A variable cyclotron line energy in GX 301-2

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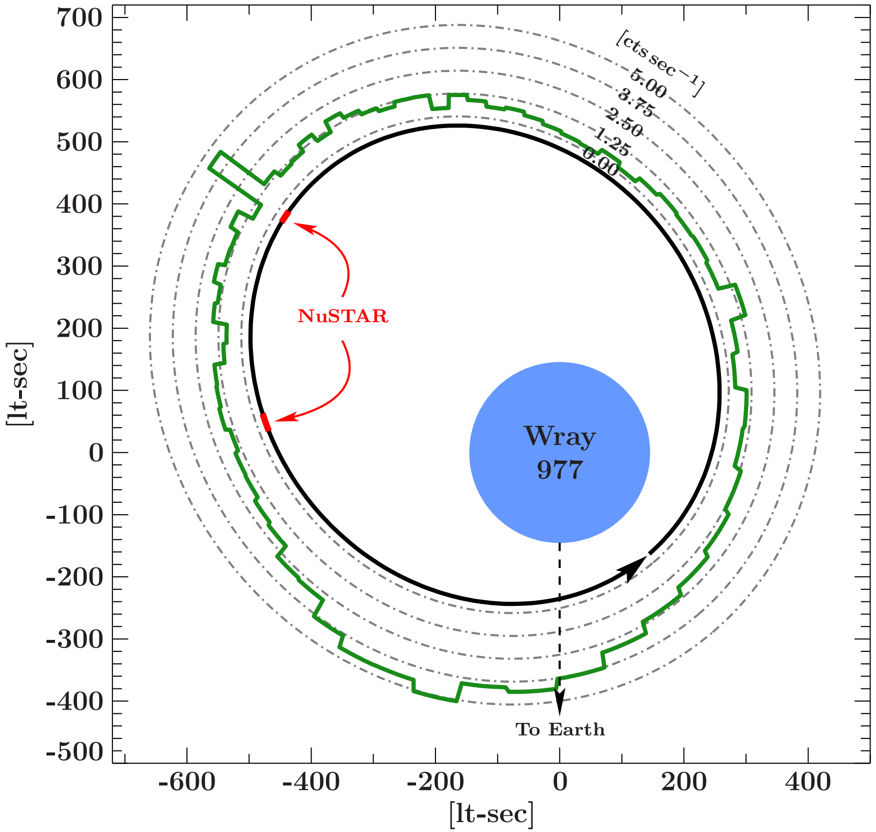
System parameters of GX 301-2

High-mass X-ray binary with a B1 Ia+ hyper-giant companion

Pre-periastron flare: neutron star overtakes accretion stream (Leahy & Kostka, 2008)

Eccentric orbit (e=0.47), orbital period 41.5d

Pulse period ~685s
Distance ~3kpc

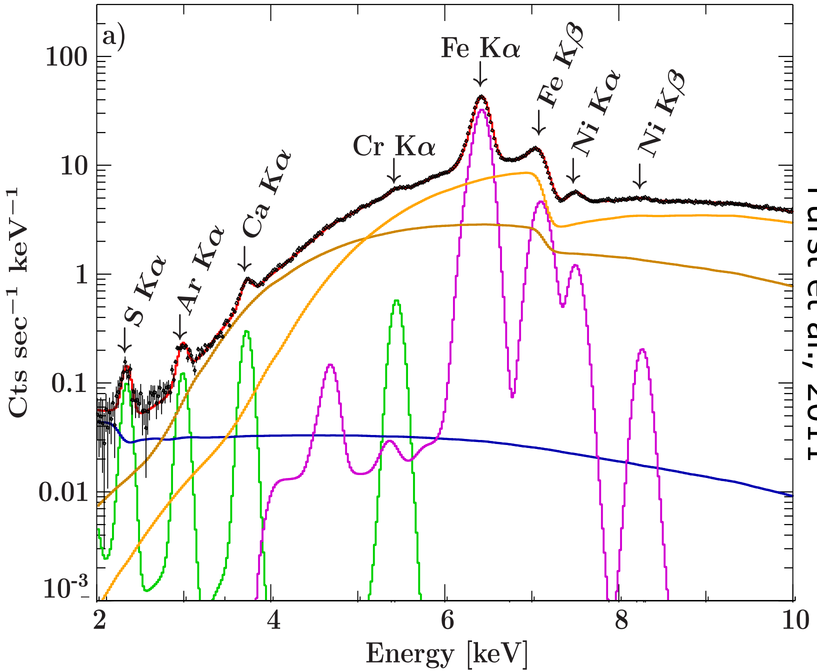


Adopted from Fürst et al., 2011

Strongly absorbed X-ray spectrum

Highly absorbed spectrum with multiple fluorescence lines.

Compton shoulder on iron line with Chandra (Watanabe et al., 2003).



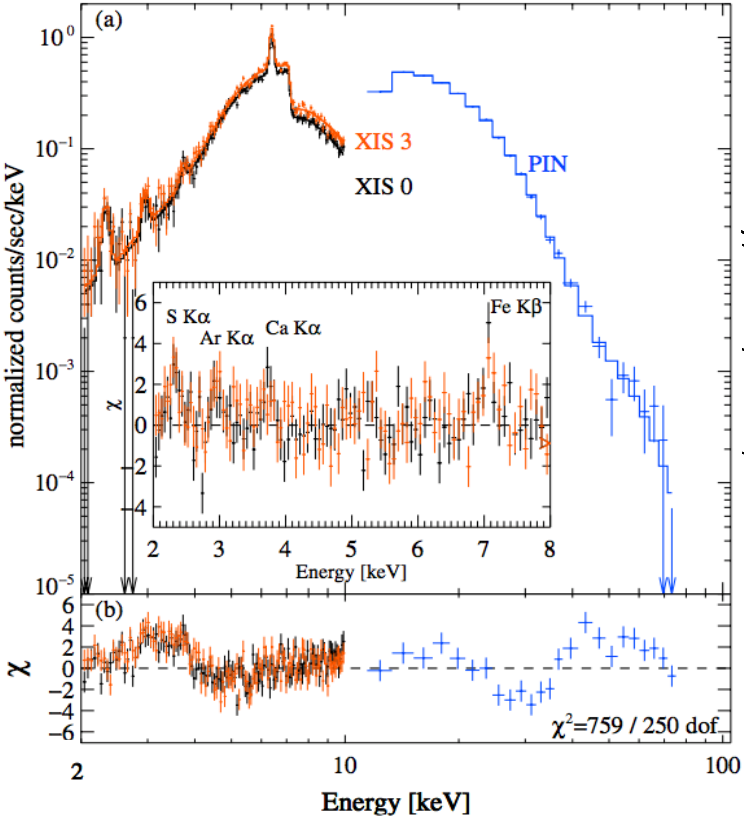
Fürst et al., 2011

Strongly absorbed X-ray spectrum

Cyclotron resonant scattering feature (CRSF) around

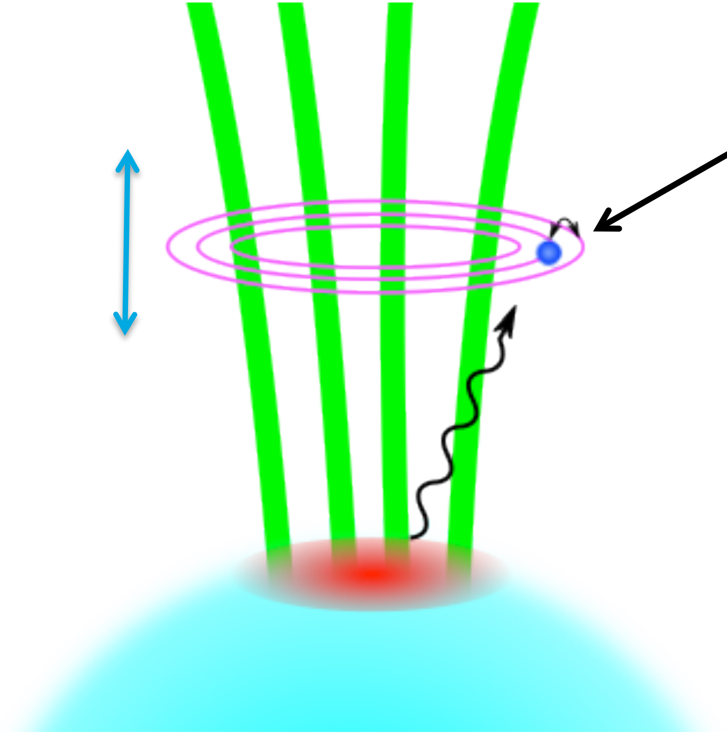
30-40keV (Kreykenbohm 2004, Suchy et al., 2012) or
45-53keV (La Barbera et al., 2005).

Possible luminosity dependence?!



Suchy, Fürst, et al., 2012

Cyclotron Resonant Scattering Features



Electrons quantized to Landau-levels perpendicular to the magnetic field.

⇒ resonant scattering removes photons at the Landau-level-energies from the observed spectrum

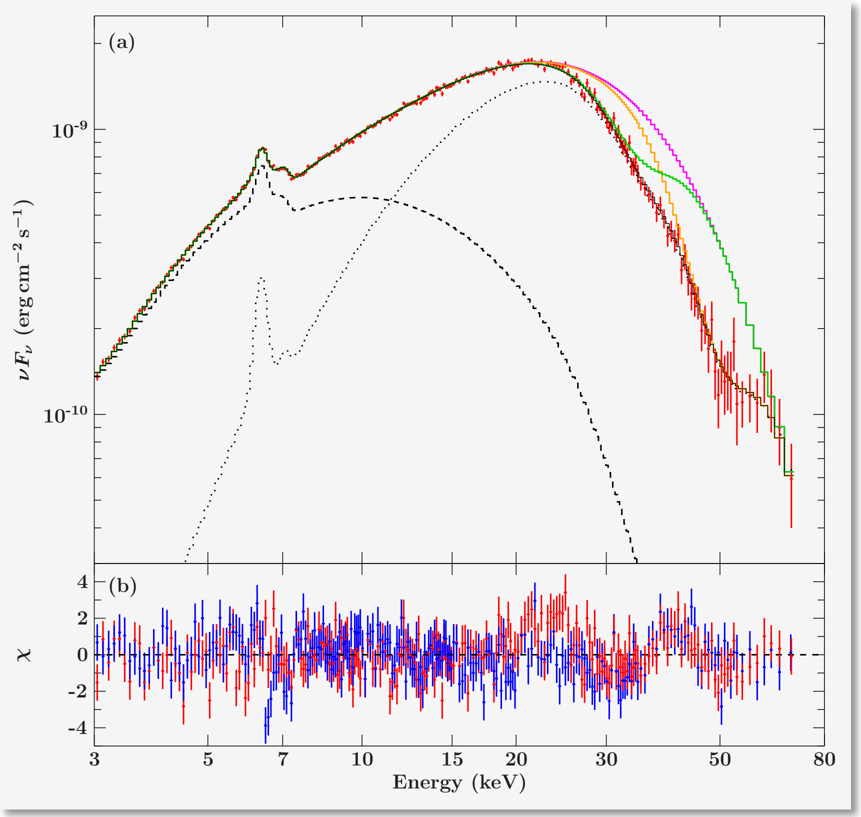
$\mathbf{E_{CRSF} \approx 12 \times B_{12}\ keV}$
(B_{12} is B-field in 10^{12} G)

NuSTAR resolves the CRSF structure

CRSF cannot be be fitted with a single Gaussian or a single Lorentzian profile!

Significant structure: evidence for asymmetric shape?
Two lines?

Best fit gives energies 34.5±1.6 keV and 49.6±1.3keV



Fürst et al., 2018, subm.

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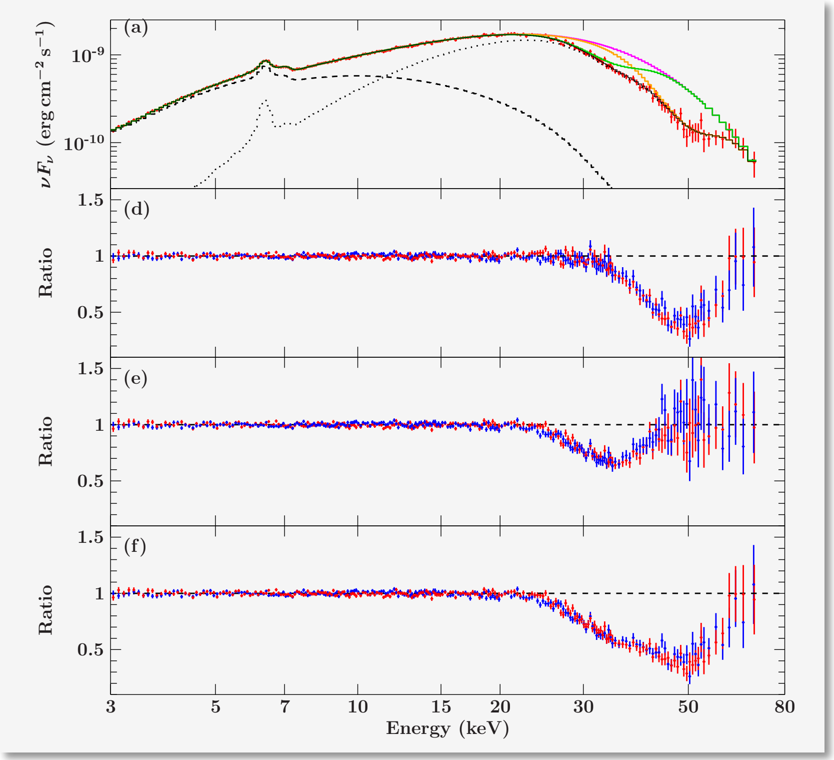


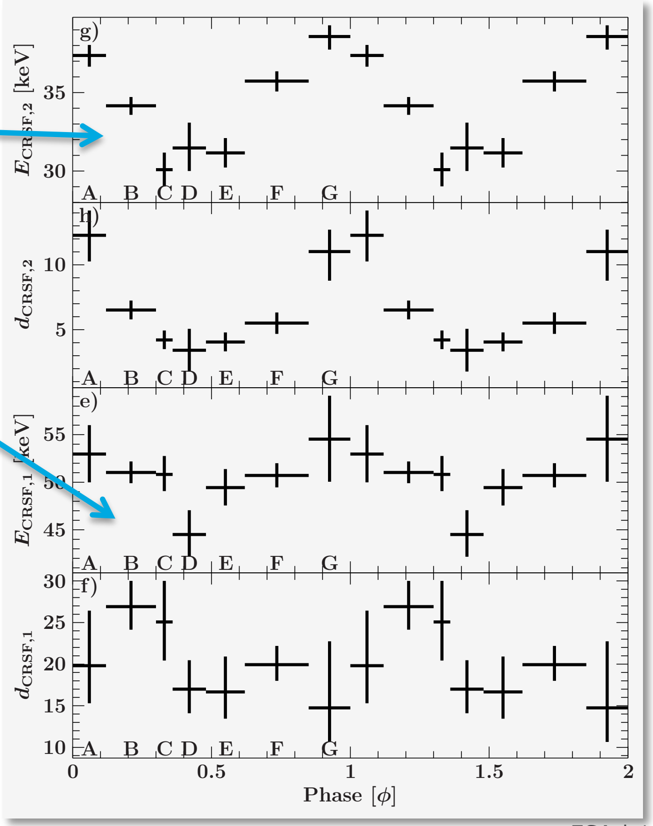
Fürst et al., 2018, subm.

Line energy is variable as function of pulse phase

Low energy line (~35keV) shows clear sinusoidal variation as function of pulse phase!

High energy line (~50keV) is not significantly varying (with the exception of bin D)

Different phase-behavior argues for different lines, and not asymmetric profile of one line!



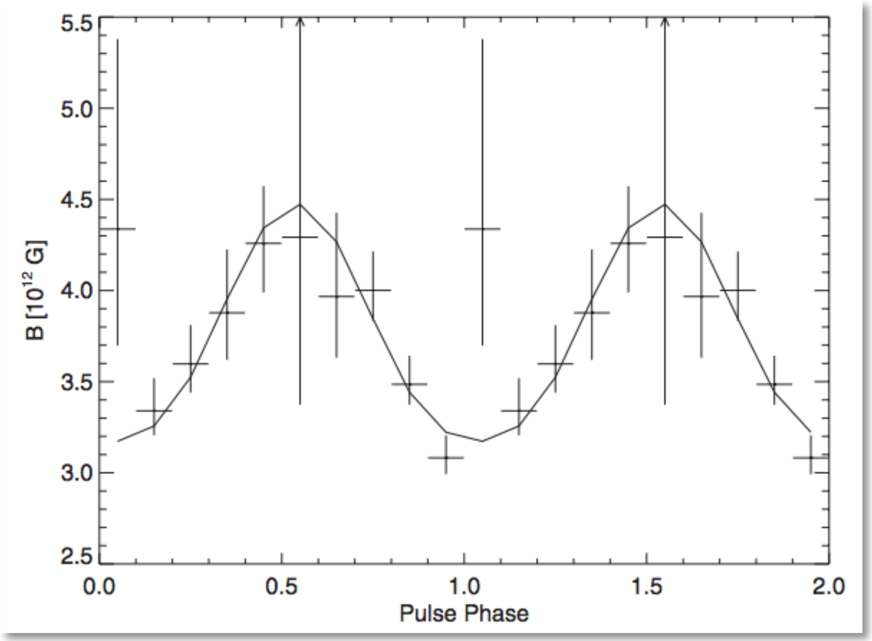
Fürst et al., 2018, subm.

Energy variation due to viewing angle?

Suchy et al. (2012) see similar behavior in CRSF energy using *Suzaku*.

Can be fitted with a simple rotating dipole, sampling different B-field strengths!

However, does not take relativistic effects into account.

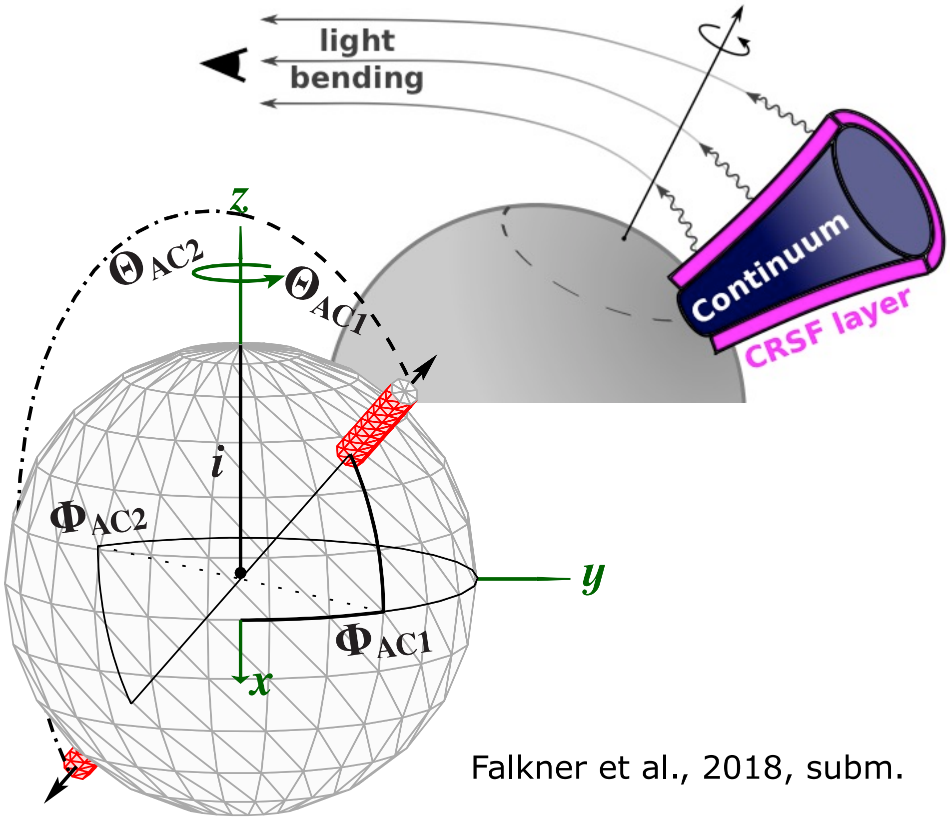


Moving to fully relativistic picture

Newly developed relativistic light-bending code.

Taking emission geometry and correct line forming mechanism into account.

Paper submitted: Falkner et al., 2018a,b.

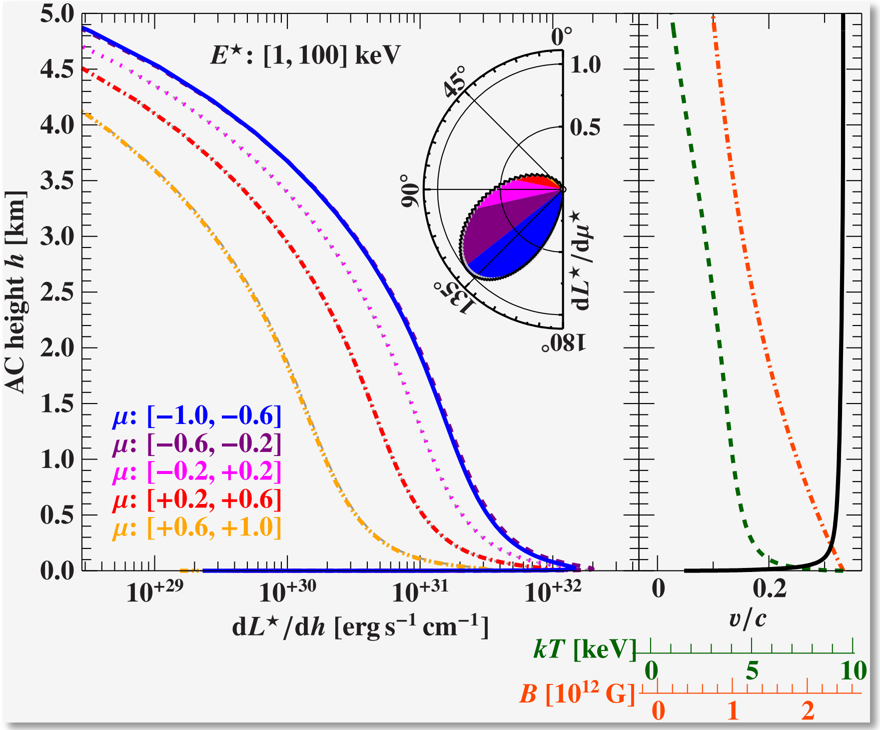


Falkner et al., 2018, subm.

Accretion column model and boosting

In-falling material is fast (up to 0.3c-0.7c), radiation is strongly boosted towards neutron star surface!

Calculations based on accretion column model (with temperature, velocities) by Postnov et al. 2015.



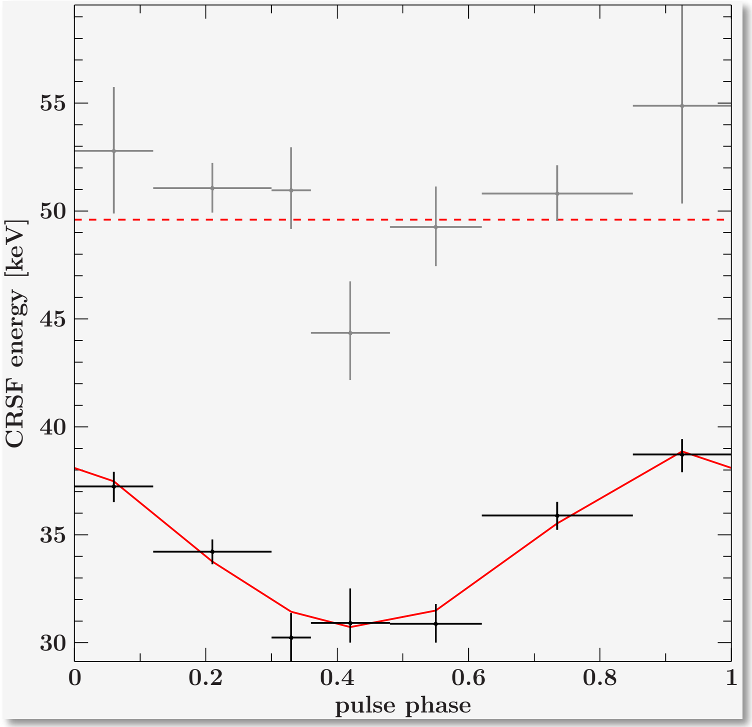
Falkner et al., 2018, subm.

Two lines formed in one column

Idea: both lines formed in the same column!

50keV formed on the surface, therefore energy not phase dependent, and samples base B-field

35keV formed in shock, energy changes as function of viewing angle, due to relativistic boosting!



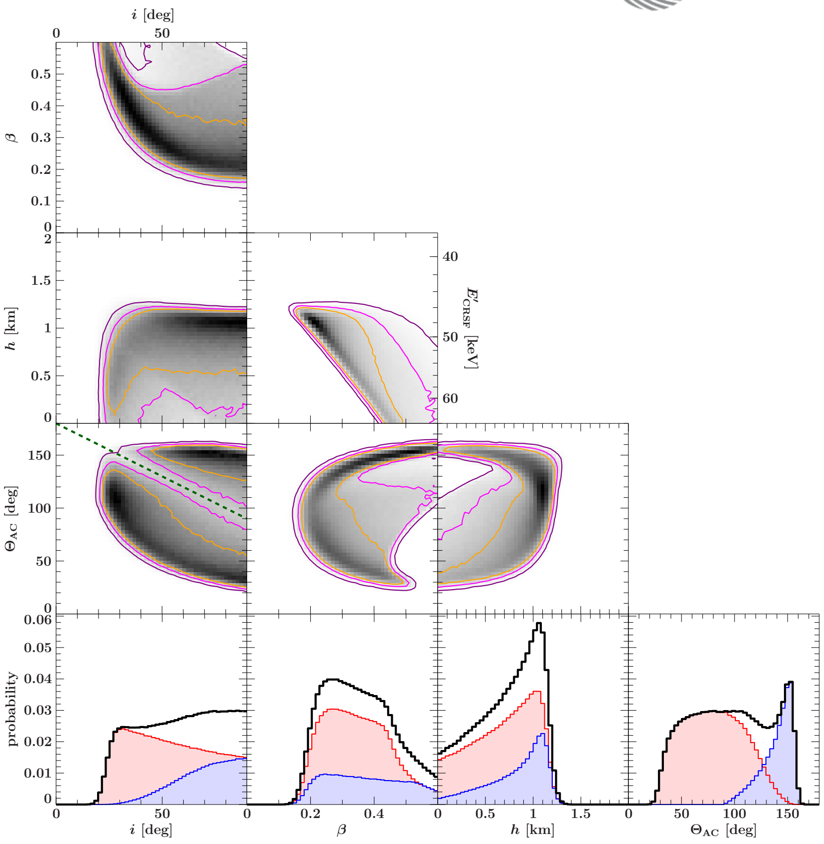
Fürst et al., 2018, subm.

Results from light-bending model

We can constrain, *i*, *β*, *h*, and Θ_{AC} (assuming only one visible column)

h gives best values around 1km
β between 0.2-0.4c
i larger than 20°

Model gives us constraints on the geometry!



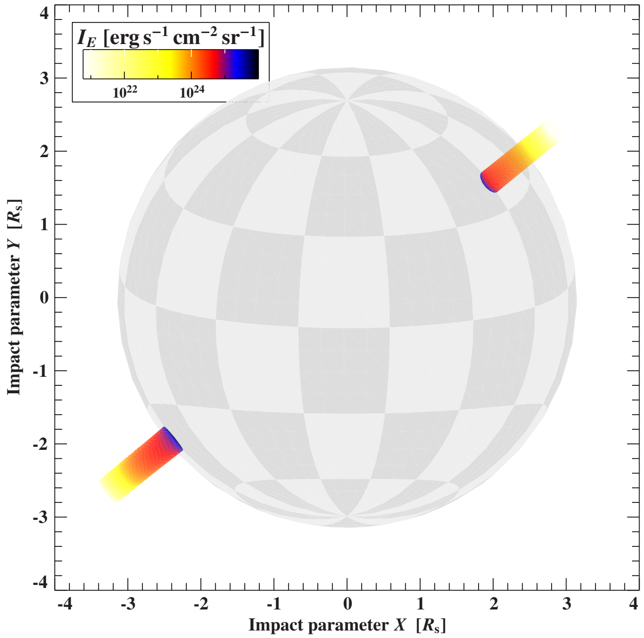
Fürst et al., 2018, subm.

Conclusions

Luminosity dependence of CRSF much weaker than expected: previous results biased because of complex, overlapping line profiles!

Phase dependence of line energy can be explained through relativistic boosting and sampling different regions of the emission pattern! Shock height ~1km.

Model gives us ideas about emission geometry, line forming region and magnetic field orientation.

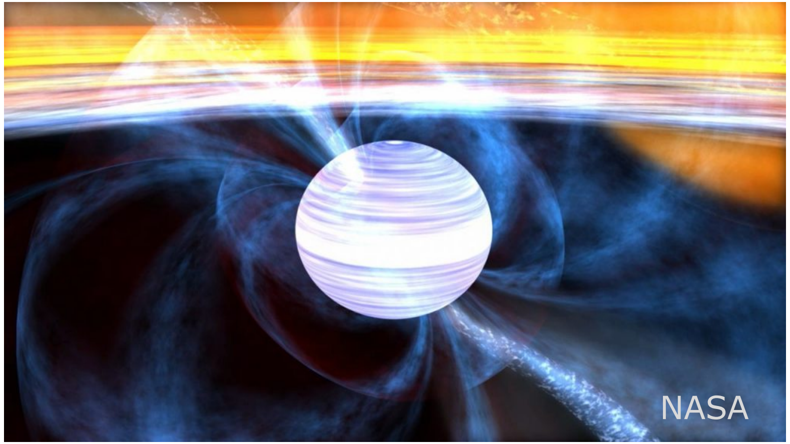


Falkner et al., 2018a, subm.

Outlook

Pulse profile modeling with same code and geometry: measure location of second accretion column?

Using physical continuum model (Becker & Wolff 2007, Wolff et al. 2012) to describe X-ray spectrum: does it align with two CRSF forming regions?



The age of physical models of accreting magnetized neutron stars has just begun!