The West-End of Perseus

A journey through star-formation in reverse.

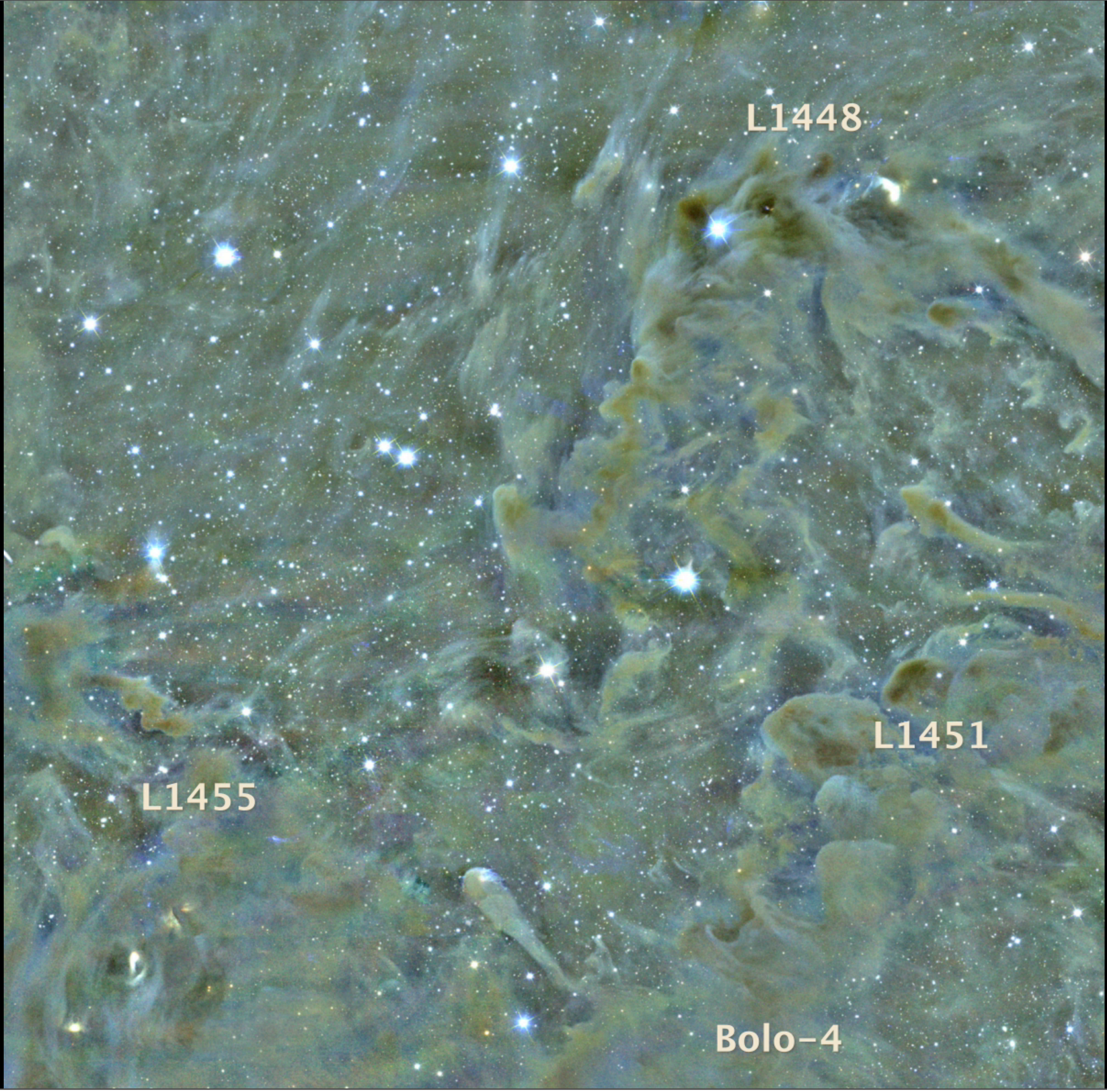
Main Image:

MMT/ Megacam *r,i,z*

Zooms/fades:

Calar Alto/ OMEGA2000 *J,H,K_s*

Animation courtesy of Jonathan Foster



Three Open Questions in Star Formation
and
How to **Taste** the Answers

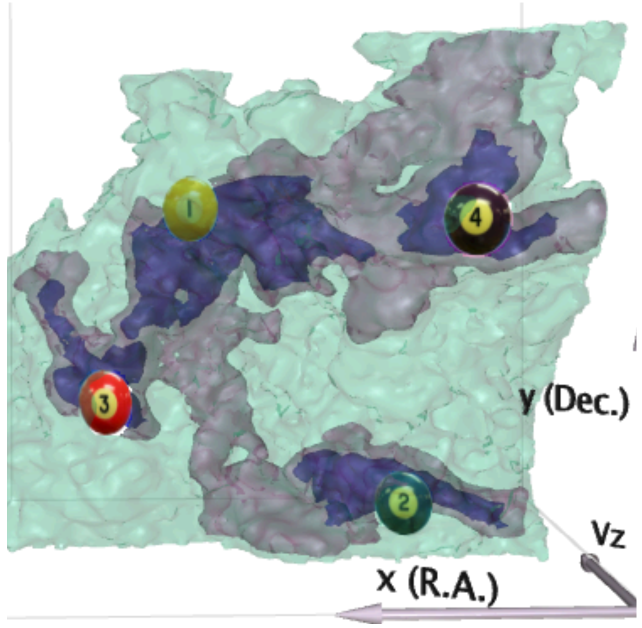
Alyssa A. Goodman
Harvard-Smithsonian Center for Astrophysics

with João Alves, Héctor Arce, Frank Bertoldi, Michelle Borkin, Paola Caselli, David Collins, Jonathan Foster, Katherine Guenthner, Michael Halle, Doug Johnstone, Jens Kauffmann, Helen Kirk, Elizabeth Lada, Kaisey Mandel, Phil Myers, Stella Offner, Jaime Pineda, Naomi Ridge, Carlos Román-Zúñiga, Erik Rosolowsky, Sana Sharma, Scott Schnee, & Rahul Shetty
+ thanks to Douglas Alan, Chris Beaumont, Kevin Covey, Nick Holliman, Gus Muench, Paolo Padoan, & Tom Robitaille

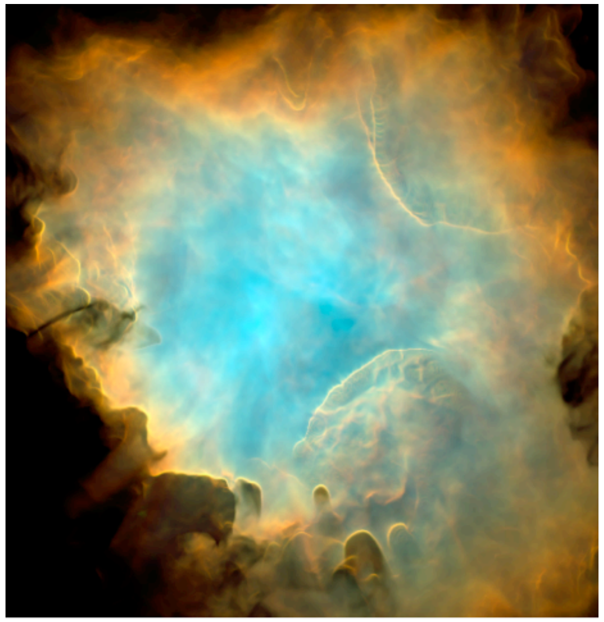
background simulation courtesy of Stella Offner
background image J. Zivick 2010 September 28, courtesy ALMA (ESO/NAOJ/NRAO)

3 Open Questions

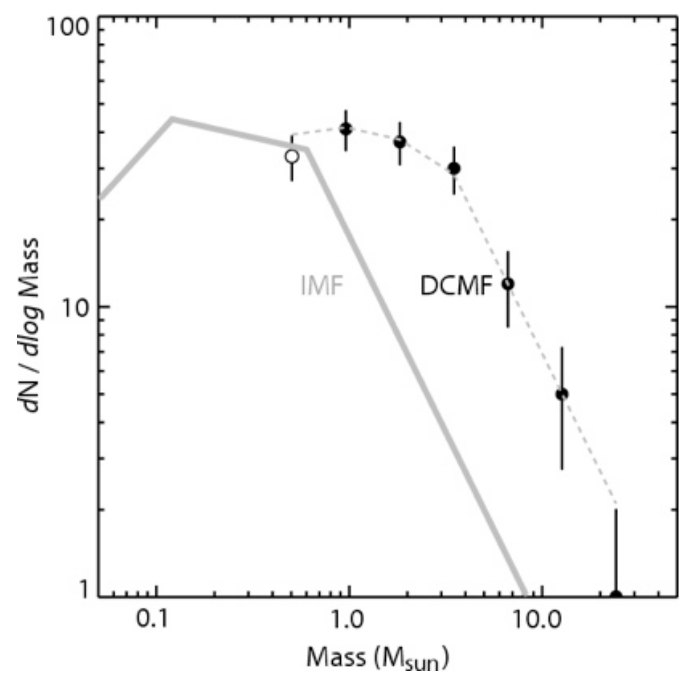
1. At what scales does **gravity** matter?



2. What do **stars** really do to clouds?

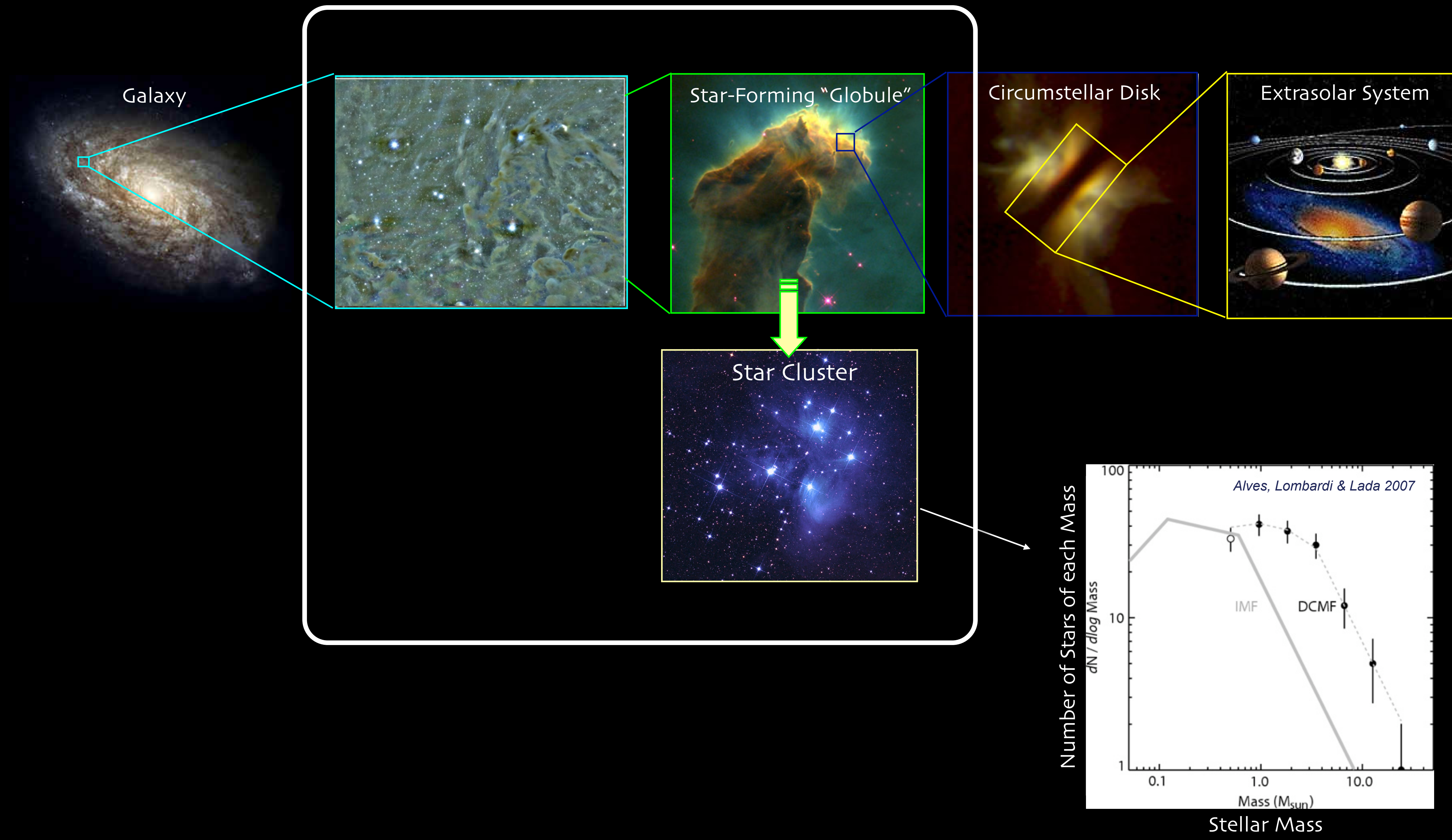


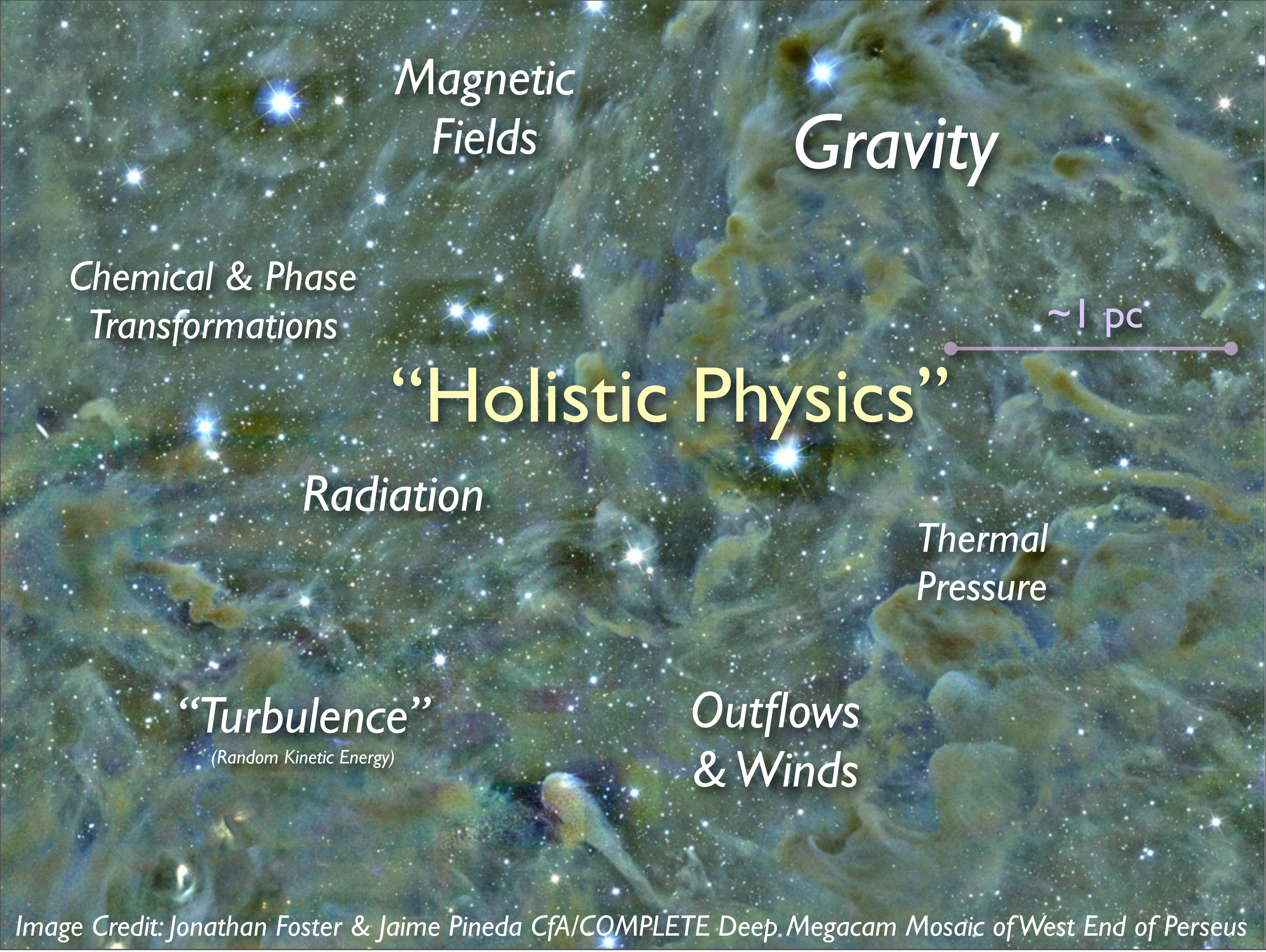
3. Is the origin of the **IMF** related (only) to the CMF?



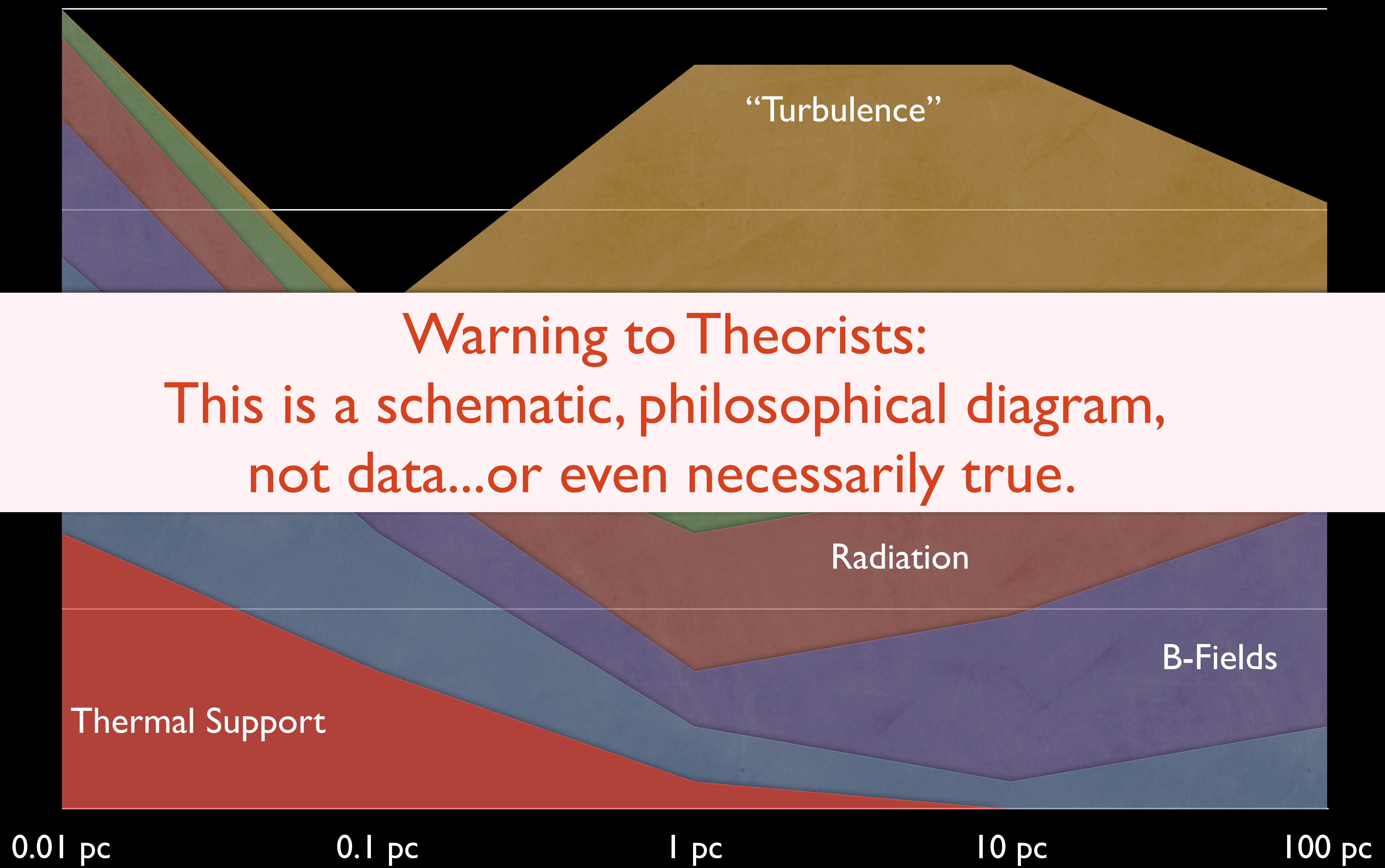
+ "tasty" approaches to answers

Star (and Planet, and Moon) Formation 301

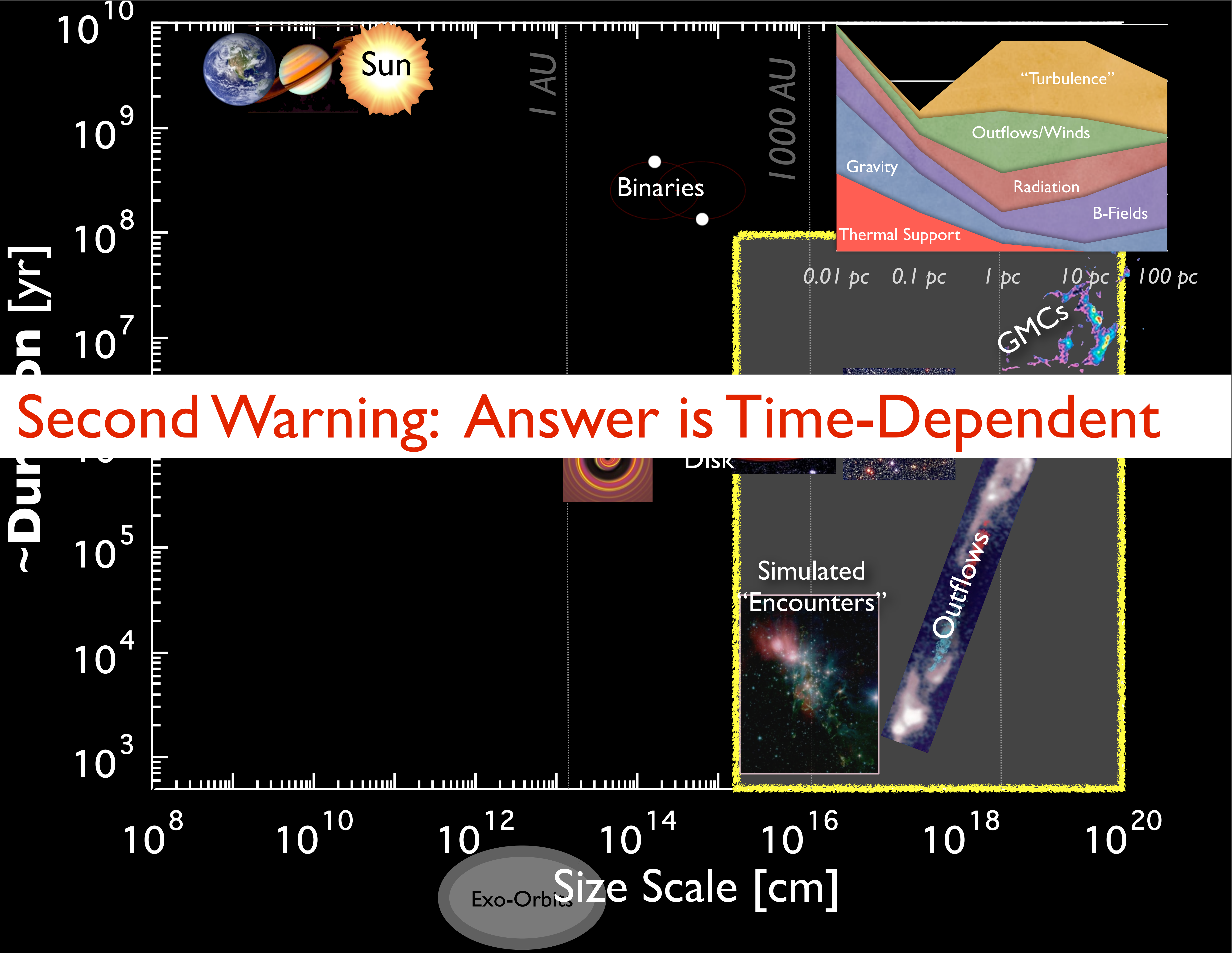



Magnetic Fields
Gravity
Chemical & Phase Transformations
~1 pc
"Holistic Physics"
Radiation
Thermal Pressure
"Turbulence"
(Random Kinetic Energy)
Outflows & Winds
Image Credit: Jonathan Foster & Jaime Pineda CfA/COMPLETE Deep Megacam Mosaic of West End of Perseus

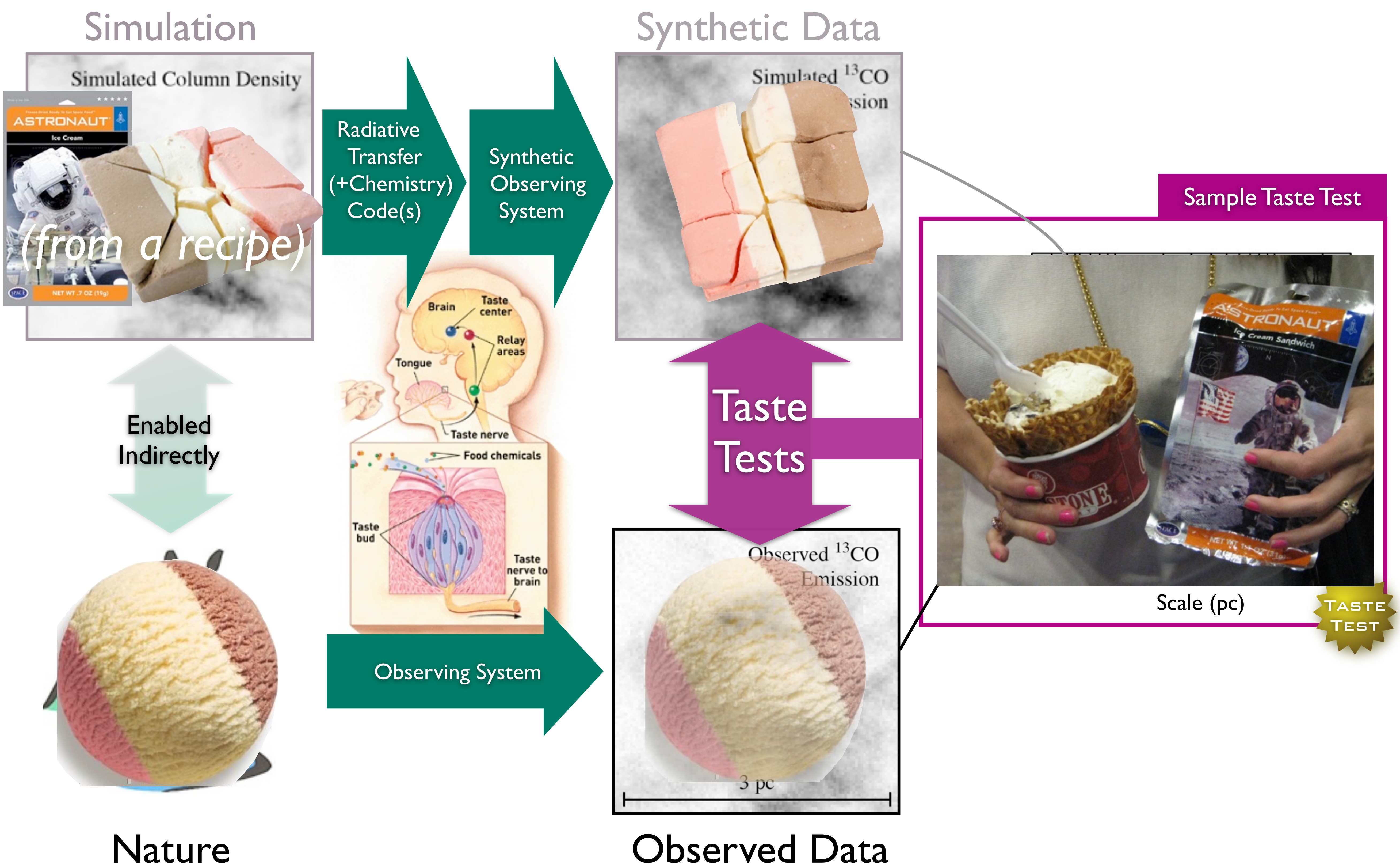
1. At what scales does gravity matter?



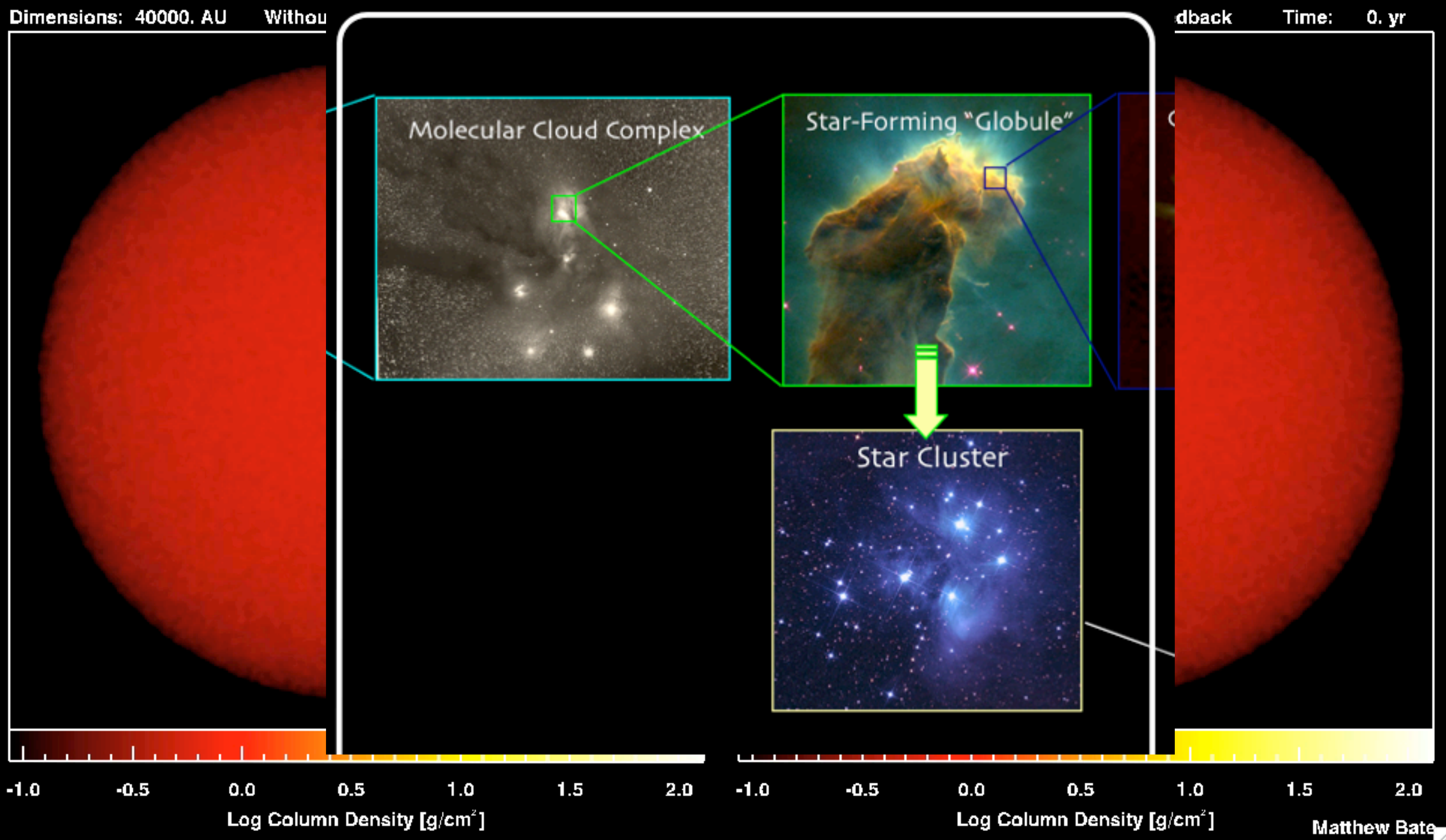
Second Warning: Answer is Time-Dependent



The Taste-Testing Process

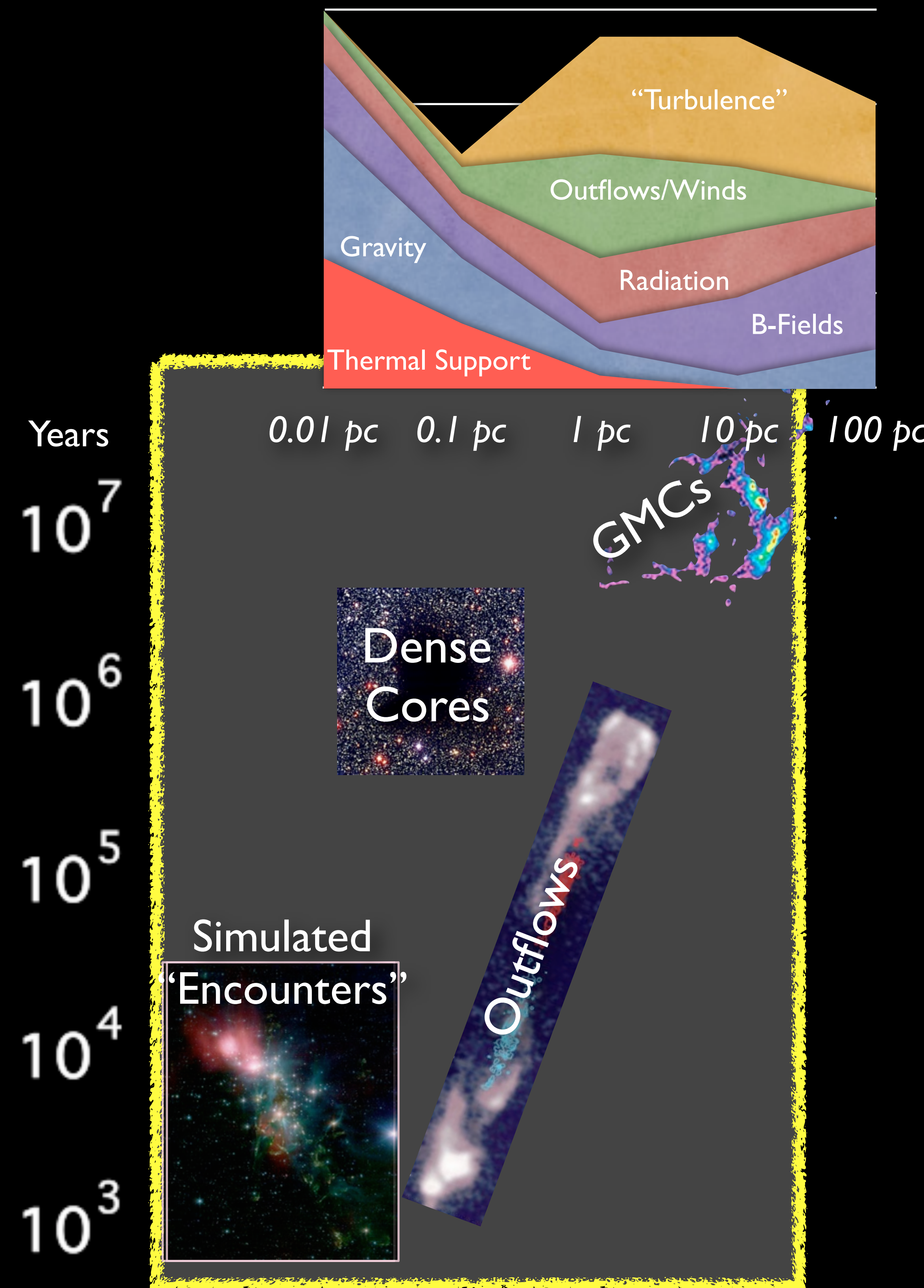


Our Goal is to "Taste" Star Formation

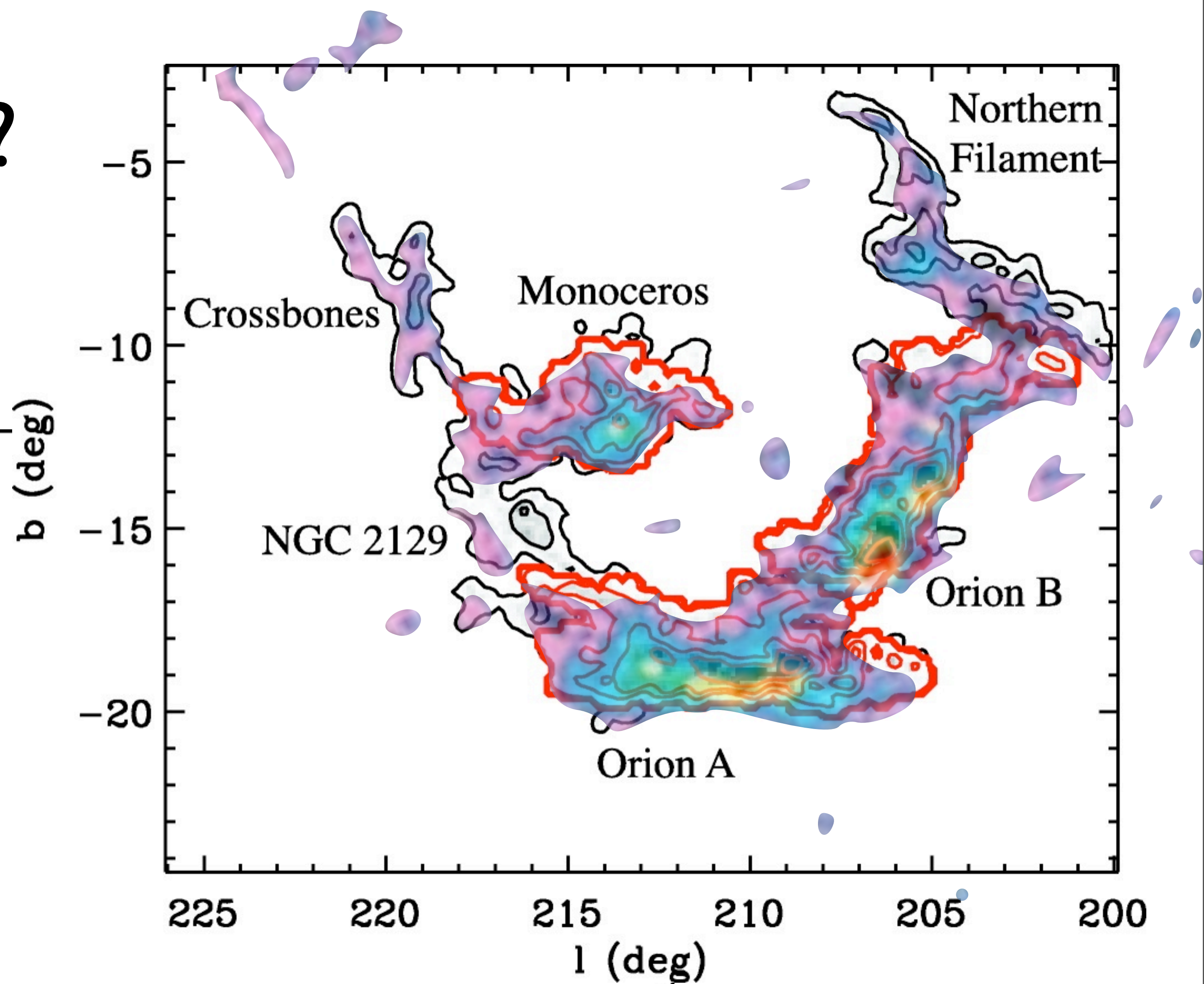


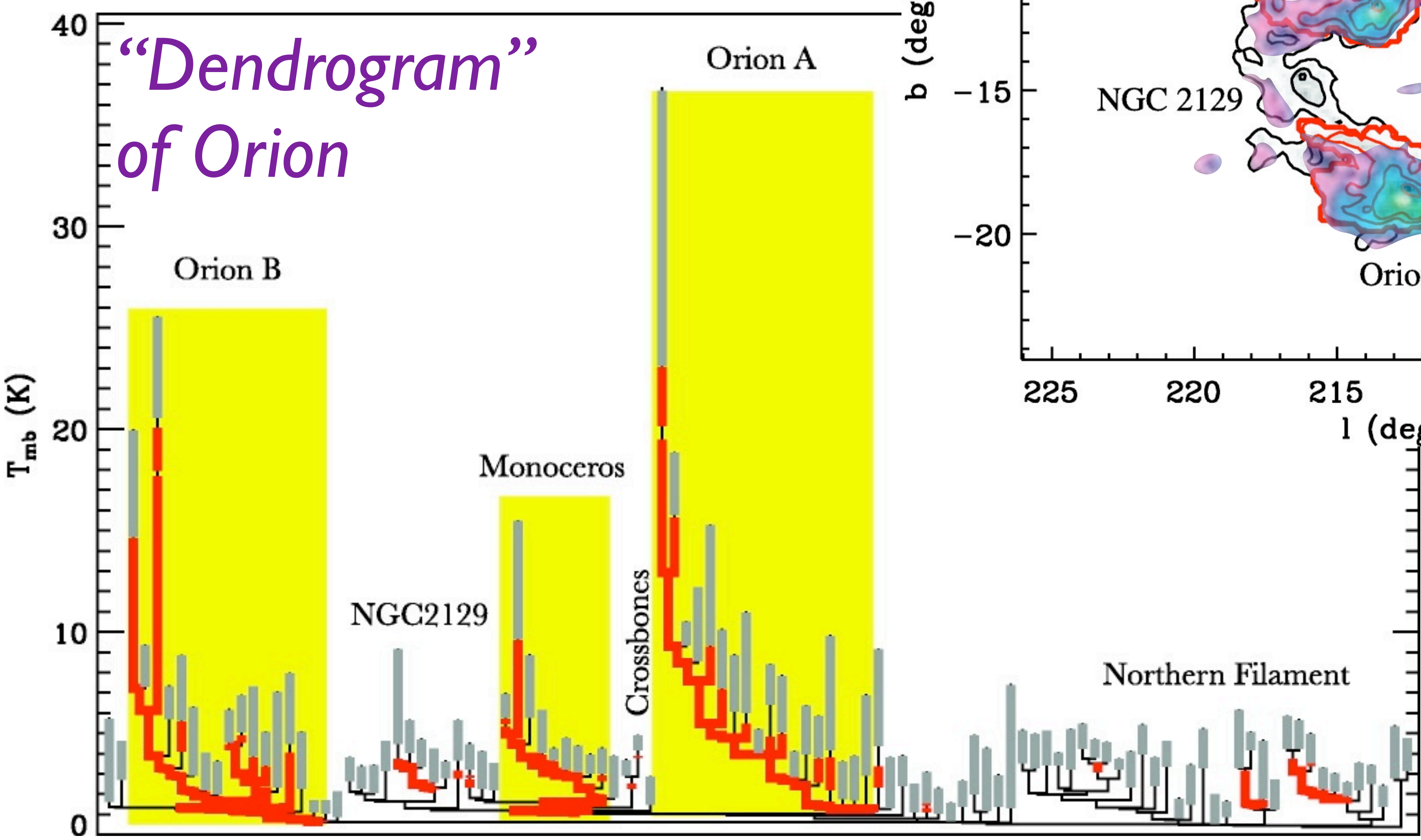
Simulations of Bate 2009

1. At what scales does gravity matter?



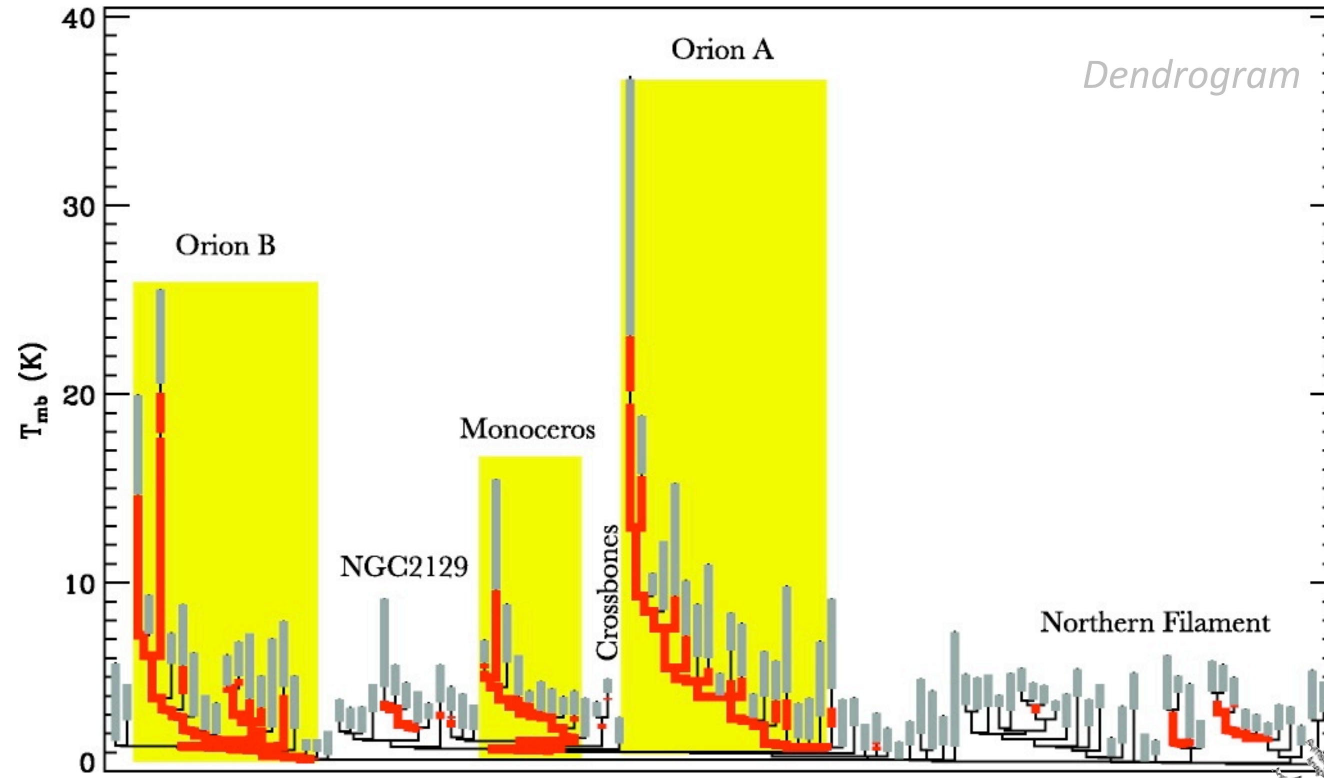
Large (100 pc) Scales:
Does Gravity *Define* GMCs?

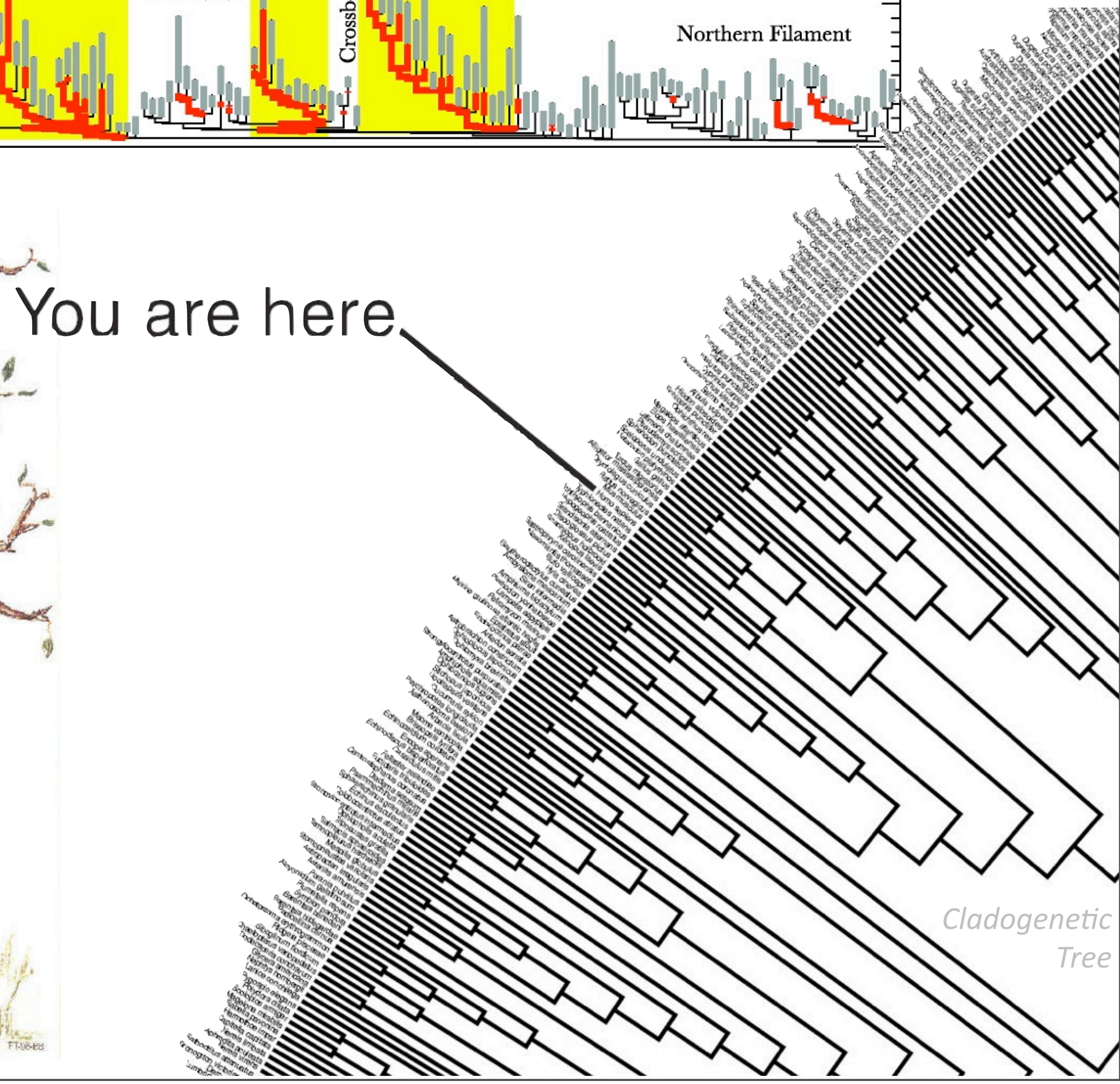




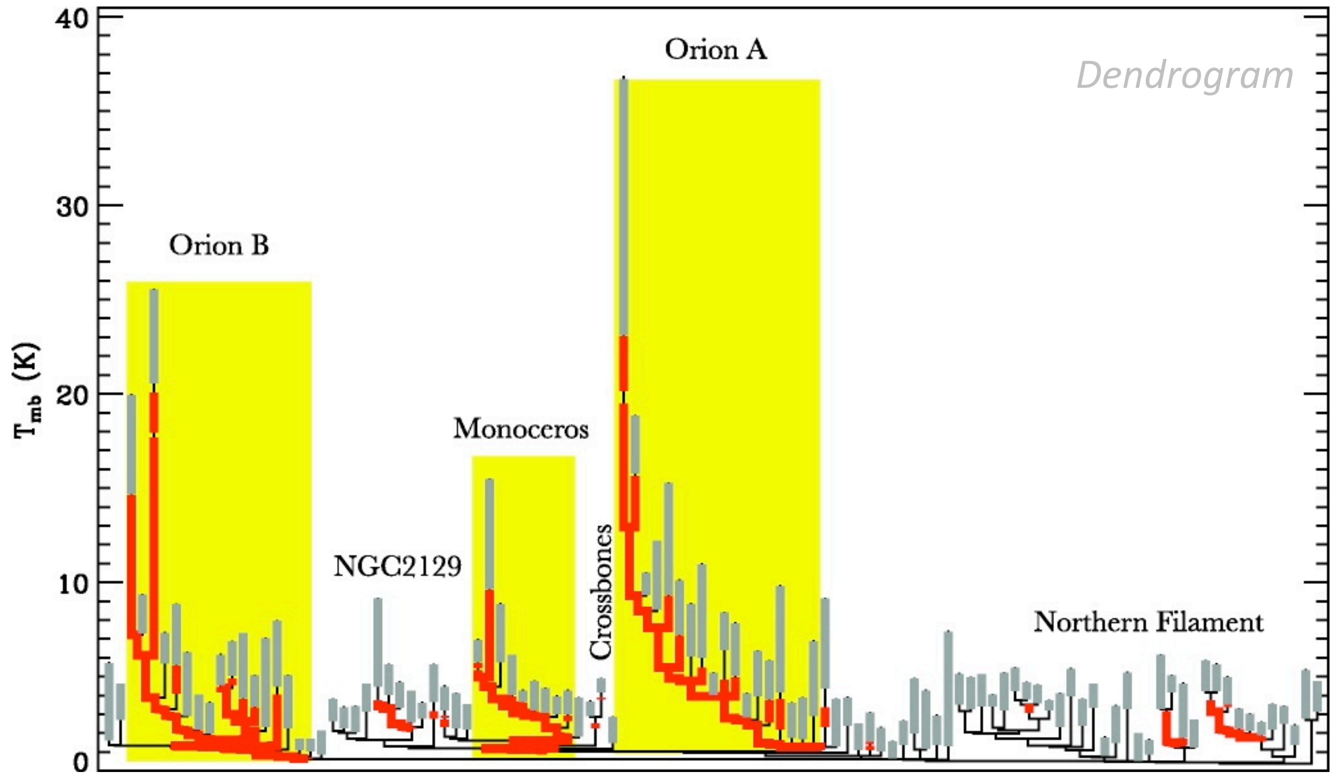
Figures from Rosolowsky et al. 2008

Dendrogram = Tree diagram showing hierarchy





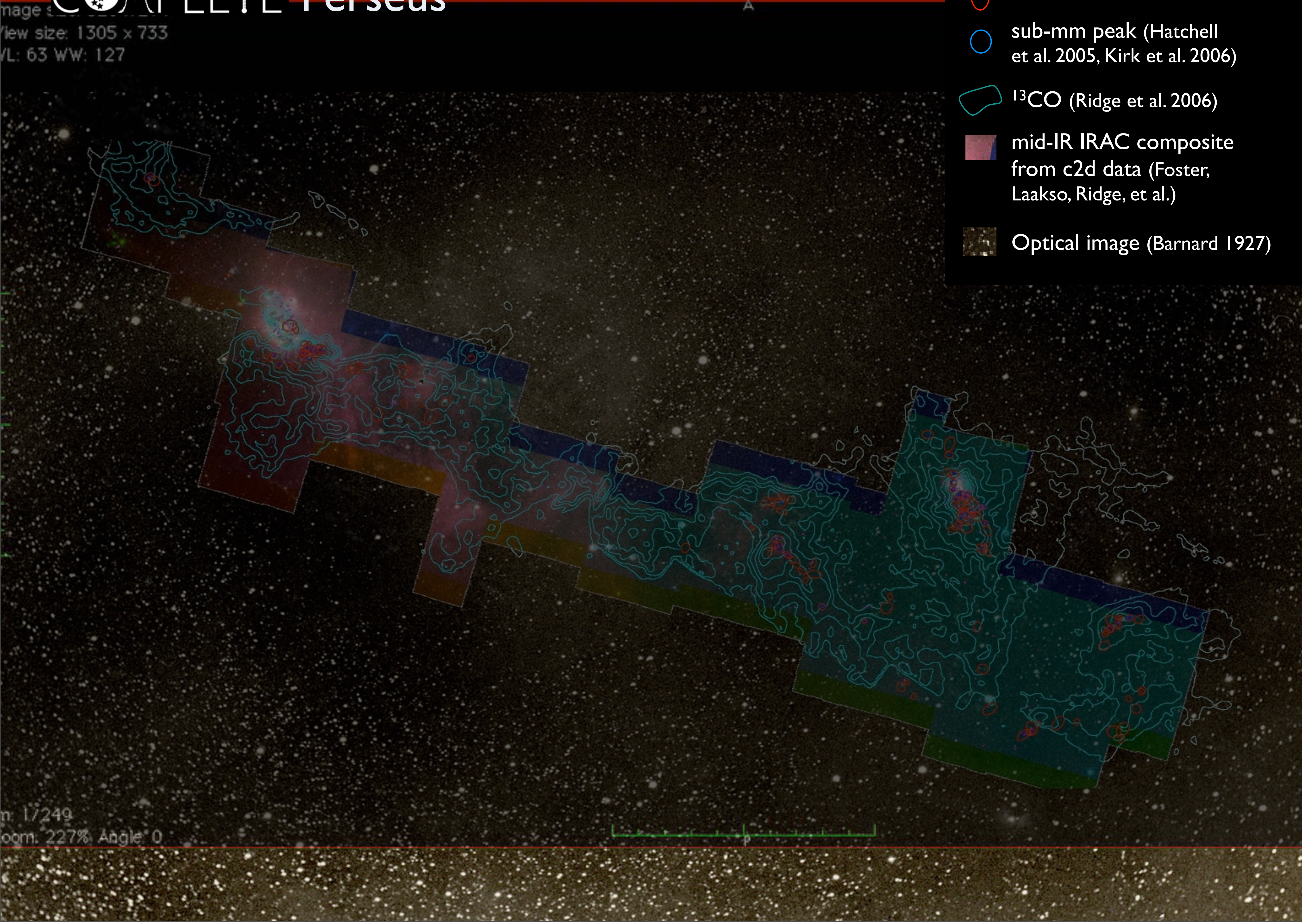
Dendrogram = Tree diagram showing hierarchy



But <u>*how*</u> *did we make this tree, and what does it mean?*

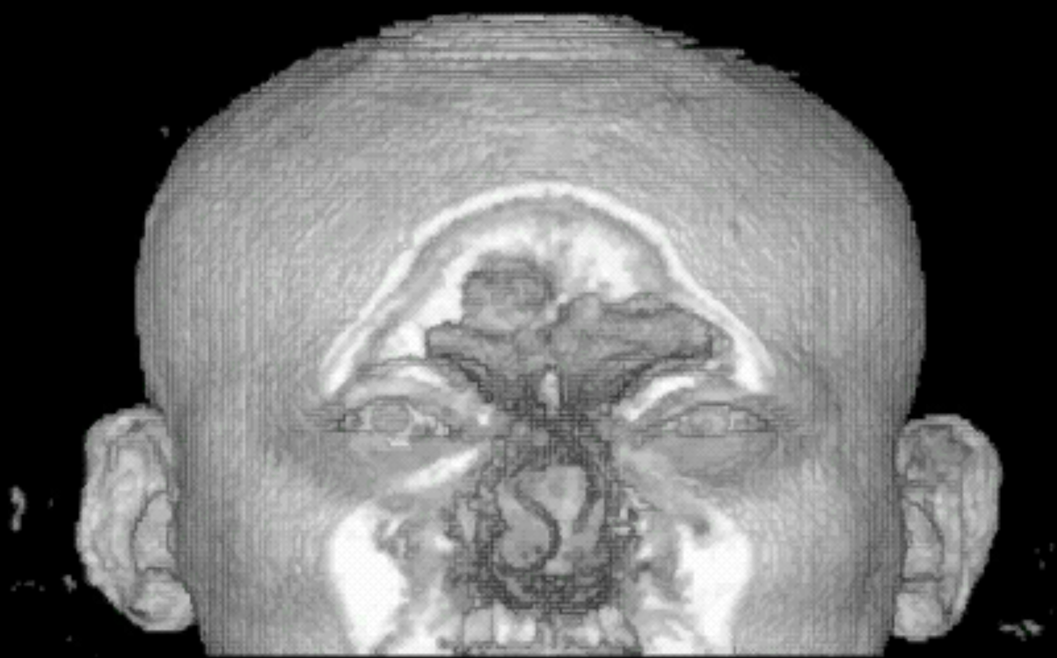
1. *position-position-velocity* data from spectroscopy
2. "dendrogram" algorithm/decomposition
3. virial analysis

COMPLETE Perseus



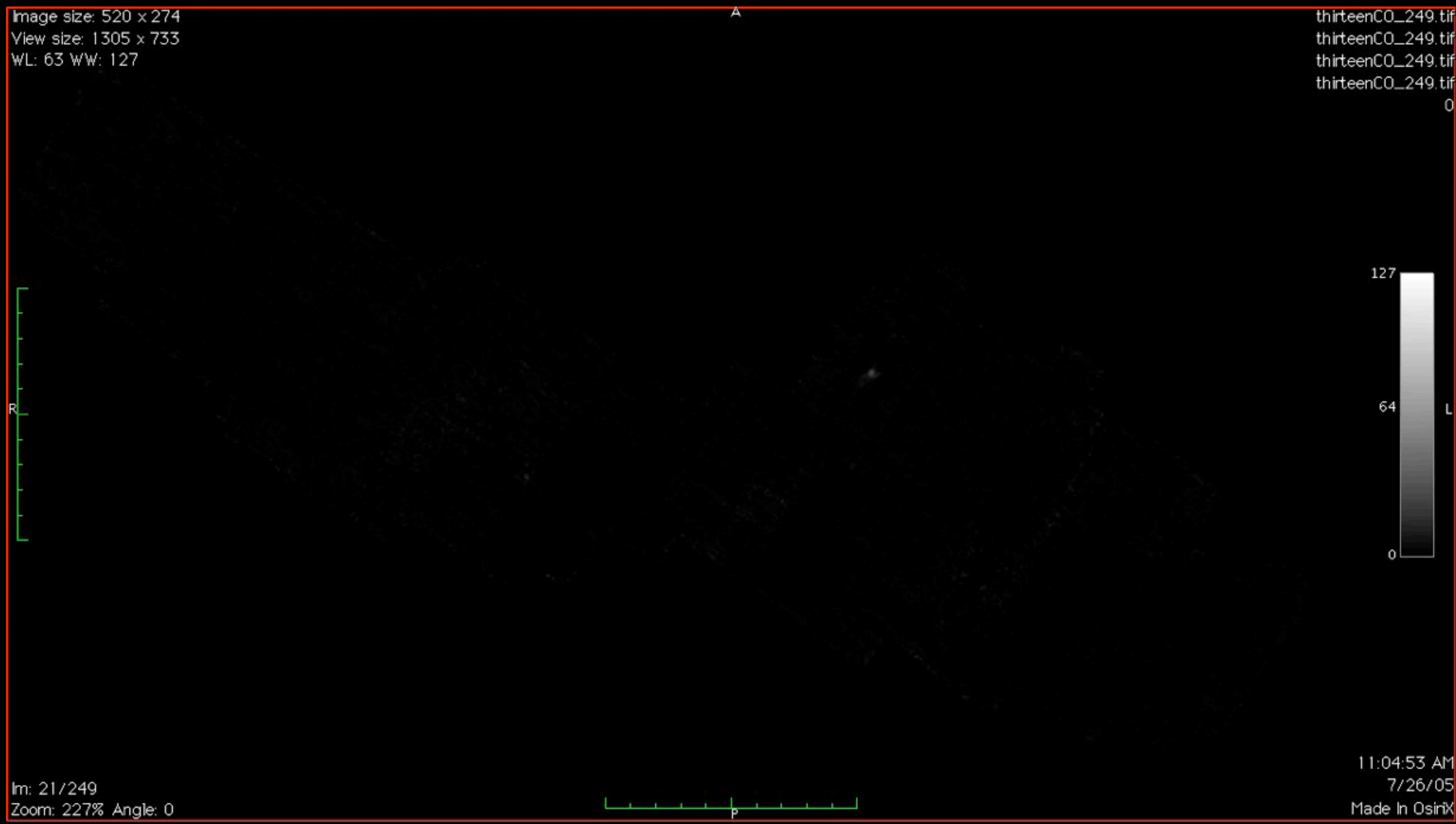
"Astronomical Medicine"

"KEITH"



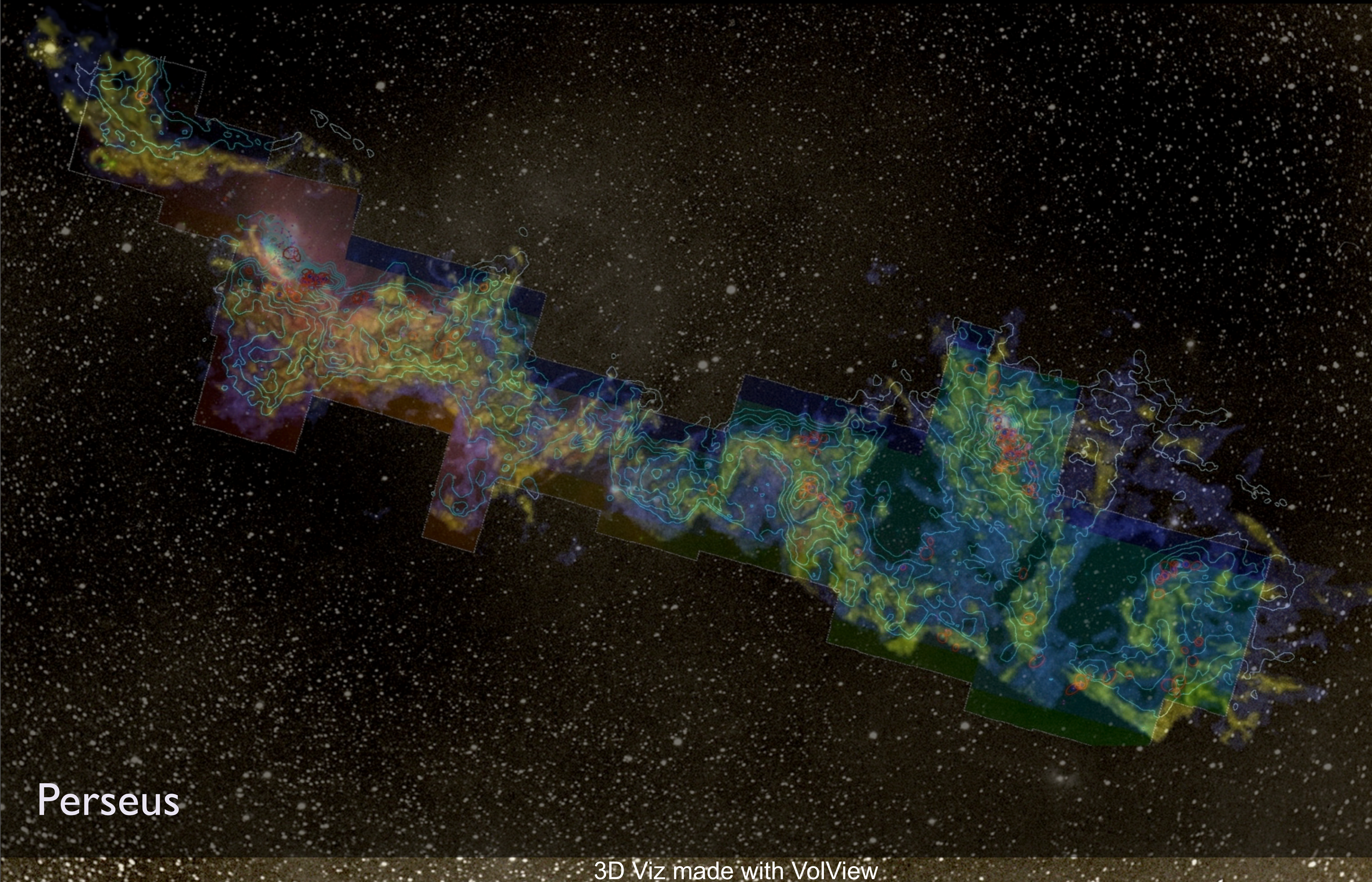
"z" is depth into head

"PERSEUS"



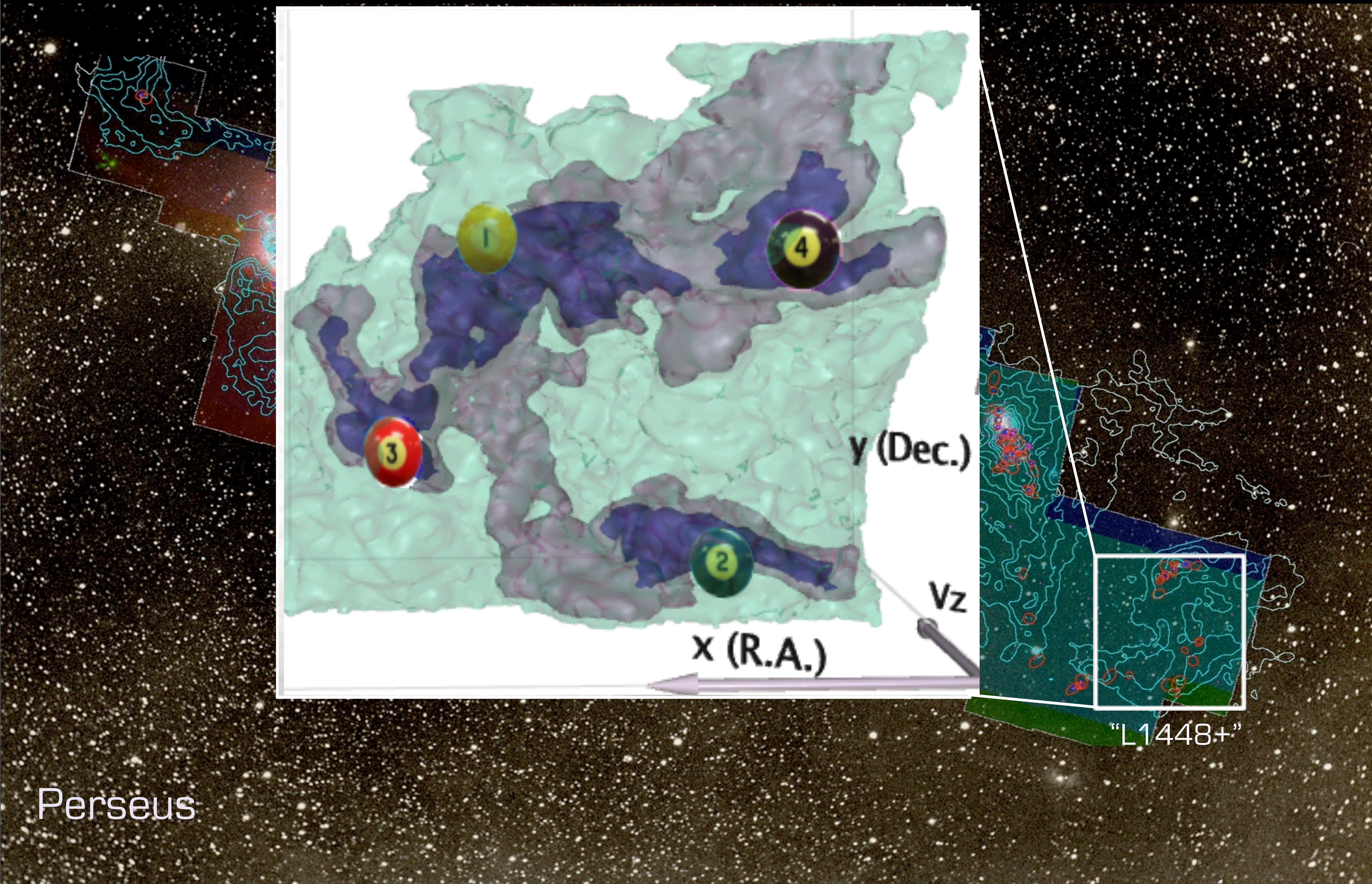
"z" is line-of-sight velocity

http://am.iic.harvard.edu/



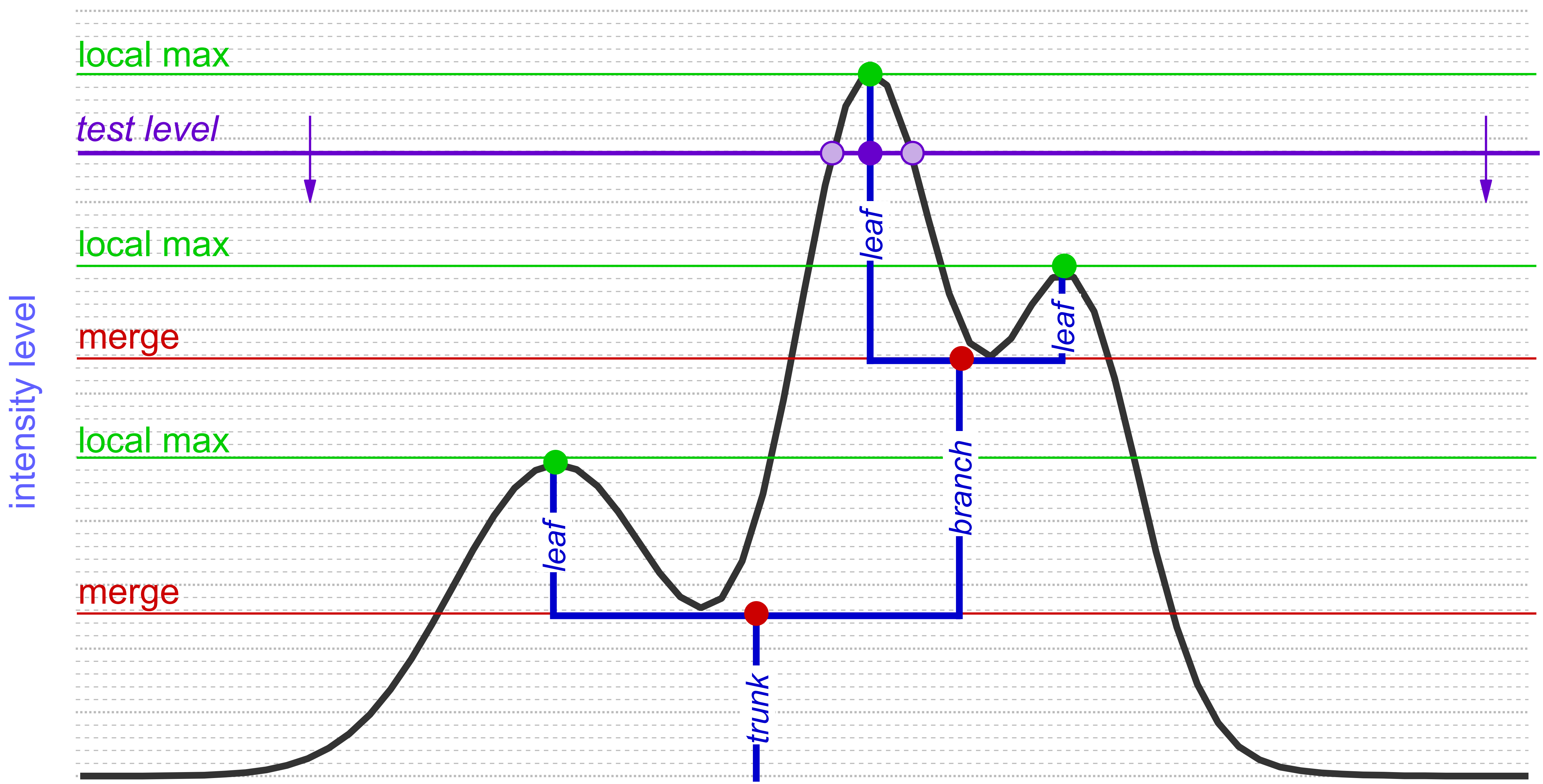
AstronomicalMedicine@IIC

COMPLETE



COMPLETE

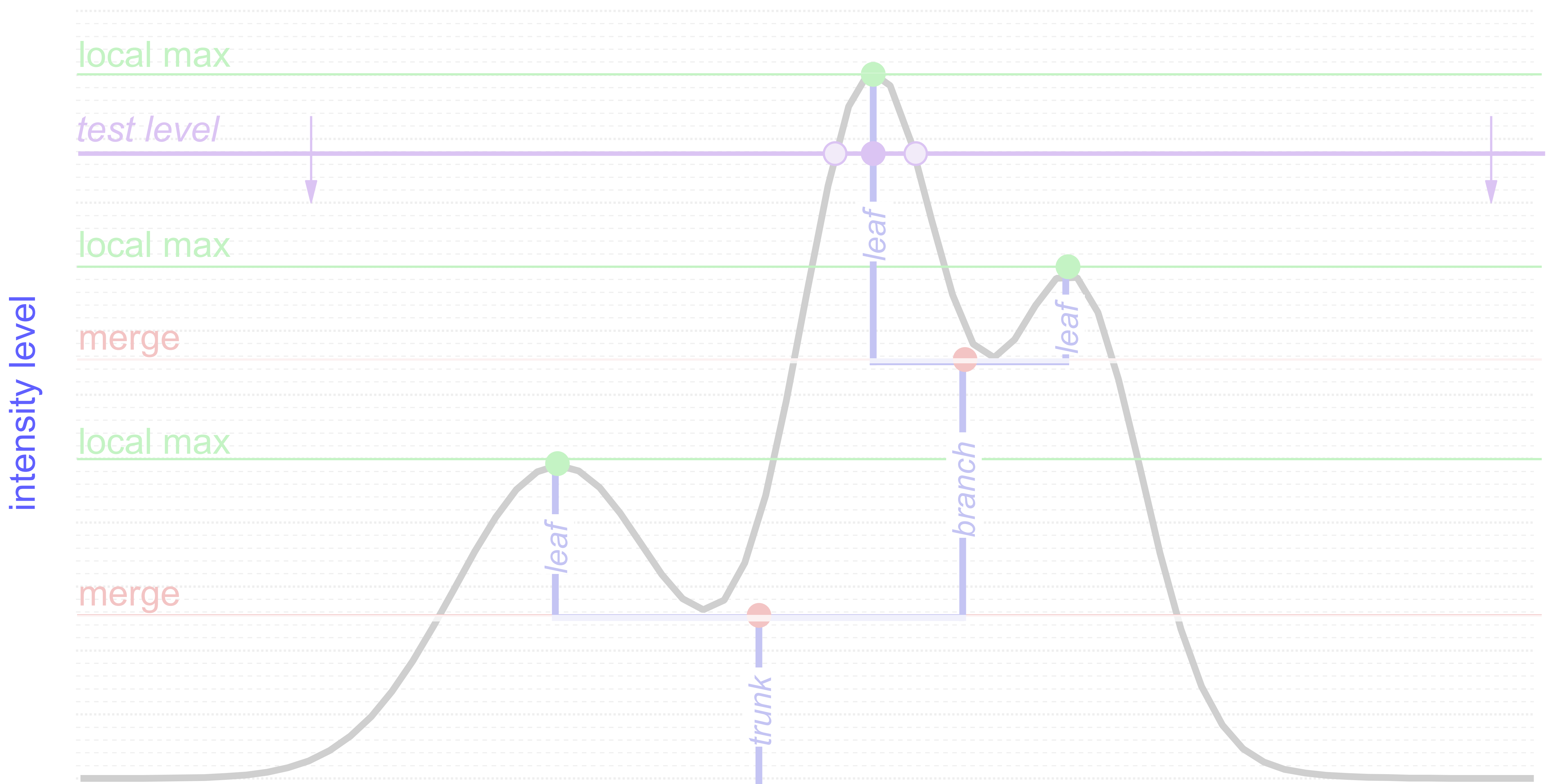
Dendrograms



Hierarchical "Segmentation"

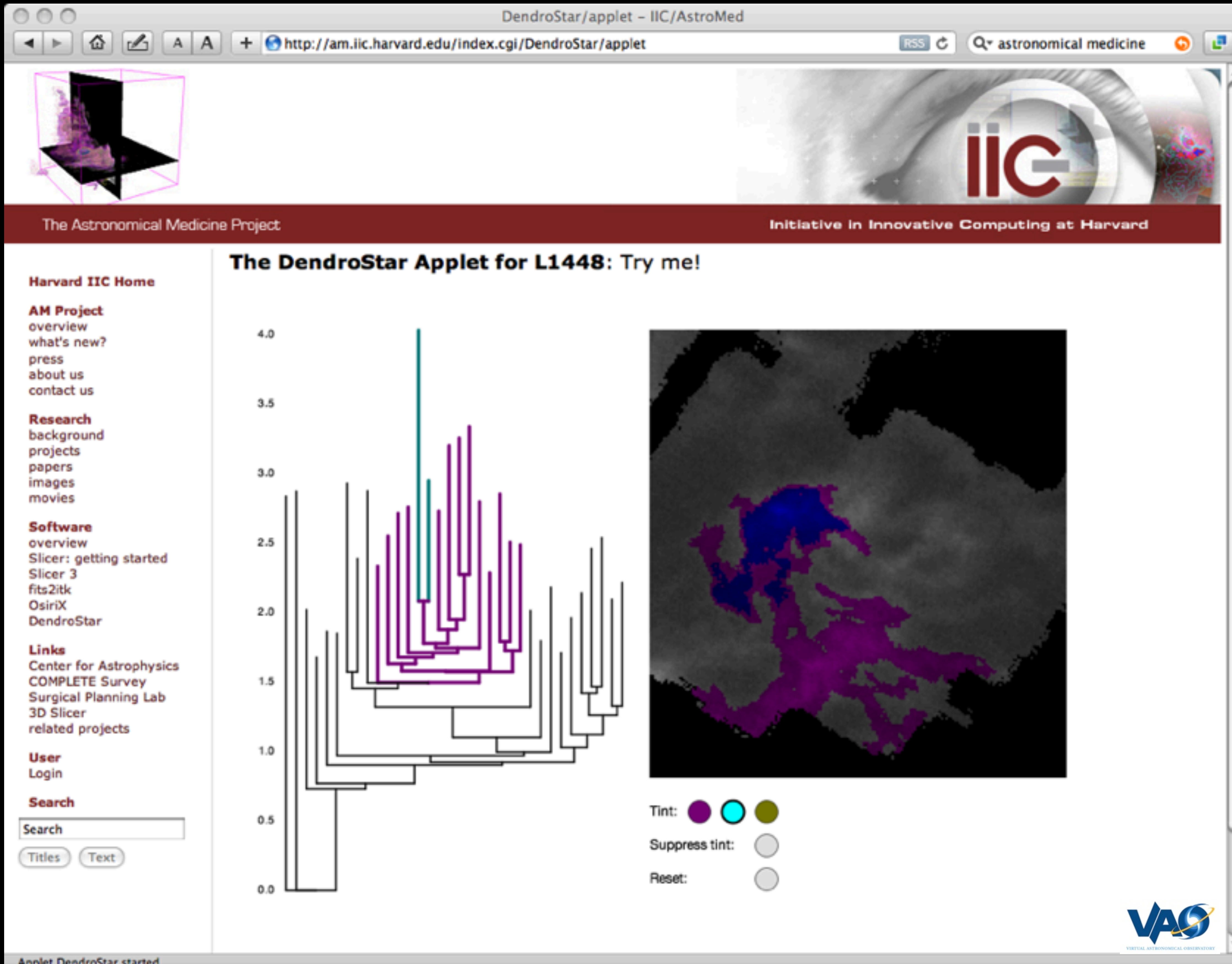
Rosolowsky, Pineda, Kauffmann & Goodman 2008

Dendrograms



1-D: points; 2-D closed curves (contours); 3-D surfaces enclosing volumes

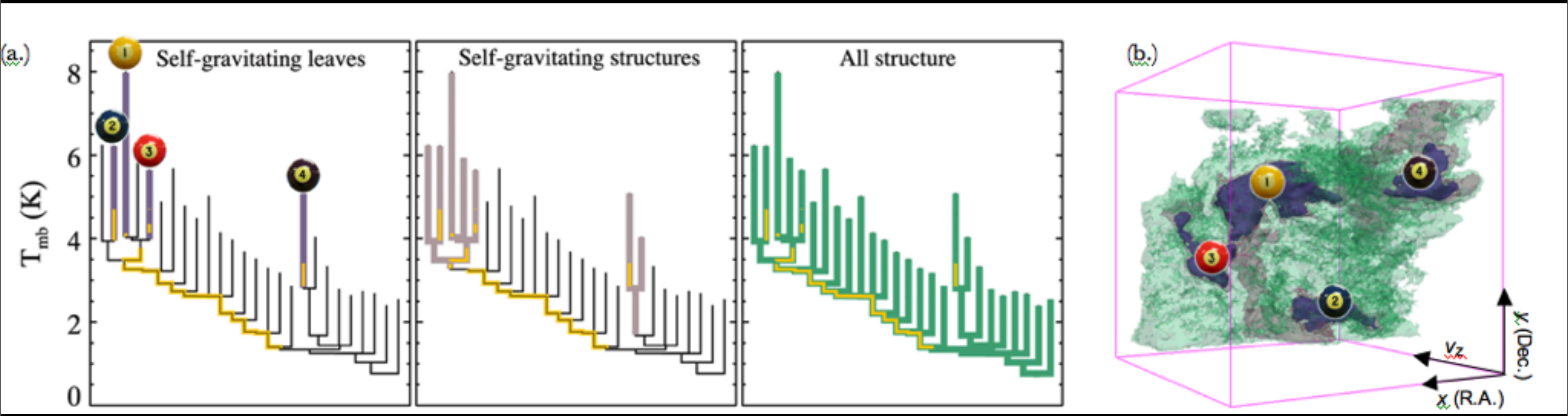
see 2D demo at *http://am.iic.harvard.edu/index.cgi/DendroStar/applet*



http://am.iic.harvard.edu/index.cgi/DendroStar/applet

Dendrogram Algorithm by Erik Rosolwosky; Applet by Douglas Alan

1. At what scales does gravity matter?



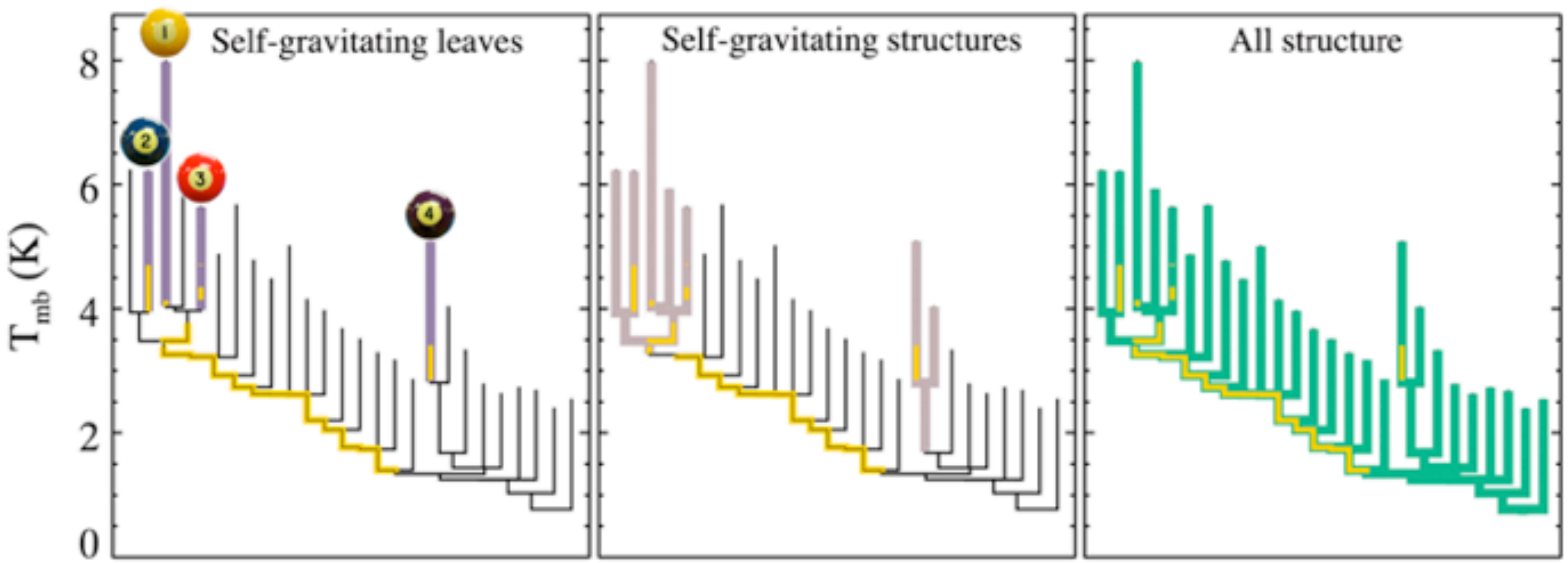
Yellow highlighting= "self-gravitating"

"Self-gravitating" here just means α_{vir} $(=5s_v^2R/GM_{lum}) < 2$
(à la Bertoldi & McKee 1992–*BUT*–see Shetty et al. 2010)

Rosolowsky et al. 2008 (ApJ) &
Goodman et al. 2009 (Nature)

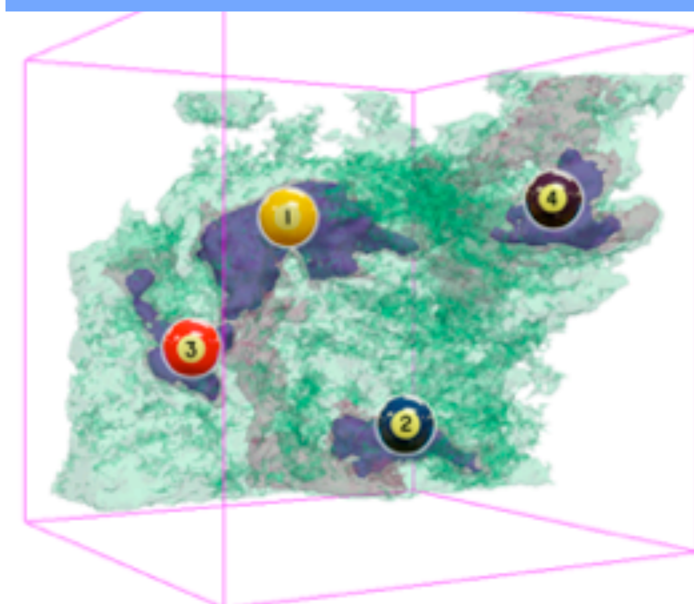
see PDF...

Real and Simulated ^{13}CO

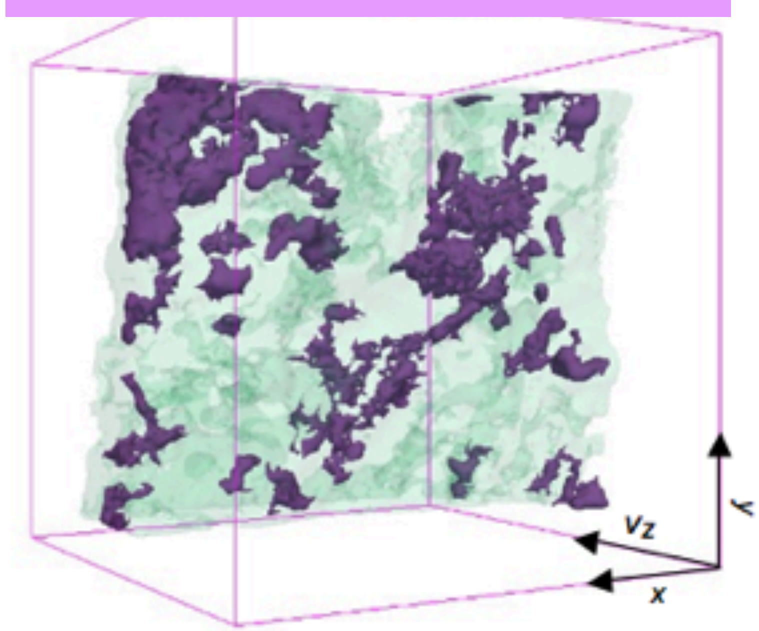


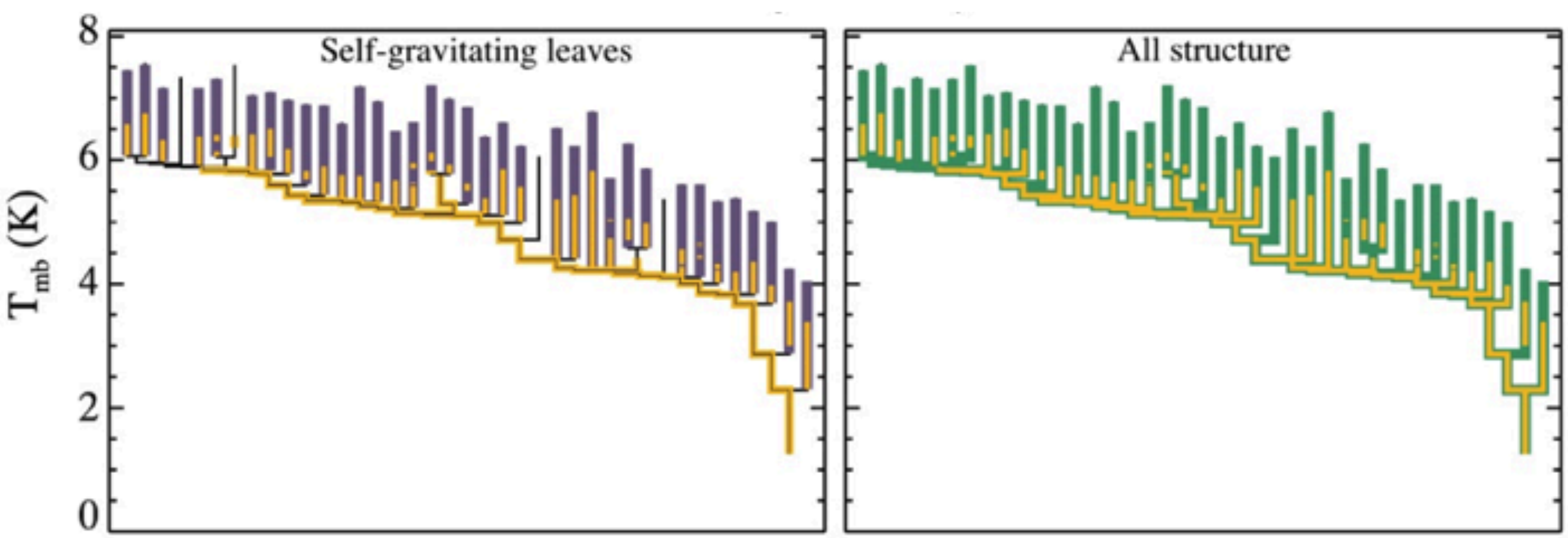
(Yellow = self-gravitating components)

Real



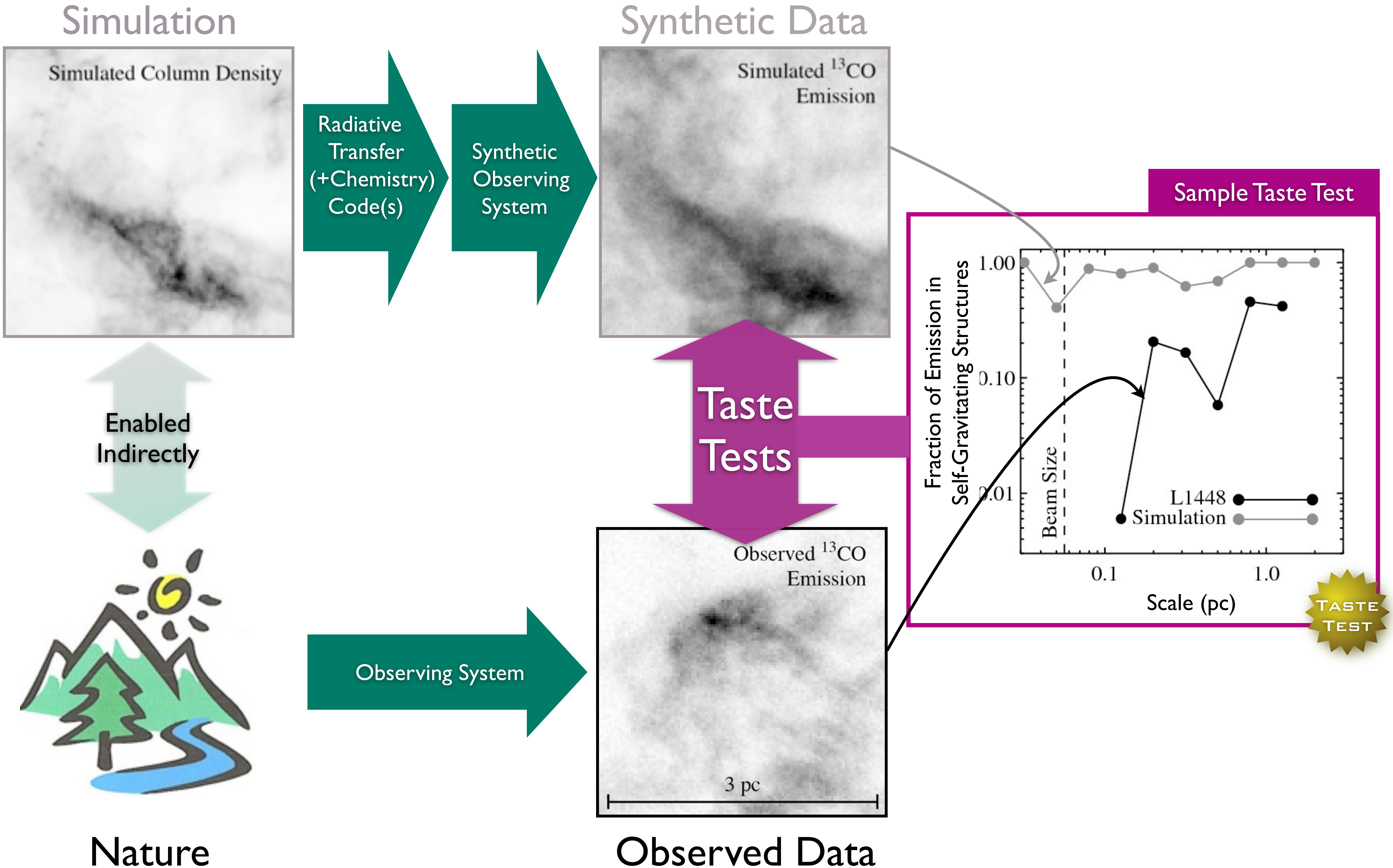
Simulated



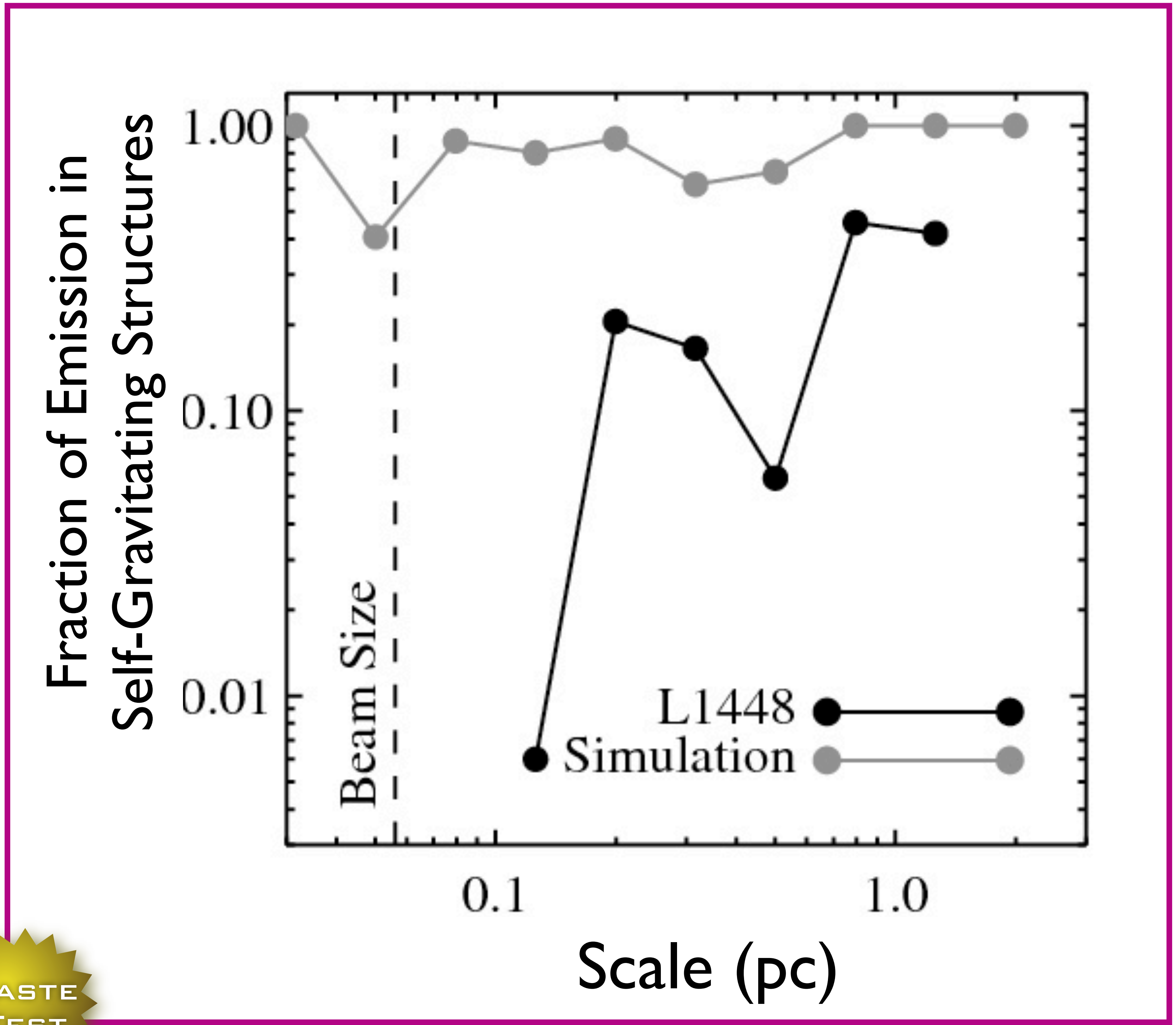


(Yellow = self-gravitating components)

The Taste-Testing Process



Taste-Testing "Gravity"



Gravity-free HD Simulations from Padoan et al. 2006;
L1448 analysis from Rosolowsky et al. 2008
both lines derived from ^{13}CO "observations"

Taste-Testing “Gravity”

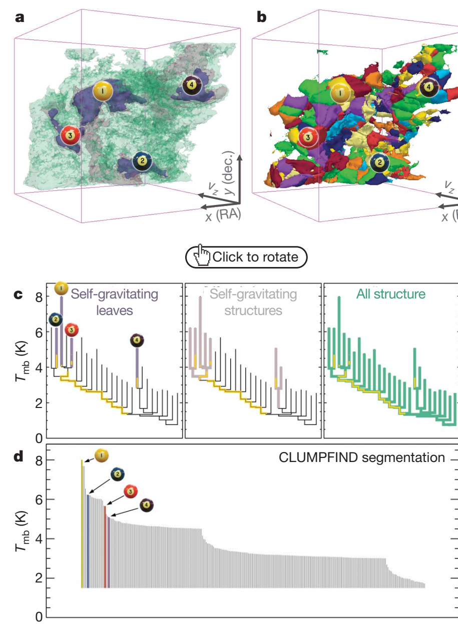


Figure 2 | Comparison of the ‘dendrogram’ and ‘CLUMPFIND’ feature-identification algorithms as applied to ^{13}CO emission from the L1448 region of Perseus. a, 3D visualization of the surfaces indicated by colours in the dendrogram shown in **c**. Purple illustrates the smallest scale self-gravitating structures in the region corresponding to the leaves of the dendrogram; pink shows the smallest surfaces that contain distinct self-gravitating leaves within them; and green corresponds to the surface in the data cube containing all the significant emission. Dendrogram branches corresponding to self-gravitating objects have been highlighted in yellow over the range of T_{mb} (main-beam temperature) test-level values for which the virial parameter is less than 2. The *x*–*y* locations of the four ‘self-gravitating’ leaves labelled with billiard balls are the same as those shown in Fig. 1. The 3D visualizations show position–position–velocity (*p*–*p*–*v*) space. RA, right ascension; dec., declination. For comparison with the ability of dendrograms (**c**) to track hierarchical structure, **d** shows a pseudo-dendrogram of the CLUMPFIND segmentation (**b**), with the same four labels used in Fig. 1 and in **a**. As ‘clumps’ are not allowed to belong to larger structures, each pseudo-branch in **d** is simply a series of lines connecting the maximum emission value in each clump to the threshold value. A very large number of clumps appears in **b** because of the sensitivity of CLUMPFIND to noise and small-scale structure in the data. In the online PDF version, the 3D cubes (**a** and **b**) can be rotated to any orientation, and surfaces can be turned on and off (interaction requires Adobe Acrobat version 7.0.8 or higher). In the printed version, the front face of each 3D cube (the ‘home’ view in the interactive online version) corresponds exactly to the patch of sky shown in Fig. 1, and velocity with respect to the Local Standard of Rest increases from front ($-0.5\ km\ s^{-1}$) to back ($8\ km\ s^{-1}$).

data, CLUMPFIND typically finds features on a limited range of scales, above but close to the physical resolution of the data, and its results can be overly dependent on input parameters. By tuning CLUMPFIND’s two free parameters, the same molecular-line data set[8] can be used to show either that the frequency distribution of clump mass is the same as the initial mass function of stars or that it follows the much shallower mass function associated with large-scale molecular clouds (Supplementary Fig. 1).

Four years before the advent of CLUMPFIND, ‘structure trees’[9] were proposed as a way to characterize clouds’ hierarchical structure using 2D maps of column density. With this early 2D work as inspiration, we have developed a structure-identification algorithm that abstracts the hierarchical structure of a 3D (*p*–*p*–*v*) data cube into an easily visualized representation called a ‘dendrogram’[10]. Although well developed in other data-intensive fields[11,12], it is curious that the application of tree methodologies so far in astrophysics has been rare, and almost exclusively within the area of galaxy evolution, where ‘merger trees’ are being used with increasing frequency[13].

Figure 3 and its legend explain the construction of dendrograms schematically. The dendrogram quantifies how and where local maxima of emission merge with each other, and its implementation is explained in Supplementary Methods. Critically, the dendrogram is determined almost entirely by the data itself, and it has negligible sensitivity to algorithm parameters. To make graphical presentation possible on paper and 2D screens, we ‘flatten’ the dendrograms of 3D data (see Fig. 3 and its legend), by sorting their ‘branches’ to not cross, which eliminates dimensional information on the *x* axis while preserving all information about connectivity and hierarchy. Numbered ‘billiard ball’ labels in the figures let the reader match features between a 2D map (Fig. 1), an interactive 3D map (Fig. 2a online) and a sorted dendrogram (Fig. 2c).

A dendrogram of a spectral-line data cube allows for the estimation of key physical properties associated with volumes bounded by isosurfaces, such as radius (R), velocity dispersion (σ_v) and luminosity (L). The volumes can have any shape, and in other work[14] we focus on the significance of the especially elongated features seen in L1448 (Fig. 2a). The luminosity is an approximate proxy for mass, such that $M_{lum} = X_{13CO} L_{13CO}$, where $X_{13CO} = 8.0 \times 10^{20}\ cm^2\ K^{-1}\ km^{-1}\ s$ (ref. 15; see Supplementary Methods and Supplementary Fig. 2). The derived values for size, mass and velocity dispersion can then be used to estimate the role of self-gravity at each point in the hierarchy, via calculation of an ‘observed’ virial parameter, $\alpha_{obs} = 5\sigma_v^2 R/GM_{lum}$. In principle, extended portions of the tree (Fig. 2, yellow highlighting) where $\alpha_{obs} < 2$ (where gravitational energy is comparable to or larger than kinetic energy) correspond to regions of *p*–*p*–*v* space where self-gravity is significant. As α_{obs} only represents the ratio of kinetic energy to gravitational energy at one point in time, and does not explicitly capture external over-pressure and/or magnetic fields[16], its measured value should only be used as a guide to the longevity (boundedness) of any particular feature.

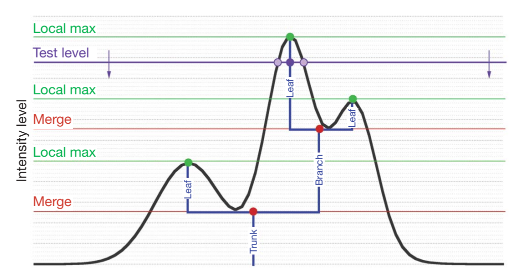


Figure 3 | Schematic illustration of the dendrogram process. Shown is the construction of a dendrogram from a hypothetical one-dimensional emission profile (black). The dendrogram (blue) can be constructed by ‘dropping’ a test constant emission level (purple) from above in tiny steps (exaggerated in size here, light lines) until all the local maxima and mergers are found, and connected as shown. The intersection of a test level with the emission is a set of points (for example the light purple dots) in one dimension, a planar curve in two dimensions, and an isosurface in three dimensions. The dendrogram of 3D data shown in Fig. 2c is the direct analogue of the tree shown here, only constructed from ‘isosurface’ rather than ‘point’ intersections. It has been sorted and flattened for representation on a flat page, as fully representing dendrograms for 3D data cubes would require four dimensions.

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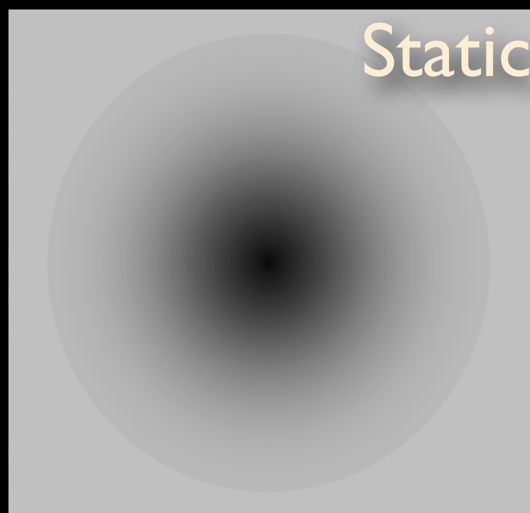
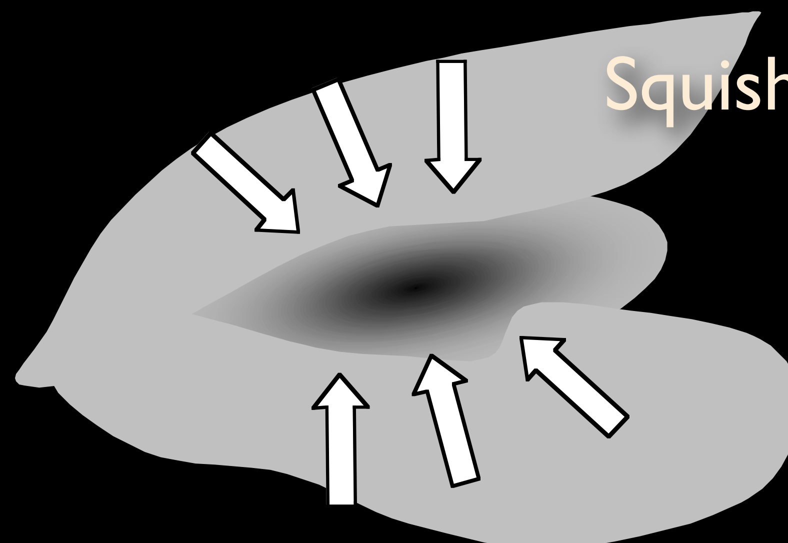
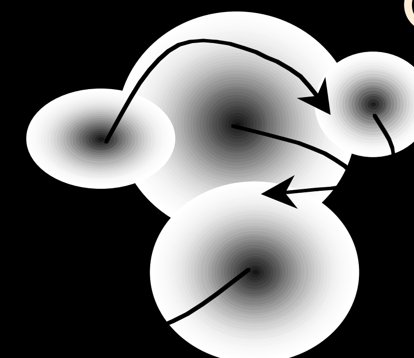
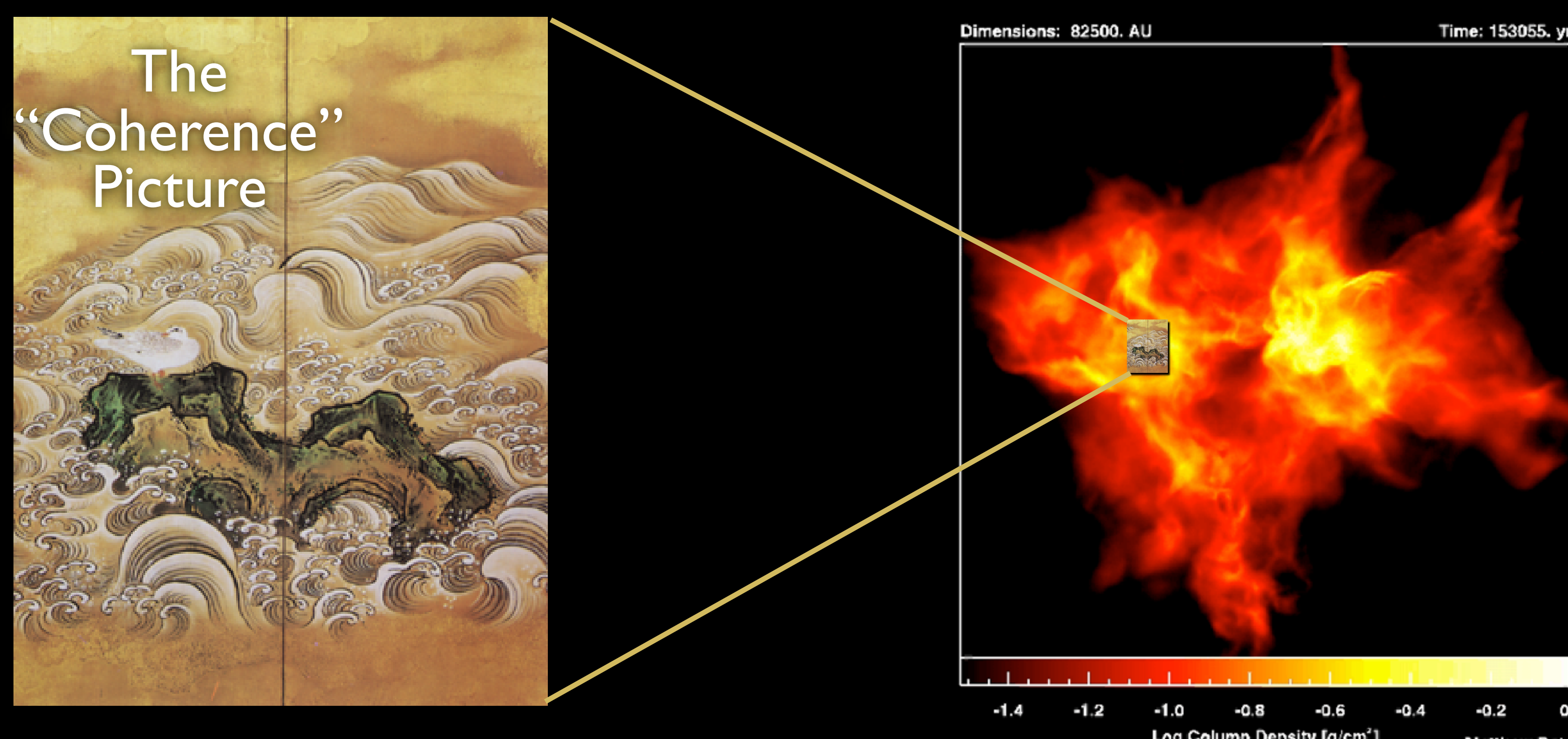
Goodman et al. *Nature*, 2009

"Modernist" Philosophy  for non-Experts

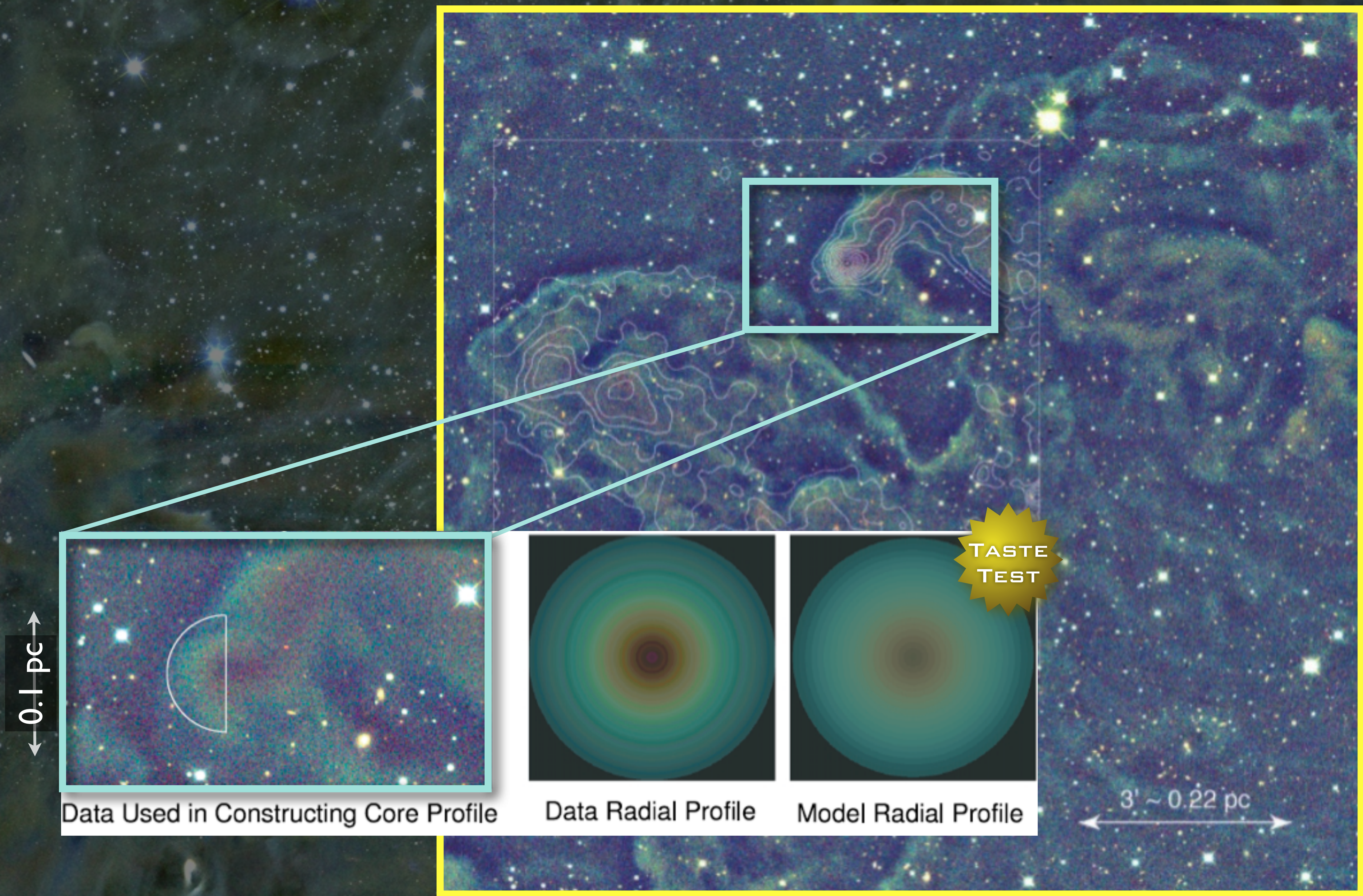




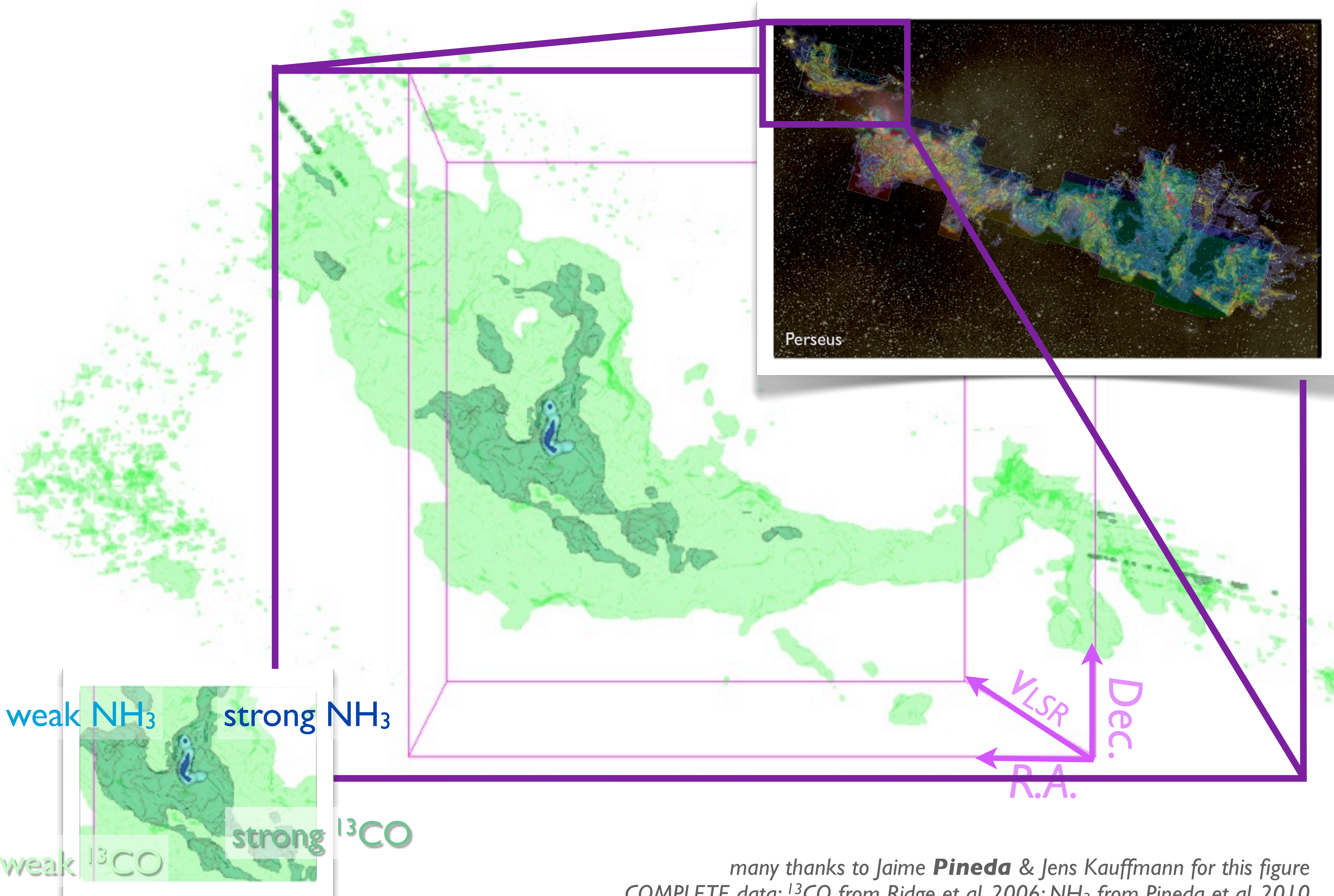




“Islands of Calm in a Turbulent Sea”

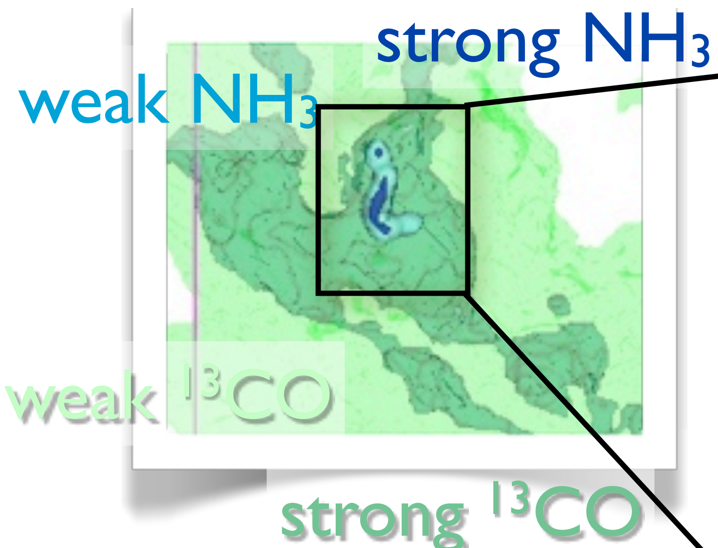


p-p-v structure of the B5 region in Perseus

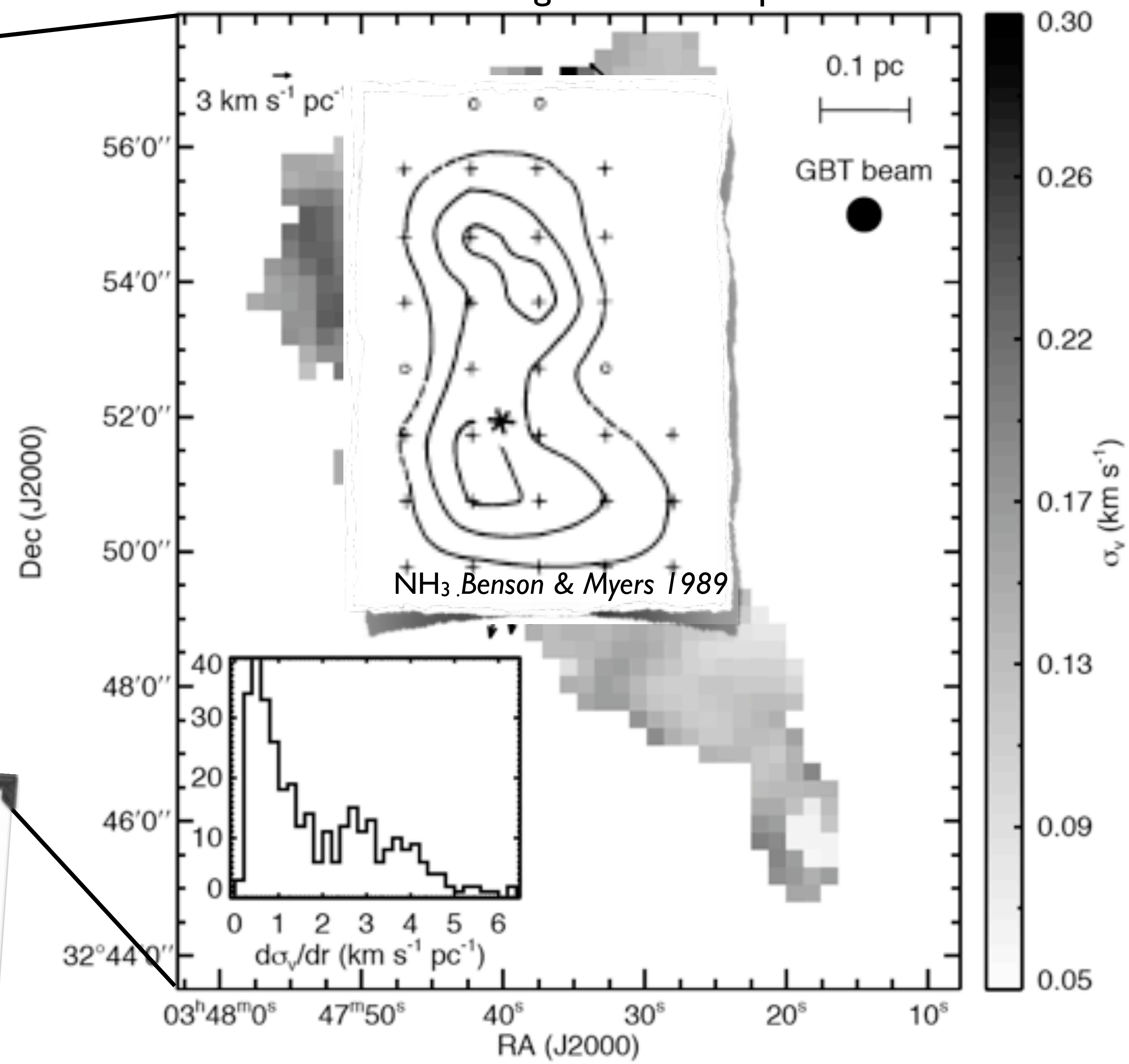


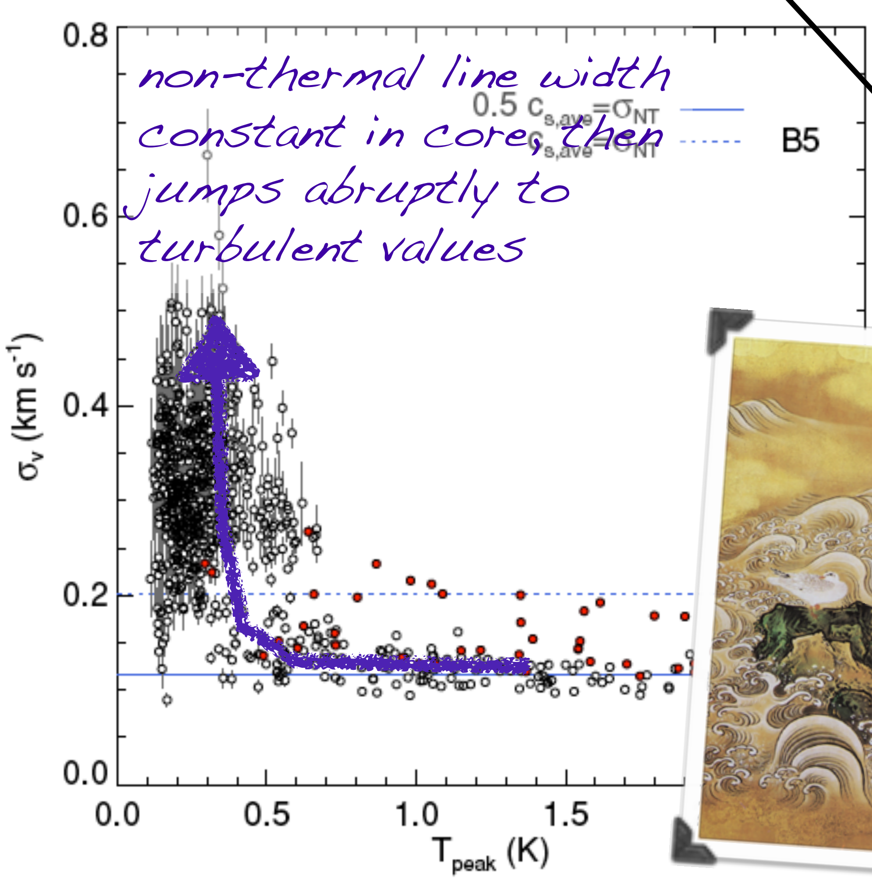
many thanks to Jaime ***Pineda*** *& Jens Kauffmann for this figure*
COMPLETE data: ^{13}CO from Ridge et al. 2006; NH_3 from Pineda et al. 2010

STRONG Evidence for Coherence in Dense Cores



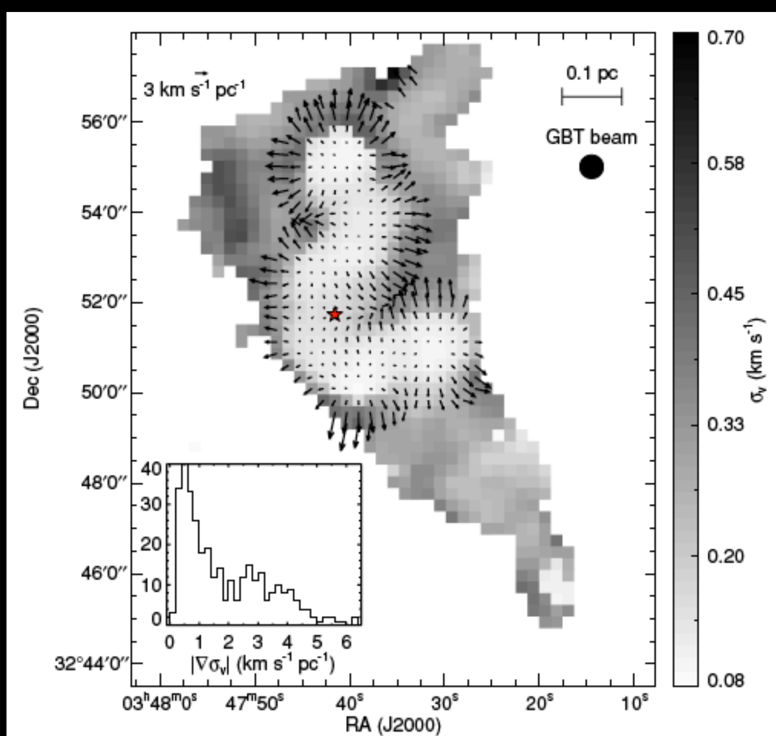
greyscale shows NH_3 velocity dispersion,
arrows show gradient in dispersion



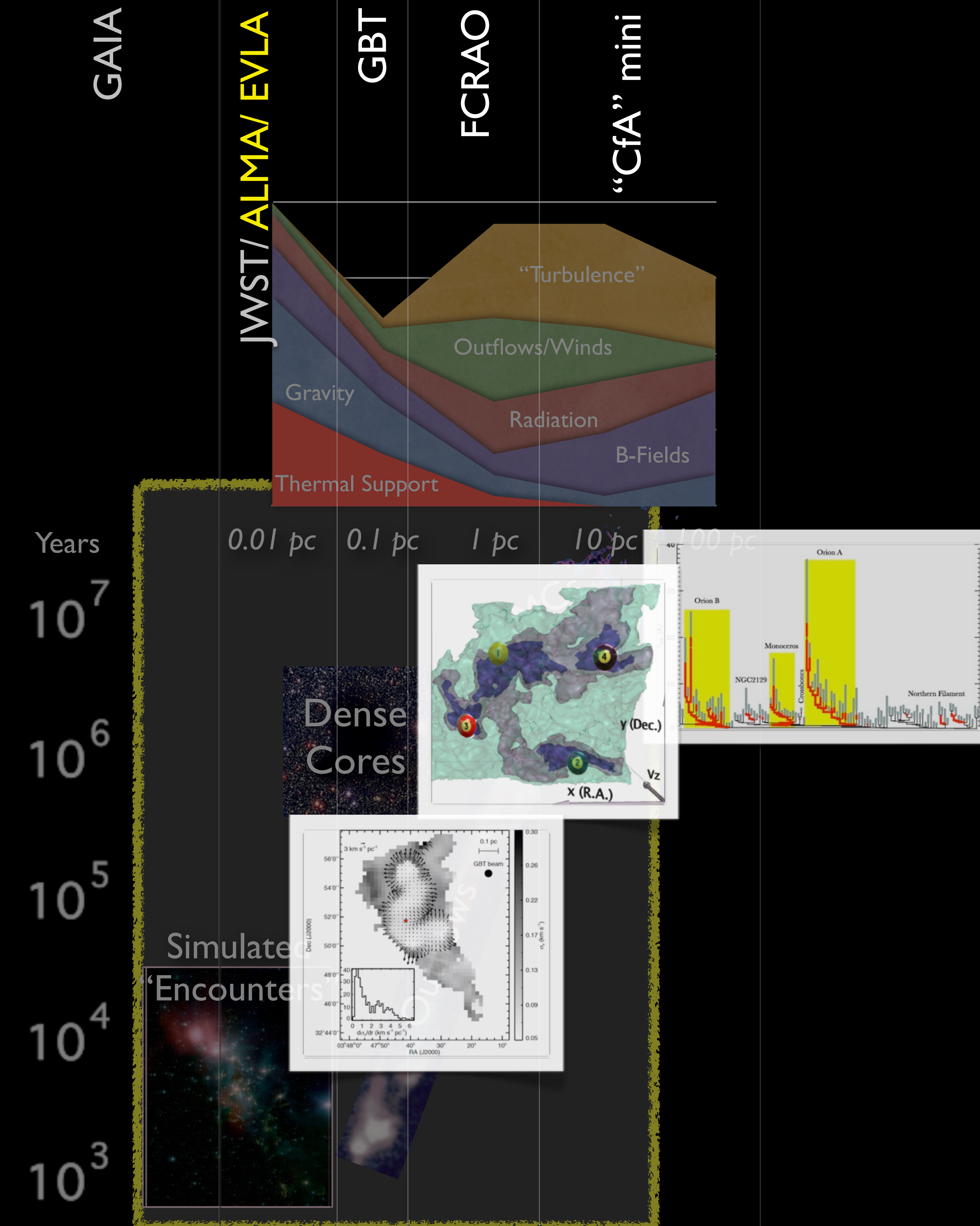


GBT NH_3 observations of the B5 core (Pineda et al. 2010)

1. At what scales does gravity matter?



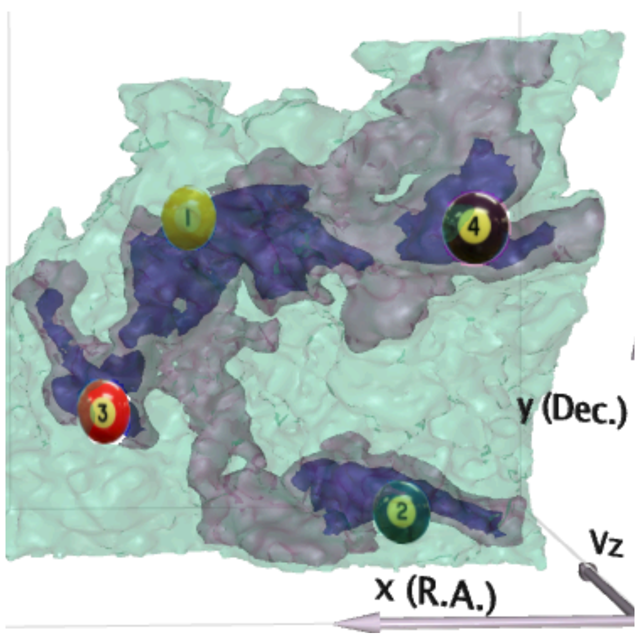
"Transition" so sharp the GBT cannot resolve it.
We need EVLA or...



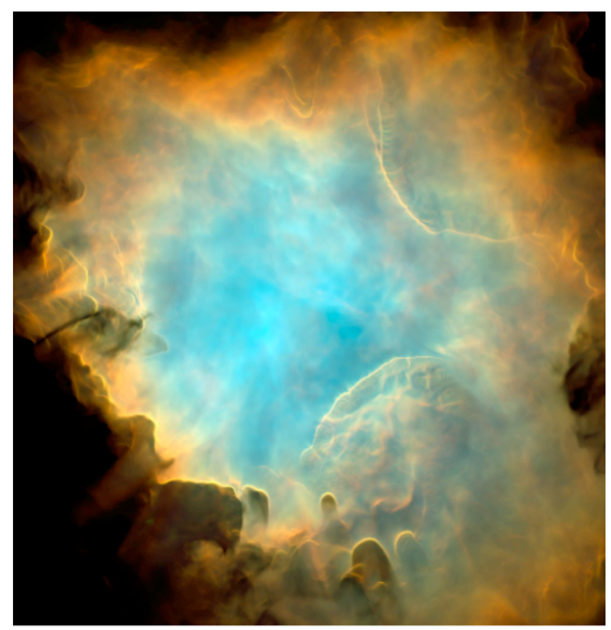
"ALMA Our Savior"

3 Open Questions

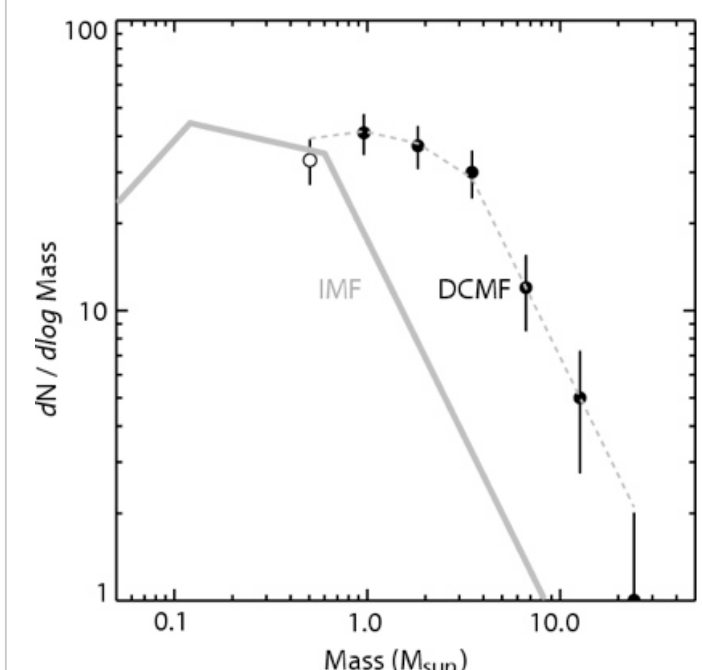
1. At what scales does **gravity** matter?



2. What do **stars** really do to clouds?

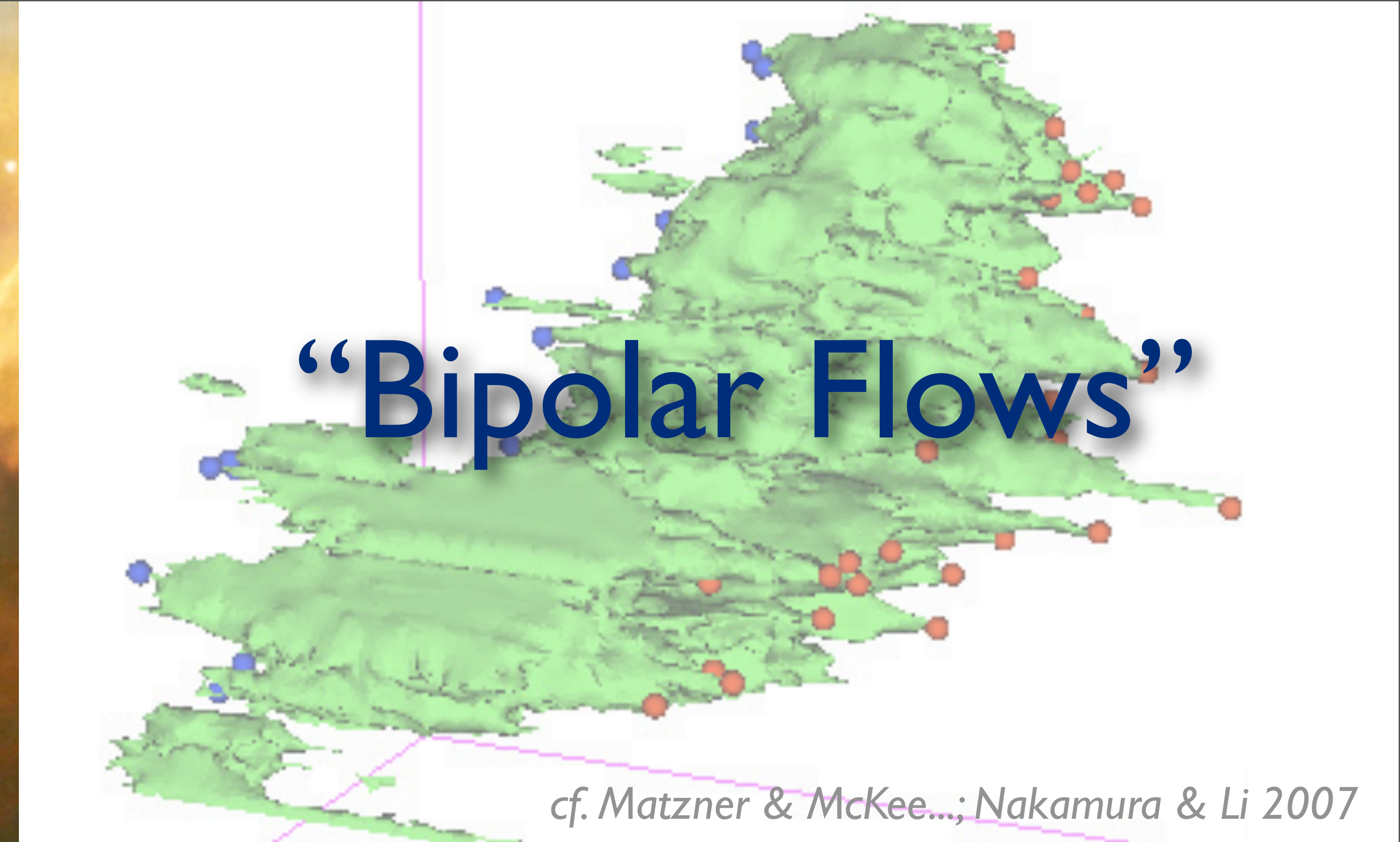


3. Is the origin of the **IMF** related (only) to the CMF?

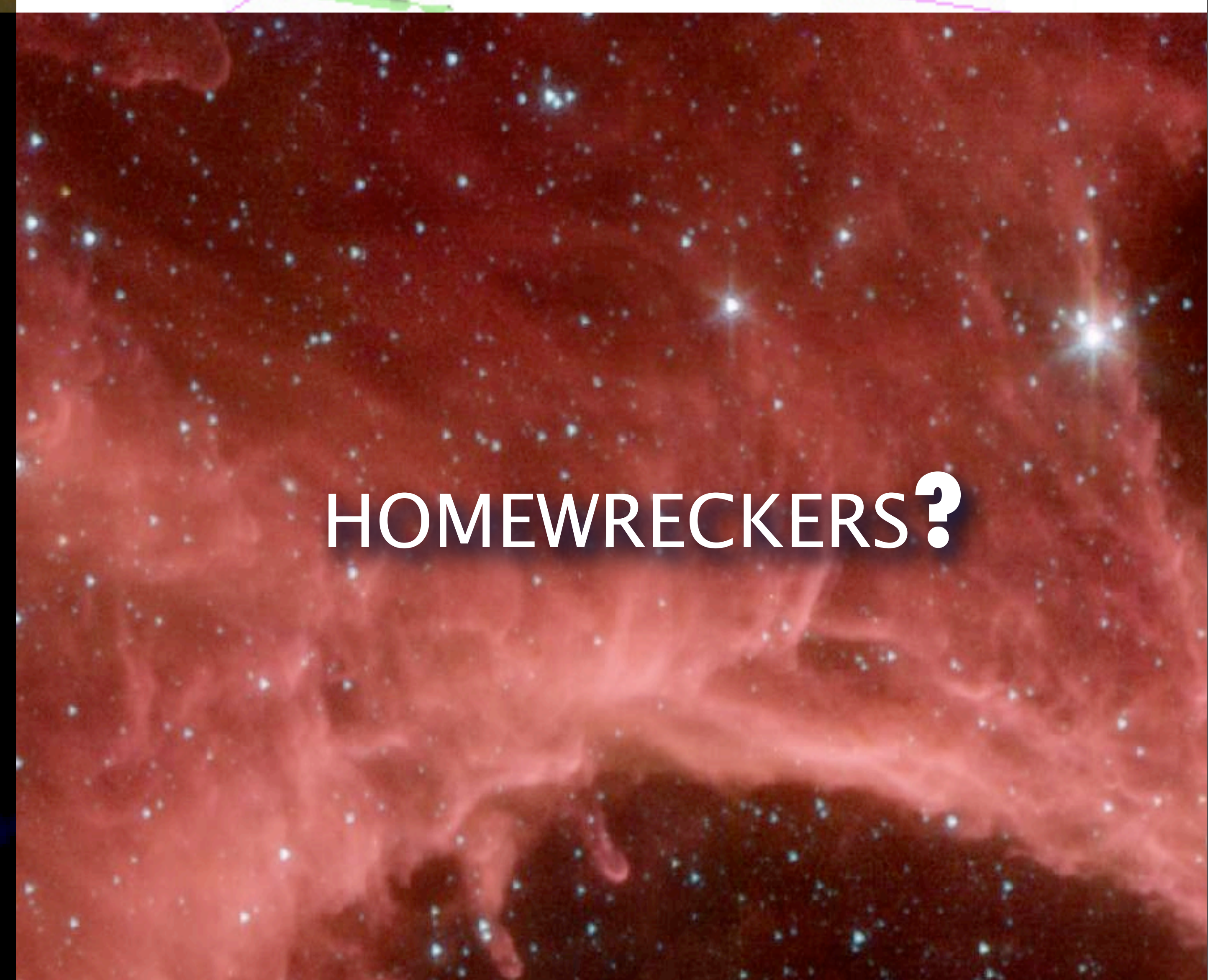


+ "tasty" approaches to answers

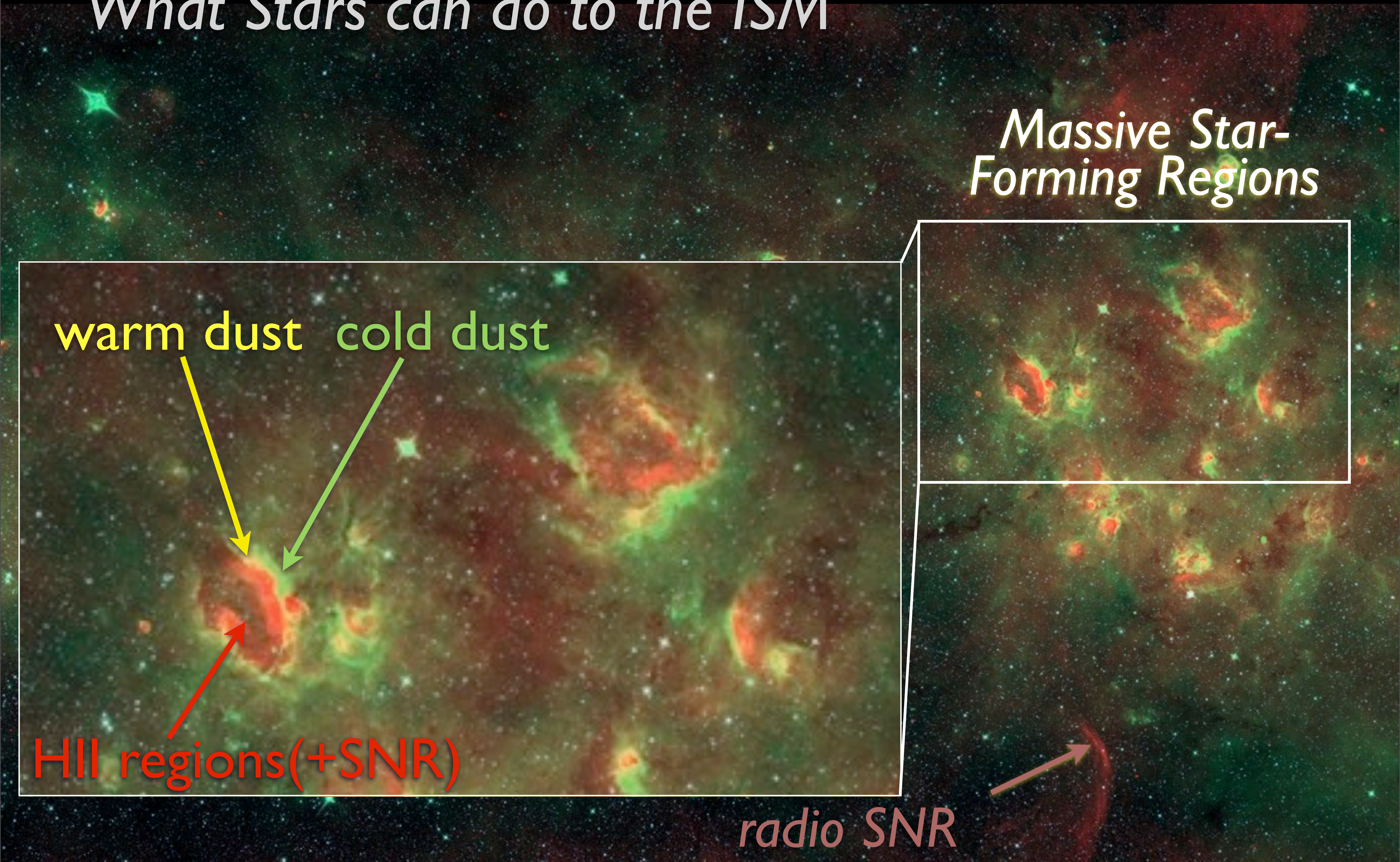

Motivation


"Bipolar Flows"
cf. Matzner & McKee...; Nakamura & Li 2007


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

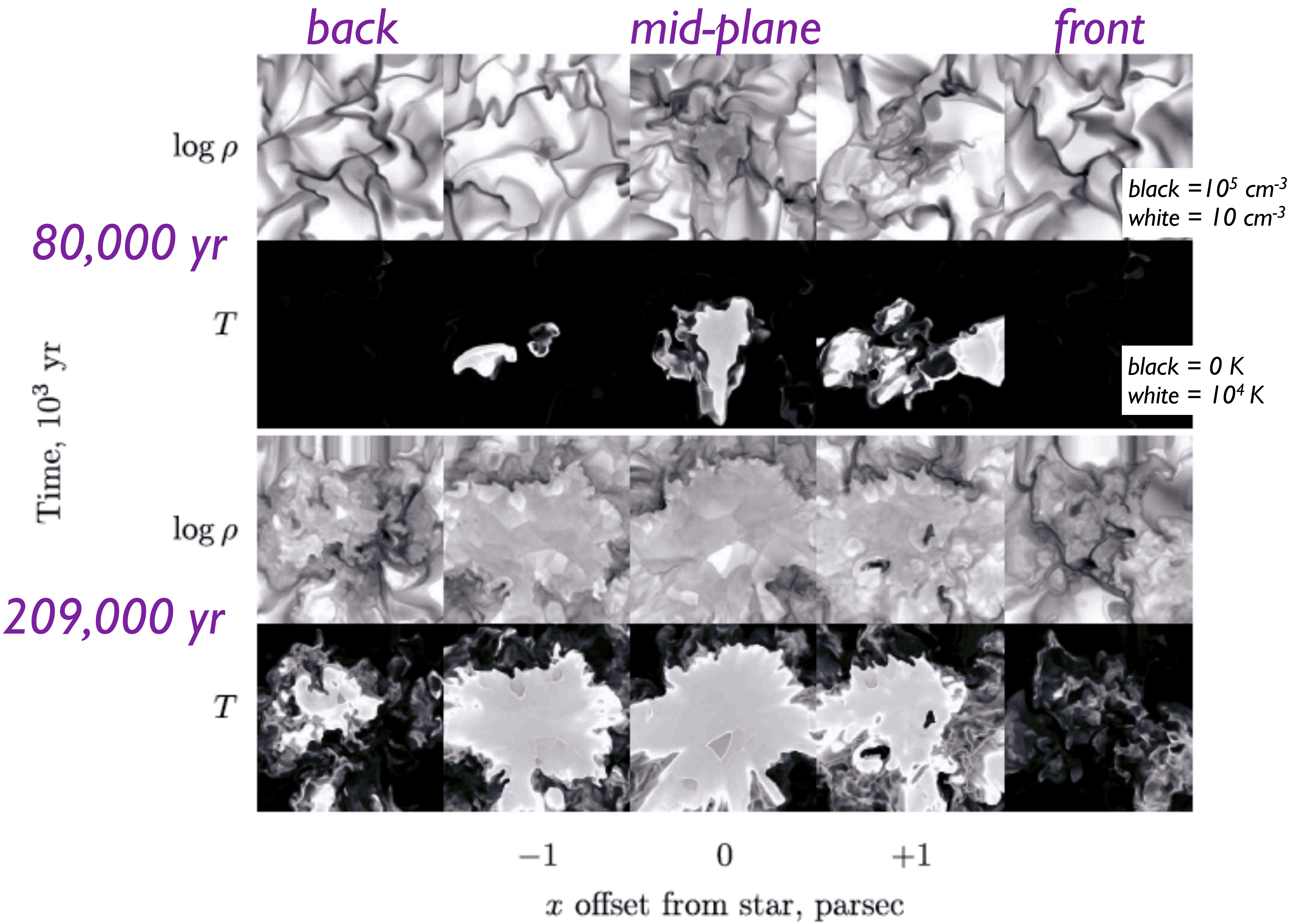

HOMEWRECKERS?

What Stars can do to the ISM



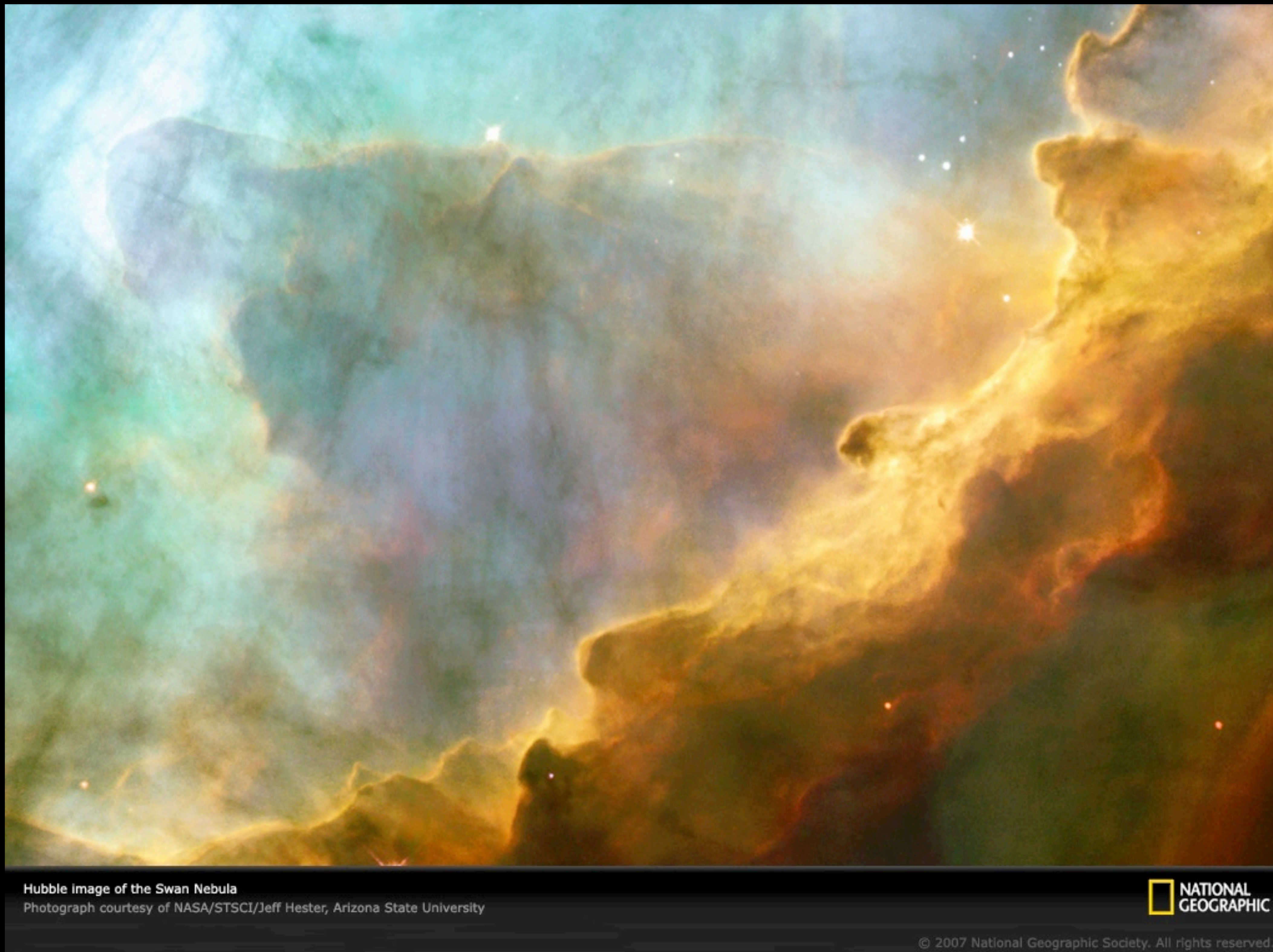
20 cm VLA from MAGPIS (Helfand et al. 2006) & MIR from Spitzer GLIMPSE (see Churchwell et al.)
3.6, 4.5, 8.0, 20cm *(Luptonized, see Lupton et al. 2004)*
image "height" is 1.6 degrees (e.g. 140 pc at 5 kpc)

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
NATIONAL GEOGRAPHIC
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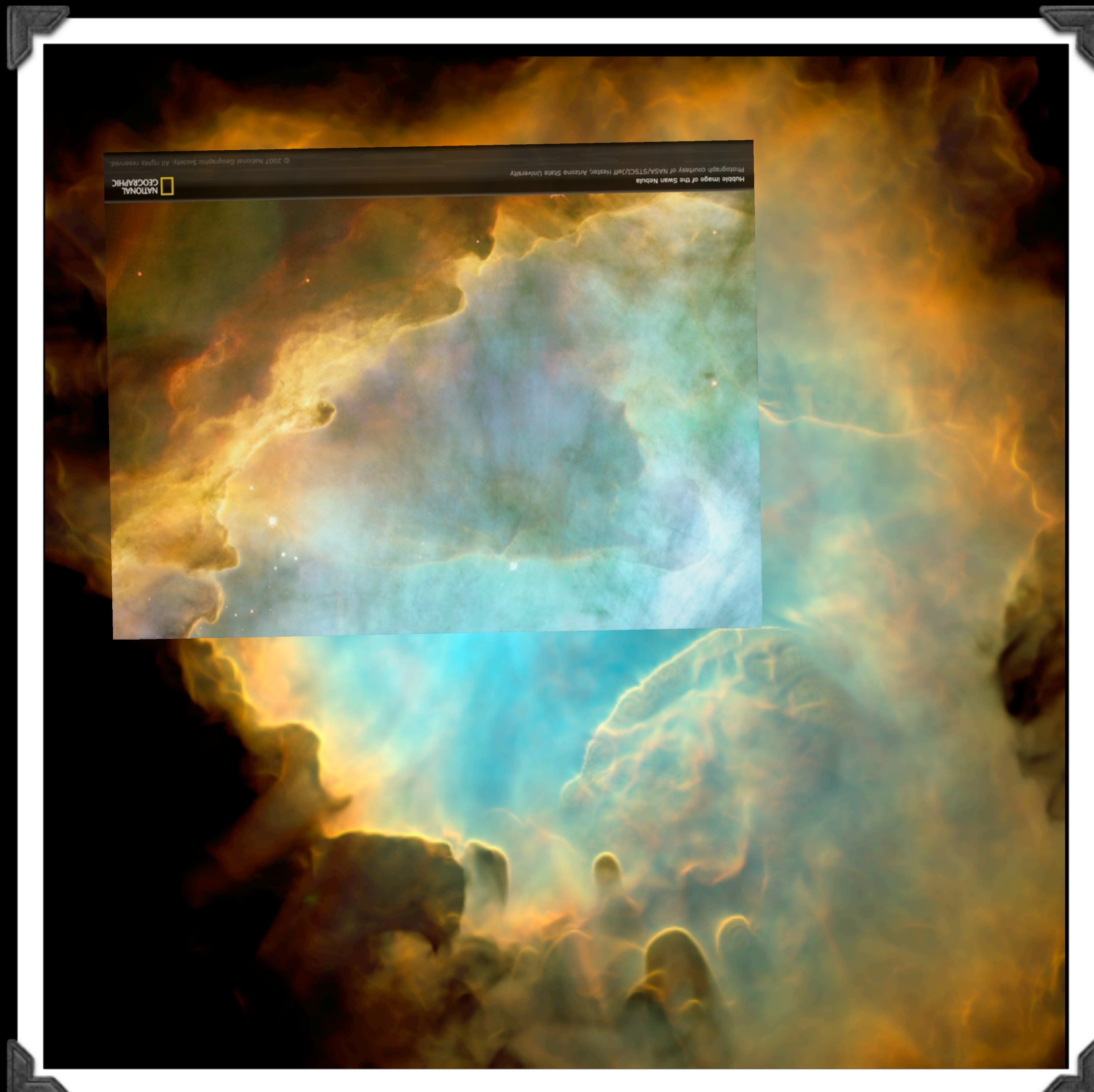
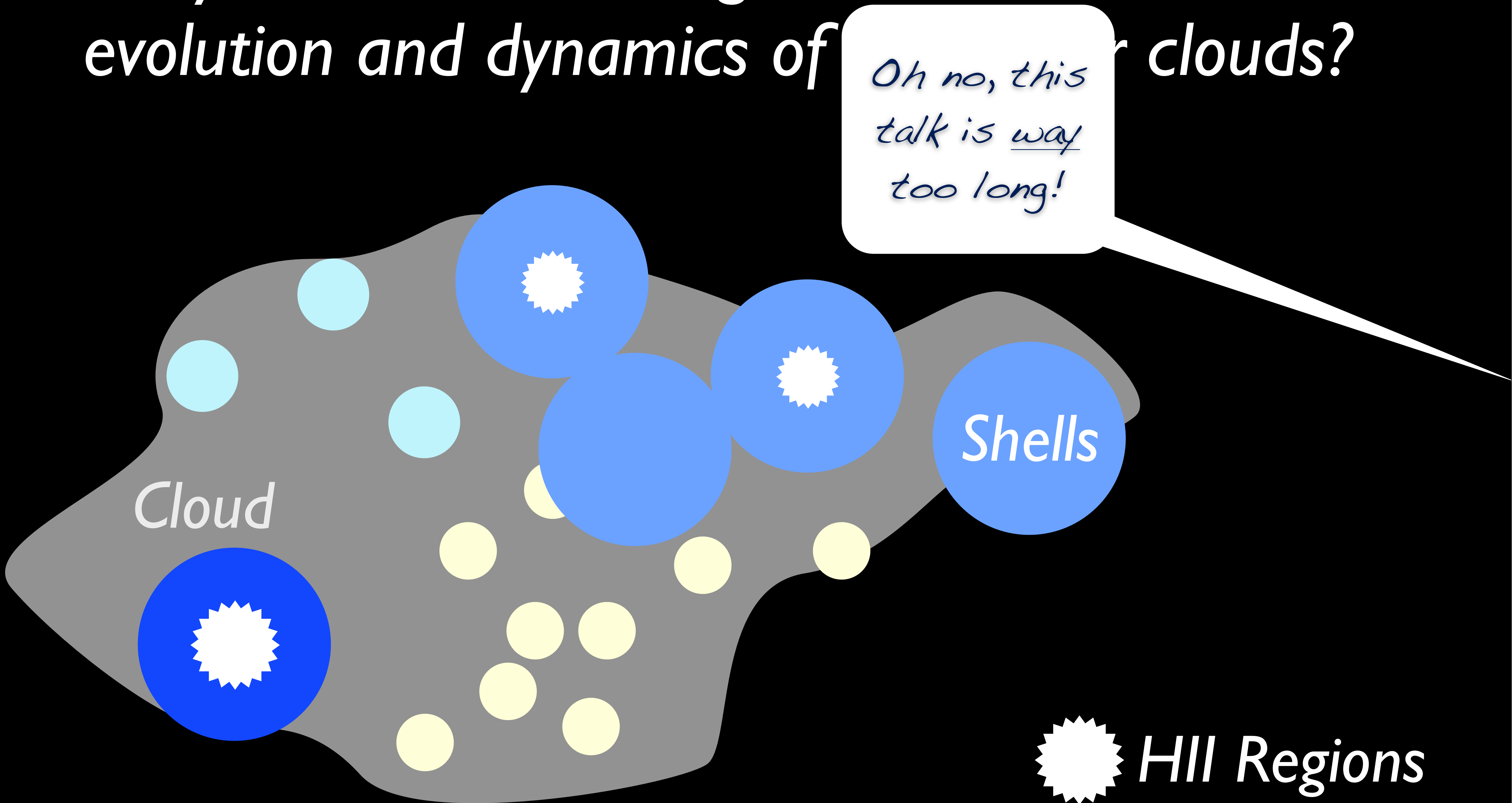
Tasting "M17"...



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" to the evolution and dynamics of … r clouds?

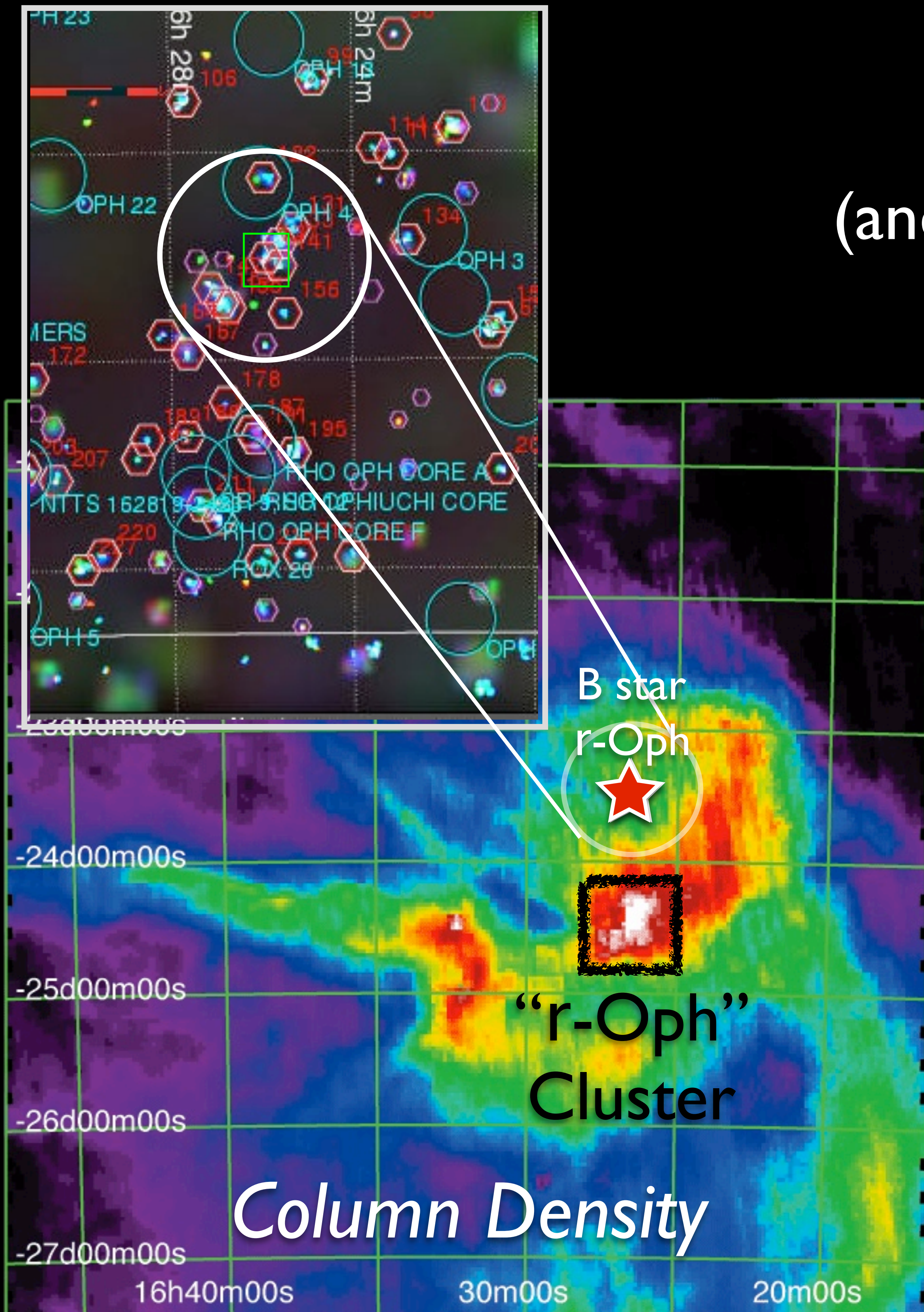


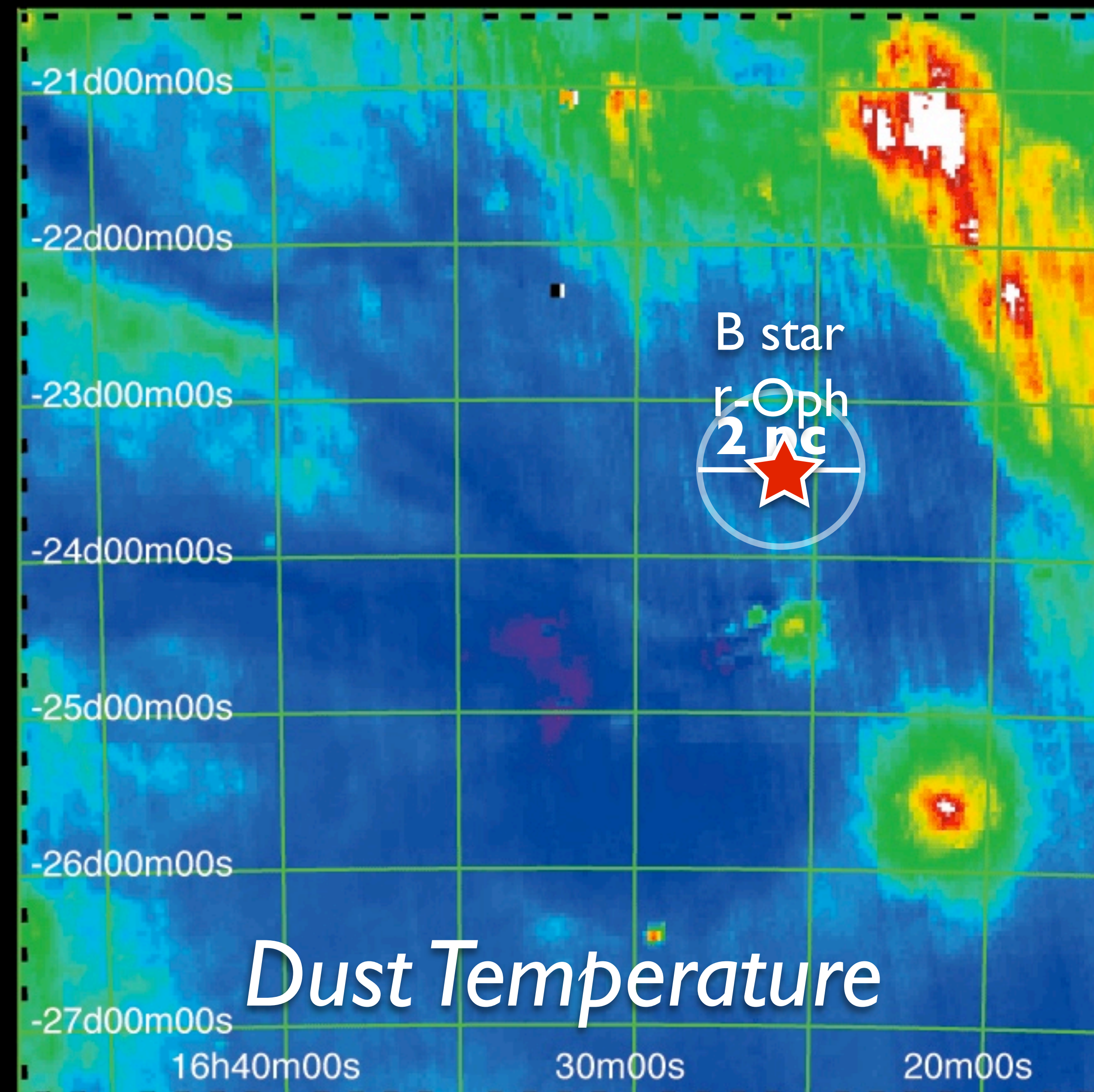
IMF O:B:A:F populations would be: 1:50:300:750.

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

r-Oph is a B*

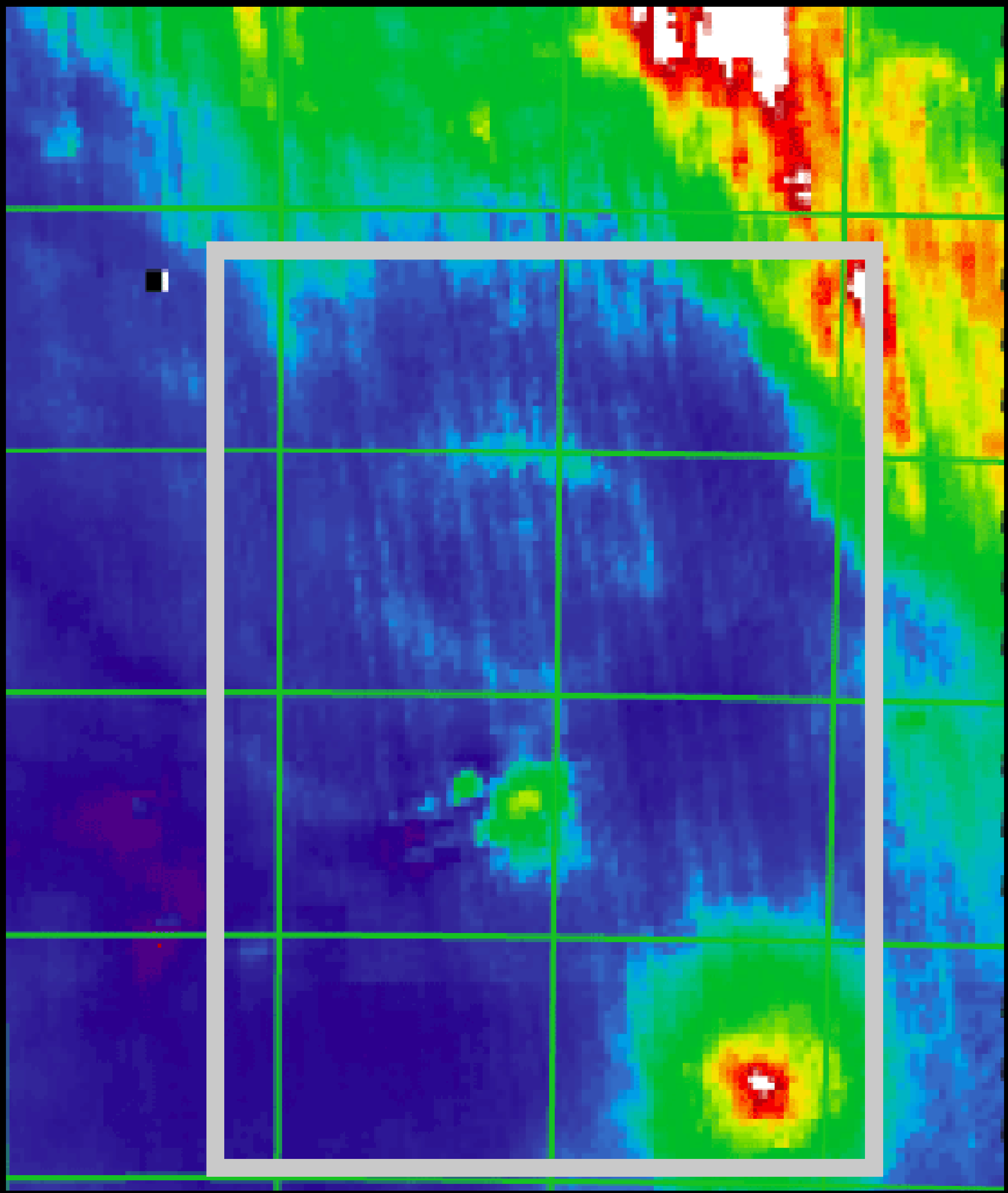
(and it's NOT in the "r-Oph" Cluster!)

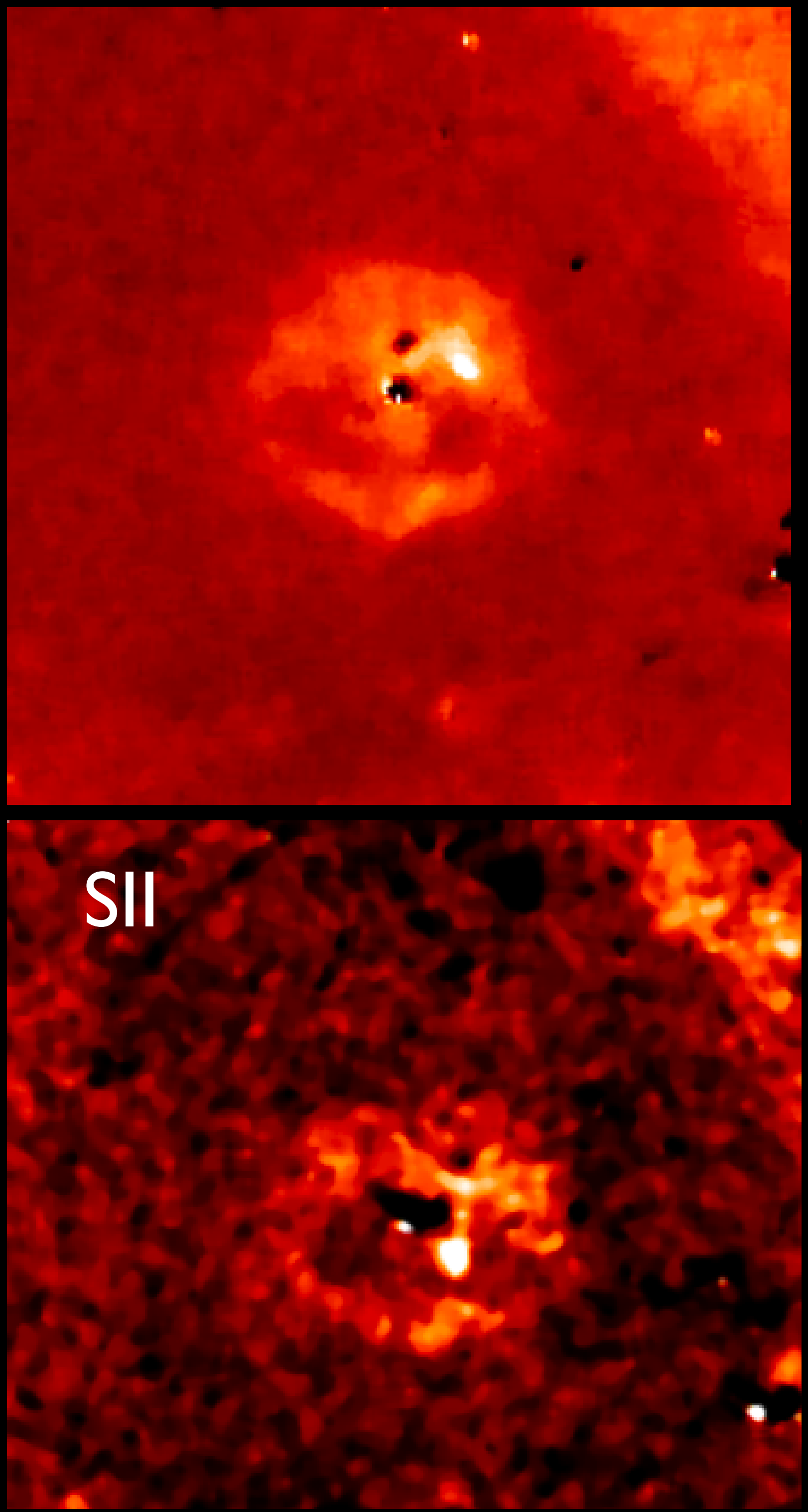




see Schnee, Ridge, Goodman & Li 2005.

Ionized Gas in the Ophiuchus Smoke Shell

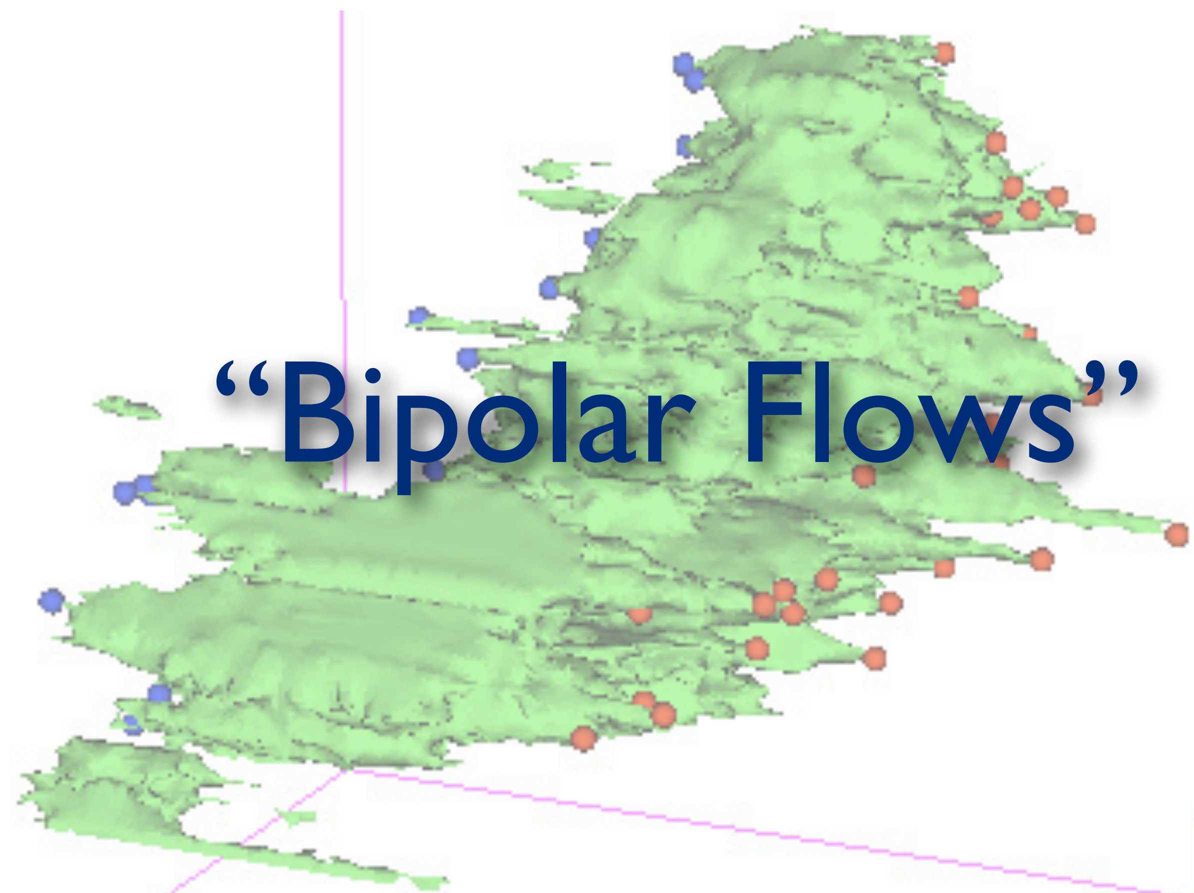




ASSA Data courtesy of John Gaustad

More on shells in a minute... but first, let's be more "conventional"....

“Bipolar Flows”



Bipolar Outflows in Perseus

The Astrophysical Journal, 715:1170–1190, 2010 June 1
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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 ($\sim$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.

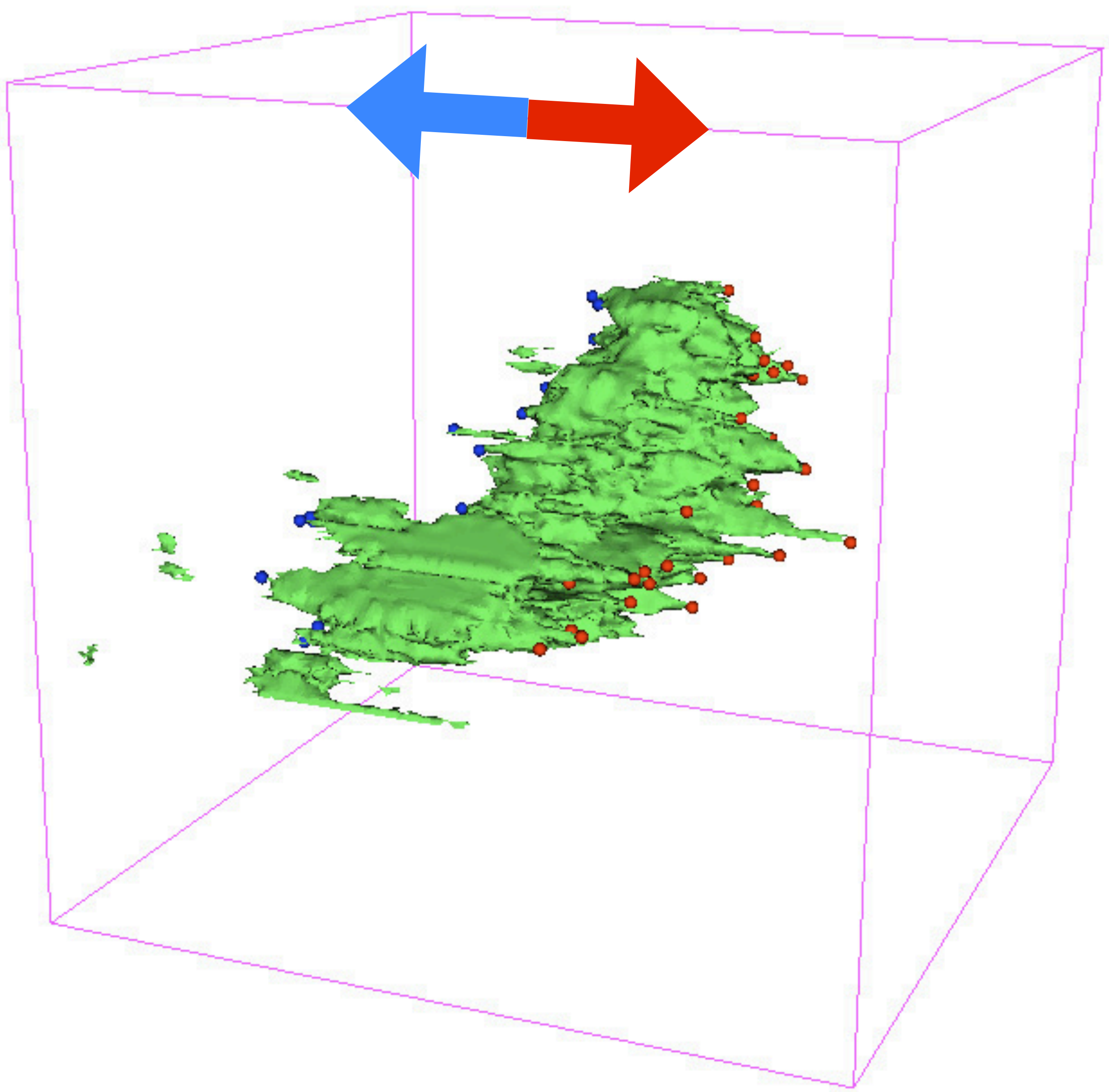
Key words: ISM: clouds – ISM: individual objects (Perseus) – ISM: jets and outflows – ISM: kinematics and dynamics – stars: formation – turbulence

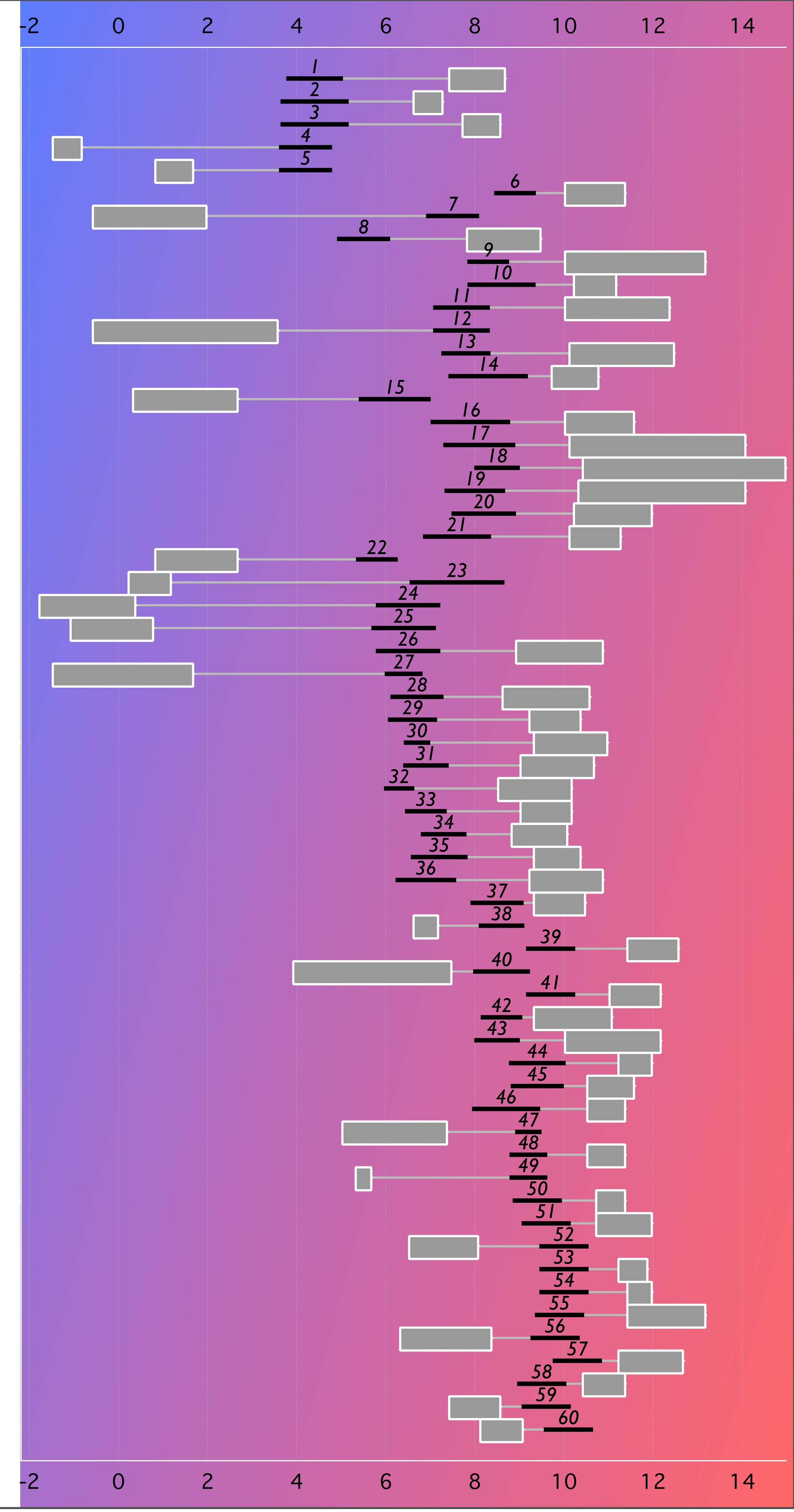
Online-only material: color figures

“CPOCs”

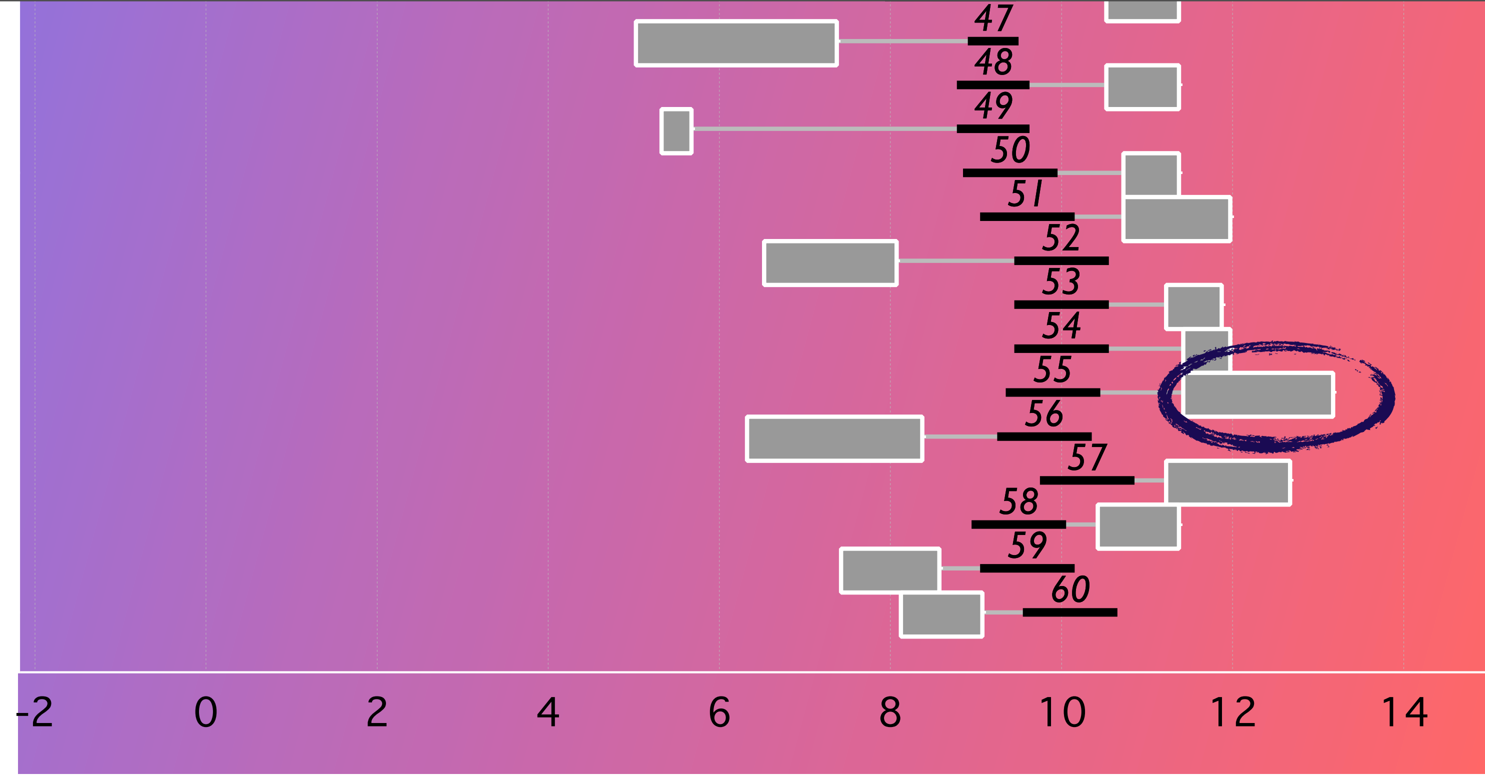
COMPLETE **P**erseus **O**utflow **C**andidates

Note: I did not make up that name!





“CPOCs”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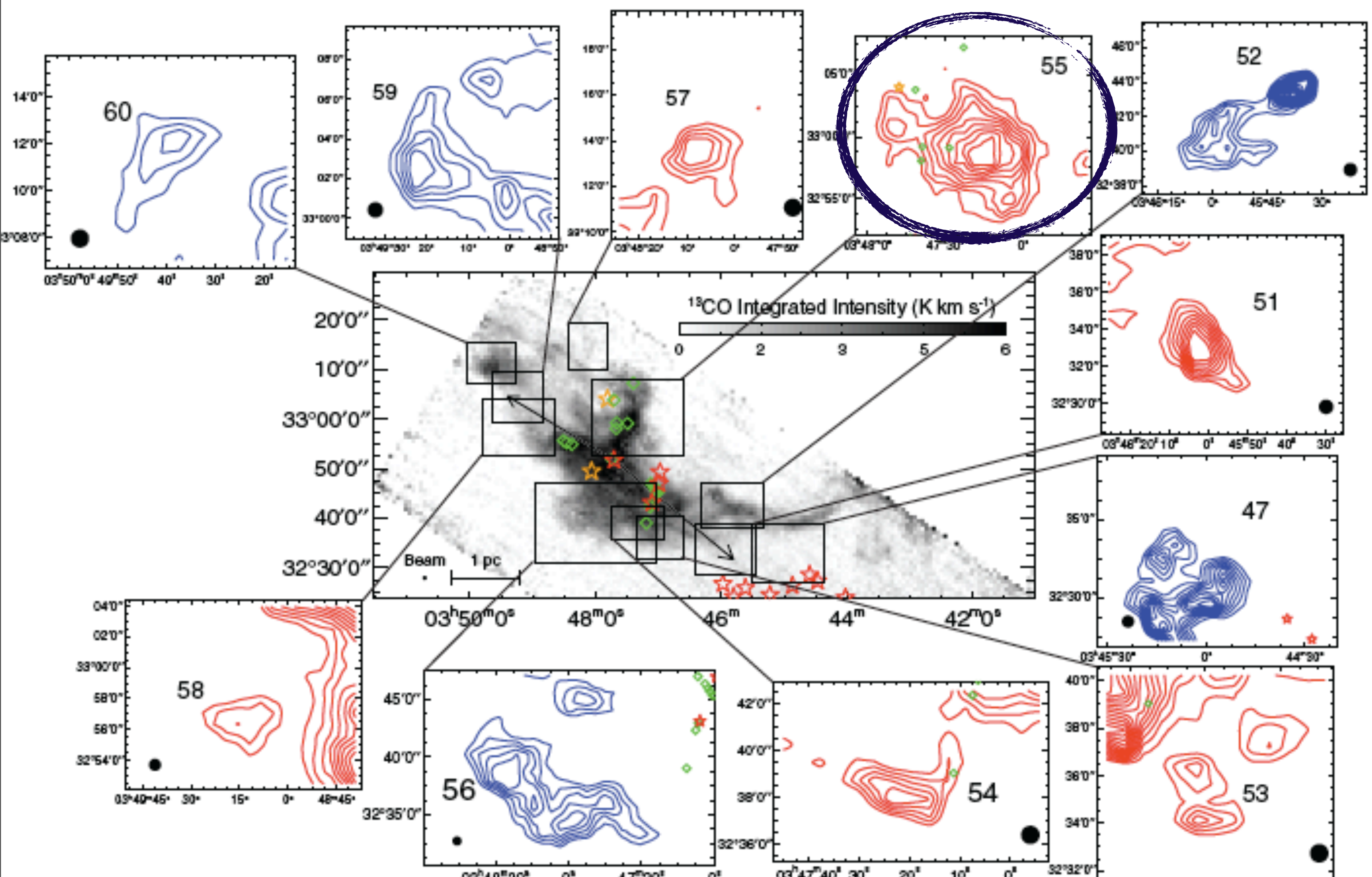
60
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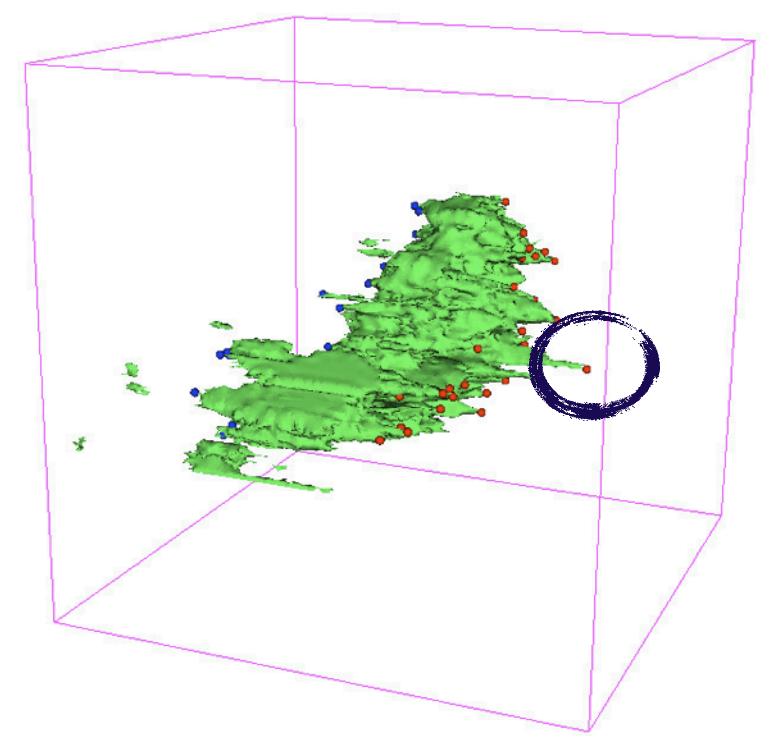
54
53
^{13}CO Integrated Intensity (K km s^{-1})
Beam
1 pc
20′0″
10′0″
33°00′0″
50′0″
40′0″
32°30′0″
03^{h}50^{m}0^s
48^{m}0^s
46^m
44^m
42^{m}0^s



Perseus Bipolar Outflows

Arce et al. 2010a

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

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^2_{reg}/R_{reg}.
[g] Turbulence energy given by $\frac{3}{16ln2}M_{reg}\Delta v^2$.
[h] Turbulence dissipation time, see Section 5.2.1.
[i] Turbulence energy dissipation rate give by E_{turb}/τ_{diss}.

Table 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.

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).

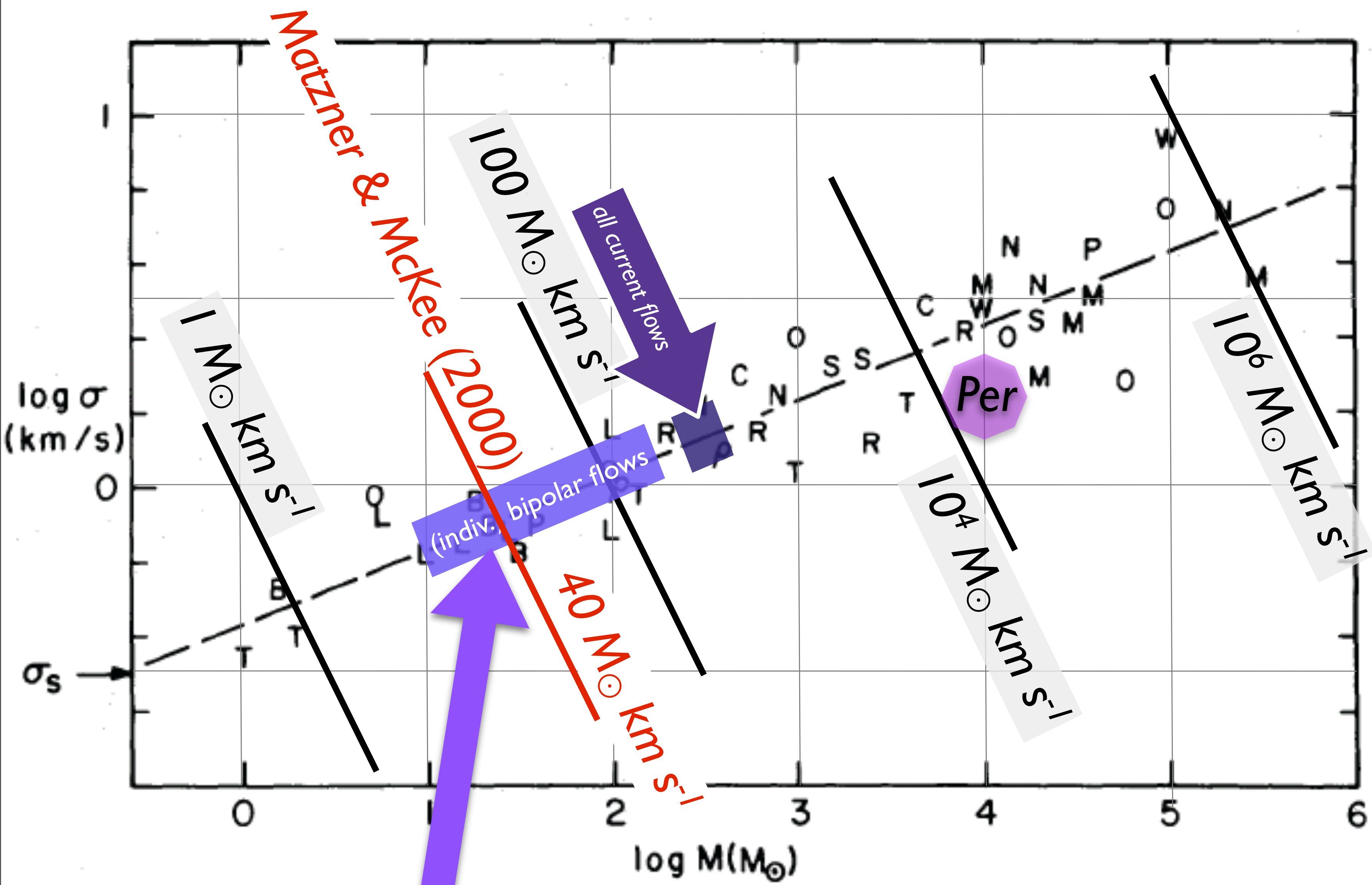
Typically 20% binding energy in flows.

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

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NGC 1333	5.0/25	17.4/121.8	6.9/69	44
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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.

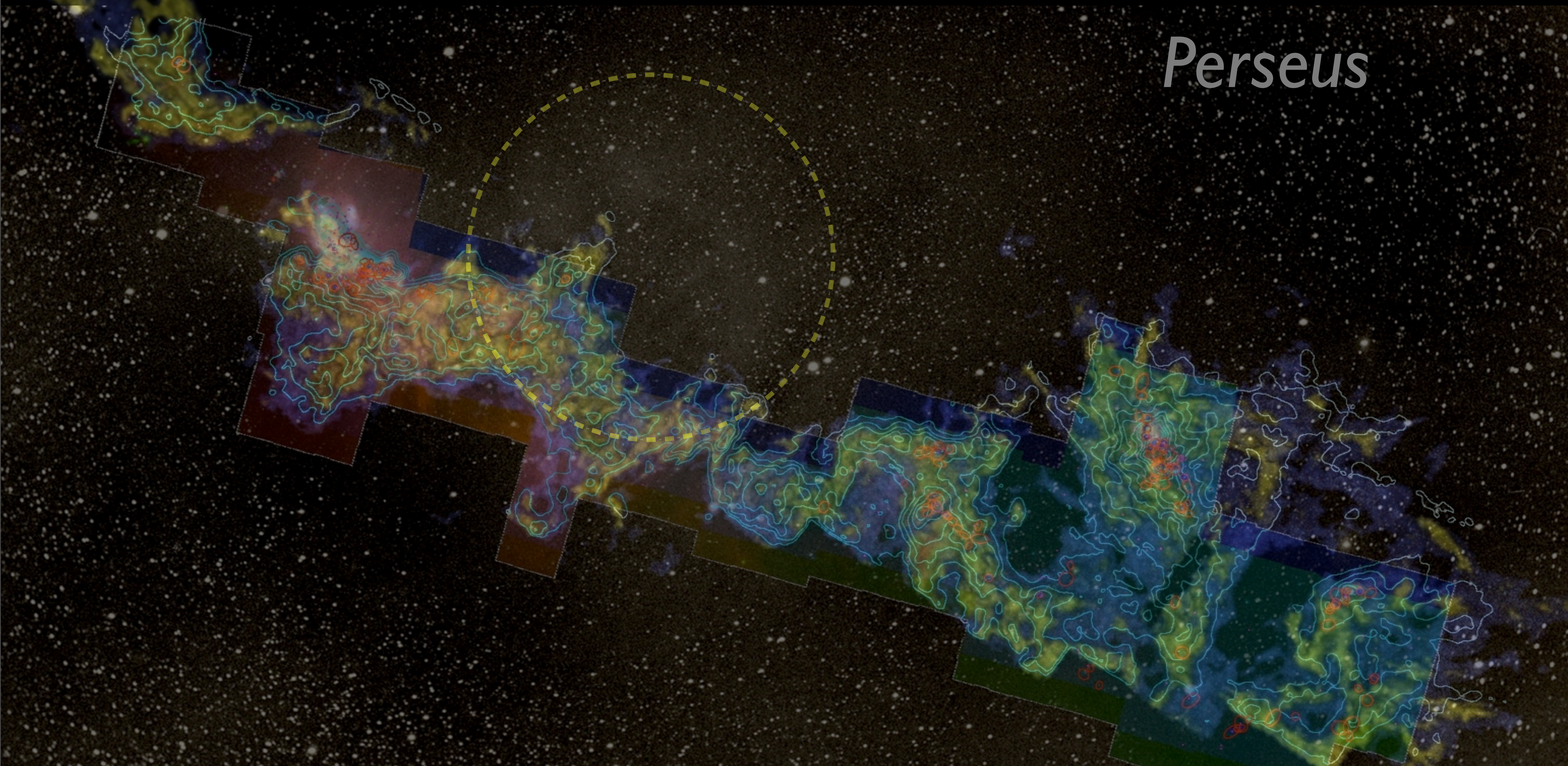
__Roughly true statement__

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


“Shells”

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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João Alves (Vienna)

Héctor Arce (Yale)

Chris Beaumont (UHawaii & CfA)

Michelle Borkin (Harvard SEAS/IIC)

Paola Caselli (Leeds, UK)

James DiFrancesco (HIA, Canada)

Jonathan Foster (B.U.)

Mark Heyer (UMASS/FCRAO)

Doug Johnstone (HIA, Canada)

Jens Kauffmann (JPL/Caltech)

Helen Kirk (CfA)

Di Li (JPL/Caltech)

Stella Offner (CfA)

Jaime Pineda (CfA, PhD Student)

Thomas Robitaille (CfA)

Erik Rosolowsky (UBC Okanagan)

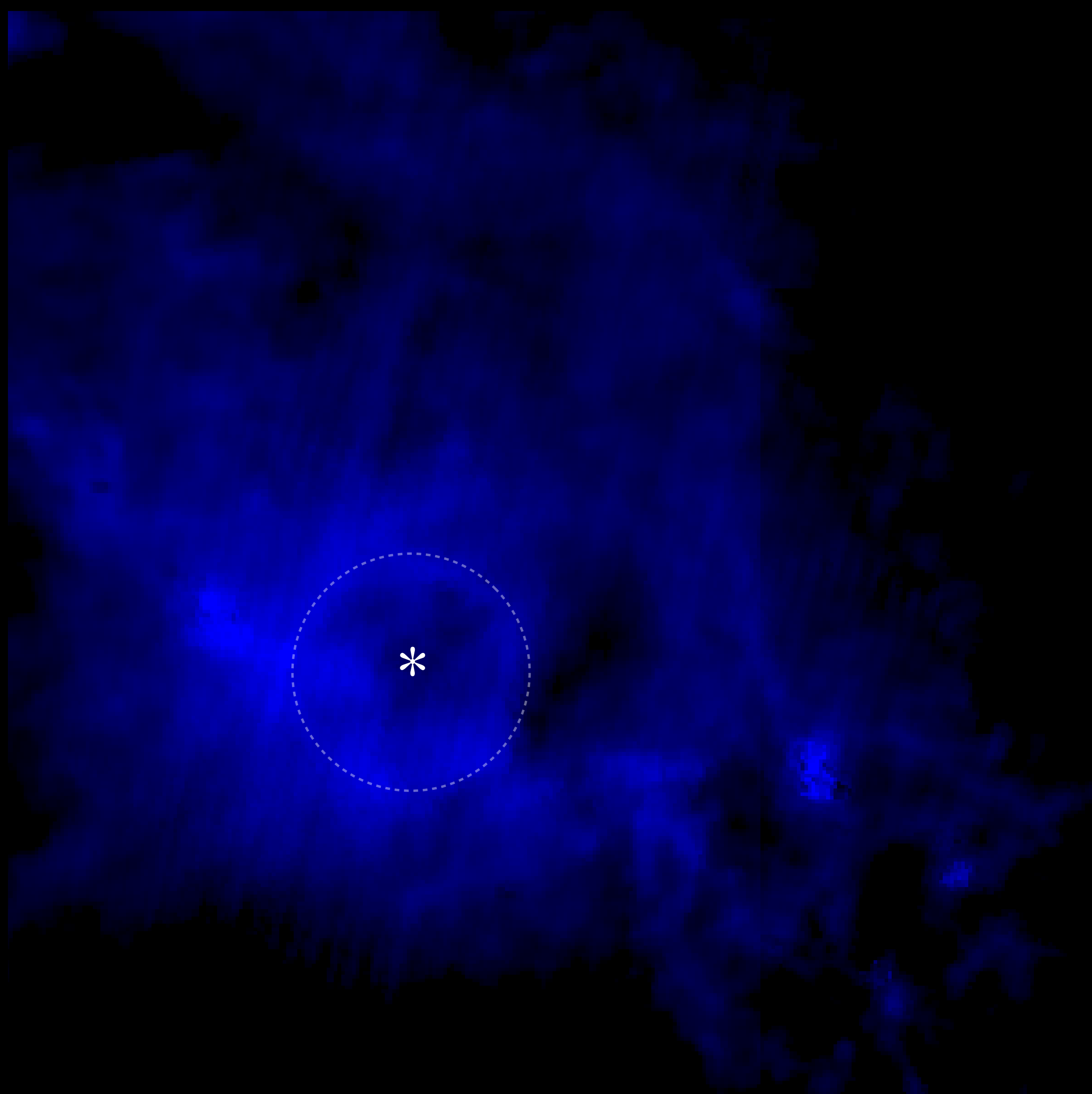
Rahul Shetty (ITA Heidelberg)

Scott Schnee (HIA Victoria)

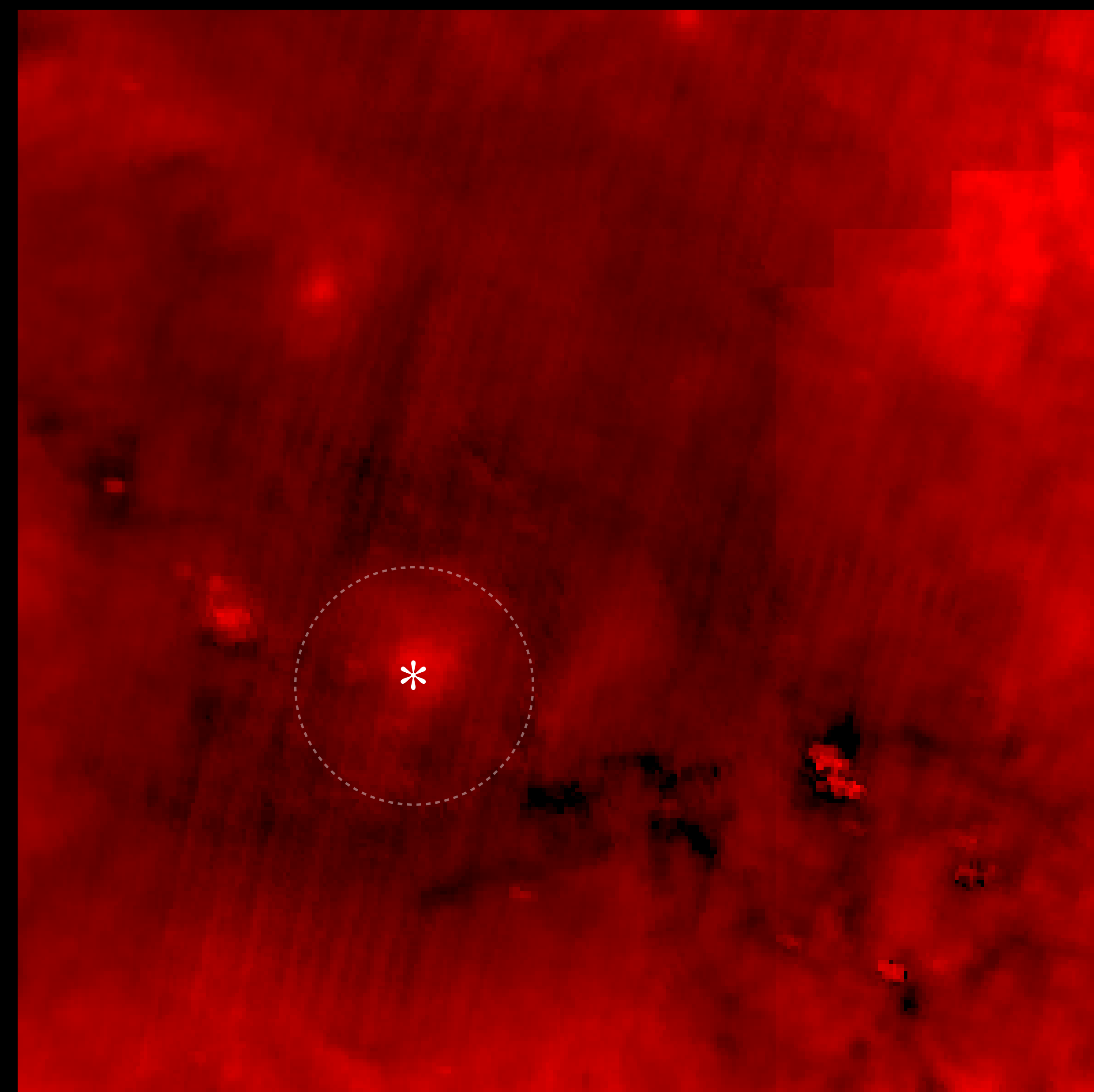
Mario Tafalla (OAN, Spain)

What B* HD 278942 Does to Perseus

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

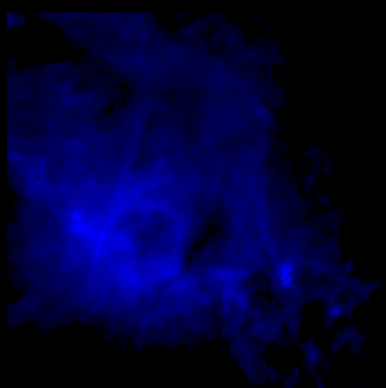


Dust **Column Temperature** (25 to 45 K)
(Based on 60/100 microns)



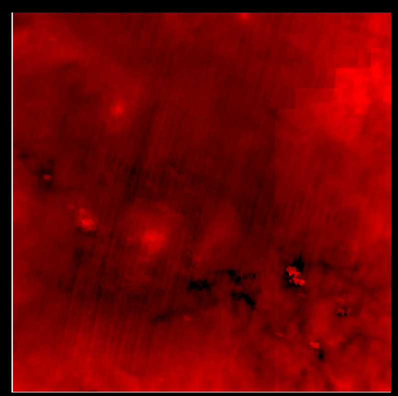
COMPLETE *see Ridge et al. 2006a,b; Schnee et al. 2007, 2008; Shetty et al. 2010* cf. c2d Spitzer images Rebull et al. 2007.

Column Density



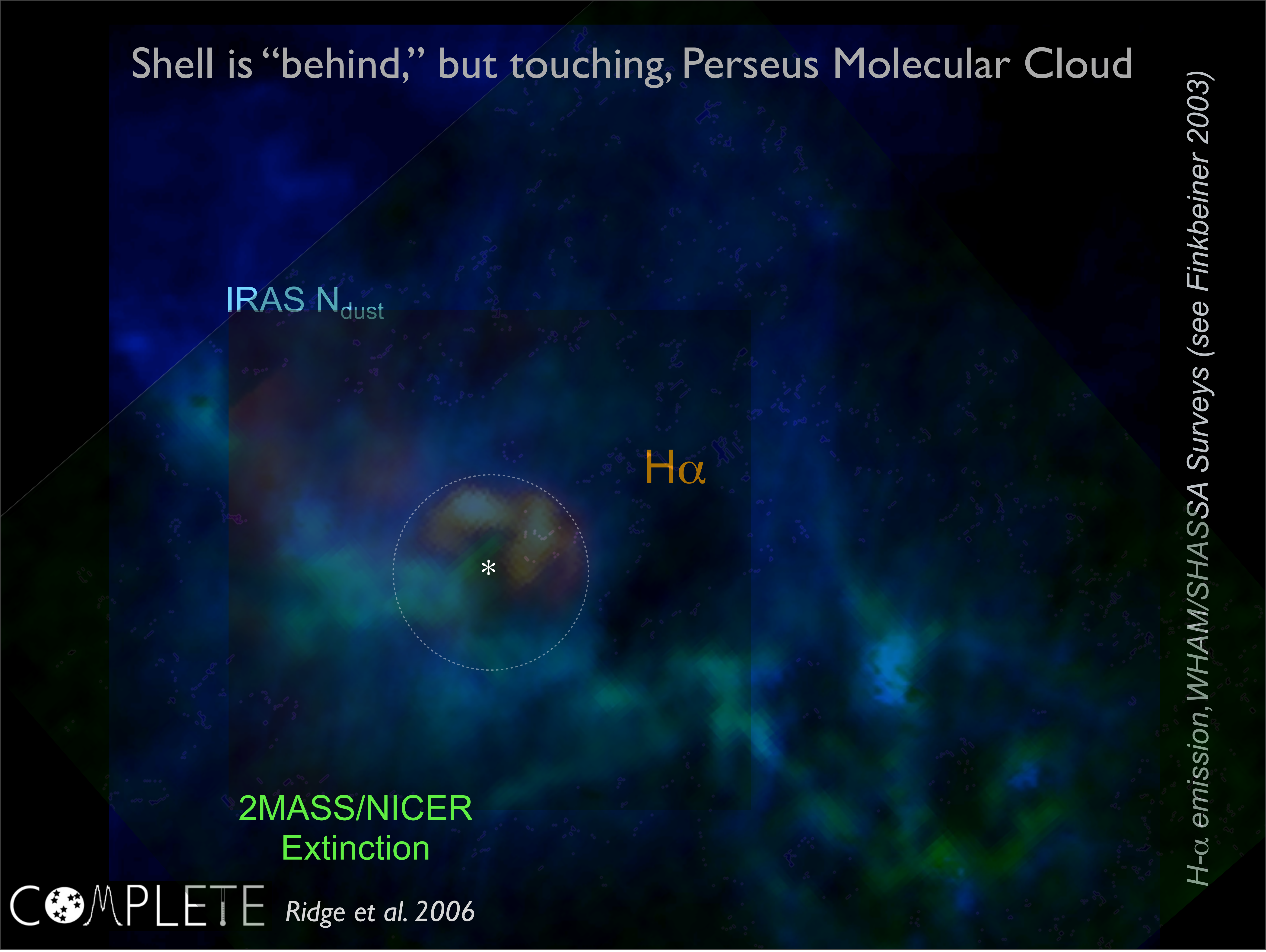
+

Column Temperature

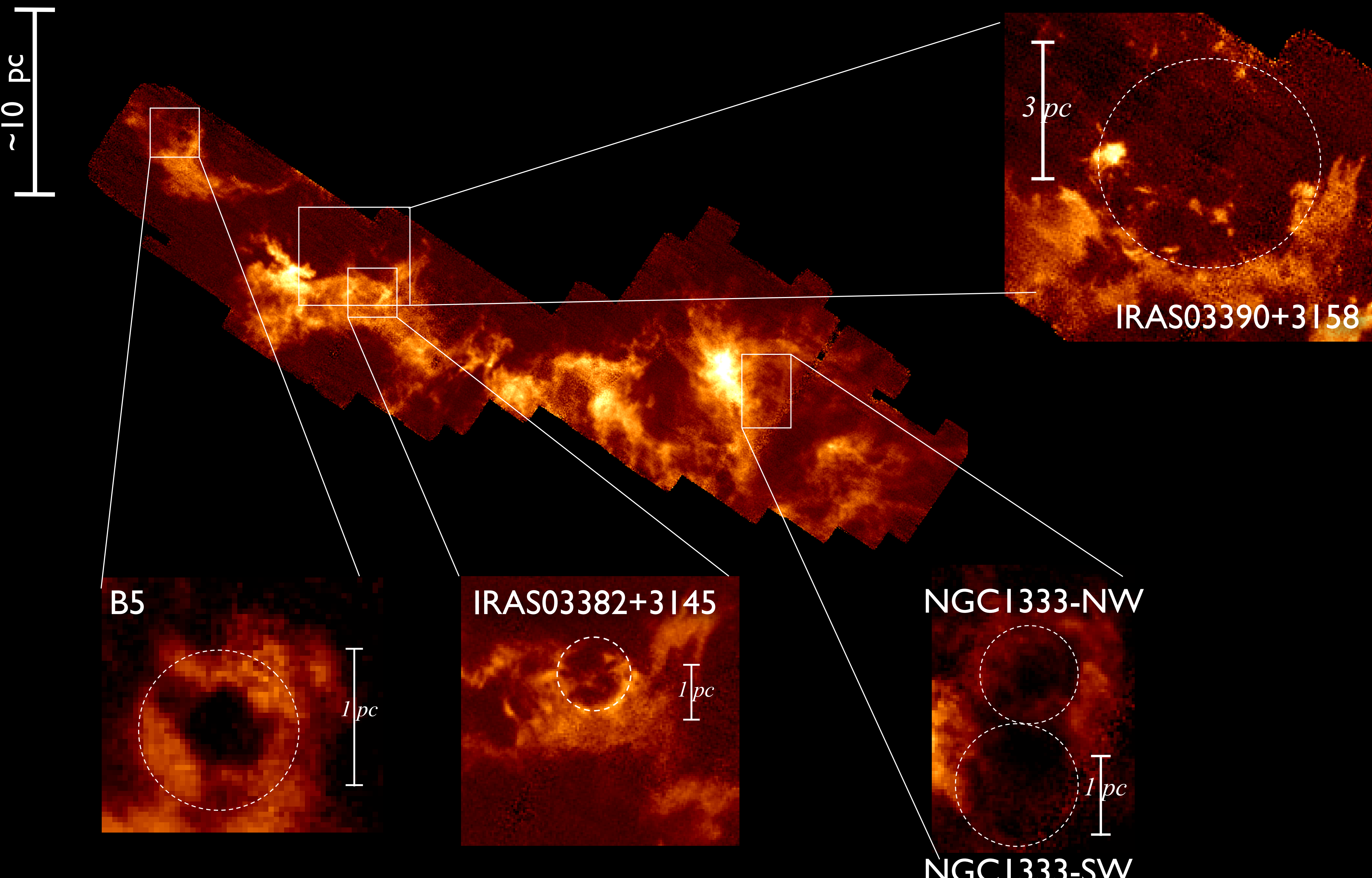


=

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

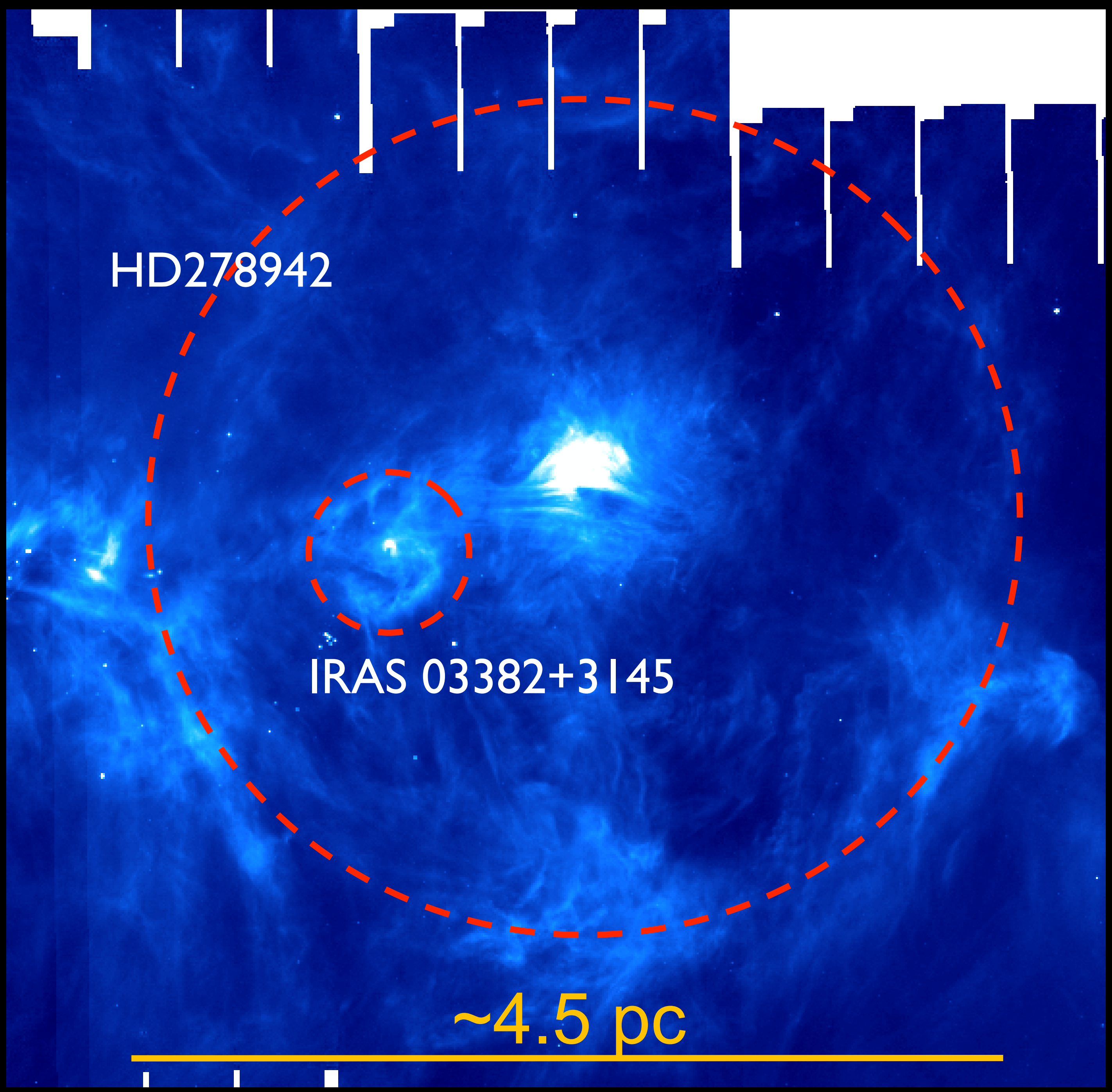

Shell is "behind," but touching, Perseus Molecular Cloud
IRAS N_dust
Hα
*
2MASS/NICER
Extinction
H-α emission, WHAM/SHASSA Surveys (see Finkbeiner 2003)
COMPLETE
Ridge et al. 2006

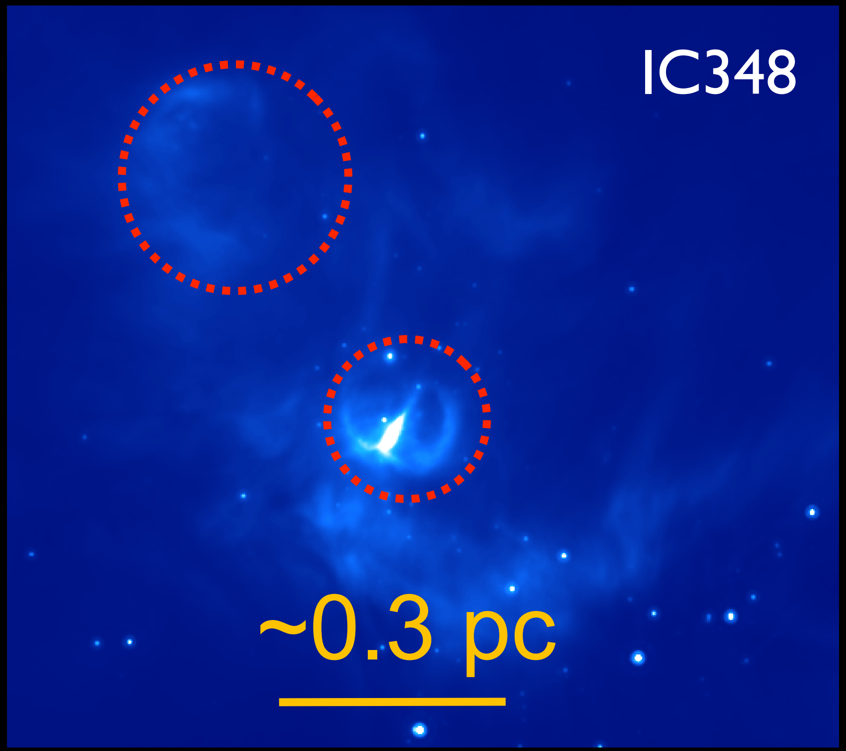
Perseus Shells in ^{13}CO

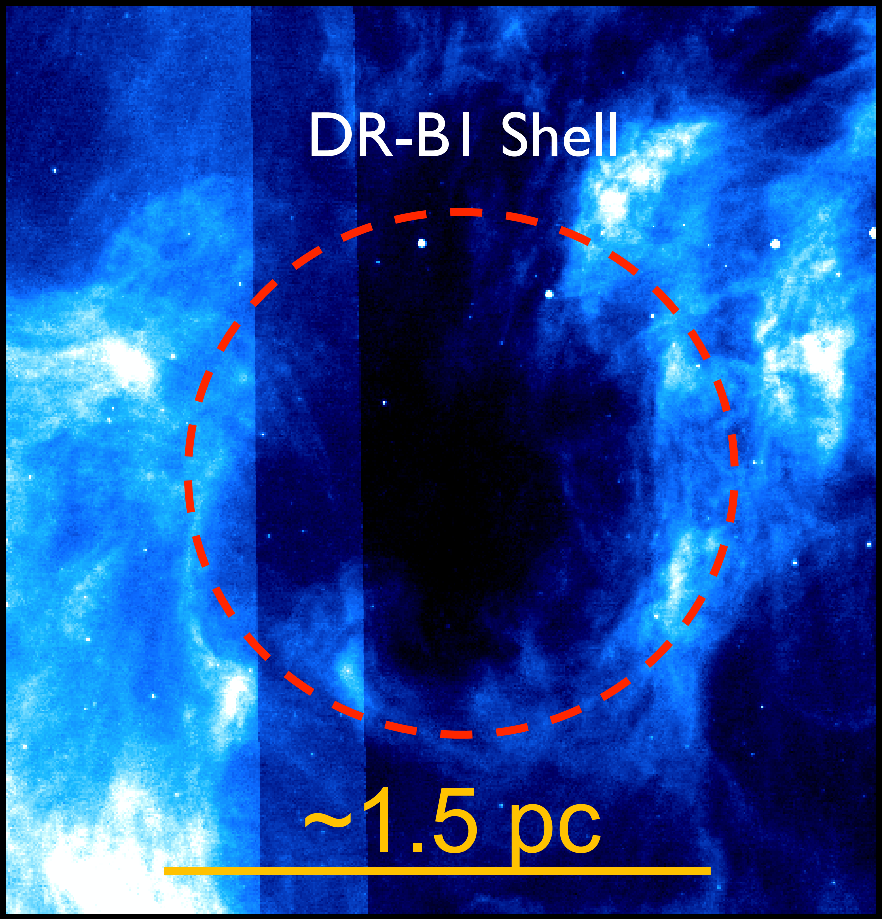


Perseus Shells in Spitzer MIPS 24 mm

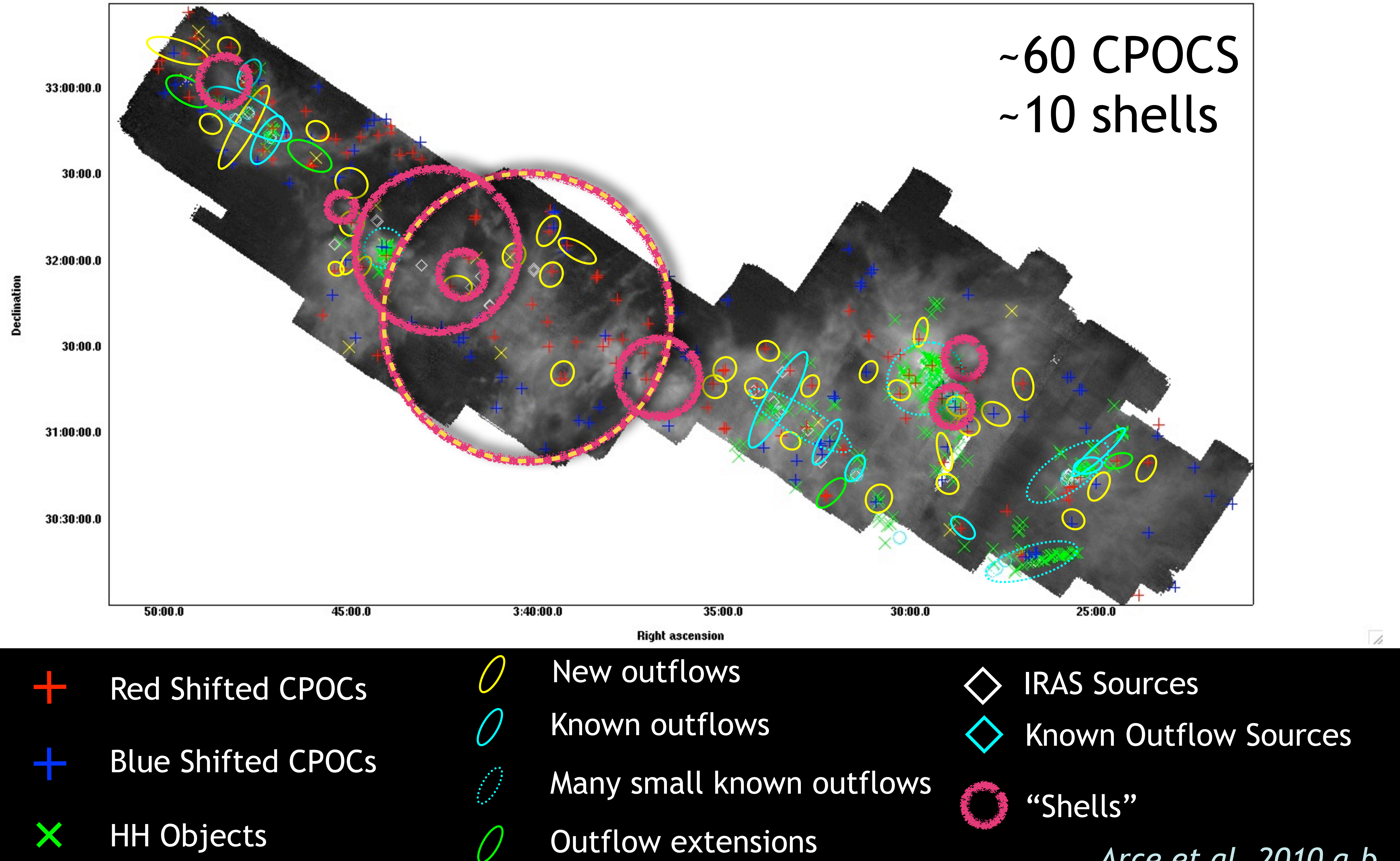
(Images from Spitzer c2d: Rebull et al. 2007)





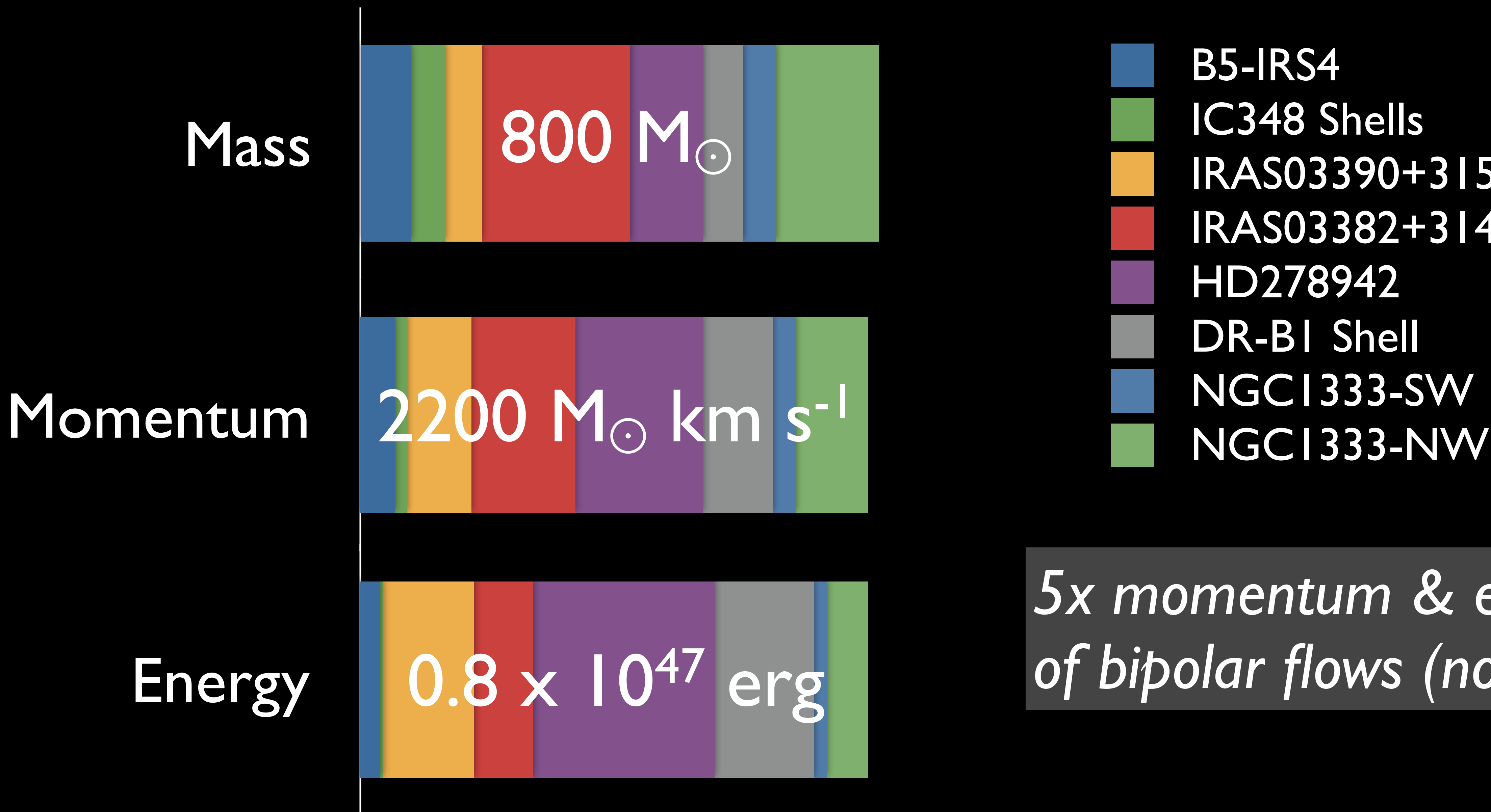


Perseus Outflows & Shells



Arce et al. 2010 a,b

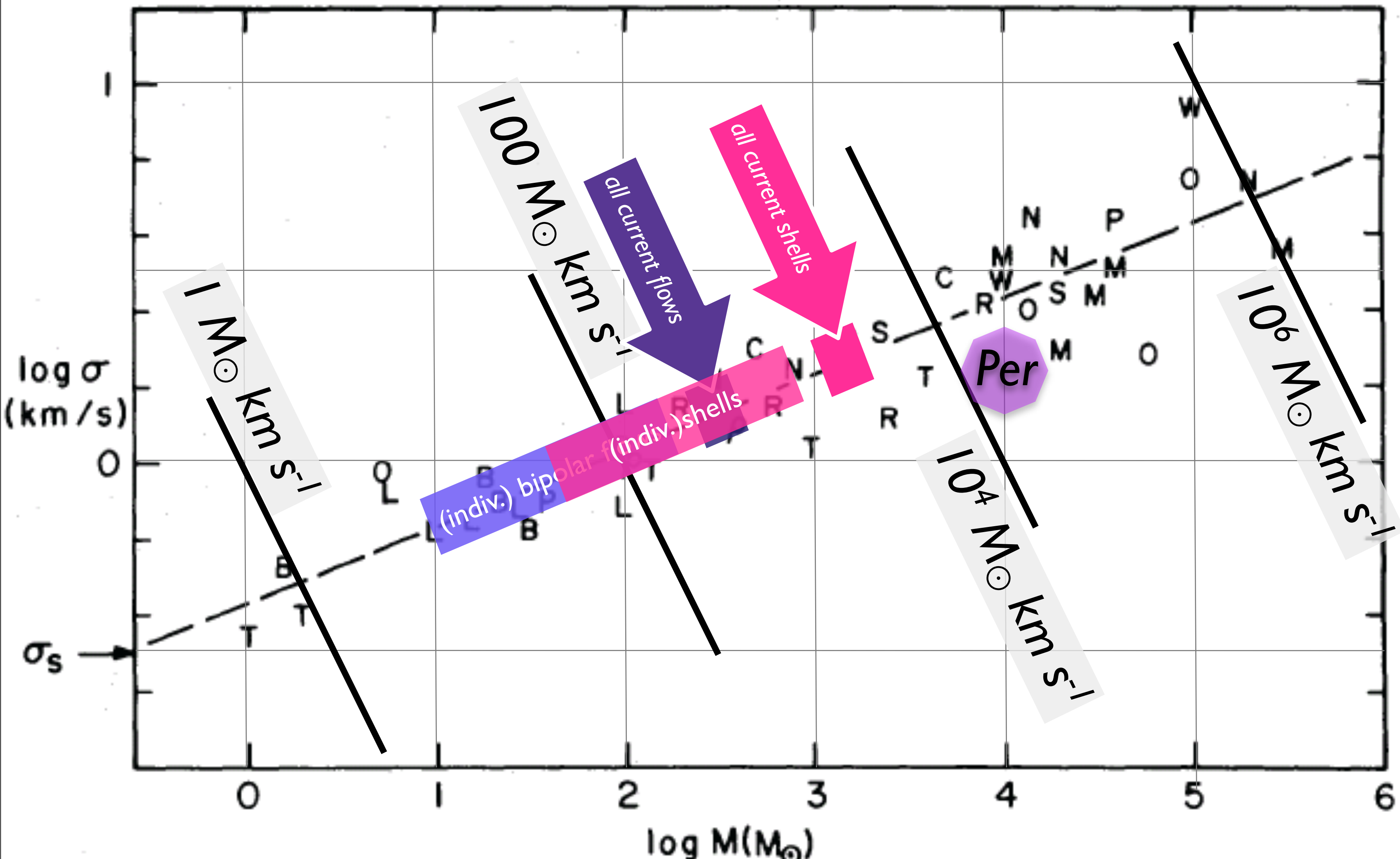
Shells in Perseus



5x momentum & energy of bipolar flows (now)

IC348/Omicron Per HII region is not included, yet


HOMEWRECKERS?



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

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

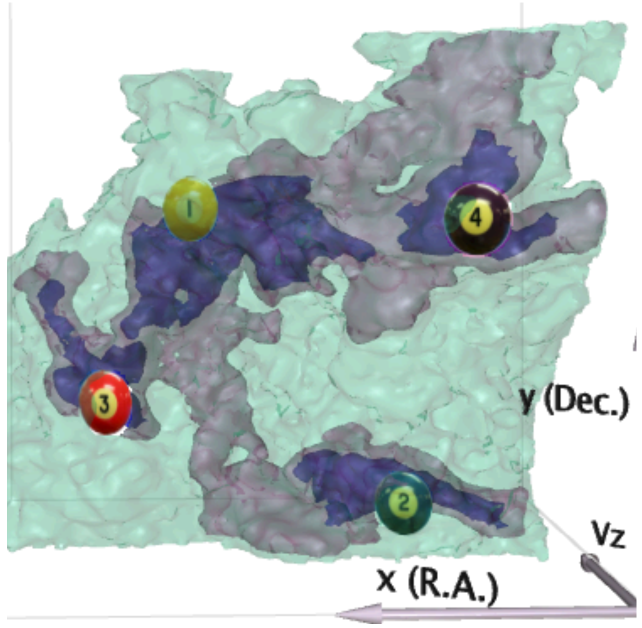
What "upshifts" are justified?....

IOTW, how do we go from a "snapshot" to cumulative effects?

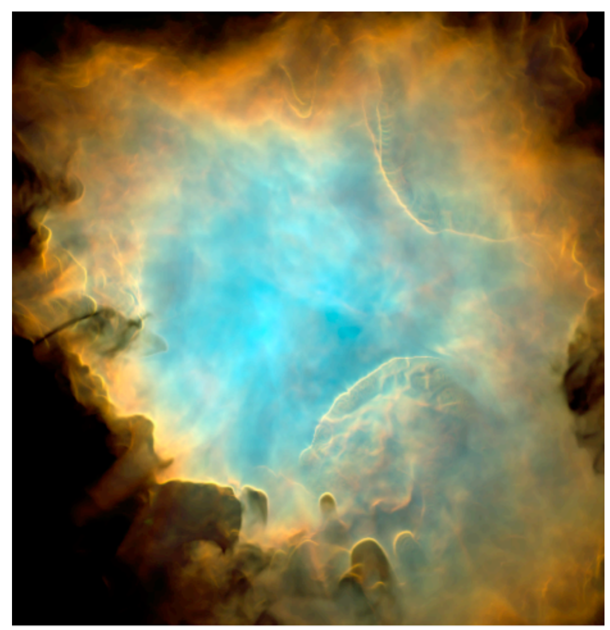
Note theory gives ~10 to 1000 $M_\odot$ km s^{-1} per B-star wind.

3 Open Questions

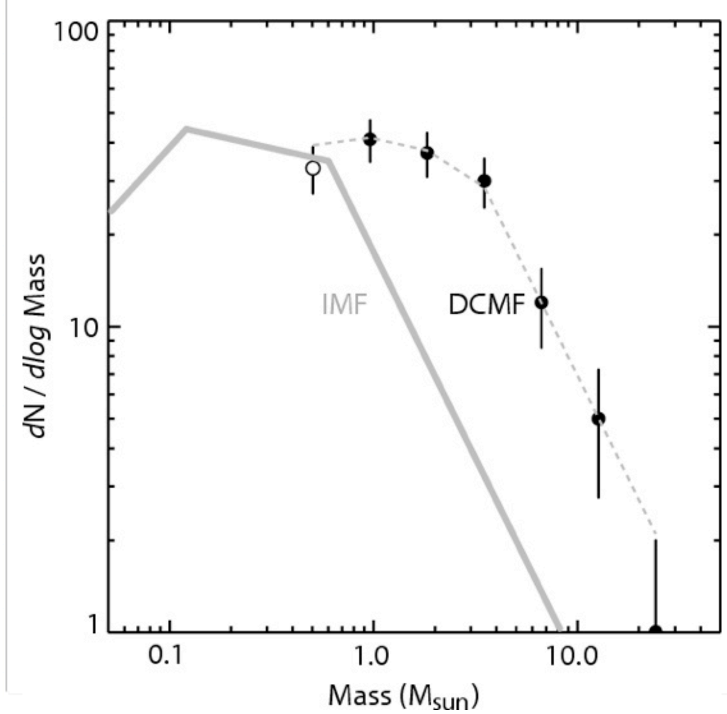
1. At what scales does **gravity** matter?



2. What do **stars** really do to clouds?

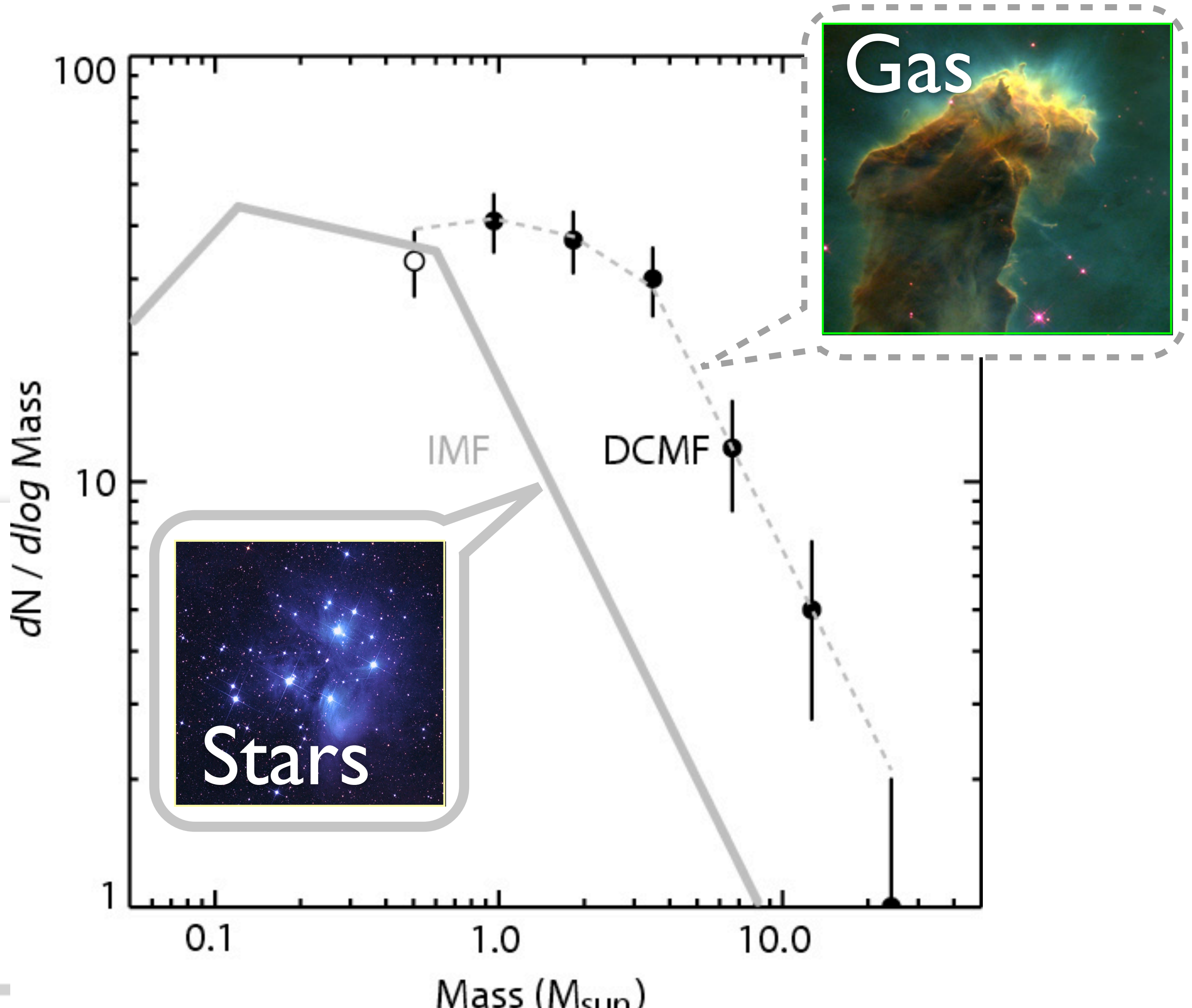


3. Is the origin of the **IMF** related (only) to the CMF?



+ "tasty" approaches to answers

"IMF" from the "CMF"?



Hmmm....

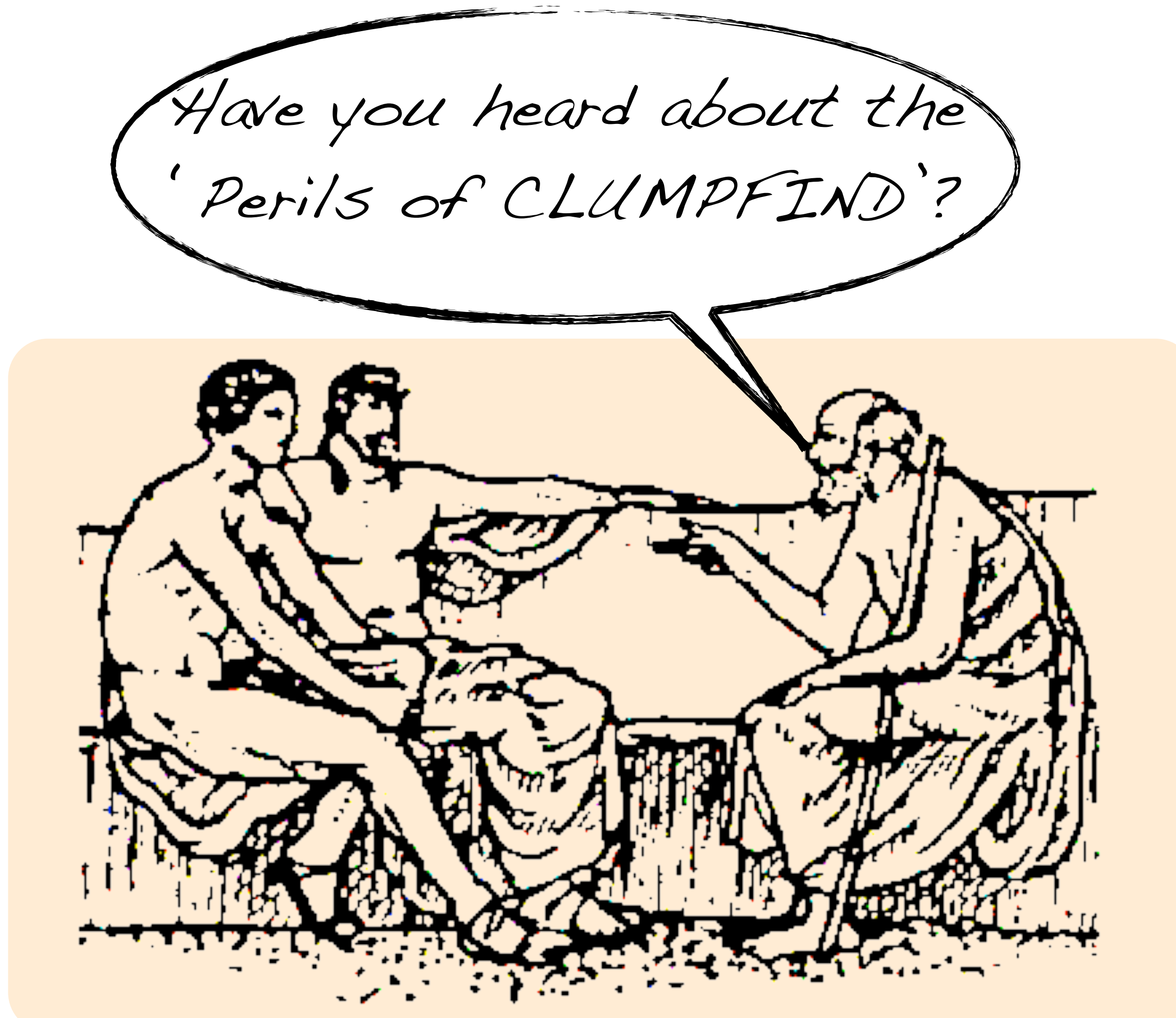
Internet Mathematics Vol. 1, No. 2: 226-251

A Brief History of Generative Models for Power Law and Lognormal Distributions

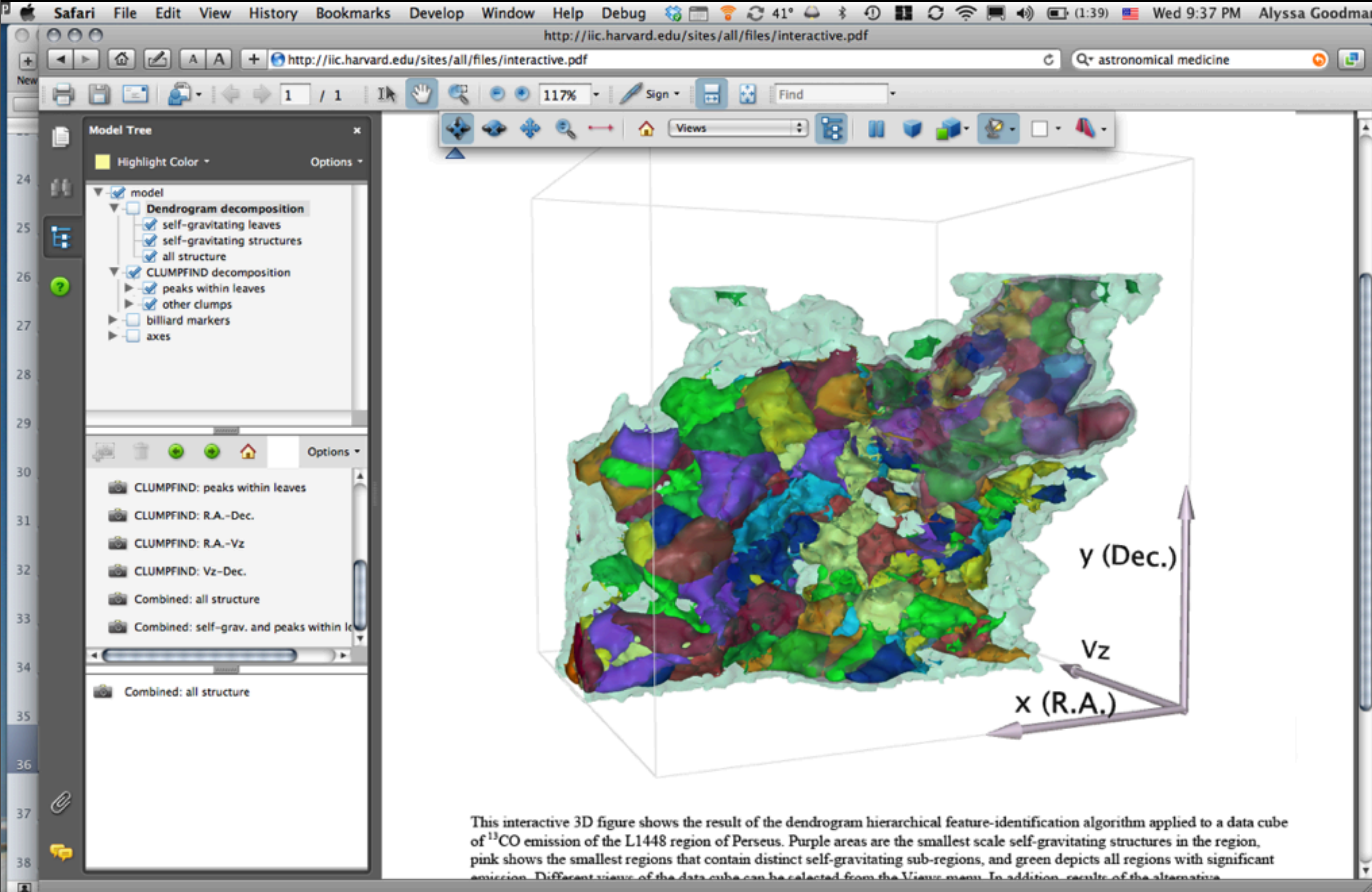
Michael Mitzenmacher

Abstract. Recently, I became interested in a current debate over whether file size distributions are best modelled by a power law distribution or a lognormal distribution. In trying to learn enough about these distributions to settle the question, I found a rich and long history, spanning many fields. Indeed, several recently proposed models from the computer science community have antecedents in work from decades ago. Here, I briefly survey some of this history, focusing on underlying generative models that lead to these distributions. One finding is that lognormal and power law distributions connect quite naturally, and hence, it is not surprising that lognormal distributions have arisen as a possible alternative to power law distributions across many fields.

Alves, Lombardi & Lada 2007



The Meaning of the "CMF"



http://iic.harvard.edu/sites/all/files/interactive.pdf;

with many thanks to Mike Halle, Michelle Borkin, Jens Kauffmann & Douglas Alan

"The Perils of CLUMPFIND" *by Pineda, Rosolowsky & Goodman 2009*

See also ***"On the fidelity of the core mass functions derived from dust column density data"*** *by Kainulainen, Lada, Rathborne & Alves 2009*

"Crowded" 3D data *(very dangerous)*

"Sparse" 2D data *(OK)*

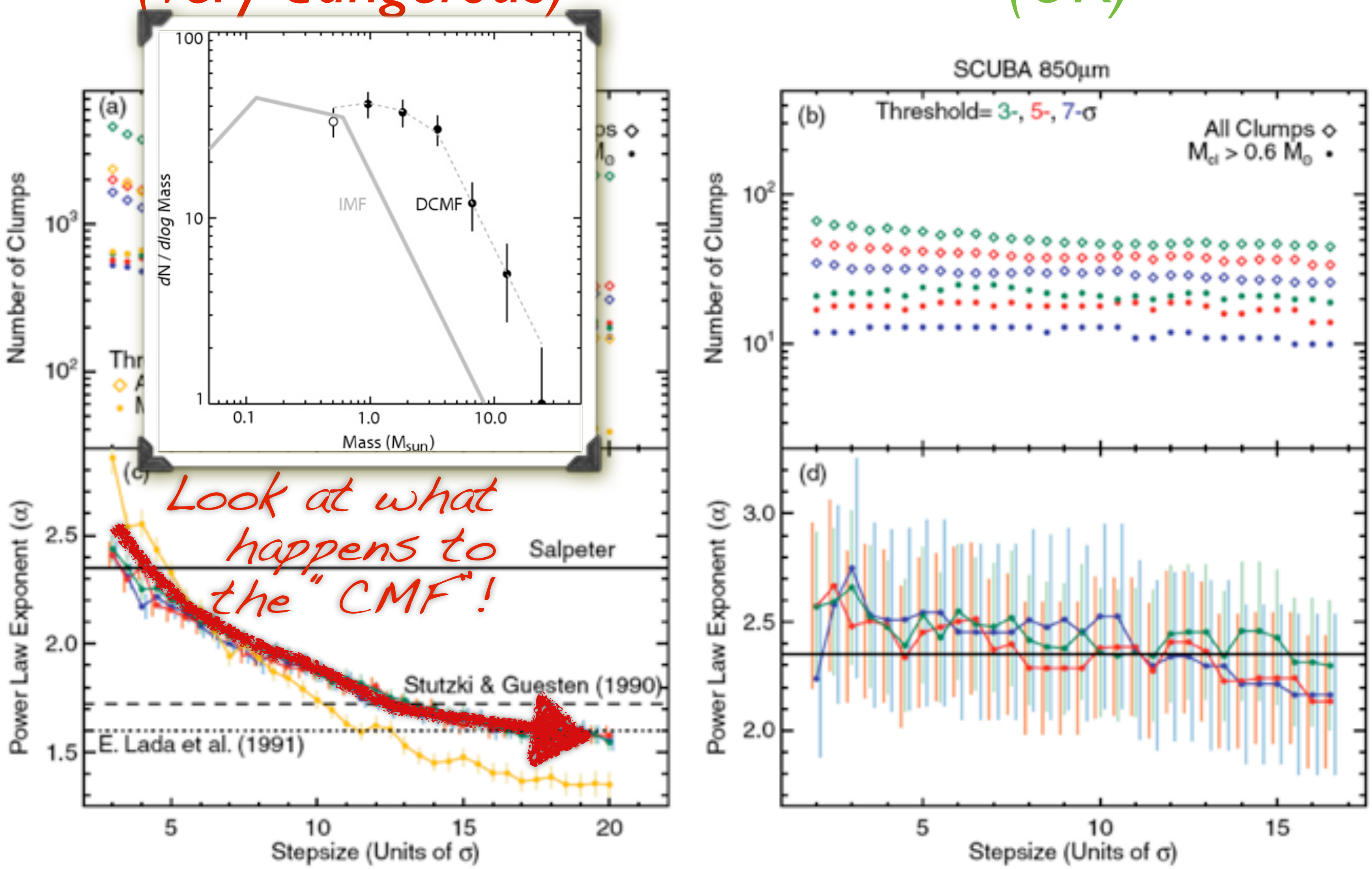
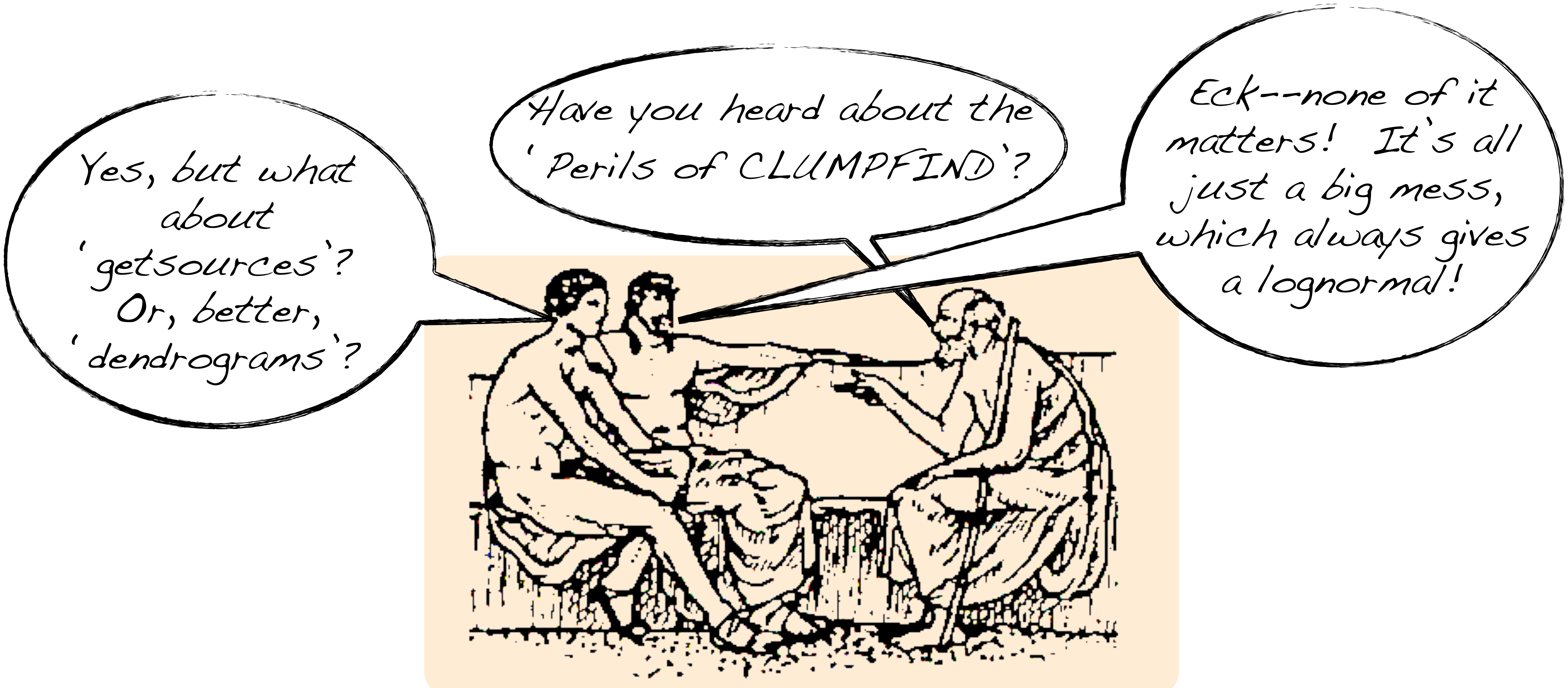
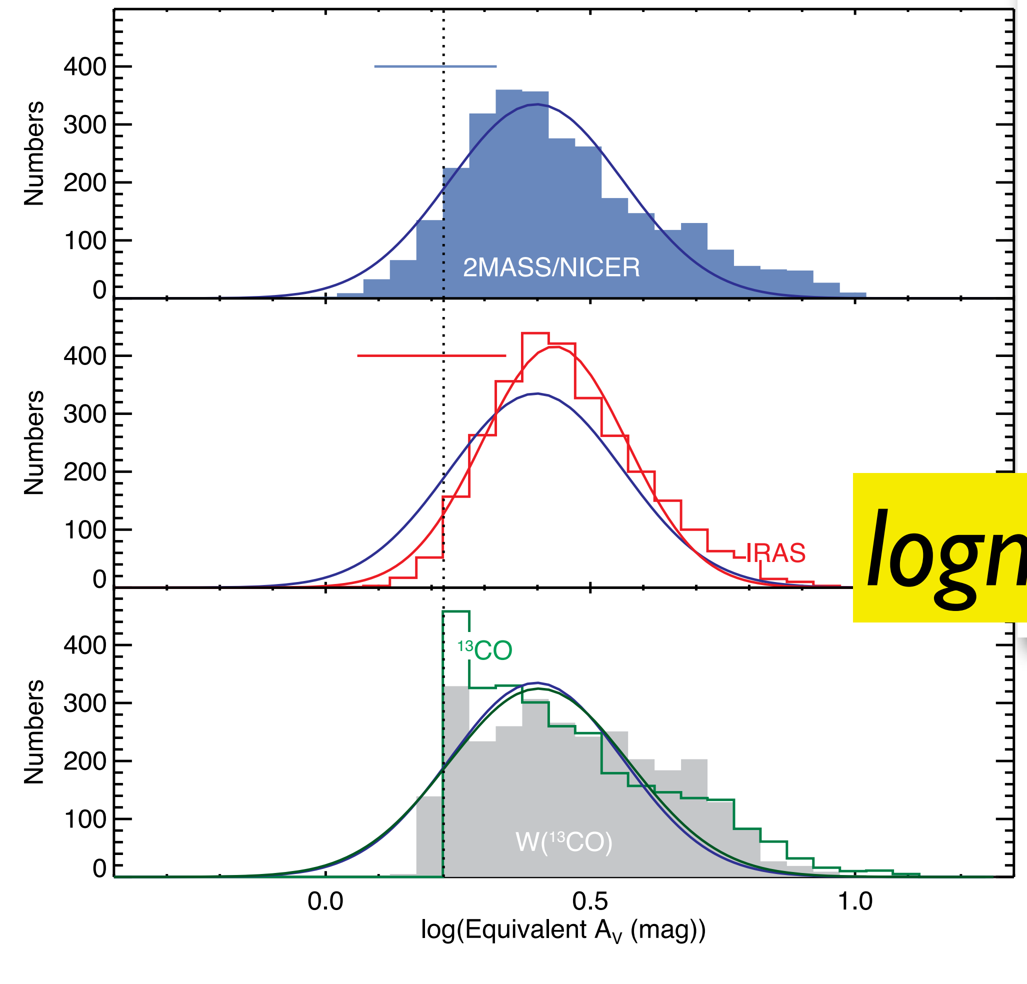


Figure 2. Summary of all Clumpfind runs as a function of stepsize. Color represent different thresholds: blue, red, and green for 3σ, 5σ, and 7σ, respectively; we also show in orange results with a threshold of 5σ for ^{13}CO data with added noise. Left and right columns show results for ^{13}CO and SCUBA data, respectively. Panels (a) and (b) show the number of clumps under a given category per model. Total number of clumps found, and total number of clumps with mass larger than the completeness limit are shown in open diamonds and filled circles, respectively. Panels (c) and (d) show the exponent of the fitted mass spectrum of clumps above the completeness limit, $dN/dM \propto M^{-\alpha}$, with error bars estimated from Equation (6). Horizontal black lines show some fiducial exponents for comparison. Average noise in ^{13}CO, ^{13}CO with added noise, and SCUBA data is 0.1 K, 0.2 K, and 0.06 Jy beam^{-1}, respectively. Completeness limit is estimated to be 4 $M_{\odot}$, 3 $M_{\odot}$, and 0.6 $M_{\odot}$ for ^{13}CO, ^{13}CO with added noise, and SCUBA data. Panel (c) also shows that for different noise level in the data, if a threshold of ~2 K (20σ and 10σ for original and noise-added data, respectively) is used, then the fitted power-law exponents are closer to previous works.



The Meaning of the "CMF"



Goodman, Pineda & Schnee 2009

IMF:CMF

It could be nested, unrelated(?) lognormals...

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Do lognormal column-density distributions in molecular clouds imply supersonic turbulence?

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lognormals, and more lognormals...

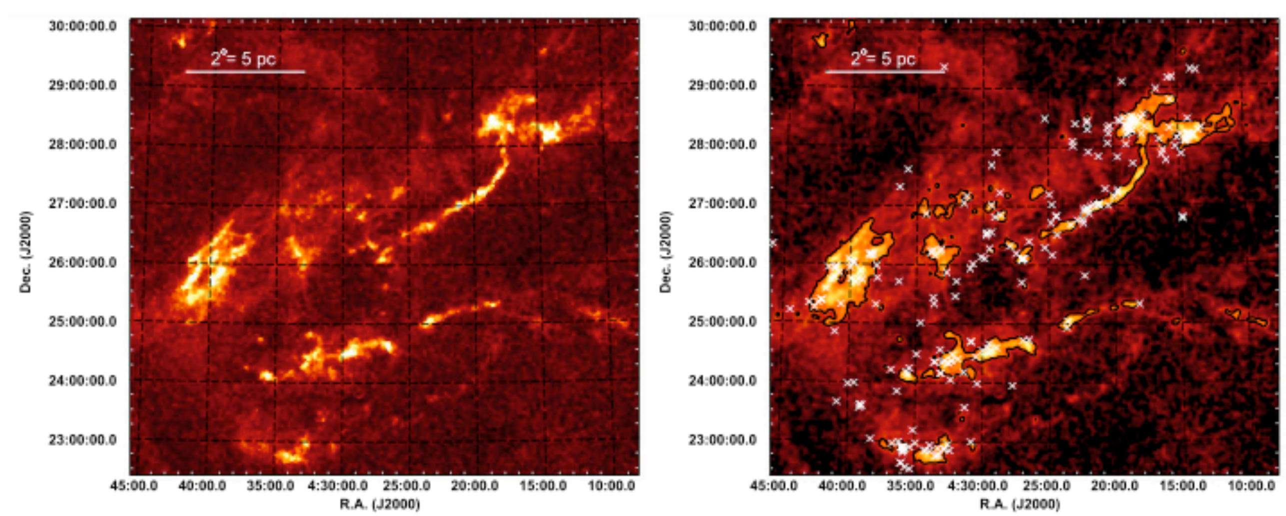


Fig. 1. *Left*: wide-field extinction map of the Taurus molecular cloud complex covering ~7.5° × 7.5° (~18 × 18 pc at d = 140 pc). The *FWHM* resolution of the map is 2.4′. *Right*: the same, but in logarithmic scaling highlighting the low column density regions. The contour at A_V = 4 mag shows the region above which the column density PDF differs from the simple log-normal form. The crosses show the embedded population of the cloud as listed by Rebull et al. (2009).

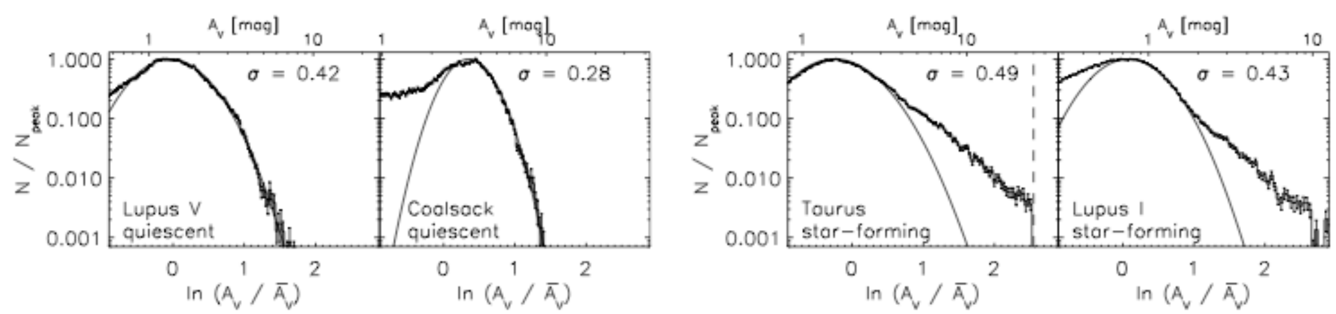
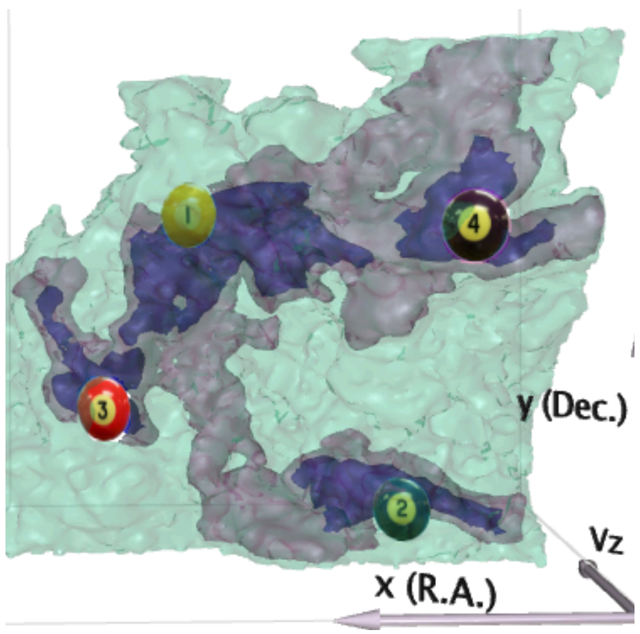


Fig. 2. *Left*: probability density functions (PDFs) of the column density for the non-star-forming clouds Lupus 5 and Coalsack. *Right*: the same for the active star-forming clouds Taurus and Lupus 1. The error bars show the $\sqrt{N}$ uncertainties. Solid lines show the fits of log-normal functions to the distributions around the peak, typically over the range $\ln A_v/\bar{A}_V$ = [−0.5, 1]. The dispersions of the fitted functions are shown in the panels. The x-axis on top of the panels shows the extinction scale in magnitudes. The vertical dashed line shows the upper limit of extinction values probed by the extinction mapping method. Similar plots for 19 other clouds are shown in Figs. 4–6 (online only).

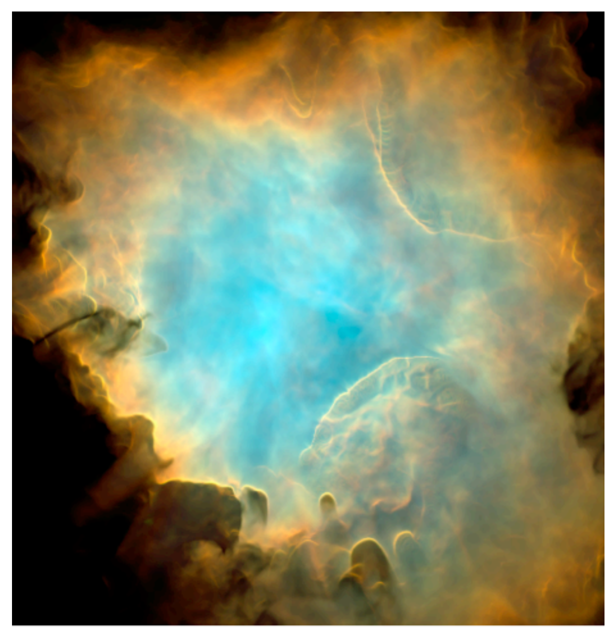
Kainulainen, Beuther, Henning, & Plume 2009

3 Open Questions

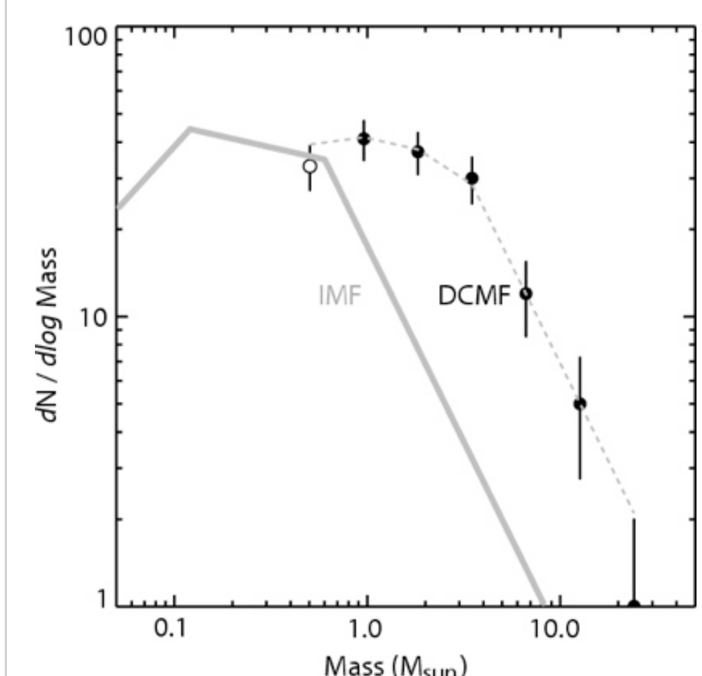
1. At what scales does **gravity** matter?



2. What do **stars** really do to clouds?



3. Is the origin of the **IMF** related (only) to the CMF?



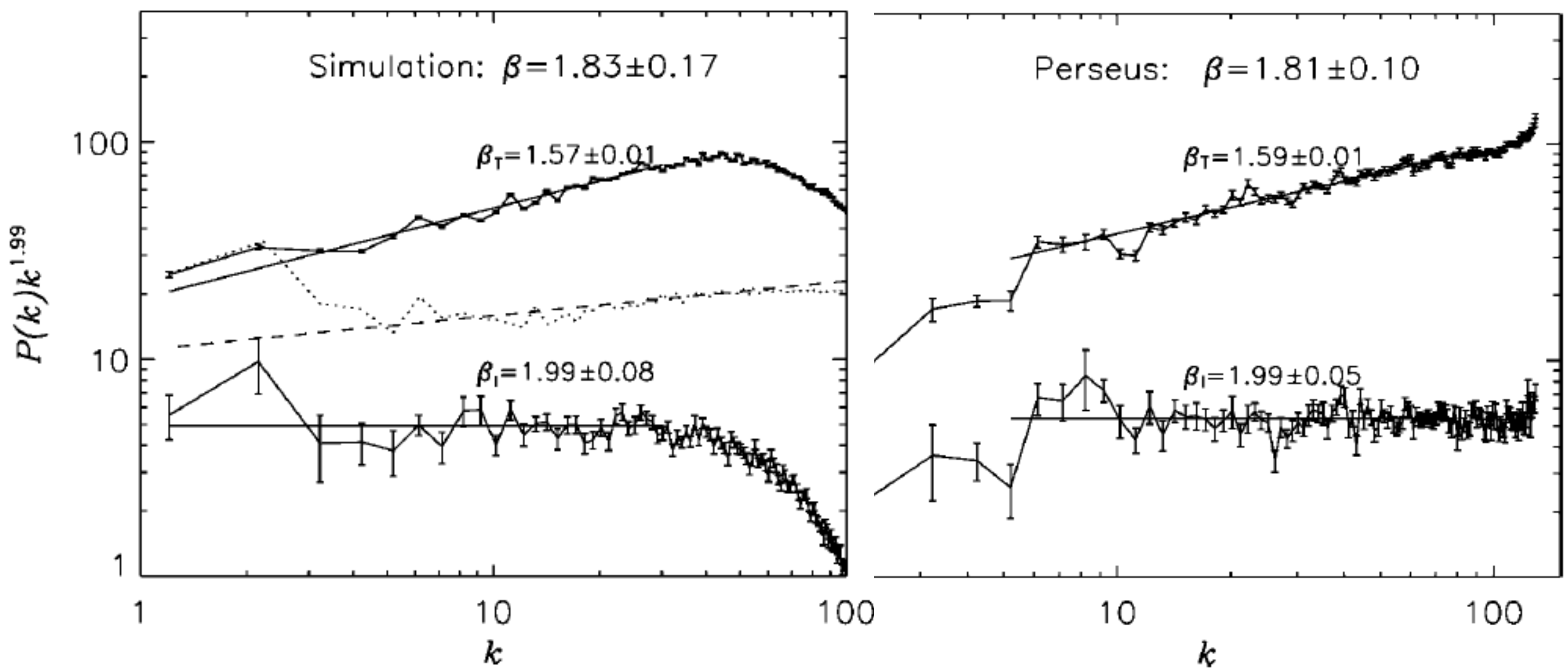
+ "tasty" approaches to answers

EXTRA SLIDES

Matching "Power Spectra" are not enough...

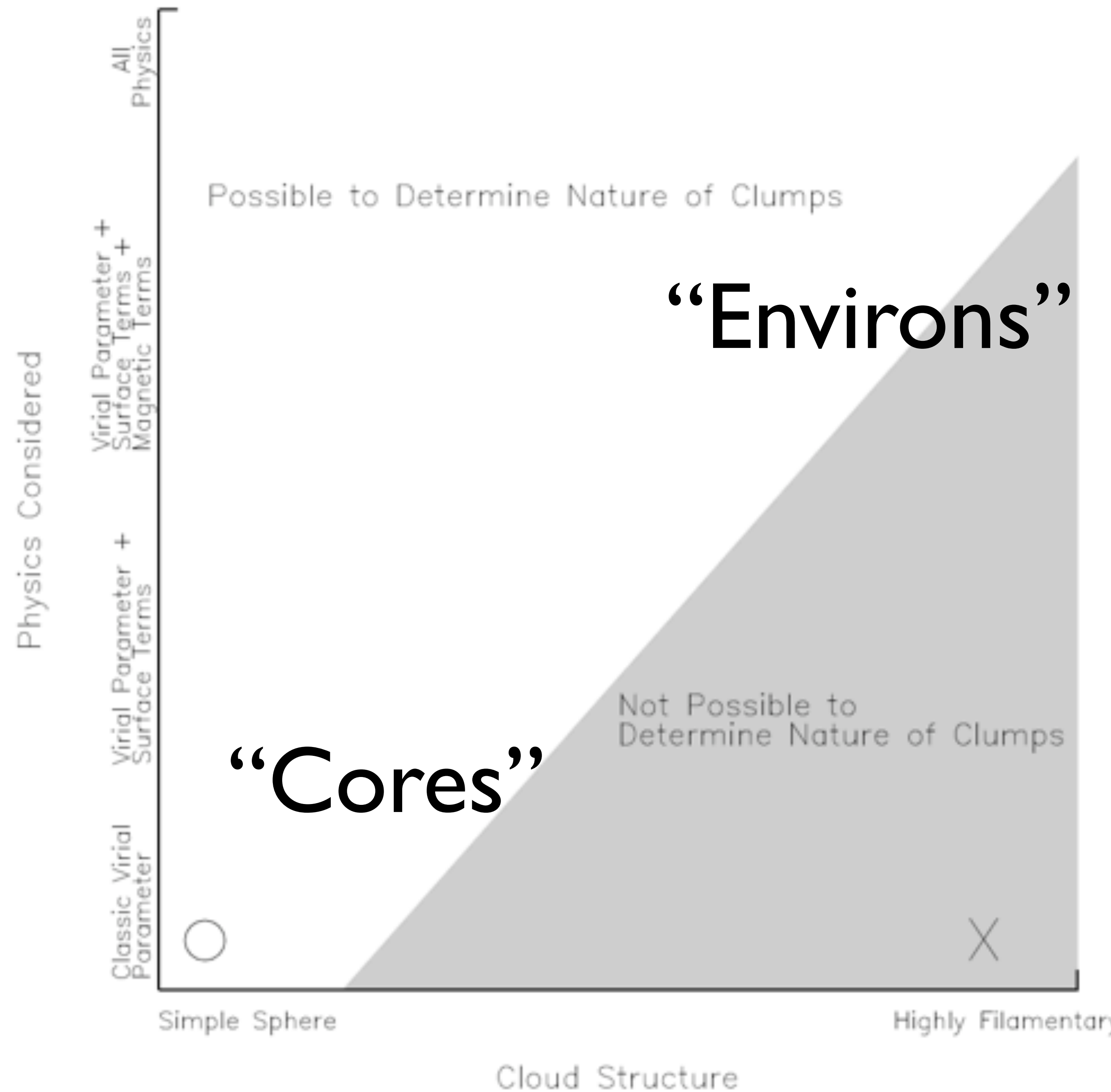
TASTE TEST

"Perseus-Matching"
Sample Simulation
from Padoan, Juvela, Kritsuk & Norman 2006
(Mach 6; Enzo; pure hydro)



Note: Padoan et al. 2006 paper was intended to test the VCS method of Lazarian & Pogosyan 2000; cf. PCA methods of Brunt & Heyer 2002a,b

Caveats/Worries about *p-p-v* (bijection) ... and the virial parameter



*from **Shetty**, Collins, Kauffmann, Goodman, Rosolowsky 2010;*
see also recent work of Dib et al., Ostriker et al., Ballesteros-Paredes et al., Myers, and Smith, Clark & Bonnell