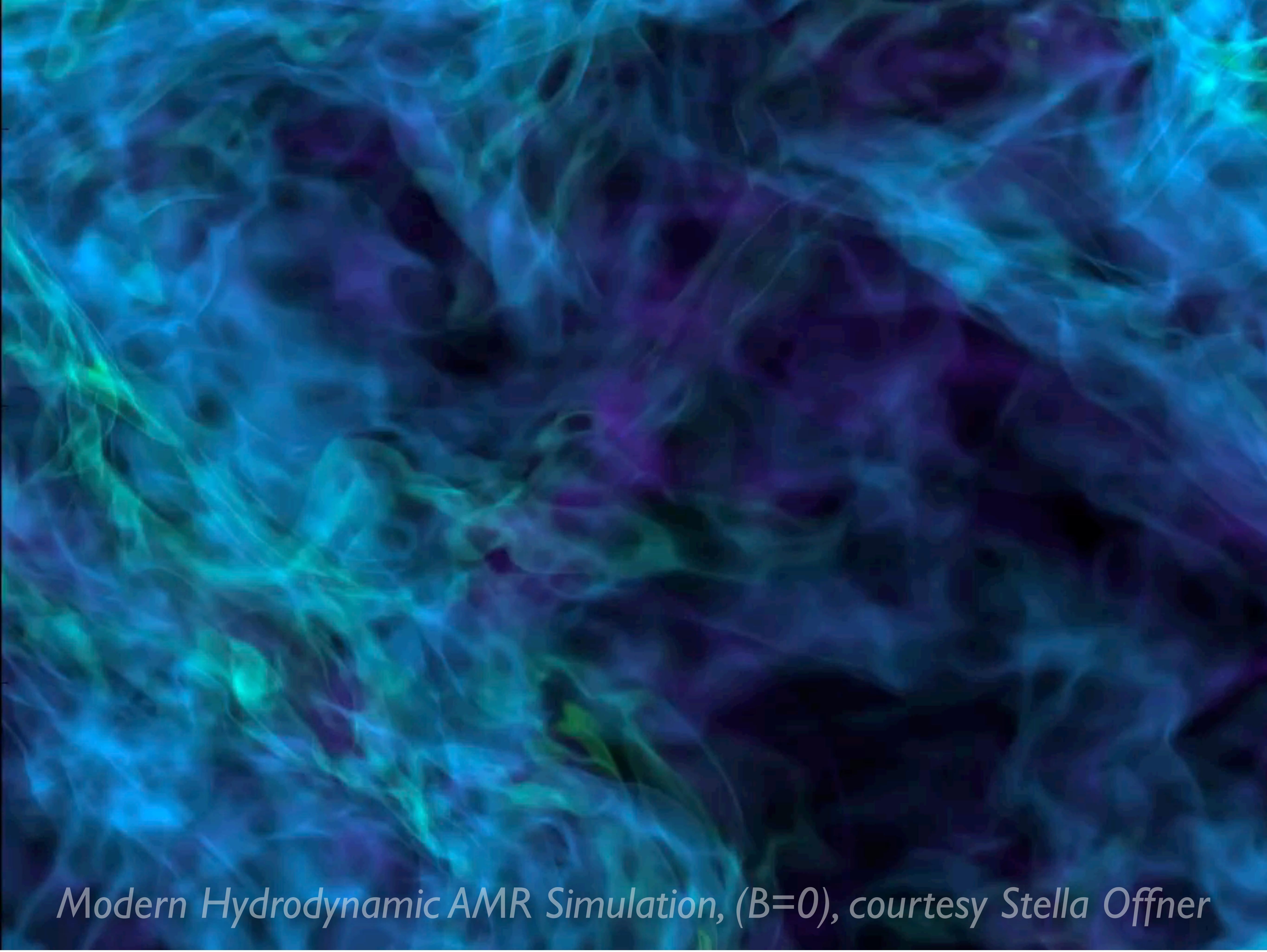

Modern Hydrodynamic AMR Simulation, (B=0), courtesy Stella Offner

Introduction to Star Formation

Alyssa Goodman

Harvard ITC Pizza Lunch, February 1, 2012

Disclaimer: This is a personal reflection, not a review: references are only examples & NOT meant as exemplary or exhaustive.

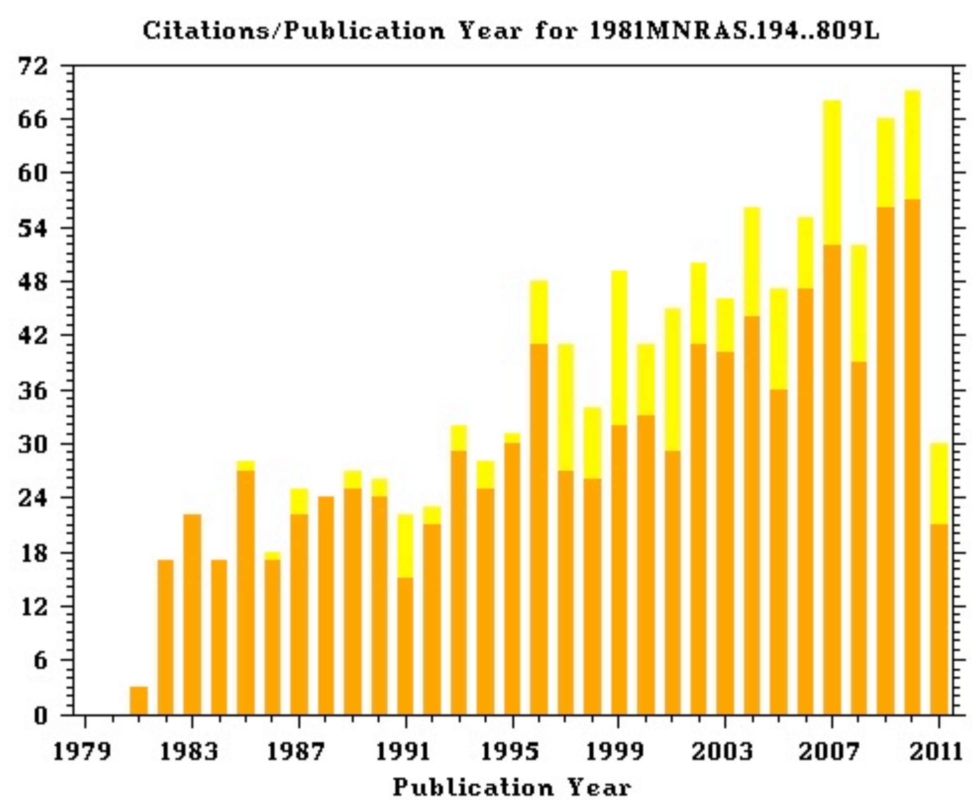
Holistic
Star Formation

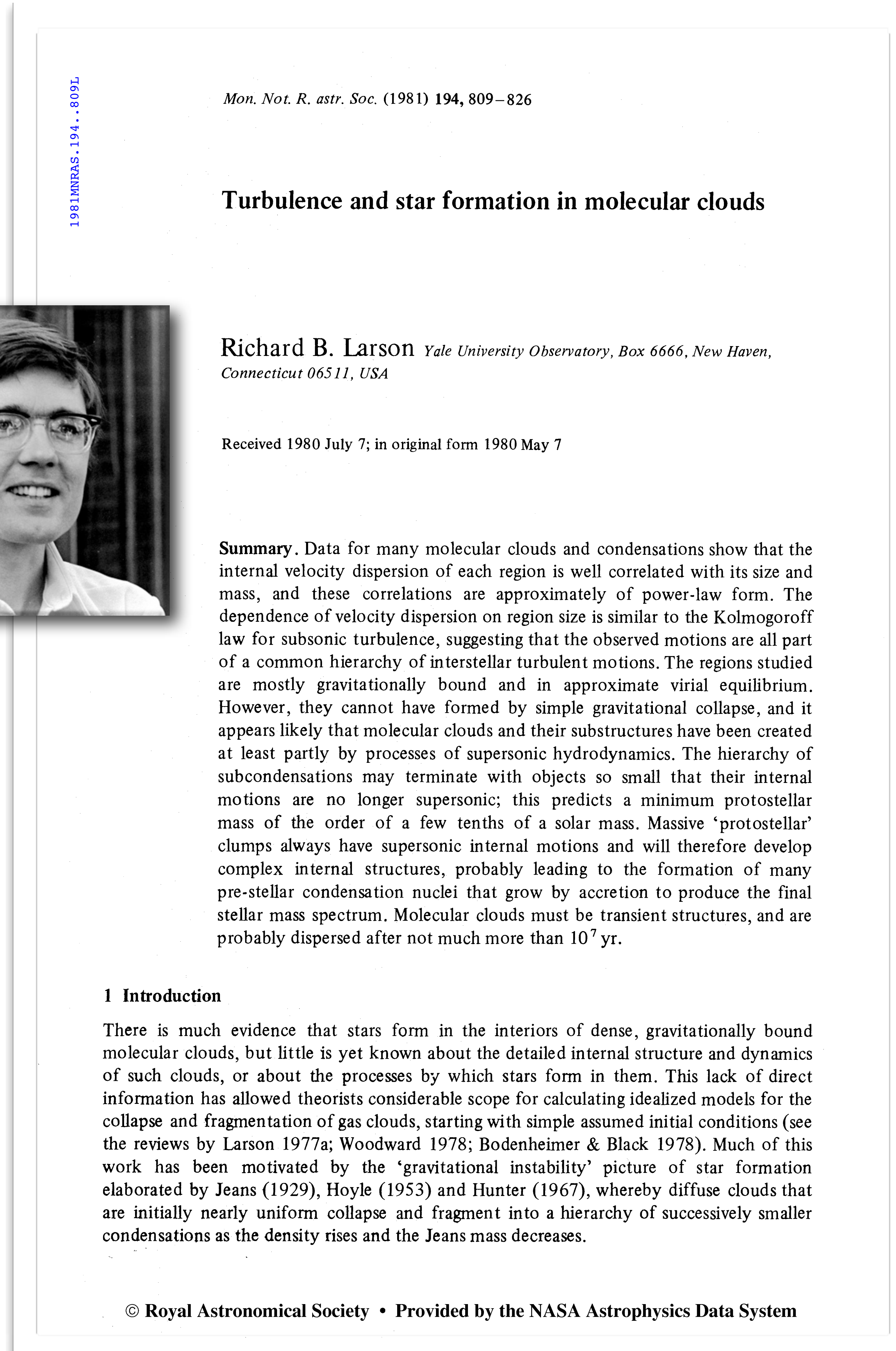
holistic |hōˈlistik|

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

Larson's Legacy

The evolution of the ideas about turbulent molecular clouds first proposed by Richard Larson in his 1981 paper.




1981MNRAS.194..809L

Mon. Not. R. astr. Soc. (1981) **194**, 809–826

Turbulence and star formation in molecular clouds

Richard B. Larson *Yale University Observatory, Box 6666, New Haven, Connecticut 06511, USA*

Received 1980 July 7; in original form 1980 May 7

Summary. Data for many molecular clouds and condensations show that the internal velocity dispersion of each region is well correlated with its size and mass, and these correlations are approximately of power-law form. The dependence of velocity dispersion on region size is similar to the Kolmogoroff law for subsonic turbulence, suggesting that the observed motions are all part of a common hierarchy of interstellar turbulent motions. The regions studied are mostly gravitationally bound and in approximate virial equilibrium. However, they cannot have formed by simple gravitational collapse, and it appears likely that molecular clouds and their substructures have been created at least partly by processes of supersonic hydrodynamics. The hierarchy of subcondensations may terminate with objects so small that their internal motions are no longer supersonic; this predicts a minimum protostellar mass of the order of a few tenths of a solar mass. Massive 'protostellar' clumps always have supersonic internal motions and will therefore develop complex internal structures, probably leading to the formation of many pre-stellar condensation nuclei that grow by accretion to produce the final stellar mass spectrum. Molecular clouds must be transient structures, and are probably dispersed after not much more than 10^7 yr.

1 Introduction

There is much evidence that stars form in the interiors of dense, gravitationally bound molecular clouds, but little is yet known about the detailed internal structure and dynamics of such clouds, or about the processes by which stars form in them. This lack of direct information has allowed theorists considerable scope for calculating idealized models for the collapse and fragmentation of gas clouds, starting with simple assumed initial conditions (see the reviews by Larson 1977a; Woodward 1978; Bodenheimer & Black 1978). Much of this work has been motivated by the 'gravitational instability' picture of star formation elaborated by Jeans (1929), Hoyle (1953) and Hunter (1967), whereby diffuse clouds that are initially nearly uniform collapse and fragment into a hierarchy of successively smaller condensations as the density rises and the Jeans mass decreases.

Slide set prepared by Alyssa Goodman, for Harvard Astronomy 201b, March 2011.

~100% Correct, but Details have Taken 30 Years (so far)

Summary. Data for many molecular clouds and condensations show that the internal velocity dispersion of each region is well correlated with its size and mass, and these correlations are approximately of power-law form. The dependence of velocity dispersion on region size is similar to the Kolmogoroff law for subsonic turbulence, suggesting that the observed motions are all part of a common hierarchy of interstellar turbulent motions. The regions studied are mostly gravitationally bound and in approximate virial equilibrium. However, they cannot have formed by simple gravitational collapse, and it appears likely that molecular clouds and their substructures have been created at least partly by processes of supersonic hydrodynamics. The hierarchy of subcondensations may terminate with objects so small that their internal motions are no longer supersonic; this predicts a minimum protostellar mass of the order of a few tenths of a solar mass. Massive 'protostellar' clumps always have supersonic internal motions and will therefore develop complex internal structures, probably leading to the formation of many pre-stellar condensation nuclei that grow by accretion to produce the final stellar mass spectrum. Molecular clouds must be transient structures, and are probably dispersed after not much more than 10^7 yr.

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Magnetic Fields in Star Formation

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HARVARD ASTRONOMY 201B, V.2011

ISM and Star Formation

"THE BOOK" "JOURNAL CLUB" COURSE "POSTS" AY208 NOTES (2000)

Our Jointly-Edited Online "Book"

This "book" accompanies Harvard University Astronomy 201b, "The Interstellar Medium and Star Formation." Contributions have been made by Prof. Alyssa Goodman, TF Chris Beaumont, and the 21 Harvard graduate students who took the course in 2011.

Links in red are transcriptions of Alyssa Goodman's notes. Links in green are student contributions. Links in blue are transcriptions from guest lecturers. Links in **olive** are the class handouts which can (hopefully!) be posted here without copyright violation.

NOTE: Lecture notes, to be used for reference, from AY208 v.Y2K are linked here in PDF format.

The scanned handwritten notes corresponding to these pages are found here

Introduction (1/25 – 2/3)

•Introductory Lectures •How do we know there is an ISM? •A sense of density scale • ISM density in the Milky Way • Density of the Intergalactic Medium (IGM) •Composition of the ISM • Topology of the ISM • Chemistry •Energy Density •Velocities in the ISM •Angular vs. Linear sizes •Molecular cloud properties •Interstellar cloud properties

Kinetic Equilibrium and Radiative Processes (2/8 – 2/15)

• Introduction to radiative processes •Thermodynamic Equilibrium •Spitzer Notation •The Saha Equation •Important properties of Local Thermodynamic Equilibrium •Definitions of Temperature •Excitation Processes •Neutral-Neutral Collisions •Ion-Neutral Collisions •The Virial Theorem •The Stromgren Sphere •Radiative Transfer •History of Saha •Bowers and Deeming excerpt on the Saha Equation •Jonathan Williams' page on measuring dust mass •NRAO "Fundamentals of Radio Astronomy": Brightness and Flux Density •Book Chapter: Interstellar Extinction and Scattering

The ISM of the Milky Way (2/17 – 3/1)

•The Cold ISM •Cold ISM (Ian Czekala) •Why is CO an important coolant in the (very) cold ISM? •Hot ISM • X-Ray Absorption by the ISM •The Leiden Atomic Molecular Database •Myers et al. Dense Cores in Dark Clouds VI: Shapes

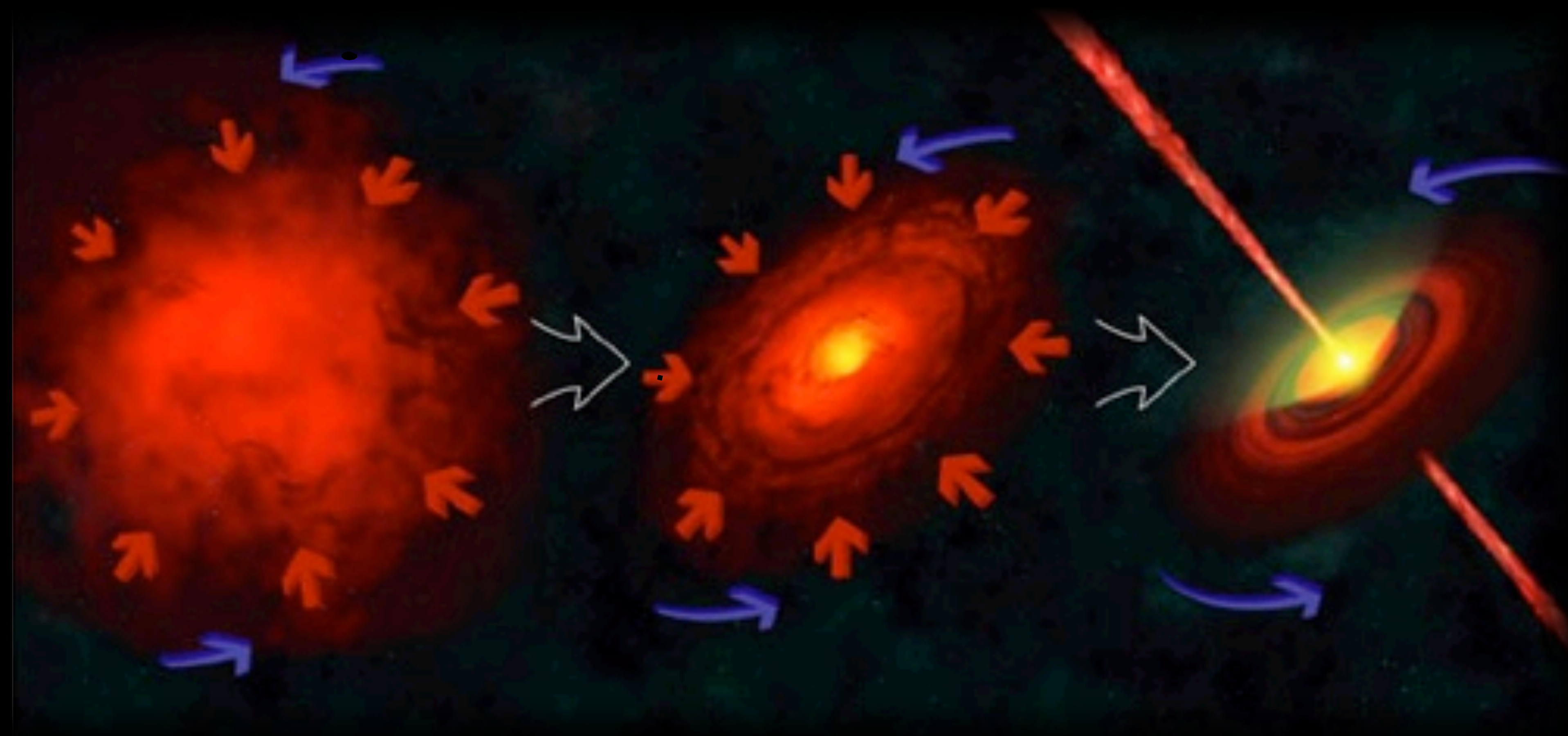
ay201b.wordpress.com

Follow

+ chemistry...!

www.flickr.com/photos/66496709@N00/6791649829/in/photostream

Star Formation 101



©Adison-Wesley 2004

Jeans Fragmentation

leads to Accretion Disks

+ Jets to get rid of angular momentum

$$M_J = \frac{1}{8}\left(\frac{\pi k T}{G\mu}\right)^{3/2}\frac{1}{\rho^{1/2}} \propto \frac{T^{3/2}}{\rho^{1/2}}$$

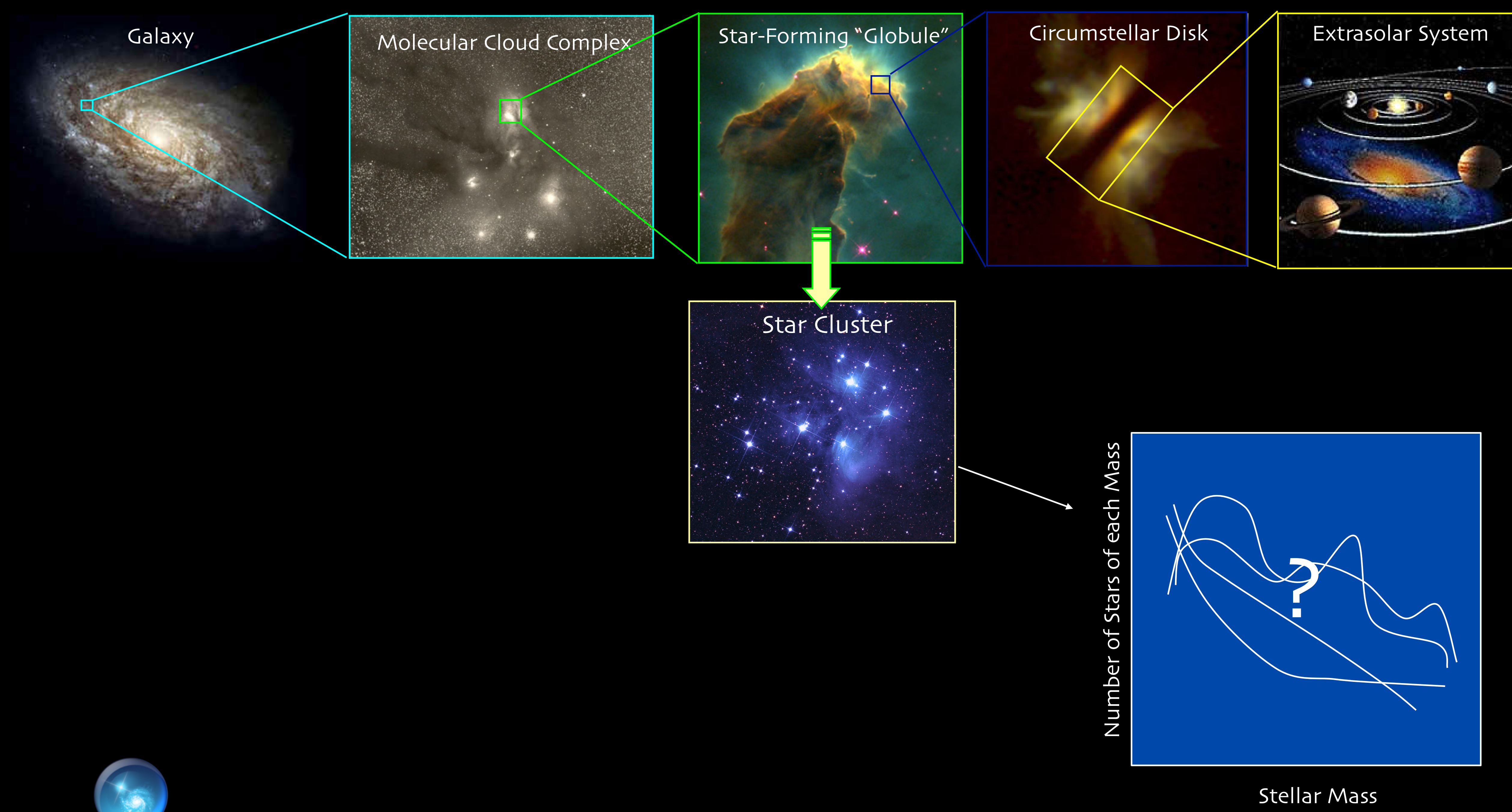
$$10K,\ 2.33\mathrm{amu},\ n_H = 2\times10^5\mathrm{cm}^{-3} \rightarrow 2M_\odot$$

$$50K,\ 2.33\mathrm{amu},\ n_H = 200\mathrm{cm}^{-3} \rightarrow 700M_\odot$$

Why does this fail on large scales? (Hiearchical "initial conditions," plus $t_{ff} \approx t_{cross} \approx t_{Jeans}$.)

ay201b.wordpress.com/2011/04/12/course-notes/#some_thoughts_on_jeans_scales

Star (and Planet, and Moon) Formation 201



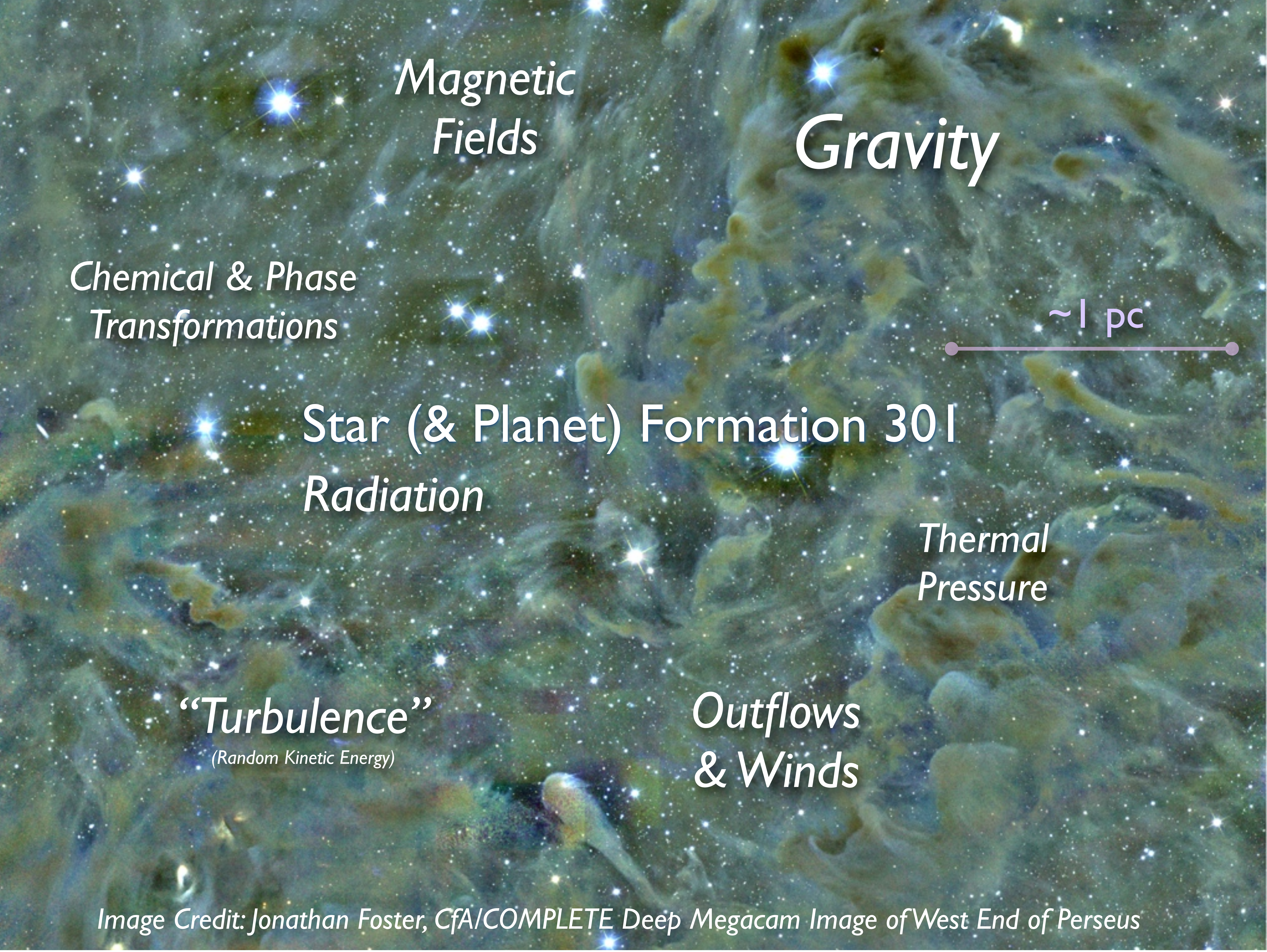
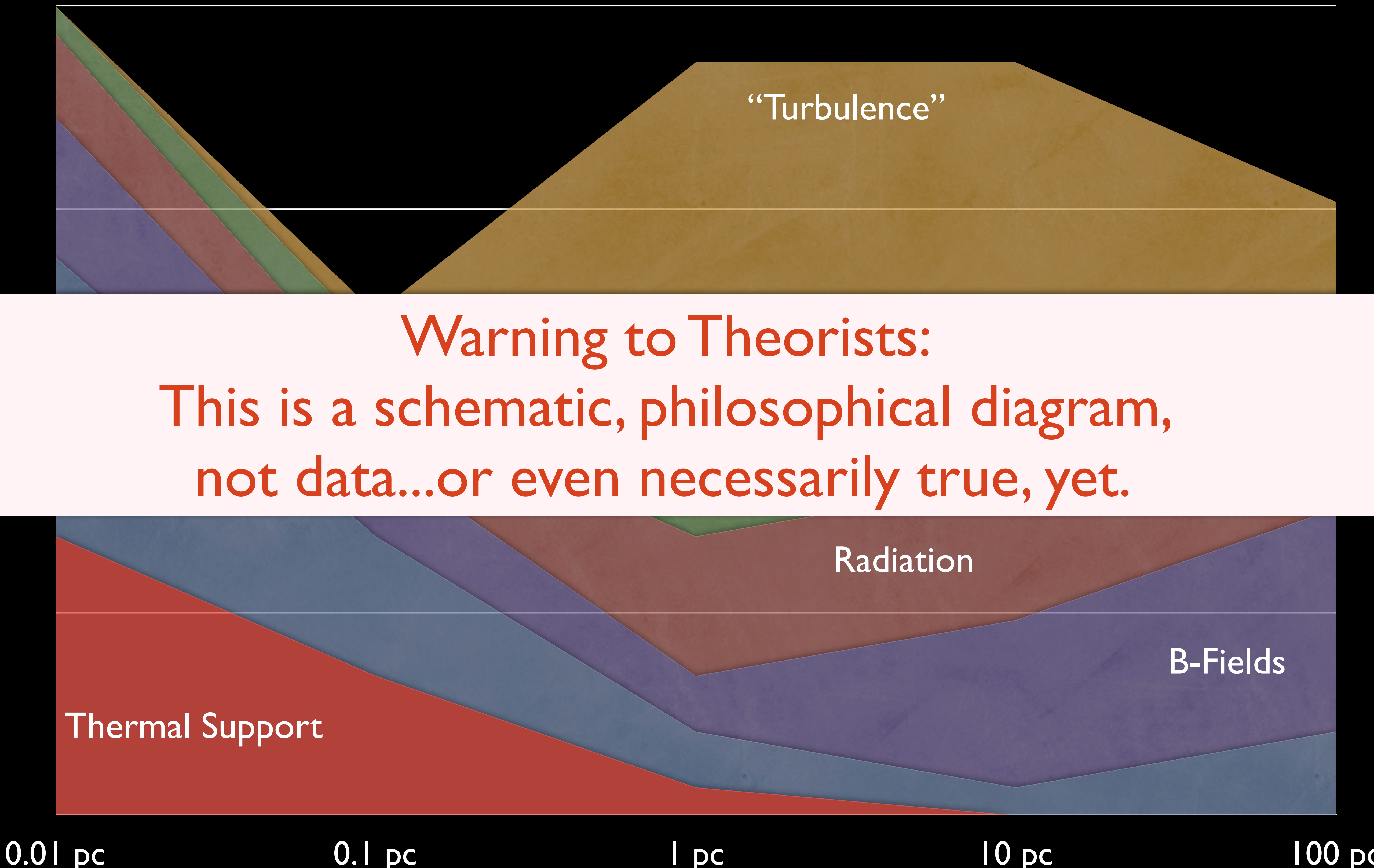


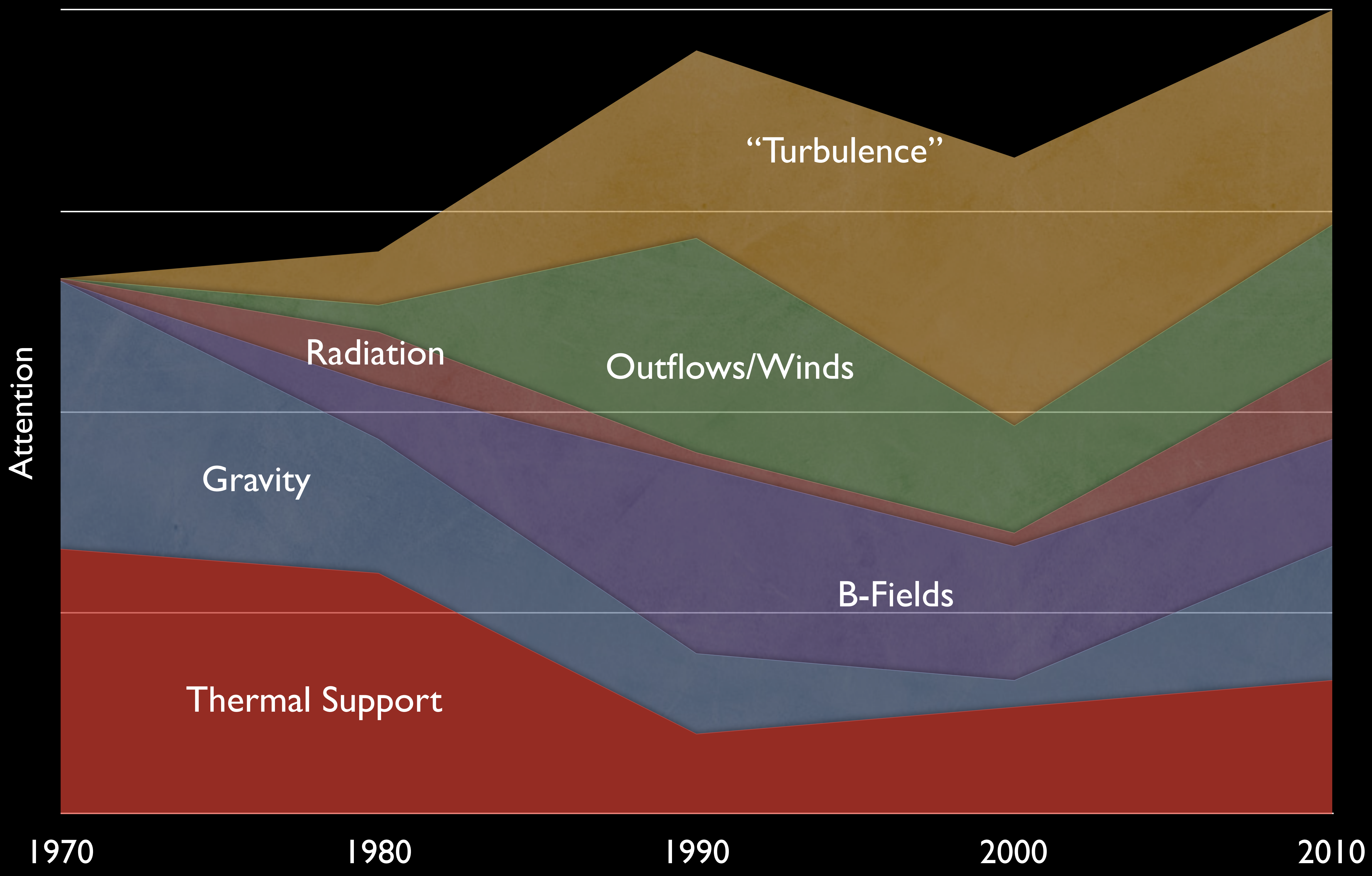
Image Credit: Jonathan Foster, CfA/COMPLETE Deep Megacam Image of West End of Perseus

What forces matter most on what scales?

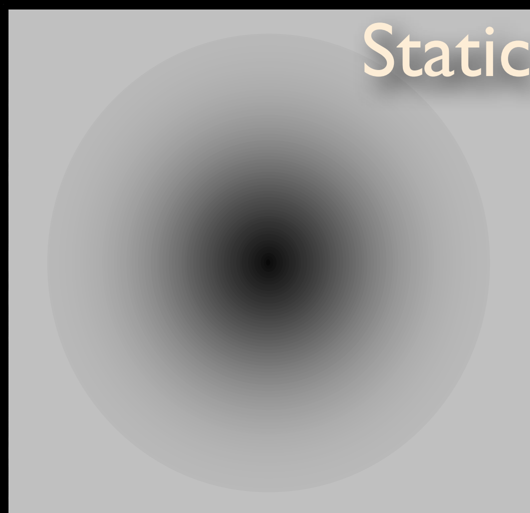


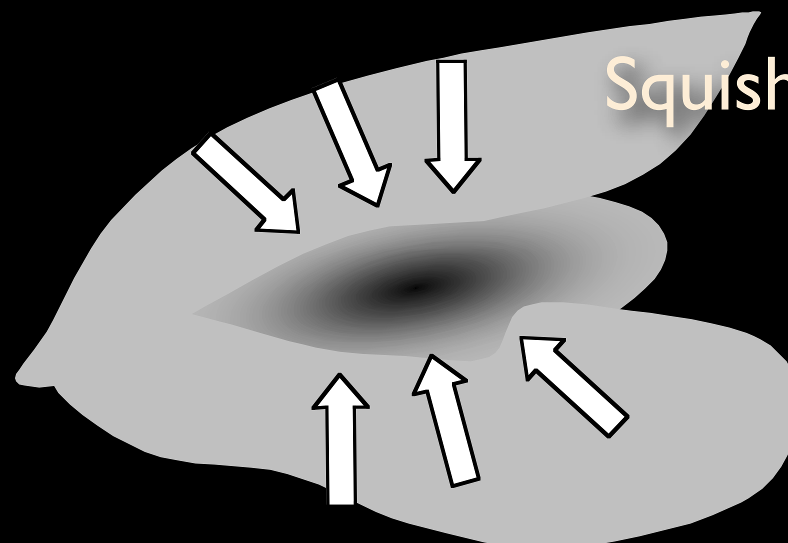
Warning to Theorists:
This is a schematic, philosophical diagram,
not data...or even necessarily true, yet.

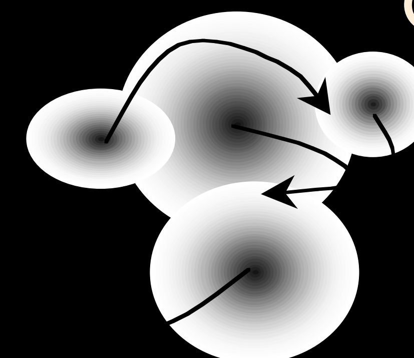
Changes of Heart, rather than in Physics...

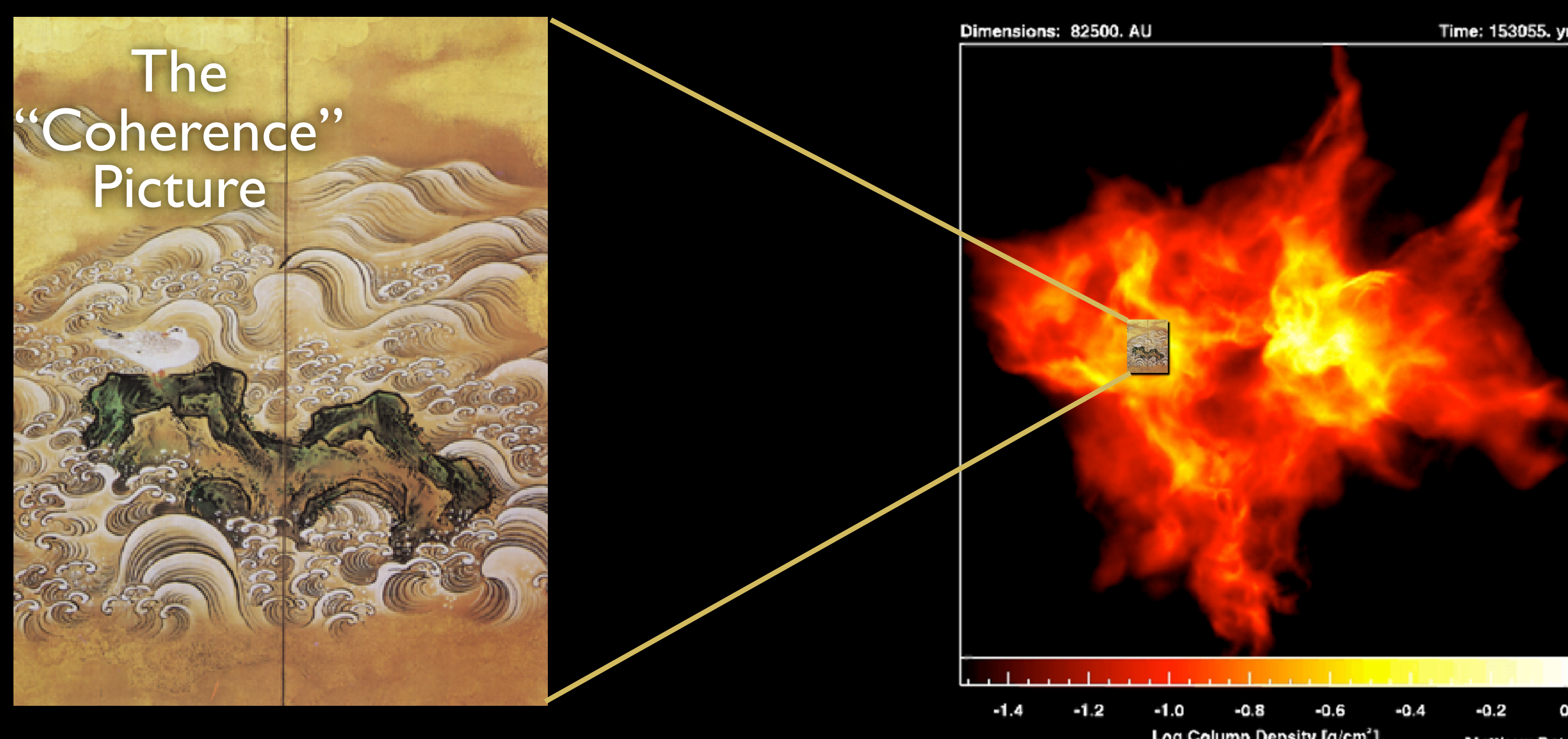


“Modernist” Philosophy  *for non-Experts*









What Observers Can "See"

(for stuff that's really, really, close by)

***Table 2:* Reading Nature's Menu** This table shows which tools are best for deteriming particular physical quantities. Grey shows possible wavelengths, and darker grey emphasizes the [illegible]est wavelengths. Green means "y[illegible]s," and yellow means "yes, but not usually very well." *Ma[illegible]* [illegible] stellar mass determinations are always model-dependent [illegible] line-of-sight velocity, while others give plane-of-the-sky; chemistry is always [illegible] model-dependent, and so-on.

Notes: C=included in COMPLETE; S=included in Spitzer c2d; +=included in both COMPLETE & c2d; Magnetic Fields: P=by polarimetry; Z=(primarily by) Zeeman, at same wavelengths shown

		optical	NIR	MIR	FIR	sub-mm	mm	cm	Density or Mass	Chemical Composition	Temperature	Velocity	Magnetic Fields
Extended Material (Clouds & Cores)	Broadband Emission (Dust)			S	+	C	+						P
	Spectra (Dust)												P
	Spectra (Gas)						C	C					Z
	Background Starlight (Extinction)		C	S									P
	Scattered Light ("Cloudshine")		C	S									
Disks & Envelopes (spatially filtered obsv'ns.)	Broadband Emission (Dust)			S	S	+							
	Spectra (Dust)			S	S								
	Spectra (Gas)												Z
Optically-Revealed (Proto) Stars	Broadband Emission			S									
	Spectra			S									Z
	Astrometry												

A Plan?

Handout
Open Issues

Handout
Jargon

Handout
Observations

Biased Slideware
(Examples from COMPLETE
+ Discussion of YSO SEDs)

WWT **Tour** of W5

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ITC Pizza Lunch: Introduction to (Current Open Issues) in Star Formation

Alyssa Goodman, February 1, 2012

Quick Intro to Scales/Background/Measurement Techniques (worldwidetelescope.org)

Jeans?.. not really.. "turbulence"/dendrograms, clusters, (coherent) cores (maybe Jeans applies there?). Role of magnetic fields? Role of feedback/winds? Importance of simulations. Virial Equilibrium/Larson's "Laws." (Understanding *p-p-v* spectral-line data cubes.)

Disks?...yes, really. But, what do they accrete *from* (cores, cluster gas?)? How do binaries (and multiples) form? Importance of answers re:planet formation.

Time evolution... Outflows are clearly episodic, meaning accretion likely is too... But how much of an effect does episodicity have? Competitive Accretion?

Stars/Measuring Ages. VERY inexact science (see many Spitzer studies), mostly based on spectral energy distributions. (Definition of Class 0, I, II, III, etc.) Models of evolution of young stars very imperfect, plus separating effects of disk/envelope/l.o.s. reddening, plus variability, is very tricky.

Origin of IMF. Log-normal? Is it from the CMF, which is also log-normal? Does the CMF come from turbulence+gravity, or any set of random processes? Interesting bits of IMF are turnover (peak) and deviations at high/low ends.

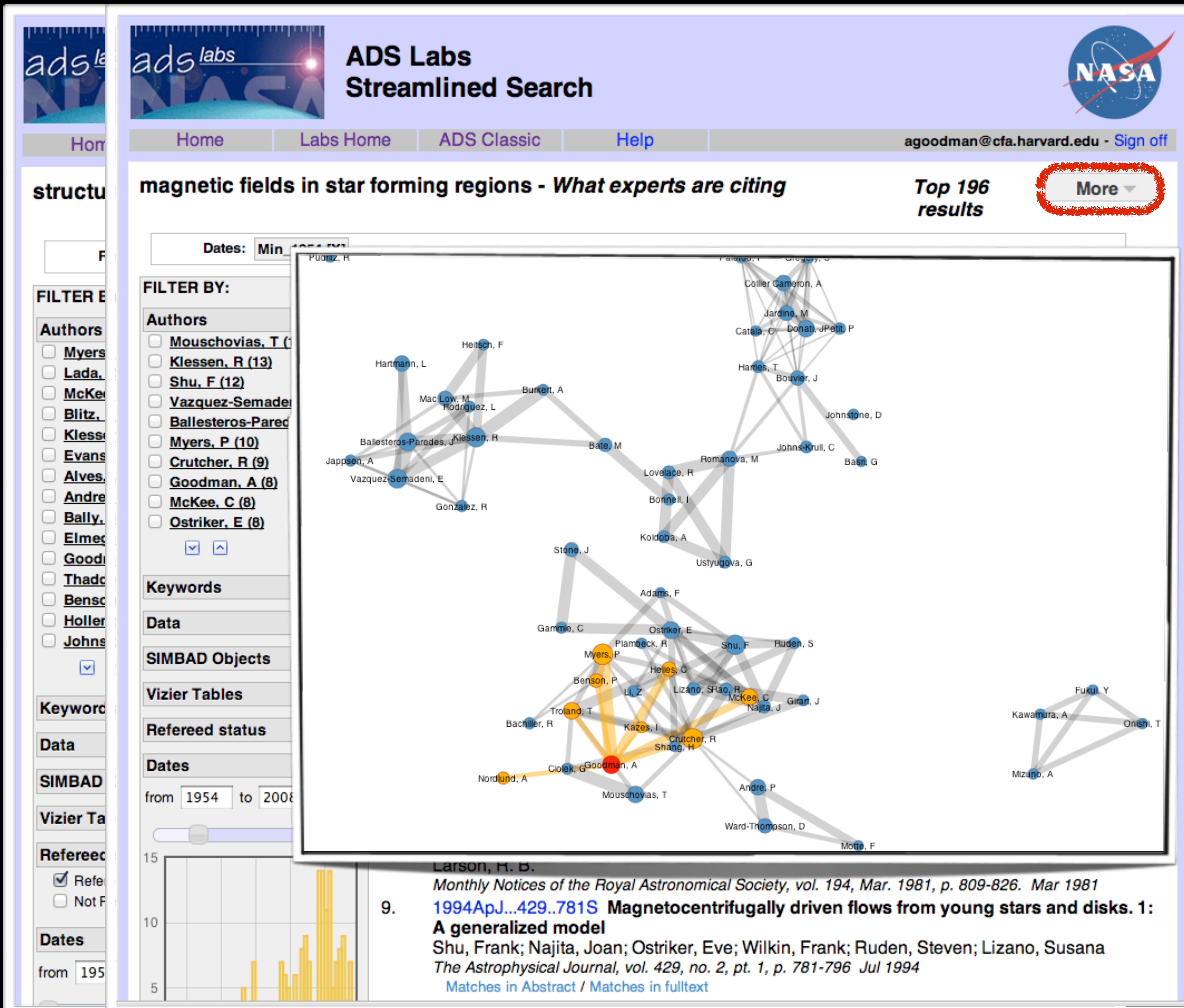
Galactic:Extragalactic connection--can we refine Kennicutt-Schmidt relation? Is there really just a star-formation "threshold" in (column) density, or is it possible to identify self-gravitating (or truly star-forming) gas?

What to do now? More taste-testing (statistical comparison of synthetic observations of simulations with "real" data), with more predictive diagnostics. Critical need for improved understanding of chemistry and dust.

New instruments: Herschel/Spitzer/WISE (more source catalogs, morphological structure, temperature measurements), eVLA & ALMA (more tracers, meaning more chemistry, kinematics, density, and time-evolution if we can interpret chemistry!, more disks), SOFIA (even more chemistry), and JWST (more dust, disks). Plus, all will improve resolution & sensitivity for extragalactic studies... but *never* to what we have nearby. GAIA will be important for getting full 3D (*p-p-p-v-v-v*) stellar motions & we will better understand how stars "leave home" and migrate within galaxies.

+ chemistry...!

Don't Forget ADS Labs



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Jargon

To study for your "Ph.D. Exam" ... (a list in semi-random order)

1. Kennicutt-Schmidt relations
2. Molecular Line Maps, CO, HINSA, "tracers," spectral-line cubes, *p-v* diagram, *p-p-v* space
3. Larson's "Laws"
4. Virial Theorem, virial parameter
5. CLUMPFIND, dendrograms
6. column density/PDF
7. extinction, reddening (law), NICE/NICER/NICEST/GNICER/GNICEST
8. thermal emission, column temperature, β-T relation (controversy)
9. spectral energy distribution
10. "cloud," "clump," "core"
11. coherent core, kernel
12. cluster
13. competitive accretion, turbulent fragmentation, (M)HD simulations
14. radiative feedback
15. [HII region]
16. IMF, CMF
17. stellar wind: PMS/MS spherical, bipolar outflow
18. disks: pseudo, accretion, protostellar/protoplanetary, debris
19. YSOs, "Class 0 Source," Class I, II, III
20. spectral and wavelength-specific features of protostars & disks
21. disk gaps [planets]
22. polarimetry: background starlight, dust emission, Goldreich-Kylafis effect
23. Zeeman splitting: thermal lines, masers
24. masers
25. galactic fountain
26. gas-grain chemistry, ion-neutral chemistry
27. freeze-out
28. depletion
29. sublimation

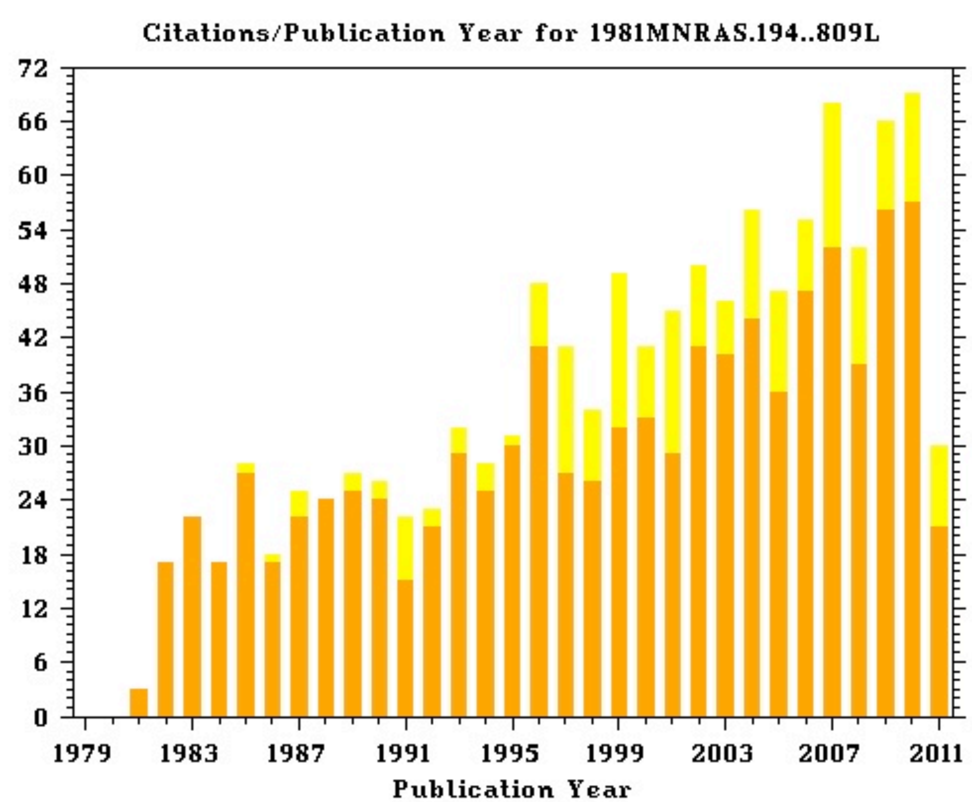
(New) Instruments you Should Know About

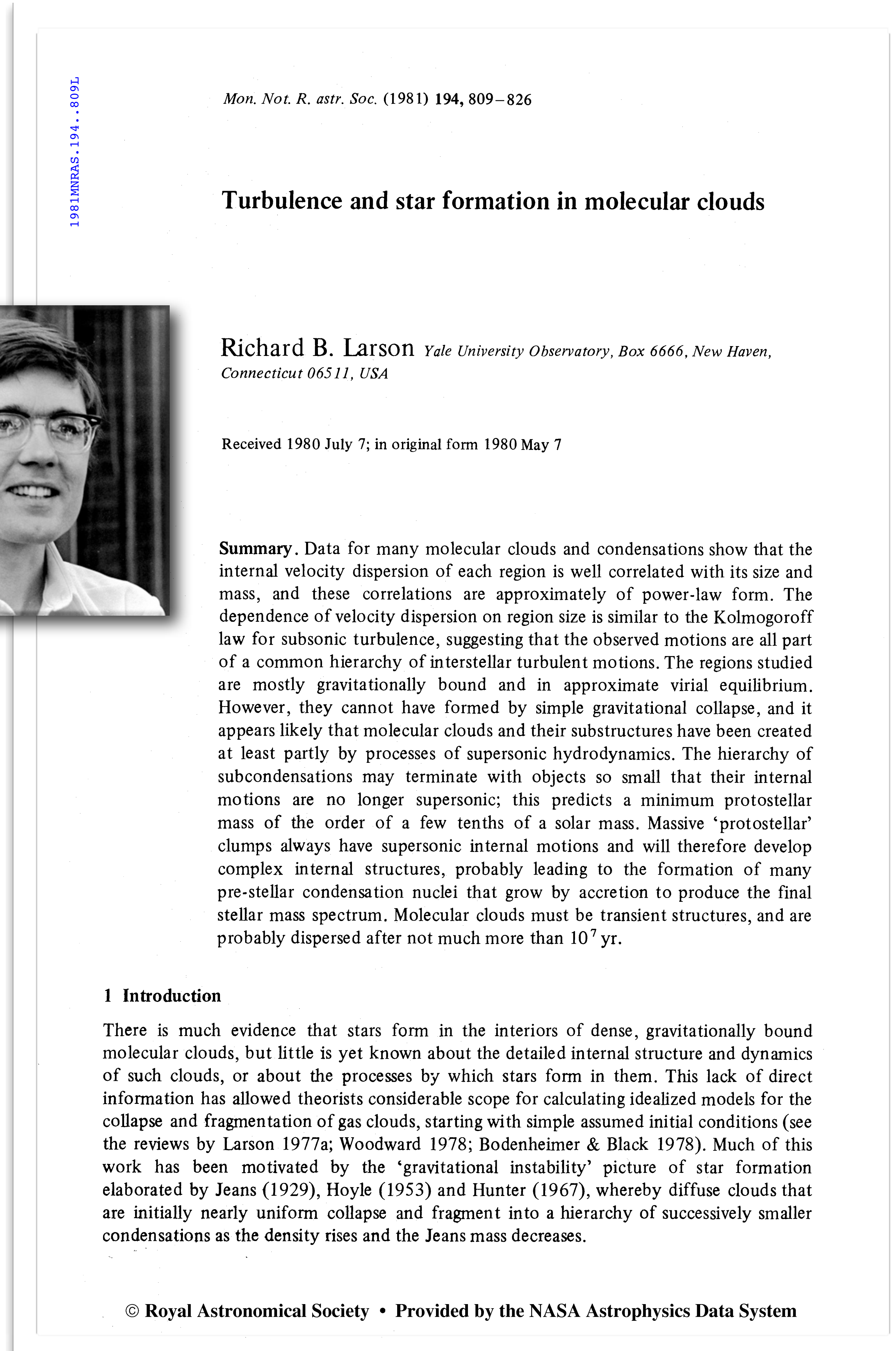
Spitzer, SOFIA, WISE, Herschel, JWST, ALMA(SMA, CARMA), eVLA,
+many new ground-based hi-res O/IR spectrometers & IFUs

+ chemistry...!

Larson's Legacy

The evolution of the ideas about turbulent molecular clouds first proposed by Richard Larson in his 1981 paper.





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Slide set prepared by Alyssa Goodman, for Harvard Astronomy 201b, March 2011.

“Line width - size” $s \sim R^{0.38}$

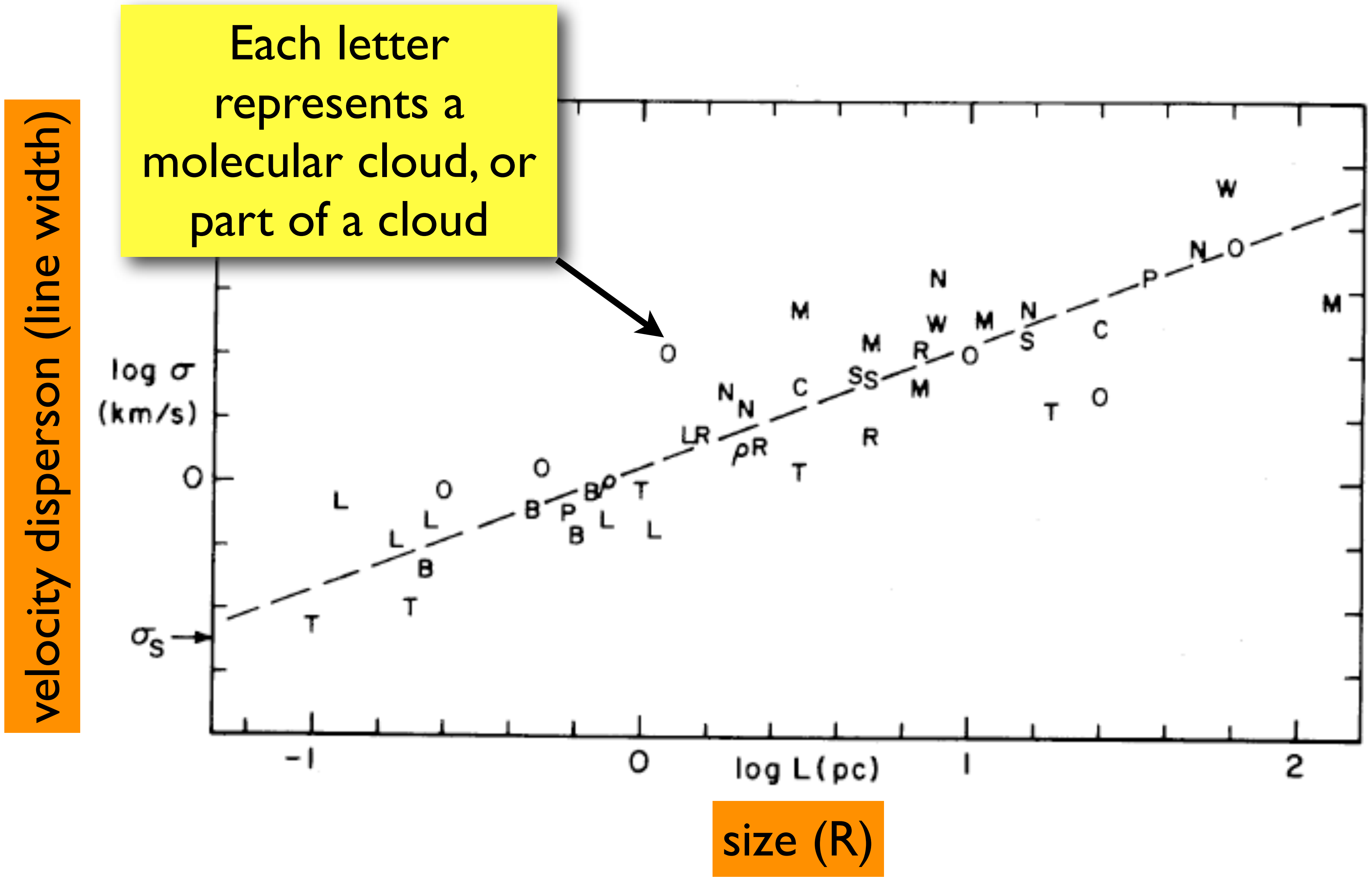


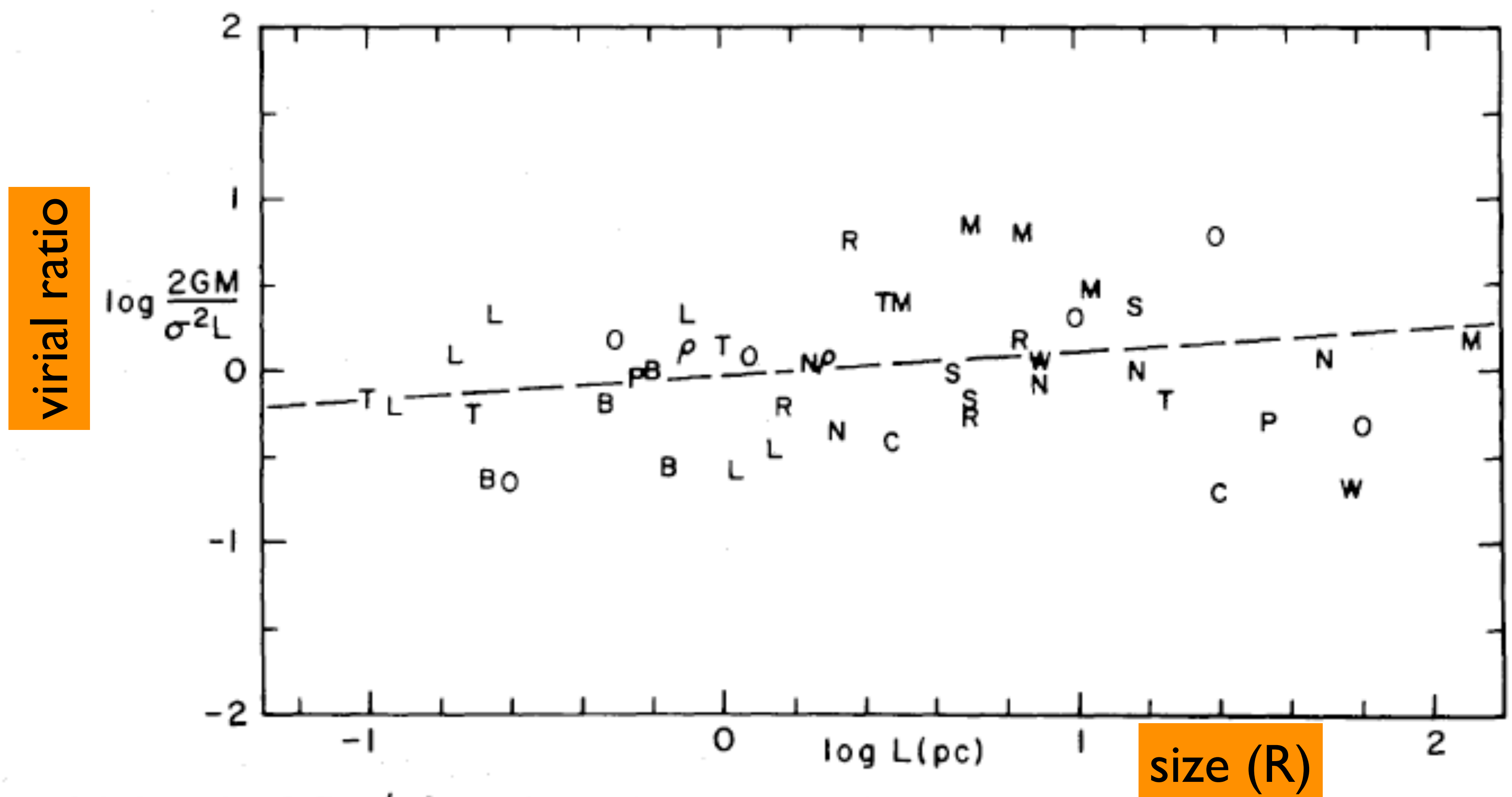
Figure 1. The three-dimensional internal velocity dispersion σ plotted versus the maximum linear dimension L of molecular clouds and condensations, based on data from Table 1; the symbols are identified in Table 1. The dashed line represents equation (1), and σ_S is the thermal velocity dispersion.

(More recently, 0.38 has become ~0.5. Larson liked 0.38 because Kolmogorov (incompressible) turbulence would give 0.33. A higher value is consistent with compressible (e.g. “Burger’s” turbulence.)

~Virial Equilibrium: Gravity Balanced by "Turbulent" Support

The dashed line in this figure is not fitted to the points, but represents the relation

$$\frac{2GM}{\sigma^2 L} = 0.92\, L\, (\mathrm{pc})^{0.14} \quad (4)$$



'igure 4. The virial ratio $2GM/\sigma^2 L$ plotted versus region size L for the same regions shown in Figs 1 and '. The dashed line represents equation (4), and is derived from equations (1) and (2).

for exact virial equilibrium, $2GM/Rs^2=1$, and points above would be on horizontal line

“Density - size” $n \sim R^{-1.1}$

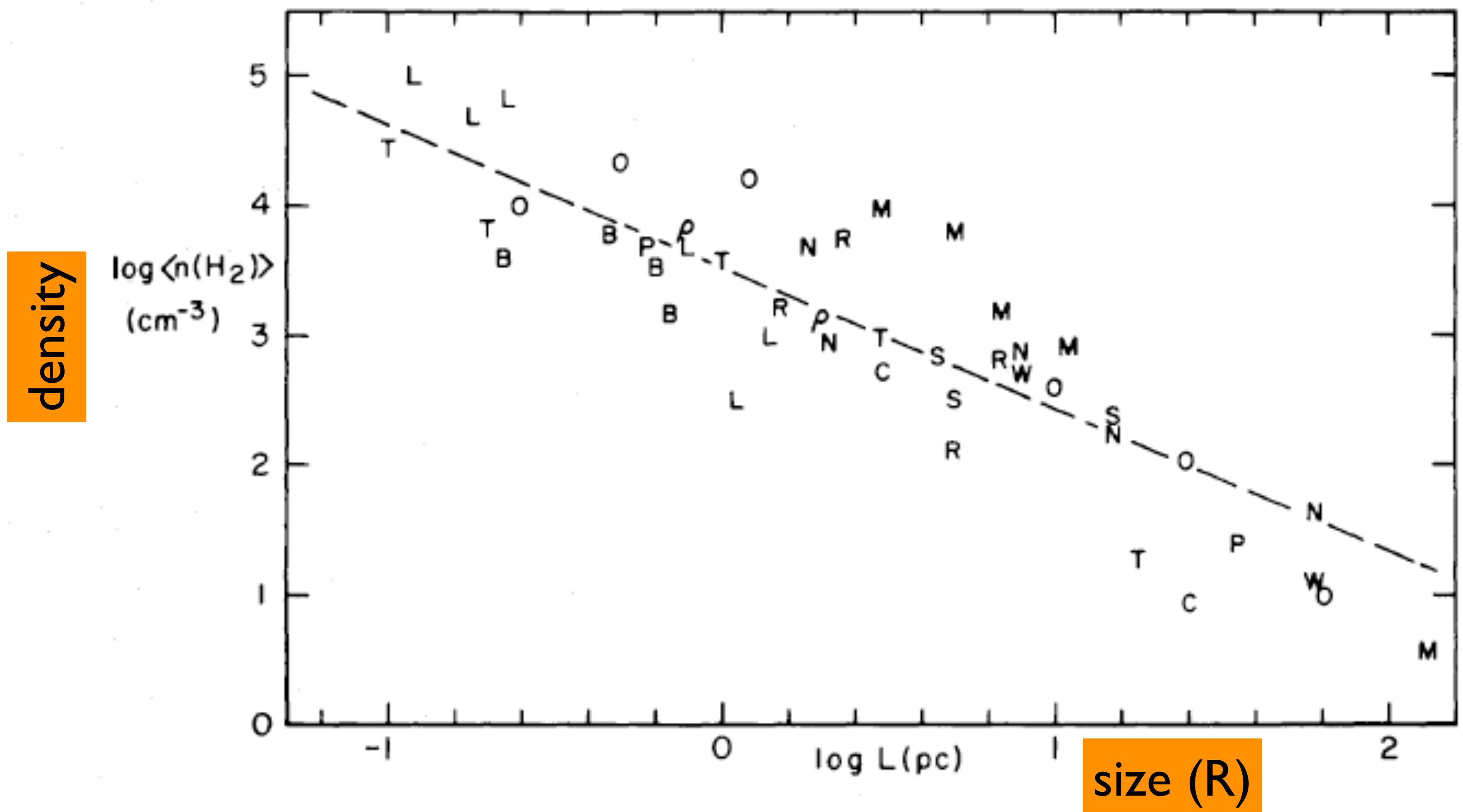


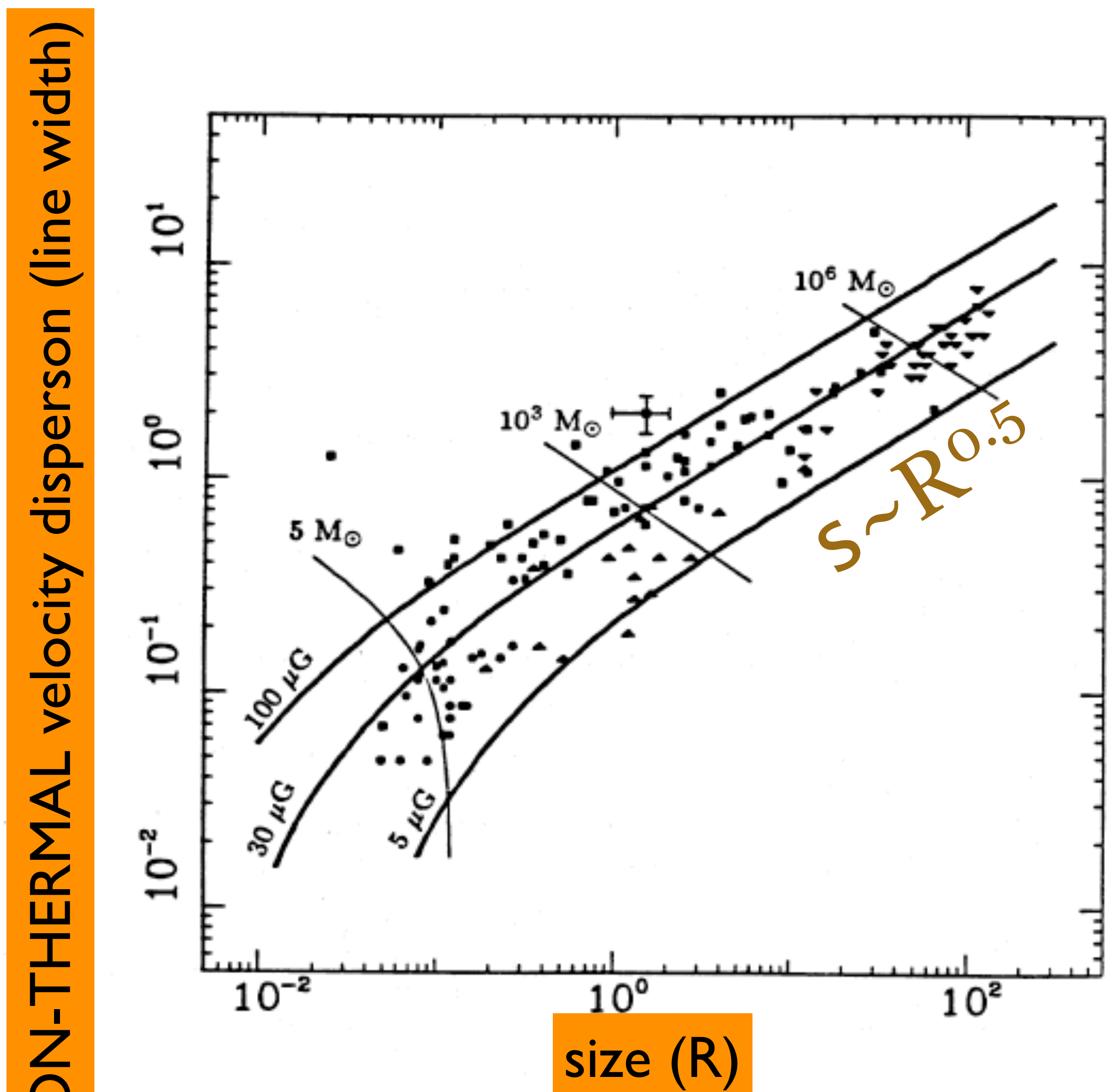
Figure 5. The average density, defined as the density of a sphere of mass M and diameter L, of all the regions shown in Figs 1 and 3 plotted versus region size L. The dashed line represents equation (5), and is derived from equations (1) and (2).

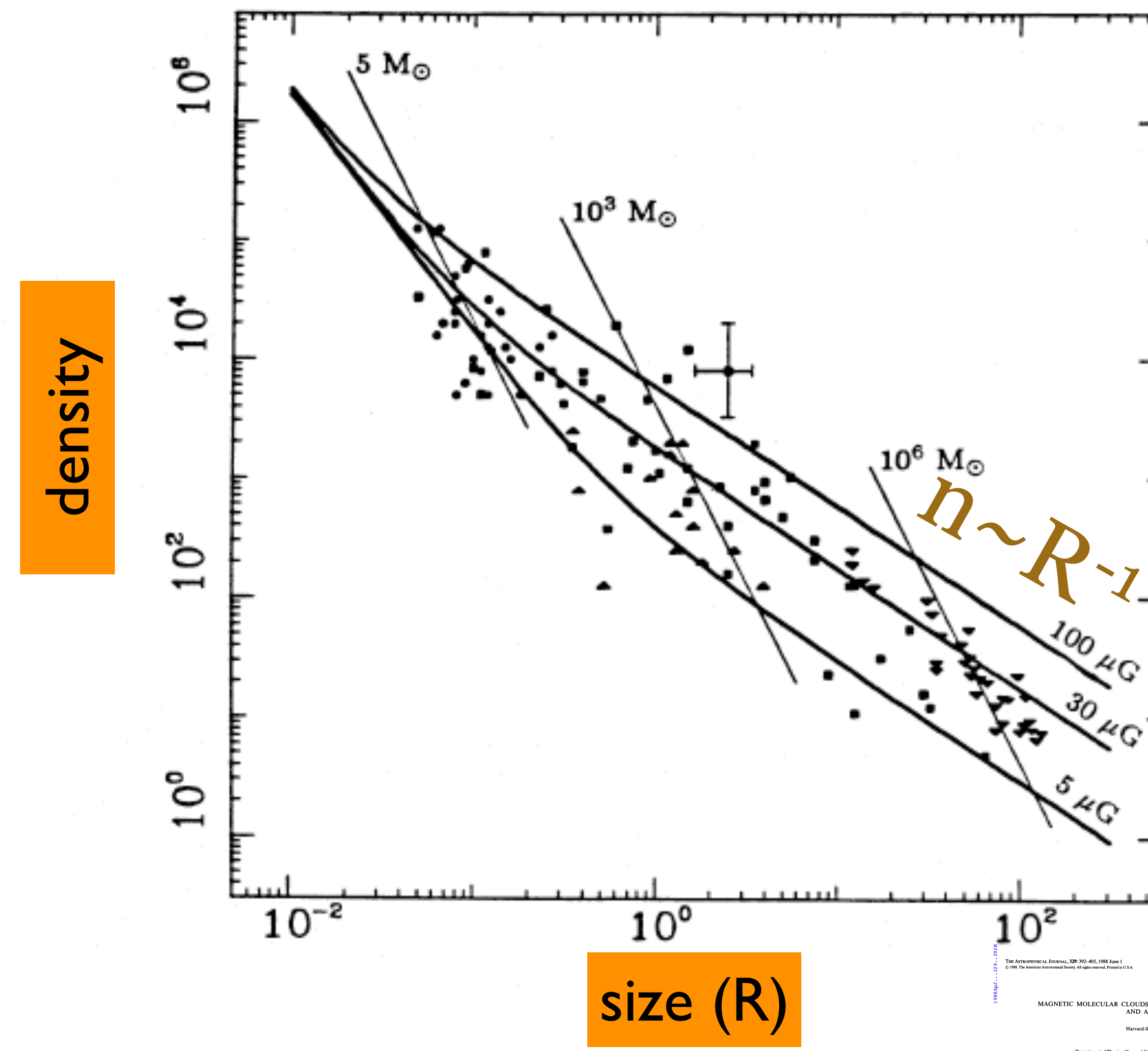
For $n \sim R^{-1}$, and $s \sim R^{0.5}$, and $2GM/Rs^2 = 1$ (virial equilibrium) any one relation follows automatically from the other two. Note implication of “constant column density.”

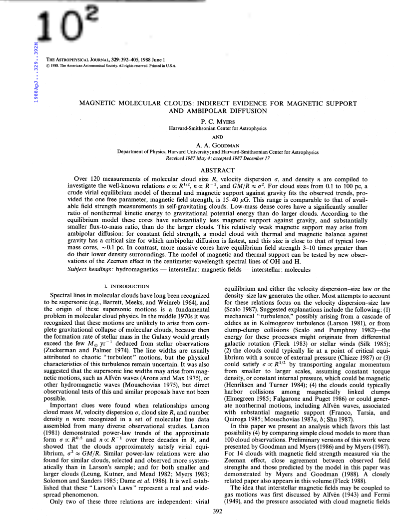
So, roughly speaking, Larson's "Laws" show that a *turbulent-like nature for the line width-size relation, plus virial equilibrium, gives the observed density-size relation.*

Magnetic Origin of Non-Thermal Motions?

(Myers & Goodman 1988)







THE ASTROPHYSICAL JOURNAL, 329:392–405, 1988 June 1

MAGNETIC MOLECULAR CLOUDS: INDIRECT EVIDENCE FOR MAGNETIC SUPPORT AND AMBIPOLAR DIFFUSION

P. C. MYERS
Harvard-Smithsonian Center for Astrophysics

AND

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Department of Physics, Harvard University; and Harvard-Smithsonian Center for Astrophysics
Received 1987 May 4; accepted 1987 December 17

ABSTRACT

Over 120 measurements of molecular cloud size R, velocity dispersion σ, and density n are compiled to investigate the well-known relations $\sigma \propto R^{1/2}$, $n \propto R^{-1}$, and $GM/R \approx \sigma^2$. For cloud sizes from 0.1 to 100 pc, a crude virial equilibrium model of thermal and magnetic support against gravity fits the observed trends, provided the one free parameter, magnetic field strength, is 15–40 μG. This range is comparable to that of available field strength measurements in self-gravitating clouds. Low-mass dense cores have a significantly smaller ratio of nonthermal kinetic energy to gravitational potential energy than do larger clouds. According to the equilibrium model these cores have substantially less magnetic support against gravity, and substantially smaller flux-to-mass ratio, than do the larger clouds. This relatively weak magnetic support may arise from ambipolar diffusion: for constant field strength, a model cloud with thermal and magnetic balance against gravity has a critical size for which ambipolar diffusion is fastest, and this size is close to that of typical low-mass cores, ~0.1 pc. In contrast, more massive cores have equilibrium field strength 3–10 times greater than do their lower density surroundings. The model of magnetic and thermal support can be tested by new observations of the Zeeman effect in the centimeter-wavelength spectral lines of OH and H.

Subject headings: hydromagnetics — interstellar: magnetic fields — interstellar: molecules

I. INTRODUCTION

Spectral lines in molecular clouds have long been recognized to be supersonic (e.g., Barrett, Meeks, and Weinreb 1964), and the origin of these supersonic motions is a fundamental problem in molecular cloud physics. In the middle 1970s it was recognized that these motions are unlikely to arise from complete gravitational collapse of molecular clouds, because then the formation rate of stellar mass in the Galaxy would greatly exceed the few $M_\odot$ yr^{-1} deduced from stellar observations (Zuckerman and Palmer 1974). The line widths are usually attributed to chaotic "turbulent" motions, but the physical characteristics of this turbulence remain uncertain. It was also suggested that the supersonic line widths may arise from magnetic motions, such as Alfvén waves (Arons and Max 1975), or other hydromagnetic waves (Mouschovias 1975), but direct observational tests of this and similar proposals have not been possible.

Important clues were found when relationships among cloud mass M, velocity dispersion σ, cloud size R, and number density n were recognized in a set of molecular line data assembled from many diverse observational studies. Larson (1981) demonstrated power-law trends of the approximate form $\sigma \propto R^{0.5}$ and $n \propto R^{-1}$ over three decades in R, and showed that the clouds approximately satisfy virial equilibrium, $\sigma^2 \approx GM/R$. Similar power-law relations were also found for similar clouds, selected and observed more systematically than in Larson's sample; and for both smaller and larger clouds (Leung, Kutner, and Mead 1982; Myers 1983; Solomon and Sanders 1985; Dame *et al.* 1986). It is well established that these "Larson's Laws" represent a real and widespread phenomenon.

Only two of these three relations are independent: virial equilibrium and either the velocity dispersion–size law or the density–size law generates the other. Most attempts to account for these relations focus on the velocity dispersion–size law (Scalo 1987). Suggested explanations include the following: (1) mechanical "turbulence," possibly arising from a cascade of eddies as in Kolmogorov turbulence (Larson 1981), or from clump-clump collisions (Scalo and Pumphrey 1982)—the energy for these processes might originate from differential galactic rotation (Fleck 1983) or stellar winds (Silk 1985); (2) the clouds could typically lie at a point of critical equilibrium with a source of external pressure (Chieze 1987) or (3) could satisfy $\sigma \propto R^{1/2}$ by transporting angular momentum from smaller to larger scales, assuming constant torque density, or constant internal pressure, which could be magnetic (Henriksen and Turner 1984); (4) the clouds could typically harbor collisions among magnetically linked clumps (Elmegreen 1985; Falgarone and Puget 1986) or could generate nonthermal motions, including Alfvén waves, associated with substantial magnetic support (Franco, Tarsia, and Quiroga 1985; Mouschovias 1987*a*, *b*; Shu 1987).

In this paper we present an analysis which favors this last possibility (4) by comparing simple cloud models to more than 100 cloud observations. Preliminary versions of this work were presented by Goodman and Myers (1986) and by Myers (1987). For 14 clouds with magnetic field strength measured via the Zeeman effect, close agreement between observed field strengths and those predicted by the model in this paper was demonstrated by Myers and Goodman (1988). A closely related paper also appears in this volume (Fleck 1988).

The idea that interstellar magnetic fields may be coupled to gas motions was first discussed by Alfvén (1943) and Fermi (1949), and the pressure associated with cloud magnetic fields

392

lines assume various field strengths...

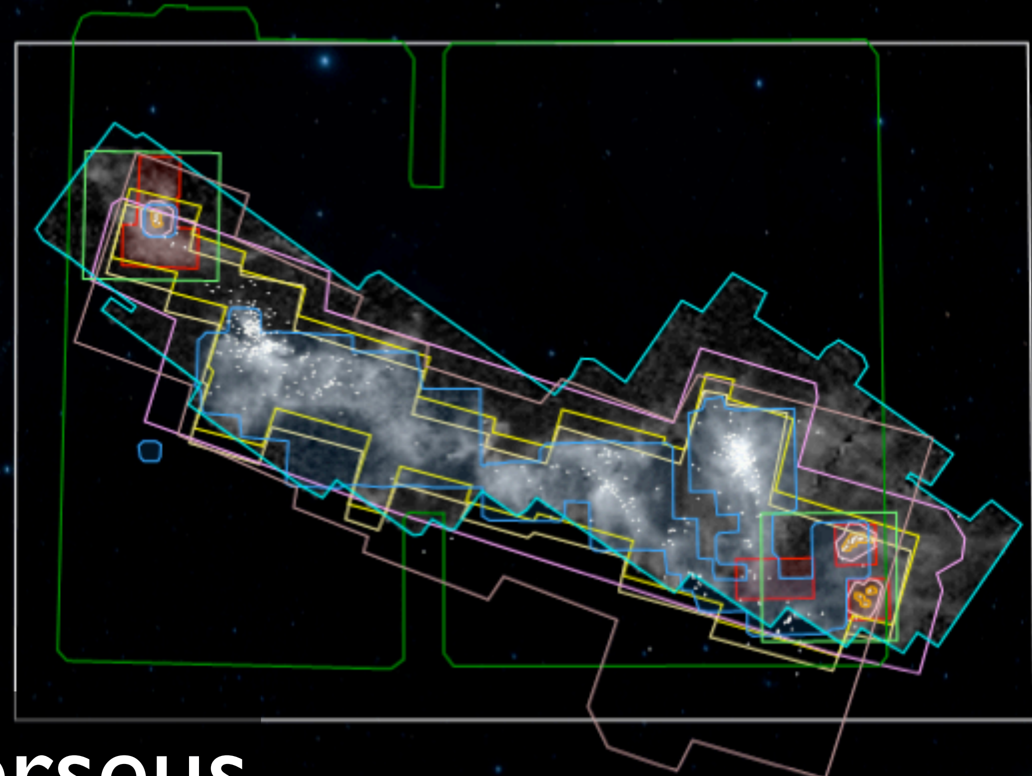
What Observers can See

For your reference...

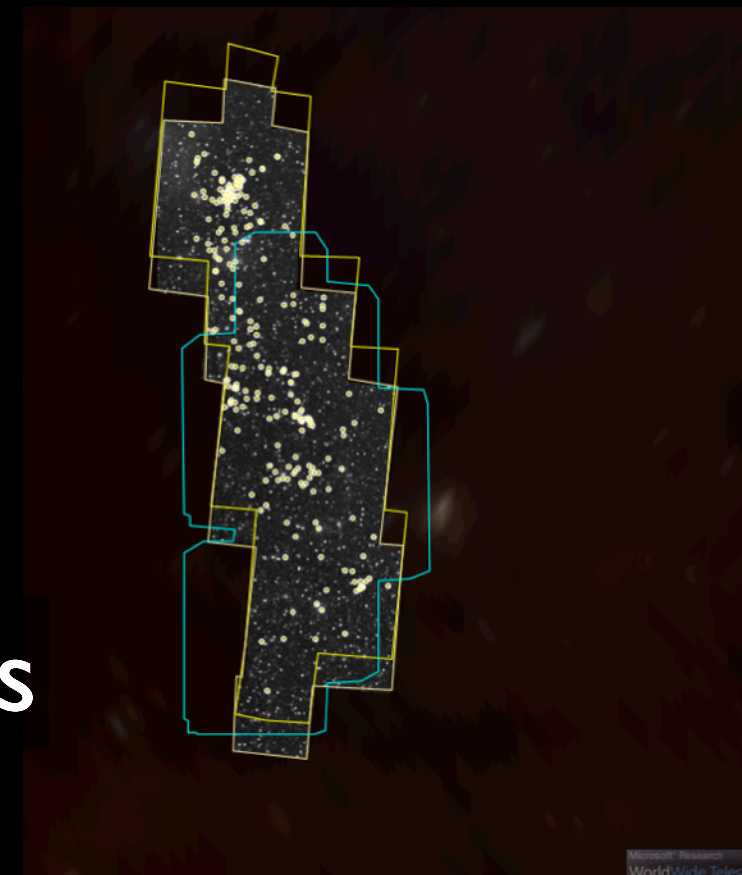
This table shows which tools are best for deteriming particular physical quantities. Grey shows possible wavelengths, and darker grey emphasizes the best wavelengths. Green means "yes," and yellow means "yes, but not usually very well." *Many subtleties cannot be shown here.* For example: stellar mass determinations are always model-dependent unless an orbit is known; some techniques give line-of-sight velocity, while others give plane-of-the-sky; chemistry is always very model dependent, and so-on.

Notes: C=included in COMPLETE; S=included in Spitzer c2d; +=included in both COMPLETE & c2d; Magnetic Fields: P=by polarimetry; Z=(primarily by) Zeeman, at same wavelengths shown

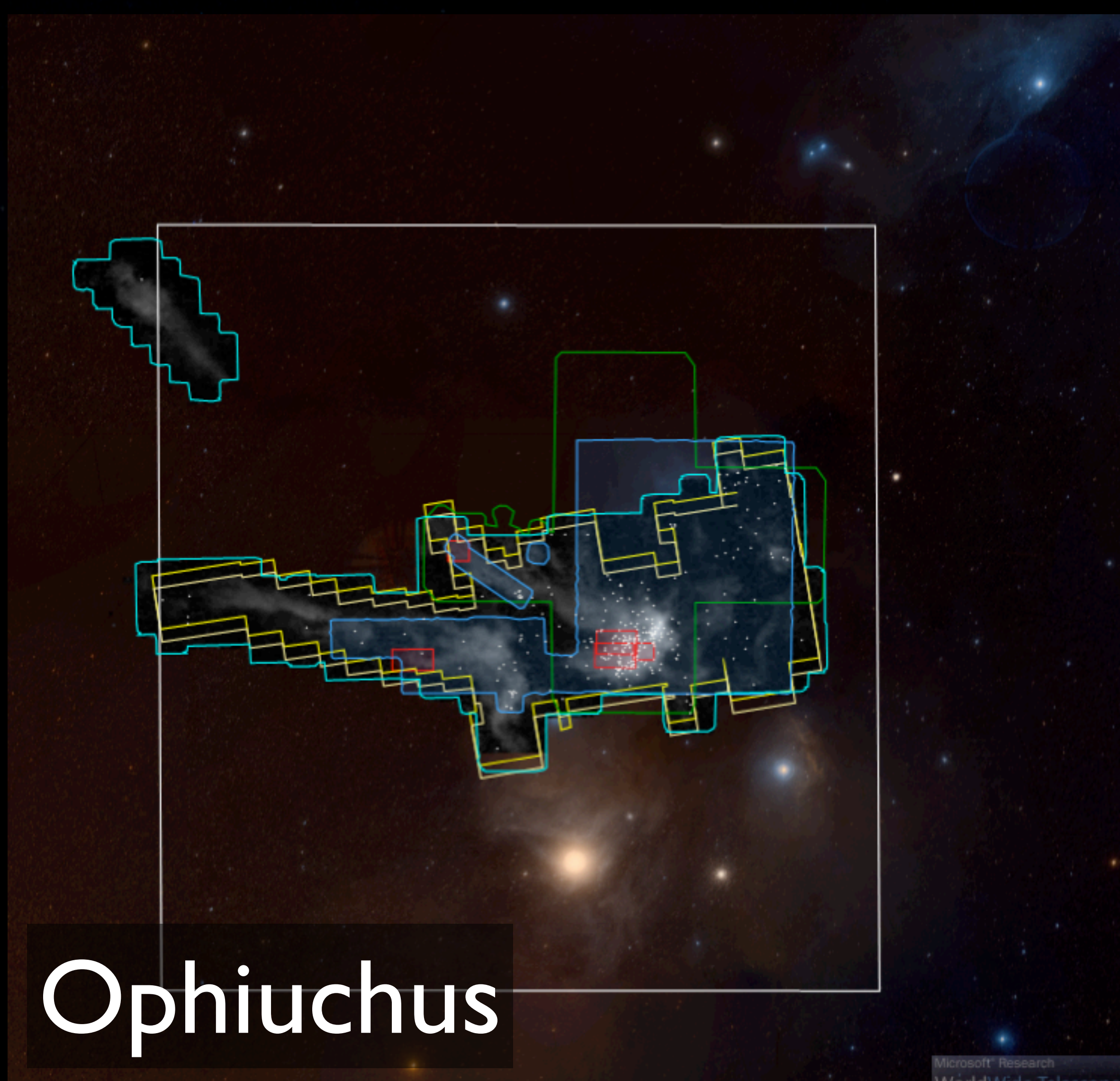
		optical	NIR	MIR	FIR	sub-mm	mm	cm	**Density or Mass**	**Chemical Composition**	**Temperature**	**Velocity**	**Magnetic Fields**
Extended Material (Clouds & Cores)	Broadband Emission (Dust)			S	+	C	+						P
	Spectra (Dust)												P
	Spectra (Gas)						C	C					Z
	Background Starlight (Extinction)		C	S									P
	Scattered Light ("Cloudshine")		C	S									
Disks & Envelopes (spatially filtered obsv'ns.)	Broadband Emission (Dust)			S	S	+							
	Spectra (Dust)			S	S								
	Spectra (Gas)												Z
Optically-Revealed (Proto) Stars	Broadband Emission			S									
	Spectra			S									Z
	Astrometry												



Perseus



Serpens

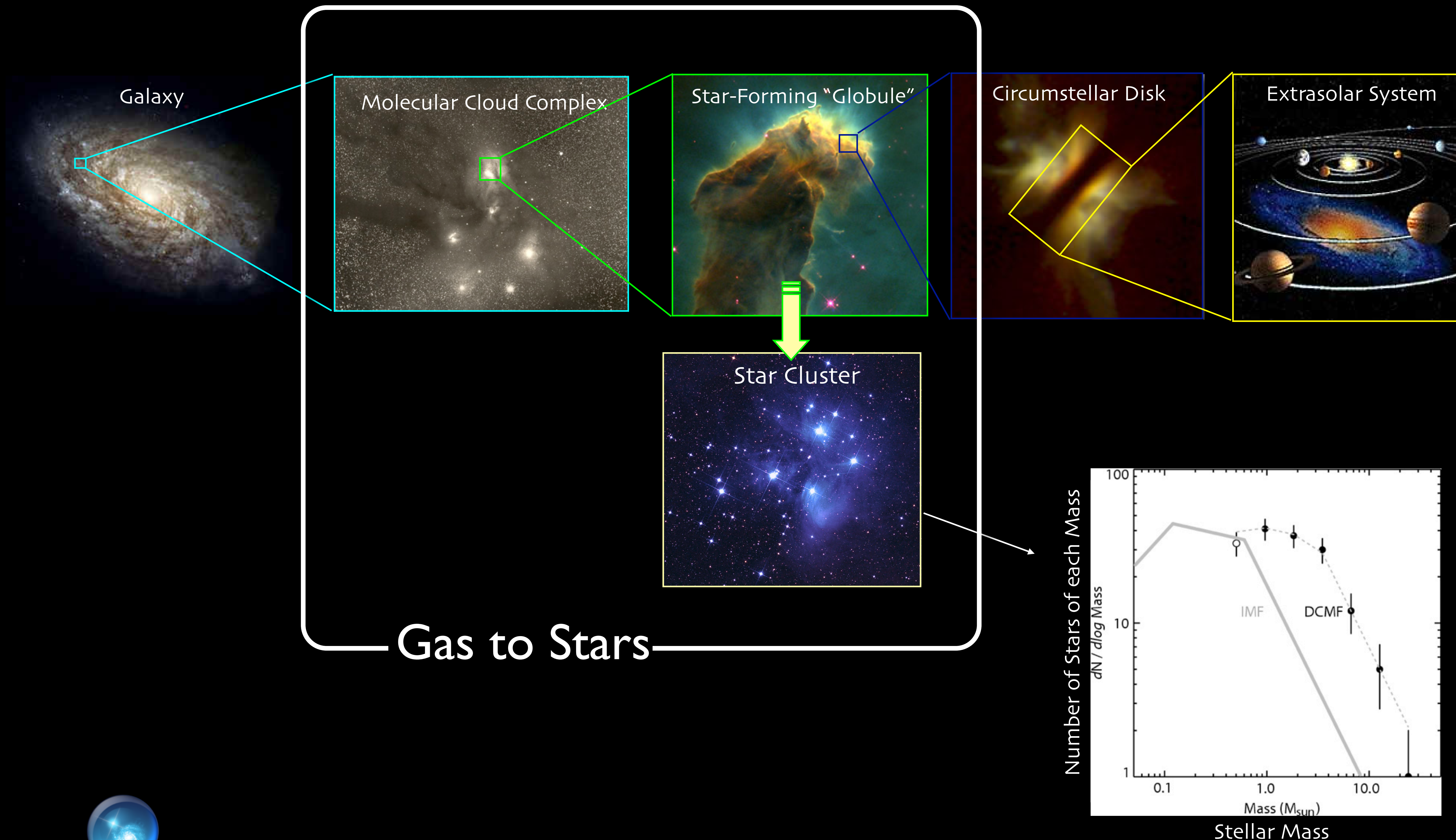


COMPLETE

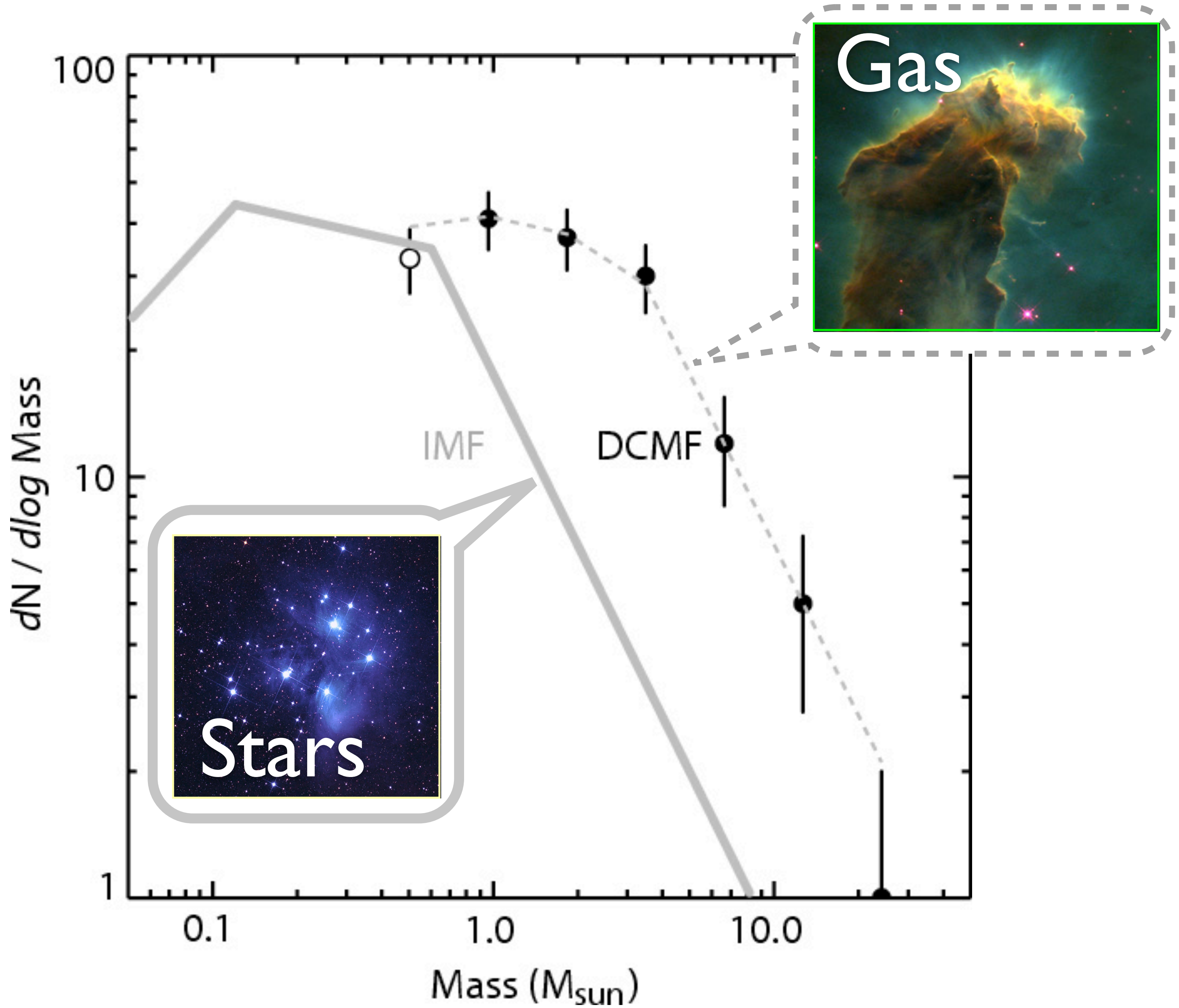
The **CO**ordinated **M**olecular **P**robe **L**ine **E**xtinction **T**hermal **E**mission Survey of Star-Forming Regions

Spitzer "Cores-to-Disks" Legacy Survey

Star (and Planet, and Moon) Formation 201



IMF from CMF ??

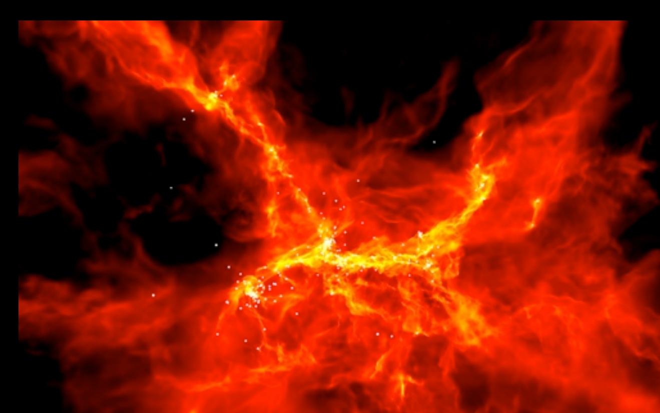


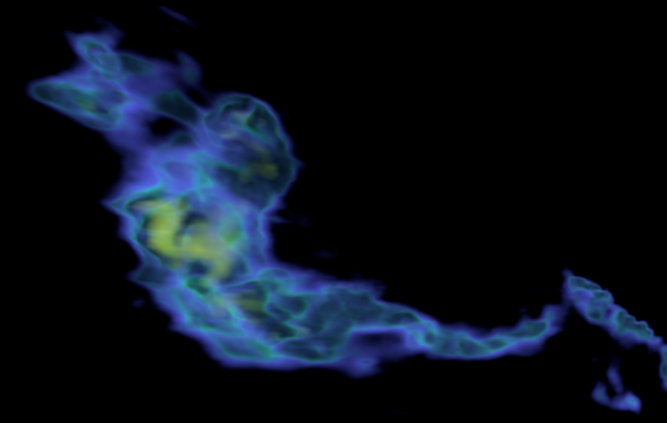
Alves, Lombardi & Lada 2007

BUT: Beautiful images like this do not reveal *internal* structure directly...

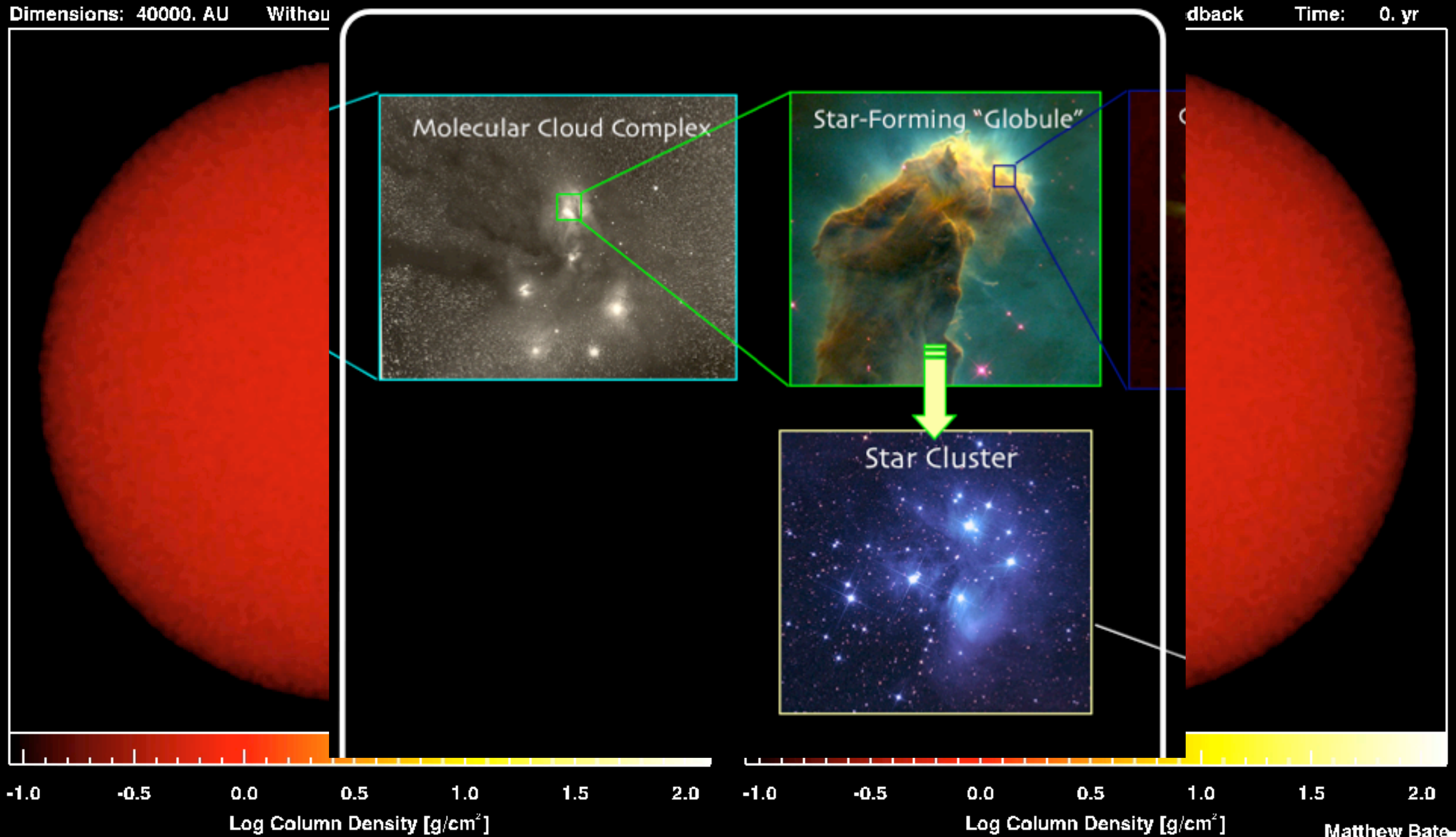
simulations

>2D observations

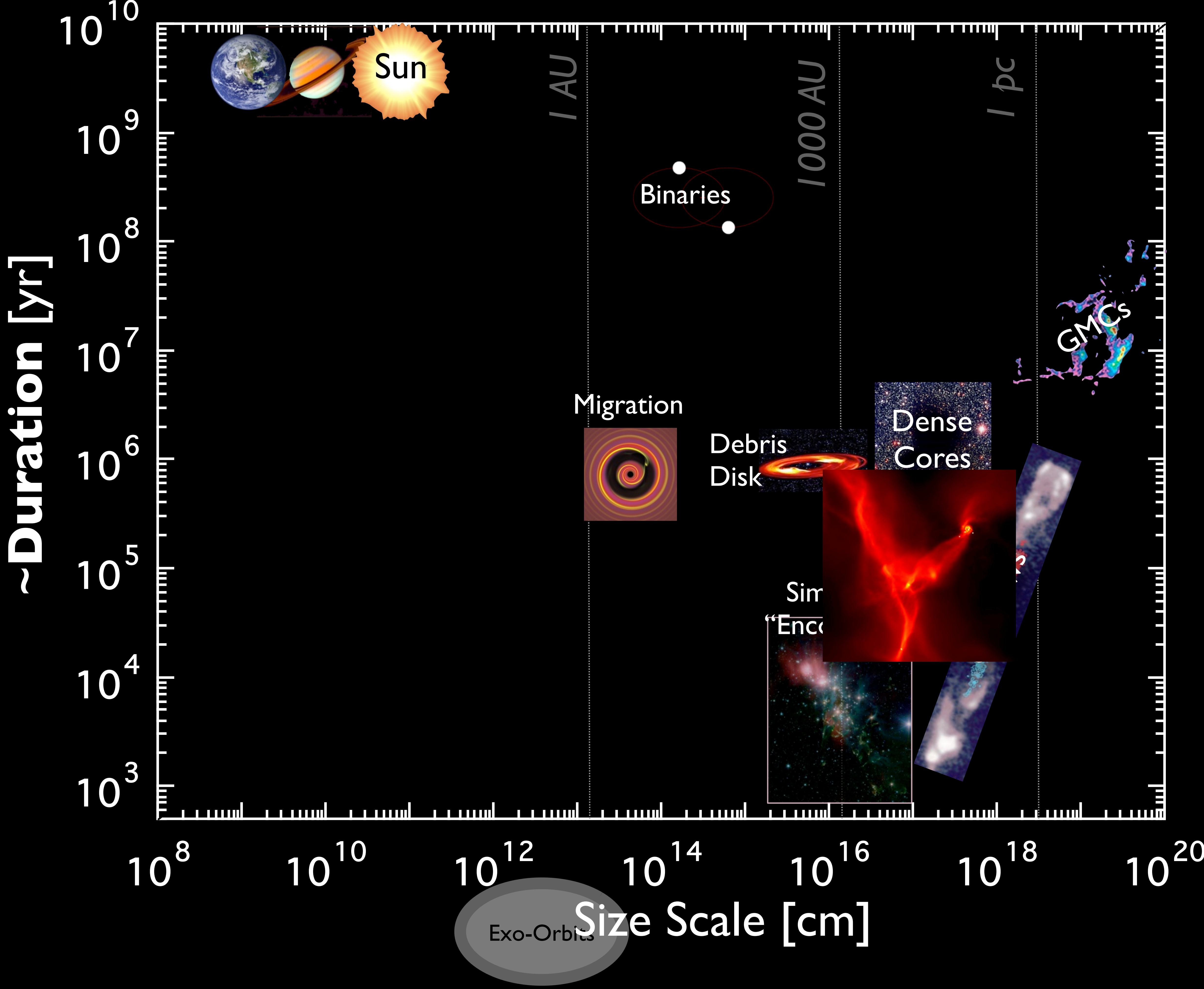


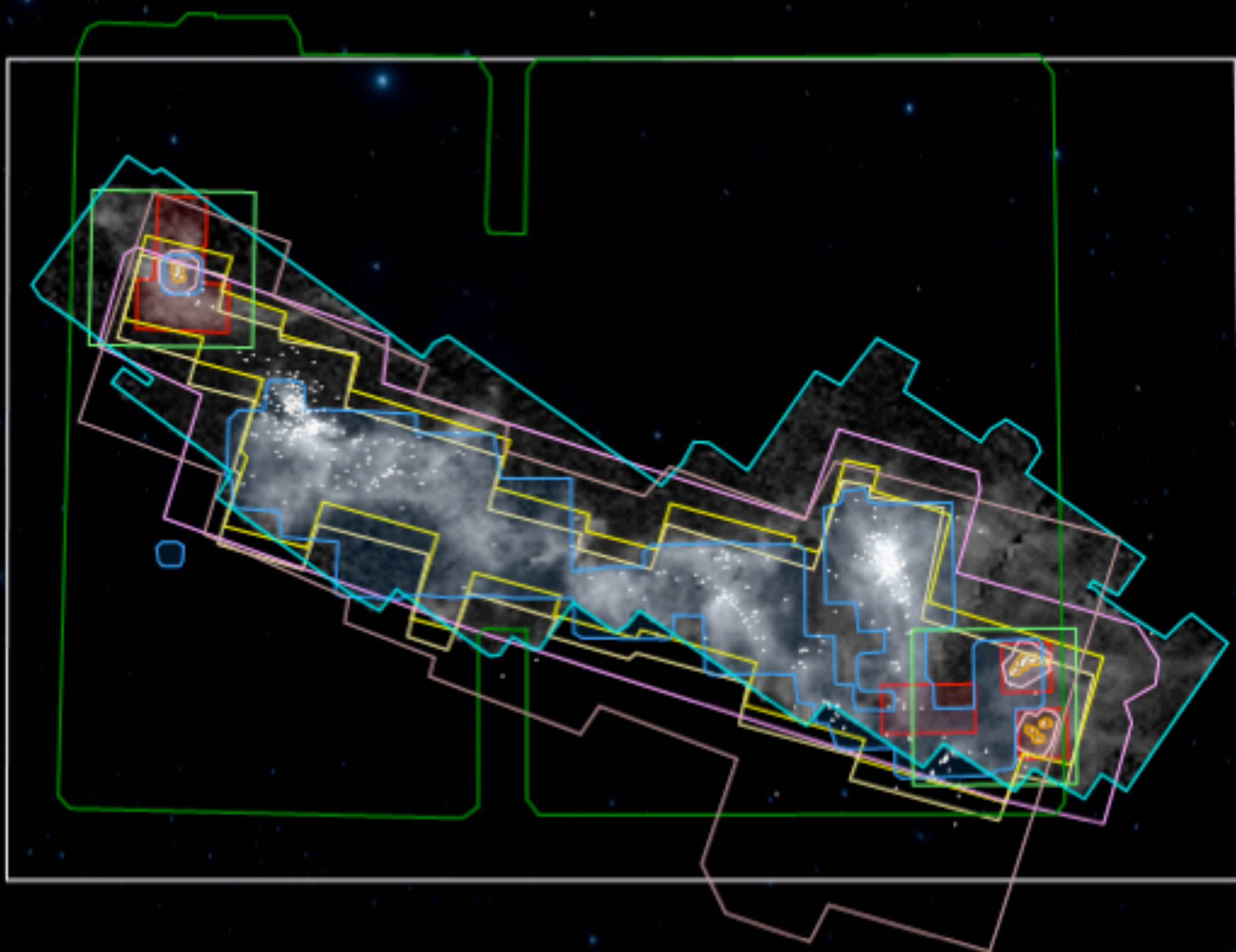


Our Goal is to "Taste" Star Formation



Simulations of Bate 2009


~Duration [yr]
Size Scale [cm]
Sun
1 AU
1000 AU
1 pc
Binaries
GMCs
Migration
Debris
Disk
Dense
Cores
Exo-Orbits



Completely

COMPLETE

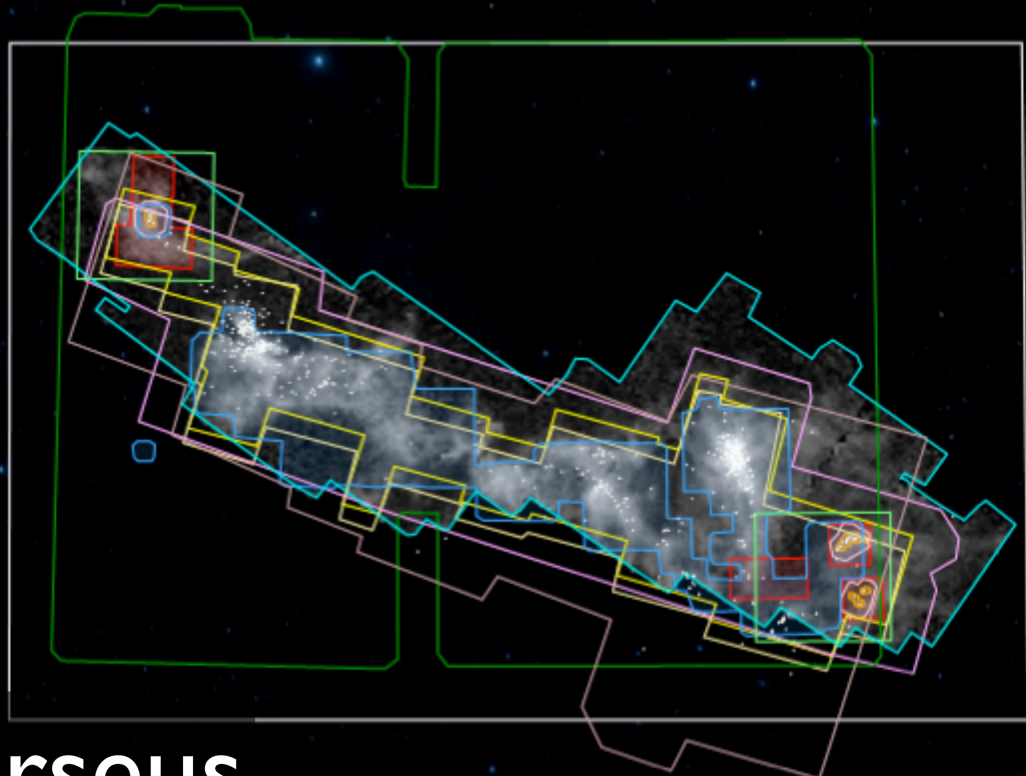
Alyssa Goodman,
Harvard-Smithsonian Center for Astrophysics

COMPLETE
up to Fall 2011

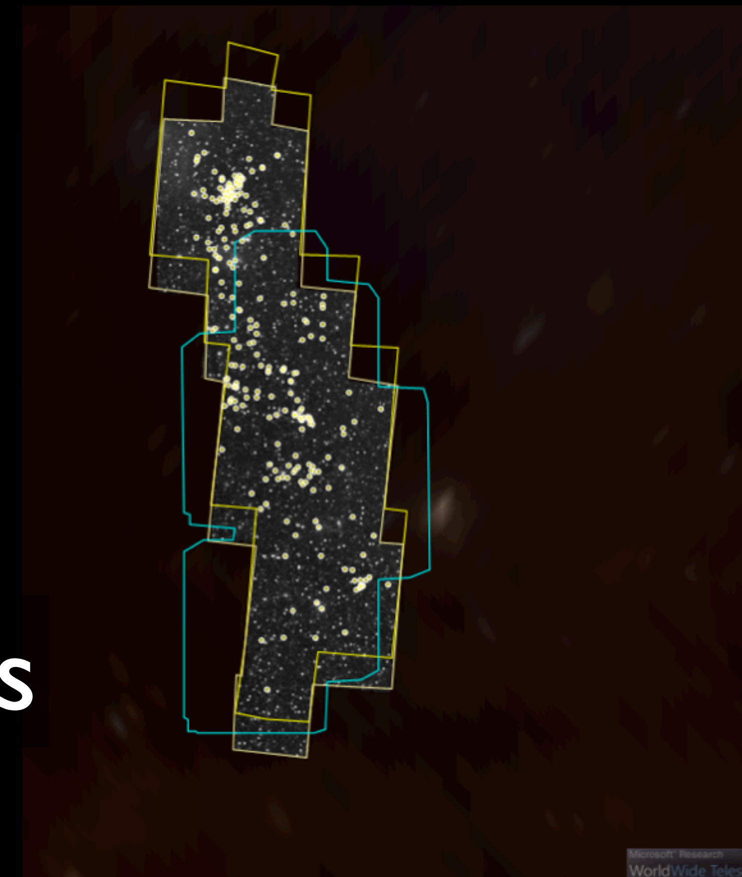
Joao **Alves**
Héctor **Arce**
Chris **Beaumont***
Michelle **Borkin***
Paola **Caselli**
James **Di Francesco**
Jonathan **Foster***
Alyssa **Goodman** (PI)
Mark **Heyer**
Doug **Johnstone**
Jens **Kauffmann**
Helen **Kirk***
Di **Li**
Jaime **Pineda***
Naomi **Ridge**
Erik **Rosolowsky**
Scott **Schnee***
Rahul **Shetty**
Mario **Tafalla**

**=COMPLETE Ph.D.*

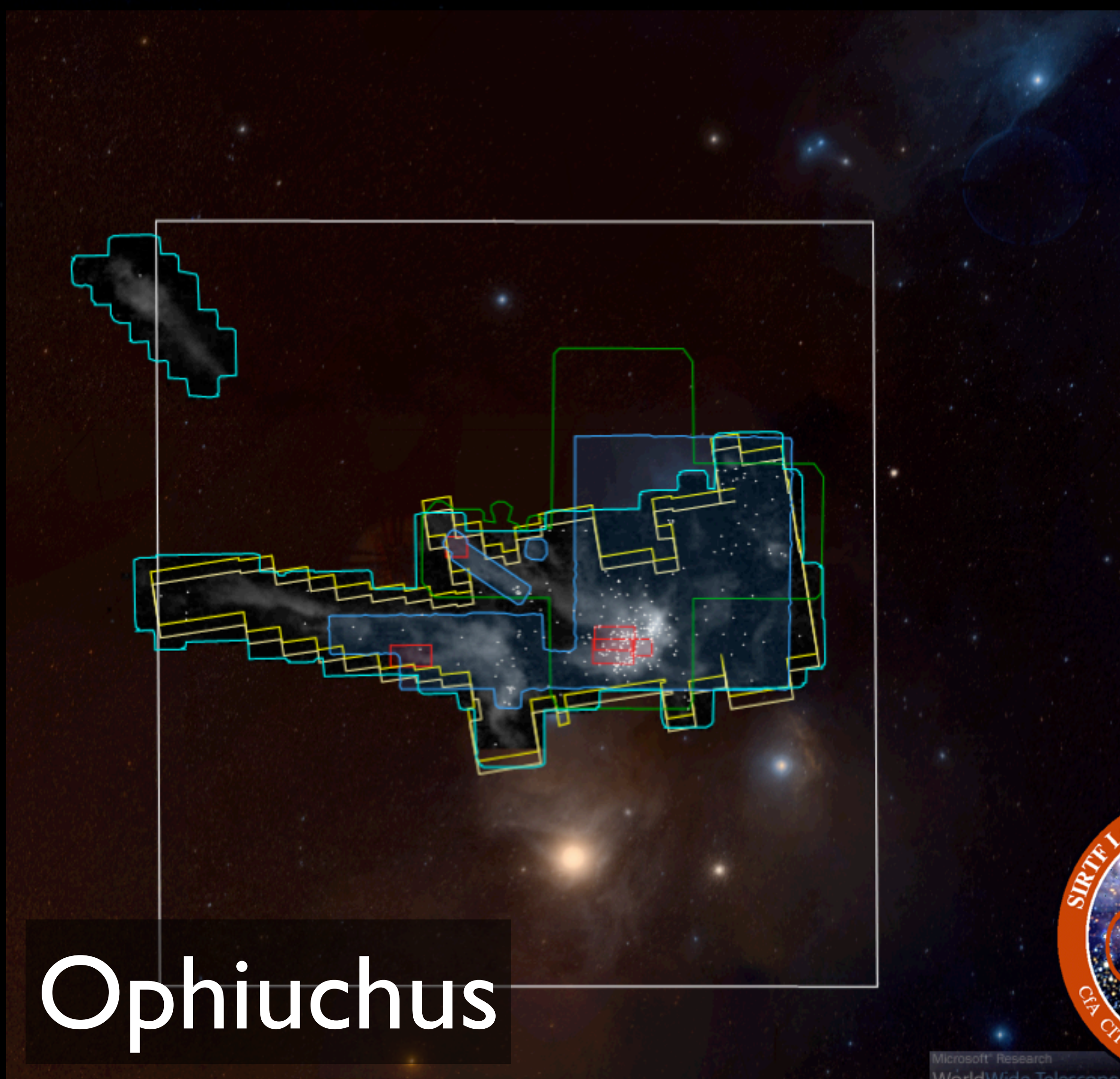
+many thanks to special friends of COMPLETE: Hope ***Chen****, Michael* ***Halle****, Marco* ***Lombardi****, Phil* ***Myers****, Stella* ***Offner****, Tom* ***Robitaille****,* ***c2d*** *Team, co-authors, undergrad interns...*



Perseus



Serpens



COMPLETE

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

SIRTF Legacy: From Cores to Disks
c2d
CfA CIT IPAC JPL NAU UL UMd UT

www.cfa.harvard.edu/COMPLETE
tinyurl.com/completepapers

COMPLETE

The "**CO**ordinated

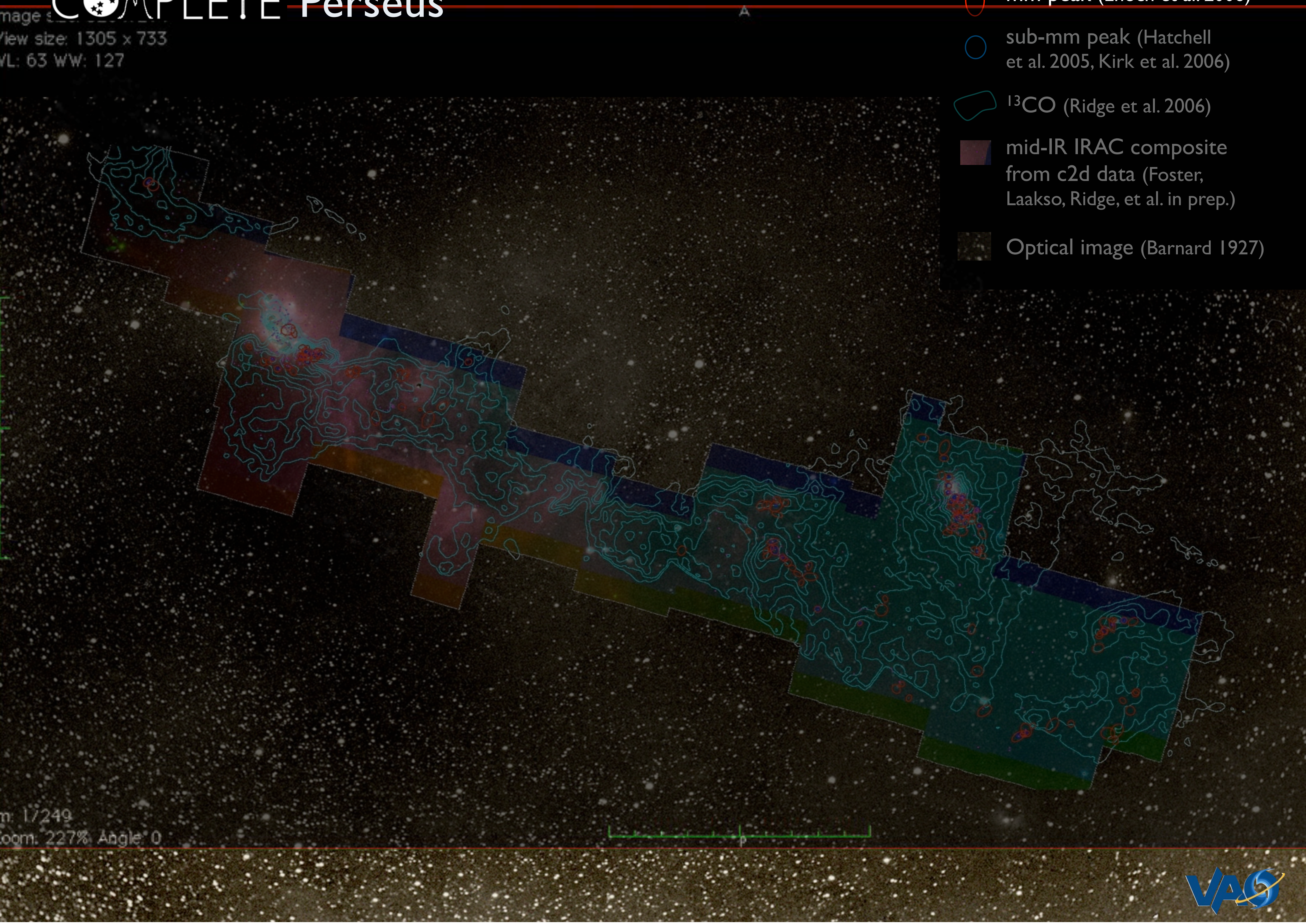
Molecular **P**robe **L**ine

Extinction

Thermal **E**mission"

Survey of Star-Forming Regions

COMPLETE Perseus



Pineda	2011	Expanded Very Large Array Observations of the Barnard 5 Star-forming Core: Embedded Filaments Revealed
Goodman	2011	A Guide to Comparisons of Star Formation Simulations with Observations
Arce	2011	A Bubbling Nearby Molecular Cloud: COMPLETE Shells in Perseus
Shetty	2010	The Effect of Projection on Derived Mass-Size and Linewidth-Size Relationships
Pineda	2010	Direct Observation of a Sharp Transition to Coherence in Dense Cores
Kirk	2010	The Dynamics of Dense Cores in the Perseus Molecular Cloud. II. The Relationship Between Dense Cores and the Cloud
Kauffmann	2010	The Mass-Size Relation from Clouds to Cores. I. A New Probe of Structure in Molecular Clouds
Kauffmann	2010	The Mass-size Relation from Clouds to Cores. II. Solar Neighborhood Clouds
Johnstone	2010	Dense Gas Tracers in Perseus: Relating the N2H+, NH3, and Dust Continuum Properties of Pre- and Protostellar Cores
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Shetty	2009	The Effect of Line-of-Sight Temperature Variation and Noise on Dust Continuum Observations
Shetty	2009	The Effect of Noise on the Dust Temperature-Spectral Index Correlation
Schnee	2009	The Gas Temperature of Starless Cores in Perseus
Pineda	2009	The Perils of Clumpfind: The Mass Spectrum of Substructures in Molecular Clouds
Kirk	2009	The Interplay of Turbulence and Magnetic Fields in Star-Forming Regions: Simulations and Observations
Goodman	2009	A role for self-gravity at multiple length scales in the process of star formation.
Goodman	2009	The "True" Column Density Distribution in Star-Forming Molecular Clouds
Foster	2009	Dense Cores in Perseus: The Influence of Stellar Content and Cluster Environment
Schnee	2008	Dust Emission from the Perseus Molecular Cloud
Rosolowsky	2008	Structural Analysis of Molecular Clouds: Dendrograms
Rosolowsky	2008	An Ammonia Spectral Atlas of Dense Cores in Perseus
Pineda	2008	CO Isotopologues in the Perseus Molecular Cloud Complex: the X-factor and Regional Variations
Jørgensen	2008	Current Star Formation in the Ophiuchus and Perseus Molecular Clouds: Constraints and Comparisons from Unbiased Submillimeter and Mid-Infrared Surveys. II
Foster	2008	Hunting Galaxies to (and for) Extinction
Kirk	2007	Dynamics of Dense Cores in the Perseus Molecular Cloud
Kirk	2007	Erratum: ``The Large- and Small-Scale Structures of Dust in the Star-forming Perseus Molecular Cloud" (ApJ, 646, 1009 [2006])
Jørgensen	2007	Current Star Formation in the Perseus Molecular Cloud: Constraints from Unbiased Submillimeter and Mid-Infrared Surveys
Schnee	2006	Estimating the Column Density in Molecular Clouds with Far-Infrared and Submillimeter Emission Maps
Ridge	2006	The COMPLETE Nature of the Warm Dust Shell in Perseus
Ridge	2006	The COMPLETE Survey of Star-Forming Regions: Phase I Data
Kirk	2006	The Large- and Small-Scale Structures of Dust in the Star-forming Perseus Molecular Cloud
Foster	2006	Cloudshine: New Light on Dark Clouds
Schnee	2005	A COMPLETE Look at the Use of IRAS Emission Maps to Estimate Extinction and Dust Temperature
Johnstone	2004	An Extinction Threshold for Protostellar Cores in Ophiuchus
Goodman	2004	The COMPLETE Survey of Star-Forming Regions on its Second Birthday

I will not do this to you...

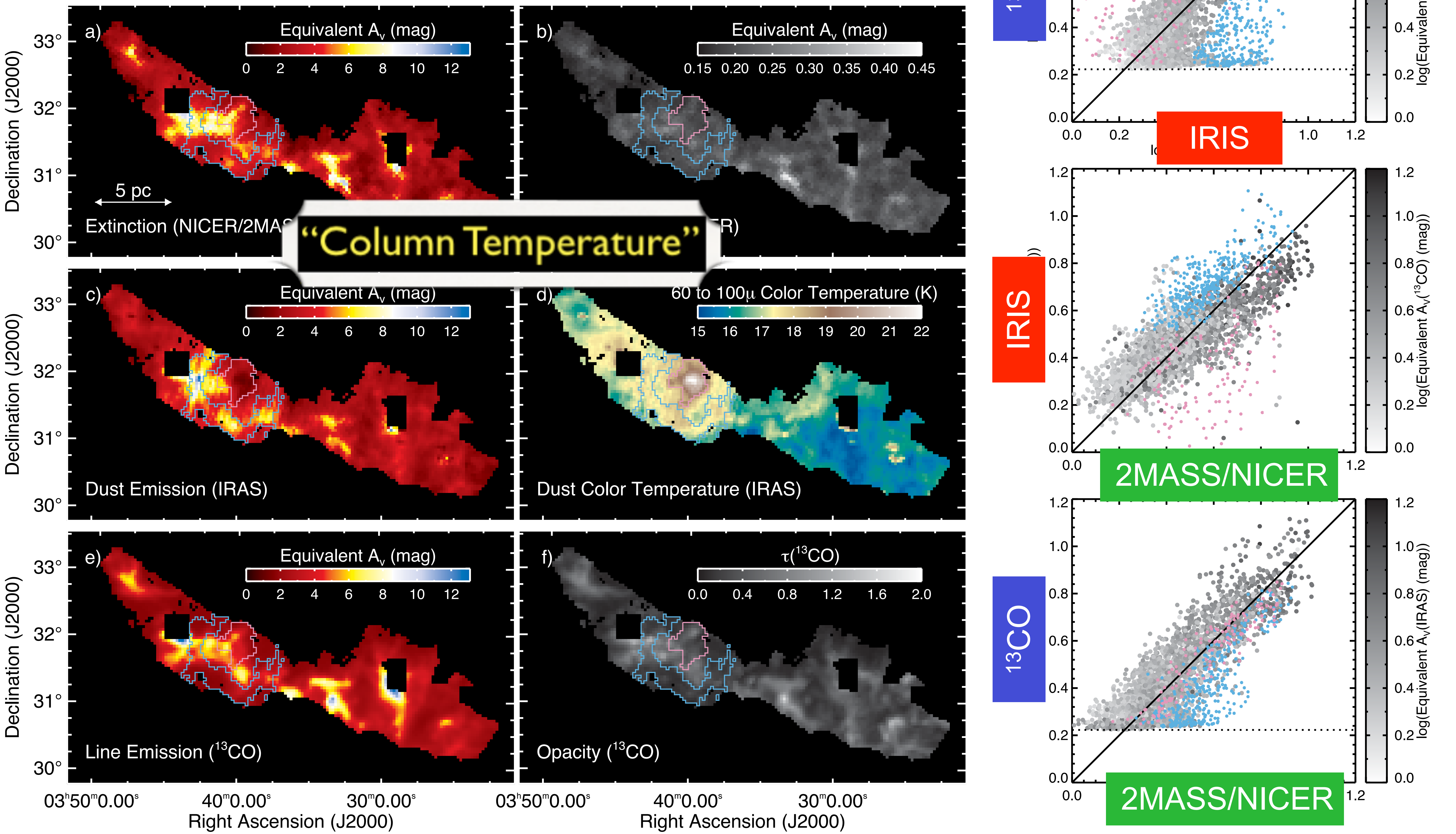
YELLOW = something I didn't know about or appreciate before COMPLETE

20 minutes from now...

- “Column Temperature”
- ^{13}CO poor tracer of column density, abundance not the problem
- “lognormal” (*but...*)
- “Cloudshine”
- GNICEST (and CS!)
- virial theorem over-used?
- Dangers of *p-p-v “observer”* space
- Perils of CLUMPFIND
- Benefits of Dendrograms
- Value of *Tasting* Dust & b-T
- Spherical(!) Outflows
- Cores in/out of Clusters NOT so Different
- Coherent Cores are Real, and they Fragment (into filaments)!?
- SLOW motion of cores & stars w.r.t. environs
- Density “thresholds” are way more complicated than they look

COMPLETE Perseus Column Density

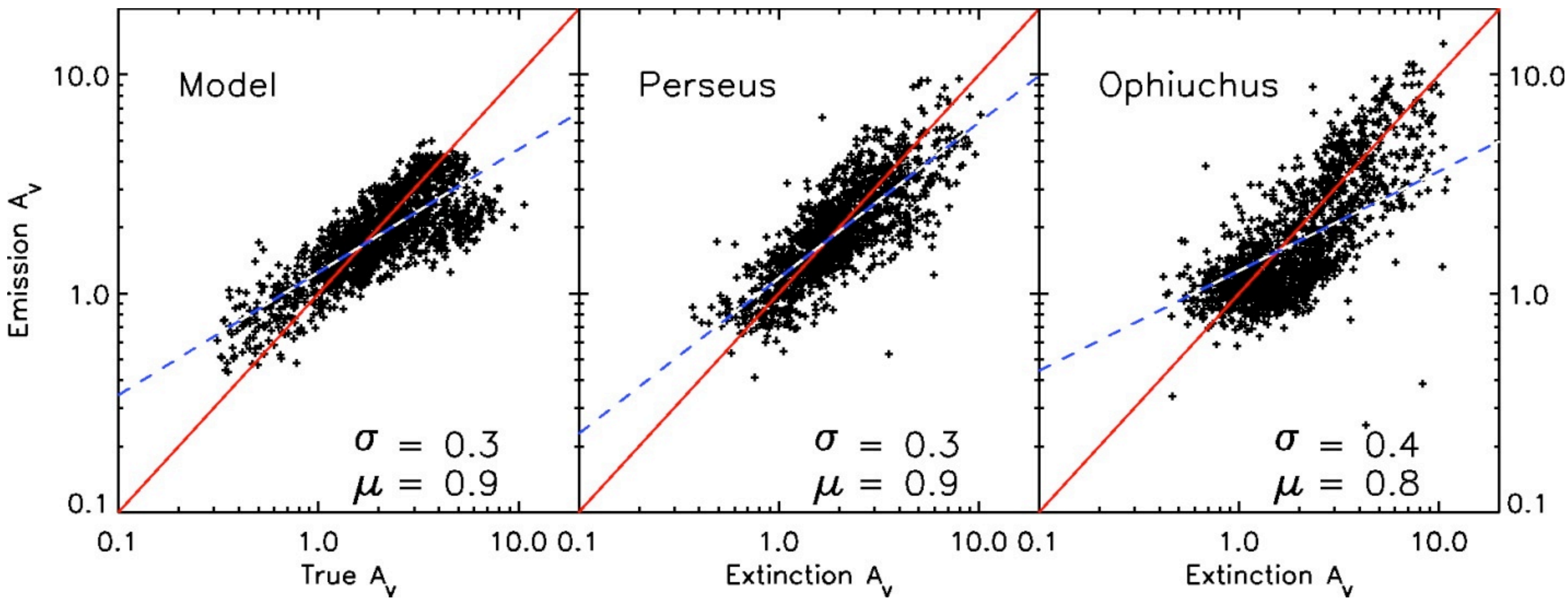
(Dust Emission, Extinction & Gas Emission)



figures: Goodman, Pineda & Schnee 2009 cf. Schnee et al. 2005, 2006, 2008; Pineda et al. 2008 ; +much work of ***Lada, Alves, Lombardi et al.***

Column Temperature

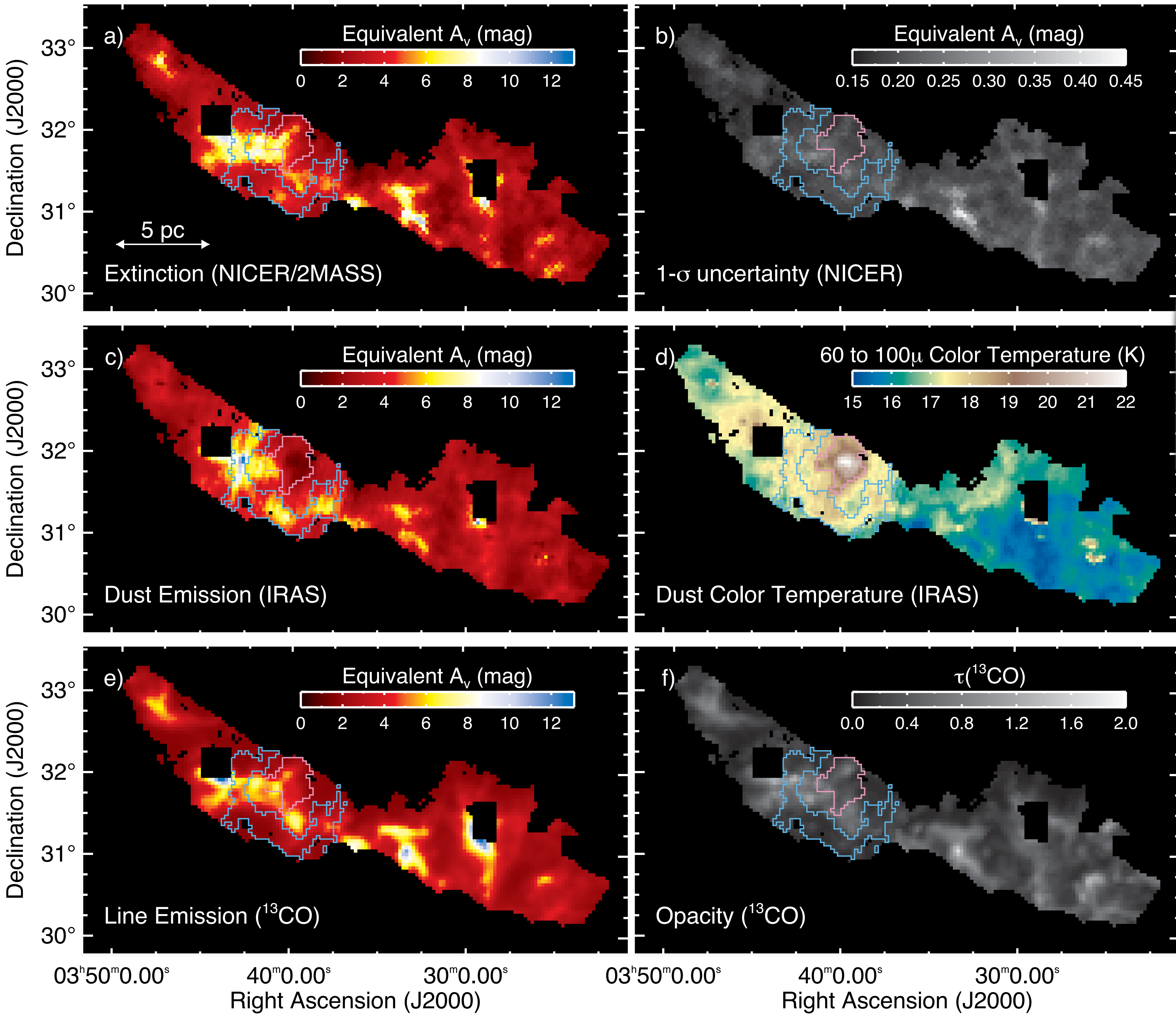
And, the value of calibrating emission with extinction...

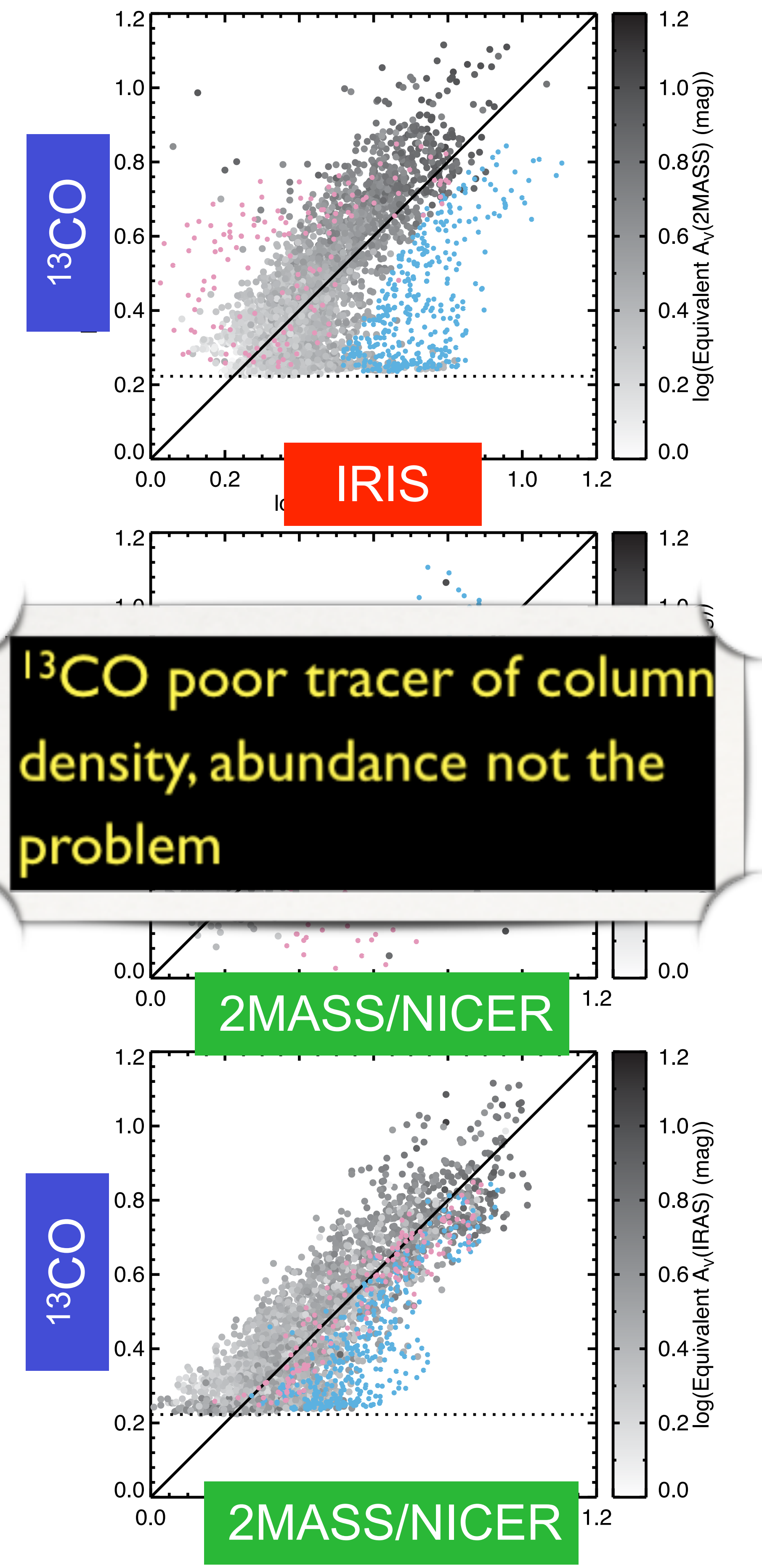


Schnee, Bethell & Goodman 2006

COMPLETE Perseus Column Density

(Dust Emission, Extinction & Gas Emission)

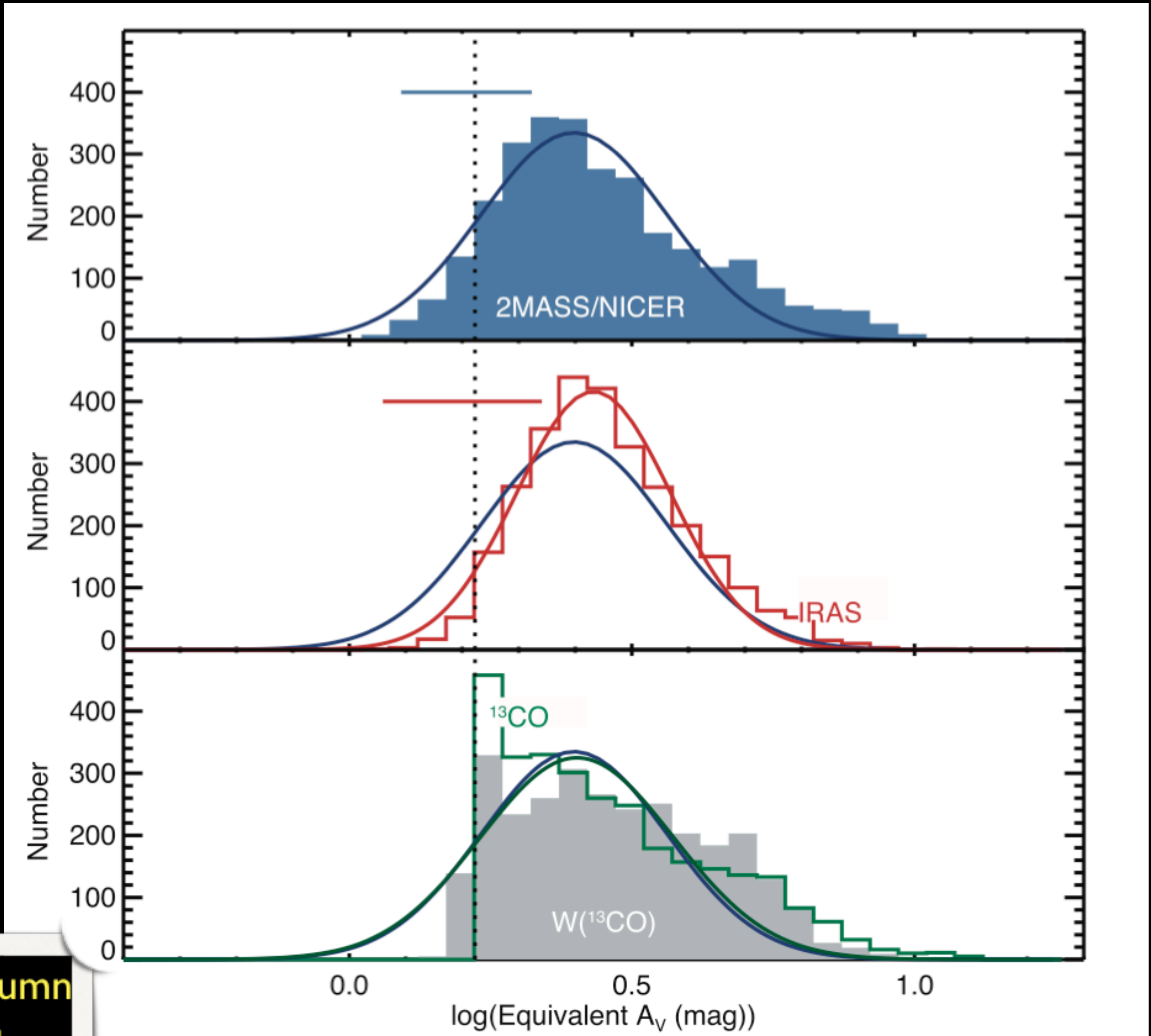




^{13}CO poor tracer of column density, abundance not the problem

figures: Goodman, Pineda & Schnee 2009 cf. Schnee et al. 2005, 2006, 2008; Pineda et al. 2008

Yes, Column Density Distribution is "lognormal" (*but...*)

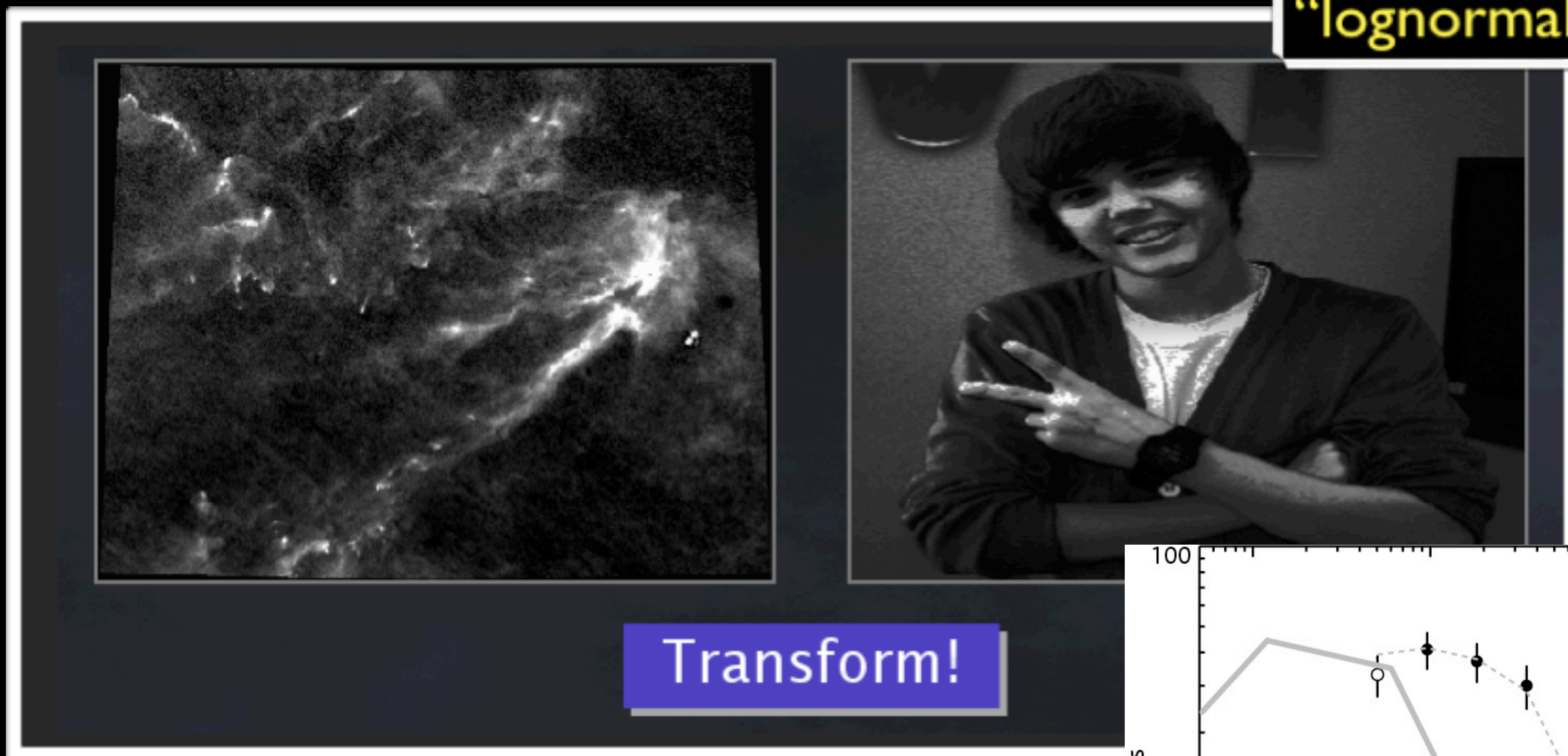


^{13}CO poor tracer of column density, abundance not the problem

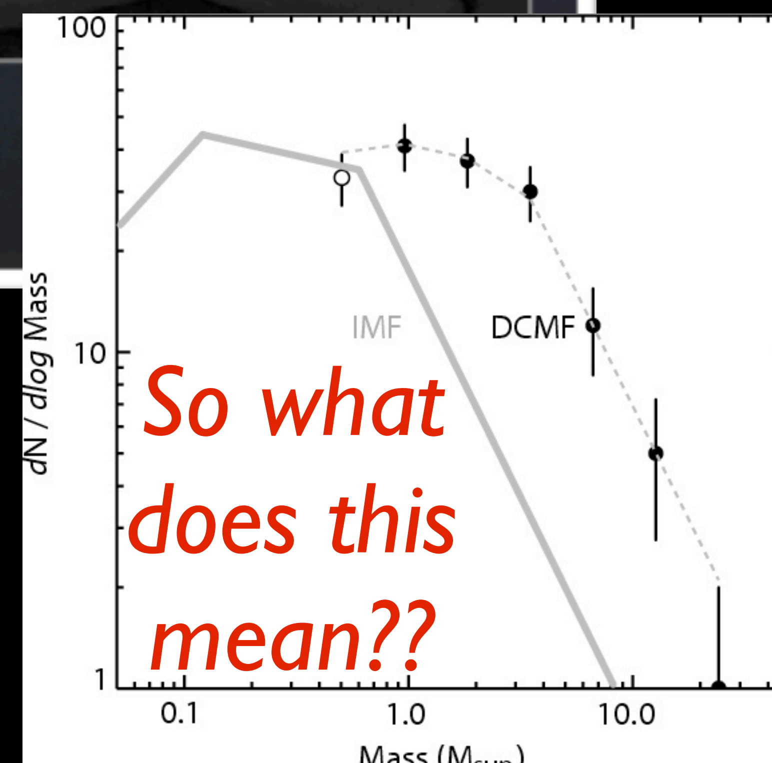
Goodman, Pineda & Schnee 2009; Pineda et al. 2008
cf. 2MASS results of Alves, Kainulainen, Lada, Lombardi et al.

...Justin Bieber, and the IMF, can be lognormal too...

"lognormal" (*but...*)



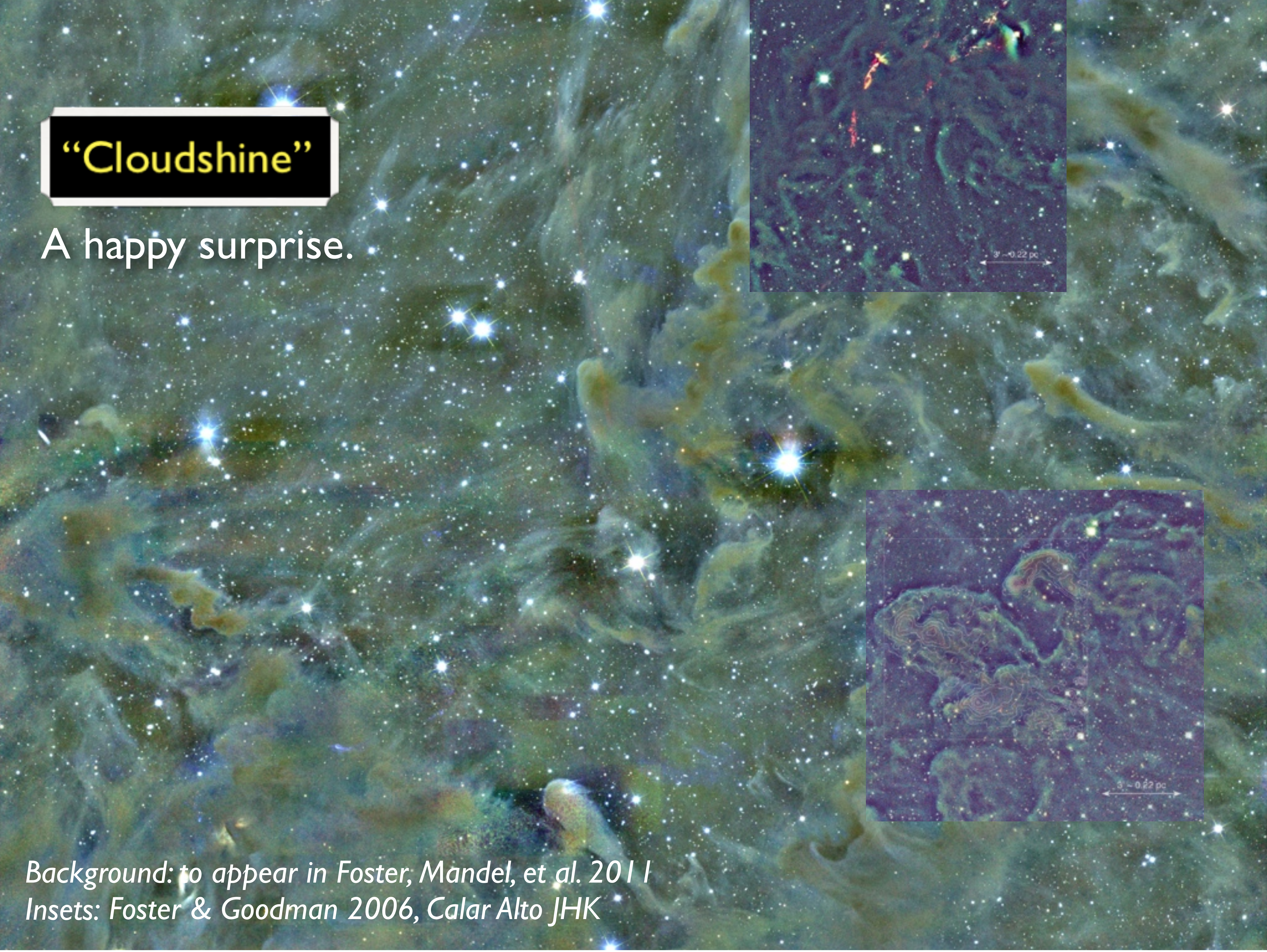
and so is any
multiplicative random process.



see Beaumont et al. 2011, and http://www.ifa.hawaii.edu/users/beaumont/histograms/index.html

“Cloudshine”

A happy surprise.



Background: to appear in Foster, Mandel, et al. 2011
Insets: Foster & Goodman 2006, Calar Alto JHK

Extinction Mapping

NICE, NICER, NICEST, GNICER, GNICEST (and CS!)

THE ASTROPHYSICAL JOURNAL, 674:831–845, 2008 February 20

HUNTING GALAXIES TO (AND FOR) EXTINCTION

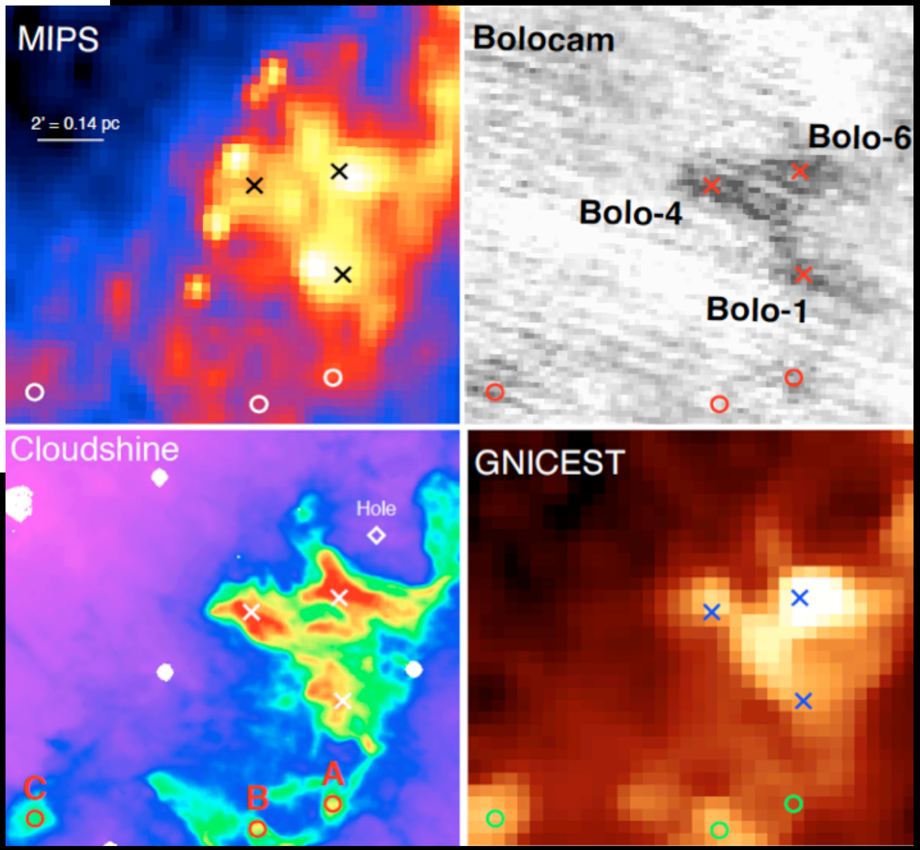
JONATHAN B. FOSTER,[1] CARLOS G. ROMÁN-ZÚÑIGA,[1,2] ALYSSA A. GOODMAN,[1] ELIZABETH A. LADA,[3] AND JOÃO ALVES[2]
Received 2007 September 1; accepted 2007 October 28

ABSTRACT

In studies of star-forming regions, near-infrared excess (NIRX) sources—objects with intrinsic colors redder than normal stars—constitute both signal (young stars) and noise (e.g., background galaxies). We hunt down (identify) galaxies using near-infrared observations in the Perseus star-forming region by combining structural information, colors, and number density estimates. Galaxies at moderate redshifts ($z = 0.1$–0.5) have colors similar to young stellar objects (YSOs) at both near- and mid-infrared (e.g., *Spitzer*) wavelengths, which limits our ability to identify YSOs from colors alone. Structural information from high-quality near-infrared observations allows us to better separate YSOs from galaxies, rejecting two out of five of the YSO candidates identified from *Spitzer* observations of our regions and potentially extending the YSO luminosity function below *K* of 15 mag where galaxy contamination dominates. Once they are identified we use galaxies as valuable extra signals for making extinction maps of molecular clouds. Our new iterative procedure, the galaxies near-infrared color excess method revisited (GNICER), uses the mean colors of galaxies as a function of magnitude to include them in extinction maps in an unbiased way. GNICER increases the number of background sources used to probe the structure of a cloud, decreasing the noise and increasing the resolution of extinction maps made far from the galactic plane.

Subject headings: dust, extinction — galaxies: fundamental parameters — ISM: structure — stars: pre–main-sequence

Online material: color figures



Foster et al. 2008;
Beaumont et al. 2011 (for "CS")

Where and when does gravity matter?

And, is the virial theorem over-used?

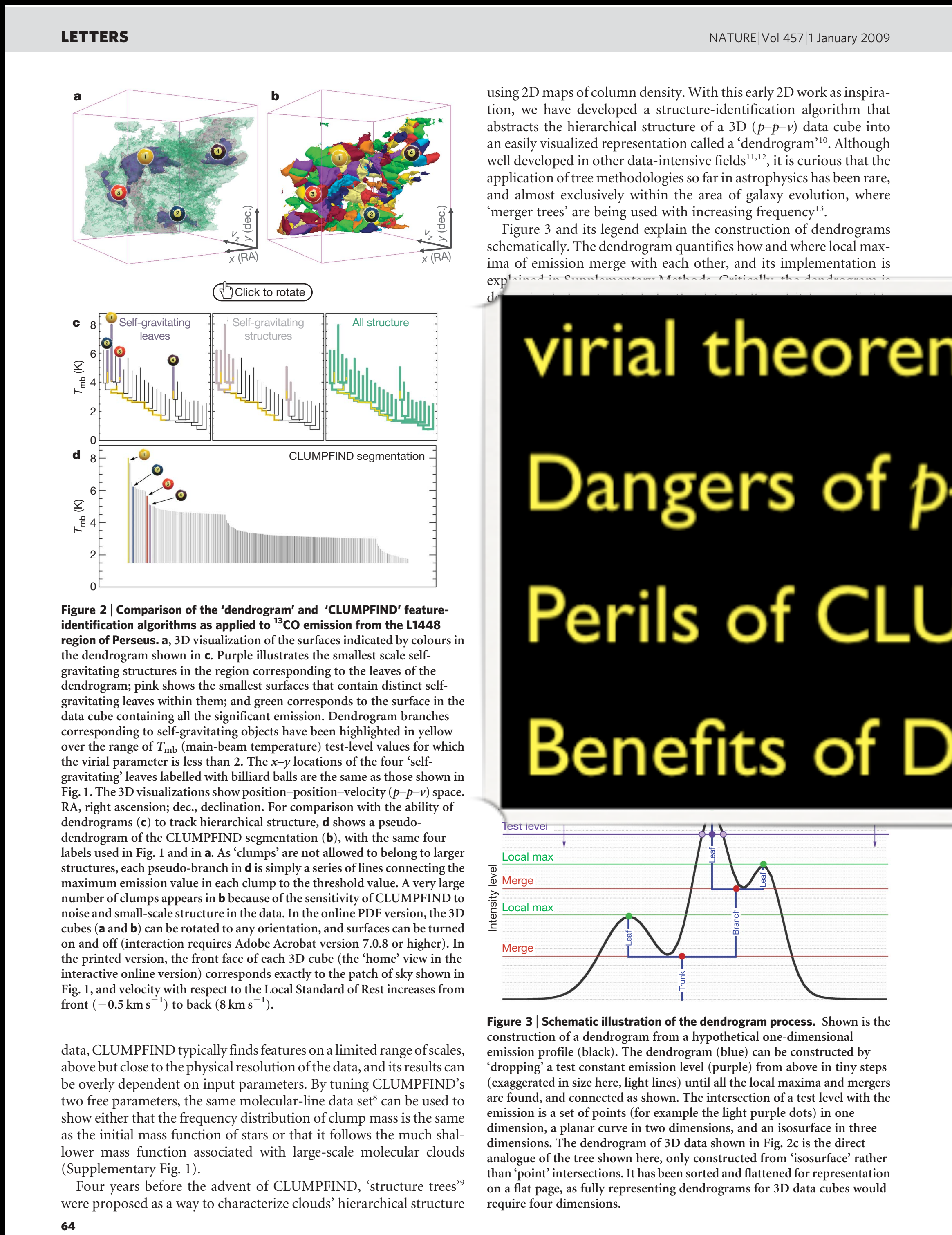


Figure 2 | Comparison of the 'dendrogram' and 'CLUMPFIND' feature-identification algorithms as applied to ^{13}CO emission from the L1448 region of Perseus. a, 3D visualization of the surfaces indicated by colours in the dendrogram shown in **c**. Purple illustrates the smallest scale self-gravitating 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 exp…

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.

virial theorem over-used?

Dangers of *p-p-v* "*observer*" space

Perils of CLUMPFIND

Benefits of Dendrograms

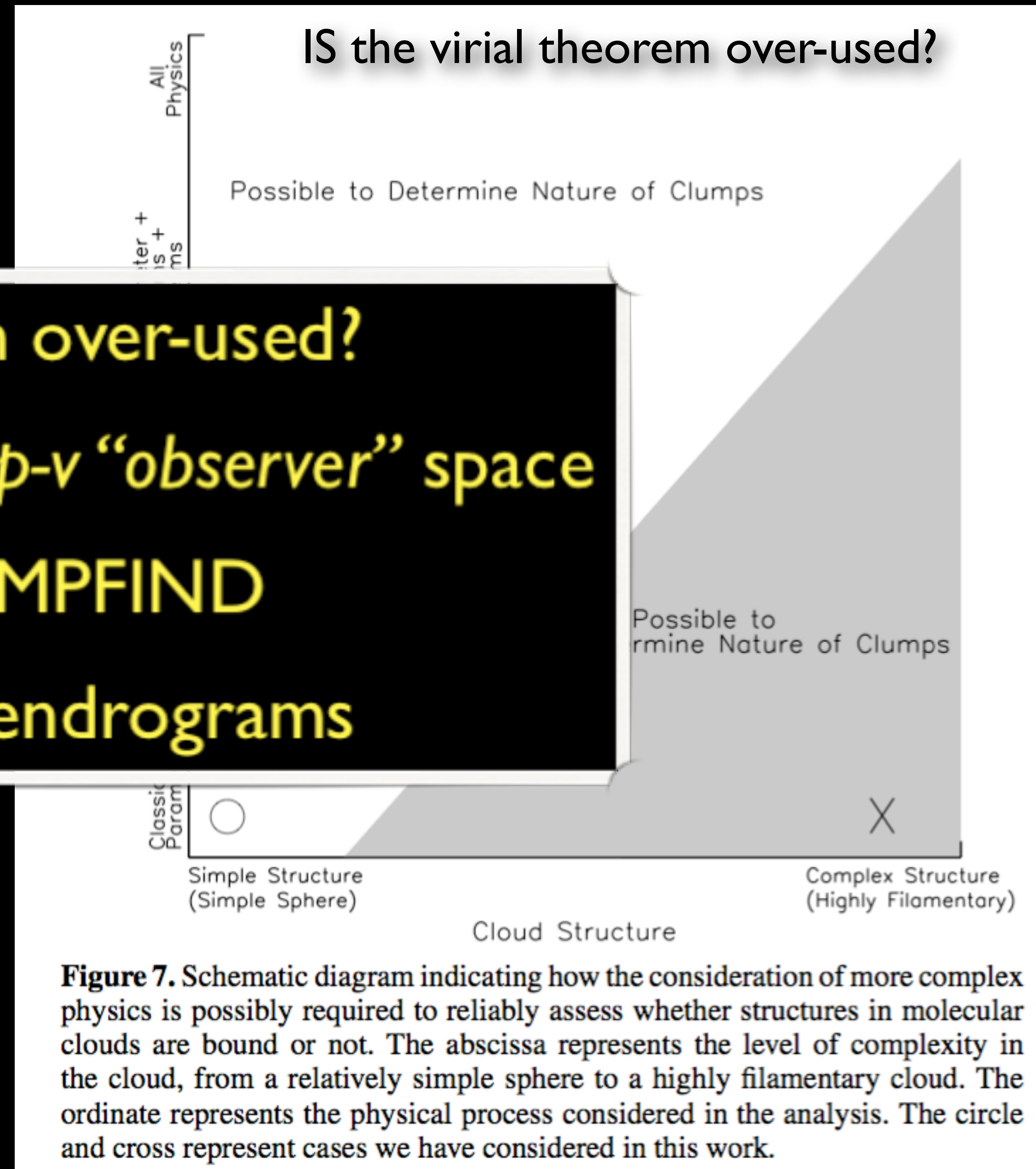


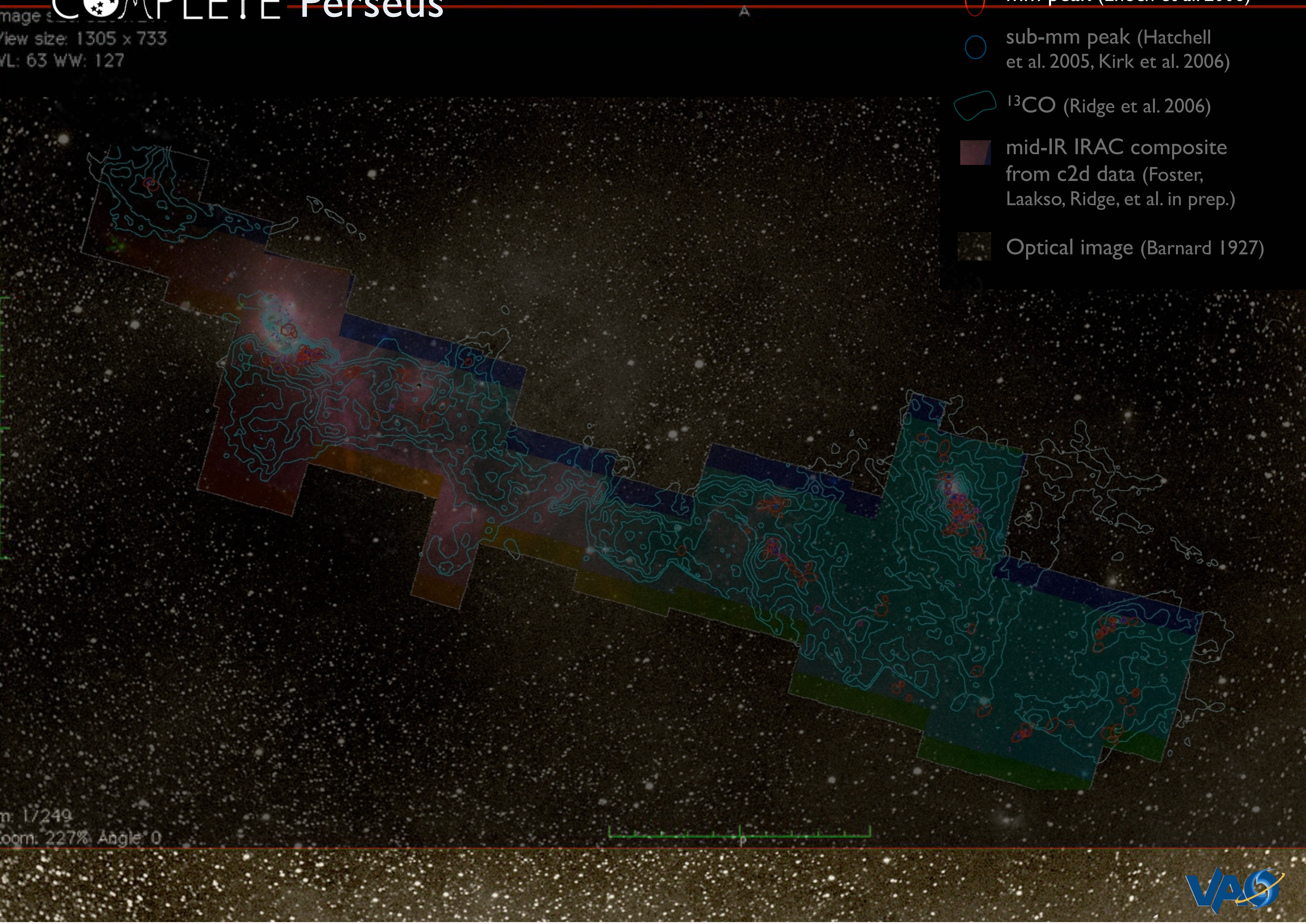
Figure 7. Schematic diagram indicating how the consideration of more complex physics is possibly required to reliably assess whether structures in molecular clouds are bound or not. The abscissa represents the level of complexity in the cloud, from a relatively simple sphere to a highly filamentary cloud. The ordinate represents the physical process considered in the analysis. The circle and cross represent cases we have considered in this work.

Goodman et al. 2009

Shetty et al. 2010

Tuesday, February 7, 2012

COMPLETE Perseus

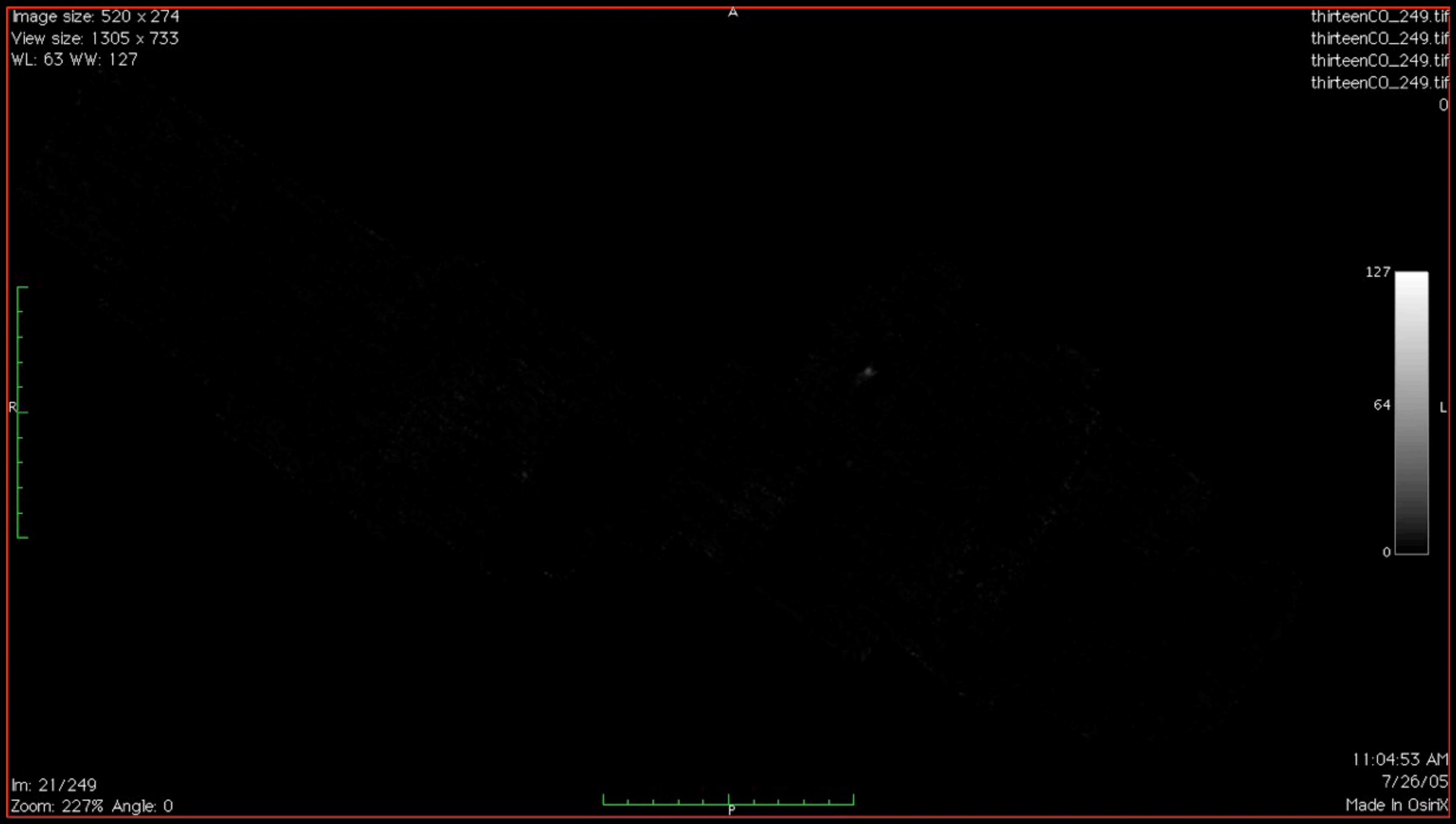


Value of High-Dimensional Visualization and "Taste-Testing"...
p-p-v space, and more...

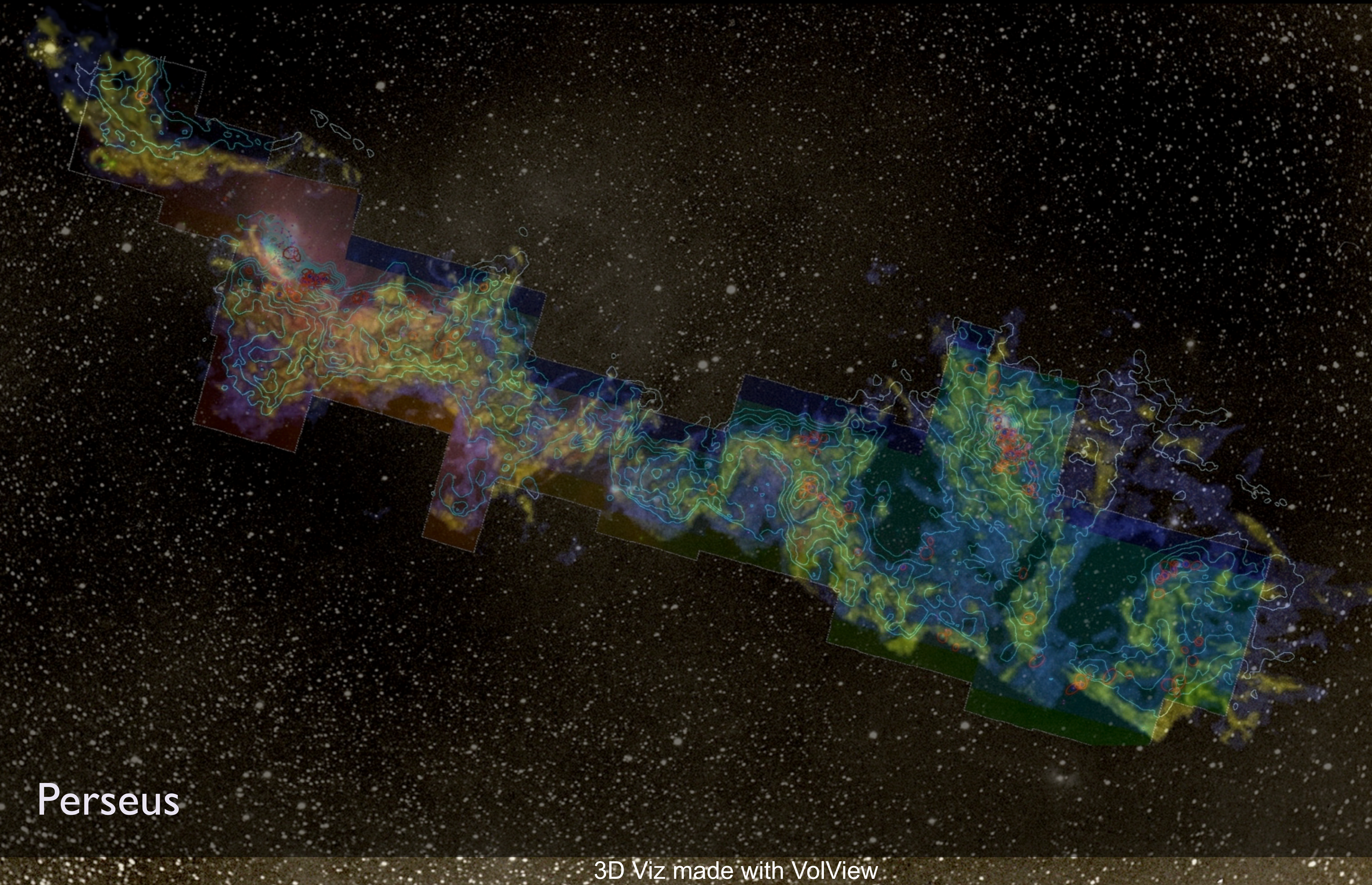
"KEITH"

"z" is depth into head

"PERSEUS"



"z" is line-of-sight velocity



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Where and when does gravity matter?

And, is the virial theorem over-used?

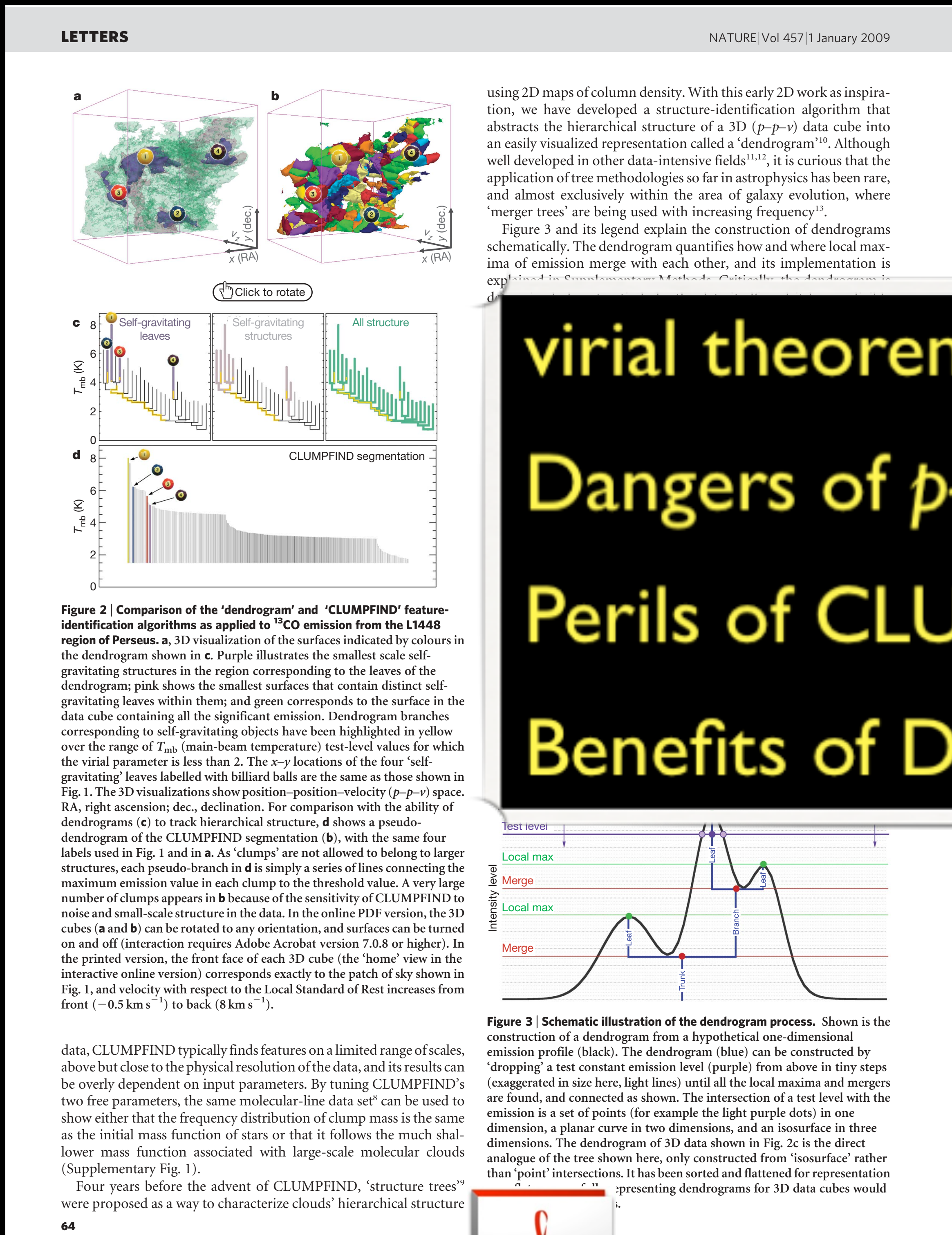


Figure 2 | Comparison of the 'dendrogram' and 'CLUMPFIND' feature-identification algorithms as applied to ^{13}CO emission from the L1448 region of Perseus. **a**, 3D visualization of the surfaces indicated by colours in the dendrogram shown in **c**. Purple illustrates the smallest scale self-gravitating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

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

virial theorem over-used?

Dangers of *p-p-v* "*observer*" space

Perils of CLUMPFIND

Benefits of Dendrograms

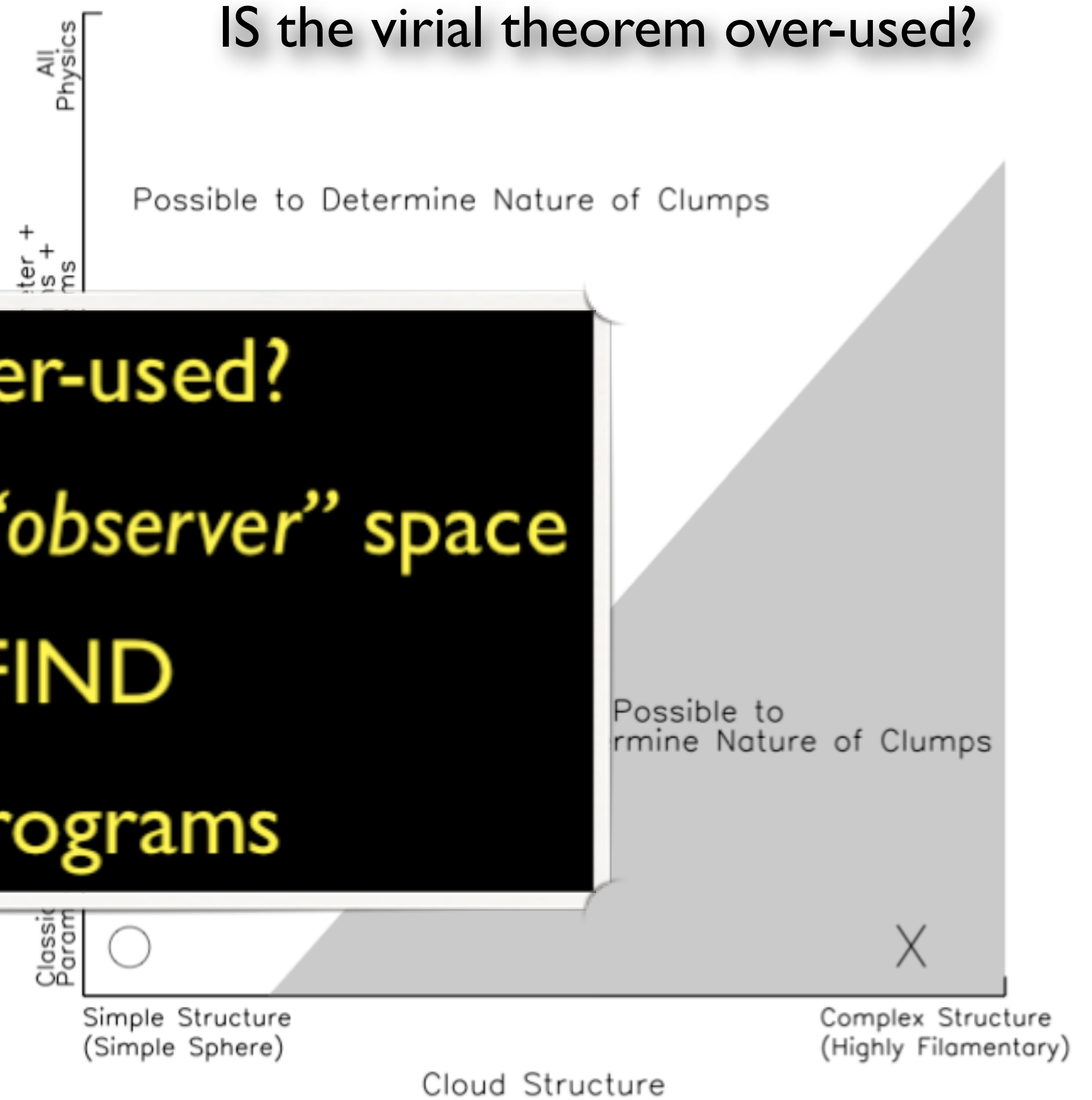
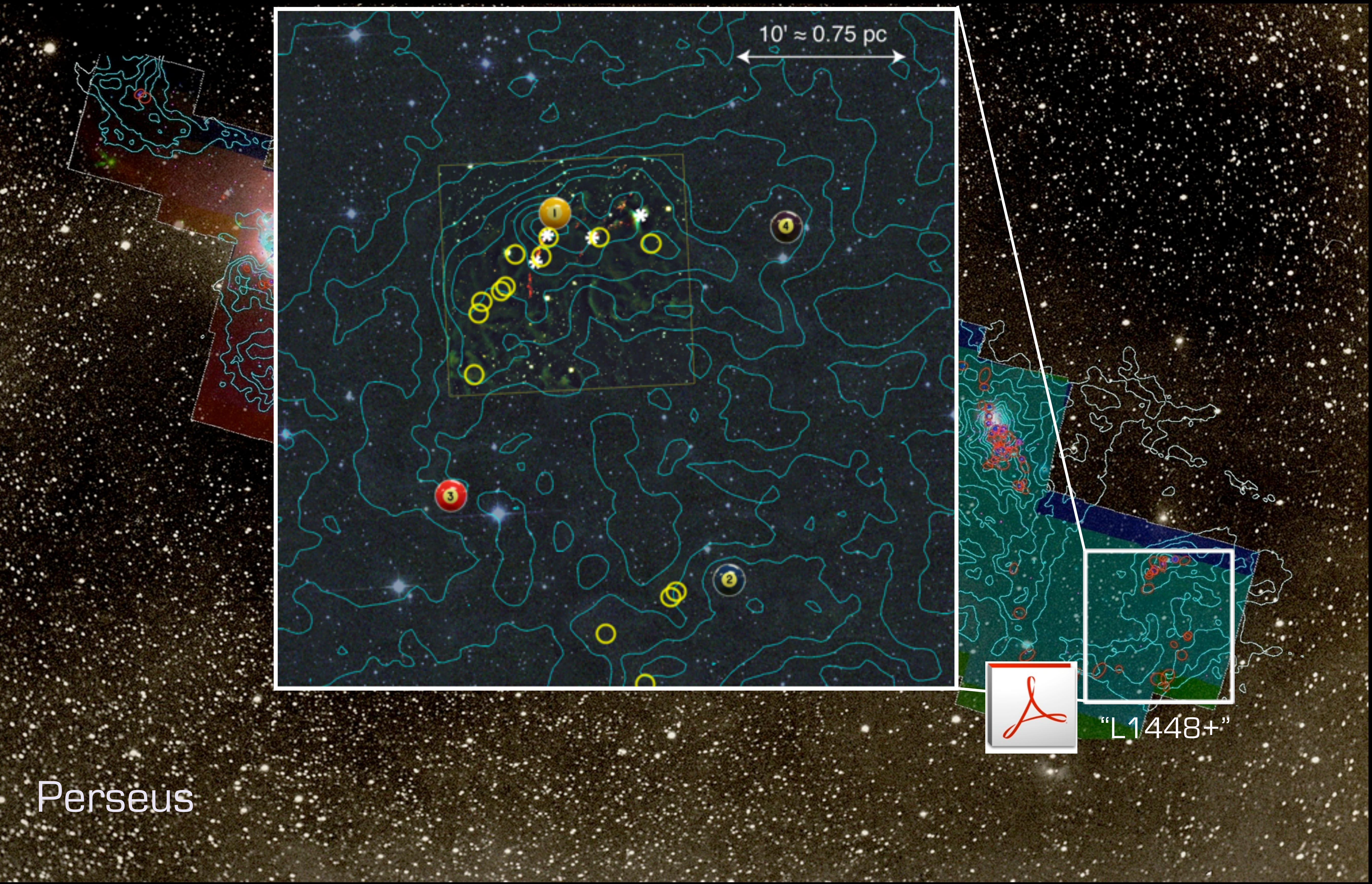


Figure 7. Schematic diagram indicating how the consideration of more complex physics is possibly required to reliably assess whether structures in molecular clouds are bound or not. The abscissa represents the level of complexity in the cloud, from a relatively simple sphere to a highly filamentary cloud. The ordinate represents the physical process considered in the analysis. The circle and cross represent cases we have considered in this work.

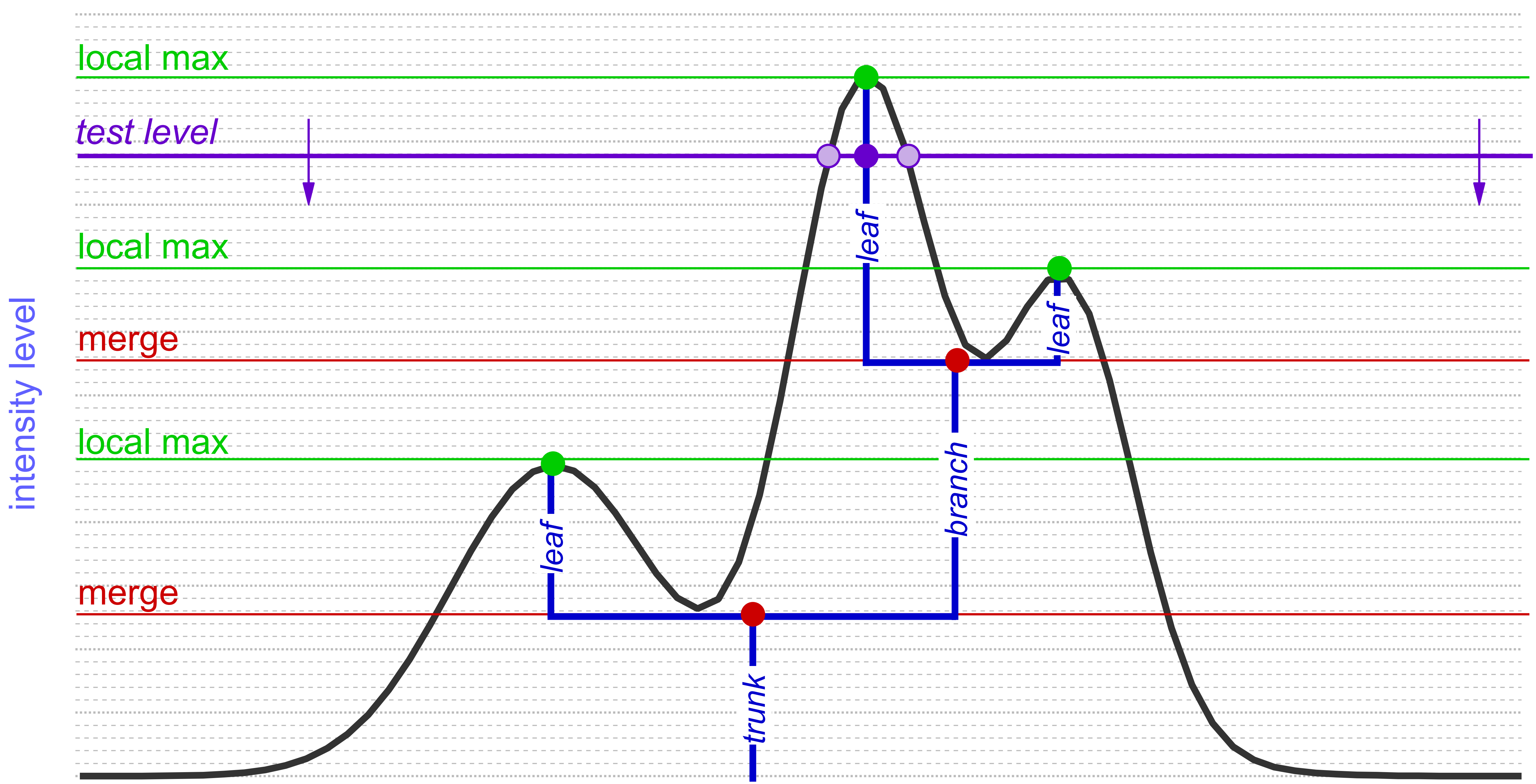
Goodman et al. 2009

Shetty et al. 2010



COMPLETE

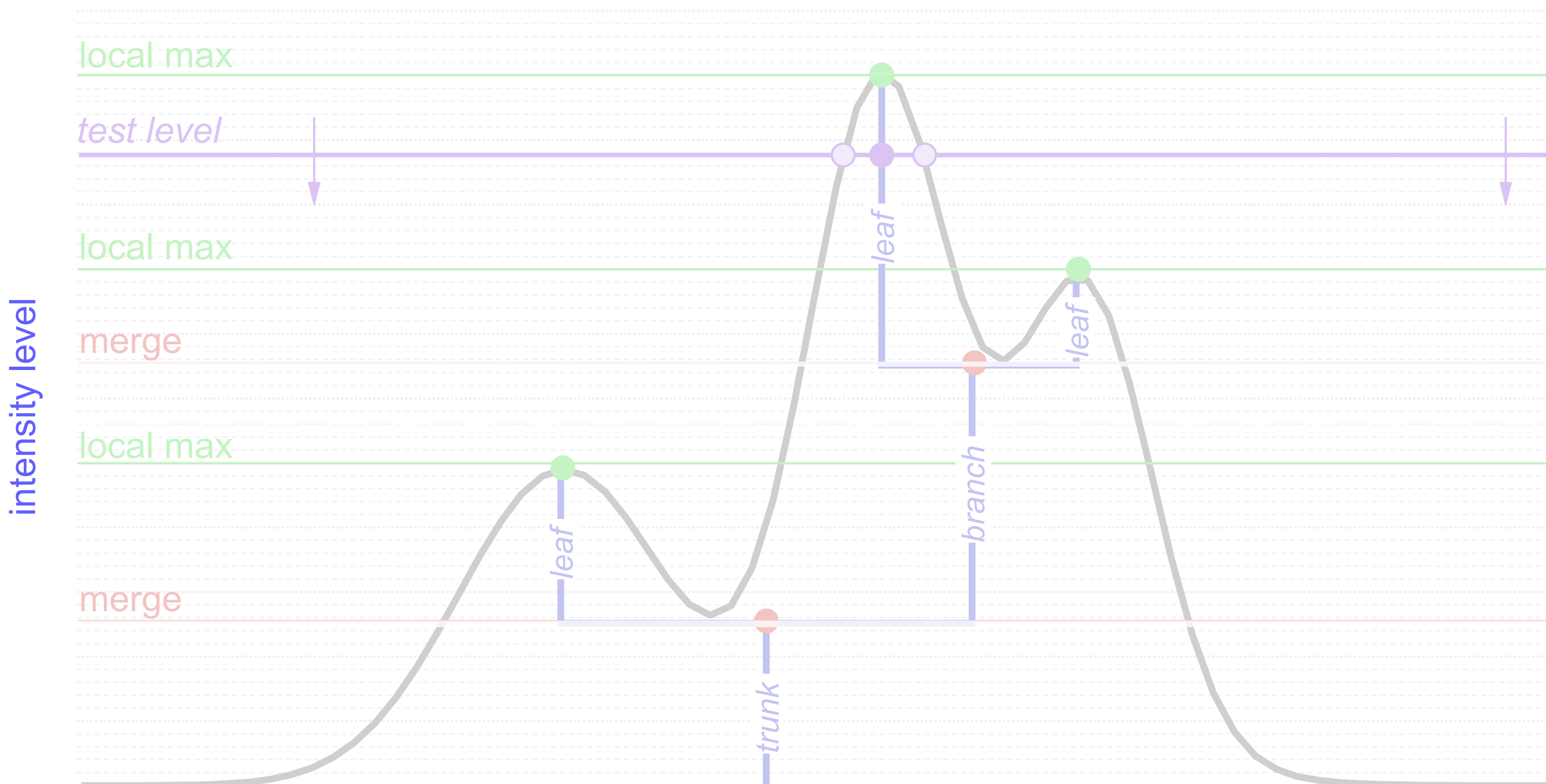
Dendrograms



Hierarchical “Segmentation”

Rosolowsky, Pineda, Kauffmann & Goodman 2008

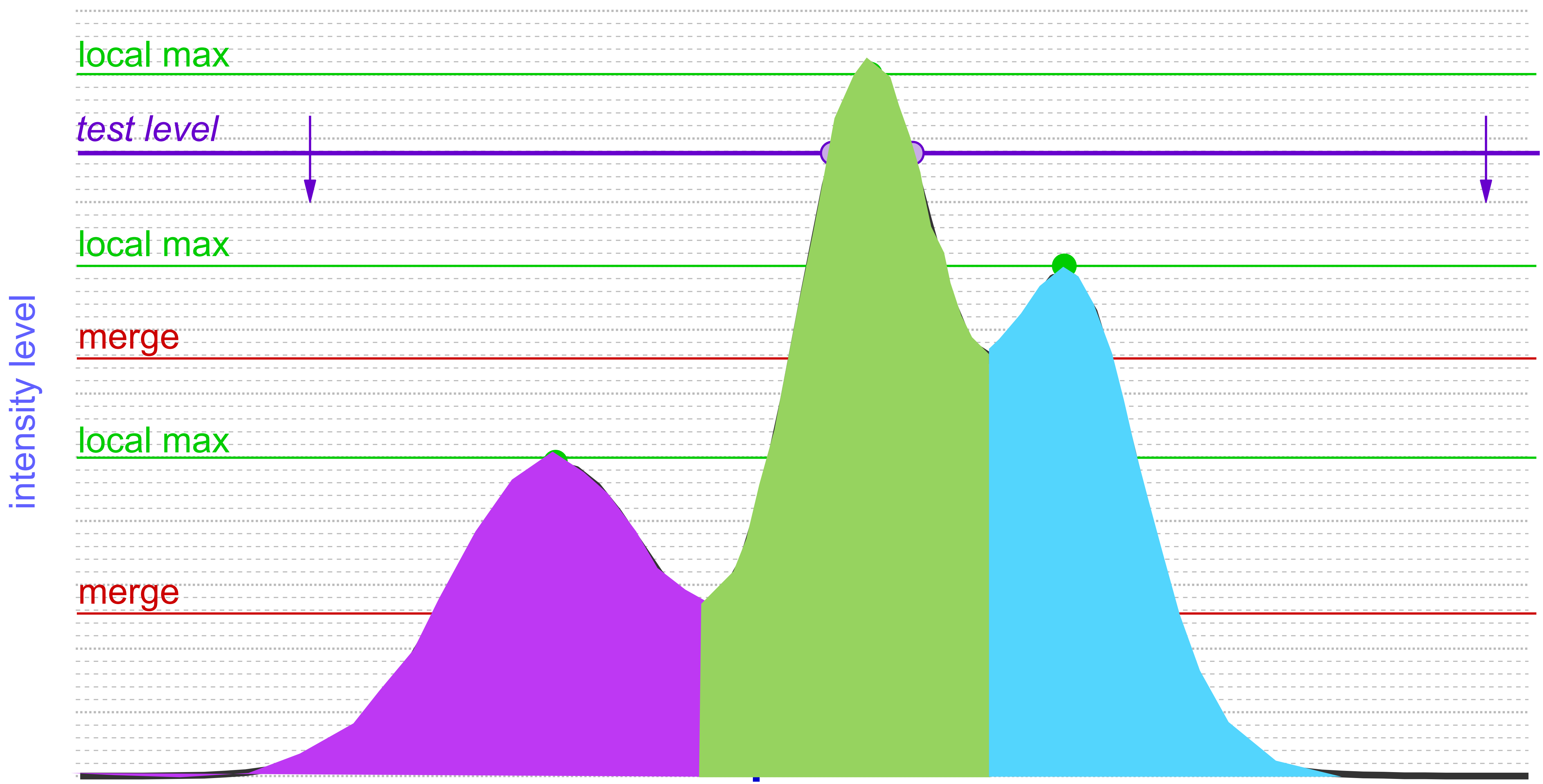
Dendrograms



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*

What would *CLUMPFIND* do?



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

(Williams, De Geus & Blitz 1994)

CLUMPFIND

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

"Sparse" 2D data *(OK)*

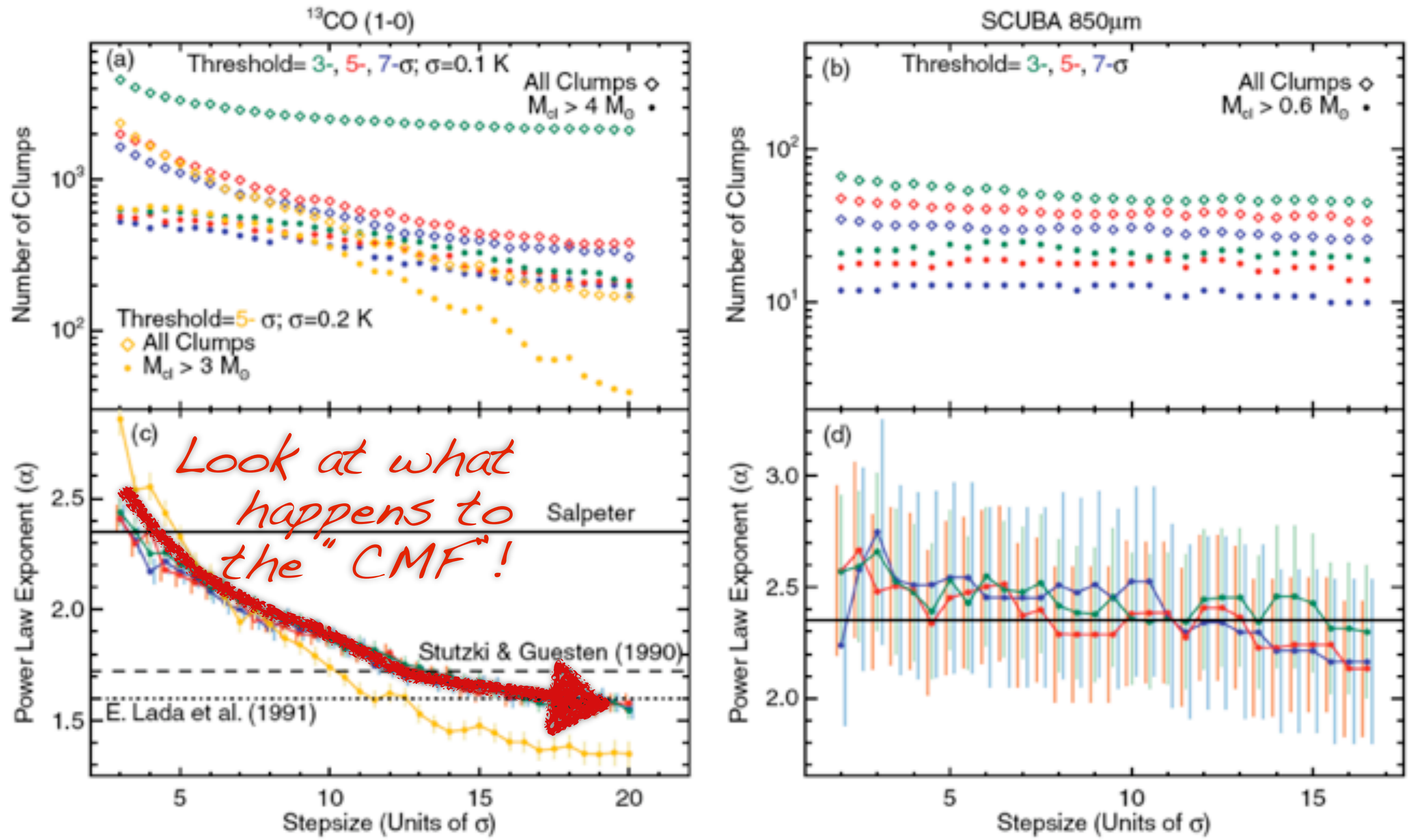
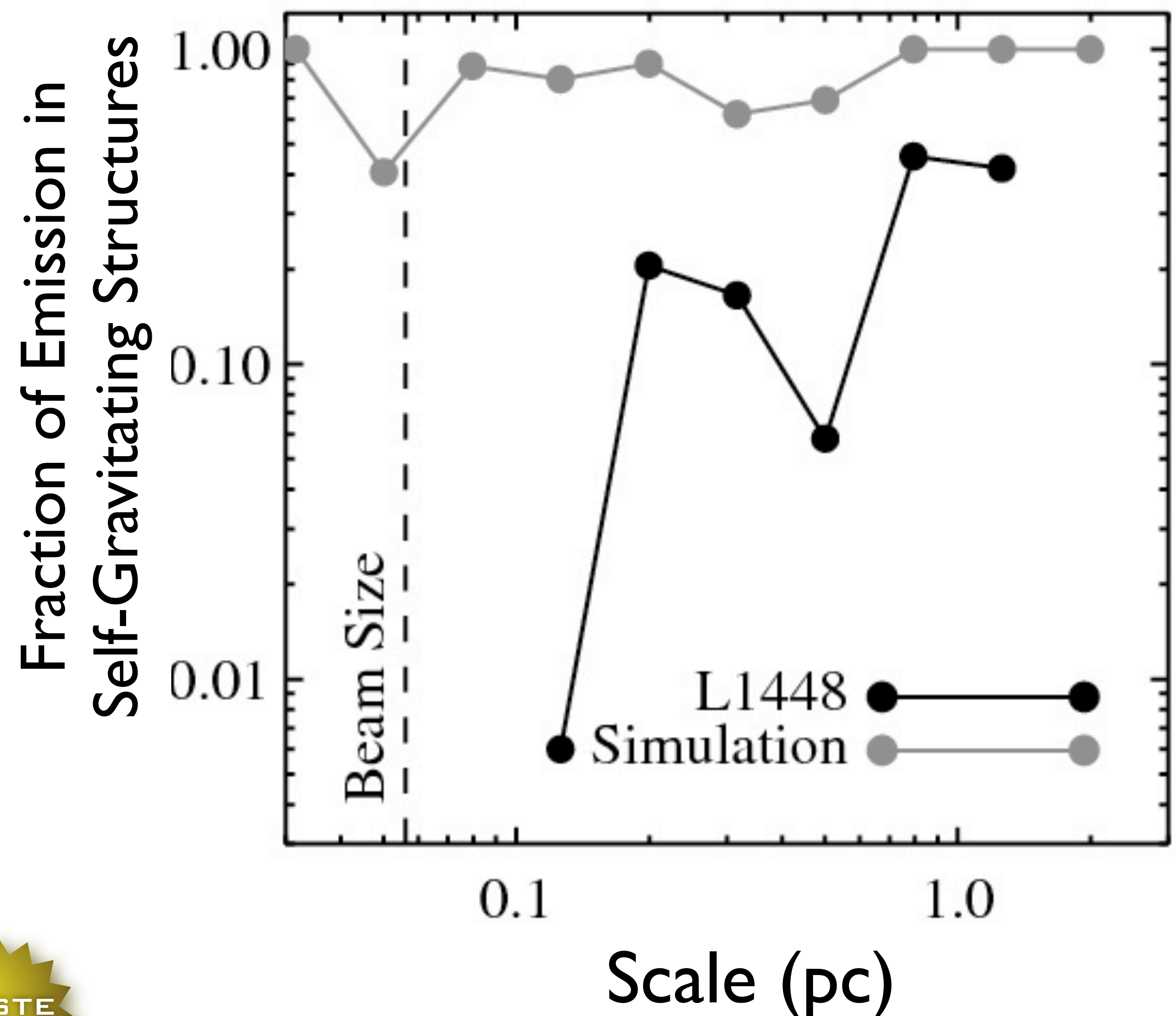
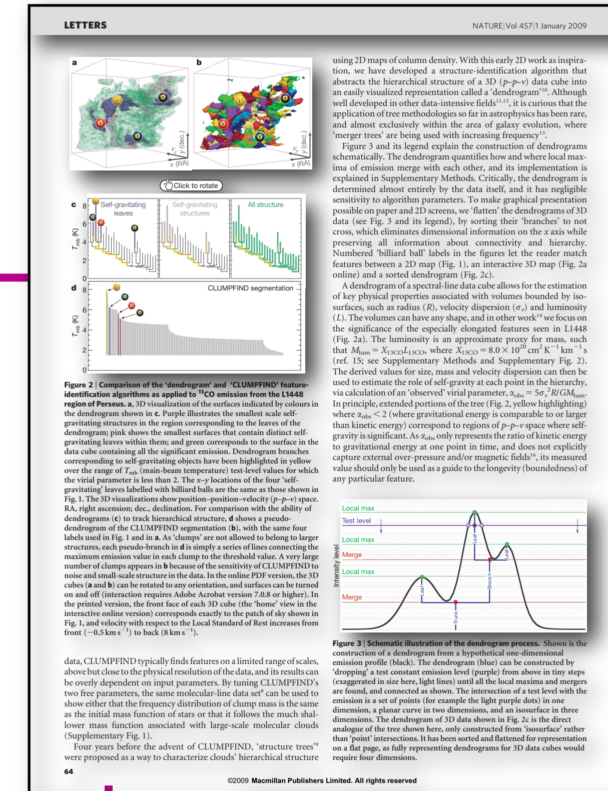


Figure 2. Summary of all Clumpfind runs as a function of stepsize. Color represent different thresholds: blue, red, and green for 3σ, 5σ, and 7σ, respectively; we also show in orange results with a threshold of 5σ for ^{13}CO data with added noise. Left and right columns show results for ^{13}CO and 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 et al. 2009*

Taste-Testing "Gravity"



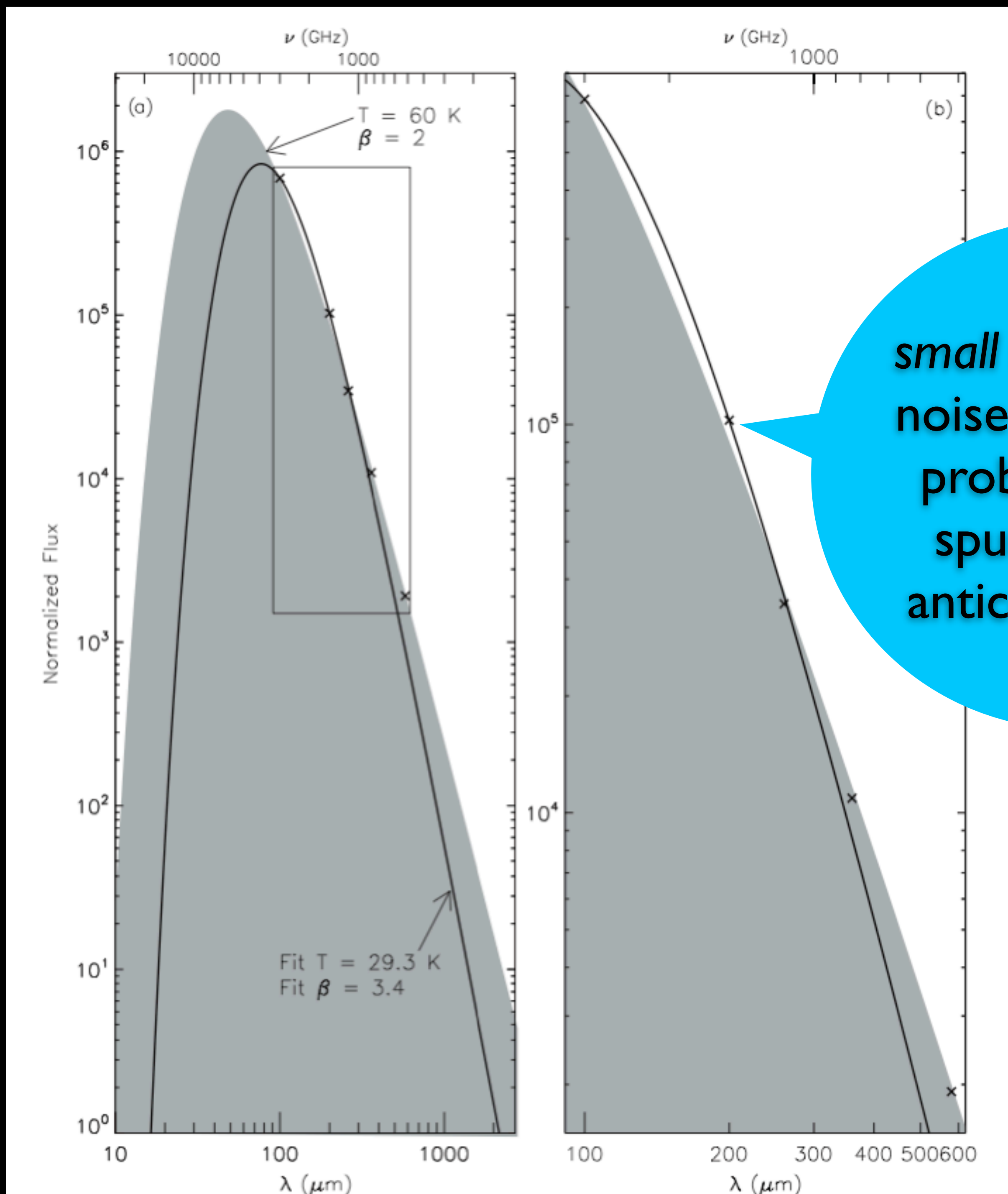

LETTERS NATURE|Vol 457|1 January 2009

TASTE TEST

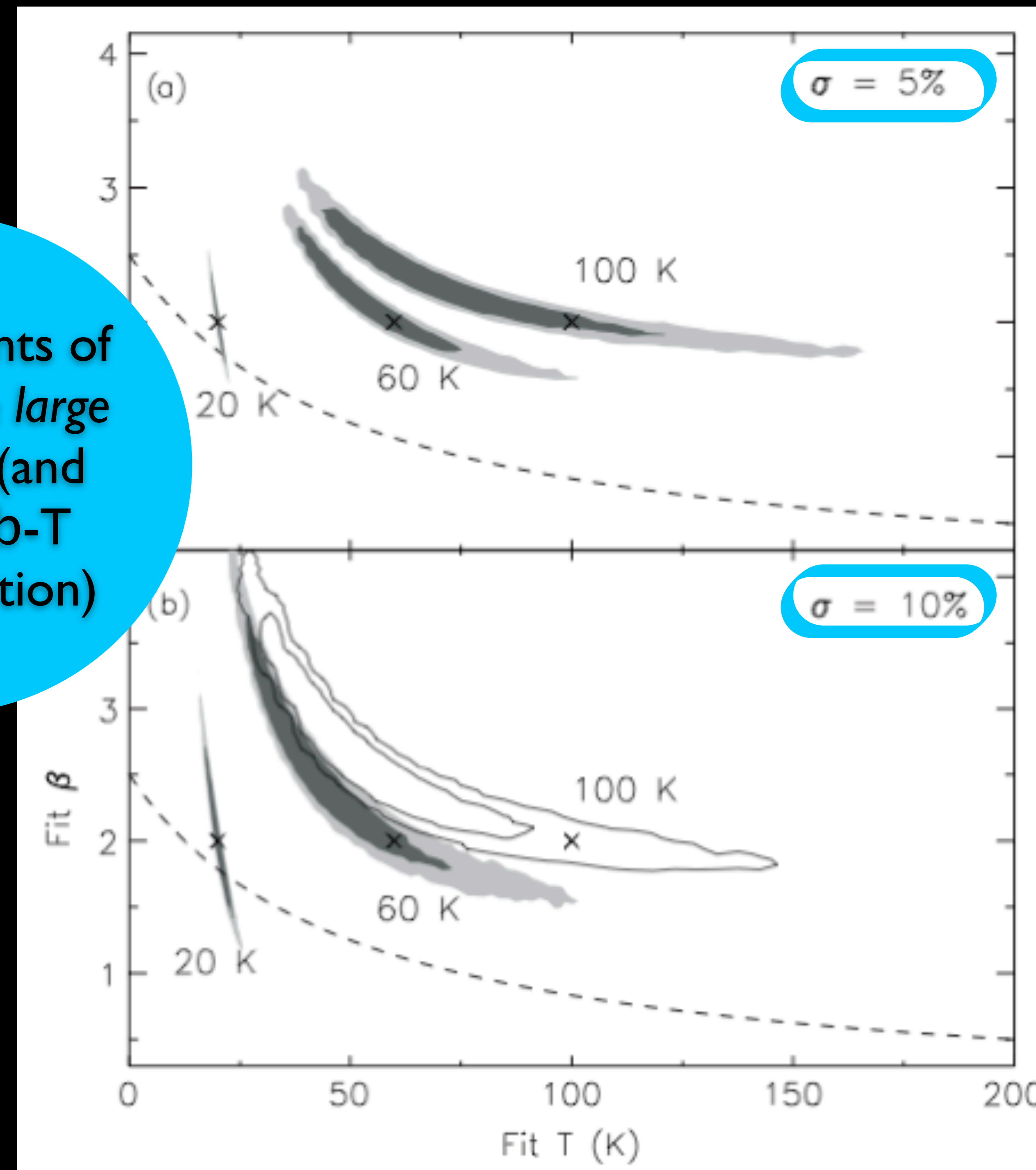
Gravity-free HD Simulations from Padoan et al. 2006;
L1448 analysis from Rosolowsky et al. 2008, Goodman et al. 2009
both lines derived from ^{13}CO "observations"

Taste-Testing...

Value of *Tasting* Dust & b-T



small amounts of noise cause *large* problems (and spurious b-T anticorrelation)



Shetty et al. 2009a, b; and see improved SED analysis method upcoming in Kelly et al. 2011(in prep.)

Outflows

Bipolar &

Spherical(!)

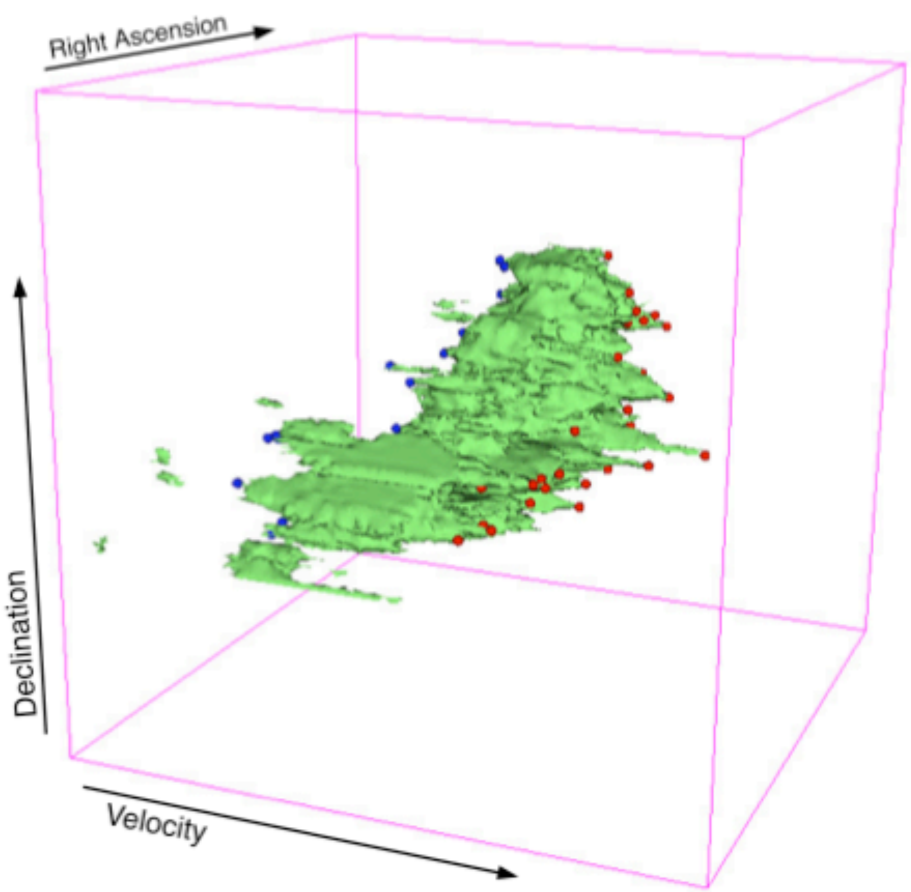
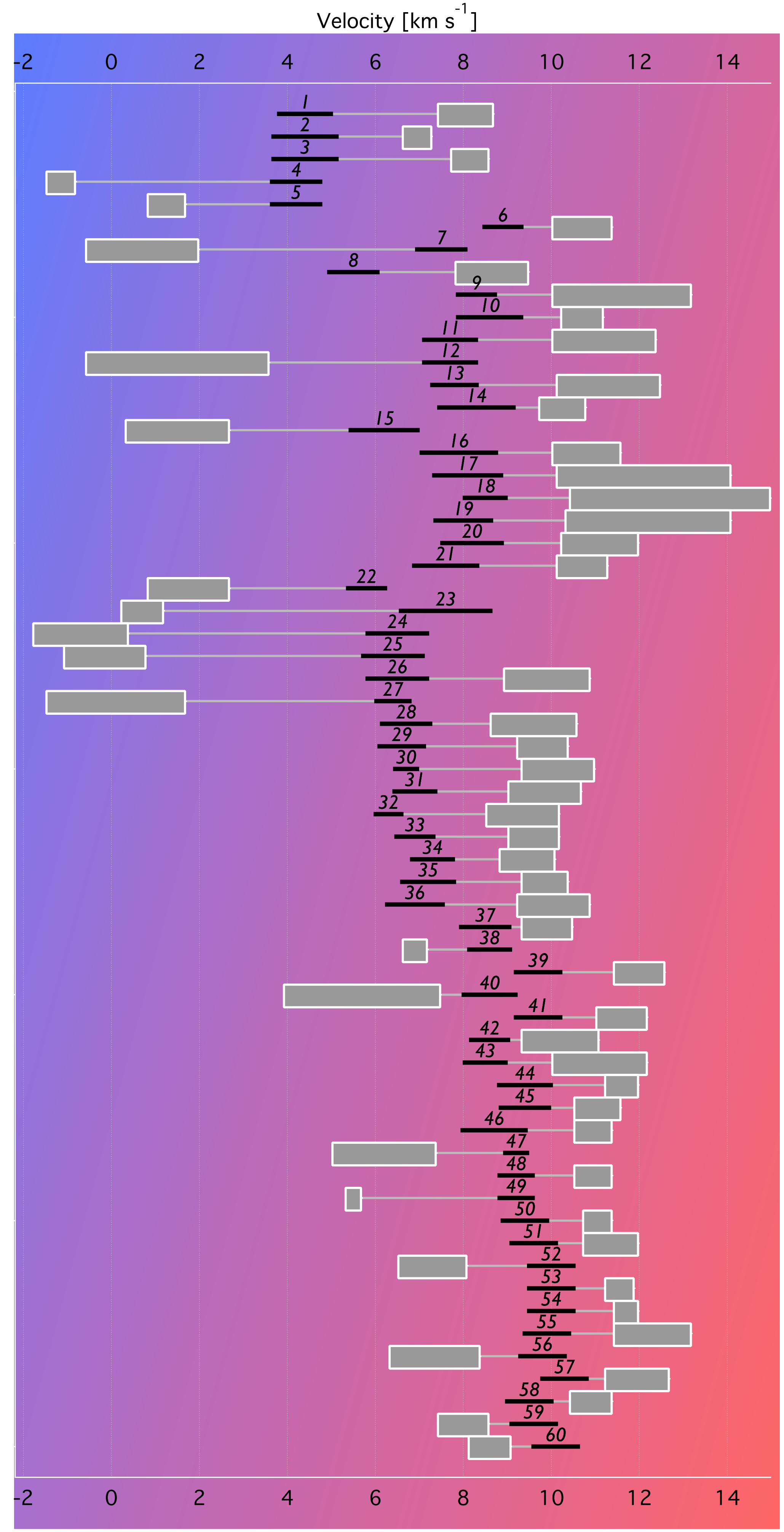


Figure 2. Three-dimensional rendering of the molecular gas in B5 (i.e., Area VI in Figure 1), using 3D Slicer. The gray (green) isosurface model shows the ^{12}CO emission in position–position–velocity space. The small circles show the locations of identified high-velocity points (with the color in the online version representing whether the point is blue- or red-shifted).

Arce et al. 2010, 2011

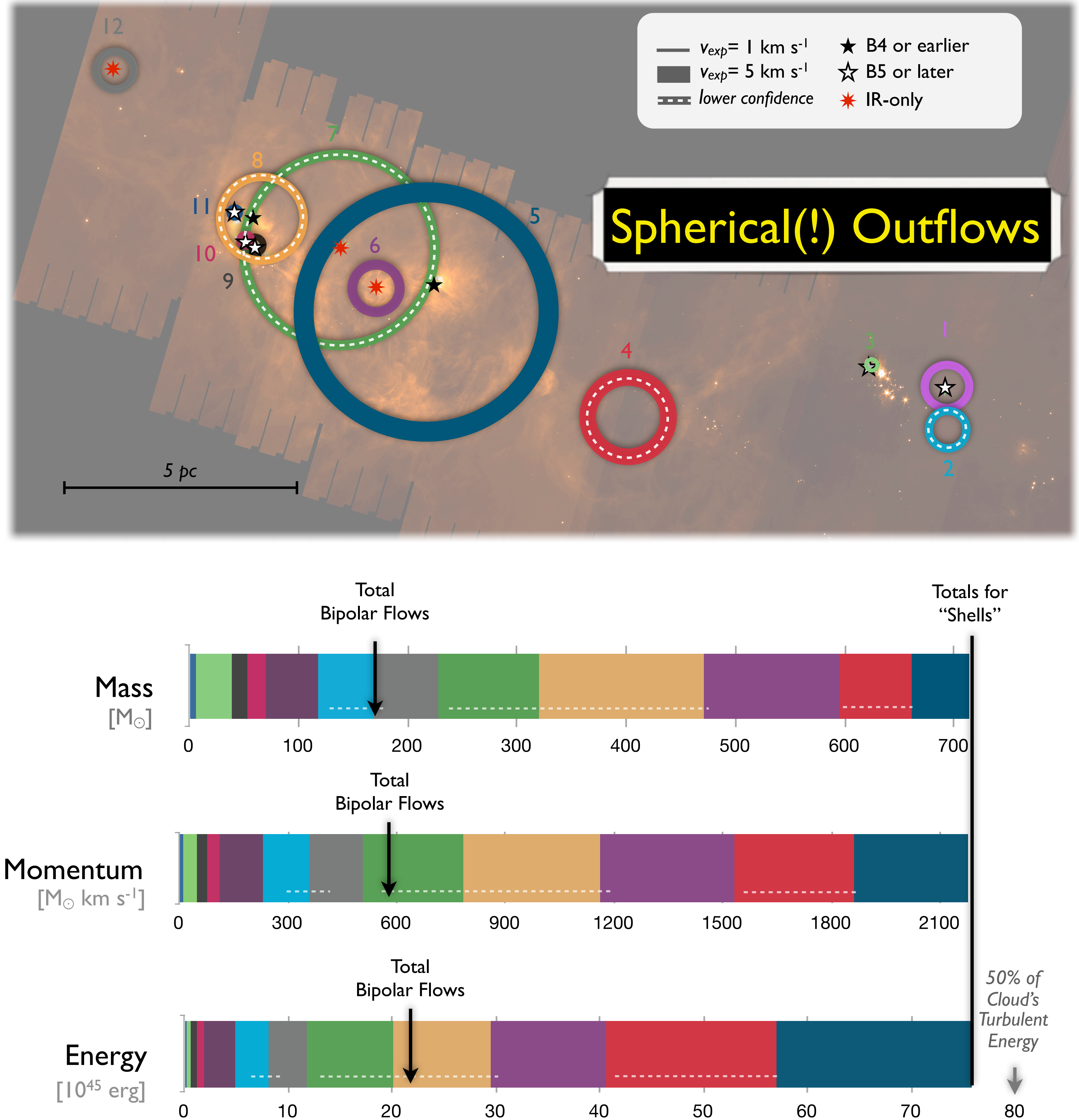


Outflows

Bipolar &
Spherical(!)

News Flash
Spherical shells from young-ish stars may stir molecular clouds (much) MORE than bipolar flows, and B-stars may matter much.

Arce et al. 2011
(in press, on astro-ph)



Cores in and out of clusters

NOT so different! *(Once cores are "ungrouped"...)*

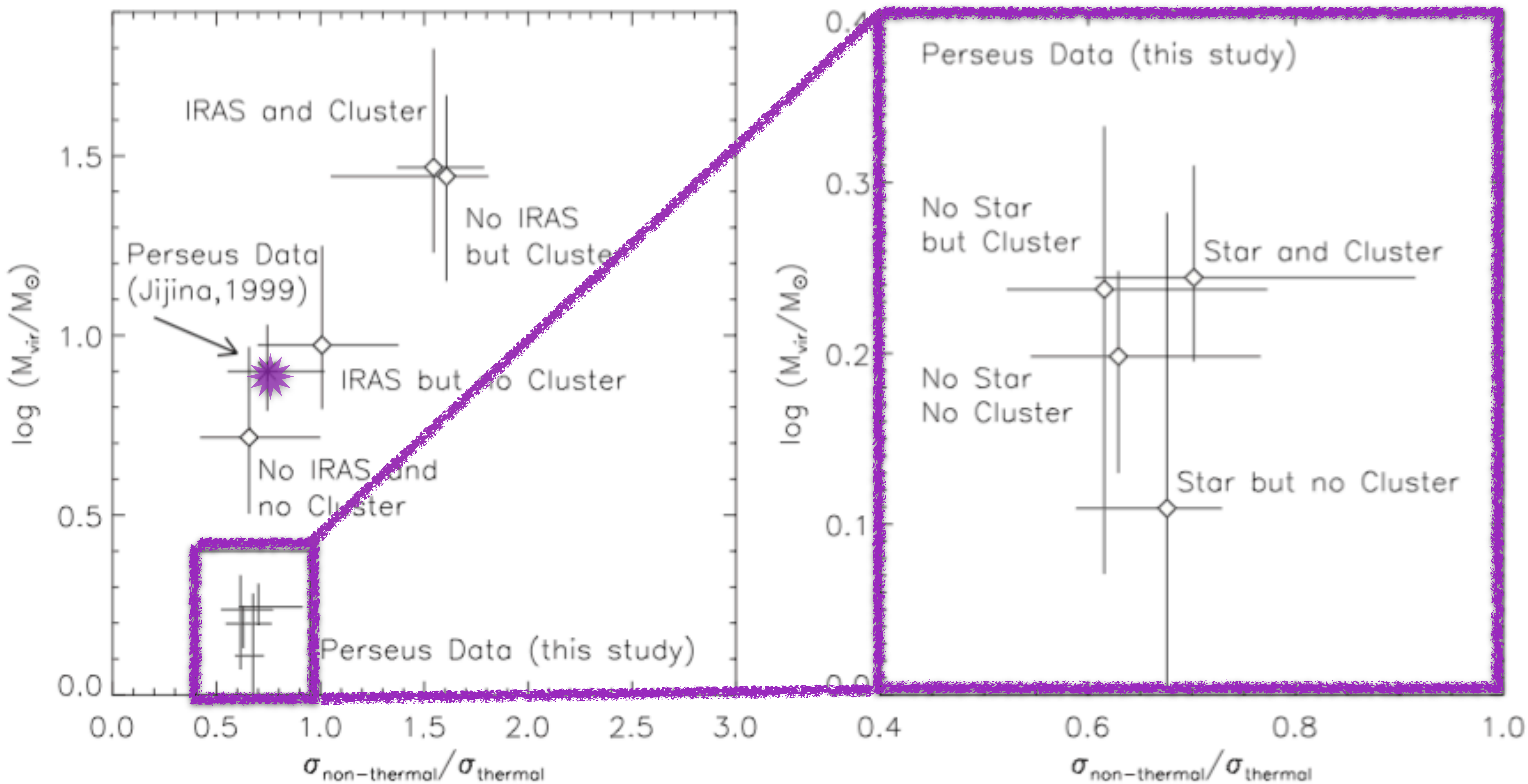


Figure 12. Median and quartile log $(M_{\rm vir}/M_{\odot})$ vs. $\sigma_{\rm nonthermal}/\sigma_{\rm thermal}$ for the four different subsamples of objects as in Figure 4 from Jijina et al. (1999). On the left, the Jijina et al. (1999) results (IRAS point sources were used as a proxy for protostellar), which span a much larger range in both axes and exhibit more separation between classifications than our Perseus data. Cores in Perseus from the Jijina et al. (1999) database are typically more massive. We zoom into our data on the right, illustrating that our different classes of objects largely overlap in this diagram.

Foster, Rosolowsky, Kauffmann, Pineda, Borkin, Caselli, Myers & Goodman 2009; using NH_3 survey of Rosolowsky et al. 2008

Coherent Cores Do Exist...and they fragment?!

The Astrophysical Journal Letters, 739:L2 (5pp), 2011 September 20

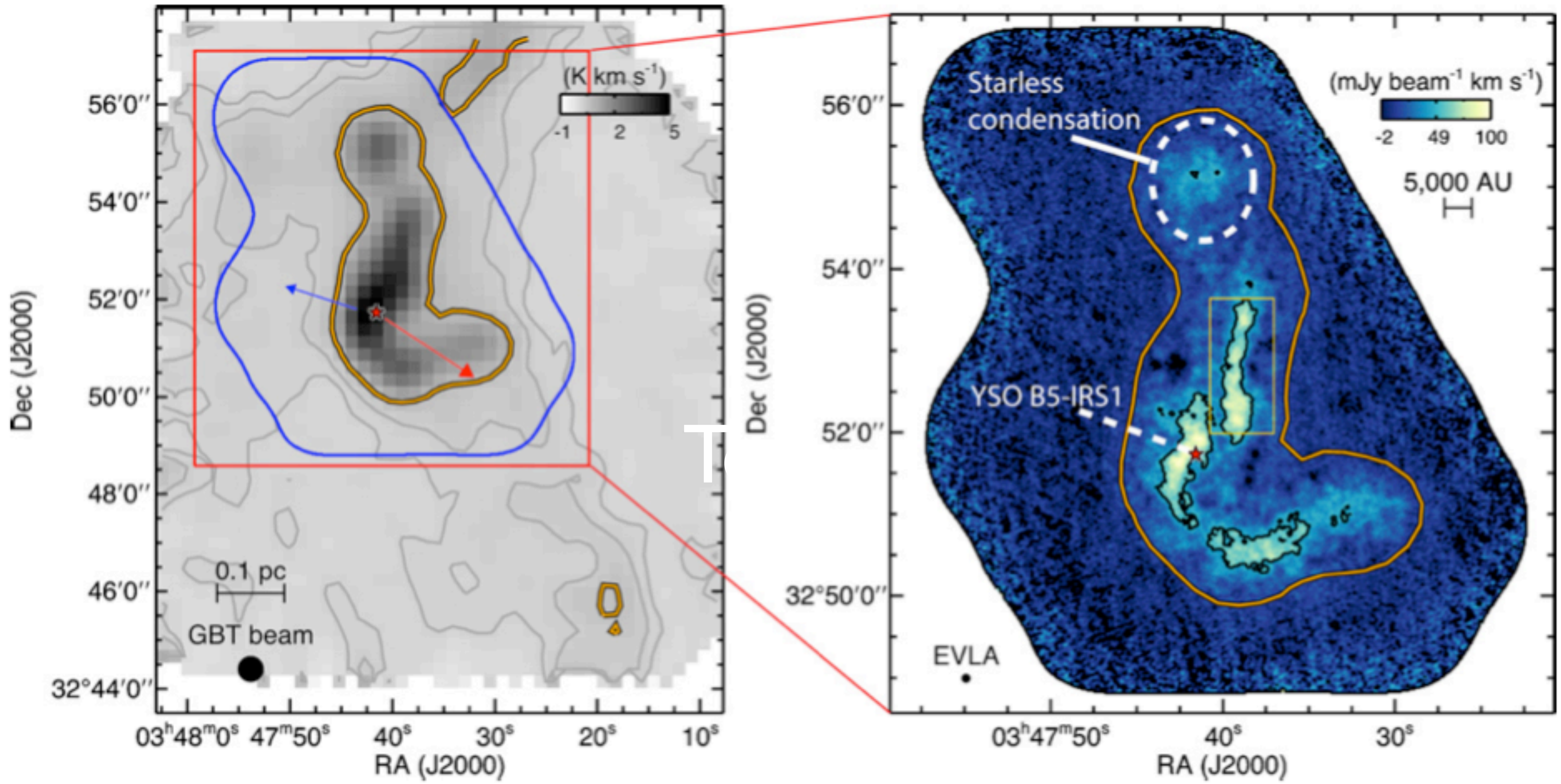
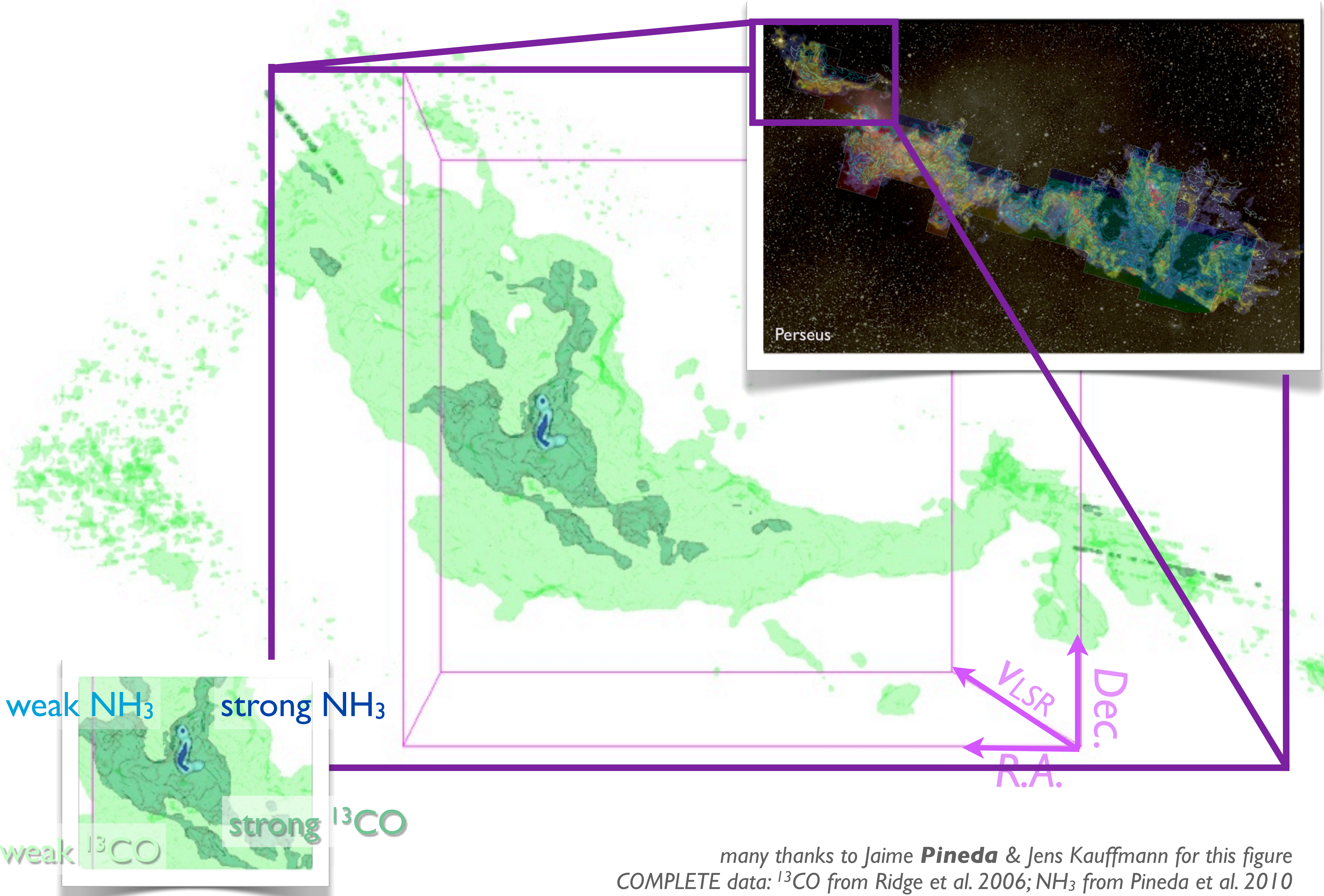


Figure 1. Left panel: integrated intensity map of B5 in NH_3 (1,1) obtained with GBT. Gray contours show the 0.15 and 0.3 K km s^{-1} level in NH_3 (1,1) integrated intensity. The orange contours show the region in the GBT data where the non-thermal velocity dispersion is subsonic. The young star, B5–IRS1, is shown by the star in both panels. The outflow direction is shown by the arrows. The blue contour shows the area observed with the EVLA and the red box shows the area shown in the right panel. Right panel: integrated intensity map of B5 in NH_3 (1,1) obtained combining the EVLA and GBT data. Black contour shows the 50 mJy $beam^{-1}$ km s^{-1} level in NH_3 (1,1) integrated intensity. The yellow box shows the region used in Figure 4. The northern starless condensation is shown by the dashed circle.

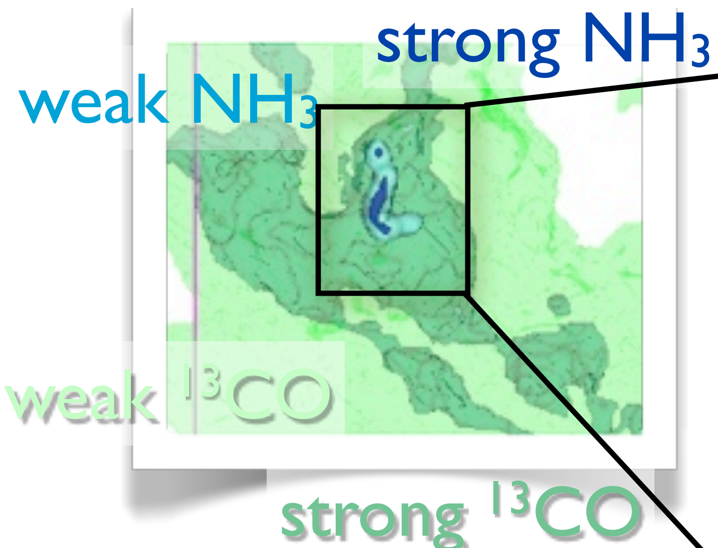
Pineda et al. 2010, 2011

(*p-p-v* structure of the) B5 region in Perseus

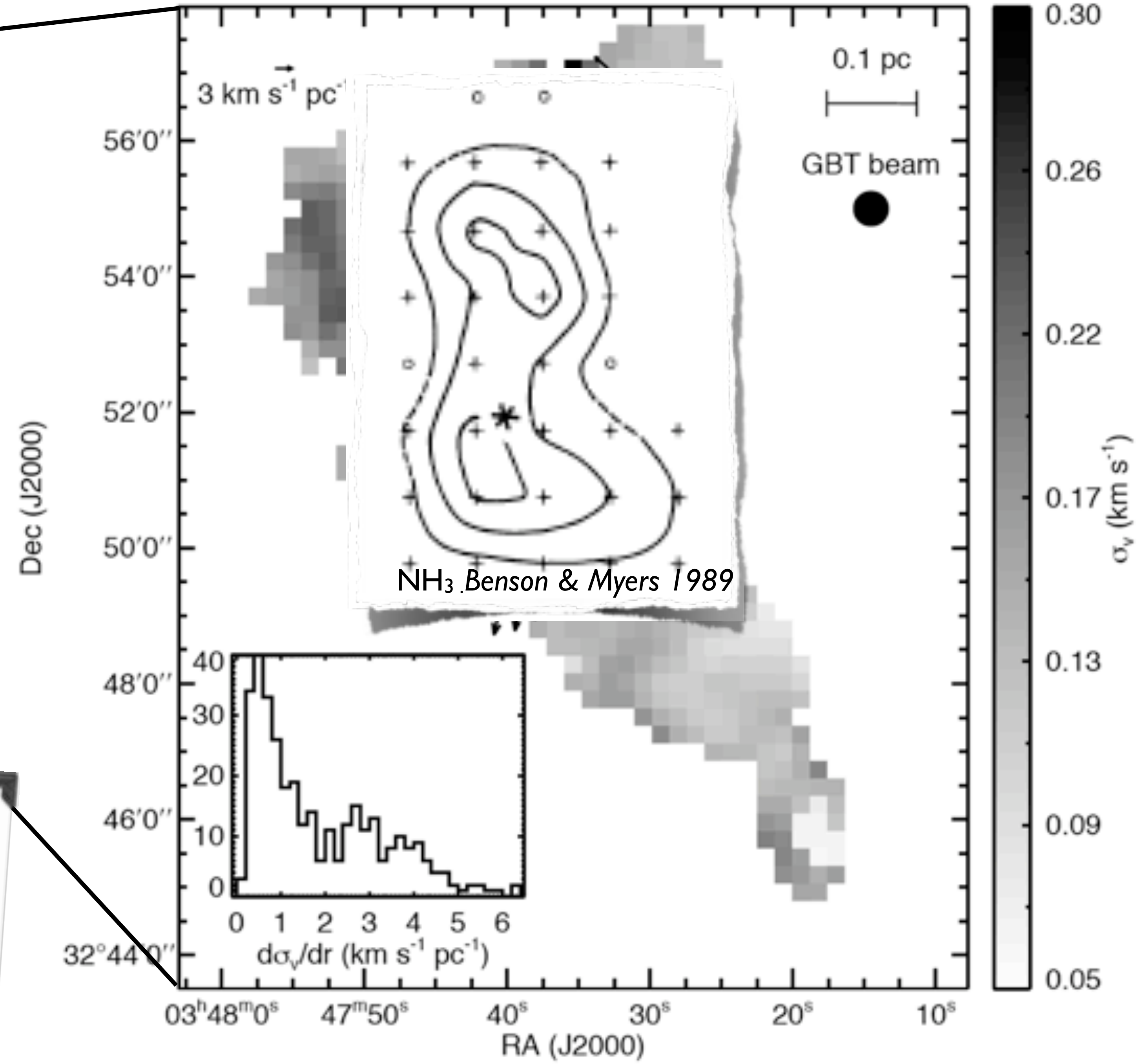


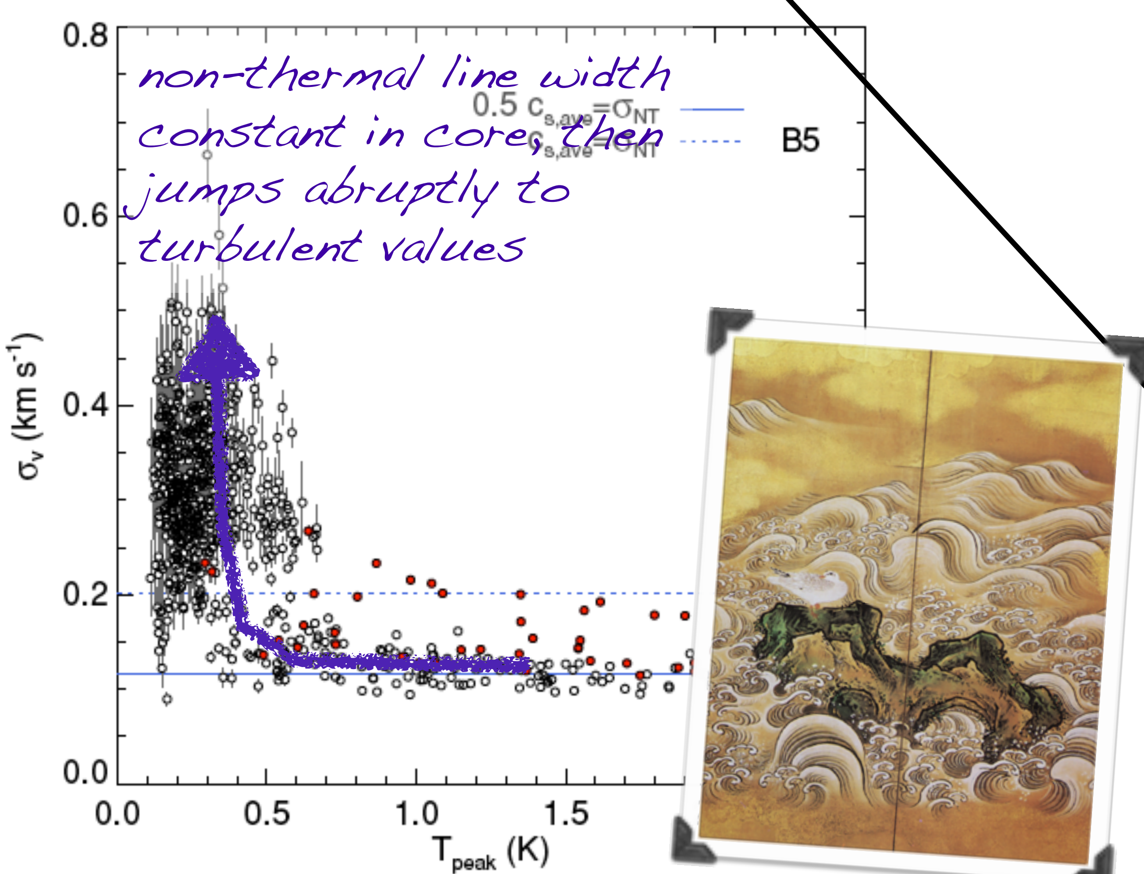
*many thanks to Jaime **Pineda** & Jens Kauffmann for this figure*
COMPLETE data: ^{13}CO from Ridge et al. 2006; NH_3 from Pineda et al. 2010

STRONG Evidence for Coherence in Dense Cores



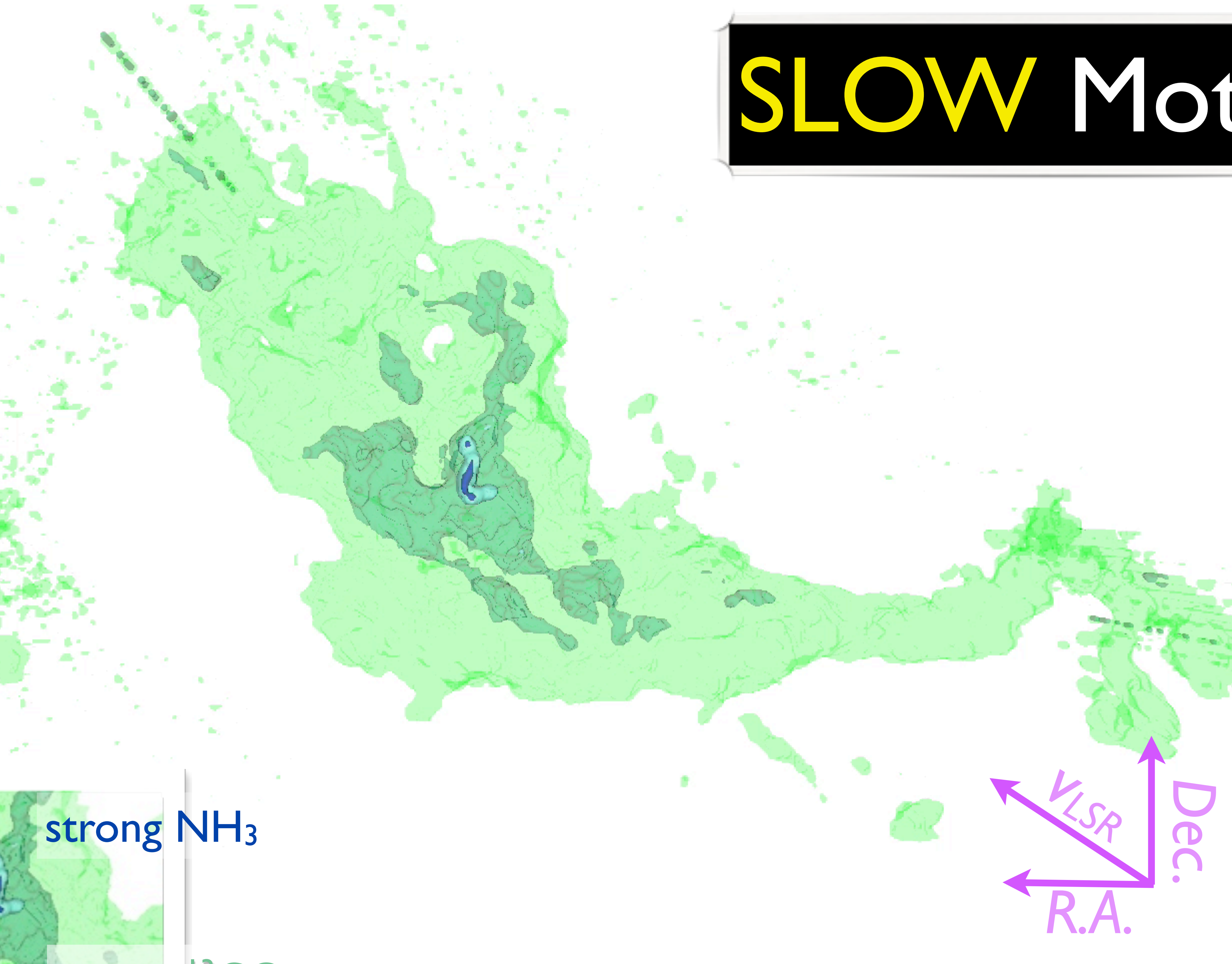
greyscale shows NH_3 velocity dispersion,
arrows show gradient in dispersion

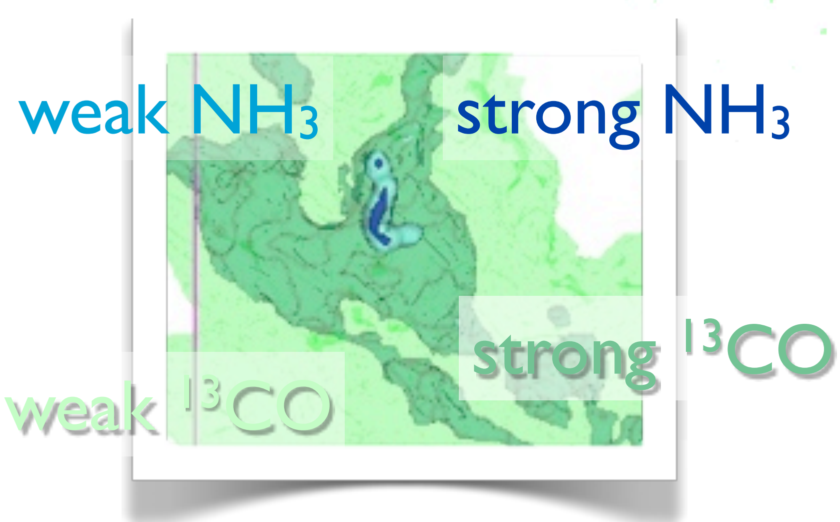




GBT NH_3 observations of the B5 core (Pineda et al. 2010)

(*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

Fragmentation *in* Coherent Cores?!

Thank you EVLA!

THE ASTROPHYSICAL JOURNAL LETTERS, 739:L2 (5pp), 2011 September 20 PINEDA ET AL.

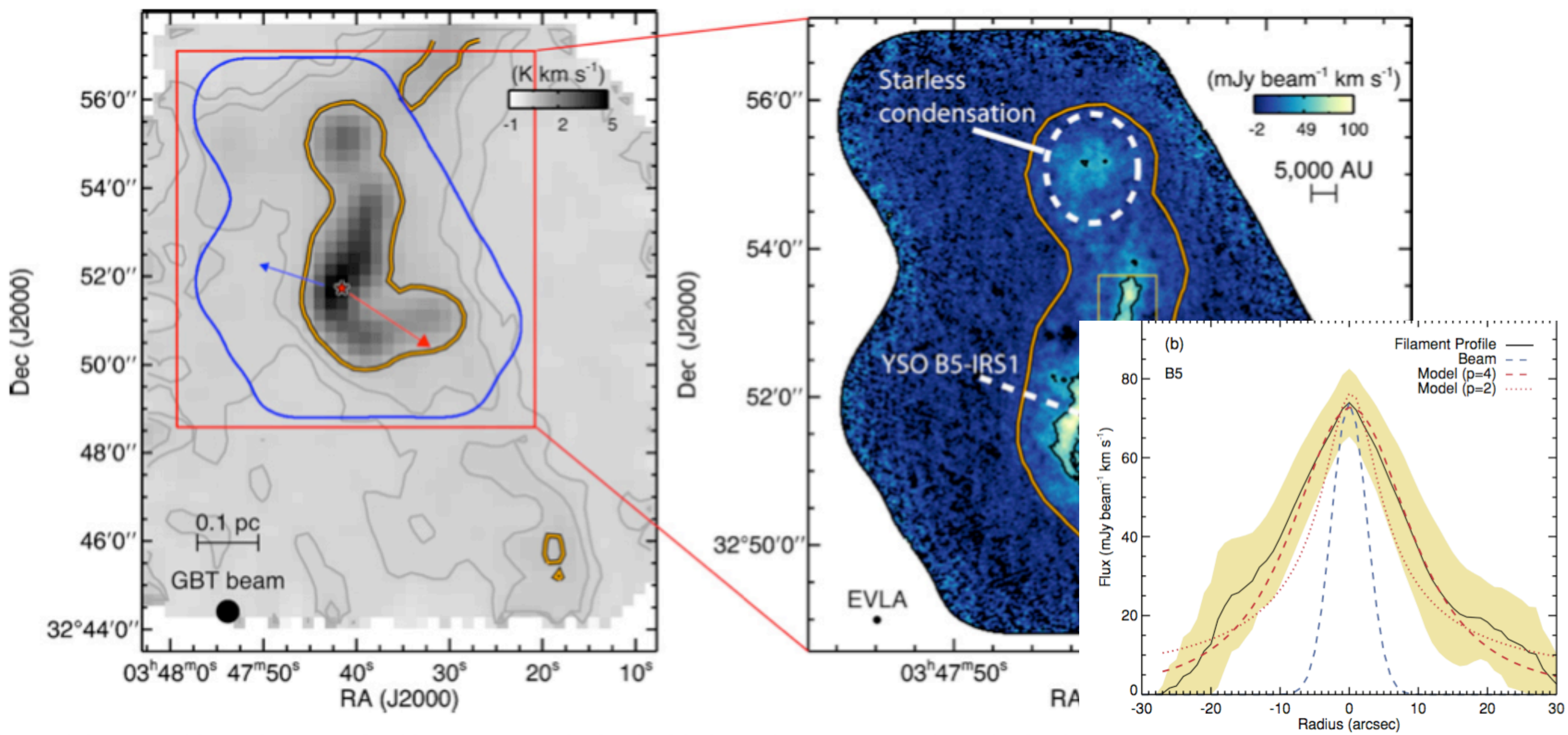
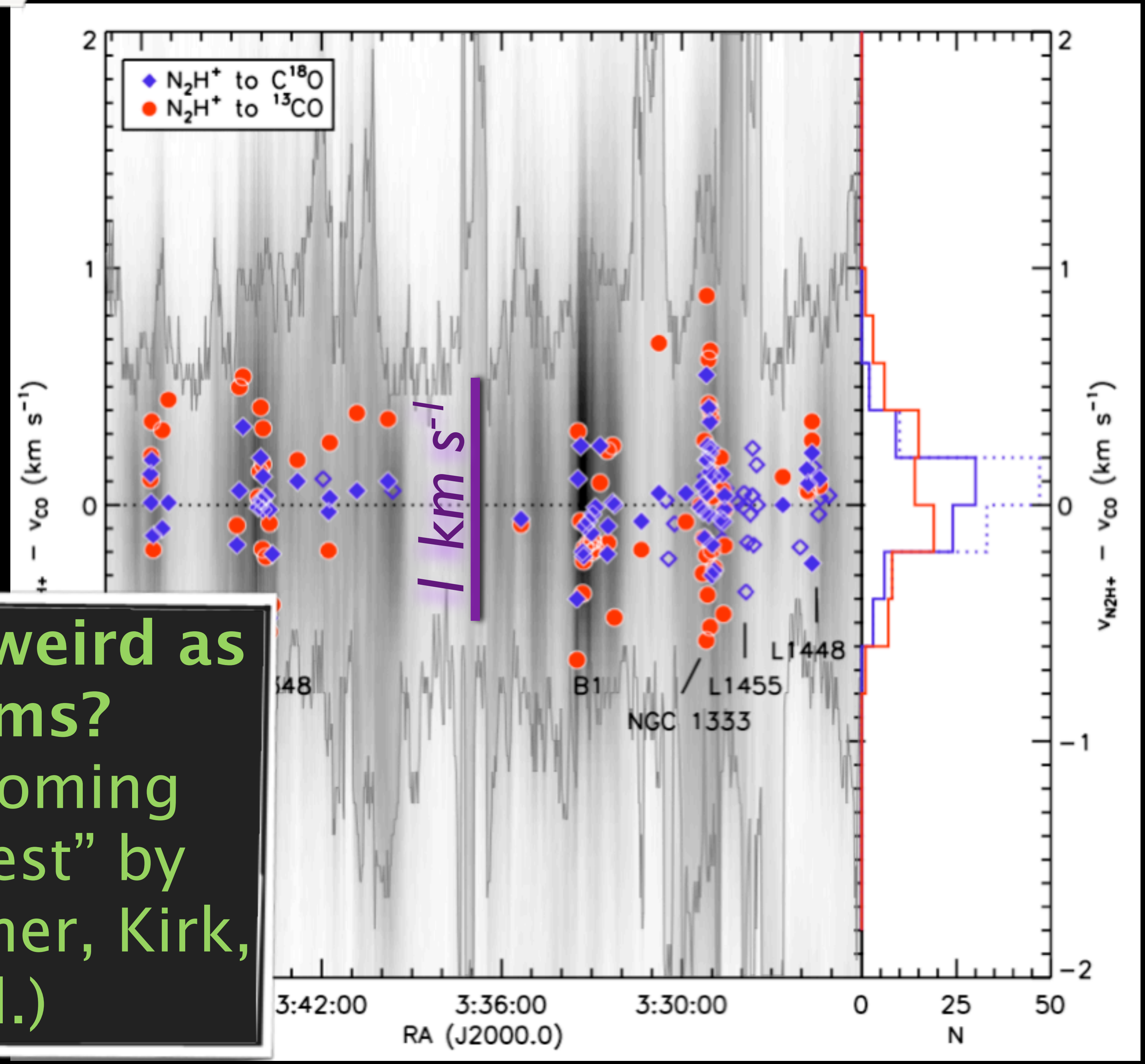


Figure 1. Left panel: integrated intensity map of B5 in NH_3 (1,1) obtained with GBT. Gray contours show the 0.15 and 0.3 K km s^{-1} level in NH_3 (1,1) integrated intensity. The orange contours show the region in the GBT data where the non-thermal velocity dispersion is subsonic. The young star, B5–IRS1, is shown by the star in both panels. The outflow direction is shown by the arrows. The blue contour shows the area observed with the EVLA and the red box shows the area shown in the right panel. Right panel: integrated intensity map of B5 in NH_3 (1,1) obtained combining the EVLA and GBT data. Black contour shows the 50 mJy beam^{-1} km s^{-1} level in NH_3 (1,1) integrated intensity. The yellow box shows the region used in Figure 4. The northern starless condensation is shown by the dashed circle.

SLOW Motion

of cores with respect to clouds
of young stars with respect to cores



Is this as weird as it seems?
(See upcoming "Taste Test" by Harris, Offner, Kirk, et al.)

Kirk et al. 2010

SLOW Motion

of cores with respect to clouds
of young stars with respect to cores

● YSO
✦ SCUBA core
1 M⊙ pc^{-3}
25 M⊙ pc^{-3}

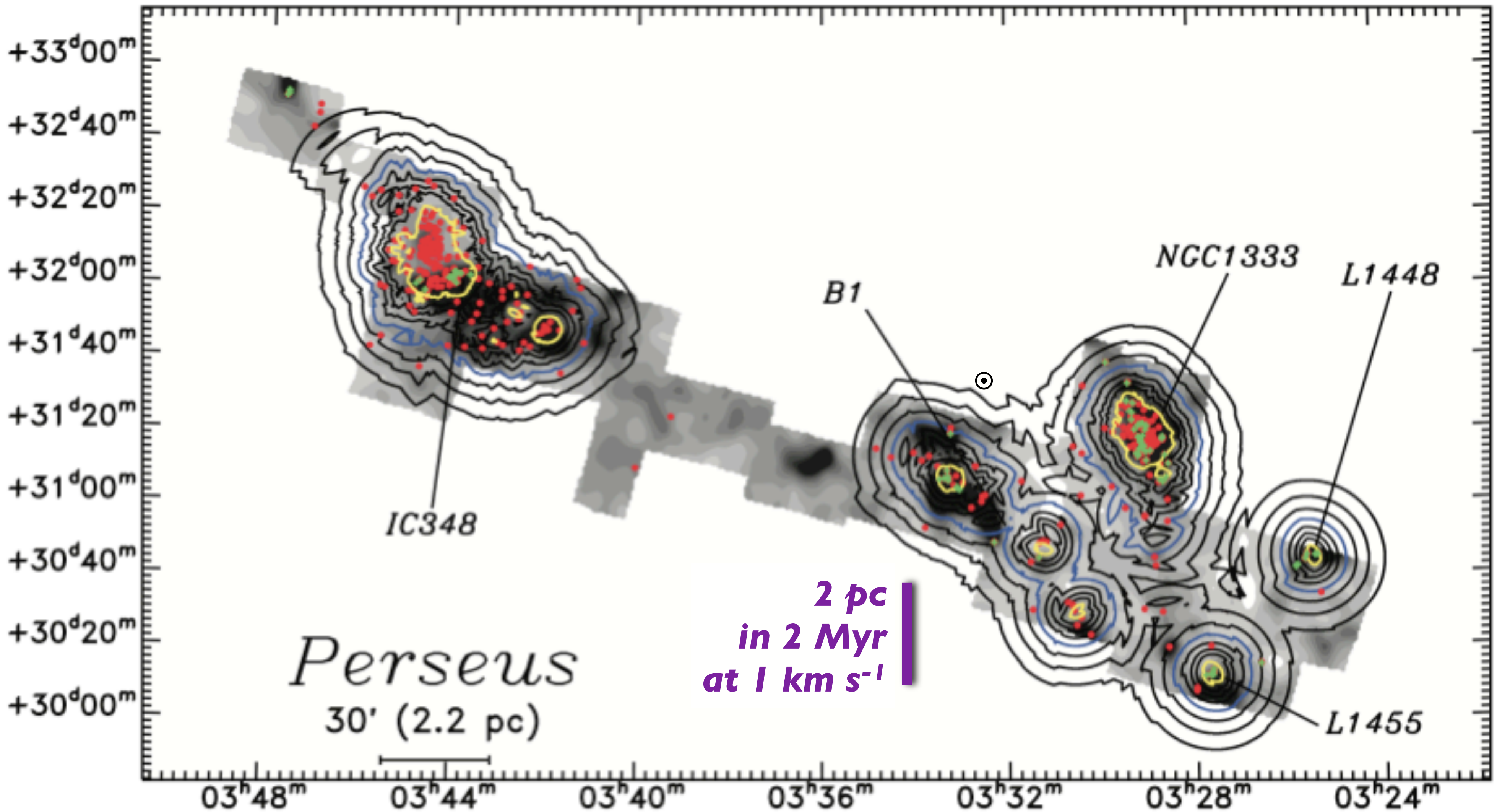
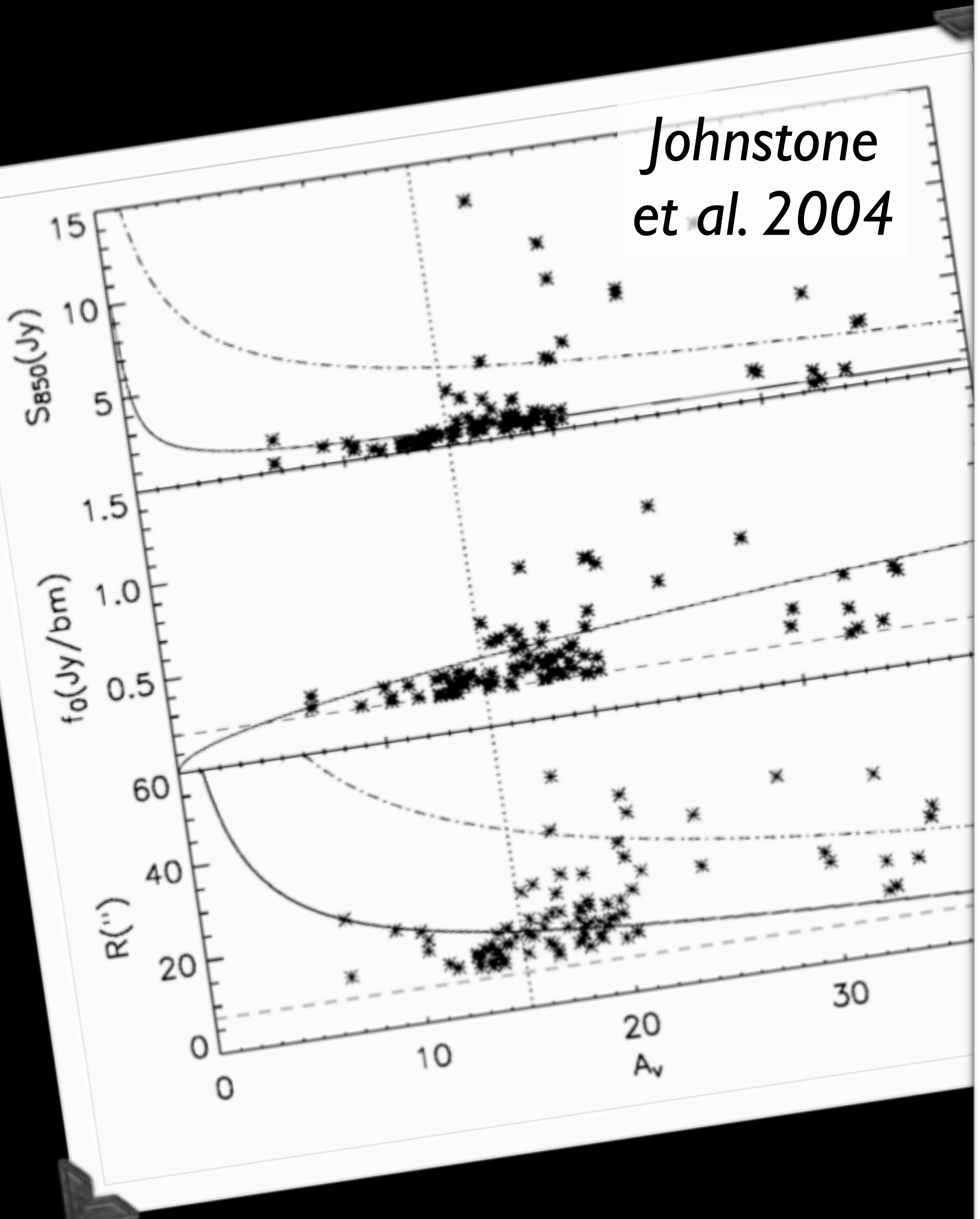


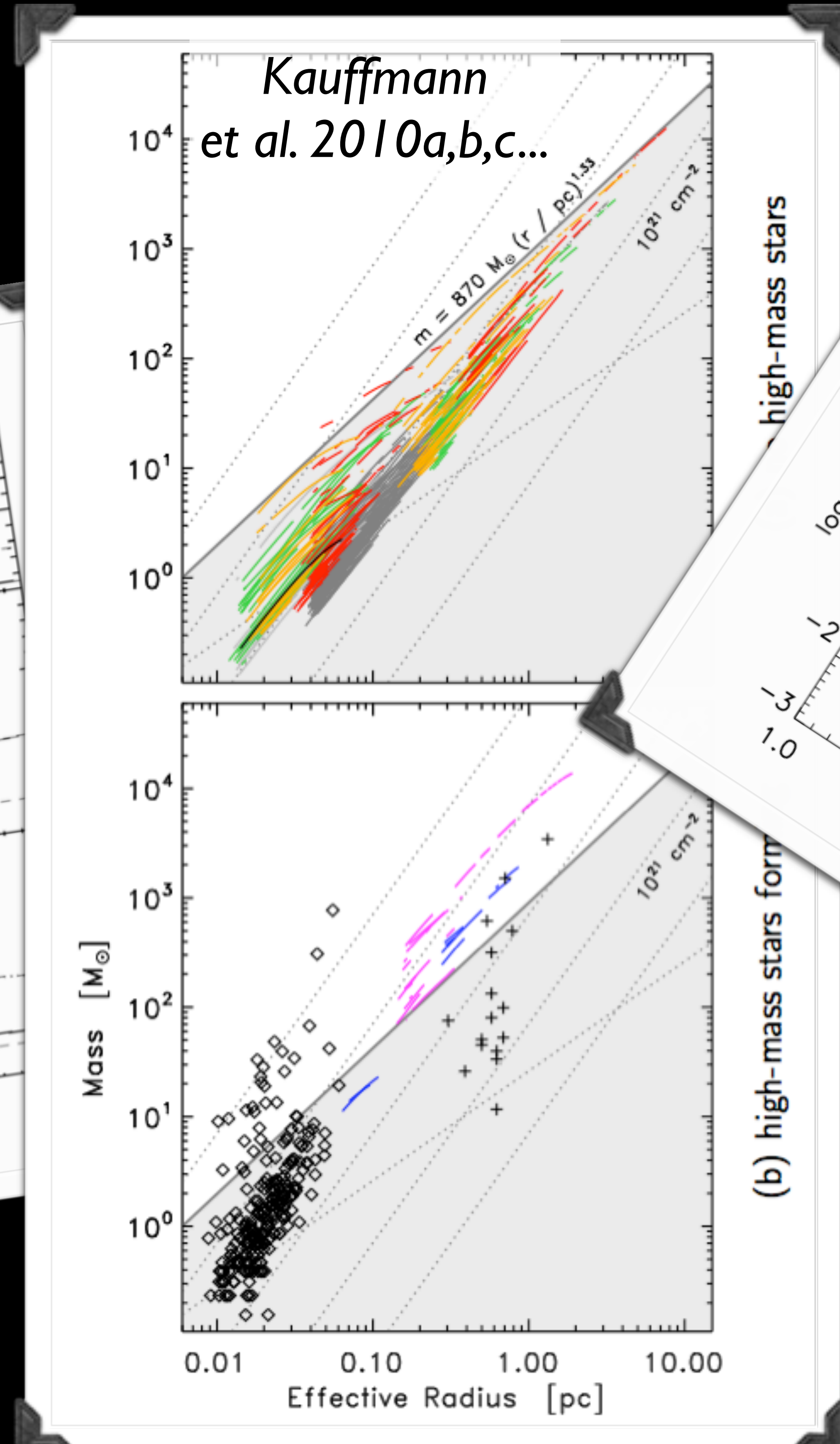
FIG. 13.—Volume density contours of the YSOs in Ophiuchus (*top panel*), Perseus (*bottom panel*) shown on top of extinction maps (*gray-scale*) based on the c2d data (Evans et al. 2007). In both panels the black contours indicate the volume densities corresponding to 0.125, 0.25, 0.50, 2.0, and 4.0 $M_\odot$ pc^{-3}. The blue contours show volume densities of 1 $M_\odot$ pc^{-3}, corresponding to the criterion (1 × LL03 in the text) for identifying clusters suggested by Lada & Lada (2003) and the yellow contours to volume densities of 25 $M_\odot$ pc^{-3} (25 × LL03 in the text). The red dots show the locations of the YSOs and the green plus signs the locations of the SCUBA cores in the two clouds.

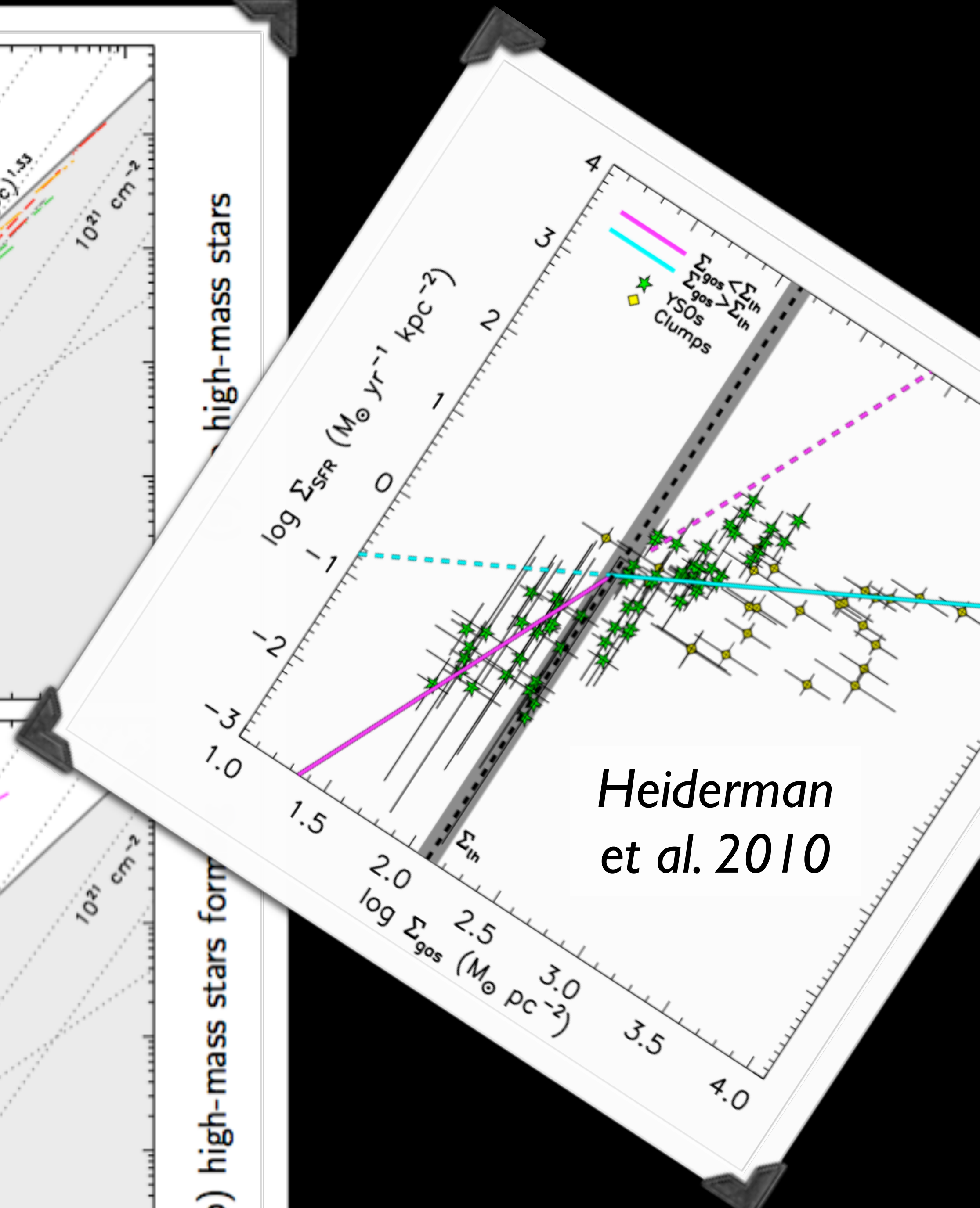
Jørgensen et al. 2008

Density and Column Density Thresholds for Star Formation

Way more complicated than they seem...







YELLOW?

(What I've learned...)

- ★ "Column Temperature"
- ★ ^{13}CO poor tracer of column density, abundance not the problem
- ★ "lognormal" (*but...*)
- ★ "Cloudshine"
- ★ GNICEST (and CS!)
- ★ virial theorem over-used?
- ★ Dangers of *p-p-v "observer"* space
- ★ Perils of CLUMPFIND
- ★ Benefits of Dendrograms
- ★ Value of *Tasting* Dust & b-T
- ★ Spherical(!) Outflows
- ★ Cores in/out of Clusters NOT so Different
- ★ Coherent Cores are Real, and they Fragment (into filaments)!?
- ★ SLOW motion of cores & stars w.r.t. environs
- ★ Density "thresholds" are way more complicated than they look

YSO AGE/Morphology from SED Modelling

Lada (1987) proposed three classes:

I. YOUNG, mostly disk emission
II. Young "T-Tauri" star, still much disk
III. Older "young" star, no disk

Later, sub-mm astronomers added "Class 0", for sources detected "only in sub-mm" (very unphysical!)

(See also "first core," and also be aware that there are other indicators of youth (line emission.)

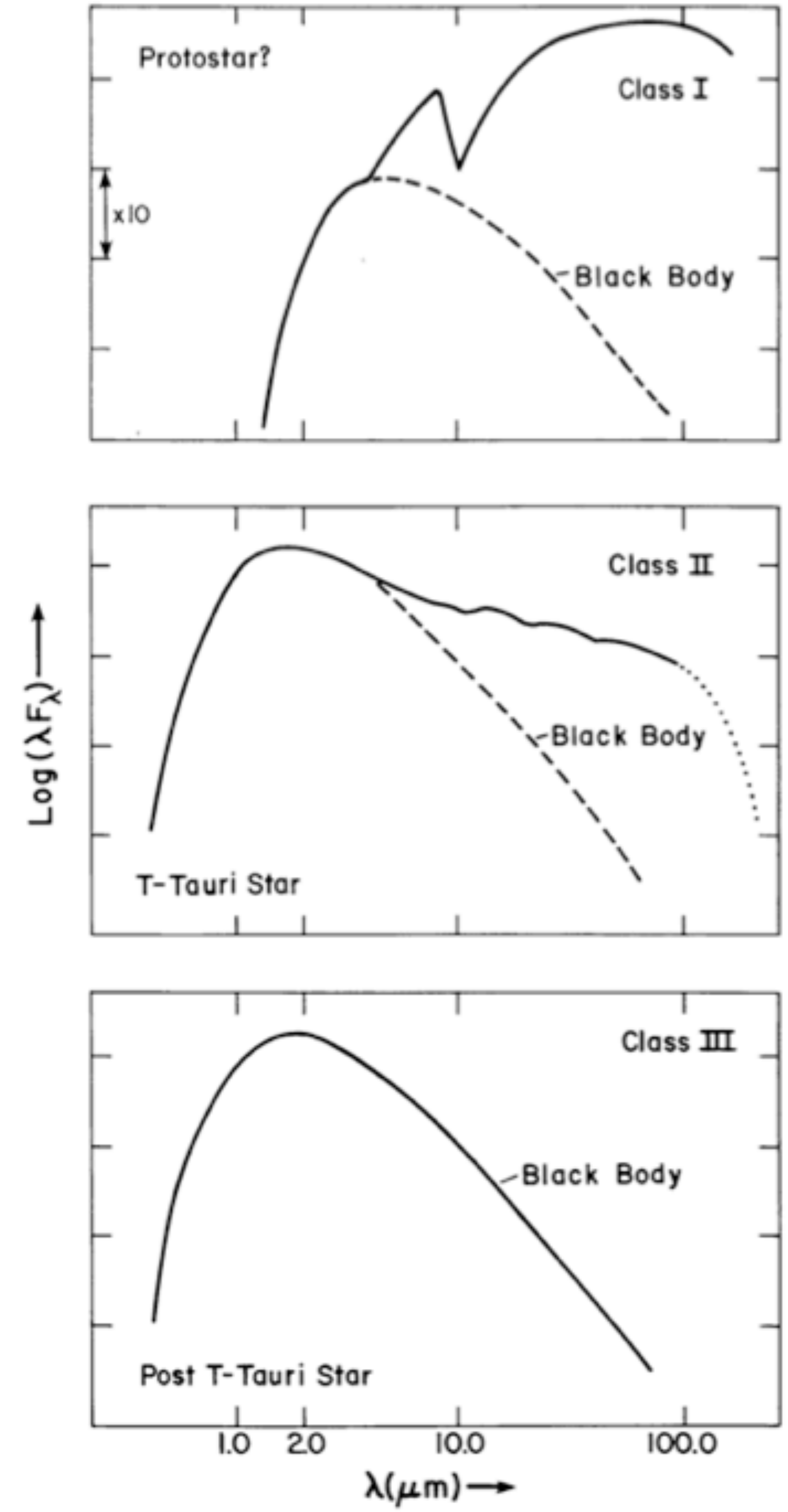
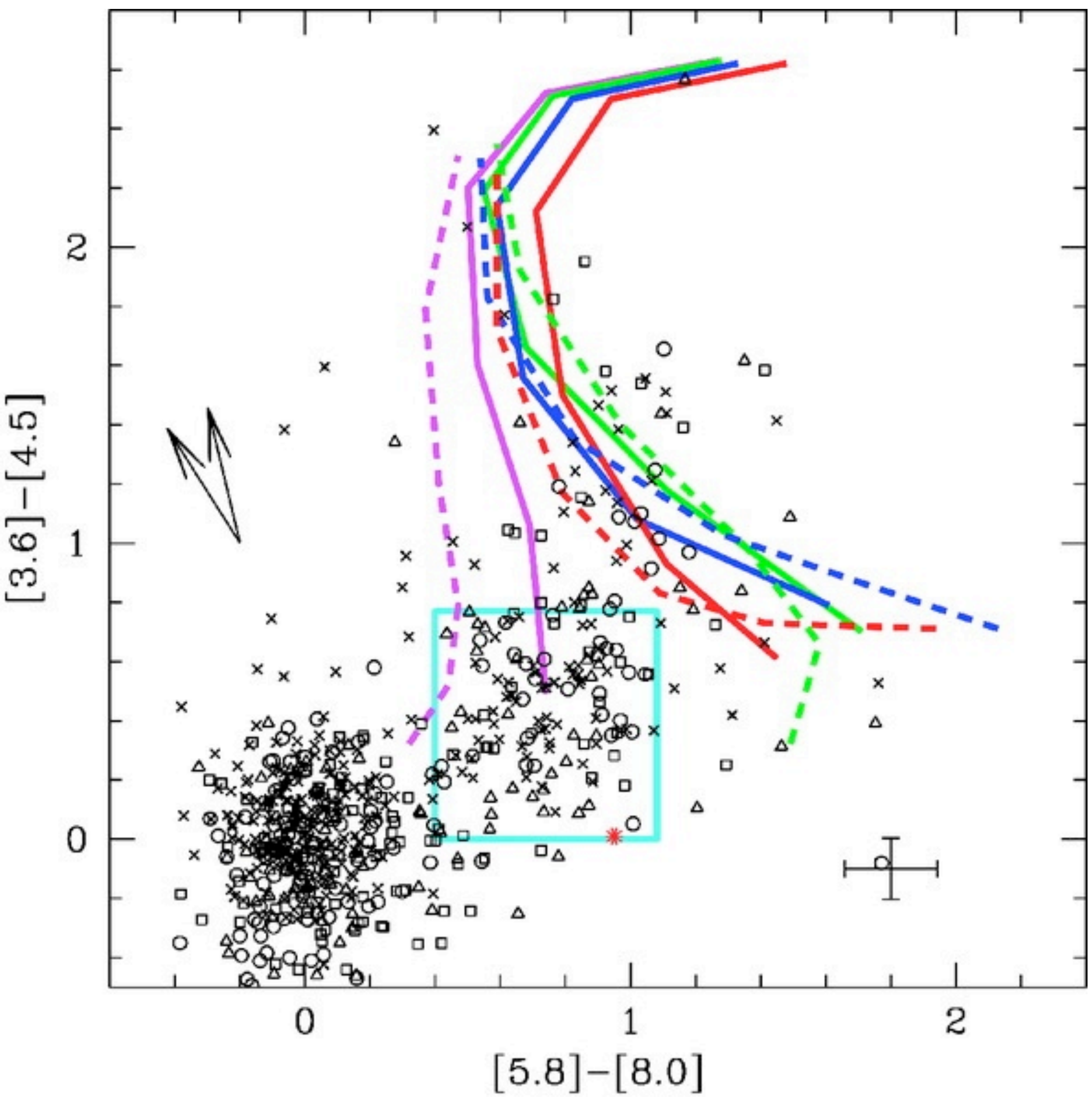
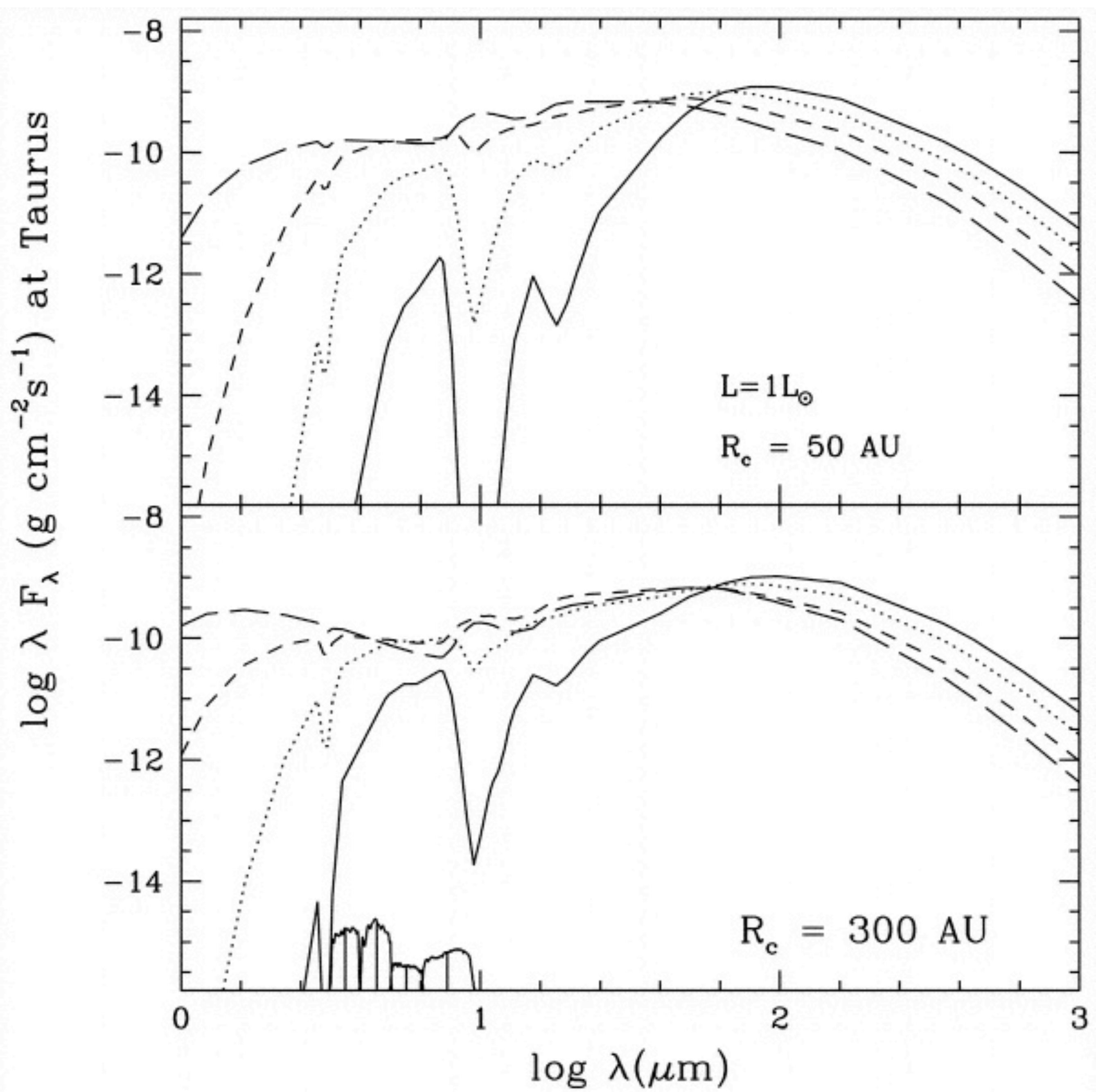


Figure 2. Proposed classification scheme for the energy distributions of embedded young stellar objects. Class I objects have broader than blackbody distributions with slopes or spectral indices which are positive longward of 2 microns wavelength; these objects may be protostars. Class II objects have broader than blackbody distributions which are flat or have negative slopes longward of two microns. Class II distributions are characteristic of T Tauri stars. Class III distributions are fit well by reddened blackbody functions and represent reddened stellar photospheres of stars very near to or on the ZAMS.

Protostellar "Ages"

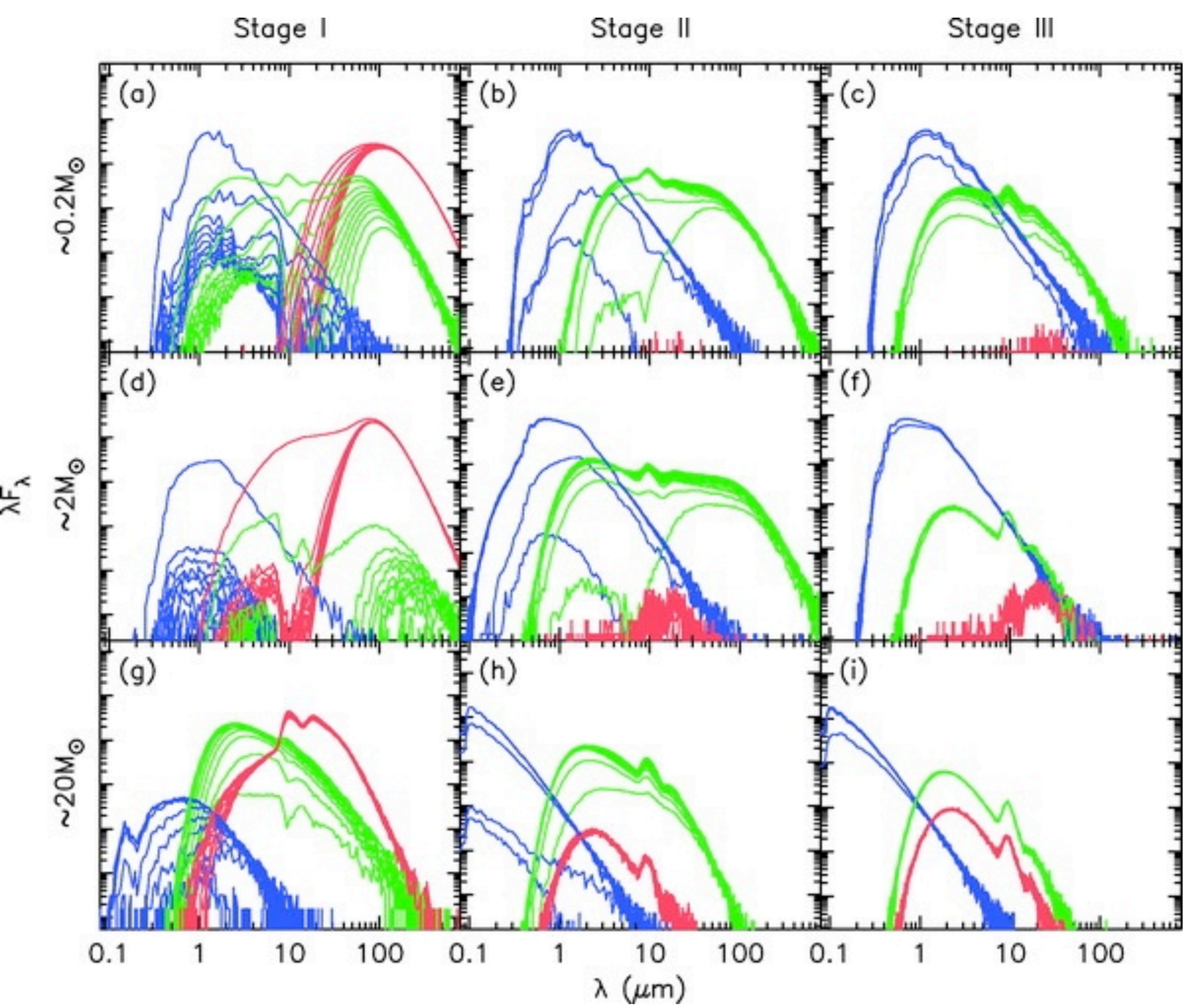
Allen et al. 2004 (early Spitzer modeling/results).



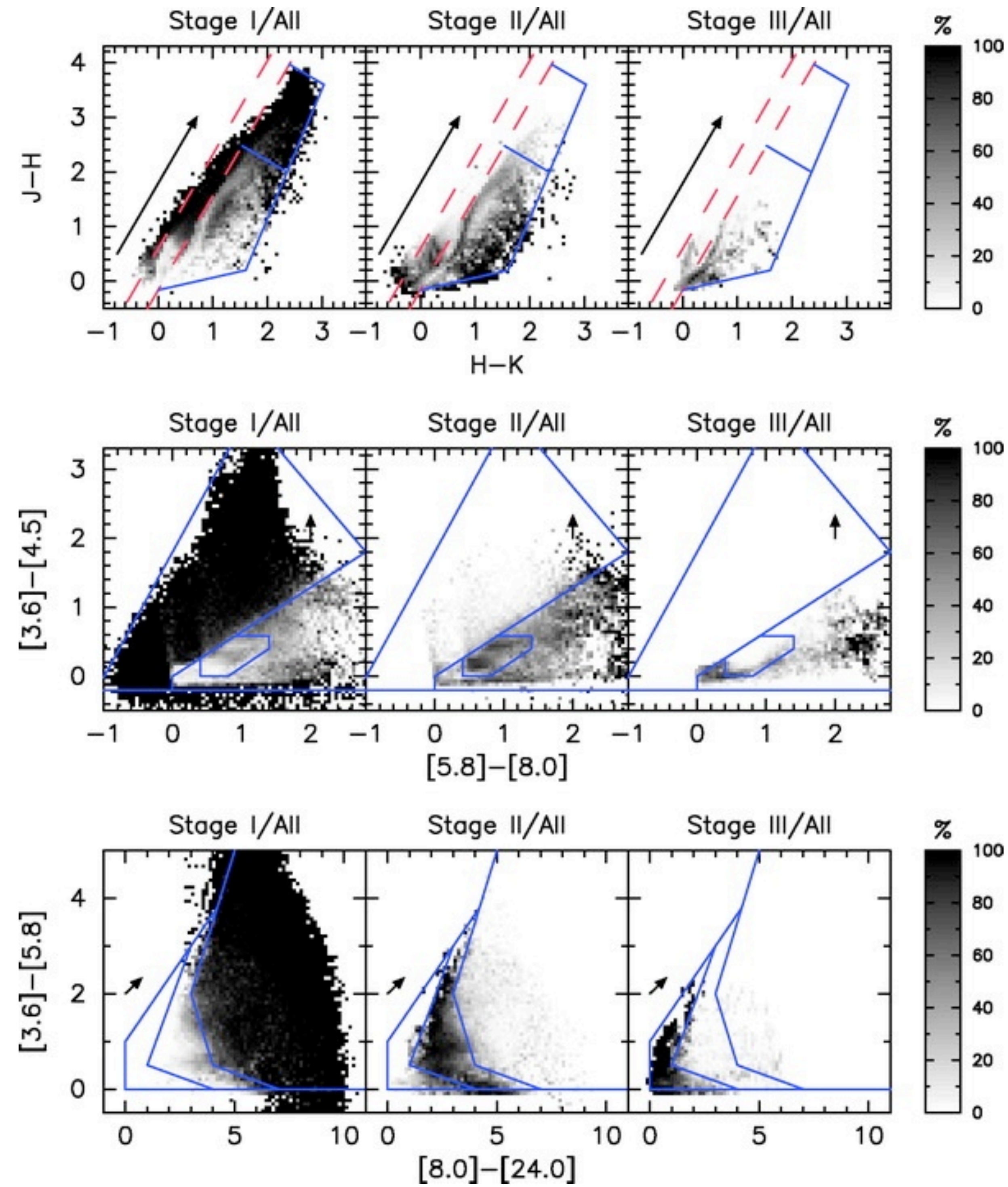


Protostellar "Ages"

Robitaille et al. 2006
(later Spitzer modeling,
grid of models).

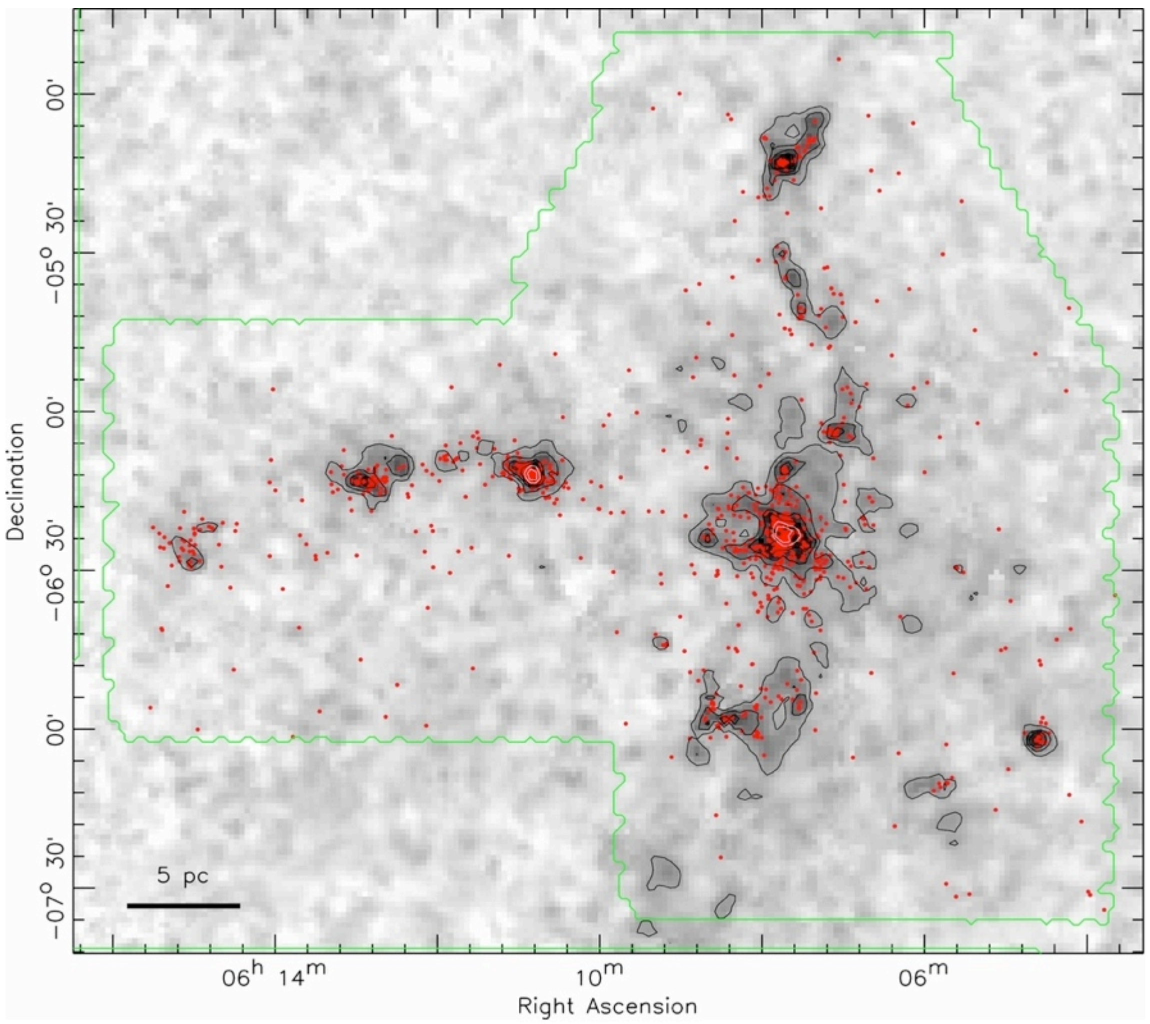


star (*blue*) disk (*green*) envelope (*red*).



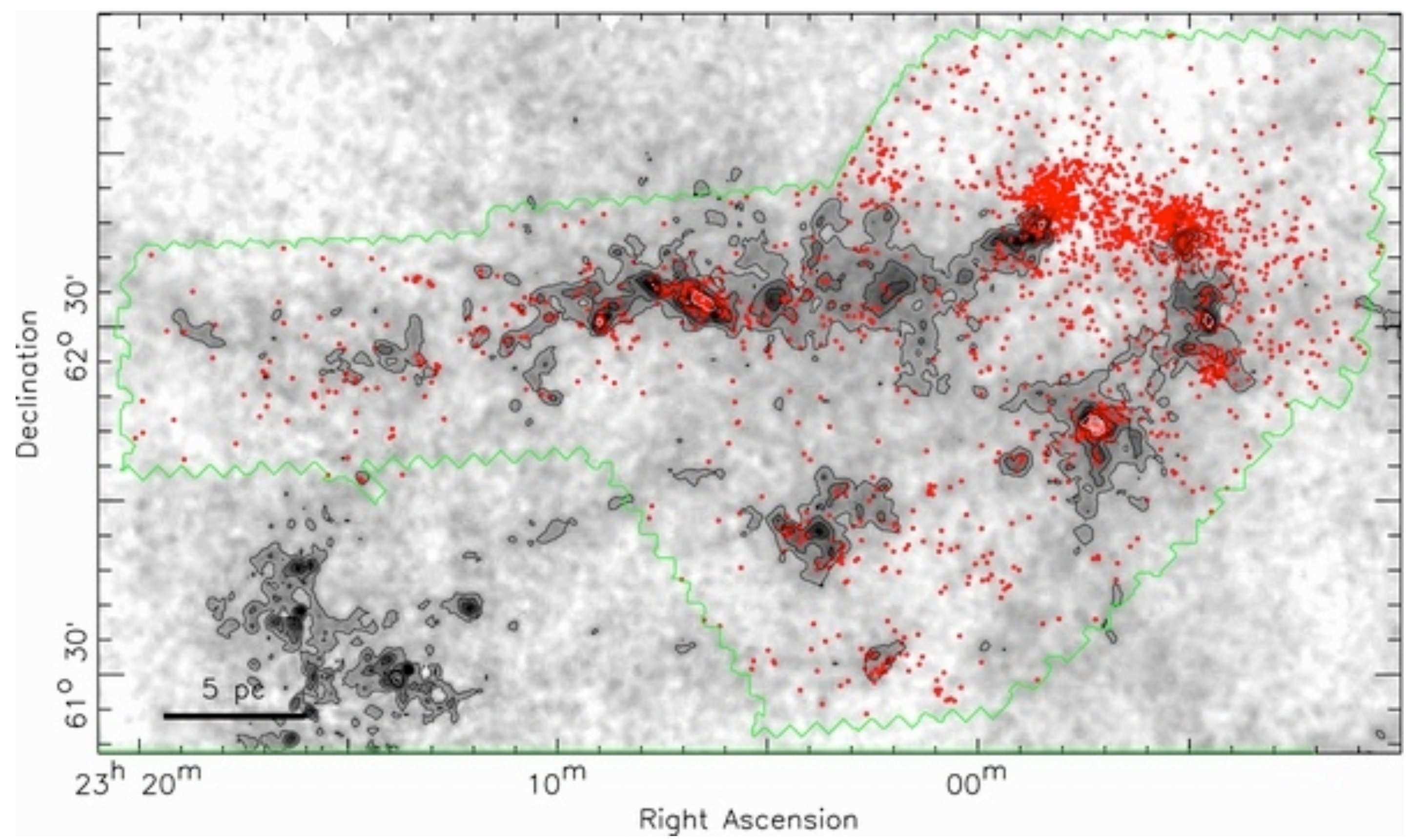
Kennicutt-Schmidt "Nearby"?

Mon R2



Greyscale=Extinction; Red=YSOs

Cep OB3



Figures 1 and 2 from
A Correlation between Surface Densities of Young Stellar Objects and Gas in Eight Nearby Molecular Clouds
R. A. Gutermuth et al. 2011 ApJ 739 84 doi:10.1088/0004-637X/739/2/84

Kennicutt-Schmidt "Nearby"?

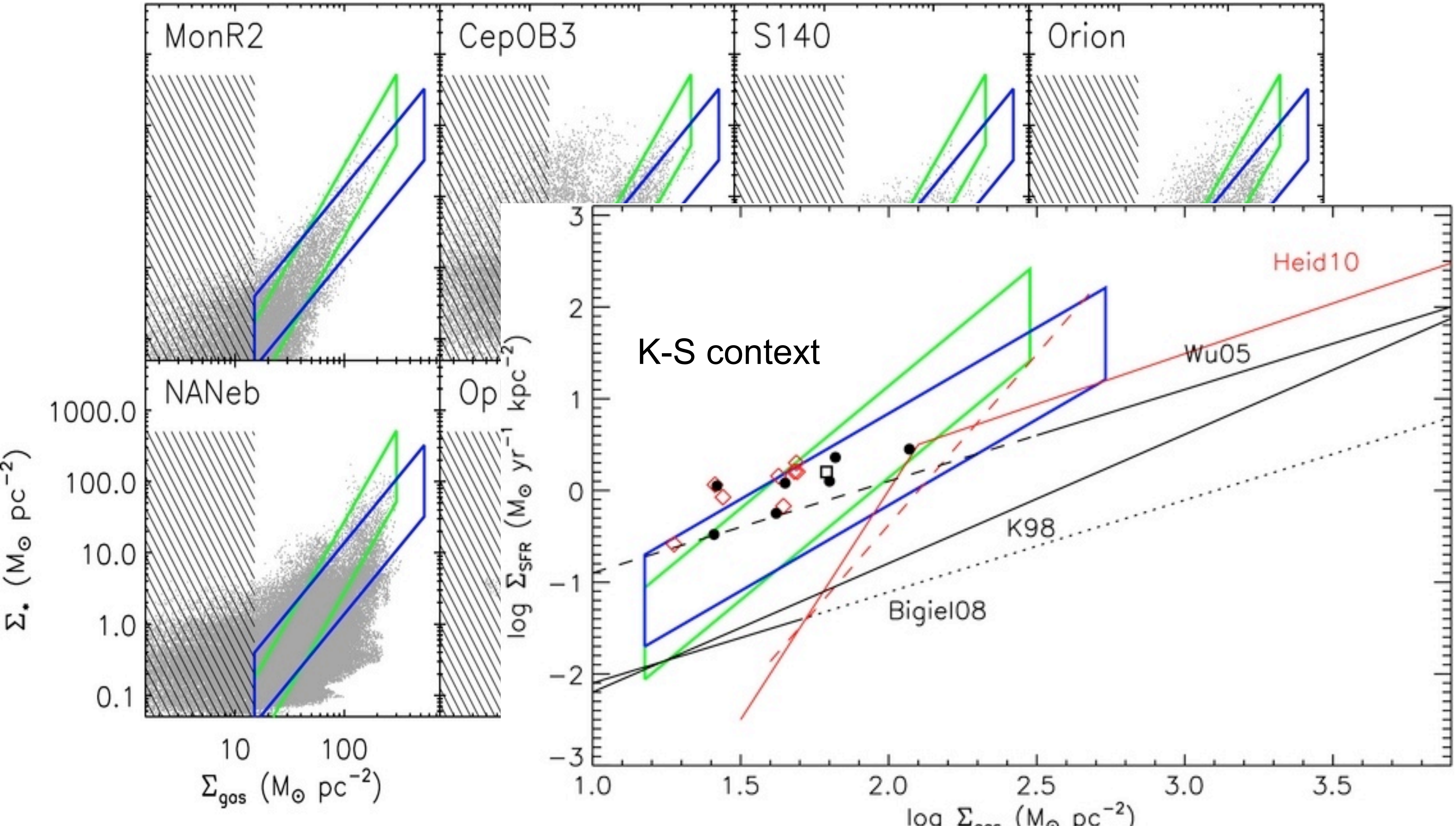


Figure 10 & 15 from
A Correlation between Surface Densities of Young Stellar Objects and Gas in Eight Nearby Molecular Clouds
R. A. Gutermuth et al. 2011 ApJ 739 84 doi:10.1088/0004-637X/739/2/84

Ask Stella for an Update...

The Astrophysical Journal, 738:140 (11pp), 2011 September 10 doi:10.1088/0004-637X/738/2/140

ON THE RELIABILITY OF STELLAR AGES AND AGE SPREADS INFERRED FROM PRE-MAIN-SEQUENCE EVOLUTIONARY MODELS

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ABSTRACT

We revisit the problem of low-mass pre-main-sequence stellar evolution and its observational consequences for where stars fall on the Hertzsprung–Russell diagram (HRD). In contrast to most previous work, our models follow stars as they grow from small masses via accretion, and we perform a systematic study of how the stars' HRD evolution is influenced by their initial radius, by the radiative properties of the accretion flow, and by the accretion history, using both simple idealized accretion histories and histories taken from numerical simulations of star cluster formation. We compare our numerical results to both non-accreting isochrones and to the positions of observed stars in the HRD, with a goal of determining whether both the absolute ages and the age dispersions inferred from non-accreting isochrones are reliable. We show that non-accreting isochrones can sometimes overestimate stellar ages for more massive stars (those with effective temperatures above ~3500 K), thereby explaining why non-accreting isochrones often suggest a systematic age difference between more and less massive stars in the same cluster. However, we also find the only way to produce a similar overestimate for the ages of cooler stars is if these stars grow from ~0.01 $M_{\odot}$ seed protostars that are an order of magnitude smaller than predicted by current theoretical models, and if the size of the seed protostar correlates systematically with the final stellar mass at the end of accretion. We therefore conclude that, unless both of these conditions are met, inferred ages and age spreads for cool stars are reliable, at least to the extent that the observed bolometric luminosities and temperatures are accurate. Finally, we note that the time dependence of the mass accretion rate has remarkably little effect on low-mass stars' evolution on the HRD, and that such time dependence may be neglected for all stars except those with effective temperatures above ~4000 K.

Key words: accretion, accretion disks – Hertzsprung-Russell and C-M diagrams – stars: evolution – stars: formation – stars: low-mass – stars: pre-main sequence

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