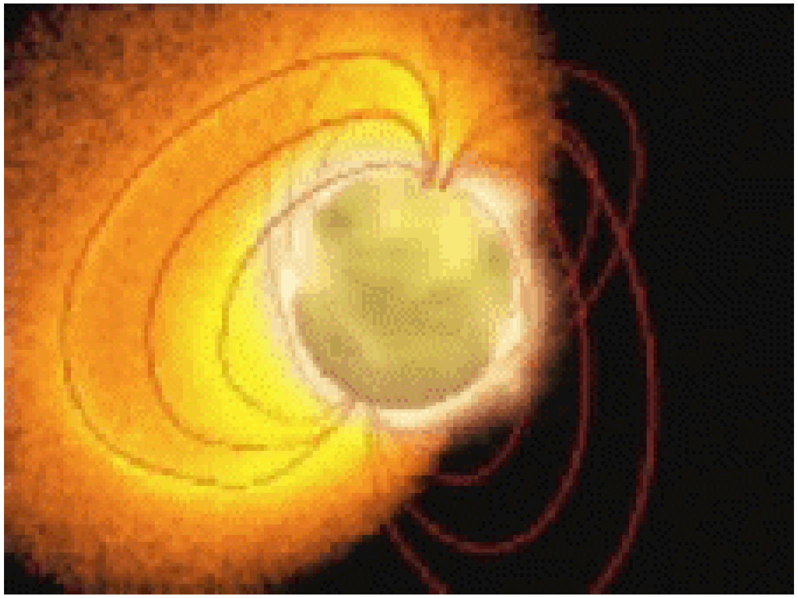
Spectra and Long-term Evolution of Magnetars



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Wideband X-ray Astronomy, Pune
January 13, 2011

AXPs and SGRs: Why Magnetars?

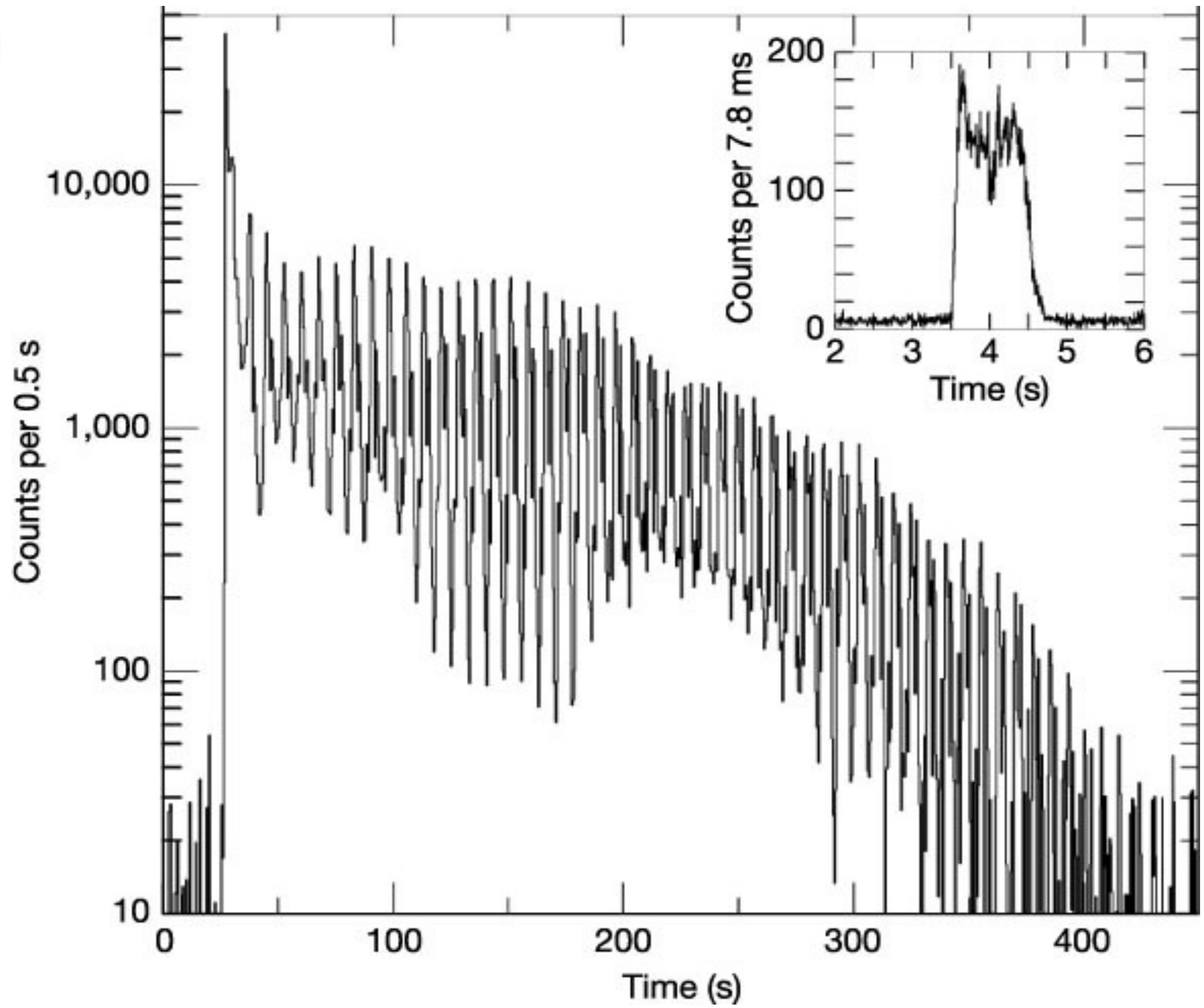
1. Dipole spindown argument:

$$B = 2 \cdot 10^{14} \left(\frac{P}{6s} \frac{\dot{P}}{10^{-11}} \right)^{1/2} G$$

2. $L_x \sim 10^{33-35}$ erg s^{-1} >> $L_{spindown}$

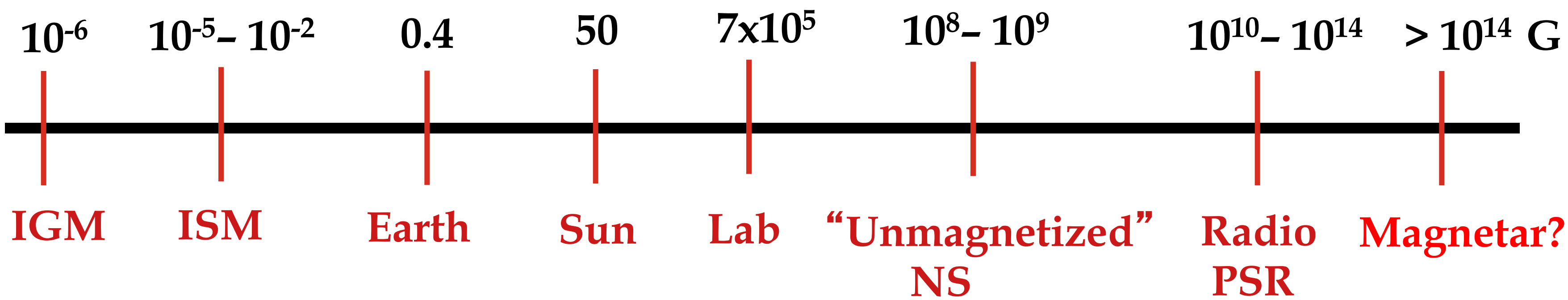
AXPs and SGRs: Why Magnetars?

3. Flares and bursts with ~ 10^{44} erg energy release



RHESSI lightcurve, Hurley et al. (2005)

Extreme Range of Magnetic Fields



Spectral Studies

- Broadband spectra can reveal magnetic field properties, temperature and evolution
- X-ray, hard X-ray, IR, radio emission: focus on X-rays
- Surface emission involves complex physics

Photon Transport in Strong Fields

Boltzmann equation for 4 interacting fluids:
electrons, protons, photons in 2 polarization modes

- electron mean-free-path is small
  => fluid approximation

- electrons and protons efficiently coupled
  => solve hydrostatic equilibrium for protons,
  energy equation for electrons

- photon mean-free-path changes from very small to infinite

- photon-electron, photon-proton and 3 species interactions

Photon Transport in Strong Fields

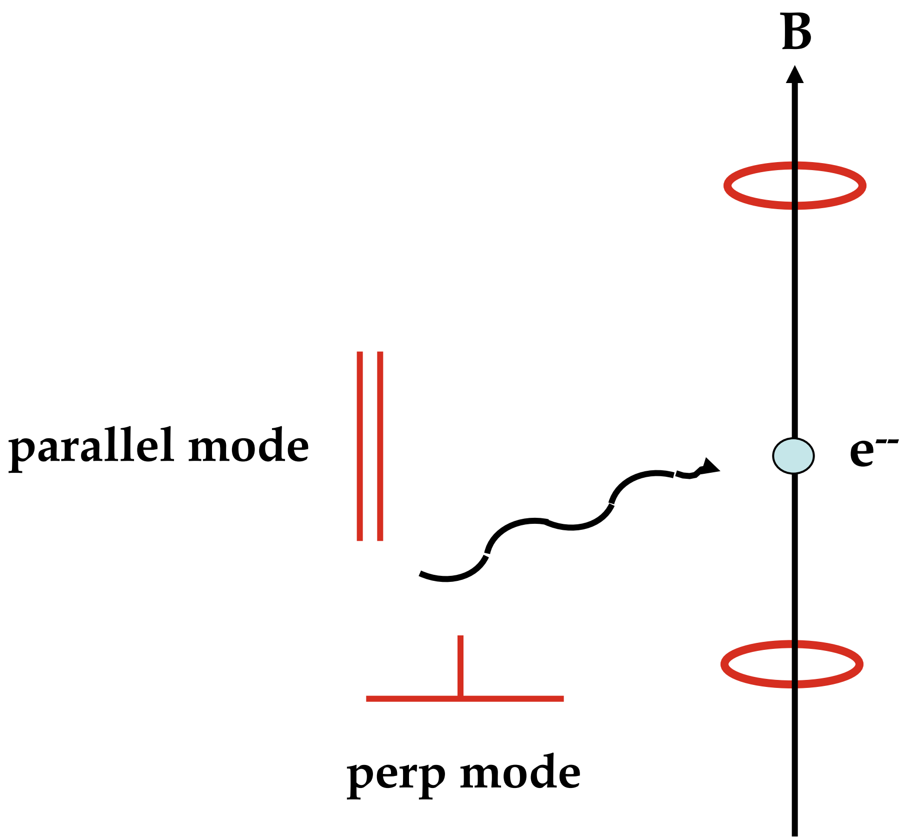
$$y_G \mu \frac{dI_E^i}{d\tau_{es}} = \chi_a^i I^i - \chi_a^i \frac{B_E}{2} + \chi_s^i I^i - \sum_{j=1,2} \int \chi_s^{ij}(\mu, \mu') I'^j d\mu'$$

for i = 1, 2

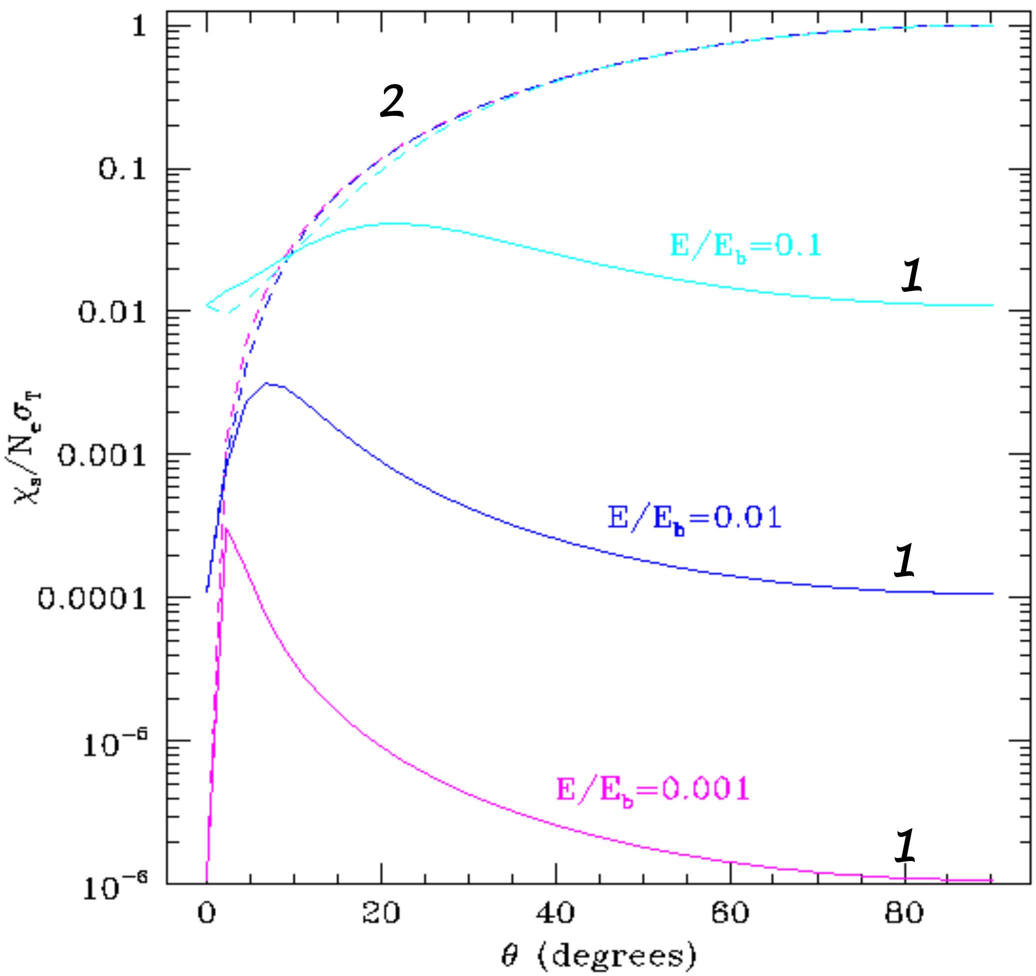
Radiative Equilibrium :

$$H(\tau) = \sigma T_{eff}^{\ 4} = \int I(\tau, \mu, E)\, \mu\, d\mu\, dE$$

Solve for electron temperature with an iterative scheme


B
parallel mode
e--
perp mode

Magnetic γ-e⁻ Interaction Cross-Sections

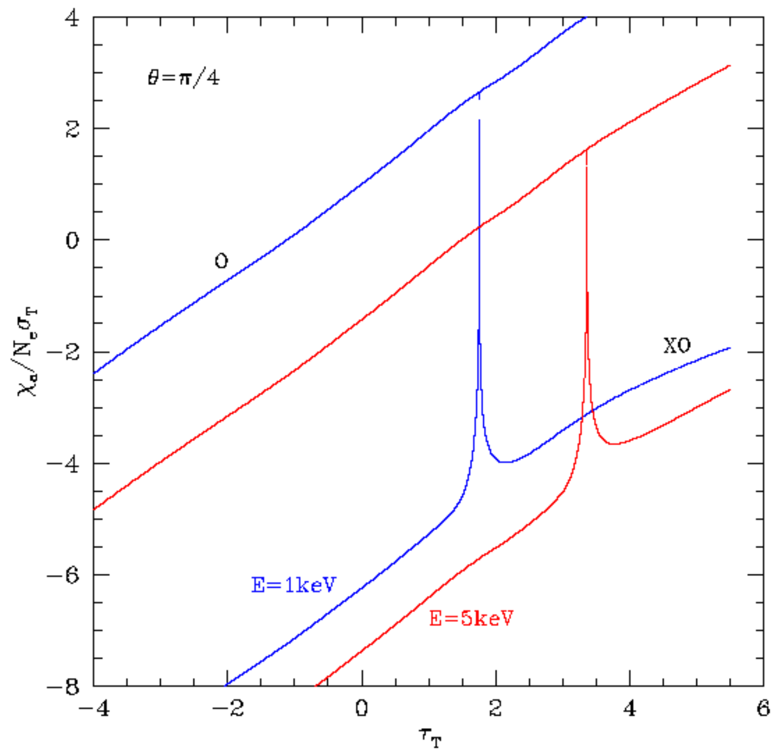


$$\chi_s^1 \approx (E / E_b)^2 \sigma_T$$

$$\chi_s^2 \approx \sigma_T$$

Energy, angle & polarization dependence

Vacuum Polarization Resonance



Vacuum-dominated ← → **Plasma-dominated**

-- at B ~ B_{cr} virtual $e^+ e^-$ pairs affect photon transport

-- resonance appears at an energy-dependent density

-- proton cyclotron absorption features appear at ~keV, and are weak

Zane et al. 2001; Ozel 2001, 2003; Ho & Lai 2001, 2003

Processes in the Magnetosphere

- large scale currents in the magnetosphere of a magnetar can result in particle densities >> Goldreich-Julian density

- mildly relativistic charges Compton upscatter atmospheric photons

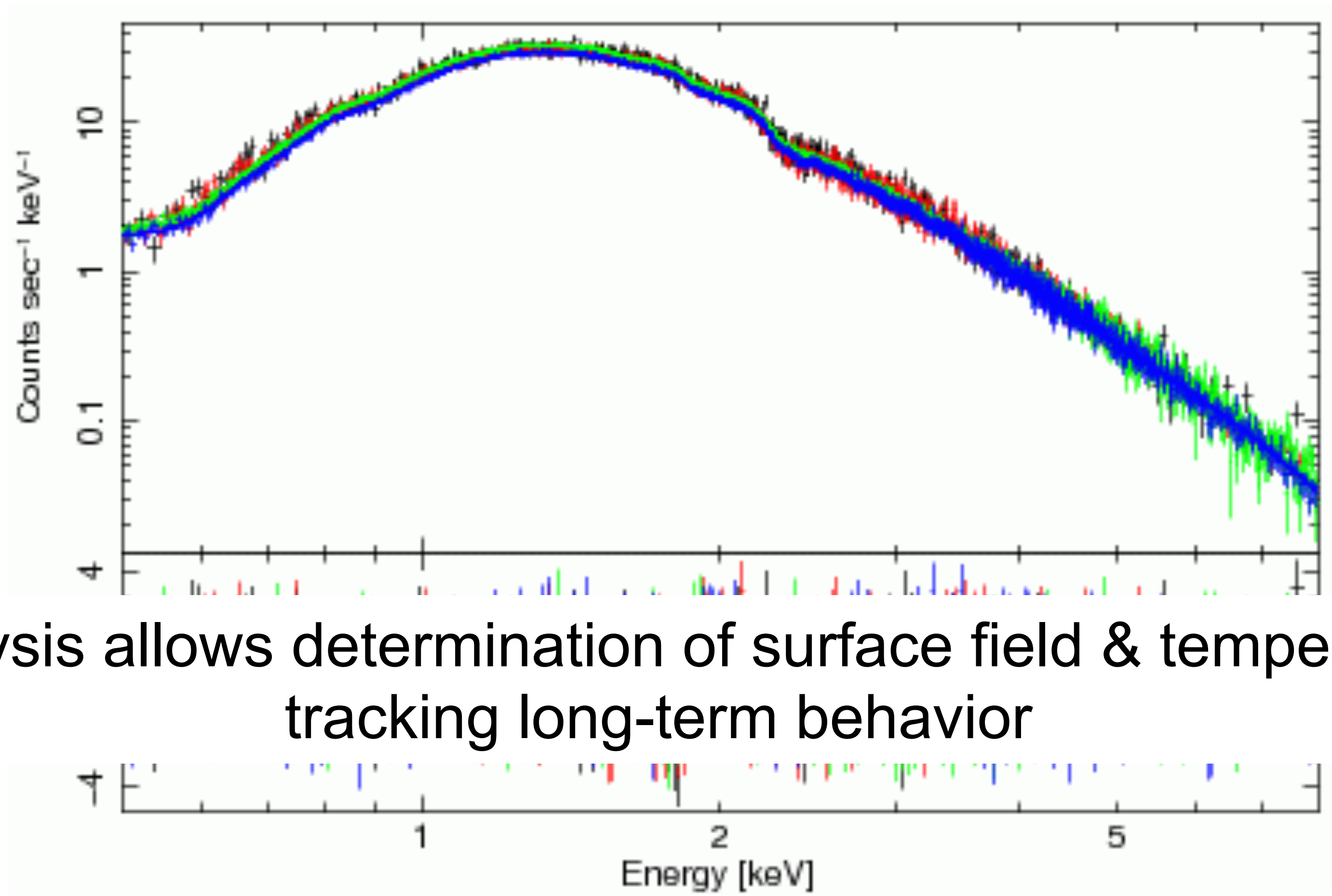
$$\tau = \int \sigma N_e dz$$

- resonant layers appear at $r \approx r_{NS}\left(\frac{heB_{NS}}{Emc}\right)^{1/3}$ for dipole fields

- solve radiative transfer using two-stream approximation for thermal electrons

Thompson, Lyutikov & Kulkarni '02, Lyutikov & Gavriil '06, Guver, Ozel & Lyutikov '06, Fernandez & Thompson '06

AXP-SGR Spectra: 4U 0142+61



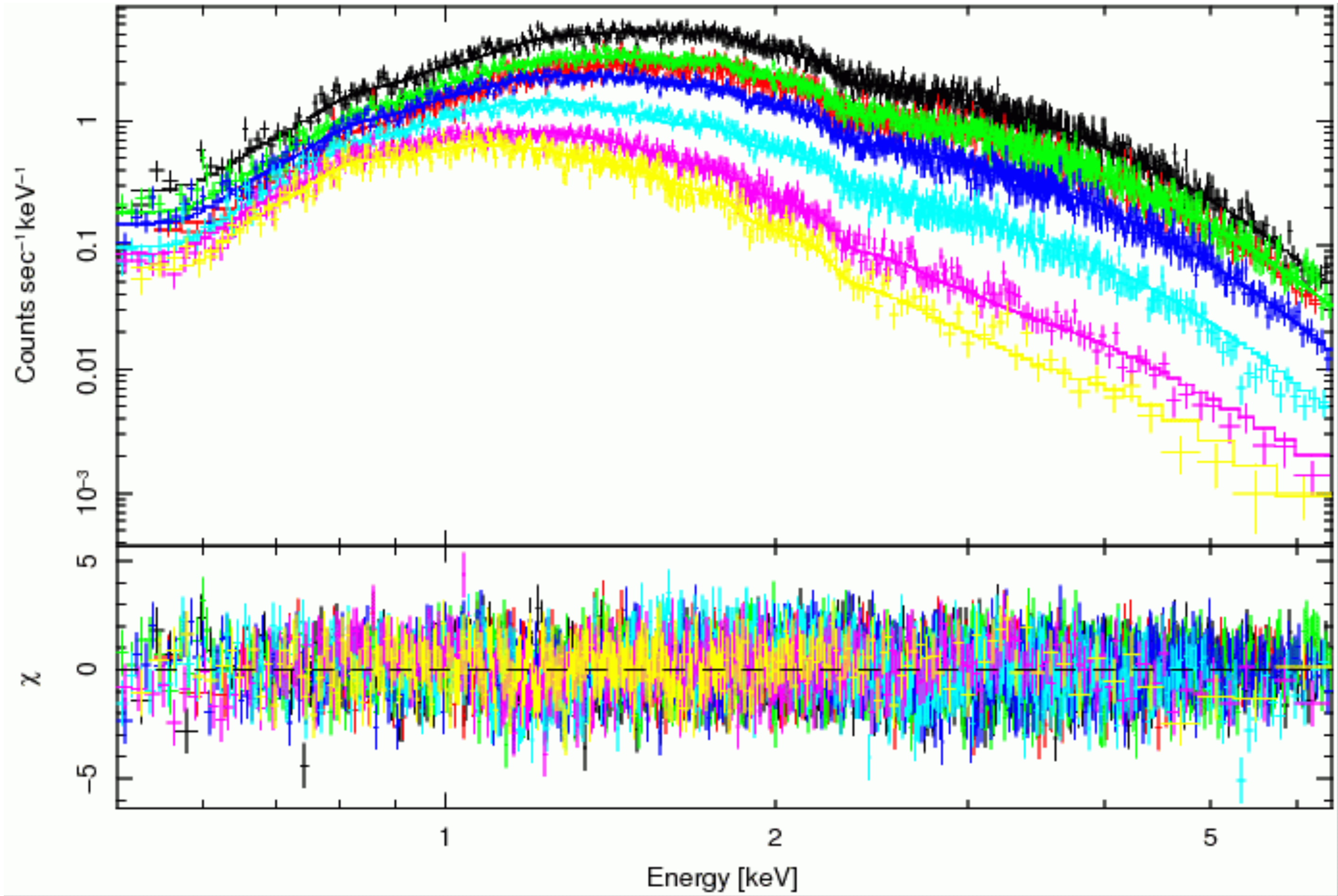
Analysis allows determination of surface field & temperature; tracking long-term behavior

$B_{surf} = (4.6 \pm 0.14) \times 10^{14}$ G (Güver, Özel & Gogus 07)

$B_{spindown} = 1.3 \times 10^{14}$ G (Gavriil & Kaspi 02)

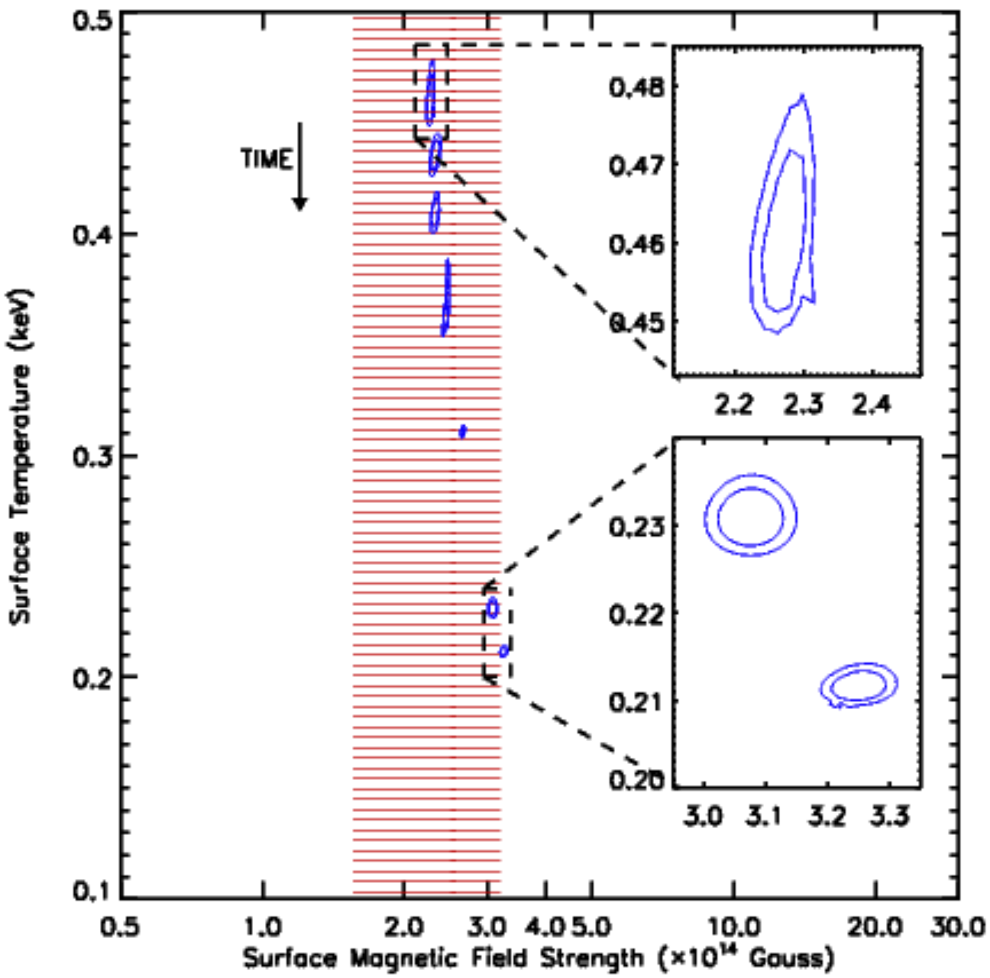
Long-term Behavior

Fits to seven epochs of XMM data from XTE J1810-197 (Gotthelf & Halpern)



Guver, Ozel, Gogus, Kouveliotou 07

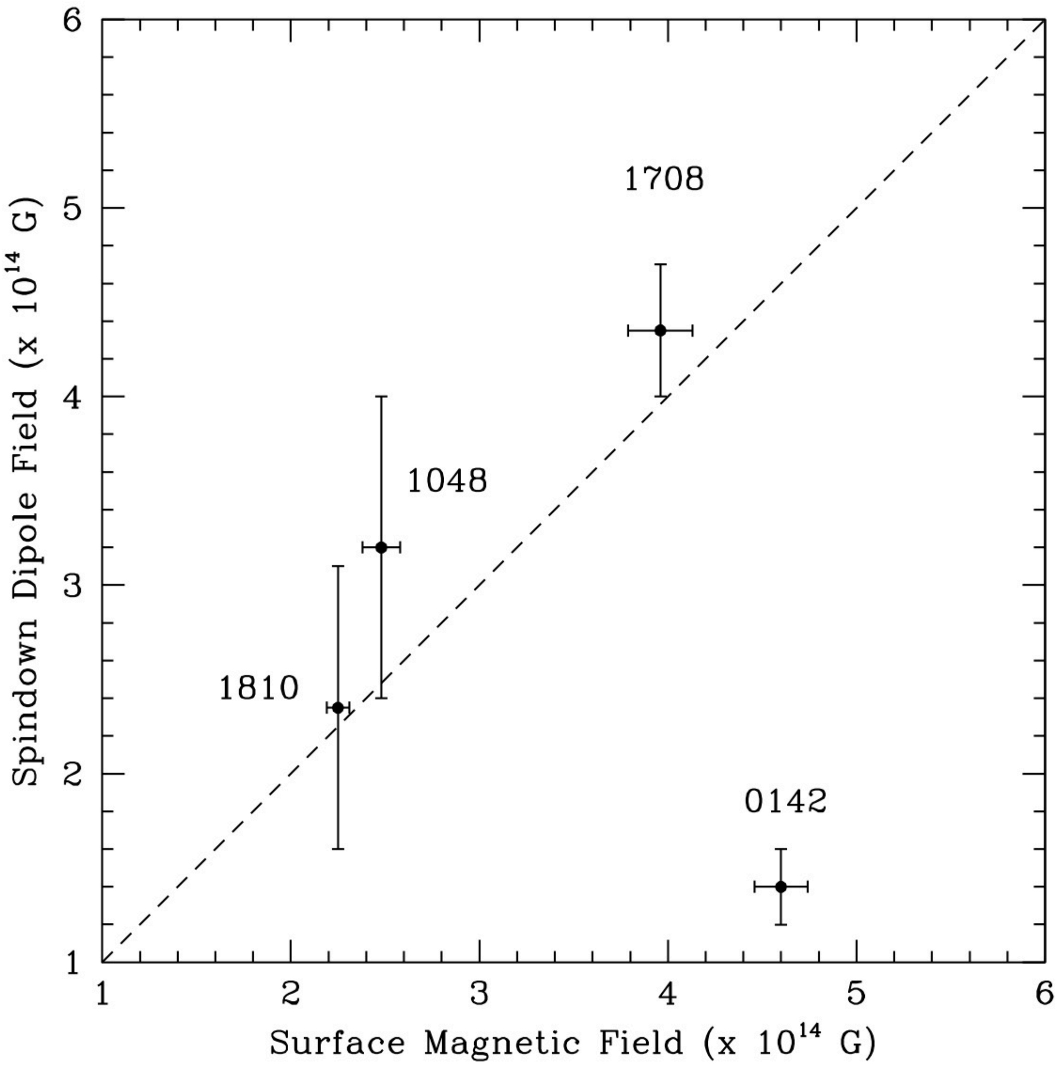
Temperature Evolution of XTE J1810-197



Post-Outburst Evolution of Magnetars

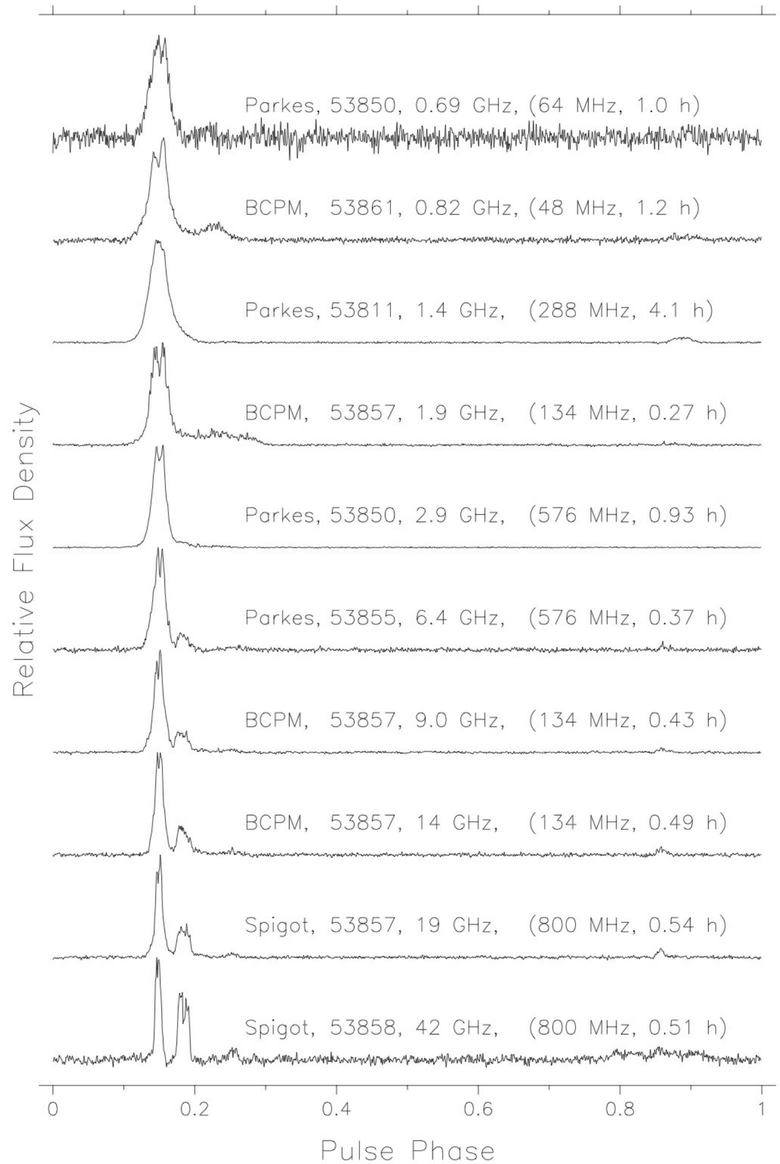
- **Magnetic field remains (nearly) constant**
- **Is equal to or close to spindown field**
- **Temperature declines steadily and often dramatically**
- **Observe this behavior in all AXP/SGR outbursts studied**

Surface and Dipole Fields



Ozel et al. 2008

Blurry Lines with Radio Pulsars: Radio Emission

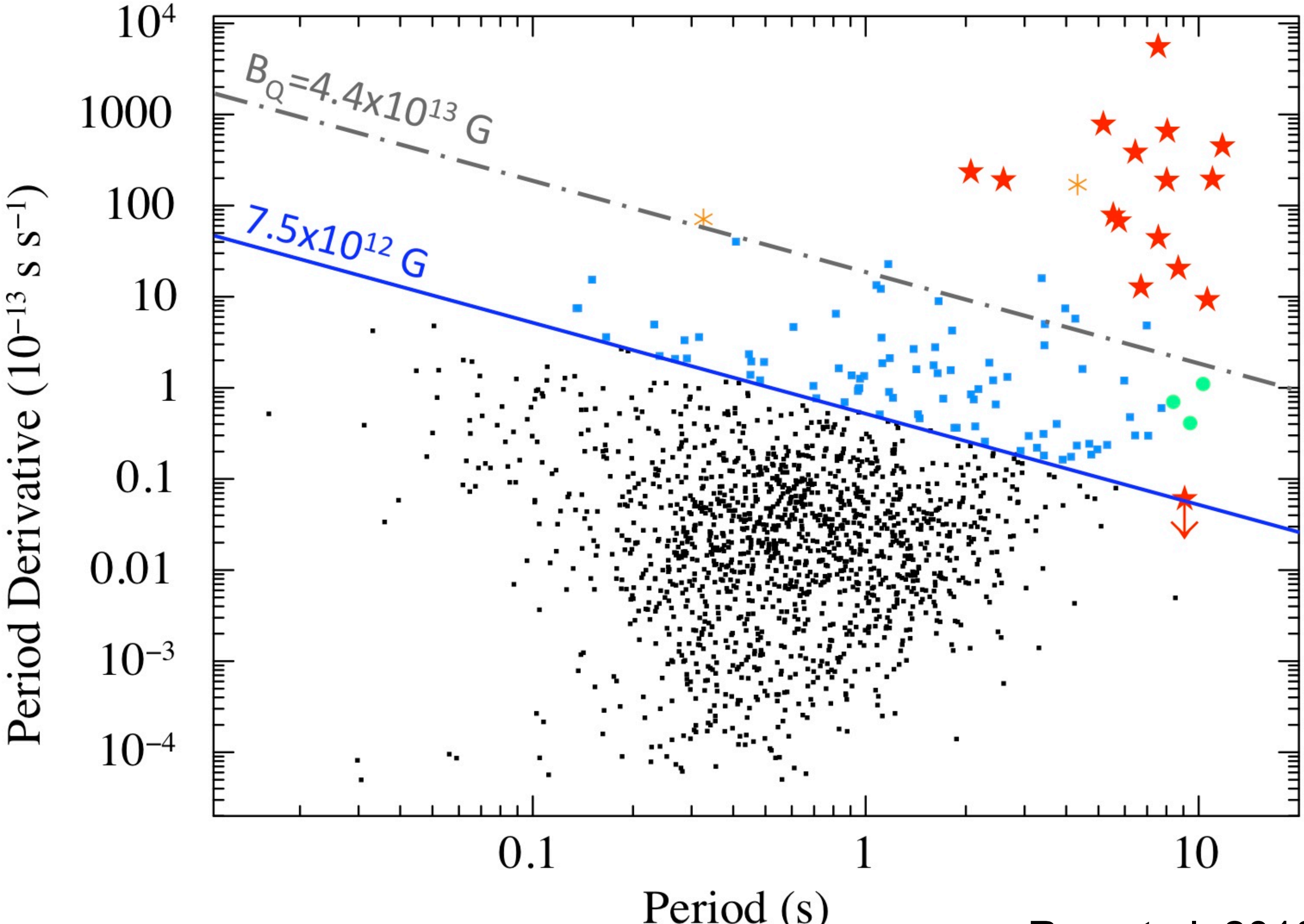


XTE J1810-197
Camilo et al. 2007

and others since

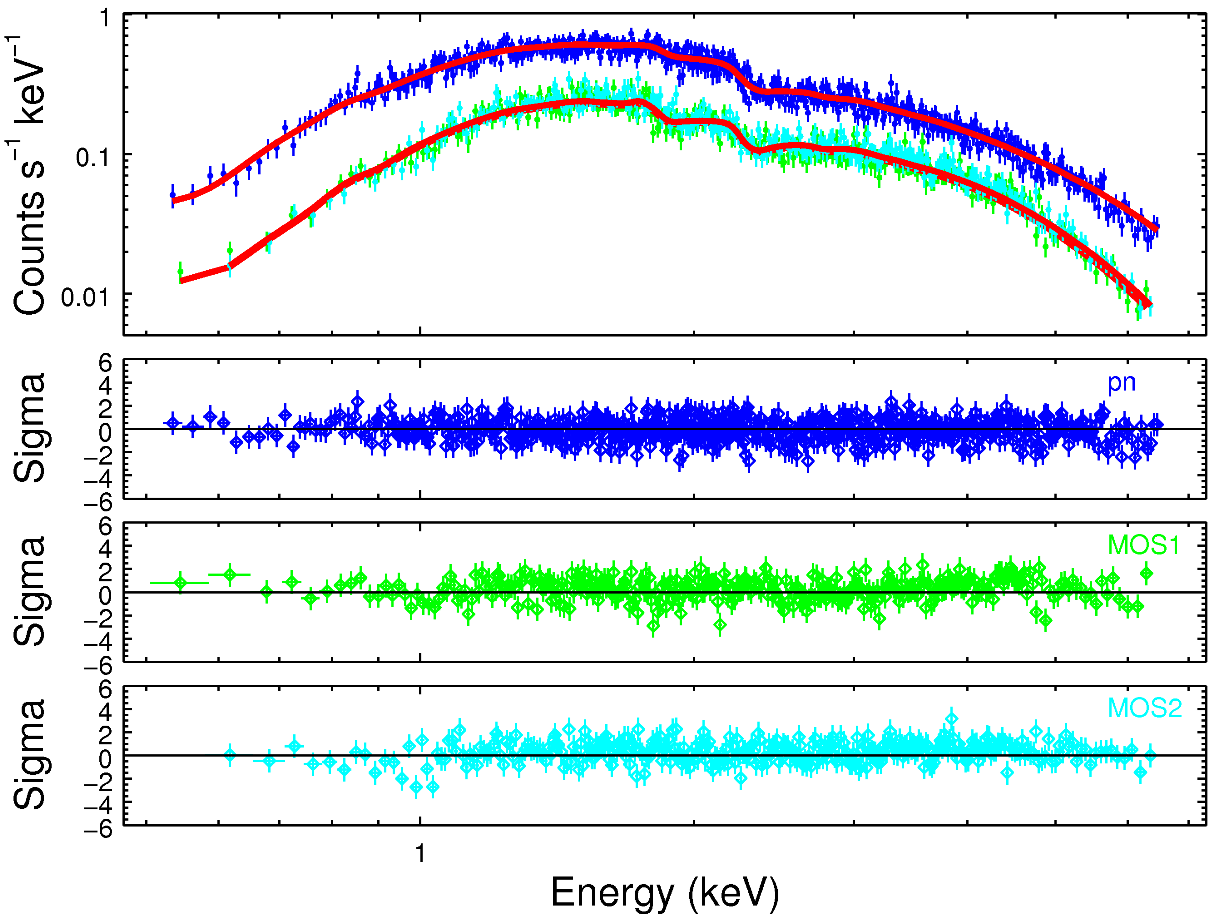
Meanwhile, discovery of high-B radio pulsars

Blurry Lines with Radio Pulsars: a low $\dot{P}$ in SGR 0418+5729



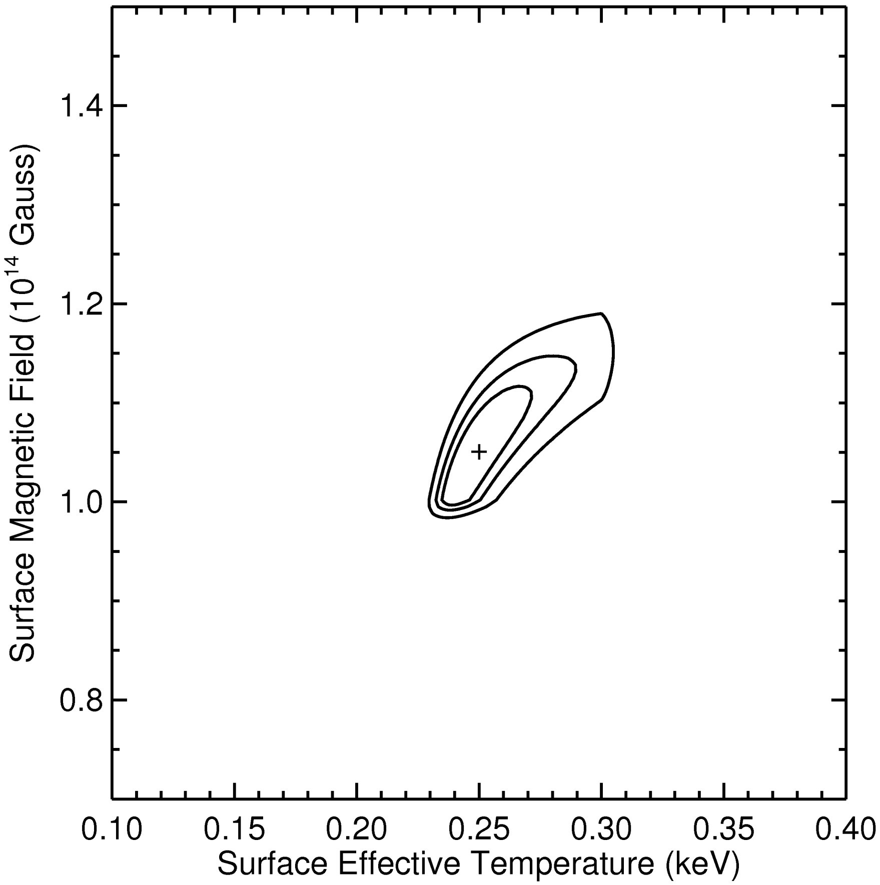
Rea et al. 2010

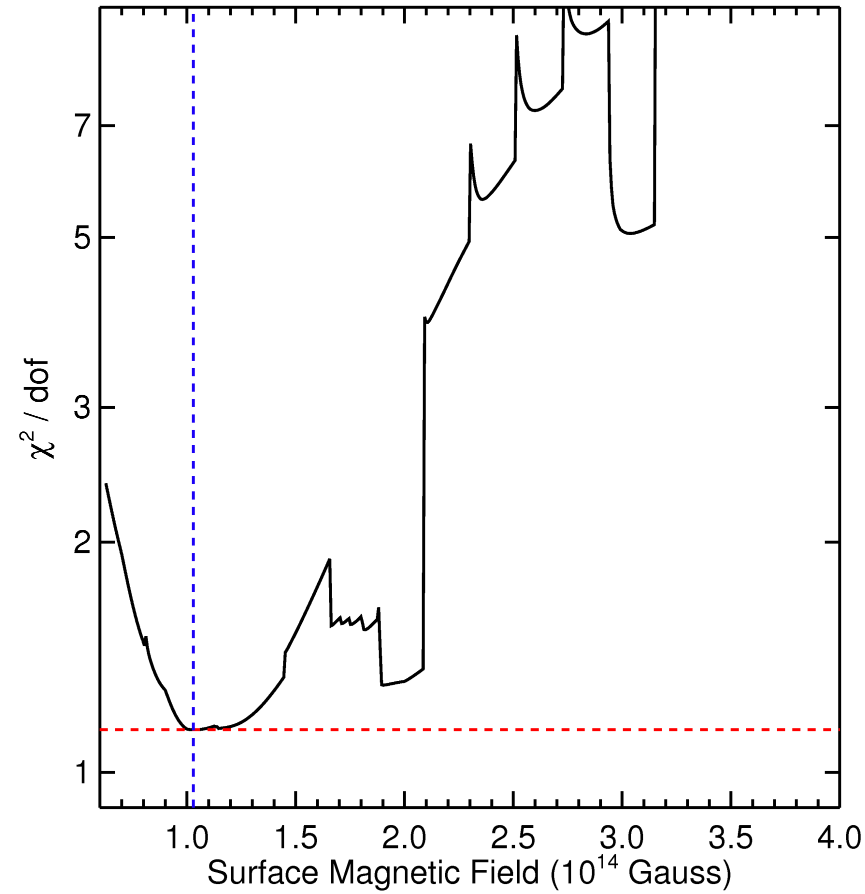
Surface Field of SGR 0418+5729



Empirical (BB+PL) and low-field NS models yield poor fits

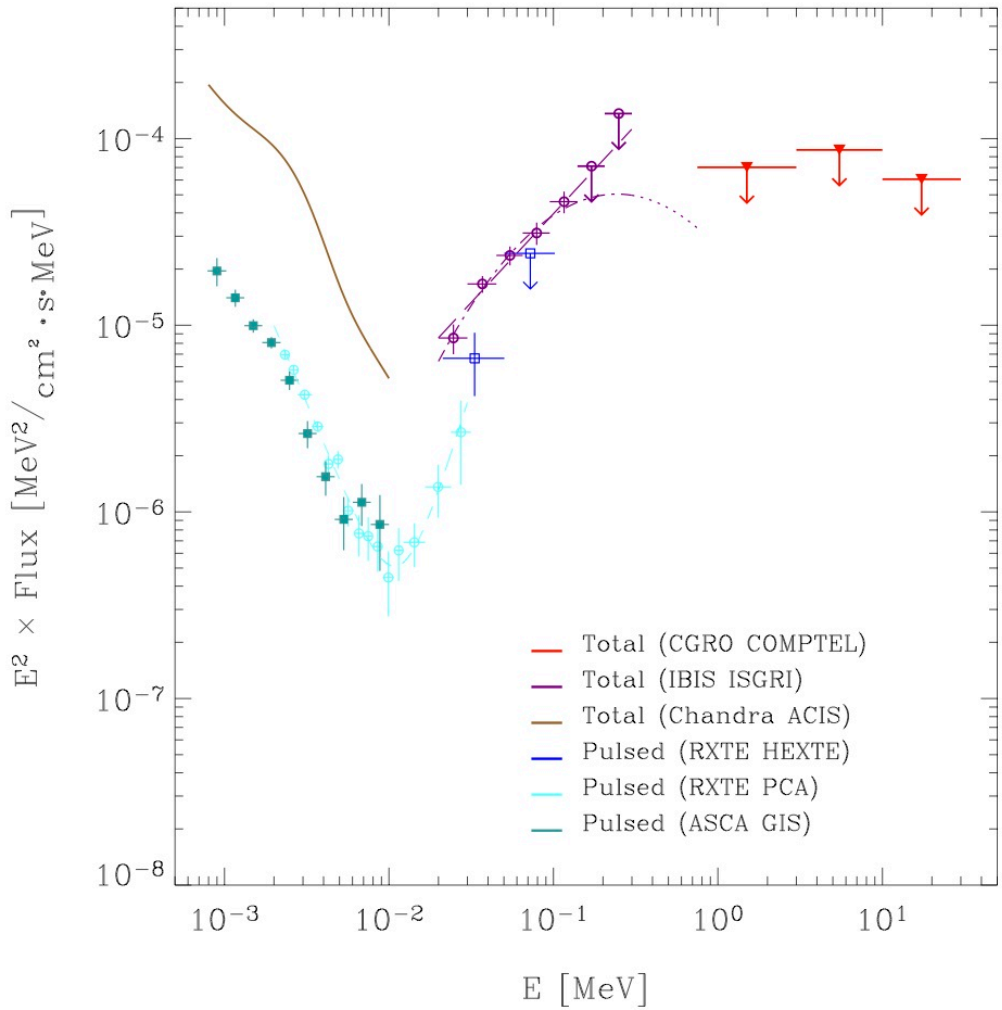
Surface Field of SGR 0418





Address why surface and dipole fields so different in this source

Hard X-ray Emission

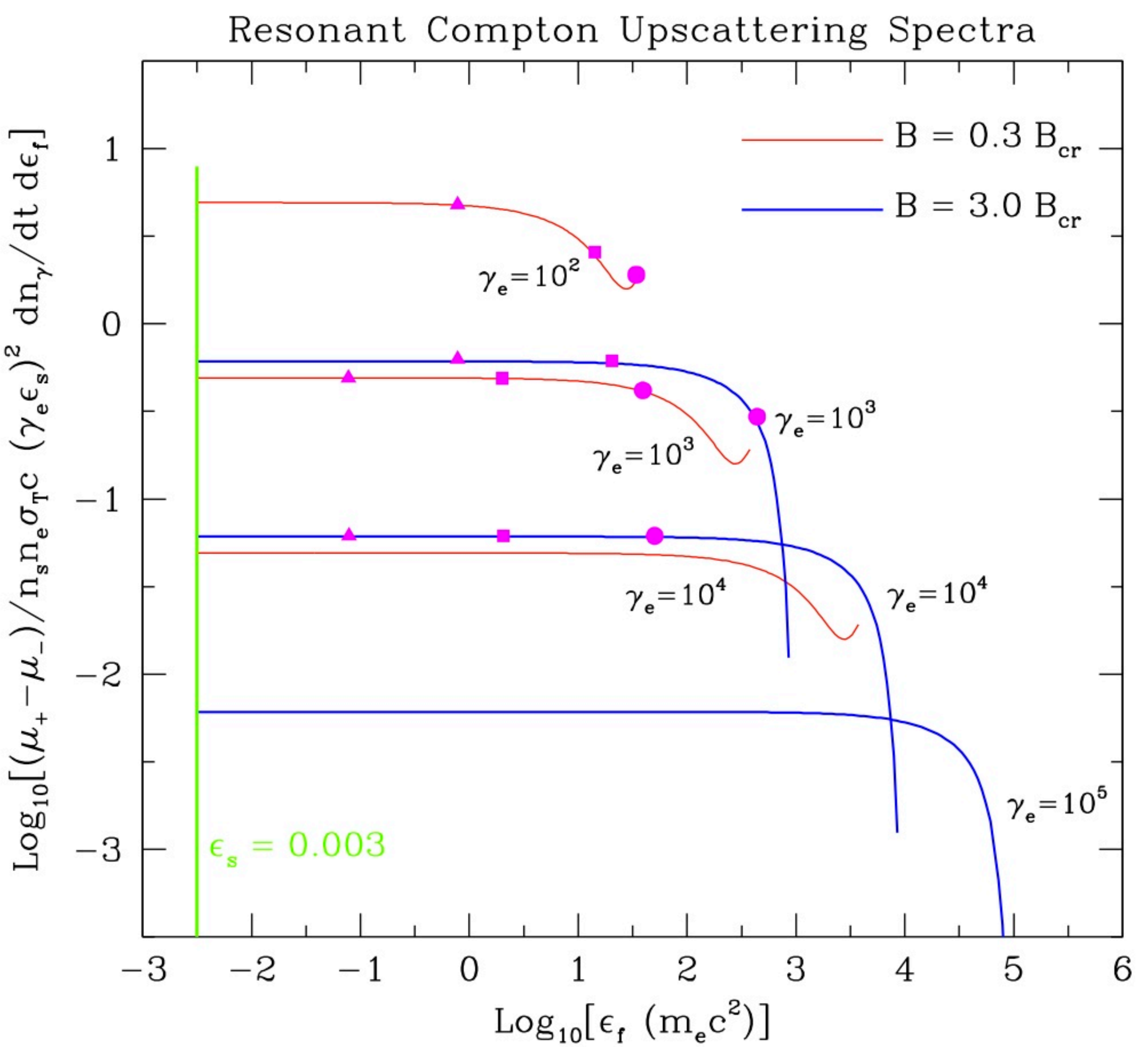


1E 1841-045 (Kuiper, Hermsen & Mendez 2004)
4U 0142+61, RXS J1708-4009 (Kuiper et al. 2006)

Hard X-ray Emission: A Theoretical Challenge

- One idea by Thompson & Beloborodov (2005)
- A thin surface layer of the star is heated by the downward beam of currents
- Layer of temperature kT~ 100 keV
- Bremsstrahlung emission up to this characteristic energy
- Stability of this layer and overall spectrum unclear

Hard X-ray Emission: A Theoretical Challenge



Baring & Harding 2008

Magnetars in the ASTROSAT Era

- We have made progress in understanding surface magnetic field strengths, temperature evolution, emission in multiple wavebands

- Measure magnetic field strength in more sources, correlate with pulse profiles: A natural area for ASTROSAT
- Monitoring sources and post-outburst behavior is key
- Simultaneous broadband spectroscopy to address consistency of hard X-ray tails with softer emission