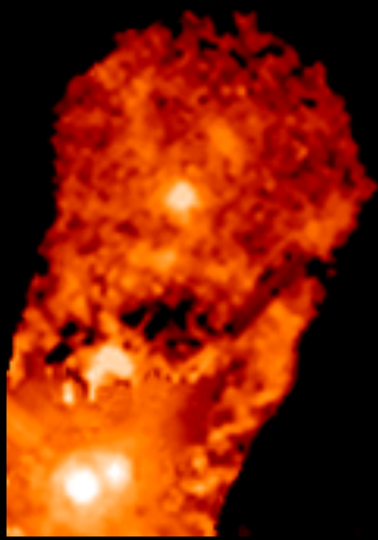
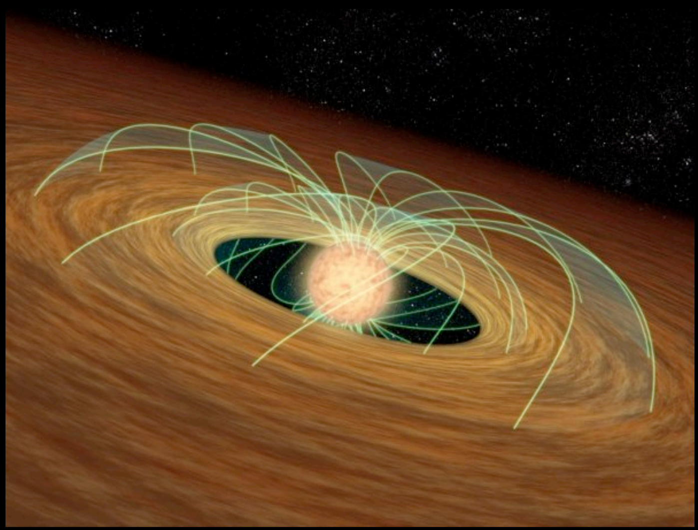
Linking Accretion and Outflows in Young Stars and Brown Dwarfs





Credit NASA/JPL

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Sources of Data

- NTT – EFOSC2 & SOFI Optical/IR spectra + Spitzer –IRS

  (Accretion Proxy Studies)
- VLT – FLAMES Multi-object spectroscopy (Accretion variability studies)
- VLT X-Shooter UV/Optical/IR Spectroscopy (BD accretion/outflow)

Outline

- What the mass outflow/mass accretion rate can tell us
- Measuring outflow parameters in jet/source
- Accretion rates – the purest approach
- Use and Abuse of Accretion Proxies
- Time Evolutionary Effects
- Outflow/Accretion Mass Dependence
- Summary

Why the Outflow/Accretion Ratio is Important

- Measuring the magnetic lever arm $\lambda = r_A/r$

$$\dot{J}_{\mathrm{W}} = \dot{M}_{\mathrm{W}} \Omega r_{\mathrm{A}}^2$$

$$\dot{J}_{\mathrm{acc}} = \tfrac{1}{2} \Omega r^2 \dot{M}_{\mathrm{acc}}$$

$$\frac{\dot{M}_{\mathrm{W}}}{\dot{M}_{\mathrm{acc}}} = \frac{1}{2}\left(\frac{r}{r_{\mathrm{A}}}\right)^2$$

- Time/mass dependencies due to varying efficiency of the central engine
- Degree of mass loading may give us clues as to how the outflow is launched

Jet – Outflow Rates

- Velocities, ionisation fraction, electron densities and hence neutral densities can be determined

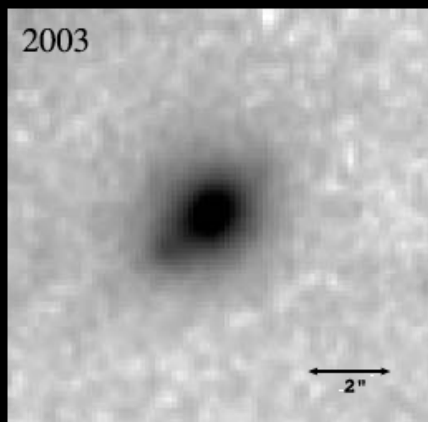
  - Radii beyond a few hundred AU from the source

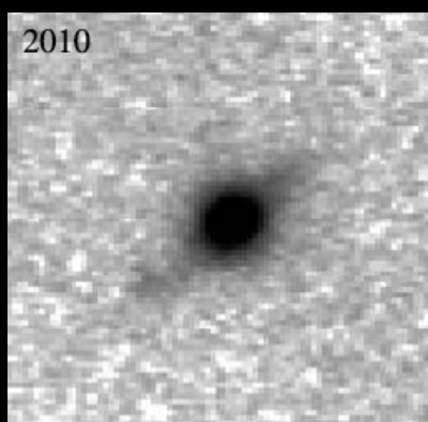
$$\dot{M}_{jet} \approx \pi r^2 \rho_{jet} V_{jet}$$

- Jet outflow rates ≈ 10^{-7} to $10^{-9} M_{\odot}/yr$ (for Classical T Tauri Stars)

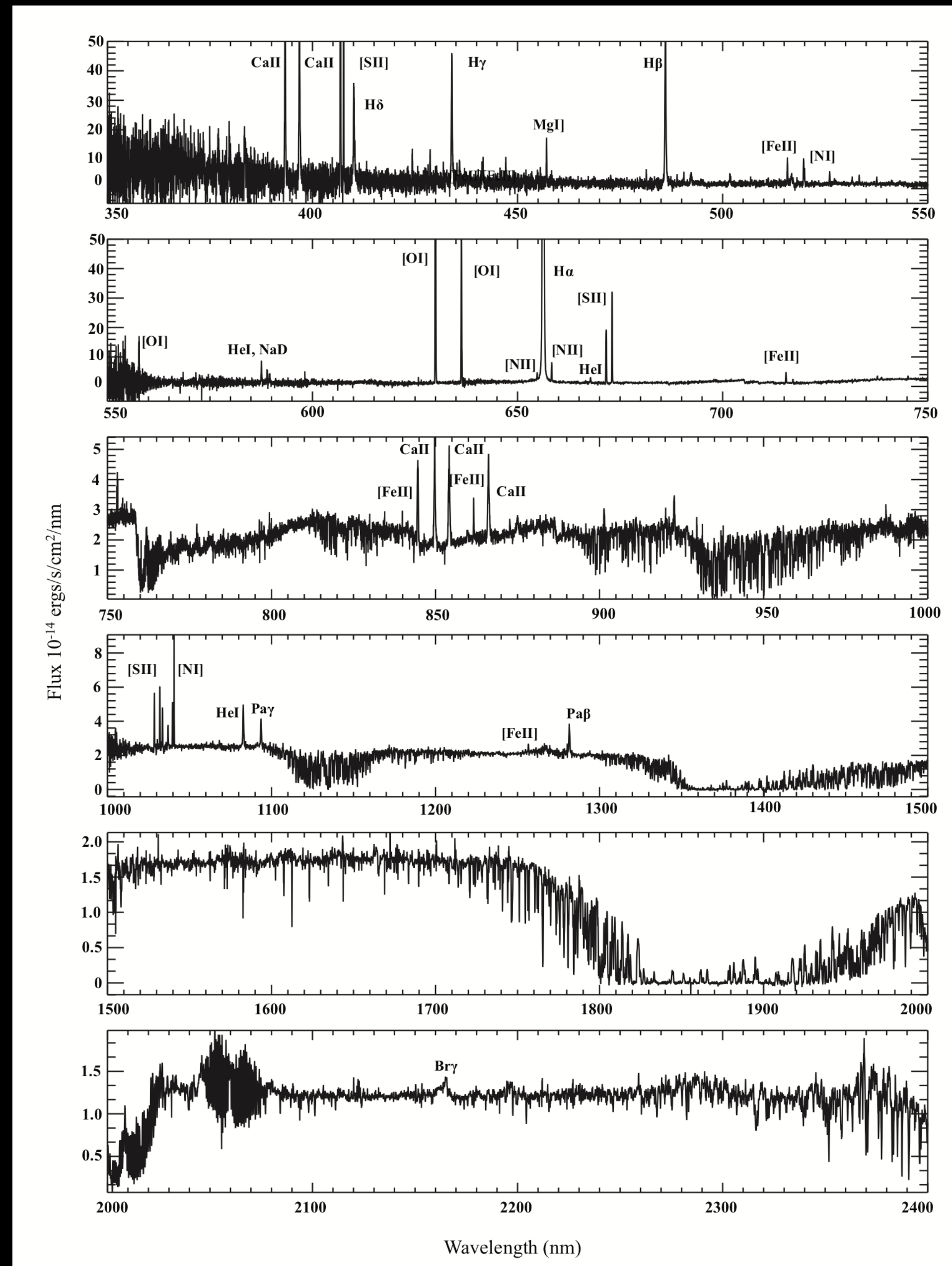
- Problem: rate varies along jet and is a “fossil record” of source activity

Par-Lup3-4
Very Low Mass Star with a bipolar jet (HH600)





Comeron & Fernandez. 2011

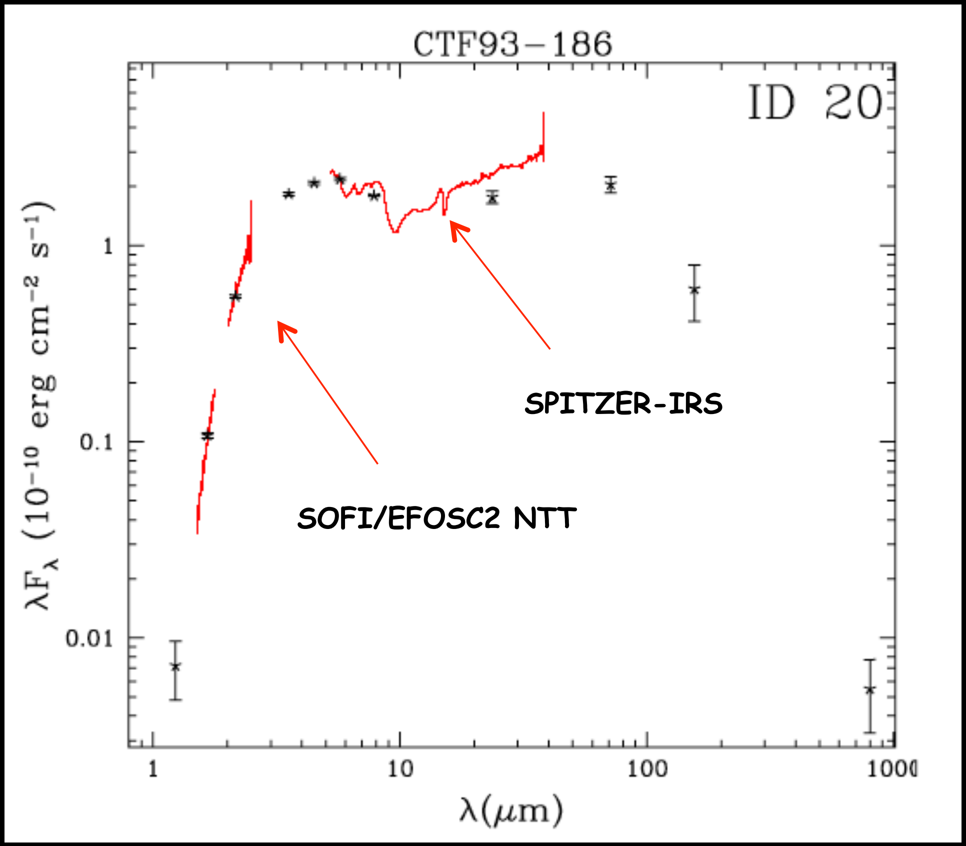


At the Source

- Numerous permitted and forbidden emission lines seen
- Similar to extended jet (e.g. Hα, [OI], [SII], [FeII]) plus others (HeI, CaII (IRT), Paβ, etc.)
- Forbidden lines trace wind/outflow at source due to low critical densities
- Permitted lines trace outflow and accretion (but mostly accretion)

Measuring Accretion: The Purist Approach

- ➢Use the Spectral Energy Distribution (SED)
- ➢ Requires A_V, Spectral type of Star, etc
- ➢ Estimate L_* and from L_{Bol} derive L_{Acc}



Estimating the Accretion Rate

- Assume R_{in} is the co-rotation radius

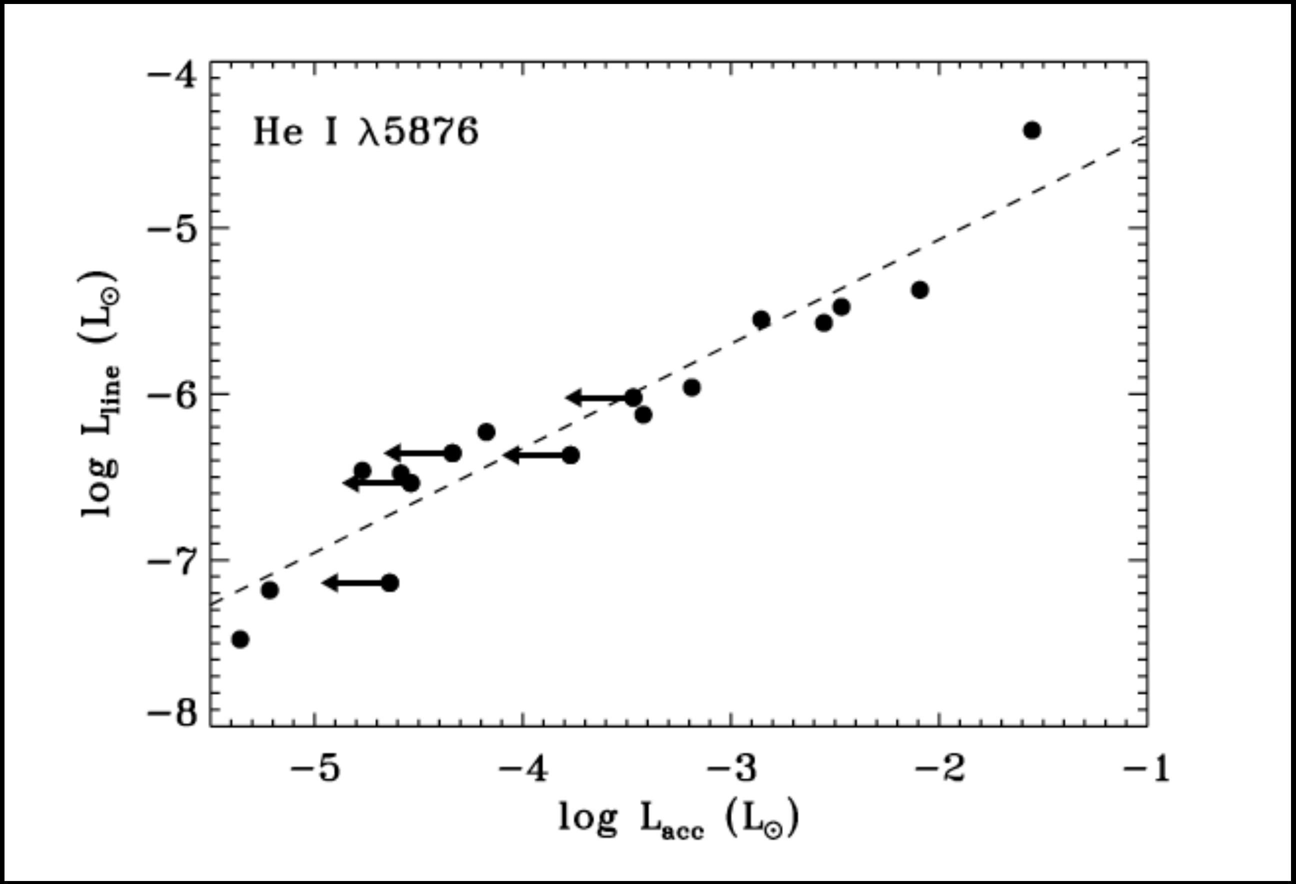
$$L_{acc} \sim GM_* \dot{M}_{acc}(1 - R_*/R_{in})/R_*$$

$$R_{in} \sim 5\, R_*$$

$$\dot{M}_{acc} = L_{acc} * 1.25 R_*/GM_*$$

- Accretion columns radiate in the UV/U band causing veiling of lines (e.g. Hartigan & Kenyon 2003)

Link Accretion Rate Measures to Line Luminosities –Act as Proxies



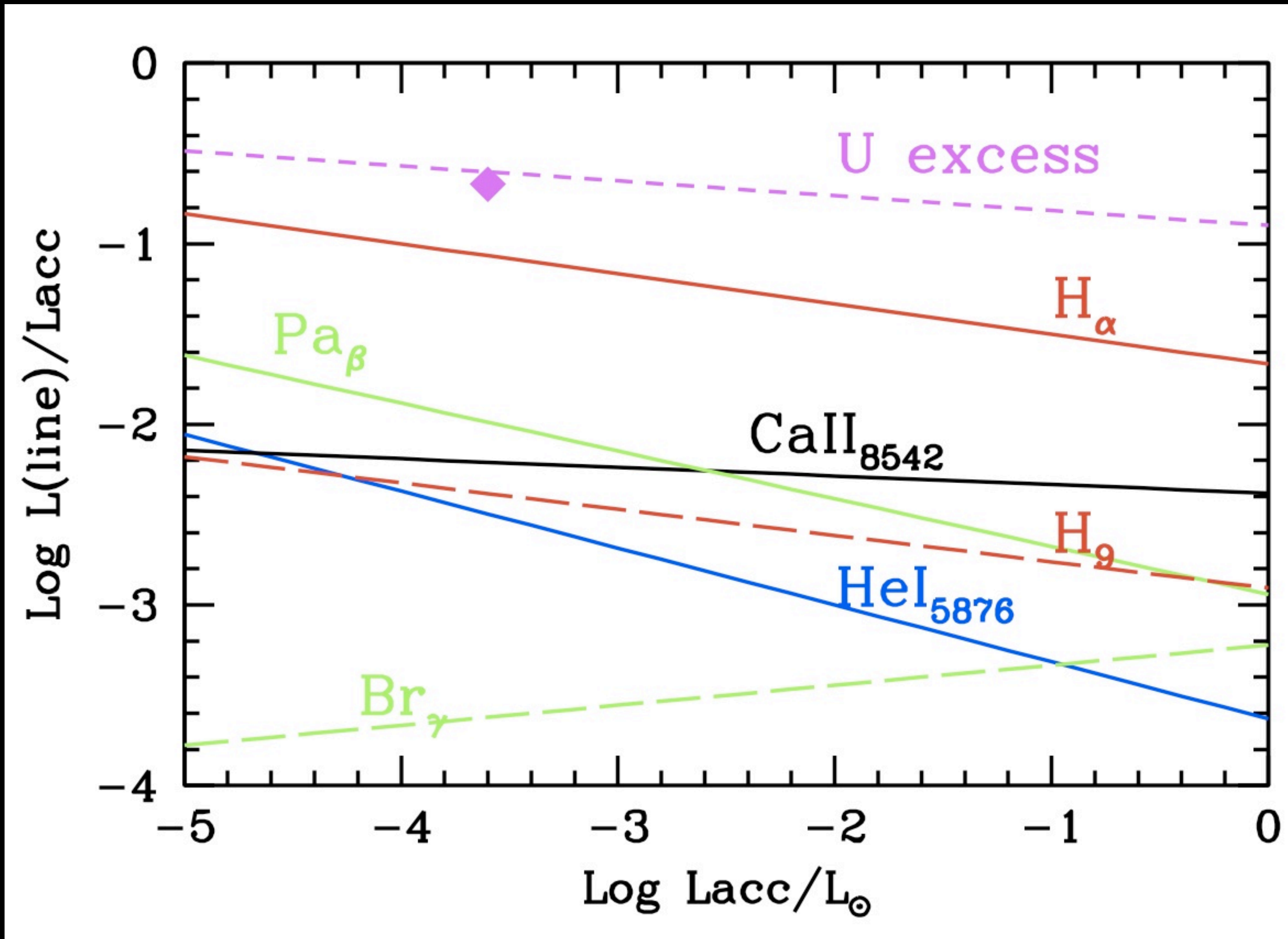
Herczeg & Hillenbrand 2008

Resultant Empirical Relationships

$$\mathrm{Log}(L_{\mathrm{acc}}/L_{\odot}) = 1.02 \times \mathrm{Log}(L_{\mathrm{CaII8542}}/L_{\odot}) + 2.5$$

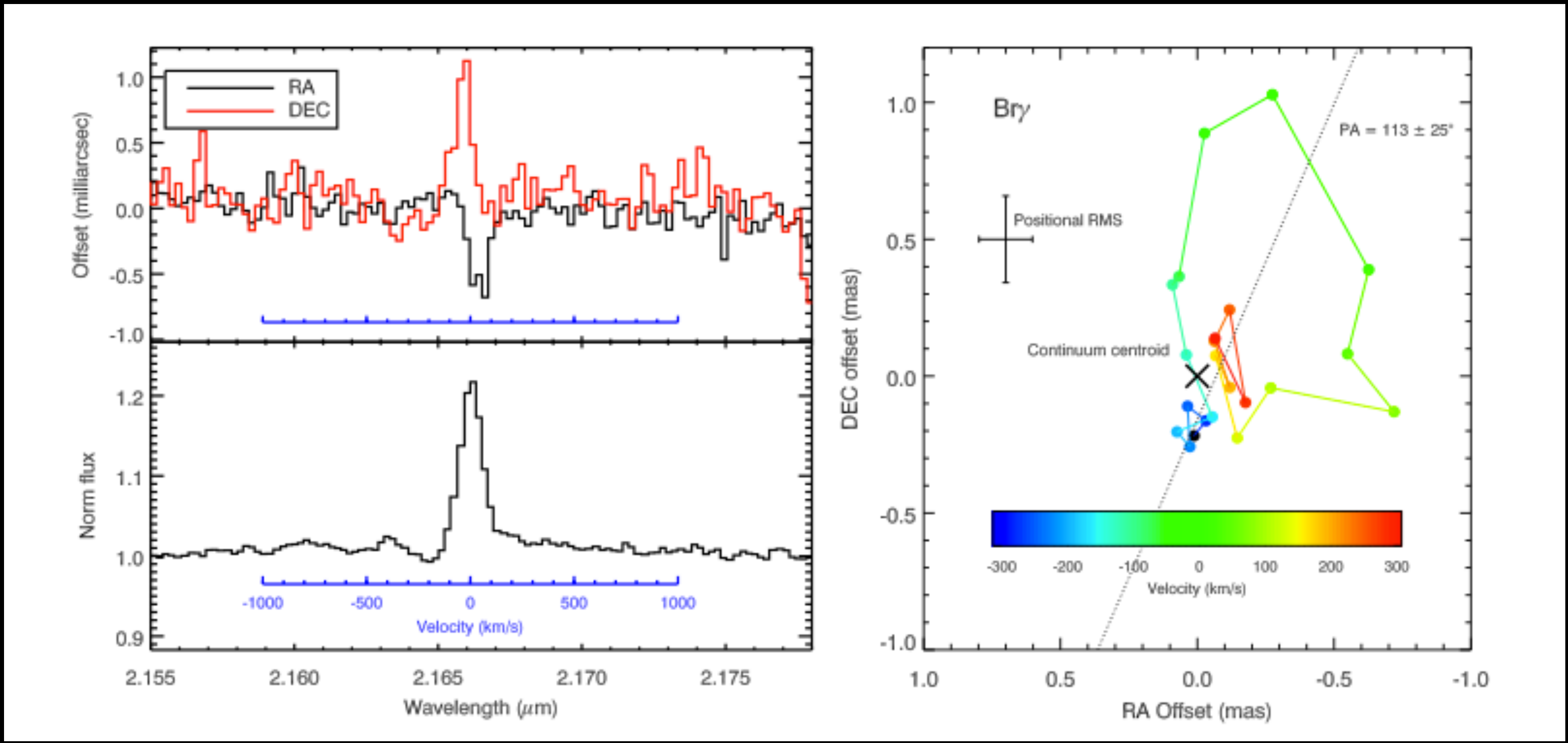
$$\mathrm{Log}(L_{\mathrm{acc}}/L_{\odot}) = 1.03 \times \mathrm{Log}(L_{\mathrm{Pa}\beta}/L_{\odot}) + 2.80$$

$$\mathrm{Log}(L_{\mathrm{acc}}/L_{\odot}) = 0.90 \times \mathrm{Log}(L_{\mathrm{Br}\gamma}/L_{\odot}) + 2.90$$



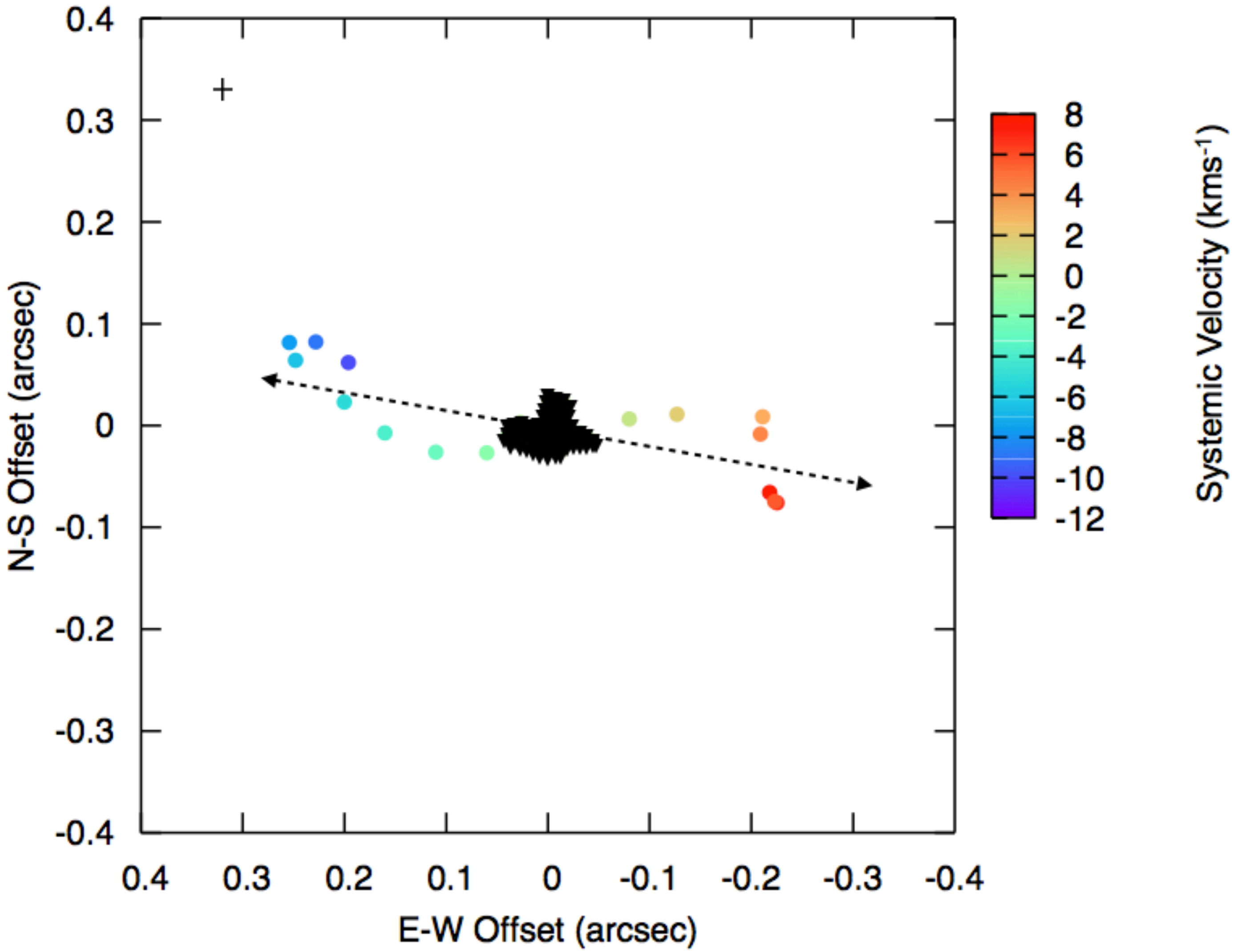
U excess
Hα
Paβ
CaII8542
H9
HeI5876
Brγ
0
−1
−2
−3
−4
−5
−4
−3
−2
−1
0
Log L(line)/Lacc
Log Lacc/L⊙

Cautionary Note: "Accretion" proxies can contain outflow components & Some Entirely Outflow!

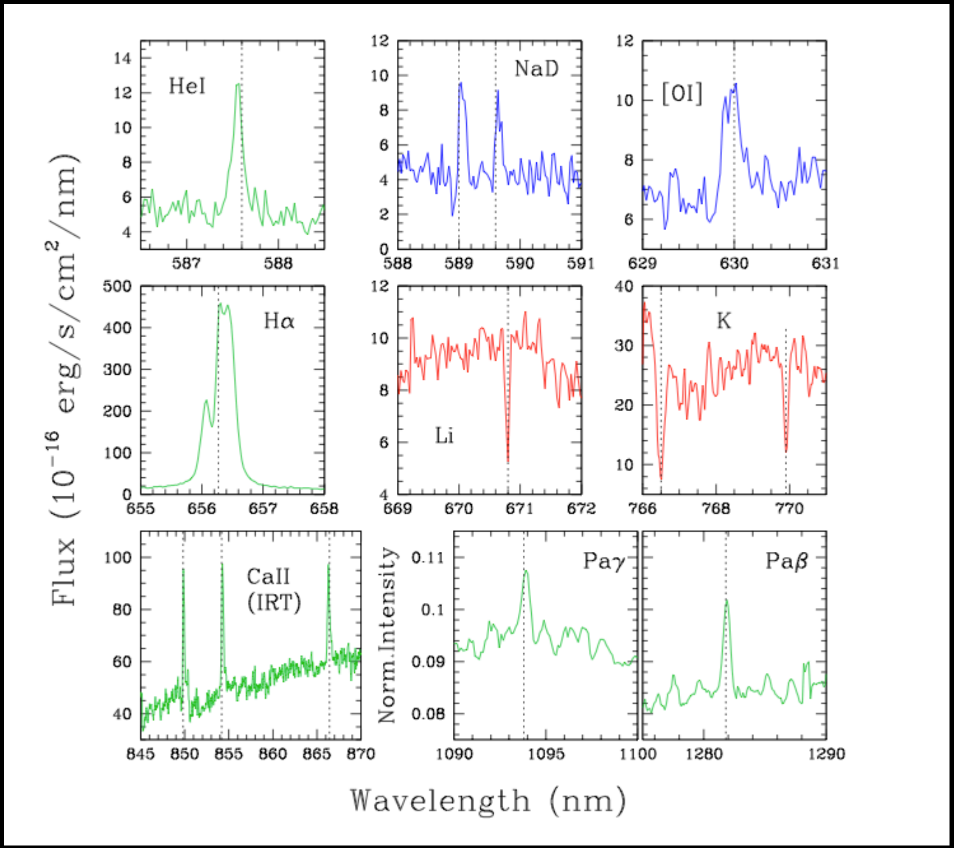


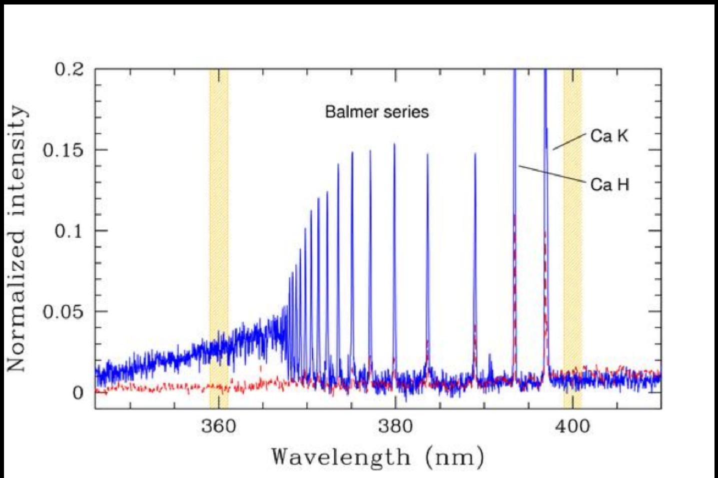
Davies et al. 2010

Caution 1: 2MASS1207-3932 (Brown Dwarf Outflow)



Brown Dwarf Accretion
(2MASS J053825.4-024241 M ~ 60 M_{jup})



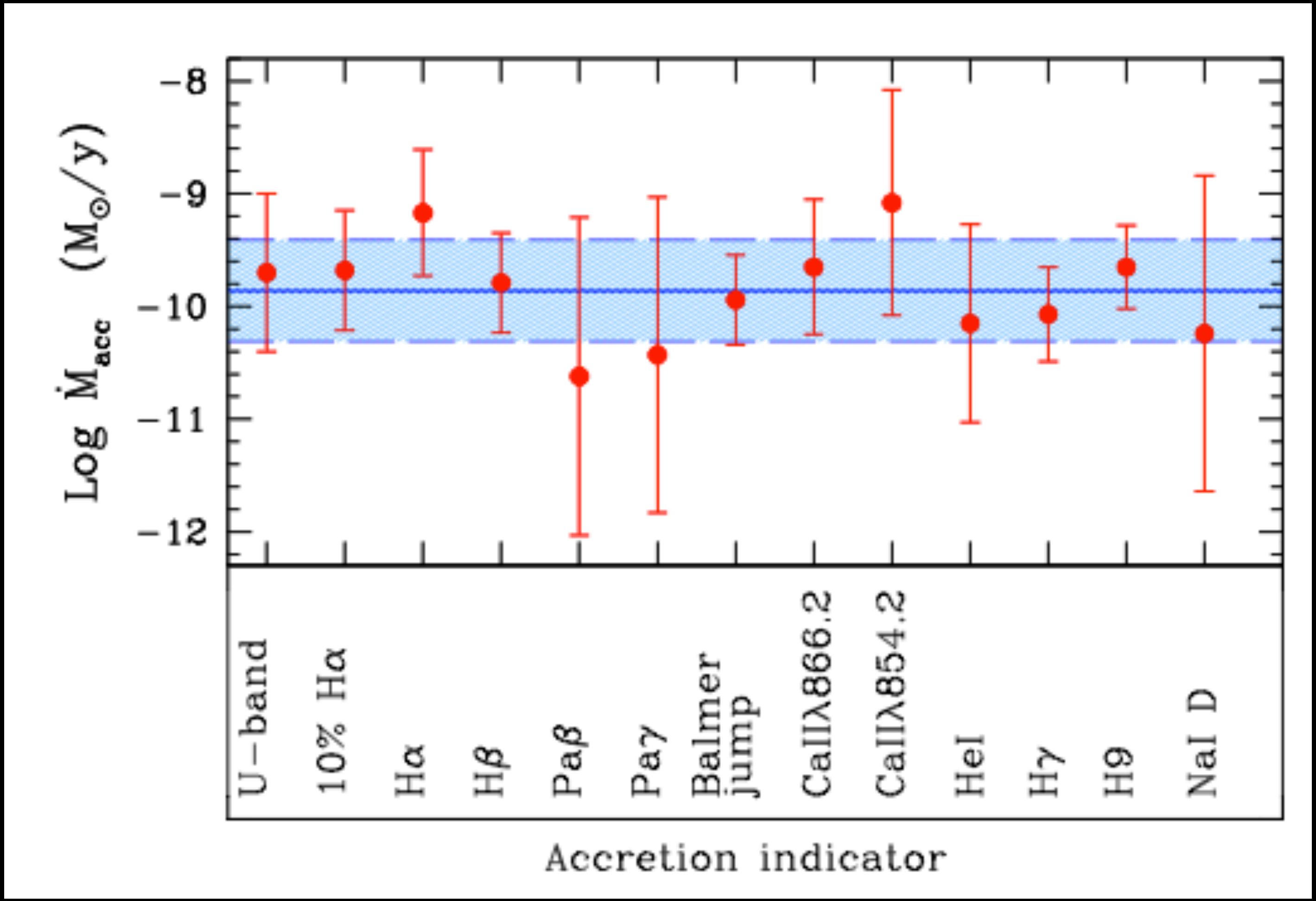


Simultaneous UV/Opt/IR Spectroscopy X-Shooter on VLT

Accretion Measures:
Luminosity of HI lines e.g. Hα, Hβ, Paβ
CaII triplet at ~ 8500 Angstroms
Balmer Jump

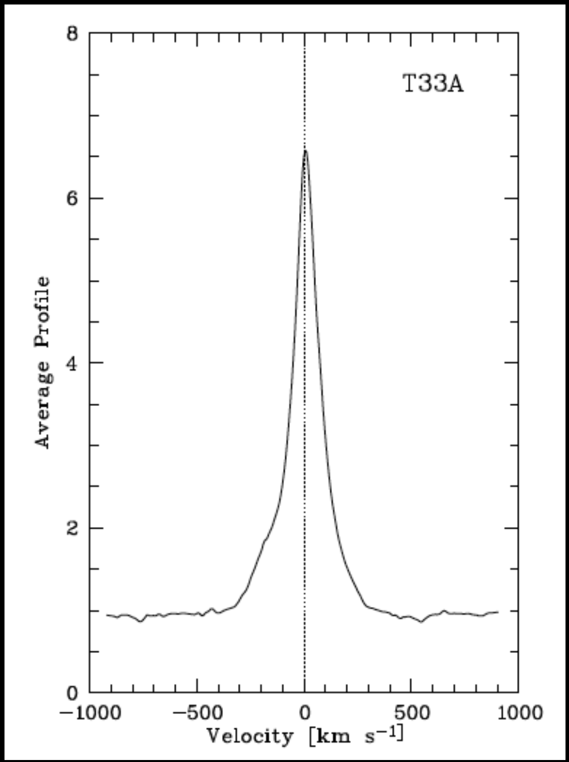
Rigliaco et al. 2011

Comparison of Accretion Proxies
(2MASS J053825.4-024241 -BD)

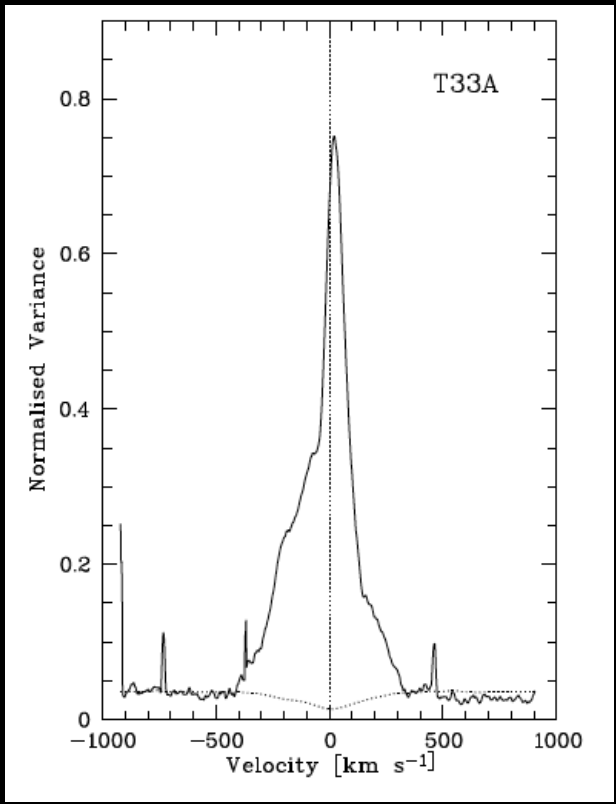


Caution 2: Variability in Accretion Profiles

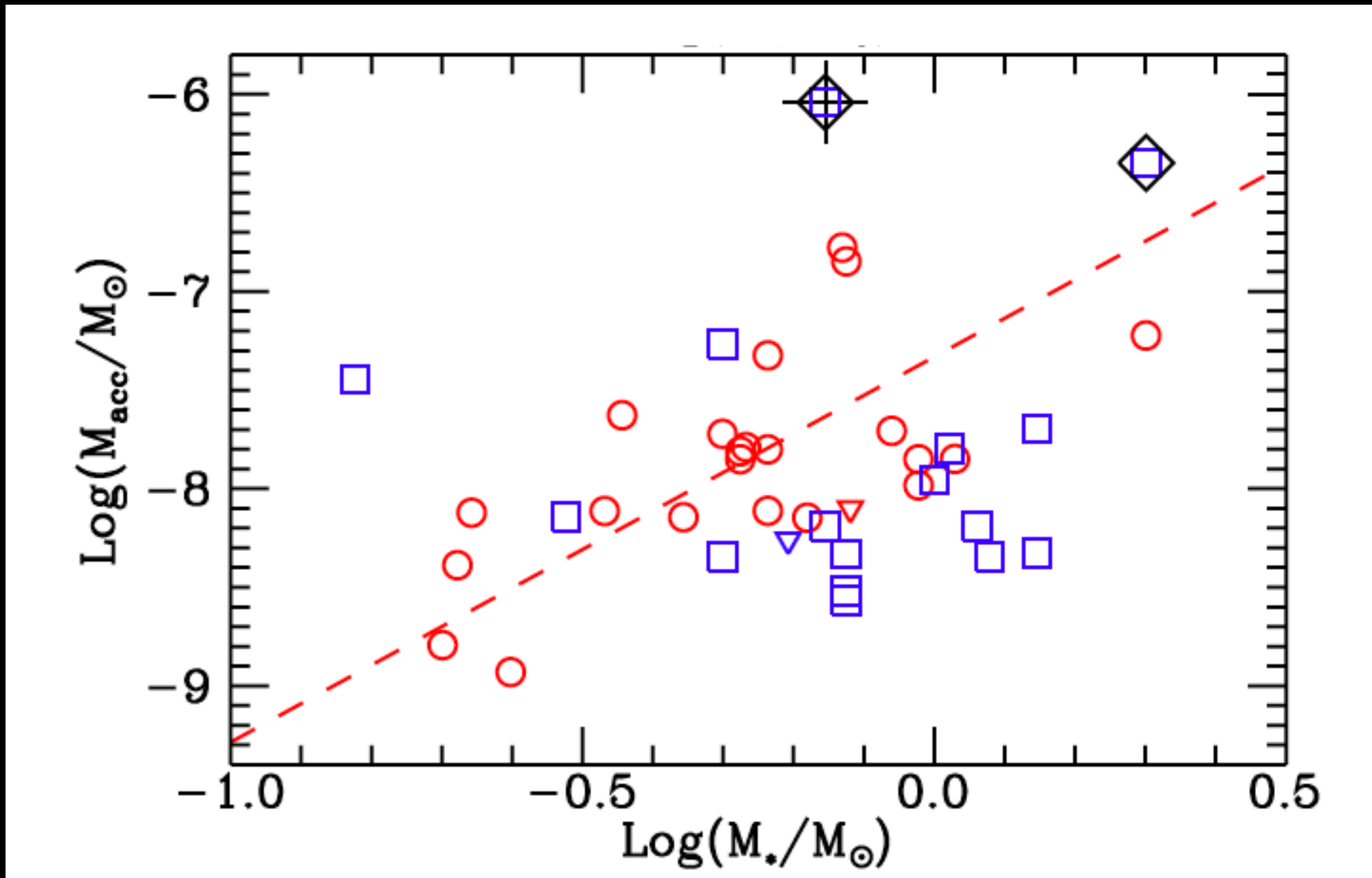
Intra-day/Intra-month/ > 1 yr time-span



Hα Average Profile



Hα Normalised Variance

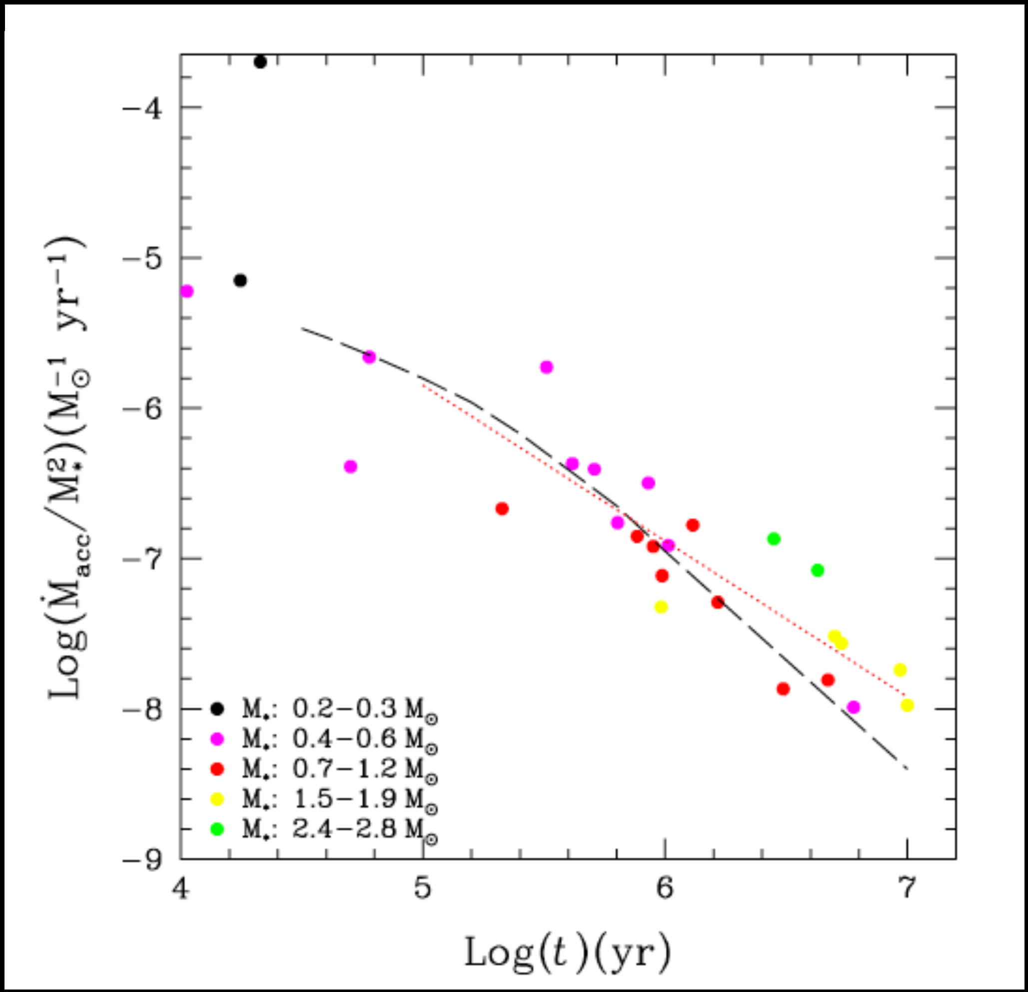


Cha I (Red) Contemp.

M_{acc} prop. M_*^2

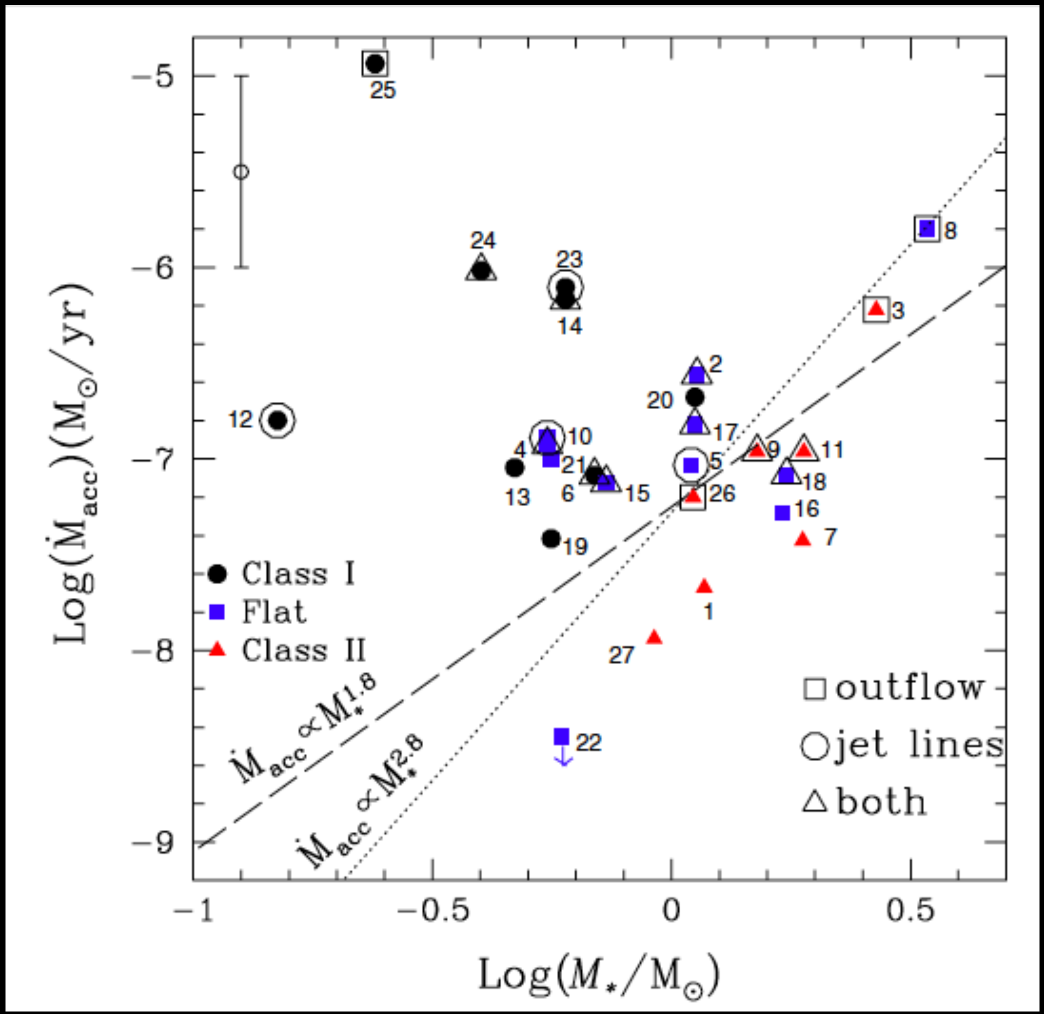
Evolution of Accretion with Time

- Normalise Accretion by M_*^2
- Find $t^{-1.2}$ decay in accretion



Underwhelmed by Accretion

- Class I accreting way too slowly to produce final mass in 10^5 yrs
- Has to be episodic major accretion events 1-5% of time

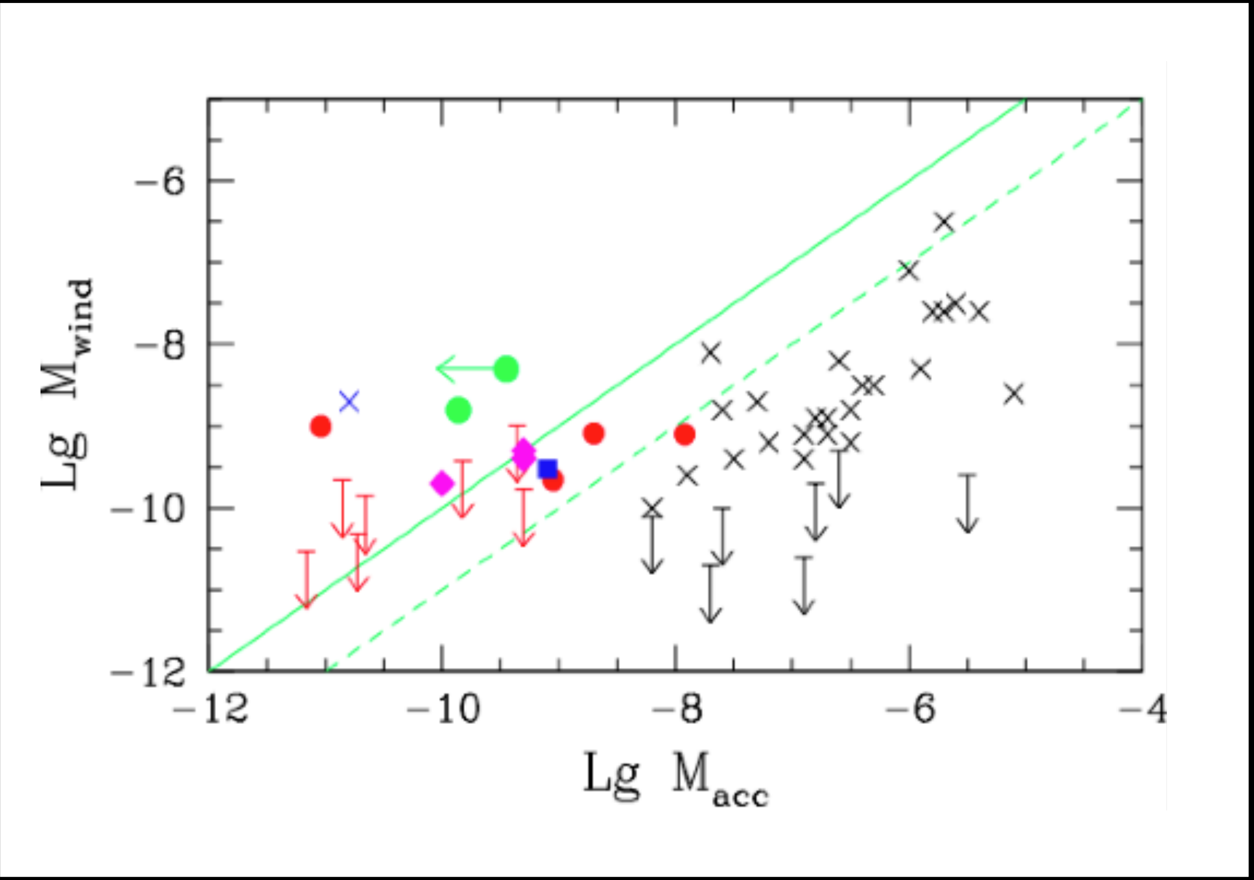


Fossil Evidence from Outflows

- Major eruptive events approximately every 10^4 yrs
- Last, say, 100 yrs, and occur 1% of the time
- This fits in with accretion studies

Mass Accretion and Mass Loss (A Mass Dependence?)

- X Hartigan et al. 1995 (TTS in Taurus)
- Herczeg & Hillenbrand 2008
- Whelan et al. 2011 (0.035-0.08 $M_\odot$)
- × Bacciotti et al. 2011 (0.13,0.5 $M_\odot$)
- Rigliaco et al. 2012 (0.16, 0.2 $M_\odot$)



Summary and Conclusions

- Outflow component can be present in accretion proxies so they are not "pure"

- Accretion rate appears to decay with ≈ $t^{-1.2}$

- Major short-term (≤ a yr) apparent "accretion variability" due to rotation

but

- Long-term dramatic changes present 1-5 % of time - consistent with large fossil outflow structures

- Outflow/Infall may increase with decreasing M_*