
SOFIA-FORCAST/Herschel/Spitzer Images

The SOFIA Mid-Infrared Giant HII Region Survey: Exploring the Largest Massive Star-Forming Regions of the Milky Way

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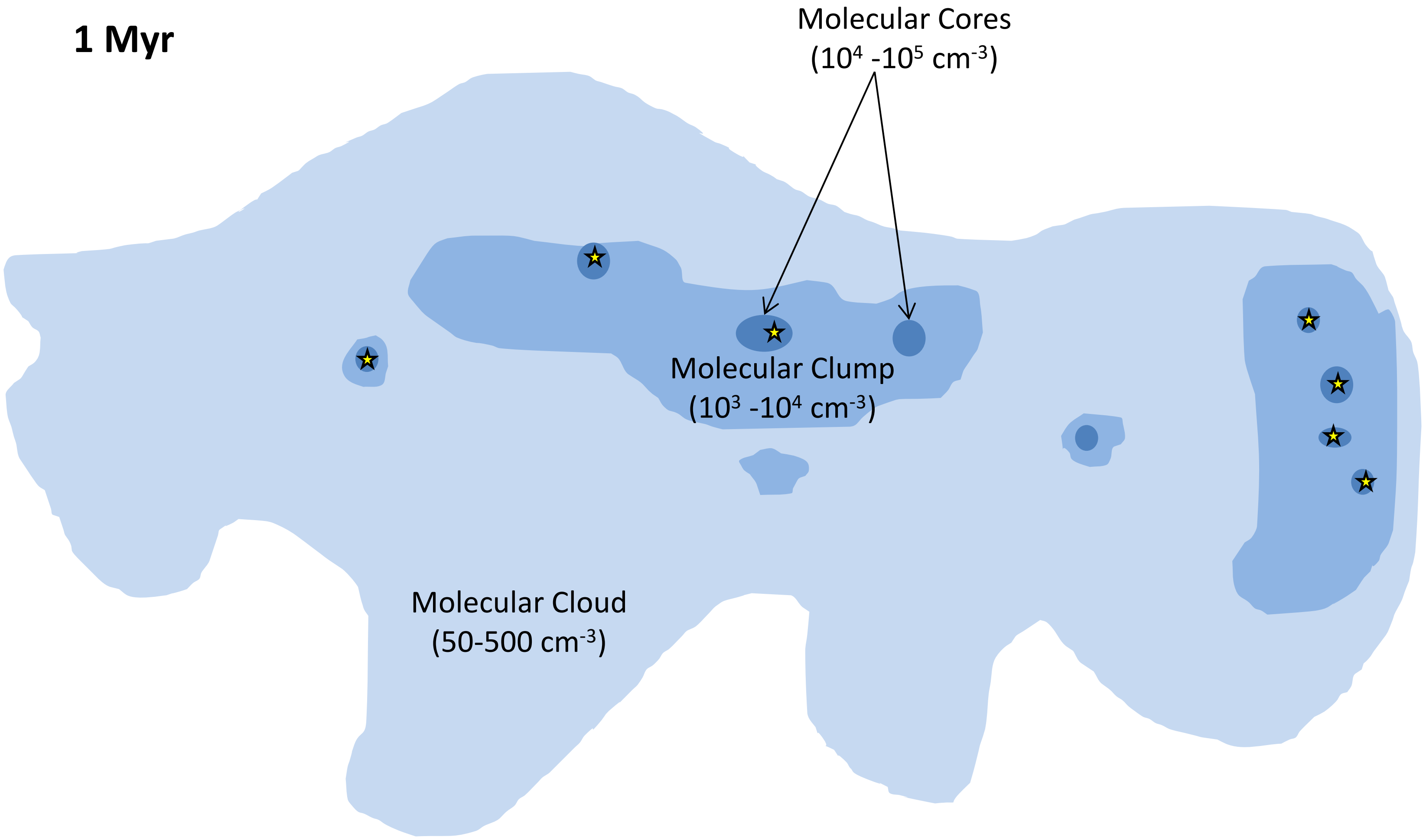
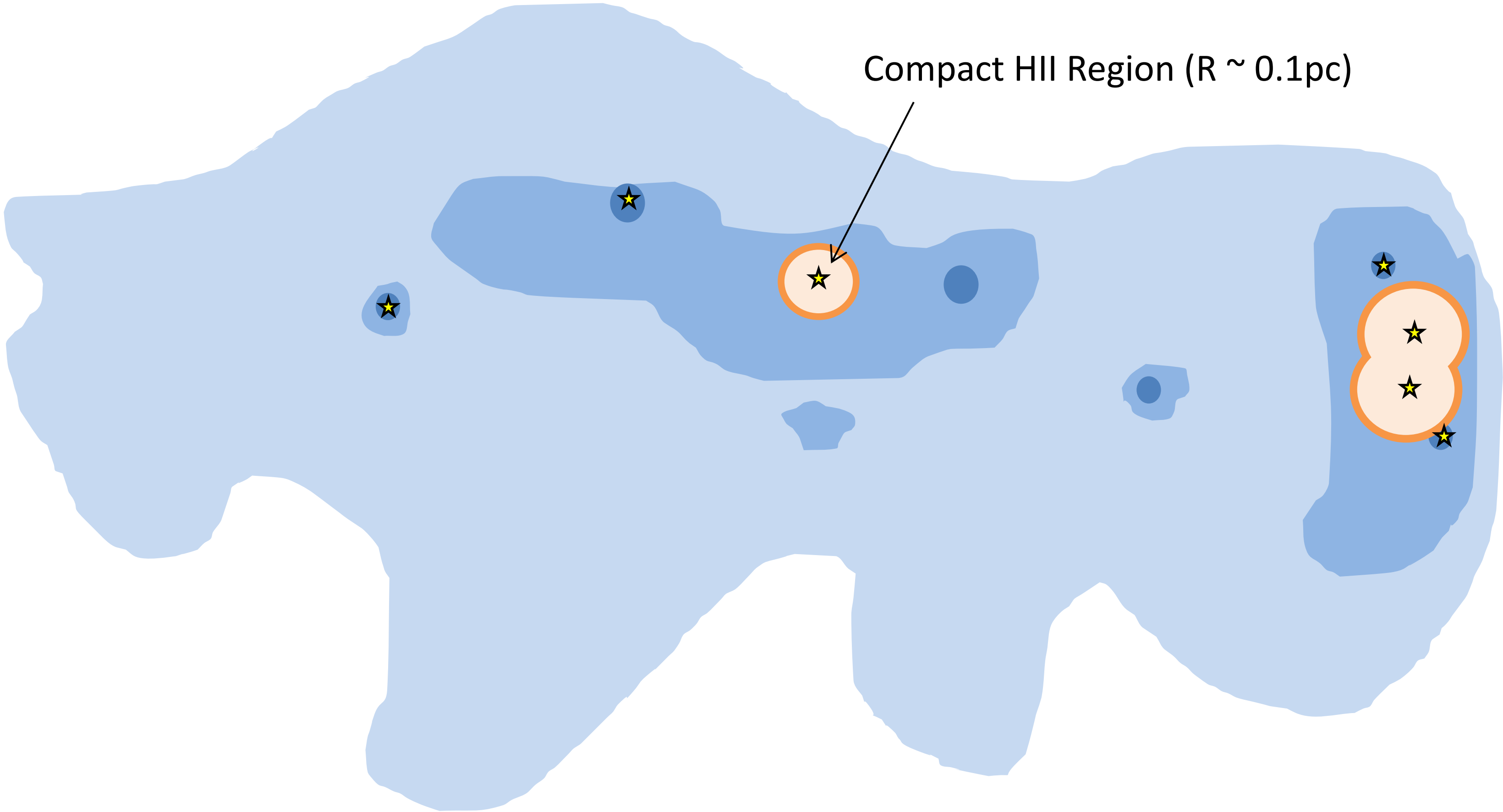


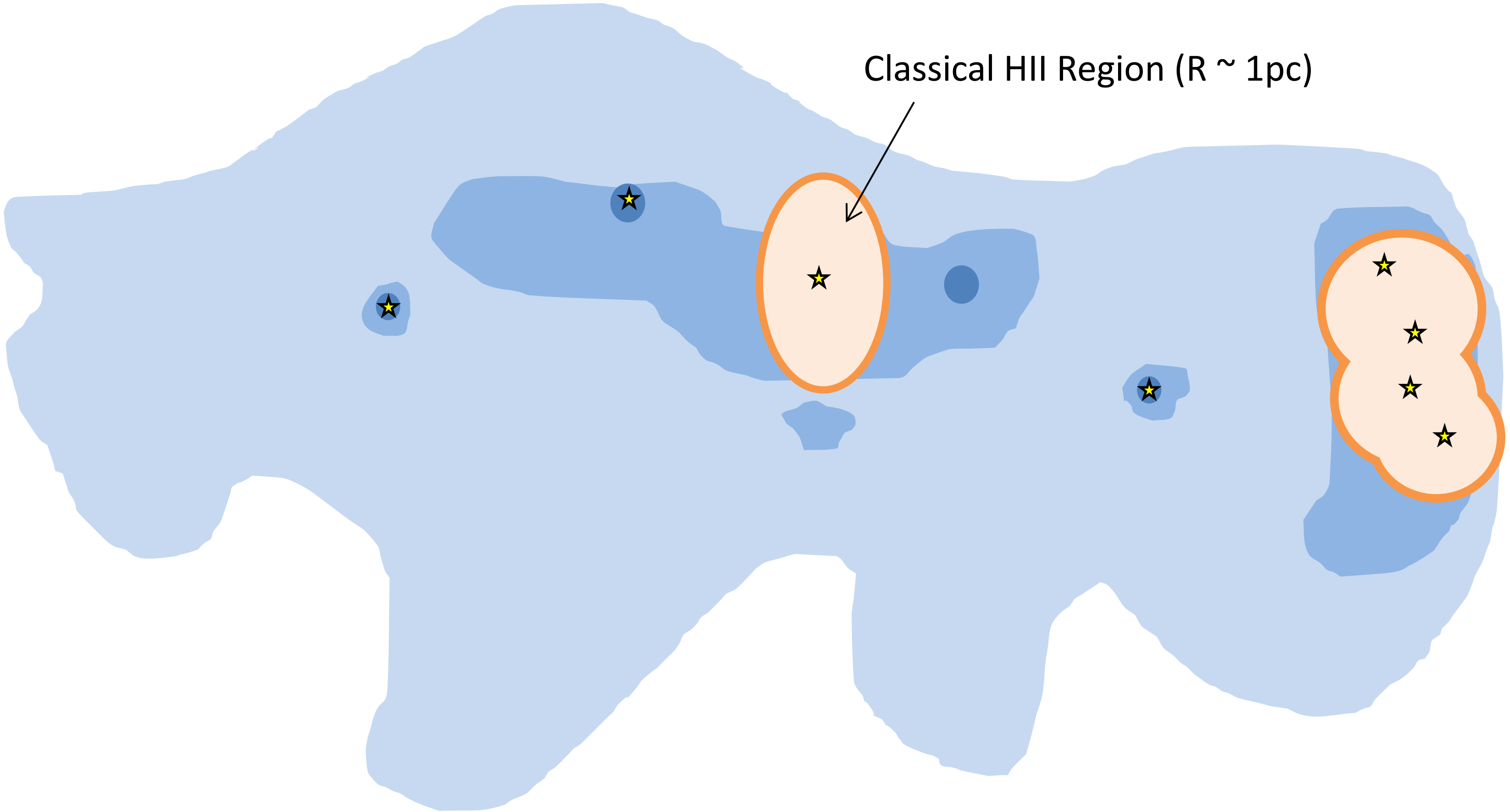
Evolution of a Giant Molecular Cloud

2 Myr

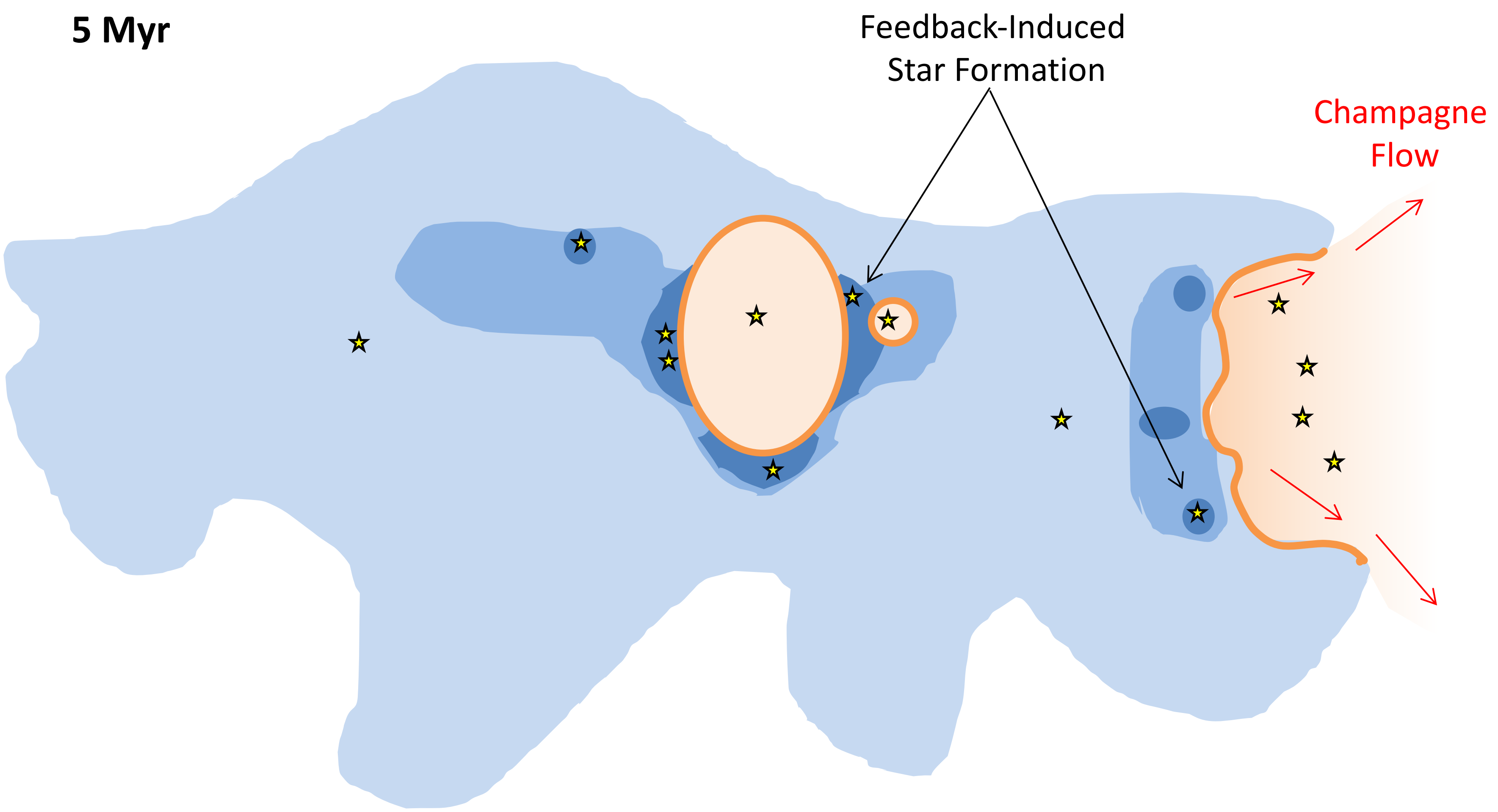


Evolution of a Giant Molecular Cloud

3 Myr

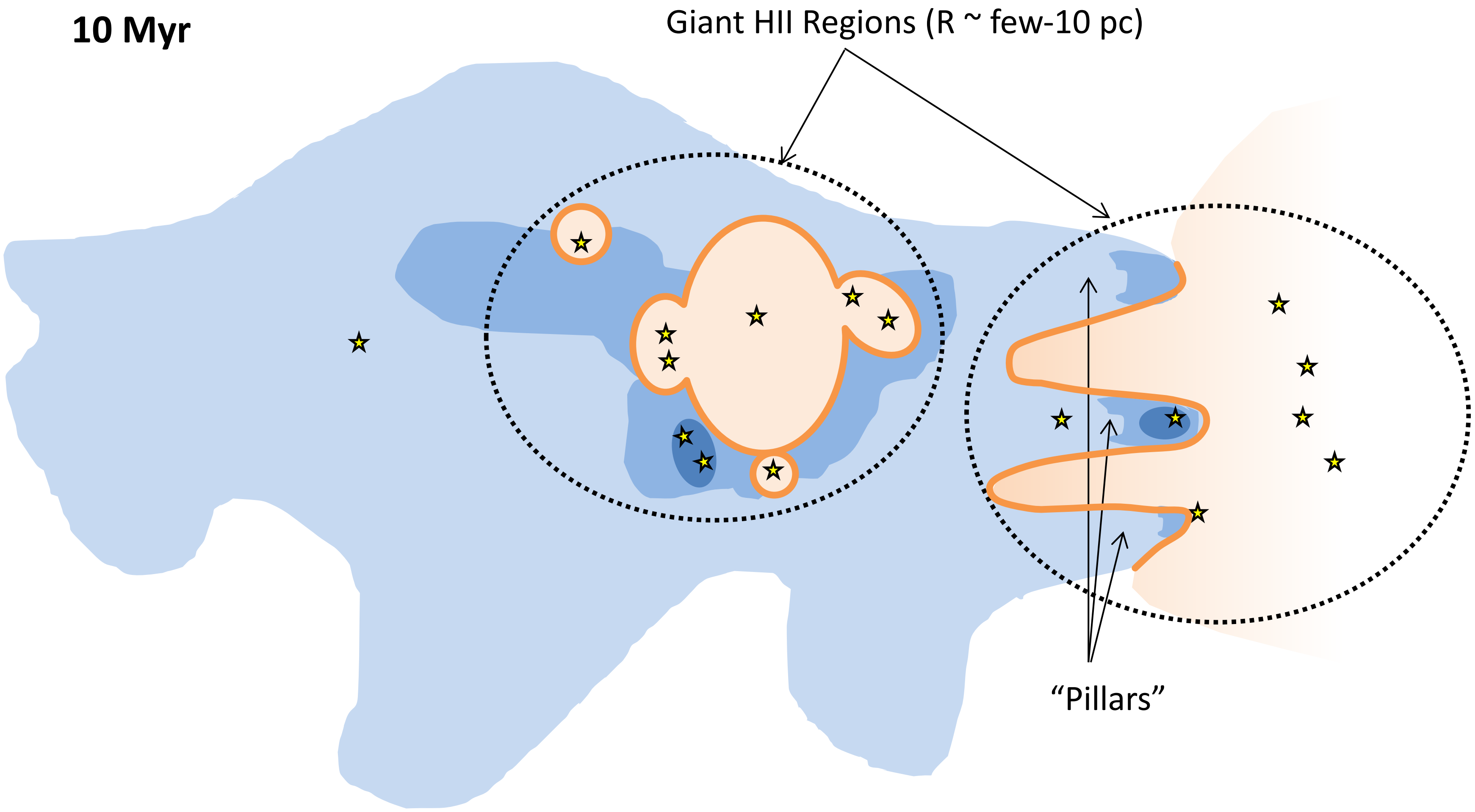


Evolution of a Giant Molecular Cloud



Evolution of a Giant Molecular Cloud

10 Myr



Evolution of a Giant Molecular Cloud

Giant HII regions have $N_{LyC} > 10^{50}$ photons/s (Mezger 1970)

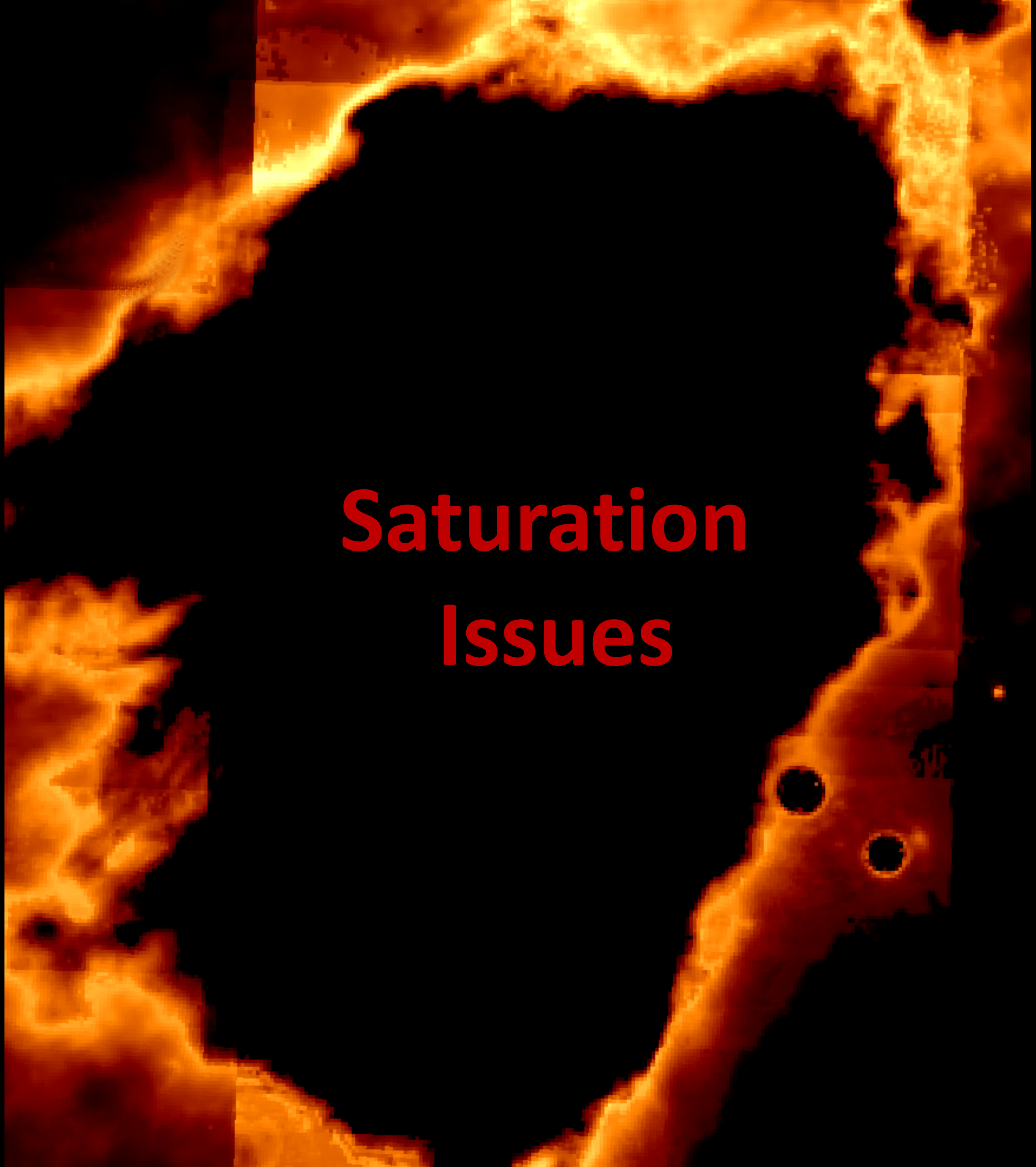
A census has found 56 IR-bright GHII regions in the Milky Way

(Conti & Crowther 2004)

Optical Image of M51 *Credit: GTC-OSIRIS, Daniel Lopez (IAC)*

Motivation is to see what we can learn about the physical properties of GHII regions separately and as a population with the hope of using the information as a template for what we can't resolve in external galaxies using FORCAST/SOFIA with the *highest resolutions* yet achieved at MIR wavelengths from 20 to 40 microns

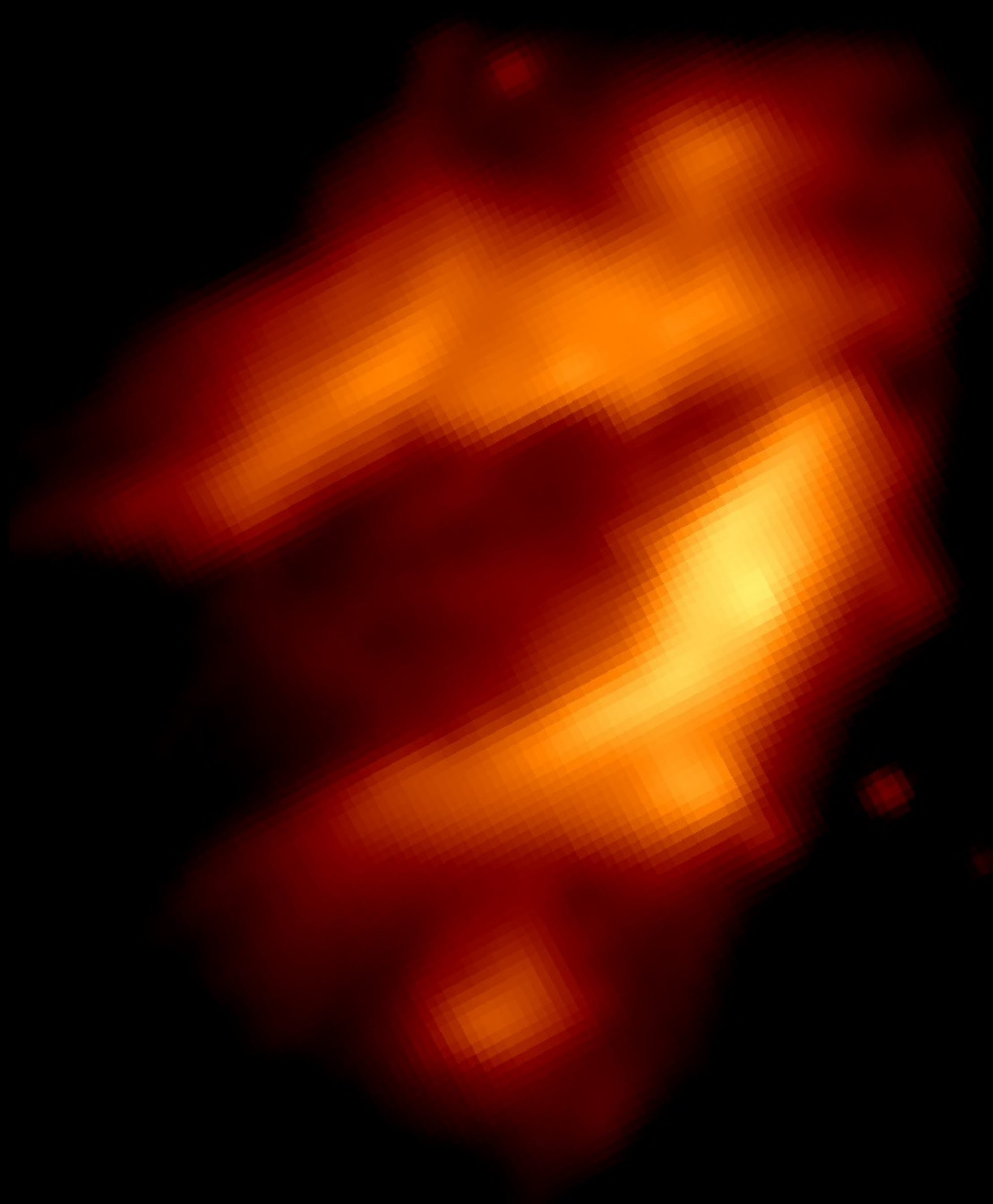
M17



Spitzer

λ = 24 µm
Θ_{res} ~ 6”

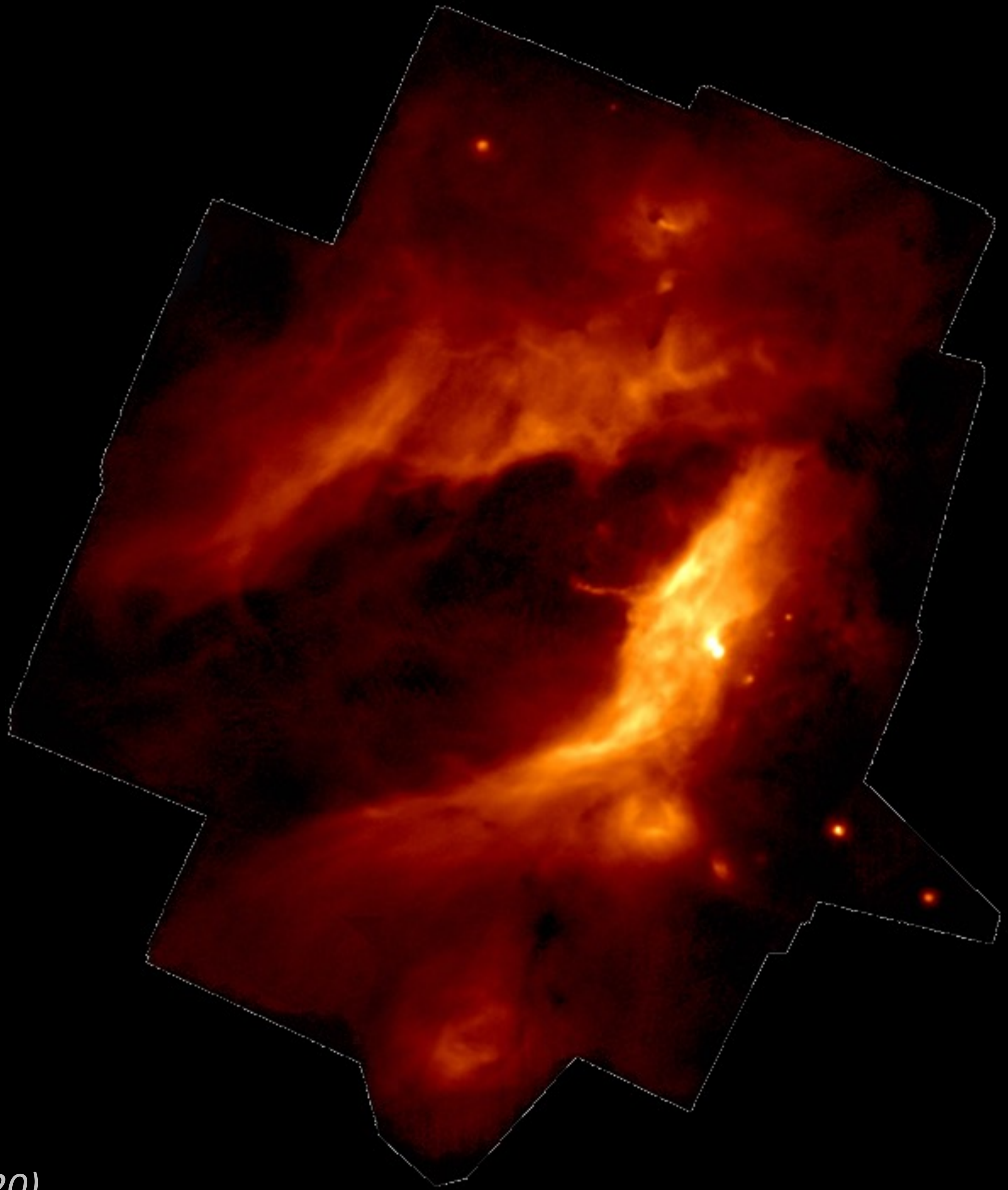
M17



MSX

λ = 22 µm
Θ_{res} ~ 18”

M17

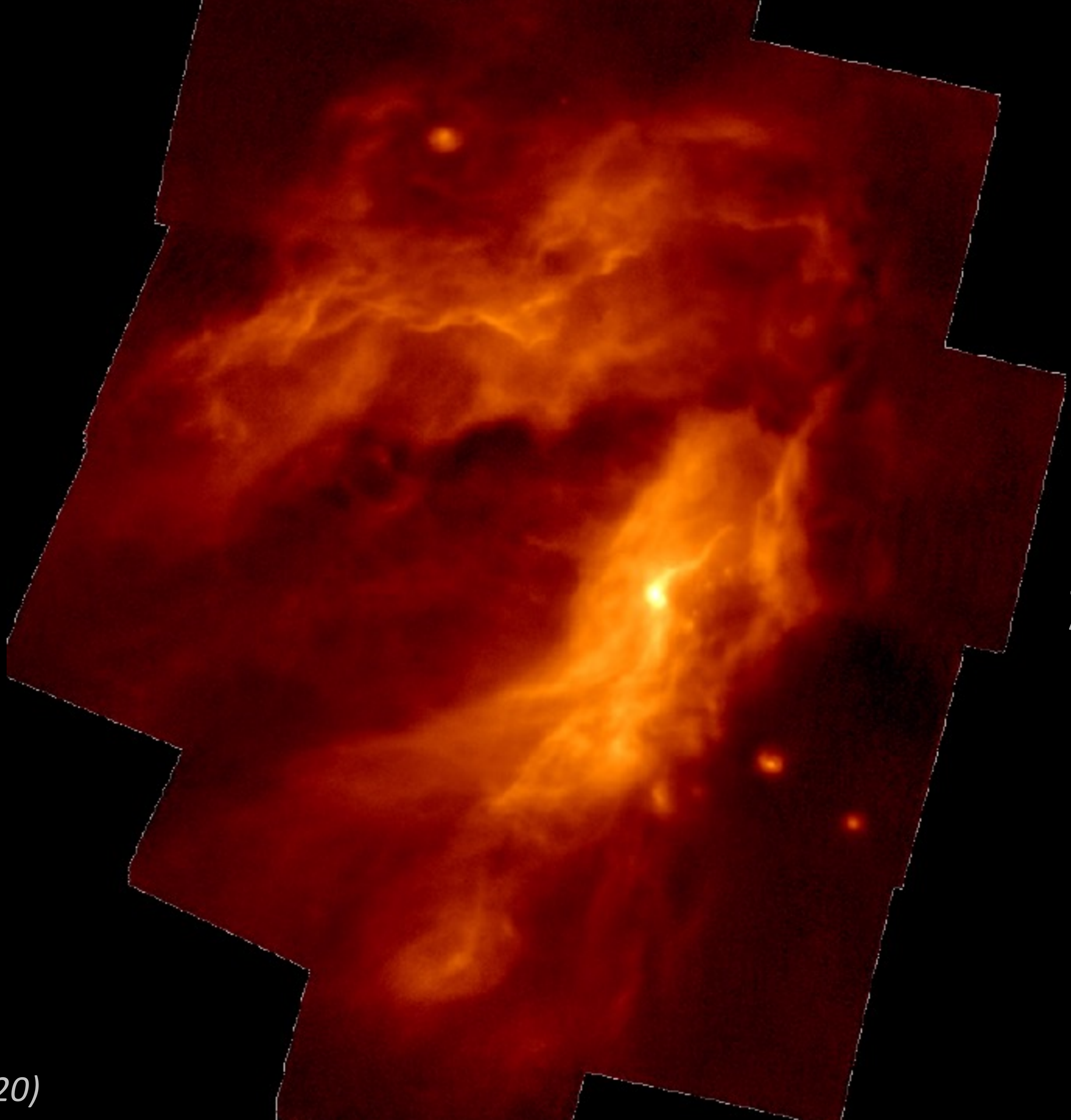


SOFIA

λ = 20 μm
Θ_{res} ~ 2.5"

Lim, De Buizer, & Radomski (2020)

M17

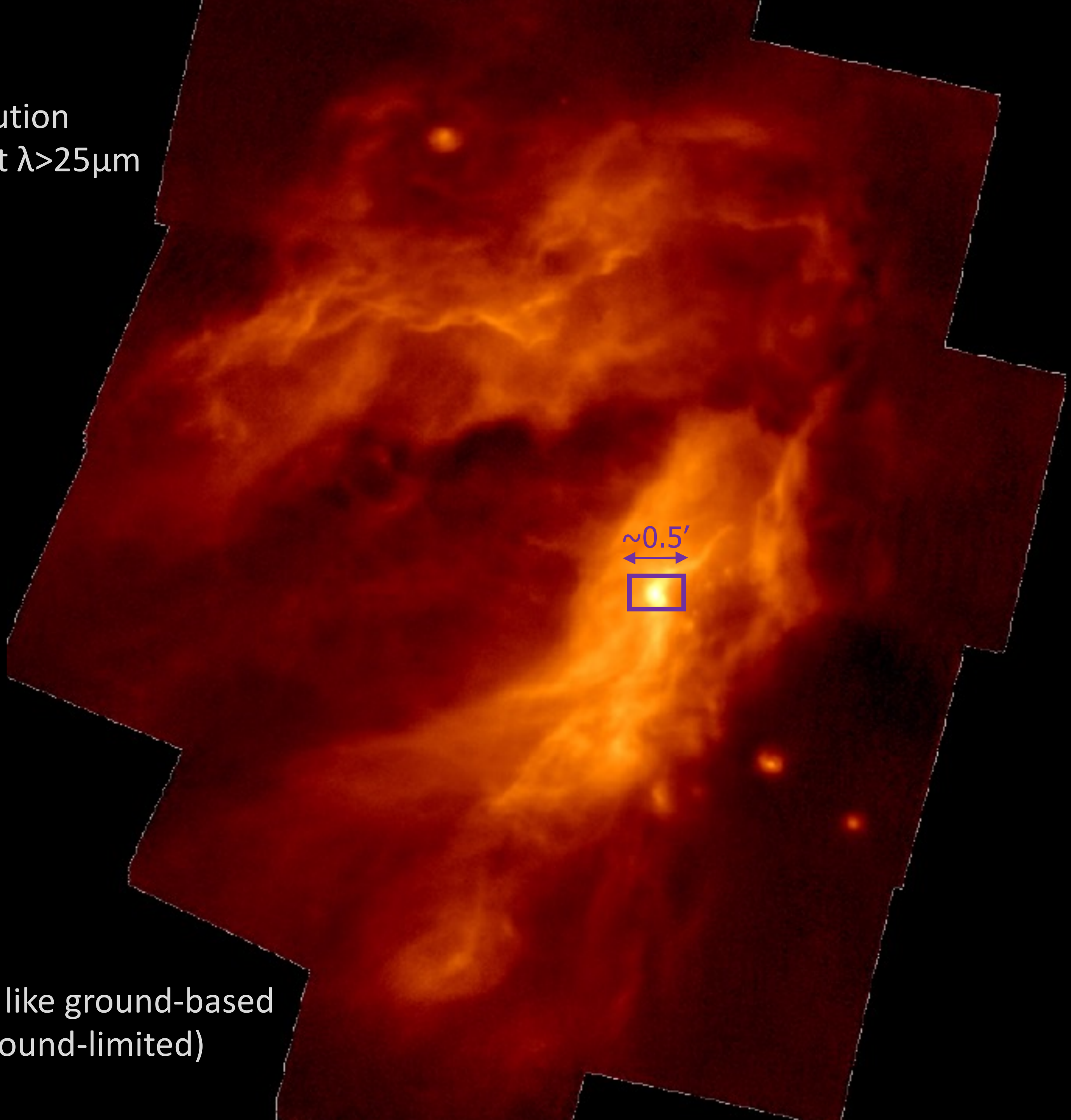


SOFIA

$\lambda = 37\ \mu m$
$\Theta_{res} \sim 3.0''$

Lim, De Buizer, & Radomski (2020)

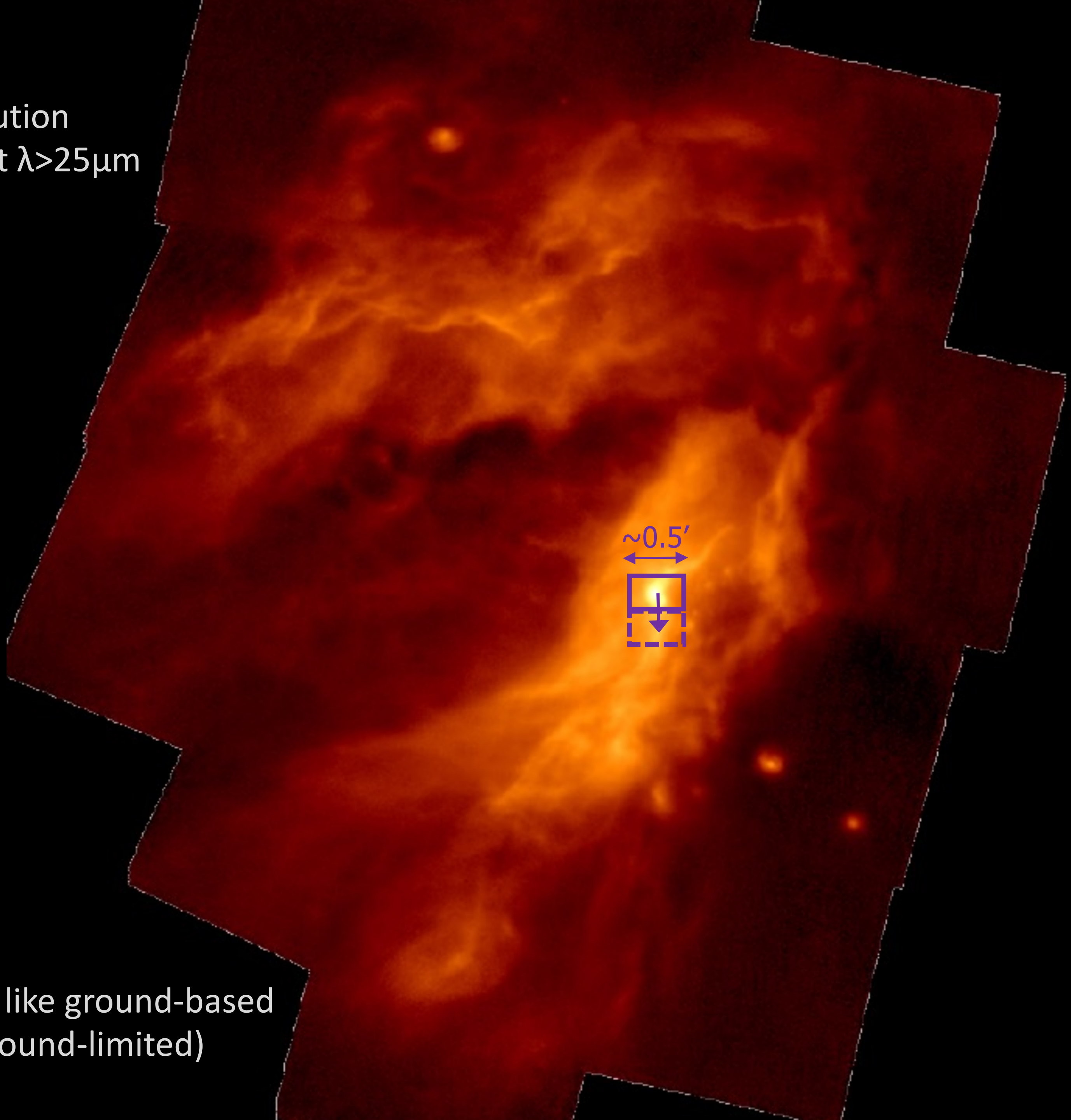
SOFIA enables best-ever resolution
MIR images of these regions at λ>25μm



SOFIA observations are more like ground-based than space-based (i.e. background-limited)

SOFIA 37 μm

SOFIA enables best-ever resolution
MIR images of these regions at λ>25μm



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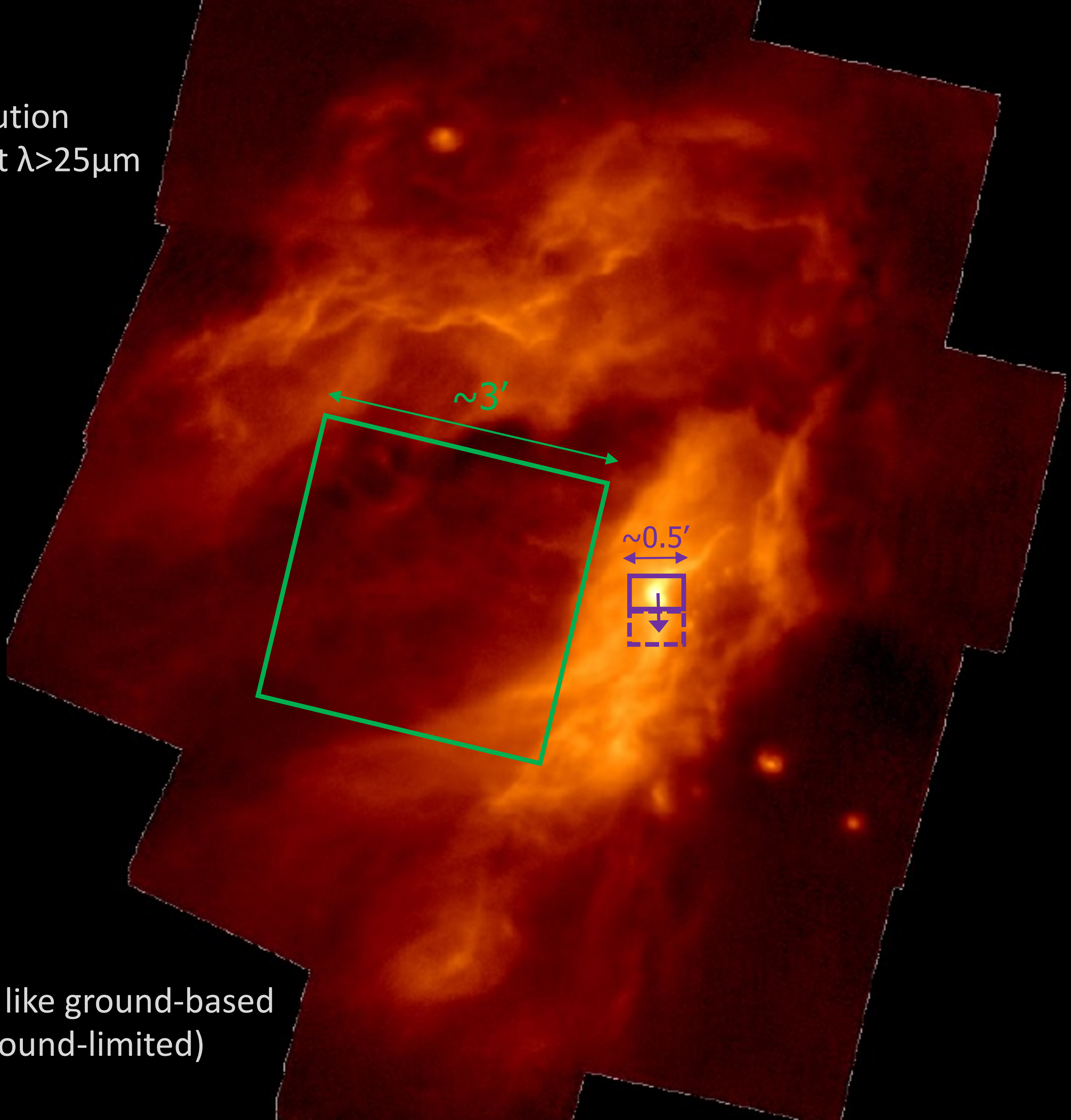

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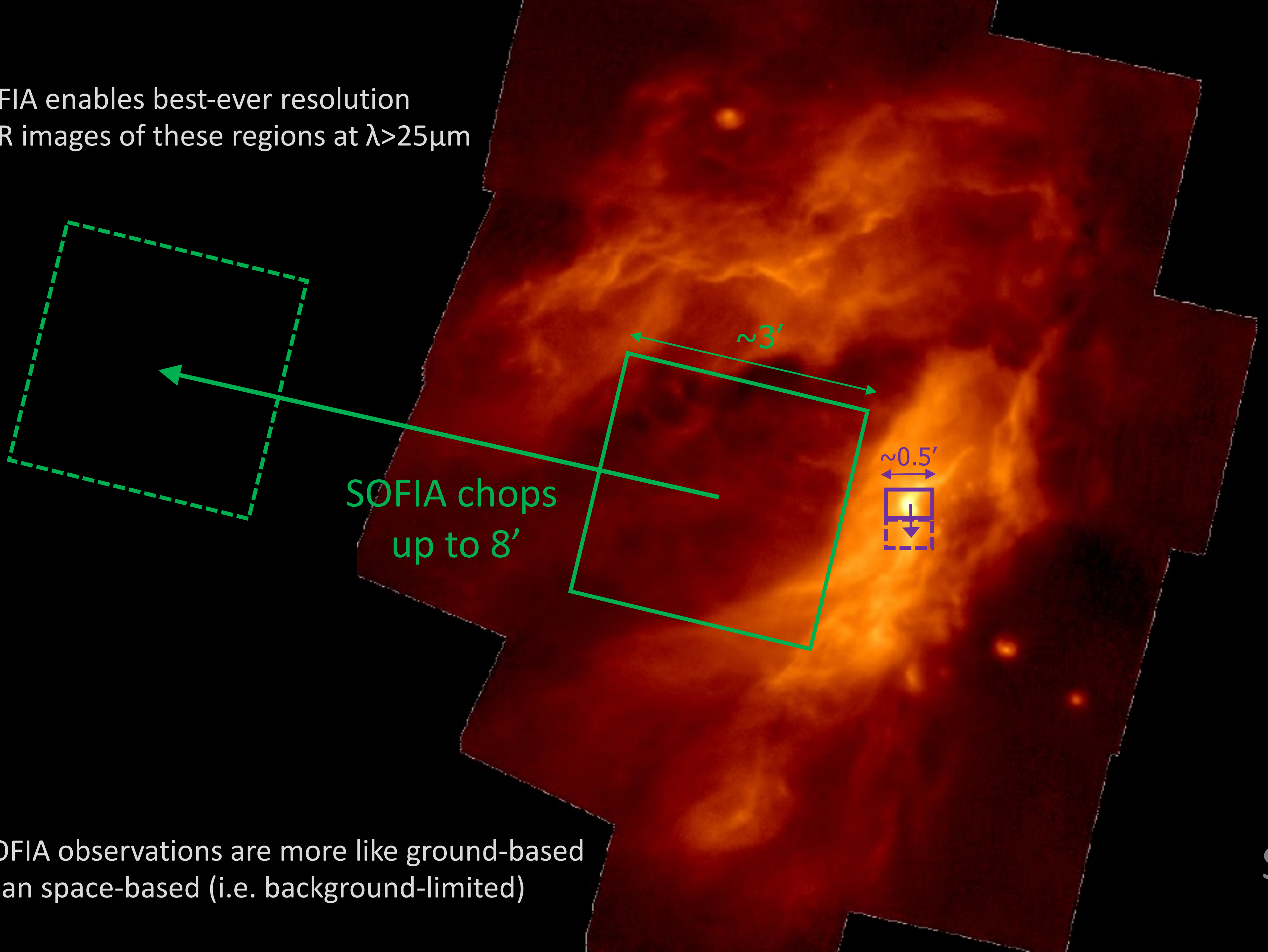
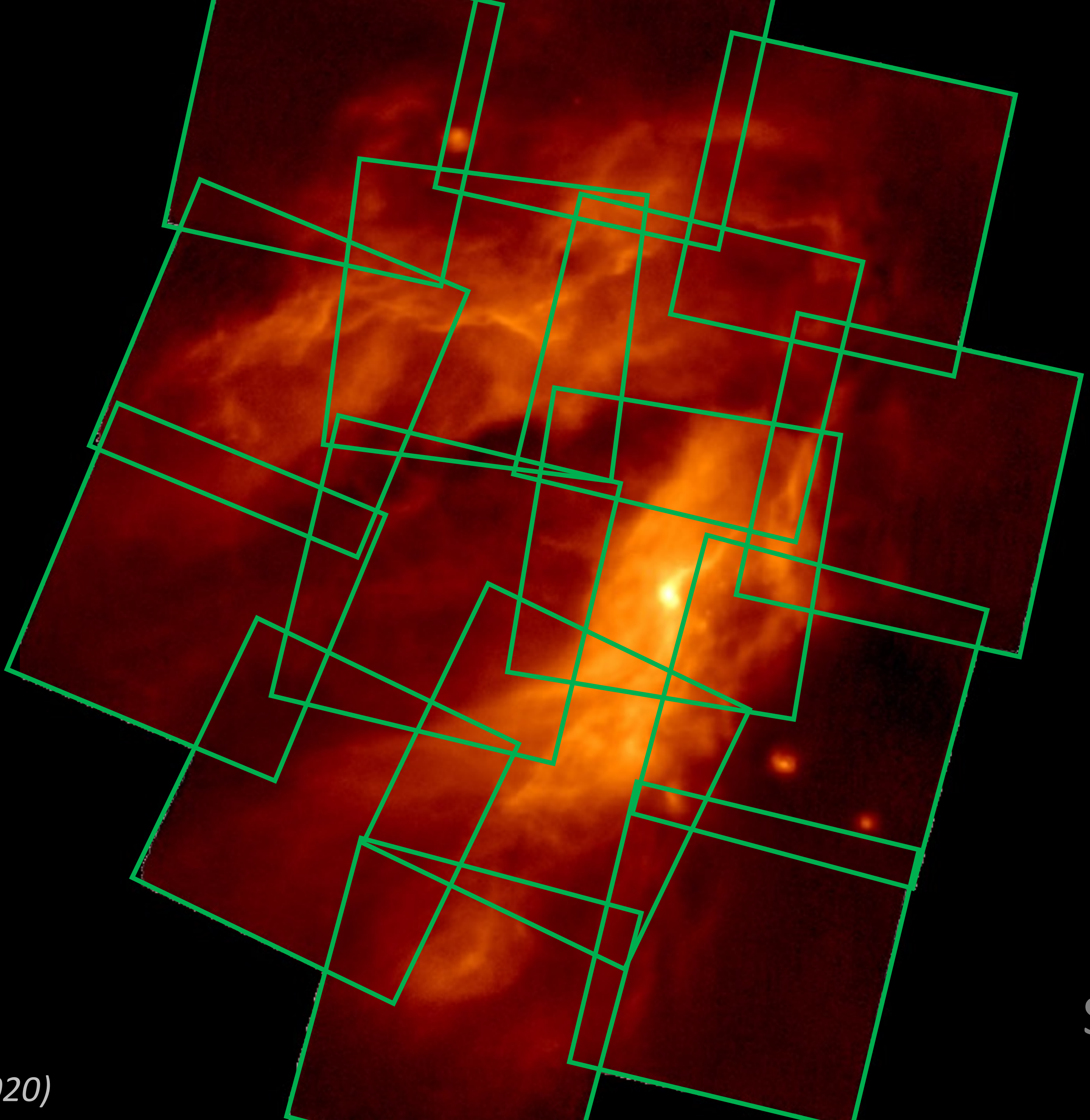


SOFIA observations are more like ground-based than space-based (i.e. background-limited)

Mapped with
15 pointings

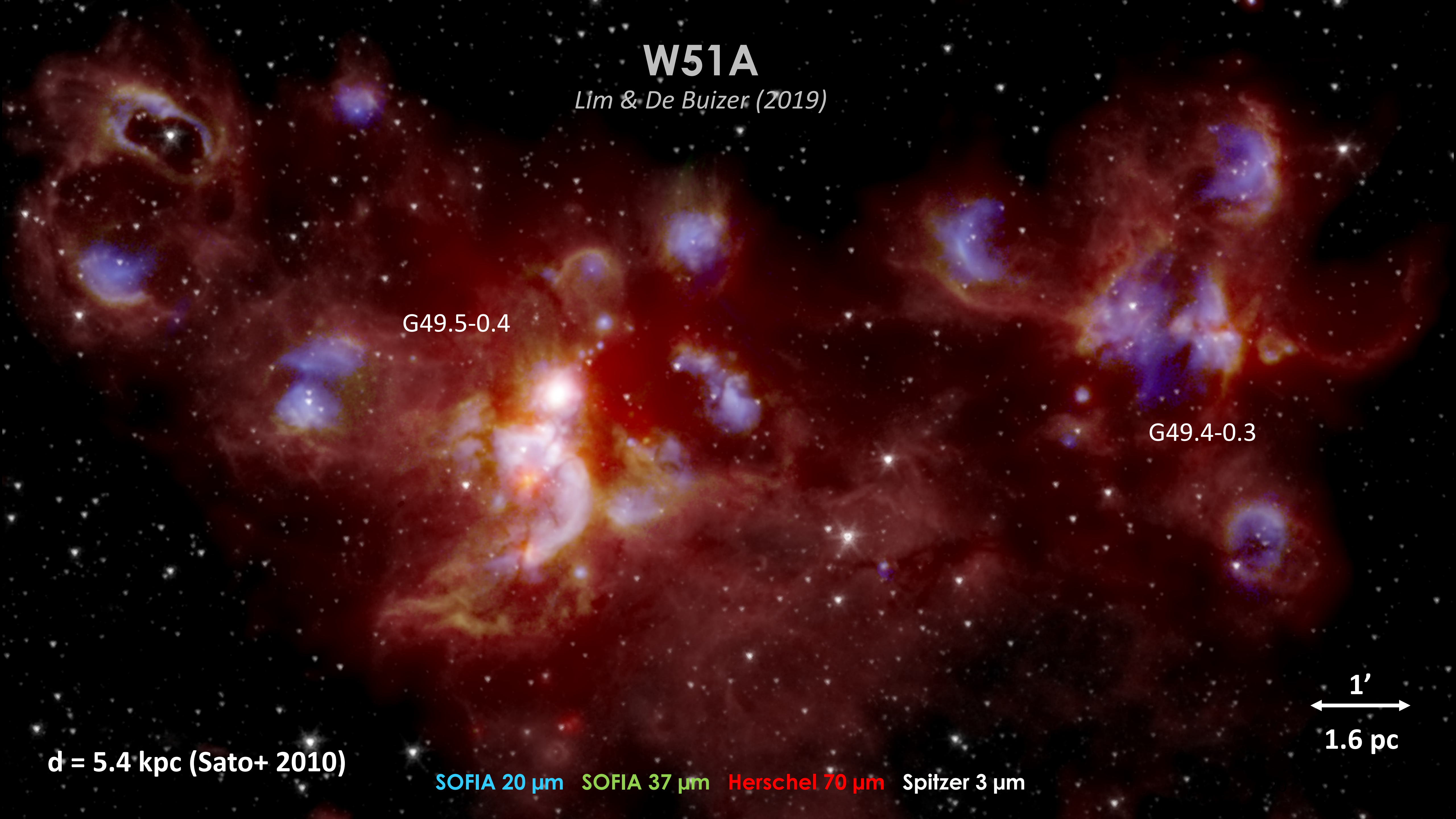


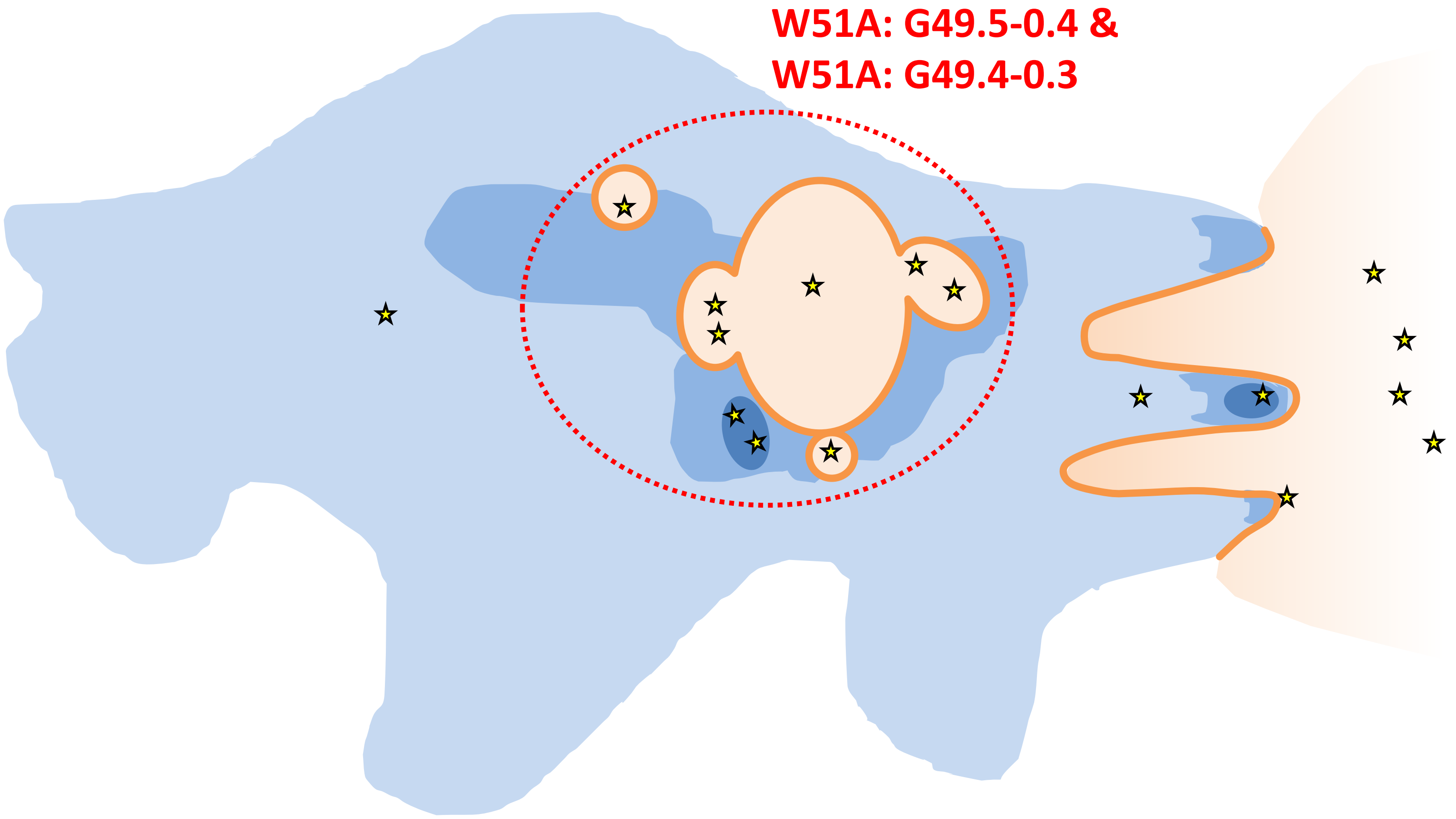
Lim, De Buizer, & Radomski (2020)


SOFIA 20 µm SOFIA 37 µm Herschel 70 µm Spitzer 3 µm

FORCAST Computer/Phone Wallpapers: http://www.jim-debuizer.net/

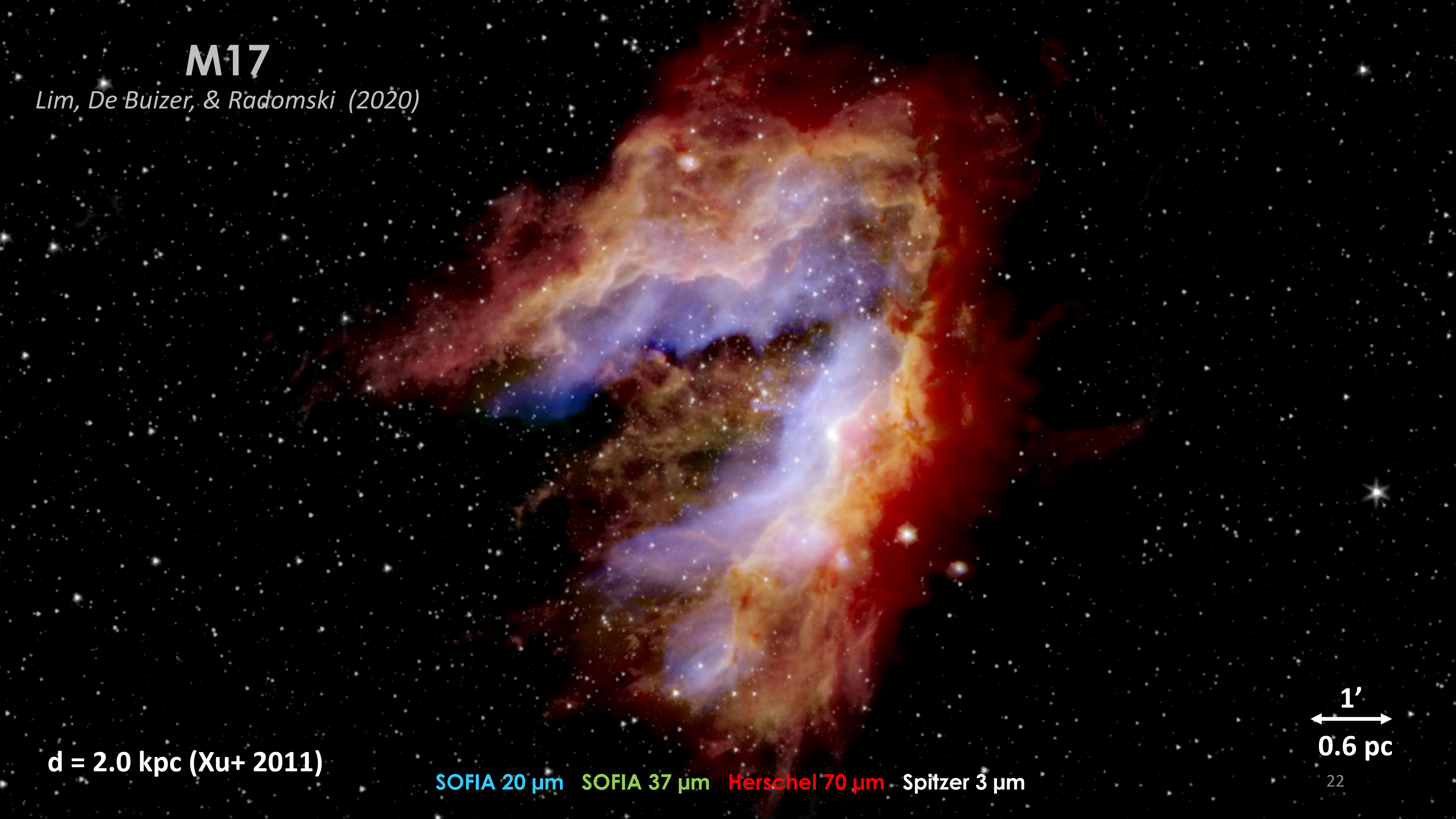
SOFIA 20 μm SOFIA 37 μm Herschel 70 μm Spitzer 3 μm


W51A
Lim & De Buizer (2019)
G49.5-0.4
G49.4-0.3
1’
1.6 pc
d = 5.4 kpc (Sato+ 2010)
SOFIA 20 μm SOFIA 37 μm Herschel 70 μm Spitzer 3 μm

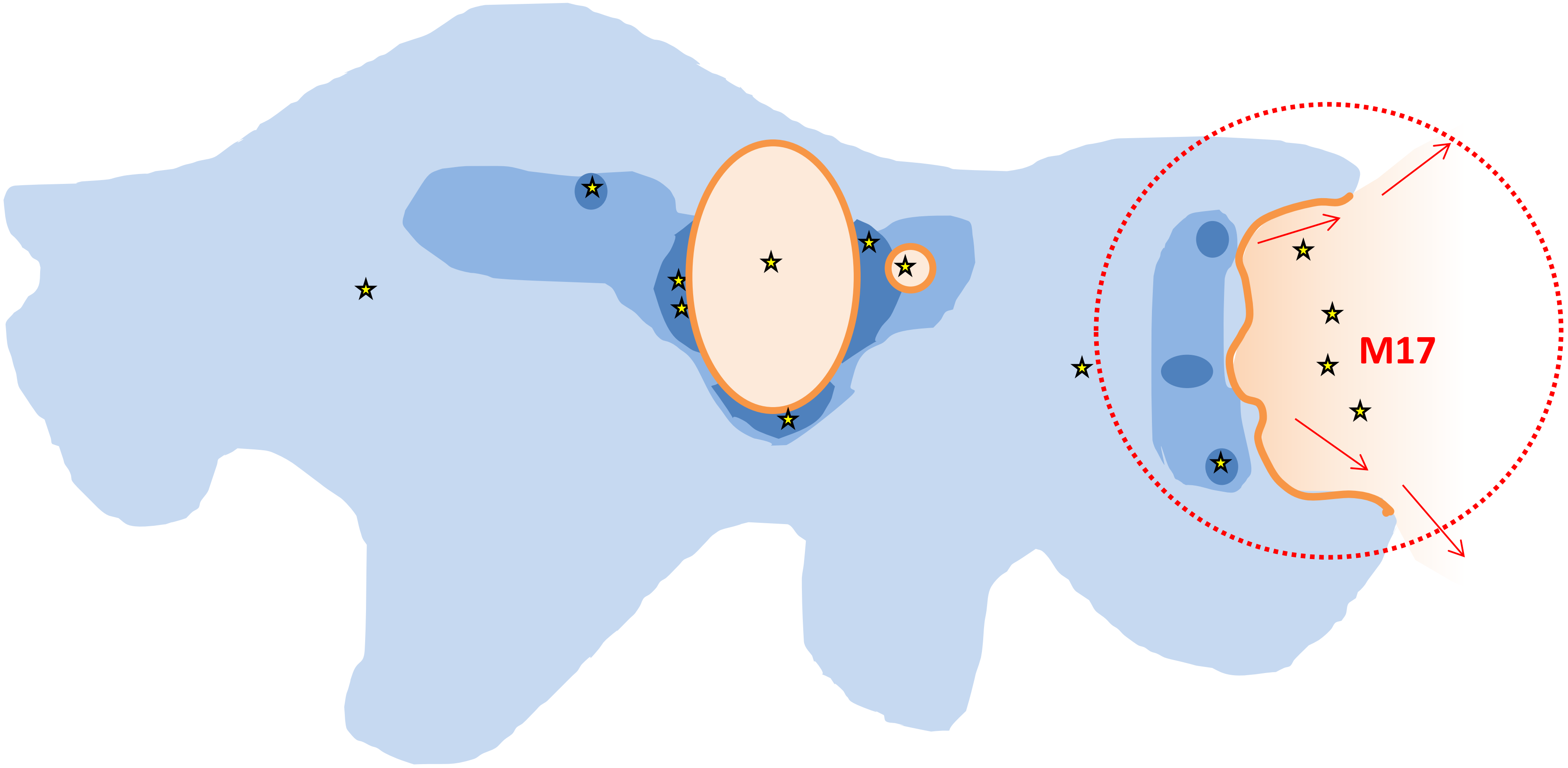

W51A: G49.5-0.4 &
W51A: G49.4-0.3

M17

Lim, De Buizer, & Radomski (2020)

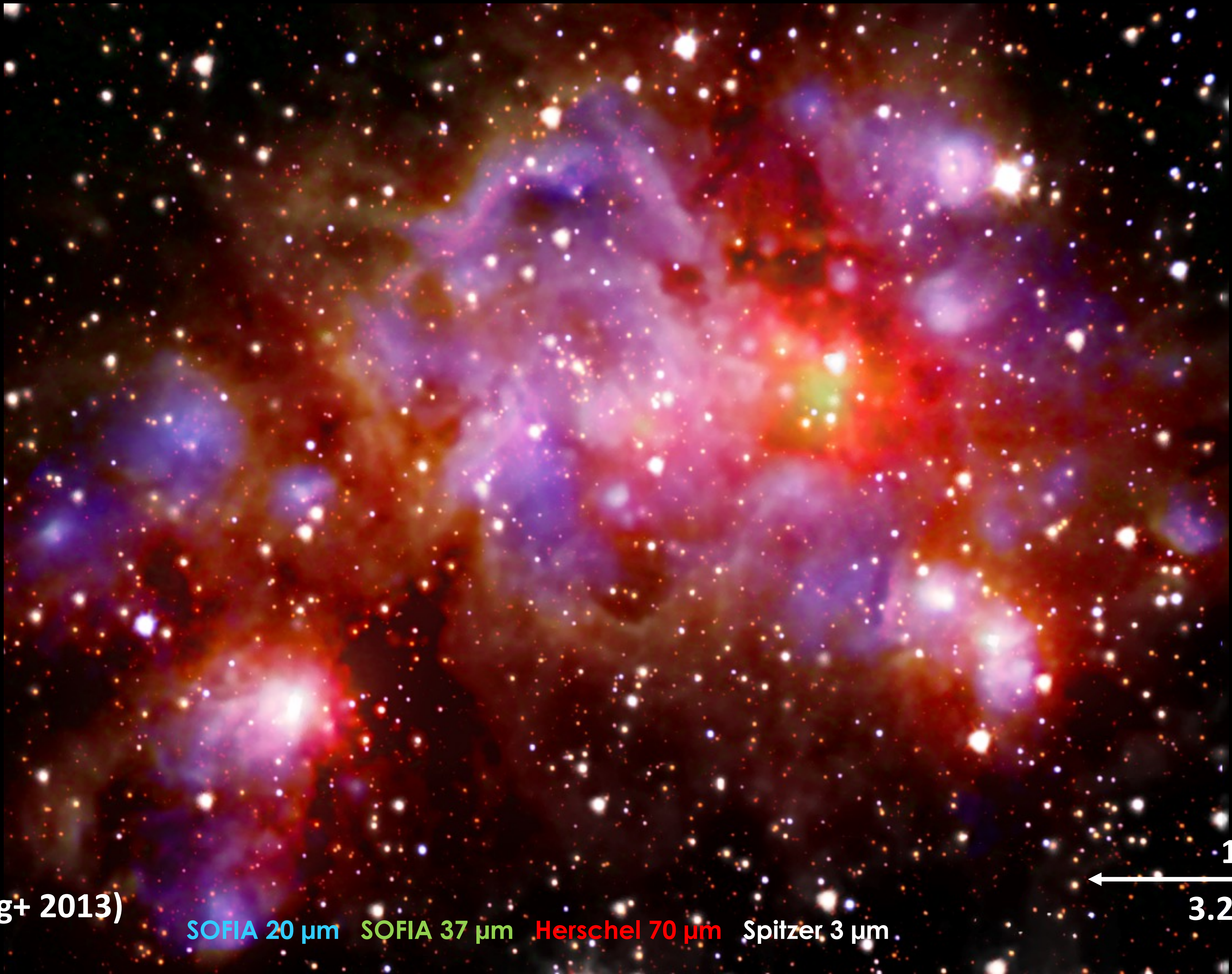


d = 2.0 kpc (Xu+ 2011)

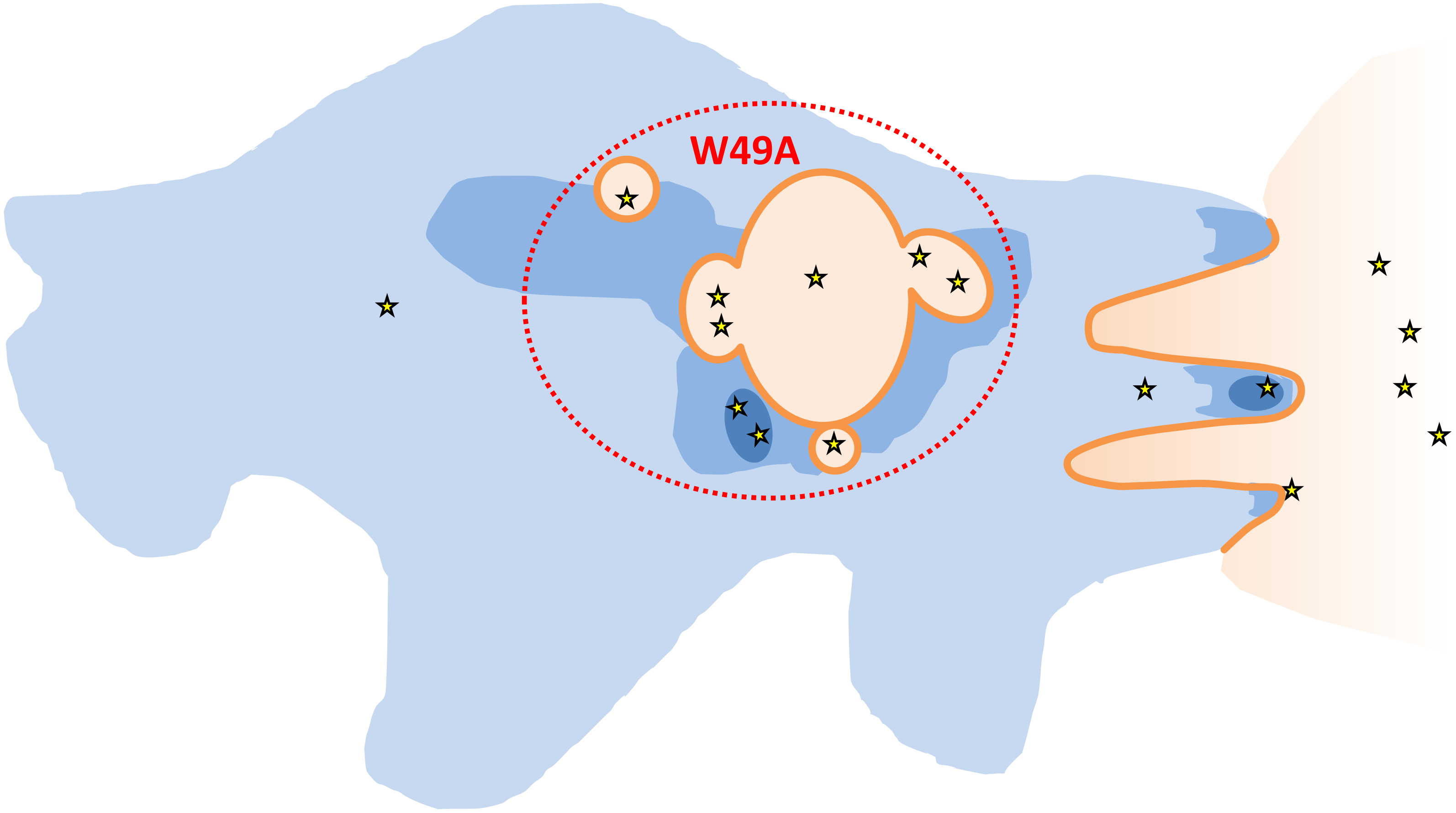

M17

W49A

De Buizer et al. (2021)

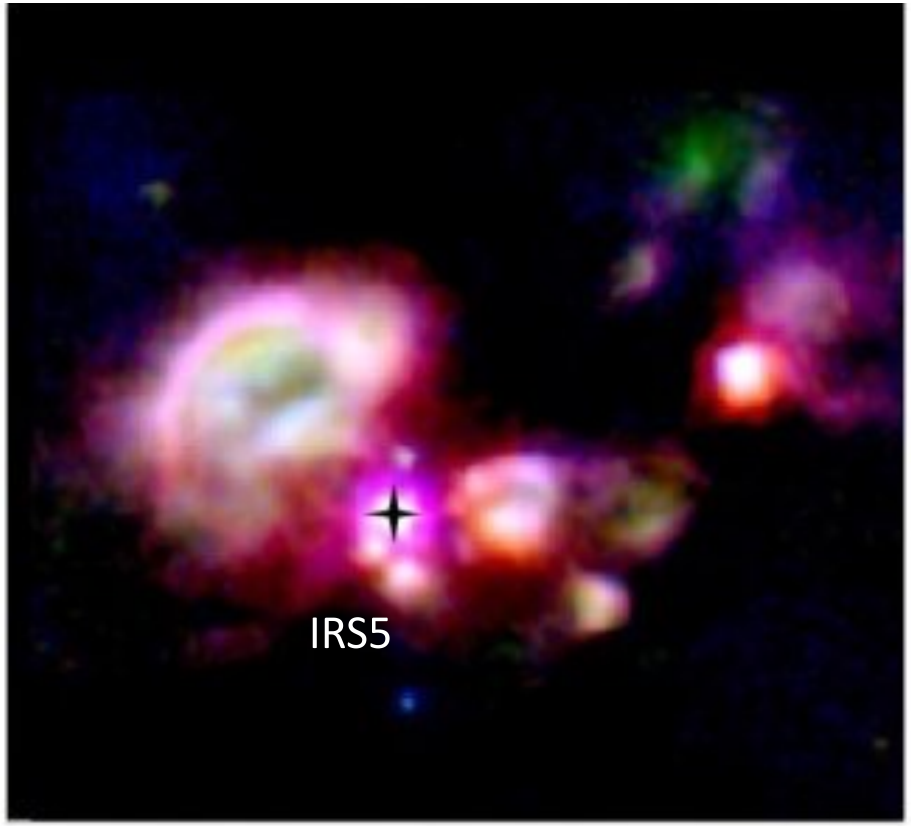


d = 11.1 kpc (Zhang+ 2013)

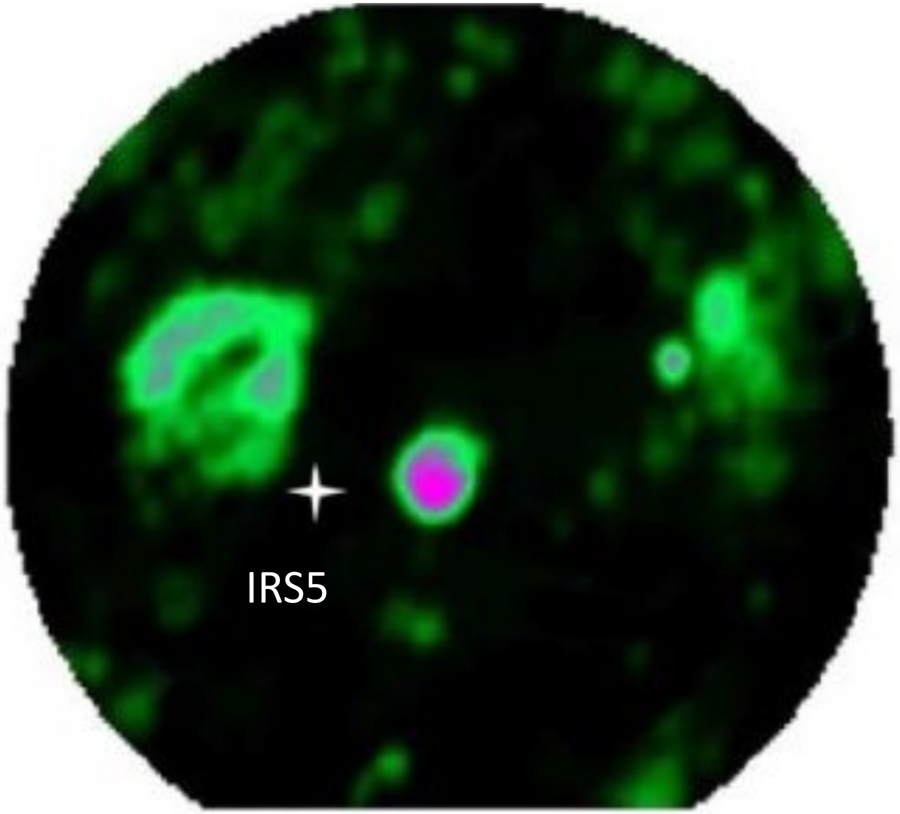

W49A

Goal #1: To quantify the *missing* embedded populations of the youngest cluster members within GHII regions to understand the present level of massive star formation occurring in each region

W3



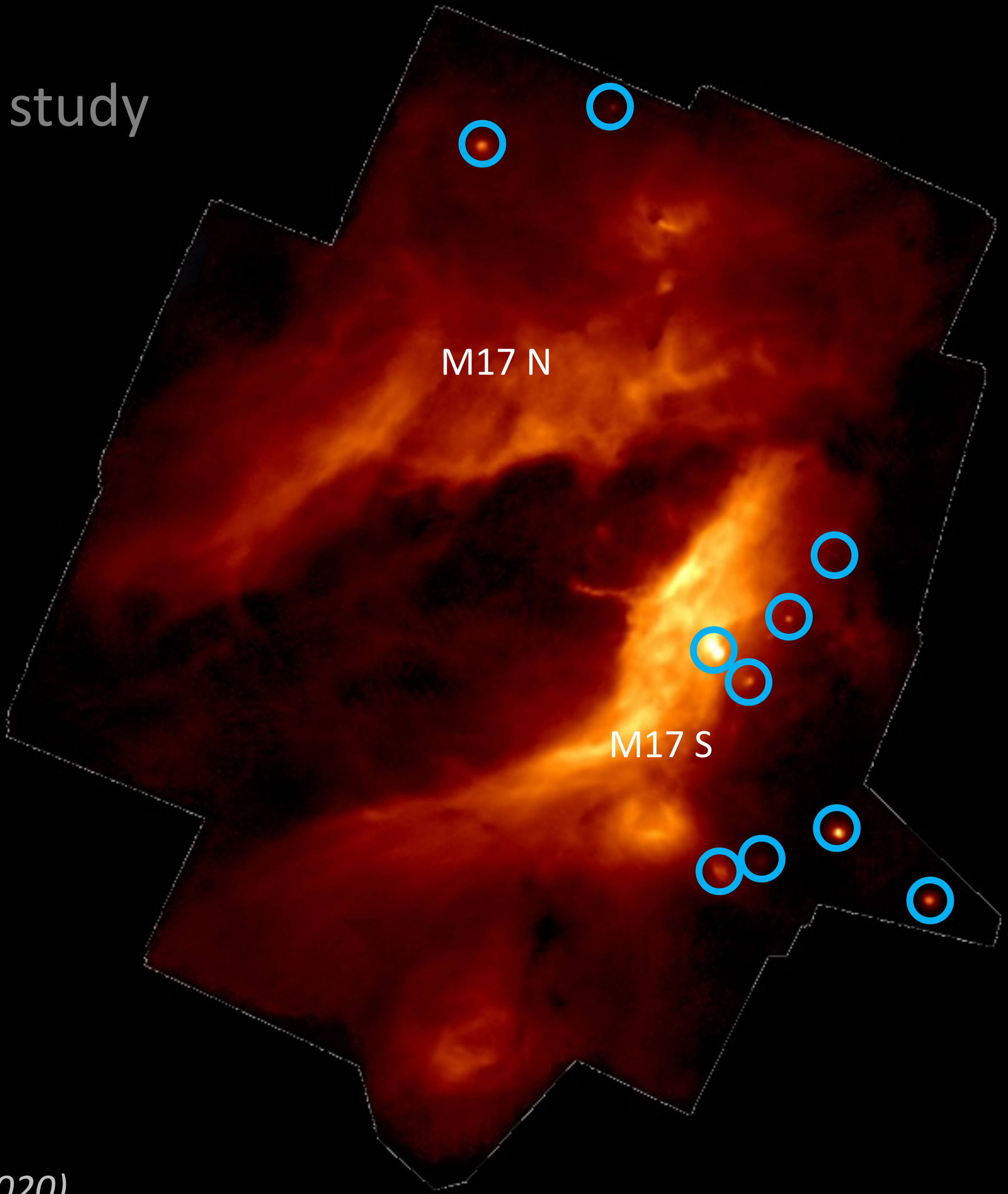
SOFIA 6µm, 19µm, 37µm



VLA 2cm

IRS5 L_{IR}= 500,000 L_{sun}

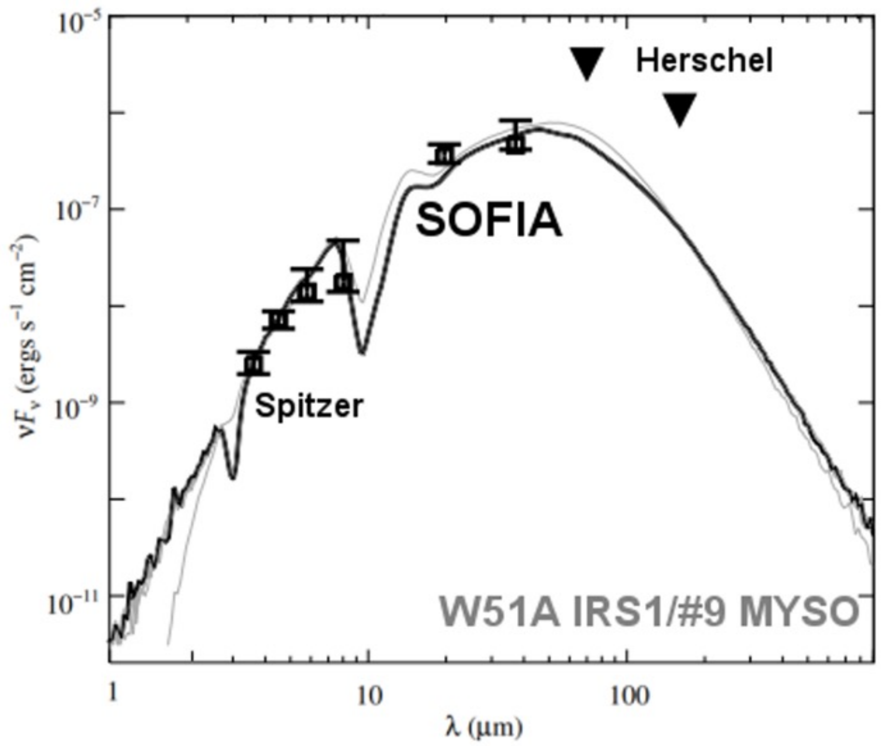
MYSO population study



SOFIA 20 µm

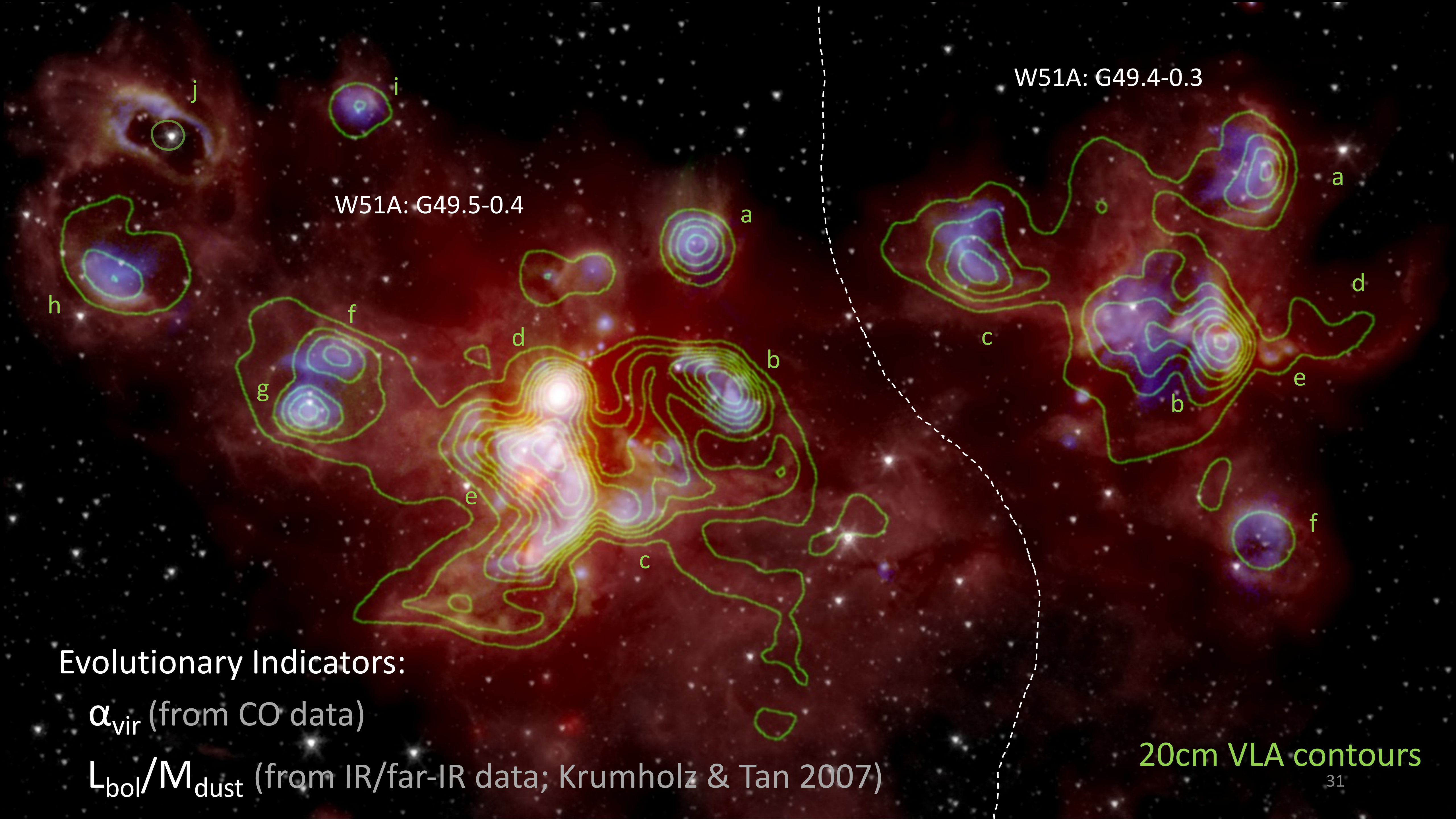
Lim, De Buizer, & Radomski (2020)

SED fitting using Zhang and Tan (2011) MYSO models



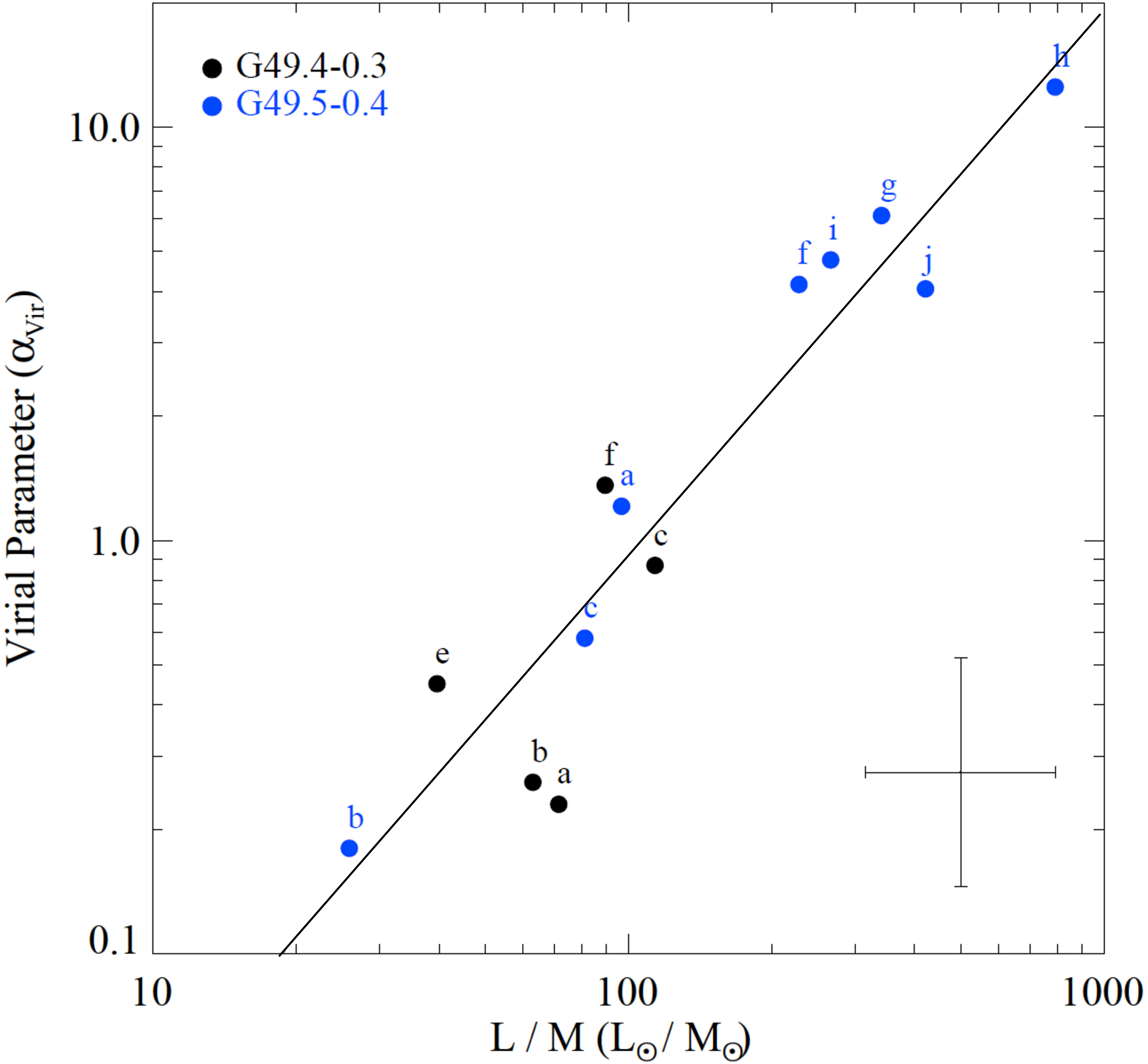
	Total # MYSOs	#Non-ionizing MYSOs	Most Massive
W51A: G49.5-0.4	34	16	96 M_{sun}
W51A: G49.4-0.3	7	4	64 M_{sun}
M17	7	5	64 M_{sun}
W49A	22	4	128 M_{sun}

Goal #2: **To discover/test the (sometimes conflicting) hypotheses regarding the internal evolution and origin of each GHII region to better understand the formation and evolution of GHII regions in general**

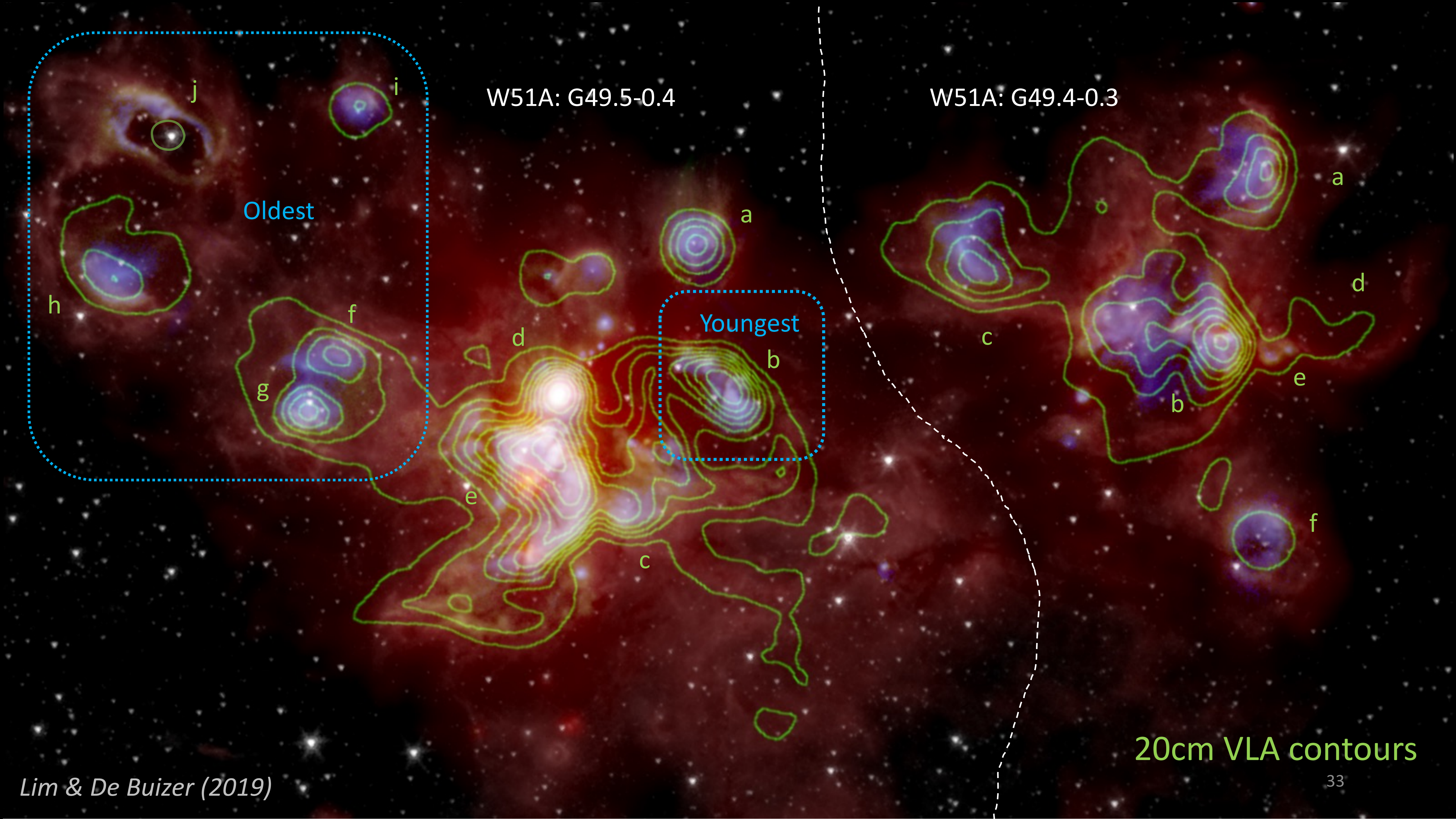


Evolutionary Indicators:

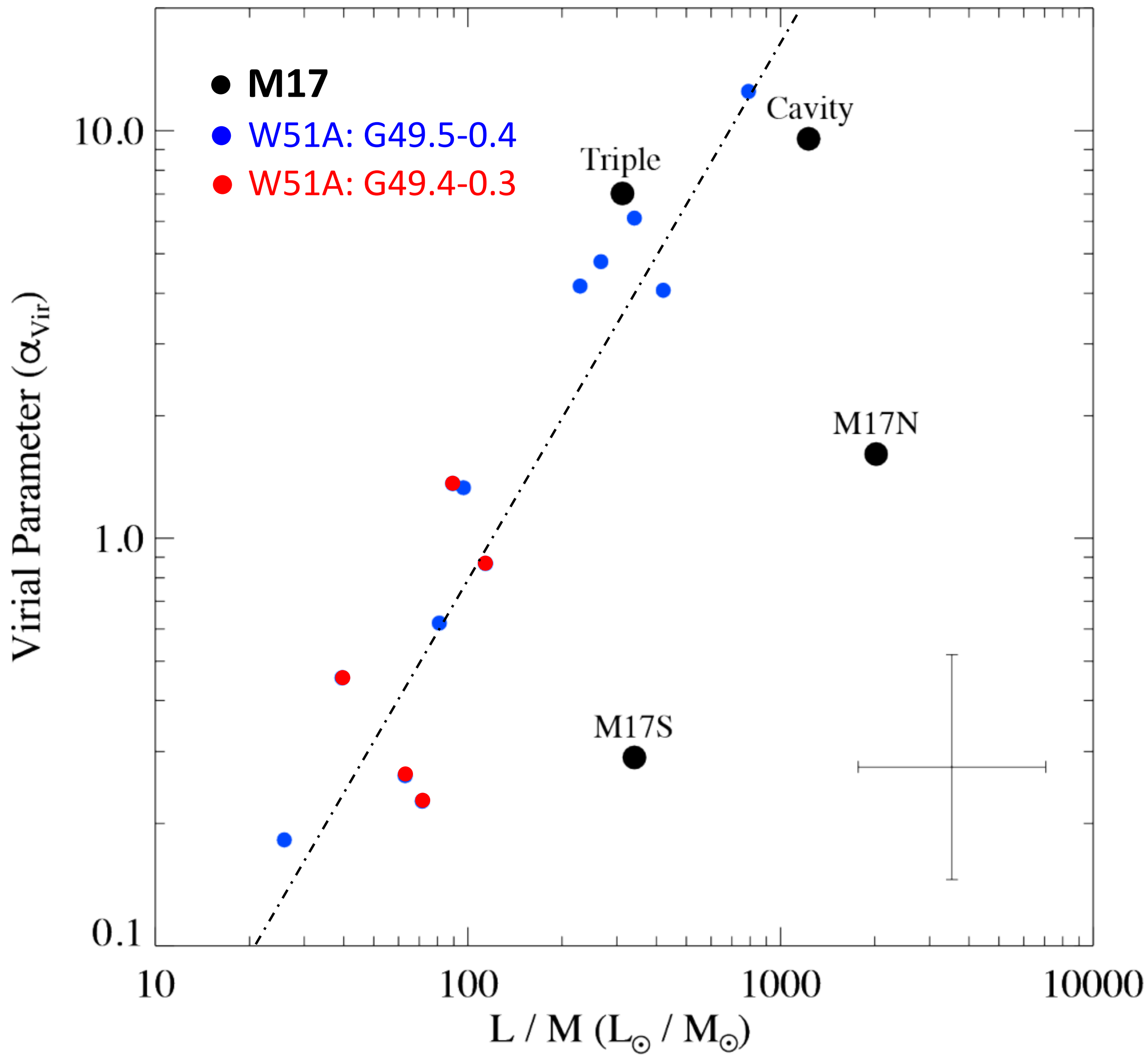
- α_{vir} (from CO data)
- L_{bol}/M_{dust} (from IR/far-IR data; Krumholz & Tan 2007)

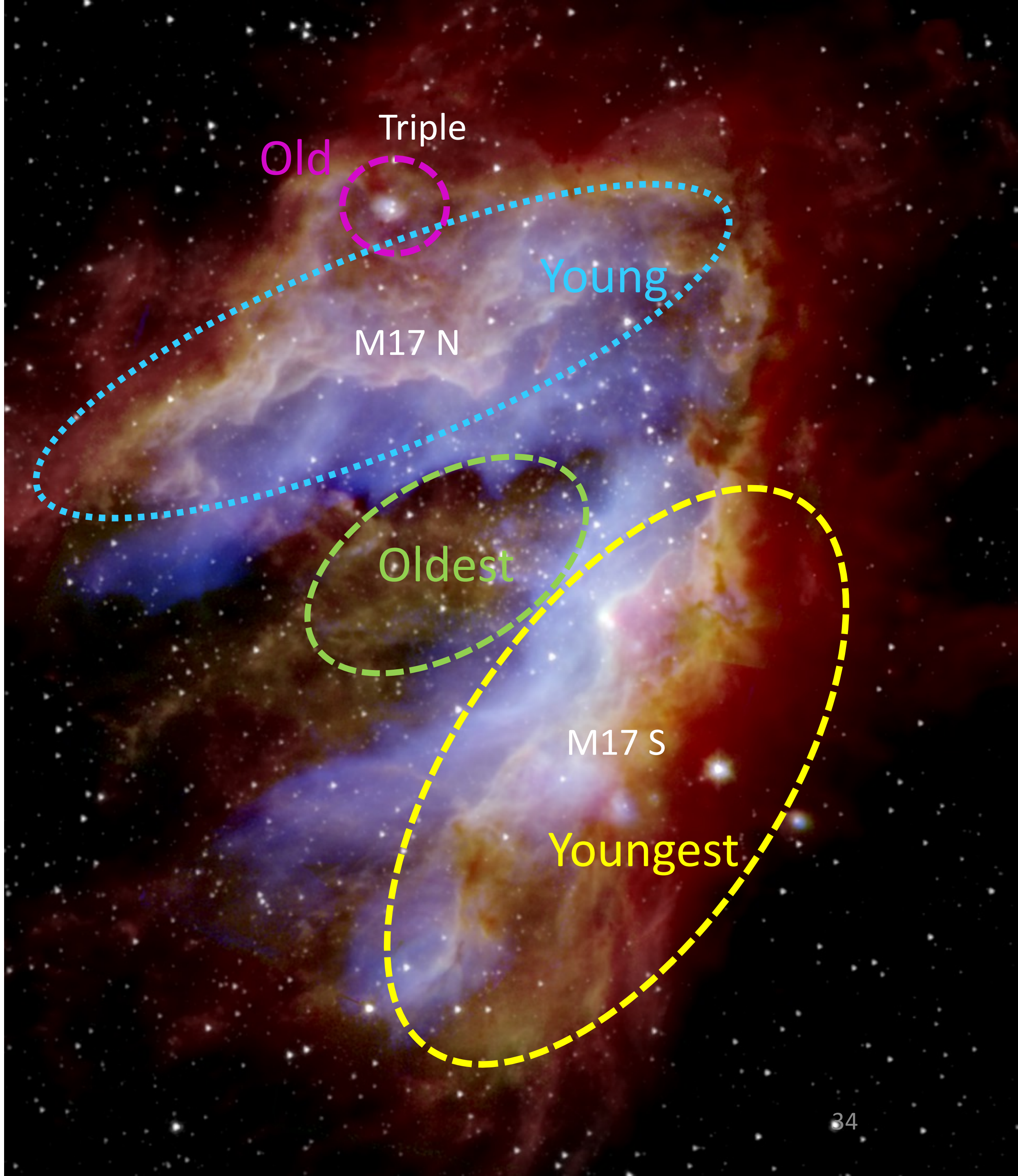


Lim & De Buizer (2019)

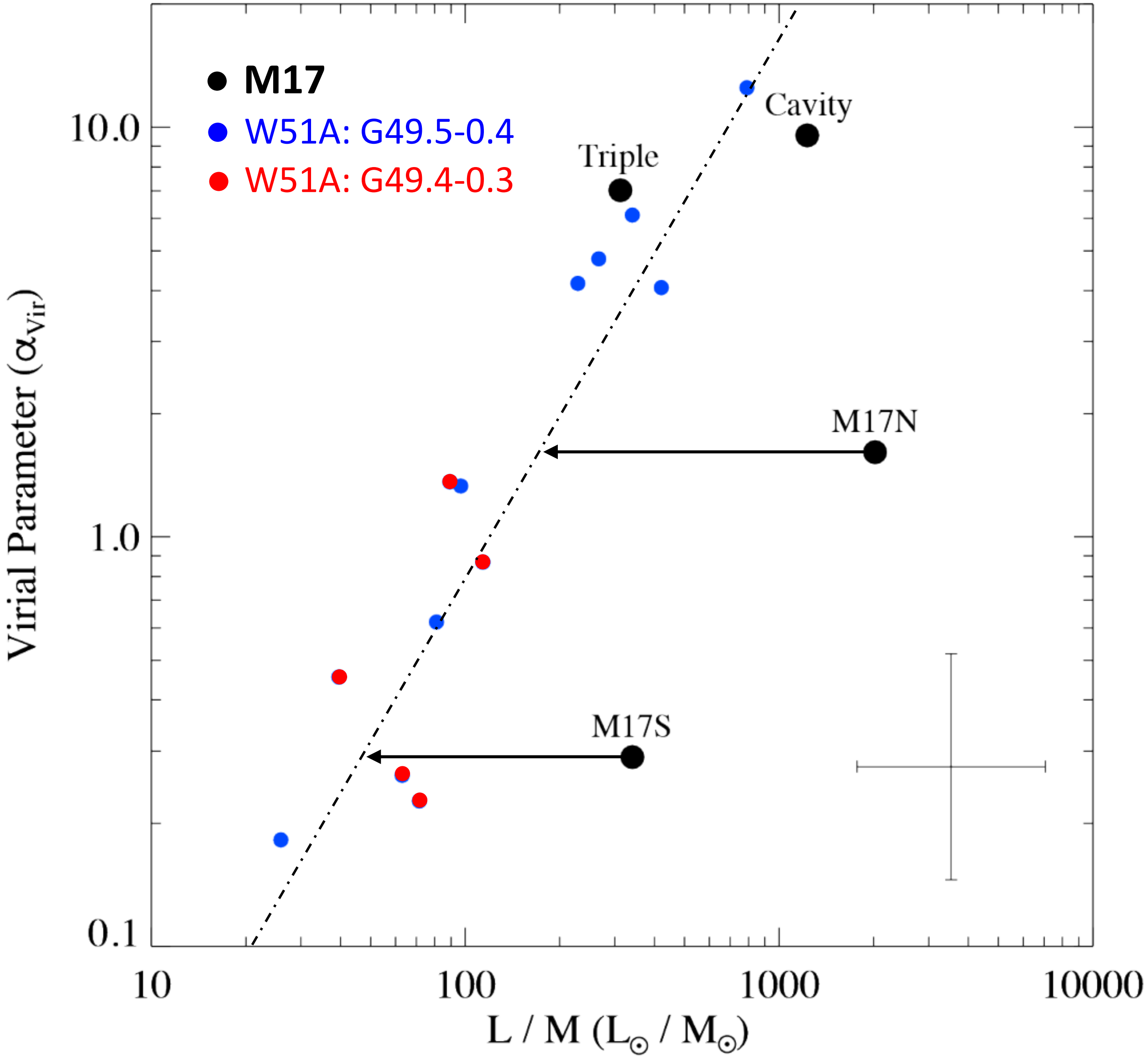


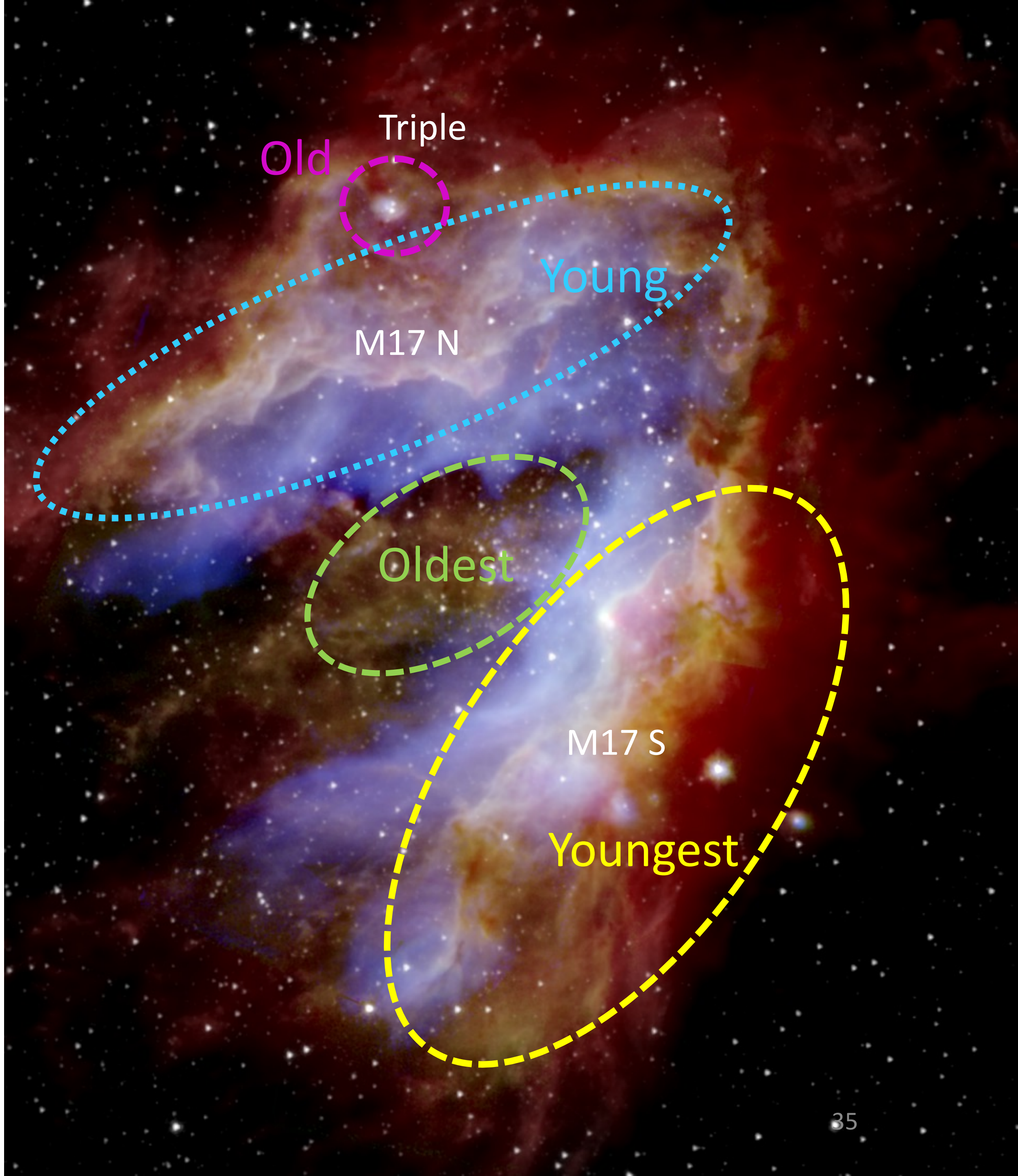
W51A: G49.5-0.4
W51A: G49.4-0.3
Oldest
Youngest
j
i
h
f
g
a
d
b
e
c
a
c
d
b
e
f
20cm VLA contours
Lim & De Buizer (2019)





Lim, De Buizer, & Radomski (2020)

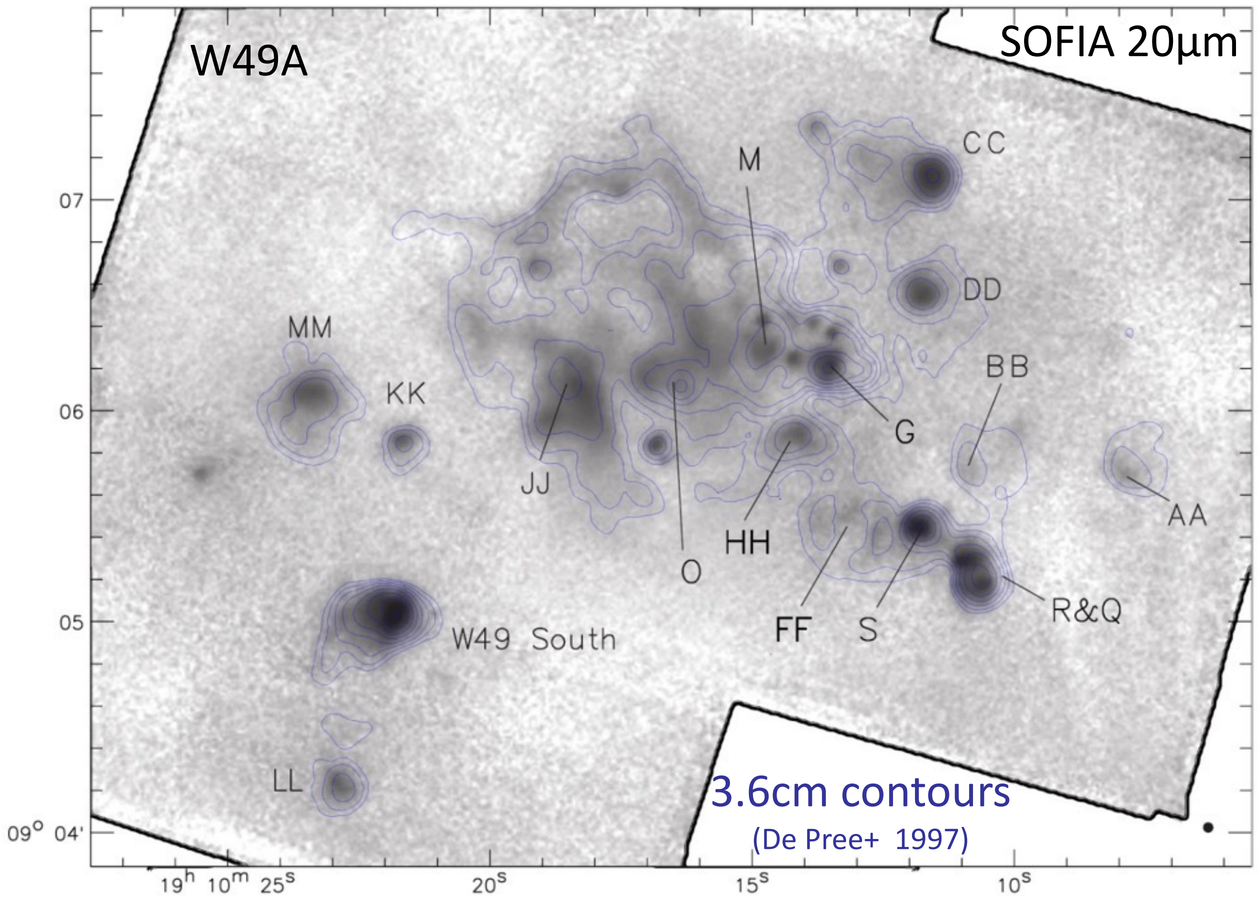


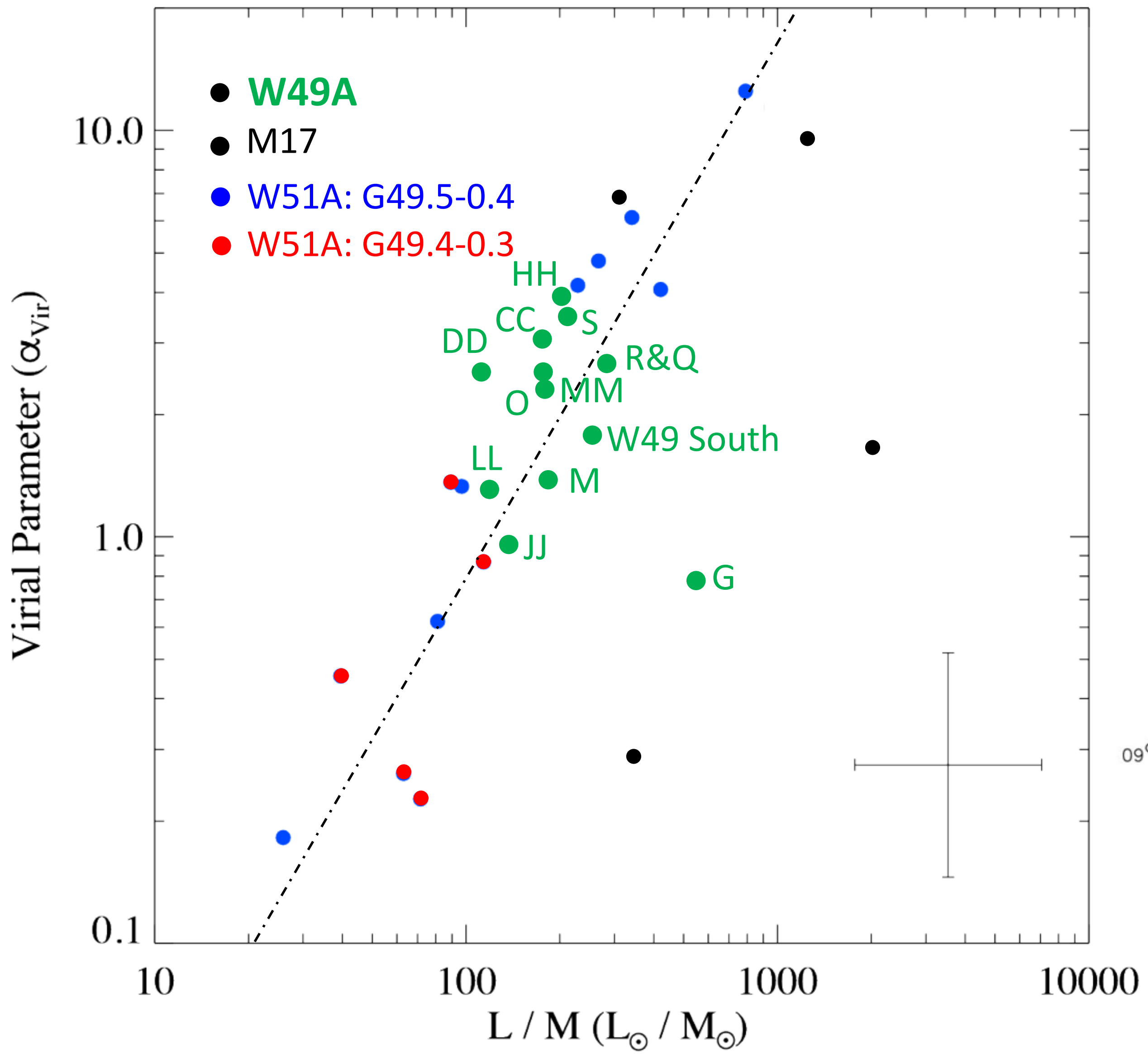


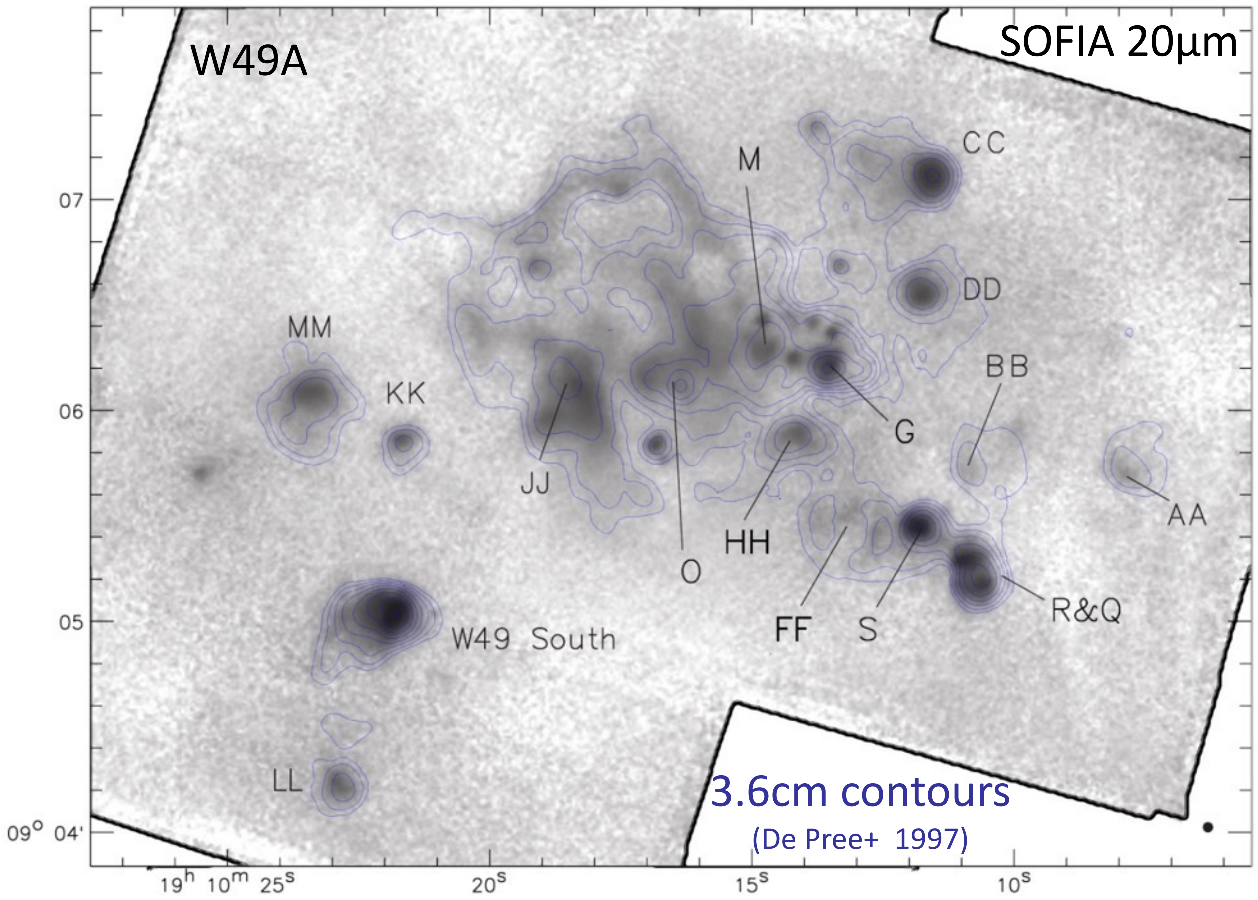
Lim, De Buizer, & Radomski (2020)

Evolutionary Hypotheses for W49A:

1. Conti & Blum 2002: star formation started from the periphery then moved to the central region
2. Peng+ 2010: star formation in the center triggered sequential star formation on the exterior
3. Mufson & Liszt 1977: global star formation throughout W49A initiated due to a cloud-cloud collision along line of sight







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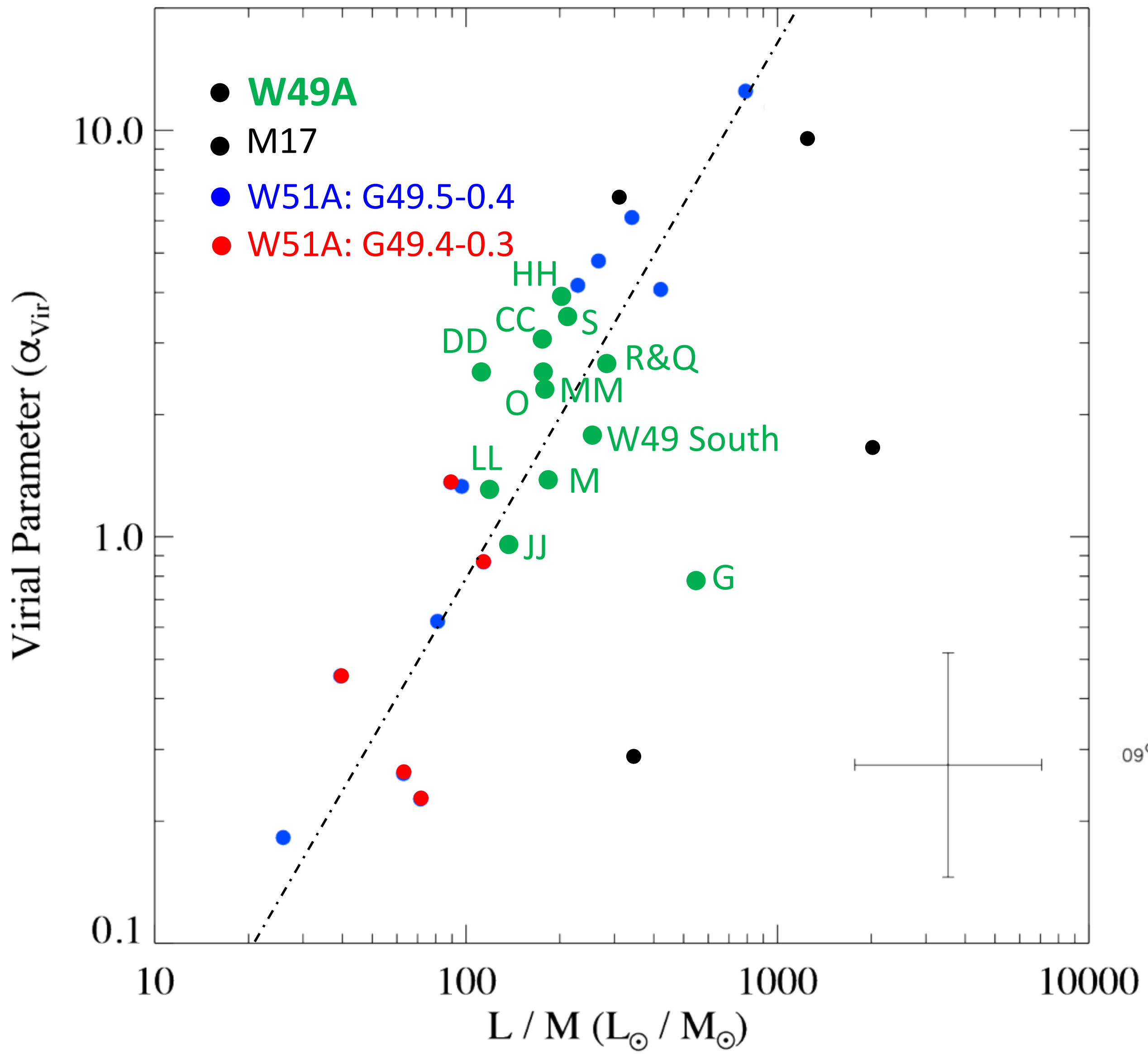

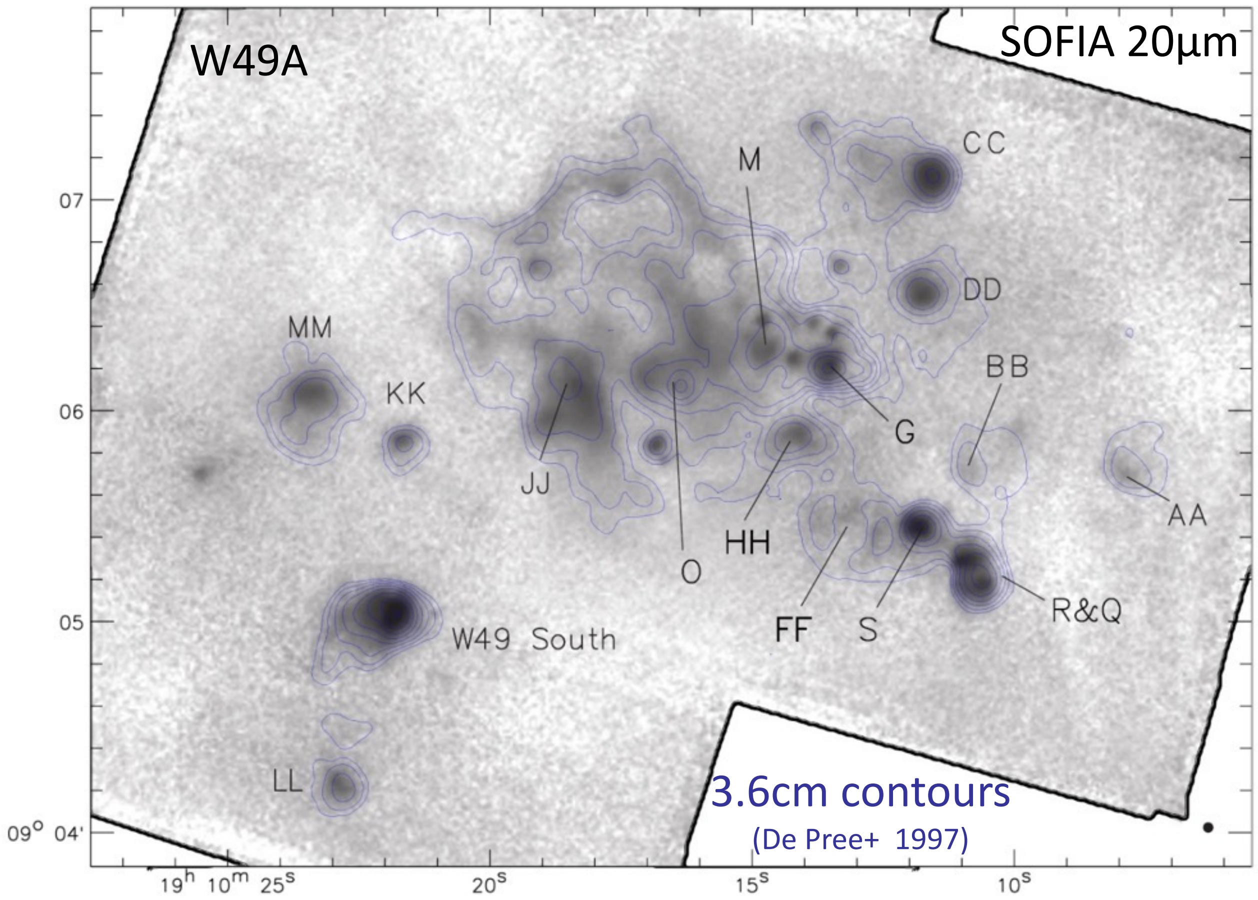

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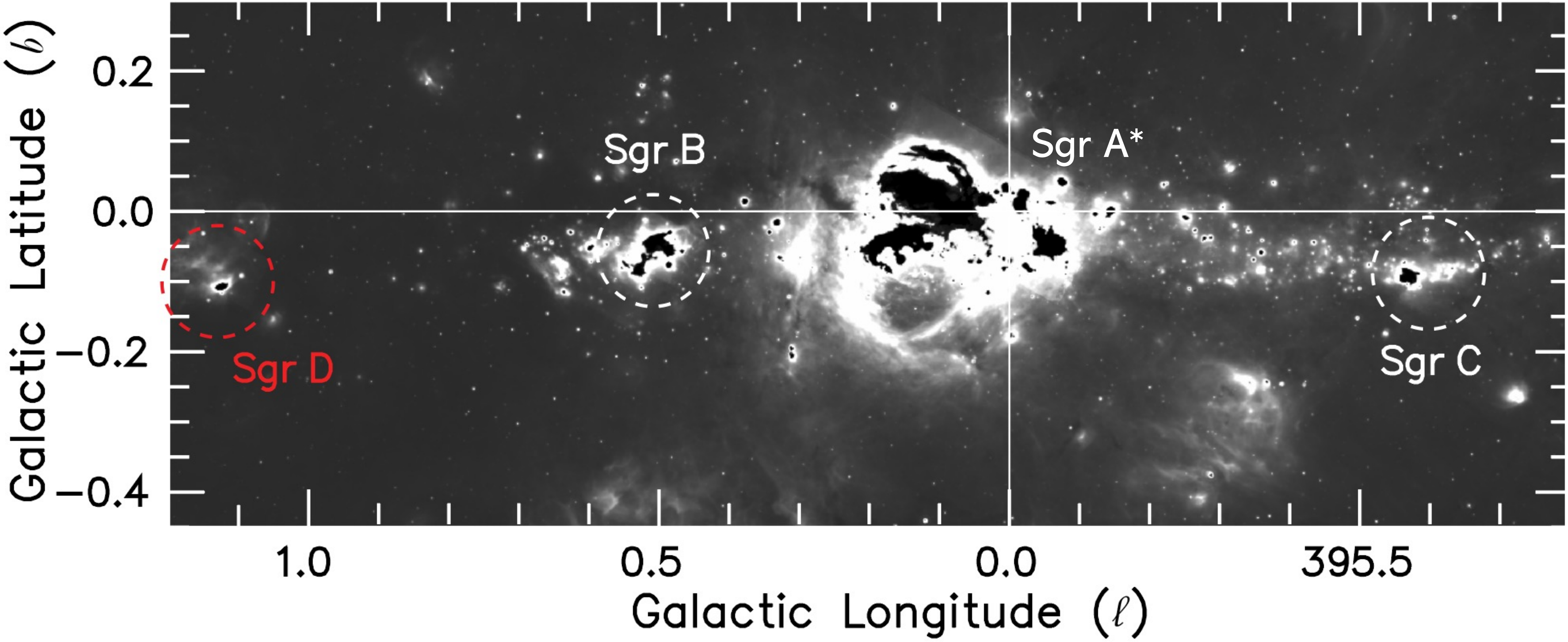
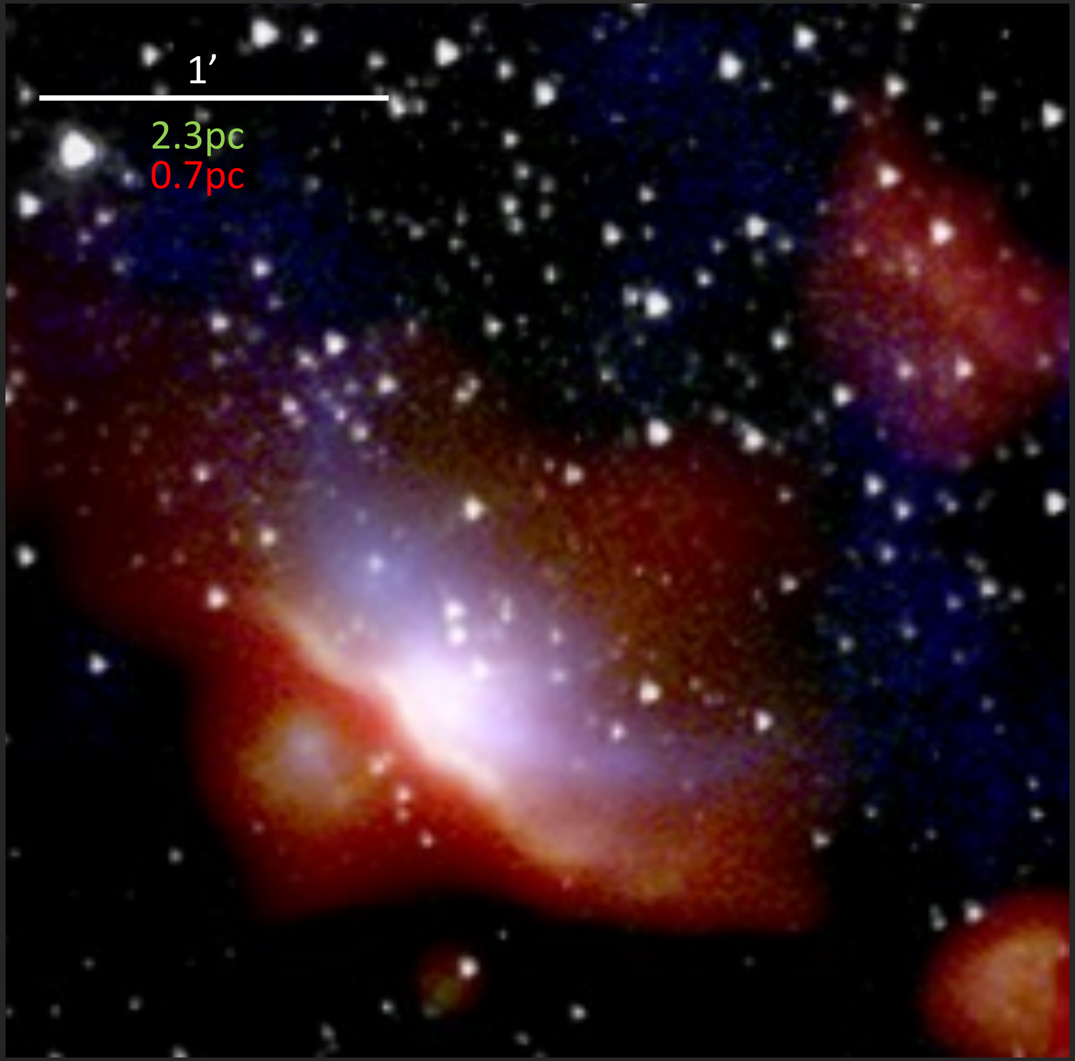
Surveying the Giant HII Regions of the Milky Way with SOFIA:

I. W51A
II. M17
III. W49A

IV. Sgr D, W42, and a Reassessment of the Giant HII Region Census


Galactic Latitude (b)
0.2
0.0
−0.2
−0.4
Sgr B
Sgr A*
Sgr C
Sgr D
1.0
0.5
0.0
395.5
Galactic Longitude (ℓ)

Sgr D



SOFIA 20 μm SOFIA 37 μm Herschel 70 μm Spitzer 3 μm

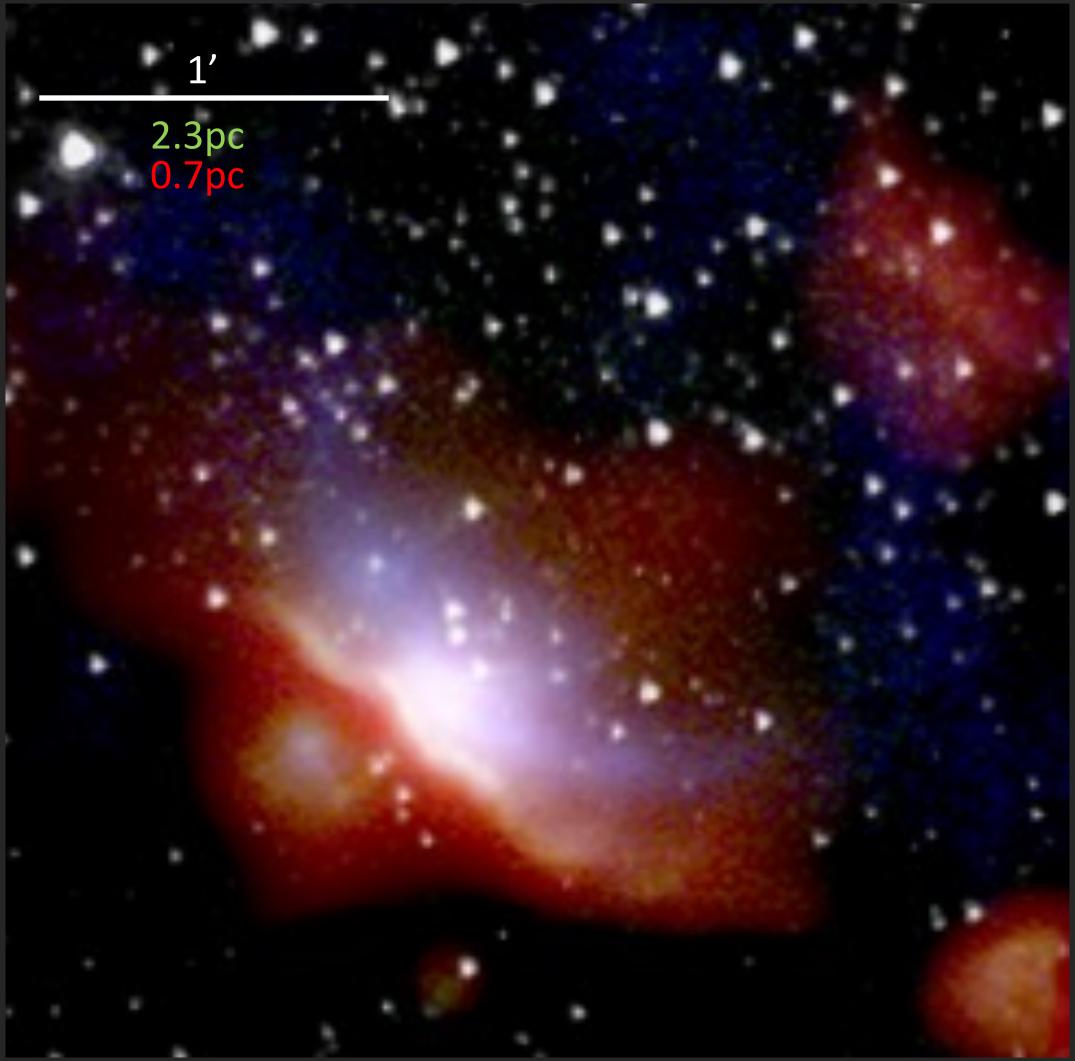
De Buizer+ (2022)

Original Distance = 8.0 kpc (assumed to be a GC source)
Original log(N_{LyC}) = 50.52 photons/s

New Distance = 2.36 kpc (maser parallax; Reid+ 2009)
New log(N_{LyC}) = 49.37 photons/s

Orion Nebula: log(N_{LyC}) = 49.47 photon/s (Inoue+ 2001)

Sgr D



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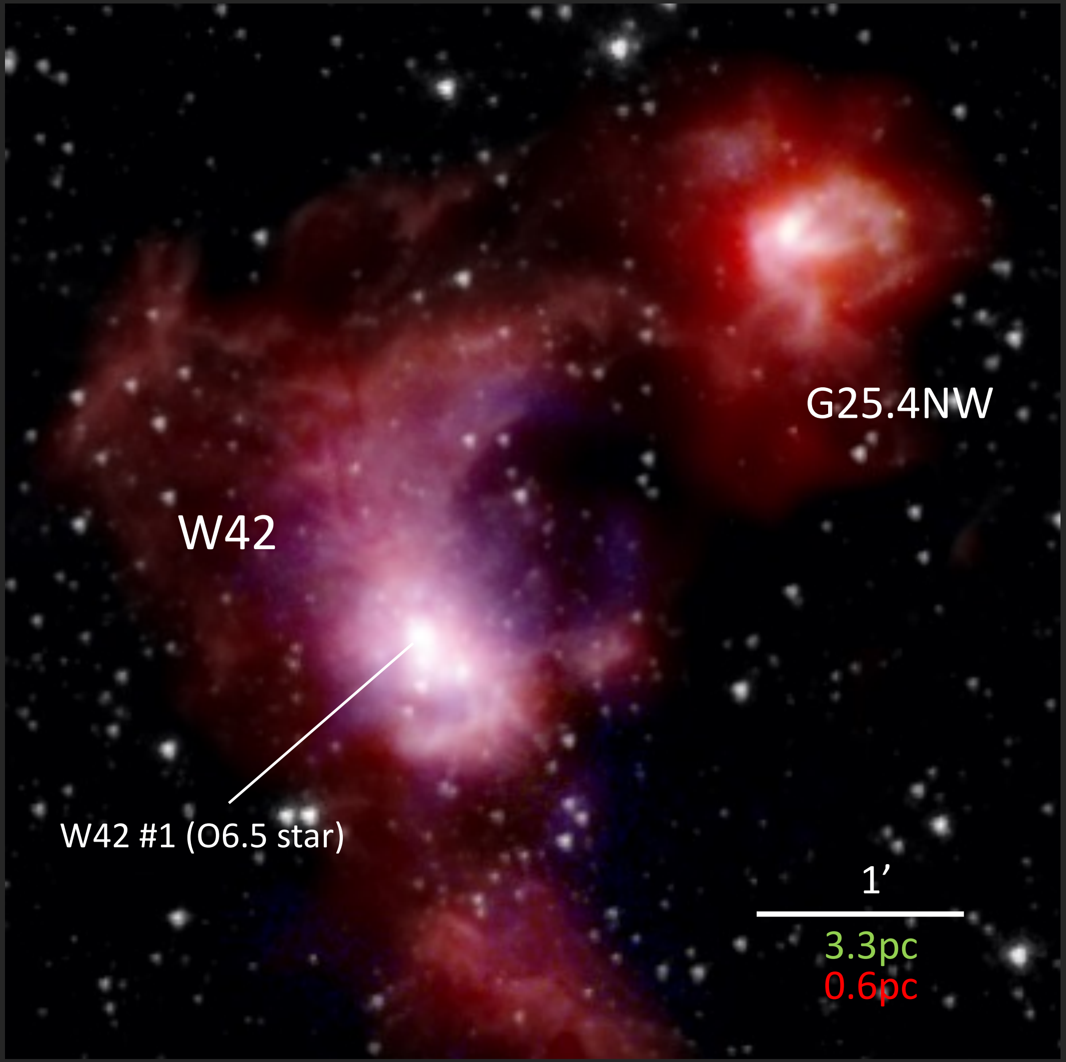
New log(N_{LyC}) = 49.37 photons/s

Sgr D is NOT a GHII region!

Orion Nebula: log(N_{LyC}) = 49.47 photon/s (Inoue+ 2001)

W42



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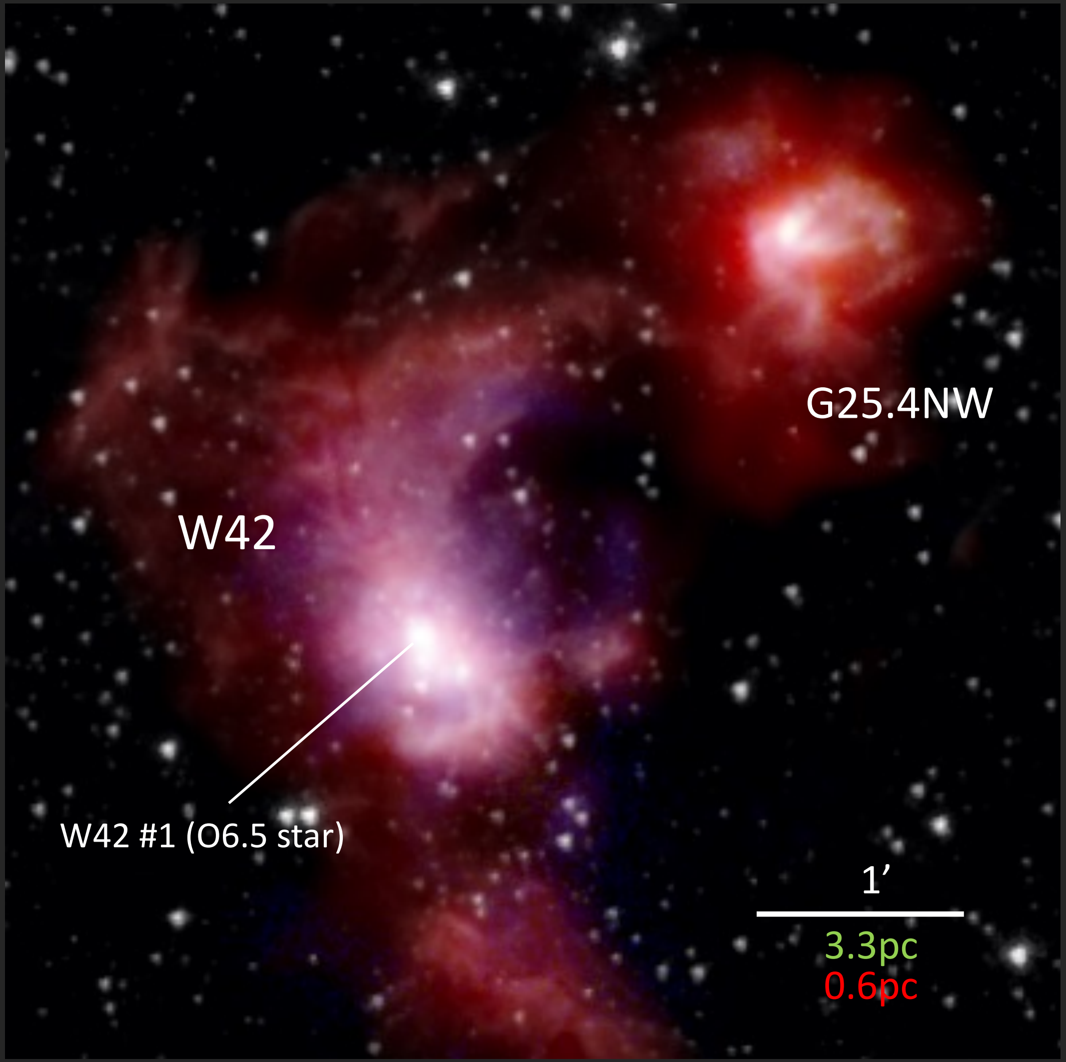
Original Distance = 11.5 kpc (kinematic far distance)
Original log(N_{LyC}) = 50.93 photons/s

New Distance = 2.20 kpc (spectrophotometric; Blum+ 2000)
New log(N_{LyC}) = 49.44 photons/s

Orion Nebula: log(N_{LyC}) = 49.47 photon/s (Inoue+ 2001)

W42



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W42 is NOT a GHII region!

Orion Nebula: log(N_{LyC}) = 49.47 photon/s (Inoue+ 2001)

We found updated distances to all regions

Tabulated the most precise distances (maser/GAIA parallax, spectrophotometric)

or

Tabulated the most precise *line velocity* (kinematic)

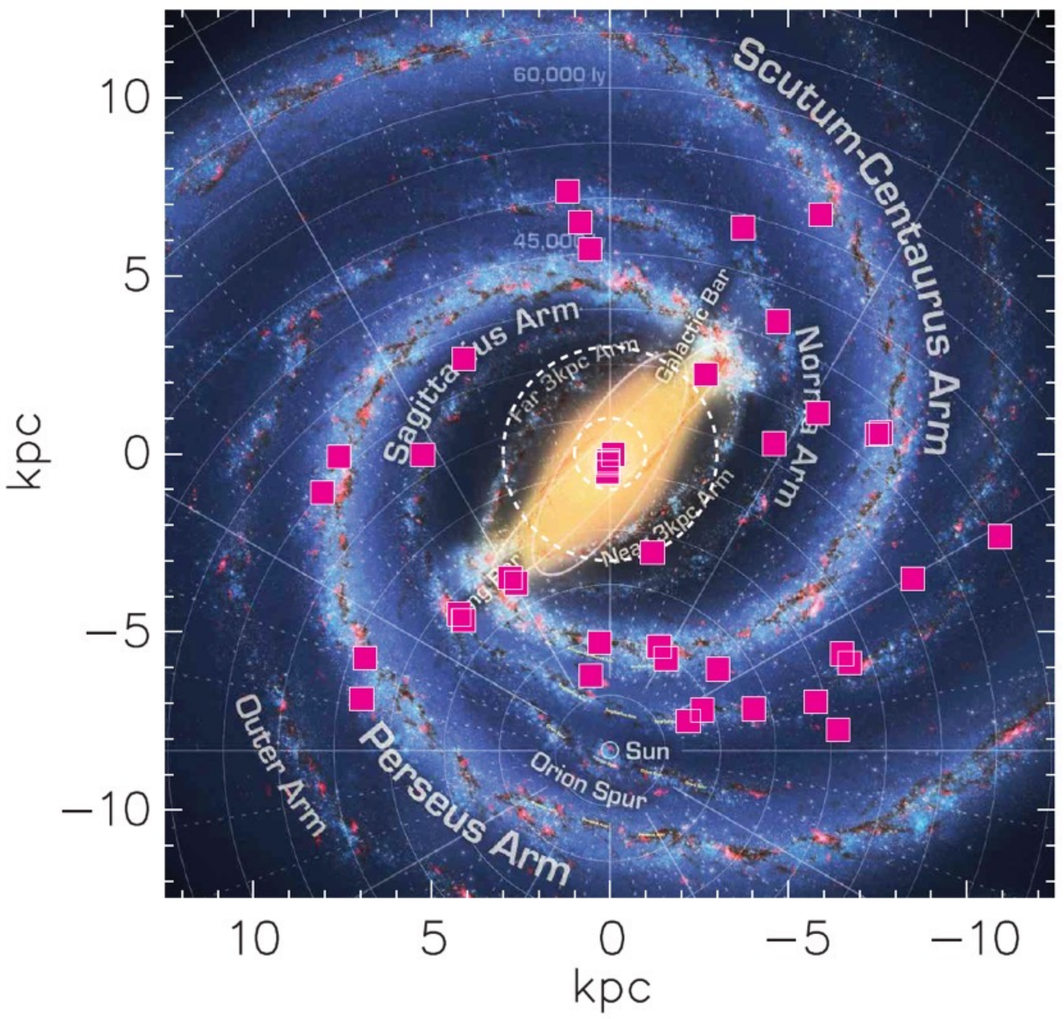
Kinematic Distances:

- Used HI absorption studies to resolve distance ambiguities
- employed Monte Carlo kinematic distance method of Wenger+ (2018) on all sources
- used the Reid et al. (2014) rotation curve and updated solar motion parameters (R_{GC}=8.34+/-0.16 kpc)

We also found updated T_e to most regions

We then recalculated N_{LyC} for all regions

New Locations of Crowther & Conti Census Sources



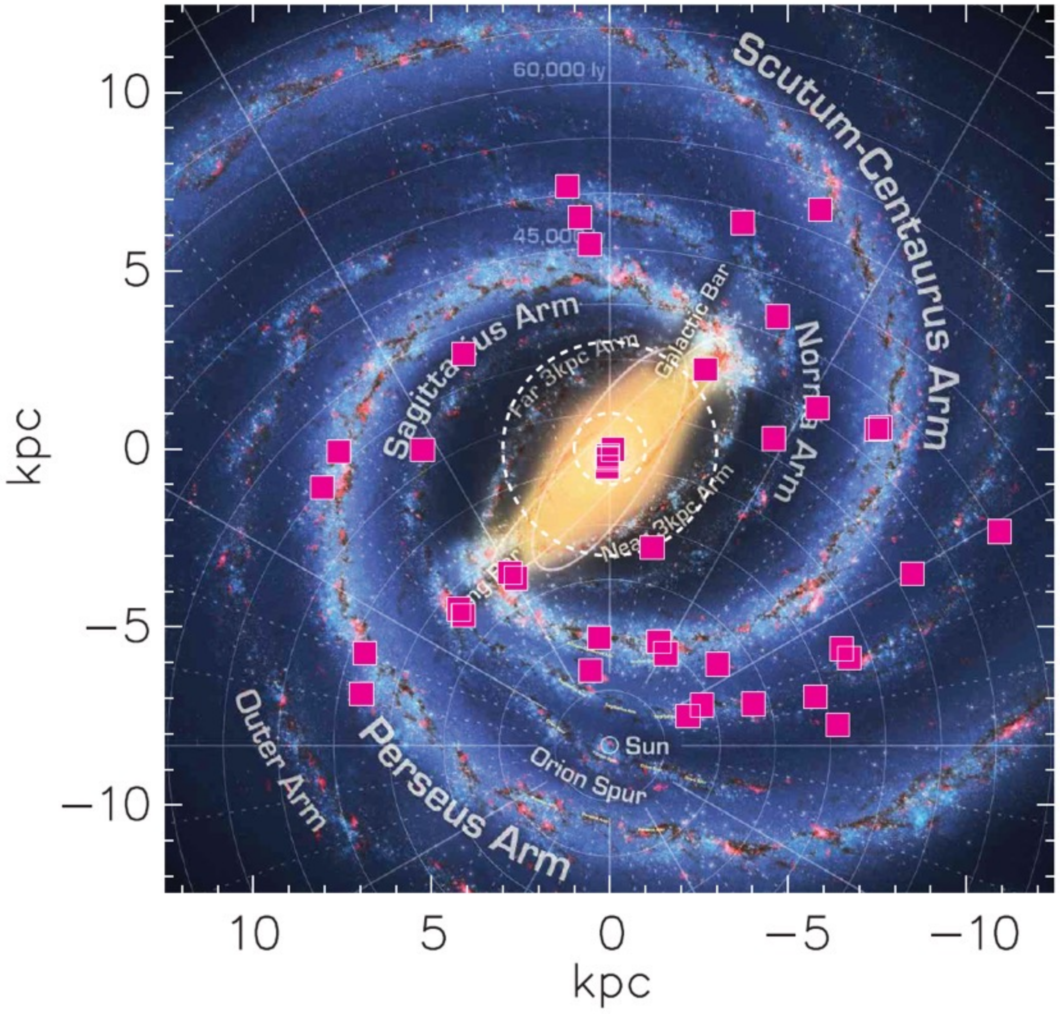
De Buizer+ (2022)

25% (14/56) **are not GHII regions**
(i.e., $N_{LyC}<10^{50}$ photons/s)

20% (11/56) have measurement errors that could place them below the $N_{LyC}=10^{50}$ photons/s cut-off

The census of Milky Way GHII regions is down to 42 (or less) sources

New Locations of Crowther & Conti Census Sources



De Buizer+ (2022)

VS.

	# of Compact Sources	# of Sub-Regions	% Overall Flux in Brightest Peak	Most Massive YSO	
W51A: G49.5-0.4	37	10	20%	96 M_{sun}	GIANT
W51A: G49.4-0.3	10	5	15%	64 M_{sun}	GIANT
M17	16	4	5%	64 M_{sun}	GIANT
W49A	24	15	25%	128 M_{sun}	GIANT
Sgr D	3	3	85%	16 M_{sun}	NOT GIANT
W42	2	1	50%	32 M_{sun}	NOT GIANT

De Buizer+ (2022)

VS.

	# of Compact Sources	# of Sub-Regions	% Overall Flux in Brightest Peak	
W51A: G49.5-0.4	37	10	20%	Distance-Independent Characteristics
W51A: G49.4-0.3	10	5	15%	
M17	16	4	5%	
W49A	24	15	25%	
Sgr D	3	3	85%	
W42	2	1	50%	

GIANT (W51A: G49.5-0.4, W51A: G49.4-0.3, M17, W49A)

NOT GIANT (Sgr D, W42)

De Buizer+ (2022)

Conclusions

SOFIA is being used to understand the present MYSO population and evolutionary status of Milky Way GHII regions

W51A:G49.5-0.4 and W49A have more vigorous MYSO formation presently than M17 and W51A:G49.4-0.3

W51A:G49.5-0.4 displays a large spread in sub-region evolutionary state, whereas W49A does not

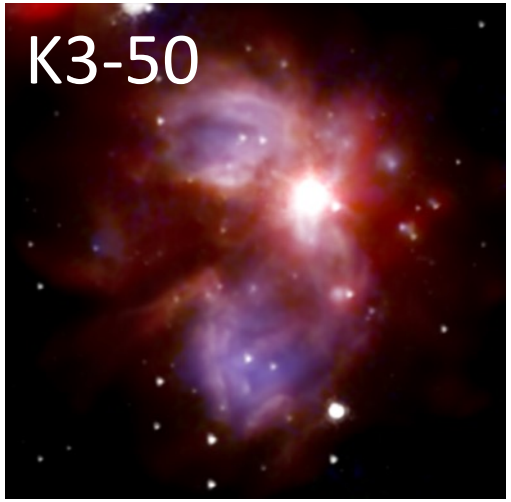
We have reassessed the GHII region census and find 25% are not GHII regions

Sgr D and W42 are not GHII regions based upon Lyman continuum flux, but also have IR observational characteristics distinct from those of bona-fide GHII regions

Project Status

Four papers published so far, covering 4 GHII regions and 2 HII regions

To be submitted by end of fall: Paper 5 on GHII regions DR7& K3-50



Have data for 6 more GHII regions (additional 4 papers)

- Have FORCAST data for 4 sources that are now known to be too close to be GHII regions

Data obtained for 14 of original list of 56 (18 from all FORCAST programs), for a total of 12 of 42 bona fide GHII regions or candidates