# Submillimeter continuum variability in Planck Galactic cold clumps using the JCMT-SCOPE survey

(Park et al. 2019, ApJS, 242, 27)

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presented by Geumsook Park

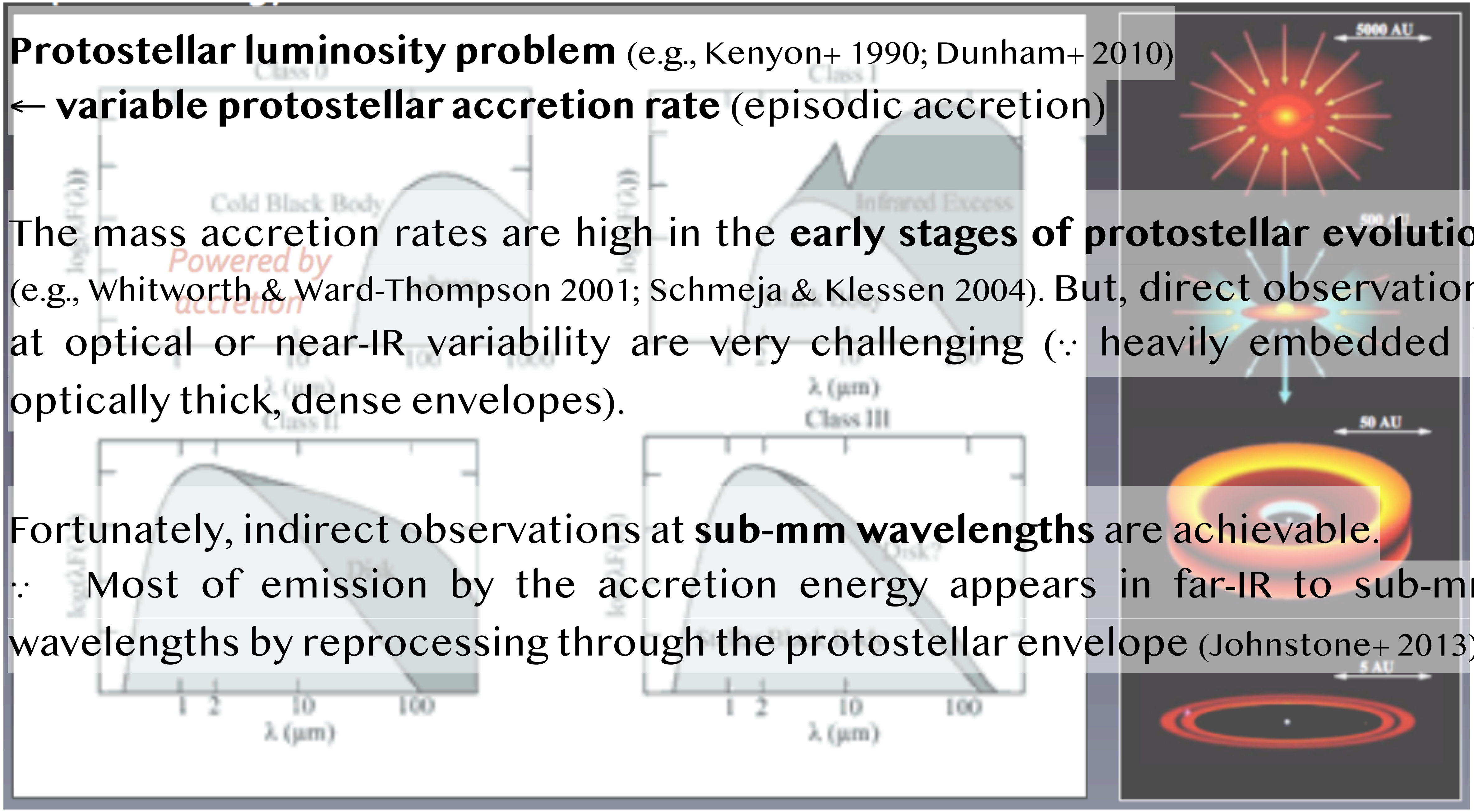
KASI

# Collaborated with:

- **Kee-Tae Kim** (KASI)
- **Doug Johnstone** (NRC Herzberg Astronomy and Astrophysics; University of Victoria)
- **Sung-ju Kang** (KASI)
- **Tie Liu** (Shanghai Astronomical Observatory)
- **Steve Mairs** (East Asian Observatory)
- **JCMT-SCOPE members**
  : Minho Choi, Jeong-Eun Lee, Patricio Sanhueza, Mika Juvela, Miju Kang, David Eden, Archana Soam, Julien Montillaud, Gary A. Fuller, Patrick M. Koch, Chang Won Lee, Dimitris Stamatellos, Jonathan Rawlings, Gwanjeong Kim, Chuan-Peng Zhang, Woojin Kwon, and Hyunju Yoo

# Why we are interested in flux variability?

- The variability of the protostellar disk accretion will be important to understand the evolution of the envelope and disk.



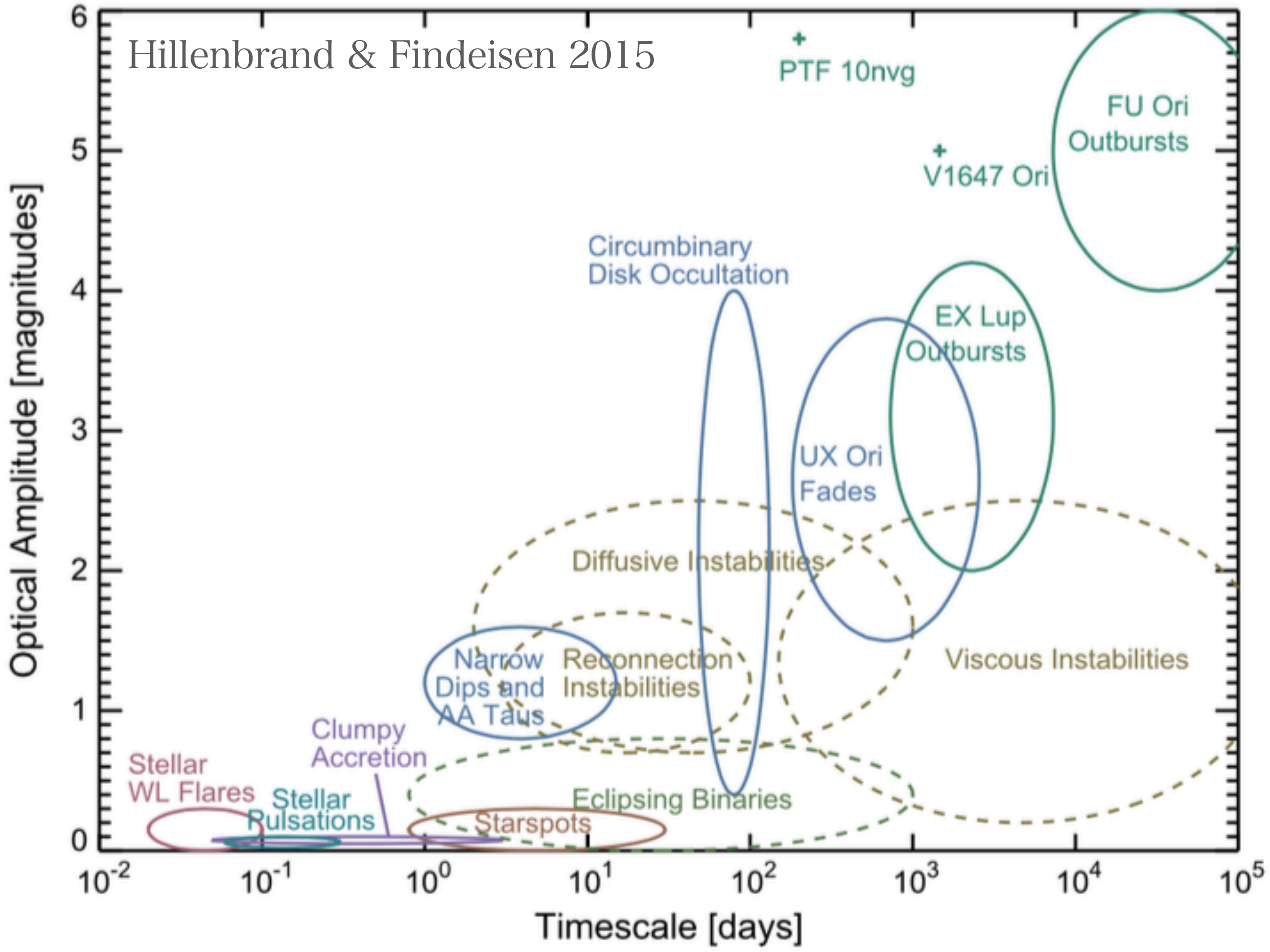
- **Protostellar luminosity problem** (e.g., Kenyon+ 1990; Dunham+ 2010)
← **variable protostellar accretion rate** (episodic accretion)

- The mass accretion rates are high in the **early stages of protostellar evolution** (e.g., Whitworth & Ward-Thompson 2001; Schmeja & Klessen 2004). But, direct observations at optical or near-IR variability are very challenging (∵ heavily embedded in optically thick, dense envelopes).

- Fortunately, indirect observations at **sub-mm wavelengths** are achievable.
∵ Most of emission by the accretion energy appears in far-IR to sub-mm wavelengths by reprocessing through the protostellar envelope (Johnstone+ 2013).

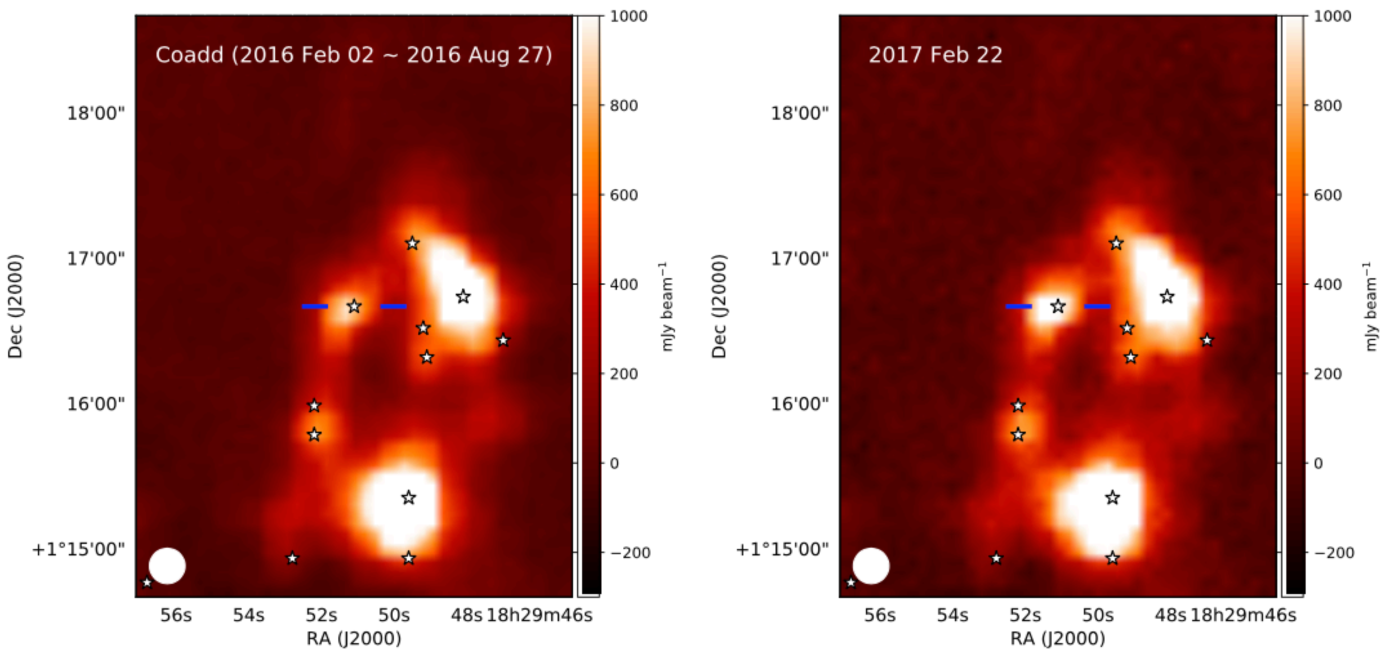
# Previous observational results

- The Majority of accretion variability observations have so far been carried out in the evolved stages of pre-main-sequence stars.
  - A large optical brightness increase of a factor of ten or more observed in FU Orionis (e.g., Herbig 1977; Hartmann & Kenyon 1996) or EX Lupi (e.g., Herbig 2008; Aspin+ 2010)

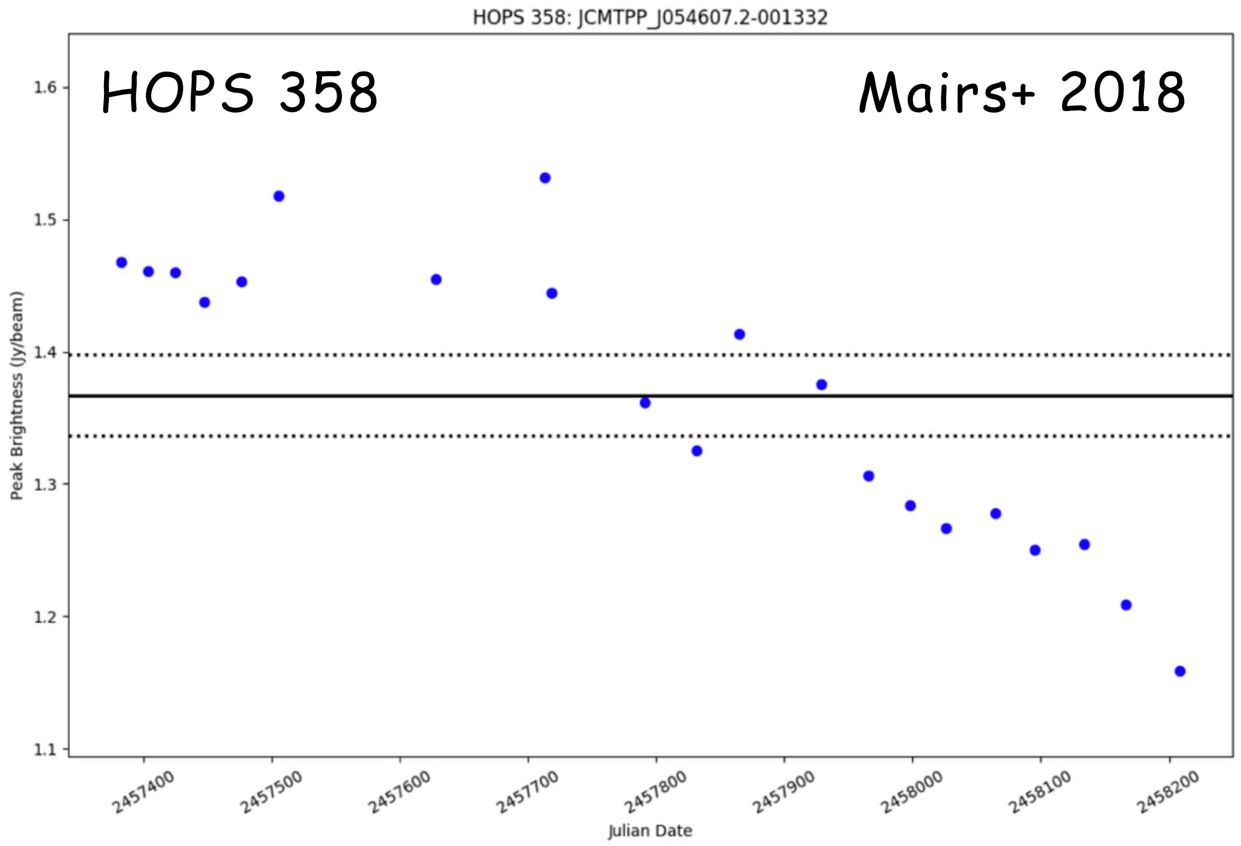


Hillenbrand & Findeisen 2015

- Recently, a few outbursts from deeply embedded protostellar objects have been reported.
    - About a-factor-of 1.5 increase at 850 μm toward Class I protostar EC53 (Yoo+ 2017)
    - About a-factor-of-2 increase at 350/450 μm toward Class 0 source HOPE 383 (Safron+ 2015)
    - Strong, declining light curve over the course of 16 months in HOPS 358 (Mairs+ 2018)
    - Also, a factor of 4.2 increase in 870 μm continuum interferometric flux in a high-mass protostellar system NGC 6334I-MM1 (Hunter+ 2017)

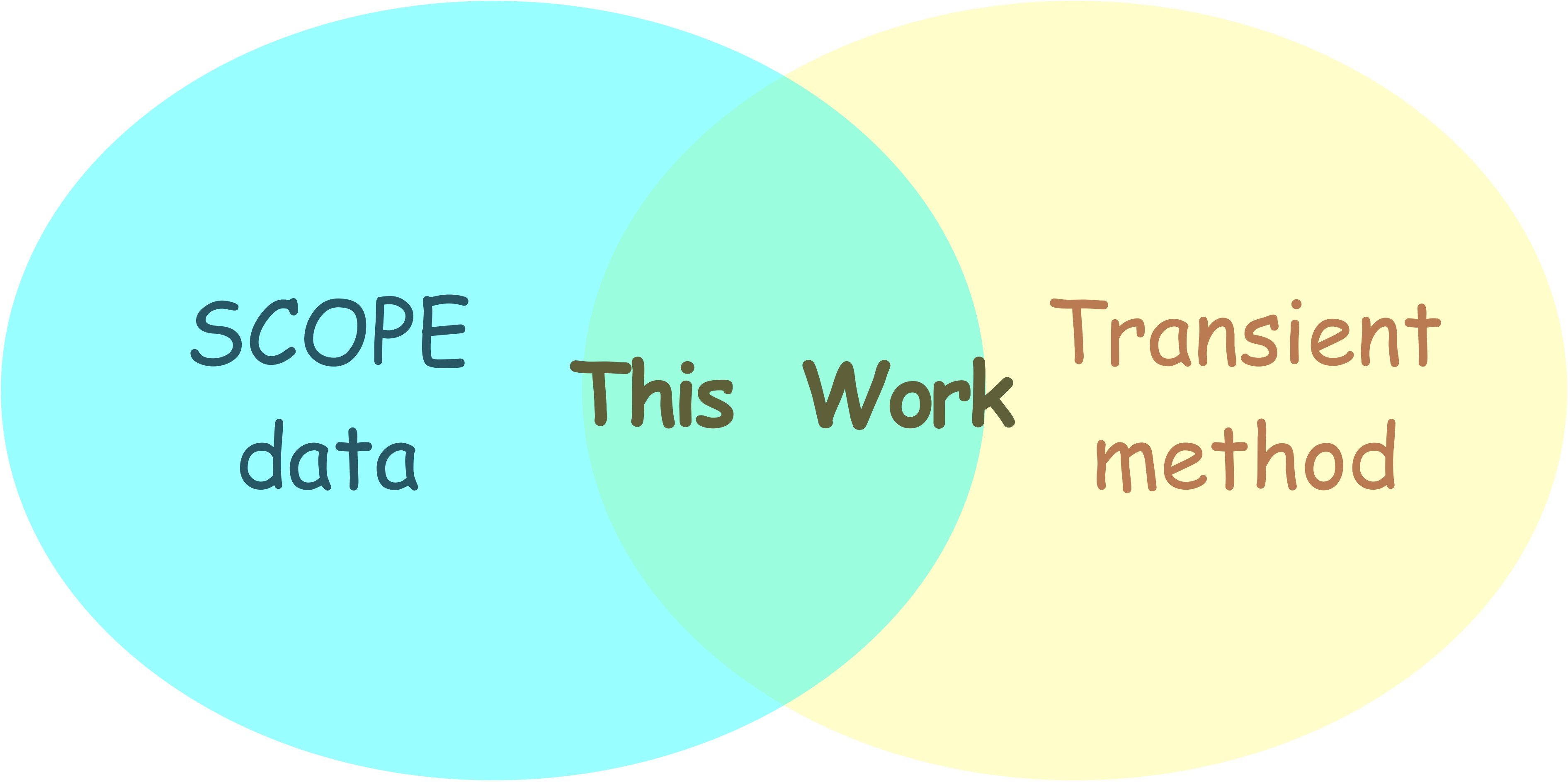


EC 53 discovered by Yoo+ 2017



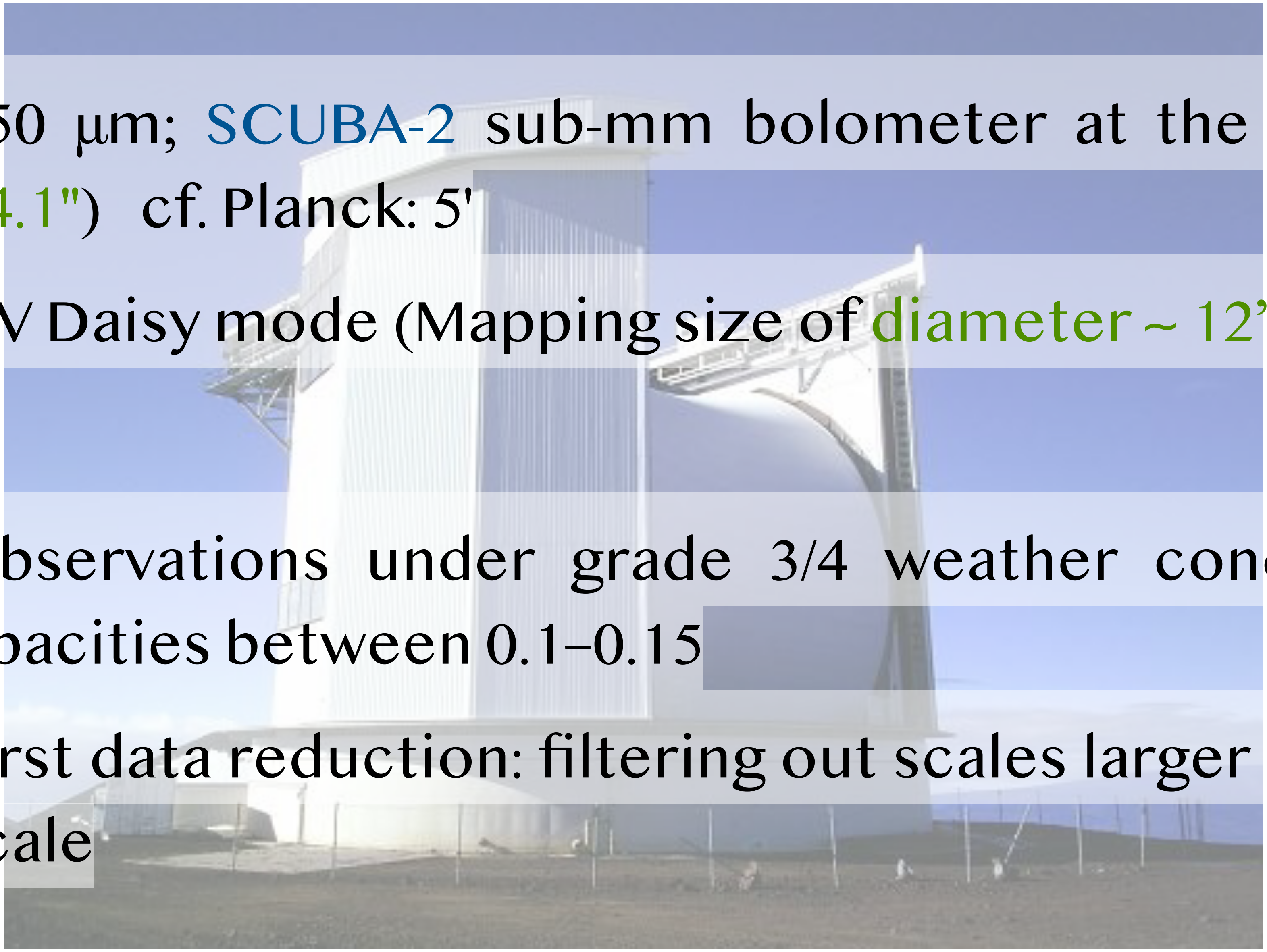
# Synergy

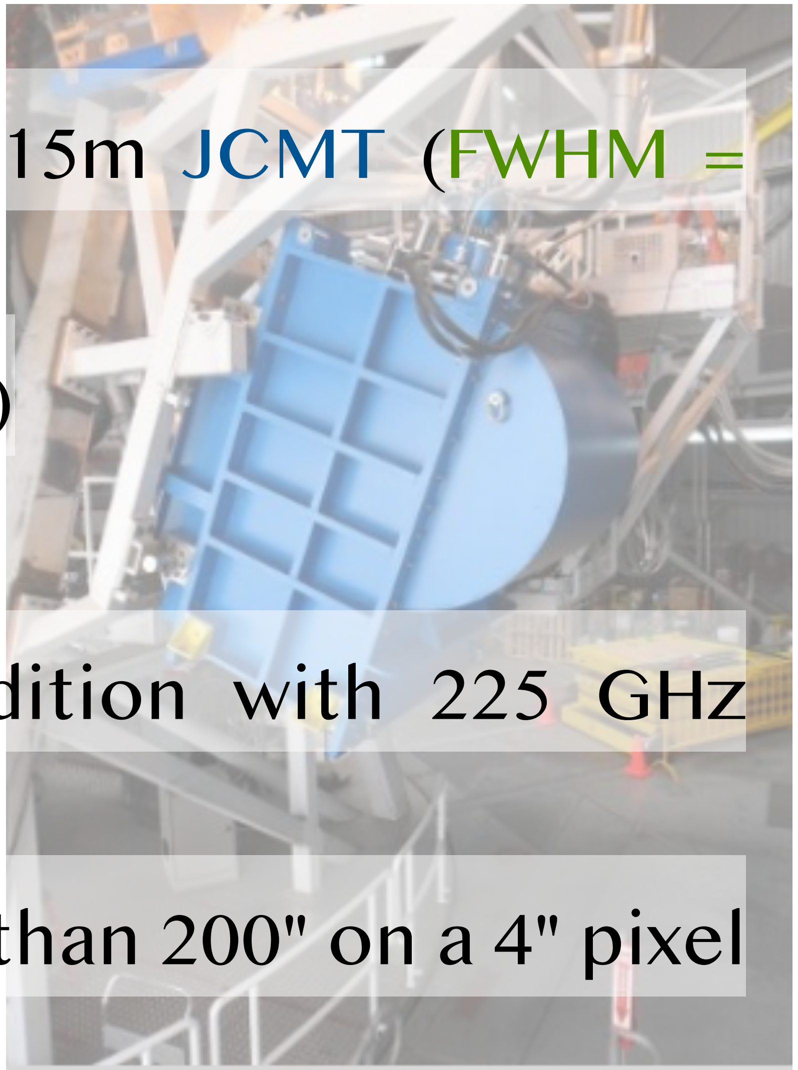
- The Transient team found that ~10% of deeply embedded protostars display varying flux at the level of 5%–10% per year. However, the nearby regions that they studied are mostly forming low-mass stars.



# SCOPE survey: Observations

- "**S**CUBA-2 **C**ontinuum **O**bservations of **P**re-protostellar **E**volution"
- begun in December 2015 and completed in July 2017





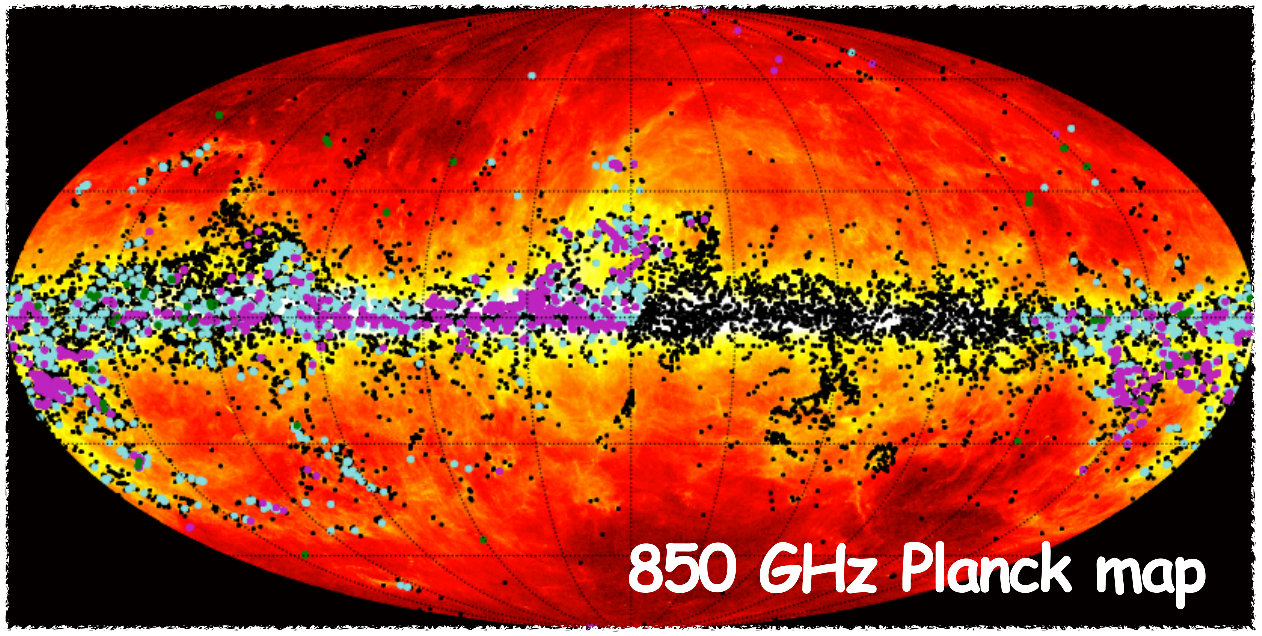
SCUBA-2 at JCMT.

- 850 µm; SCUBA-2 sub-mm bolometer at the 15m JCMT (FWHM = 14.1")   cf. Planck: 5'
- CV Daisy mode (Mapping size of diameter ~ 12')
- Observations under grade 3/4 weather condition with 225 GHz opacities between 0.1–0.15
- First data reduction: filtering out scales larger than 200" on a 4" pixel scale

# JCMT-SCOPE Survey: Targets

- **Main aim: Statistical study the initial conditions occurring during star formation across a wide range of environments**

- Source selection (~1200 PGCCs):
  - high column density PGCCs ($> 1 \times 10^{21}$ cm$^{-2}$ in Planck meas.)
  - randomly selected lower column density clumps at high latitudes ($> 5 \times 10^{20}$ cm$^{-2}$ in Planck meas.)



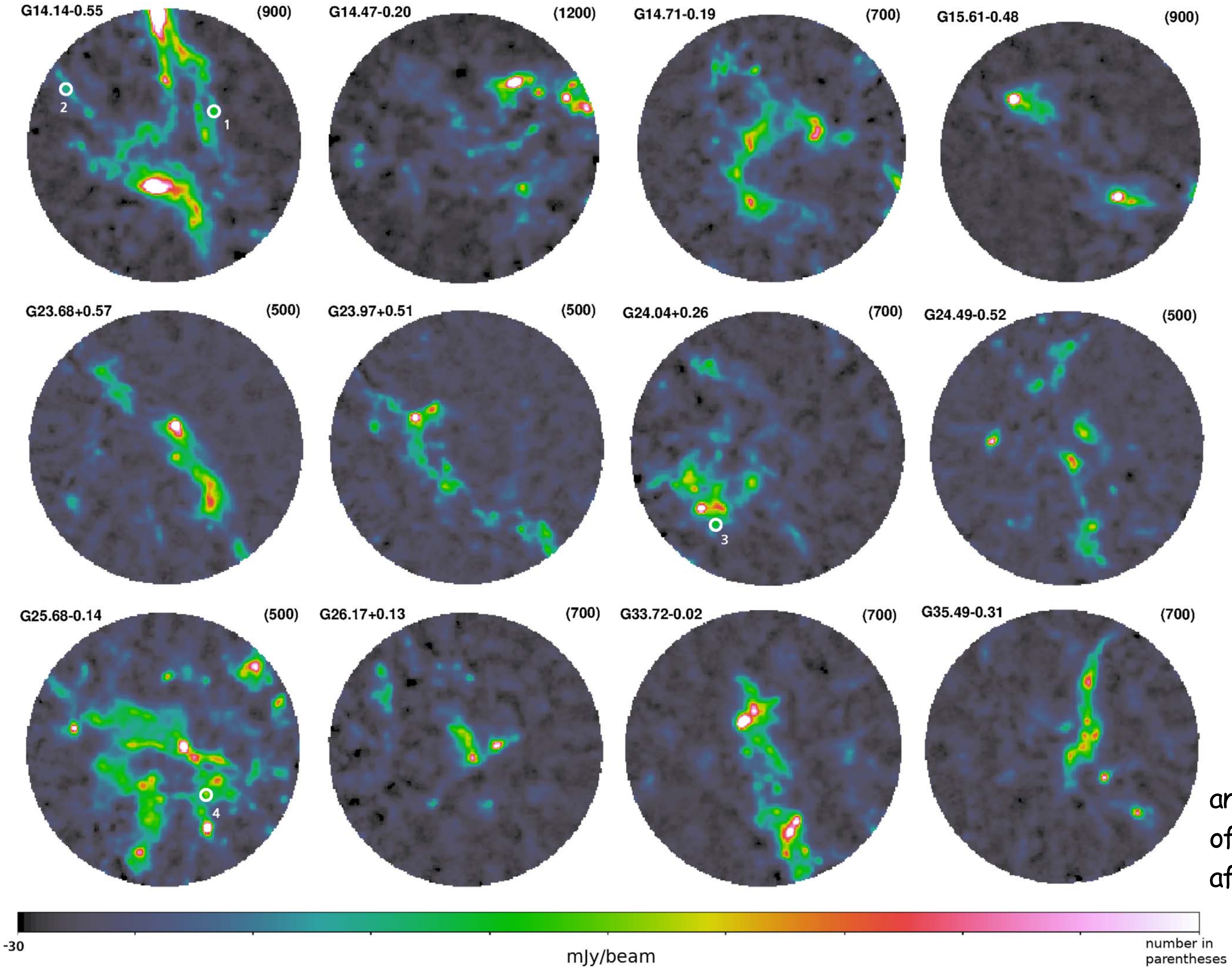
**SCOPE sources (magenta dots)** selected from 13188 PGCCs (black dots) (Liu+ 2018)

- For about 3/5 of the SCOPE sample (Planck Collaboration+ 2016):
  - About 70% among them are concentrated within 1 kpc while the others are widely distributed at up to ~8 kpc, with an average angular size of ~8'.
  - The mass range is from 0.1 $M_\odot$ to $10^5$ $M_\odot$.

- **The SCOPE survey done three times separate observations for some (< 30) of PGCCs which seem to contain massive clumps (with multiple substructures) in order to obtain deep images of high-mass star forming regions as well as to detect large flux variation events.**

- See Liu+ 2018 for detailed description of the survey and Eden+ 2019 for information of the first data release and the catalog of compact sources resolved with the JCMT.

# 12 SCOPE fields: CO-added images



angular resolution of 16.2 FWHM after smoothing

# 12 SCOPE fields: Information

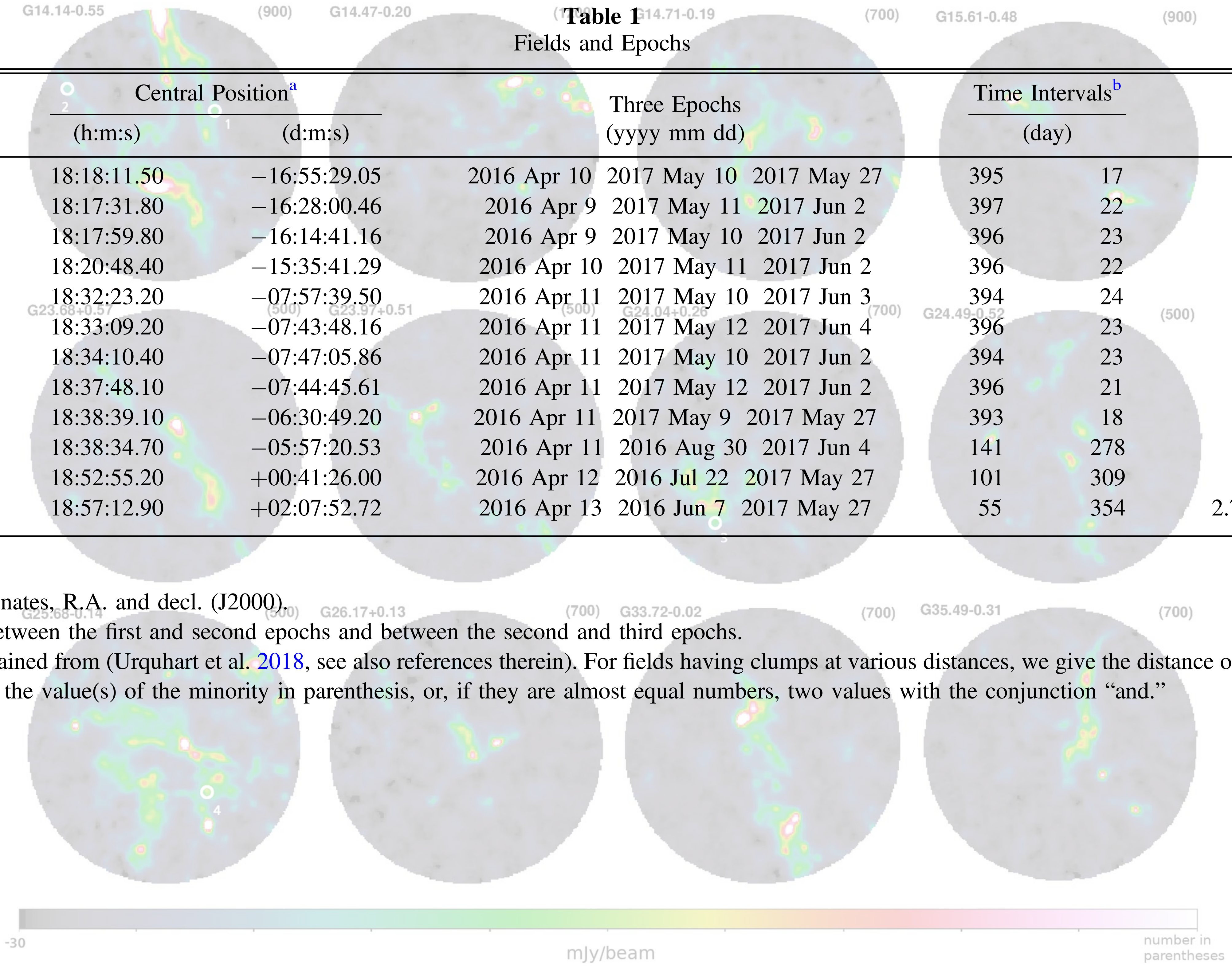


**Table 1**
Fields and Epochs

| Field | Central Position[a] (h:m:s) | (d:m:s) | Three Epochs (yyyy mm dd) | | | Time Intervals[b] (day) | | Distance(s)[c] (kpc) |
|---|---|---|---|---|---|---|---|---|
| G14.14−0.55 | 18:18:11.50 | −16:55:29.05 | 2016 Apr 10 | 2017 May 10 | 2017 May 27 | 395 | 17 | 1.5 |
| G14.47−0.20 | 18:17:31.80 | −16:28:00.46 | 2016 Apr 9 | 2017 May 11 | 2017 Jun 2 | 397 | 22 | 3.1 (11.5) |
| G14.71−0.19 | 18:17:59.80 | −16:14:41.16 | 2016 Apr 9 | 2017 May 10 | 2017 Jun 2 | 396 | 23 | 3.1 |
| G15.61−0.48 | 18:20:48.40 | −15:35:41.29 | 2016 Apr 10 | 2017 May 11 | 2017 Jun 2 | 396 | 22 | 1.8 and 16.9 |
| G23.68 + 0.57 | 18:32:23.20 | −07:57:39.50 | 2016 Apr 11 | 2017 May 10 | 2017 Jun 3 | 394 | 24 | 5.8 |
| G23.97 + 0.51 | 18:33:09.20 | −07:43:48.16 | 2016 Apr 11 | 2017 May 12 | 2017 Jun 4 | 396 | 23 | 5.8 |
| G24.04 + 0.26 | 18:34:10.40 | −07:47:05.86 | 2016 Apr 11 | 2017 May 10 | 2017 Jun 2 | 394 | 23 | 7.8 |
| G24.49−0.52 | 18:37:48.10 | −07:44:45.61 | 2016 Apr 11 | 2017 May 12 | 2017 Jun 2 | 396 | 21 | 11.3 |
| G25.68−0.14 | 18:38:39.10 | −06:30:49.20 | 2016 Apr 11 | 2017 May 9 | 2017 May 27 | 393 | 18 | 10.2 (7.4) |
| G26.17 + 0.13 | 18:38:34.70 | −05:57:20.53 | 2016 Apr 11 | 2016 Aug 30 | 2017 Jun 4 | 141 | 278 | 7.6 |
| G33.72−0.02 | 18:52:55.20 | +00:41:26.00 | 2016 Apr 12 | 2016 Jul 22 | 2017 May 27 | 101 | 309 | 6.5 (2.2) |
| G35.49−0.31 | 18:57:12.90 | +02:07:52.72 | 2016 Apr 13 | 2016 Jun 7 | 2017 May 27 | 55 | 354 | 2.7 (3.2 and 10.3) |

**Notes.**

[a] Equatorial coordinates, R.A. and decl. (J2000).

[b] Time intervals between the first and second epochs and between the second and third epochs.

[c] Distances are obtained from (Urquhart et al. 2018, see also references therein). For fields having clumps at various distances, we give the distance of the majority of clumps along with the value(s) of the minority in parenthesis, or, if they are almost equal numbers, two values with the conjunction "and."

# Need for Relative Flux calibration

- Telescope pointing uncertainty: 2-6”
- Default absolute flux calibration uncertainty for SCUBA-2 images: ~ 5-10%
- References: Dempsey+ 2013; Mairs+ 2017b

- To detect a 3 $\sigma_{rms}$ change in the peak flux of a source, the brightness variation would need to be at least 15%–30%.
- But, less dramatic flux variations are more common (e.g., Bae+ 2014; Vorobyov & Basu 2015; Mairs+ 2017a; Johnstone+ 2018).
- In order to increase detection reliability, We performed additional relative flux calibration using the method of Mairs+ 2017b.

# Data Analysis

- Make data arrays to have same grid coordinates (wcsaslign in STARLINK)
- Smoothing using a Gaussian kernel with FWHM = 2 px (gausmooth in STARLINK) (finally, FWHM = 16.2″)
- Make a co-added image (picard MOSAIC JCMT IMAGES in STARLINK)
- Estimate RMS noise levels as a function of exposure times in areas of no or very little emission for each epoch image
- Find clumps using the co-added image (findclump in STARLINK: method= clumpfind) and remove if a clump peak is located beyond 370″ from the central position
- **Apply relative flux calibration and then read peak fluxes from three epochs**
- Check clumps showing somewhat higher **$SD_{meas}/SD_{fid}$**

# Clumpfinding & relative flux calibration

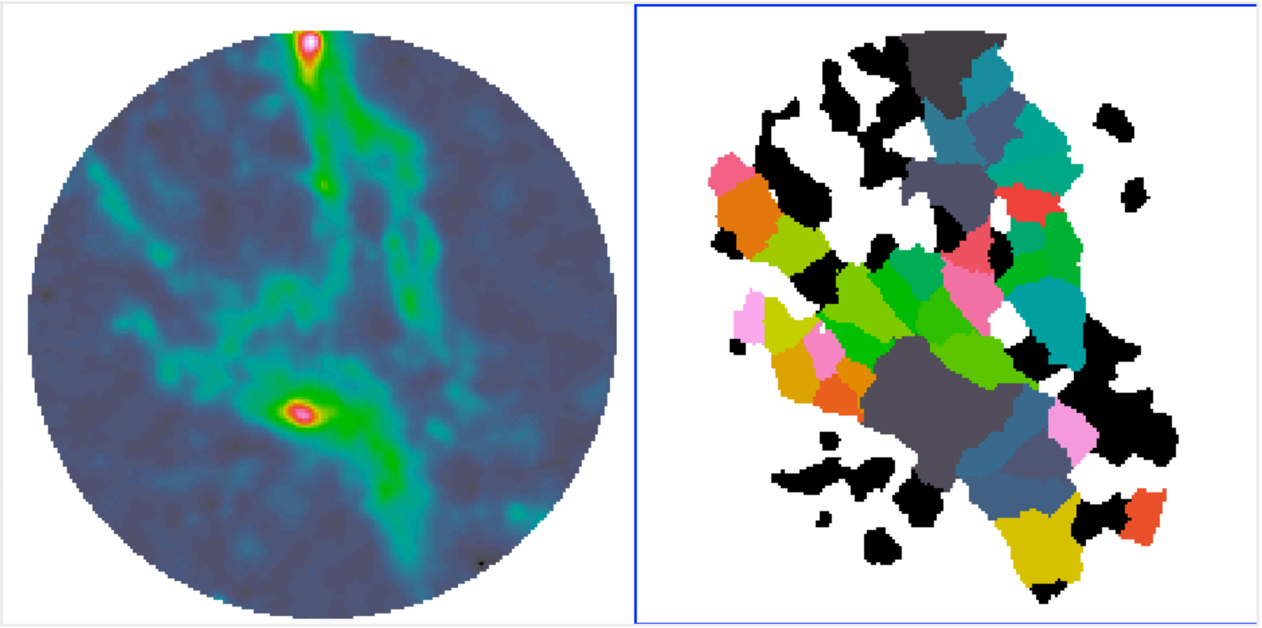
- We found clumps in the co-added image.
  :only sources having a mean peak flux ≥ 250 mJy/beam
  (~25 S/N in a single epoch; noise ~10 mJy/ beam)

- We used any clumps having
  $\sigma_{\rm std,meas}/\sigma_{\rm std,fid} < 1.7$ for calibration.

$$\sigma_{\rm std,fid}(i) = \sqrt{\sigma_{\rm rms}(i)^2 + (u_{\rm cal} \times F_{\rm m}(i))^2}\,,$$

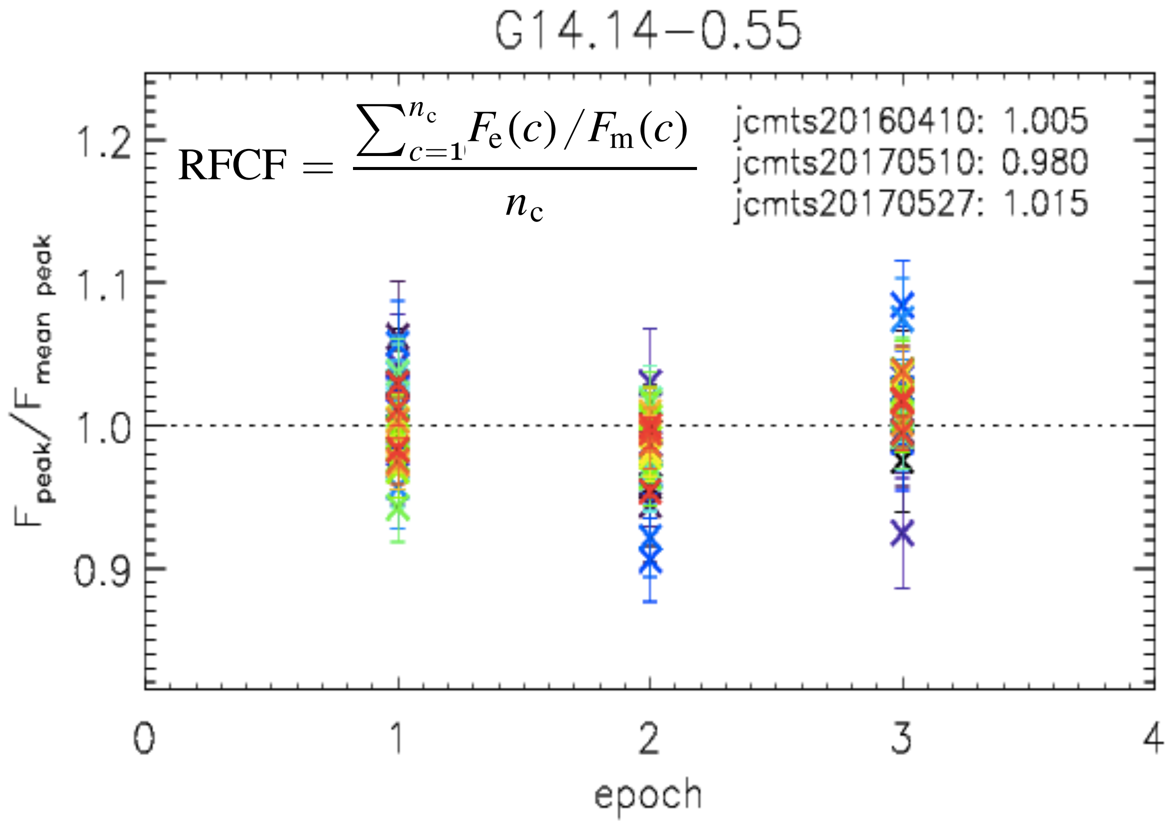
$$u_{\rm cal} = \sqrt{\frac{\sum_{c=1}^{n_{\rm c}} \sigma_{\rm std,meas}(c)^2 / F_{\rm m}(c)^2}{n_{\rm c} - 1}}\,.$$

Johnstone+ 2018

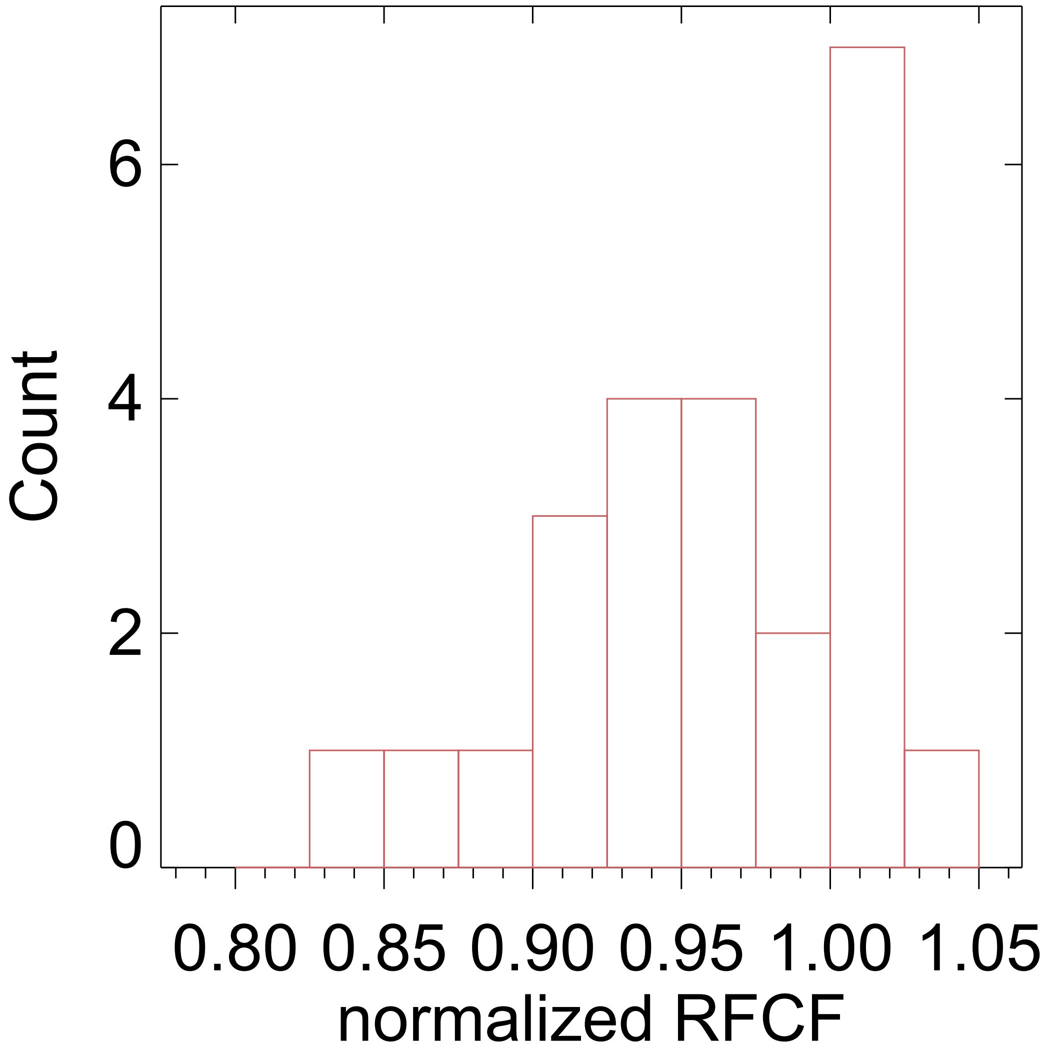


- We derived a relative flux calibration factor (RFCF) for each epoch and then each epoch data were divided by RFCF.

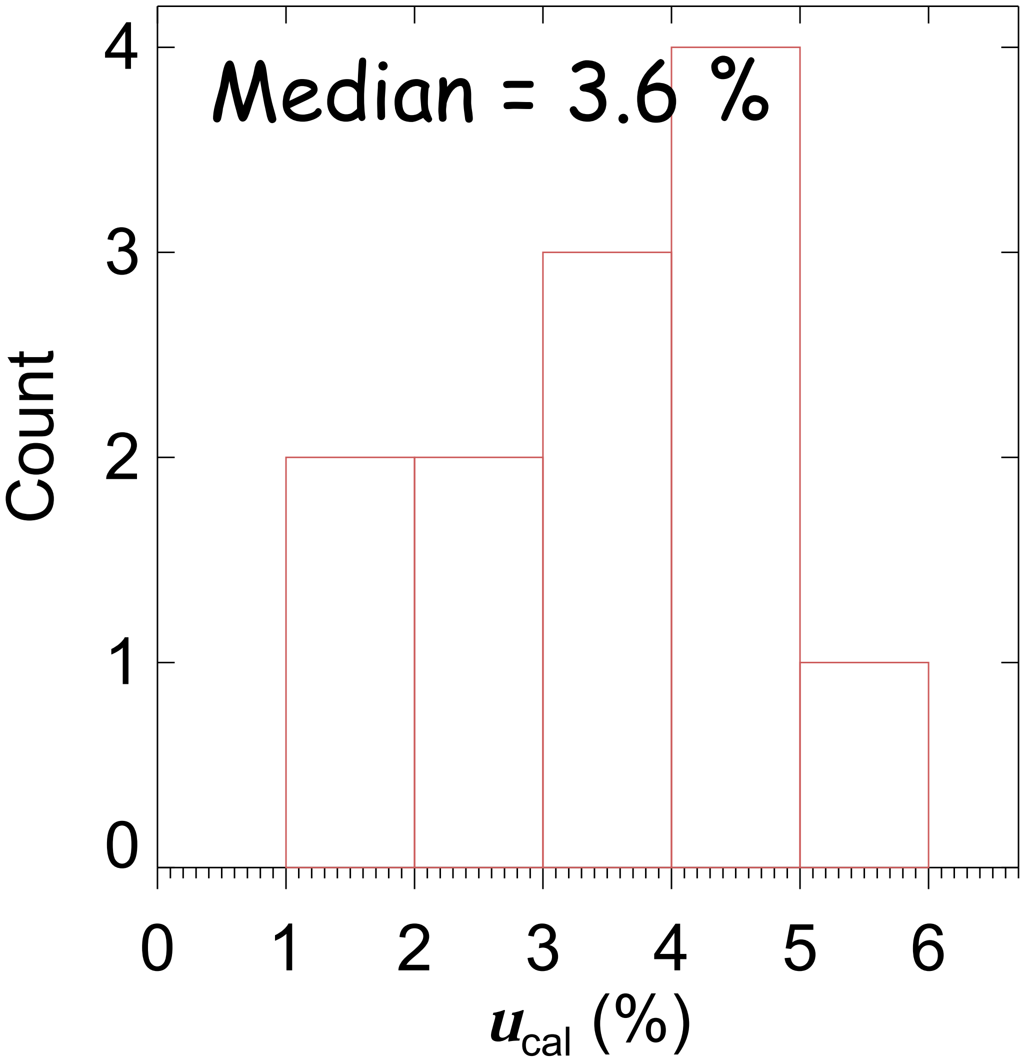
- The relative calibration steps were repeated using a clipping process to identify a set of stable calibrators.



# Results of Relative flux Calibration



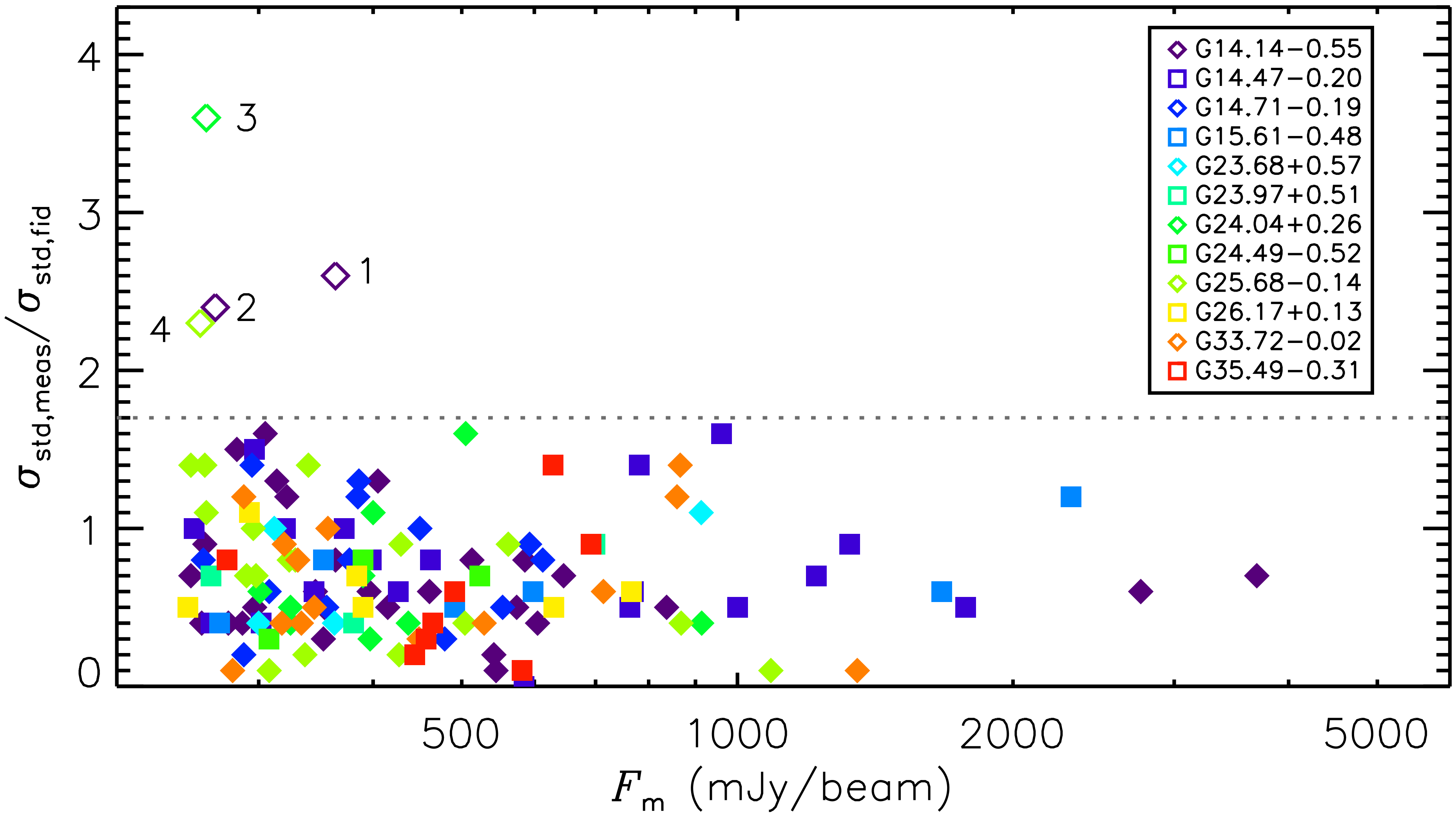
Relative Flux Calibration Factor



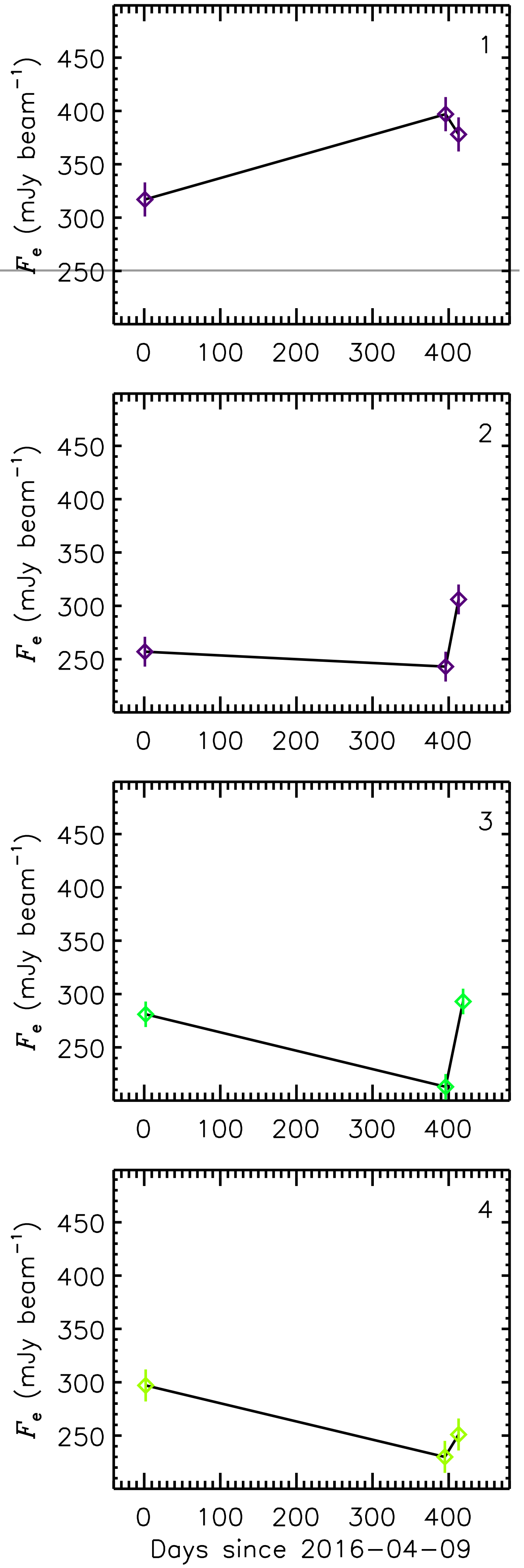
calibration uncertainty ($u_{cal}$)

# 4 Outliers

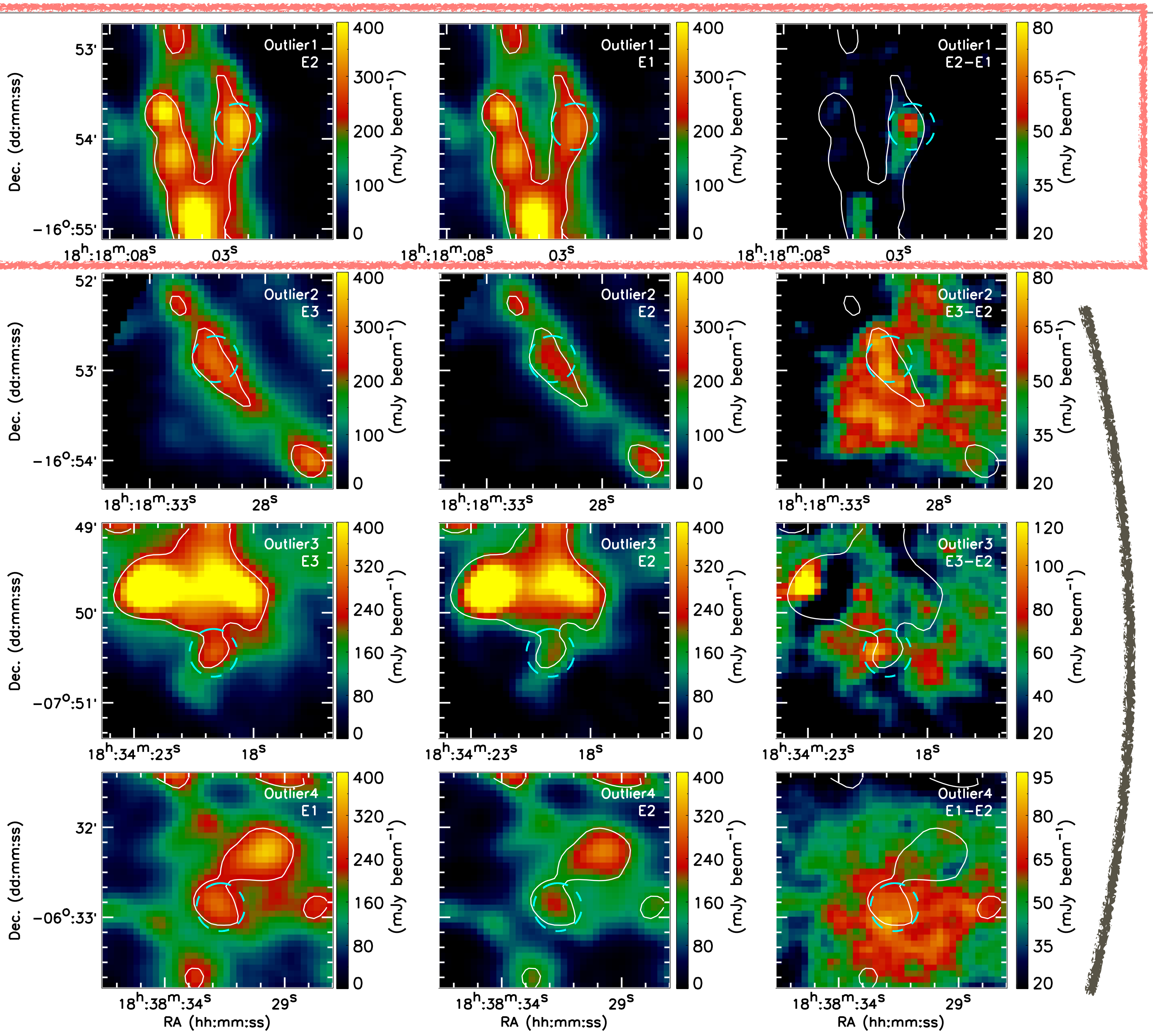
4 outliers of 136 clump peaks in 12 fields



cf. EC 53: SD/SD$_{\rm fid}$ = 5.6 (Johnstone+ 2018)



# Large Scale Bias Check



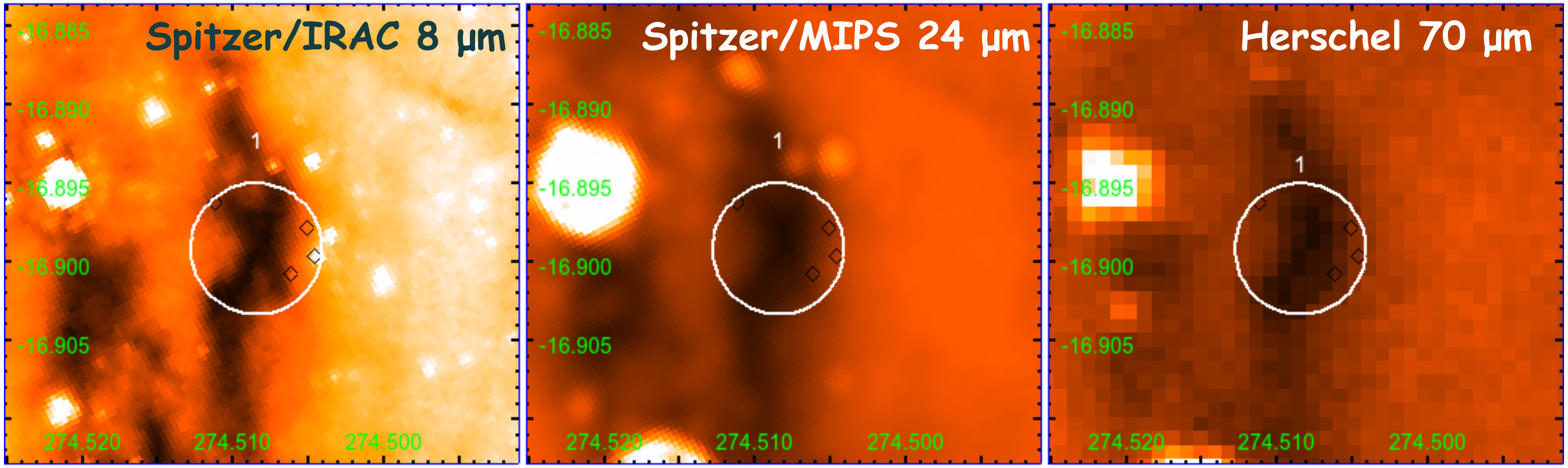
The flux variation indeed originates from the brightness of the localized source.

These are probably caused by artificial large-scale structure. (∵ We do not expect to observe large variations in the brightness of an extended structure in star-forming regions)

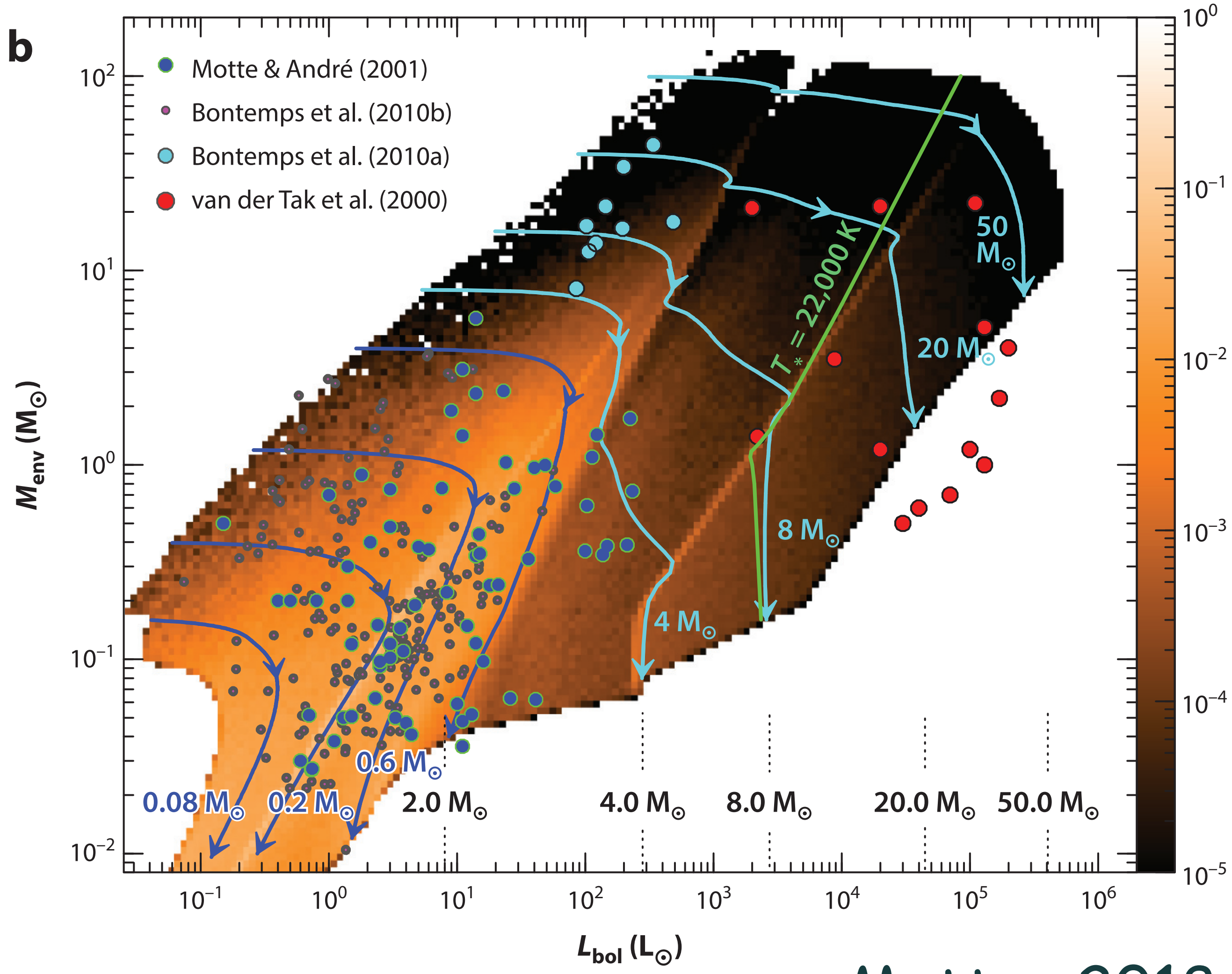
# One potential Variable Candidate

- Outlier 1: G14.143–0.508 in found in the G14.14–0.55 field
- $\sigma_{\rm std,meas}/\sigma_{\rm std,fid} = 2.6$

- matched with ATLASGAL clump AGAL014.142–00.509: $v_{\rm LSR} = 21.1$ km/s; d = 1.5 kpc (Urquhart+ 2015)
- deeply embedded in an IR dark cloud filament, seemingly starless ← It can't completely rule out presence of at least one undetected heavily embedded (proto)star(s).
- **We suggest that the detected flux change could potentially be caused by accretion variability.**



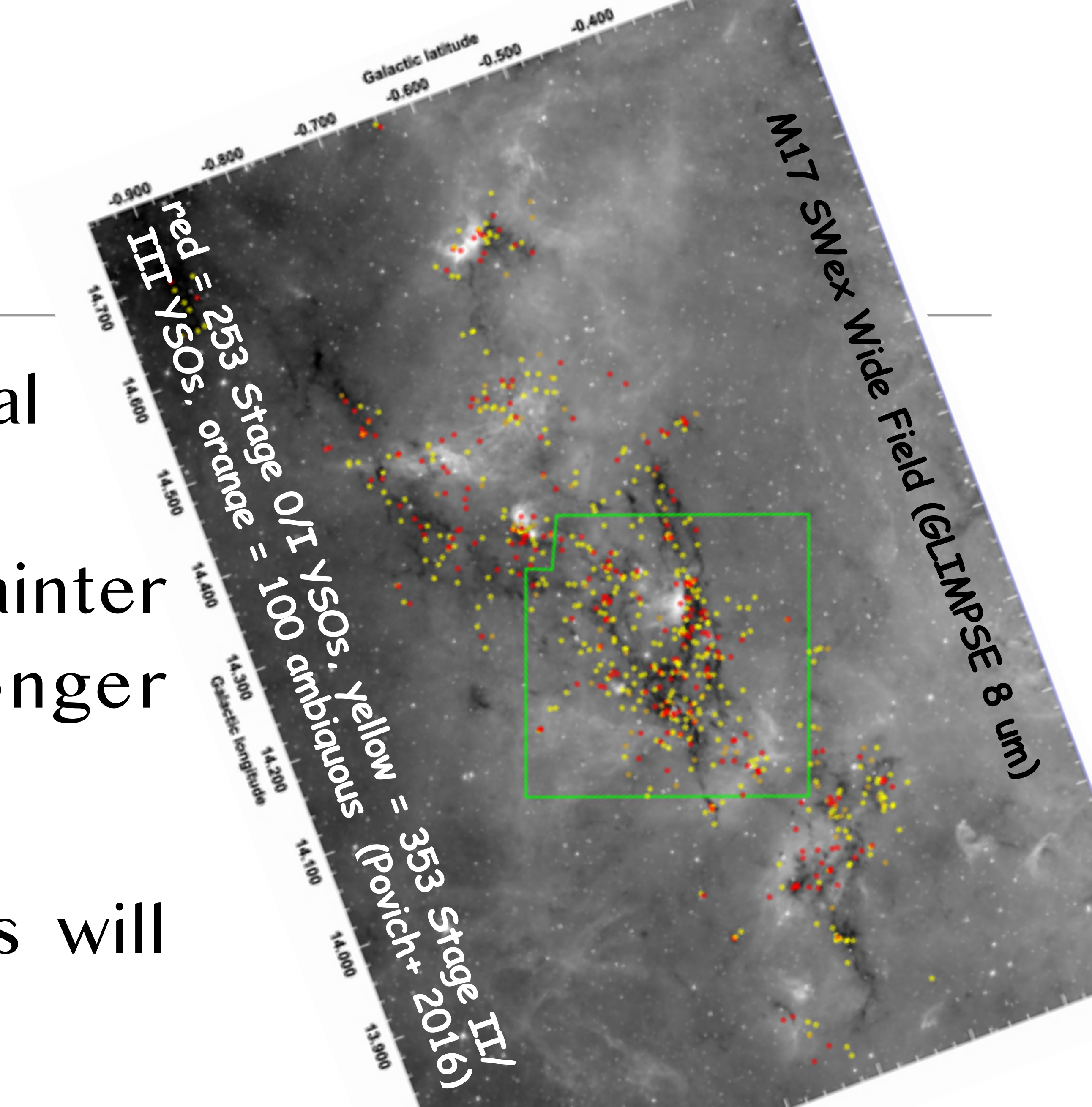
- How to determine whether there is low- or high-mass star formation occurring?
  - Relationship between the bolometric luminosity and the envelope mass is useful (e.g., Molinari+ 2008; Urquhart+ 2014; Motte+ 2018).
  - Clump of Outlier 1 :luminosity (≃ 37 $L_\odot$) and the mass (≃ 23 $M_\odot$) (Urquhart+ 2018)
→ likely related to low- or intermediate- mass star formation



Motte+ 2018

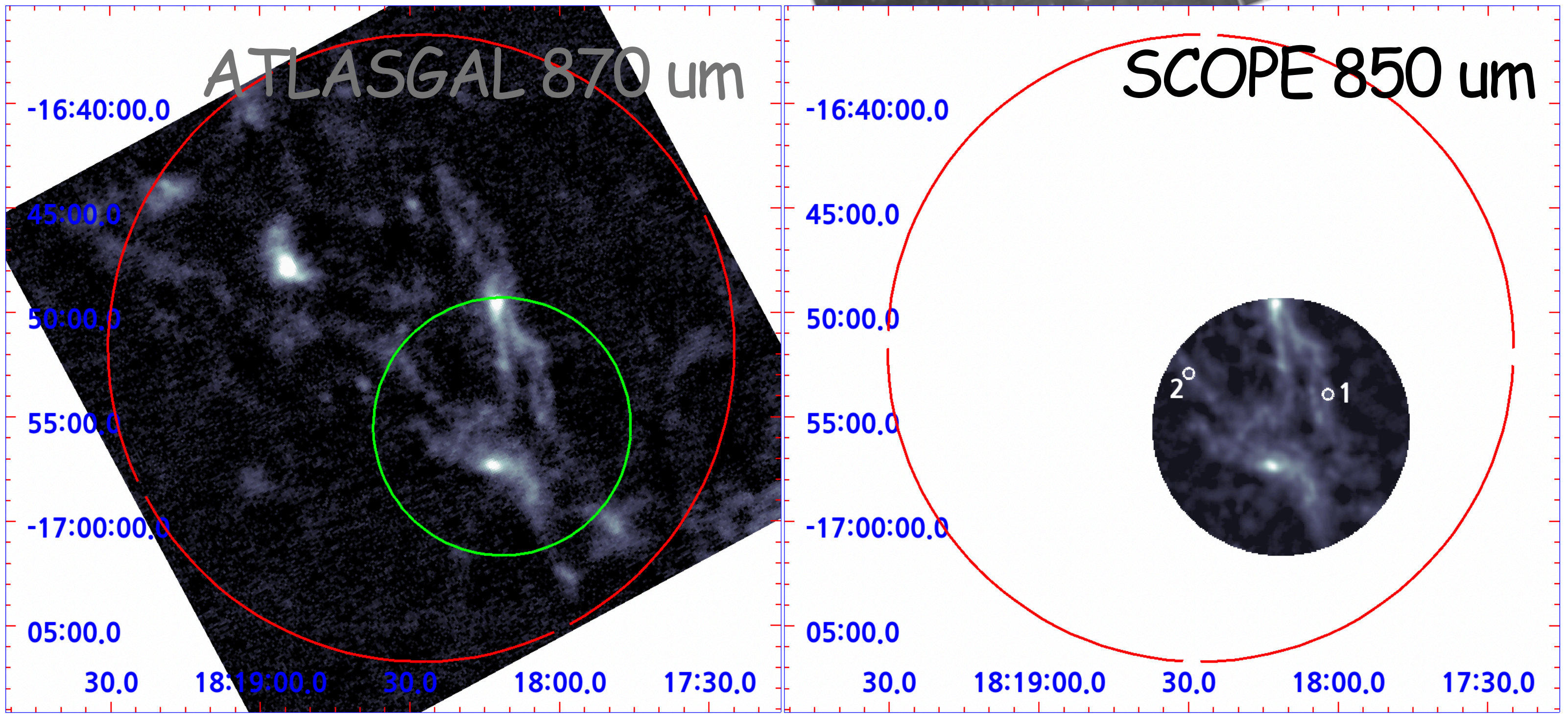
# Future Work

- The Transient expansion proposal has been submitted last month. “The JCMT Transient Survey: Fainter Objects, **Higher Masses**, Longer Timescales” (Herczeg et al.)
- High-mass star forming regions will be studied.
  - **M17**
  - **M17 SWex**
  - **S255**
  - **three fields in DR21**



M17 SWex Wide Field (GLIMPSE 8 um)

red = 253 Stage 0/I YSOs, yellow = 353 Stage II/III YSOs, orange = 100 ambiguous (Povich+ 2016)



ATLASGAL 870 um

SCOPE 850 um

(RA, Dec)

# Summary

- Among the SCOPE 850 μm survey data, we investigated sub-mm flux-variability of cold Planck sub-clumps (peak flux ≥ 250 mJy/beam) in 12 fields.

- We applied a relative flux calibration and achieved a calibration uncertainty of ~3.6% on average.

- Total of 136 clumps were identified in all fields. We found four outliers showing peak flux variations.

- One of them is likely to be a potential variable candidate. The variations from the remains appear to be primarily due to large-scale contamination.

- The flux change of the candidate may be associated with low- or intermediate-mass star formation assuming a distance of 1.5 kpc.