Explaining hard X-ray emission from magnetars with a coronal outflow model

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Magnetar spectra

- Emission of a magnetar made of 2 components: soft & hard
- Pulsations over the whole energy range [0.5-300] keV

Soft component (≲ 10 keV)

A modified black-body?

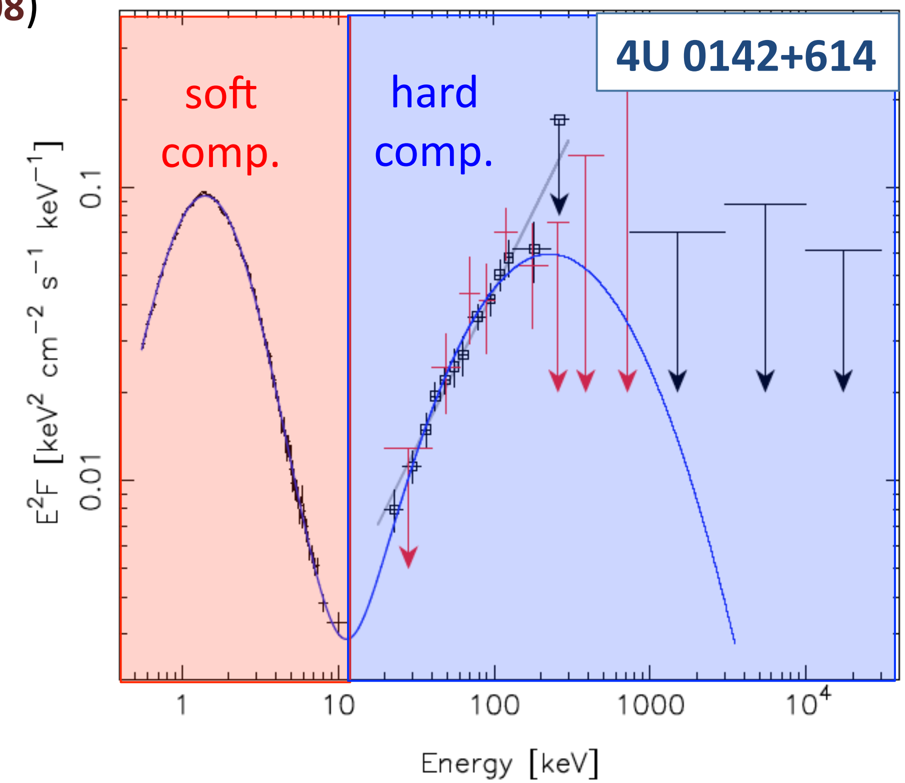
→ broadening by resonant cyclotron scattering of **mildly reslativistic** $e^{\pm}$ pairs?

(e.g. **Fernandez & Thompson 2007, Rea et al. 2008**)

--- problematic ---

Hard component (≳ 10 keV)

→ resonant cyclotron scattering of **highly relativisitic** $e^{\pm}$ pairs injected in a twisted magnetosphere? (**Beloborodov 2013**)



phase averaged total emission

den Hartog et al., A&A, 489, 245 (2008)

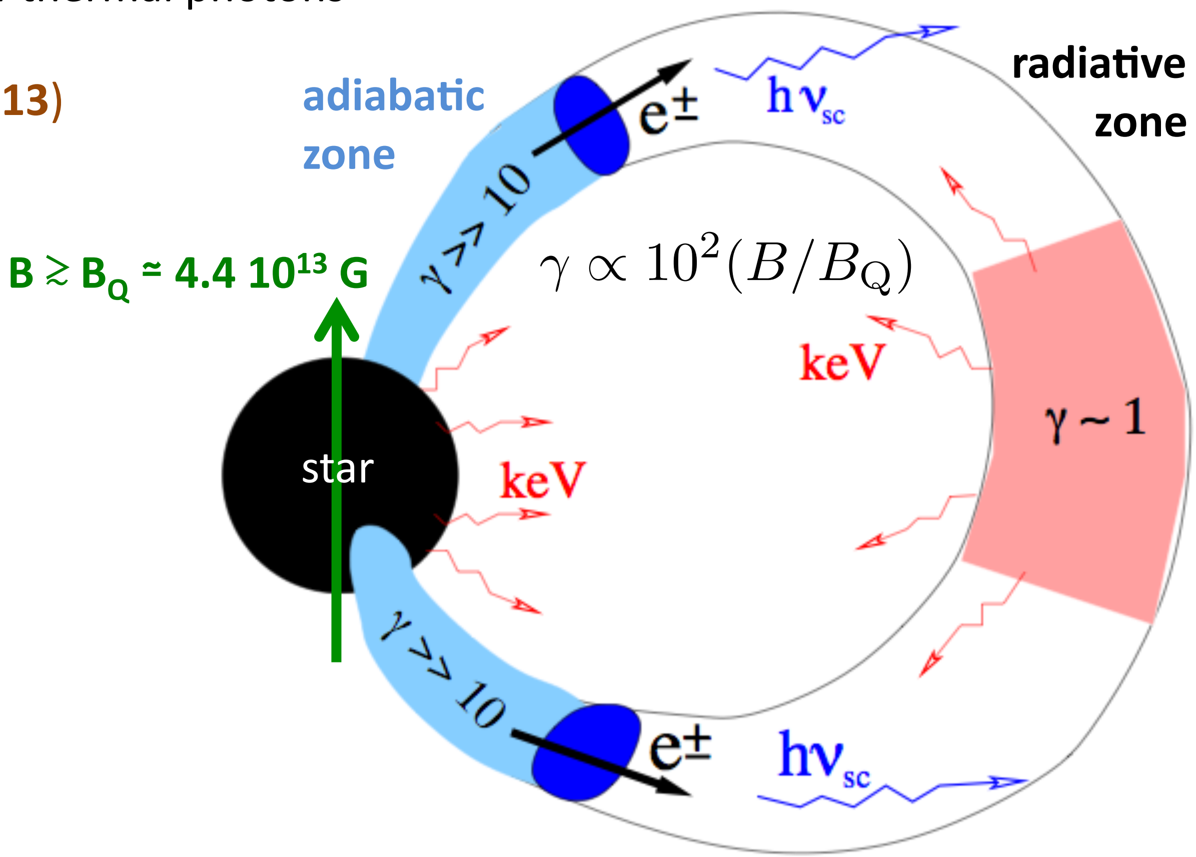
Short description of the magnetar model

Hard X-rays from resonant scattering of thermal photons by relativistic pairs $e^{\pm}$

• Deformation (twist) of the magnetosphere by surface motions
→ generates currents (rotB≠0) in a magnetic loop (j-bundle)
• Close to the star $e^{\pm}$ pairs are created with $\gamma \sim 10^3$

• At large radii the $e^{\pm}$ flow loses its kinetic energy through resonant scattering of thermal photons
→ **hard X-ray emission**

Beloborodov, Apj, 762, 15 (2013)



Selected Objects

AXP 4U 0142+614

- IR and optical counterpart **(Hulleman et al. 2000, 2004)**
- bursting activity in 2006 after several years of quiescence **(Gavriil et al. 2011)**
- evidence for long term variability below 10 keV **(Gonzalez et al. 2010)**

AXP 1RXS J1708-40

- IR counterpart candidate **(e.g. Testa et al. 2008)**
- detection of glitches **(Israel et al. 2007; Dib et al. 2008)**

Composite spectra (sub-keV → MeV)

- Phase averaged spectrum of the total emission
XMM-Newton, INTEGRAL, CGRO-Comptel
- 3 phase resolved spectra of the pulsed emission
RXTE-PCA, INTEGRAL

den Hartog et al., A&A, 489, 263 (2008)

den Hartog et al., A&A, 489, 245 (2008)

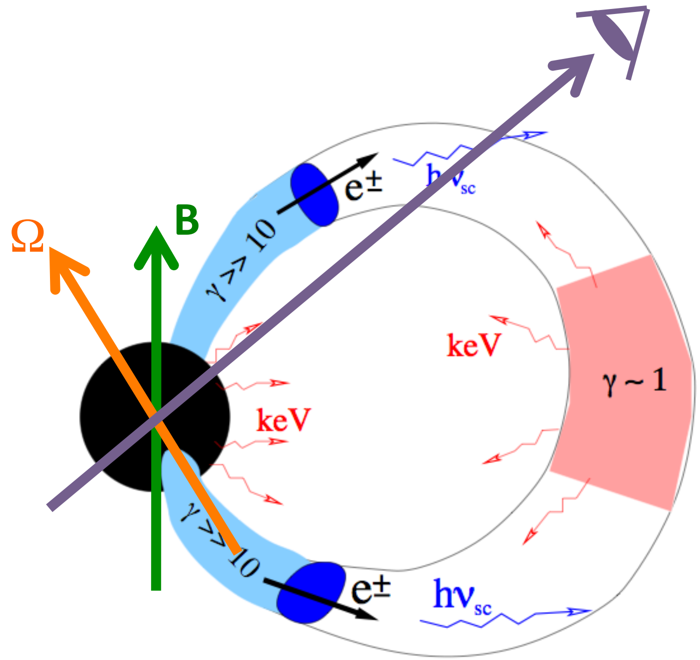
AXP 1E 1841-045

- Glitches & bursts (**Dib et al. 2008)**
- Optical counterpart candidate **(Testa et al. 2008)**

NuSTAR data (5→ 80 keV)

→ see Hongjun An's talk for more details on data

Method



Exploration of the whole parameter space

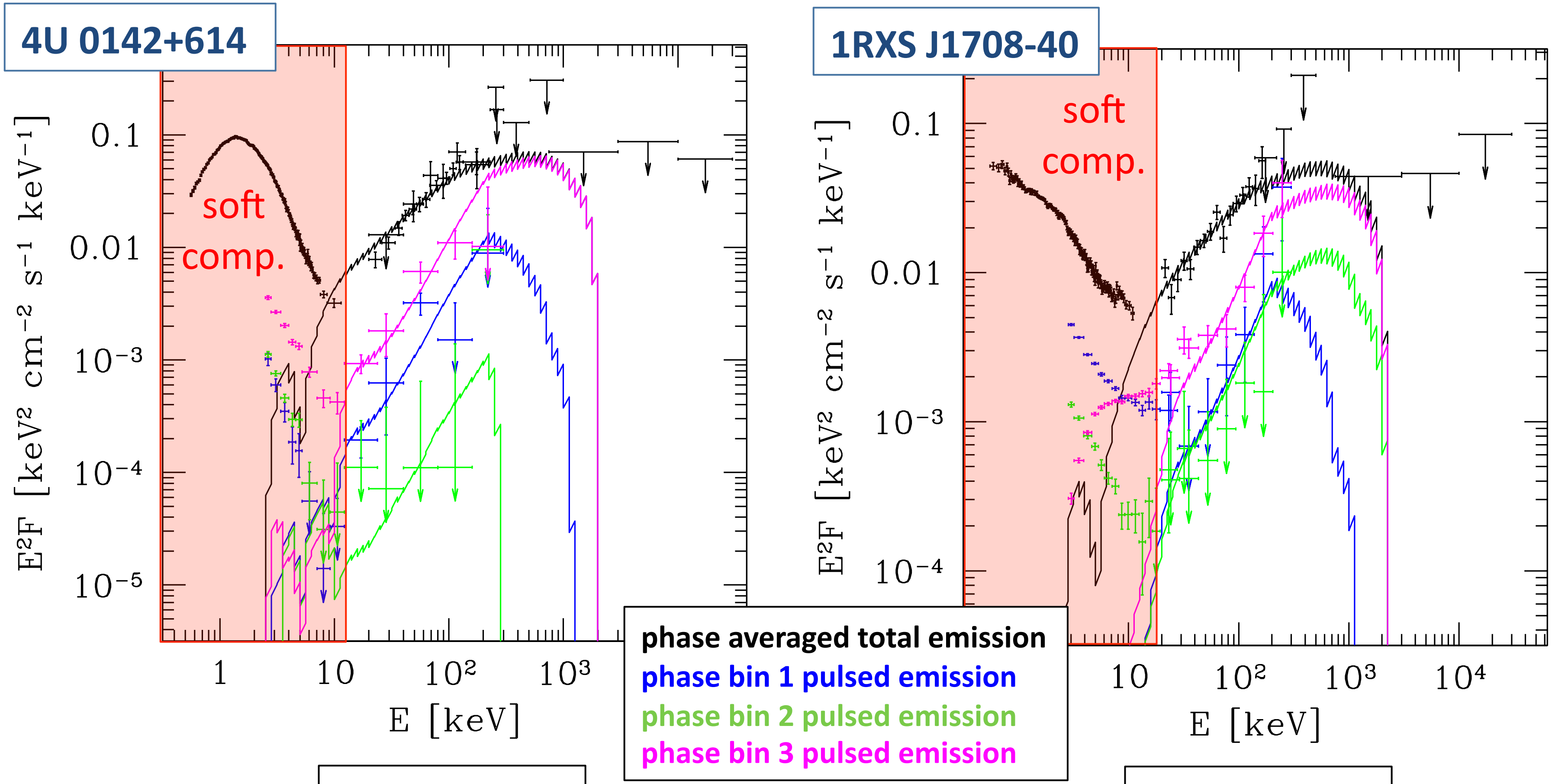
- Fitted spectra ($\gtrsim$ 10 keV):
  - phase averaged spectra of the total emission
  - 3 phase resolved spectra of the pulsed emission
- Assumptions:
  - dipole configuration for the magnetic field
  - the active magnetic loop (j-bundle) is symmetric around magnetic axis

Parameters of the model

1. α_{mag} : angle between the rotation axis and the magnetic axis
2. β_{obs} : angle between the rotation axis and the observer line of sight
3. θ_j : latitude extension of the j-bundle footprint
4. L : total luminosity (⇔ normalization)
5. ϕ_0 : reference point for rotational phase (when fitting phase resolved spectra)
6. μ_{mag} : strength of the magnetic dipole (⇔ surface magnetic field B_{surf})

only a lower-limit on μ_{mag}

Results — Best fit



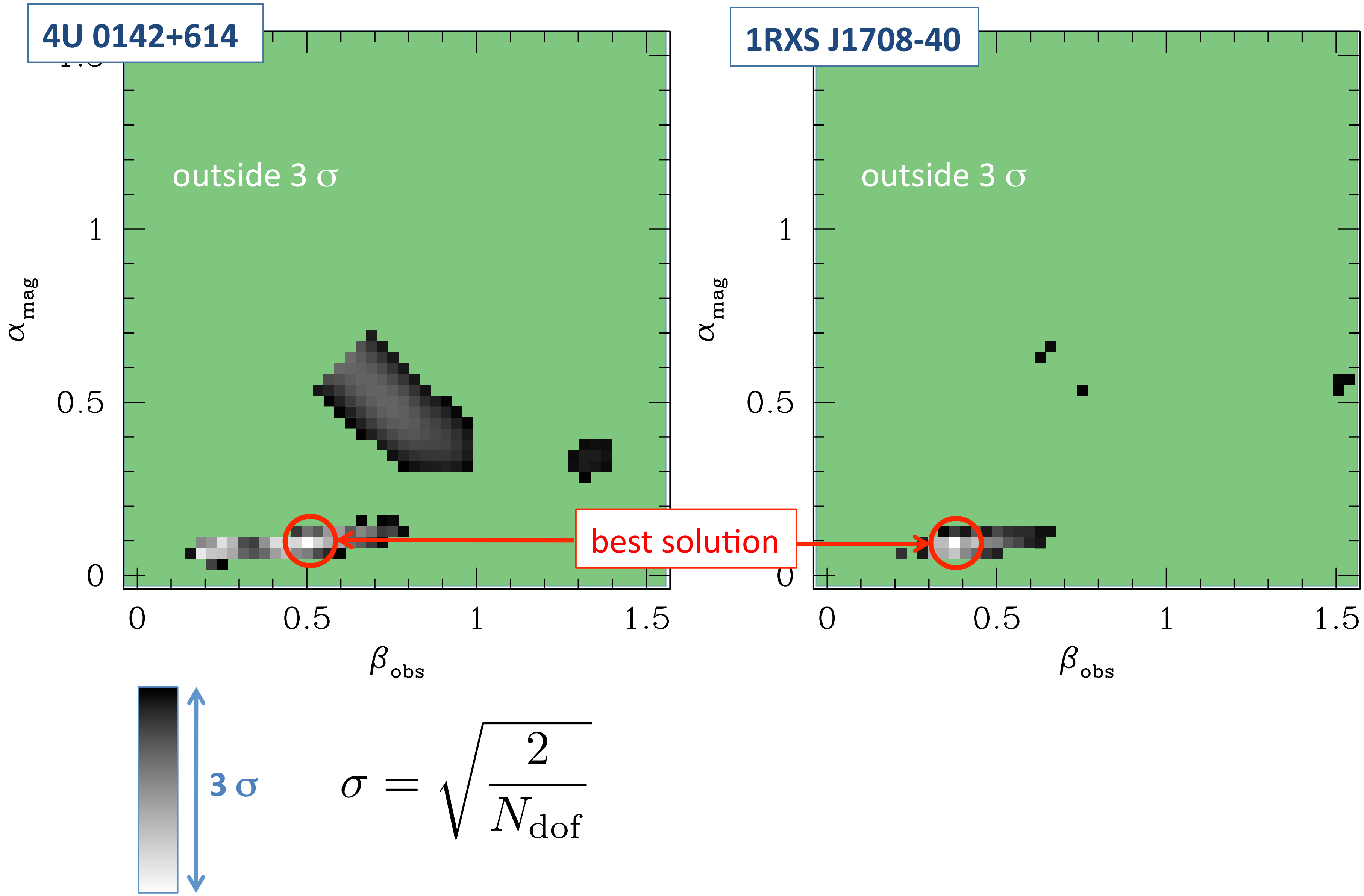
$\chi^2/N_{dof} = 1.14$

$N_{dof} = 41$

$\chi^2/N_{dof} = 1.34$

$N_{dof} = 37$

Results — χ^2 map



$$\sigma = \sqrt{\frac{2}{N_{\mathrm{dof}}}}$$

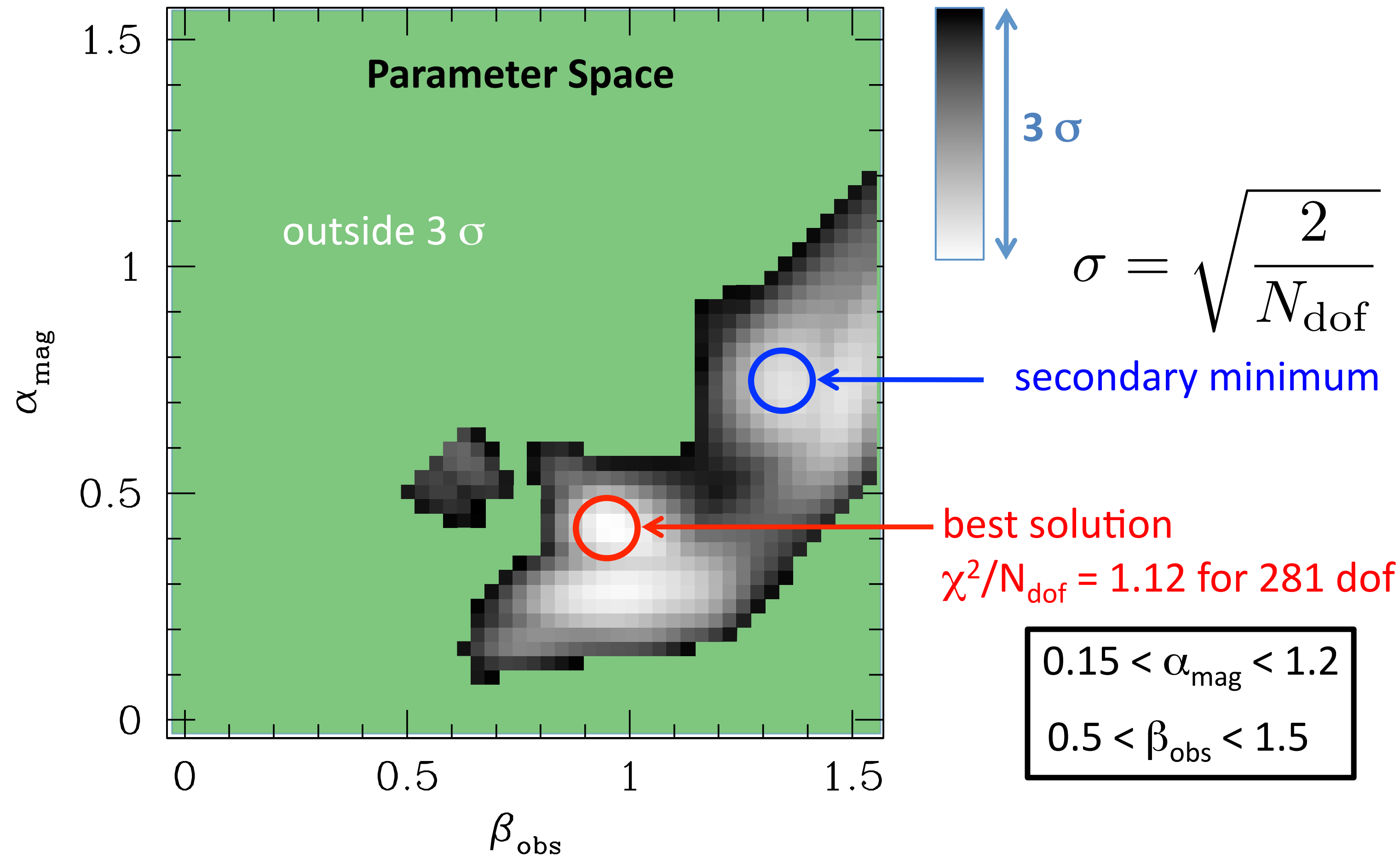
Results — Constraints on physical parameters

	4U 0142+614	1RXS J1708-40
α_{mag} – angle between the rotation axis and the magnetic dipole axis	$0.03 < \alpha_{mag} < 0.15$	$0.06 < \alpha_{mag} < 0.12$
β_{obs} – angle between the rotation axis and the observer line of sight	$0.16 < \beta_{obs} < 0.79$	$0.2 < \beta_{obs} < 0.65$
θ_j – latitude extension of the j-bundle footprint	$\theta_j < 0.23$	$\theta_j < 0.15$
L – total luminosity	$1.5 < \frac{L}{10^{35}\ \mathrm{erg\ s^{-1}}} < 6.2$ @ D = 3.6 kpc	$1.7 < \frac{L}{10^{35}\ \mathrm{erg\ s^{-1}}} < 5.2$ @ D = 3.8 kpc
μ_{mag} – strength of the magnetic dipole (⇔ surface magnetic field B_{surf})	consistent with the value inferred from spindown	

The constraints are similar for both magnetars.
→ Not surprising since they have similar spectra

χ^2 map for 1E 1841-045

NuSTAR data – preliminary



The spectrum of 1E 1841-045 is softer

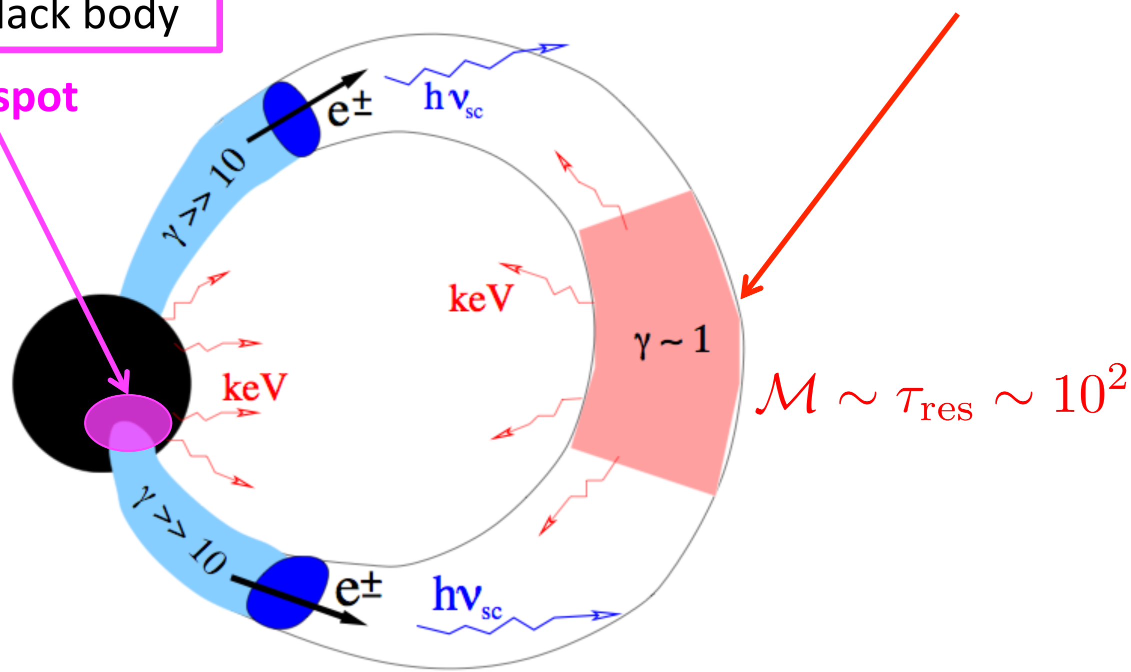
→ The constraints are different compared to 4U 0142+614, 1RXS J1708-40

What about the soft X-ray component?

How to produce a modified black-body?

1. Resonnant scattering by mildly relativisitic $e^{\pm}$ at the equator

2. footprint of the j-bundle heated by backflow of energetic particles
→ « multi-temperature » black body



What about the soft X-ray component?

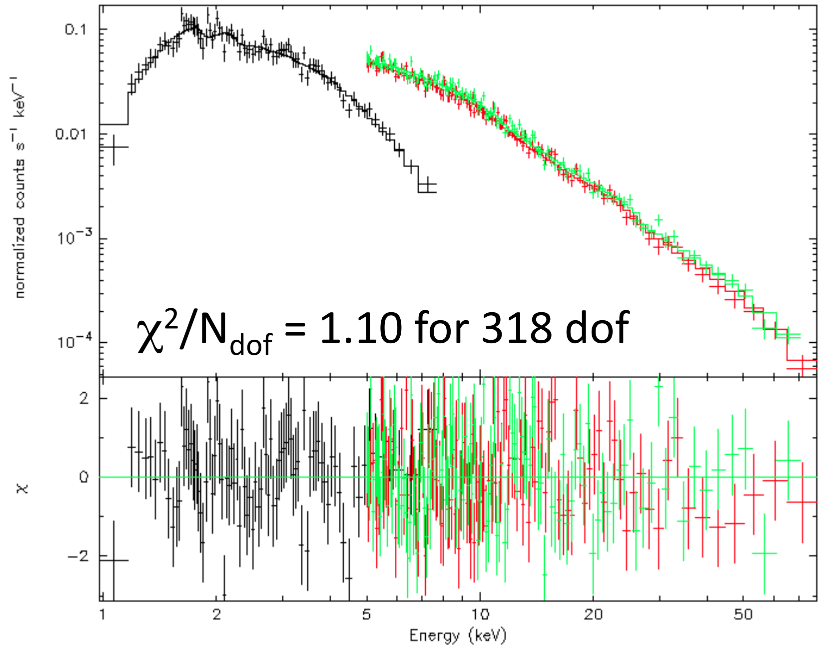
Fit of 1E 1841-045 soft component by 2 black bodies – Preliminary

Areas of the two BBs $\begin{cases} \mathcal{A}(BB_1) \sim \mathcal{A}_{star}/3.5 \\ \mathcal{A}(BB_2) \sim \mathcal{A}_{star}/170 \end{cases}$ @ D=8.5 kpc

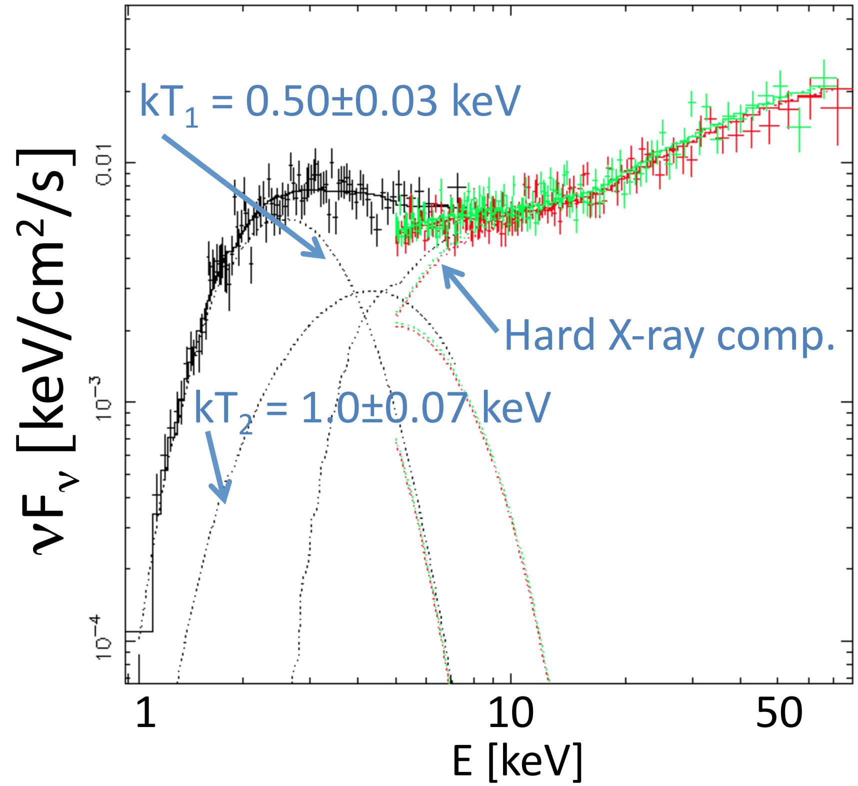
of the order of the size of the j-bundle hotspot!

Swift-XRT
NuSTAR A & B

folded spectra



unfolded spectra



Conclusions

• The coronal outflow model successfully fits phase resolved spectra of the hard component of the three magnetars 4U 0142+614, 1RXS J1708-40, 1E 1841-045
→constraints on the geometry of the objects

• The pulse fraction at ≃ 100 keV is less than 50%
(recent GBM and INTEGRAL observations – W. Hermsen, NS 2013, Amsterdam)
→ the j-bundle has to be rather broad
consistent with the fact that axisymetry hypothesis gives reasonable fits

• Models for the soft component have to be reconsidered in this coronal outflow framework
1. hot spot at the j-bundle footprint?
2. resonant scattering by the mildly relativisitic flow at the equator? $\mathcal{M} \propto \tau_{\rm res} \propto 10^2$