

X-ray spectra of CTTS

Modelling the accretion shock

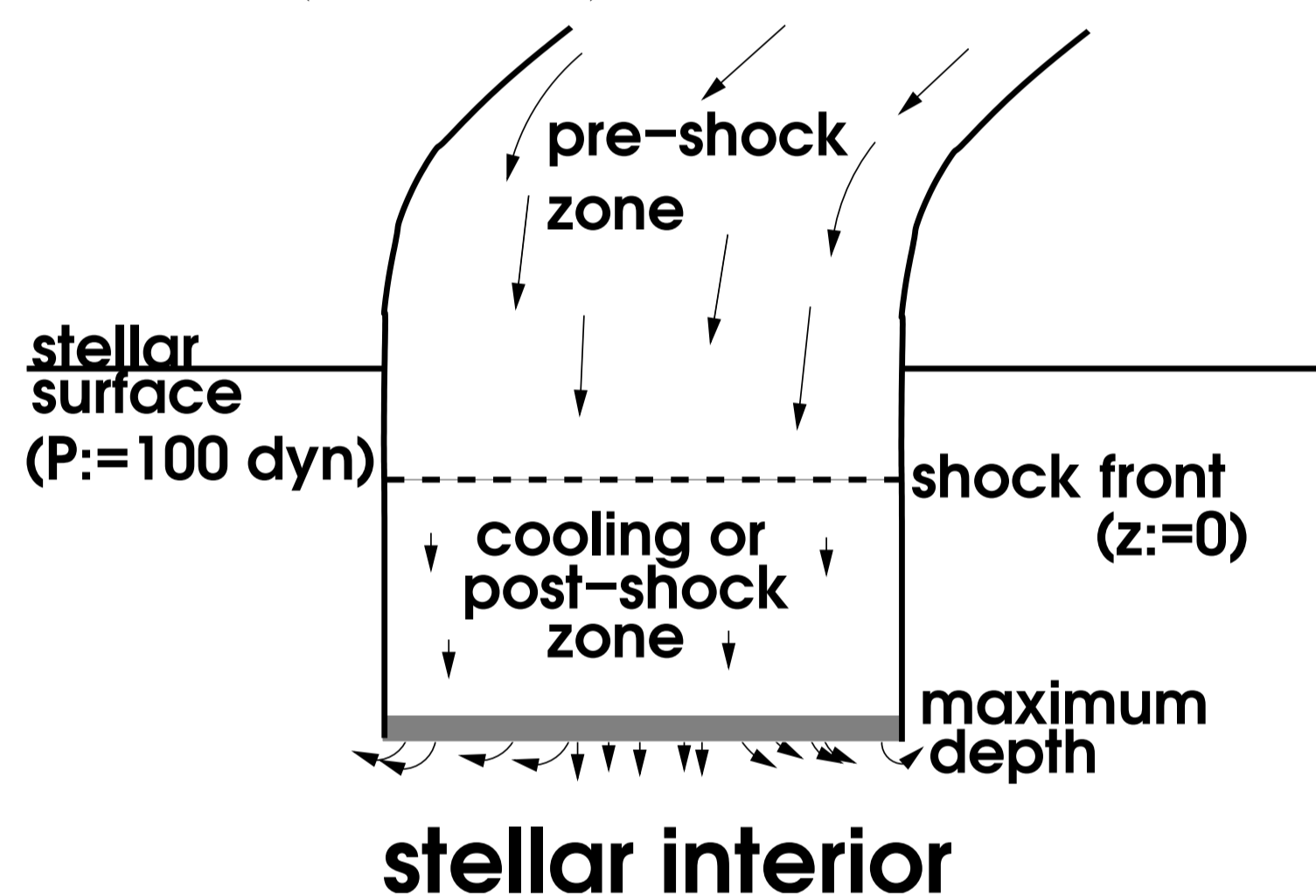
HANS MORITZ GÜNTHER AND JÜRGEN. H. M. M. SCHMITT
Hamburger Sternwarte, Universität Hamburg, e-mail: moritz.guenther@hs.uni-hamburg.de

Abstract

Three classical T Tauri stars (CTTS) have been observed with high S/N high resolution X-ray spectroscopy yet, TW Hya, BP Tau and V4046 Sgr. They show high densities and it is still a matter of debate if they are exceptional objects or representatives of their class. V4046 Sgr is a close binary consisting of two K stars with typical signatures of CTTS. It has been observed with Chandra/HETGS for 150 ks. The helium-like triplets of Si, Ne and O are clearly detected. Using a 1-dim, stationary, non-equilibrium model of the post shock accretion zone, the emission observed can be decomposed in accretion and coronal components. The accretion with its comparatively high densities explains unusual f/i ratios in the triplets, the coronal component explains the activity seen in the light curve and the high energy emission from temperatures, which are not reached in an accretion shock.

Model: Geometry and Assumptions

The accreted material follows the field lines and impacts on the stellar surface (Shu et al. 1994). A shock develops, where the ram pressure equals the thermodynamic pressure of the surrounding stellar atmosphere (see sketch).



A sketch of the accretion shock geometry

The shock is treated as a mathematical discontinuity, where the ion gas gets heated according to the Rankine-Hugoniot conditions. It sets the origin of the z coordinate. In the post shock cooling zone we stepwise integrate the hydrodynamic and the ionisation equations under the following assumptions:

- No heat conduction
- No viscosity
- Maxwell distribution in each component
- Stationarity of problem
- No optical depth effects
- Magnetic field $\vec{B} \parallel \vec{v} \Rightarrow$ The magnetic field does not influence the flow.
- Hydrodynamics and atomic physics can be treated separately during each step.

This leads to an equation for the ion temperature T_{ion} in depth z :

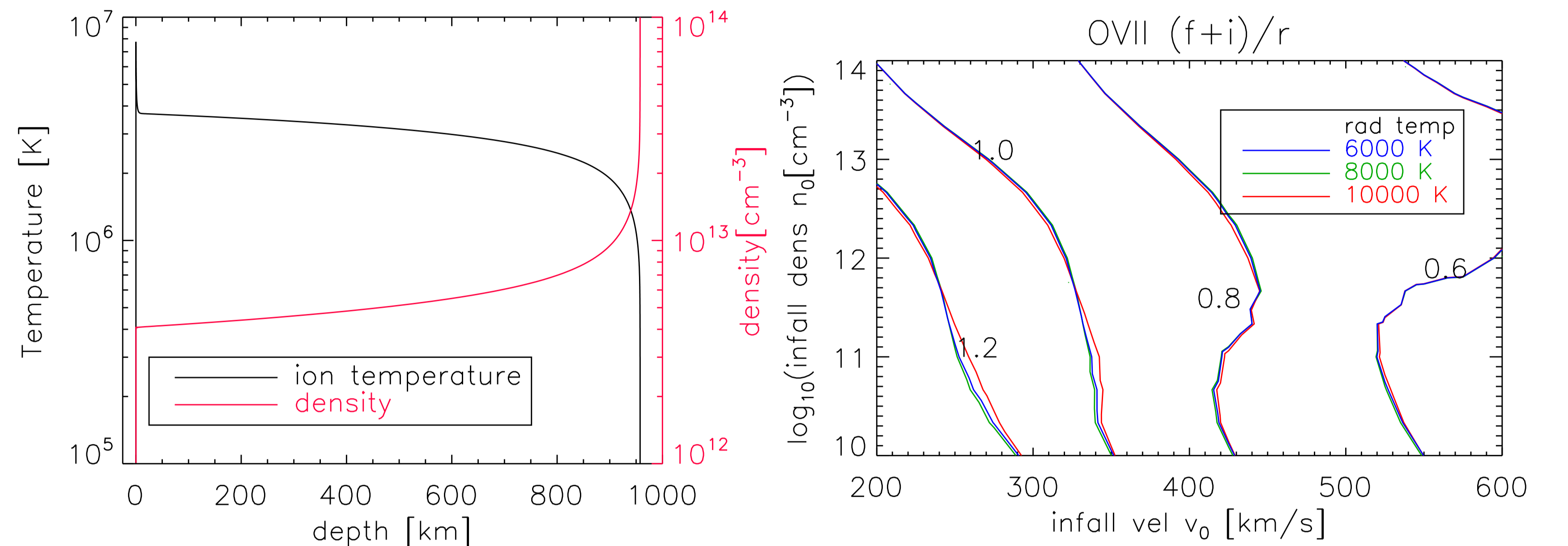
$$v \frac{d}{dz} \left(\frac{3}{2} k T_{\text{ion}} \right) + v n k T_{\text{ion}} \frac{d}{dz} \left(\frac{1}{n} \right) = -\omega_{ei} \quad (1)$$

for the ions with number density n and bulk velocity v , where k is the Boltzmann constant. ω_{ei} describes the heat flow from the ions to the cooler electrons according to Coulomb interactions.

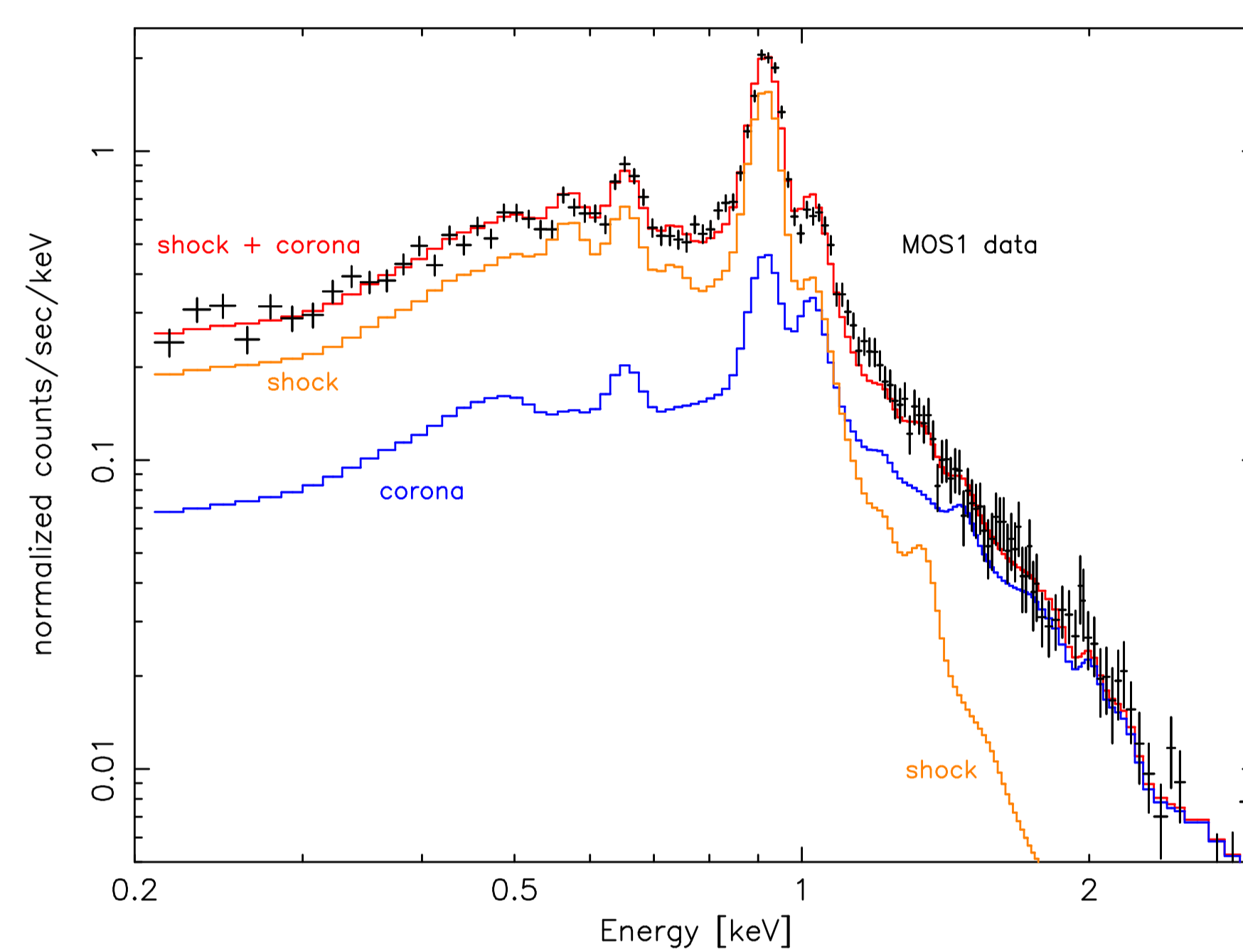
Model Parameters: The infall velocity v_0 , the pre-shock density n_0 and the abundances of C, N, O, Ne, Mg, Si, S and Fe.

References

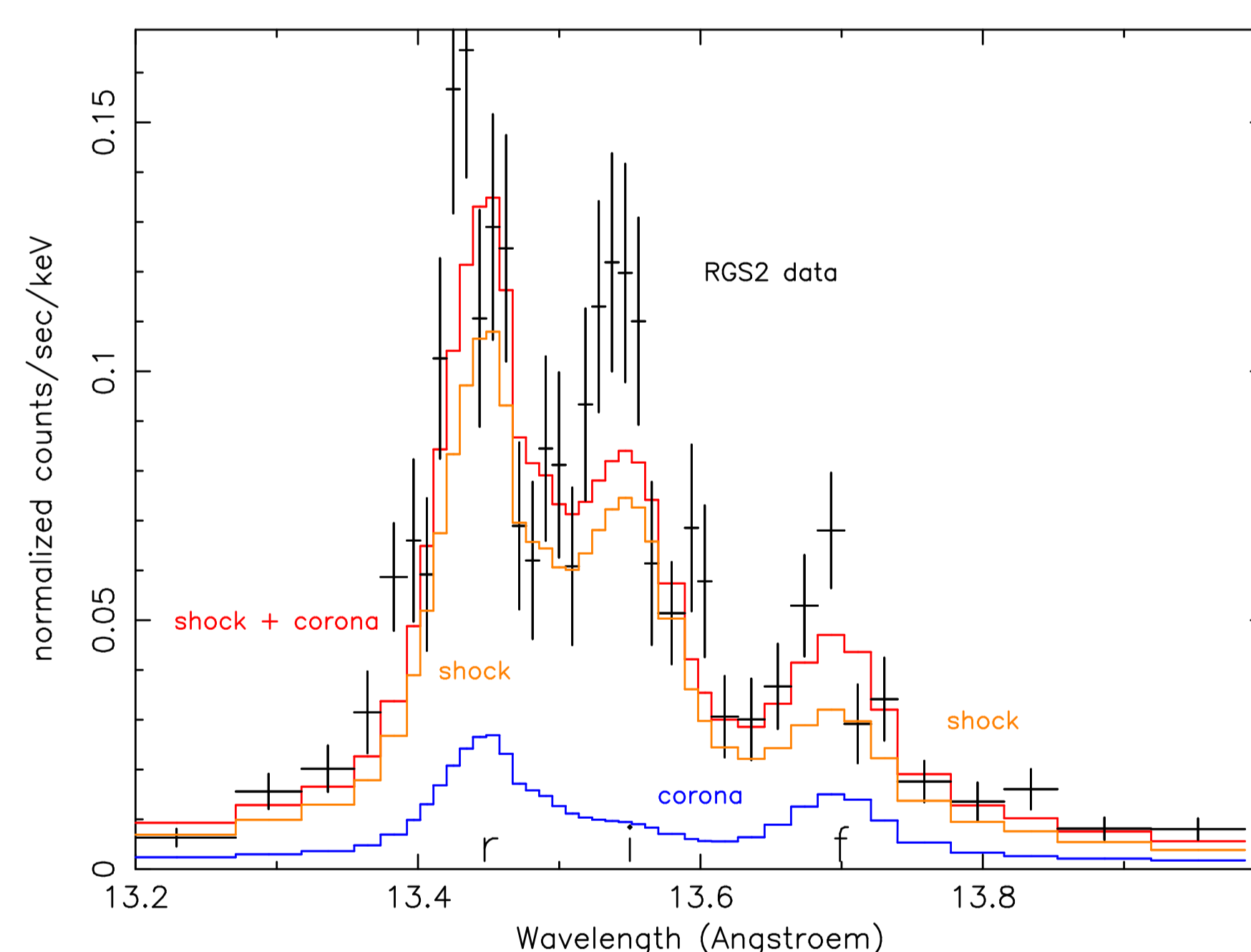
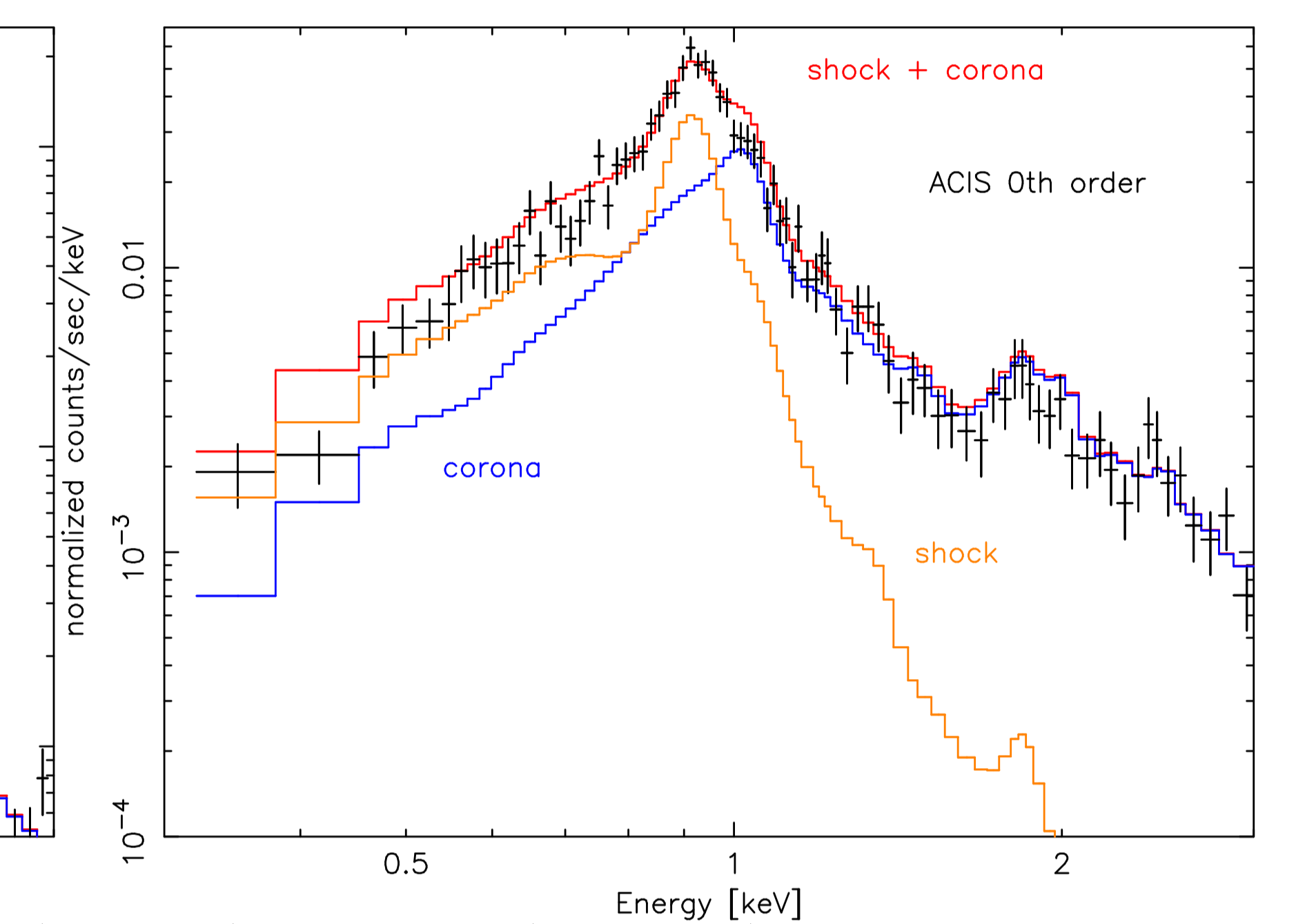
Alencar, S. H. P. & Batalha, C. 2002, ApJ, 571, 378
Batalha, C., Batalha, N. M., Alencar, S. H. P., Lopes, D. F., & Duarte, E. S. 2002, ApJ, 580, 343
Kastner, J. H., Huenemoerder, D. P., Schulz, N. S., Canizares, C. R., & Weintraub, D. A. 2002, ApJ, 567, 434
Shu, F., Najita, J., Ostriker, E., et al. 1994, ApJ, 429, 781

Results: Temperature and density in the shock and predicted line ratios

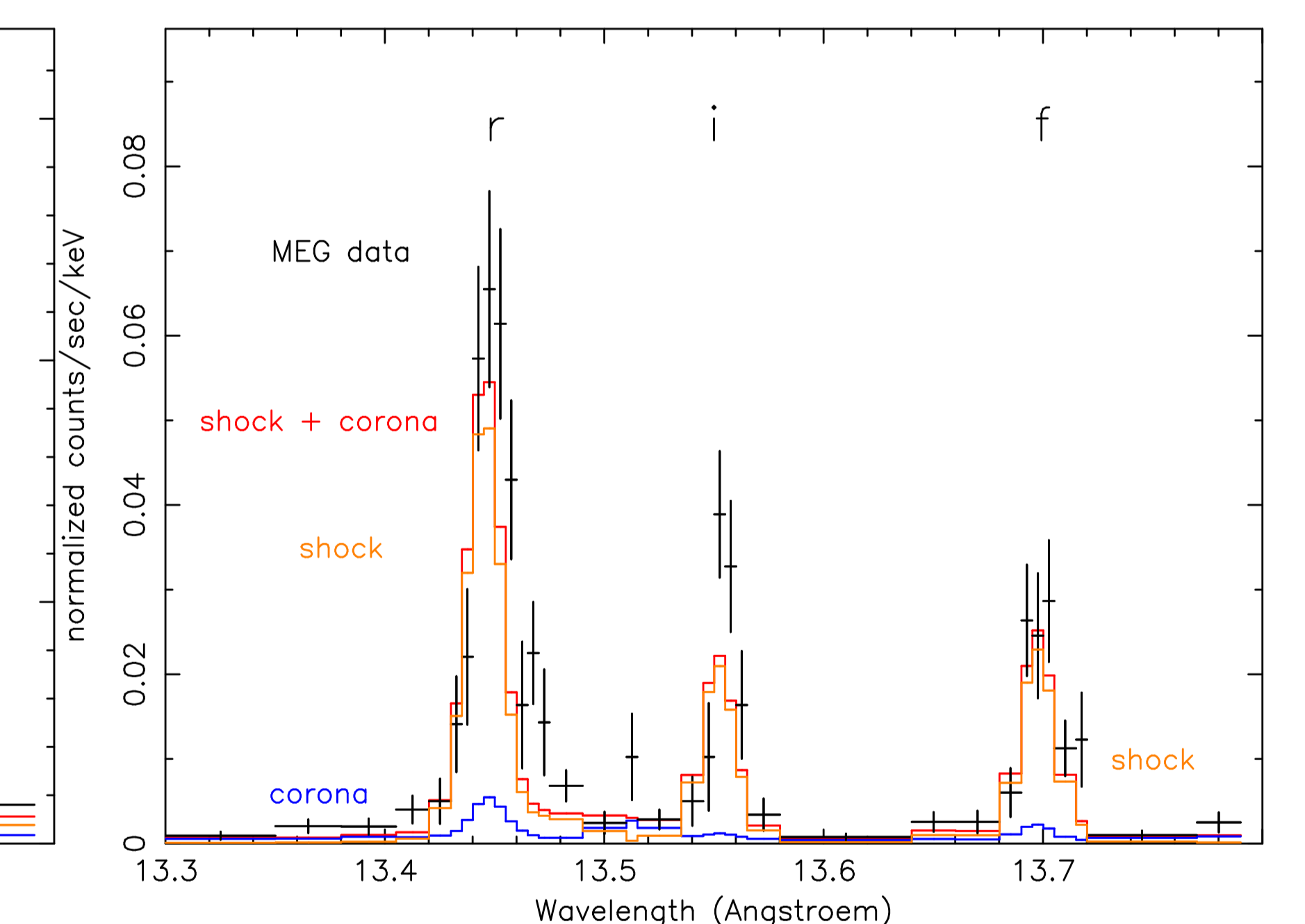
left: Temperature (black) and density (red) profiles – right: O VII ratio of forbidden and intercombination line to resonance line for different v_0 , n_0 and background radiation temperatures.

Application to classical T Tauri stars: Separating accretion and corona**TW Hya**

Low resolution spectra decomposed in the coronal (hard, blue) and accretion (soft, orange) contribution.

V4046 Sgr

Emission in the He-like neon triplet. Labelled are the resonance, intercombination and forbidden line of the He-like triplet. Only the high-density accretion component contributes to the i line.

**Best fit results**

Parameter	TW Hya	V4046 Sgr
v_0	525 km/s	535 km/s
n_0	10^{12} cm^{-3}	$2 \times 10^{11} \text{ cm}^{-3}$
filing factor	0.2%	0.1%
$\frac{dM}{dt}$	$2 \times 10^{-10} M_{\odot}/\text{yr}$	$3 \times 10^{-11} M_{\odot}/\text{yr}$
χ^2 (dof)	1.57(577)	1.23 (1113) ^a
observed flux (energy band 0.3-2.5 keV) in $\text{erg}/\text{cm}^2/\text{s}$		
shock	3.7×10^{-12}	1.2×10^{-12}
corona	2.0×10^{-12}	1.2×10^{-12}

^a: Churazov weighting necessary because of the small number of counts per bin

Interpretation

- Accretion shock can be simulated with well matched f/i lines ratios in the He-like triplets
- Shock: Soft component — Corona: Hard component
- Mass accretion very low \Rightarrow only fast accretion stream seen in X-rays \Rightarrow accretion spot likely inhomogeneous

Comparison to other mass accretion rate estimates

For comparison: Mass accretion rates for TW Hya

- optical: $1 \times 10^{-9} M_{\odot}/\text{yr}$ (Alencar & Batalha 2002)
- optical: $1 \times 10^{-8} M_{\odot}/\text{yr}$ (Batalha et al. 2002)
- UV: $3 \times 10^{-8} M_{\odot}/\text{yr}$ (Kastner et al. 2002)

Our rates are much smaller, but we probe only the highest energies!