

# Star Formation Taste Tests

Alyssa A. Goodman

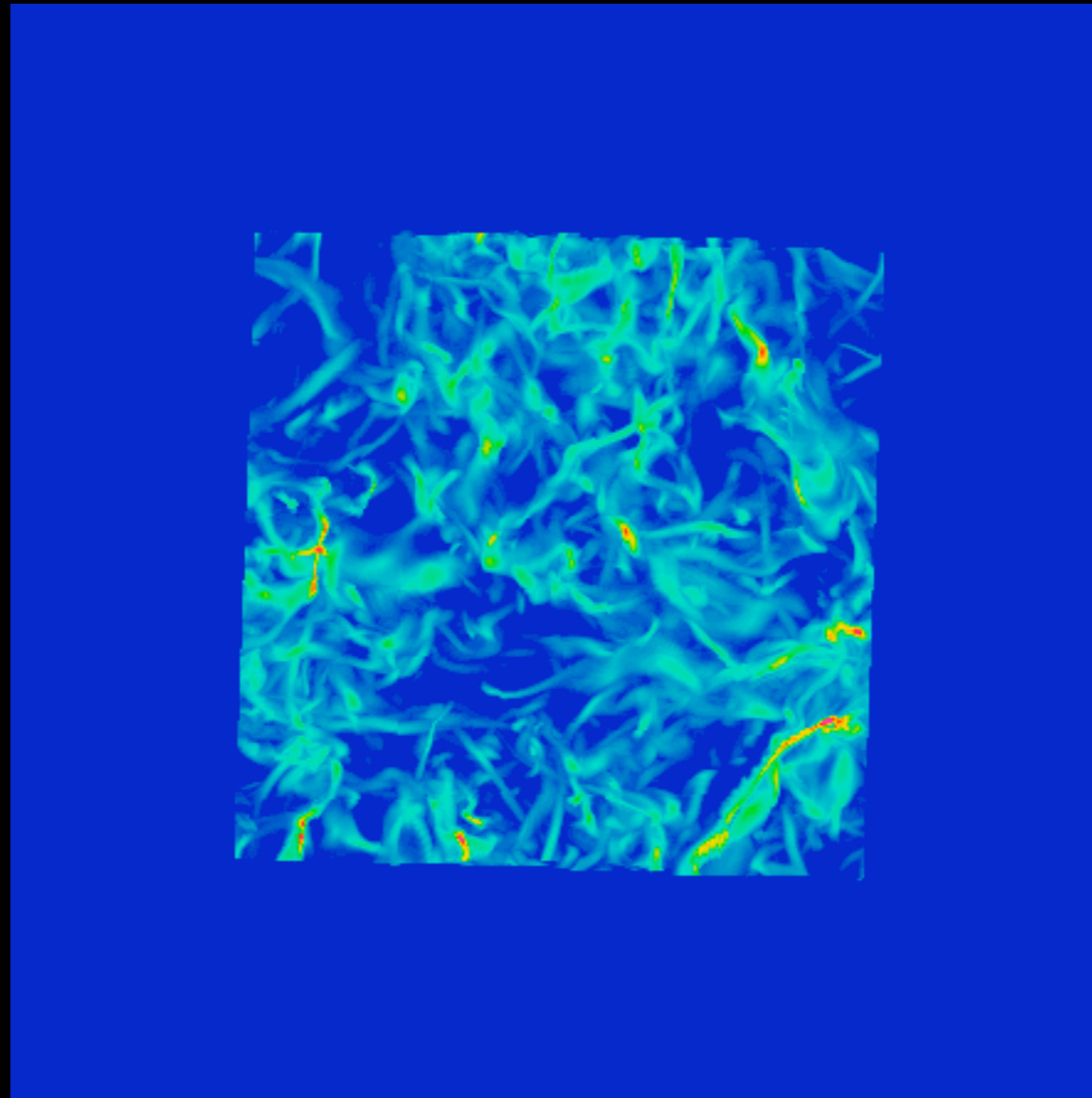
Harvard-Smithsonian Center for Astrophysics

&

Initiative for Innovative Computing at Harvard



# What theorists are used to...

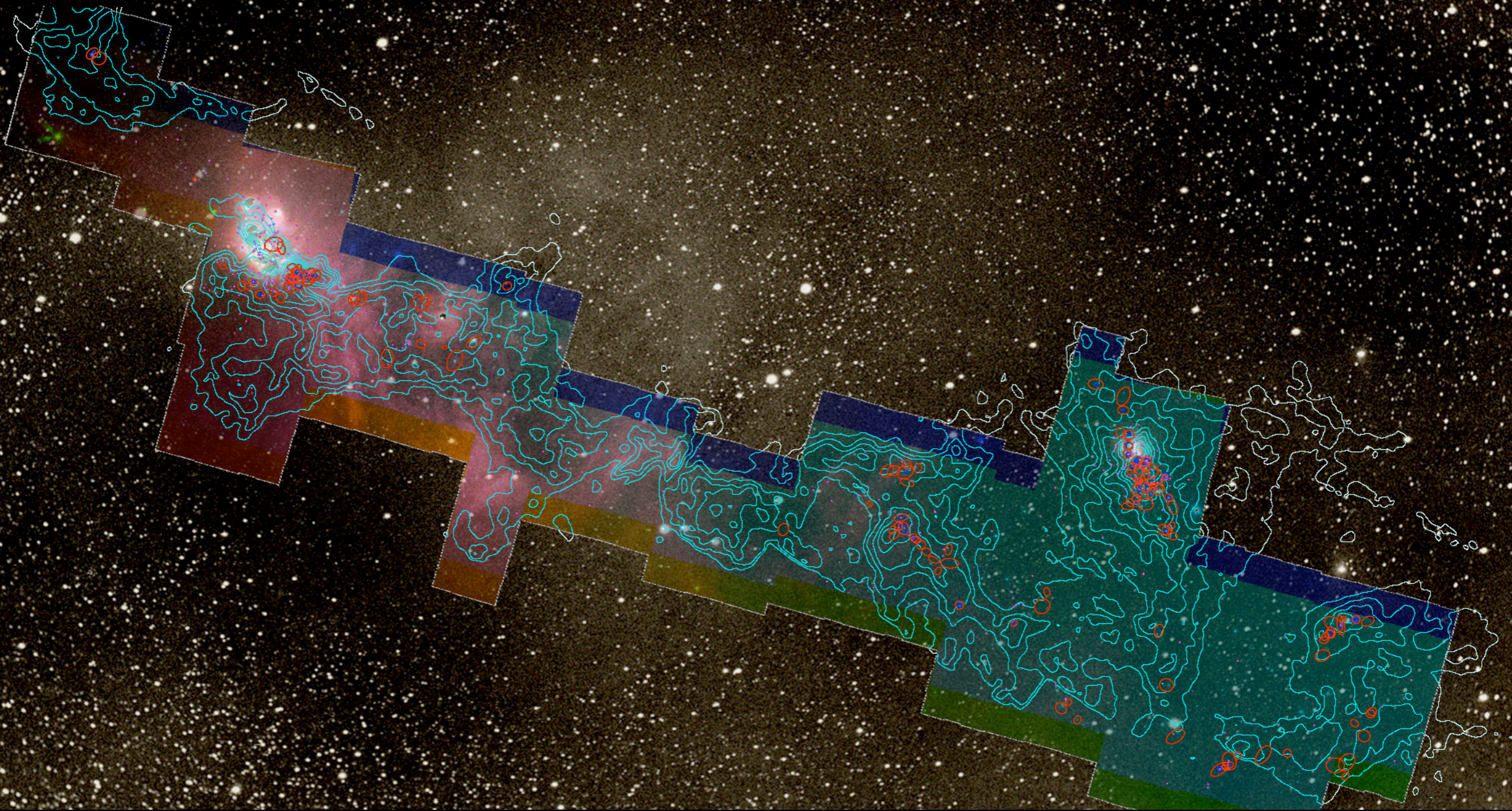


“Three-dimensional visualization of density structure in a turbulent cloud”

*Courtesy Eve Ostriker, Jim Stone & Charles Gammie*

...but, alas, observers cannot live in that space.

# COMPLETE = COordinated MOlecular PRobe LIne EXtinction Thermal Emission Survey of Star-Forming Regions



## COMPLETE Collaborators, Summer 2007:






Alyssa A. **Goodman** (CfA/IIC)  
João Alves (Calar Alto, Spain)  
Héctor Arce (AMNH to Yale)

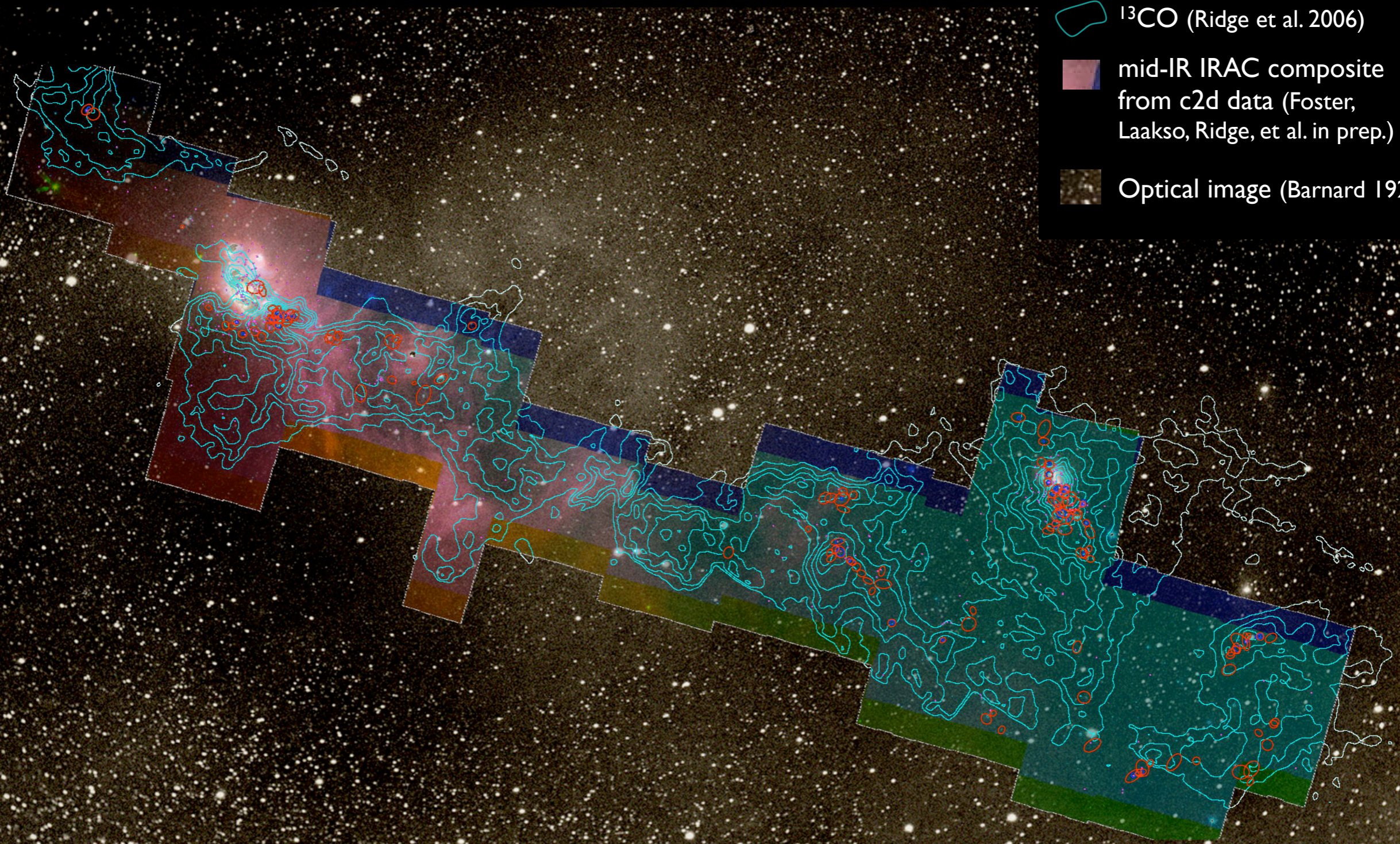
Michelle Borkin (IIC)  
Paola **Caselli** (Leeds, UK)  
James DiFrancesco (HIA, Canada)  
Jonathan **Foster** (CfA, PhD Student)  
Sebastian Guillot (U. Victoria, Canada)

Mark **Heyer** (UMASS/FCRAO)  
Doug **Johnstone** (HIA, Canada)  
Jens **Kauffmann** (CfA/IIC)  
Helen Kirk (HIA, Canada)  
Di Li (JPL)

Jason Li (Harvard College)  
Jaime **Pineda** (CfA, PhD Student)  
Erik **Rosolowsky** (CfA)  
Scott **Schnee** (Caltech)  
Mario Tafalla (OAN, Spain)






# COMPLETE Perseus

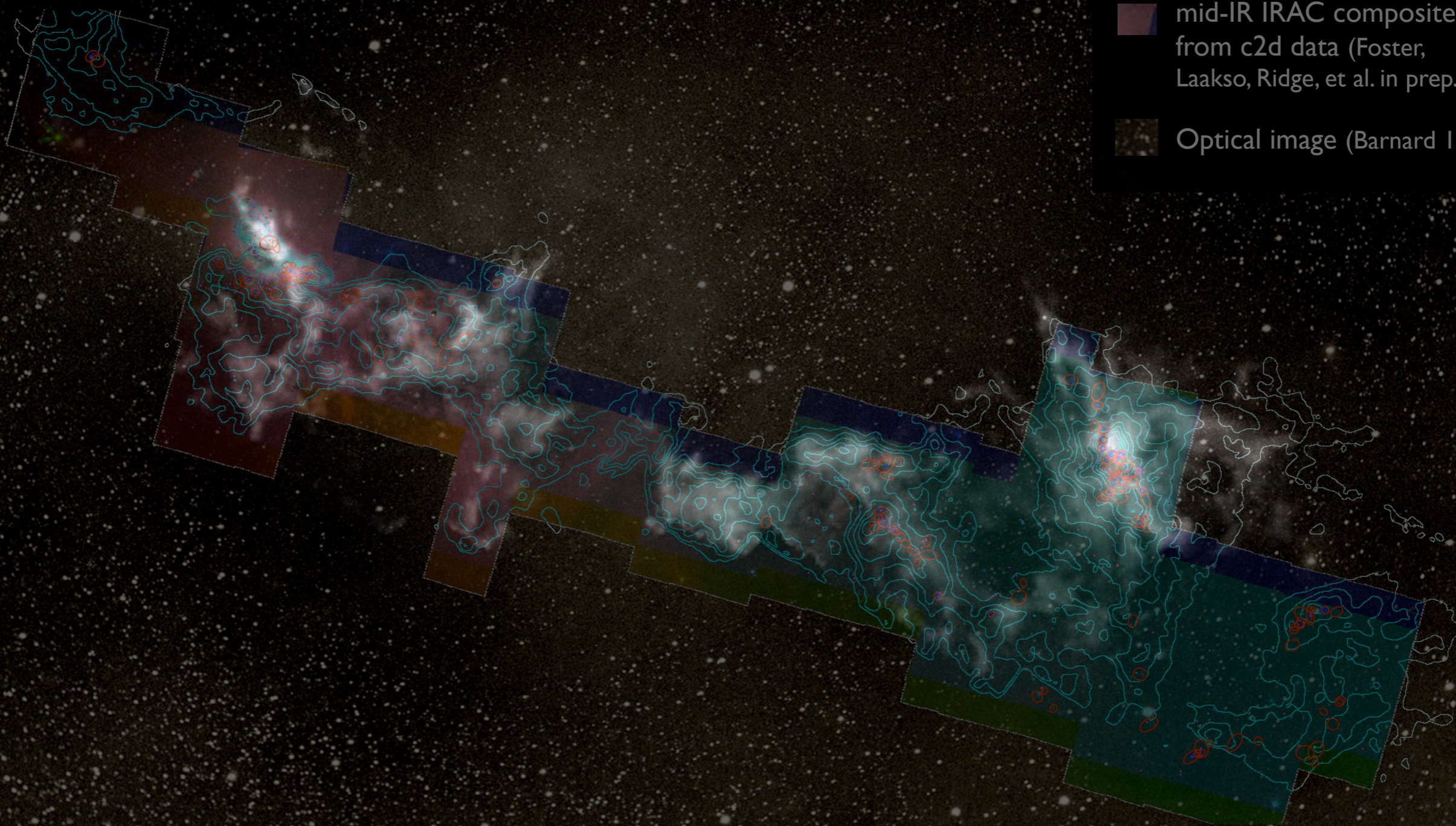
-  mm peak (Enoch et al. 2006)
-  sub-mm peak (Hatchell et al. 2005, Kirk et al. 2006)
-   $^{13}\text{CO}$  (Ridge et al. 2006)
-  mid-IR IRAC composite from c2d data (Foster, Laakso, Ridge, et al. in prep.)
-  Optical image (Barnard 1927)



# COMPLETE Perseus

Image size: 1305 x 733  
H/L: 63 WW: 127






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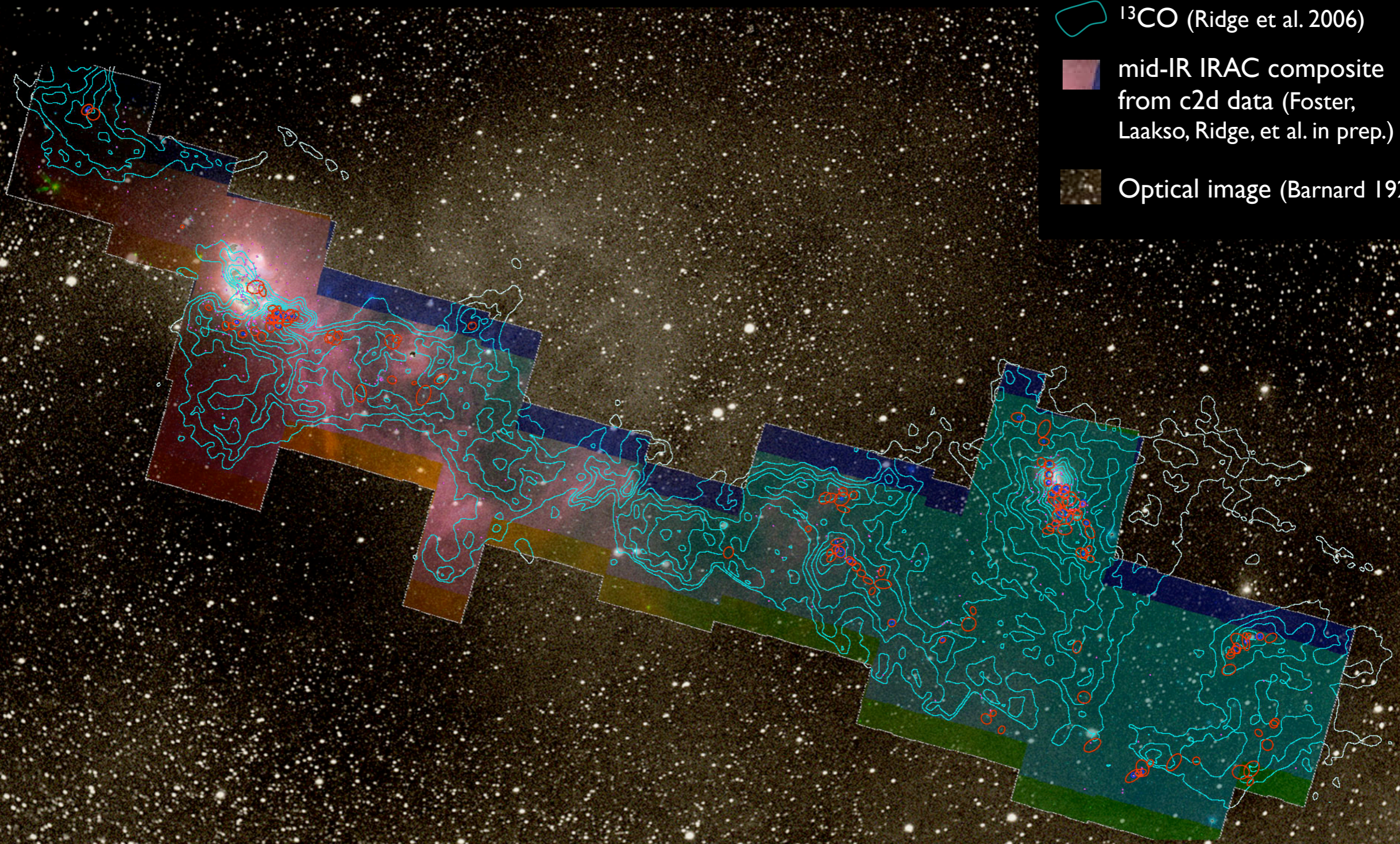


m: 163/249  
Zoom: 227% Angle: 0






1 p

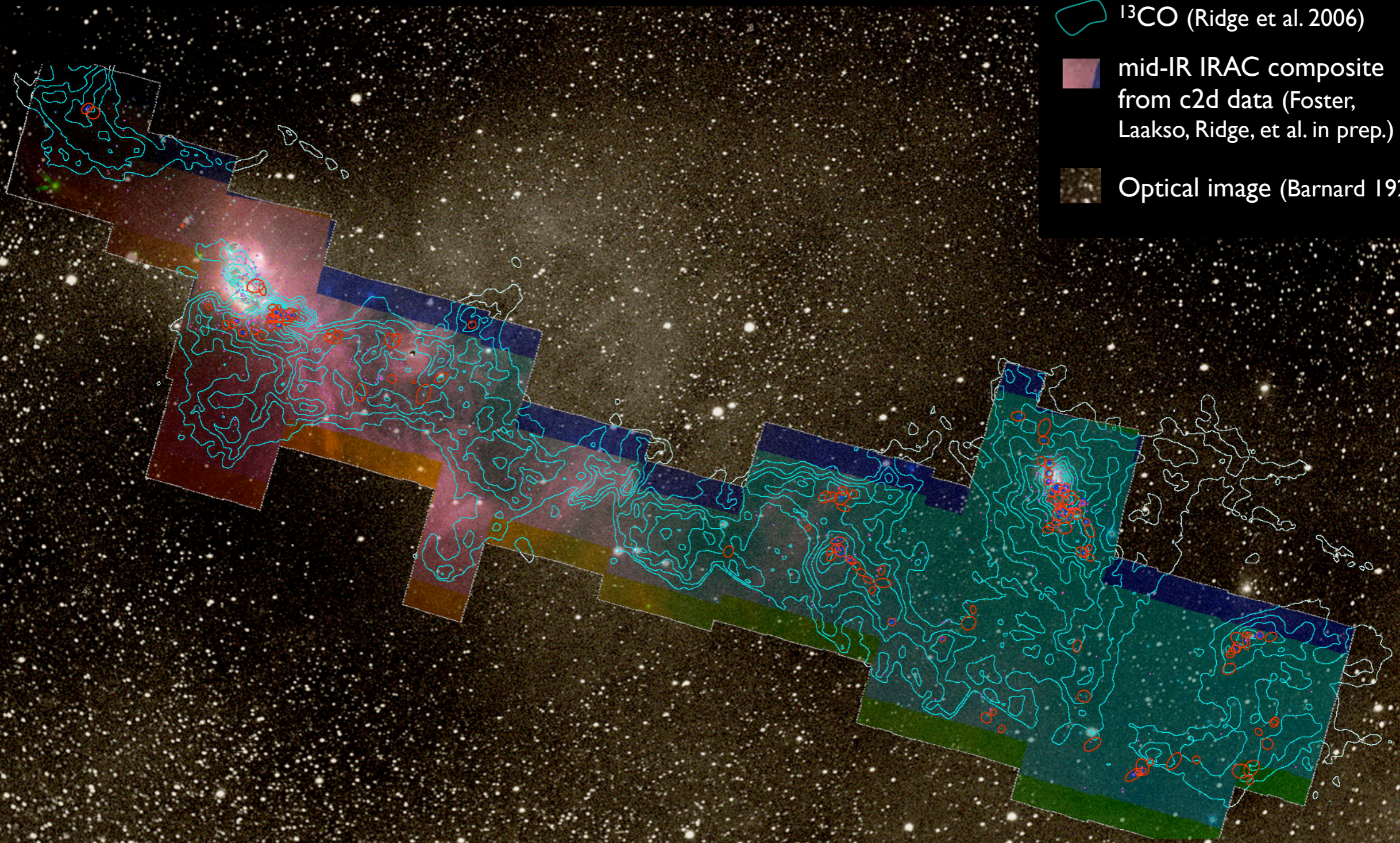
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

position-position-velocity is **NOT the same** as  
position-position-position-velocity-velocity-velocity  
cf. Ostriker, Stone & Gammie 2001

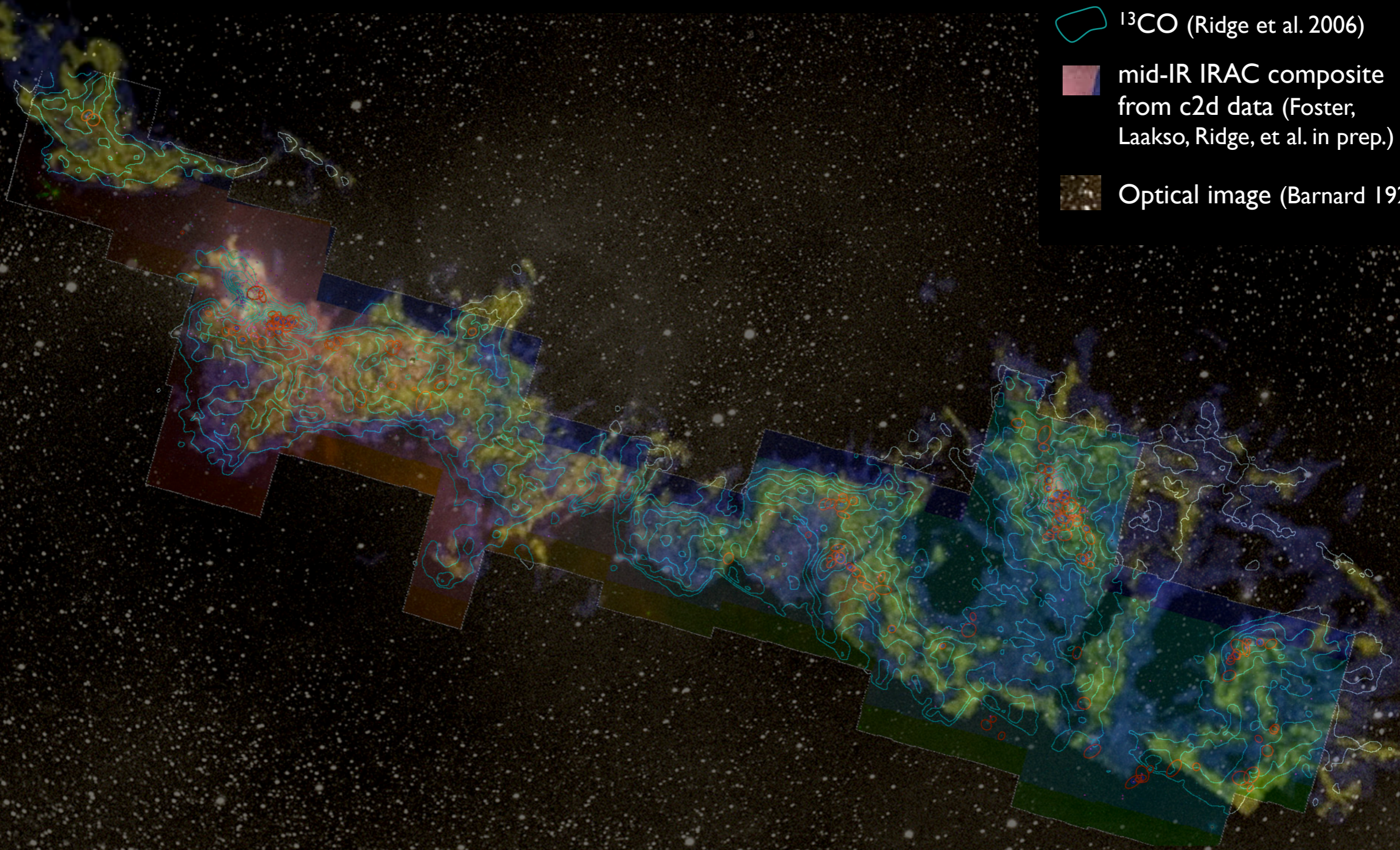
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



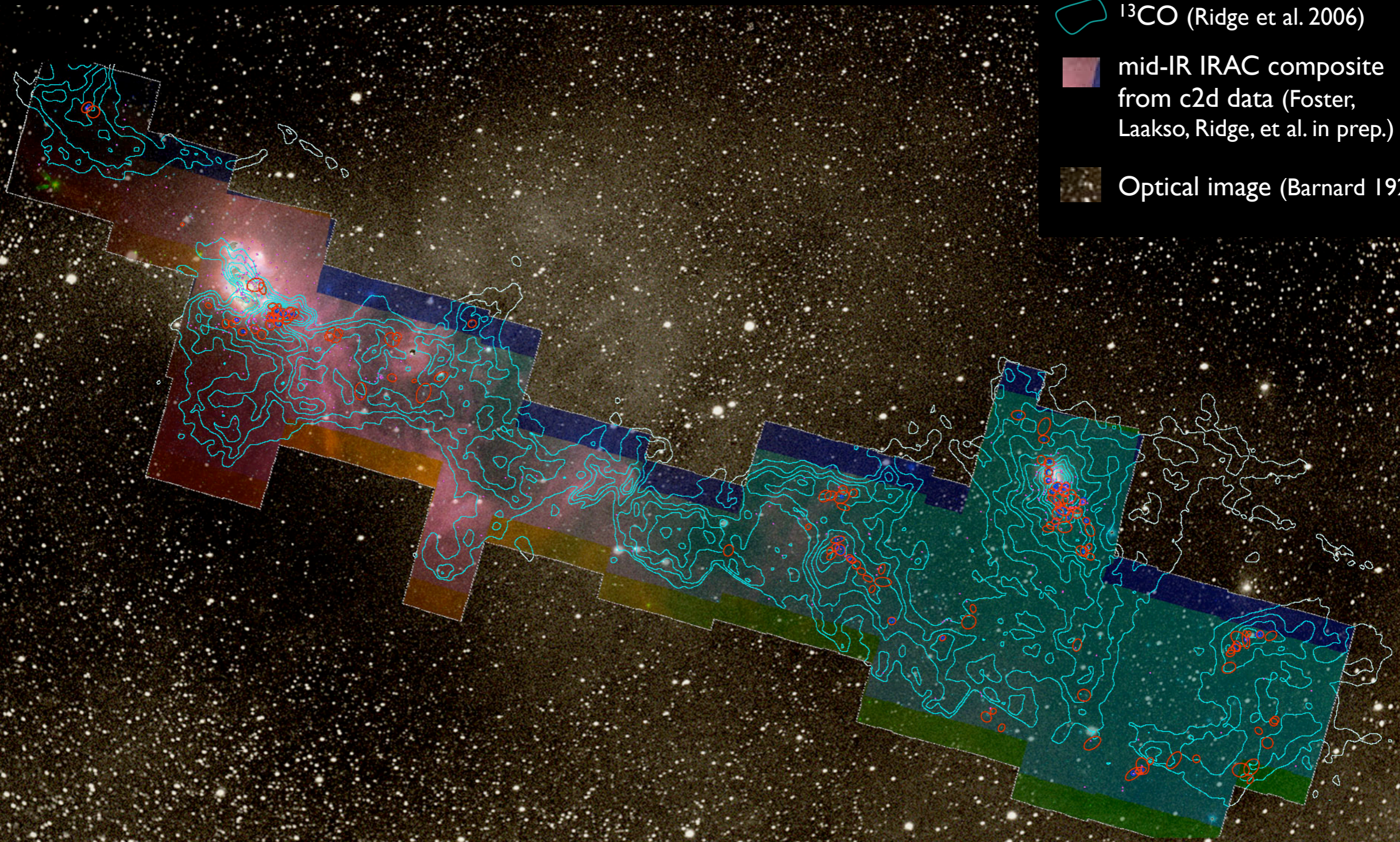
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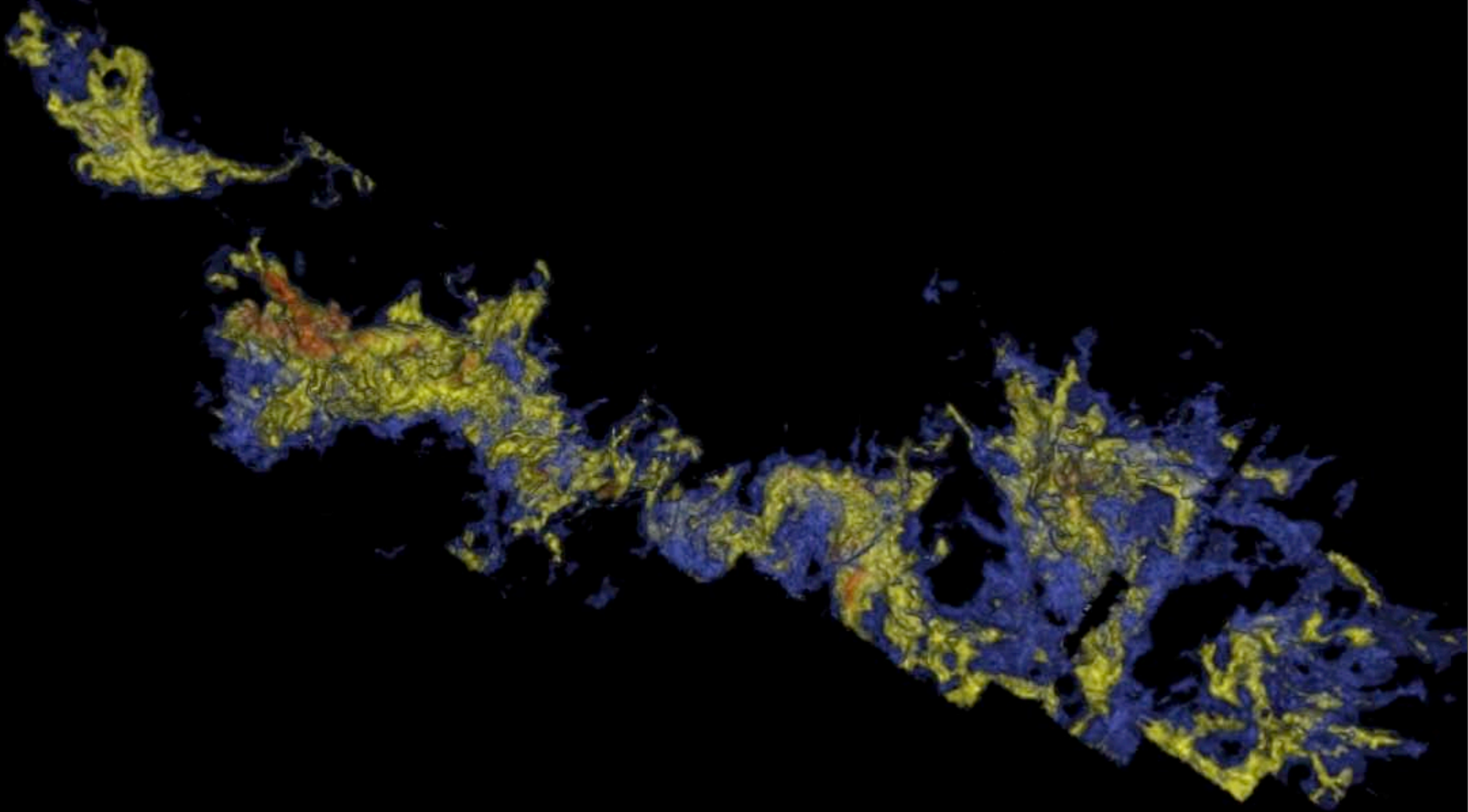


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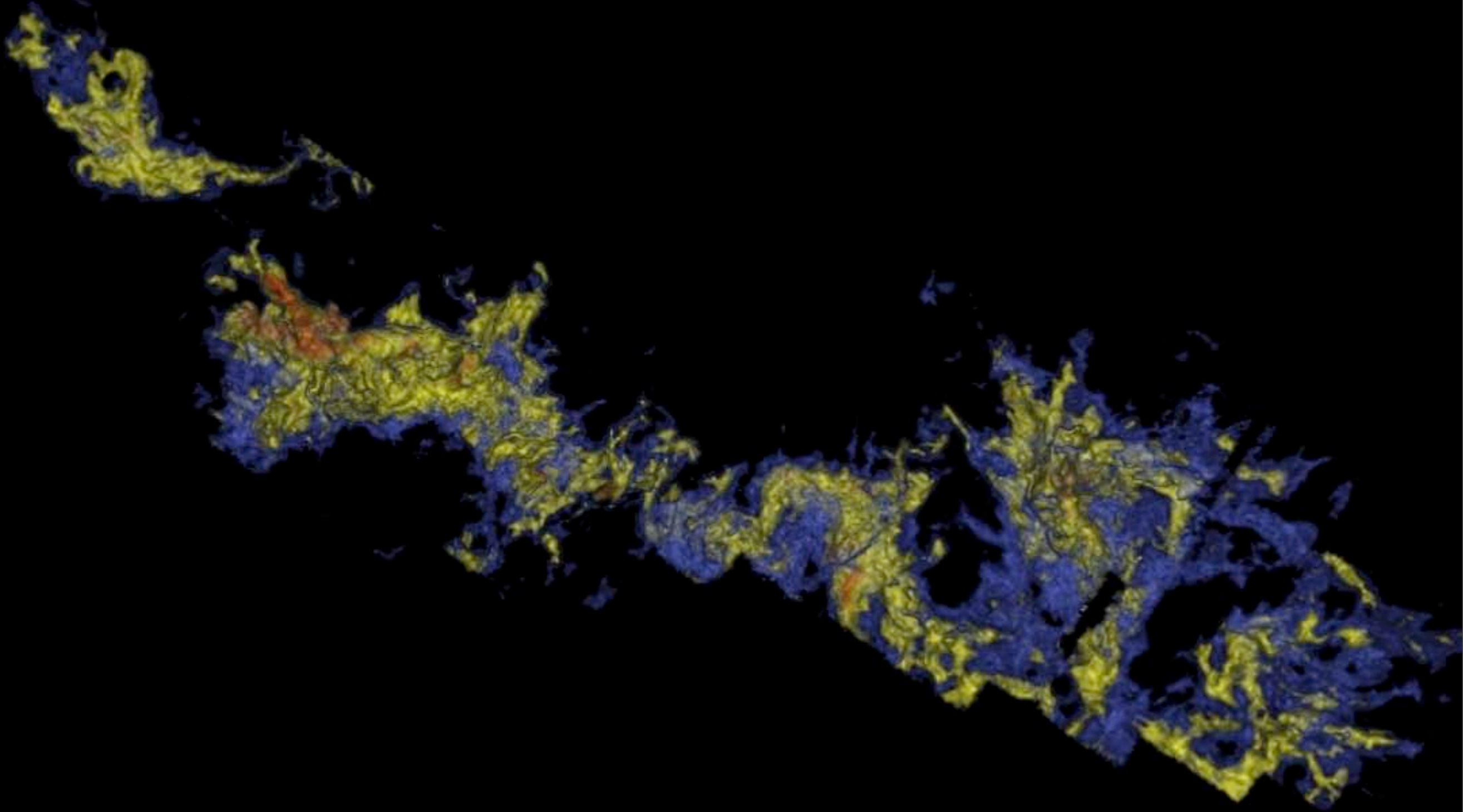


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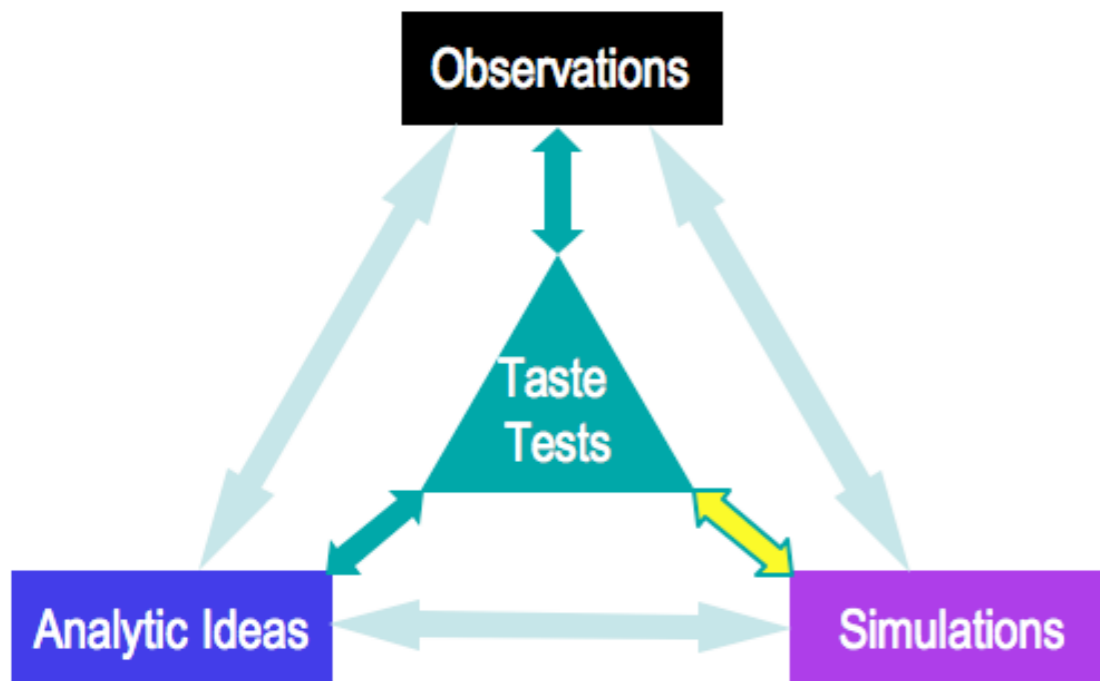
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Rendering shows COMPLETE  $^{13}\text{CO}$   
(as given in Ridge et al. 2006)  
starting frame is plane-of-sky  
“z” axis is line-of-sight velocity



3D rendering courtesy AstroMed team @ IIC & Nick Holliman, Durham, UK

# Taste Tests



*“Taste Tests”?* We frame this project by analogy. How does a great chef, making a complicated dish, know if she has created what she originally intended when she is done cooking? She “tastes.” She informs her cooking with her extensive knowledge of food chemistry (**analytic theory**), uses all the cooking equipment (**simulations**) she has in the kitchen to try to make something edible and tasty (**starforming, and realistic**), and then she uses her senses (**observations**) to see if what she made tastes as intended. *“Tasting” in cooking actually encompasses the joint action of many senses: we propose here a combination of statistical techniques that we call “taste tests.”* The tests will allow us to discerningly decide if what we sense (observe) and what we can cook (simulate) might actually be tasty (form stars), and how (analytic theory) that happens.



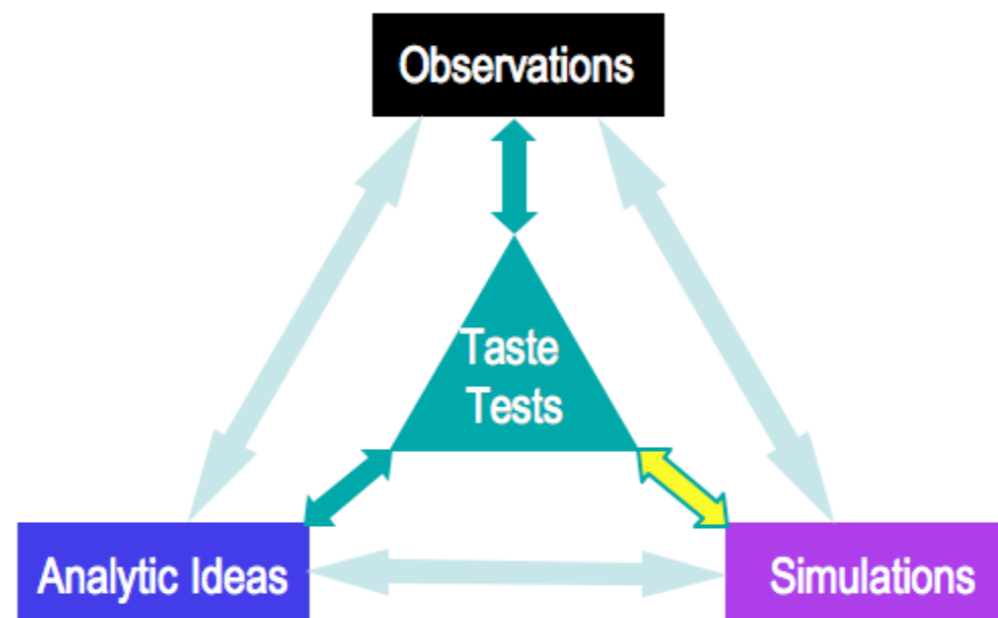
# Earlier Tests...

## Inspired by the “Theory Cube”

- Power Spectra (of density, velocity)
- pdfs
- Autocorrelation Functions
- $\Delta$ -Variance
- Structure Functions

## Data-Oriented

- Wavelet Analysis
- Spectral Correlation Function
- Structure Trees
- Velocity Centroid Analysis VCA (see also VCS)
- Principal Component Analysis



**Today: Take-Out Only**



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Column density is **log-normal-ish** on 10's of pc scales

- ★ turbulence prevails, mostly(?)
- ★ Can we relate distribution details to Mach # & B?



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- ★ Can we relate distribution details to Mach # & B?

Self-gravity matters on a range of scales, at *identifiable* locations

- ★ quantification of hierarchical structure (**dendrograms**)

# Full Workshop: Five-Course In-House Meal



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I. Column density is log-normalish on 10's of pc scales

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Star Formation Taste Tests > Overview

https://iic.grouphub.com/projects/700257/project/log

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## Star Formation Taste Tests CFA


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#### Welcome to the Tasting Room



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**TODAY**

**Writeboard** [Notes on KITP Simulation Talks](#) Added by Alyssa G.

WEDNESDAY, 8 AUGUST


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### Computational Astrophysics Data Analysis Center

http://cadac.sdsc.edu/

# CADAC

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## The Computational Astrophysics Data Analysis Center

The Computational Astrophysics Data Analysis Center (CADAC) collects and stores results of large astrophysical simulations and provides data analysis resources to researchers worldwide. Because only a fraction of computational resources is typically available for data-analysis, early publication and sharing of large computational datasets are not commonplace in astrophysics.

The CADAC is a worldwide service that provides powerful data-storage and data-analysis resources to the astrophysical community, encouraging the early publication of complete numerical datasets. The CADAC will foster a new system and culture whereby data-analysis tools and computational data are shared. Its use will encourage scientific collaboration, increase the impact of numerical experiments, and facilitate the review process of journal papers based on computational simulations.

### More Information

- Read more [about](#) the CADAC.
- Find out [who](#) is a member.
- Get some [help](#) joining.
- Visit the [wiki pages](#) for the [KITP](#) workshop [Star Formation Through Cosmic Time](#).
- Read the CADAC [announcement](#).

**SDSC**  
SAN DIEGO SUPERCOMPUTER CENTER

**UCSD**

**lca** Laboratory for Computational Astrophysics

Official web page of the University of California, San Diego.

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The image shows a screenshot of a web browser with two overlapping windows. The background window is titled "Star Formation Taste Tests > Overview" and shows a project overview page. The foreground window is titled "Writeboard: Krumholz, Klein, McKee: Collapse of Massive Cores" and shows a detailed page for a specific simulation project.

**Star Formation Taste Tests > Overview**


Dashboard | Choose a project

## Star Formation Taste Test

Overview Messages To-Do Milestones

### Project overview & activity

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Posted by Alyssa G.

**Writeboard: Krumholz, Klein, McKee: Collapse of Massive Cores**

Go back to Star Formation Taste Tests (Share this Writeboard using <https://ilic.grouphub.com/W300475>)

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## Krumholz, Klein, McKee: Collapse of Massive Cores

### Radiation-Hydrodynamic Simulations of the Collapse and Fragmentation of Massive Protostellar Cores

Year of Simulation

- 2006, 2007

#### Purpose(s) of Simulation

The goal is to do a realistic simulation of the collapse and initial fragmentation phase for massive cores with observed properties. The simulations include radiation (and compare to a control simulation without it) to study how radiation feedback affects fragmentation. The primary scientific question was how strongly massive cores fragment.

In a subsequent paper, we post-processed this simulation with a radiative transfer code to produce detailed predictions for the molecular line emission of massive protostellar disks. The goal is to predict what ALMA and the EVLA should see, and suggest how to use such observations to distinguish between models.

#### Submitter

Mark Krumholz

#### Authors

- Mark R. Krumholz
- Richard I. Klein
- Christopher F. McKee

#### Versions

You're viewing the latest version

- 3 - 09 May 07 Mark Krumholz
- 2 - 10 Nov 06 Mark Krumholz
- 1 - 10 Nov 06 Mark Krumholz

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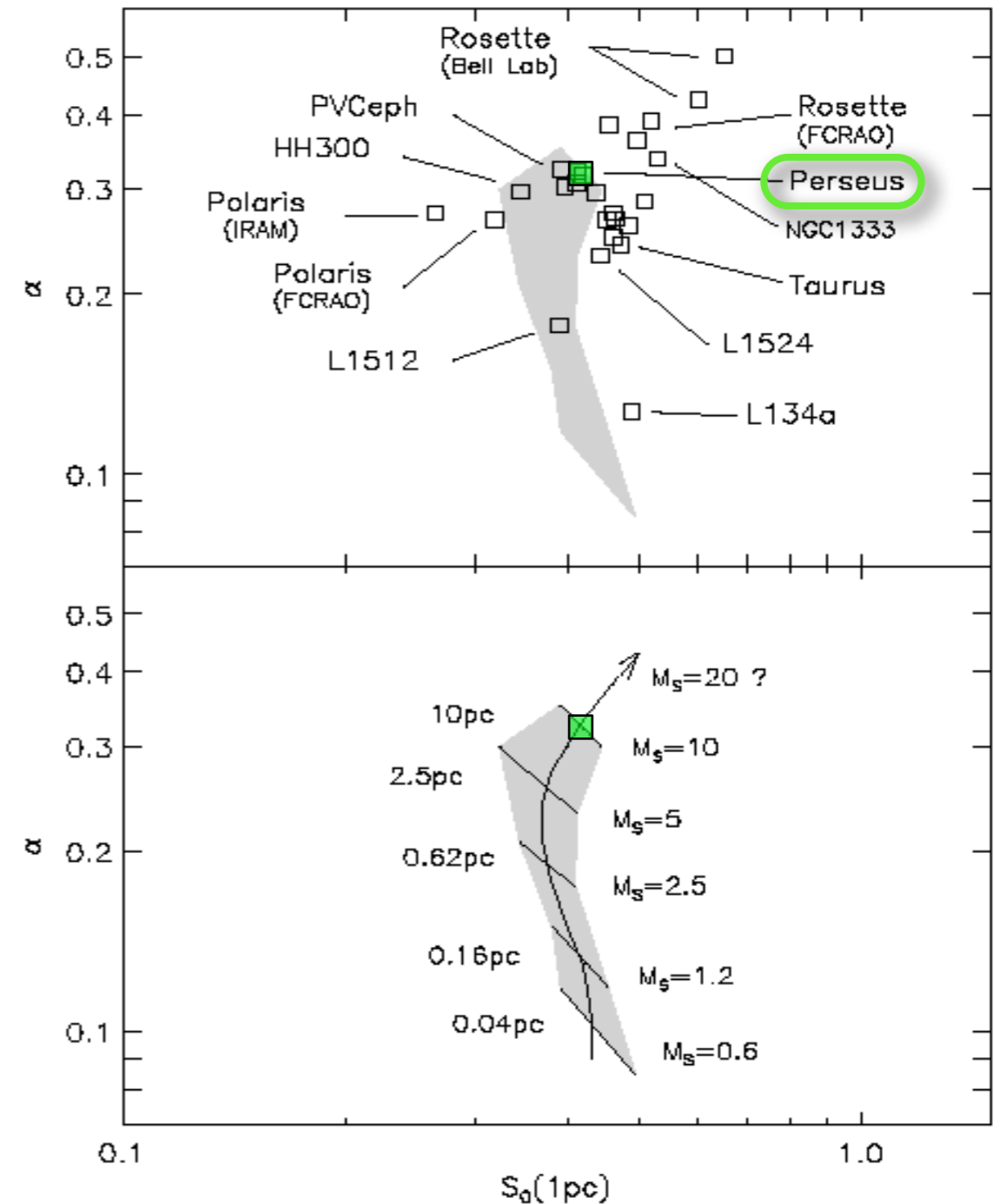
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# Living in “Observational Space”

Ideally includes...

- Projection to 2D sky plane, or “3D” of spectral-line data cubes
- Radiative Transfer
- Chemical Model
- Adding appropriate noise
- Imposing observing characteristics of a telescope



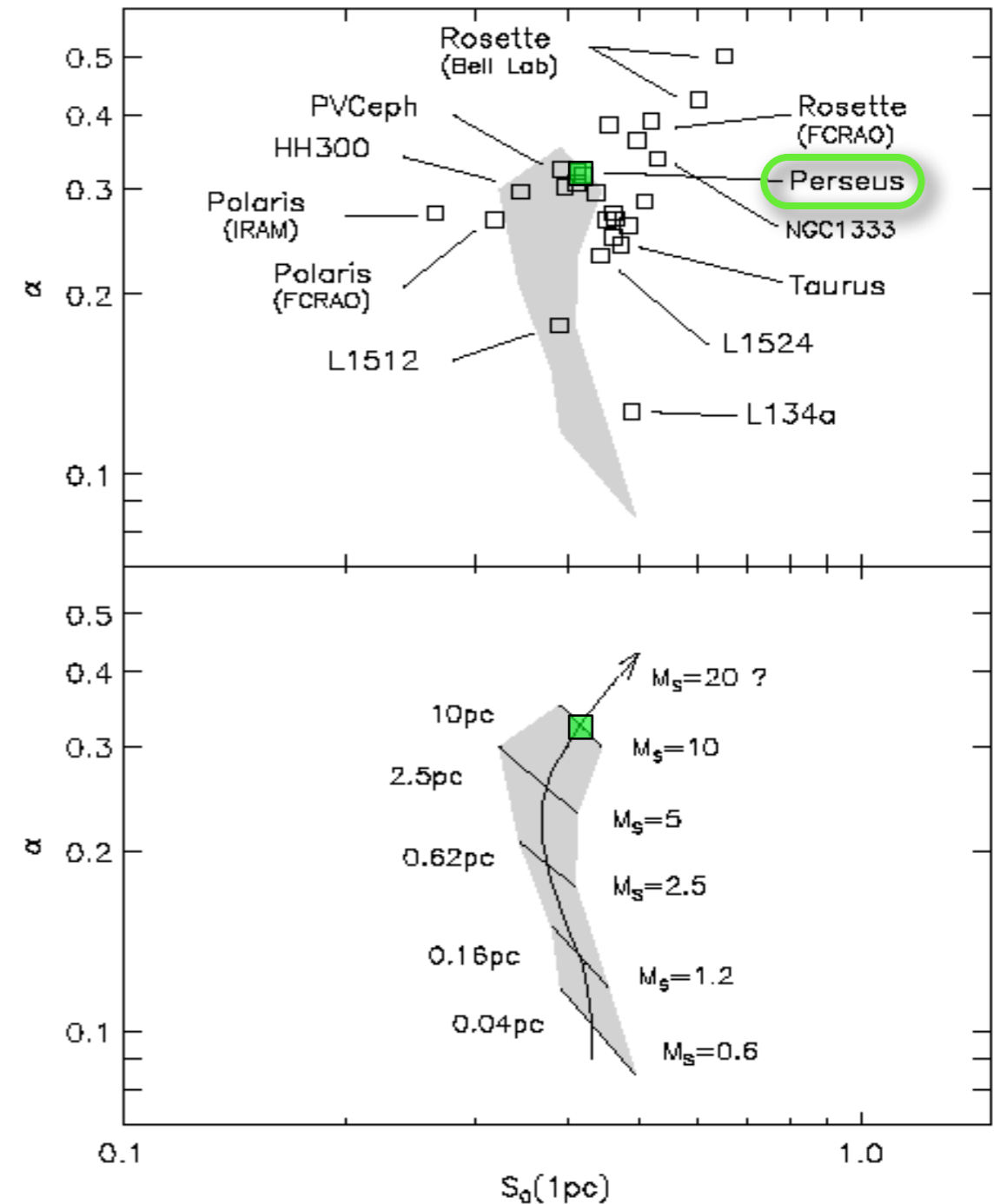
**Example:**  
**The Spectral Correlation Function**

(Padoan, Goodman & Juvela 2003)

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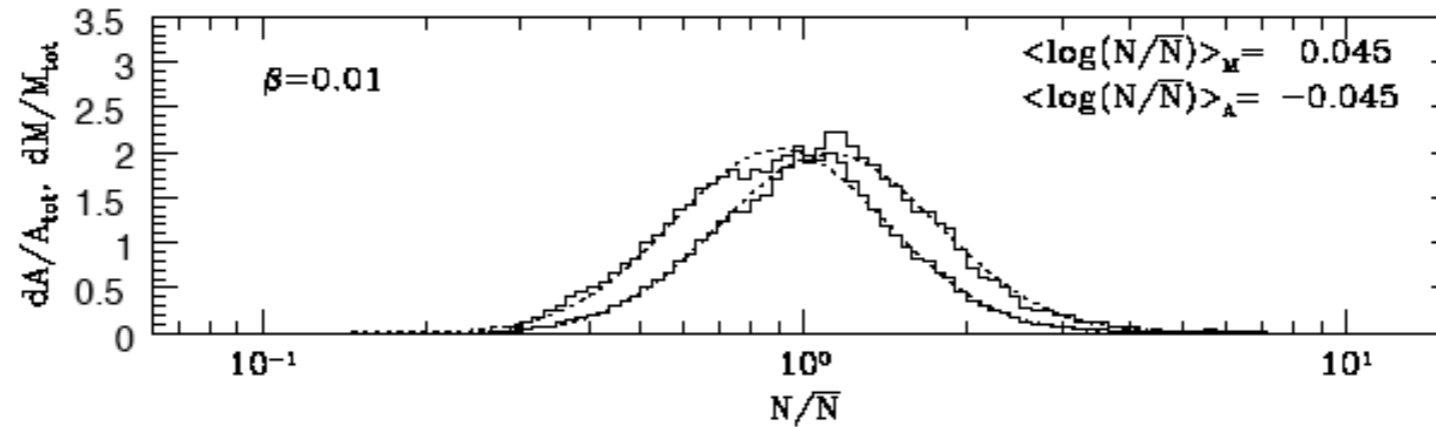


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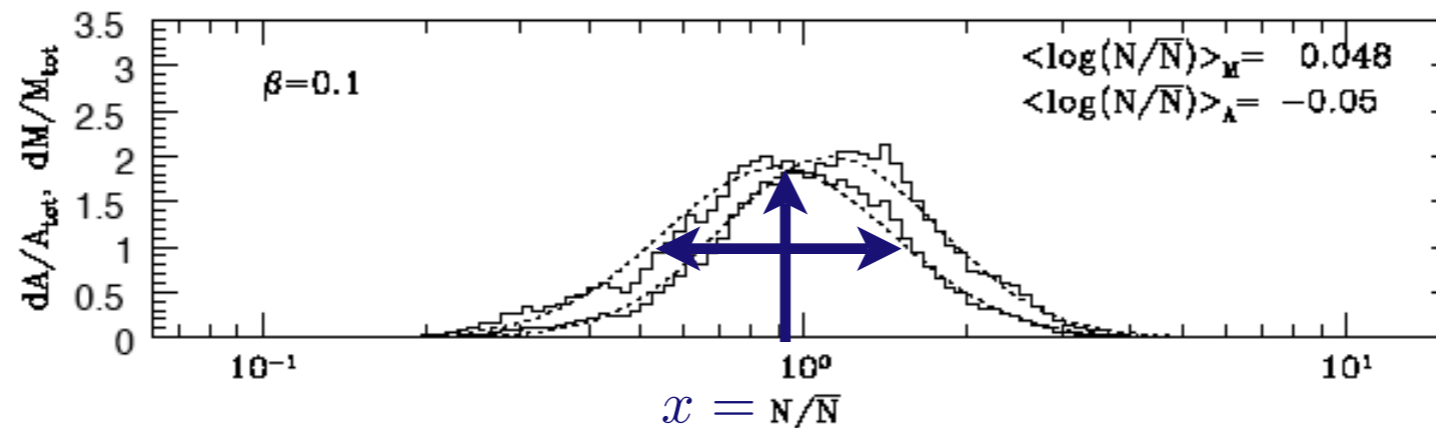
(Padoan, Goodman & Juvela 2003)

# “1. Column density is log-normal(ish) on 10’s of pc scales”

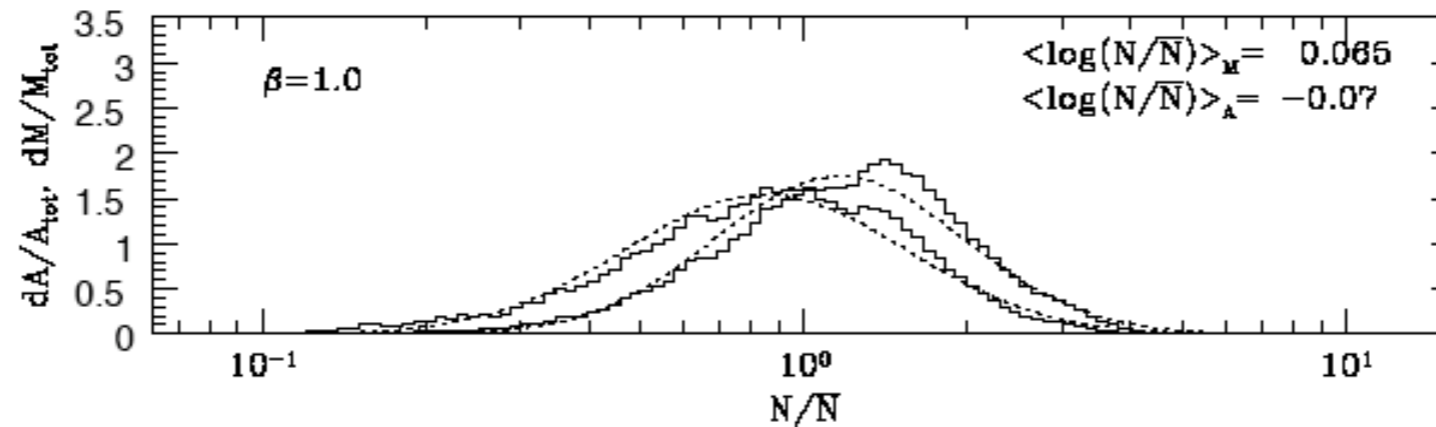
Results from MHD simulations



Strong B-Field



Medium B-Field



Weak B-Field

$$\overline{\ln x} = -\frac{\sigma_{\ln x}^2}{2}$$

↑

↔

**Example: log-normal column density distribution**

(Ostriker, Stone & Gammie 2001)

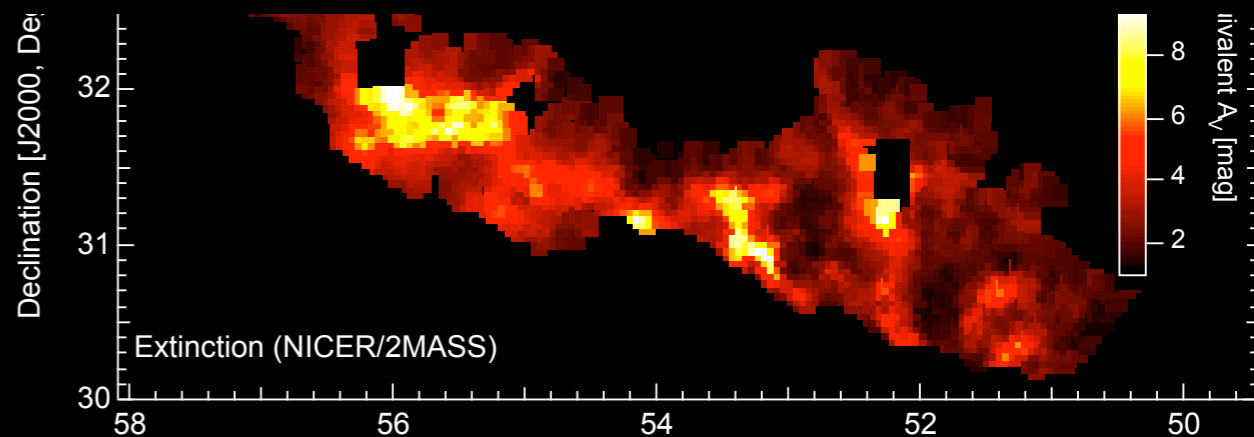




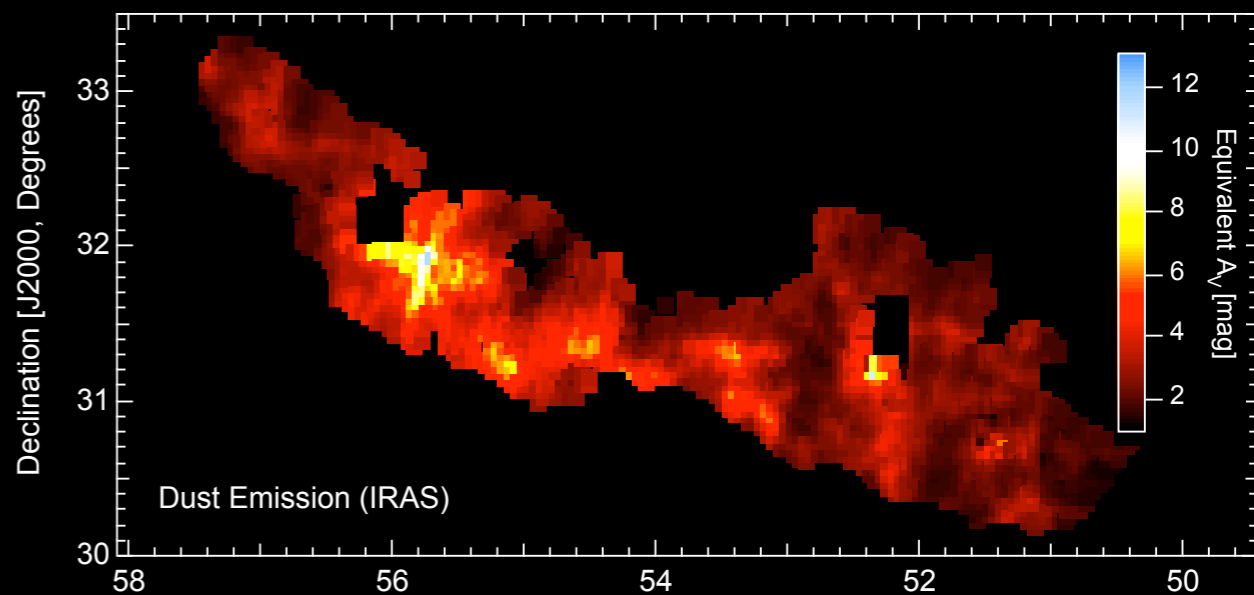
# Is the gas density distribution lognormal or not? (2D)

The (secret) uncertainties inherent in column density mapping.

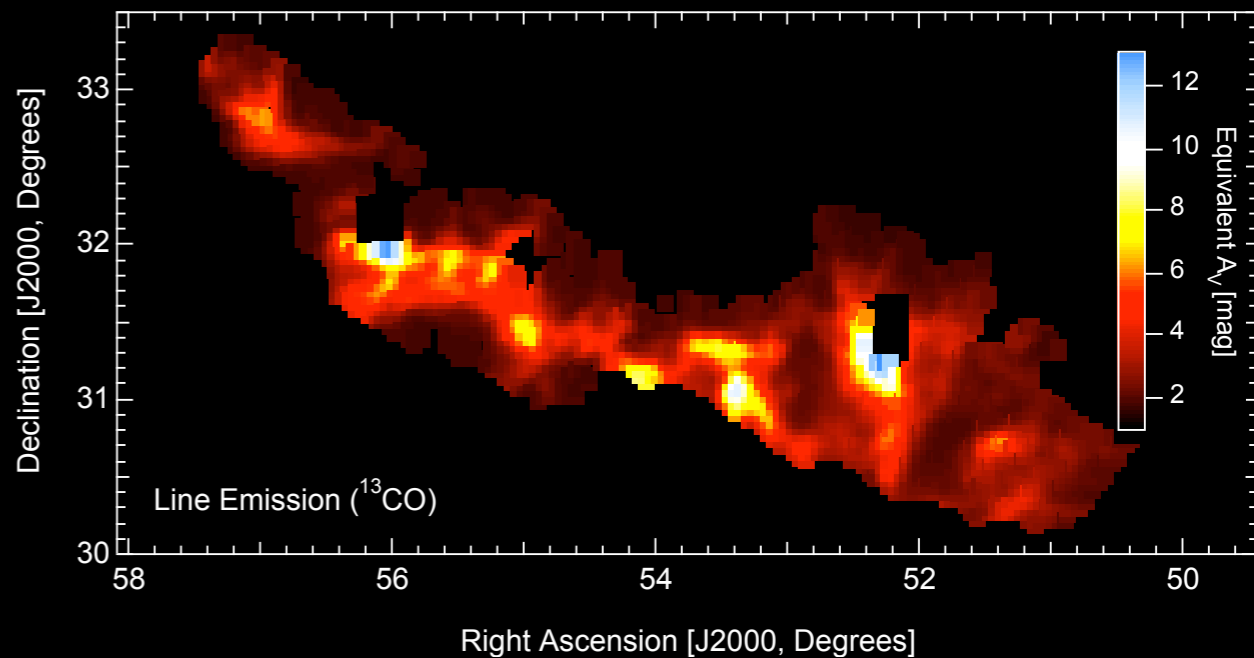
Extinction



Dust Emission

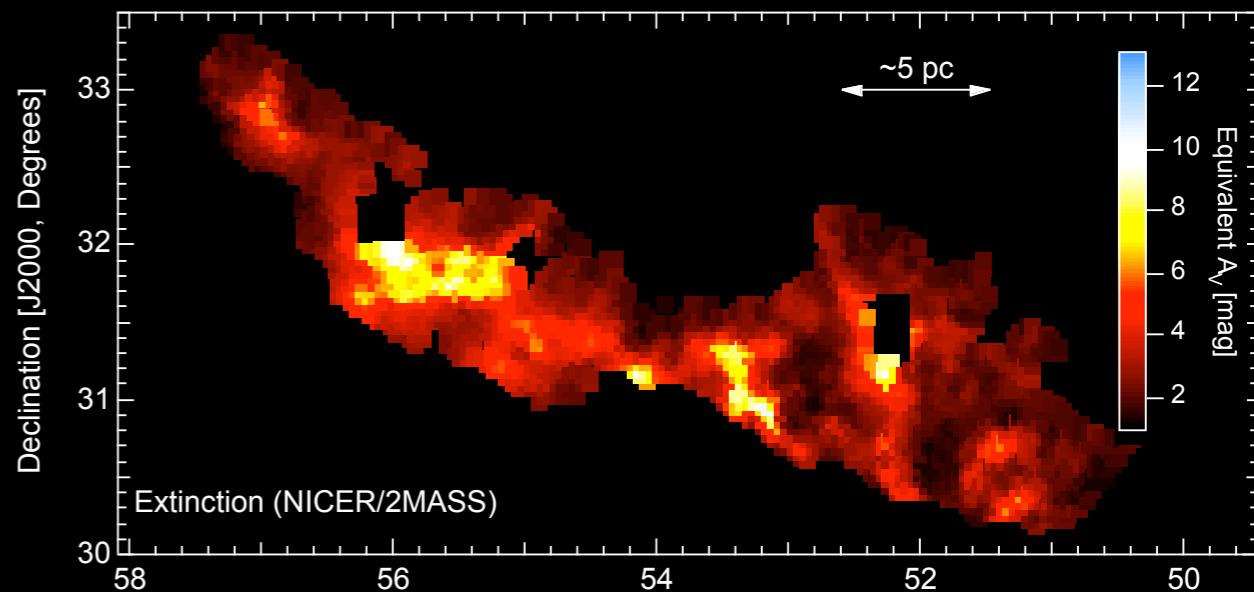


$^{13}\text{CO}$  Emission

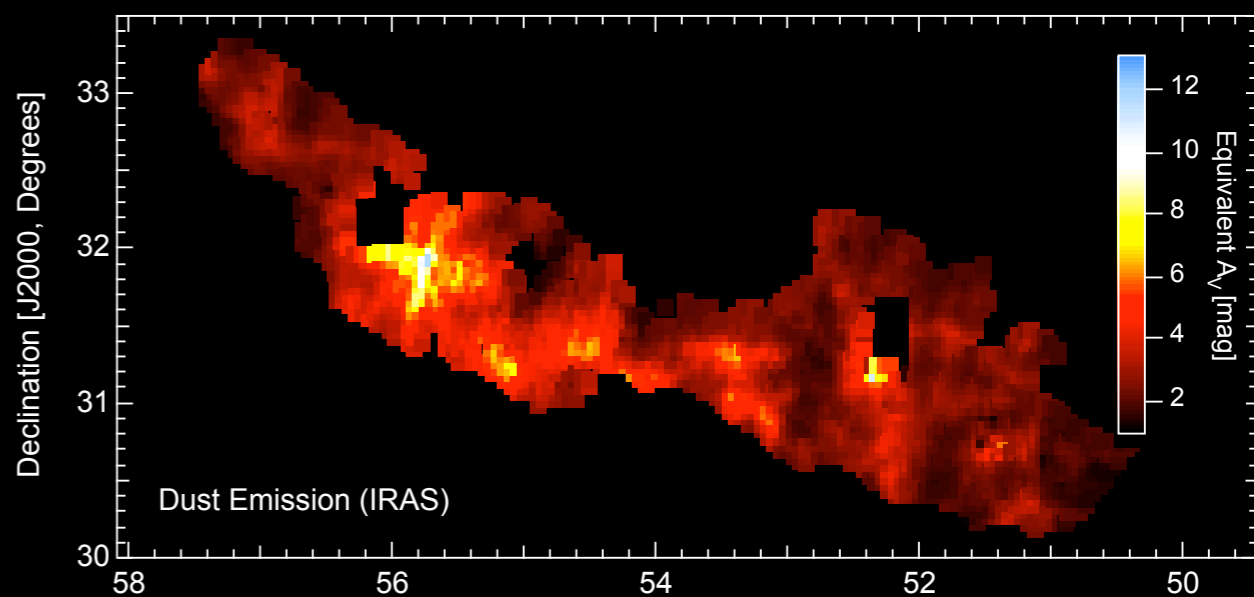


The (secret)  
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column density  
mapping.

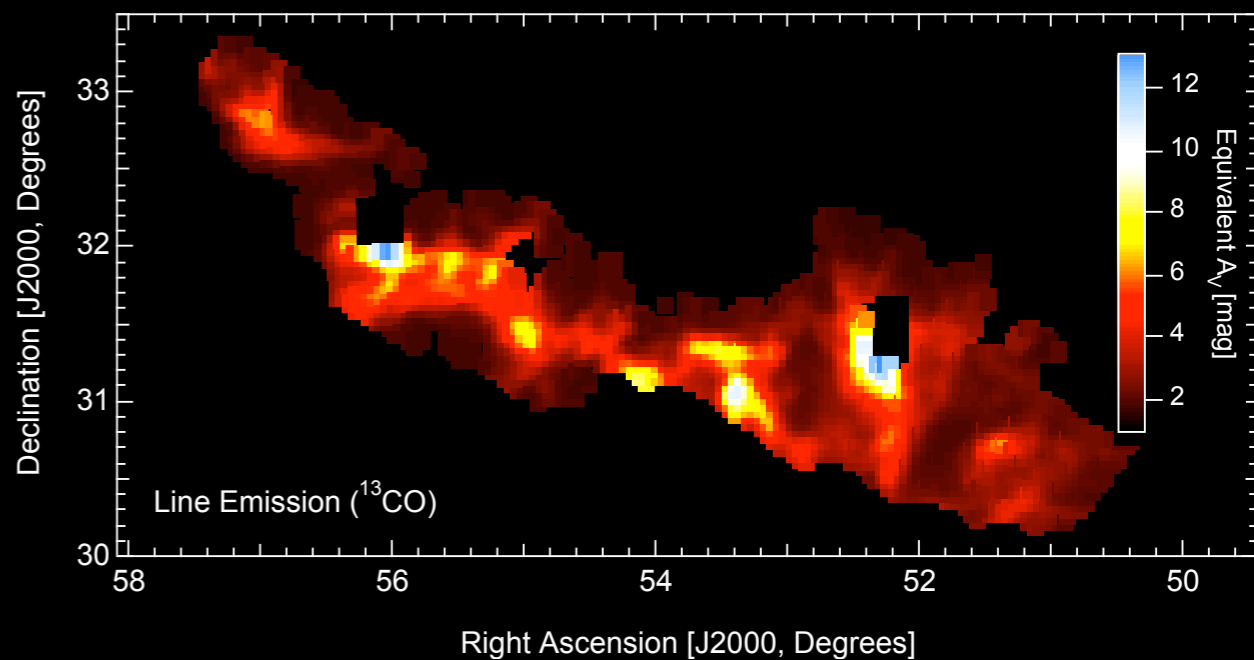
Extinction



Dust Emission

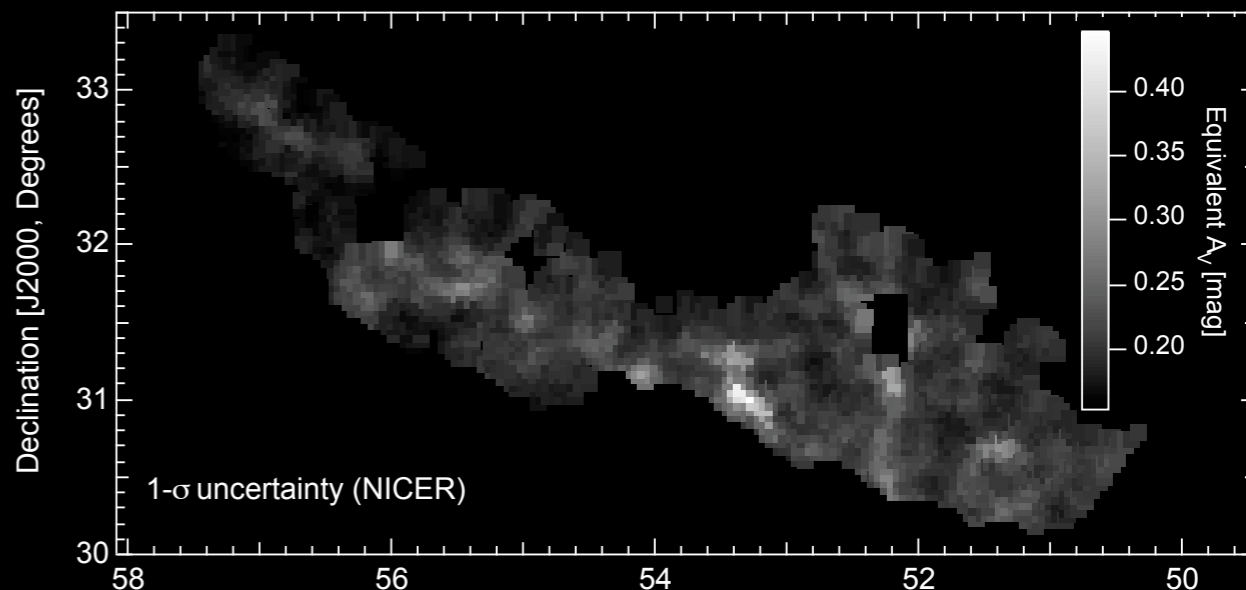


$^{13}\text{CO}$  Emission

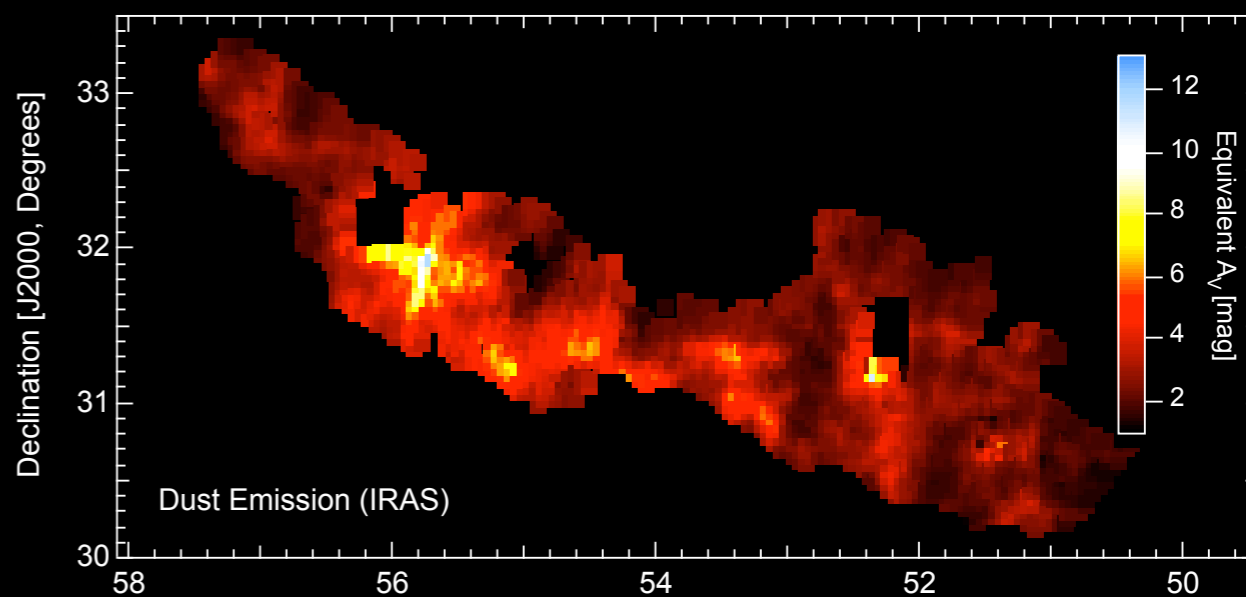


The (secret)  
uncertainties  
inherent in  
column density  
mapping.

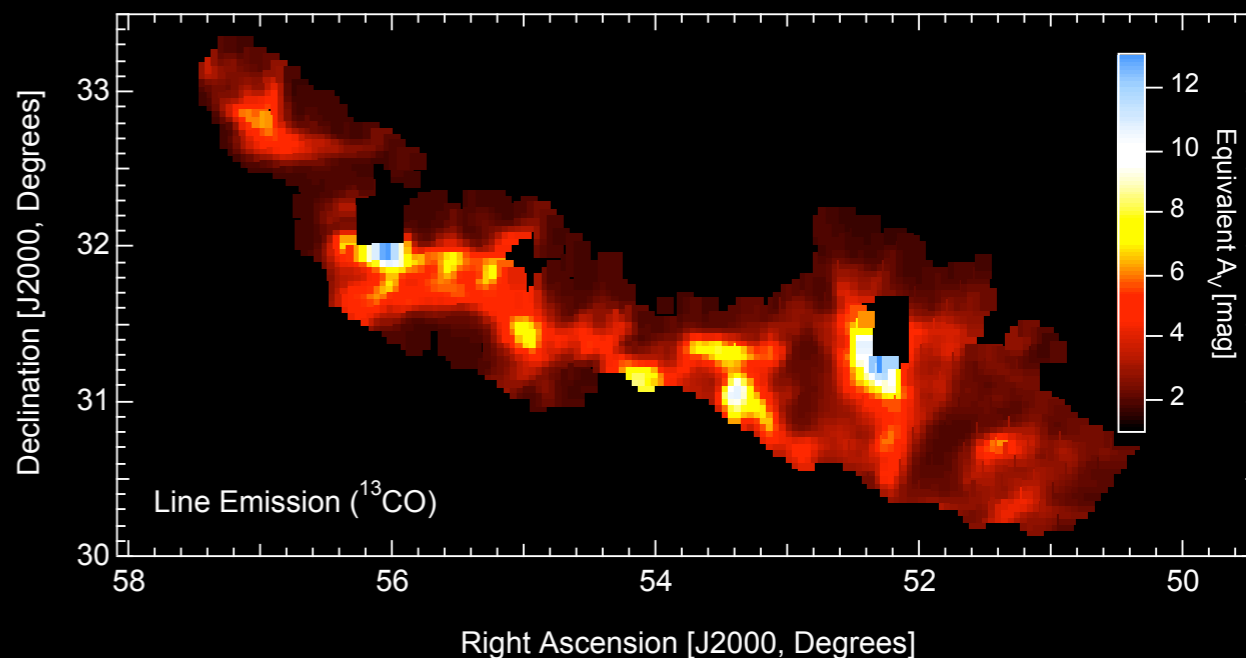
Extinction



Dust Emission

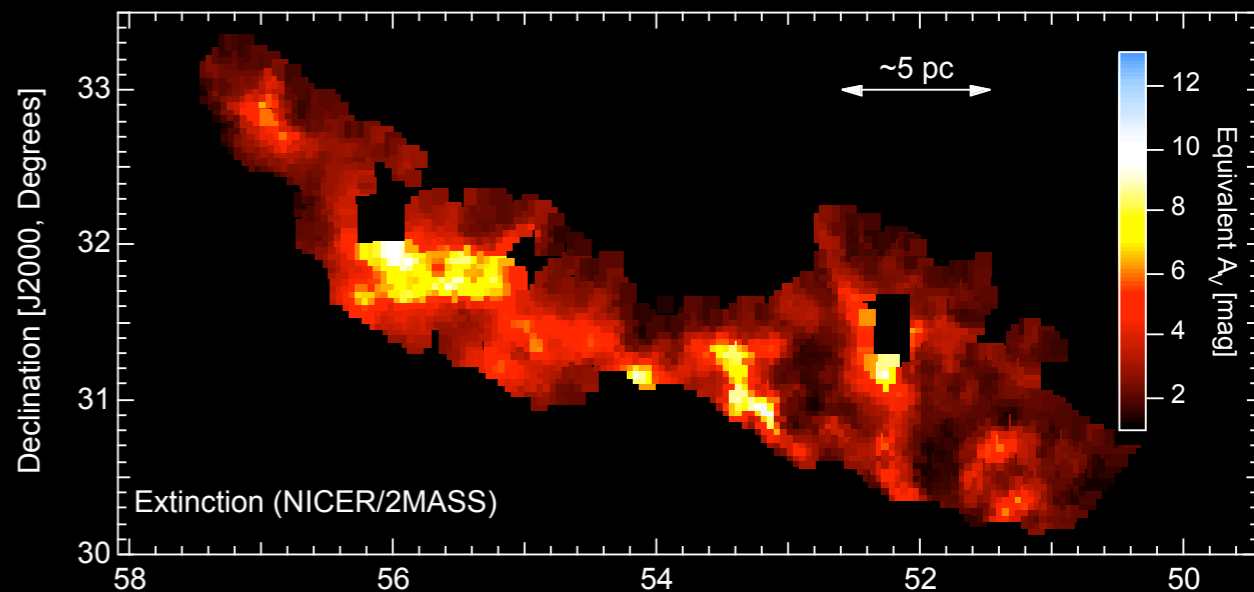


$^{13}\text{CO}$  Emission

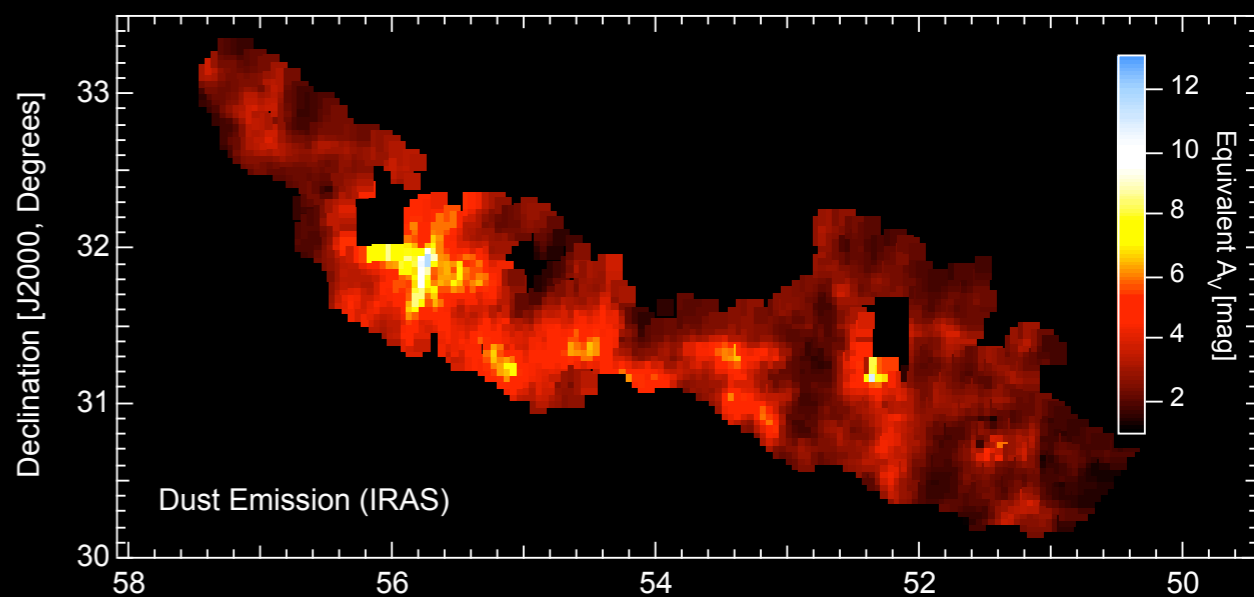


The (secret)  
uncertainties  
inherent in  
column density  
mapping.

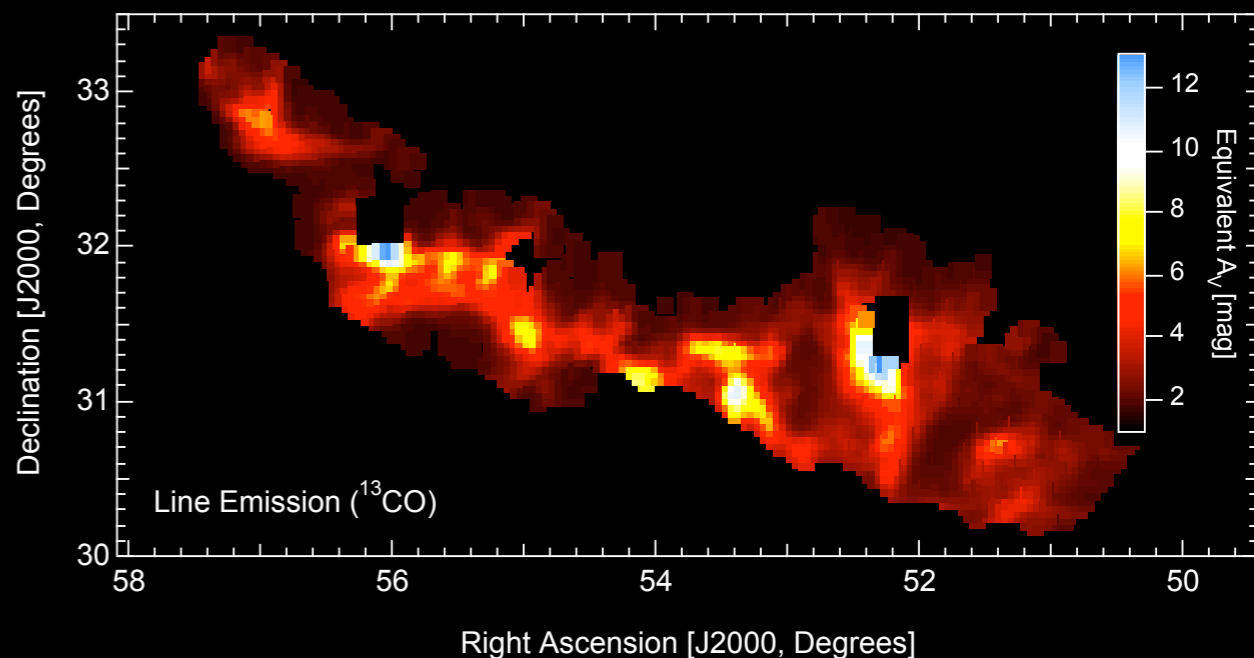
Extinction



Dust Emission

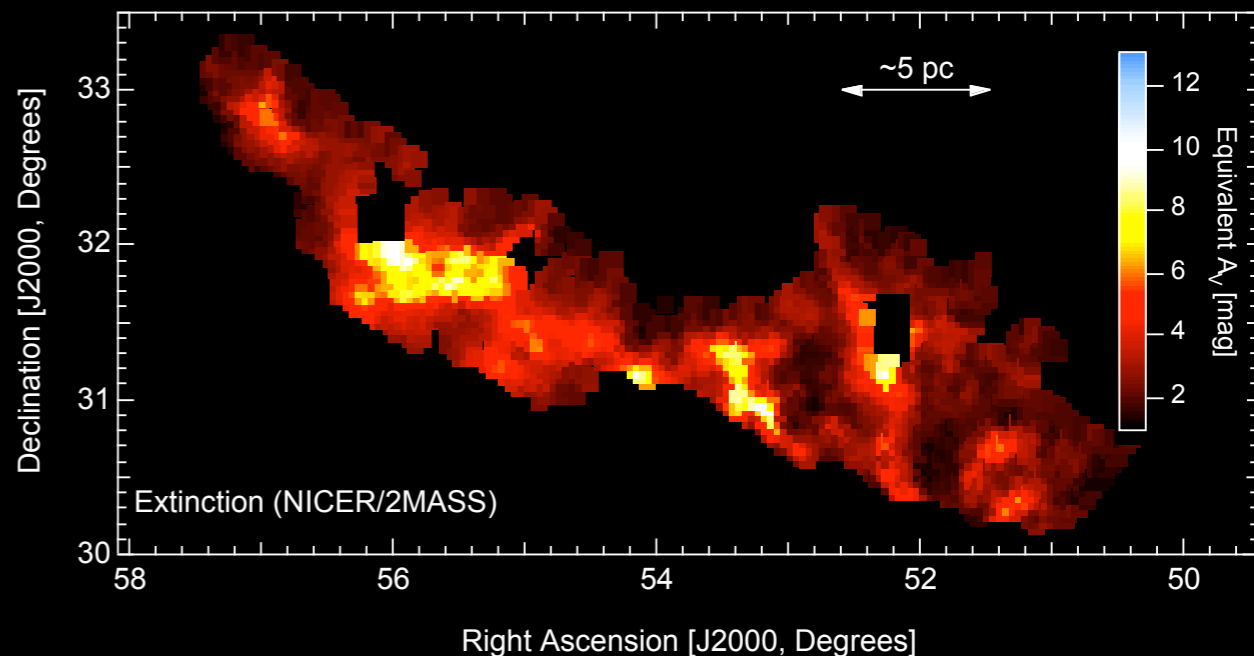


$^{13}\text{CO}$  Emission

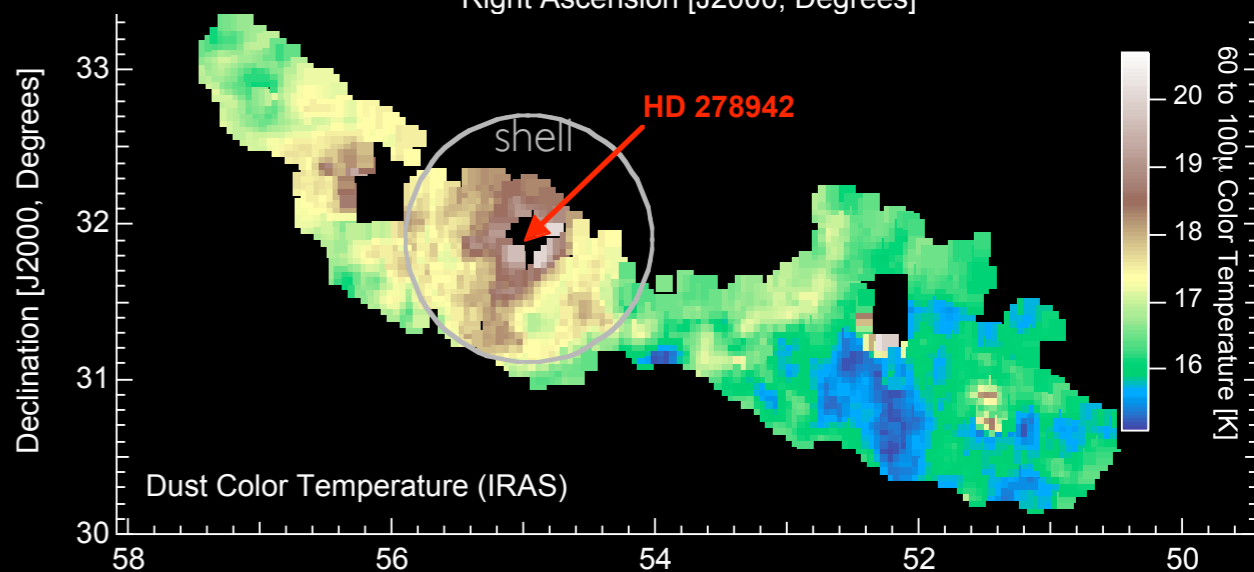


The (secret)  
uncertainties  
inherent in  
column density  
mapping.

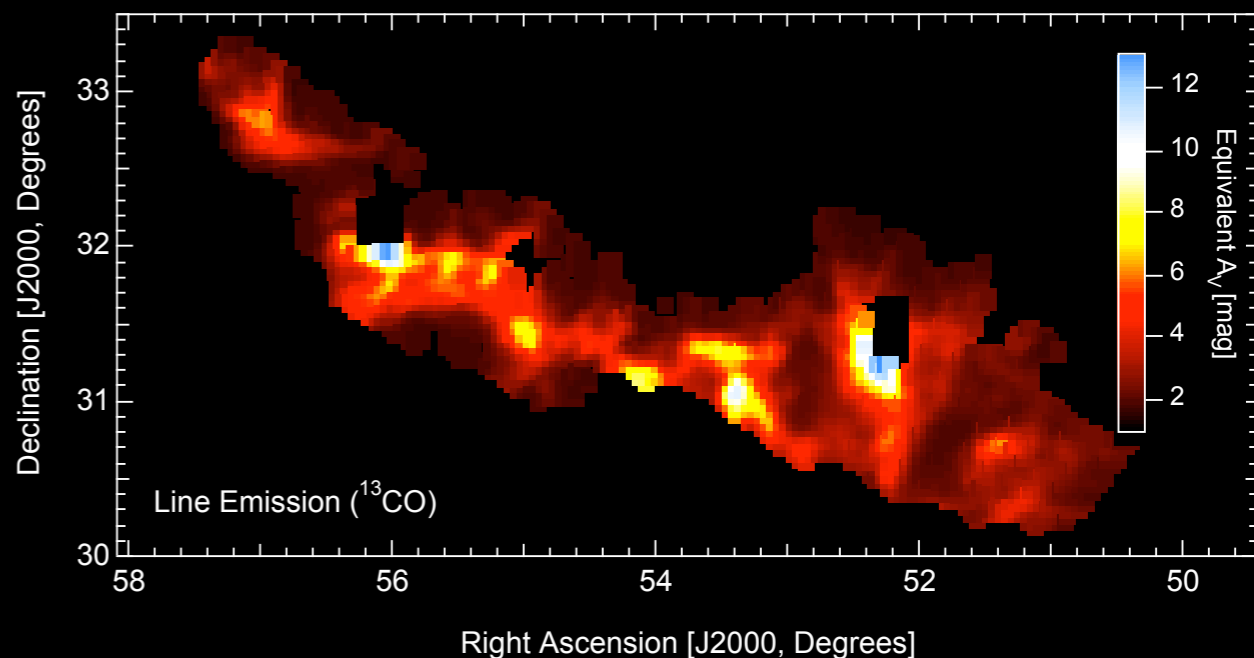
Extinction



Dust Emission

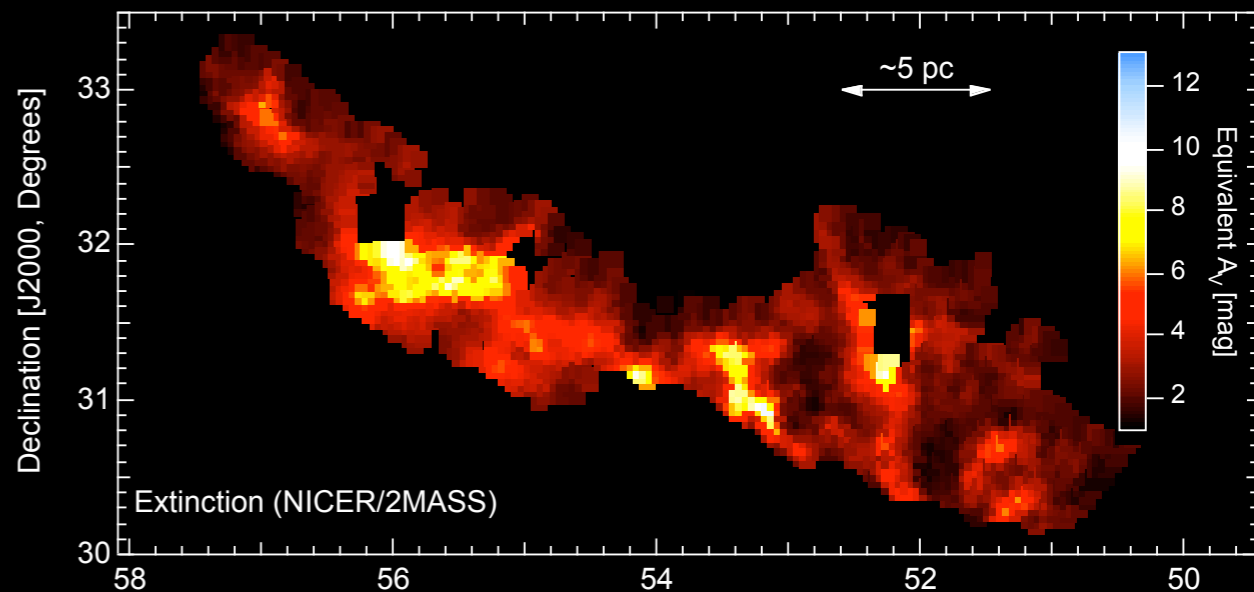


$^{13}\text{CO}$  Emission

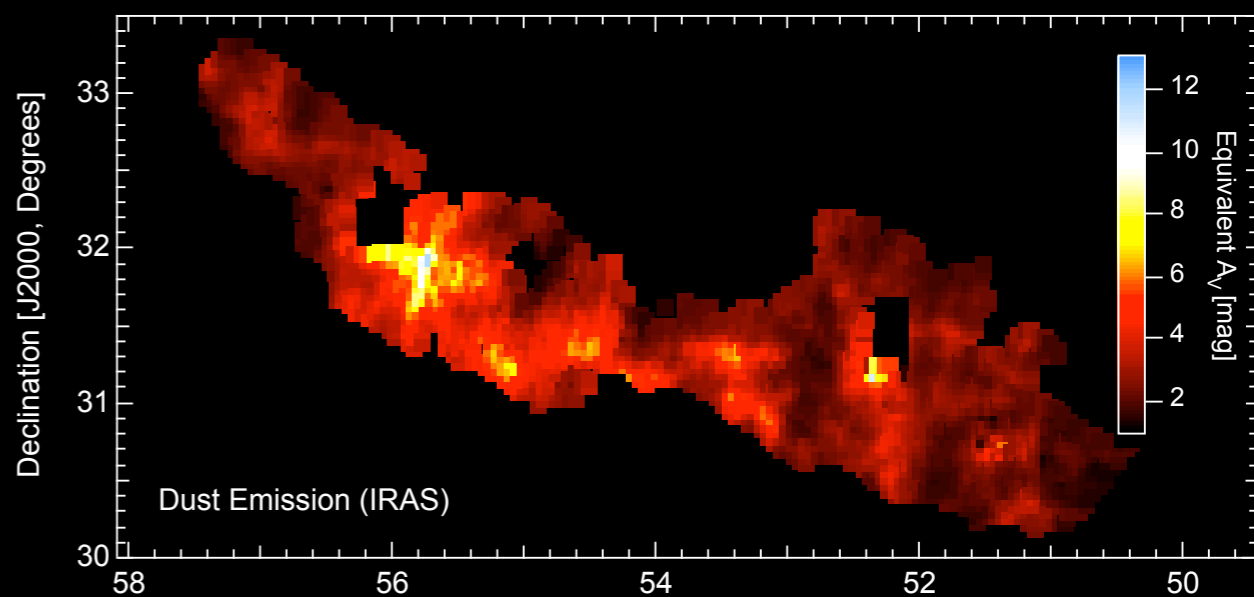


The (secret)  
uncertainties  
inherent in  
column density  
mapping.

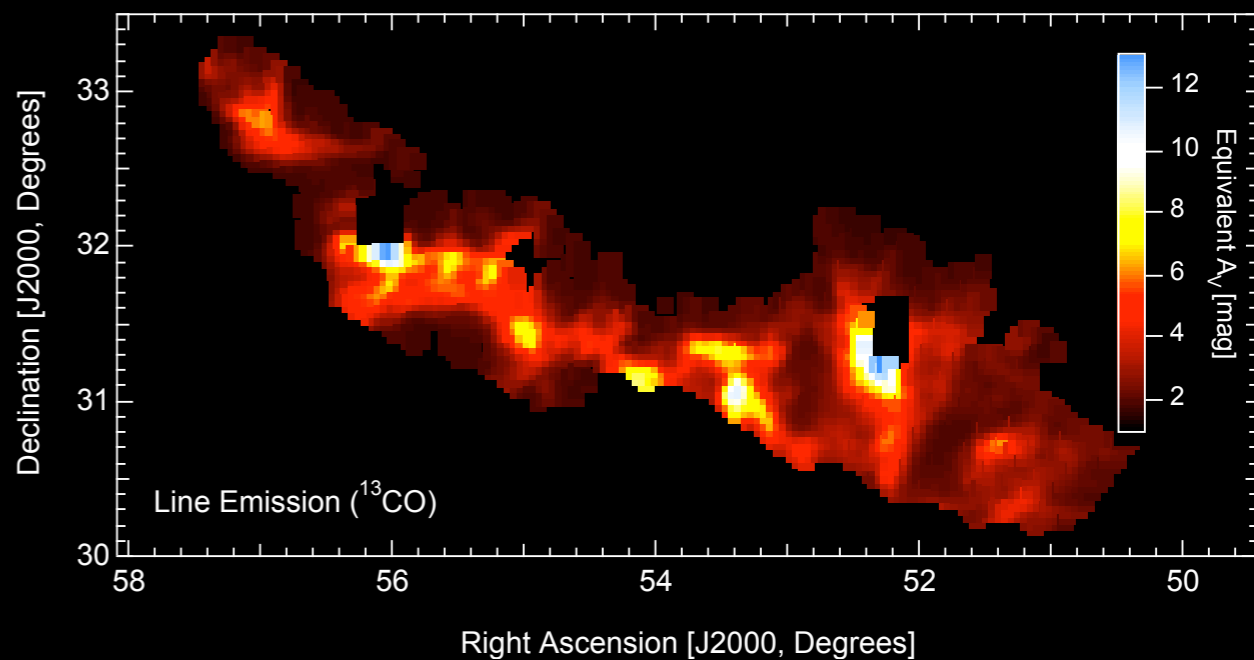
Extinction



Dust Emission

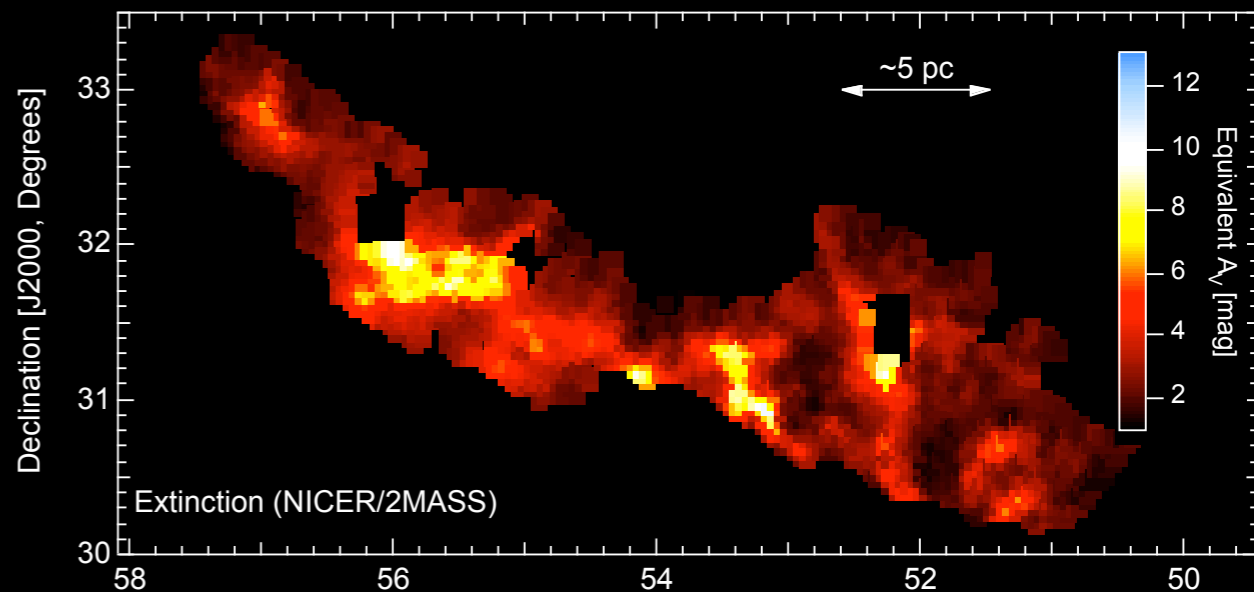


$^{13}\text{CO}$  Emission

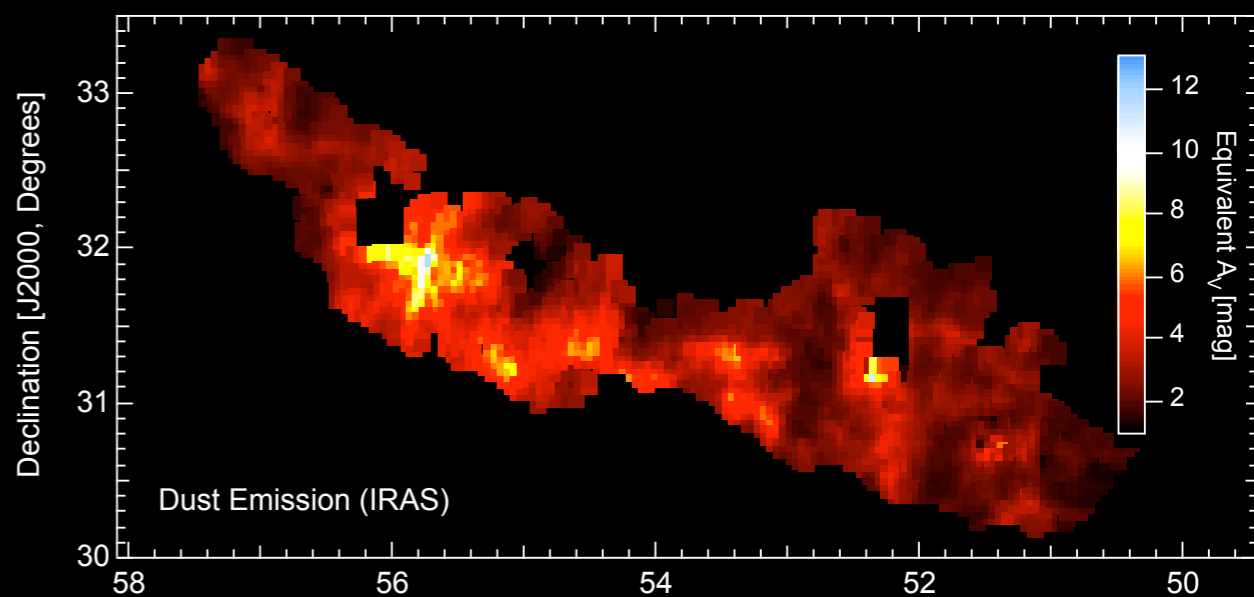


The (secret)  
uncertainties  
inherent in  
column density  
mapping.

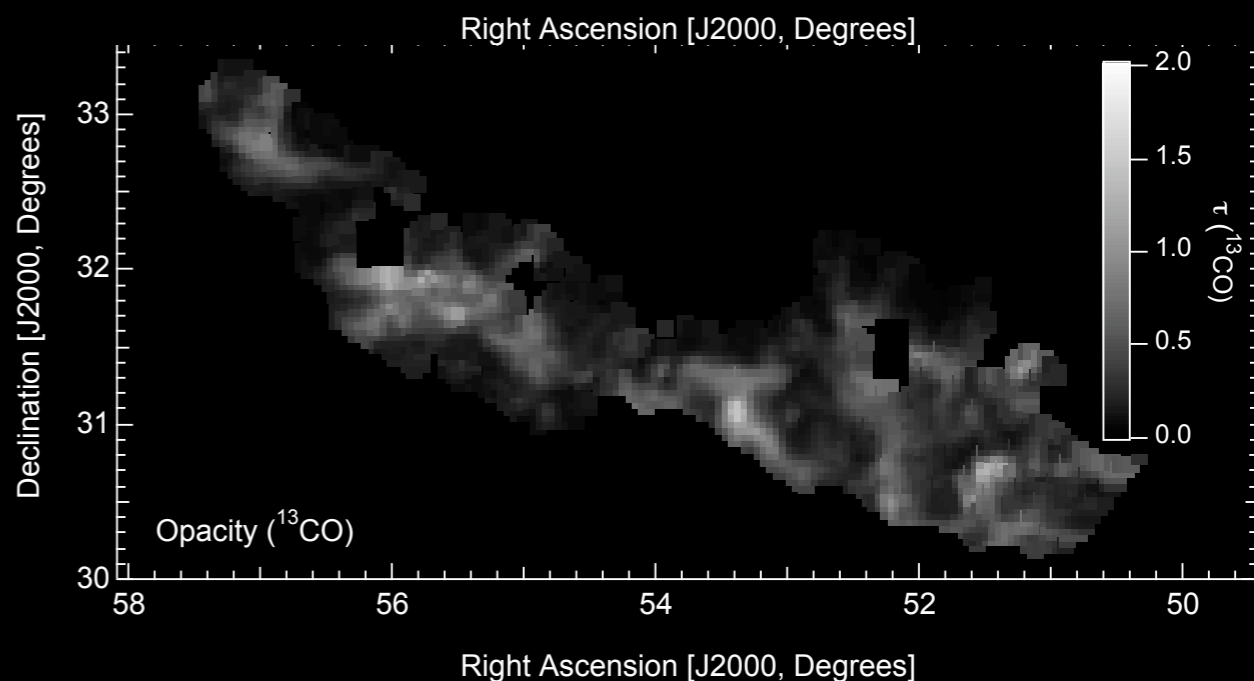
Extinction



Dust Emission

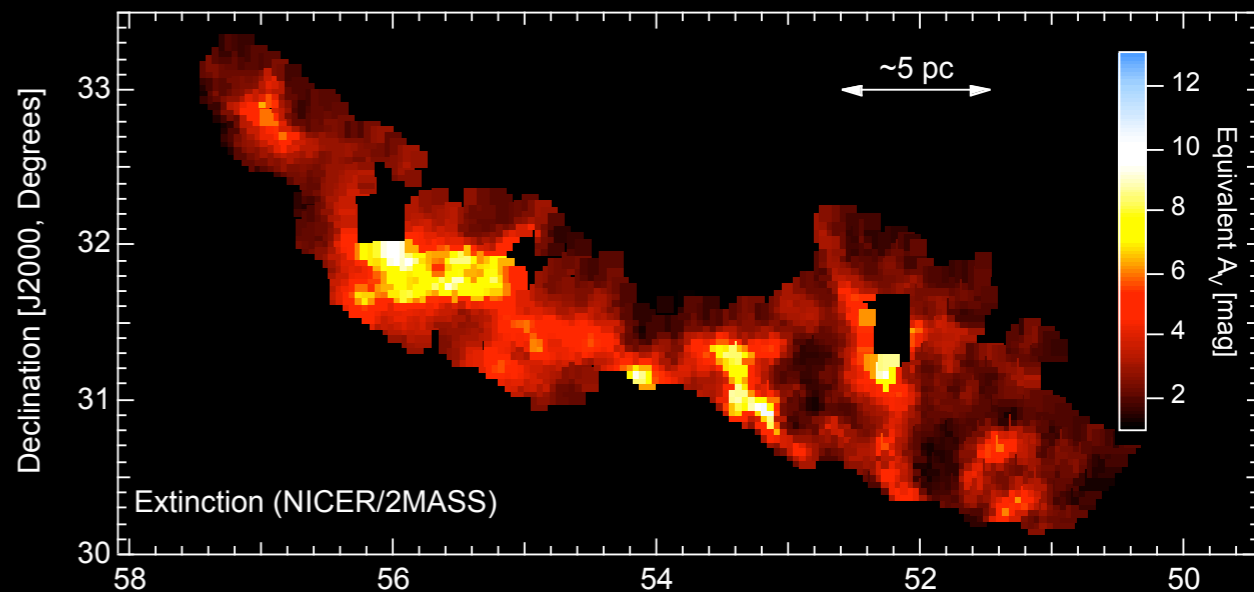


$^{13}\text{CO}$  Emission

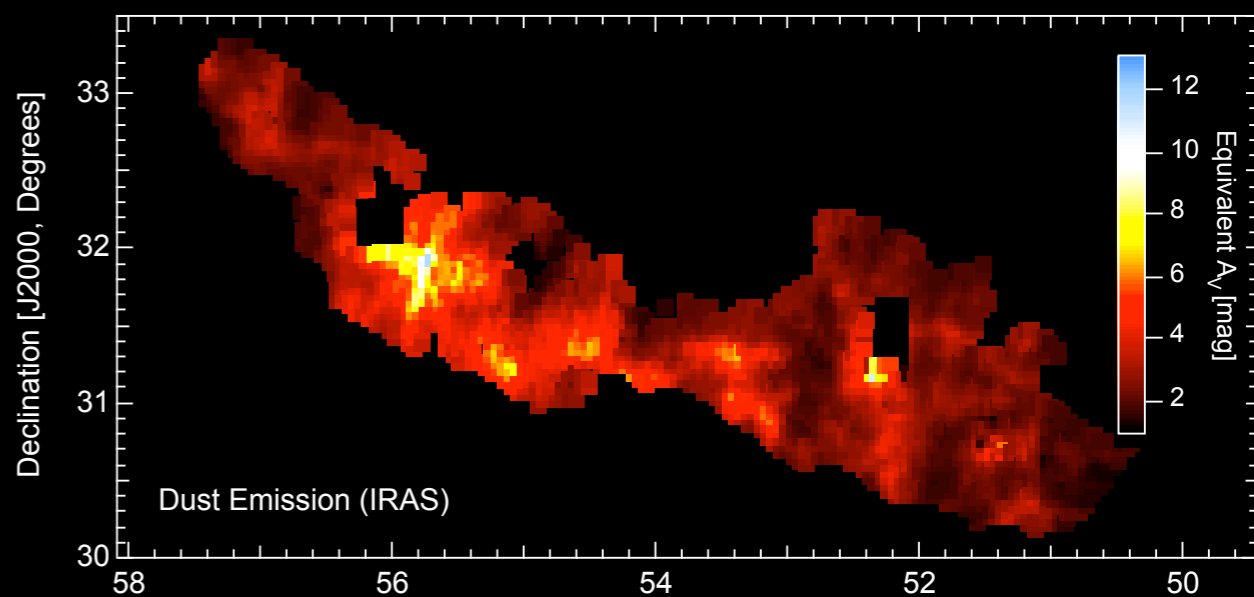


The (secret)  
uncertainties  
inherent in  
column density  
mapping.

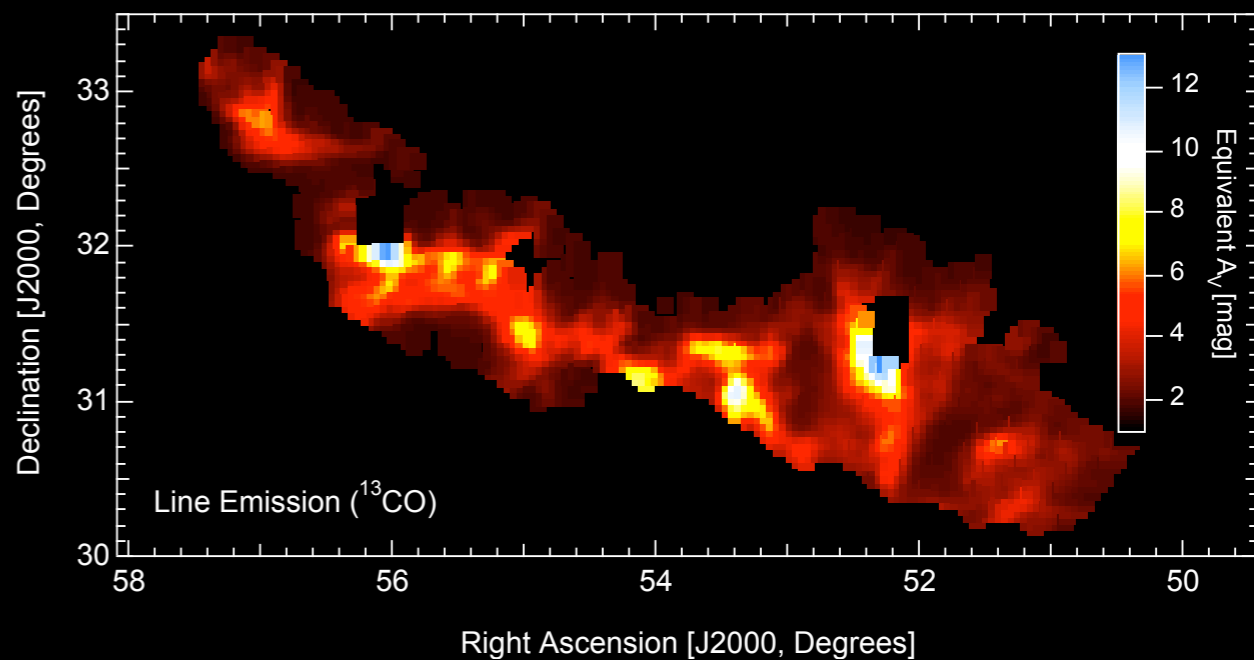
Extinction



Dust Emission



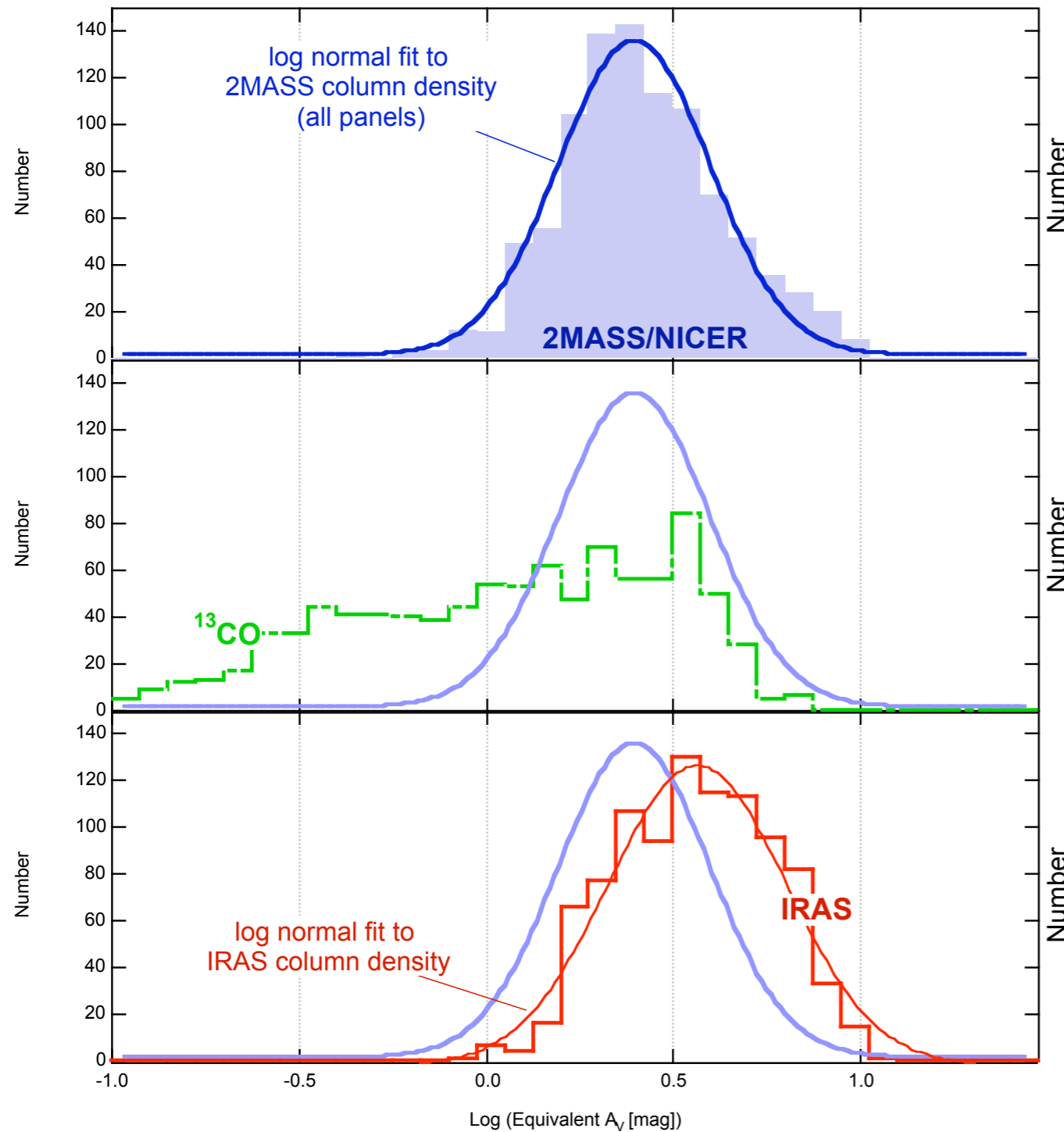
$^{13}\text{CO}$  Emission



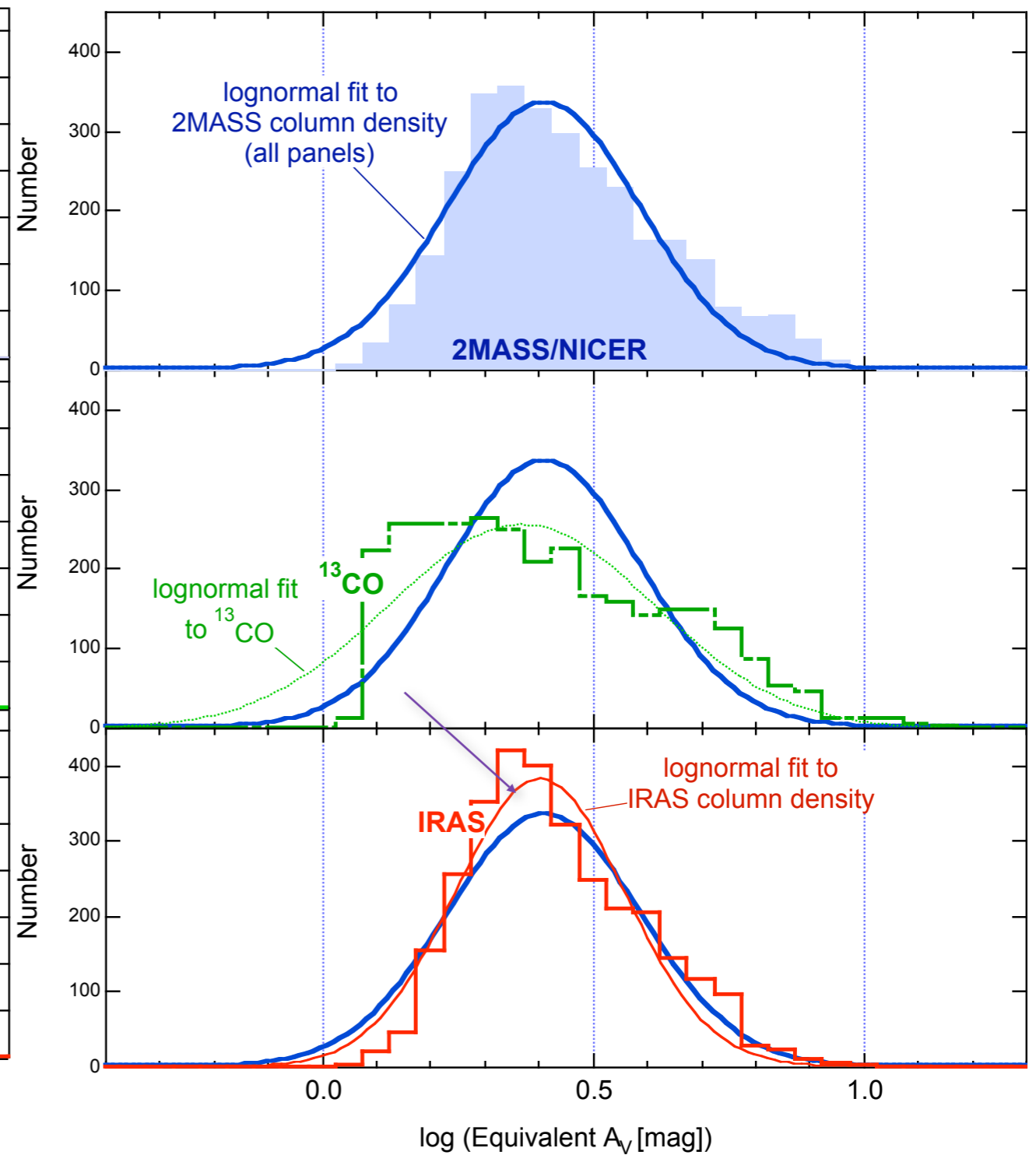


# “Bias & Uncertainty”: A Never-ending Challenge

State of the Art, 2004

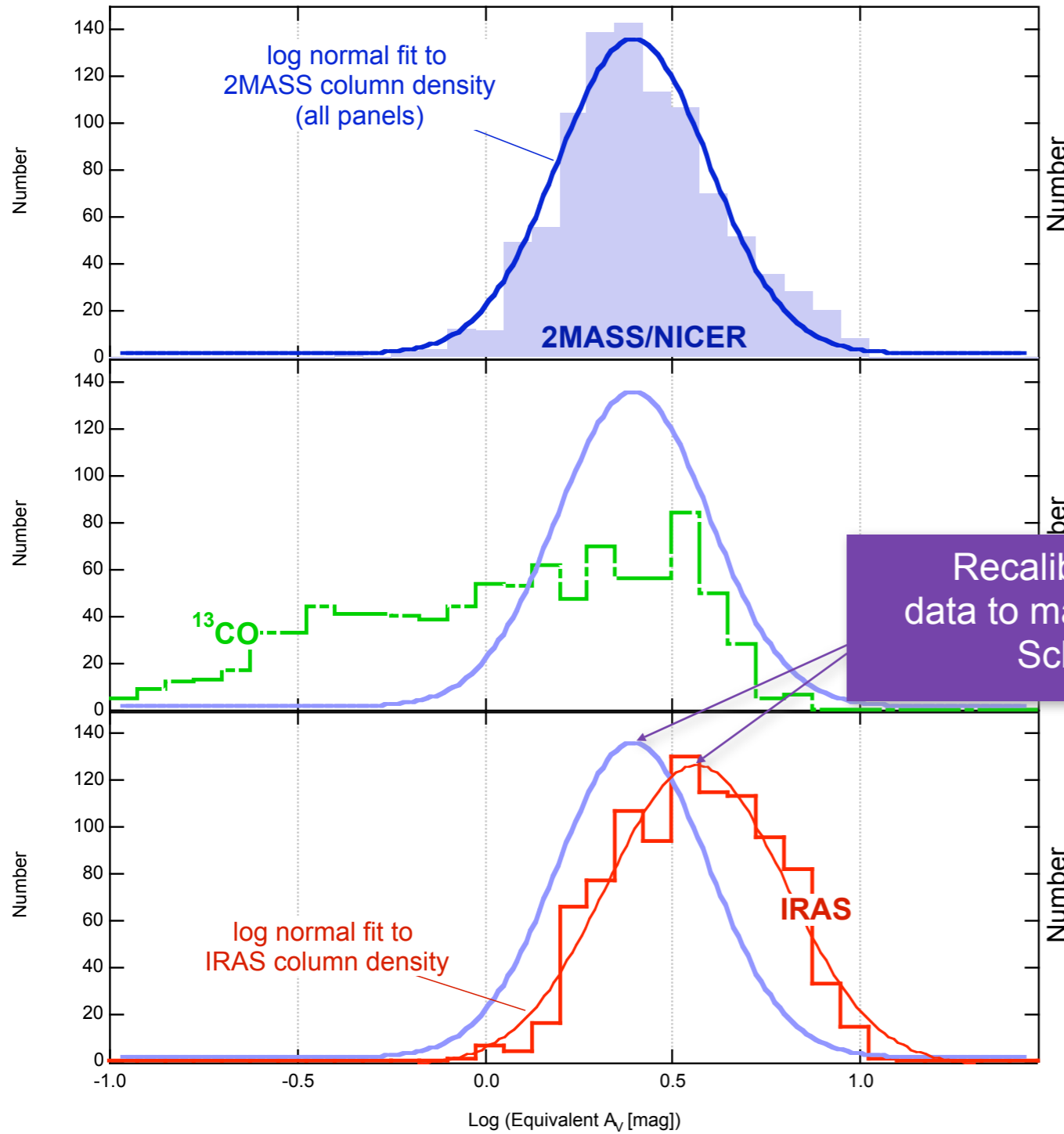


After 2 Years of Refinement...!

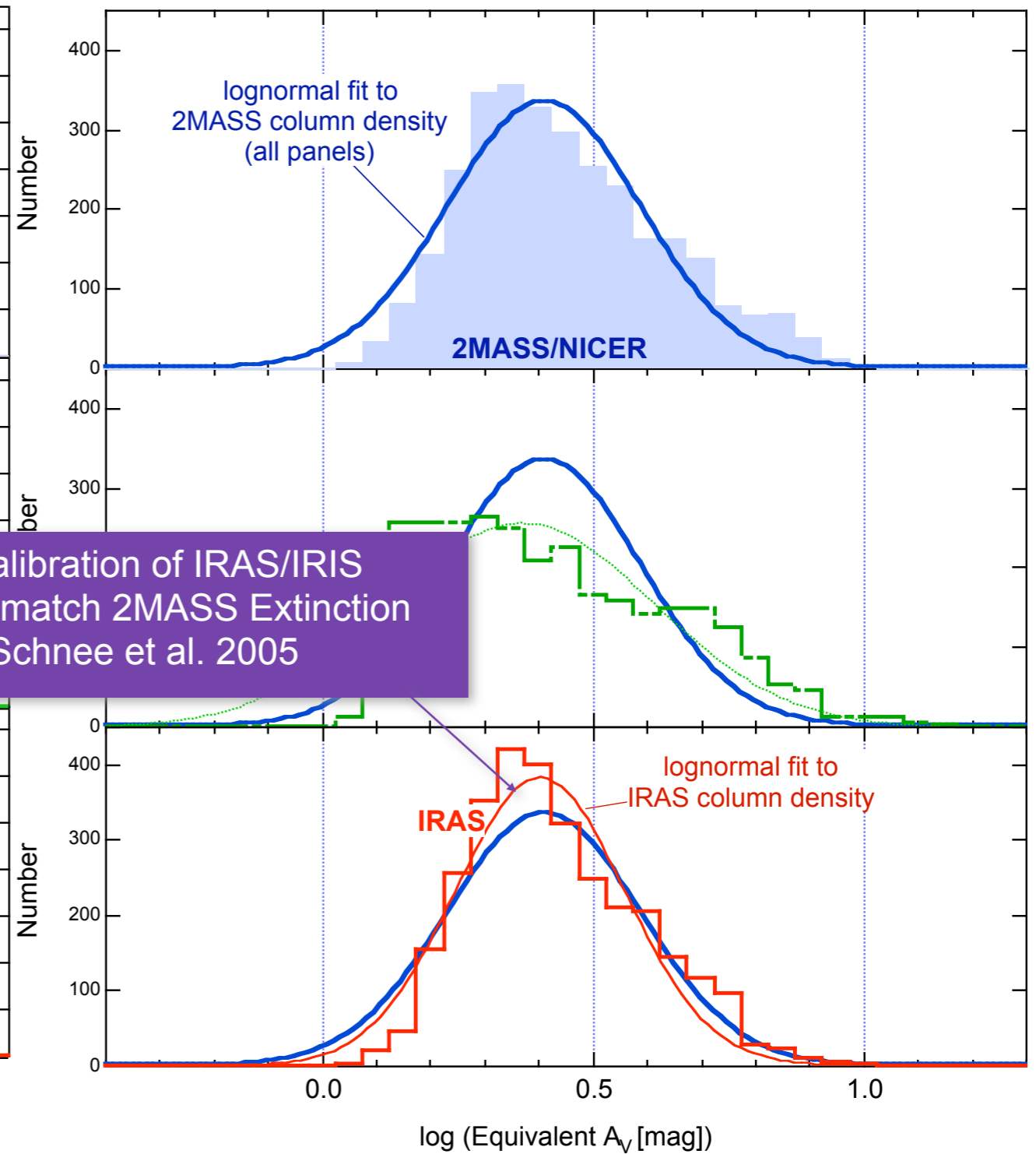


# “Bias & Uncertainty”: A Never-ending Challenge

State of the Art, 2004



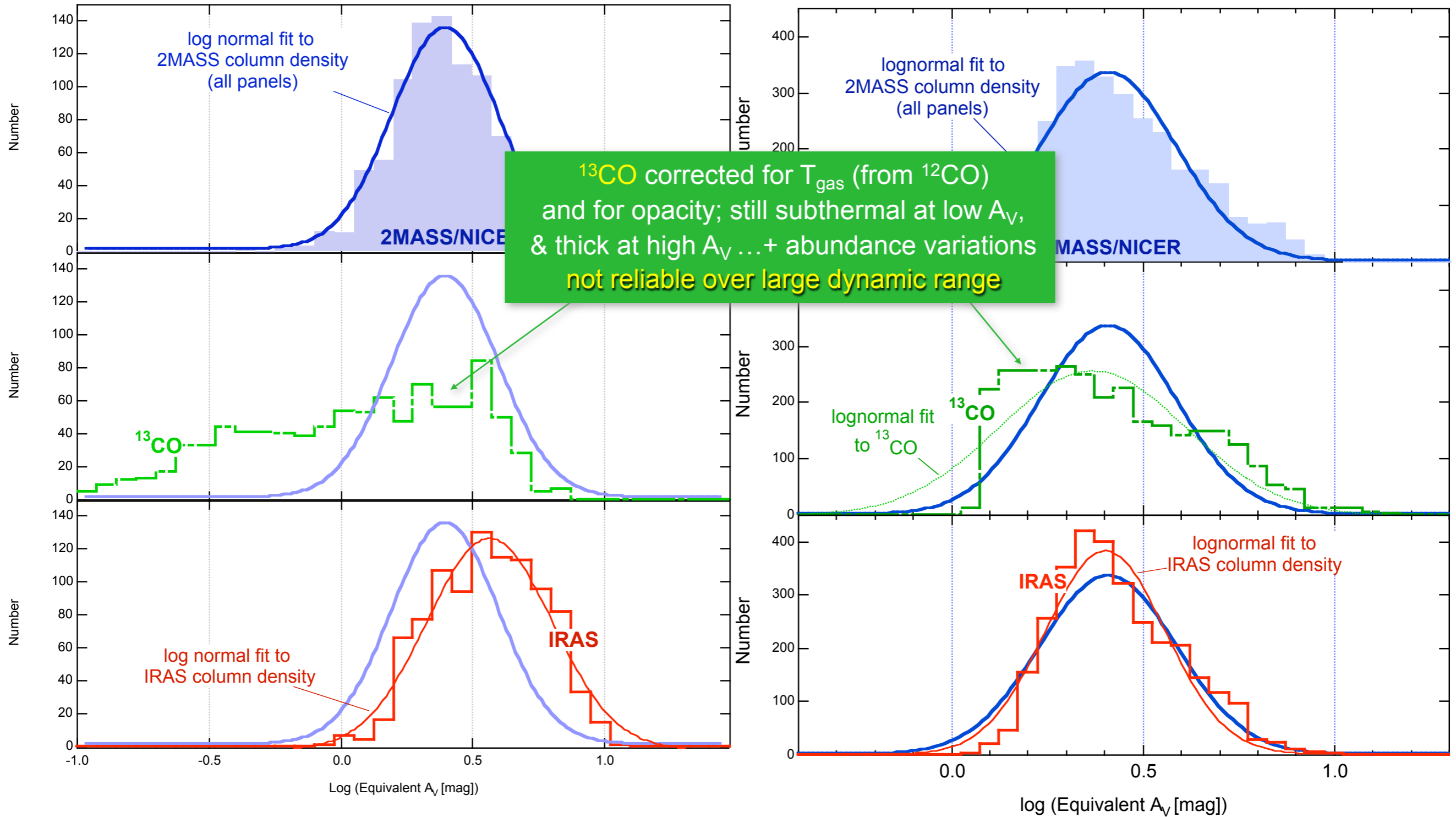
After 2 Years of Refinement...!



# "Bias & Uncertainty": A Never-ending Challenge

State of the Art, 2004

After 2 Years of Refinement (2006)



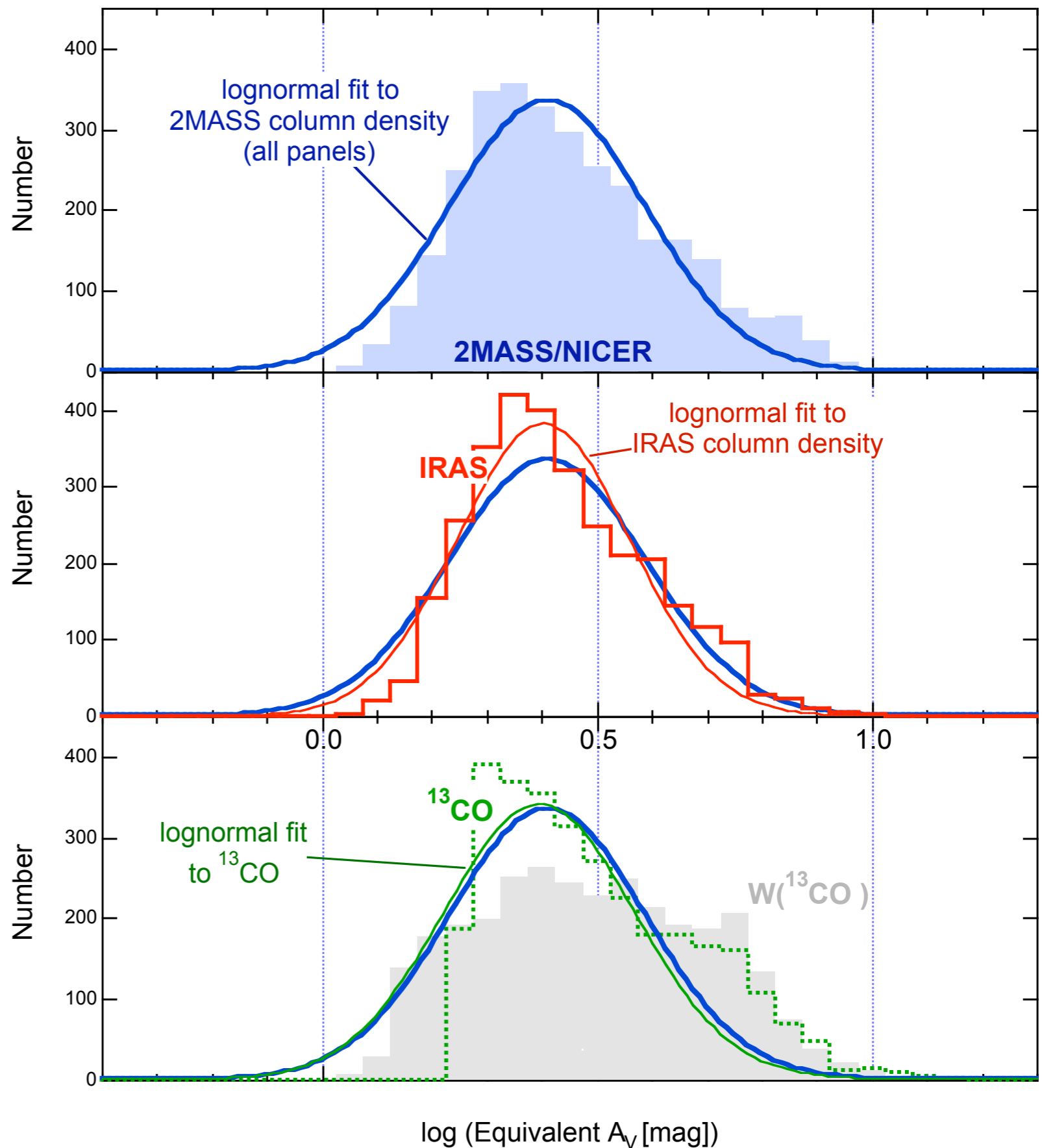
# Some results...

Extinction & thermal emission are log-normal-ish (& more so when points undetected in  $^{13}\text{CO}$  are included.)

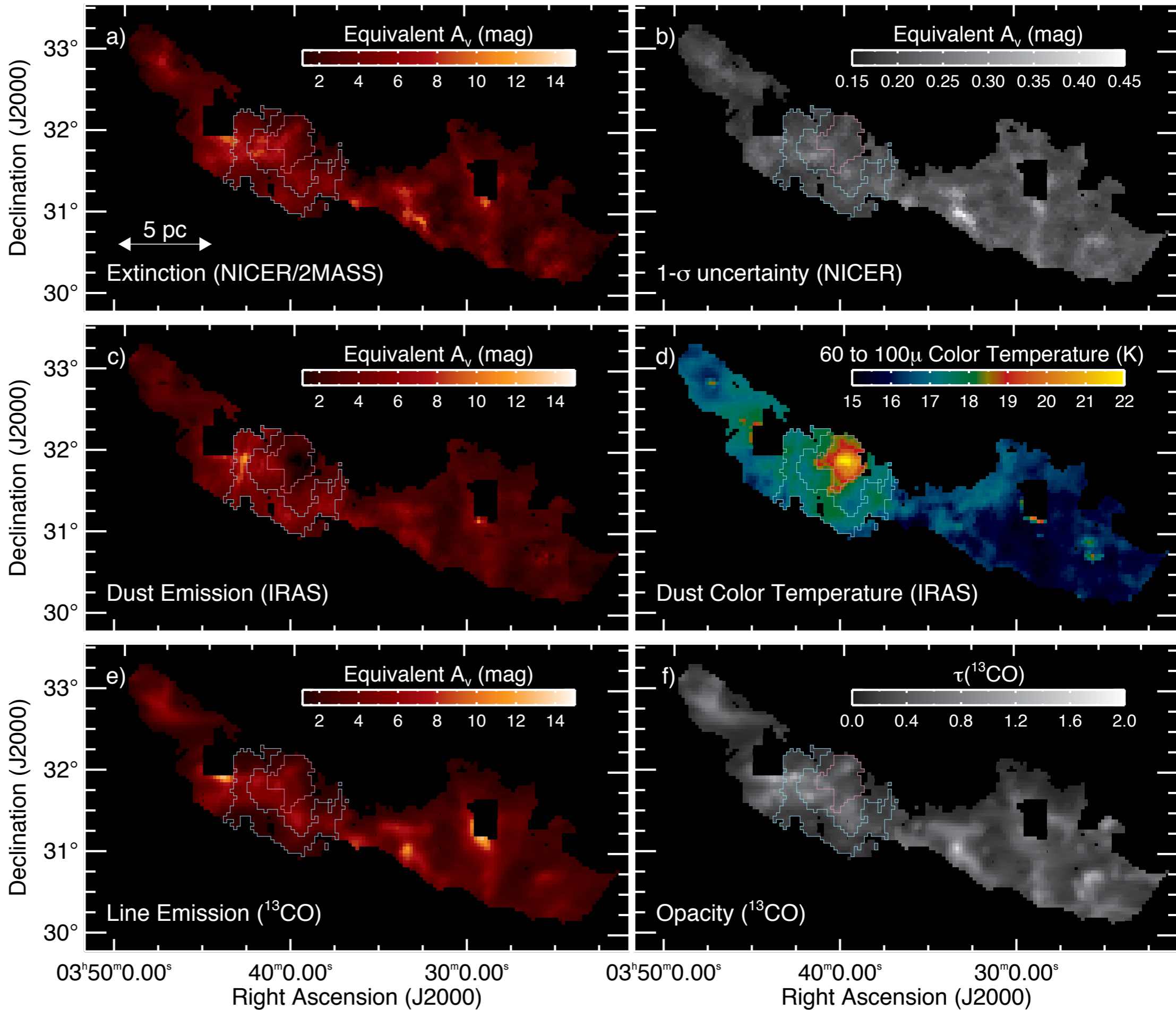
$^{13}\text{CO}$  is not a very faithful tracer of column density

But, we're not done...

Implied Column Density Distributions and lognormal Fits  
(Perseus COMPLETE data)



Today

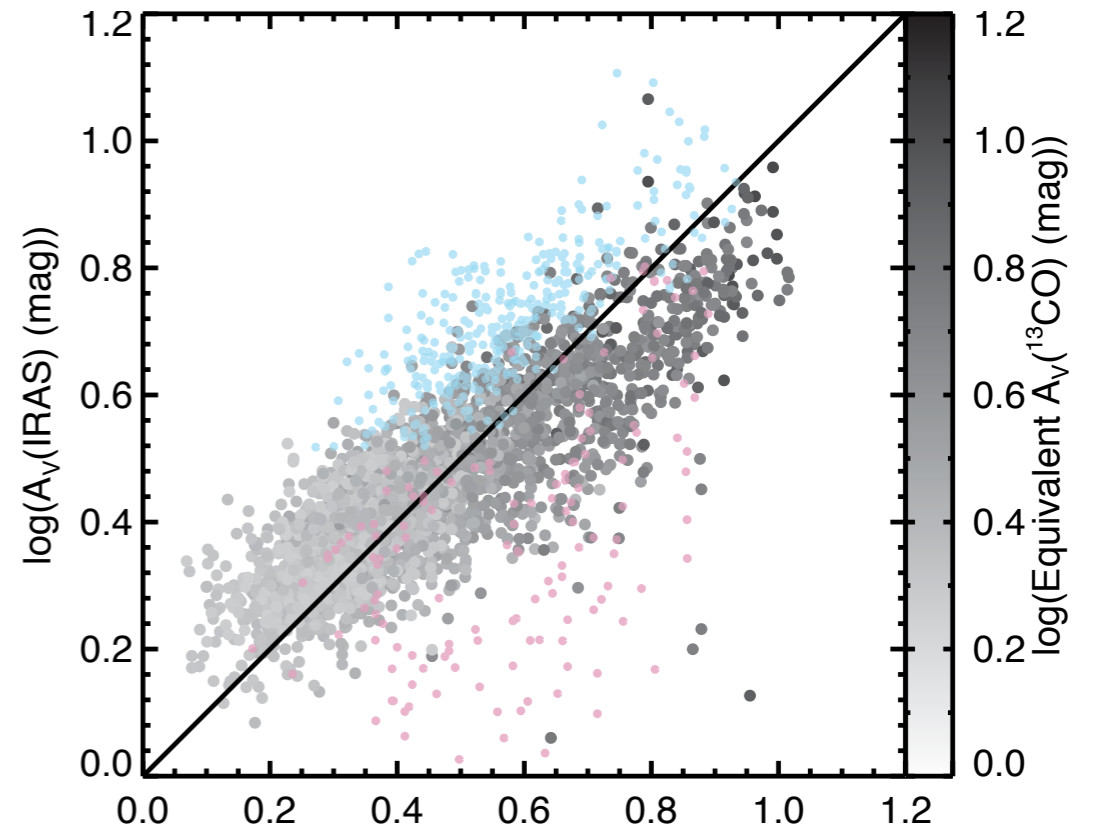


“Bias & Uncertainty”:  
A Never-  
ending  
Challenge

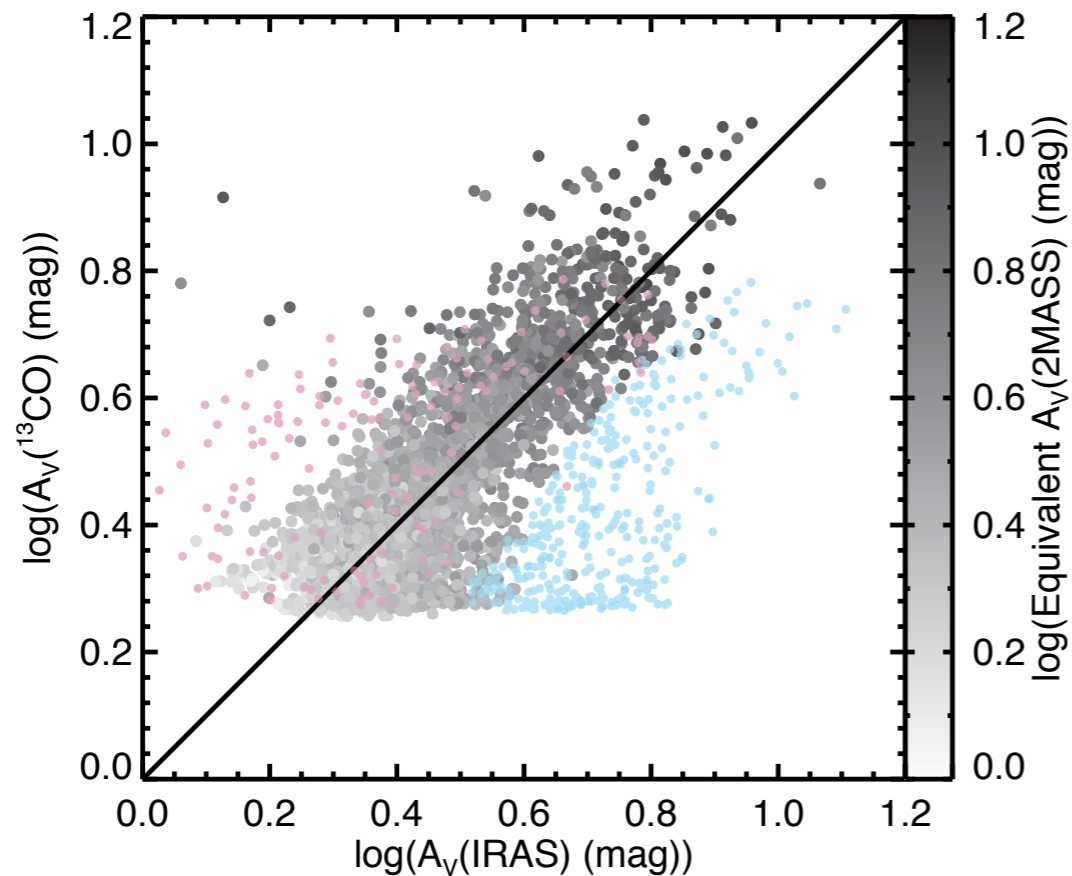
# “Bias & Uncertainty”: A Never-ending Challenge

Today

IRIS

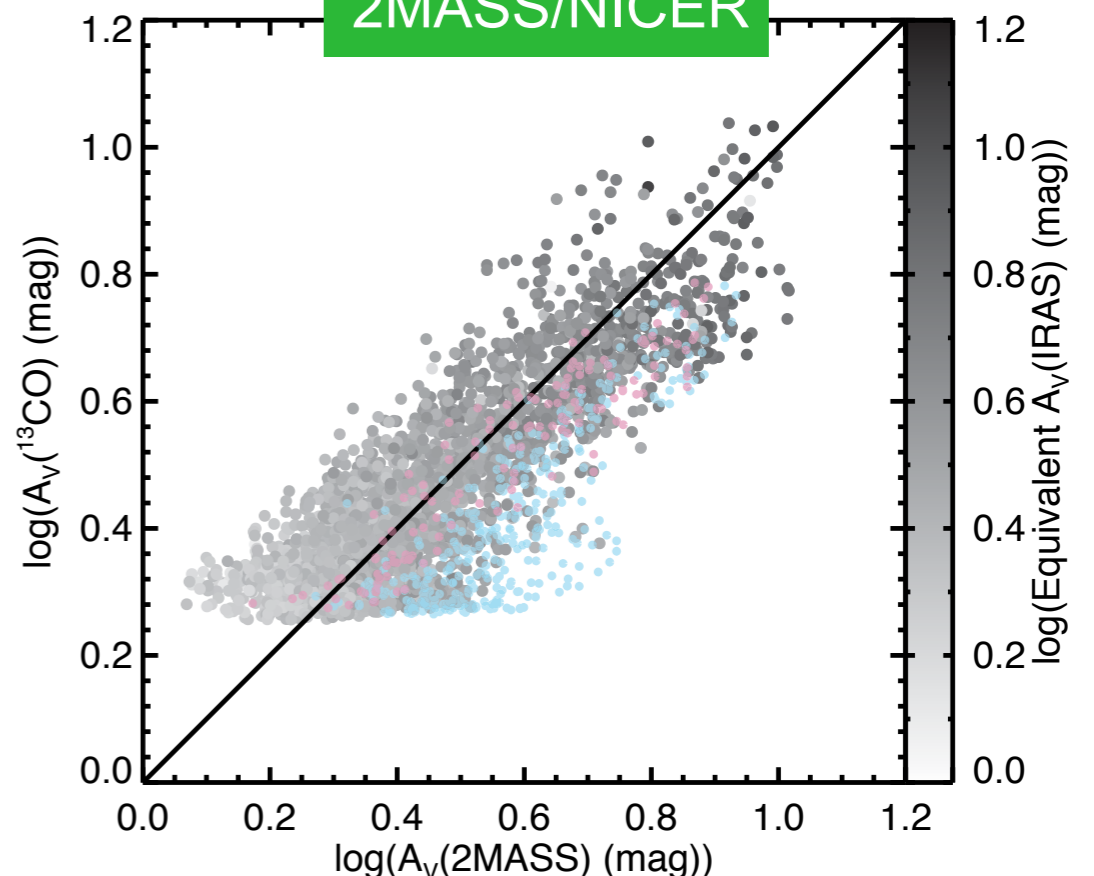


2MASS/NICER



$^{13}\text{CO}$

$^{13}\text{CO}$

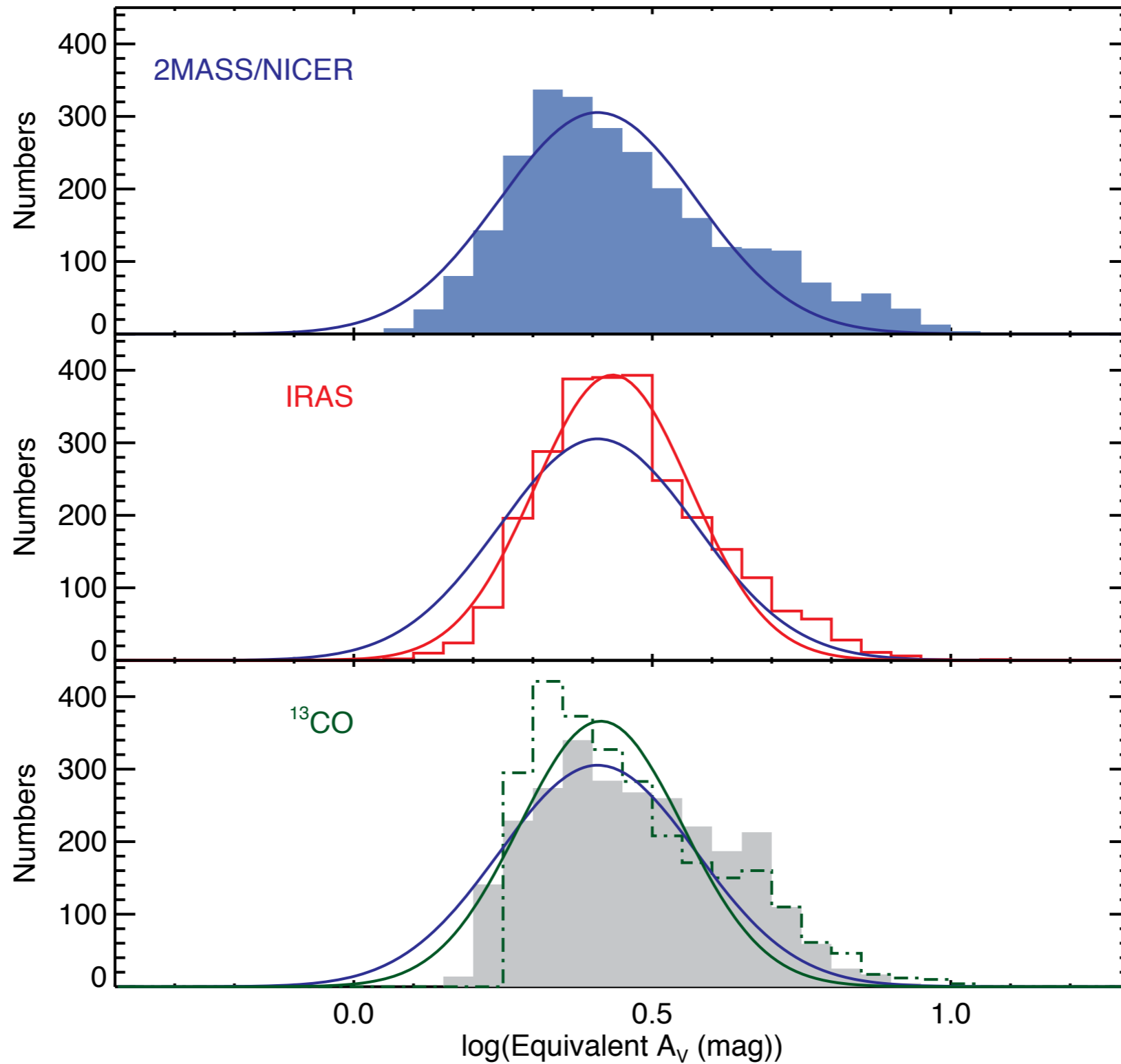


2MASS/NICER

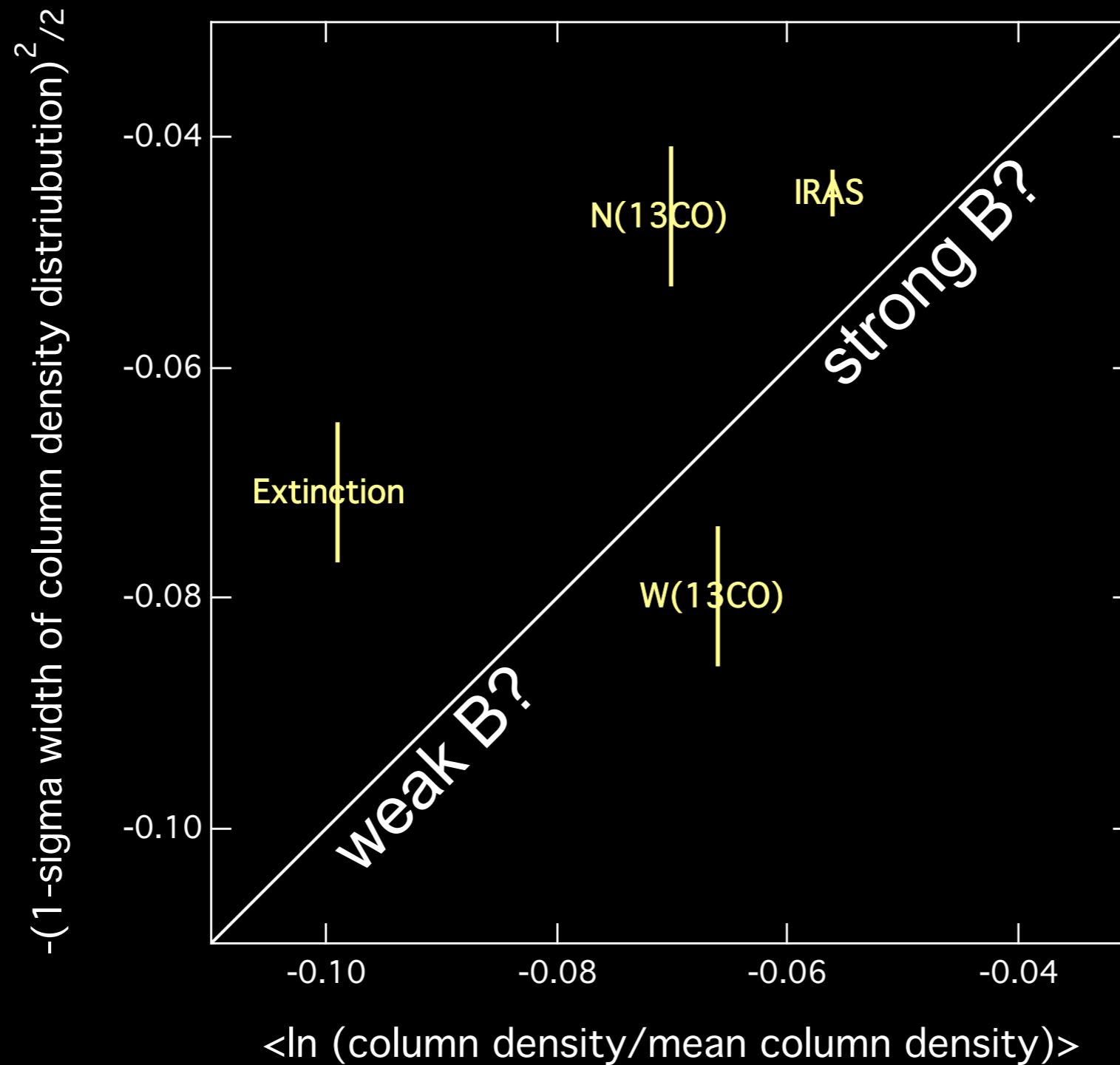
IRIS

Today

# “Bias & Uncertainty”: A Never-ending Challenge



# Can we say what these distributions mean, quantitatively?

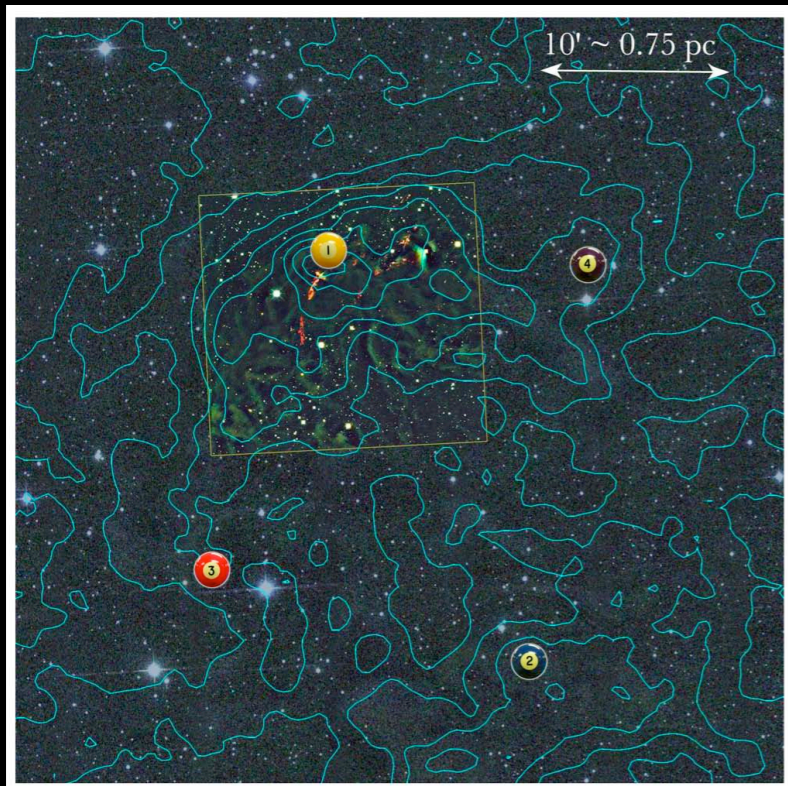


Notes: 1:1 line is predicted for turbulence & log-normal distribution, and “weak” and “strong” markers are based on (some, but not all!) simulations in Ostriker, Stone & Gammie 2001--an illustrative example. (cf. Vazquez-Semadeni et al.; Padoan et al.)

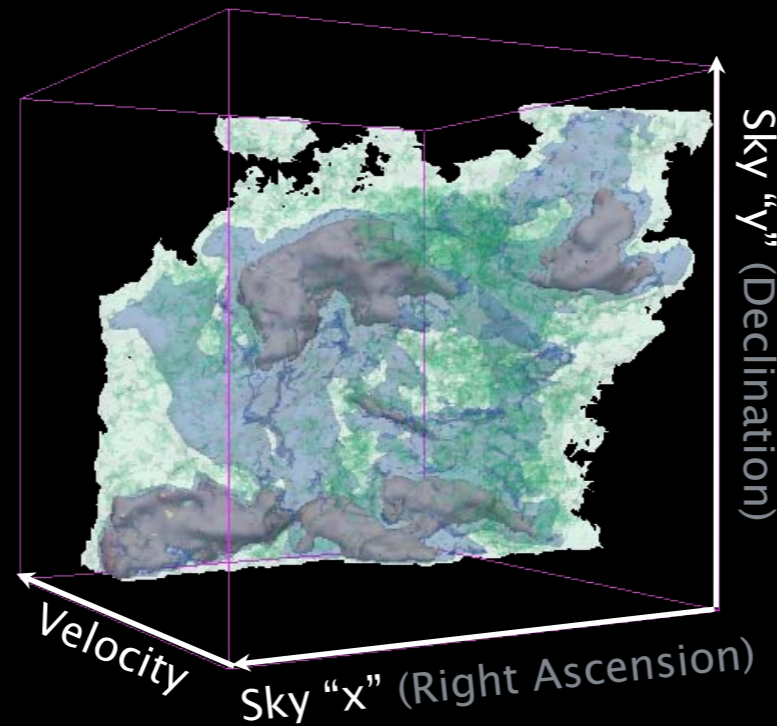


2. Self-gravity matters on a range of scales,  
at *identifiable* locations  
(Dendrograms)

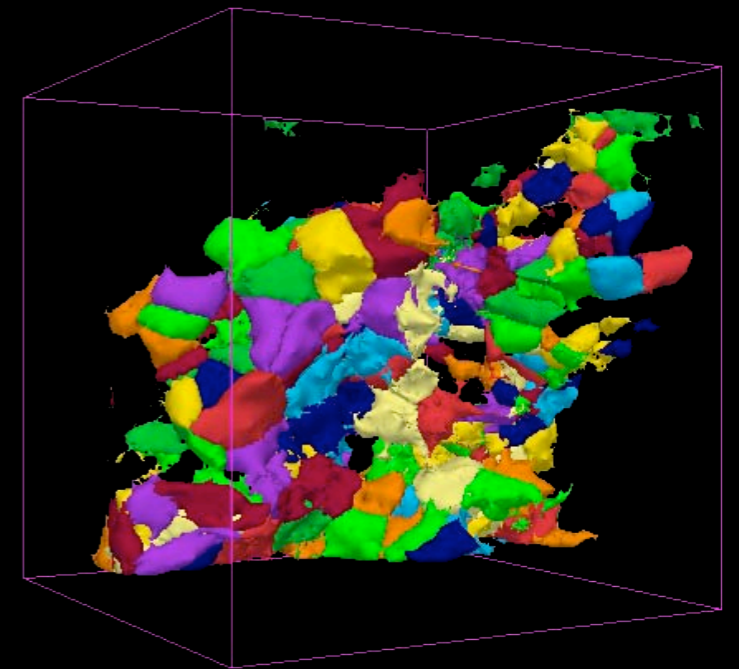
# What's at issue?



## (Dendro)Surfaces



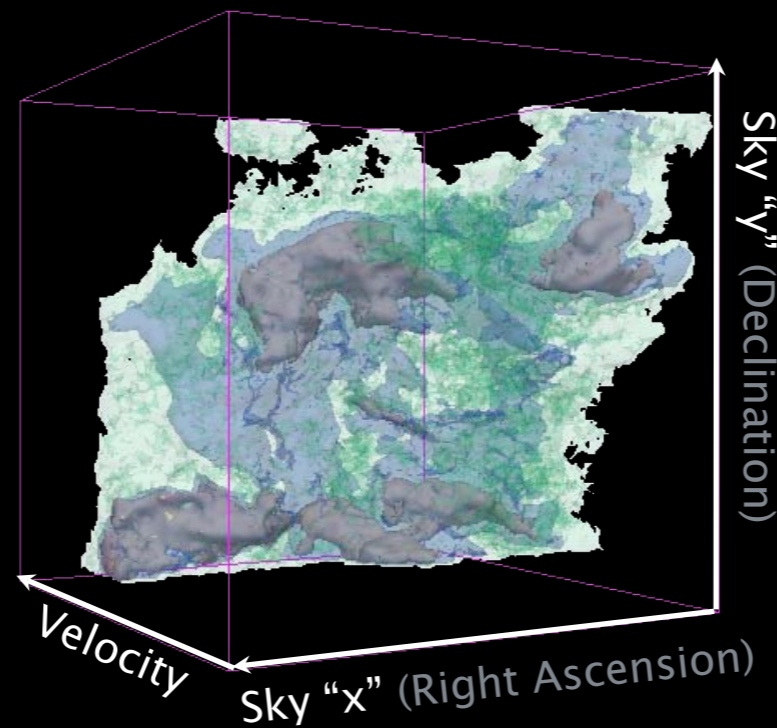
## "CLUMPFIND"



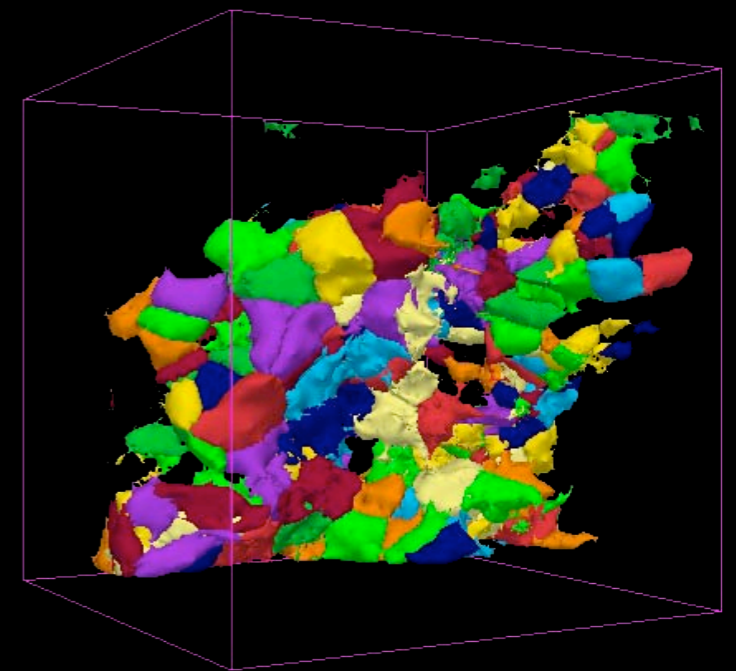
*work of Rosolowsky, Foster, Pineda, Kauffmann, Borkin, Padoan, Halle & Goodman;  
figures based on Foster & Goodman 2006; Goodman et al. 2007*

# What's at issue?

## (Dendro)Surfaces



## "CLUMPFIND"



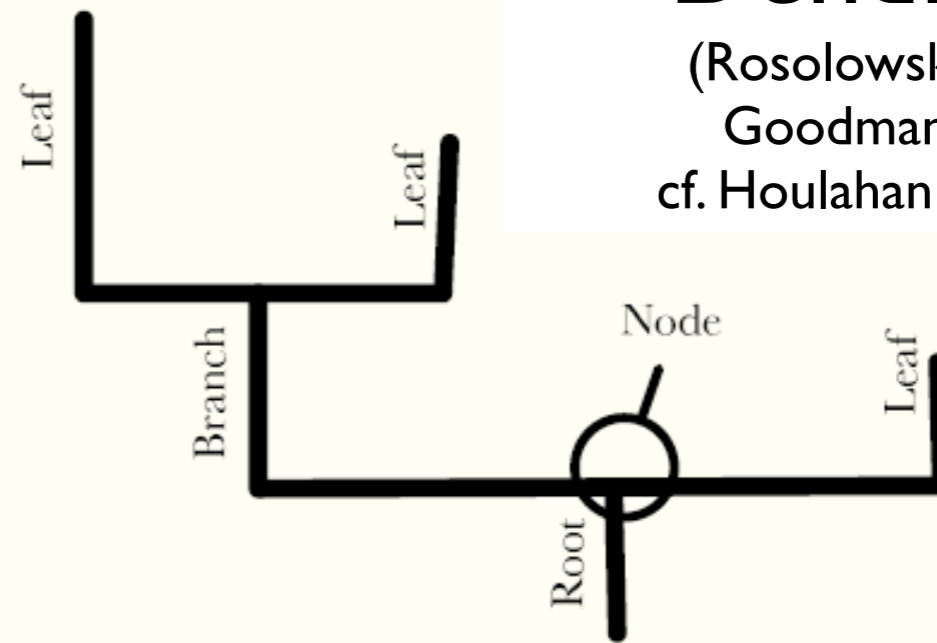
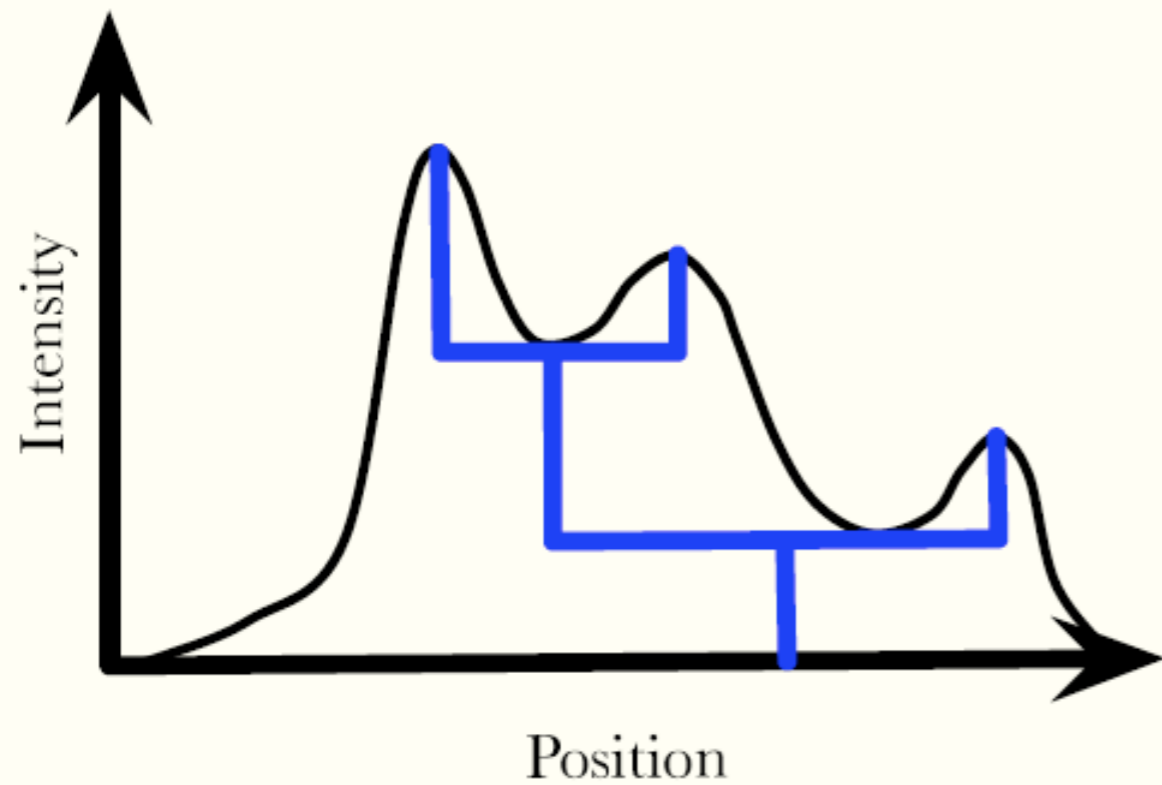
*work of Rosolowsky, Foster, Pineda, Kauffmann, Borkin, Padoan, Halle & Goodman;  
figures based on Foster & Goodman 2006; Goodman et al. 2007*



Meaningful structure in position-position-velocity space (3D)

# Dendrograms (Hierarchical) vs. CLUMPFIND (Non-hierarchical)

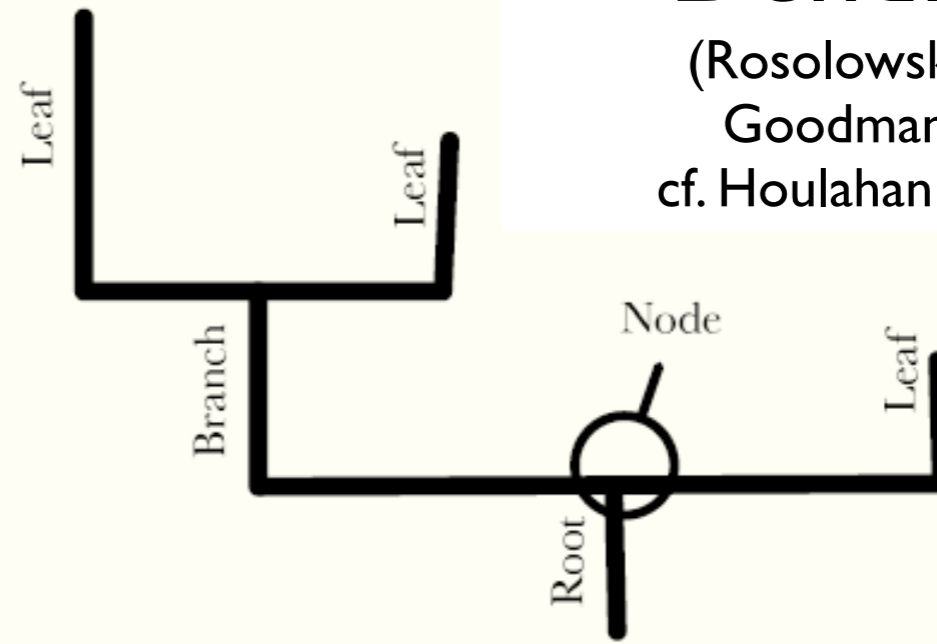
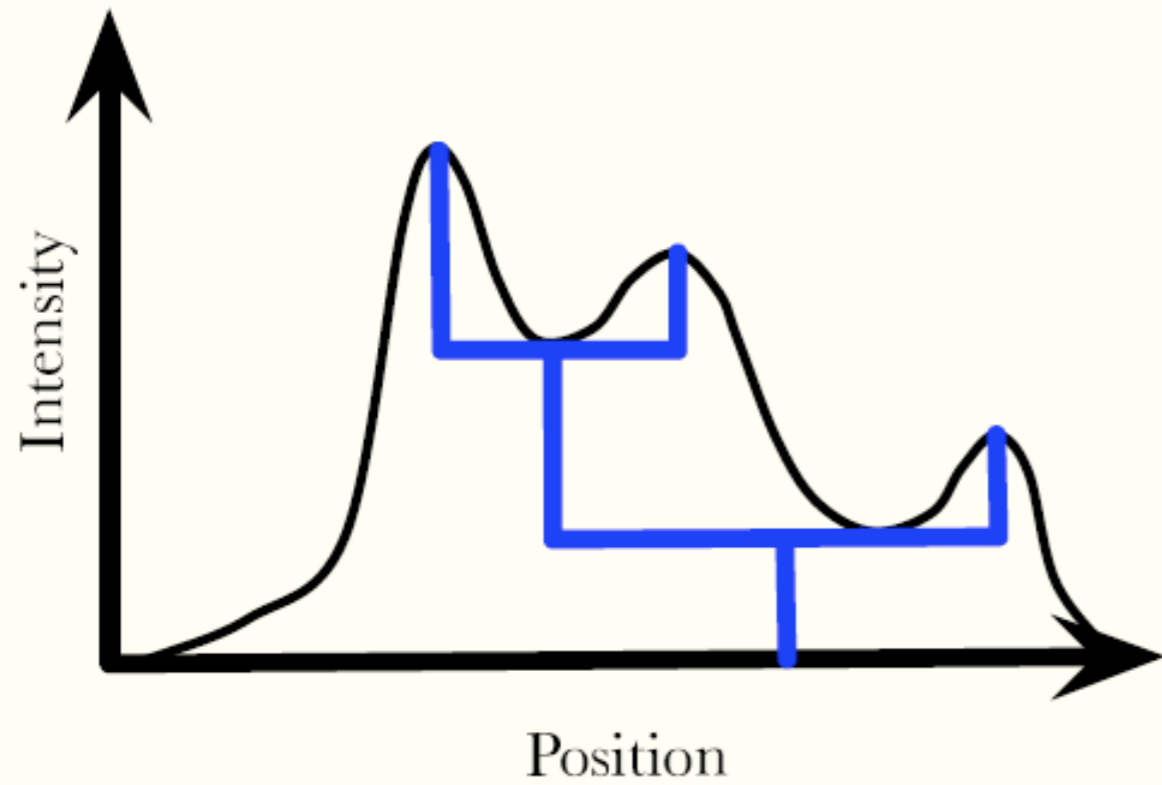
# Dendrograms (Hierarchical) vs. CLUMPFIND (Non-hierarchical)



## Dendrogram

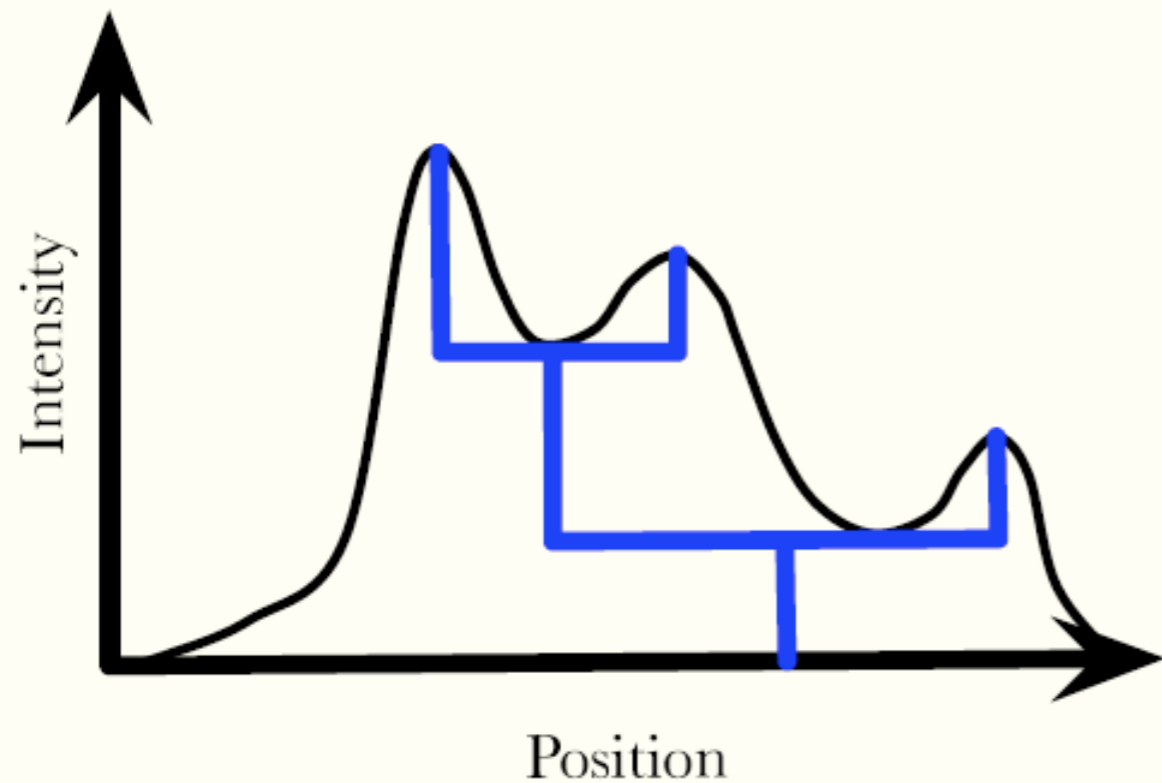
(Rosolowsky et al. 2007;  
Goodman et al. 2007  
cf. Houlahan & Scalo 1992)

# Dendrograms (Hierarchical) vs. CLUMPFIND (Non-hierarchical)



## Dendrogram

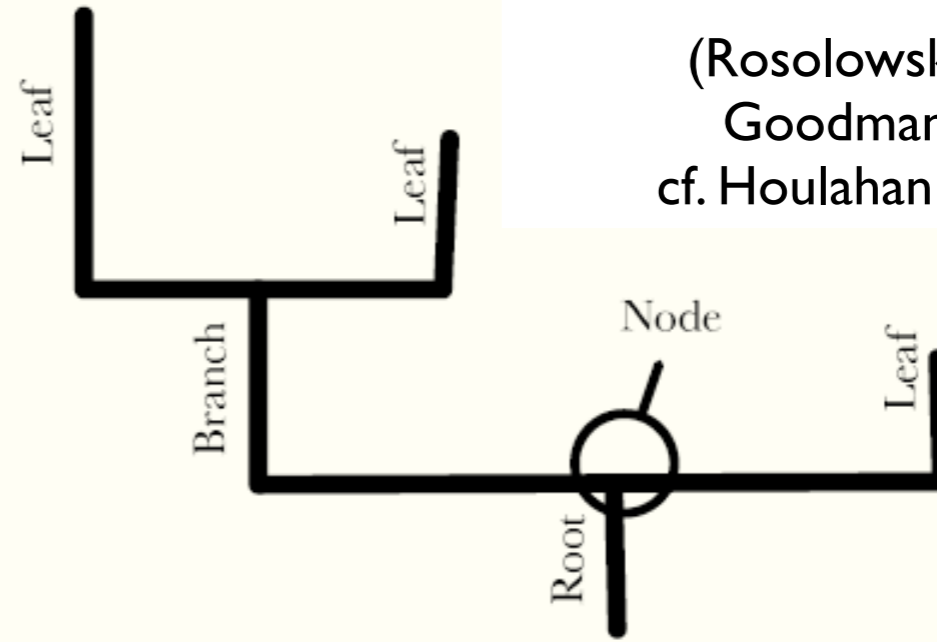
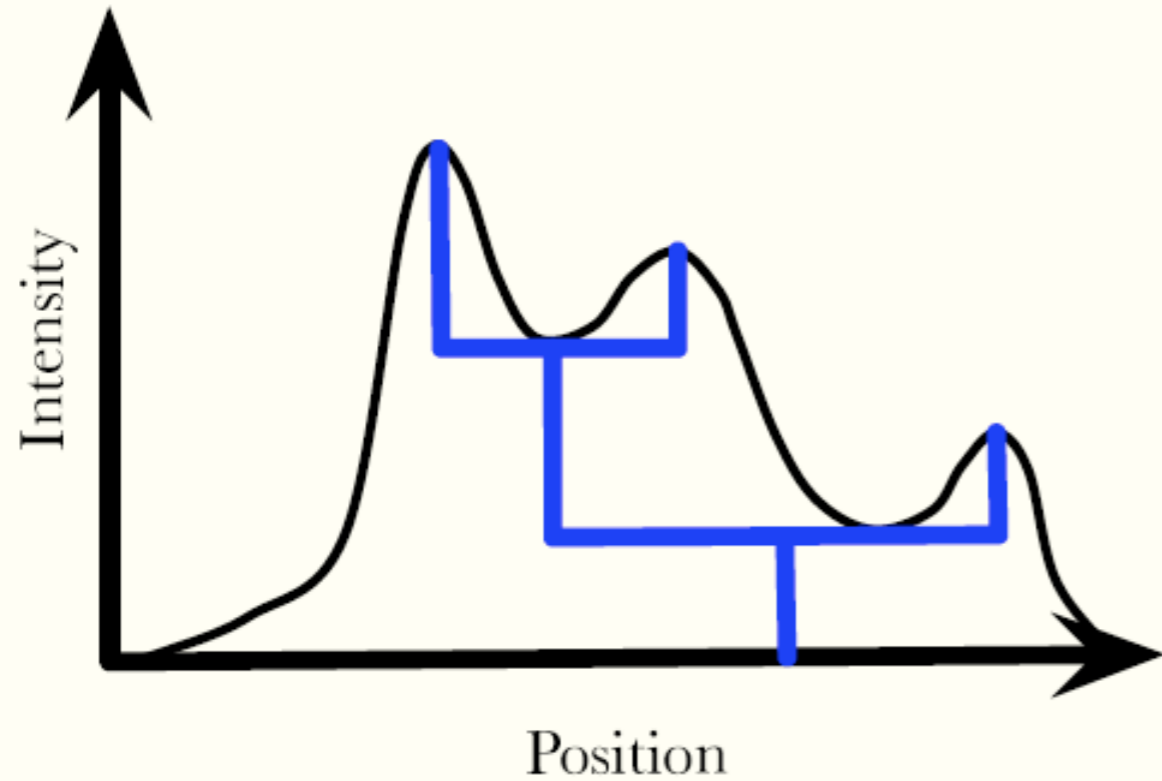
(Rosolowsky et al. 2007;  
Goodman et al. 2007  
cf. Houlahan & Scalo 1992)



## CLUMPFIND

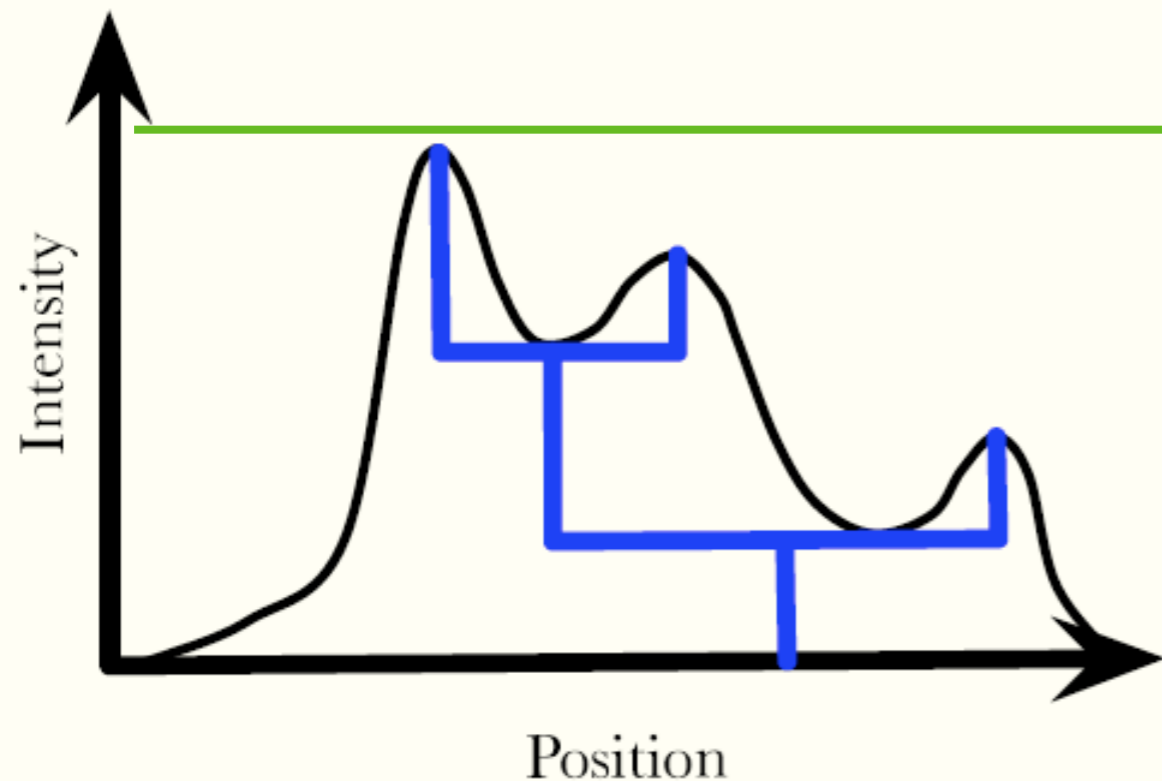
(Williams et al. 1994)

# Dendrograms (Hierarchical) vs. CLUMPFIND (Non-hierarchical)



## Dendrogram

(Rosolowsky et al. 2007;  
Goodman et al. 2007  
cf. Houlahan & Scalo 1992)

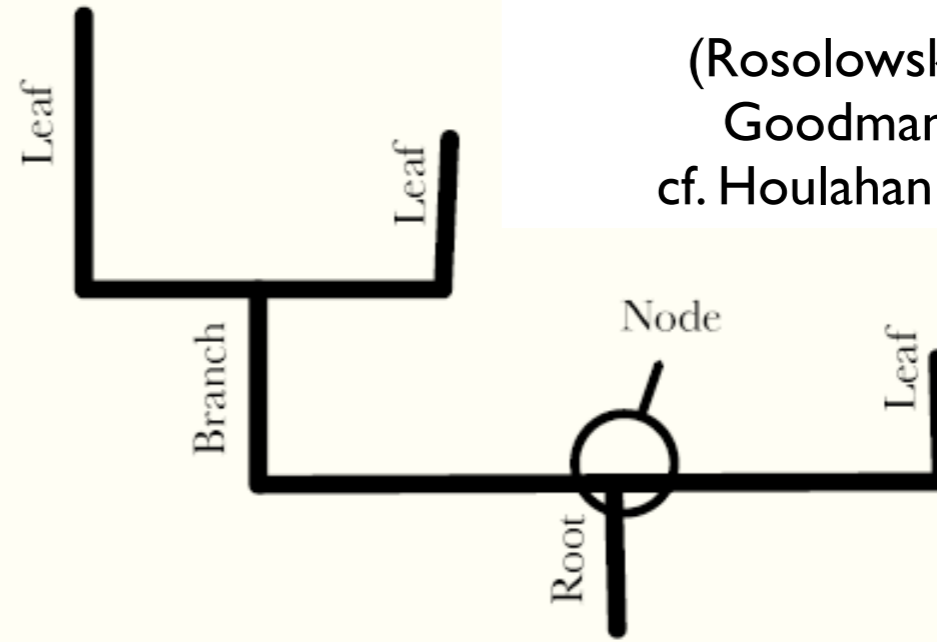
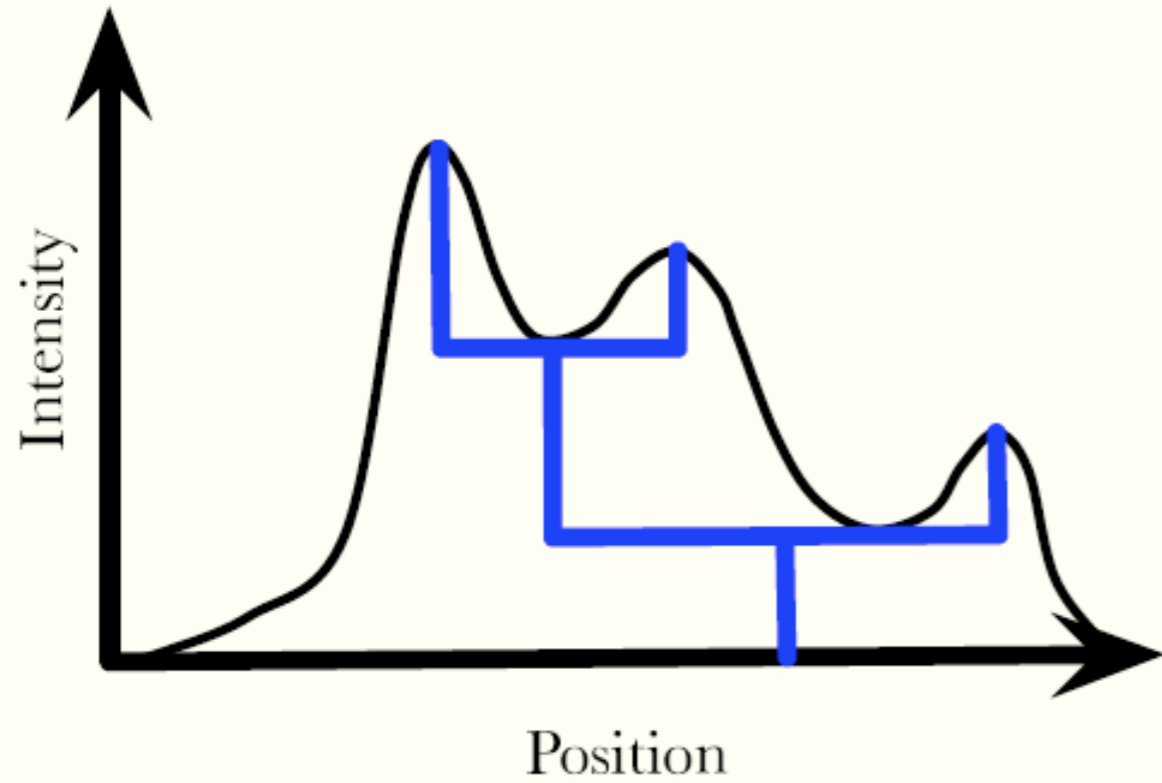


## CLUMPFIND

(Williams et al. 1994)

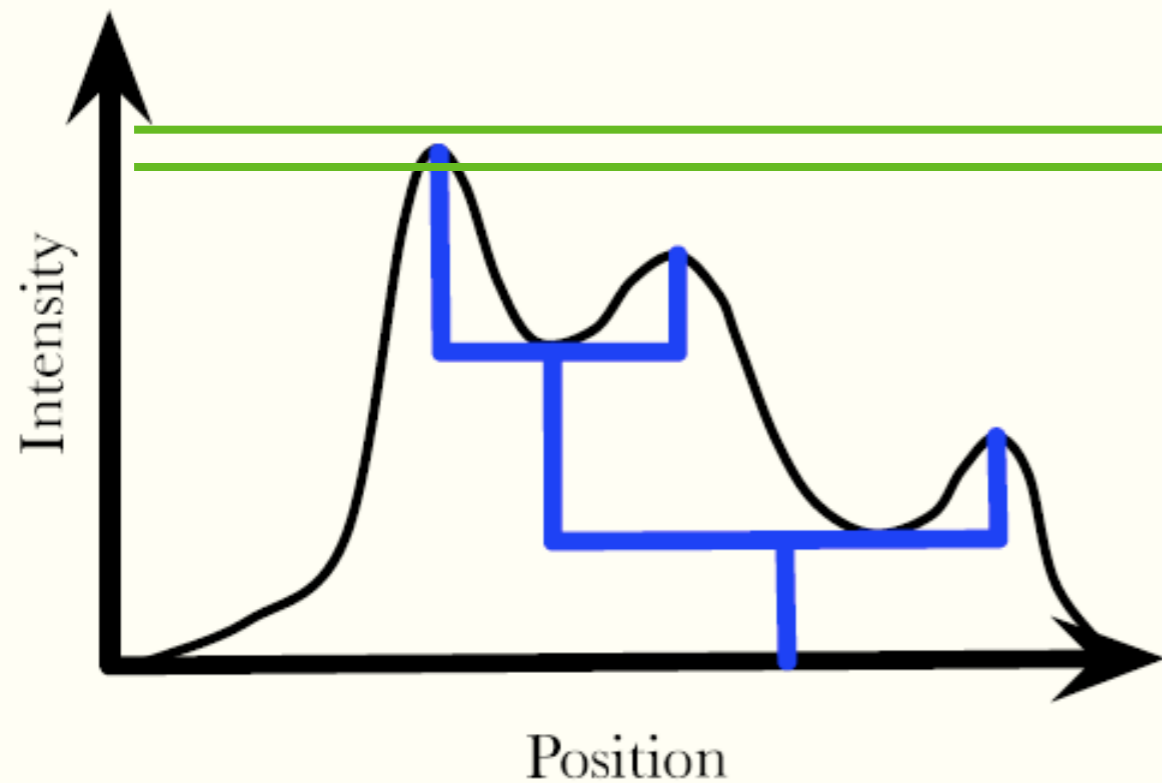


# Dendrograms (Hierarchical) vs. CLUMPFIND (Non-hierarchical)



## Dendrogram

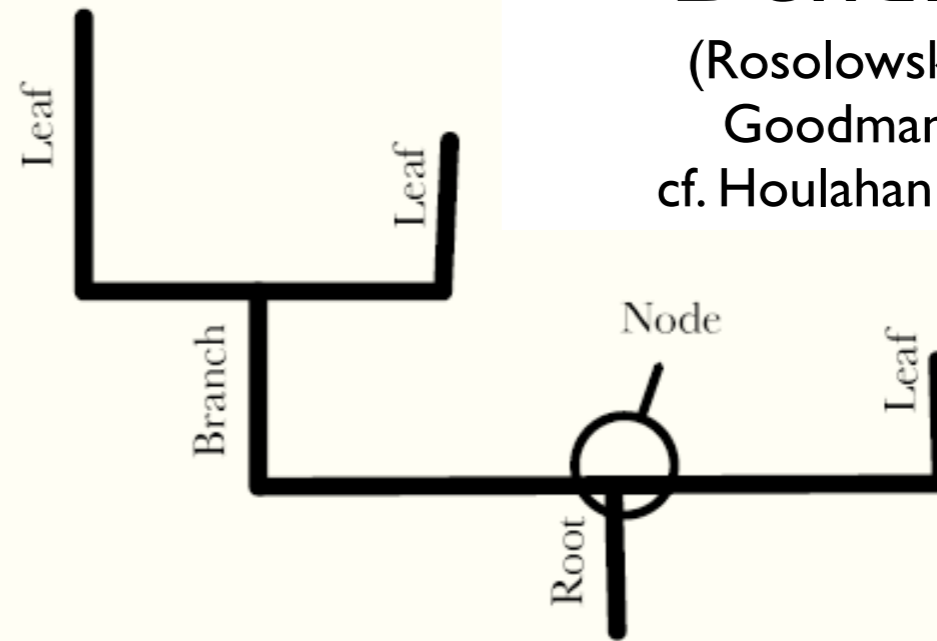
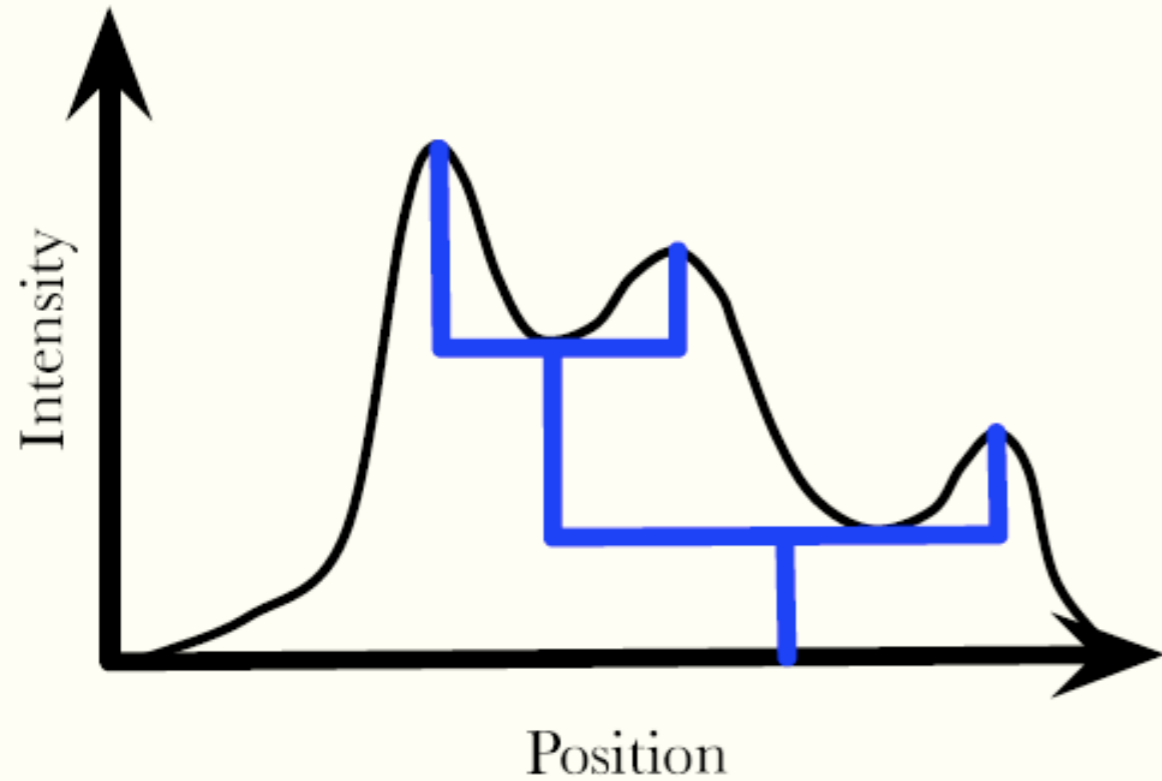
(Rosolowsky et al. 2007;  
Goodman et al. 2007  
cf. Houlahan & Scalo 1992)



## CLUMPFIND

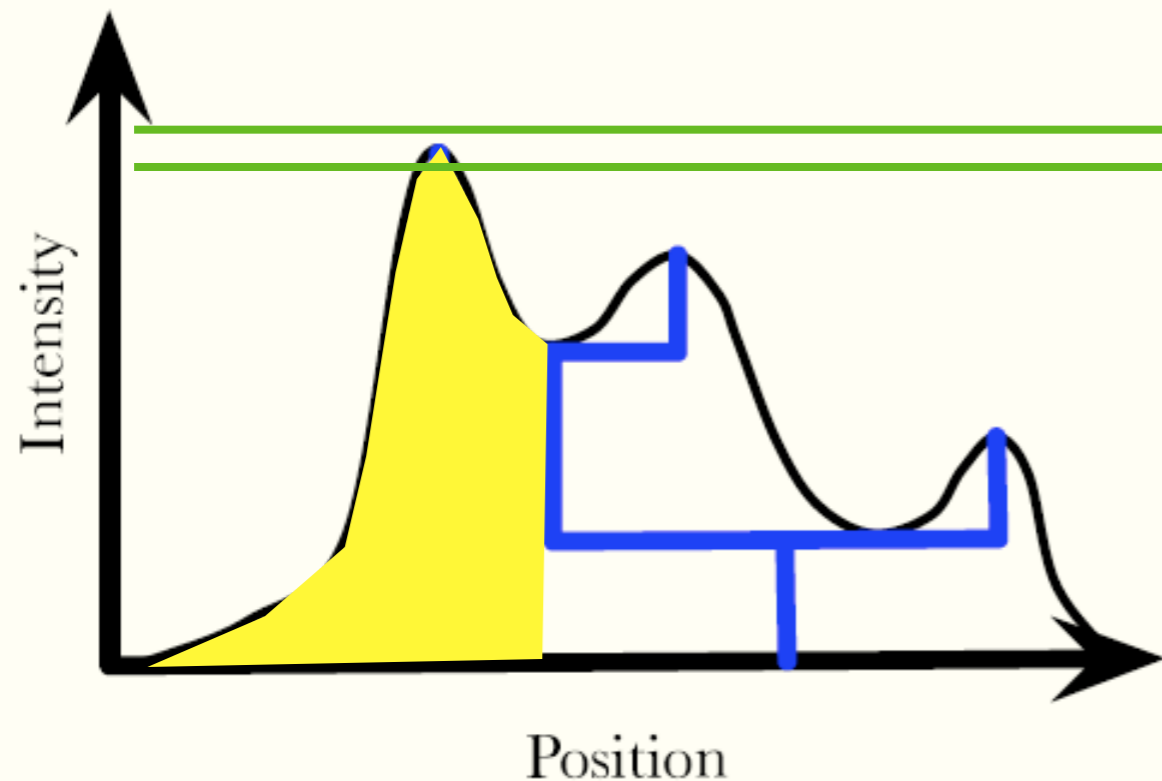
(Williams et al. 1994)

# Dendrograms (Hierarchical) vs. CLUMPFIND (Non-hierarchical)



## Dendrogram

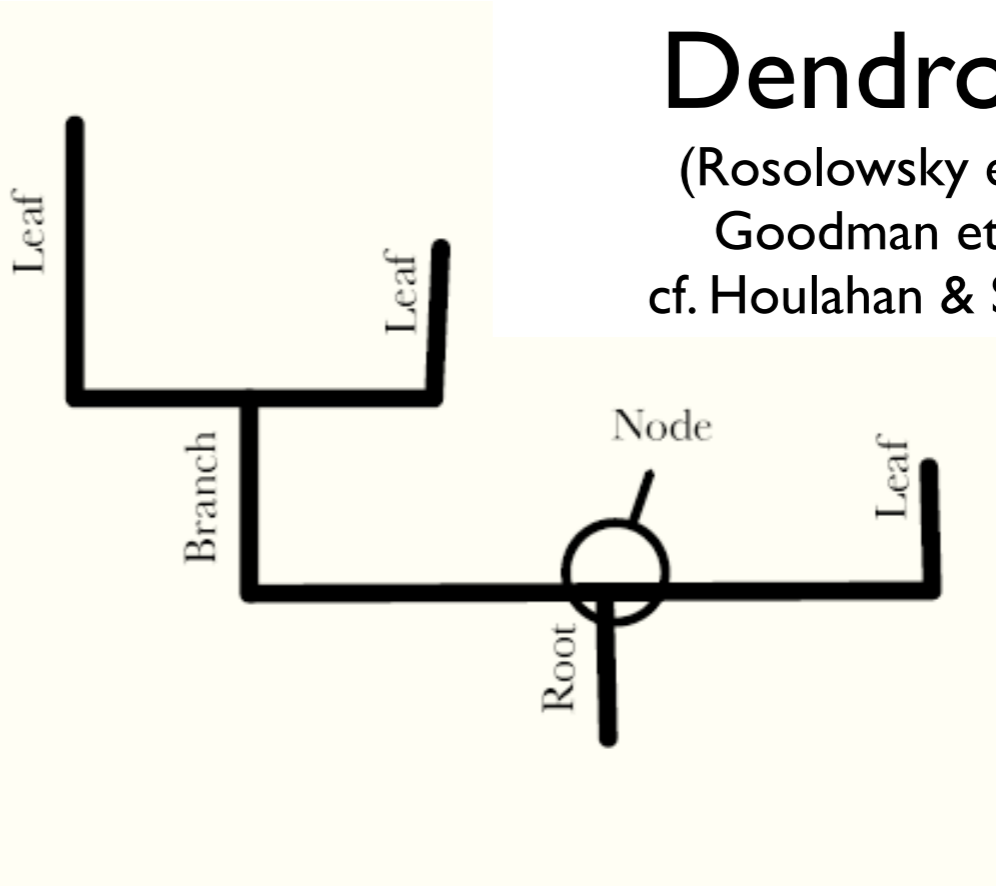
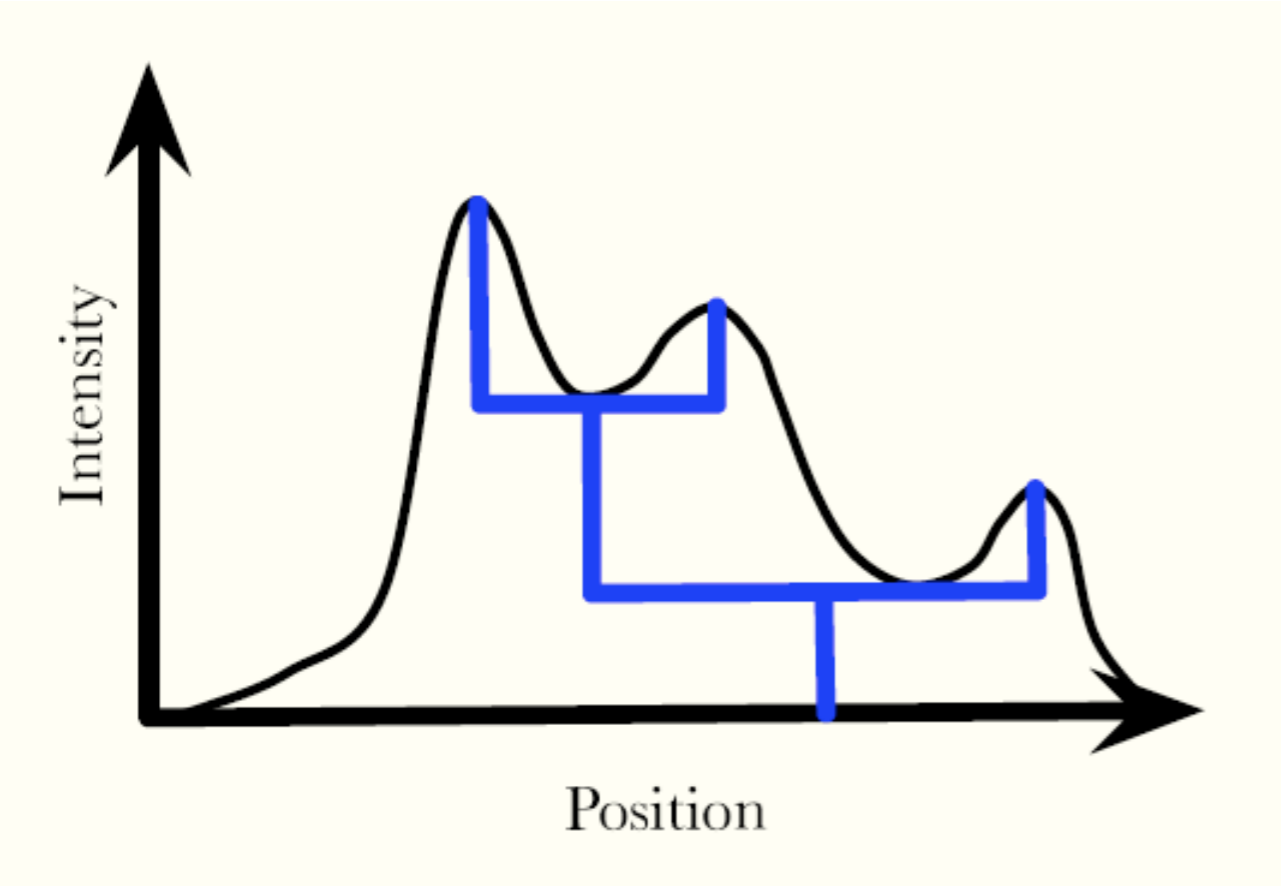
(Rosolowsky et al. 2007;  
Goodman et al. 2007  
cf. Houlahan & Scalo 1992)



## CLUMPFIND

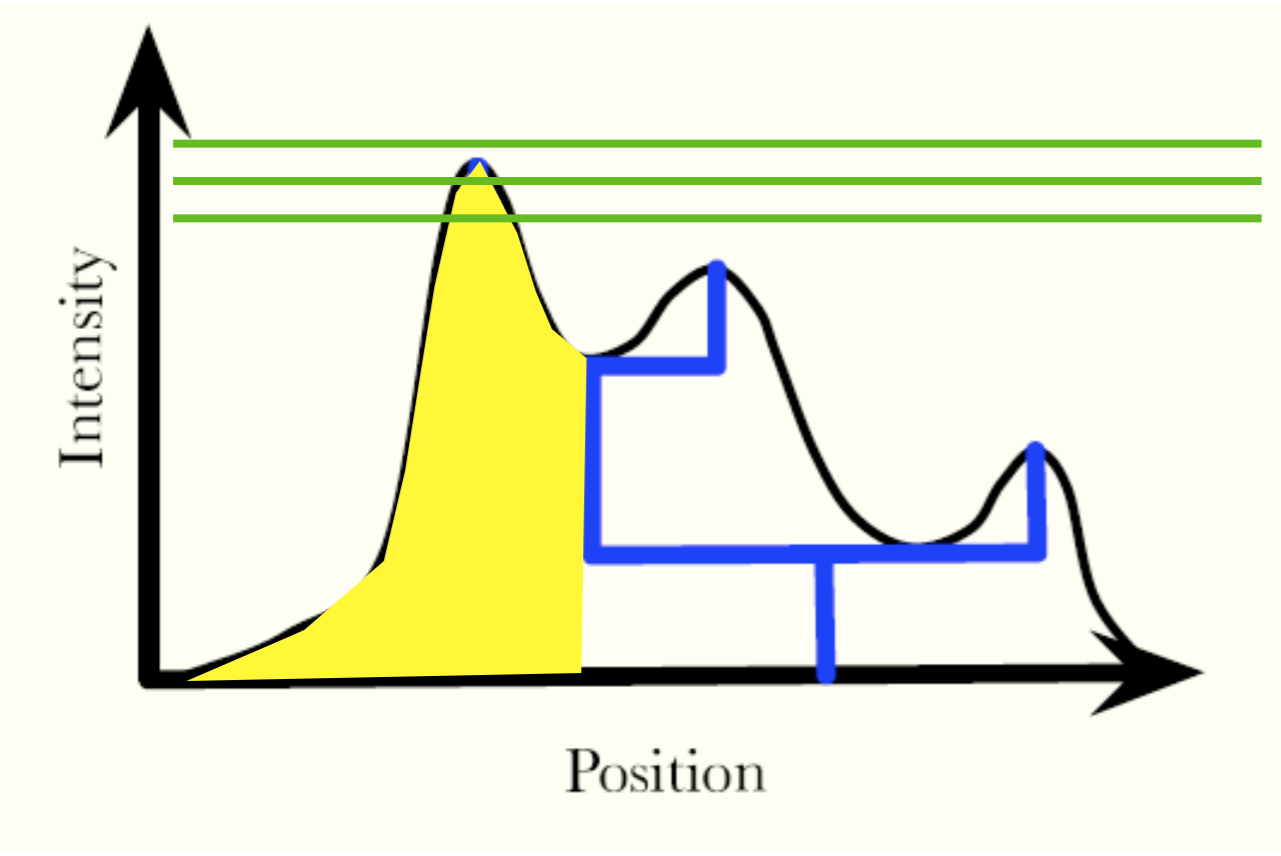
(Williams et al. 1994)

# Dendrograms (Hierarchical) vs. CLUMPFIND (Non-hierarchical)



## Dendrogram

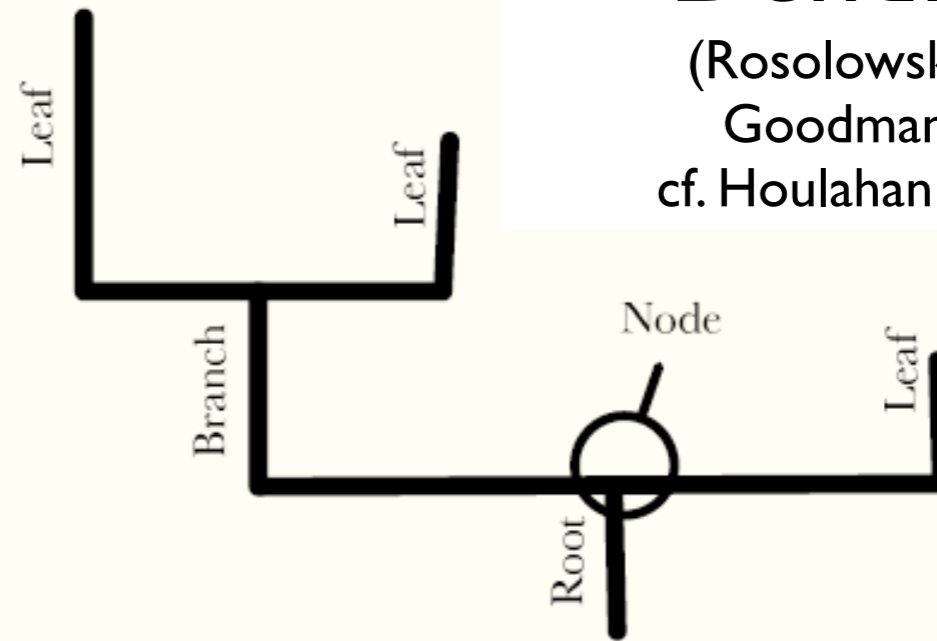
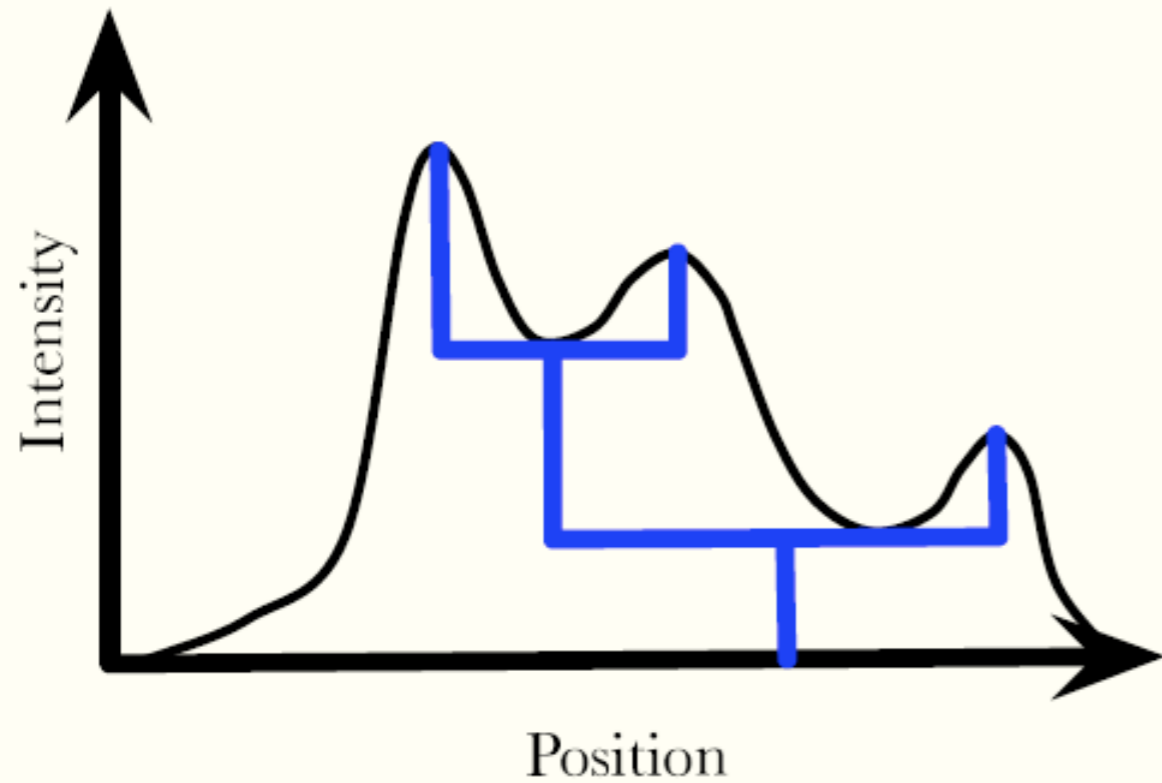
(Rosolowsky et al. 2007;  
Goodman et al. 2007  
cf. Houlahan & Scalo 1992)



## CLUMPFIND

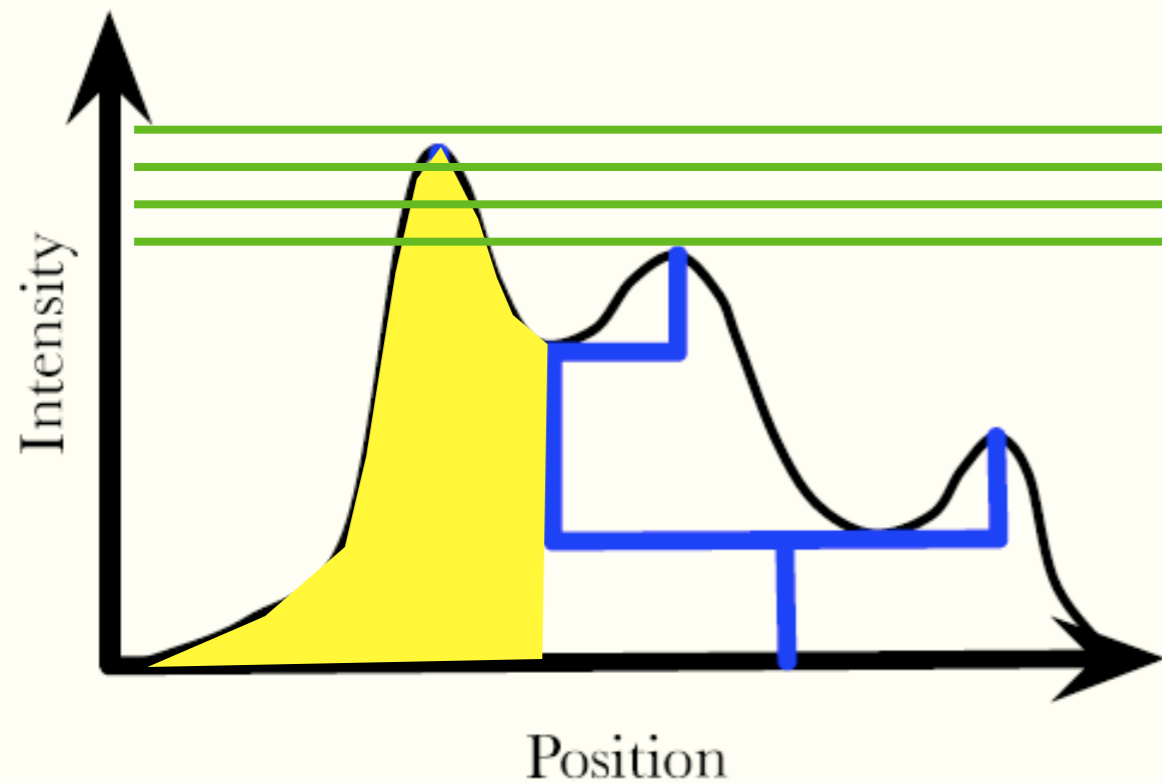
(Williams et al. 1994)

# Dendrograms (Hierarchical) vs. CLUMPFIND (Non-hierarchical)



## Dendrogram

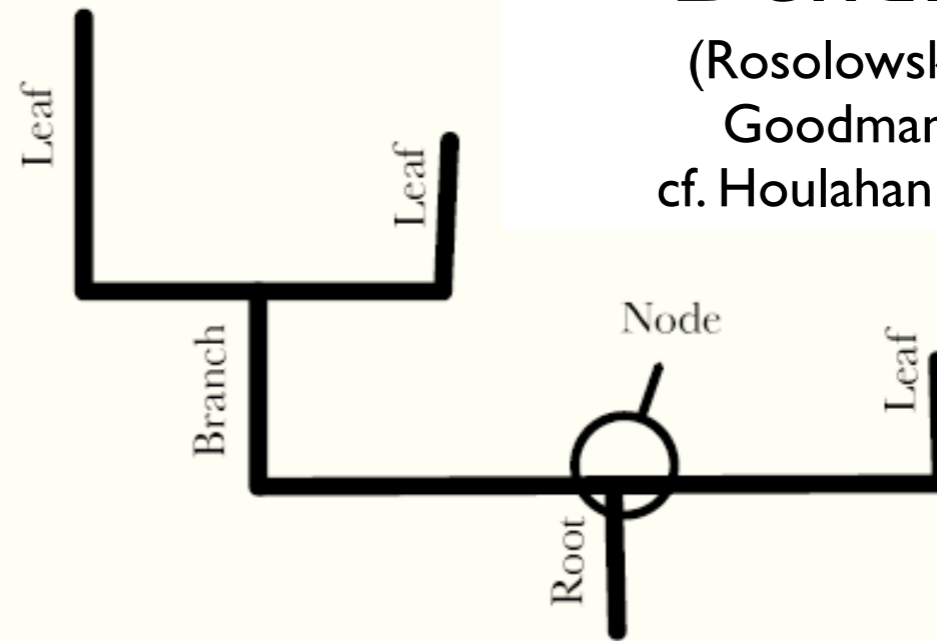
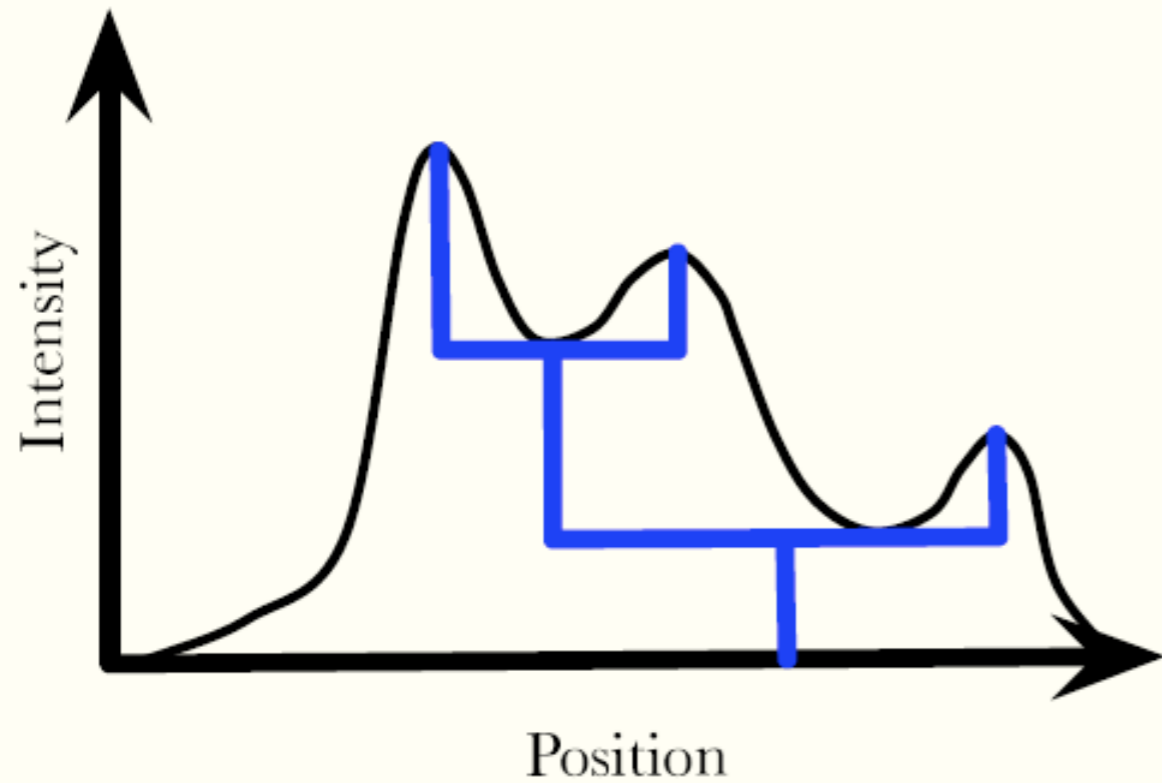
(Rosolowsky et al. 2007;  
Goodman et al. 2007  
cf. Houlahan & Scalo 1992)



## CLUMPFIND

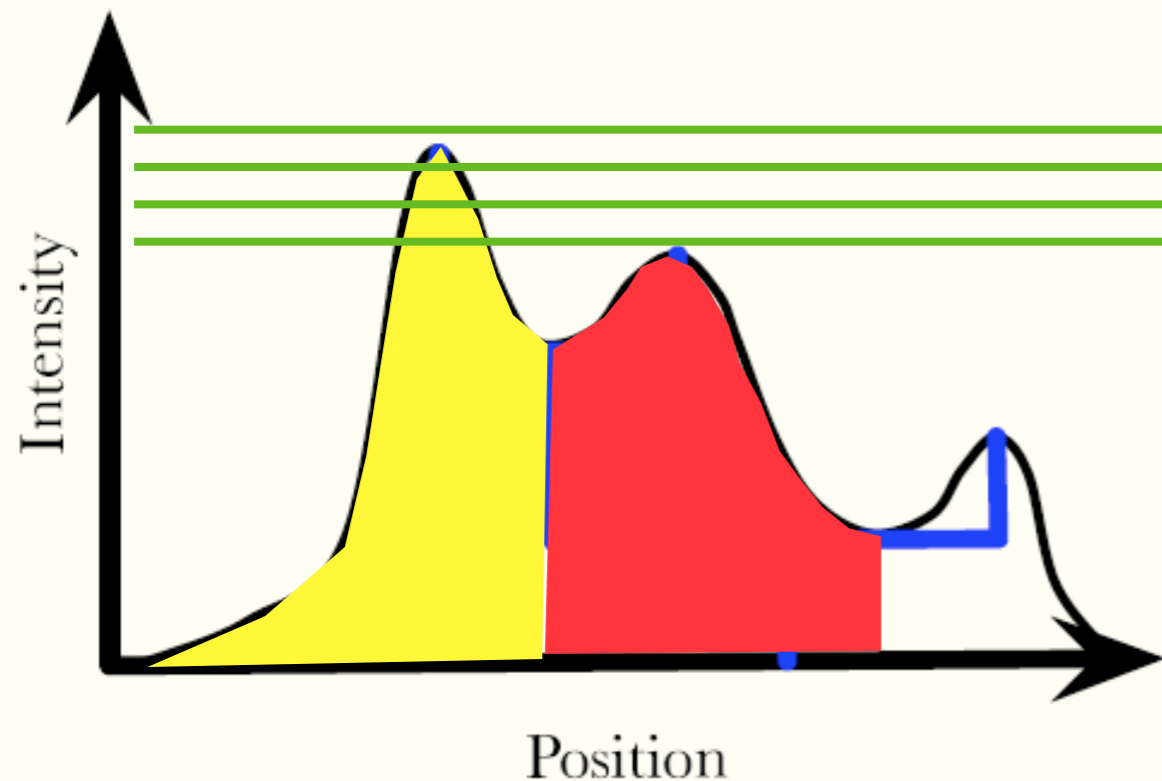
(Williams et al. 1994)

# Dendrograms (Hierarchical) vs. CLUMPFIND (Non-hierarchical)



## Dendrogram

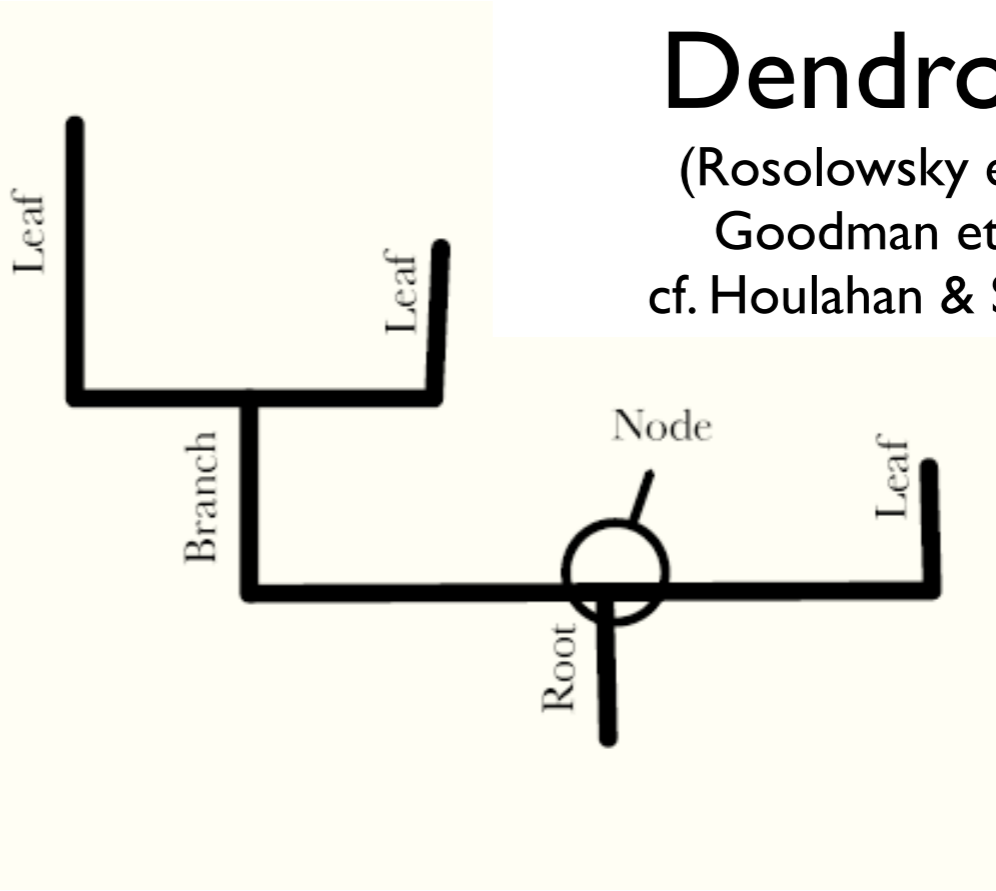
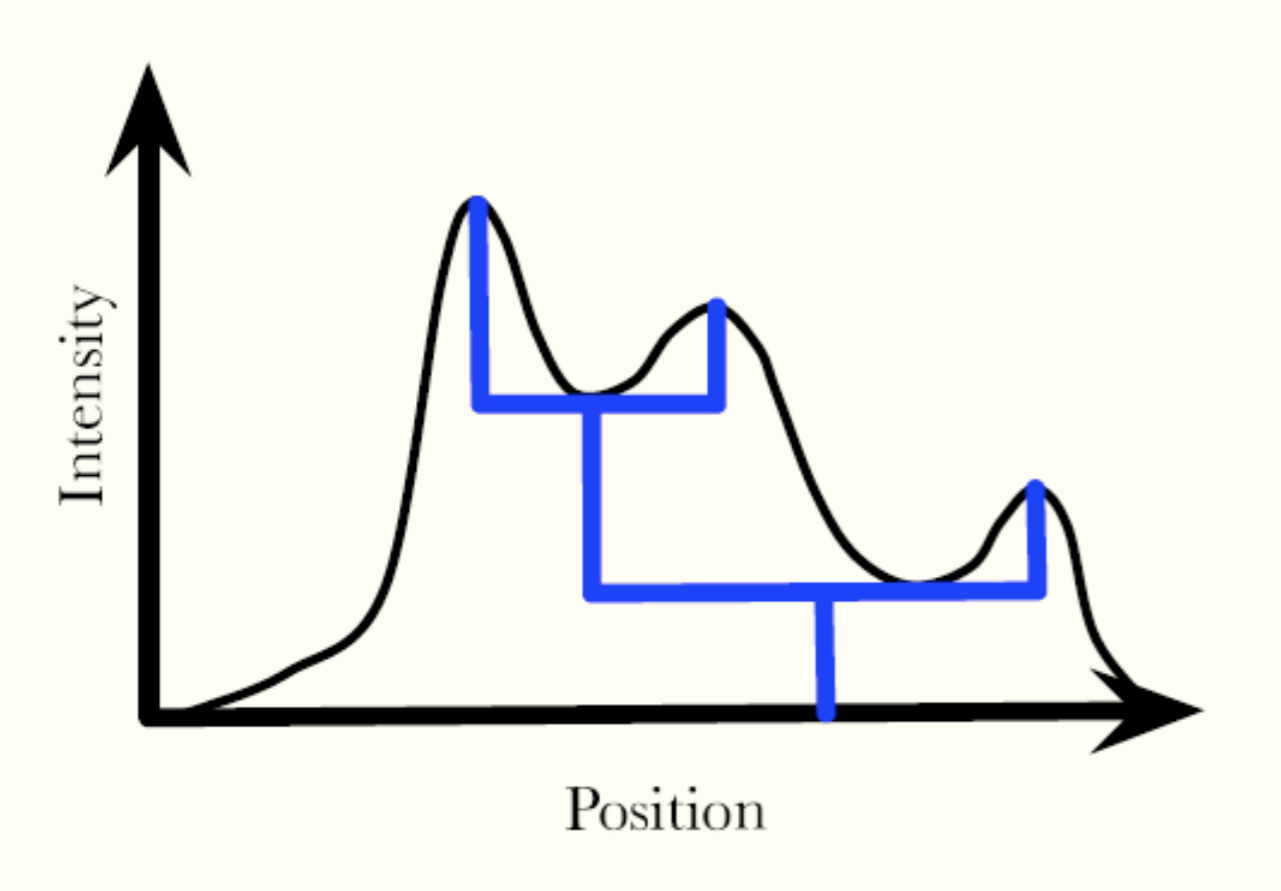
(Rosolowsky et al. 2007;  
Goodman et al. 2007  
cf. Houlahan & Scalo 1992)



## CLUMPFIND

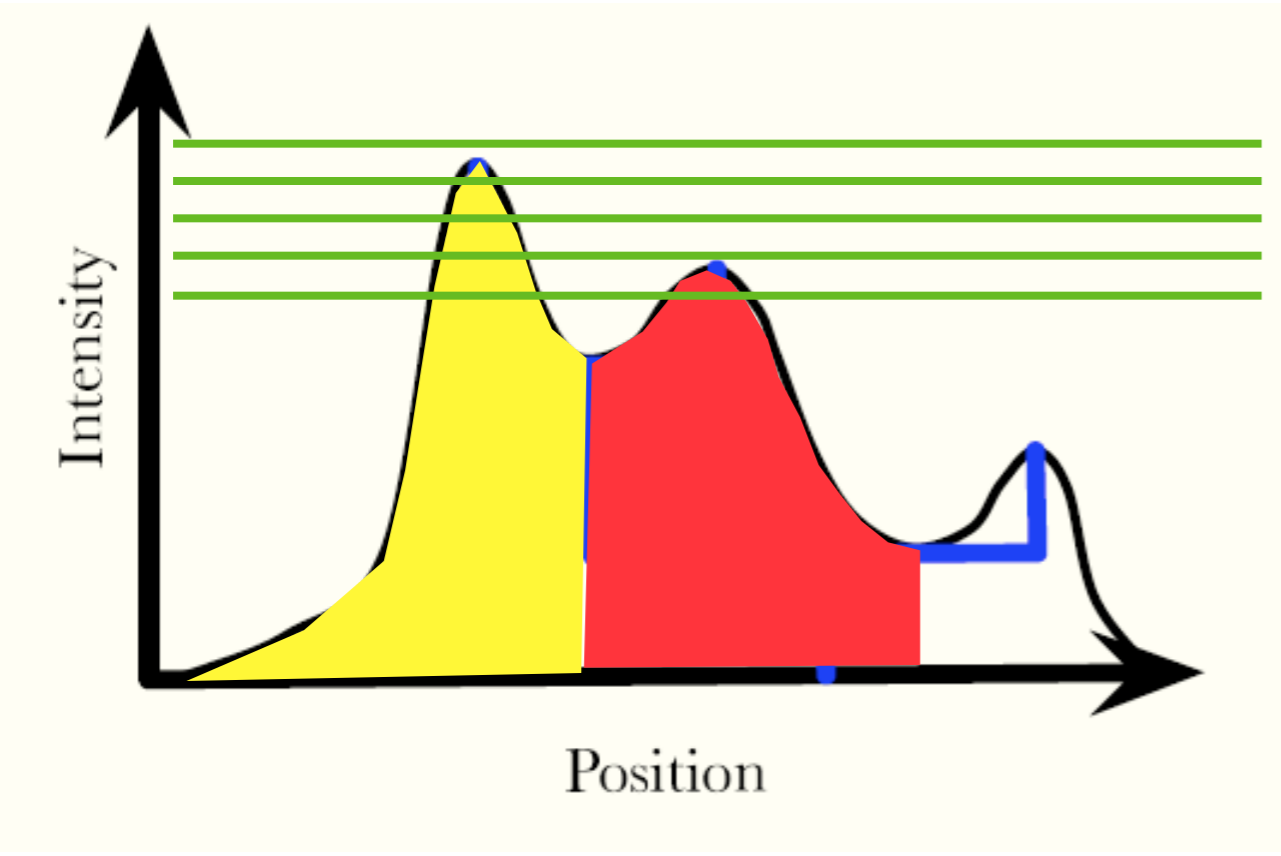
(Williams et al. 1994)

# Dendrograms (Hierarchical) vs. CLUMPFIND (Non-hierarchical)



## Dendrogram

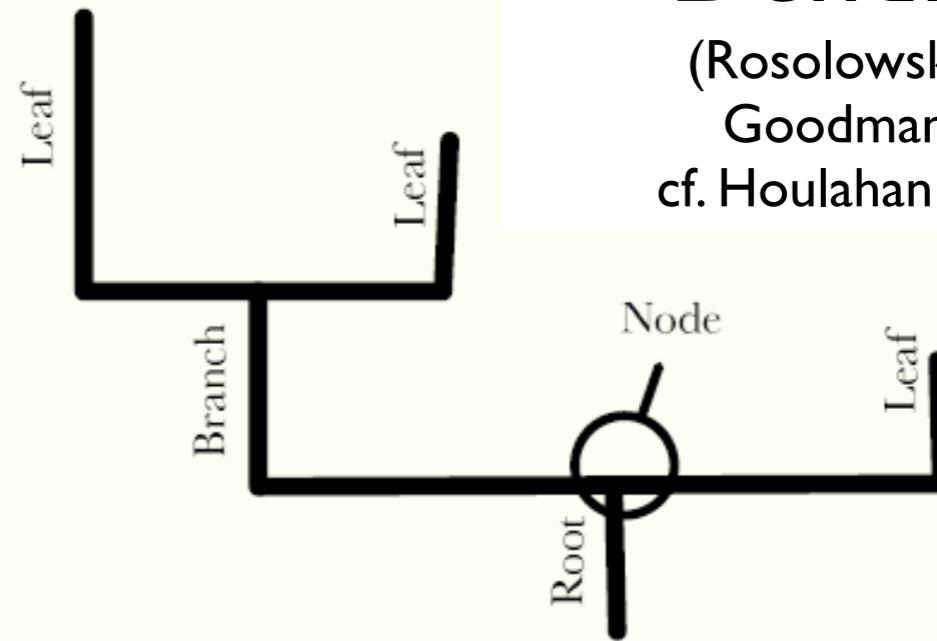
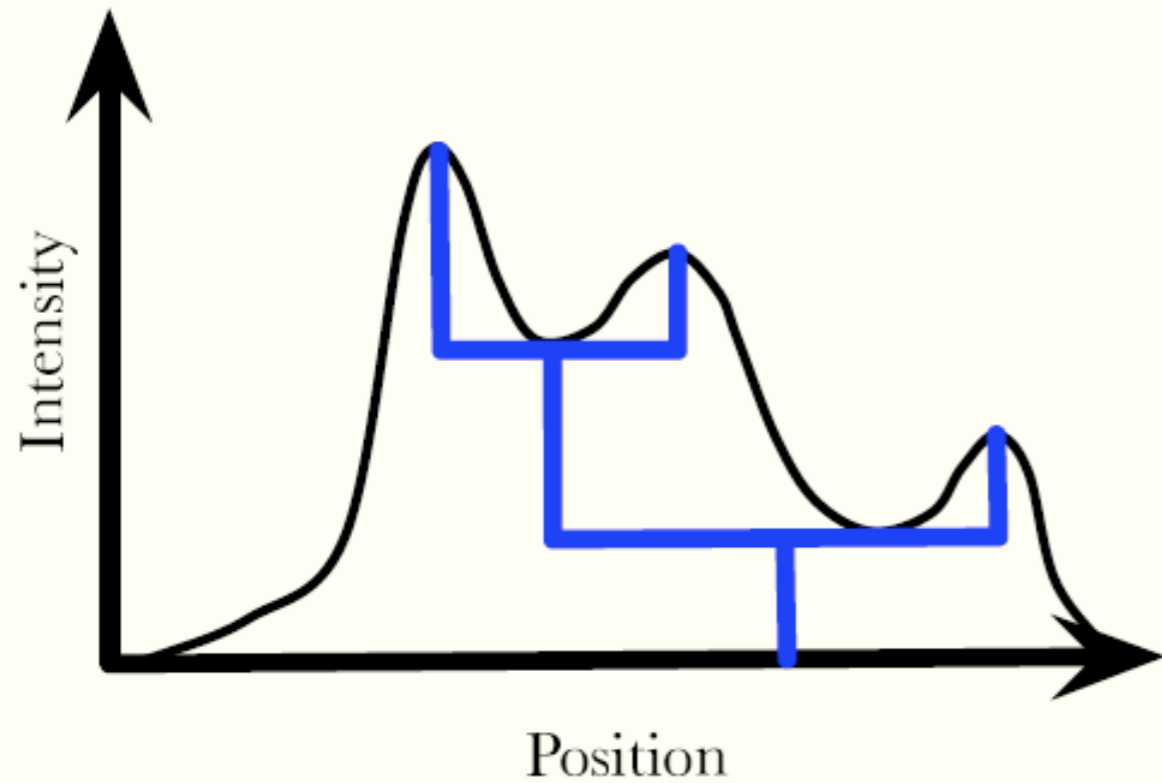
(Rosolowsky et al. 2007;  
Goodman et al. 2007  
cf. Houlahan & Scalo 1992)



## CLUMPFIND

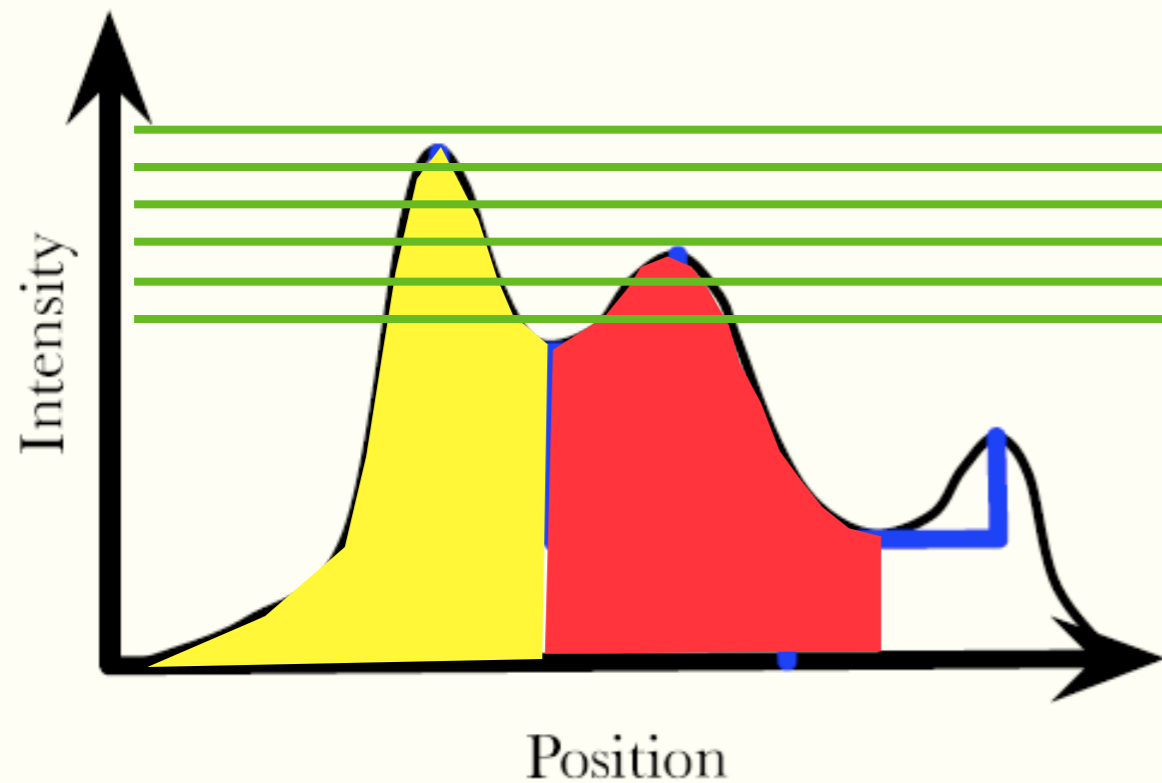
(Williams et al. 1994)

# Dendrograms (Hierarchical) vs. CLUMPFIND (Non-hierarchical)



## Dendrogram

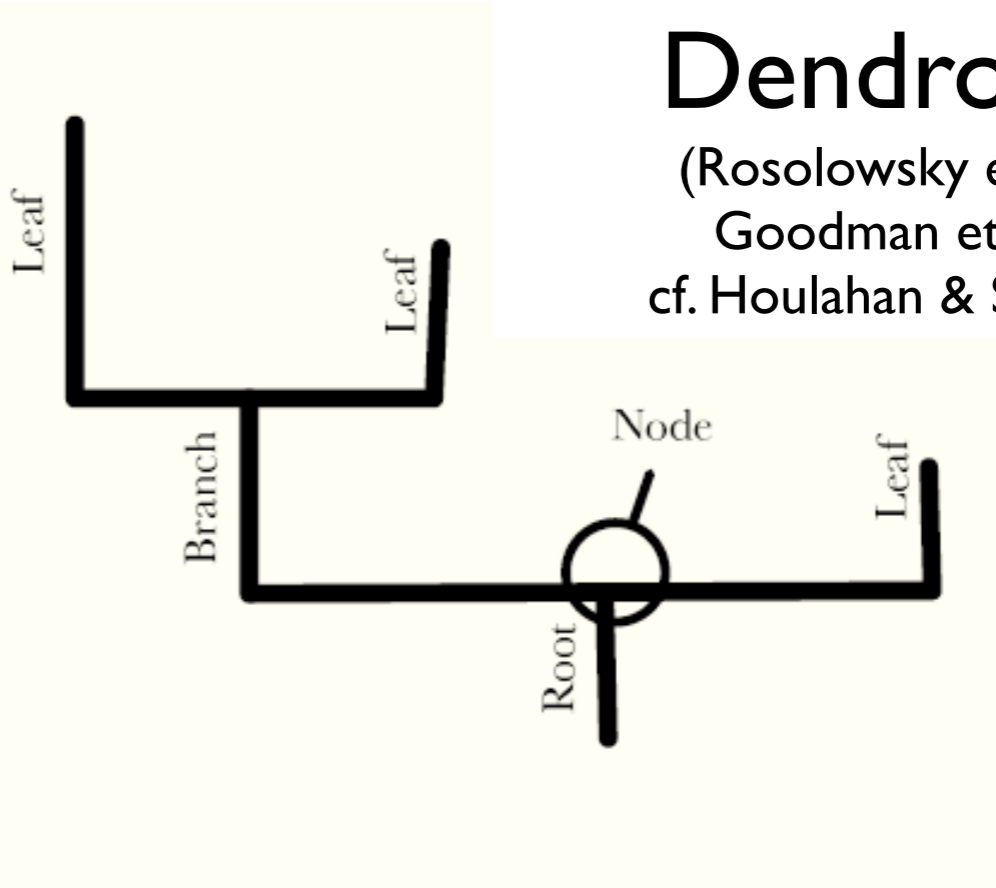
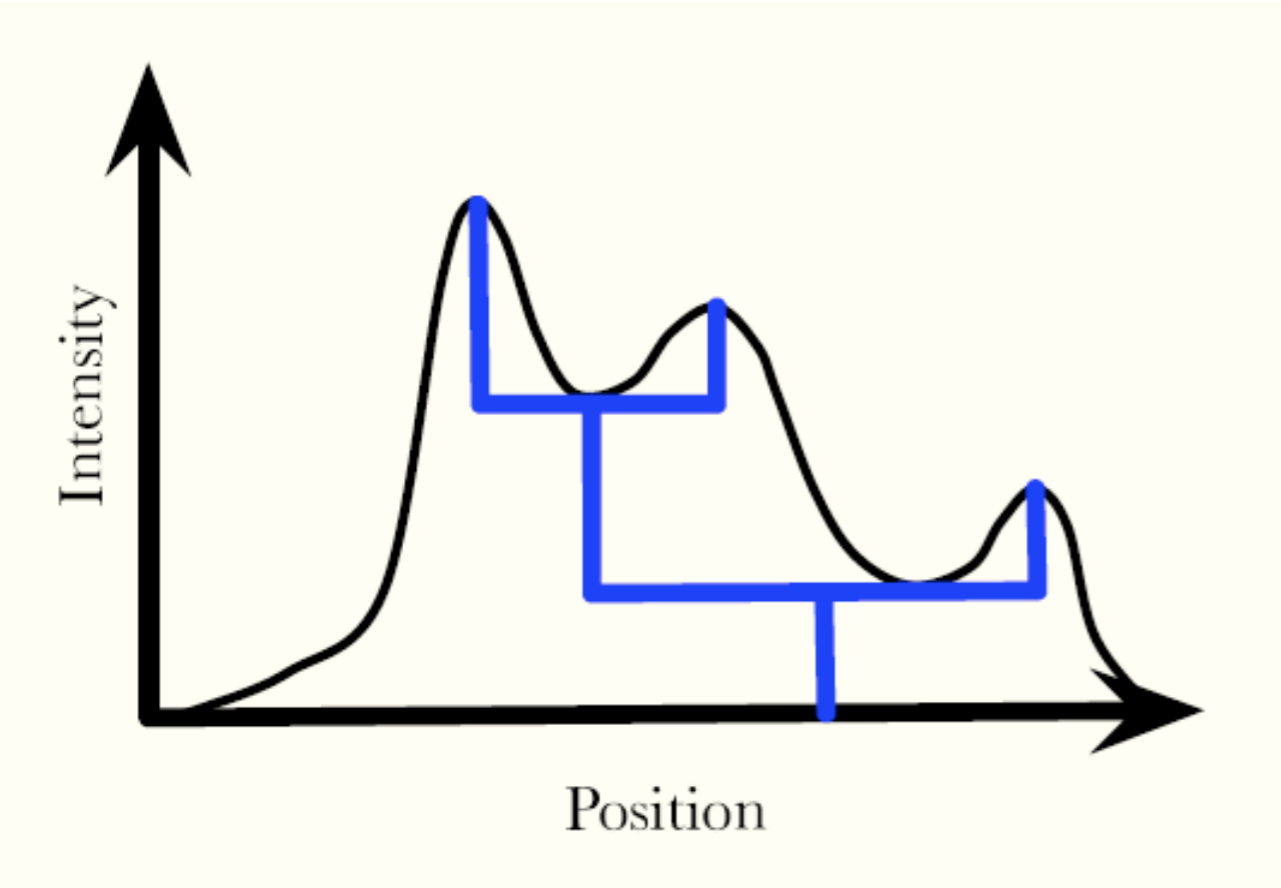
(Rosolowsky et al. 2007;  
Goodman et al. 2007  
cf. Houlahan & Scalo 1992)



## CLUMPFIND

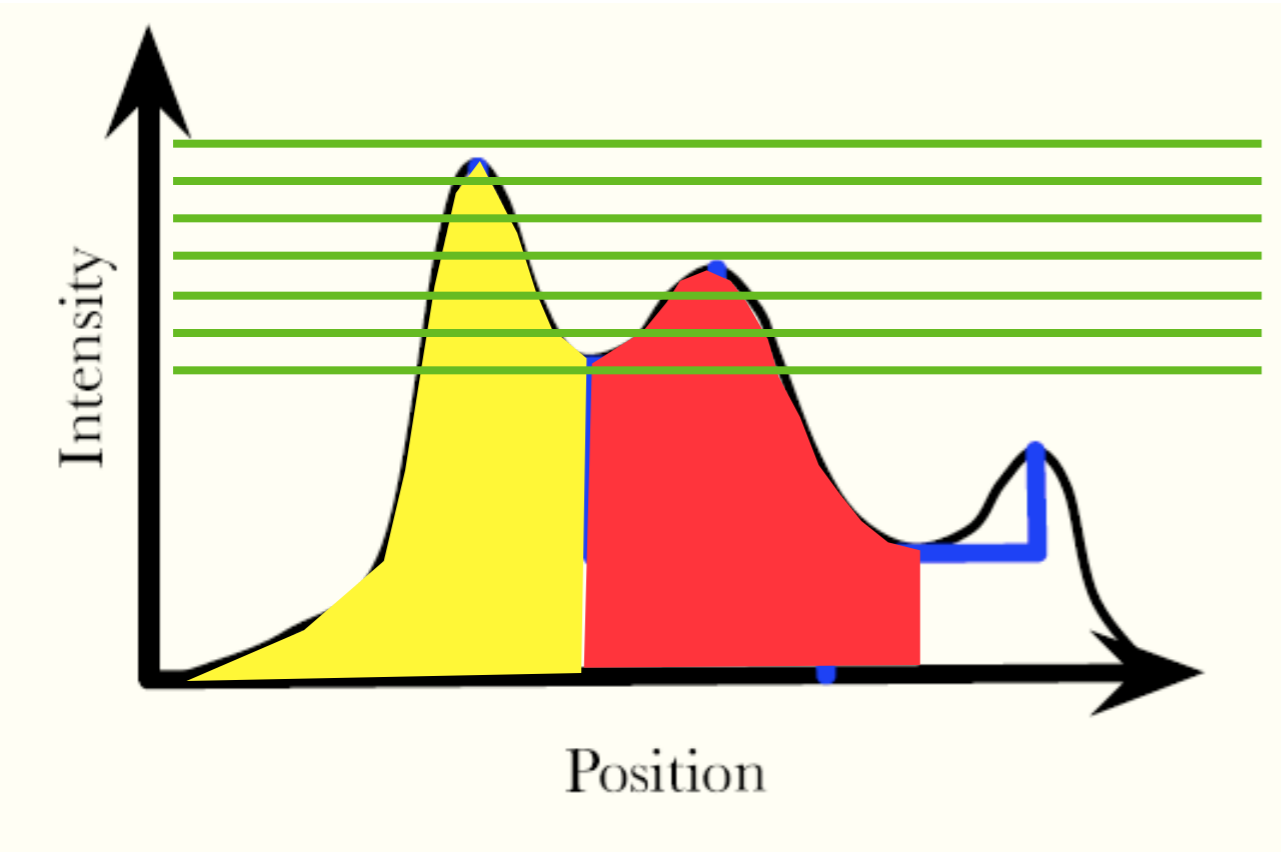
(Williams et al. 1994)

# Dendrograms (Hierarchical) vs. CLUMPFIND (Non-hierarchical)



## Dendrogram

(Rosolowsky et al. 2007;  
Goodman et al. 2007  
cf. Houlahan & Scalo 1992)

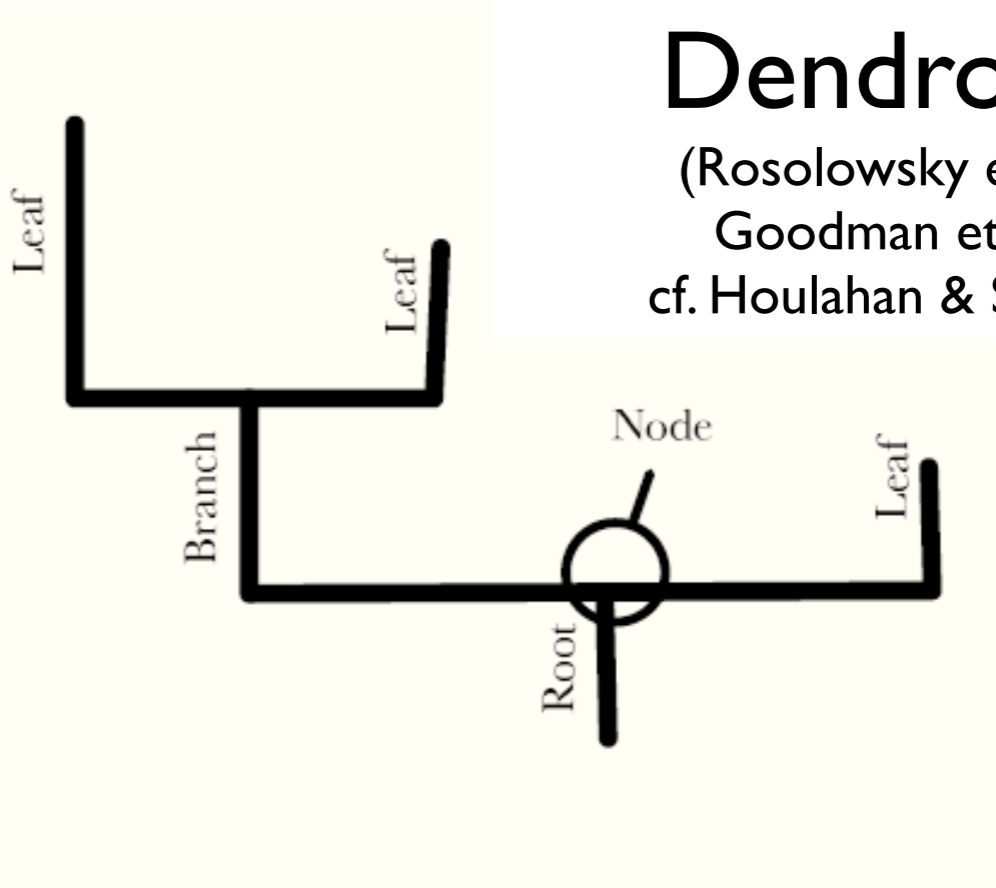
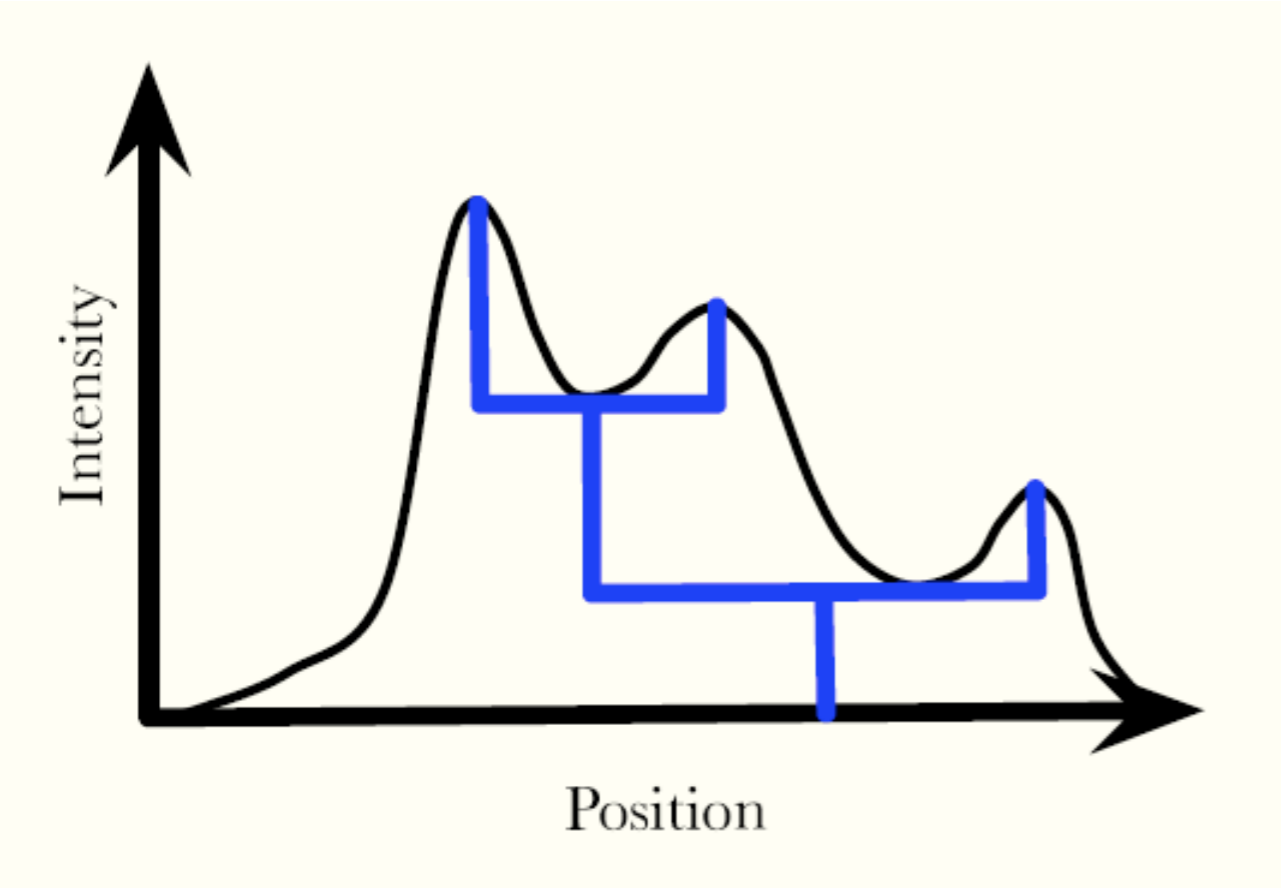


## CLUMPFIND

(Williams et al. 1994)

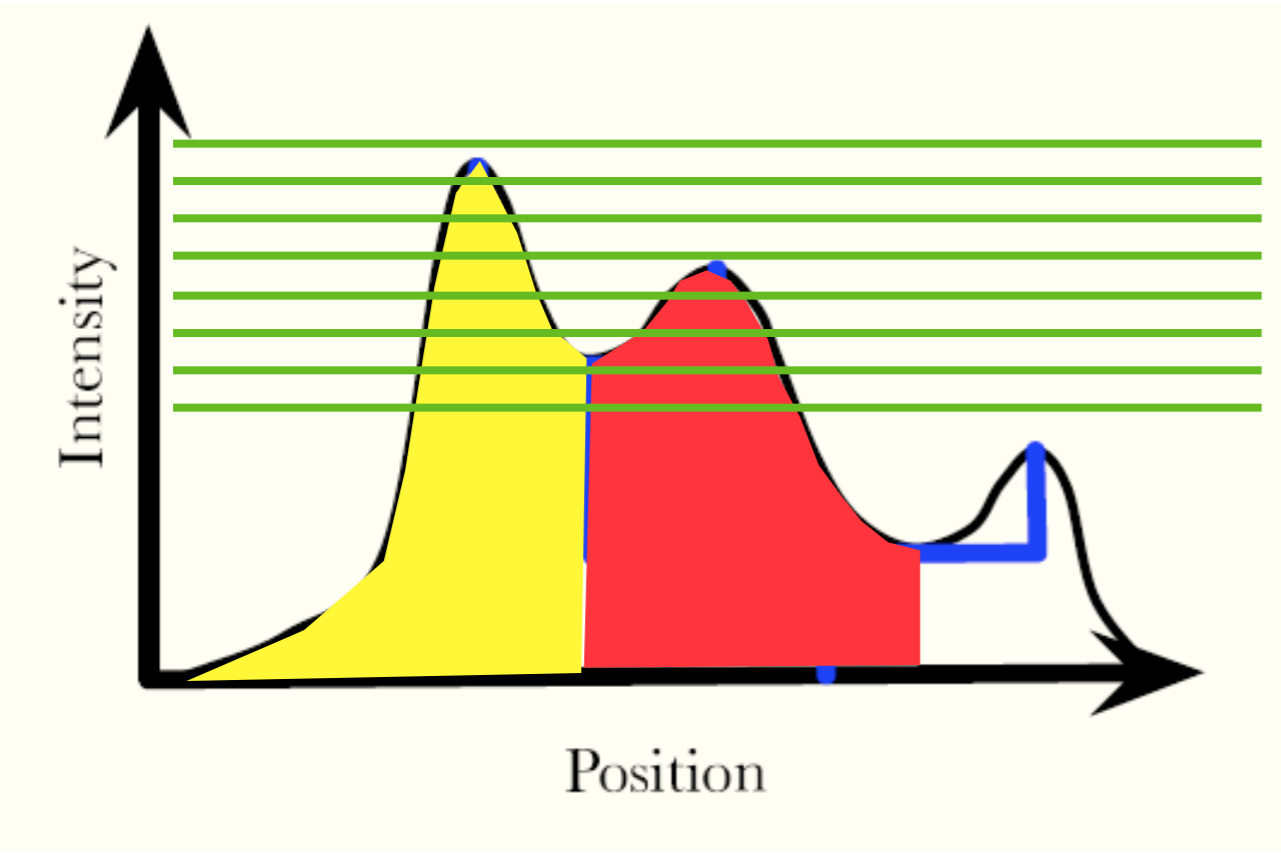


# Dendrograms (Hierarchical) vs. CLUMPFIND (Non-hierarchical)



## Dendrogram

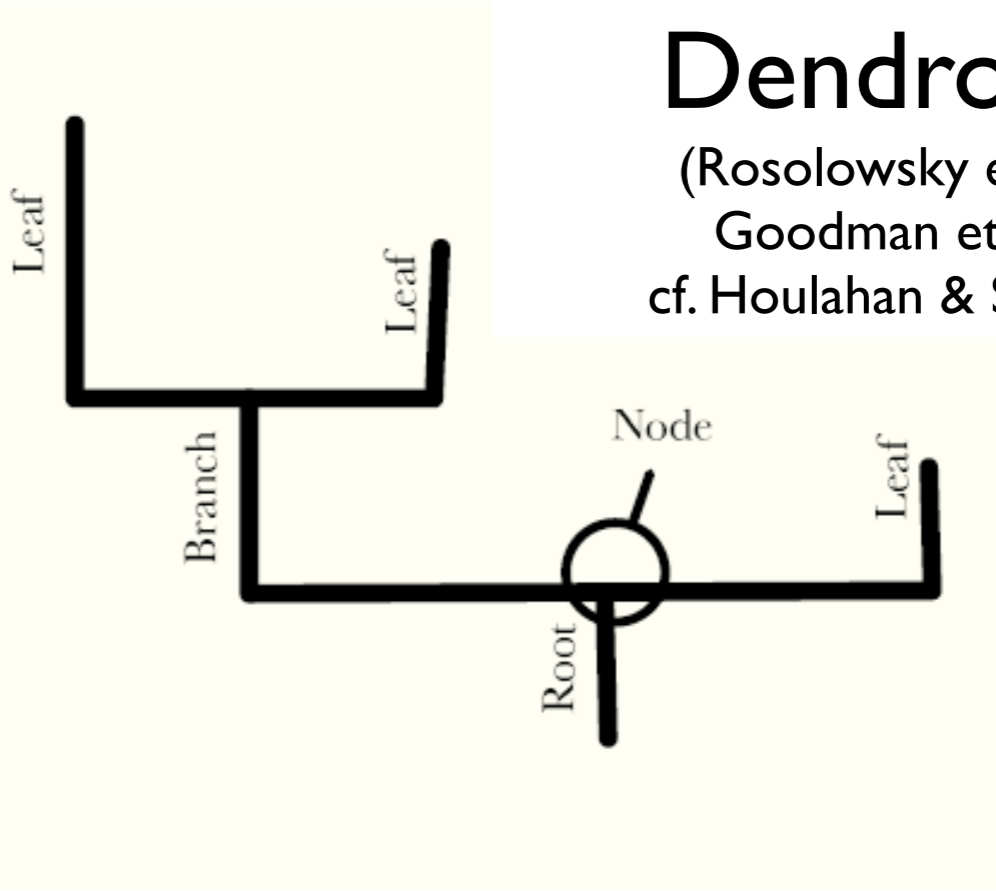
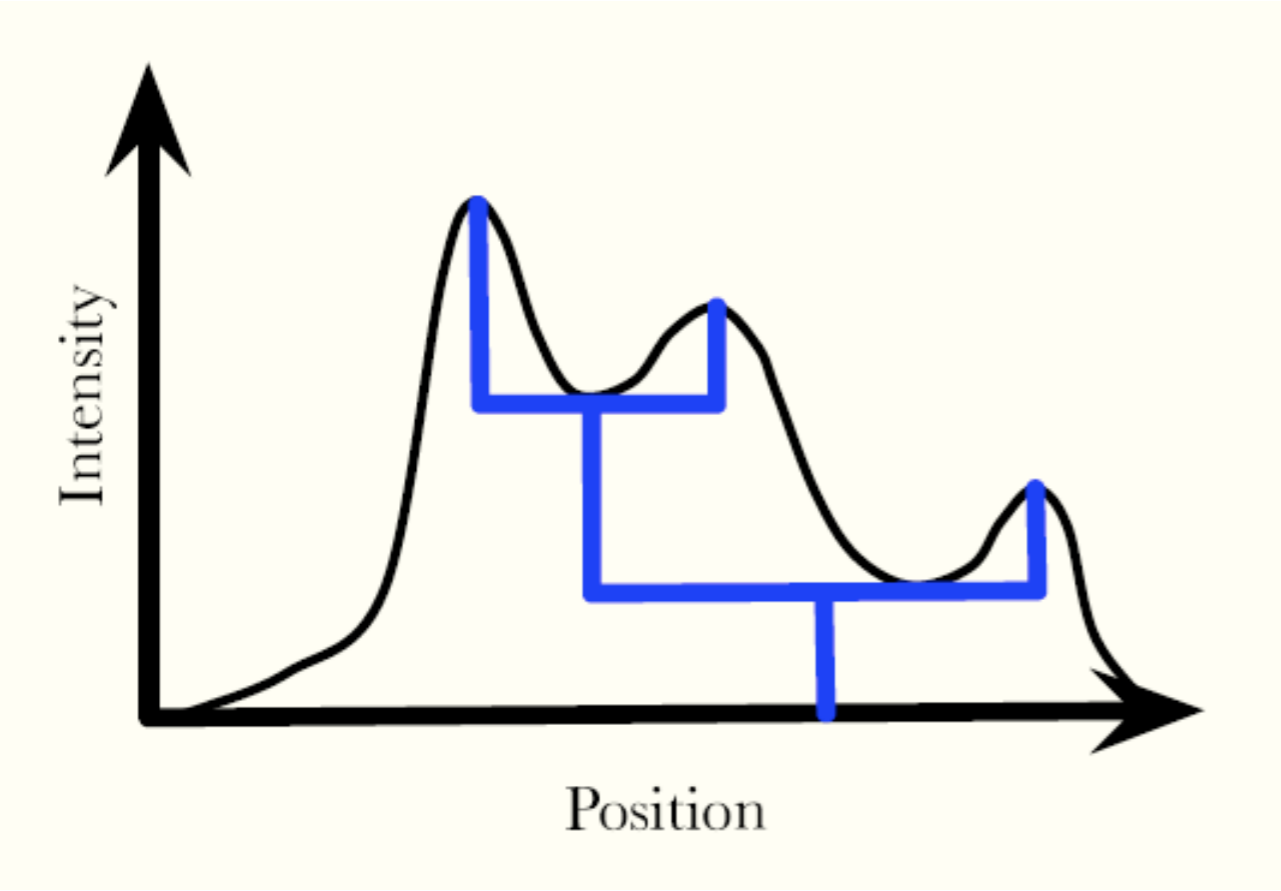
(Rosolowsky et al. 2007;  
Goodman et al. 2007  
cf. Houlahan & Scalo 1992)



## CLUMPFIND

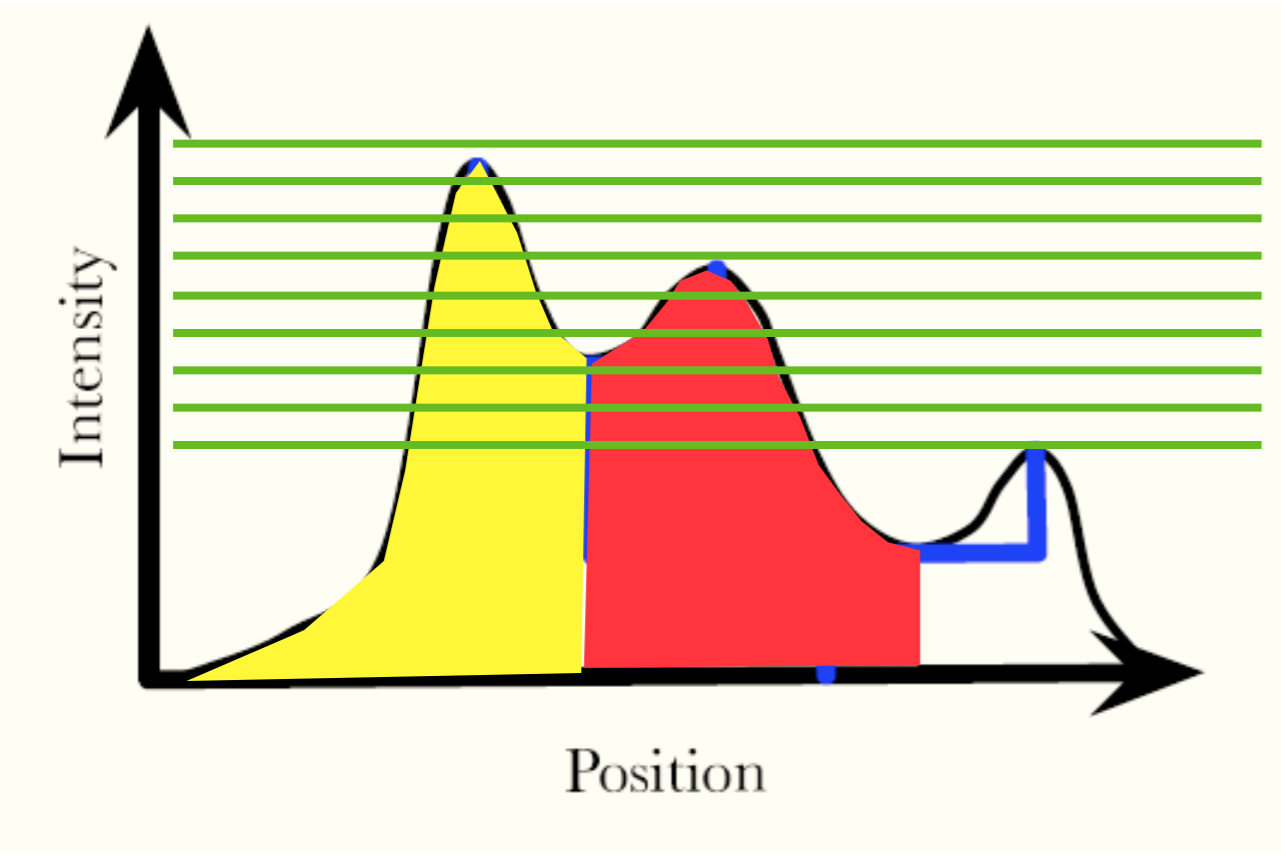
(Williams et al. 1994)

# Dendrograms (Hierarchical) vs. CLUMPFIND (Non-hierarchical)



## Dendrogram

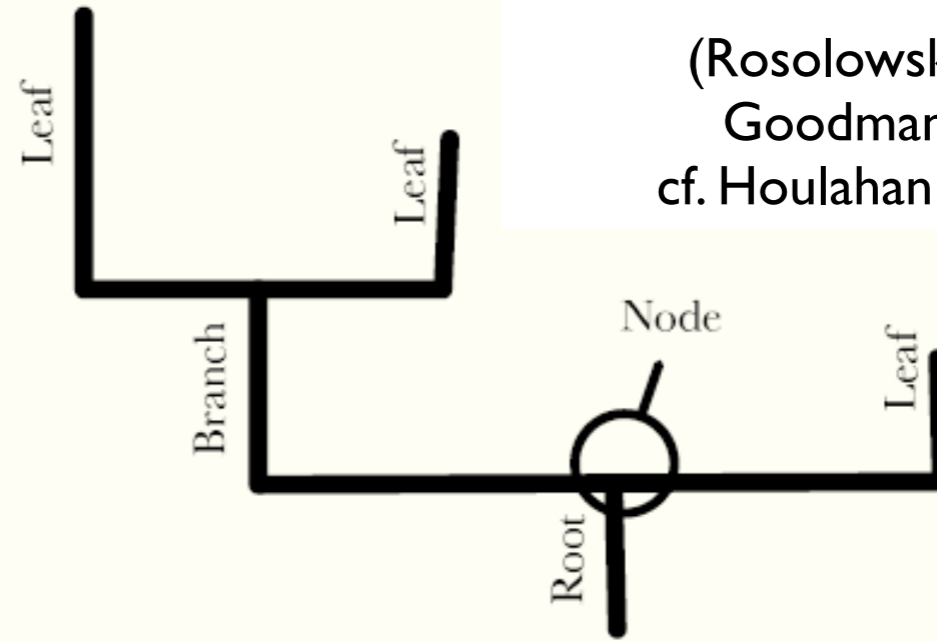
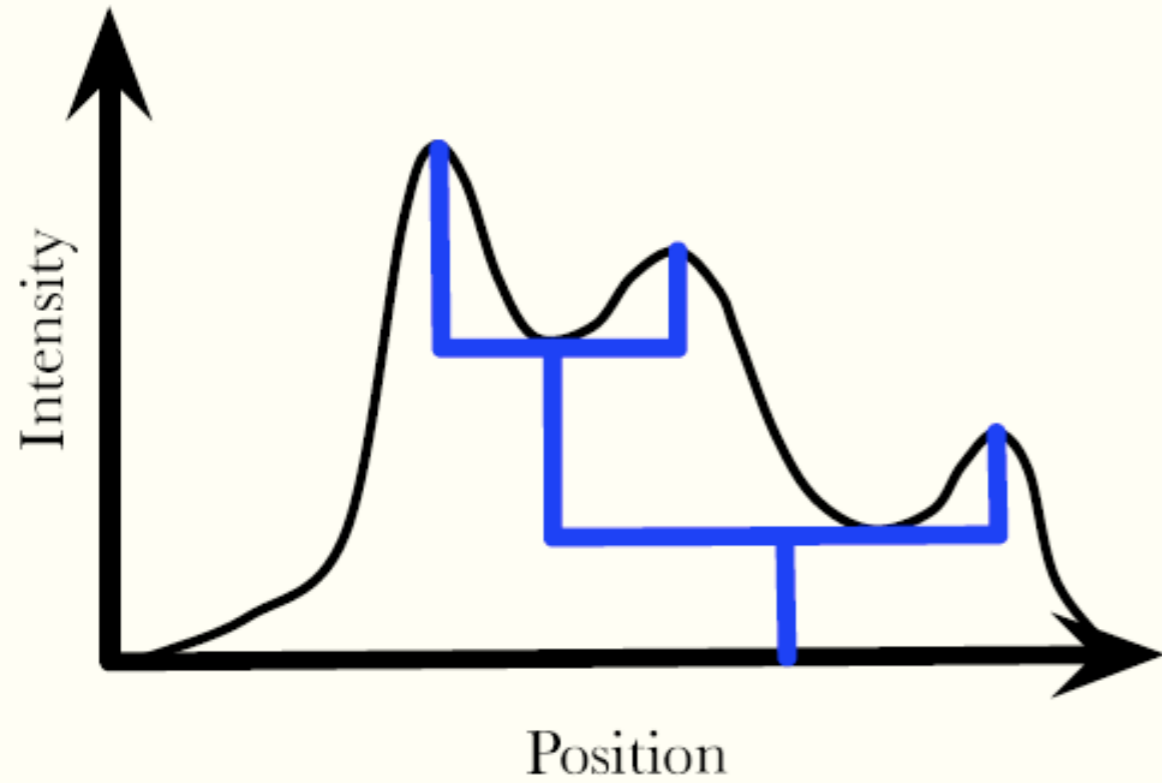
(Rosolowsky et al. 2007;  
Goodman et al. 2007  
cf. Houlahan & Scalo 1992)



## CLUMPFIND

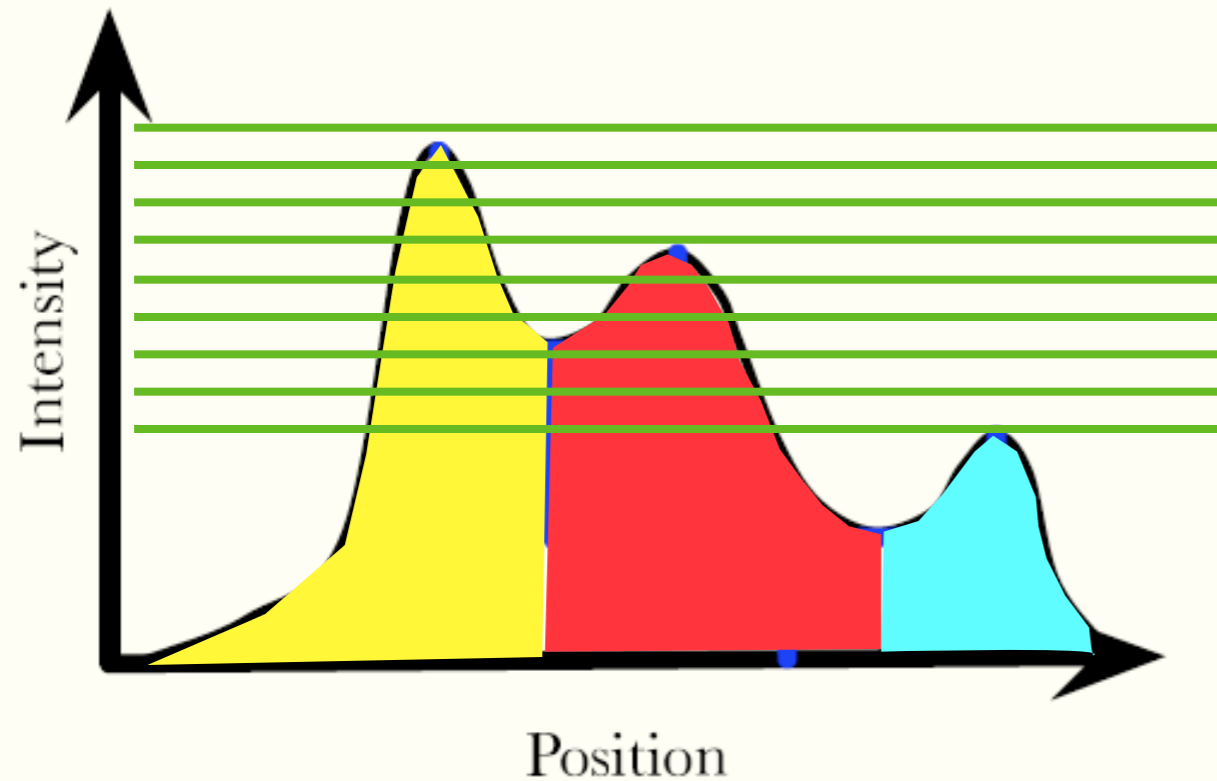
(Williams et al. 1994)

# Dendrograms (Hierarchical) vs. CLUMPFIND (Non-hierarchical)



## Dendrogram

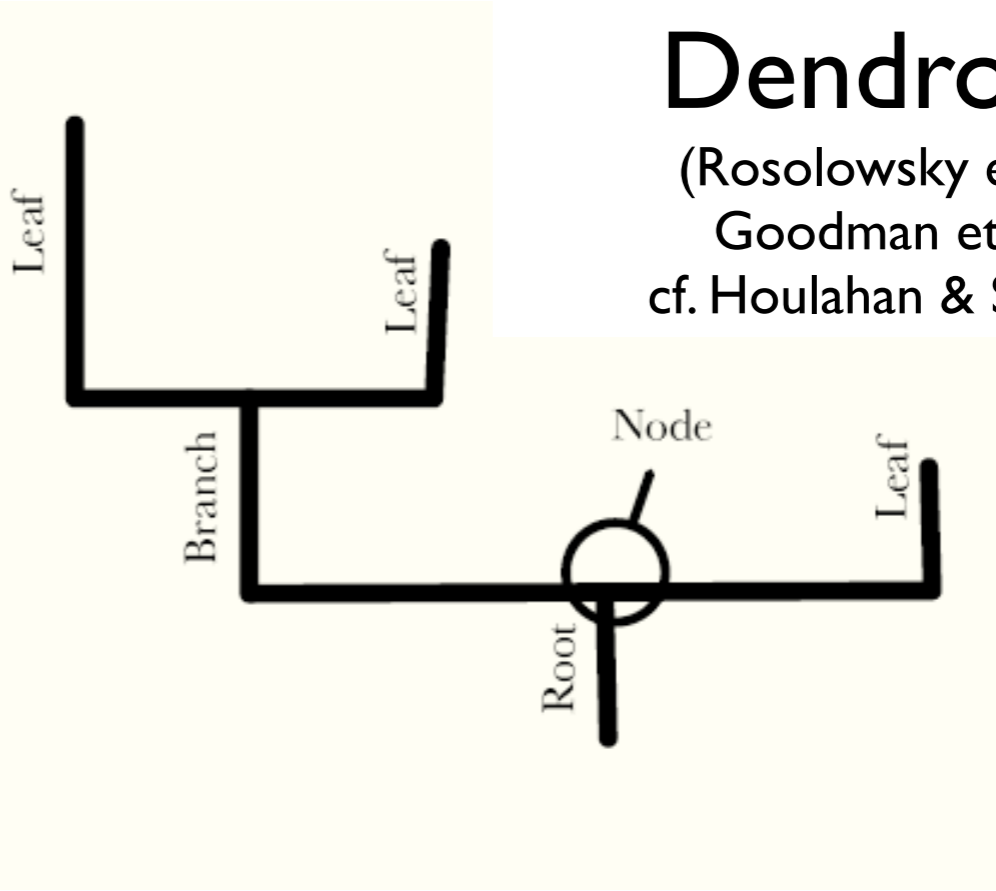
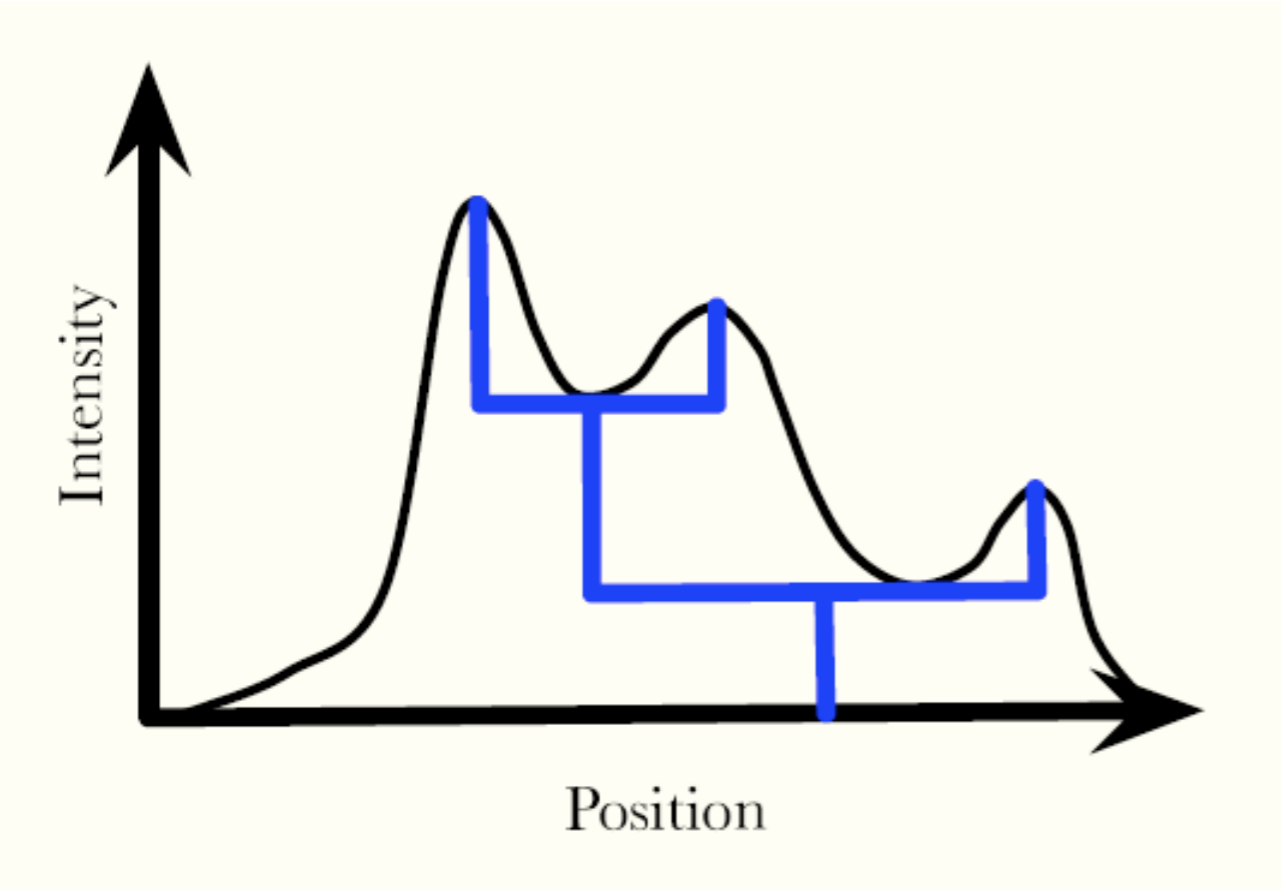
(Rosolowsky et al. 2007;  
Goodman et al. 2007  
cf. Houlahan & Scalo 1992)



## CLUMPFIND

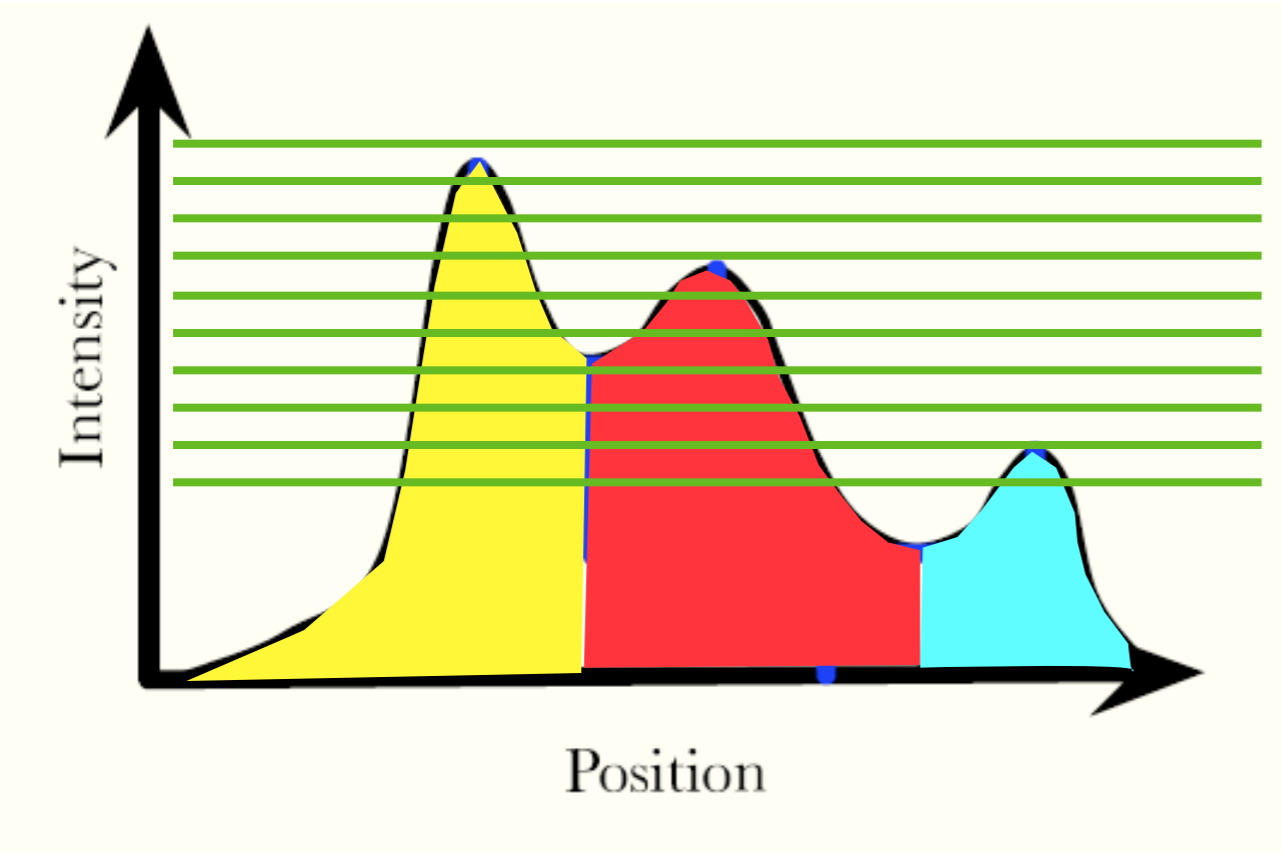
(Williams et al. 1994)

# Dendrograms (Hierarchical) vs. CLUMPFIND (Non-hierarchical)



## Dendrogram

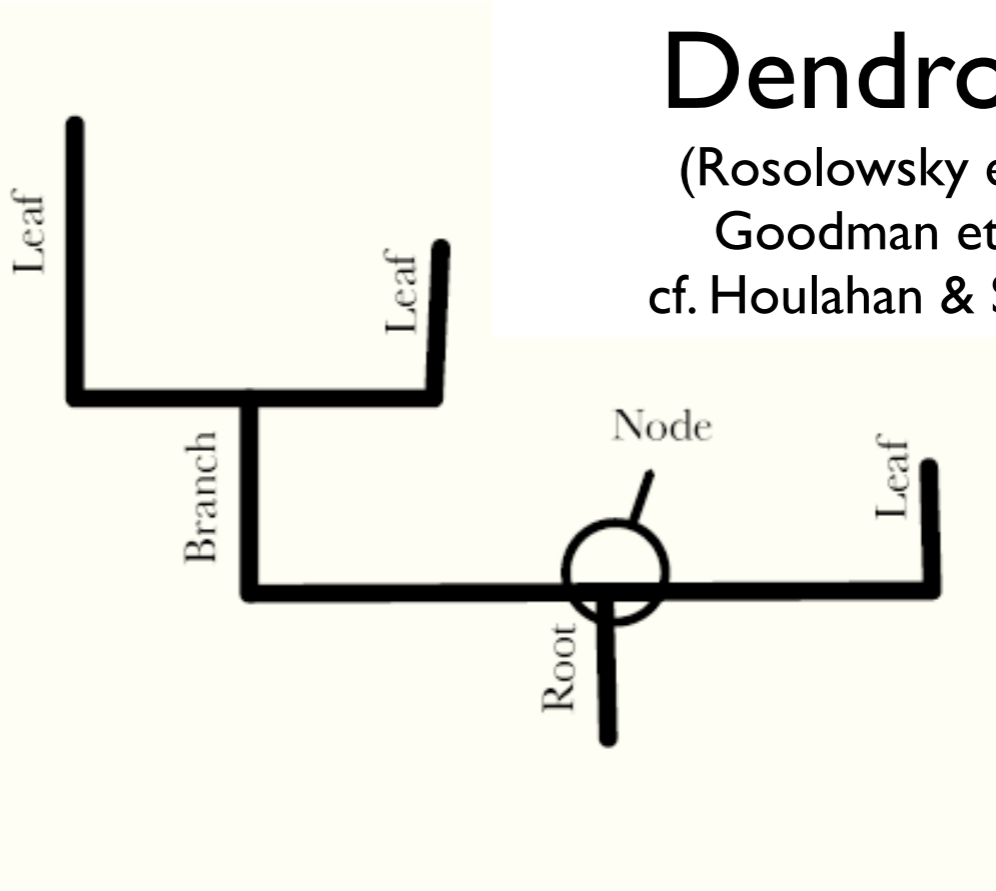
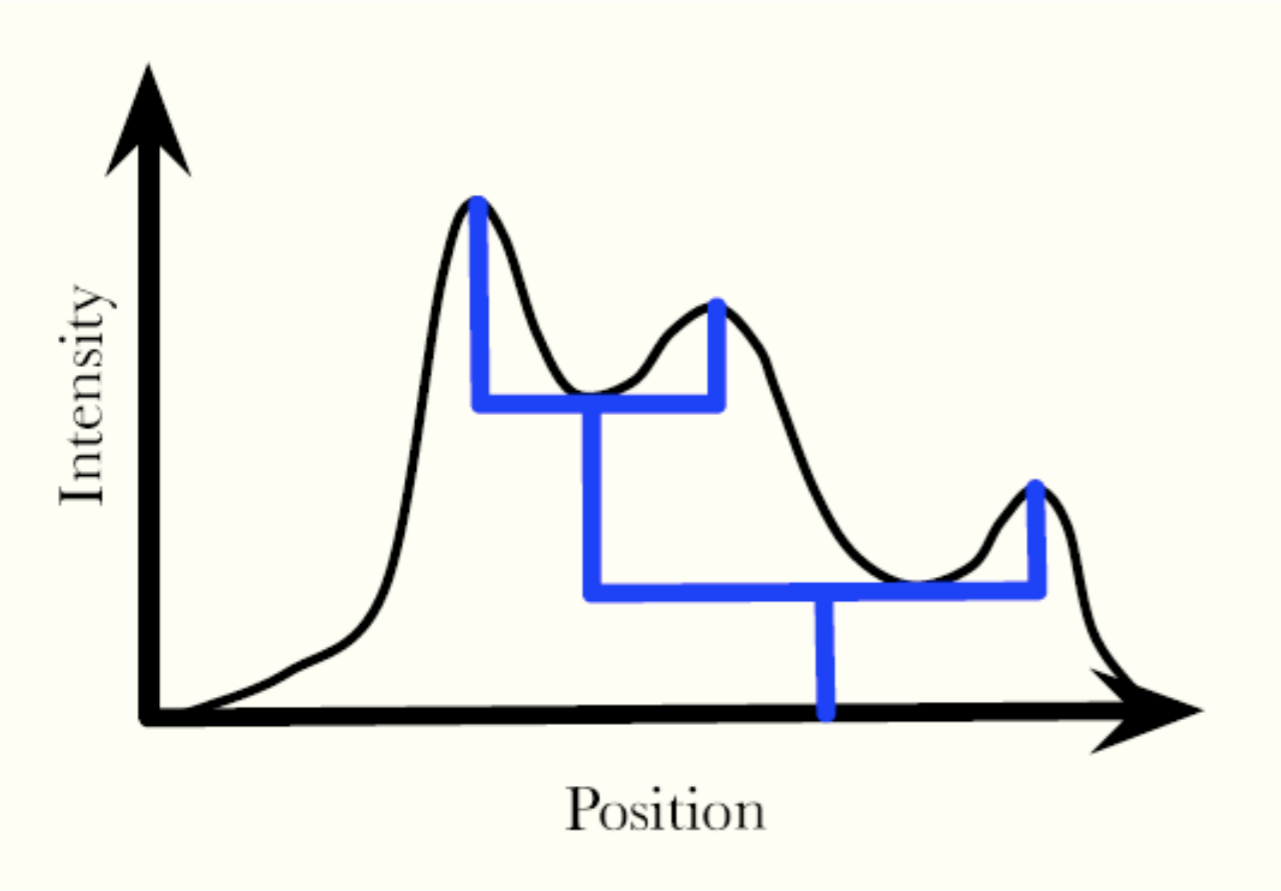
(Rosolowsky et al. 2007;  
Goodman et al. 2007  
cf. Houlahan & Scalo 1992)



## CLUMPFIND

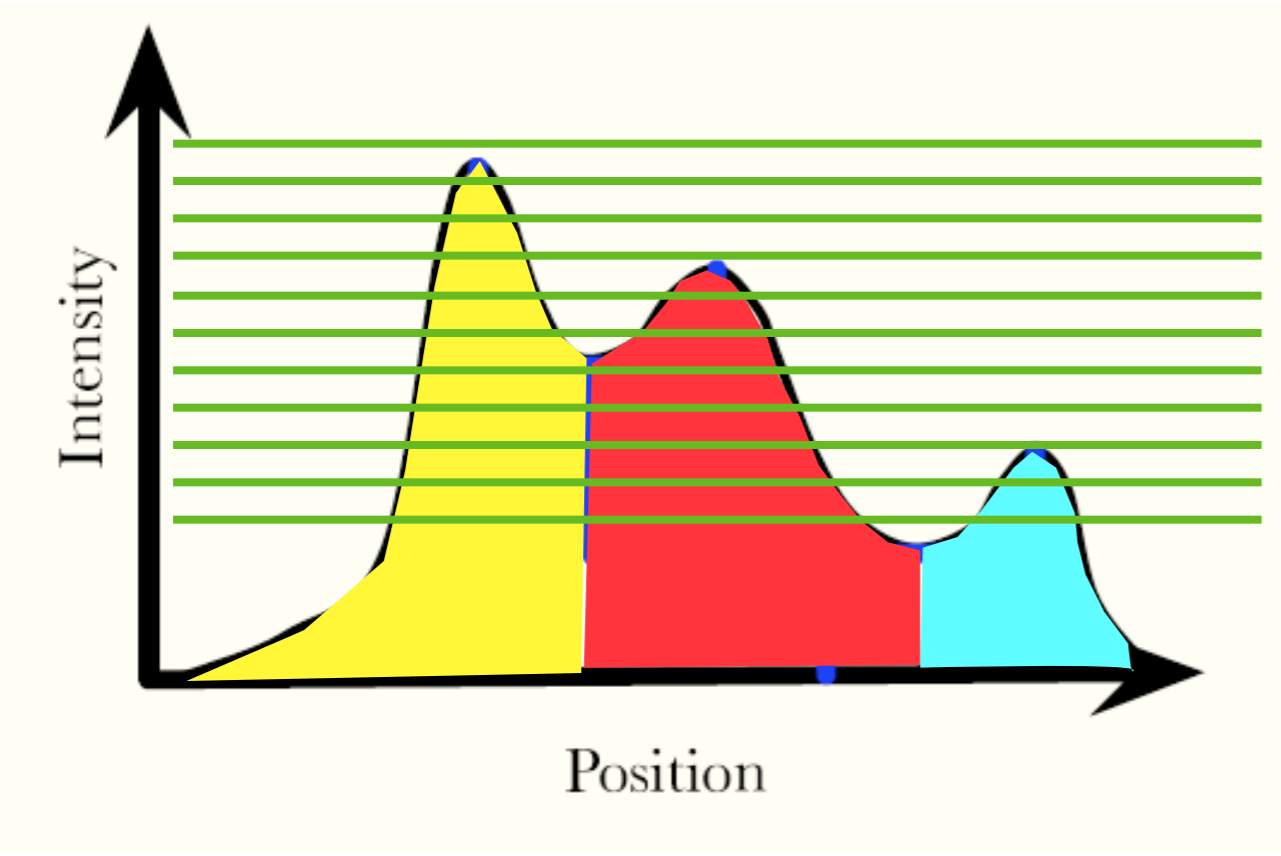
(Williams et al. 1994)

# Dendrograms (Hierarchical) vs. CLUMPFIND (Non-hierarchical)



## Dendrogram

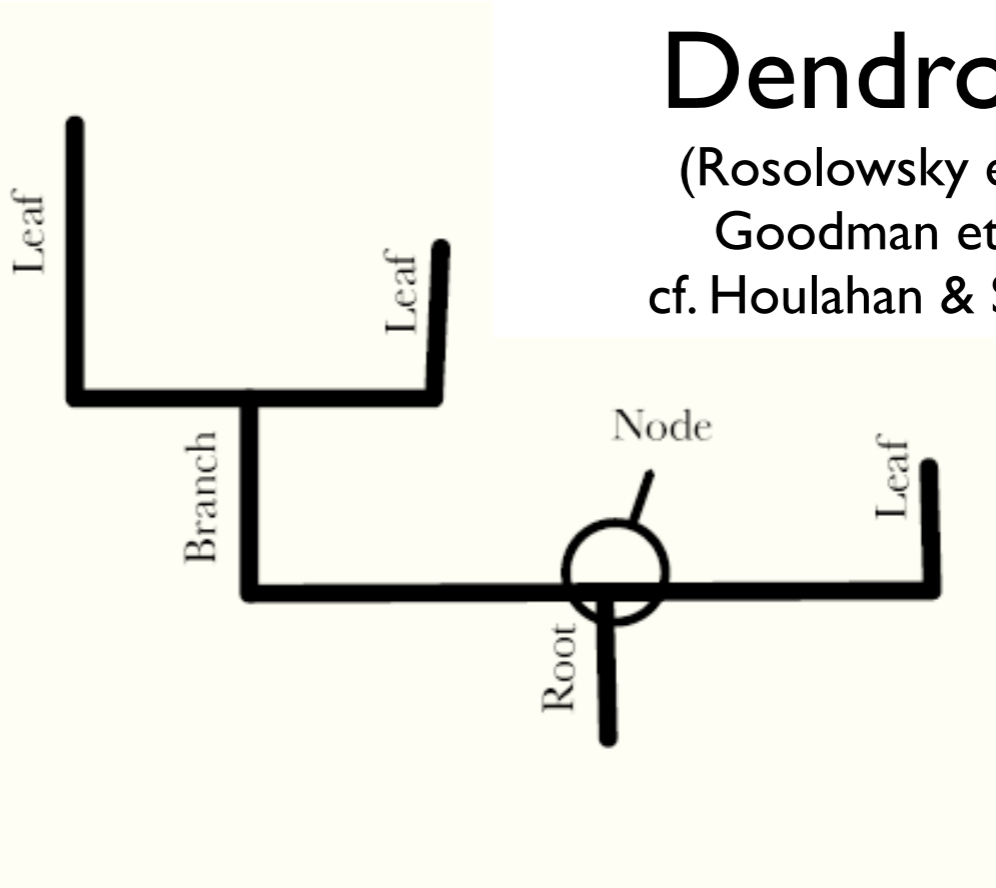
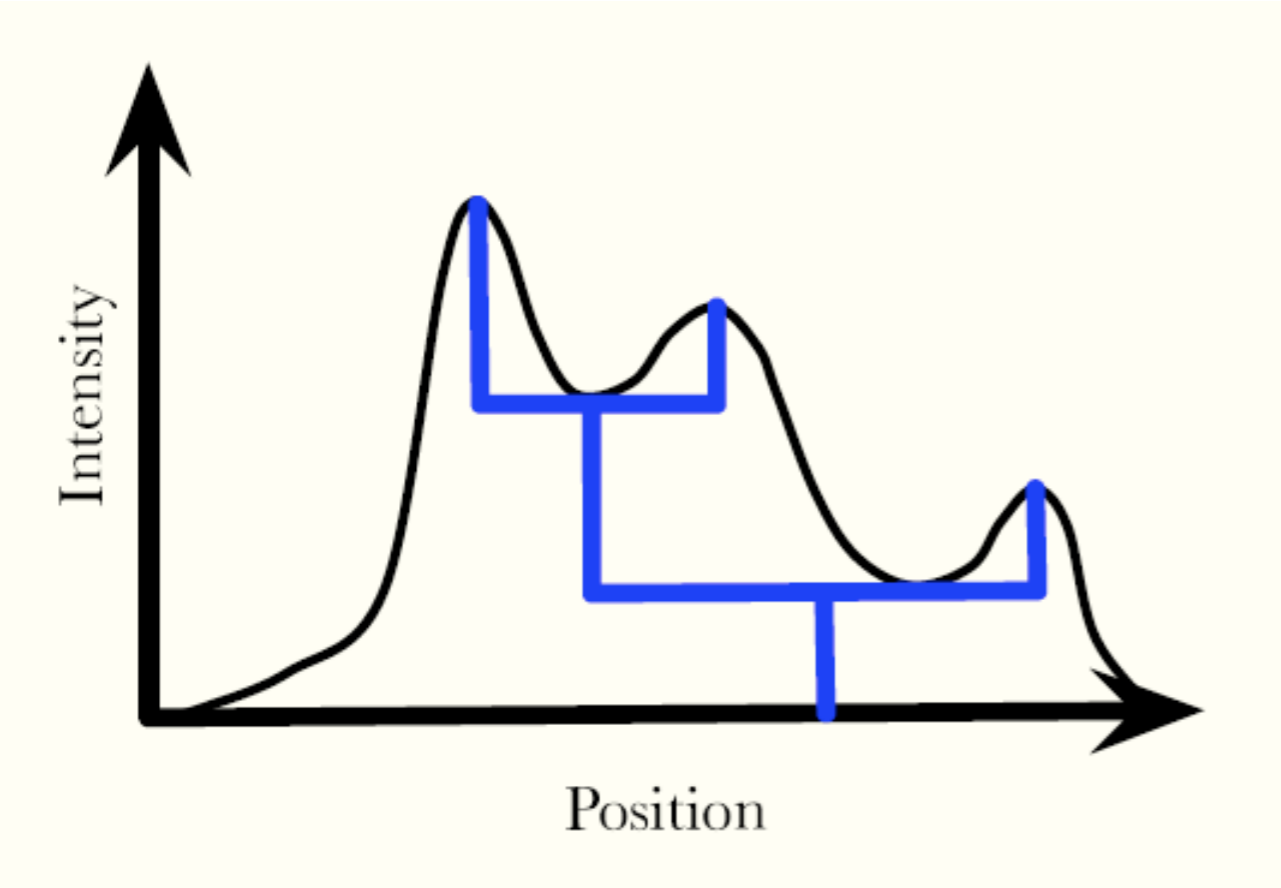
(Rosolowsky et al. 2007;  
Goodman et al. 2007  
cf. Houlahan & Scalo 1992)



## CLUMPFIND

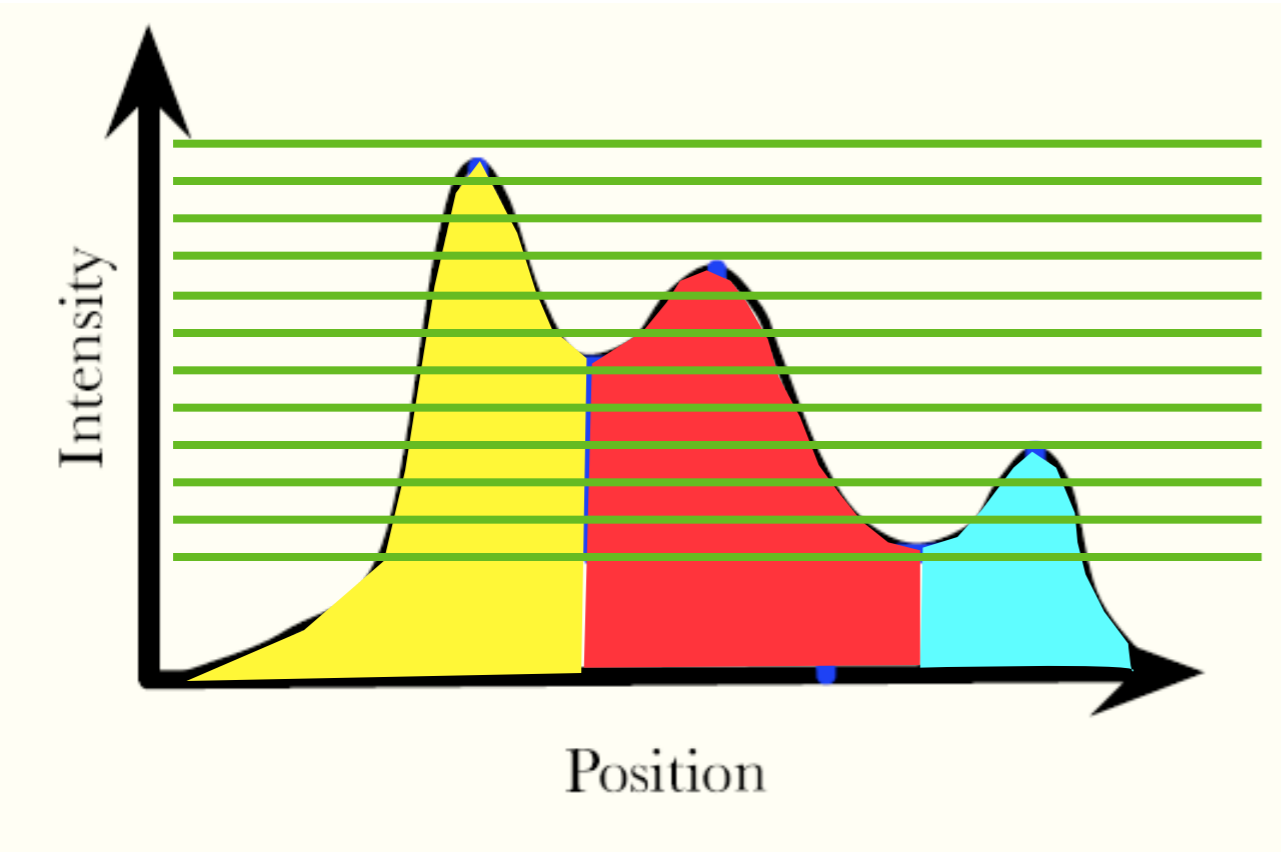
(Williams et al. 1994)

# Dendrograms (Hierarchical) vs. CLUMPFIND (Non-hierarchical)



## Dendrogram

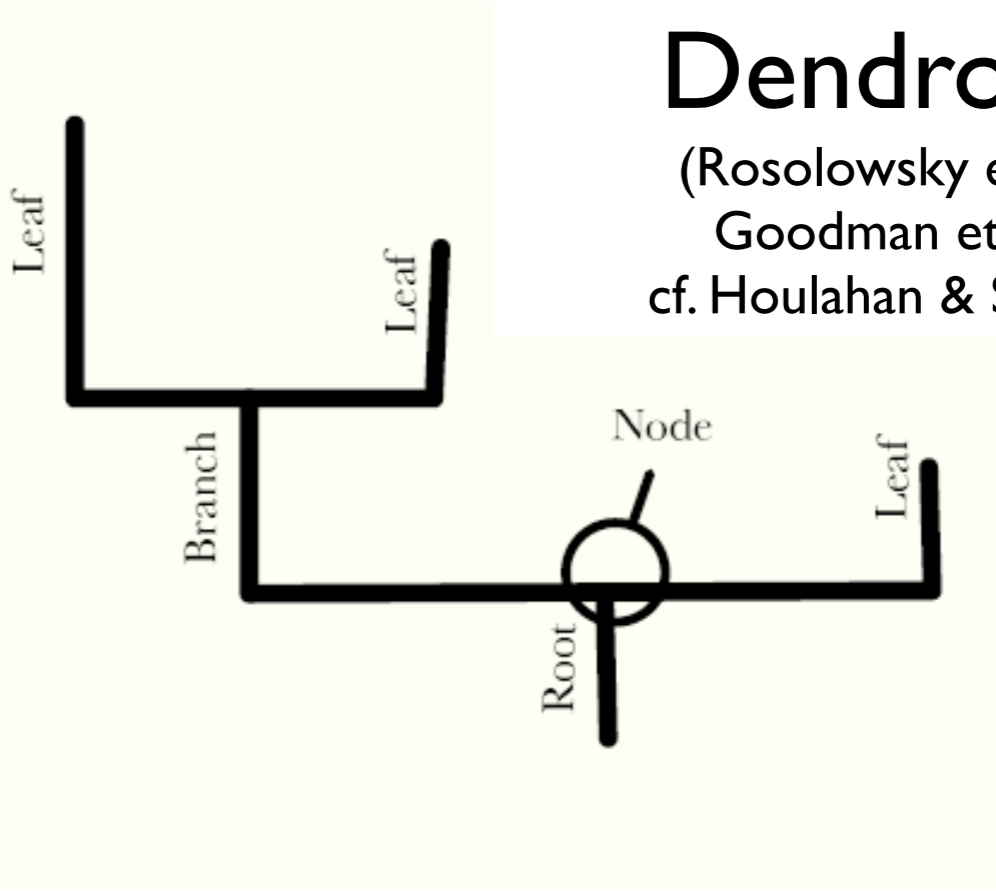
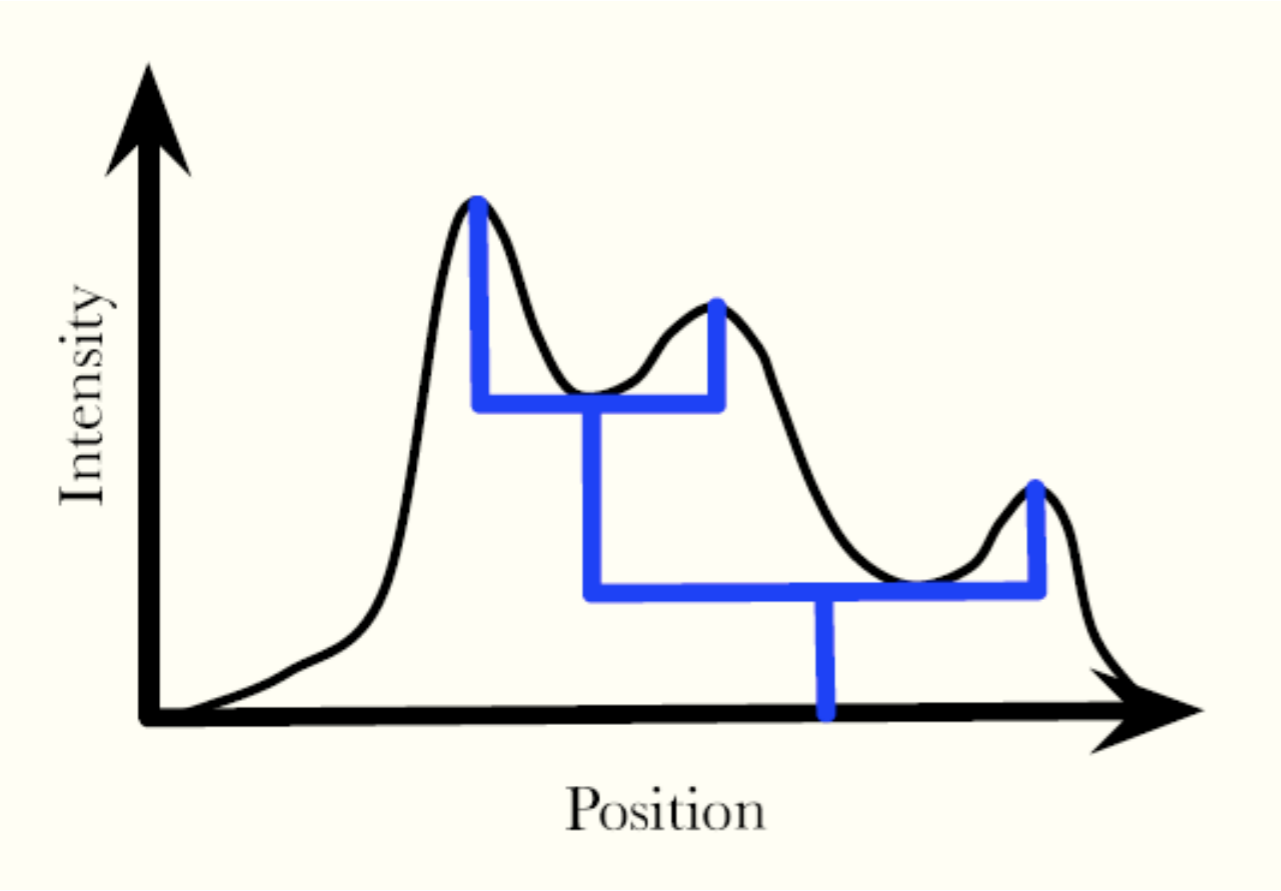
(Rosolowsky et al. 2007;  
Goodman et al. 2007  
cf. Houlahan & Scalo 1992)



## CLUMPFIND

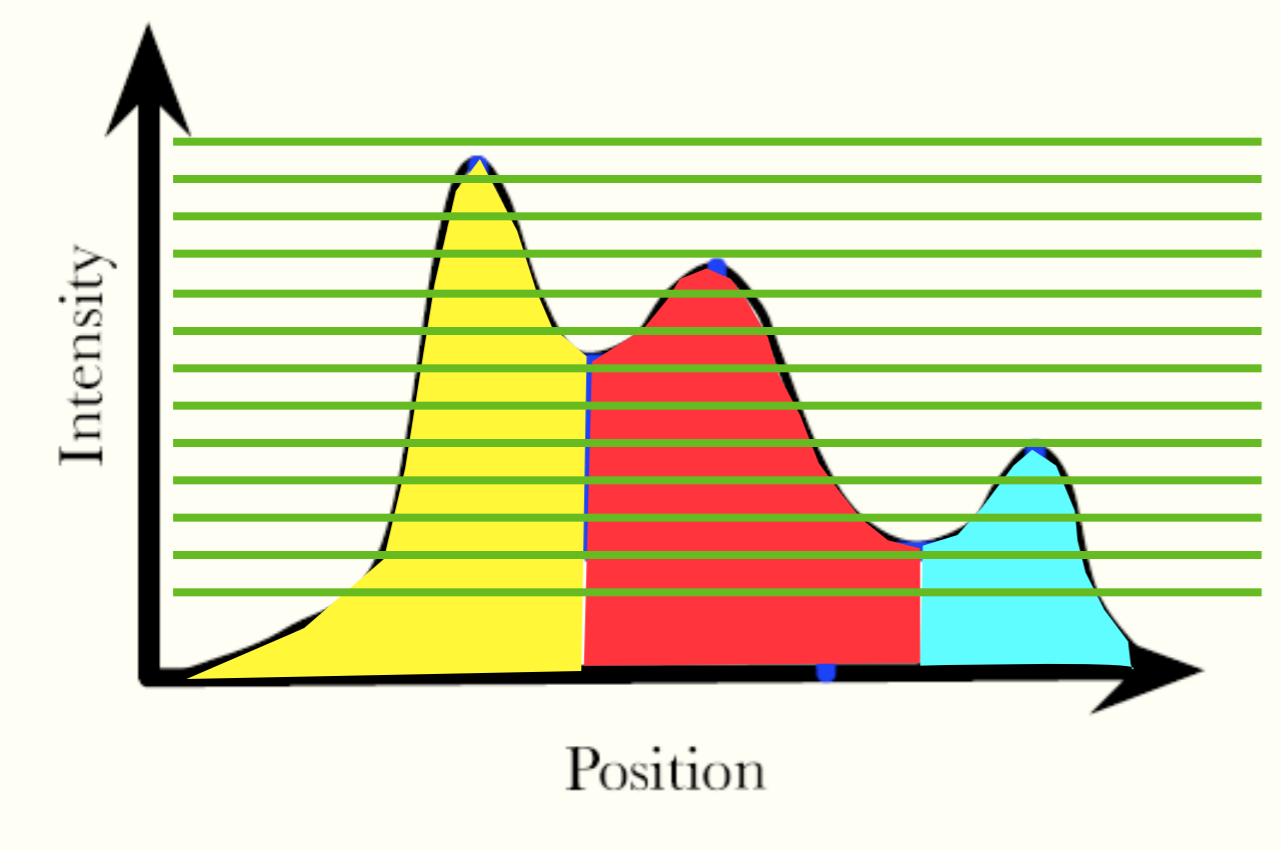
(Williams et al. 1994)

# Dendrograms (Hierarchical) vs. CLUMPFIND (Non-hierarchical)



## Dendrogram

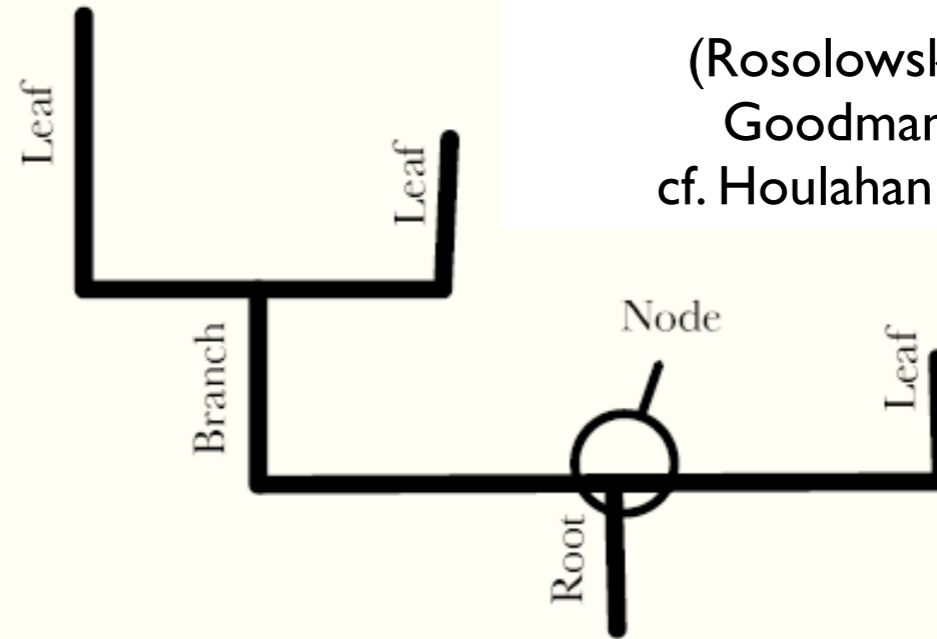
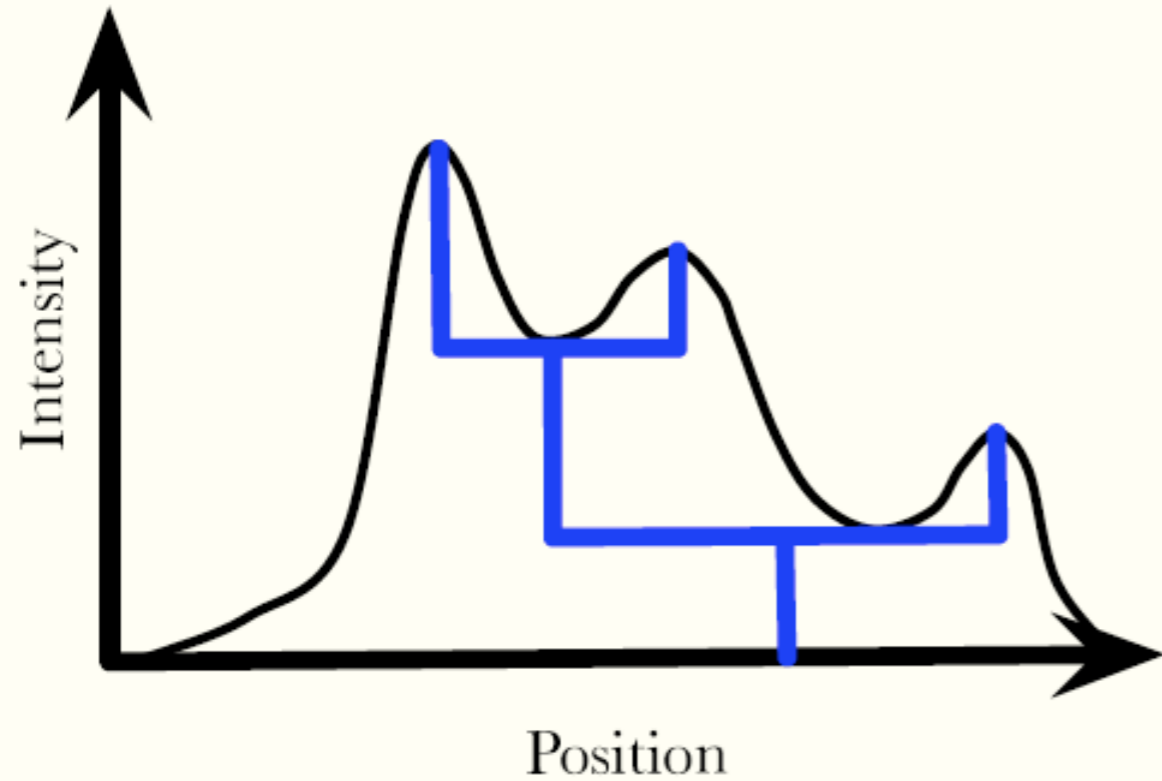
(Rosolowsky et al. 2007;  
Goodman et al. 2007  
cf. Houlahan & Scalo 1992)



## CLUMPFIND

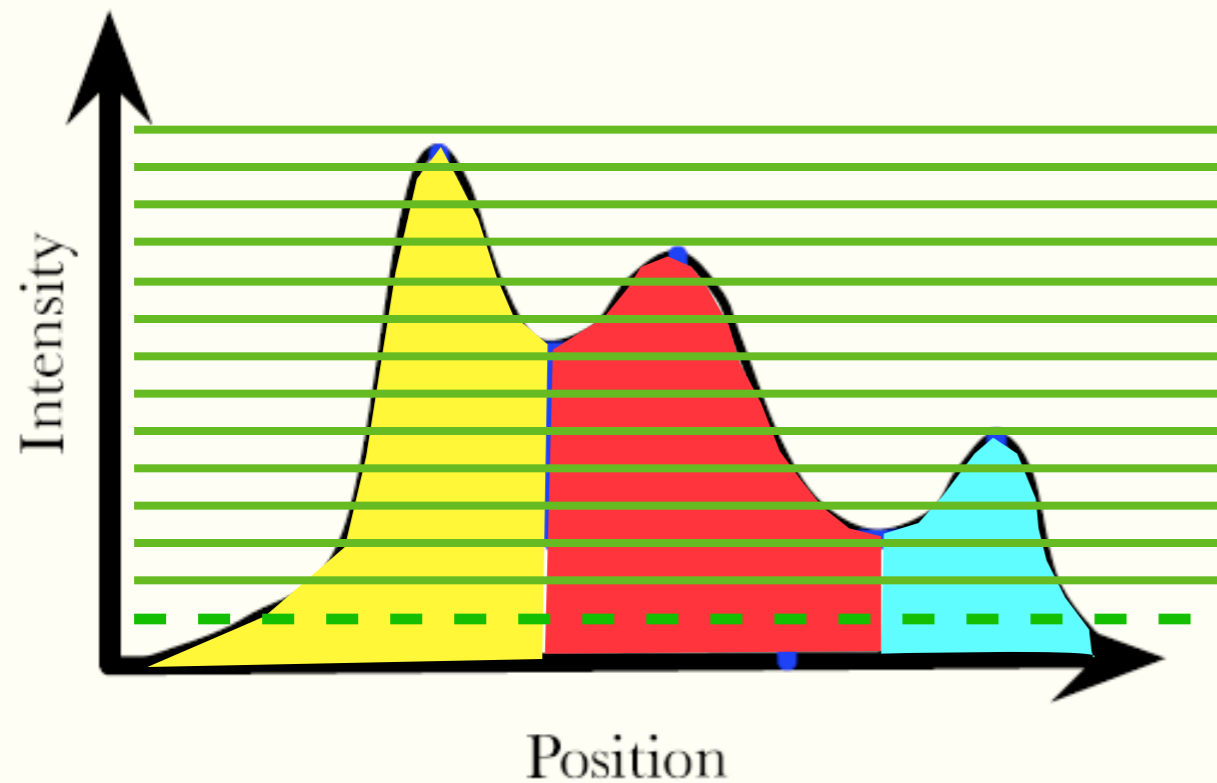
(Williams et al. 1994)

# Dendrograms (Hierarchical) vs. CLUMPFIND (Non-hierarchical)



## Dendrogram

(Rosolowsky et al. 2007;  
Goodman et al. 2007  
cf. Houlahan & Scalo 1992)

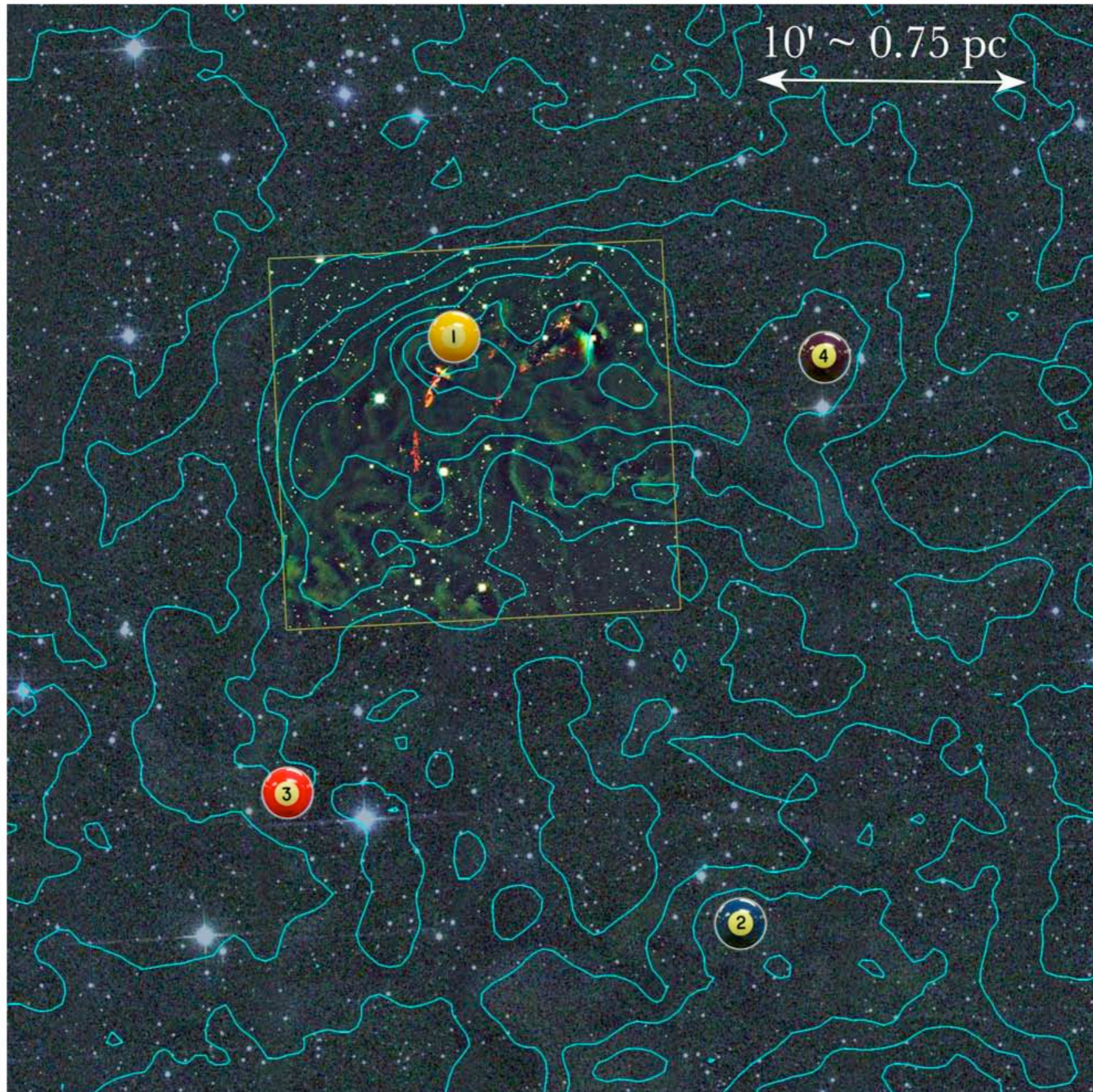


## CLUMPFIND

(Williams et al. 1994)

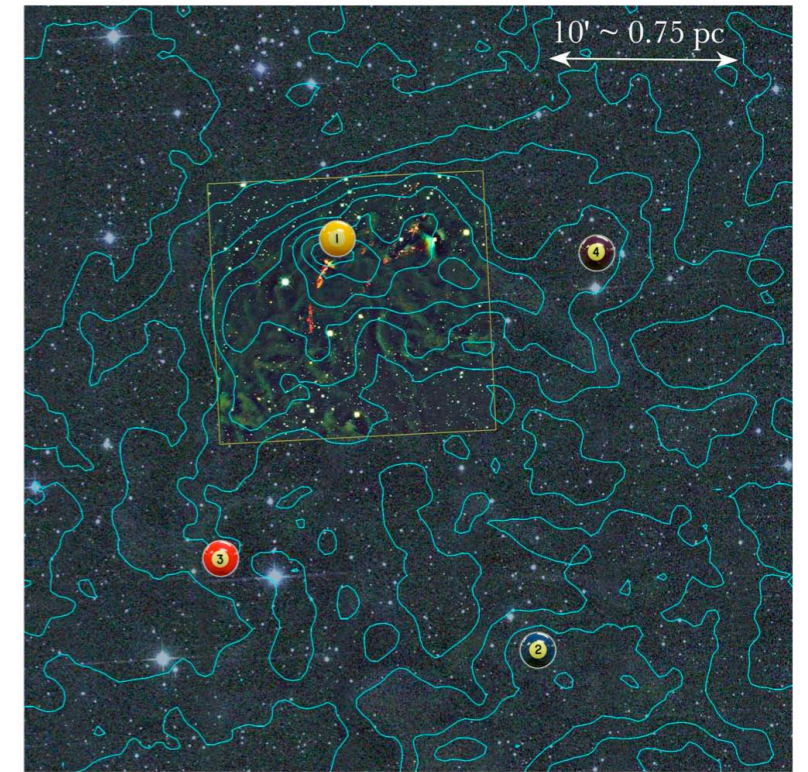
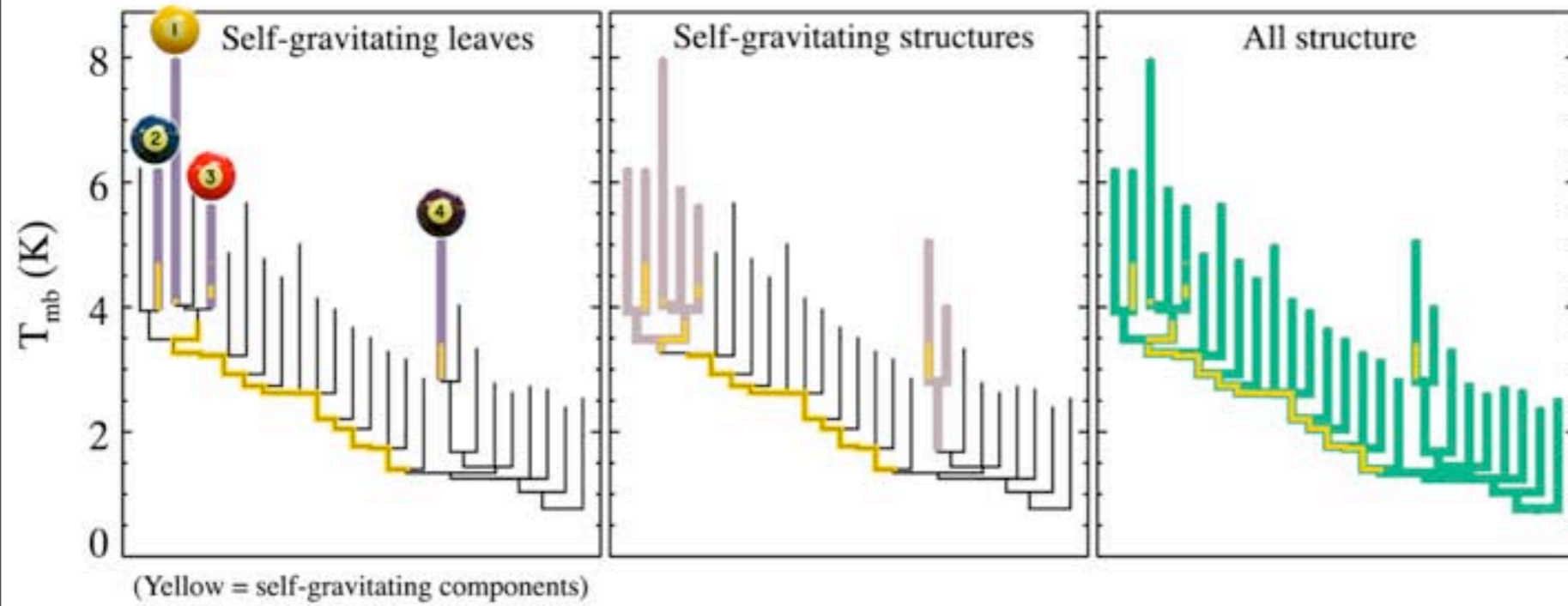



# 2D View of L1448: Cloudshine + Integrated $^{13}\text{CO}$

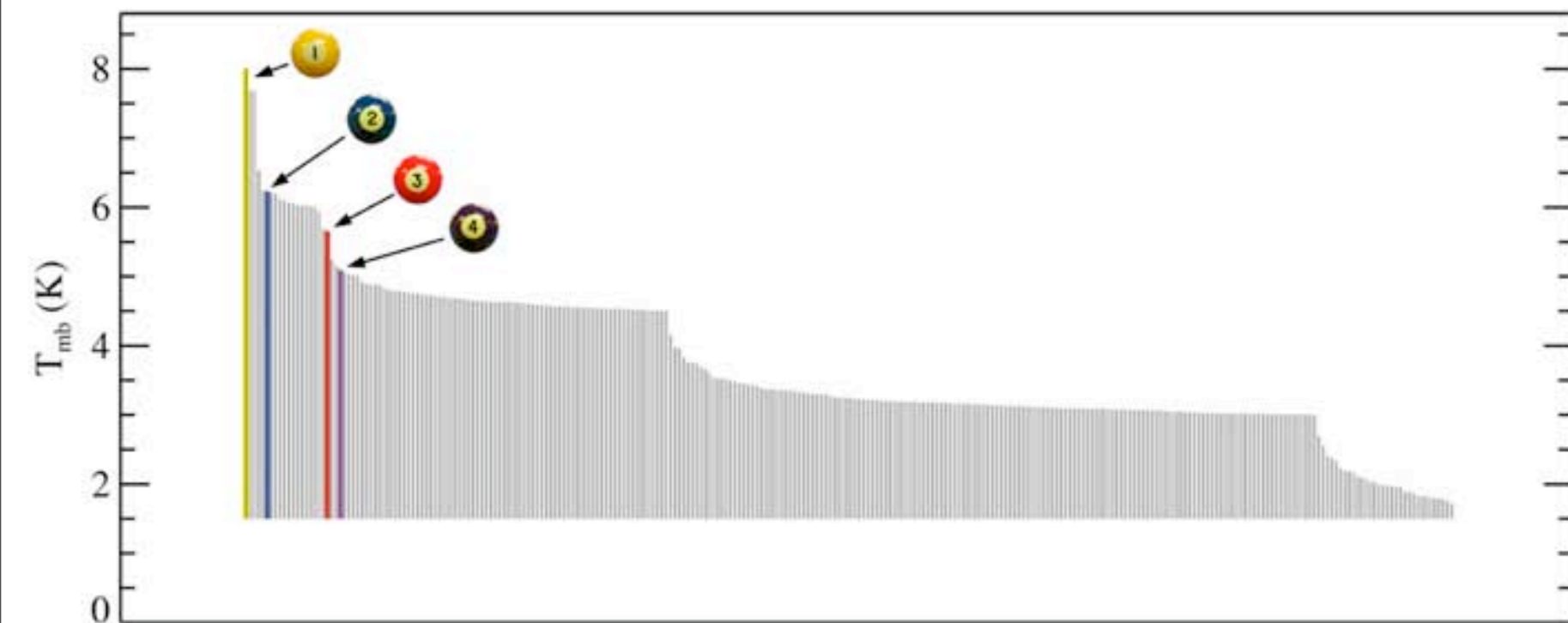


*Foster & Goodman 2006; Goodman et al. 2007*

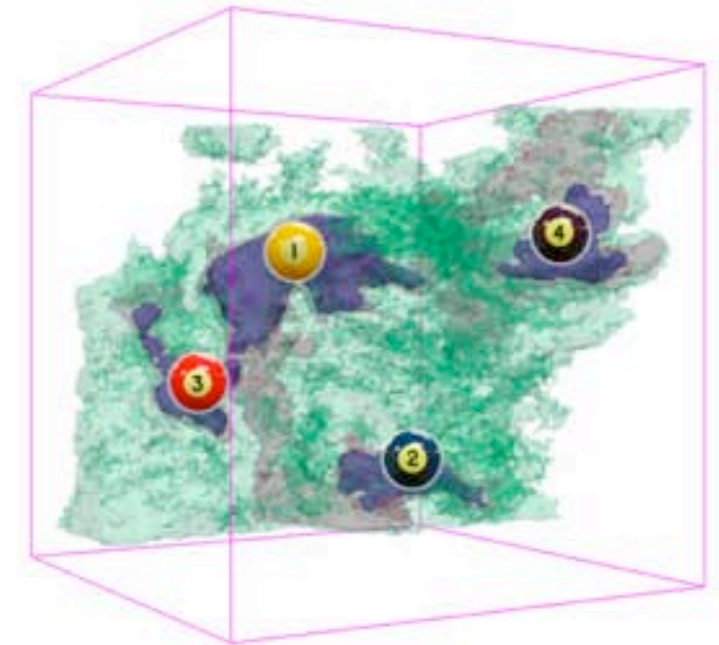
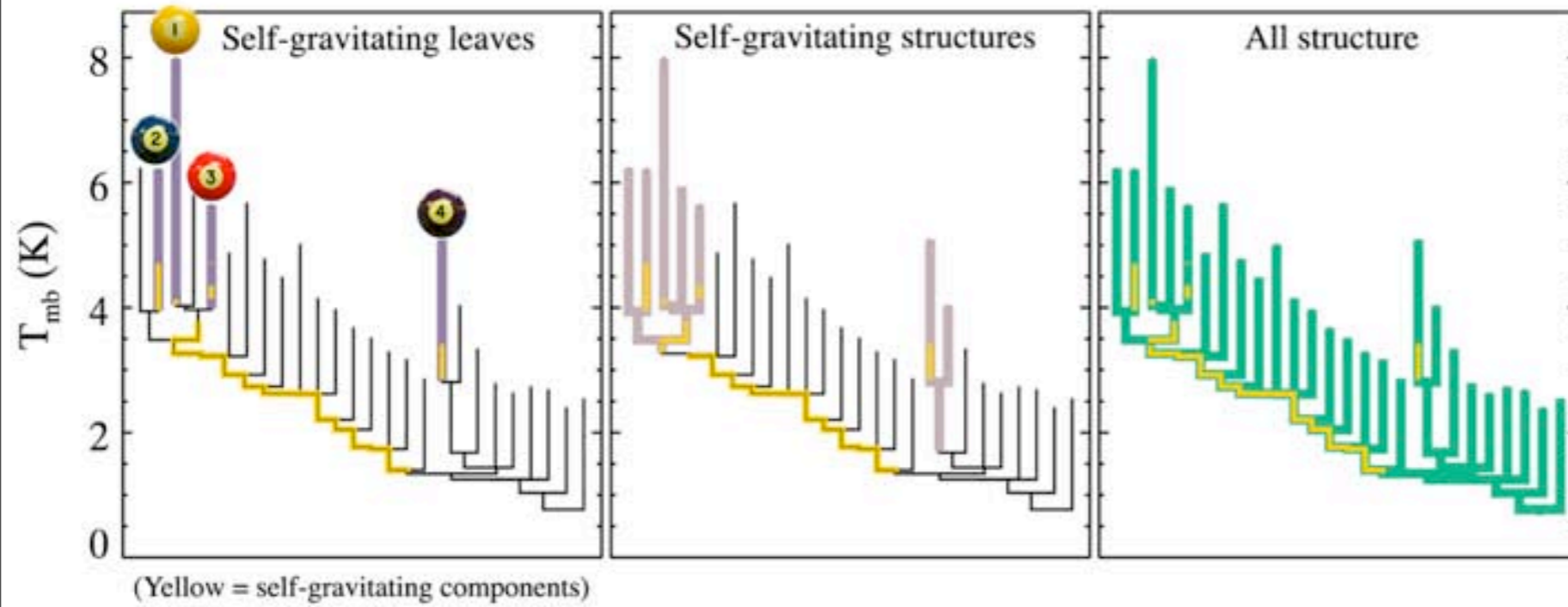
# Dendrograms (Hierarchical) vs. CLUMPFIND (Non-hierarchical)



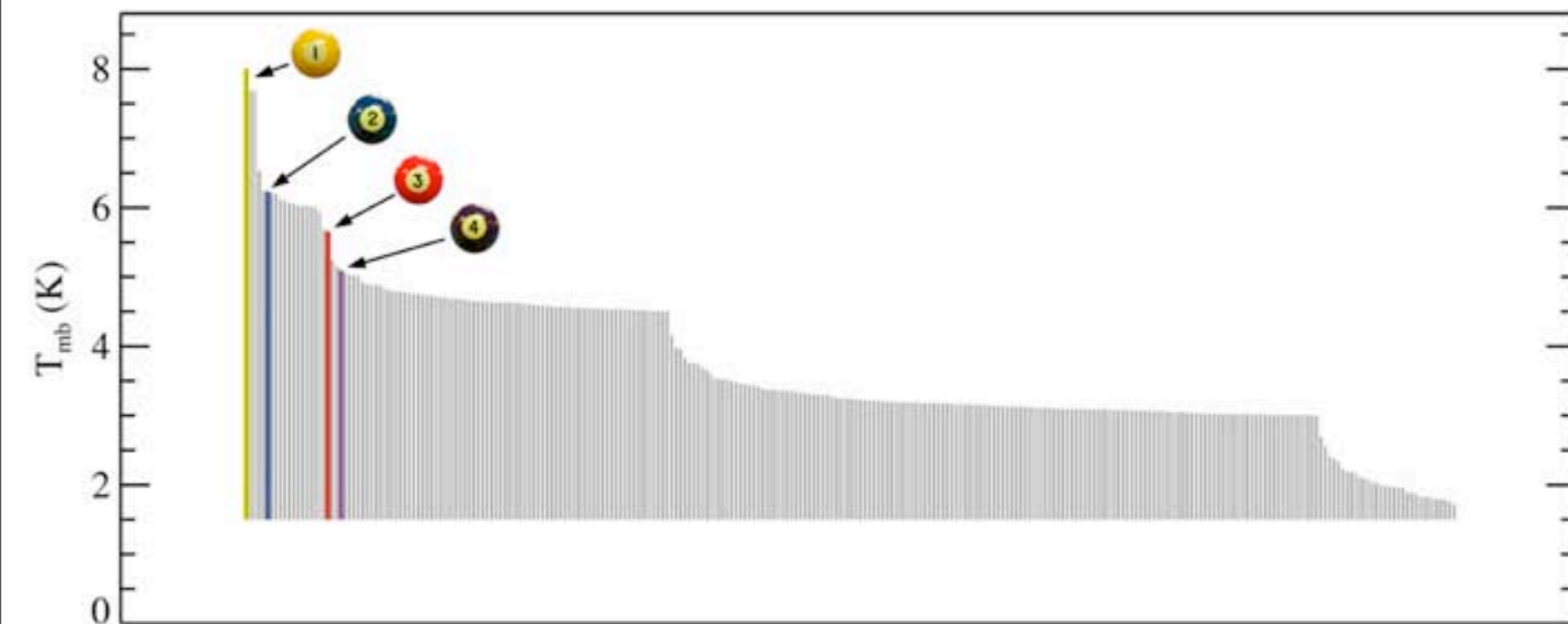
 The online PDFs of these insets are interactive, and can be rotated and manipulated by the viewer.



# Dendrograms (Hierarchical) vs. CLUMPFIND (Non-hierarchical)



*i* The online PDFs of these insets are interactive, and can be rotated and manipulated by the viewer.



And, coming soon, to a cookbook (Journal) near you... (3D PDF)

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Sticky Note Text Edits 66.7% Find

Model Tree

- node #-1
  - Group
    - outer contour
    - Drawings
    - Vectorized Layer

Options

- Sky Plane
- Left
- Top
- Front
- Right
- Bottom

Property

- Number of Lights
- Number of Children
- Number of Vertices
- Number of Faces
- Number of Textures
- Bounding Box Dimensions (Mete

structures, but also many odd features corresponding to dimples on the surfaces of larger ones.

So, in a simple picture of star formation, where one "clump" lasts a long time, and forms one star, it makes sense to think about breaking up the cloud into non-overlapping volumes and creating a "clump mass spectrum" from the result. But, in a turbulent picture, where hierarchical structure pervades the cloud and structures are transient, it seems foolhardy to break up the full volume of the cloud into non-overlapping clumps. The analysis is further complicated by the aforementioned 2 spatial-1 velocity dimension nature of the observational data. Segmentation based analysis algorithms typically ignore this subtlety and operate in three dimensions despite the fact that much of the clumpy structure identified is thought to result from chance superpositions along the line of sight (Ostriker et al). We note that the segmentation of sparse two-dimensional maps via the CLUMPFIND is not as fraught since the standard application of the algorithm in this case is to relatively unblended data for source identification (similar to the standard Source EXtractor algorithm Bertin, E.; Arnouts, S. A&AS 1996).

In this letter, we borrow heavily on techniques used in other fields to show that a novel application of commonly used structure trees (e.g. refs. from NSF proposals) to molecular line data provides a method to characterize the hierarchical structure and the results to identify physically relevant features in the data. While well-developed in other fields such as computer science and computational biology, the application of the tree methodology in astrophysics has been relatively lacking. In cosmological simulations, the merger history of galaxies is frequently parameterized as a function of redshift with a structure tree (e.g. Kauffmann & White, MNRAS 1993). In the field of star formation, Houlahan & Scalo (1990) proposed applying structure trees to extinction maps to characterize their hierarchical structure. Using this as an inspiration, we developed an algorithm that "abstracts" the hierarchical structure of a p-p-v data cube into an easily visualized representation; and then we use this abstraction to identify the structures relevant to star formation in the data.

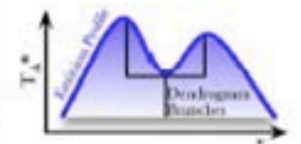
**DENDROGRAMS**

A schematic illustration of the dendrogram process appears, showing the construction of a dendrogram from a hypothetical 1D emission profile (blue). The "dendrogram" (in black) graphically represents the peaks of the emission structure as separate branches. At the highest  $T_{mb}$  value that still spans both peaks, the two branches are connected into a single branch. By repeating this process for every peak of the emission, dendrograms abstract a complete topological description of the emission in a data cube<sup>1</sup>. We construct analogous dendrogram diagrams for 3D data cubes; however, to plot them most clearly in 2D, we flatten them, eliminating any meaningful spatial information on the z-axis.

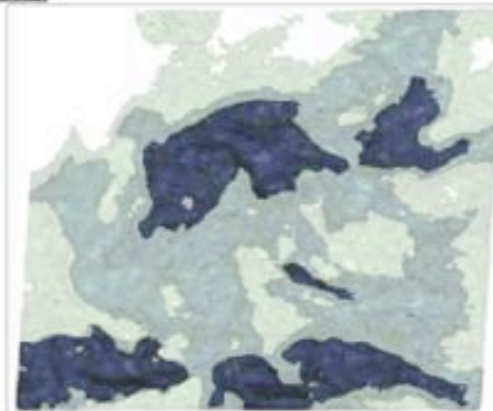
Our new contribution to the dendrogram technique is the calculation physical properties for every object corresponding to a branch in the dendrogram<sup>2</sup>. To determine what features might be important, we calculate a virial parameter as the ratio of kinetic

energy to gravitational binding energy (without external pressures or a magnetic field) for every branch in the dendrogram. We highlight in red every branch that corresponds, in our simplified model, to a self-gravitating object. The standard feature identification algorithms may find the objects at the top branches of the dendrogram trees, since these correspond to the peaks of "clumps," but would be unable to identify objects at the base of the dendrogram "tree."

In Figure 1 we show the dendrogram of the L1448 region in the star-forming molecular cloud Perseus. The original data (Figure 2) are <sup>13</sup>CO(1-0) emission taken from the COMPLETE survey of Star Forming Regions survey of the Perseus region (Ridge et al.). The main complex in L1448, represented by the dominant branch of the dendrogram, has gravitational and kinetic energies that are comparable and encompasses a large fraction of the region.



The dendrogram indicates the importance of gravity over a large range of scales in the molecular cloud from the individual small clumps indicated with the "leaves" of the dendrogram down into the base of the structure tree. In contrast, the dendrogram indicates that the feature found at large velocities is dynamically as well as kinematically distinct from the majority of the region. In addition, the dendrogram identifies several "leaves" which have distinct regions where gravity dominates on the smallest scales. Such features are interesting since they represent where the molecular gas is closest to forming stars.



**Figure 2 | Isointensity surface models of L1448 in <sup>13</sup>CO.** The models are in p-p-v space, where the front of the cube is the plane of the sky. The intensity thresholds shown are chosen using the "dendrogram" procedure described.

<sup>1</sup> Dendrogram construction is completely determined by the data without relying on choices algorithm parameters, such as the stop size in the CLUMPFIND algorithm or the relative weights of the c2 components in GameChamps.

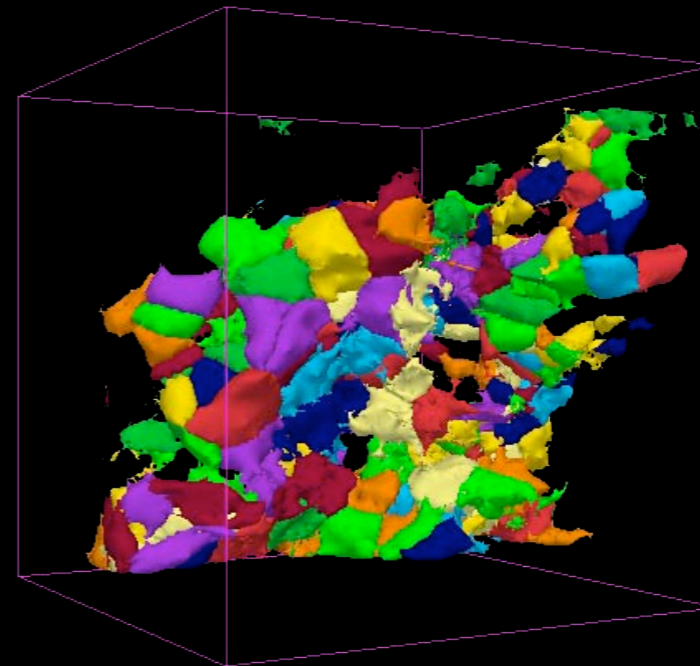
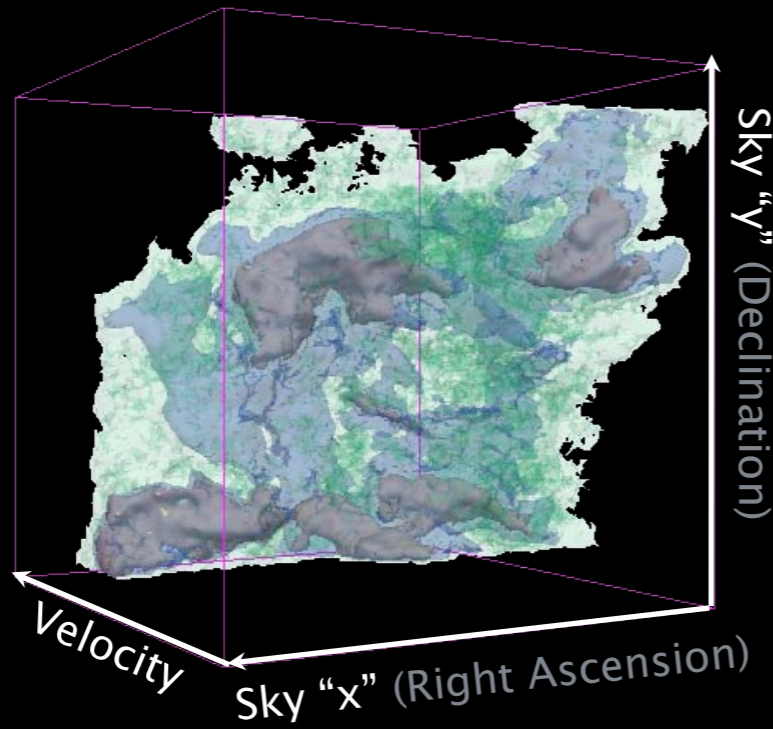
4

# Taste-Test

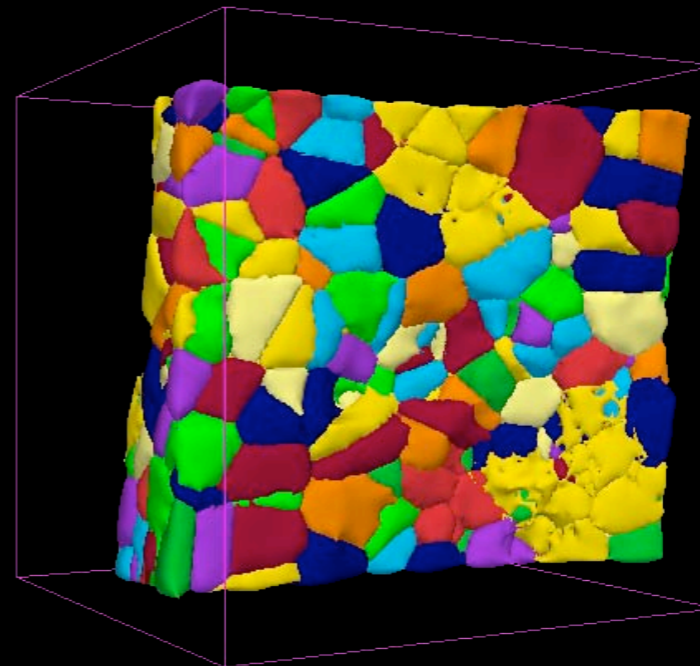
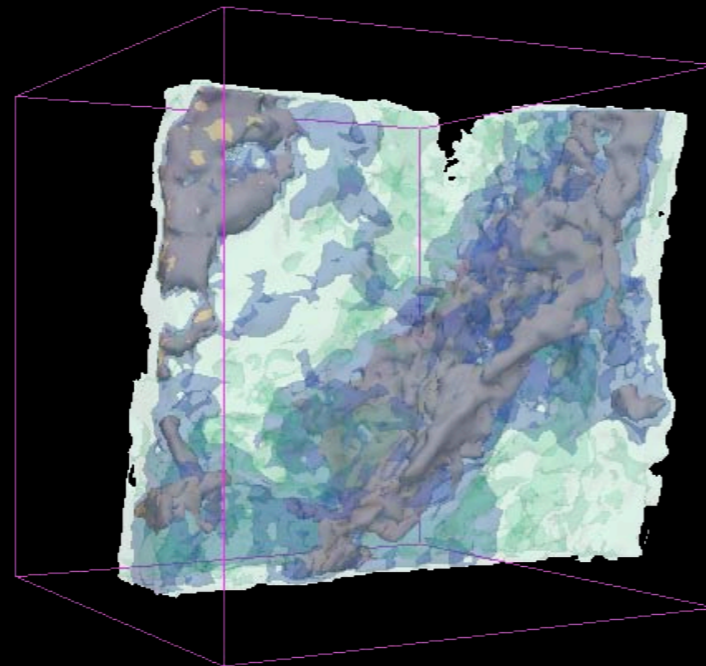
(Dendro)Surfaces

“CLUMPFIND”

Observed  
Reality

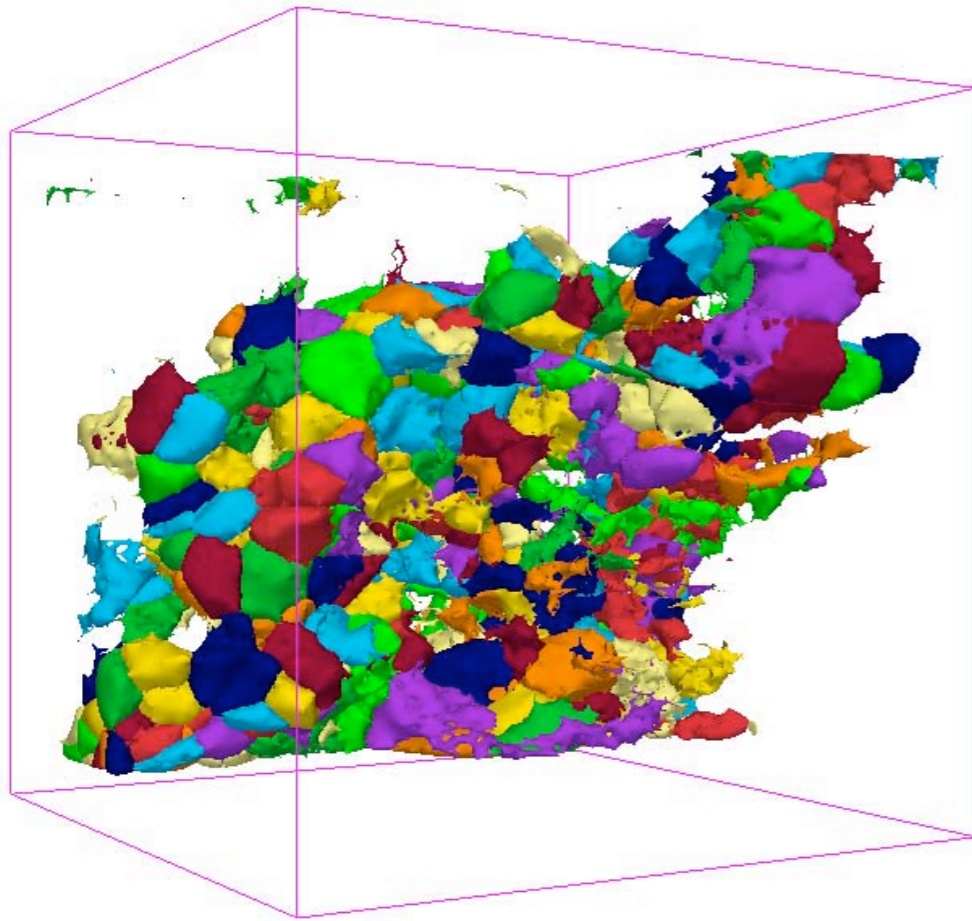


“Observed”  
Simulations



*work of Rosolowsky, Pineda, Kauffmann, Borkin, Padoan, Halle & Goodman;  
figure from Goodman & Rosolowsky NSF “Star Formation Taste Tests” Proposal, Fall 2006*

# Is CLUMPFIND OK as a Statistic? (Like Cayenne Pepper?)

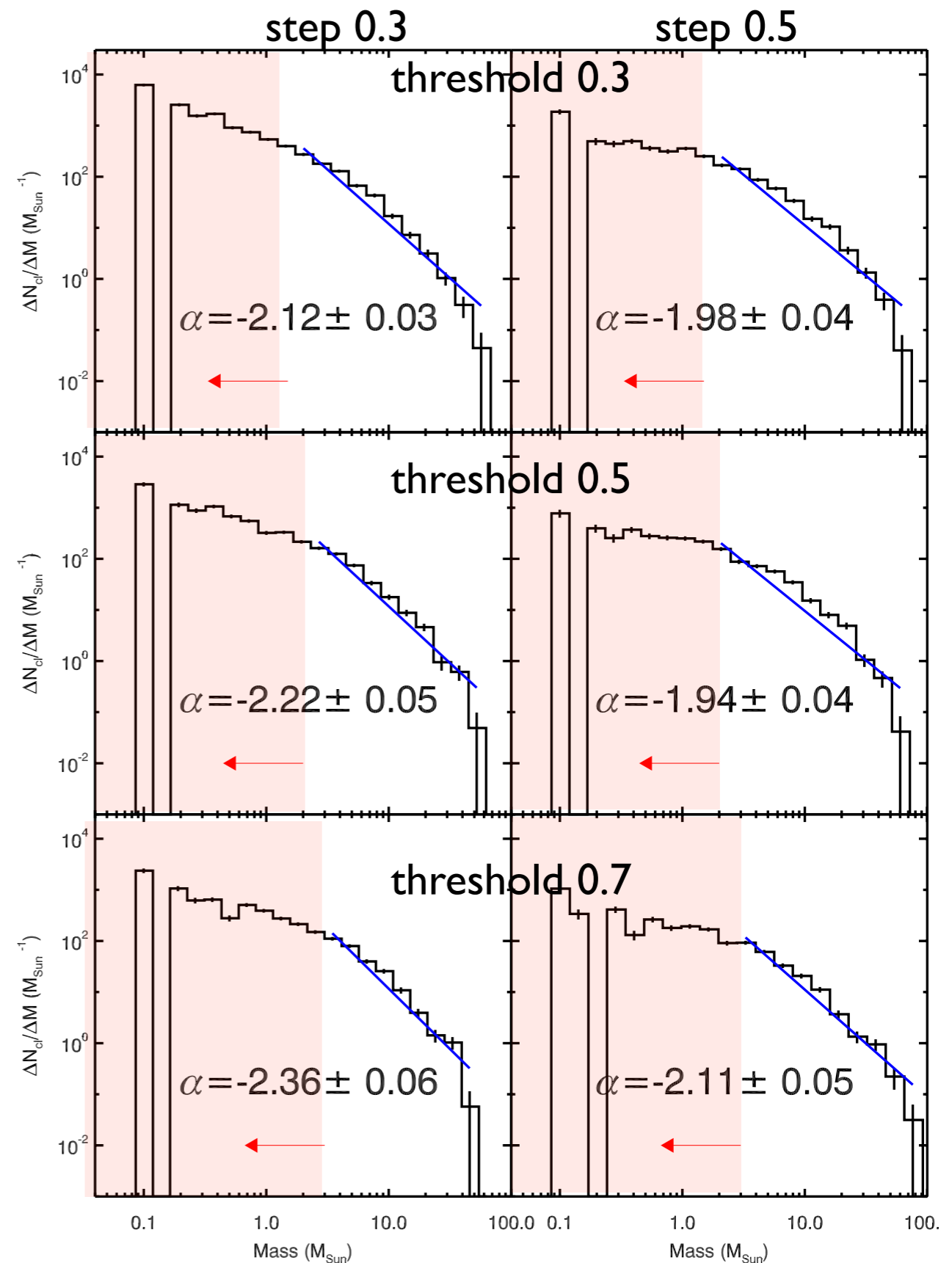


CLUMPFIND output for LI 448

(1.2K step & threshold; lower values give too many clumps to show!)

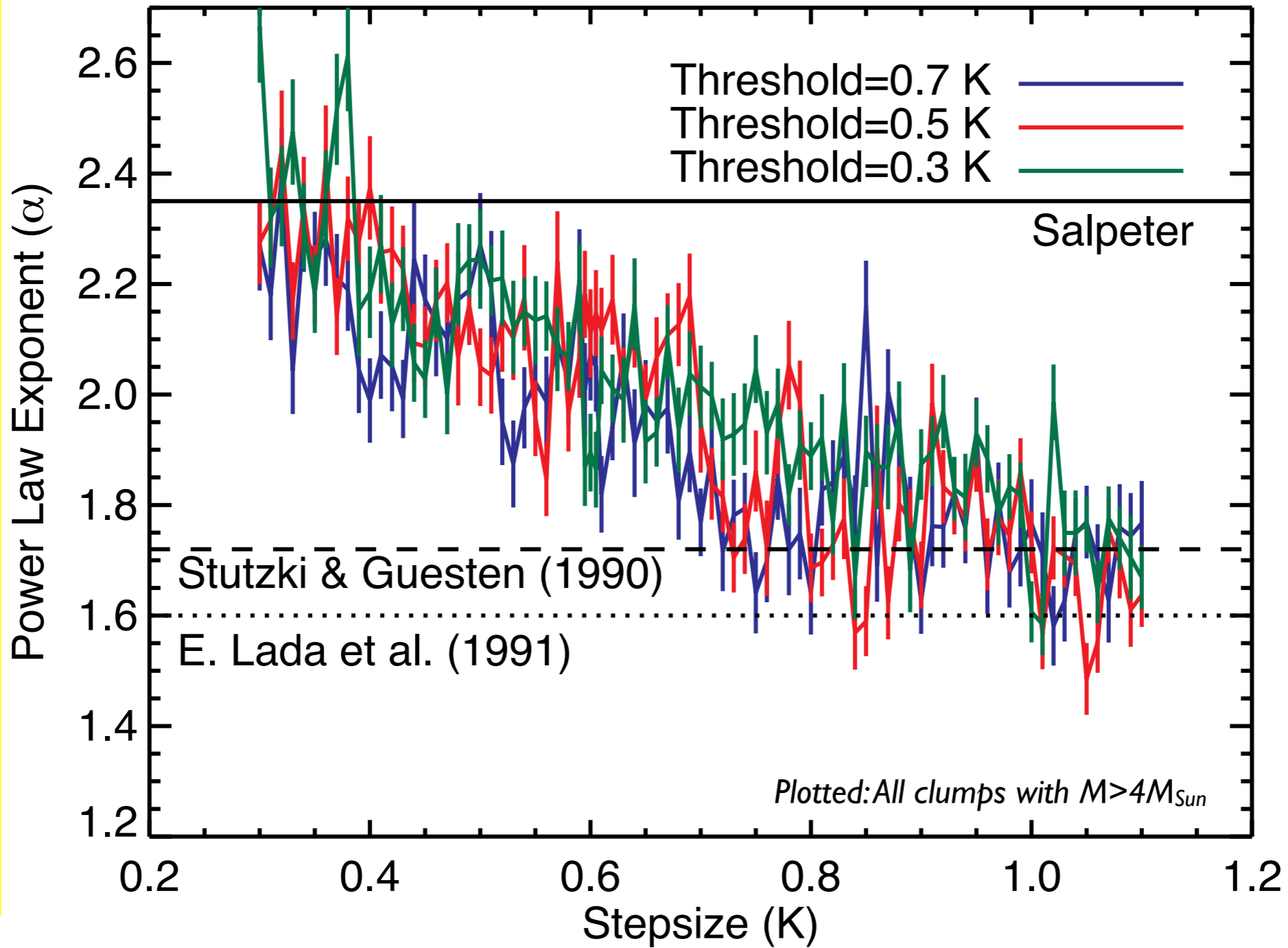
Results for full Perseus Map

Threshold	Step size	total number of Clump	% above sensitivity limit Mass v/s Radius	% above sensitivity limit FWHM v/s Radius	% above both curves
0.3	0.3	5199	47.32%	58.03%	46.59%
0.3	0.5	3844	40.74%	46.96%	40.30%
0.5	0.3	2141	79.12%	89.72%	78.14%
0.5	0.5	1420	86.83%	89.01%	86.20%
0.7	0.3	1748	79.06%	90.79%	78.60%
0.7	0.5	1168	87.07%	90.58%	86.73%



# Is CLUMPFIND OK as a Statistic? Be VERY careful of the recipe.

## Slope of Mass Spectrum



## Advice for Cooks & Tasters

The menu may offer something for everyone, but taste carefully to be sure you got what you ordered.

Also, be careful to mind the difference between “numerical experiments” and “simulations”: don’t taste them in life-threatening ways.



# E Extinction and scattering! (Cloudshine)

L106

FOSTER & GOODMAN  
2006

Vol. 636

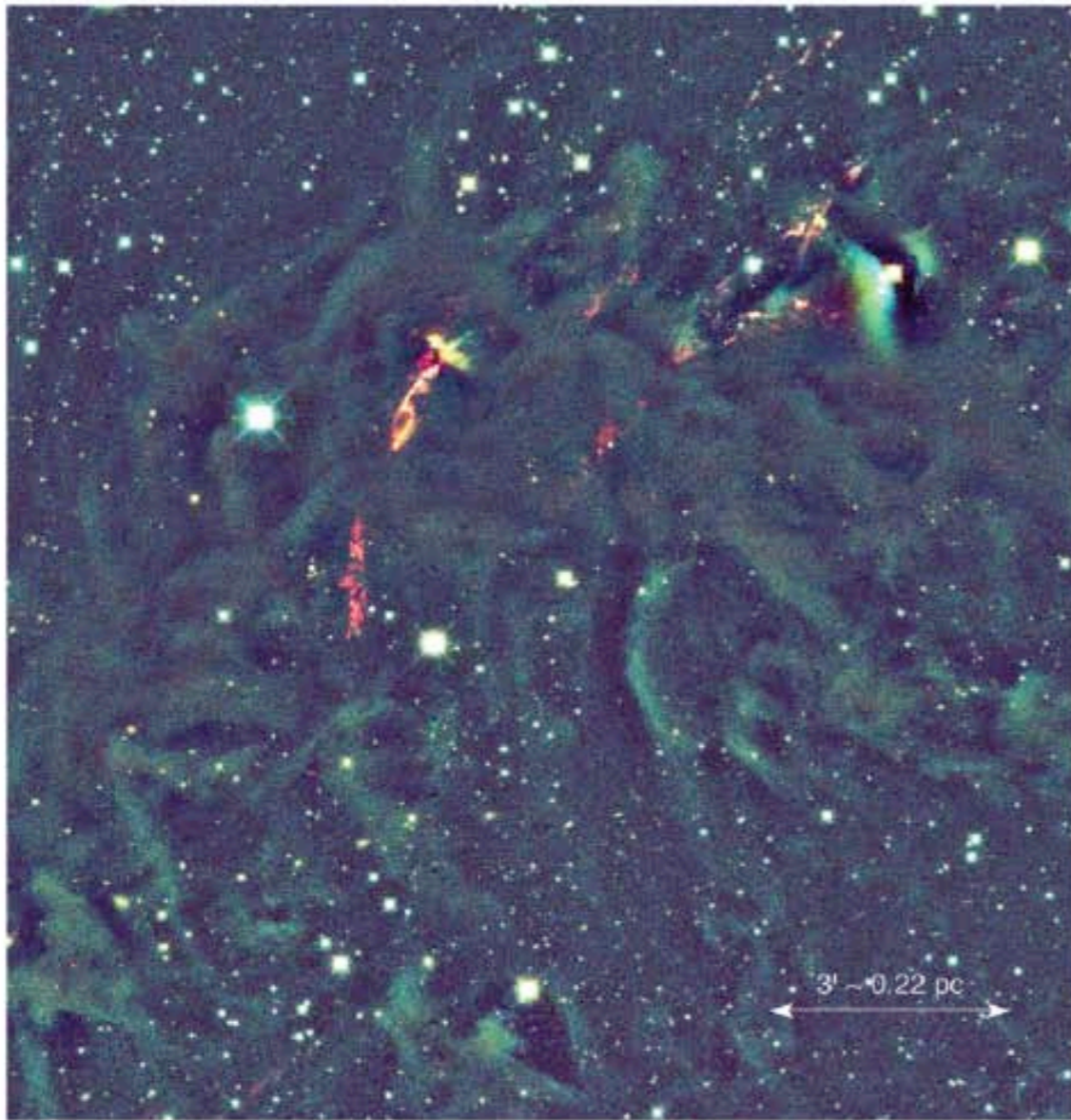


FIG. 1.—L1448 in false color. Component images have been weighted according to their flux in units of  $\text{MJy sr}^{-1}$ .  $J$  is blue,  $H$  is green, and  $K_s$  is red. Outflows from young stars glow red, while a small fan-shaped reflection nebula in the upper right is blue-green. Cloudshine, in contrast, is shown here as a muted glow with green edges. Dark features around extended bright objects (such as the reflection nebula) are the result of self-sky subtraction.

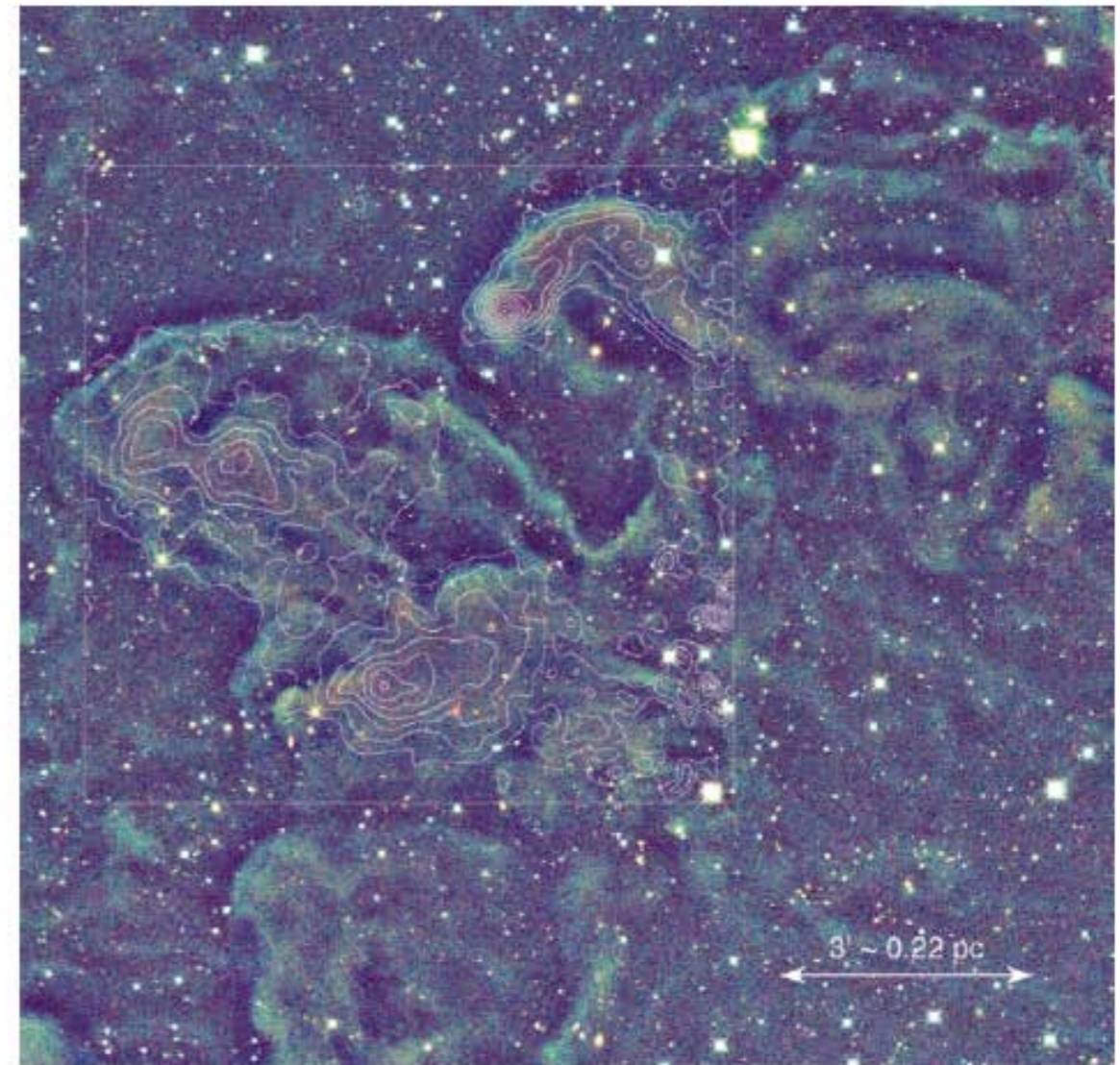


FIG. 2.—L1451 in false color. Again, each component image has been scaled to the same flux scale in units of  $\text{MJy sr}^{-1}$ ; and  $J$  is blue,  $H$  is green, and  $K_s$  is red. A smaller map of 1.2 mm dust emission contours from COMPLETE (M. Tafalla 2006, in preparation) has been overlaid, showing that the color of cloudshine is a tracer of density. Redder regions have high dust continuum flux, and the edges of cloudshine match the edges of the dust emission. Dark edges around bright features (particularly noticeable along the northern edges) are the result of self-sky subtraction.

# “Cloudshine”=Scattered Ambient Starlight

L106

FOSTER & GOODMAN  
2006

Vol. 636

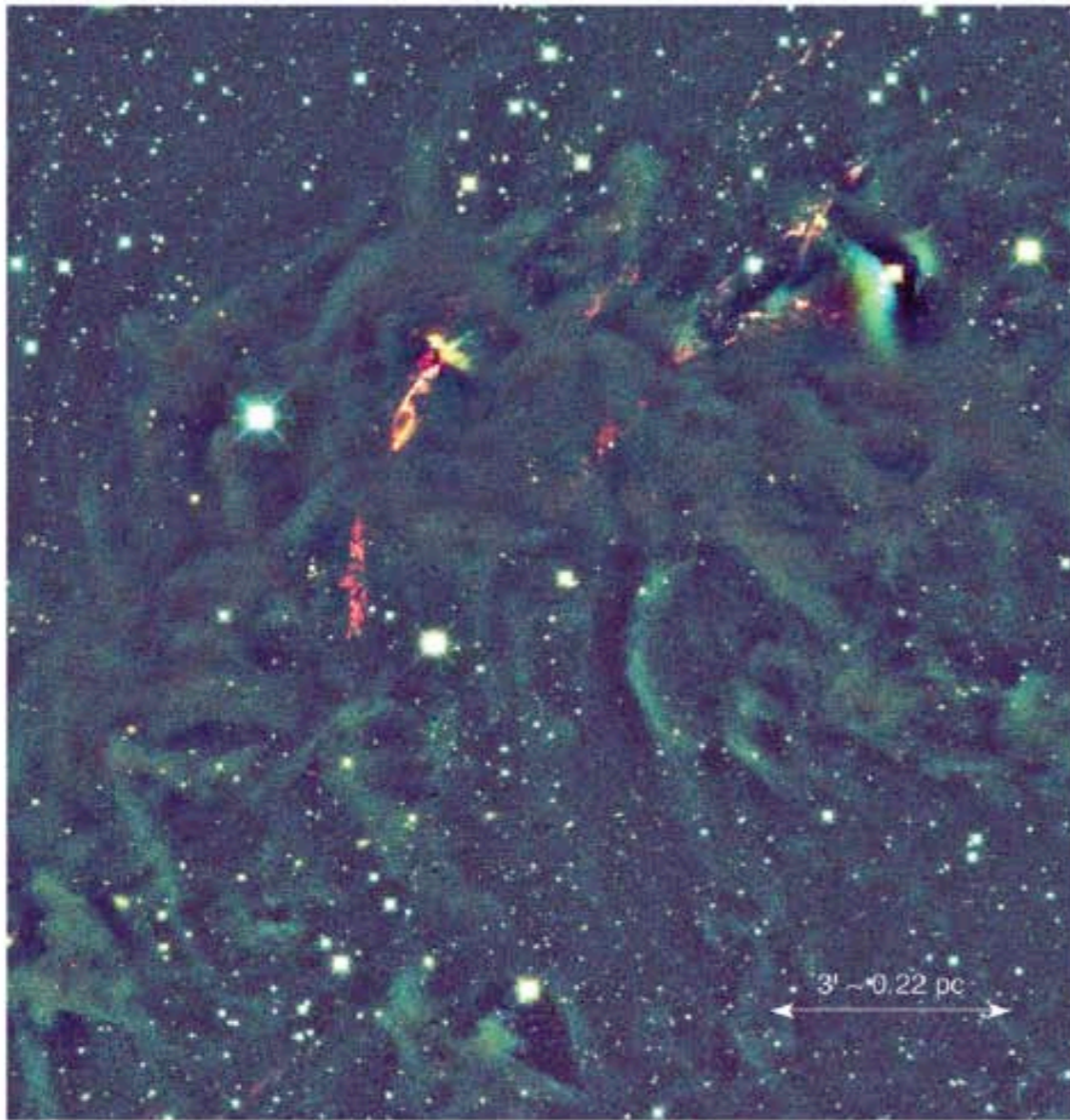


FIG. 1.—L1448 in false color. Component images have been weighted according to their flux in units of  $\text{MJy sr}^{-1}$ .  $J$  is blue,  $H$  is green, and  $K_s$  is red. Outflows from young stars glow red, while a small fan-shaped reflection nebula in the upper right is blue-green. Cloudshine, in contrast, is shown here as a muted glow with green edges. Dark features around extended bright objects (such as the reflection nebula) are the result of self-sky subtraction.

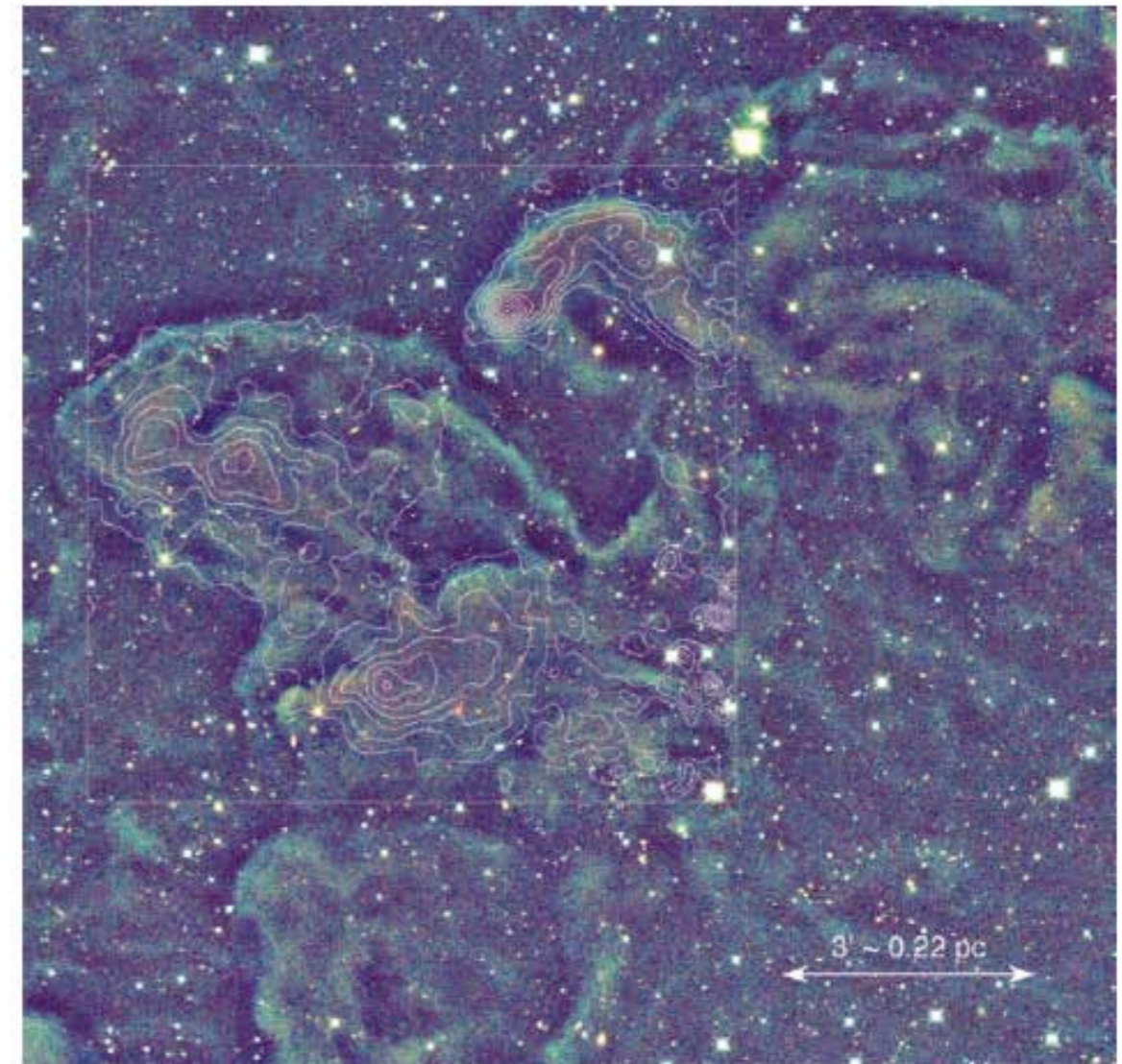
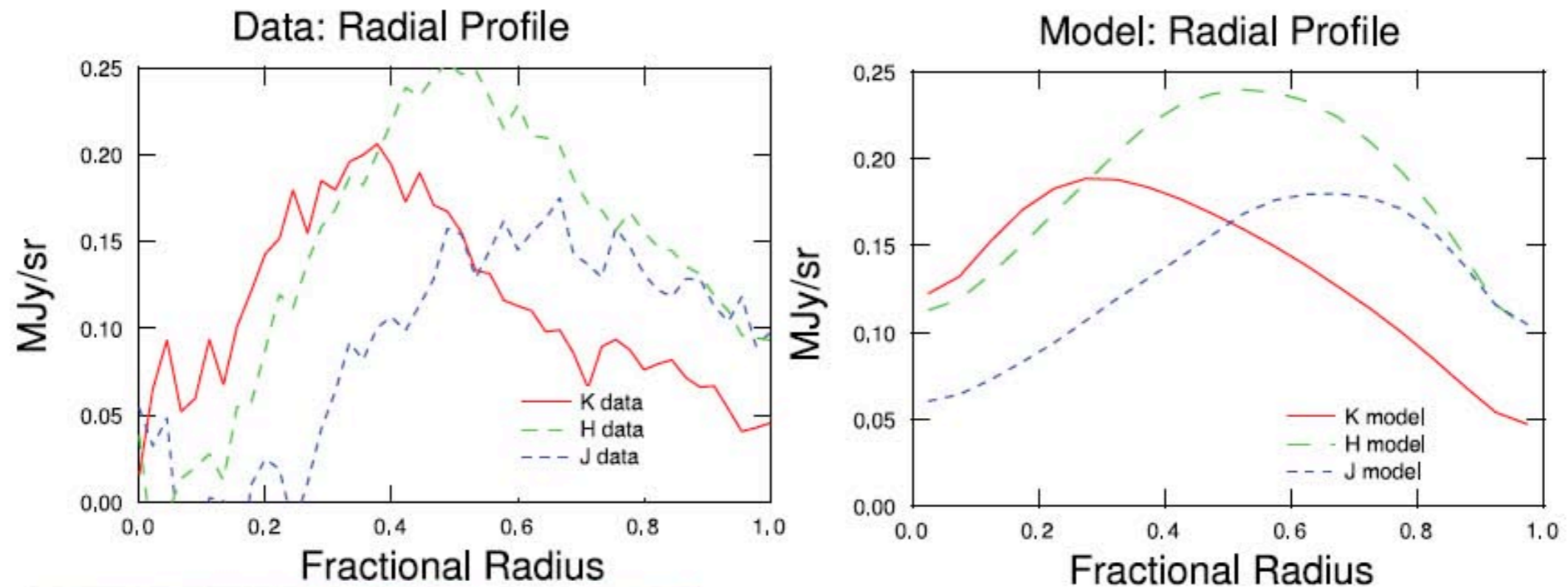


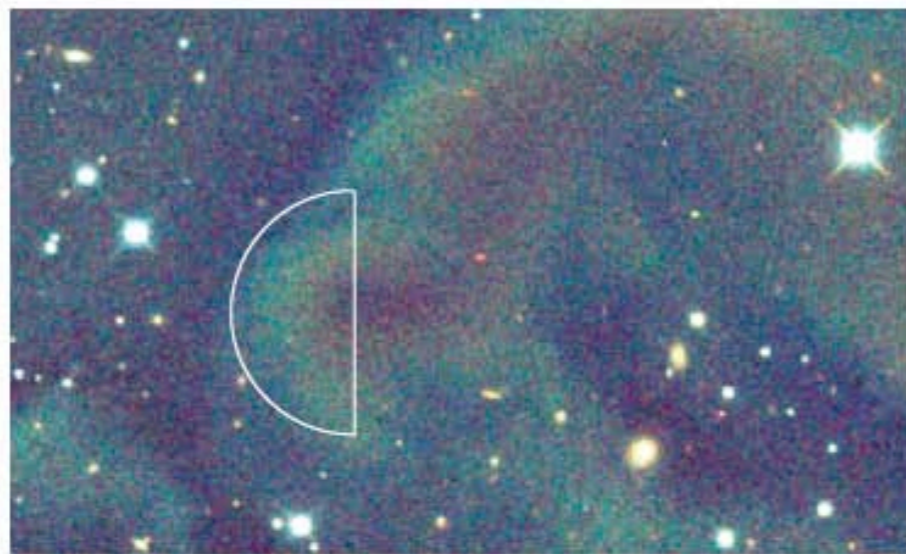
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Extra Slides Only  
Beyond Here

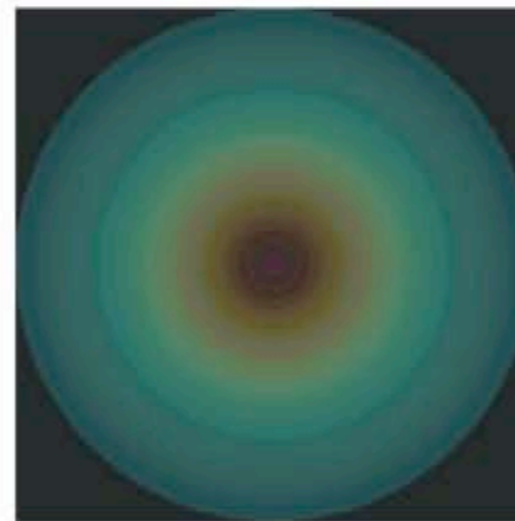
# Extinction and scattering! (Cloudshine)



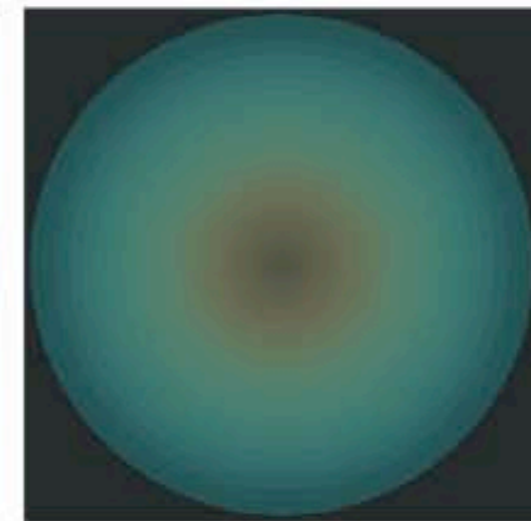
Foster &  
Goodman  
2006



Data Used in Constructing Core Profile



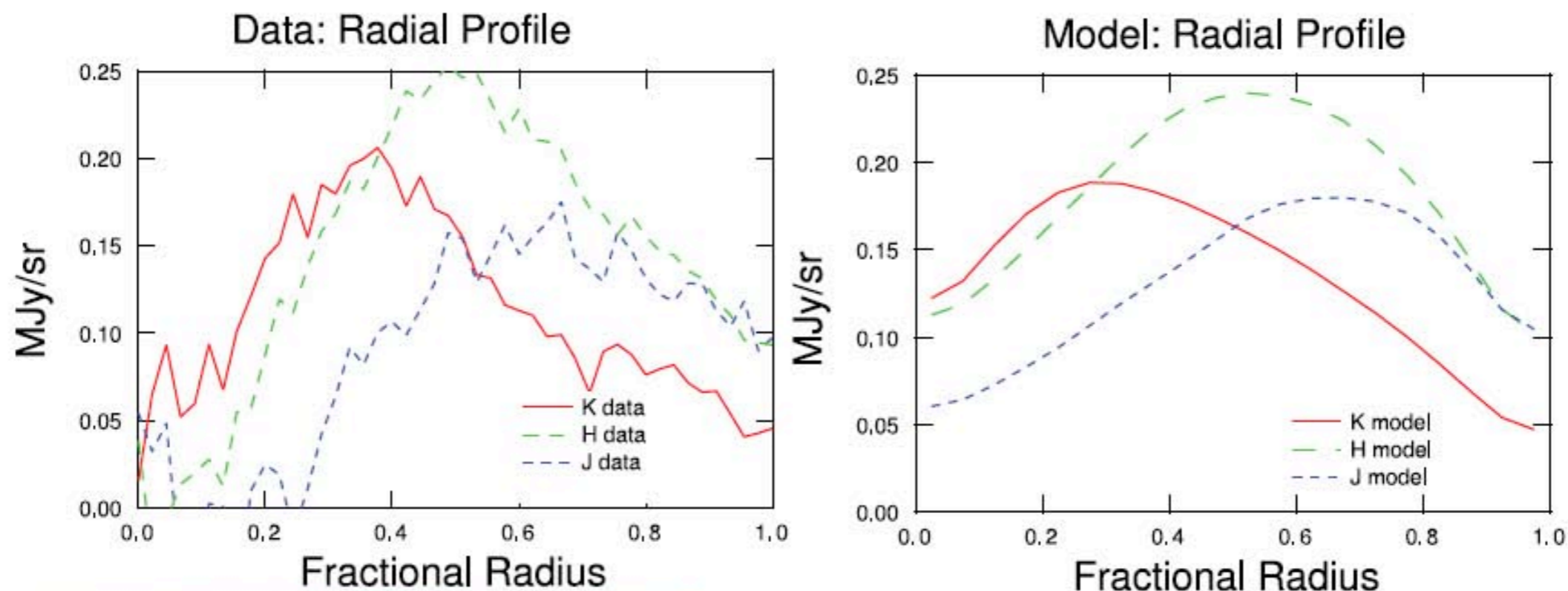
Data Radial Profile



Model Radial Profile

FIG. 3.—Model of cloudshine in one core as reflected interstellar radiation. The lower left panel shows the roughly circular feature we chose to model as a sphere. Due to the surrounding structure, only the left half of the circle was used to derive an angle-averaged radial profile. The comparison between this radial profile and our best-fit model (an  $r^{-2}$  density profile and a total optical depth of 120 mag of visual extinction) is shown in two ways: above as radial flux profiles in individual bands and in the lower right as a synthetic color-composite image that allows for an overall comparison. Although the fit is good, the central region of the core is darker than predicted by the model. Some of this may be due to self-sky subtraction in the image (which causes dark edges around bright features) and a nonspherical, nonisotropically illuminated core, and some may be due to a failure to adequately model the density structure at the center of the core.

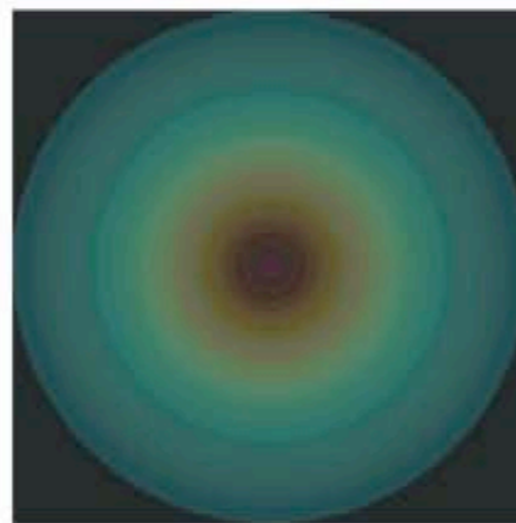
# Almost Tasting a Very Simple Recipe



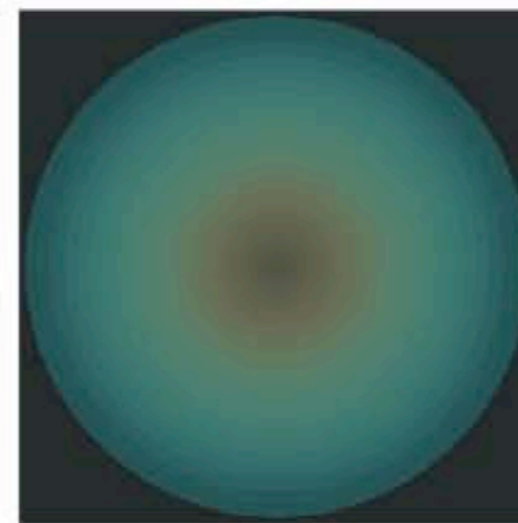
*Foster &  
Goodman  
2006*



Data Used in Constructing Core Profile



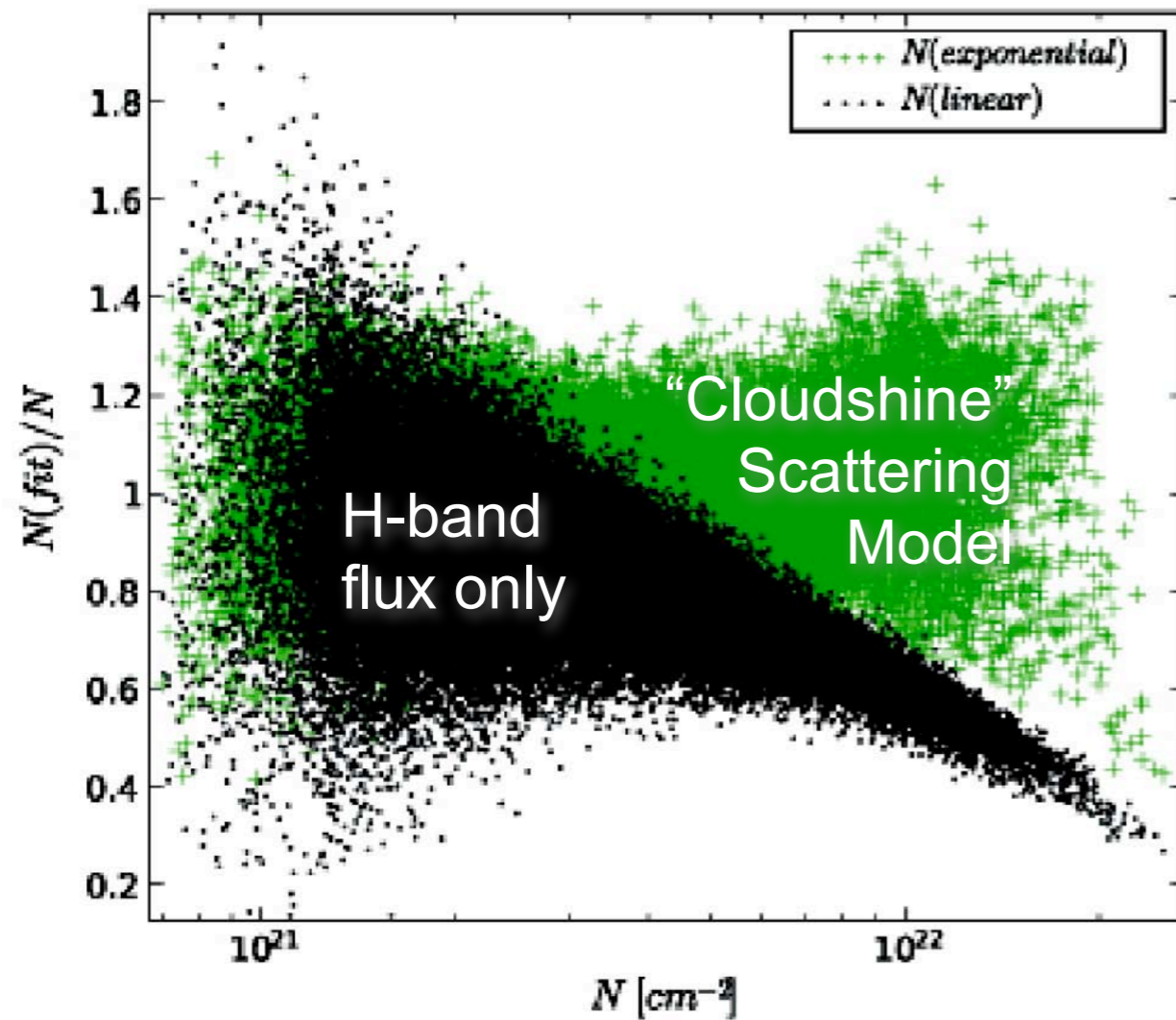
Data Radial Profile



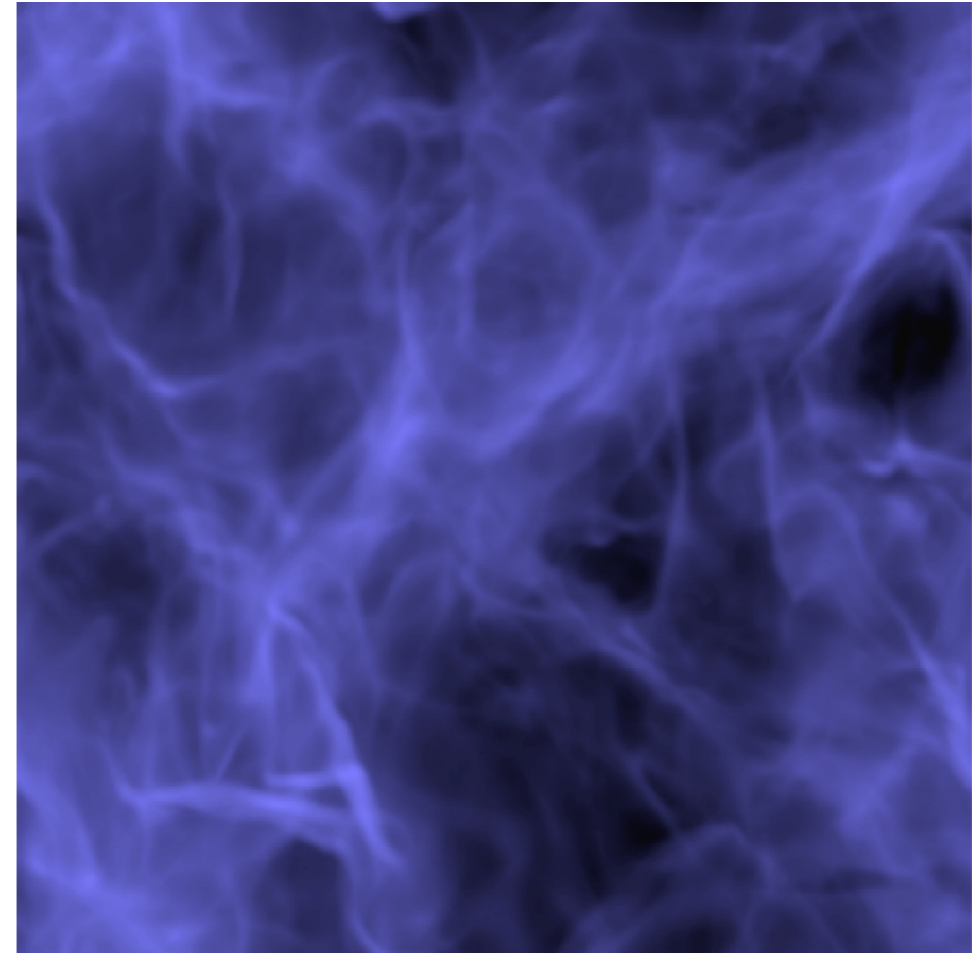
Model Radial Profile

FIG. 3.—Model of cloudshine in one core as reflected interstellar radiation. The lower left panel shows the roughly circular feature we chose to model as a sphere. Due to the surrounding structure, only the left half of the circle was used to derive an angle-averaged radial profile. The comparison between this radial profile and our best-fit model (an  $r^{-2}$  density profile and a total optical depth of 120 mag of visual extinction) is shown in two ways: above as radial flux profiles in individual bands and in the lower right as a synthetic color-composite image that allows for an overall comparison. Although the fit is good, the central region of the core is darker than predicted by the model. Some of this may be due to self-sky subtraction in the image (which causes dark edges around bright features) and a nonspherical, nonisotropically illuminated core, and some may be due to a failure to adequately model the density structure at the center of the core.

# Extinction and scattering! (Cloudshine)

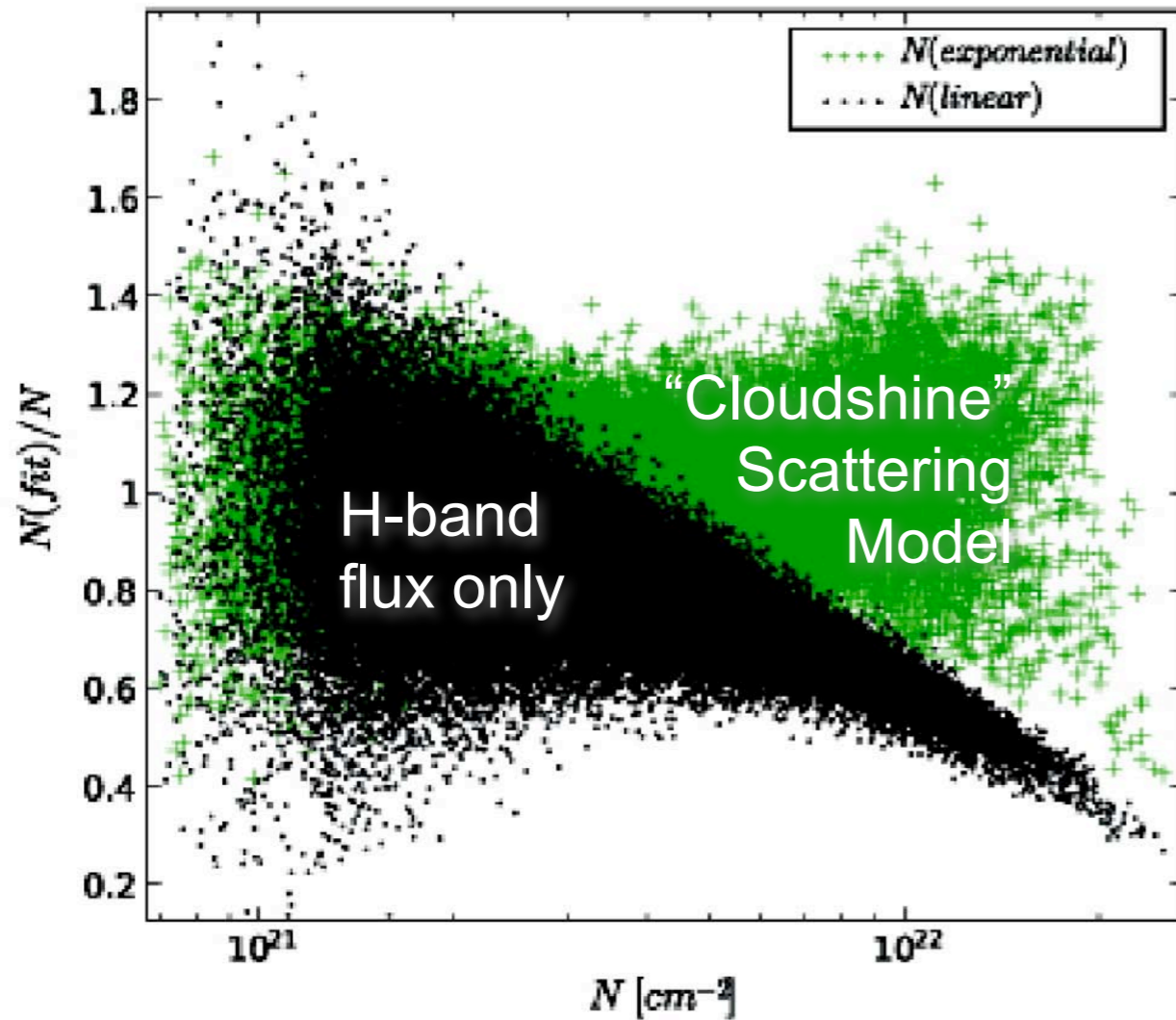


*Simulation*

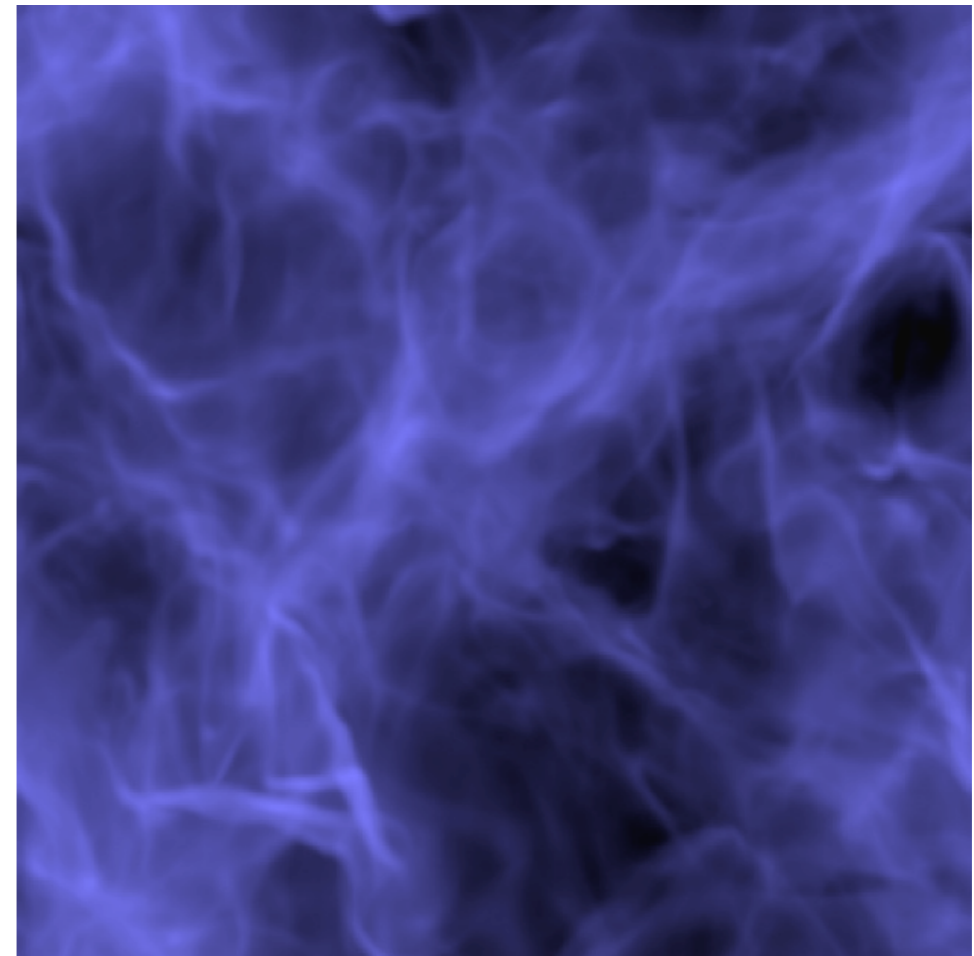


Tastes "right", with 20% scatter, at  $1 < A_V < 10$ , for NIR.

# Theorists doing the Tasting!

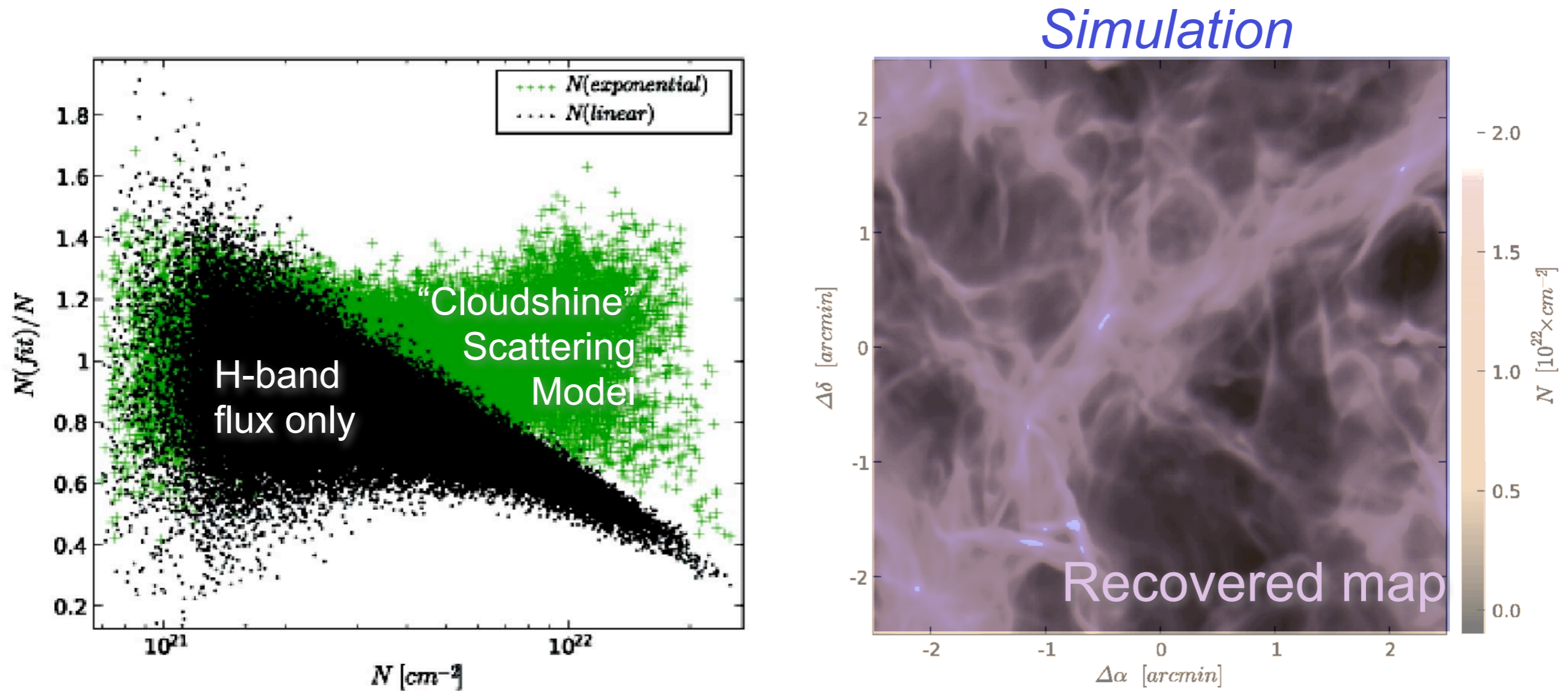


*Simulation*



Tastes "right", with 20% scatter, at  $1 < A_V < 10$ , for NIR.

# Theorists doing the Tasting!



Tastes "right", with 20% scatter, at  $1 < A_V < 10$ , for NIR.



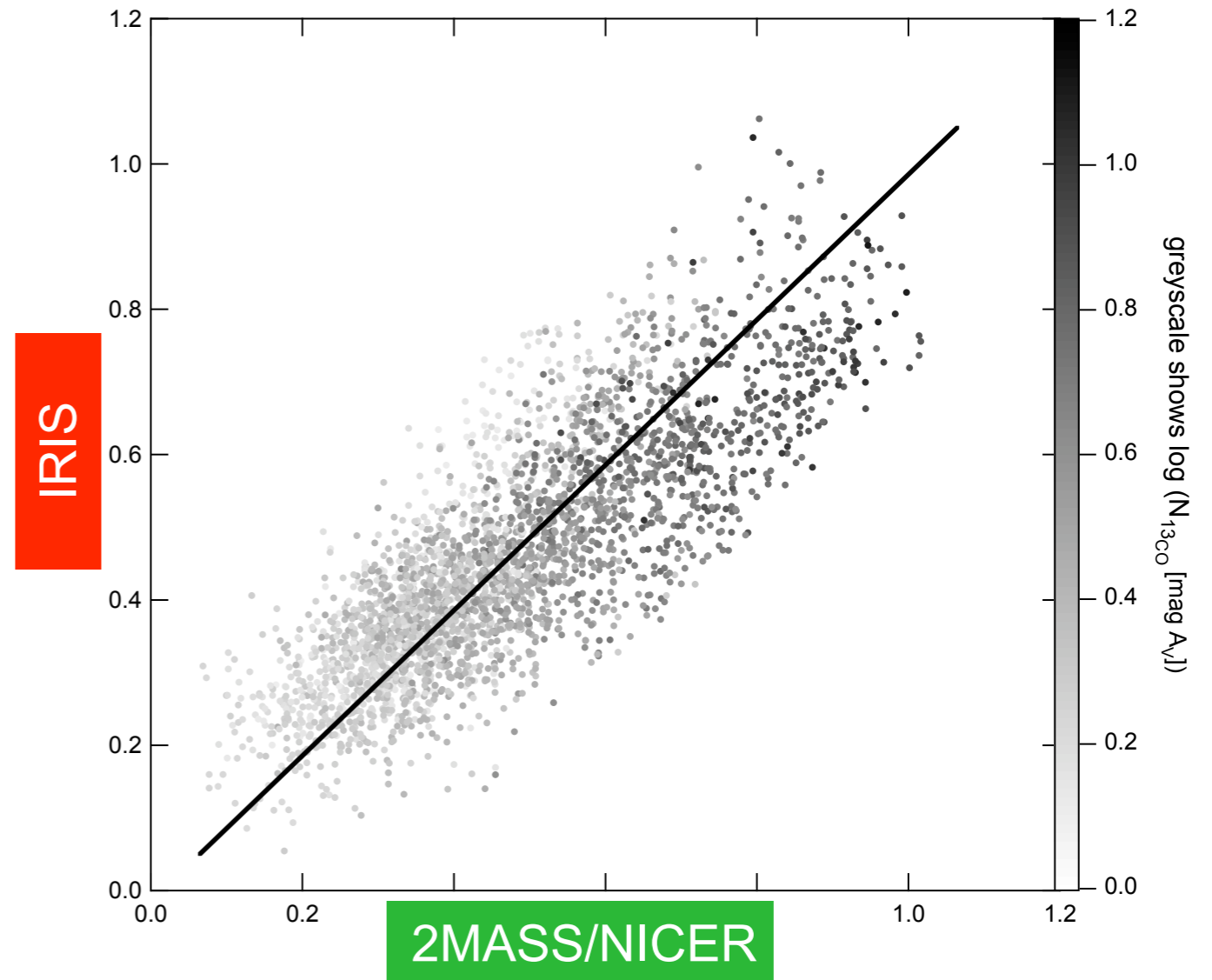


# Modeling line-of-sight temperature fluctuations

Errors introduced by the assumption of **isothermal dust** along each line of sight

Variable fraction of emission from **transiently heated** very small dust grains

**Variable dust properties** (e.g. emissivity or emissivity spectral index)



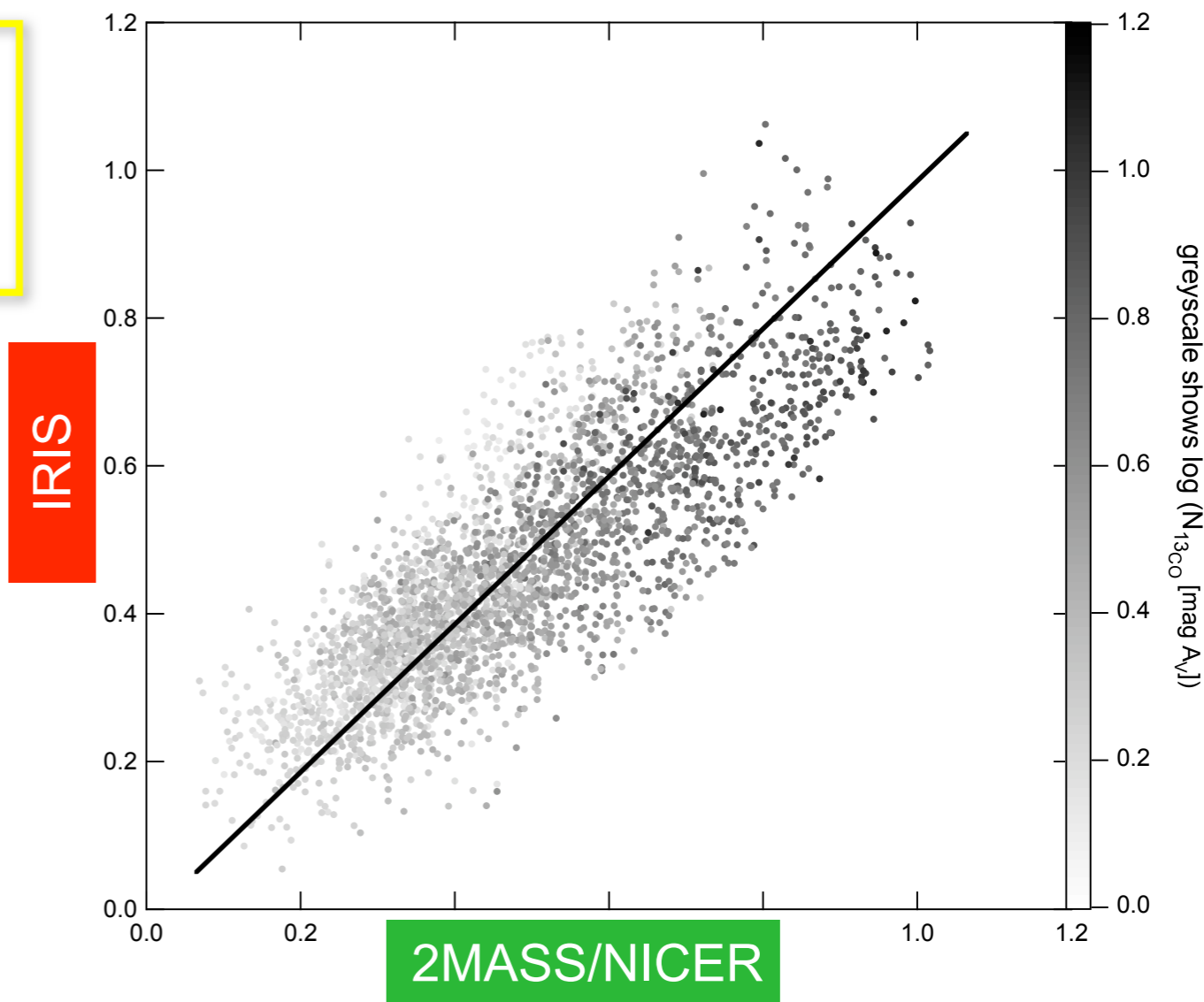


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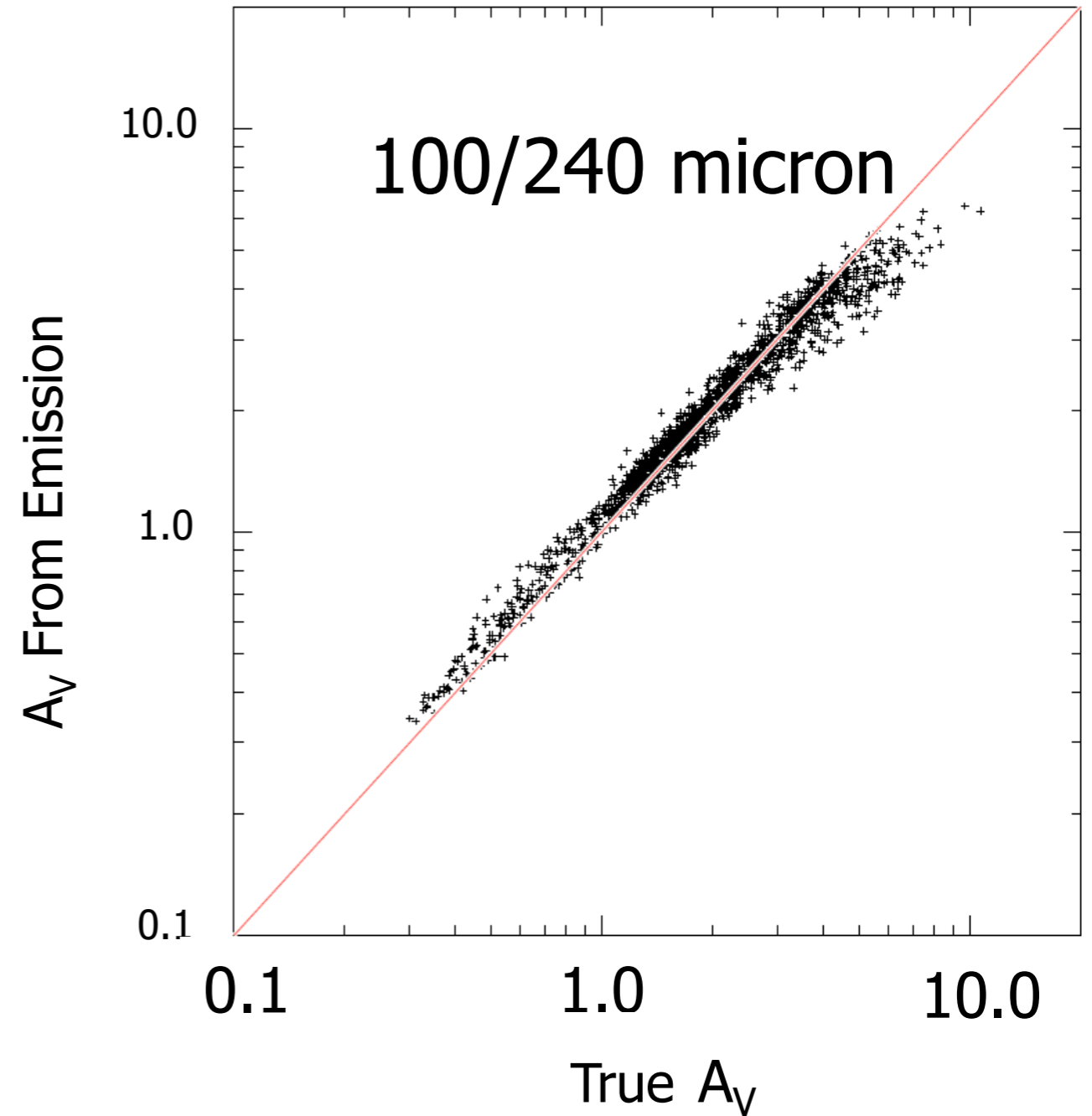
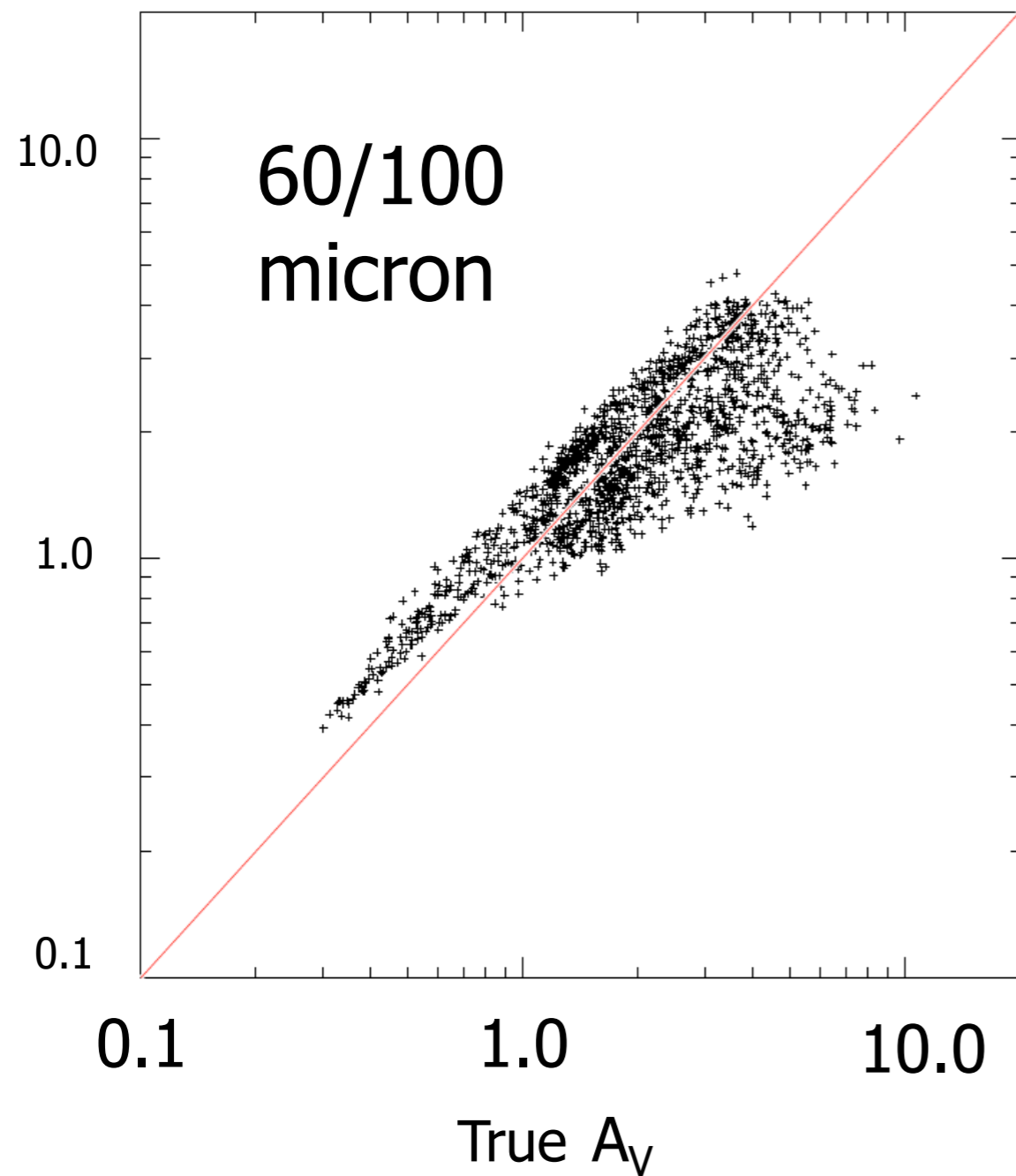
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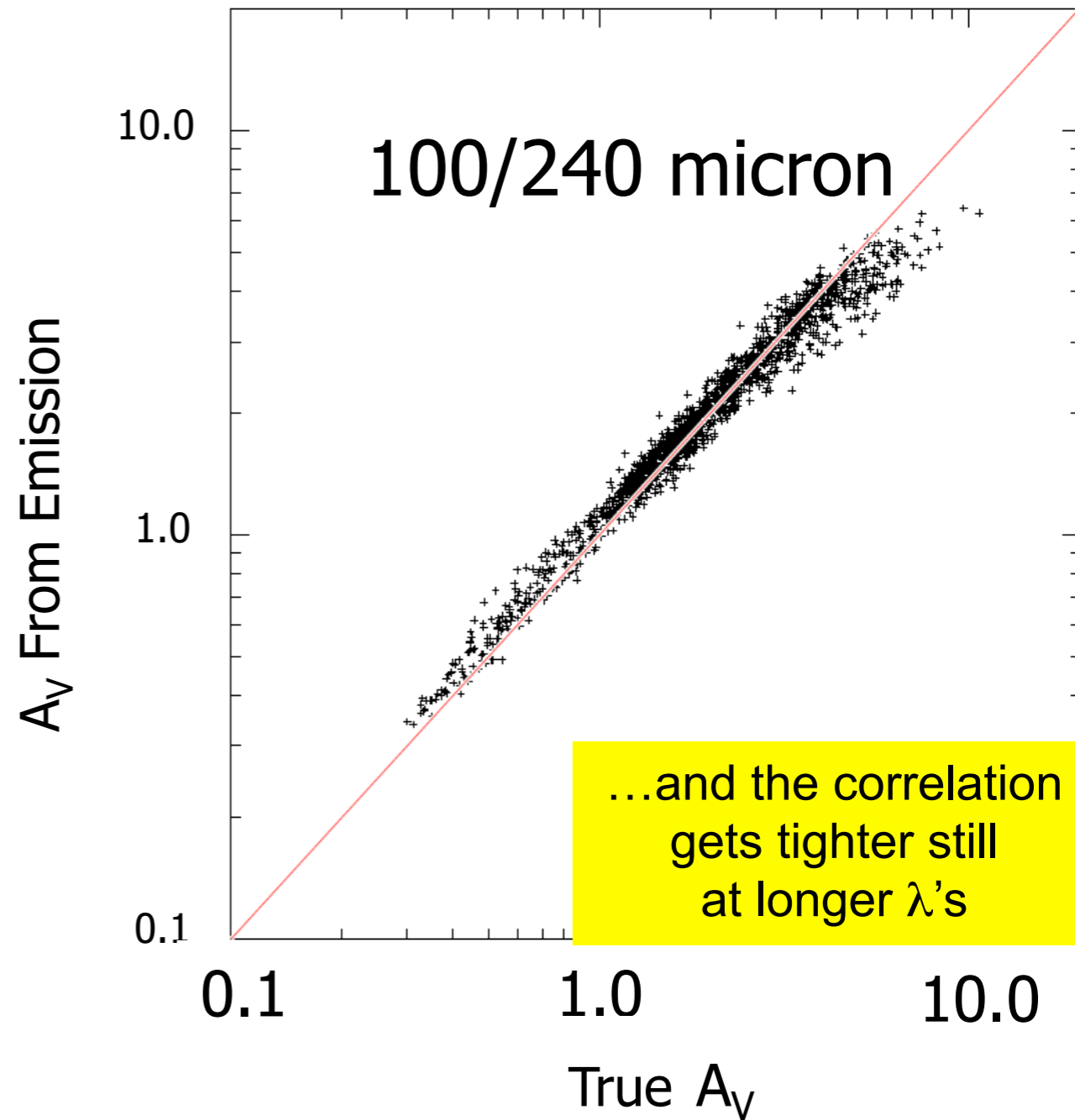
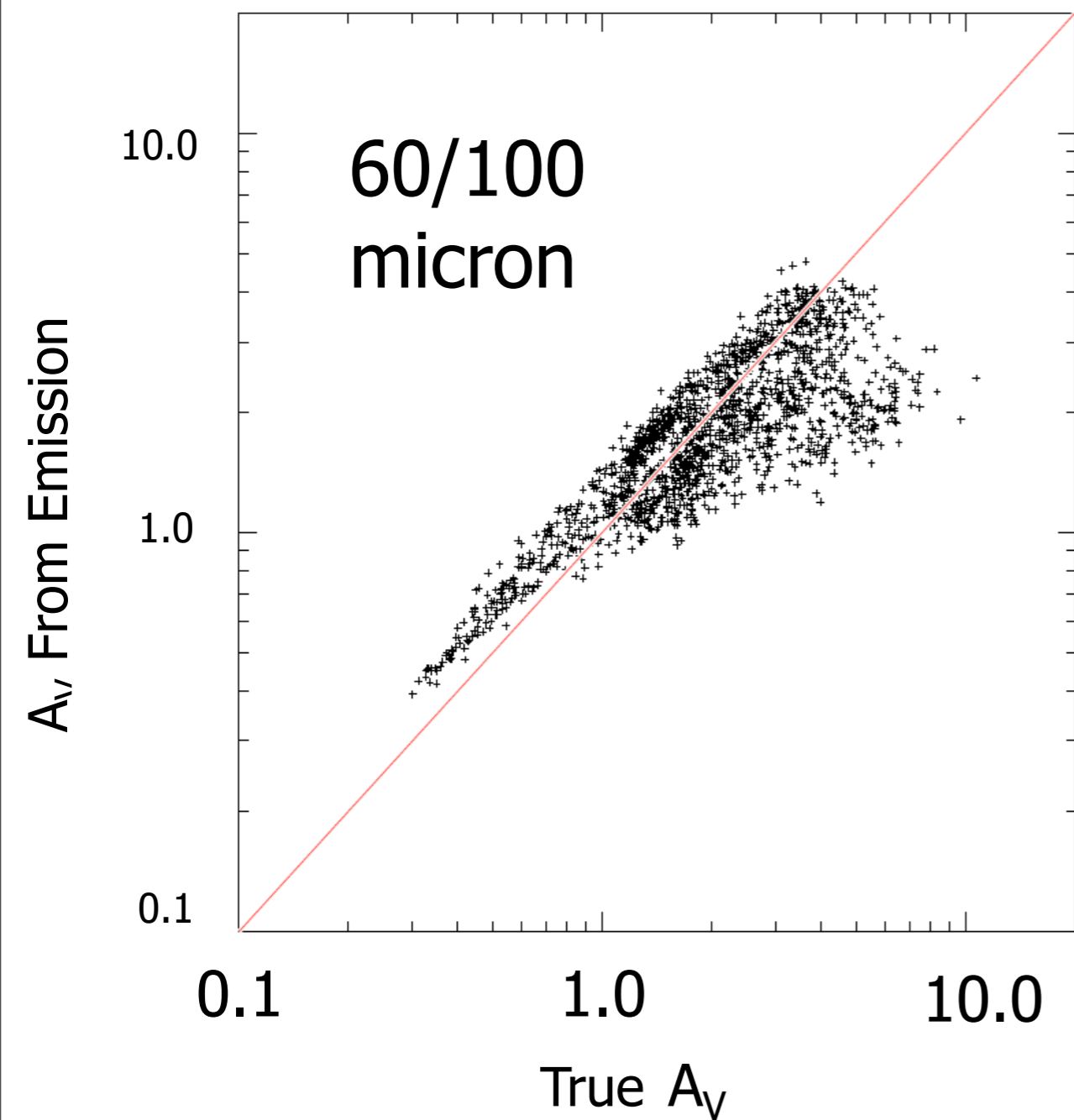


# Modeling line-of-sight temperature fluctuations

MHD Simulation+Radiative Xfer Code (No NOISE)

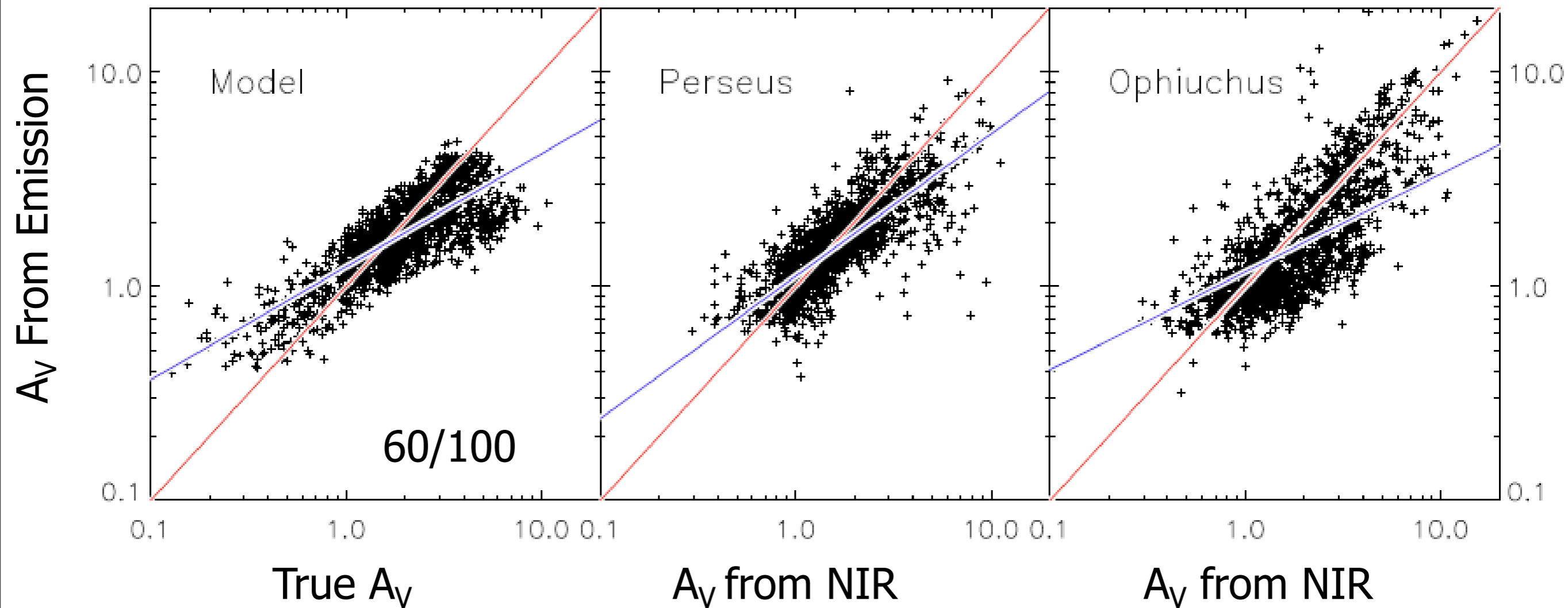


# MHD Simulation+Radiative Xfer Code (No NOISE)

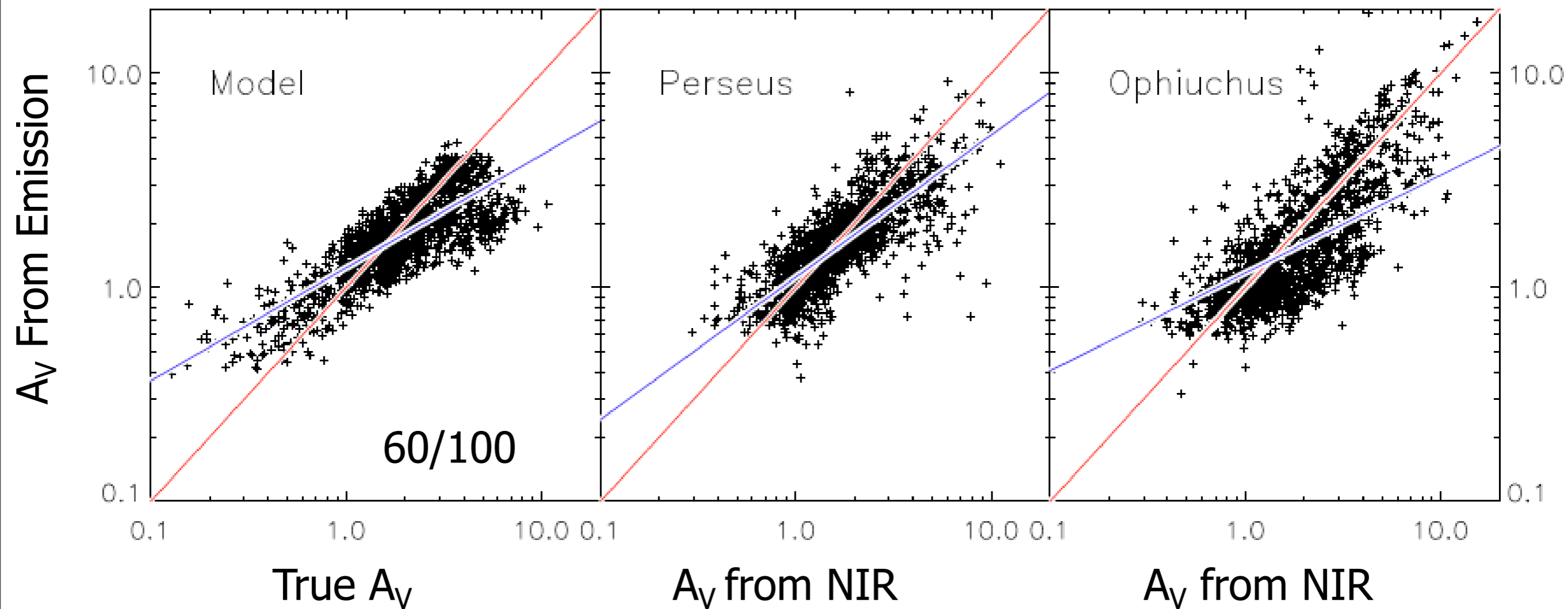




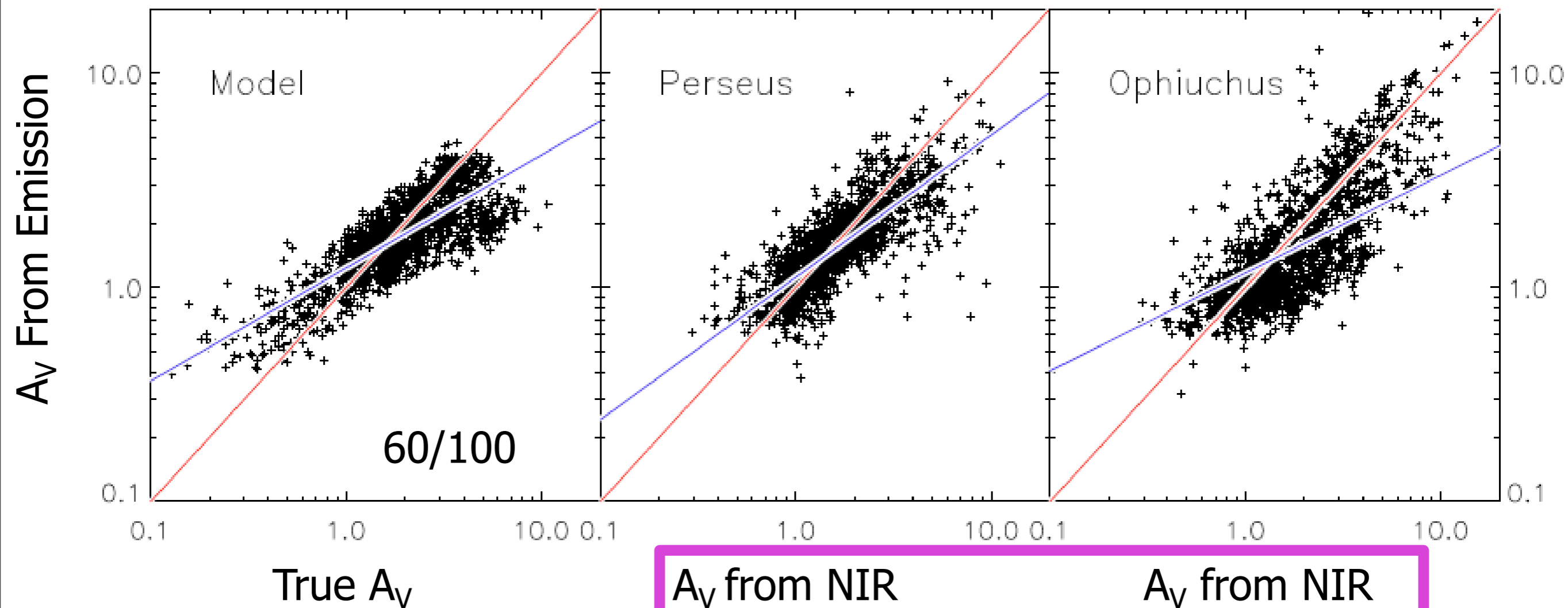
## Tasting the Simulations



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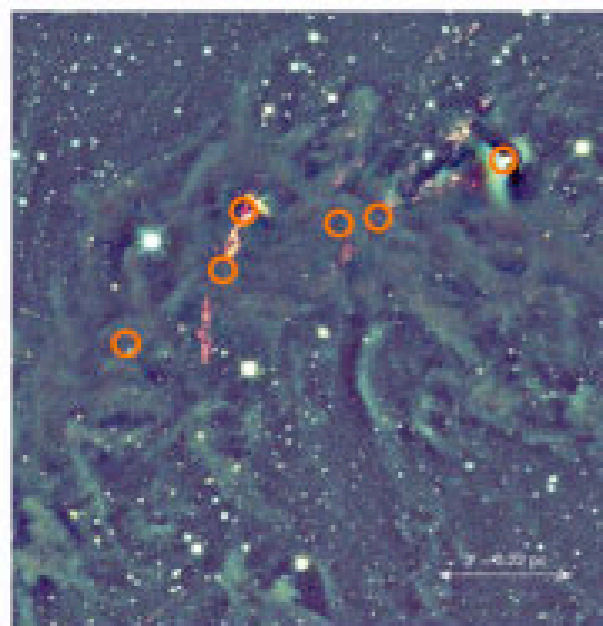
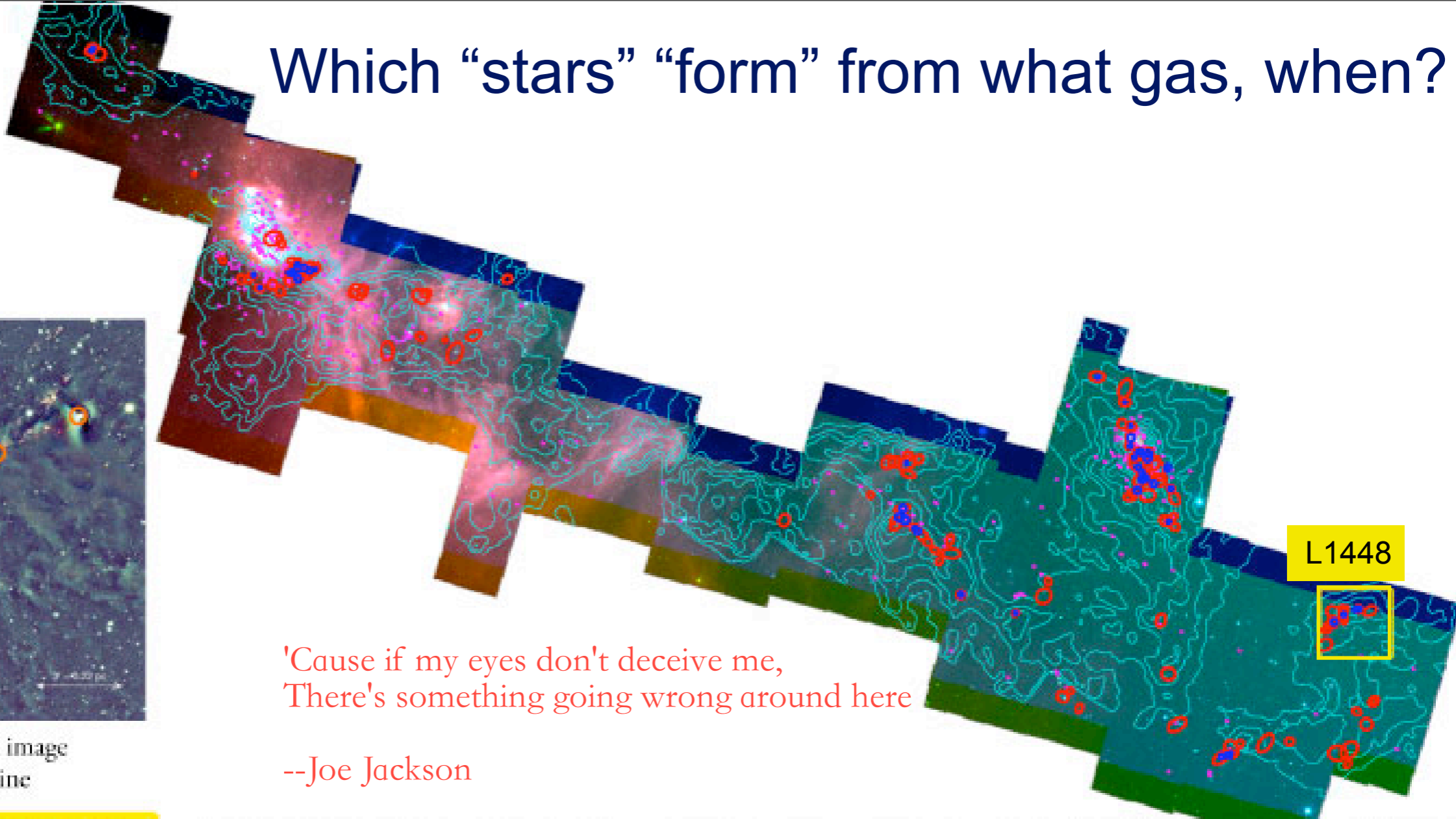


A<sub>V</sub> from NIR

A<sub>V</sub> from NIR

*I'll show you later why that's "True A<sub>V</sub>"*

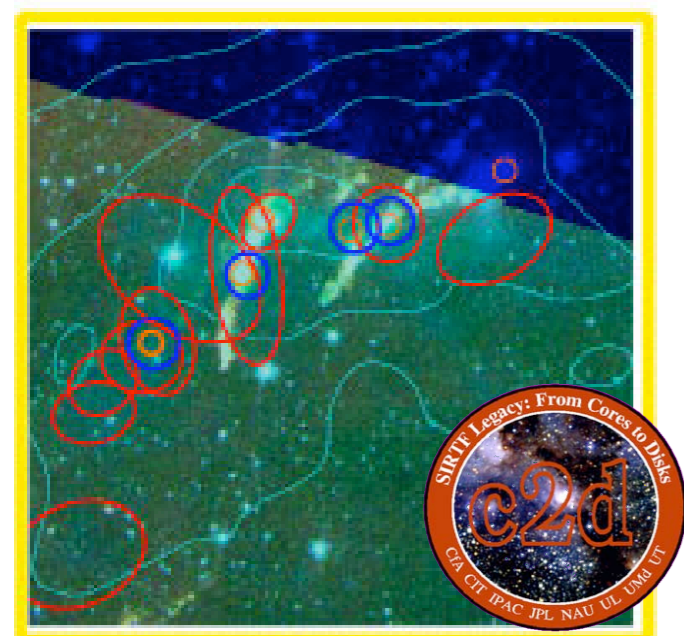
# Which "stars" "form" from what gas, when?



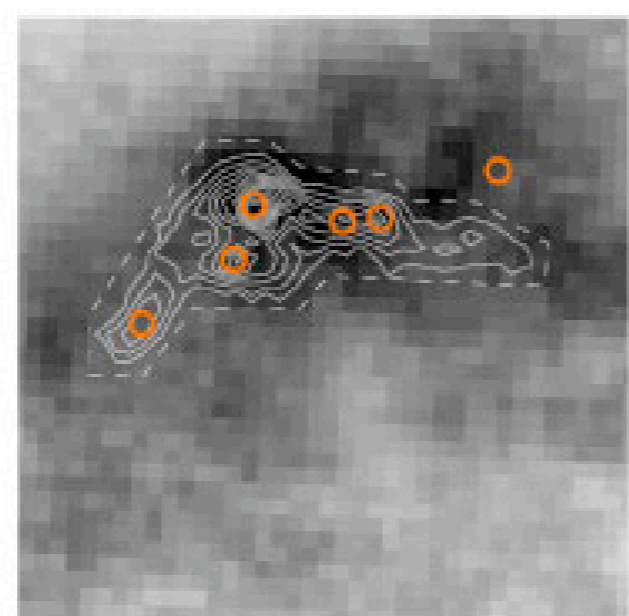
J,H,K Near-IR image of Cloudshine

'Cause if my eyes don't deceive me,  
There's something going wrong around here

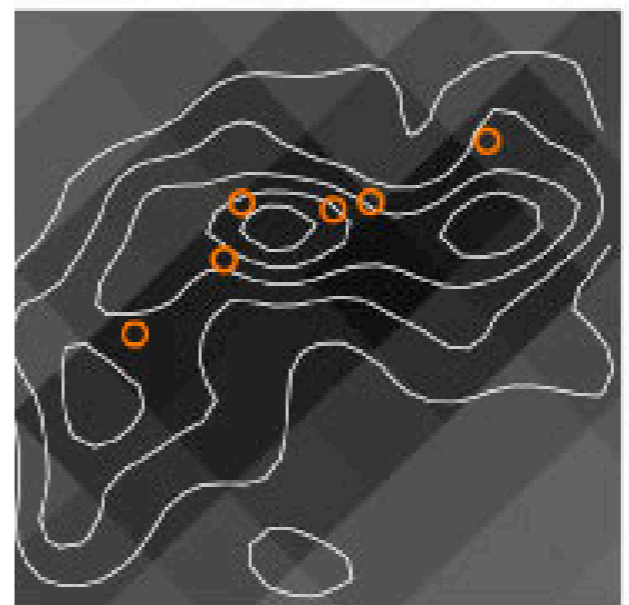
--Joe Jackson



**C** 850 micron and 1.1 mm clumps on a c2d IRAC 3-color image



**MPL** N<sub>2</sub>H<sup>+</sup> on <sup>13</sup>CO integrated intensity



**E** Deep NIR Extinction on 2MASS Extinction



**TE** 1.2 mm (IRAM) on 850 micron (SCUBA) continuum



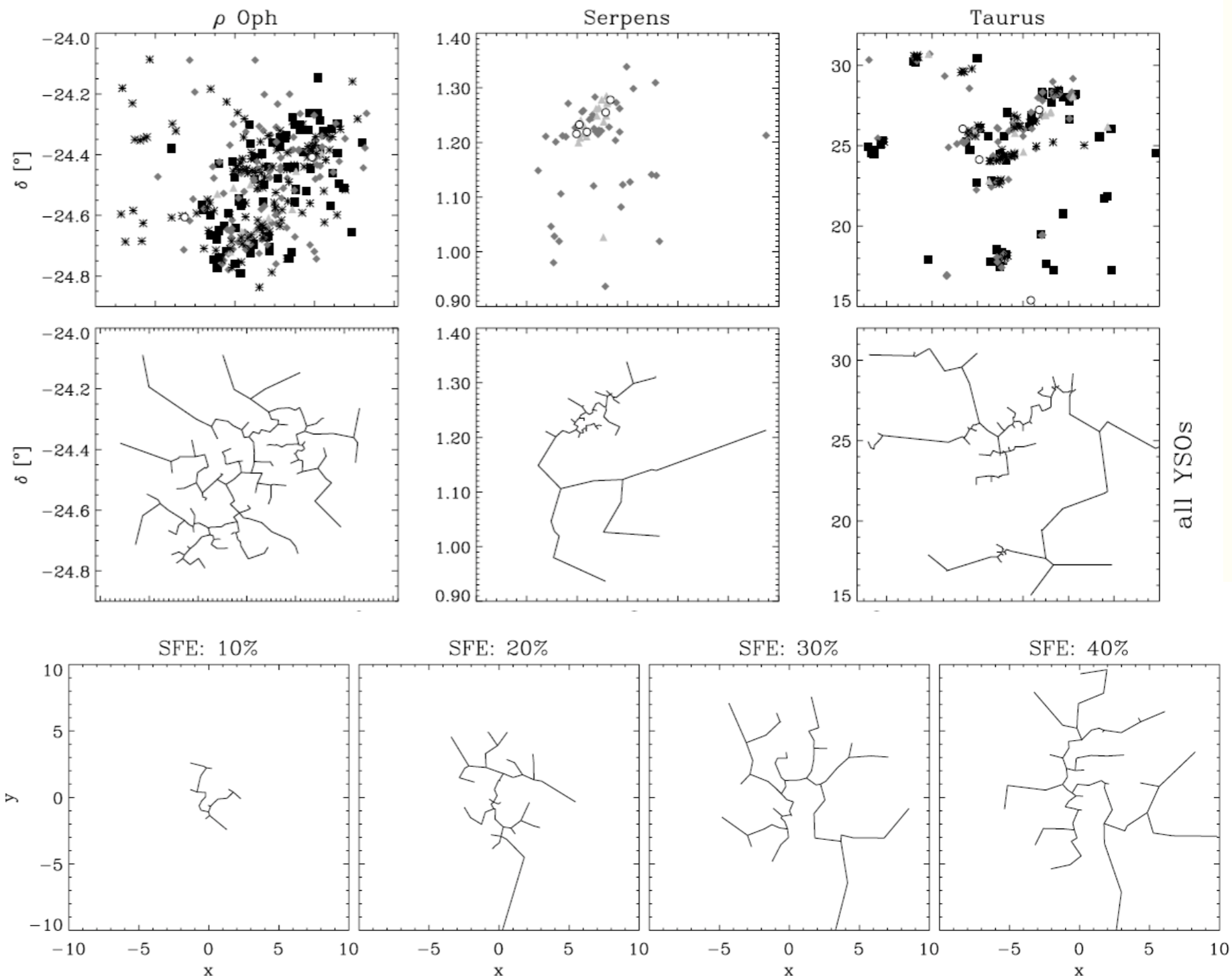


# What stars form from what gas, when?

Theorists  
using  
Observers  
Ingredients

e.g. Schmeja &  
Klessen 2006

S. Schmeja and R. S. Klessen: Evolving structures of star-forming clusters



# Are you hungry yet?

Star Formation Taste Tests > Overview

Dashboard | Choose a project


Star Formation Taste Tests CFA

Overview Messages To-Do Milestones Writeboards Chat Time Files

People Search Permissions

Project overview & activity [New message](#) [New to-do list](#) [New milestone](#) [New file](#)

### Welcome to the Tasting Room



This is the collaborative space for those who do simulations of star forming regions, and those who observe them. It was inspired, in the Fall of 2006, by the NSF proposal entitled "Star Formation Taste Tests," by A. Goodman & E. Rosolowsky. Today, it is used to host conversations about and short descriptions of simulations, along with links to longer descriptions (e.g. Journal articles & web sites). In the future, we are planning to connect more enhanced descriptions of those simulations directly to online code bases and sample outputs (likely with help from our friends at NCSA and SDSC). So, stay tuned.

**TODAY**

**Writeboard** [Notes on KITP Simulation Talks](#) Added by Alyssa G.

**WEDNESDAY, 8 AUGUST**


**Writeboard** [archived Announcement for NSF Reviewers \(from Fall 2006\)](#) Added by Alyssa G.

**Message** [Computational Astrophysics Data Analysis Center \(CADAC\) to be piloted at KITP Workshop](#) Posted by Alyssa G.

**MONDAY, 25 JUNE**

**Message** [Taking a Cue from Climate Modelers](#) Posted by Alyssa G.

**THURSDAY, 7 JUNE**



### This project's RSS feed

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### People on this project

**Harvard IIC**

- Alyssa Goodman
- Helene Tingle  
Last login 2 days ago
- Douglas Alan  
Last login 2 days ago
- Michelle Borkin  
Last login 2 days ago
- Jens Kauffmann  
Last login 2 days ago
- Felice Frankel  
Last login 10 days ago
- Emily Lohmann  
Last login 11 days ago
- Tim Clark  
Last login 13 days ago
- Michael Halle  
Last login 16 days ago

**American Museum of Natural History**

- Héctor Arce  
Last login 4 months ago
- Mordecai-Mark Mac Low  
Last login 9 months ago

# Let's not let food go to waste, even if it is full of artificial ingredients...



The Astrophysics Simulation Collaboratory:  
A Science Portal Enabling Community Software Development

Michael Russell<sup>†</sup>   Gabrielle Allen\*   Greg Daues<sup>‡</sup>   Ian Foster<sup>†¶</sup>   Tom Goodale\*  
Edward Seidel\*   Jason Novotny<sup>‡</sup>   John Shalf<sup>‡§</sup>   Wai-Mo Suen<sup>||</sup>  
Gregor von Laszewski<sup>¶</sup>

April 4, 2001

<http://ascl.net/>

**Abstract**

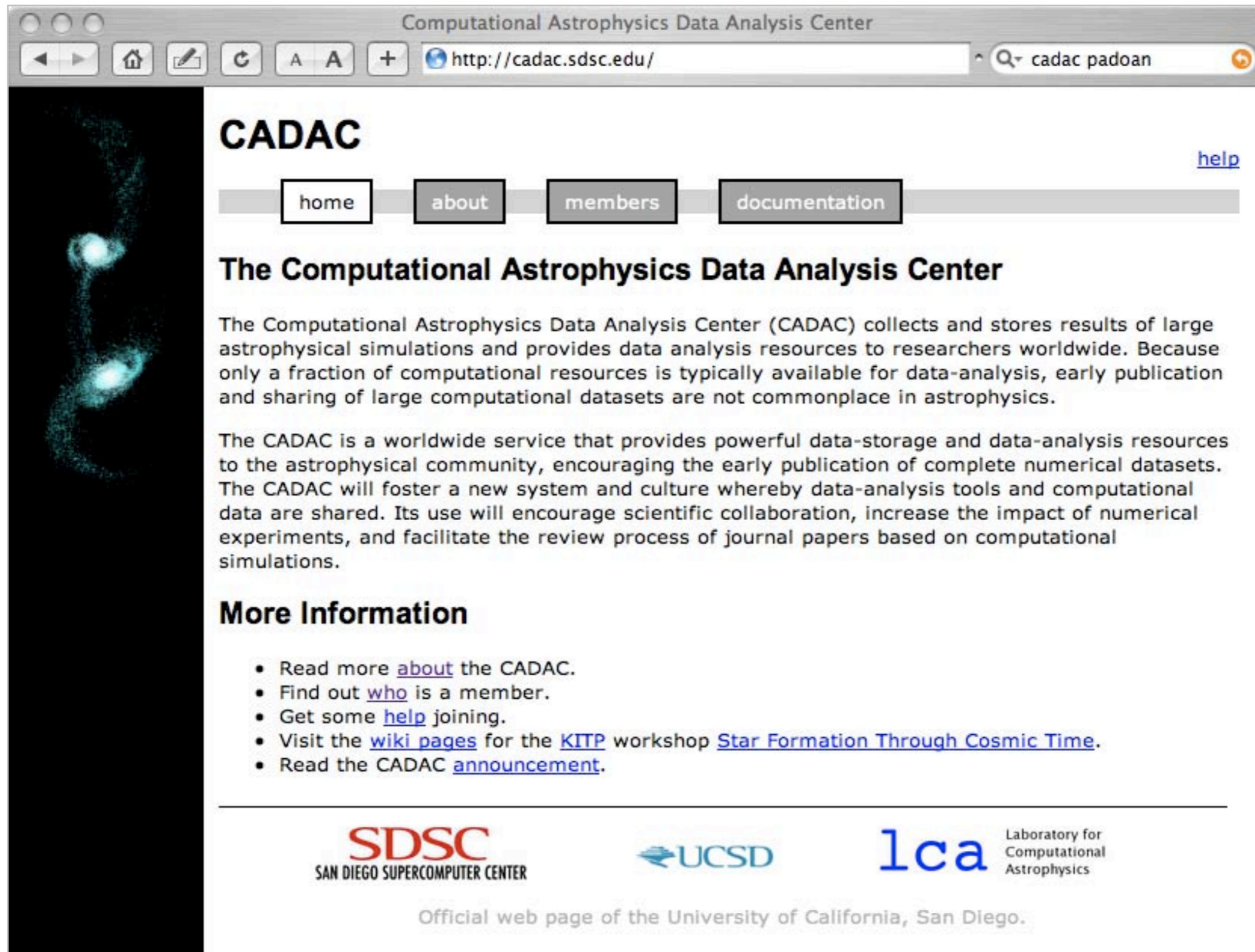
We describe the design and implementation of the Astrophysics Simulation Collaboratory Web Portal.



**US National Virtual Observatory**

Data formats, software, middleware, and infrastructure matter.

# Let's not let food go to waste, even if it is full of artificial ingredients...



The image shows a screenshot of a web browser displaying the homepage of the Computational Astrophysics Data Analysis Center (CADAC). The browser's address bar shows the URL <http://cadac.sdsc.edu/>. The page features a navigation menu with buttons for 'home', 'about', 'members', and 'documentation', along with a 'help' link. The main content area includes a title 'The Computational Astrophysics Data Analysis Center' and two paragraphs of text describing the center's mission and services. A 'More Information' section lists several links for further reading. The footer contains logos for SDSC, UCSD, and lca, along with a footer note.

Computational Astrophysics Data Analysis Center

<http://cadac.sdsc.edu/> cadac padoan

## CADAC

[home](#) [about](#) [members](#) [documentation](#) [help](#)

### The Computational Astrophysics Data Analysis Center


The Computational Astrophysics Data Analysis Center (CADAC) collects and stores results of large astrophysical simulations and provides data analysis resources to researchers worldwide. Because only a fraction of computational resources is typically available for data-analysis, early publication and sharing of large computational datasets are not commonplace in astrophysics.

The CADAC is a worldwide service that provides powerful data-storage and data-analysis resources to the astrophysical community, encouraging the early publication of complete numerical datasets. The CADAC will foster a new system and culture whereby data-analysis tools and computational data are shared. Its use will encourage scientific collaboration, increase the impact of numerical experiments, and facilitate the review process of journal papers based on computational simulations.

### More Information

- Read more [about](#) the CADAC.
- Find out [who](#) is a member.
- Get some [help](#) joining.
- Visit the [wiki pages](#) for the [KITP](#) workshop [Star Formation Through Cosmic Time](#).
- Read the CADAC [announcement](#).

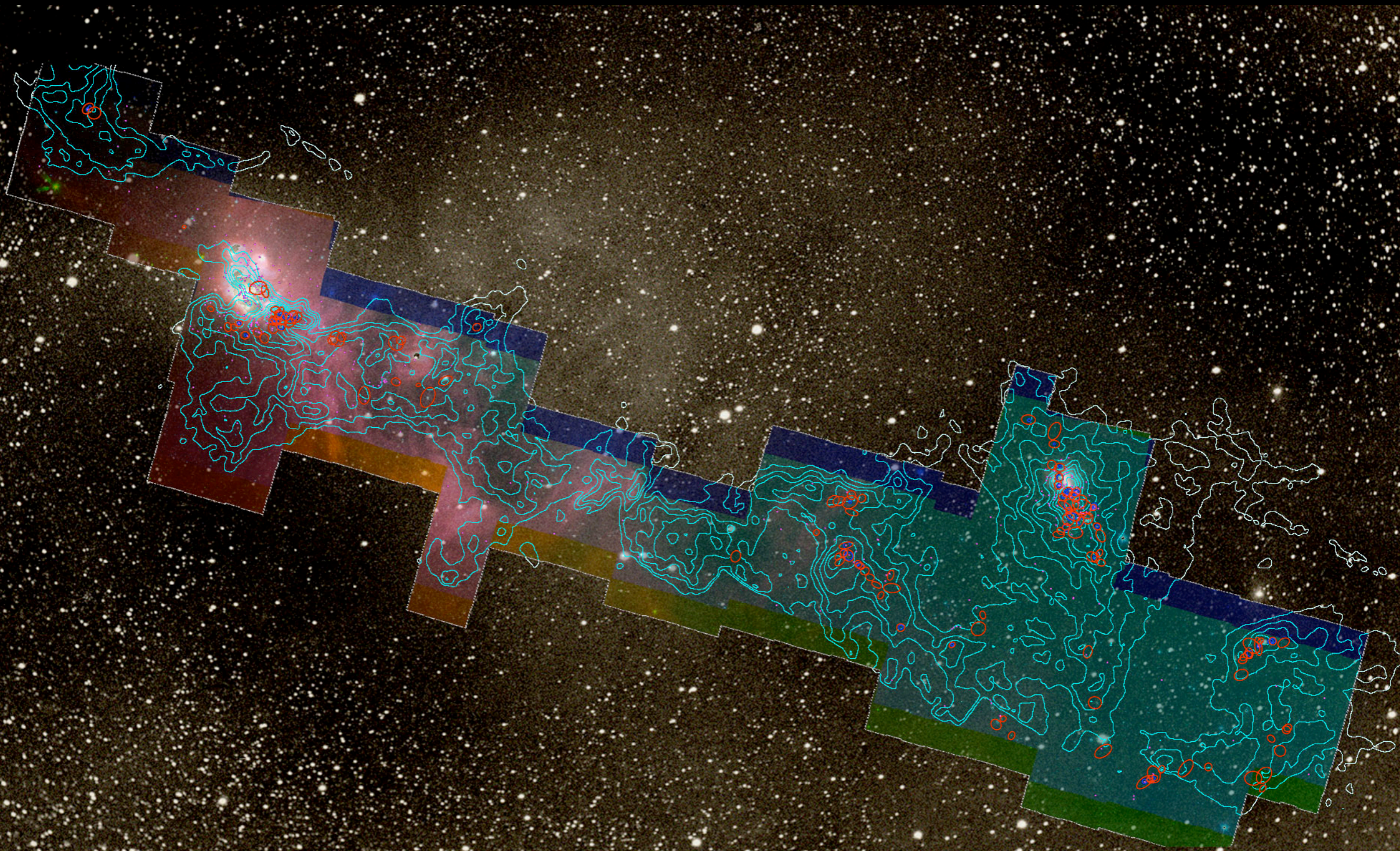
**SDSC**  
SAN DIEGO SUPERCOMPUTER CENTER

 UCSD

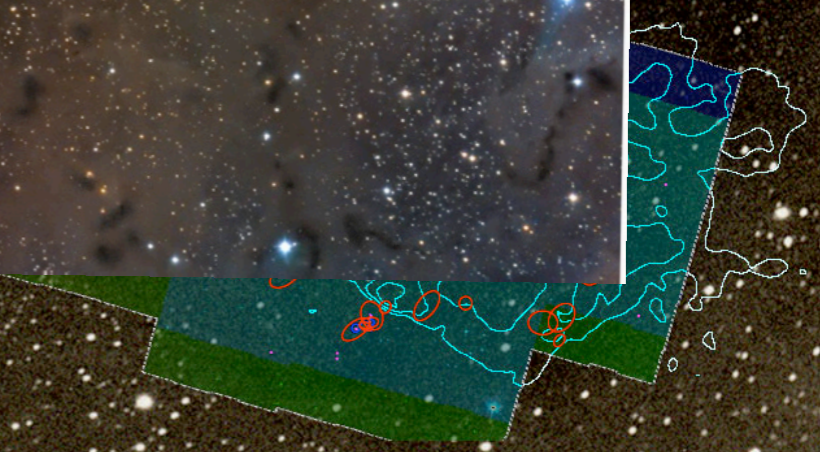
**lca** Laboratory for Computational Astrophysics

Official web page of the University of California, San Diego.

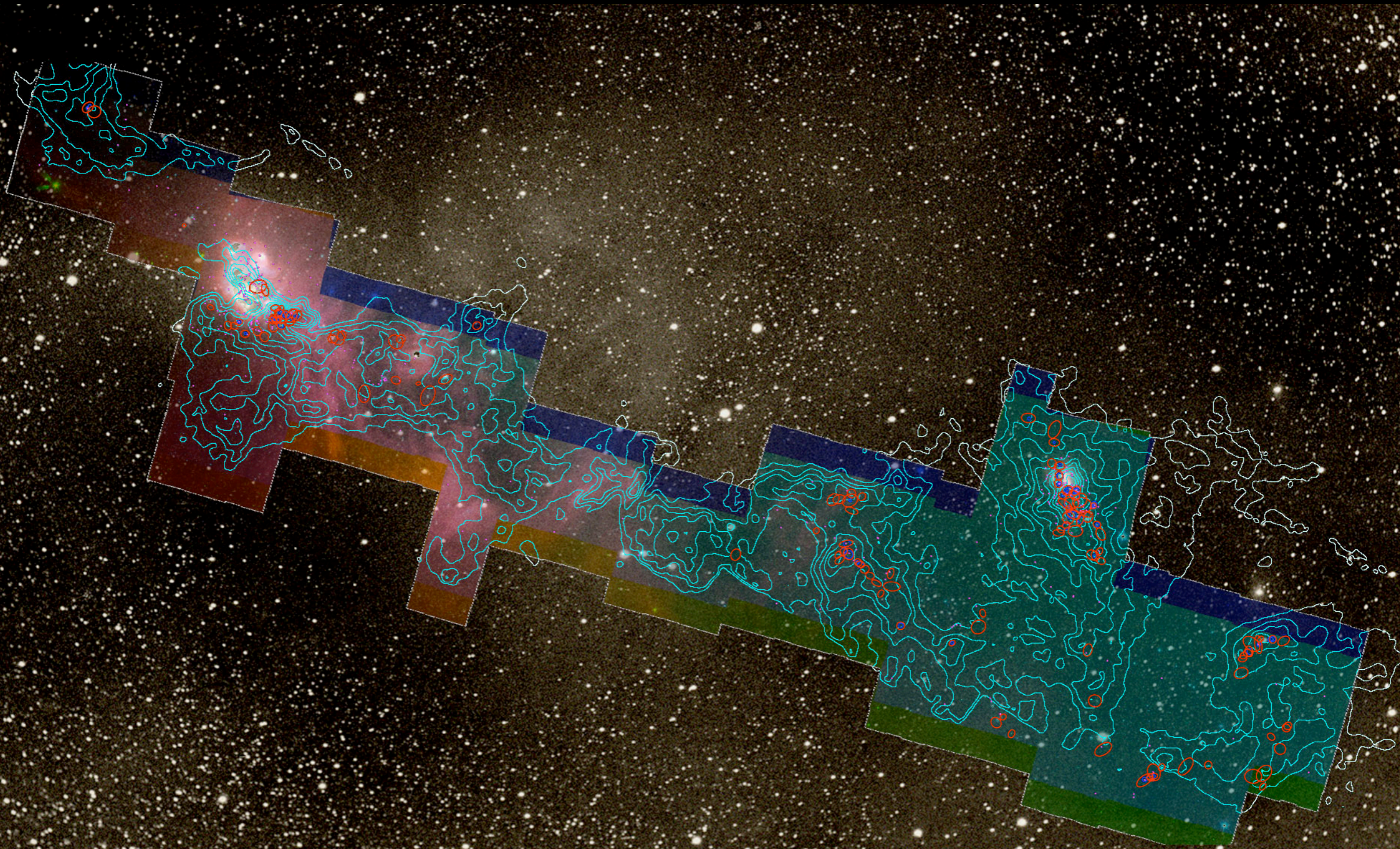
Who can make this?



Who can make this?



Who can make this?



Who can make this?

