

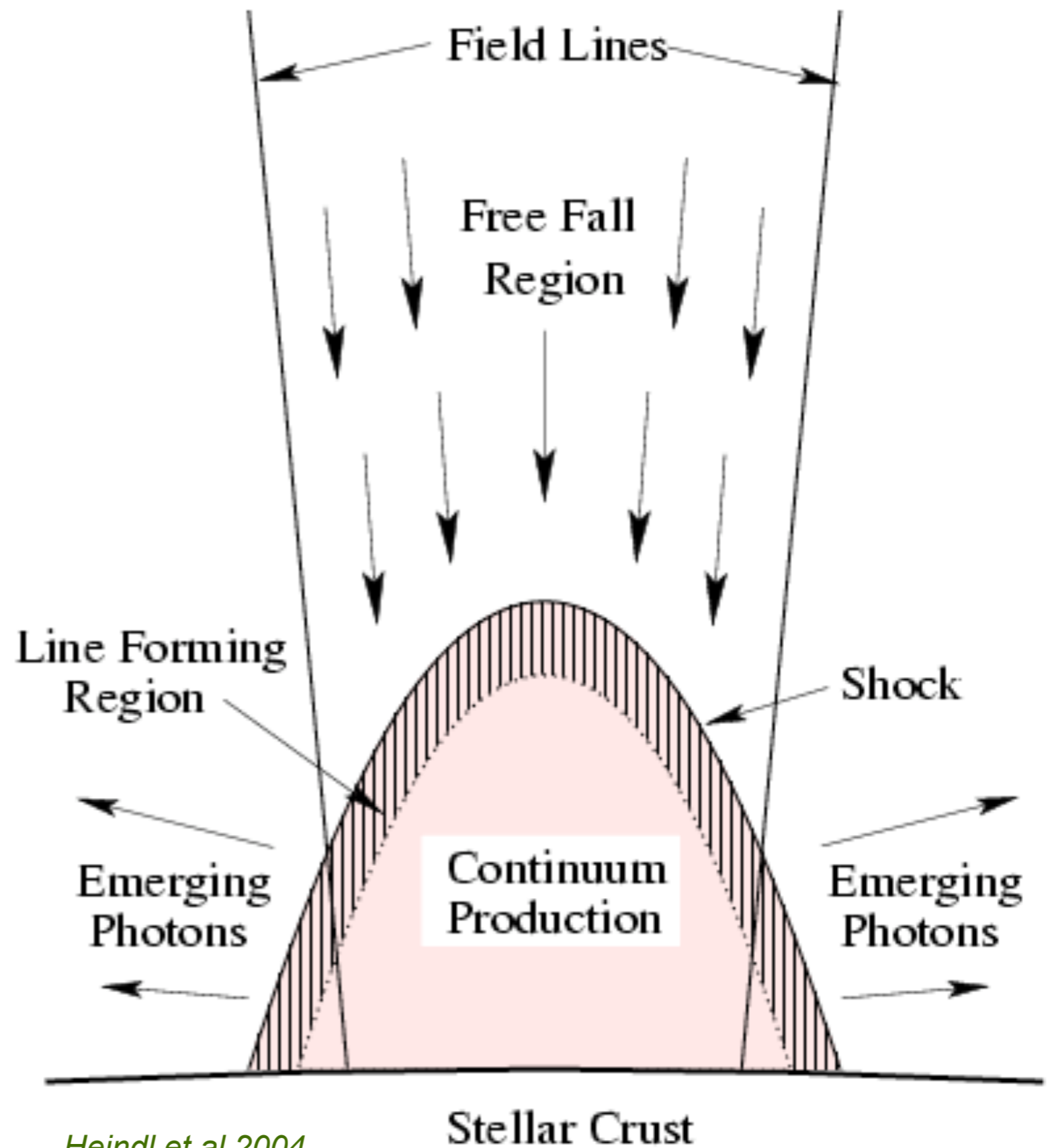
Cyclotron Resonance lines with ASTROSAT

A Hard X-ray study with LAXPC and CZTI

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IUCAA, Pune

Cyclotron Resonance lines with ASTROSAT

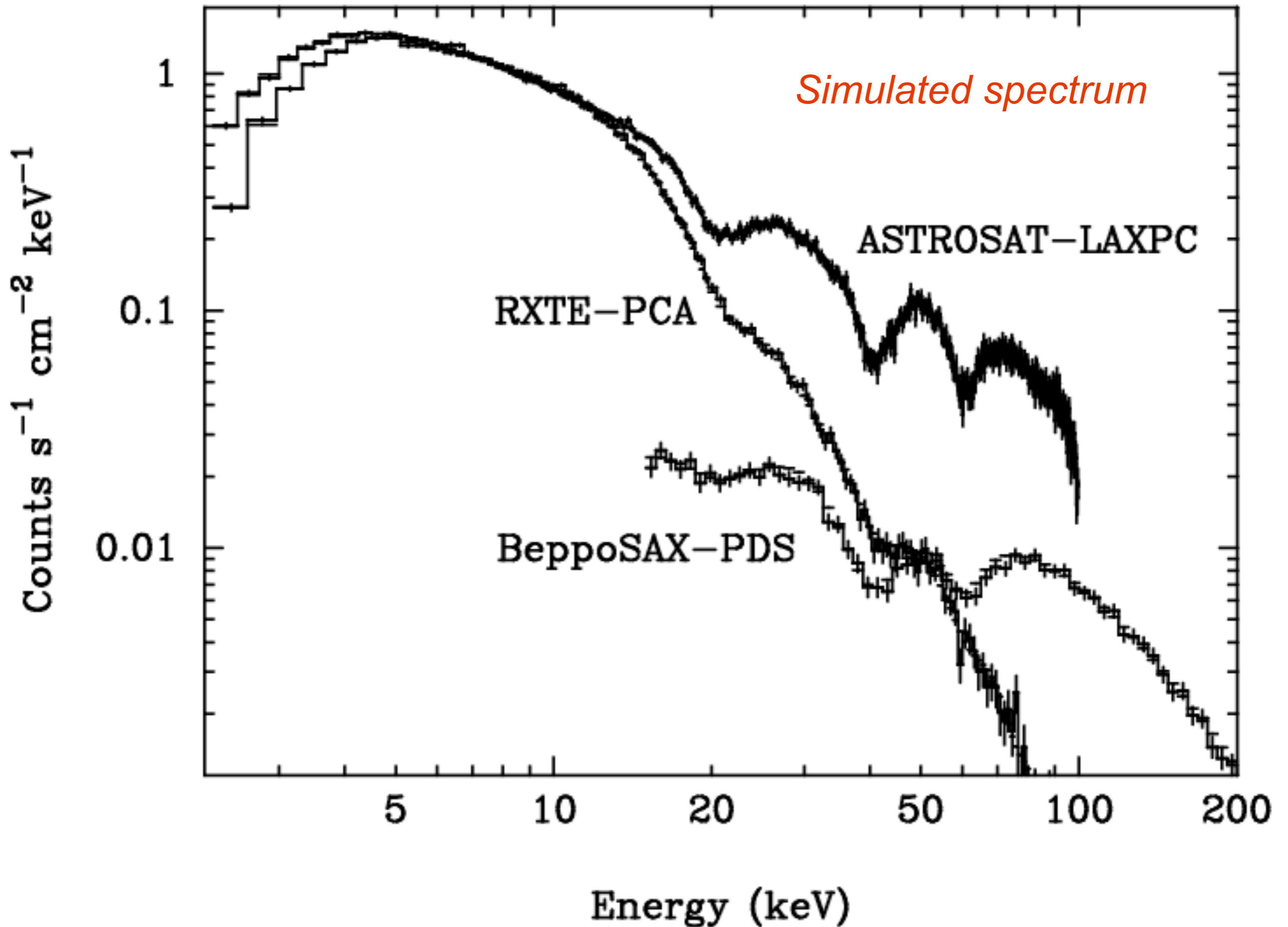
**Primary Targets:
Accreting X-ray
Pulsars**



Cyclotron Resonance lines with ASTROSAT

ASTROSAT will have excellent sensitivity for Cyclotron lines from typical accreting X-ray pulsars:

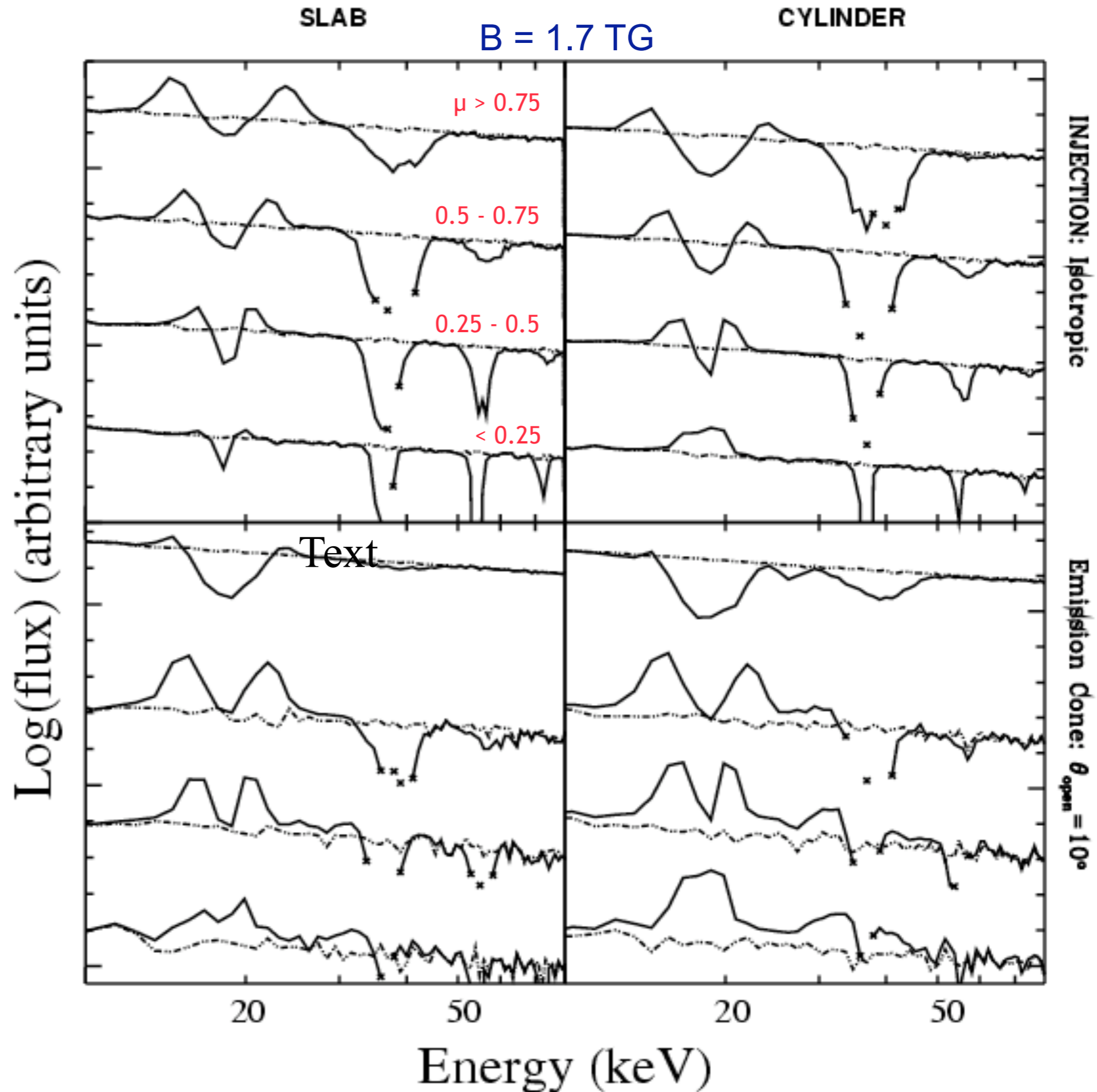
- The lines are expected in hard X-ray bands ($\sim 10 - 80$ keV)
- Large effective area of LAXPC in hard X-rays
- LAXPC spectral resolution adequate
- Excellent spectral resolution of CZTI for bright sources with CRSF



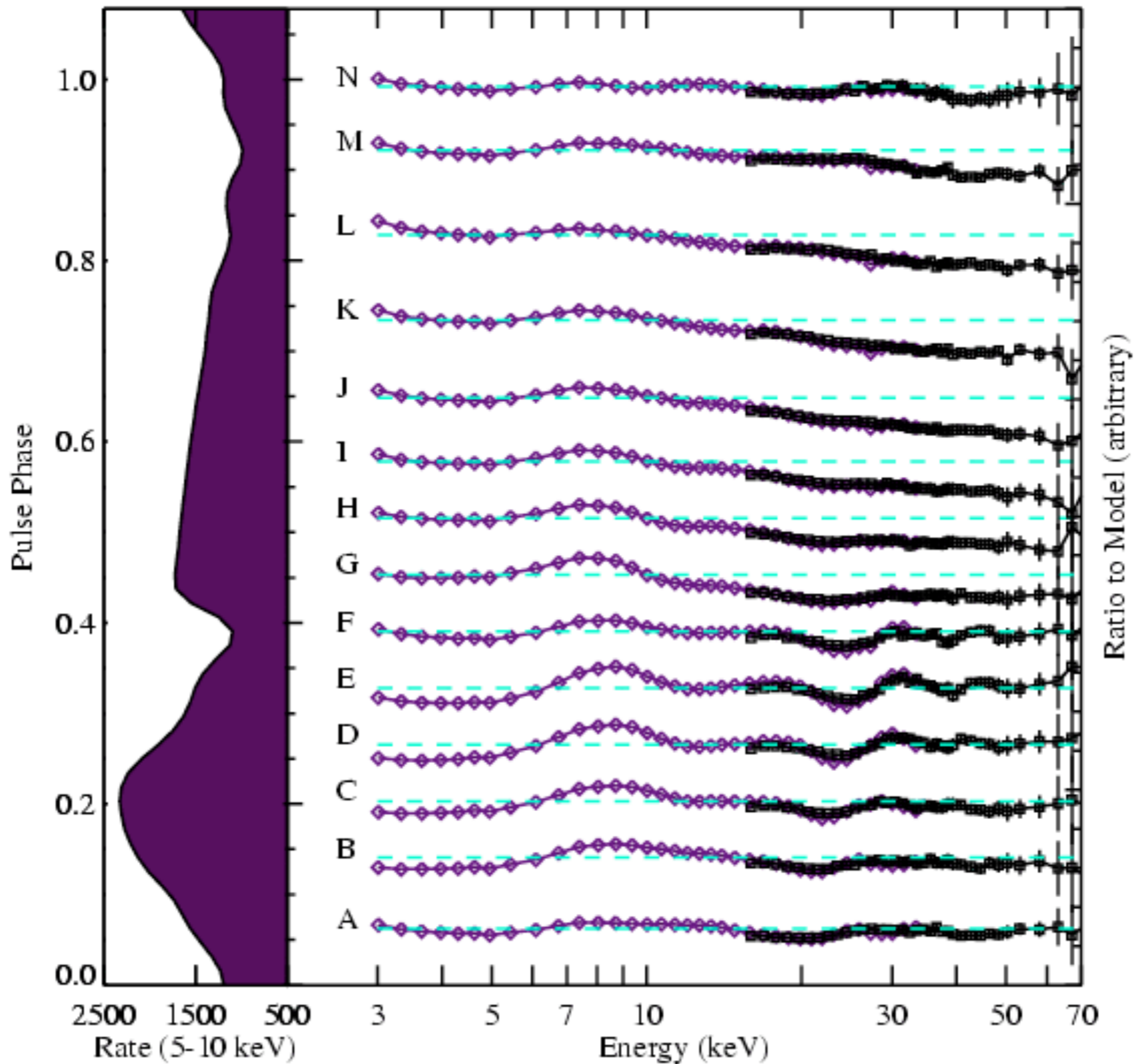
Predicted cyclotron line profiles at different angles to the magnetic axis

Phase-resolved spectroscopy best way to study cyclotron lines: needs high sensitivity

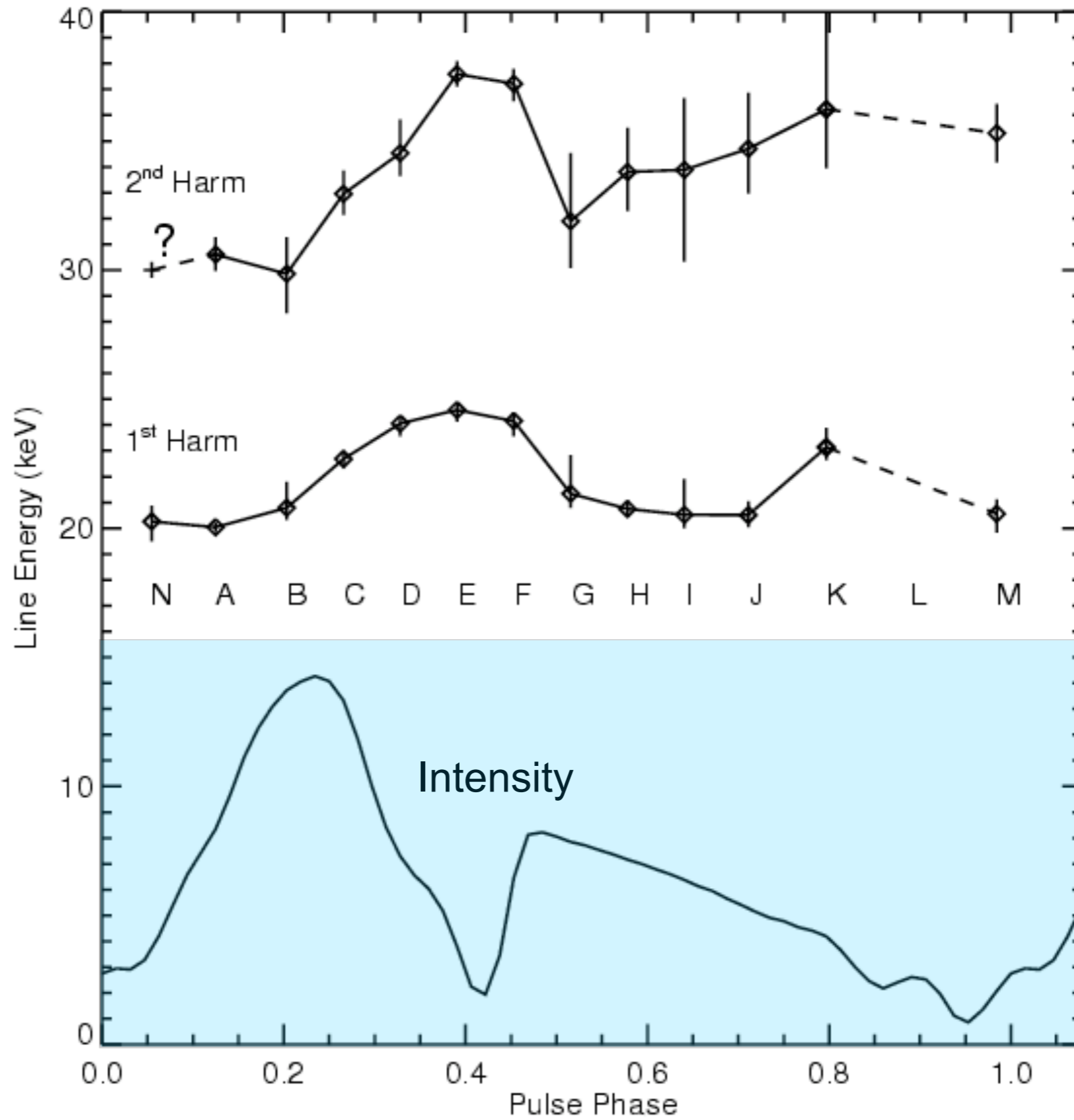
Also need good continuum modelling



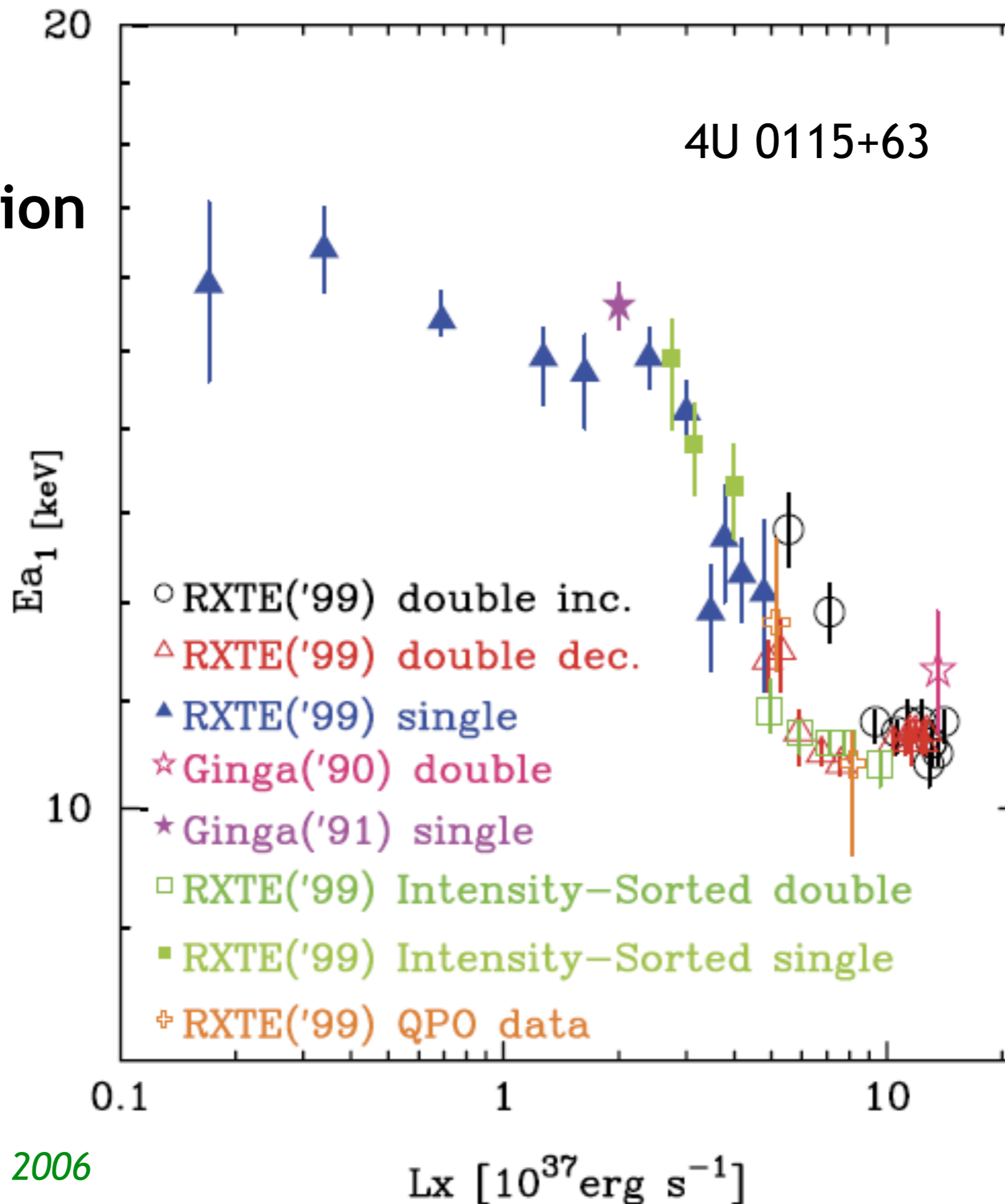
4U0115+63



4U0115+63

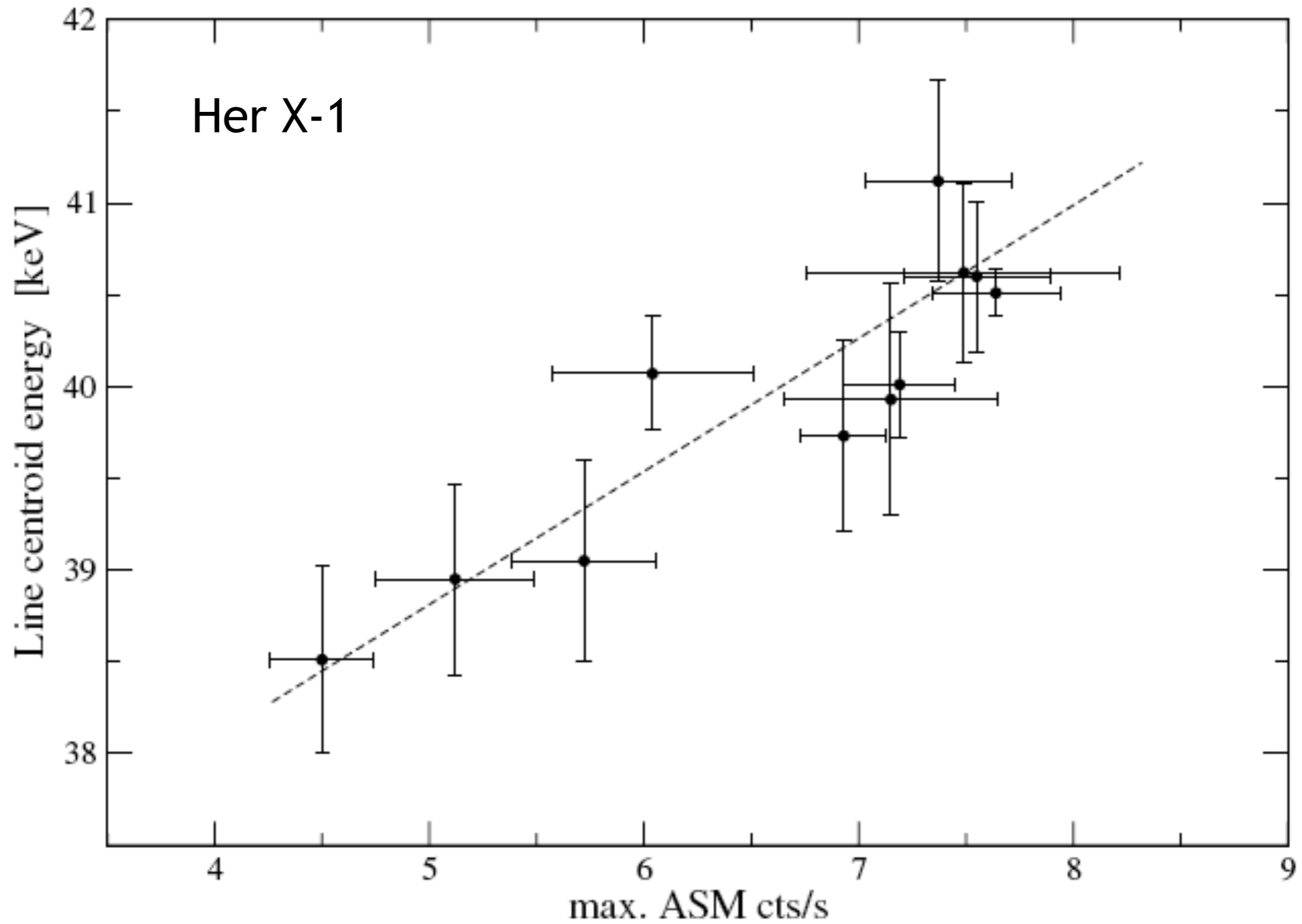


$E_{cyc} - L_x$ correlation



Larger L_x
=> more accretion
=> higher mound
=> line formation further away from the star
=> smaller local field strength
=> lower E_{cyc}

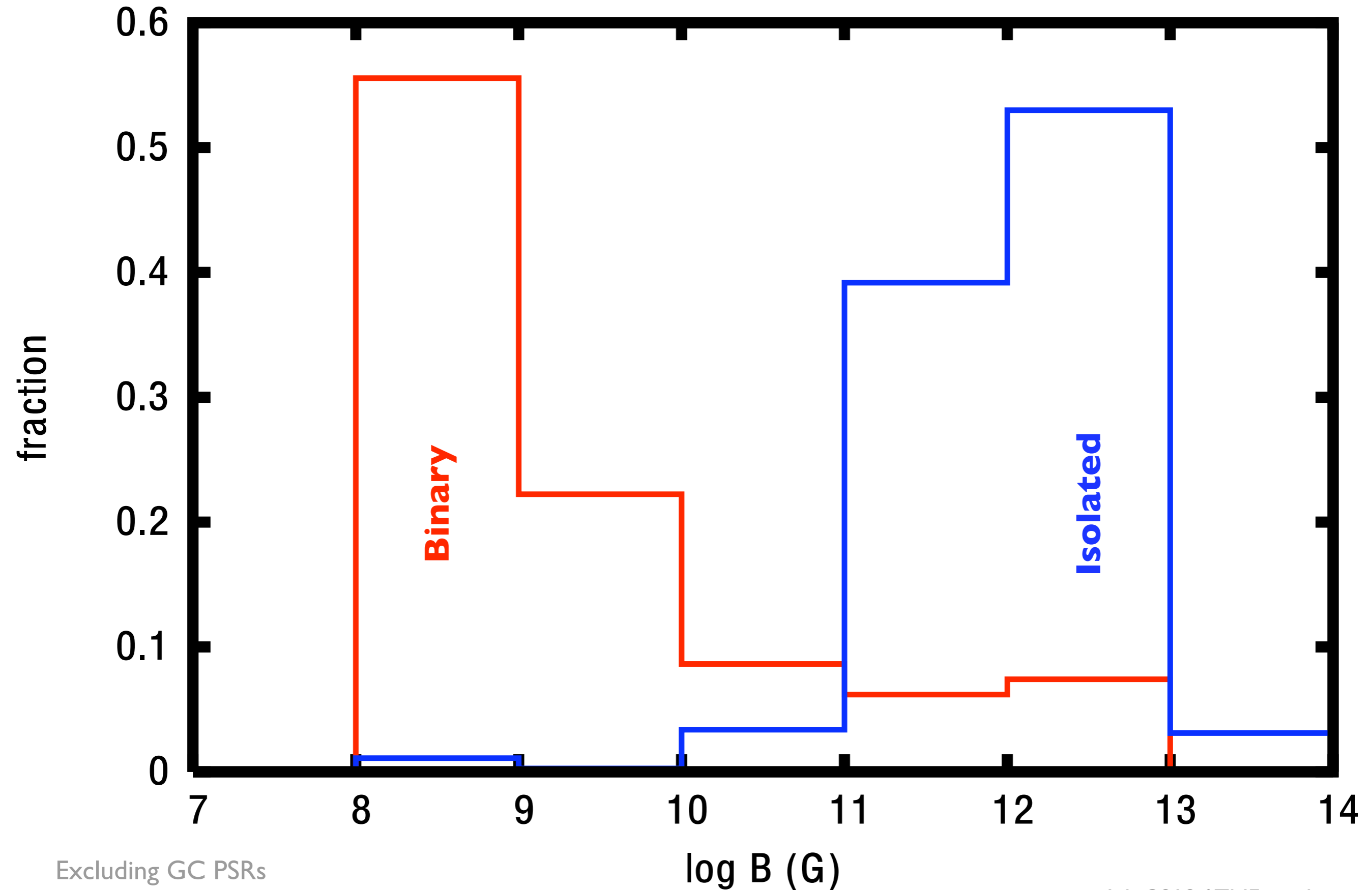
$E_{\text{cyc}} - L_X$ correlation



Secular Evolution of Neutron Star Magnetic Fields

What role does accretion play?

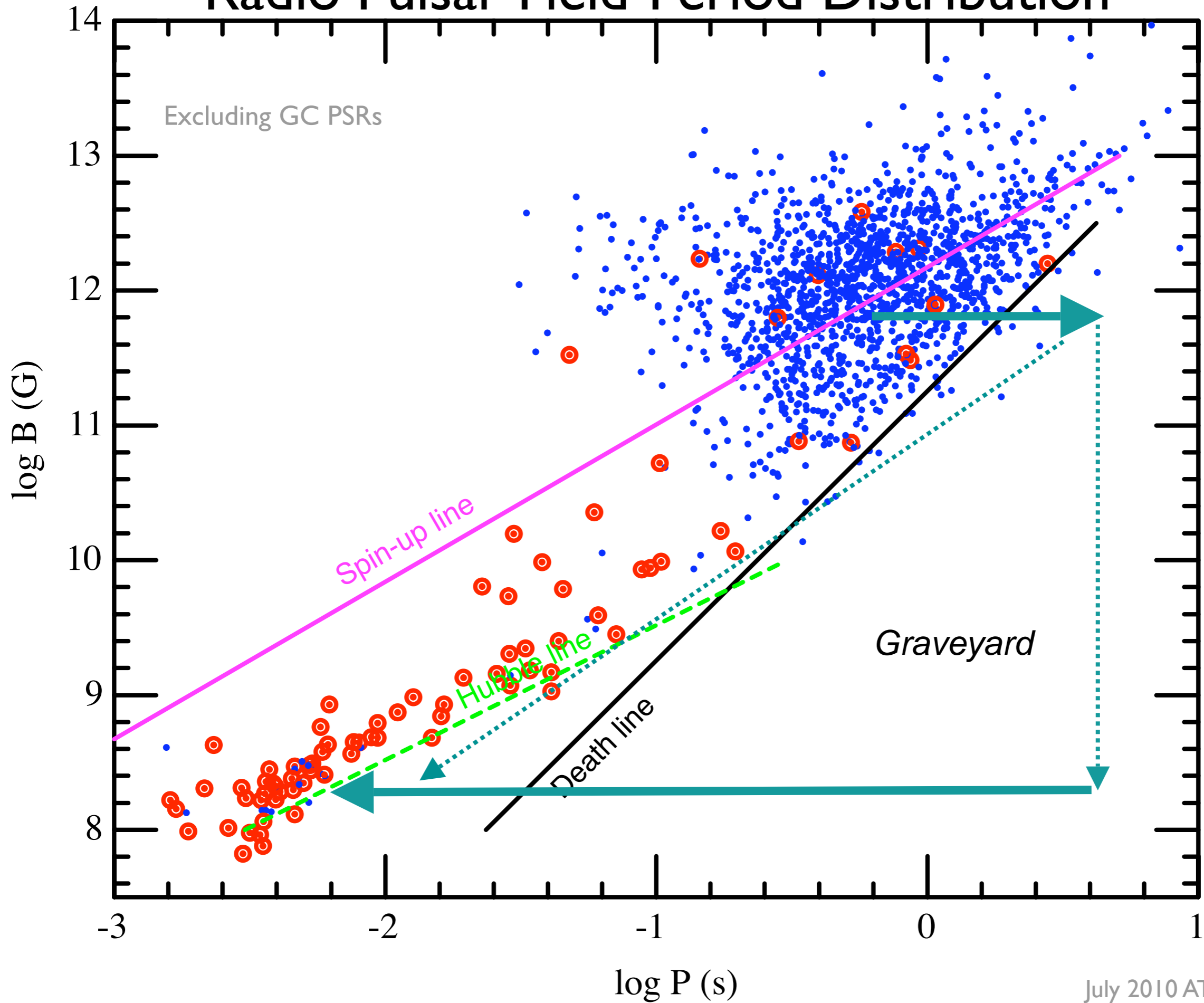
Pulsars in Binary systems have predominantly low magnetic fields.
Accretion causing field decay?



Excluding GC PSRs

July 2010 ATNF catalogue

Radio Pulsar Field-Period Distribution



Secular Evolution of Neutron Star Magnetic Fields

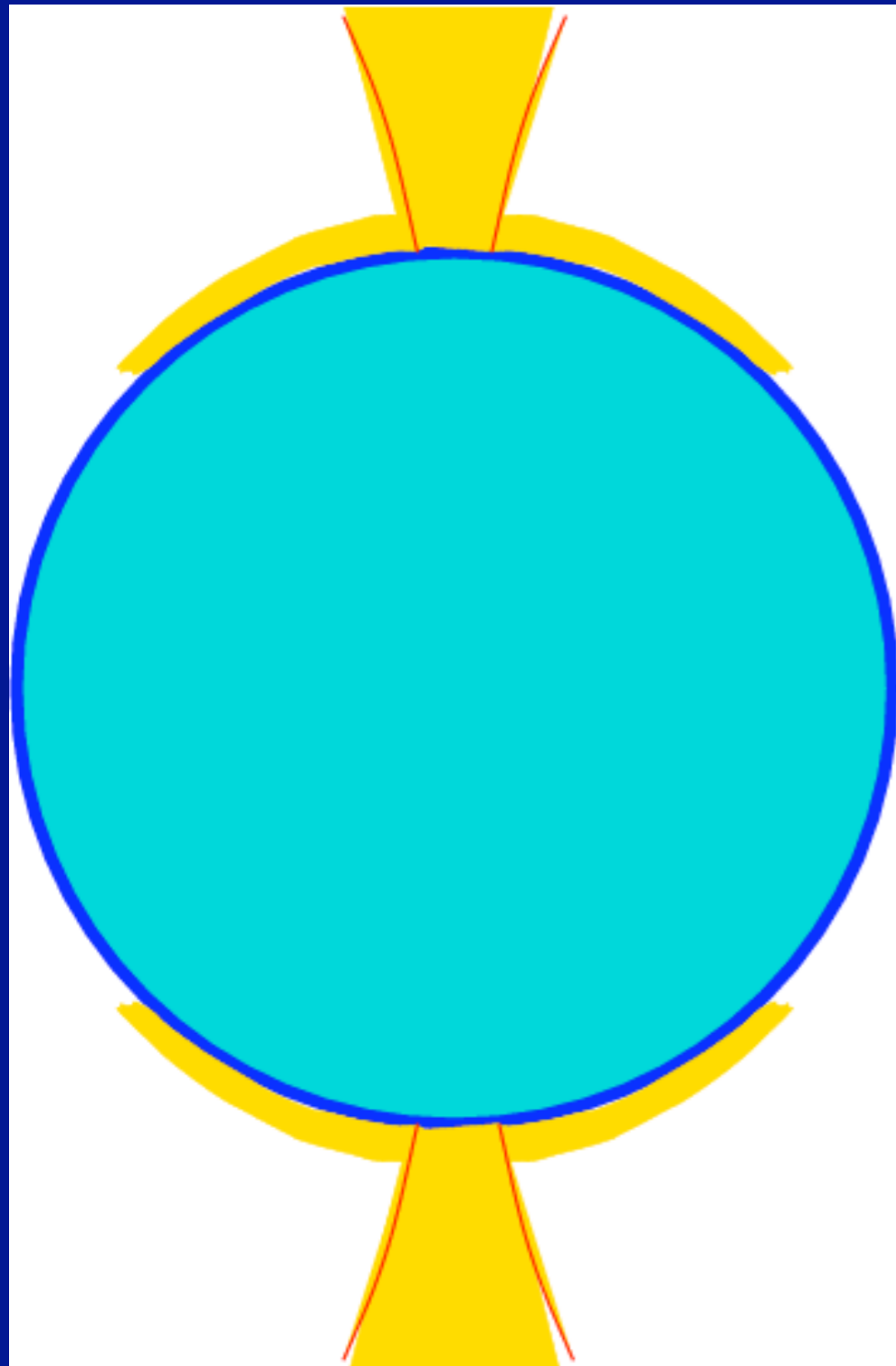
What role does accretion play?

Vortex expulsion by spin-down?

Enhanced ohmic dissipation due to heating?

Screening by accreted matter?

*DB '89, Srinivasan et al '90; Jahan Miri & DB '94; DB & Srinivasan '86,95; Konar & DB '97,98,99;
DB '94,99,02*



Screening of magnetic field by accreted matter?

Matter accreted on magnetic poles must spread on the neutron star surface

Does the matter drag the field and bury it?

Bisnovatyi-Kogan & Komberg 1978

Romani 1990, 1993

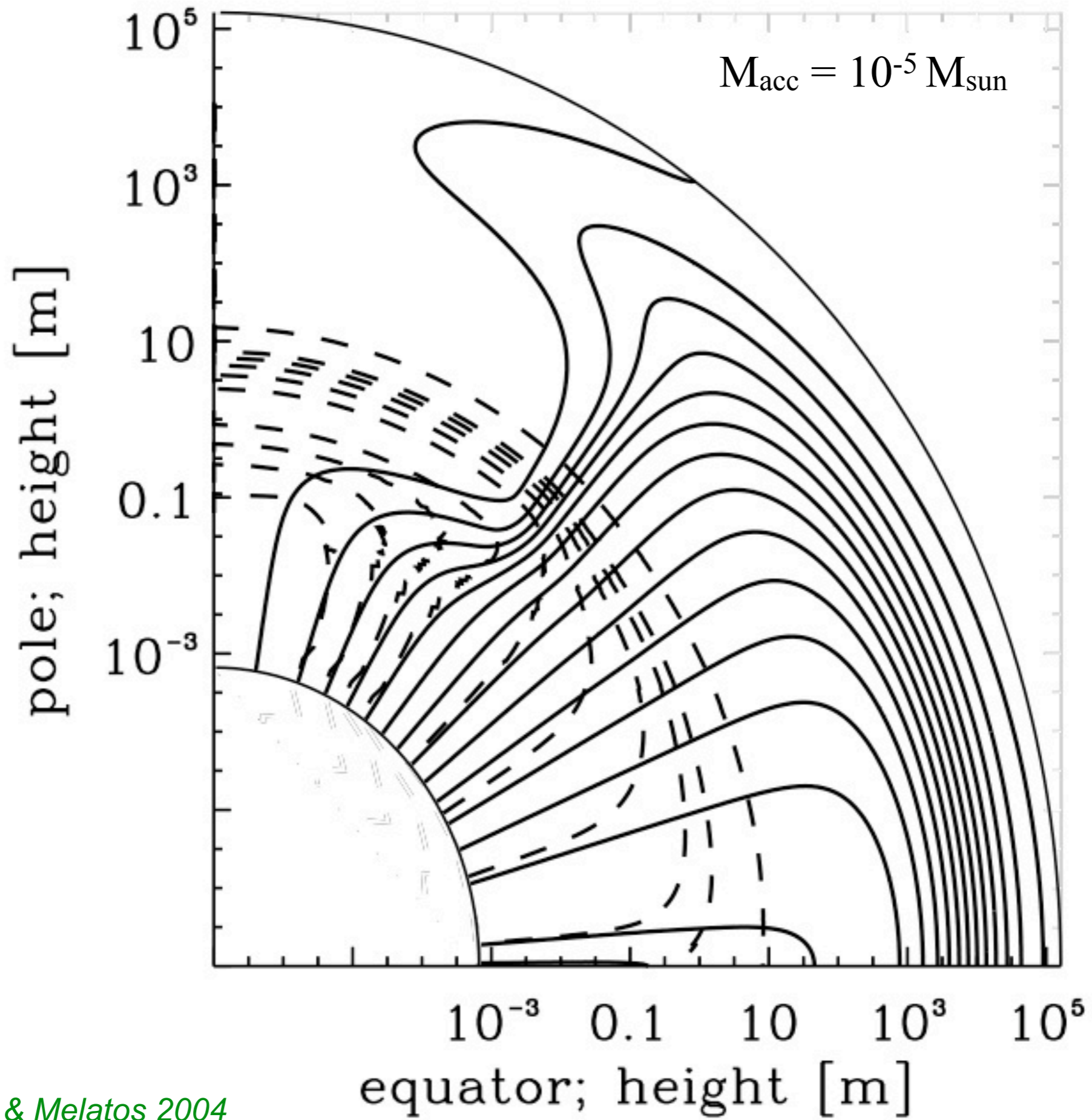
Litwin, Brown & Rosner 2001

Melatos & Phinney 2001

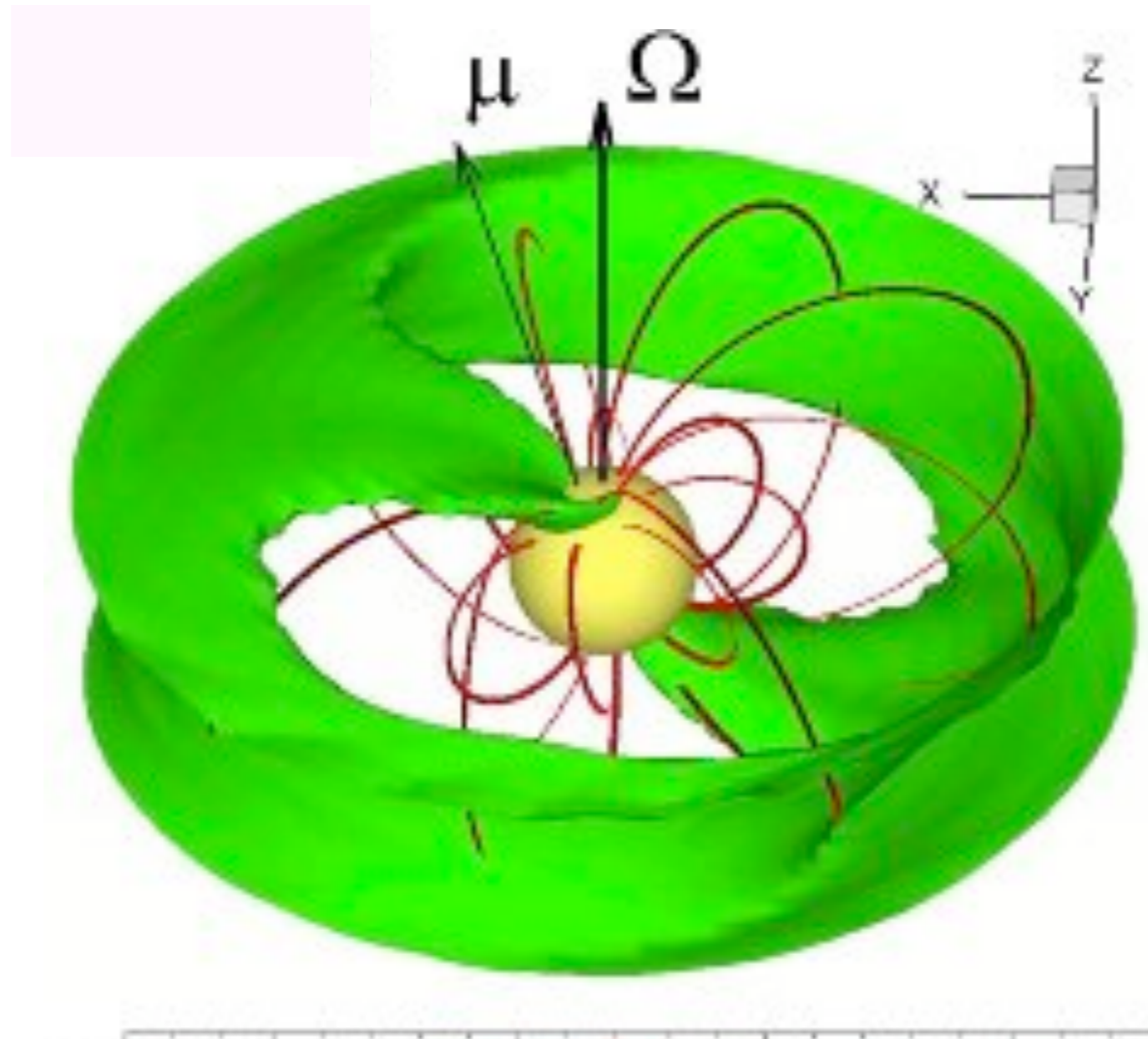
Choudhuri & Konar 2002

Payne & Melatos 2004, 2007

Vigelius et al 2008



From Accretion Disk to the polar cap



Romanova, Kulkarni and Lovelace 2008

Polar Mountain

Incoming plasma is highly conducting
Flux freezing is satisfied to the leading order

magnetostatic balance:

$$-\nabla P - \rho \nabla \Phi + (4\pi)^{-1} (\nabla \times \mathbf{B}) \times \mathbf{B} = 0$$

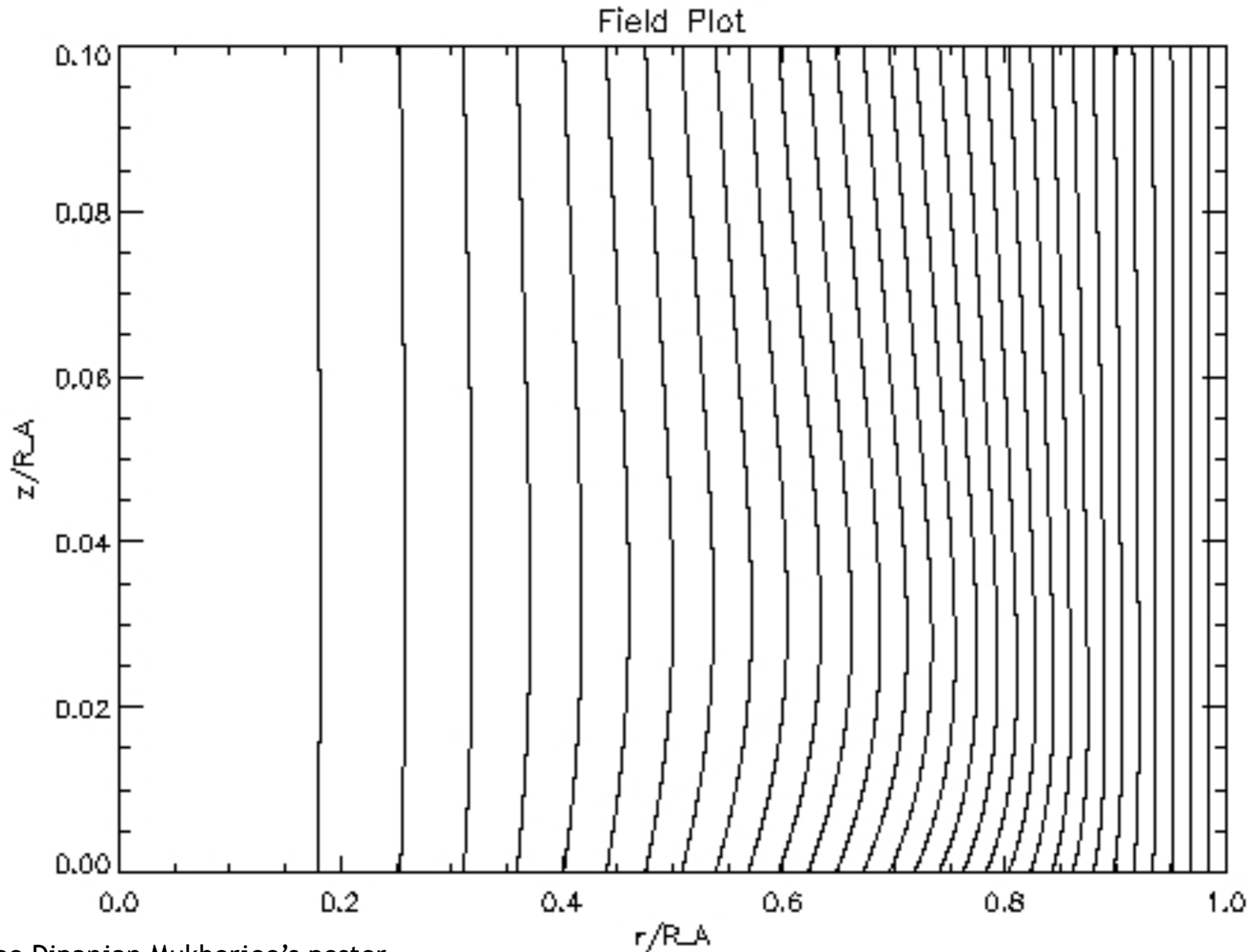
$$\nabla^2 \Phi = 4\pi G \rho ; \quad P = K \rho^\Gamma ; \quad B_\phi = 0$$

$$\mathbf{B} = (r \sin \theta)^{-1} \nabla \psi(r, \theta) \times \hat{\mathbf{e}}_\phi$$

$\psi \equiv$ flux function

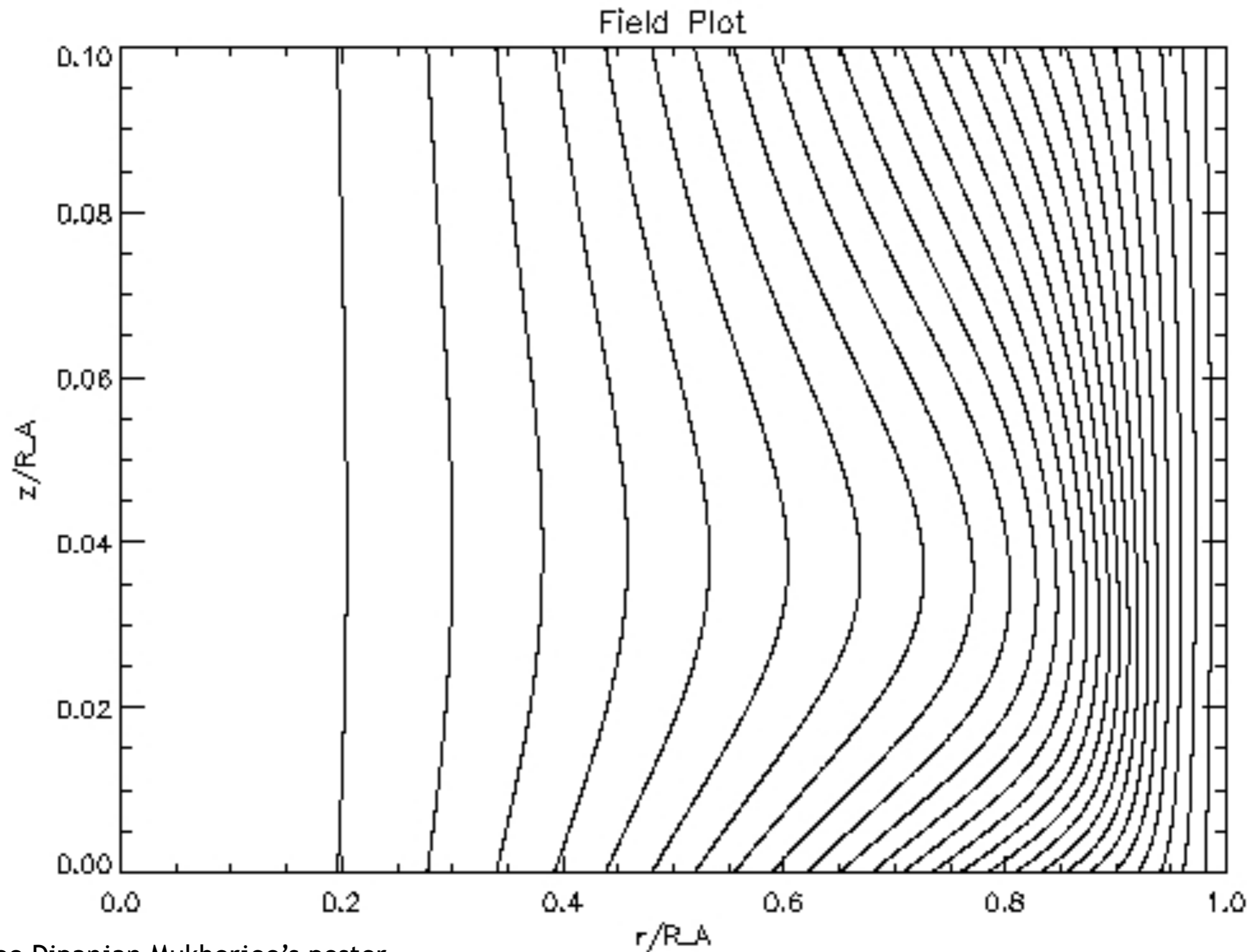
assume azimuthal symmetry at polar cap

Grad-Shafranov solution in cylindrical geometry

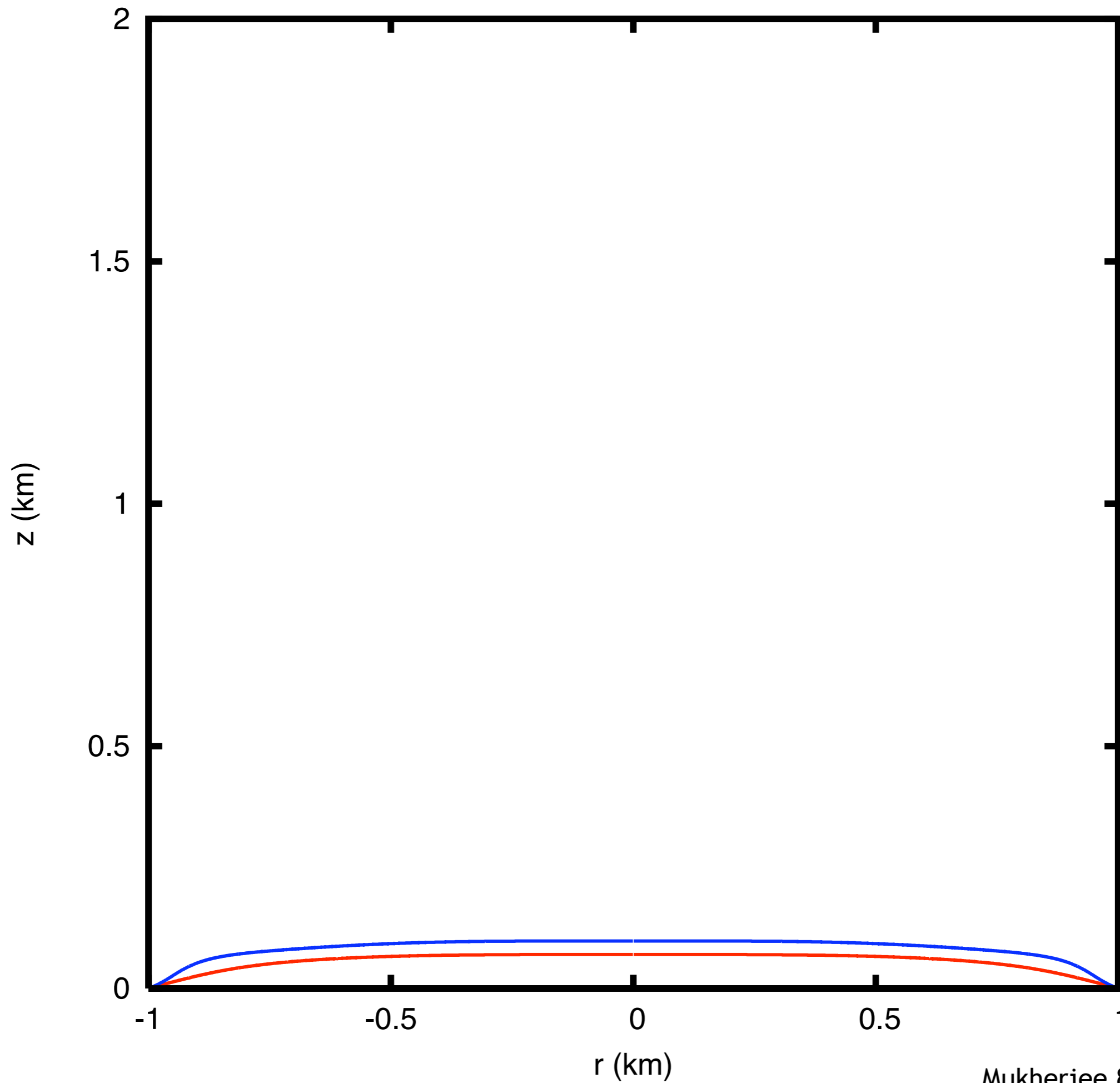


See Dipanjan Mukherjee's poster

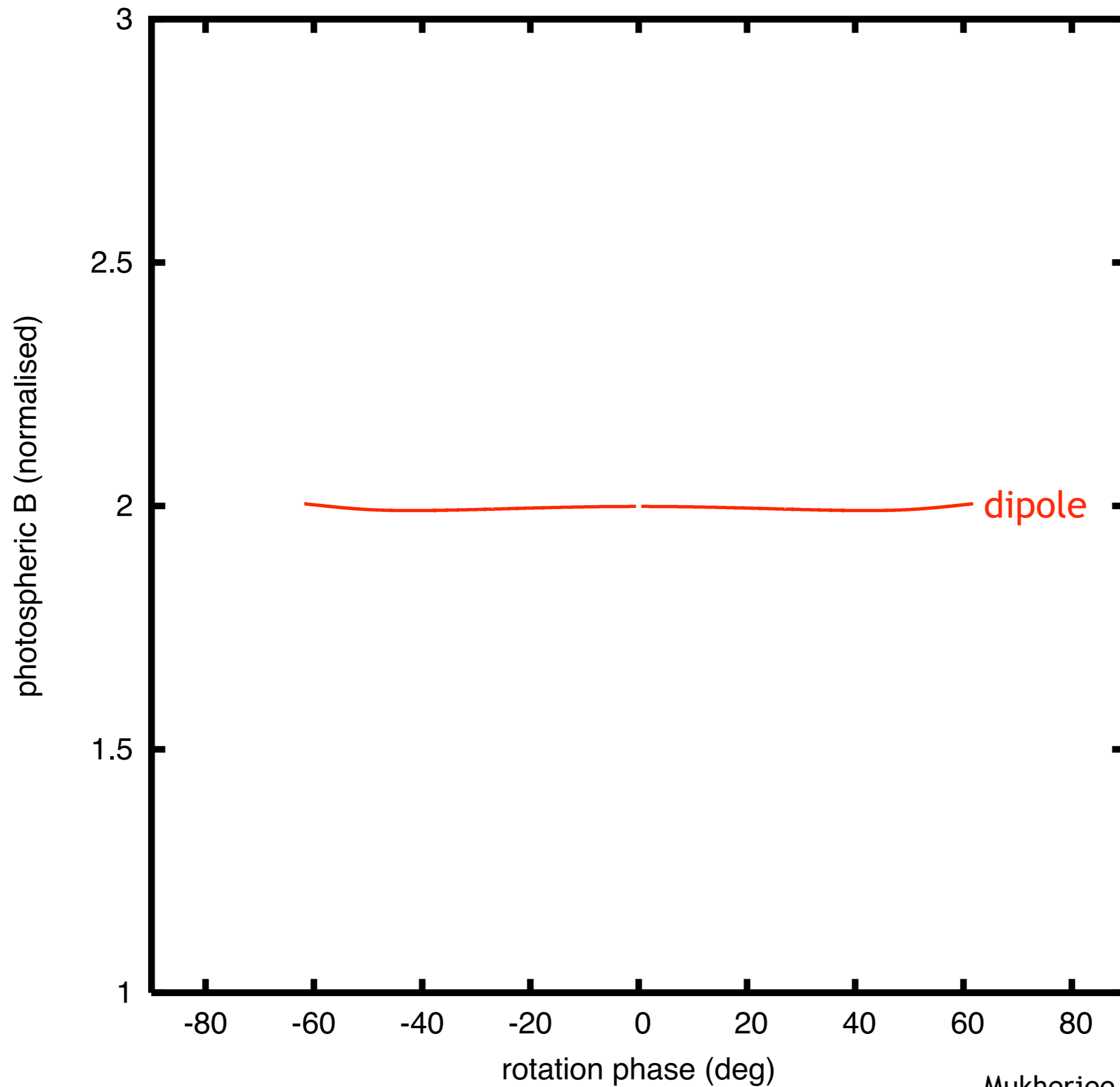
Grad-Shafranov solution in cylindrical geometry



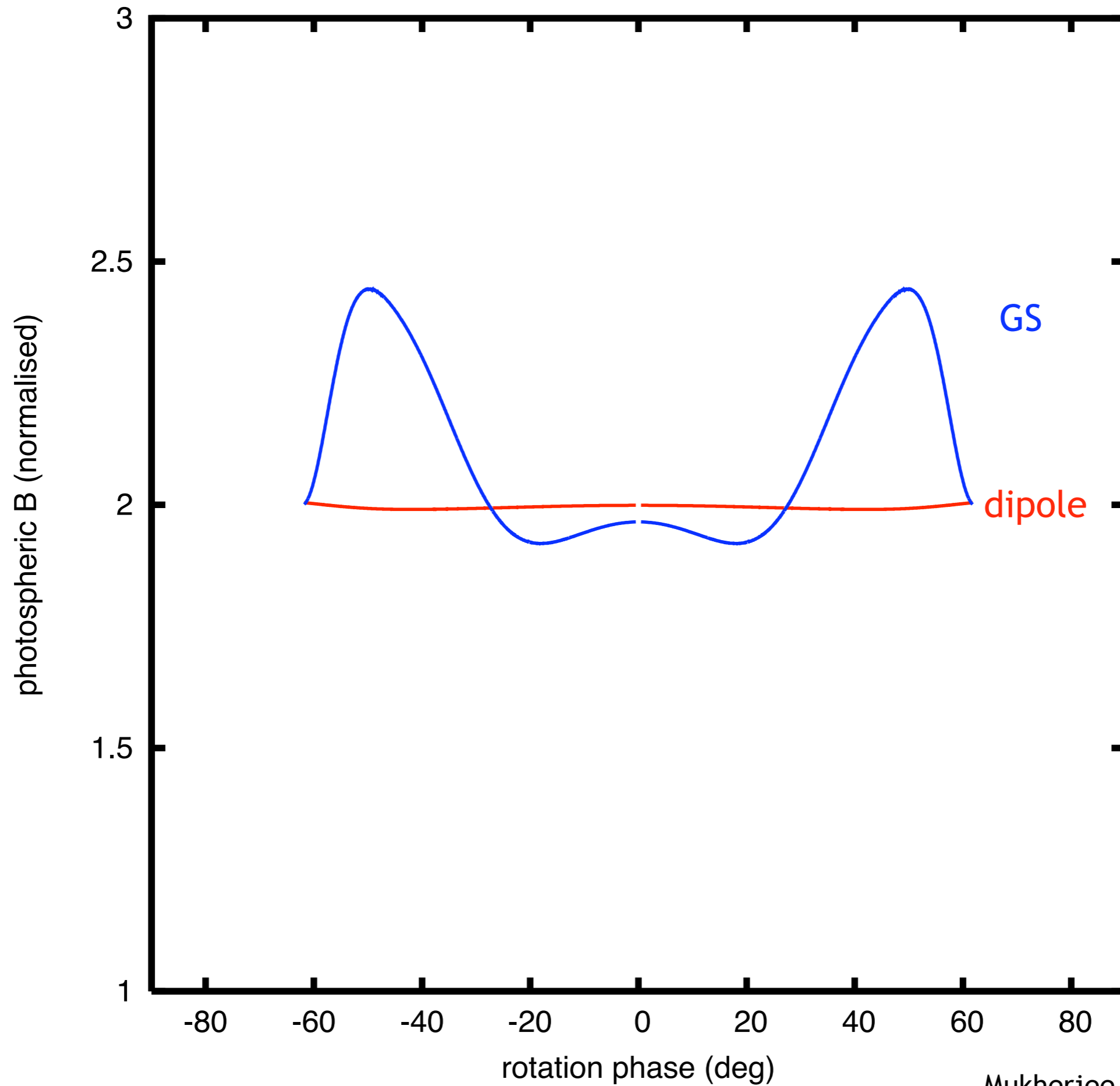
See Dipanjan Mukherjee's poster



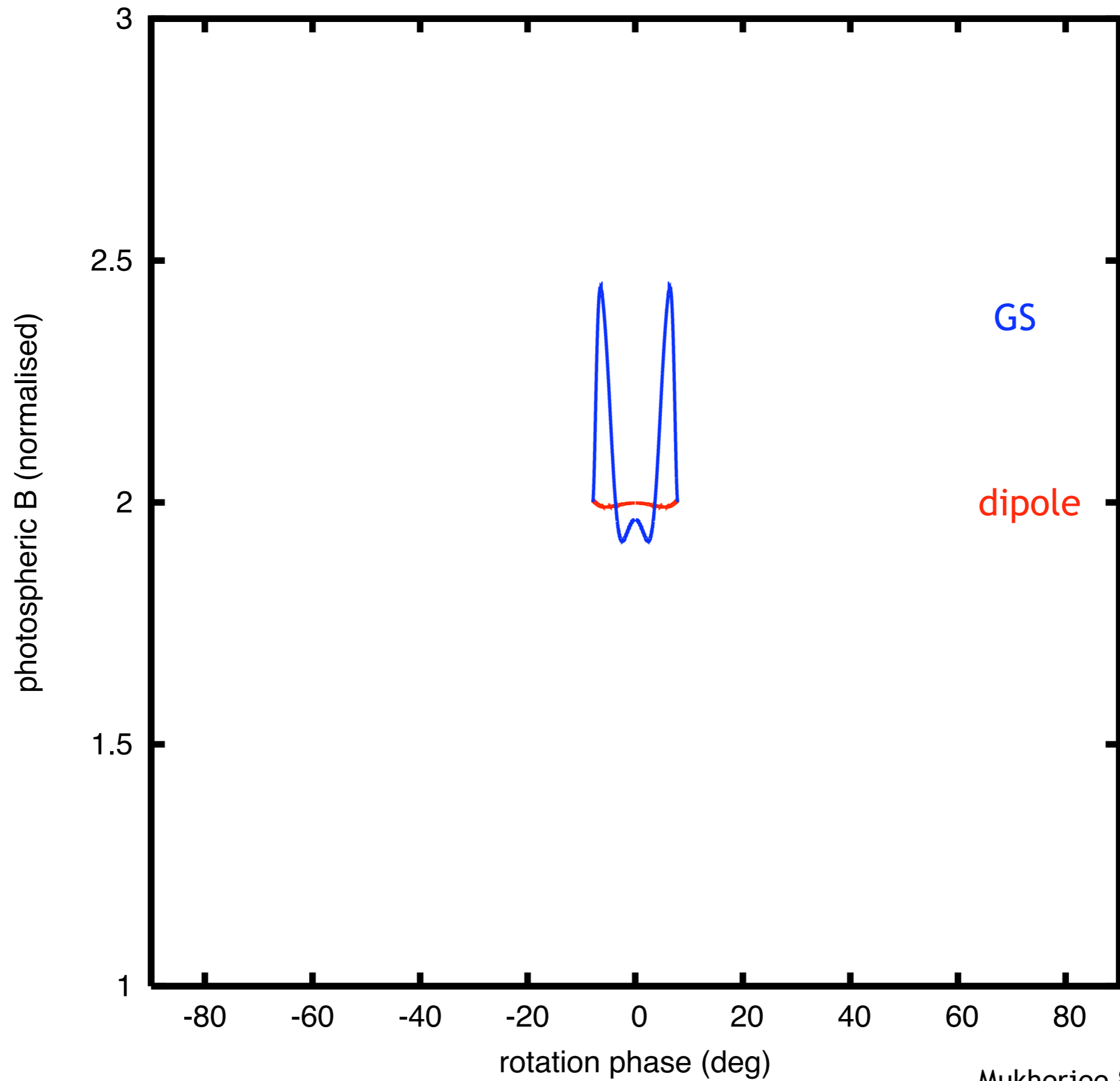
$\alpha = 5 \text{ deg}$



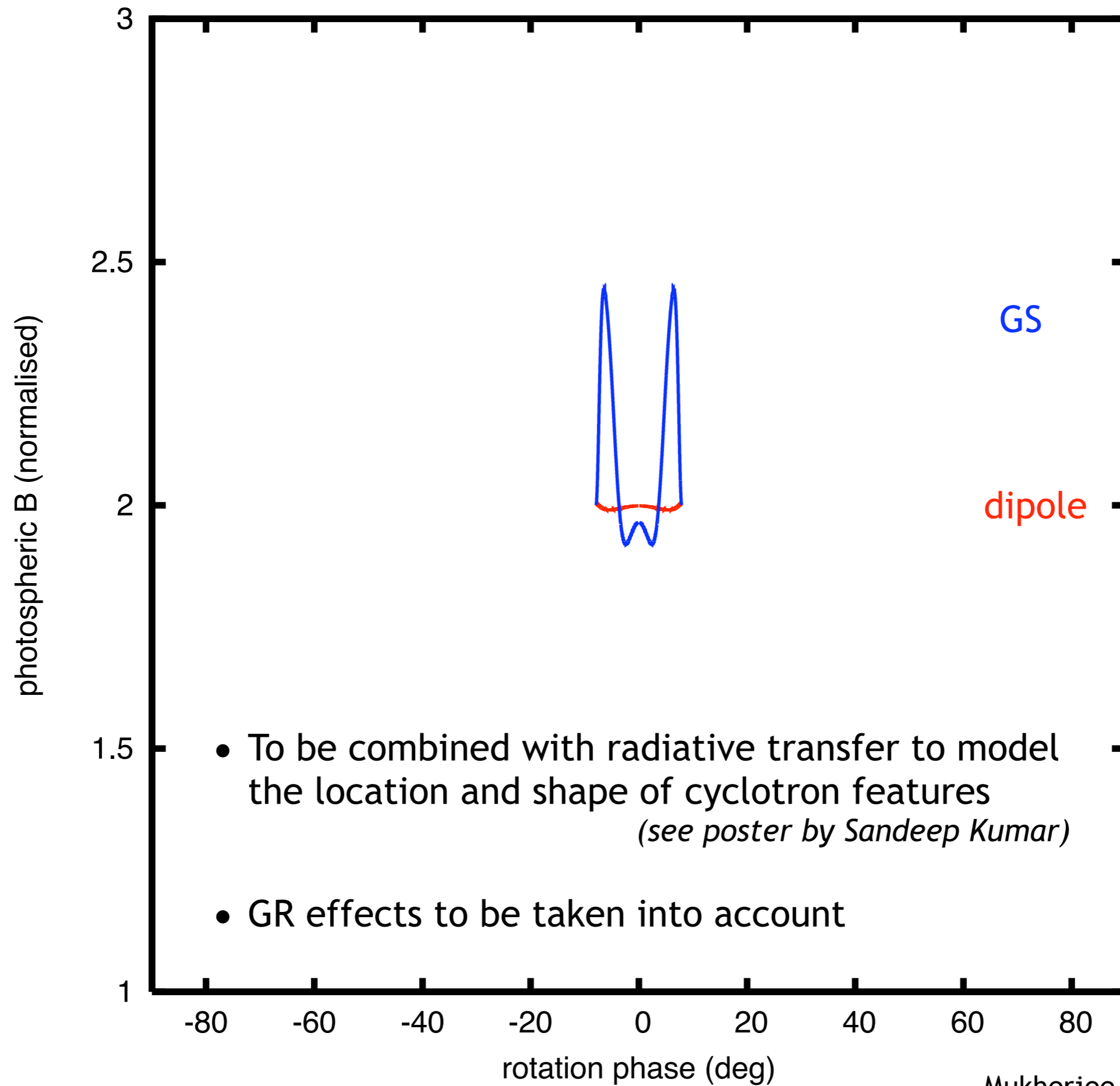
$\alpha = 5 \text{ deg}$



$\alpha = 45$ deg

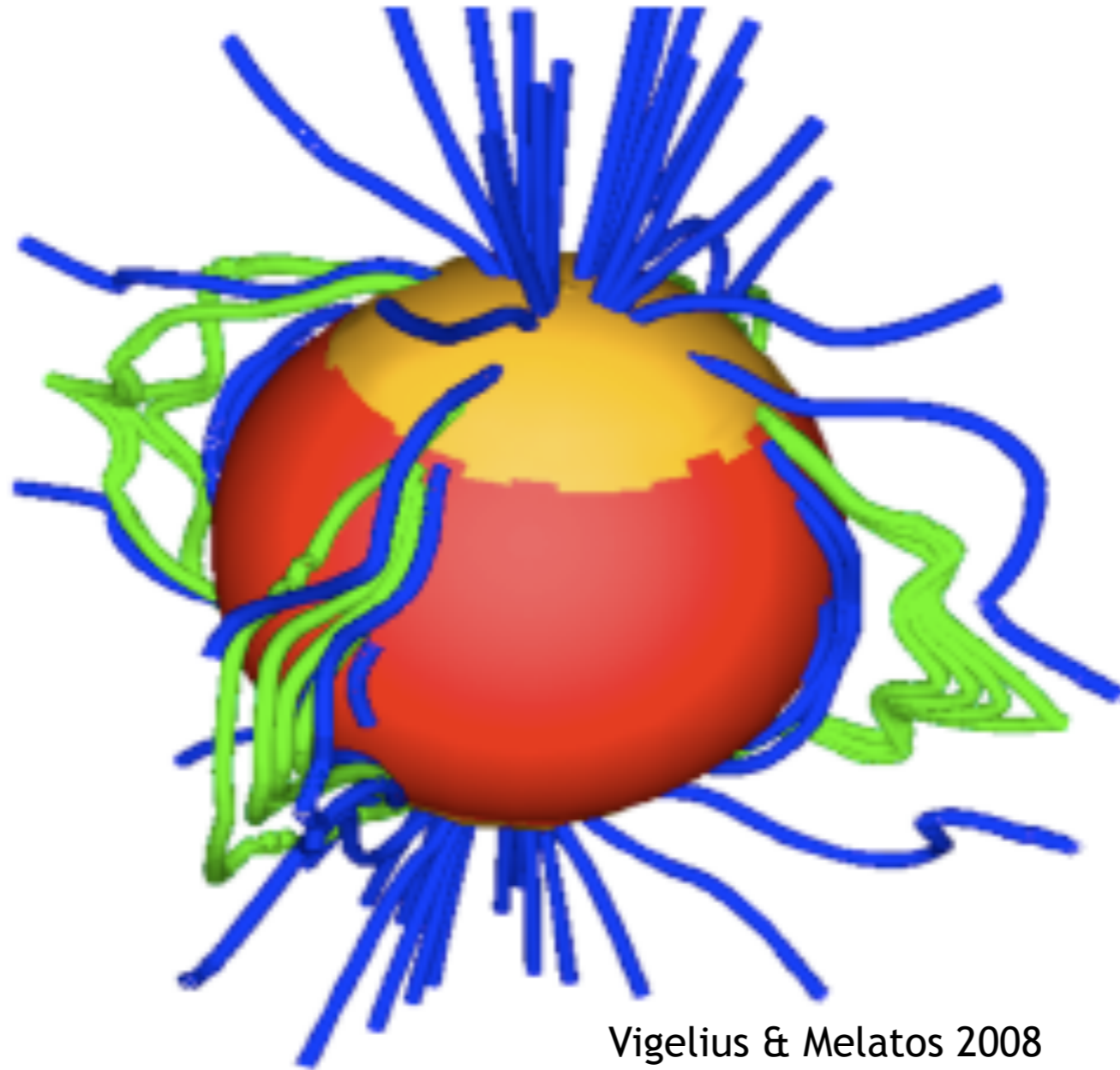


$\alpha = 45$ deg



Polar cap of an accreting neutron star

Cross-field plasma transport due to instabilities



Vigelius & Melatos 2008

Phase resolved cyclotron line spectroscopy can probe such magnetic distortions

Probing polar cap field with phase resolved spectroscopy

- Need to separate the effect of luminosity (accretion rate) variation from that due to field structure
- Averaging of data only over similar accretion rates
- Short-duration averages: require high sensitivity
- Continuum modelling important: wide energy coverage helpful
- Will require good knowledge of response matrix

Cyclotron line projects with ASTROSAT

Rotation Phase resolved spectroscopy of accreting X-ray pulsars

Different orbital phases and luminosity states to be probed

Sample size: 15 objects, total exposure ~1.5 Mega second

Search for CRSF in other bright X-ray pulsars

Sample size: ~5 objects, time required ~0.5 Ms

Search for proton cyclotron features in bright SGR/AXP outbursts

Sample size: ~5 objects, time required ~0.5 Ms, TOO

CRSF search in INTEGRAL hard X-ray pulsars

Sample size: ~10 objects, time required ~1 Ms

CRSF search in transient (Be) HMXBs

TOO

Timing study of these objects can be carried out simultaneously

Summary

- Astrosat will provide excellent sensitivity and energy coverage for a detailed study of Cyclotron Lines
- Careful phase-resolved spectroscopy can detect magnetic structures on the polar cap
- Estimate of field distortion can set limits on the size of the polar mountain and hence on the secular evolution of the field structure
- Good spectral calibration and long exposures will be necessary for the success of this investigation

Cyclotron line
pulsars known

4U 0115+63
4U 1907+09
4U 1538-52
Vela X-1
V 0332+53
Cep X-4
Cen X-3
X Per
GX 1+4
XTE J1946+274
MX 0656-072
4U 1626-67
GX 301-2
Her X-1
A 0535+26

Bright X-ray
pulsars for
CRSF search

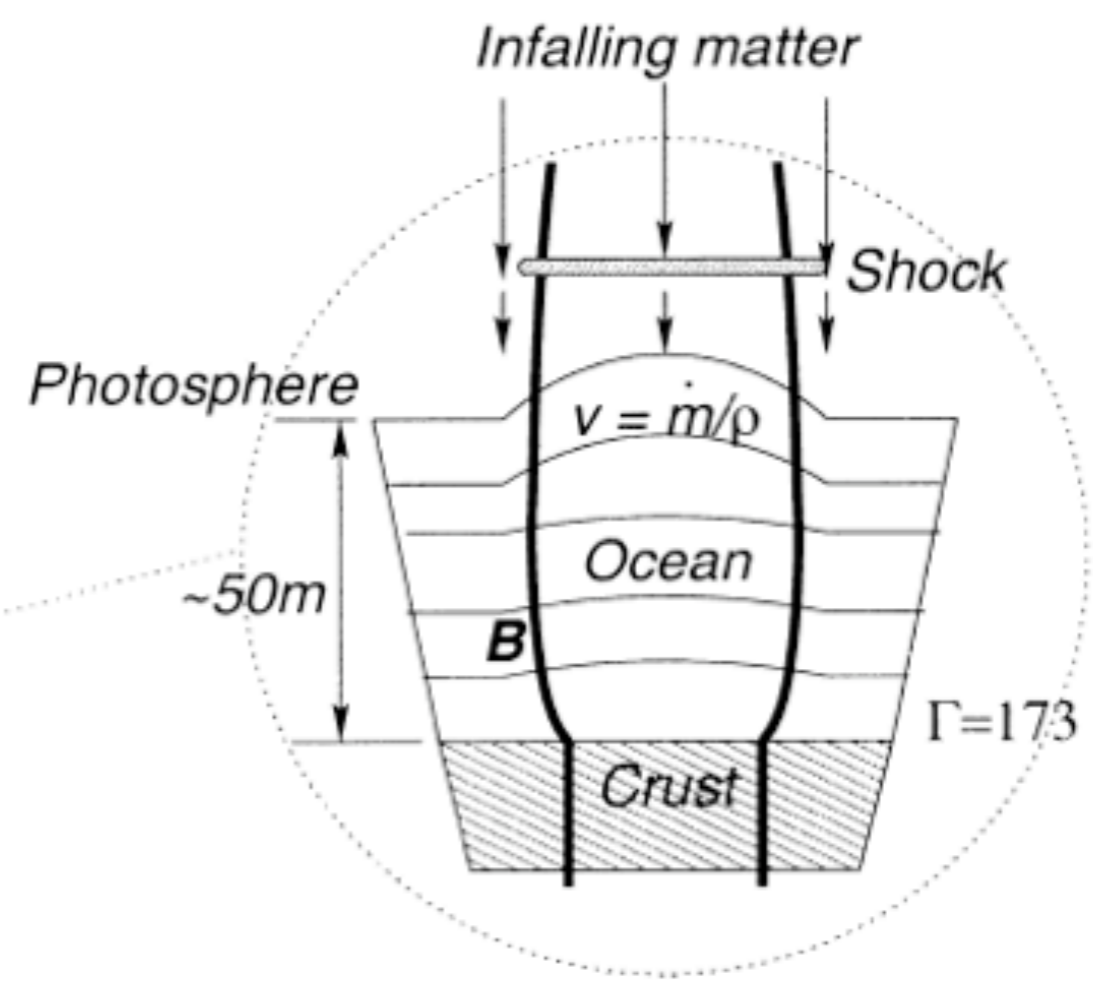
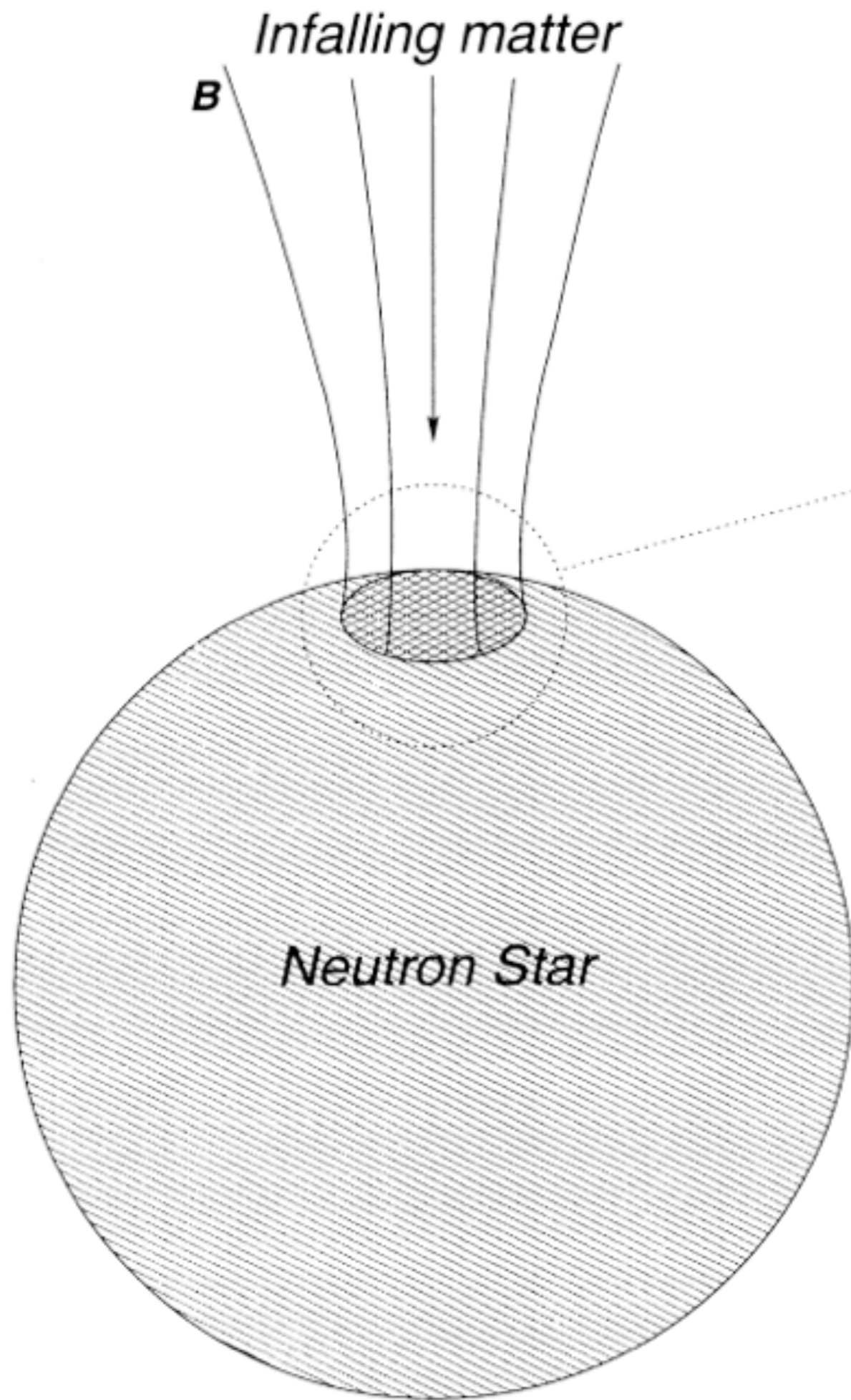
SMC X-1
LMC X-4
2S 0114+650

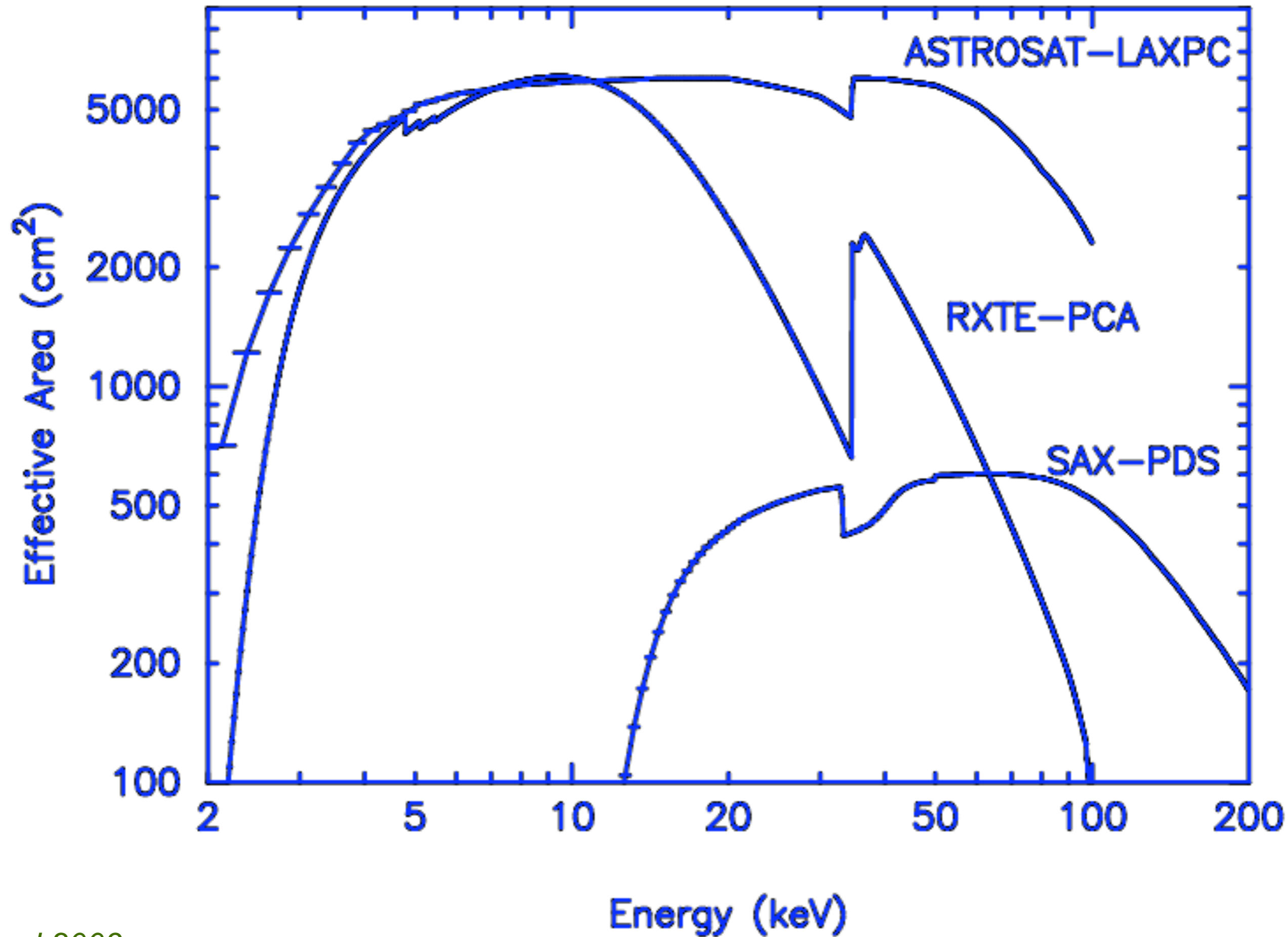
SGR/AXP

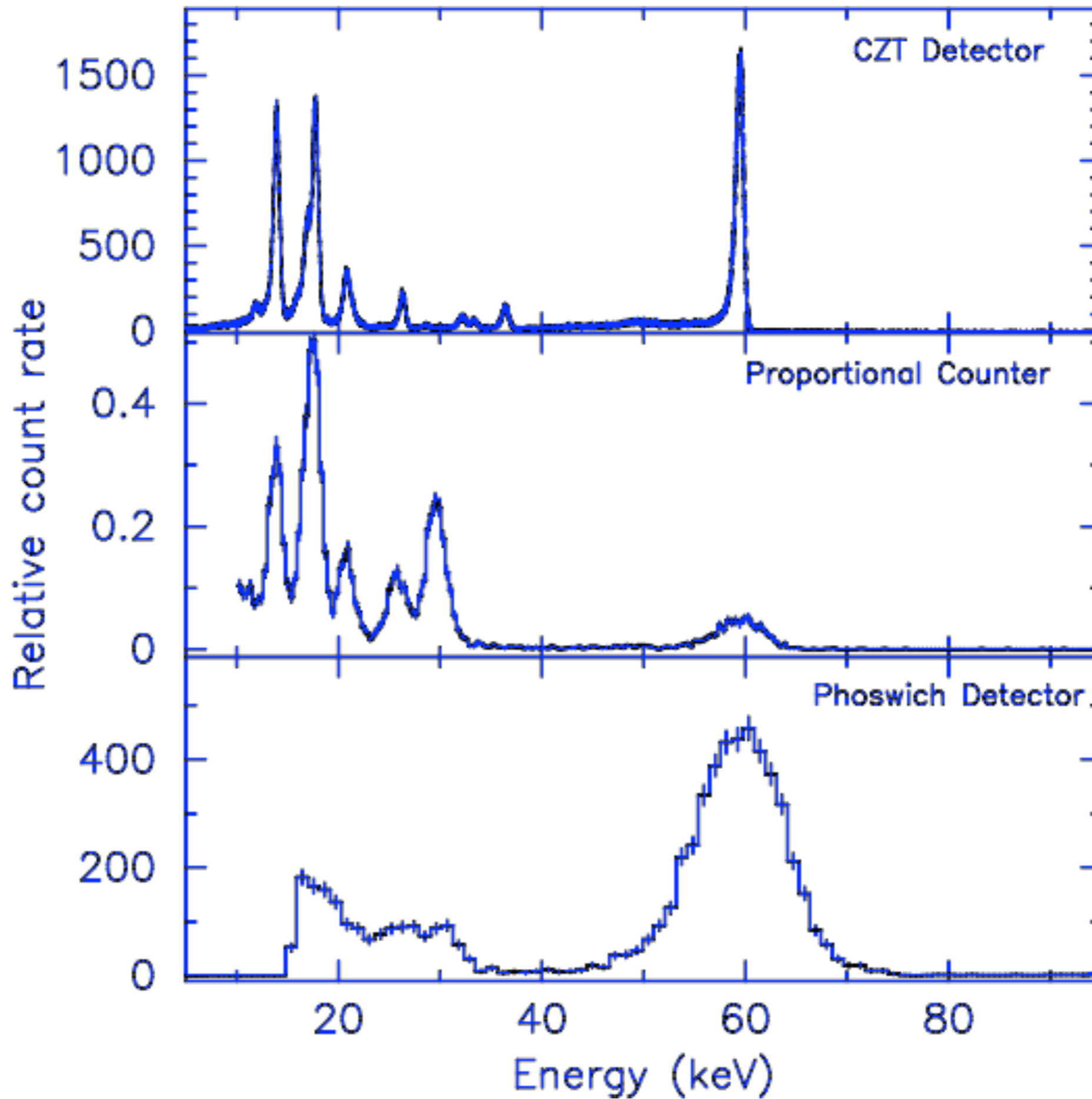
1806-20
1900+14
1810-197
164710.2
1627-41

IGR sources
(from)

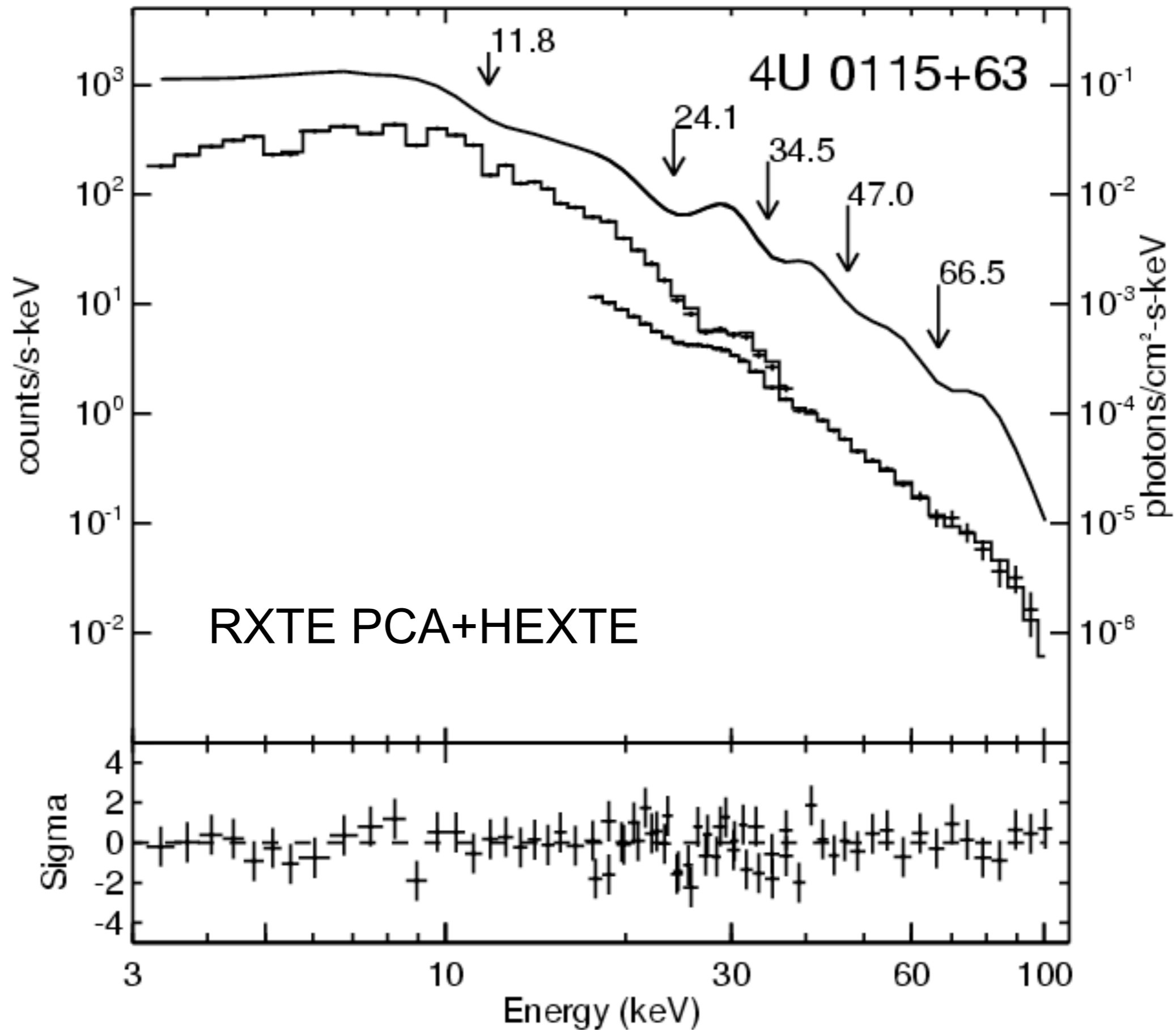
06253+7334
11215-5952
11435-6109
13020-6359
15479-4529
16320-4751
16358-4726
16393-4643
15418-4532
17088-4008
17252-3616
17303-0601
18027-2016
18410-0535
21335+5105



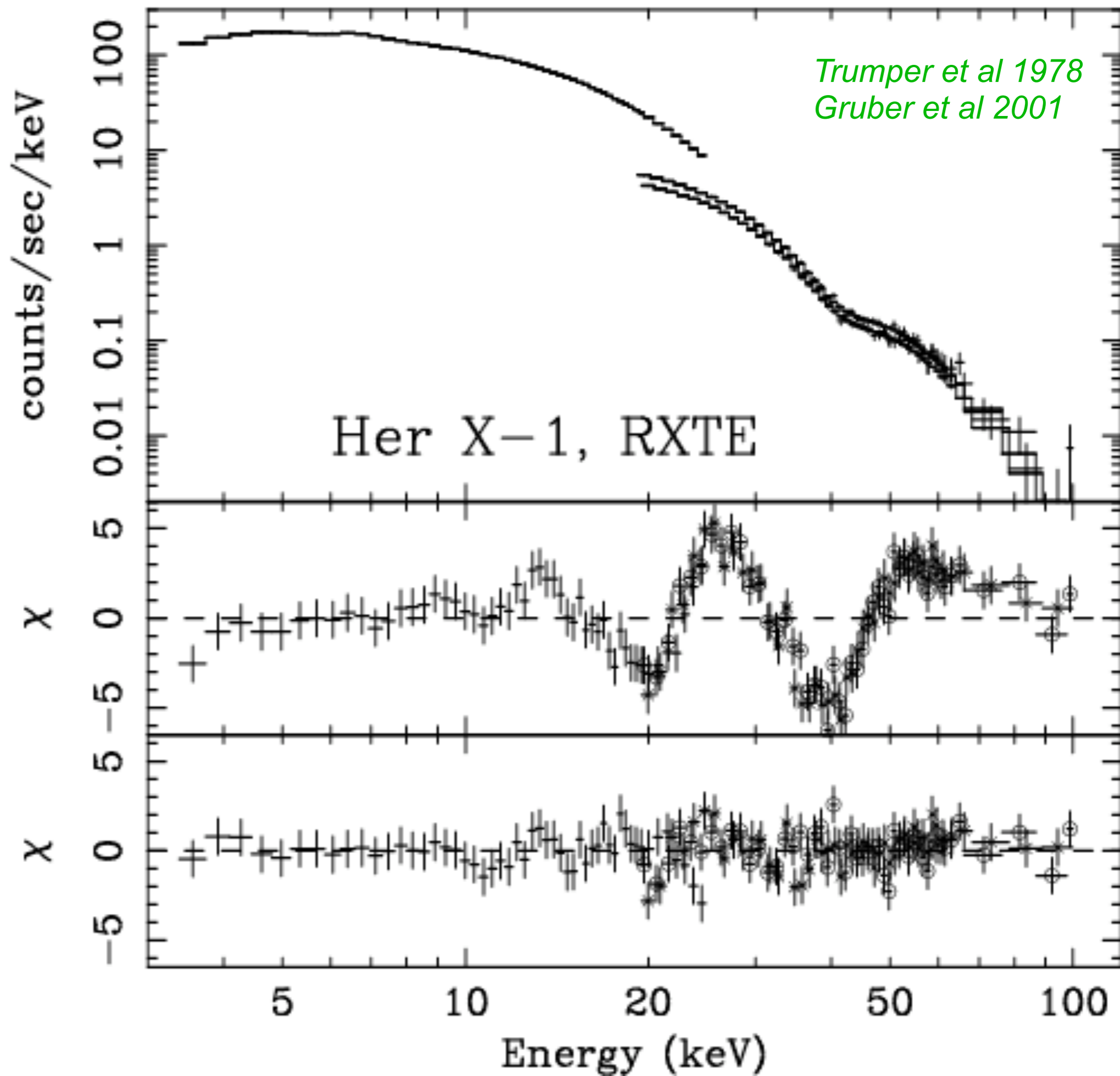




Am^{241}
spectral
response



Her X-1:
Neutron Star
with a 2 Msun
companion
in beginning
atmospheric
Roche lobe
overflow



Non-relativistic

$$E_{\text{cyc}} \text{ (fund.)} = \frac{\hbar e B}{mc} = 11.6 B_{12} \text{ keV (e}^{-}\text{)}$$
$$6.3 B_{15} \text{ keV (p}^{+}\text{)}$$

Relativistic

$$E_{\text{cyc}} = \frac{mc^2}{\sin^2 \theta} \left[\left(1 + 2n \frac{B}{B_{\text{crit}}} \sin^2 \theta \right)^{1/2} - 1 \right]$$

$$B_{\text{crit}} = \frac{m^2 c^3}{e \hbar} = 4.4 \times 10^{13} \text{ G (for e}^{-}\text{)}$$

Observed E_{cyc} will also contain gravitational redshift effect