HOMEWRECKERS

Stars disturbing their ancestral homes

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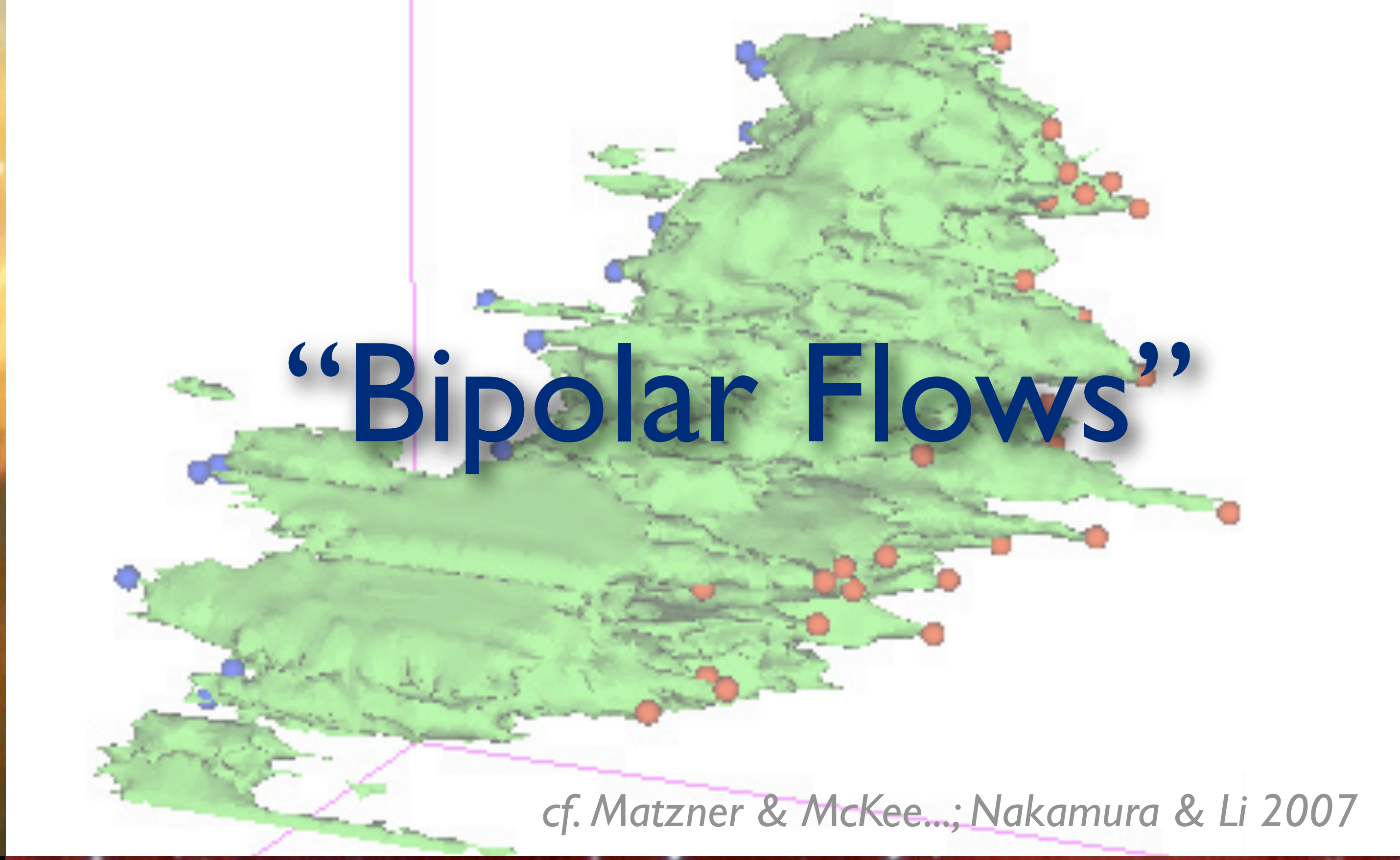
**=also Harvard Initiative in Innovative Computing*

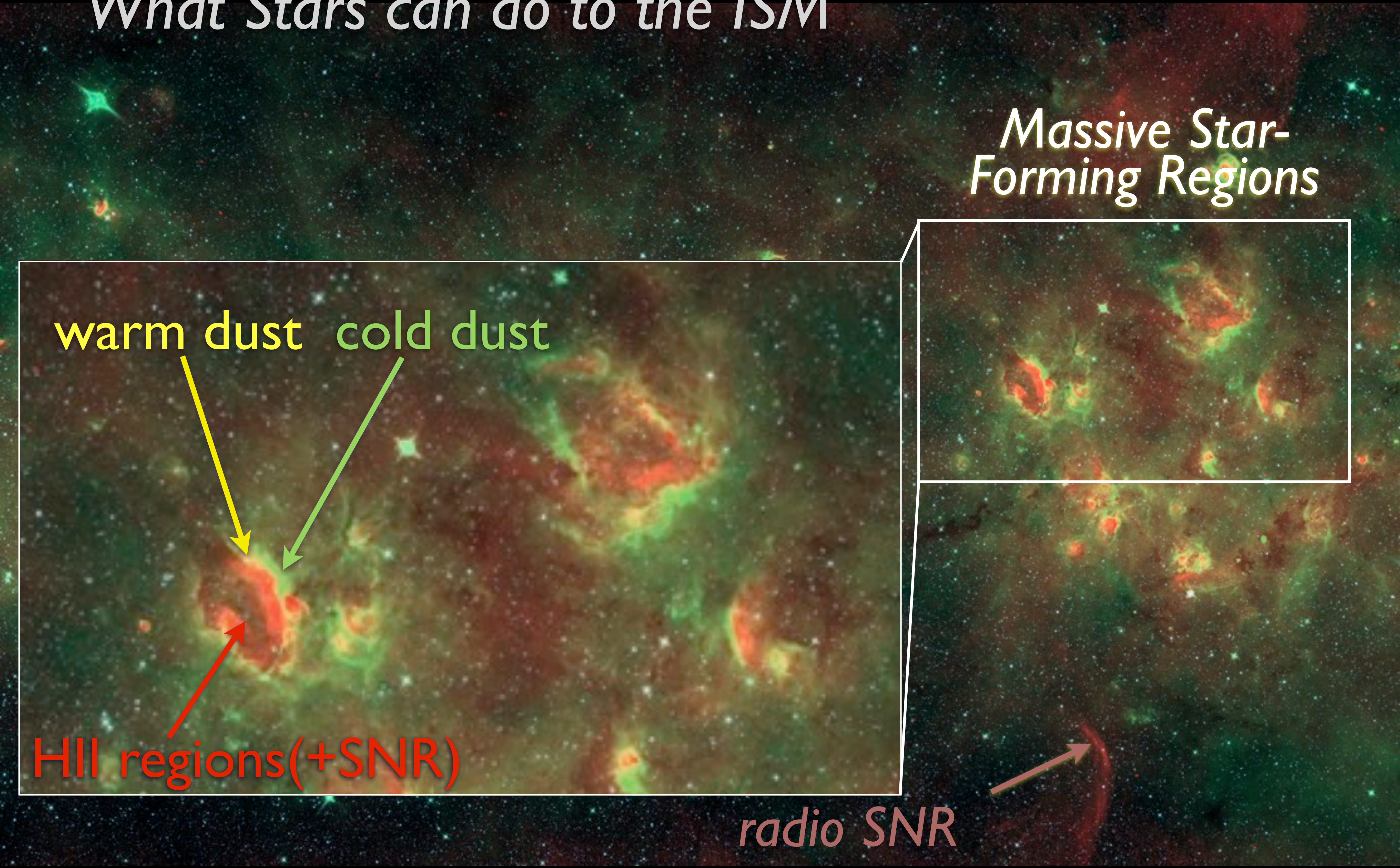

Motivation


“Bipolar Flows”
cf. Matzner & McKee...; Nakamura & Li 2007


“Shells”
cf. Quillen et al. 2005; Churchwell et al....; Beaumont & Williams 2009

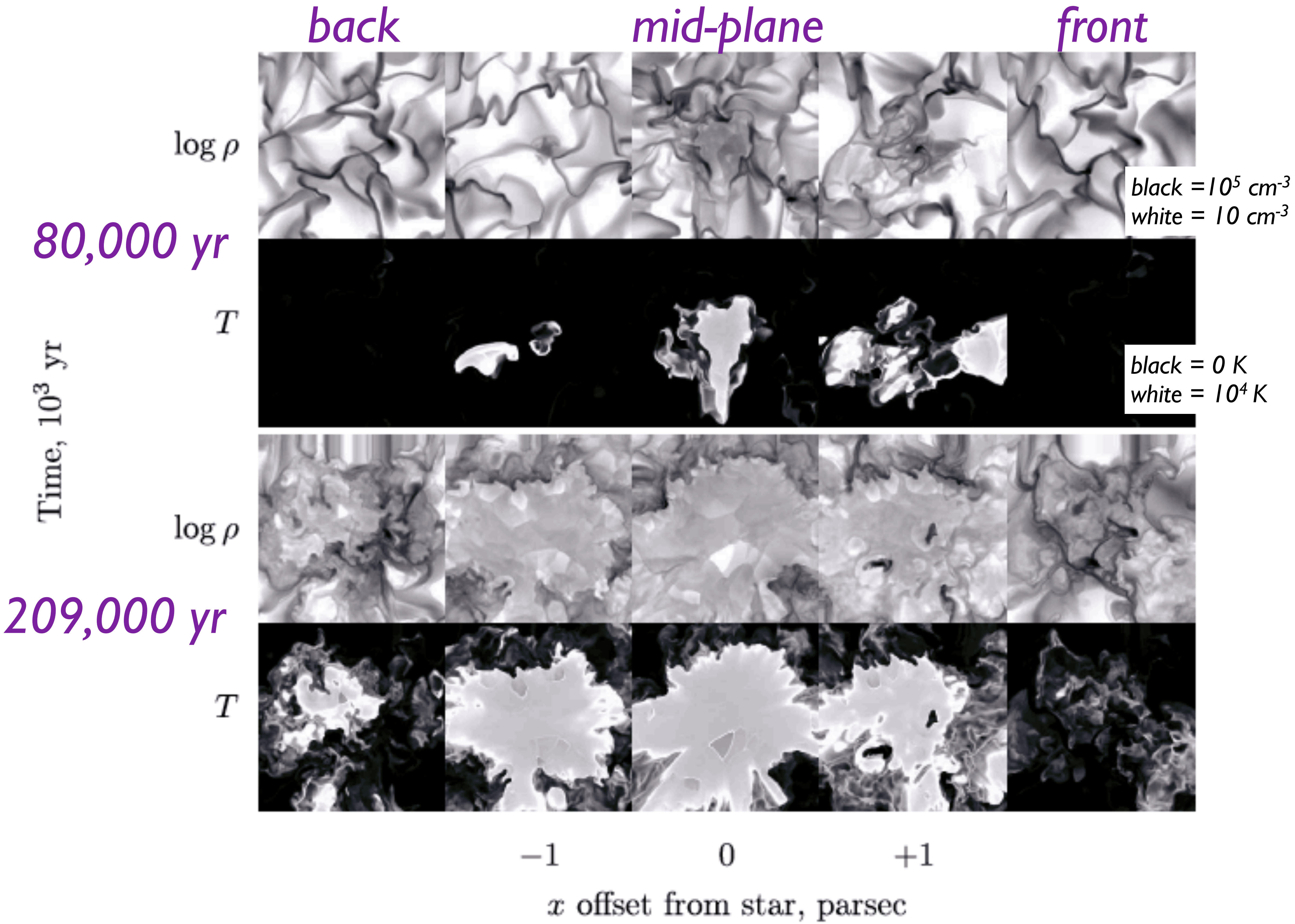

HOMEWRECKERS?

What Stars can do to the ISM



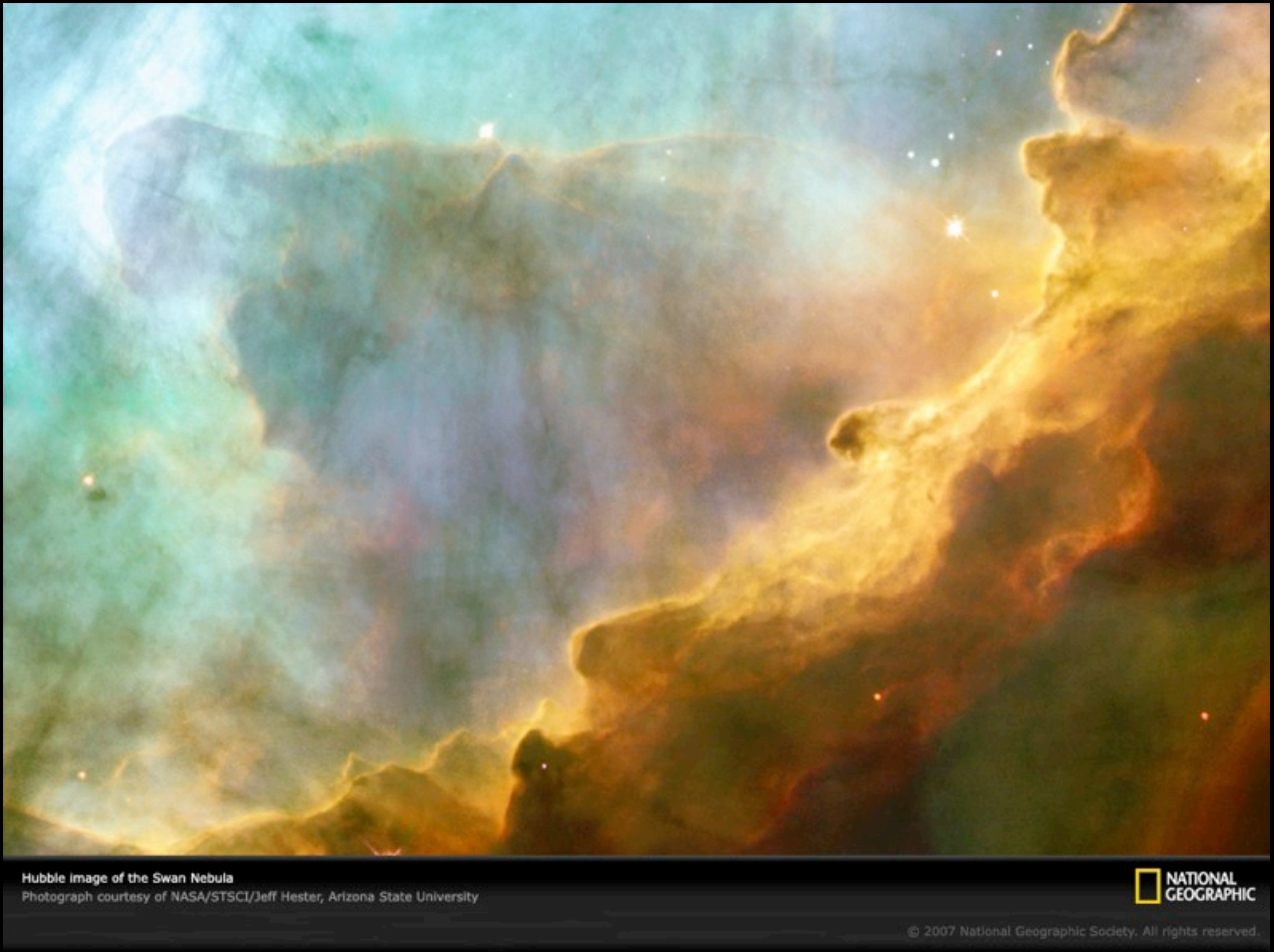
20 cm VLA from MAGPIS (Helfand et al. 2006) & MIR from Spitzer GLIMPSE (see Churchwell et al.)
3.6, 4.5, 8.0, 20cm *(Luptonized, see Lupton et al. 2004)*
image "height" is 1.6 degrees (e.g. 140 pc at 5 kpc)

Evolution of an HII Region in a Turbulent Medium



from S.J. Arthur 2007

M17


Hubble image of the Swan Nebula
Photograph courtesy of NASA/STSCI/Jeff Hester, Arizona State University
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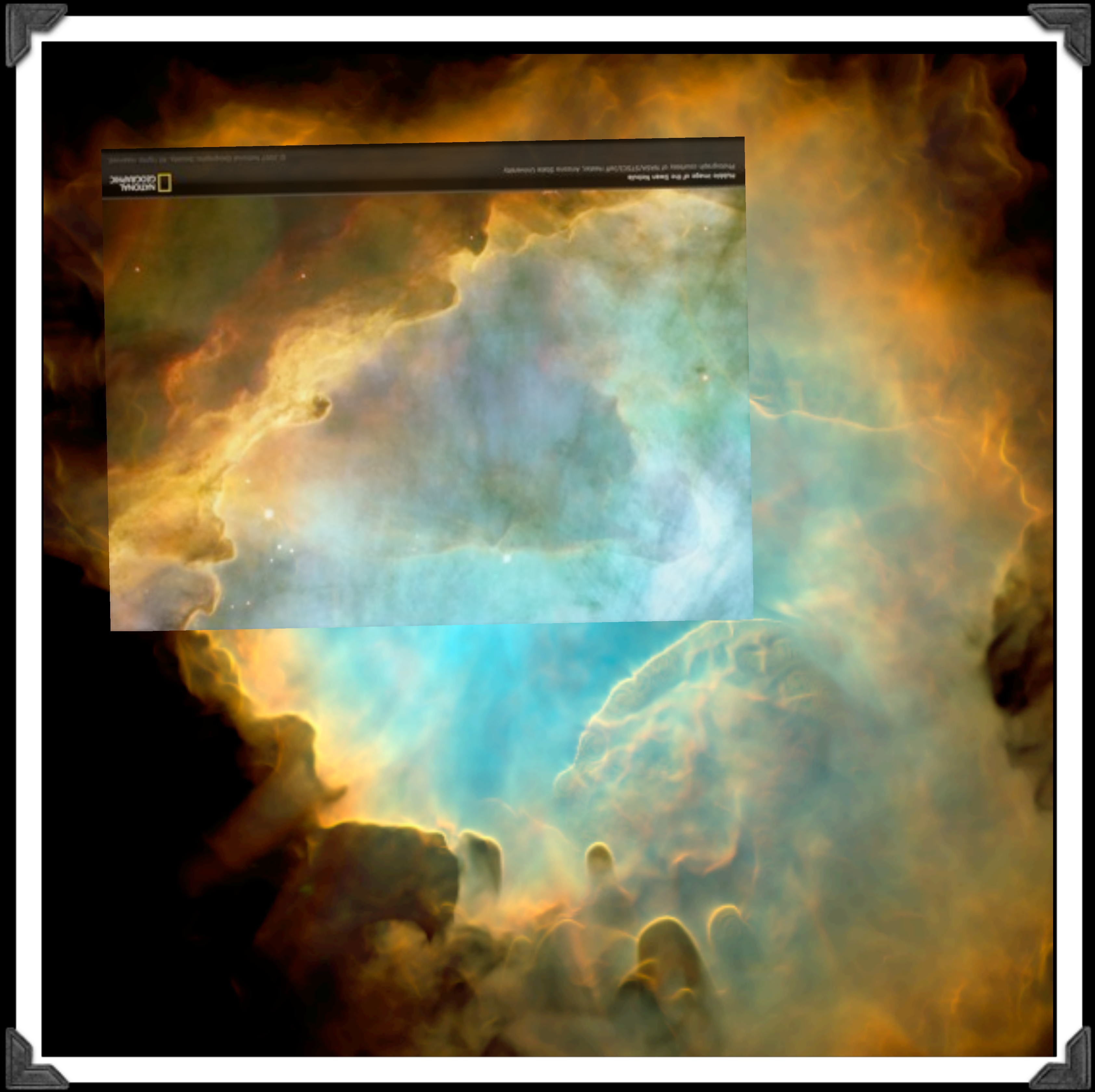
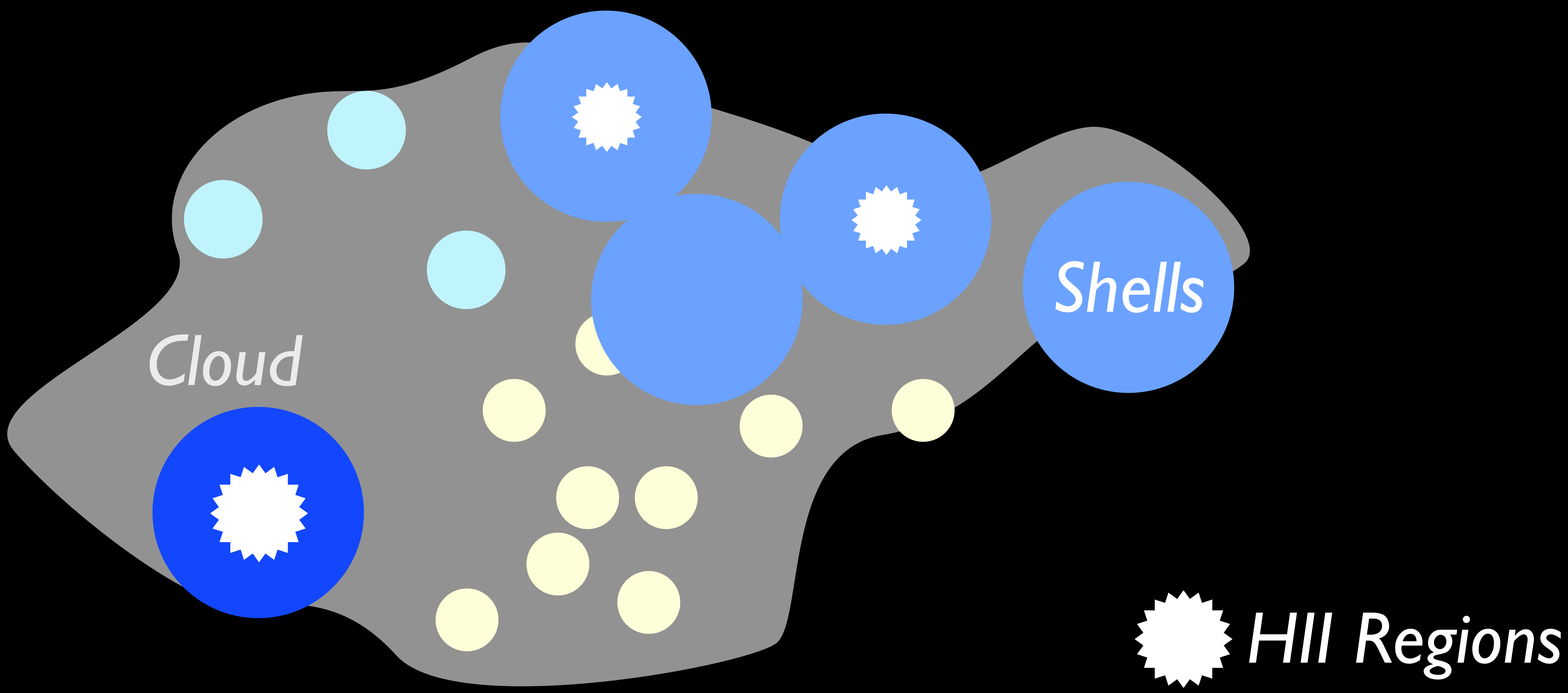
This is not real...but it could be.



Synthetic [OIII], Hα and [NII] emission-line image from a 512^3 numerical simulation: Mellema, Henney, Arthur & Vàzquez-Semadeni 2009

Is it only O stars & HII regions that "matter"?

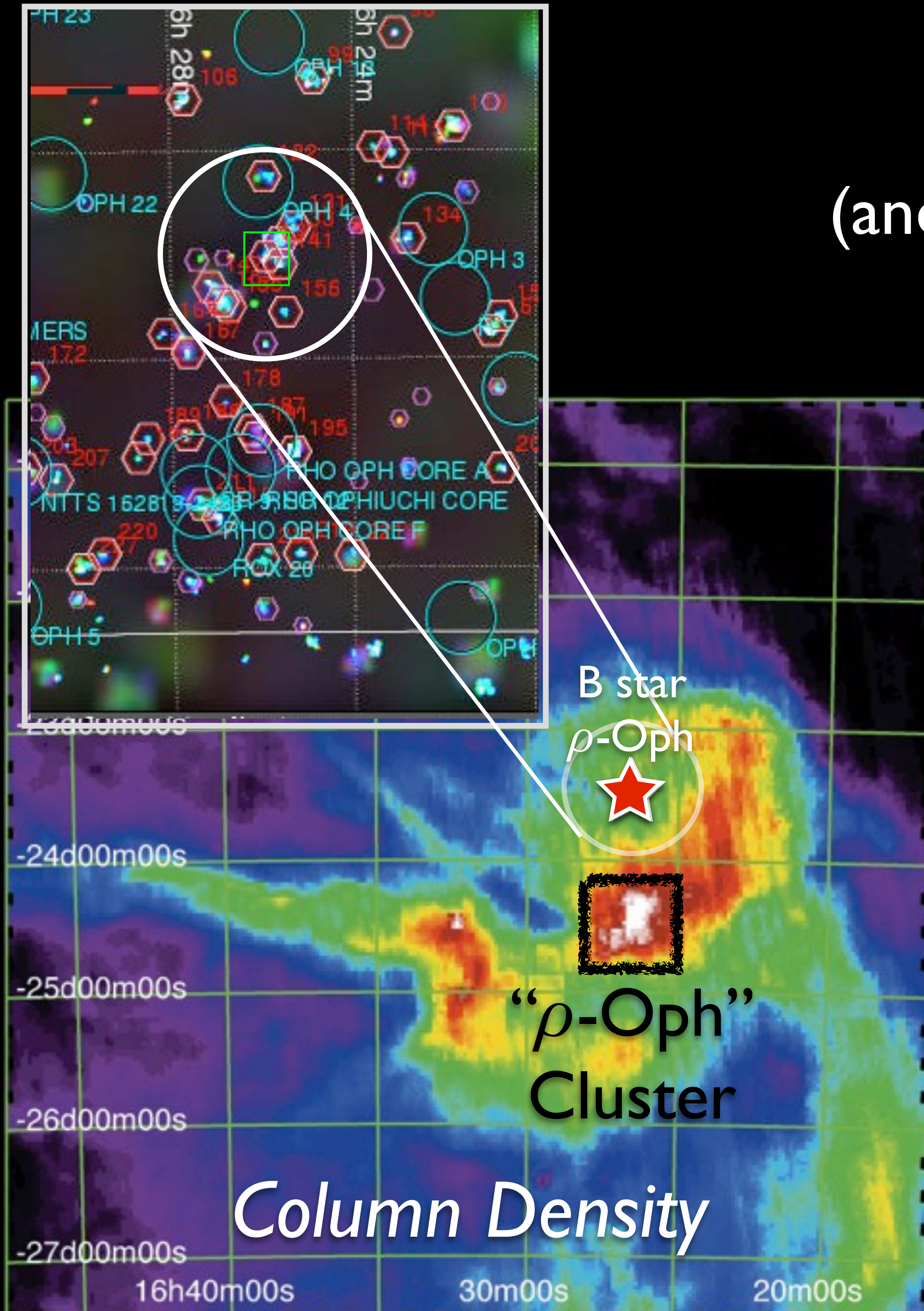


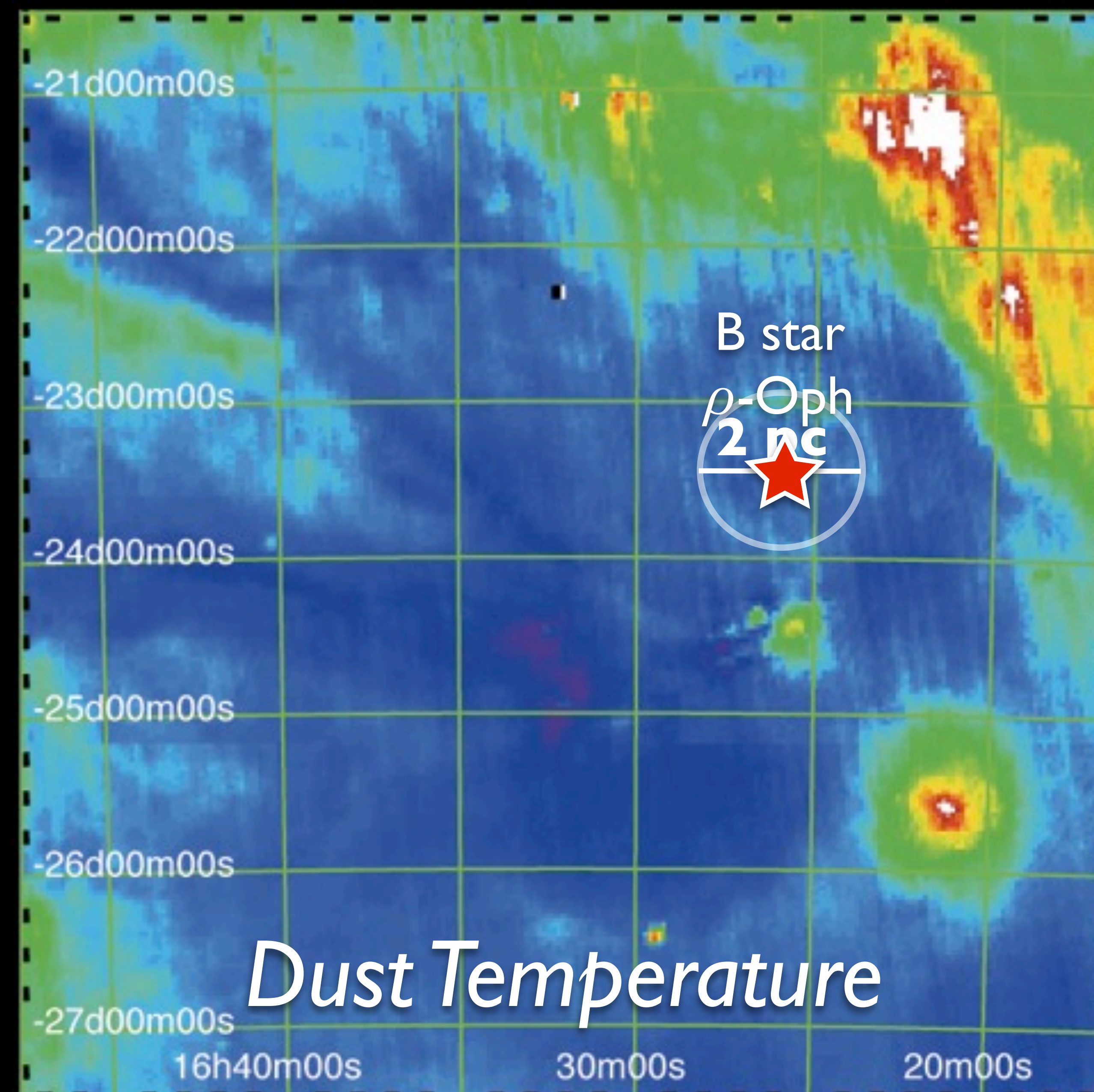
IMF O:B:A:F populations would be: 1:50:300:750.

Field O:B:A:F populations: 1:4e3:2e4:1e5.

ρ-Oph is a B*

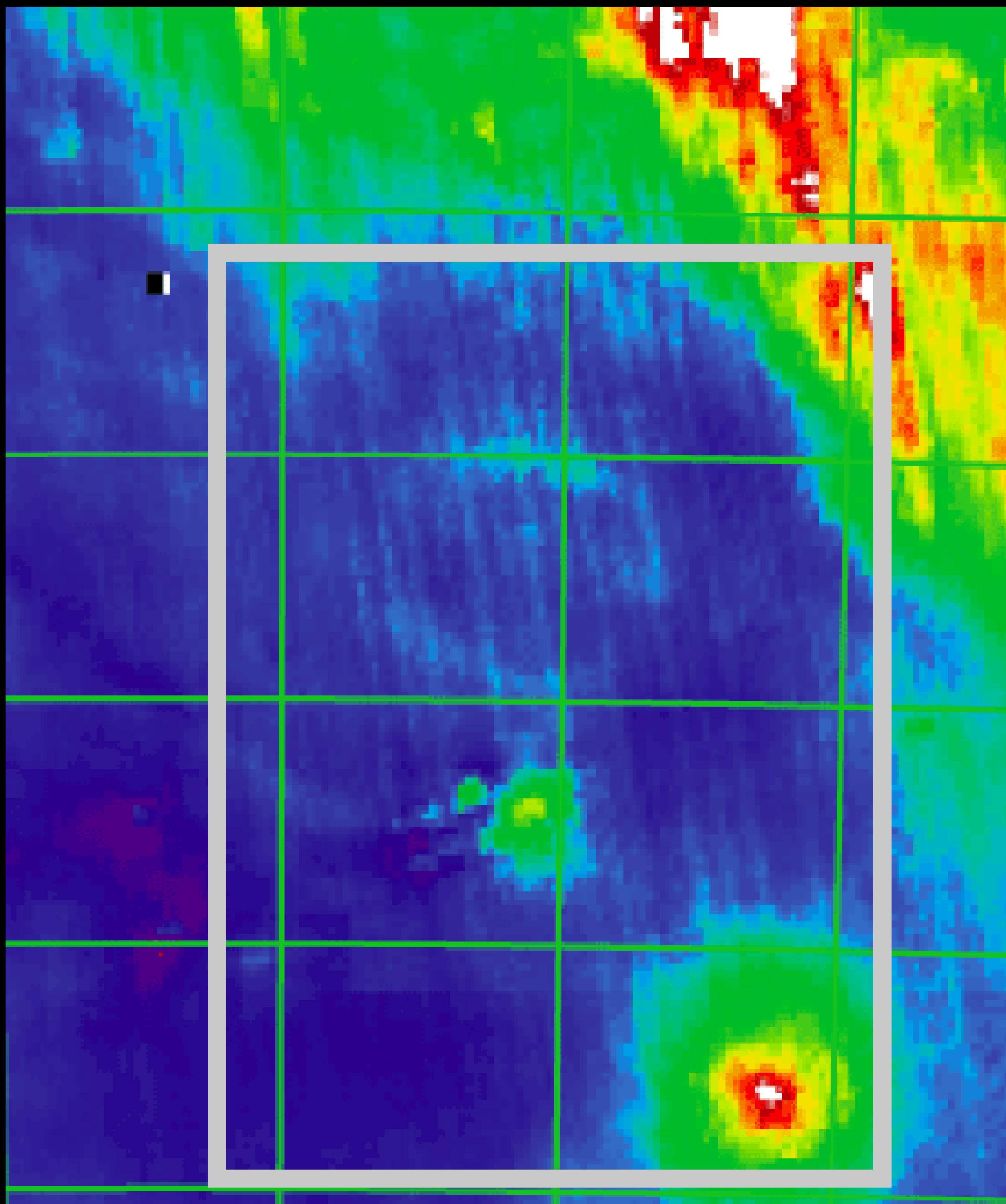
(and it's NOT in the "ρ-Oph" Cluster!)

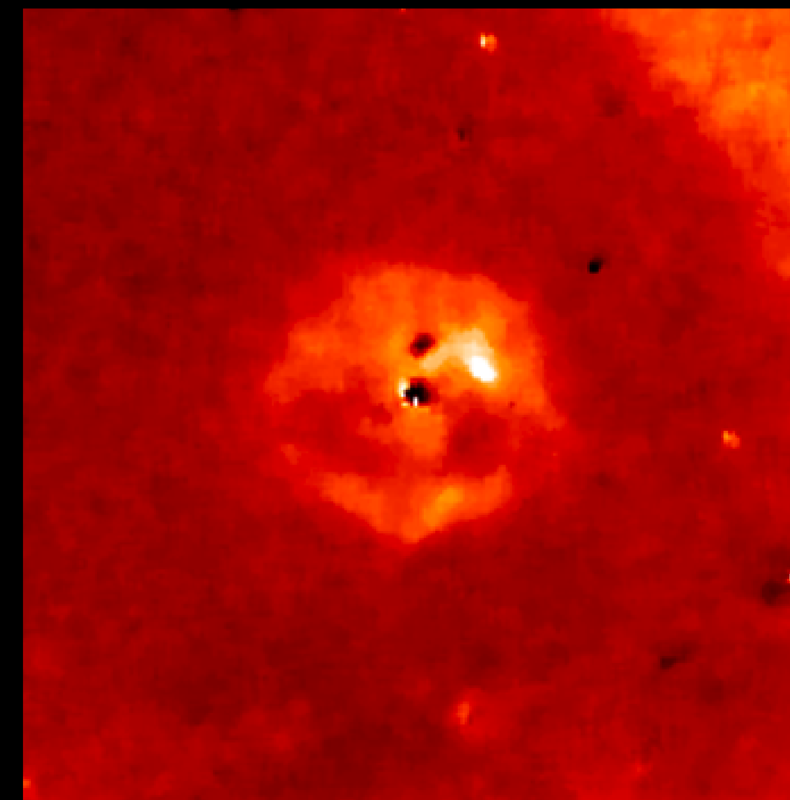


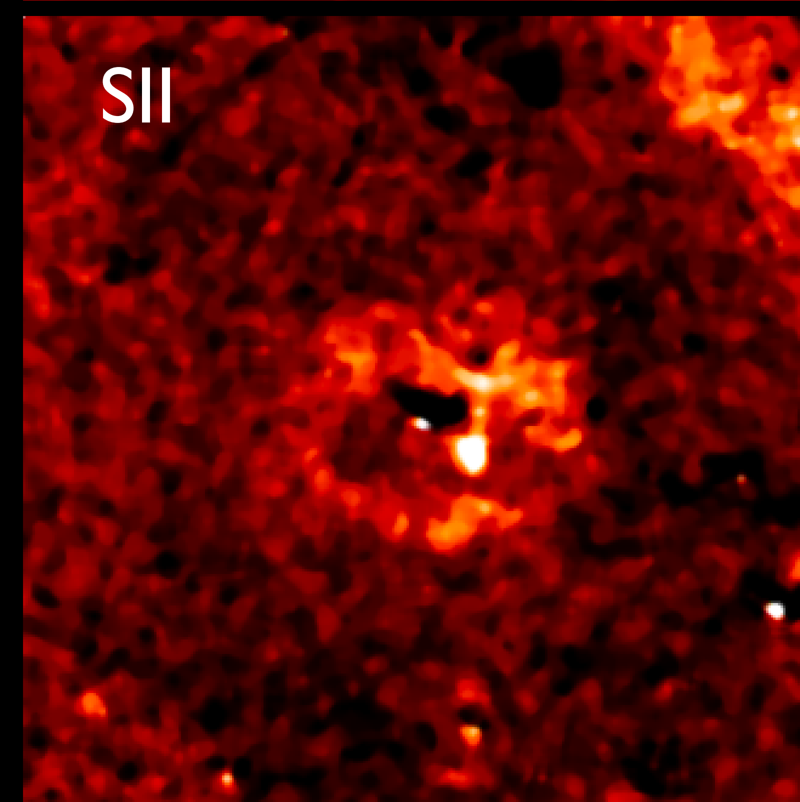


see Schnee, Ridge, Goodman & Li 2005.

Ionized Gas in the Ophiuchus Smoke Shell

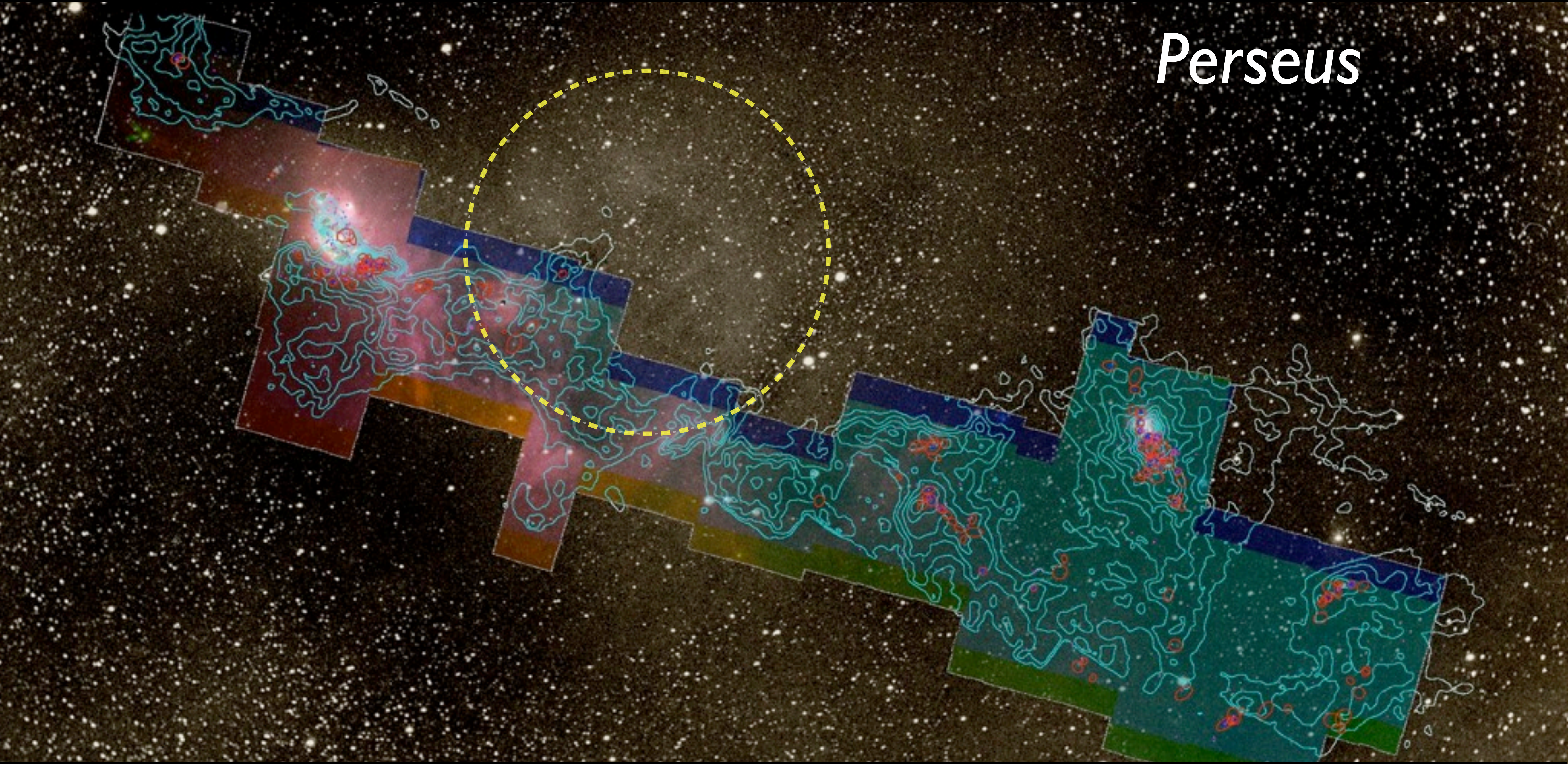






SHASSA Data courtesy of John Gaustad

COMPLETE = **CO**ordinated **M**olecular **P**robe **L**ine **E**xtinction **T**hermal **E**mission Survey of Star-Forming Regions



COMPLETE Collaborators, 2010:

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Héctor Arce (Yale)

Michelle Borkin (Harvard SEAS/IIC)

Paola Caselli (Leeds, UK)

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Jonathan Foster (B.U.)

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Doug Johnstone (HIA, Canada)

Jens Kauffmann (JPL/Caltech)

Helen Kirk (CfA)

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Stella Offner (CfA)

Jaime Pineda (CfA, PhD Student)

Thomas Robitaille (CfA)

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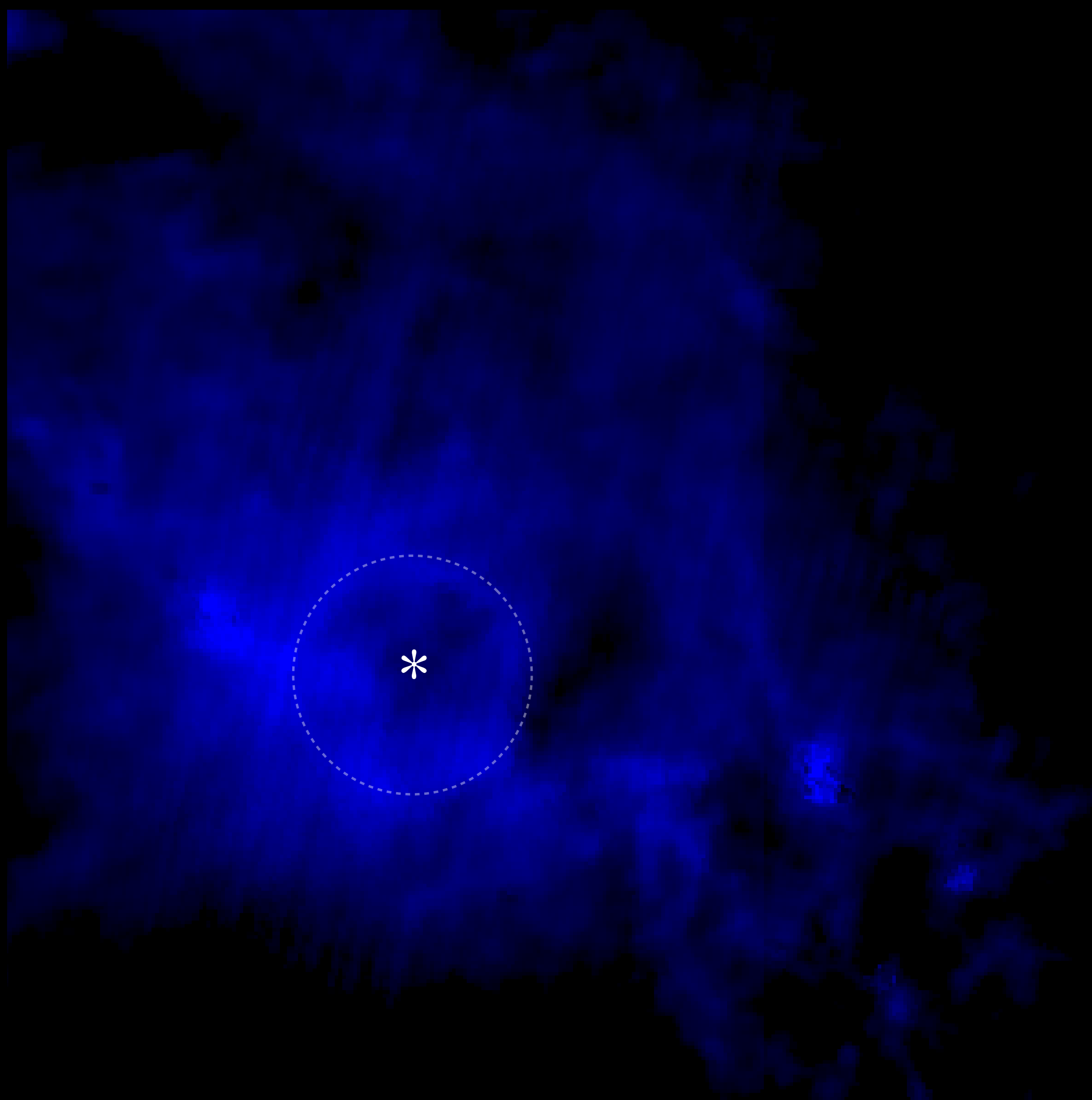
Rahul Shetty (ITA Heidelberg)

Scott Schnee (HIA Victoria)

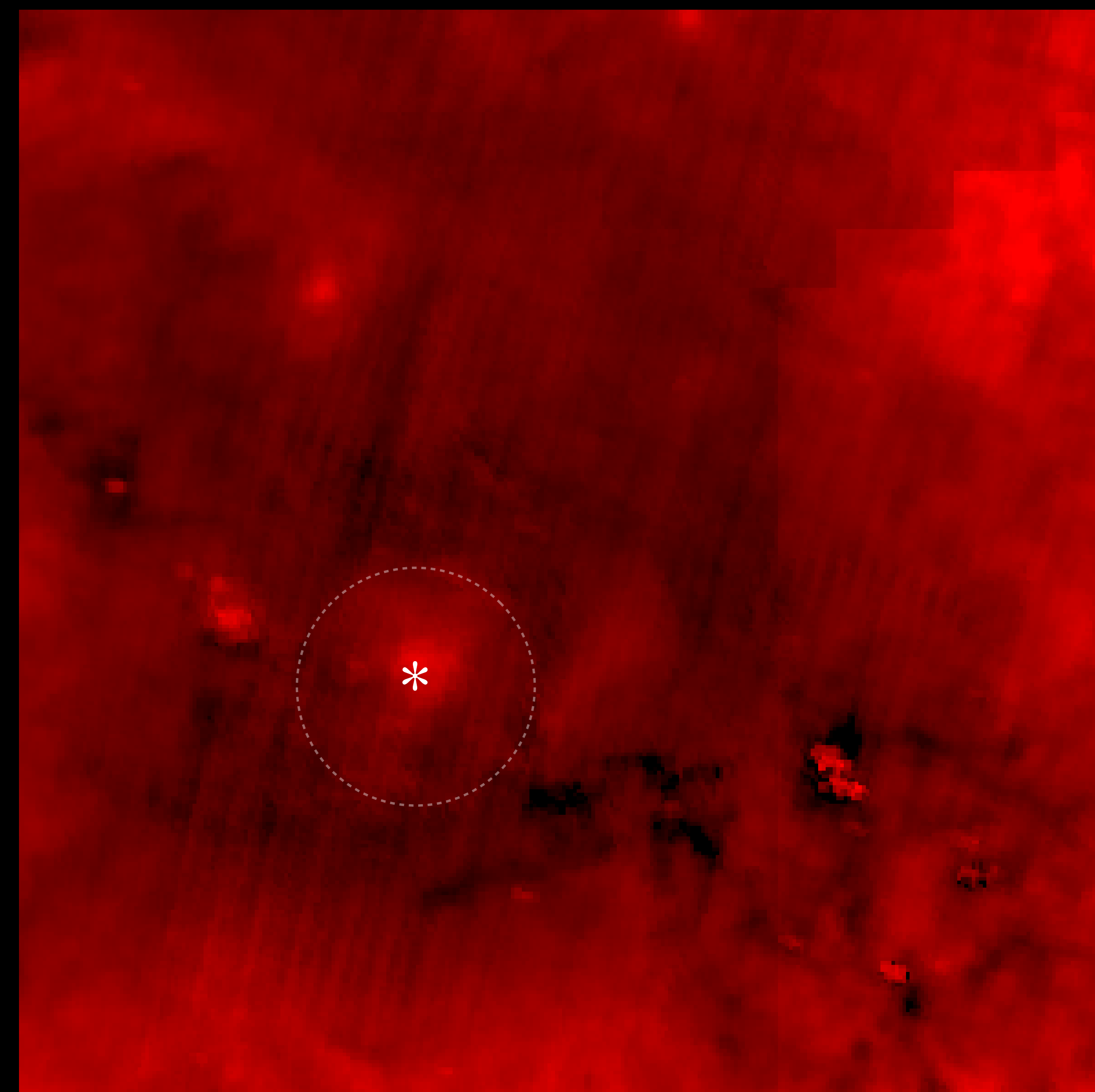
Mario Tafalla (OAN, Spain)

What B* HD 278942 Does to Perseus

Total Dust **Column Density** (0 to 15 mag A_V)
(Based on 60/100 microns)

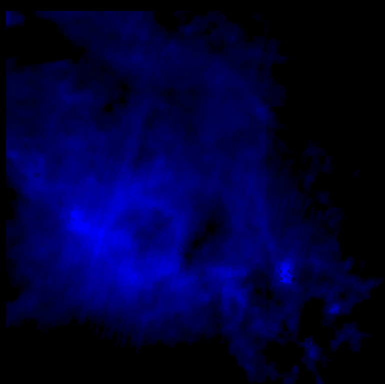


Dust **Column Temperature** (25 to 45 K)
(Based on 60/100 microns)



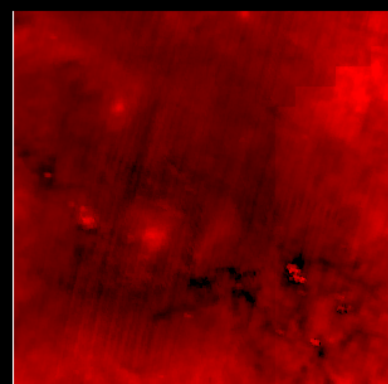
see Ridge et al. 2006a,b; Schnee et al. 2007, 2008; Shetty et al. 2010 cf. c2d Spitzer images Rebull et al. 2007.

Column Density



+

Column Temperature



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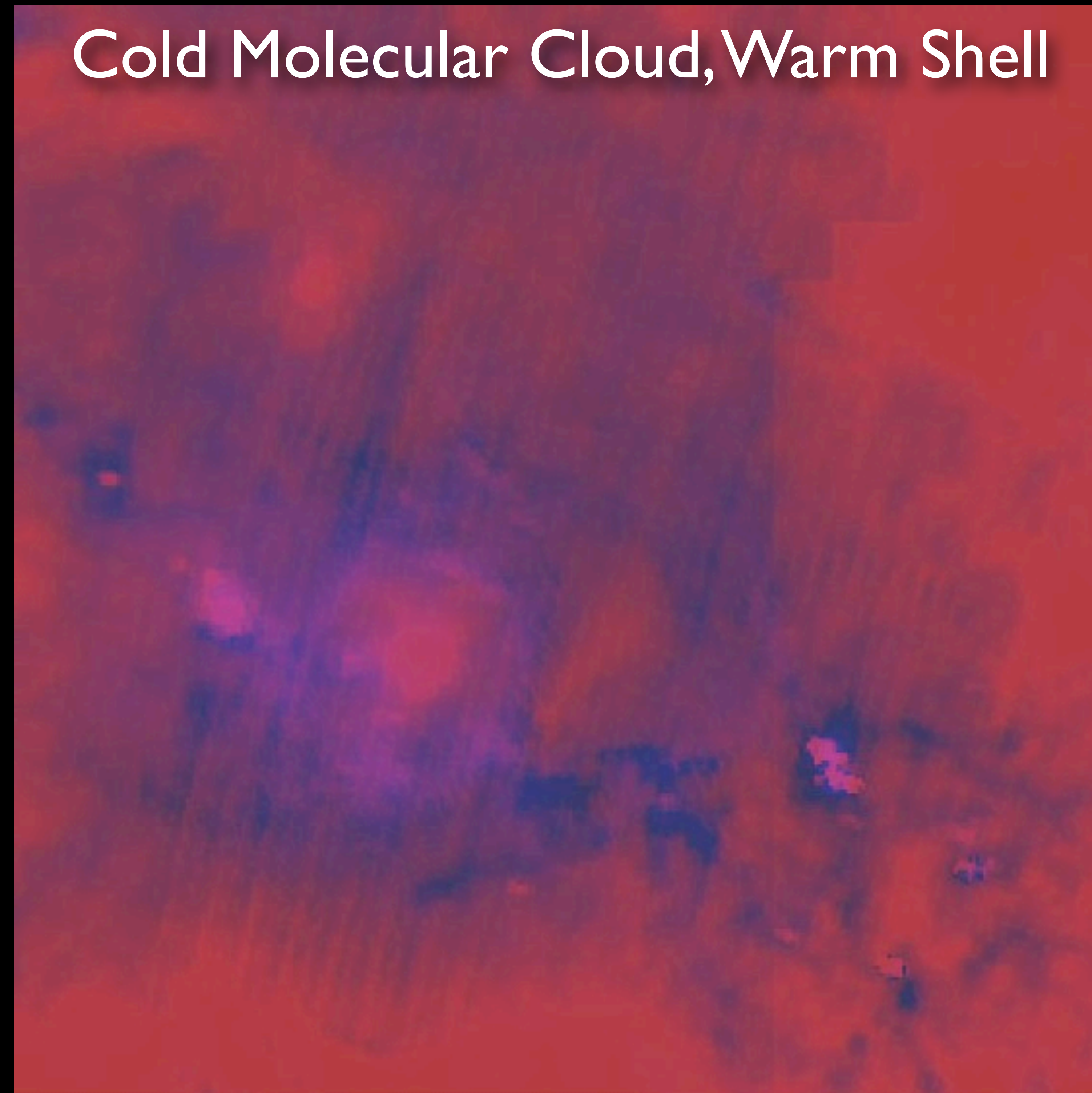
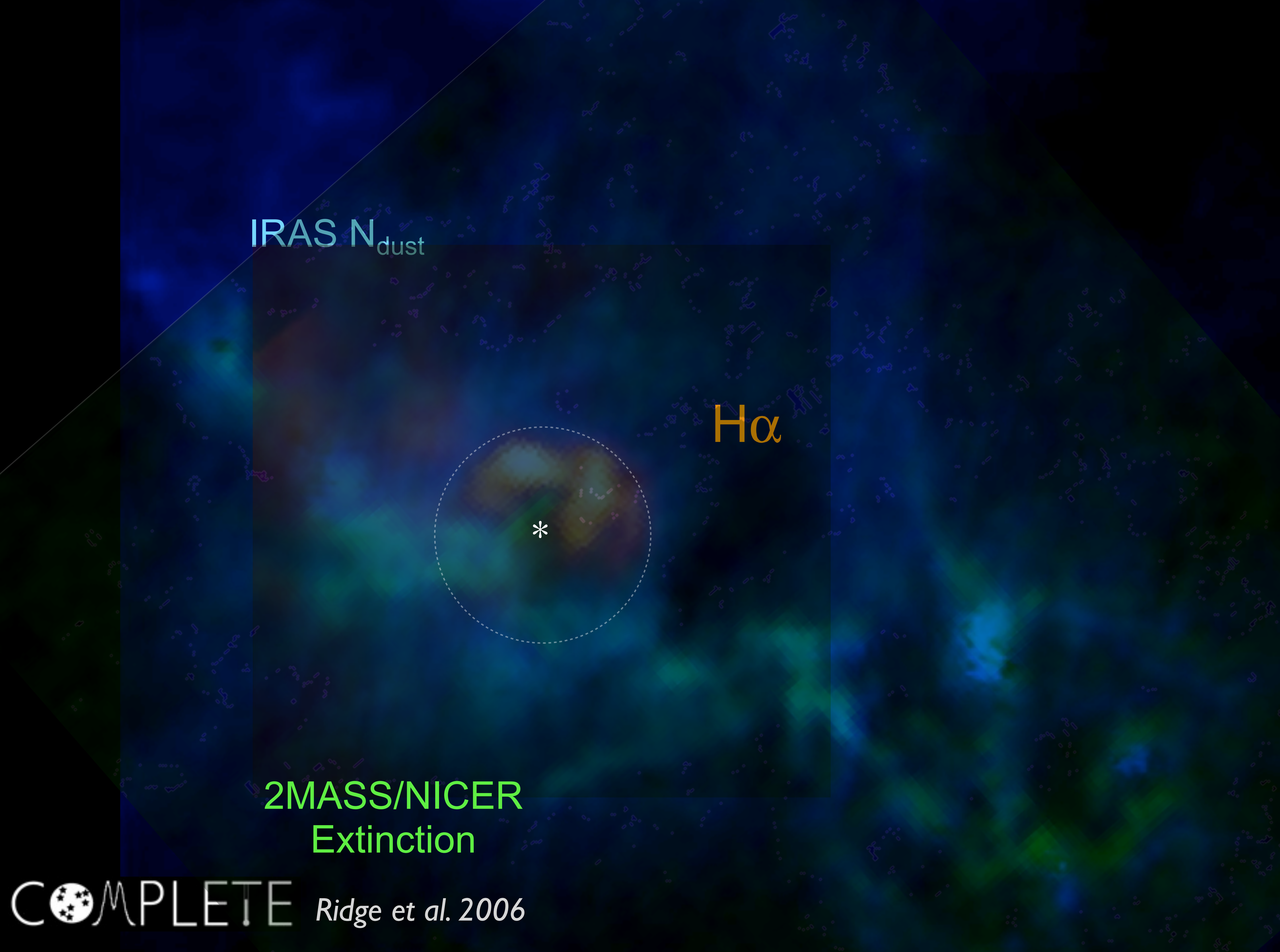


Note: see Shetty et al. 2010 for "column temperature" discussion

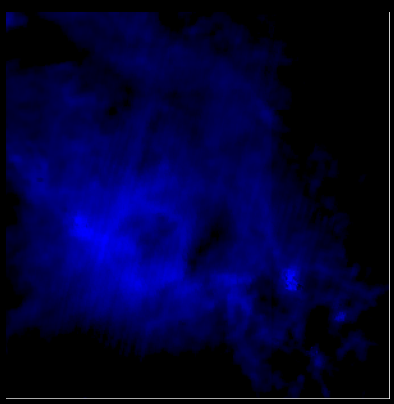
Shell is "behind," but touching, Perseus Molecular Cloud



H-α emission, WHAM/SHASSA Surveys (see Finkbeiner 2003)

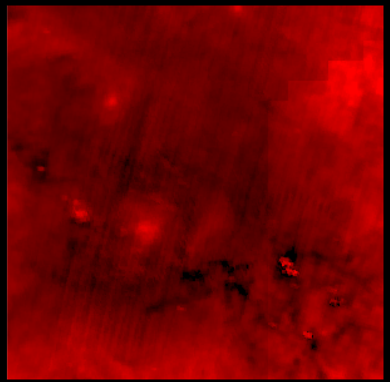
COMPLETE *Ridge et al. 2006*

Column Density



+

Column Temperature



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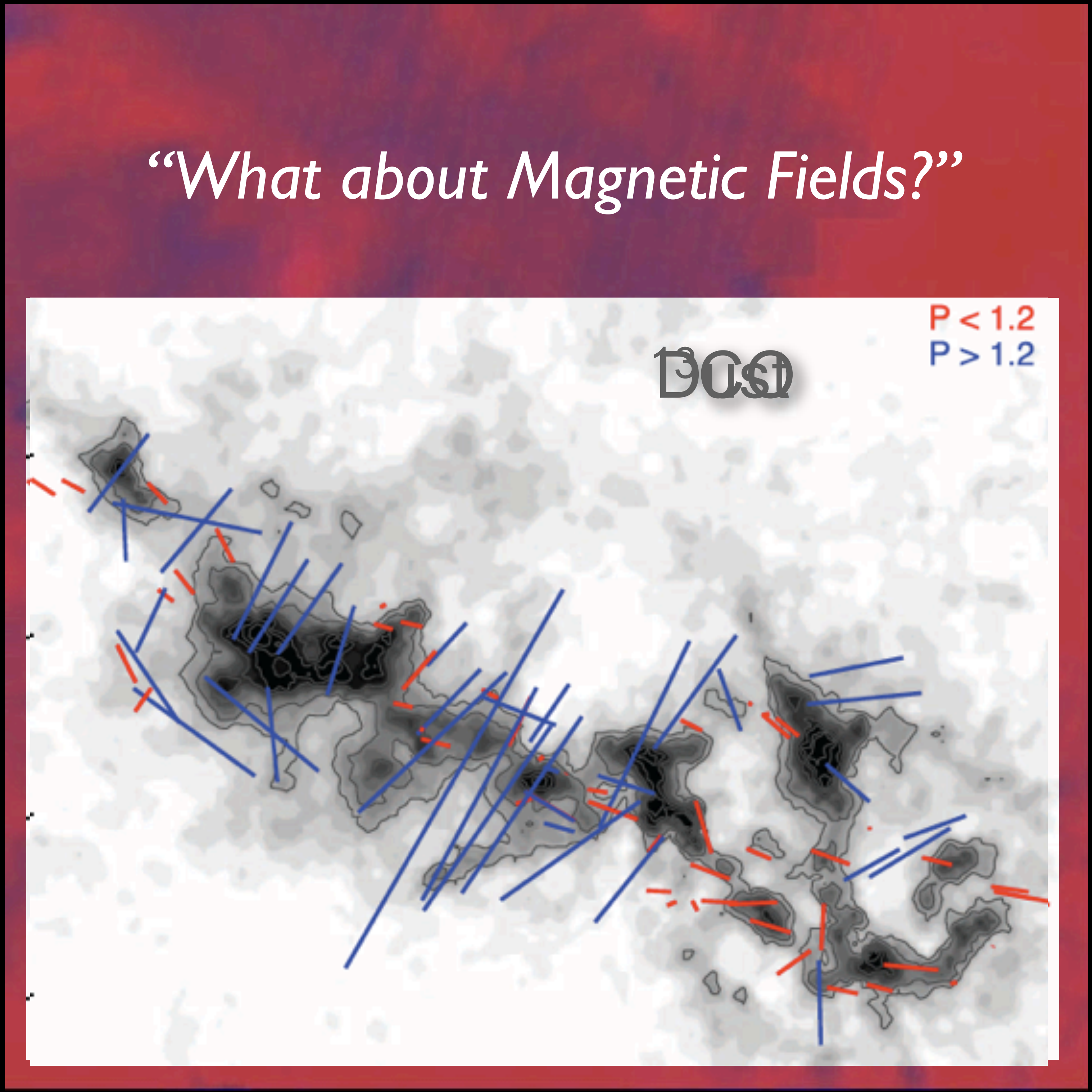
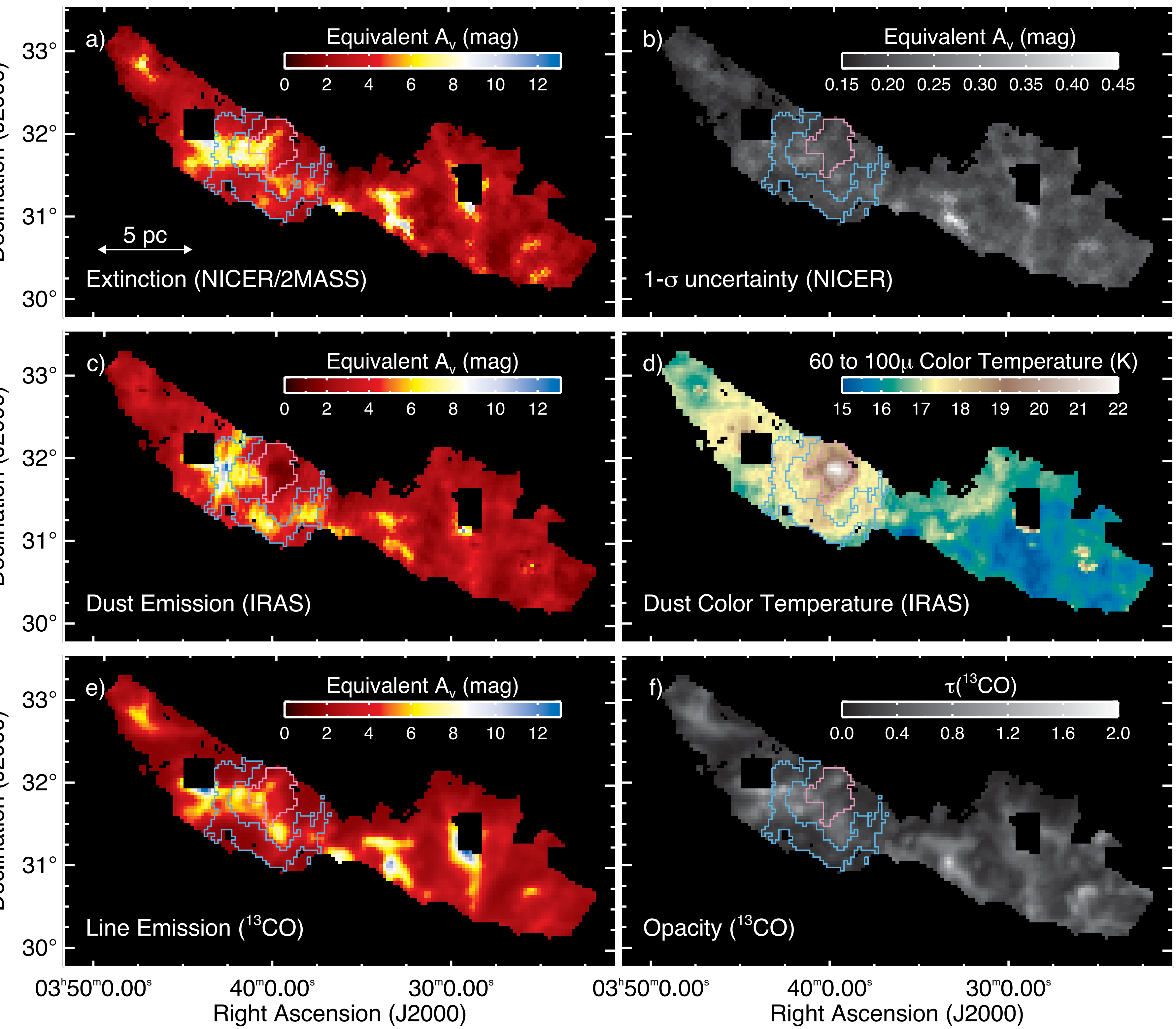
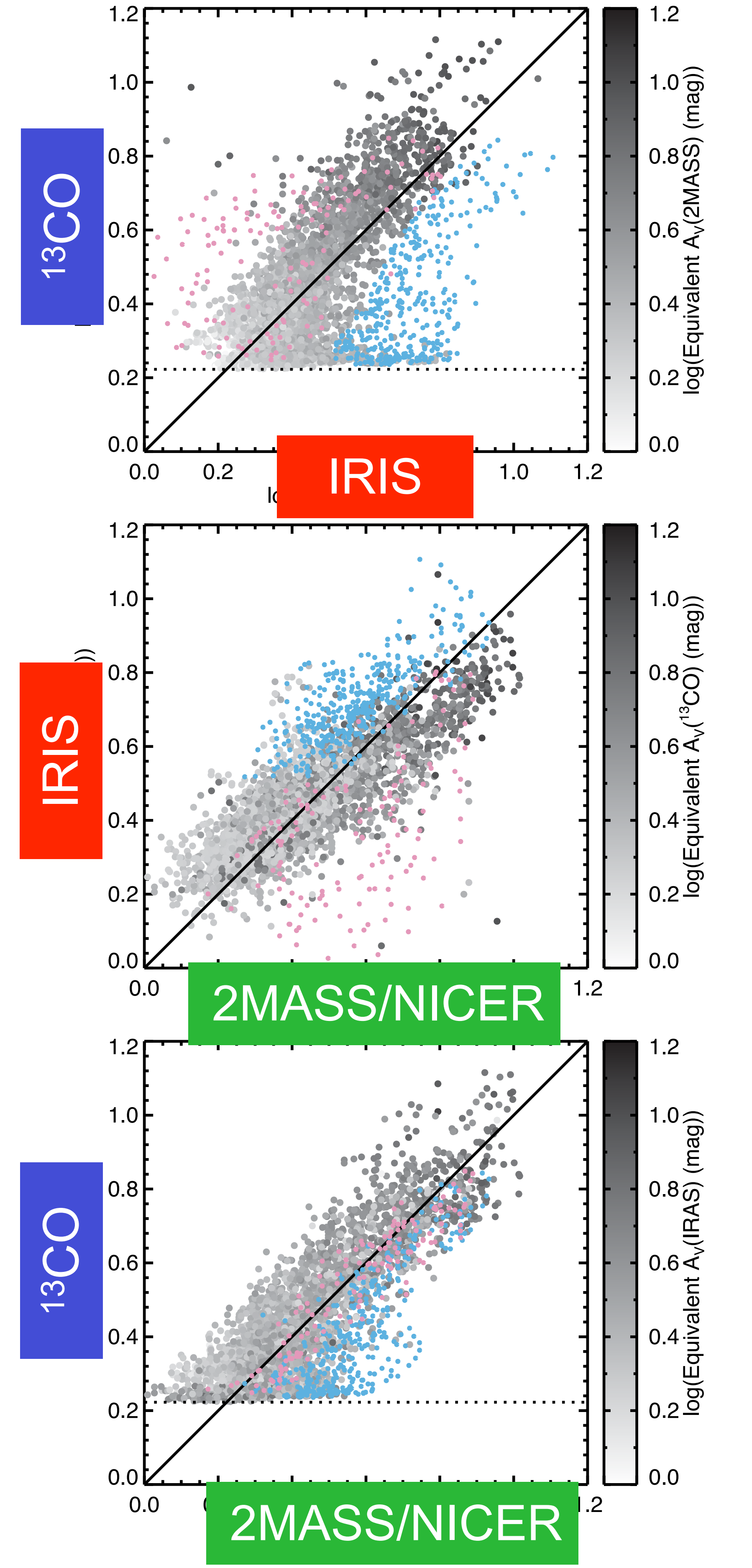


Overlays from *Ridge et al. 2006*, showing polarizaiton (magnetic field?) deeply influenced by shell

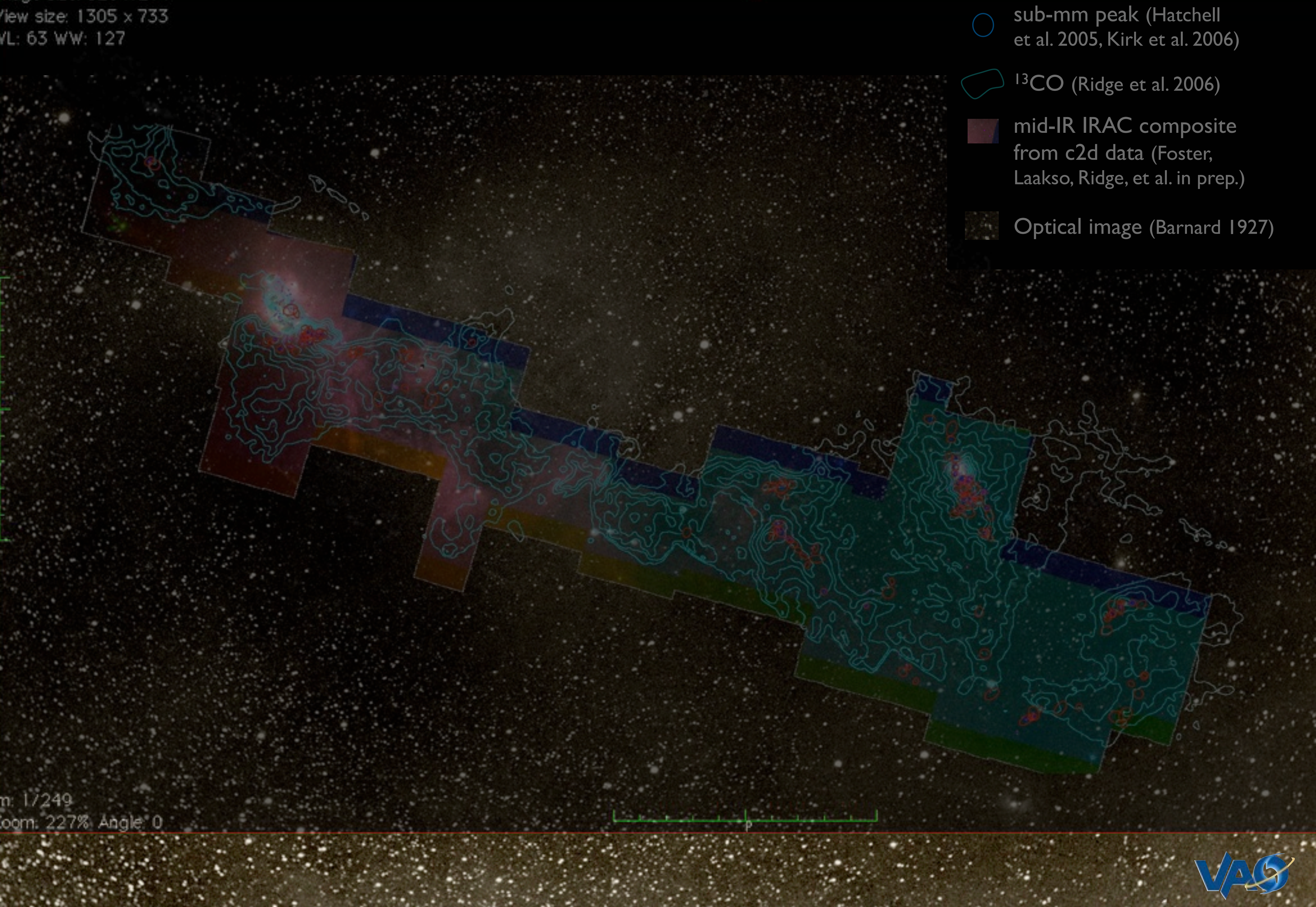
And, the shell effects CO/dust ratio too...

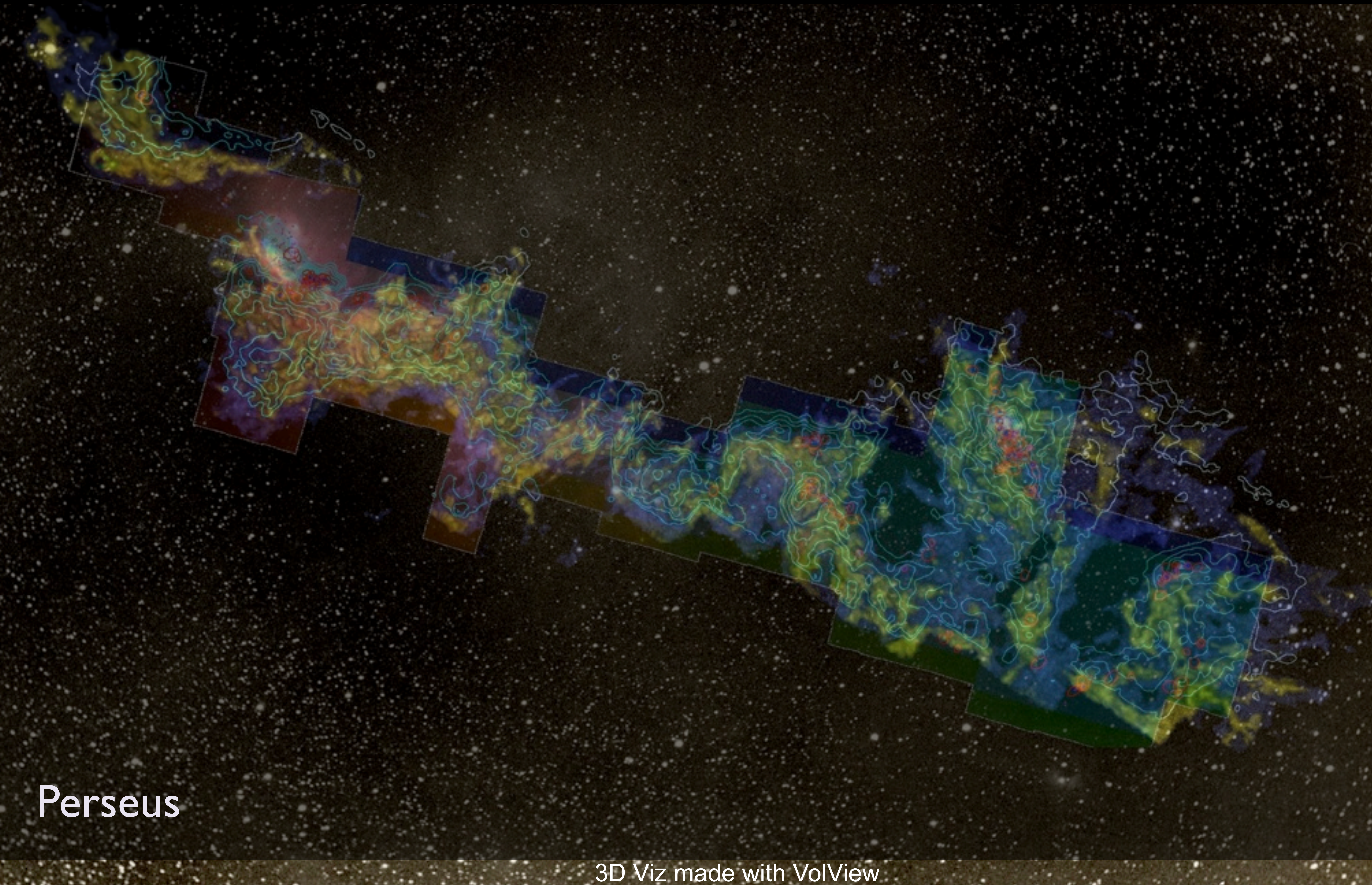




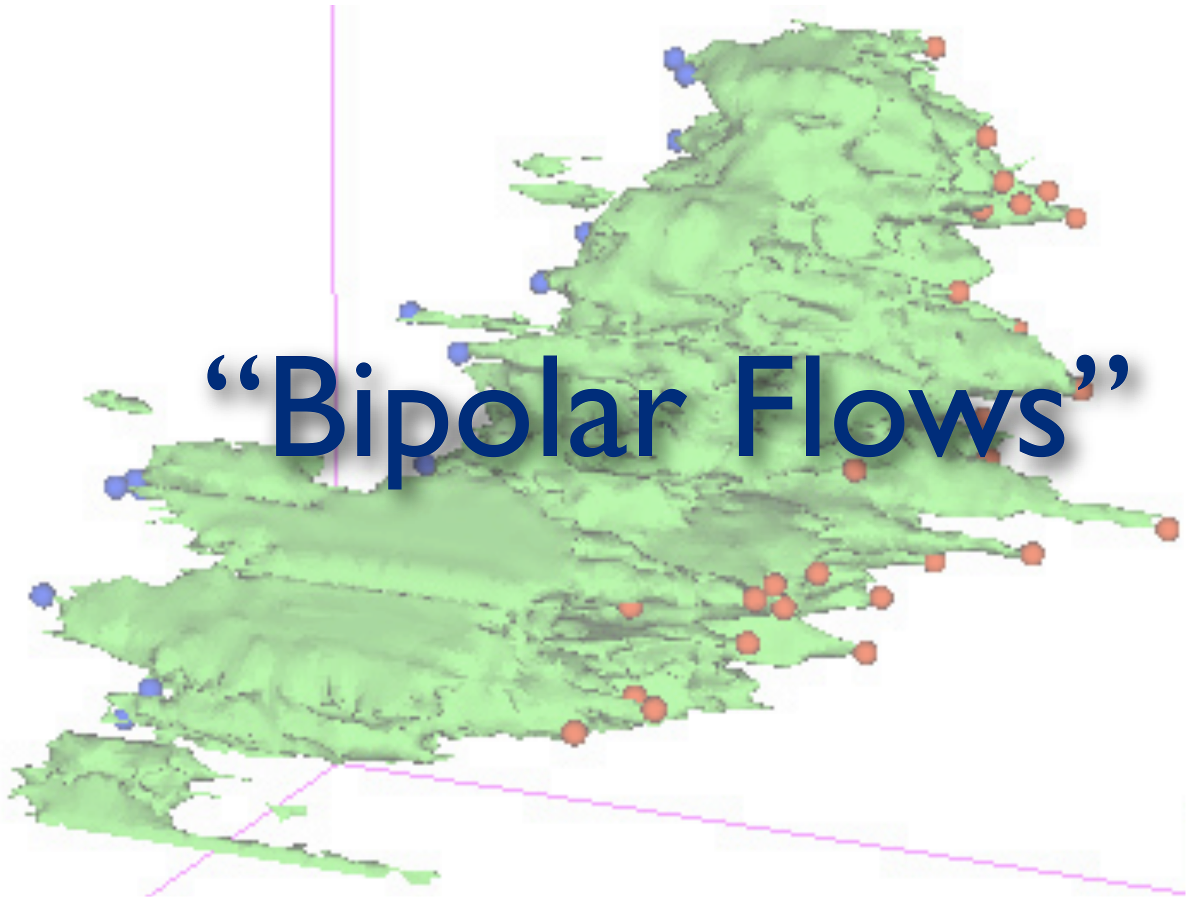
Goodman, Pineda & Schnee 2009

COMPLETE Perseus



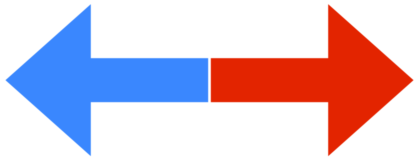

Perseus
3D Viz made with VolView

“Bipolar Flows”



Bipolar Outflows in Perseus

THE ASTROPHYSICAL JOURNAL, 715:1170–1190, 2010 June 1



doi:10.1088/0004-637X/715/2/1170

THE COMPLETE SURVEY OF OUTFLOWS IN PERSEUS

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Received 2009 October 7; accepted 2010 April 9; published 2010 May 7

ABSTRACT

We present a study on the impact of molecular outflows in the Perseus molecular cloud complex using the COMPLETE Survey large-scale ^{12}CO(1–0) and ^{13}CO(1–0) maps. We used three-dimensional isosurface models generated in right ascension–declination–velocity space to visualize the maps. This rendering of the molecular line data allowed for a rapid and efficient way to search for molecular outflows over a large (~16 deg^2) area. Our outflow-searching technique detected previously known molecular outflows as well as new candidate outflows. Most of these new outflow-related high-velocity features lie in regions that have been poorly studied before. These new outflow candidates more than double the amount of outflow mass, momentum, and kinetic energy in the Perseus cloud complex. Our results indicate that outflows have significant impact on the environment immediately surrounding localized regions of active star formation, but lack the energy needed to feed the observed turbulence in the *entire* Perseus complex. This implies that other energy sources, in addition to protostellar outflows, are responsible for turbulence on a global cloud scale in Perseus. We studied the impact of outflows in six regions with active star formation within Perseus of sizes in the range of 1–4 pc. We find that outflows have enough power to maintain the turbulence in these regions and enough momentum to disperse and unbind some mass from them. We found no correlation between outflow strength and star formation efficiency (SFE) for the six different regions we studied, contrary to results of recent numerical simulations. The low fraction of gas that potentially could be ejected due to outflows suggests that additional mechanisms other than cloud dispersal by outflows are needed to explain low SFEs in clusters.

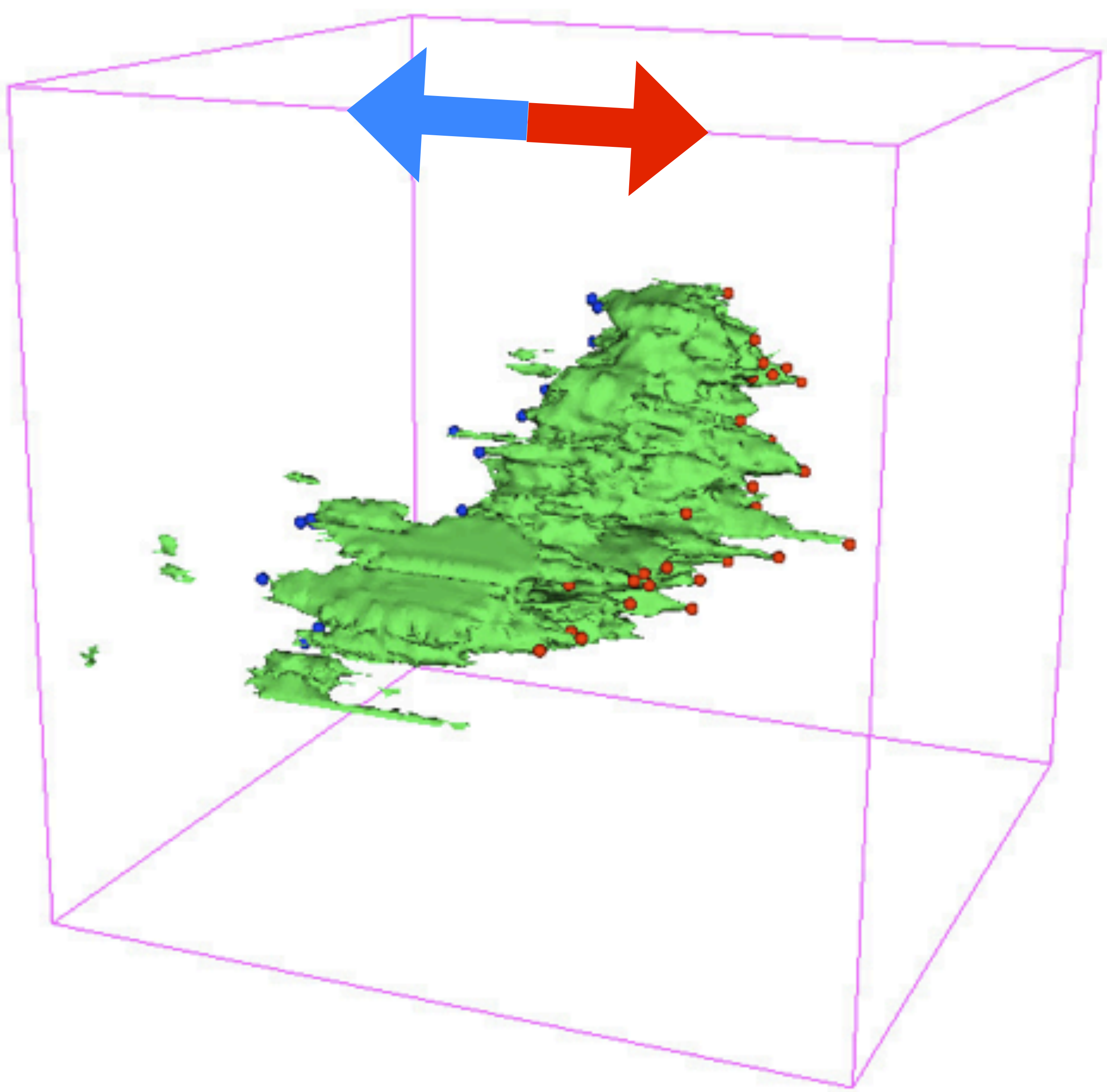
Key words: ISM: clouds – ISM: individual objects (Perseus) – ISM: jets and outflows – ISM: kinematics and dynamics – stars: formation – turbulence

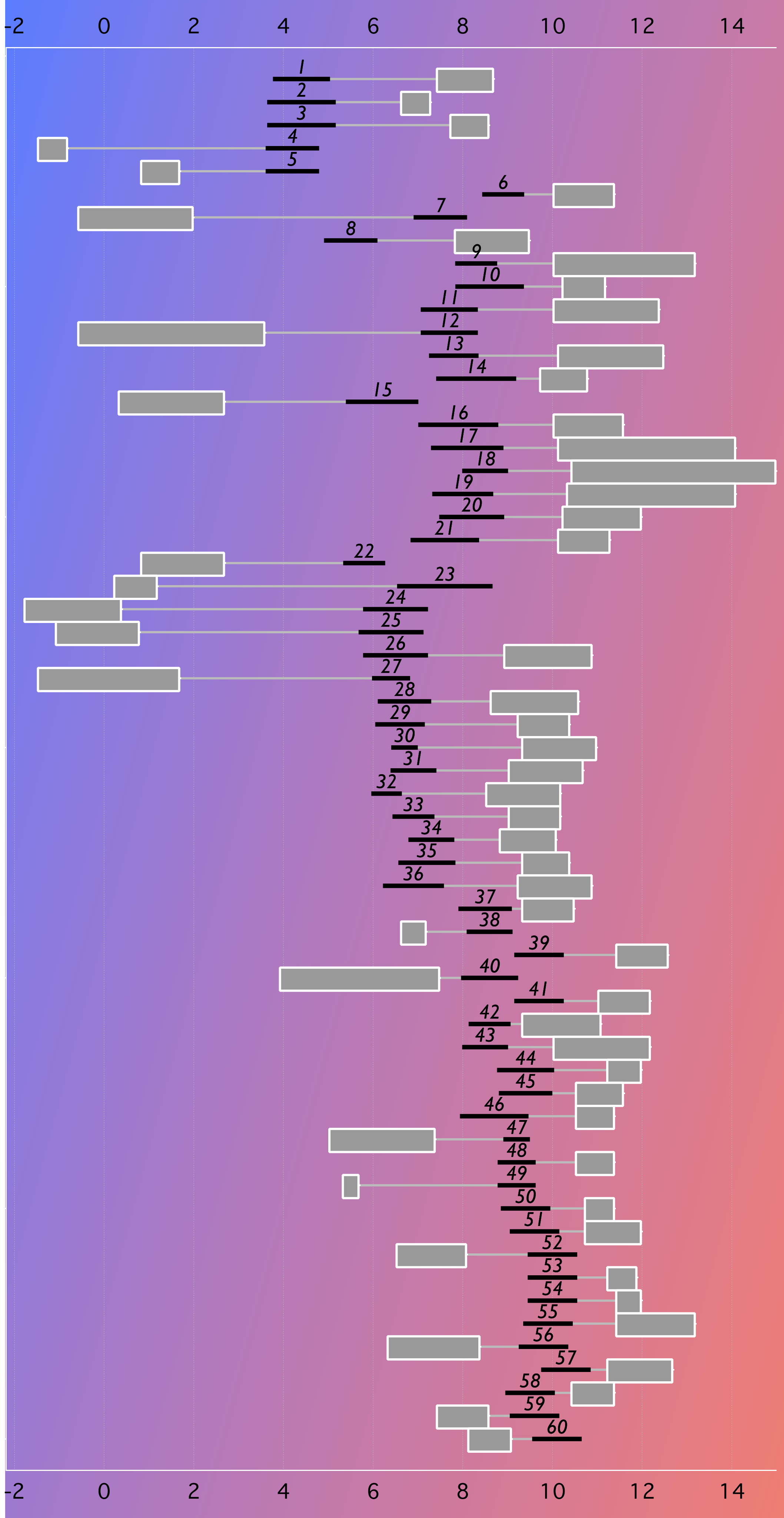
Online-only material: color figures

"CPOCs"

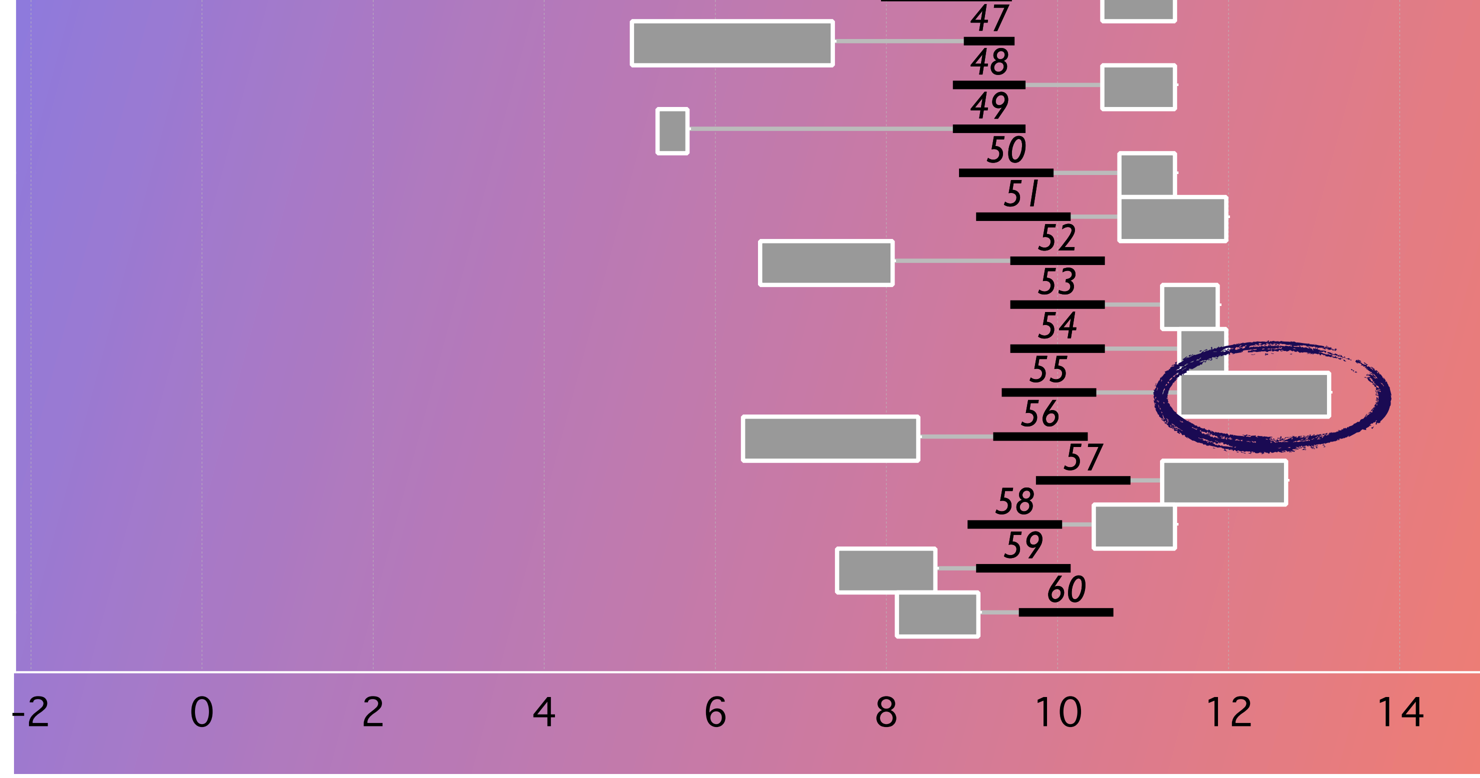
COMPLETE **P**erseus **O**utflow **C**andidates

Note: I did not make up that name!





“CPOCs”



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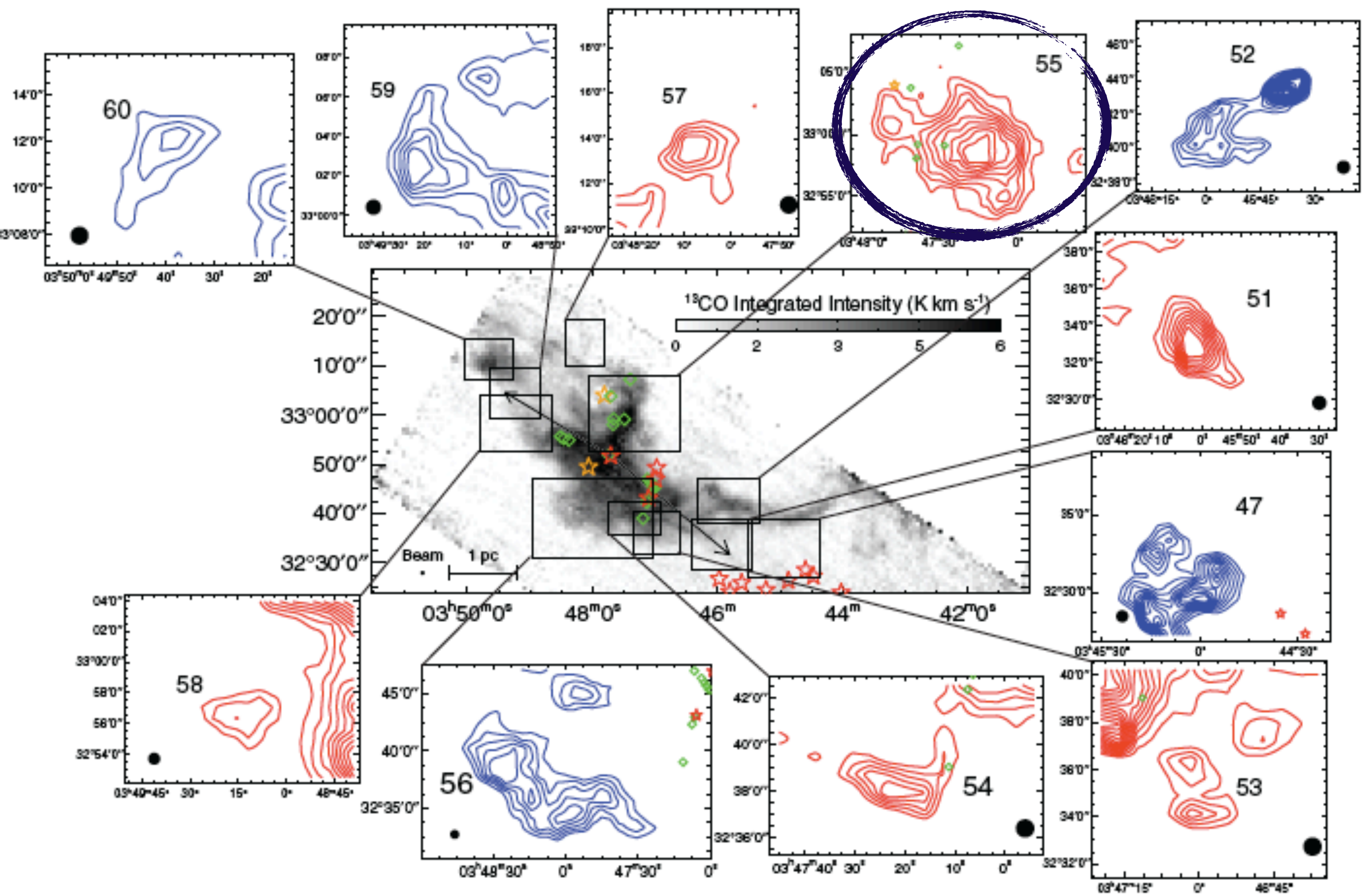
-2 0 2 4 6 8 10 12 14



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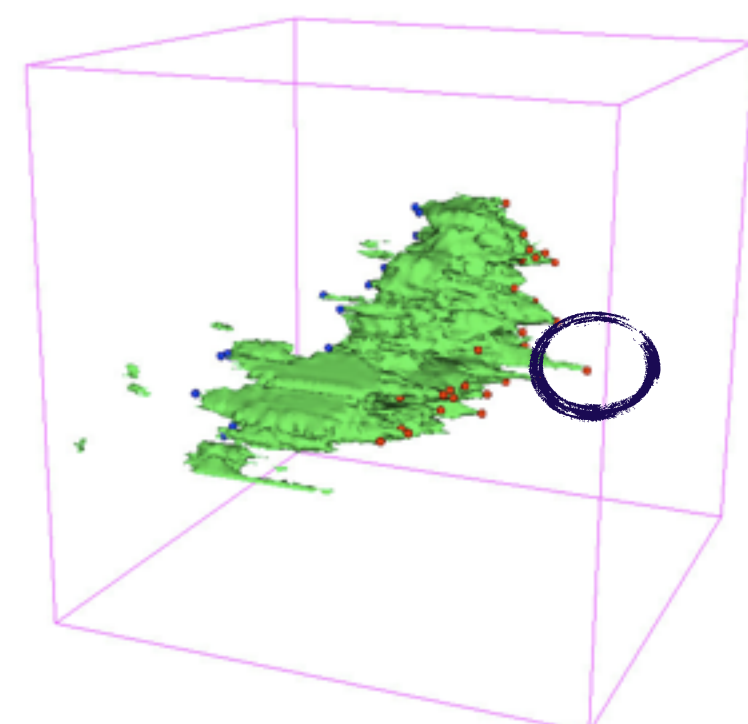
54
53
13CO Integrated Intensity (K km s-1)
0 2 3 5 6
20′0″
10′0″
33°00′0″
50′0″
40′0″
32°30′0″
Beam
1 pc
03h50m0s
48m0s
46m
44m
42m0s



Perseus Bipolar Outflows

Arce et al. 2010a

Table 5
Physical Parameters of Active Star-forming Regions in Perseus

Name	M_{reg}[a] ($M_\odot$)	R_{reg}[b] (pc)	Δv[c] (km s^{-1})	T_{ex}[d] (K)	v_{esc}[e] (km s^{-1})	E_{grav}[f] (10^{46} erg)	E_{turb}[g] (10^{45} erg)	t_{diss}[h] (10^5 yr)	L_{turb}[i] (10^{32} erg s^{-1})
L1448	150	0.6	1.9	10	1.5	0.3	2.9	2.6	3.6
NGC 1333	1100	2.0	2.2	13	2.2	5.2	28.8	5.7	15.9
B1-Ridge	210	0.7	1.9	13	1.6	0.5	4.1	3.1	4.1
B1	430	0.9	2.1	13	2.0	1.8	10.2	2.9	11.2
B5	420	1.4	1.5	12	1.6	1.1	5.1	7.6	2.1
IC 348	620	0.9	1.8	15	2.4	3.7	10.9	3.0	11.4

Notes.
[a] Mass of star-forming region, obtained using the procedure described in Section 5.1.
[b] Radius estimate of the region obtained from the geometric mean of minor and major axes of the extent of the ^{13}CO integrated intensity emission.
[c] Average velocity width (FWHM) of the ^{13}CO(1–0) line in the region.
[d] Average excitation temperature of region.
[e] Escape velocity, given by $\sqrt{2GM_{reg}/R_{reg}}$.
[f] Gravitational binding energy given by GM_{reg}^2/R_{reg}.
[g] Turbulence energy given by $\frac{3}{16 ln2} M_{reg} \Delta v^2$.
[h] Turbulence dissipation time, see Section 5.2.1.
[i] Turbulence energy dissipation rate give by E_{turb}/τ_{diss}.

Table 7
Quantitative Assessment of Outflow Impact on Star-forming Regions

Name	E_{flow}/E_{turb}	$r_L = L_{flow}/L_{turb}$	E_{flow}/E_{grav}	M_{esc}[a] ($M_\odot$)	M_{esc}/M_{reg}
L1448	0.41	2.1	0.40	15	0.10
NGC 1333	0.30	3.4	0.17	76	0.07
B1-Ridge	0.24	1.5	0.20	14	0.07
B1	0.30	1.7	0.17	21	0.05
IC 348	0.14	0.8	0.04	23	0.04
B5	0.80	12.4	0.37	98	0.23

Note. [a] Escape mass, given by $M_{esc} = P_{out}/v_{esc}$ (see Section 5.2.3).

Table 6
Total Outflow Mass, Momentum, Energy, and Luminosity in Star-forming Regions

Name	M_{flow}[a] ($M_\odot$)	P_{flow}[a] ($M_\odot$ km s^{-1})	E_{flow}[a] (10^{44} erg)	L_{flow}[b] (10^{32} erg s^{-1})
L1448	1.0/5	3.1/21.7	1.2/12	8
NGC 1333	5.0/25	17.4/121.8	6.9/69	44
B1-Ridge	1.1/5.5	3.2/22.4	1.0/10	6
B1	1.5/7.5	6.2/43.4	3.1/31	20
IC 348	4.2/21	7.7/53.9	1.5/15	10
B5	12.8/64	22.3/156.1	4.1/41	26

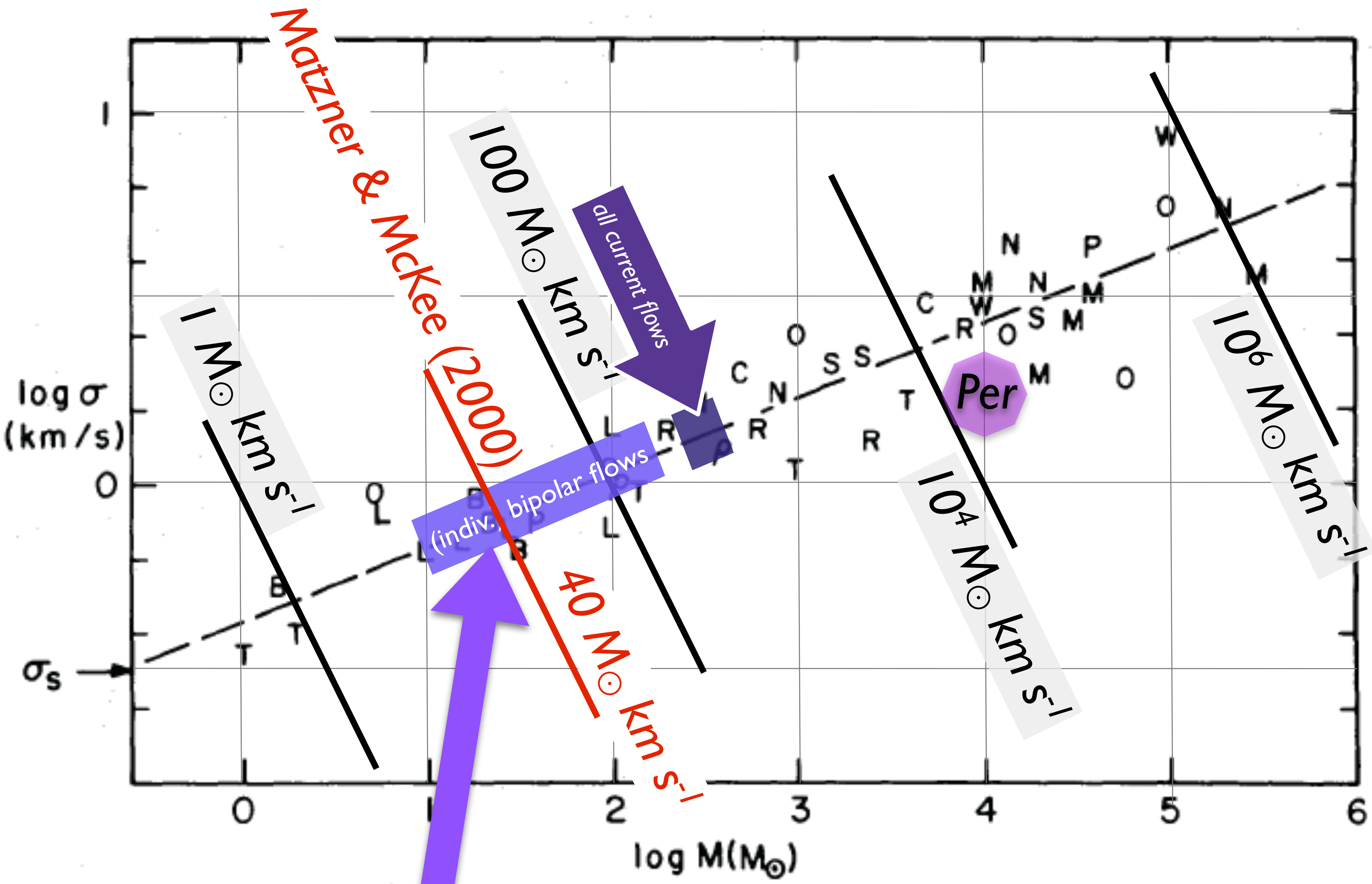
Notes.
[a] Values before and after the slash are the original estimates and the estimates adjusted by the correction factor, respectively (see Section 5.1).
[b] Outflow luminosity, $L_{flow} = E_{flow}/\tau_{flow}$, obtained using the value of the total outflow kinetic energy adjusted by the correction factor and using an average outflow timescale of 5×10^4 yr.

Typically 20% binding energy in flows.

Bottom line

local influence *significant*,

HOMEWRECKERS *not*.



Properties of Molecular Clouds as "Equivalent Momentum" (using Larson 1981)

grey boxes mark lines of constant "momentum," as labeled

Table 6
Total Outflow Mass, Momentum, Energy, and Luminosity in Star-forming Regions

Name	$M_{\rm flow}$[a] ($M_\odot$)	$P_{\rm flow}$[a] ($M_\odot$ km s^{-1})	$E_{\rm flow}$[a] (10^{44} erg)	$L_{\rm flow}$[b] (10^{32} erg s^{-1})
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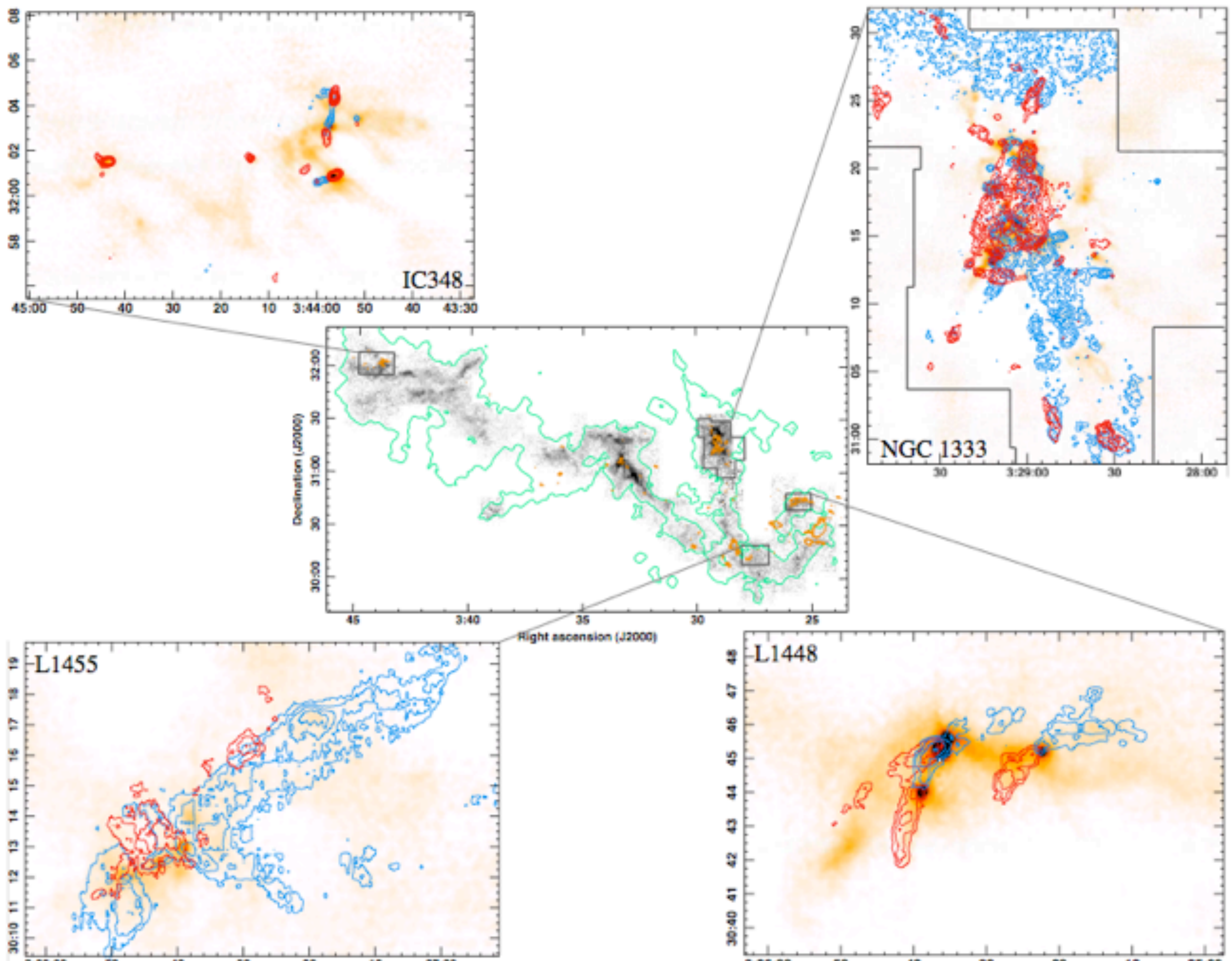
__Roughly true statement__

Simulations show that ~kinetic energy observed must be injected every crossing time to maintain turbulence.

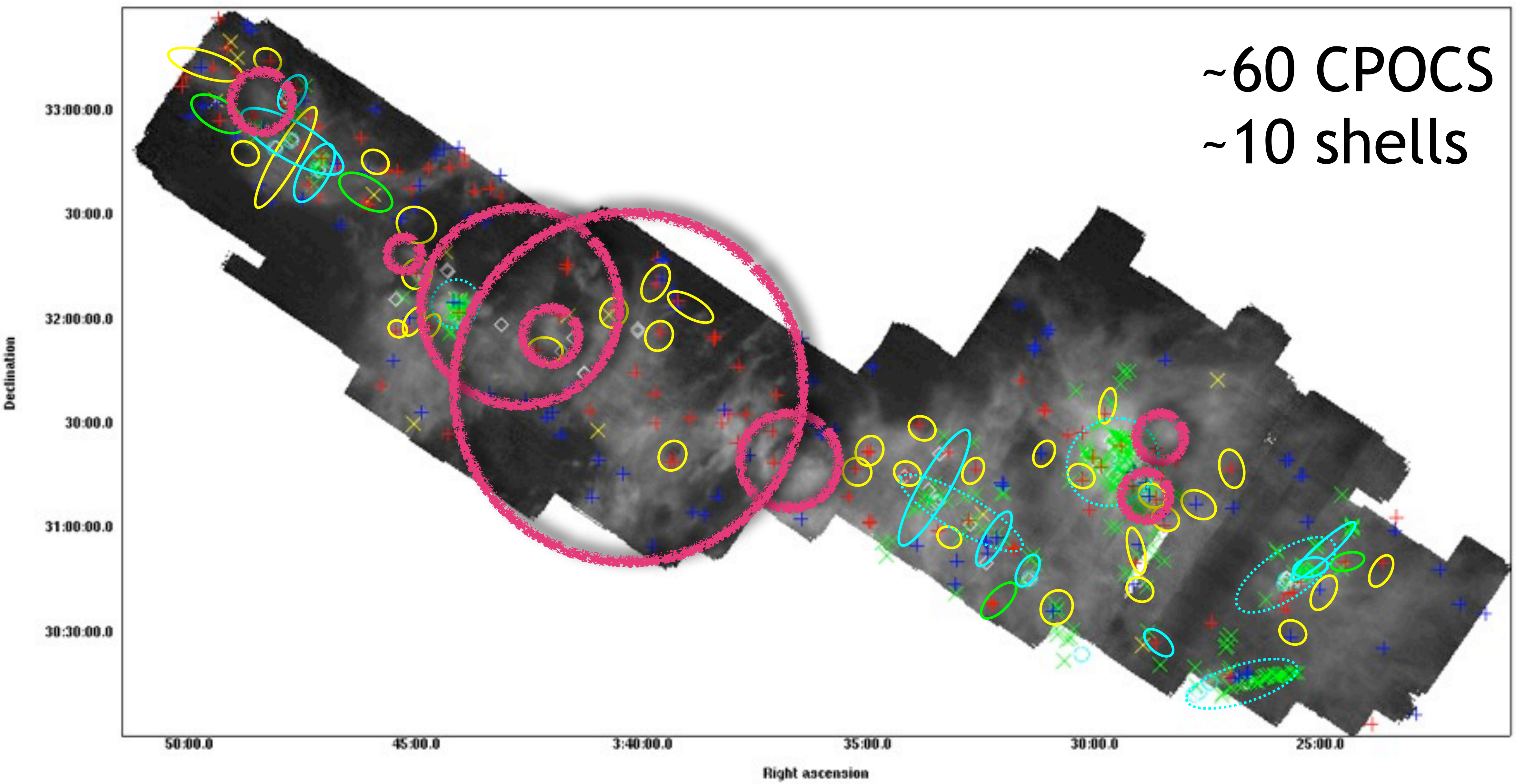
For reference: crossing time ~ 10 pc/2 km s^{-1}=5 Myr;
"flow time"=0.05 Myr, so
flows per crossing time= 5Myr/0.05Myr =100

Curtis et al. (today's astro-ph) is nice targeted study (*not a full census*)




“Shells”

Perseus Outflows & Shells



Red Shifted CPOCs

Blue Shifted CPOCs

HH Objects

New outflows

Known outflows

Many small known outflows

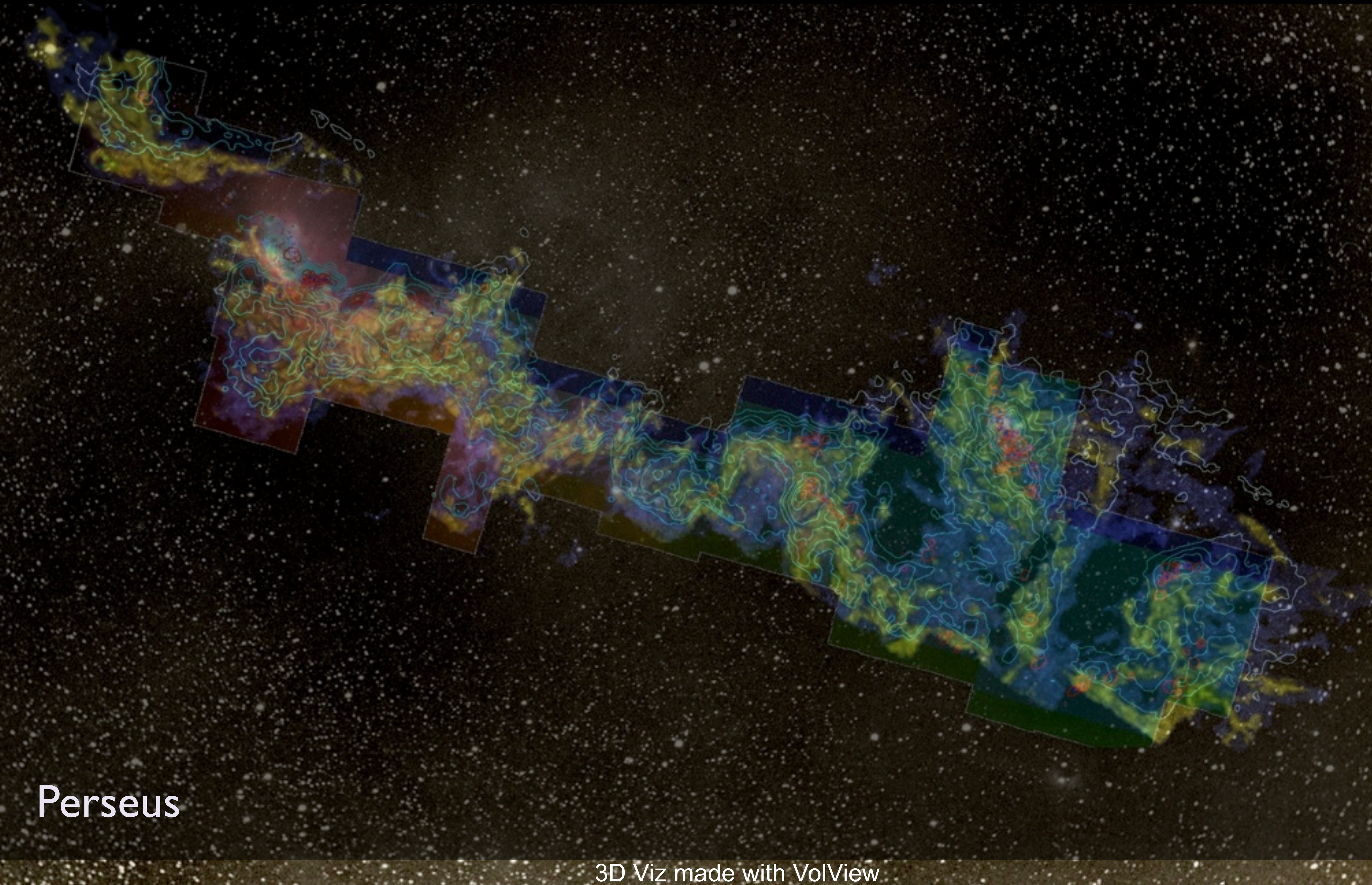
Outflow extensions

IRAS Sources

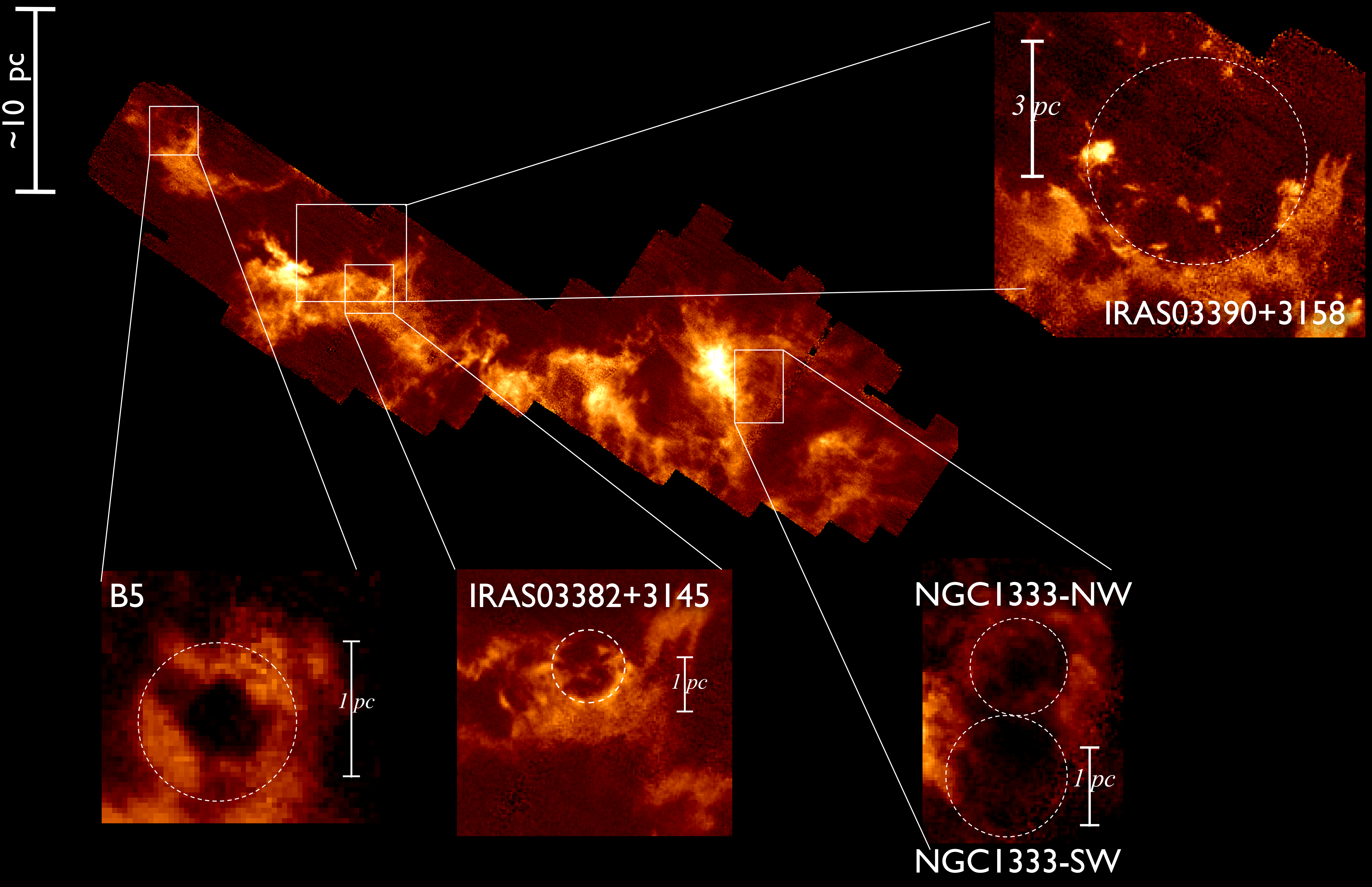
Known Outflow Sources

"Shells"

Arce et al. 2010 a,b

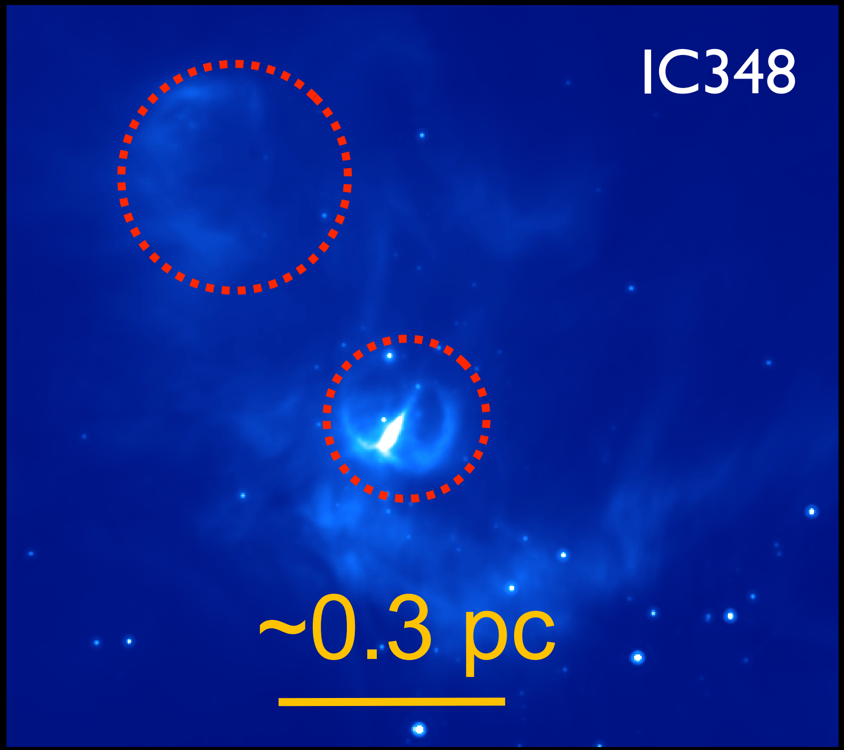

Perseus
3D Viz made with VolView

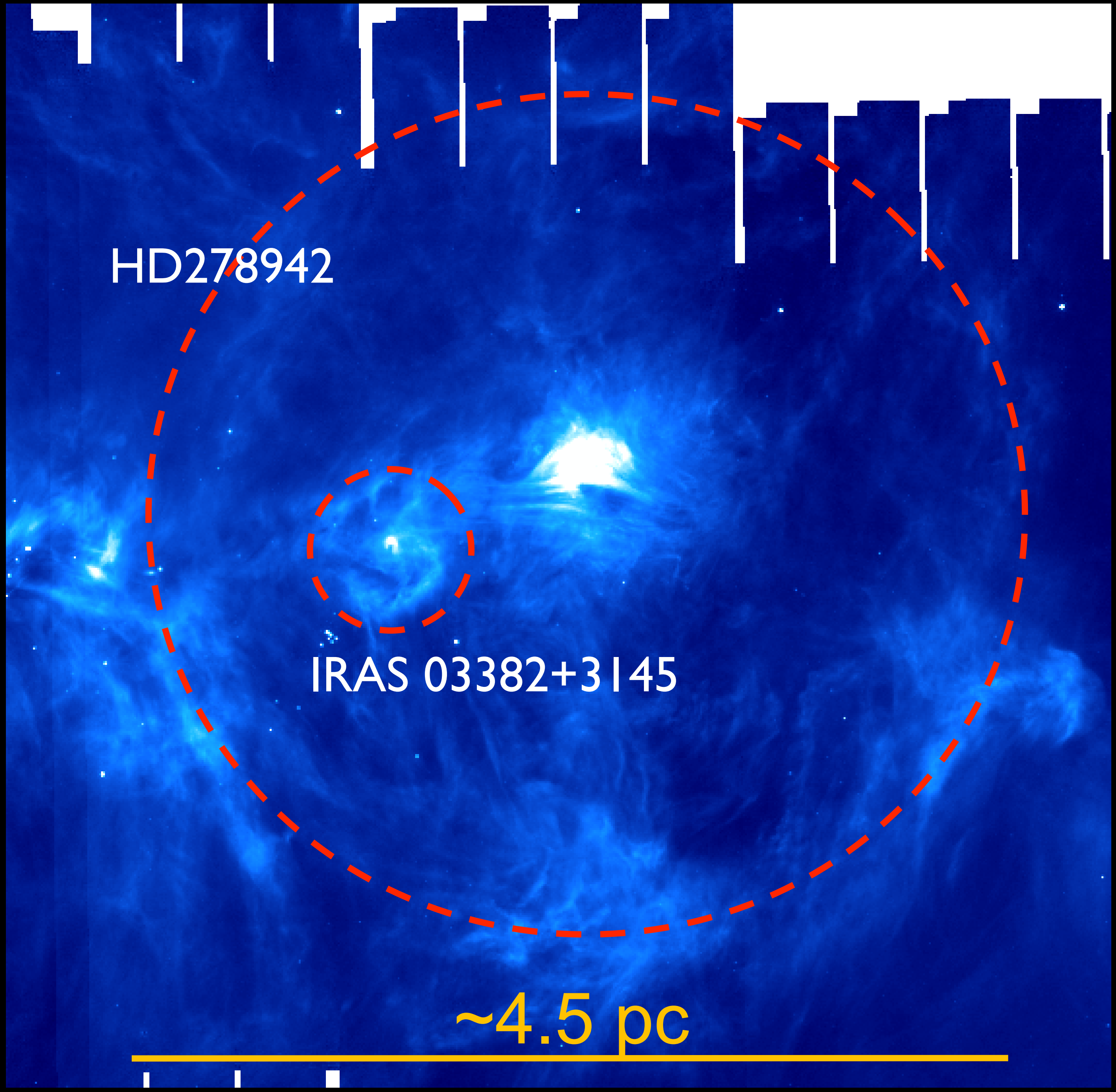
Perseus Shells in ^{13}CO

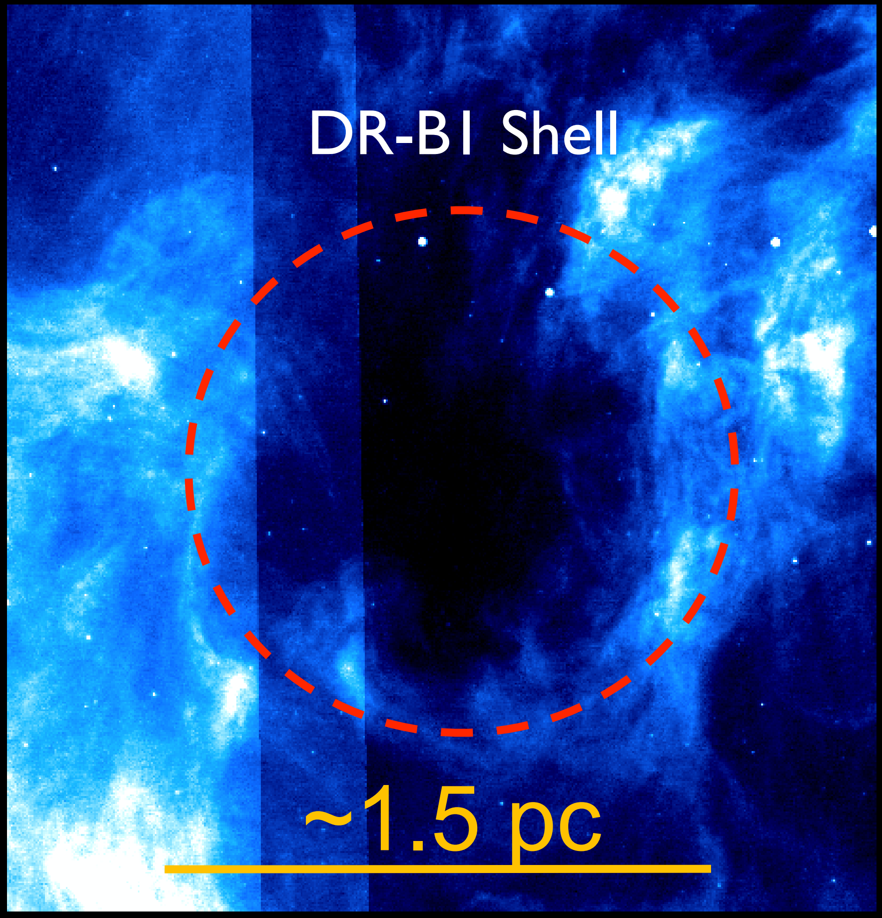


Perseus Shells in Spitzer MIPS 24 μm

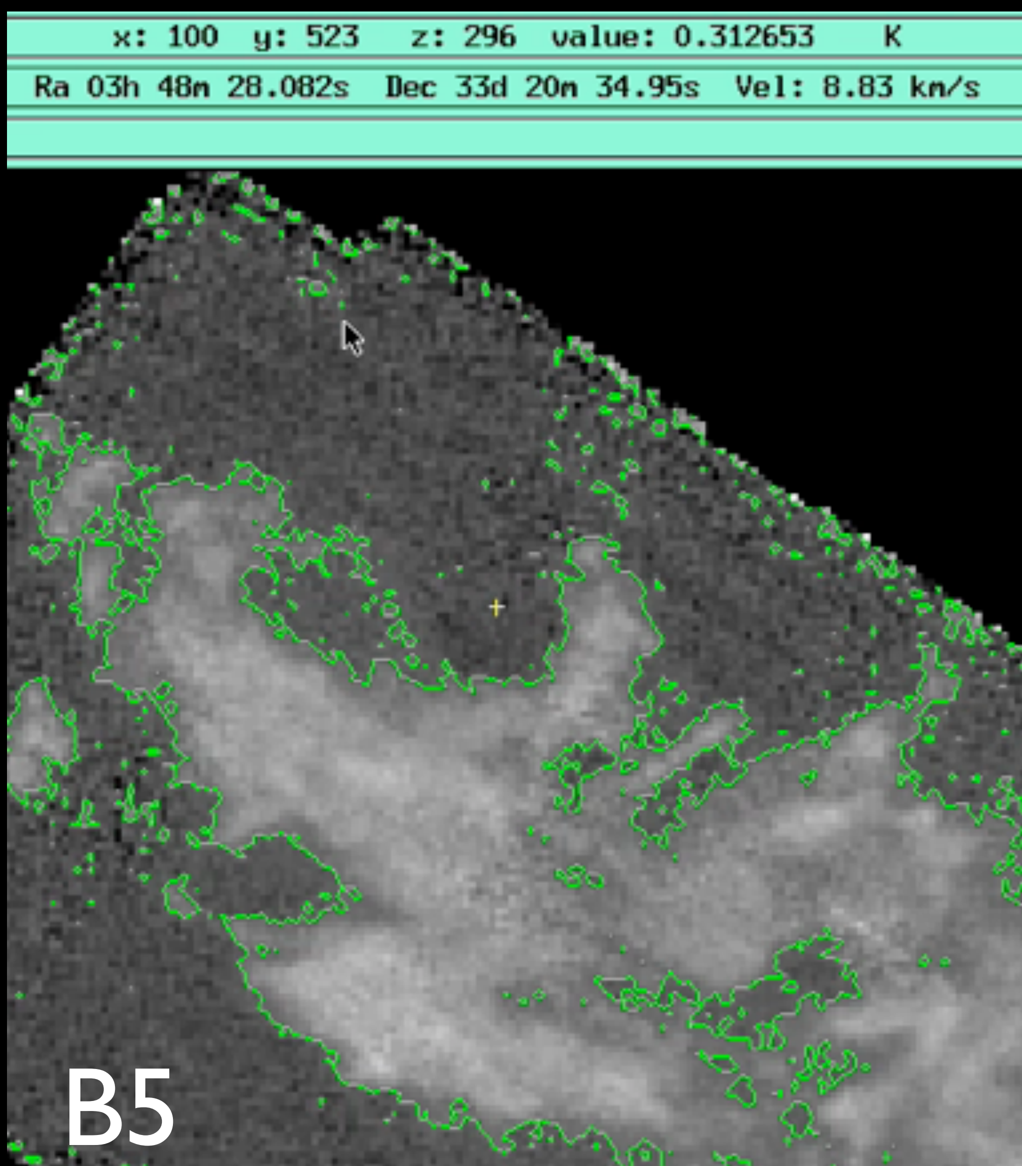
(Images from Spitzer c2d: Rebull et al. 2007)

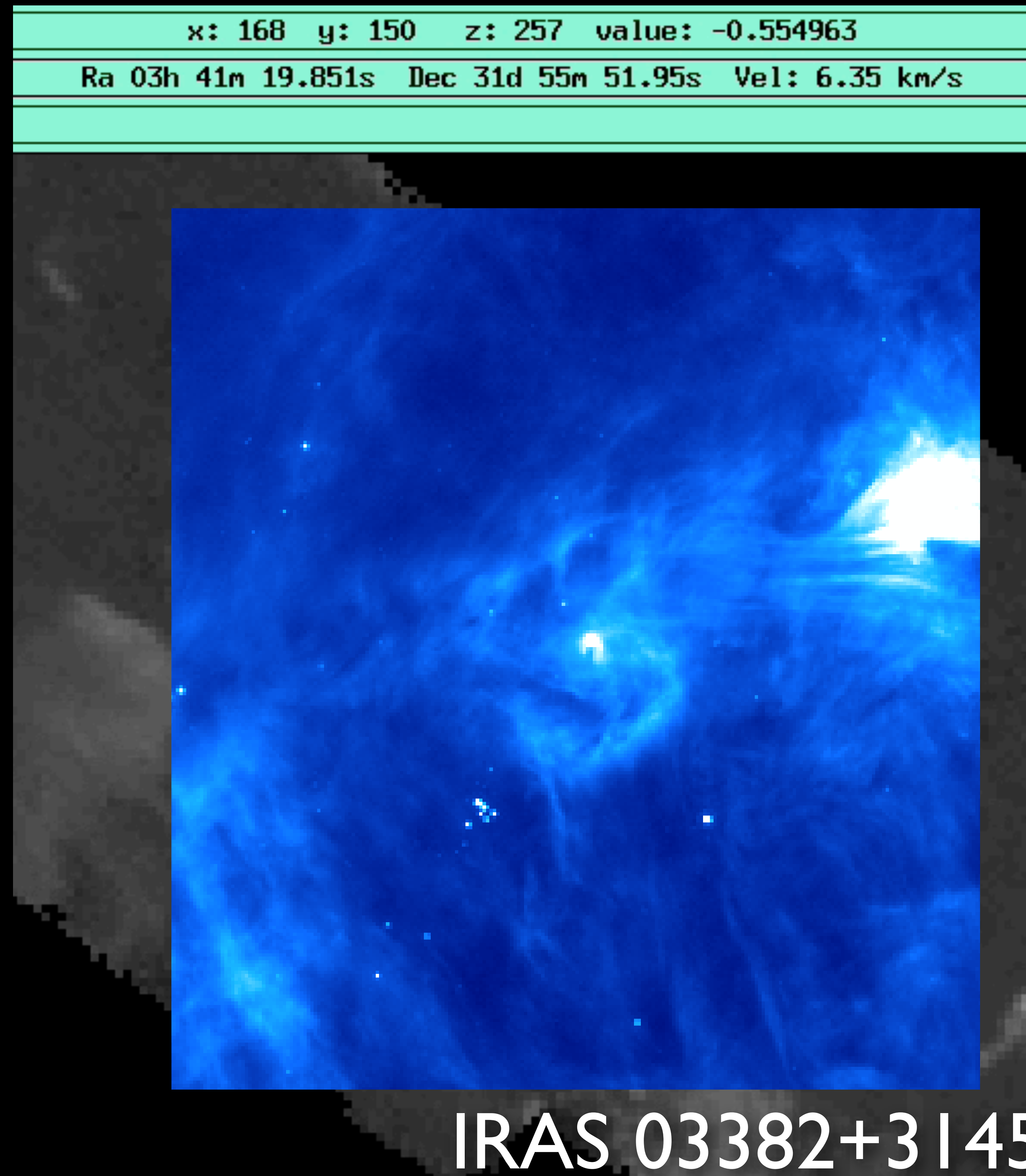




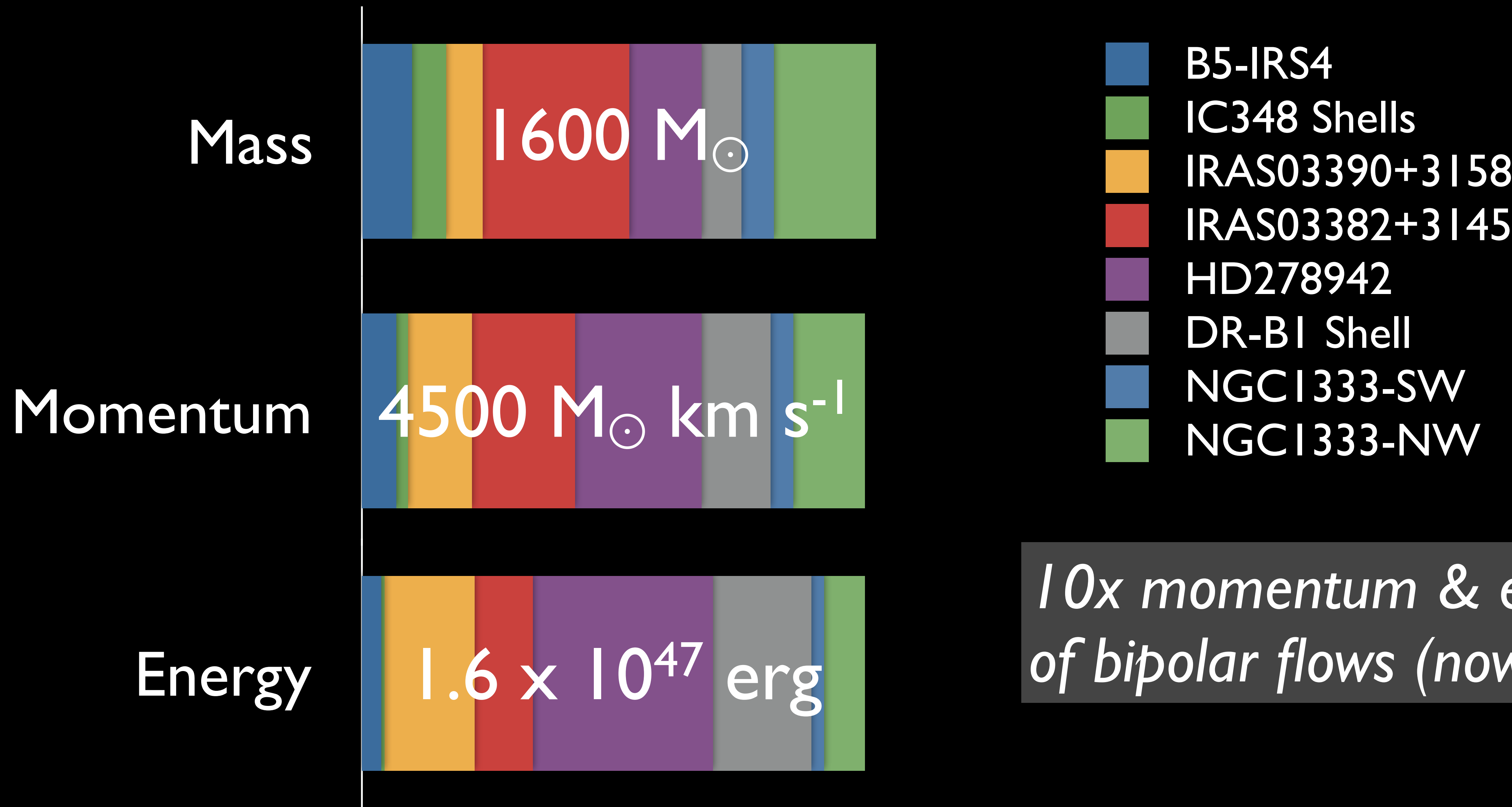


“Cinema Arce”


x: 100 y: 523 z: 296 value: 0.312653 K
Ra 03h 48m 28.082s Dec 33d 20m 34.95s Vel: 8.83 km/s
B5


x: 168 y: 150 z: 257 value: -0.554963
Ra 03h 41m 19.851s Dec 31d 55m 51.95s Vel: 6.35 km/s
IRAS 03382+3145

Shells in Perseus



10x momentum & energy of bipolar flows (now)

mass has been multiplied by 2.5 to estimate opacity correction (full correction coming soon!)
also, IC348/Omicron Per HII region is not included, yet

Perseus

Arce et al. 2010a,b

OBSERVED Momemtum in Shells is ~10x ***more*** than in bipolar flows...

"Bipolar" Flows

Table 6
Total Outflow Mass, Momentum, Energy, and Luminosity in Star-forming Regions

Name	M_{flow}[a] ($M_\odot$)	P_{flow}[a] ($M_\odot$ km s^{-1})	E_{flow}[a] (10^{44} erg)	L_{flow}[b] (10^{32} erg s^{-1})
L1448	1.0/5	3.1/21.7	1.2/12	8
NGC 1333	5.0/25	17.4/121.8	6.9/69	44
B1-Ridge	1.1/5.5	3.2/22.4	1.0/10	6
B1	1.5/7.5	6.2/43.4	3.1/31	20
IC 348	4.2/21	7.7/53.9	1.5/15	10
B5	12.8/64	22.3/156.1	4.1/41	26

Notes.
[a] Values before and after the slash are the original estimates and the estimates adjusted by the correction factor, respectively (see Section 5.1).
[b] Outflow luminosity, $L_{flow} = E_{flow}/\tau_{flow}$, obtained using the value of the total outflow kinetic energy adjusted by the correction factor and using an average outflow timescale of 5×10^4 yr.

Shells

Name	Mass	Vexp	Momentum	Energy	Driver
B5-IRS4	62	2	124	2.5	IRAS 03446+3254 (B5-IRS4)
IC348 Shells	42	1	42	0.4	Dust Bowl, HD281159, and J03442106+32073862MASS
IRAS03390+3158	45	5	225	11.1	IRAS 03390+3158
IRAS03382+3145	181	2	362	7.2	IRAS 03382+3145
HD278942	89	5	446	22.2	HD278942
DR-B1 Shell	49	5	244	12.1	SSTcd2 J033525.4+310925
NGC1333-SW	40	2	80	1.6	multiple candidates
NGC1333-NW	126	2	252	5	multiple candidates
Totals	**634**		**1775**	**62.1**	

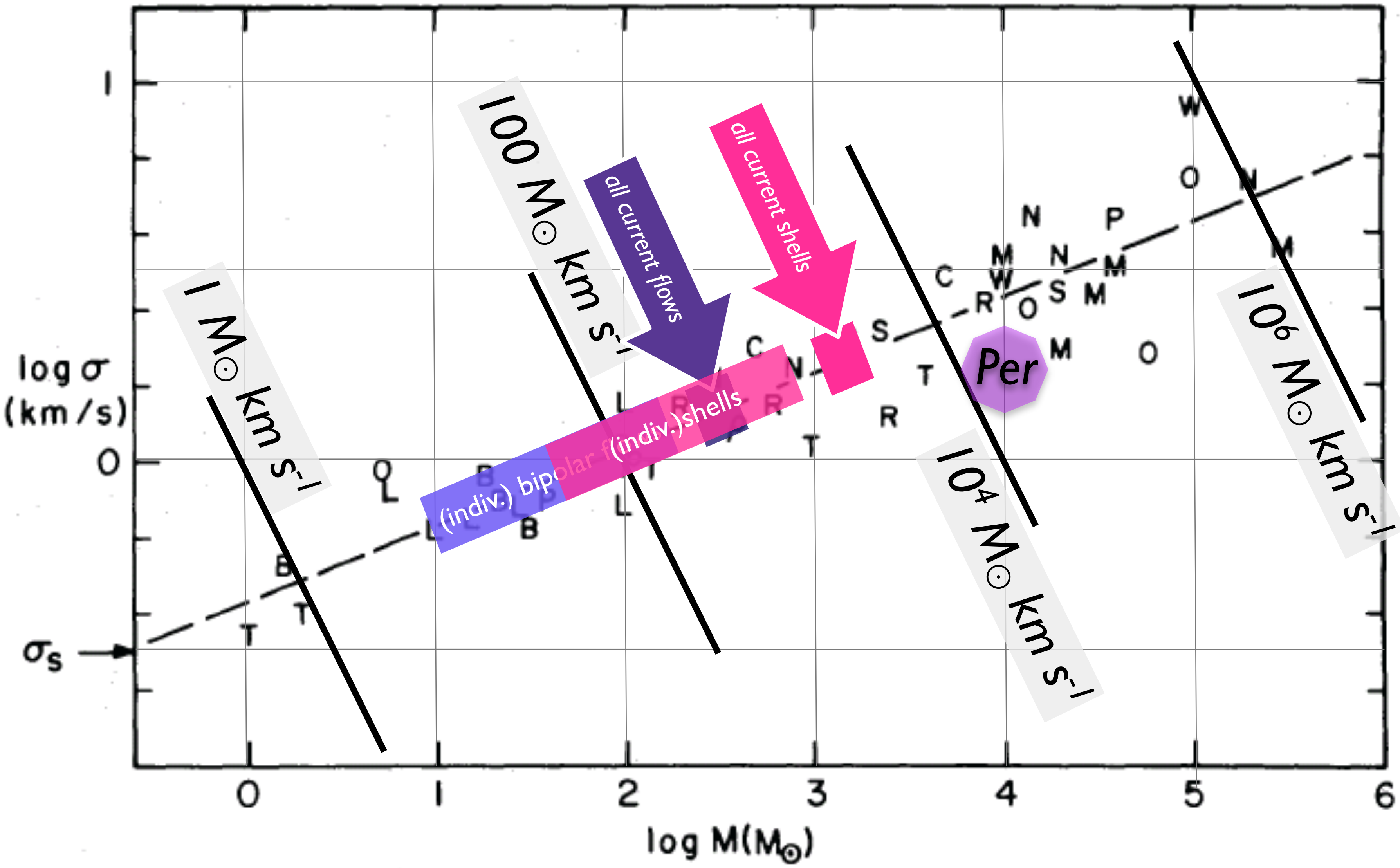
130 $M_\odot$
420 $M_\odot$ km s^{-1}
1.8 x 10^{46} erg

x10=

1600 $M_\odot$
4500 $M_\odot$ km s^{-1}
16 x 10^{46} erg

*For reference: the shell surrounding B-star **HD 278942** (G159.6-18.5; Ridge et al. 2006) is found to have a momentum of approximately **1400 $M_\odot$ km s^{-1}** and **5 x 10^{46} ergs of energy.***


HOMEWRECKERS?



Properties of Molecular Clouds as “Equivalent Momentum” (using Larson 1981)

grey boxes mark lines of constant “momentum,” as labeled

Are “upshifts” needed or correct?

Note theory gives ~10 to 1000 $M_\odot$ km s^{-1} per B-star wind.

Let's think about the basics...

(Underlined quantities are "measured"...others are "derived" or estimated.)

To calculate "***work***" done by flows, we need

work = (*force* * *distance*) [ergs = gm cm^2 s^{-2}]

force of flow = (*momentum*/*time*) [gm cm s^{-2}]

instantaneous *momentum* = *mass* * *velocity* [gm cm s^{-1}]

mechanical luminosity= "*kinetic energy*"/*time* [erg s^{-1}]

Note that work has units of energy but is not necessarily = (1/2) mv^2.

For a nice analytic treatment, see Matzner 2007.

How much do (spherical) winds matter more generally?

Why should we even think about this?
(Perseus HD 278942 example Ridge et al. 2006; Arce, Borkin, Pineda, Goodman 2010a,b)

What **energy/momentum would be needed** to drive "turbulence"?
(Larson plot, analytic ideas, simulations)

How many (B) stars are available in "relevant" volumes?
(Sharma Catlog)

What **could/do (B) stars** do?
(Valverde Thesis)

Where, exactly are stars with winds, and **when** (for how long)?
(very hard to deduce from observations!)

What is **net effect** of stellar winds in **context** to e.g. bipolar outflows, HII regions?
(HII regions>> shells >= bipolar outflows)

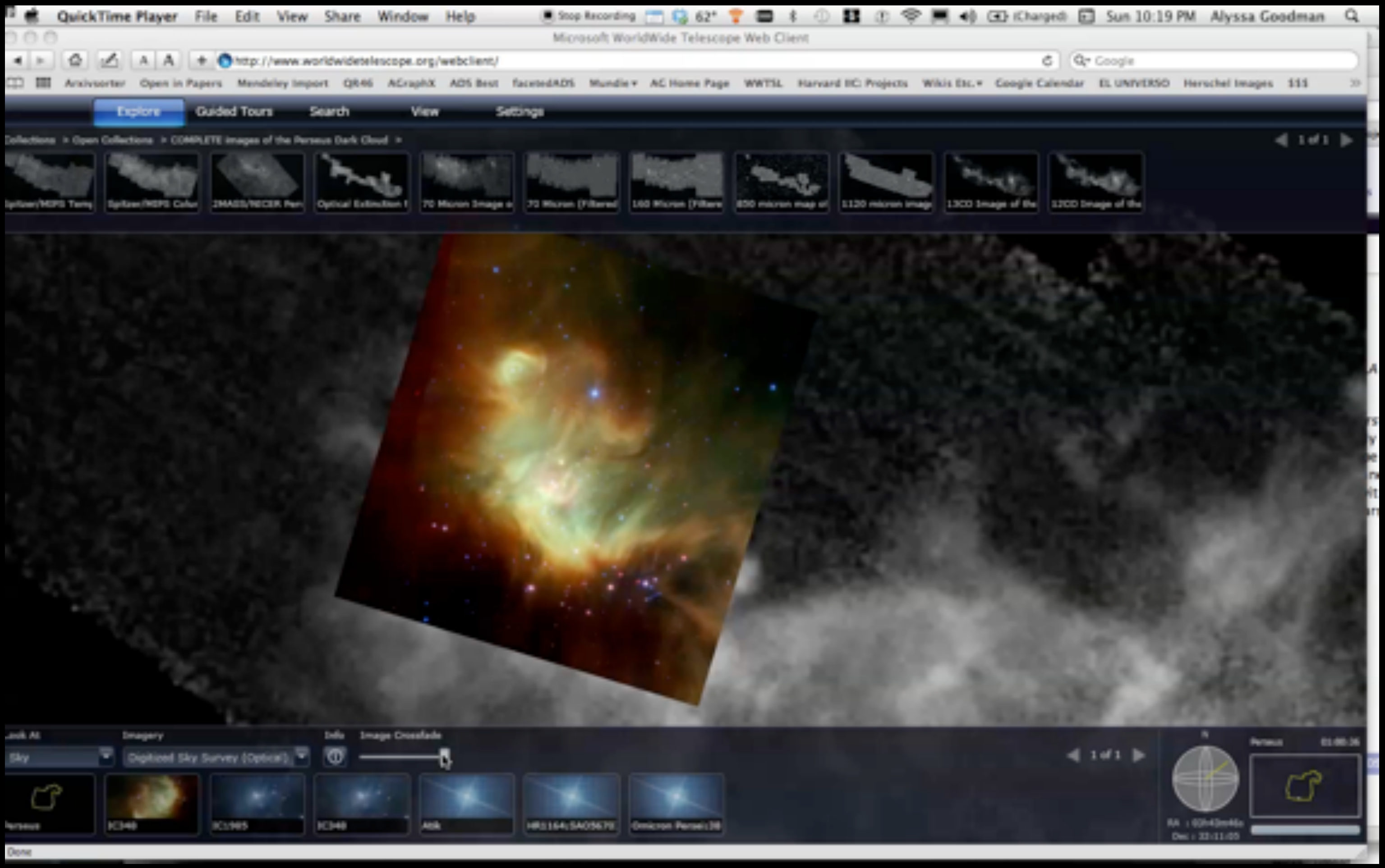
What are the biggest **uncertainties** in this story?
*("net" momentum/energy deposition for various stellar types, **space-time-evolution** of winds)*

Differential Diagnosis

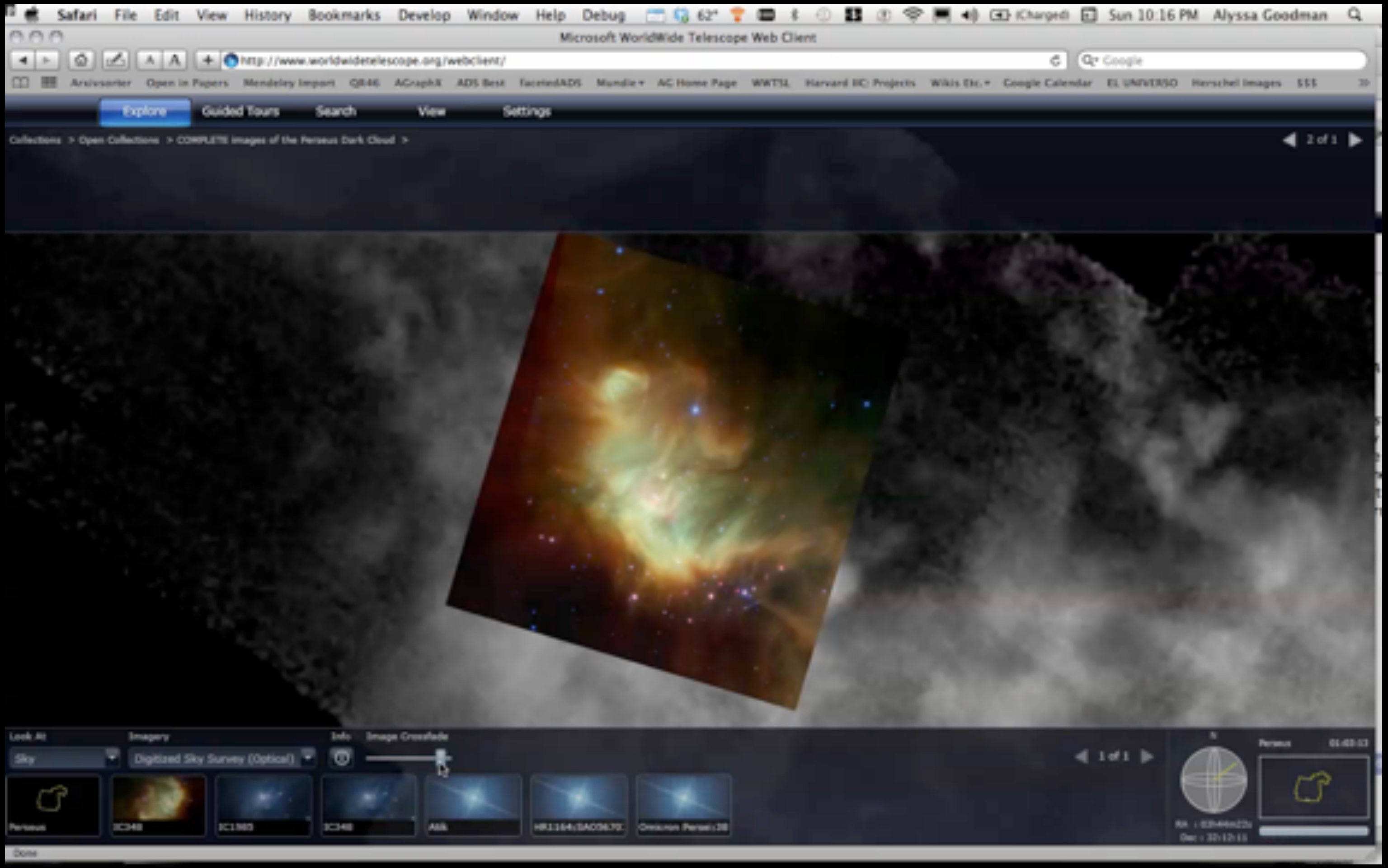
- **Spitzer** Data suggests **shells** in **massive SFRs** *(...but see Beaumont & Williams 2009)*; **COMPLETE** data suggests several **shells** in **wimpier** locales
- **Theorists** suggest spherical "mass-loaded winds" from massive stars don't matter, b/c ***radiation*** is **dominant**.
- **Length** & **time** scales effected by shells may be **different** (larger & longer) than for bipolar outflows.
- Recent **numerical** work by Wang et al., Nakamura & Li, makes **outflows** look better (more **effective**) than Perseus data do (Arce et al. 2010). Why?
- **Time/spatial** scales + **coupling** are not well-known.
- *We need a way to learn patient **histories,** as "**all patients lie.**"*

HOUSE
FOX.COM/HOUSE

^{13}CO is in the "middle"



^{12}CO is at the "edges"



Extra Slides from Ringberg 2010

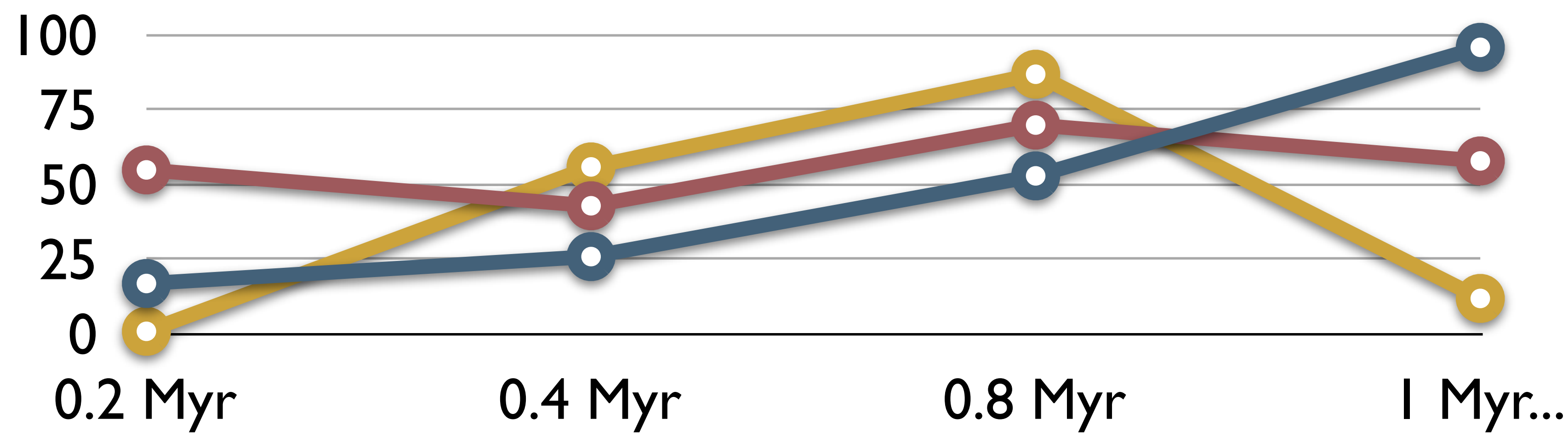
Sanjana Sharma's new Catalog (10,000 B-stars w/in 600 pc)
+
Lawrence Valverde's Harvard Senior Thesis
(theoretical/observational comparison for B-stars like HD278942)

Preliminary Conclusion:
Plausible that B-stars (and maybe less massive stars too!?) make key contribution where they are most massive stars around.
Goodman et al. 2011

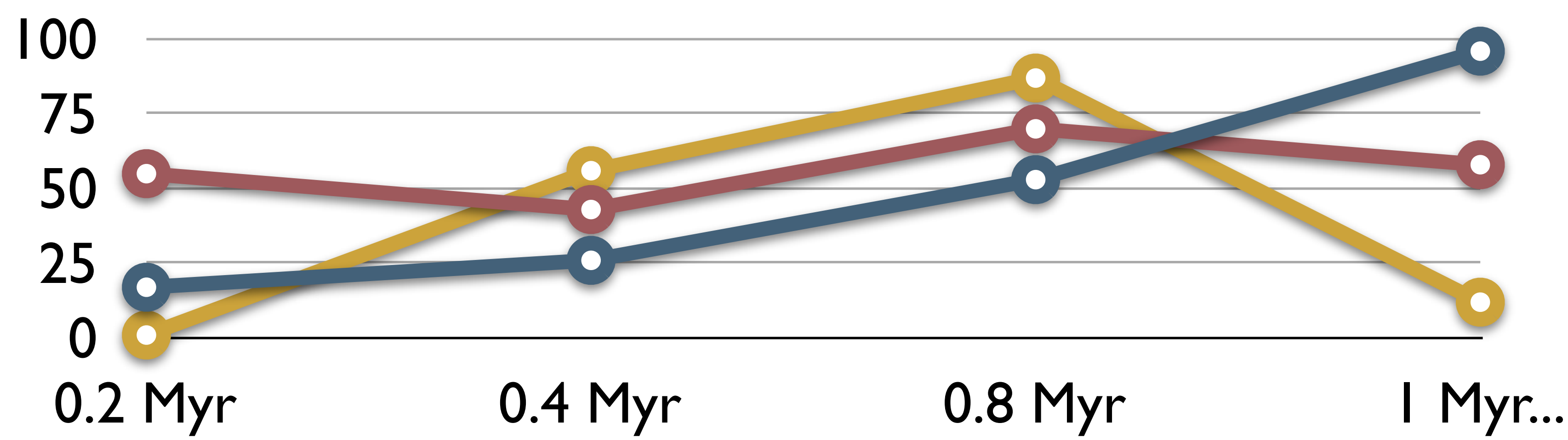
For various conditions, we need to estimate:

Bipolar Flows   "Shells"   HII Regions

on pc scales



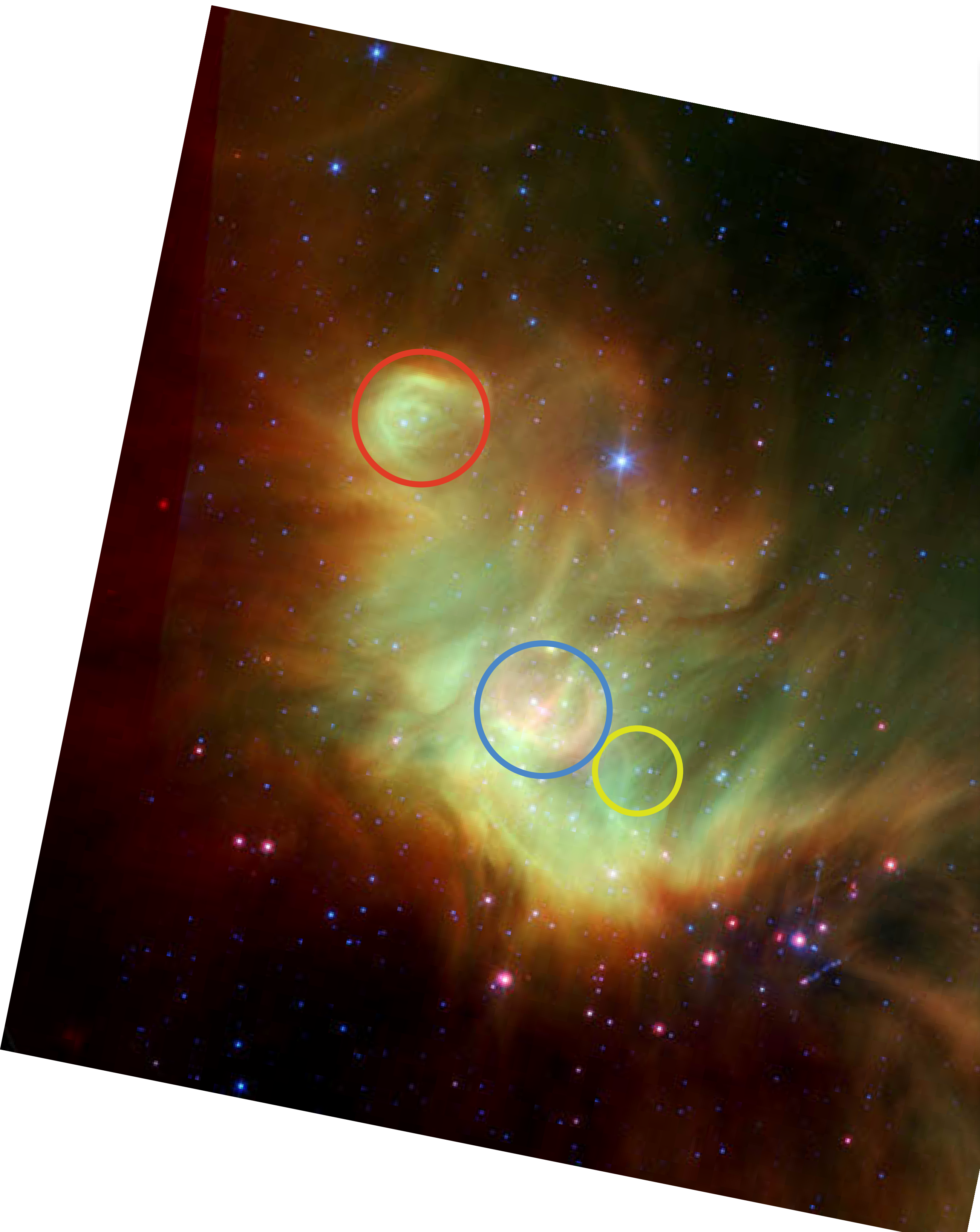
on 10 pc scales

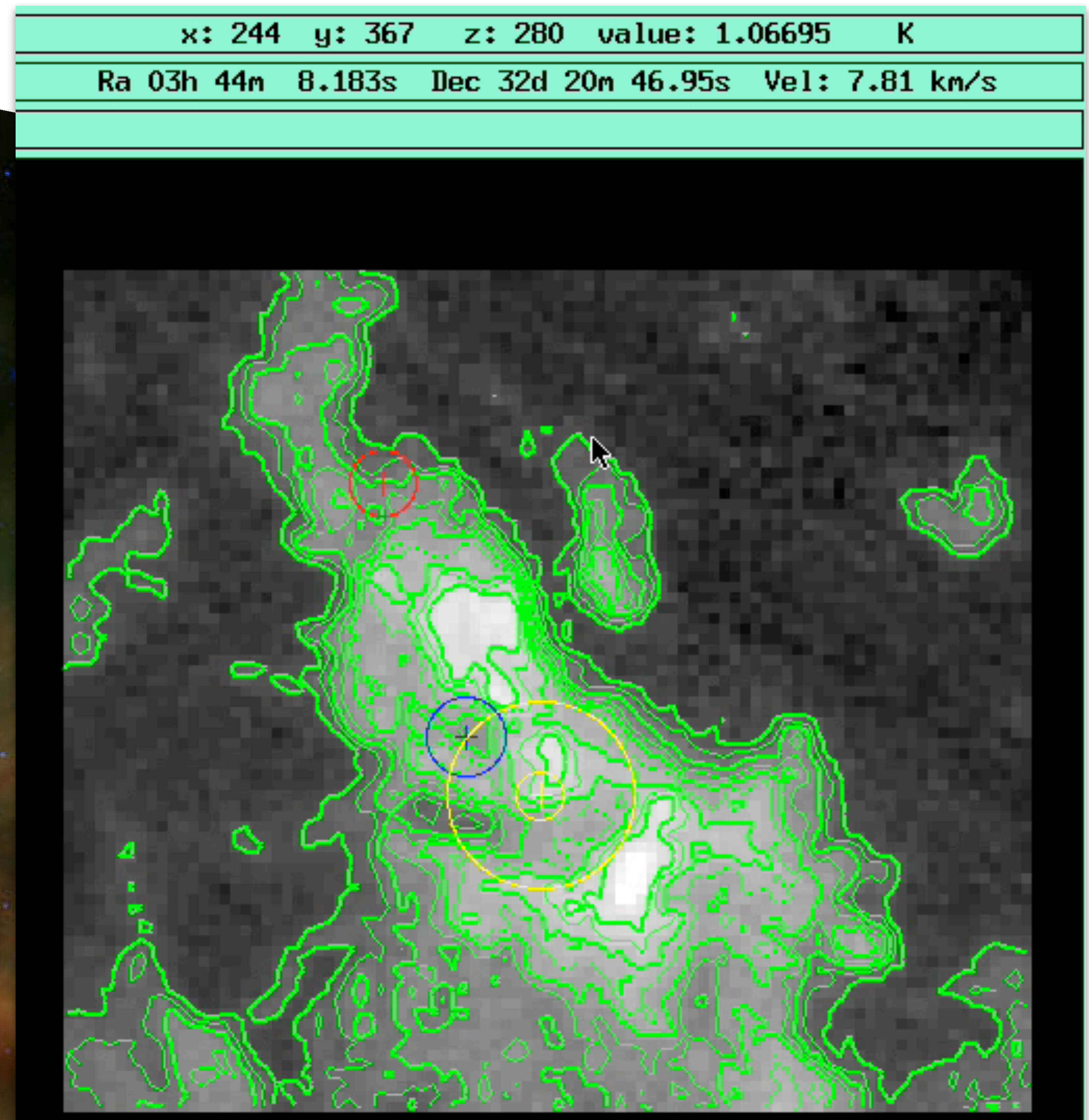


etc...

IRAC and MIPS composite image from Spitzer Space Telescope website:
Color image made with: 4.5 μm (blue); 8.0 μm (green); 24 μm (red).

Color circles show position of shells shown in SnapZ movie. Note that the circles are included just to show the approximate positions of the shells (the size of the circle does not mean anything). The shells shown with the red and the blue circles were discovered using the Spitzer imgaes (and are a bit hard to see in the 12CO channel maps. The yellow circle denotes a shell that was found in the 12CO channel maps, but it is not seen in the Spitzer images .





Where do shells go on Larson's diagram?

HST view of NGC 604 in M33 (1 Mpc away)

**...but, see Beaumont & Williams 2009*

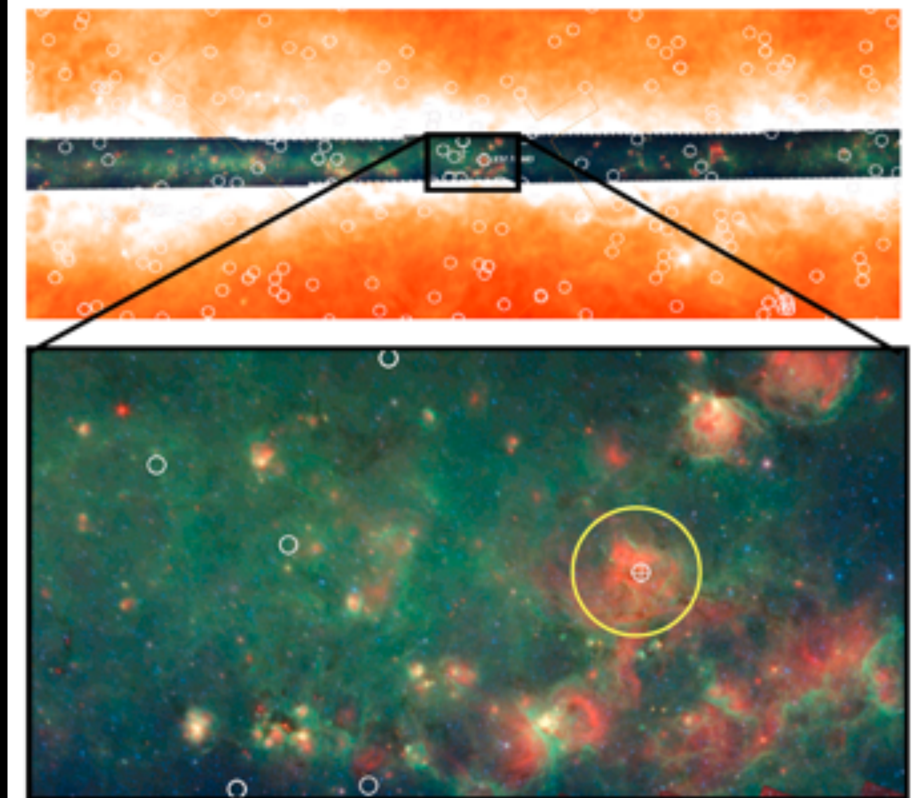
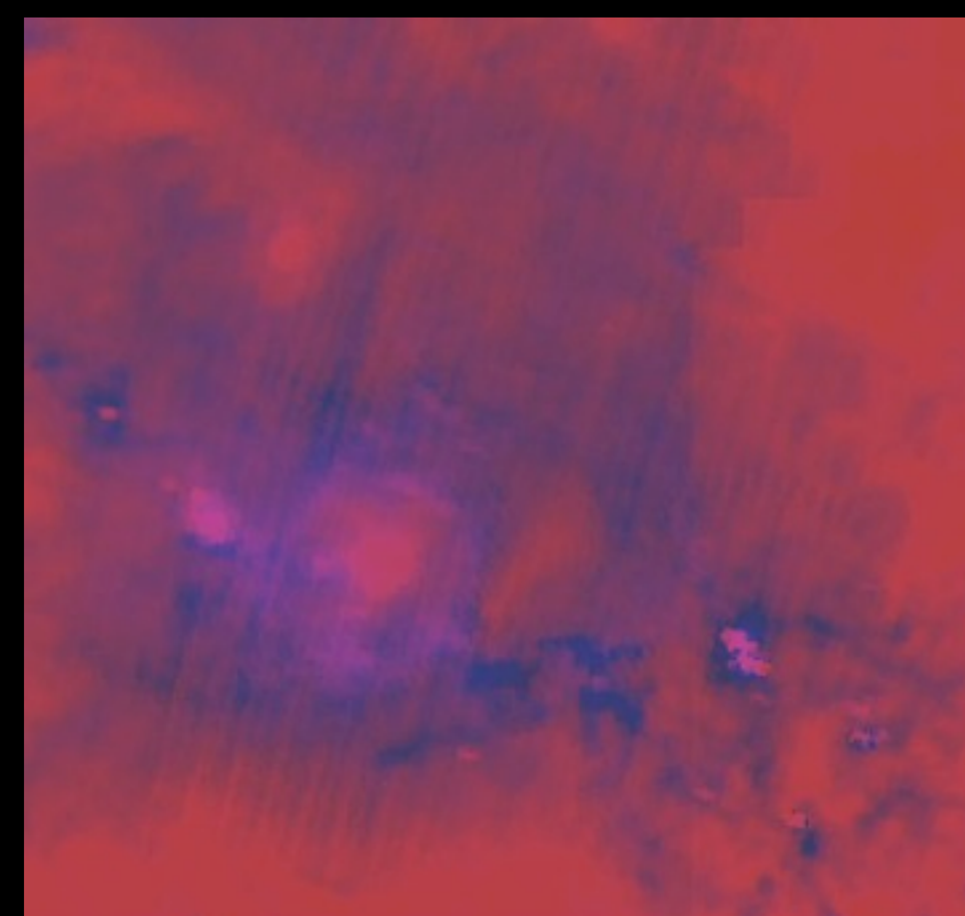
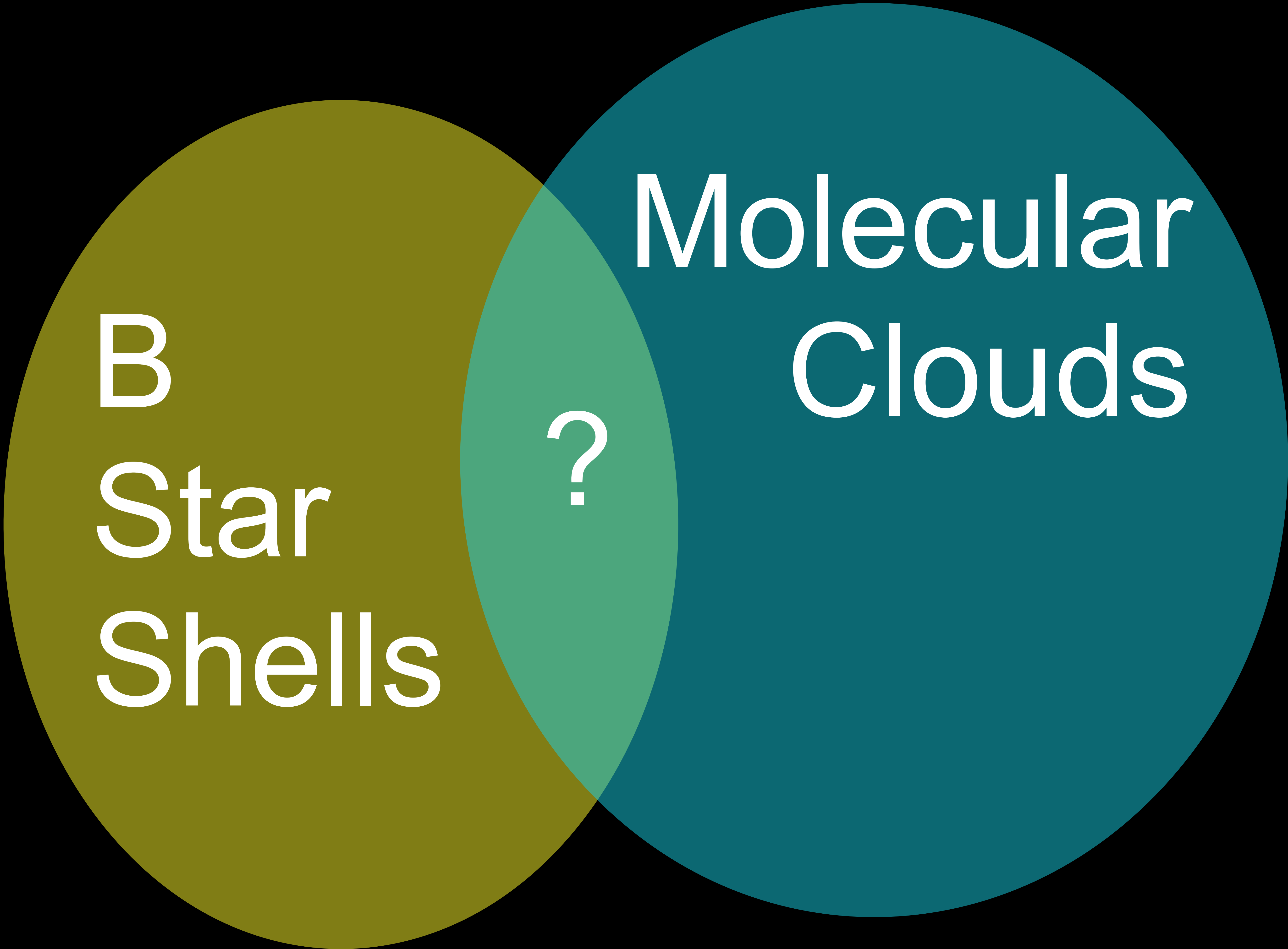


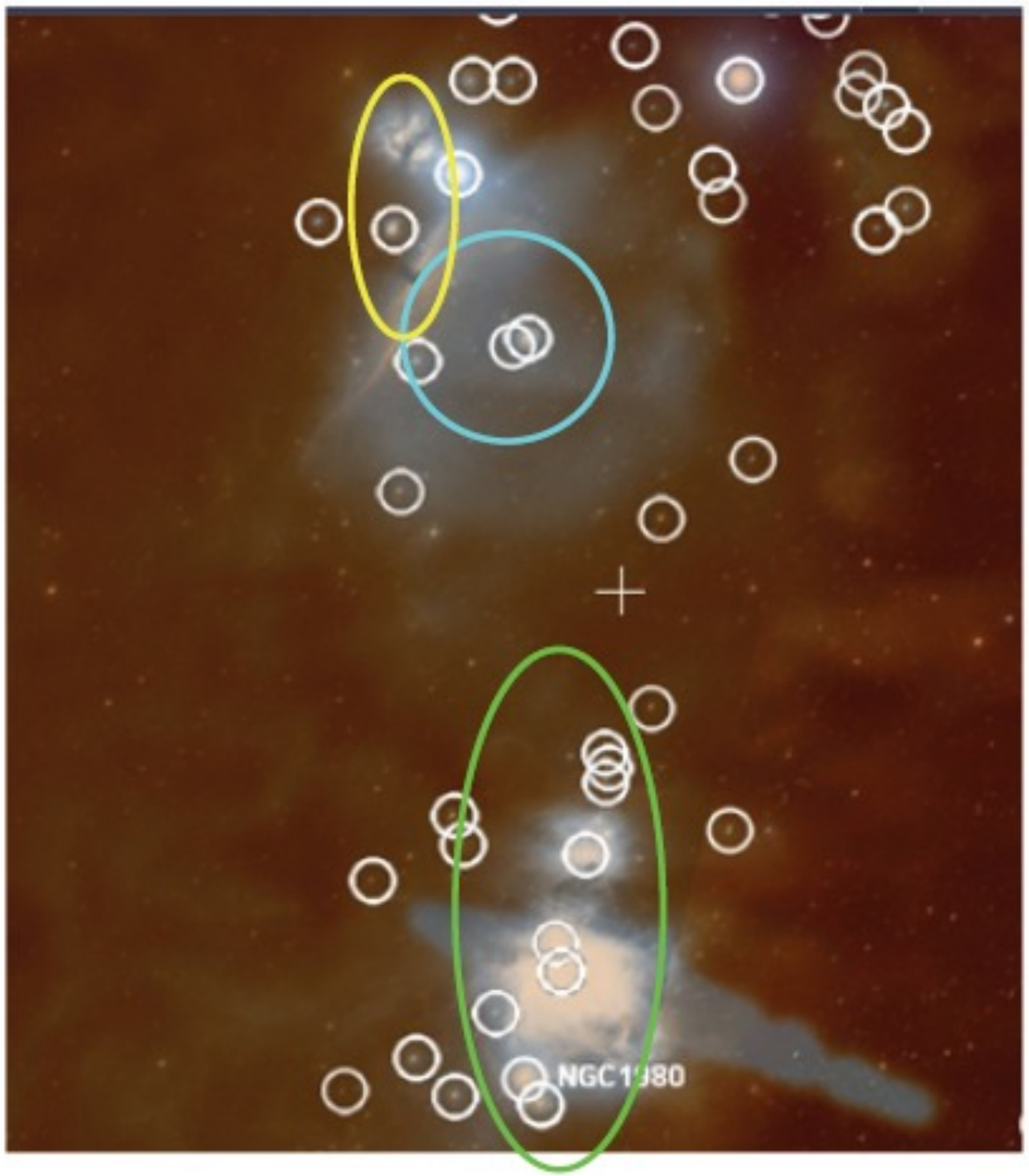
Figure 3.9: Apparent B Star Shell in Glimpse Data
The yellow circle surrounds an example of coincidental overlap between B stars and molecular cloud structure separated radial to our line of sight by hundreds of parsecs.




B
Star
Shells
?
Molecular
Clouds

World Wide Telescope

OB Associations in Orion
B Stars in Orion's Belt



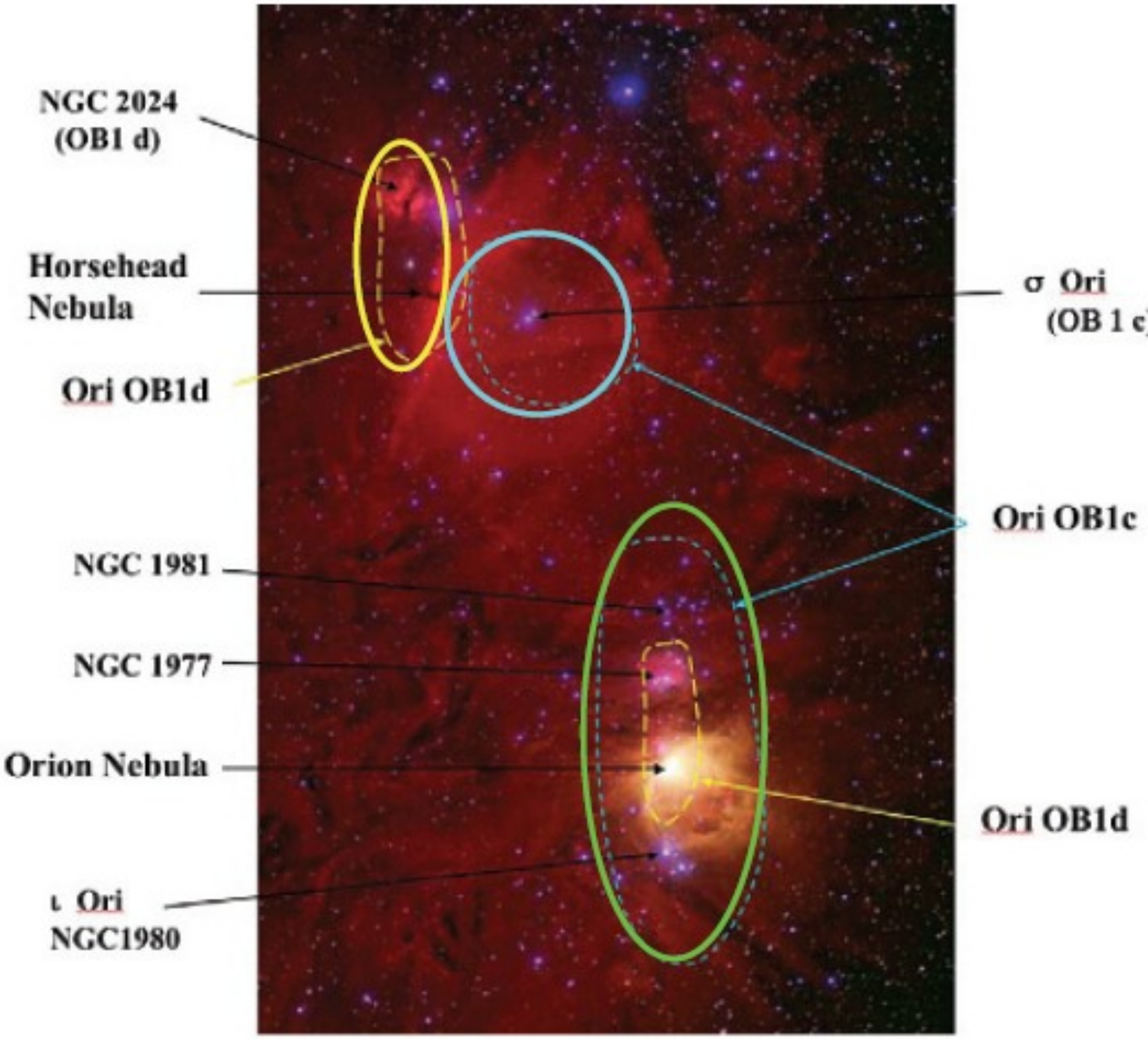


Table 3.2: Variables for Molecular Cloud – B Star Shell Intersection

Variable	Meaning	Estimated Value
R_s	Radius of one B star shell	3 pc
V_s	Volume of one B star shell	1.1×10^{2} pc^3
N	Number of B stars within volume, V_{space}	10^4
V_{space}	Volume of catalogue region	1.7×10^{8} pc^3
V_w	Volume of space for ff	2.4×10^{10} pc^3
ff	Molecular cloud filling factor	8×10^{-3}
f	Fraction of B star shells located within Molecular Clouds[1]	$5\times10^{-5} – 8\times10^{-1}$

3.1 General Formulation

The effect of B stars on turbulence in molecular clouds can be inferred from the energy and momentum deposited by B stars into molecular clouds. For a given environment, this energy is a function over time of the number of B stars and the energy deposited into molecular clouds per star. This can be represented symbolically as

$$\dot{E} = N \dot{E}_d \qquad (3.1)$$

where $\dot{E}$ is the total energy imparted to a molecular cloud per unit time, N is the number of B stars within a given volume of space, and $\dot{E}_d$ is a function giving the energy deposited by each B star into a molecular cloud per unit time. The function $\dot{E}_d$ can be further defined as

$$\dot{E}_d = f \dot{E}_S \varepsilon \qquad (3.2)$$

where f is the integrated volume of shells from B stars per volume of molecular clouds in the galaxy, $\dot{E}_S$ is the energy output of one B star per unit time, and ε is the energy transfer efficiency from the B star winds to the molecular cloud. Finally, this formula must be integrated over the total B star lifetime for which winds are active. Thus, the final equation for which values must be found in order to determine the impact of B stars on molecular clouds is

$$E = \int_{InteractionStart}^{InteractionStop} (Nf\varepsilon \dot{E}_S)dt \qquad (3.3)$$

How much energy/time? How many stars?

What is geometric overlap? (deposition)

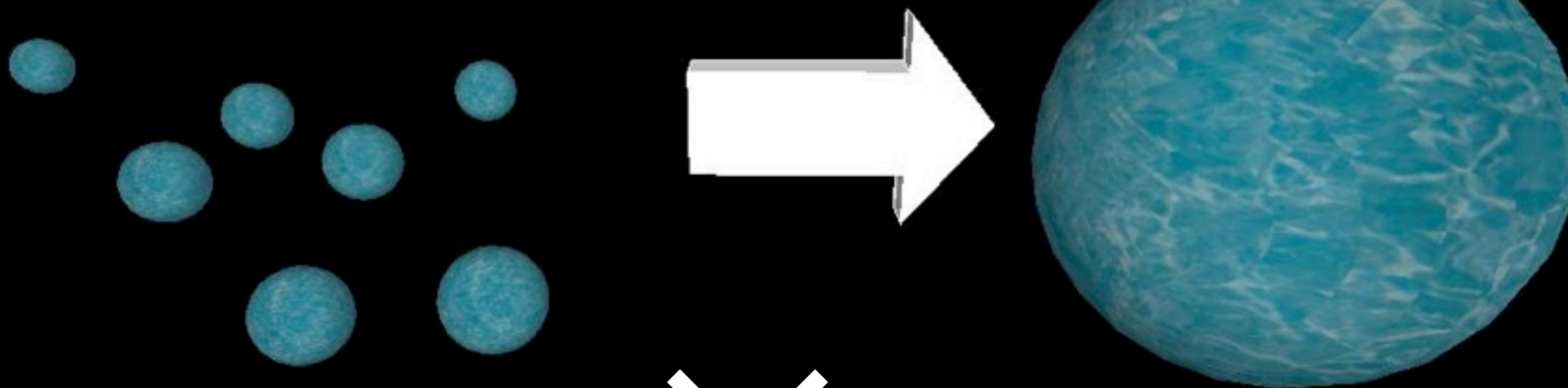
Energy transfer efficiency? (hardest part?)

Duration of interaction?

Since only the kinetic part of the energy is relevant in relation to turbulence, a similar relation in terms of momentum is more illuminating and can be defined as

$$MV_{\infty} = \int_{InteractionStart}^{InteractionStop} (Nf\mu \dot{M} V_{\infty S})dt \tag{3.4}$$

where MV_{∞} is the momentum imparted to the interstellar medium, $\dot{M} V_{\infty S}$ is the momentum output per unit time per star, and μ is the momentum transfer efficiency from the B star winds to the molecular clouds.



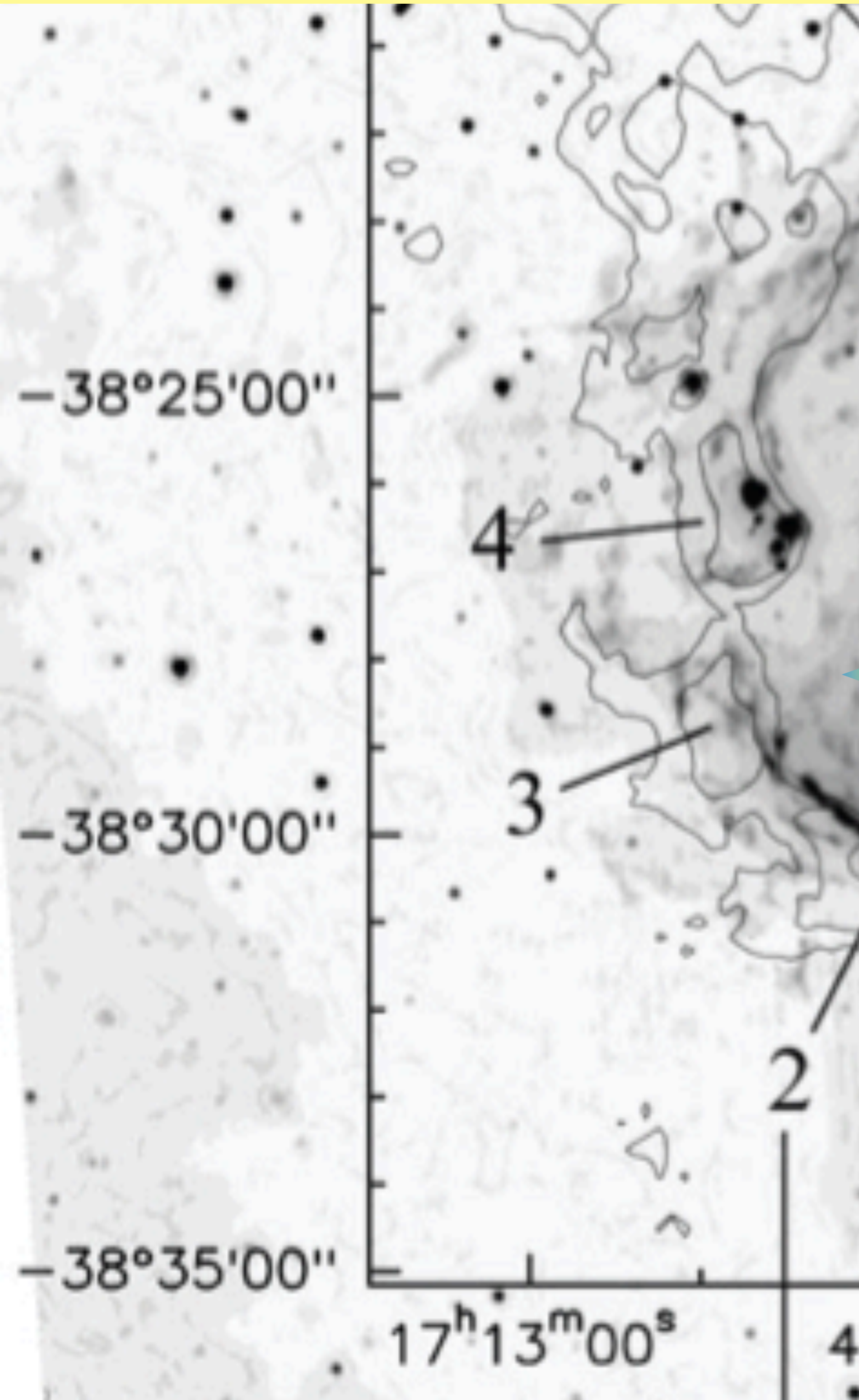
×

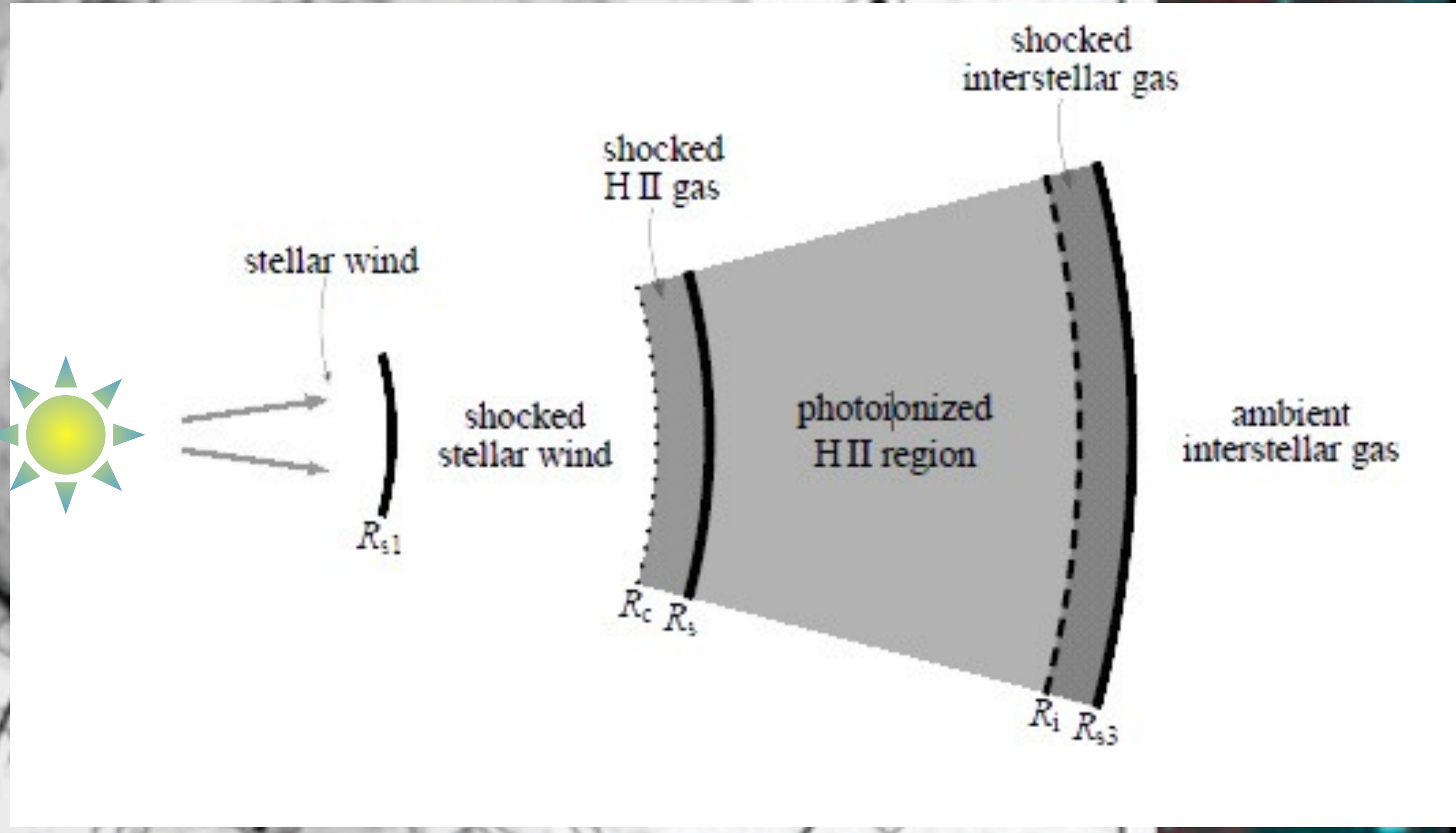
$$ff = 0.008$$

$$ff \times \frac{N \times V_S}{V_{space}} \approx 5.3 \times 10^{-5}$$

$$\frac{\text{Volume of B Star Shells}}{\text{Volume of Molecular Clouds}} \approx 0.8$$

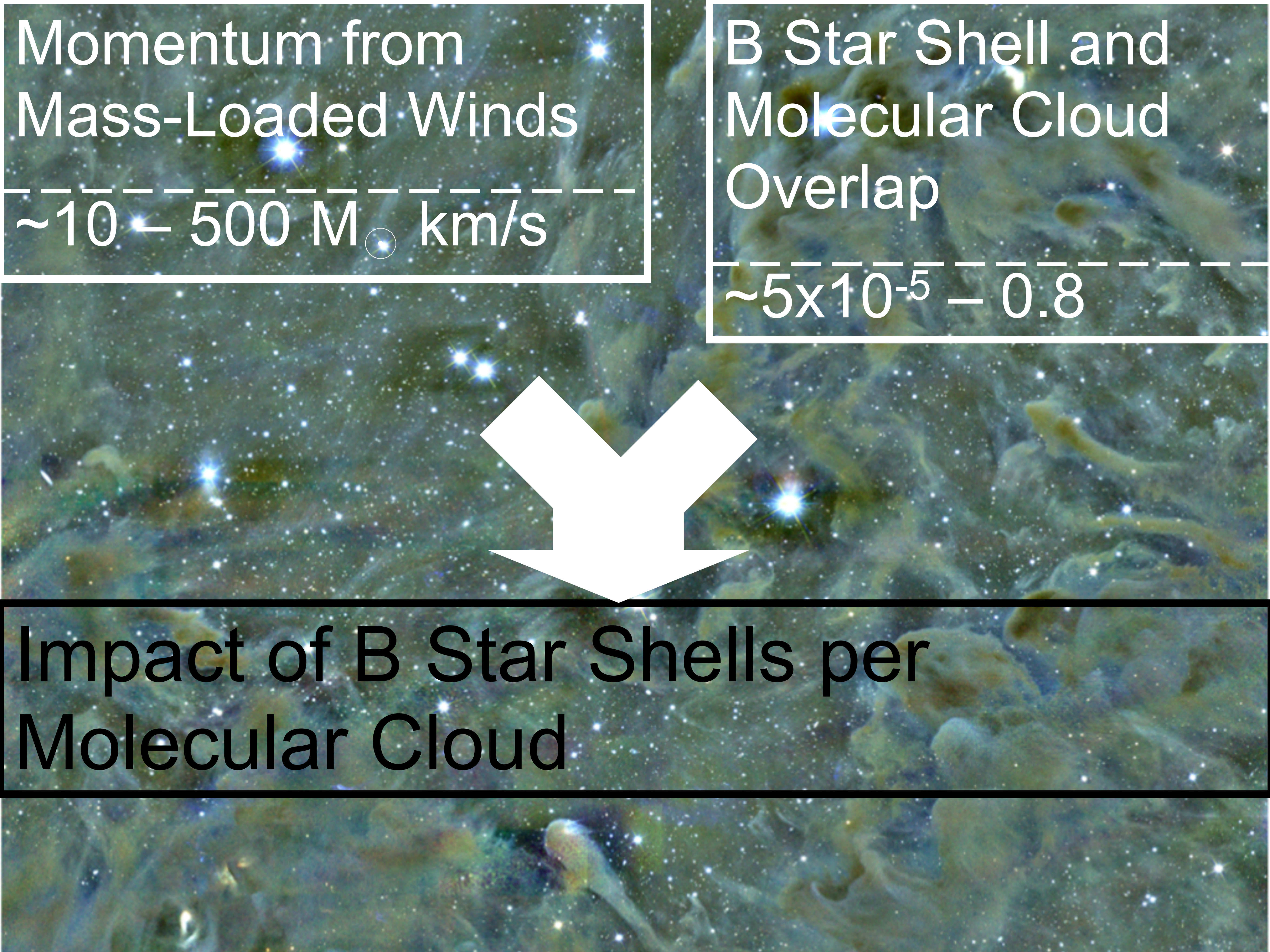
AG Comments: Differentiating between (near-star) effects of mass-loaded wind, and ultimate effects of (far-from-star) net momentum (mass-loaded + radiation-driven expanding heated shell) is hard... needs simulations....

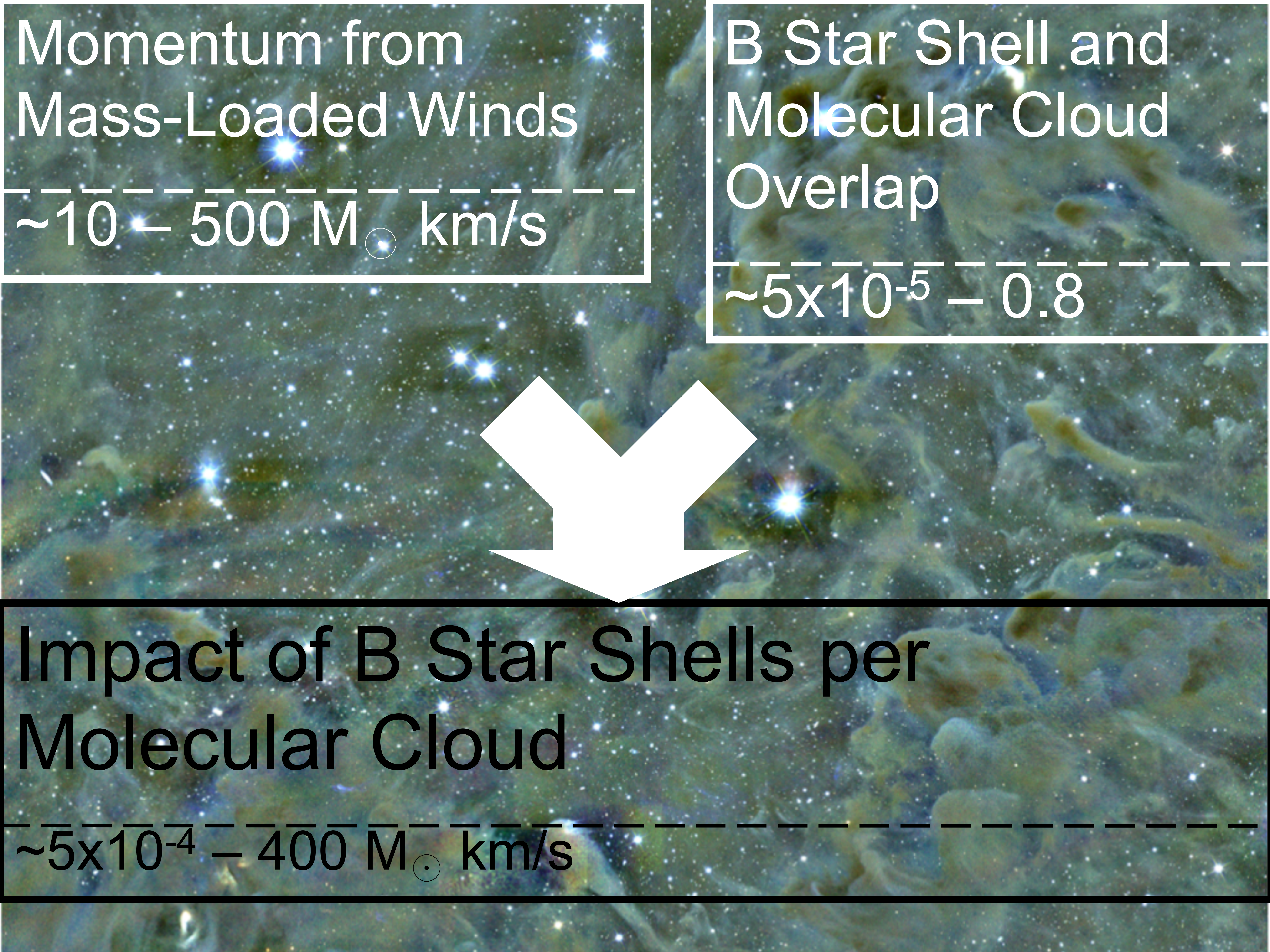




Summary of Momentum Ranges for HD 278942

Method	Lower Bound ($M_\odot$ km s^{-1})	Upper Bound ($M_\odot$ km s^{-1})
$\dot{M} V_\infty = \eta \left(\frac{L_*}{c} \right)$	11	1100
$MV_\infty = \dot{M} * (V_\infty / V_{esc}) * V_{esc}$	10	300
Observation	500	


Momentum from Mass-Loaded Winds
~10 – 500 $M_{\odot}$ km/s
B Star Shell and Molecular Cloud Overlap
~5x10^{-5} – 0.8
Impact of B Star Shells per Molecular Cloud

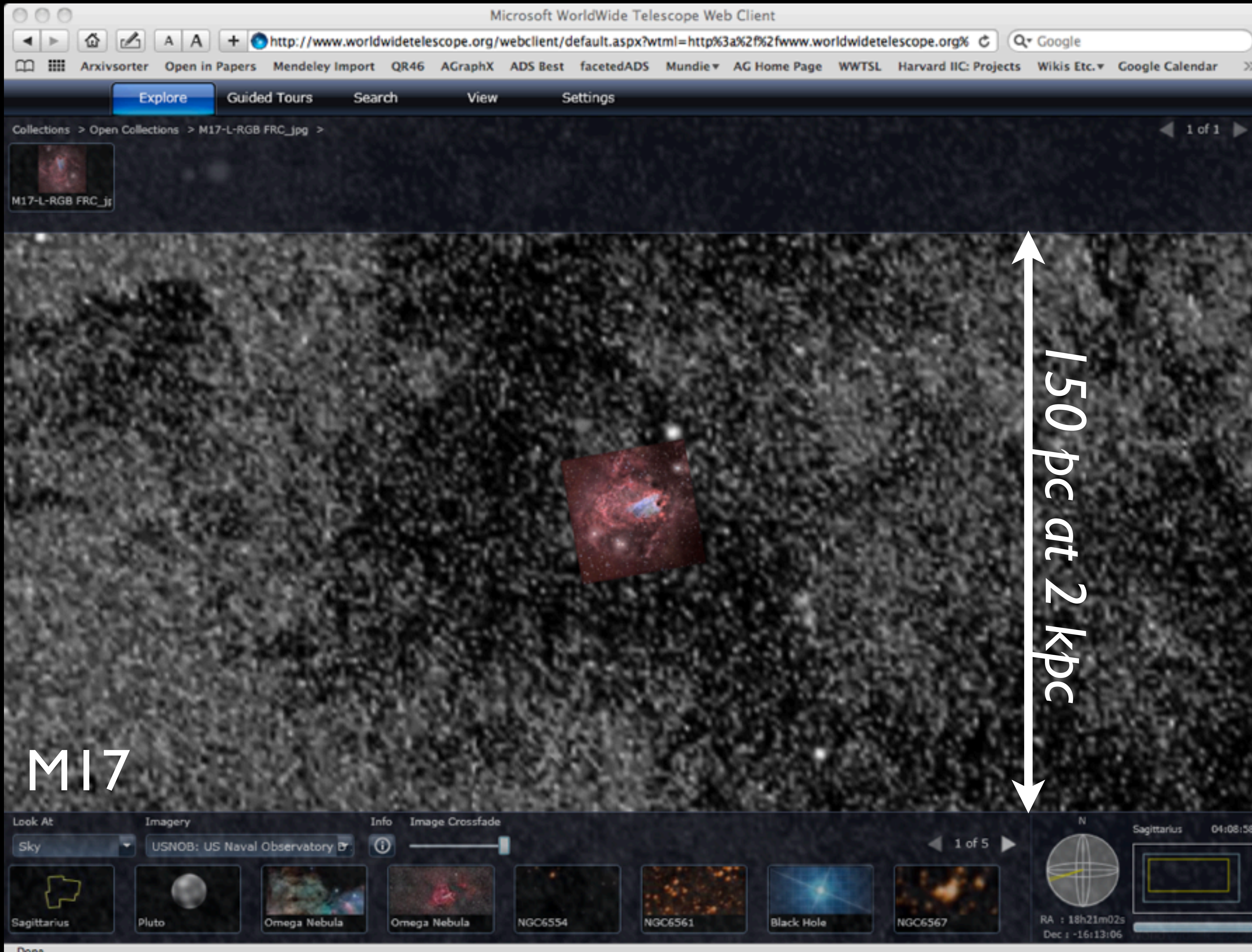

Momentum from Mass-Loaded Winds
~10 – 500 $M_\odot$ km/s
B Star Shell and Molecular Cloud Overlap
~5×10^{-5} – 0.8
Impact of B Star Shells per Molecular Cloud
~5×10^{-4} – 400 $M_\odot$ km/s

How Influential?

Relative Number	"Typical" Mass	Spectral Type	Wind Energy	Kinetic Energy	Lifetime (Myr)
1	20	0			6
50	4	B			300
300	1.8	A			2000
750	1.2	F			~10,000
>1500	0.9	G-K-M			>10,000

$L \propto M^{3.5}$

$$\tau_{ms} \approx 10^{10} \text{years} \cdot \left[\frac{M}{M_{\odot}}\right] \cdot \left[\frac{L_{\odot}}{L}\right] = 10^{10} \text{years} \cdot \left[\frac{M_{\odot}}{M}\right]^{2.5}$$


Microsoft WorldWide Telescope Web Client
http://www.worldwidetelescope.org/webclient/default.aspx?wtml=http%3a%2f%2fwww.worldwidetelescope.org%
Arxivsorter
Open in Papers
Mendeley Import
QR46
AGraphX
ADS Best
facetedADS
Mundie
AG Home Page
WWTSL
Harvard IIC: Projects
Wikis Etc.
Google Calendar
Explore
Guided Tours
Search
View
Settings
Collections > Open Collections > M17-L-RGB FRC_jpg >
1 of 1
150 pc at 2 kpc
M17
Look At
Sky
Imagery
USNOB: US Naval Observatory
Info
Image Crossfade
1 of 5
Sagittarius
Pluto
Omega Nebula
Omega Nebula
NGC6554
NGC6561
Black Hole
NGC6567
Sagittarius
Done

Perseus (Valverde Slide!)

Results of Ridge et al. 2006

mm peak (Enoch et al. 2006)

sub-mm peak (Hatchell et al. 2005, Kirk et al. 2006)

^{13}CO (Ridge et al. 2006)

mid-IR IRAC composite from c2d data (Foster, Laakso, Ridge, et al. in prep.)

Optical image (Barnard 1927)