Sub-mm flux variability in Planck cold clumps

presented by Geumsook Park

Korea Astronomy and Space Science Institute

Collaborators:
Kee-Tae Kim, Sung-ju Kang, Tie Liu, Minho Choi, Miju Kang (KASI);
Doug Johnstone (NRC-HAA)

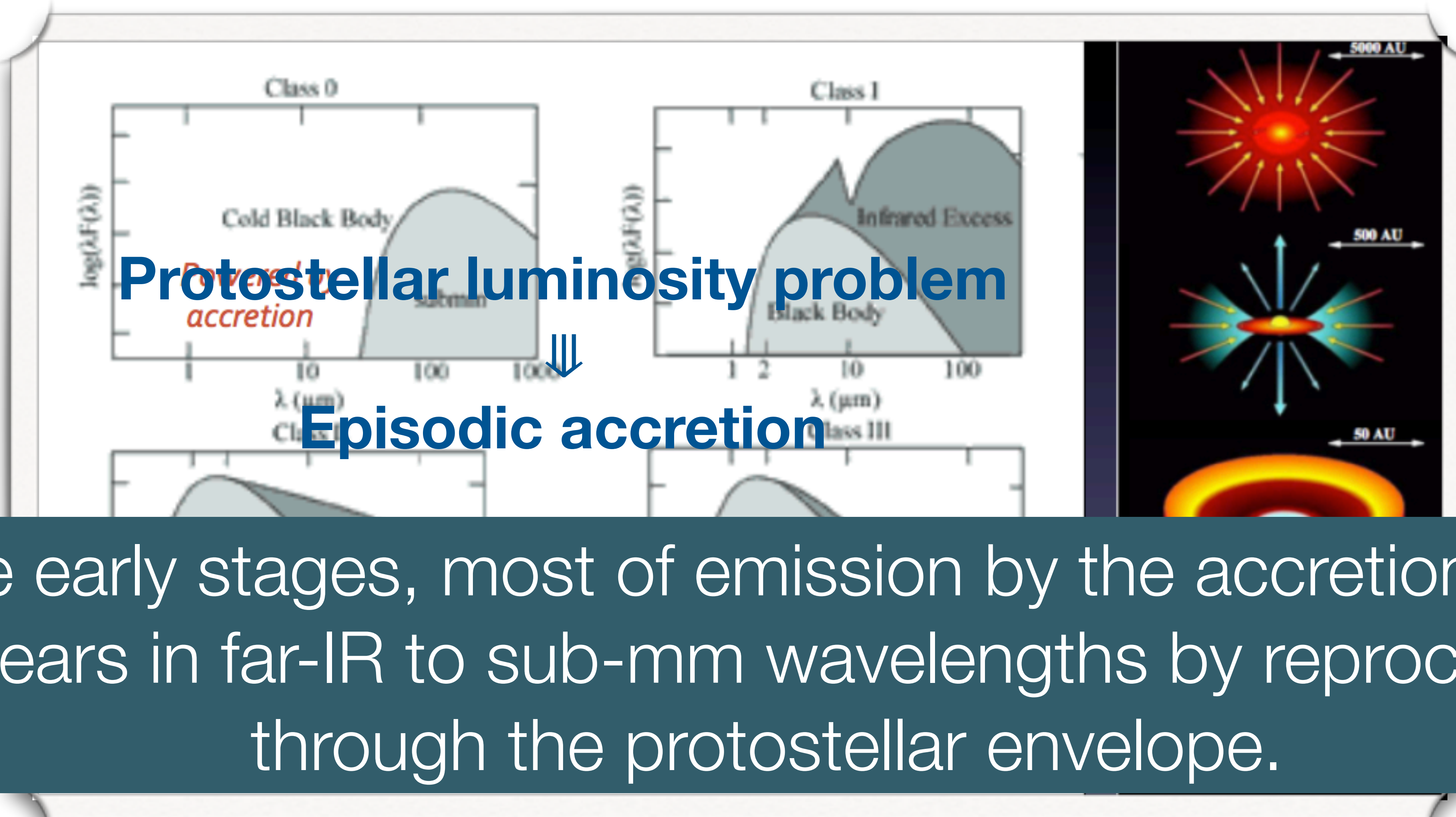
Tracing the Flow 2018 in Windermere, UK

Contents

- Introduction:
  - Why we are interested in flux variability?
  - Observational examples
- JCMT SCOPE survey and the data used in this study
- Technical issue
- Data analysis
- Results
- Summary

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

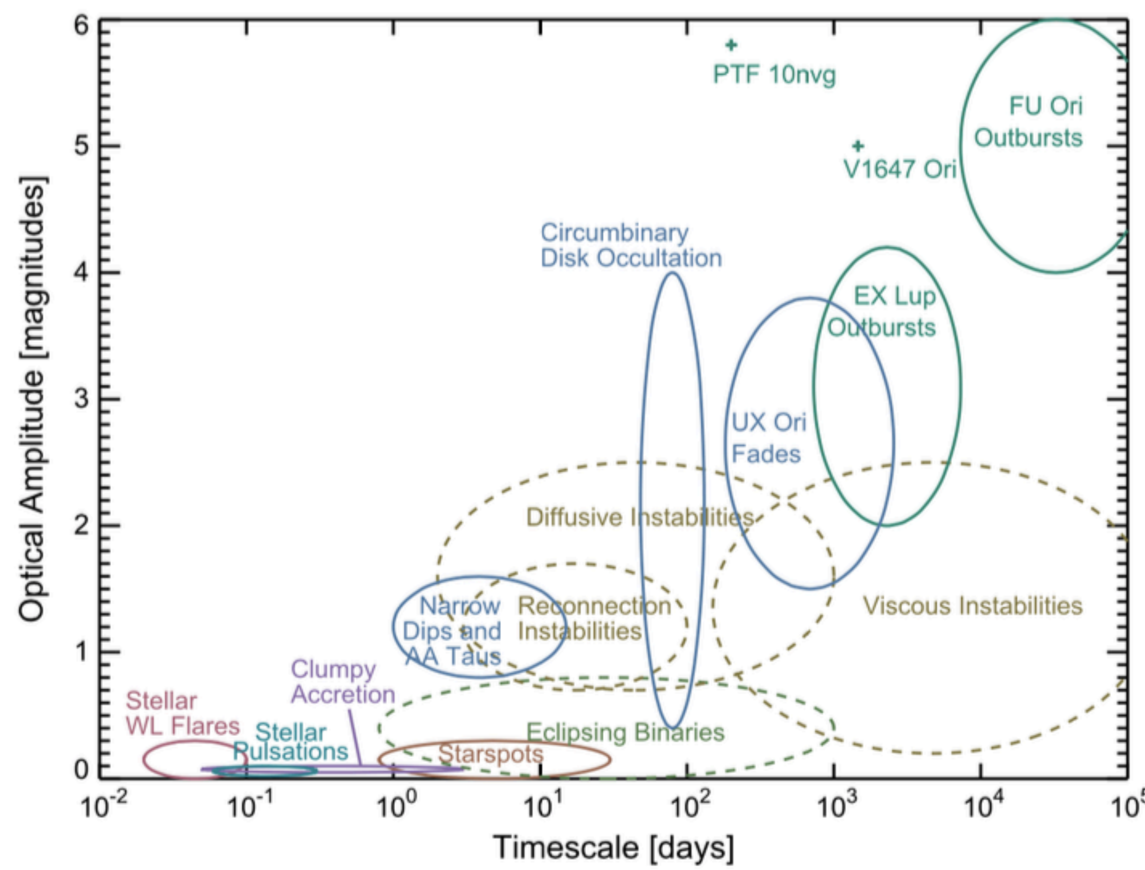
⇓

Episodic accretion

At the early stages, most of emission by the accretion energy appears in far-IR to sub-mm wavelengths by reprocessing through the protostellar envelope.

Observational examples

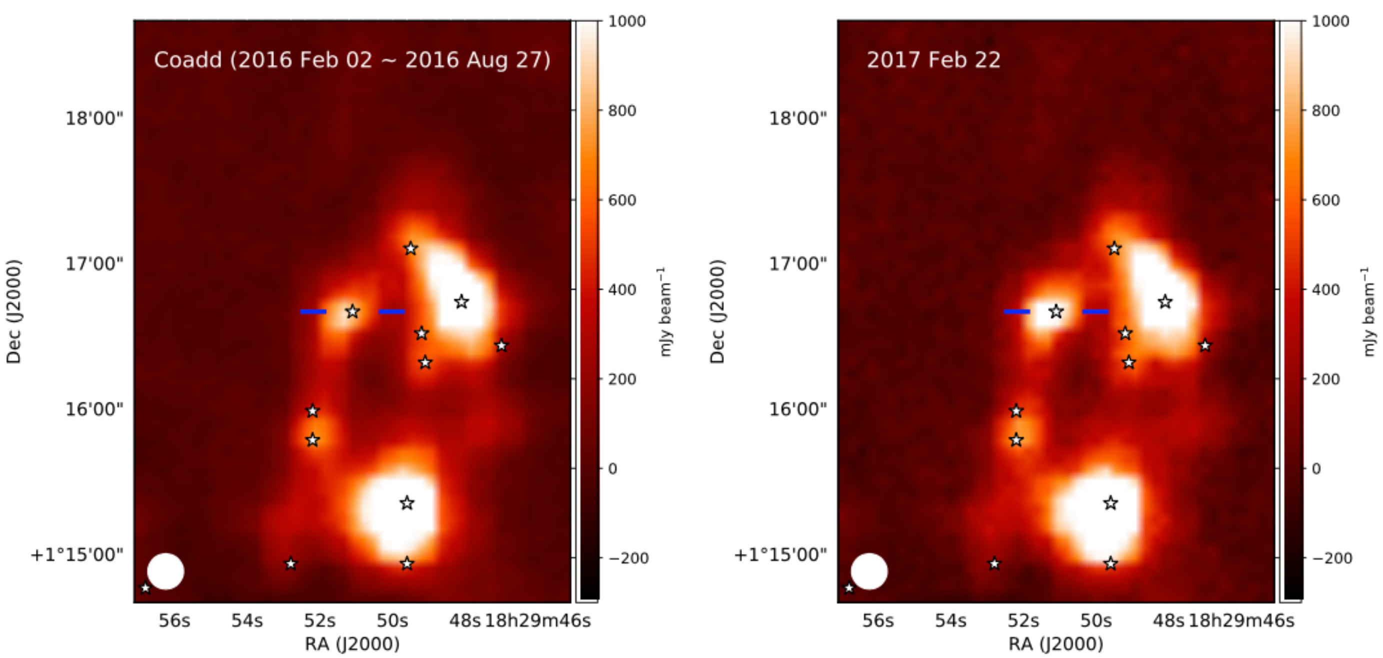
- A **large optical brightness increase** of a factor of ten or more observed in **FU Orionis** (e.g., Herbig 1977; Hartmann & Kenyon 1996) or **EX Lupi** (e.g., Herbig 2008; Aspin+2010)
- About a-factor-of 1.5 increase in **sub-mm** flux toward **Class I protostar EC53** (Yoo+2017)
- About a-factor-of-2 increase in **sub-mm** flux (350 μm and 450 μm) toward **Class 0 source HOPE 383** (Safron+2015)
- Also, high-mass protostellar system **NGC 6334I-MM1** (Hunter+2017)



Hillenbrand & Findeisen 2015

Observational examples

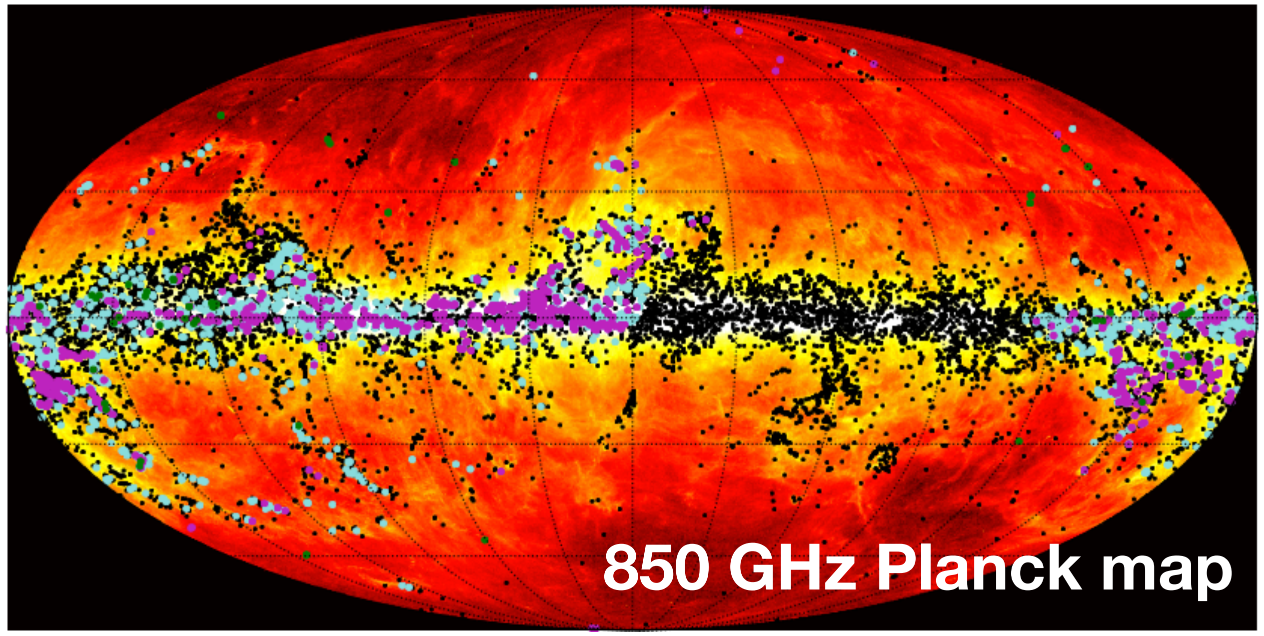
- A **large optical brightness increase** of a factor of ten or more observed in **FU Orionis** (e.g., Herbig 1977; Hartmann & Kenyon 1996) or **EX Lupi** (e.g., Herbig 2008; Aspin+2010)
- About a-factor-of 1.5 increase in **sub-mm** flux toward **Class I protostar EC53** (Yoo+2017)
- About a-factor-of-2 increase in **sub-mm** flux (350 μm and 450 μm) toward **Class 0 source HOPE 383** (Safron+2015)
- Also, high-mass protostellar system **NGC 6334I-MM1** (Hunter+2017)



EC 53 discovered by Yoo+2017 in the JCMT Transient team

JCMT SCOPE survey

- "**S**CUBA-2 **C**ontinuum **O**bservations of **P**re-protostellar **E**volution"
- begun in December 2015 and completed in July 2017
- Main aim: **Statistical study the initial conditions occurring during star formation across a wide range of environments**
- Source selection:
  - regions covered by Herschel observations or **high** column density (> 1×10^{21} cm^{-2} in Planck meas.)
  - also, many **lower** column density (> 5×10^{20} cm^{-2} in Planck meas.) clumps at high latitudes

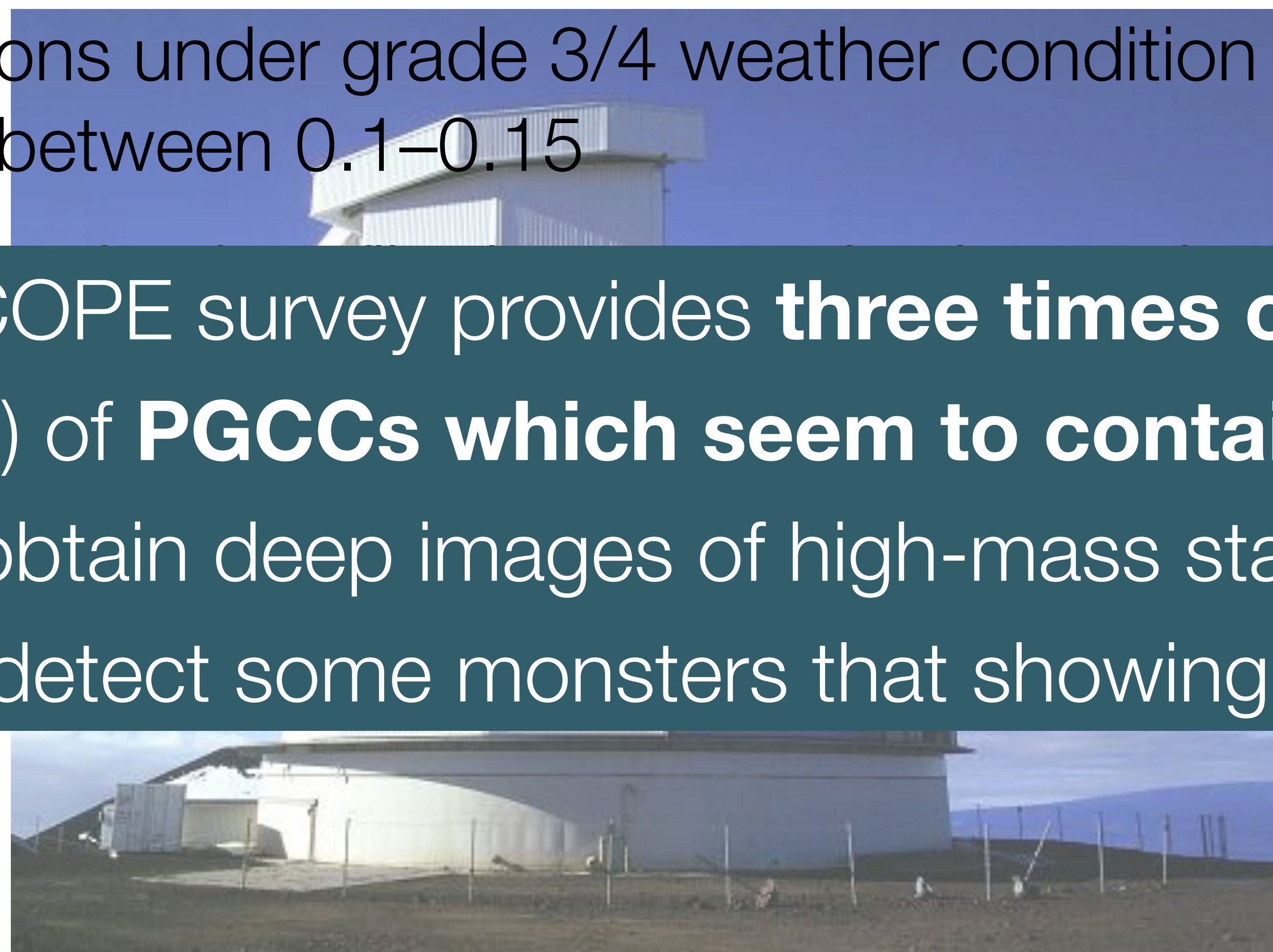


1000 (magenta dots) among 13188 PGCC sources (black dots) selected for SCOPE (Tie+2018)

SCOPE survey: Observations

cf. **Planck (5')**

- 850 μm
- SCUBA-2 sub-mm bolometer at the 15m JCMT (FWHM = 14.1″)
- CV Daisy mode (Mapping size of diameter ~ 12′)
- Observations under grade 3/4 weather condition with 225 GHz opacities between 0.1–0.15



SCUBA-2 at JCMT.

The SCOPE survey provides **three times observations** for some (< 30) of **PGCCs which seem to contain massive clumps** in order to obtain deep images of high-mass star forming regions as well as to detect some monsters that showing a big flux variance.

The data used in this study: 12 fields

Table 1. Fields and Epochs

Field	Central Position[1] (h:m:s)	Central Position[1] (d:m:s)	Three Epochs (yyyymmdd)			Time Intervals[2] (day)		Distance(s)[3] (kpc)
G14.14−0.55	18:18:11.50	−16:55:29.05	20160410	20170510	20170527	395	17	1.9
G14.47−0.20	18:17:31.80	−16:28:00.46	20160409	20170511	20170602	397	22	∼ 3.1 (∼ 12)
G14.71−0.19	18:17:59.80	−16:14:41.16	20160409	20170510	20170602	396	23	∼ 3.1 (12.6)
G15.61−0.48	18:20:48.40	−15:35:41.29	20160410	20170511	20170602	396	22	1.8/16.9
G23.68+0.57	18:32:23.20	−07:57:39.50	20160411	20170510	20170603	394	24	5.8
G23.97+0.51	18:33:09.20	−07:43:48.16	20160411	20170512	20170604	396	23	5.6
G24.04+0.26	18:34:10.40	−07:47:05.86	20160411	20170510	20170602	394	23	∼ 6.0 (∼ 9.2)
G24.49−0.52	18:37:48.10	−07:44:45.61	20160411	20170512	20170602	396	21	3.8/11.3
G25.68−0.14	18:38:39.10	−06:30:49.20	20160411	20170509	20170527	393	18	∼ 4–9
G26.17+0.13	18:38:34.70	−05:57:20.53	20160411	20160830	20170604	141	278	∼ 8.6 (5.7)
G33.72−0.02	18:52:55.20	+00:41:26.00	20160412	20160722	20170527	101	309	6.5 (2.2)
G35.49−0.31	18:57:12.90	+02:07:52.72	20160413	20160607	20170527	55	354	2.2 (3.2/10.3)

[1] Equatorial coordinates, RA and Dec (J2000)

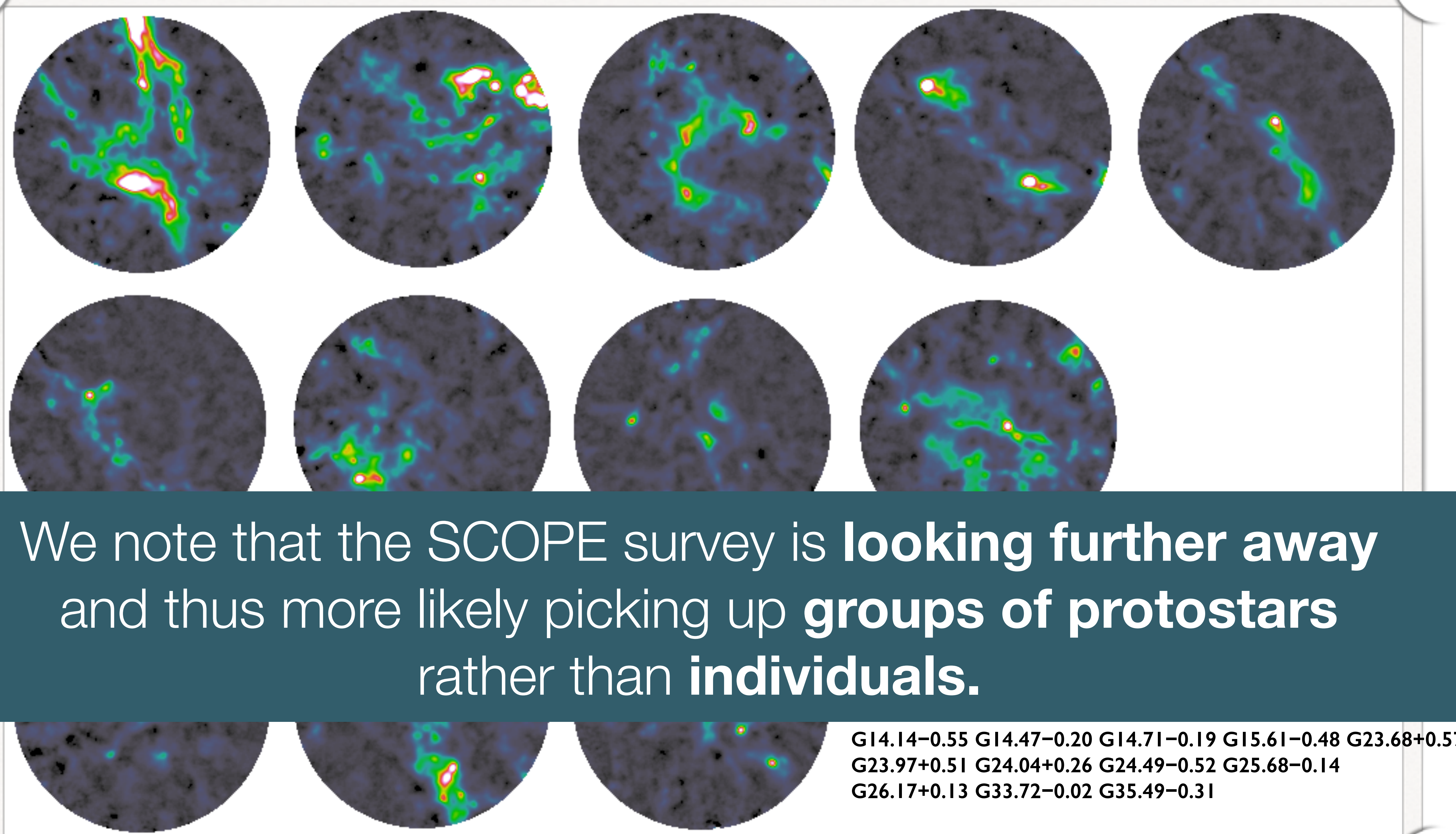
[2] The delta time between the first and second epochs and between the second and third epochs.

[3] Distances are obtained from Urquhart et al. (2018, see also references therein).

Korea Astronomy and Space Science Institute
한국천문연구원

Tracing the Flow 2018 in Windermere, UK

SCOPE data: 'coadded' images



We note that the SCOPE survey is **looking further away** and thus more likely picking up **groups of protostars** rather than **individuals.**

Technical Issue

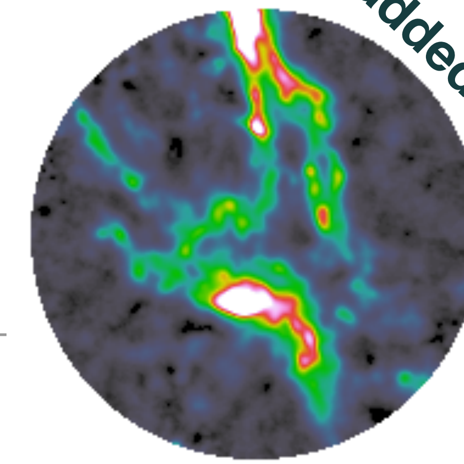
- Non-uniform noise level of a Daisy-mode image
- Telescope pointing uncertainty: 2-6”
- Default absolute flux calibration uncertainty for SCUBA-2 images: ~ 5-10%
- References: Dempsey+2013; Mairs+2017a

Data Analysis

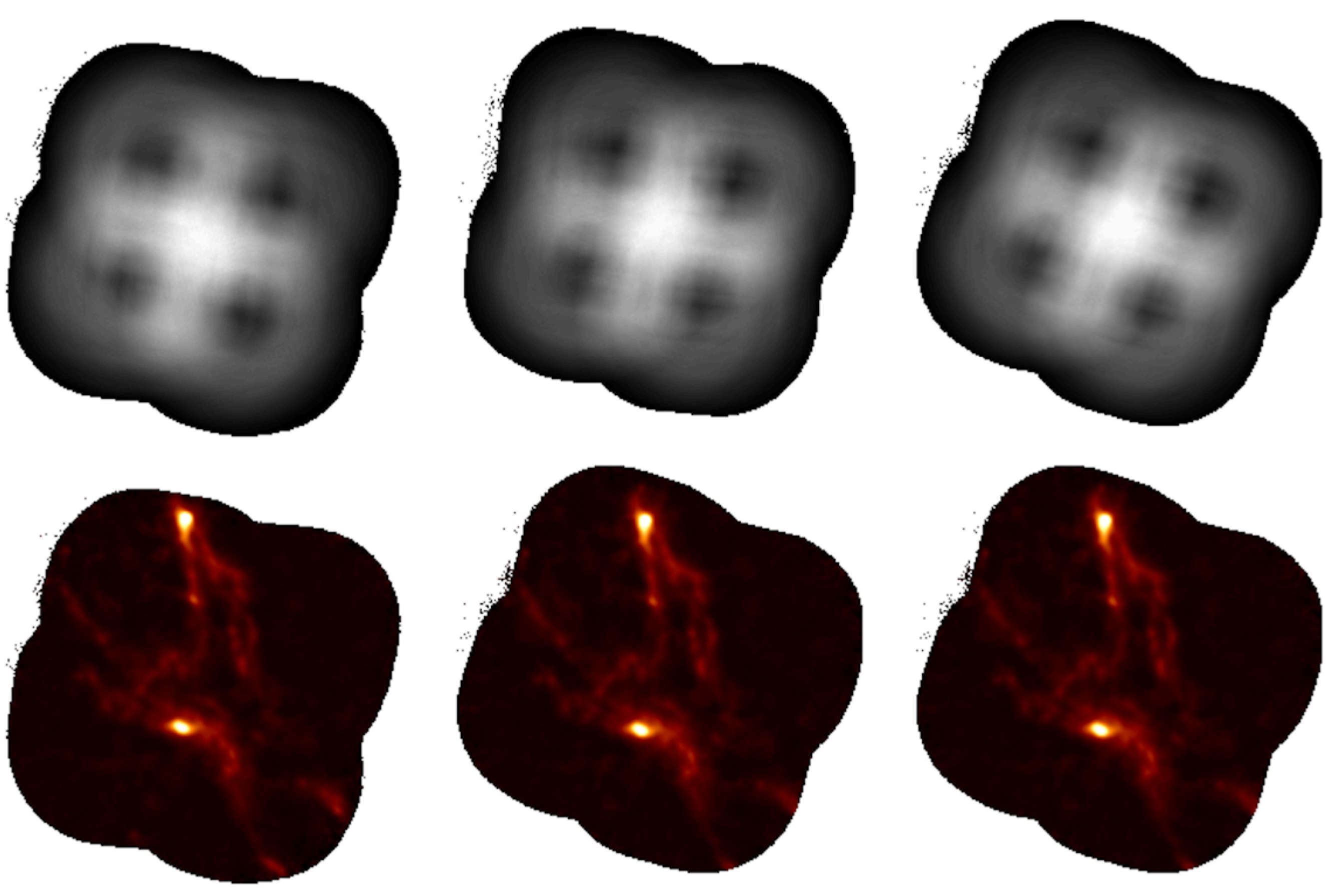
- Make data arrays to have same grid coordinates (wcsaslign in STARLINK)
- Smoothing using a Gaussian kernel with FWHM = 2 px (gausmooth in STARLINK) (finally, FWHM = 16.2″)
- Make a co-added image (picard MOSAIC JCMT IMAGES in STARLINK)
- Estimate RMS noise levels as a function of exposure times in 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 significance (= SD/SD_{fid})

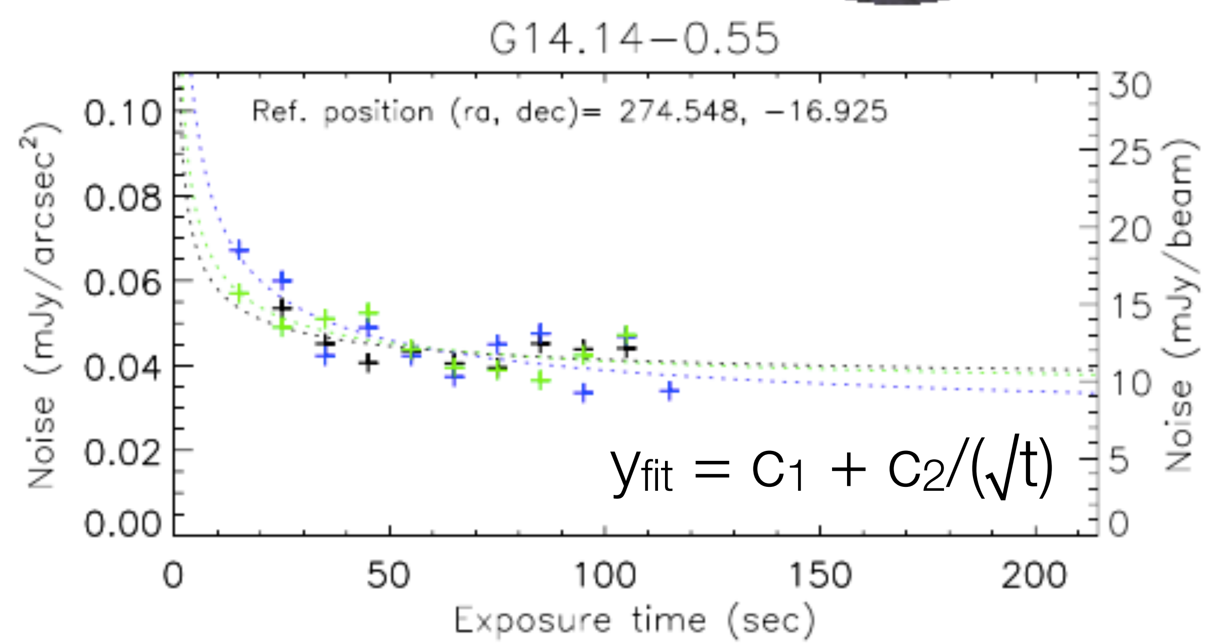
Noise Profiles

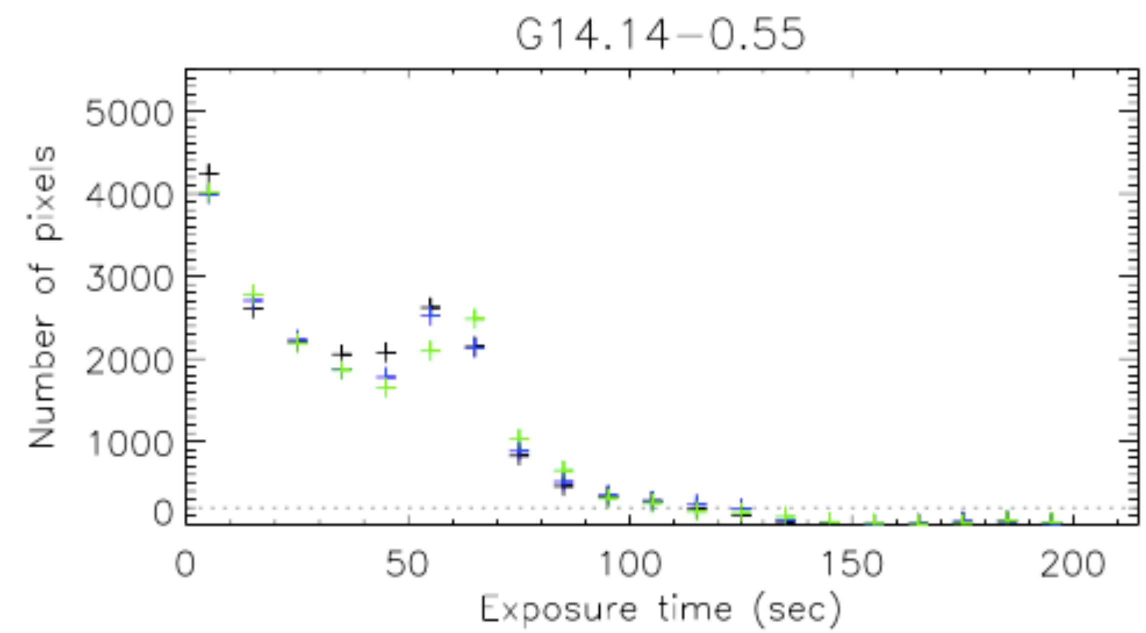
coadded image



Exposure-time and 850 um continuum images at three epochs







Clumpfinding and relative flux calibration

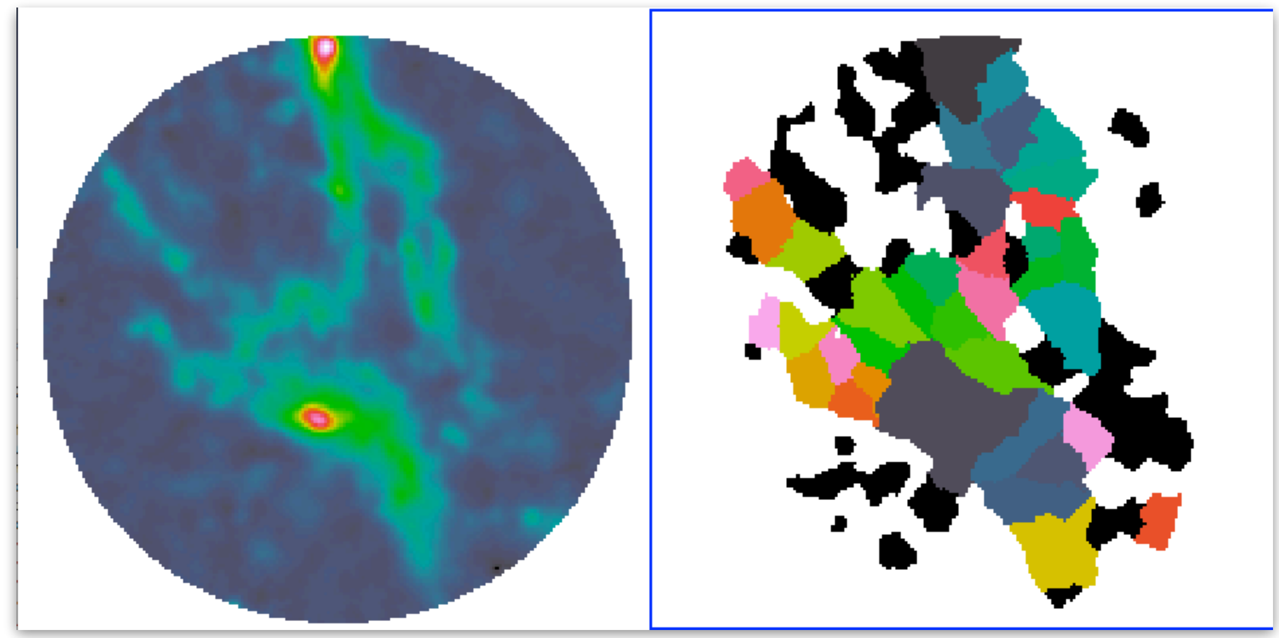
- We found clumps in the co-added image.
- only sources having a mean peak flux > 250 mJy/beam
- We used any clumps having $SD/SD_{fid} \leq 1.7$ for calibration.

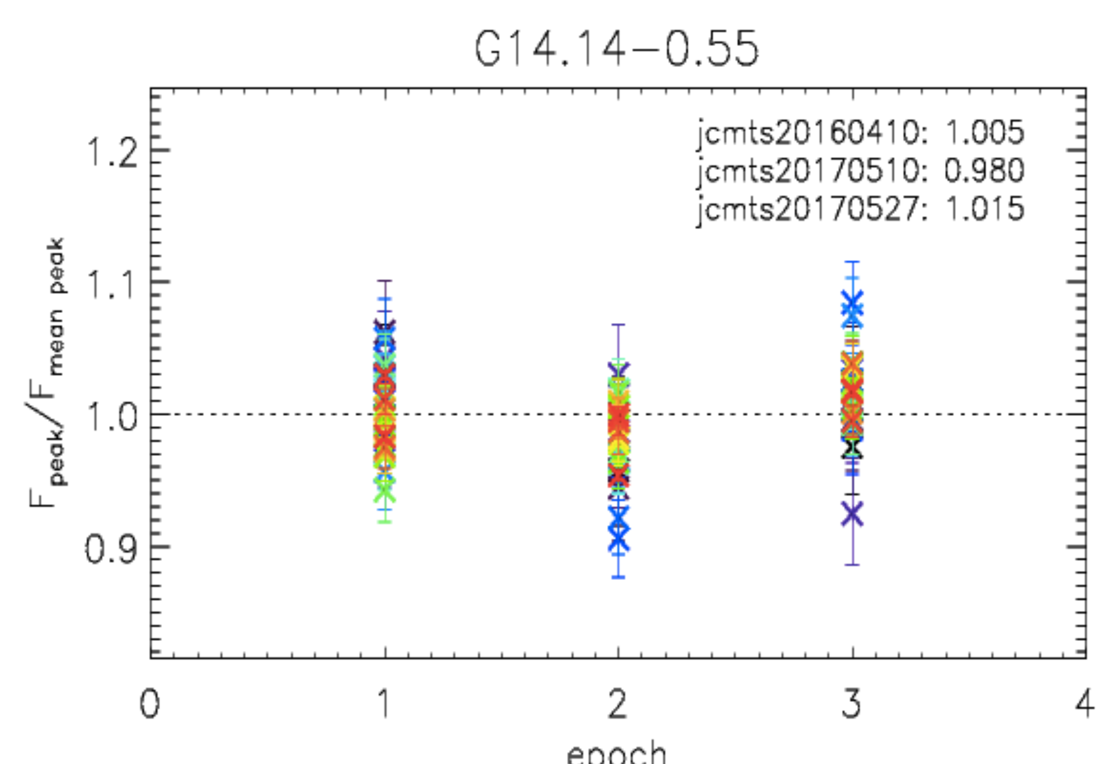
$$SD_{fid}(i) = [\sigma(i)^2 + (u_{cal} \times f_m(i))^2]^{1/2} \text{ mJy/beam}$$

$$u_{cal} = [\Sigma[SD(i)^2/f_m(i)^2]/(n_c - 1)]^{1/2}.$$

Johnstone+2018

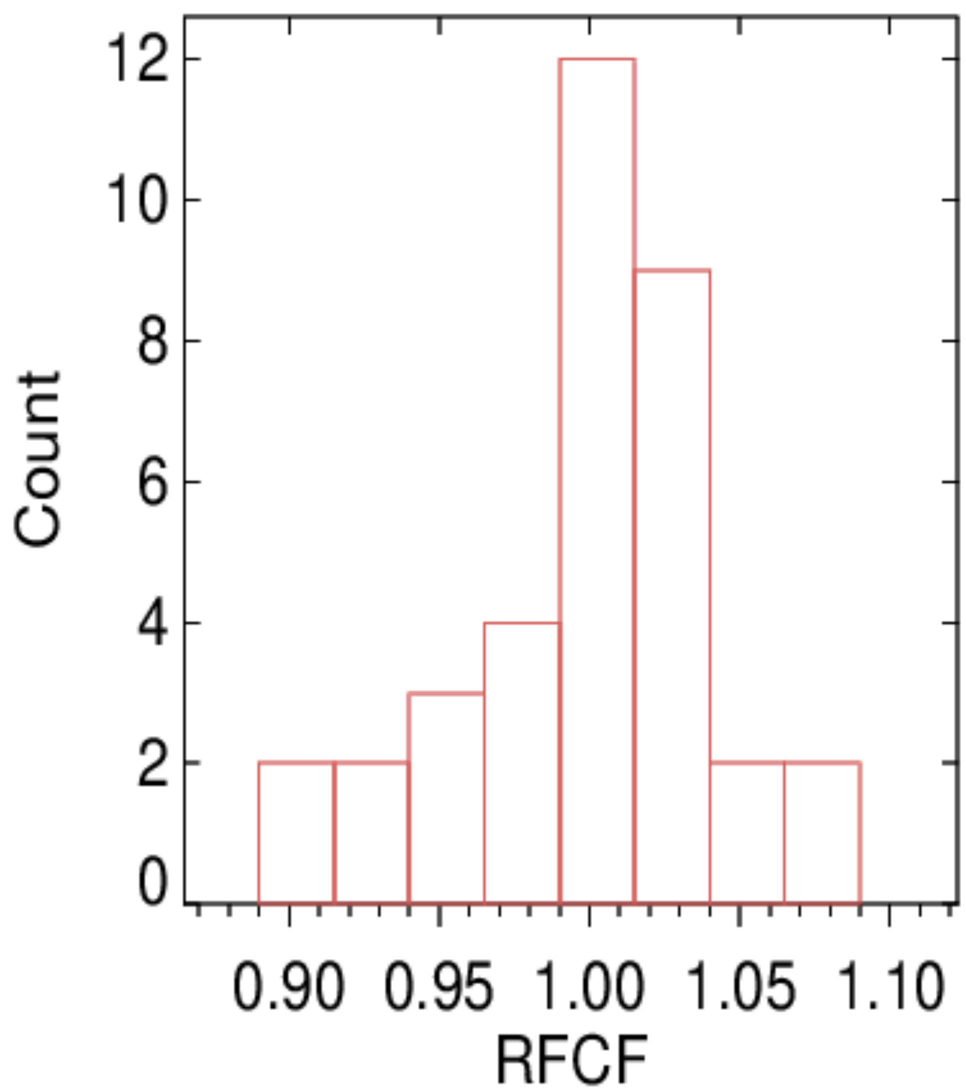
- We derived a relative flux calibration factor (RFCF) for each epoch and then each epoch data were divided by RFCF.



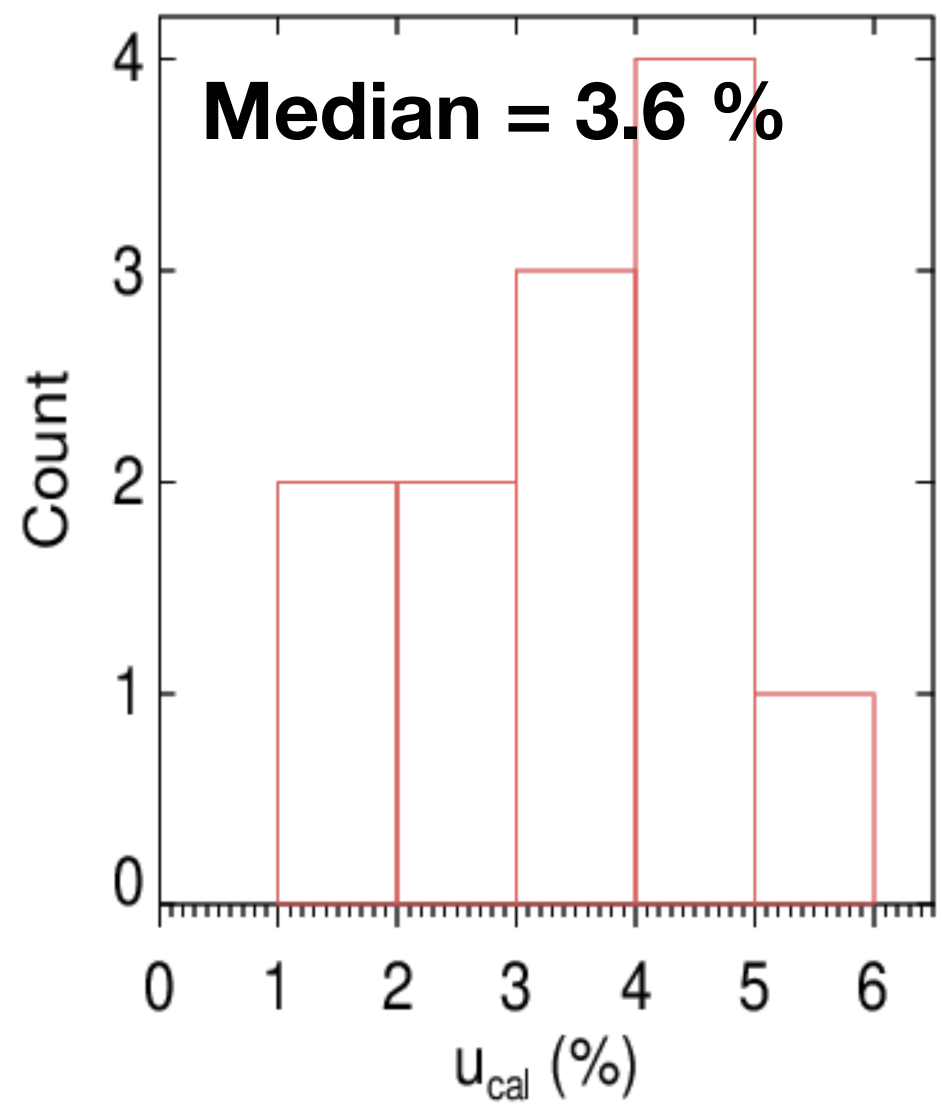


Korea Astronomy and Space Science Institute 한국천문연구원

Results: Relative flux Calibrations

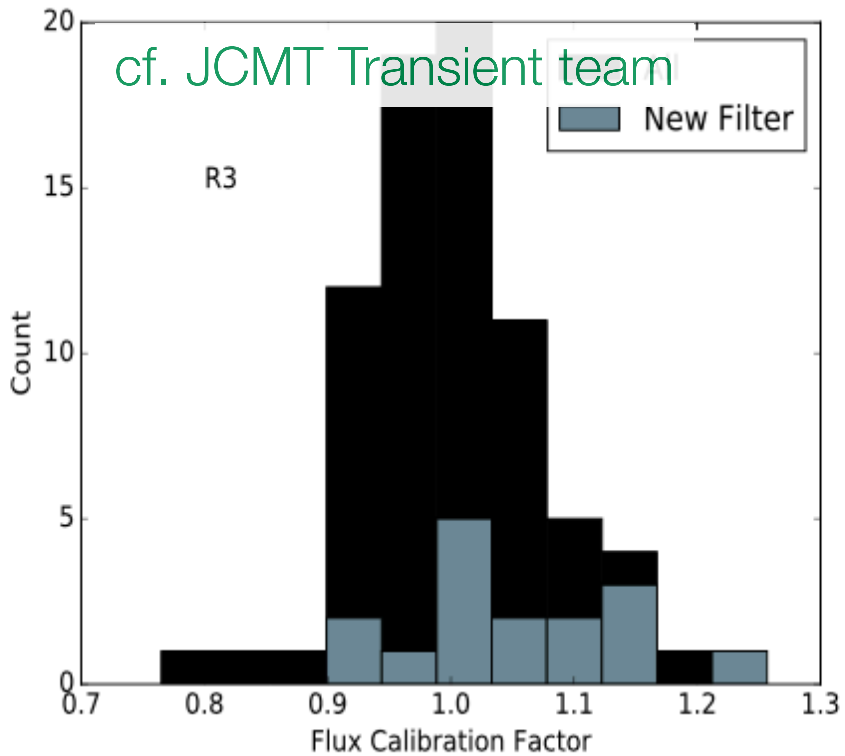


Relative Flux Calibration Factor

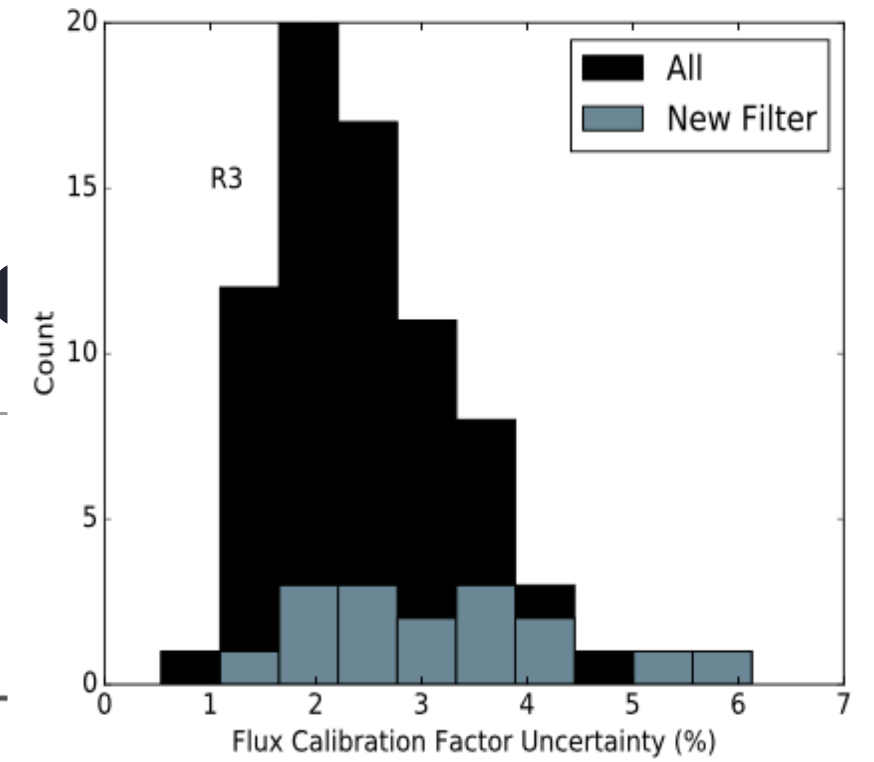


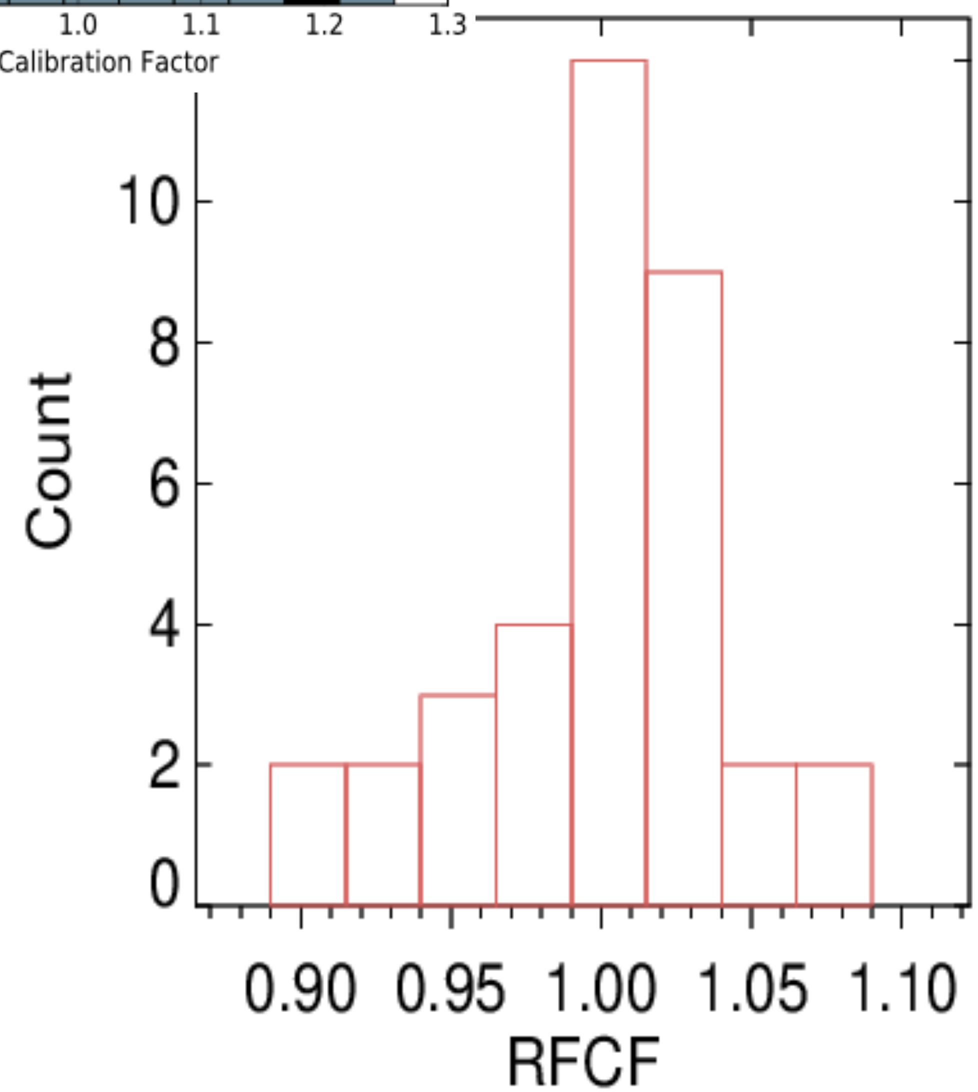
calibration uncertainty (u_{cal})

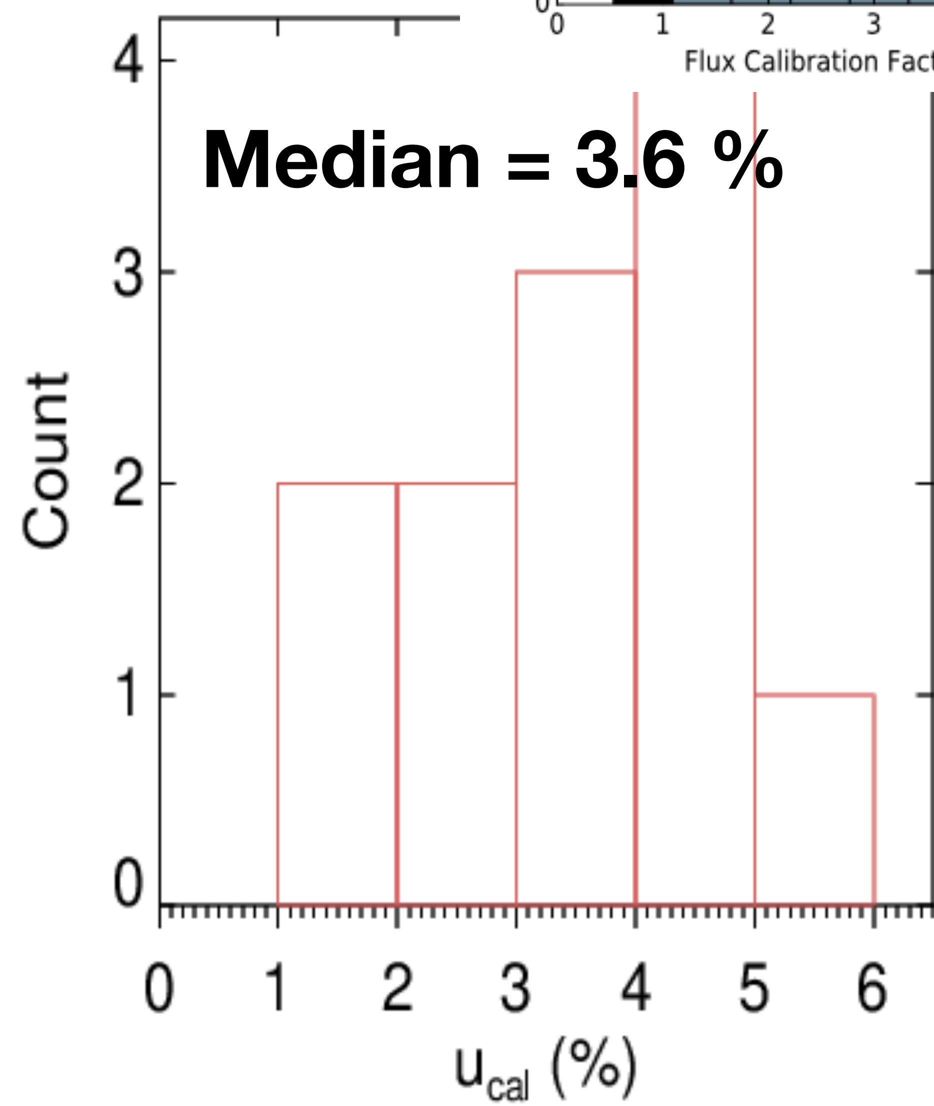
$$u_{cal} = [\Sigma[SD(i)^2/f_m(i)^2]/(n_c-1)]^{1/2}.$$



ative flux Calibrati



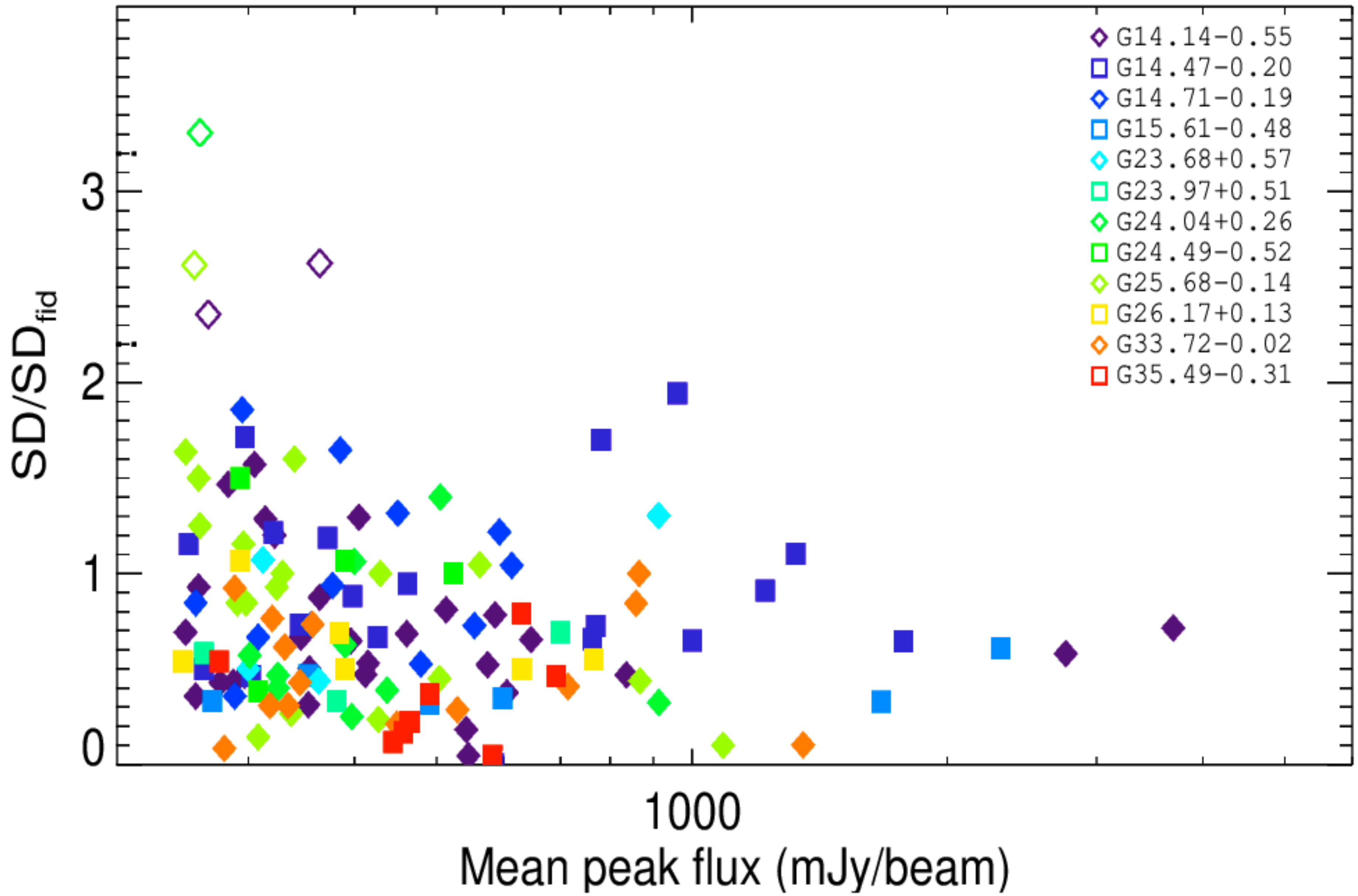




Relative Flux Calibration Factor

calibration uncertainty (u_{cal})

Results: Outliers



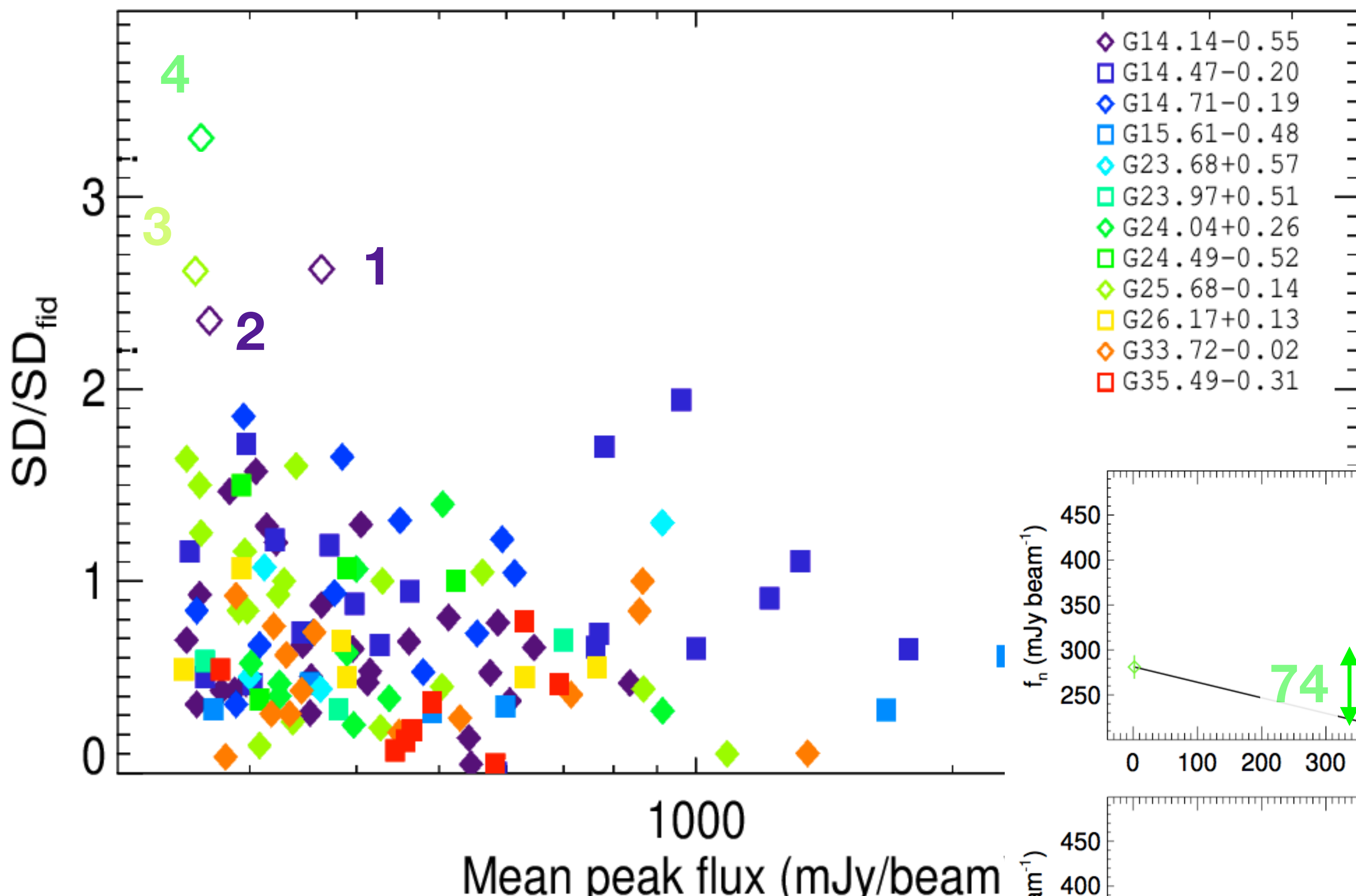
cf. EC 53

SD/SD_{fid} = 5.6

$$SD_{fid}(i) = [\sigma_{noise}(i)^2 + (u_{cal} \times f_m(i))^2]^{1/2} \text{ mJy beam}^{-1}$$

$^*u_{cal} = 3.6\%$

Results: Outliers

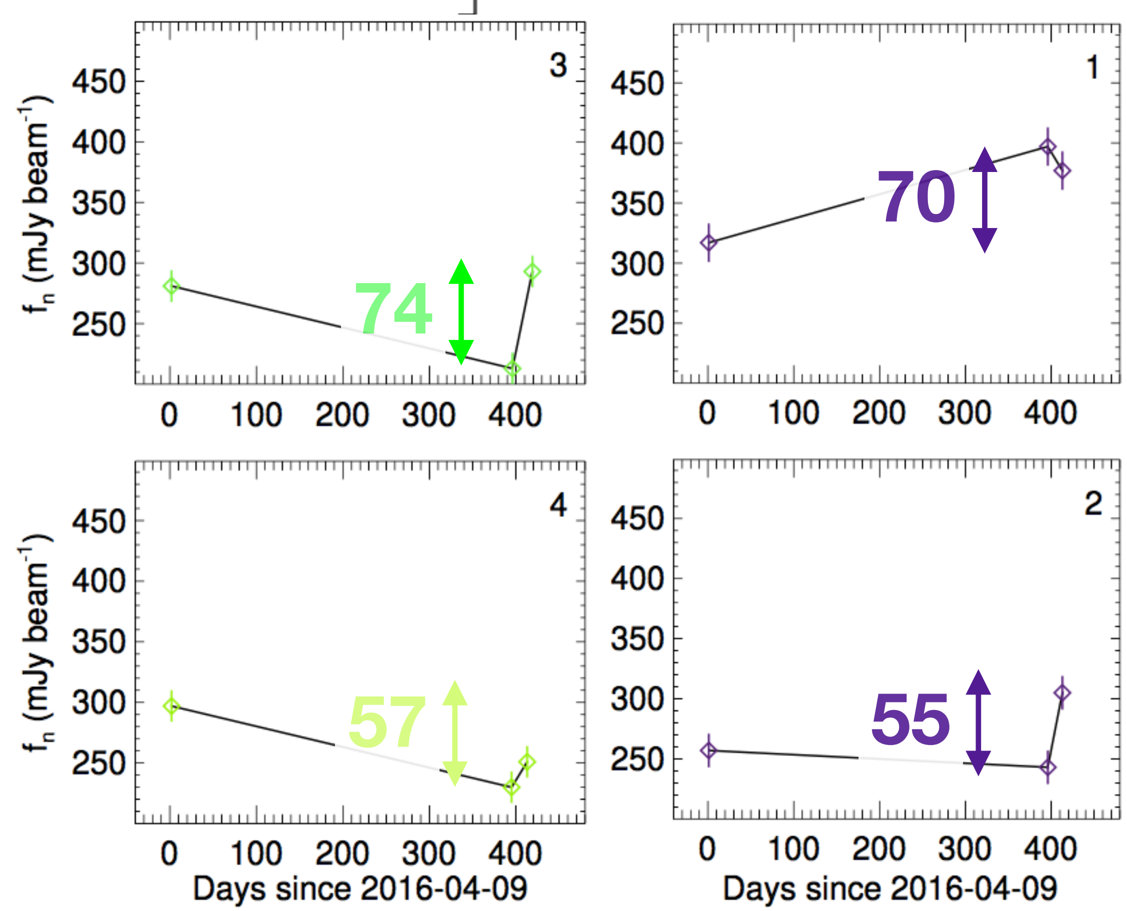


cf. EC 53

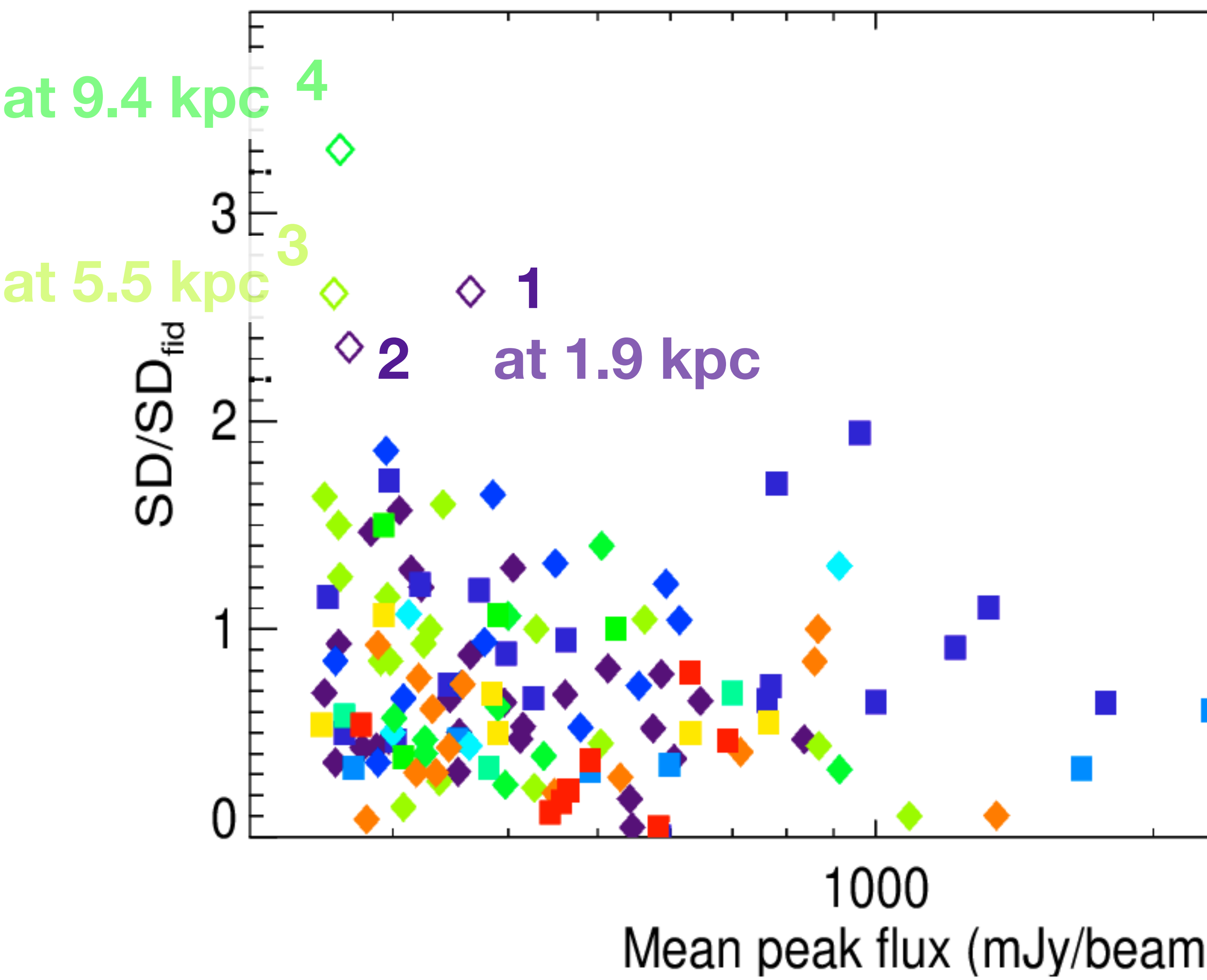
SD/SD$_{fid}$ = 5.6

flux increase @ 850 um:

490 mJy/beam



Results: Outliers



at 436 pc
(Ortiz-Leon+2017)

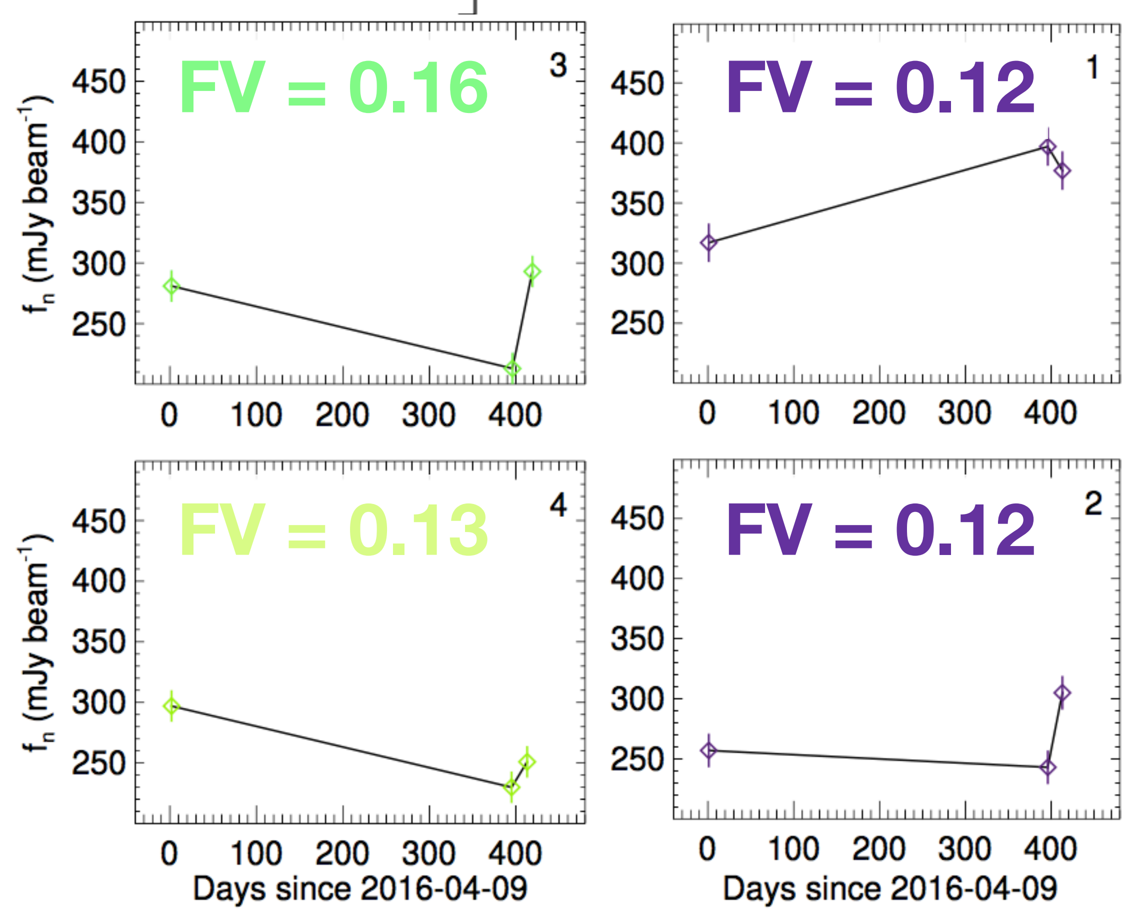
cf. EC 53

$SD/SD_{fid} = 5.6$

Fractional variance (FV)

= SD/ mean peak flux

= 0.12



* outliers' distances from Urquhart et al. (2018; also, see references therein)

Tracing the Flow 2018 in Wi

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.
- Total of 136 clumps were identified in all fields.
- There was no big burst-like event.
- However, we found four outliers which will be possible candidates ($SD/SD_{fid} > 2.2$; Fractional variance ~ 0.12 to 0.16) although it may be hard to assure with three observational epochs.
- Additional monitoring observations (at least 5 times, uniform-noisy mapping mode) may give more hints about flux-variability in star-forming regions.

Geumsook Park - pgs@kasi.re.kr

Four outliers

Outlier 1
G14.14-0.55

Outlier 2
G14.14-0.55

Outlier 3
G24.04+0.26

Outlier 4
G25.68-0.14