SOFIA Tele-talk 07/05/23

SOFIA Stratospheric Observatory for Infrared Astronomy | USRA | NASA | DSI | DLR | Caltech | ipac

Surveying the Giant HII Regions of the Milky Way with SOFIA: V. DR7 and K3-50

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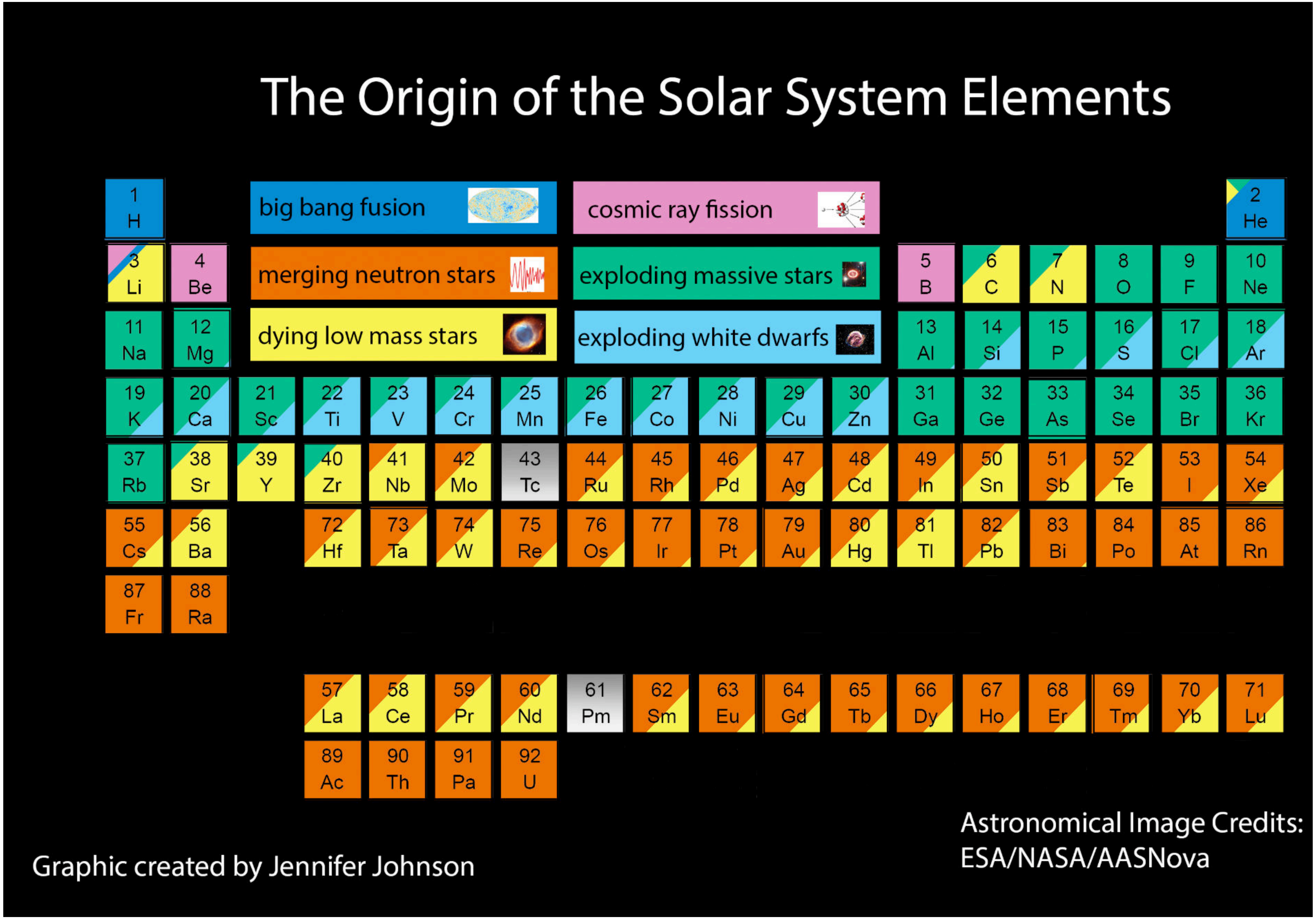
Why massive stars are important?

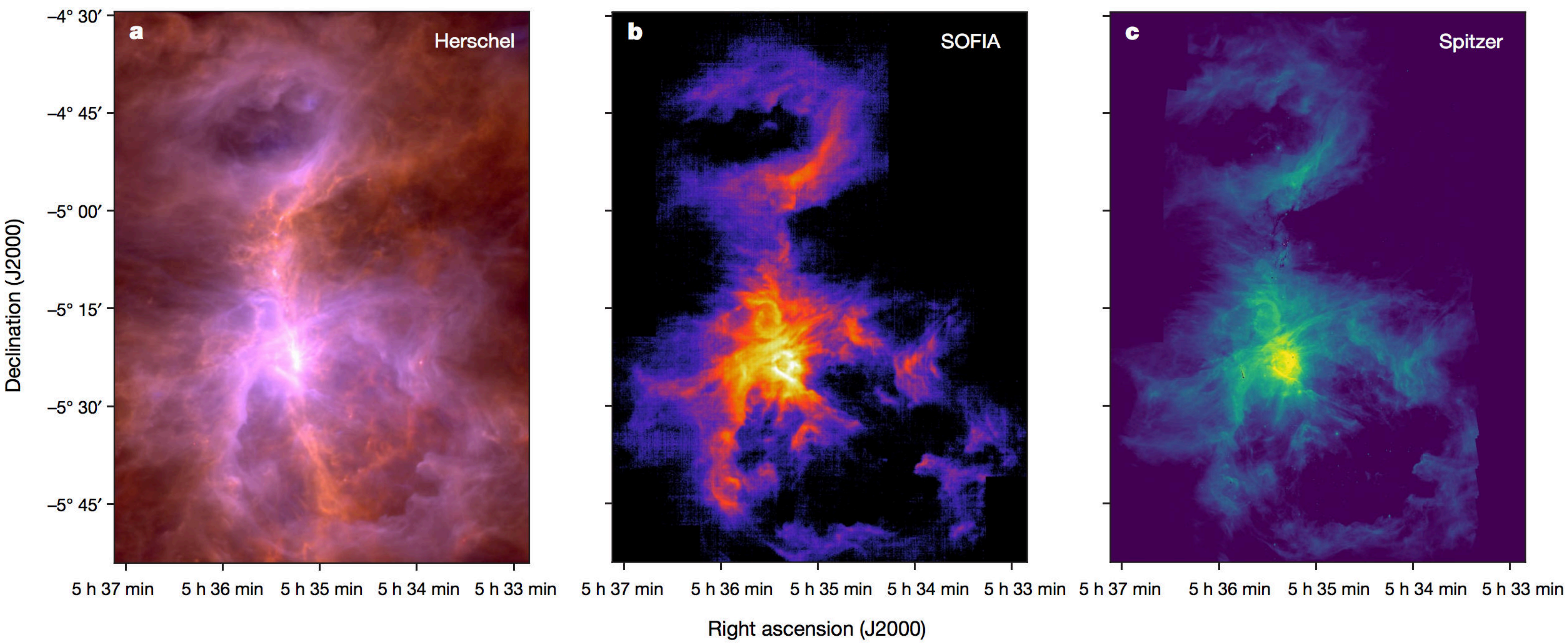
Reason #1 - Chemical Input

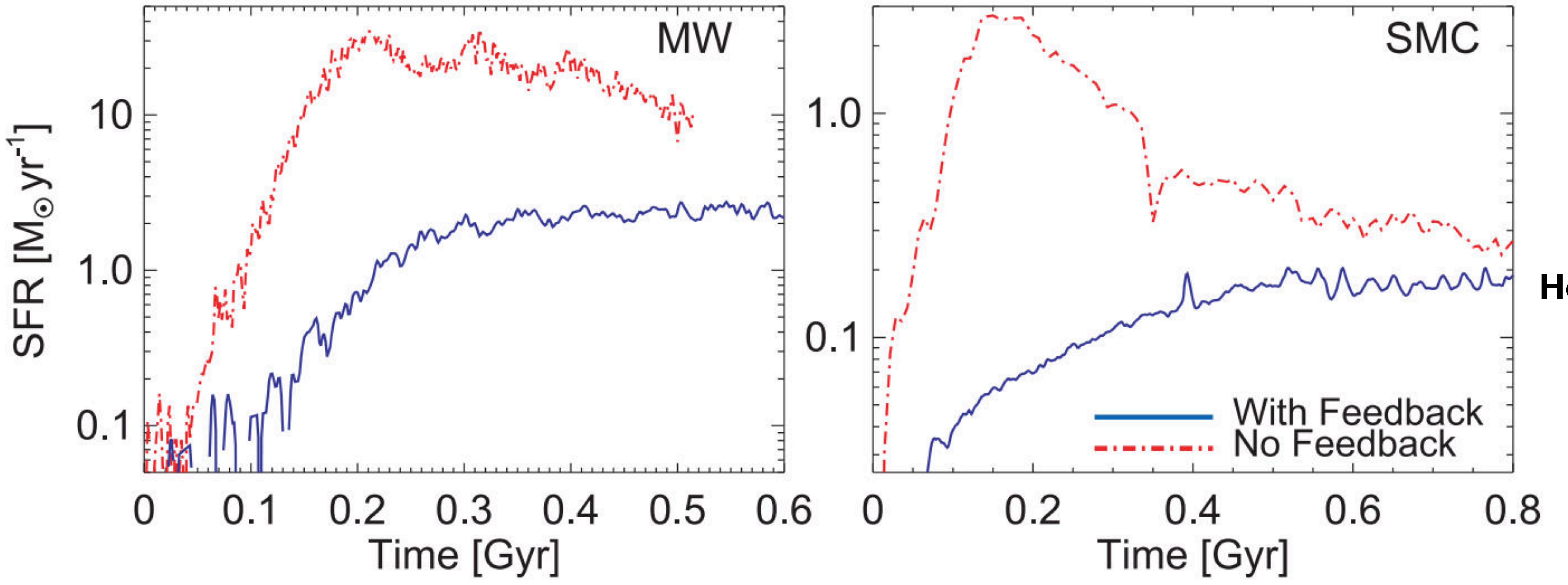


Pabst ea 2019

Why massive stars are important?

Reason #2 - Energetic feedbacks





Hopkins ea 2019

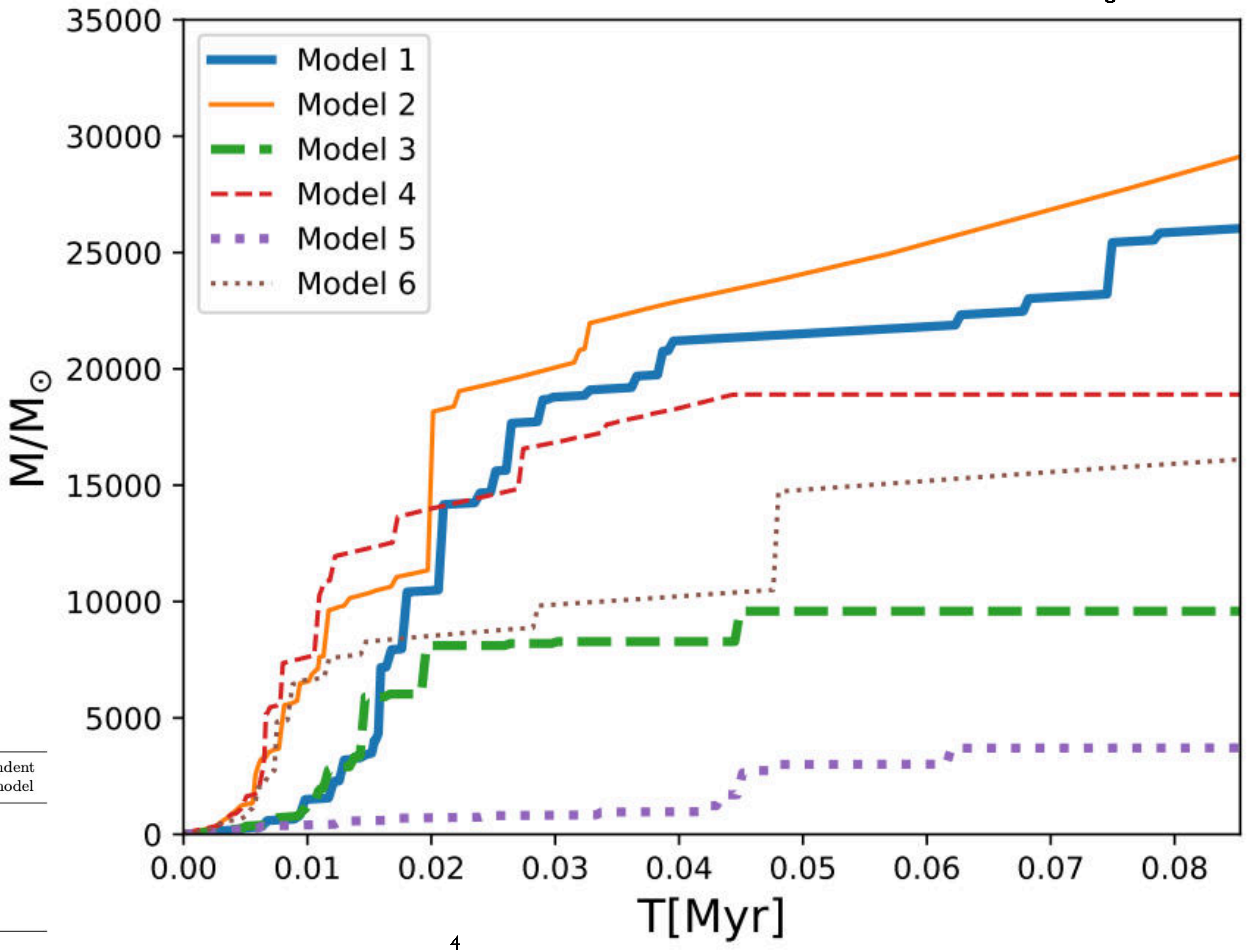
The enormous massive star feedback can be a critical source to form and maintain the shapes of the environmental GMCs!

Alister Seguel ea 2019

Why massive stars are important?

Reason #3 - Seeds of SMBHs

Model	Gas reservoir	Position dependent accretion model	Time dependent accretion model
1	Infinite	No	No
2	Infinite	Yes	No
3	Finite	No	No
4	Finite	Yes	No
5	Finite	No	Yes
6	Finite	Yes	Yes



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

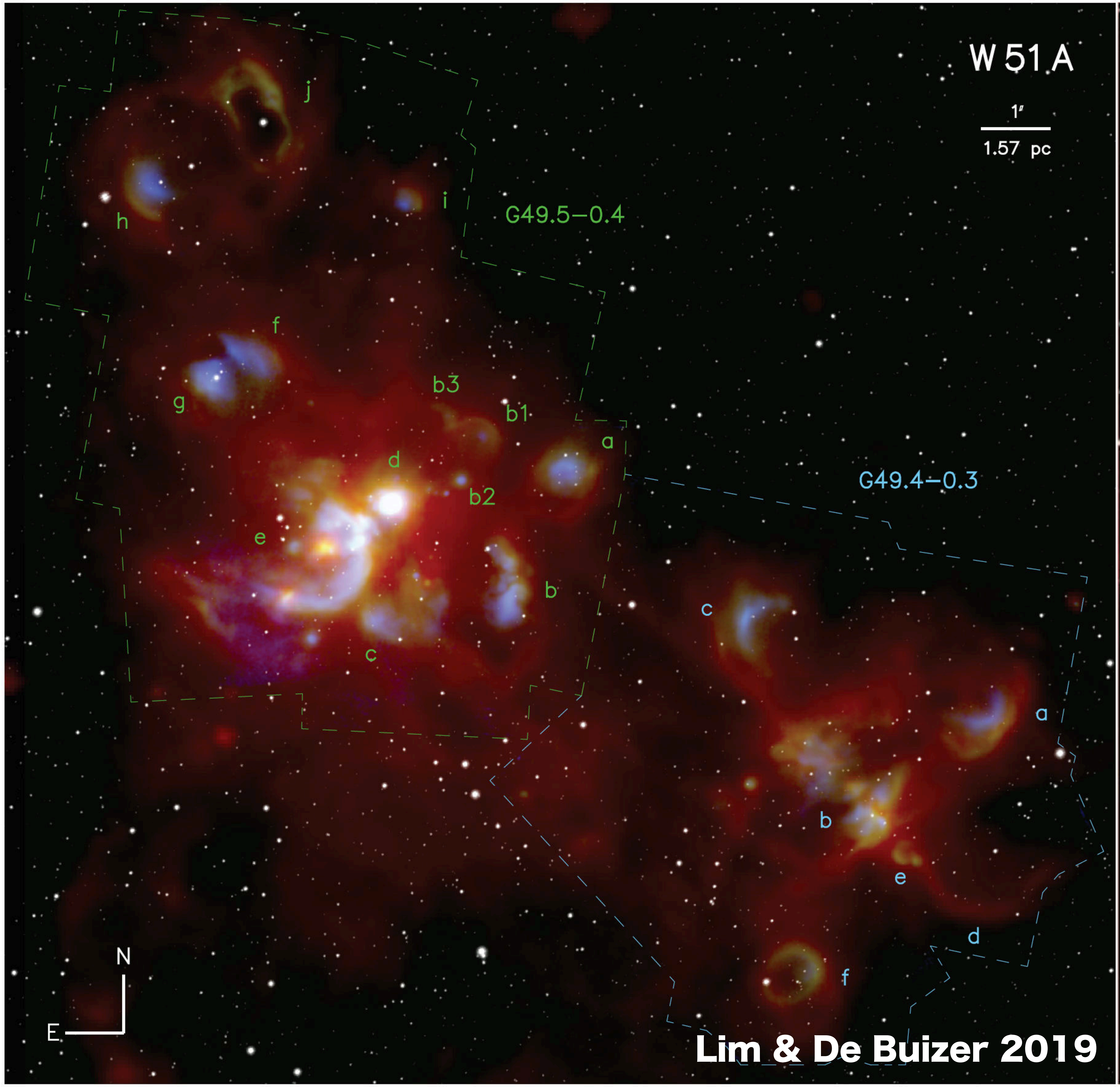
Two simple stages
- Infrared Quiescent
- Infrared Bright

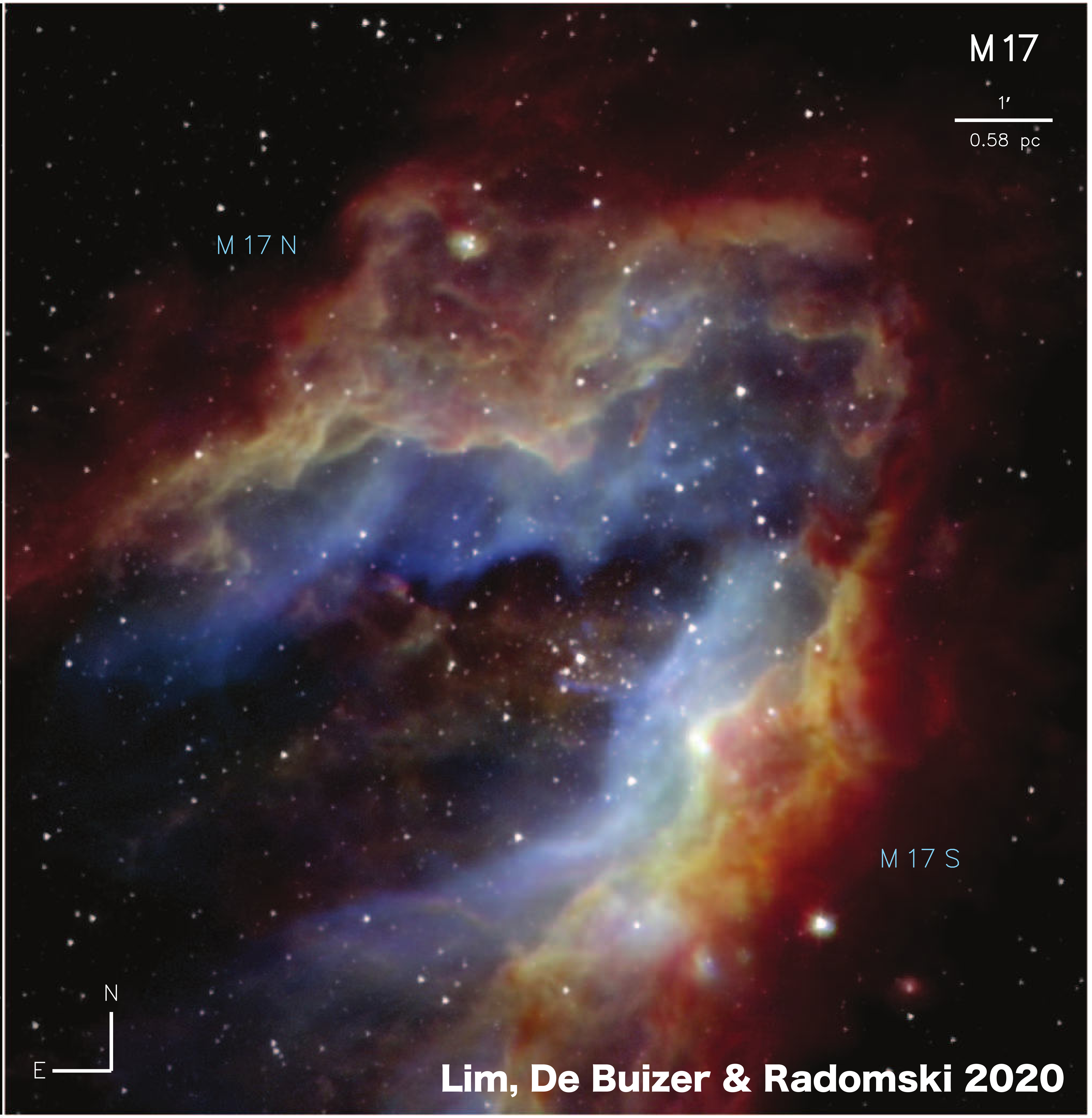
Giant HII (GHII) regions are…

- well known active massive star forming regions.
- bright across almost all wavelengths.
- only IR bright objects you can recognize easily from external galaxies.

Thus, it is important to study Galactic GHII regions to understand star formation even in external galaxies.

- W51A : one of the most massive Galactic GHII regions (Lim & De Buizer 2019)
- M17 : one of the closest GHII regions in from Sun (Lim, De Buizer & Radomski 2020)
- W49A : the most luminous GHII region of the Milky Way (De Buizer et al 2021)
- DR7 & K3-50 : Galactic GHII regions as the 'edge cases' (De Buizer et al 2022, De Buizer et al 2023)





D~5.4kpc **D~2kpc**

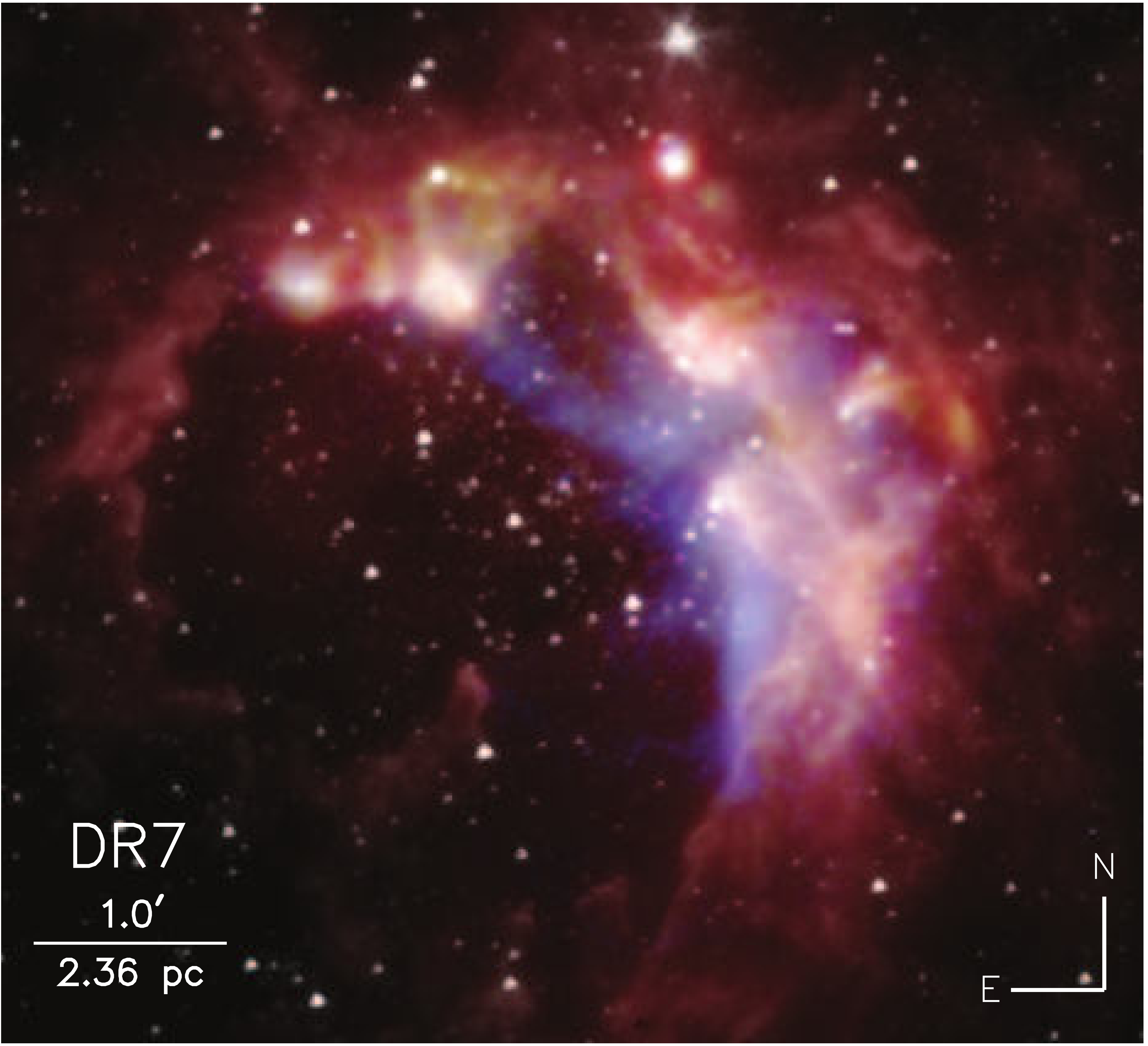
Blue - 20μm, Green - 37μm, Red - 70μm, White - 3.6μm

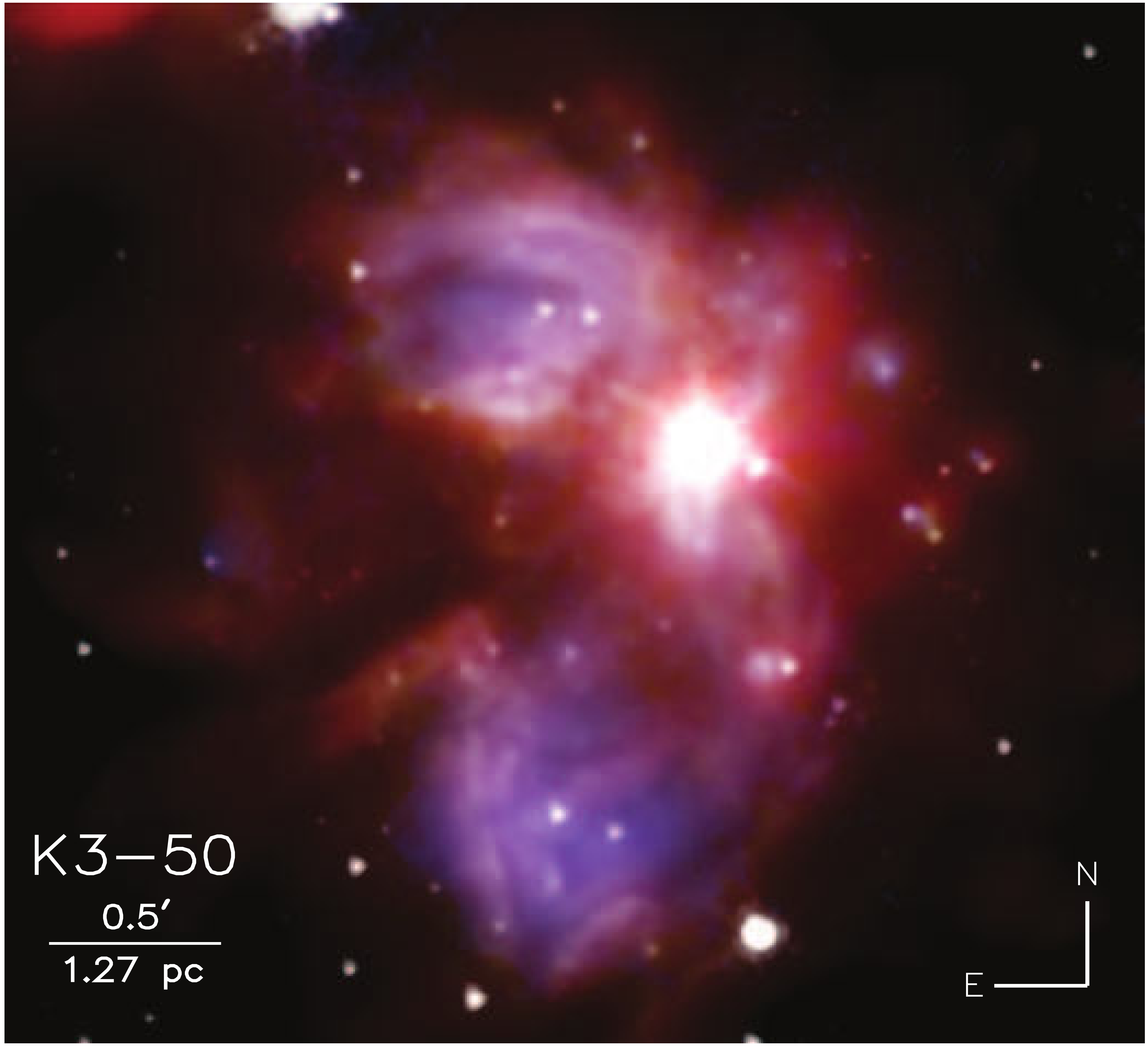
D~11.1kpc

De Buizer ea 2021

Blue - 20μm, Green - 37μm, Red - 70μm, White - 3.6μm

De Buizer ea 2023



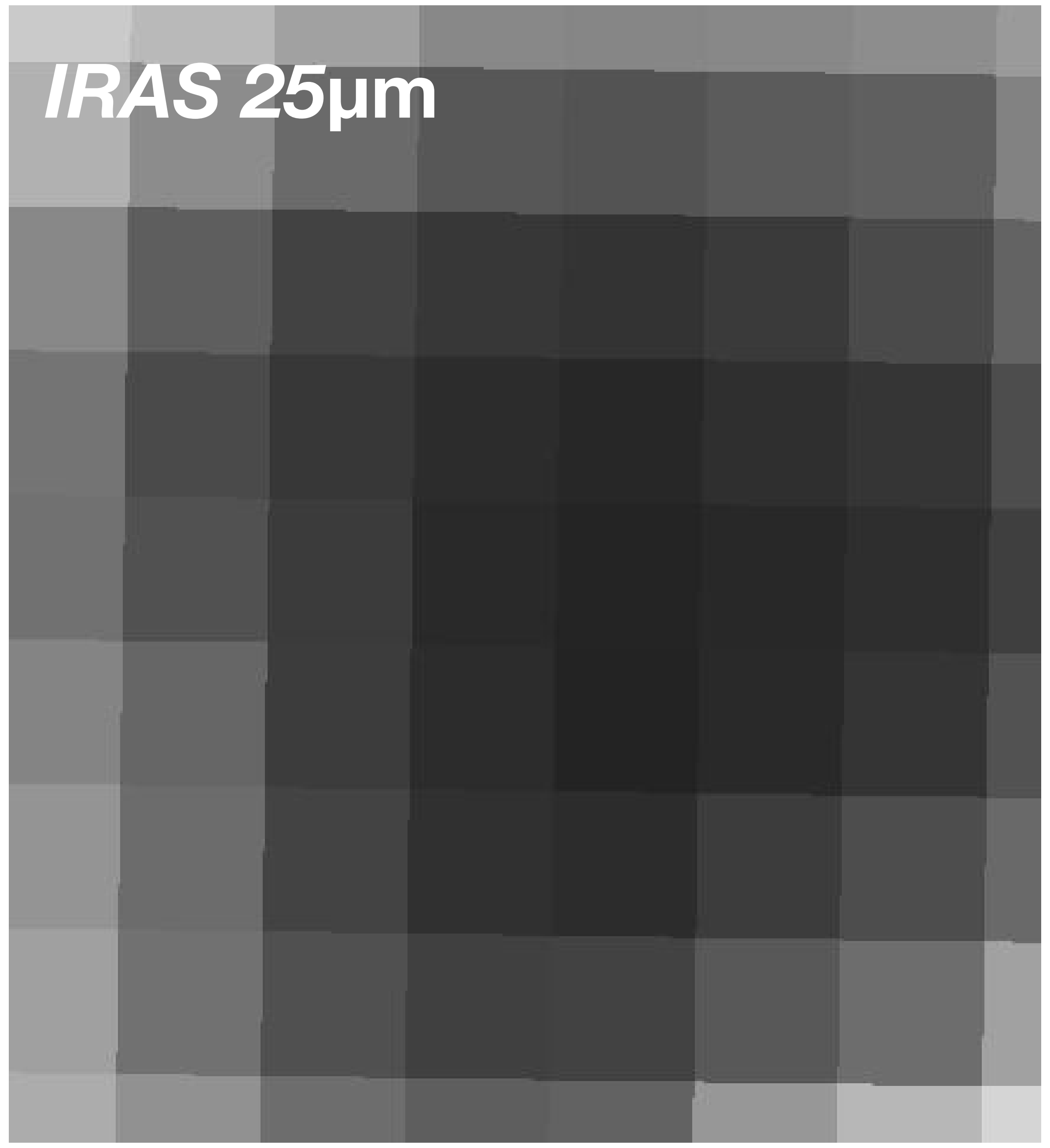


D~7.3kpc

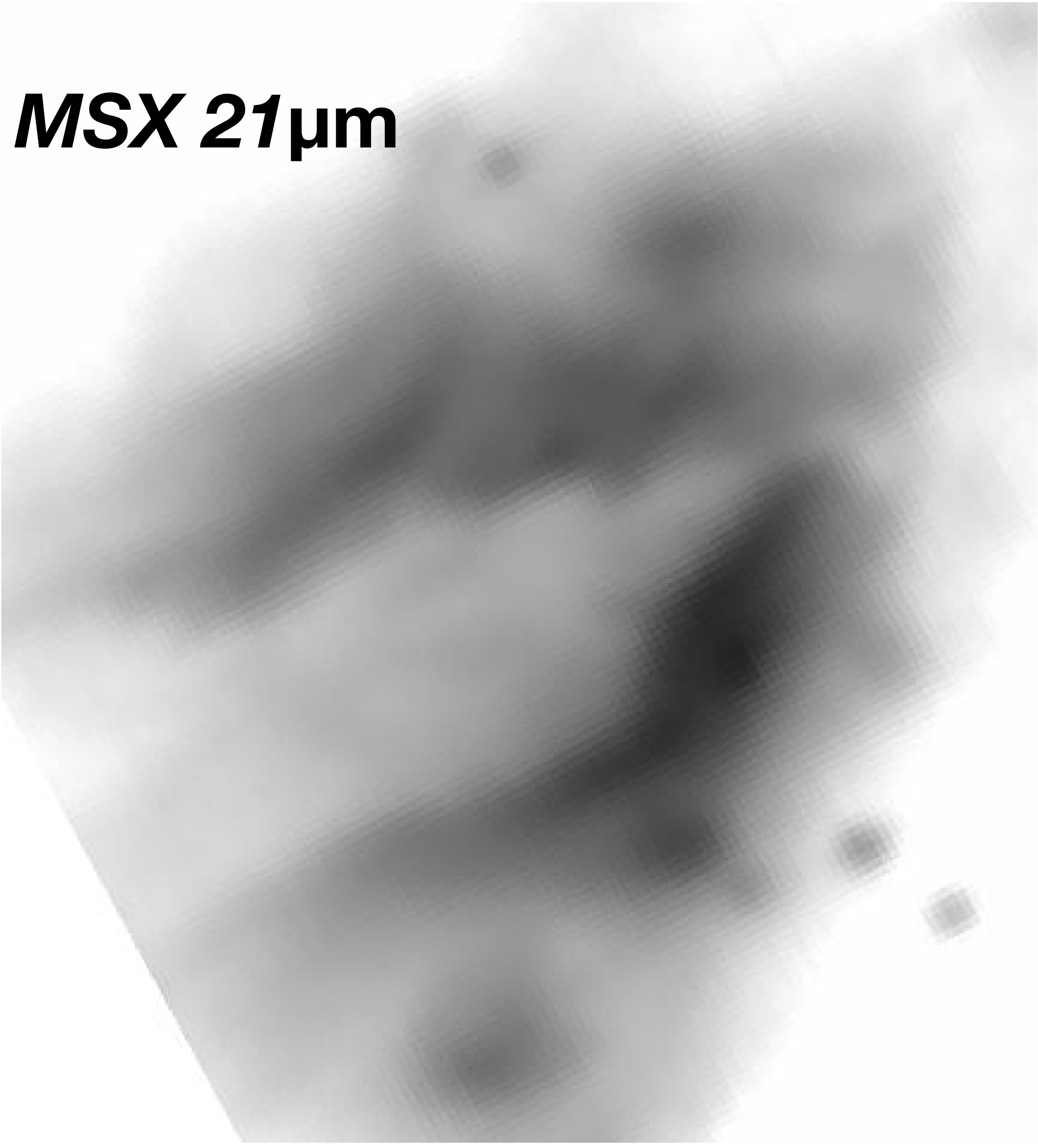
D~7.6kpc

Blue - 20μm, Green - 37μm, Red - 70μm, White - 3.6μm

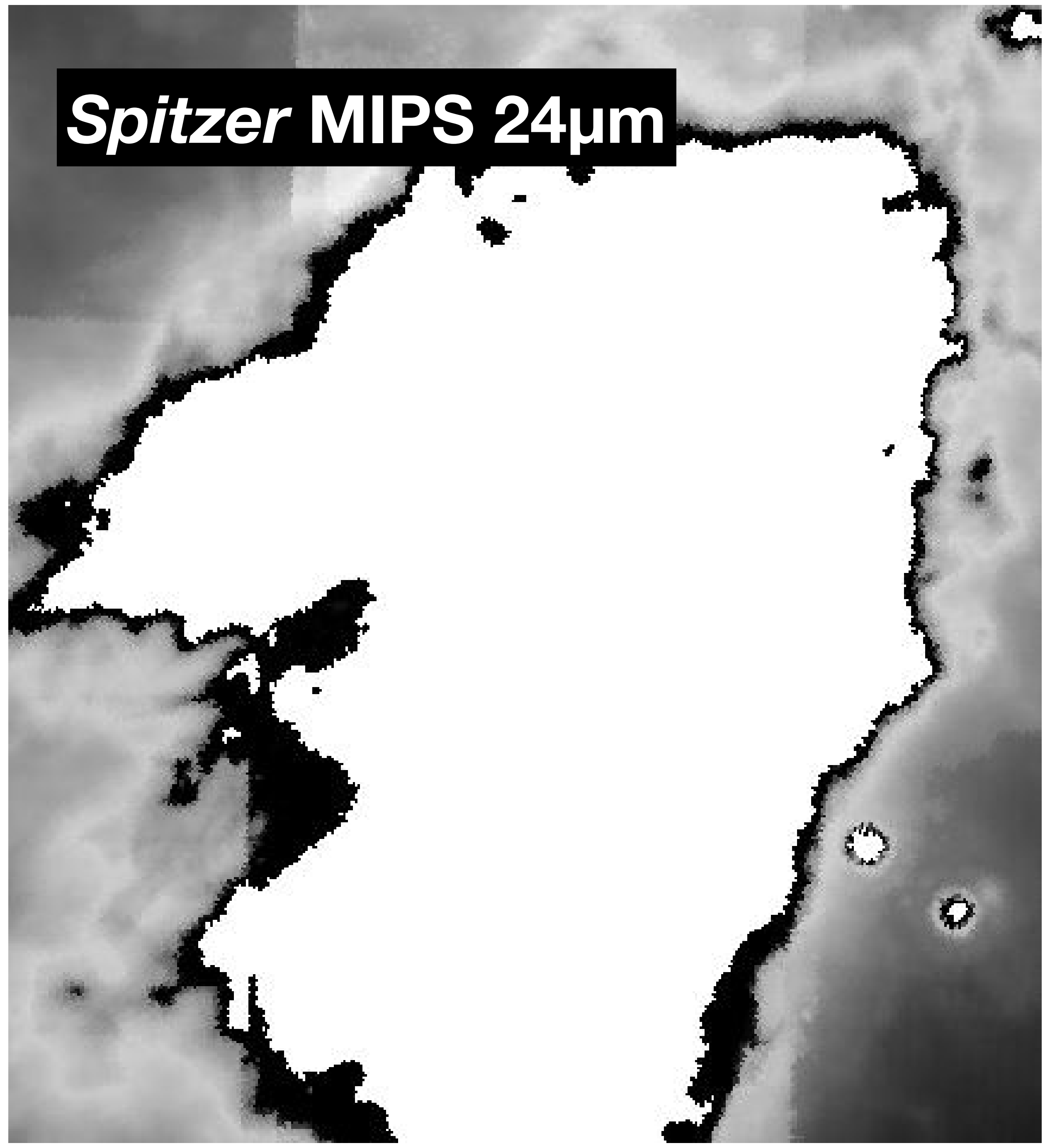
M17



IRAS 25μm



MSX 21μm



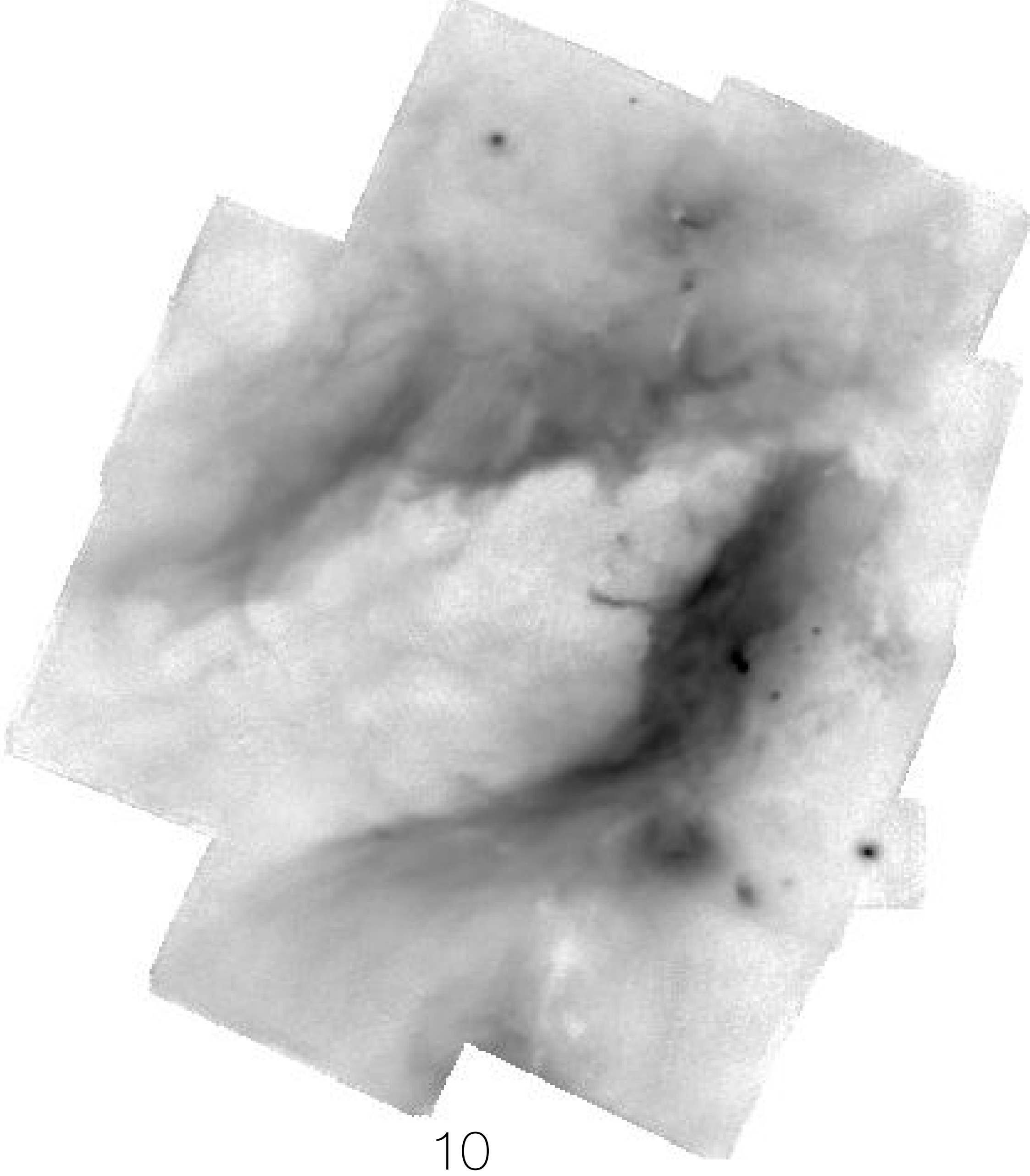
Spitzer MIPS 24μm

Why we need SOFIA?

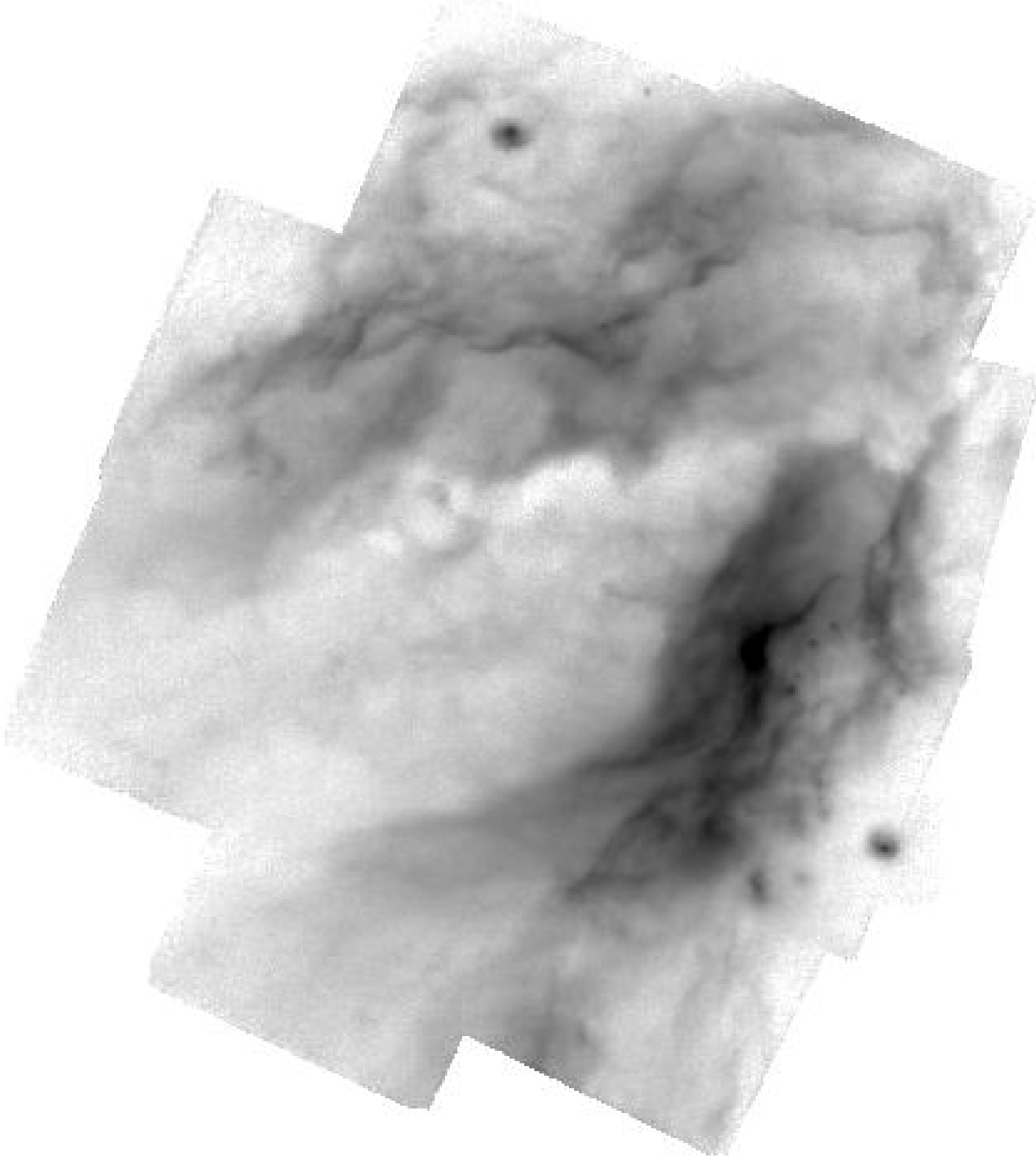
Angular resolutions of
Space/Airborne Telescopes

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

SOFIA FORCAST 20μm



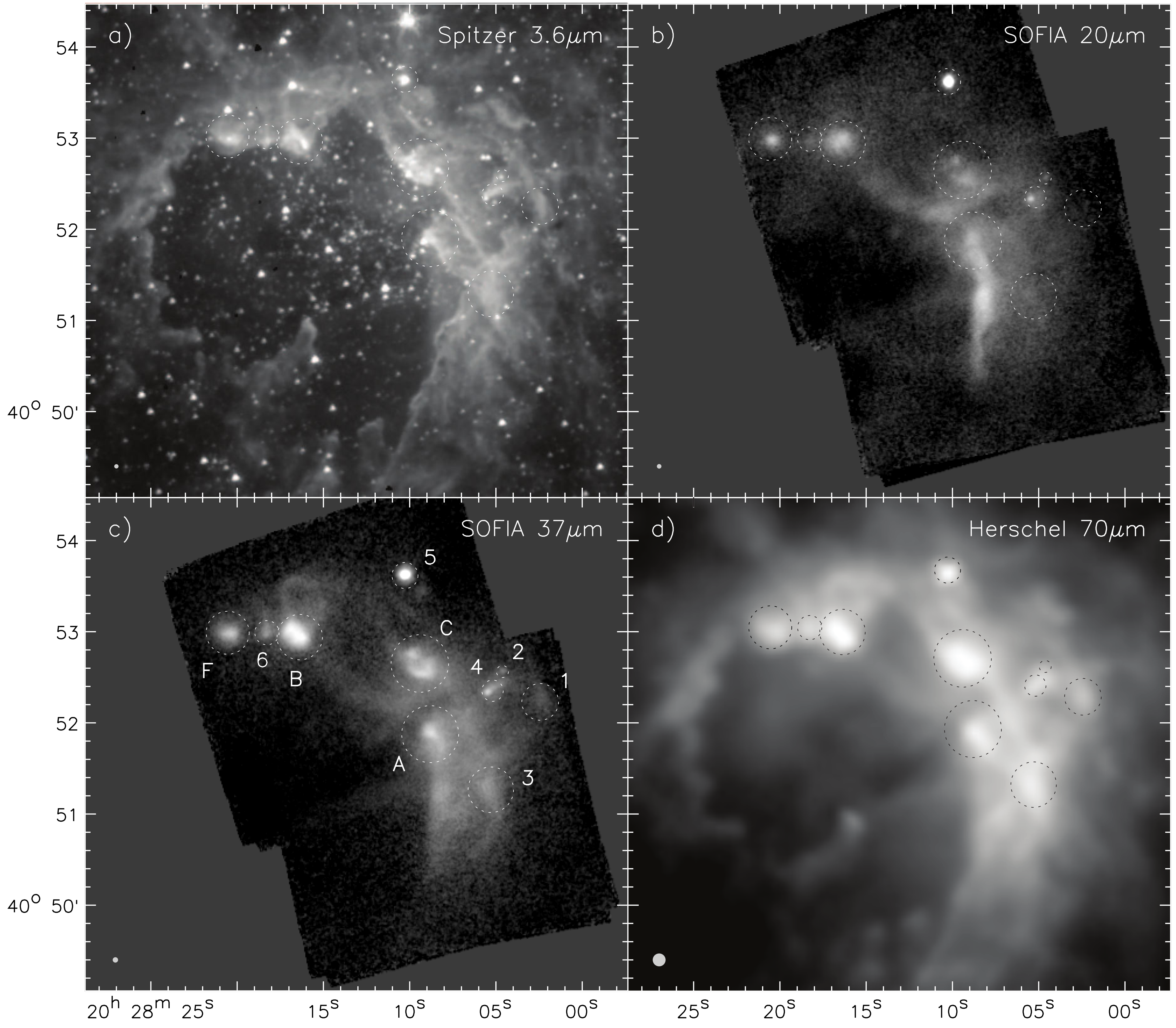
SOFIA FORCAST 37μm



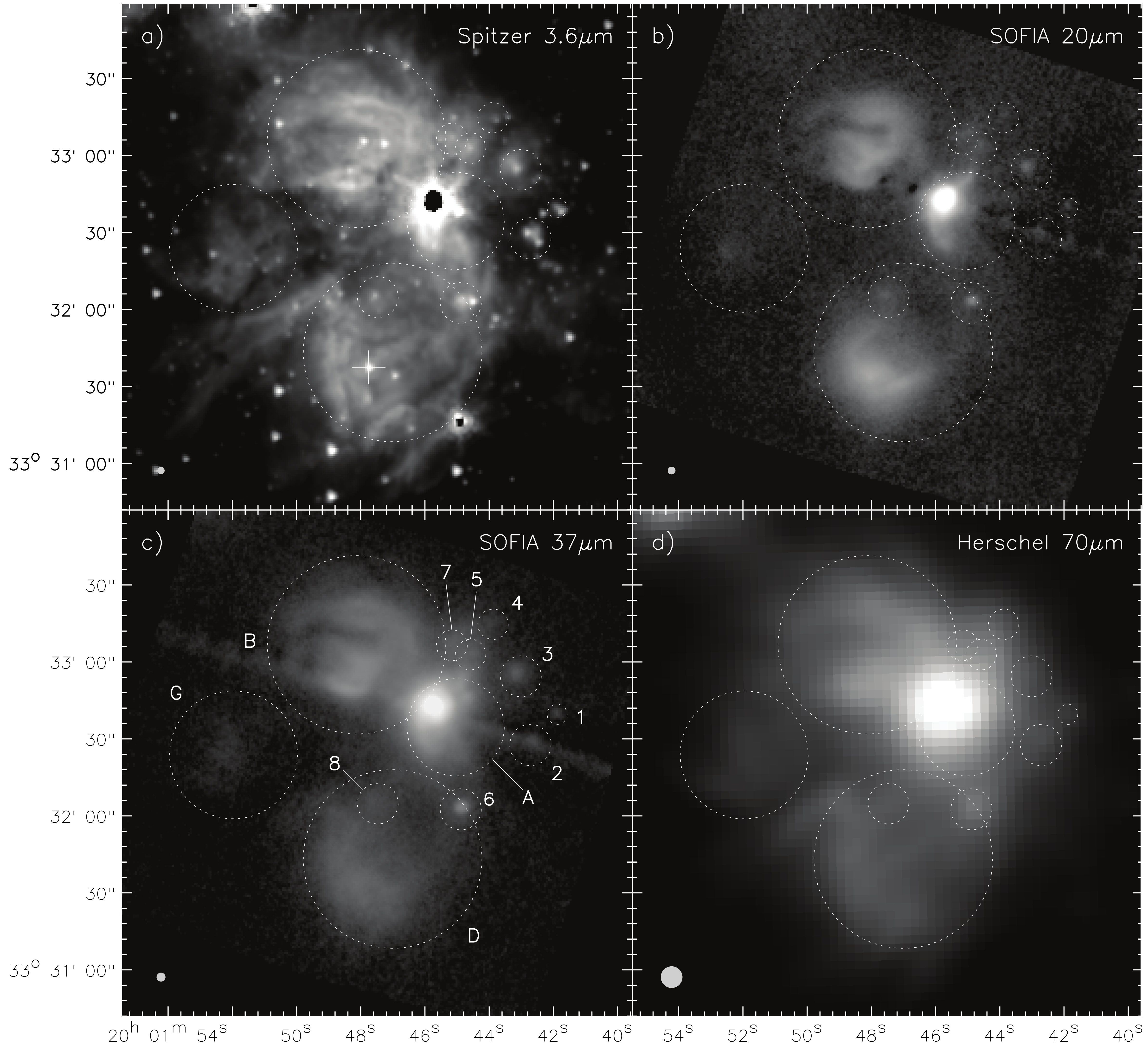
Result 1.
We have found an embedded population of MYSOs.

MYSO Candidates

DR7

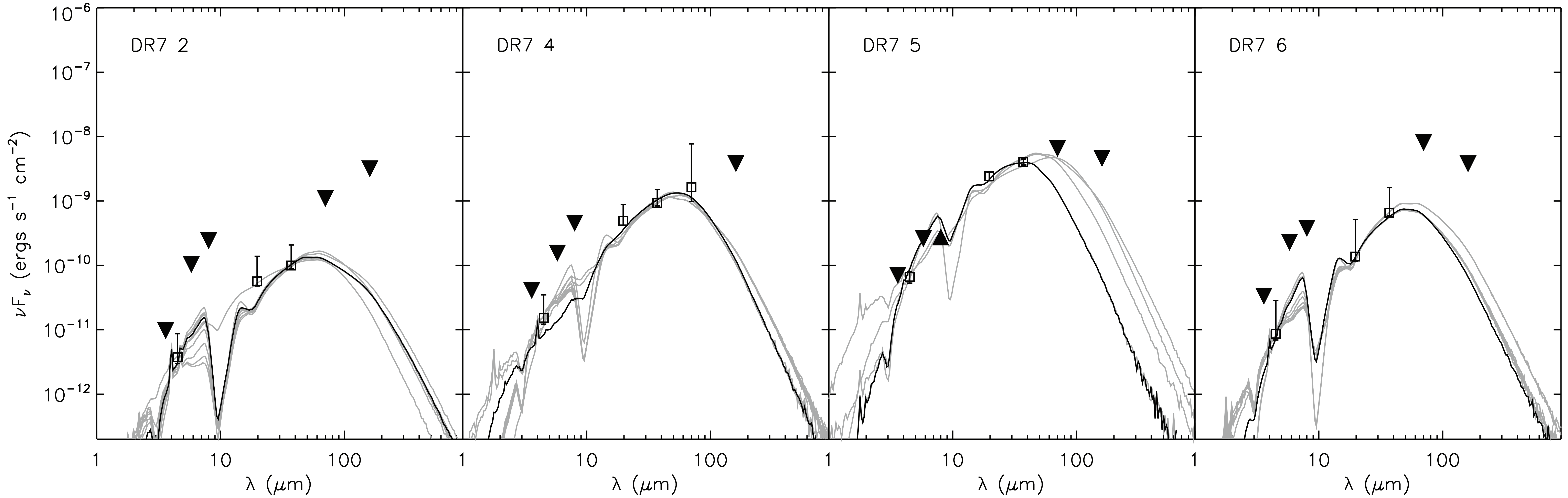


K3-50



De Buizer ea 2023

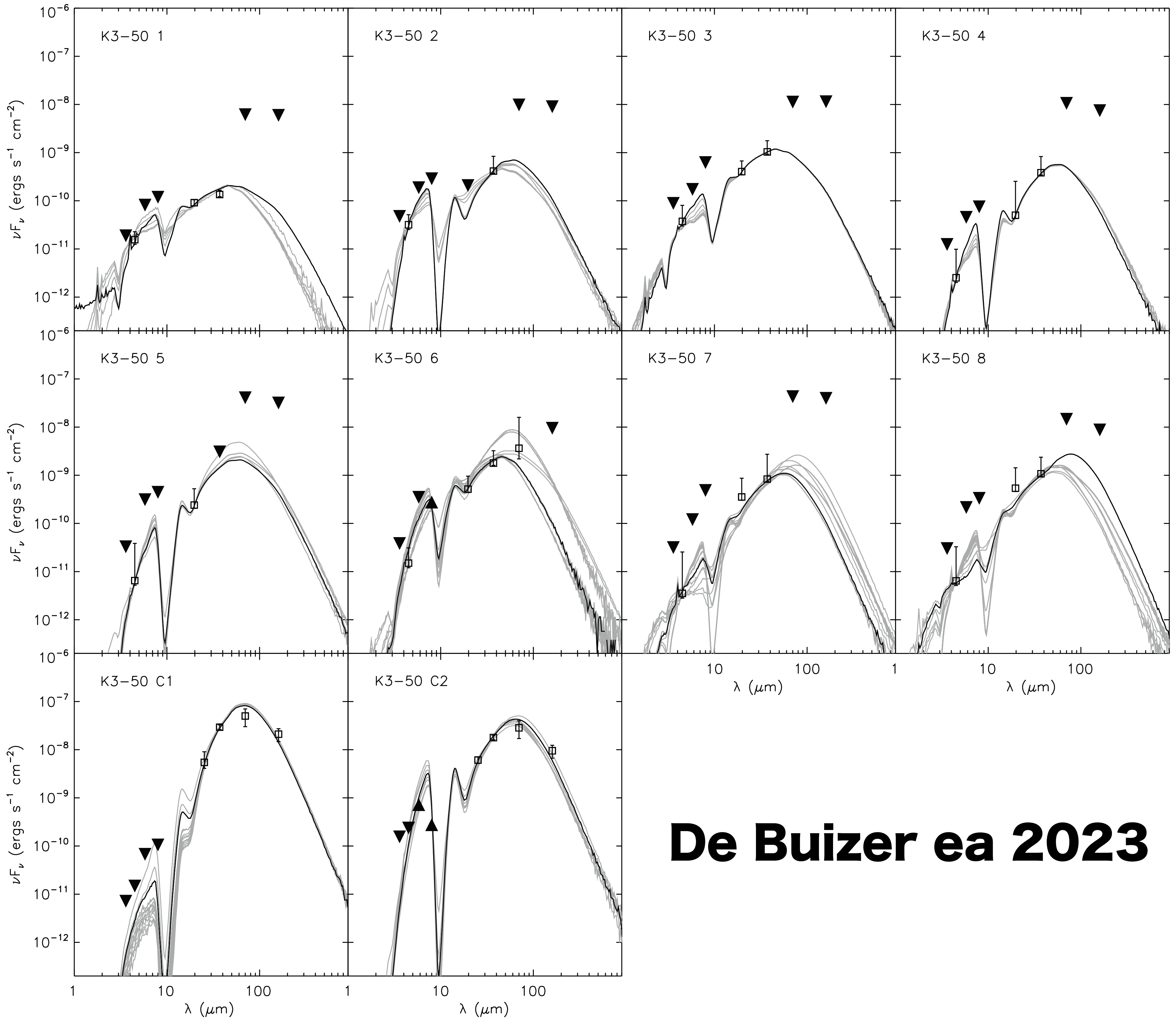
MYSO Candidates



Source	L_{obs} ($\times10^3 L_\odot$)	L_{tot} ($\times10^3 L_\odot$)	A_v (mag.)	M_{star} ($M_\odot$)	A_v Range (mag.)	M_{star} Range ($M_\odot$)	Best Models	Notes
DR7 2	0.35	0.77	19.3	4.0	2.5–54.5	4.0–4.0	11	[a]
DR7 4	3.01	13.30	26.5	8.0	8.4–79.5	8.0–16.0	11	MYSO
DR7 5	9.06	101.57	26.5	16.0	1.7–26.5	8.0—16.0	5	MYSO
DR7 6	1.61	11.20	58.7	8.0	10.6–78.8	8.0–12.0	9	MYSO

De Buizer ea 2023

MYSO Candidates



De Buizer ea 2023

Source	L_{obs} ($\times 10^3 L_\odot$)	L_{tot} ($\times 10^3 L_\odot$)	A_v (mag.)	M_{star} ($M_\odot$)	A_v Range (mag.)	M_{star} Range ($M_\odot$)	Best Models	Notes
K3-50 1	0.70	0.79	0.8	4.0	0.8–31.8	4.0–32.0	6	
K3-50 2	1.71	11.66	159.0	8.0	21.0–159.3	8.0–16.0	7	MYSO
K3-50 3	3.23	9.48	12.6	8.0	2.5–12.6	8.0–8.0	9	MYSO
K3-50 4	1.25	11.20	100.6	8.0	55.6–100.6	8.0–12.0	6	MYSO
K3-50 5	5.23	10.84	52.8	8.0	42.4–82.2	8.0–24.0	8	MYSO
K3-50 6	5.47	457.90	79.5	48.0	12.6–106.0	8.0–64.0	14	MYSO
K3-50 7	2.53	13.30	53.0	8.0	26.5–75.5	2.0–16.0	16	pMYSO[a]
K3-50 8	6.24	7.70	26.5	4.0	8.4–56.2	4.0–16.0	16	[a]
K3-50 C1	159.90	300.82	132.5	24.0	106.0–132.5	24.0–24.0	14	MYSO
K3-50 C2	89.60	460.33	212.0	32.0	111.3–262.3	24.0–128.0	8	MYSO

- 8 / 10 (K3-50), 3 / 4 (DR7) SOFIA compact sources are under MYSO criteria.
  c.f.
  41/47 MYSOs from W51A
  7 / 16 MYSOs from M17
  22 / 24 MYSOs from W49A

- A MYSO in DR7 and 7 in K3-50 have no radio counterparts.
  c.f.
  20 MYSOs in W51A
  1 MYSO in M17
  4 MYSOs in W49A

Likely at their very early stage. Not enough time to expend the Strömgren Spheres.

Result 2.
We trace the evolutionary states of proto-clusters in GHII regions.

Proto-cluster Evolution

Virial analysis

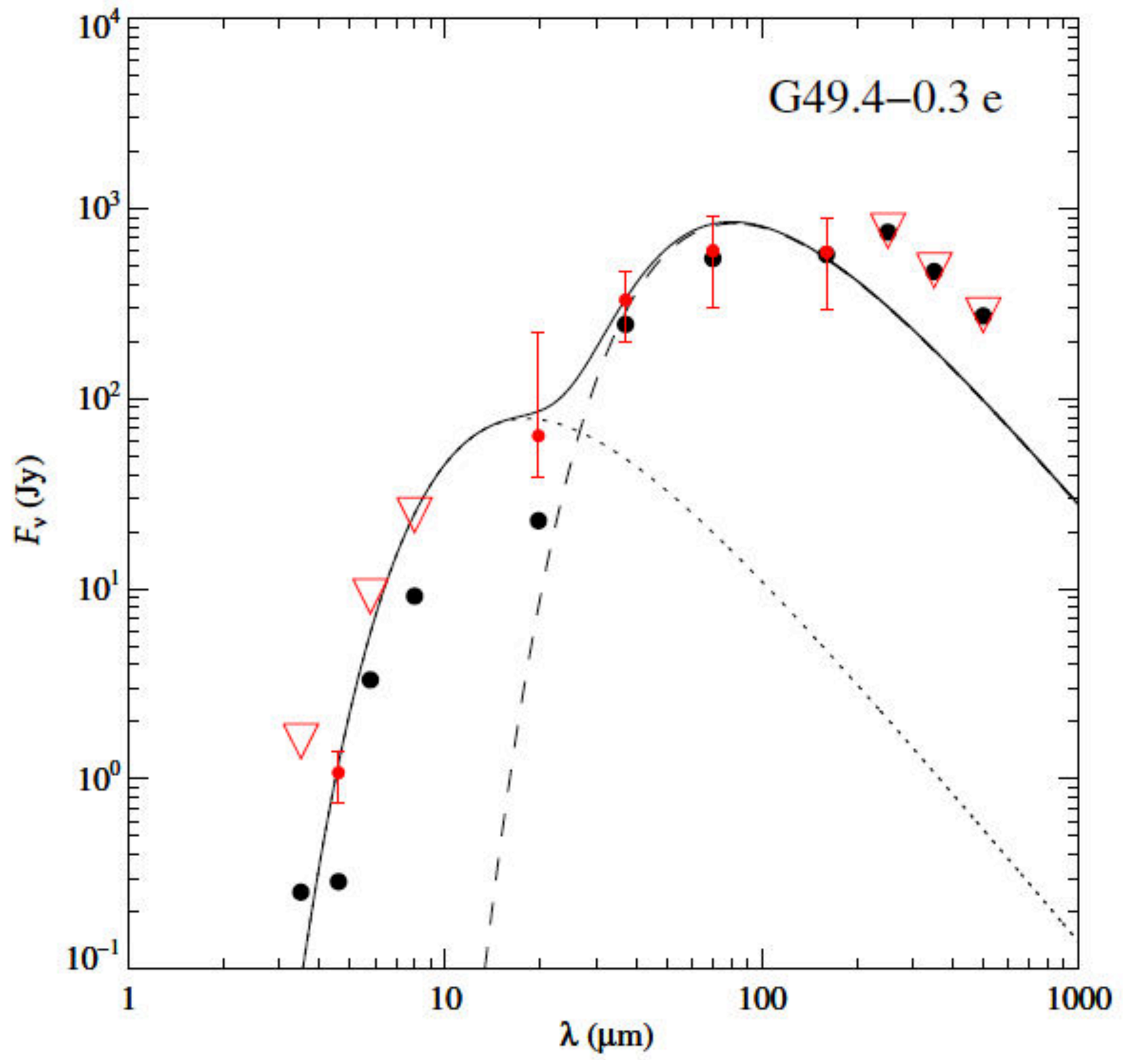
$$\alpha_{\rm vir} = \frac{2\mathcal{T}}{|\mathcal{W}|} \approx \frac{5\sigma^2 R}{GM}$$

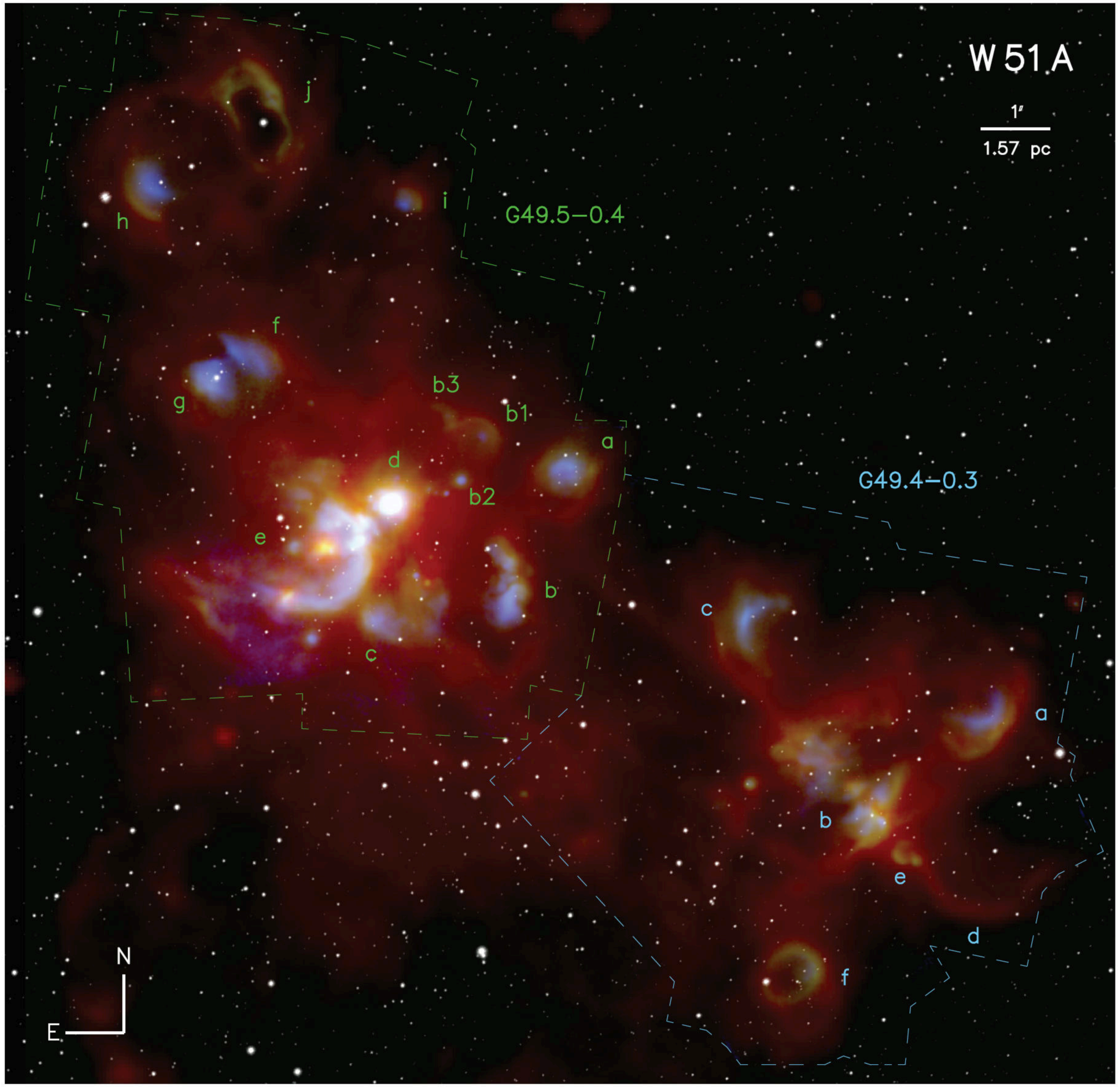
(Bertoldi & McKee 1992)

Higher α_{vir} may indicate the later clump evolutionary stages (i.e. more internal feedback makes higher kinetic energy).

L_{bol}/M_{dust}

Higher L/M might indicate older clump due to more formed stars and less dust mass (used to make stars).

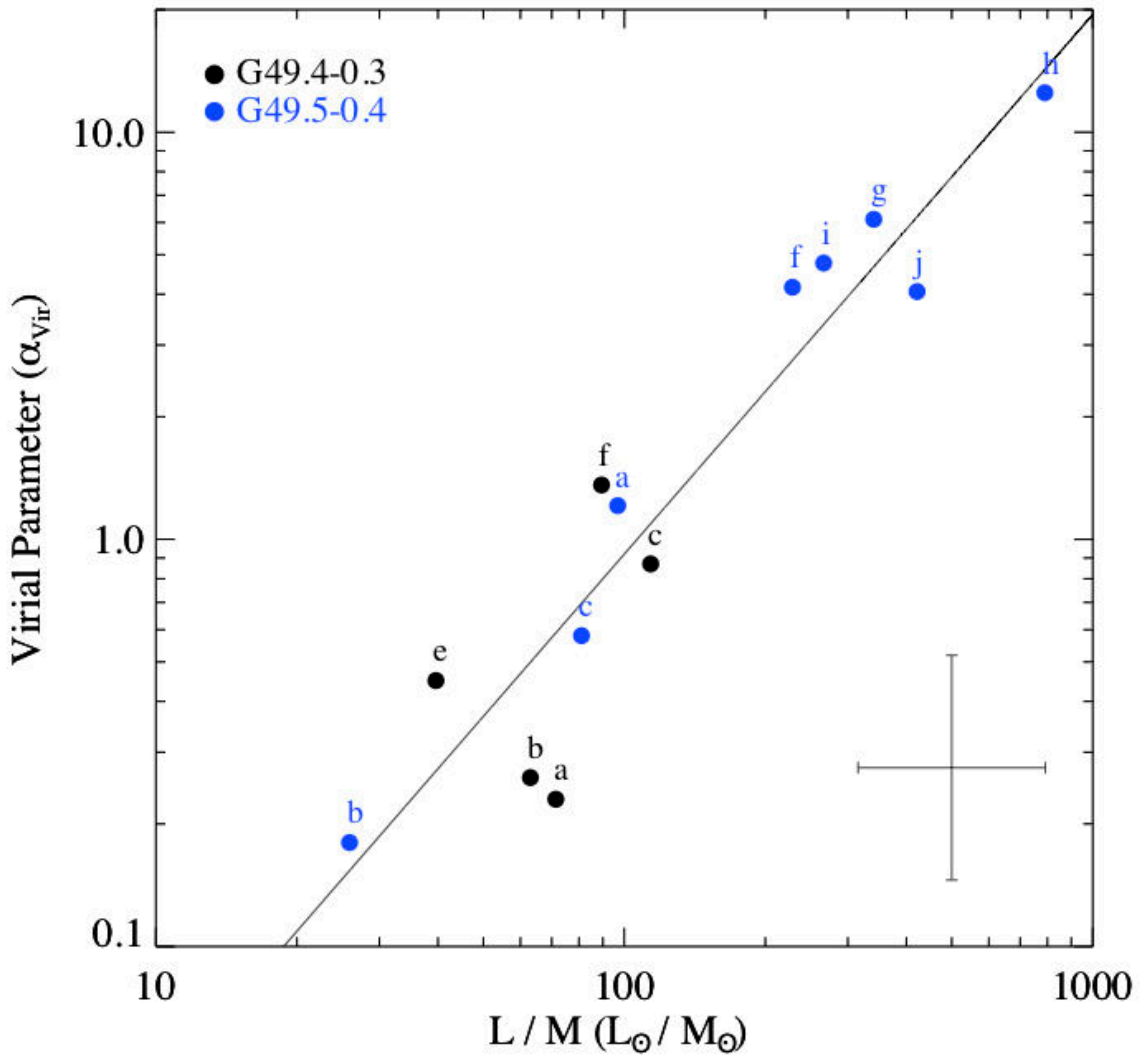




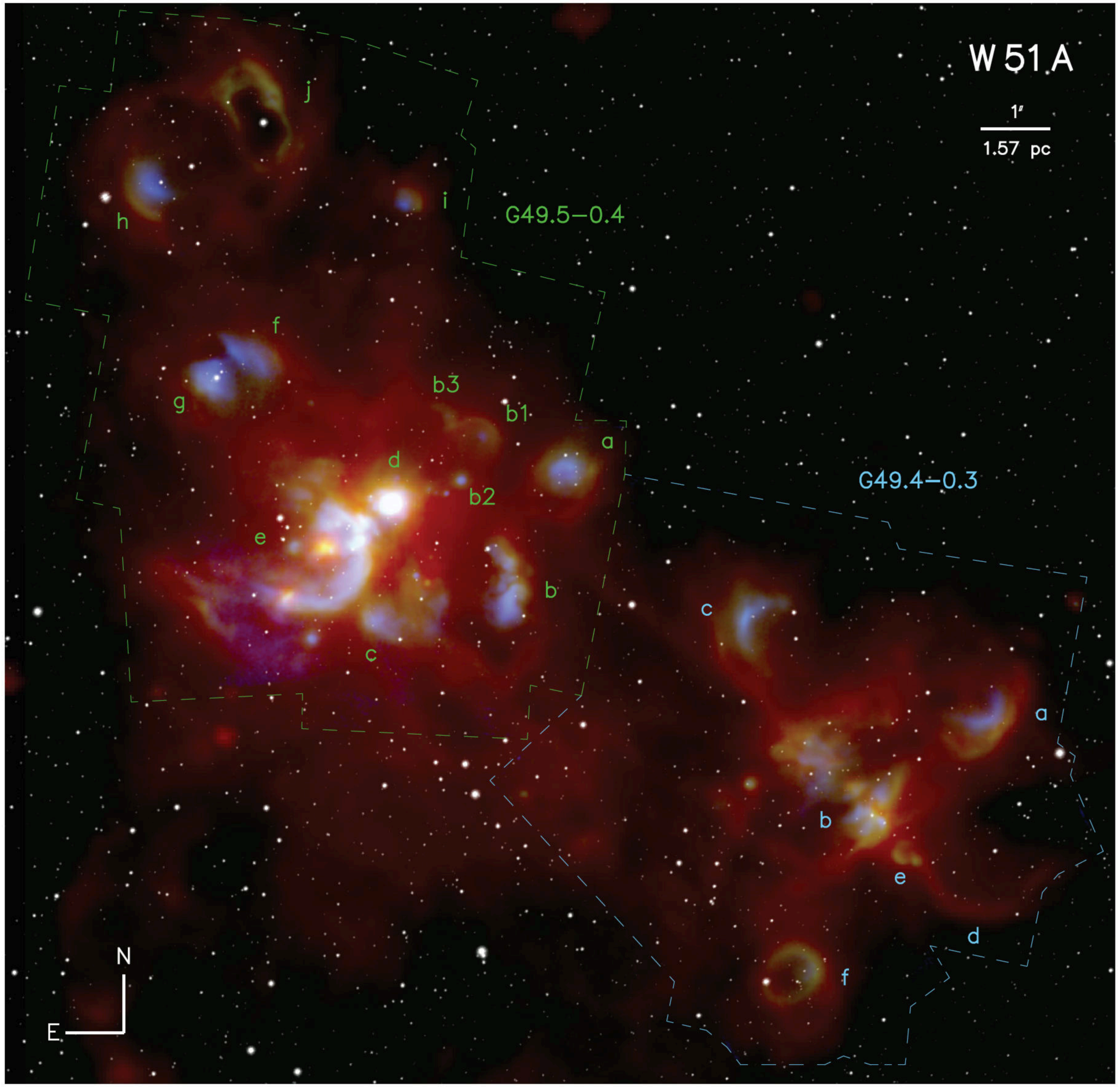
Proto-cluster Evolution

α_{vir} vs. L/M

Lim ea 2019

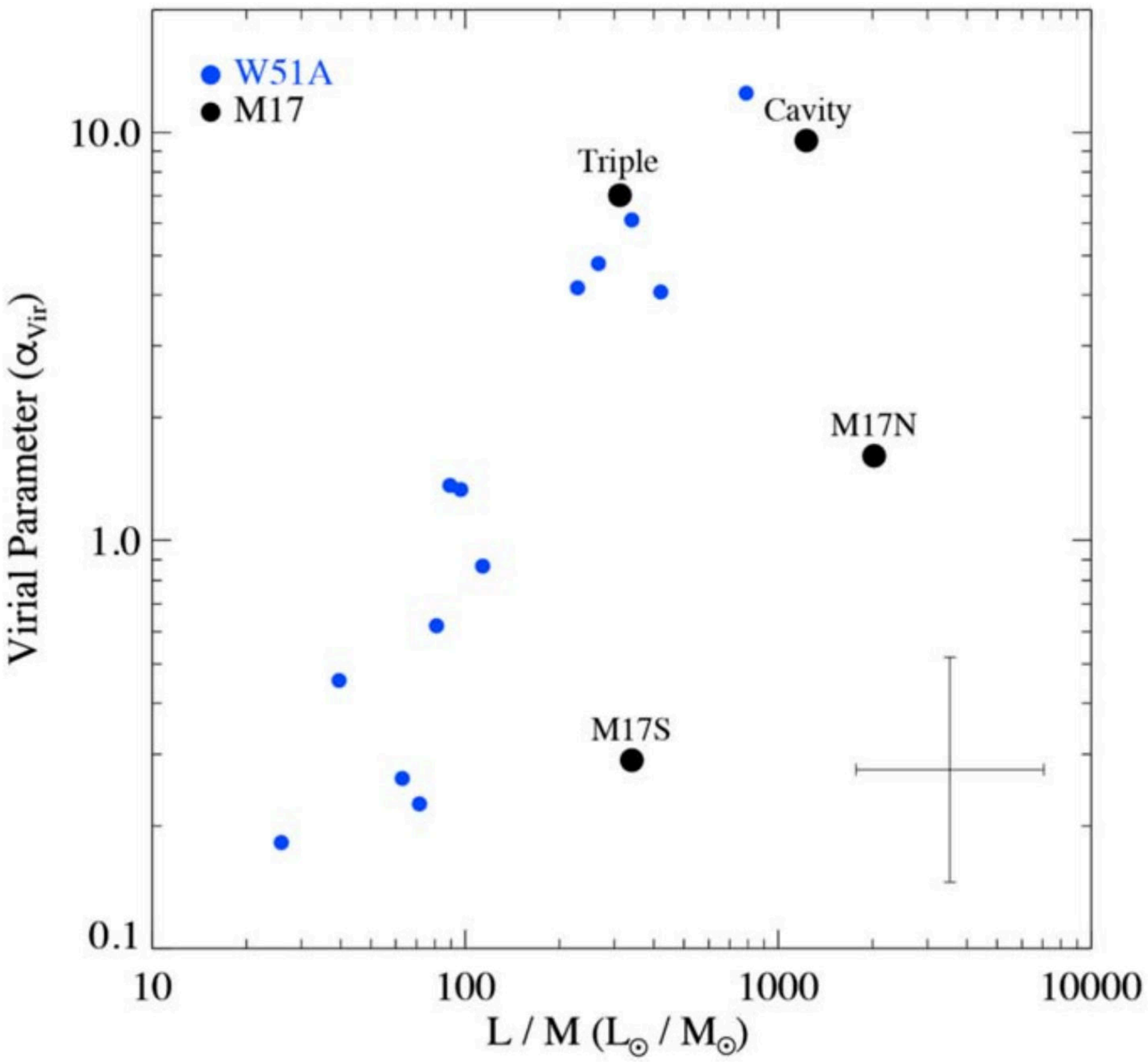


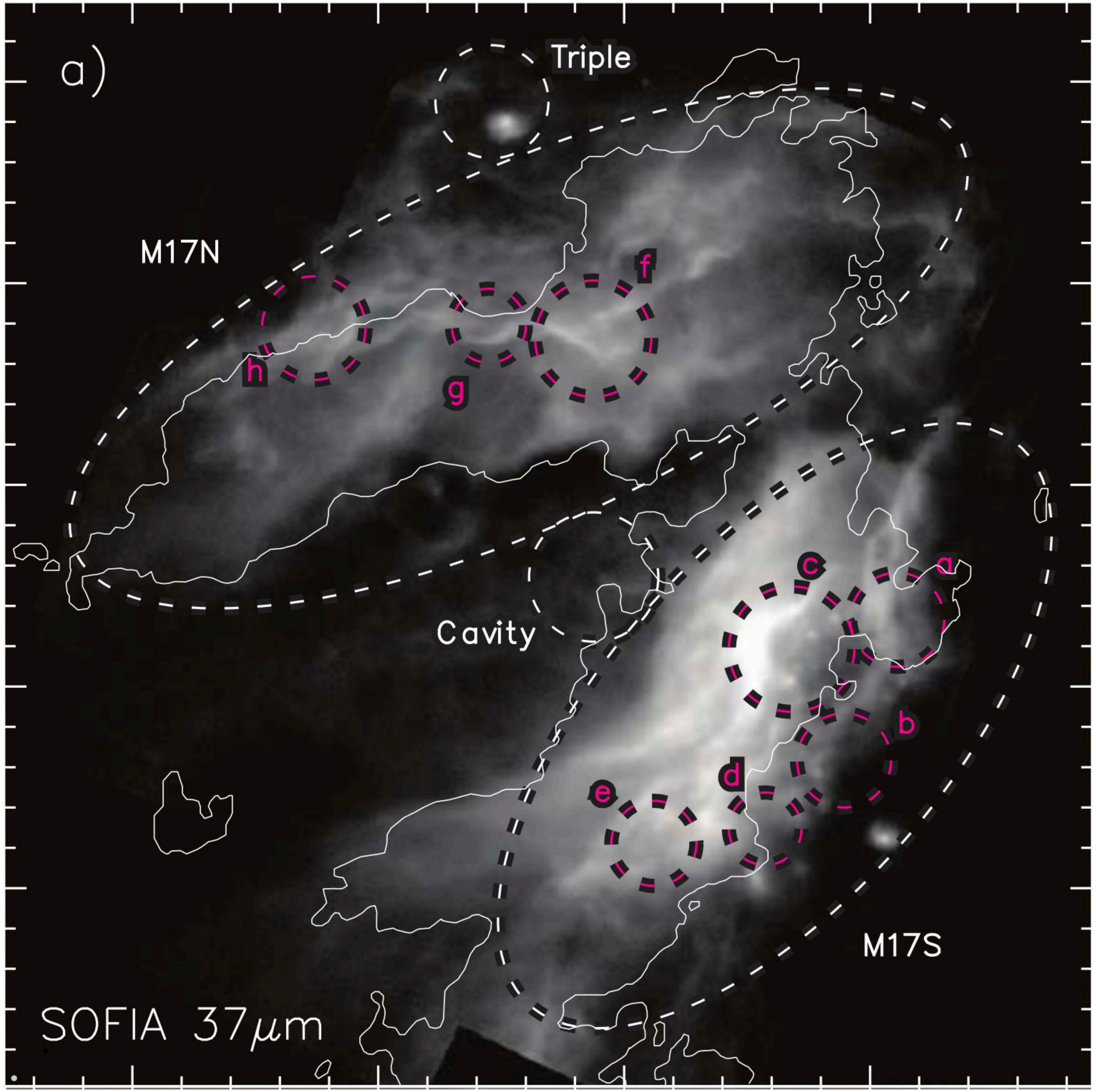
Lim ea 2019



Proto-cluster Evolution
α_{vir} vs. L/M

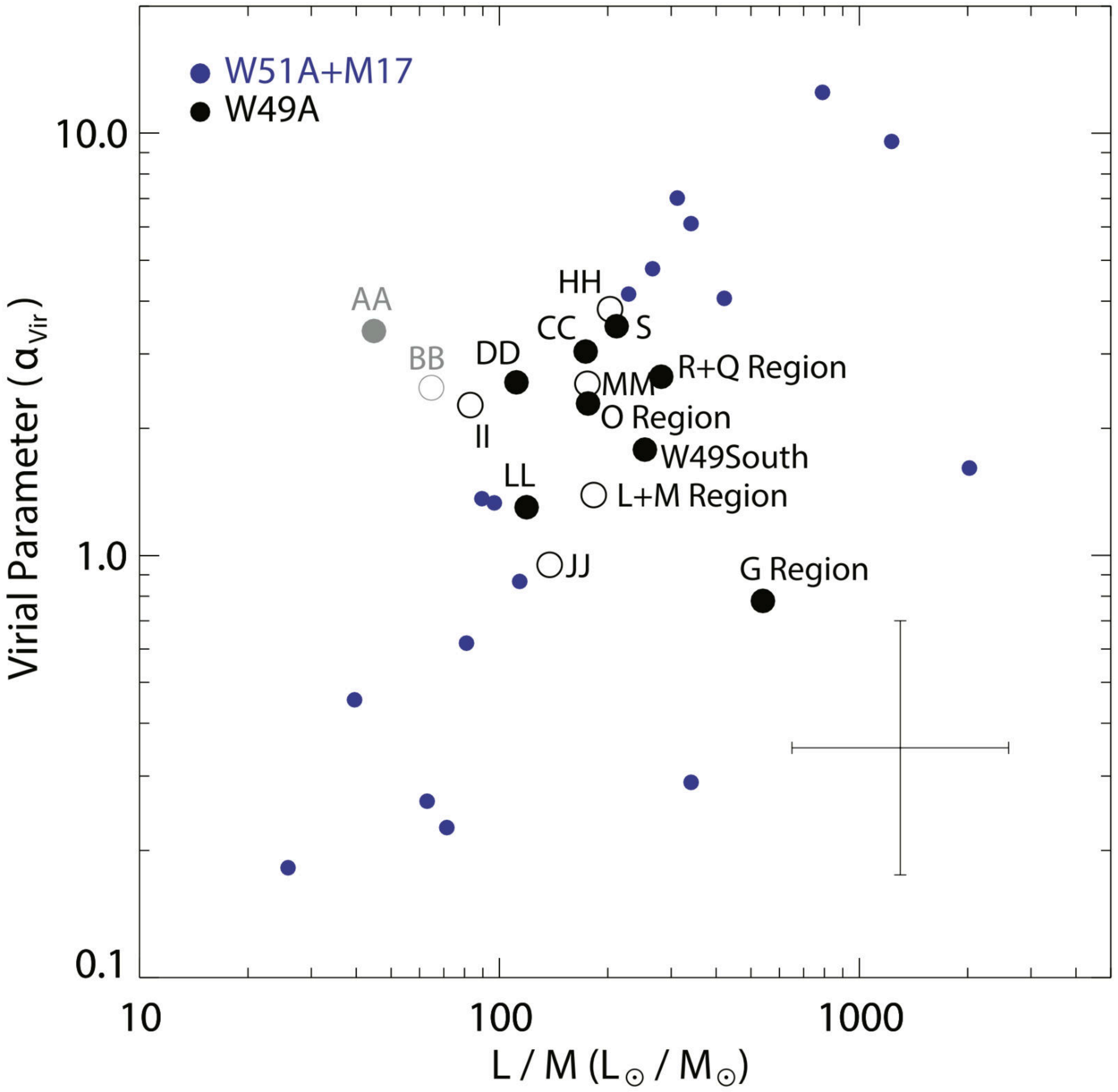
Lim ea 2020

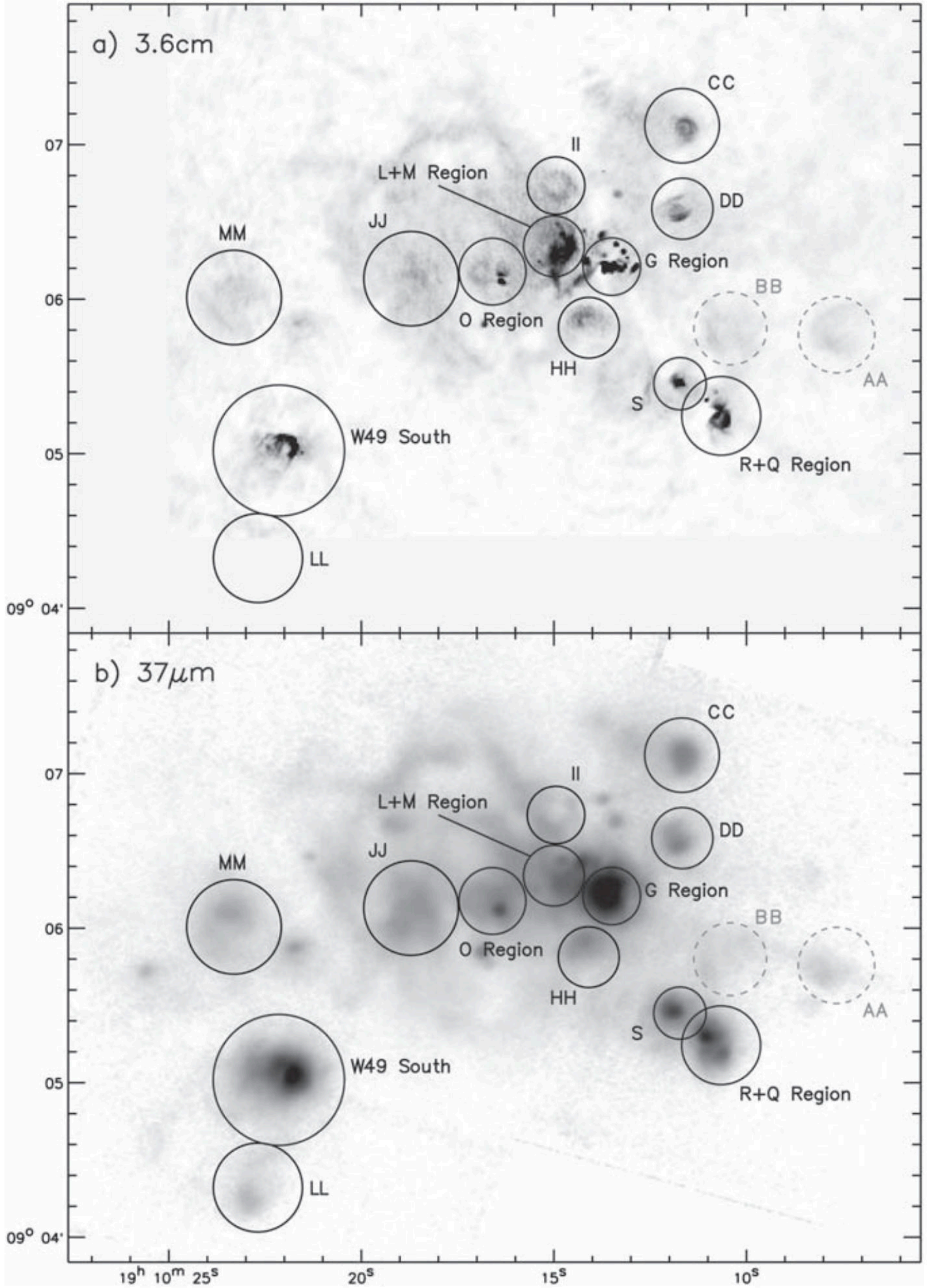




Proto-cluster Evolution
α_{vir} vs. L/M

De Buizer ea 2021

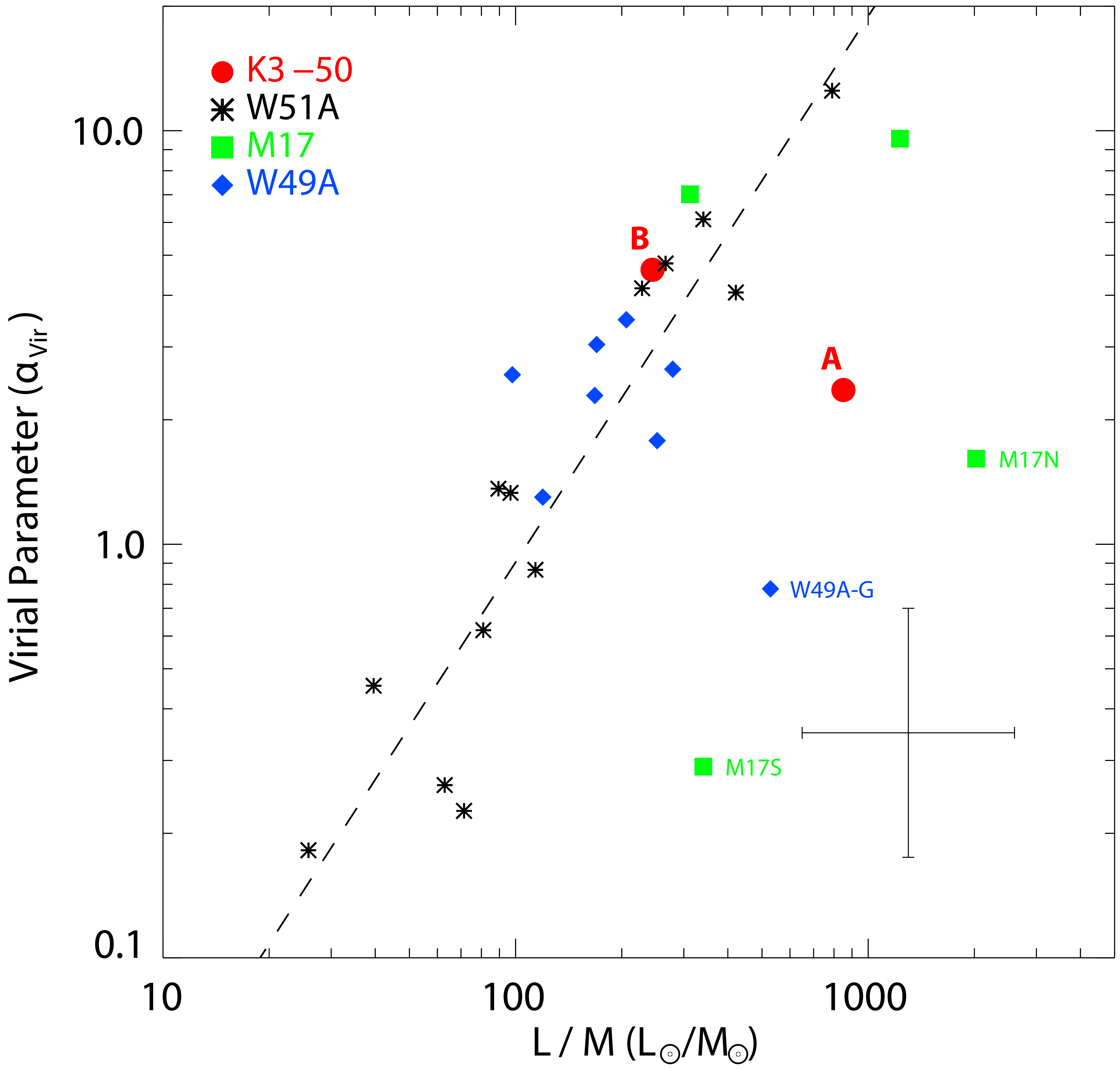




Proto-cluster Evolution

α_{vir} vs. L/M

De Buizer ea 2023



Source	M ($M_\odot$)	L ($\times10^4 L_\odot$)	T_{cold} (K)	T_{warm} (K)	L/M $L_\odot/M_\odot$
DR7 A	110.9	4.85	65.3	256.7	218.5
DR7 B	98.7	4.27	62.6	273.6	216.4
DR7 C	318.8	5.68	55.1	285.7	89.2
DR7 F	62.6	2.50	50.4	274.5	199.8

Source	M_{vir} ($M_\odot$)	M ($M_\odot$)	L ($\times10^4 L_\odot$)	T_{cold} (K)	T_{warm} (K)	L/M $L_\odot/M_\odot$	α_{vir}
K3-50 A	1993.6	845.2	144	69.0	212.4	850.7	2.36
K3-50 B	3037.9	659.4	32.3	68.8	284.1	244.6	4.61
K3-50 C	...	904.6	36.2	60.2	276.0	200.3	...
K3-50 D	...	152.4	24.7	69.7	266.6	811.3	...
K3-50 G	...	27.7	2.33	44.8	315.1	421.2	...

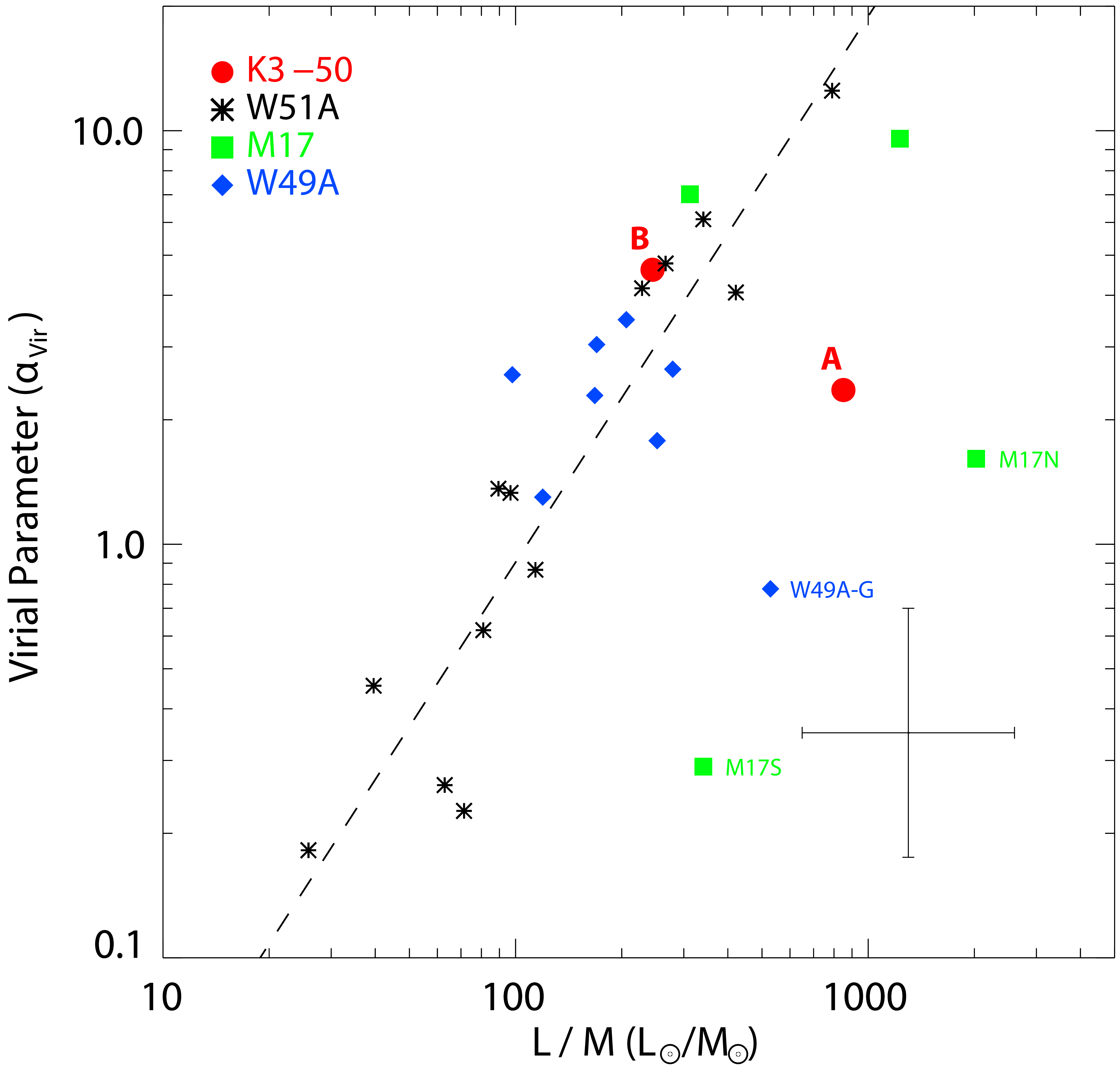
- No proper molecular line data toward DR7.
- Only HCO+ (4-3) data toward K3-50 A and B sources.
- L / M parameters of K3-50 show relatively large spread (200 - 850) while DR7 has similar values across all 4 sources.

This may indicate K3-50 underwent multi-phase star formation activities while DR7 is coeval.

Proto-cluster Evolution

α_{vir} vs. L/M

De Buizer ea 2023



- W51A and M17 show various evolutionary stages of porto-cluster thus structures in these GHII regions are not coeval.
- Revealed stellar clusters (M17) and a LBV candidate (W51A) show the highest α_{vir} and L/M values.
- All W49A proto-clusters show relatively consistent α_{vir} and L/M values indicating they are more likely coeval.
- The L/M spread of DR7 and K3-50 indicates that DR7 looks to be coeval while K3-50 might not.

Result 3.
Additional analyses imply which are genuine GHII regions.

Edge case study
Are they genuine GHII regions?

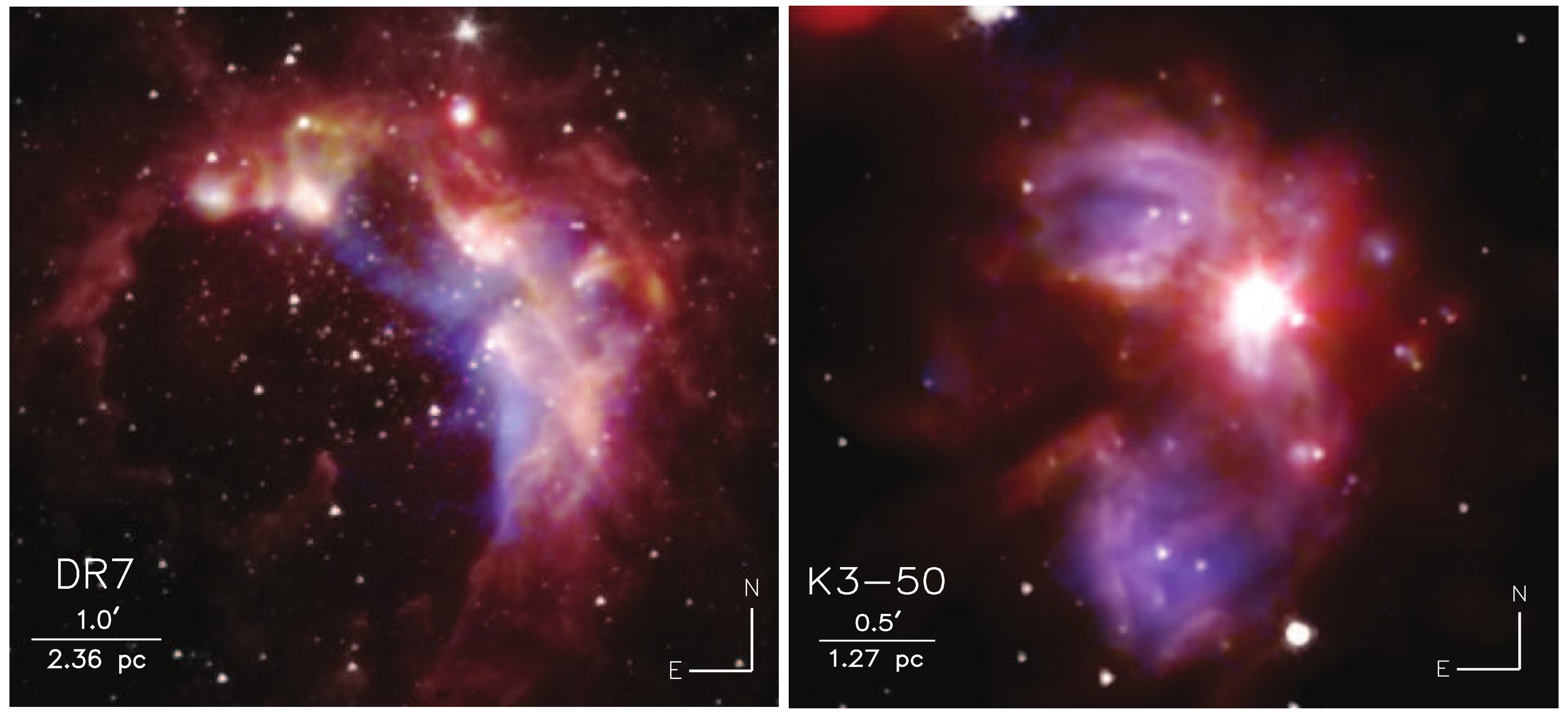
De Buizer ea 2023

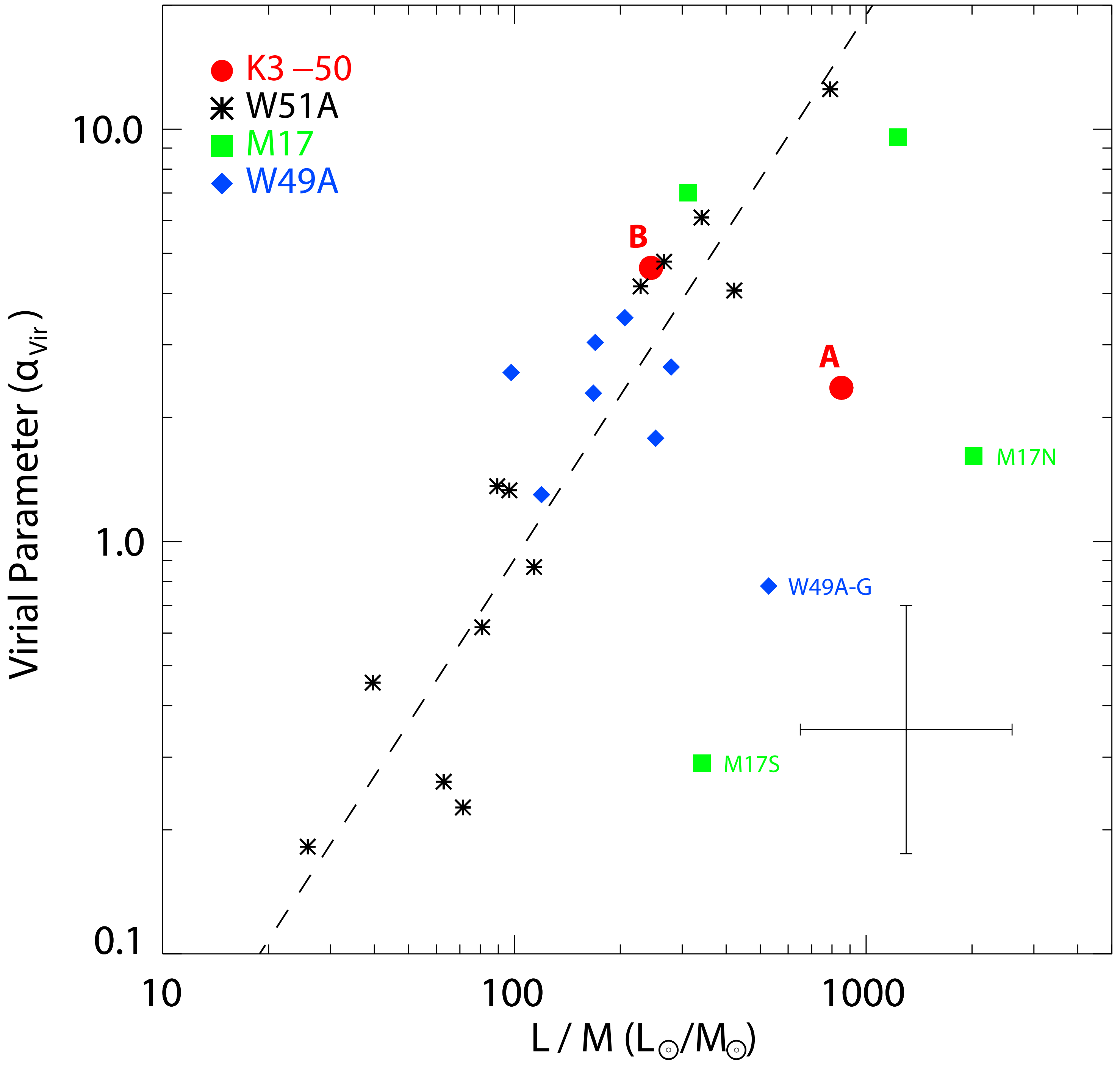
Region	No. Compact Sources	No. Subregions	% Flux in Peak	Highest Mass YSO	Type
W51A: G49.5-0.4	37	10	20	96	GH II
W49A	24	15	25	128	GH II
M17	16	4	5	64	GH II
W51A: G49.4-0.3	10	5	15	64	GH II
K3-50	10	5	59	48	GH II?
DR7	4	1	15	16	H II?
Sgr D	3	3	85	16	H II
W42	2	1	50	32	H II

- In De Buizer et al. 2022, we argued the four observational criteria to be considered as a GHII region (in addition to the Lyman continuum cutoff '$N_{LyC} = 10^{50}$ s^{-1}').
    1. The number of compact sources
    2. The number of extended sources (sub-regions)
    3. The peak flux ratio (peak source flus / total flux)
    4. The mass of the most massive YSO in the area
- K3-50 is likely a GHII region and DR7 might not.

Summary

- FORCAST 20, 25 & 37μm imaging survey toward Galactic GHII regions has been executed.
- The SOFIA data revealed a previously hidden population of MYSOs and gave us better understanding the physical nature of several already known sources.
- Independent evolutionary analyses traces unique histories of stellar cluster formation in GHII regions.
- Analyses on ‘edge case GHII regions’ (K3-50 & DR7) indicate K3-50 is likely GHII while DR7 is not.





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