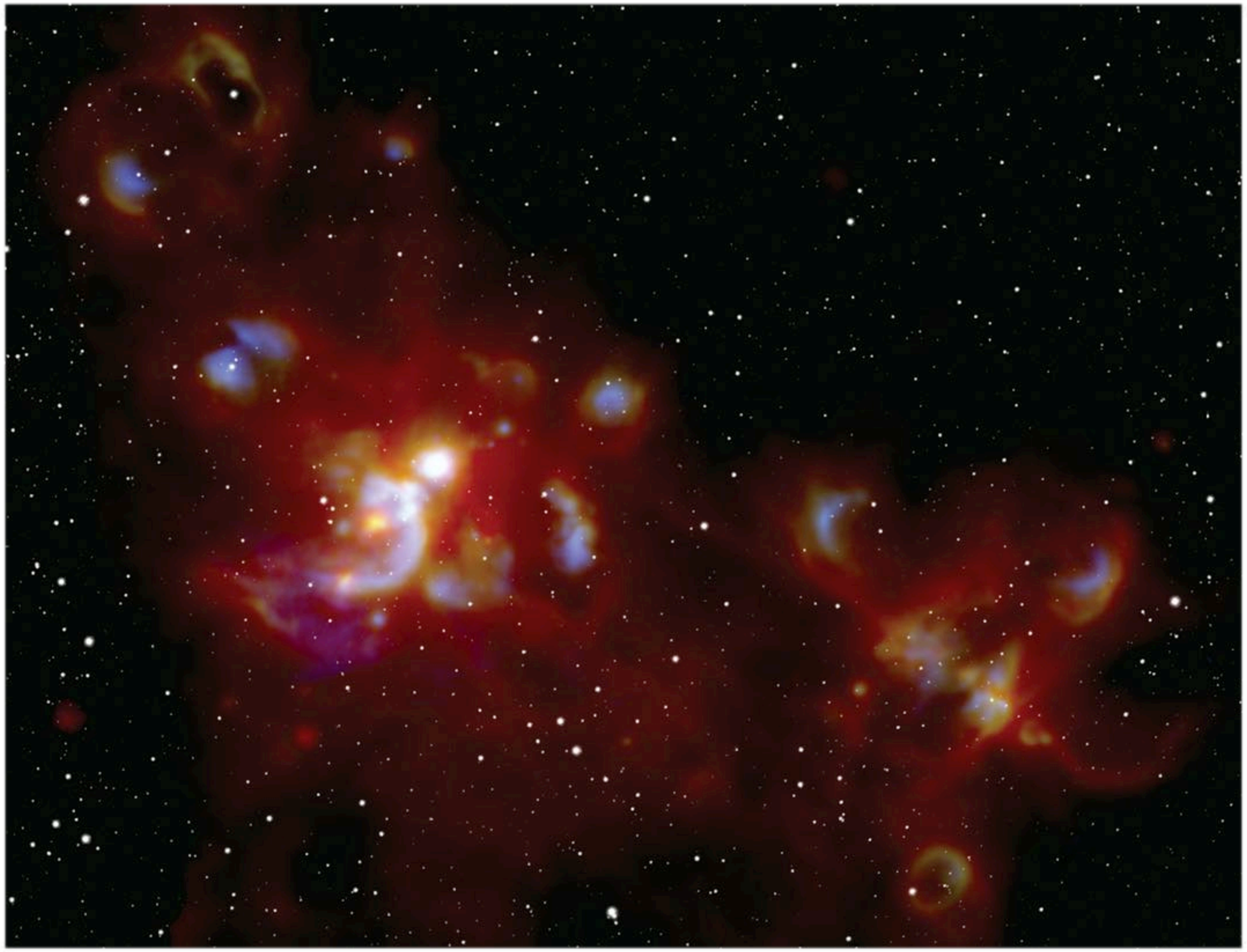


SOFIA-FORCAST Survey Toward the GHII regions of the Galaxy

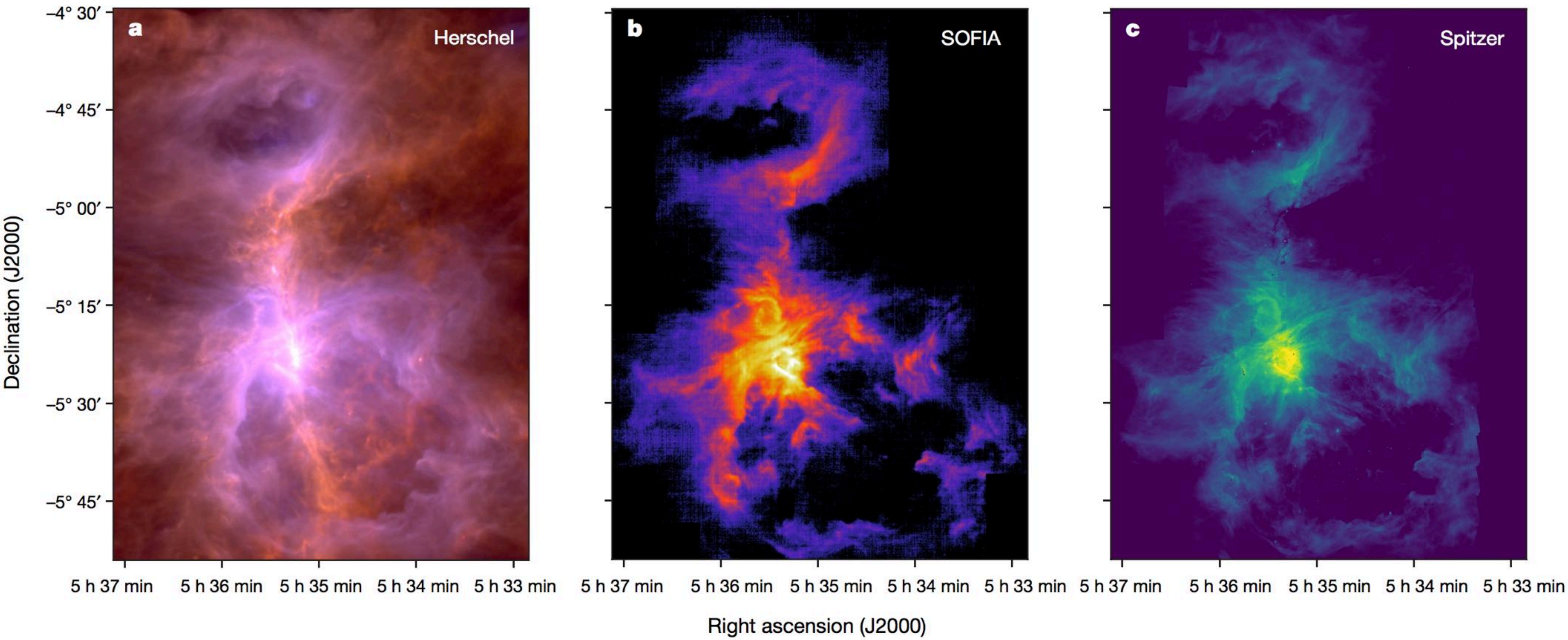
Wanggi Lim PostDoc (SOFIA Science Center)

Motivation & Overview

- Massive stars are important but 'still' poorly understood.
- (Massive) stars are formed in clusters (Lada & Lada 2003; Gutermuth ea 2009).
- Giant HII regions are OB clusters and you see these from external galaxies.
- Conti & Crowther 2004 defined 56 GHII regions in Milky Way.
- SOFIA FORCAST GHII survey plans to observe all of them with 20 & 37µm.
- W51A : one of the most massive and brightest GHII regions in Milky Way.

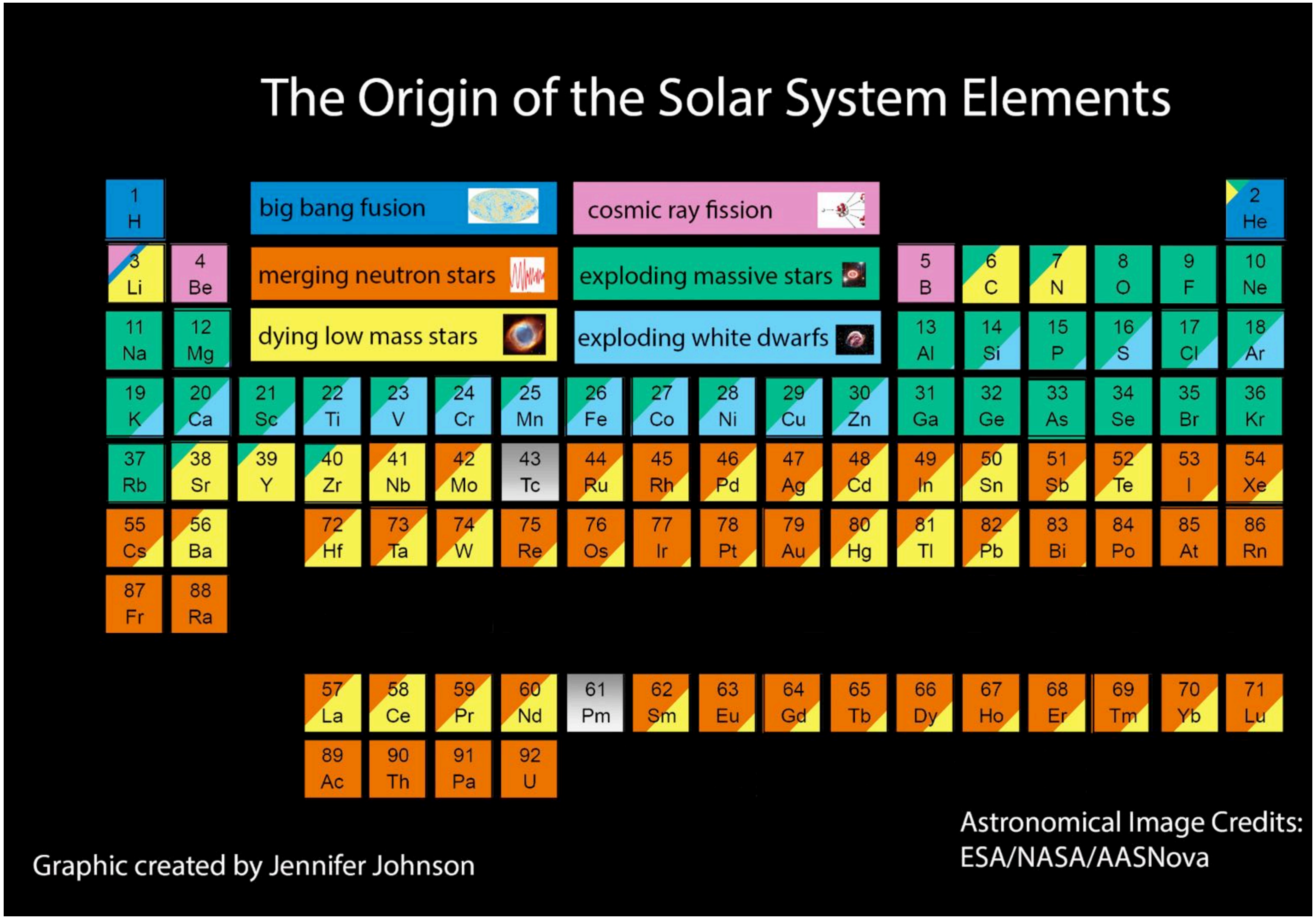
An example : Why massive stars are important?

Pabst ea 2019



The enormous massive star feedback can be a critical source to form and maintain the shapes of the environmental GMCs!

An example : Why massive stars are important?



Without massive stars, the form of living creatures should be so much different from now!

Evolutionary sequence of High-mass stars and star clusters

(Beuther et al. 2007)

Cores to stars
→ High-mass starless cores (HMSCs)
→ High-mass cores harboring accreting low/intermediate mass protostar(s) destined to become a high-mass star(s)
→ High-mass protostellar objects (HMPOs) - HII regions
→ Final stars

Clumps to clusters
→ Massive starless clumps
→ Protoclusters - HII regions
→ Stellar clusters

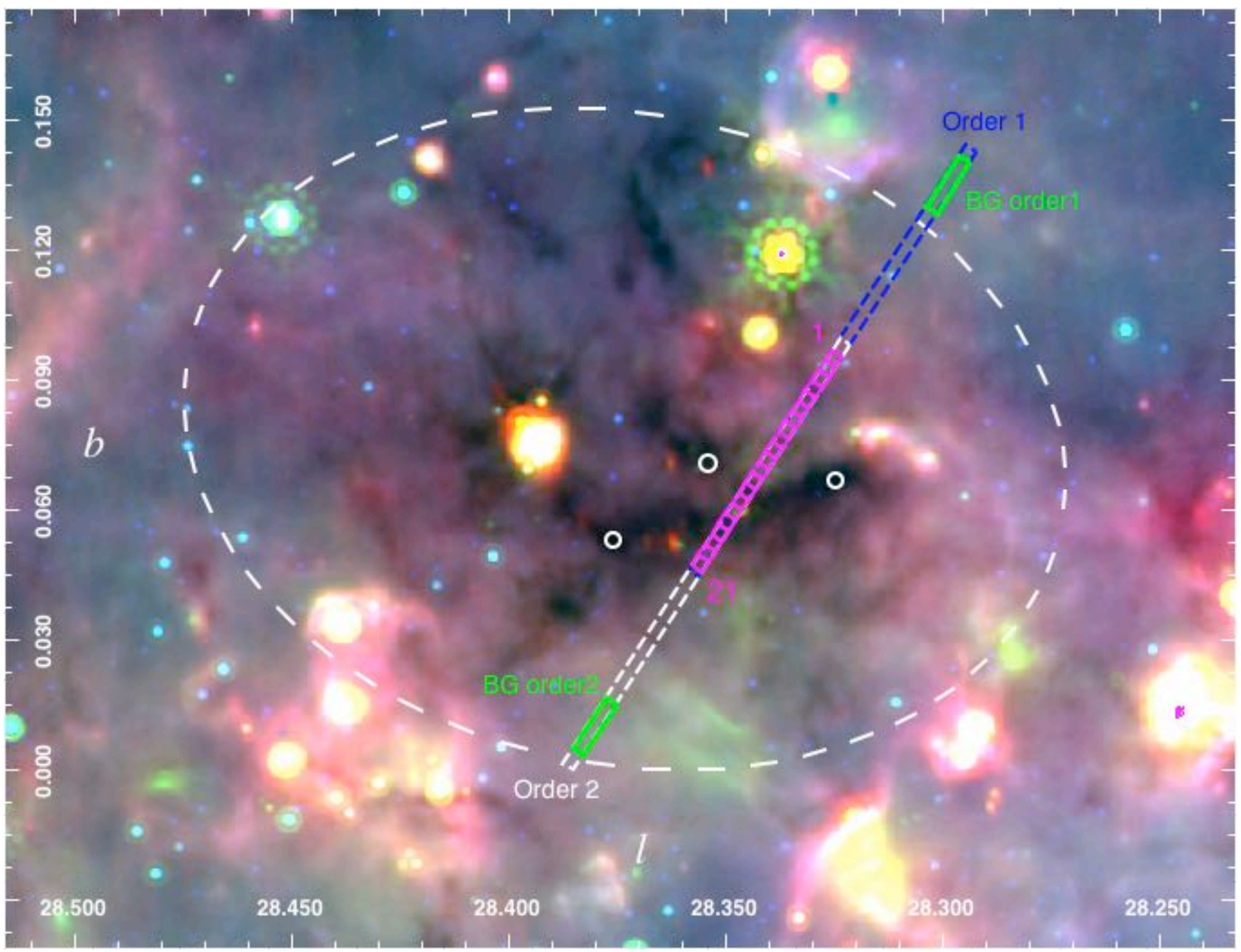
Two simple stages

- Infrared Quiescent
- Infrared Bright

Classical and non-classical eyes on MSFR

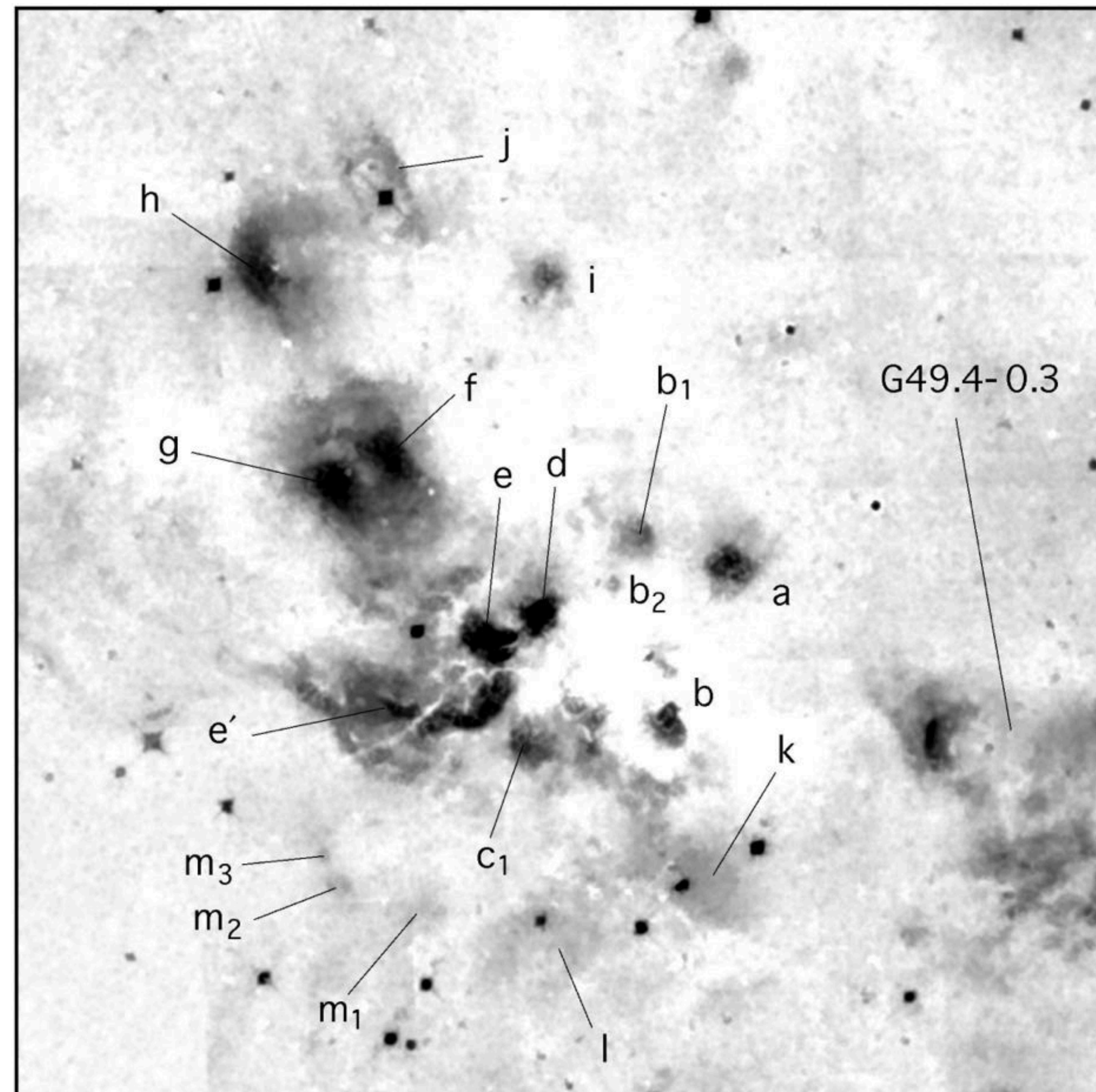
Modern(?) IR observation toward High-mass SFR (IR quiescent)

IRDC : 8, 24 & 70μm image (Lim ea 2015)



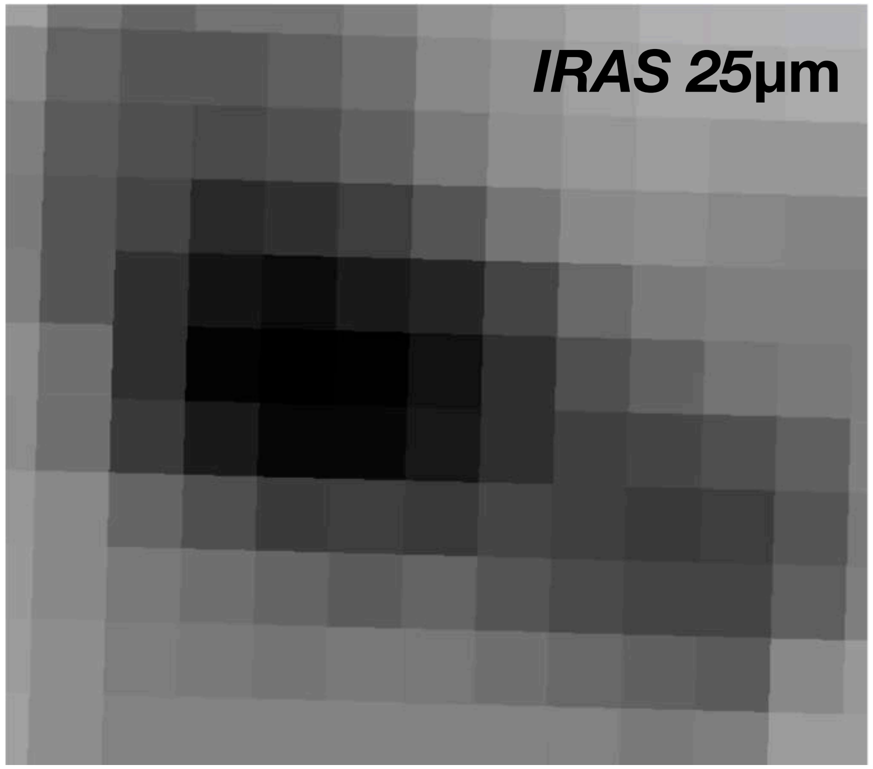
Classical IR observation toward High-mass SFR (IR bright)

GHII region : Brγ NIR image (Okumura ea 2000)

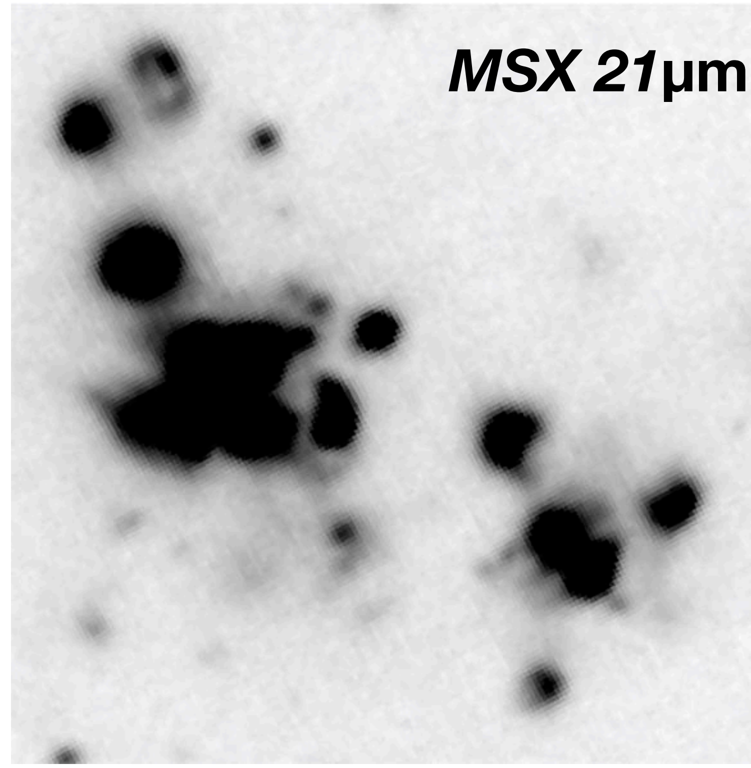


A brief history of MIR observation toward a GHII region (W51A)

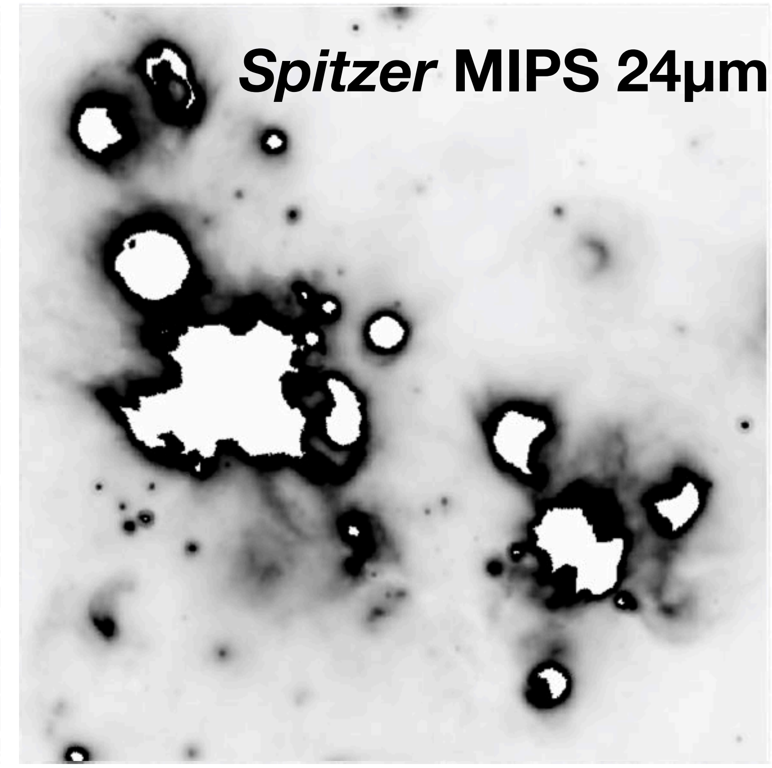
Early 1980s



Mid 1990s



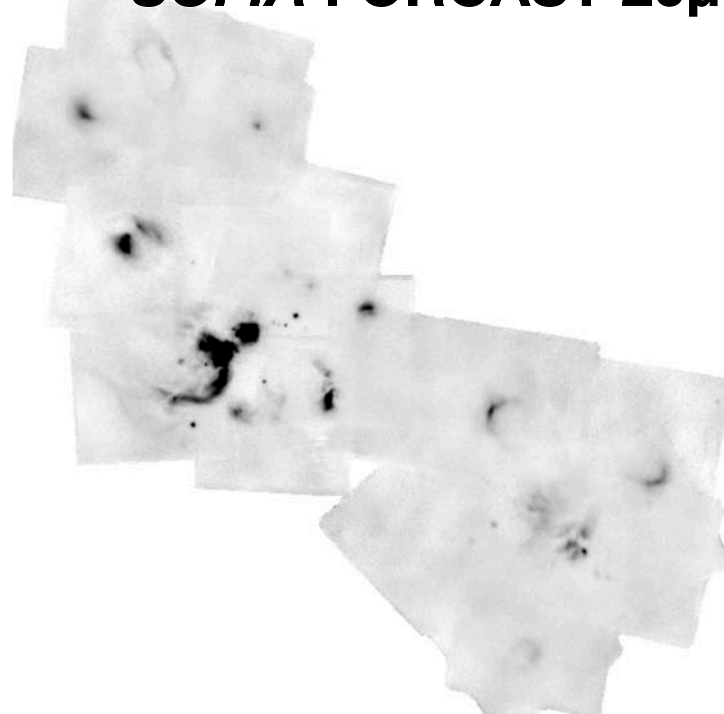
Late 2000s (observation)



Angular resolutions of
Space/Airborne Telescopes

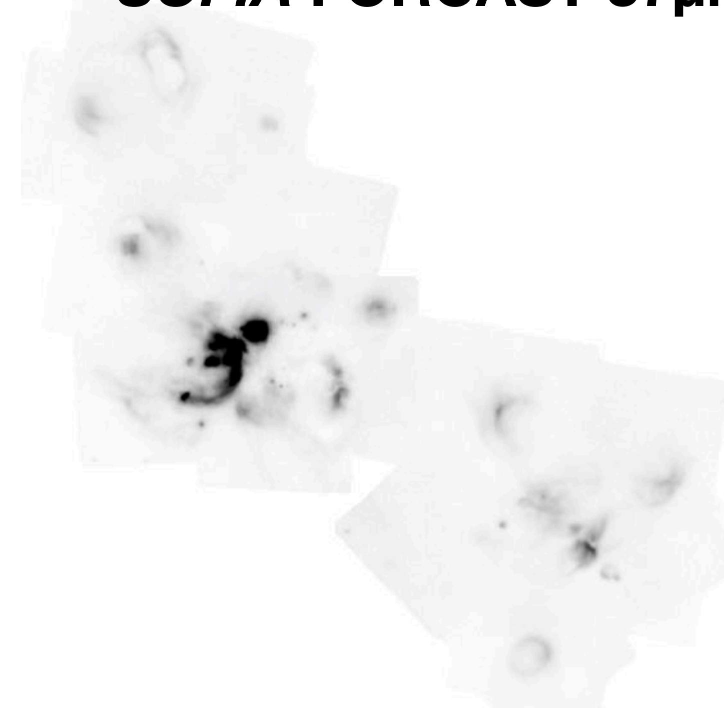
IRAS ~ 1x4 arcmin
MSX ~ 18 arcsec
MIPS ~ 6 arcsec
FORCAST ~ 3 arcsec

SOFIA FORCAST 20μm



Mid 2010s

SOFIA FORCAST 37μm



Mid 2010s

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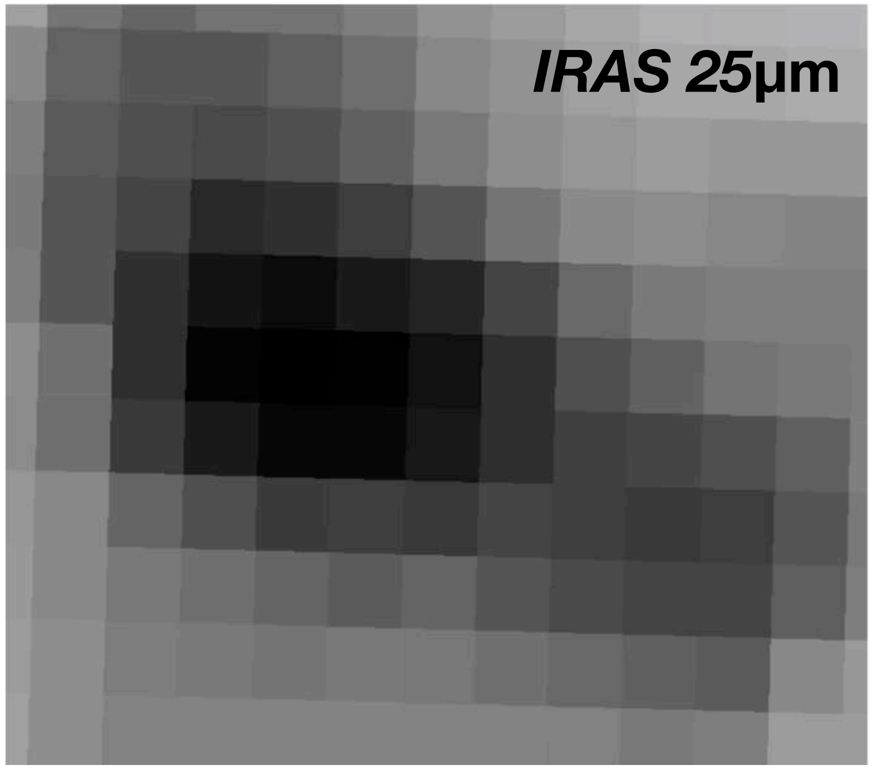

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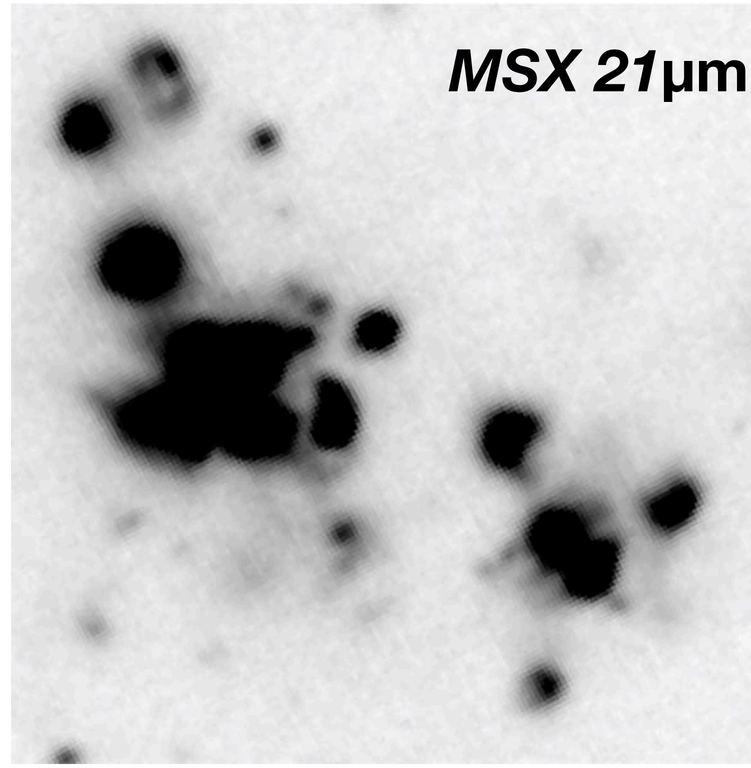

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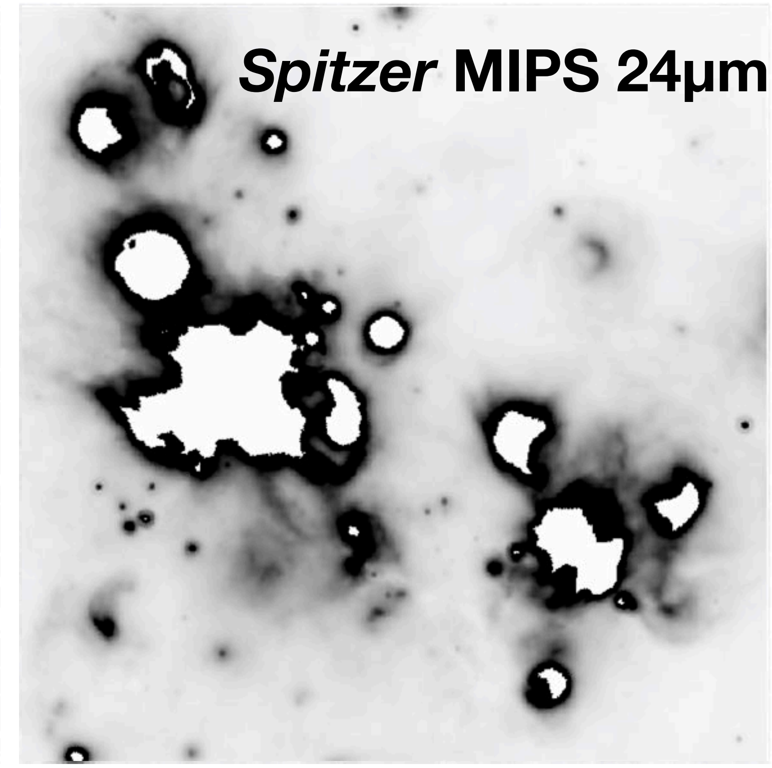
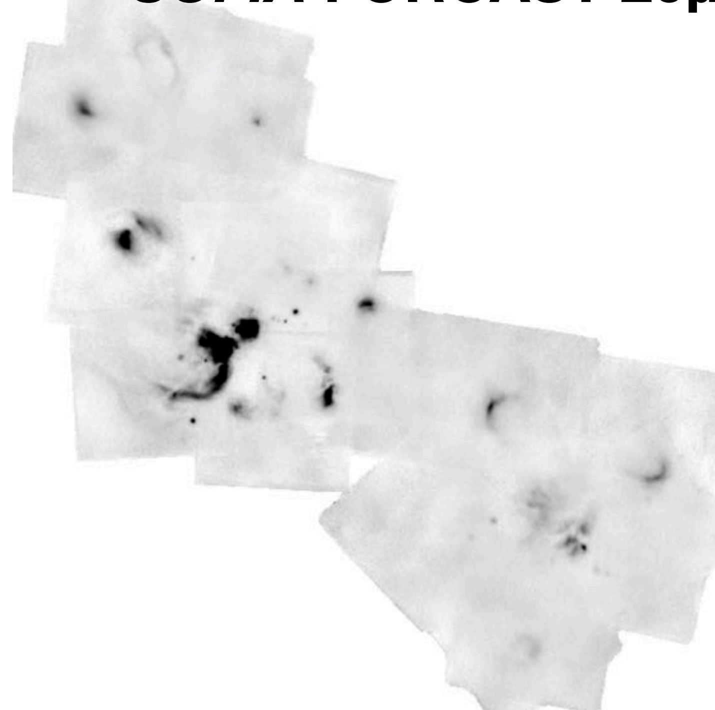


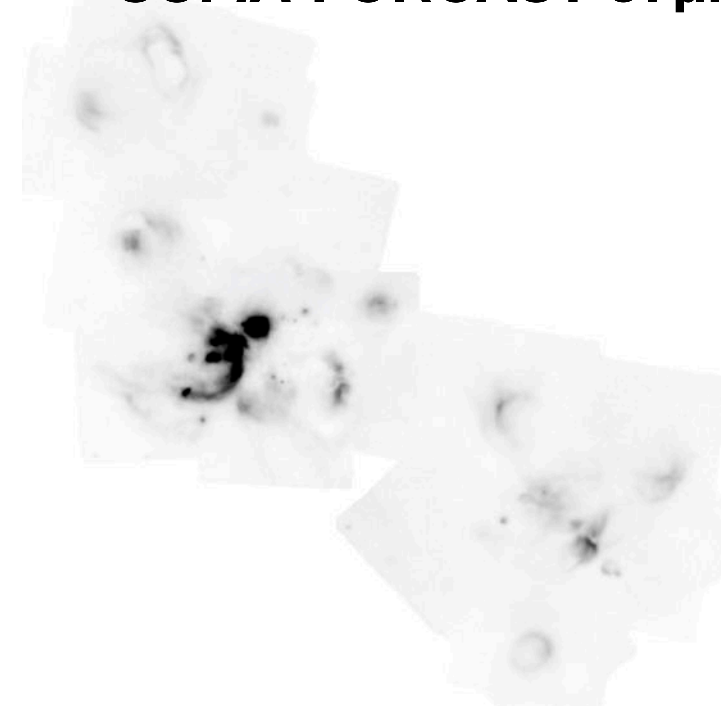
SOFIA FORCAST 20 & 37μm provide us the unique λ observation with the best angular resolution ever achieved in the λ regimes! (and not saturated)

SOFIA FORCAST 20μm



Mid 2010s

SOFIA FORCAST 37μm



Mid 2010s

W51A

(Lim & De Buizer 2019)

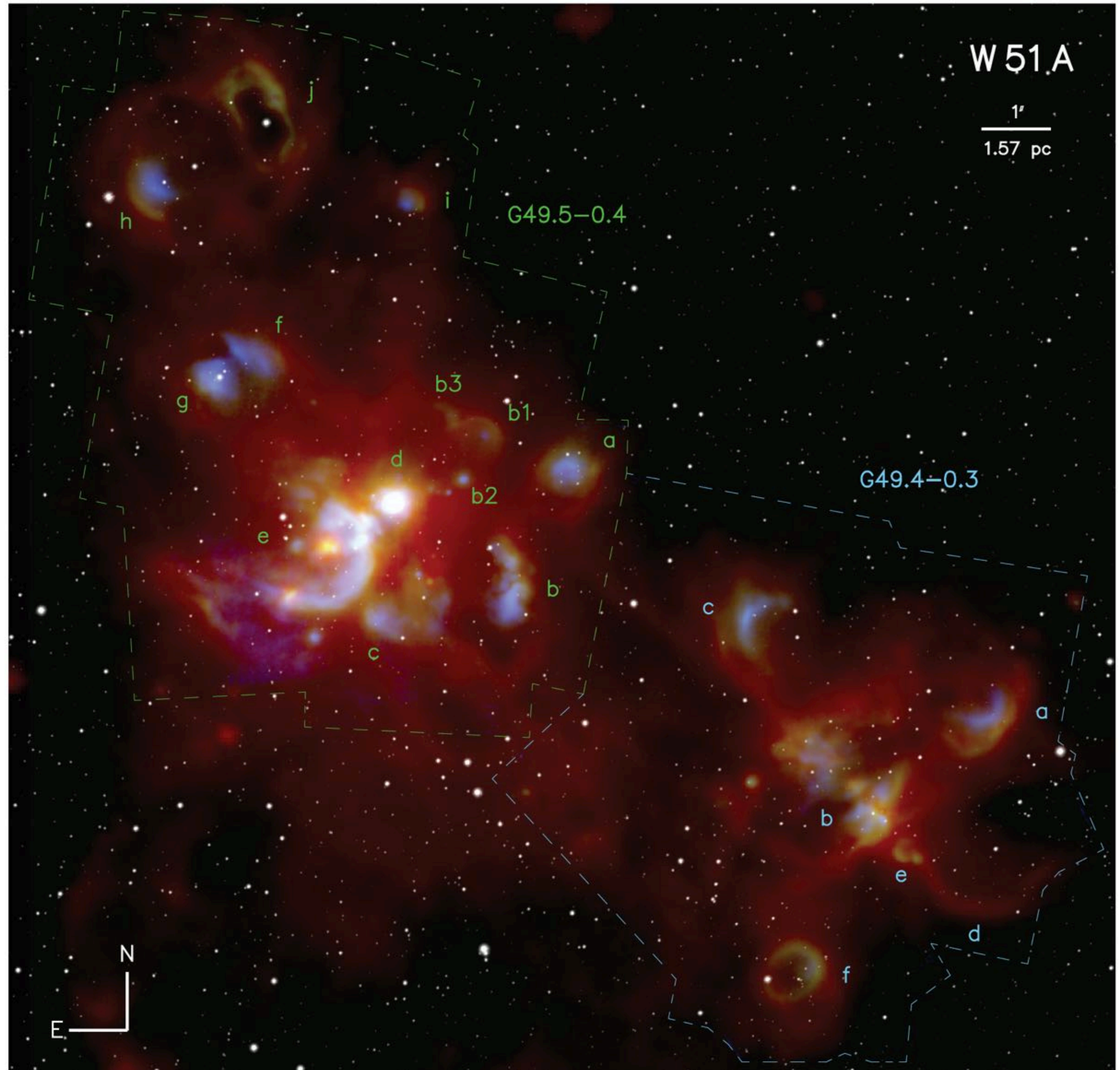
Blue - FORCAST 20μm

Green - FORCAST 37μm

Red - PACS 70μm

White - SDSS z-band

This paper (and this figure) was recently press-released on AASNova and NASA.



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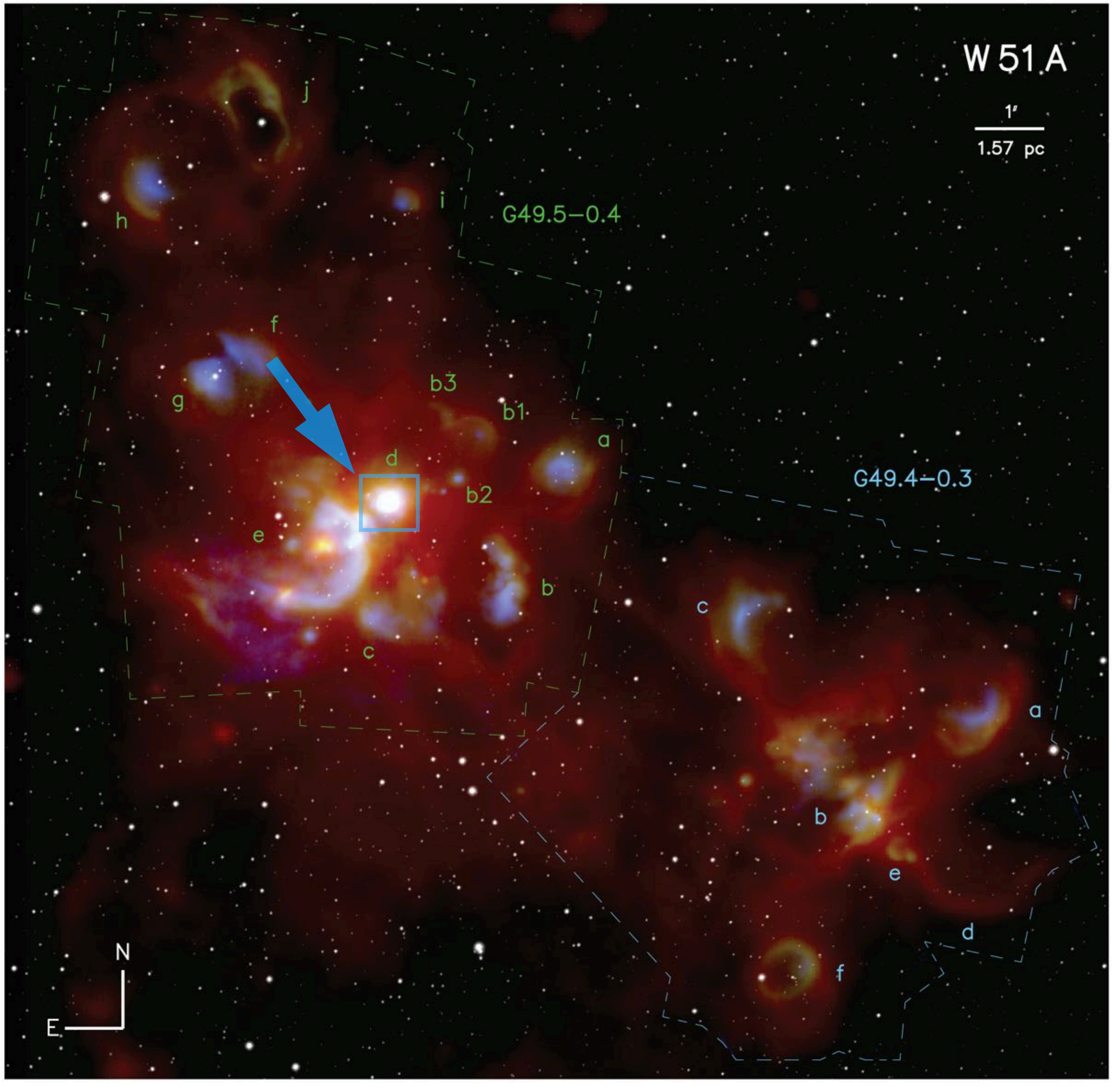
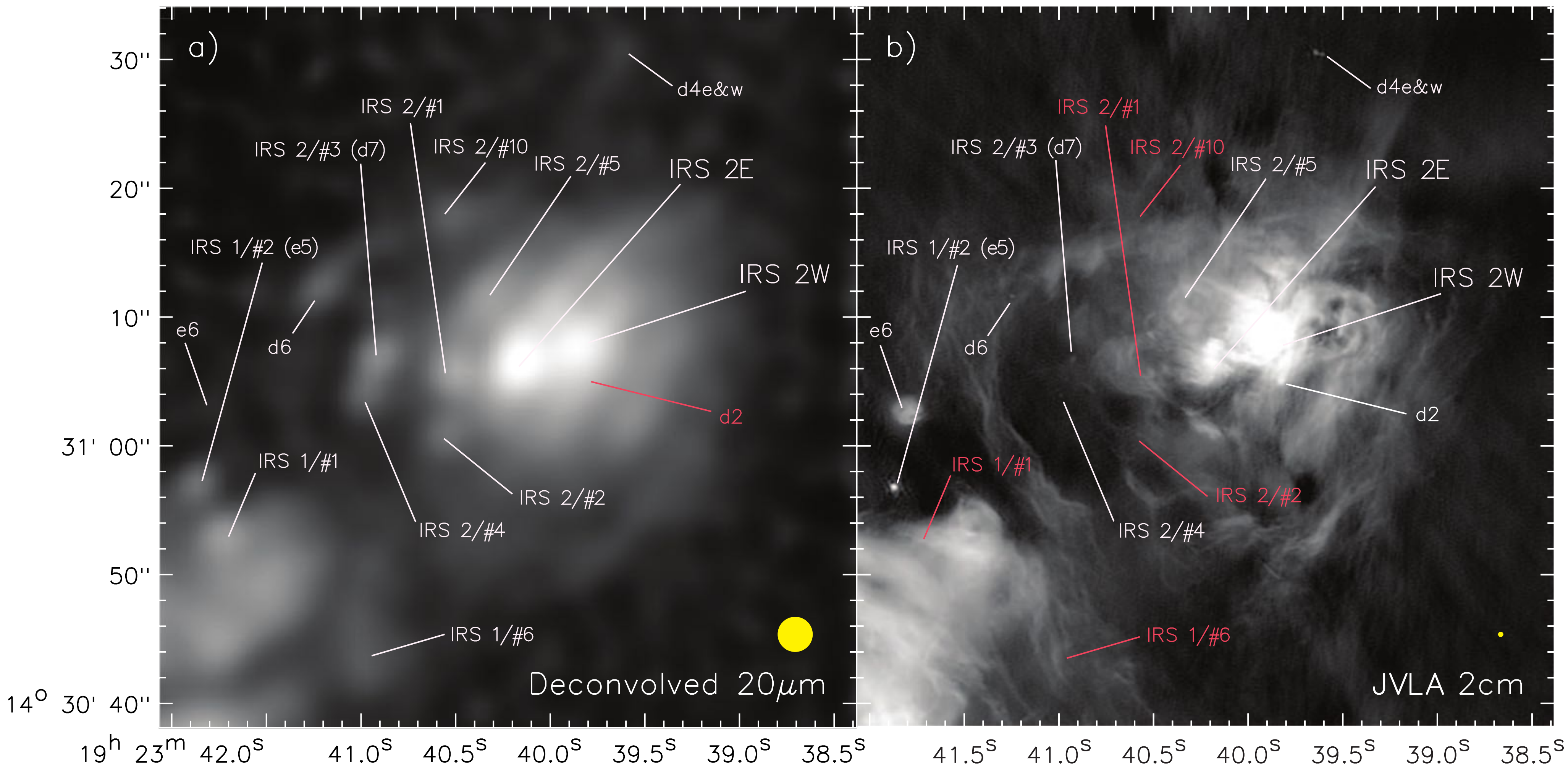


Result 1. We have found an embedded population of MYSOs



The original JVLA data is from Ginsburg ea 2016

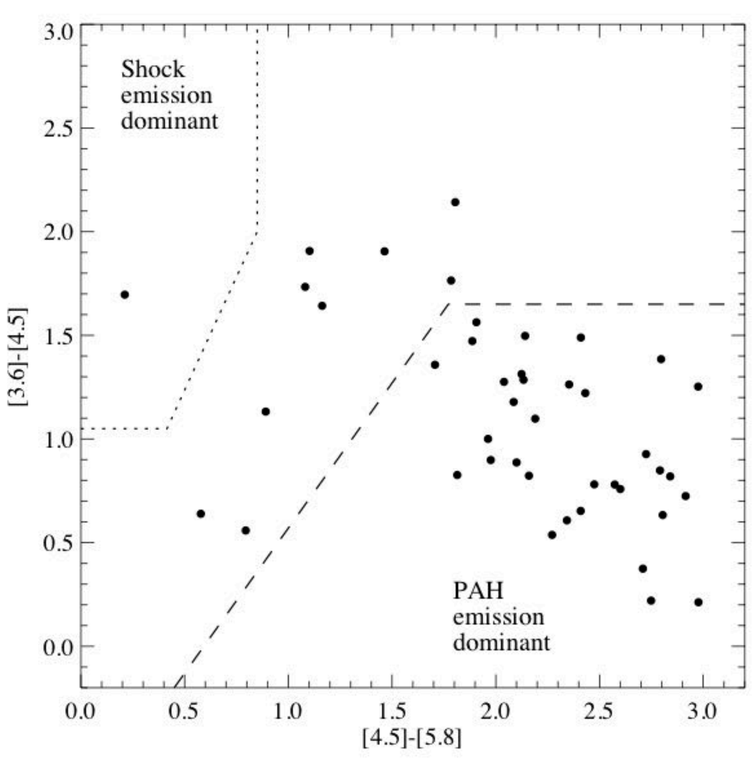
(Lim & De Buizer 2019)

We found 47 MIR point-like sources.

Comparing to JVLA cm data, 20 of them do not have radio counterparts indicating at their very early stages of MSF, even before the HCHII regions.

Result 1. We have found an embedded population of MYSOs

- 33 / 47 sources are PAH contaminated.
- Only one source is dominated by shock.

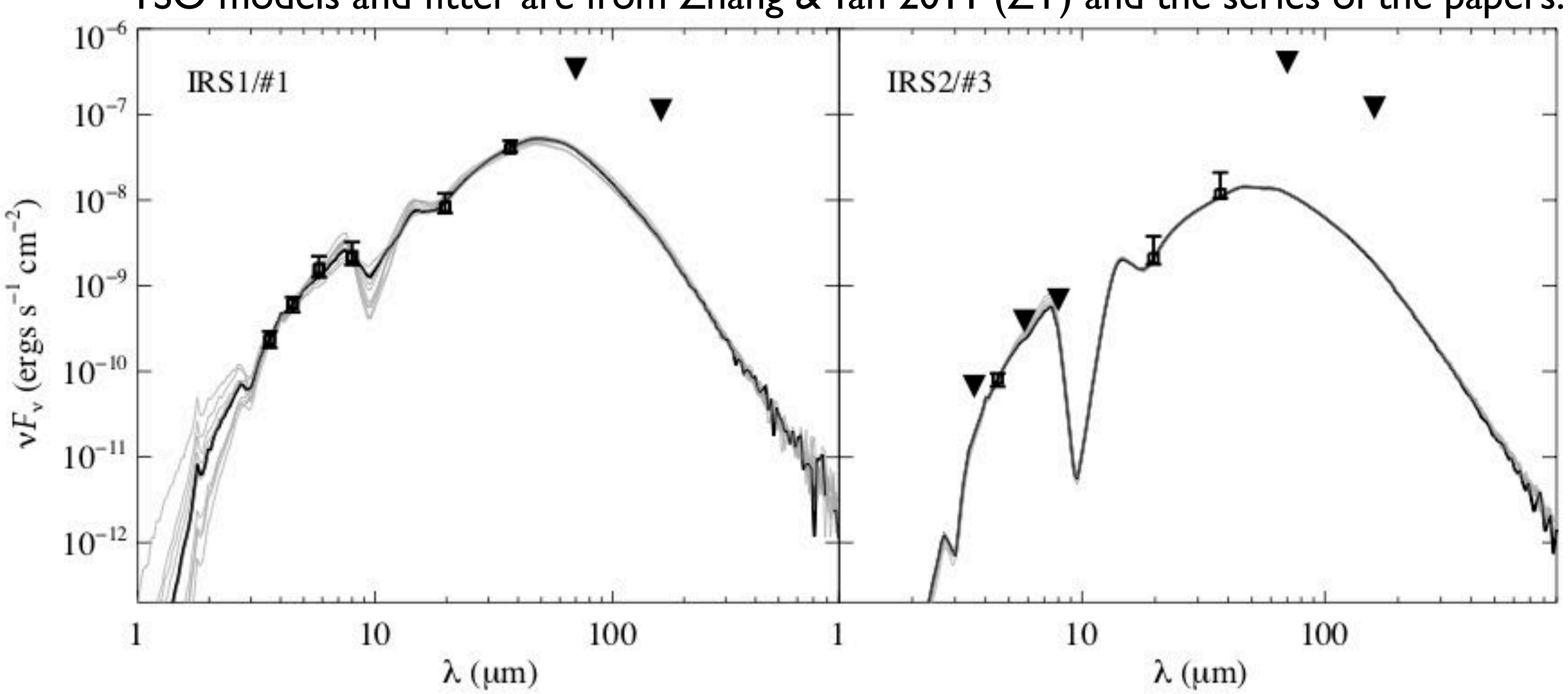


- 41 / 47 SOFIA sub-components and point sources are under MYSO criteria.

- 20 / 41 MYSO do not have Radio counterparts (maybe in youngest stage).

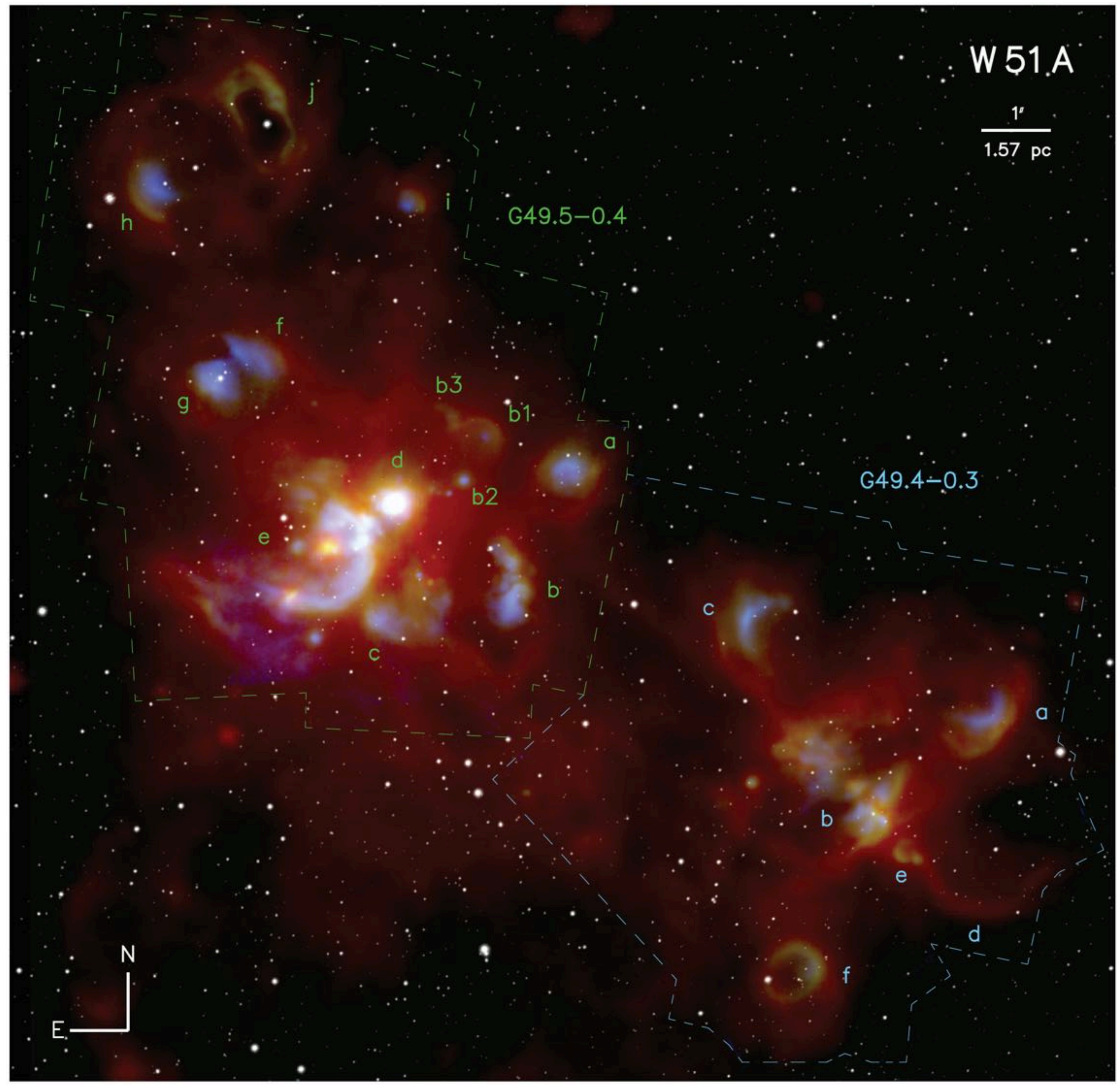
- 20 & 37 μm data points are necessary to achieve the envelop SEDs.

YSO models and fitter are from Zhang & Tan 2011 (ZT) and the series of the papers.



Result 2. - We confirmed the star formation history of W51A analytically

We assume the individual extended sources as molecular clumps, i.e. proto-clusters, and try to understand their evolutionary stages with two different analytic tracers of clump evolution (L/M and virial parameter).



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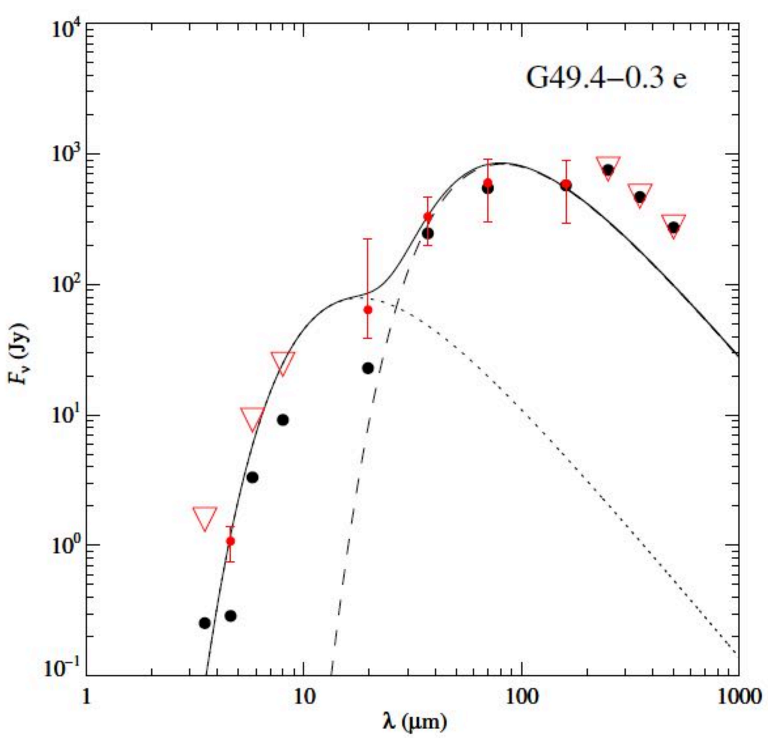
Two independent Proto-cluster (clump) evolutionary tracers

L/M

The L/M is probably a good tracer of clumps evolution. (Krumholz & Tan 2007; Molinari et al. 2019)

Both L and M are derived from the two temperature graybody fit to clump SED.



20 & 37μm are at the edges of the different T components.

Virial analysis

$$\alpha_{\rm vir} = \frac{2\mathcal{T}}{|\mathcal{W}|} \approx \frac{5\sigma^2 R}{GM}$$

$$\sigma = \Delta v \;/\; (8 \ln 2)^{1/2}$$

(Bertoldi & McKee 1992)

Higher $\alpha_{\rm vir}$ might indicate later clump evolutionary stages (i.e. more internal feedback makes higher kinetic energy).

We utilized HHT 13CO (J=2-1) and GRS 13CO (J=1-0) data to figure the velocity width.

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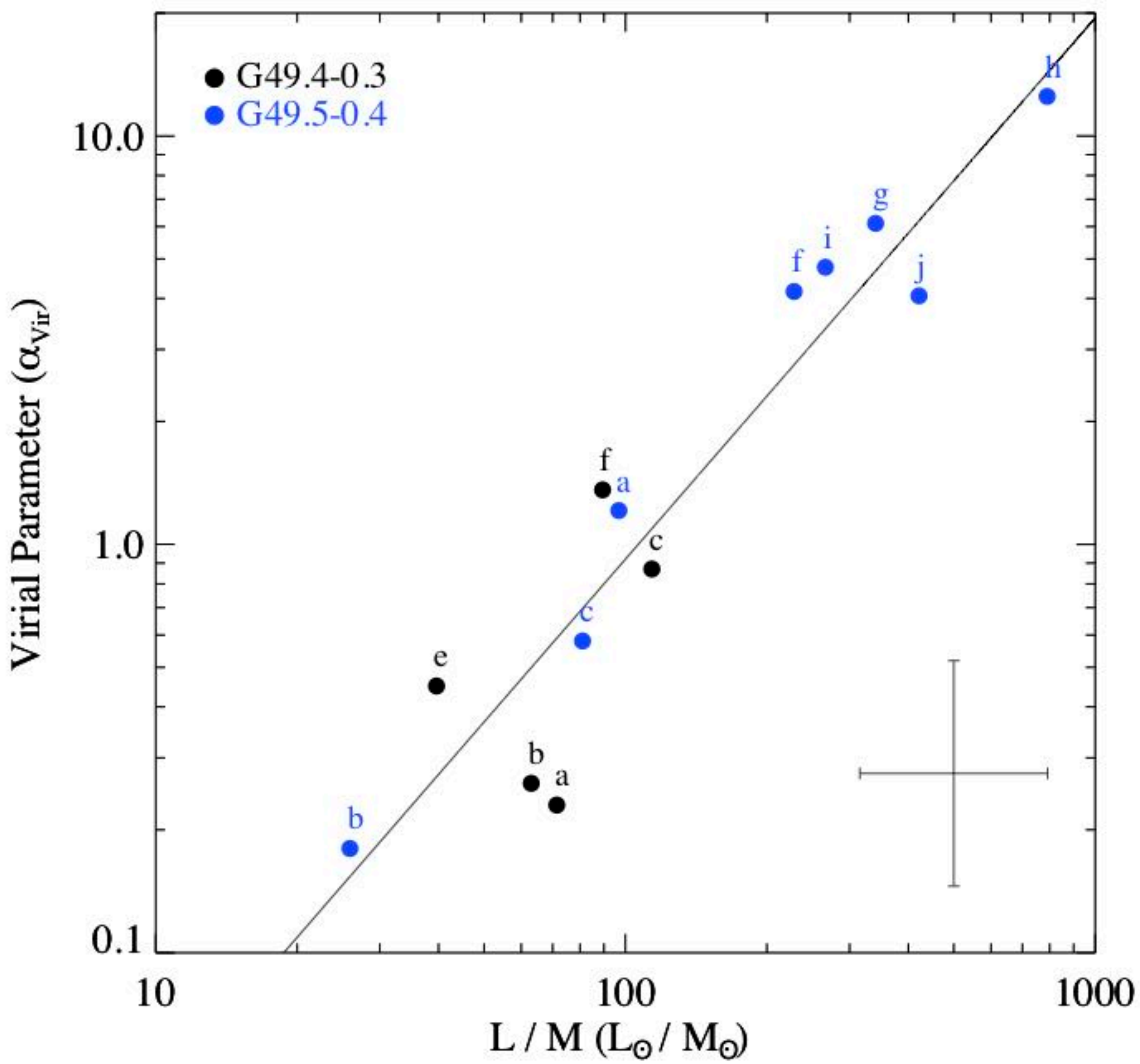

L/M vs. α_{vir}

- Indicating the spread of evolutionary stages.
- Showing tentative evidences of independent formation histories in individual proto-clusters.
- G49.5-0.4 'b' might be the youngest source and possibly formed by recent cloud-cloud collision (Kang ea 2010).

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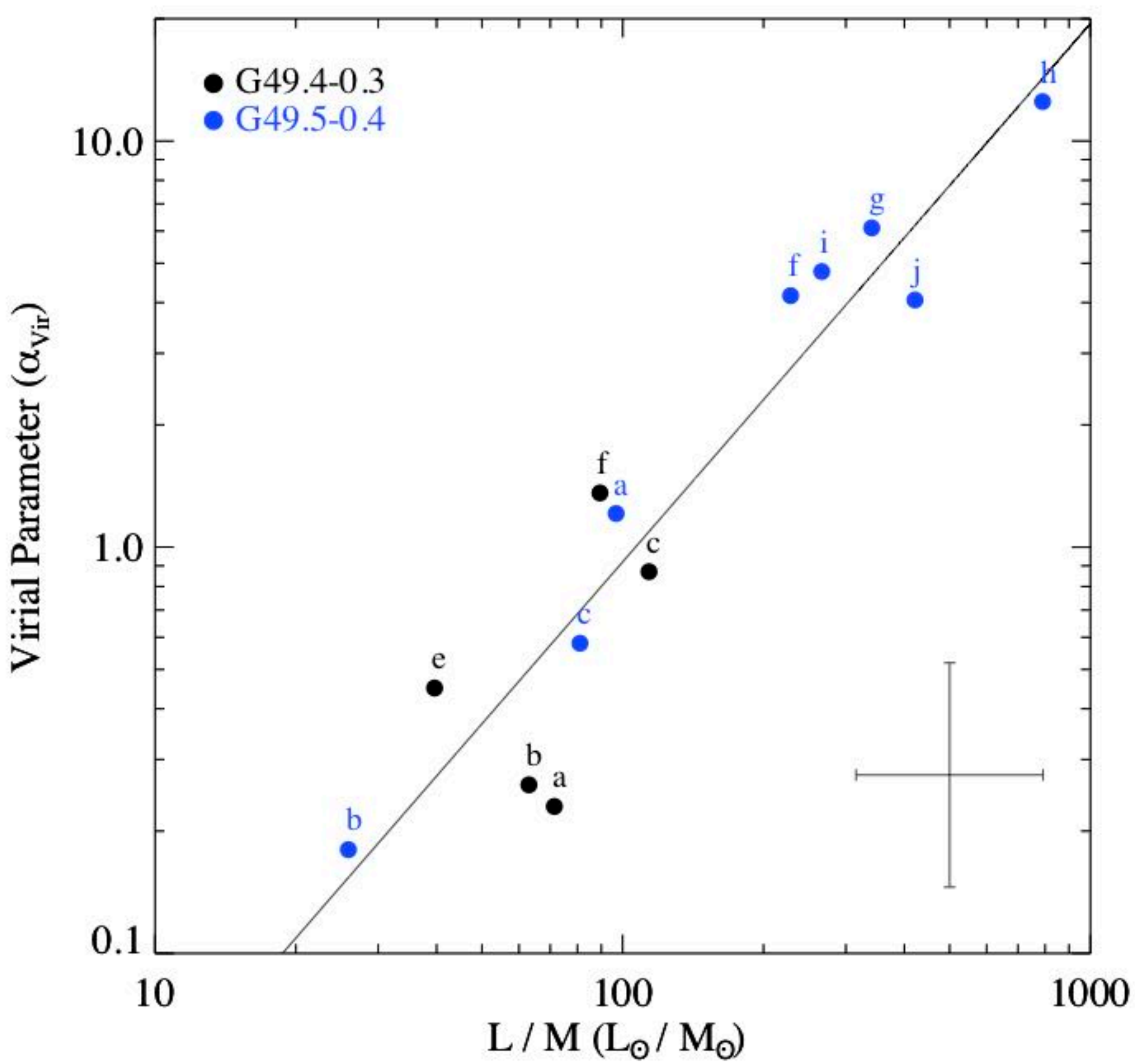

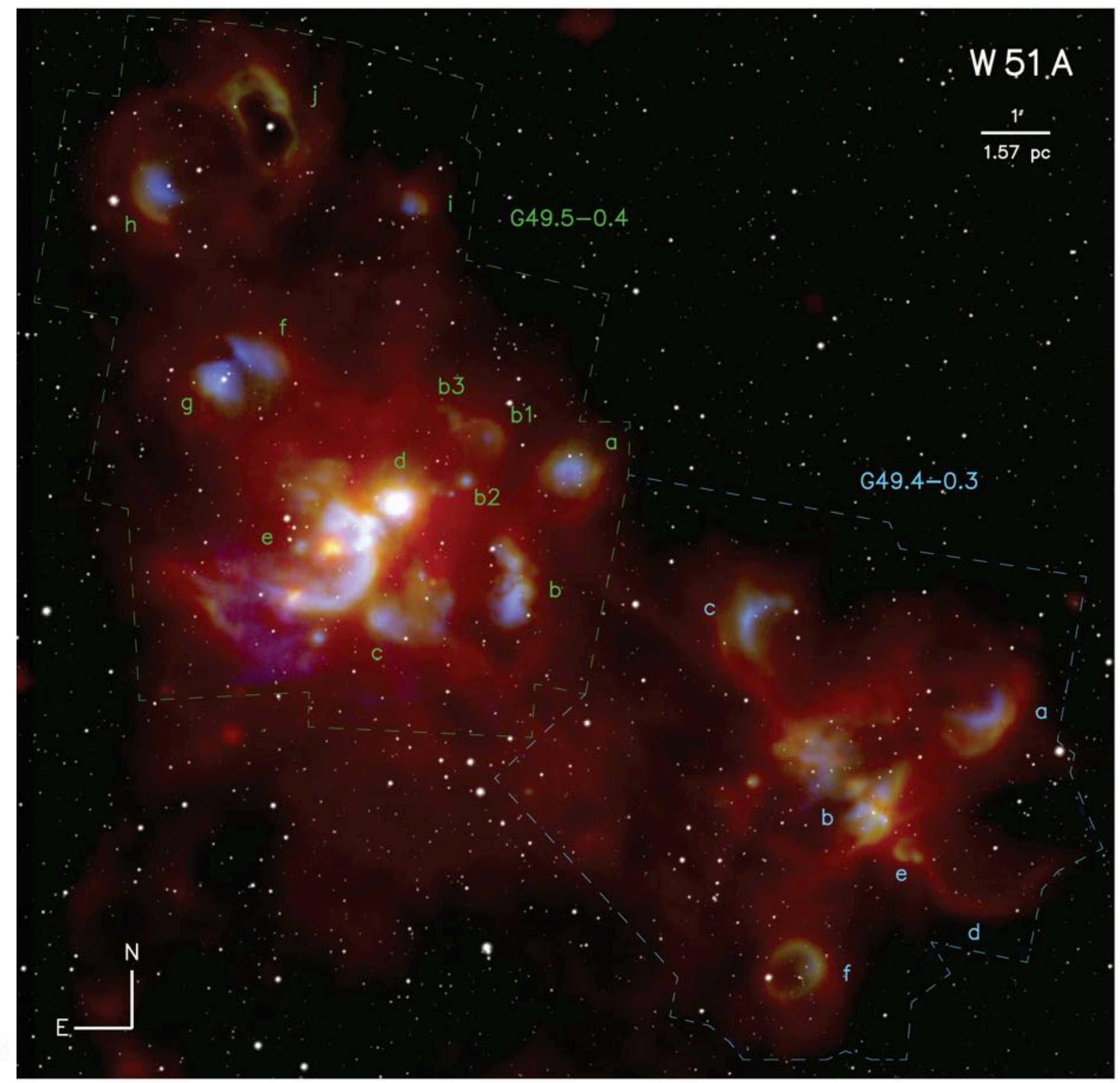

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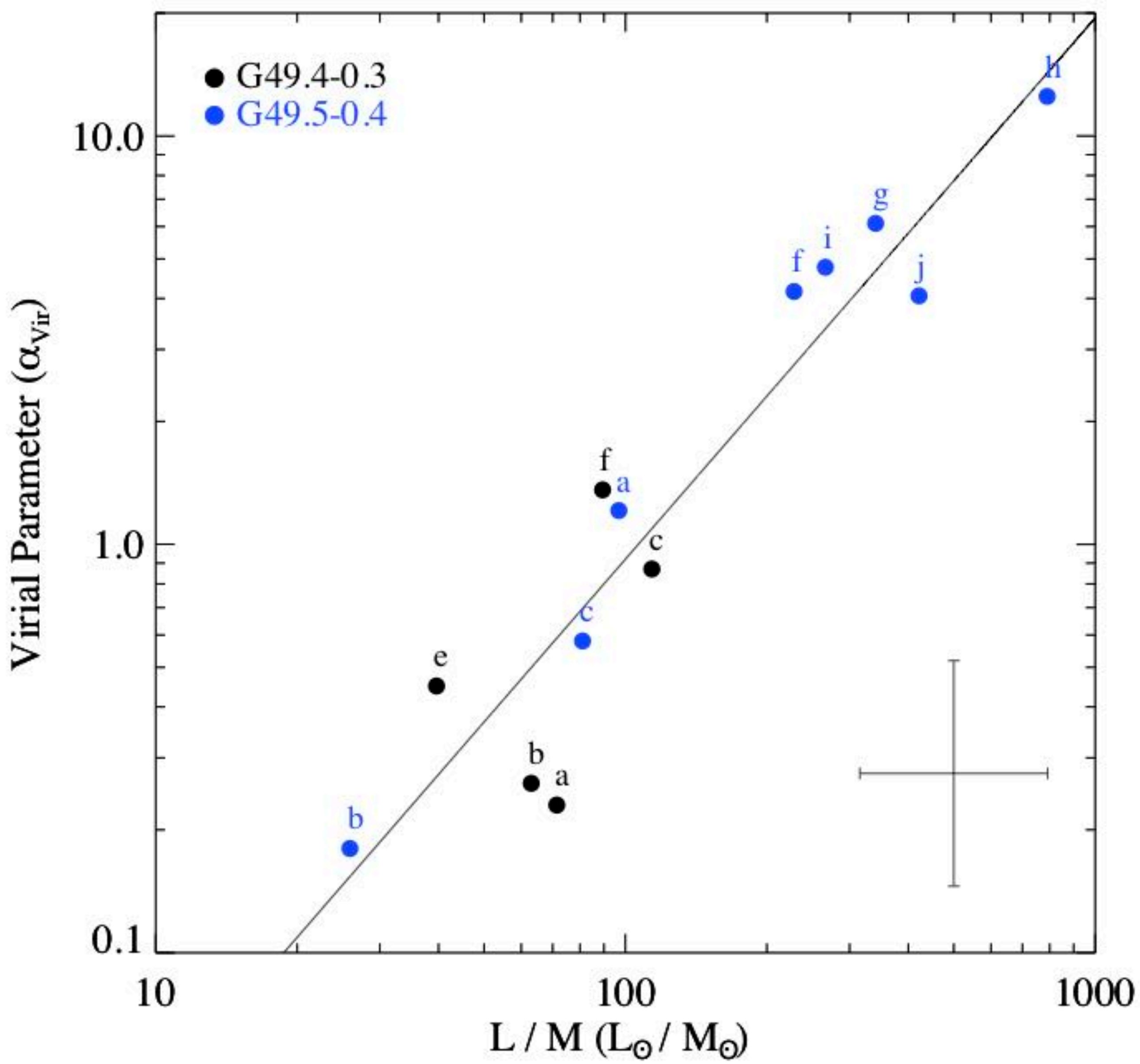

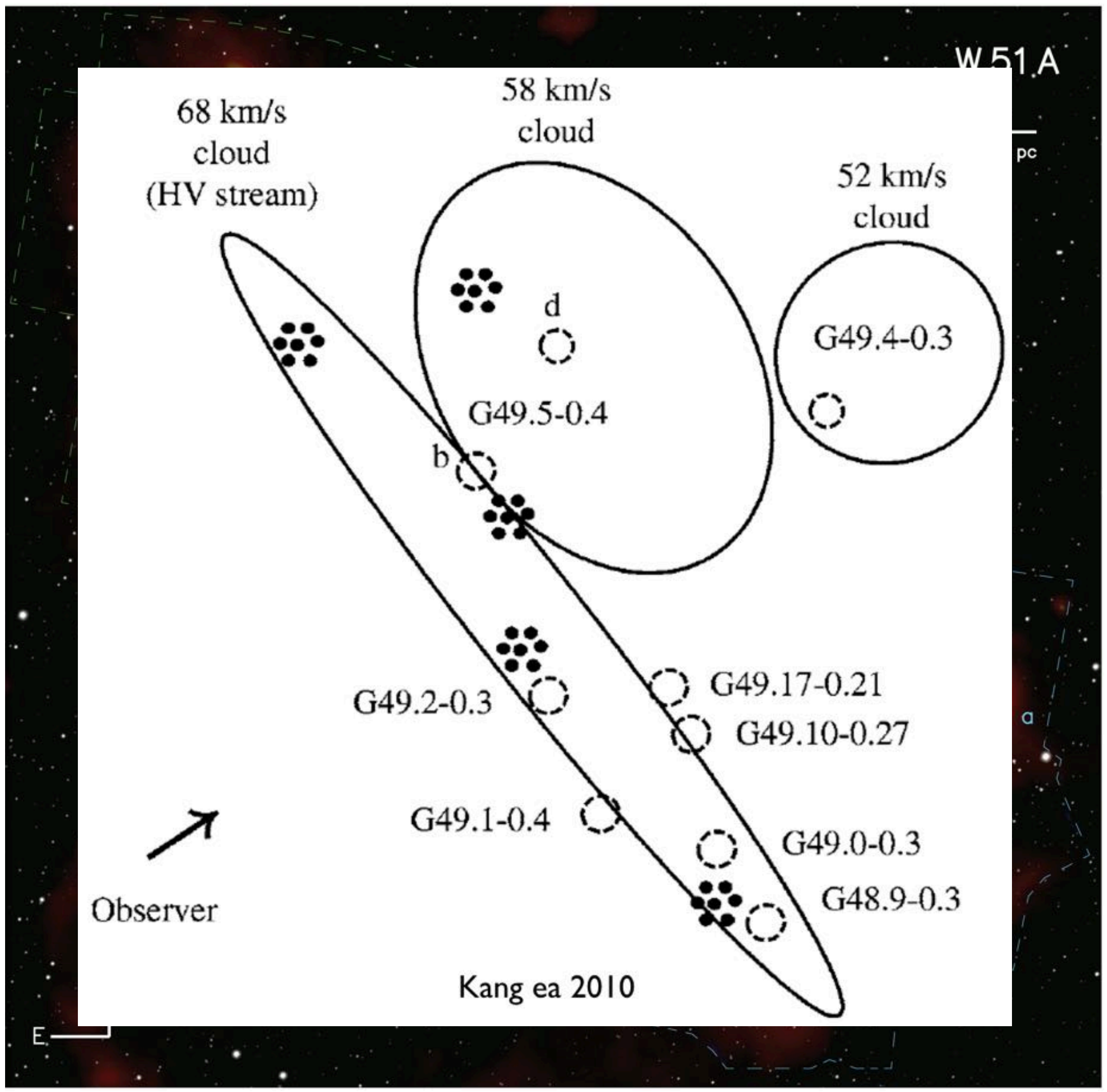

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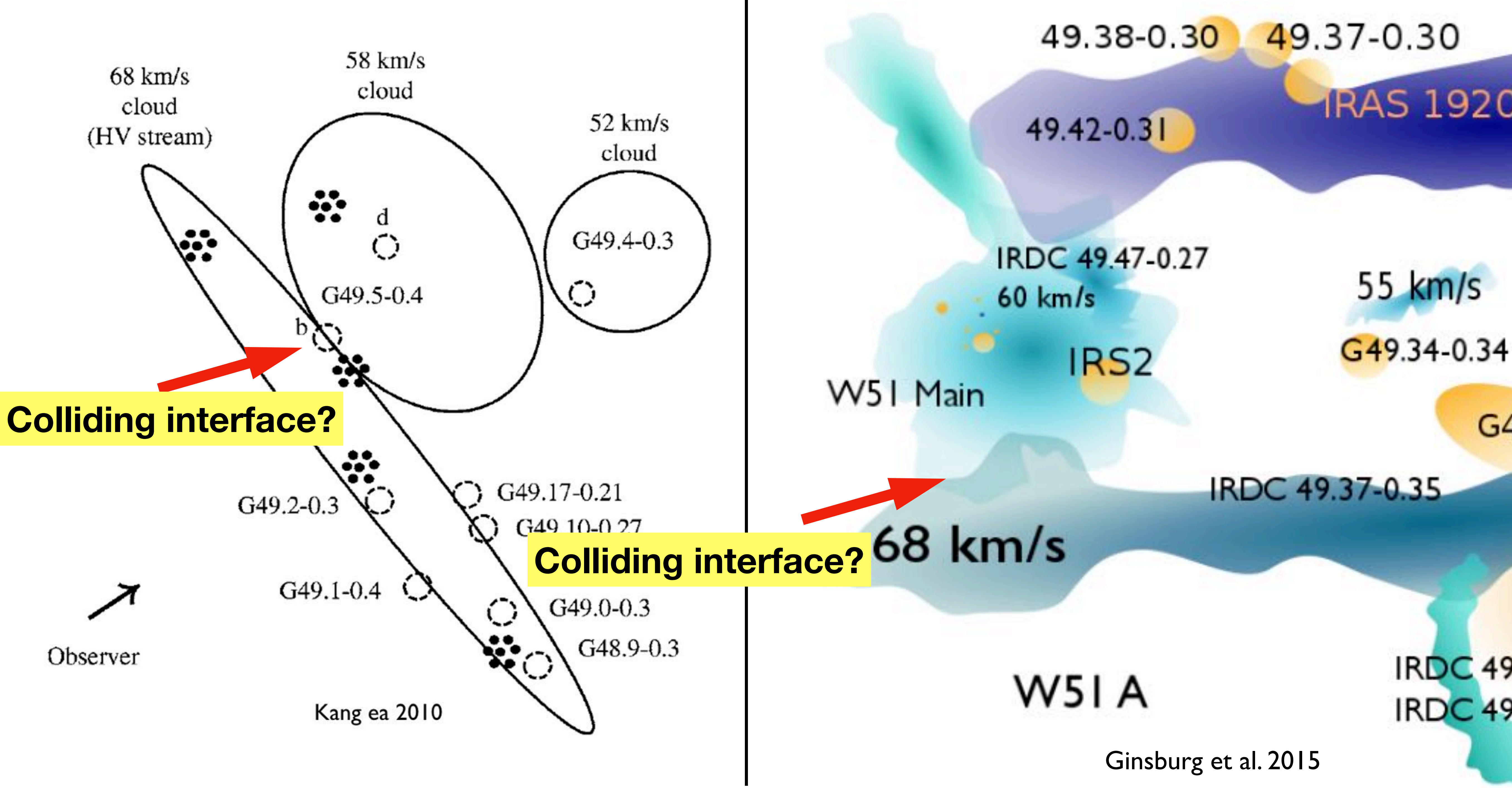


Summary

- FORCAST 20 & 37μm bands are crucial to analyze YSO model fitting as well as dust continuum graybody fitting of two temperature components.
- FORCAST revealed 41 massive YSOs where ~20 of them are first defined in this study.
- We found ~20 massive YSOs are possibly at their earliest ages (no cm counterparts).
- L/M vs. α_{vir} of extended sources shows that W51A possesses proto/young clusters at various evolutionary stages.
- We are repeating these analyses to remaining GHII regions which will give us overall view of MSFRs of Milky Way!
- A lot of future follow-up studies are possible from these studies (e.g. testing CCC scenario of 49.5-0.4 with [CII] vs. CO).
- Next couple of slides show on-going & future projects.

On-Going & Future Projects

M17

(Lim, De Buizer,
Radomski ea in preparation)

Blue - FORCAST 20µm

Green - FORCAST 37µm

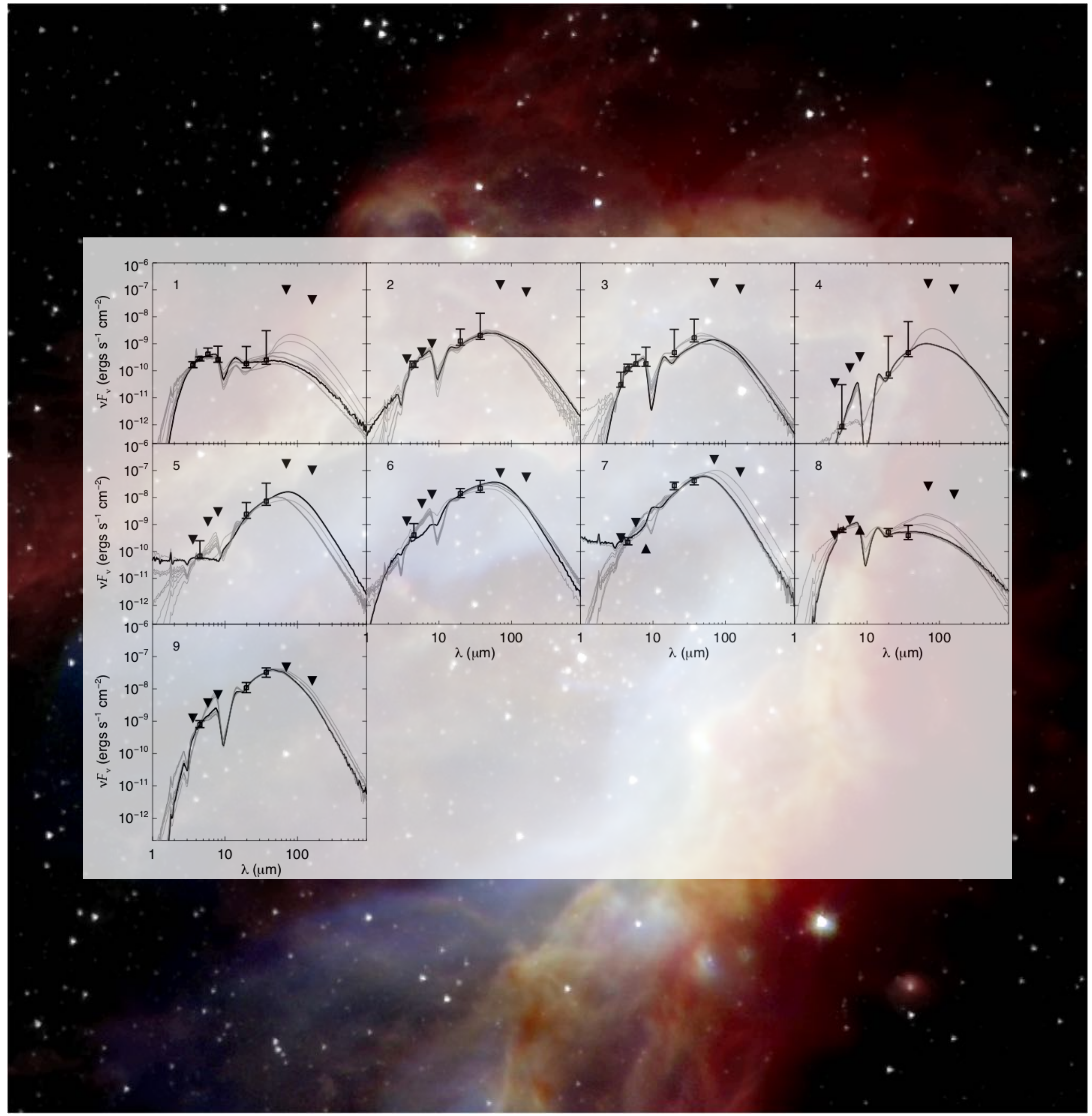
Red - PACS 70µm

White - IRAC 3.6µm

On-Going & Future Projects

Preliminary results of M17

- **Finding half dozen of marginally MYSOs.**
- **Extended sources are not as obvious as W51A but could identify about 10 extended sources by comparing sub-mm continuum images (Herschel and JCMT).**
- **The L/M vs. α_{vir} shows similar trend with W51A but more scattered, probably due to more complex backgrounds.**



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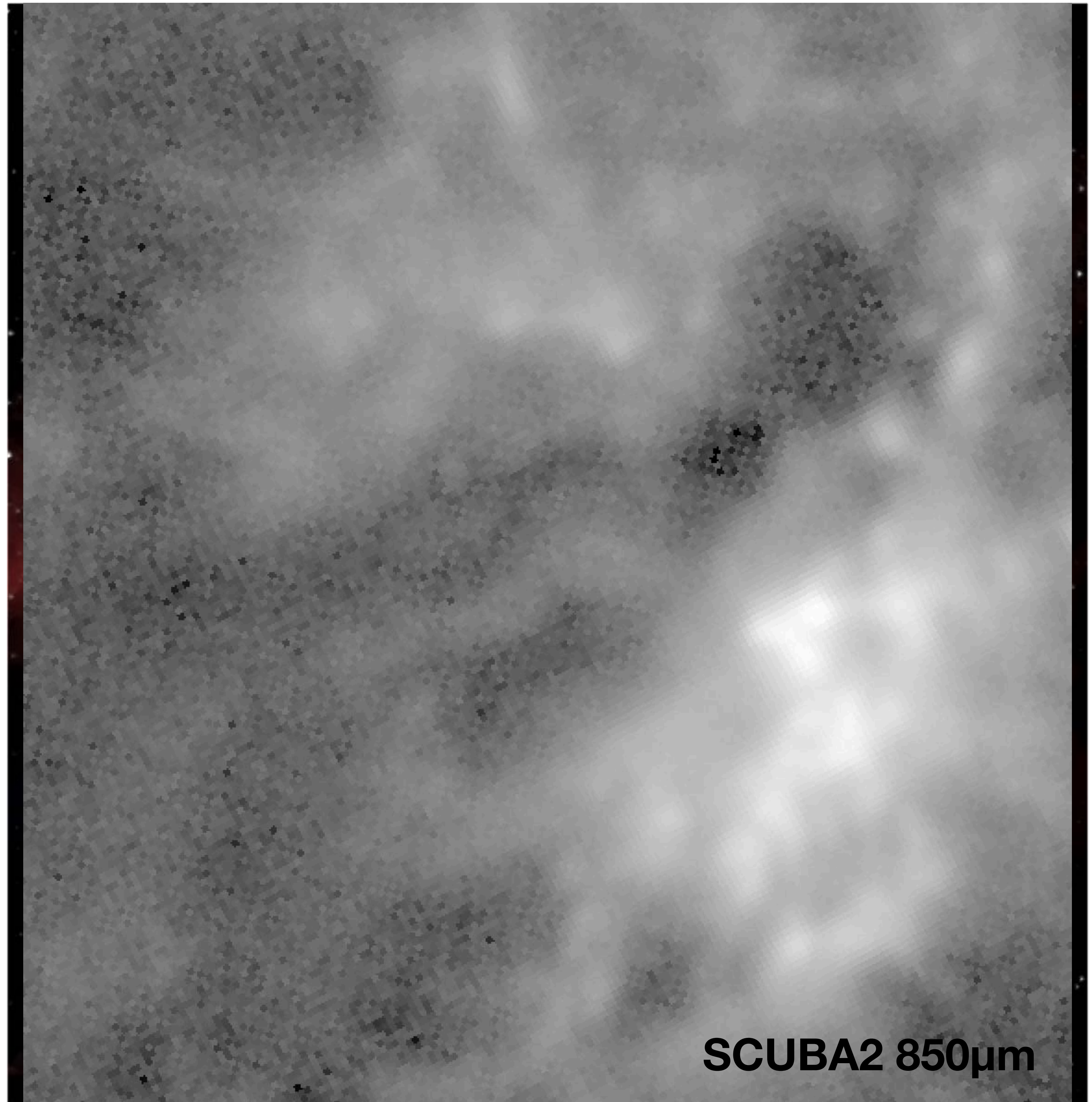

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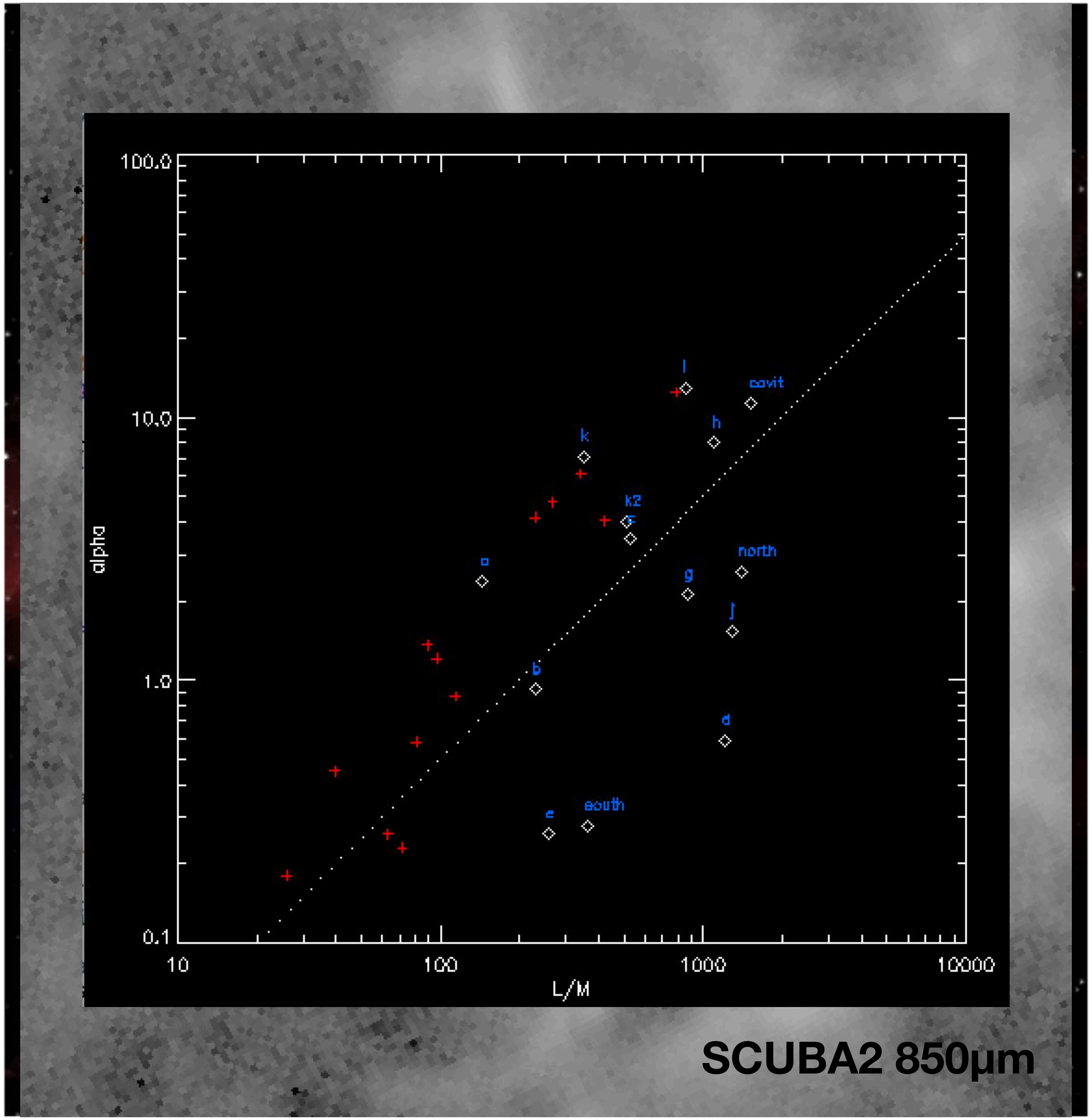
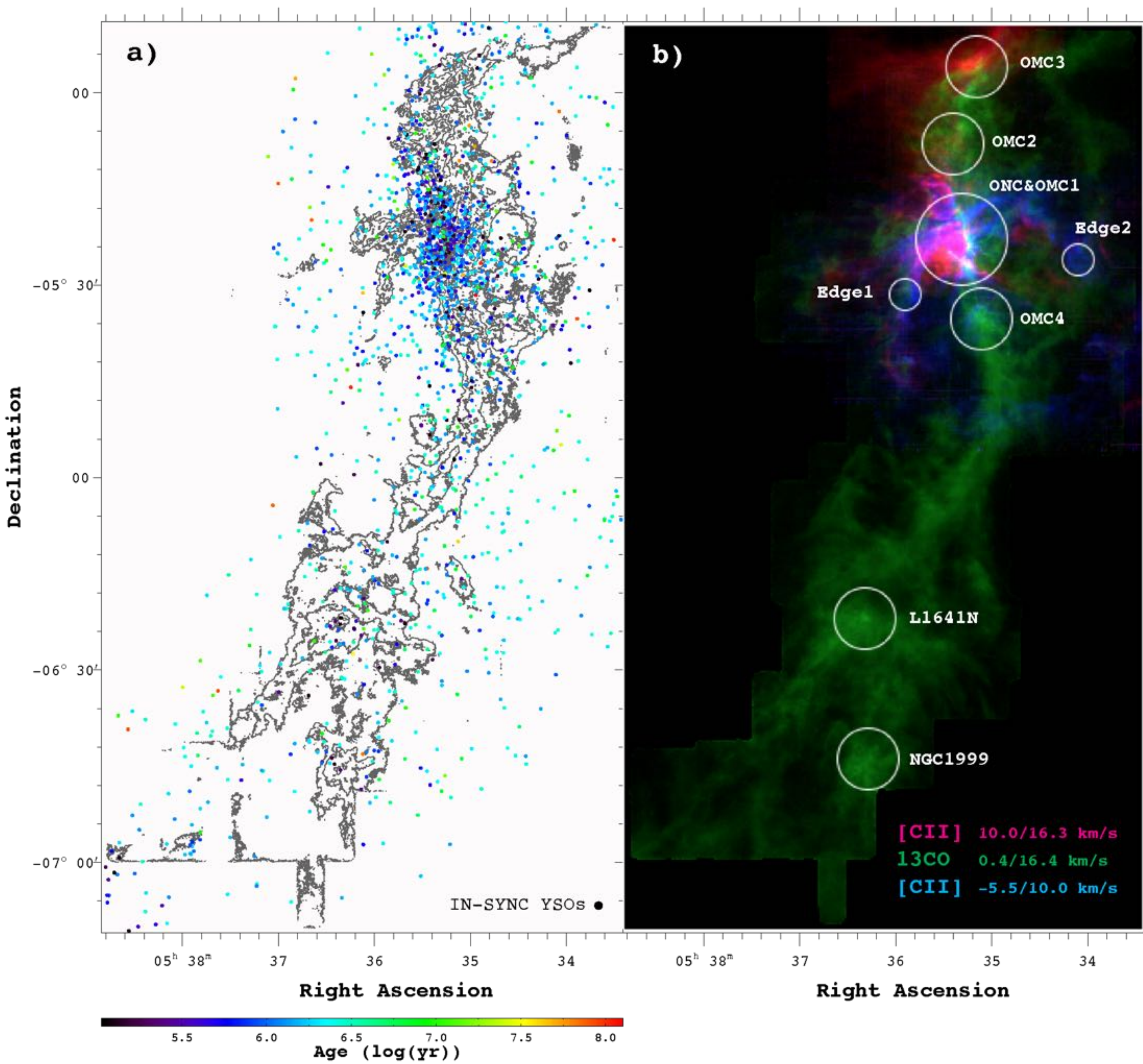
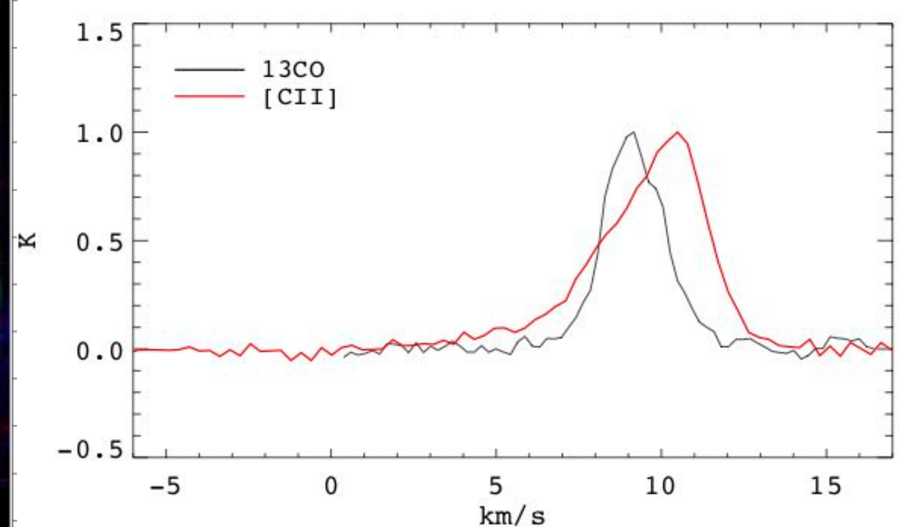


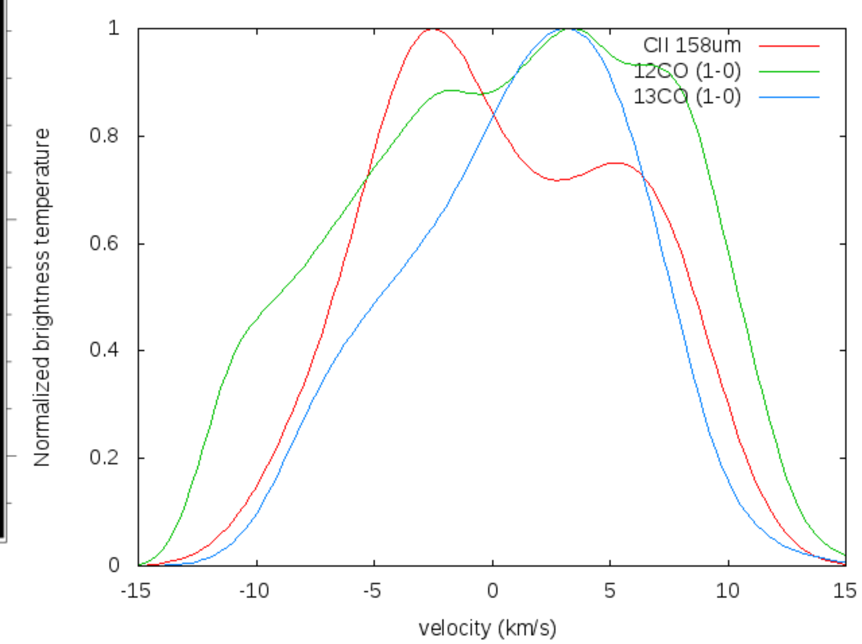
On-Going & Future Projects

Cloud-Cloud Collision

It might be possible to determine whether 49.5-0.4 b underwent CCC or not.
by this method (CO vs. [CII]).







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