Herschel/PACS variability survey of IC348

Zoltan Balog

MPIA

Collaborators:

James Muzerolle (STScI)

Kevin Flaherty (Univ. of Arizona)

Rob Guthermuth (Umass)

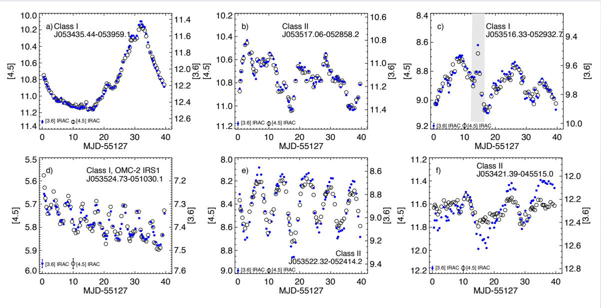
Elise Furlan (IPAC)

Ors Hunor Detre & Jeroen Bouwmann (MPIA)

Gabor Marton (Konkoly Observatory)

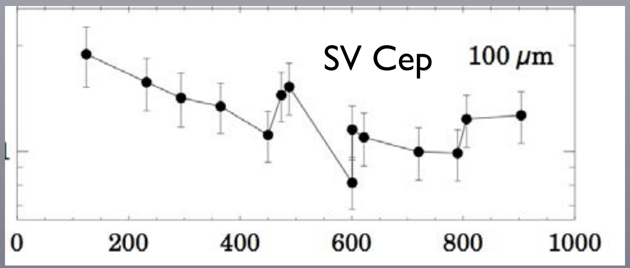
Variability of YSOs

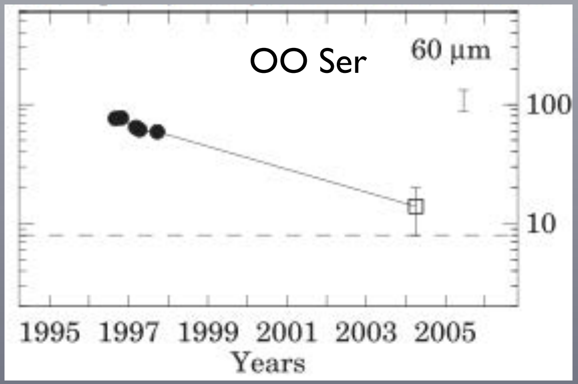
- **Variability is a common property of YSOs (Joy, 1945)**
  - optical / near-IR: <u>accretion shocks</u>
    - several surveys at different wavelengths
  - mid-IR: <u>inner disk structure (warped disks, variable scale height)</u>
    - *Spitzer*/YSOVAR Morales-Calderón et al. 2009
    - Flaherty et al. 2011,2013 (*Spitzer* - IC348)



  - far-IR: <u>variable illumination of cold outer disk (class II) or luminosity fluctuations (class 0/I)</u>

    reason: variable accretion, variation in the scale-height of the inner disk
    - very little pre-*Herschel* data
      - Juhász et. al. (2007), Kóspál et al. (2007) ISOPHOT
      - Harvey et al. (1998), KAO

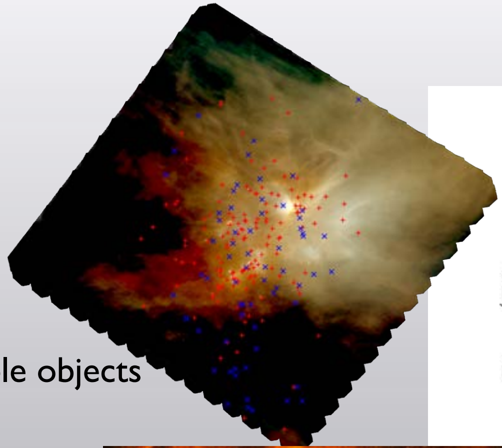


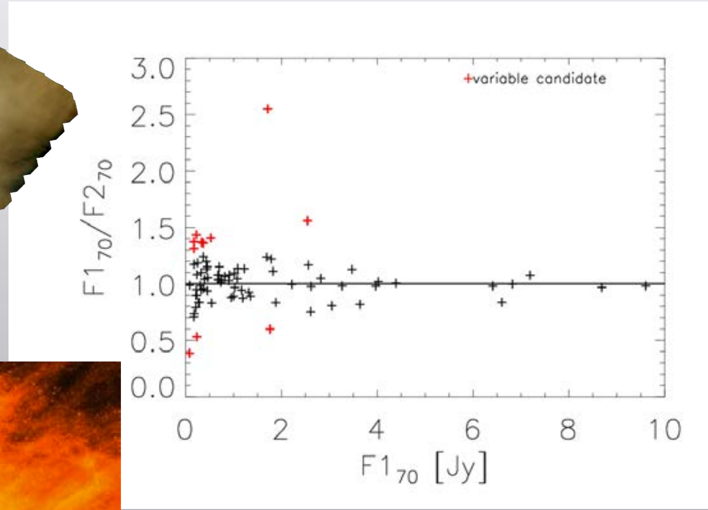


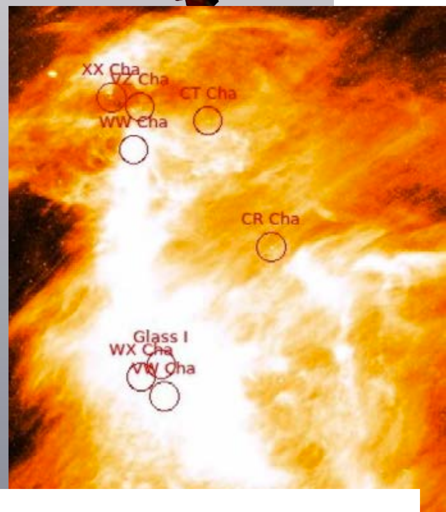
Variability of YSOs

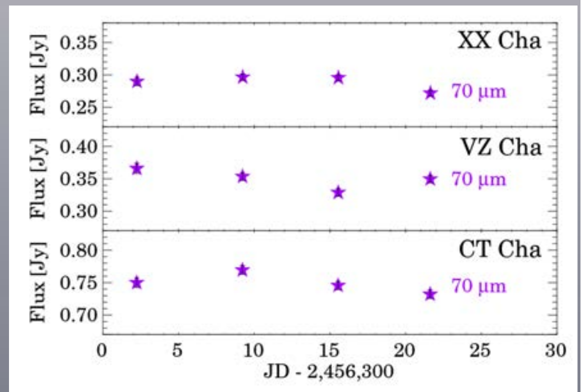
The situation improved a lot with *Herschel*

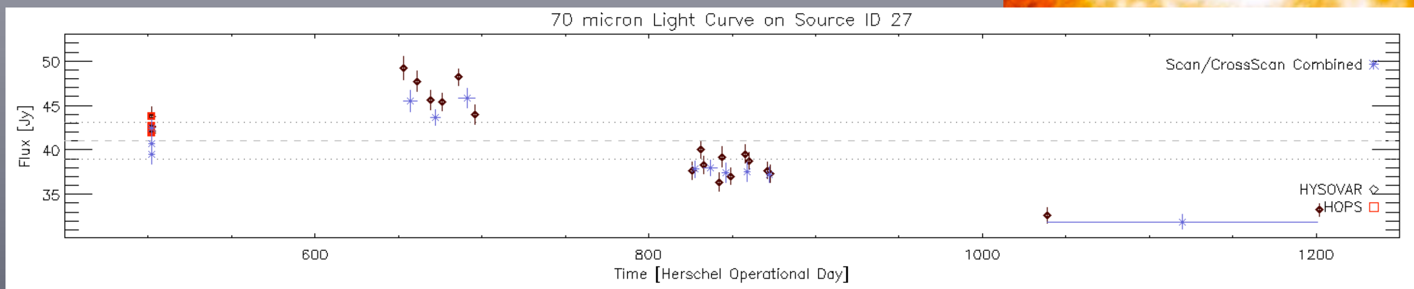
- P27: Ábrahám et al.
  - Deep 70 μm map of LDN 1688, obtained 2 years after the HGBS
  - Comparison of the two maps revealed 11 variable objects at the >30% level
- P50: Kóspál et al.
  - 4-epoch weekly monitoring of 8 selected T Tauris in Cha I
  - 6 sources show 5–11% variability on weekly timescale
- P32: HYSOVAR Billot et al. 2012
  - 18-epoch through 4 visibility windows
  - several variable object on the 10%-50% level
  - see also Billot et al. 2012



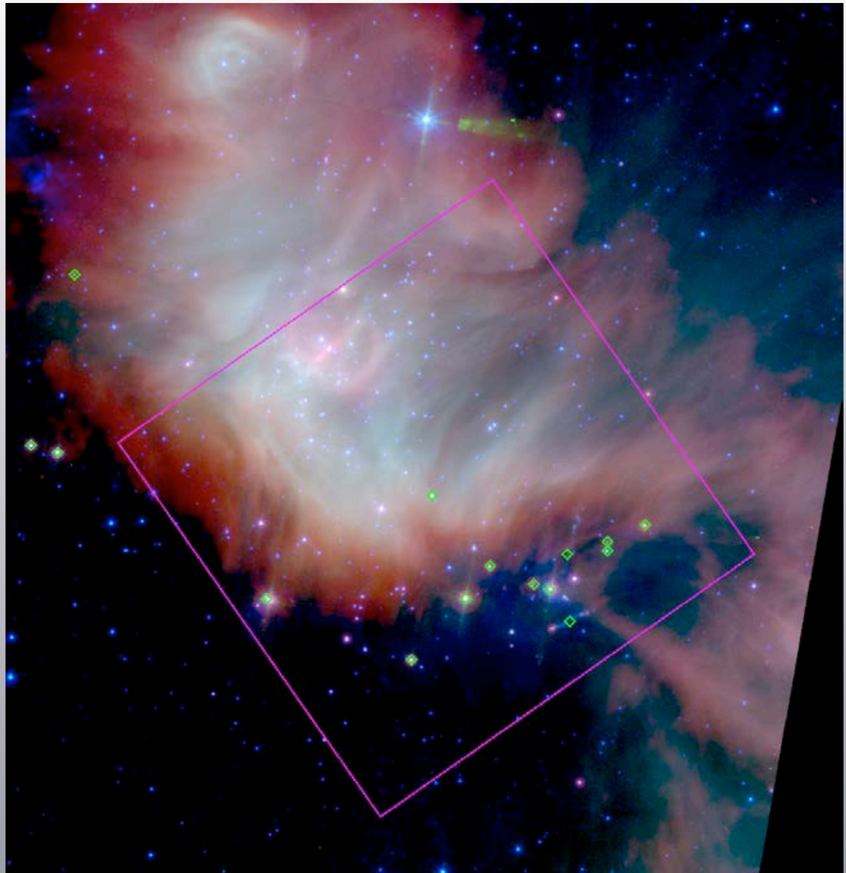








Observations and Data Reduction



Gutermuth et al. 2009

red: 24 µm; green: 5.8 µm; blue: 3.6 µm

IC348

- relatively nearby ~400pc
- contains all kinds of YSOs class 0 - class II
- well studied at shorter wavelengths

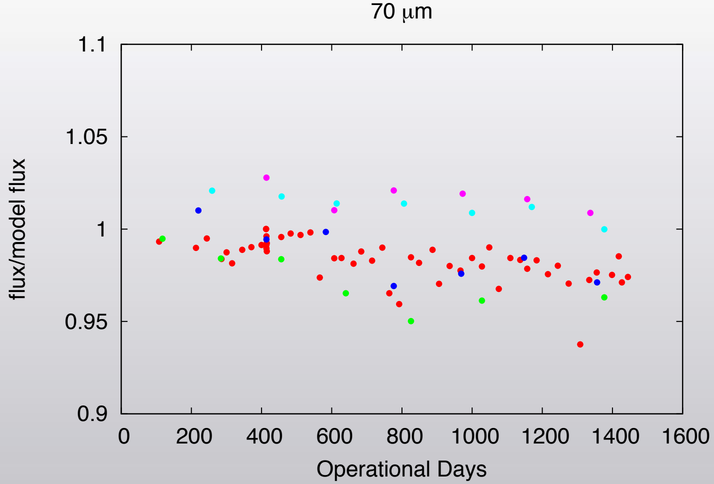
DATA

- 29 epoch in three visibility windows
- covering more than a year in time with different timescales
  - ~1 year, ~2 months, ~2 weeks, ~2 days
- ~15'x15' area
- most of the Spitzer 70 µm detections
  - trade-off had to be made to keep observing time reasonable

PROCESSING

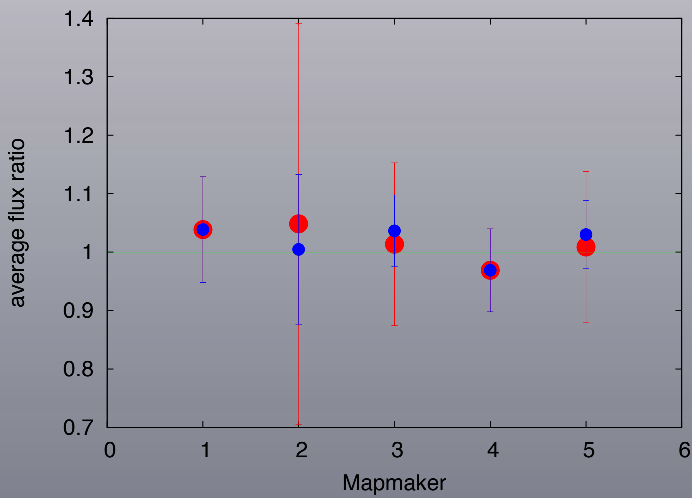
- The data were uniformly processed with three methods
  - Scanamorphos
  - JScanam
  - High Pass Filtering
- Photometry was performed in HIPE using circular apertures and using the the boloSource() algorithm
- all gave similar results with some systematic differences, however it did not influenced the variability

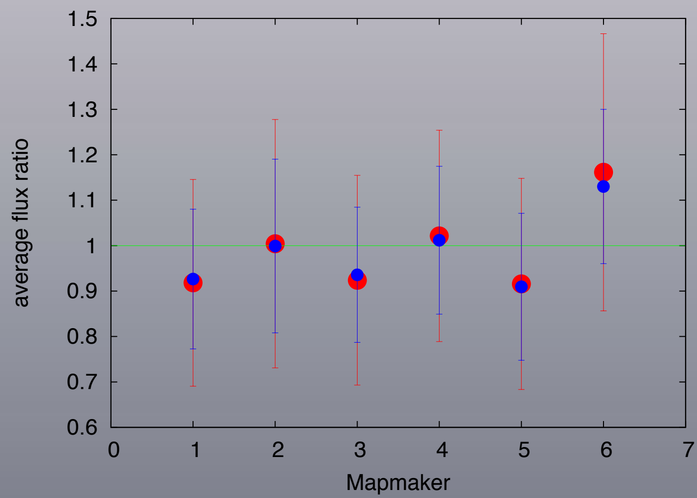
Photometric stability of the PACS instrument



- absolute flux accuracy ~7%
- repeatability ~2%
  - it is tested only in high-pass filter + photProject
  - other processing methods might introduce a up to 5-10% systematic error see:

http://herschel.esac.esa.int/2013MapmakingWorkshop/presentations/PACS_PointSourcePhotometry_ZBalog_MapMaking2013_DPWS.pdf

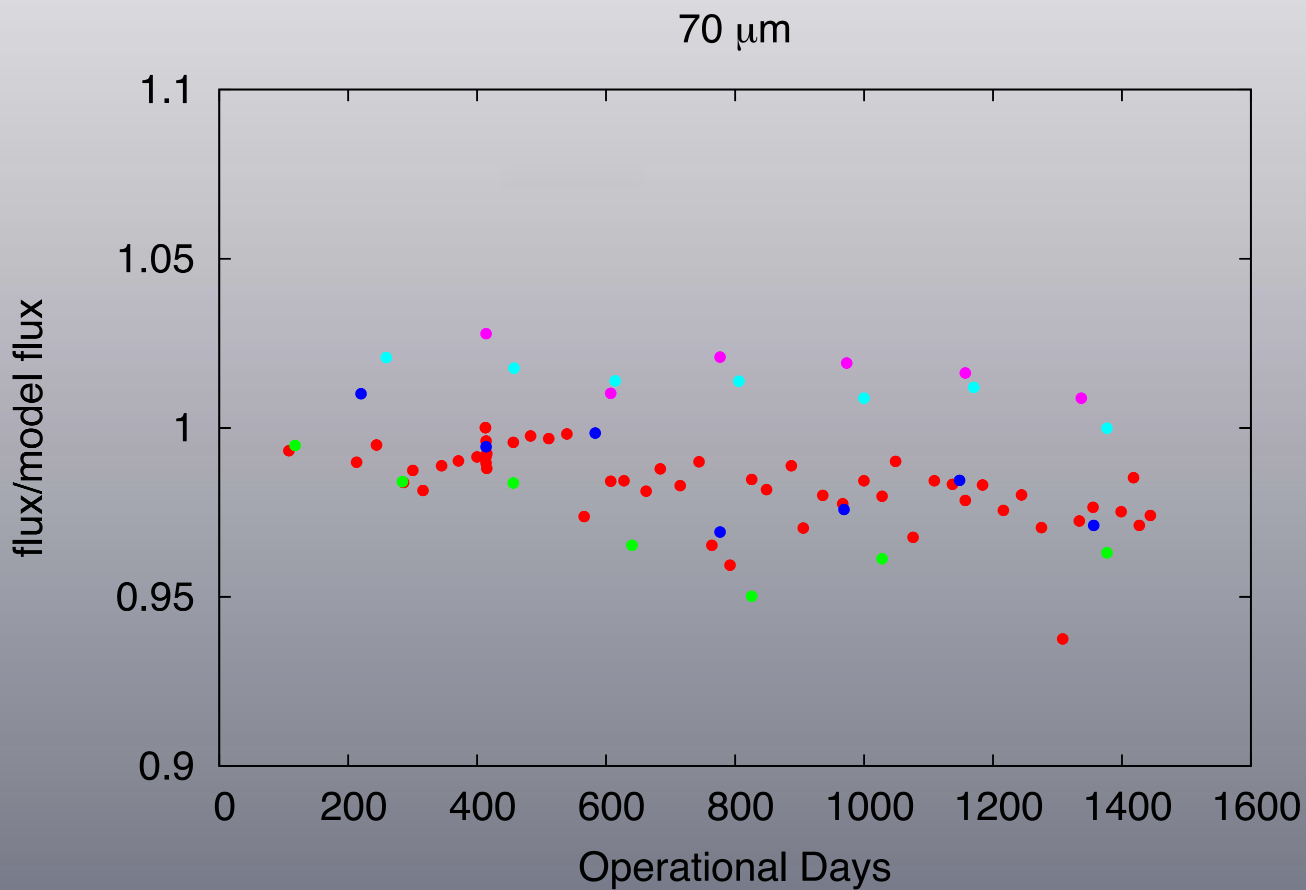




- for more information on the calibration see Balog et al. 2013 Exp. Astr. in press: http://link.springer.com/article/10.1007%2Fs10686-013-9352-3

Photometric stability of the PACS instrument

- Tools are in place to improve the repeatibility.
- They are being tested
- Final goal: ~0.5% in the blue camera and 2% in the red



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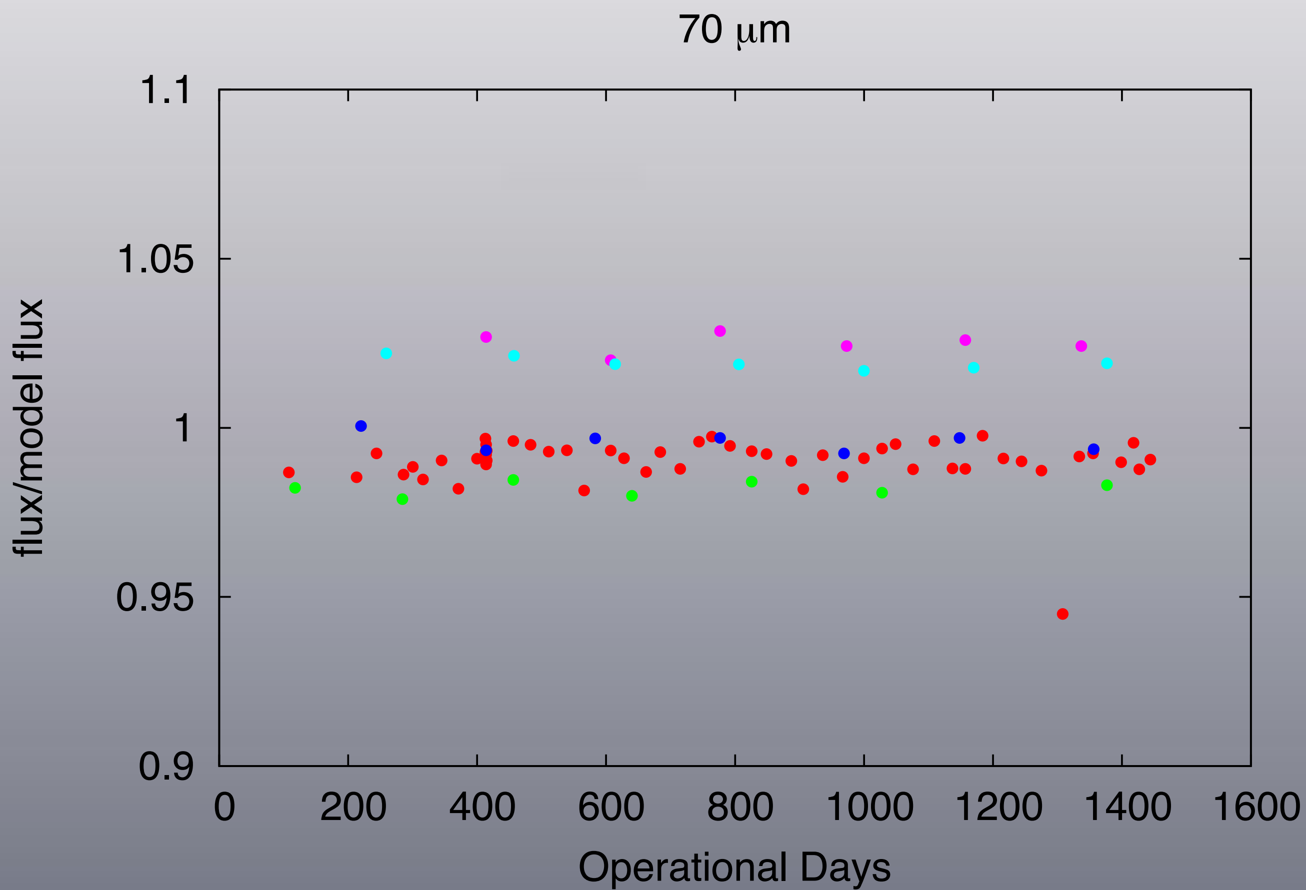
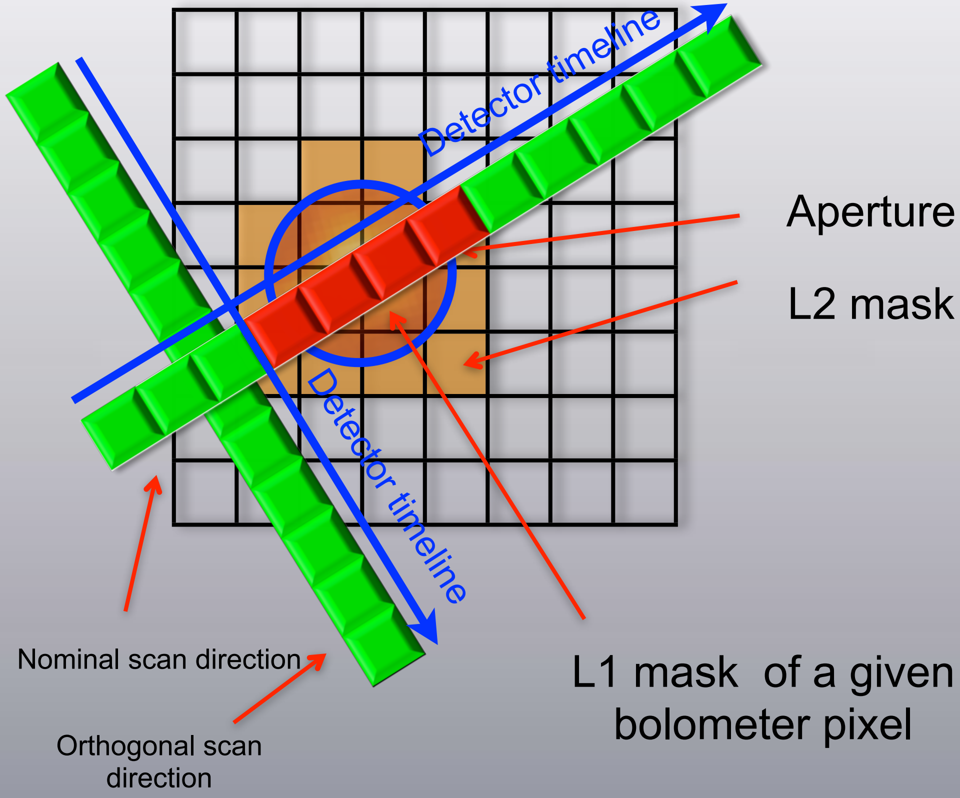
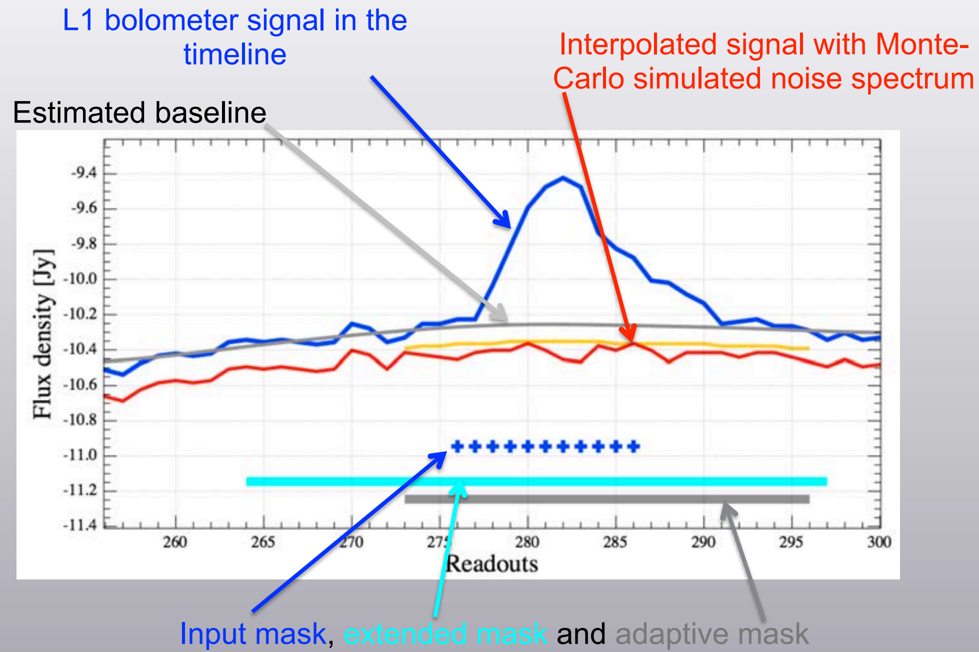
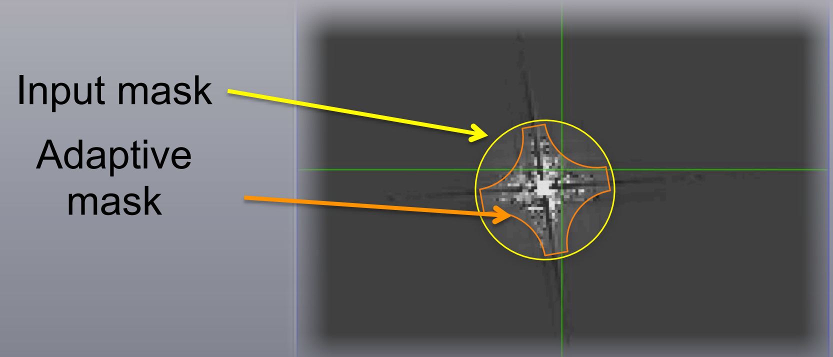


boloSource() - interpolation in the timeline

Projected L2 map

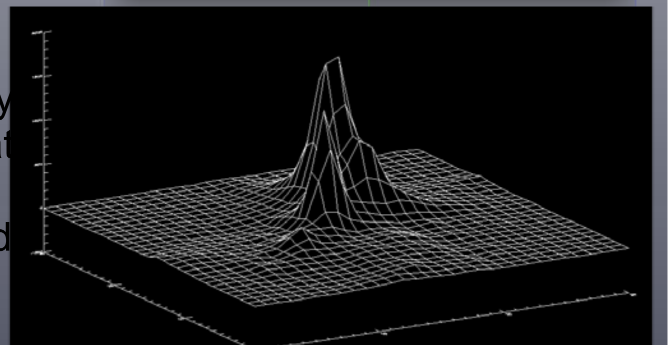






Signal decomposition with Stationary Wavelet Transform:

$$\underbrace{I_{(t)}}_{\text{Interpolated intensity in masked timeline}} = \underbrace{N_{(t)}^{1/f} + N_{(t)}^{D} + N_{(t)}^{det}}_{\text{Simulated noise}} + \underbrace{I_{(t)}^{S(lowfreq)}}_{\text{Baseline estimate from data}}$$

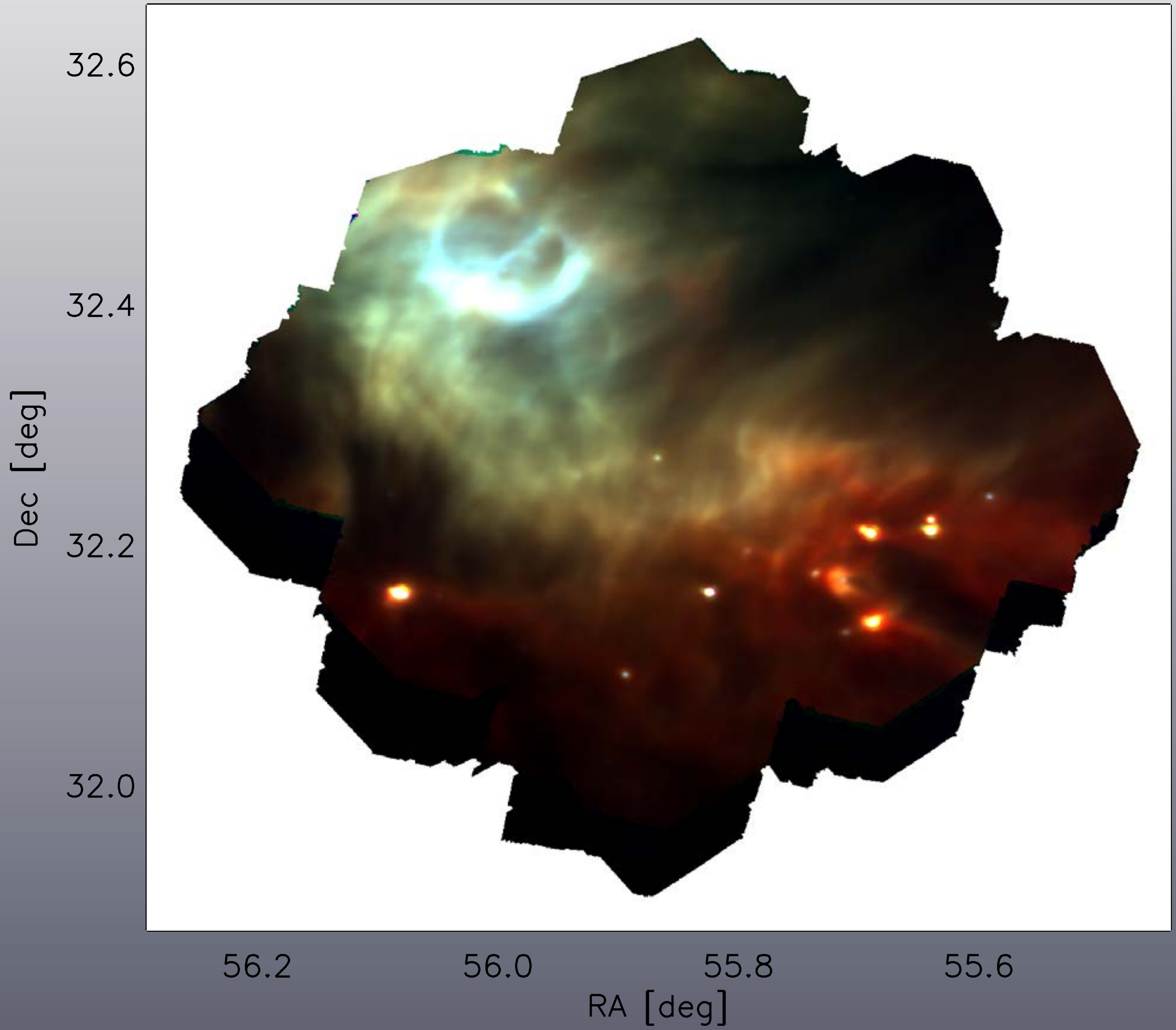


Source-only map with flat zero level background

boloSource() - interpolation in the timeline

Original images processed with Scanamorphos

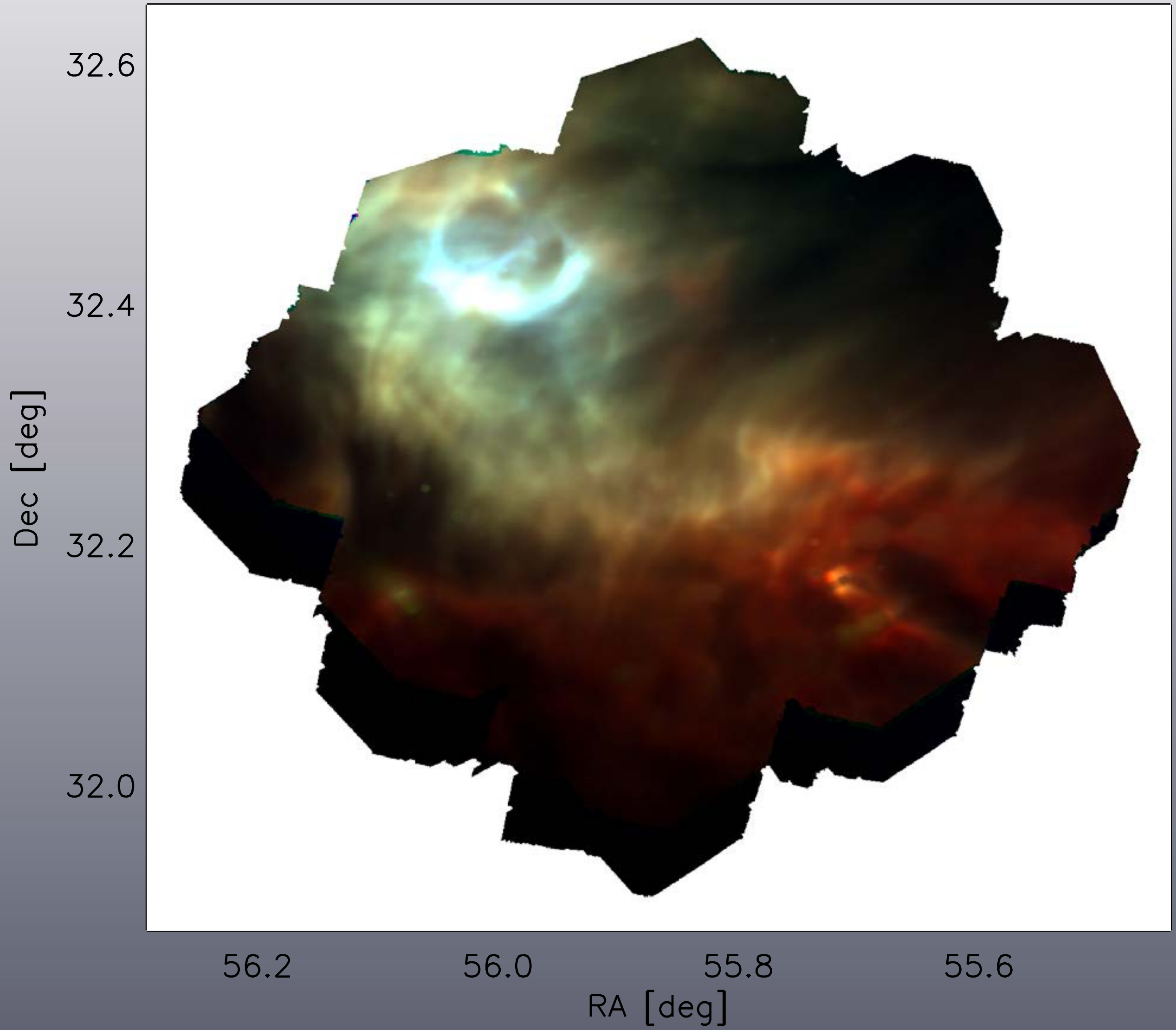
Red: 160 μm Green: 100 μm Blue: 70 μm



boloSource() - interpolation in the timeline

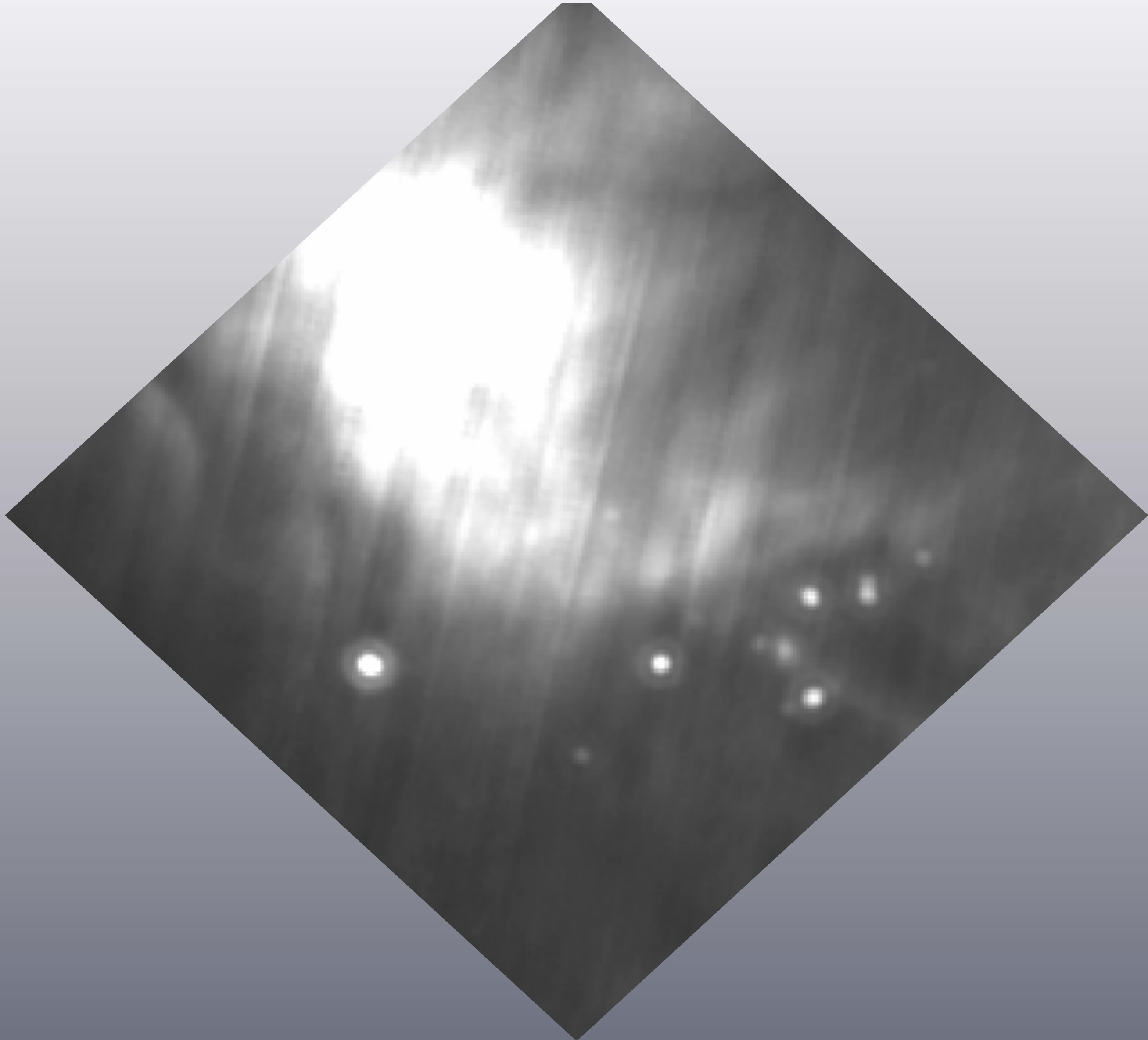
Interpolated images processed with Scanamorphos

Red: 160 µm Green: 100 µm Blue: 70 µm



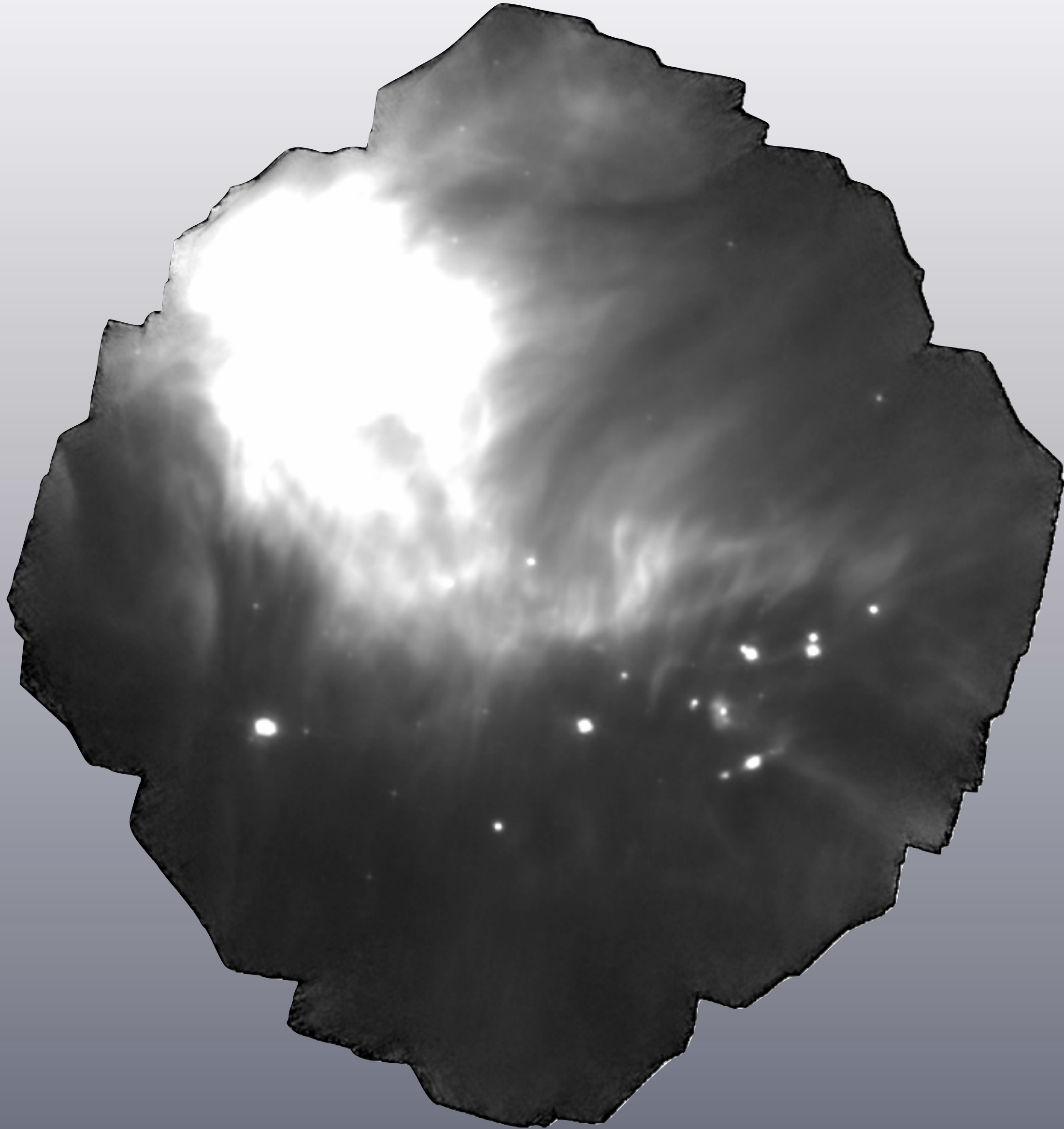
Maps and detected sources

Spitzer/MIPS 70 µm image



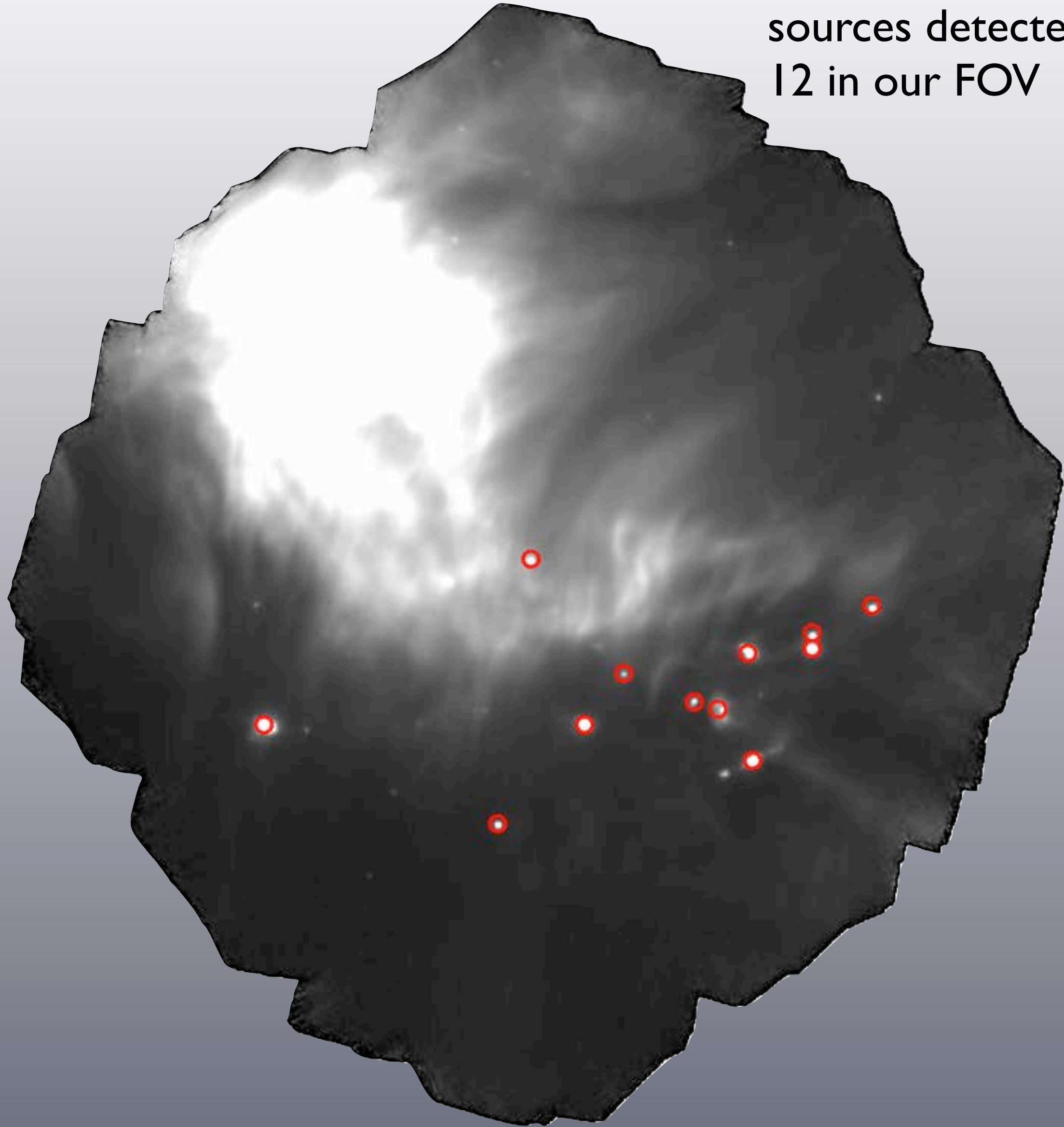
Maps and detected sources

Herschel/PACS 70 μm image



Maps and detected sources

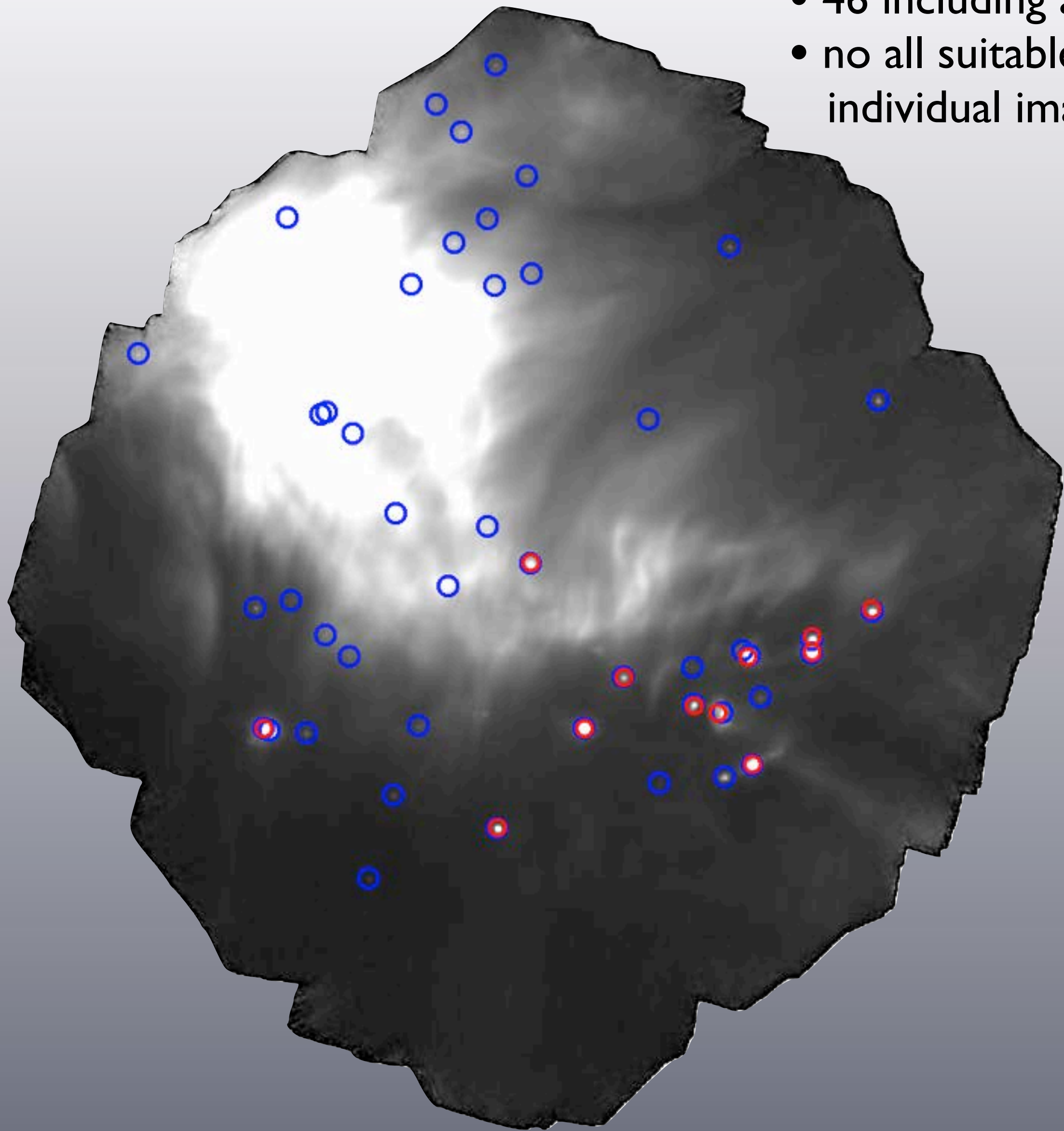
sources detected with *Spitzer at 70* μm
12 in our FOV



Maps and detected sources

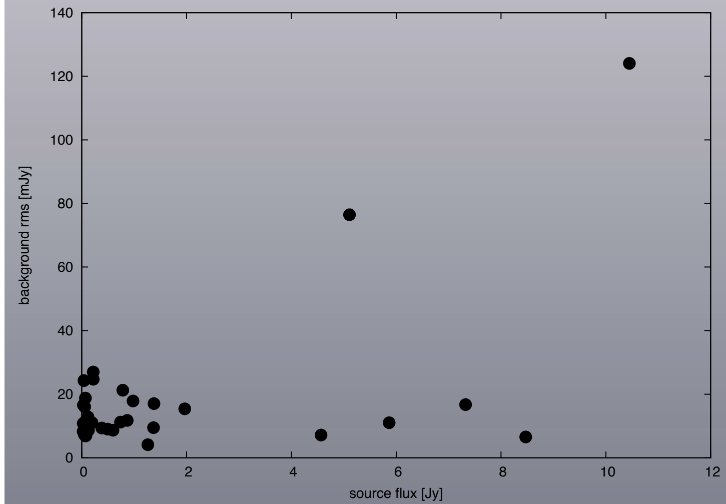
sources detected with *Herschel* at 70 µm

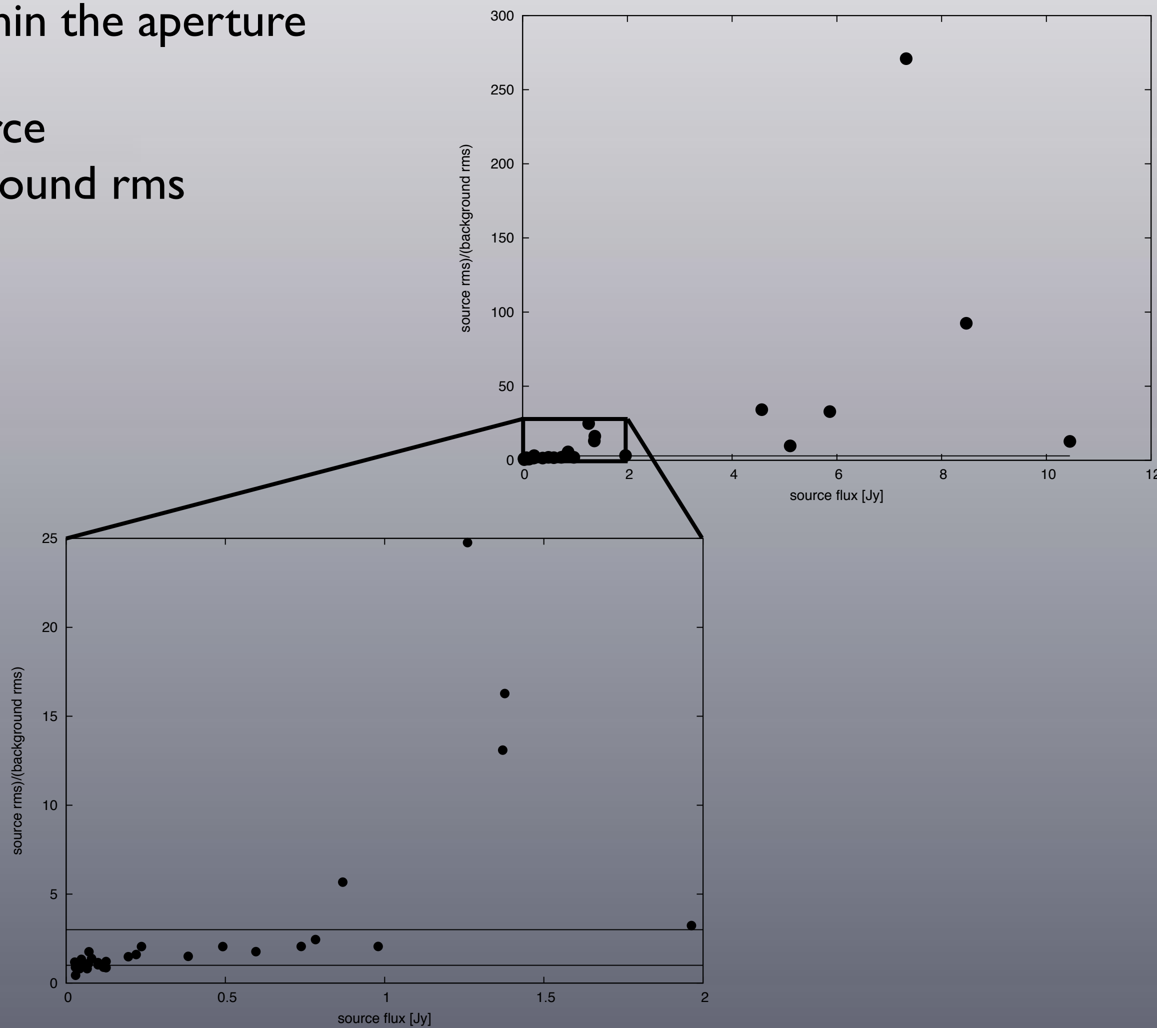
- 46 including all *Spitzer* detections
- no all suitable for photometry on the individual images



Variability

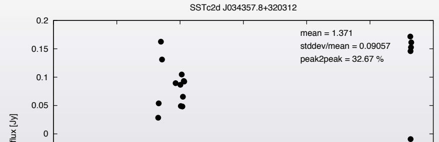
- 46 sources detected on the combined images
- 37 sources were suitable for photometry on the individual images
  - 30 mJy - 10.5 Jy at 70 µm
- photometric uncertainity is impossible to estimate on the single epoch maps
- the rms of the background flux within the aperture after interpolation
- compare it with the rms of the source
  - variable: source rms > 3 x background rms
    source rms > 5%

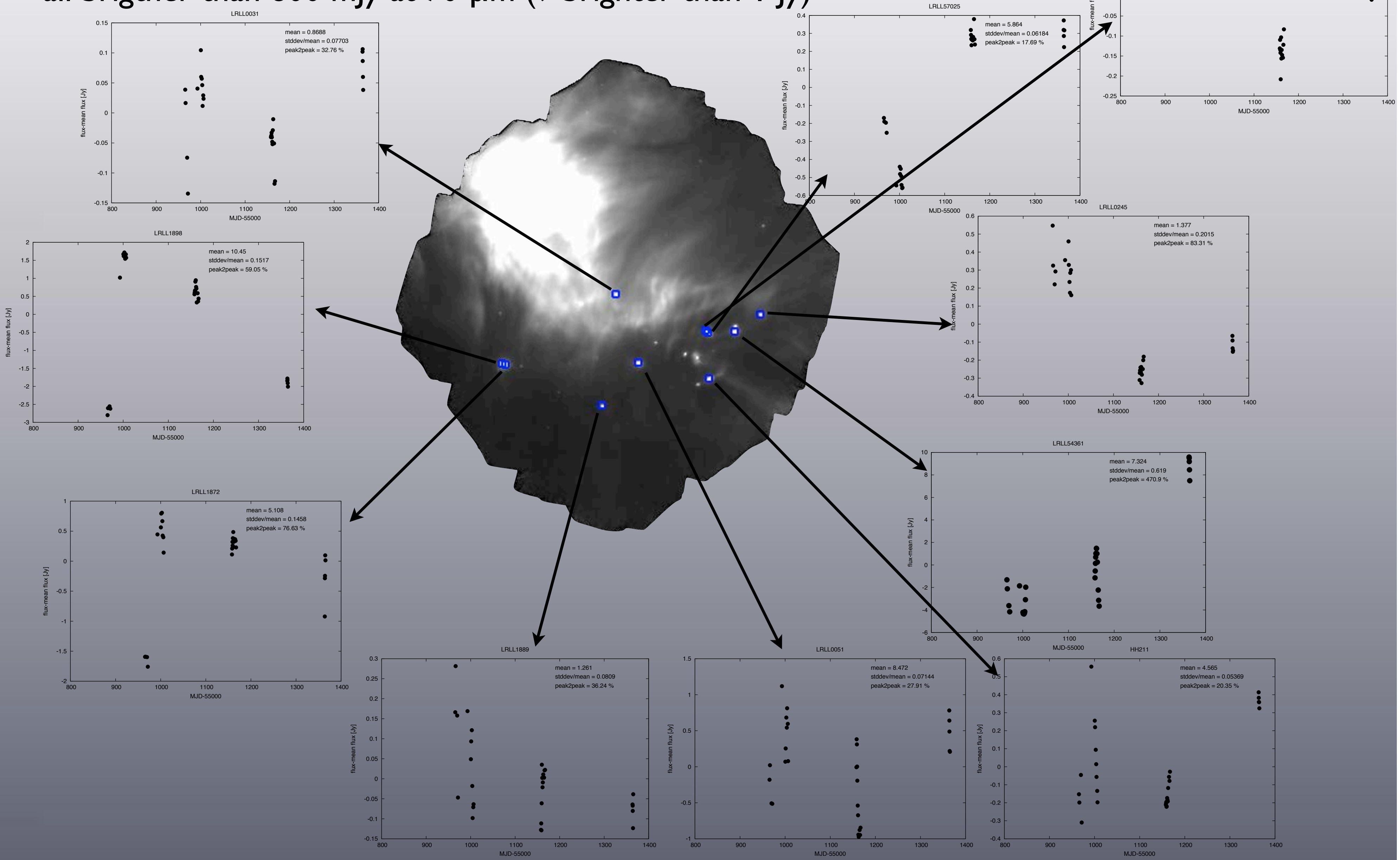




Variability

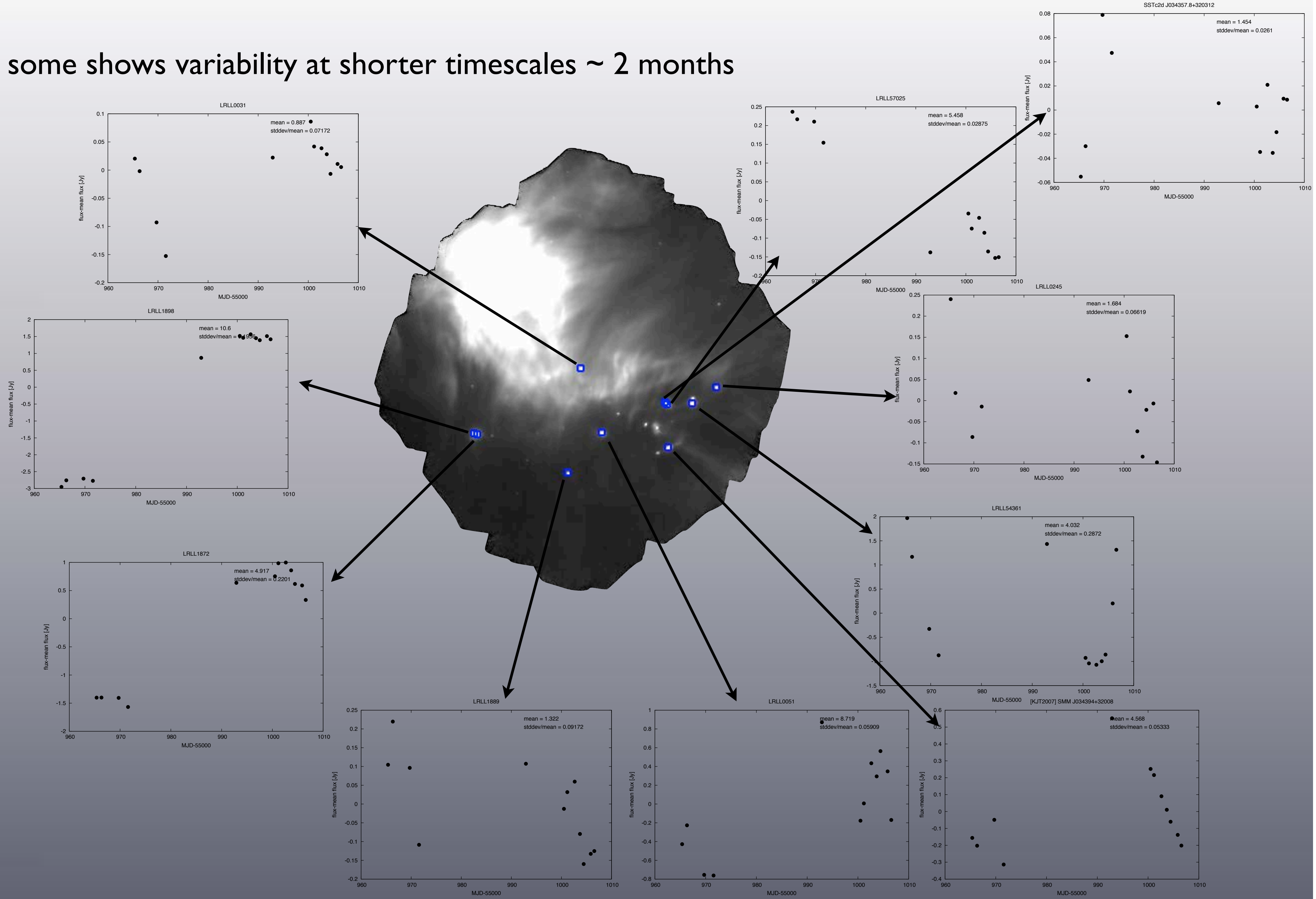
- 10 sources show reliable variability at wavelengths of 70 µm and 160 µm
  - all brigther than 800 mJy at 70 µm (9 brighter than 1 Jy)





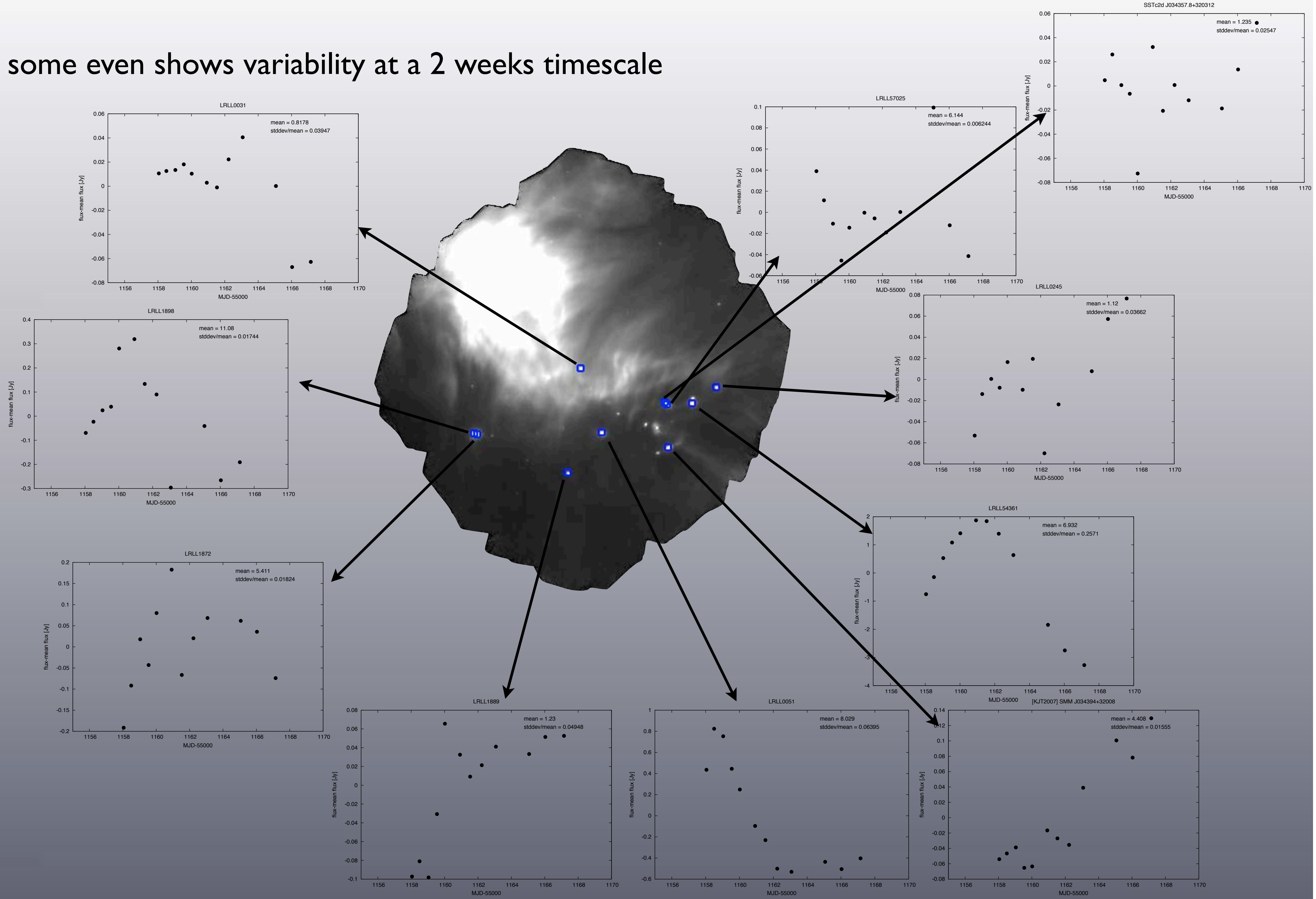
Variability

- some shows variability at shorter timescales ~ 2 months



Variability

- some even shows variability at a 2 weeks timescale



Variability

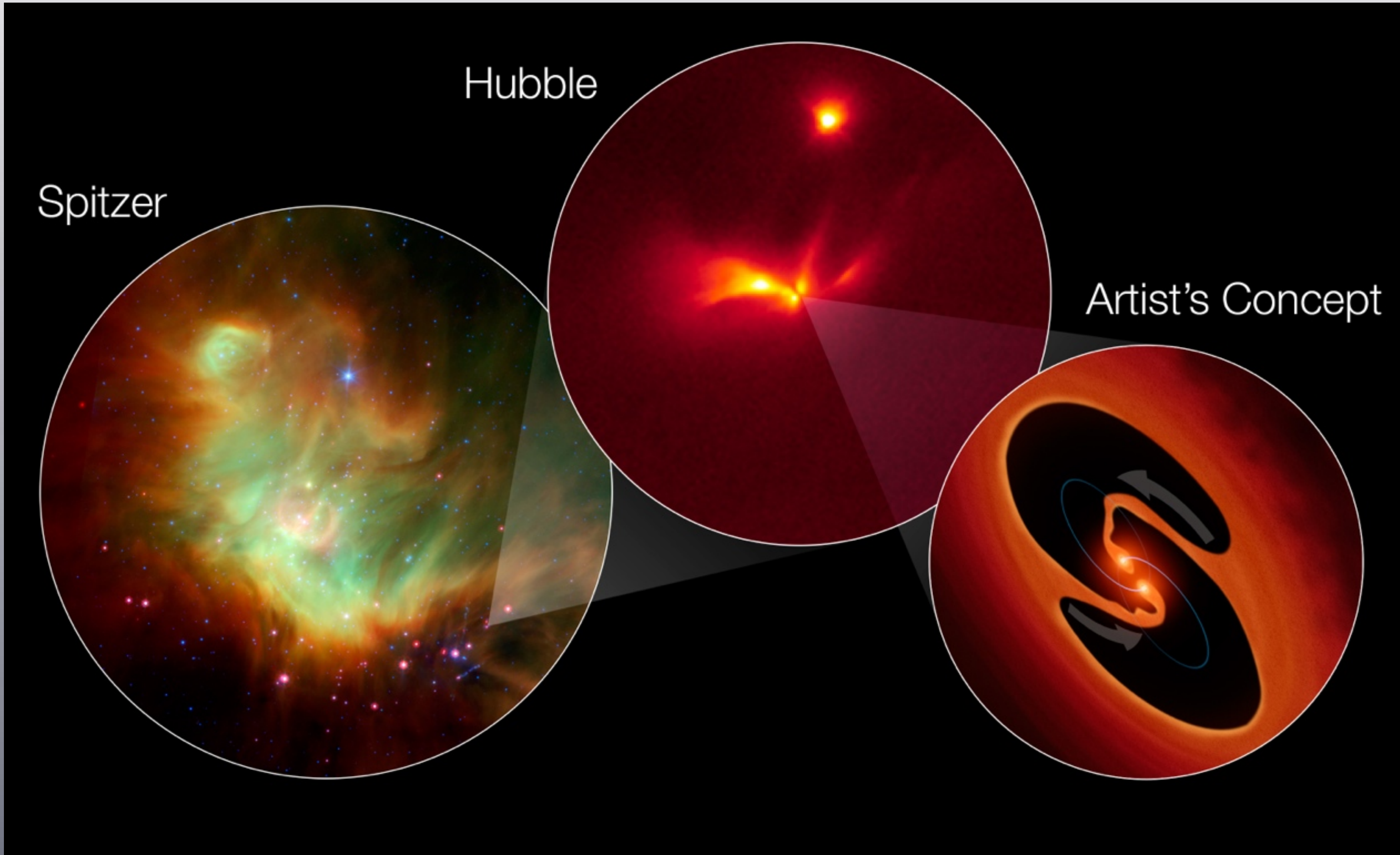
Name		70	160	rms: ~1 year	rms ~2 months	rms ~2 weeks	rms ~3 days
LRLL0245	class I/II	1.377	1.039	0.201	0.066	0.037	0.031
LRLL54361	class I	7.324	9.668	0.619	0.287	0.257	0.054
HH211	class 0	4.565	31.054	0.054	0.053	0.016	0.007
LRLL57025	class 0/I	5.864	25.456	0.0618	0.029	0.006	0.009
SSTc2d_J034357.8+320312	---	1.371	12.392	0.091	0.026	0.026	0.050
LRLL0051	class I/II	8.472	5.952	0.071	0.059	0.064	0.028
LRLL0031	class II	0.869	1.244	0.077	0.071	0.040	0.031
LRLL1889	class I	1.261	1.884	0.081	0.092	0.050	0.026
LRLL1872	class I	5.108	16.114	0.146	0.220	0.018	0.083
LRLL1898	class I	10.450	25.586	0.152	0.200	0.017	0.010

LRLL54361

• large variations at all IRAC wavelengths detected in our *Spitzer*/IRAC survey with a period of 25.34 days
• HST observations reveal a spectacular light echo (Muzerolle et al. 2013)

LRLL54361

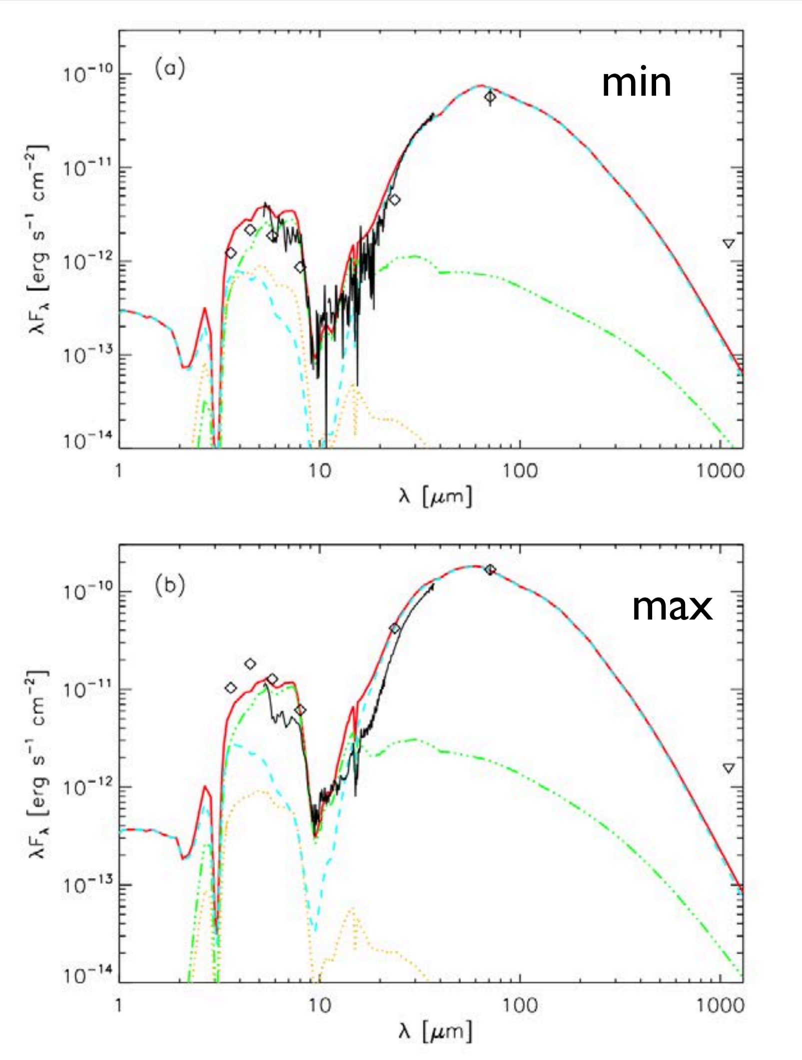
Explanation: binary induced pulsed accretion



LRLL54361

Explanation: binary induced pulsed accretion

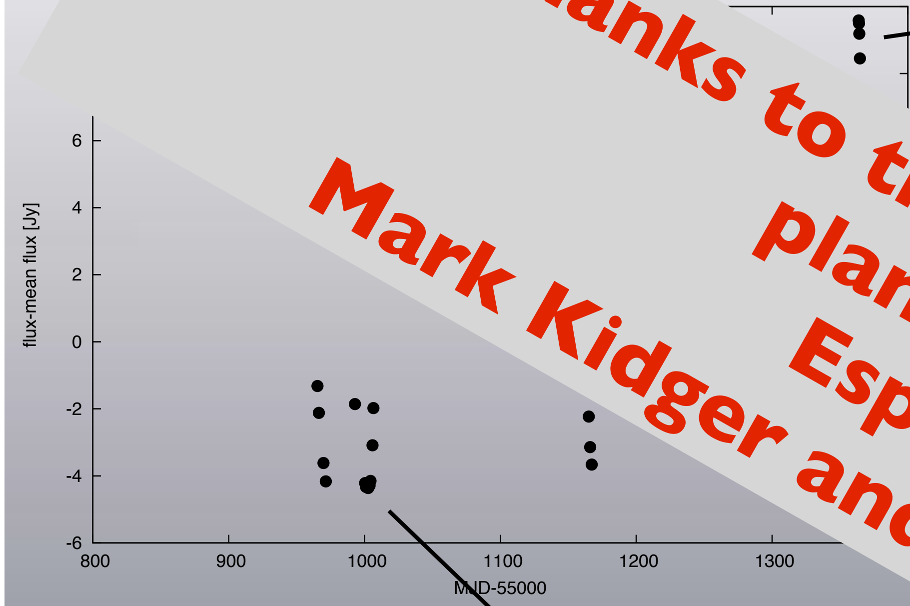
Static models of the minimum and maximum reveal the physical properties of the source:

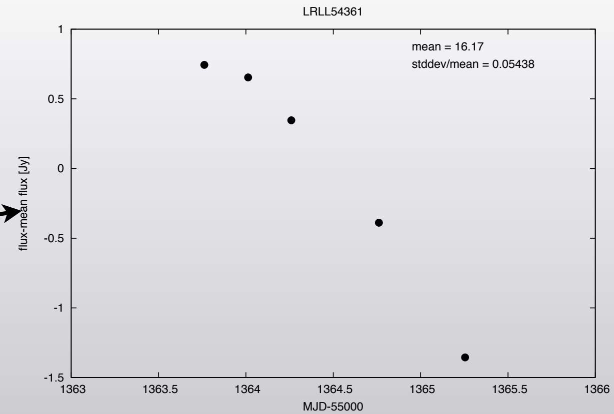


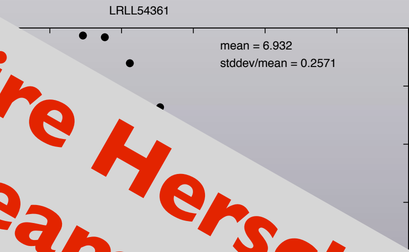
Envelope infall rate: 3×10^{-6} $M_\odot yr^{-1}$
envelope centrifugal radius: R_C = 30 AU
outflow cavity opening angle: θ = 30°
angle of the outflow/stellar rotation axis to the line of sight: i = 70°
total central luminosity (stellar plus accretion) L = 0.5 $L_\odot$ and 1.3 $L_\odot$
η_{star} = 0.5 (min) and 0.19 (max)
CO_2 ice abundance of 10^{-4}, and an H_2O ice abundance of 2×10^{-3}
disk accretion rate: 10^{-6}

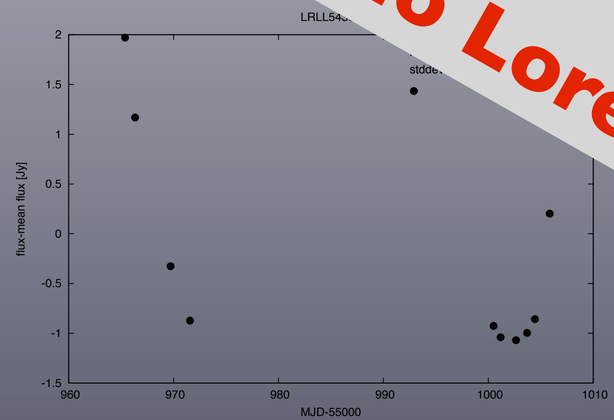
LRLL54361

Hersc[obscured] also reveal periodic variations









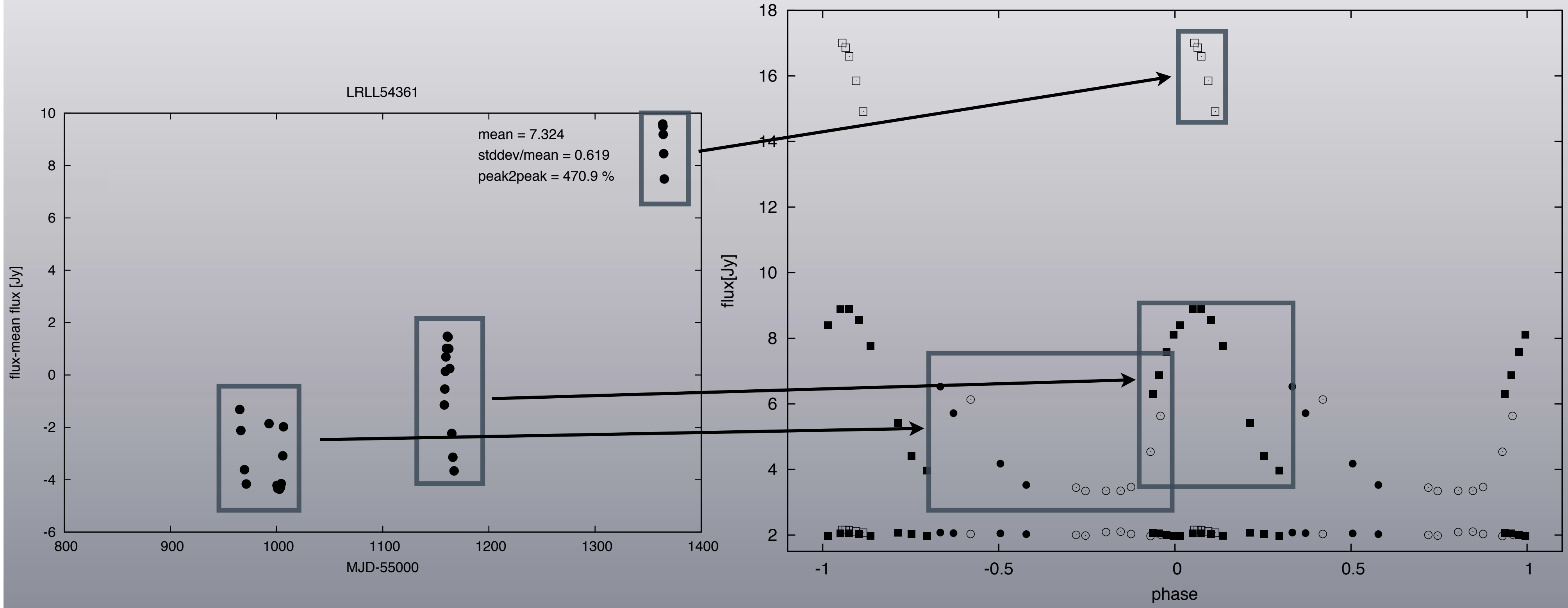
Huge thanks to the entire Herschel mission planning team

Especially:

Mark Kidger and Rosario Lorente

LRLL54361

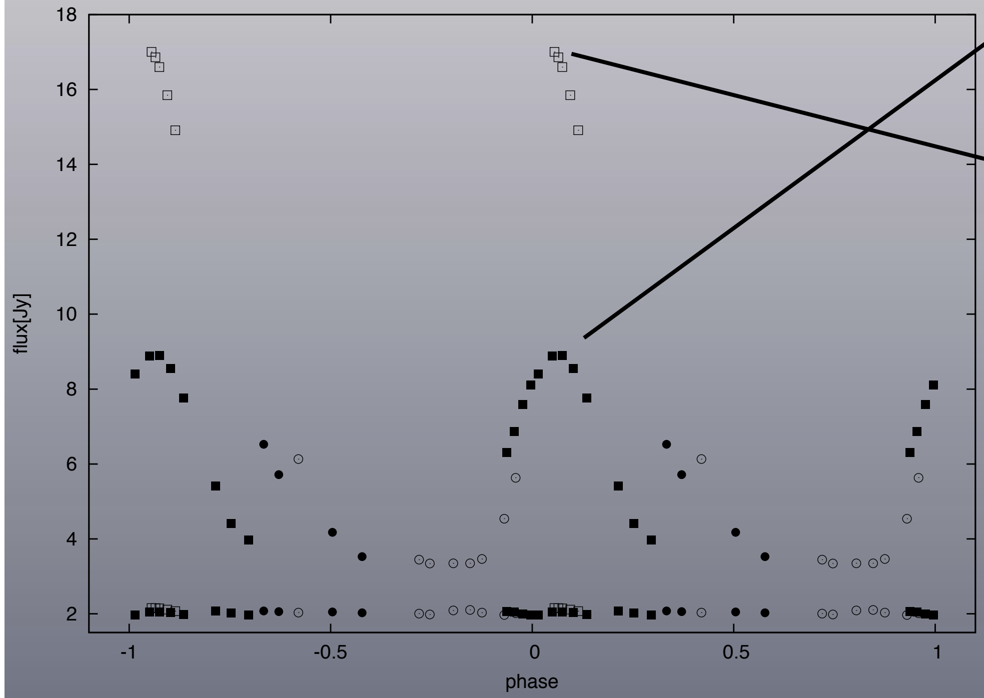
Herschel observations also reveal periodic variations

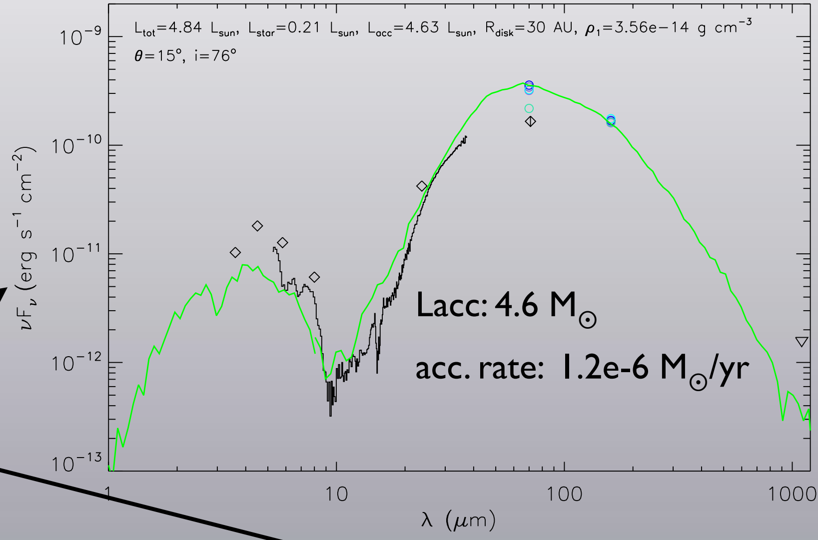


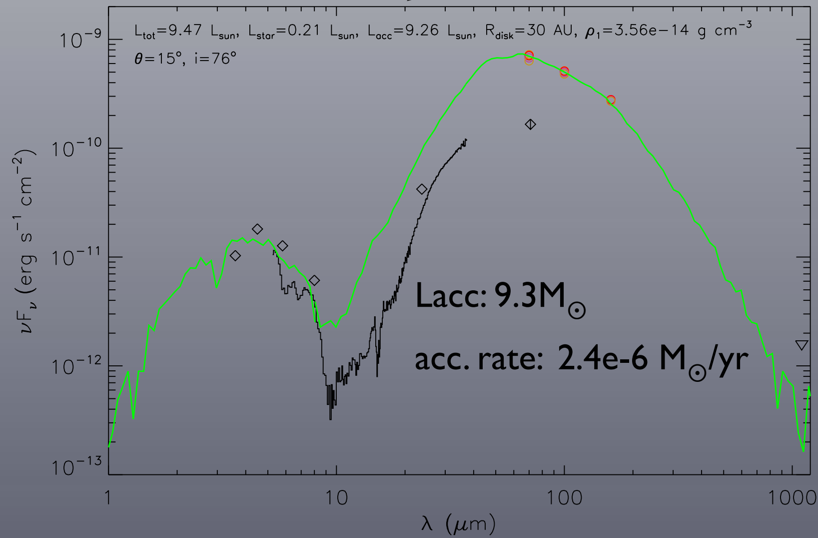
LRLL54361

Two different maxima showed that there is a difference between two periods. It can be modeled entirely with accretion variations

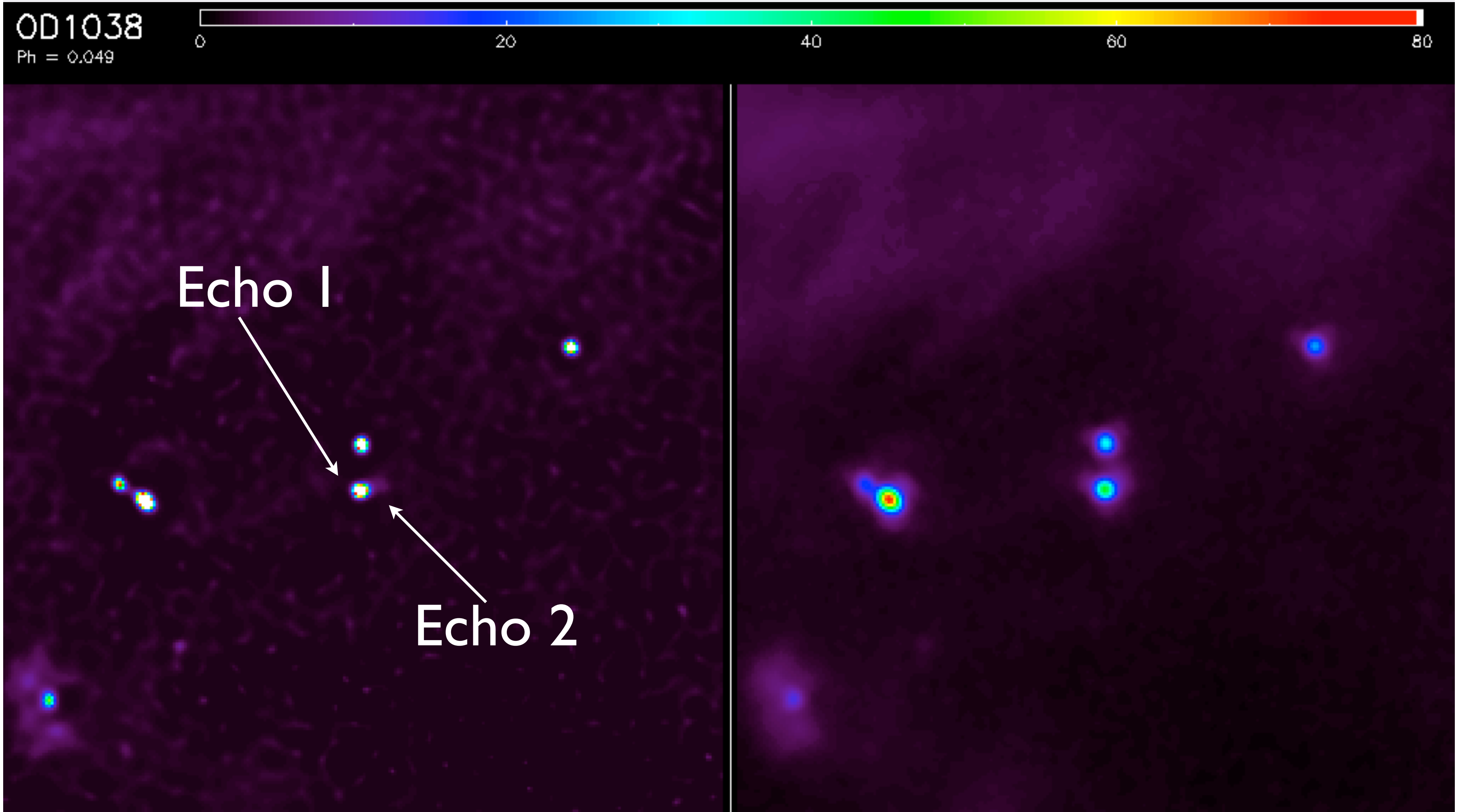
accretion rate may vary by a factor of 2







LRLL54361 - light echo



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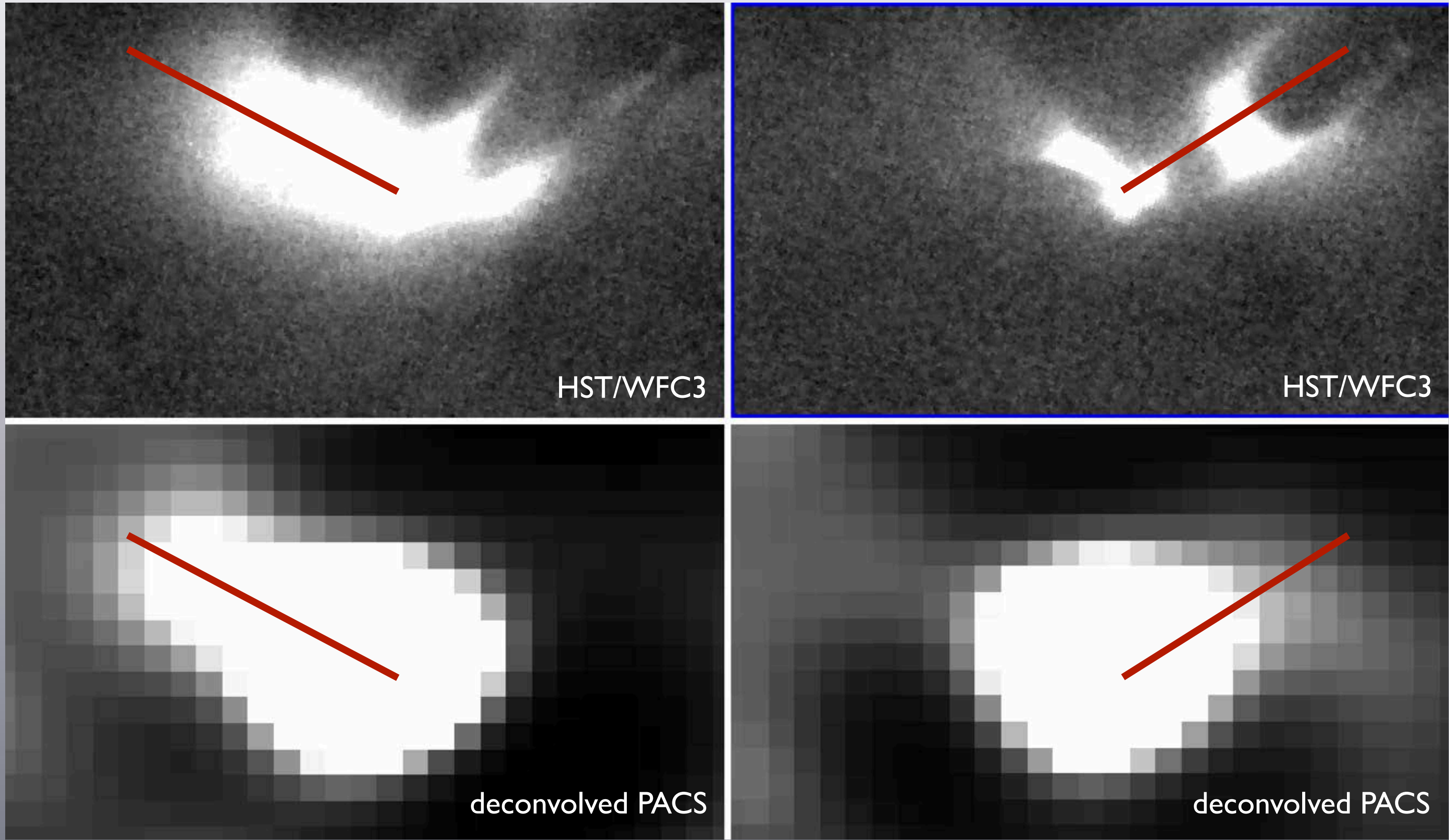

Summary

- multi epoch photometric survey of IC348 with *Herschel*/PACS at 70 μm and 160 μm
- 46 sources detected including all sources detected with *Spitzer*/MIPS at 70 μm
  - brightness range ~ 30 mJy - 10.5 Jy
- 10 sources shows reliable variability on the scale of ~1 year
  - majority of the sources show variability on the scale of 2 months
  - some show even reliable weekly or daily variability
  - all brighter than 800 mJy
  - fainter sources show some sign of variability but needs confirmation
- periodic variation of LRLL54361 is confirmed in the far-IR
  - the maximum flux varies from period to period (also in mid-IR)
  - accretion rate at maximum light varies by an order of magnitude
  - tentative detection of the near-IR light echo at 70 μm