MEASURE OF THE ACCRETION STREAM VELOCITY OF TW HYA FROM THE X-RAY DOPPLER SHIFT

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CONTEXT

1. ACCRETION IN LOW MASS STARS

In Classical T Tauri Stars (CTTS) the accretion process is regulated by the intense stellar magnetic fields, that disrupt the inner disk at a few stellar radii, and guide accreting material in a free fall toward the central star (Fig. 1). There infalling material impacts with the denser stellar atmosphere with velocities $v_{pre} \approx 300 - 500$ km s^{-1}, forming strong shocks (Königl 1991) .

2. X-RAYS FROM ACCRETION

High-resolution X-ray spectra of CTTS showed the presence of a high density plasma (Kastner et al. 2002), at odds with the low density coronal plasma of non-accreting low-mass stars (e.g. Testa et al. 2004). This high density plasma in CTTS is thought to be material heated in the accretion shock (Fig. 1). **The infall pre-shock velocities, v_{pre}, are expected be so high to generate a post shock plasma with:**

- **temperature of a few MK emitting X-rays;**
- **post-shock velocity $v_{post} \approx 100$ km s^{-1} ($v_{post} = v_{pre}/4$).**

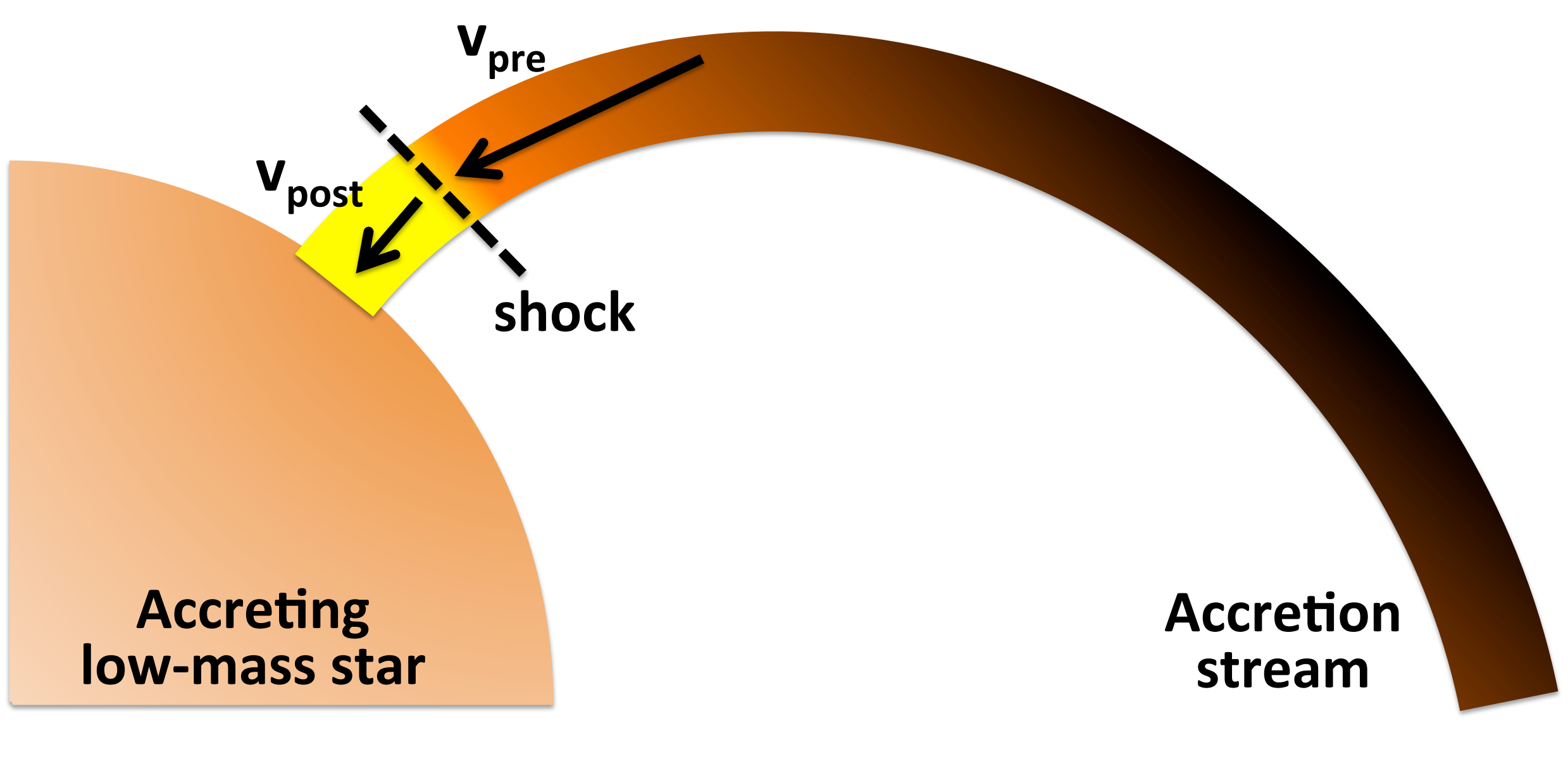

Figure 1. Schematic view of the accretion stream in a CTTS. The yellow area at the base of the stream indicates the hot plasma heated in the accretion shock and emitting X-rays.

3. THE CHANDRA AND XMM ERA

High-resolution X-ray spectra allow to infer the physical conditions of the accreting material (density, temperature, chemical composition, velocity). Several open questions are however still debated: the mass accretion rate estimates (Curran et al. (2011), or the possibility to have an accretion feed corona (Brickhouse et al. 2010).

4. AIMS OF THIS WORK

We estimated for the first time the radial velocity of the X-ray emitting plasma in CTTS by measuring the line Doppler shifts. A redshift with respect to the stellar photosphere, expected for the plasma located in the post-shock region (Fig. 1), would definitively:

- **indicate that the plasma is located in the post-shock region;**
- **constrain the geometry of the system.**

To this aim we analyzed the deep (500 ks) *Chandra*/HETG observation of TW Hya, **a** single 0.7 $M_{\odot}$ star, 8 Myr old, located at 55 pc, observed pole on, and with an accretion rate of ≈ 10^{-9} $M_{\odot}$ yr^{-1}.

DOPPLER SHIFT MEASUREMENTS WITH CHANDRA/HETG

5. METHOD

To measure the Doppler shift in *Chandra*/HETG spectra we:

- selected a sample of strong and isolated emission lines (Table 1),
- fitted each line individually, with a gaussan profile (two examples are reported in Fig. 2),
- determined the velocity corresponding to the displacement of each line with respect to its rest wavelength,
- computed the weighted mean v_X of these velocities,
- evaluated the Earth velocity toward the target (indicated with v_E),
- compared v_X+v_E (i.e. the X-ray plasma radial velocity with respect to the barycentric reference system) with the predicted radial velocity of the star (indicated with v_0).

6. REFERENCE STAR SELECTION

To test the reliability of our method we applied it to TW Hya, and to low-mass stars that:

- have *Chandra*/HETG spectra with high signal to noise ratio,
- are not affected by orbital motion with high radial velocities,
- have X-ray emission due only to coronal plasma (no bulk motions are expected with respect to the stellar photosphere).

All the stars, and the corresponding *Chandra*/HETG spectra analyzed, are listed in Table 2.

7. RESULTS

The radial velocities measured from the X-ray spectra (v_X) and their comparison with the expected photospheric velocities are reported in Table 2, and plotted in Fig. 3. From these values we find that:

- the X-ray emitting plasma on TW Hya shows a significant redshift with respect to the stellar surface, corresponding to a velocity of 36.5 ± 4.7 km s^{-1};
- all the other stars show X-ray emitting plasma velocities compatible with that of the stellar photosphere, validating the adopted method, and the absolute calibration of the *Chandra*/HETG.

Figure 4 reports the comparison of the O VIII line profiles of all the targets. This comparison confirms the accuracy of the absolute line positions of *Chandra*/HETG, and the redshifted emission of TW Hya.

Table 1. Line selected for the Doppler shift measurements.

wavelength (Å)	Ion	T_{max} (MK)
10.24	Ne X	6
13.70	Ne IX	4
16.01	O VIII	3
18.97	O VIII	3
21.60	O VII	2

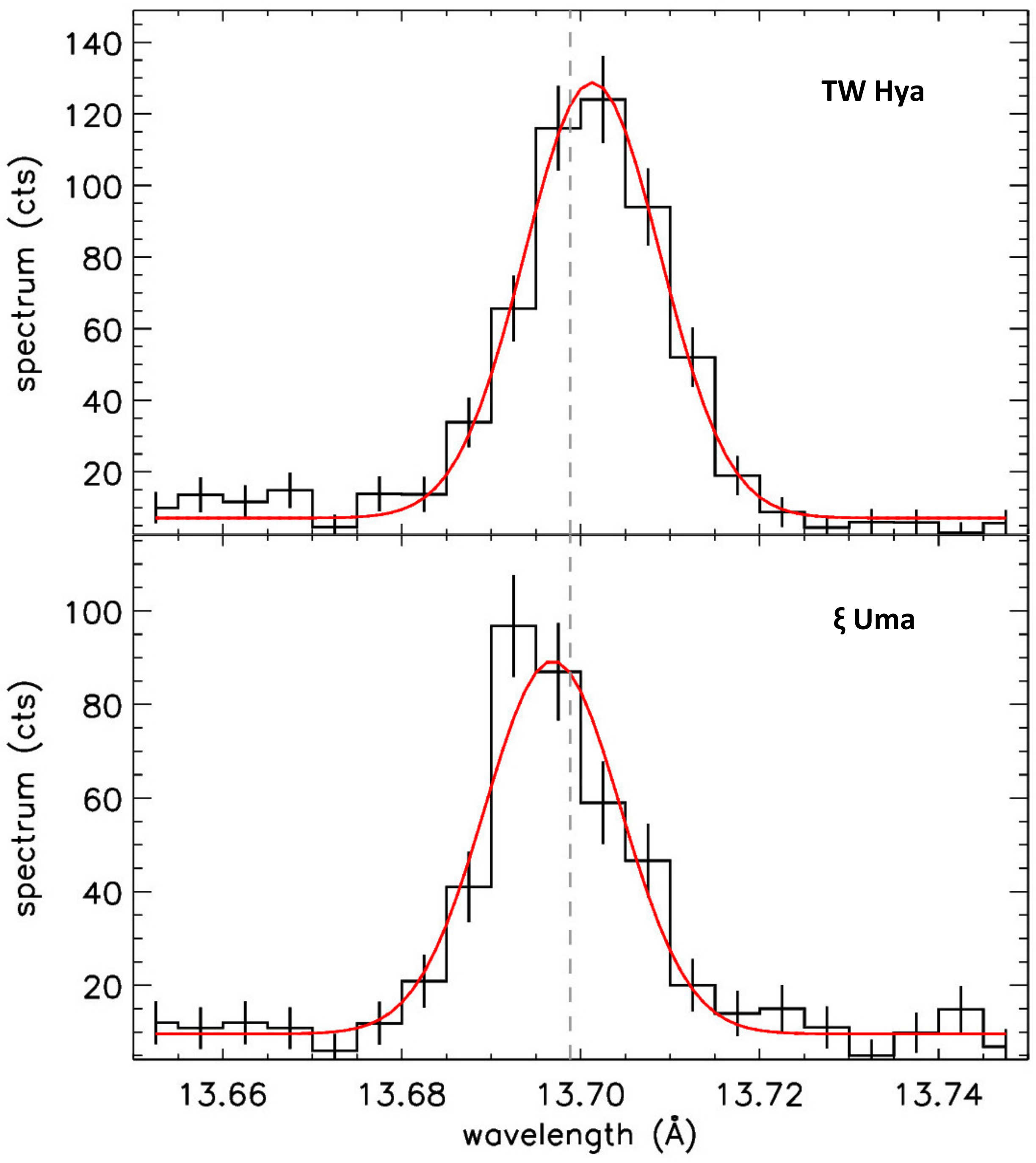

Figure 2. Observed spectra (black line) in the region of Ne IX line at 13.70 Å. Red curve indicates the best fit of the line. The two spectra, TW Hya in the upper panel and ξ Uma in the lower panel, represent the case of a red shifted and blue shifted line, respectively. The v_X corresponding to these spectra are reported in Table 2.

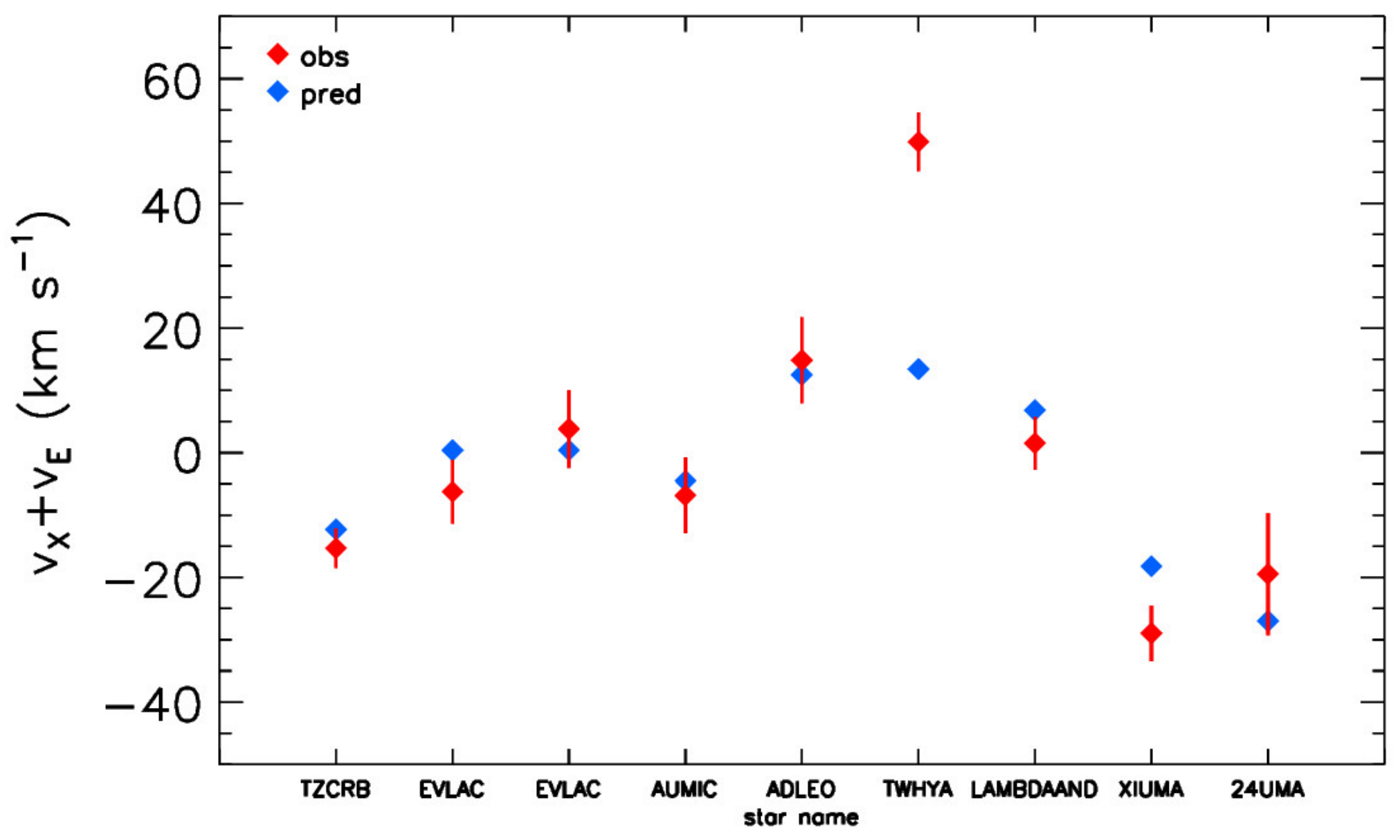

Figure 3. Comparison between the observed radial velocity in X-rays, v_X + $v_{E,}$ (velocity with respect to the barycentric reference system, red diamonds), and the radial photospheric velocity (blue diamonds) for each inspected star.

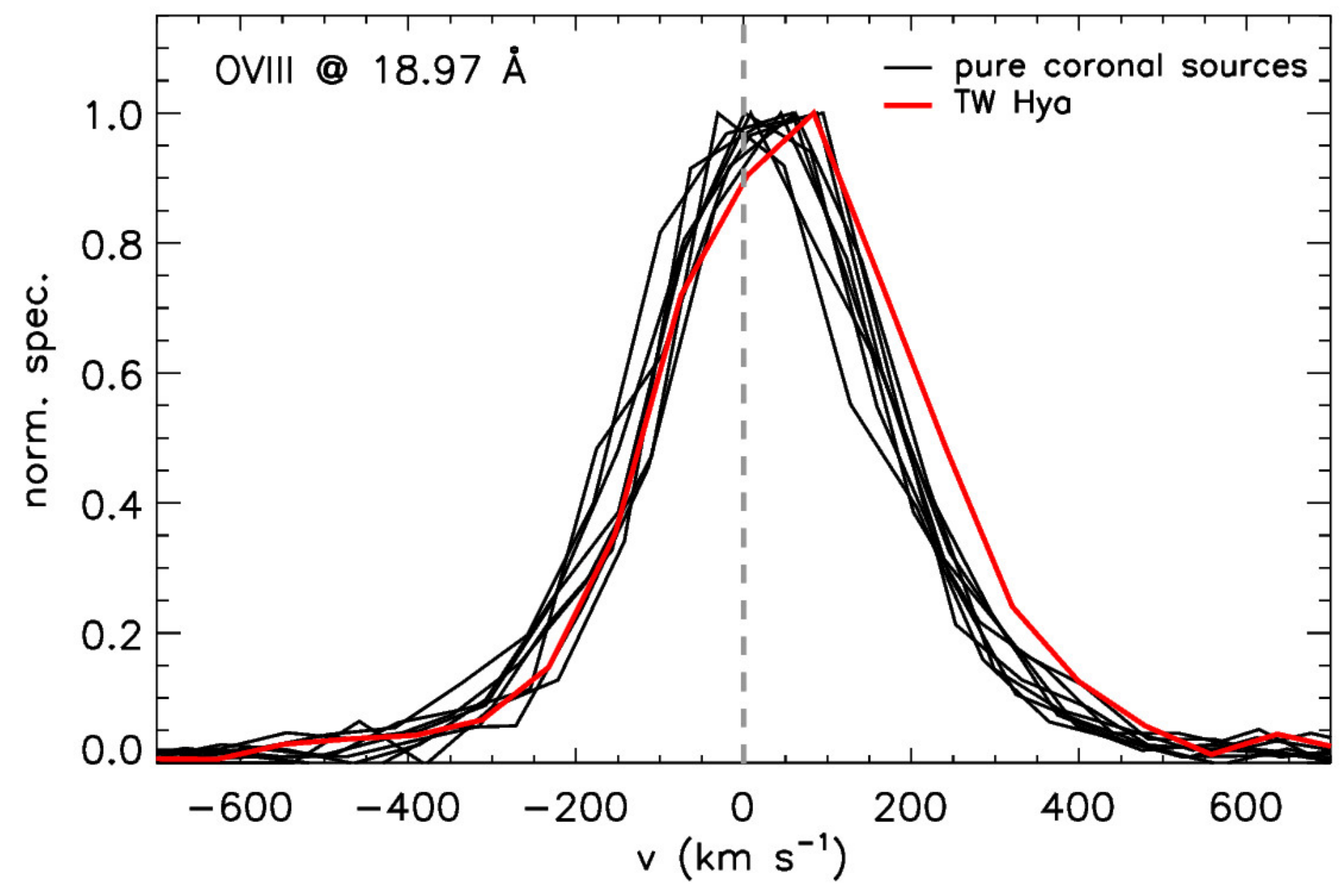

Figure 4. Observed profiles of the O VIII Lyα line, of all the X-ray spectra analyzed, with respect to the stellar reference frame. All the inspected stars, but TW Hya, show no shift with respect to the stellar frame. The redshift of the TW Hya X-ray spectrum is small but significant.

Table 2. Velocities measured from the X-ray emission lines, and velocities expected.

Star	*Chandra* Obs Id	v_X (km s^{-1})	v_E (km s^{-1})	v_0 (km s^{-1})	(v_X + v_E)- v_0 (km s^{-1})	*n* σ
TZ Crb	15	−5.0 ± 3.2	−10.3	−12.3	−3.0 ± 3.2	0.9
EV Lac (1)	1885	−9.0 ± 5.0	2.7	0.4	−6.7 ± 5.0	1.3
EV Lac (2)	10679	8.7 ± 6.2	−4.8	0.4	3.4 ± 6.2	0.5
AU Mic	17	21.3 ± 6.0	−28.2	−4.5	−2.4 ± 6.0	0.4
AD Leo	2570	43.4 ± 6.9	−28.5	12.5	2.4 ± 6.9	0.3
TW Hya	7435+7436+7437+7438	38.3 ± 4.7	11.6	13.4	36.5 ± 4.7	7.8
λ And	609	21.7 ± 4.2	−20.2	6.8	−5.3 ± 4.2	1.3
ξ UMa	1894	−52.7 ± 4.4	23.7	−18.2	−10.8 ± 4.4	2.4
24 UMa	2564+3471	−1.9 ± 9.7	−17.6	−27.0	7.5 ± 9.7	0.8

CONCLUSIONS

8. THE ACCRETION ONTO TW HYA

We measured for the first time the radial velocity of the X-ray emitting plasma in a CTTS: **we found that the plasma at a few MK on TW Hya is redshifted of 36.5 ± 5 km s^{-1}** with respect to the stellar photosphere. We can deduce that:

1. **soft X-rays in CTTS are indeed produced in the post-shock region;**
2. for TW Hya X-ray and UV lines (in particular the narrow component of the C IV doublet, Ardila et al. 2013) provide very similar radial velocities, suggesting that **the plasma components at 10^6 K and 10^5 K are both located in the same post-shock region** (Fig. 5);
3. the post-shock plasma is expected to have a velocity v_{post} of ≈ 100 km s^{-1} (a minimum value of v_{pre} is needed to have a post shock hot enough to radiate in X-rays, Sacco et al. 2010); then, since TW Hya is observed from the pole, an observed radial velocity for the post shock of ≈ 35 km s^{-1} suggests that **the base of the accretion stream is located at low latitudes** (≈20 deg) on the stellar surface (Fig. 5).

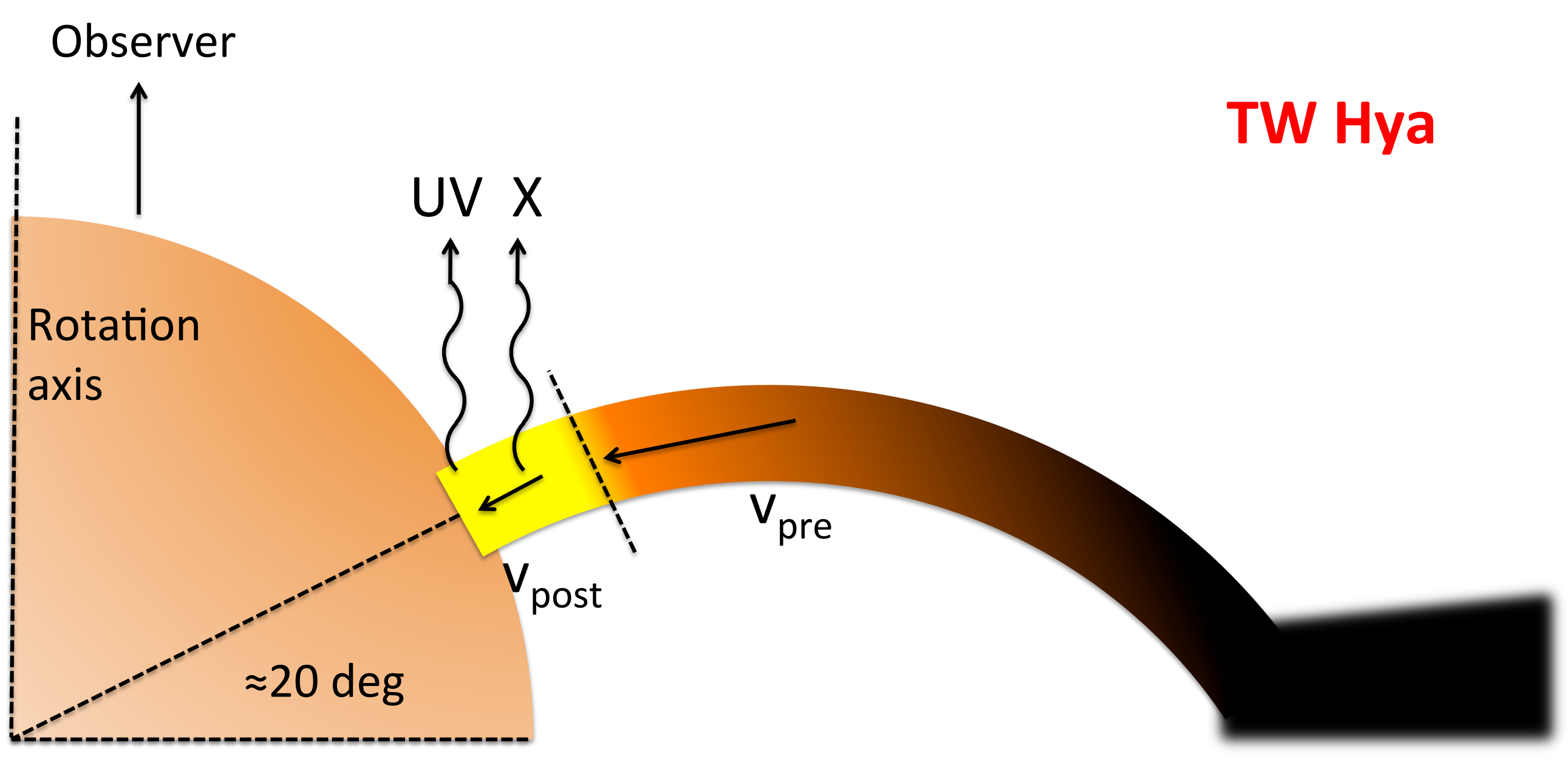

Figure 5. Schematic view of the accretion geometry of TW Hya.

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