An Extraordinary Submillimetre Flare in a T Tauri Binary System

Steve Mairs, East Asian Observatory, JCMT

Overview

The JCMT Transient Survey

The Search for Flares

Flare Detection

SCUBA-2 Light Curve

The Nature of JW 566

Studying Variability = Understanding Mass Assembly

The Luminosity Problem

Kenyon et al. (1990); Dunham et al. (2009); Enoch et al. (2009); Evans et al (2009)

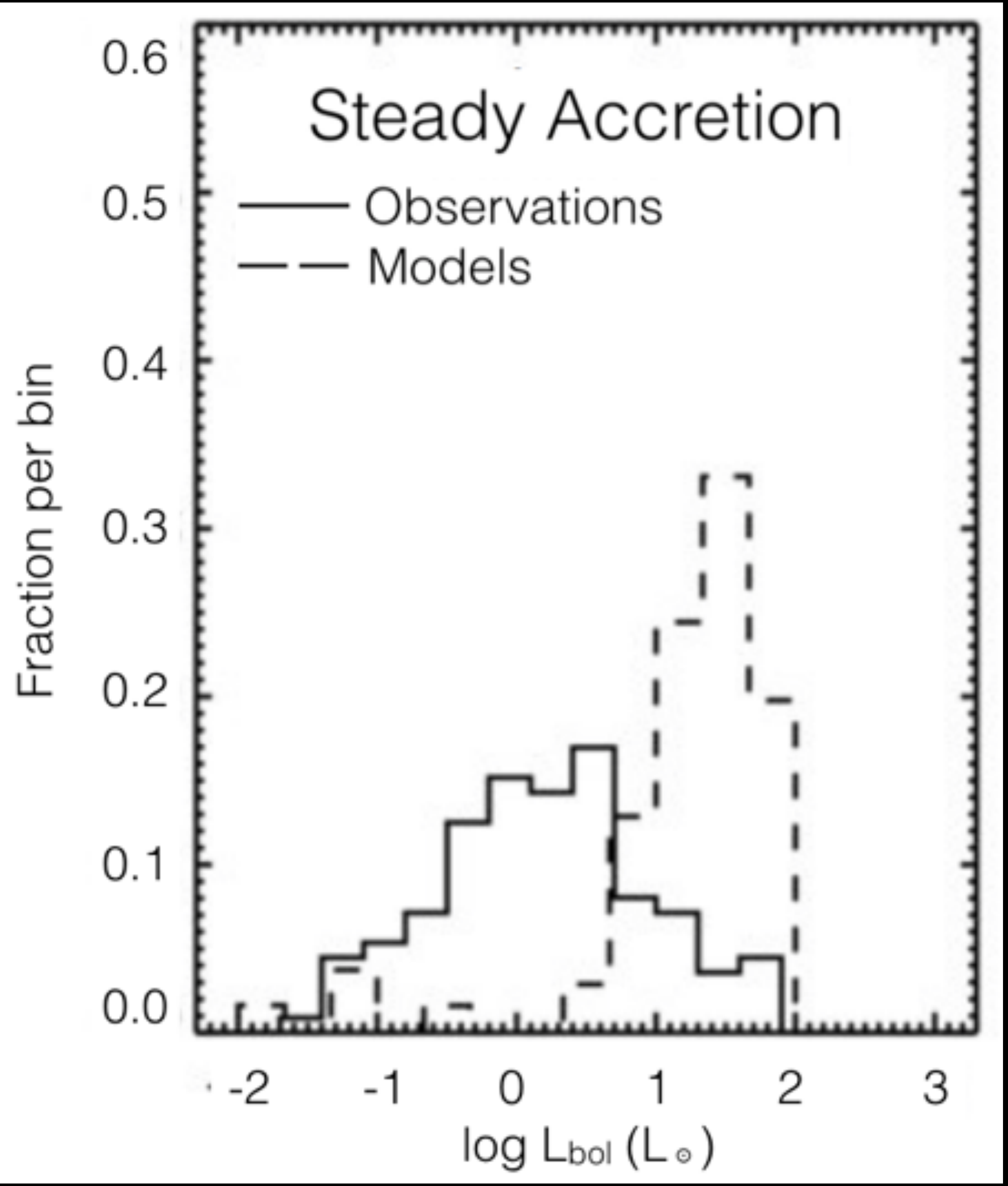
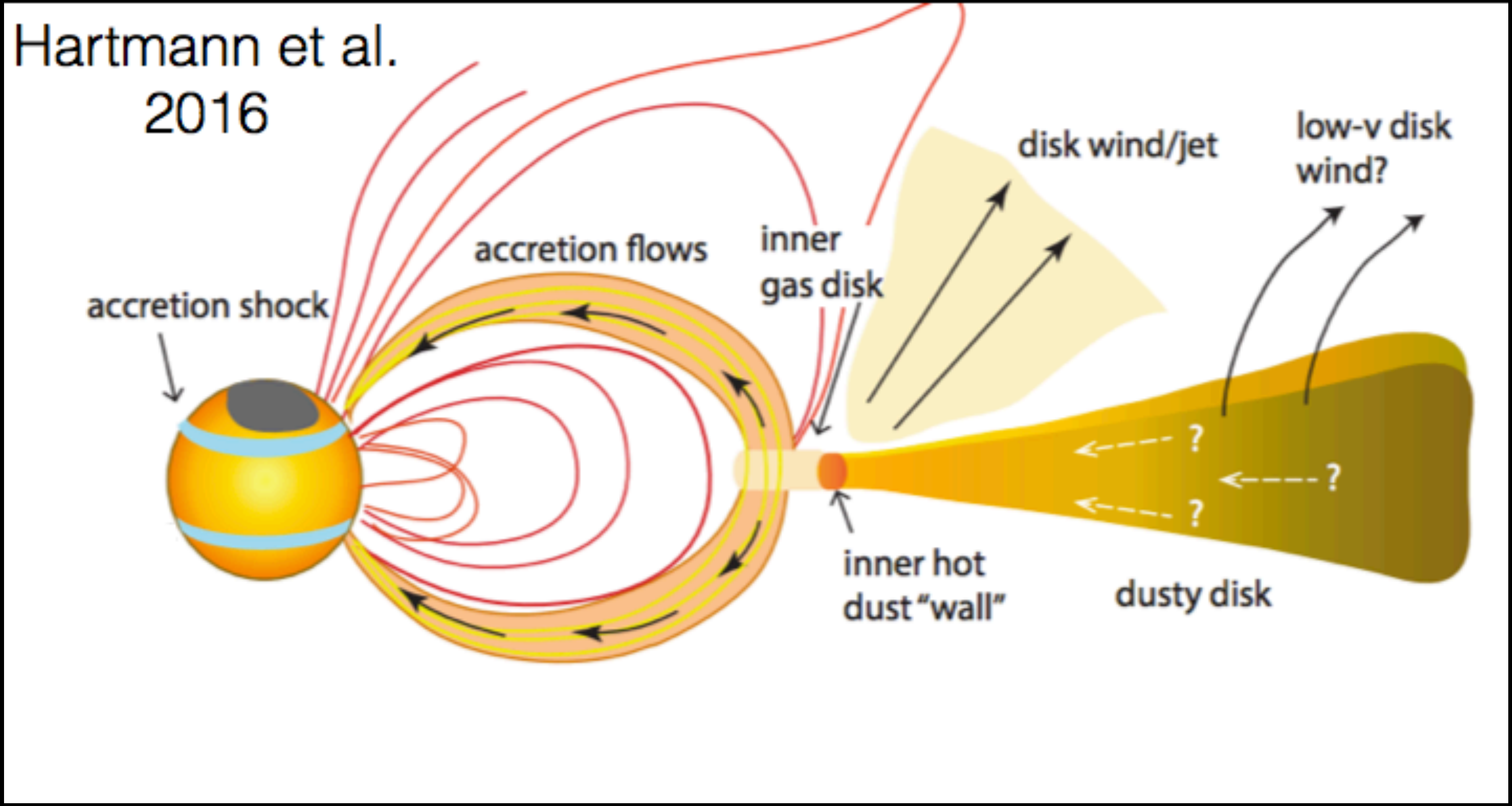


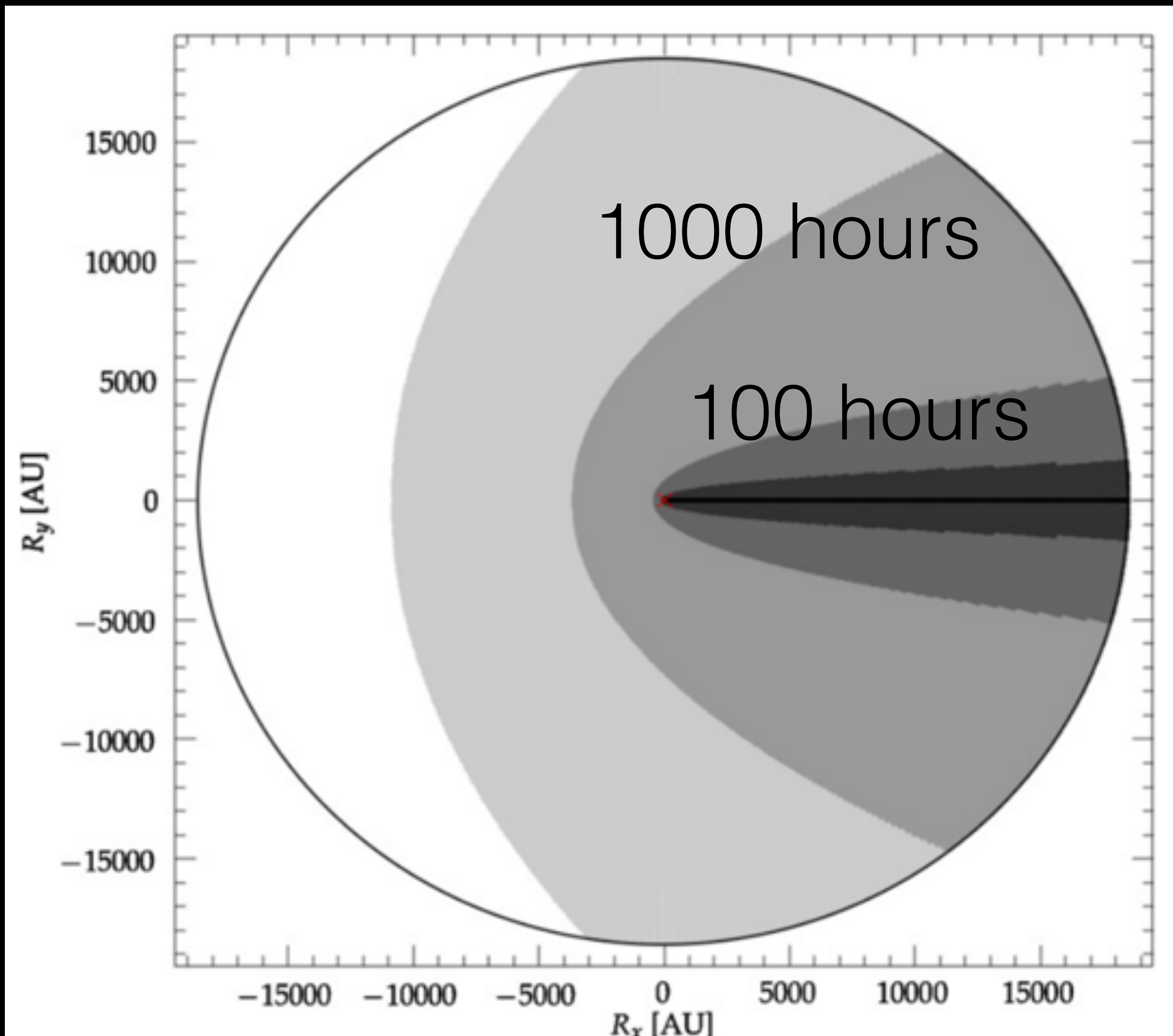
Figure adapted from Young & Evans (2005) and Dunham et al. (2010)

The Physical Conditions of Young Stars

Gravitational and magneto-rotational instabilities lead to clumping material and intermittent accretion bursts



Variability at Submillimetre Wavelengths



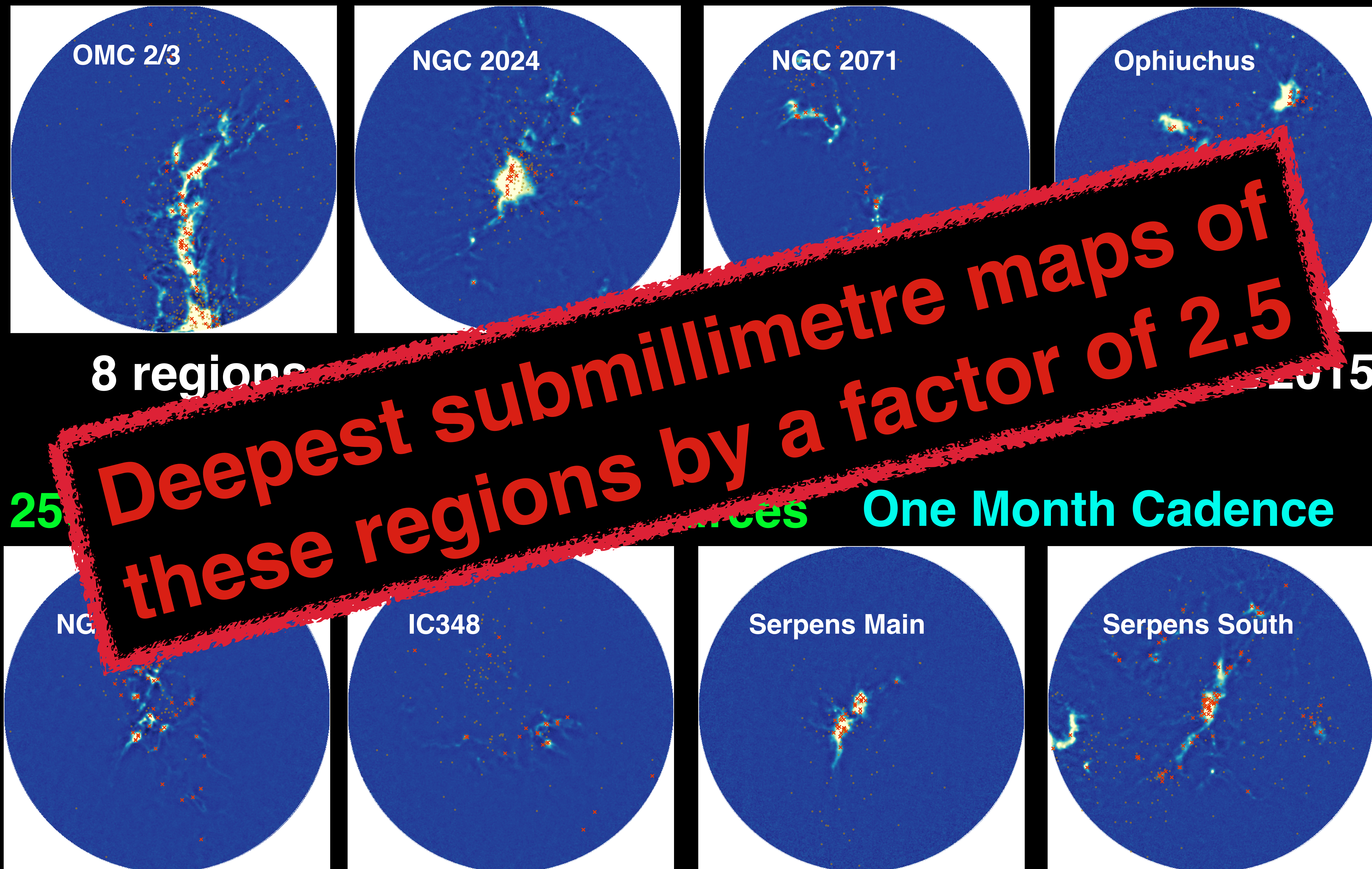
Johnstone et al (2013)
Modelled the SED of a deeply embedded Protostar undergoing an accretion burst using *DUSTY*

The light from the central source is reprocessed by the surrounding dust

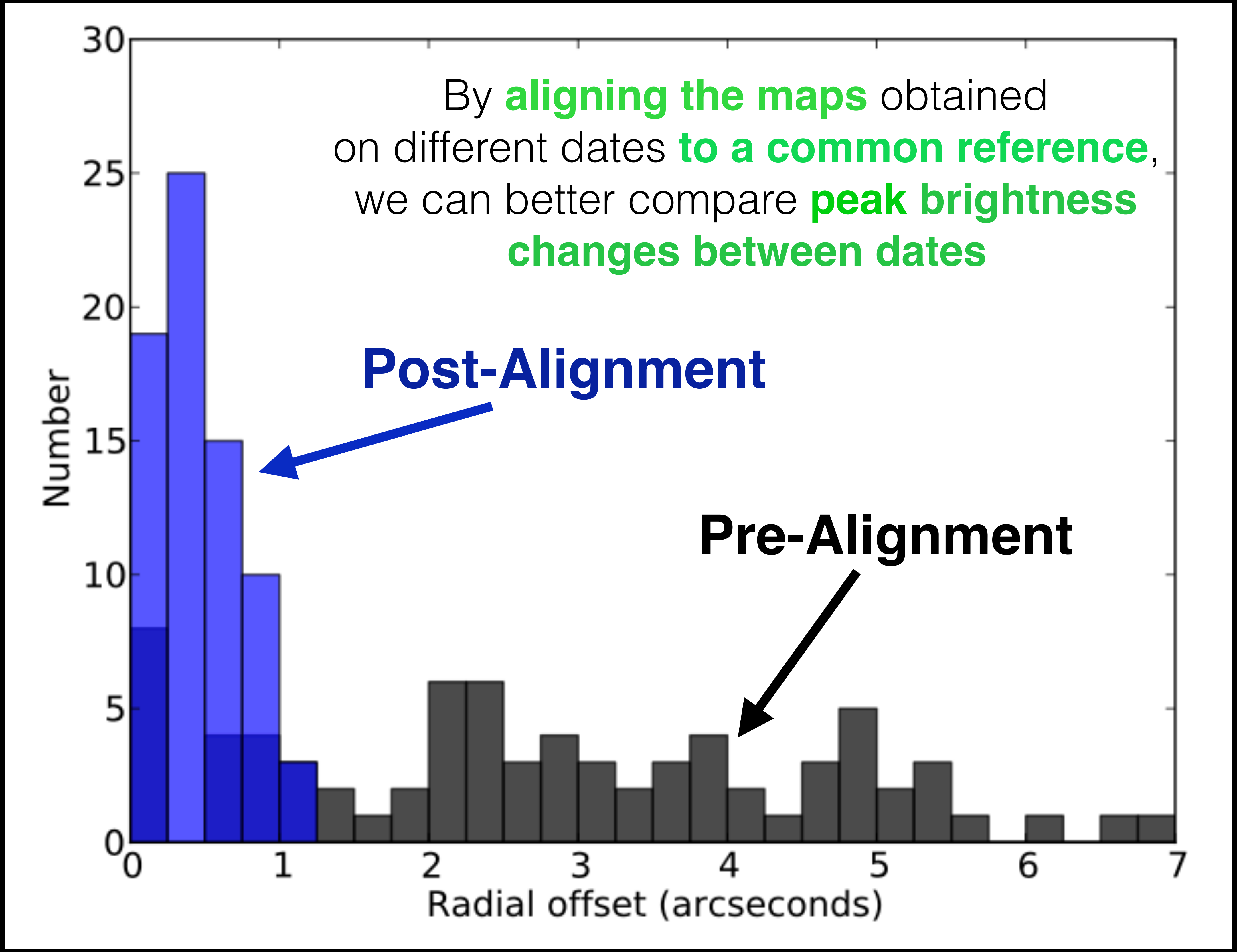
A typical low-mass star-forming envelope Takes ~weeks to months to brighten and be detected in Submm

***Hops 383**
Safron et al (2015)

The JCMT Transient Survey



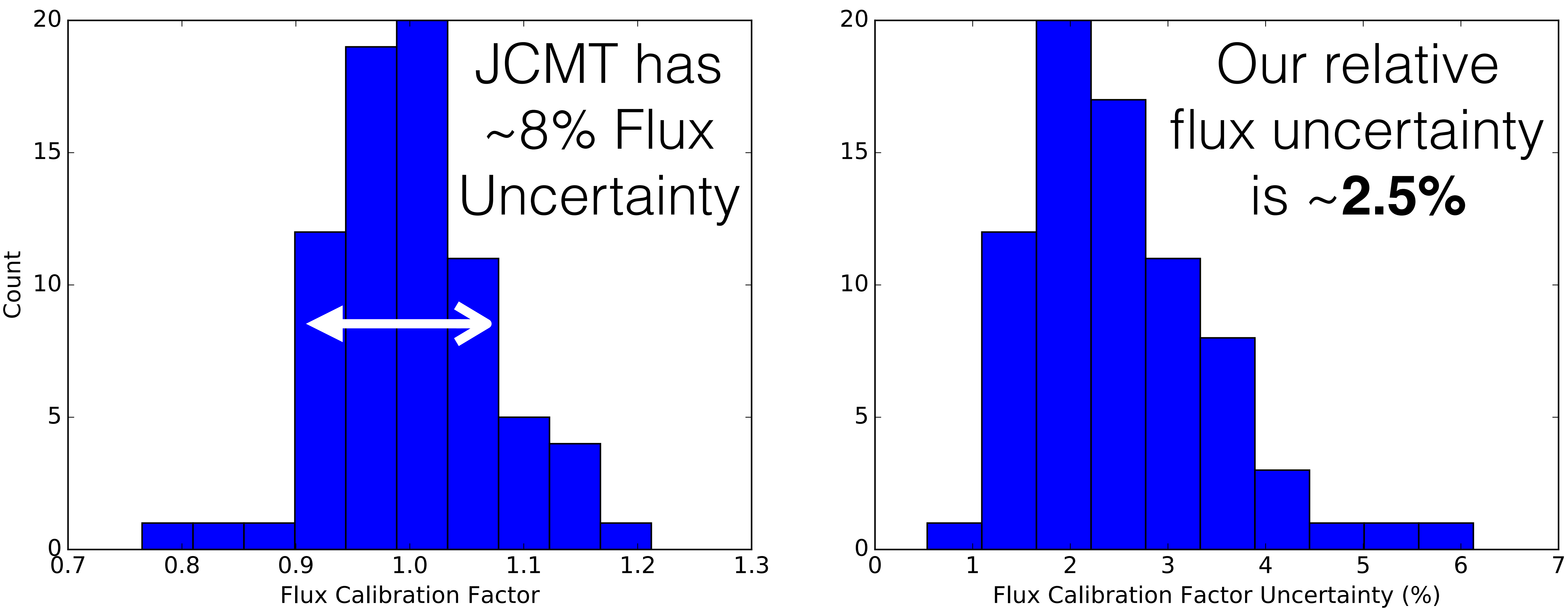
The JCMT Transient Survey: Early Results



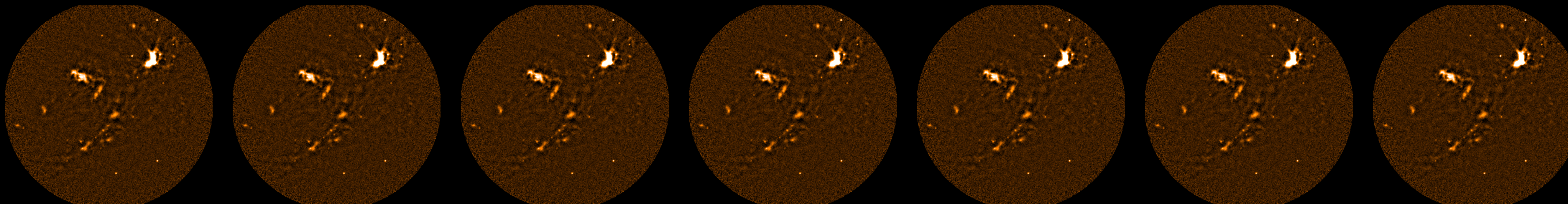
The JCMT Transient Survey: Early Results

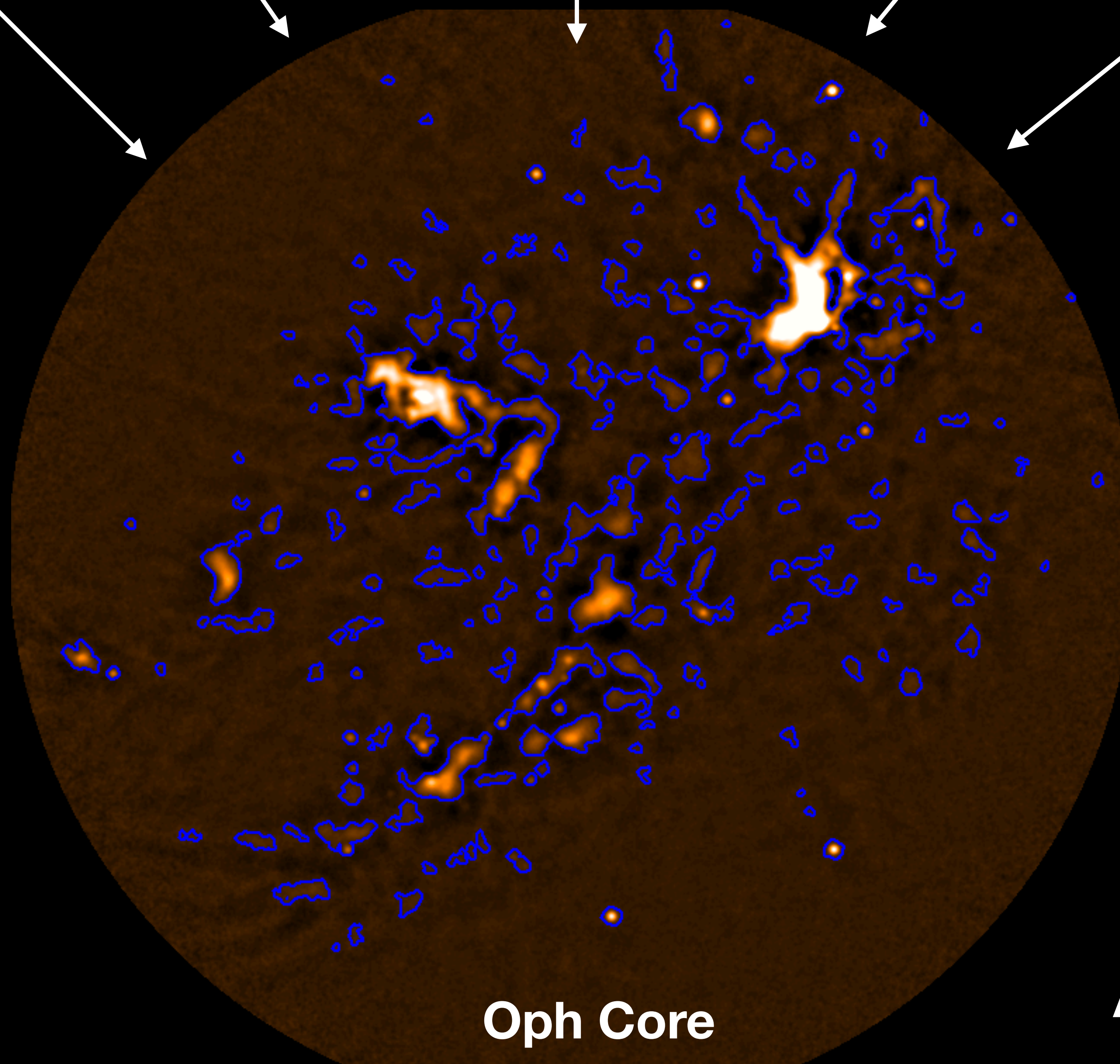
We measure the **relative brightness changes of stable sources** over time

This gives us a *relative* calibration factor for each observation



A Catalogue of Bright, Compact Sources

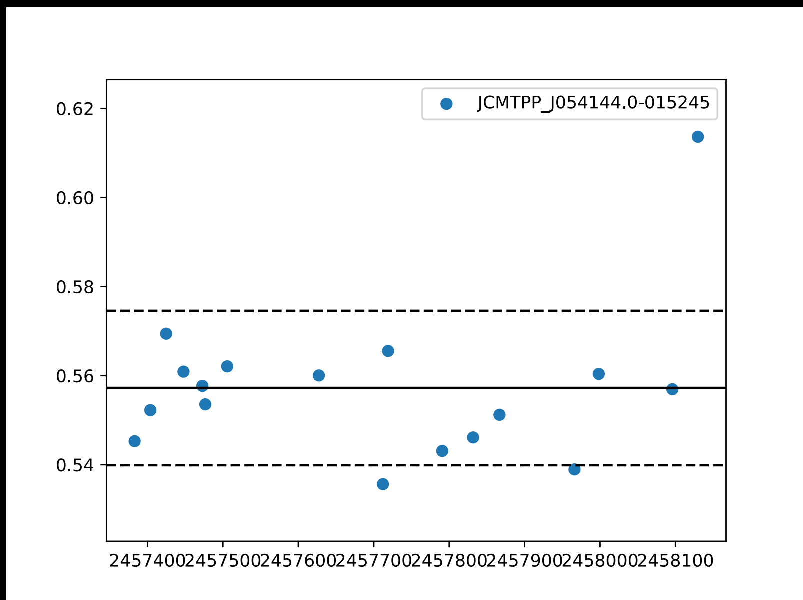


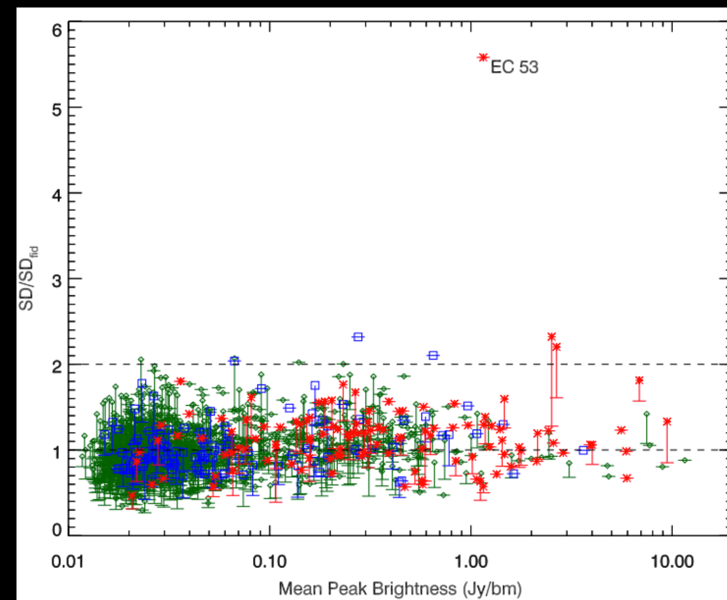


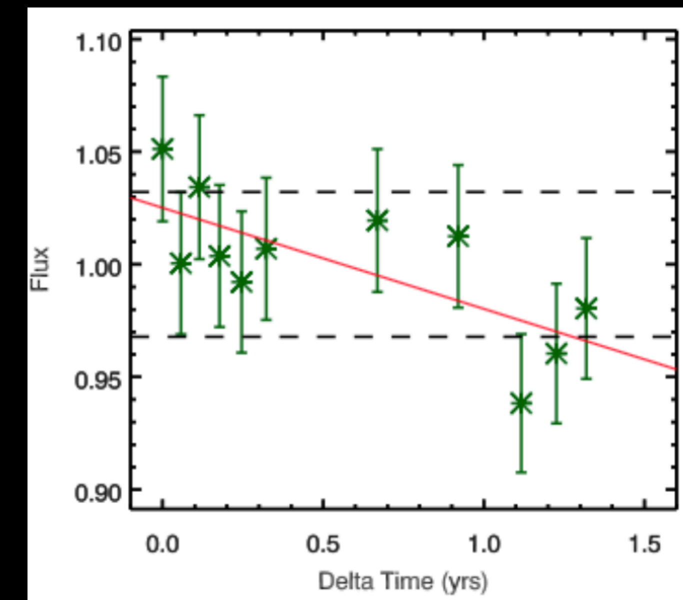
David Berry's
FellWalker
to find sources

***A robust set of**
1643 sources
Across 8 regions

Three Tests For Variability







We are currently tracking these sources using 3 statistical tests outlined in Johnstone, Herczeg, Mairs et al. 2018 (ApJ. 854:31)

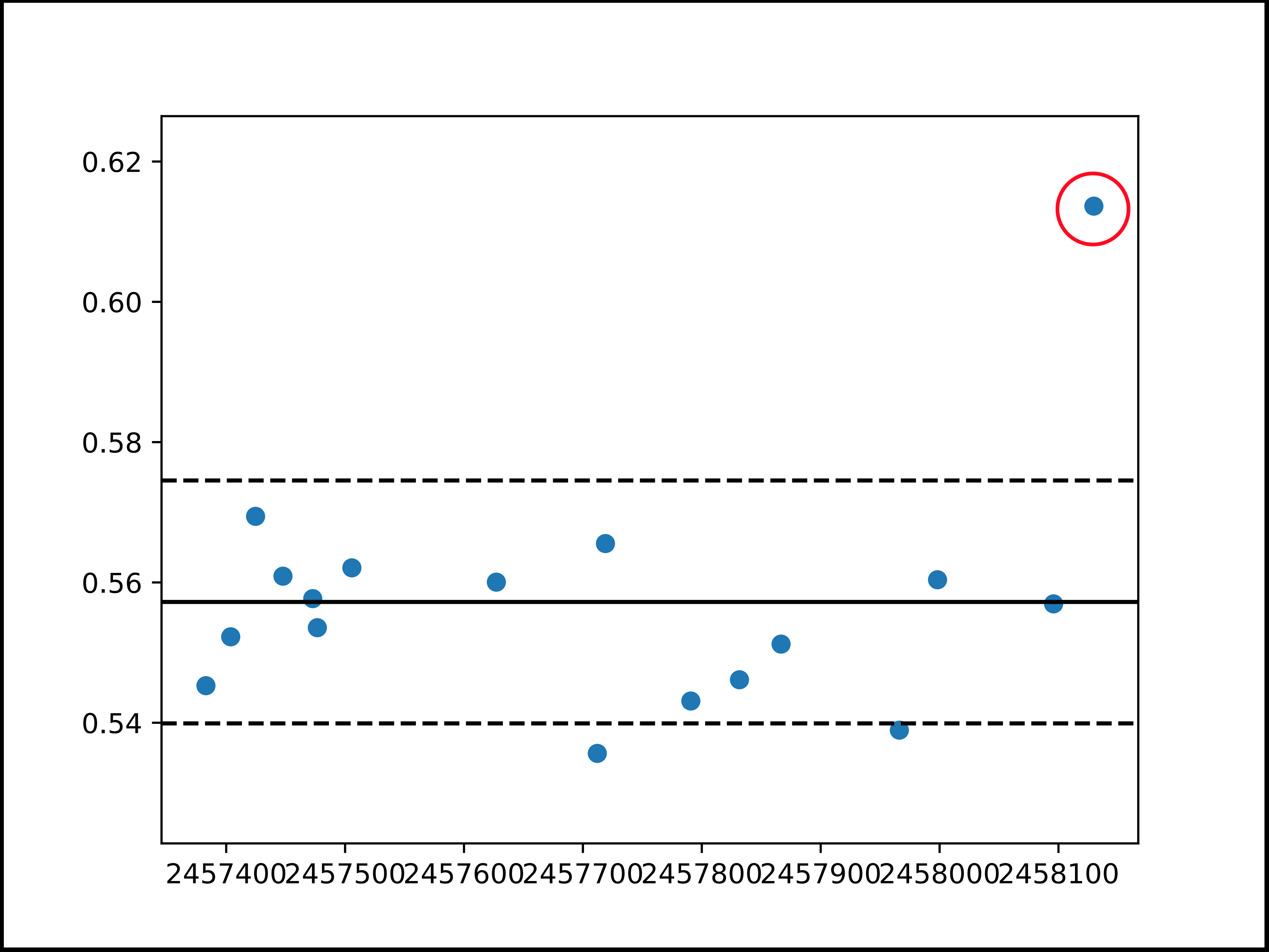
A huge Mahalo to Graham Bell for helping us automate the whole process!

Example Email:

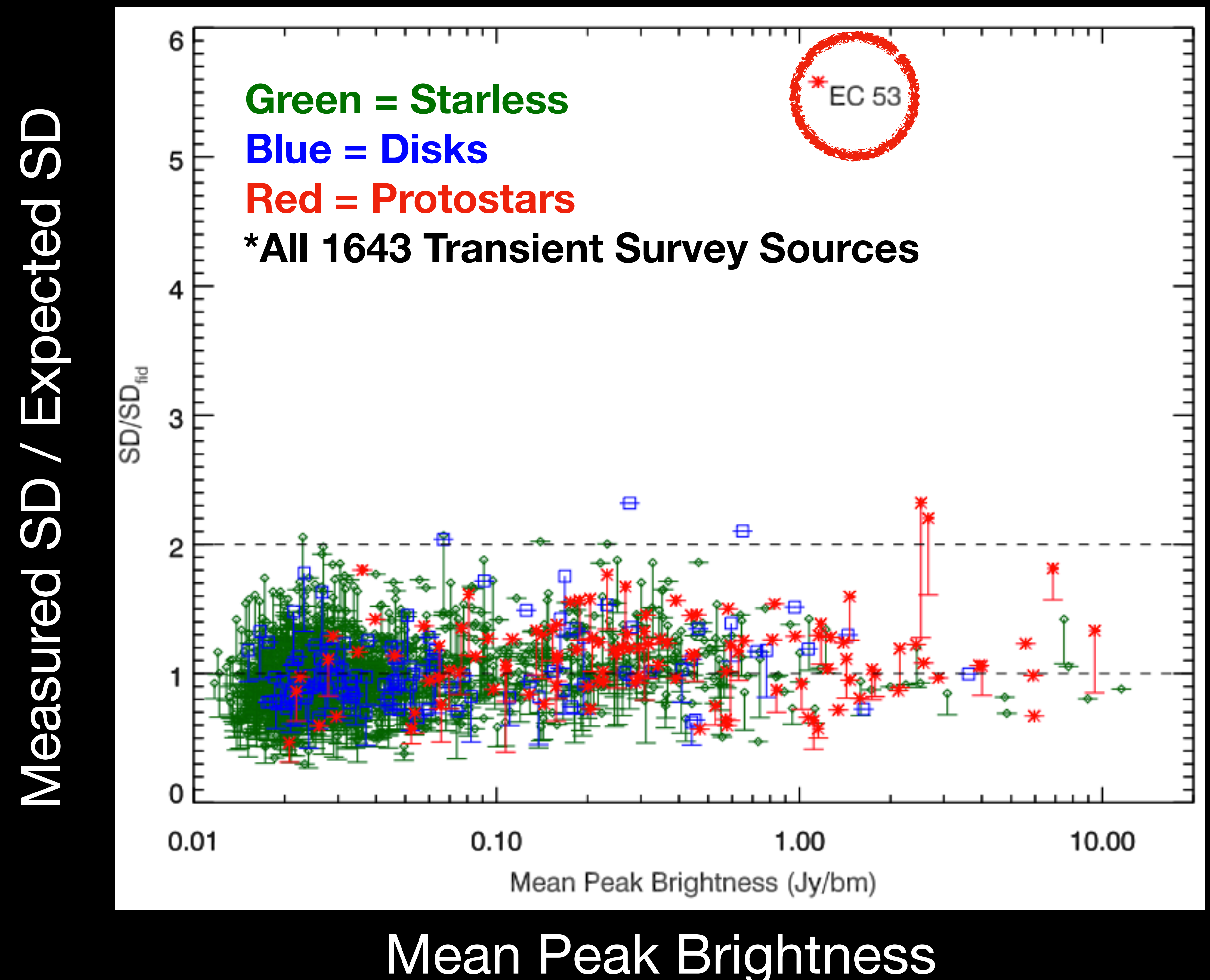
Source JCMTPP_J054144.0-015245 has abs(flux - flux_m)/SD = 6.17
On JD: 2458129.75634 = 2018/01/11
This is greater than the current threshold: 4.
Mean Source Brightness: 0.5572 Jy/beam.
This source is located at (RA, dec) = (85.43334,-1.8792)
The nearest protostar is 41.38" away and the nearest disc is 11.82" away.

1. Detecting Atypical Fluxes Points

$$\text{Significance} = \frac{\text{Flux\_}i - \text{Flux\_mean}}{\text{SD\_Flux}}$$



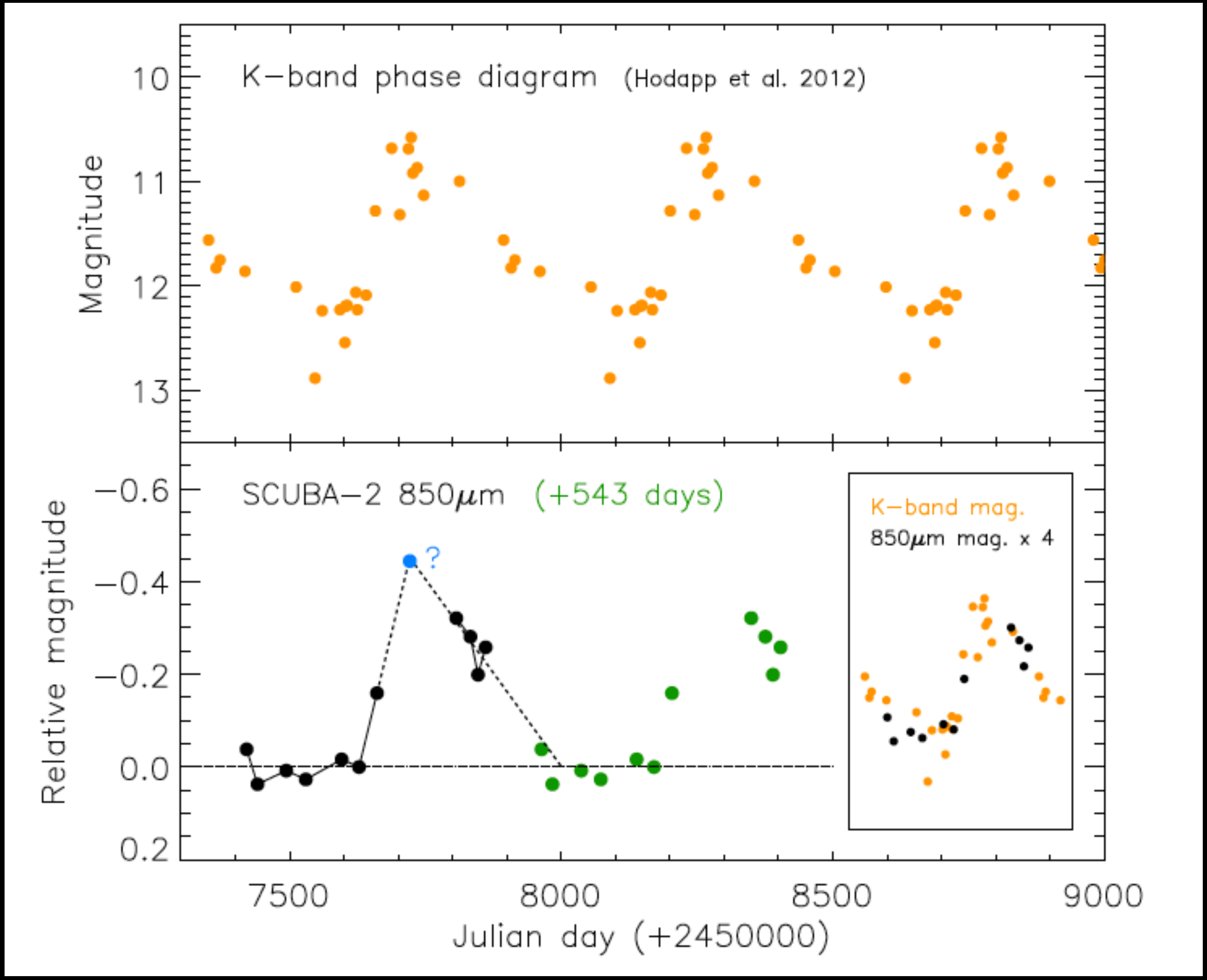
2. Comparing Light Curves to a Fiducial Model



EC 53: A Periodic Variable

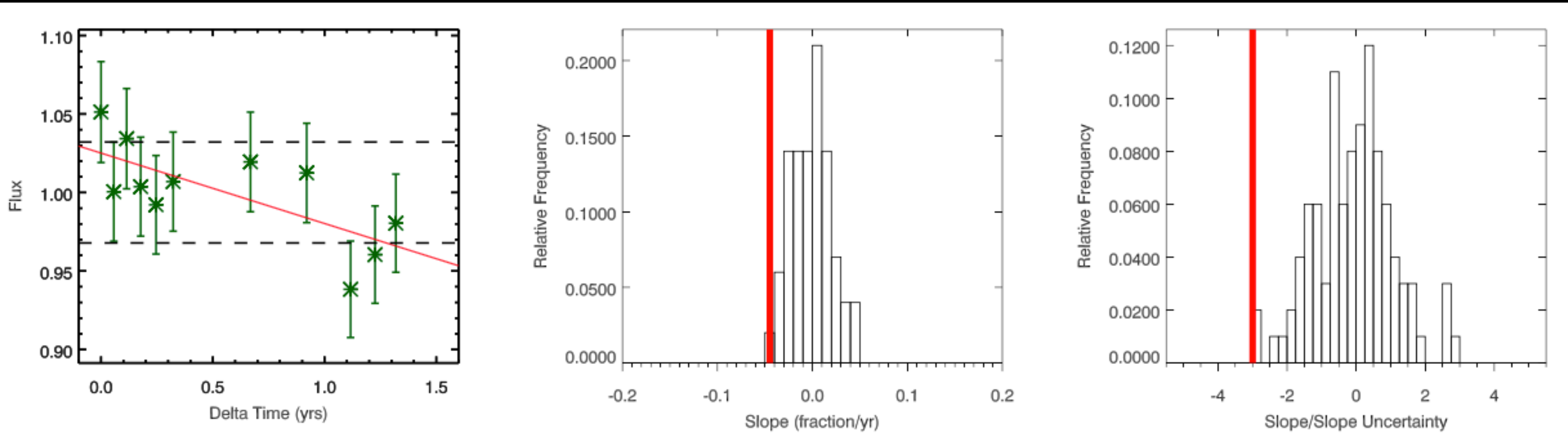
2017 ApJ 849:69. Yoo, H. et al.

EC 53: A periodic variable detected at infrared and submillimetre wavelengths



3. Linear Fitting to Light Curves

We also measured a **linear slope of each source's light curve** and compared it with the slope uncertainty.

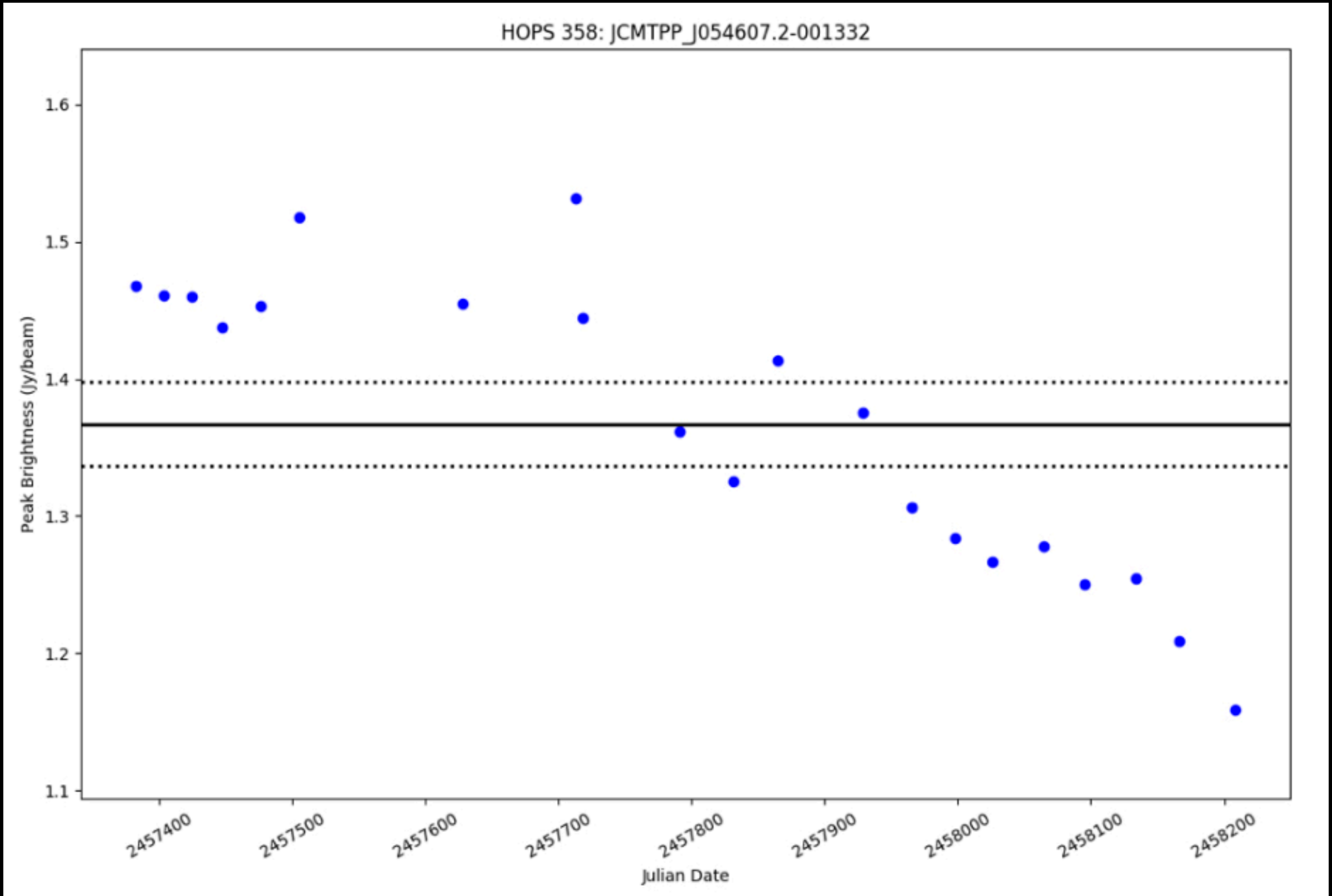


This metric is getting better over time!

We have used this analysis to compare JCMT data over 4 year timescales

3. HOPS 358

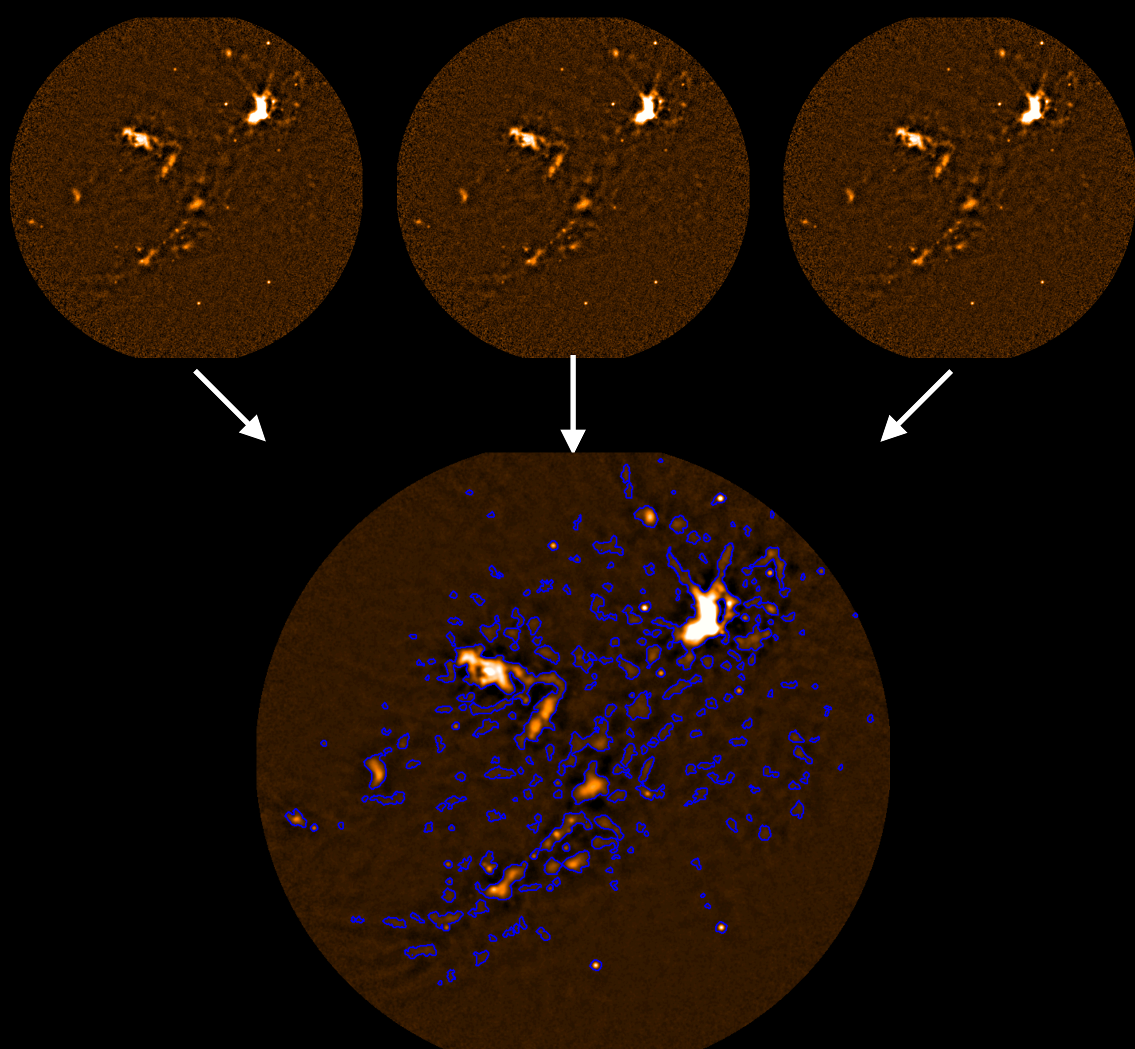
First ATel with Keywords YSO and Submillimetre, together



Detecting Flares

The Problem:

We have only been tracking sources that appear in the co-add!

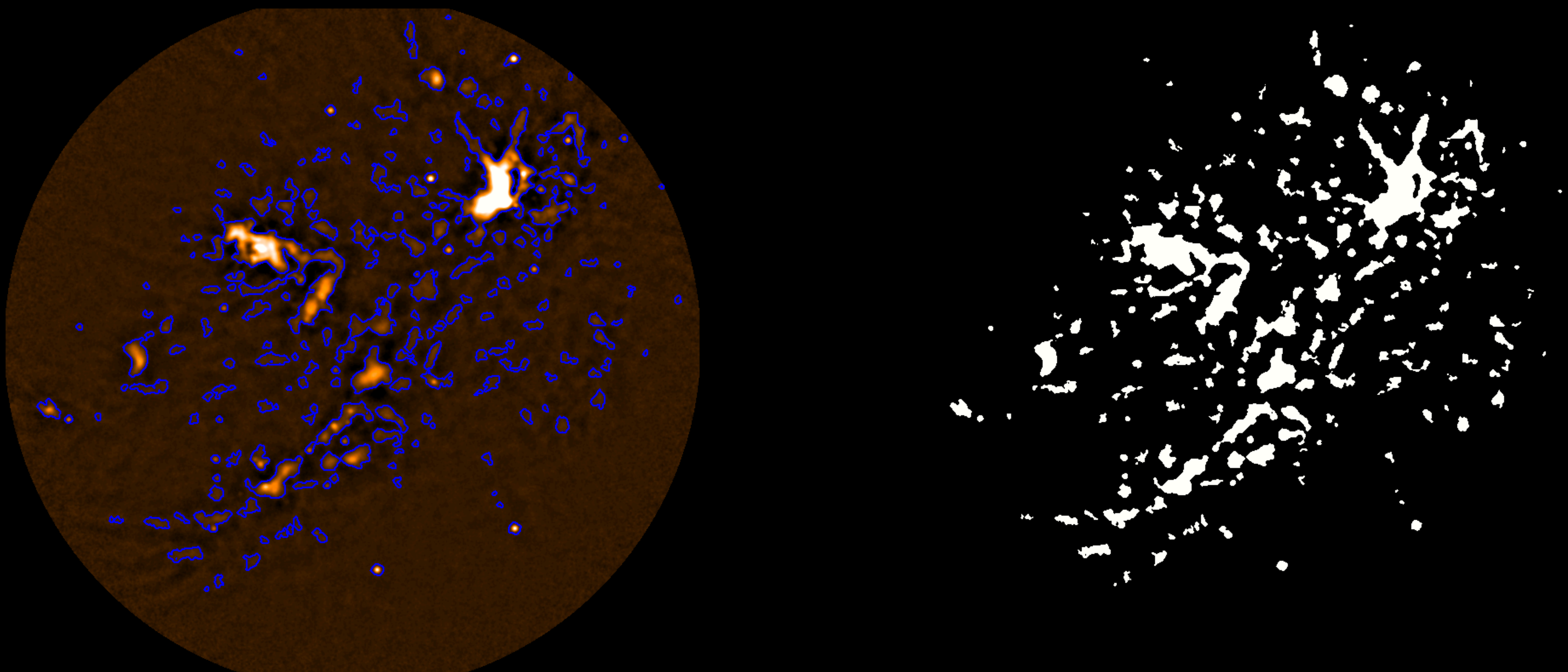


Imagine a source appears at 5σ in only one epoch

Co-added with 9 other images, a $5\sigma_i$ detection averages out to a $1.5\sigma_{co\text{-}add}$ non-detection.

Detecting Flares

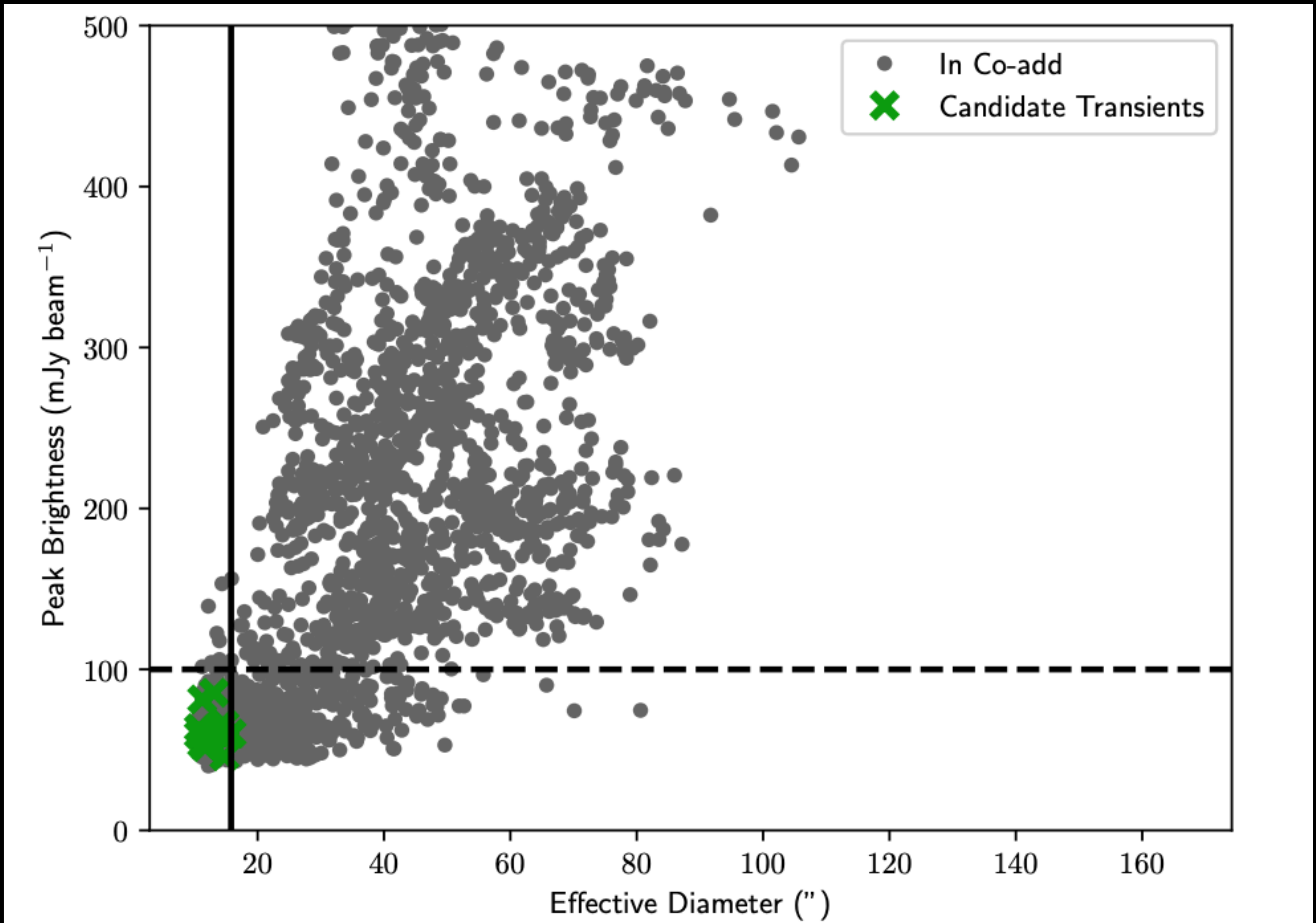
FellWalker produces a “Clump Map” the same size and shape of the image



We run FellWalker on every single image and compare the result to the “master” clump catalogue

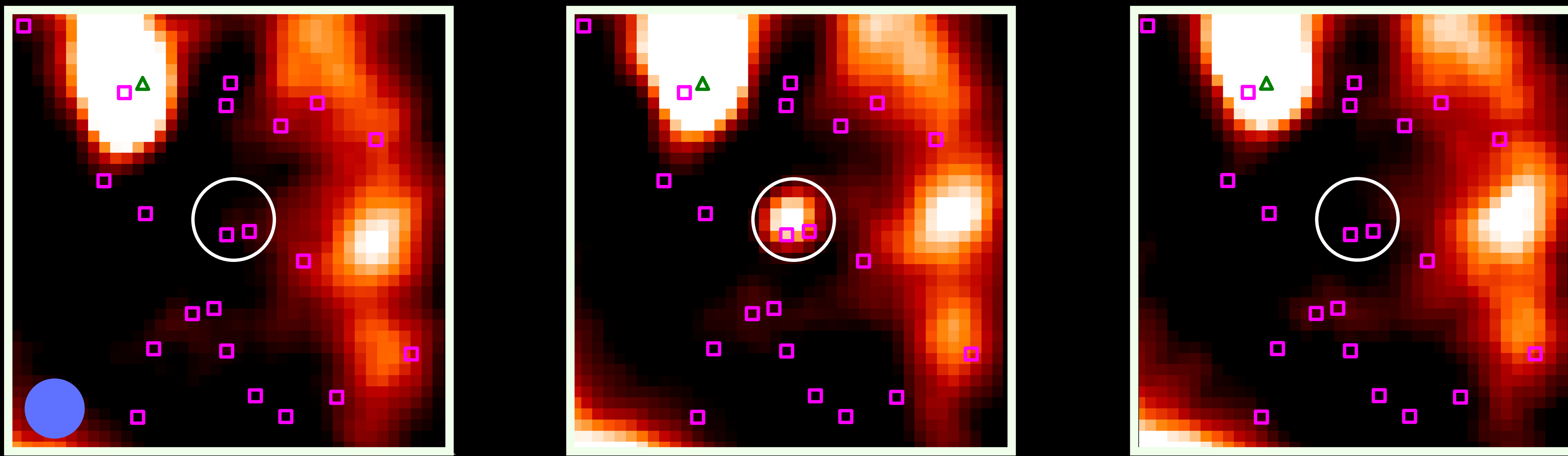
We then follow up on sources that do not appear in the master catalogue

Detecting Flares



An Extraordinary Submillimetre Flare Event

(Mairs et al, 2018, ApJ 871:72)



2016-11-20 2016-11-26 2017-02-06

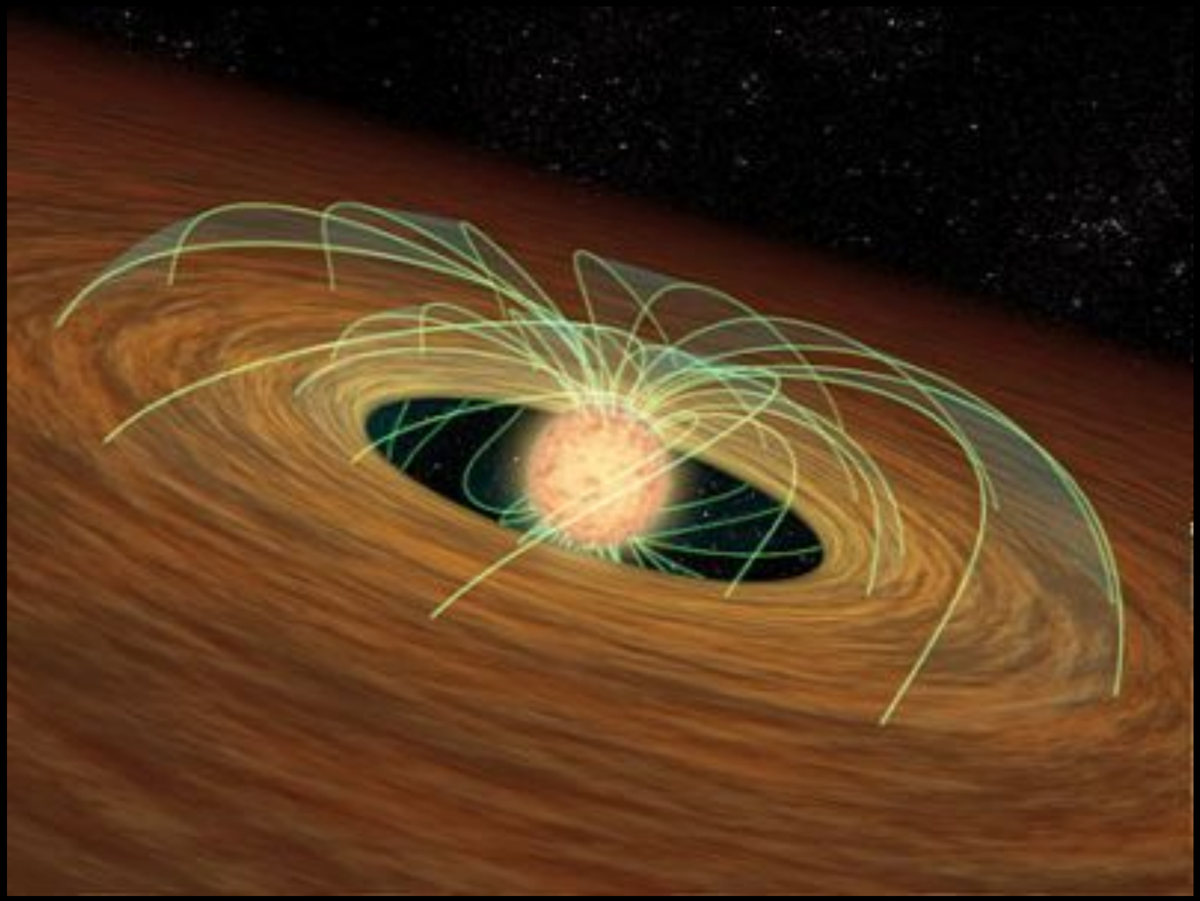
= Previously Identified Class II (Disk) Source (Megeath et al. 2012)

= JCMT Beam size (~15” at 850 microns)

✳ Point Source
✳ Coincident with binary disk system JW 566
✳ Previously known X-ray Variable (timescales of hours)
✳ No simultaneous optical, infrared, x-ray, or radio data

JW 566

(Jones, B. F., & Walker, M. F. 1988, AJ: 95, 1755)



K7+M1.5 T Tauri binary system with a projected separation of 0.86” = 335 AU

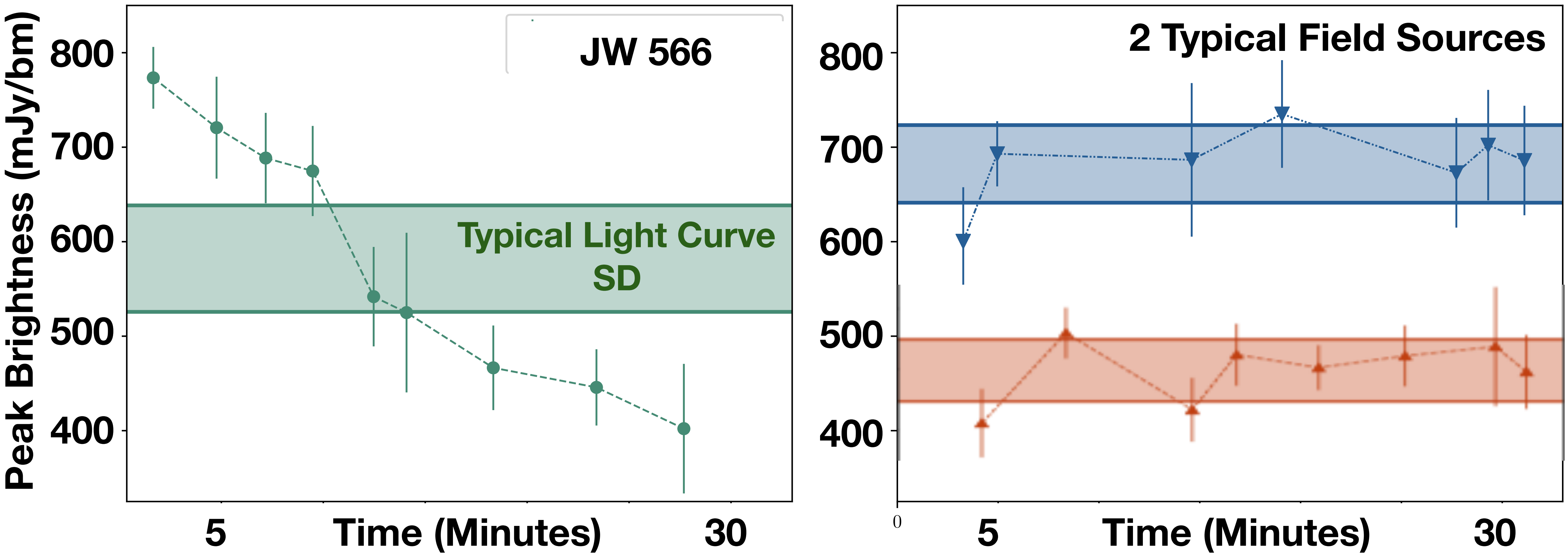
No high-resolution spectra available to determine if each component is a spectroscopic binary

One of the most luminous X-ray sources ($L_X = 10^{31}$ erg s^{-1}) for its mass range in the COUP X-ray monitoring survey of the Orion Nebula (Getman et al. 2005). Shown evidence of variation on hourly timescales

Kounkel et al. (2014) classify the source as variable at both 4.5 and 7.5 GHz over several week timescales

The SCUBA-2 850 micron Light Curve

(Mairs et al 2018, ApJ 871:72)

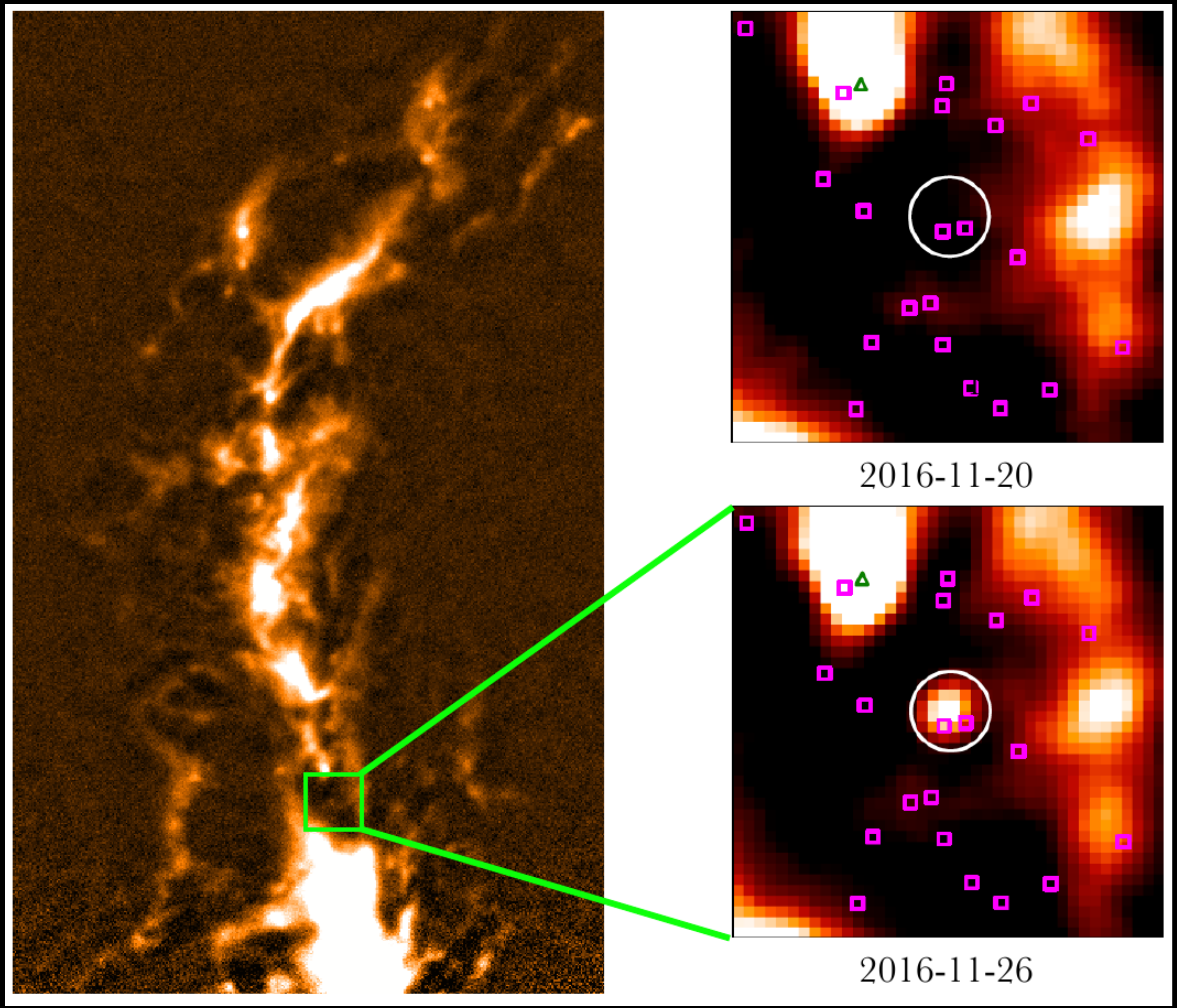


Raw SCUBA-2 data records the flux received over time in 30 sec intervals as the JCMT scans over the sky

With the help of Graham Bell, we were able to select the intervals that contain information on JW 566 as well as 5 other “typical” point sources covering JW 566’s flux range. Each point has SNR of 5->25

JW 566: Negative Bowling

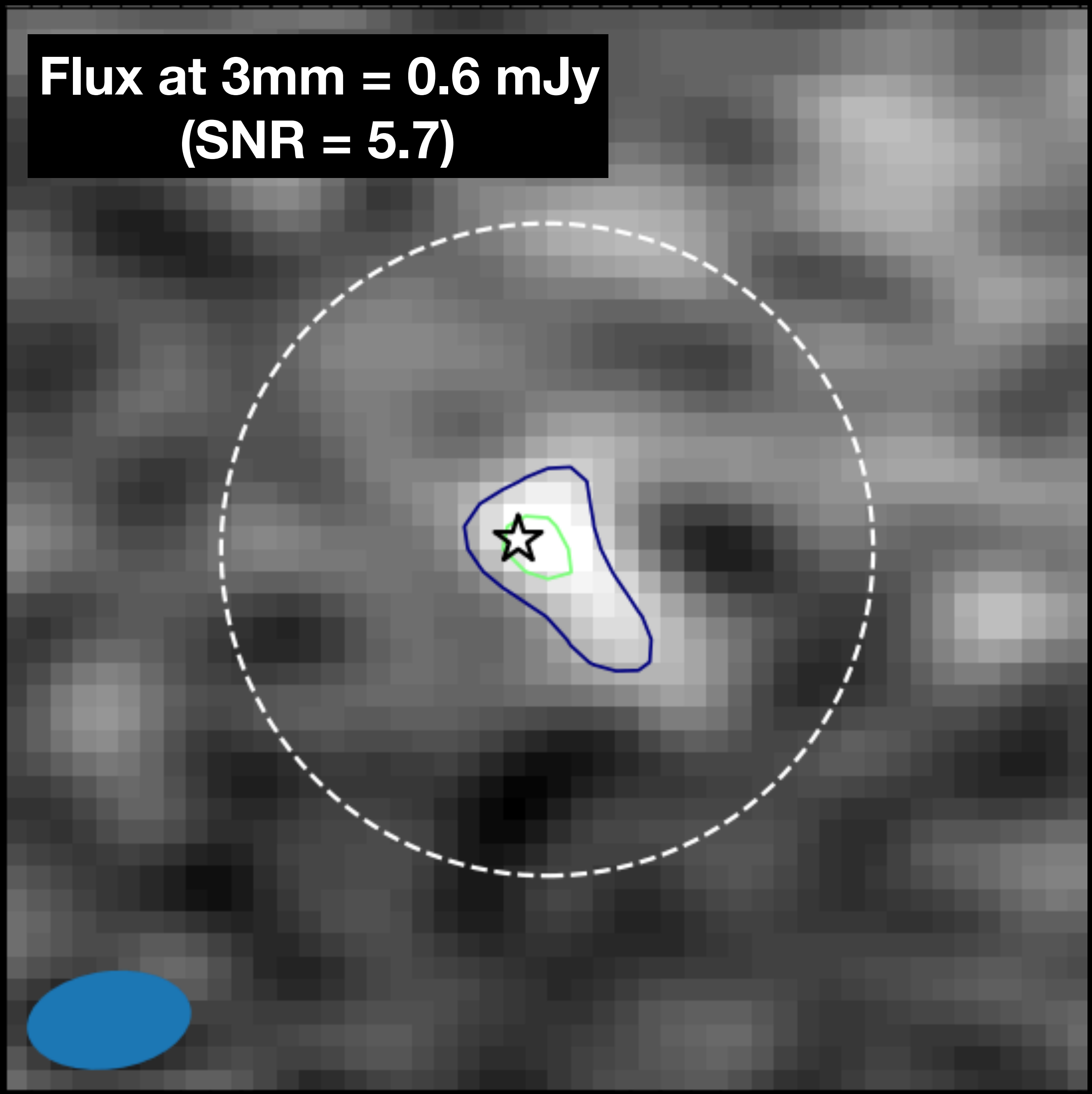
Originally, the source did not appear in the co-add due to Negative Bowling



In all but one epoch, the flux was artificially negative, so the bright source was washed out in the co-add (a new mask was applied for this analysis)

JW 566: Can we estimate the brightness change?

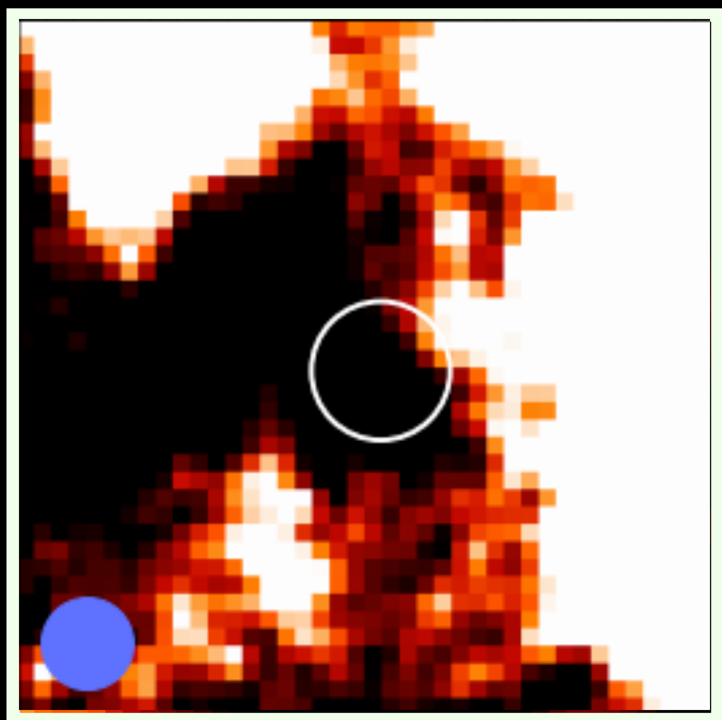
JW 566, 3 mm continuum image: ALMA, 2015-12-26 (Hacar et al. 2018)



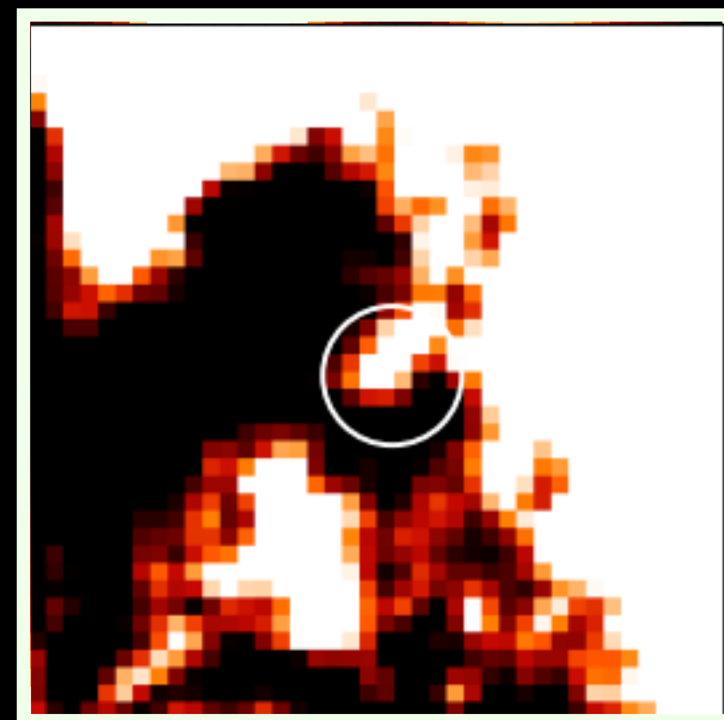
Assuming reasonable spectral indices, in its quiescent state, JW 566 is still buried in noise at both 450 and 850 microns

JW 566 at 450 microns

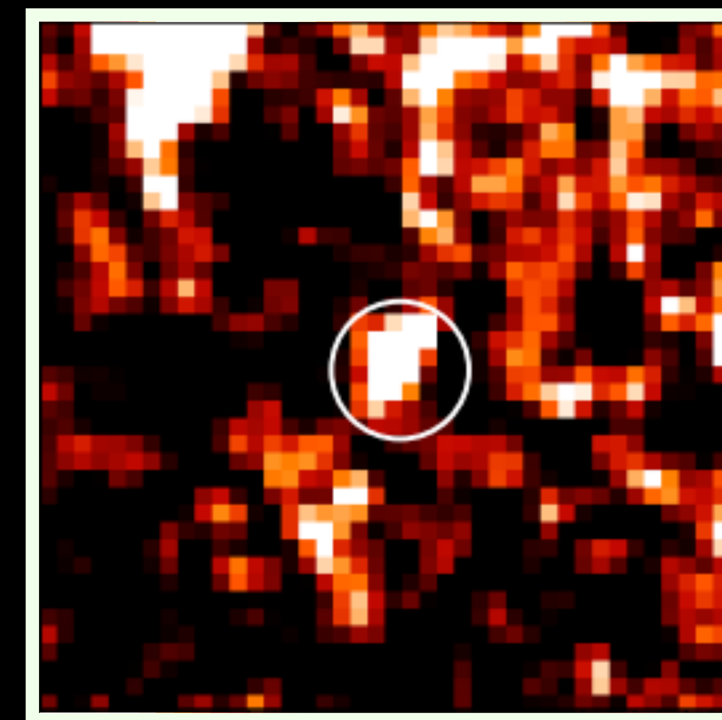
(Mairs et al, 2018, ApJ 871:72)



Co-add
excluding 2016-11-26



2016-11-26



2016-11-26 minus Co-add

Only the 2016-11-26 data has an indication of compact structure

The SNR is not sufficient at 450 microns to produce a light curve analysis

A fit to the residual 450 μm image a peak of 500 ± 107 mJy beam−1 (SNR=6)

= JCMT Beam size (~10” at 450 microns)

Non-thermal Emission

We calculate a spectral index of: $\alpha = 0.11 \pm 0.49$

This is consistent with non-thermal emission

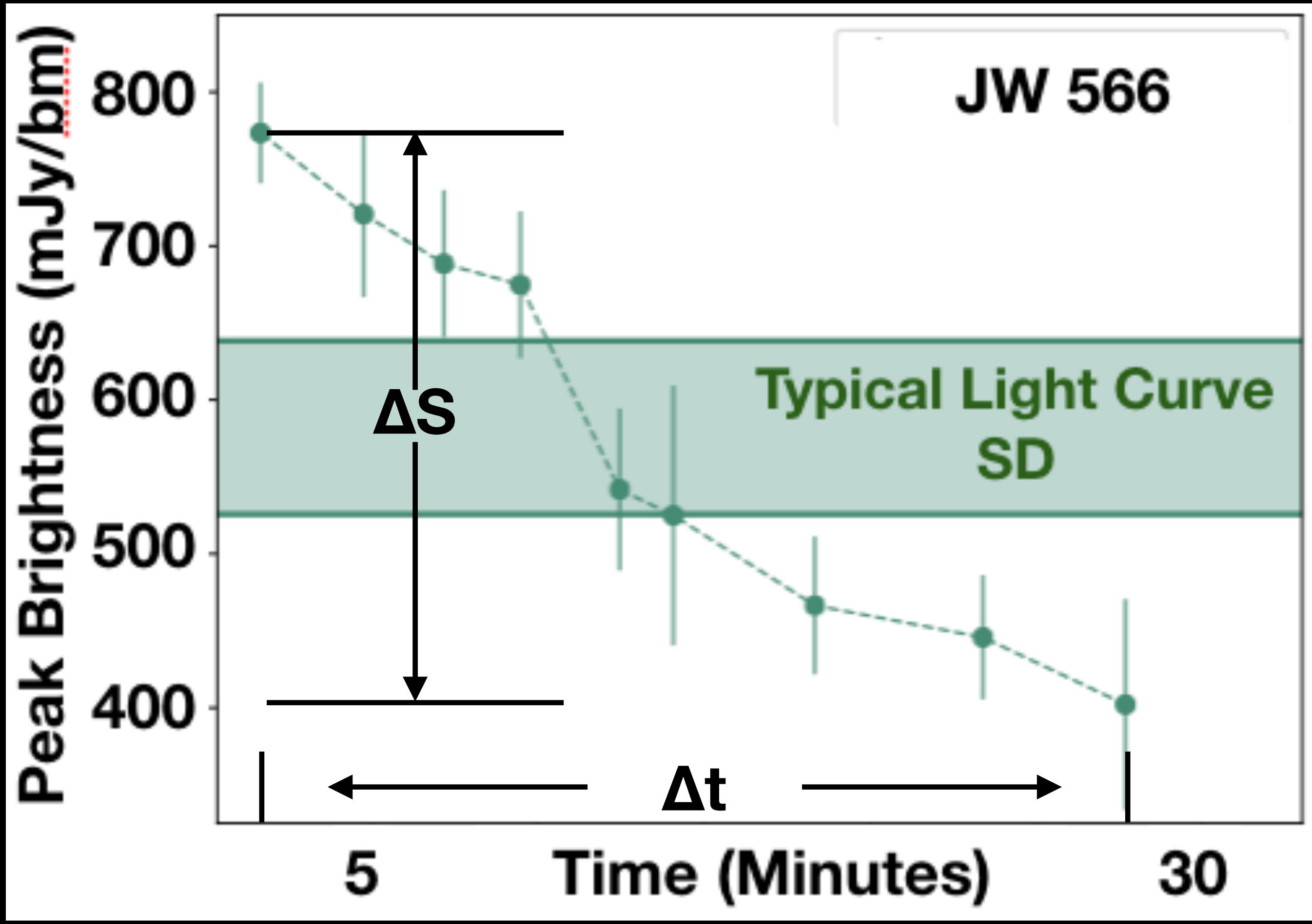
For thermal emission, the temperature would need to be 4.9 K to reproduce α

We can approximate the brightness temperature by:

$$T_b = \left(\frac{1}{2k_B}\right) \times \lambda^2 \Delta S \times \left(\frac{D}{c\Delta t}\right)^2$$

(light crossing distance $c\Delta t$ = 3.3 AU)

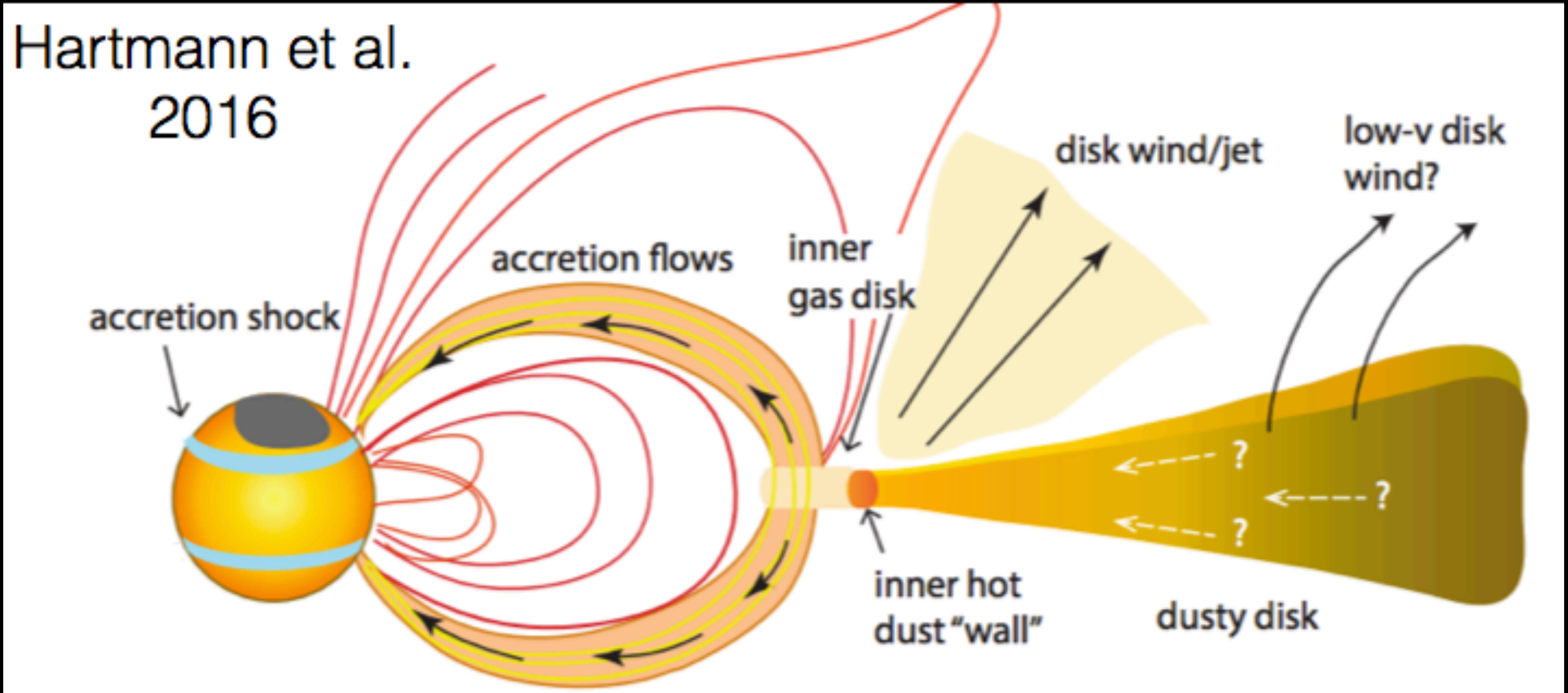
$$T_b = 6 \times 10^4 \text{ K}$$



If we take $c\Delta t$ to be be the stellar radius, $2.5R_\star$ → $T_b = 5 \times 10^9 \text{ K}$

The Nature of the Flare

Observations consistent with a magnetic reconnection event

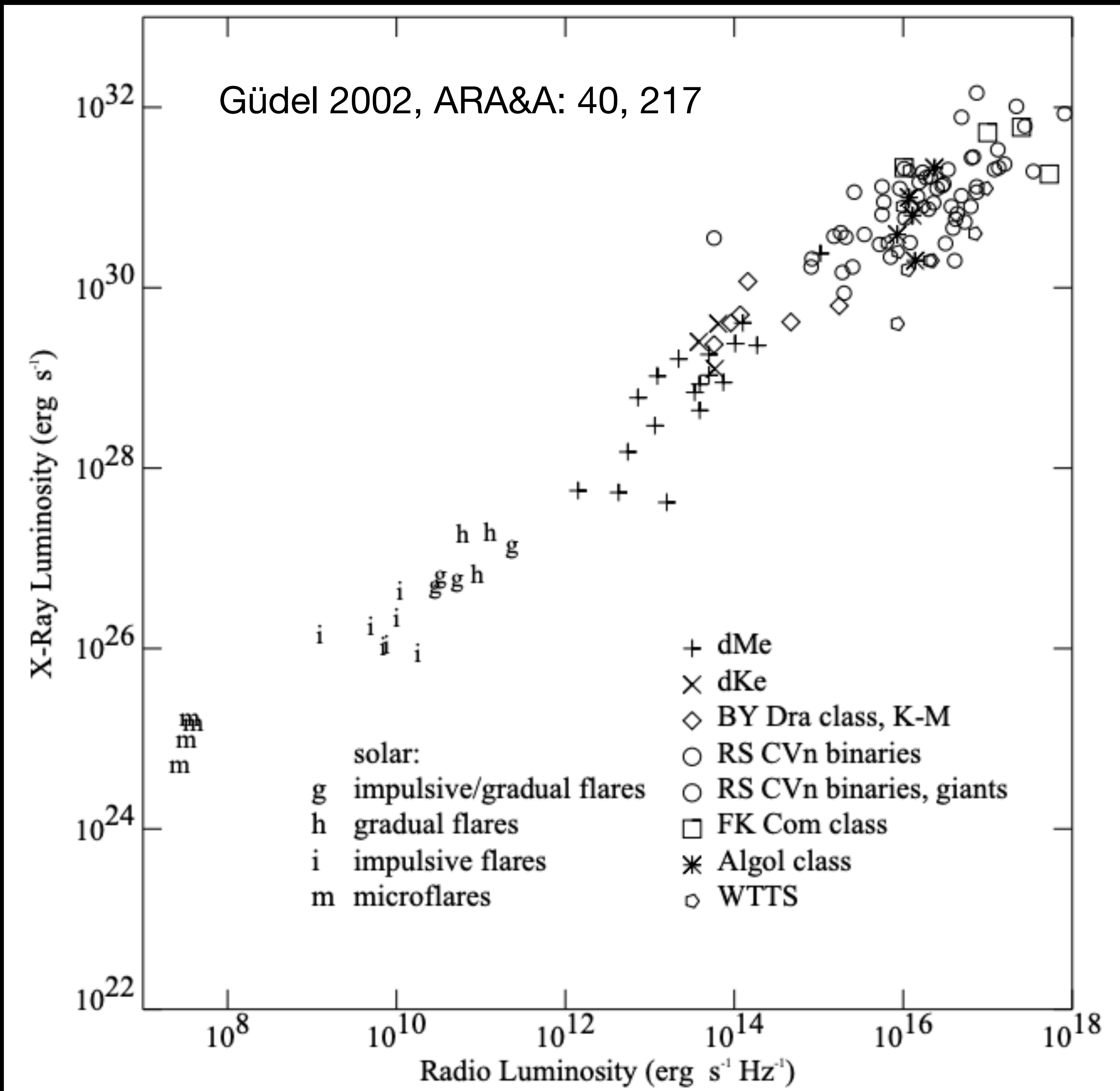


A magnetic reconnection event energizes non-thermal particles, producing synchrotron radiation

Constraining the angular scale of the event to the stellar radius ($2.5\ R_\odot$), we calculate a brightness temperature of 5×10^9 K

Radio Luminosity

At a distance of 389 pc, average radio luminosity = 8 x 10^{19} erg s^{-1} Hz^{-1}:

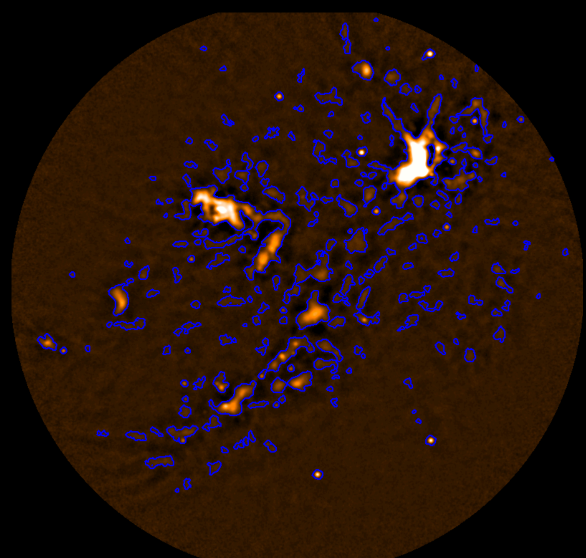


Natural comparison:
2003 outburst GMR-A, a
T Tauri star in Orion that
had flare of radio luminosity
$L_\nu = 3 \times 10^{19}$ erg s^{-1} Hz^{-1}
(Bower et al. 2003;
Furuya et al. 2003)

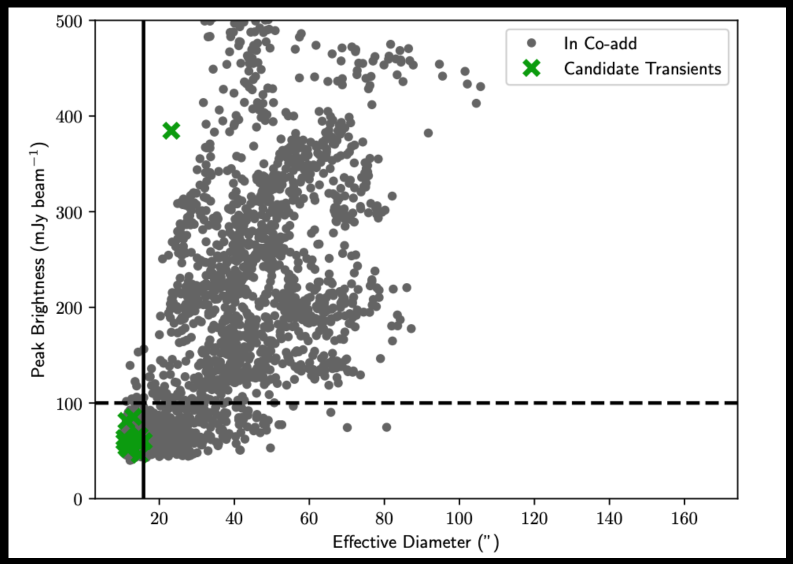
The JW 566 flare was
10 orders of magnitude
more powerful than
typical solar flares

Summary

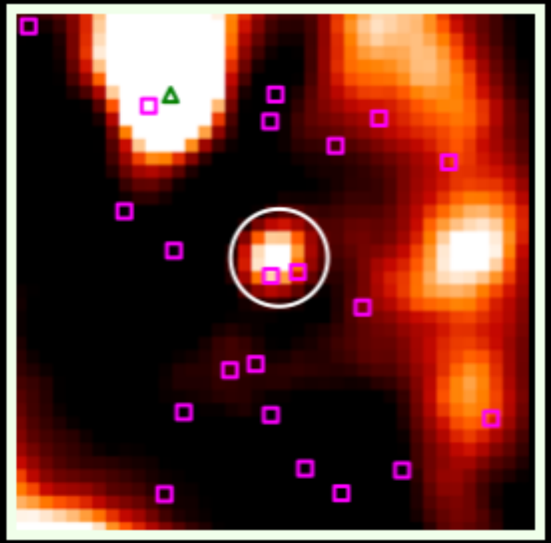
The JCMT Transient Survey is tracking 1600 sources across 8 nearby regions



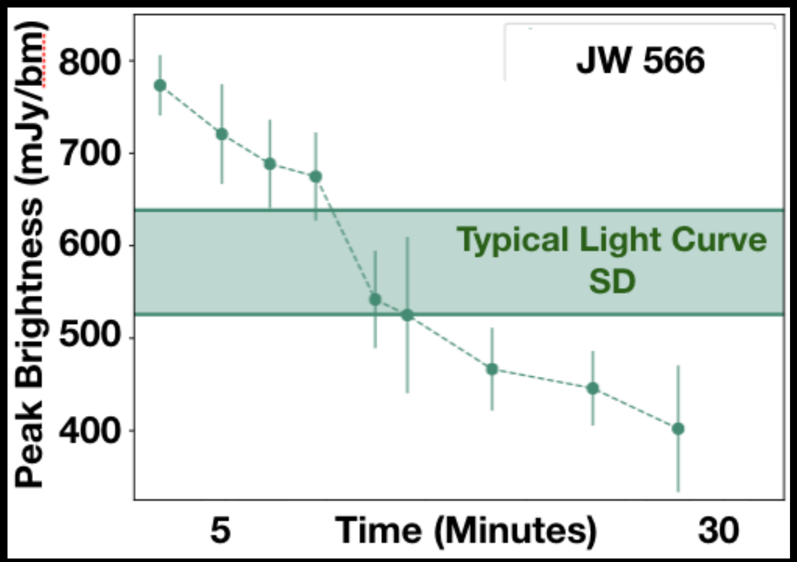
We are developing robust methods to investigate short timescale variability



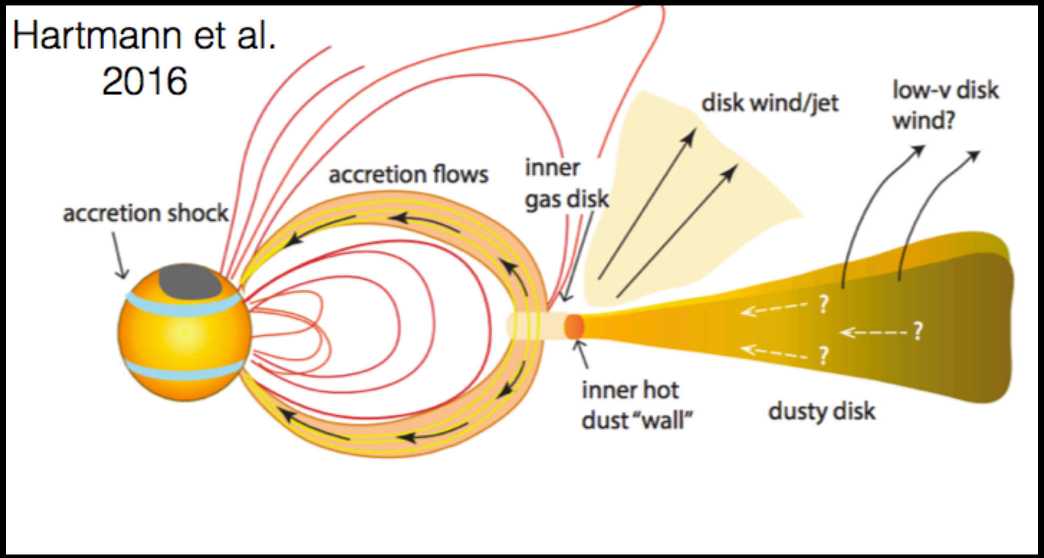
The JW 566 event is the first Submm flare recorded



The flux decreased by ~50% in less than 30 minutes @ 850um



The timescale, α and T_b suggest a non-thermal event



The Survey Continues through January 2020