YSOVAR: Mid-infrared Variations in Young Stars

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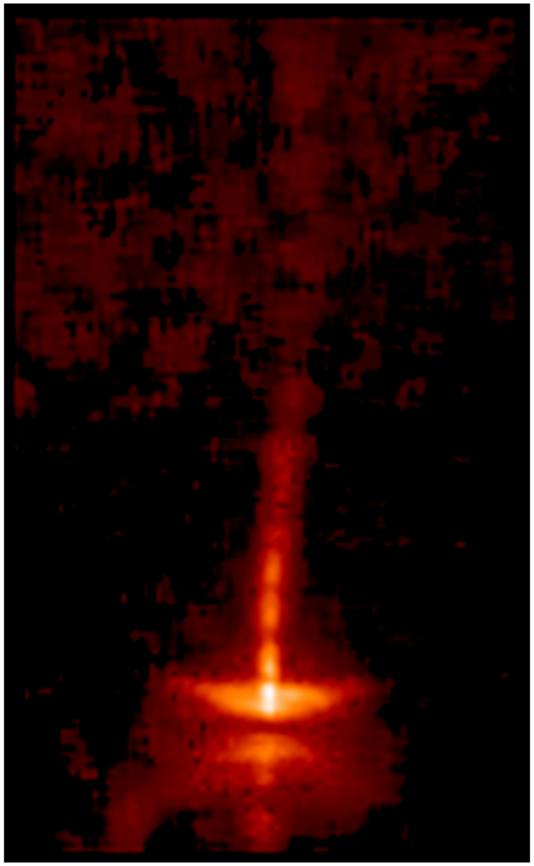
HH 30



HH30 w/ HST/ WFPC2, about 1 frame per year. (Light beam likely P~7.5d.) (disk dia ~ 450 AU)

(Duran-Rojas et al. 2009; Watson & Stapelfeldt 2007)

Young Stars Vary

- Young star environment is incredibly dynamic.
- (Optical) variability was one of the original, defining characteristics of YSOs (Joy 1945; Herbig 1952).
- Much of literature YSO monitoring work is in optical.
- They also vary in X-rays (e.g., Feigelson & Montmerle 1999),
- And in radio (e.g., Güdel & Benz 1993; Choi this morning),
- And in UV (e.g., Rydgren & Vrba 1983),
- And they vary in IR too! Some (quite laborious!) work done indicating YSOs vary in IR (1994-2005); only one (with ISO; Juhasz et al. 2007) that sought variability and did simultaneous ground monitoring.

IC1396A (with Cold Spitzer)

- Morales-Calderon et al. (2009): First *high-cadence* monitoring of young stars in IRAC bands (3.6, 4.5, 5.8, 8 um).
- More than half of the YSOs showed variations, from ~0.05 to ~0.2 mag, on variety of timescales → physical interpretations.
- Larger amplitude variables tend to be younger (more embedded)

Warm Spitzer

- Cryogen gone 15 May 2009 22:11:27 UTC.
- Telescope passively remains at ~30 K.
- IRAC 3.6 and 4.5 μm channels operate ~as before; 120-1000x faster than VLT/Keck!
- NASA has committed to fund warm operations at least through FY14 (hoping for more).
- Cy10: plan to solicit 7000-10000 hours of Exploration Science+Large+Small GO. CP out May 2013, due August 2013. (White papers for programs needing >2000 hrs due May 1.)
- GREAT for YSO photometric monitoring: *Stable*, *sensitive*, wide-field, no day-night aliasing, bands see photospheres & dust, and 7-8000 hrs/year of "just" two channels.

http://ysovar.ipac.caltech.edu/

What is YSOVAR?

- Originally: Cy6 Exploration Science Spitzer Program: YSO VARiability
- 550 hours
- First sensitive, wide-area, MIR (3.6 and 4.5 μm) time series photometric monitoring of SFRs on t~hours to years.
- Includes ~1 square degree of Orion plus smaller regions in 11 other well-known SFRs: AFGL 490, NGC 1333, Mon R2, NGC 2264, Serpens Main, Serpens South, GGD 12-15, L1688, IC1396A, Ceph C, IRAS 20050+2070
- (Cy8) YSOVAR II == CSI:2264, Coordinated Synoptic Investigation of NGC 2264, e.g., Spitzer+CoRoT+MOST+Chandra for Dec 2011.
- (We also include under the YSOVAR umbrella some affiliated programs such as original IC1396 work, Stauffer's Cy7 Orion follow-up, Plavchan's Cy6 Rho Oph intensive monitoring, Covey's CXO/Spitzer Ceph C monitoring, Forbrich's GGD 12-15 CXO/Spitzer monitoring.)
- → ~750 hours total of Spitzer time monitoring young stars
- Stauffer, Rebull, Morales-Calderon, Cody, et al.

YSOVAR Science Goals

- Provide empirical constraints characterizing the interaction between the star, inner disk/envelope, and accretion flows (including non-steady accretion).
- Specifically study variability properties of embedded (Class I) objects (11 smaller “YSOVAR-classic” clusters).

Some progress…

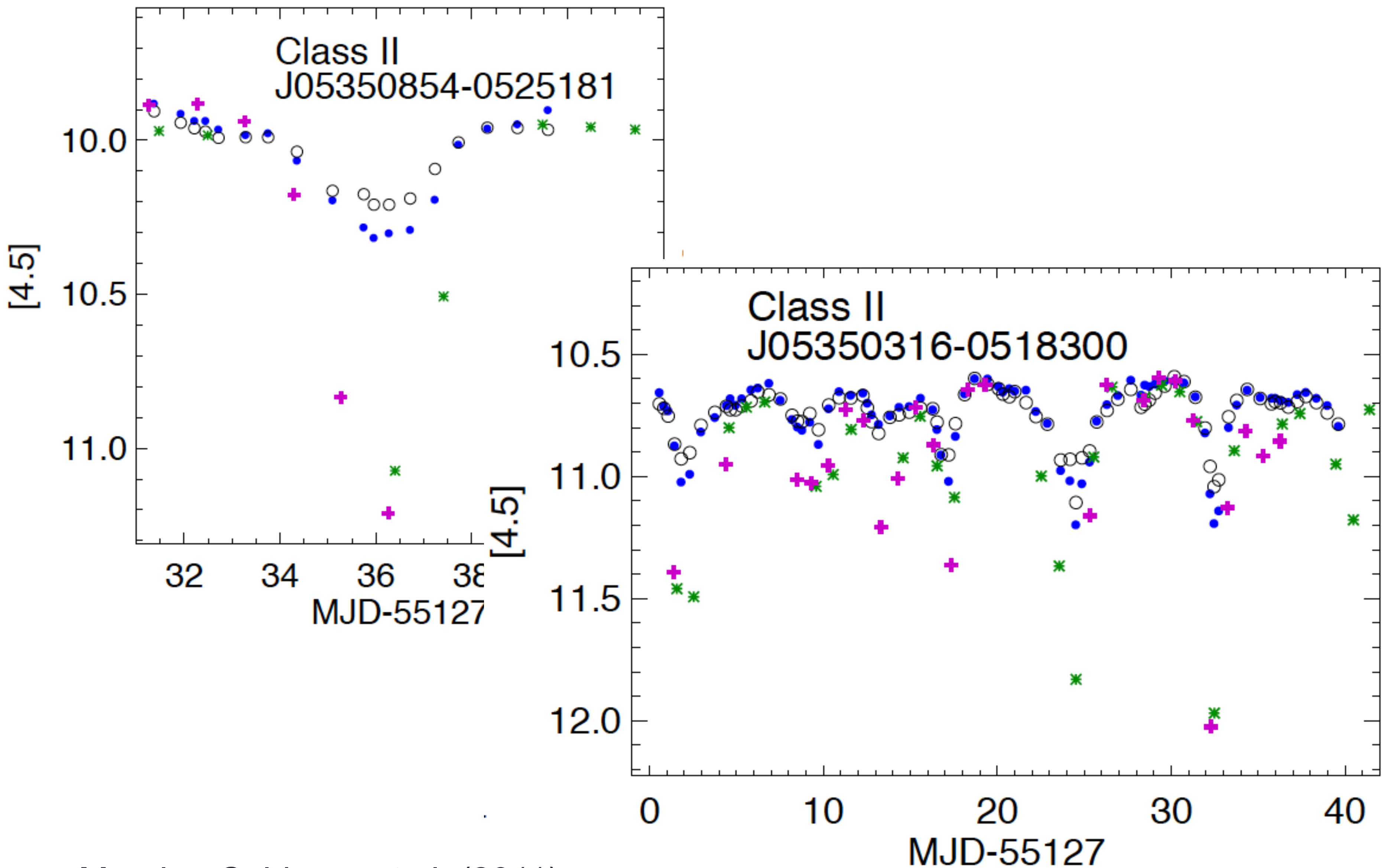
- Orion, year one : Morales-Calderon et al. (2011) identified “dipper stars” and others; Morales-Calderon et al. (2012) identified eclipsing binaries.
- CSI:2264 : HUGE amount of data. CoRoT makes huge difference in how we can interpret the light curves; have been able to classify objects. High precision photometry, high resolution spectra; timescales from <1 min to >1 mon.
  - Stauffer et al., 2013 in prep
  - Cody et al., 2013 in prep
- The 11 (10) smaller clusters:
  - Papers on each cluster – NGC 1333 (Rebull et al. 2013 in prep)
  - Statistics on the ensemble (Rebull et al. 2013 in prep)

“Dipper” objects

- Stars with narrow flux dips, t~days, typically >1 seen over our 40d window.
- Like AA Tau…
- Require >1 epoch unless corroborating data at another band.
- Optical or J band deeper by at least 50%.
- Continuum flat enough that dip “stands out.”
- 38 Class I or II objects (~3%) in our Orion Year 1 set are dippers.
- Interpret as structure in the disk (clouds, warps).

Morales-Calderon et al. (2011)

•=[3.6], o=[4.5], * or * =J, +=Ic

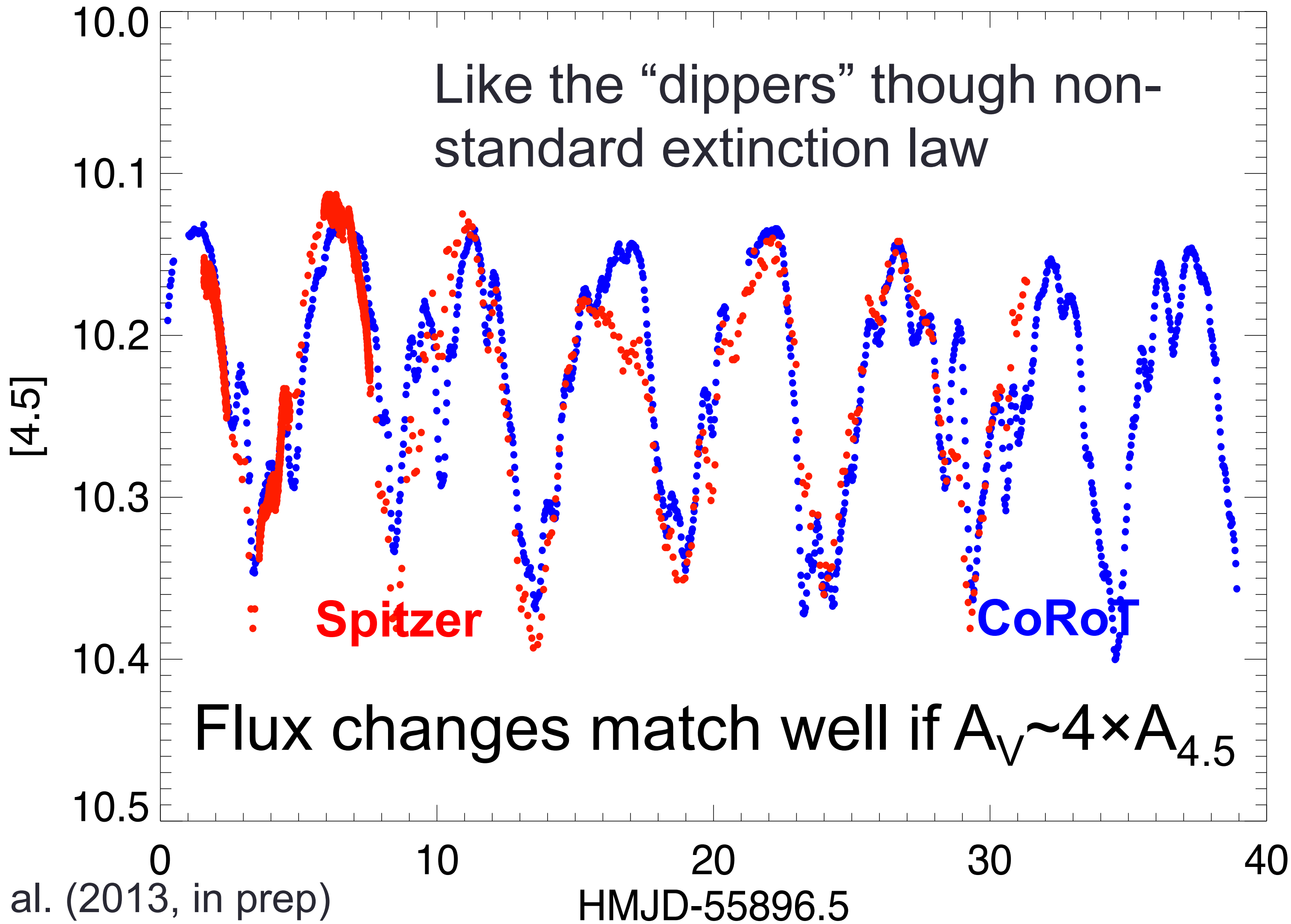


Morales-Calderon et al. (2011)

Questions about dippers

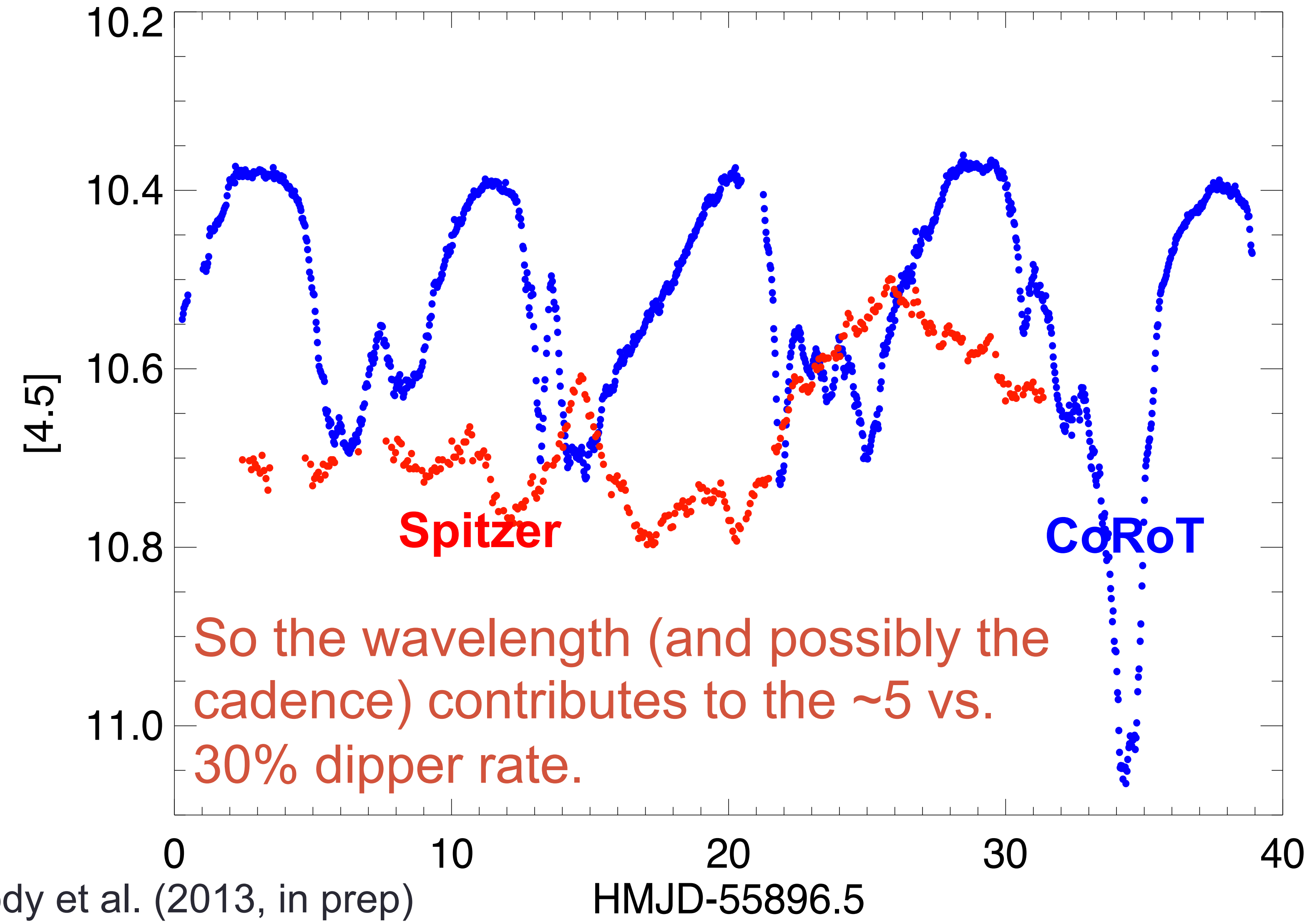
- Disk must be seen at relatively high (and relatively narrow range of) inclinations to do this, so expect that they are ~rare.
- YSOVAR Orion (year 1): Morales-Calderon et al. (2011) finds overall fraction likely ~5% (2011).
- First CoRoT short run (2008) on NGC2264: Alencar et al. (2010) finds overall fraction likely ~30%.
- What's going on? Different ages of stars (Orion vs. NGC 2264)? Different wavelengths (optical vs. IR)? Different cadences? (Different definitions of the category?)

Some patterns: dust obscuration



Cody et al. (2013, in prep)

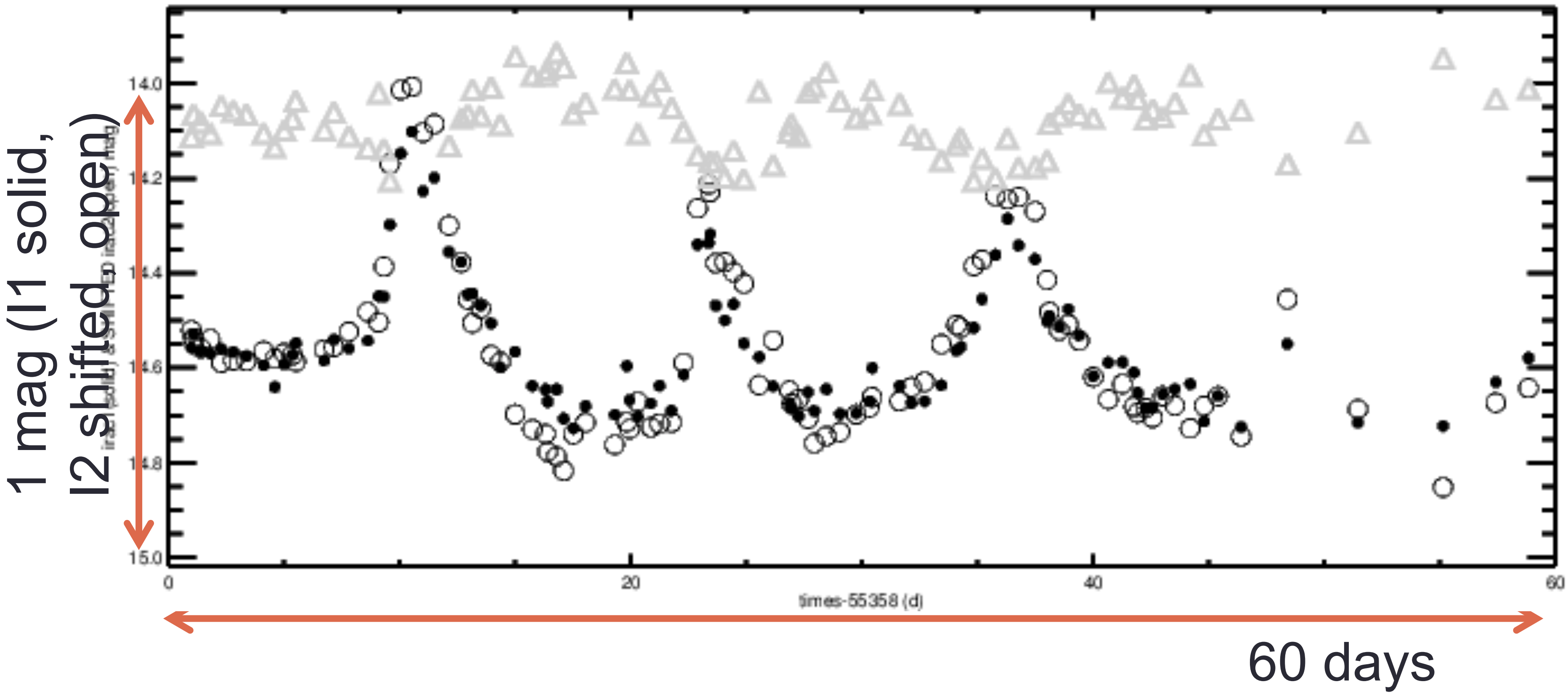
Some patterns: NOT dust…



Cody et al. (2013, in prep)

IRAS 20050 Class I source

Similar to other Class I sources in Orion!



Young stars vary in the MIR

- Do young stars vary in the MIR? Yes, a lot.
- On what timescales? Pretty much anything you can measure.
- What's causing it? And where is the emission coming from? Some is disk structure. We think we can sometimes see accretion, binaries, other things too.
- **Simultaneous multi-wavelength data is apparently critical** for understanding what is going on.