Discovery of an Accretion-Fed Corona in a Young Star

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Accretion or Corona?

Chandra Large Observing Program
TW Hydrae (TW Hya)
High Energy Transmission Grating
~500 ks

• Test argument for X-rays from accretion
  (Kastner et al. 2002)
• If accretion, test accretion-shock model
  (Brickhouse et al. 2009)
TW Hya

- Classical T Tauri star (accreting)
- 10 million yr old
- $i=7^\circ$ (pole-on)
- $M = 0.8 \ M_{\text{Sun}}$
- $R = 0.7 \ R_{\text{Sun}}$
- Distance 57 pc

- X-ray plasma has high Neon abundance
  (Kastner et al. 2002; Drake et al. 2005)
Spectral Line Diagnostics

Segment of HETG spectrum showing H- and He-like Ne series

Series lines are sensitive to absorption
He-like Ions: O VII, Ne IX, and Mg XI

Diagnostics for $T_e$ and $N_e$
X-Ray Line Ratio Diagnostics for Density and Temperature

\[ N_e = 6 \times 10^{12} \text{ cm}^{-3} \]
\[ 3 \times 10^{12} \]
\[ 6 \times 10^{11} \]

Mg XI
Ne IX
O VII

This looks like the accretion shock!

\[ T_e = 2.50 \pm 0.25 \text{ MK} \]
Hot “coronal” lines exhibit a large flare. The “accretion” lines do NOT flare. Variability occurs in both.
Complex absorption

- O VII: $N_H = 4.1 \times 10^{20}$ cm$^{-2}$
- Ne IX: $N_H = 1.8 \times 10^{21}$ cm$^{-2}$

Not resonance scattering: 
$\tau = g f \lambda$, for a given ion

Series line ratios rule out
Testing the Accretion Shock Model

\[ V_{ff} = \frac{2GM_*}{R_*} \left(1 - \frac{R^*}{r_t}\right)^{1/2} \]
~ 510 km/s

\[ T_e = 3.4 \text{ MK} \]

\[ M_{\text{acc}} = f \ A_* \ \rho_{\text{pre}} \ \nu_{ff} \]

(Konigl 1991; Calvet & Gullbring 1998; Gunther et al. 2007; Cranmer 2008)
- Temperature and Density at Shock Front Agree with Model.

- Predicted density at O VII is 7 times larger than observed.

Consider a new 2-Region model for the shock:
Region 1 = the shock front
Region 2 = the post-shock cooling region

Each region has $N_e$, $T_e$, $N_H$, and $V$

Predict the $r$, $i$, and $f$ lines of the He-like ions

$V_2 = 300 \times V_1 \Rightarrow M_2 = 30 \times M_1$

Note Gudel et al. 2007
Gudel & Telleschi 2007
TW Hya Campaign: Four Continents Plus Chandra

Dupree et al. 2009
Conclusions

• High S/N, high resolution spectrum obtained with Chandra HETG shows 3 regions: a hot 10 MK corona, an accretion shock, and a post-shock cooling region.

• Diagnostics show excellent agreement with models of the shock itself.

• Diagnostics show that standard, one-dimensional models of the post-shock cooling plasma don’t work.

• We need a new type of coronal structure, an “accretion-fed corona” to be heated and ionized by the shocked plasma.

• Accretion-fed coronae may be common in accreting young star systems.