HST & Chandra observations of the RY Tau jet

S. Skinner1, M. Audard2, M. Güdel3, and C. Schneider4

1 Univ. of Colorado, CASA, Boulder, CO 80309, USA
e-mail: stephen.skinner@colorado.edu
2 Univ. of Geneva, Dept. of Astronomy, CH-1290 Versoix, Switzerland
3 Univ. of Vienna, Dept. of Astrophysics, A-1180 Vienna, Austria
4 Hamburger Sternwarte, D-21029 Hamburg, Germany

Abstract. We summarize observations of the accreting T Tauri star (TTS) RY Tau with HST and Chandra. RY Tau drives a bipolar jet that has been extensively studied in the optical. A sensitive observation of RY Tau with Chandra in 2009 revealed faint X-rays extending outward to a separation of ≈1″.7 arcsecs from the star, overlapping the bluehifted jet (P.A. ≈ 295°). The extended X-ray emission arises in plasma heated to at least T ≥ few MK by an as yet unidentified mechanism that is likely associated with the jet. To probe the inner jet at higher spatial resolution, we obtained HST STIS UV grating observations in 2014 with the STIS long-slit aligned along the optical jet. Spatially-resolved medium-resolution STIS G140M grating spectra show extended emission in the C IV doublet (1548/1551 Å ) out to at least 1″ along the forward (blueshifted) jet and out to ≈0″.5 along the redshifted counterjet. The extended C IV emission traces warm plasma (T ≈ 10^5 K) in the innermost jet and its presence will constrain jet-heating models.

Key words. stars: pre-main sequence – stars: jets – stars: individual (RY Tau)

1. Introduction

Chandra: A 55 ks ACIS-S X-ray observation in 2009 provided high-quality CCD images, spectra, and light curves (Skinner et al. [2011]). Higher-resolution grating spectra (ACIS-S/HETG) were acquired in 2014 (Skinner et al. [2016]). RY Tau is a luminous highly-variable X-ray source (log L_x = 30.5 - 31.2 erg s^{-1} at d = 134 pc). Short-term (~hours) flare-like variability is present in addition to a slower modulation (~days) that may be linked to the star’s rapid rotation. The characteristic X-ray temperature of the star is T_x ~ 50 MK but can increase to T_x ~ 100 MK during flares. The strong variability and high X-ray temperatures are indicative of intense magnetic activity. Fluorescent Fe emission at 6.4 keV is present, originating in cold material near the star irradiated by hard stellar X-rays. Deconvolved ACIS-S images in the 0.2 - 2 keV band (Fig. 1) reveal faint X-ray emission extending outward along the blueshifted optical jet, at least some of which is likely associated with the jet.

HST: STIS/MAMA UV grating observations were obtained in Dec. 2014 with the 52″ × 0″.2 slit aligned along the jet. We focus here on medium-resolution (0.075 Å FWHM) G140M spectra which spectrally resolve the C IV doublet. STIS spatial resolution is ≈0″.1. STIS/MAMA 2D spectral images provide spatially-resolved spectra along the jet.
2. HST view of the inner jet

The STIS data clearly show warm plasma (T \( \sim 10^5 \) K) traced by C IV out to \( \sim 200 \) along the blueshifted jet and to \( \sim 0.5 \) along the fainter redshifted jet (Fig. 2; Skinner et al. in prep.). The C IV 1548.2 \( \AA \) line in a 1D spectrum extracted along the stellar trace with a spatial binning of 5 MAMA pixels (0.00145) is broad and asymmetric suggesting multiple contributions (e.g. star, unresolved inner jet, and possible H\(_2\)). The C IV 1550.7 \( \AA \) line in the stellar trace spectrum is more symmetric and is roughly approximated by a Gaussian with FWHM \( = 136 \pm 10 \) km s\(^{-1}\). The C IV doublet lines become more symmetric and narrower moving outward away from the star along the jet. Spectra extracted at offsets of 0.0050 \( \pm 0.0007 \) (67 \( \pm 9 \) AU at 134 pc) in the blue jet are nearly Gaussian with a centroid shift of \( -130 \pm 8 \) km s\(^{-1}\) relative to the stellar systemic velocity and line width FWHM \( = 136 \pm 10 \) km s\(^{-1}\).

3. Jet heating

What heats the jet to UV and X-ray emitting temperatures? The maximum predicted shock temperature is \( T_s = 0.15[v_s/100 \text{ km s}^{-1}]^2 \) MK where \( v_s \leq v_{\text{jet}} \) is the shock speed. For an estimate we use a radial jet velocity \( v_{\text{rad}} = -130 \) km s\(^{-1}\) at an offset of 0.5 in the approaching jet, as noted above. The deprojected jet speed \( v_{\text{jet}} \) depends on the jet inclination relative to the line-of-sight which is not well-constrained but previous work suggests \( i_{\text{jet}} = 61^\circ \pm 16^\circ \) (Agra-Amboage et al. 2009). This gives \( v_{\text{jet}} = 268 [184 - 578] \) km s\(^{-1}\). These values are high enough to account for the UV plasma (T \( \sim 0.5 \) MK) but cannot explain the hotter X-ray plasma unless \( v_{\text{jet}} \) is near the high-end of the allowed range and \( v_s \approx v_{\text{jet}} \). Such high shock speeds comparable to the jet speed are questionable (Agra-Amboage et al. 2009). Thus, other heating mechanisms besides shocks may be involved. Magnetic heating (Ohmic dissipation) has been considered as a possible heating mechanism for the DG Tau jet (Schneider et al. 2013). But jet B-fields are weak (\( \mu G \approx 0.1 \); Carrasco-González et al. 2010) and probably non-uniform. More reliable B-field measurements are needed to test magnetic heating models. Hot plasmoids (T \( \sim 10 - 100 \) MK) ejected during magnetic-reconnection flares (Hayashi et al. 1996) could also produce faint extended X-rays. But if not reheated the plasmoids quickly cool below X-ray temperatures and any extended X-ray structure would be ephemeral.

Acknowledgements. S.S. acknowledges support from grants SAO GO4-15012X and HST-GO 13714.

References