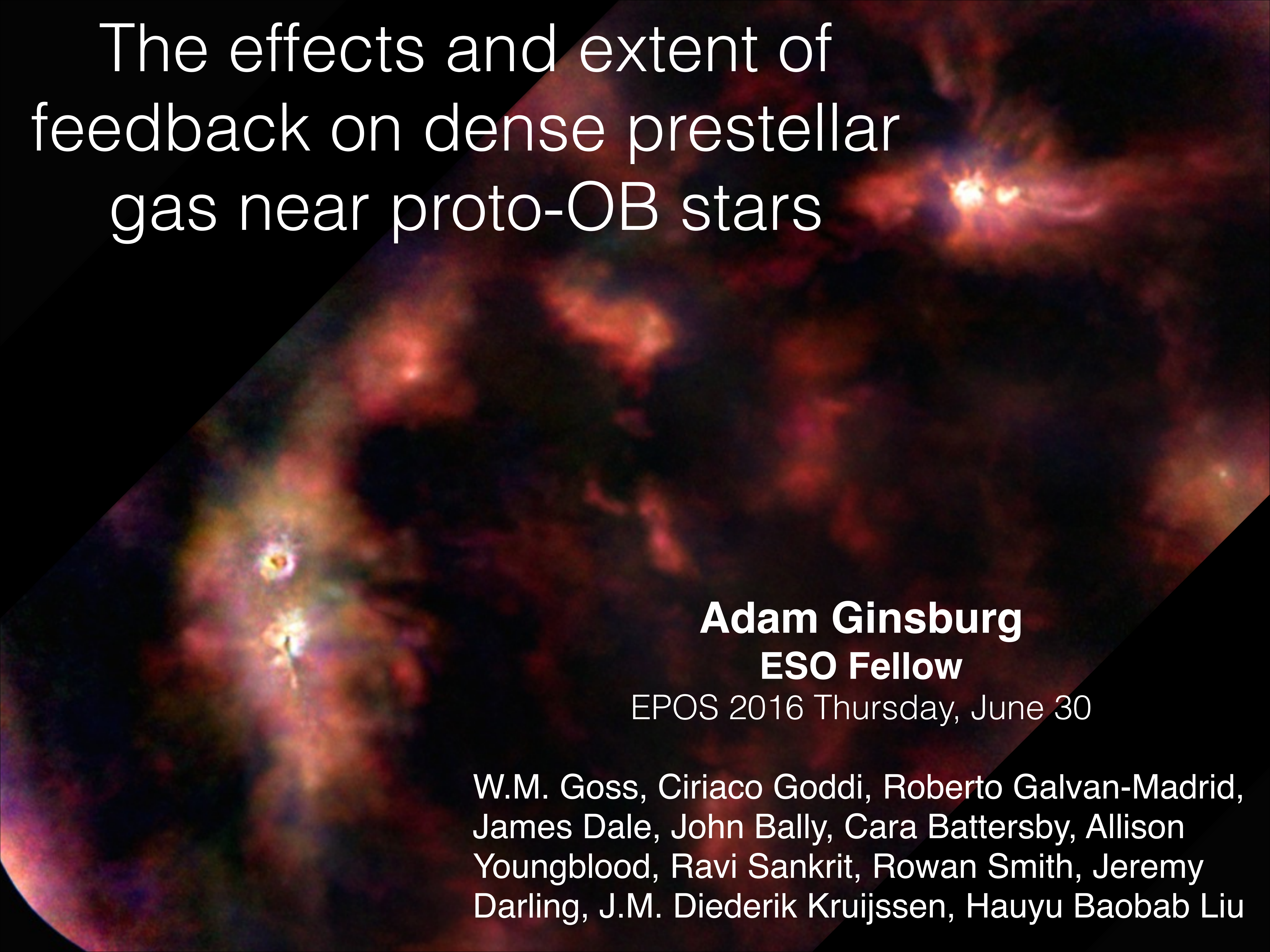


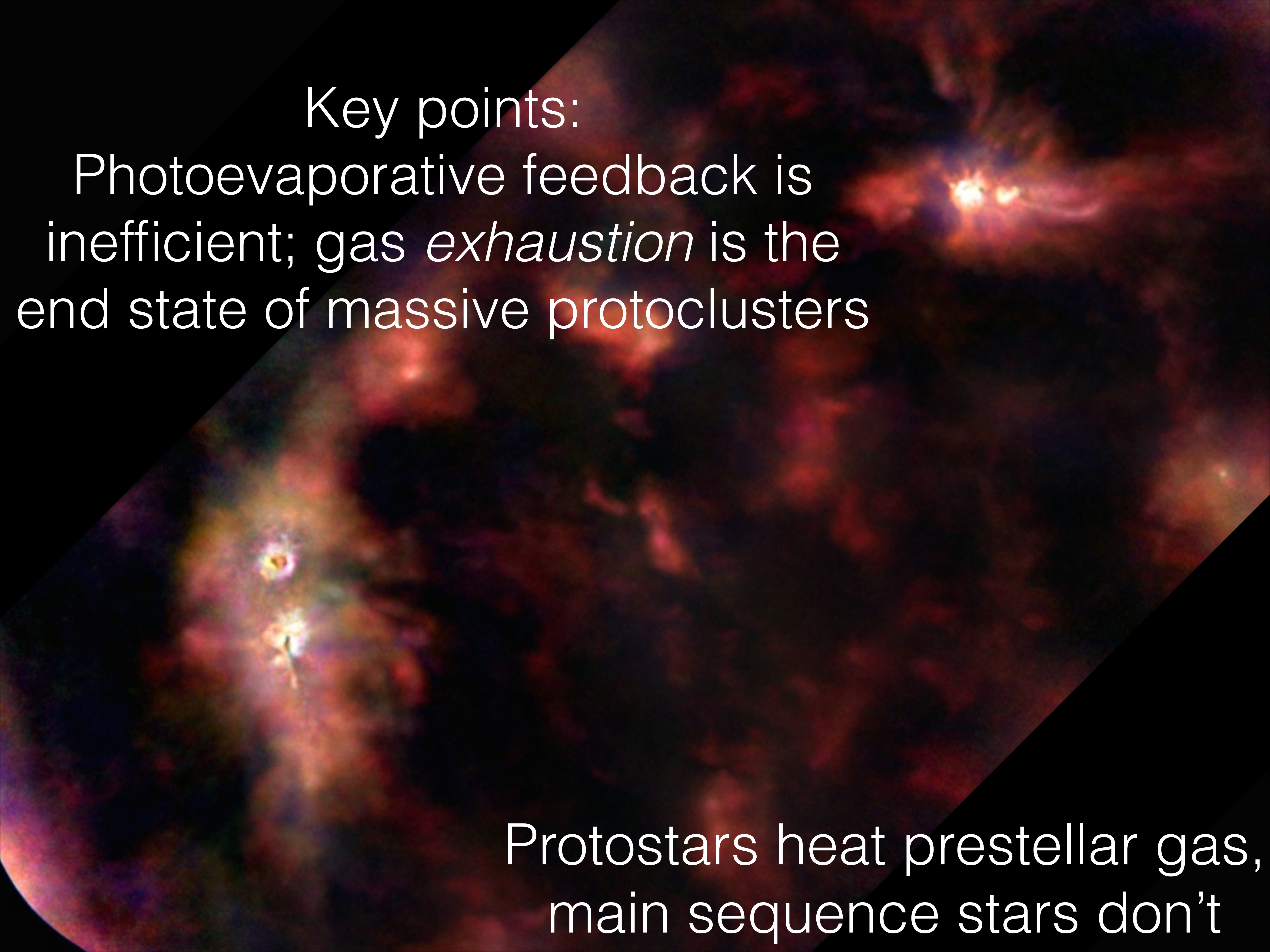
The effects and extent of feedback on dense prestellar gas near proto-OB stars

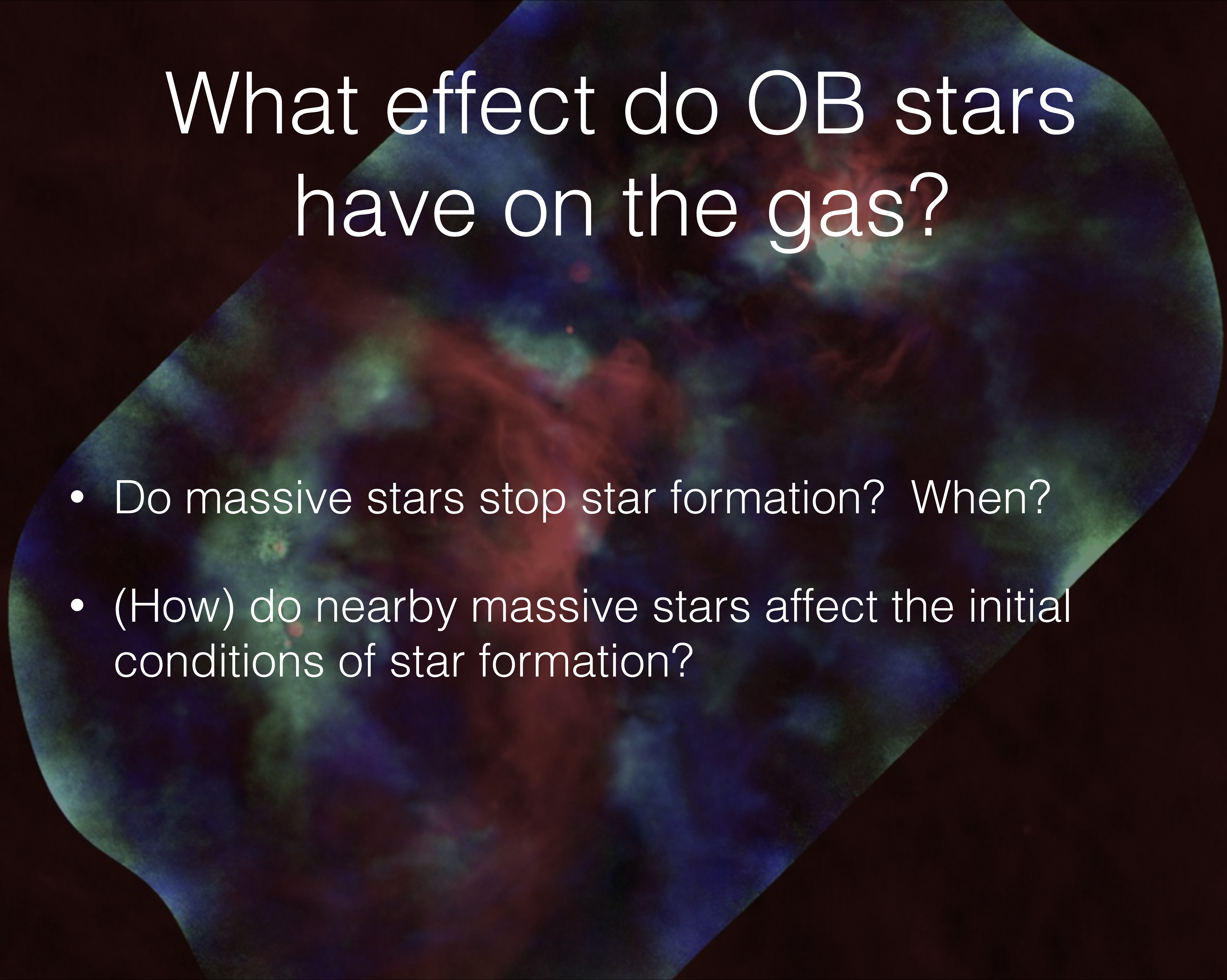
Adam Ginsburg

ESO Fellow

EPOS 2016 Thursday, June 30

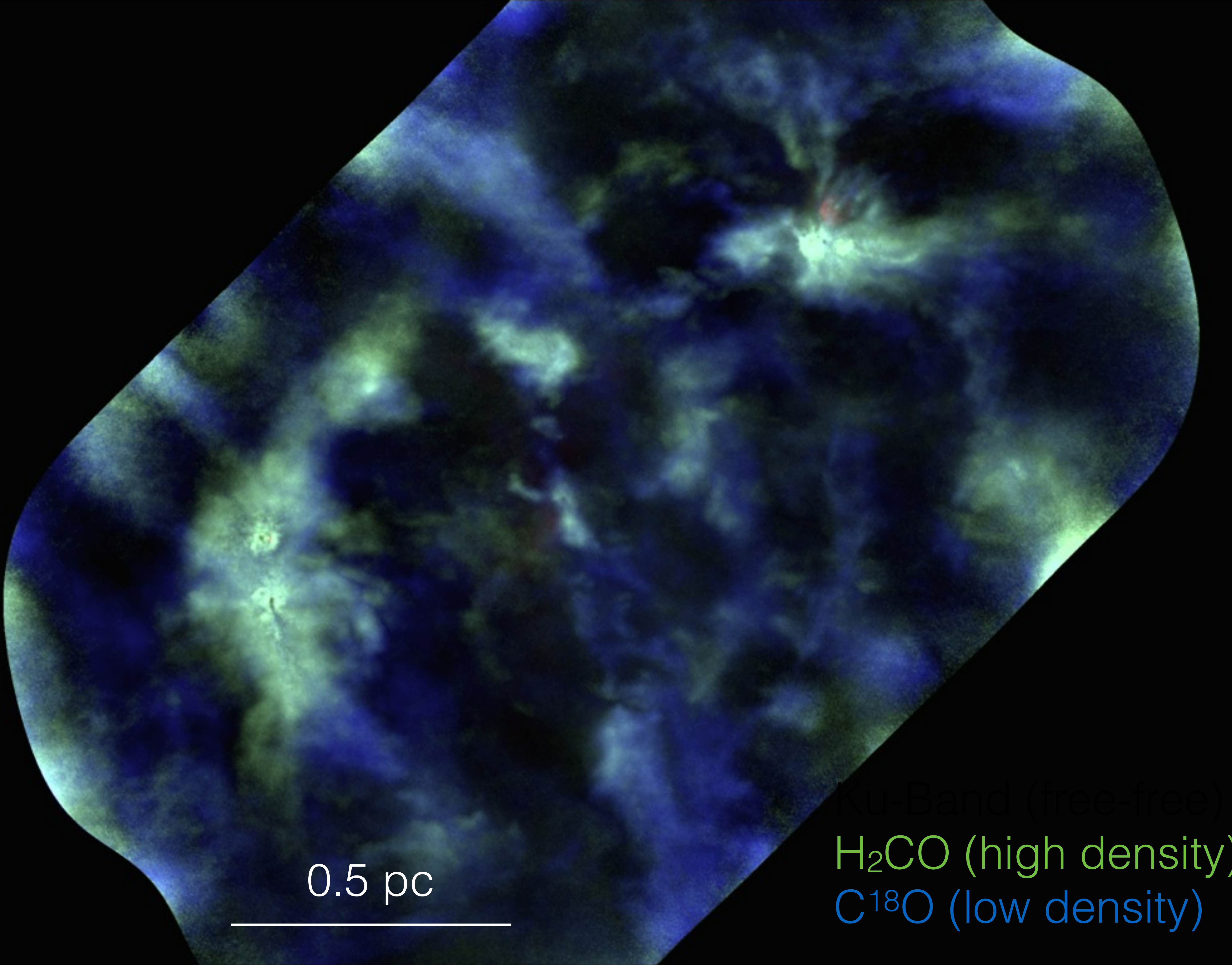
W.M. Goss, Ciriaco Goddi, Roberto Galvan-Madrid, James Dale, John Bally, Cara Battersby, Allison Youngblood, Ravi Sankrit, Rowan Smith, Jeremy Darling, J.M. Diederik Kruijssen, Hauyu Baobab Liu


Key points:
Photoevaporative feedback is inefficient; gas *exhaustion* is the end state of massive protoclusters
Protostars heat prestellar gas, main sequence stars don’t

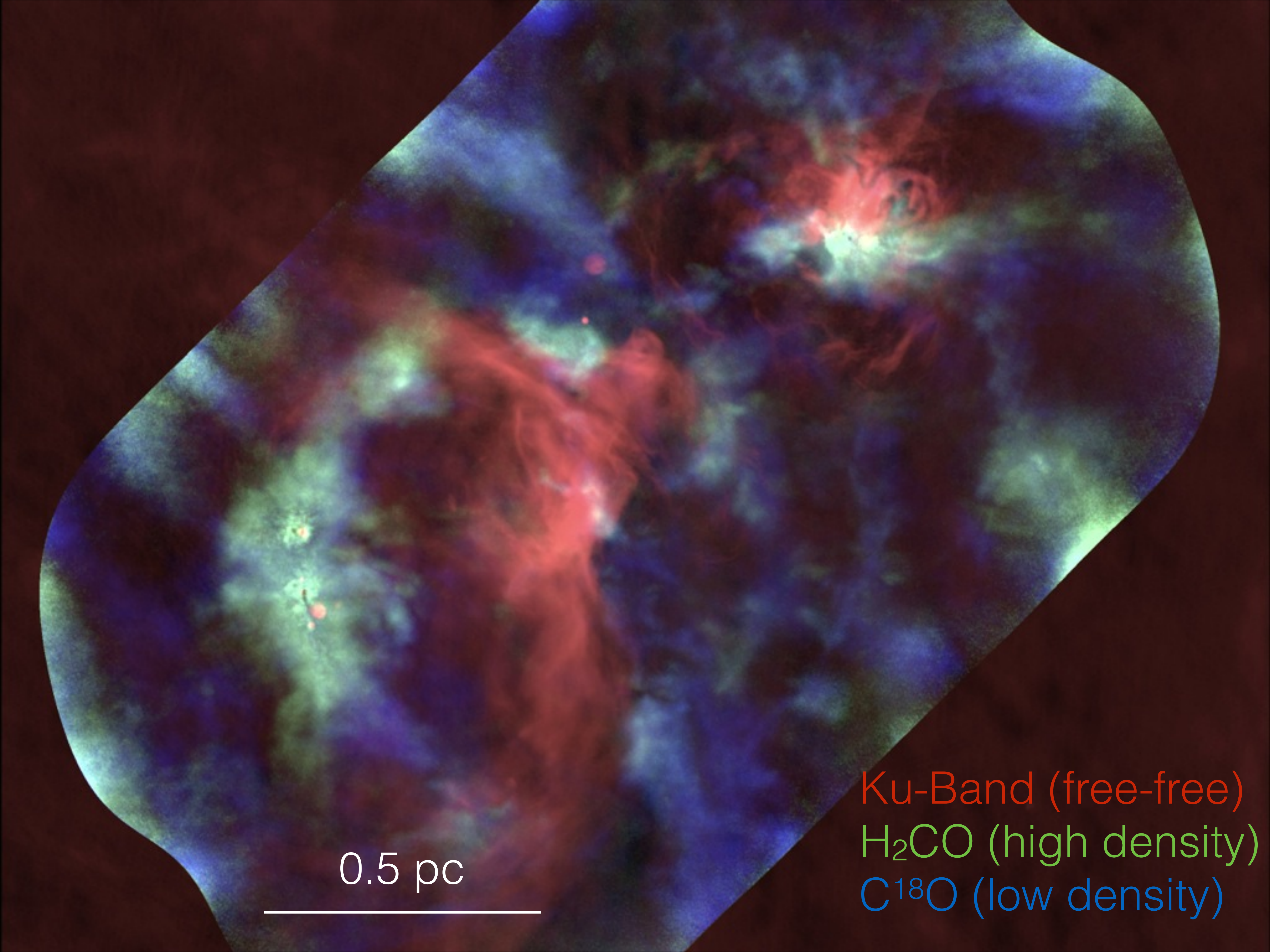


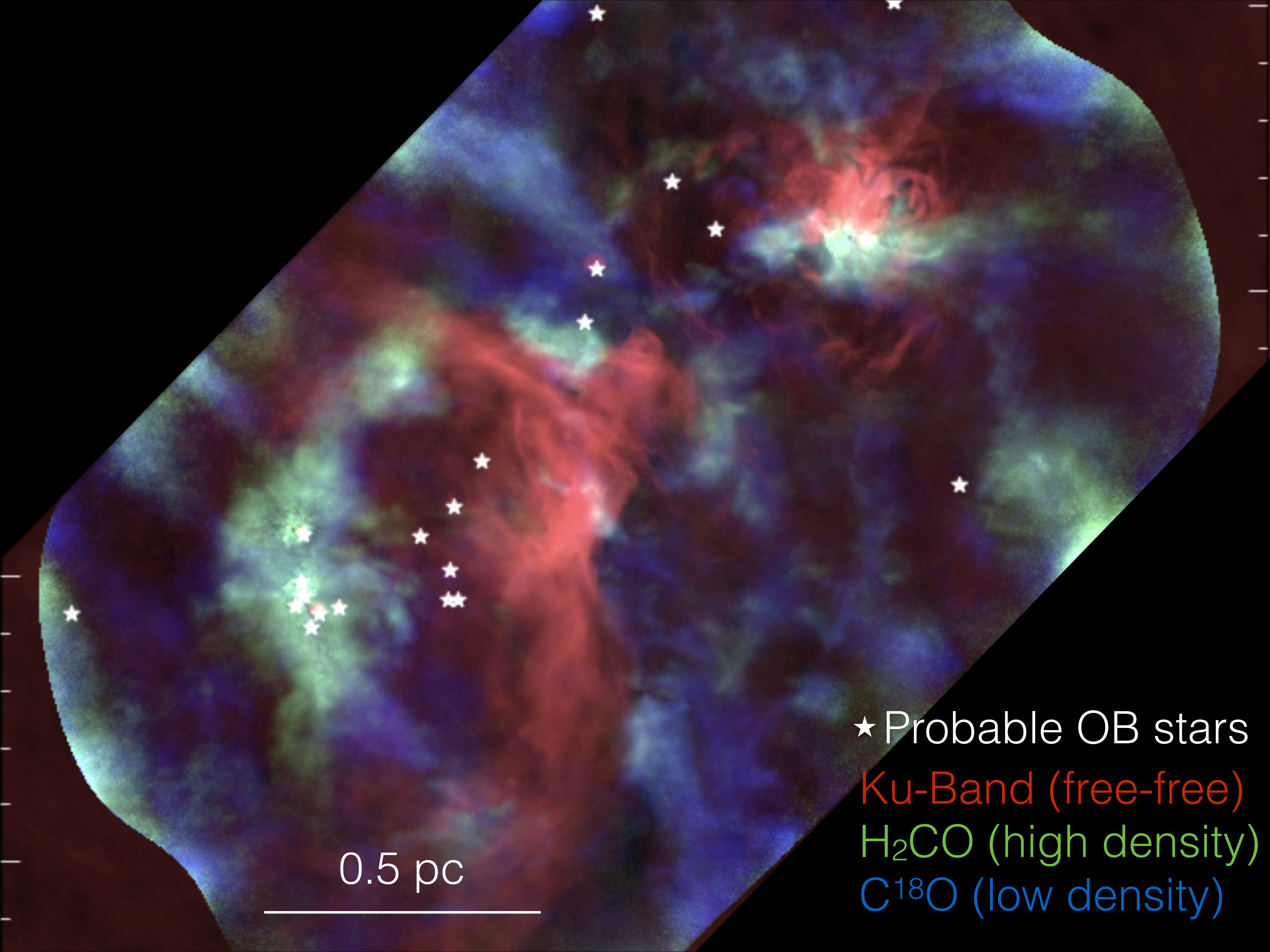
What effect do OB stars have on the gas?

- Do massive stars stop star formation? When?
- (How) do nearby massive stars affect the initial conditions of star formation?

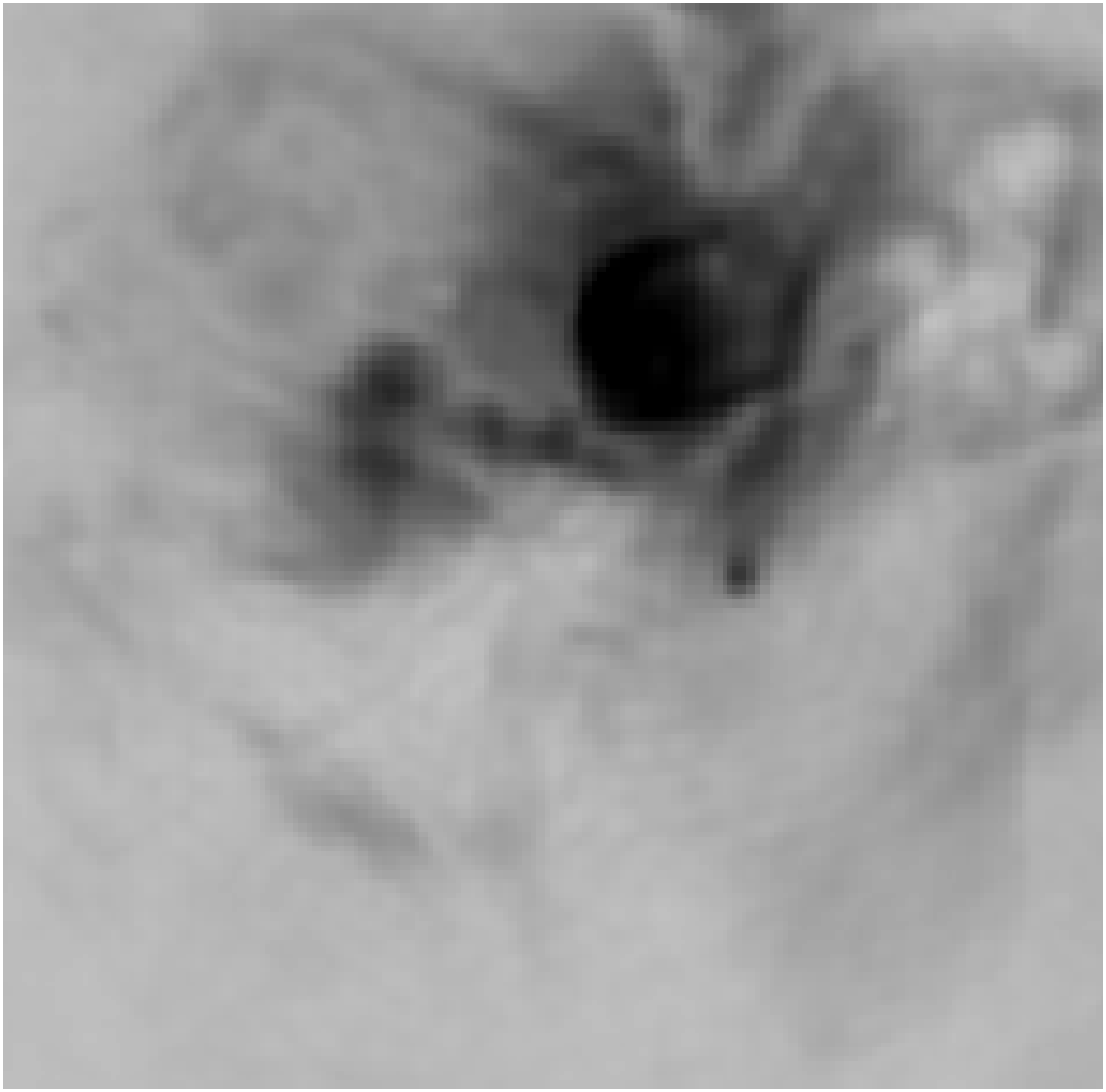


0.5 pc
Ku-Band (free-free)
H_2CO (high density)
$C^{18}O$ (low density)


0.5 pc
Ku-Band (free-free)
H2CO (high density)
C18O (low density)


★ Probable OB stars
Ku-Band (free-free)
H2CO (high density)
C18O (low density)
0.5 pc

In W51 North, massive stars are forming within an HII region

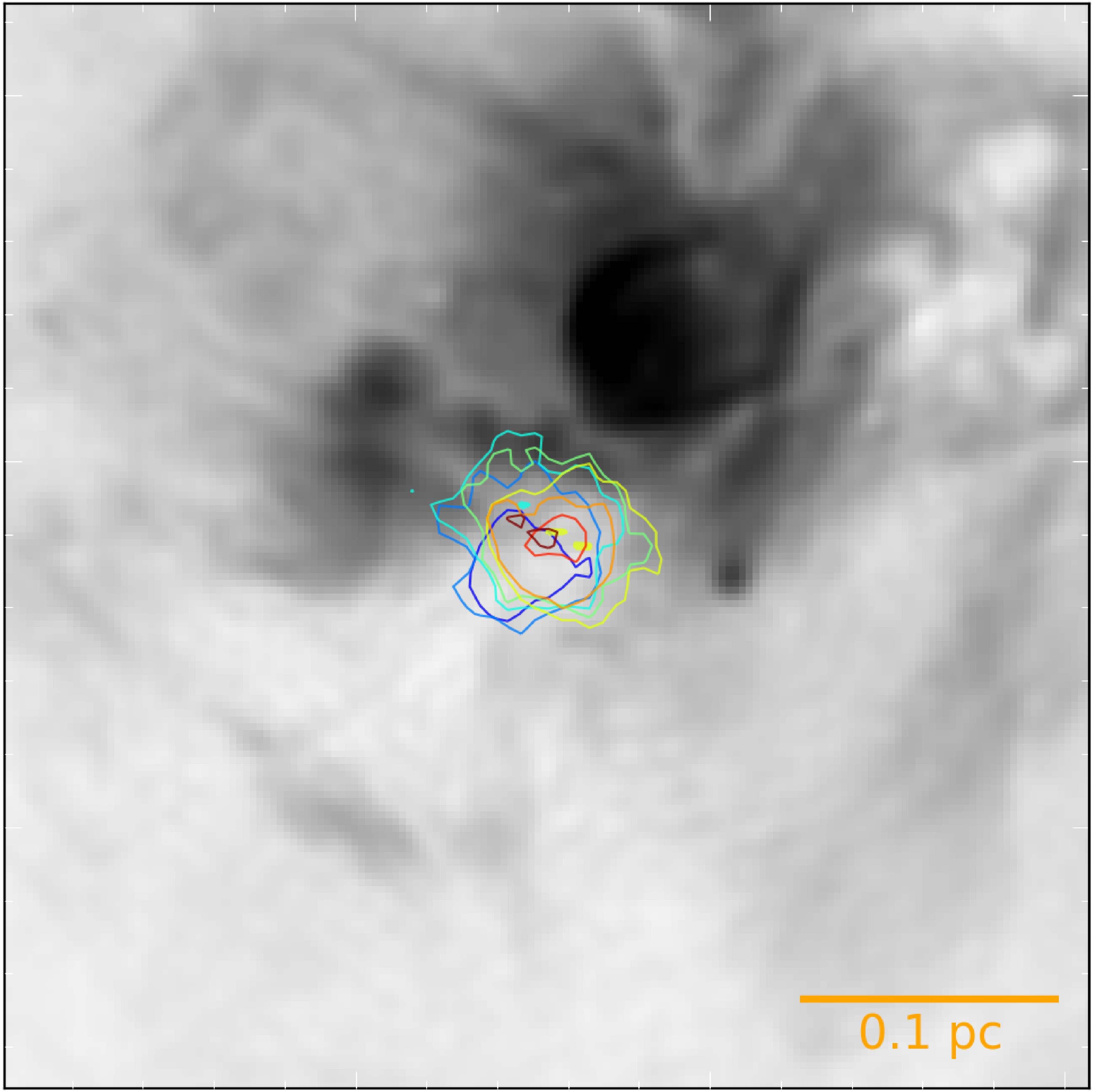


$L \sim 10^7 L_\odot$

$M^* \sim$ few $10^3 M_\odot$

Free-free:
Ginsburg et al 2016

In W51 North, massive stars are forming within an HII region



H_2CO core:
W51 North

(Henkel et al 2013,
Goddi et al 2015:
NH_3 masers)

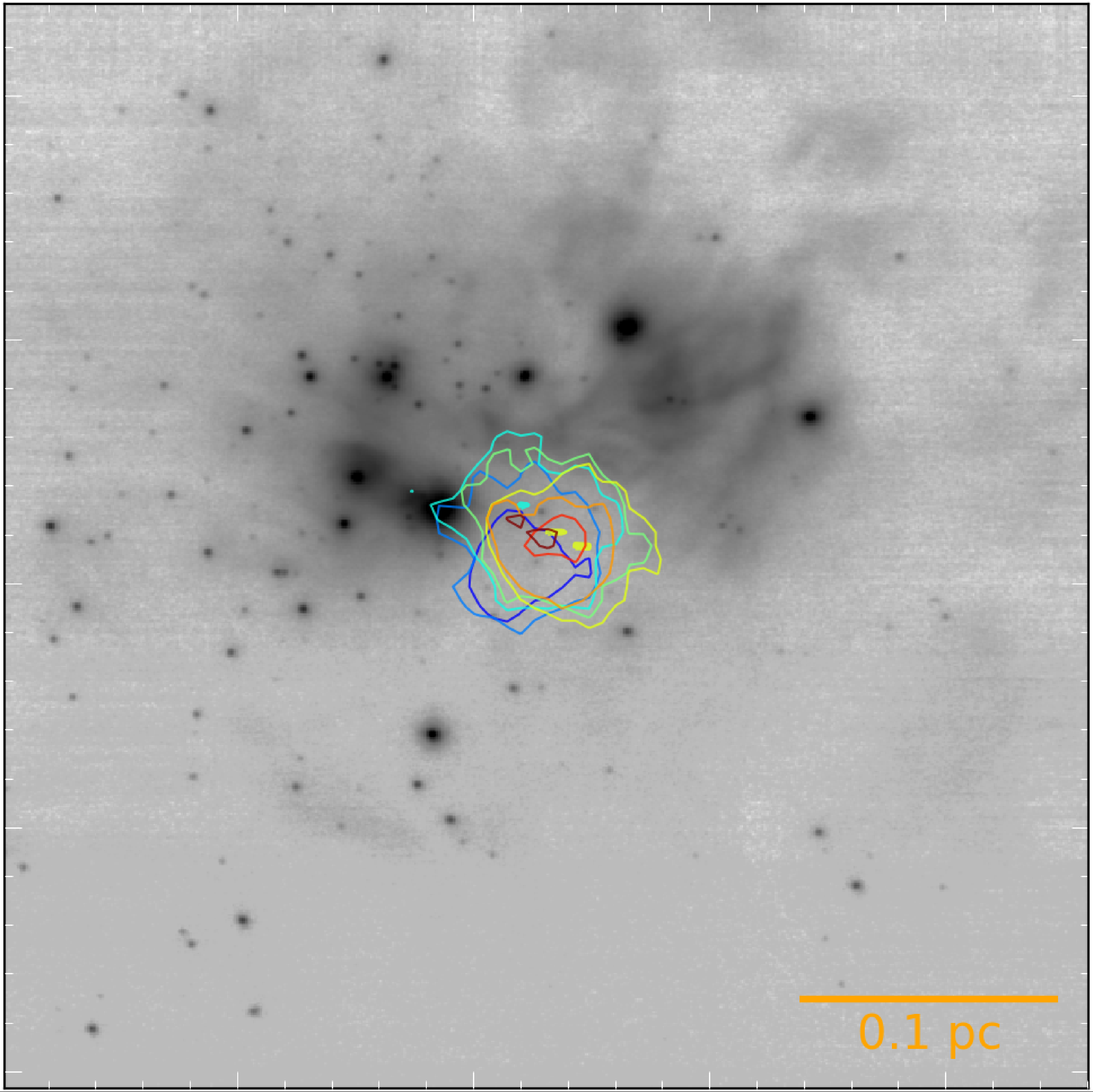
$L \sim 10^7\ L_O$

$M^* \sim few\ 10^3\ M_O$

$M_g \sim few\ 10^3\ M_O$

Free-free:
Ginsburg et al 2016

In W51 North, massive stars are forming within an HII region



H_2CO core:
W51 North

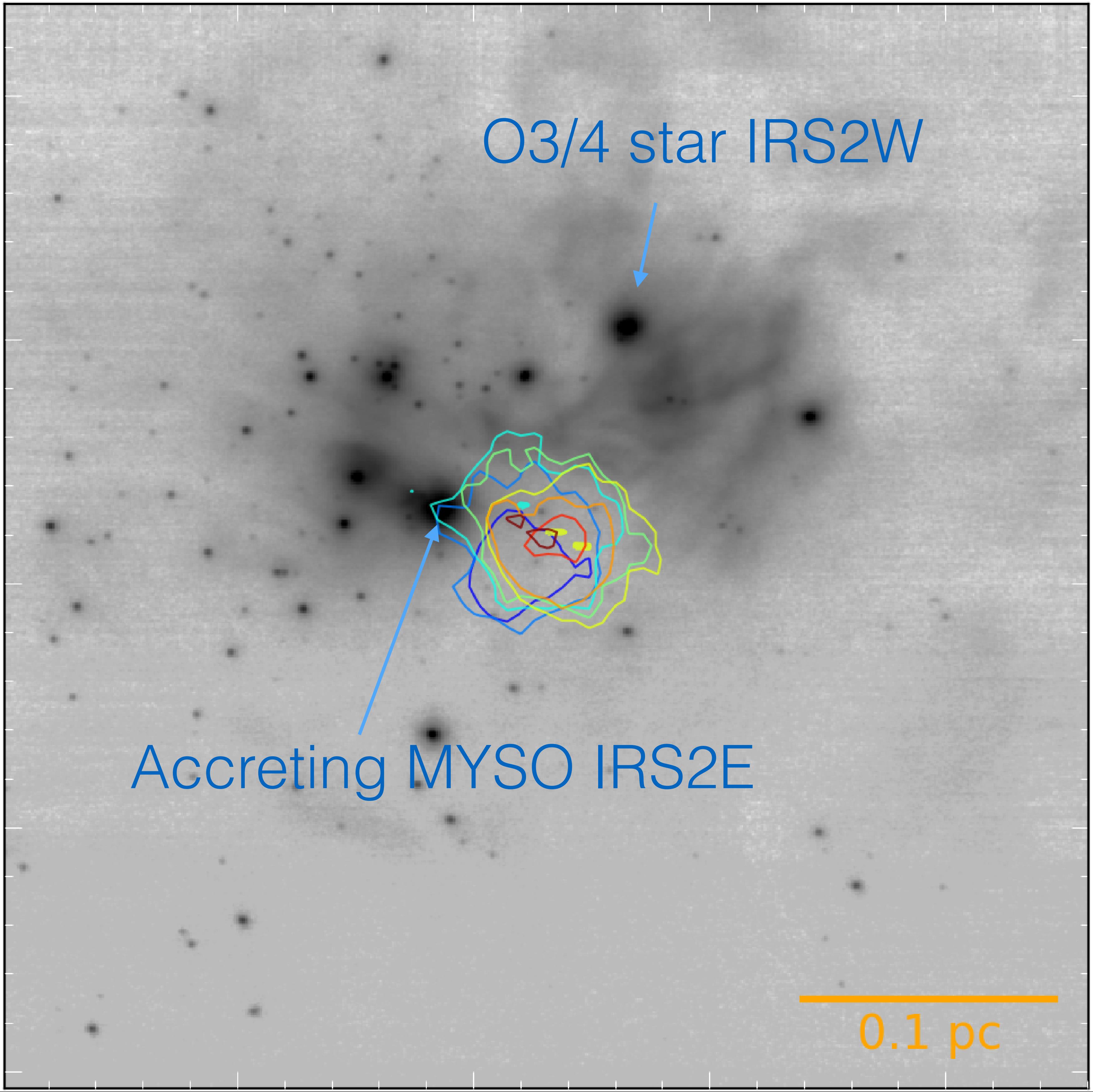
$L \sim 10^7\ L_O$

$M^* \sim$ few $10^3\ M_O$

$M_g \sim$ few $10^3\ M_O$

NACO K-band
(Figuerêdo et al 2008)

In W51 North, massive stars are forming within an HII region

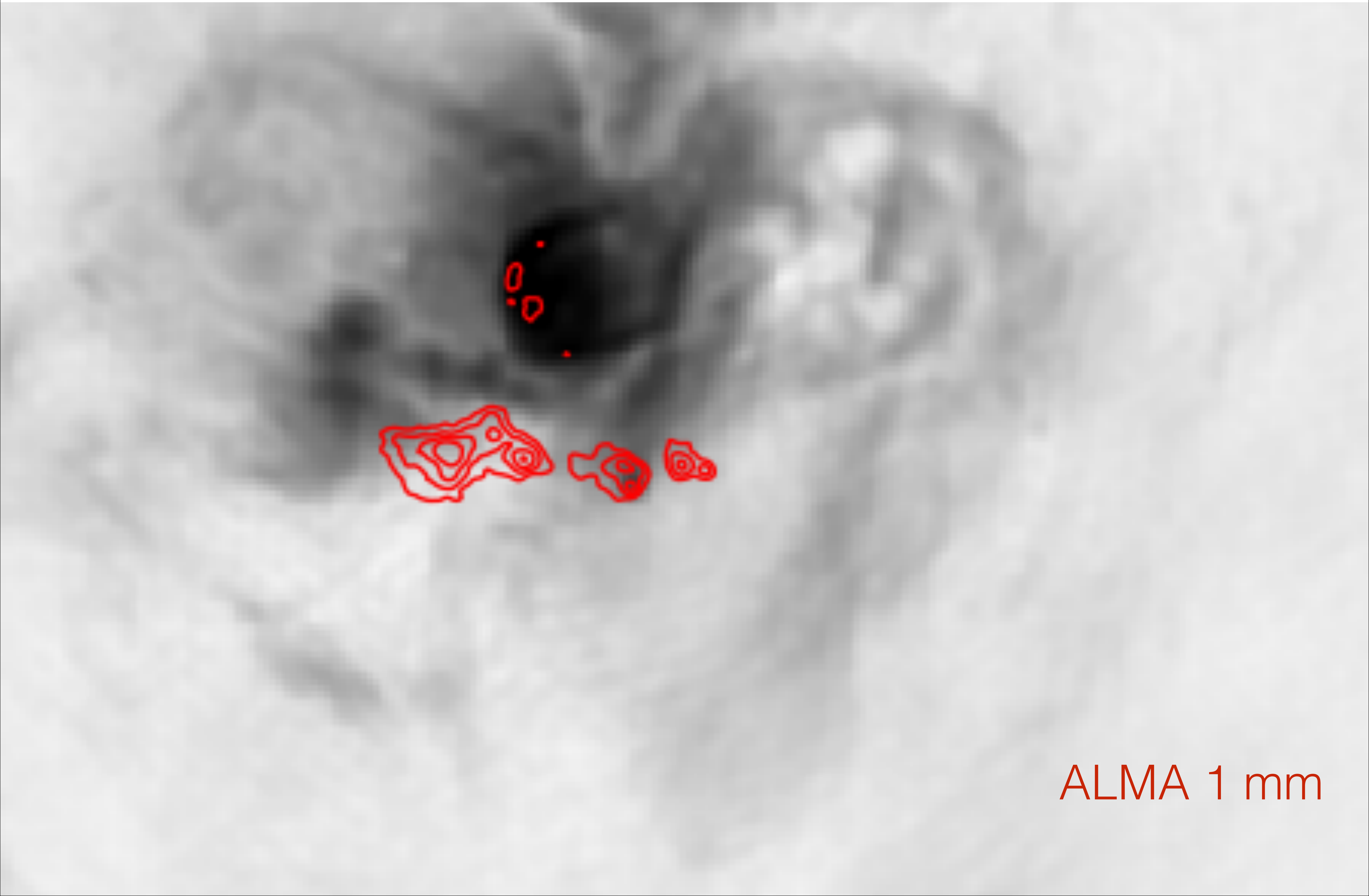


H_2CO core:
W51 North

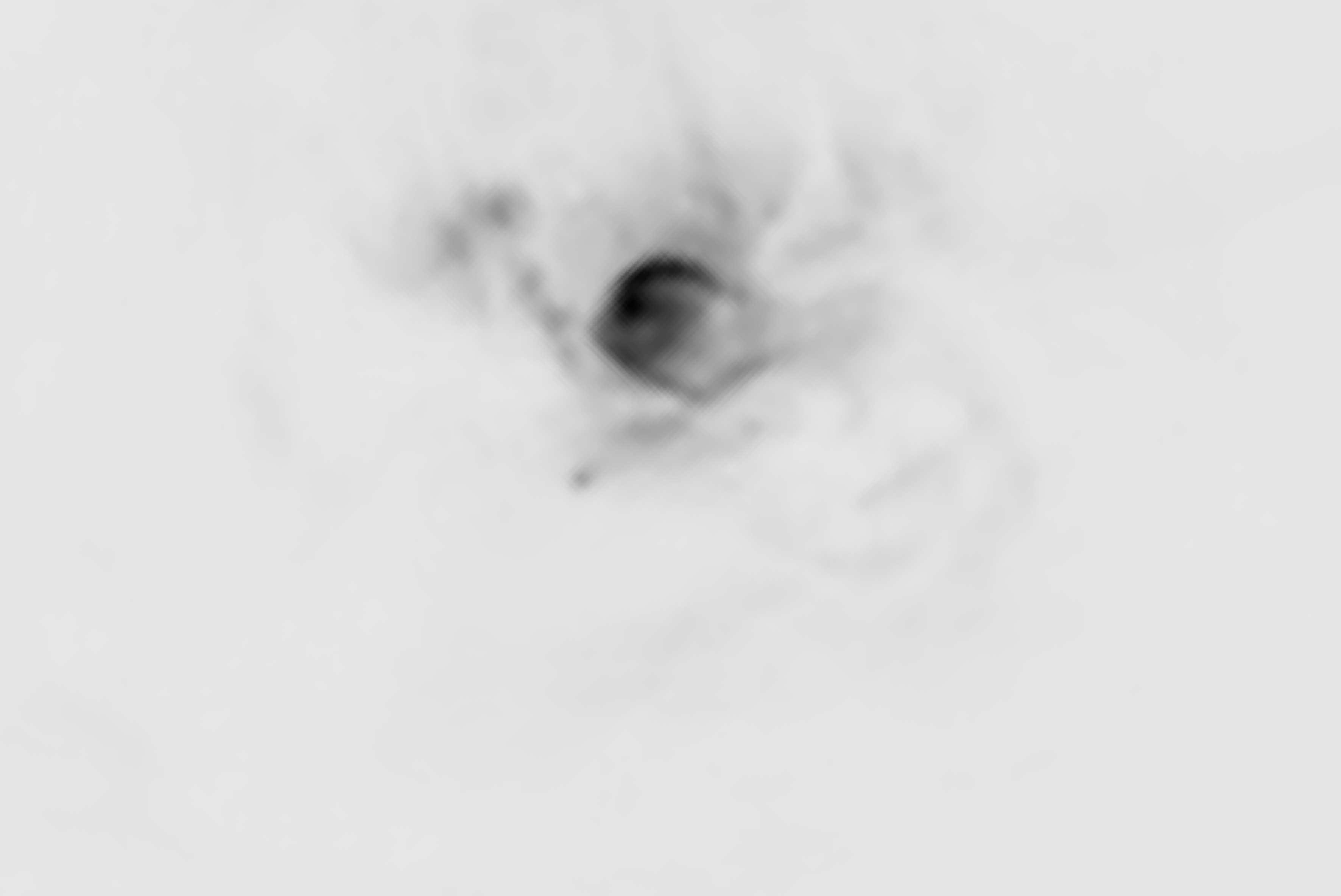
$L \sim 10^7\ L_O$
$M^* \sim$ few $10^3\ M_O$
$M_g \sim$ few $10^3\ M_O$

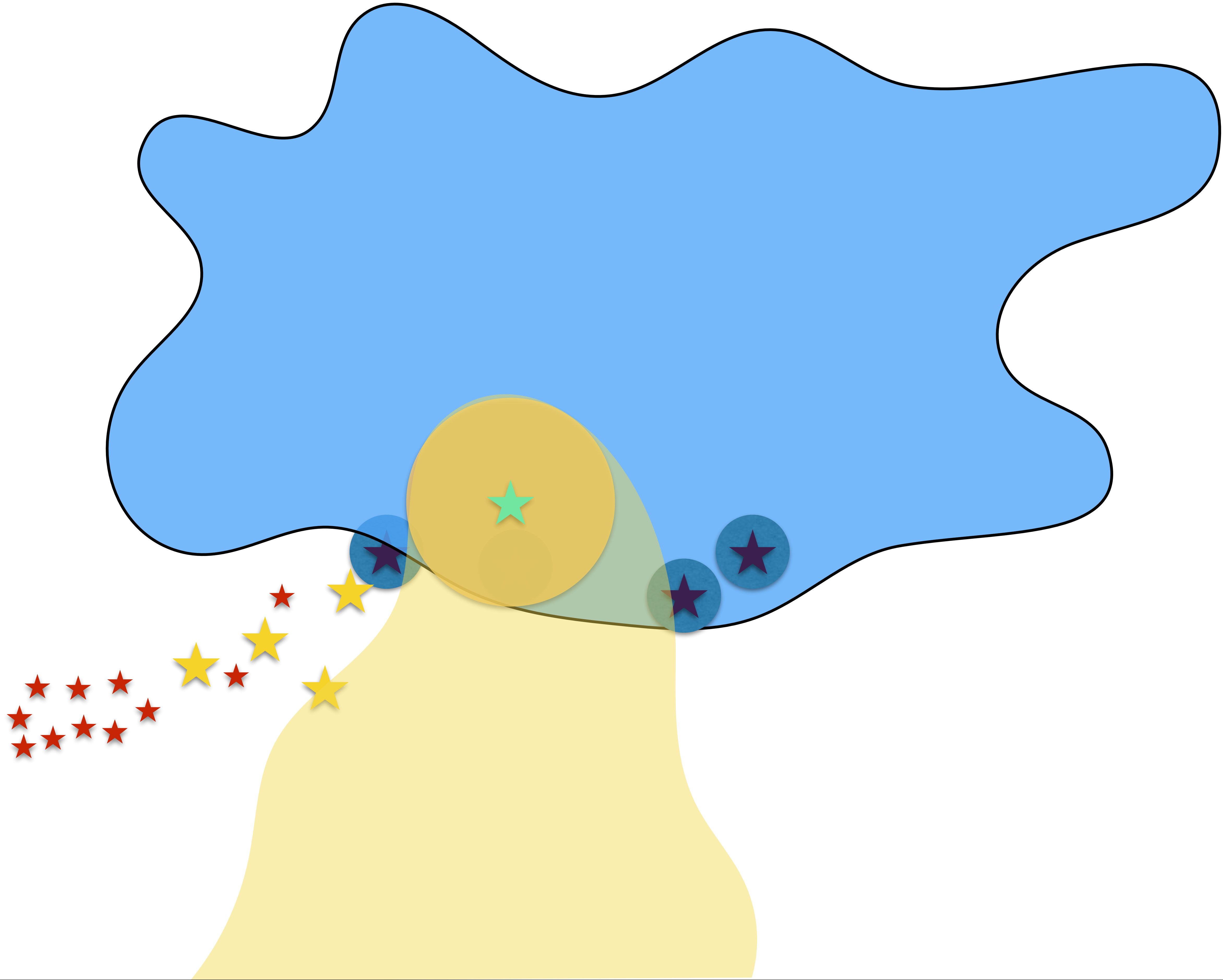
NACO K-band
(Figuerêdo et al 2008)

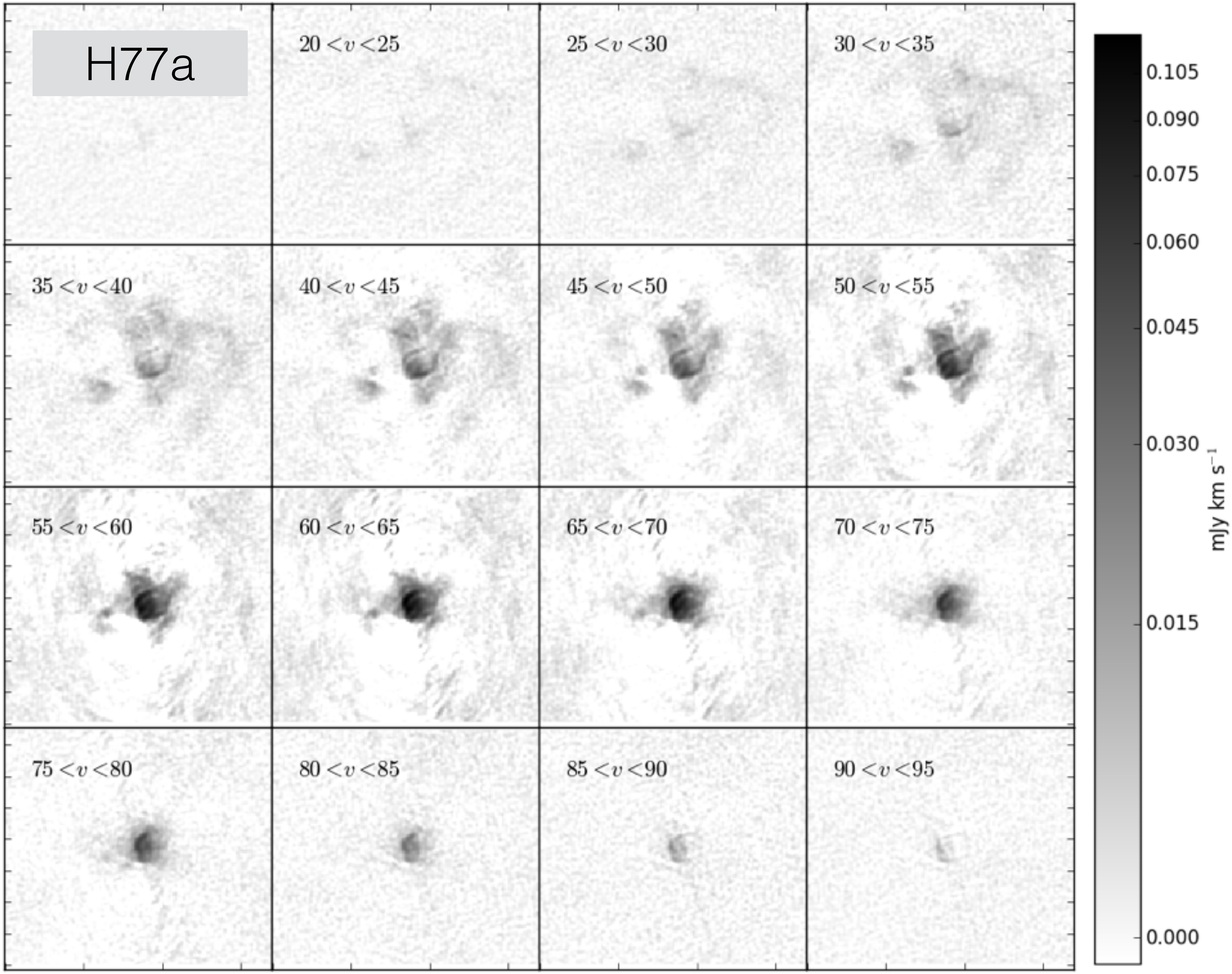
In W51 North, massive stars are forming within an HII region

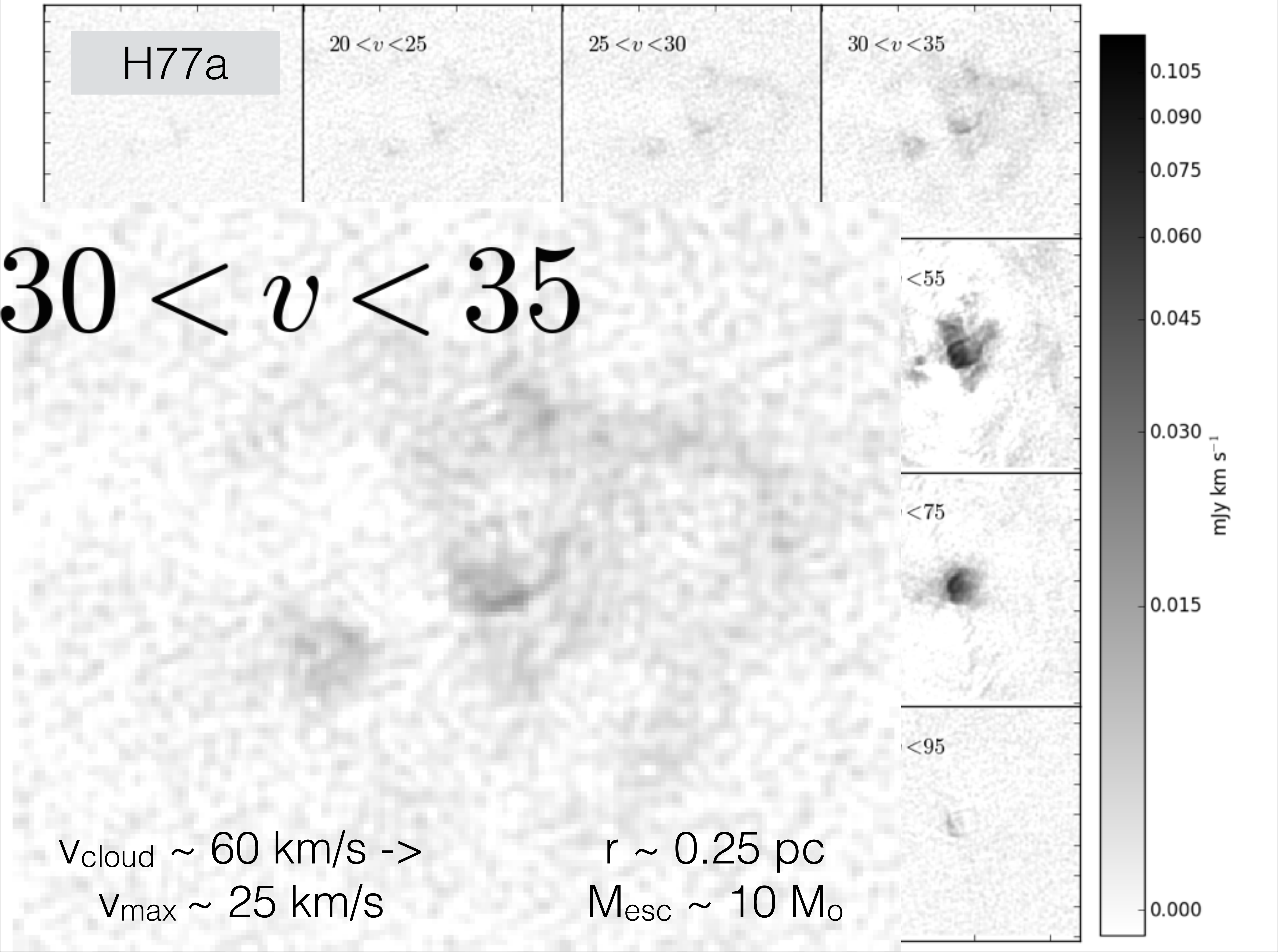


Photoevaporative Feedback in IRS2

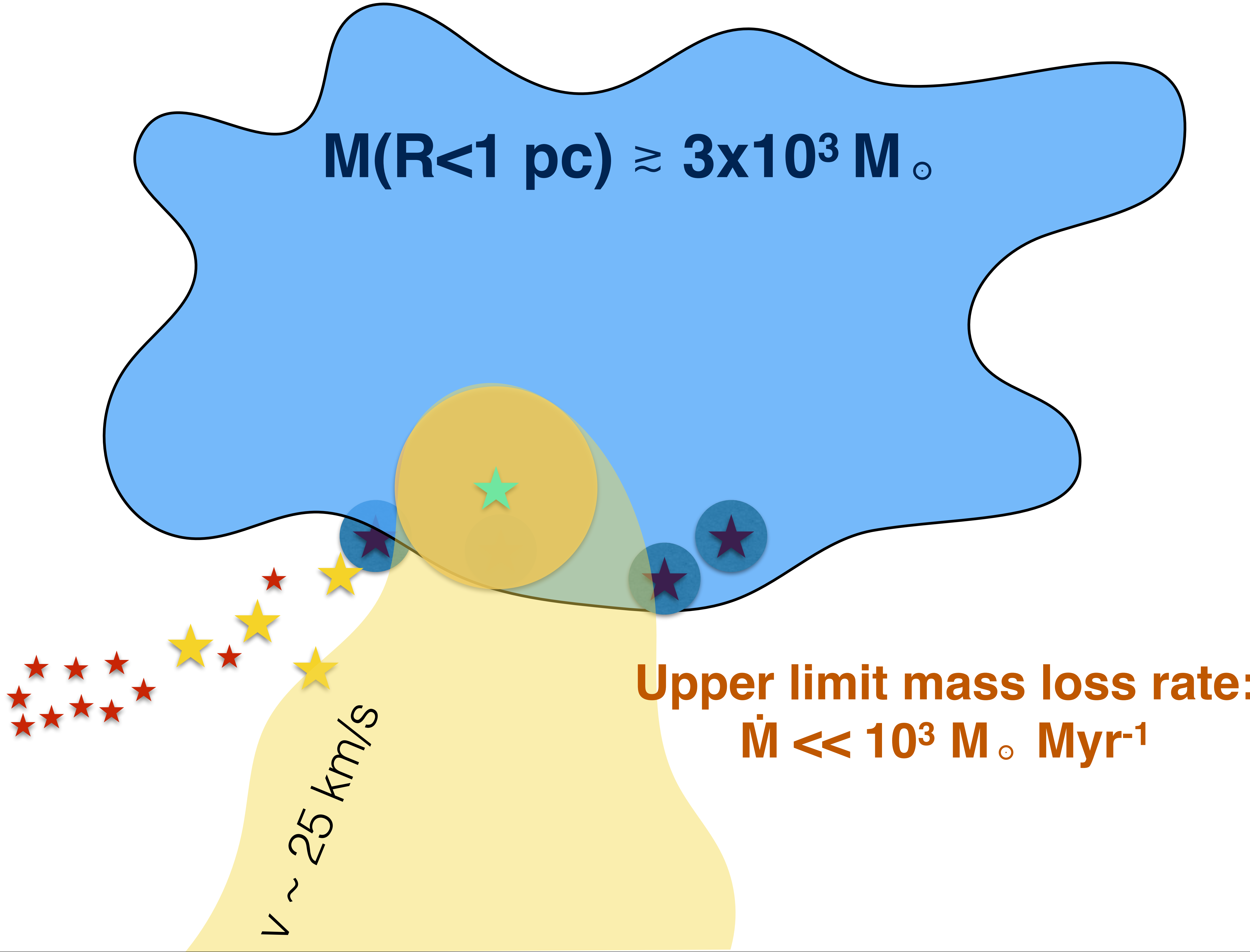





H77a
20 < v < 25
25 < v < 30
30 < v < 35
35 < v < 40
40 < v < 45
45 < v < 50
50 < v < 55
55 < v < 60
60 < v < 65
65 < v < 70
70 < v < 75
75 < v < 80
80 < v < 85
85 < v < 90
90 < v < 95
0.105
0.090
0.075
0.060
0.045
0.030
0.015
0.000
mJy km s⁻¹



H77a
20 < v < 25
25 < v < 30
30 < v < 35
30 < v < 35
<55
<75
<95
0.105
0.090
0.075
0.060
0.045
0.030
0.015
0.000
mJy km s⁻¹
v_cloud ~ 60 km/s ->
v_max ~ 25 km/s
r ~ 0.25 pc
M_esc ~ 10 M_o



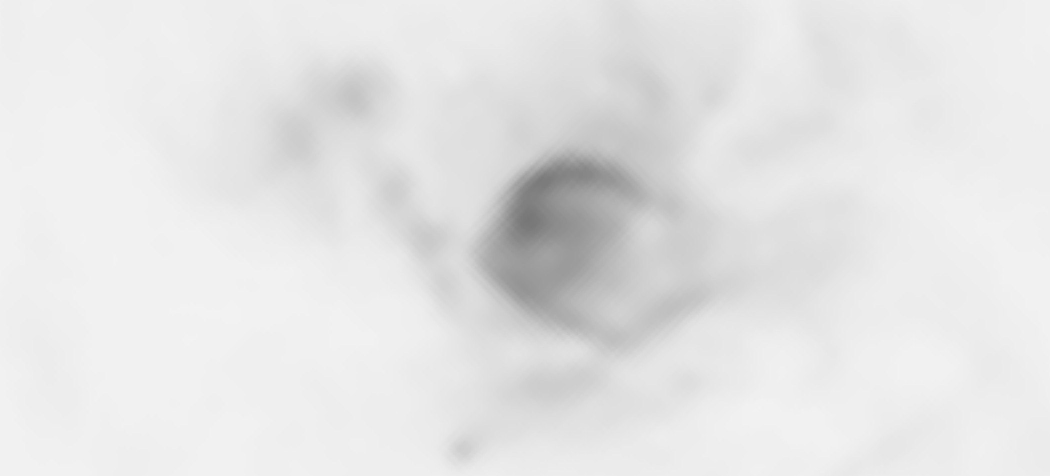
M(R<1 pc) ≳ 3x10³ M☉
Upper limit mass loss rate:
Ṁ << 10³ M☉ Myr⁻¹
v ~ 25 km/s

Ionization-driven mass loss rate $<<10^3\ M_\odot\ \mathrm{Myr}^{-1}$

$n>10^4\ \mathrm{cm}^{-3}$ -> $t_{ff} < 0.5$ Myr

Evaporation timescale $t_{ev} > 5\text{-}10\ t_{ff}$

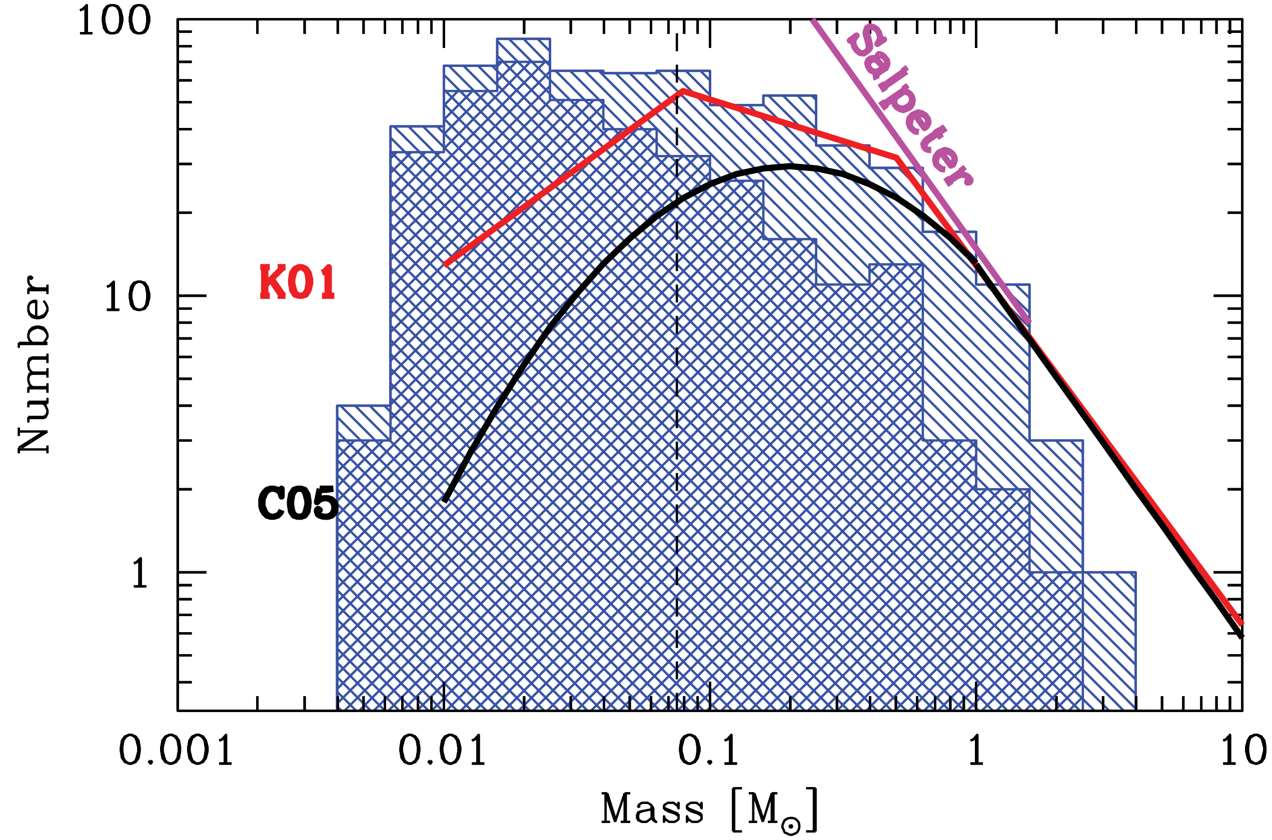
SFR > ionization mass loss

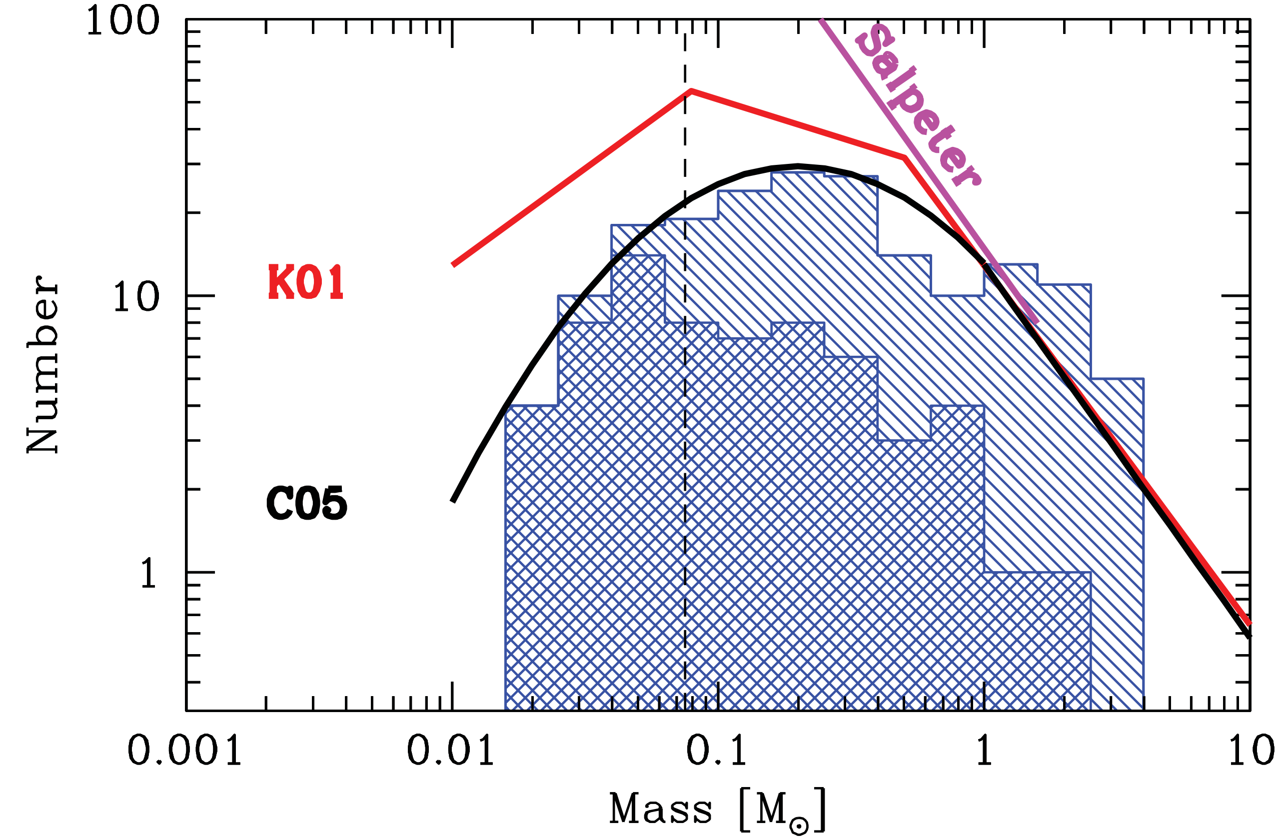


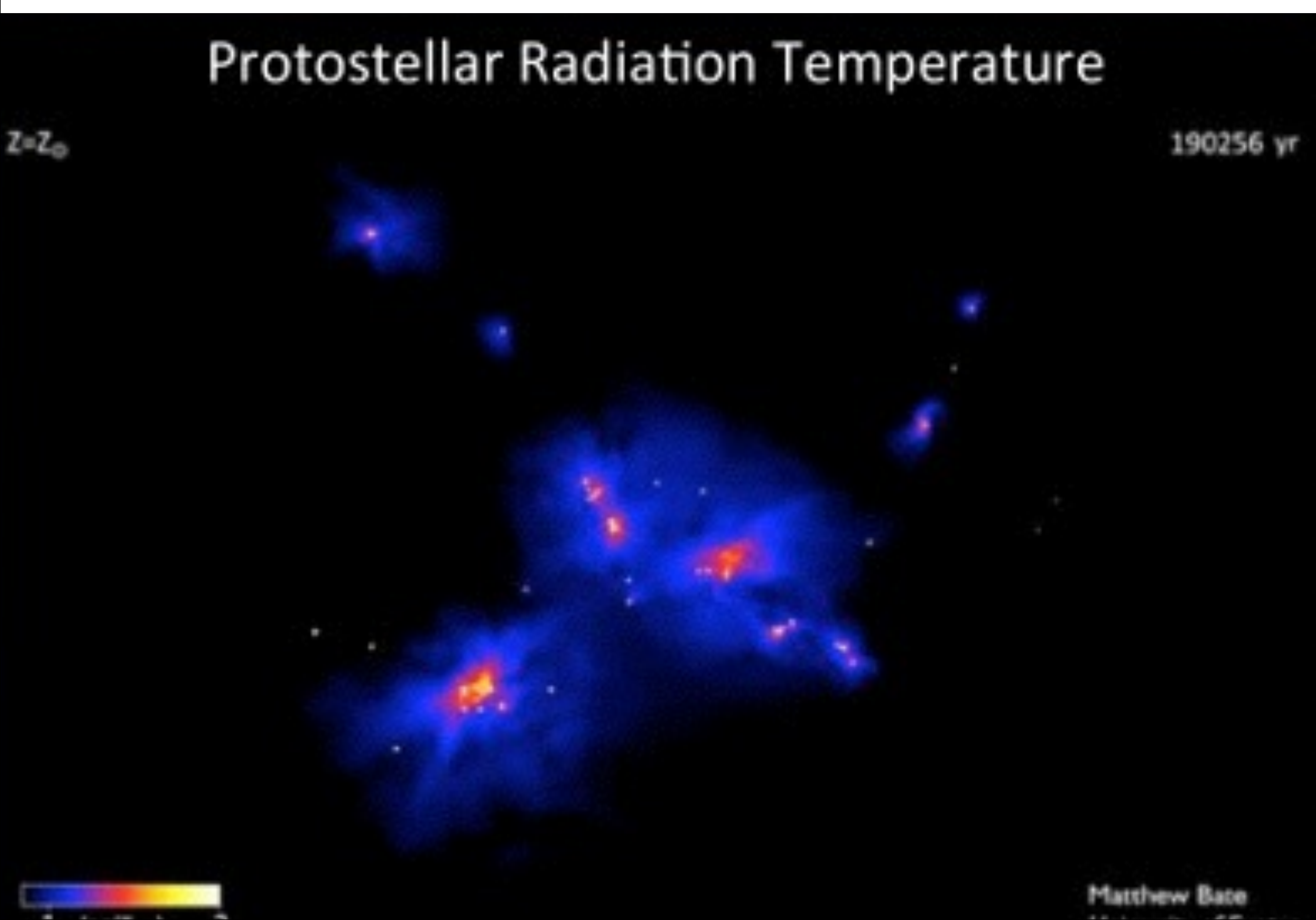
Gas exhaustion, not expulsion, will end star formation in IRS2

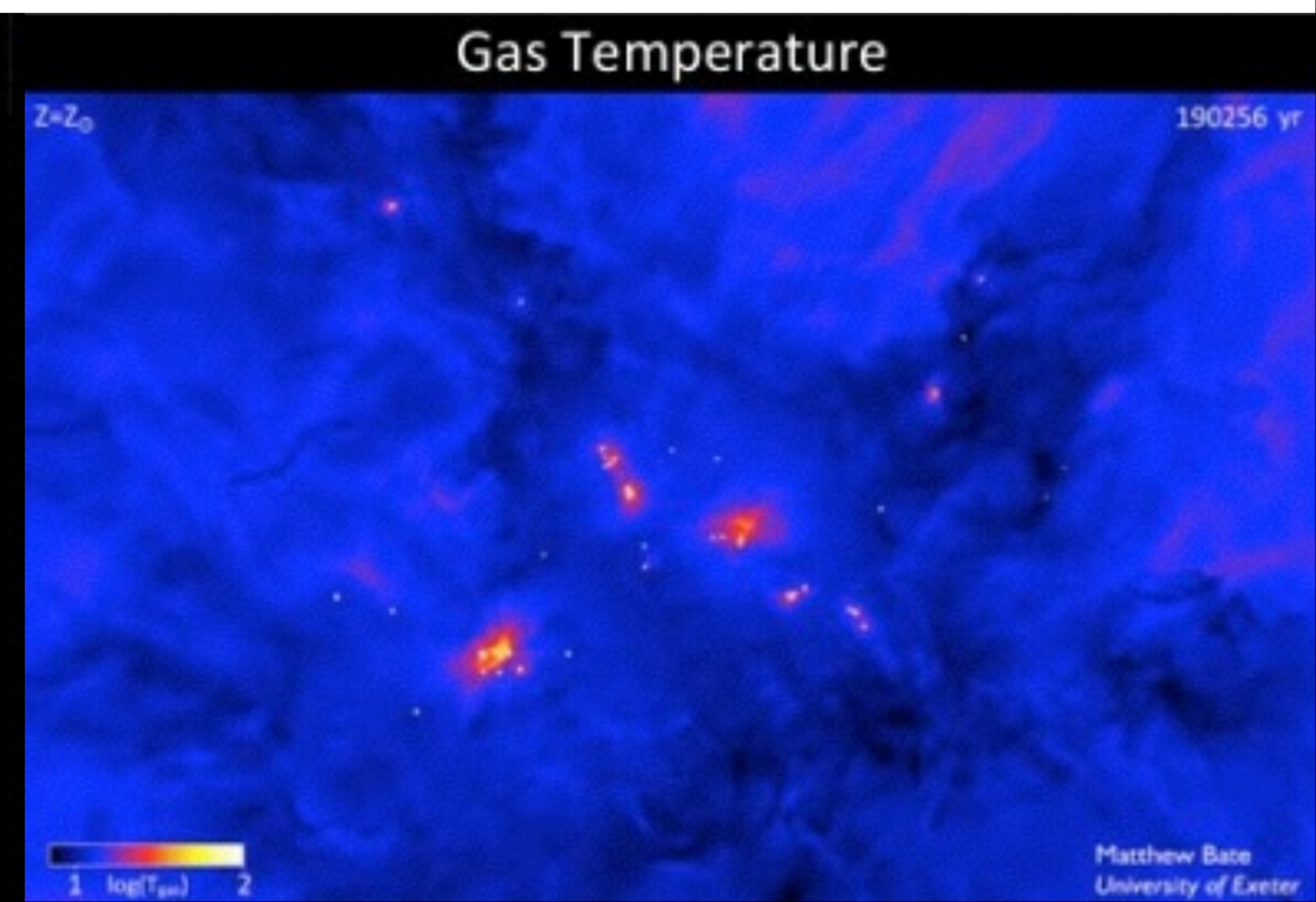
(e.g., Kruijssen et al 2012)

Stellar thermal feedback is critical for setting the IMF

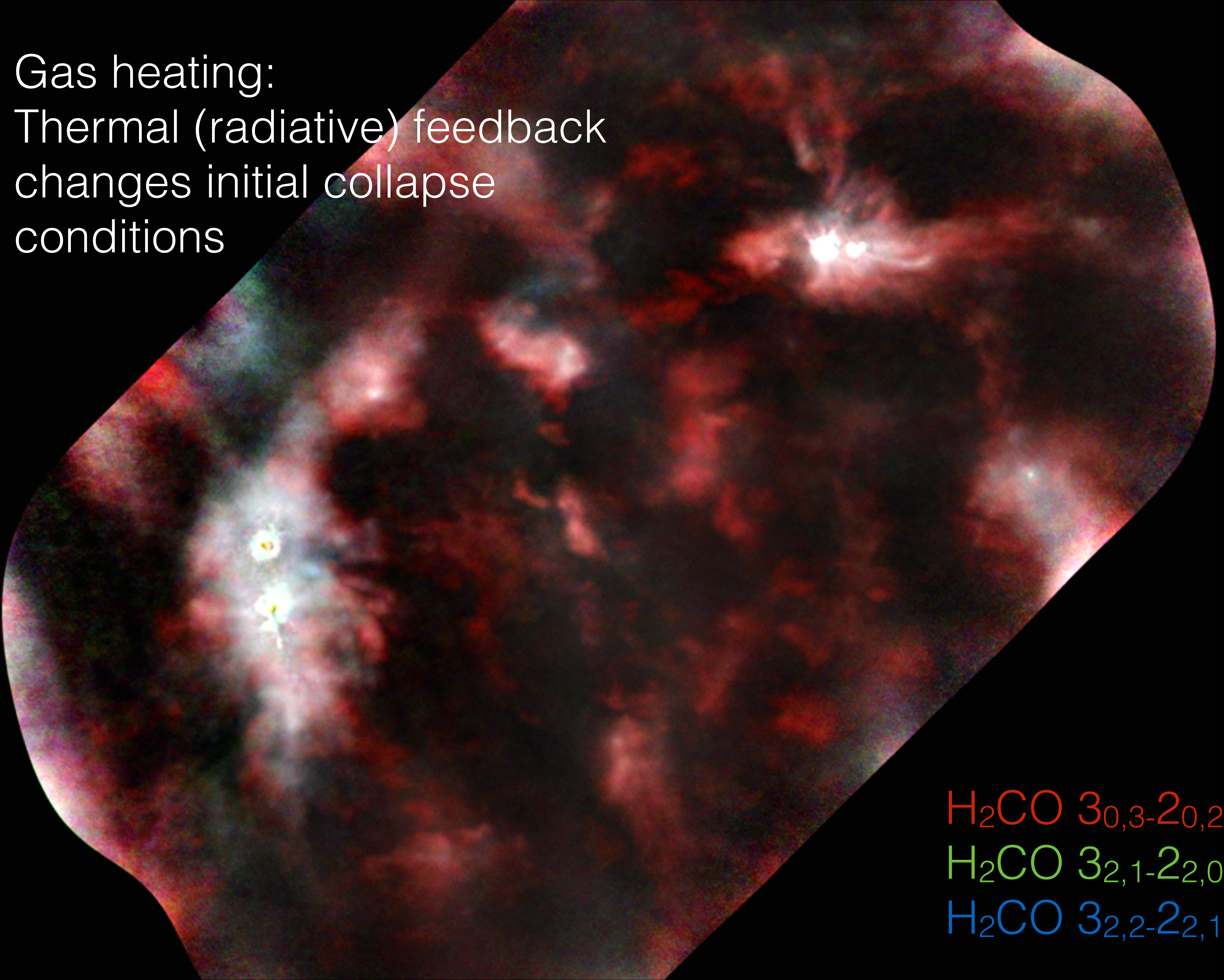


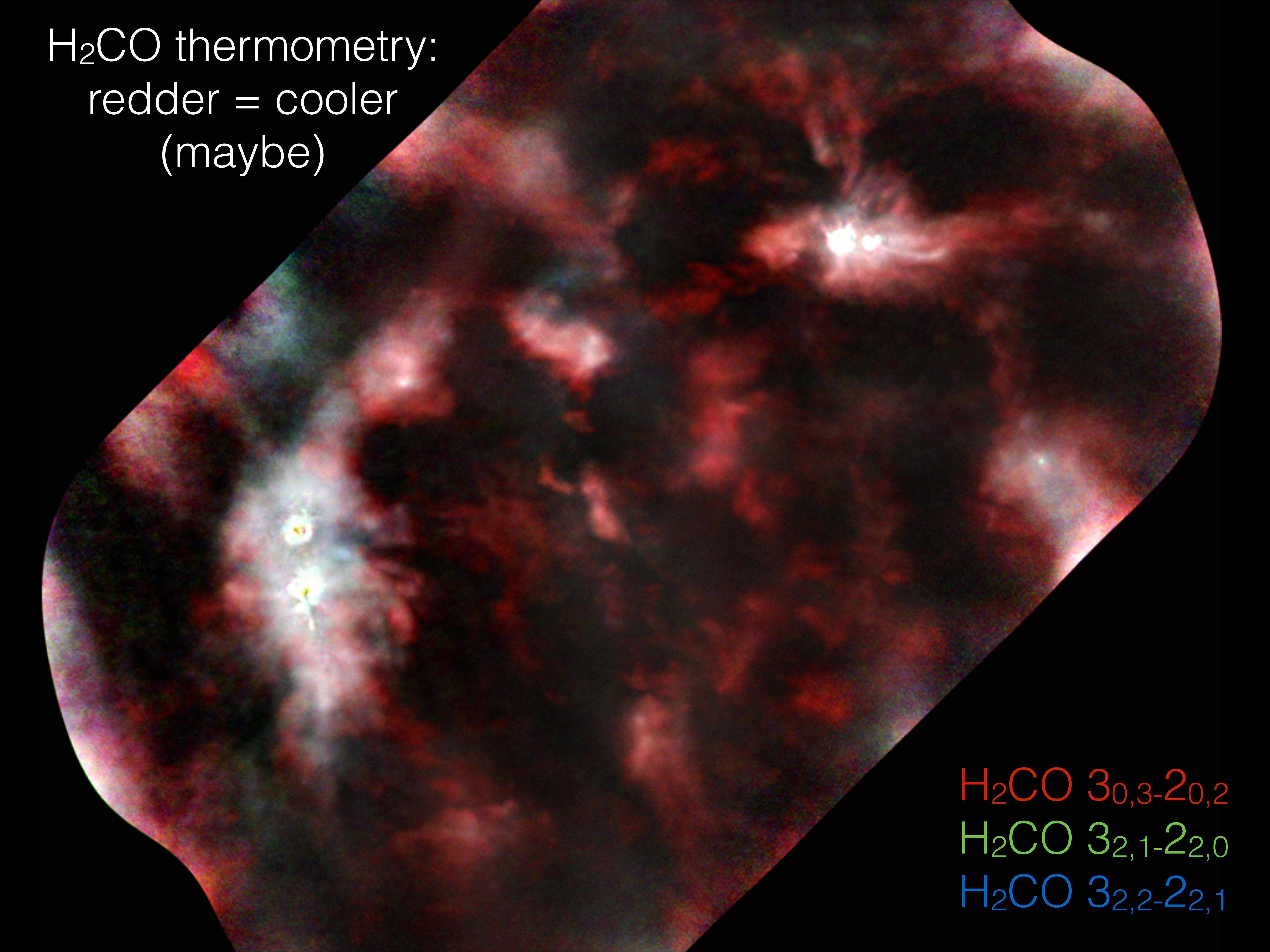


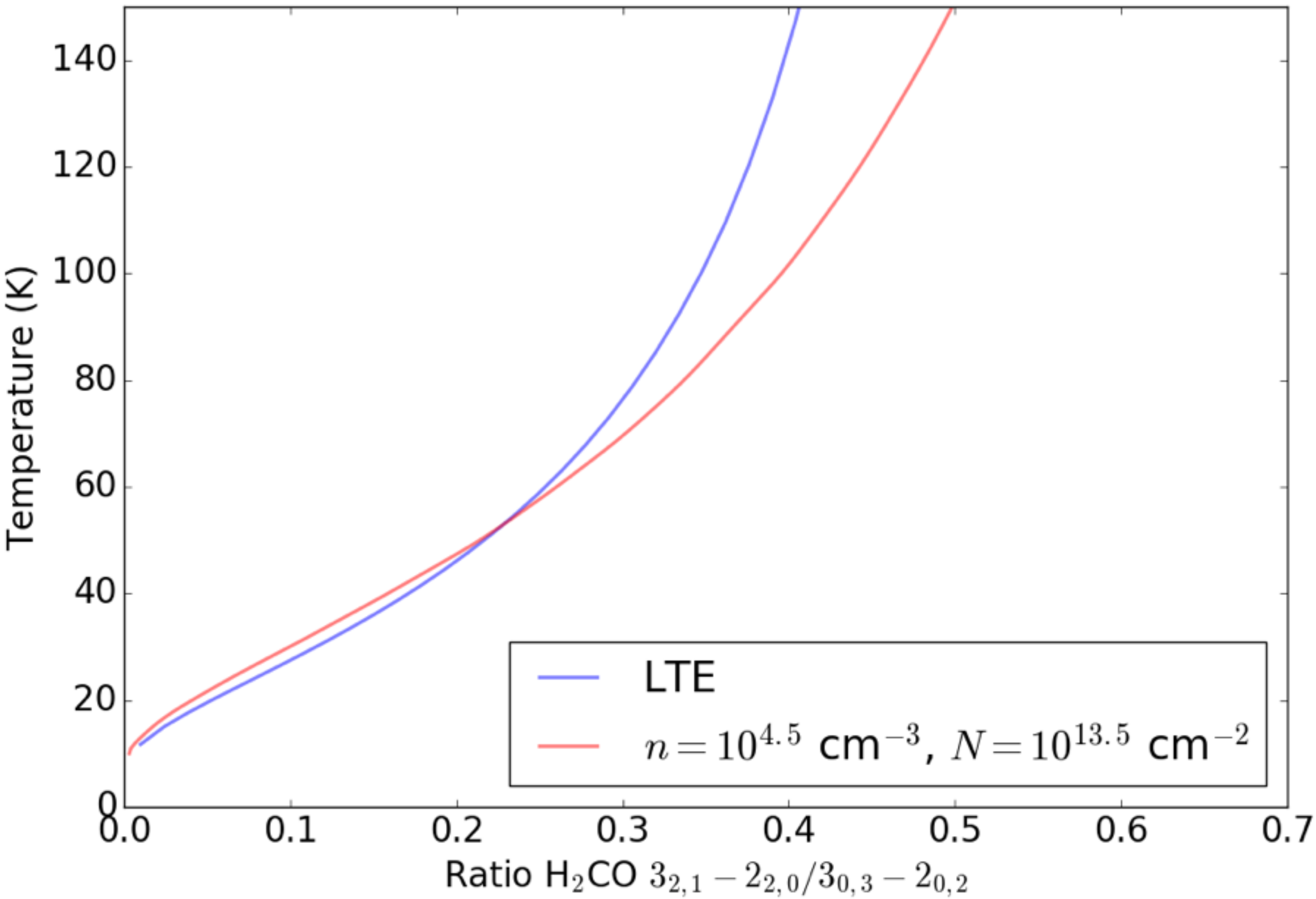




Gas heating:
Thermal (radiative) feedback
changes initial collapse
conditions

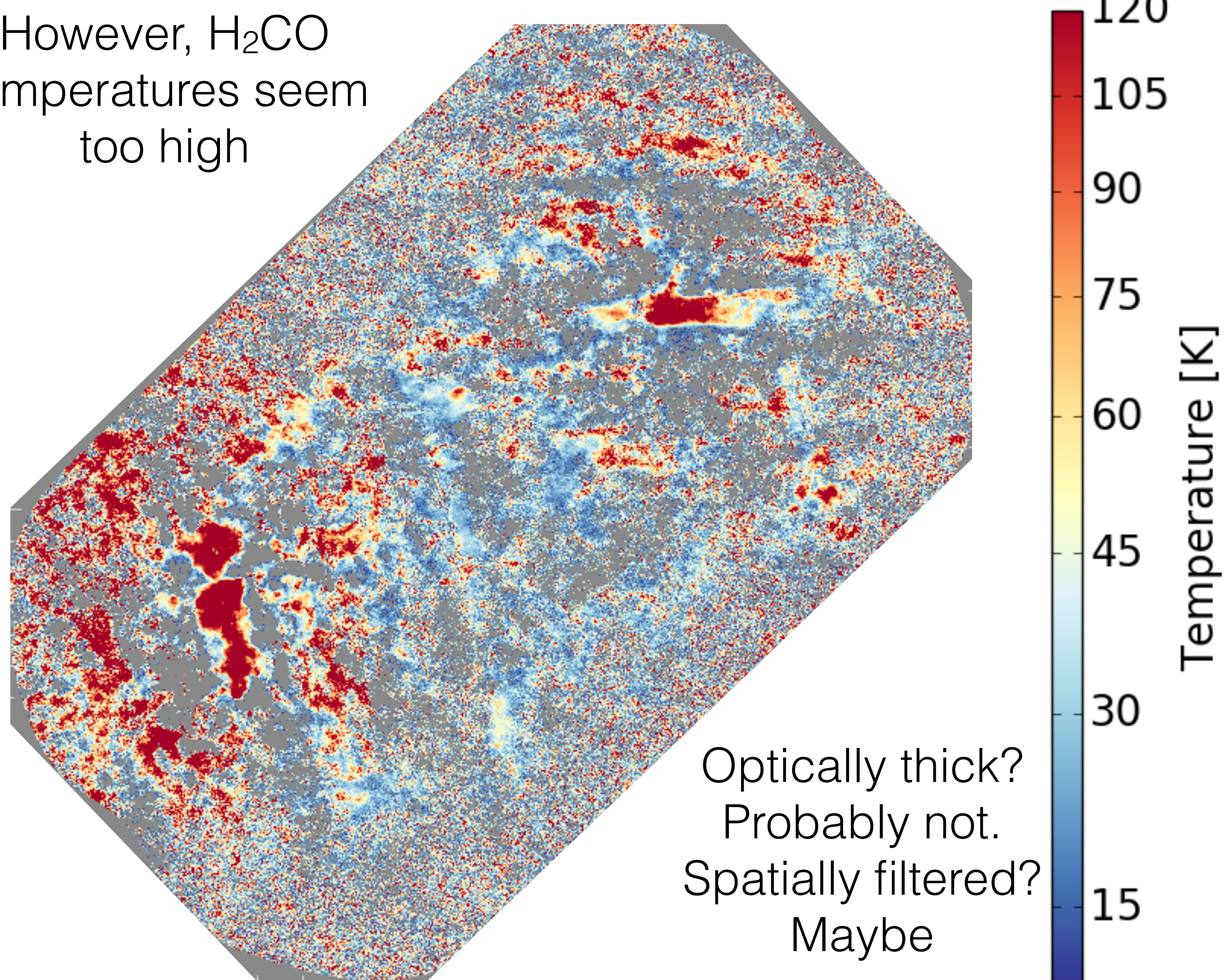



H_2CO thermometry:
redder = cooler
(maybe)
H_2CO $3_{0,3}$-$2_{0,2}$
H_2CO $3_{2,1}$-$2_{2,0}$
H_2CO $3_{2,2}$-$2_{2,1}$



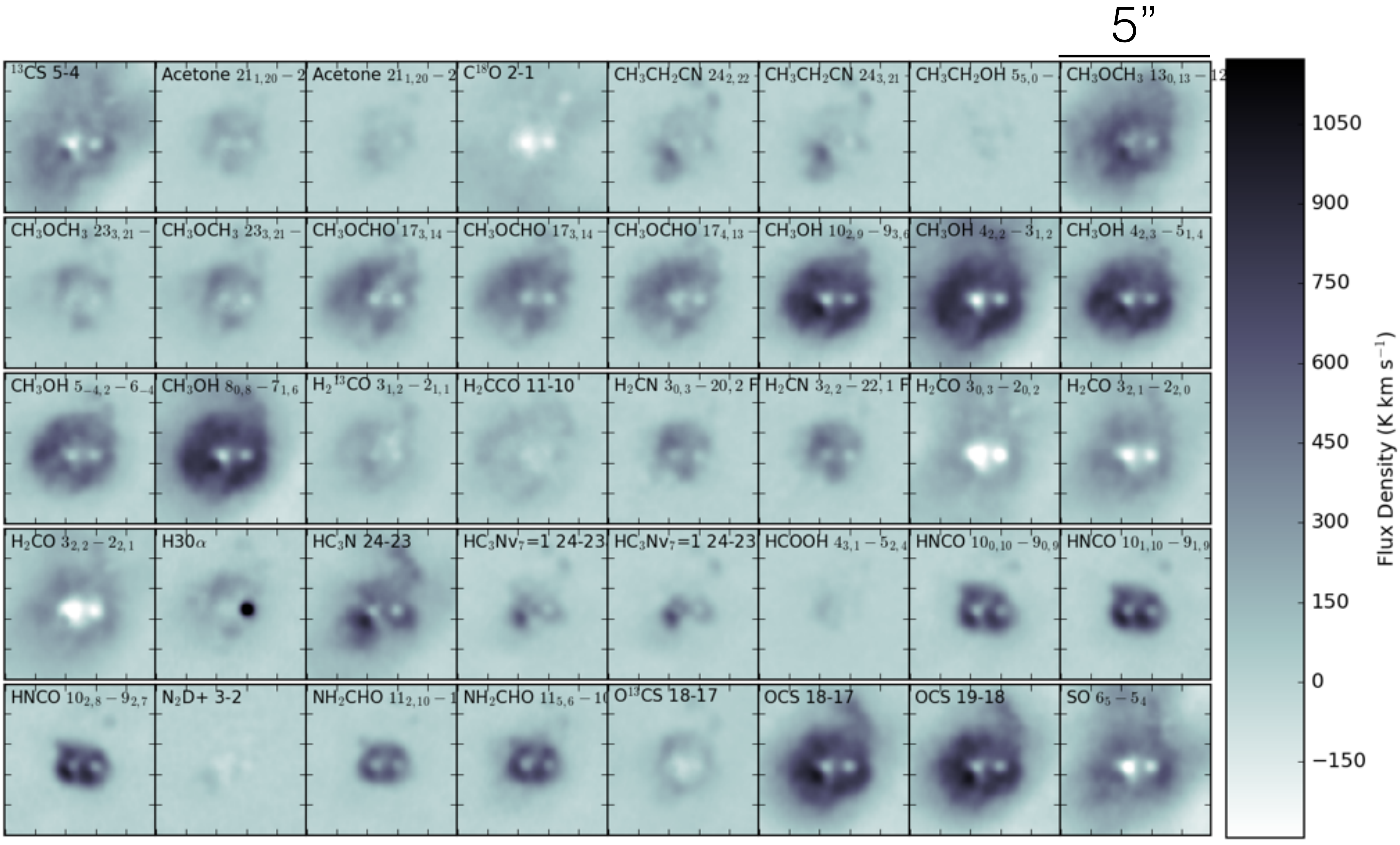
Ginsburg et al 2016 APEX CMZ survey

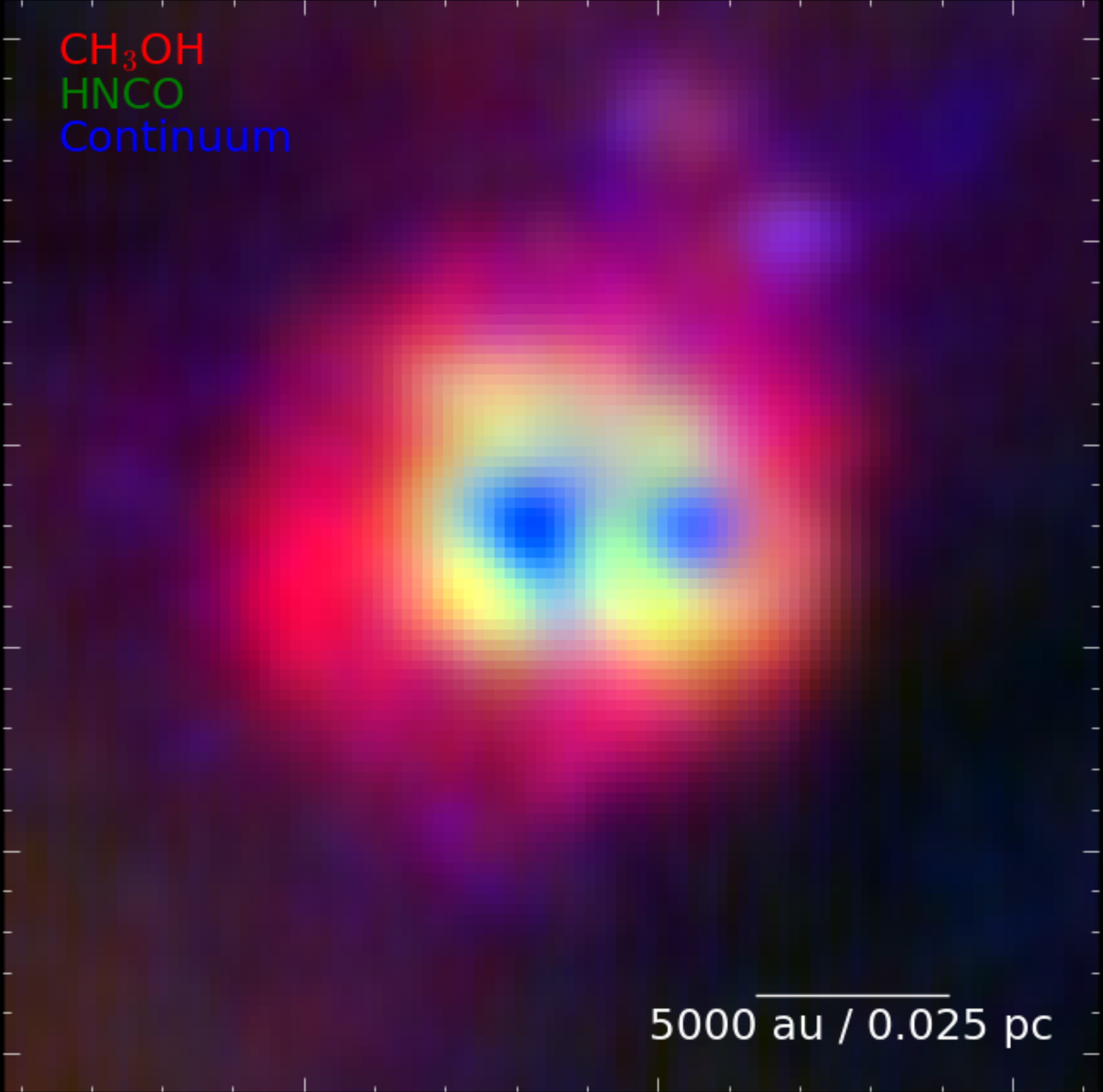
However, H_2CO temperatures seem too high

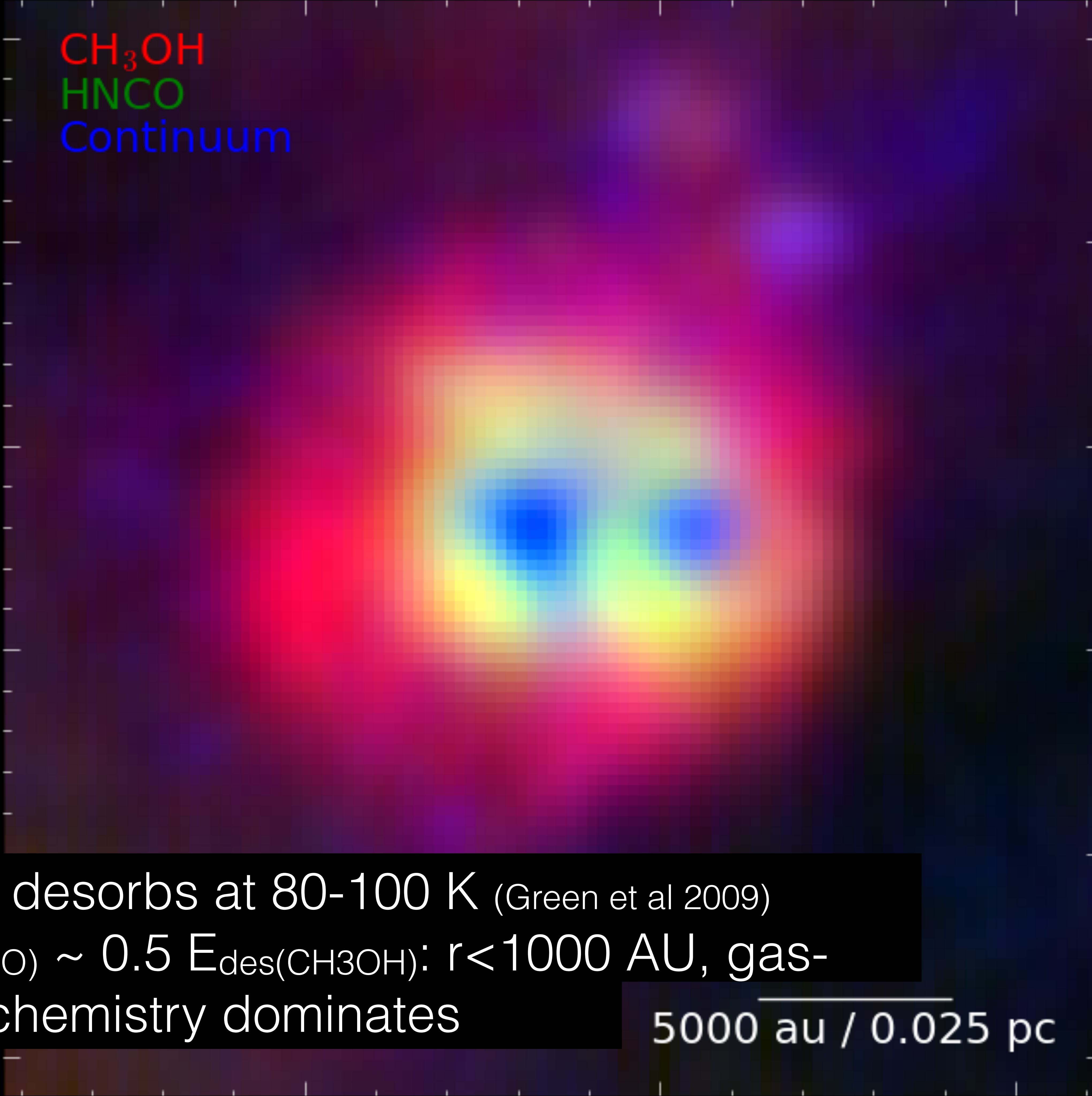


Optically thick? Probably not.
Spatially filtered? Maybe

ALMA molecule maps:
Multi-layered chemically enriched zones



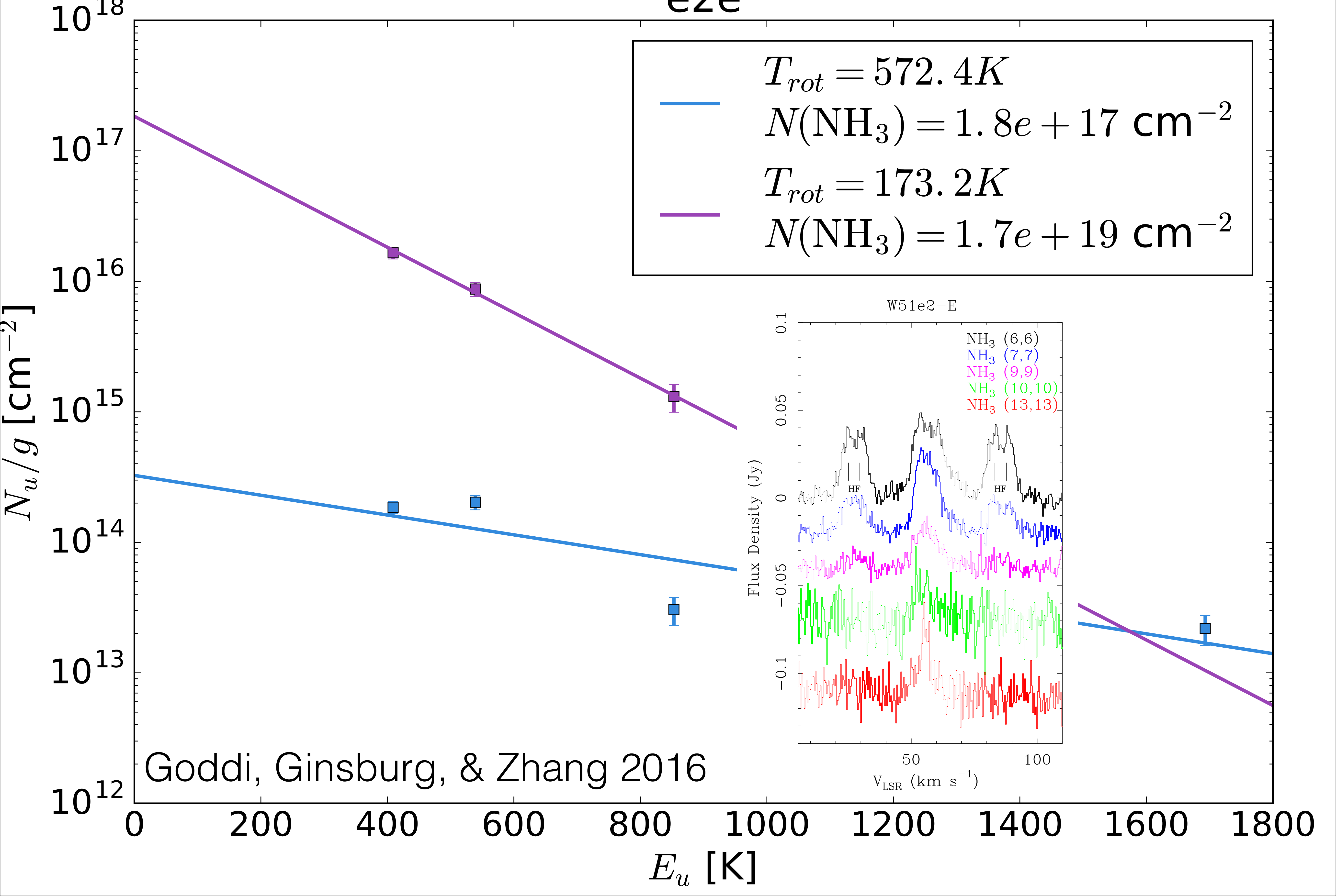

CH_3OH
HNCO
Continuum
5000 au / 0.025 pc

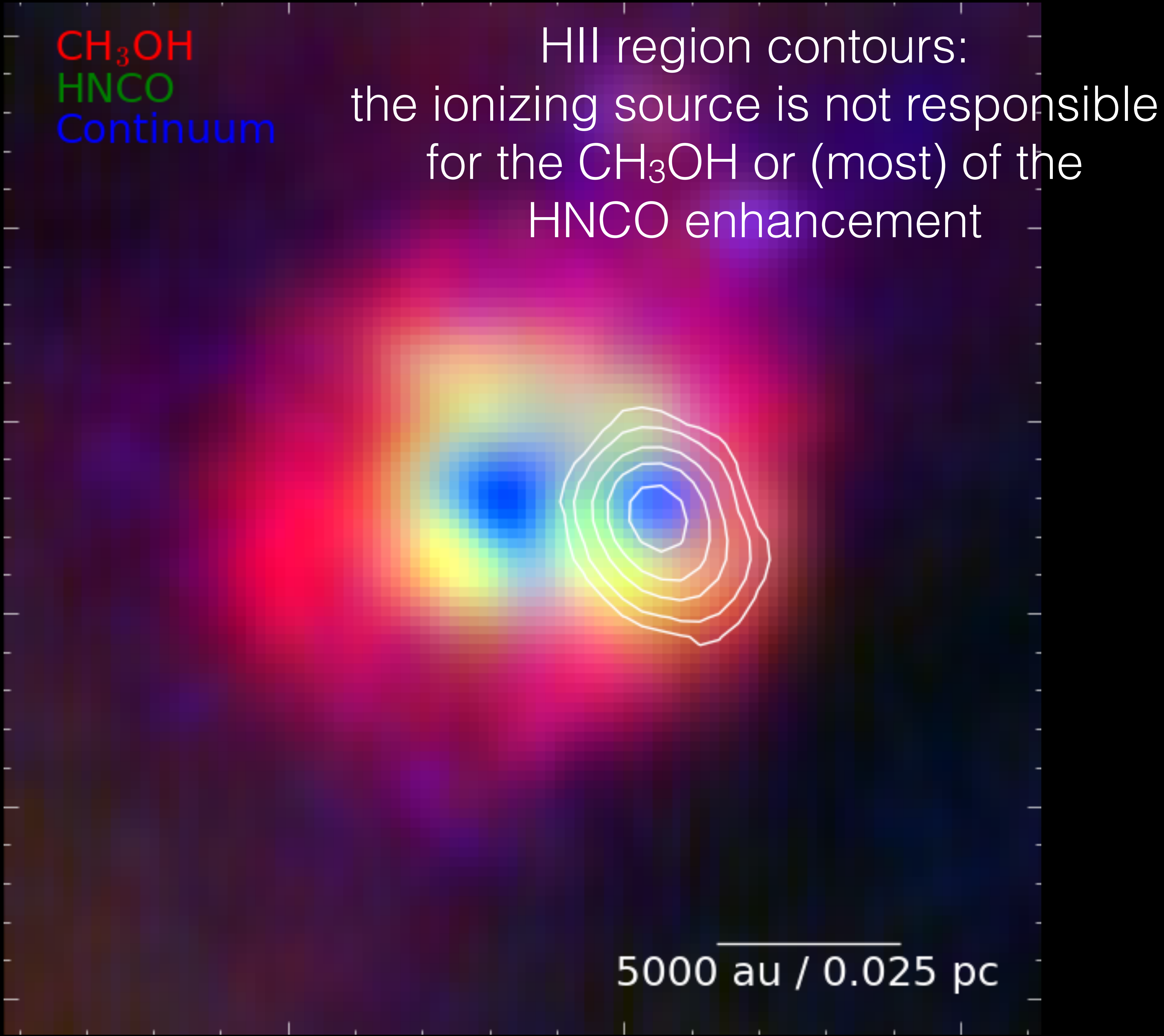


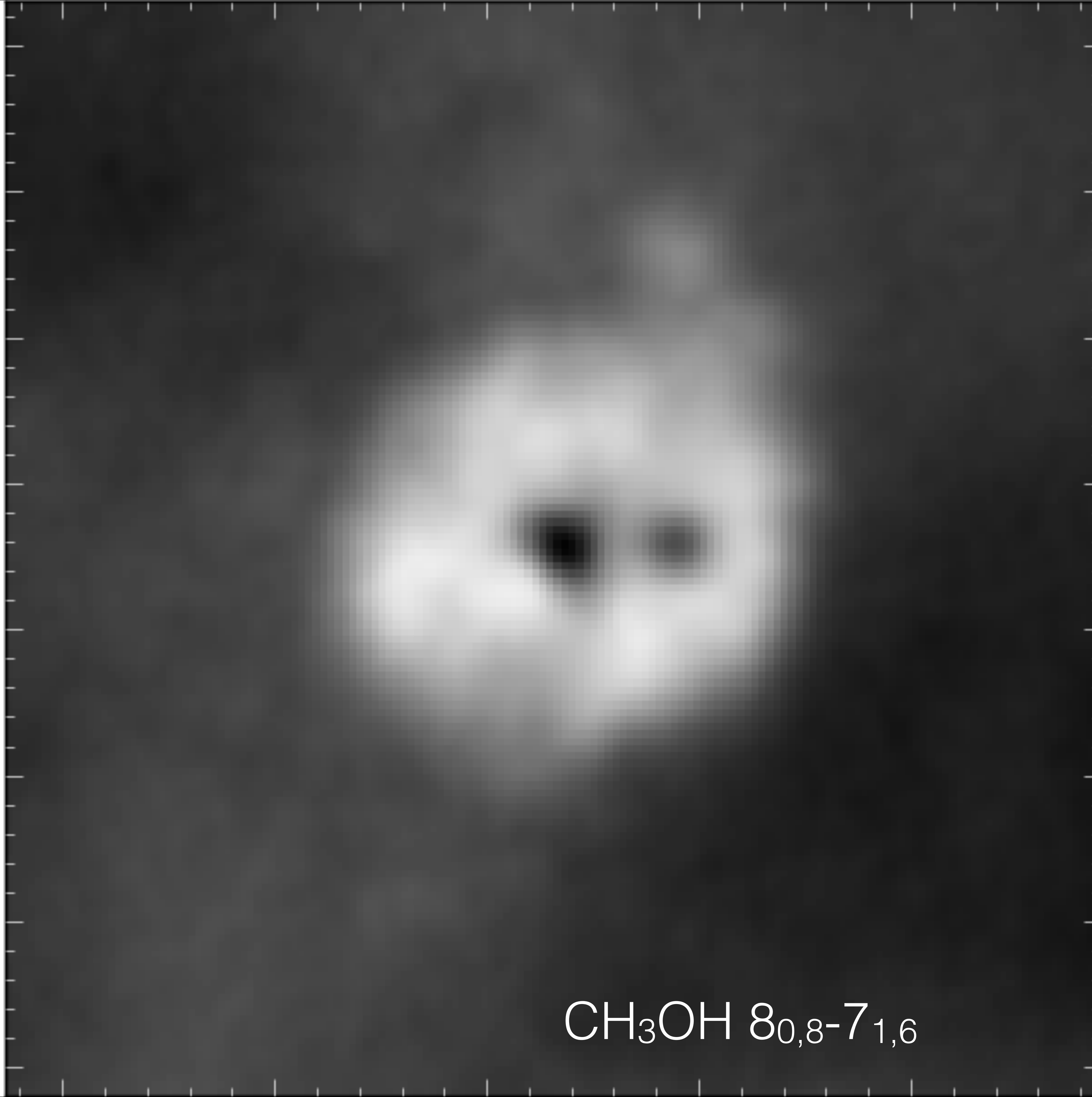
CH_3OH desorbs at 80-100 K (Green et al 2009)

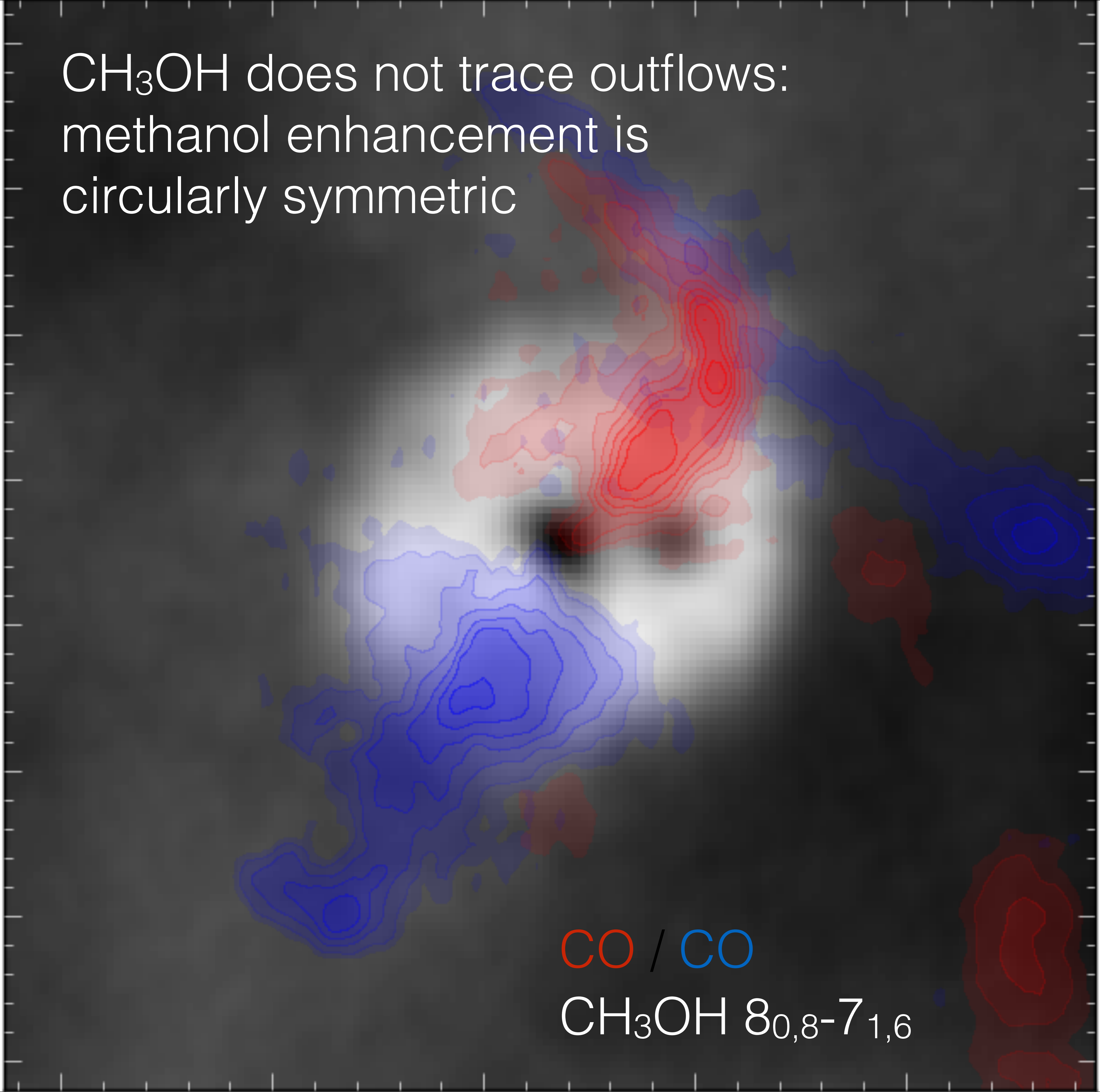
$E_{des(HNCO)}$ ~ 0.5 $E_{des(CH3OH)}$: r<1000 AU, gas-phase chemistry dominates

“Core” temperature in e2e

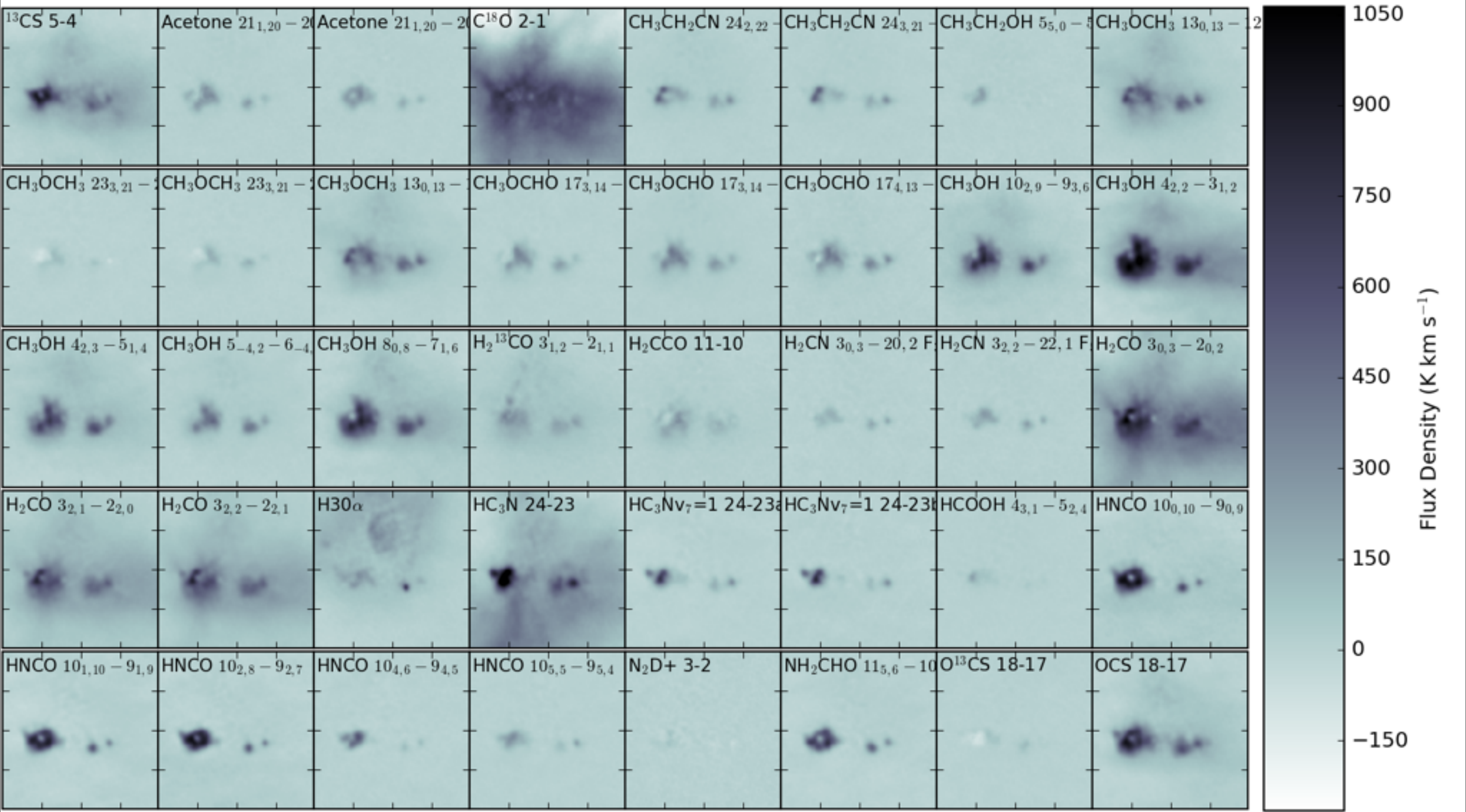



CH$_3$OH
HNCO
Continuum
HII region contours:
the ionizing source is not responsible
for the CH$_3$OH or (most) of the
HNCO enhancement
5000 au / 0.025 pc

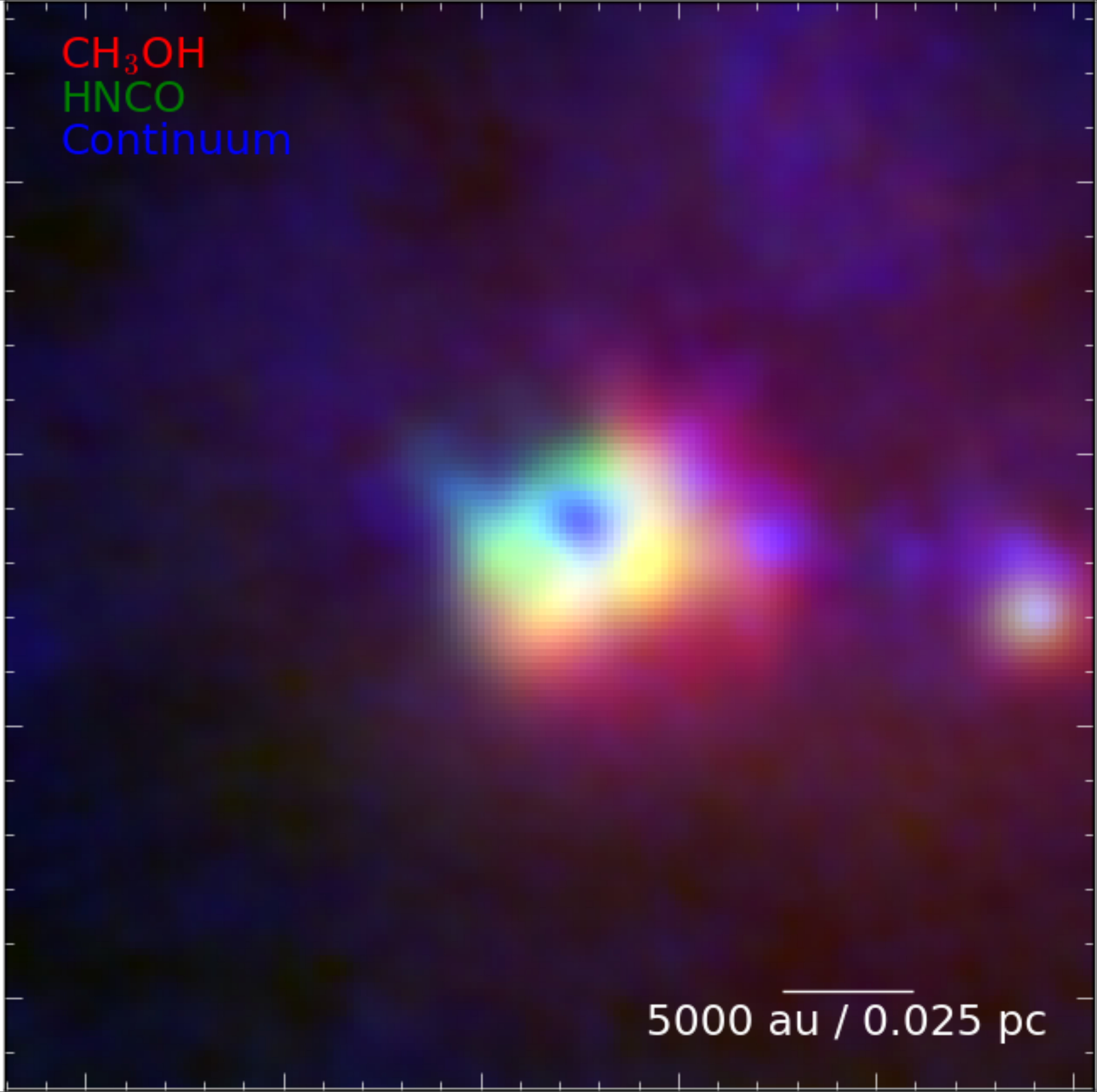

CH_3OH $8_{0,8}$-$7_{1,6}$


CH3OH does not trace outflows:
methanol enhancement is
circularly symmetric
CO / CO
CH3OH 80,8-71,6

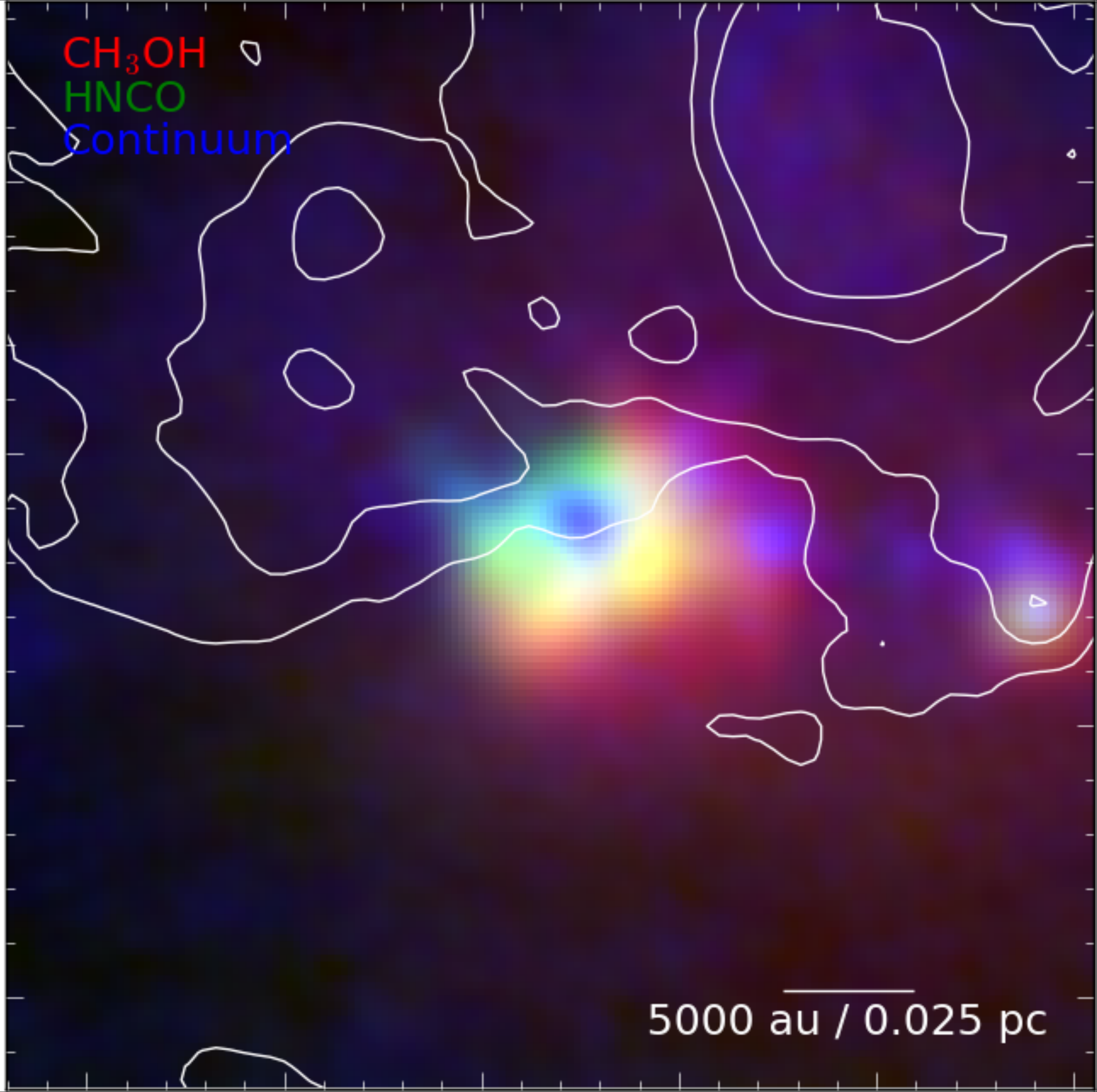
Chemical Maps: North



W51 North: similar heating

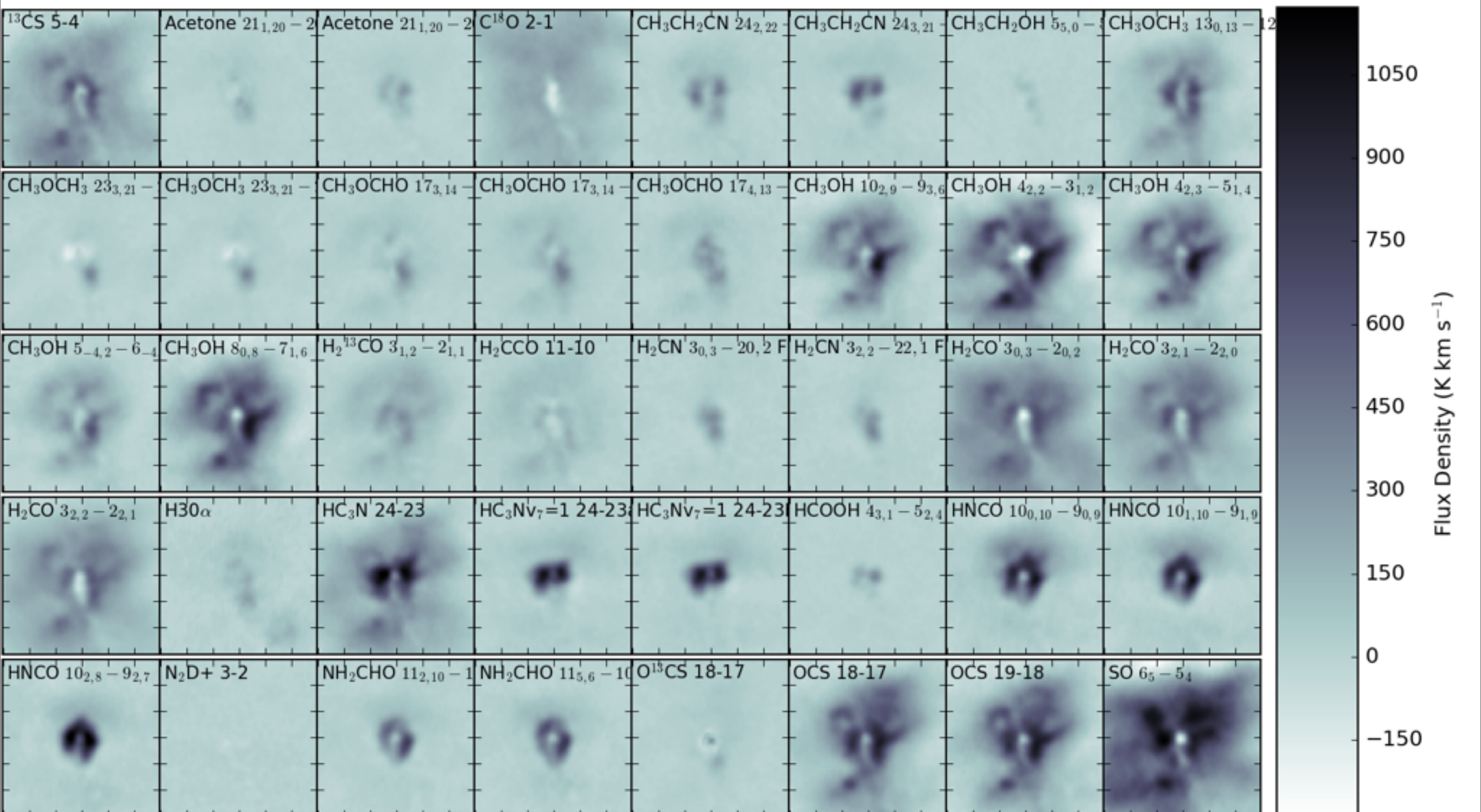


W51 North: similar heating

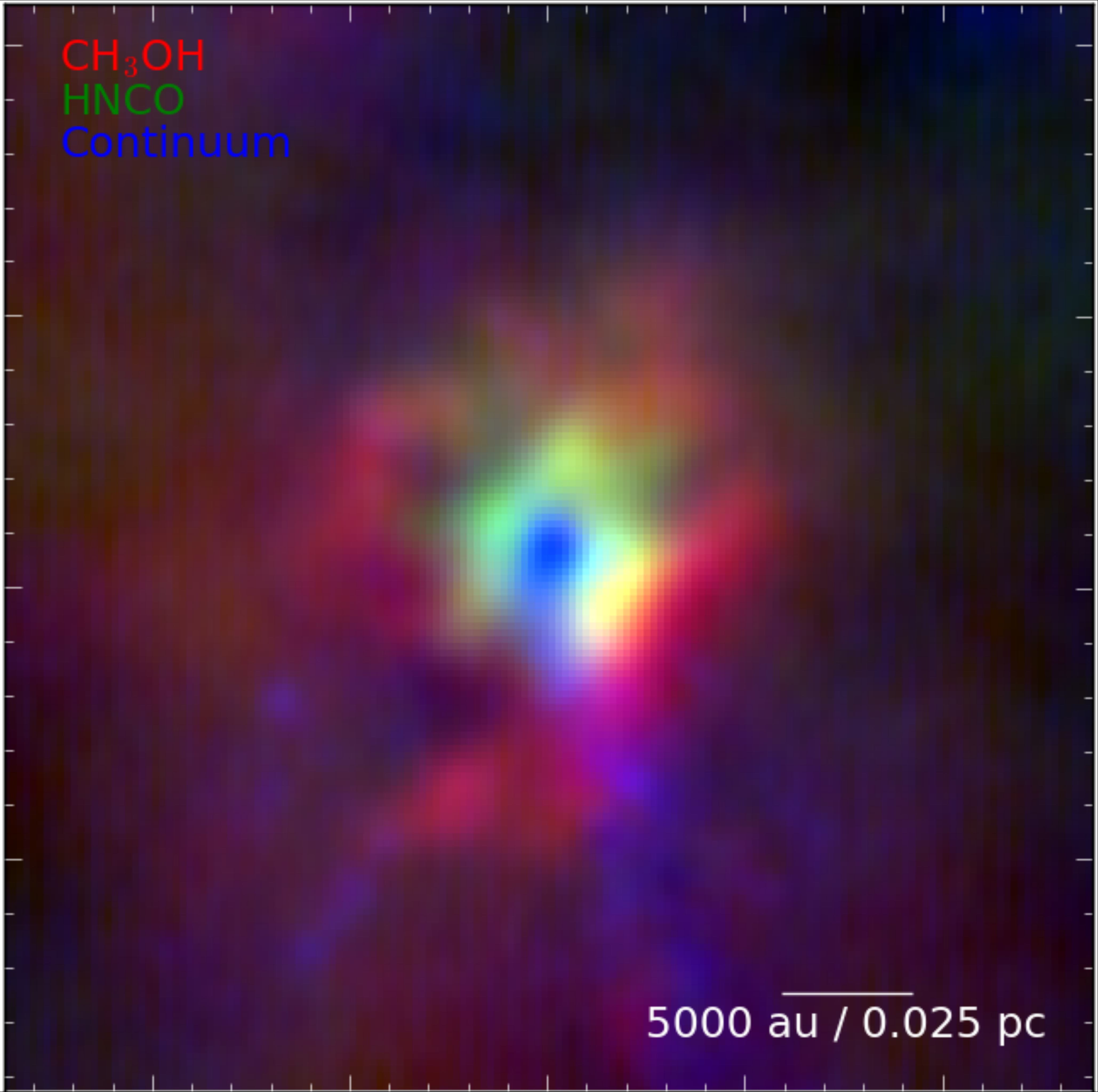


Ionizing radiation is destroying the outer envelope?

Chemical Maps: e8

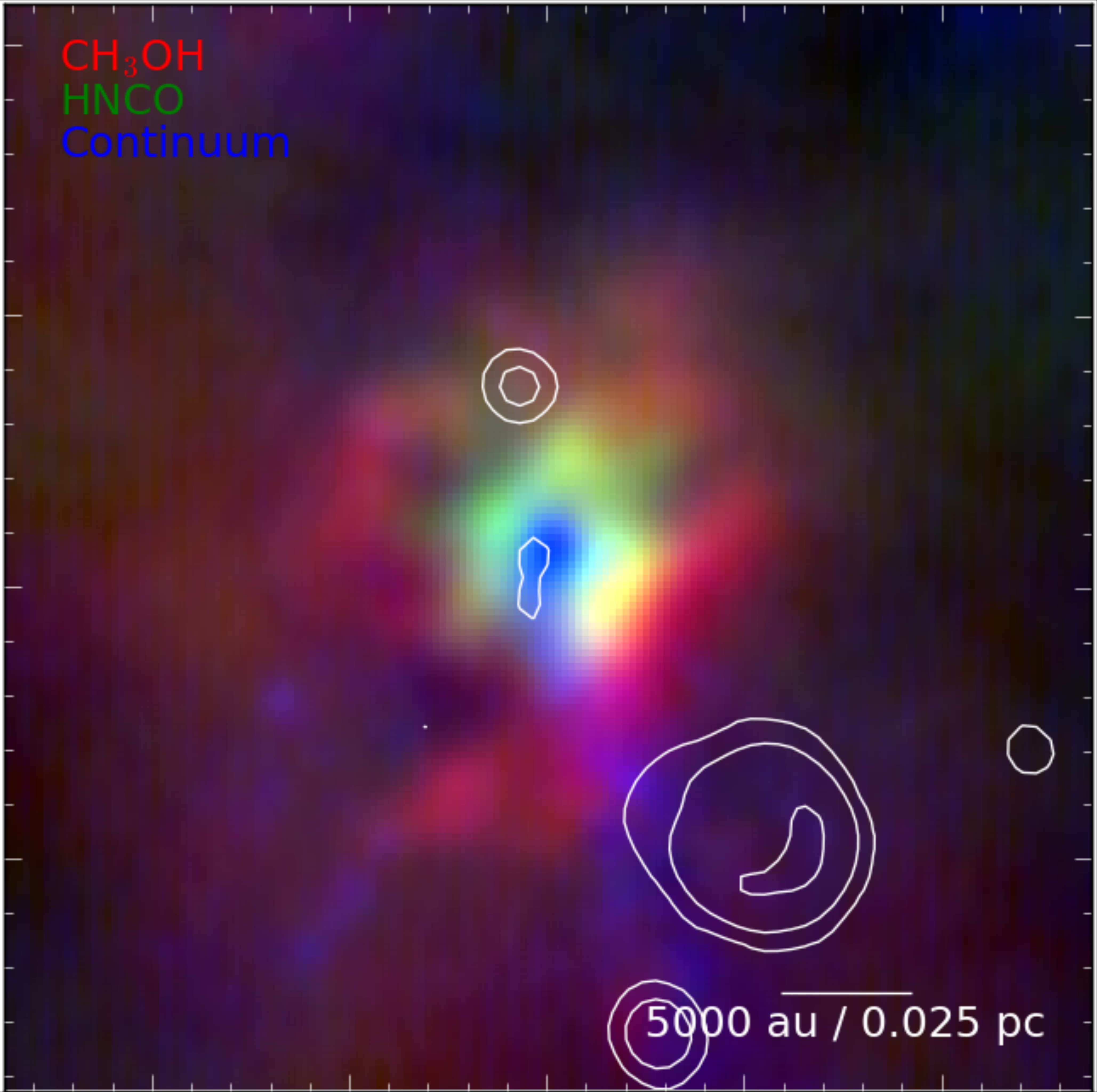


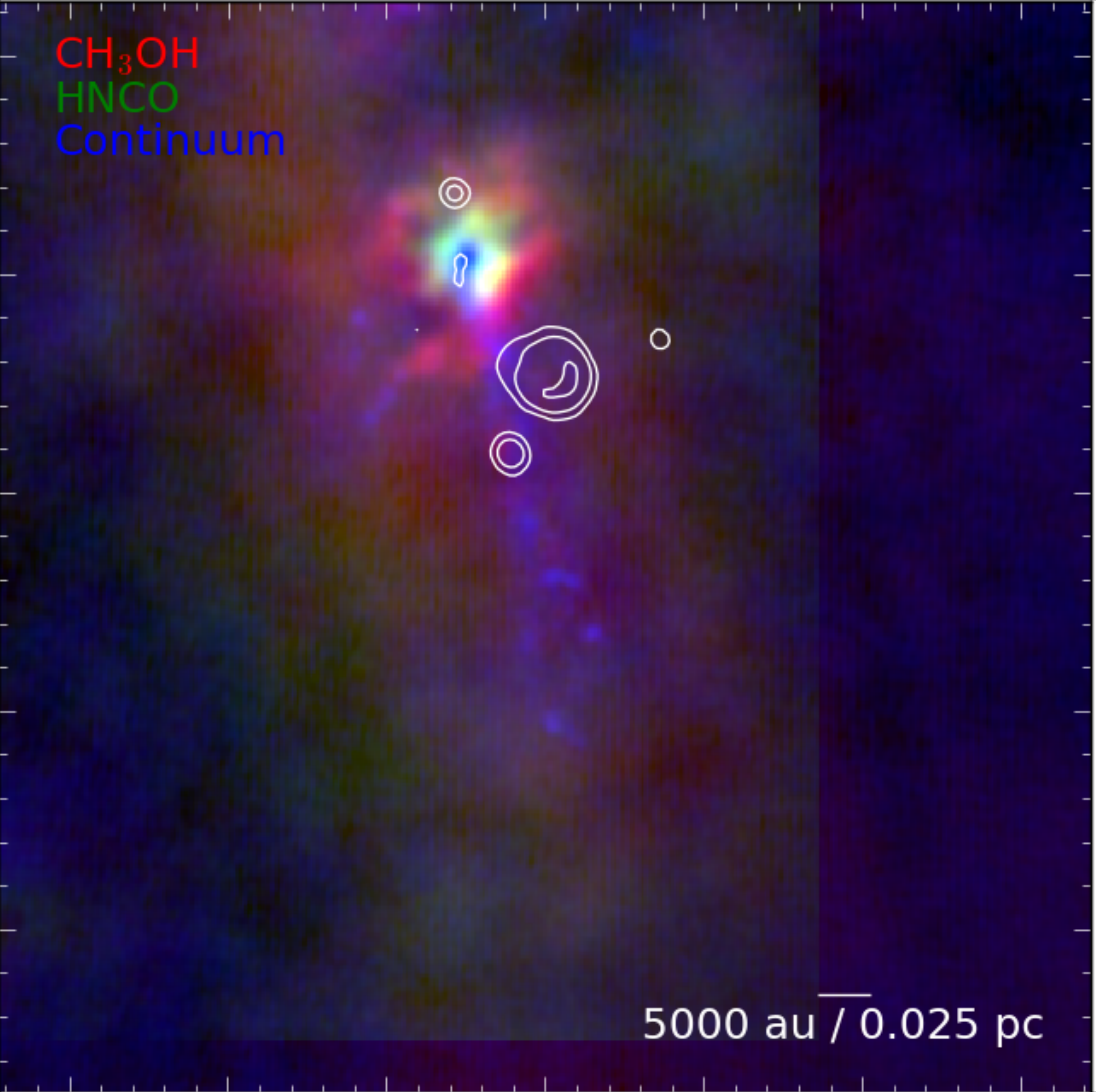
W51 e8:
again,
similar heating



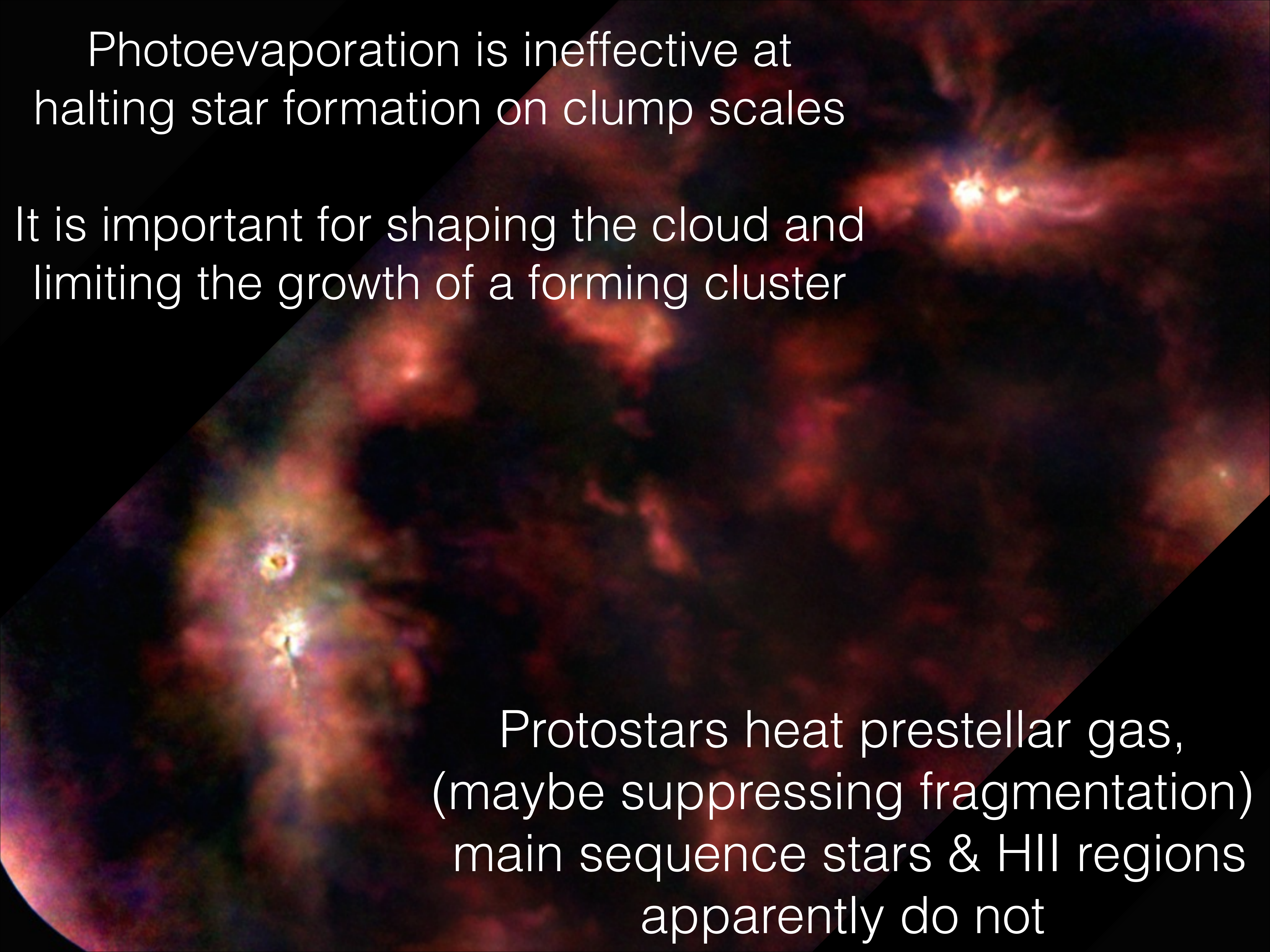
W51 e8: again, similar heating

No sign of excess warm gas near HII regions

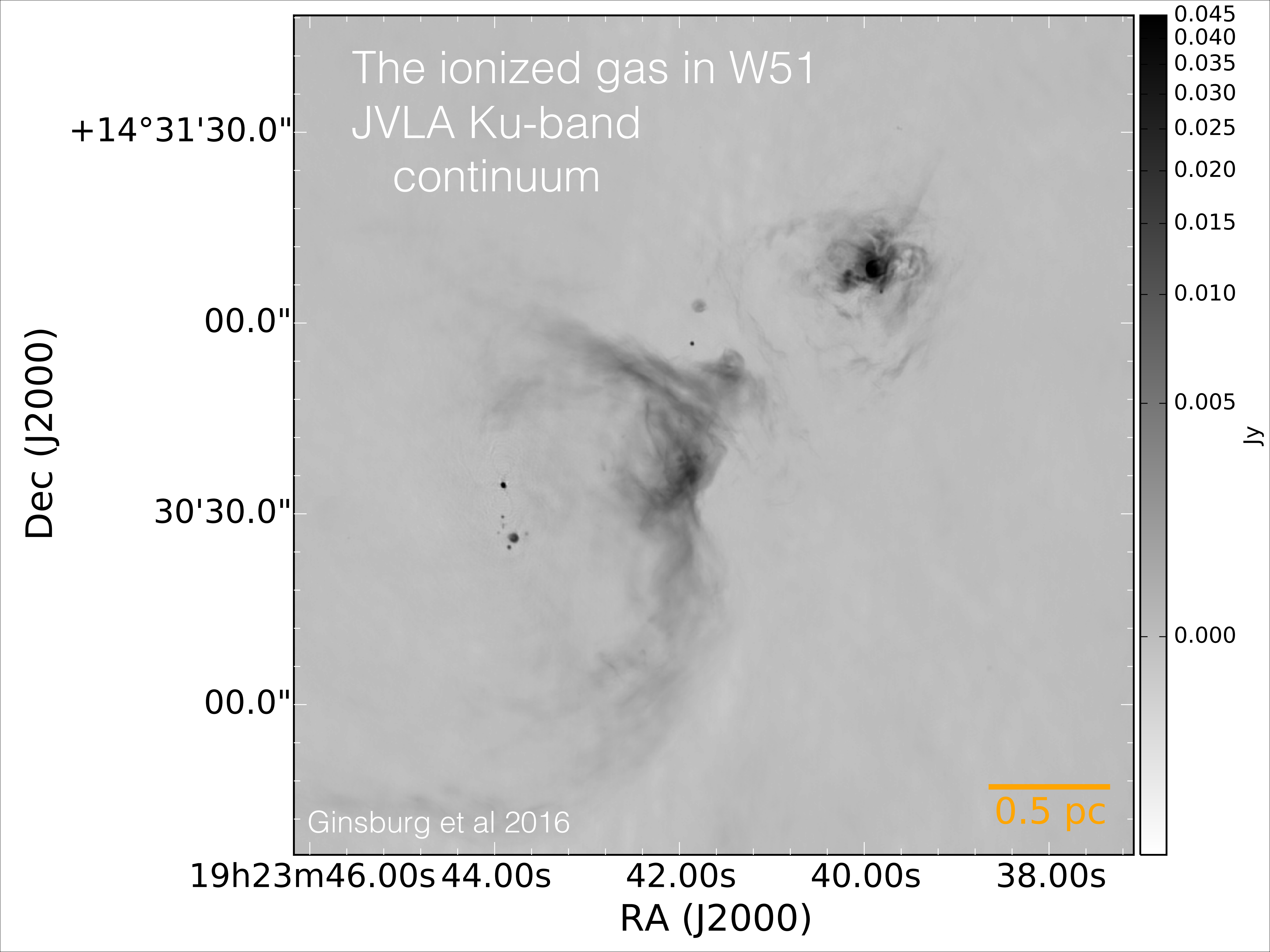




Only the most massive cores produce ~0.1 pc-scale extreme heating

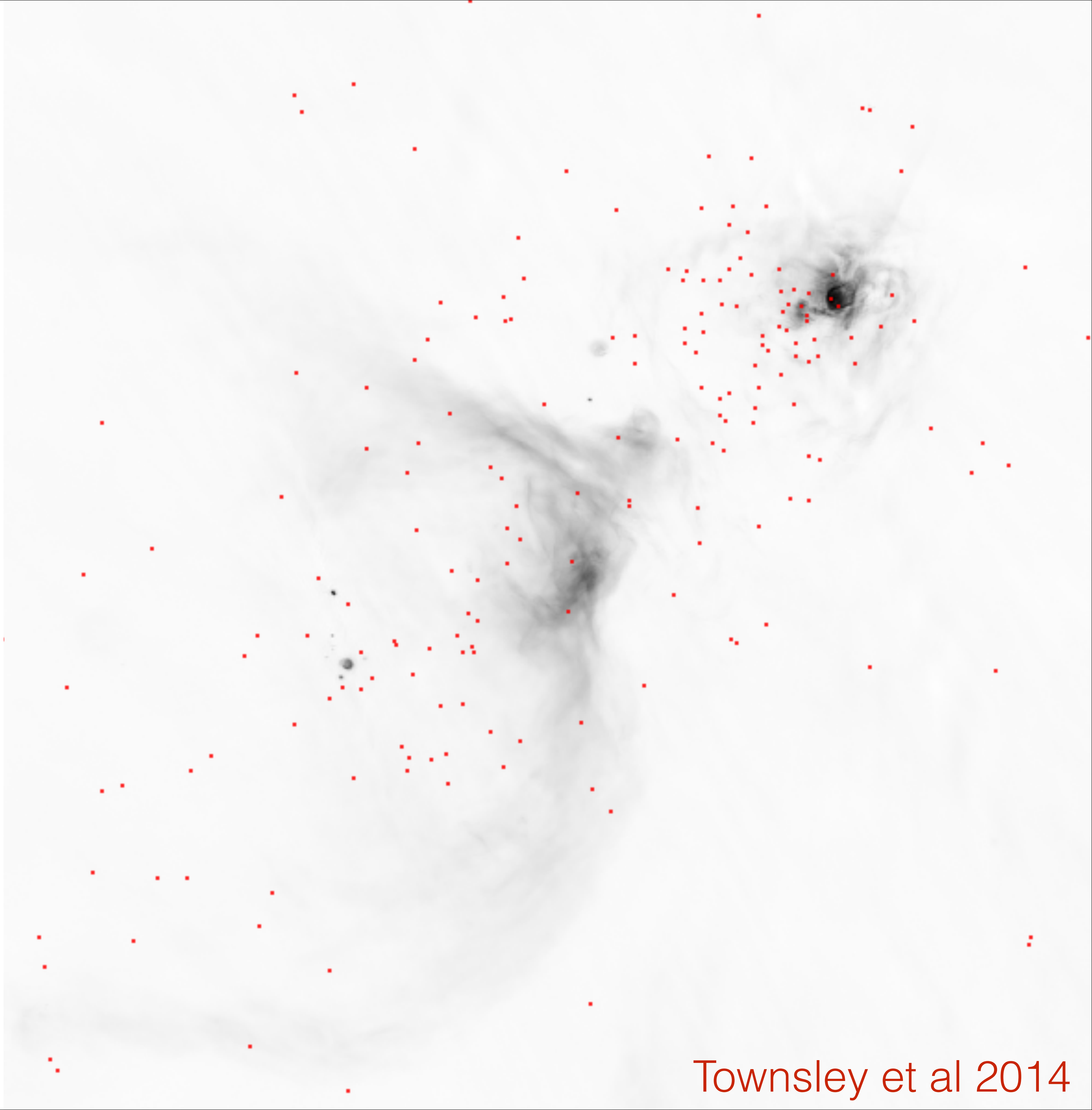

Photoevaporation is ineffective at
halting star formation on clump scales
It is important for shaping the cloud and
limiting the growth of a forming cluster
Protostars heat prestellar gas,
(maybe suppressing fragmentation)
main sequence stars & HII regions
apparently do not


BONUS SLIDES START HERE



The ionized gas in W51
JVLA Ku-band
continuum
Ginsburg et al 2016
0.5 pc
+14°31'30.0"
00.0"
30'30.0"
00.0"
Dec (J2000)
19h23m46.00s
44.00s
42.00s
40.00s
38.00s
RA (J2000)
0.045
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
Jy

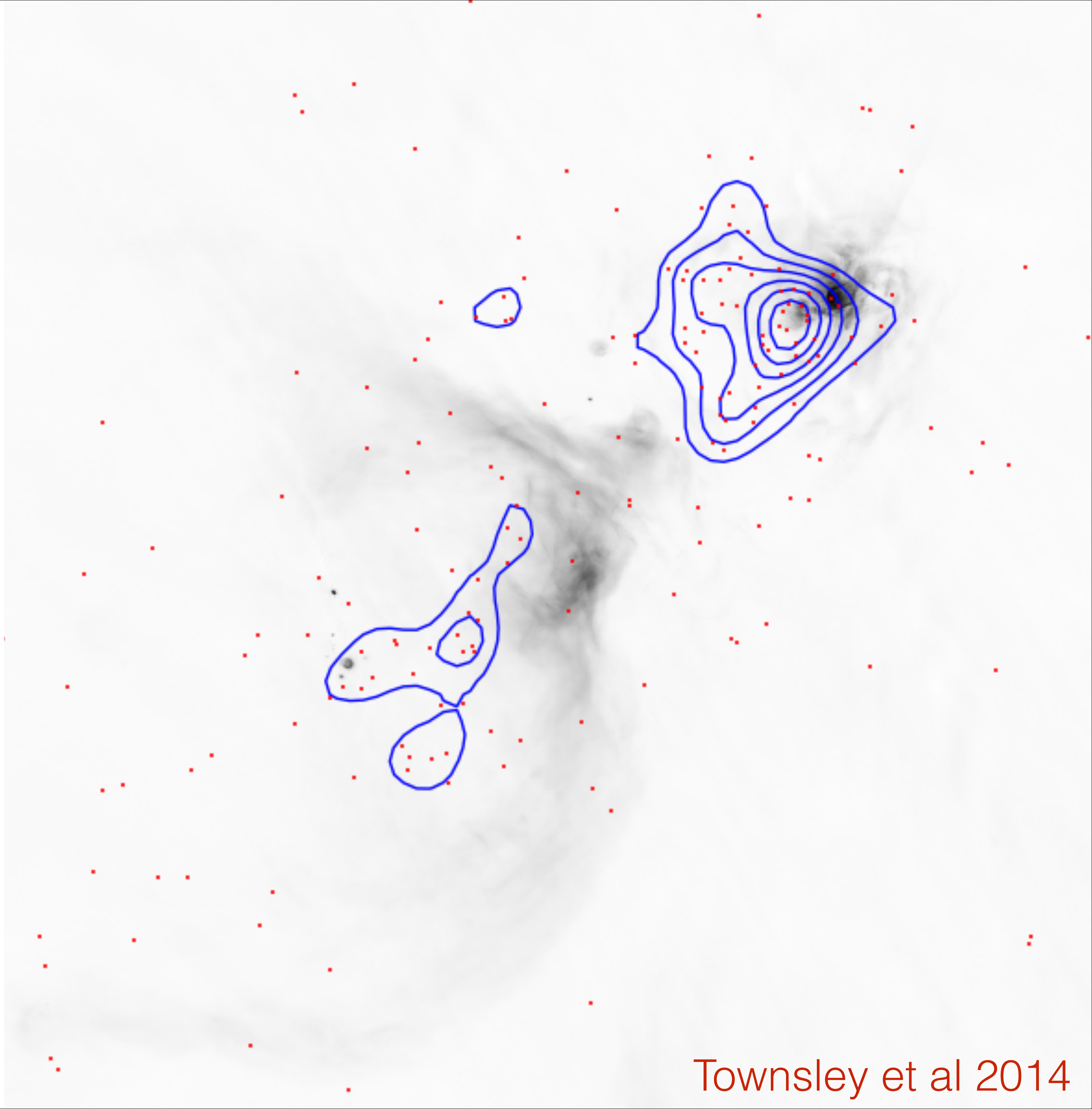
MOXC X-ray
sources
(young stars)



Townsley et al 2014

MOXC X-ray sources (young stars)

MOXC X-ray source density

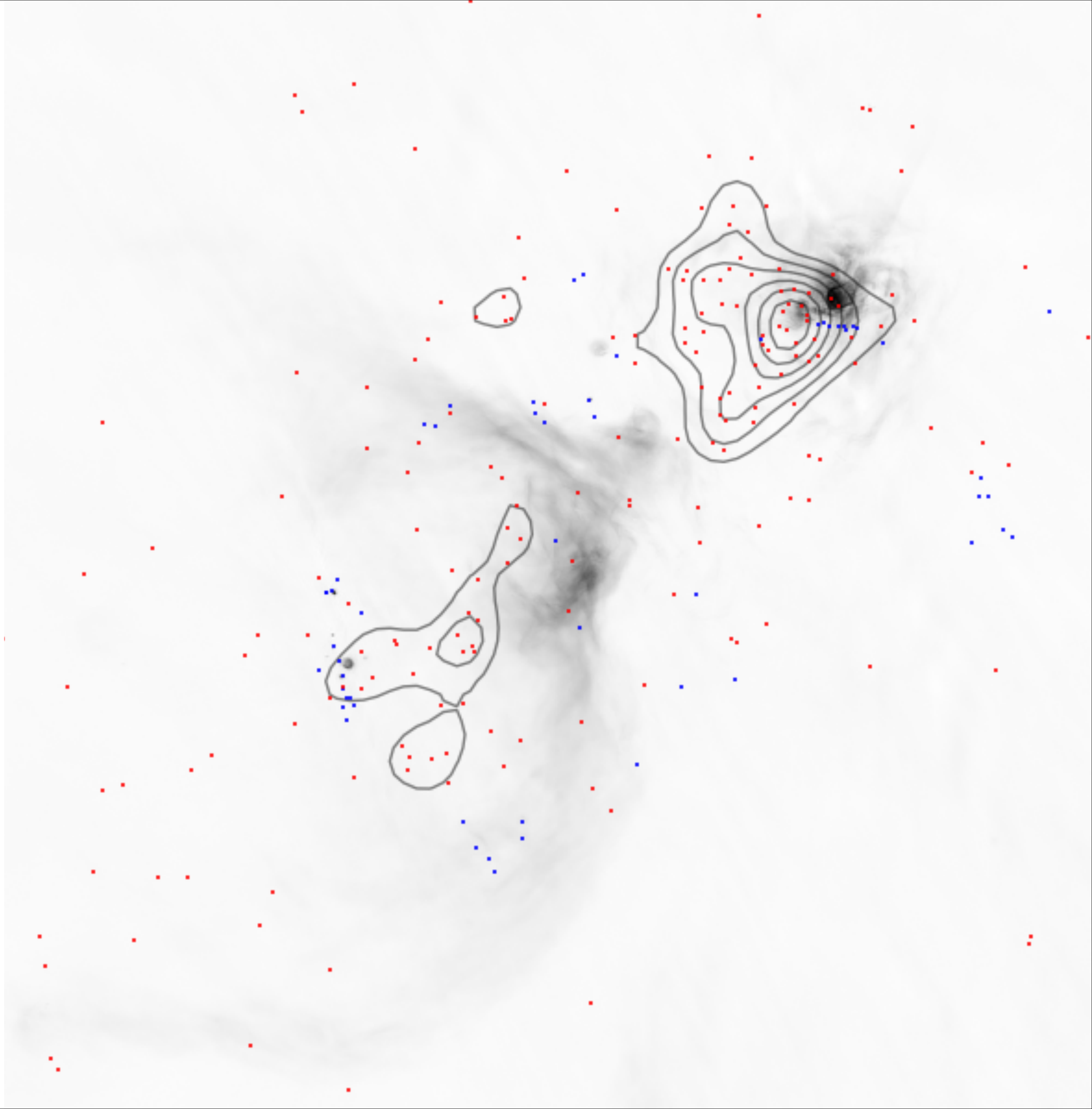


Townsley et al 2014

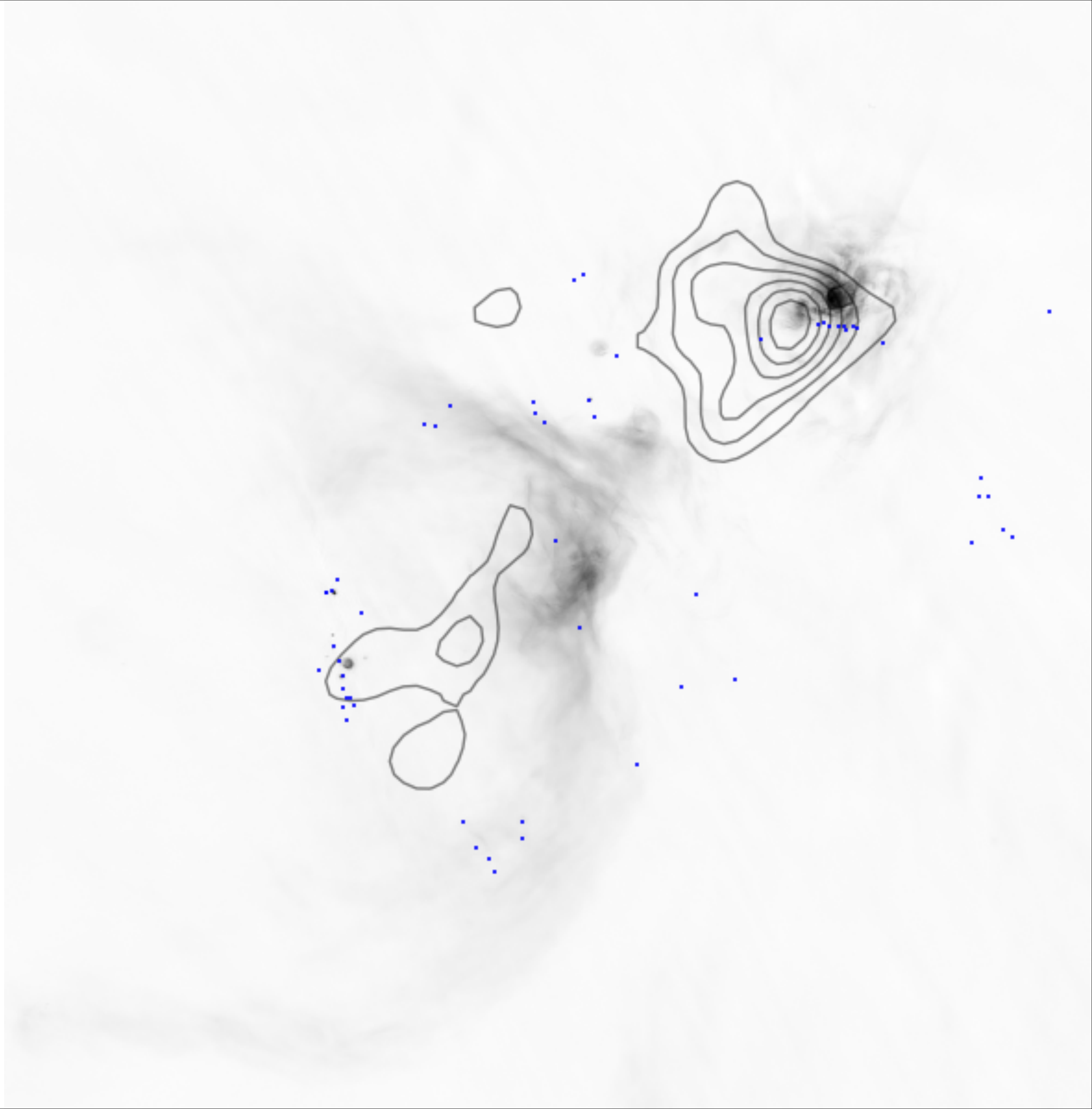
MOXC X-ray sources (young stars)

MOXC X-ray source density

ALMA mm sources (cores, protostars)



MOXC X-ray
source density

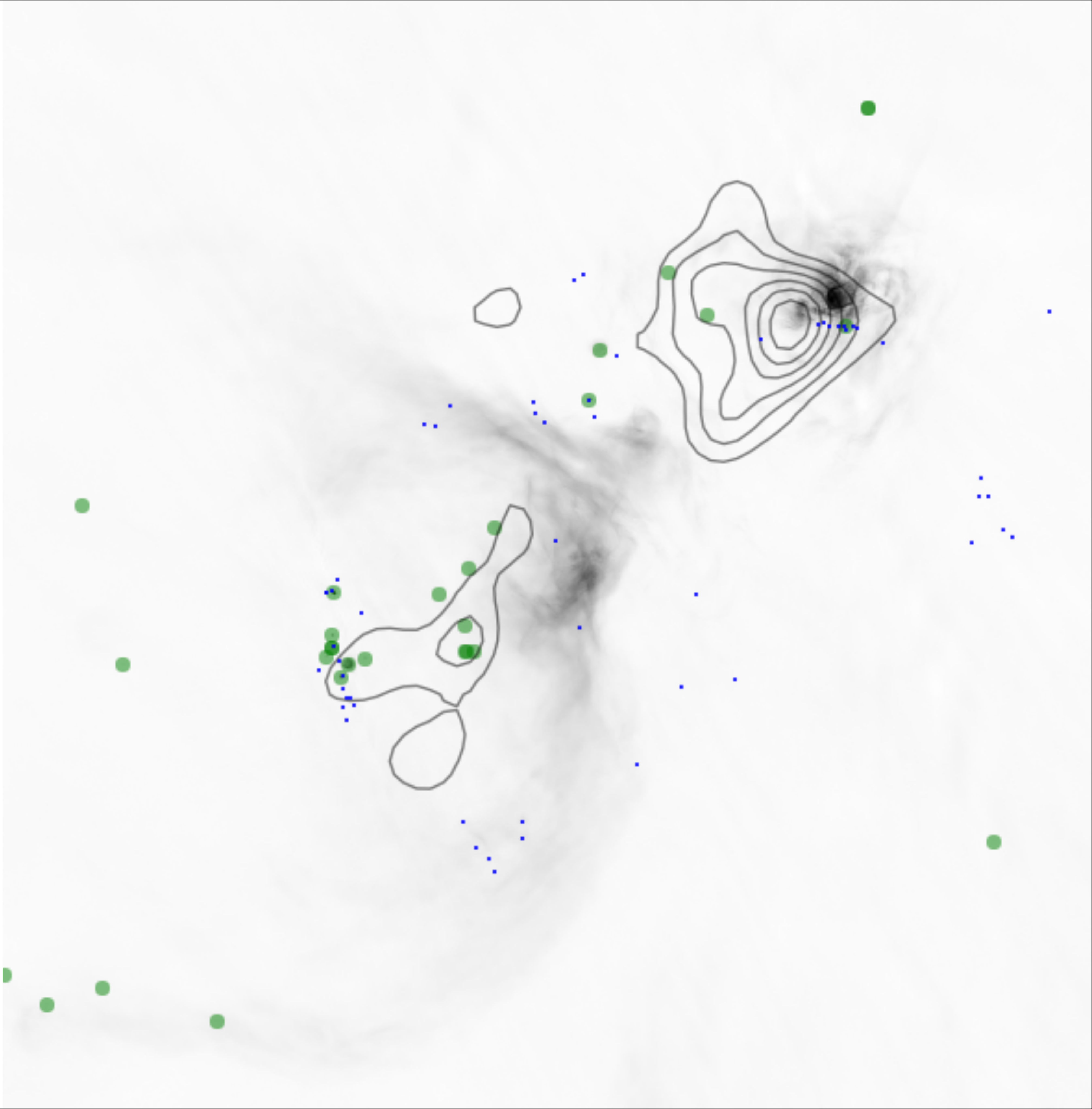


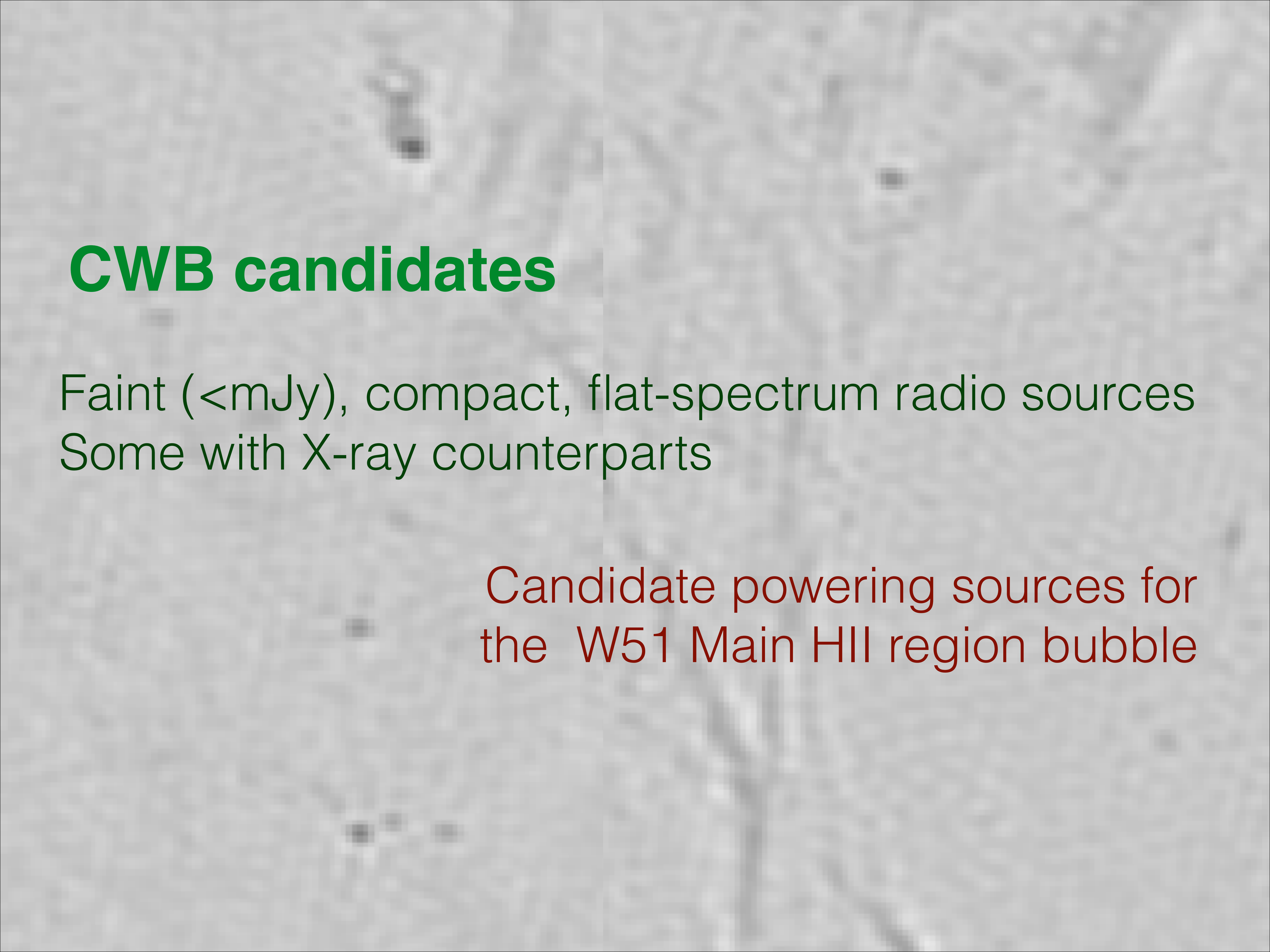
ALMA mm
sources
(cores, protostars)

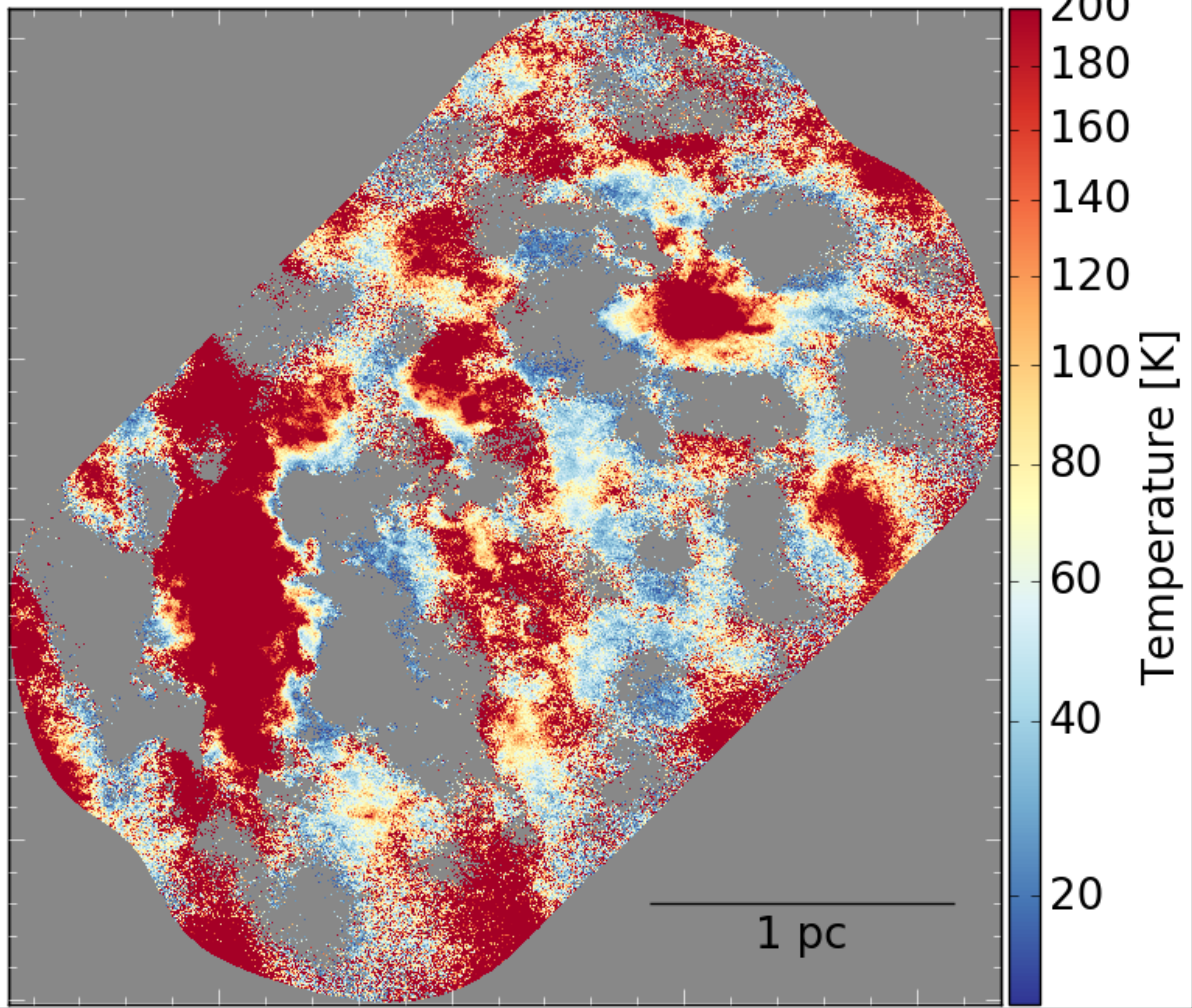
MOXC X-ray source density

ALMA mm sources (cores, protostars)

EVLA cm sources (CWBs, HCHIIs)



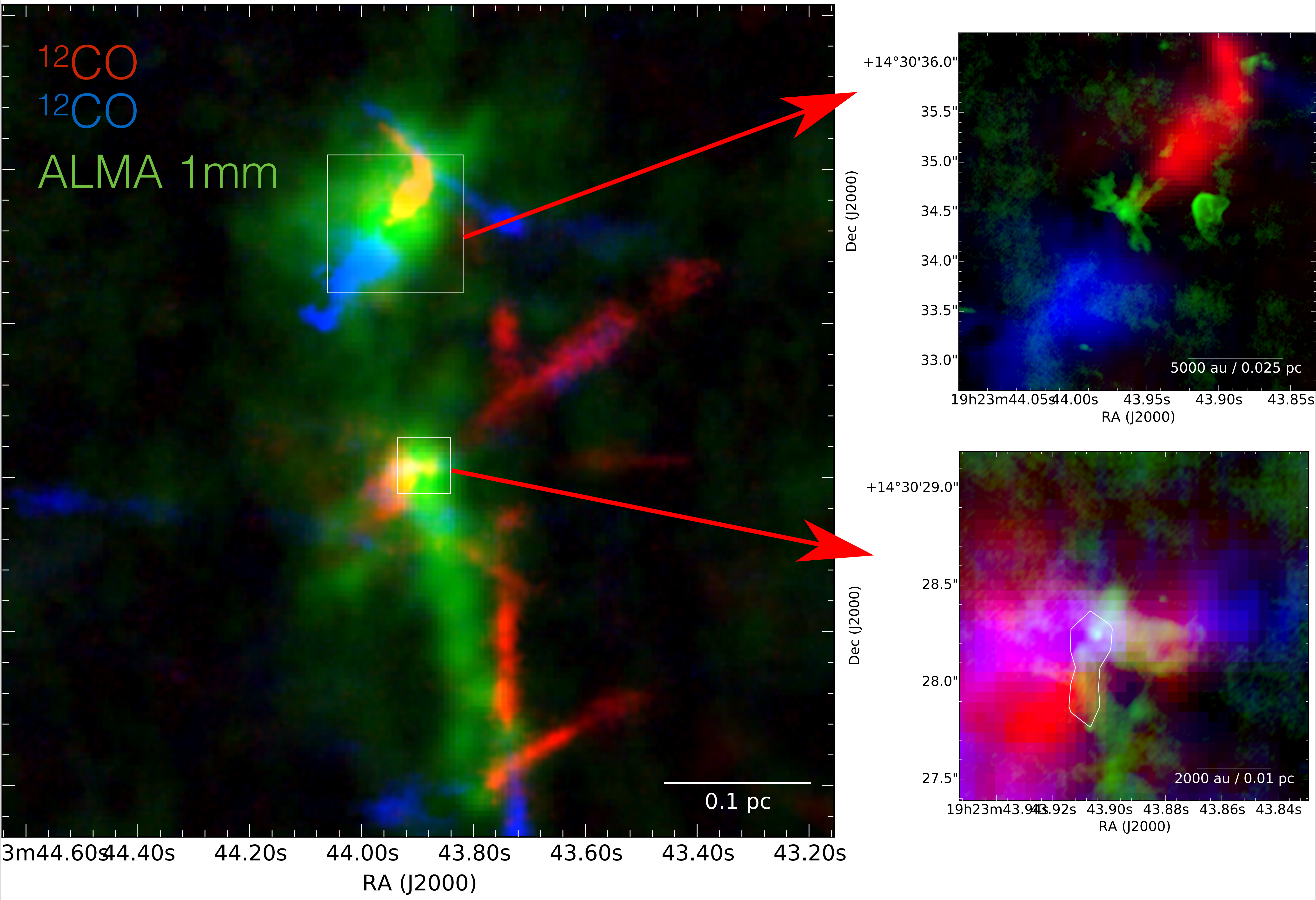

CWB candidates
Faint (<mJy), compact, flat-spectrum radio sources
Some with X-ray counterparts
Candidate powering sources for
the W51 Main HII region bubble



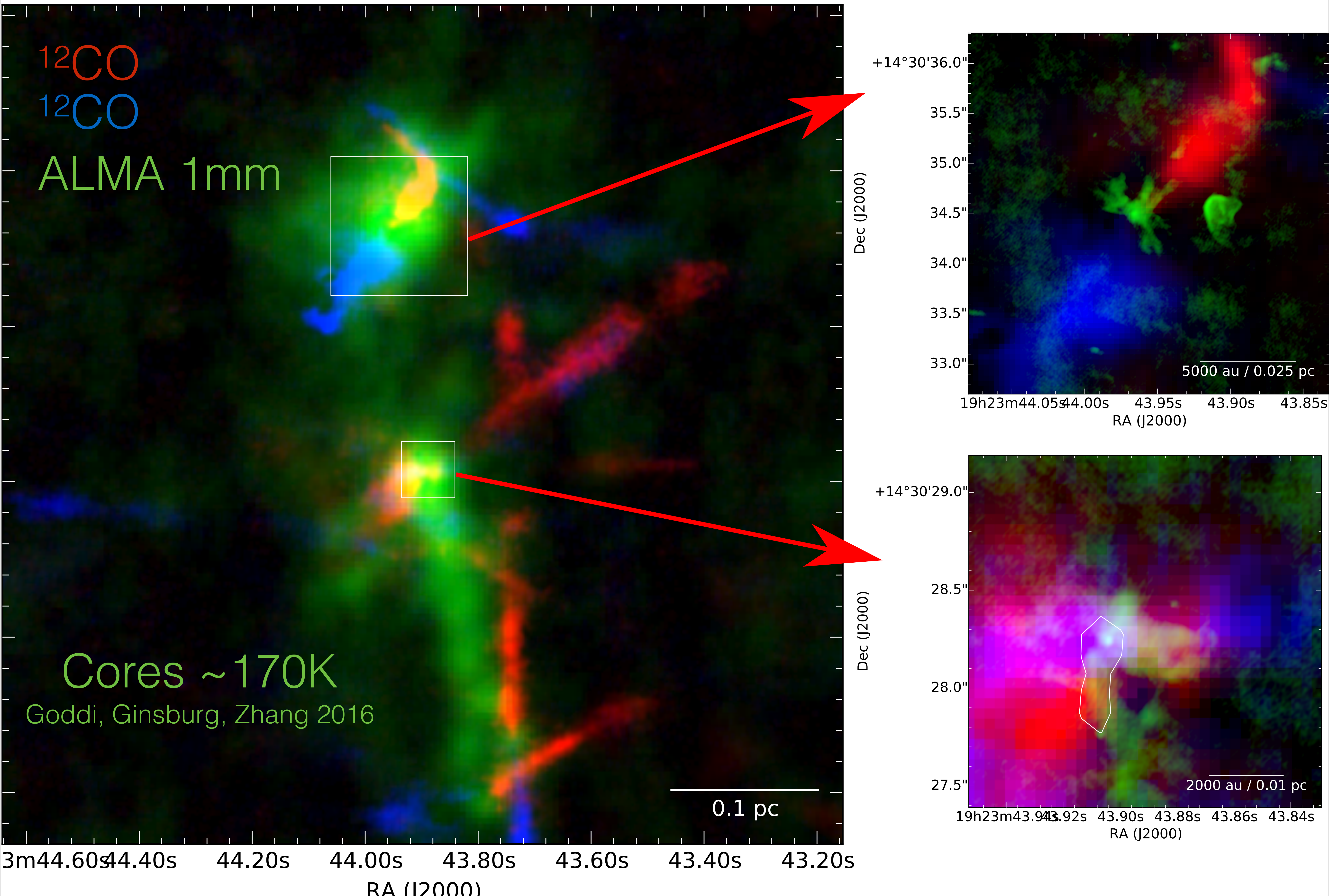
200
180
160
140
120
100
80
60
40
20
Temperature [K]
1 pc

Feedback around forming MYSOs

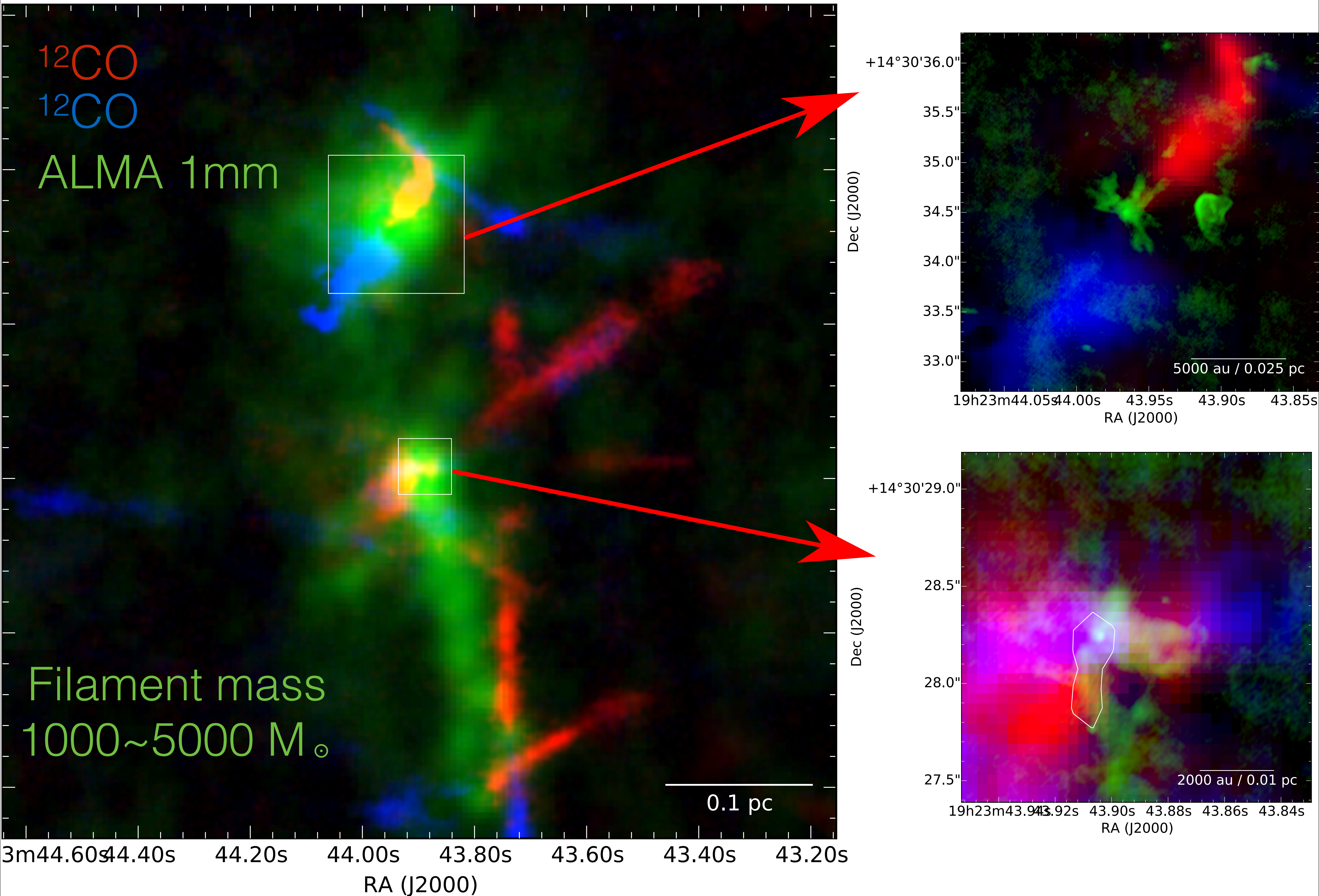
- Outflows
- Infrared Radiation
- Ionizing Radiation



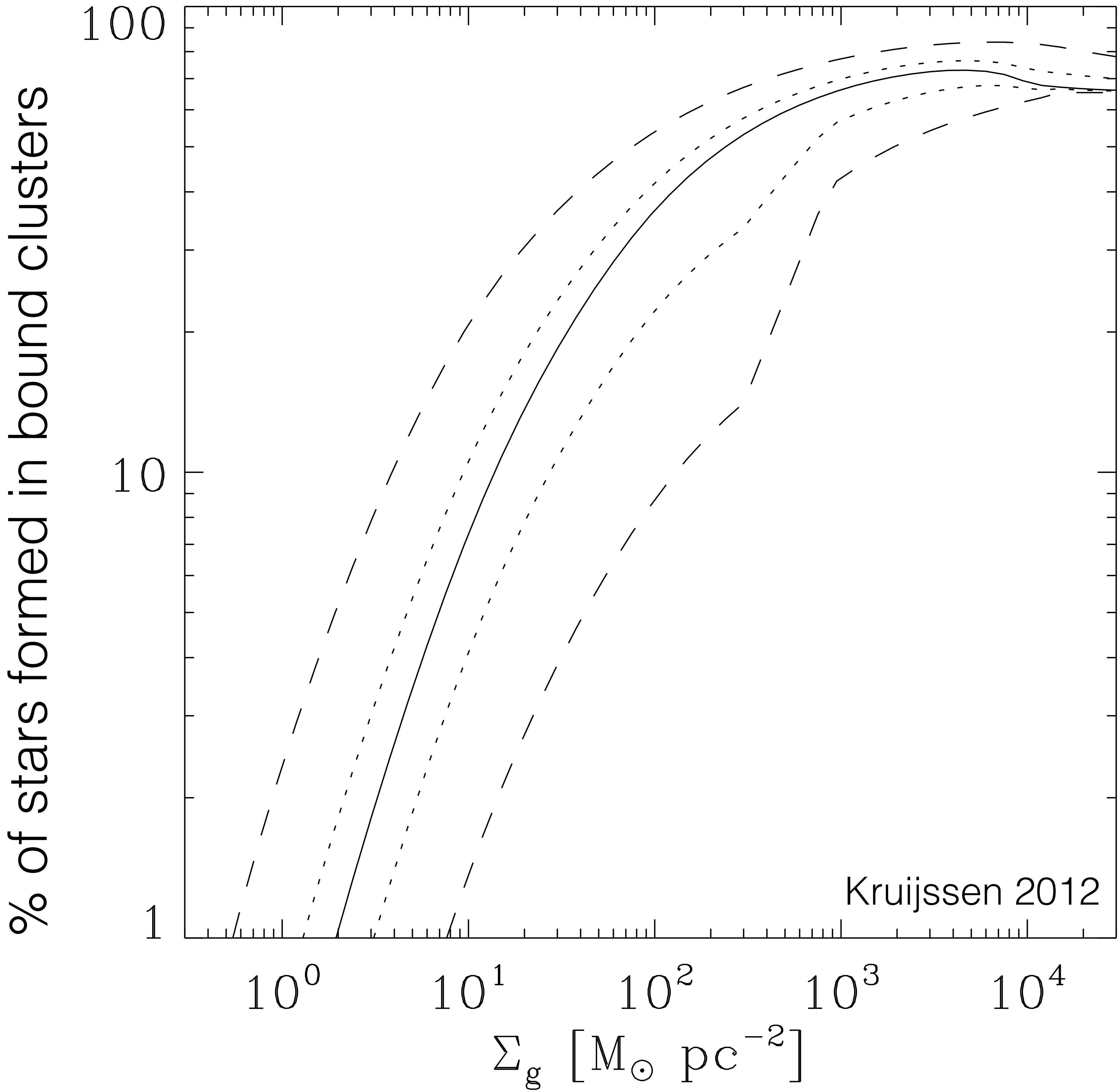
12CO
12CO
ALMA 1mm
0.1 pc
3m44.60s
44.40s
44.20s
44.00s
43.80s
43.60s
43.40s
43.20s
RA (J2000)
+14°30'36.0"
35.5"
35.0"
34.5"
34.0"
33.5"
33.0"
Dec (J2000)
5000 au / 0.025 pc
19h23m44.05s
44.00s
43.95s
43.90s
43.85s
RA (J2000)
+14°30'29.0"
28.5"
28.0"
27.5"
Dec (J2000)
2000 au / 0.01 pc
19h23m43.94s
43.92s
43.90s
43.88s
43.86s
43.84s
RA (J2000)



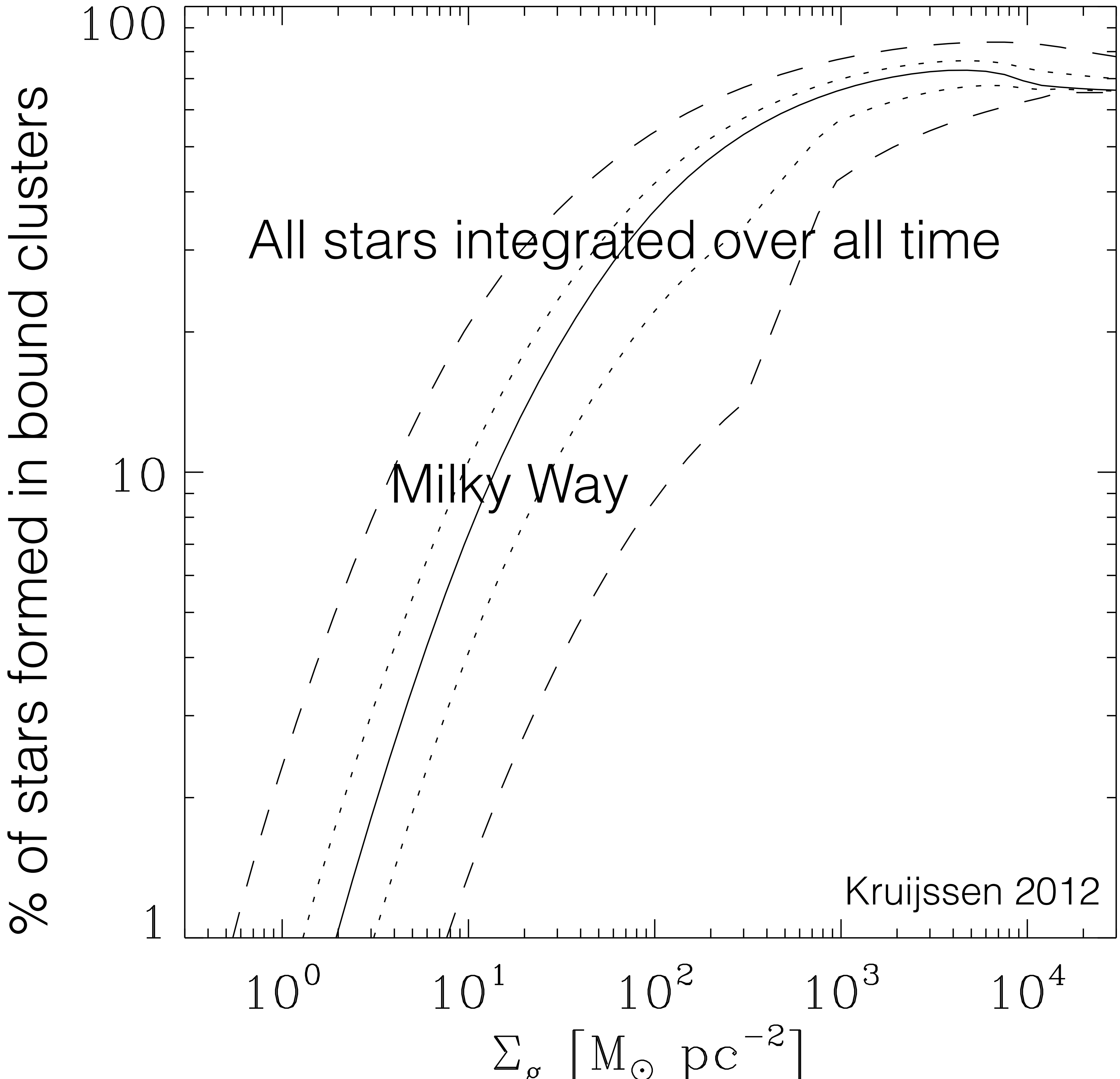
^{12}CO
^{12}CO
ALMA 1mm
Cores ~170K
Goddi, Ginsburg, Zhang 2016
0.1 pc
3m44.60s 44.40s 44.20s 44.00s 43.80s 43.60s 43.40s 43.20s
RA (J2000)
+14°30'36.0" 35.5" 35.0" 34.5" 34.0" 33.5" 33.0"
Dec (J2000)
5000 au / 0.025 pc
19h23m44.05s 44.00s 43.95s 43.90s 43.85s
RA (J2000)
+14°30'29.0" 28.5" 28.0" 27.5"
Dec (J2000)
2000 au / 0.01 pc
19h23m43.94s 43.92s 43.90s 43.88s 43.86s 43.84s
RA (J2000)



12CO
12CO
ALMA 1mm
Filament mass
1000~5000 M☉
0.1 pc
3m44.60s 44.40s 44.20s 44.00s 43.80s 43.60s 43.40s 43.20s
RA (J2000)
+14°30'36.0" 35.5" 35.0" 34.5" 34.0" 33.5" 33.0"
Dec (J2000)
5000 au / 0.025 pc
19h23m44.05s 44.00s 43.95s 43.90s 43.85s
RA (J2000)
+14°30'29.0" 28.5" 28.0" 27.5"
Dec (J2000)
2000 au / 0.01 pc
19h23m43.94s 43.92s 43.90s 43.88s 43.86s 43.84s
RA (J2000)



100
10
1
% of stars formed in bound clusters
10^0
10^1
10^2
10^3
10^4
Σ_g [$M_\odot$ pc^{-2}]
Kruijssen 2012

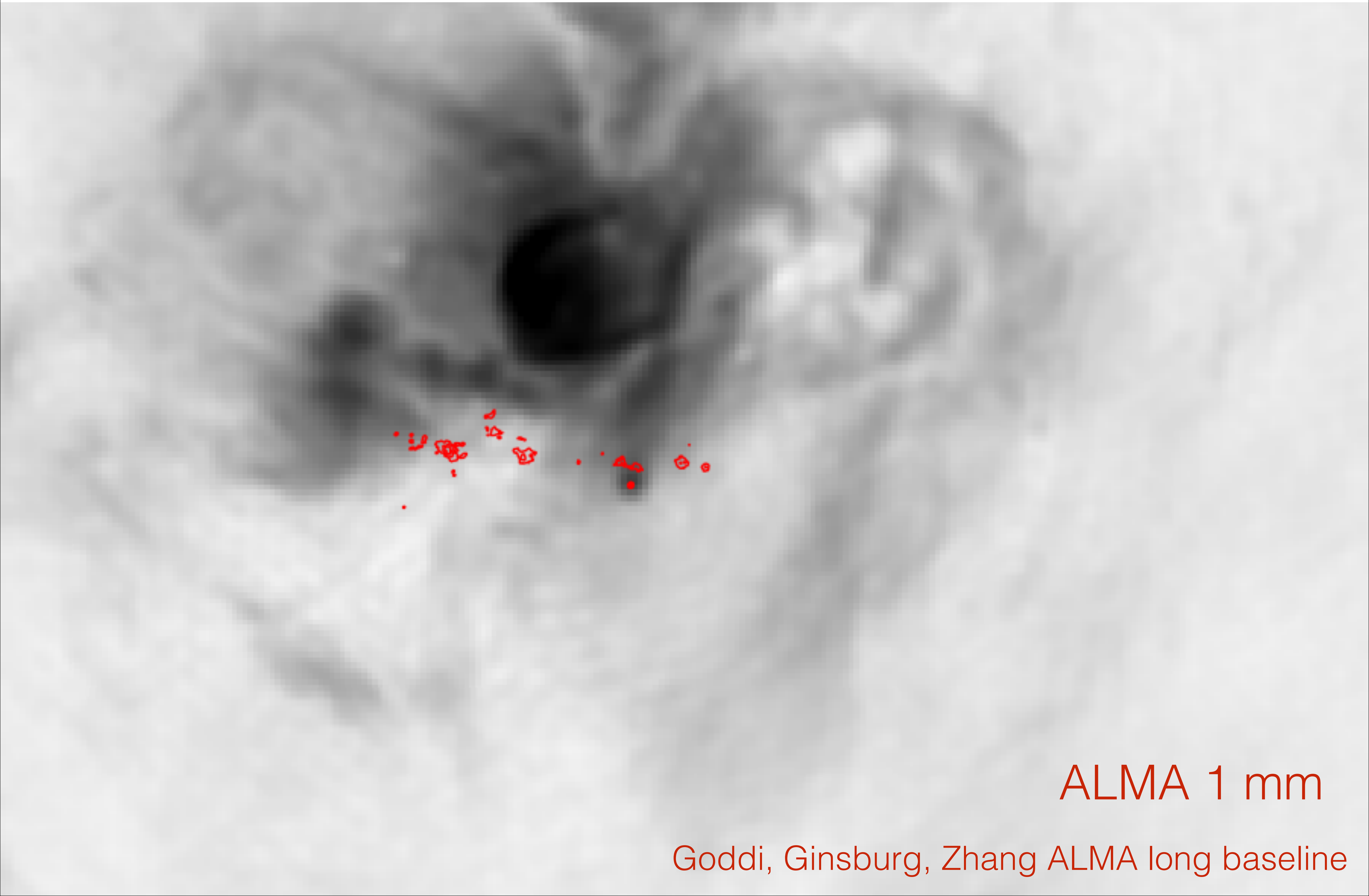


% of stars formed in bound clusters
100
10
1
All stars integrated over all time
Milky Way
Kruijssen 2012
10^0
10^1
10^2
10^3
10^4
$\Sigma_g\ [M_\odot\ pc^{-2}]$

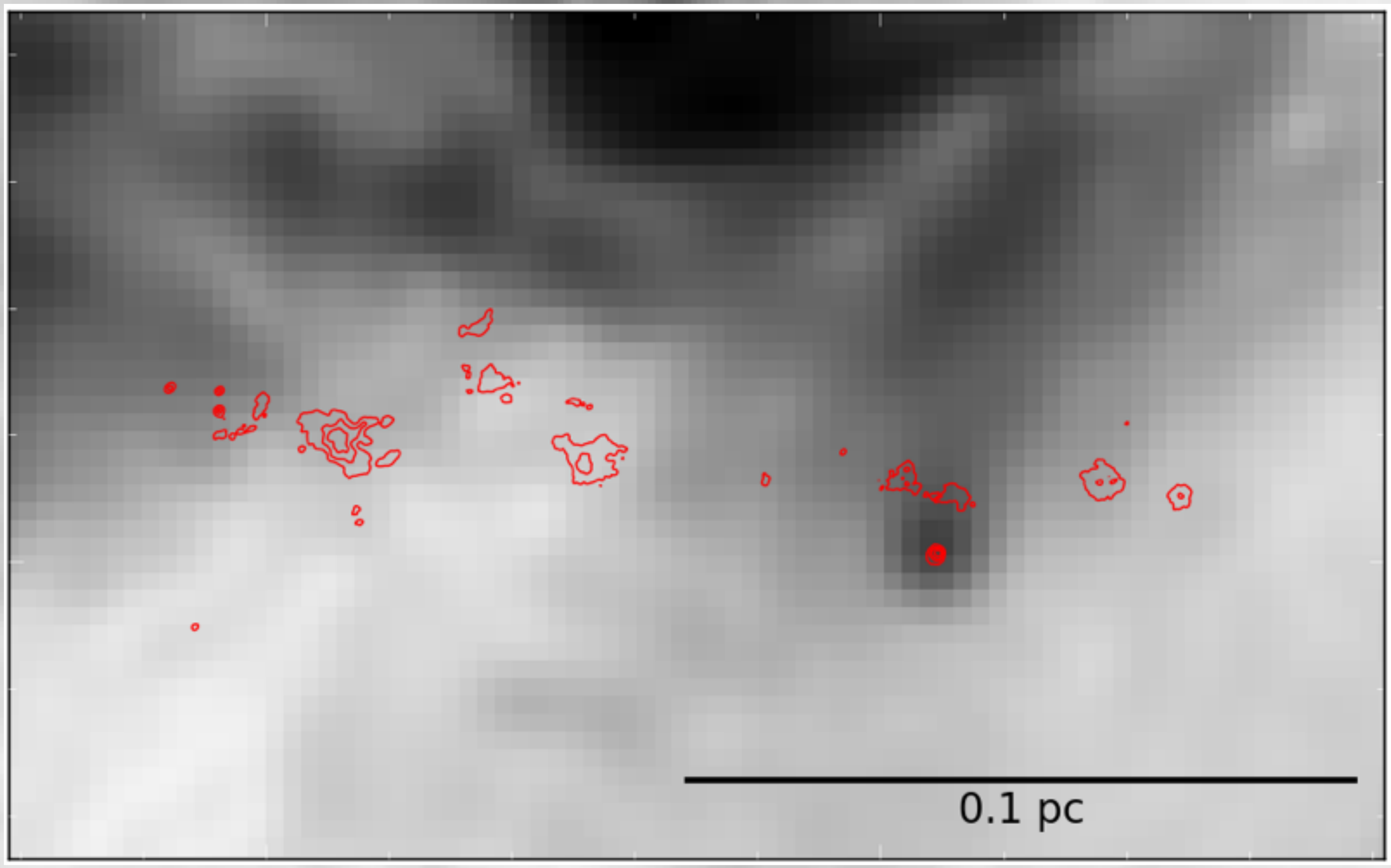
Stars form near other stars

- How do (nearby) massive stars affect the initial conditions of star formation?

In W51 North, massive stars are forming within an HII region

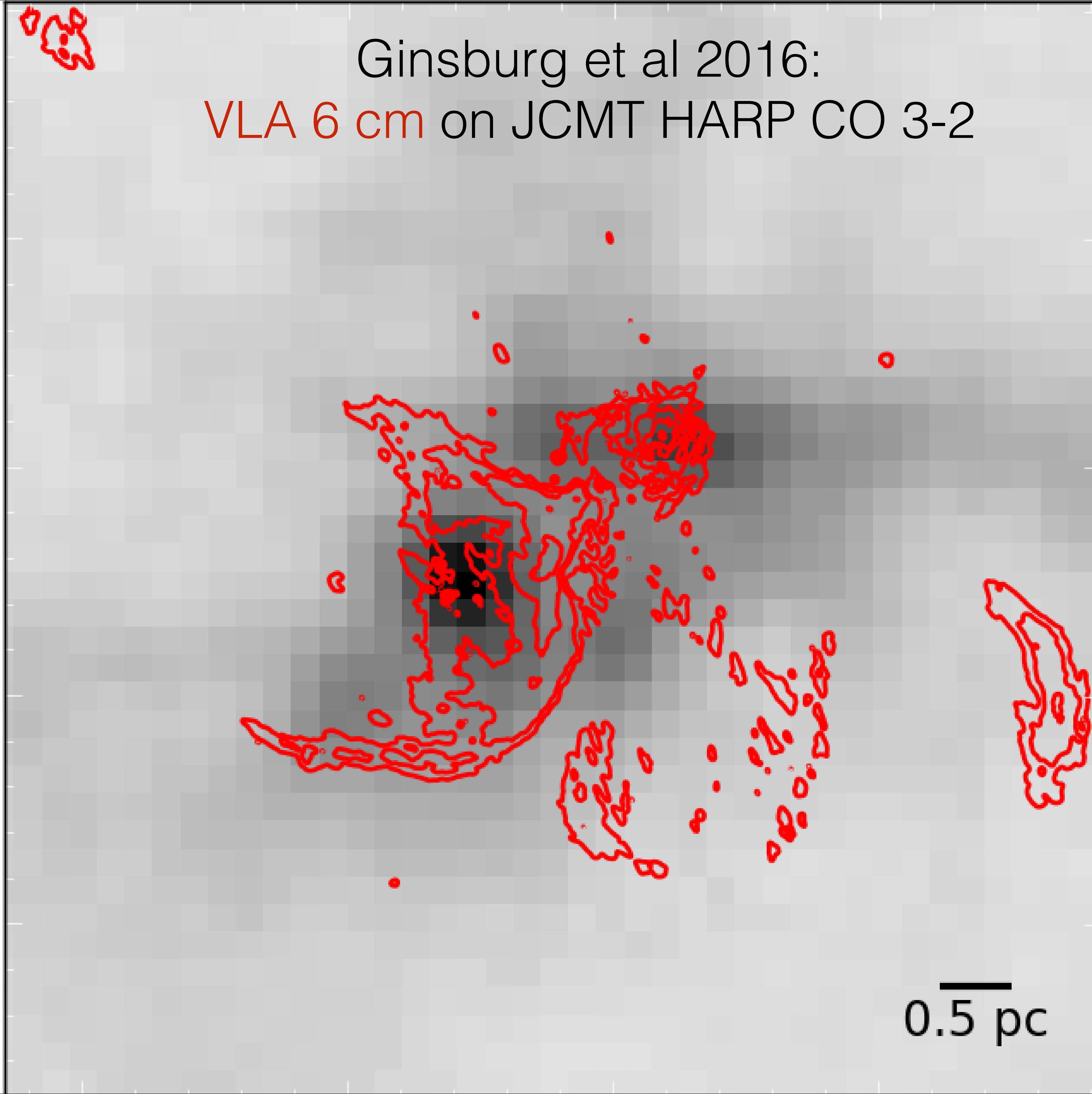


In W51 North, massive stars are forming within an HII region



ALMA 1 mm

Goddi, Ginsburg, Zhang ALMA long baseline


Ginsburg et al 2016:
VLA 6 cm on JCMT HARP CO 3-2
0.5 pc