REDSHIFTED X-RAYS FROM THE MATERIAL ACCRETING ONTO TW HYA: EVIDENCE OF A LOW LATITUDE ACCRETION SPOT

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ACCRETION IN YOUNG STARS

- exchanges of mass/angular momentum/energy
- stellar evolution
- rotation evolution
- circumstellar disk evolution
- accretion vs magnetic activity interplay
MAGNETOSPHERIC ACCRETION

- Rotational modulation → hot spots and disk warps
- Spectral energy distribution → inner disk disruption, hot spots
- Magnetic field measurements (1 kG) → inner disk disruption
- Line profiles → velocities of material at different temperature
ACCRETION-SHOCK REGION

\[ v_{\text{pre}} \approx 300 - 500 \text{ km s}^{-1} \]

\[ v_{\text{post}} = v_{\text{pre}} / 4 \approx 100 \text{ km s}^{-1} \]

- \( n_{\text{post}} = 4 \, n_{\text{pre}} \)
- \( T_{\text{post}} = \frac{3 m v_{\text{pre}}^2}{16 k_b} \approx 1 - 3 \text{ MK} \)

ACCRETION-SHOCK REGION

uncorrelated X-ray vs UV emission
unexpected $n_{\text{post}}$ vs $T$ pattern

Accretion fed or modified corona?

Güdel & Telleschi 2007, Brickhouse et al. 2010

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DOPPLER SHIFT TO CONSTRAIN PLASMA ORIGIN

\[ v_{post} = \frac{v_{pre}}{4} \approx 100 \text{ km/s} \]

Detectable with Chandra/HETGS

**X-ray redshift**

Confirmation of the post-shock origin of the high-density cool plasma

**no X-ray redshift**

High-density cool plasma is also located in modified coronal structures
TW HYA: THE NEAREST YOUNG ACCRETING STAR

TW Hya:
d ≈ 59.5 pc
age ≈ 8 Myr
M ≈ 0.8 M☉
R ≈ 1.1 R☉
dM/dt ≈ 10^{-9} M☉ yr^{-1}
P_{rot} ≈ ?
B ≈ 1-3 kG
i ≈ 7°

• No rotational modulation

• Chandra/HETGS LP of 500 ks
500 ks CHANDRA/HETG OBS OF TW HYA

Brickhouse et al. 2010

MEG spectrum
500 ks

Brickhouse et al. 2010

Counts

Wavelength (Angstroms)

log EM (cm$^{-3}$)

log T (K)

accretion

corona

$n_e \sim 10^{12} \text{ cm}^{-3}$

$T \approx 3 \text{ MK}$
X-RAY DOPPLER SHIFT MEASURE: METHOD 1

Method 1: individual line position
- isolated lines
- hot and cool line subsets
- measure the shift of each line
- $v_{\text{cool}}$ and $v_{\text{hot}}$ as weighted average from cool and hot line subsets
Method 2: spectral fitting
- cool and hot plasma components
- two different velocities
- fit the whole spectrum
X-RAY PLASMA MOTIONS IN TW HYA

\[ v_{\text{cool}} \approx 38 \pm 5 \text{ km/s} \]
$v_{\text{cool}} \approx 38 \pm 5 \text{ km/s}$

$V_{\text{hot}} \approx V_{\text{cool}} \approx V_{\text{phot}}$

X-RAY PLASMA MOTIONS IN TW HYA

- Cool plasma
- Hot plasma
- Method 1
- Method 2

Tw Hyo

AU Mic
EV Loc (1)
EV Loc (2)
AD Leo
β Cet
λ And
ξ Uma
24 Uma

$V^*_x \ (\text{km s}^{-1})$
X-RAY PLASMA MOTIONS IN TW HYA

Ne IX
4 MK
51 ± 10 km s\(^{-1}\)
X-RAY PLASMA MOTIONS IN TW HYA

O VIII
3 MK
34 ± 7 km s$^{-1}$
O VII
2 MK
54 ± 15 km s⁻¹
1. SOFT X-RAYS ORIGINATE IN THE POST SHOCK

\[ v_{\text{cool}} \approx 38 \pm 5 \, \text{km/s} \]

✓ Strength of B

Brickhouse et al. 2010

X-ray, UV

Accretion in Stellar Systems, Cambridge, MA, US, Aug 2018

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2. THE STREAM TERMINATES AT LOW LATITUDE

observer

stellar equator

Rotation axis

\[ v_{\text{rad}} \approx 38 \pm 5 \text{ km s}^{-1} \]

\[ v_{\text{post}} \approx 110 - 120 \text{ km s}^{-1} \]

\[ \alpha \approx 10^\circ - 30^\circ \]
DOPPLER SHIFT TO CONSTRAIN ACCRETION GEOMETRY

Magnetic field in TW Hya is dominated by the octupolar component (Donati et al. 2011)

Gregory et al. 2006, Gregory et al. 2011
3. SOFT X-RAYS AND UV ORIGINATE IN THE SAME LOW-LATITUDE ACCRETION SHOCK

C IV @ 1550 Å
0.5 MK

Ardila et al. 2013

$\nu_{\text{NC-UV}} \approx 30 \text{ km s}^{-1}$
$\nu_{X} \approx 40 \text{ km s}^{-1}$

same low-latitude accretion shock
CONCLUSIONS

The detected redshifted X-rays indicate that:

• soft X-rays entirely come from the post-shock region, as predicted by MHD simulations,

• the observed accretion shock is located at low latitude,

• soft X-rays and NC of UV lines likely originate in the same post-shock region,

• Chandra/HETGS absolute wavelength calibration allows velocity measurements down to $\approx 10\text{-}20\ \text{km s}^{-1}$.