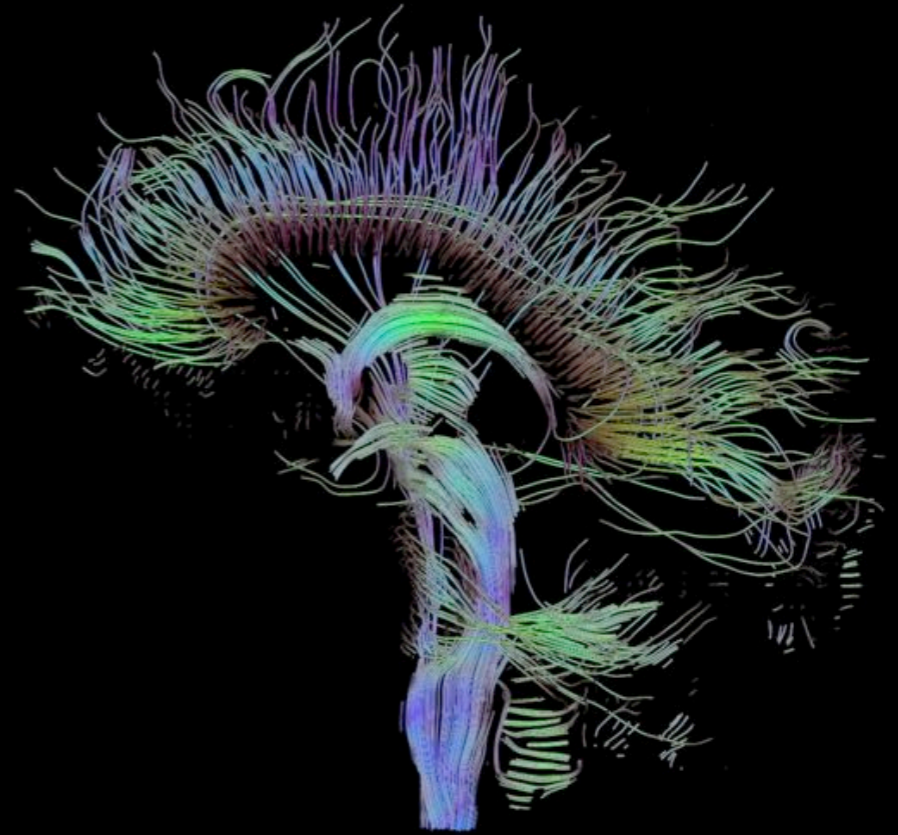
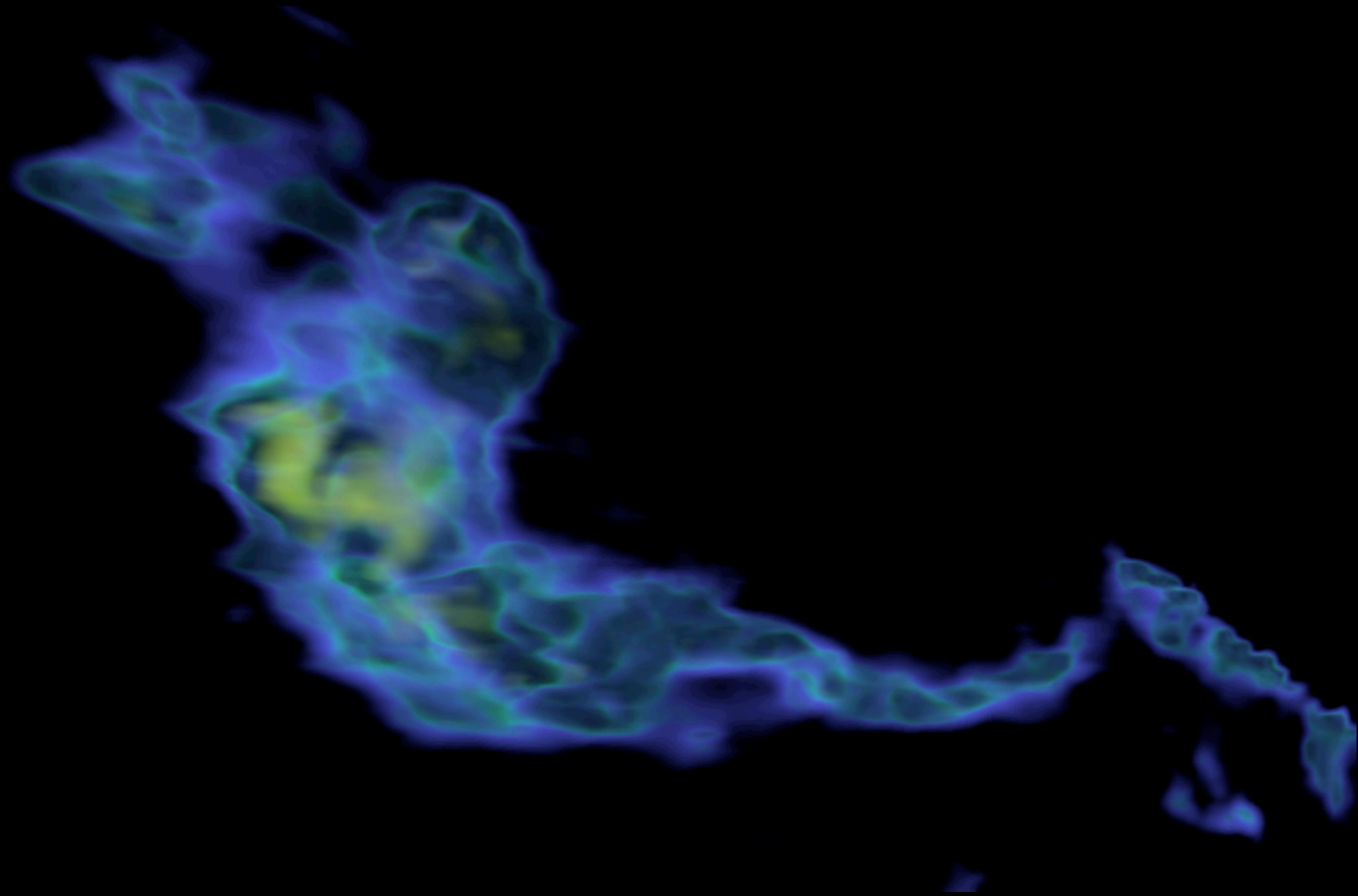


Astronomy + Medicine = Understanding



Alyssa A. Goodman



Initiative in Innovative Computing @ Harvard
and



Harvard-Smithsonian Center for Astrophysics

Special Thanks to...

COMPLETE

M. **Borkin** (IIC), J. **Foster** CfA), J. **Kauffmann** (CfA/IIC), J. **Pineda** (CfA)
& E. **Rosolowsky** (CfA) + many COMPLETErs beyond Cambridge!

Astronomical Medicine

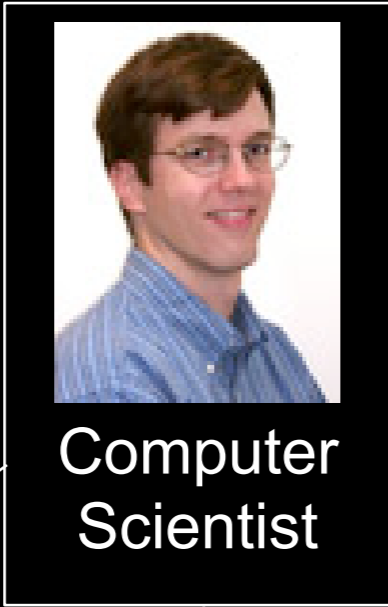
D. **Alan** (IIC), M. **Borkin** (IIC), M. **Halle** (IIC/BWH-SPL), N. **Holliman**
(Durham, UK), J. **Kauffmann** (CfA/IIC), R. **Kikinis** (BWH-SPL)

3D Software you will see...

3D Slicer, OsiriX, VolView

more at: <http://astromed.iic.harvard.edu/>

The Astronomical Medicine Story



“Viz has failed the scientific community...”

The screenshot shows the IIC website header with the logo and the text "Initiative in Innovative Computing at Harvard". Below the header, there is a section titled "projects" with a sub-section for "Astronomical Medicine". This section features two images: a 3D visualization of a complex structure within a wireframe cube, and a 2D heatmap image. Below the images, the text lists the "Lead Investigators" (Alyssa Goodman, Mike Halle, Ron Kikinis, David Kennedy), the "Project Staff" (Doug Alan, Michelle Borkin, Jens Kauffmann), and a "Description" of the "AstroMed" project.

- +Nick Holliman (CS, 3D expert)
- +Doug Alan (S/W Engineer)
- +Jens Kauffmann (postdoc)



Relative Strengths

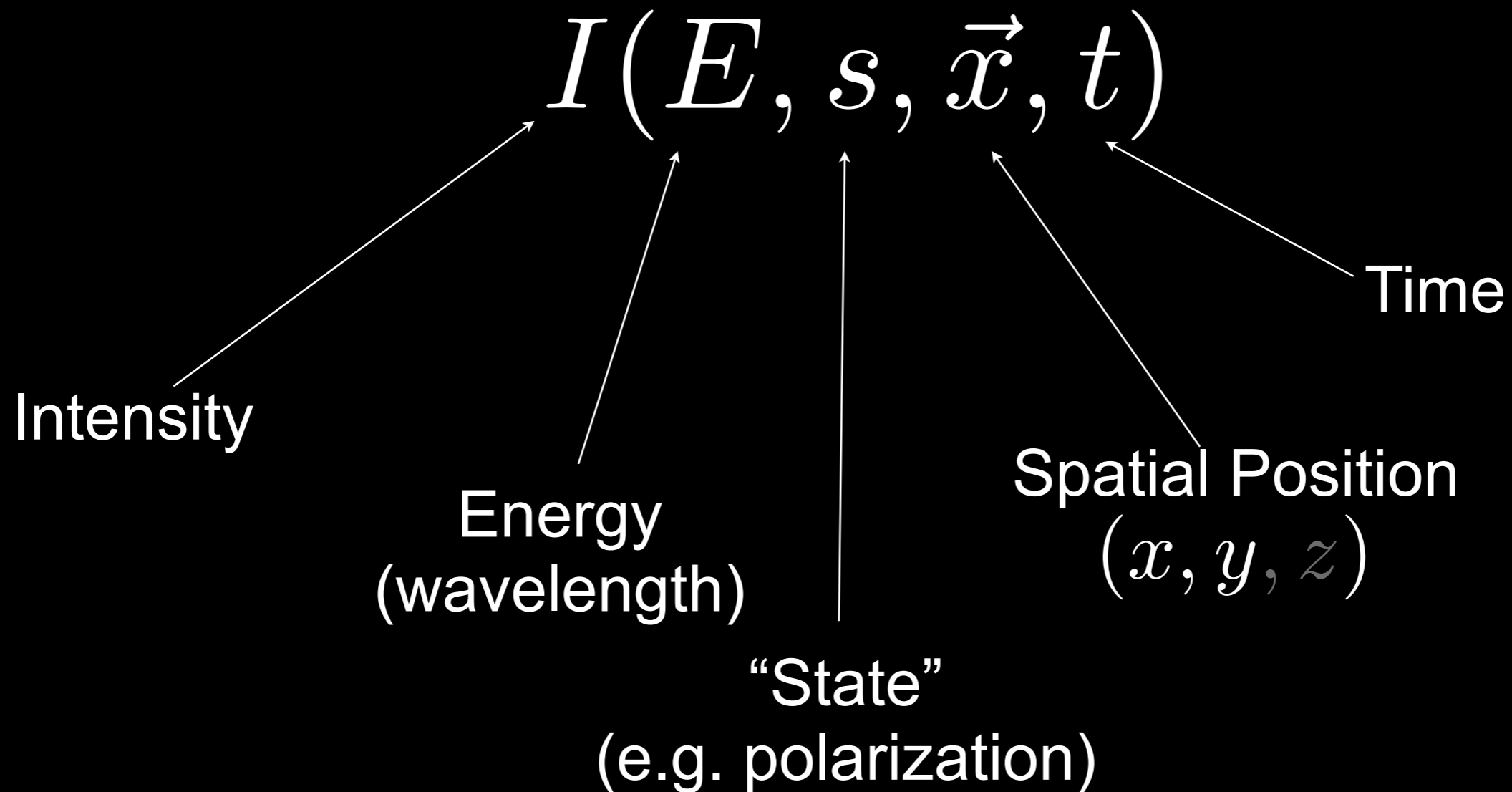


Pattern Recognition
Creativity



Calculations

What can we observe?



...and the science is in the interpretation of these measurements into physical quantities & processes.

What can we observe?

$$I(\vec{x})$$

Intensity



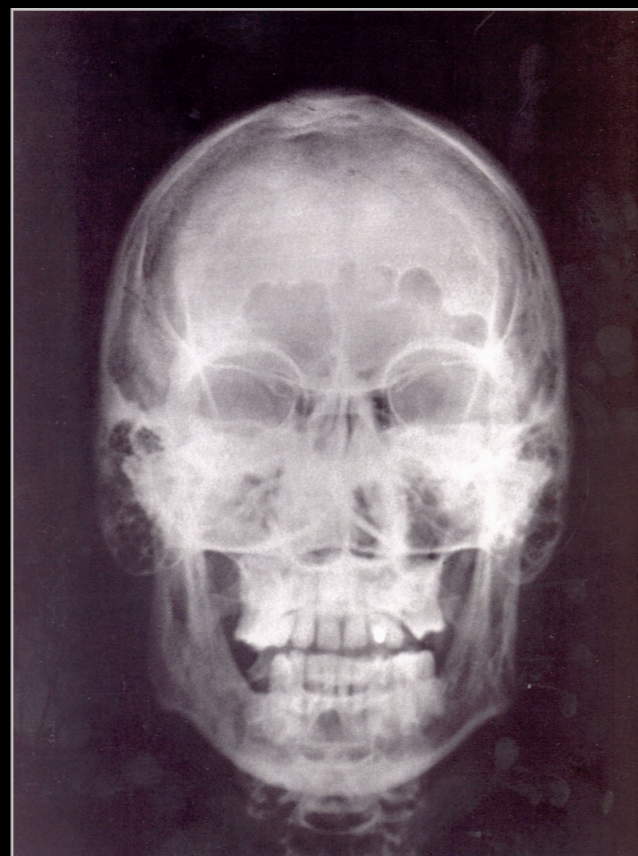
Optical Single-Band
Image of NGC1333

Spatial Position
(x, y)

What can we observe?

$$I(\vec{x})$$

Intensity



Spatial Position
(x, y)

X-Ray of Human Skull, c. 1920

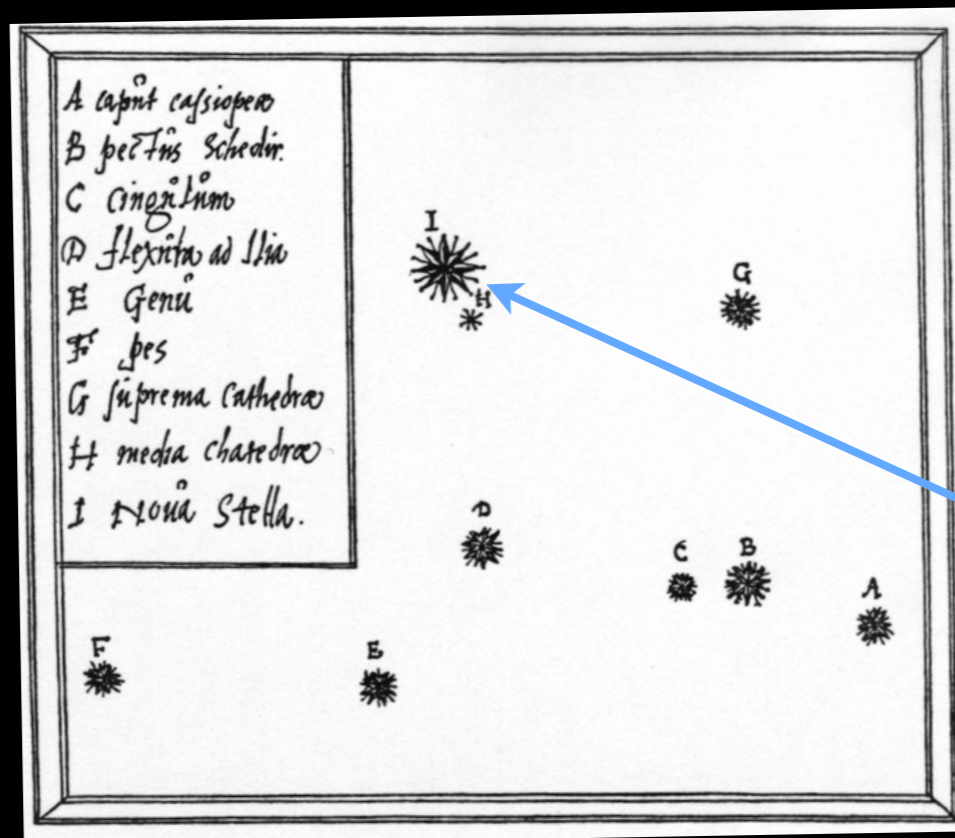
What can we observe?

$$I(\vec{x}, t)$$

Intensity

Time

Spatial Position
(x, y, z)



“Nova Stella”
of Tycho, 1572

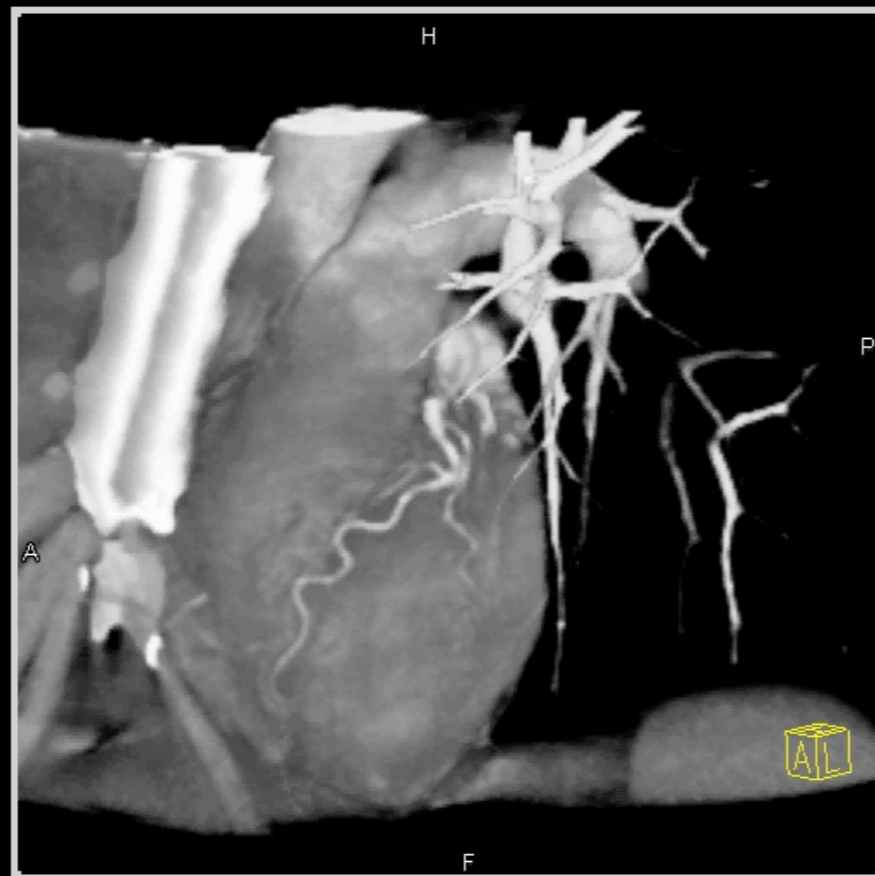
What can we observe?

$$I(\vec{x}, t)$$

Intensity

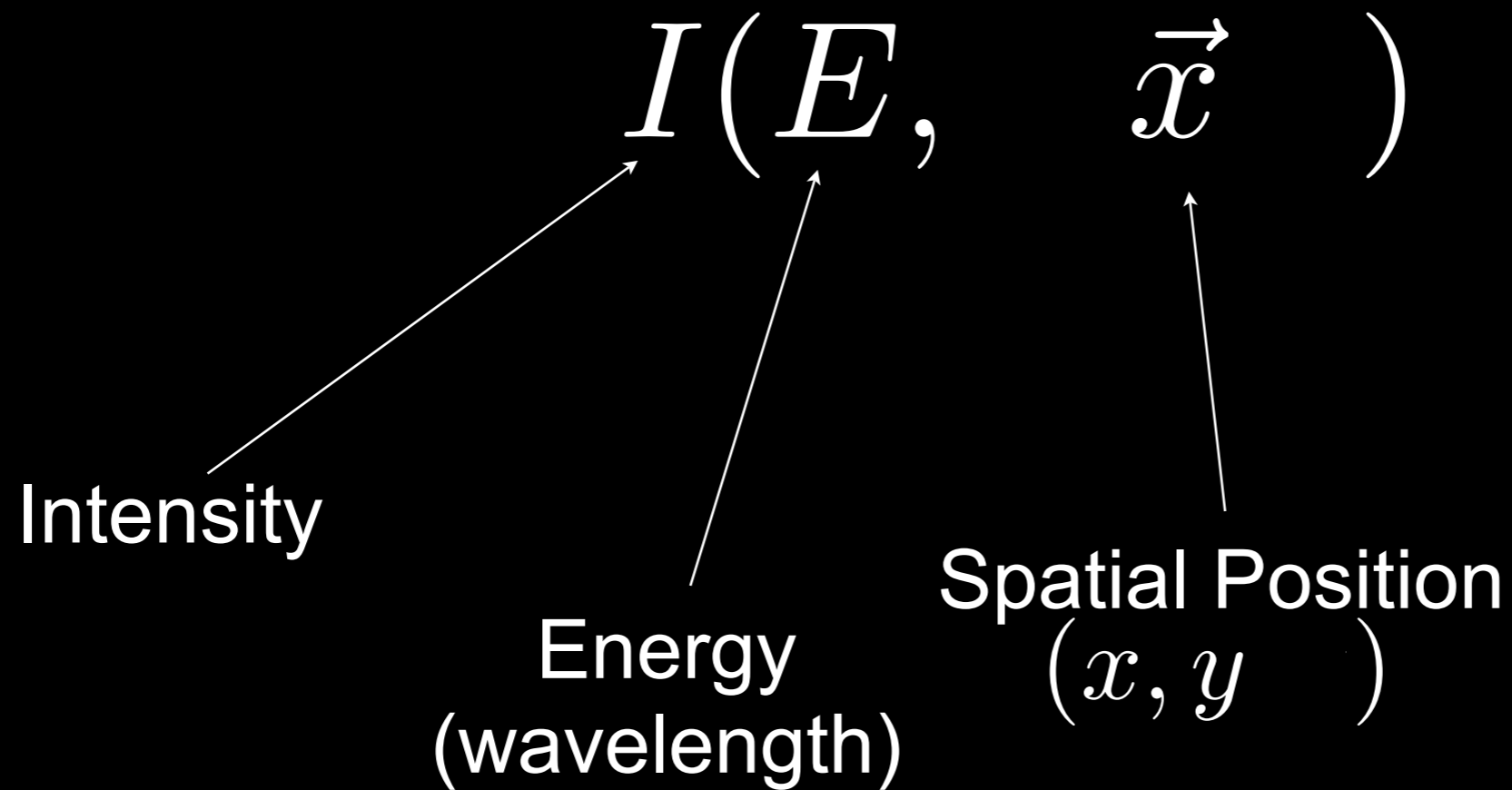
Time

Spatial Position
 (x, y, z)



Cardiac Motion

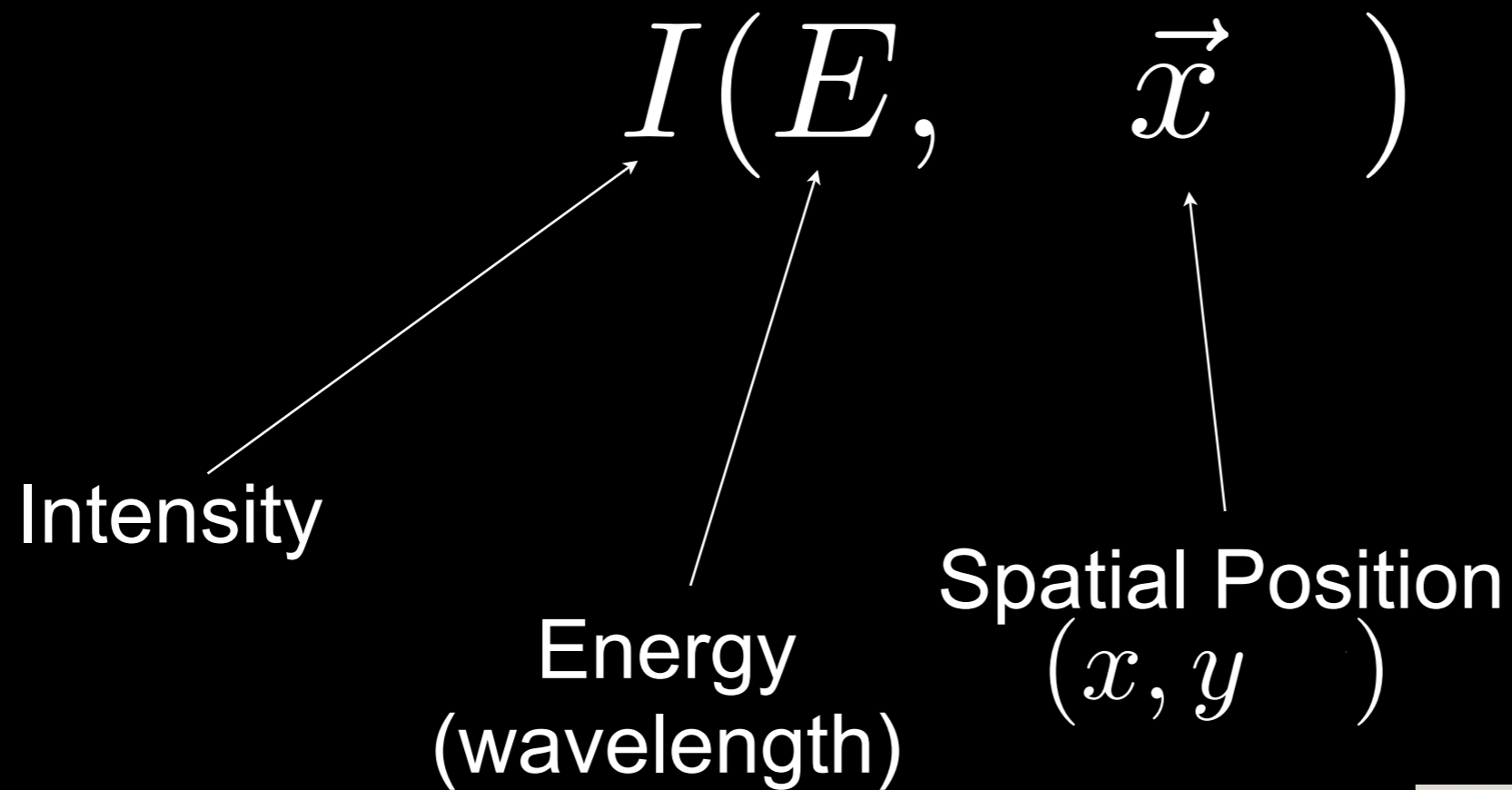
What can we observe?



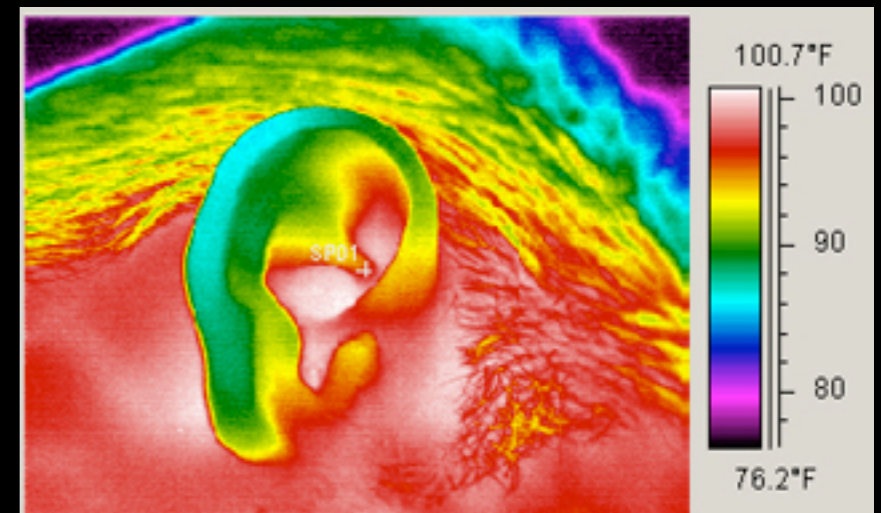
Optical (B,V,R) image
of NGC1333



What can we observe?



Human Ear,
Thermal Infrared



What can we observe?

$$I(s, \vec{x})$$

Intensity

Spatial Position
(x, y)

“State”
(e.g. polarization)

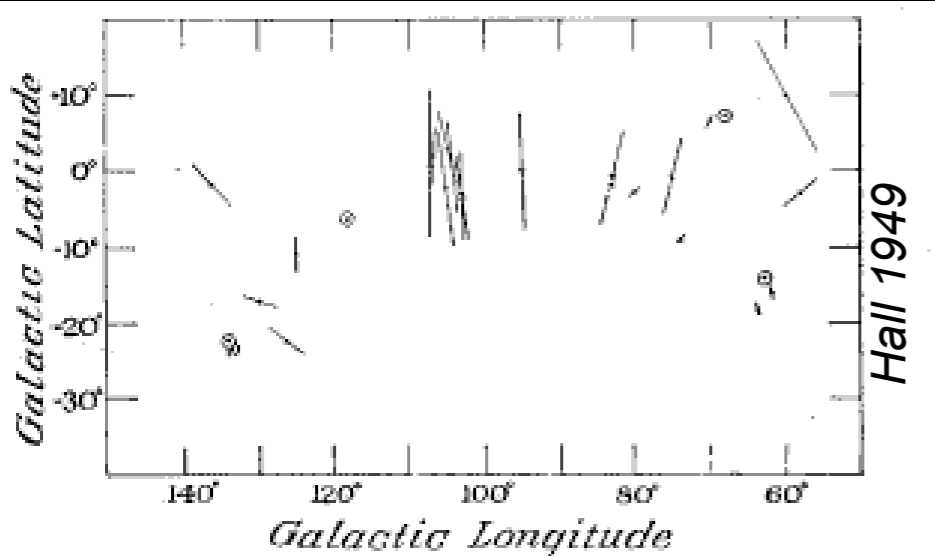


FIG. 4. Observational evidence that there is no one preferential orientation of the plane of polarization. Stars showing no polarization are represented by circles.

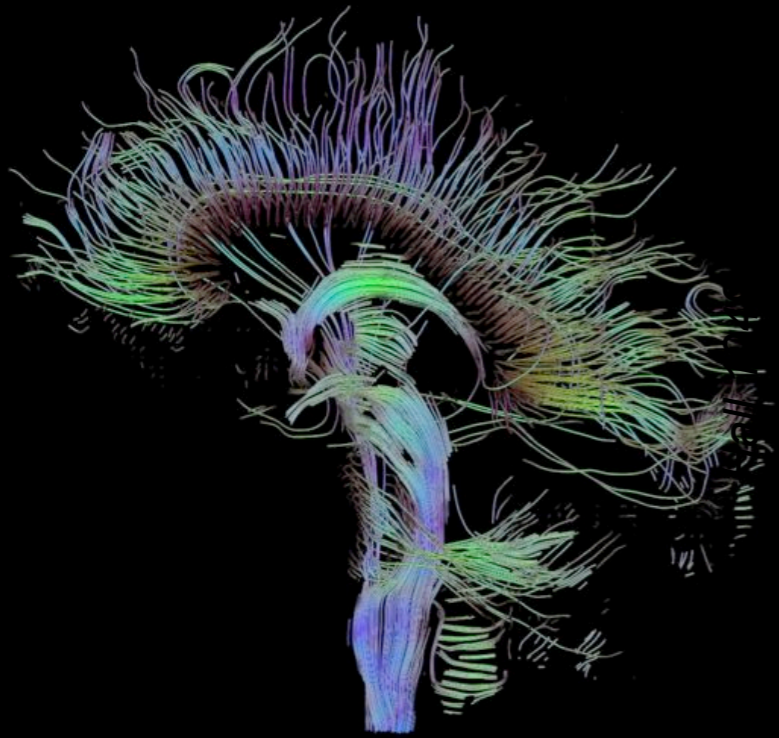
What can we observe?

$$I(s, \vec{x})$$

Intensity

Spatial Position
(x, y, z)

“State”
(~diffusivity)



Our current
interest in
 $I(E, s, \vec{x}, t)$



COMPLETE Home Page

http://www.cfa.harvard.edu/COMPLETE/

Google Calendar Wikis Etc. Directories Delicious RSS (1423) ADS Best BeyondADS Image Search Weather

COMPLETE

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

- Data
- Results
- Projects
- People
- Learn
- Restricted

Project Description

The **CO**ordinated **M**olecular **P**robe **L**ine **E**xinction **T**hermal **E**mission Survey of Star Forming Regions (COMPLETE) provides a range of data complementary to the Spitzer Legacy Program "[From Molecular Cores to Planet Forming Disks](#)" (c2d) for the Perseus, Ophiuchus and Serpens regions. In combination with the Spitzer observations, COMPLETE will allow for detailed analysis and understanding of the physics of star formation on scales from 500 A.U. to 10 pc.

Phase I, which is now complete, provides fully sampled, arcminute resolution observations of the density and velocity structure of the three regions, comprising: extinction maps derived from the Two Micron All Sky Survey (2MASS) near-infrared data using the NICER algorithm; extinction and temperature maps derived from IRAS 60 and 100um emission; HI maps of atomic gas; 12CO and 13CO maps of molecular gas; and submillimeter continuum images of emission from dust in dense cores.

Click on the "Data" button to the left to access this data.

Phase II (which is still ongoing) uses targeted source lists based on the Phase I data, as it is (still) not feasible to cover every dense star-forming peak at high resolution. Phase II includes high-sensitivity near-IR imaging (for high resolution extinction mapping), mm-continuum imaging with MAMBO on IRAM and high-resolution observations of dense gas tracers such as N₂H⁺. These data are being released as they are validated.

[COMPLETE Postdoc, 2007](#)

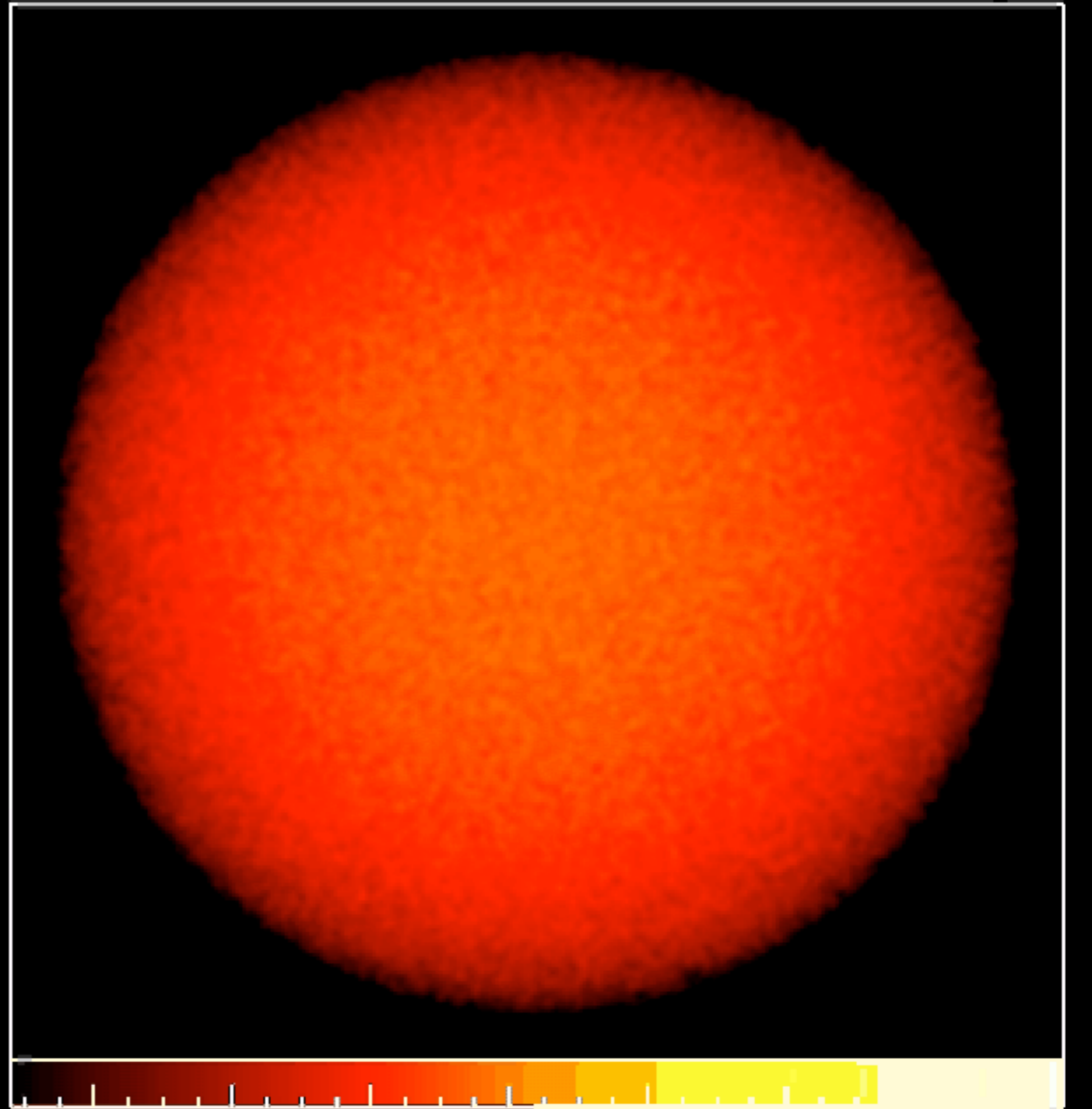
Referencing Data from the COMPLETE Survey

COMPLETE data are non-proprietary. Please reference **Ridge, N.A. et al., "The COMPLETE Survey of Star Forming Regions: Phase 1 Data". 2006. AJ, 131, 2921** as

3D Simulation of a Star-Forming Cluster

Dimensions: 82500. AU

Time: 0. yr



HD turbulence gives "t=0" conditions; Jeans
mass = $1 M_{\text{sun}}$

$50 M_{\text{sun}}$ **0.38 pc**, $n_{\text{avg}} = 3 \times 10^5$ ptcls/cc

forms ~ 50 objects

$T = 10$ K

SPH, no B or Λ , Γ

movie = 1.4 free-fall times






Bate, Bonnell & Bromm 2002

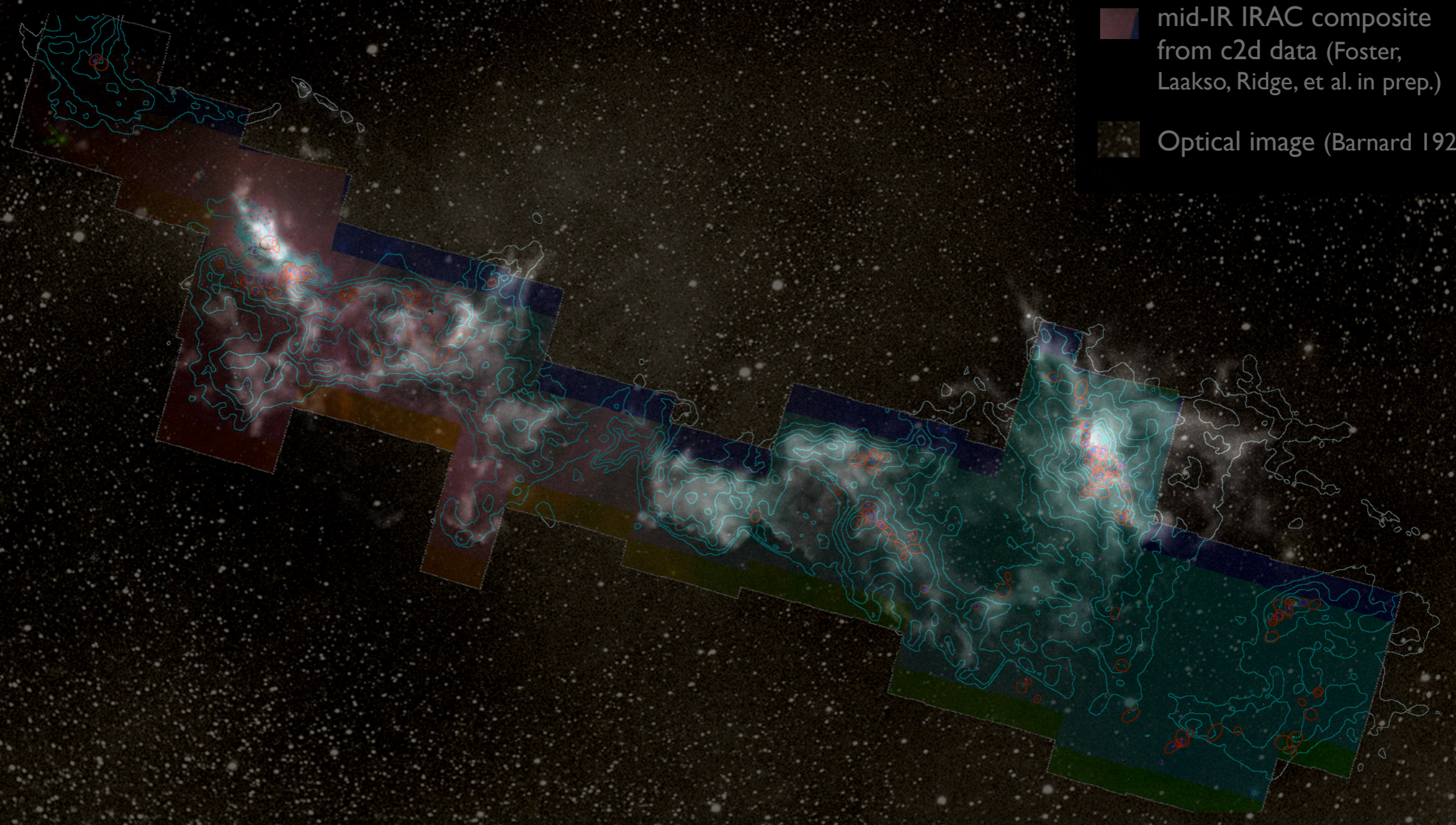
Log Column Density [g/cm^2]

Matthew Bate

COMPLETE = COordinated Molecular Probe Line Extinction Thermal Emission

image size: 520 x 274
view size: 1305 x 733
W/L: 63 W/W: 127

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



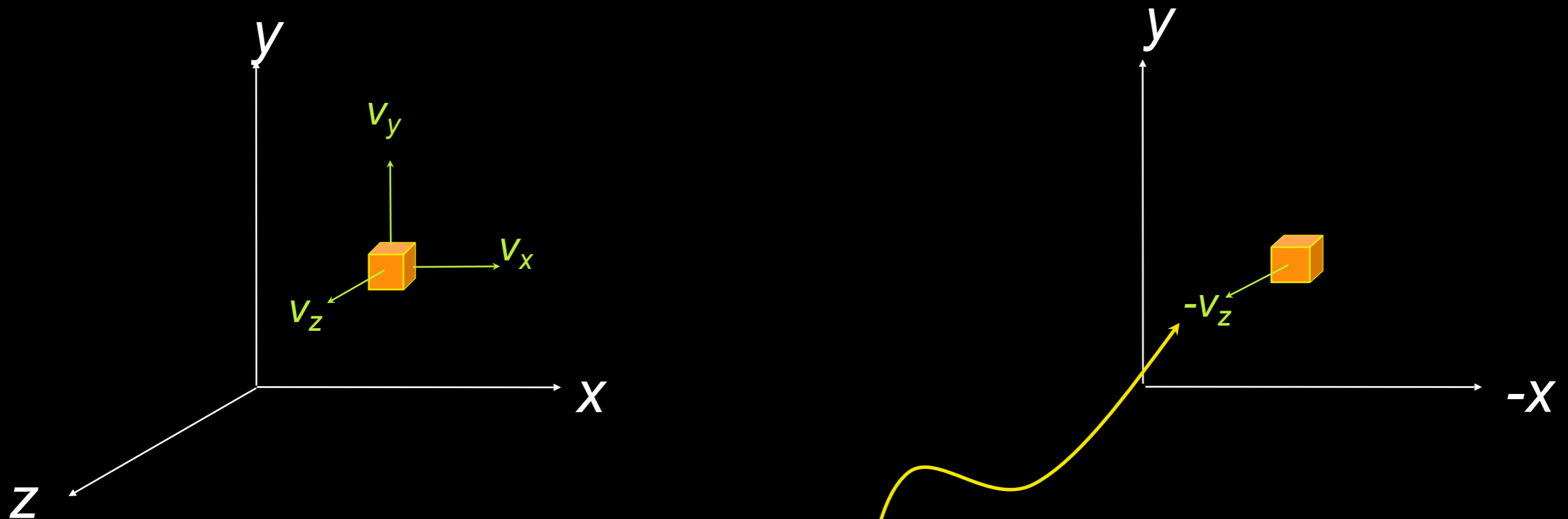
m: 163/249
zoom: 227% Angle: 0



“Three” Dimensions: Spectral-Line Mapping

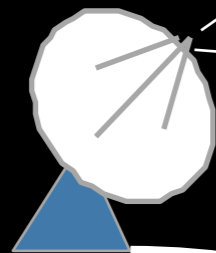
We wish we could measure...

But we can measure...

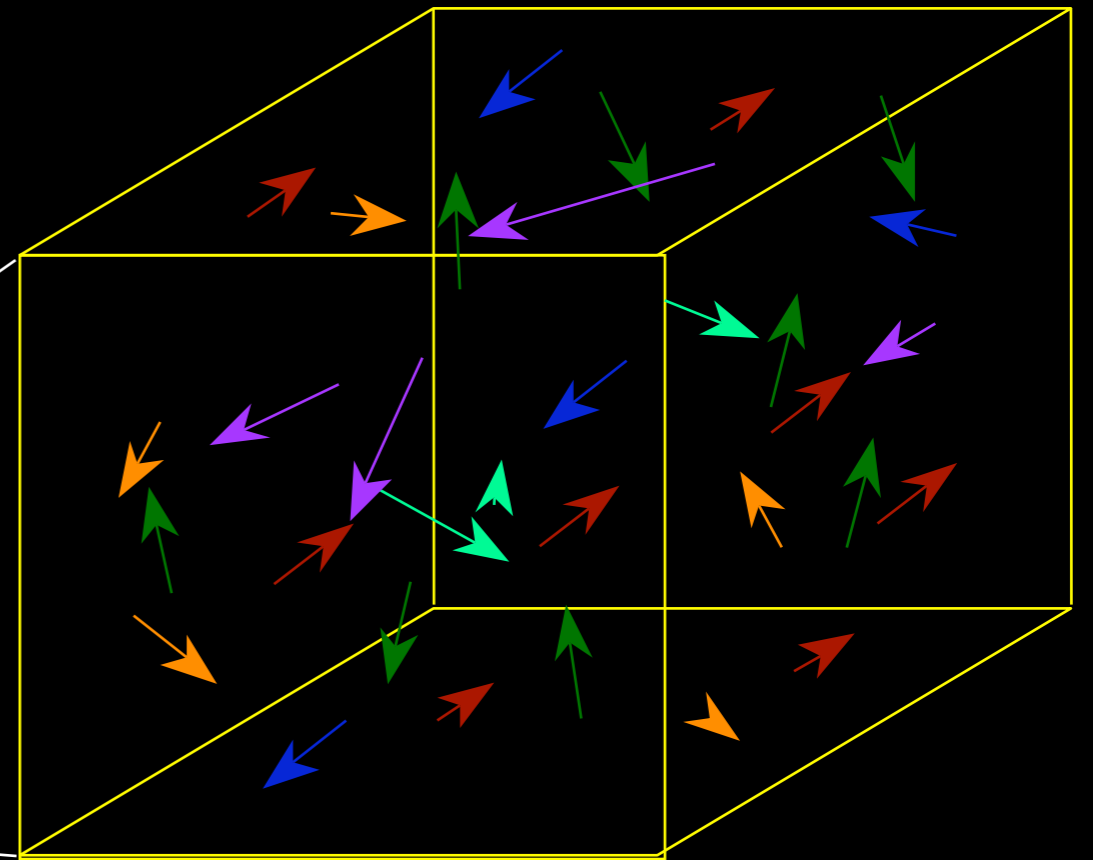


v_z *only* from
“spectral-line
maps”

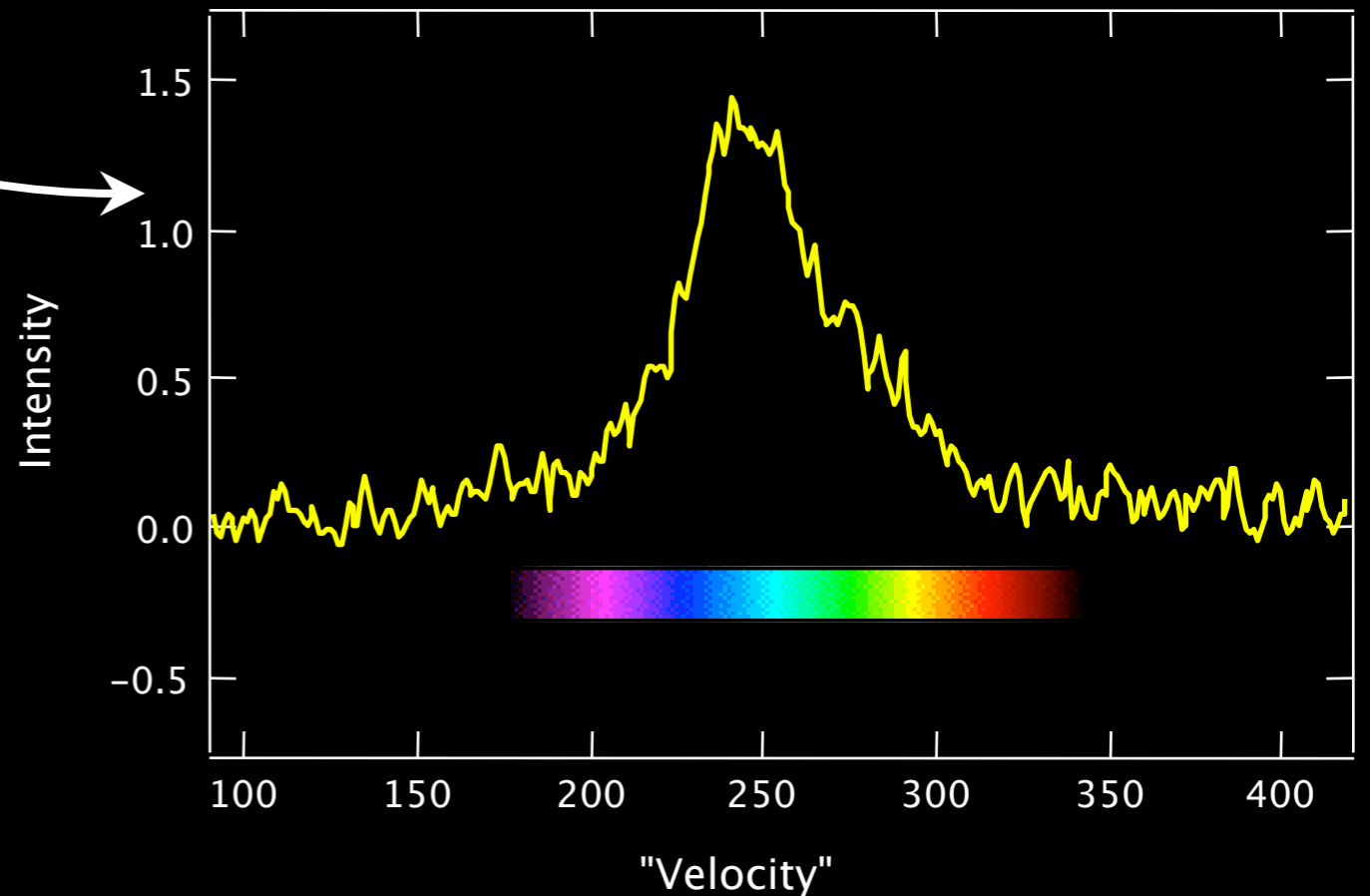
Velocity from Spectroscopy



Telescope +
Spectrometer

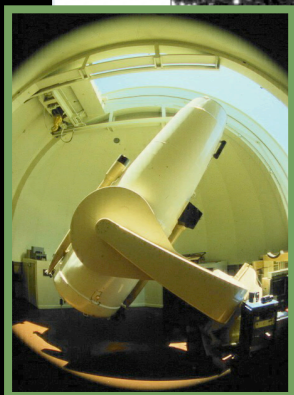
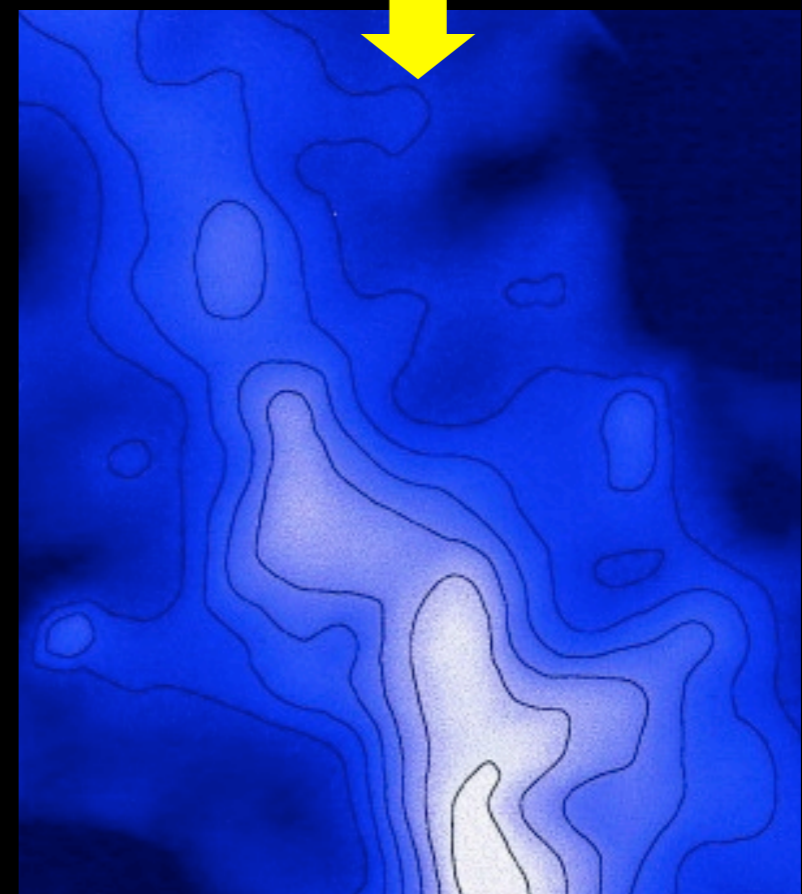
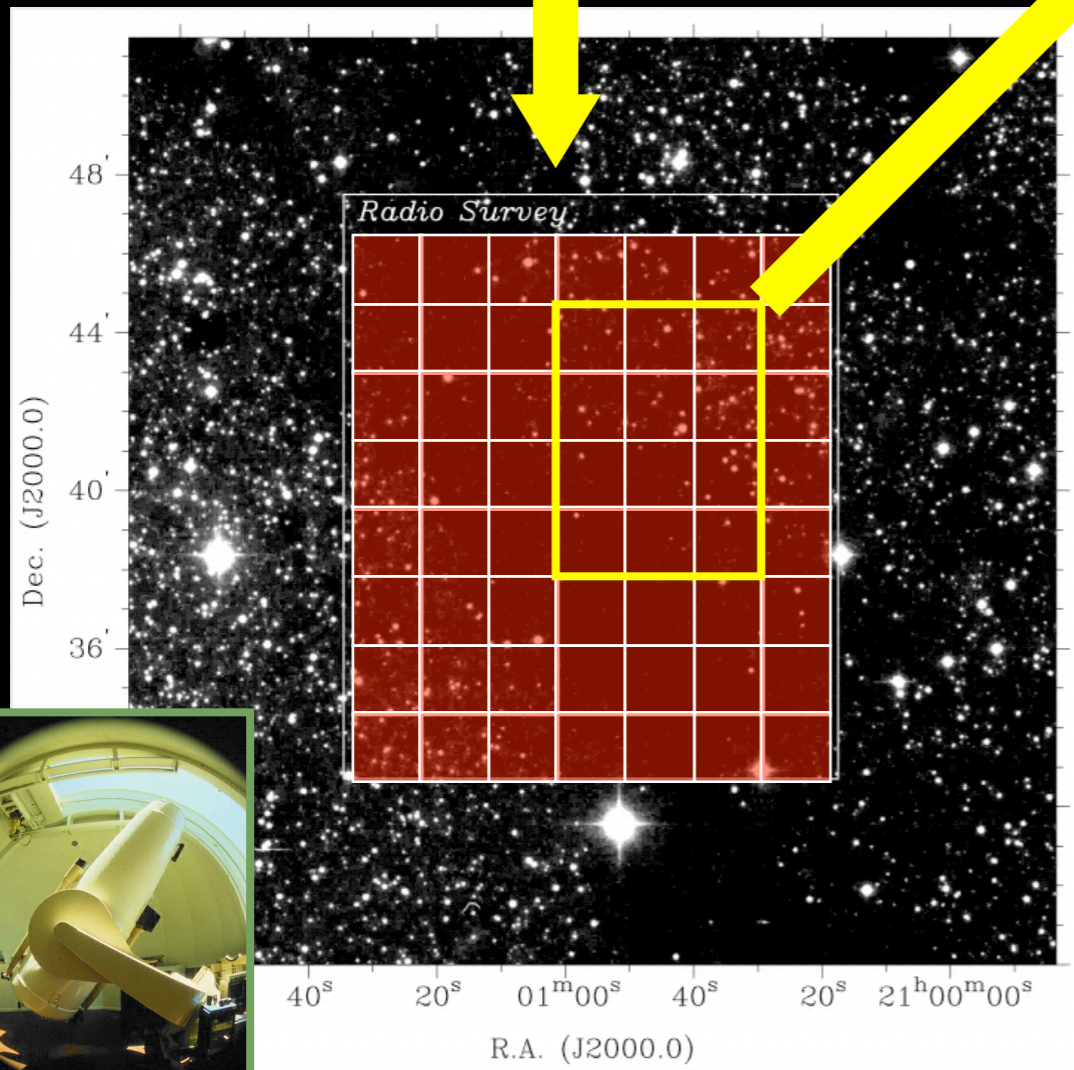
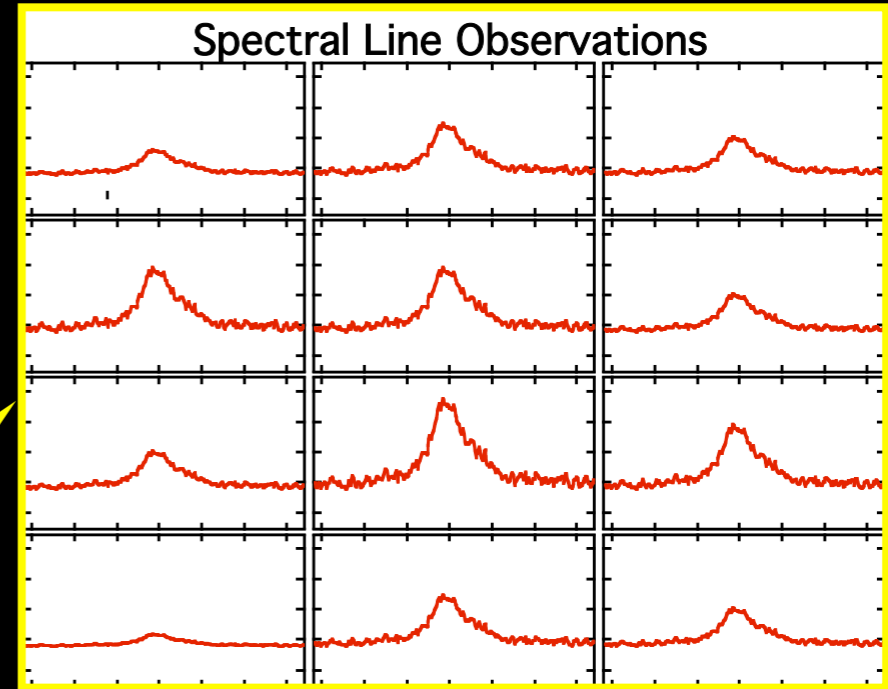


Observed Spectrum

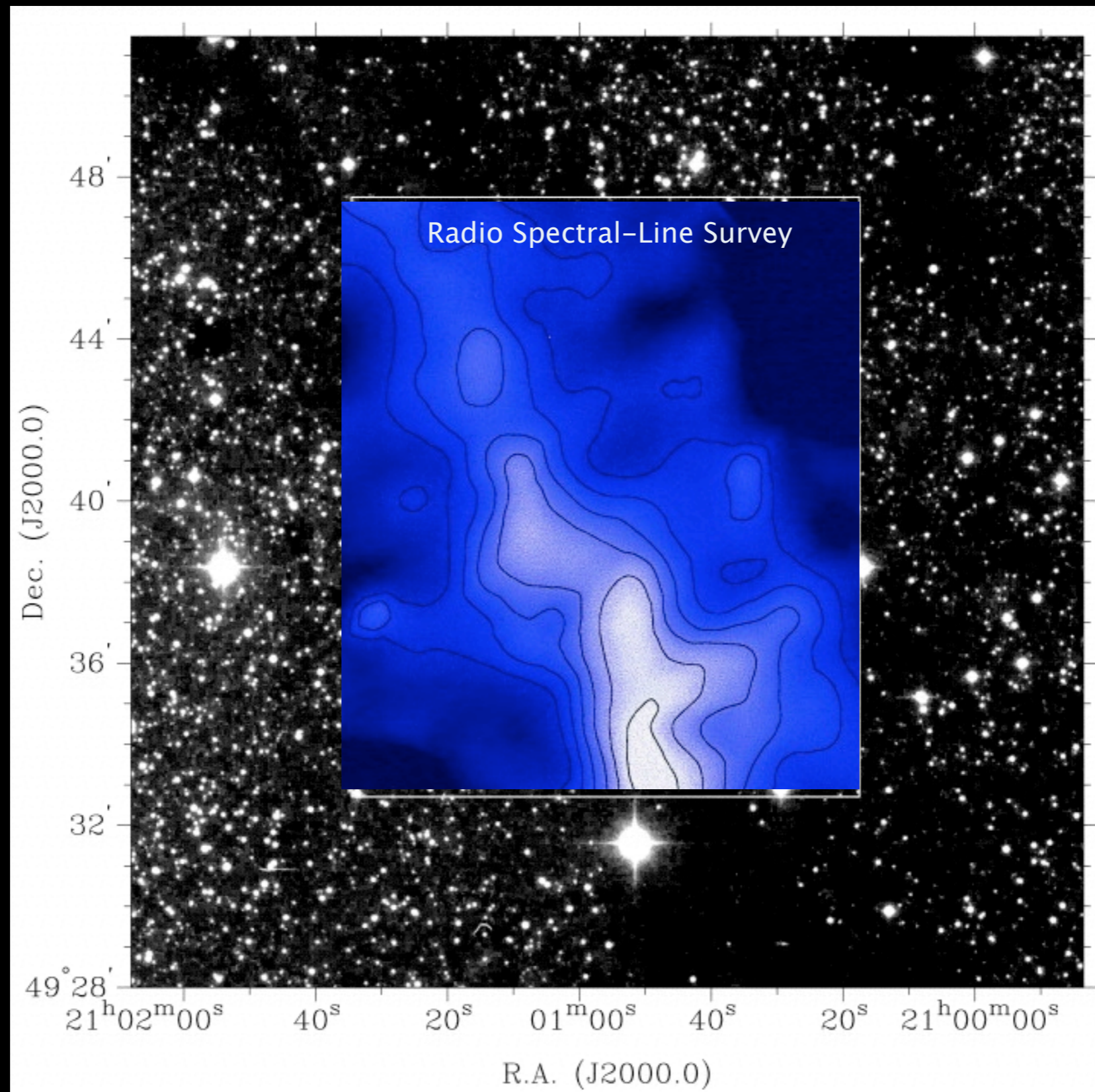


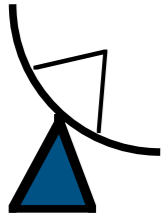
All thanks to *Doppler*

Radio Spectral-line Observations of Interstellar Clouds

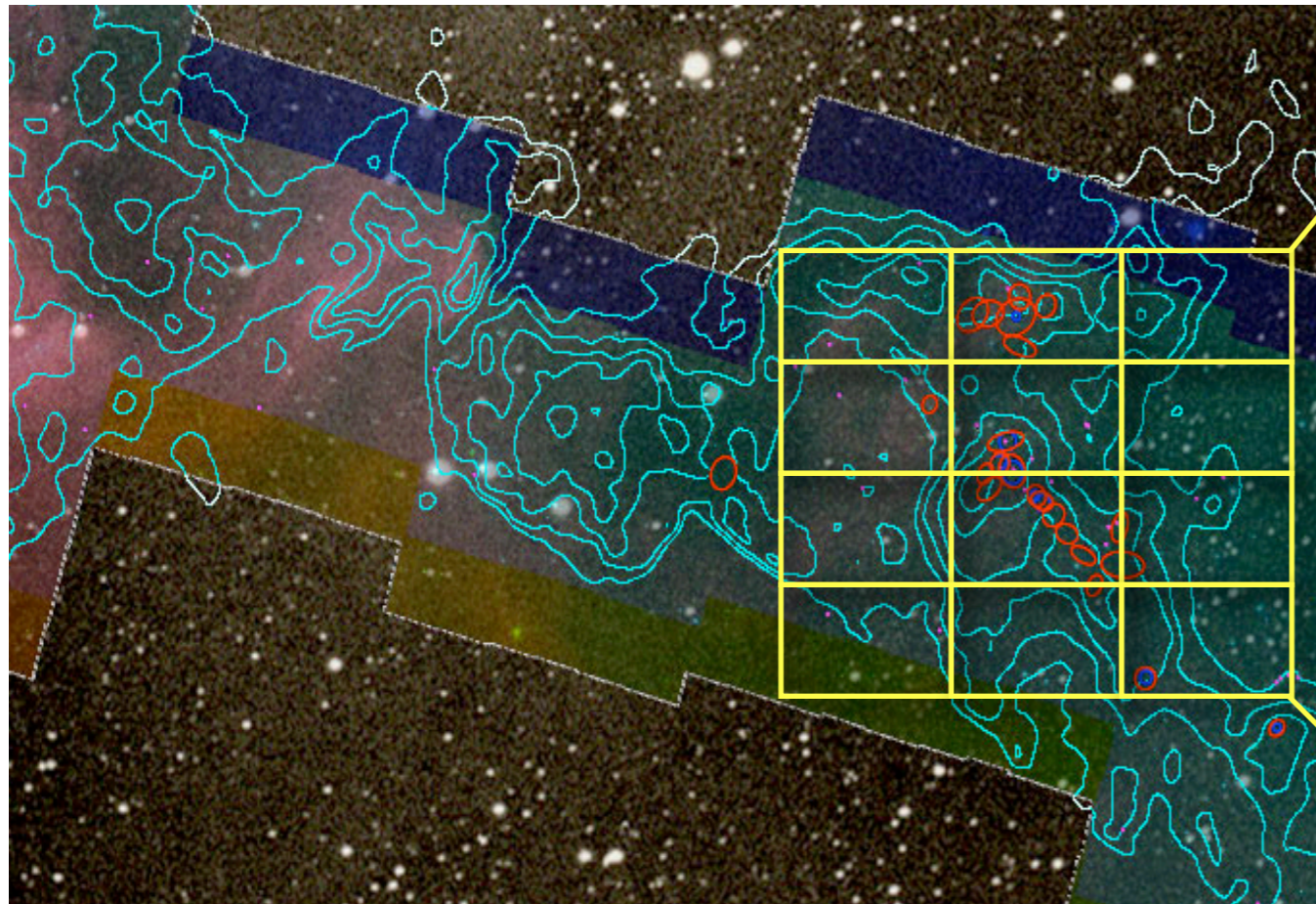


Radio Spectral-line Observations of Interstellar Clouds

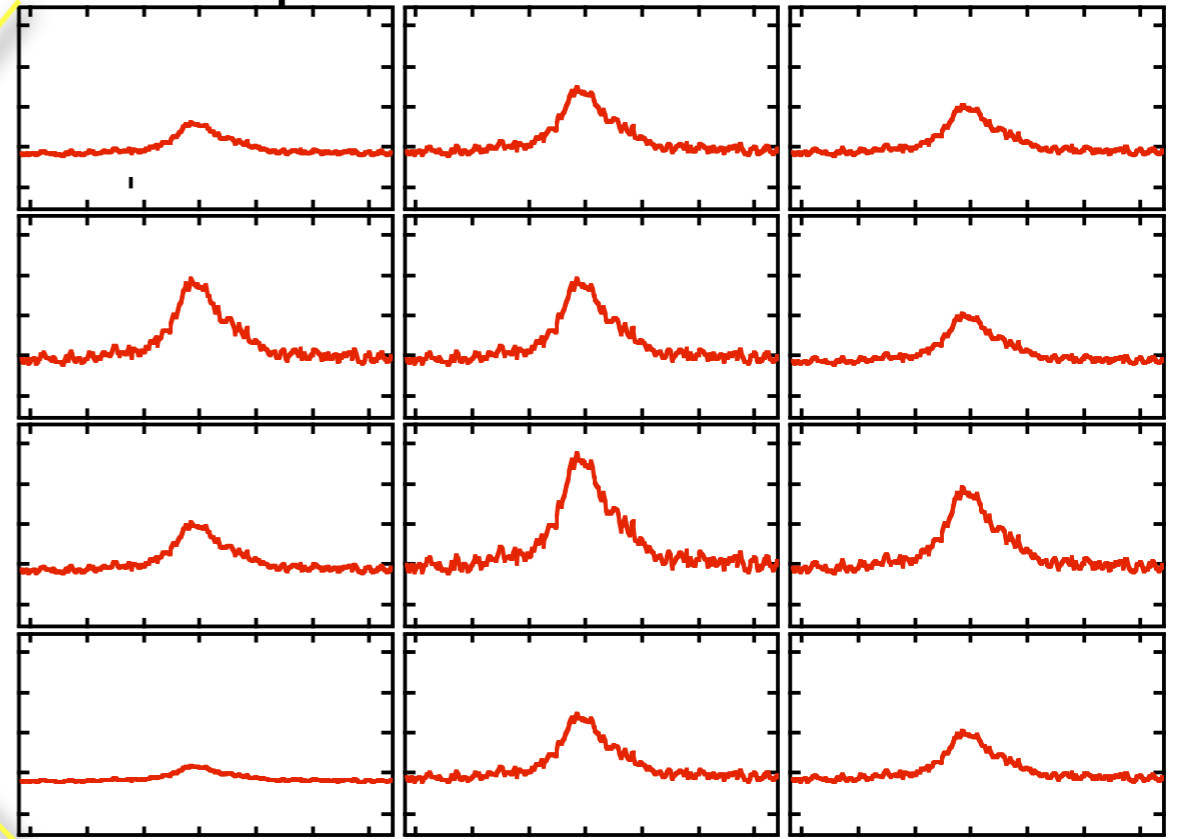




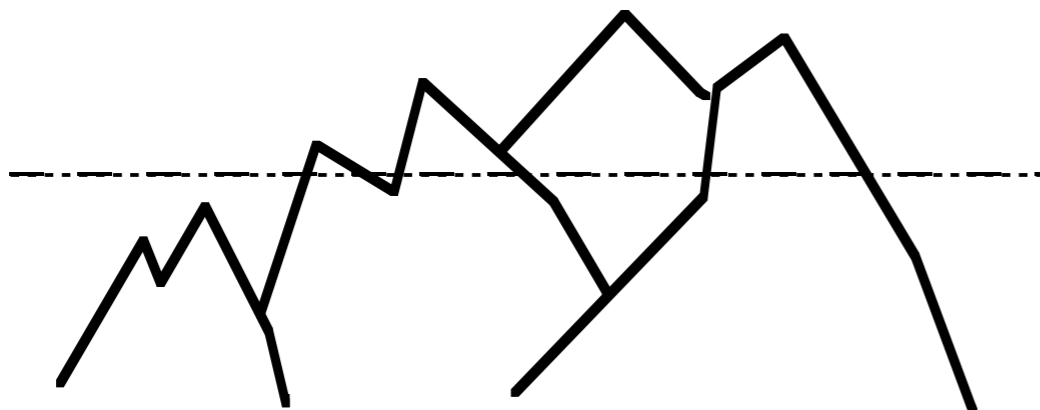
Velocity as a "Fourth" Dimension



Spectral Line Observations



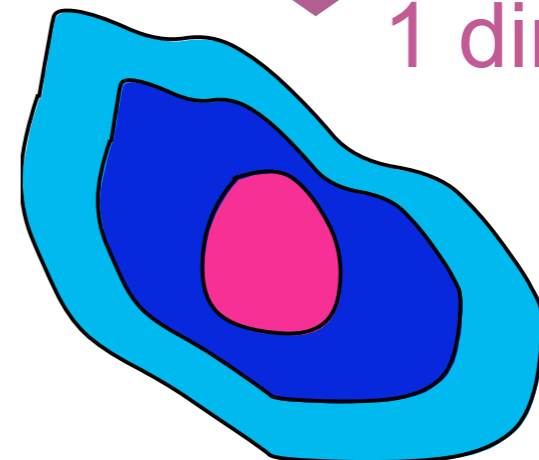
Loss of 1 dimension



Mountain Range

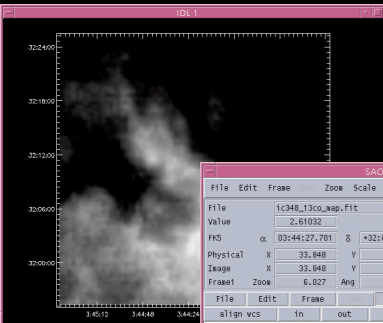


No loss of information

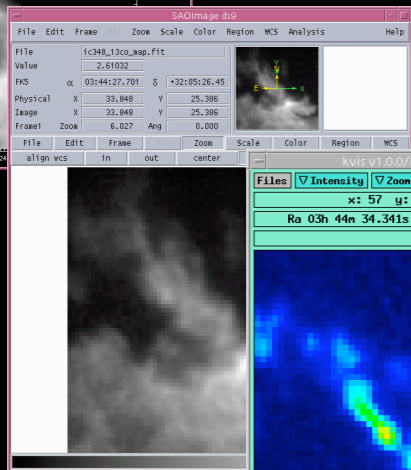


Astronomical Visualization Tools are Traditionally 2D

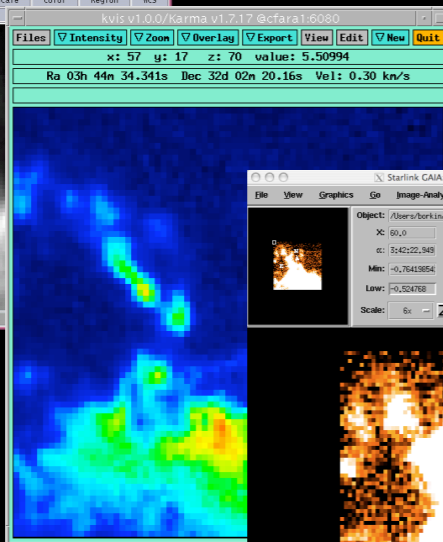
IDL



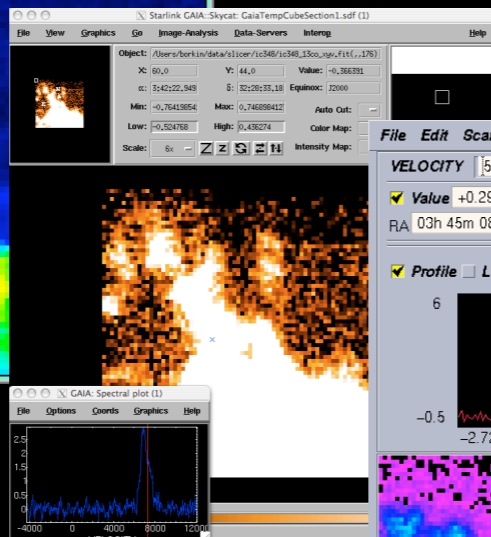
DS9



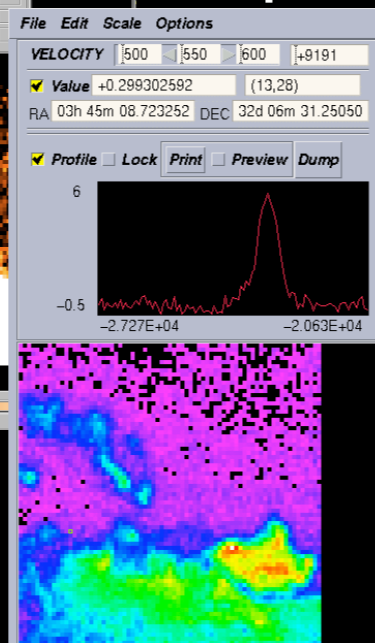
Karma*



GAIA

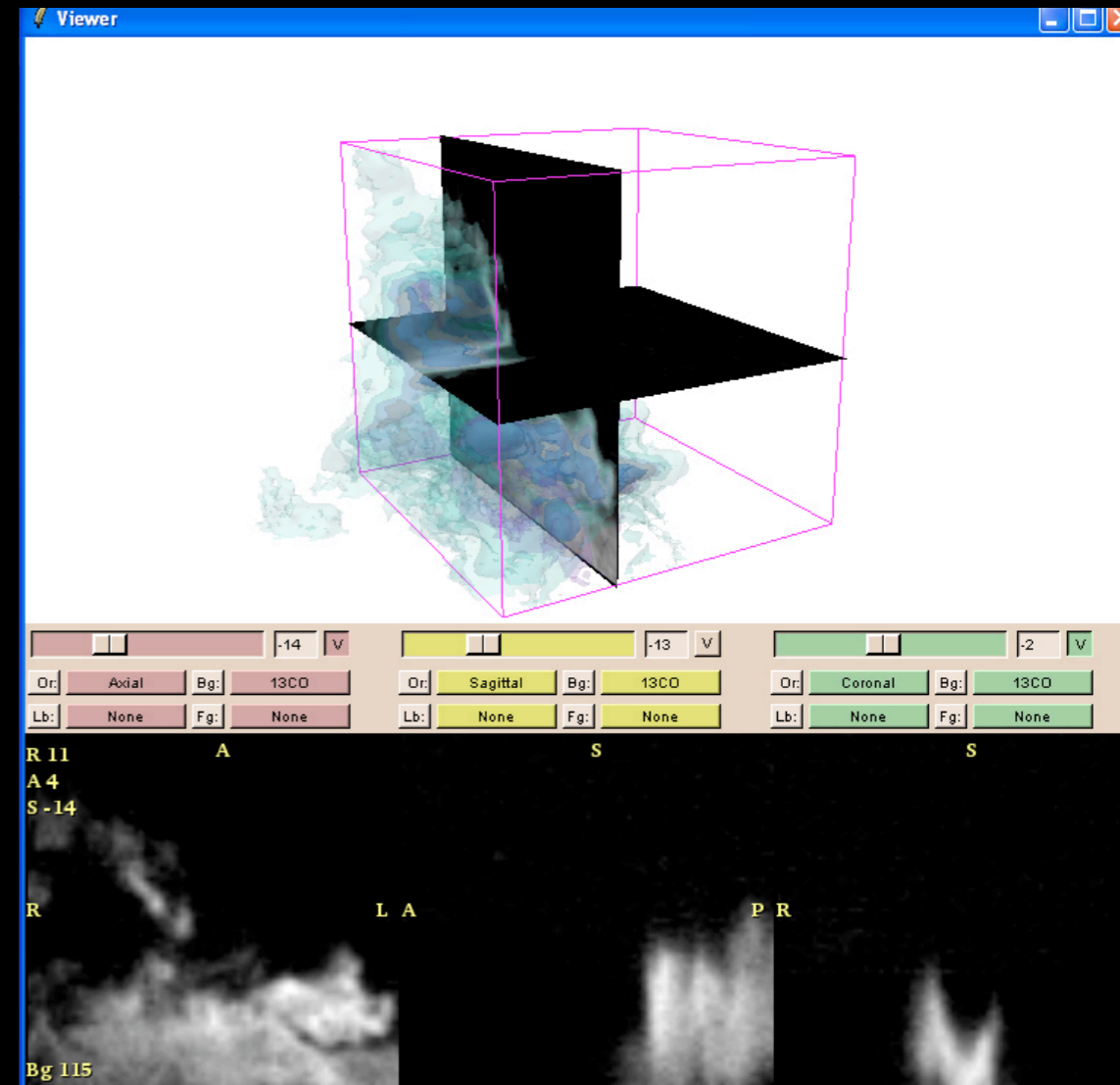


Aipsview








“3D”=movies

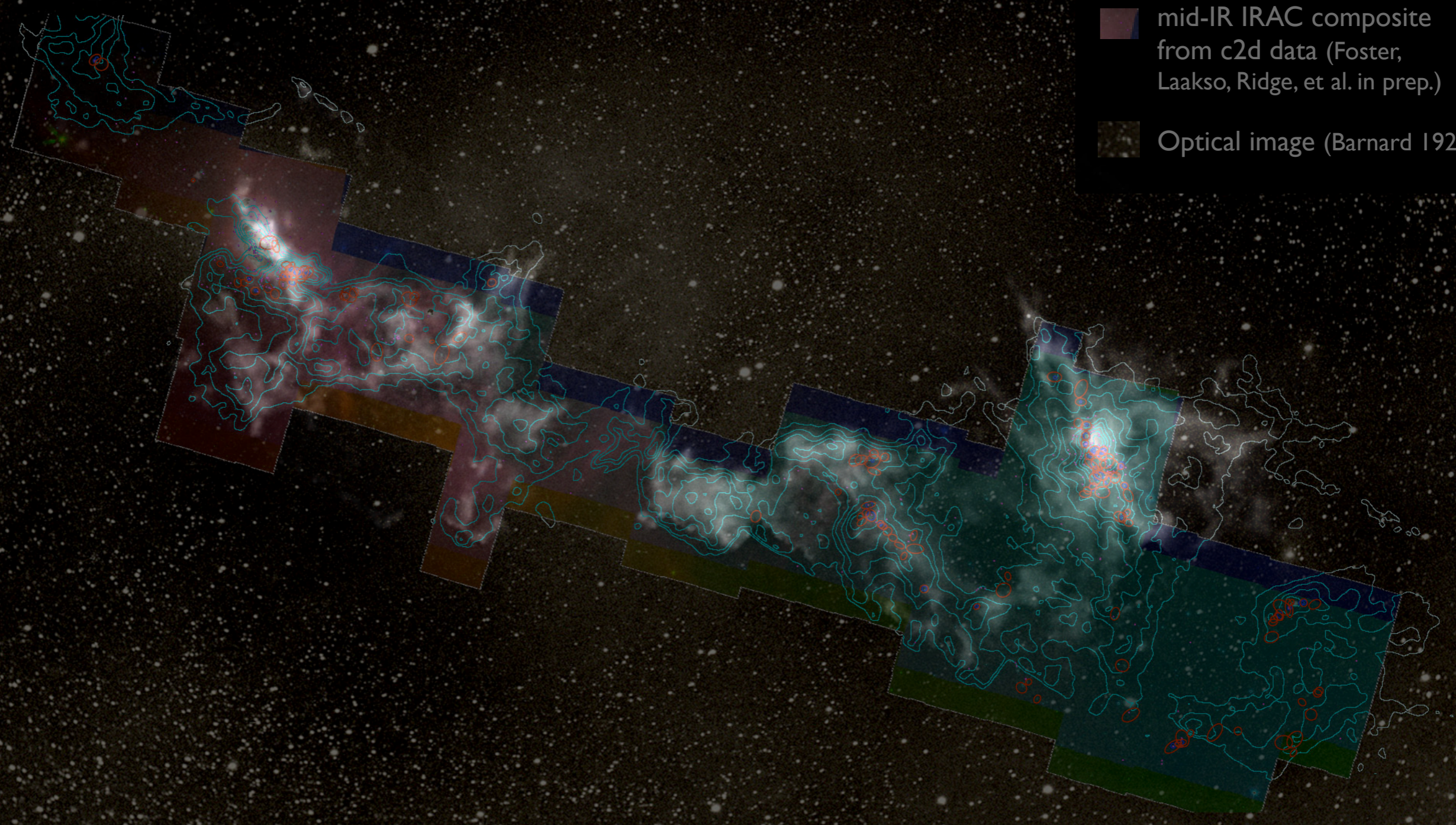
3D Slicer



COMPLETE = COordinated Molecular Probe Line Exinction Thermal Emission

image size: 520 x 274
view size: 1305 x 733
W/L: 63 W/W: 127

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

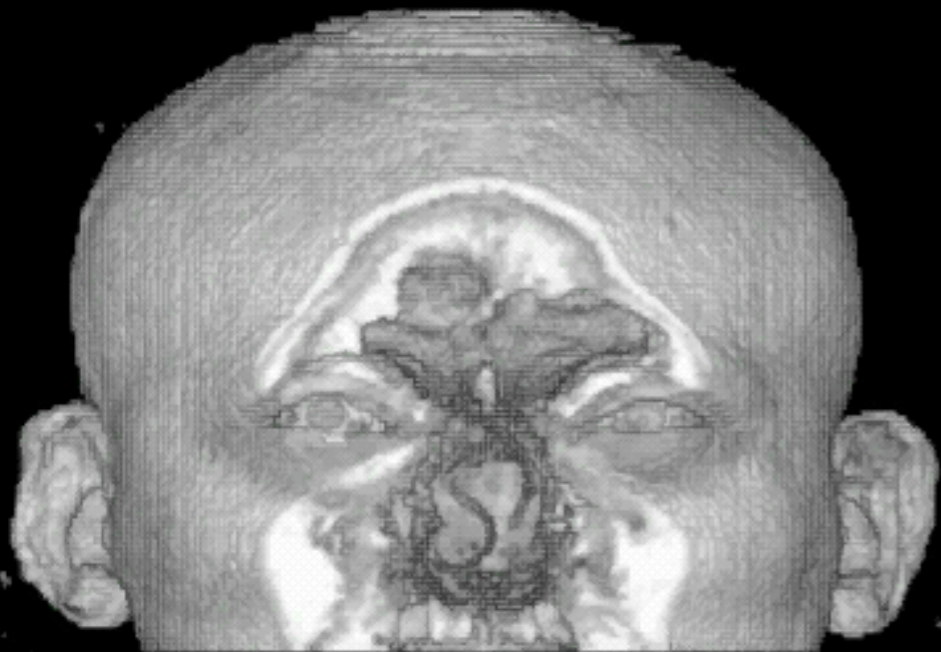


m: 163/249
zoom: 227% Angle: 0



"Slices"

"KEITH"



"PERSEUS"



"z" is depth into head

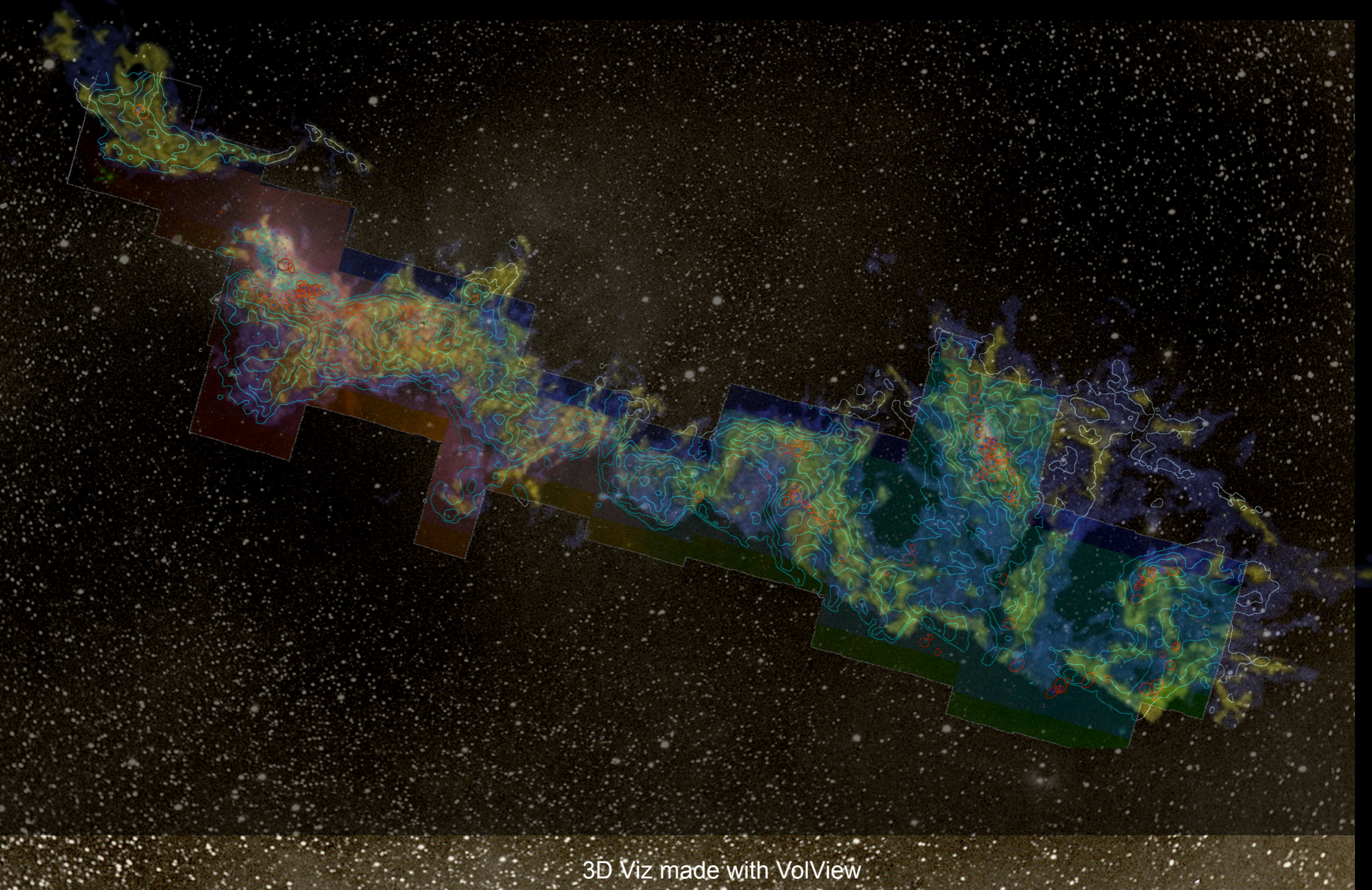
"z" is line-of-sight velocity

Real 3D space

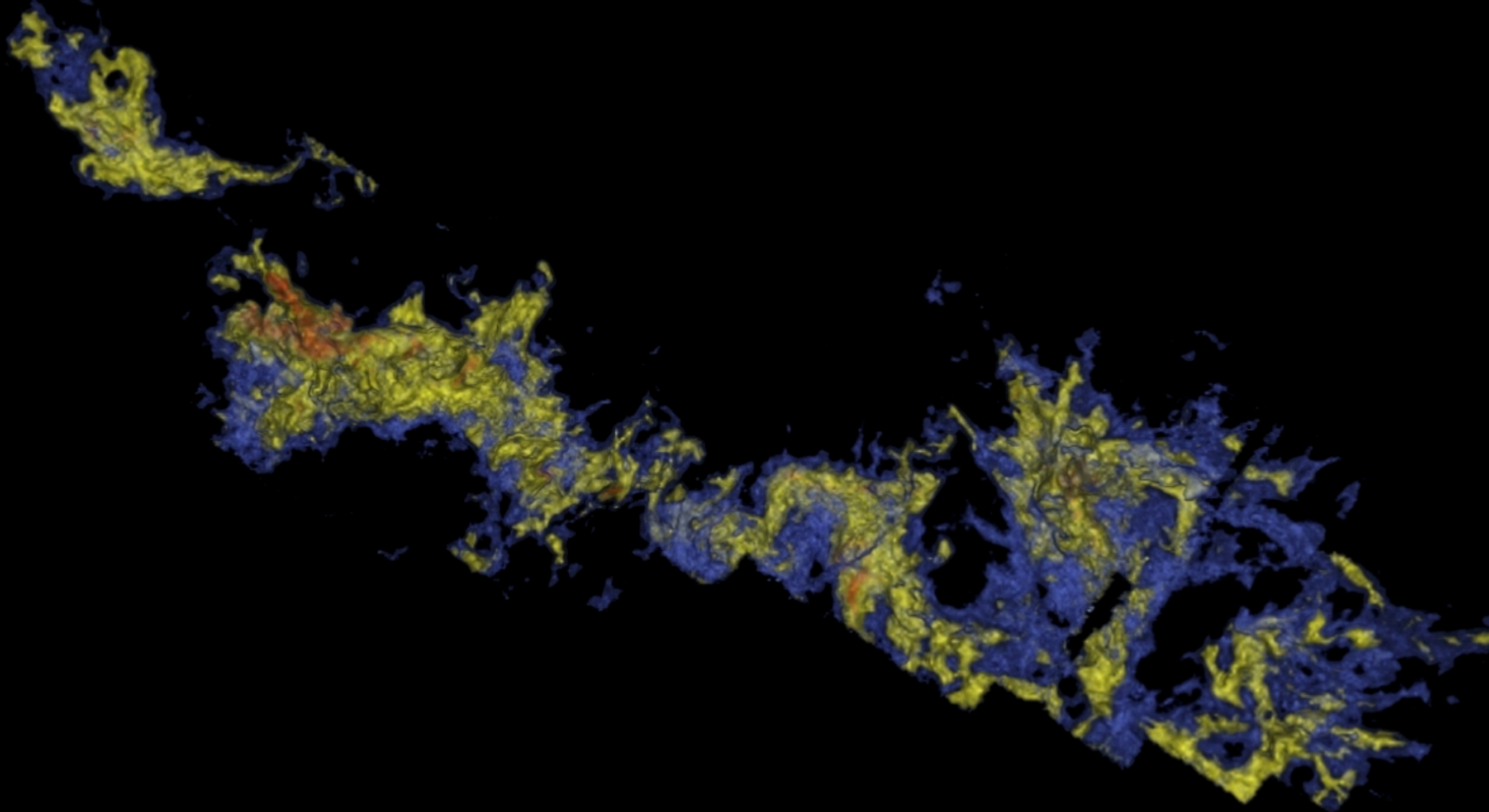


“Position-Position-Velocity” Space





3D Viz made with VolView

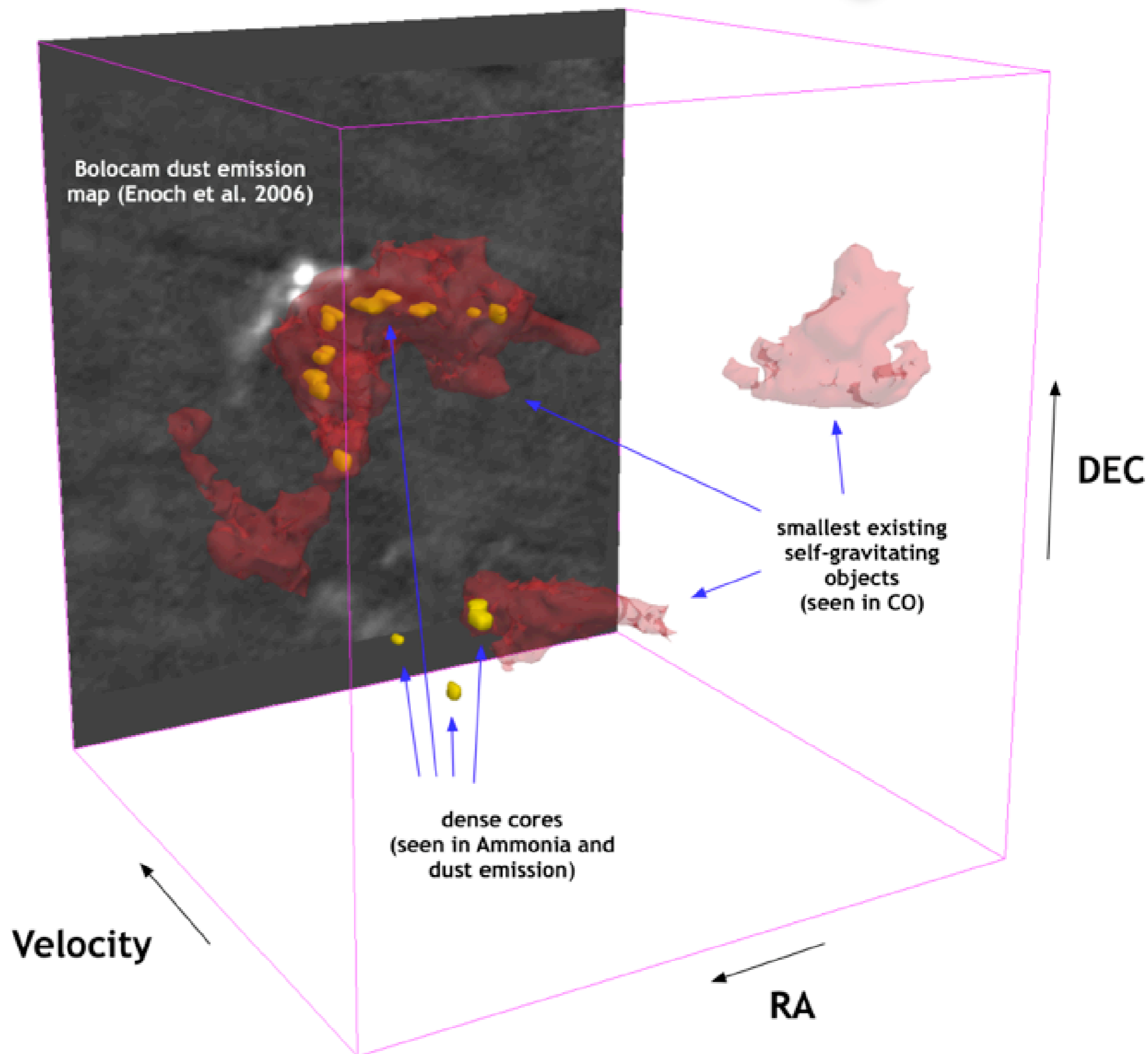


3D Viz made with VolView

Astronomy + Medicine = Understanding

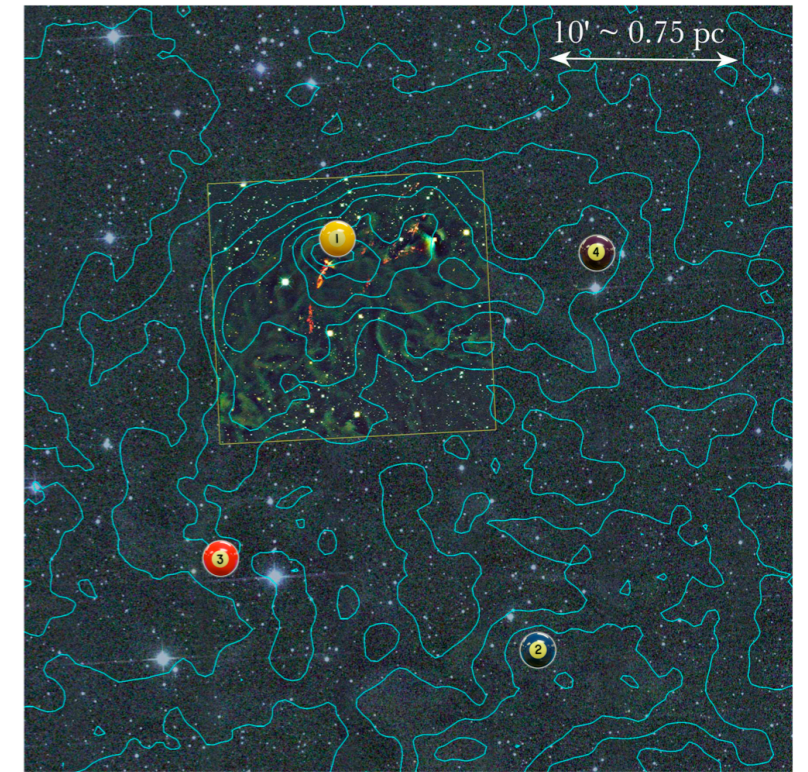
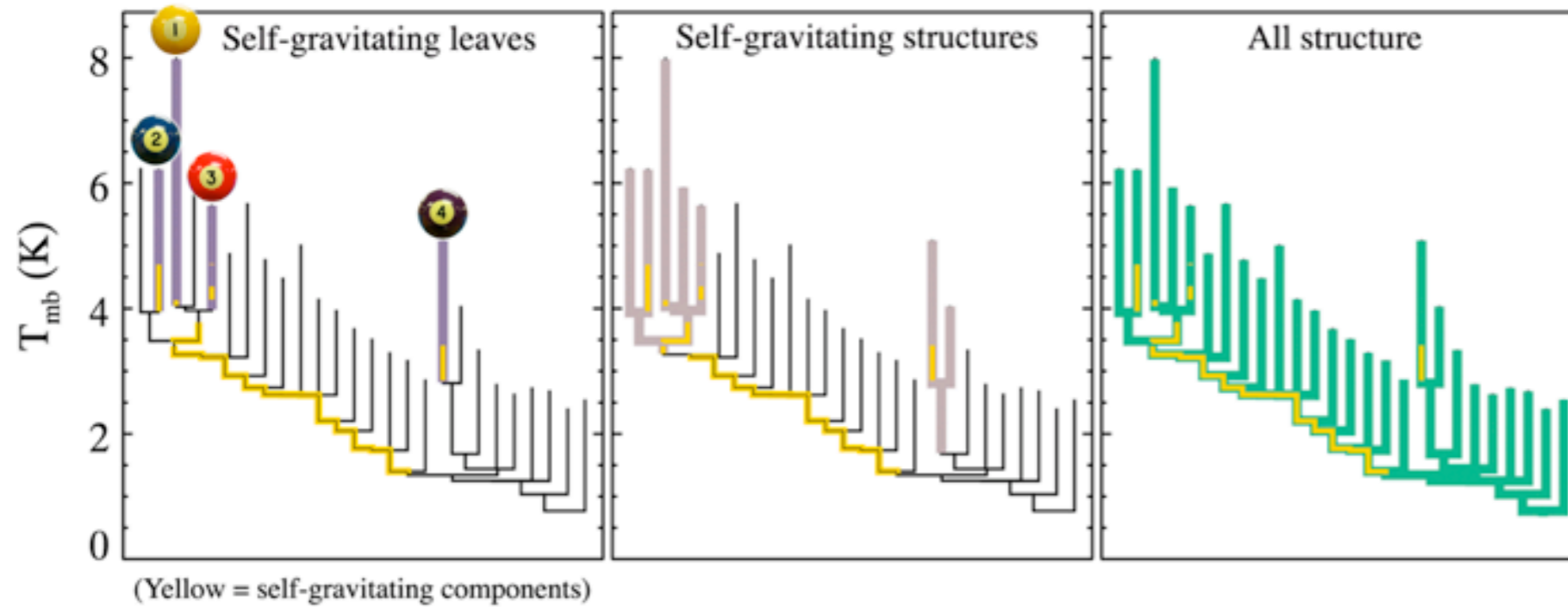
What have we learned, so far?

(see Michelle Borkin's talk next, and our demo table--in 3D!--too!)

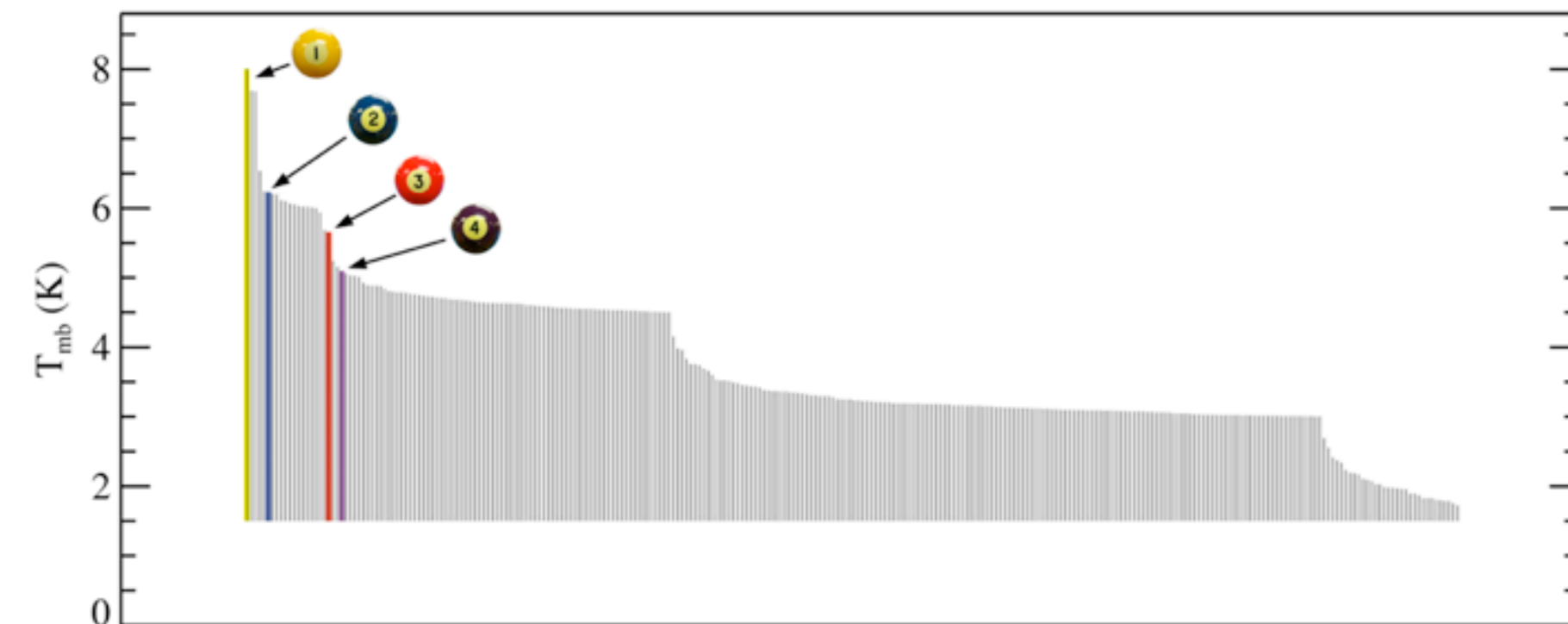


Visualization created by Jens Kauffmann (CfA/IIC) using 3D Slicer

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



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

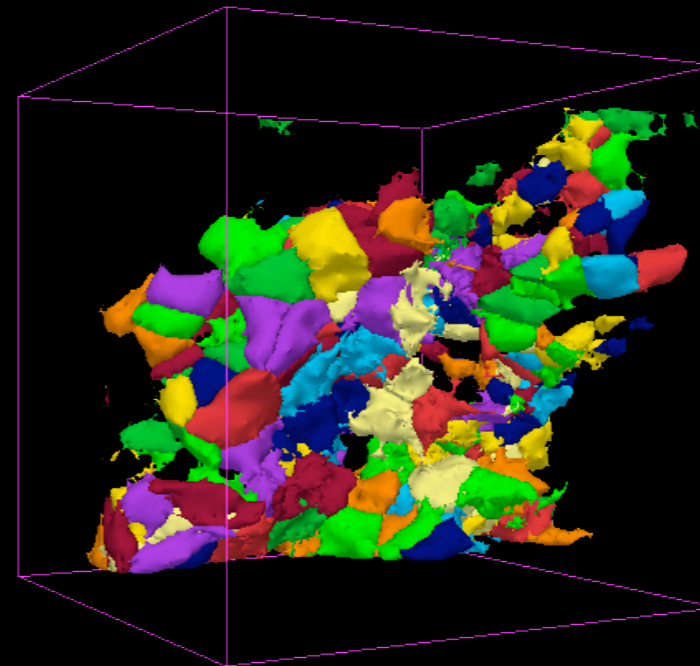
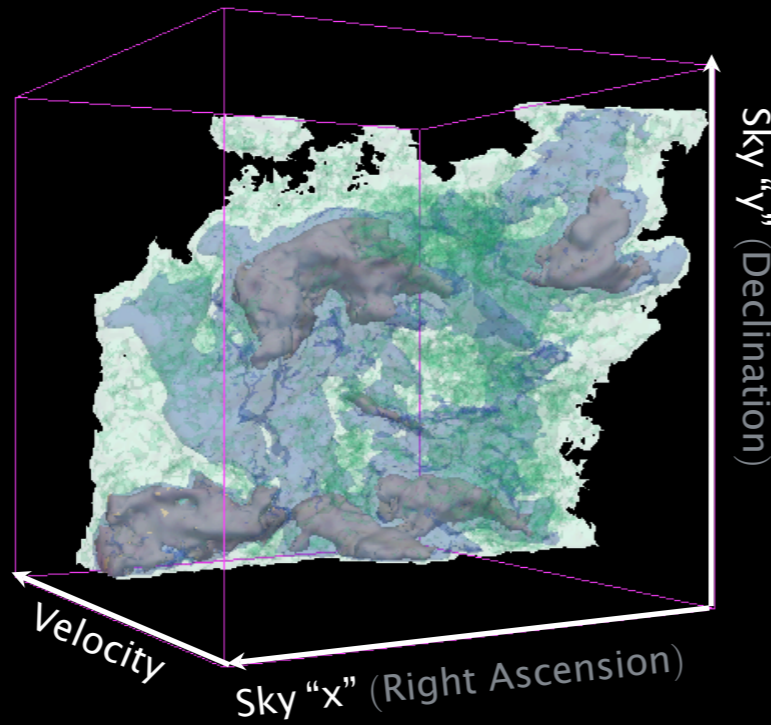


“Reality” and “Unreality”?

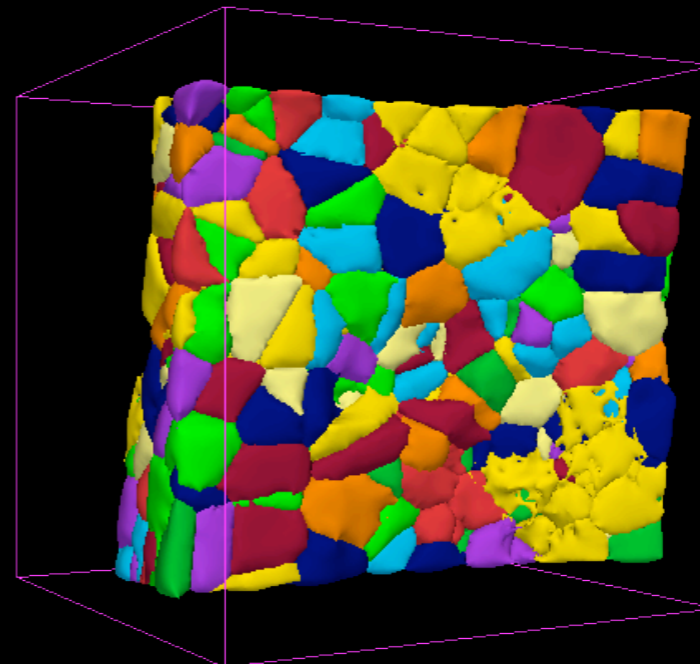
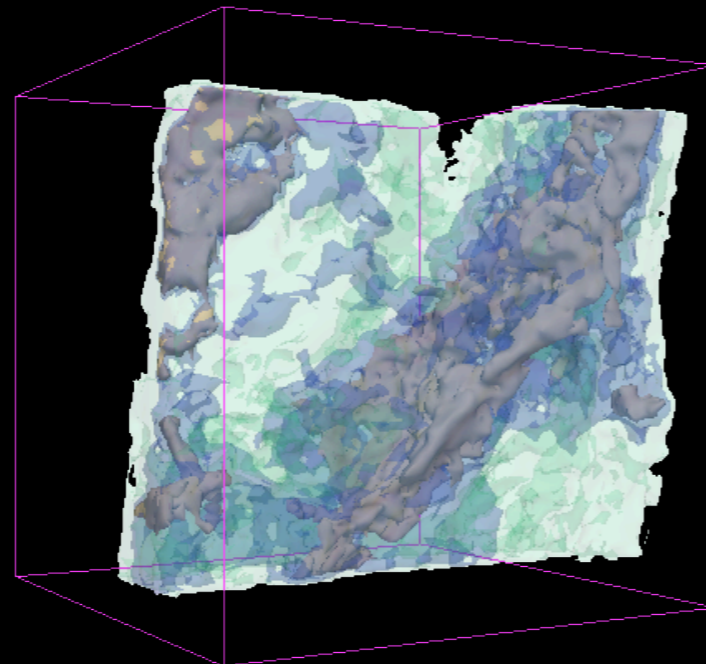
(Dendro)Surfaces

“CLUMPFIND”

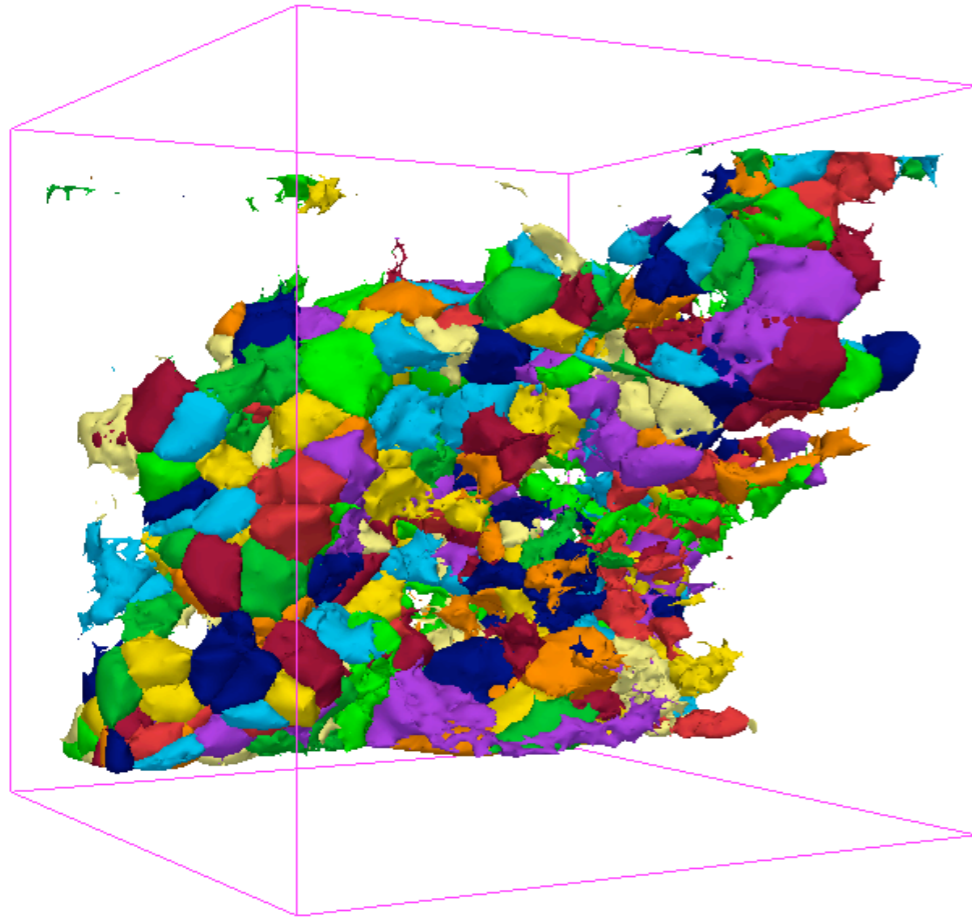
Observed
Reality



“Observed”
Simulations



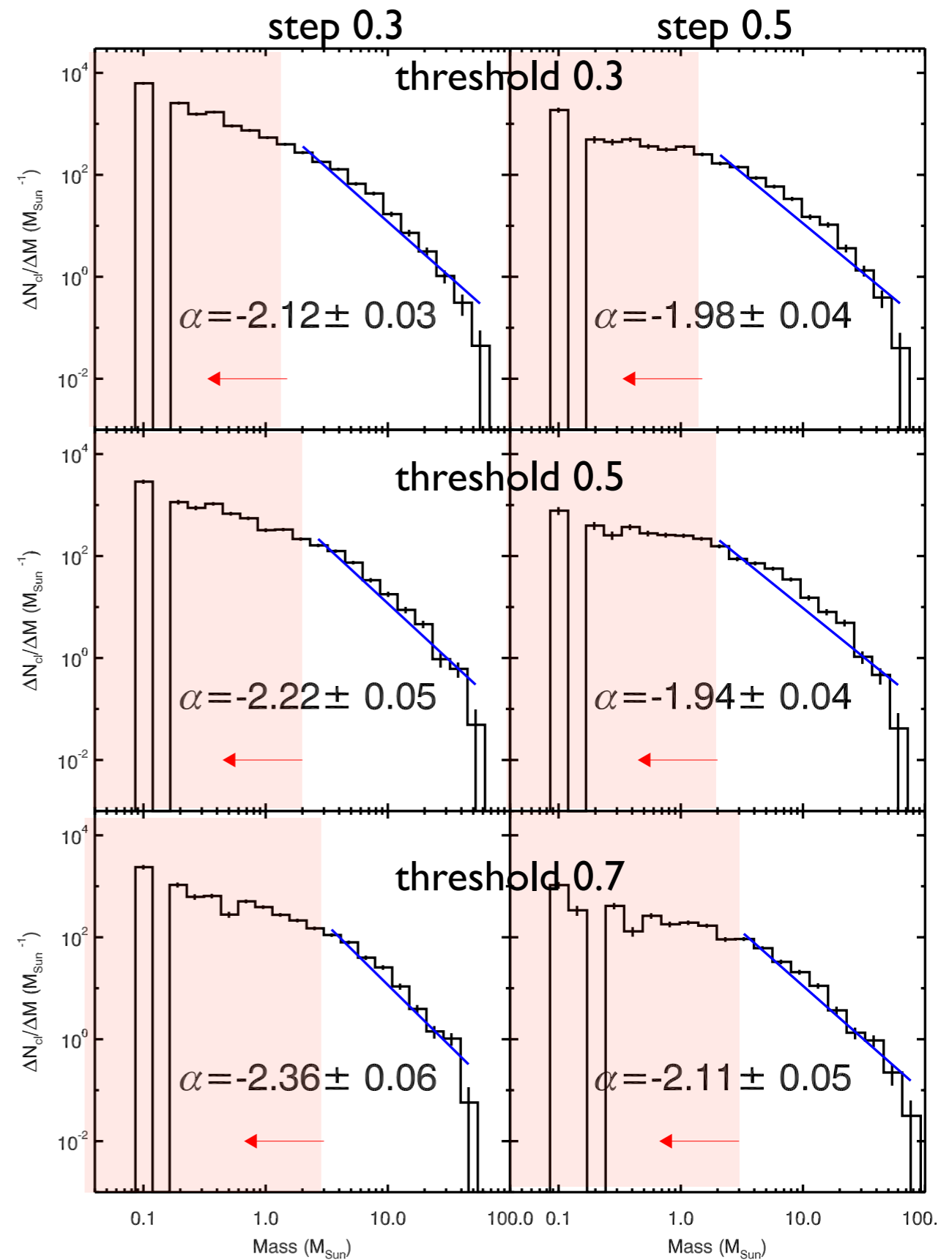
Is CLUMPFIND OK as a Statistic?



CLUMPFIND output for L1448
(1.2K step & threshold; lower values give too many clumps to show!)

Results for full Perseus Map

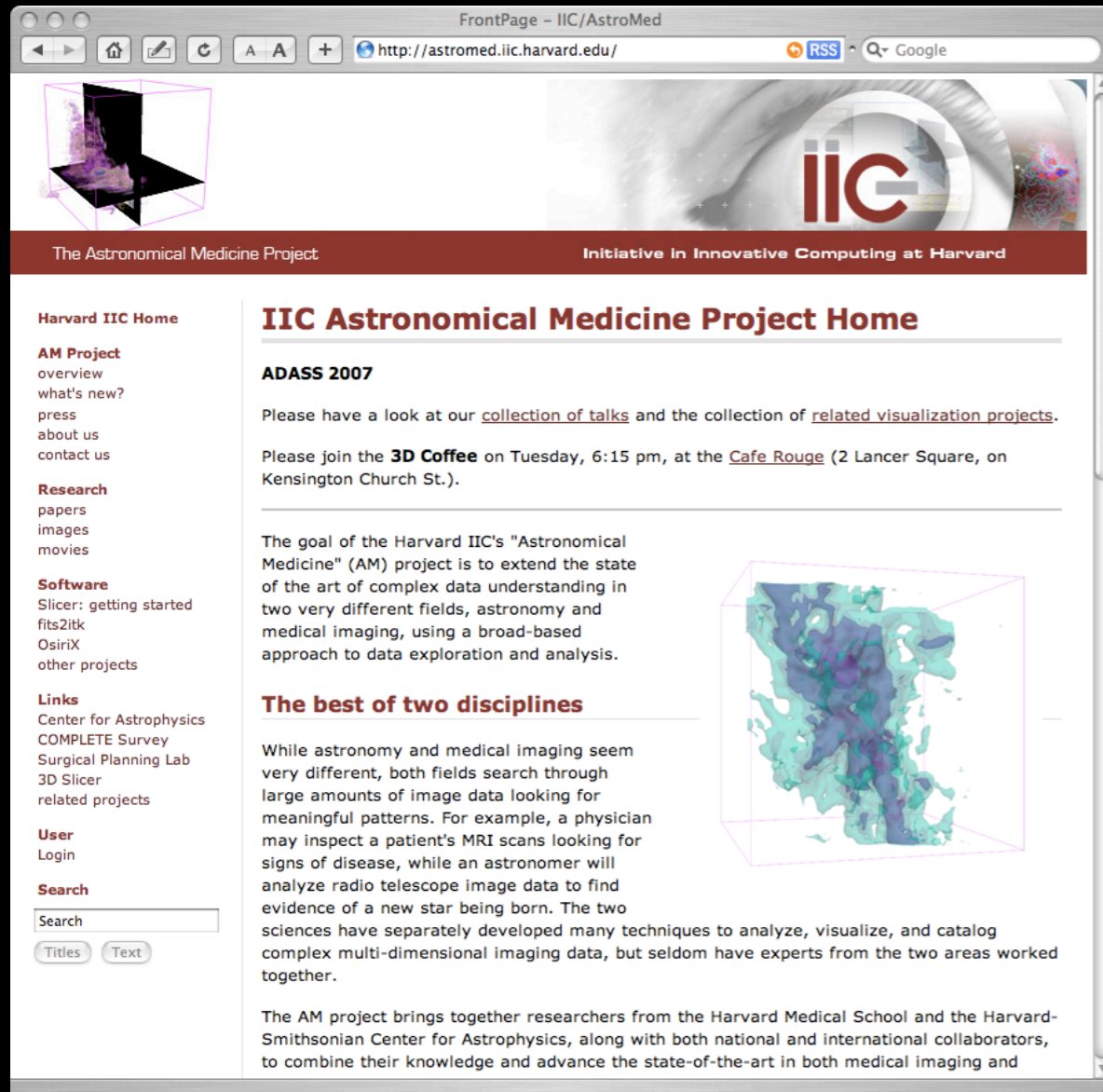
Threshold	Step size	total number of Clump	% above sensitivity limit Mass v/s Radius	% above sensitivity limit FWHM v/s Radius	% above both curves
0.3	0.3	5199	47.32%	58.03%	46.59%
0.3	0.5	3844	40.74%	46.96%	40.30%
0.5	0.3	2141	79.12%	89.72%	78.14%
0.5	0.5	1420	86.83%	89.01%	86.20%
0.7	0.3	1748	79.06%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



Generalizing & Sharing

Open-Source code released, and explained, as it is developed.

Changing the future of scientific publishing.



FrontPage - IIC/AstroMed
http://astromed.iic.harvard.edu/

The Astronomical Medicine Project Initiative in Innovative Computing at Harvard

IIC Astronomical Medicine Project Home

ADASS 2007

Please have a look at our [collection of talks](#) and the collection of [related visualization projects](#).

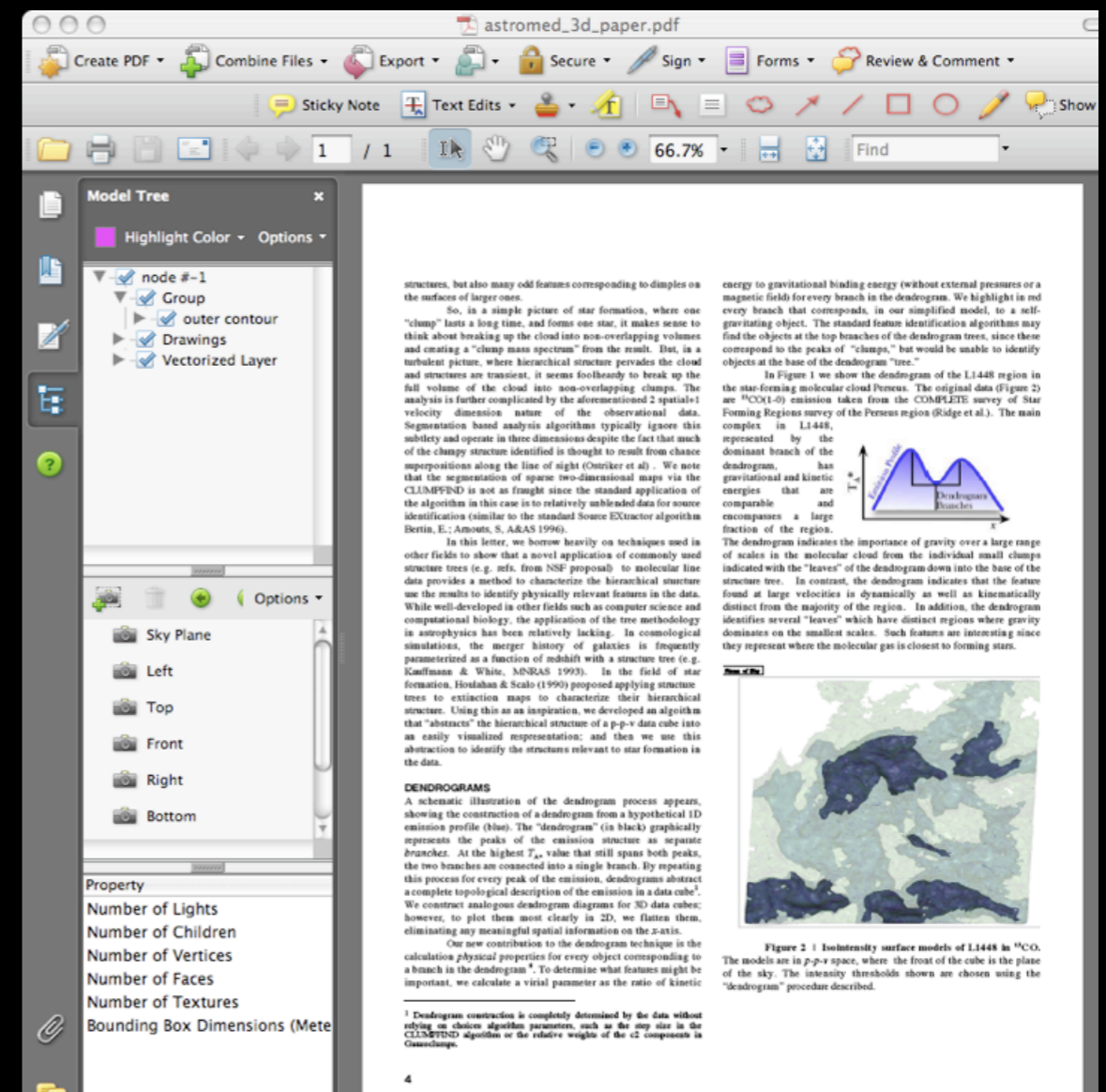
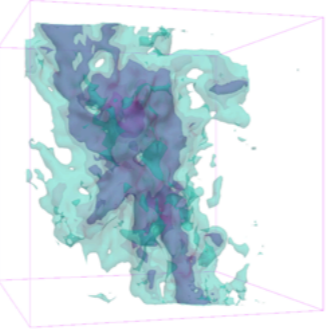
Please join the **3D Coffee** on Tuesday, 6:15 pm, at the [Cafe Rouge](#) (2 Lancer Square, on Kensington Church St.).

The goal of the Harvard IIC's "Astronomical Medicine" (AM) project is to extend the state of the art of complex data understanding in two very different fields, astronomy and medical imaging, using a broad-based approach to data exploration and analysis.

The best of two disciplines

While astronomy and medical imaging seem very different, both fields search through large amounts of image data looking for meaningful patterns. For example, a physician may inspect a patient's MRI scans looking for signs of disease, while an astronomer will analyze radio telescope image data to find evidence of a new star being born. The two sciences have separately developed many techniques to analyze, visualize, and catalog complex multi-dimensional imaging data, but seldom have experts from the two areas worked together.

The AM project brings together researchers from the Harvard Medical School and the Harvard-Smithsonian Center for Astrophysics, along with both national and international collaborators, to combine their knowledge and advance the state-of-the-art in both medical imaging and



astromed_3d_paper.pdf

Model Tree

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

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., & IAS 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 proposal) to molecular line data provides a method to characterize the hierarchical structure we use 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, Houshan & Scalzo (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 cube¹. We construct analogous dendrogram diagrams for 3D data cubes; however, to plot these 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 dendrogram². To determine what features might be important, we calculate a virtual 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 ¹³CO(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.

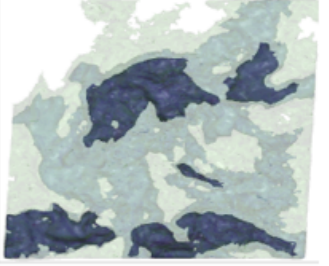


Figure 2 | Intensity surface models of L1448 in ¹³CO. The models are in p-p-v space, where the front of the cube is the plane of the sky. The intensity thresholds shown are chosen using the "dendrogram" procedure described.

¹ Dendrogram construction is completely determined by the data without relying on choices algorithm parameters, such as the step size in the CLUMPFIND algorithm or the relative weight of the σ_2 component in Gaussianfit.

4



Goodman et al., *Nature*, submitted June 2007; see also Barnes & Fluke 2007 arXiv:0709.2734



Scalability

10^6 pixels

10^7 voxels

10^8 voxels

10^{14} voxels

10^{16} pixels

10^{18} voxels

10^{19} voxels

10^{22} voxels

this projector

an MRI of your brain, at 0.5 mm resolution

Perseus COMPLETE data cube

the **Connectome**, 0.5 mm^3 of brain tissue

Google **Earth Imagery** at 1 foot resolution

200 nights **LSST** data, at 6 wavelengths (x,y,t)

Google **Earth 3D**, ± 1000 feet of elevation, 1 ft. res.

the **Connectome**, **full human brain**



BRIDGE THE GAP

SCIENTIFIC DISCIPLINES



COMPUTER SCIENCE

Increasingly, core problems in science require computational solution

Typically hire/“home grow” computationalists, but often lack the expertise or funding to go beyond the immediate pressing need

Academic researchers often focused on finding elegant solutions to basic computer science challenges

Often see specific, “applied” problems as outside their interests

Higher-dimensional visualization and analysis is a generic problem.

Solutions:

Think Web 2.0, think PLASTIC. Think “my 2-D grapher is yours” ... “my renderer is yours” ... “my spectral analysis tools are yours” ... “my bookmarks are your bookmarks” ... “my library is your library” ... etc.

So, we need **both**:

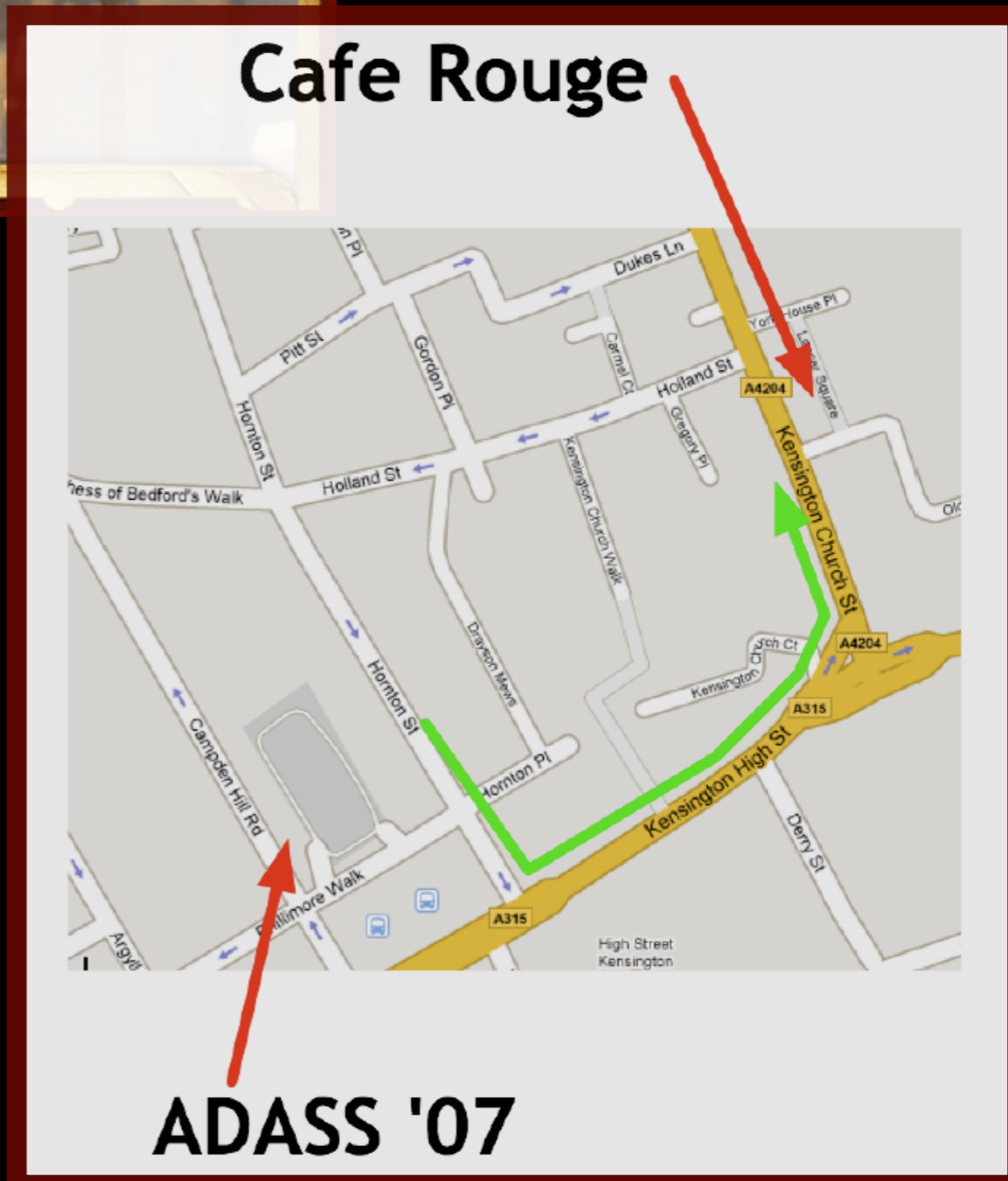
parts to share

& (easier!) ways to share them.

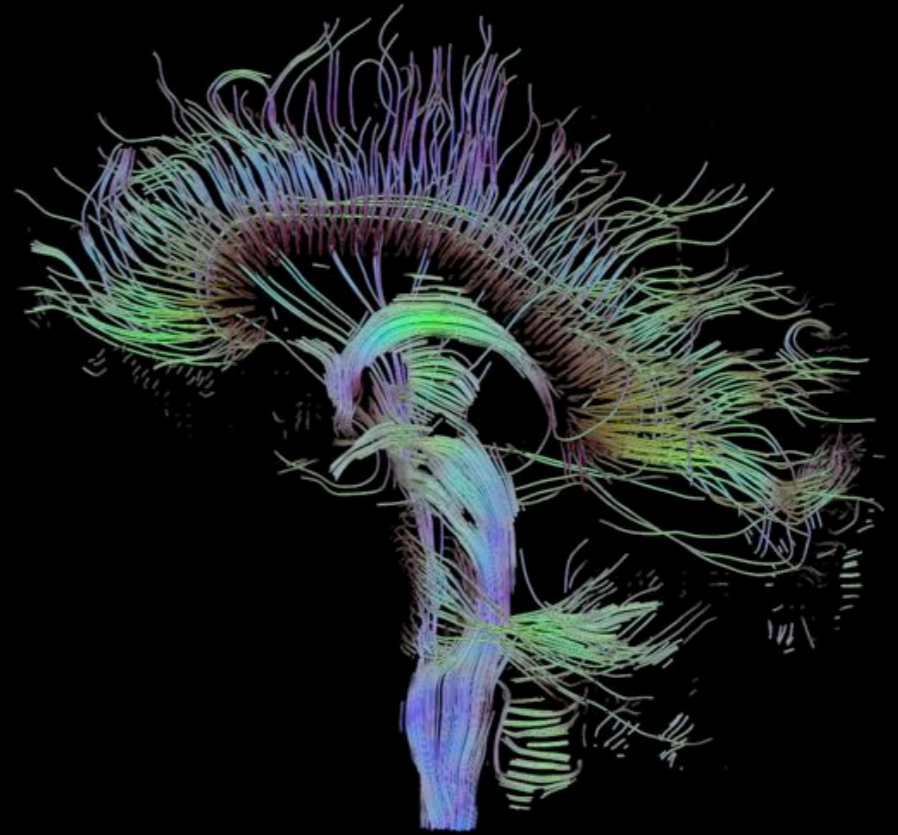
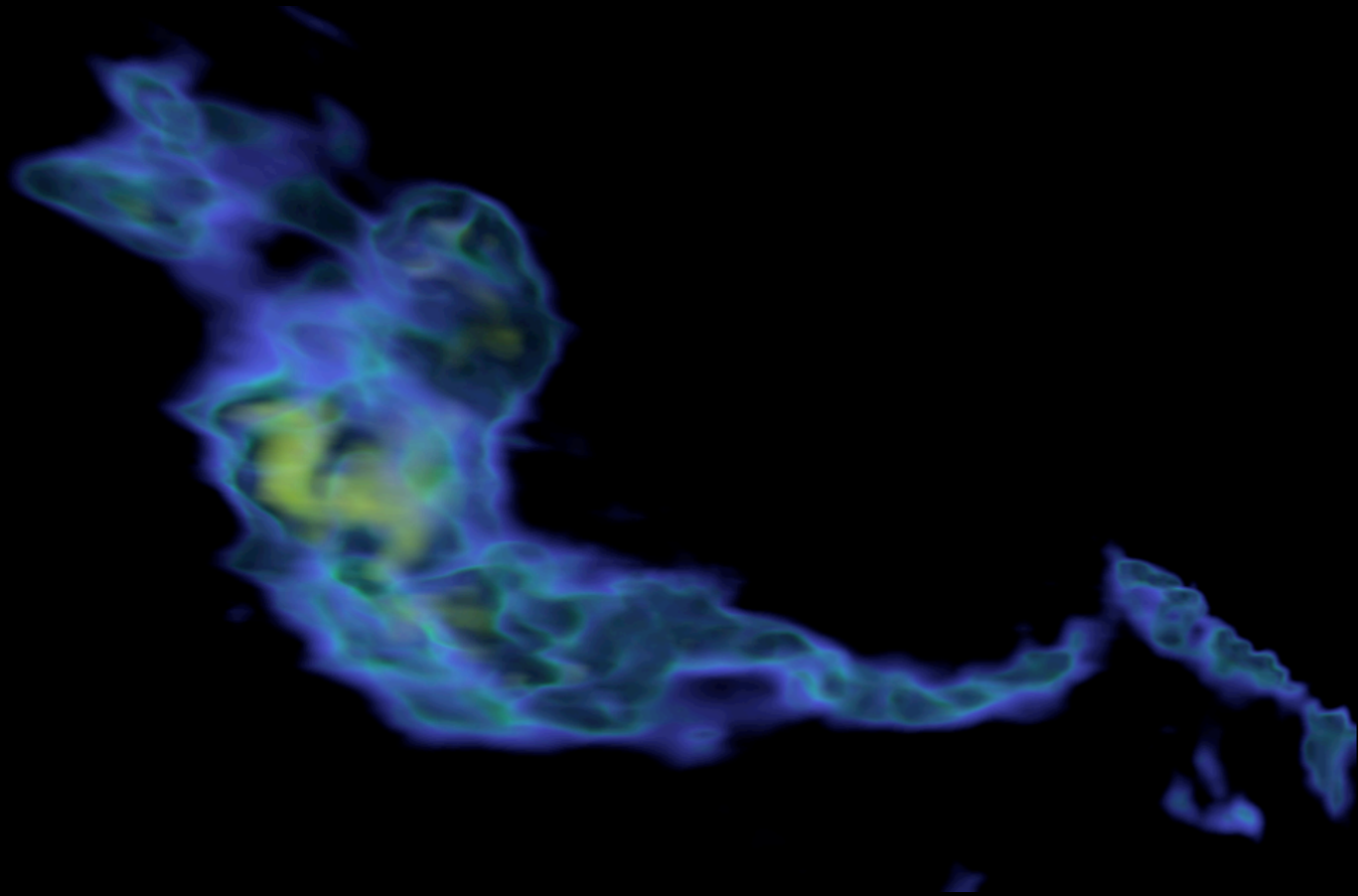




More 3D, later...6:15
meet outside of this
building, see J. Kauffmann



Astronomy + Medicine = Understanding



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Initiative in Innovative Computing @ Harvard
and
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Official Abstract

(O7.1) Astronomy + Medicine = Understanding

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Astronomy and medicine are two fields that rely heavily on imaging for insight. The "Astronomical Medicine" project, based at Harvard's new "Initiative in Innovative Computing," seeks to combine the best advances in both medical and astronomical image display, manipulation, and analysis techniques, in order to create tools that are better for everyone. To date, our focus has been on three-dimensional data, such as the position-position-velocity data cubes typically produced by spectral-line observations. We have leveraged several existing medical imaging packages, all built upon ITK and VTK, in order to give astronomers easy access to views of their data as 3D surfaces and volumes.

The talk will focus both on the **general overlap of the astronomical and medical challenges** and solutions and on **specific examples of successes to date**. In one particularly noteworthy example, we have used the 3D Slicer package (see Note) to show that traditional "**segmentation**" (a.k.a. "**clumpfinding**") **techniques** used in the study of star formation need to be reconsidered, and that alternative "**tree-based**" **techniques** may prove superior.

Note: The "3D Slicer" package, developed for **surgical planning**, has proven especially useful in our work, and a tutorial featuring 3D Slicer will be offered before the ADASS meeting. For more information, please see <http://astromed.iic.harvard.edu/>.