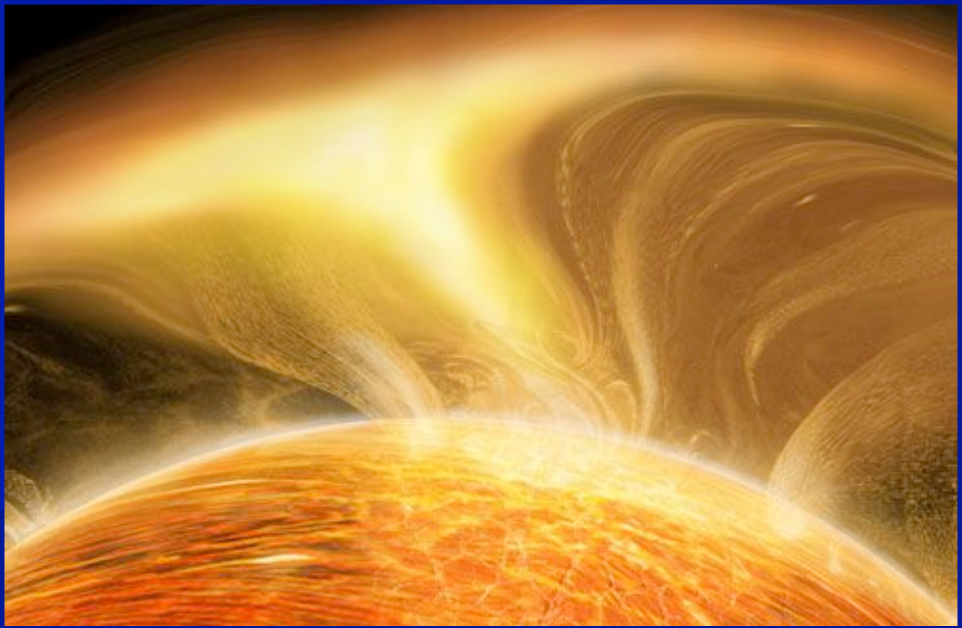
X-ray Spectra from Magnetar Candidates

A Twist in the Field



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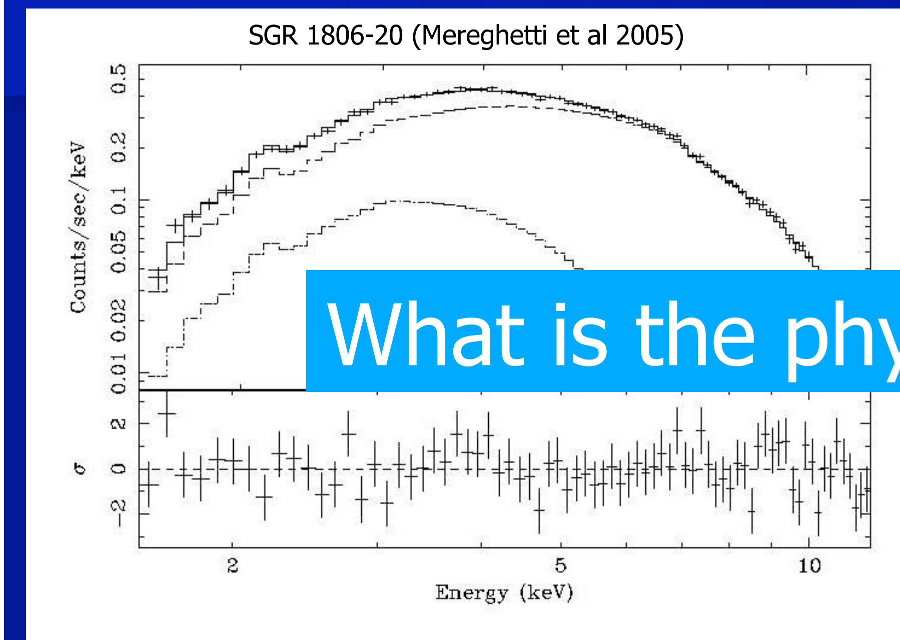
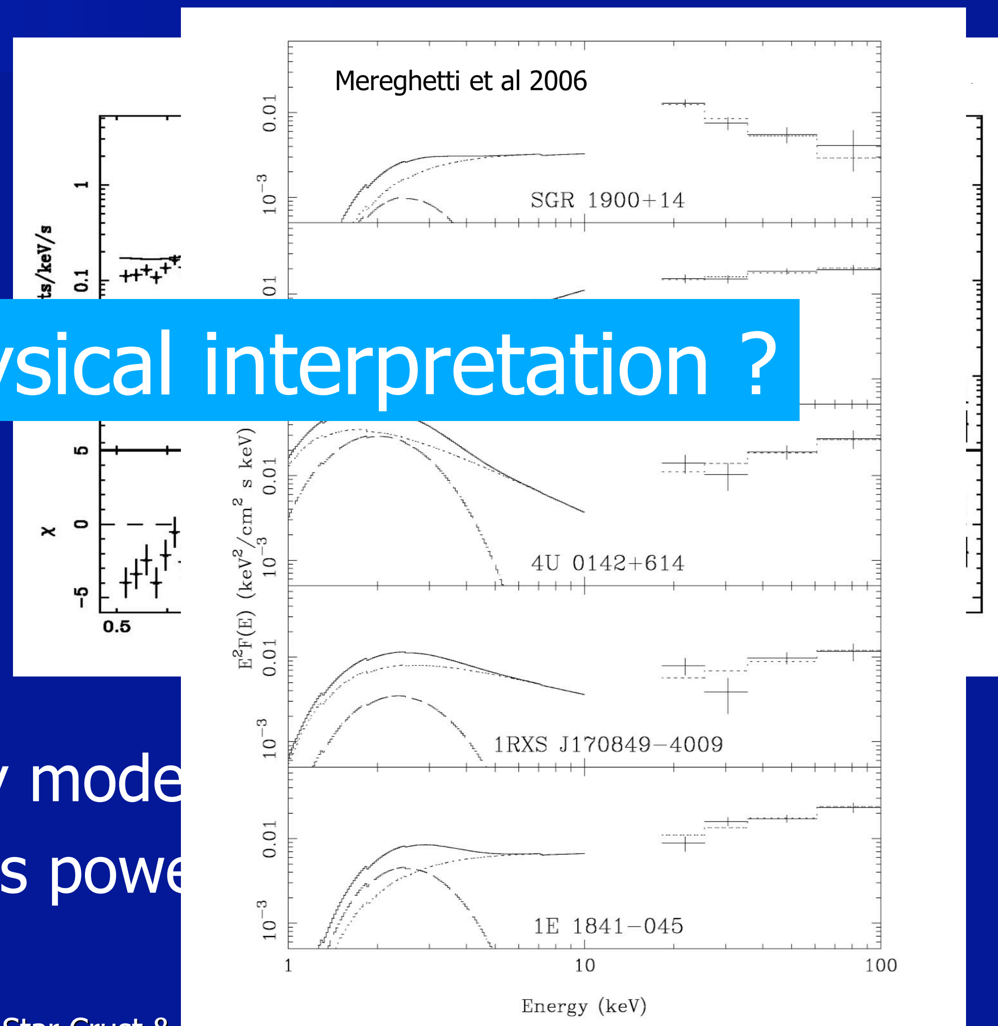
GL Israel, N Rea

The Neutron Star Crust & Surface:
Observations & Models, Seattle, June
25-29 2006

SGRs and AXPs X-ray Spectra





What is the physical interpretation ?

0.5 – 10 keV emission usually mode
blackbody (kT ~ 0.5 keV) plus powe

Twisted Magnetospheres – I

- The magnetic field inside a magnetar is "wound up"
- The presence of a toroidal component induces a rotation of the surface layers
- The crust tensile strength resists
- A gradual (quasi-plastic ?) deformation of the crust
- The external field twists up (Thompson, Lyutikov & Kulkarni 2002)

Twisted Magnetospheres - II

- TLK02 investigated force-
  magnetic equilibria
- [illegible]

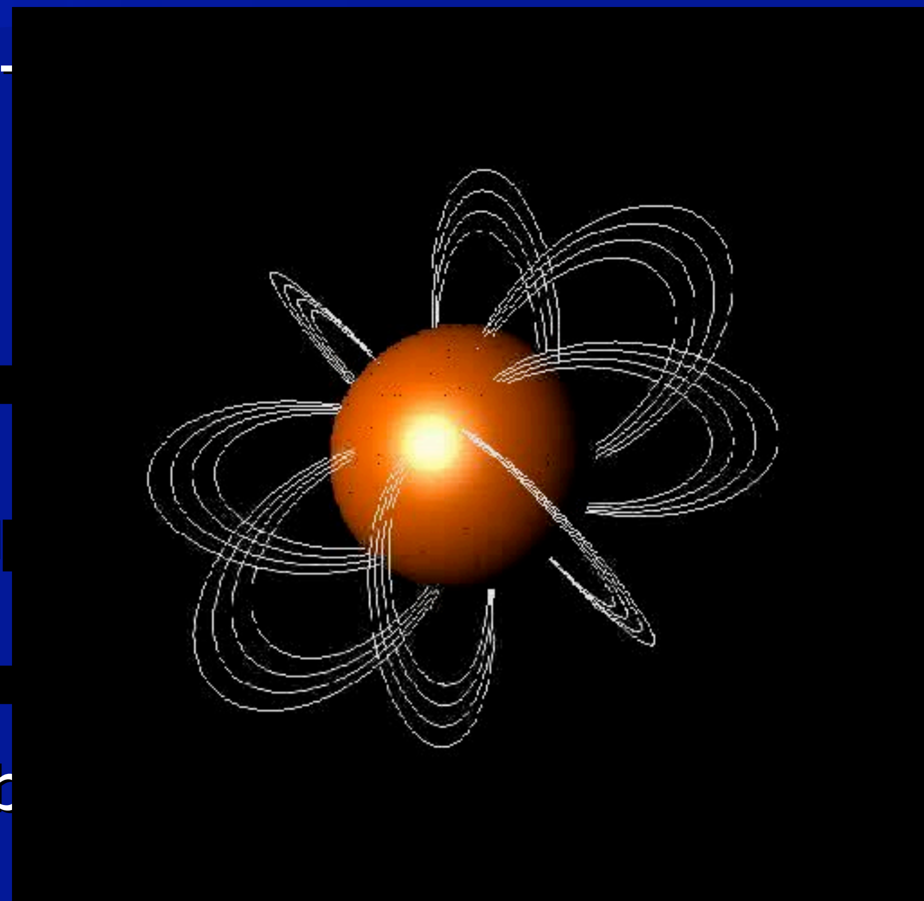
  [illegible]

  [illegible]

  [illegible]

- A sequence of models lab

  [illegible]



Twisted Magnetospheres - III

- Twisted magnetospheres are threaded by currents
- Charged particles provide large optical depth [redacted] to resonant cyclotron scattering
- Because [redacted] and [redacted], a power-law tail expected instead of an absorption line
- [redacted], [redacted] and [redacted]
- Both [redacted] and [redacted] increase with the twist angle

A Monte Carlo Approach

- Follow individually a large sample of photons, treating probabilistically their

Preliminary investigation (1D) by Lyutikov & Gavriil (2006)

More detailed modeling by Fernandez & Thompson (2007)

New, up-to-dated code (Nobili, Turolla, Zane 2007)

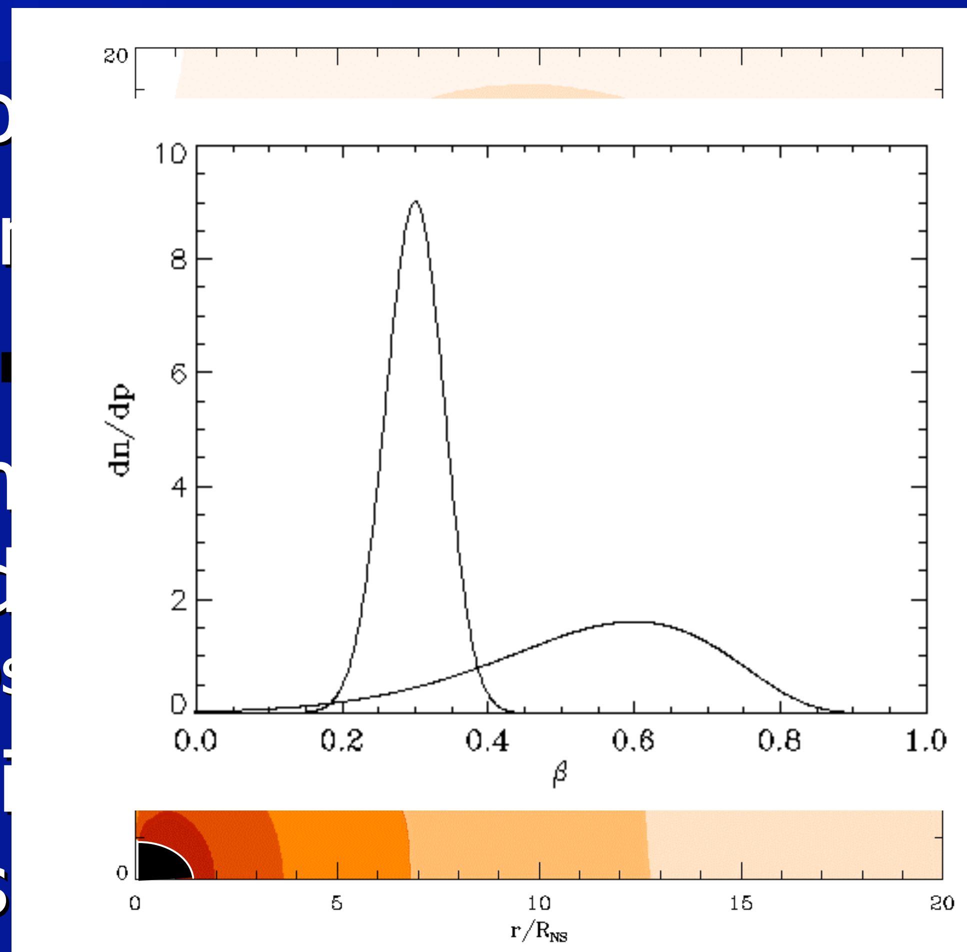
$N_{scat} \approx 1$

Magnetospheric Currents

- Charges move alo
- Spatial distributio

Electron contribution only
1D relativistic Mawellian at
T_e centred at v_{bulk}

- Particle motion ch
  velocity, v_{bulk}, and
  (Beloborodov & Thomps
- There may be $e^{\pm}$ i
  detailed model as

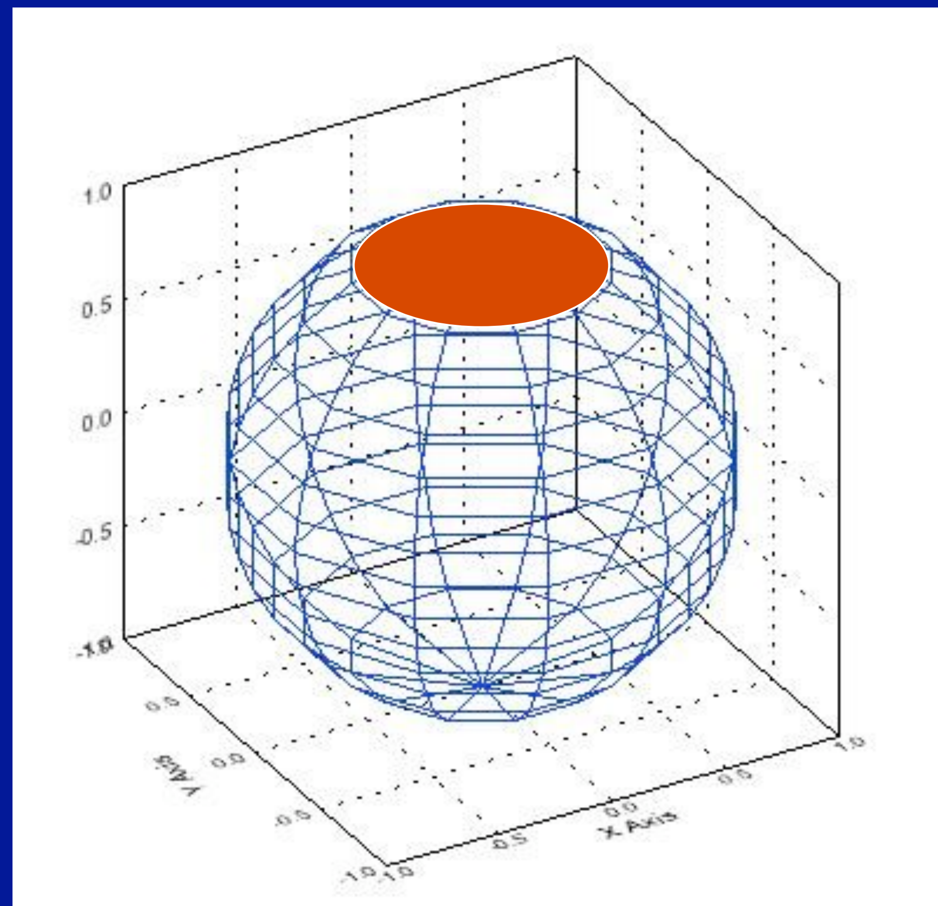


Surface Emission

The star surface is divided into patches by a cos θ – φ grid

Each patch has its own temperature to reproduce different thermal maps

Blackbody (isotropic) emission



Photons in a Magnetized Medium

- Magnetized plasma is anisotropic and birefringent, radiative processes sensitive to polarization state
- Two normal, elliptically polarized modes in the magnetized "vacuum+cold plasma"
- At [redacted] the modes are almost linearly polarized

The extraordinary (X) and ordinary (O) modes

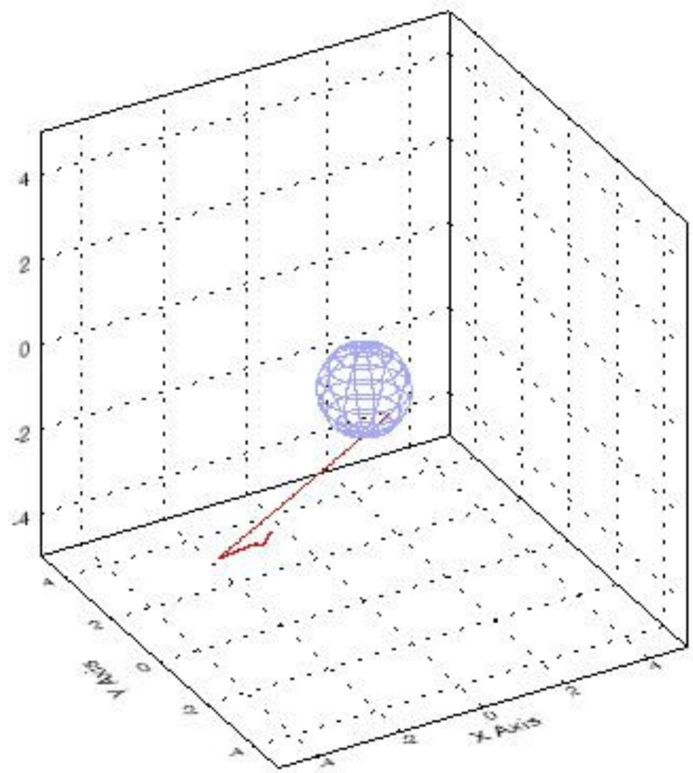
Scattering Cross Sections - I

- QED cross section for ma... scattering available (e.g. H... 1991; Araya & Harding 1999; Gon...
- Because of charge motio...

Completely differential cross sections a...

$$\left.\frac{d\sigma}{d\Omega'}\right|_{O-O} = \frac{3\pi r_0 c}{8}\delta(\omega-\omega_c)\cos^2\theta\cos^2\theta \ldots \vartheta$$

$$\left.\frac{d\sigma}{d\Omega'}\right|_{X-X} = \frac{3\pi r_0 c}{8}\delta(\omega-\omega_c) \ldots \vartheta'$$



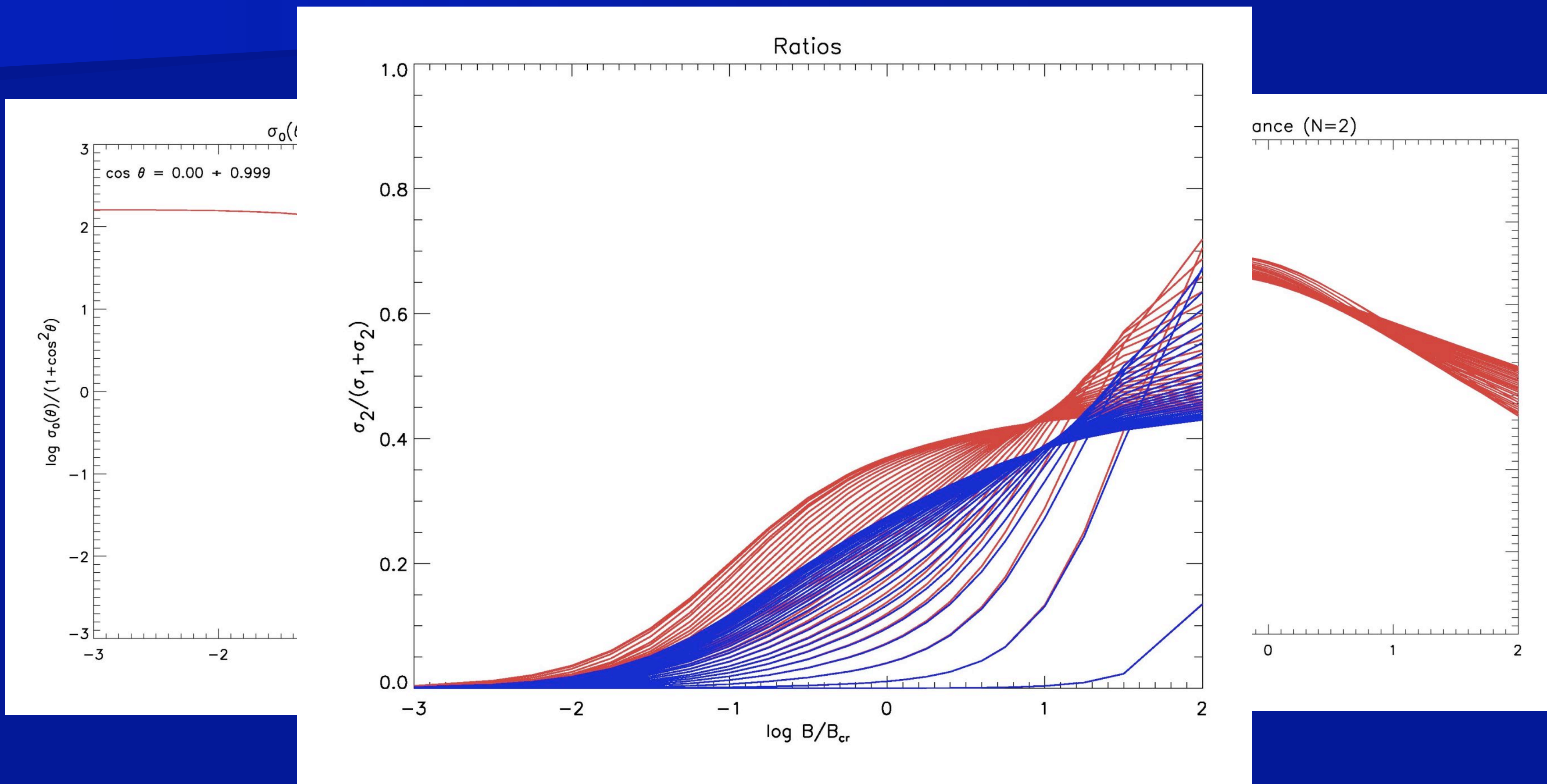
$r_0 = e^2/mc^2, \omega_c = eB/mc, \theta, \theta'$ angles between photon direction and particle velocity before and after scattering

Scattering Cross Sections - II

- Through repeated scatterings photons may gain enough energy to
  - Violate the condition $\omega << m_e c^2/\gamma$
  - Scatter in regions where $B \sim B_{QED}$
- Hard tails produced by up-scattering onto high-energy (non-thermal) electrons (Baring & Harding 2007) ?

Complete treatment of magnetic Compton scattering highly desirable

Scattering Cross Sections - III



Nuts and Bolts

[illegible]

[illegible]

[illegible]

Generate uniform deviate R, scatter occurs when $\tau = -\ln R$

Generate second deviate R_1 to decide if polarization switching

Generate third deviate R_2 to pick up electron velocity (if $v_{1,2} > 0$)

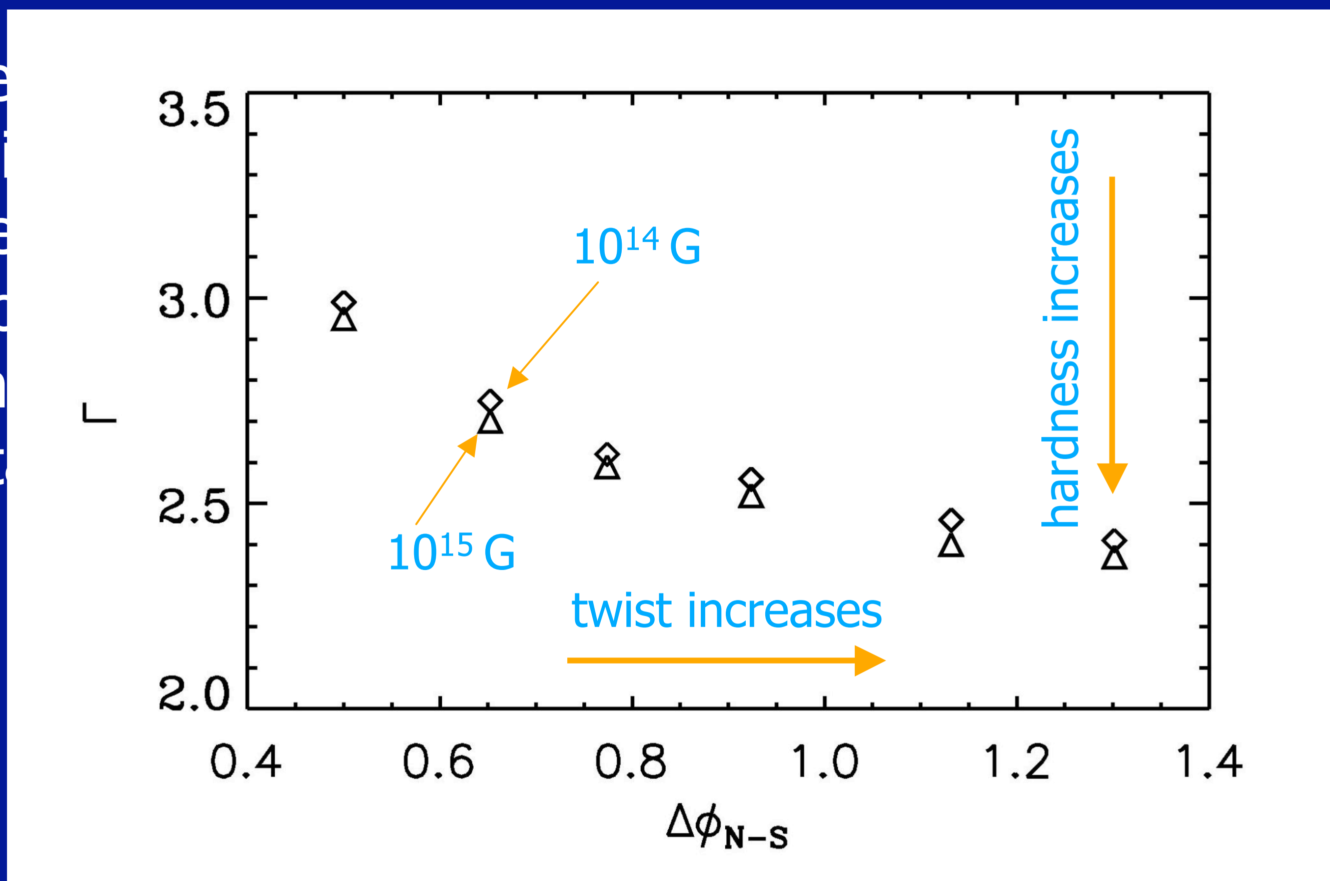
Generate to further deviates R_3 and R_4 to decide photon direction after scattering

Model Spectra

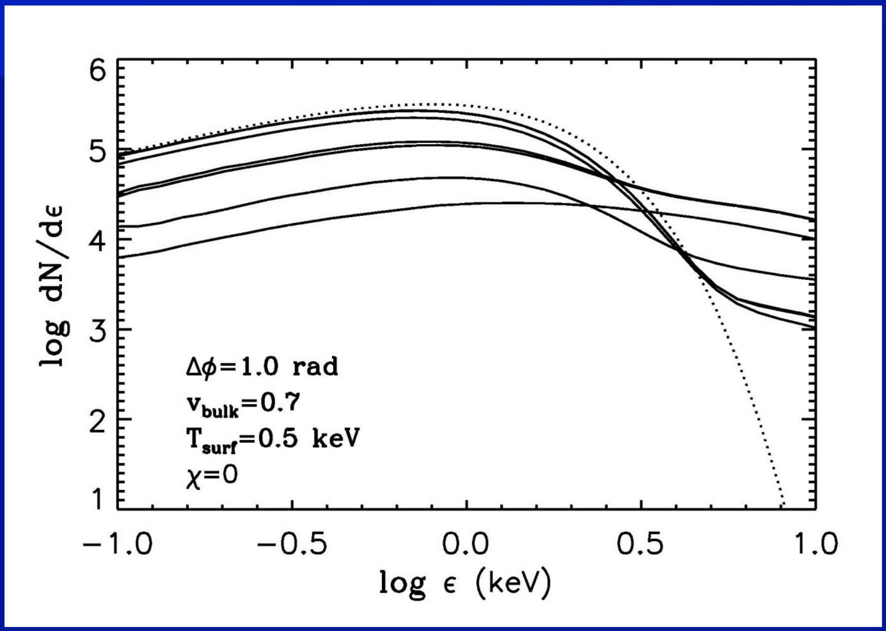
Model parameters: $\Delta\Phi_{N\text{-}S}$, B_{pole}, T_e, v_{bulk}
Surface emission geometry, geometrical angles (χ, ξ)

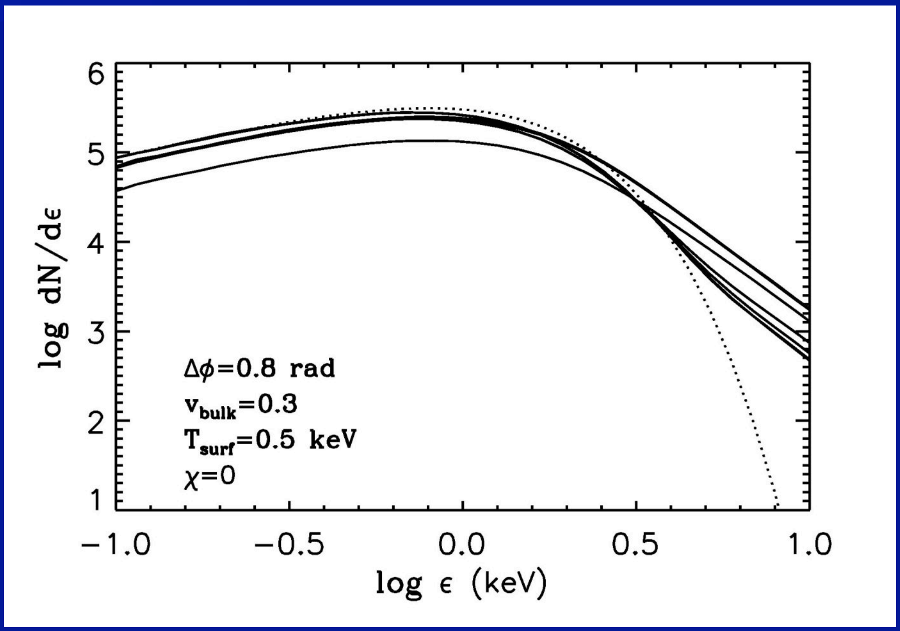
Mode

- Emi
- The ergy
- Geo MC
  run n phases)
- Tot



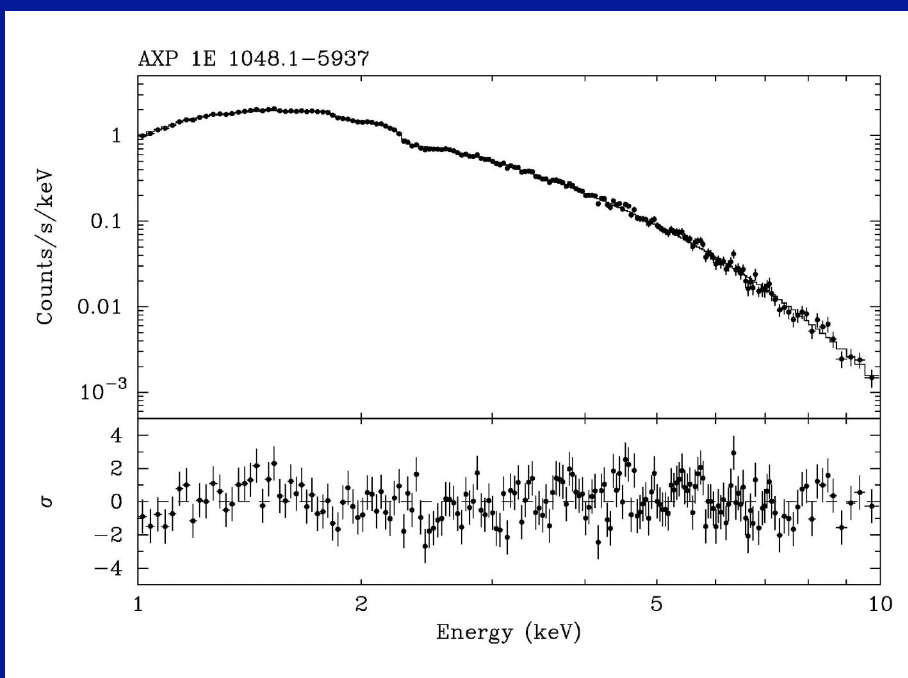
Phase-averaged spectra ($B_{pole} = 10^{14}$ G)

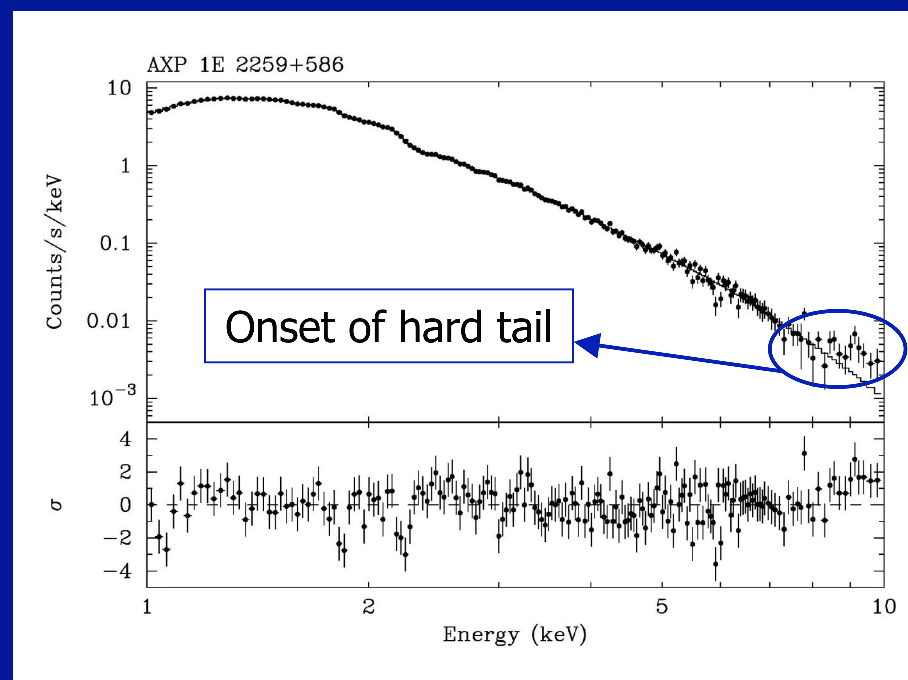




Spectral Fitting

Model archive with $B_{pole} = 10^{14}$ G completed and implemented in XSPEC (with N.Rea))
Applications to AXPs under way



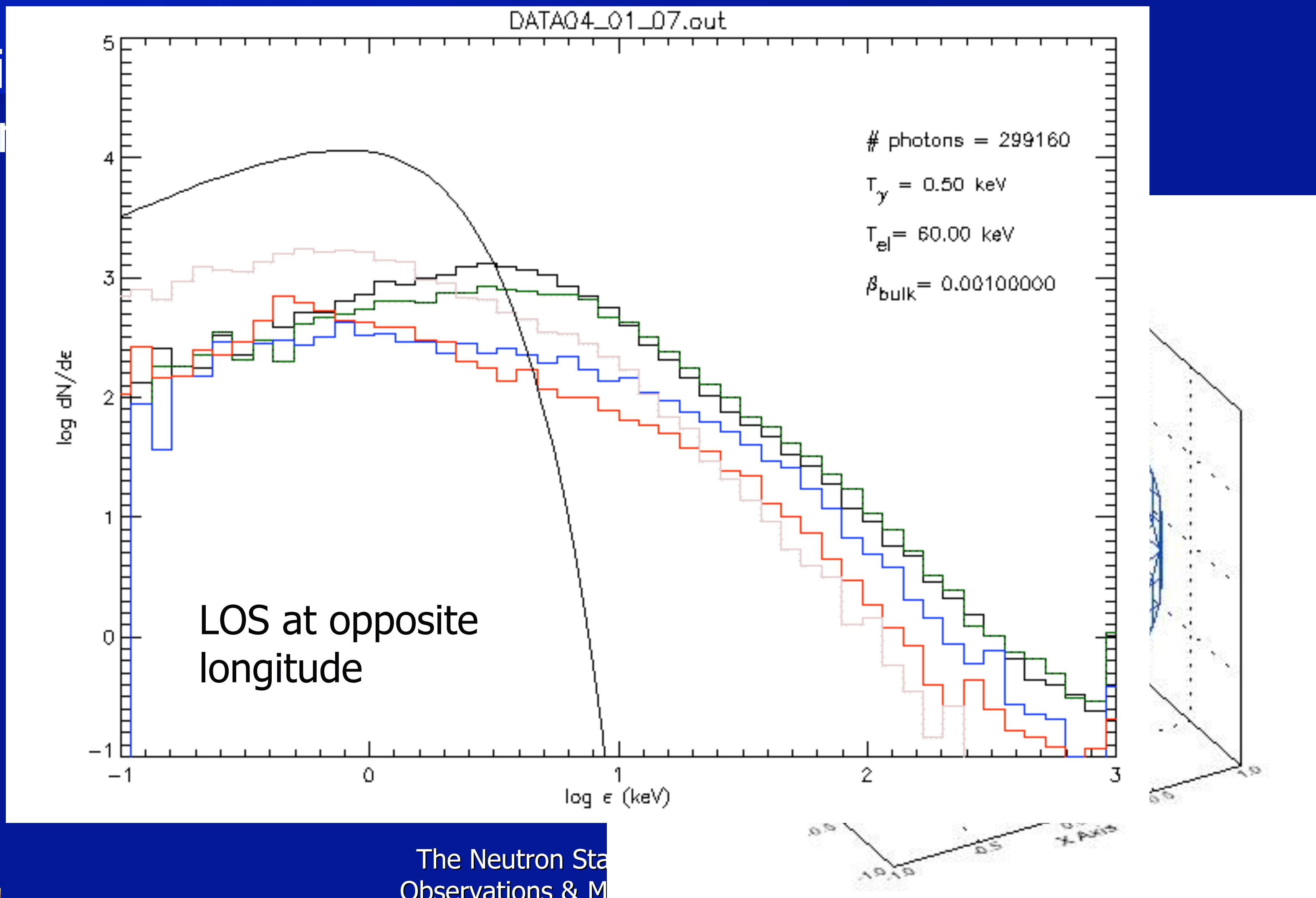


Conclusions & Future Developments

- Twisted magnetosphere model, within magnetar scenario, in general agreement with observations
- Resonant scattering of thermal, surface photons produces spectra with correct properties
- Many issues need to be investigated further
  - Twist of more general external fields
  - Detailed models for magnetospheric currents
  - More accurate treatment of cross section including QED effects and electron recoil (in progress)
  - 10-100 keV tails: up-scattering by (ultra)relativistic ($e^{\pm}$) particles ?
  - fit of model spectra to observations (in progress)

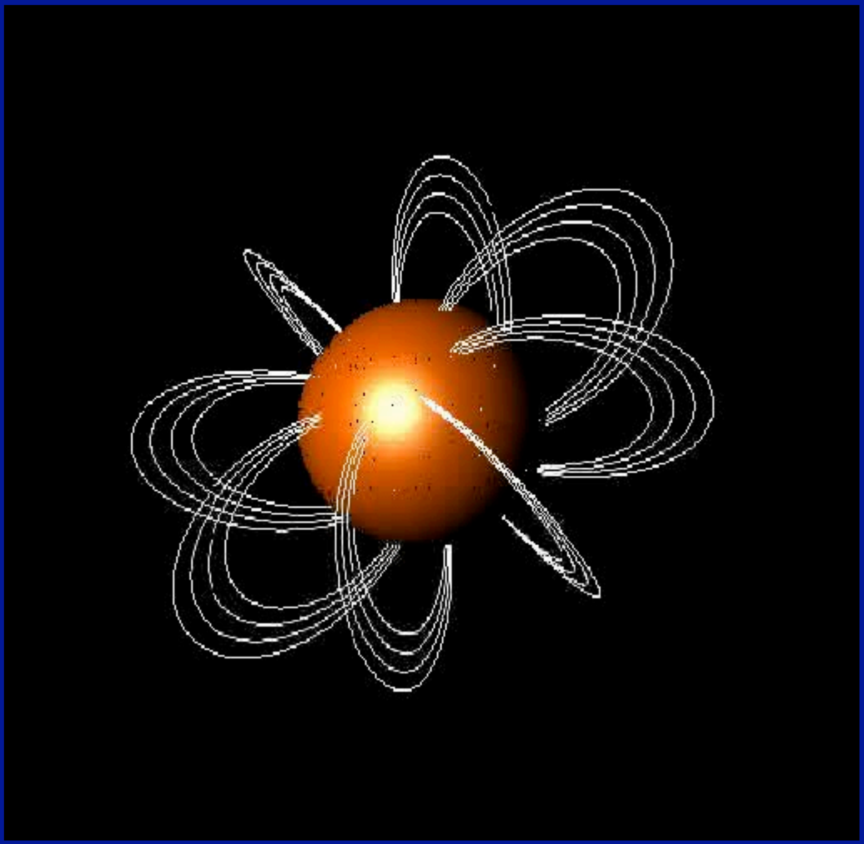
Model Spectra - II

Li
Er



Post-Flare Evolution

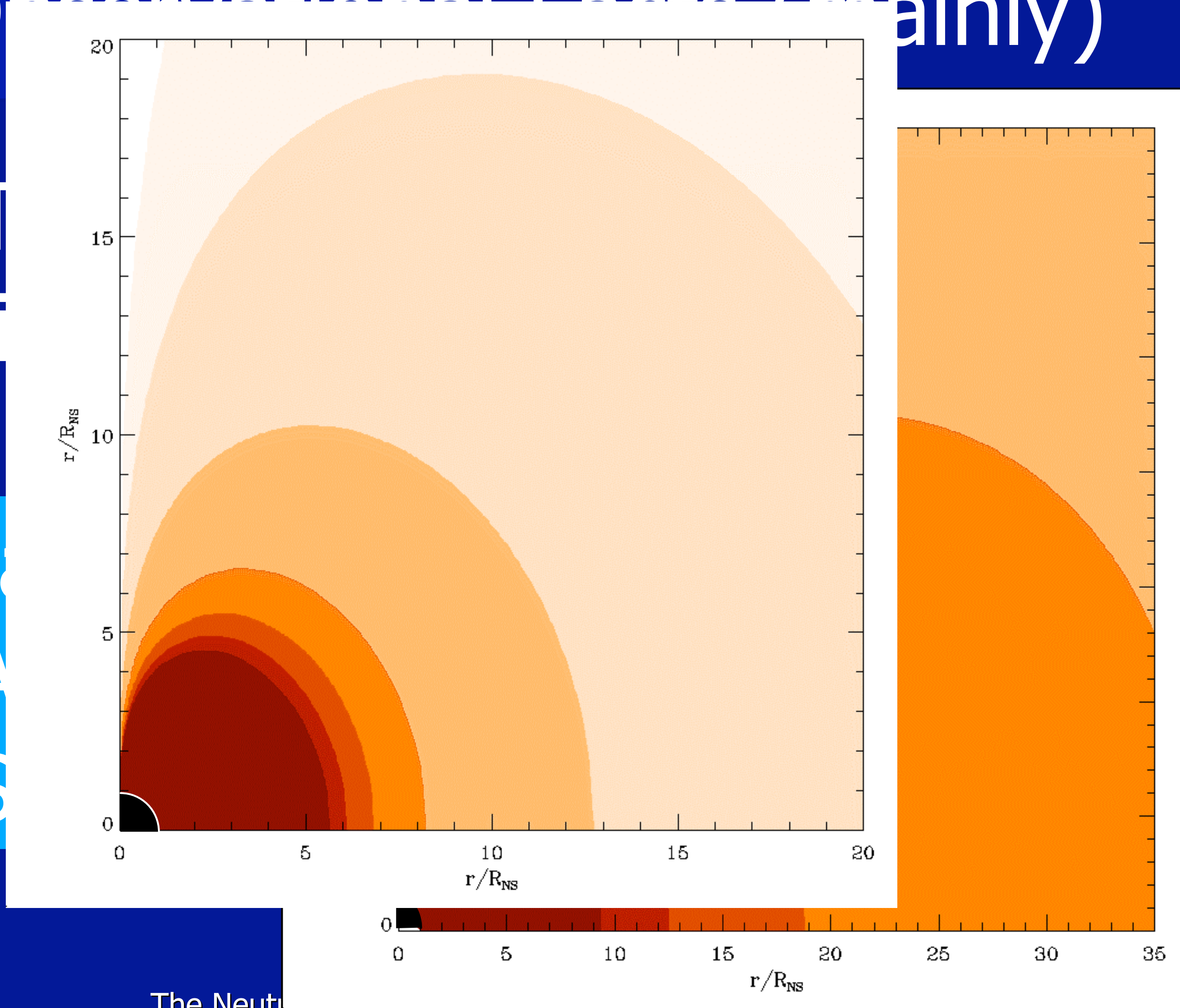
- After the GF SGR 1806-20 persistent X-ray emission is softer and spin-down rate smaller
- Evidence for an untwisting of the magnetosphere



Part I: O… ainly)

Part II: T…
Speculati…

Soft G…
ULTRA…
STARS…



SGRs and AXPs X-ray Spectra - II

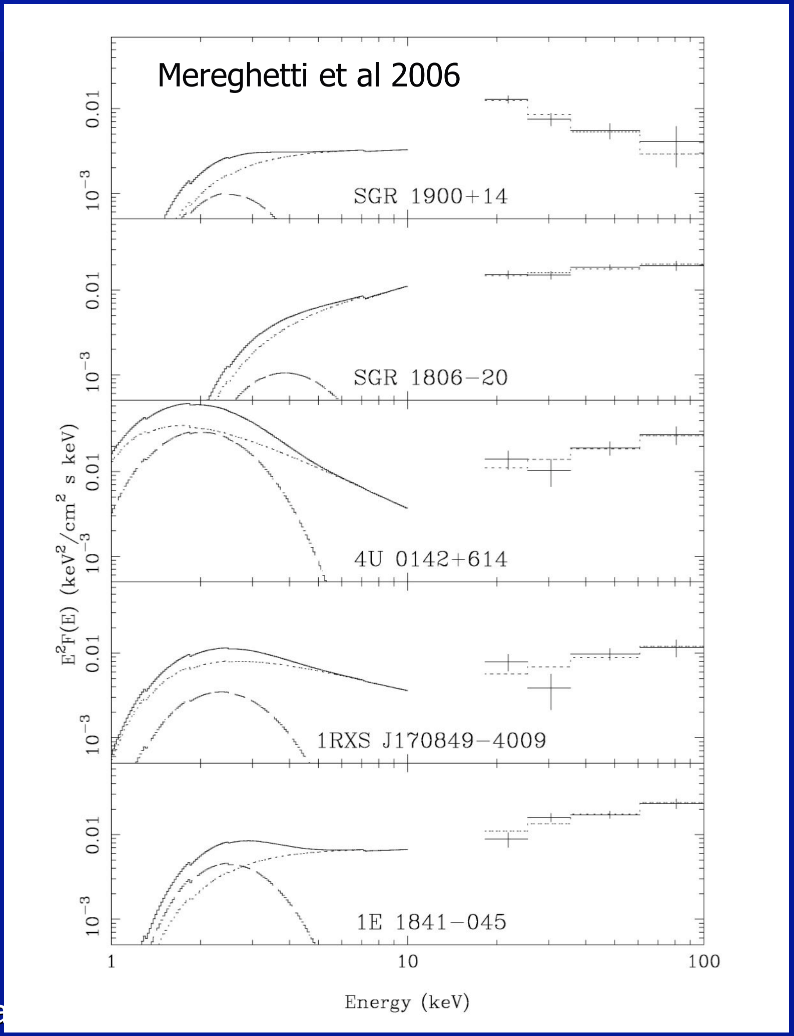
- $kT_{BB} \sim 0.5$ keV, does not change much in different sources
- Photon index $\Gamma \approx 1 - 4$, AXPs tend to be softer
- SGRs and AXPs persistent emission is variable (months/years)
- Variability mostly associated with the non-thermal component

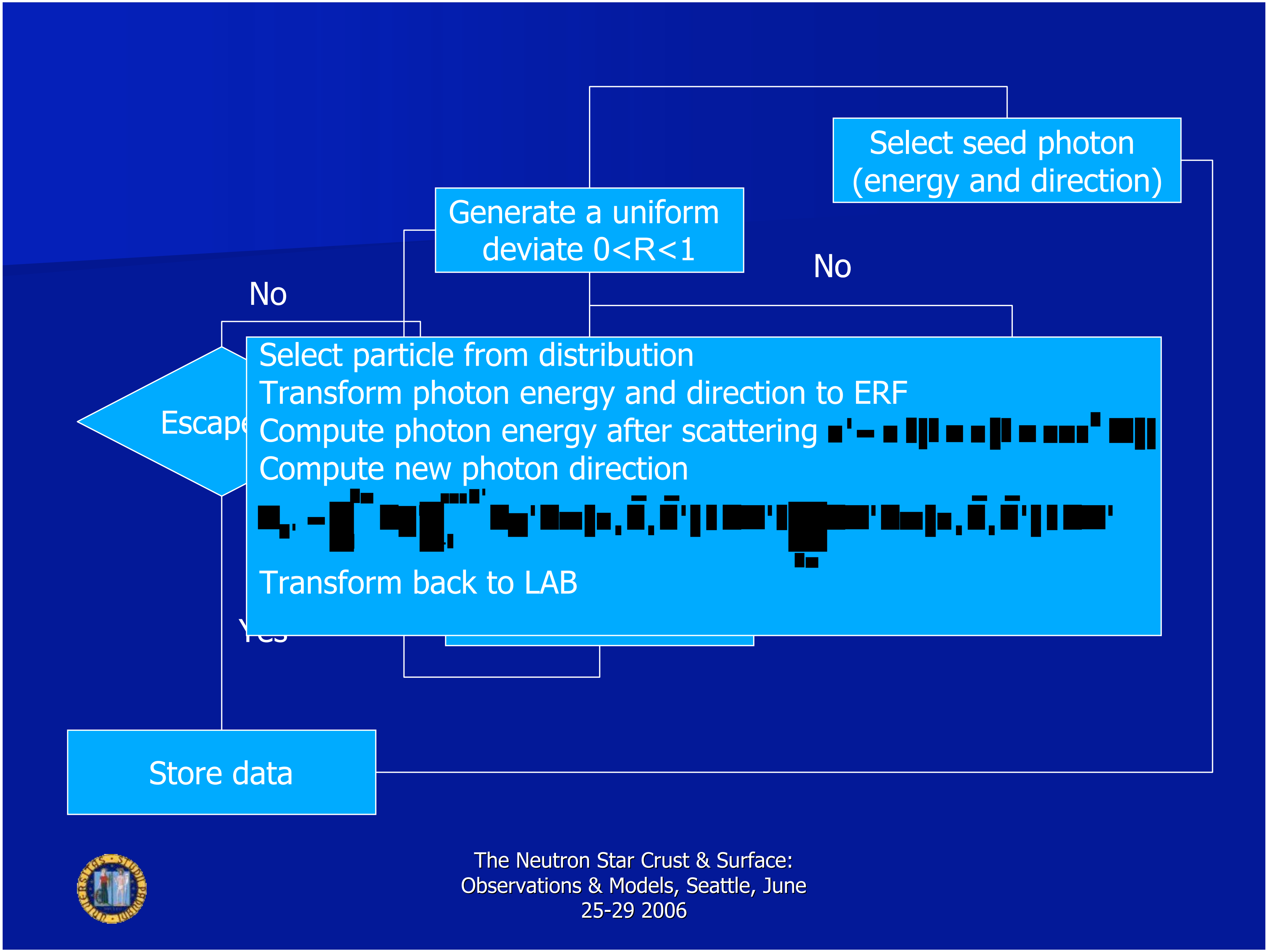
Hard X-ray Emission

INTEGRAL revealed substantial emission in the 20 -100 keV band from SGRs and APXs

Hard power law tails with Γ ≈ 1-3, hardening wrt soft X-ray emission required in AXPs

Hard emission pulsed




Select seed photon (energy and direction)
Generate a uniform deviate 0<R<1
No
No
Escape
Select particle from distribution
Transform photon energy and direction to ERF
Compute photon energy after scattering
Compute new photon direction
Transform back to LAB
Store data
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