Accretion and activity on the brown dwarf FU Tau A: A testbed for stellar evolutionary models

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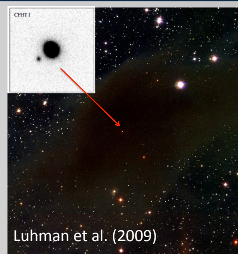
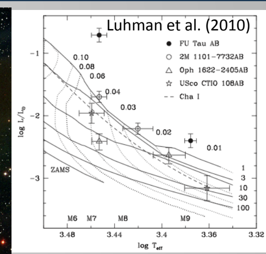
The FU Tau binary (see Luhman et al. 2009):

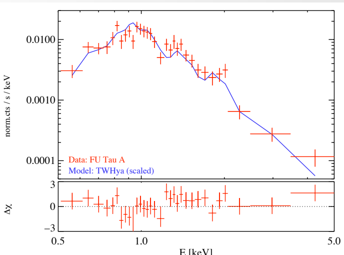
** One of only 4 known wide brown dwarf binaries (200 AU; M7.25+M9.25).
** Located isolated on the B215 dark cloud it questions brown dwarf formation mechanisms that involve the presence of higher-mass stars.
** Both components have disks (infra-red excess) and accretion (Hα equivalent width >> 10 Å)
** The binary is located above the 1 Myr isochrone in the HRD, esp. FU Tau A





BOX 2: X-ray Properties of the FU Tau binary

40ks Chandra/ACIS-S observation (Obs-ID 10984):
FU Tau A is detected at log L_x [erg/s] = 29.5 and log (L_x/L_{bol}) = -3.3 while FU Tau B is not with log L_x [erg/s] < 27.2 and log (L_x/L_{bol}) < -3.8.



Stelzer et al. (2010)

Table 2. X-ray spectral parameters of the absorbed 2-T APEC model for FU Tau A compared to those of TW Hya.

Object	Instrument	χ^2_{red} (d.o.f.)	log N_H (cm^{-2})	kT_1 (keV)	kT_2 (keV)	log EM_1 (cm^{-3})	log EM_2 (cm^{-3})	log L_x[a] ($erg\,s^{-1}$)
FU Tau A	*Chandra*/ACIS	0.9 (27)	$21.8^{21.9}_{21.5}$	$0.24^{0.34}_{0.19}$	$1.12^{1.28}_{0.99}$	$52.9^{53.5}_{52.1}$	$52.3^{52.4}_{52.2}$	29.5
TW Hya[b]	*XMM–Newton*/EPIC-pn	2.3 (216)	20.8	0.23	1.22	53.0	52.2	29.8

The extraordinary similarity of the X-ray spectrum of FU Tau A with that of TW Hya, in particular the cool temperature, suggests emission from an accretion shock rather than from the corona.

$v_0 := v_{H\alpha} \approx 175\,\mathrm{km/s}$ and $\dot{M}_{acc,HeI} = 7.5 \cdot 10^{-10}\,\dot{M}_{\odot}/\mathrm{yr}$

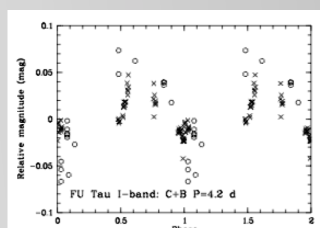
$\longrightarrow k_B T_{psh} = \frac{3}{16}\mu m_p v_0^2 \approx 0.03\,\mathrm{keV} << k_B T_1$

$\longrightarrow EM_{psh} = \dot{M}_{acc,HeI} \cdot \frac{3 k_B \cdot T_{psh}}{\mu m_p P(T_{psh})} \approx 10^{52.7} \approx EM_1$

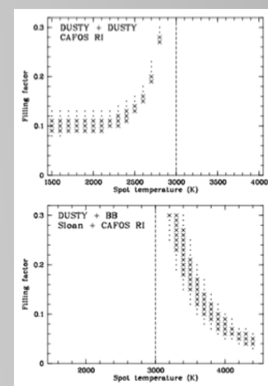
→The accretion scenario is consistent with the observed emission measure but predicts a temperature outside the X-ray band.

BOX 3: Rotation period and spots of FU Tau A

Photometric monitoring of FU Tau A on Calar Alto (Nov/Dec 2010) with CAFOS and BUSCA:

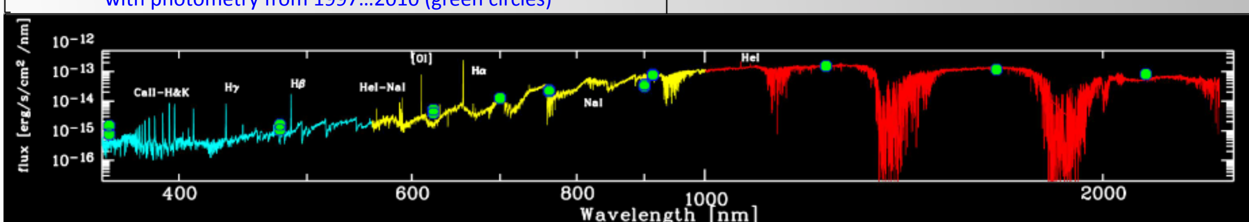


Scholz et al. (2011)



- periodic variation with P ~ 4d interpreted as rotation
- simple spot model with one spot characterized by filling factor and temperature:
  (A) Calar Alto data: cool spot, asymmetric distribution
  (B) Calar Alto and SDSS: hot spot, axisymmetric but variable on time-scale of years

BOX 4: Broad-band X-Shooter spectrum of FU Tau A (from Jan 2011) with photometry from 1997…2010 (green circles)

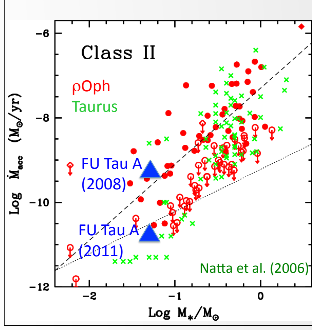


BOX 5: FU Tau A and the mass vs. mass-accretion rate relation

Accretion measurements for FU Tau A:

Instr.	Date	$\lambda/\Delta\lambda$	$EW_{H\alpha}$ [Å]	$W_{H\alpha,10\%}$ [km/s]	$\dot{M}_{acc}$ [$\dot{M}_{\odot}$/yr]	log (L_{acc}/L_{bol})
GEMINI	Mar 2008	4000	146	352	$3.5 \cdot 10^{-10}$	−2.8
X-Shooter	Jan 2011	9000	90	219	$1.6 \cdot 10^{-11}$	−3.1
Chandra	Oct 2009	$\dot{M}_{acc}$ derived from L_{OVII} is:			$3.5 \cdot 10^{-11}$	−4.1

$\dot{M}_{acc}$ and log (L_{acc}/L_{bol}) calculated with $M = 0.05\,M_{\odot}$, $R = 1.8\,R_{\odot}$, $R_{in} = 2\,R$, $L_{bol} = 0.2\,L_{\odot}$.



The accretion rate of FU Tau A is variable by > 1 order of magnitude.

In 2008 FU Tau A accreted at a rate typical for very young BDs (as in ρ Oph)
In 2011 FU Tau A accreted at much lower rate typical for BDs in Taurus.

The spread in the $\dot{M}$ vs. M diagram may have a significant contribution from variability.

SUMMARY & CONCLUSIONS:

The over-luminosity of FU Tau A in the HR diagram may be due to:

• reduced convection due to strong activity and/or fast rotation (Chabrier et al. 2007)
making T_{eff} higher and radius larger, i.e. the mass smaller than predicted from evolutionary models
(0.2 M_{sun} if shifted horizontally onto the 1Myr isochrone vs. 0.05 M_{sun} from the observed L_{bol} and T_{eff})
supported by strong X-ray activity (BOX 2)
and presence of cool spots (BOX 3)
supported because the observed period (4days; BOX 3) is in better agreement with the period-mass relation if the mass is higher

• excess luminosity from accretion
not supported because small L_{bol} would imply very high L_x/L_{bol} ratio;
not supported because L_{acc} < 1% L_{bol} (BOX 5)
supported by presence of hot spots (BOX 3)

• extreme youth; possibly still in phase of episodic accretion
supported by L_x/L_{bol} level (BOX 2) and variation of $\dot{M}$ (BOX 5)