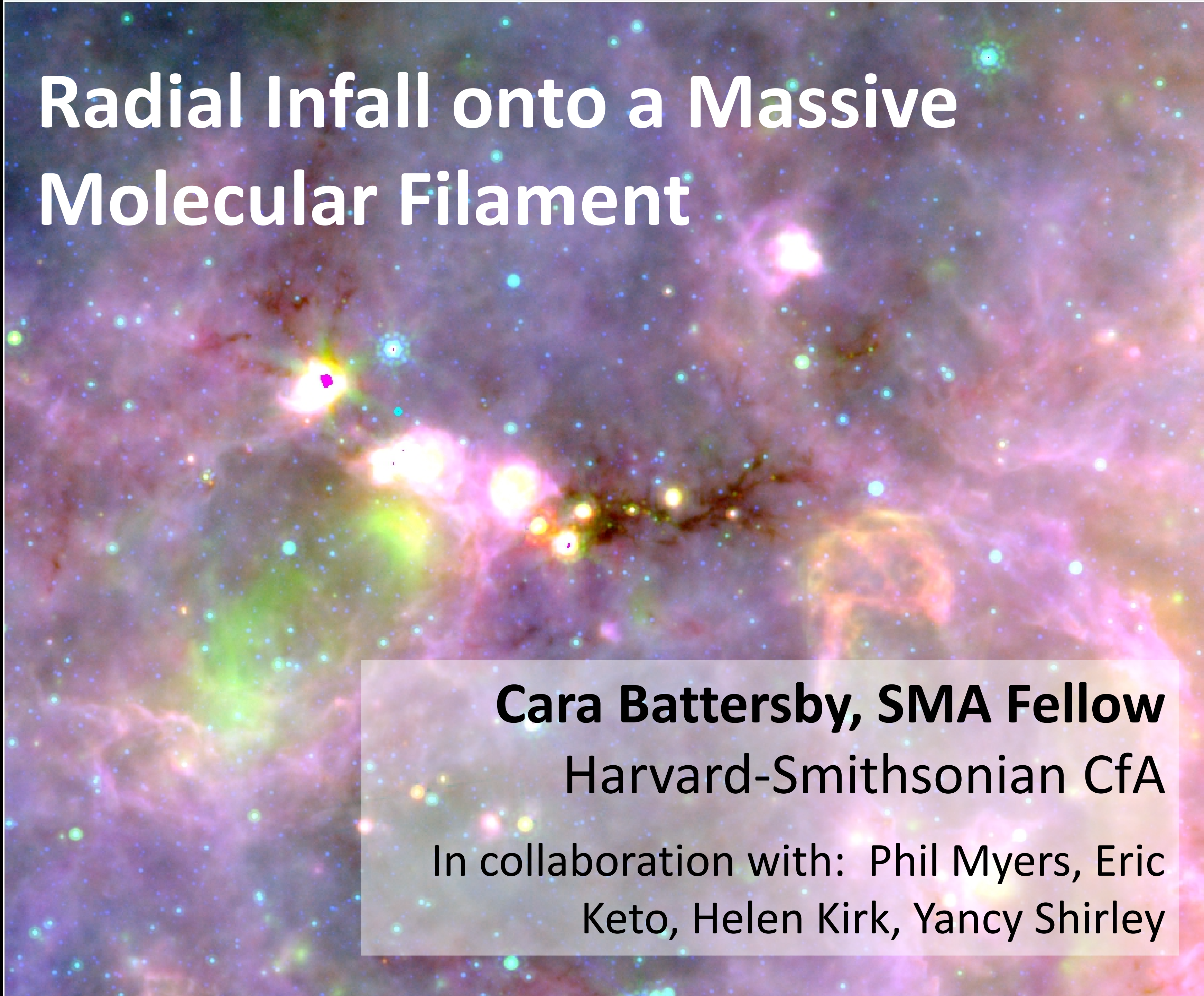


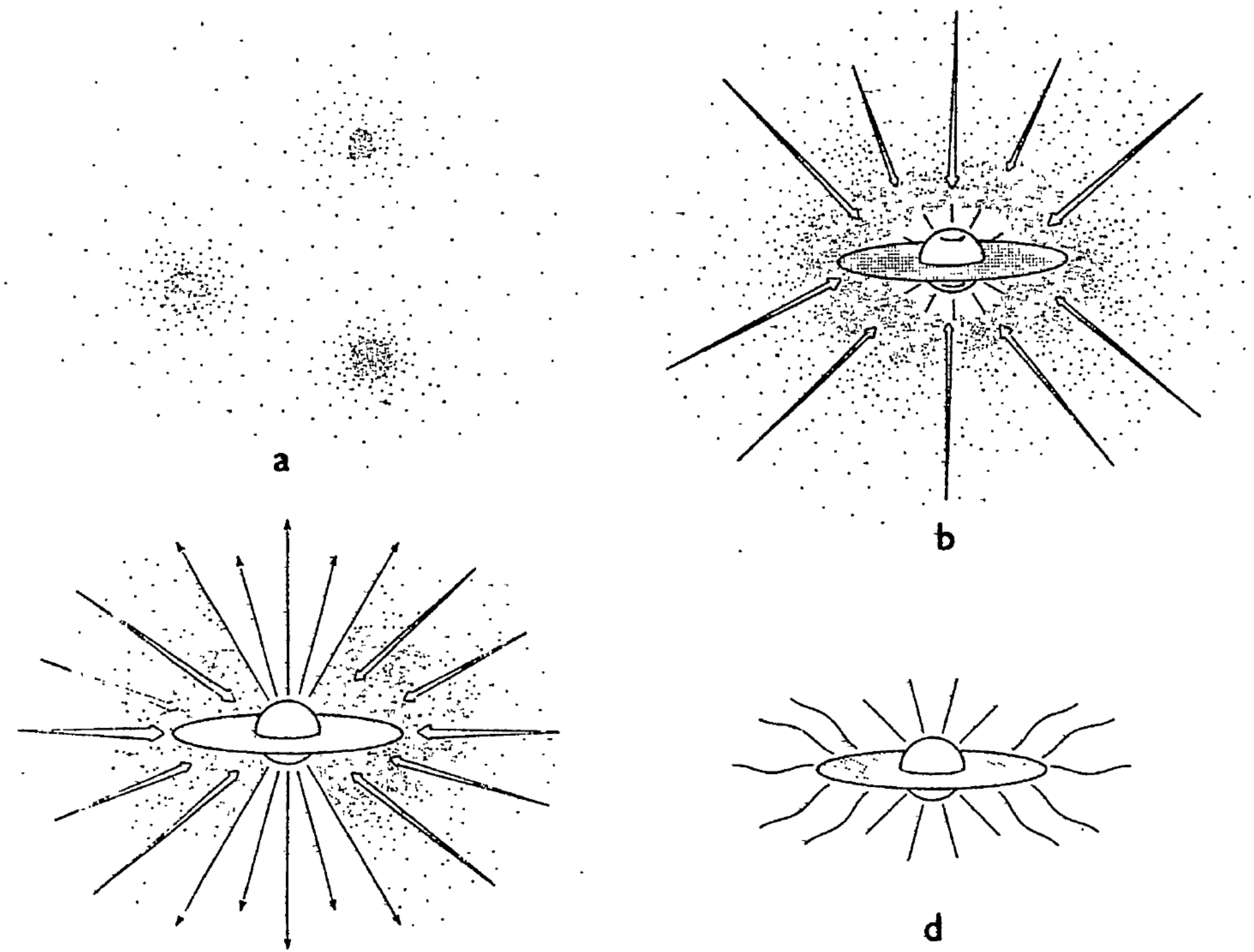
Radial Infall onto a Massive Molecular Filament

Cara Battersby, SMA Fellow
Harvard-Smithsonian CfA

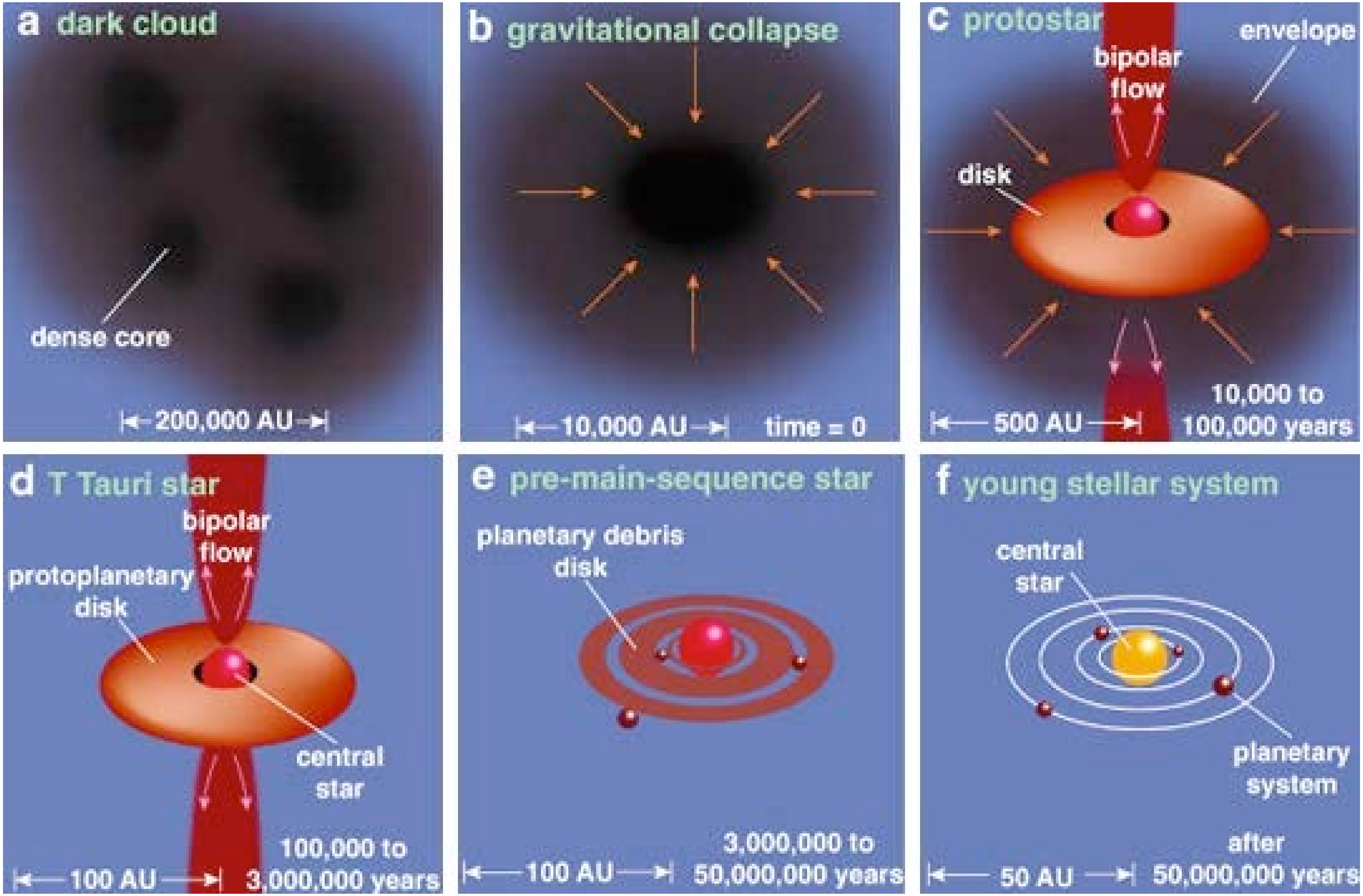
In collaboration with: Phil Myers, Eric Keto, Helen Kirk, Yancy Shirley

Formation of Star Clusters

- Physical properties of cluster-forming regions
- Evolution of these regions

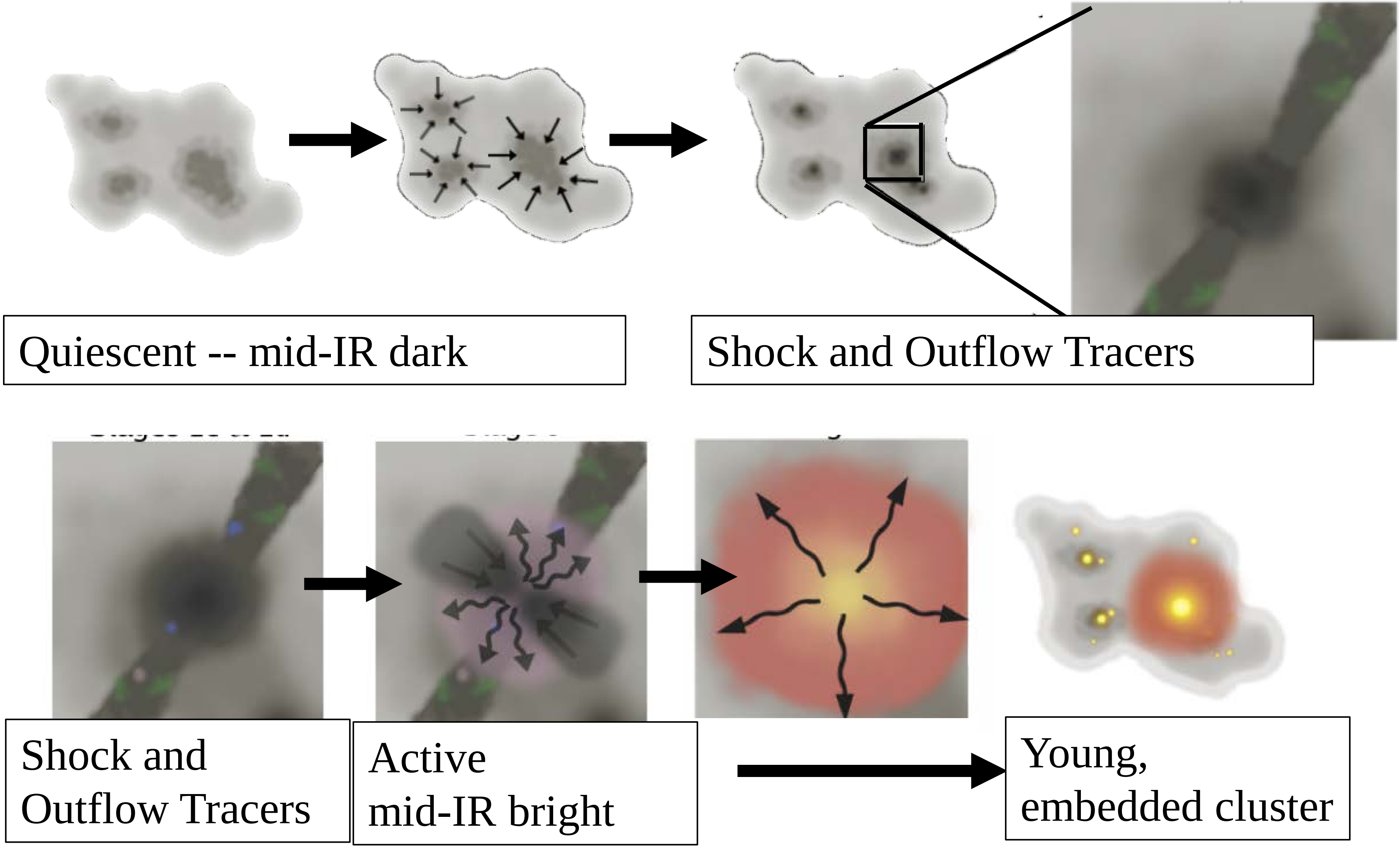


Shu et al. 1987



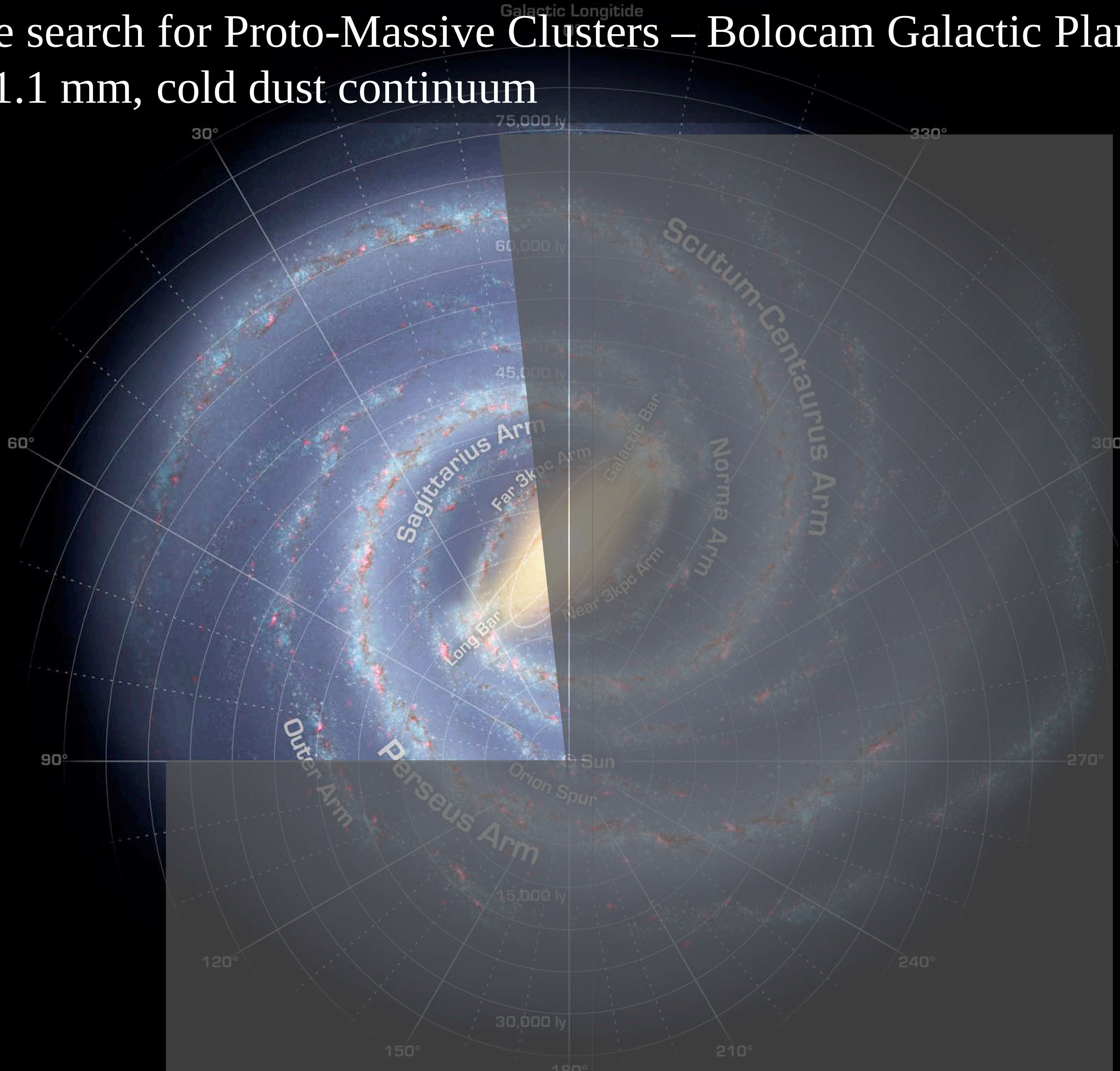
Cartoon from T. Greene, American Scientist, Jul-Aug 2001

Evolution



Battersby et al. 2010

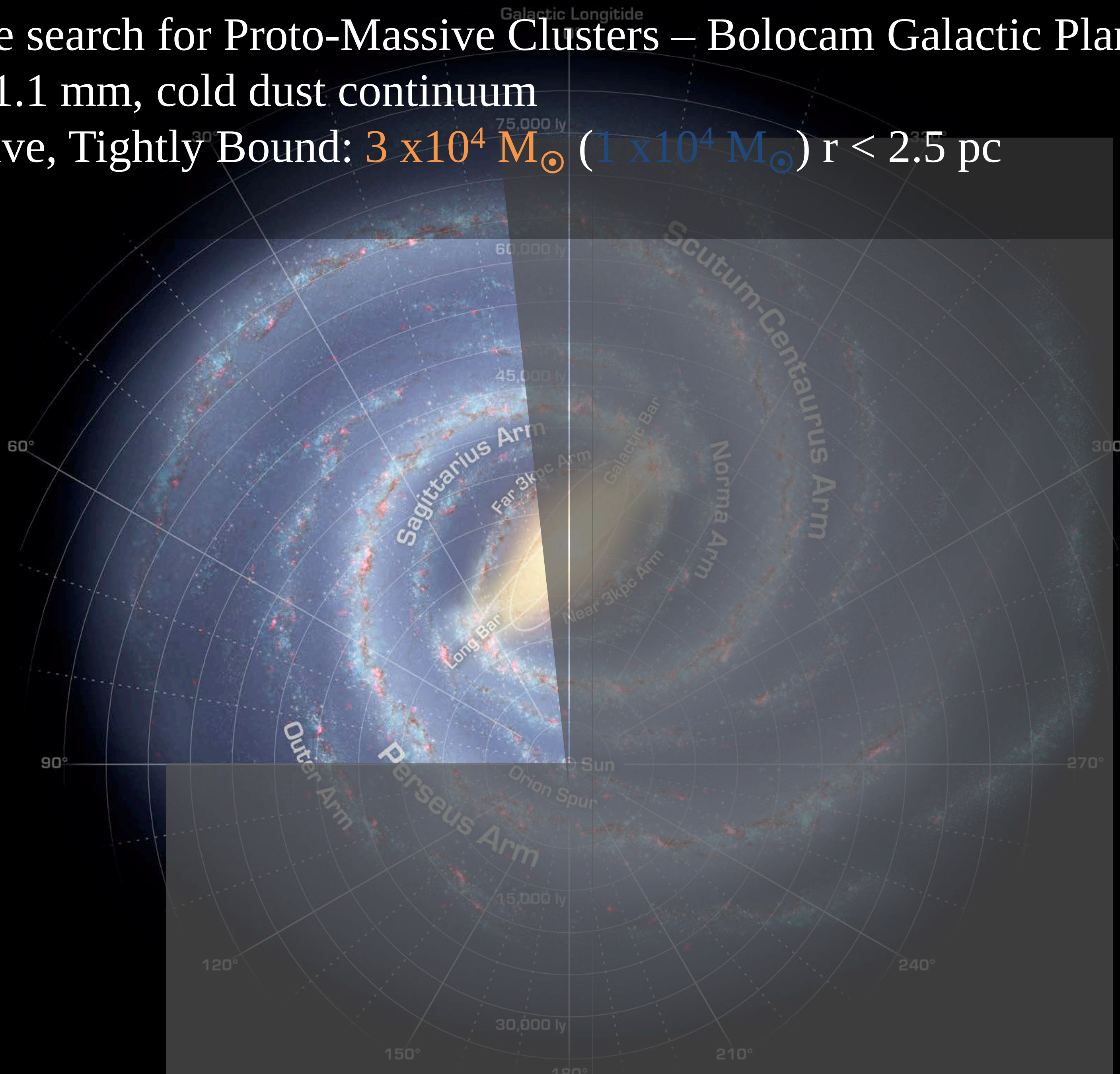
Complete search for Proto-Massive Clusters – Bolocam Galactic Plane Survey: 1.1 mm, cold dust continuum



BGPS Search for Massive Cluster Progenitors: Ginsburg, A., Bressert, E., Bally, J., Battersby, C., 2012

Complete search for Proto-Massive Clusters – Bolocam Galactic Plane Survey: 1.1 mm, cold dust continuum

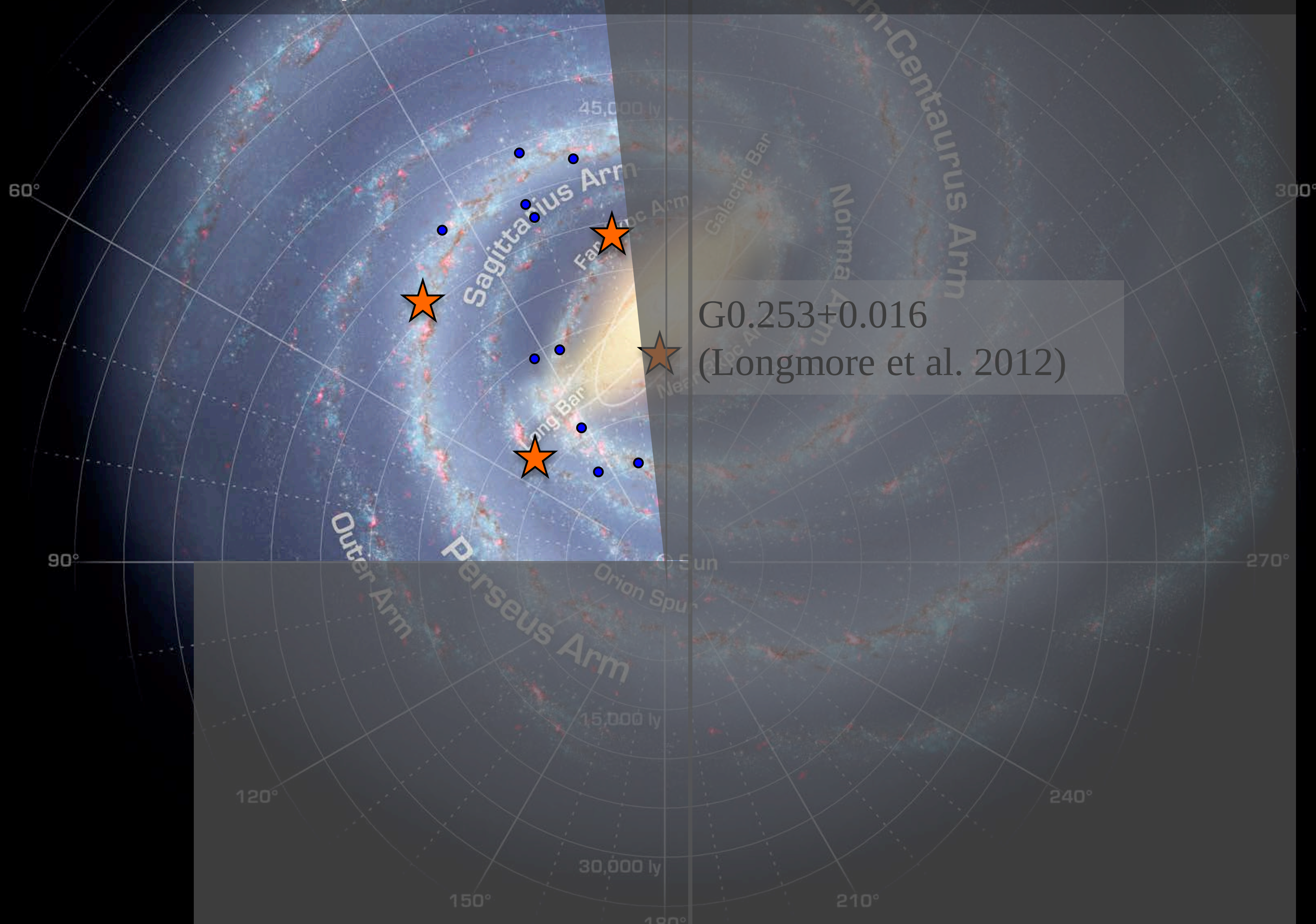
- Massive, Tightly Bound: $3 \times 10^4\ M_\odot$ ($1 \times 10^4\ M_\odot$) r < 2.5 pc



BGPS Search for Massive Cluster Progenitors: Ginsburg, A., Bressert, E., Bally, J., Battersby, C., 2012

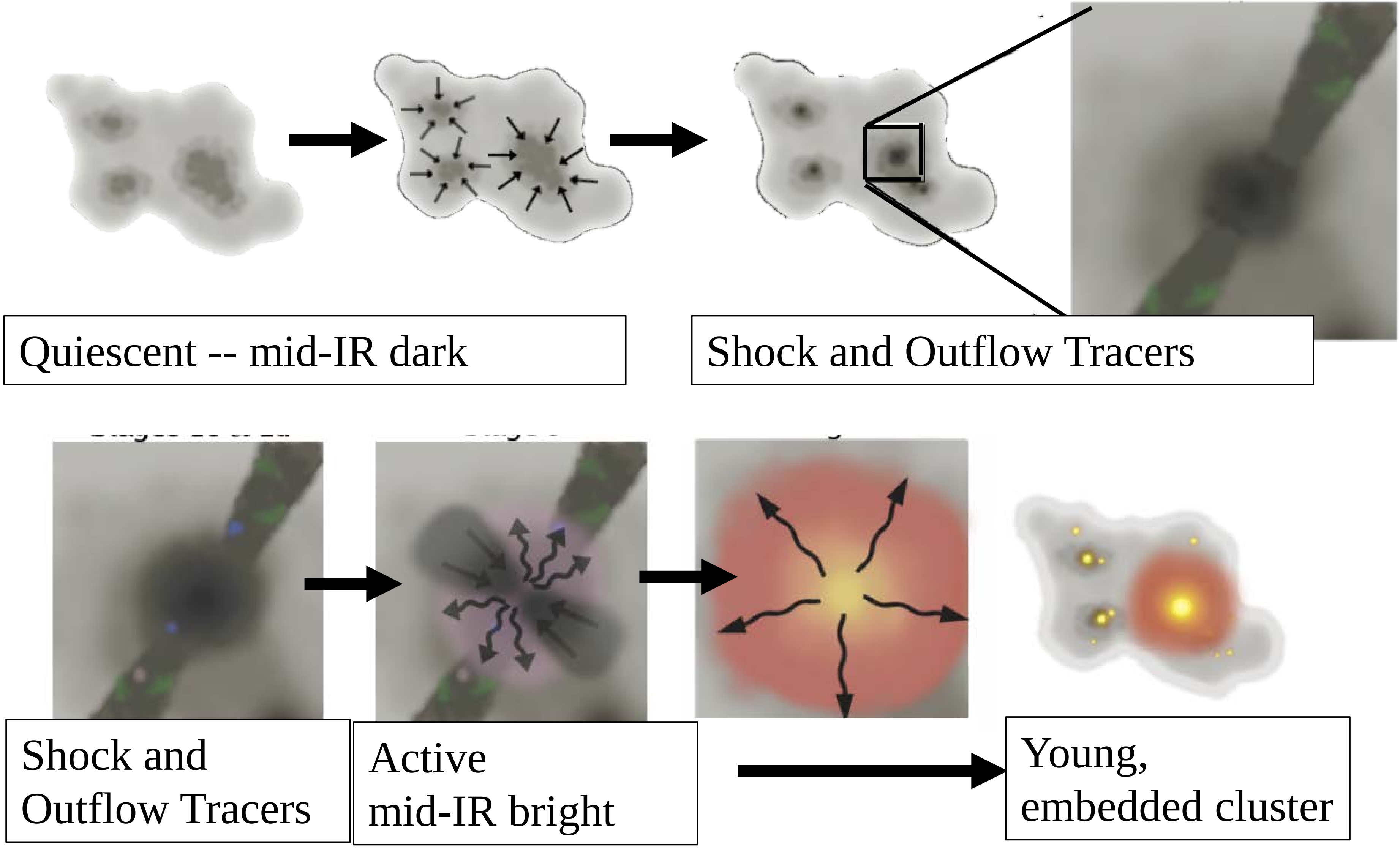
Complete search for Proto-Massive Clusters – Bolocam Galactic Plane Survey: 1.1 mm, cold dust continuum

- Massive, Tightly Bound: 3 x10^4 $M_\odot$ (1 x10^4 $M_\odot$) r < 2.5 pc
- in the First Quadrant using the Bolocam Galactic Plane Survey… yields 3 (18) sources – *none of which are starless!*

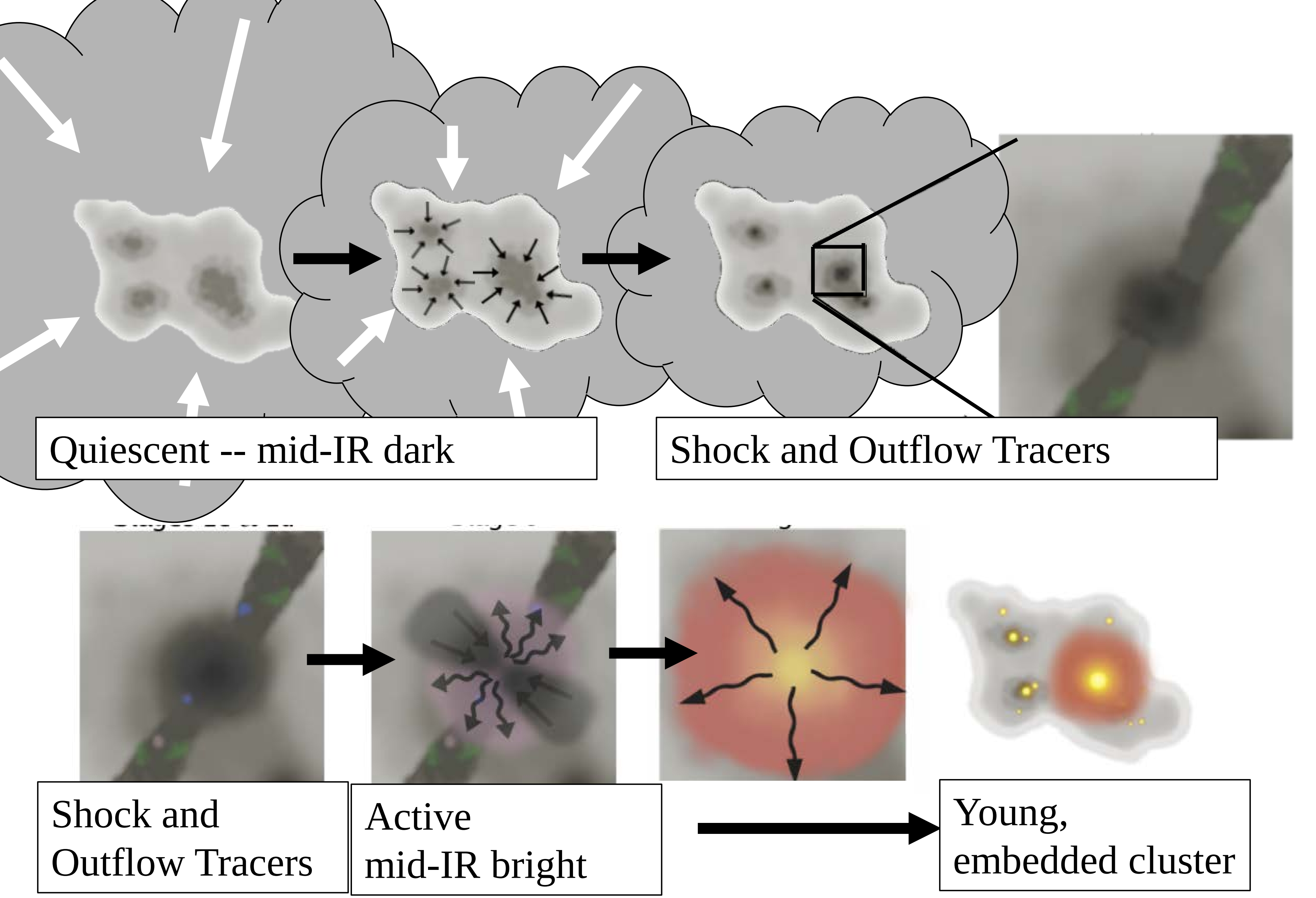


BGPS Search for Massive Cluster Progenitors: Ginsburg, A., Bressert, E., Bally, J., Battersby, C., 2012

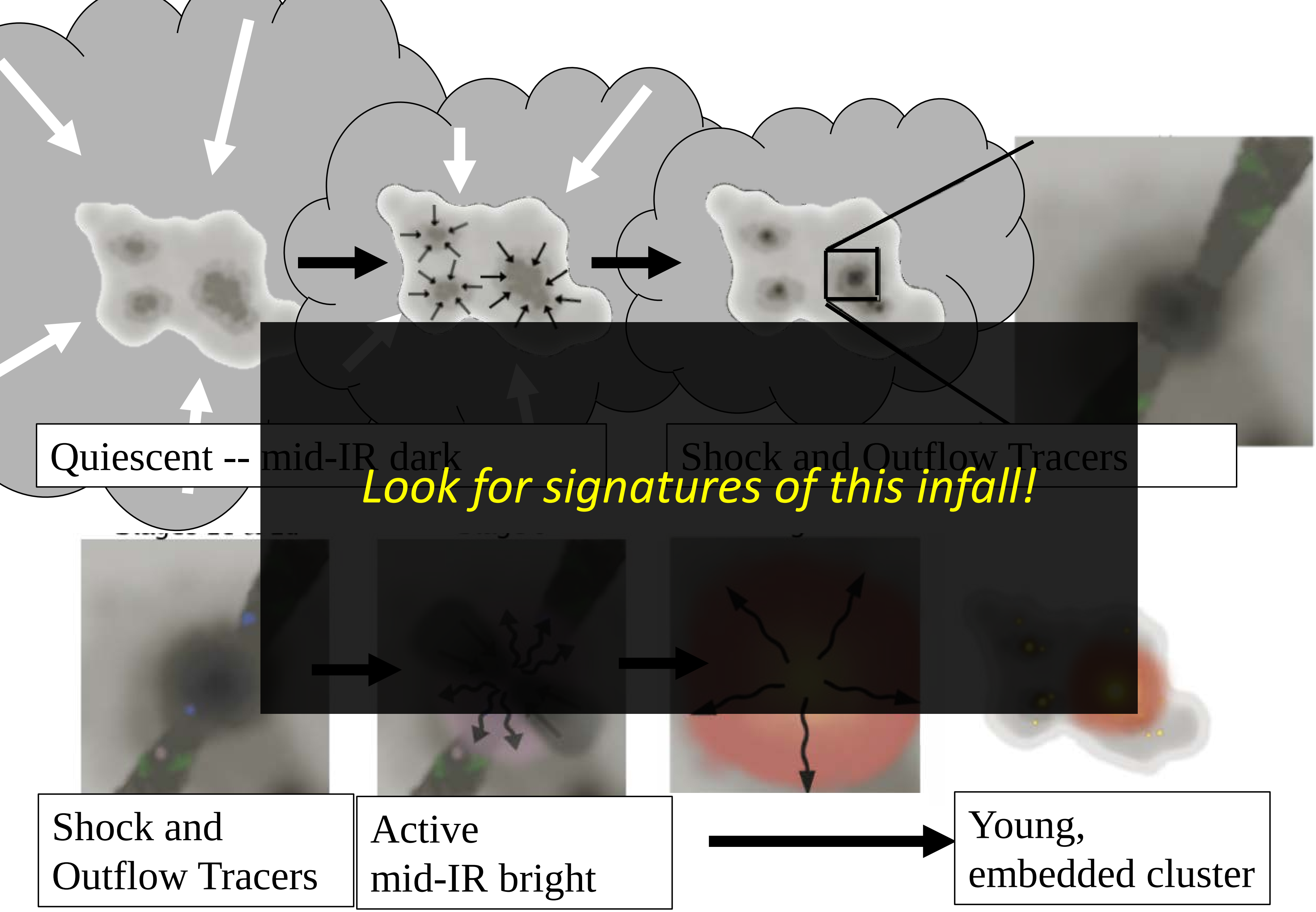
Evolution



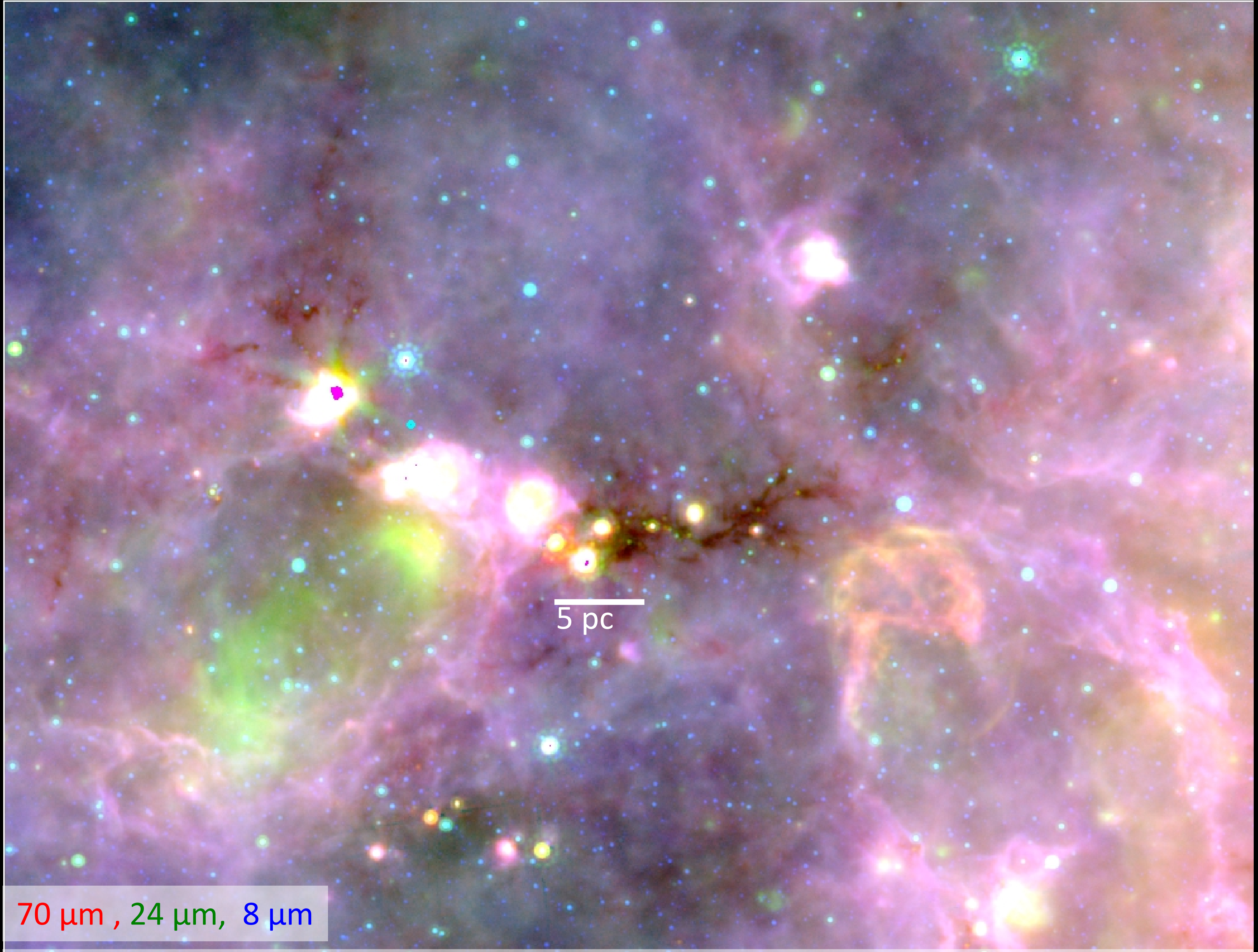
Battersby et al. 2010



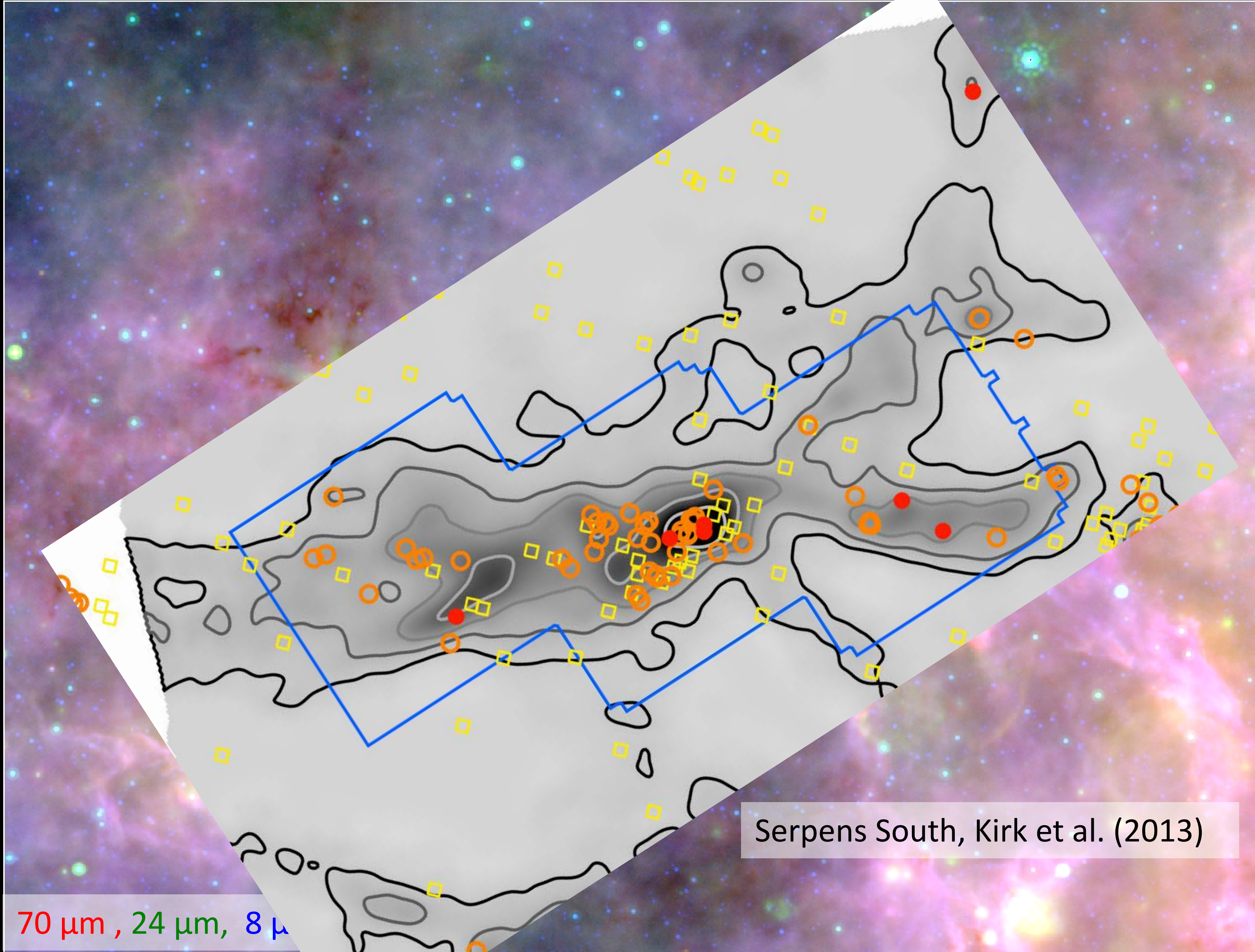
(e.g. Longmore et al. (2011); Peretto et al. 2006, 2013; Schneider et al. 2010; Barnes et al. 2010; Galván-Madrid et al. 2010; Liu et al. 2012)



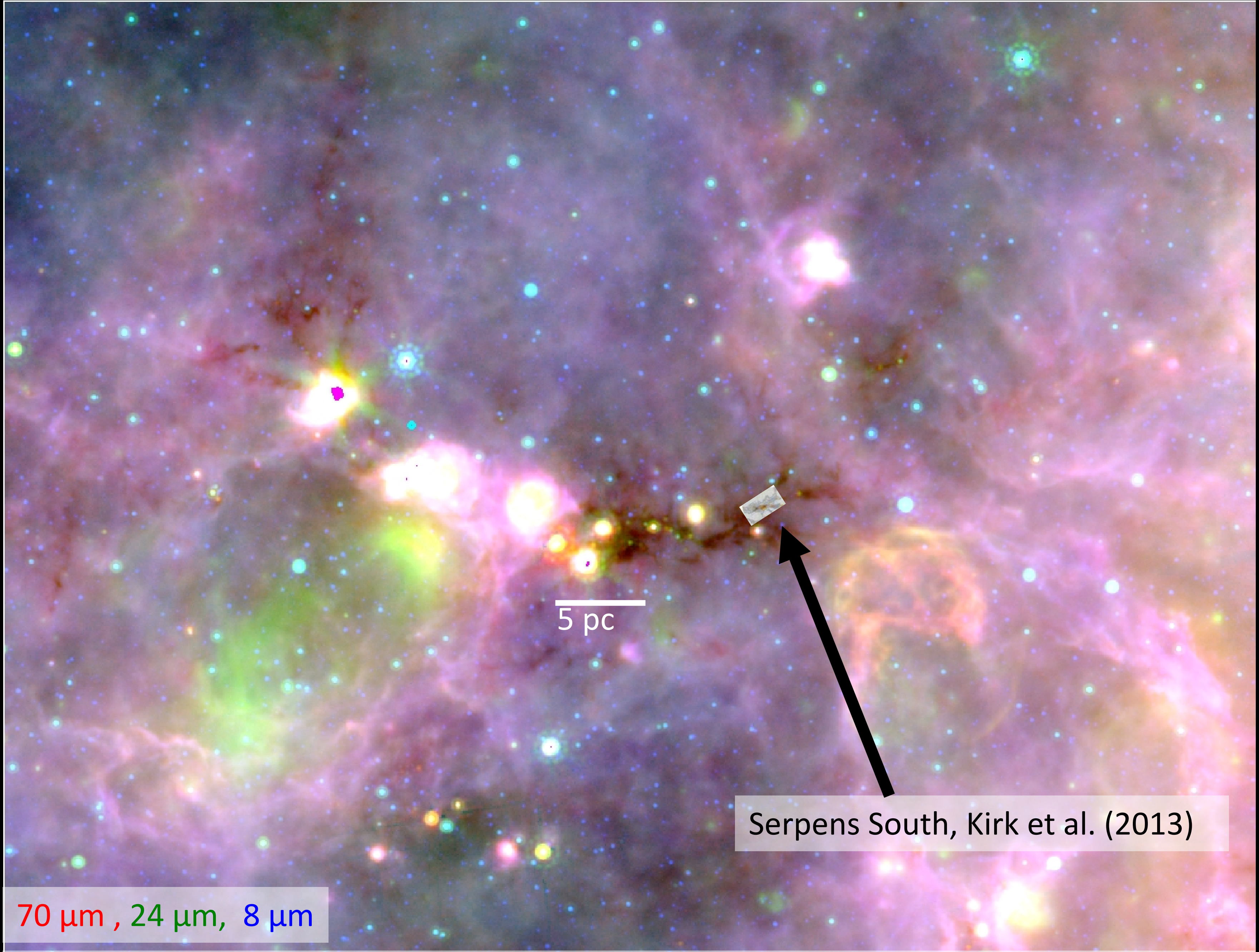
(e.g. Longmore et al. (2011); Peretto et al. 2006, 2013; Schneider et al. 2010; Barnes et al. 2010; Galván-Madrid et al. 2010; Liu et al. 2012)



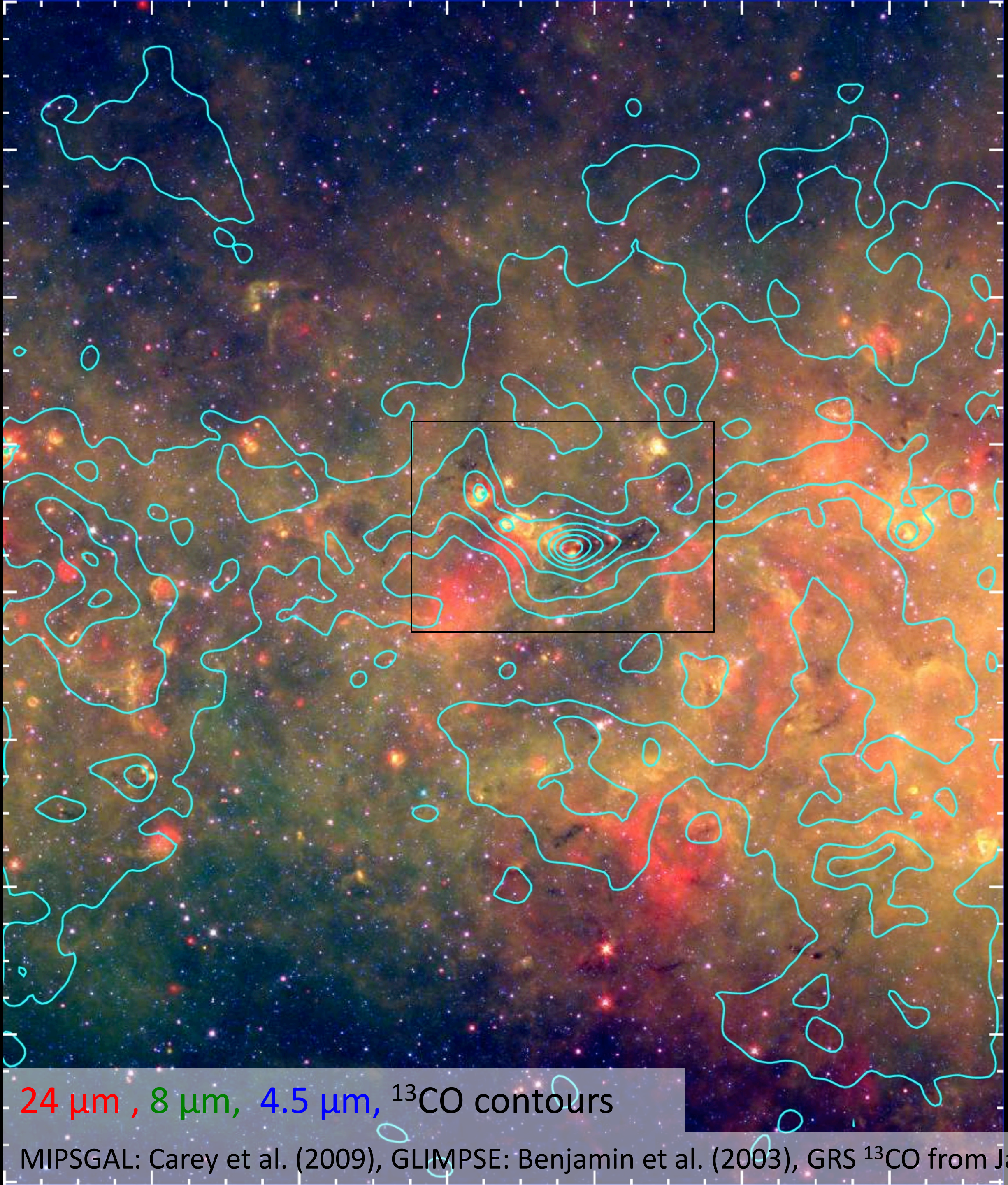
From Battersby et al. 2014b; Hi-GAL: Molinari et al. (2011), MIPSGAL: Carey et al. (2009), GLIMPSE: Benjamin et al. (2003), 20 cm from MAGPIS: White et al. (2005), Helfand et al. (2006), GRS ^{13}CO from Jackson et al. (2006)



From Battersby et al. 2014b, olinari et al. (2011), MIPSGAL: Carey et al. (2009), GLIMPSE: Benjamin et al. (2003), 20 cm from MAGPIS hite et al. (2005), Helfand et al. (2006), GRS ^{13}CO from Jackson et al. (2006)

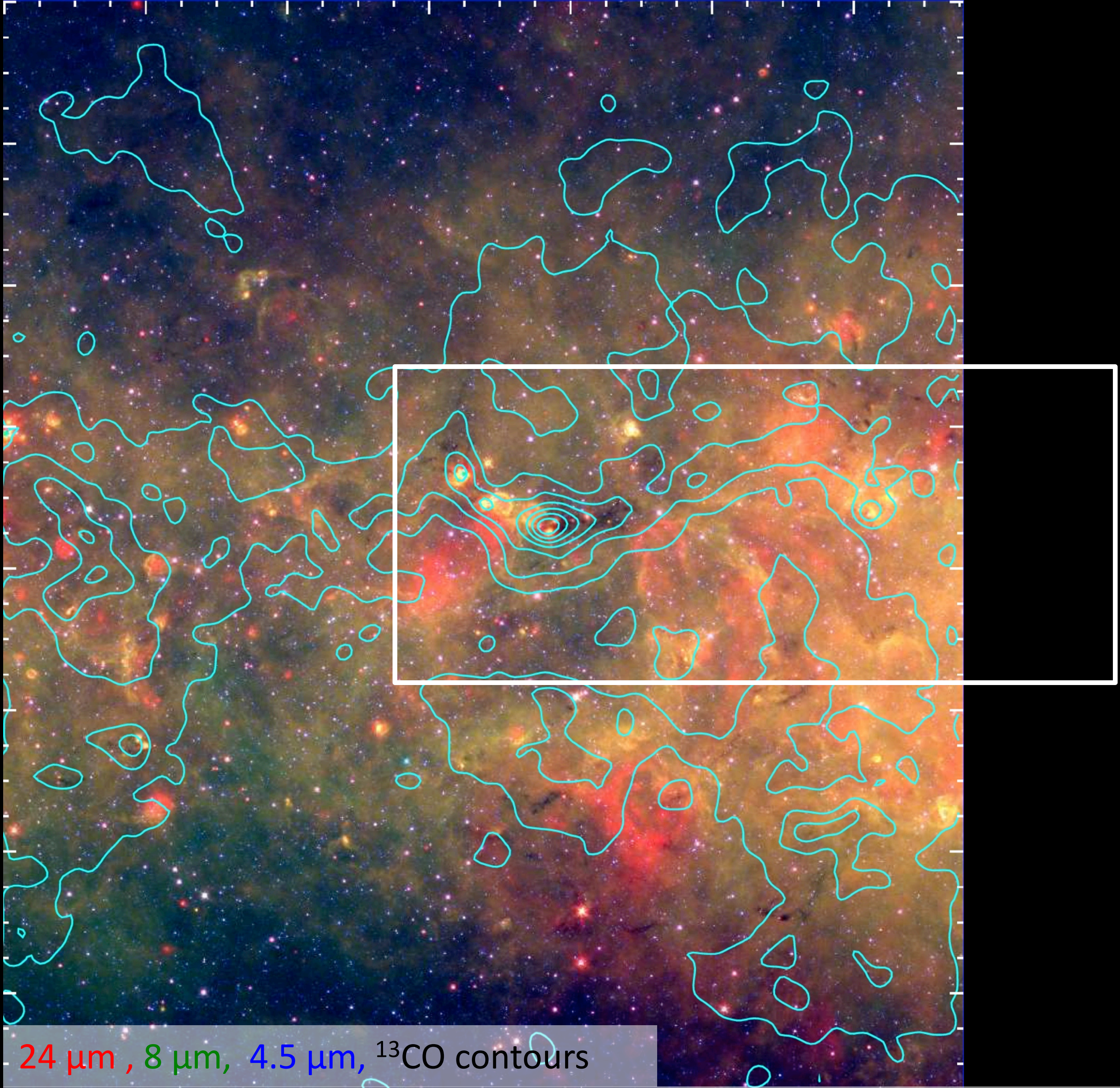


From Battersby et al. 2014b; Hi-GAL: Molinari et al. (2011), MIPSGAL: Carey et al. (2009), GLIMPSE: Benjamin et al. (2003), 20 cm from MAGPIS: White et al. (2005), Helfand et al. (2006), GRS ^{13}CO from Jackson et al. (2006)

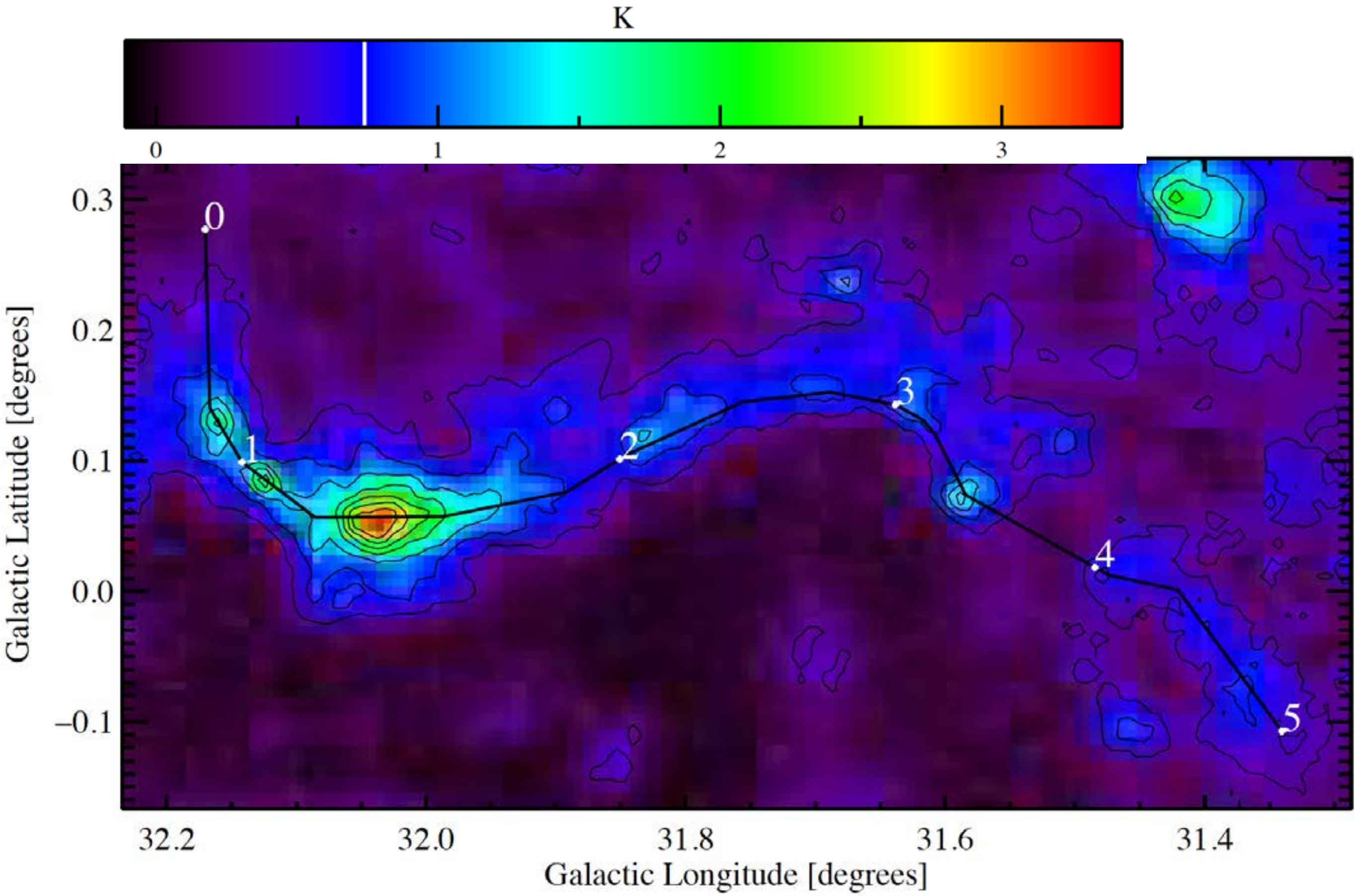


24 μm , 8 μm, 4.5 μm, ^{13}CO contours

MIPSGAL: Carey et al. (2009), GLIMPSE: Benjamin et al. (2003), GRS ^{13}CO from Jackson et al. (2006)

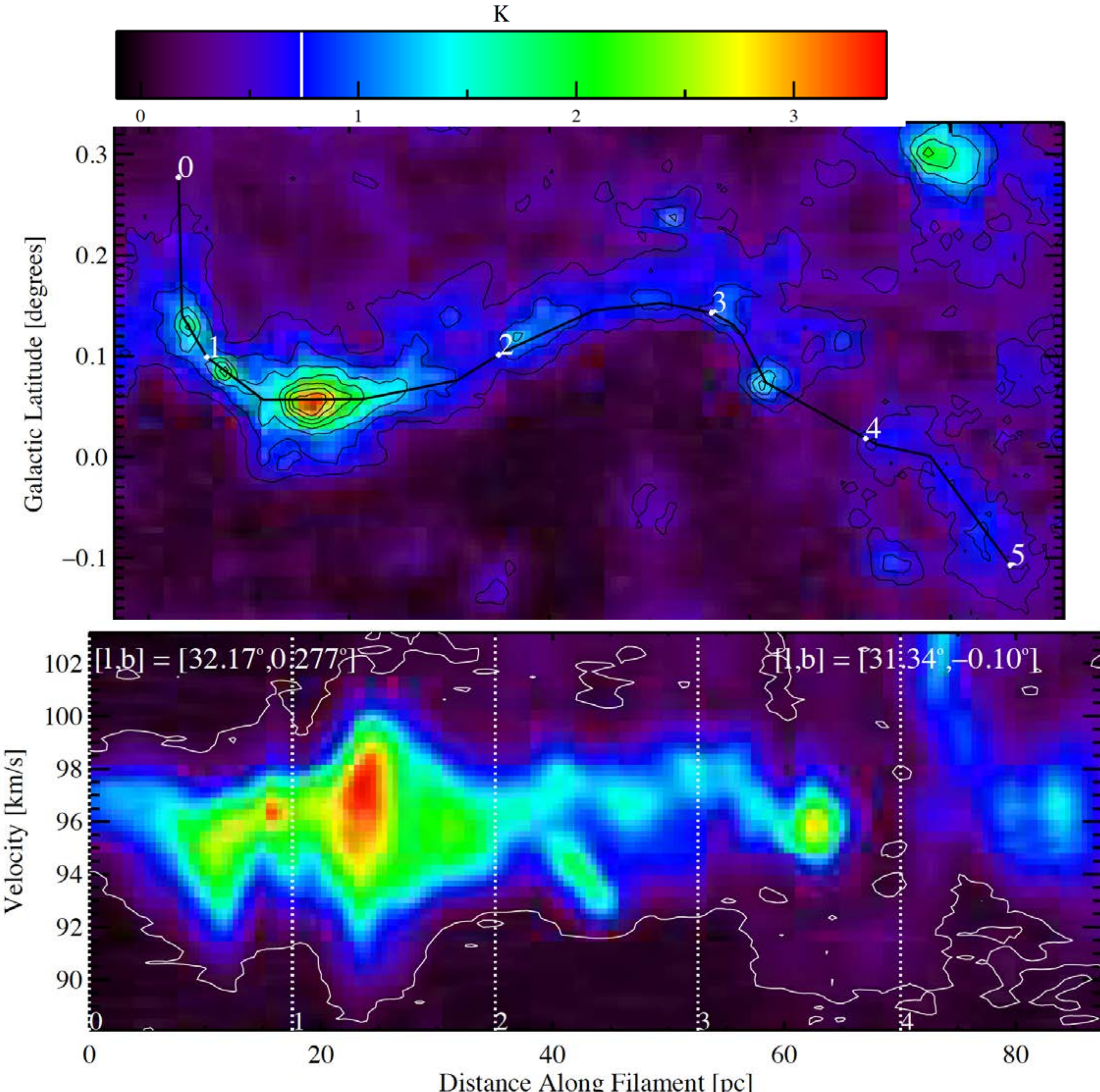


MIPSGAL: Carey et al. (2009), GLIMPSE: Benjamin et al. (2003), GRS ^{13}CO from Jackson et al. (2006)



G32.03+0.05

Figure from Battersby et al. 2014b, GRS ^{13}CO from Jackson et al. 2006



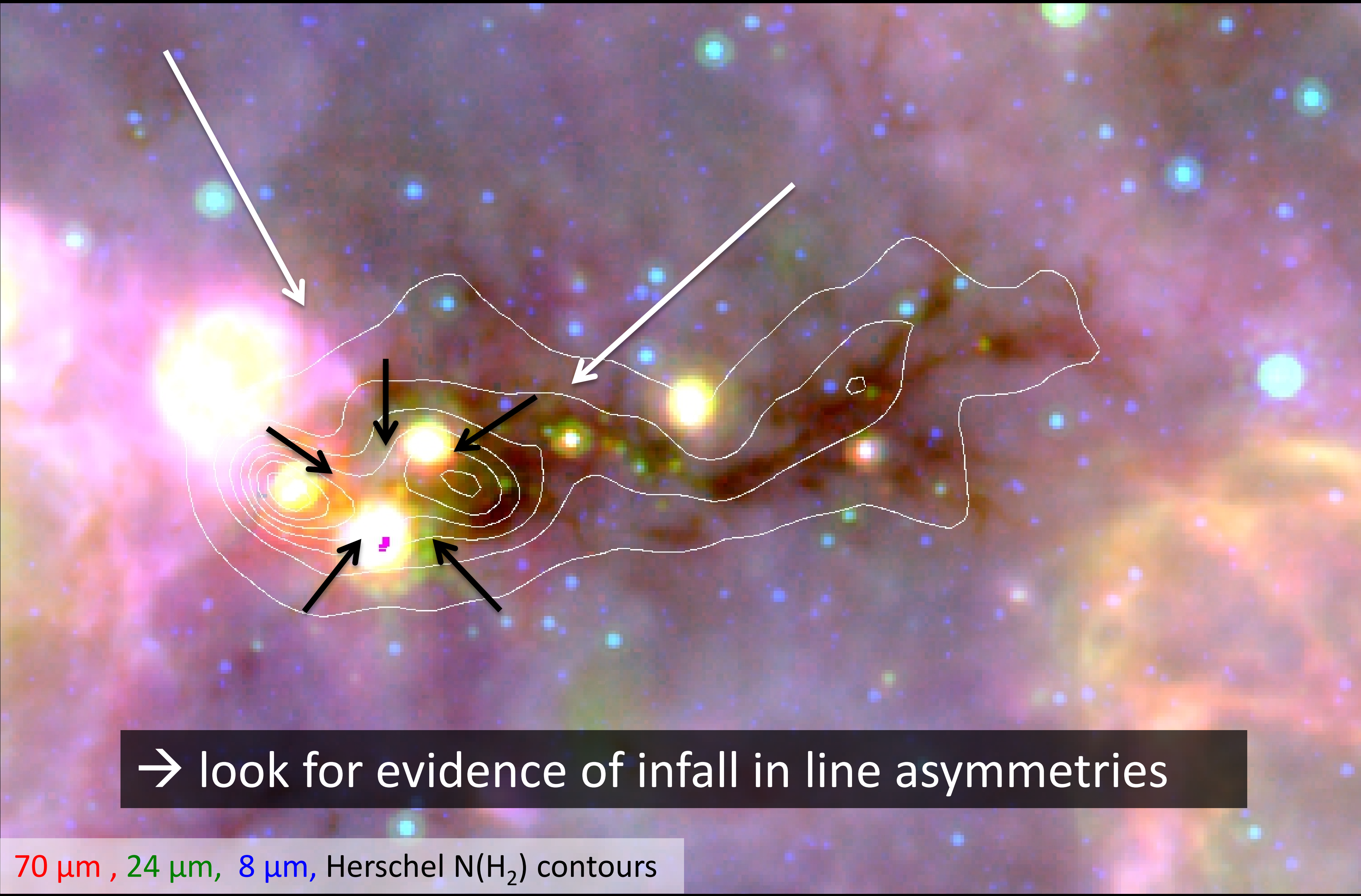
Massive Molecular Filament (MMF)

M > 10^5 $M_\odot$
length ~ 70 pc
Δv < 5 km/s

(see also GMFs; Ragan et al. (2014))

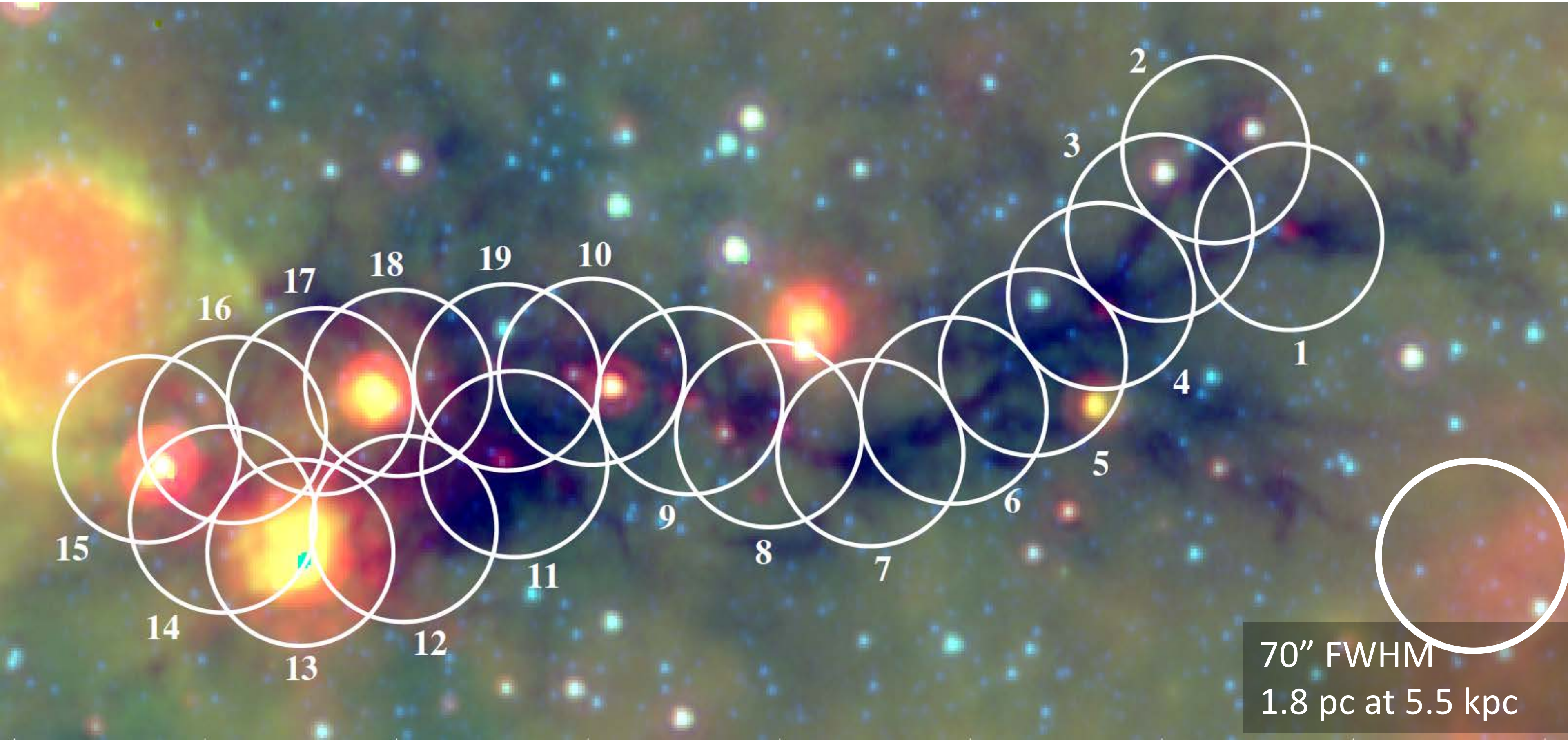
G32.03+0.05

Figure from Battersby et al. 2014b, GRS ^{13}CO from Jackson et al. 2006

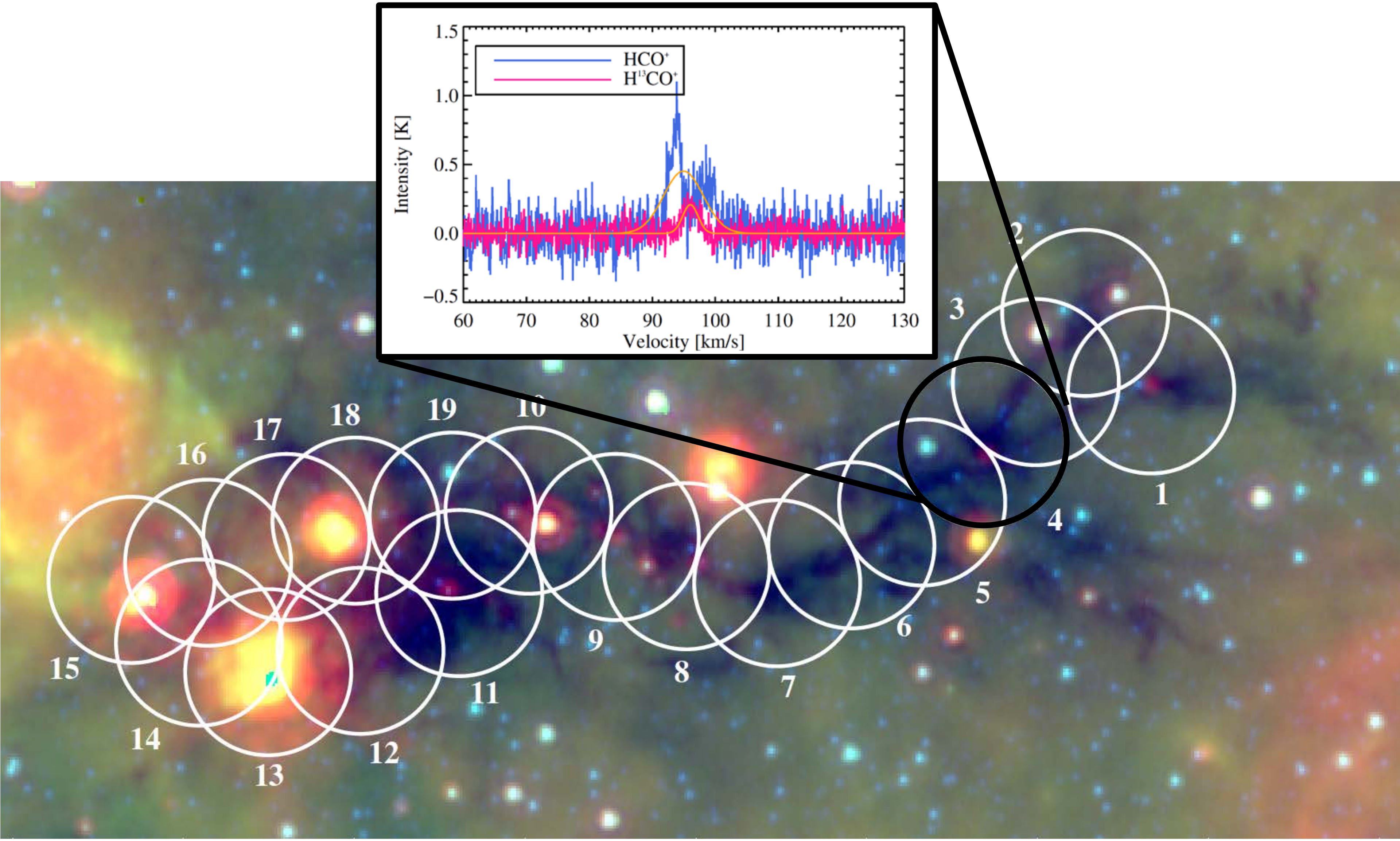


G32.03+0.05, Battersby+ in prep

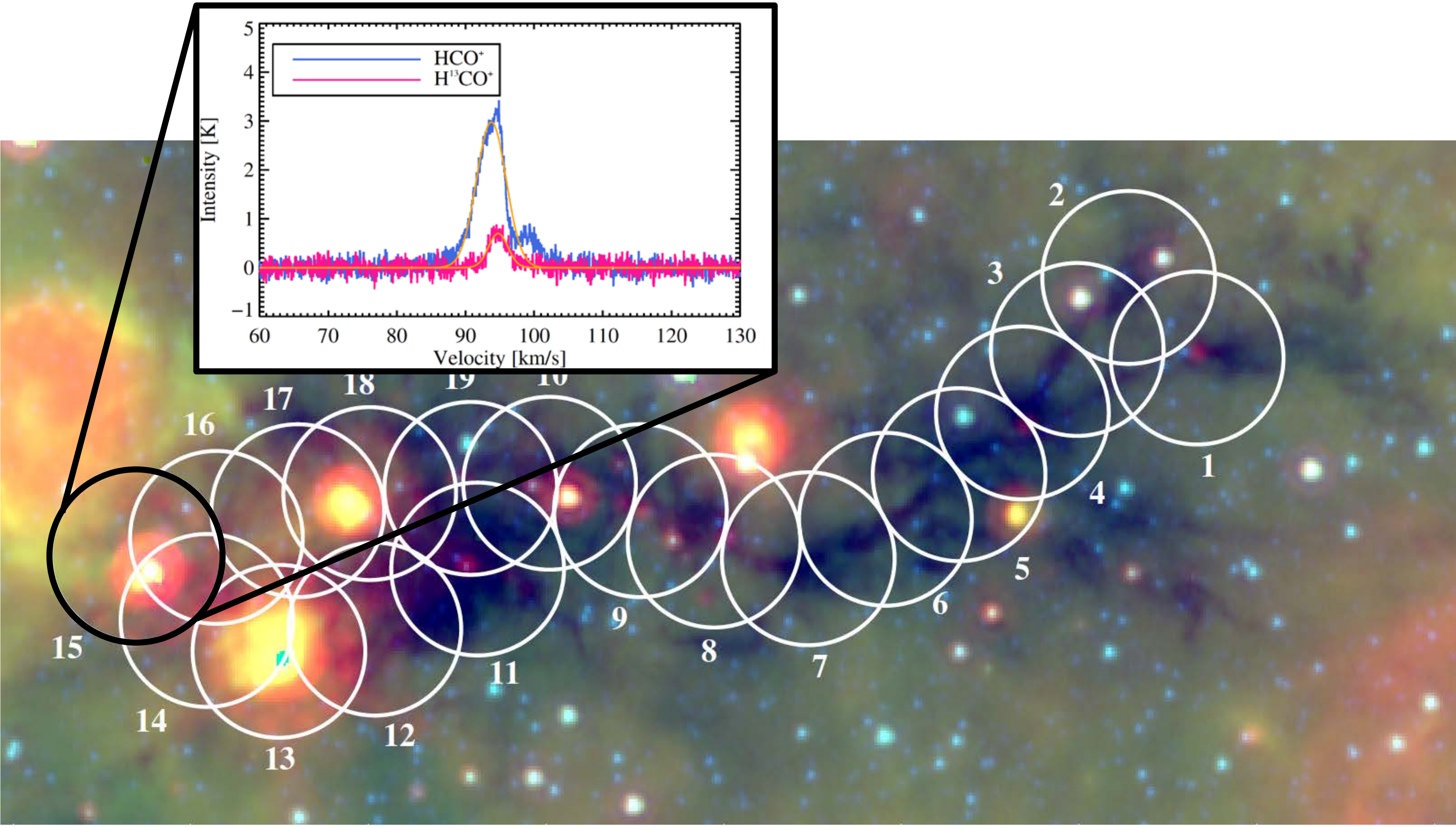
HCO$^+$ (1-0) and H^{13}CO$^+$ (1-0) on the ARO 12m



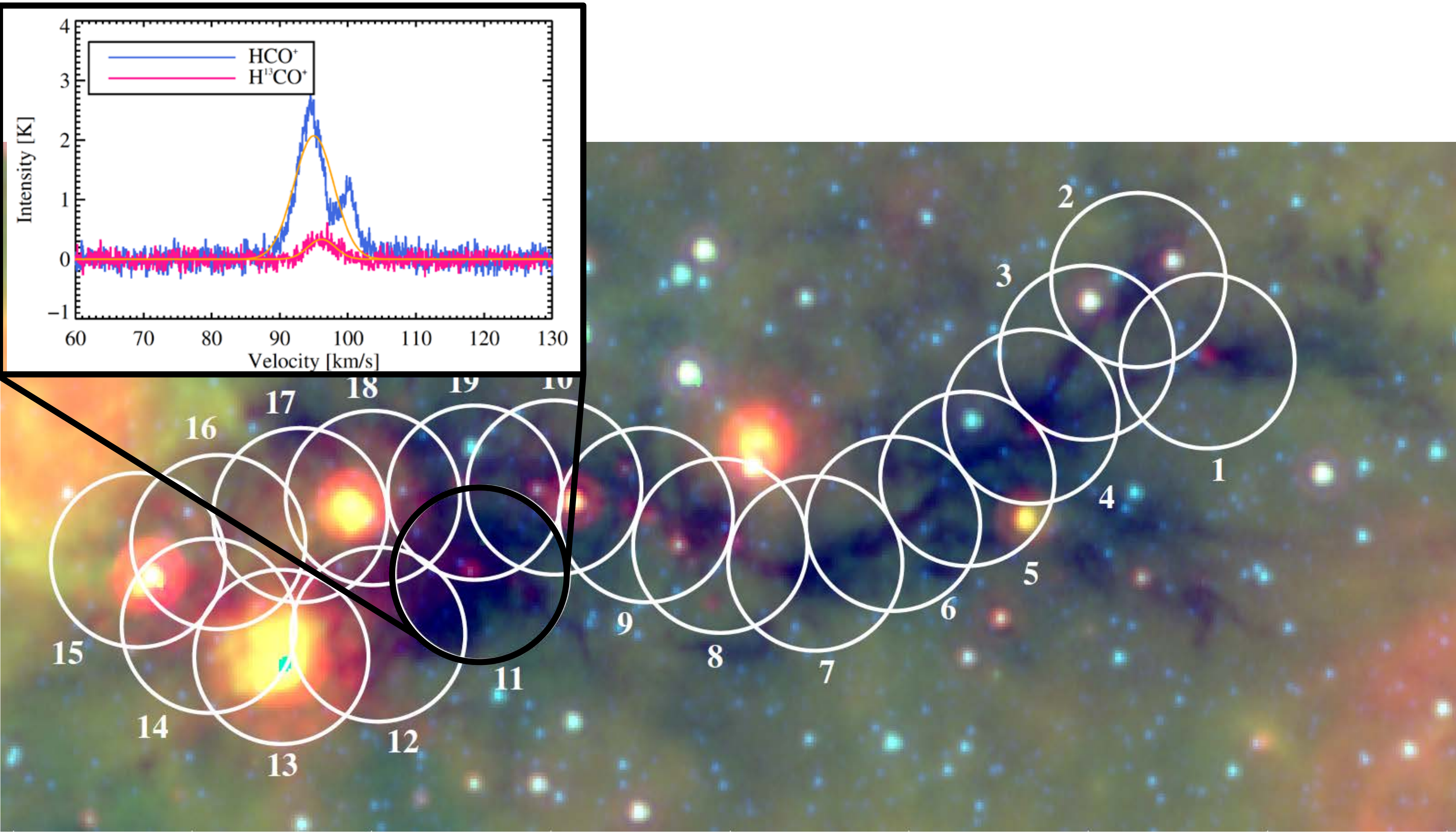
Battersby et al., in prep



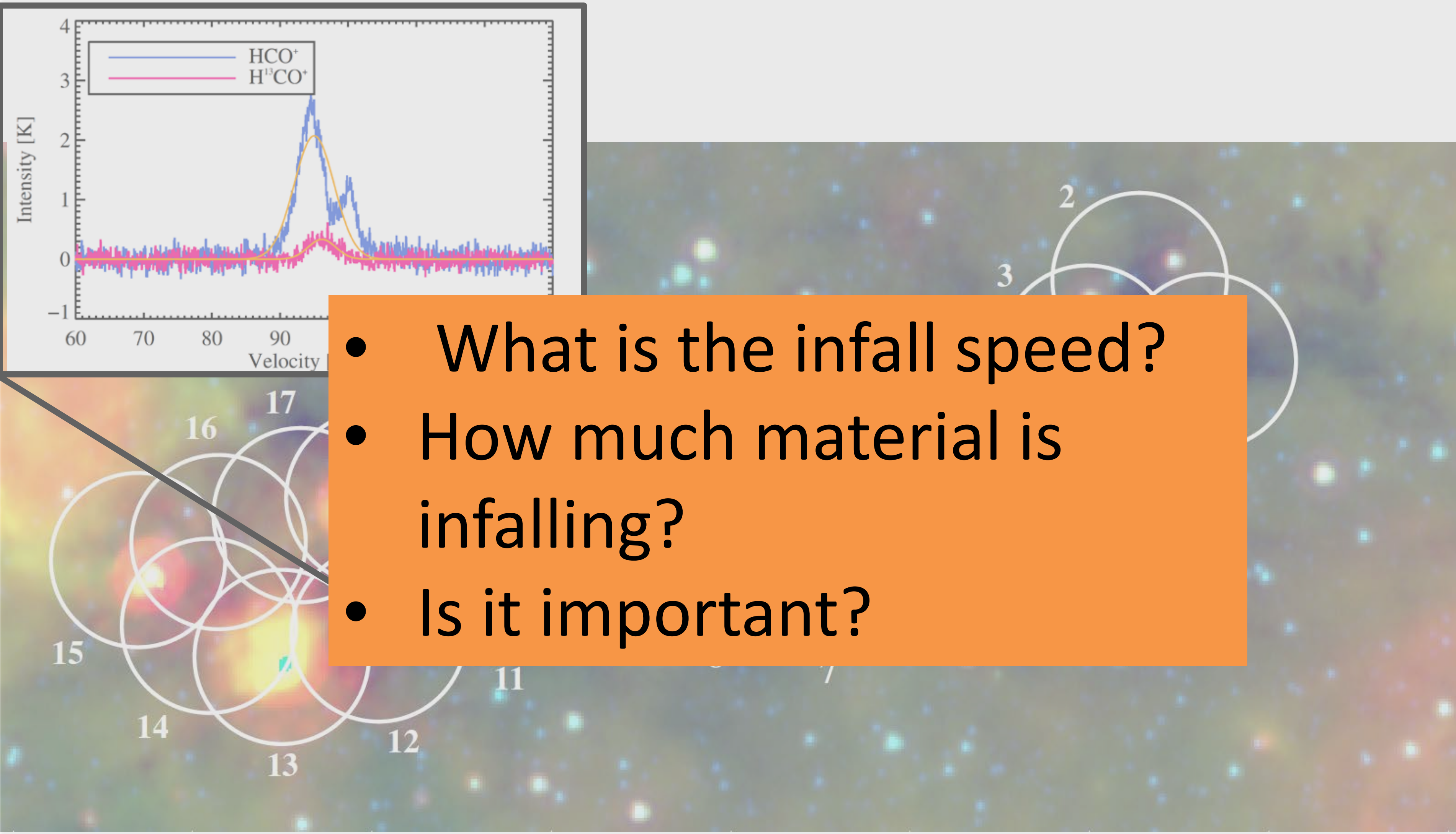
Battersby et al., in prep



Battersby et al., in prep

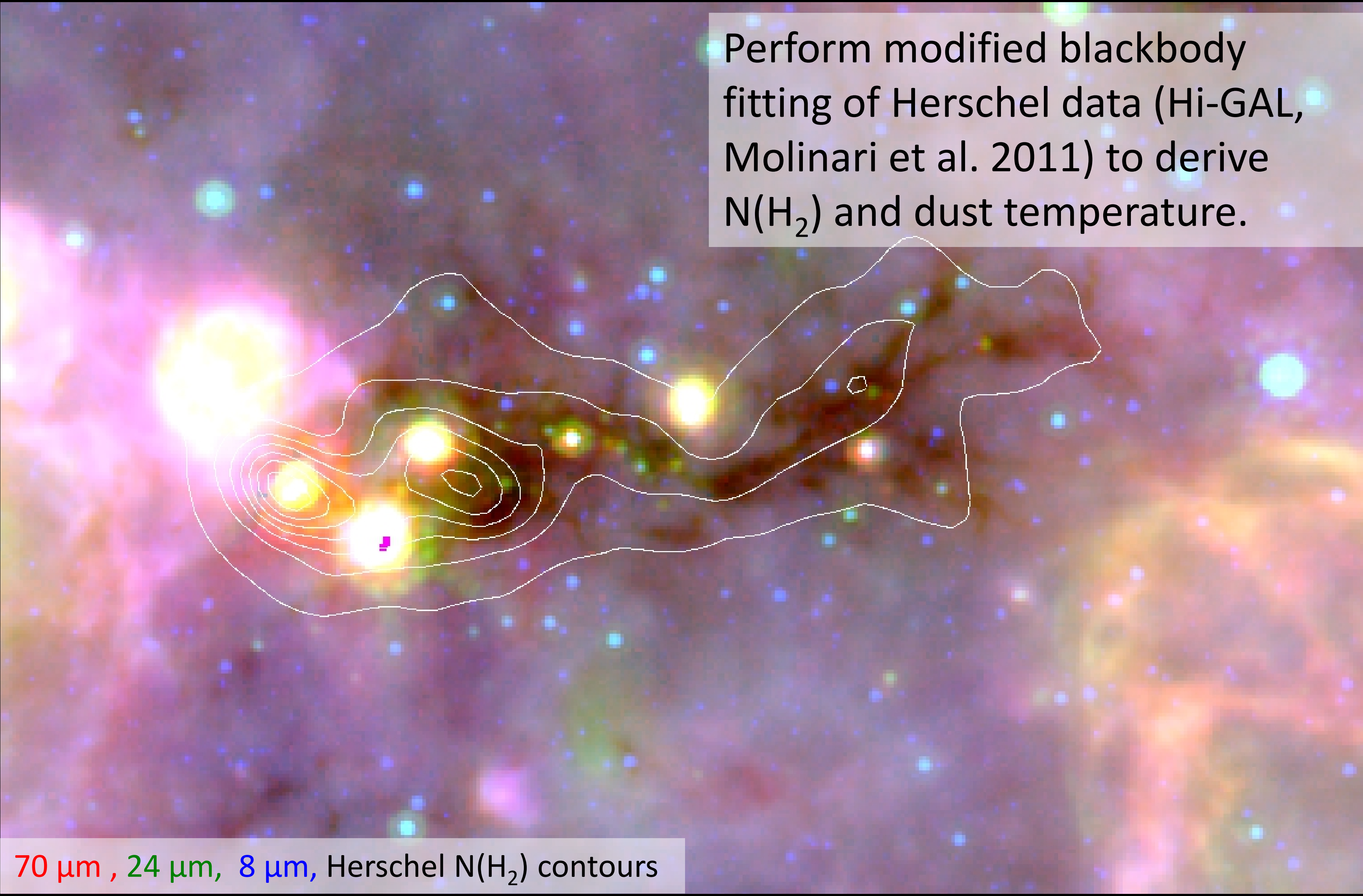


Battersby et al., in prep



- What is the infall speed?
- How much material is infalling?
- Is it important?

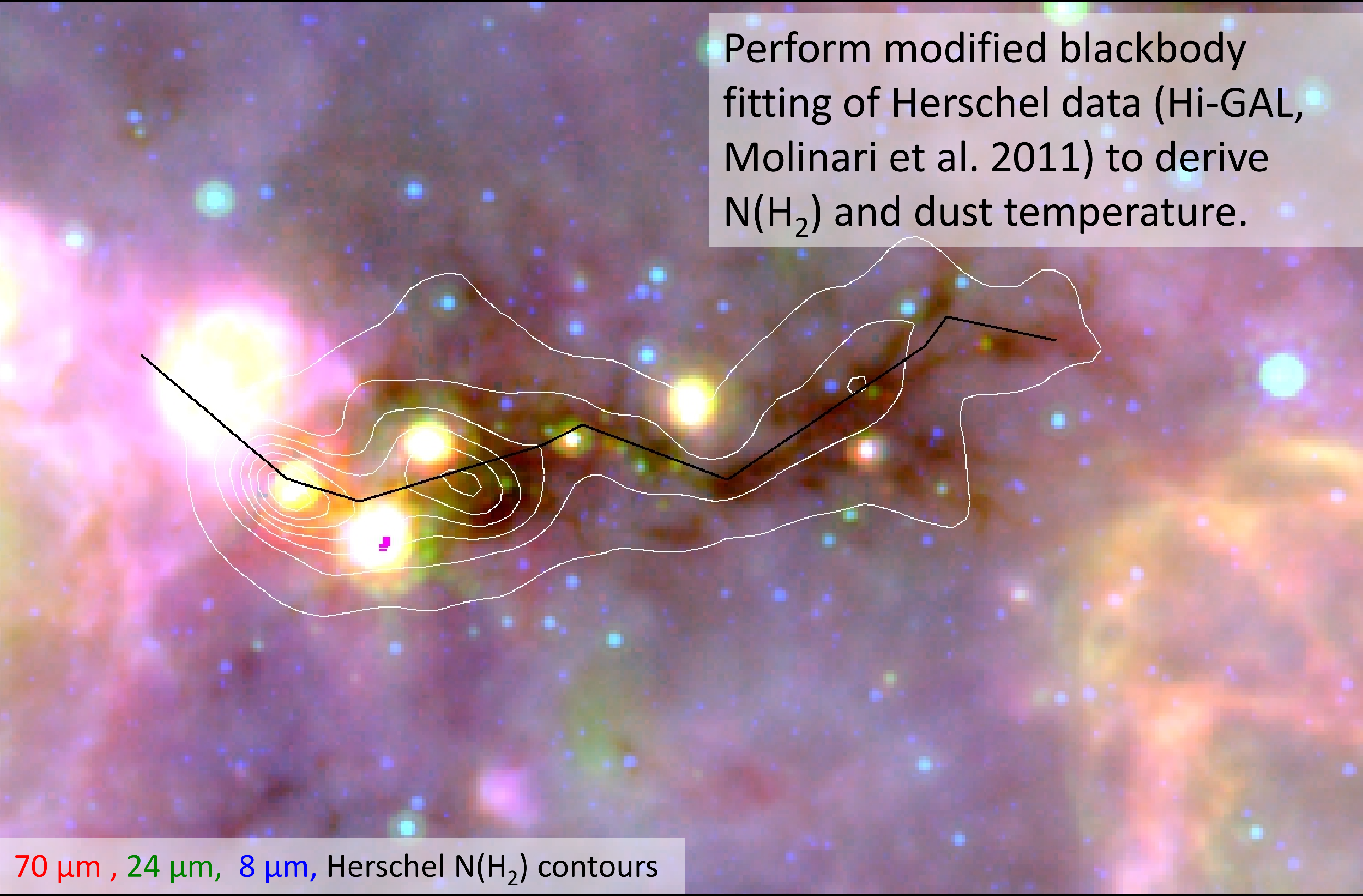
Perform modified blackbody fitting of Herschel data (Hi-GAL, Molinari et al. 2011) to derive $N(H_2)$ and dust temperature.



70 µm , 24 µm, 8 µm, Herschel $N(H_2)$ contours

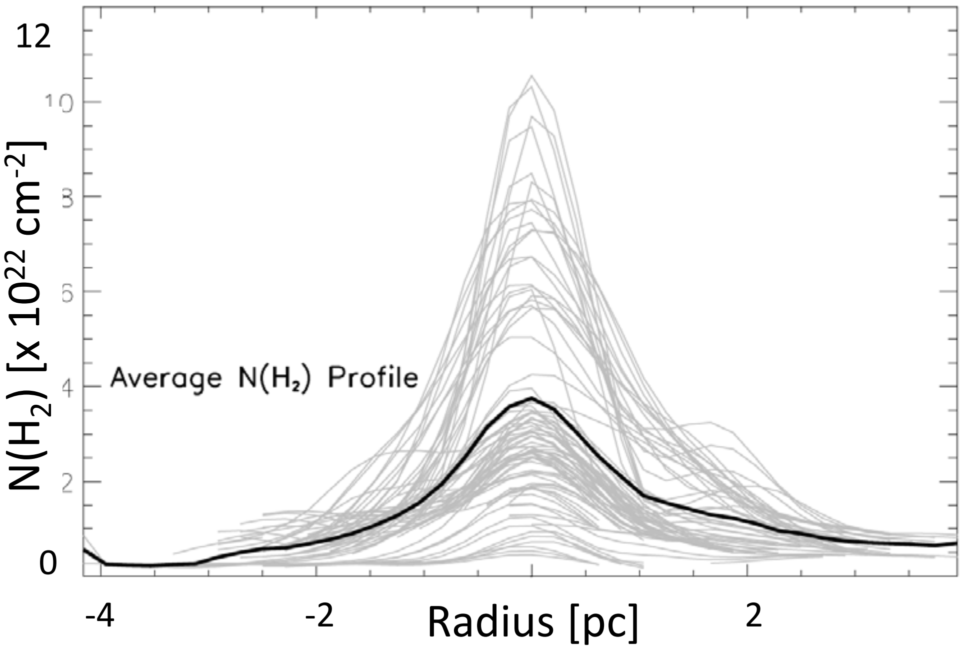
G32.03+0.05, Battersby, Myers, Keto, et al. in prep

Perform modified blackbody fitting of Herschel data (Hi-GAL, Molinari et al. 2011) to derive $N(H_2)$ and dust temperature.

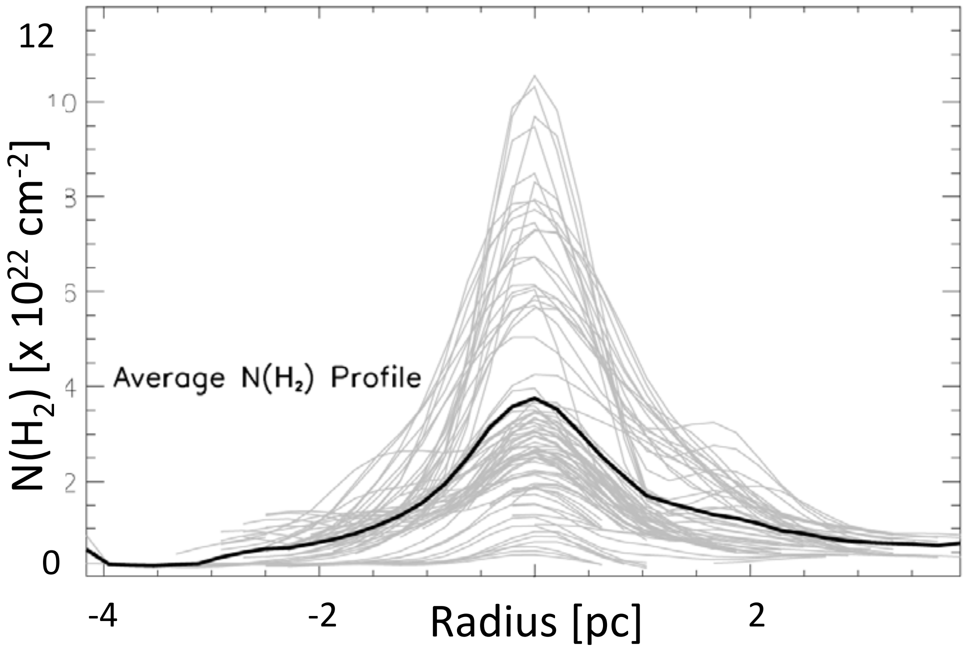


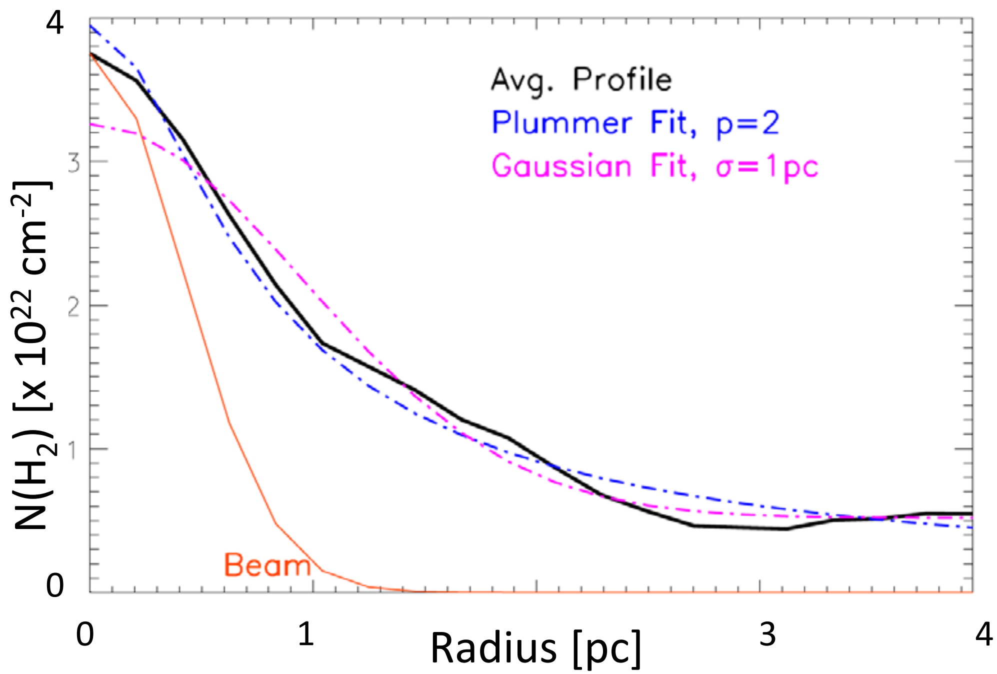
70 µm , 24 µm, 8 µm, Herschel $N(H_2)$ contours

G32.03+0.05, Battersby, Myers, Keto, et al. in prep



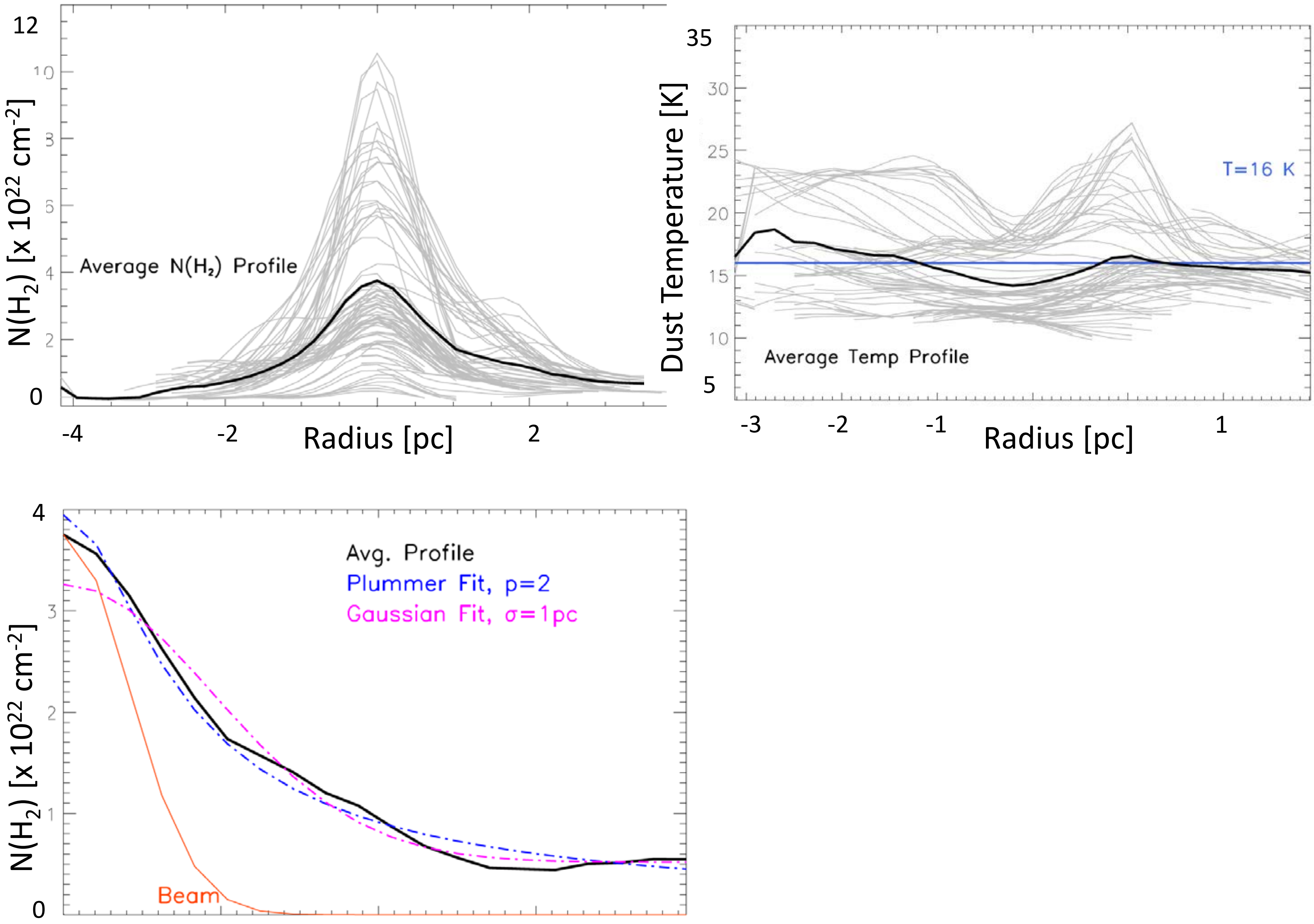
Battersby et al., in prep



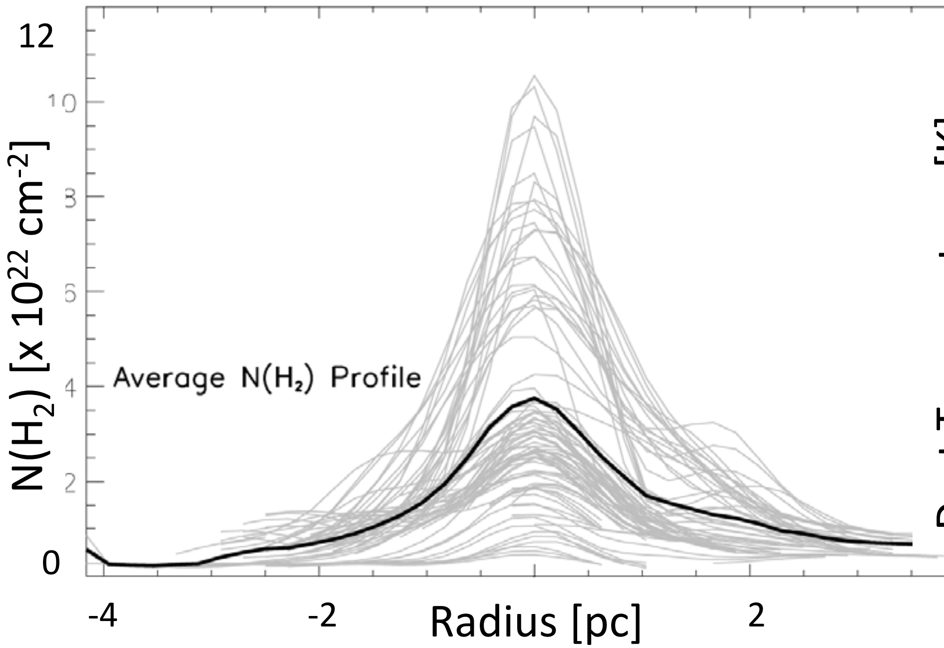


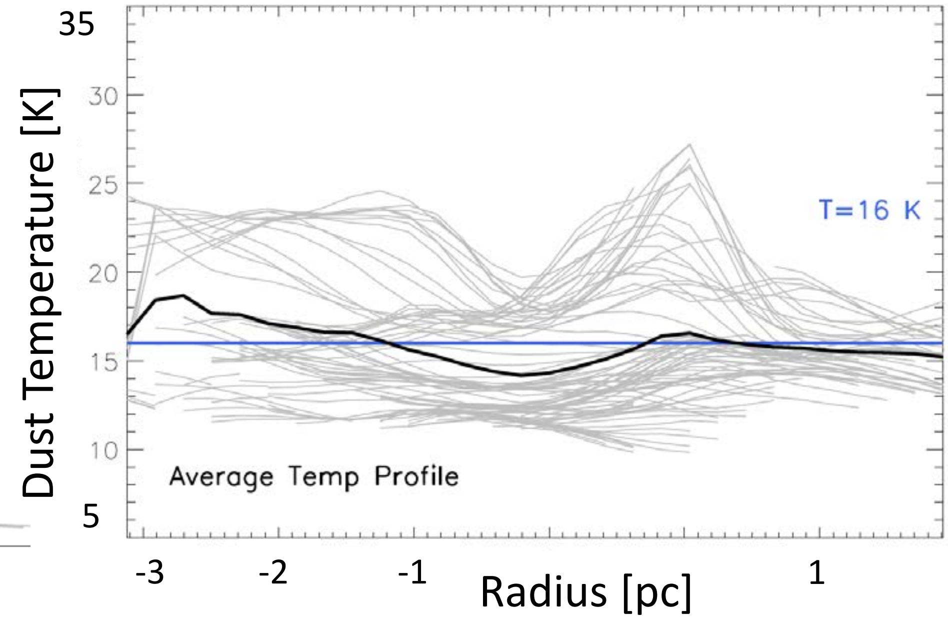
Plummer profile formulation from Arzoumanian et al. (2011), also p=2, but r_{flat} is about 15 times bigger (1.5 pc in their formulation of width).

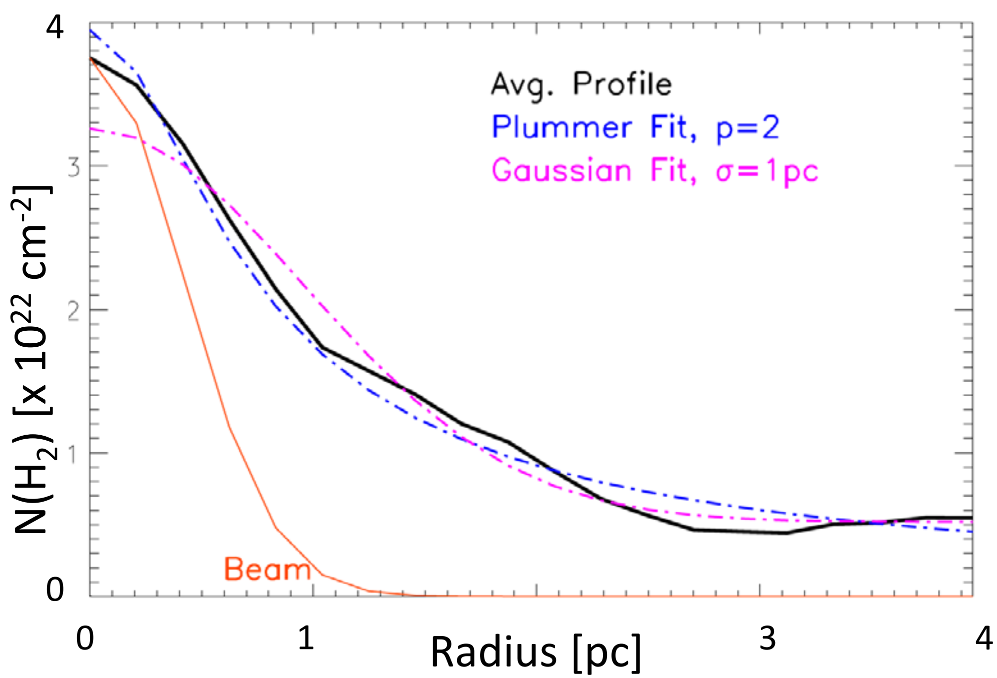
Battersby et al., in prep



Battersby et al., in prep

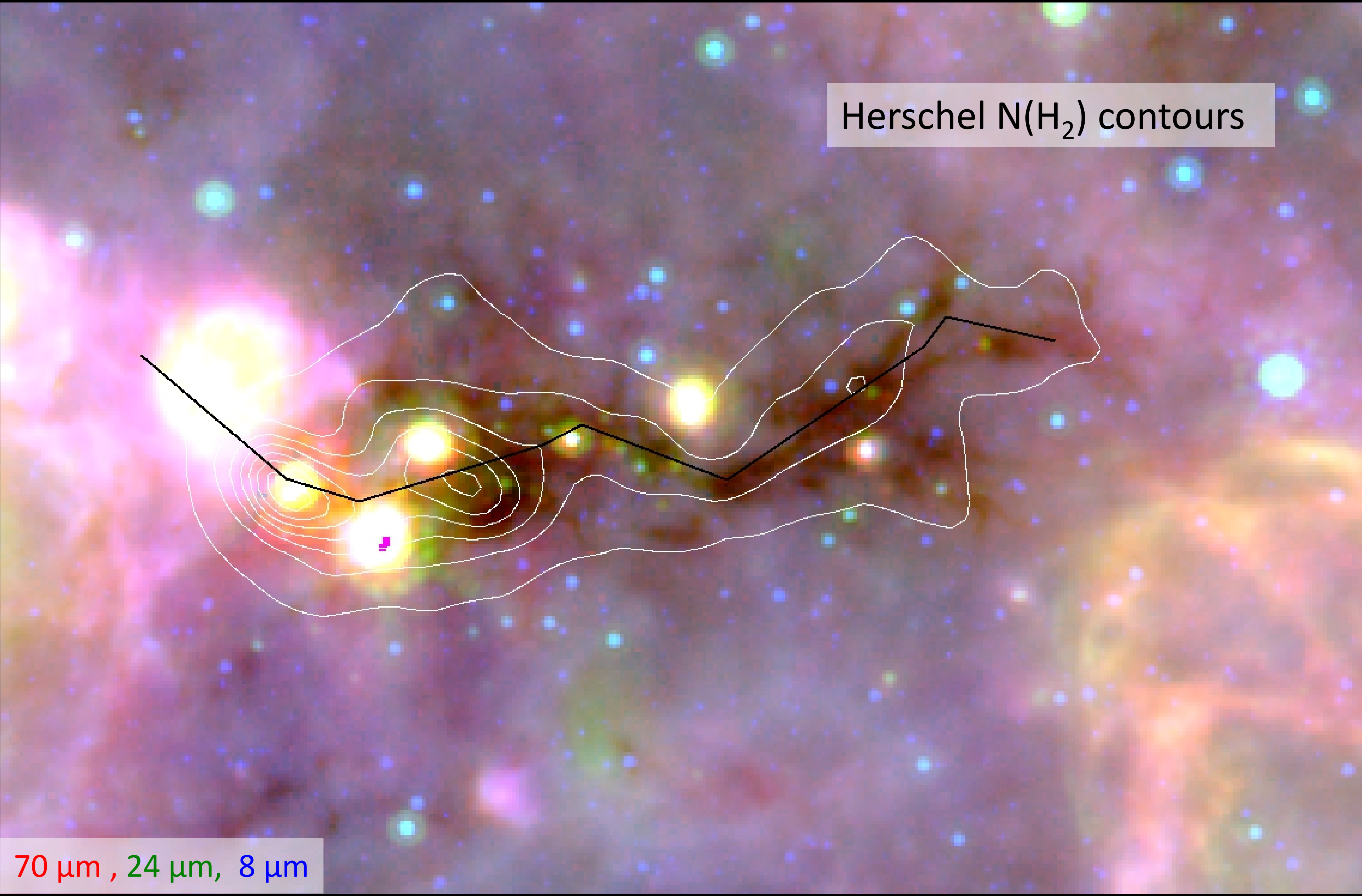




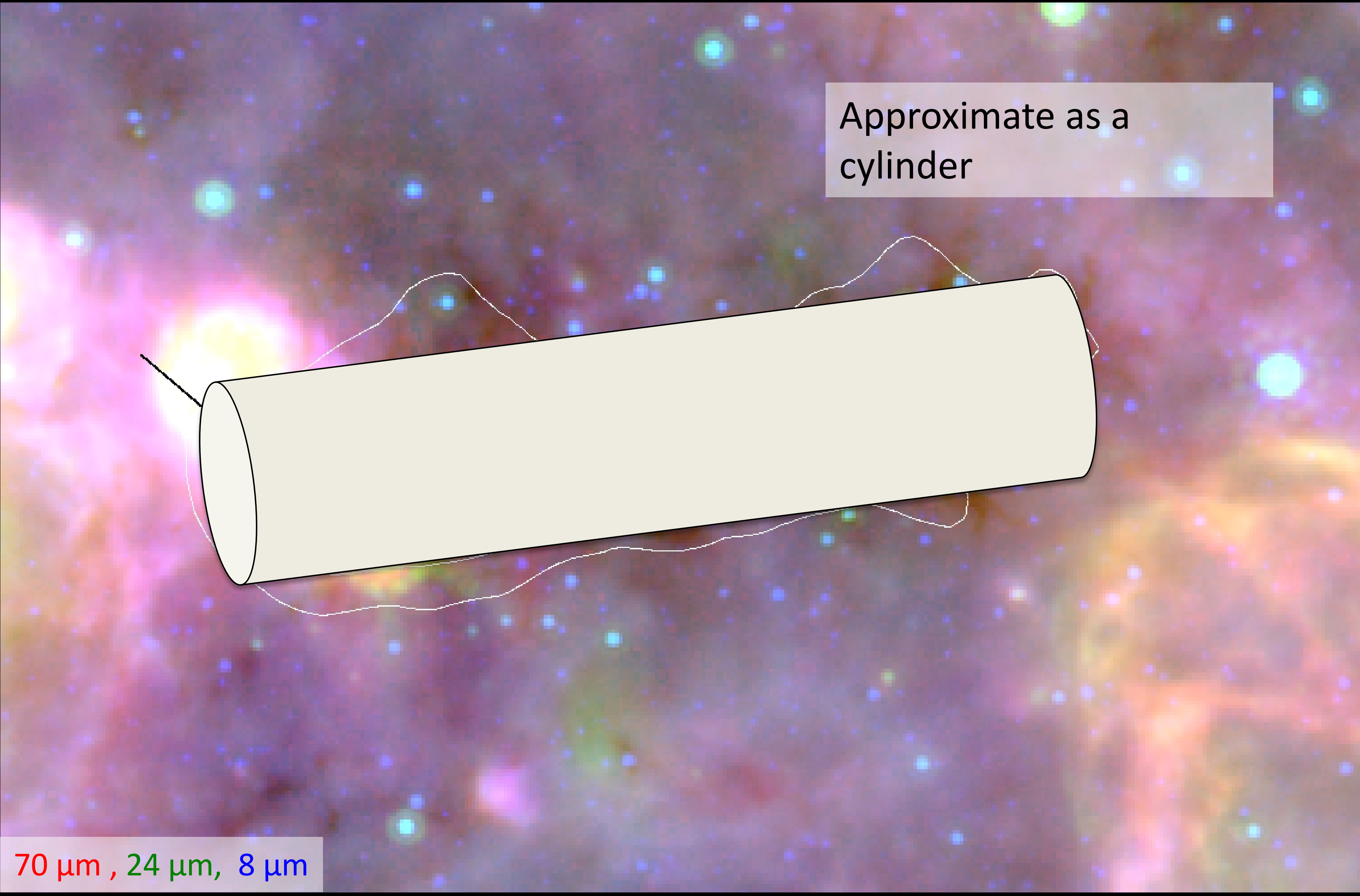


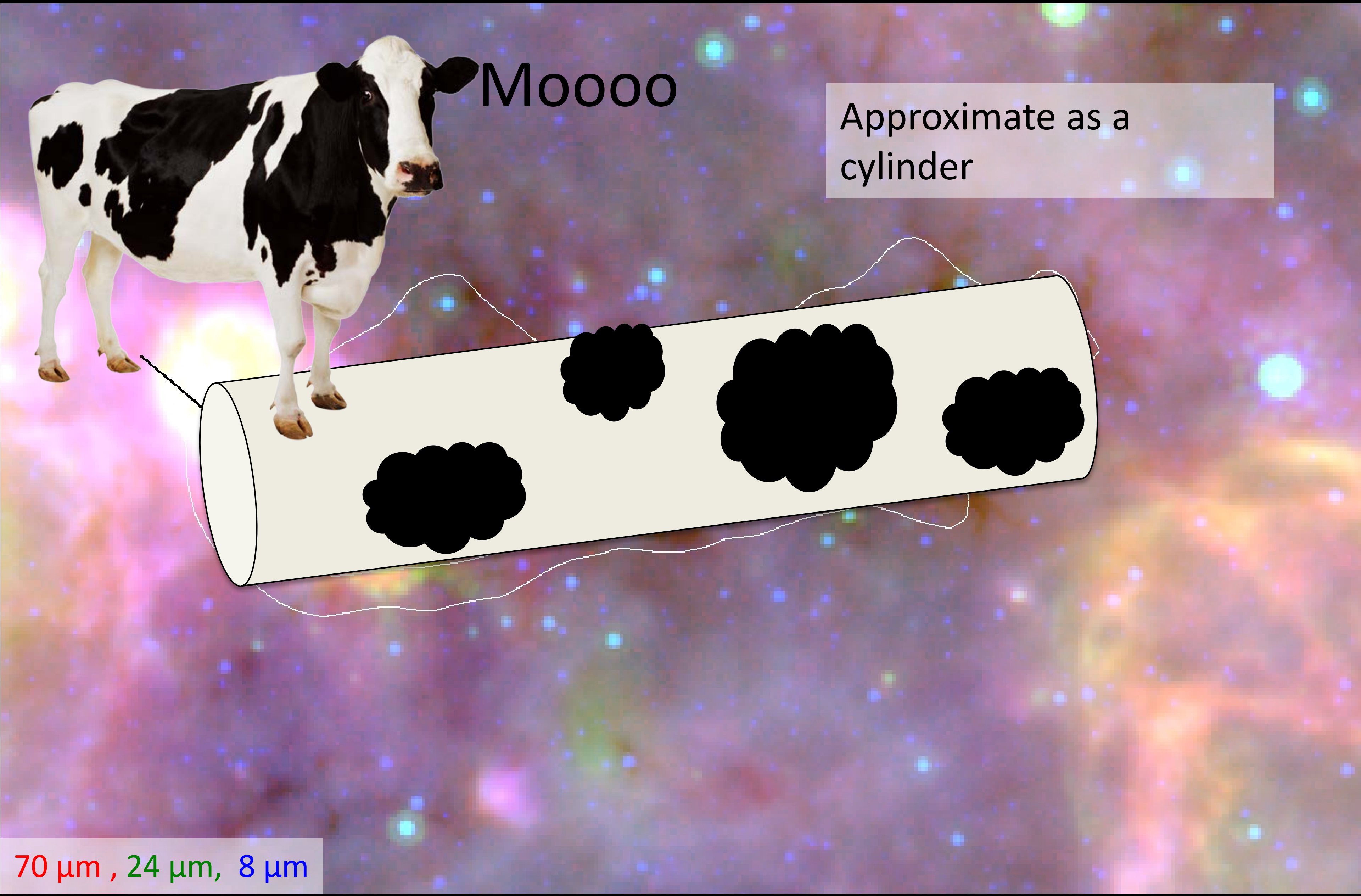
Use our knowledge of the physical structure to inform the radiative transfer model (MOLLIE, Keto et al.)

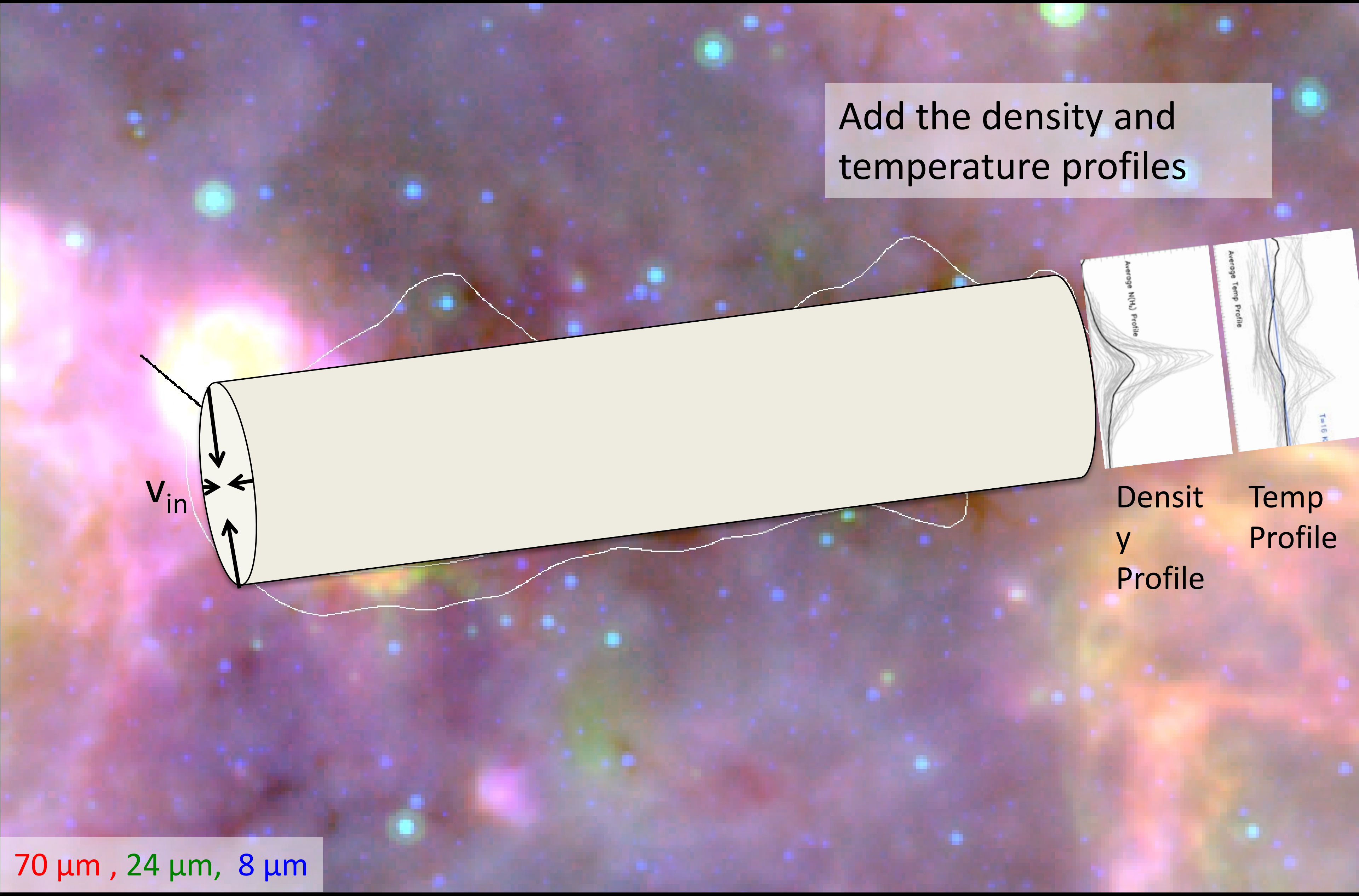
- Plummer profile, p = 2, r_{flat} = 0.5 pc
- Flat temperature profile, T = 16 K

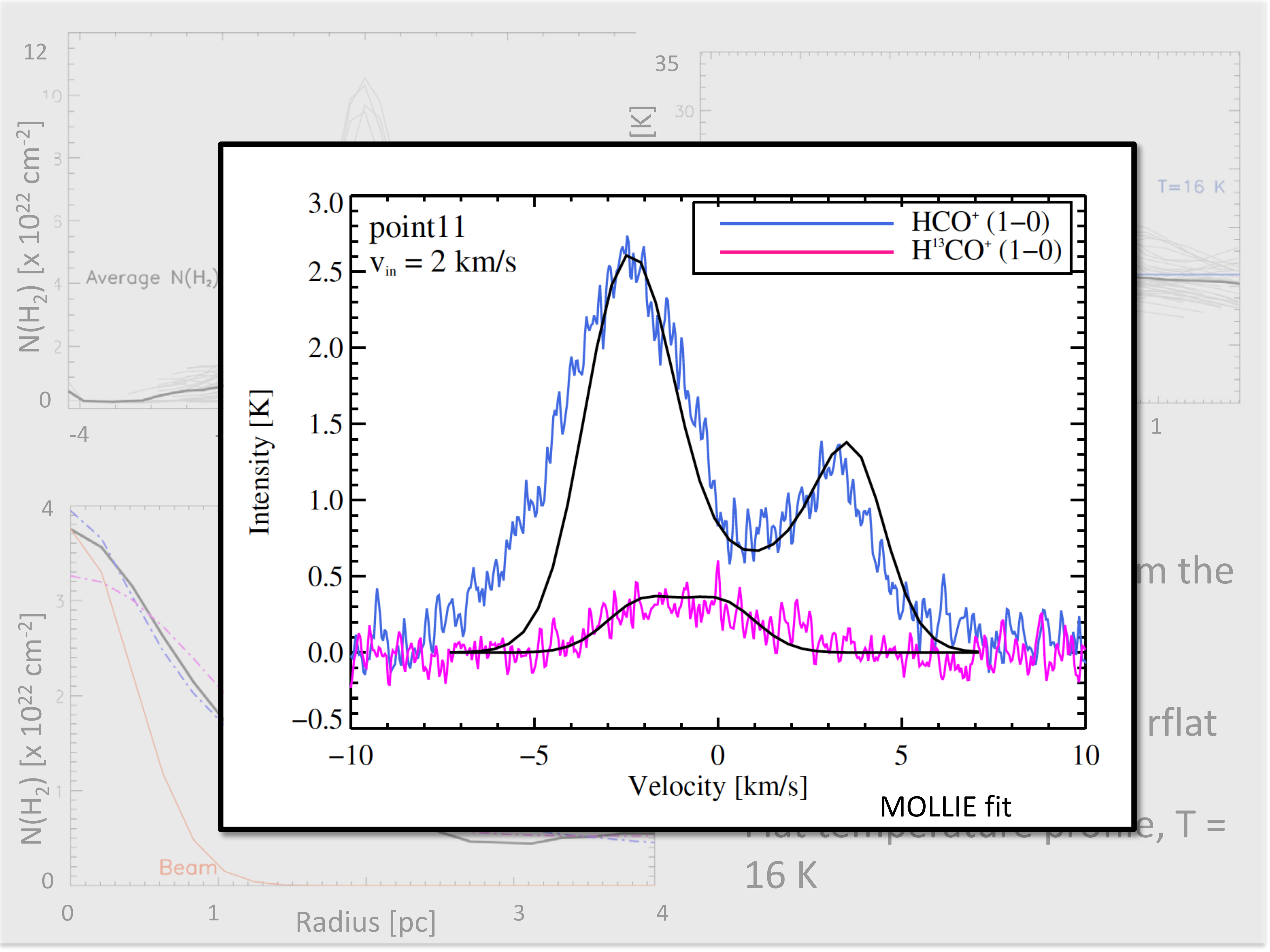


Herschel N(H2) contours
70 µm , 24 µm, 8 µm

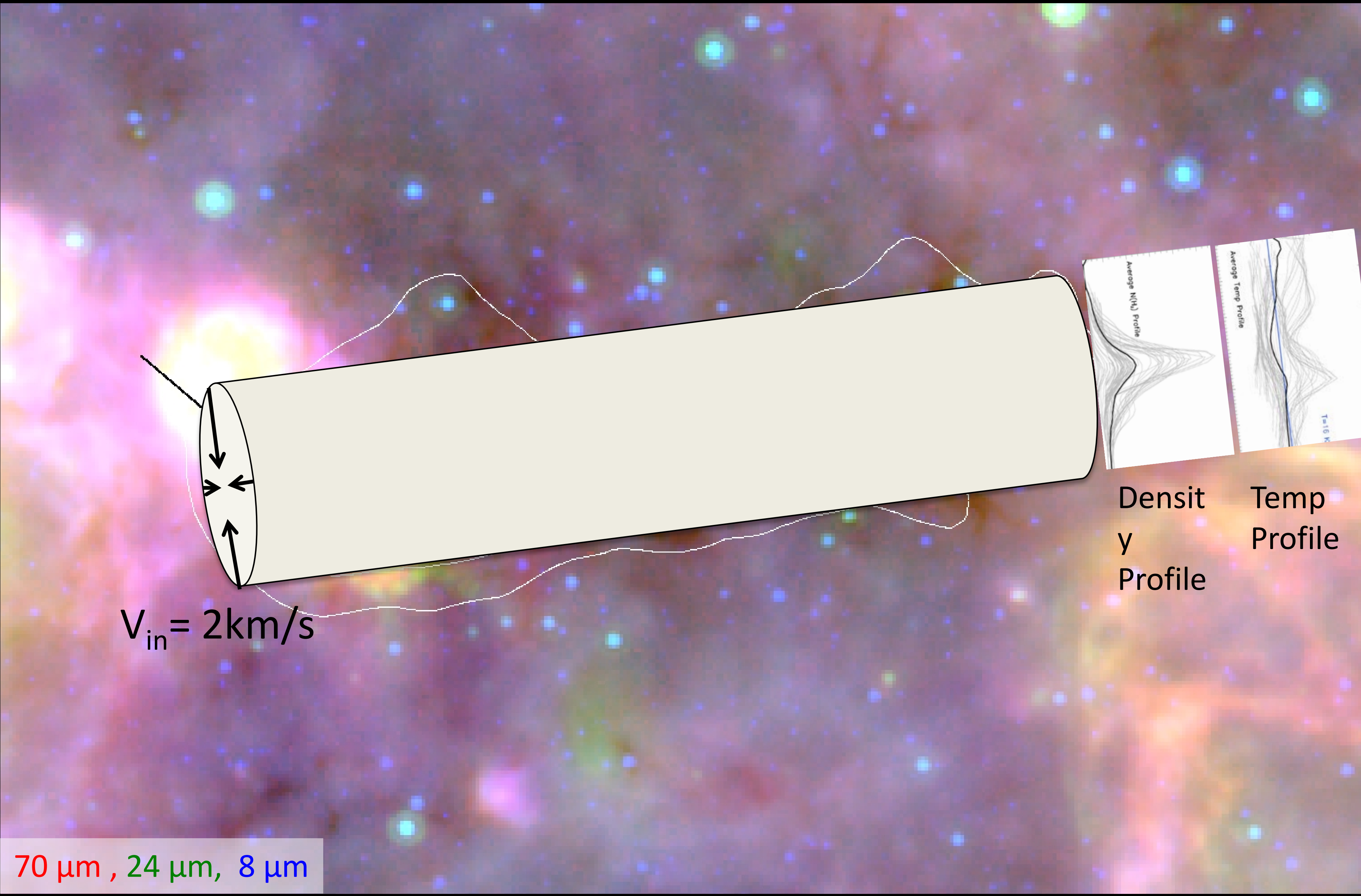

Approximate as a cylinder
70 µm , 24 µm, 8 µm


Moooo
Approximate as a cylinder
70 µm , 24 µm, 8 µm

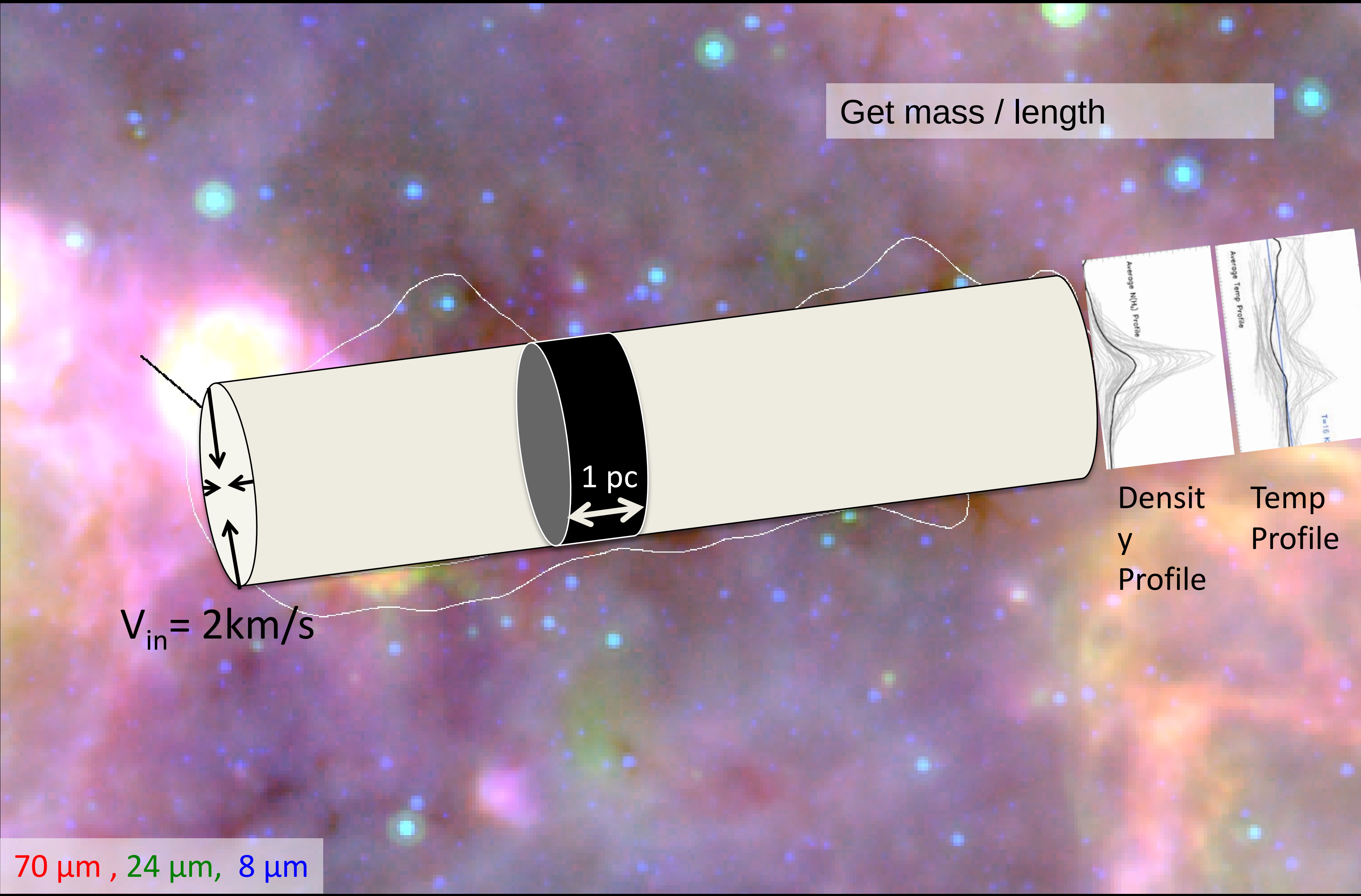

Add the density and temperature profiles
v_{in}
Densit
y
Profile
Temp
Profile
70 µm , 24 µm, 8 µm

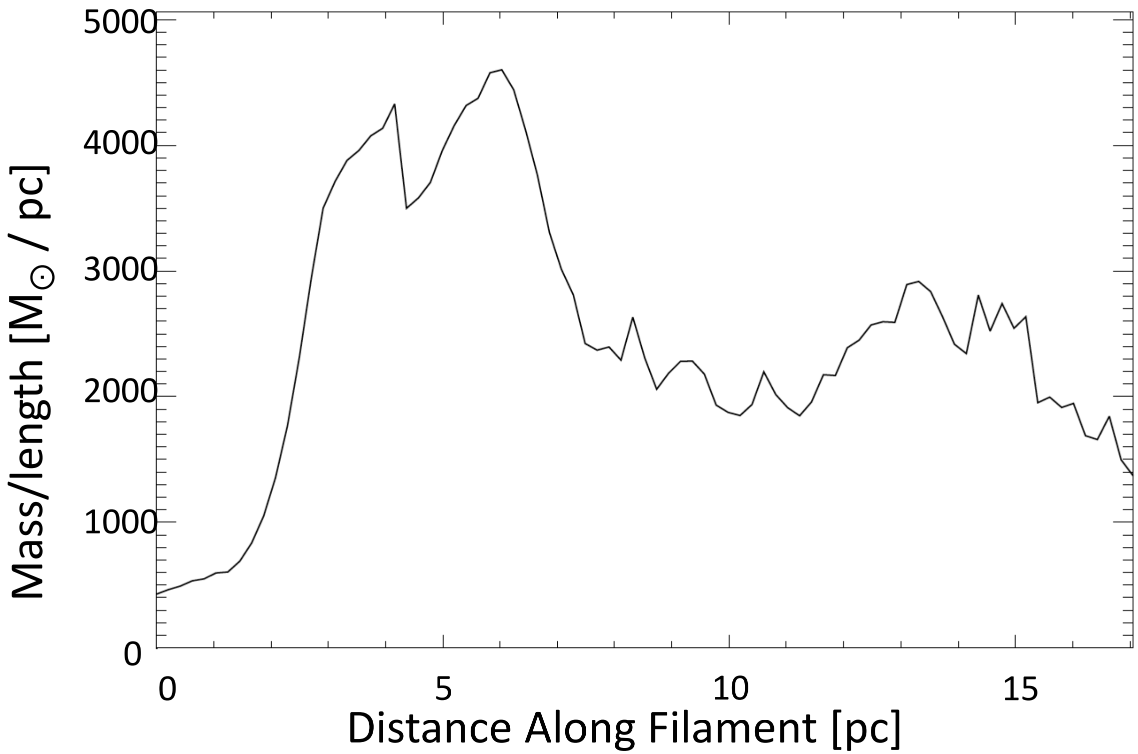


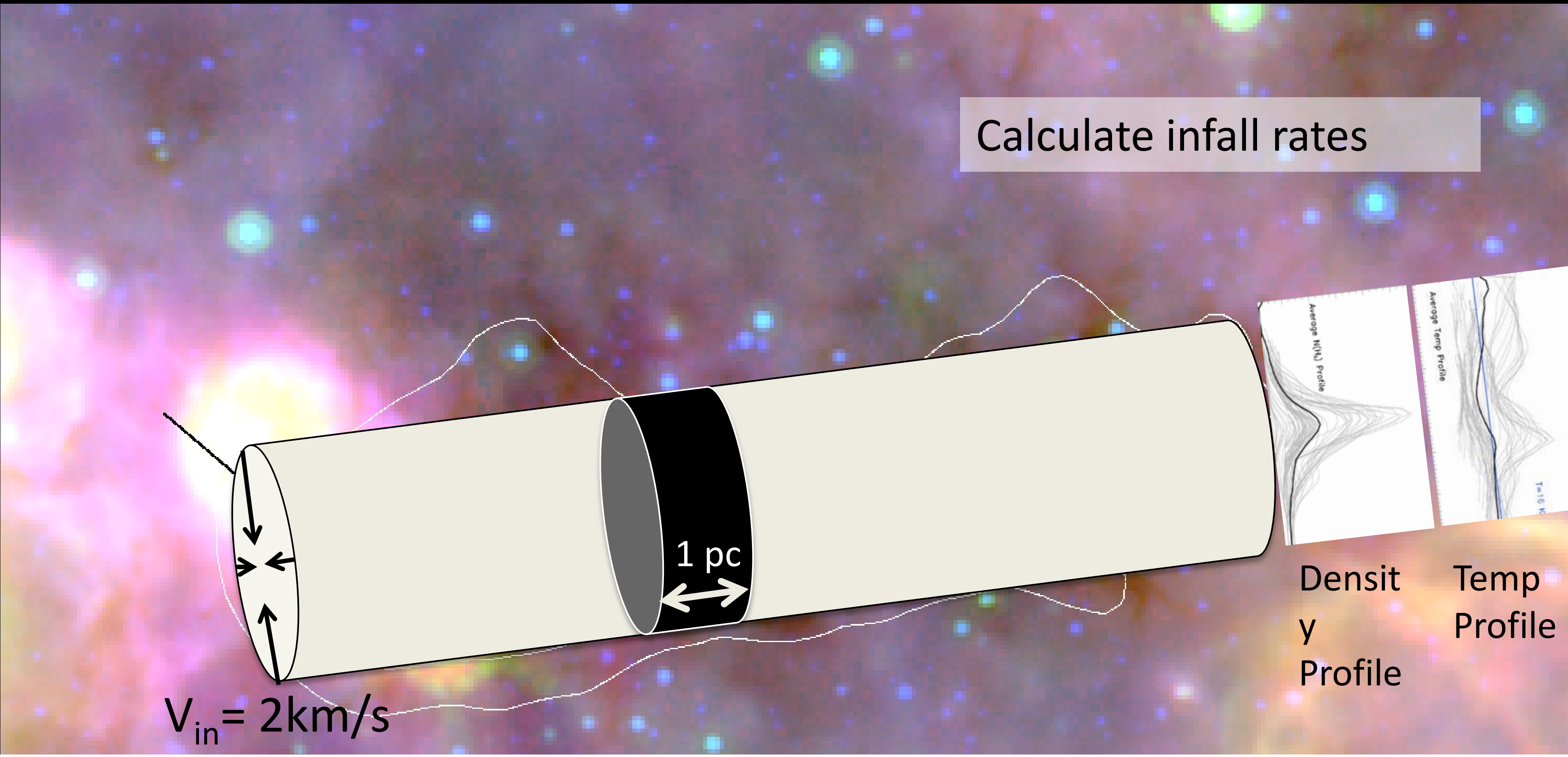
point11
v_{in} = 2 km/s
HCO^+ (1–0)
$H^{13}CO^+$ (1–0)
Intensity [K]
Velocity [km/s]
MOLLIE fit
Average N(H₂)
N(H₂) [x 10²² cm⁻²]
Radius [pc]
Beam
T=16 K
[K]
m the
rflat
T =
16 K



V_{in}= 2km/s
Densit
y
Profile
Temp
Profile
70 μm , 24 μm, 8 μm


Get mass / length
1 pc
V_{in}= 2km/s
Density Profile
Temp Profile
70 µm , 24 µm, 8 µm


5000
4000
3000
2000
1000
0
0
5
10
15
Mass/length [$M_\odot$ / pc]
Distance Along Filament [pc]

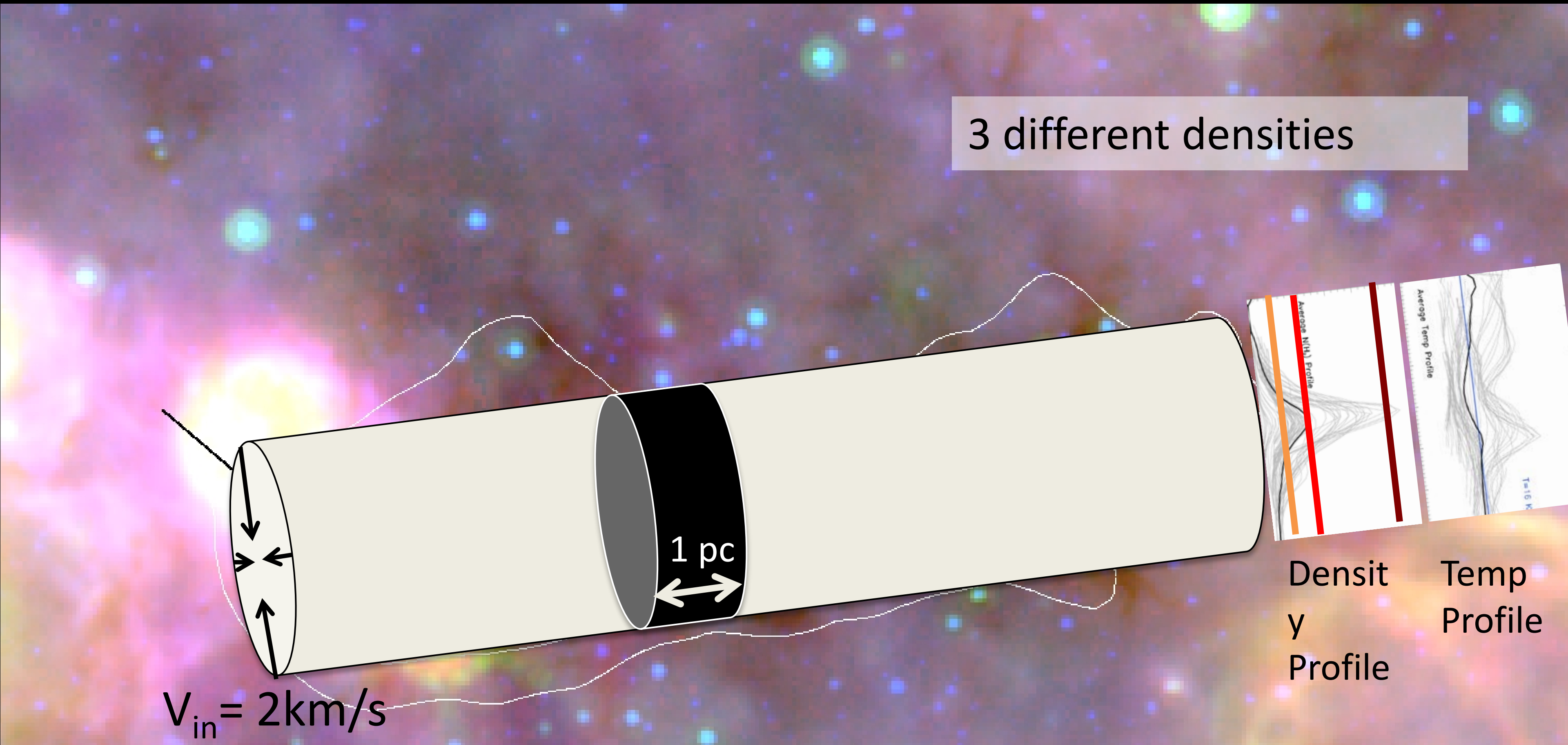


$$\dot{M} = \rho\sigma v = \left[\frac{n}{10^4\ cm^{-3}}\right]\left[\frac{\sigma}{pc^2}\right]\left[\frac{v}{kms^{-1}}\right] 700\ M_\odot/Myr$$

Density from Plummer fit

Surface area of cylinder

HCO^+ line profile fit



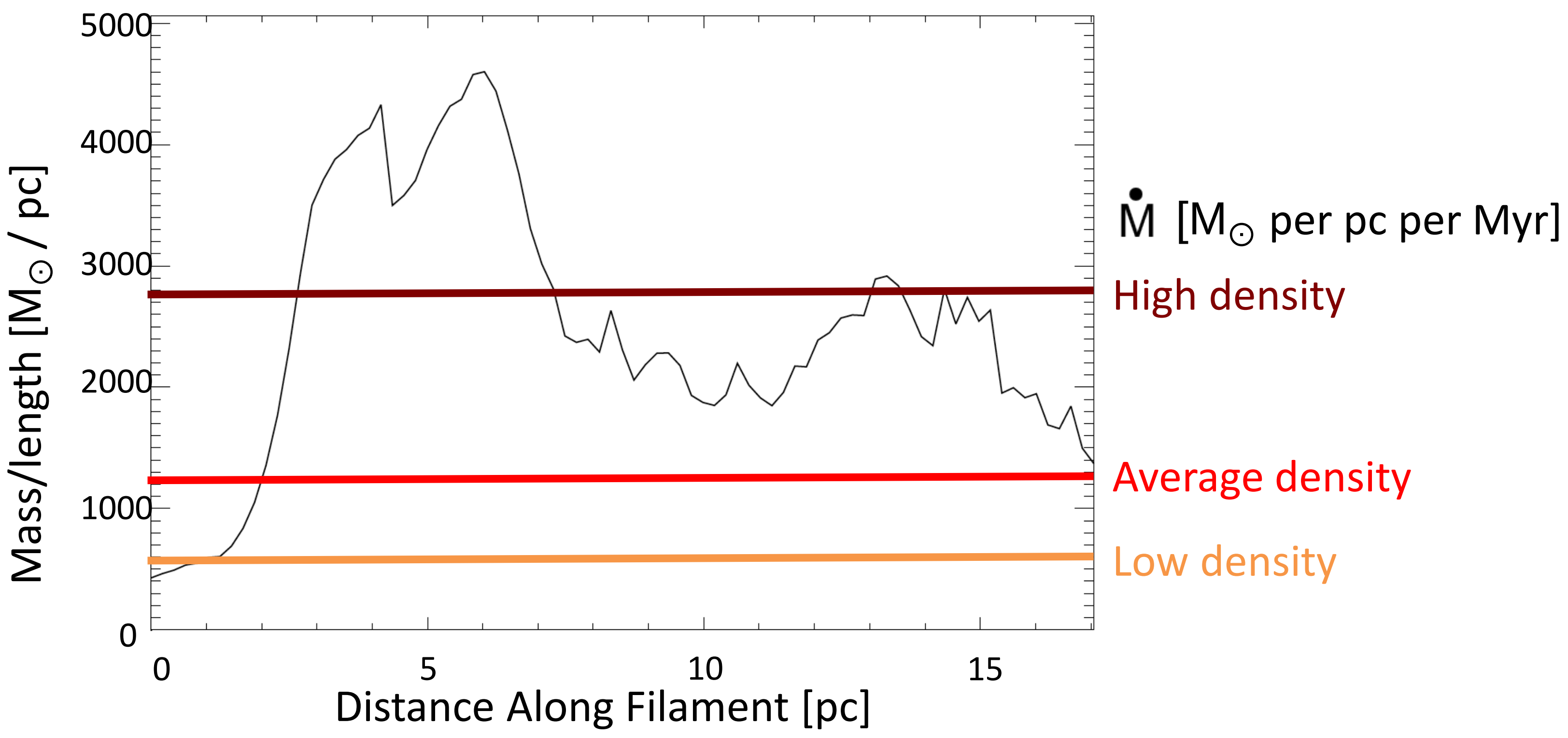
$$\dot{\mathrm{M}} = \rho\sigma \mathrm{v} = \left[\frac{\mathrm{n}}{10^4\ \mathrm{cm}^{-3}}\right]\left[\frac{\sigma}{\mathrm{pc}^2}\right]\left[\frac{\mathrm{v}}{\mathrm{kms}^{-1}}\right] 700\ \mathrm{M}_\odot/\mathrm{Myr}$$

Density from Plummer fit

Surface area of cylinder

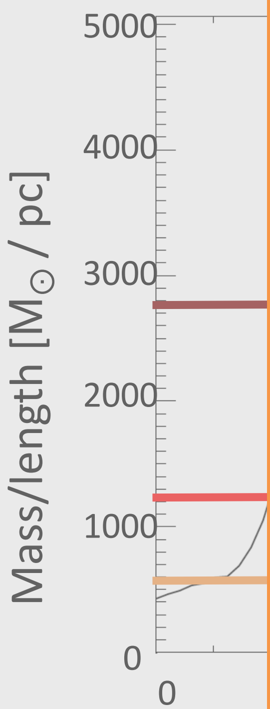
HCO^+ line profile fit

Infall Rates



Battersby et al., in prep. See also Peretto et al. (2013), SDC335 Mass infall rate of 700 $M_\odot$ / Myr.

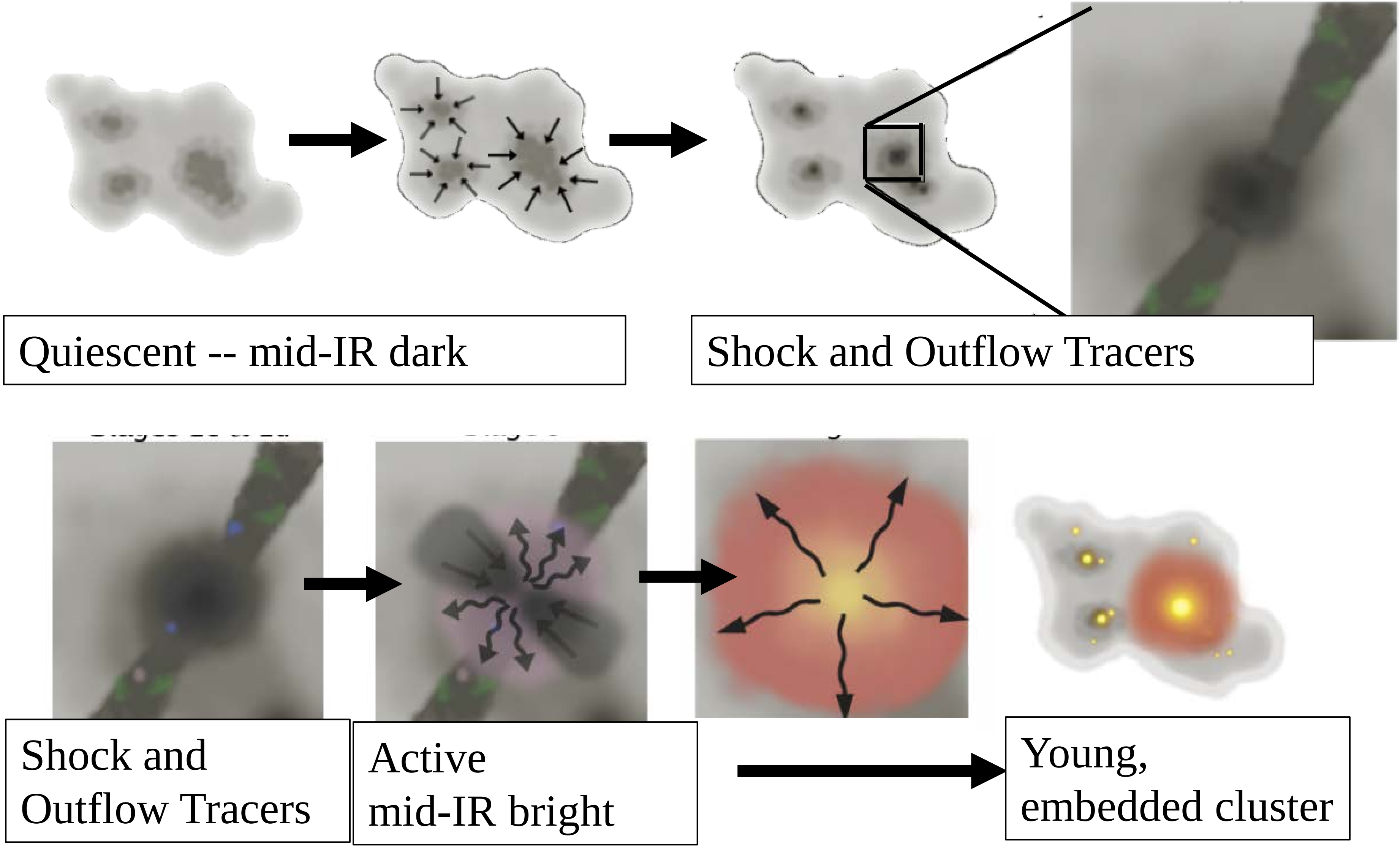
Infall Rates



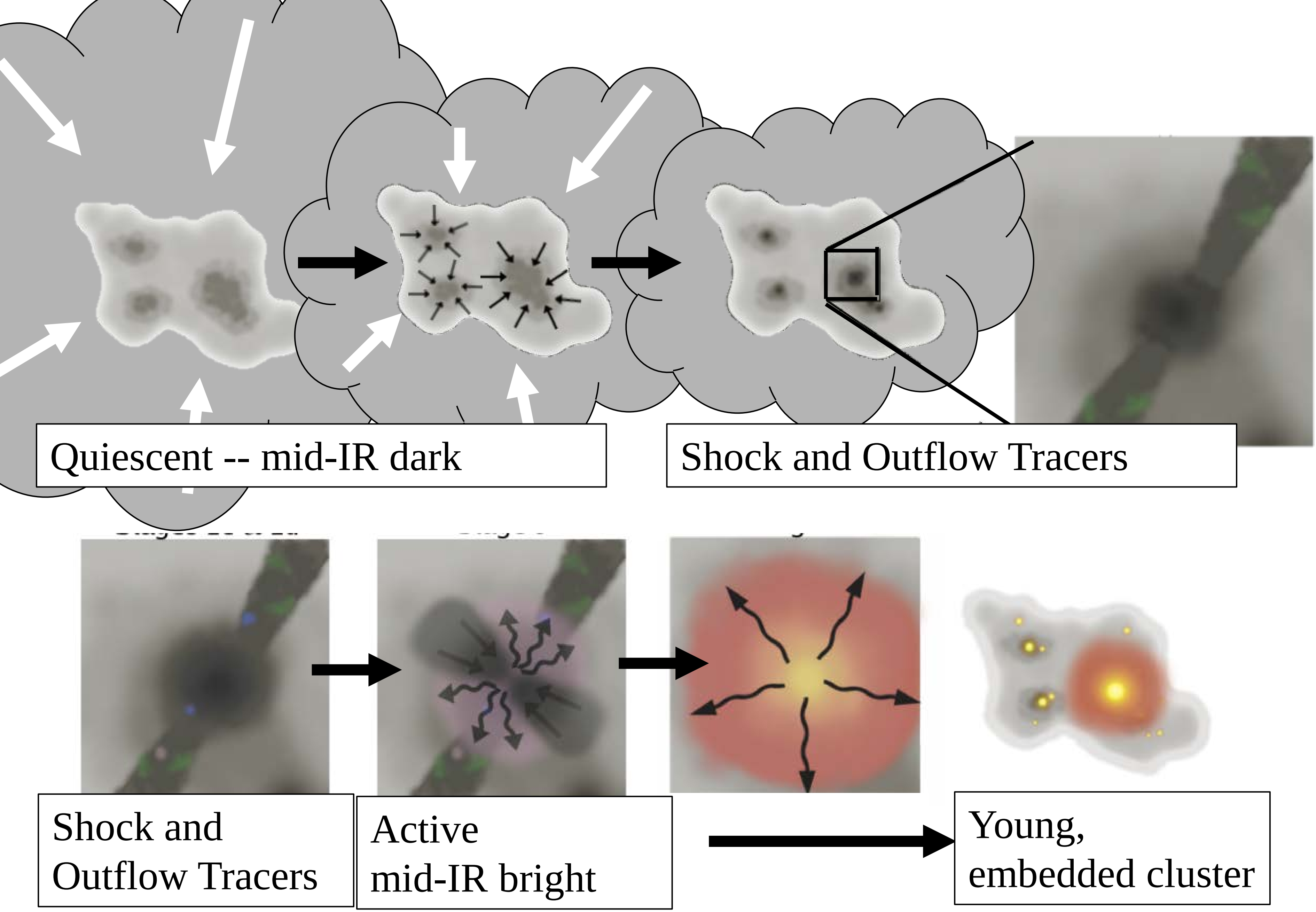
- What is the infall speed?
  - ~ 2 km/s
- How much material is infalling?
  - ~1000 $M_\odot$ / pc / Myr
- Is it important?
  - Yes!

Battersby et al., in prep. See also Peretto et al. (2013), SDC335 Mass infall rate of 700 $M_\odot$ / Myr.

Evolution

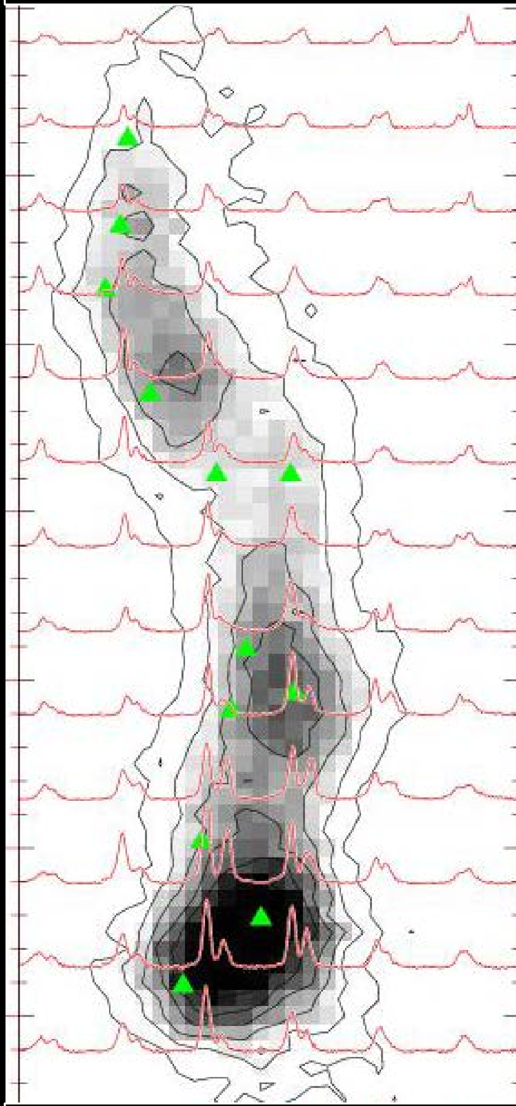


Battersby et al. 2010

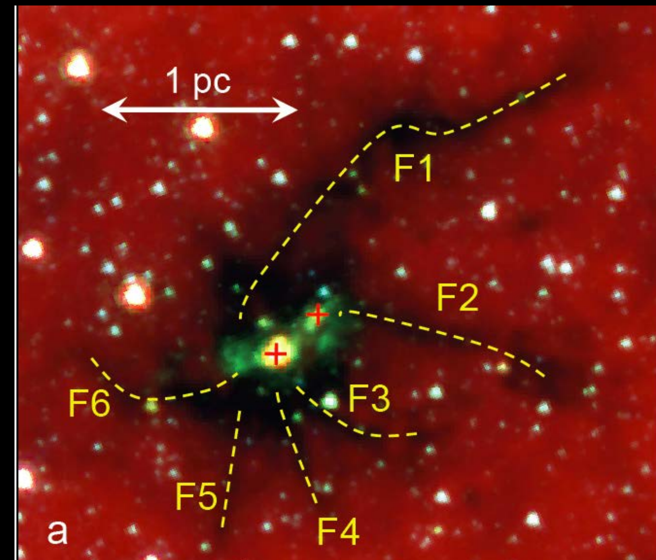


(e.g. Longmore et al. (2011); Peretto et al. 2006, 2013; Schneider et al. 2010; Barnes et al. 2010; Galván-Madrid et al. 2010; Liu et al. 2012)

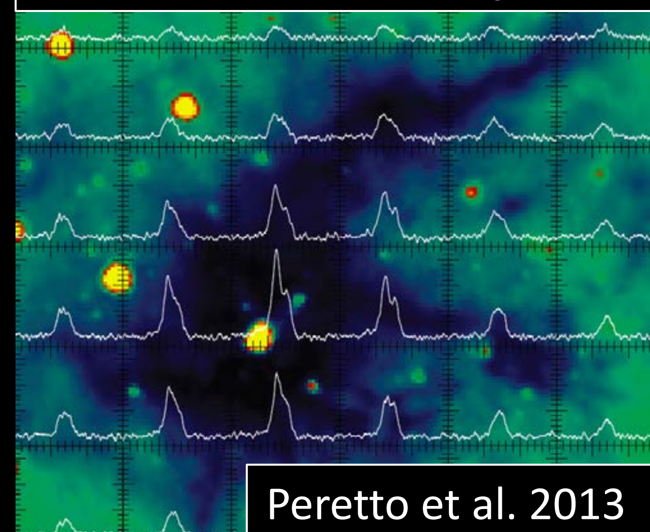
DR21 – Schneider et al. (2010)



▲ mm-continuum sources Motte et al. (2007)

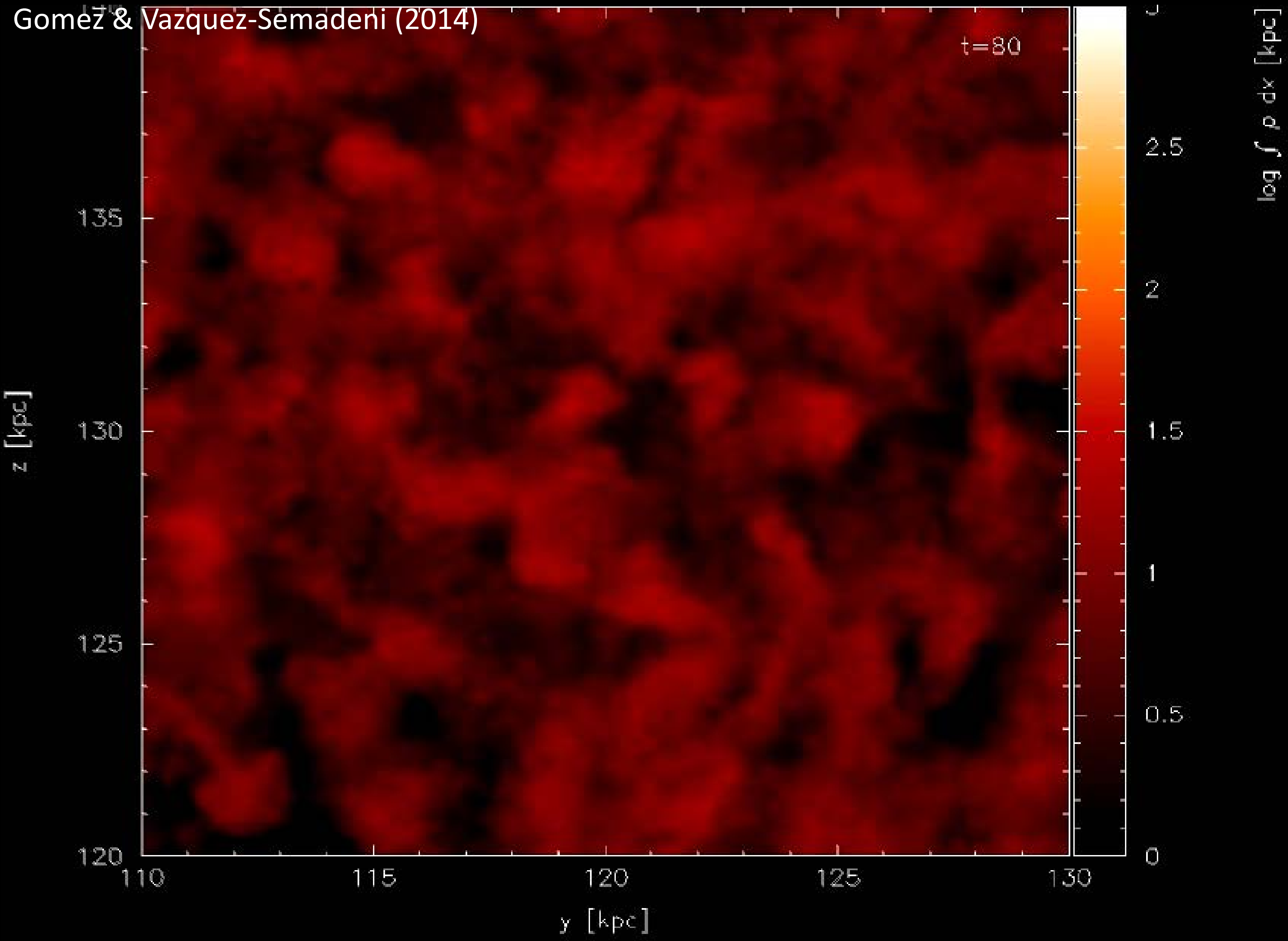


SDC335, 5500 $M_\odot$ total, accreting 700 - 2500 $M_\odot$ / Myr



Peretto et al. 2013

Gomez & Vazquez-Semadeni (2014)



Conclusions

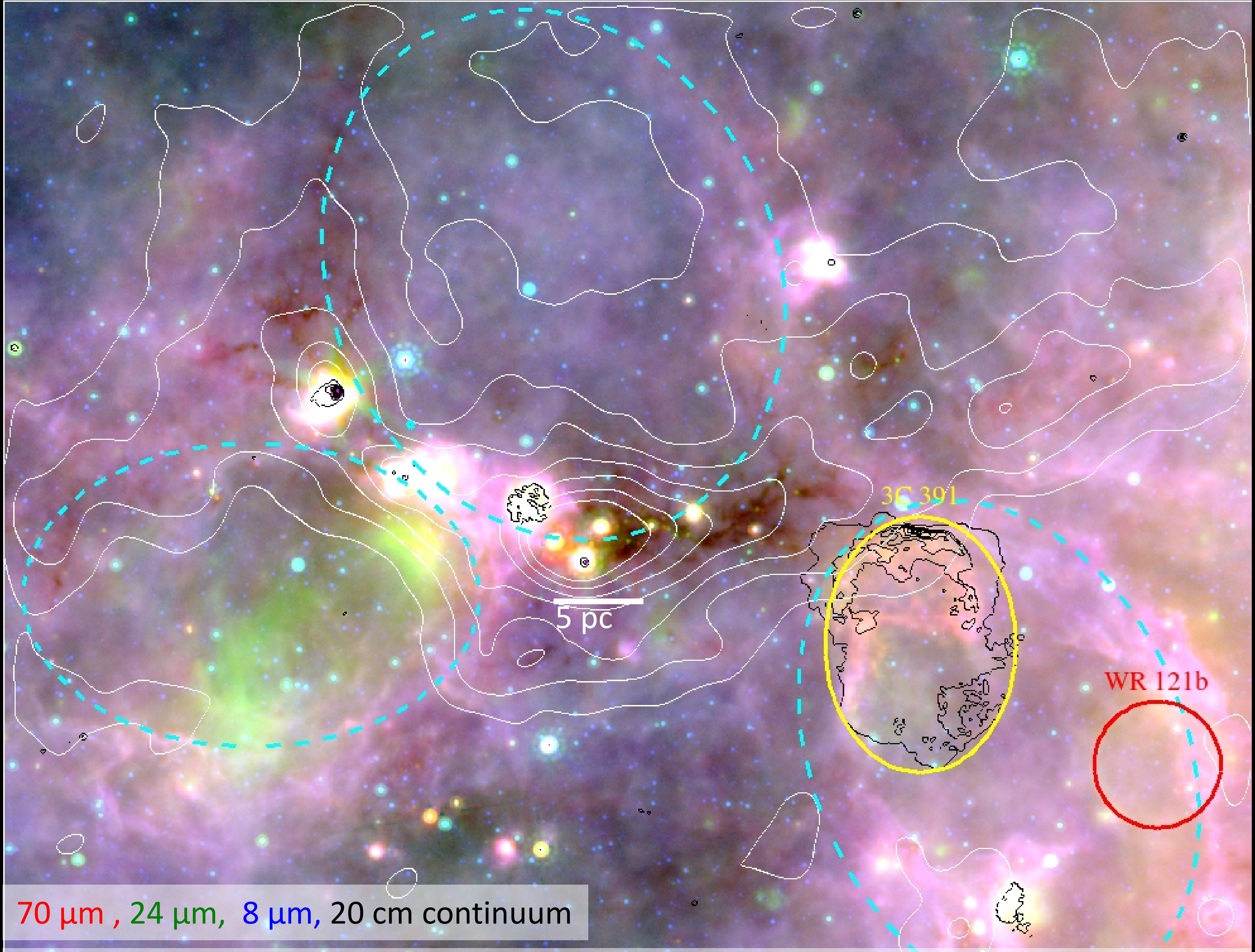
We detect large-scale infall toward a massive molecular filament

- Use physical model (plummer profile, p=2, r_flat = 0.5 pc, Flat temperature distribution at 16 K) to inform radiative transfer
- Derive infall speed of ~ 2 km/s, translates to several 1000 $M_\odot$ / pc / Myr or 50% - 2x total mass.

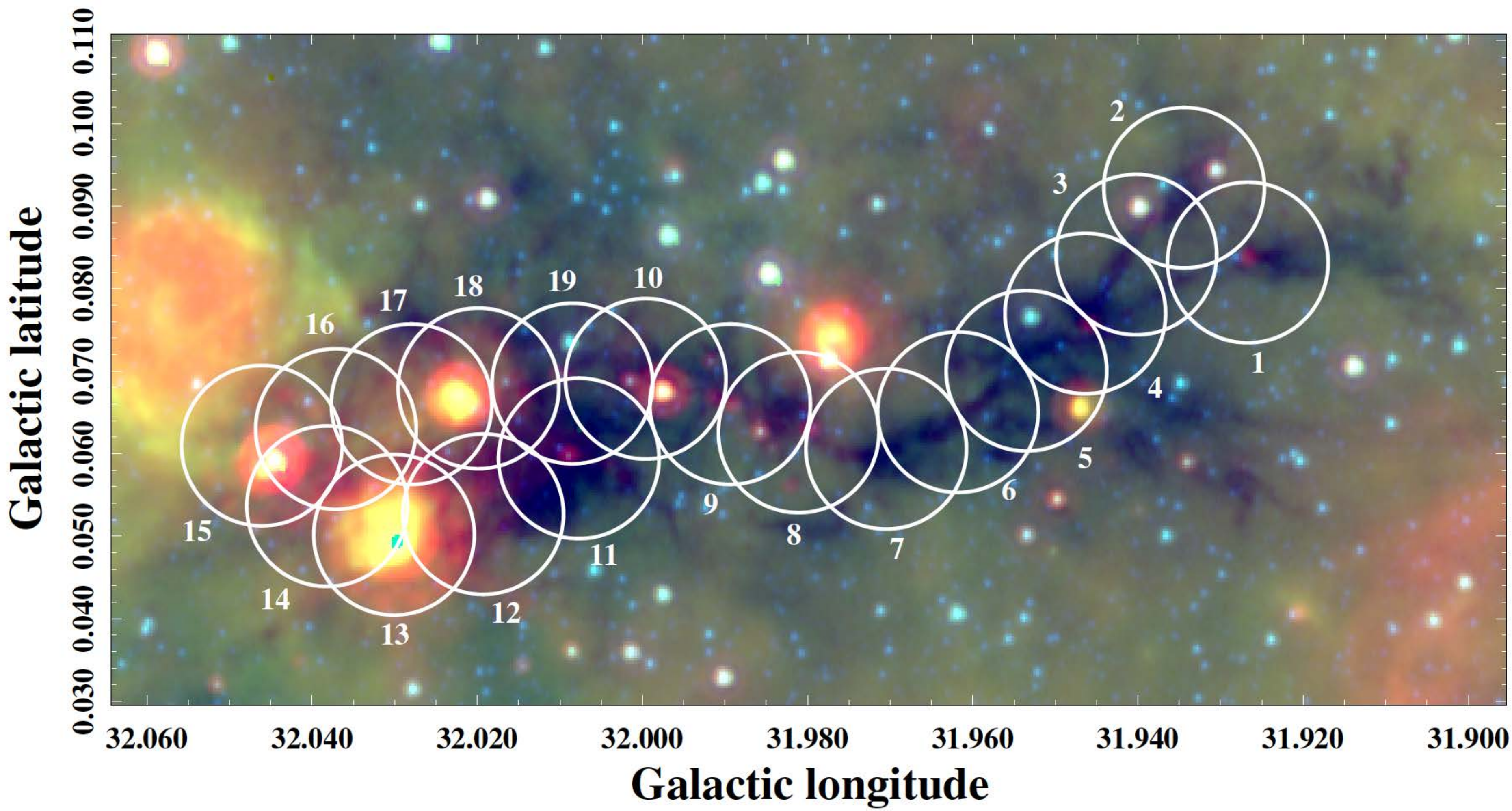
An appreciable amount of mass is accreting on larger scales

Implications:

- Clumps can grow as they evolve
- Central densities should rise
- The formation of the densest star clusters may occur in regions where mass continues to accrete
- Star clusters form stars in early burst which may be fueled by new gas



From Battersby et al. 2014b; Hi-GAL: Molinari et al. (2011), MIPSGAL: Carey et al. (2009), GLIMPSE: Benjamin et al. (2003), 20 cm from MAGPIS: White et al. (2005), Helfand et al. (2006), GRS ^{13}CO from Jackson et al. (2006)


Galactic latitude
0.110
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
Galactic longitude
32.060
32.040
32.020
32.000
31.980
31.960
31.940
31.920
31.900
1
2
3
4
5
6
7
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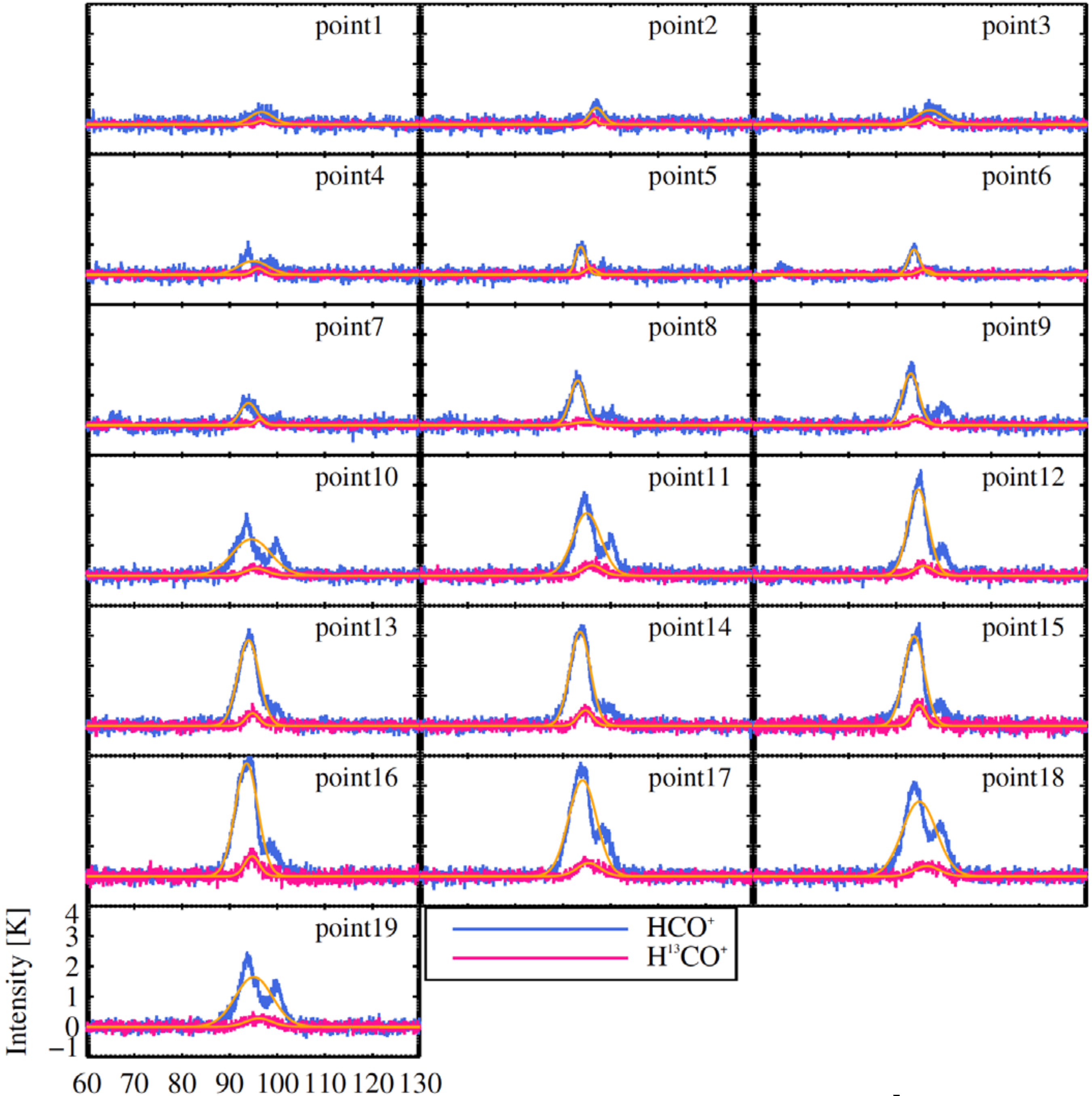
15
16
17
18
19



G32.03+0.05, Battersby, Myers, et al. in prep