Accretion regimes and variability in the young open cluster NGC 2264

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Open issues in the study of accretion

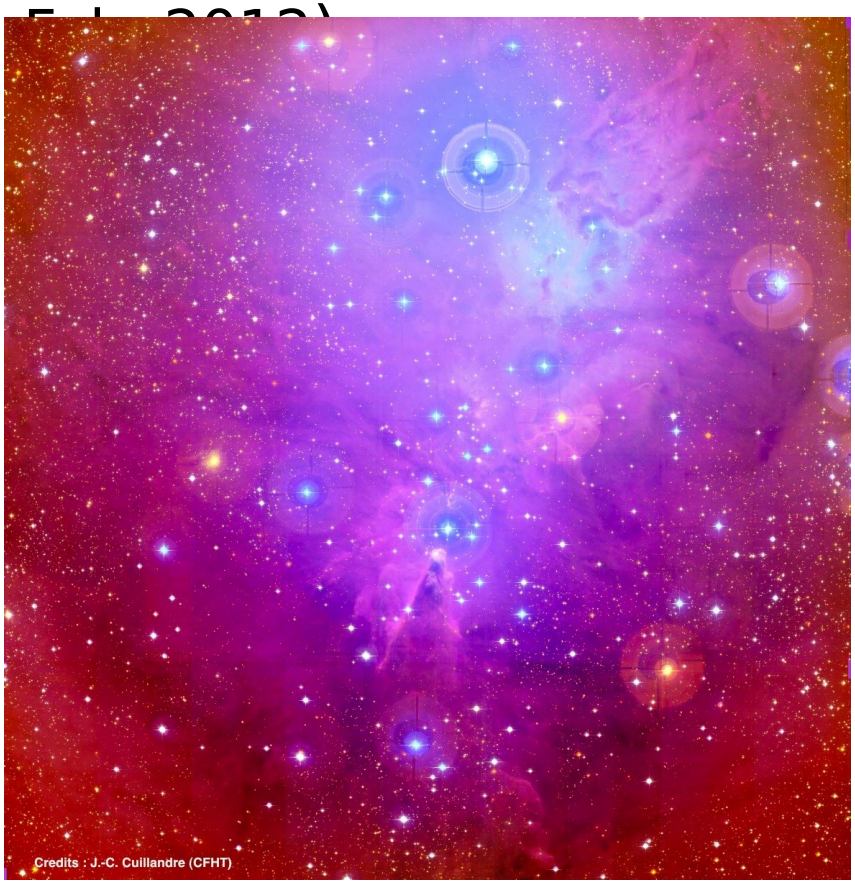
- What mechanisms regulate the accretion process in young stars?
- How stable is the accretion process?
- What are the timescales of variability for the accretion process?
- How does accretion evolve in time?
- What are the signatures of different physical mechanisms on stellar photometric variations?

Why are we interested in accretion?

- Impact on early stellar evolution (mass, angular momentum)
- Impact on disk evolution (disk-clearing)
- Impact on planet formation/migration within the disk

The *Coordinated Synoptic Investigation of NGC 2264*

CSI 2264 (P.I. = J. Stauffer & G. Micela; Dec. 2011 – [illegible])



CFHT *ugr* color picture of NGC 2264 (credits: J.-C. Cuillandre, CFHT)

NGC 2264

- Distance: 760 pc
- Age: 3 Myr
- <AV>: < 0.4 mag
- Population: >1000 known members (disk-bearing objects are about 40%)

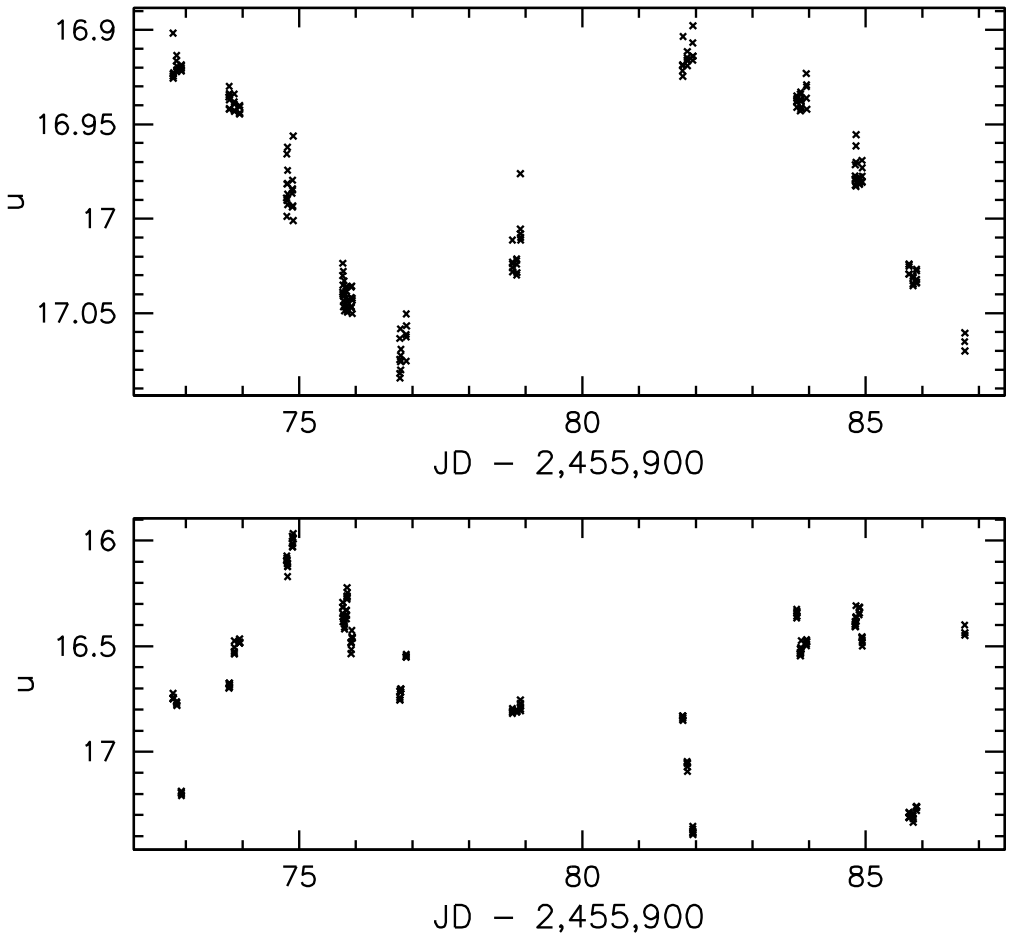
Observing campaign

- Spitzer: 30 days, 3.6 + 4.5 μm
- CoRoT: 40 days, optical
- Chandra: 3.5 days, X-rays
- MOST: 40 days, optical

+

- **CFHT**: u,r
- VLT/Flames: 20 epochs

CSI 2264 @ CFHT:
UV variability of young stars in NGC 2264



CFHT *u*-band light curves of two NGC 2264 members

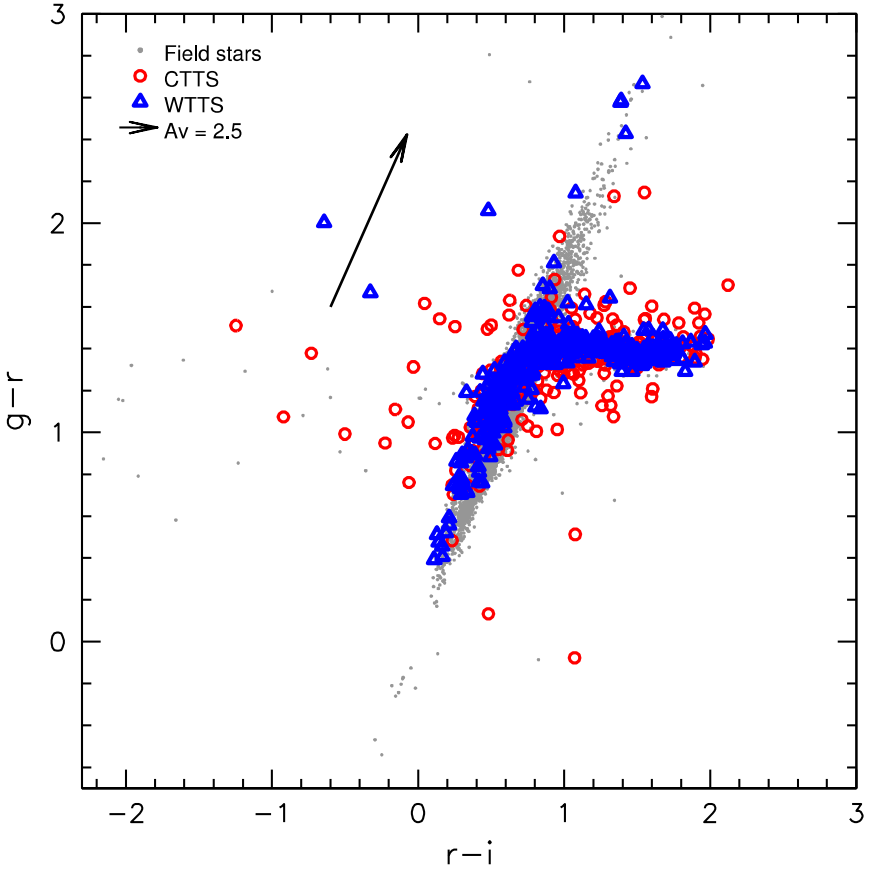
NGC 2264 with CFHT/MegaCam:

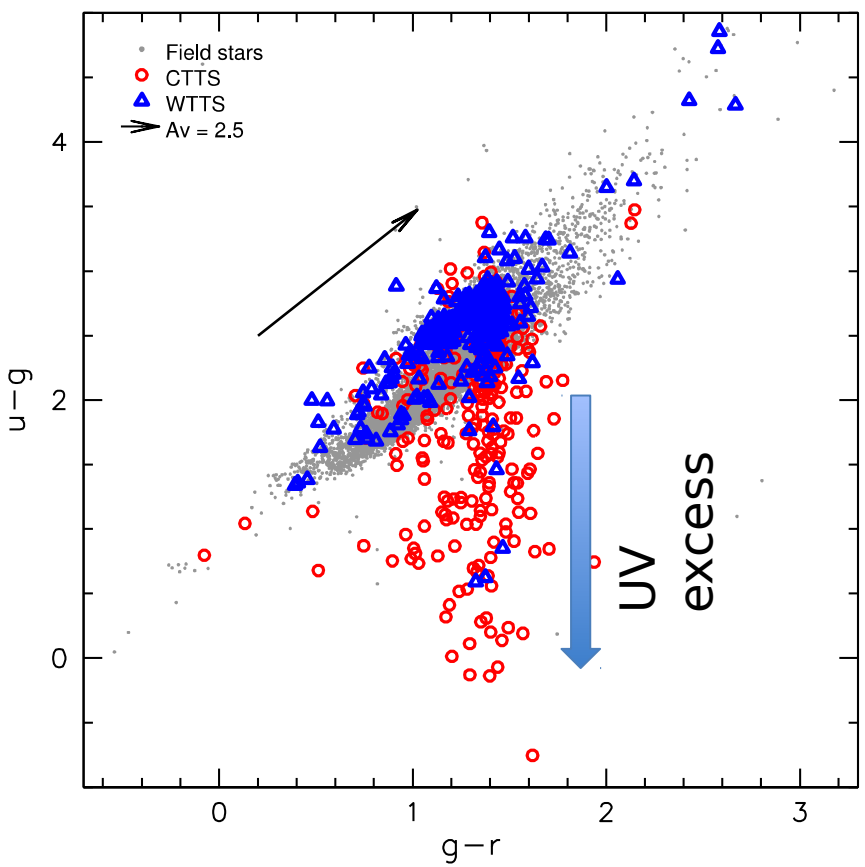
- **deep u,g,r,i mapping**
  - 9000 sources in the FOV
  - > 750 members, 40% CTTS (A.M. Cody, E. Flaccomio, L. Venuti)
  - mass range 0.1-2.0 M☉
- **u+r monitoring**
  - 11 observing nights (7 photometric) from Feb. 14 to 28, 2012
  - several measurements per night (cadence 20 min ÷ 1.5 h)

Goal: *investigate accretion variability throughout the cluster from the UV excess*

Colors of PMS stars in NGC 2264

Venuti et al. 2014, A&A 570, A82



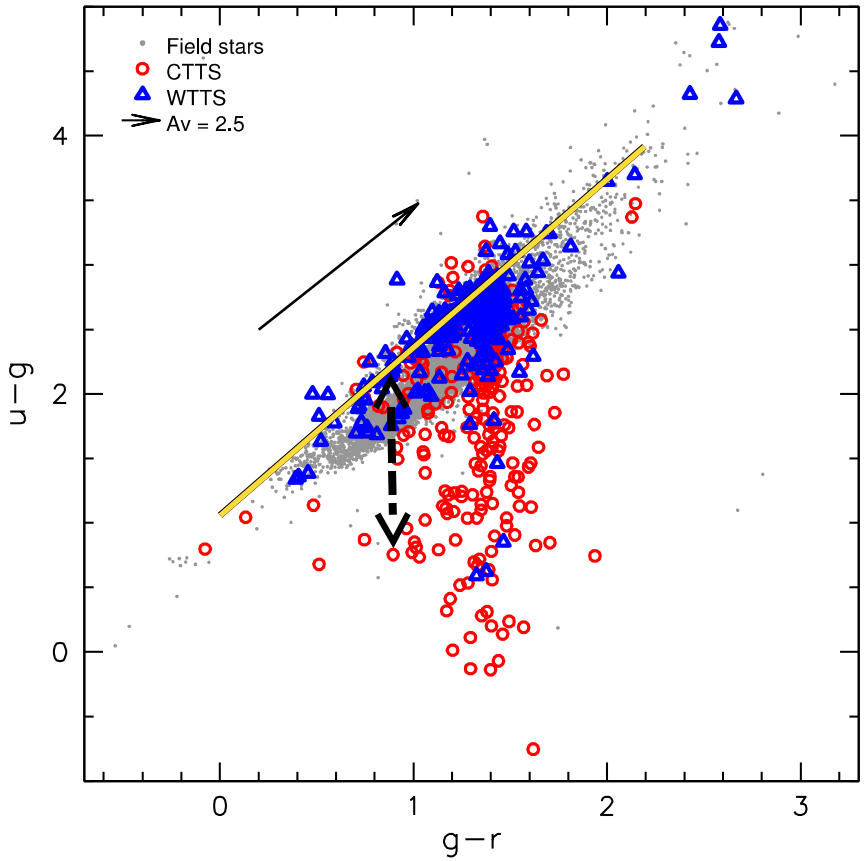


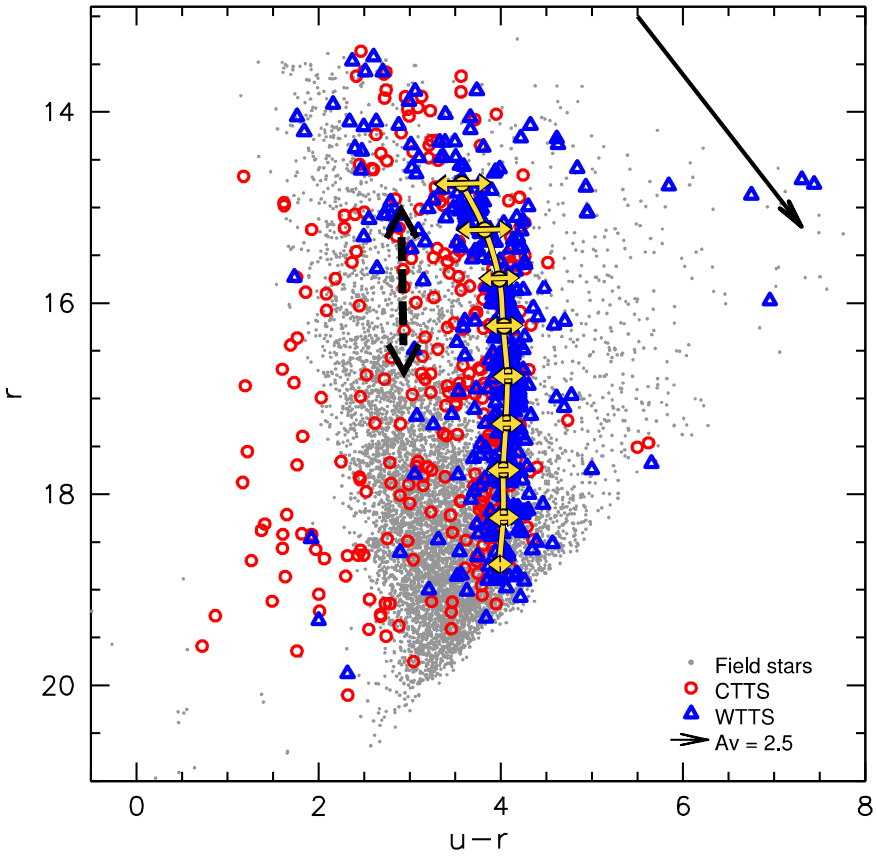
- Optical colors of accreting and non-accreting members are consistent with each other and with those of field stars

- Several accreting objects (CTTS) exhibit a **UV excess**, i.e., bluer u-g colors than non-accreting members and field stars

Measuring the UV excess

Venuti et al. 2014, A&A 570, A82

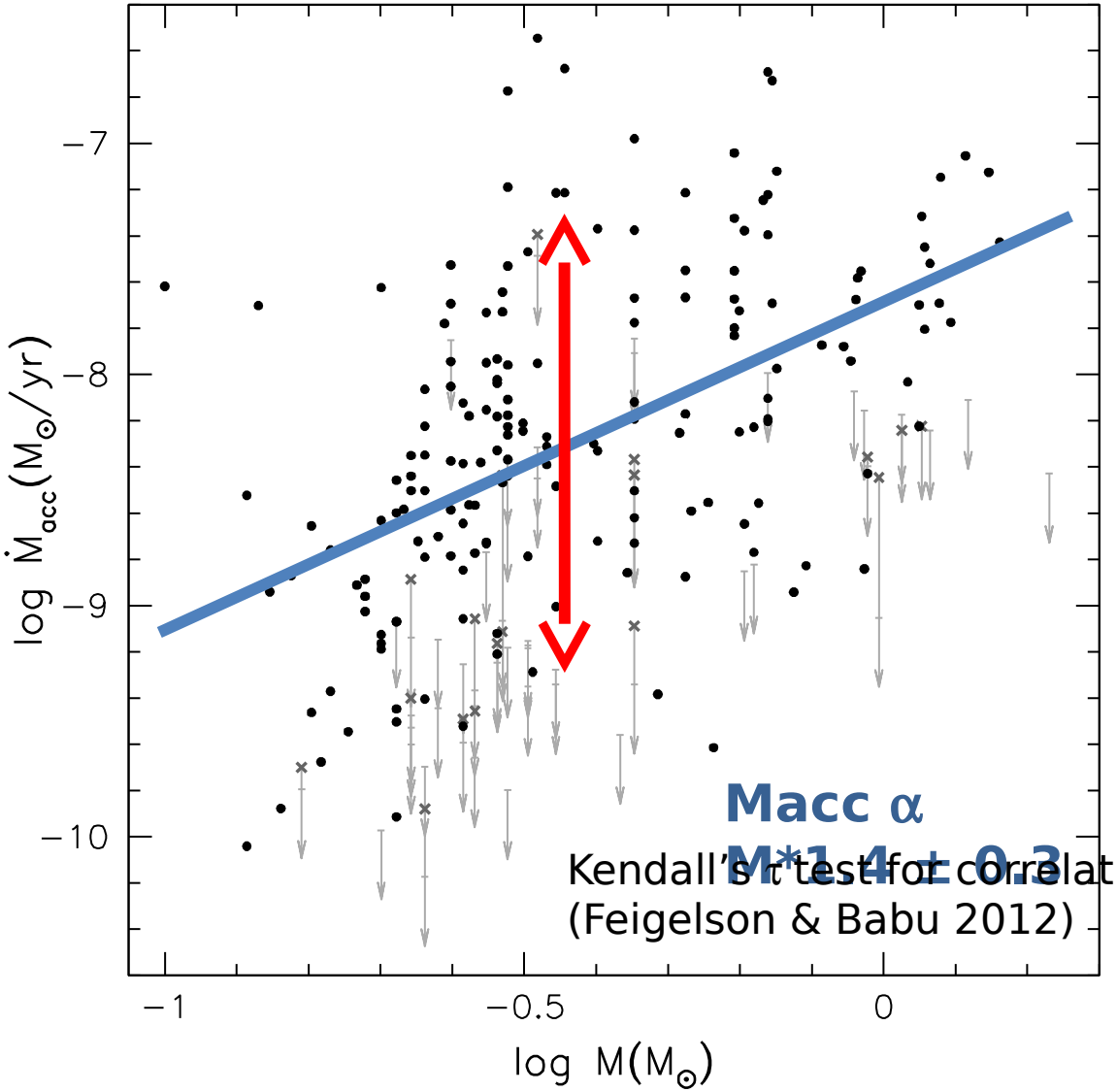




- WTTS define the reference colors for non-accreting young stars (includes chromospheric activity)
- The dispersion of WTTS around the reference sequence is a measure of the sensitivity

Accretion in NGC 2264

Venuti et al. 2014, A&A 570, A82



Macc measurements:

- *u*-band excess measured relative to WTTS
- UV excess -> Lacc -> Macc
- detection limits estimated from the scatter of WTTS colors around ref. sequence
- *Macc measured for 240 CTTS*

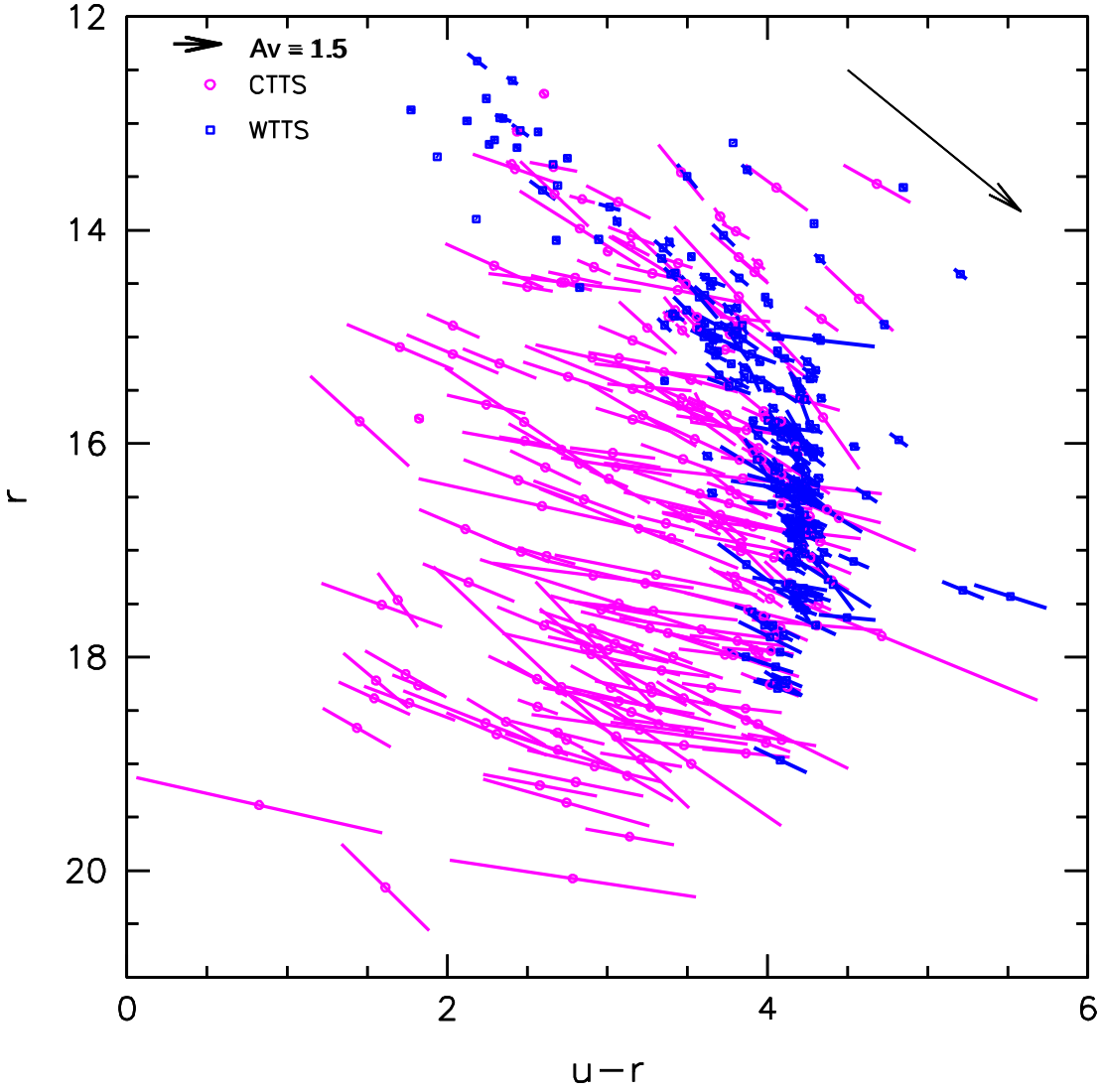
Macc – M* relationship:

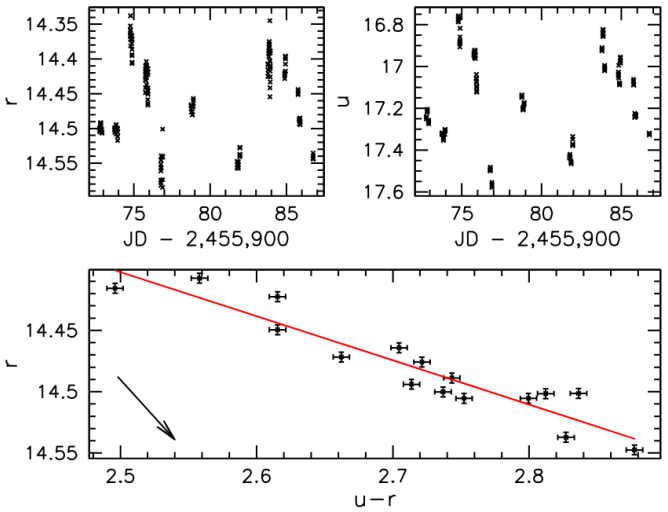
- statistical correlation to >5σ (Kendall's τ test)
- significant spread (up to 2 dex) in Macc at any given stellar mass

Can the scatter be due to accretion variability?

UV excess and variability

Venuti et al. 2015, A&A 581, A66

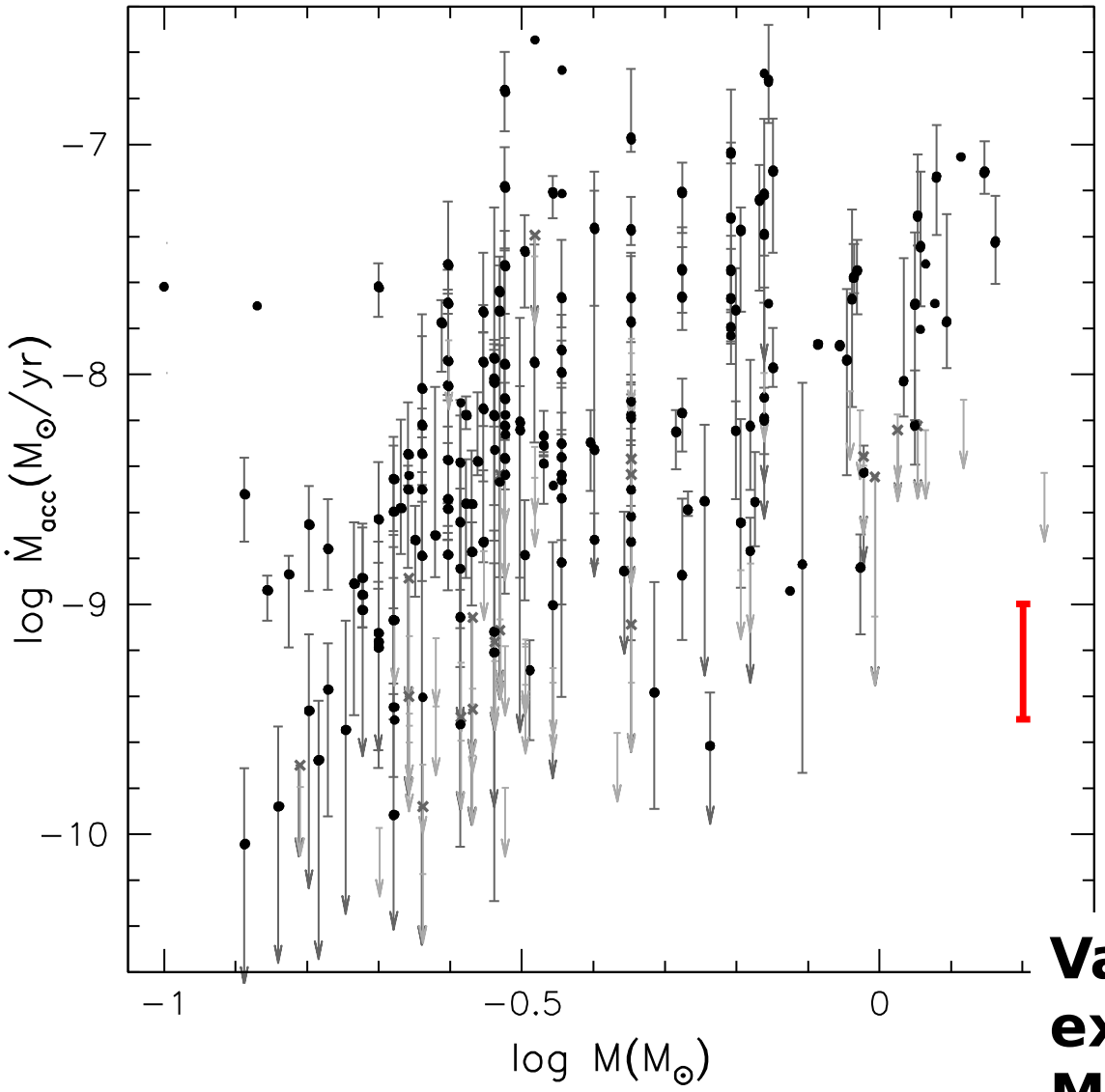




- **Variability bars**:
  - Δ(u-r) = (u-r)max – (u-r)min
  - Δr = rmax – rmin
- CTTS typically exhibit significantly larger variability than WTTS and a variable UV excess

Macc variability on week timescales

Venuti et al. 2014, A&A 570, A82



Variability bars:

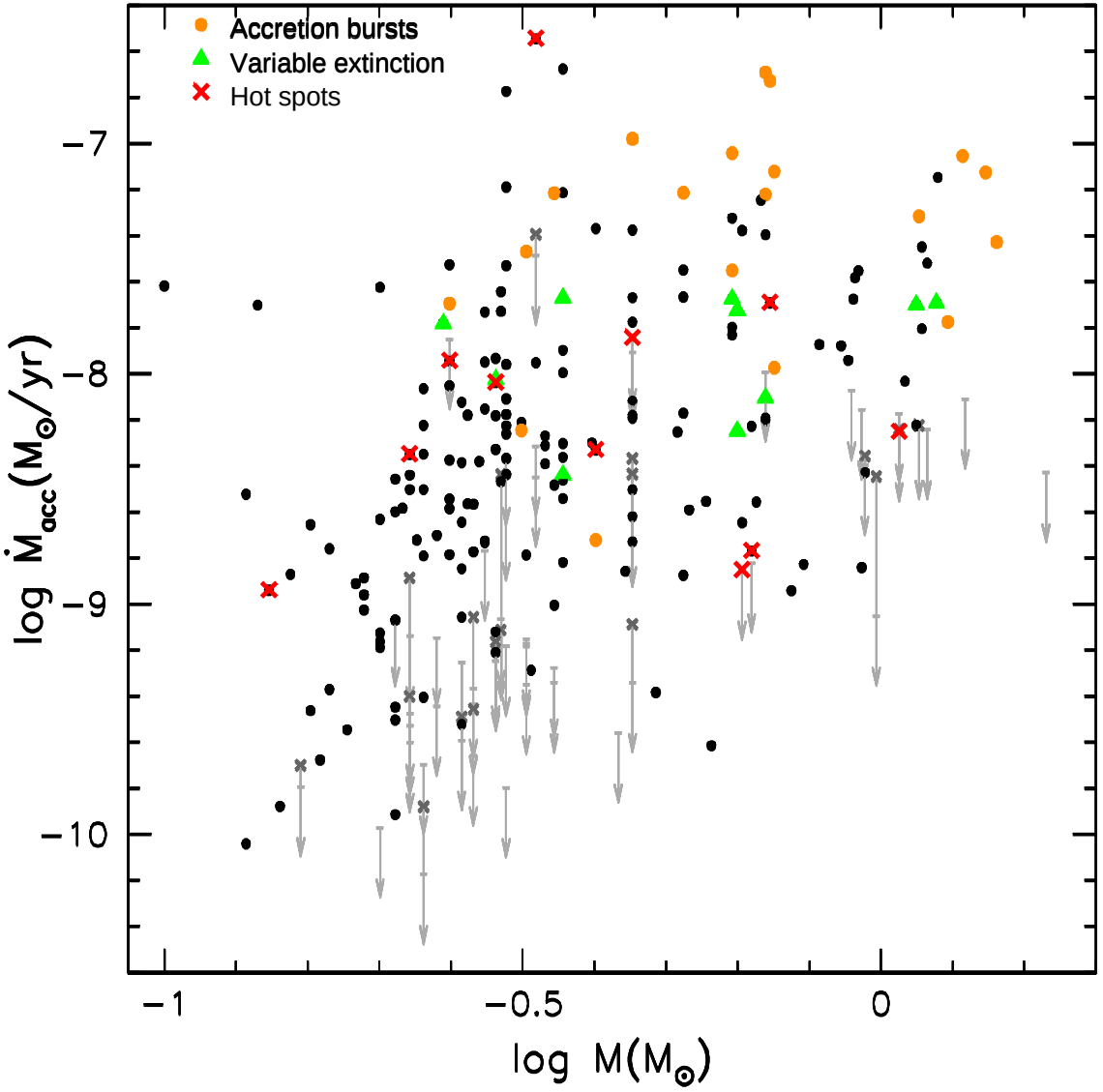
- encompass 17 epochs over 2 weeks
- connect maximum-minimum Macc detected during monitoring

Average variability on week timescales: 0.5 dex

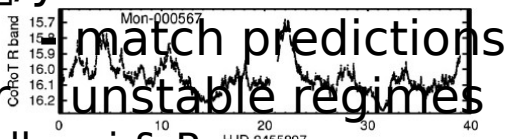
<< spread in Macc at a given stellar mass

Variability does not explain the spread in Macc at a given M*

Origin of Macc spread: different accretion regimes?



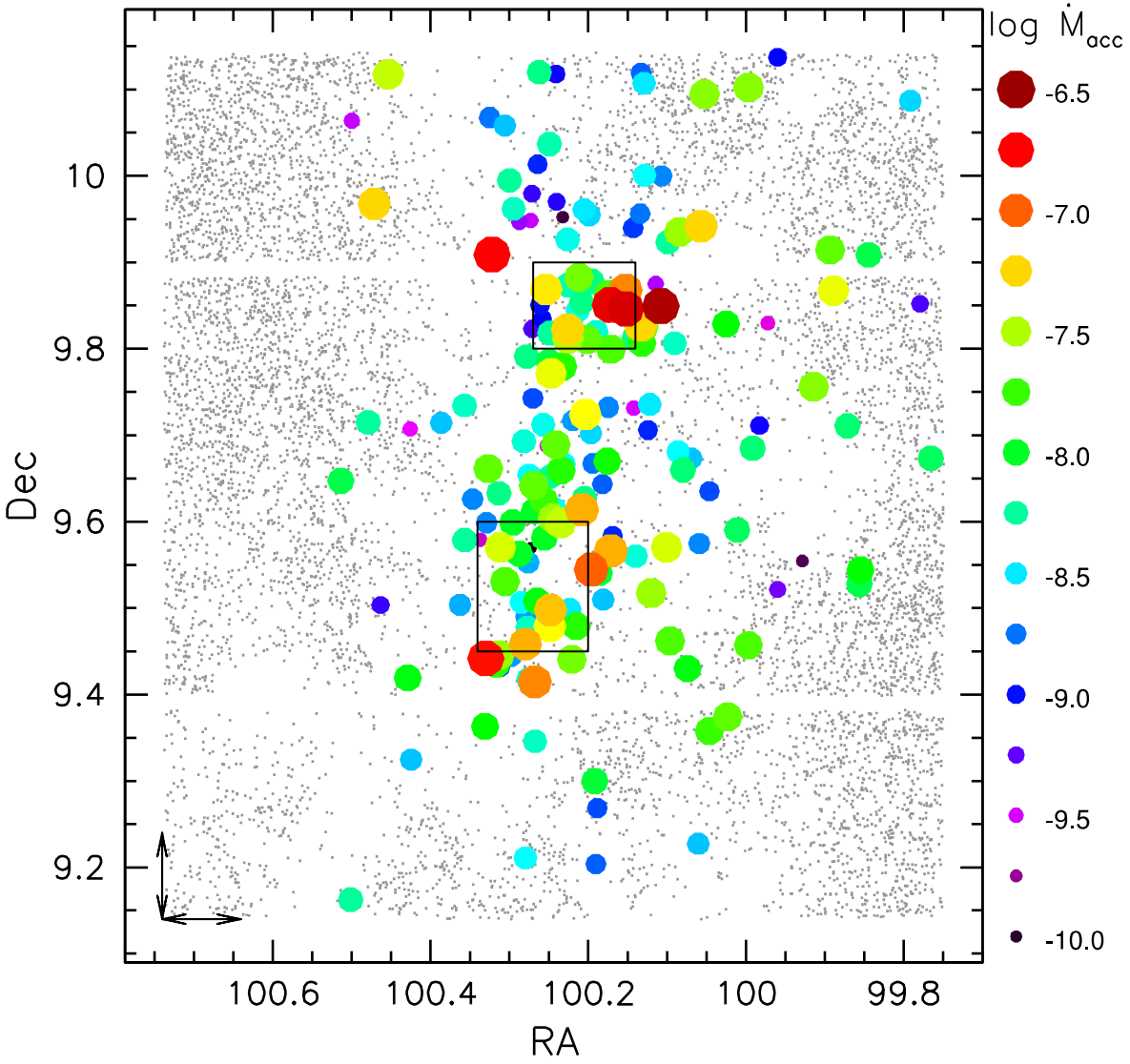
1. **Bursters (Stauffer+2014):**
   - stochastic accretion
   - Macc ≈ 7x10-8 M□/yr
   - match predictions for unstable regimes (Kulkarni & Romanova 2008)



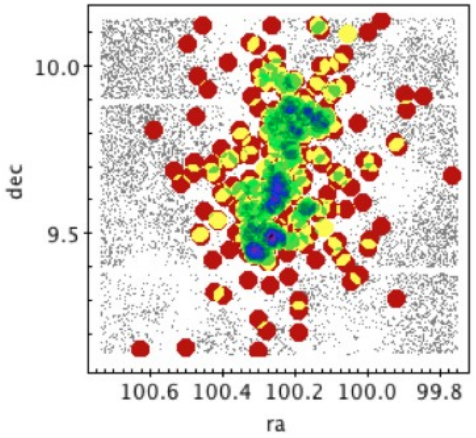
3. **Variable extinction (McGinnis+2015):**
   - circumstellar occultation
   - Macc ≈ 2x10-8 M□/yr
   - periodic -> AA

Origin of Macc spread: cluster evolution?

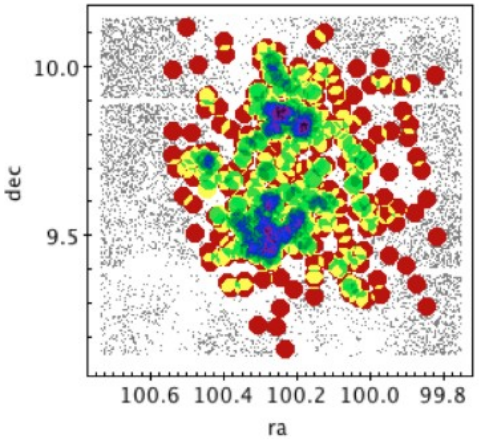
Venuti et al. 2014, A&A 570, A82



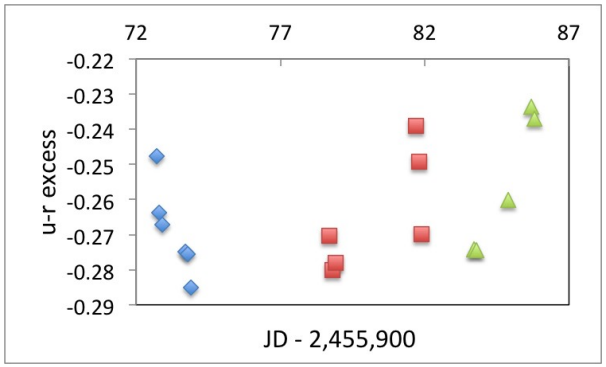
CTTS



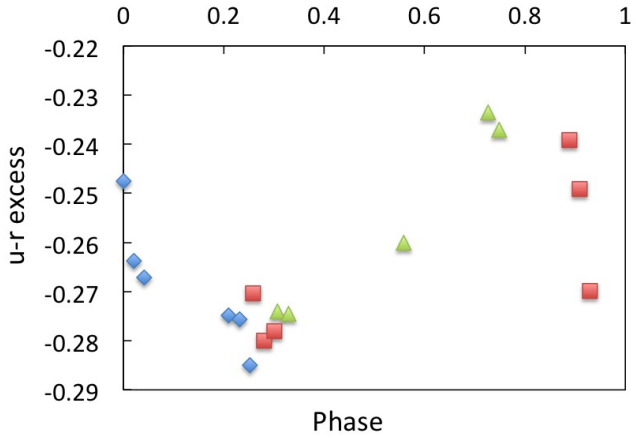
WTTS



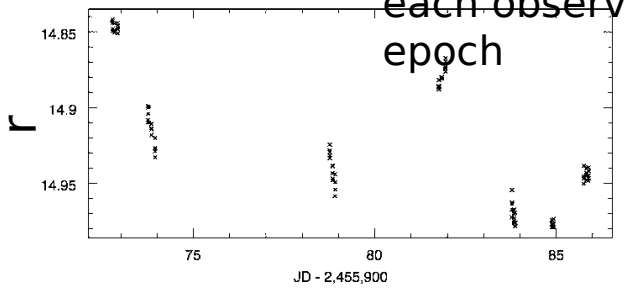
Modulated vs. intrinsic variability in CTTS

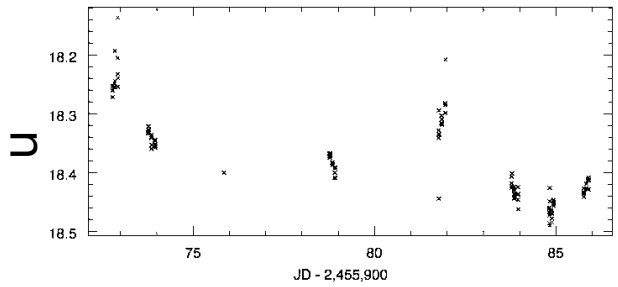


Folding in phase at the stellar rotation period



UV excess measurement at each observing epoch



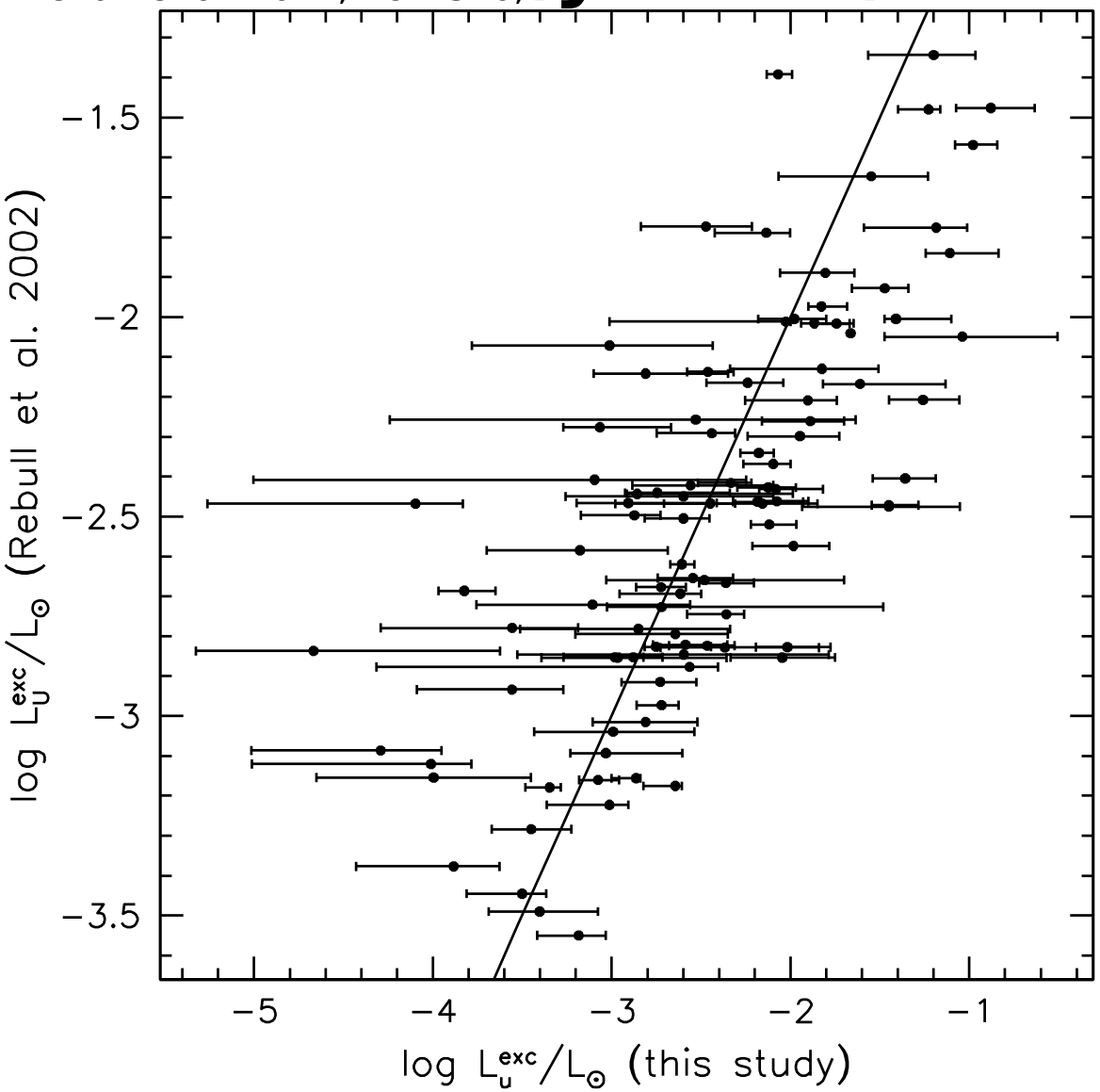


- In each phase bin, measurement of intrinsic *rms* variability within the same cycle (hour timescale) and from cycle to cycle (day timescale)
- Sum of hour+day intrinsic variability and comparison with the total amplitude of the phased UV excess curve

Up to 75% of the variability detected on week timescales can be explained with rotational modulation

Long-term variability (years): CTTS

Venuti et al. 2014, A&A 570, A82



- Rebull et al. (2002): single-epoch survey of accretion from U-band
- Venuti et al. (2014): typical LUV value and variability bar on week timescales

Large-epoch difference on the average consistent with mid-term variability

Timescales of weeks dominate the picture of variability up to baselines of years

Conclusions

- Homogeneous survey of accretion variability for about 240 CTTS in NGC 2264 from UV excess monitoring:

  - The average Macc correlates with M* (**Macc α M*1.4±0.3**)
  - A **variety of accretion regimes** are detected across the cluster; this may reflect **different accretion mechanisms** as well as **evolutionary spread** among cluster members
  - Unstable accretion mechanisms may prevail at the highest Macc
  - Stable regimes may be found at more moderate accretion rates
  - **Timescales of weeks** dominate the variability of both WTTS and CTTS up to baselines of years

Thank you!