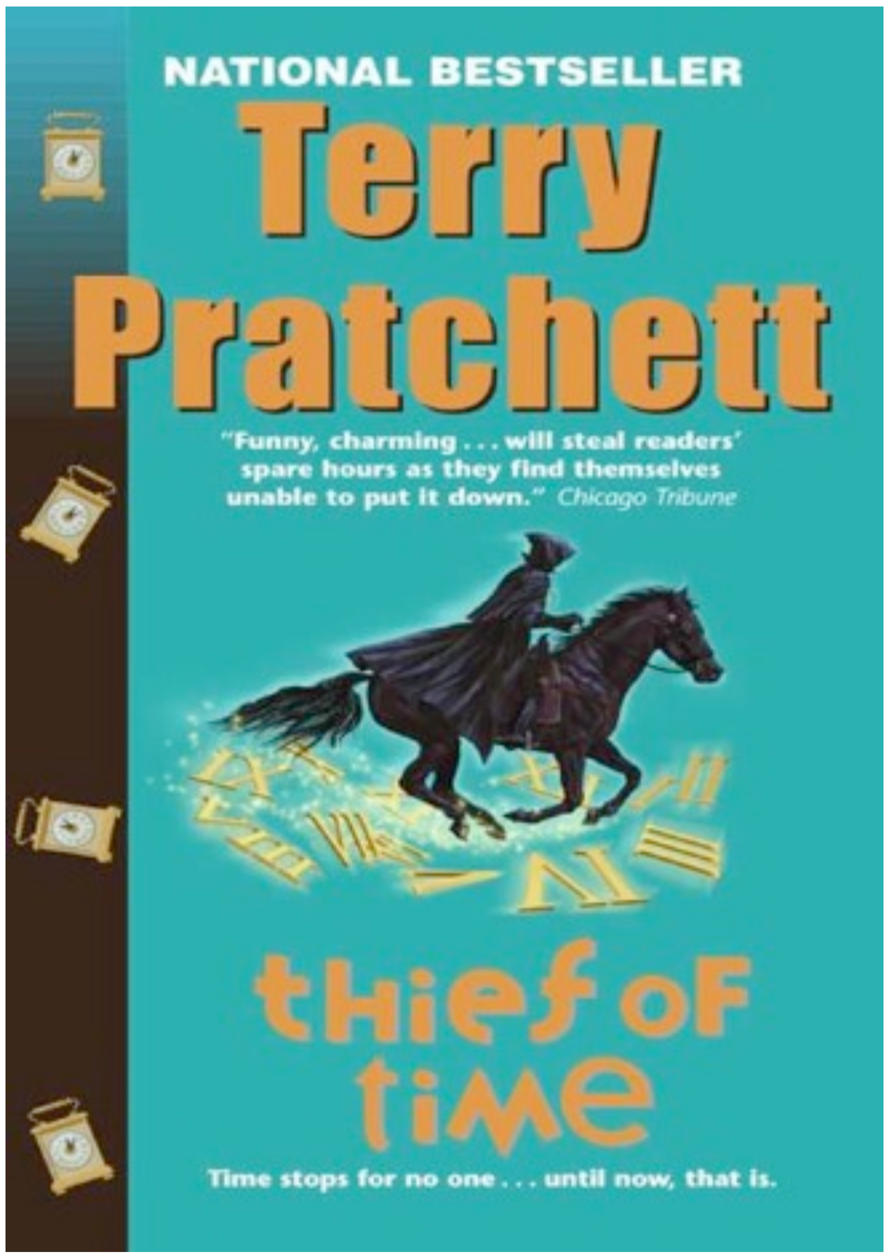
Making Stars

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, Jens Kauffmann, Helen Kirk, Elizabeth Lada, 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, Doug Johnstone, Kaisey Mandel, Gus Muench, Paolo Padoan, & Tom Robitaille

FYI: "Accounting" won't work



For something to exist, it has to be observed.

For something to exist, it has to have a position in time and space.

And this explains why nine-tenths of the mass of the universe is unaccounted for.

Nine-tenths of the universe is the knowledge of the position and direction of everything in the other tenth. Every atom has its biography, every star its file, every chemical exchange its equivalent of the inspector with a clipboard. It is unaccounted for because it is doing the accounting for the rest of it, and you cannot see the back of your own head.*

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*Except in very small universes.

Holistic Star Formation

holistic |hōˈlistik|

adjective chiefly Philosophy

characterized by comprehension of the parts of something as intimately interconnected and explicable only by reference to the whole

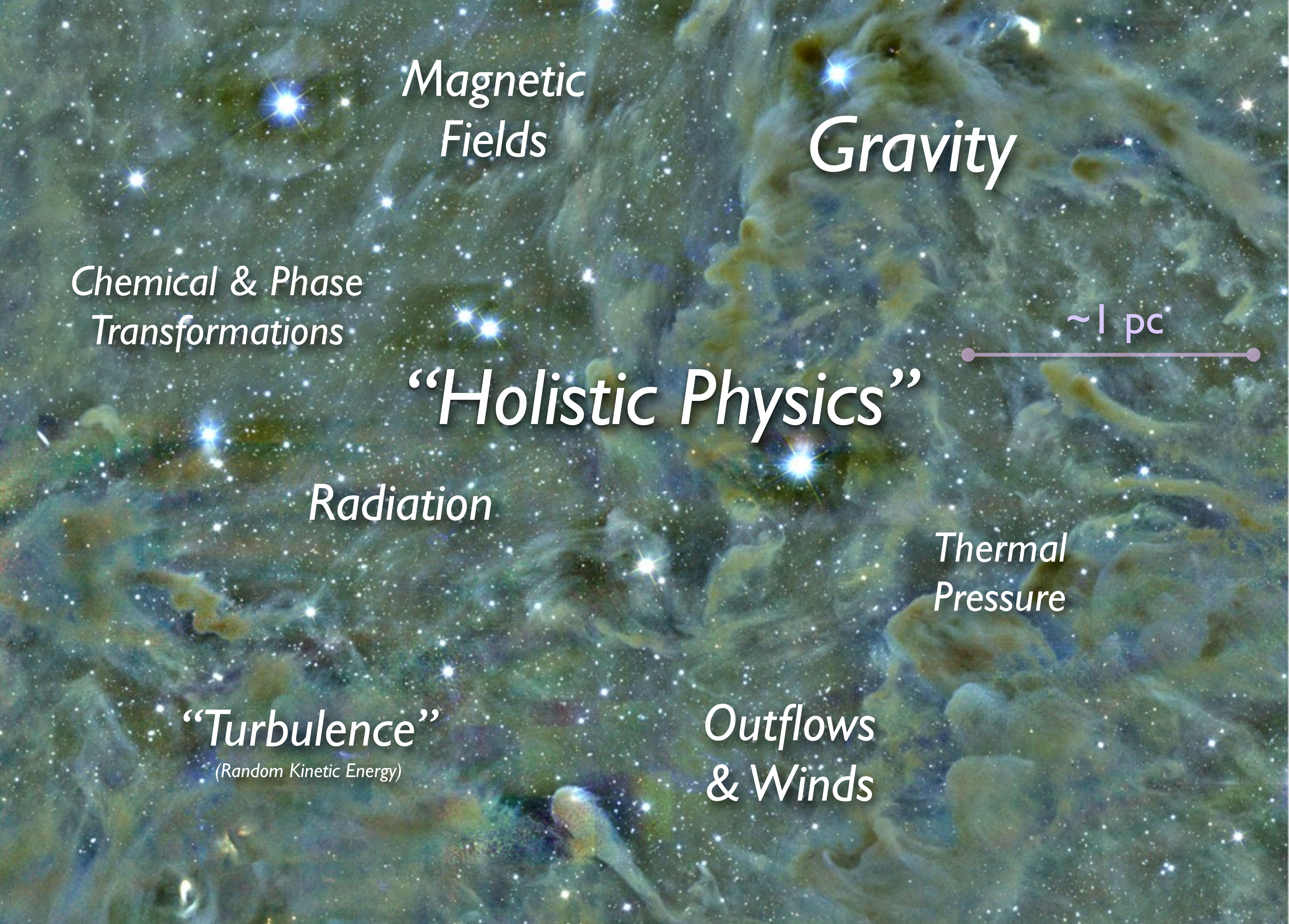
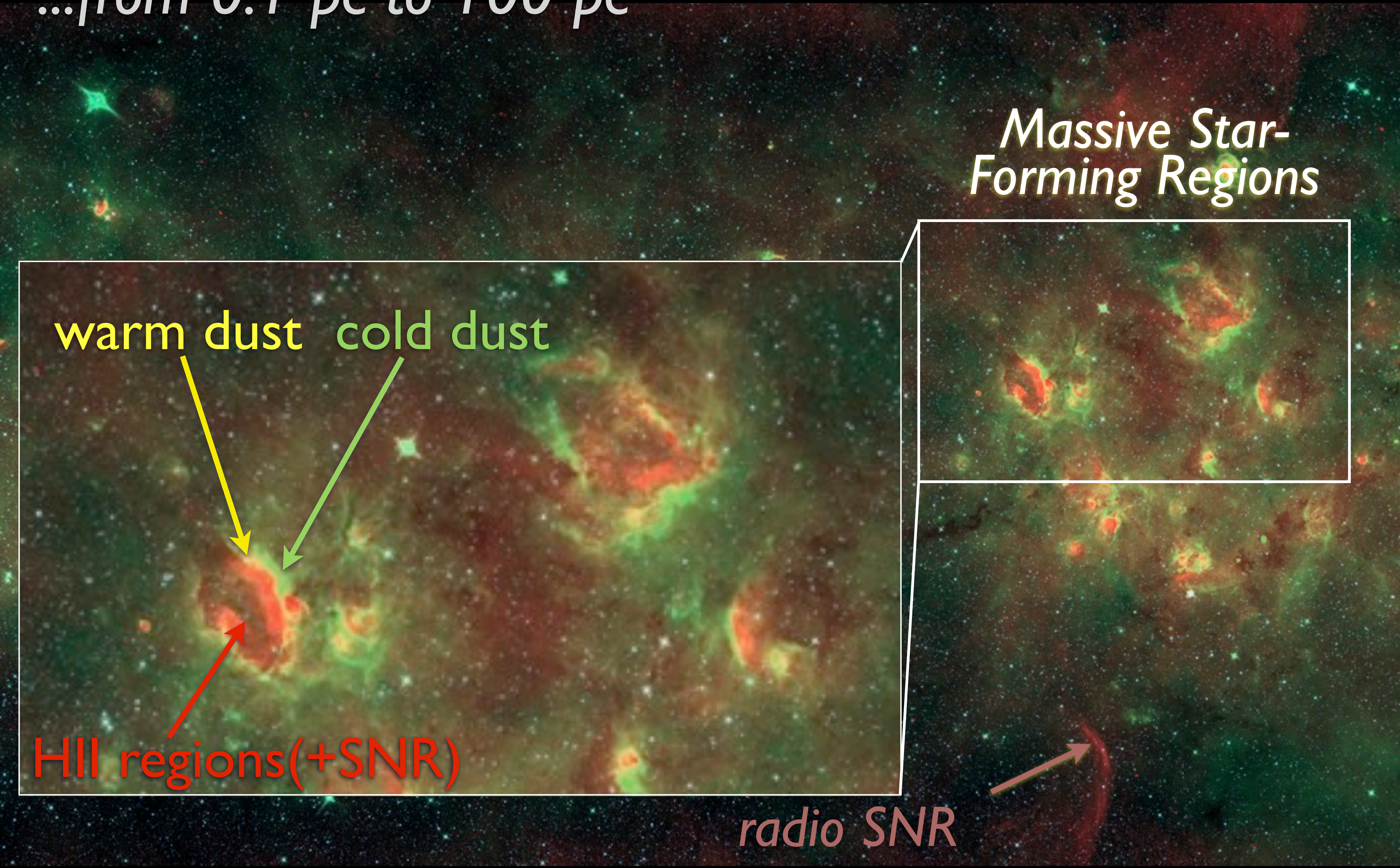


Image Credit: Jonathan Foster & Jaime Pineda CfA/COMPLETE Deep Megacam Mosaic of West End of Perseus

...from 0.1 pc to 100 pc



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)

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

COMPLETE Collaborators, 2010:

Alyssa A. Goodman (CfA/IIC)
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Michelle Borkin (Harvard SEAS/IIC)
Paola Caselli (Leeds, UK)
James DiFrancesco (HIA, Canada)
Jonathan Foster (B.U.)
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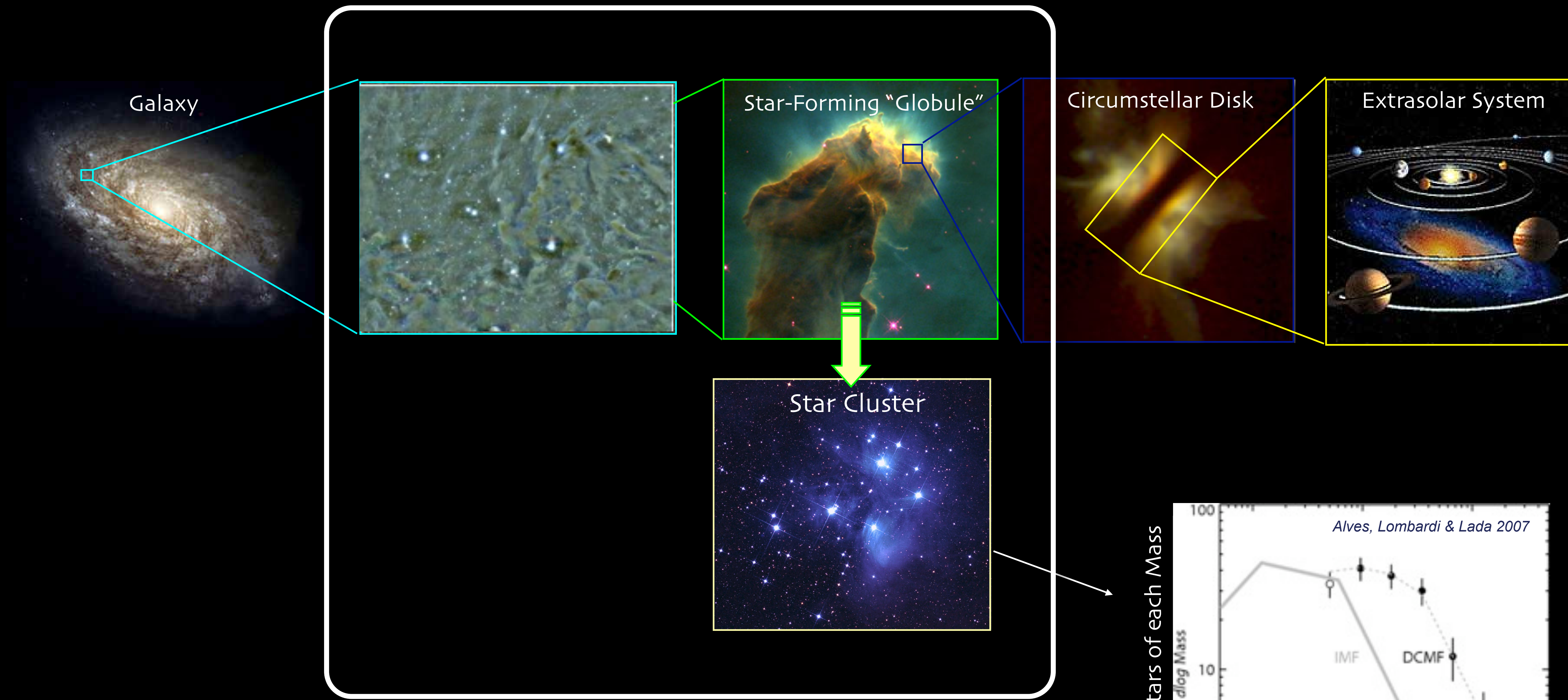
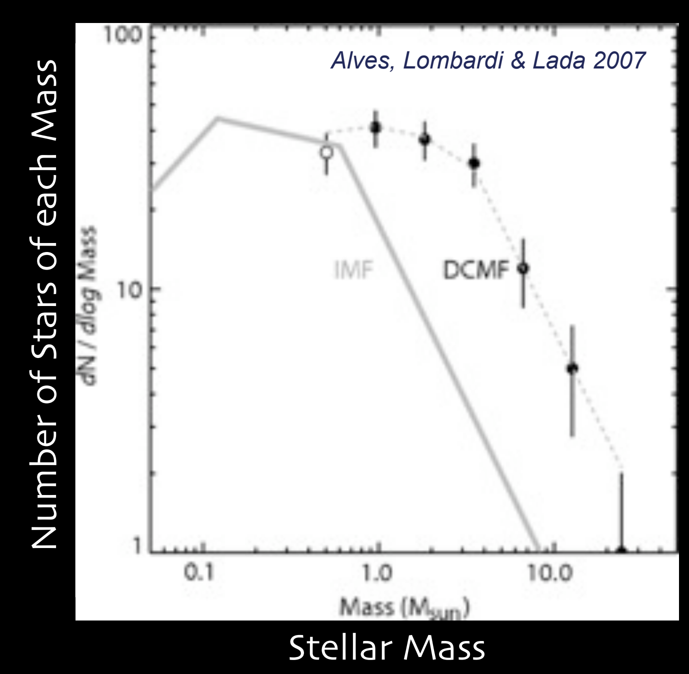
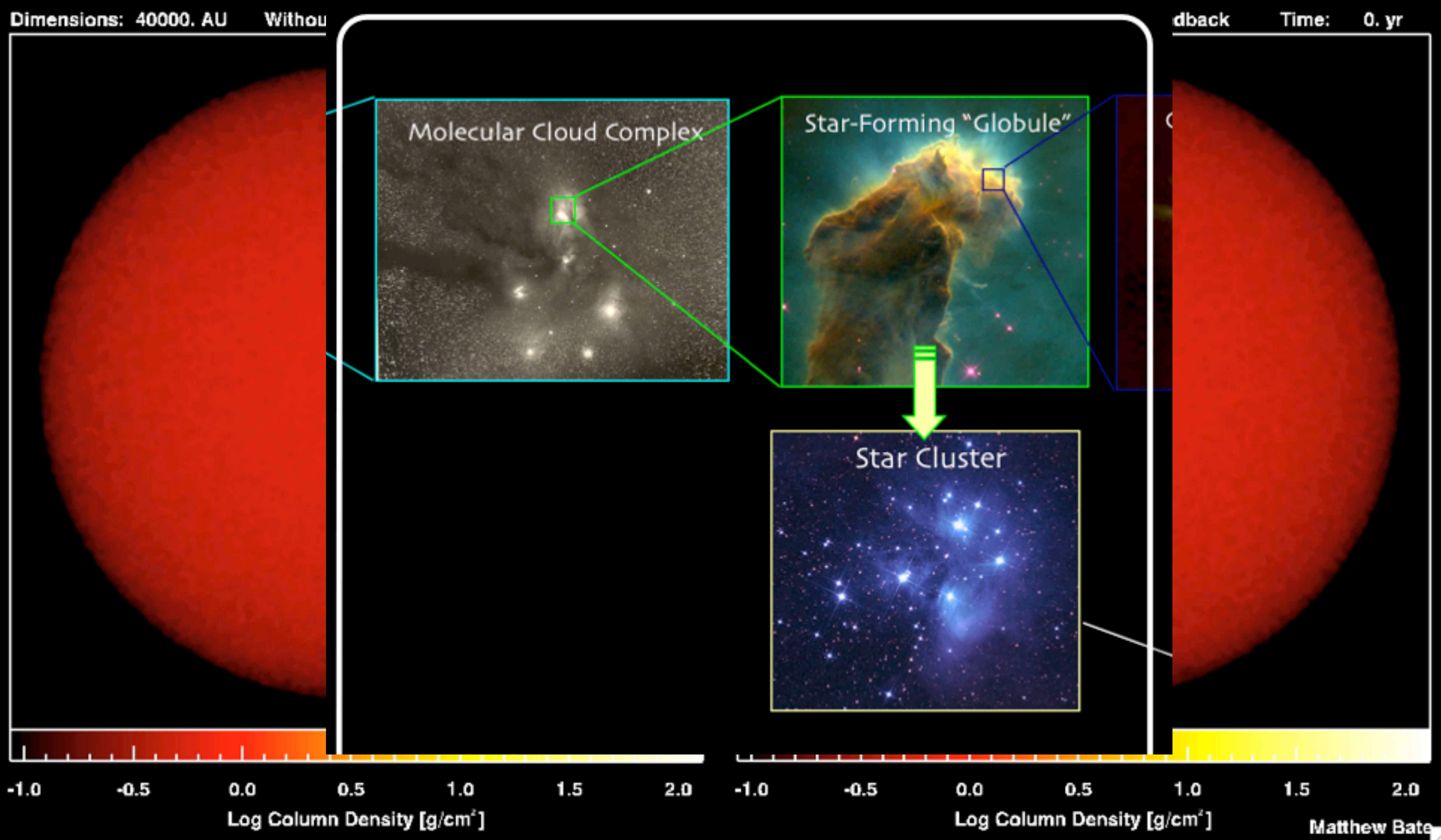
Doug Johnstone (HIA, Canada)
Jens Kauffmann (JPL/Caltech)
Helen Kirk (CfA)
Di Li (JPL/Caltech)
Stella Offner (CfA)
Jaime Pineda (CfA, PhD Student)
Thomas Robitaille (CfA)
Erik Rosolowsky (UBC Okanagan)
Rahul Shetty (ITA Heidelberg)
Scott Schnee (HIA Victoria)
Mario Tafalla (OAN, Spain)

Star (and Planet, and Moon) Formation 301

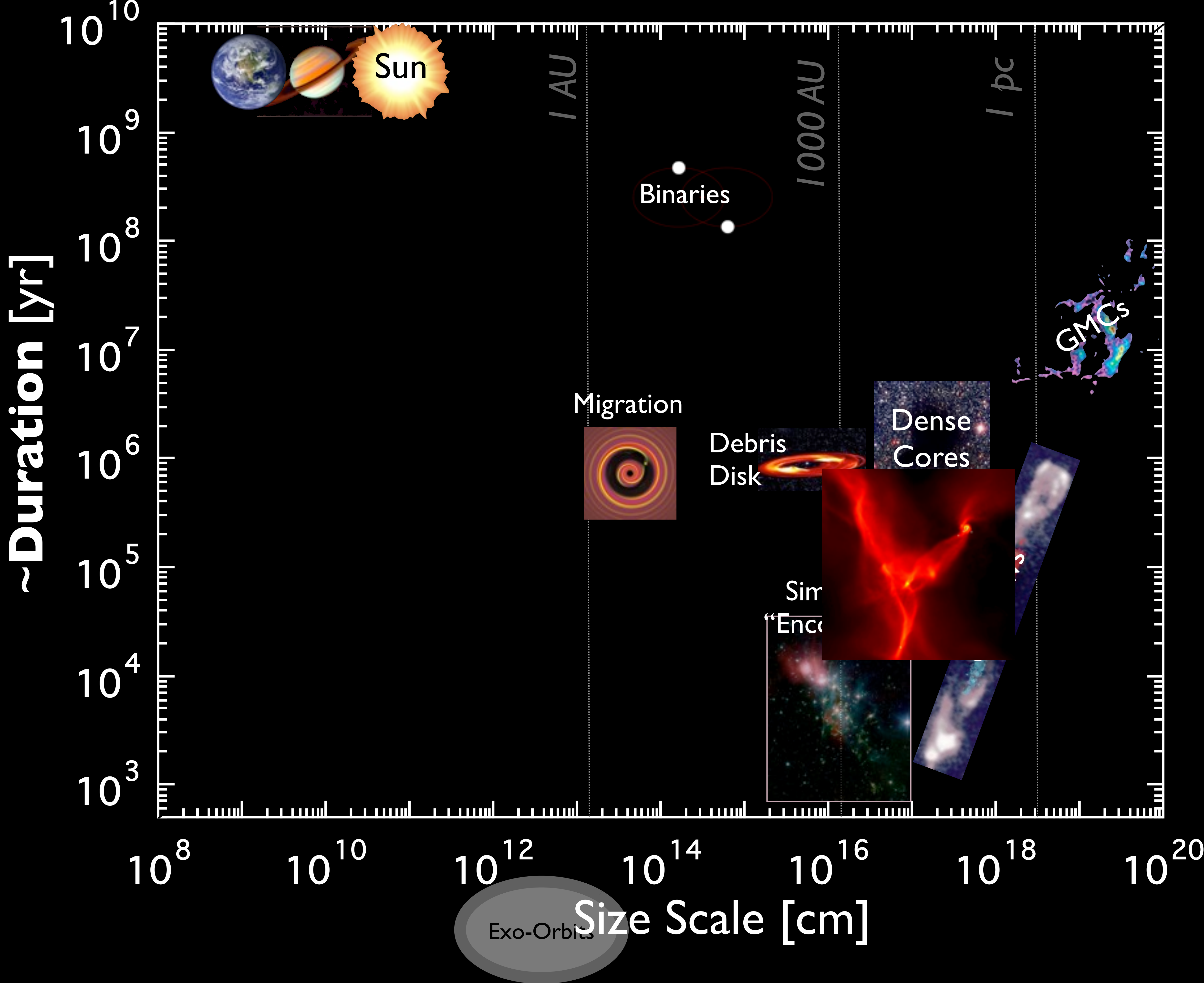




Our Goal is to "Taste" Star Formation

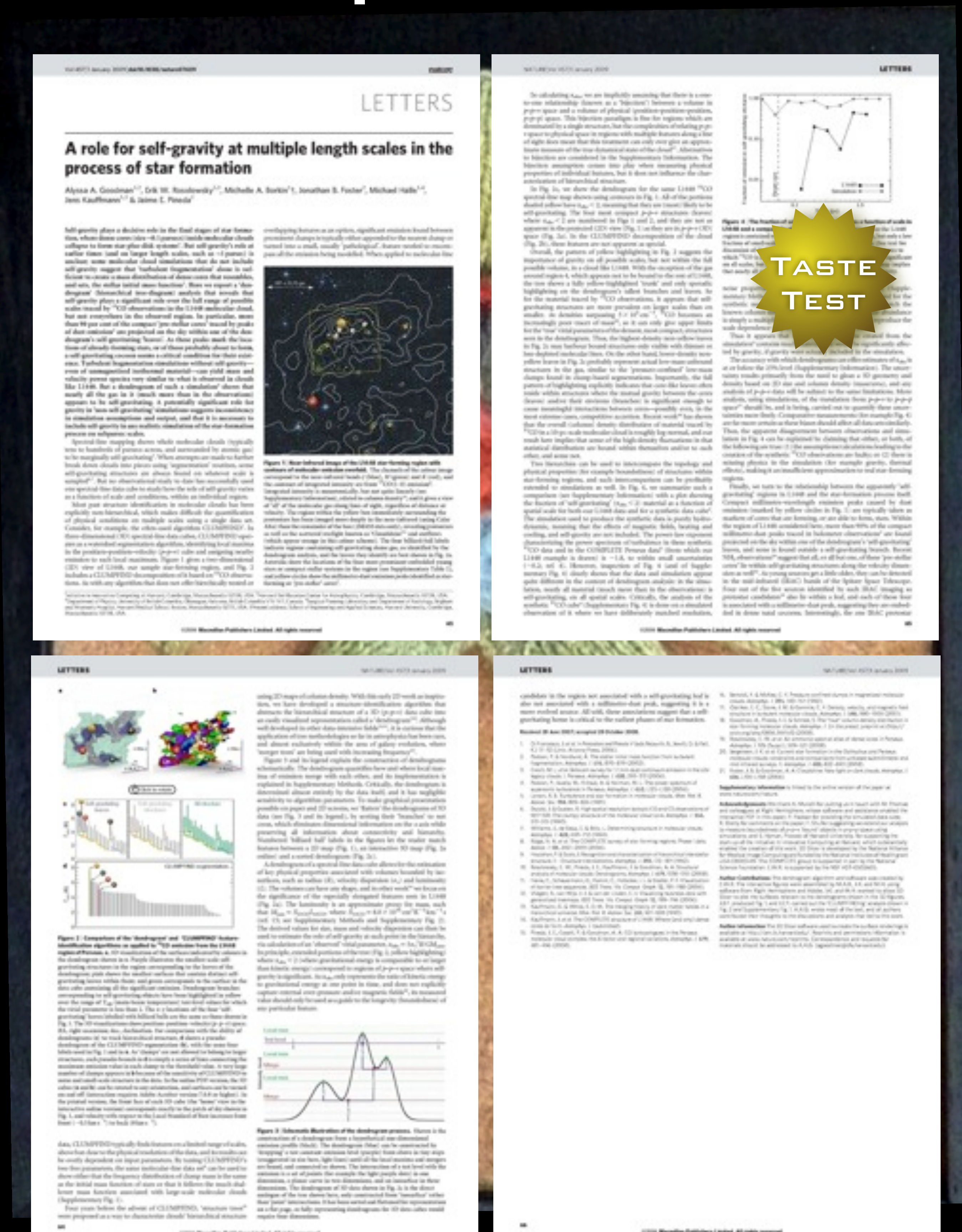


Simulations of Bate 2009



10^{10}
10^{9}
10^{8}
10^{7}
10^{6}
10^{5}
10^{4}
10^{3}
~Duration [yr]
Sun
1 AU
1000 AU
1 pc
Binaries
GMCs
Migration
Debris
Disk
Dense
Cores
10^{8}
10^{10}
10^{12}
10^{14}
10^{16}
10^{18}
10^{20}
Size Scale [cm]
Exo-Orbits

An Exemplar Dissection



Goodman, Rosolowsky, Borkin, Foster, Halle, Kauffmann & Pineda 2009, Nature, 457, 63.

"turbulent fragmentation" "L1448" "(magneto-)hydrodynamic simulation"

"Cloudshine"

"pre-stellar core"

"protostar"

"integrated intensity"

"p-p-v cube"

"segmentation"

"CLUMPFIND"

"Dendrogram"


LETTERS

A role for self-gravity at multiple length scales in the process of star formation

"COMPLETE" "3D PDF"

"bi-jection"

"virial parameter"

"column density"

"turbulent power spectrum"

"synthetic observation"

"depletion, opacity"

"taste-test"

caveats

"turbulent fragmentation"

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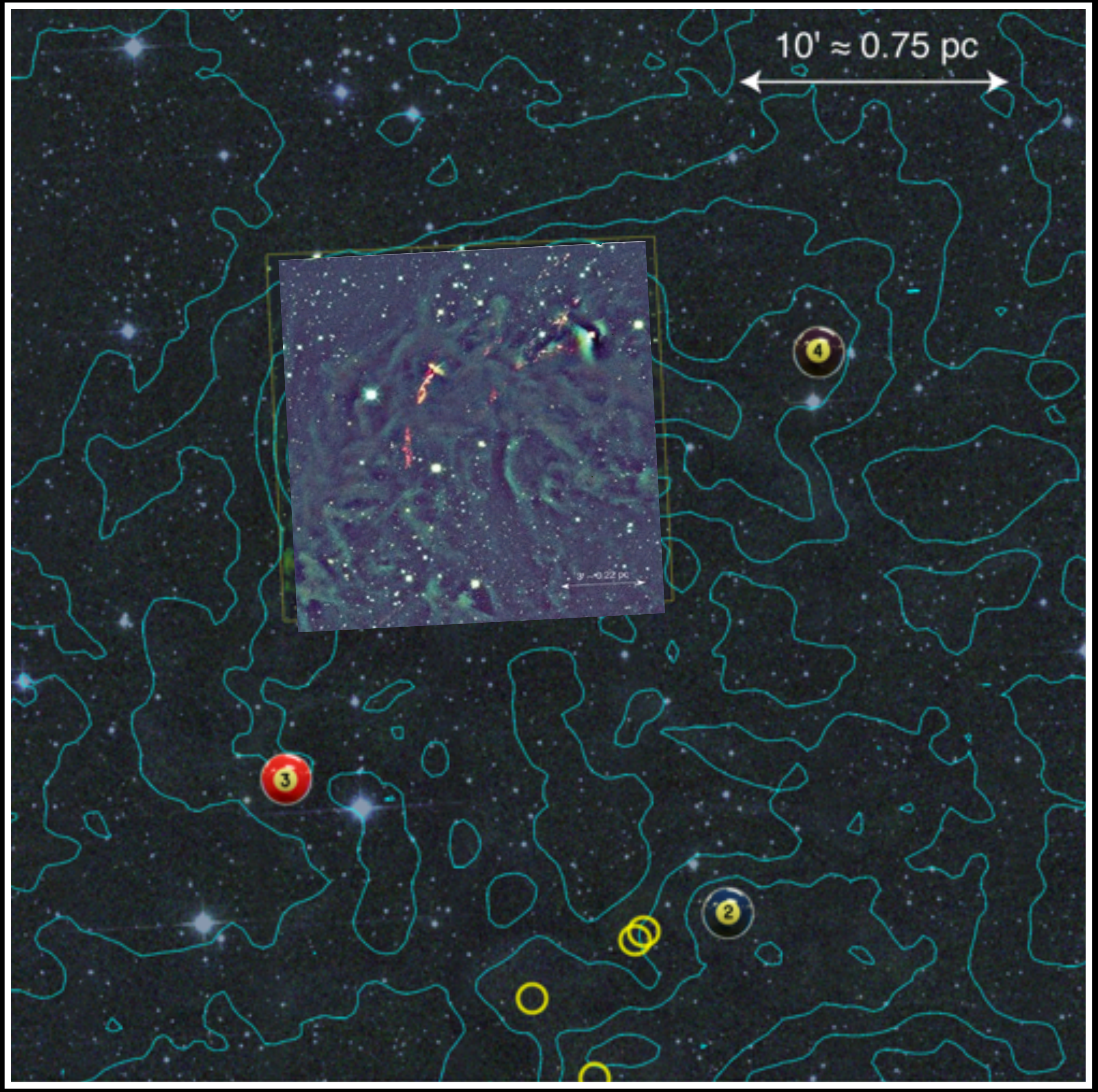
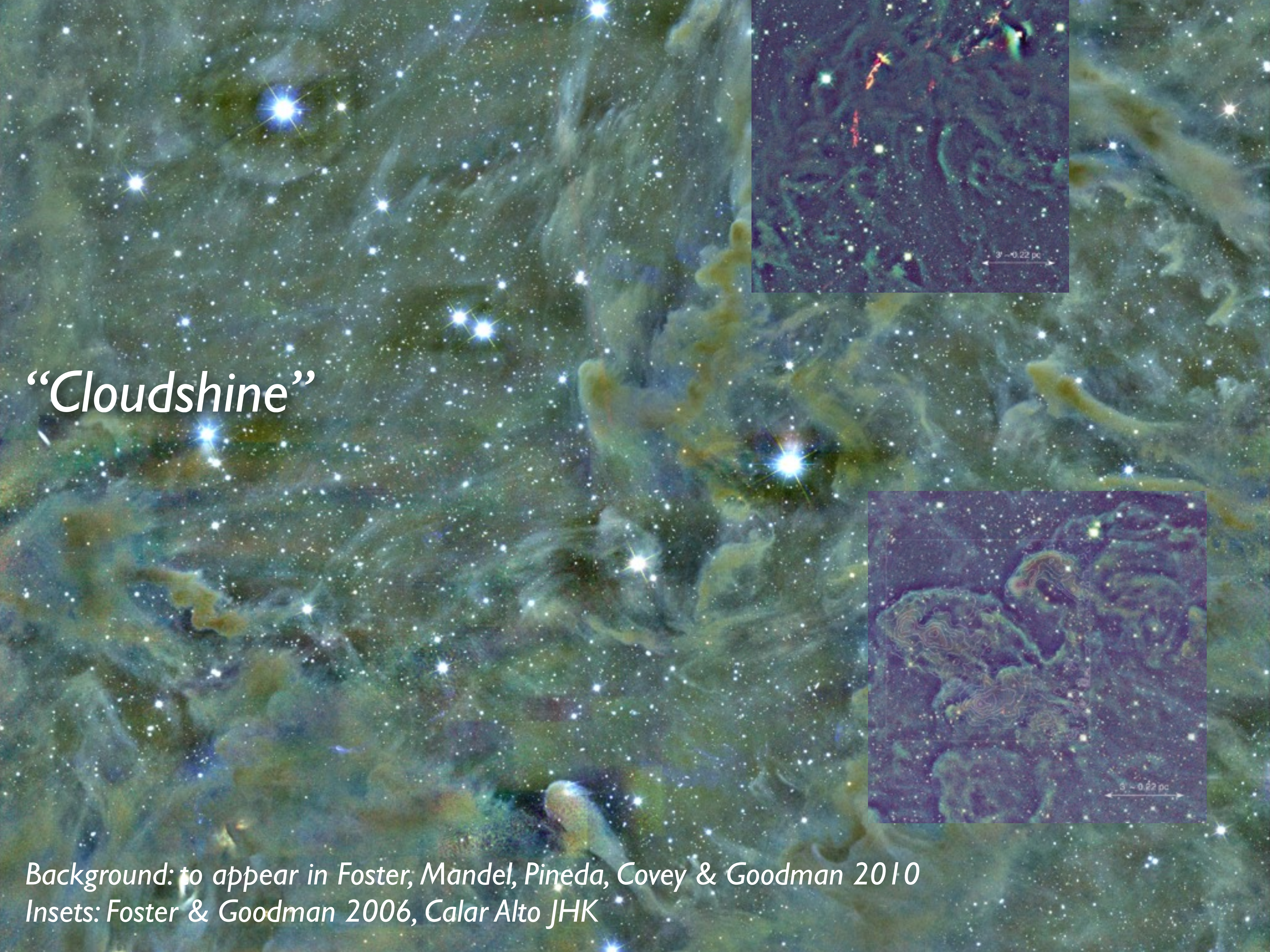


“column density”

“COMPLETE”



“Cloudshine”

Background: to appear in Foster, Mandel, Pineda, Covey & Goodman 2010
Insets: Foster & Goodman 2006, Calar Alto JHK

✔ "L1448"

"Cloudshine" ✔

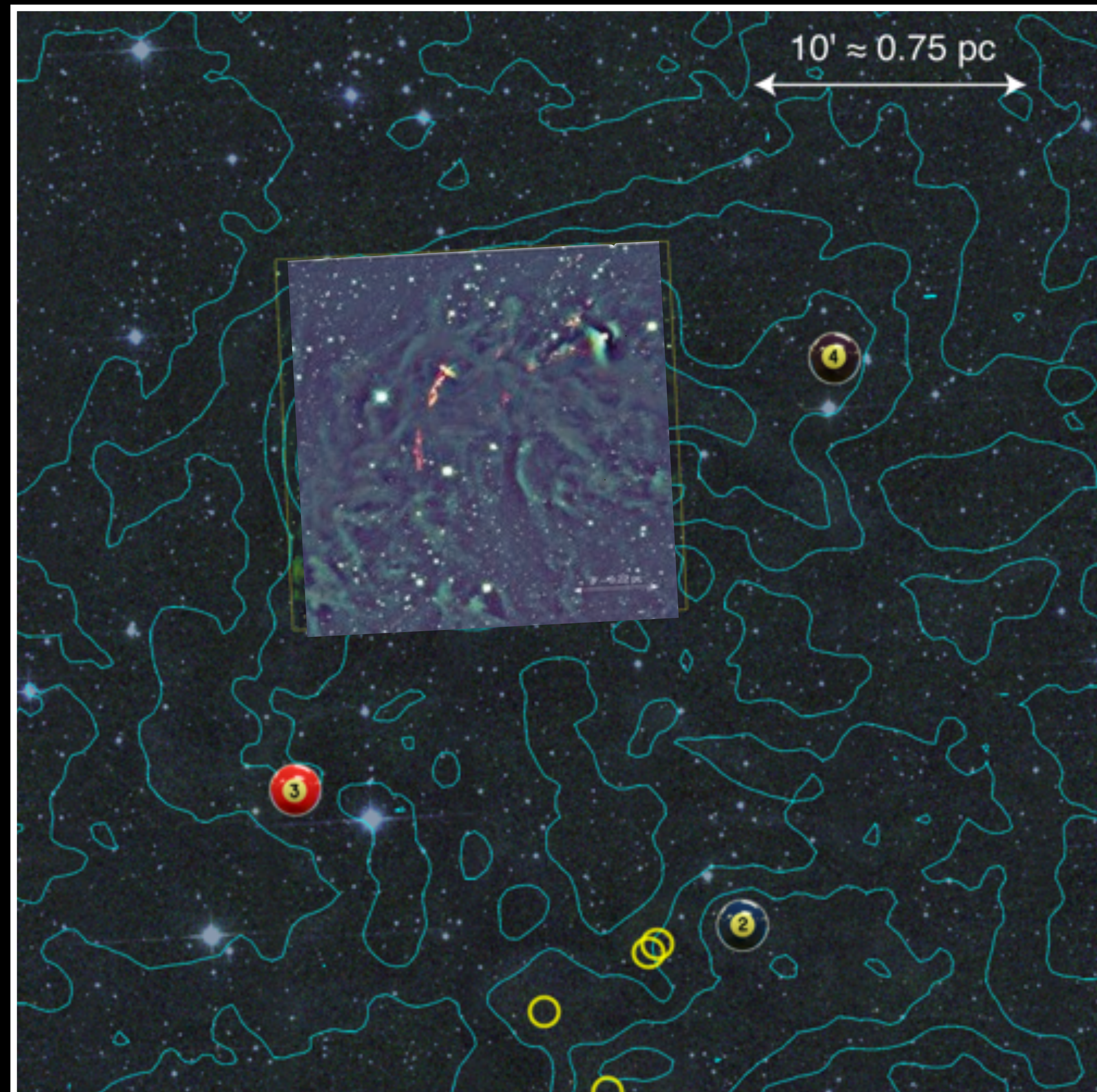
○ "pre-stellar core"

...compact thermal dust peak ✔

* "protostar" ✔

...Spitzer c2d (MIR) point source with "right" SED

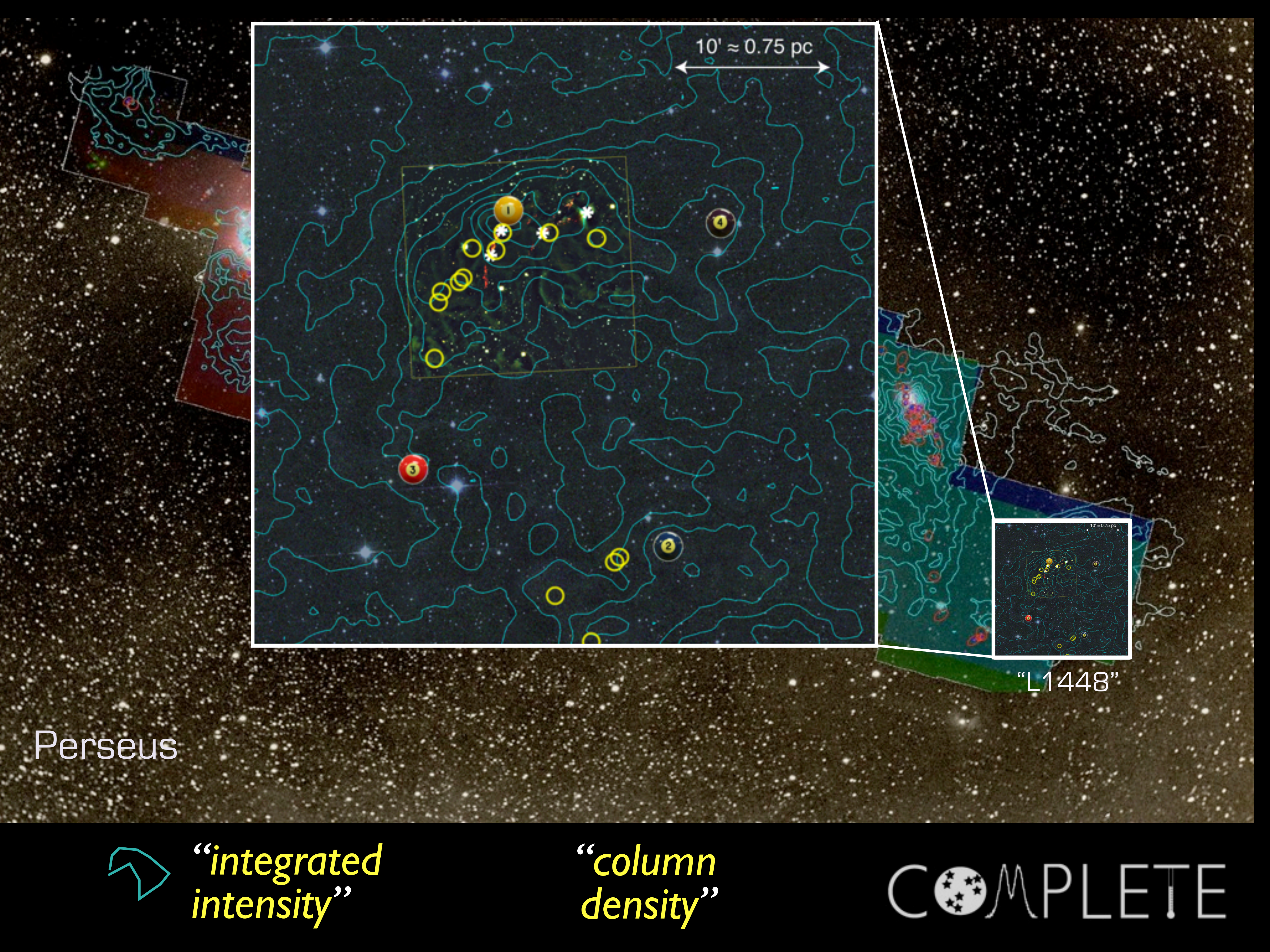
"integrated intensity"



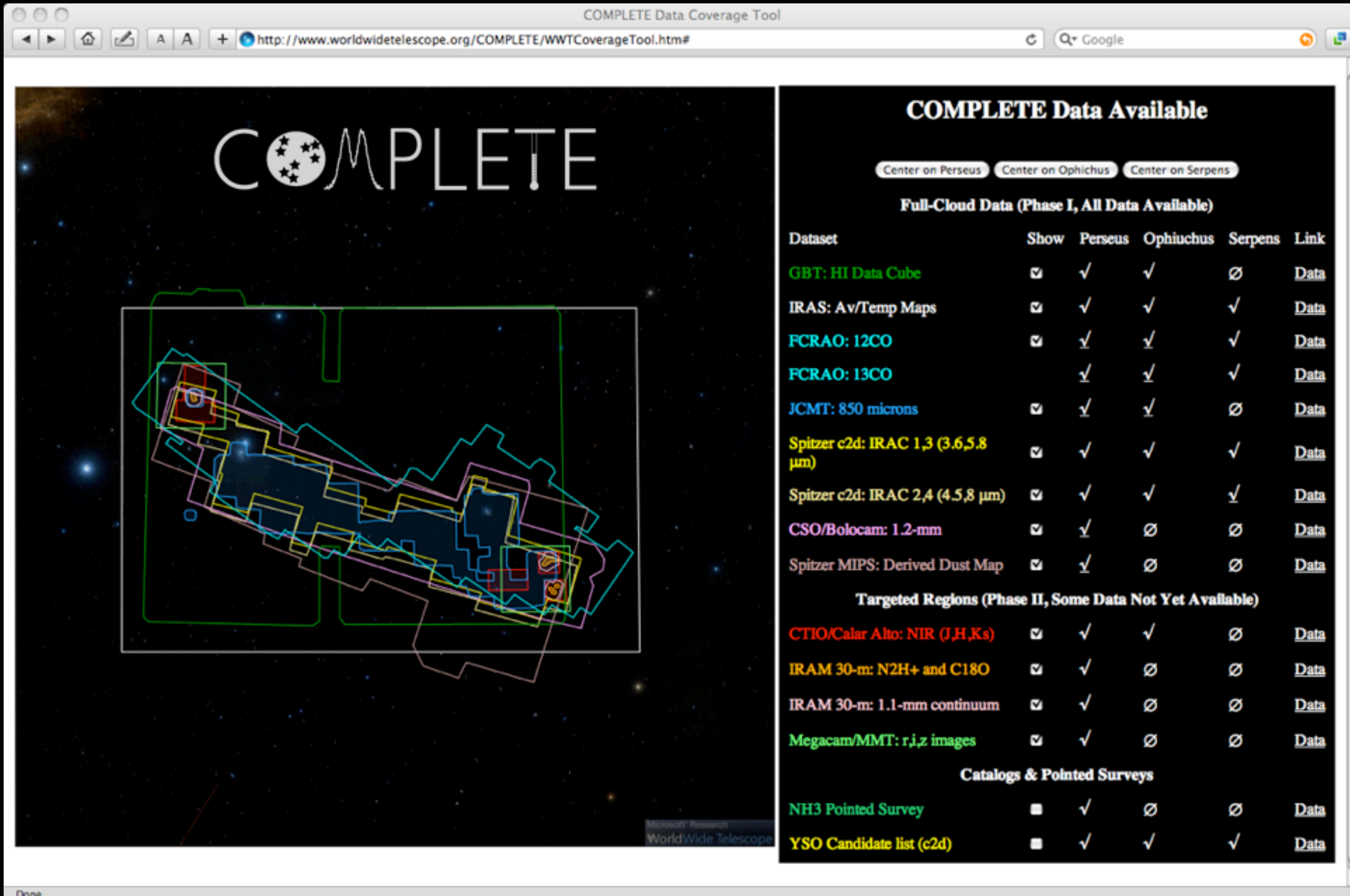
"column density"

"COMPLETE"

( ...later)



10' ≈ 0.75 pc
"L1448"
Perseus
"integrated intensity"
"column density"



COMPLETE Data Available

Full-Cloud Data (Phase I, All Data Available)

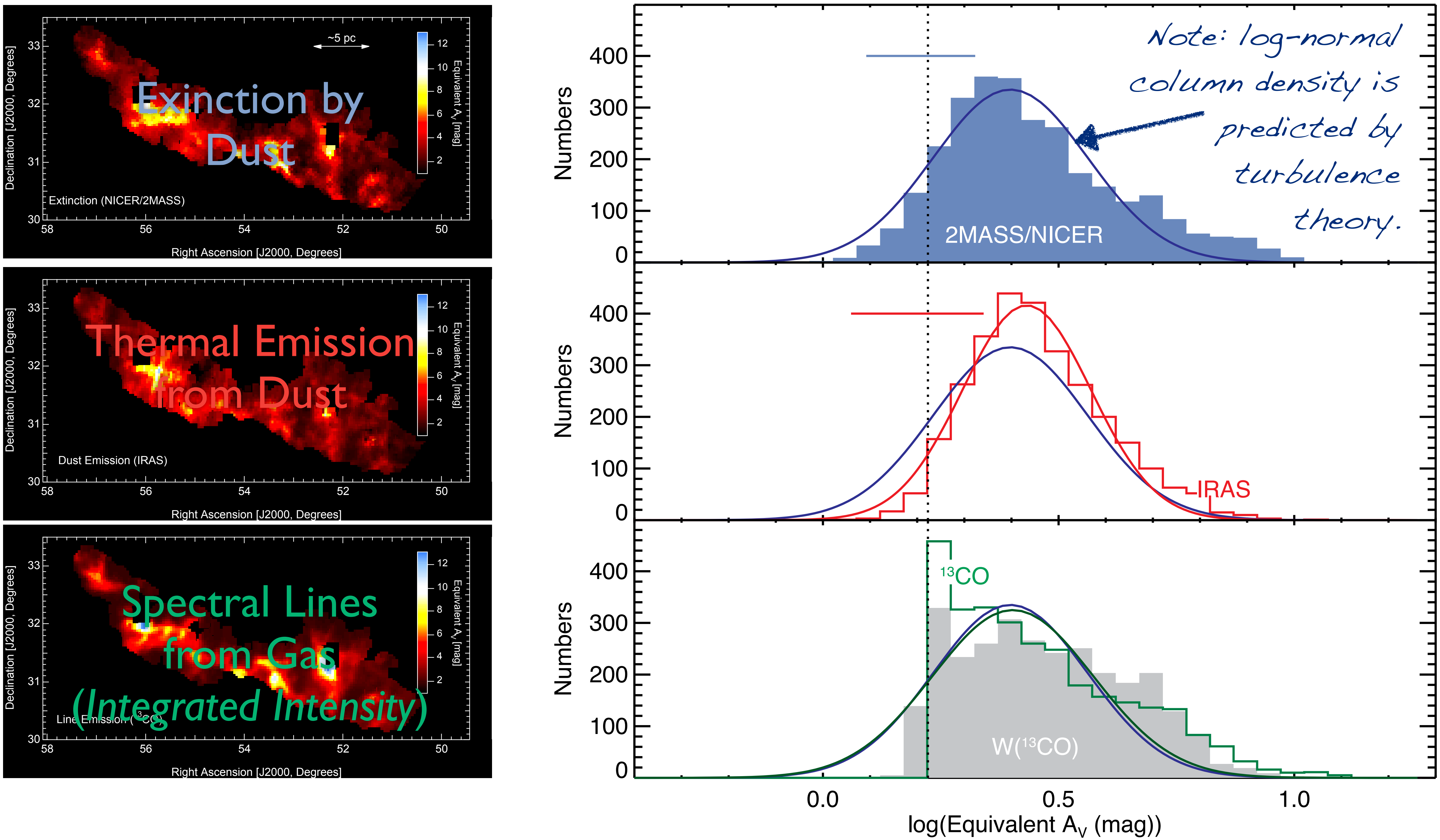
Dataset	Show	Perseus	Ophiuchus	Serpens	Link
GBT: HI Data Cube	☑	√	√	∅	Data
IRAS: Av/Temp Maps	☑	√	√	√	Data
FCRAO: 12CO	☑	√	√	√	Data
FCRAO: 13CO		√	√	√	Data
JCMT: 850 microns	☑	√	√	∅	Data
Spitzer c2d: IRAC 1,3 (3.6,5.8 µm)	☑	√	√	√	Data
Spitzer c2d: IRAC 2,4 (4.5,8 µm)	☑	√	√	√	Data
CSO/Bolocam: 1.2-mm	☑	√	∅	∅	Data
Spitzer MIPS: Derived Dust Map	☑	√	∅	∅	Data
Targeted Regions (Phase II, Some Data Not Yet Available)					
CTIO/Calar Alto: NIR (J,H,Ks)	☑	√	√	∅	Data
IRAM 30-m: N2H+ and C18O	☑	√	∅	∅	Data
IRAM 30-m: 1.1-mm continuum	☑	√	∅	∅	Data
Megacam/MMT: r,i,z images	☑	√	∅	∅	Data
Catalogs & Pointed Surveys					
NH3 Pointed Survey	☐	√	∅	∅	Data
YSO Candidate list (c2d)	☐	√	√	√	Data

To explore on your own, go to http://www.cfa.harvard.edu/COMPLETE/, then click on **Data** and choose to see the Interactive Coverage Tool in either Google Sky or WorldWide Telescope.

Many thanks to Jonathan Foster, Gus Muench & Jonathan Fay (MSR/WWT team) for these tools!

Column Density in Perseus, Measured 3 Ways

TASTE TEST



Goodman, Pineda & Schnee 2009, see also Pineda, Caselli & Goodman 2008 "turbulent fragmentation" "L1448" "(magneto-)hydrodynamic simulation"

"Cloudshine"

"pre-stellar core"

"protostar"

"integrated intensity*"

"p-p-v cube"

"segmentation"

"CLUMPFIND"

"Dendrogram"

*...more to come

LETTERS

A role for self-gravity at multiple length scales in the process of star formation

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"bi-jection"

"virial parameter"

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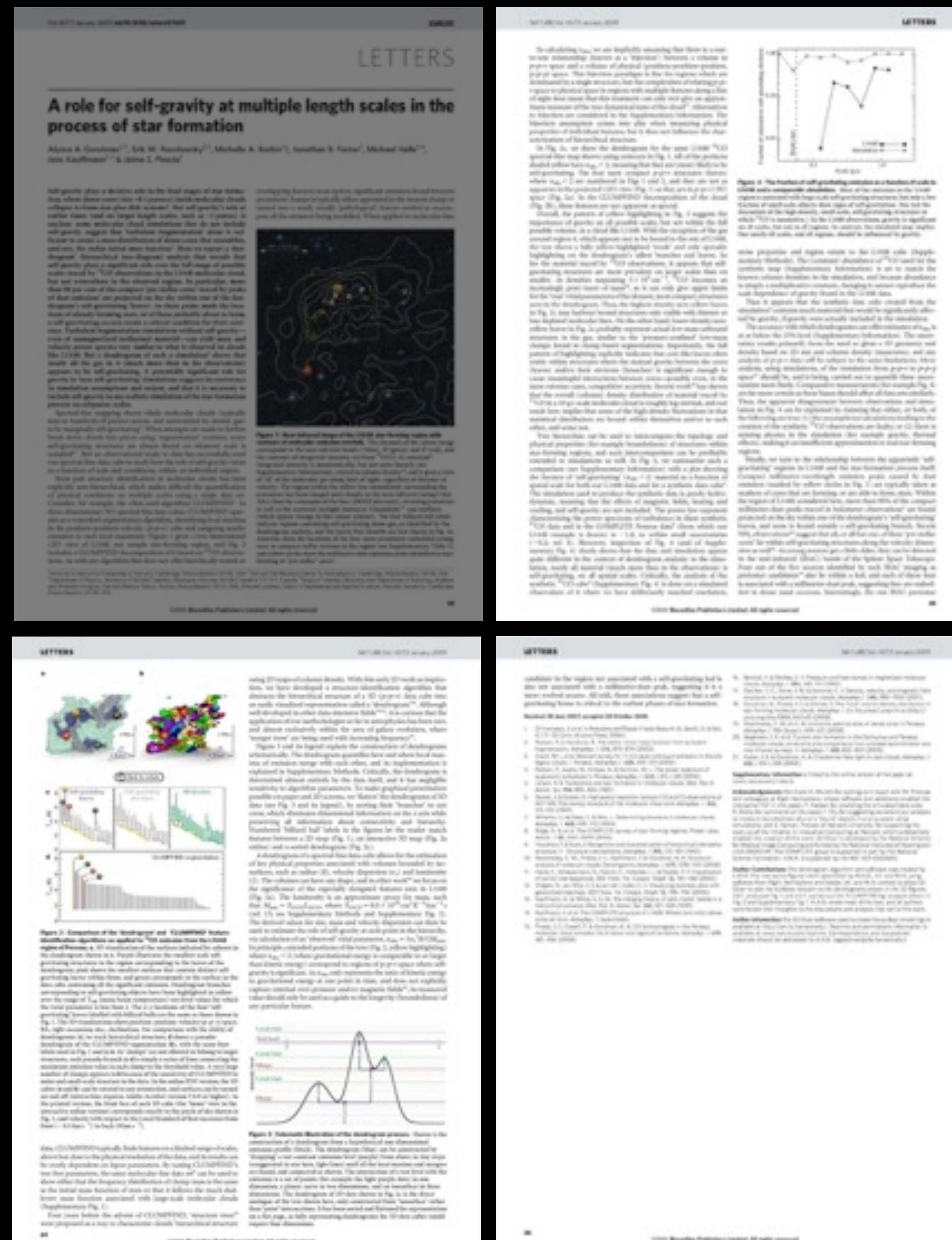
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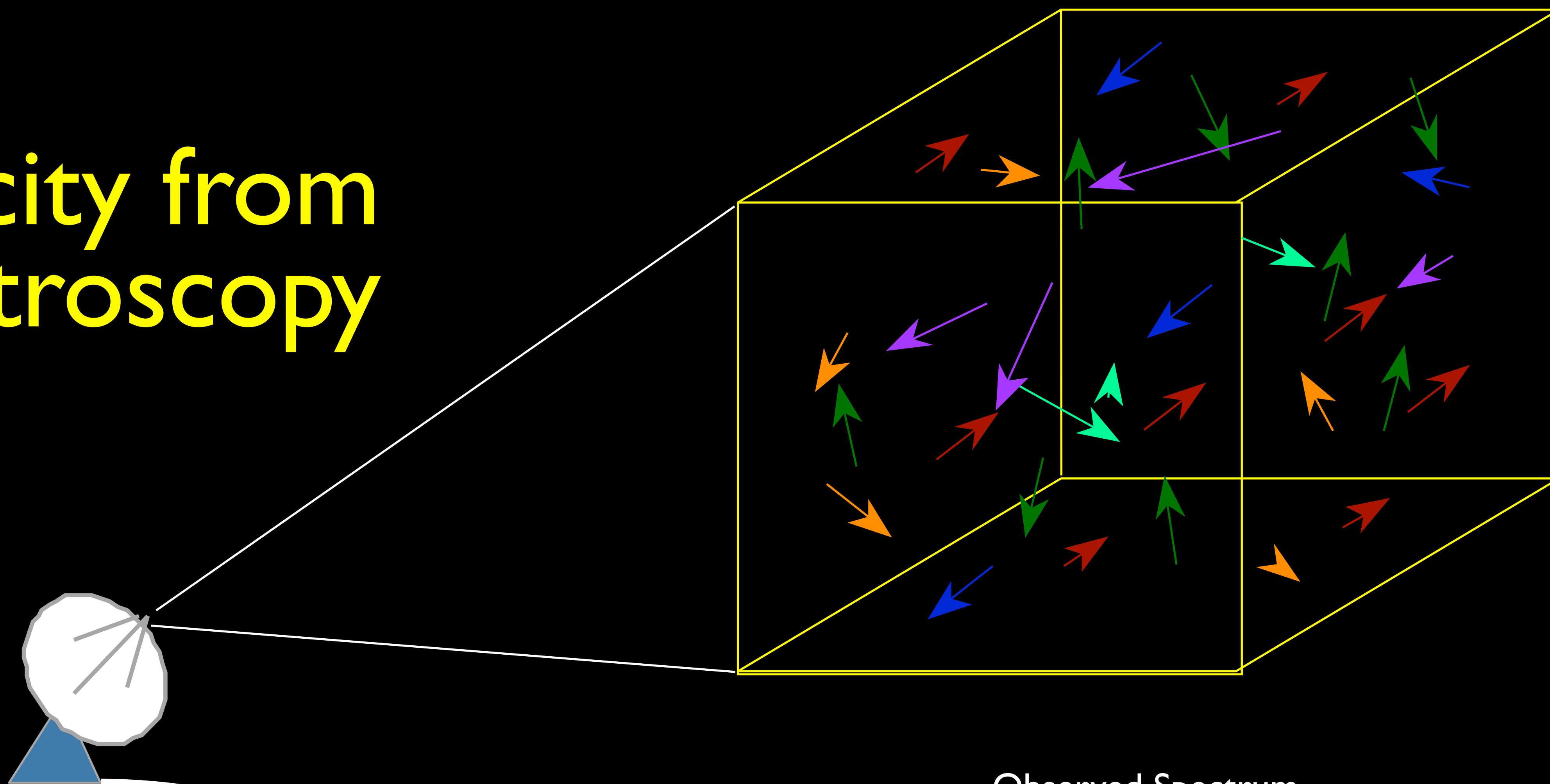
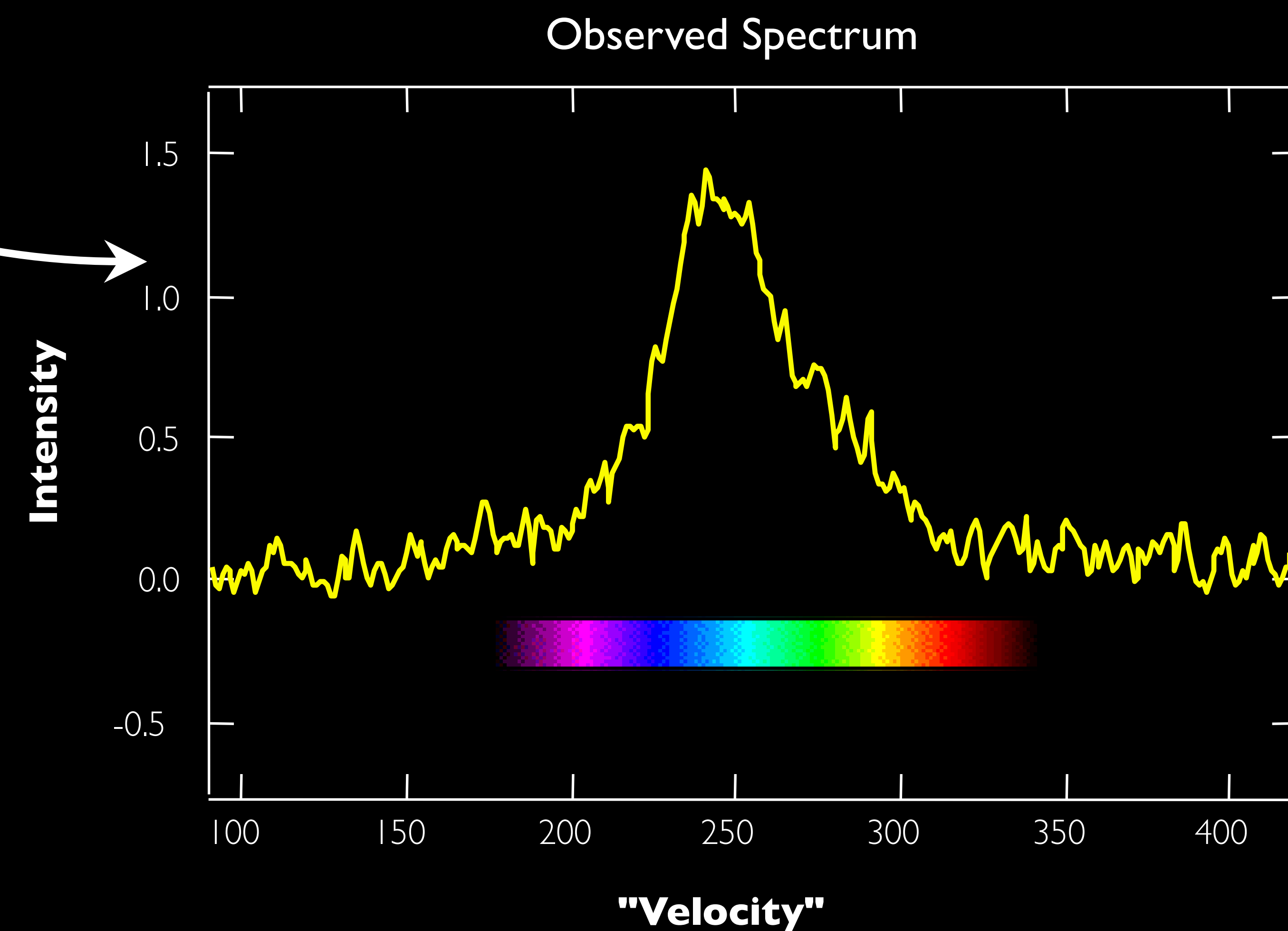
Velocity from Spectroscopy



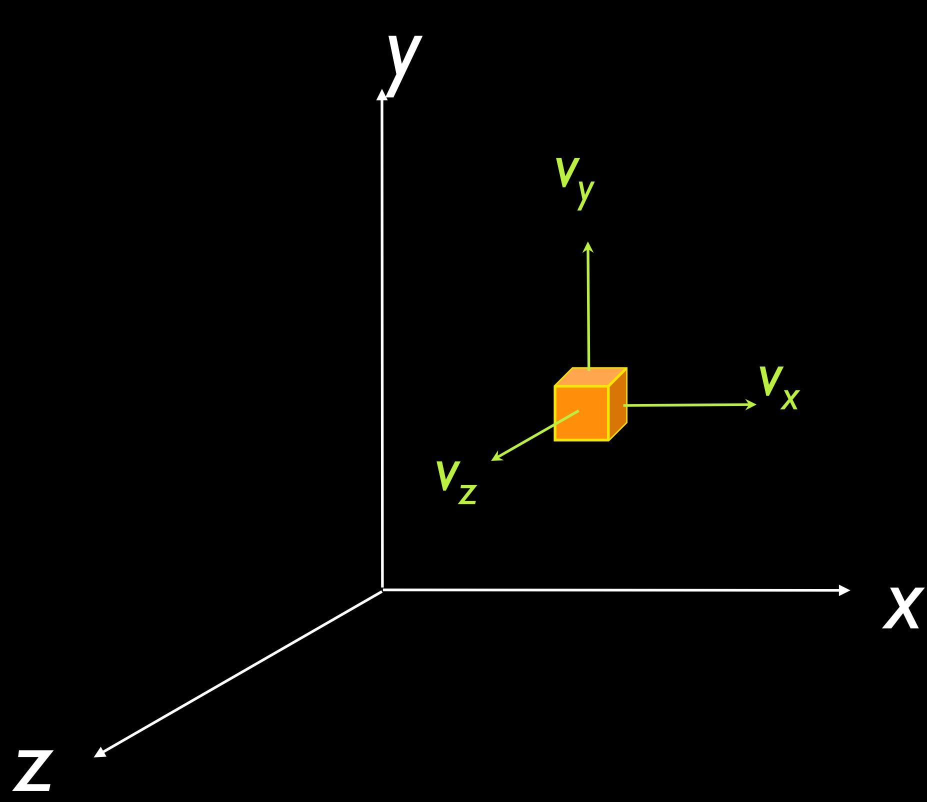
Telescope +
Spectrometer



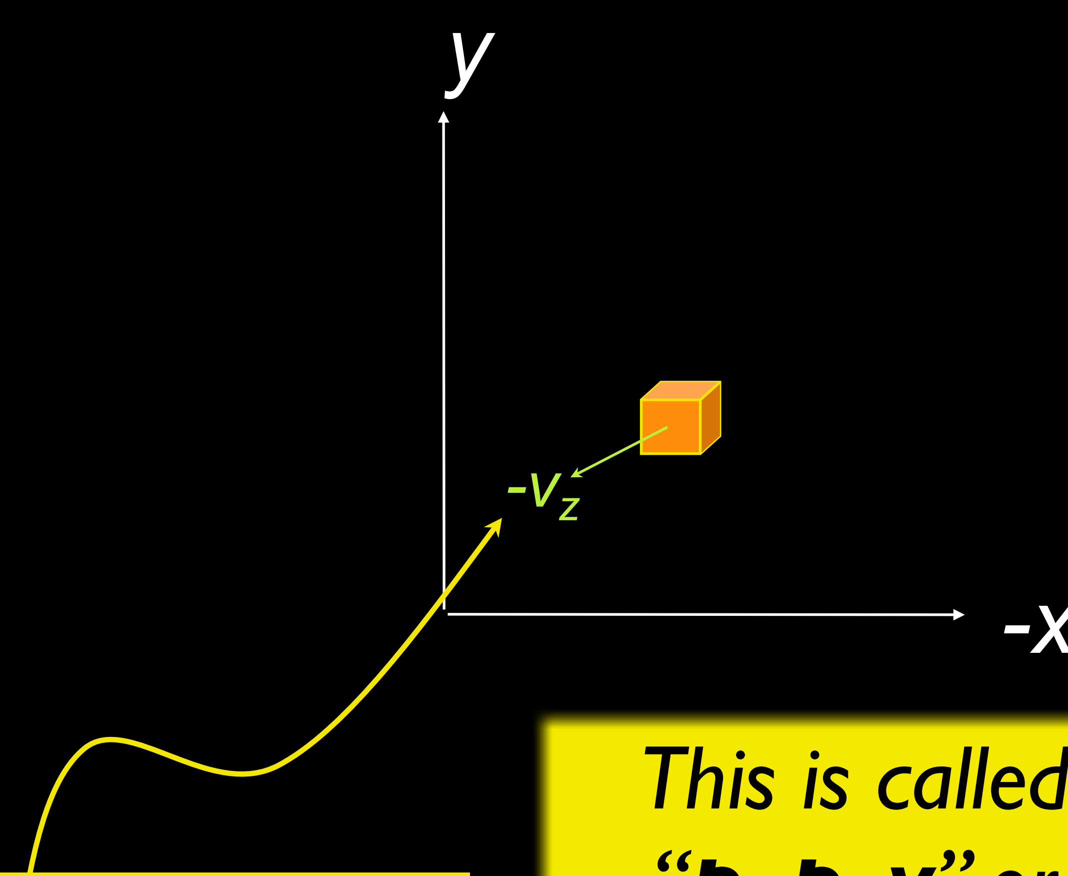
All thanks to Doppler

"Three" Dimensions: Spectral-Line Mapping

We wish we could measure…



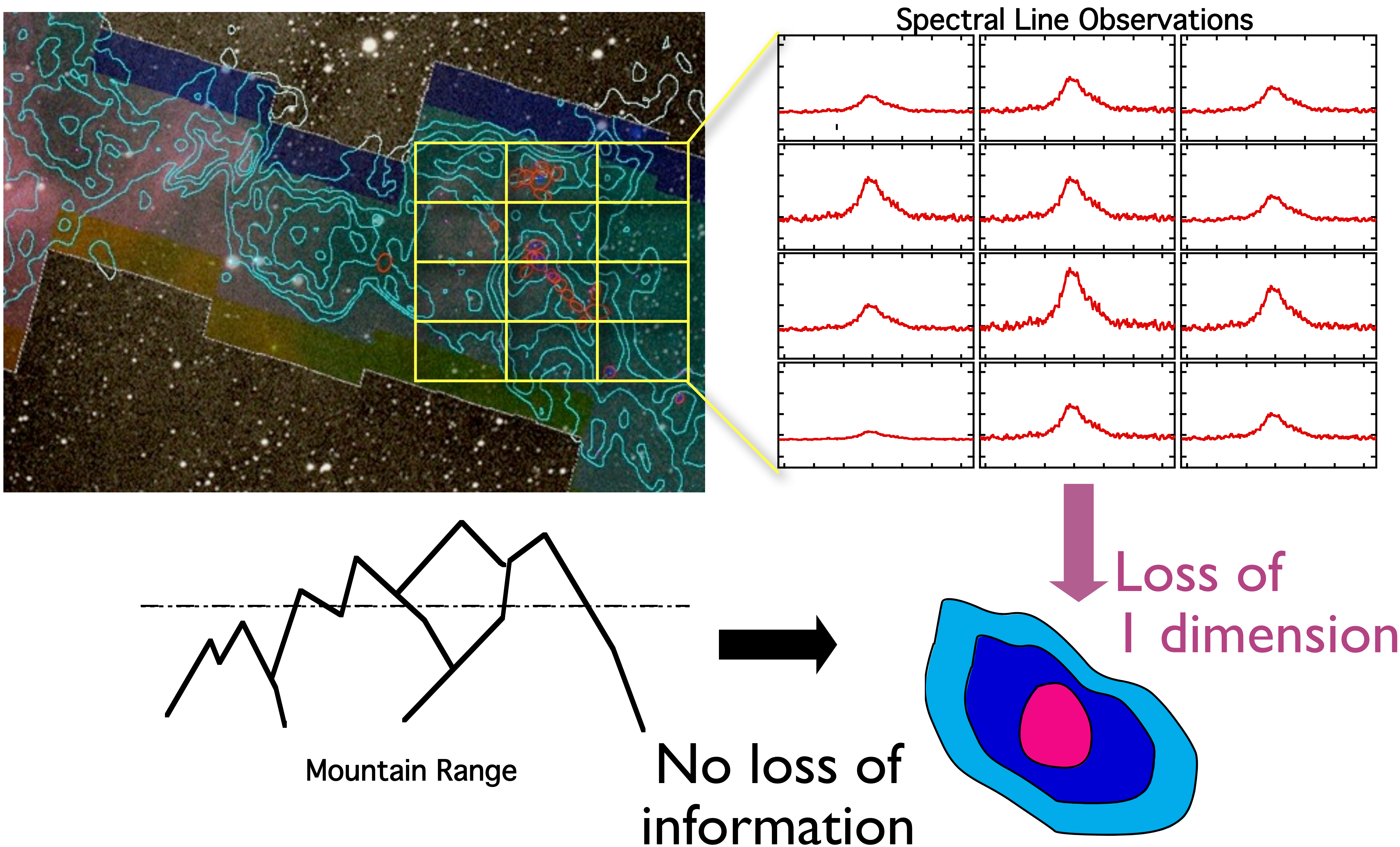
But we can measure…



v_z *only* from "spectral-line maps"

*This is called "**p-p-v**" or "position-position-velocity" space.*

There's much more to life than "integrated intensity"



Astronomical Visualization Tools are Traditionally 2D

IDL

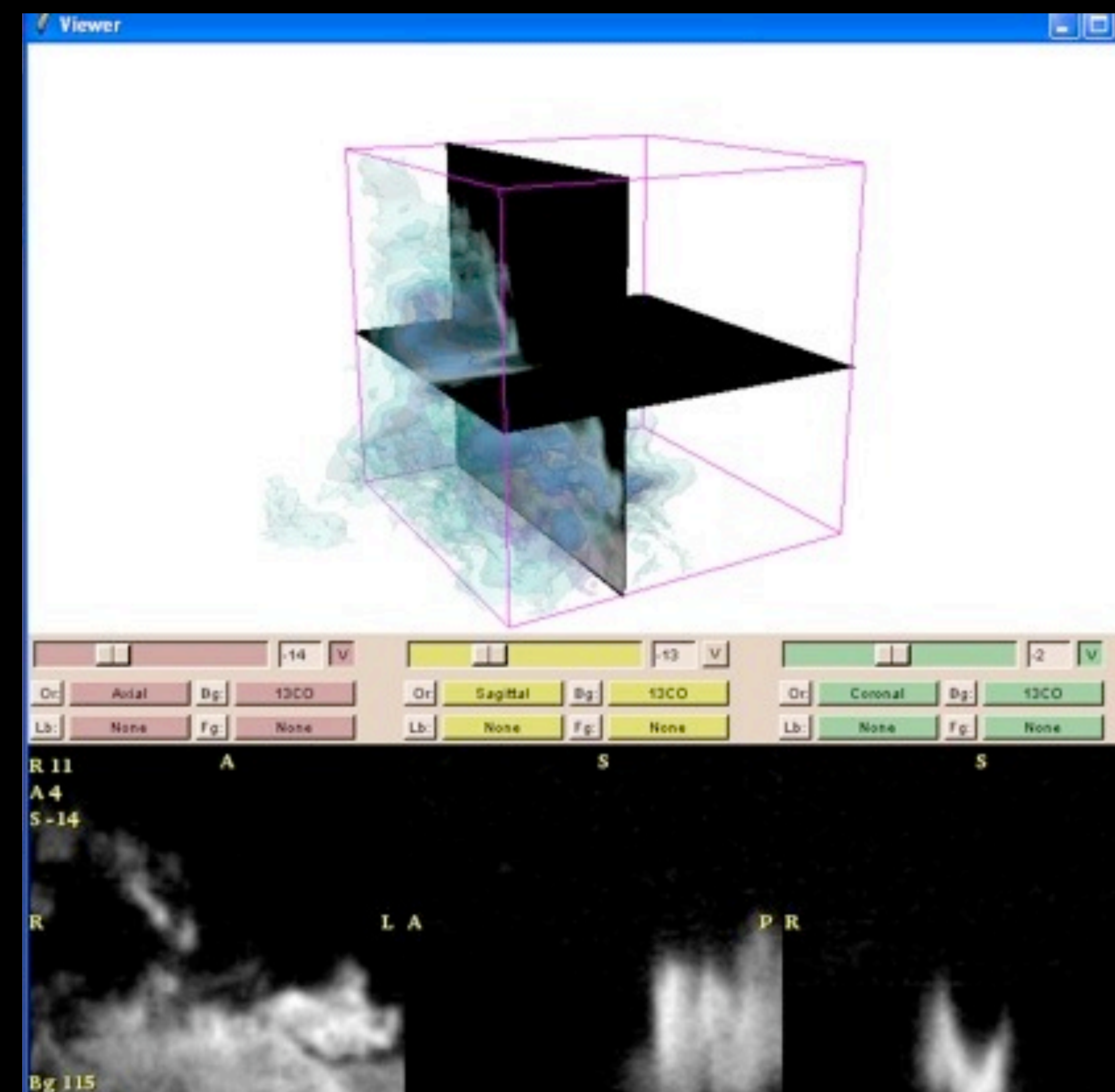
DS9

Karma*

GAIA

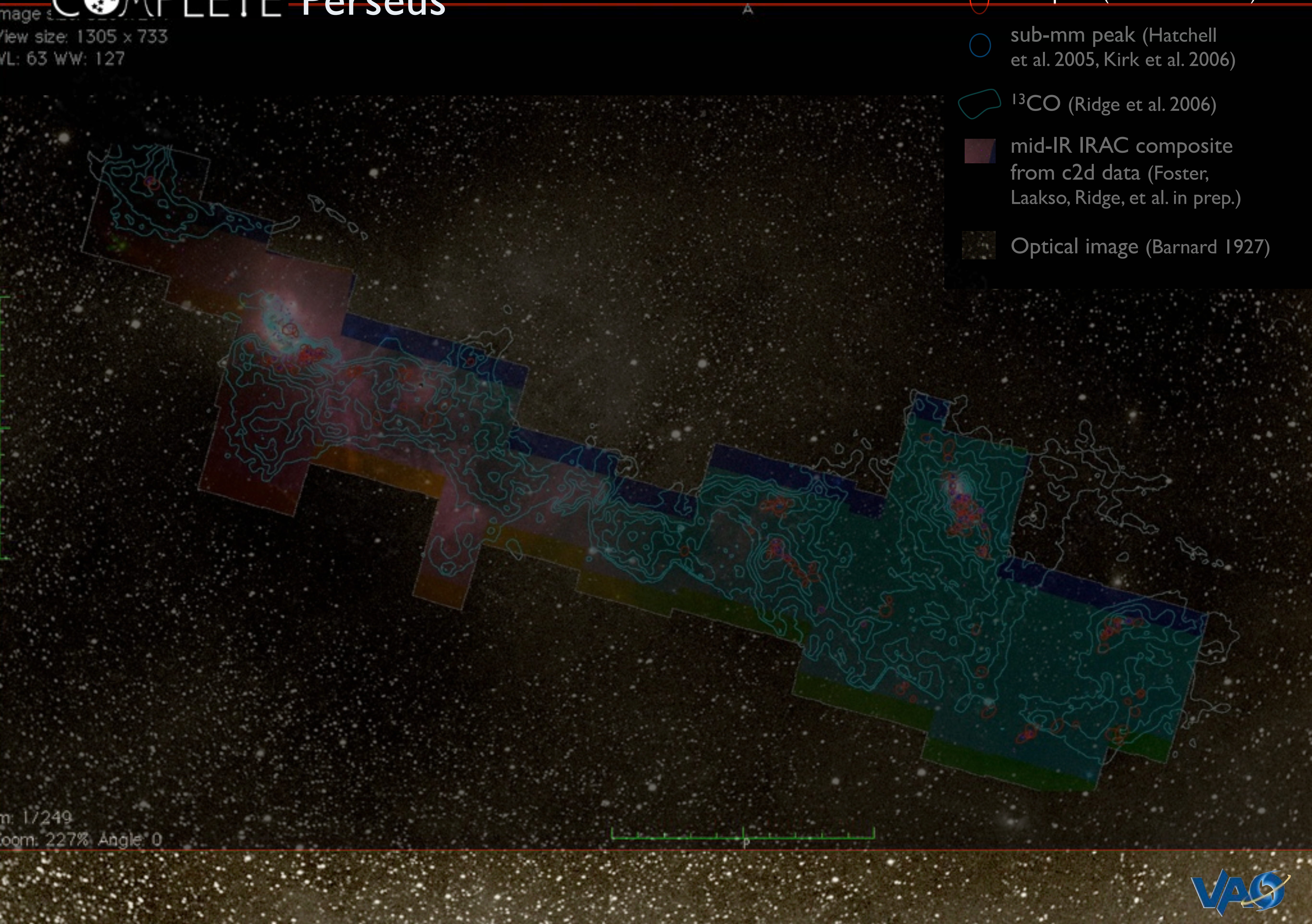
Aipsview

3D Slicer



"3D"=movies

C●MPLETE Perseus



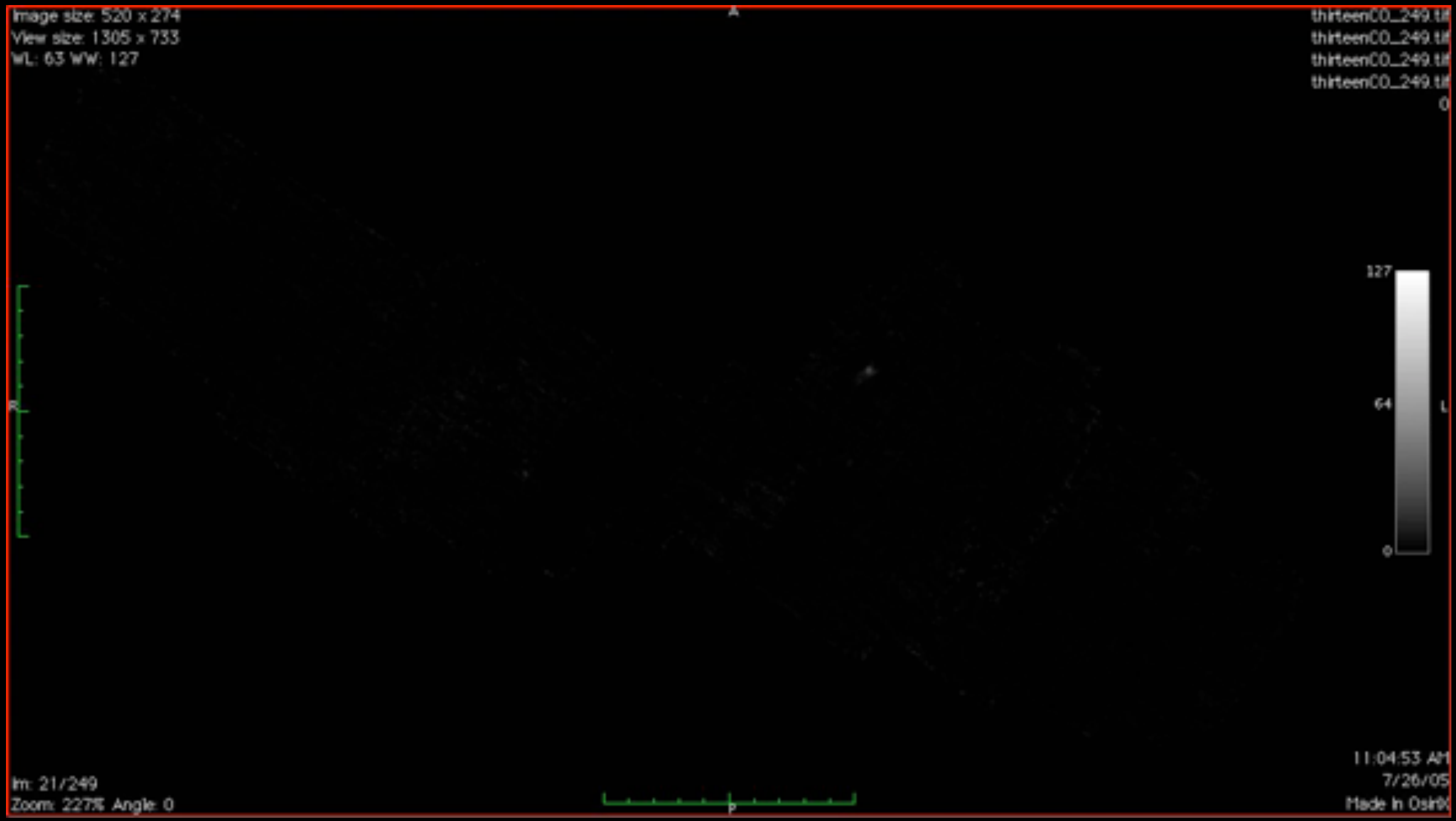
- mm peak (Enoch et al. 2006)
- sub-mm peak (Hatchell et al. 2005, Kirk et al. 2006)
- ^{13}CO (Ridge et al. 2006)
- mid-IR IRAC composite from c2d data (Foster, Laakso, Ridge, et al. in prep.)
- Optical image (Barnard 1927)

“Astronomical Medicine”

“KEITH”

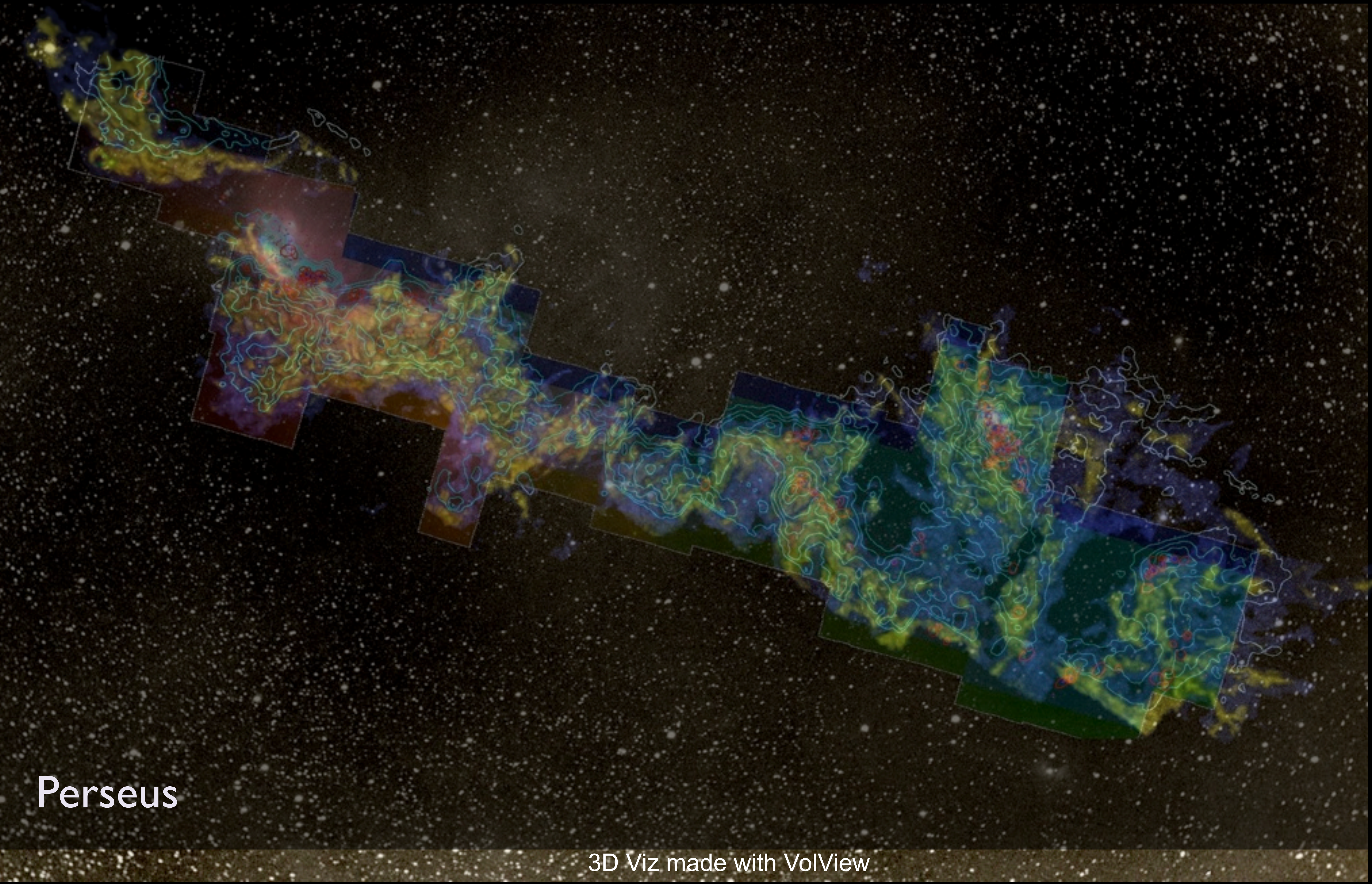
“z” is depth into head

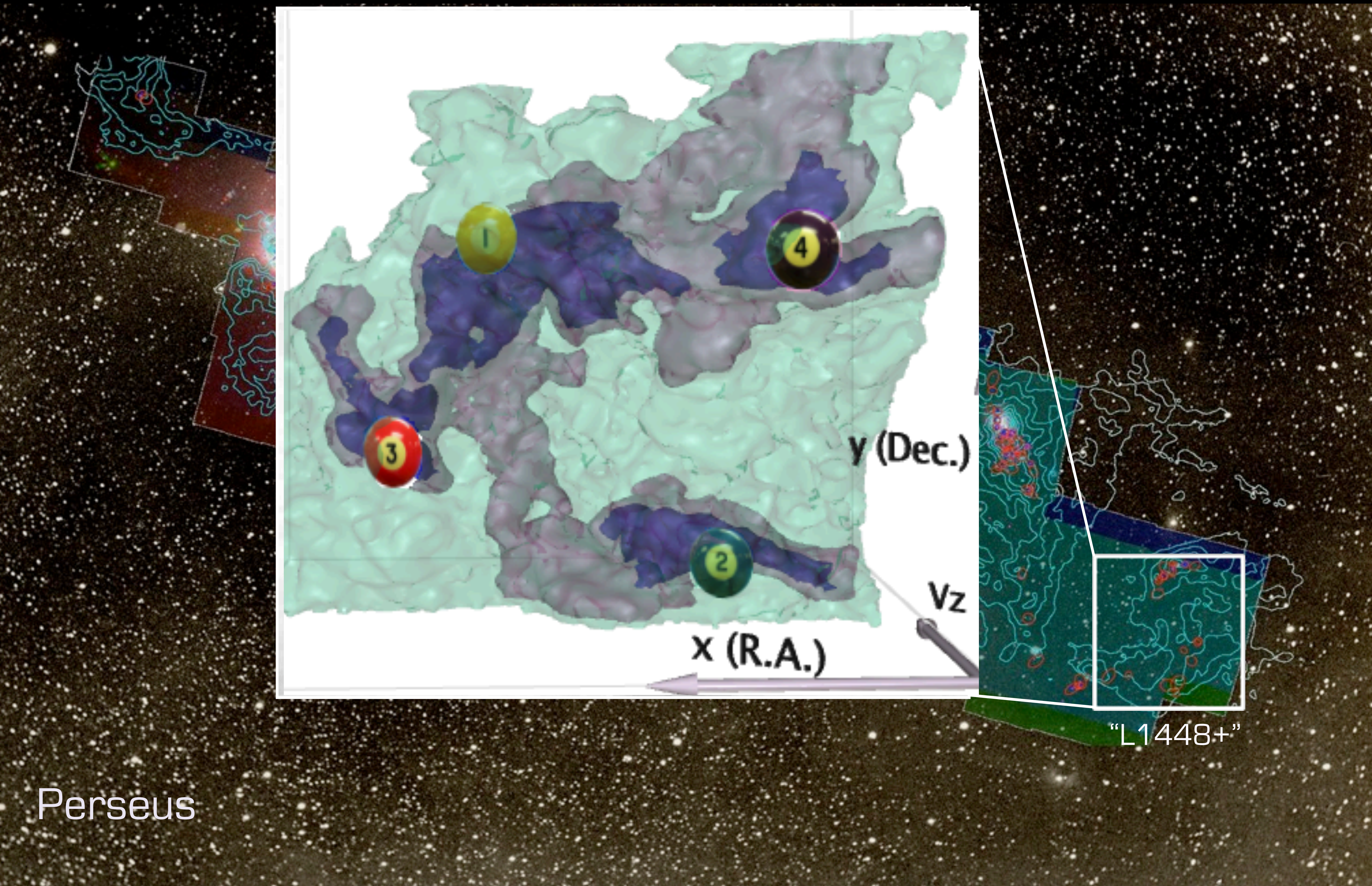
“PERSEUS”



“z” is line-of-sight velocity

(This kind of “series of 2D slices view” is known in the Viz as “the grand tour”)


Perseus
3D Viz made with VolView



COMPLETE

“turbulent fragmentation”

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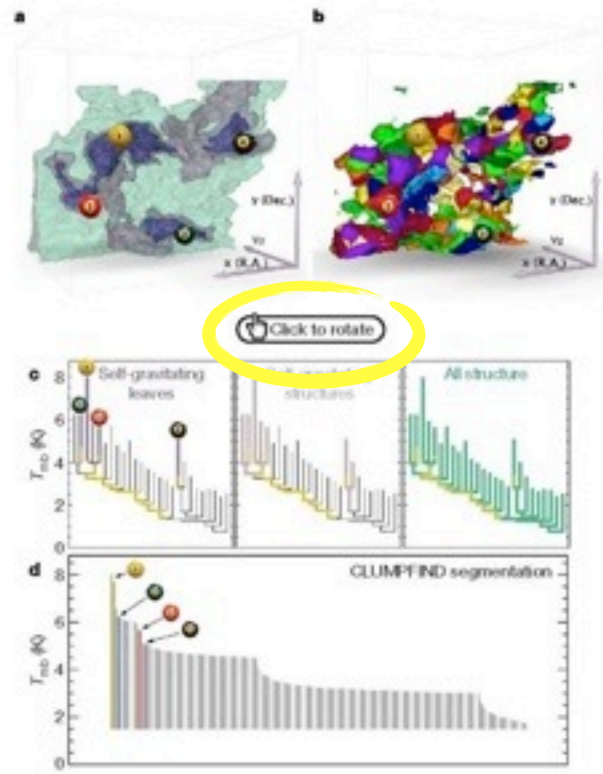


Figure 2 | Comparison of the 'dendrogram' and 'CLUMPFIND' feature-identification algorithms as applied to ^{13}CO emission from the L1448 region of Perseus. a, 3D visualization of the surfaces indicated by colours in the dendrogram shown in **c**. Purple illustrates the smallest scale self-gravitating 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 ($-0.5\ \mathrm{km\ s^{-1}}$) to back ($8\ \mathrm{km\ s^{-1}}$).

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 $X_{13CO} = 8.0 \times 10^{20}\ \mathrm{cm^2\ K^{-1}\ km^{-1}\ s}$ (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.

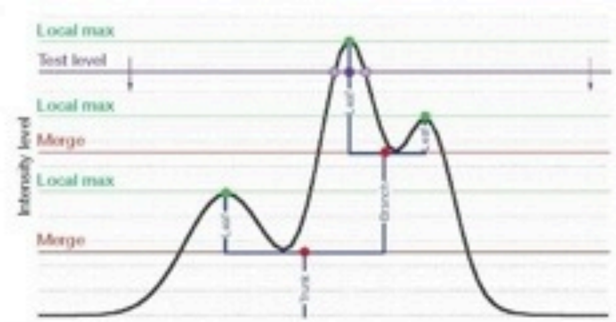


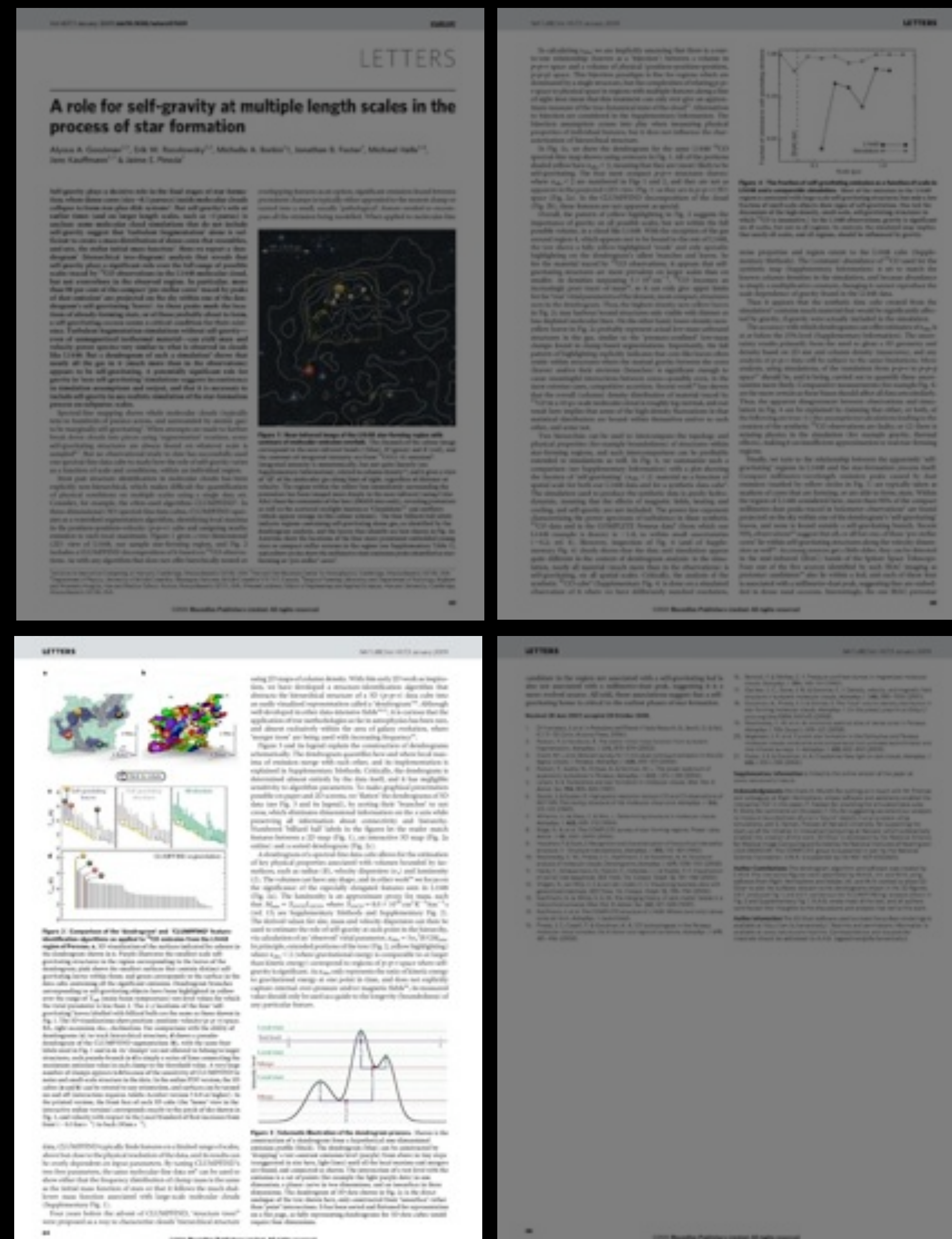
Figure 3 | Schematic illustration of the dendrogram process. Shown is the construction of a dendrogram from a hypothetical one-dimensional emission profile (black). The dendrogram (blue) can be constructed by 'dropping' a test constant emission level (purple) from above in tiny steps (exaggerated in 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.

“turbulent fragmentation”

“(magneto-)hydrodynamic simulation”

“bi-jection”

“virial parameter”


LETTERS

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✔ “3D PDF”

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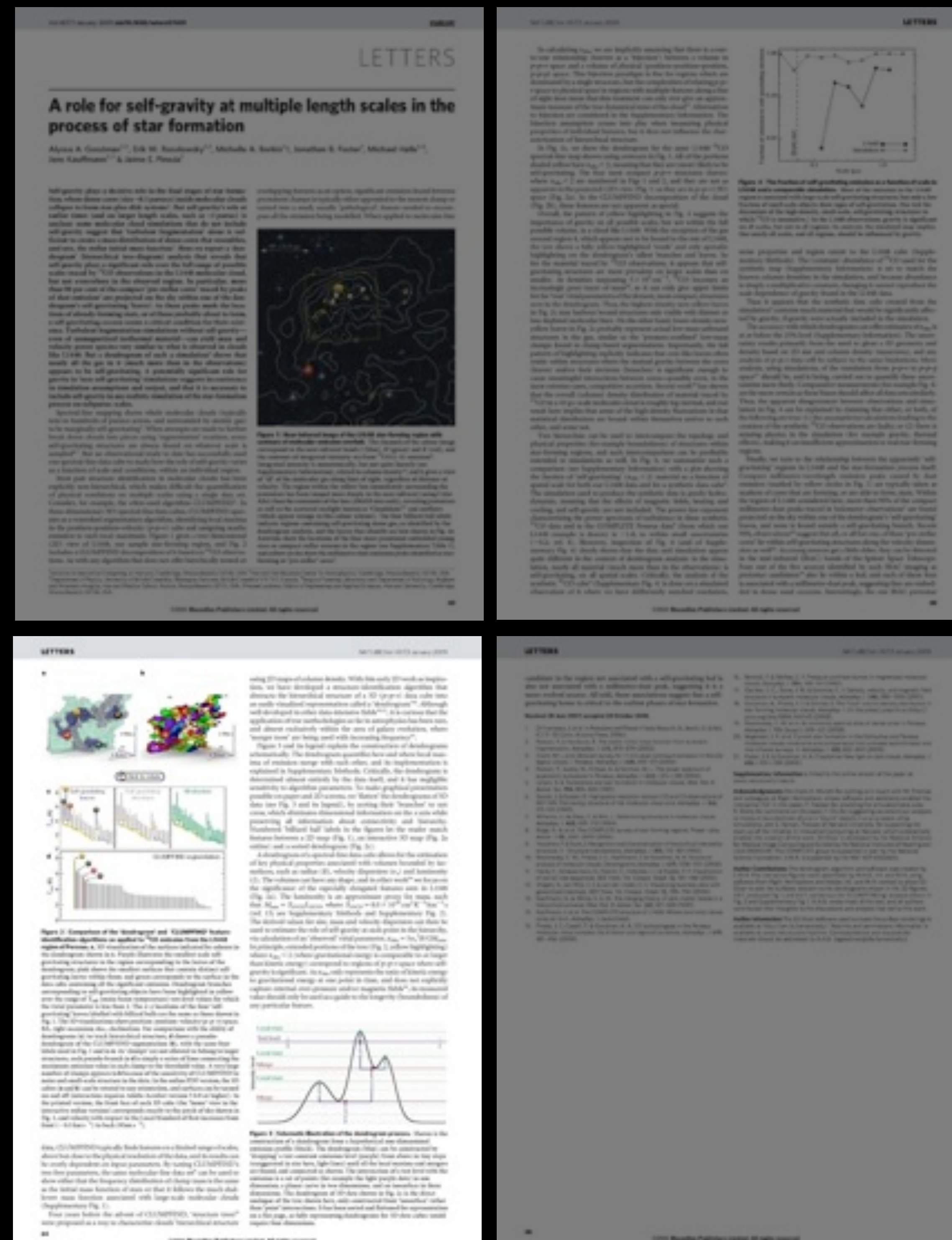
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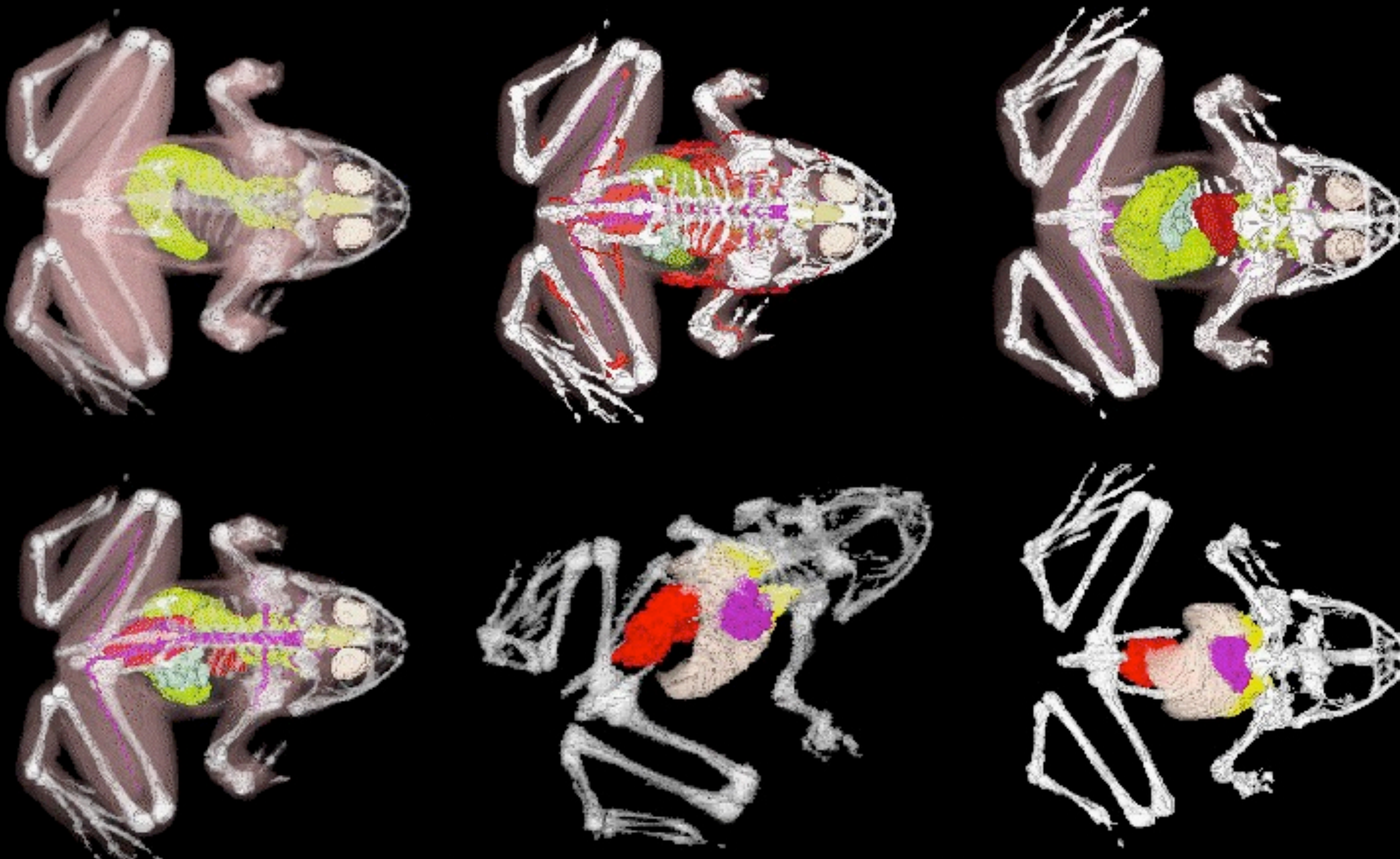
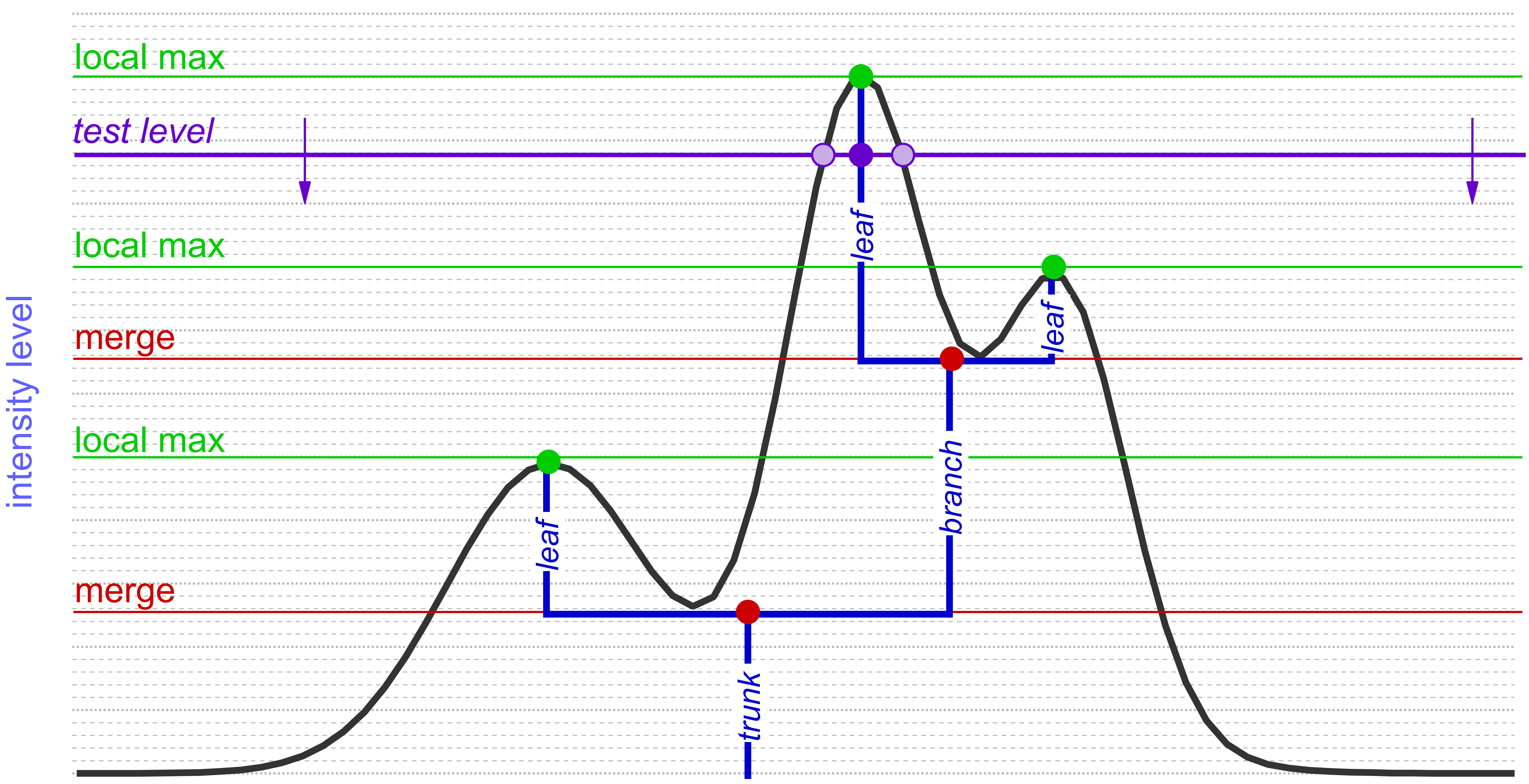


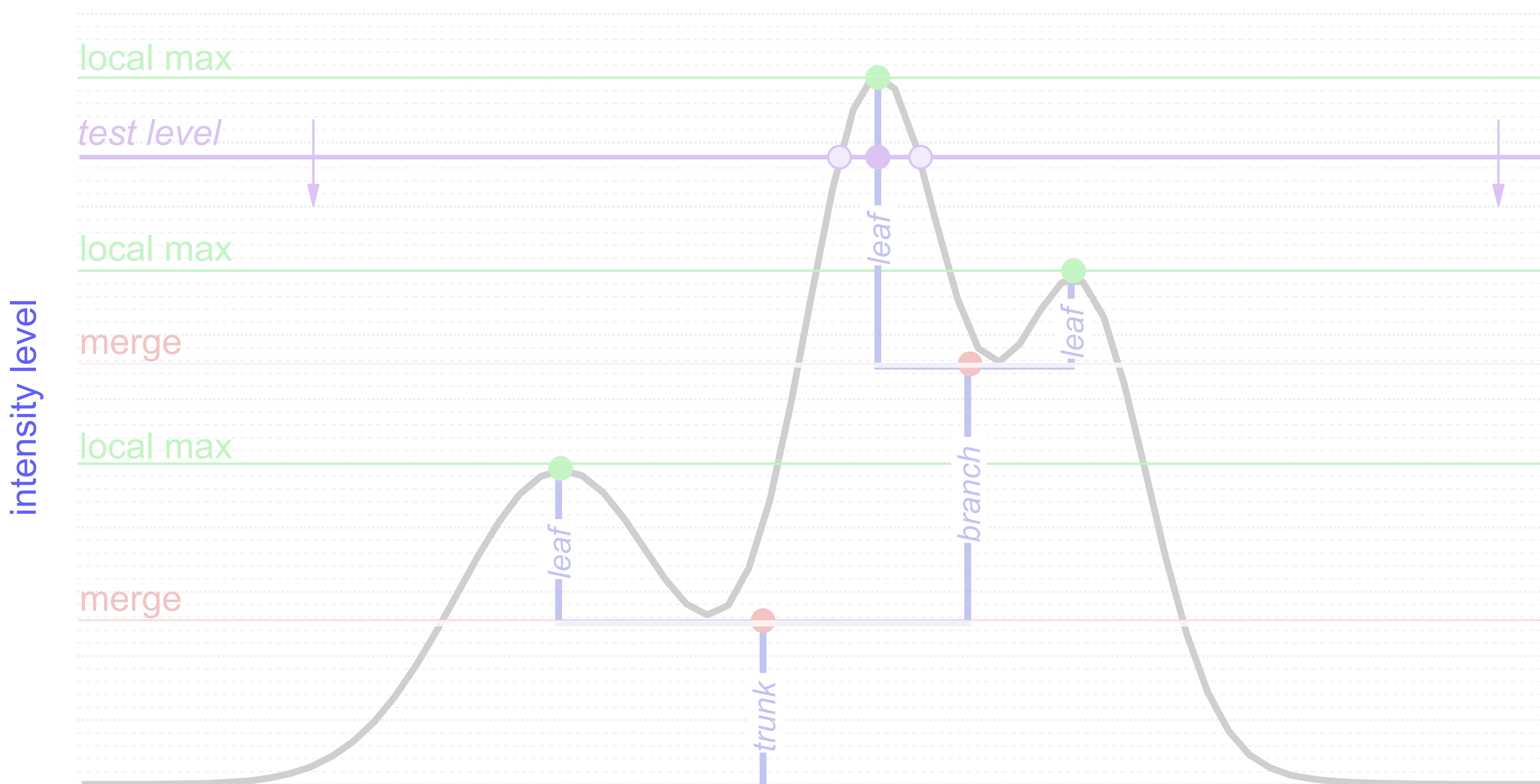
Dendrograms



Hierarchical "Segmentation"

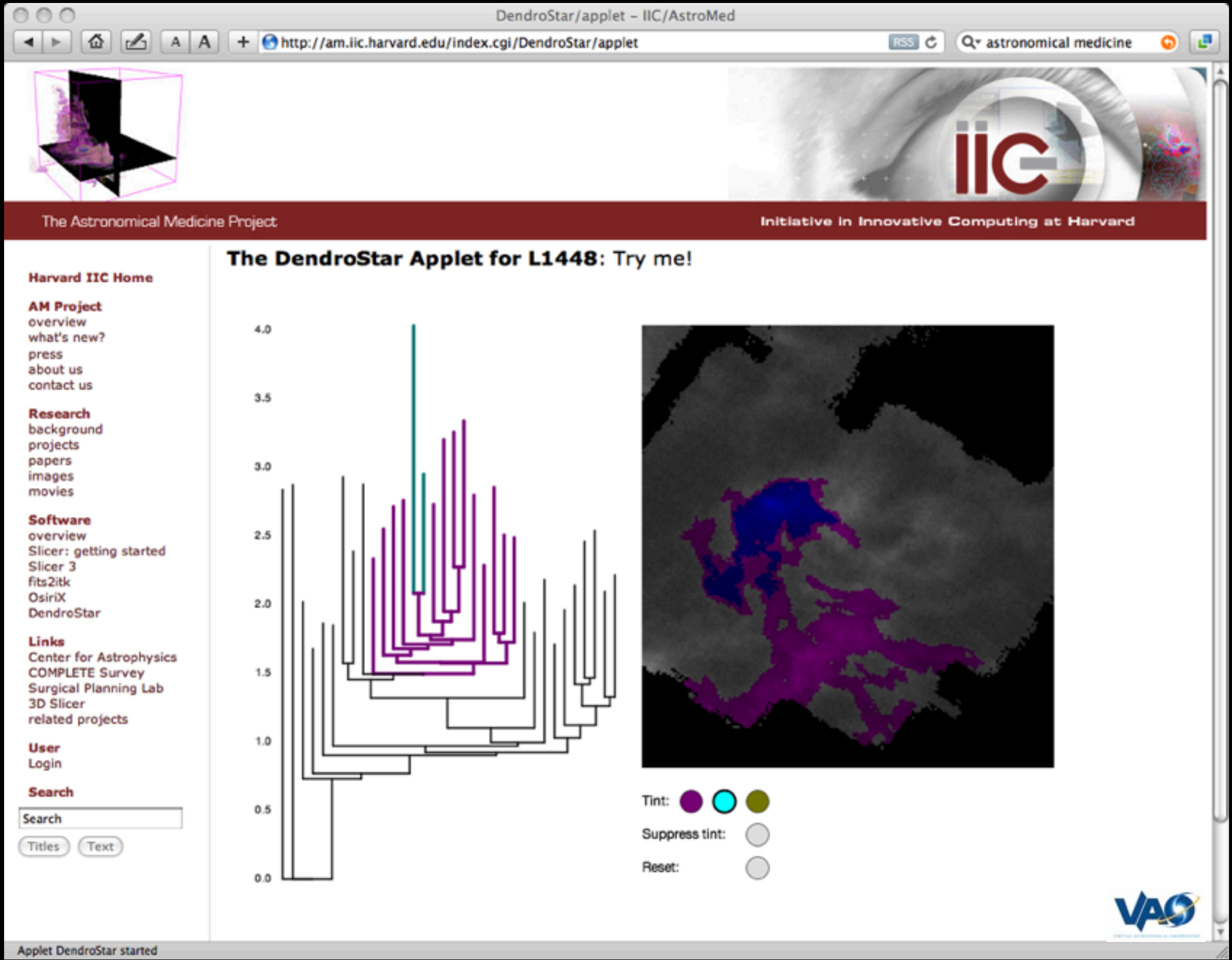
Rosolowsky, Pineda, Kauffmann & Goodman 2008

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*

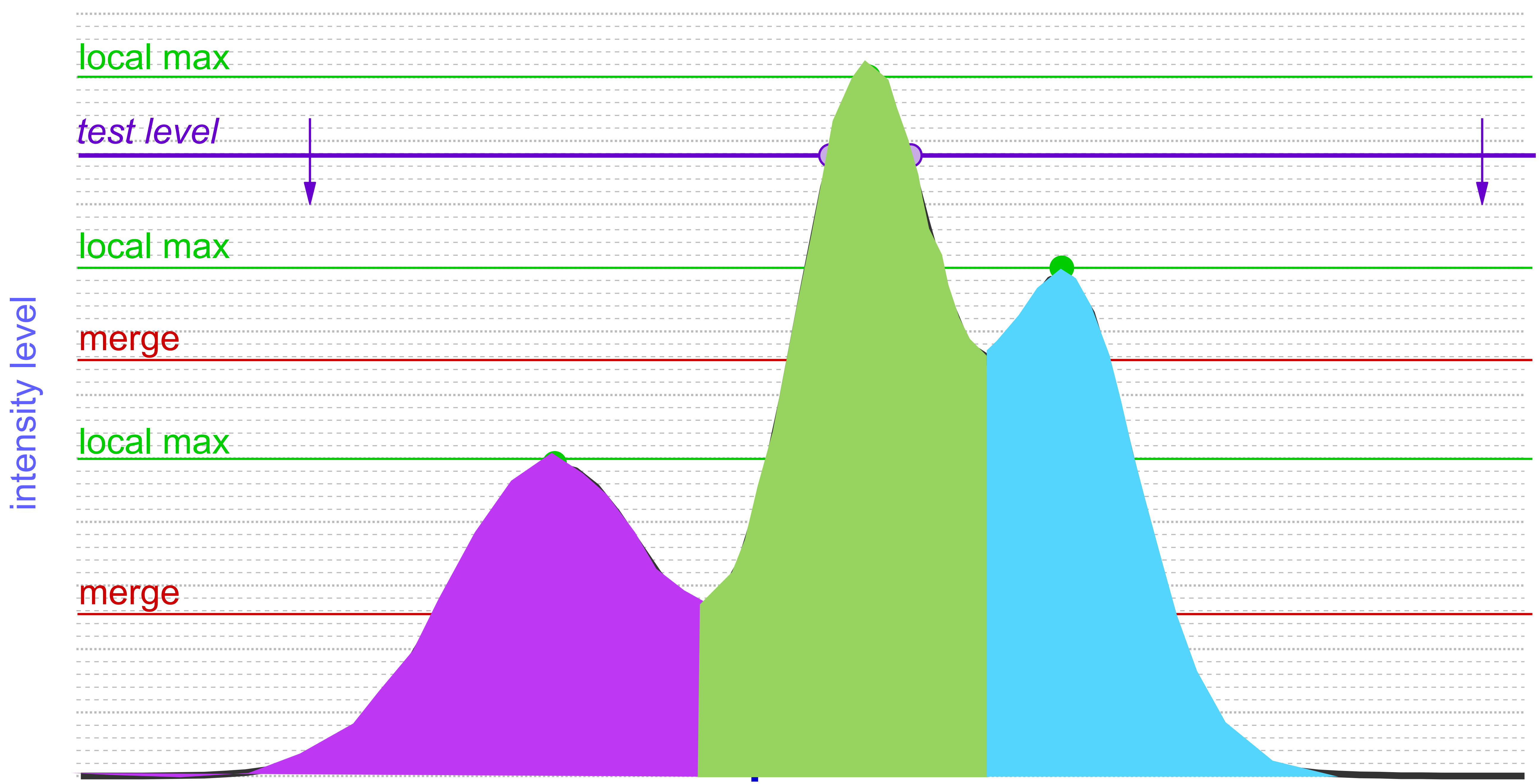


http://am.iic.harvard.edu/index.cgi/DendroStar/applet

Dendrogram Algorithm by Erik Rosolwosky; Applet by Douglas Alan

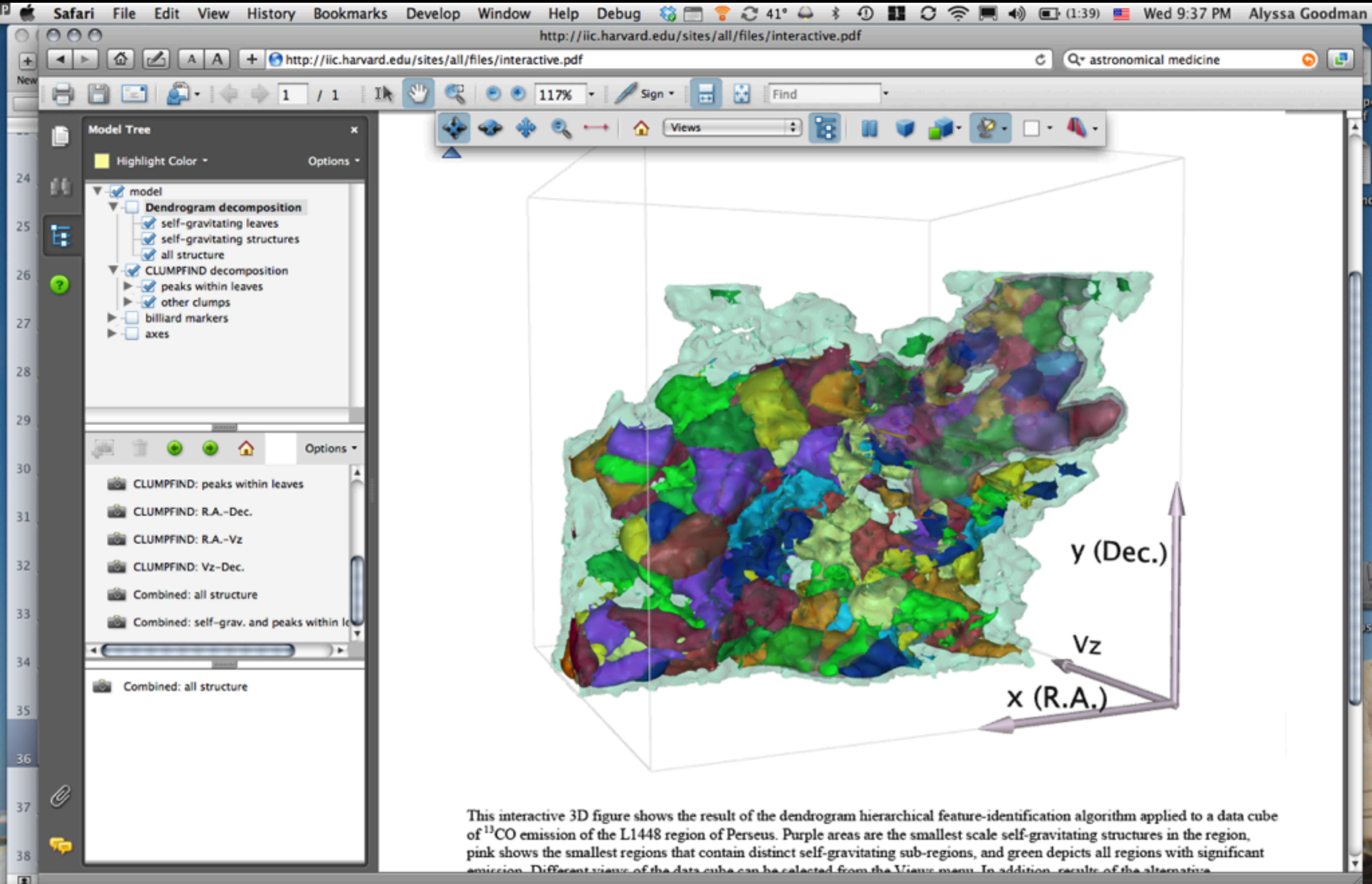
3D, see PDF...

What would *CLUMPFIND* do?



No hierarchy is allowed, all clumps go to the baseline.

(Williams, De Geus & Blitz 1994)



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

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

“Crowded” 3D data *(very dangerous)*

“Sparse” 2D data *(OK)*

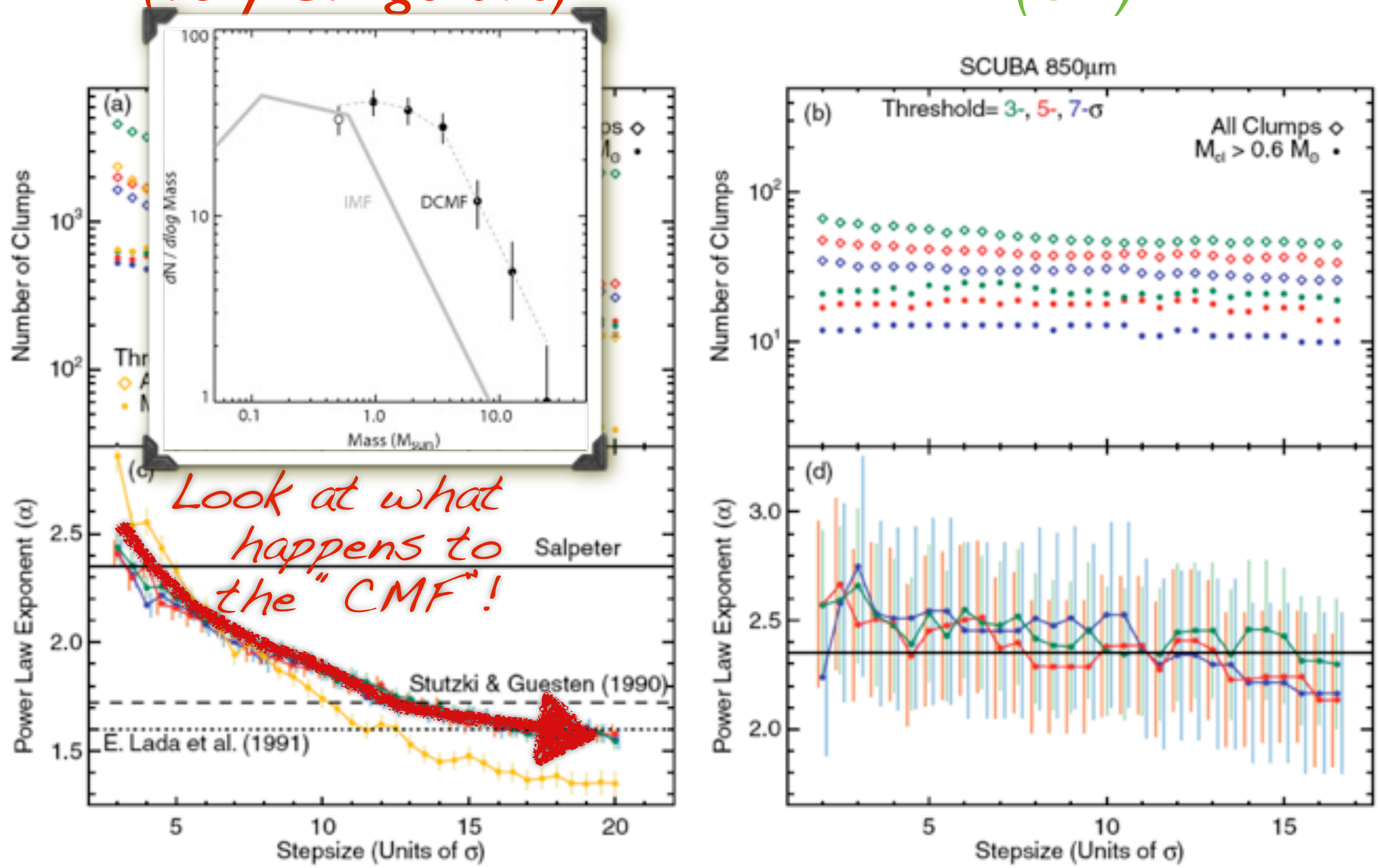


Figure 2. Summary of all Clumpfind runs as a function of stepsize. Color represent different thresholds: blue, red, and green for 3σ, 5σ, and 7σ, respectively; we also show in orange results with a threshold of 5σ for ^{13}CO data with added noise. Left and right columns show results for ^{13}CO and 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.

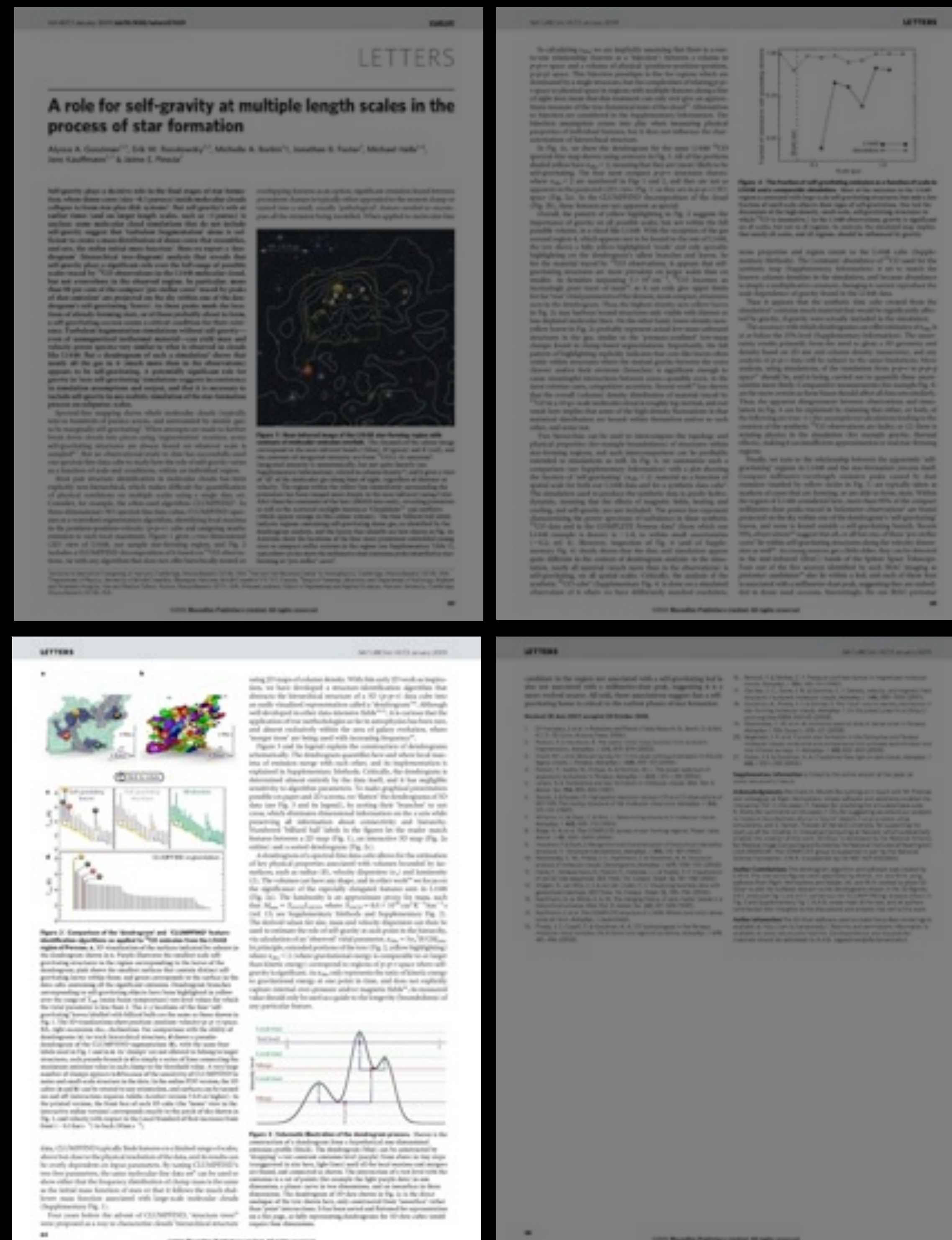
from ***“The Perils of CLUMPFIND”*** *by Pineda, Rosolowsky & Goodman 2009*

“turbulent fragmentation”

“(magneto-)hydrodynamic simulation”

“bi-jection”

“virial parameter”


LETTERS

A role for self-gravity at multiple length scales in the process of star formation

“turbulent power spectrum”

“synthetic observation”

“depletion, opacity”

“taste-test”

caveats

✔“segmentation”

✔“CLUMPFIND”

✔“Dendrogram”

“turbulent fragmentation”

“(magneto-)hydrodynamic simulation”


LETTERS

A role for self-gravity at multiple length scales in the process of star formation

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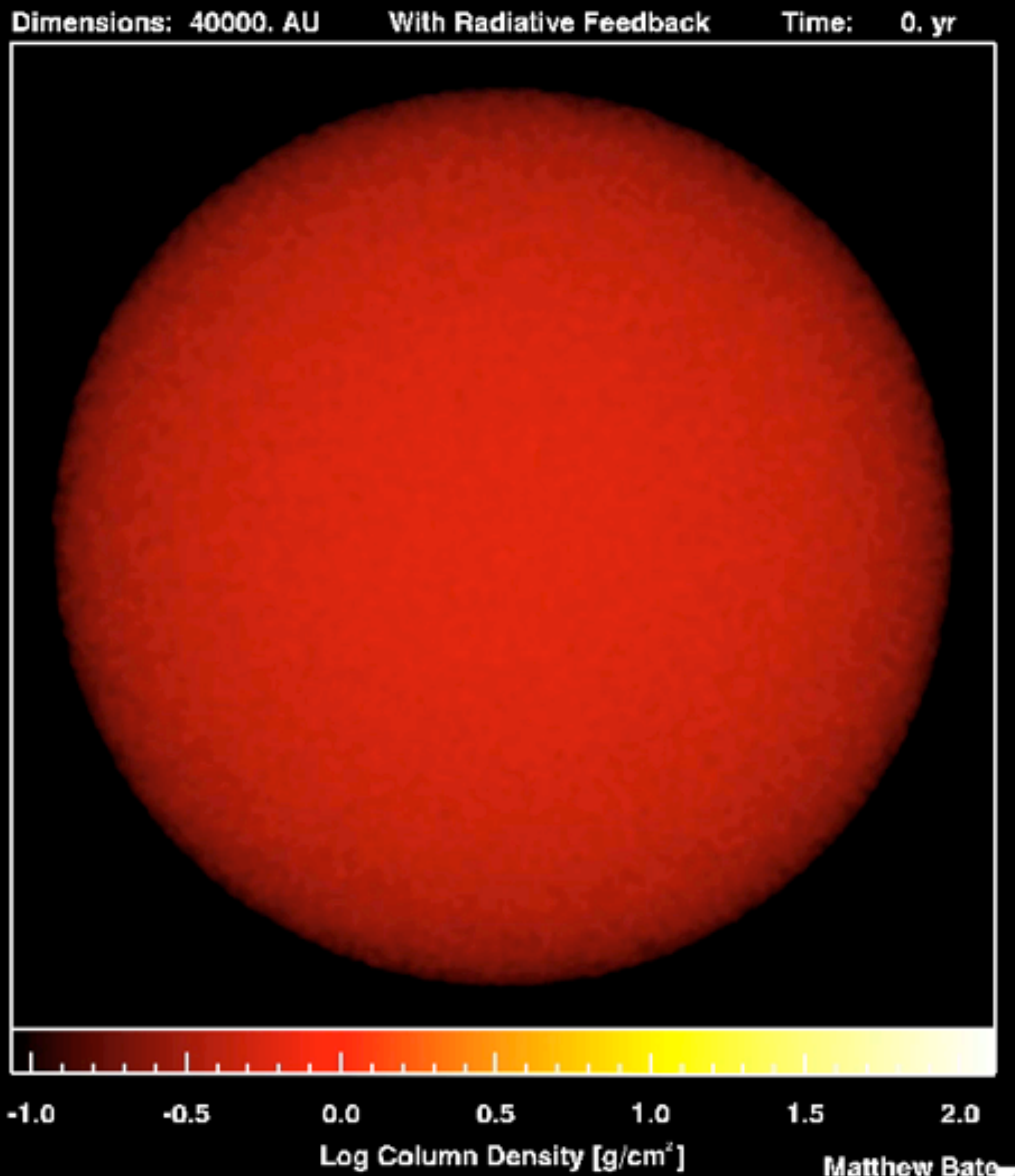
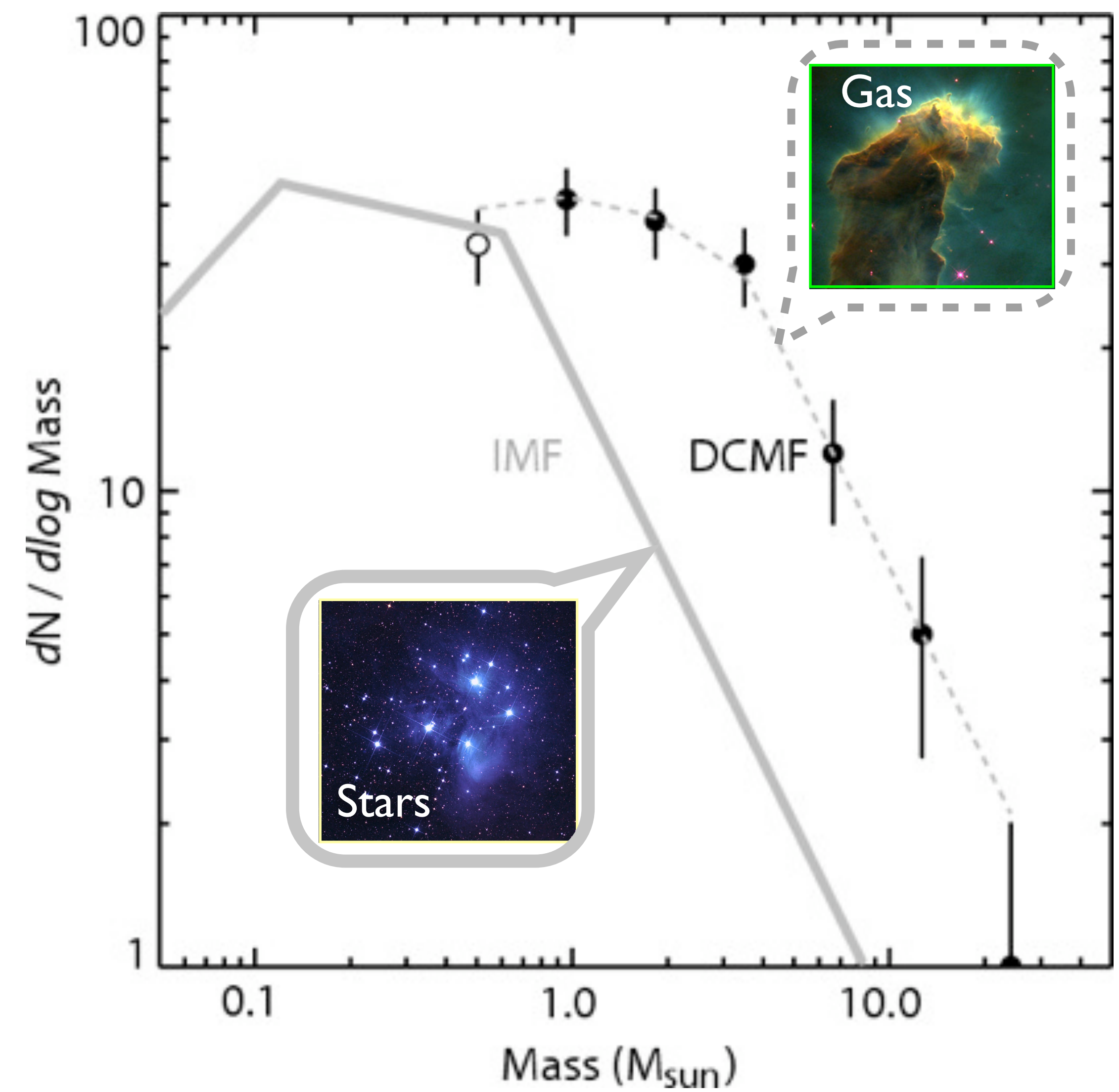
caveats

(MHD) Simulations, Turbulent Fragmentation



cf. Padoan & Nordlund 2002



Alves, Lombardi & Lada 2007

✔"turbulent fragmentation"

✔"(magneto-)hydrodynamic simulation"

"bi-jection"

"virial parameter"

"turbulent power spectrum"

"synthetic observation"

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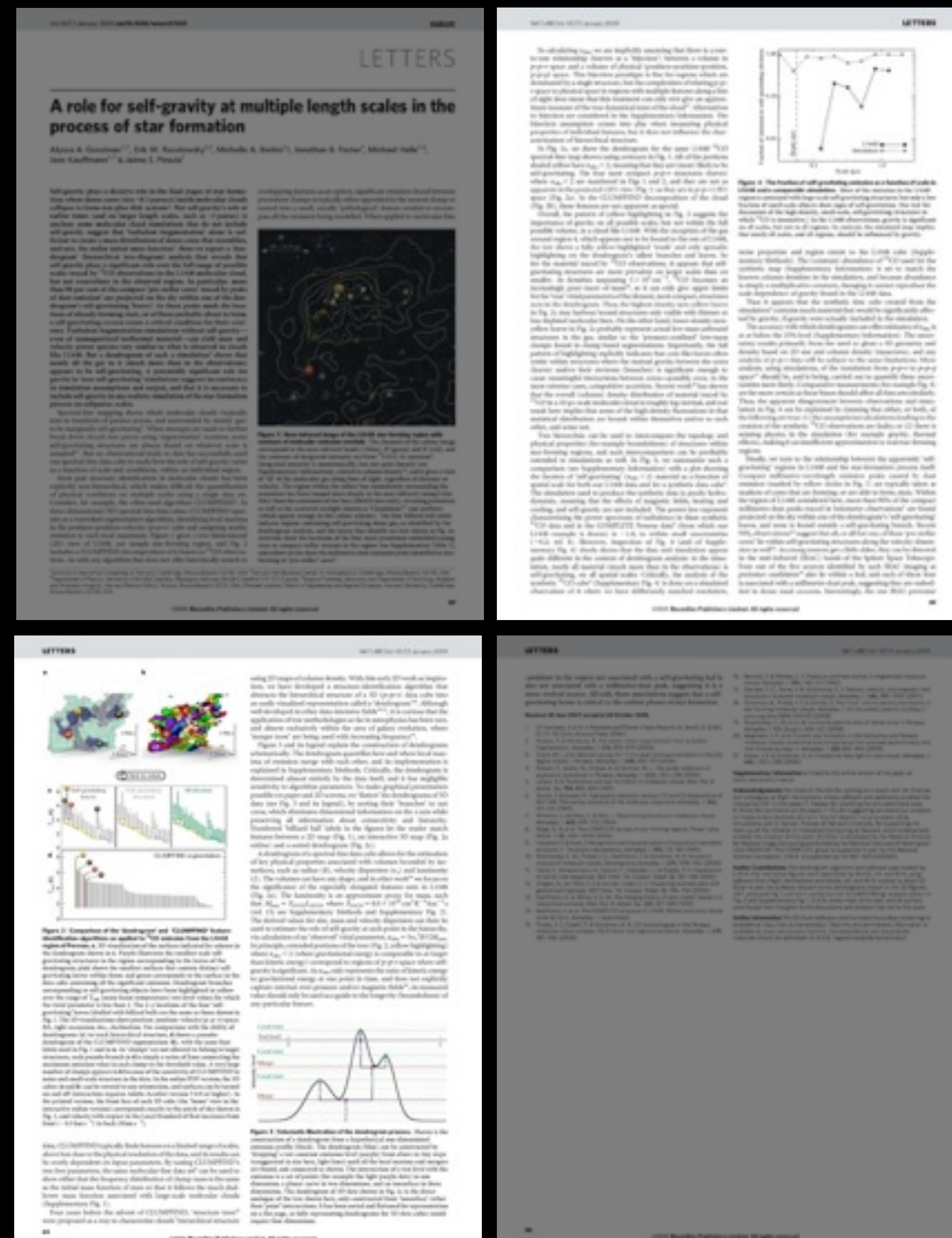
caveats


LETTERS

A role for self-gravity at multiple length scales in the process of star formation

"bi-jection"

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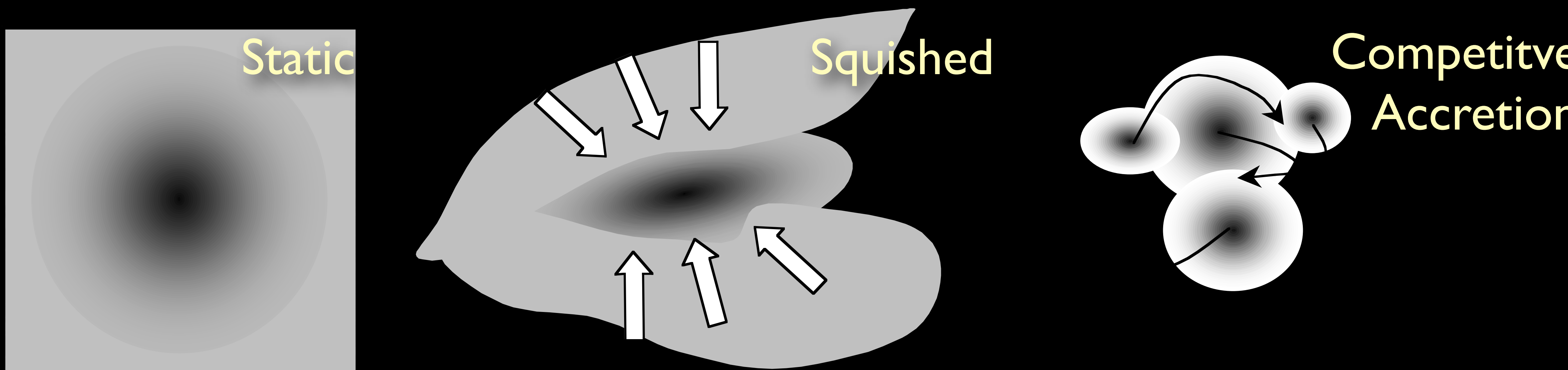
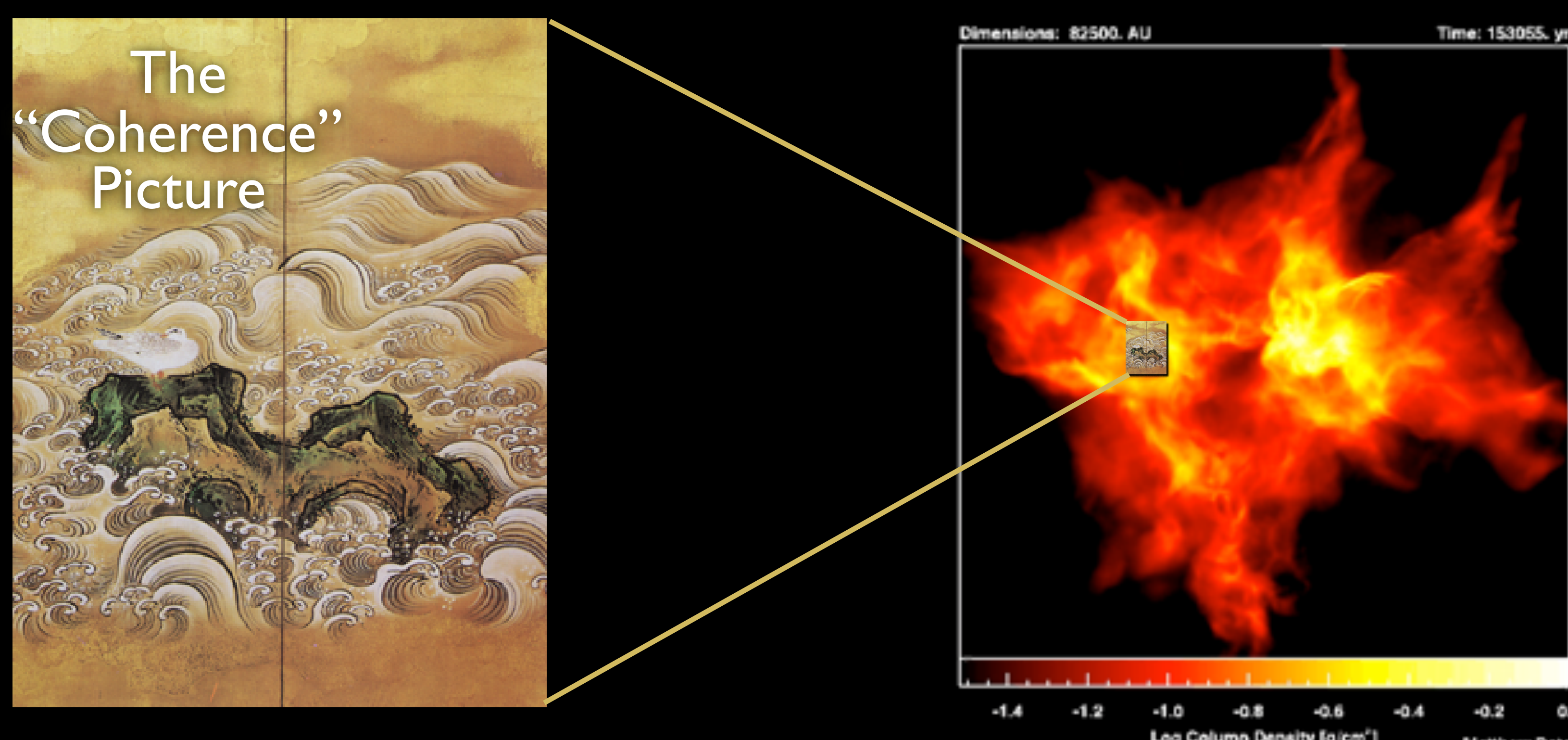
caveats

How calm, and how long-lasting are cores?

(relevant motions/forces & the "*virial parameter*")

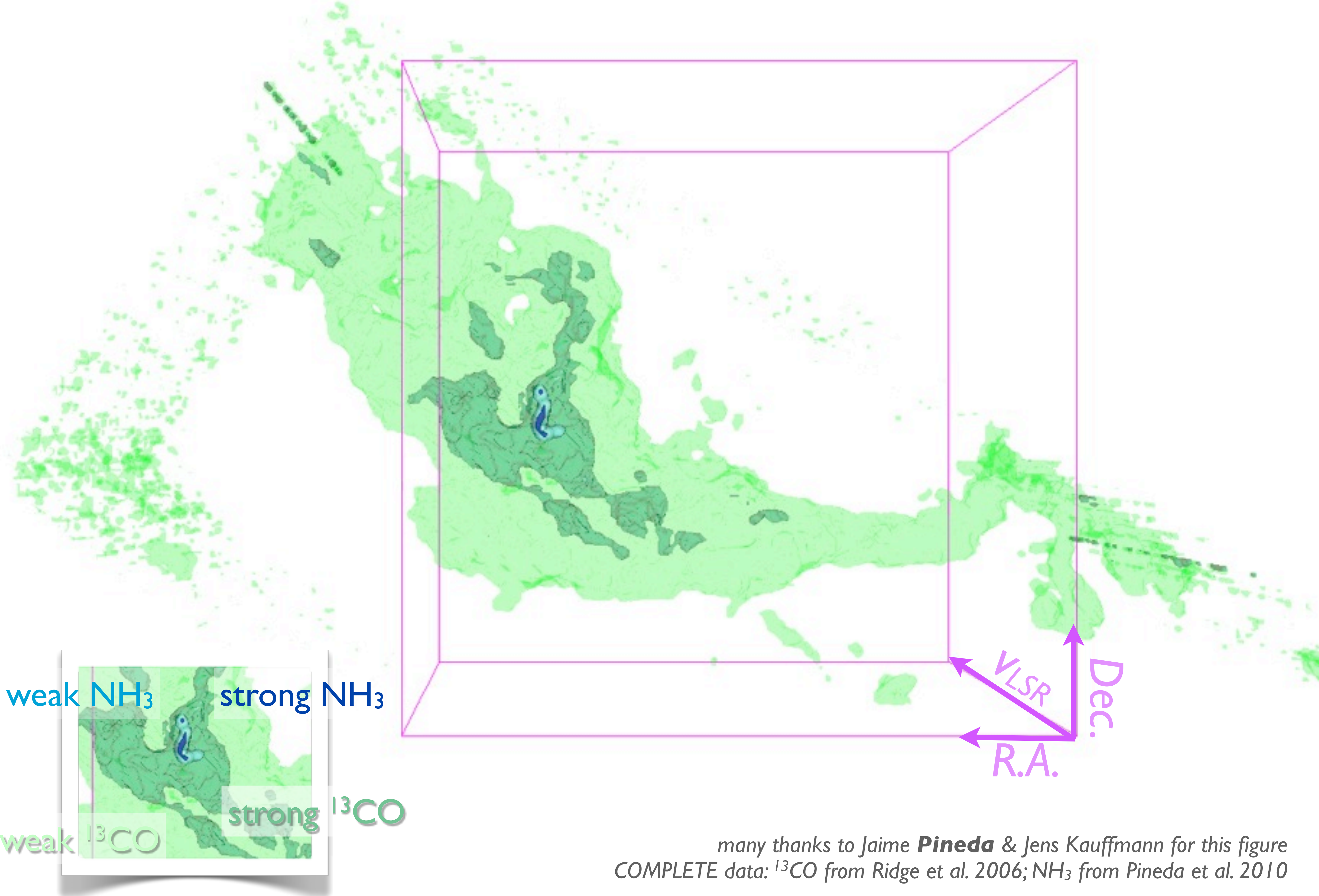
Three main views at present...





The "bijection" problem... this is p-p-p, but we have only p-p-v...

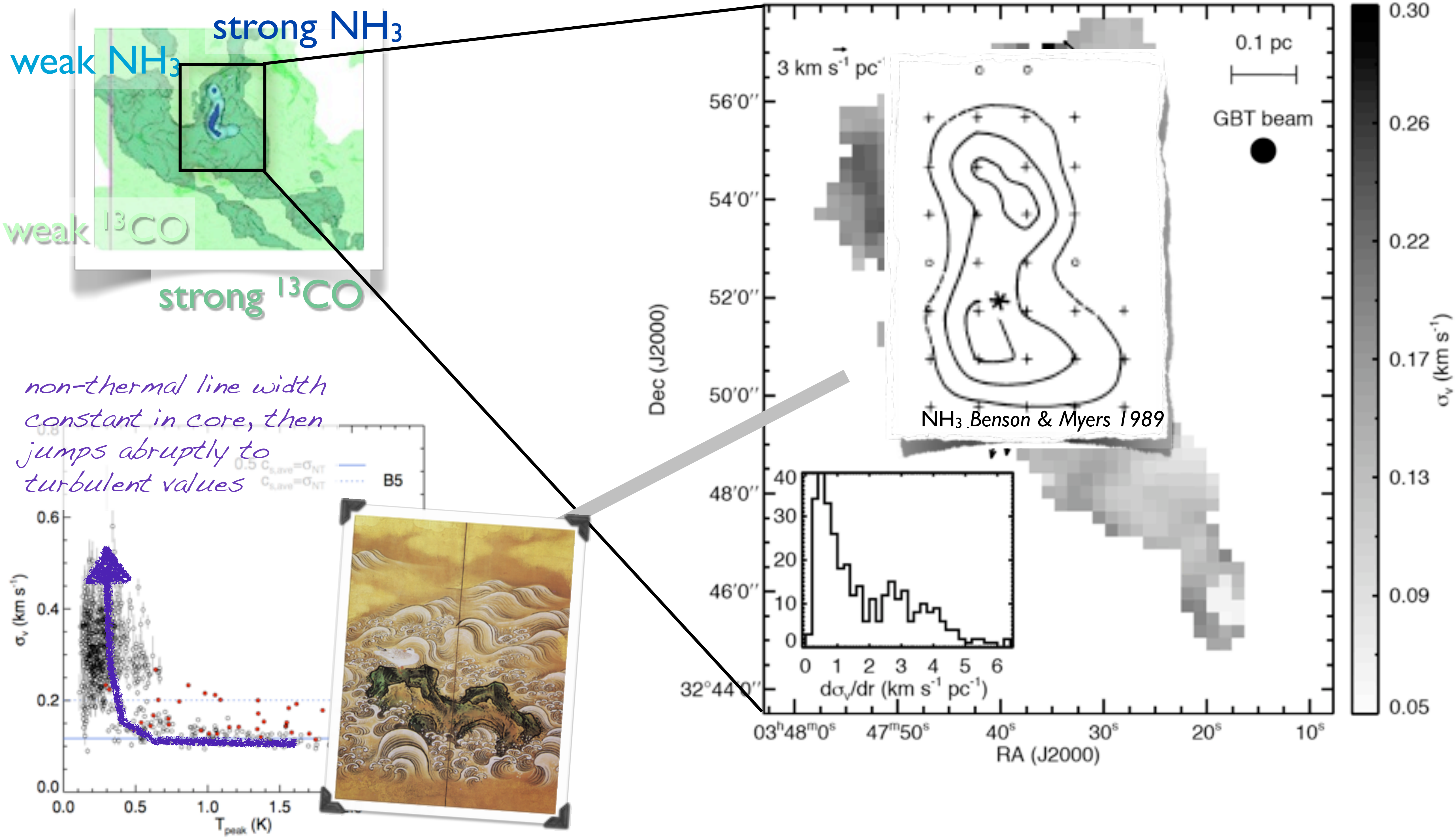
p-p-v structure of the B5 region in Perseus



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

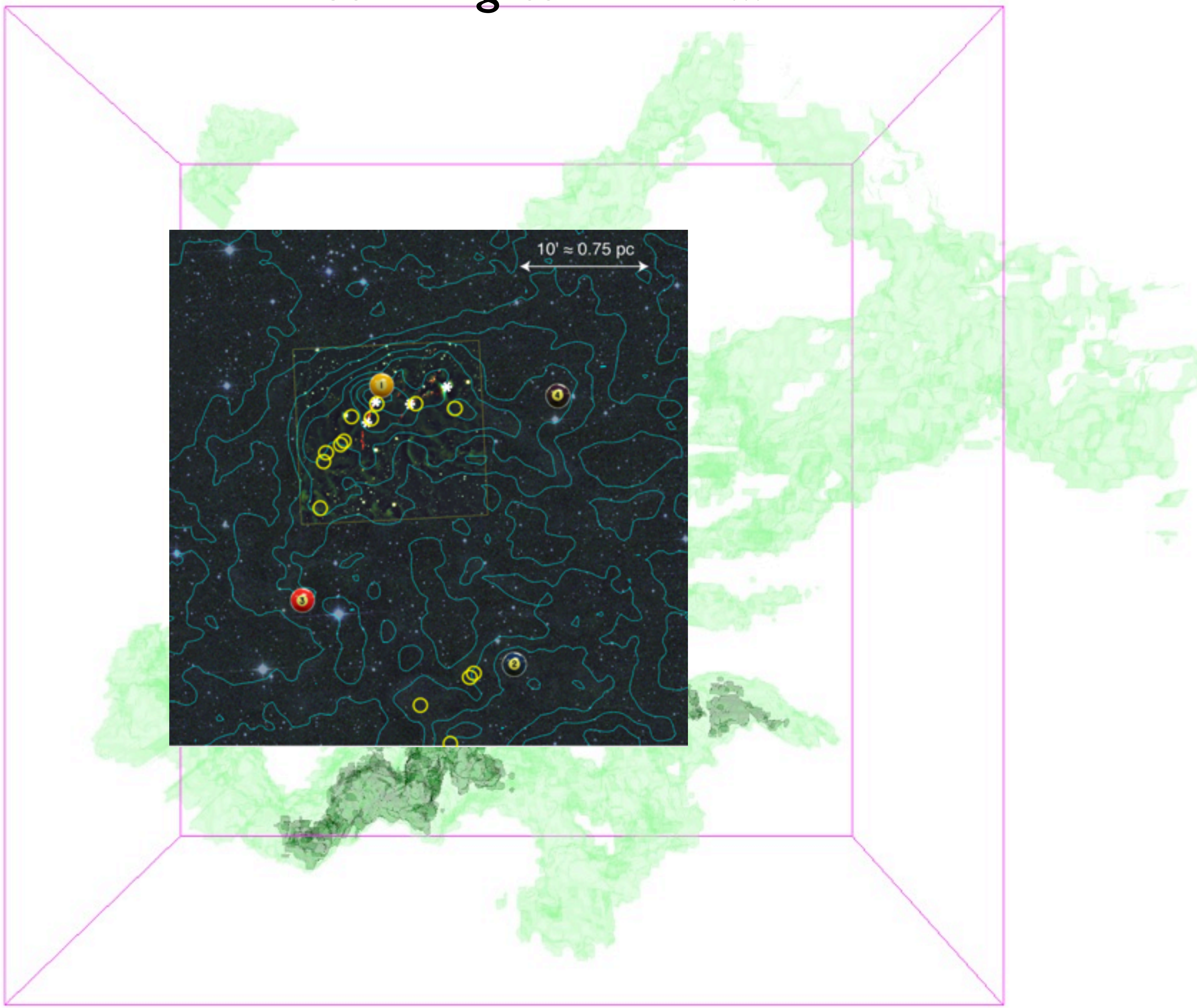
STRONG Evidence for Coherence in Dense Cores

greyscale shows NH_3 velocity dispersion,
arrows show gradient in dispersion

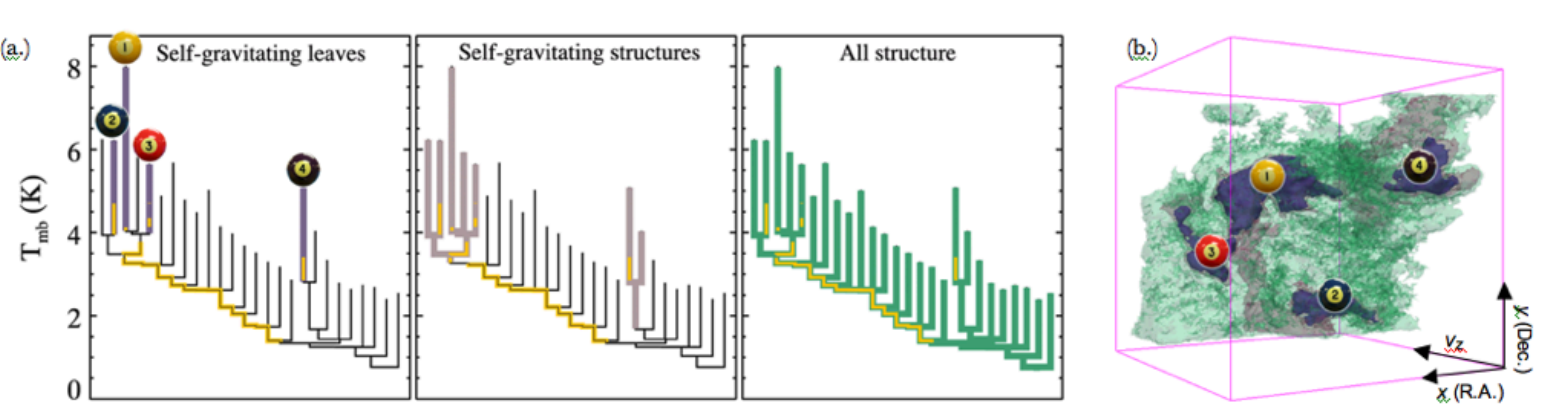


*GBT NH_3 observations of the B5 core, **Pineda** et al. 2010 ApJL;*
more cores show same behavior, Pineda et al. 2010 ApJ paper

Returning to L1448...



Dendrograms & "Self-Gravity"



Yellow highlighting= "self-gravitating"

"Self-gravitating" here just means α_{vir} $(=5\sigma_v{}^2R/GM_{lum}) < 2$
(à la Bertoldi & McKee 1992)

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

see PDF...


LETTERS

A role for self-gravity at multiple length scales in the process of star formation

✔ “bi-jection”

✔ “virial parameter”

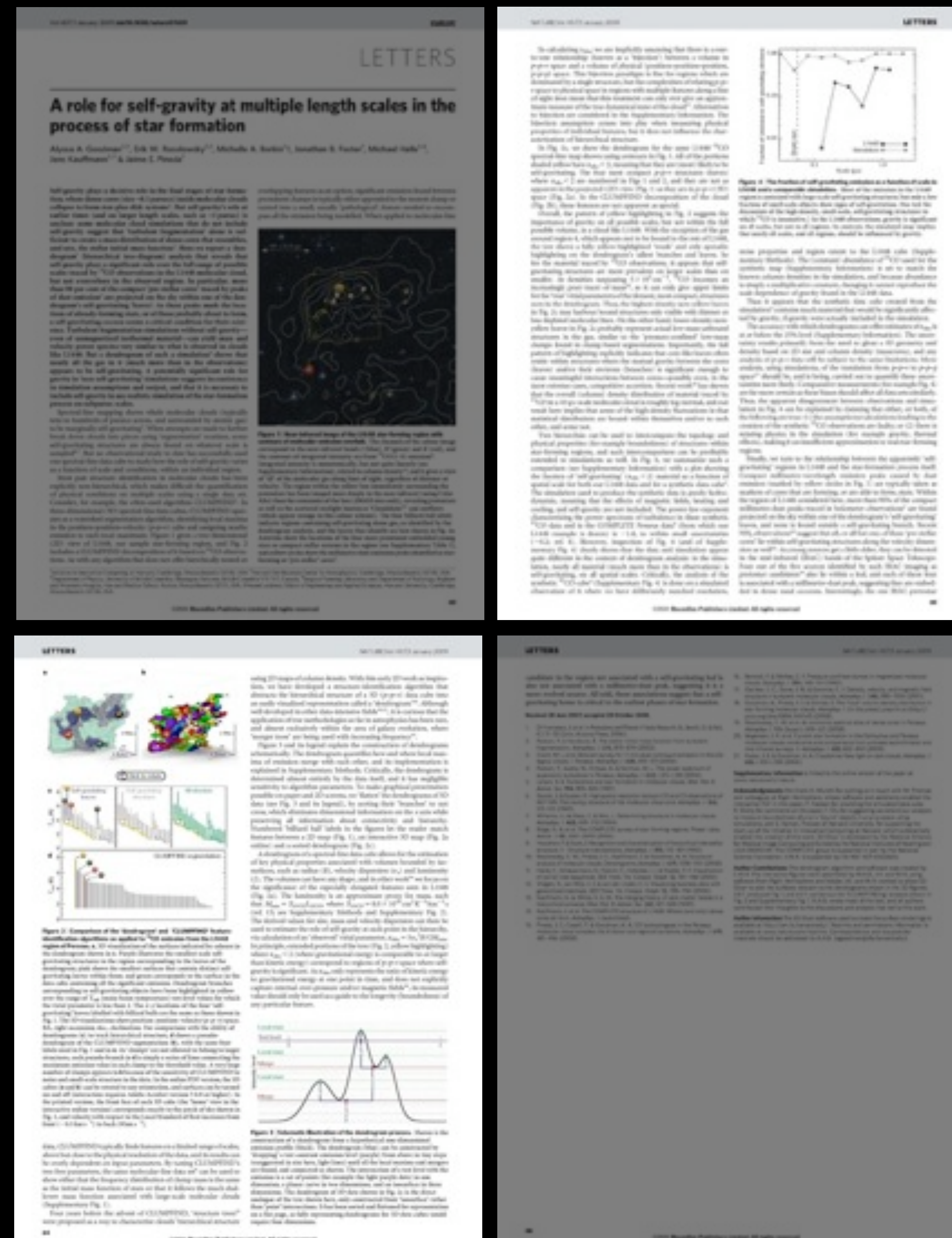
“turbulent power spectrum”

“synthetic observation”

“depletion, opacity”

“taste-test”

caveats


LETTERS

A role for self-gravity at multiple length scales in the process of star formation

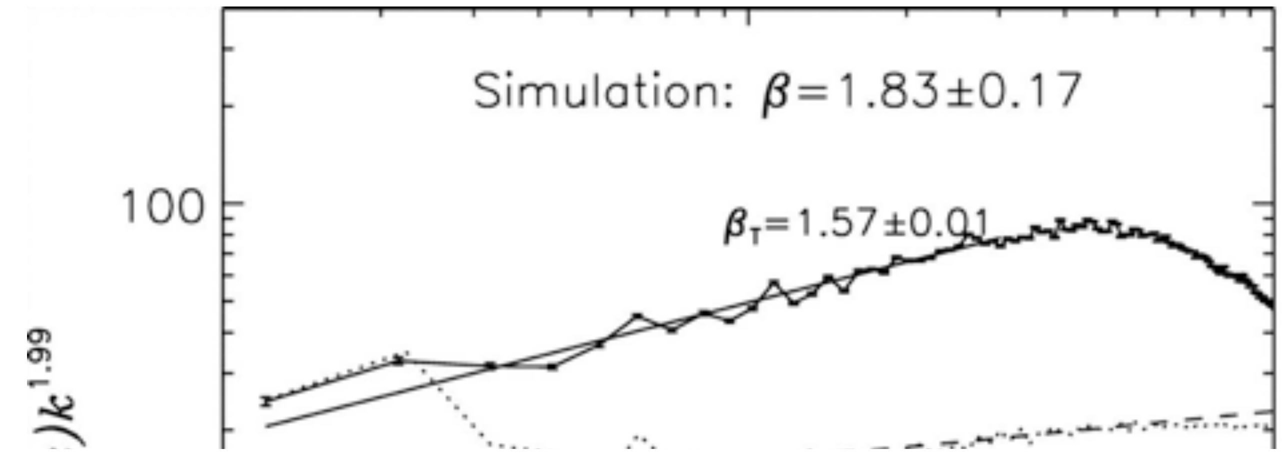
"*turbulent power spectrum*"

"*synthetic observation*"

"*depletion, opacity*"

"*taste-test*"

caveats



THE POWER SPECTRUM OF SUPERSONIC TURBULENCE IN PERSEUS

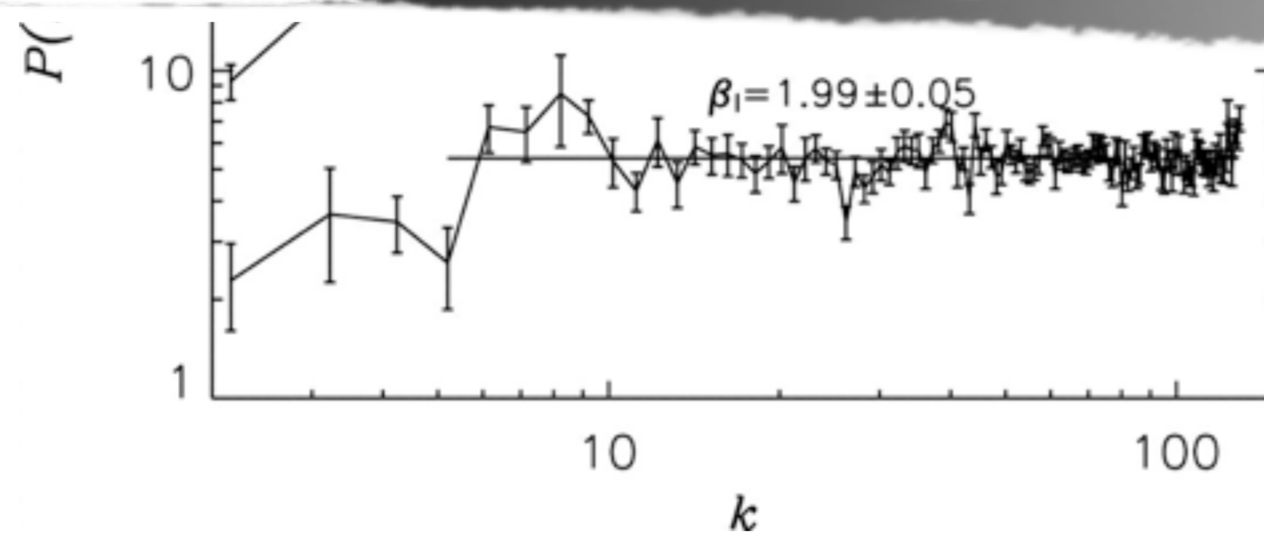
Paolo Padoan,[1] Mika Juvela,[2] Alexei Kritsuk,[1] and Michael L. Norman[1]

Received 2006 August 29; accepted 2006 November 6; published 2006 November 30

ABSTRACT

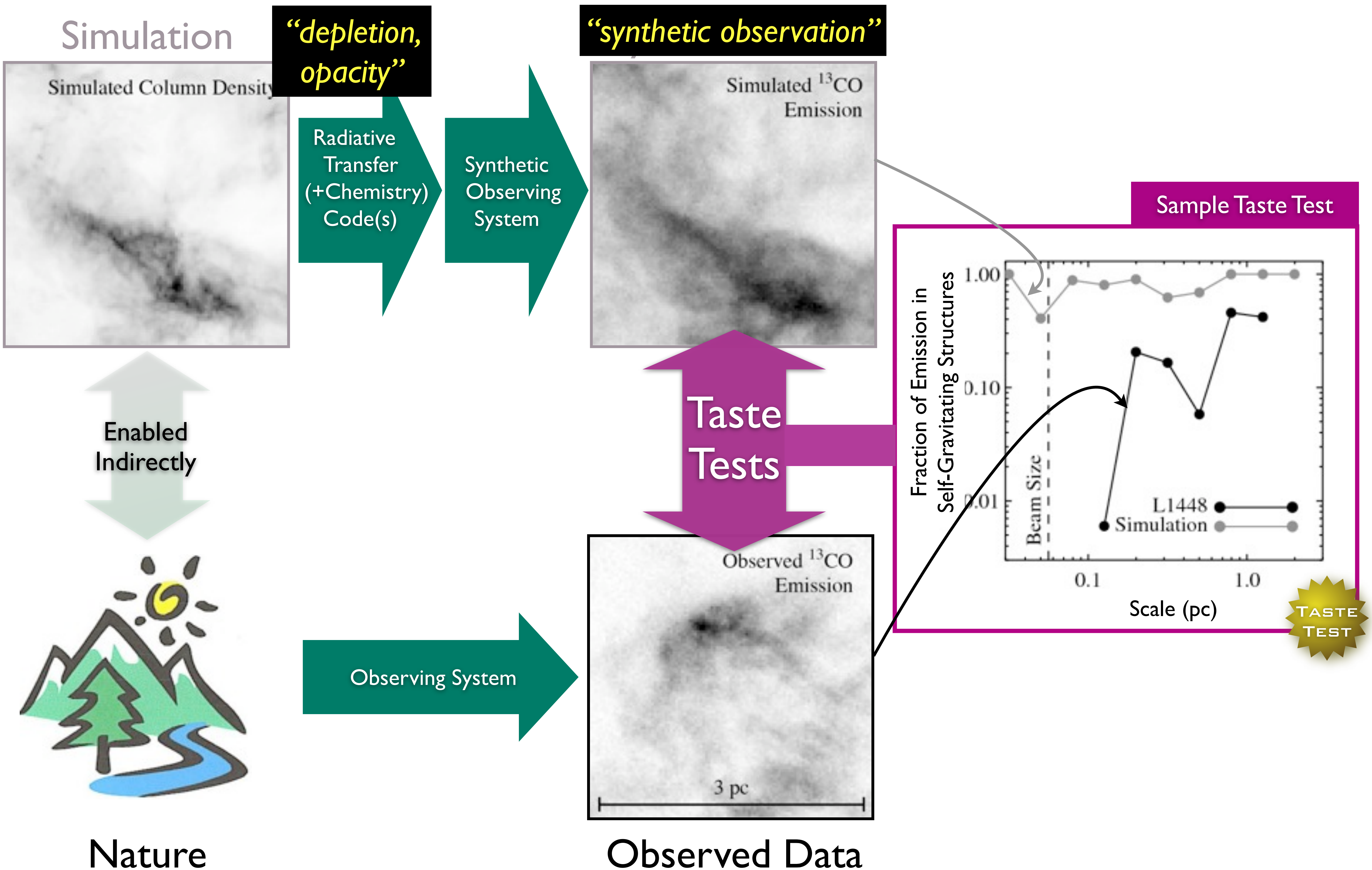
We test a method of estimating the power spectrum of turbulence in molecular clouds based on the comparison of power spectra of integrated intensity maps and single–velocity-channel maps, suggested by A. Lazarian and D. Pogosyan. We use synthetic ^{13}CO data from non-LTE radiative transfer calculations based on density and velocity fields of a simulation of supersonic hydrodynamic turbulence. We find that the method yields the correct power spectrum with good accuracy. We then apply the method to the Five College Radio Astronomy Observatory ^{13}CO map of the Perseus region, from the COMPLETE Web site. We find a power-law power spectrum with slope $\beta = 1.81 \pm 0.10$. The values of β as a function of velocity resolution are also confirmed using the lower resolution map of the same region obtained with the AT&T Bell Laboratories antenna. Because of its small uncertainty, this result provides a useful constraint for numerical codes used to simulate molecular cloud turbulence.

Subject headings: ISM: clouds — ISM: kinematics and dynamics — ISM: structure

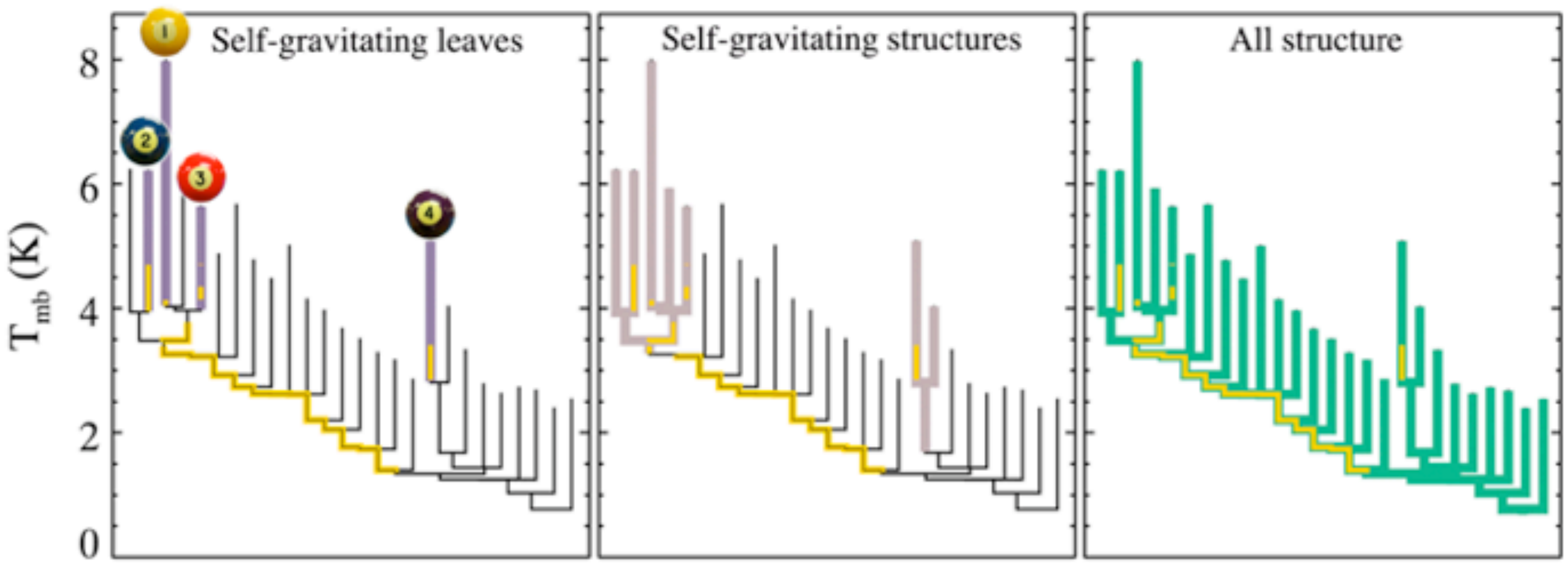


Note: This simulation does NOT include gravity, magnetic fields, radiative effects, or explicit heating & cooling–it is pure hydrodynamics.

The Taste-Testing Process

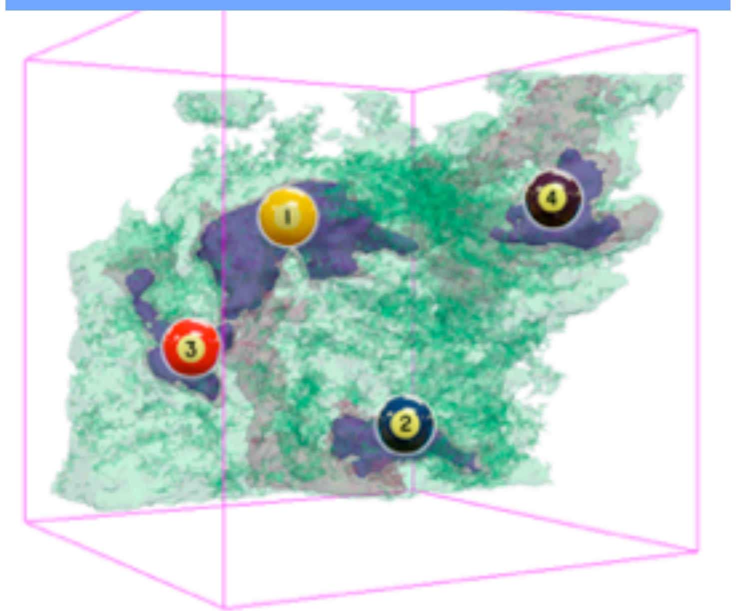


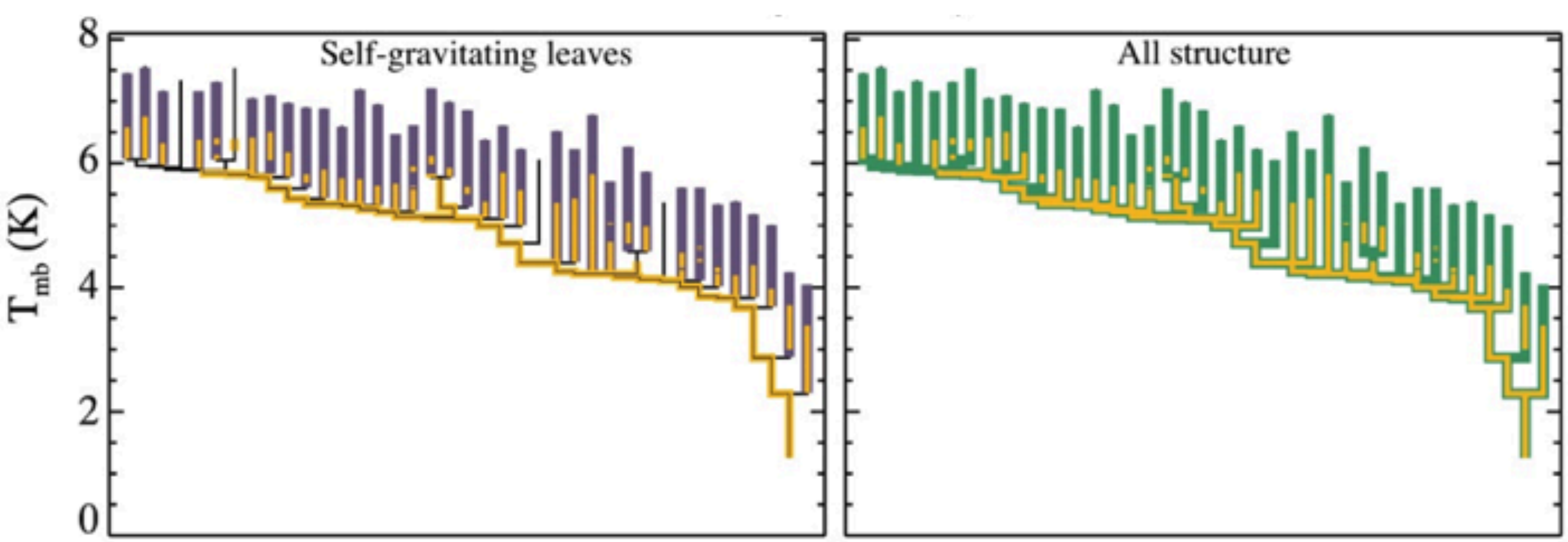
Real vs. Simulated ^{13}CO



(Yellow = self-gravitating components)

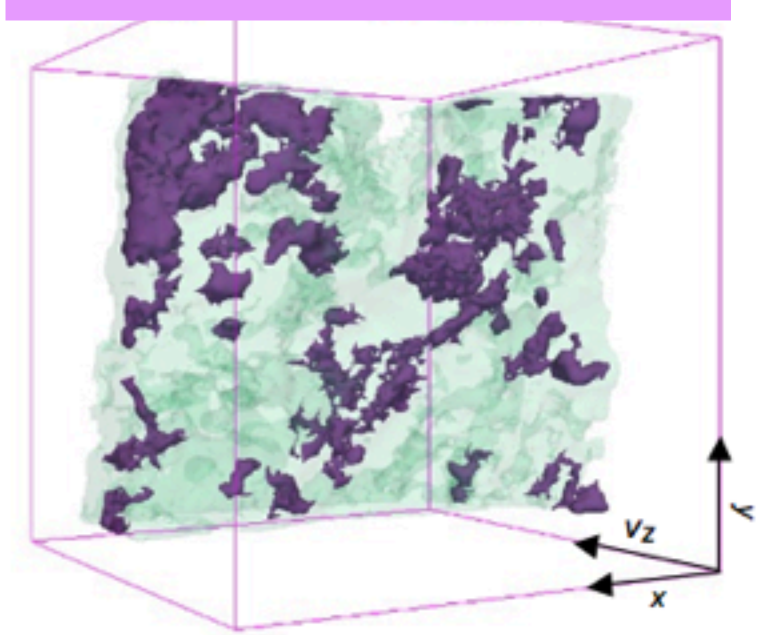
Real



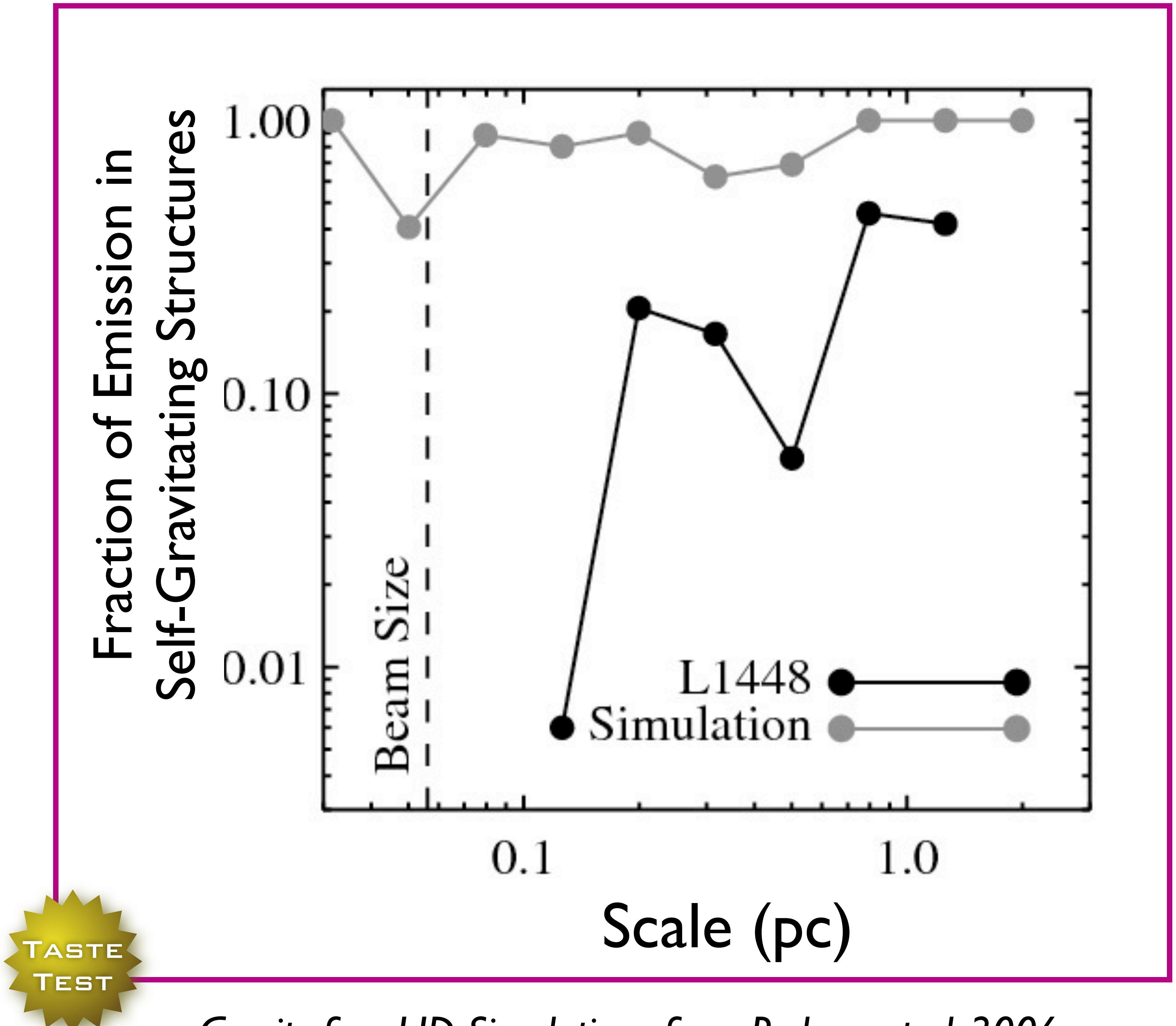


(Yellow = self-gravitating components)

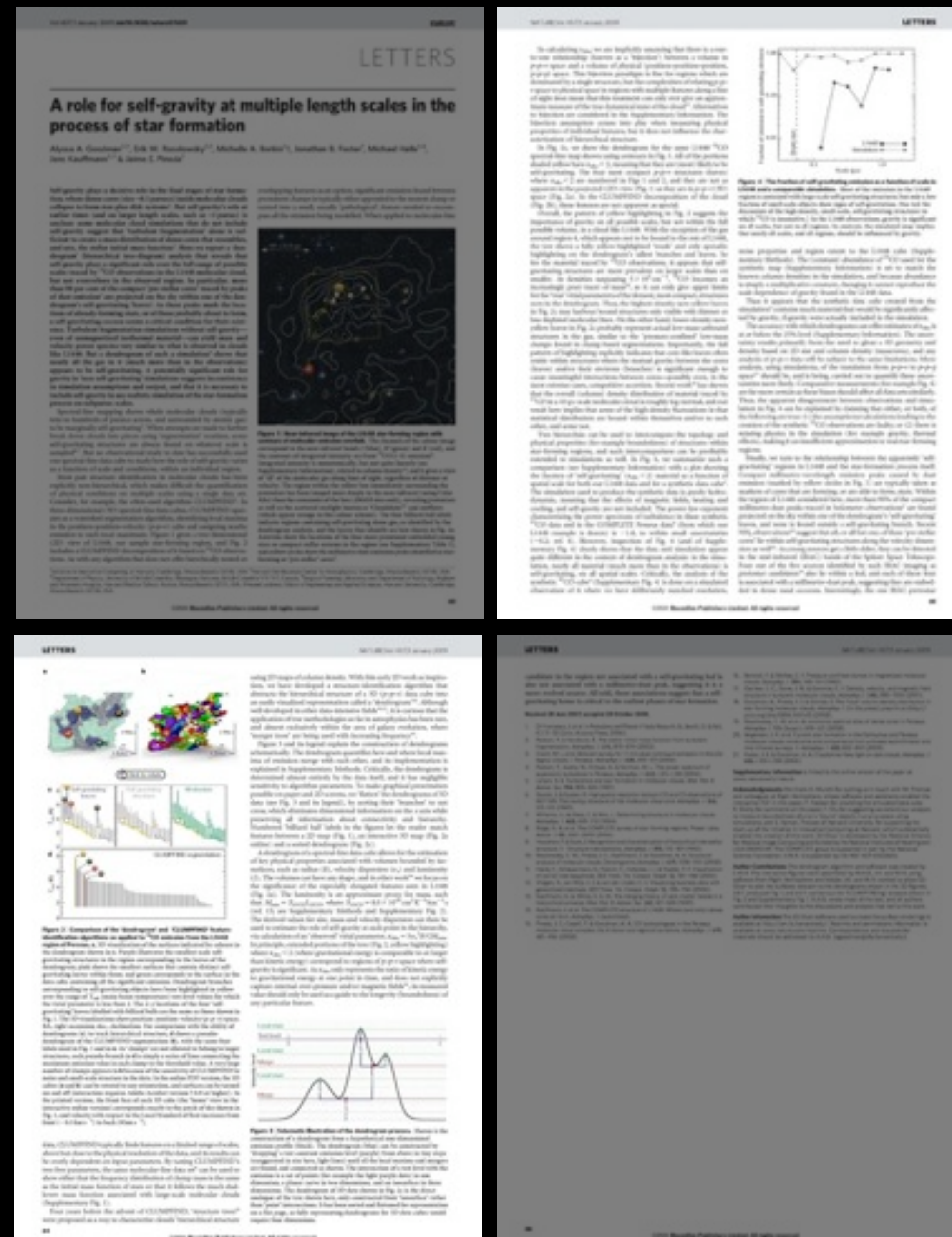
Simulated



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"


LETTERS

A role for self-gravity at multiple length scales in the process of star formation

"turbulent power spectrum" ✔

✔"synthetic observation"

✔"depletion, opacity"

✔"taste-test"

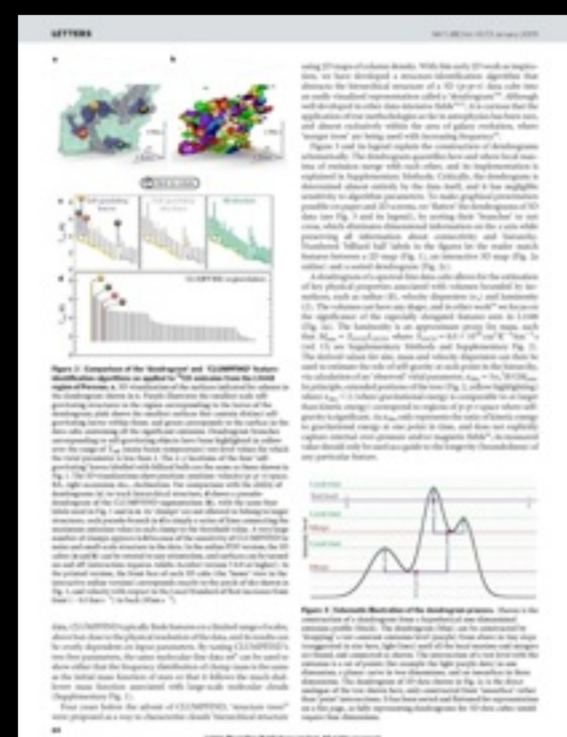
caveats


LETTERS

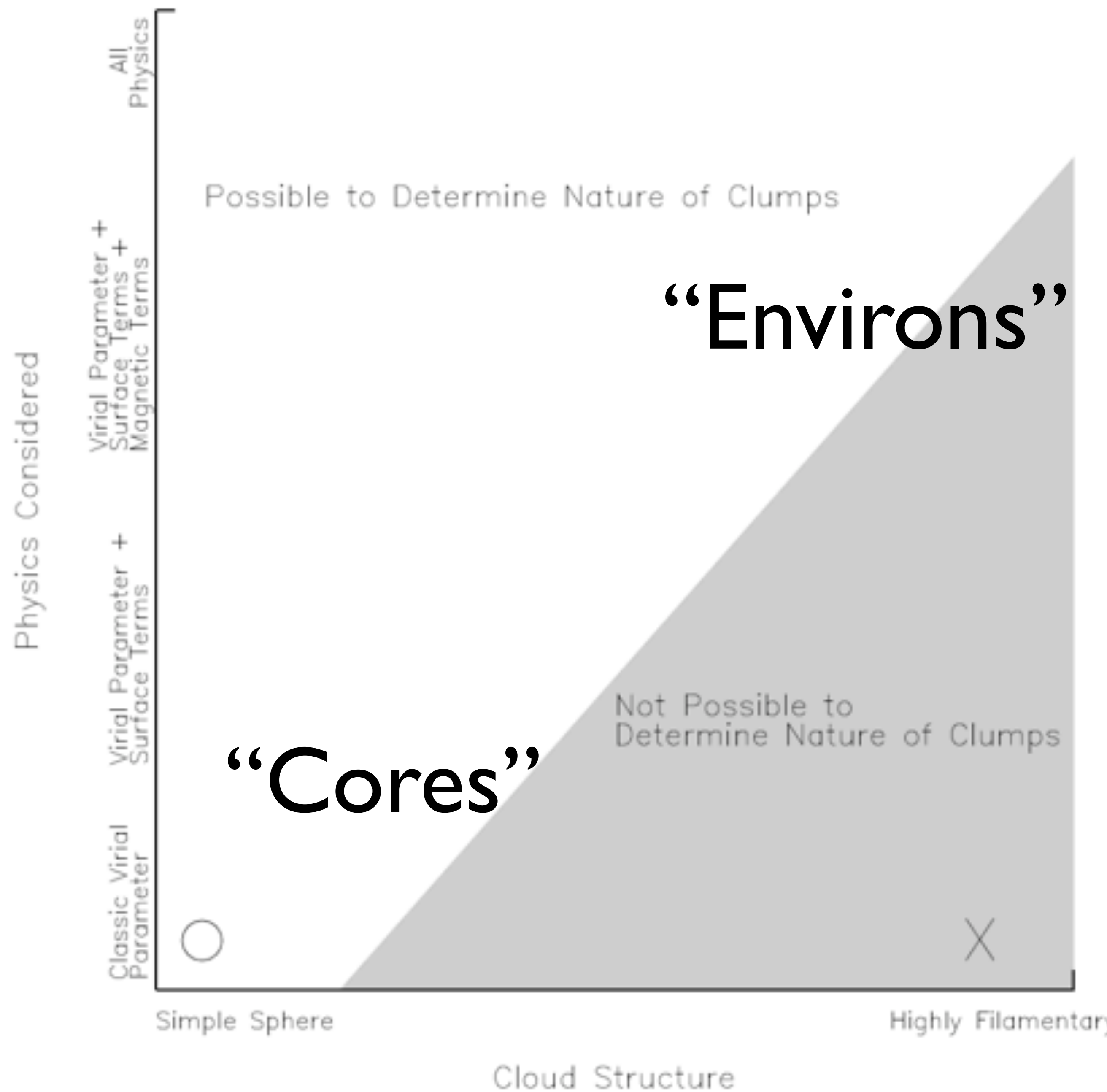
A role for self-gravity at multiple length scales in the process of star formation

conclusions & caveats

Star formation takes place in self-graviatating "coccoons," and some of those coccoons are bound to each other.



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

What (else) keeps me up at night now...

"Bi-jection" or "*p-p-p* to/from *p-p-v*"& the impact of missing terms in virial analysis in each space
[Shetty, Collins, et al.]

Projection effects in analyzing spatial & velocity offsets
*[**Kirk**, **Pineda**, **Offner**, et al.]*

When/how can we best measure YSO velocities & what *should* they be?
[Covey, Offner, et al.]

How much exess column is there beyond "log-normal"?
[Foster, Offner, et al.]

Effects of Cloudshine on Deep NIR Point Source Photometry (e.g. **JWST**) *[Foster!]*

Can we differentiate simulations with known & simple new "taste tests"
[**Rosolowsky**, Shetty, et al.]
...for example, how do cores connect to their environment?
*[**Kauffmann**, Myers, Pineda, Alves, Foster, Rosolowsky, Offner, et al.]?*

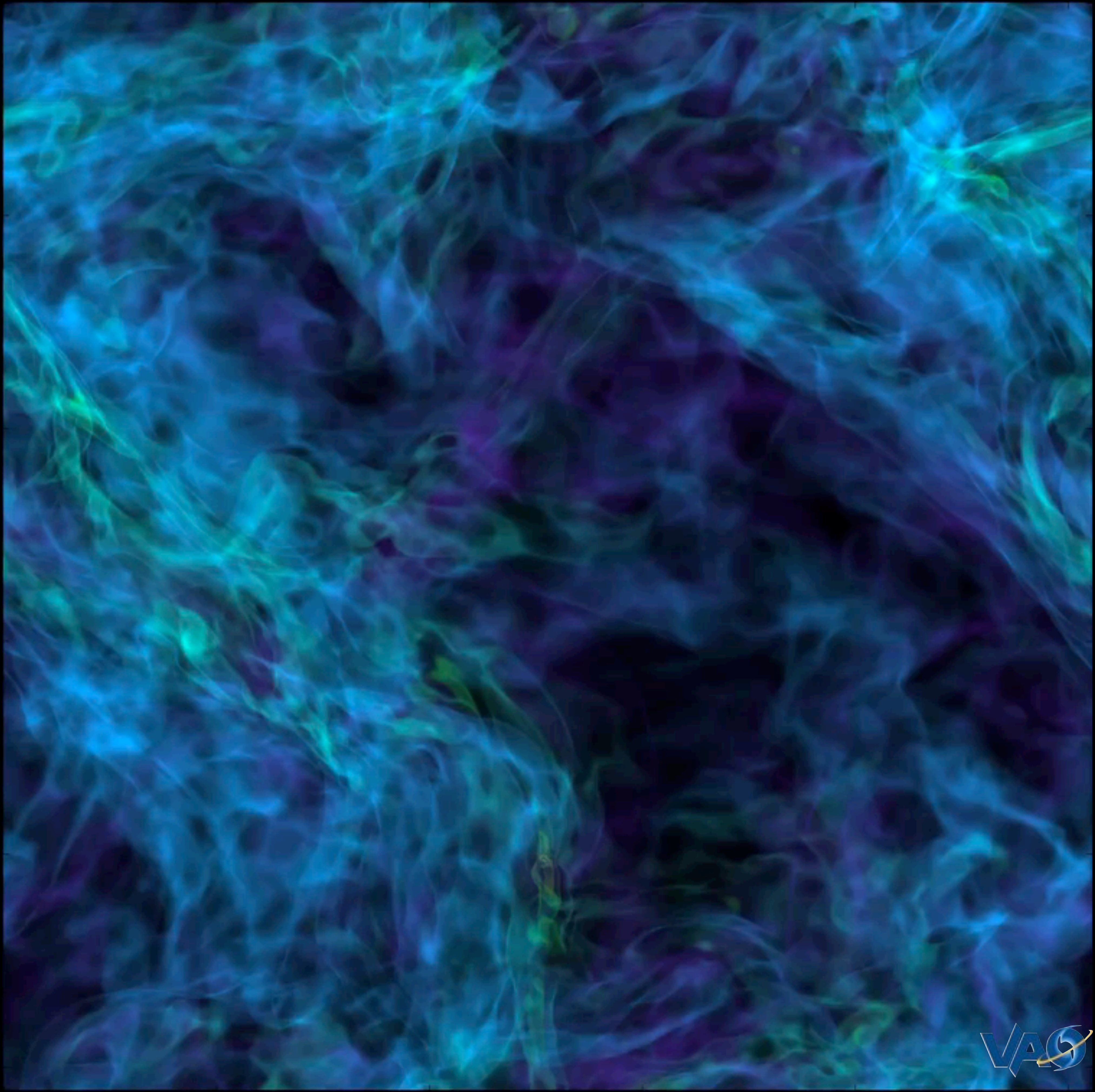
Can we do better than Kennicutt-Schmidt, really?
[Cox, Narayanan, Shetty, Rosolowsky et al.]

Effects of B-Star Winds on Cloud Evolution
*[Covey, Sharma, **Valverde**, Borkin, **Arce** et al.]*

Do dendrograms give a different CMF?
[Alves, Rosolowsky, Pineda et al.]

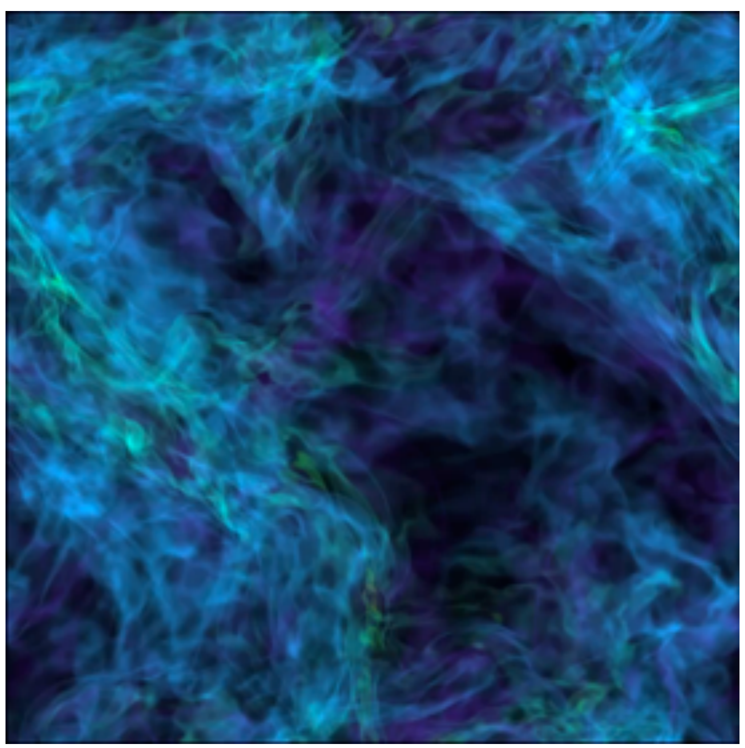
And, what about magnetic fields?!
[Li et al. 2009...]

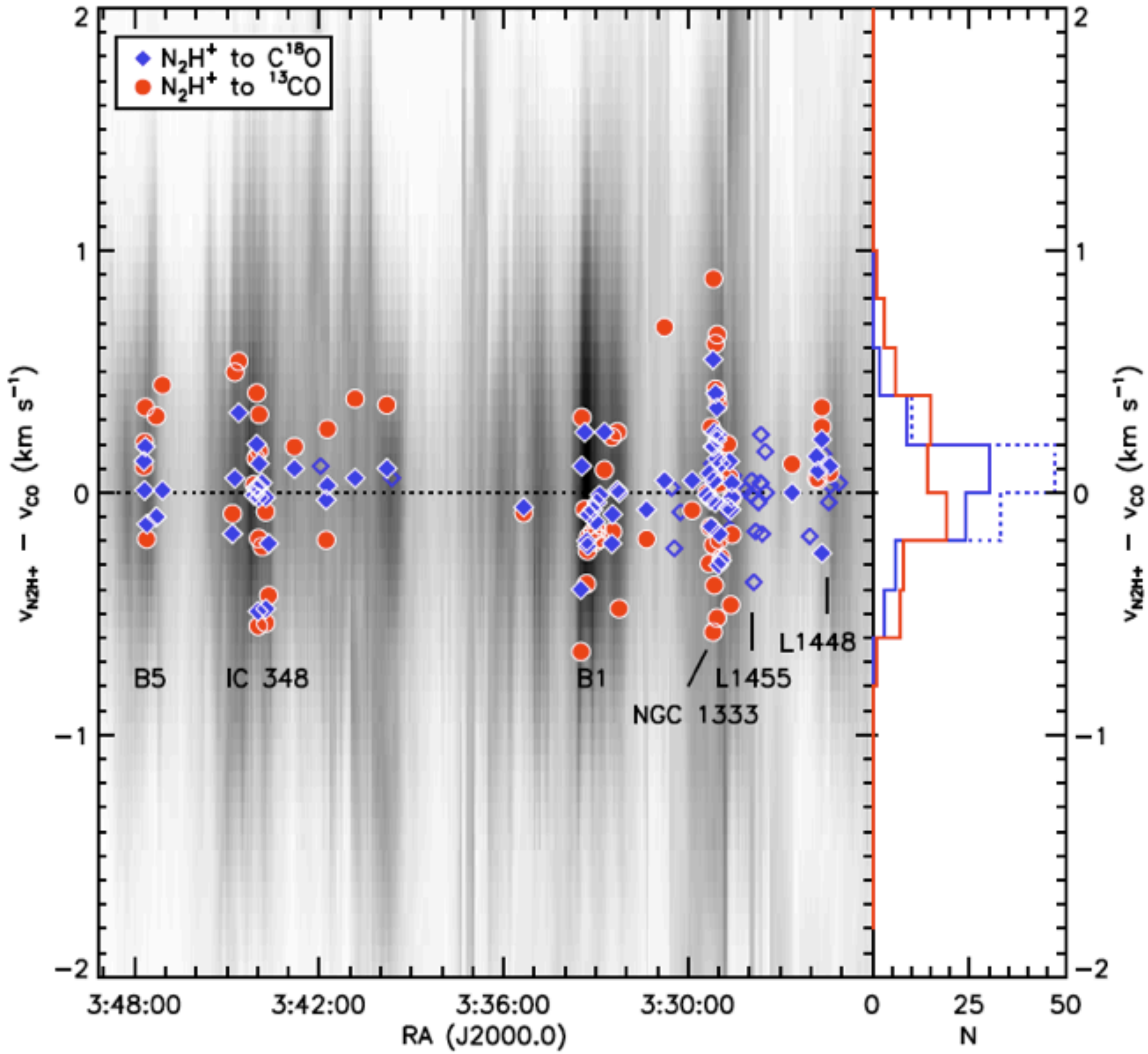
...and WWT, IIC, 3D Data Desk, WGBH, VAO...and my family.



*Molecular cloud gas densities from an AMR simulation with radiation feedback (**Offner** et al. 2009)." The movie is 0.65pc on a side and covers about 0.15 Myr.*

Why so still?





Kirk, Pineda, Johnstone & Goodman 2010 *"turbulent fragmentation"* *"L1448"* *"(magneto-)hydrodynamic simulation"*

"Cloudshine"

"pre-stellar core"

"protostar"

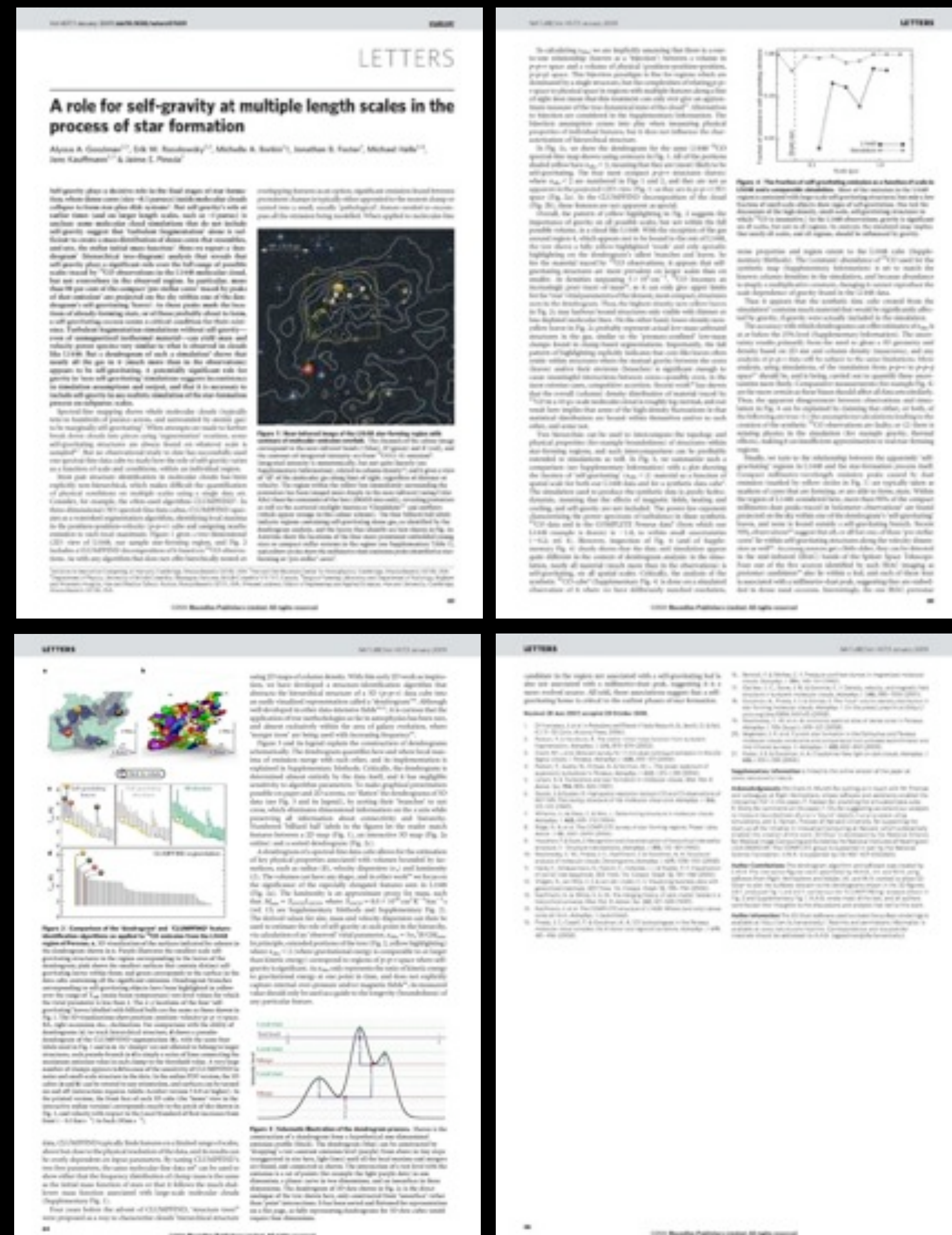
"integrated intensity"

"p-p-v cube"

"segmentation"

"CLUMPFIND"

"Dendrogram"



"COMPLETE" *"3D PDF"*

"bi-jection"

"virial parameter"

"column density"

"turbulent power spectrum"

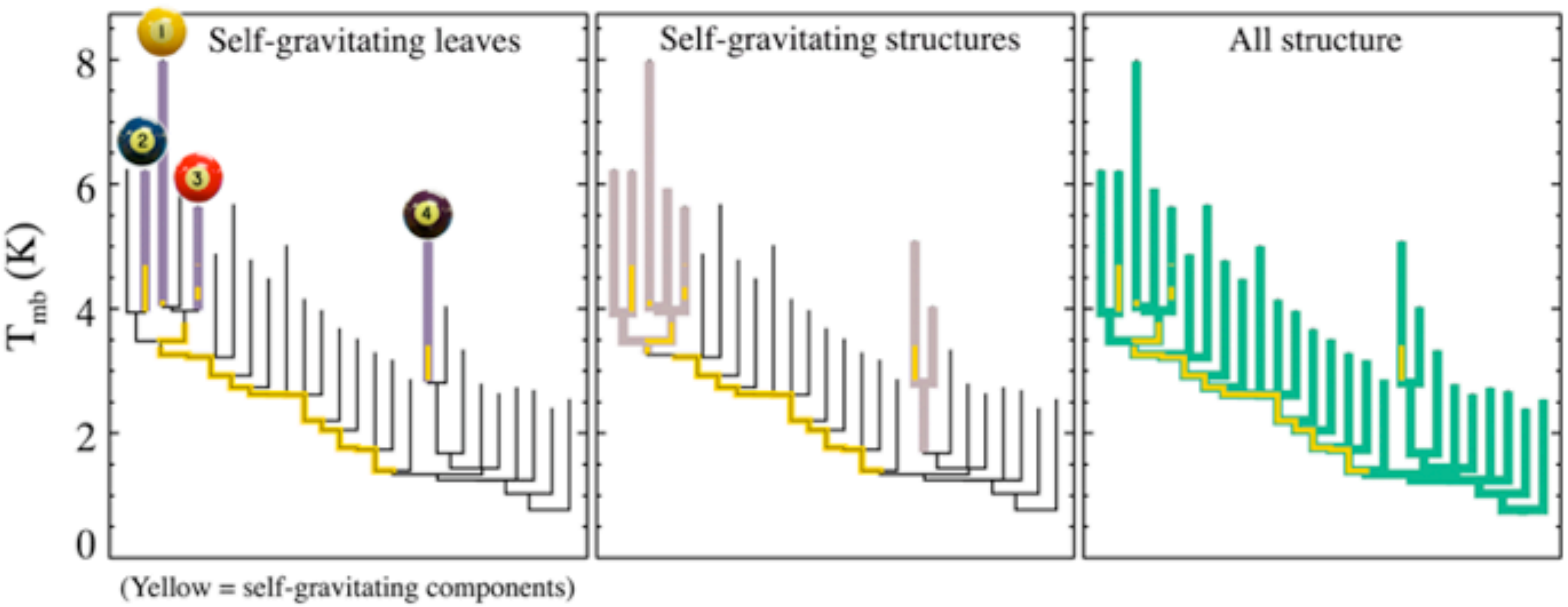
"synthetic observation"

"depletion, opacity"

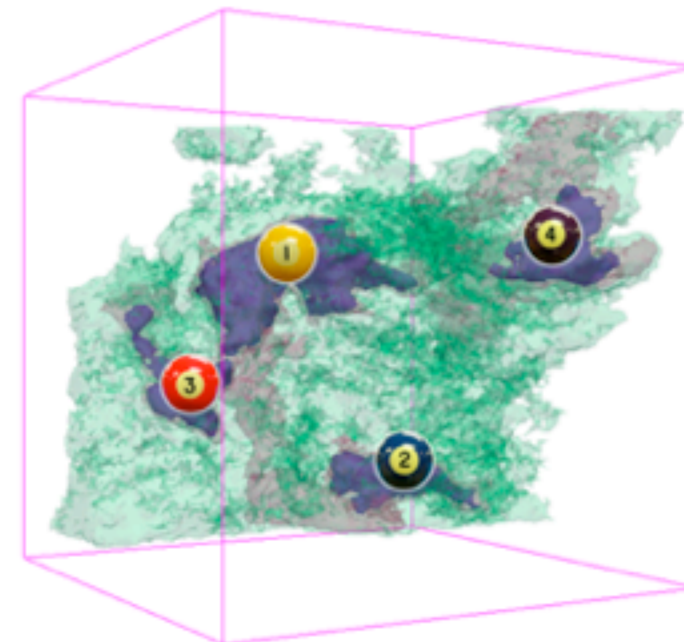
"taste-test"

caveats

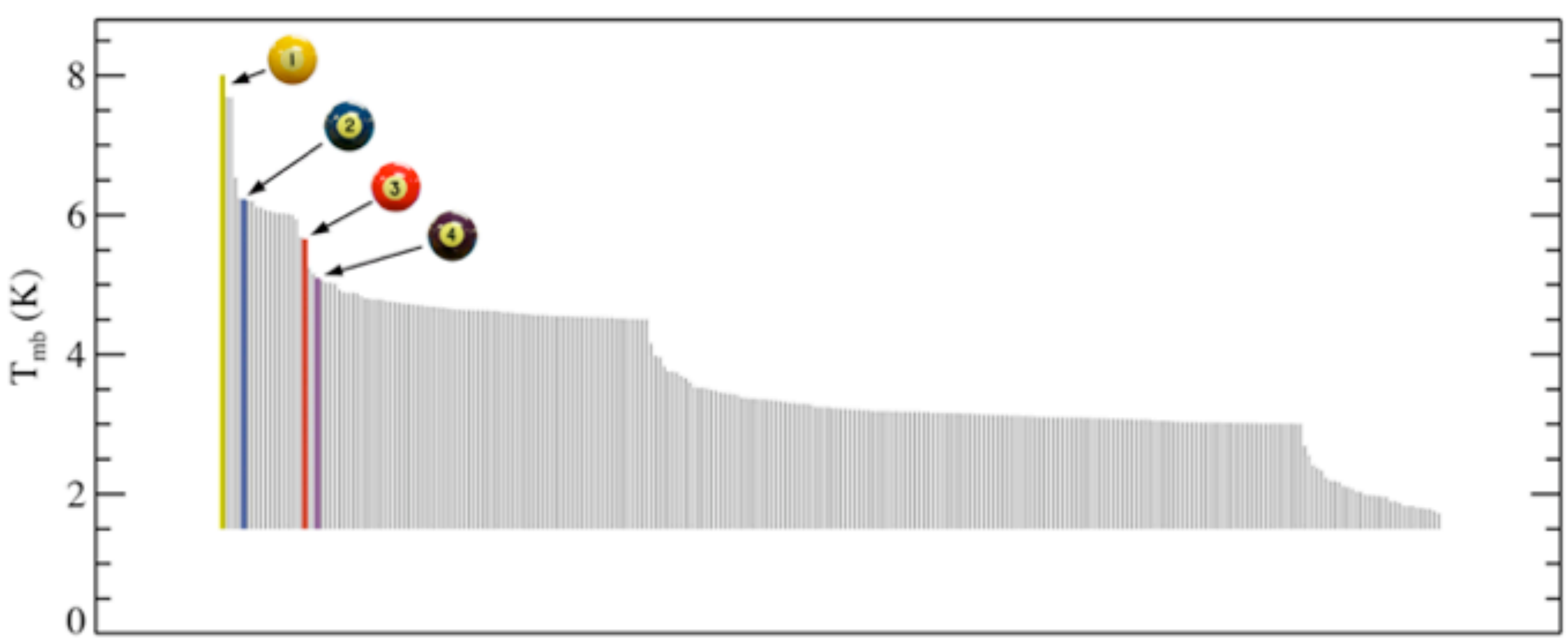
CLUMPFIND vs. Dendrograms: L1448



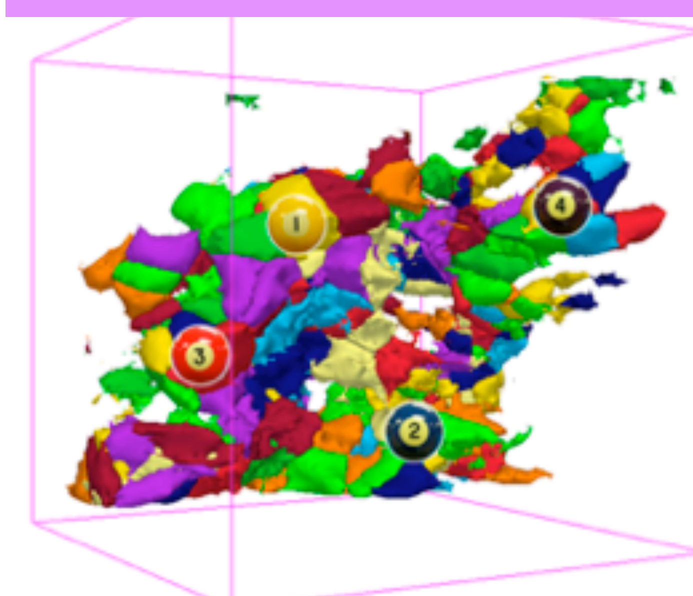
Dendrograms



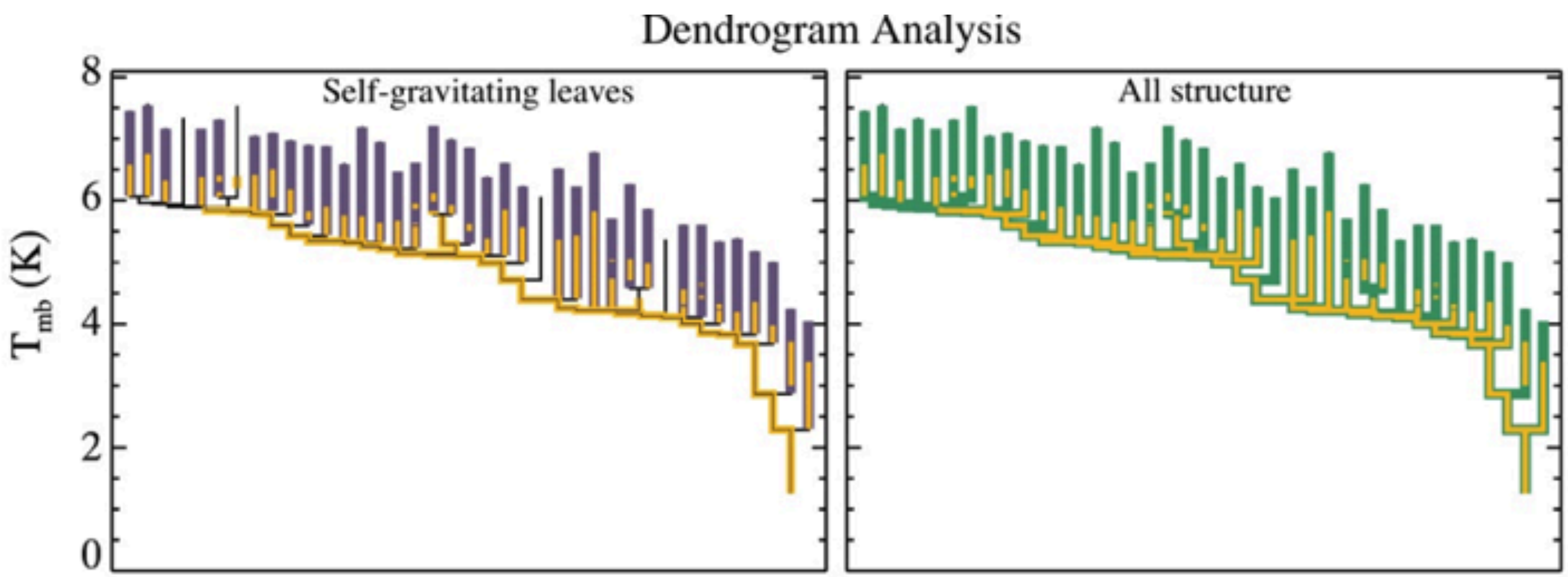
The online PDFs of these insets



"CLUMPFIND"

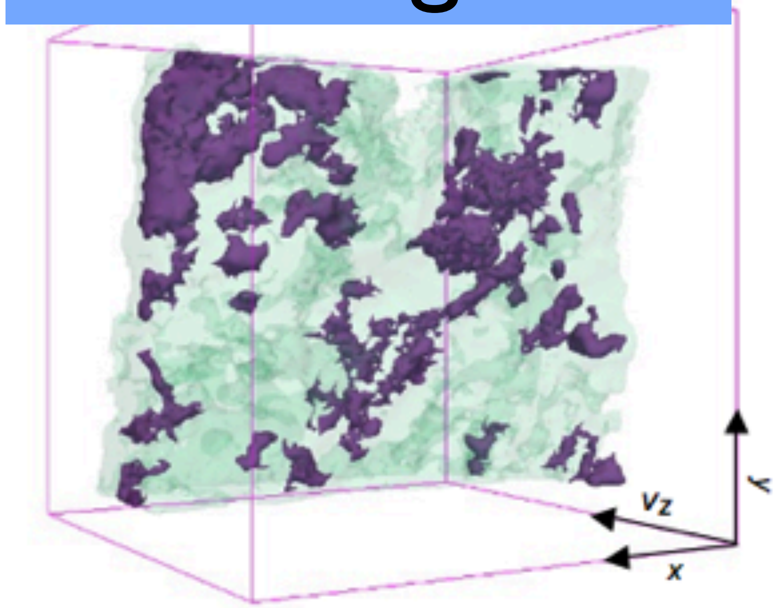


CLUMPFIND vs. Dendrograms: Synthetic Data

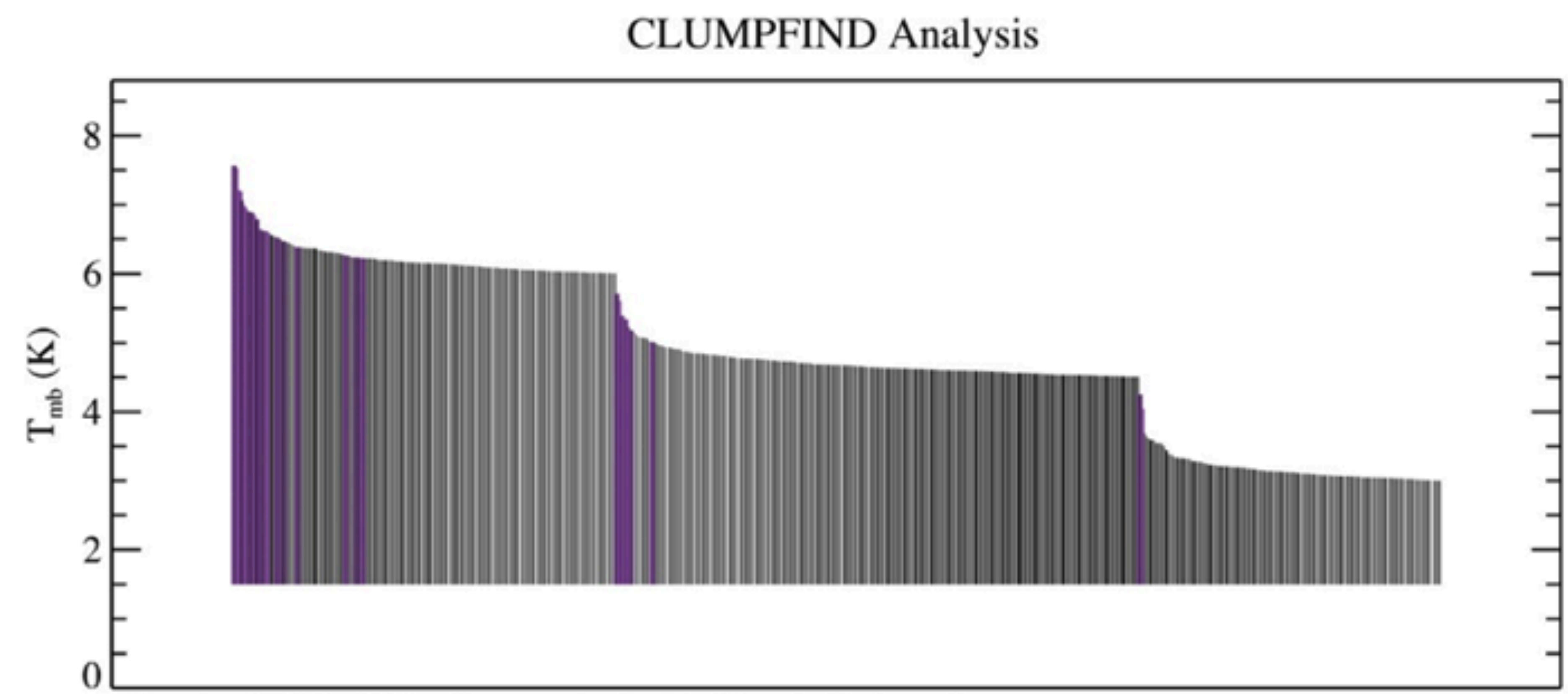


(Yellow = self-gravitating components)

Dendrograms

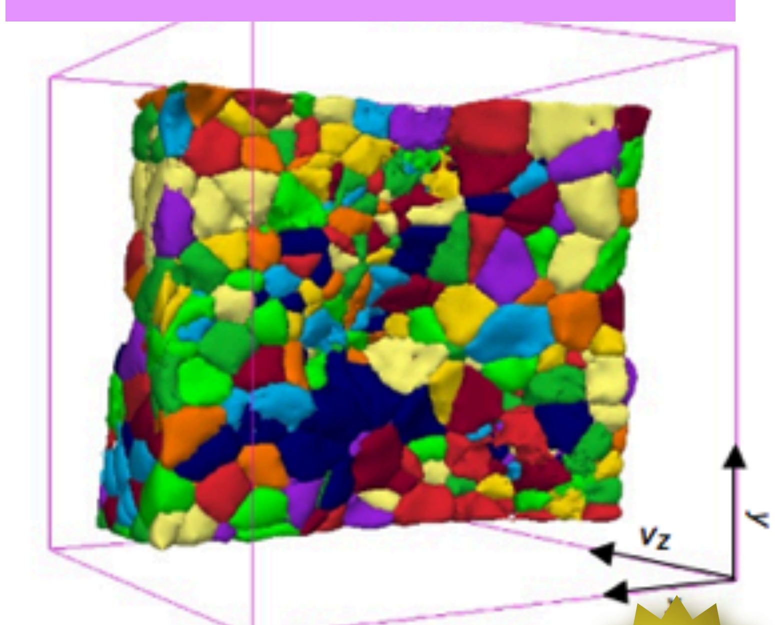


The online PDFs of these insets are interactive, offer additional surfaces, and can be rotated and manipulated by



(Purple = CLUMPFIND regions associated with self-gravitating leaves)

"CLUMPFIND"



TASTE TEST

HOMEWRECKERS

Stars disturbing their ancestral homes

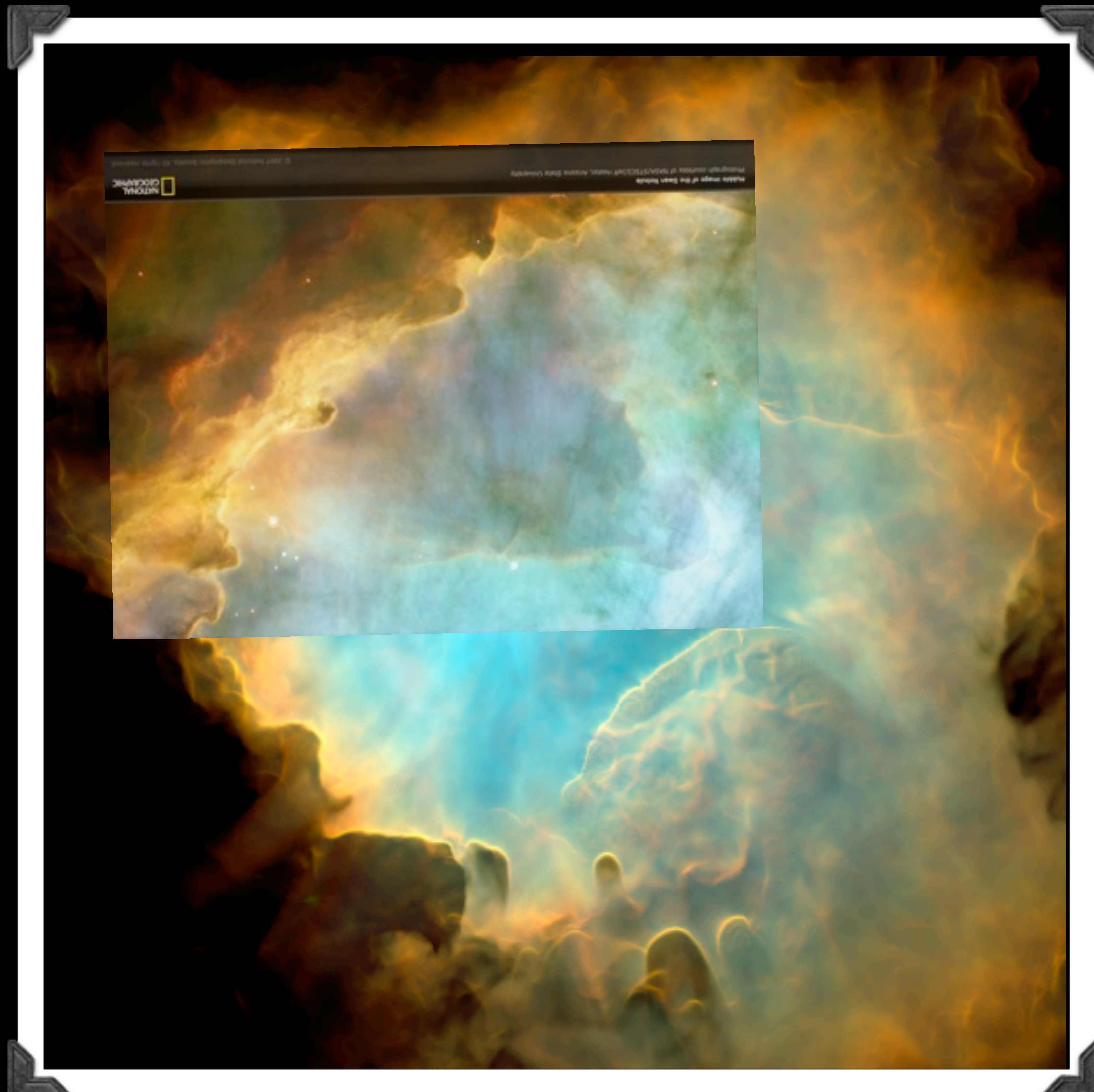
Alyssa Goodman *(Harvard-Smithsonian Center for Astrophysics)*
Héctor Arce *(Yale University)*
Lawrence Valverde *(Harvard College)*

M17

Hubble image of the Swan Nebula
Photograph courtesy of NASA/STSCI/Jeff Hester, Arizona State University

NATIONAL GEOGRAPHIC

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