YSOVAR: Mid-infrared Variations in Young Stars

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HH 30 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

- Telescope passively remains at \(~30\) K.
- IRAC 3.6 and 4.5 \(\mu\)m channels operate \(~as before; 120-1000x faster than VLT/Keck!\)
- NASA has committed to fund warm operations at least through FY14 \(\text{(hoping for more).}\)
- Cy10: plan to solicit 7000-10000 hours of Exploration Science+Large+Small GO. CP out May 2013, due August 2013. \(\text{(White papers for programs needing >2000 hrs due May 1.)}\)
- GREAT for YSO photometric monitoring: \textit{Stable, sensitive}, wide-field, no day-night aliasing, bands see photospheres & dust, and 7-8000 hrs/year of “just” two channels.
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, Cepheus 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 Cepheus C monitoring, Forbrich’s GGD 12-15 CXO/Spitzer monitoring.)
• \(\Rightarrow\) ~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, + = l c

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.
- 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

Like the “dippers” though non-standard extinction law

Flux changes match well if $A_V \sim 4 \times A_{4.5}$

Cody et al. (2013, in prep)
Some patterns: NOT dust...

So the wavelength (and possibly the cadence) contributes to the ~5 vs. 30% dipper rate.

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.