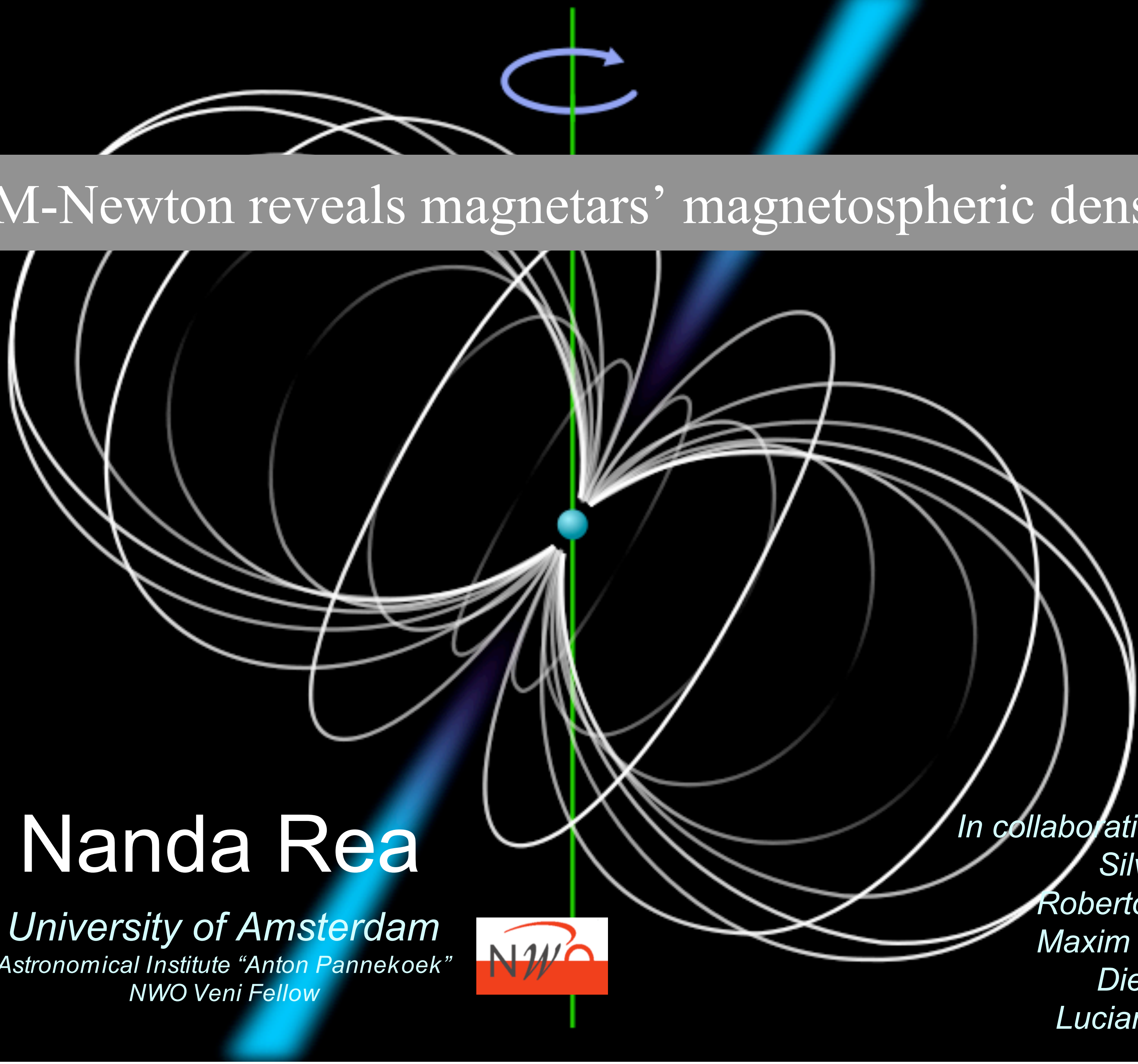
XMM-Newton reveals magnetars' magnetospheric densities



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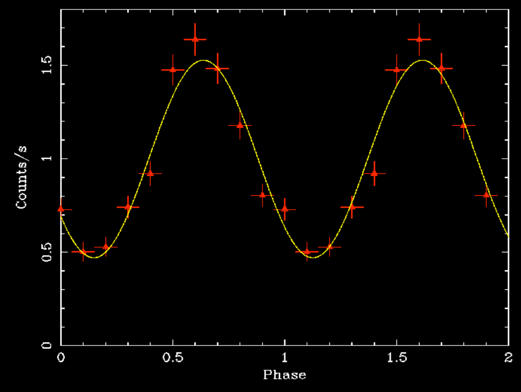
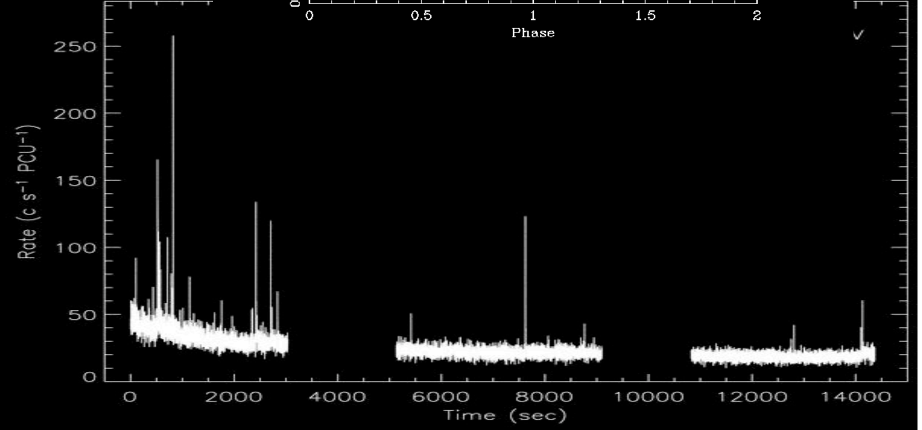
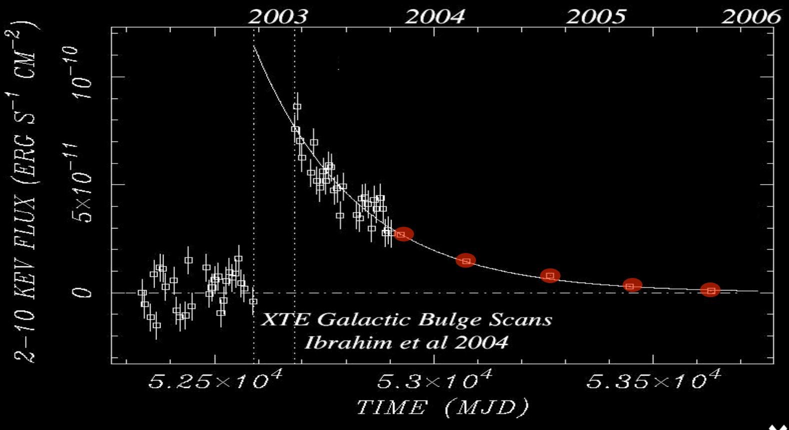
- bright X-ray pulsars Lx ~ 10^{33}-10^{36} erg/s
- rotating with periods of 2-12s
- large period derivatives
- glitches
- bursts on many timescales (ms to 100s)
- transient outbursts
- radio pulsars only during outbursts

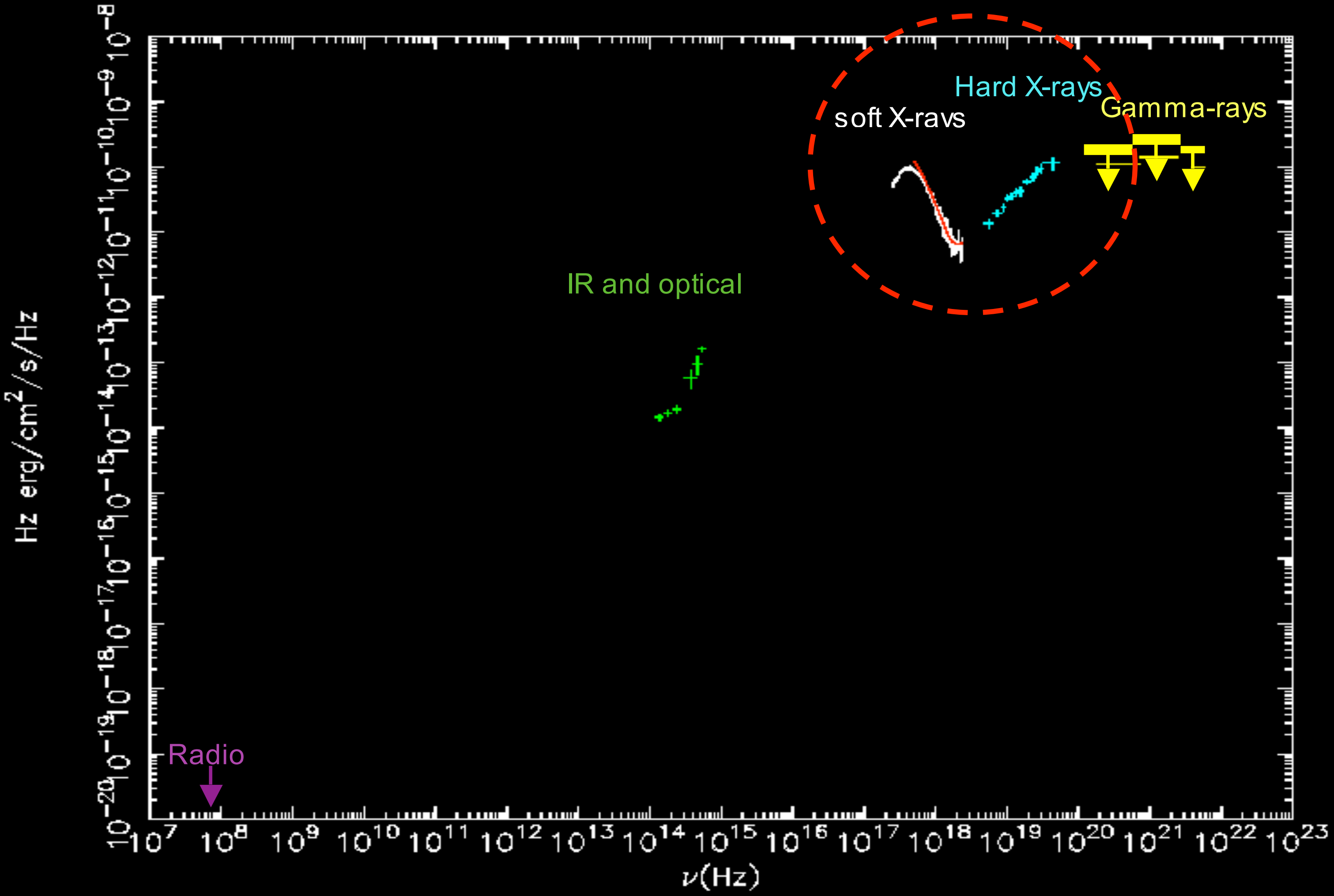






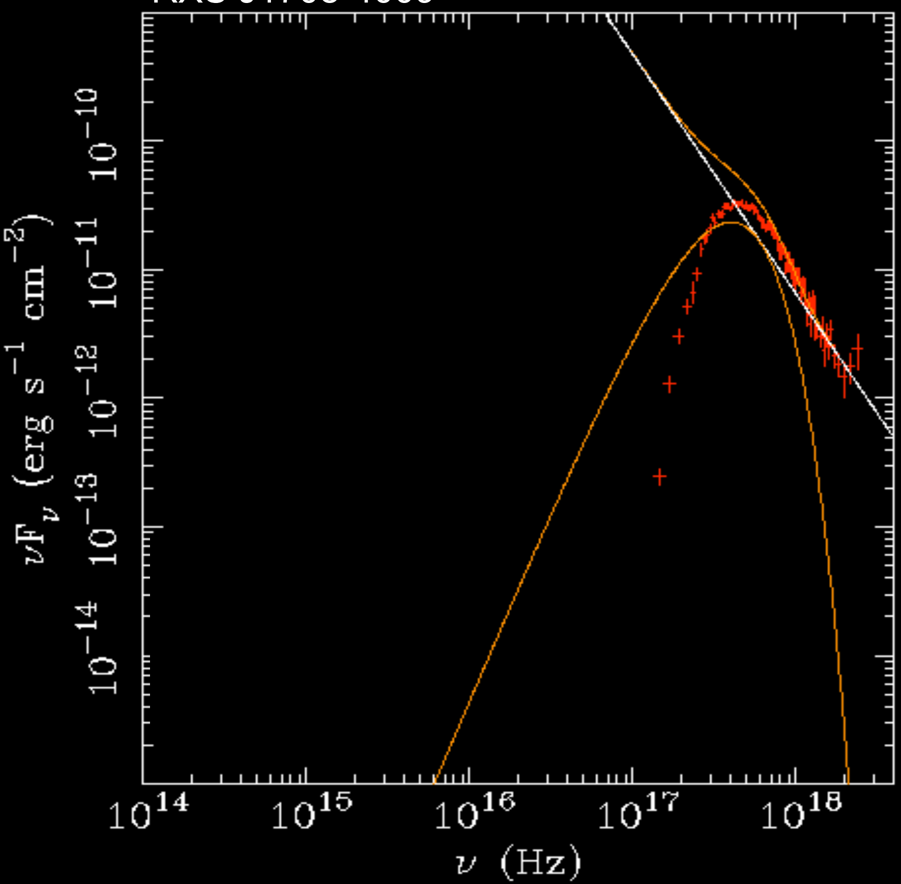
(review: Woods & Thompson 2006, Cambridge Press; Mereghetti 2008, A&AR)

Introduction: Magnetars

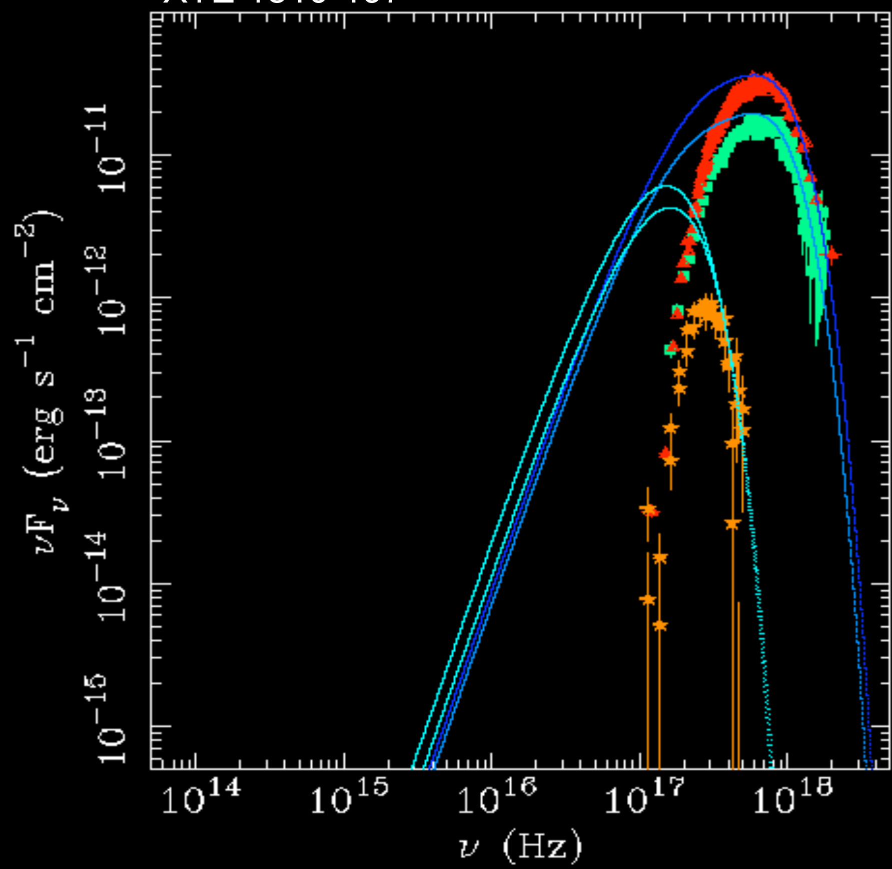


Introduction: Magnetars

RXS J1708-4009



XTE 1810-197



(Rea et al. 2005, MNRAS; Gotthelf et al. 2004, ApJ)

Resonant Cyclotron Scattering in Magnetars

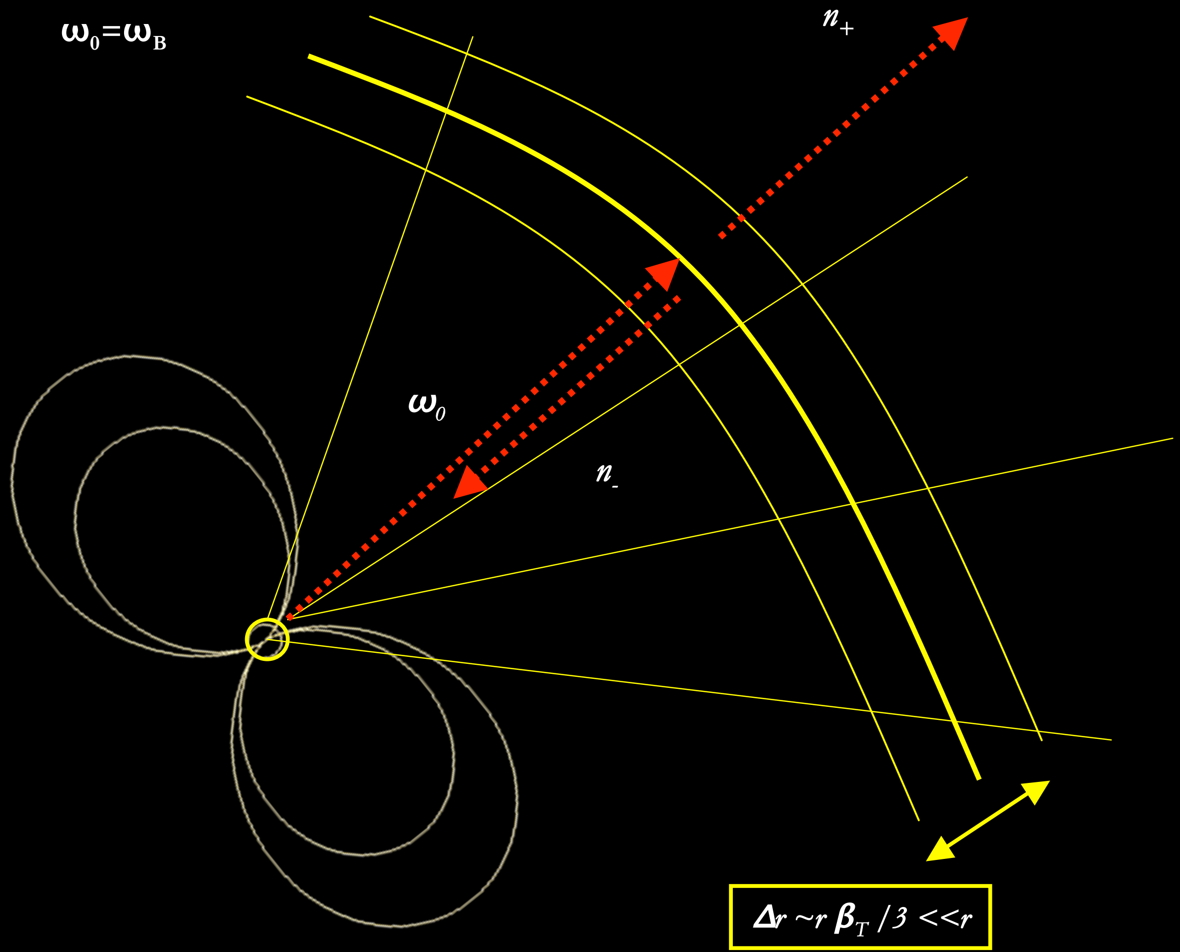
Main point: closed field lines in NS magnetospheres are not dead.
Populated by hot, highly over-dense plasma, n >> nGJ

(e.g. Thompson, Lyutikov & Kulkarni 2002; Liutykov & Gavriil 2006)

Twisted magnetospheres are filled with plasma which may modify radiation properties.

at 1 keV $$\sigma_{RCS} \sim \left(\frac{R_L}{r_e}\right)\sigma_T \sim 10^5 \sigma_T$$ with $$R_L \sim 8 R_{NS} \left(\frac{B_{NS}}{B_{crit}}\right)^{1/3} \left(\frac{1keV}{\hbar\omega_B}\right)^{1/3}$$

Resonant Cyclotron Scattering in Magnetars

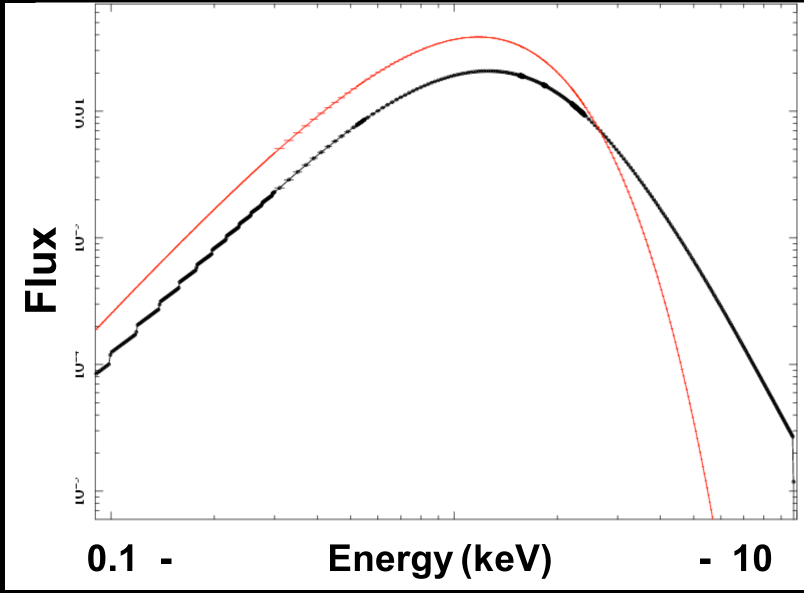


How does a warm plasma in the magnetosphere modify the emergent spectra?

Resonant Cyclotron Scattering in Magnetars

3 free parameters, same as for the empirical blackbody+powerlaw model:

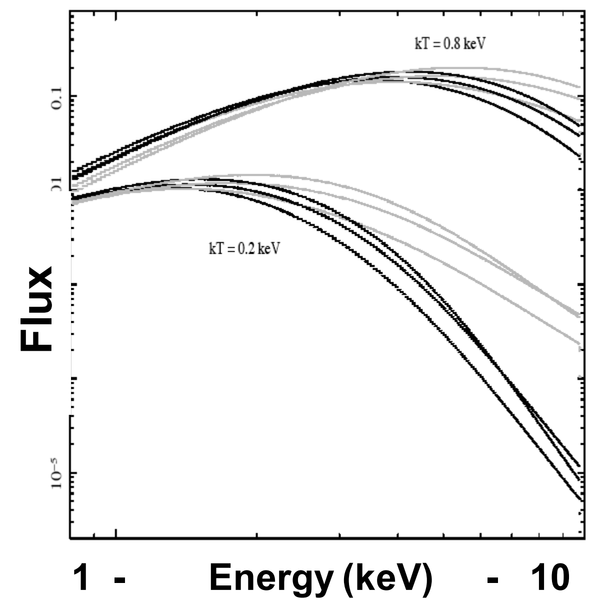
same statistical significance



Optical depth $\tau_{RCS} = \int \sigma_{RCS} n_e dz$ (1-10)

Electron thermal velocity β_T (0.1-0.5)

Surface Temperature (keV) kT (0.1-1.3)



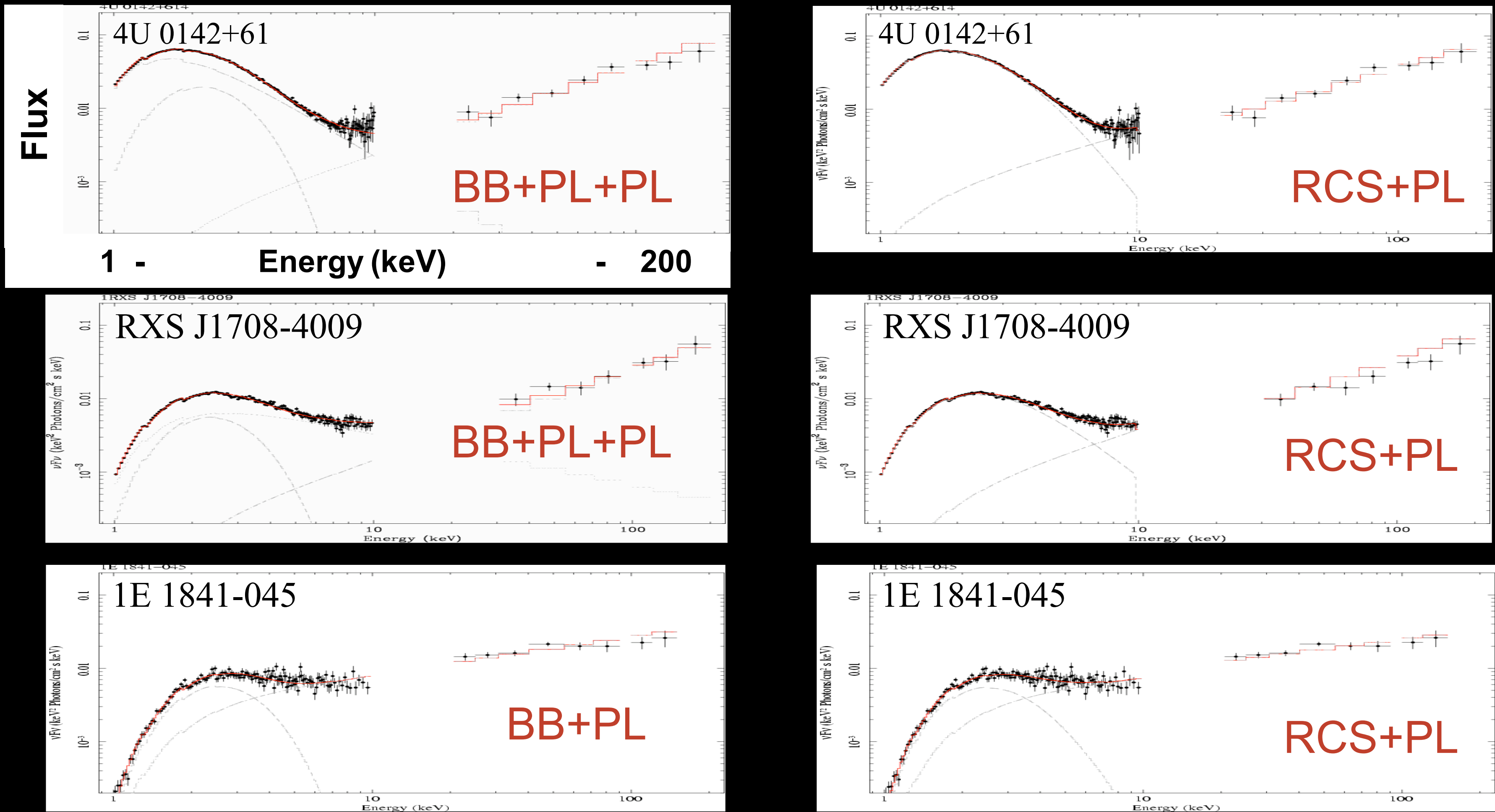
Rea, Zane, Turolla, Lyutikov & Gotz 2008, ApJ submitted, arXiv:0802.192v2

The Magnetar Sample

	Hosts	P (s)	B (10^{14}G)	kT(keV) / Γ	L (10^{33} erg/s) (0.2-10keV)	comments
4U 0142+61		8.7	1.3	0.46 / 3.4	72	hard X
RXS J1708-4009		11	4.7	0.44 / 2.4	80-190	hard X
1E 1841-045	Kes 73	11.8	7.1	0.44 / 2.0	110	hard X
1E 2259+586	CTB 109	7.0	0.6	0.41 / 3.8	17 - 159	~ transient/hard X
CXO J0100-72	in SMC	8.0	3.9	0.38 / 2.0	200	
1E 1048-5937		6.4	3.9	0.63 / 2.9	5.3 - 250	~ transient
1E 1547-5408		2.0	2.2	0.52 / 2.9	2.6 - 170	transient/radio
XTE 1810-197		5.5	2.9	0.67 / 3.7	5 - 260	transient/radio
CXO 1647-4552	in Wes1	10.6	1.5	0.68/2.0	1-130	transient
AX J1845-0258	G29.6+0.1	7.0	-	/ 4.6	5 - 120	transient
SGR 1900+14	OB	5.2	5.7	0.43 / 2.0	200 - 350	GF/hardX
SGR 1806-20	OB	7.5	7.8	0.6 / 1.4	320 - 540	GF/hardX/outburst
SGR 0526-66	in LMC	8.0	7.4	0.53 / 3.1	260	GF/?
SGR 1627-41	G337.0-0.1?	6.4 ?	-	/ 2.9	4 - 100	outburst

Resonant Cyclotron Scattering in Magnetars

AXPs with hard X-ray emission



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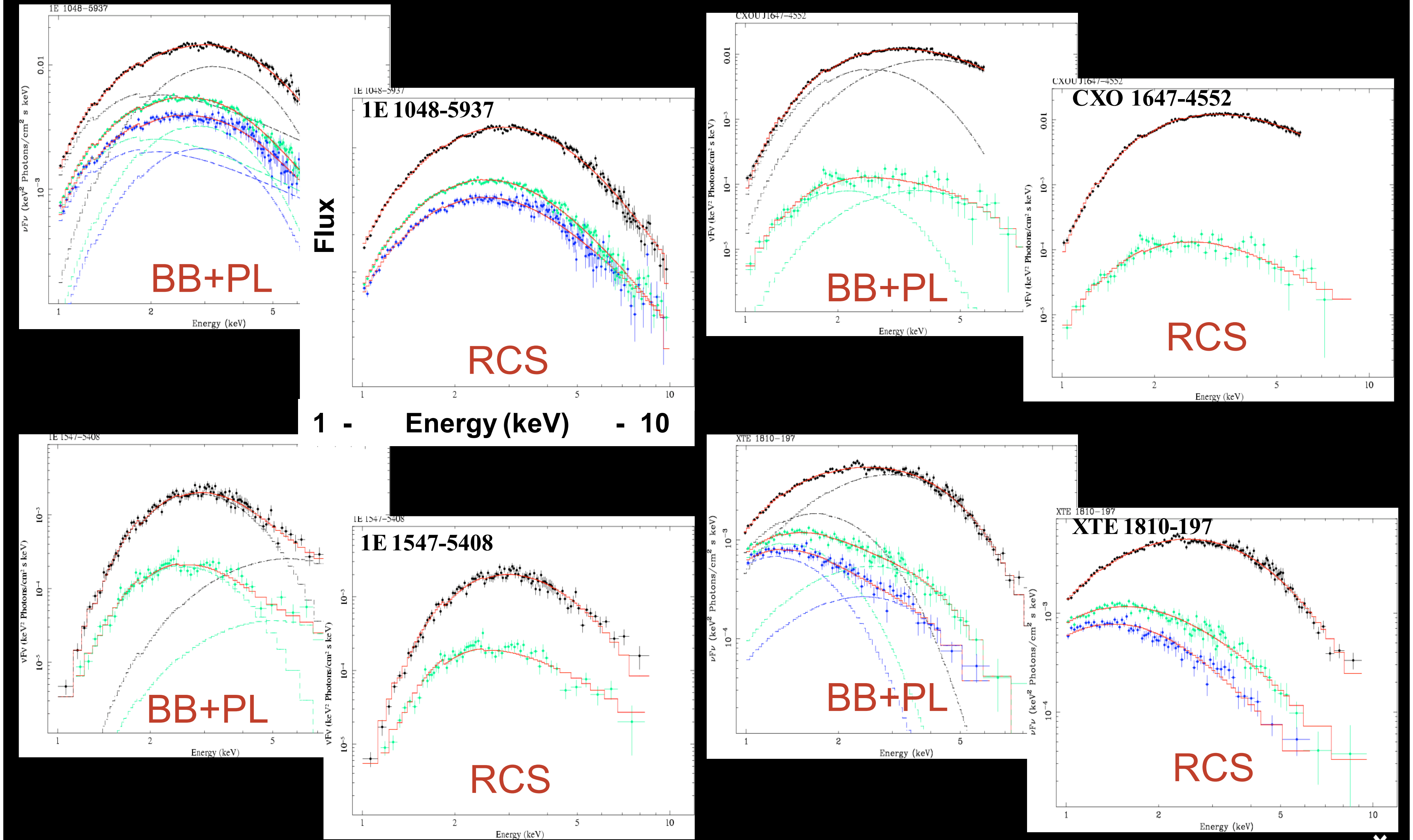
Resonant Cyclotron Scattering in Magnetars

Transient AXPs



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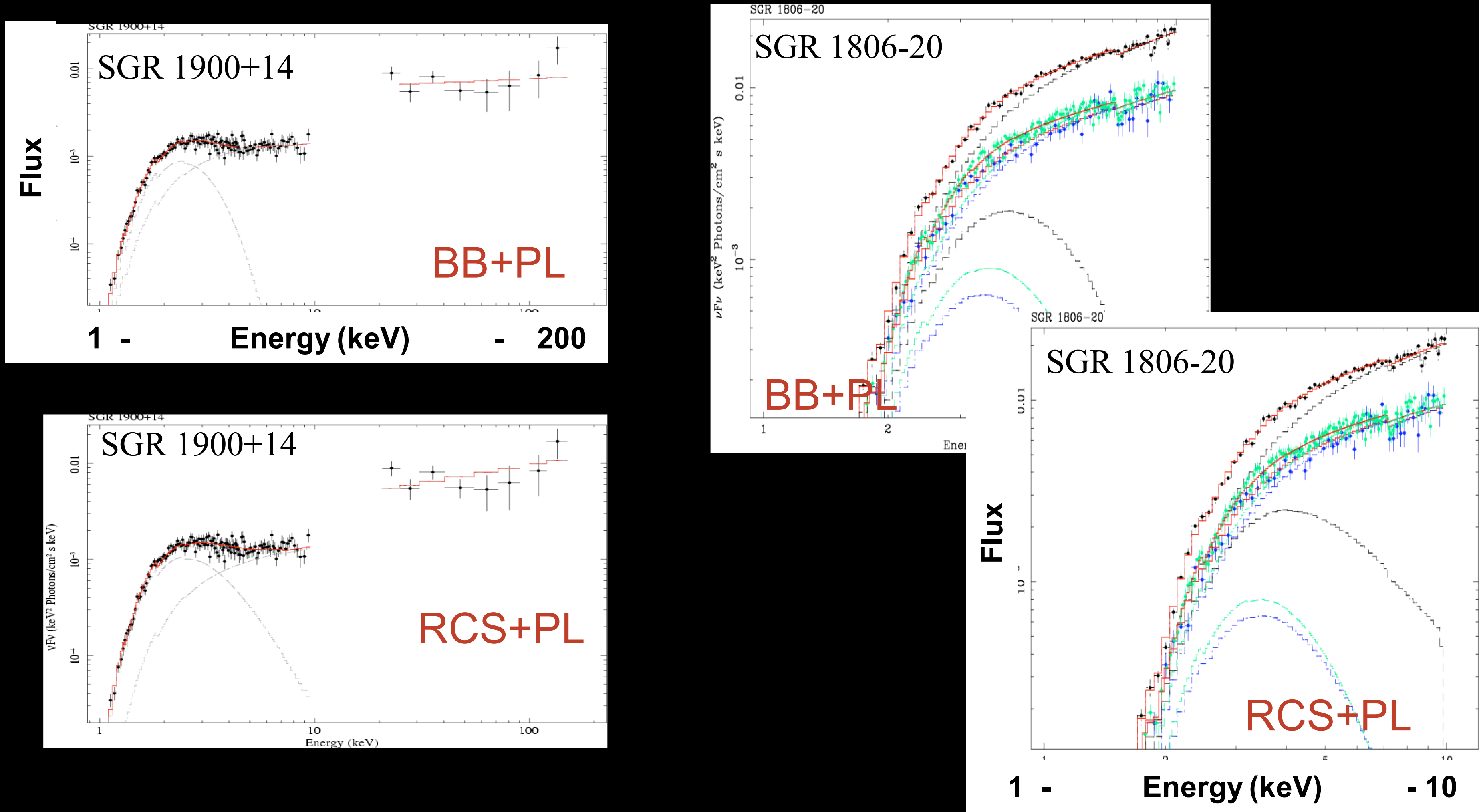
Resonant Cyclotron Scattering in Magnetars

SGRs with hard X-ray emission



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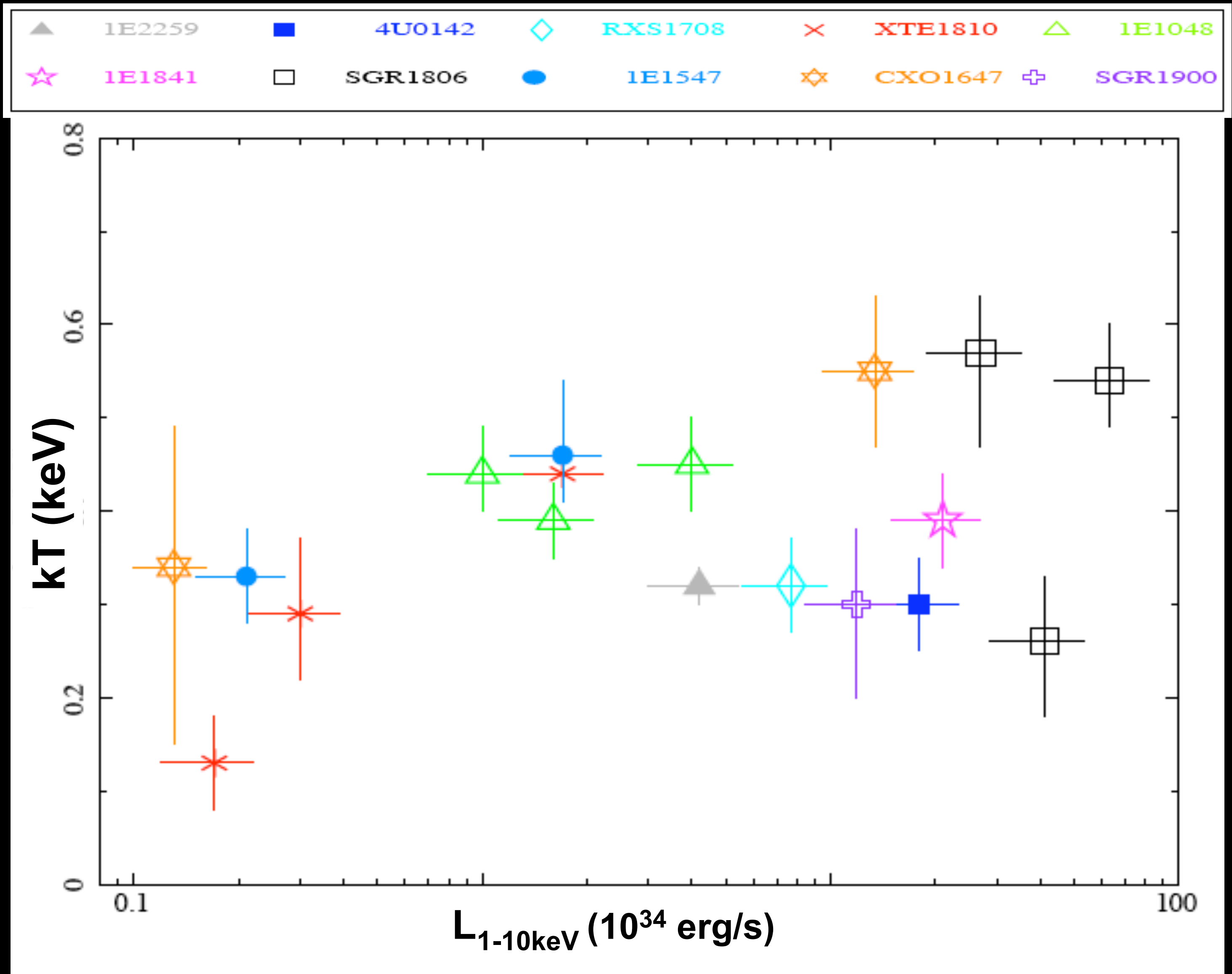
Resonant Cyclotron Scattering in Magnetars



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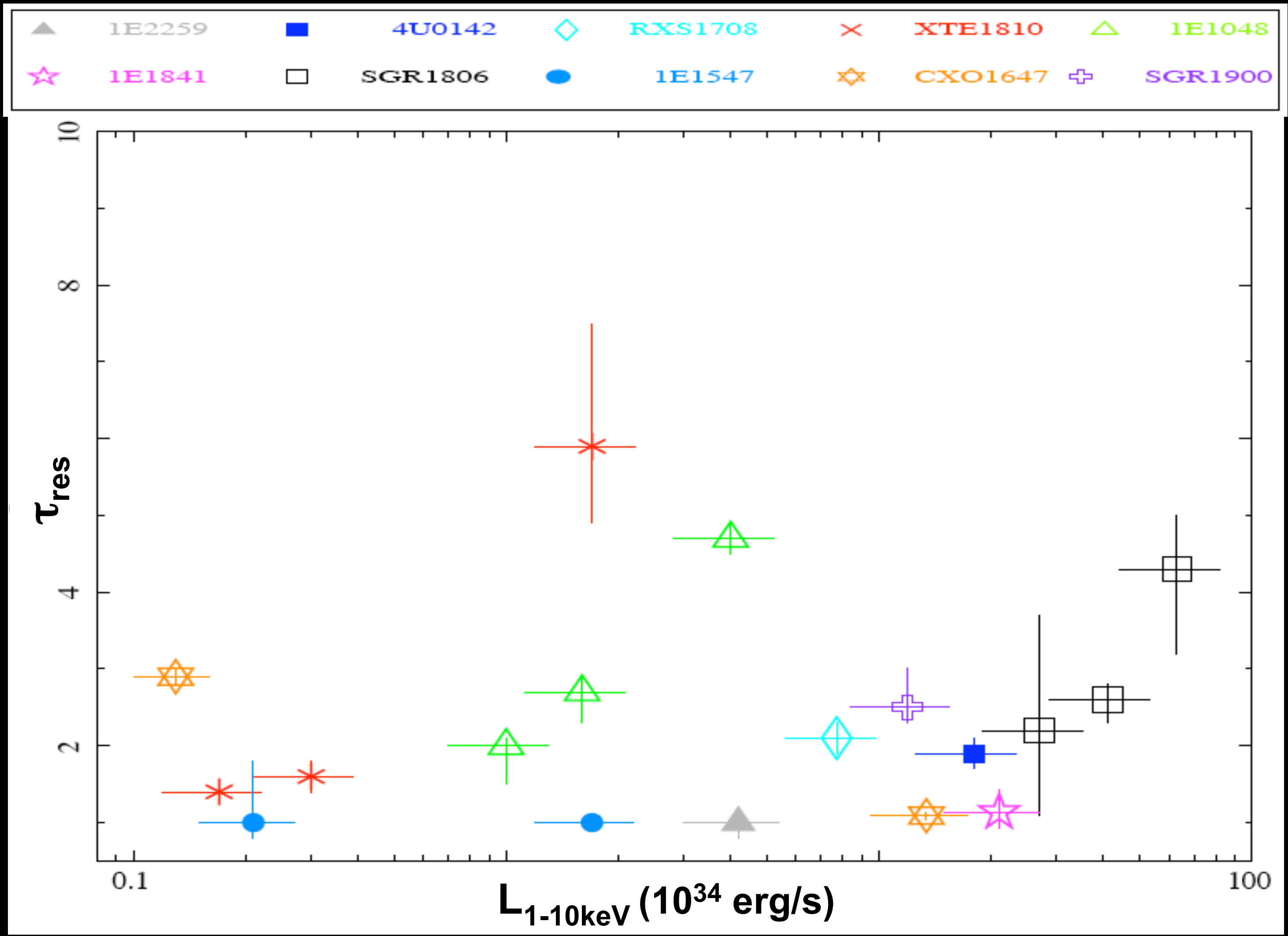
Resonant Cyclotron Scattering in Magnetars



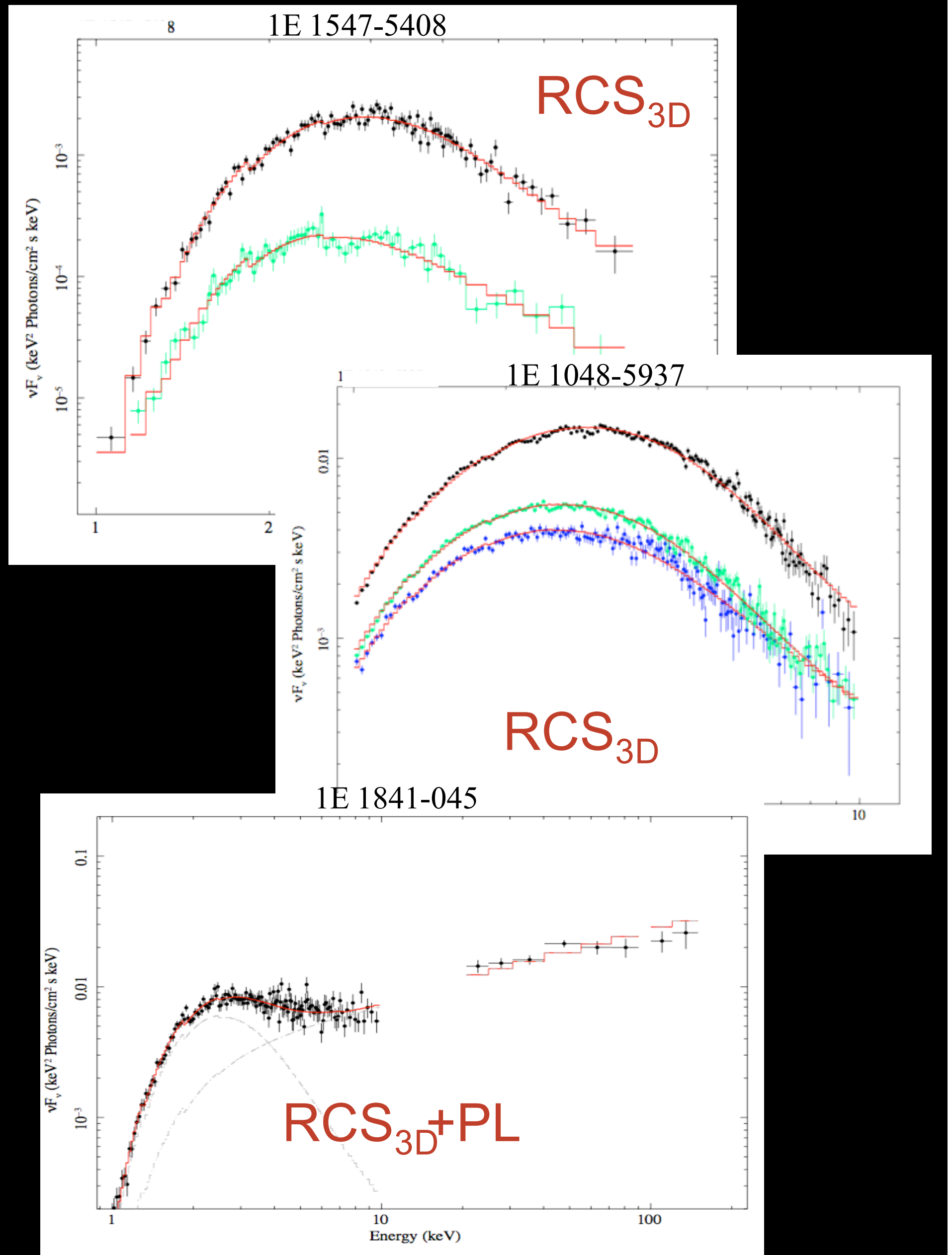
Magnetospheric e- density of $n \sim 1.5 \times 10^{13}$ cm^{-3} = 10^3 n_{GJ}

Rea, Zane, Turolla, Lyutikov & Gotz 2008, ApJ submitted, arXiv:0802.192v2

3D Monte Carlo RCS: applications (preliminary)

kT ~ 0.2-0.6 keV
β_{bulk} ~ 0.2-0.4
$\Delta\varphi$ ~ 1 -1.8

Magnetospheric e- density consistent with the simplified 1D model, hence being ~ 10^3 n_{GJ}



(Nobili, Turolla & Zane 2008, MNRAS; Rea et al. 2008, in prep; Albano et al. 2008, in prep)

Conclusions

…done

- We built an analytical model to threat resonant cyclotron scattering
  - Implementing it in XSPEC for real data fitting
- Resonant cyclotron scattering reproduces all magnetar spectra
  - This model has a clear physical motivation, unlike BB+PL models
- We could derive for the first time the magnetospheric density of magnetars
  - Much larger than for normal pulsars, as indeed predicted by the theory
- Absorption values now matches what has been derived from single edge fitting
  - The BB+PL model overestimates the N_H

http://heasarc.gsfc.nasa.gov/docs/xanadu/xspec/models/rcs.html

in progress…

- More advanced 3D Monte-Carlo models for magnetar magnetospheres
  - Full 3-D magnetosphere (Fernandez & Thompson 2007; Nobili, Turolla & Zane 2008)
  - Application to the data (Rea et al. in prep; Albano et al. in prep)