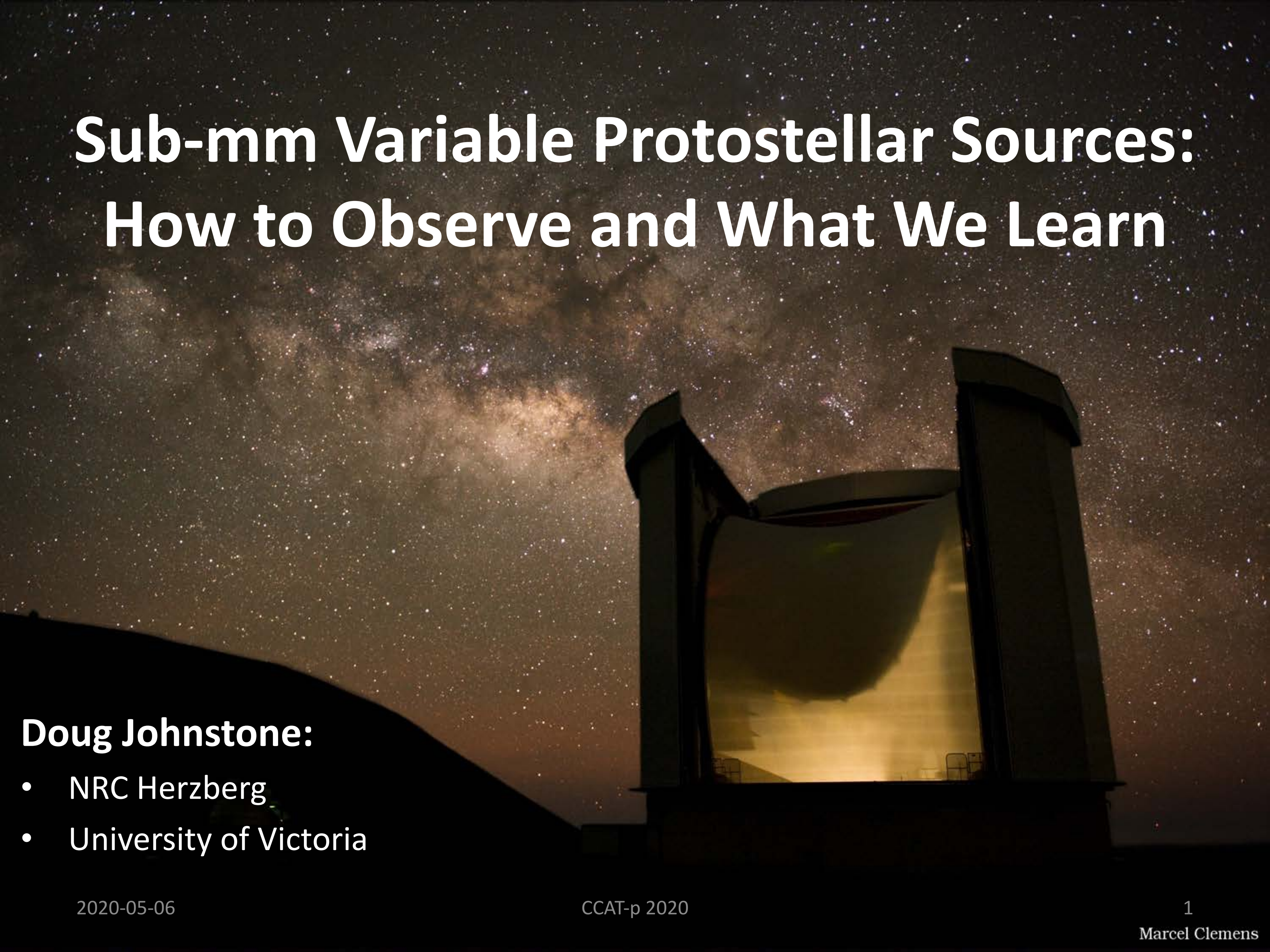
Sub-mm Variable Protostellar Sources: How to Observe and What We Learn

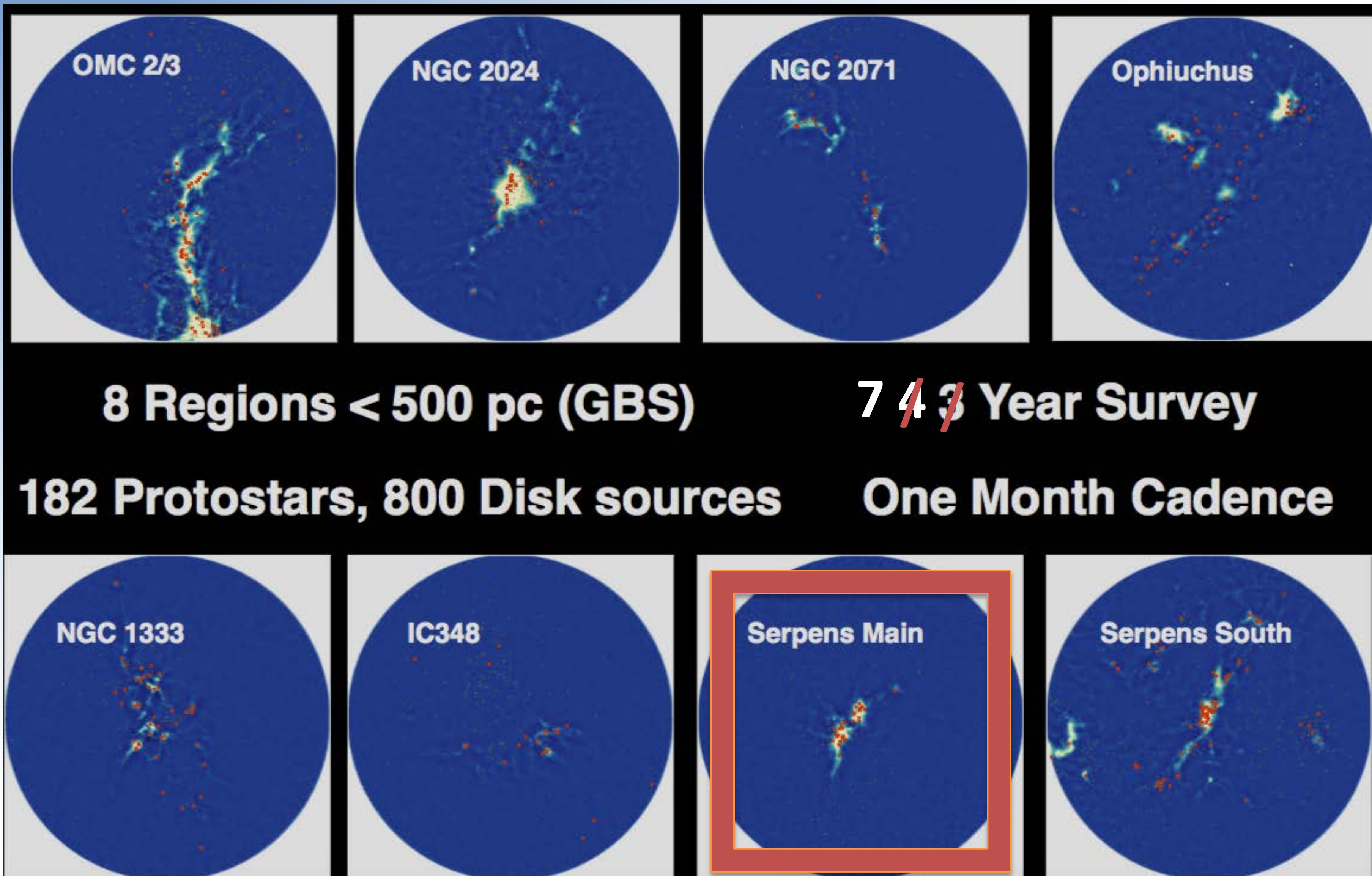


Doug Johnstone:

- NRC Herzberg
- University of Victoria

Marcel Clemens

The EAO/JCMT Transient Survey



(Herczeg et al. 2017, ApJ)

The First Sub-mm Protostellar Variable:

Observing Strategy:

850 micron – SCUBA2 @ JCMT
-Also 450 (but harder to reduce)

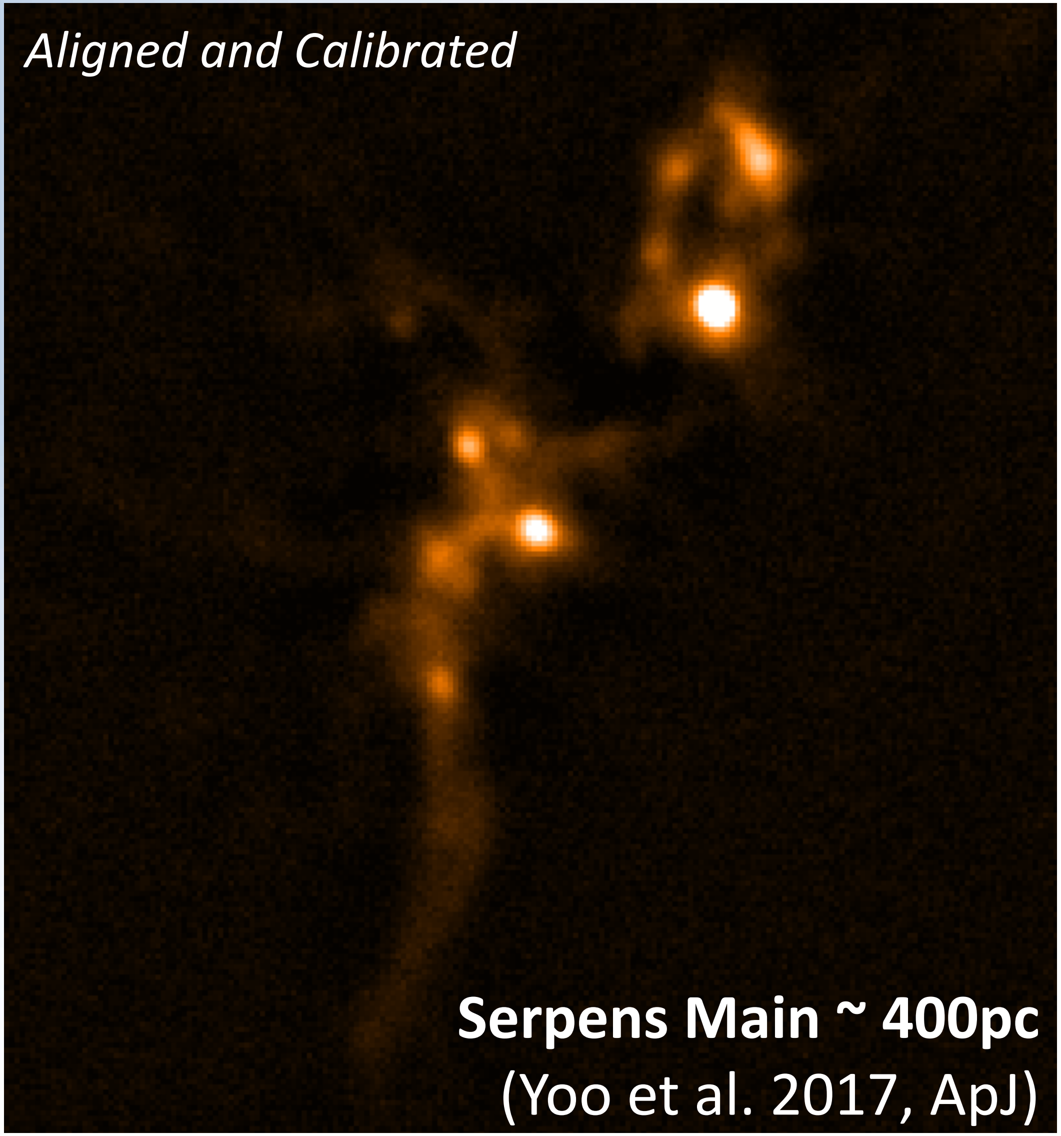
0.5 degree diameter field of view
-Efficient use of SCUBA2

14” beam at 850 microns
-Sufficient to separate nearby cores

10 mJy/bm sensitivity per epoch
-Obs time matched to weather

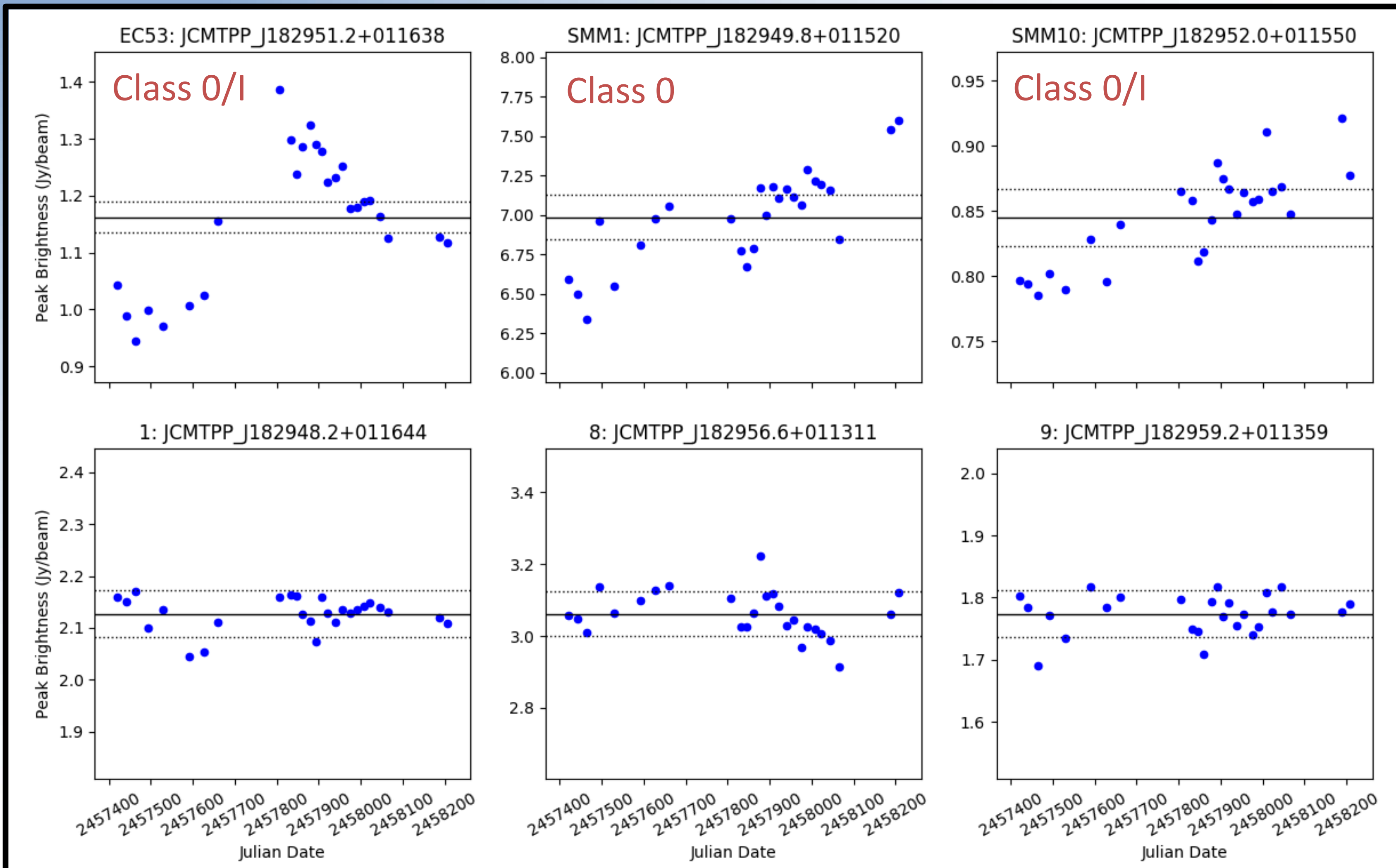
Relative flux calibration ~2%
-Extra care observing/reducing
-Still investigating best practice

Bi-Weekly observations
-Most regions monthly epochs



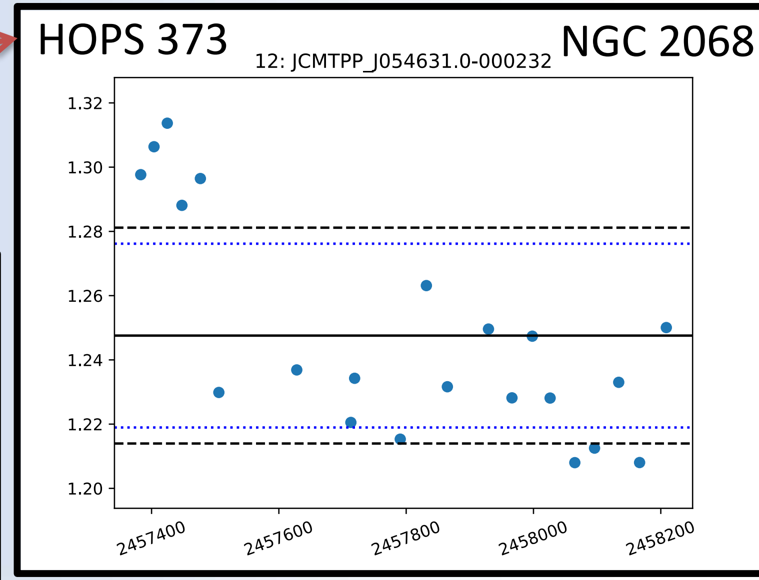
Calibrated Light Curves and Variance:

Light Curves at 850 microns over multiple years (Johnstone et al. 2018, ApJ)

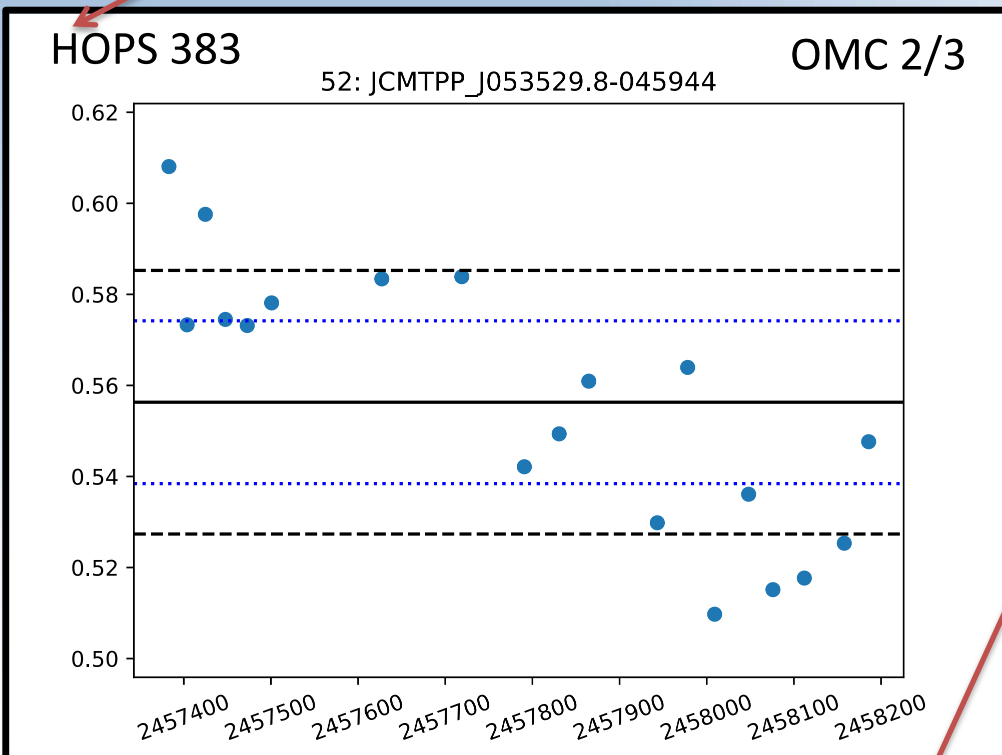


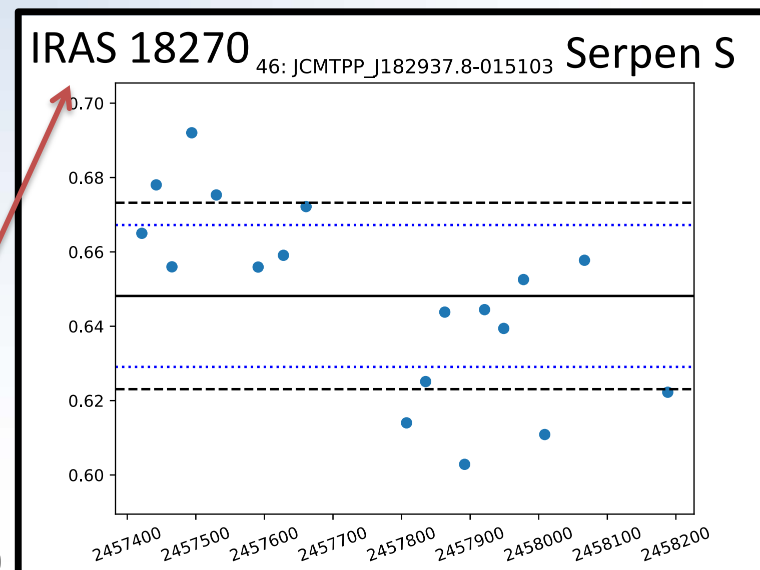
Calibrated Light Curves and Variance:

PBRS object (Stutz et al. 2013)



Mid-IR Outburst (Safron, Fischer et al. 2015)



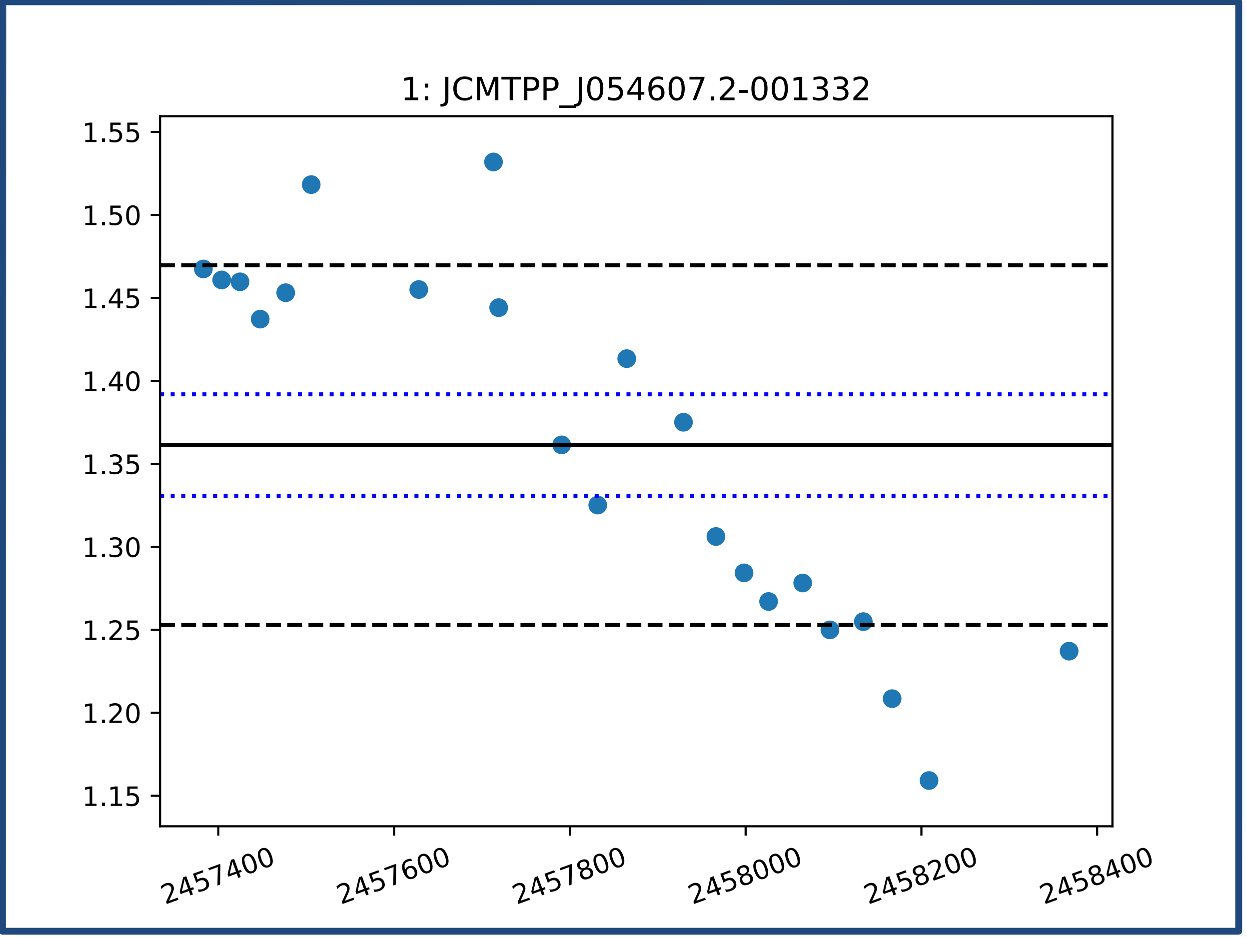


FU Ori Candidate (Connelley & Greene 2010)

Automation to Detect Variables:

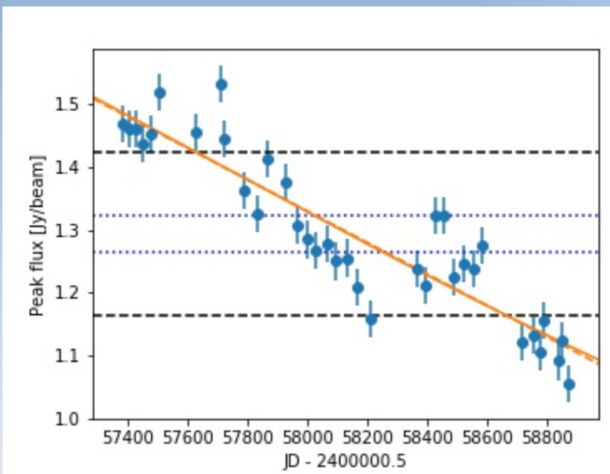
HOPS 358 in NGC 2068: Another ***PBRS*** (Stutz et al. 2013) – and our ***First Atel*!**

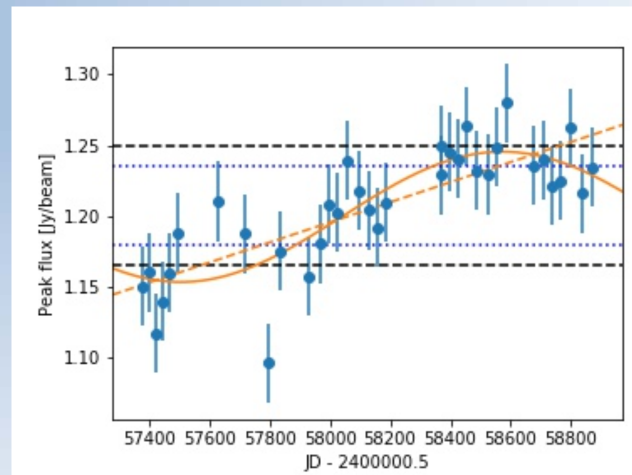
~30% decline in sub-mm flux over 2 yrs -> est. 75% decline in accretion

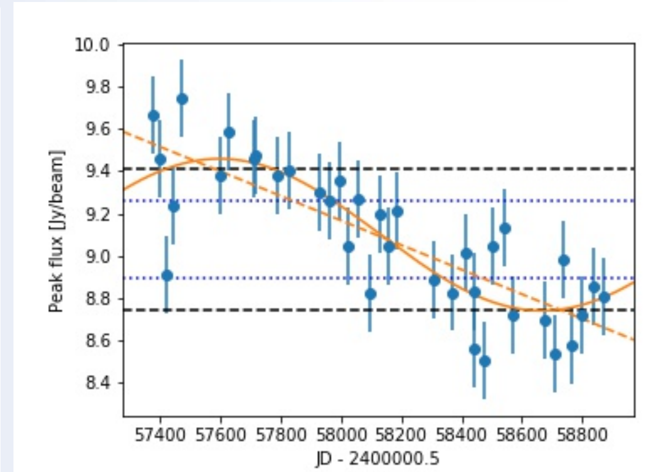


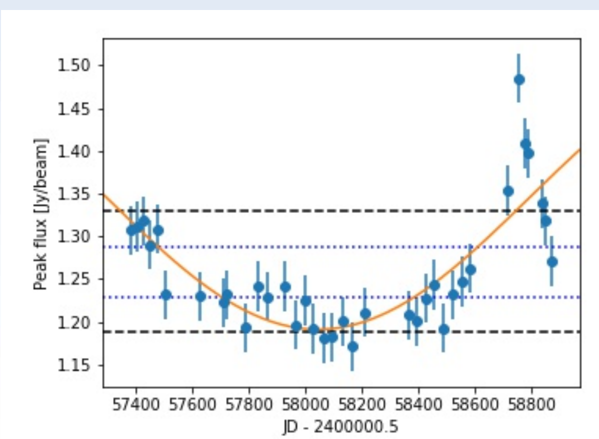
Teasing Out the Physical Parameters:

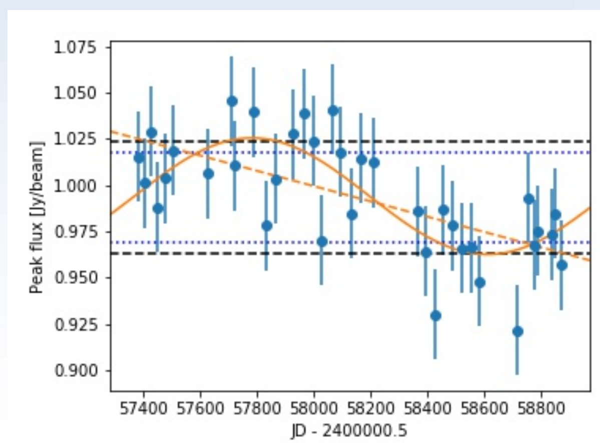
Fit ***periodograms*** to light curves, measure ***timescales*** and ***amplitudes***.

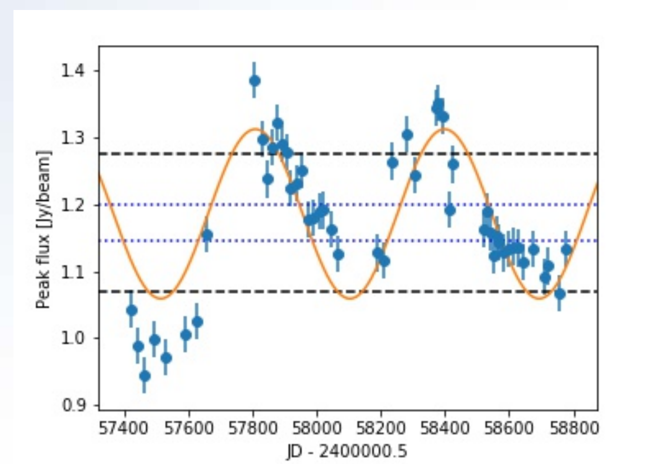










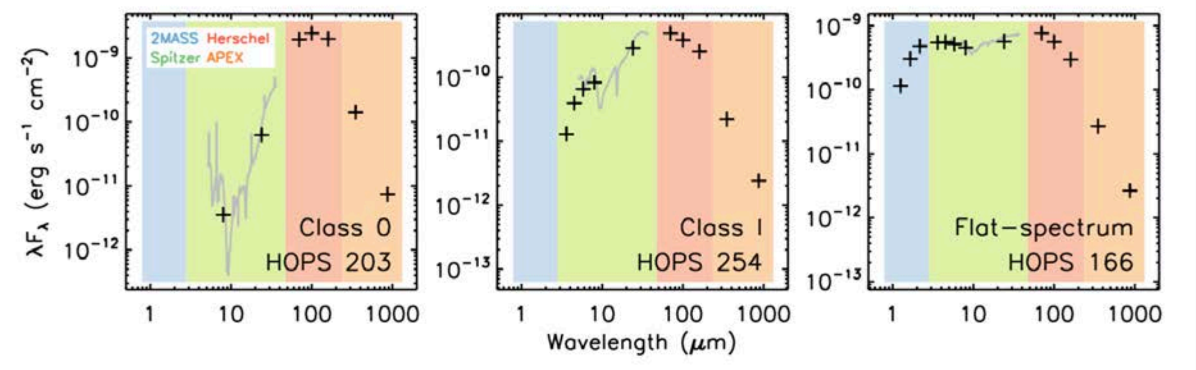


Spectral Energy Distribution (SED):

- For a low mass star, the *mass accretion* releases more energy than the protostar itself produces; therefore,

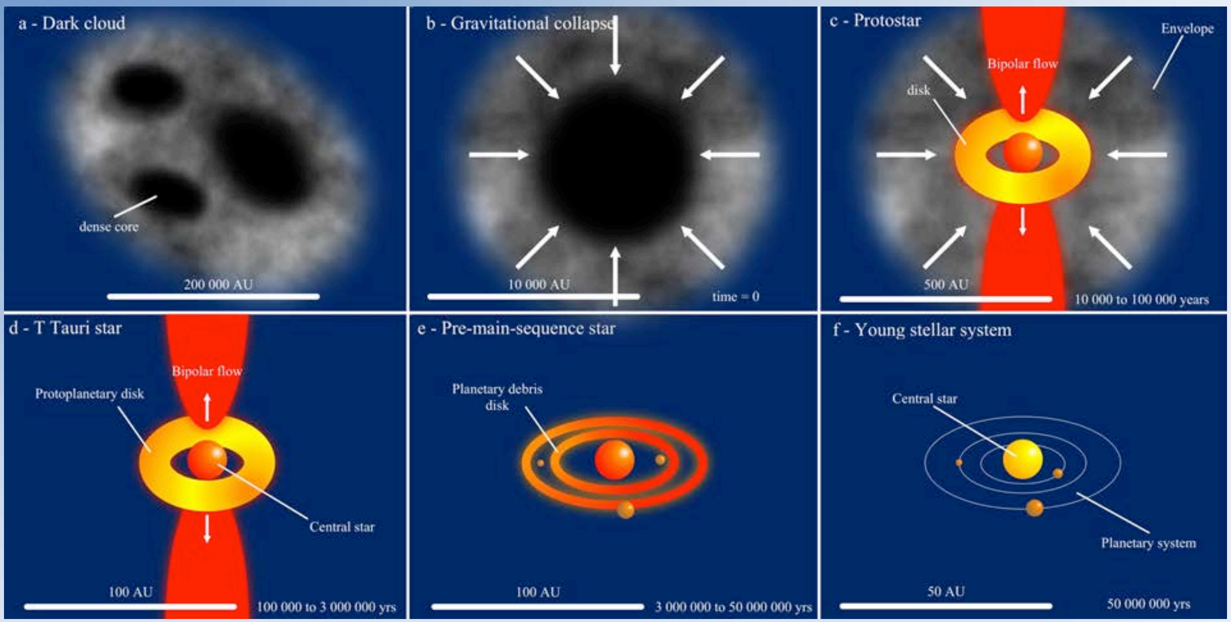
$$L_{\rm acc} \sim \frac{GM_*}{R_*}\dot{M}_{\rm acc}$$

- This radiation is absorbed by the envelope and re-radiated in the far-IR to mm. Thus, the SED acts as a ***calorimeter*** for accretion.



- Measurements near the SED peak provide a proxy for accretion. Thus, the *JCMT Transient Survey and* potential *CCAT-p Variability Surveys* observe accretion variability through brightness variations.

Formation of a star in one slide!



Variability Diagnostics:

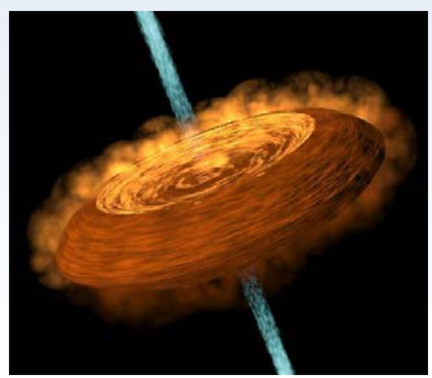
Years timescale … Inner Disk?

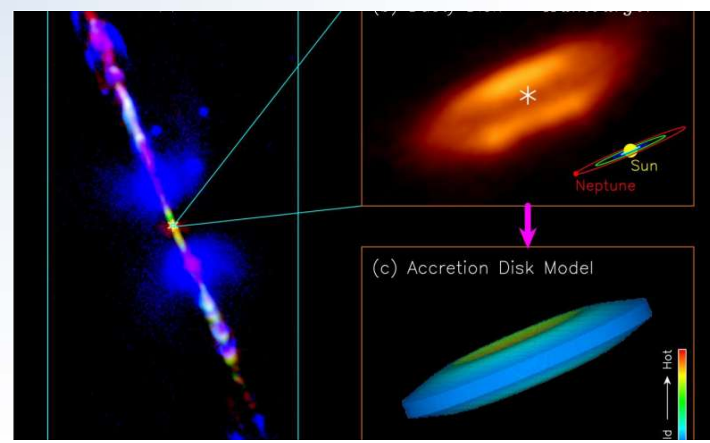
Order unity amplitudes …

SED variations … extinction vs luminosity/temp changes

Circumstantial Evidence for Protostellar Variability

- CO emission in envelopes
- Bullets seen observed in jets
- Snow line location in disks
- Need for episodic accretion to account for the protostar 'Luminosity Problem'





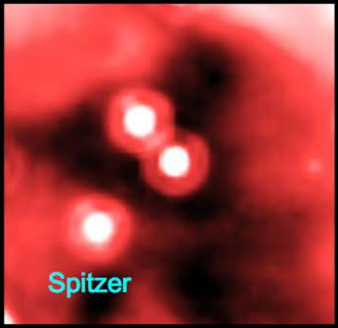
Spitzer/Wise Variability …

Slide from W. Fischer

Outbursts seem to be common

McNeil's Nebula / V1647 Ori (2003)

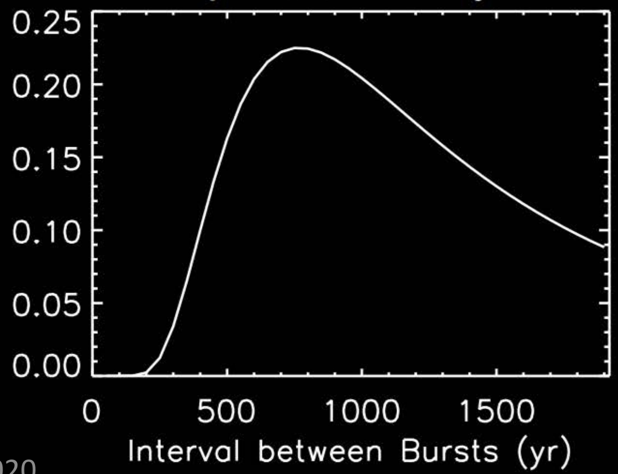
HOPS 383 (~2005)



HOPS 223 (~2006)

- Over 7 years, 3 of 329 protostars began outbursts
- Suggests ~ 800 yrs between outbursts; each protostar has many over its formation period
- But these three luminosity increases are of order ~ 10x (canonical FU Oris are > 100x)

Probability of 3 outbursts among 329 protostars in 7 years



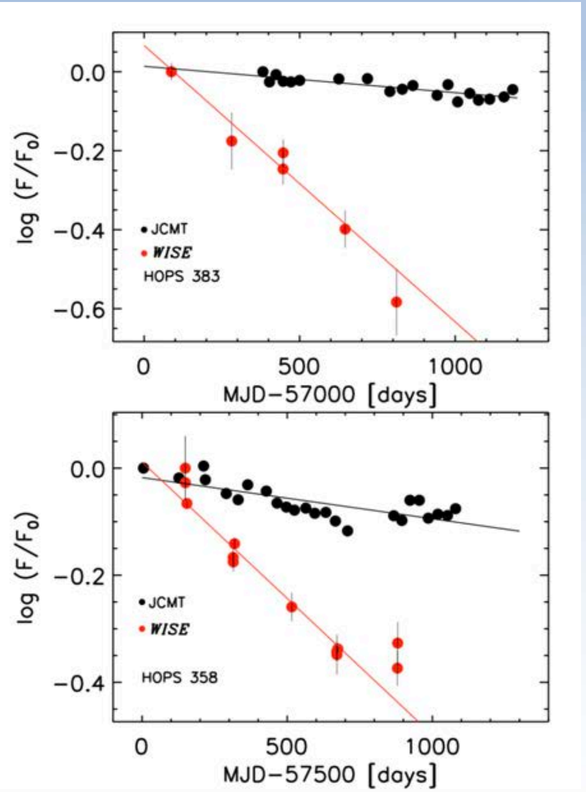
Spectral Energy Distribution (SED):

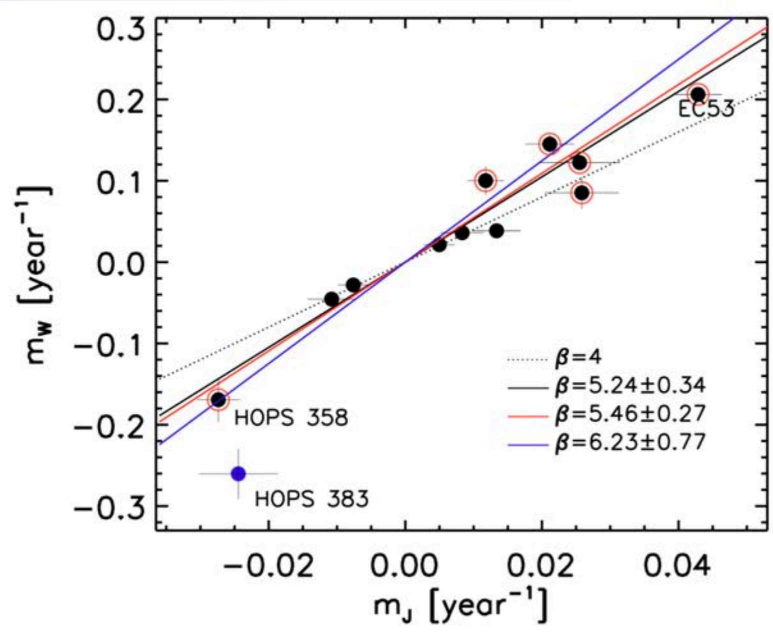
Accretion energy is absorbed by the envelope and re-radiated in the far IR through mm. The SED acts as a ***calorimeter*** for accretion.

$$L_{acc} \sim \frac{GM_*}{R_*}\dot{M}_{acc}$$

F(IR) ~ L_{acc}

F(sub-mm) ~ T_{dust}

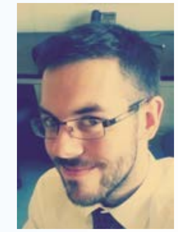




Contreras Pena et al. 2020 submitted


and
now
for something
completely different

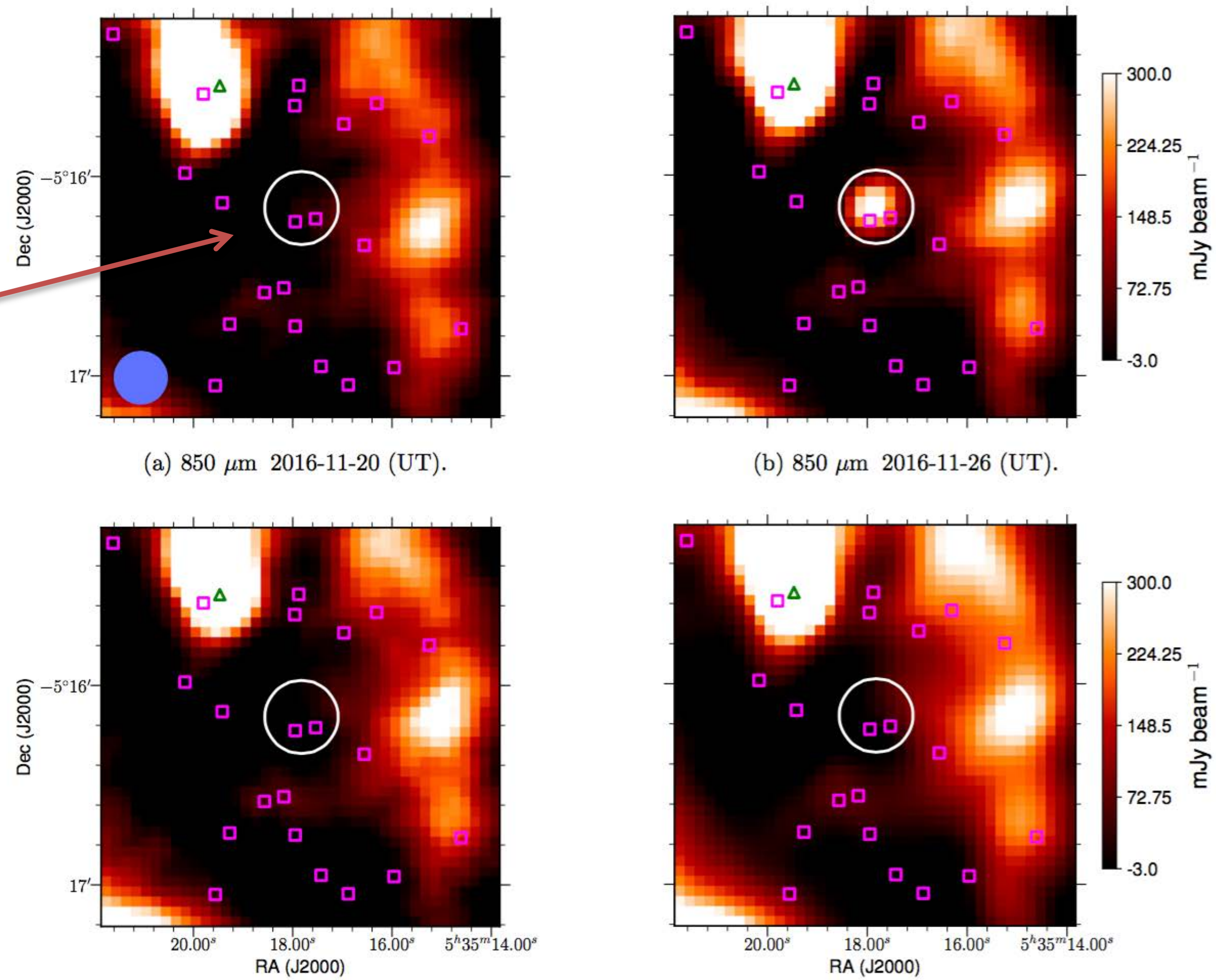
A Truly Transient Event



Searching for sources that appear in *only one* epoch:

Mairs et al. 2019 ApJ

Location of
T Tauri binary
JW 566



(a) 850 μm 2016-11-20 (UT).

(b) 850 μm 2016-11-26 (UT).

(c) 850 μm 2017-02-06 (UT).

(d) The co-add of all 850 μm epochs not including 2016-11-26.

A Truly Transient Event

Searching for sources that appear in *only one* epoch:

Mairs et al. 2019 ApJ

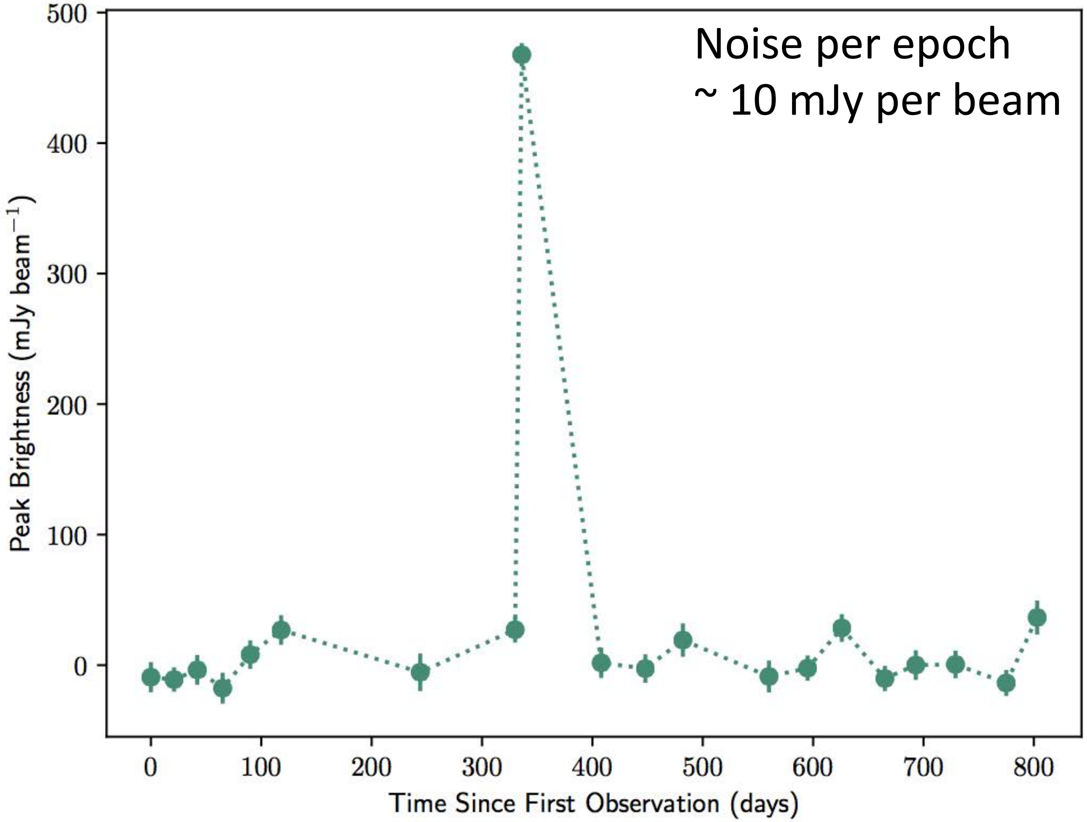
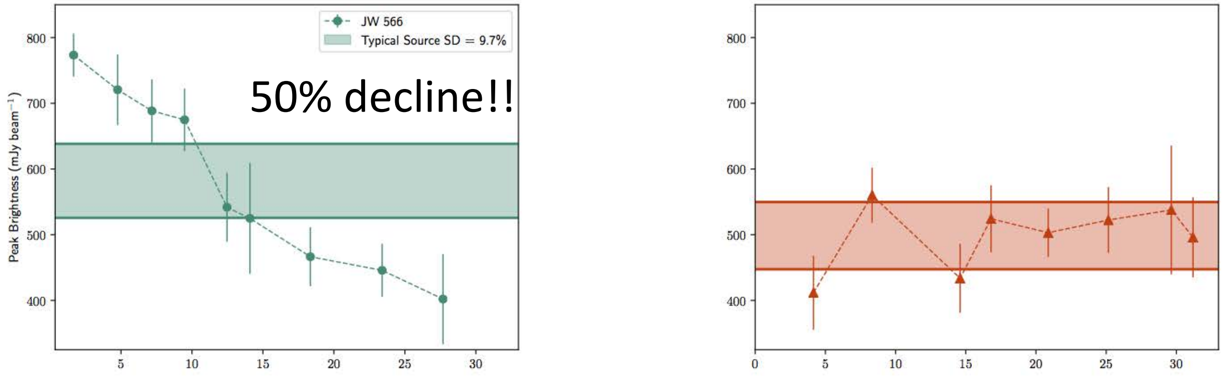


Figure 2. The 850 μm light curve of JW 566 over all observed epochs (see Table 1).

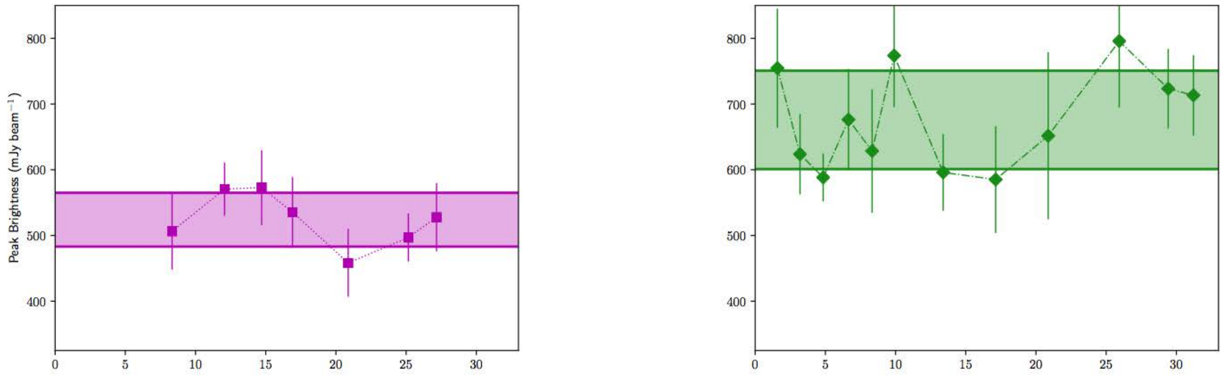
A Truly Transient Event

Searching for sources that appear in *only one* epoch:

Mairs et al. 2019 ApJ



30 minute epoch observation broken into ~5 minute bins



CCAT-p Protostellar Variability

1. **Availability of wide wavelength range for monitoring brightness changes**
   - 350µm through 1 mm (temperature/luminosity diagnostic)
   - Thermal sources are brighter at shorter wavelengths with stronger variability!

2. **CCAT-p is an efficient survey machine**
   - Need for regularly spaced observations (nightly to monthly) over years

3. **Ability to monitor moderate-sized region ~10 sq. degrees**
   - 10 mJy/bm @ 850µm requires ~10 minutes per epoch (every ~3 days)
   - 100 mJy/bm @ 350µm requires ~10 minutes per epoch (in best weather)
   - Over time this also will produce extremely deep maps of these regions

4. **Experience shows monitoring surveys support/enhance observatory**
   - Enhanced data reduction and analysis methods
   - Enhanced calibration and observation diagnostics
   - Telescope health diagnostics every epoch

JCMT Transient Survey: Refereed Publications to Date

1. Herczeg+ 2017, ApJ, 849, 43 - JCMT Transient Survey Overview
2. Mairs+ 2017a, ApJ, 843, 55 - Survey Data Reduction and Calibration Methods
3. Yoo et+ 2017, ApJ, 849, 69 - EC 53 in Serpens Main: A Sub-mm Periodic Variable
4. Mairs+ 2017b, ApJ, 849, 107 - Variability Across Multiple Years (Transient vs GBS)
5. Johnstone+ 2018, ApJ, 854, 31 - Secular and Stochastic Sources after 18 Months
6. Mairs+ 2019, ApJ, 871, 72 - JW 566 in Orion: An Extraordinary Sub-mm Flare
7. MacFarlane+ 2019a, MN, 487 - Rad Tran Modeling Simulated Outbursting Protostars I
8. MacFarlane+ 2019b, MN, 487 - Rad Tran Modeling Simulated Outbursting Protostars II
9. Lee+ 2020, ApJ, 889, 20 - EC 53 : ALMA Observations of the Circumstellar Disk

10. Lee+ 2019, Nature Ast, 3, 314 - V883 Ori: ALMA Observations of ice in disk
11. Francis+ 2019, ApJ, 871, 149 - ALMA and CARMA Continuum Variability in Serpens
12. Park+ 2019, ApJS, 242, 27 - Sub-mm Variability in Planck Cold Clumps

13. Baek+ ApJ, submitted - EC 53: Near-IR through Far-IR SED Modelling
14. Contreras Pena+ MN, submitted - Mid-IR and Sub-mm Variability of Protostars

Fin