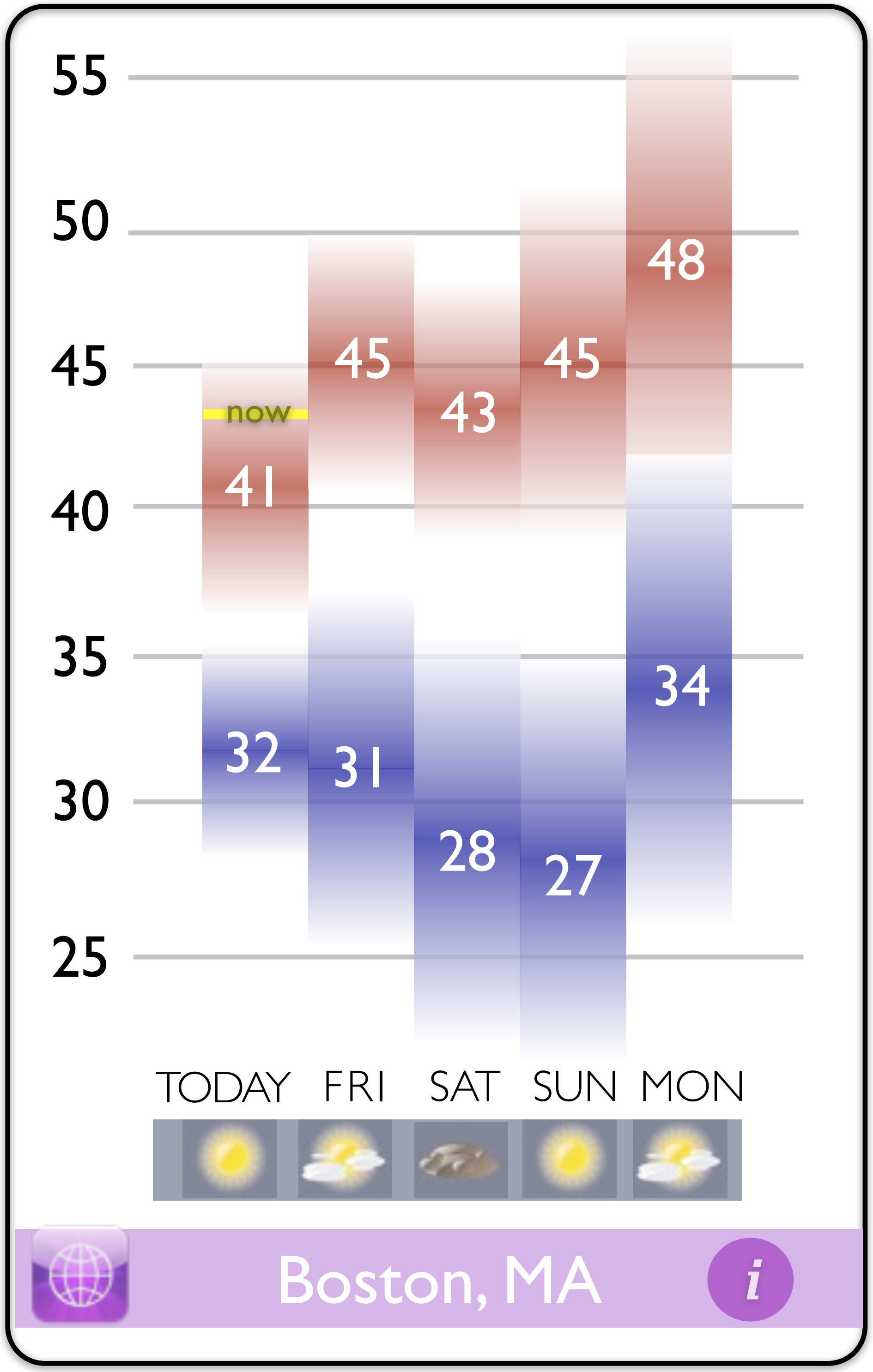
While you are waiting...here's an in-the-works [iPhone] App on "Uncertainty" being made in conjunction with my course & a project on "Prediction" we're doing at WGBH...

main screen

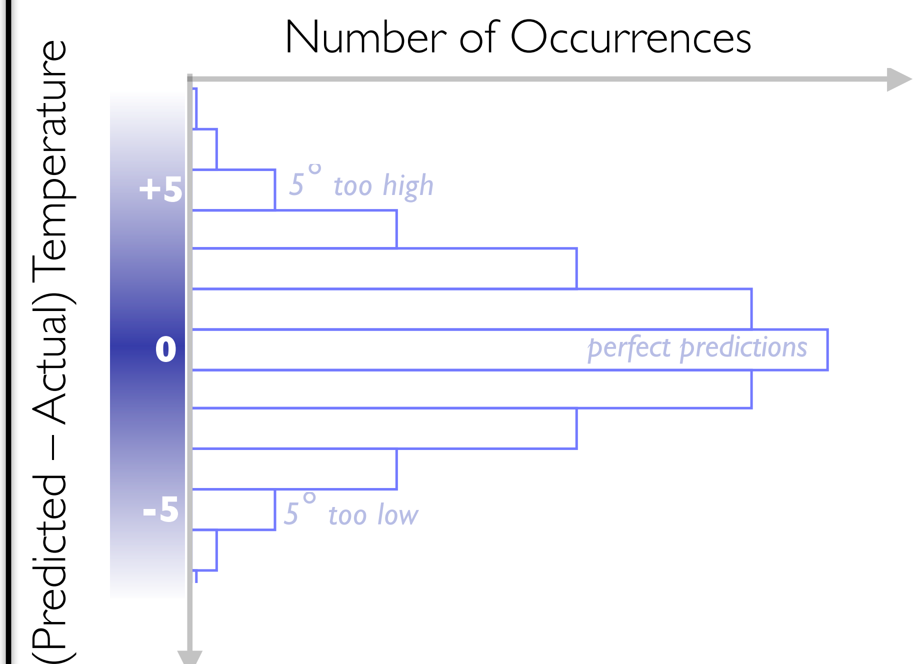


info screen

back

about

The graph below shows a sample "distribution" of how far off temperature predictions have been in the past. Perfect predictions give zero as a difference value. The shaded bars just summarize the graph: the darker the shaded bar, the more predictions fell in that difference zone.



To learn more about this App and about how predictions are made, visit prediction.wgbh.org.

goes to location screen

i goes to info screen

about goes to about screen

From Baby Pictures to Baby Stars: What Scientists *Can* See

What kind of credentials are those??

Alyssa A. Goodman

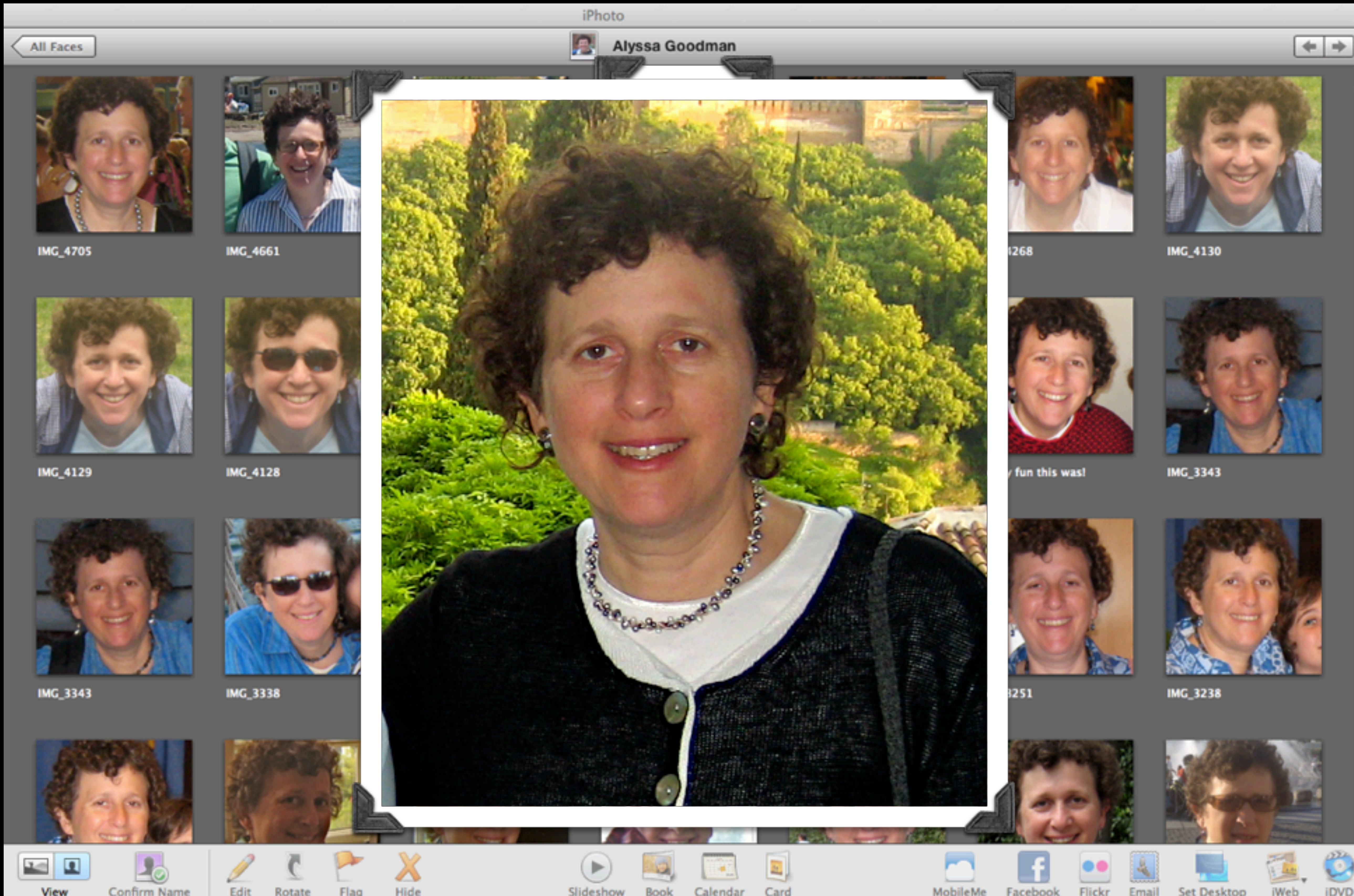
Harvard University (HCO+IIC)

Smithsonian Astrophysical Observatory

Scholar-in-Residence, WGBH







iPhoto
All Faces
Alyssa Goodman
IMG_4705
IMG_4661
268
IMG_4130
IMG_4129
IMG_4128
fun this was!
IMG_3343
IMG_3343
IMG_3338
251
IMG_3238
View
Confirm Name
Edit
Rotate
Flag
Hide
Slideshow
Book
Calendar
Card
MobileMe
Facebook
Flickr
Email
Set Desktop
iWeb
iDVD







19 out of 22?

You & I can see what I will show thanks to...

Astronomical Medicine & 3D PDF: Mike Halle, Michelle Borkin, Jens Kauffmann, Doug Alan, Ron Kikinis, Erik Rosolowsky, Nick Holliman, Jonathan Foster, Jaime Pineda, Héctor Arce, Dave Kennedy, Mark Thomas, Timo Hannay & Phil Campbell

WorldWide Telescope: Curtis Wong, Jonathan Fay & Gus Muench + MSR supporters

Touch: Chia Shen & Hanspeter Pfister

Image & Meaning: Felice Frankel & Ros Reid

Cognition — “Tools” — Nature

Cognition —— "Tools" —— Nature

Cognition — "Tools" — Nature

These limit what we "can" see.

My Fuller Meaning of “Tools”

(hardware)

(nerdware)

(imageware)

Nature?!

Cognition — “Tools” — Nature

Can this process ever be generalized in a “theory of data graphics”?

Shall we discuss that later??

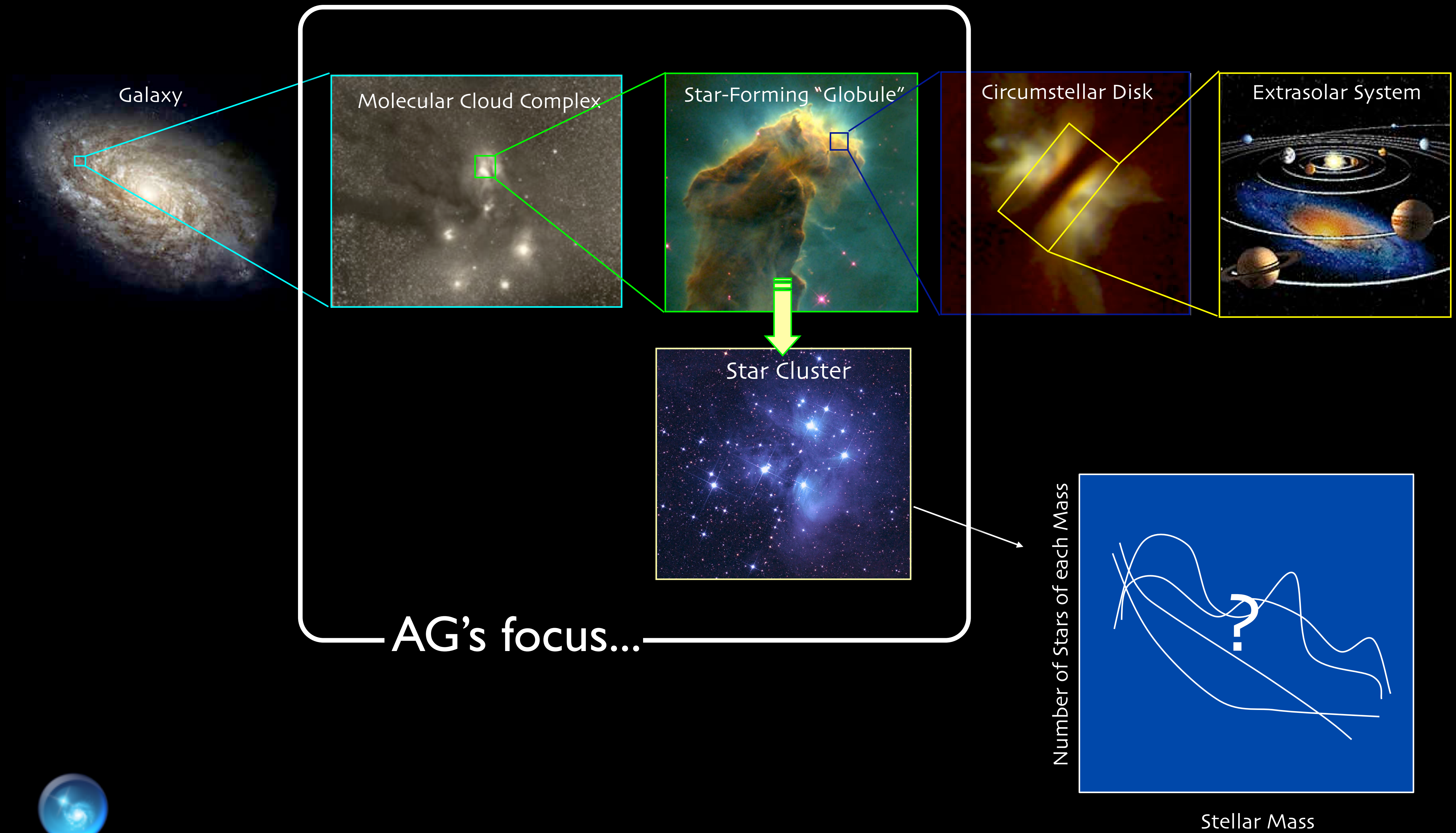
Baby Stars: What Scientists "Can" See

What Astronomers "Can" See

as distinguished from what they "Cannot" vs. "Could" See

<u>Can</u>	<u>Cannot</u>	<u>Could</u>
2D (our sky)	aliens' views	3D proxies, 4D Astronomical Medicine
static graph(ic)s	N/A	interactive graph(ic)s 3D PDF, "3D" DataDesk w/selector
their own data	proprietary data	"free" data WWT, Google Sky
baby pix	*matches to adult pix*	*with practice?...*

Star (and Planet, and Moon) Formation 101

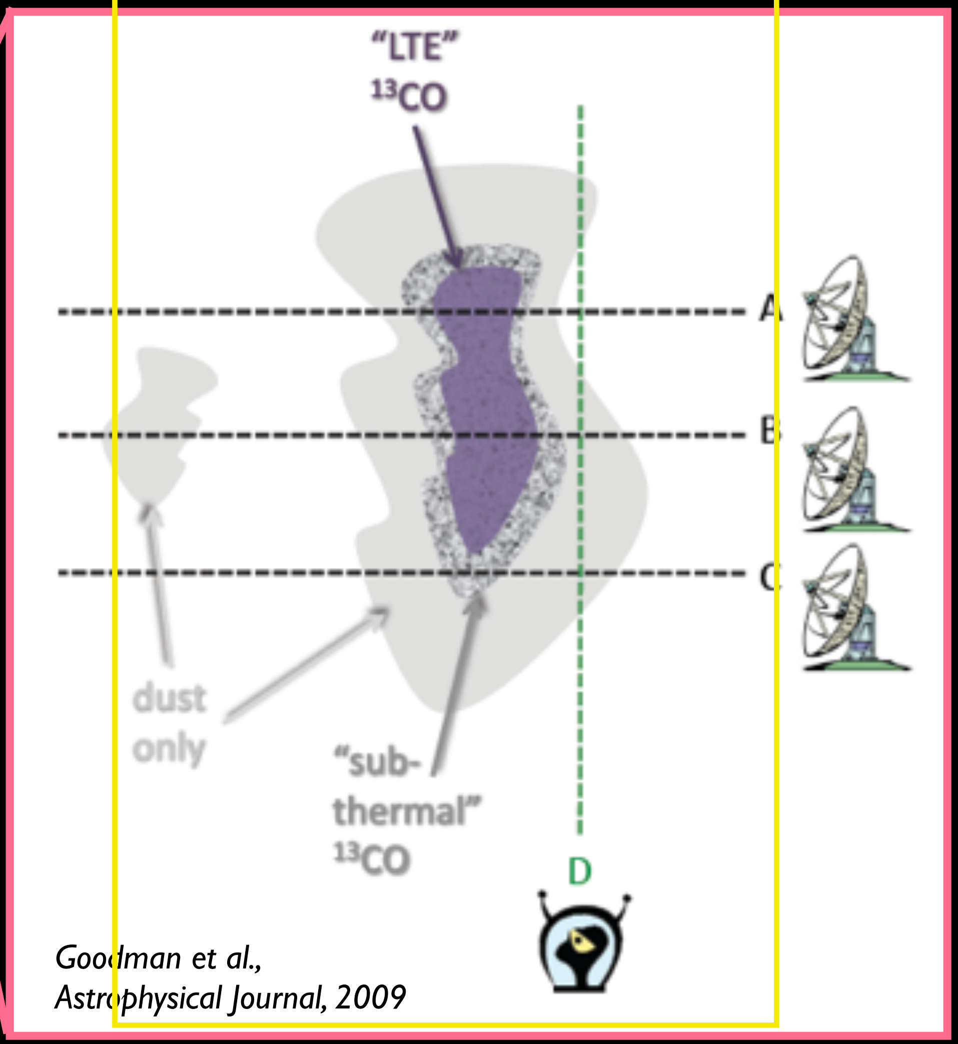


Demo

What Astronomers "Can" See

as distinguished from what they "Cannot" vs. "Could" See

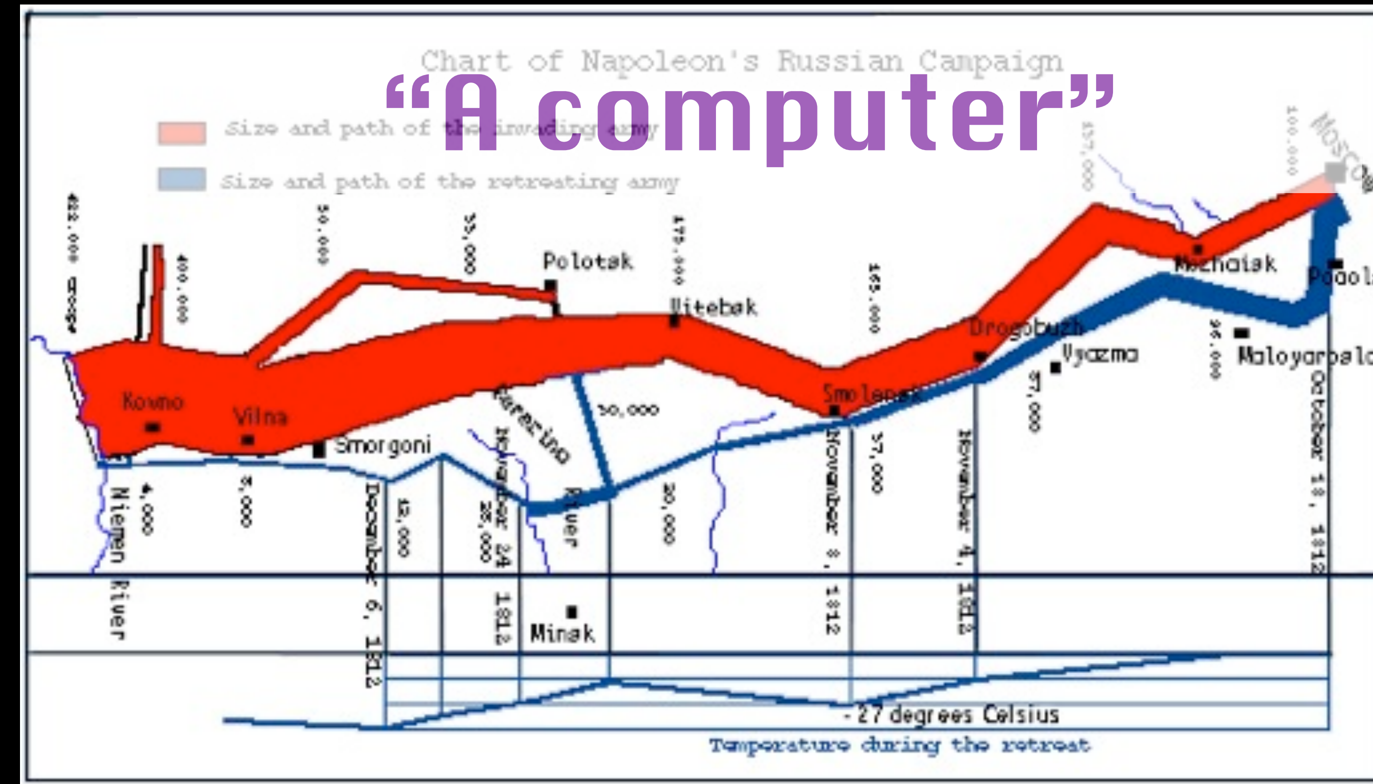
Can	Cannot	
2D (our sky)	aliens' views	
static graph(ic)s	N/A	
their own data	proprietary data	
baby pix	*matches to adult pix*	*with practice?...*

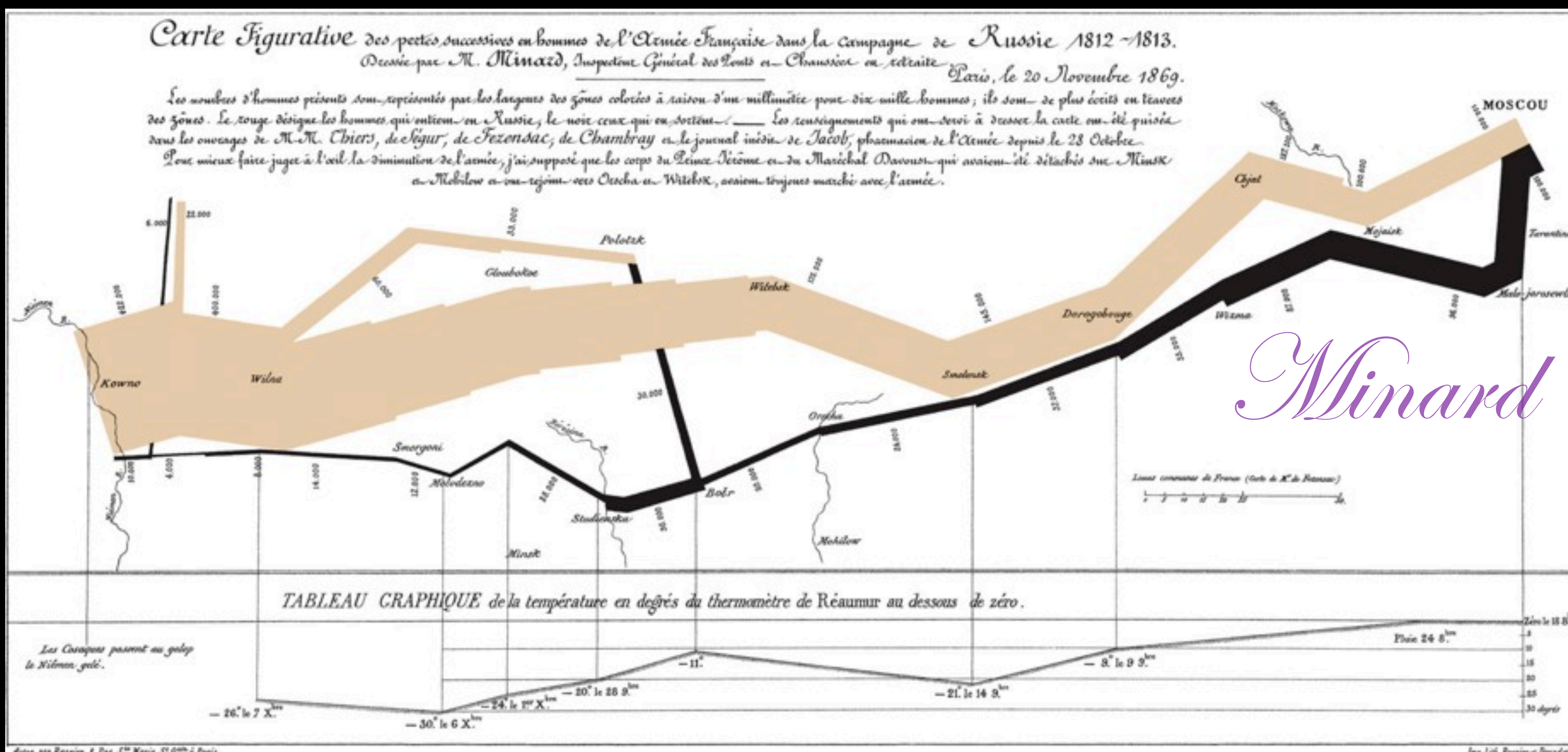


Goodman et al., Astrophysical Journal, 2009

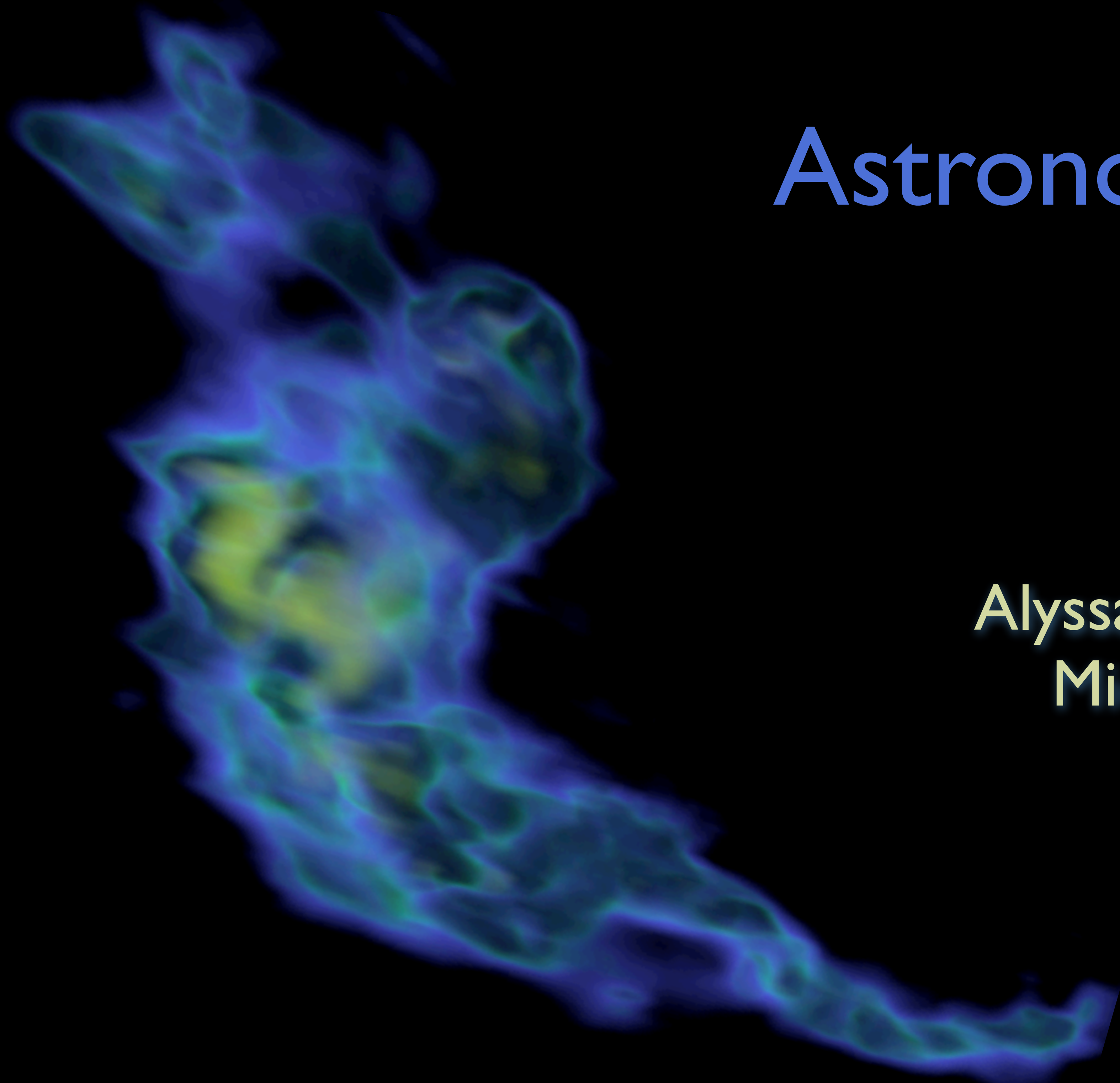
-?-

Are creativity and discovery held back from "could" by confining technological <u>tools</u>?





Astronomical Medicine



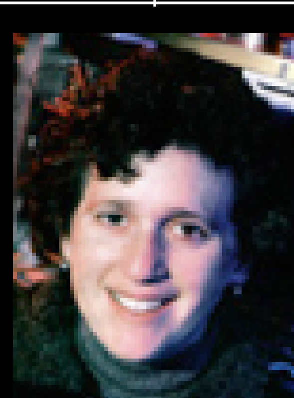
Alyssa Goodman (IIC/CfA/FAS)
Michael Halle (IIC/SPL/HMS)
Ron Kikinis (SPL/HMS)
Douglas Alan (IIC)
Michelle Borkin (FAS/IIC)
Jens Kauffmann (CfA/IIC)
Erik Rosolowsky (CfA/UBC Okanagan)
Nick Holliman (U. Durham)

The Astronomical Medicine Story

Computer Scientist

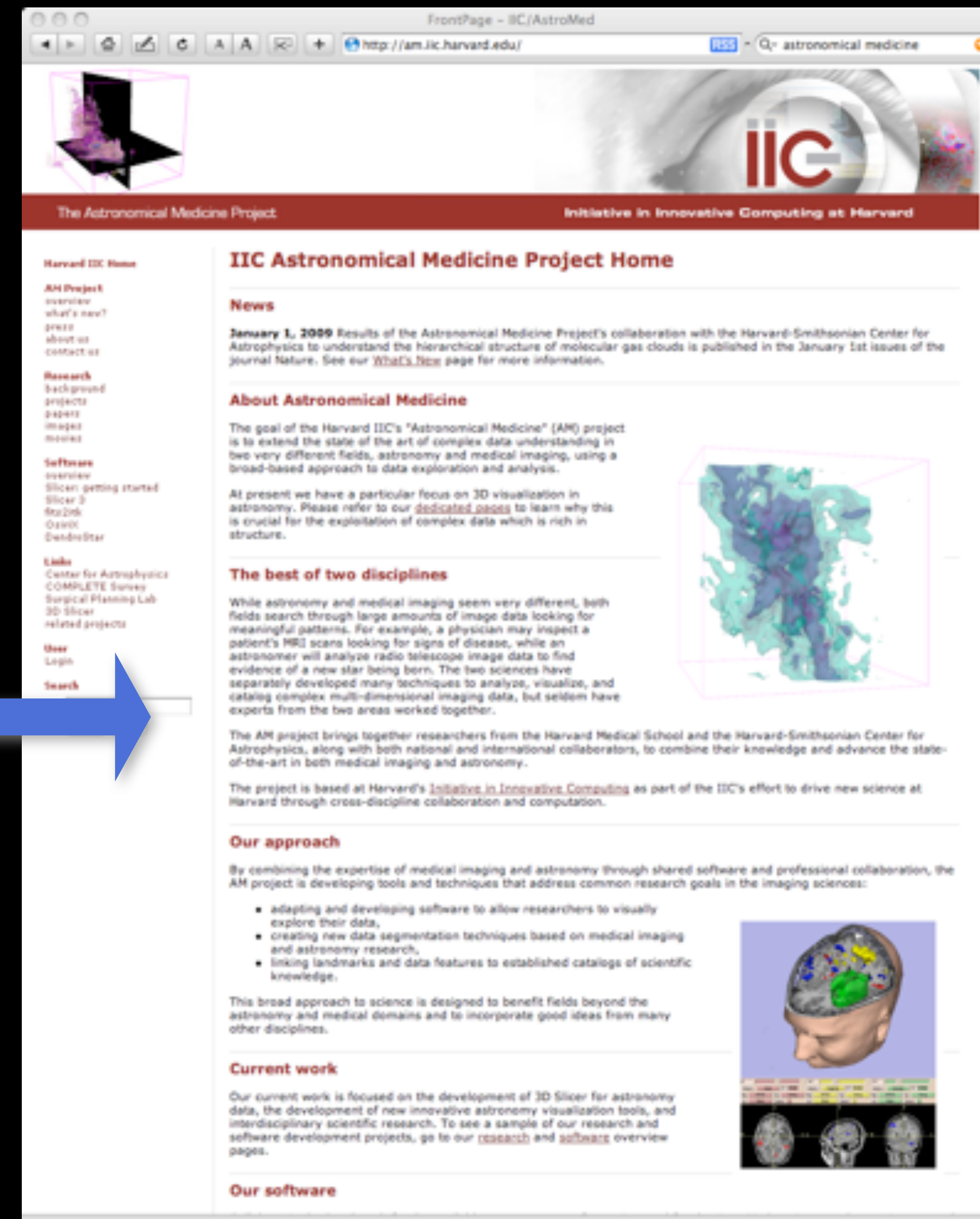
Computer Scientist

"Viz has failed the scientific community…"



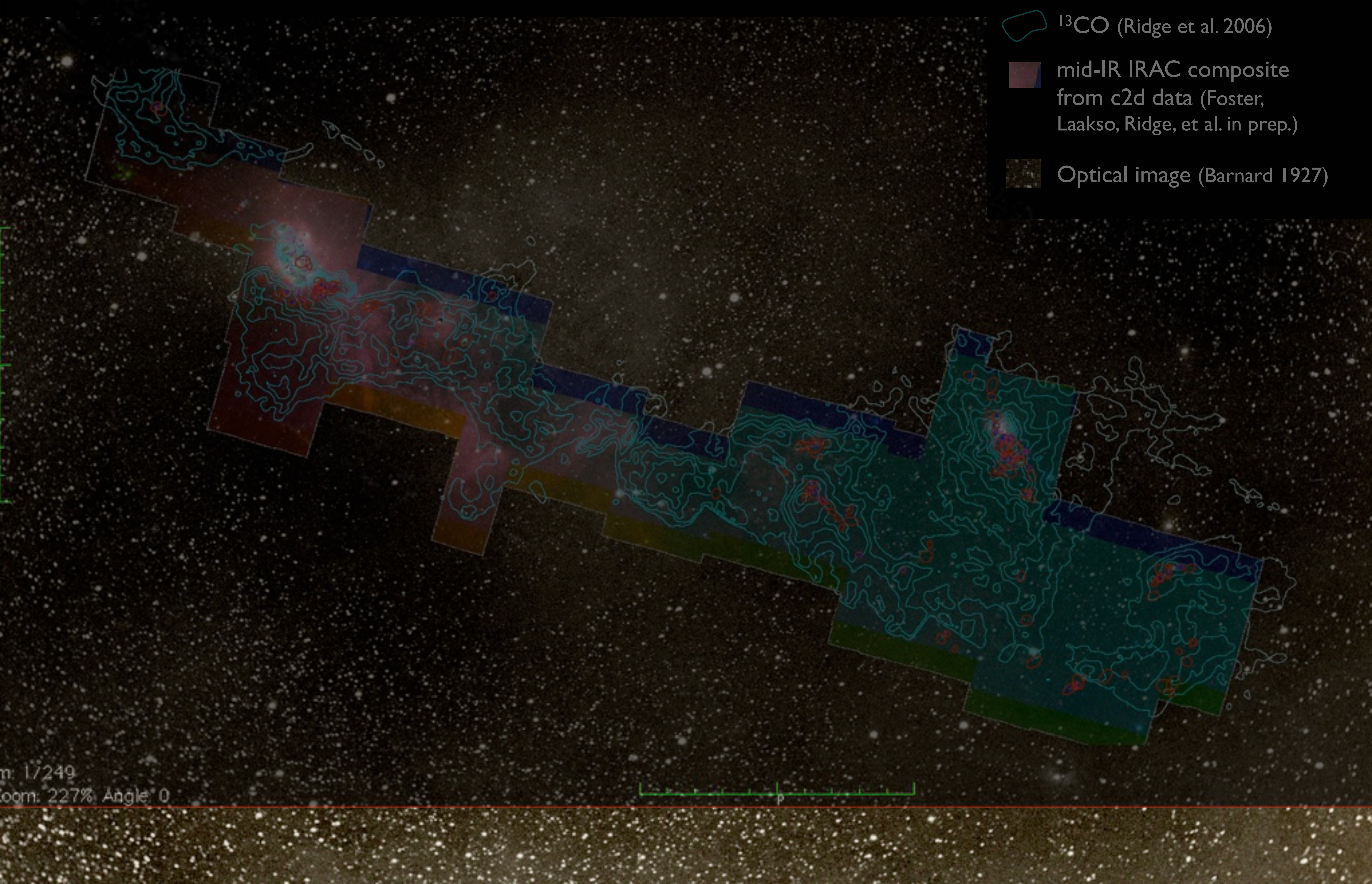
Astronomer

Unsuspecting Undergrad



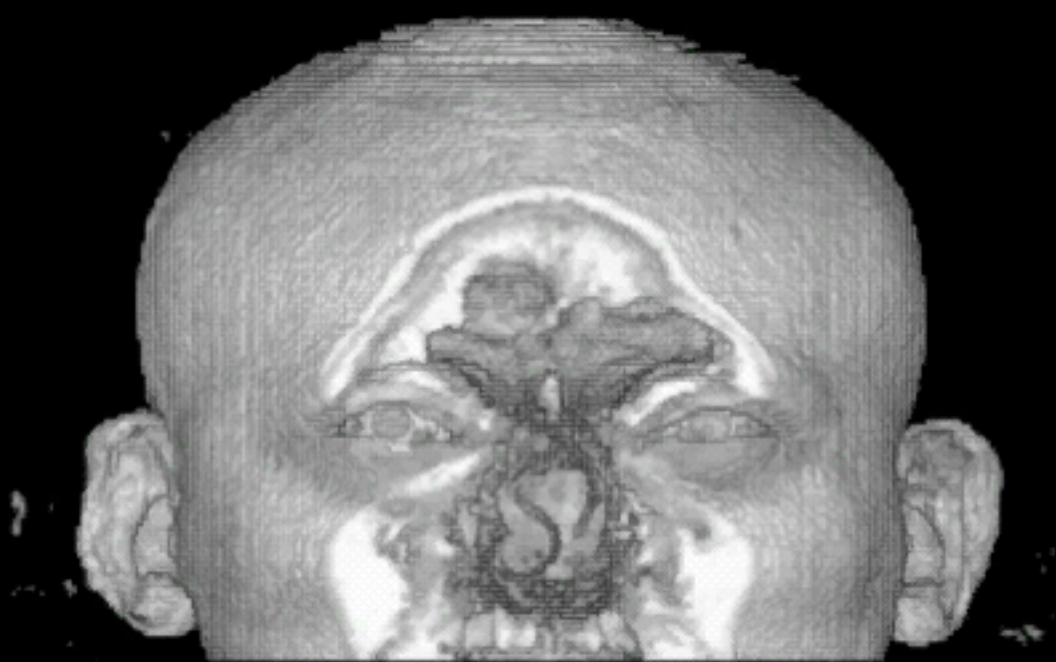
+Nick Holliman (CS, 3D expert)
+Doug Alan (S/W Engineer)
+Jens Kauffmann (postdoc)
+Erik Rosolowsky (postdoc) + …

COMPLETE = COordinated Molecular Probe Line Exinction Thermal Emission



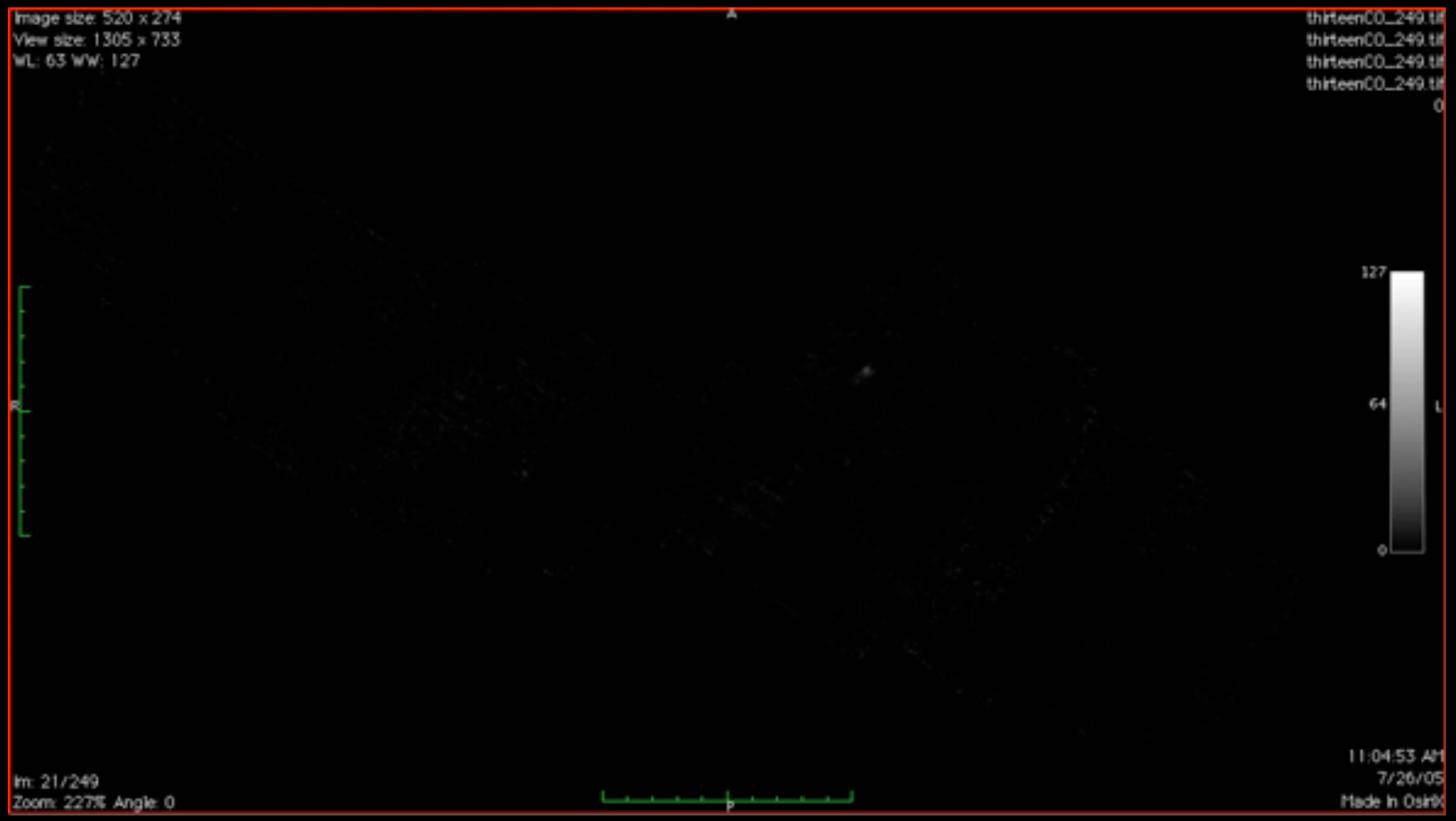
“Astronomical Medicine”

“KEITH”



“z” is depth into head

“PERSEUS”



“z” is line-of-sight velocity

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

What can we observe?

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

Intensity

Energy
(wavelength)

"State"
(e.g. polarization)

Spatial Position
(x, y, z)

Time

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

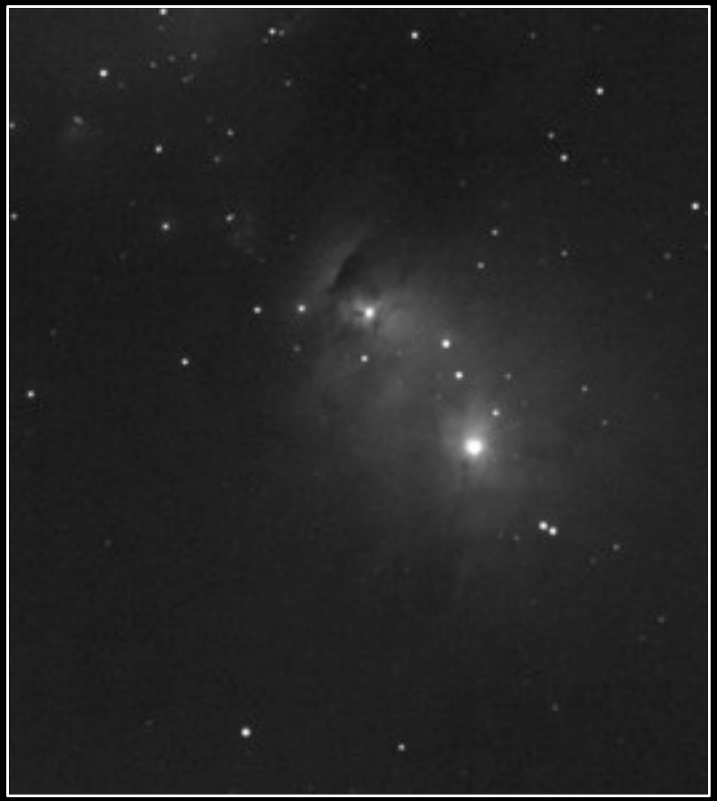
What can we observe?

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

Intensity

Spatial Position

$$(x, y \quad)$$



Optical Single-Band
Image of NGC1333

What can we observe?

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

Intensity

Spatial Position

$(x, y \quad)$

X-Ray of Human Skull, c. 1920

What can we observe?

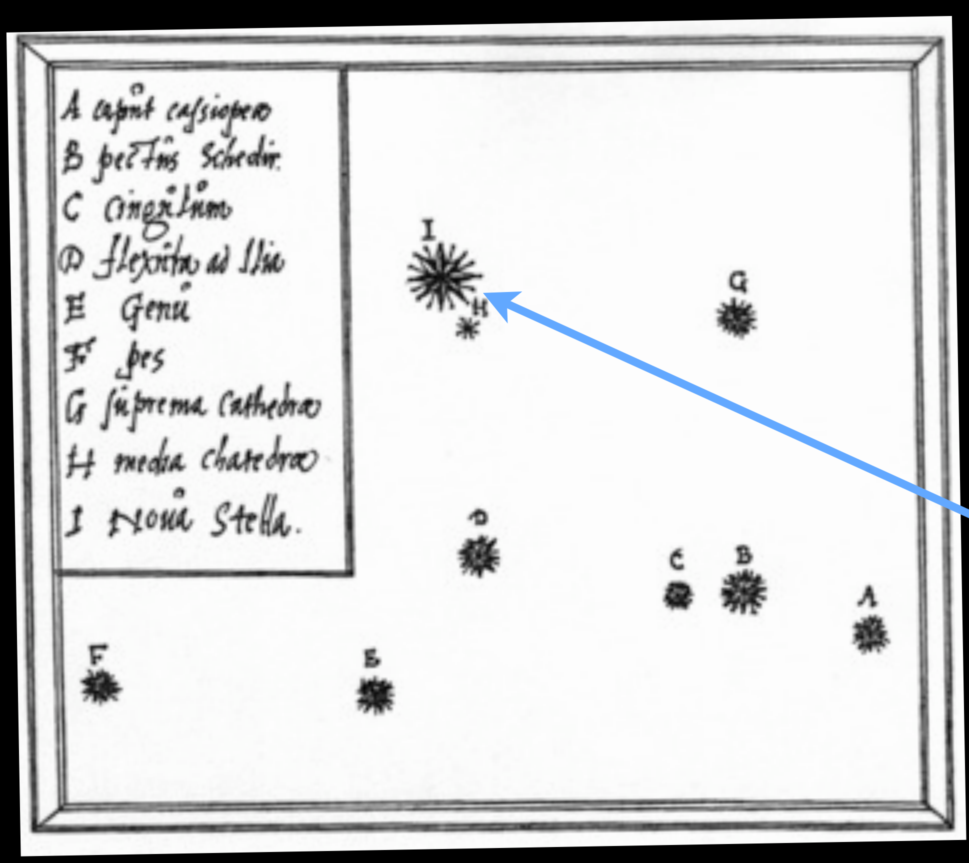
$$I(\vec{x}, t)$$

Intensity

Spatial Position

(x, y, z)

Time



"Nova Stella" of Tycho, 1572

What can we observe?

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

Intensity

Spatial Position

(x, y, z)

Time

Cardiac Motion

What can we observe?

$$I(E, \quad \vec{x} \quad)$$

Intensity

Energy
(wavelength)

Spatial Position
$(x, y \quad)$

Optical (B,V,R) image
of NGC1333

What can we observe?

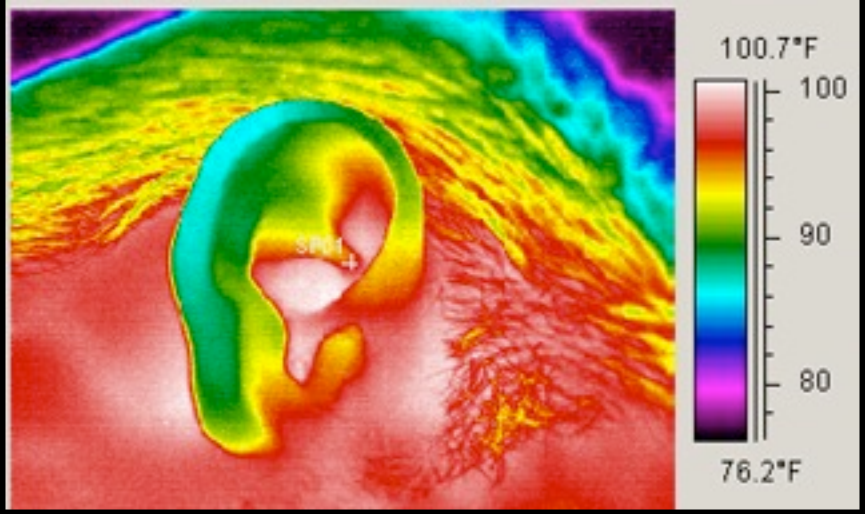
$$I(E, \quad \vec{x} \quad)$$

Intensity

Energy
(wavelength)

Spatial Position
$(x, y \quad)$

Human Ear,
Thermal Infrared



What can we observe?

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

Intensity

"State"
(e.g. polarization)

Spatial Position
$(x, y \quad)$

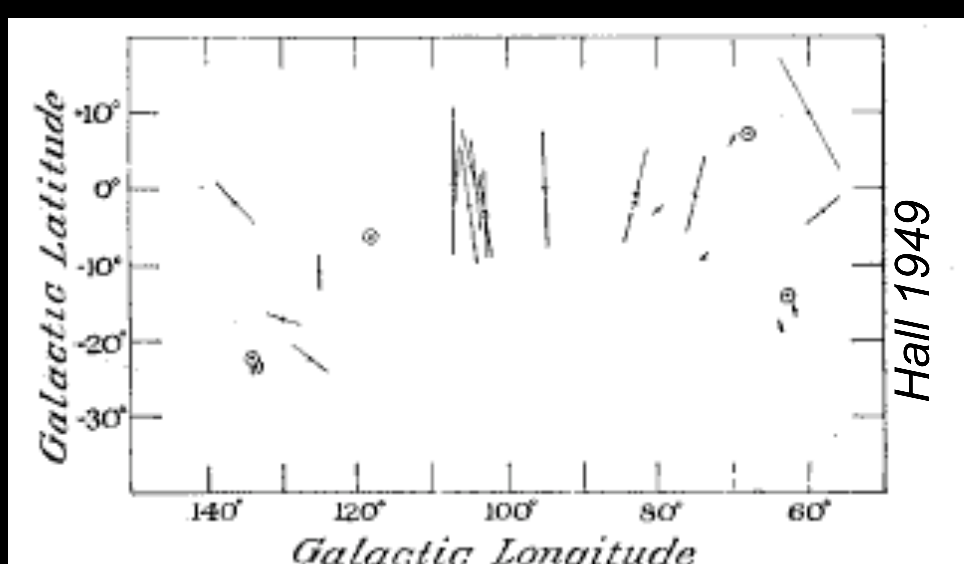


FIG. 4. Observational evidence that there is no one preferential orientation of the plane of polarization. Stars showing no polarization are represented by circles.

What can we observe?

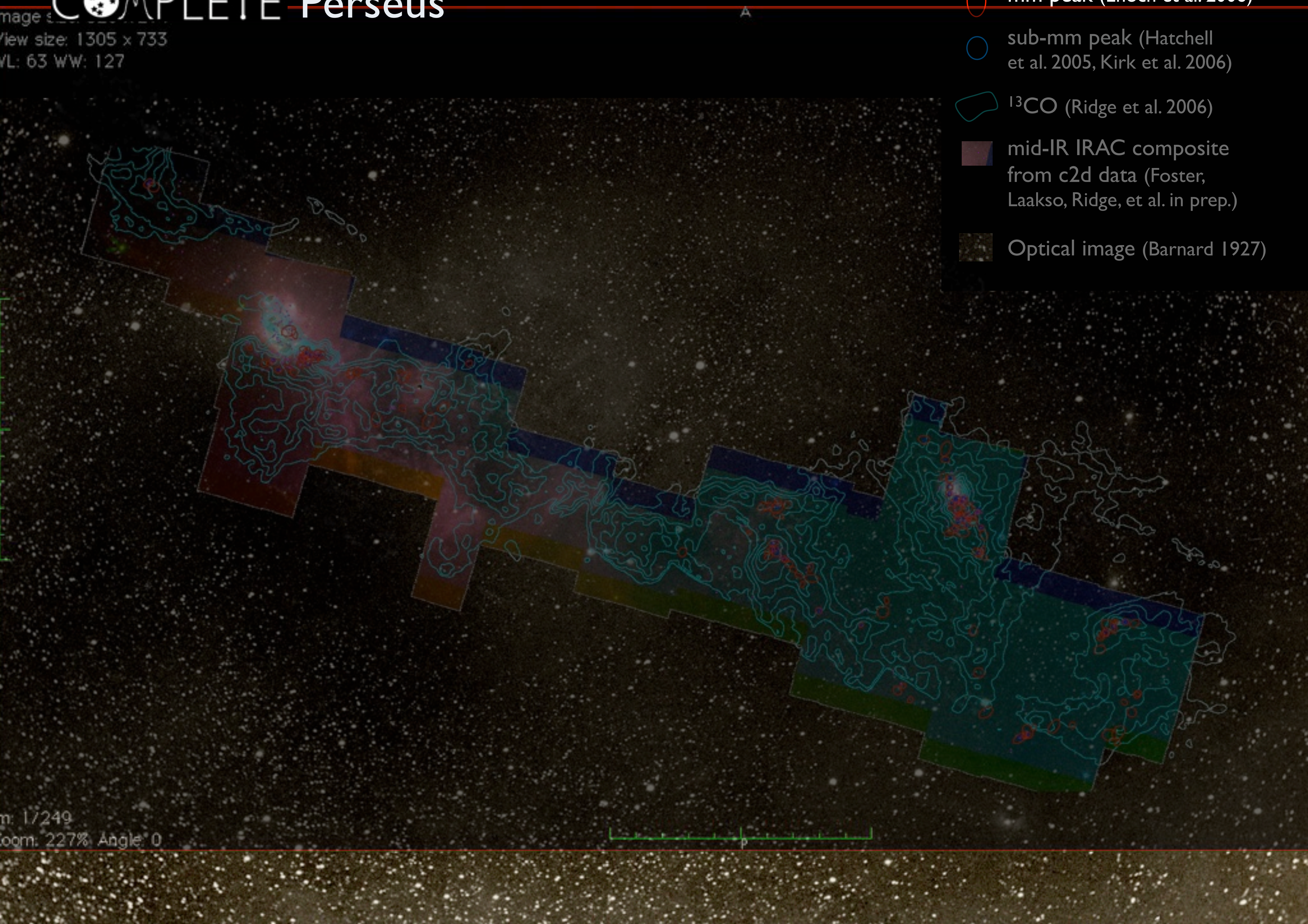
$$I(\quad s, \vec{x}\quad)$$

Intensity

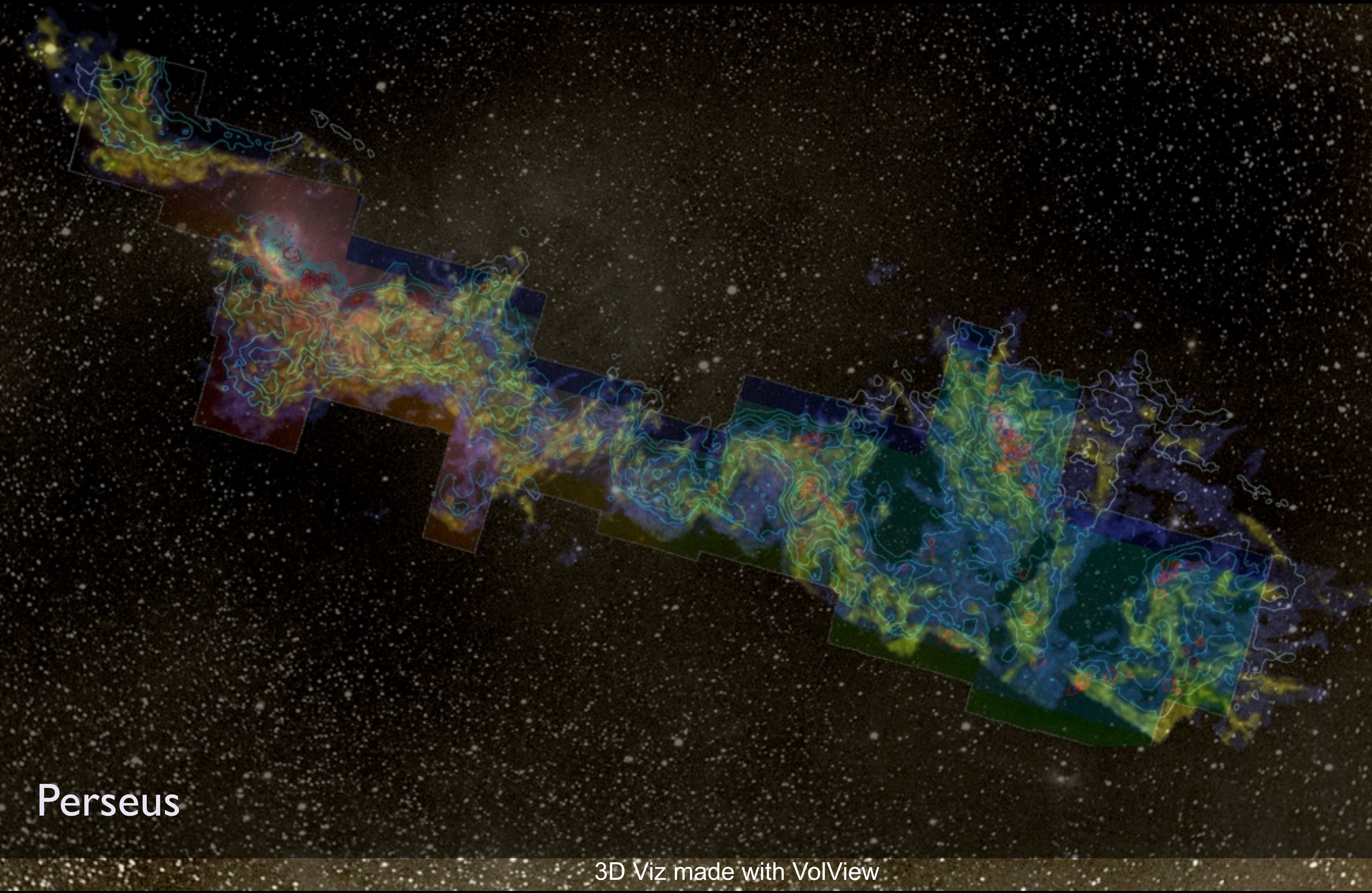
"State"
(~diffusivity)

Spatial Position
(x, y, z)

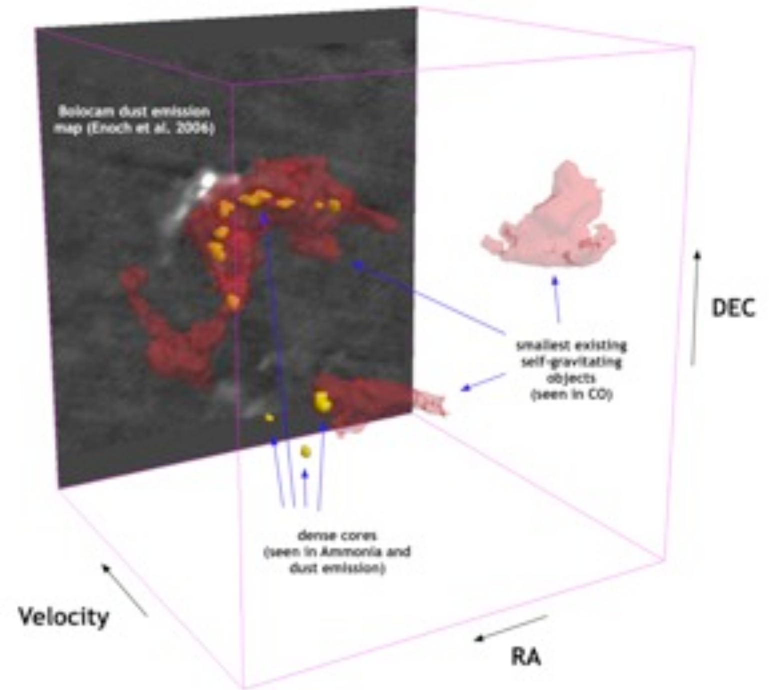
C●MPLETE Perseus



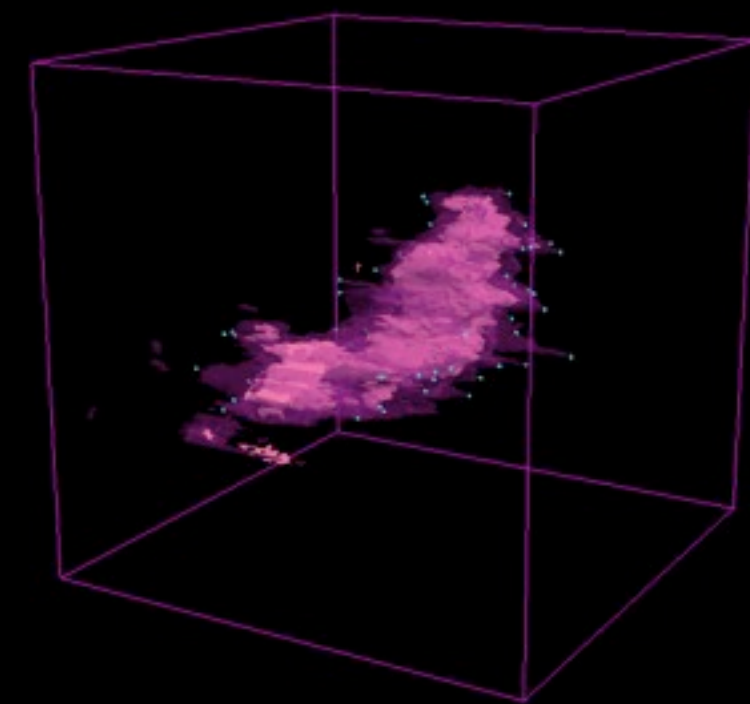
- mm peak (Enoch et al. 2006)
- sub-mm peak (Hatchell et al. 2005, Kirk et al. 2006)
- ^{13}CO (Ridge et al. 2006)
- mid-IR IRAC composite from c2d data (Foster, Laakso, Ridge, et al. in prep.)
- Optical image (Barnard 1927)


Perseus
3D Viz made with VolView

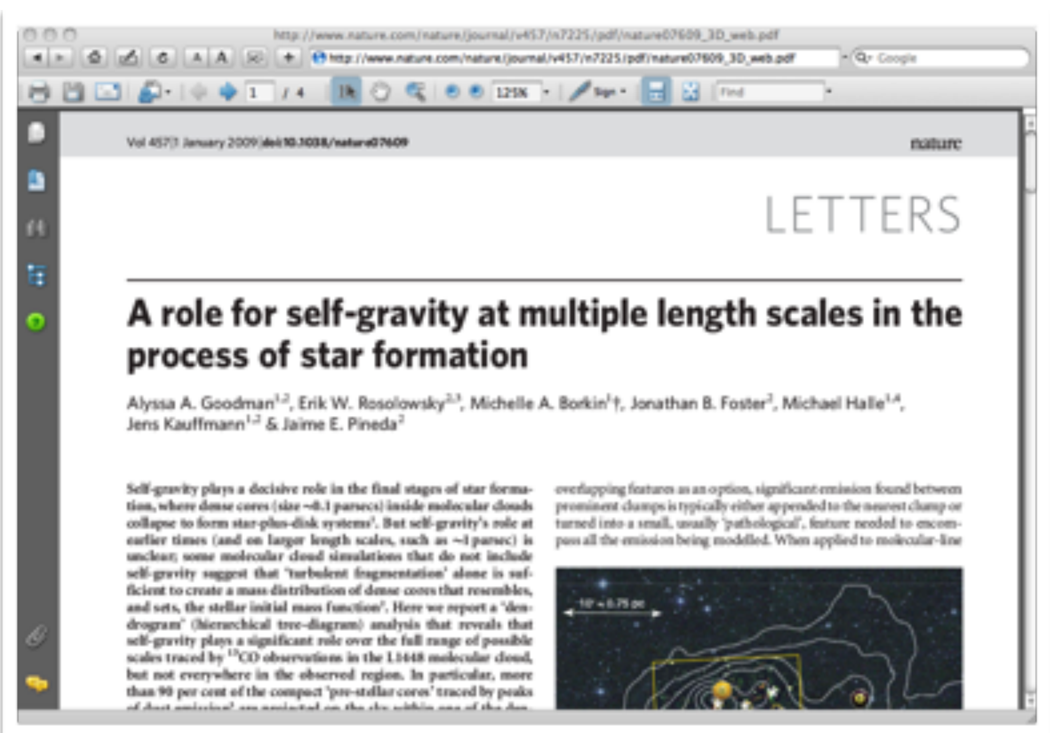
Some of What We've Discovered...



Cores nest in coccoons
(Kauffmann et al. 2009)



Tripled Outflows
(Borkin et al. 2008, Arce et al. 2009a)



Vol 457|1 January 2009|doi:10.1038/nature07609 nature

LETTERS

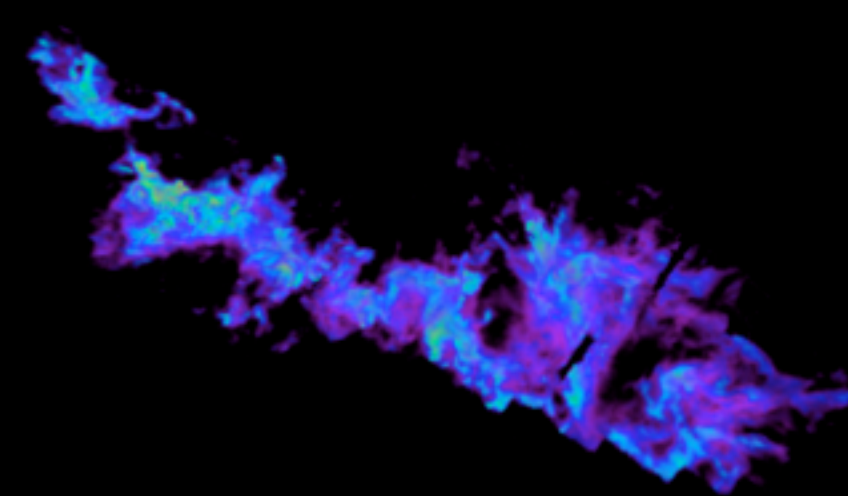
A role for self-gravity at multiple length scales in the process of star formation

Alyssa A. Goodman[1,2], Erik W. Rosolowsky[2,3], Michelle A. Borkin[1]†, Jonathan B. Foster[2], Michael Halle[1,4], Jens Kauffmann[1,2] & Jaime E. Pineda[2]

Self-gravity plays a decisive role in the final stages of star formation, where dense cores (size ~0.1 parsecs) inside molecular clouds collapse to form star-plus-disk systems. But self-gravity's role at earlier times (and on larger length scales, such as ~1 parsec) is unclear; some molecular cloud simulations that do not include self-gravity suggest that 'turbulent fragmentation' alone is sufficient to create a mass distribution of dense cores that resembles, and sets, the stellar initial mass function. Here we report a 'dendrogram' (hierarchical tree-diagram) analysis that reveals that self-gravity plays a significant role over the full range of possible scales traced by ¹³CO observations in the L1448 molecular cloud, but not everywhere in the observed region. In particular, more than 90 per cent of the compact 'pre-stellar cores' traced by peaks

overlapping features as an option, significant emission found between prominent clumps is typically either appended to the nearest clump or turned into a small, usually 'pathological', feature needed to encompass all the emission being modelled. When applied to molecular-line

Gravity Matters
(Goodman et al. 2009)



Shells Rule
(Arce et al. 2009b)

“Seeing” the Role Self-Gravity in Star Formation

NATURE|Vol 457|1 January 2009

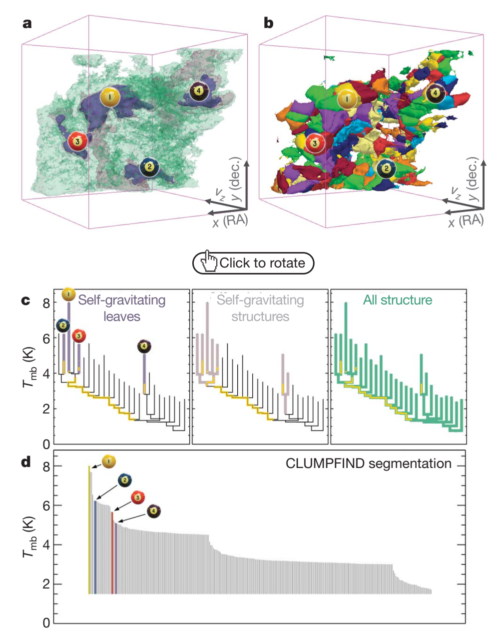


Figure 2 | Comparison of the ‘dendrogram’ and ‘CLUMPFIND’ feature-identification algorithms as applied to ^{13}CO emission from the L1448 region of Perseus. a, 3D visualization of the surfaces indicated by colours in the dendrogram shown in **c**. Purple illustrates the smallest scale self-gravitating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

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

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

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

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

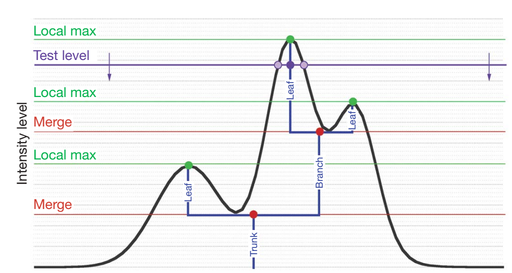


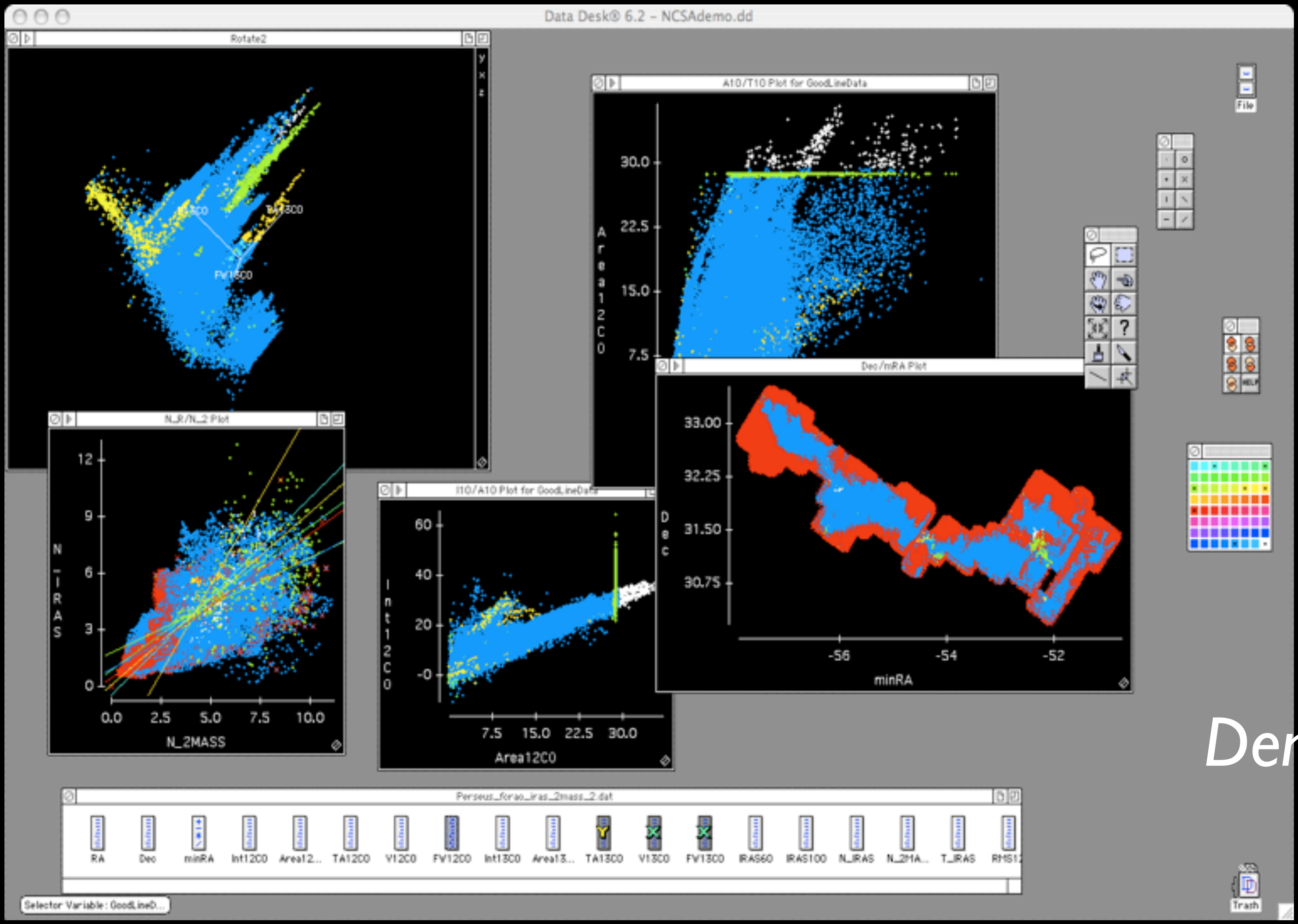
Figure 3 | Schematic illustration of the dendrogram process. Shown is the construction of a dendrogram from a hypothetical one-dimensional emission profile (black). The dendrogram (blue) can be constructed by ‘dropping’ a test constant emission level (purple) from above in tiny steps (exaggerated in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

Goodman et al. *Nature*, 2009

Interactivity for the Future

(from "Could" to "Can")

"Data Desk"



Demo!

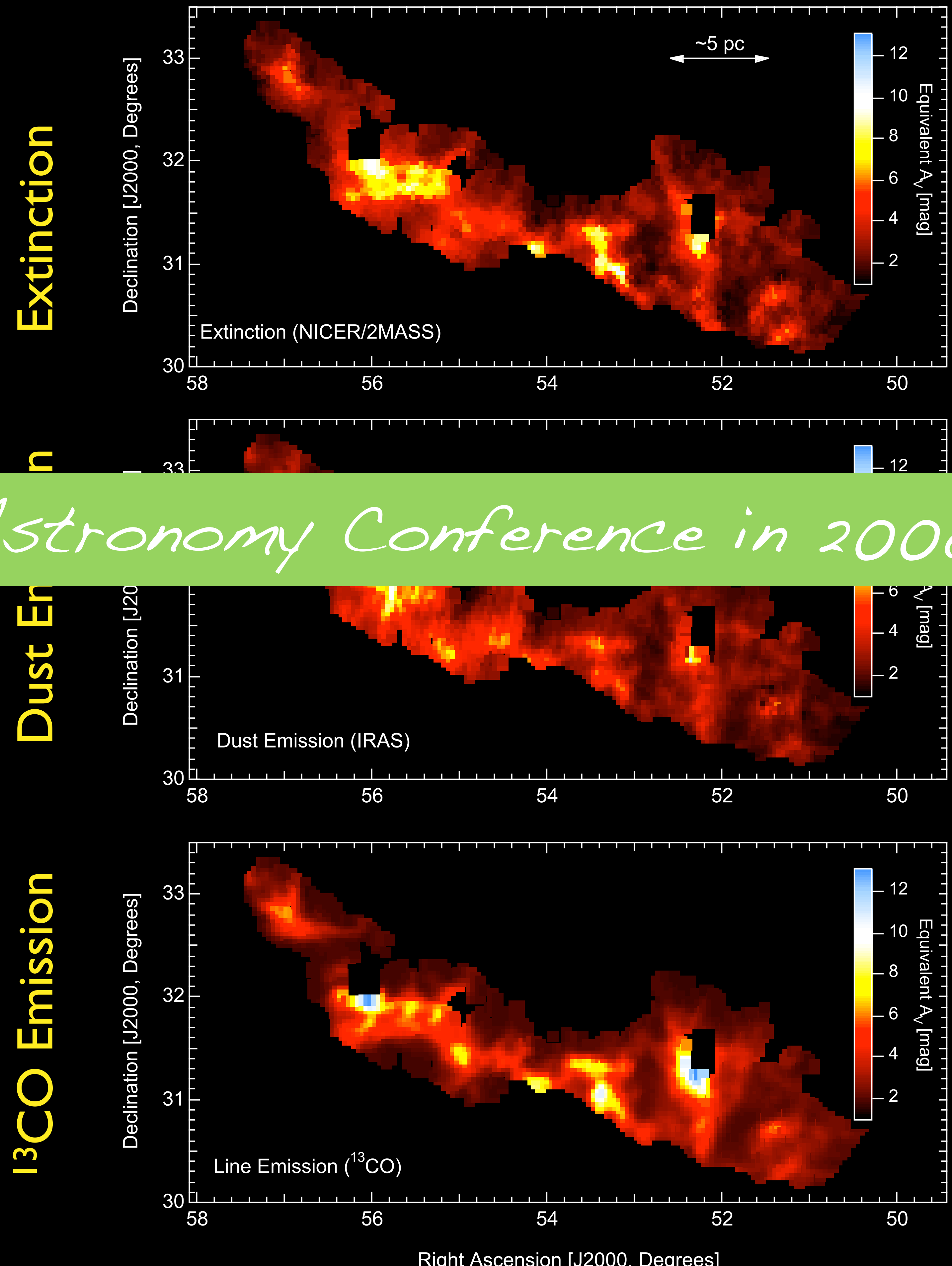
If only DataDesk were >2D...??

3D selction tools (& interaction) are challenging

The (secret)

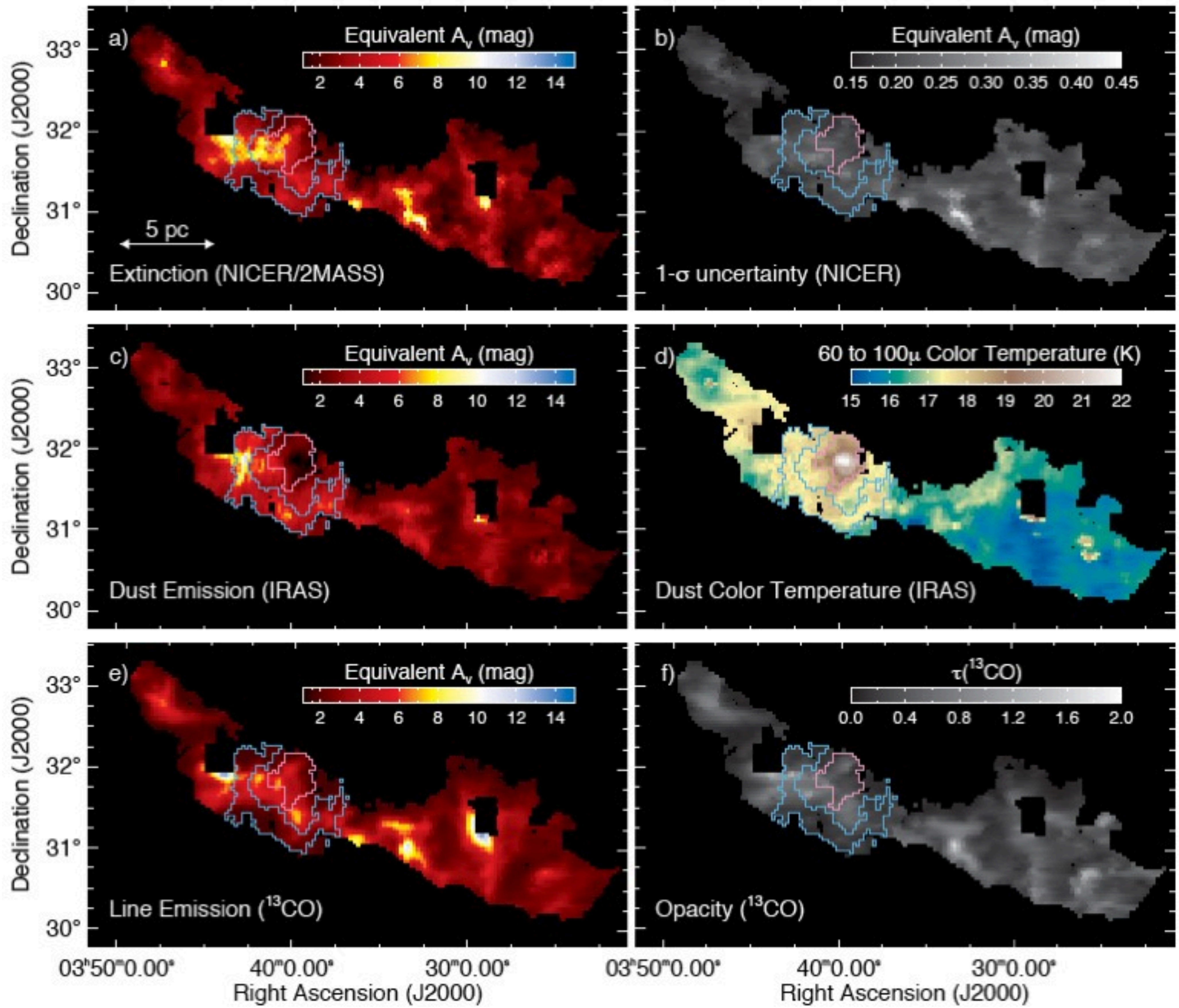
Real Slide from Real Astronomy Conference in 2006

inherent in
column density
mapping.



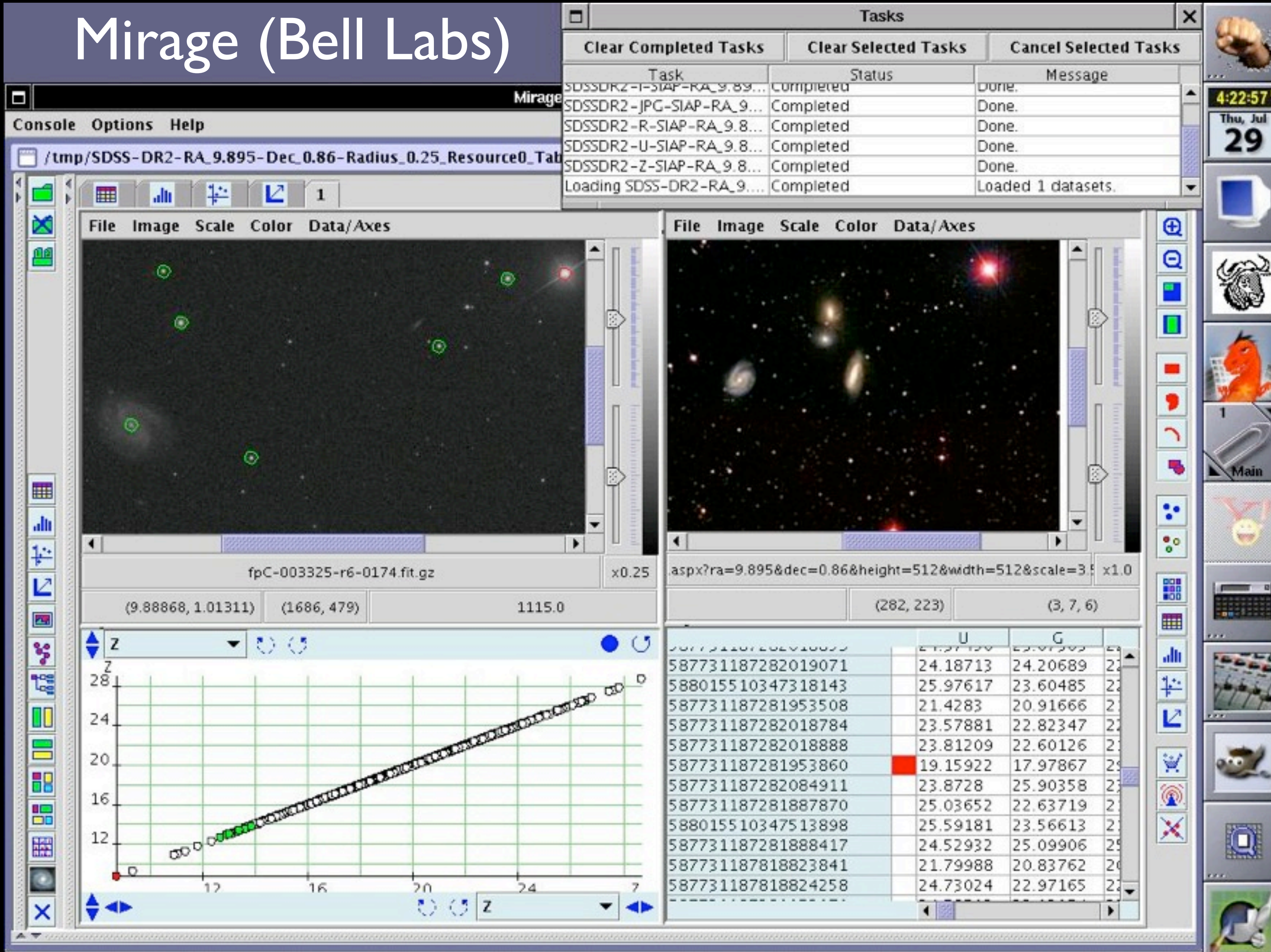
Goodman, Pineda & Schnee, 2007; see also Pineda, Caselli & Goodman 2007.

FYI: Published, 2009, like this...



Goodman, Pineda & Schnee,2009; see also Pineda, Caselli & Goodman 2008.

Mirage (Bell Labs)



cf. Avizo (Mercury Systems); some aspects of GenePattern; Taverna...

What we *can* (and others *could*) see off the desktop...

IIC Member login

home
about the iic
research
education
people
events
employment
reaching the iic

iic

Initiative in Innovative Computing at Harvard

INITIATIVE IN INNOVATIVE COMPUTING (IIC) NEWSLETTER

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home › research

scientists' discovery room lab (sdr lab)

Lead investigators
Chia Shen (IIC) and Hanspeter Pfister (SEAS/IIC)

Project staff
Michael Horn, Meekal Bajaj, Matthew Tobiasz and Matthias Lee

Description

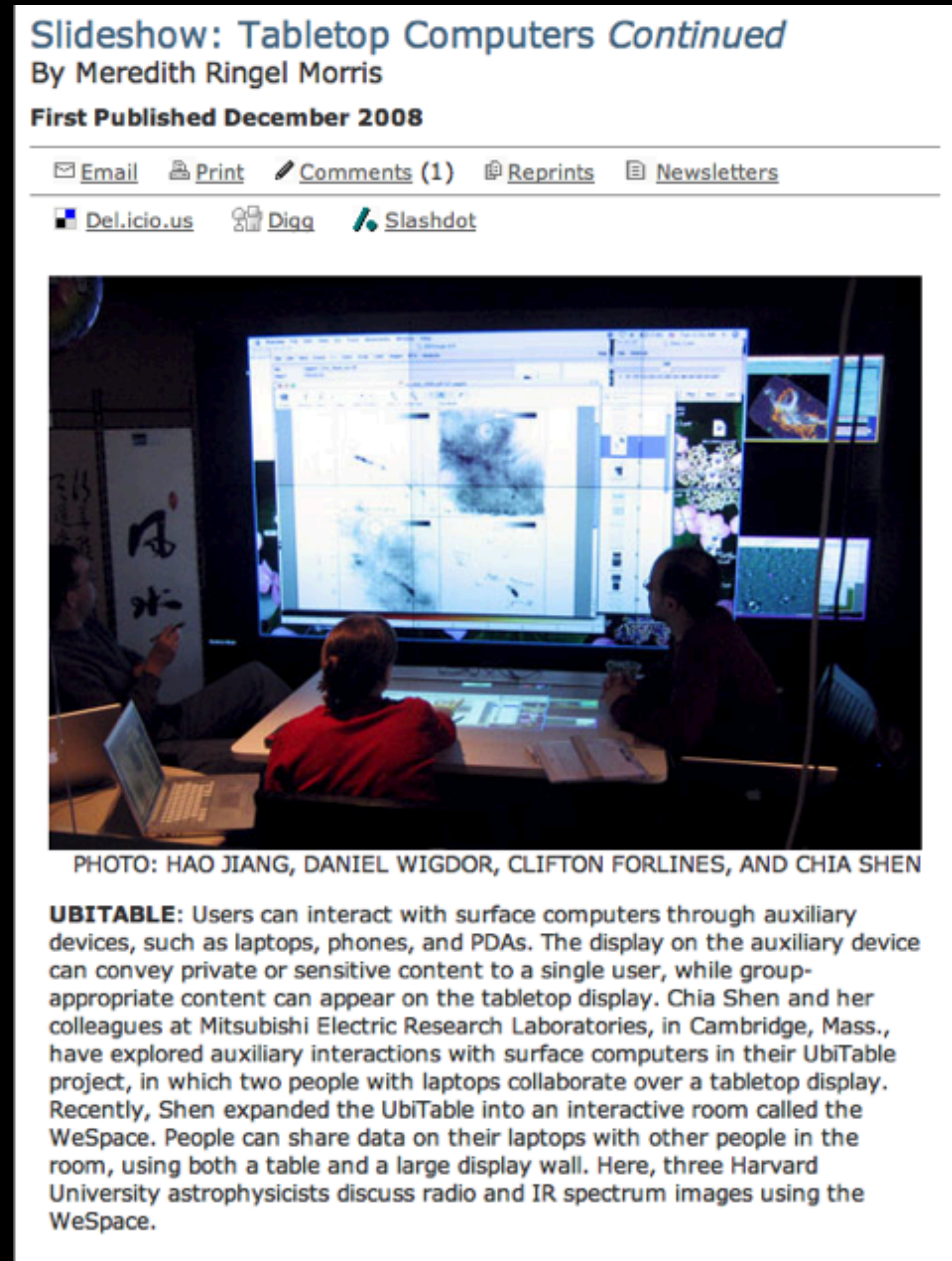
The Scientists' Discovery Room (SDR) is a next-generation visual digital laboratory for science discovery, collaborative learning and education. Our research focuses on experimenting with new modalities of human-computer interaction and visualization, to create a new genre of navigation, exploration and detailed analyses in multi-dimensional information spaces. All projects in SDR are in close collaboration with domain scientists and educators.

INVOLV is a generalizable multi-user interactive visualization framework for large hierarchical data sets. In this project, we address the visual layout of both the primary data representation and the overlay of alternate structures of the same data. Our first case study is the visualization of life on earth based on the Encyclopedia of Life (www.eol.org) and Tree of Life (www.tolweb.org). The user interface provides free-form exploration of more than 1.2 million named species while communicating issues of biodiversity and phylogeny. The current visualization combines a Voronoi Treemap tessellation with innovative human-computer interaction designs to support collaborative exploration and learning. Please visit www.involvweb.org for more information on this project.

CThru, a collaborative endeavor with Molecular and Cellular Biology faculty, aims to develop a self-guided learning environment. In CThru, we examine methods for constructing interactive video-based educational modules. Using the animation "The Inner Life of the Cell" as a testbed, CThru addresses research issues of embedding interactive visible objects, extensive multimedia information and manipulatable 3D models within a video flow, replacing sequential video viewing with the experience of exploring and manipulating in a multi-dimentional information space.

WeSpace is a collaborative work space that integrates a large data wall with a multi-user multi-touch table. WeSpace has been developed for a population of scientists who frequently meet in small groups for data exploration and visualization. It provides a low overhead walk-up and share environment for users with their own personal applications and laptops.

LivOlay is an interactive image overlay tool that enables the rapid visual overlay of live data rendered in different applications. Our tool addresses datasets in which visual registration of the information is necessary in order to allow for thorough understanding and visual analysis.



Slideshow: Tabletop Computers *Continued*

By Meredith Ringel Morris

First Published December 2008

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PHOTO: HAO JIANG, DANIEL WIGDOR, CLIFTON FORLINES, AND CHIA SHEN

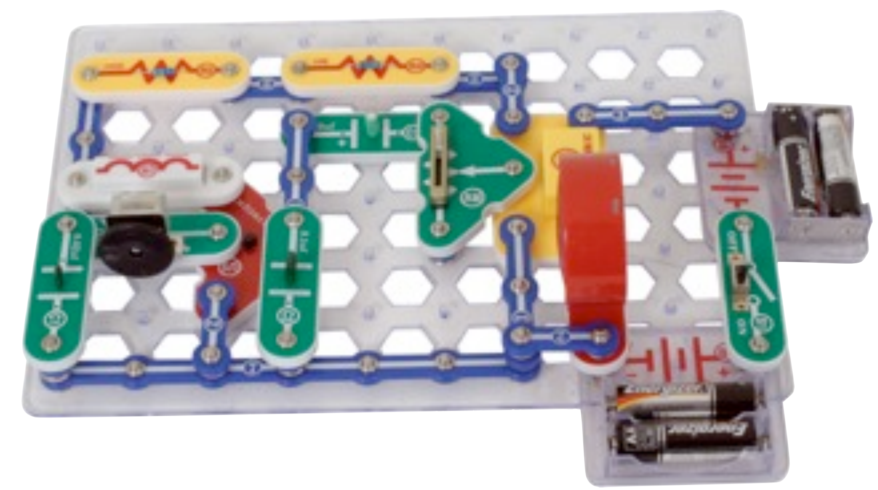
UBITABLE: Users can interact with surface computers through auxiliary devices, such as laptops, phones, and PDAs. The display on the auxiliary device can convey private or sensitive content to a single user, while group-appropriate content can appear on the tabletop display. Chia Shen and her colleagues at Mitsubishi Electric Research Laboratories, in Cambridge, Mass., have explored auxiliary interactions with surface computers in their UbiTable project, in which two people with laptops collaborate over a tabletop display. Recently, Shen expanded the UbiTable into an interactive room called the WeSpace. People can share data on their laptops with other people in the room, using both a table and a large display wall. Here, three Harvard University astrophysicists discuss radio and IR spectrum images using the WeSpace.

http://iic.harvard.edu/research/scientists-discovery-room-lab-sdr-lab

http://spectrum.ieee.org/dec08/6999/9

The Scientists' Discovery Room
(Shen & Pfister)

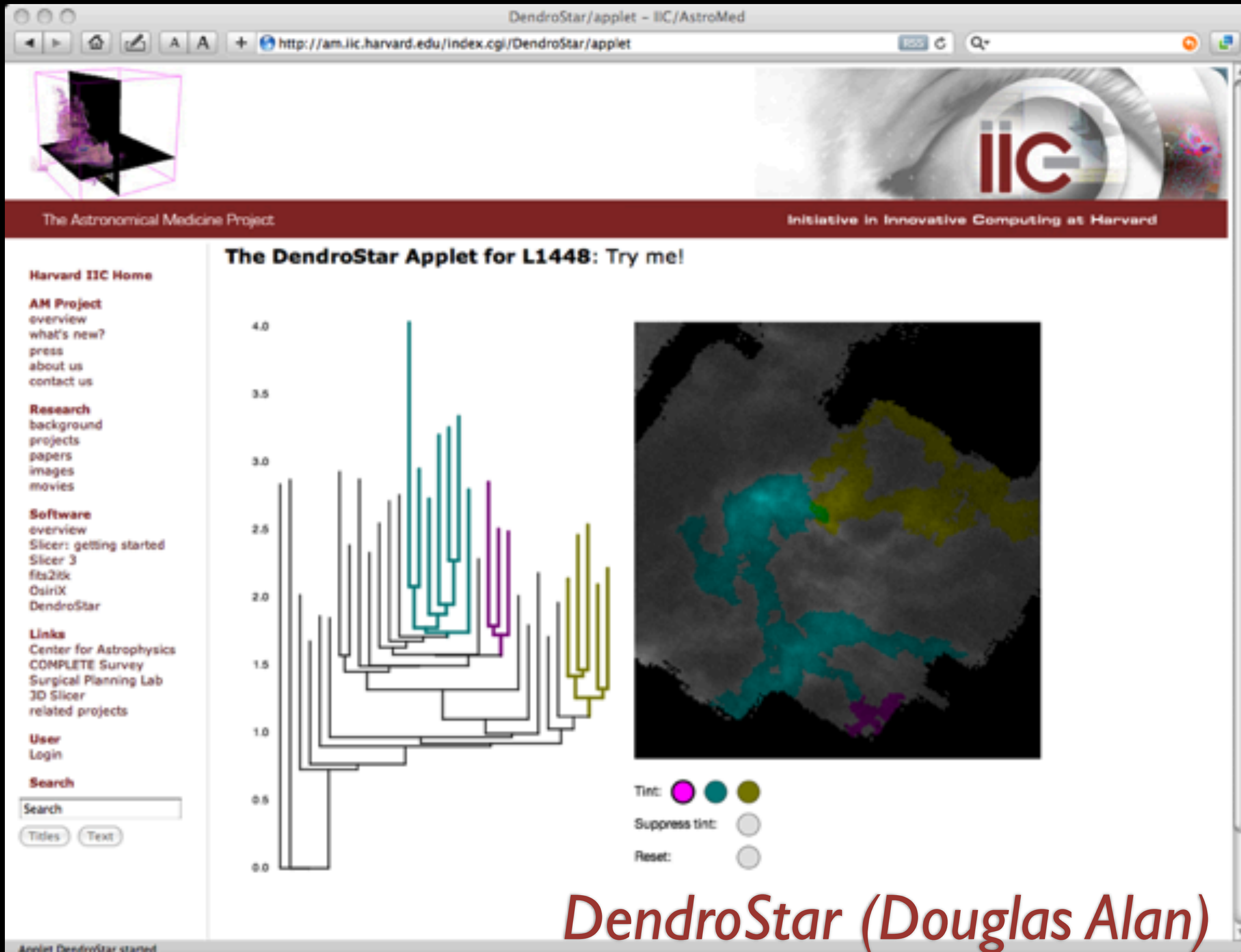
movie courtesy Daniel Wigdor, equipment now in Chia Shen's SDR lab at Harvard SEAS



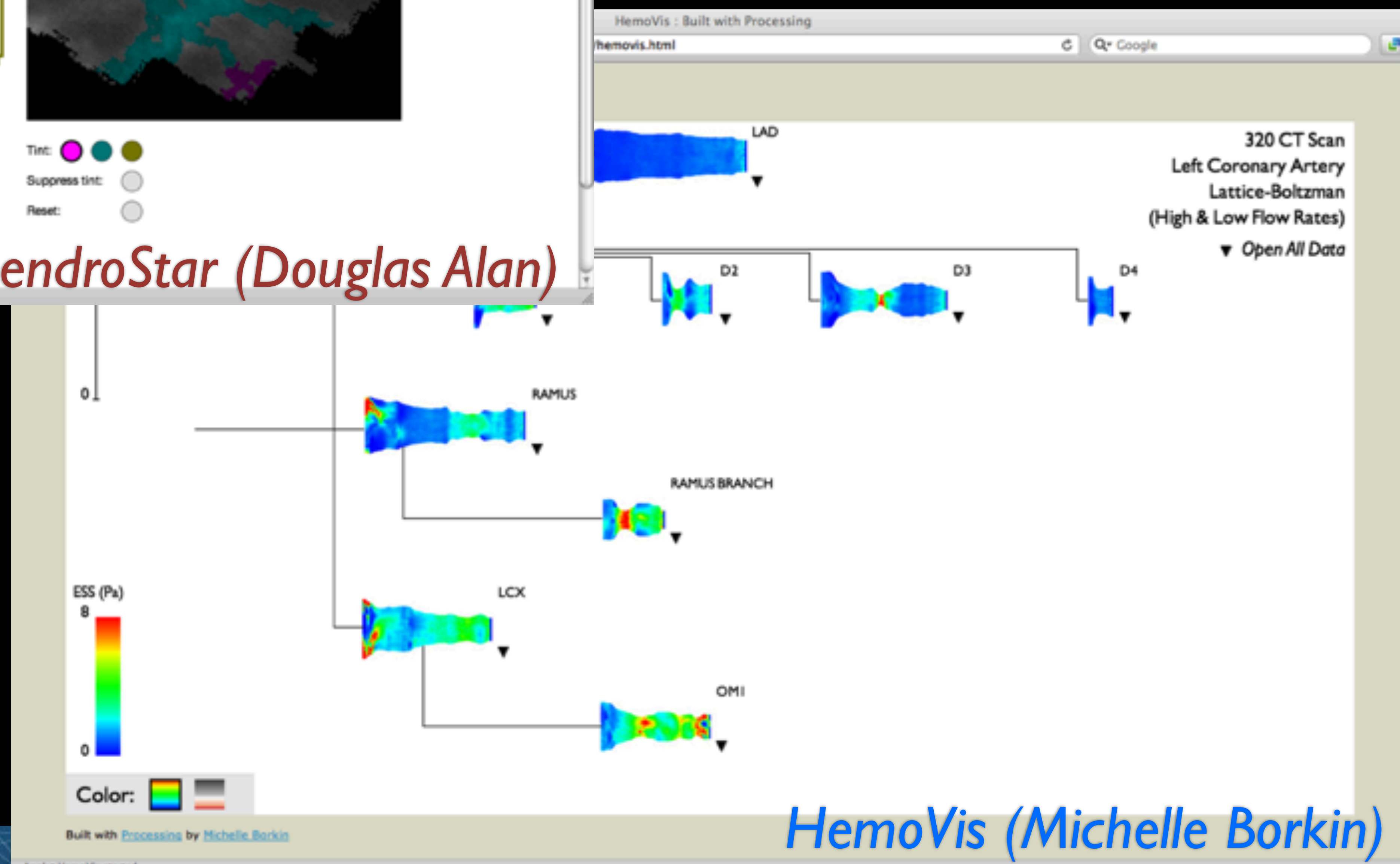
The *Modular, Personalizable,* Approach we "Can", "Could" (& Should!?) Take to *Ineractions*

"Made with *Processing*"

(see Reas & Fry 2006)



DendroStar (Douglas Alan)



HemoVis (Michelle Borkin)

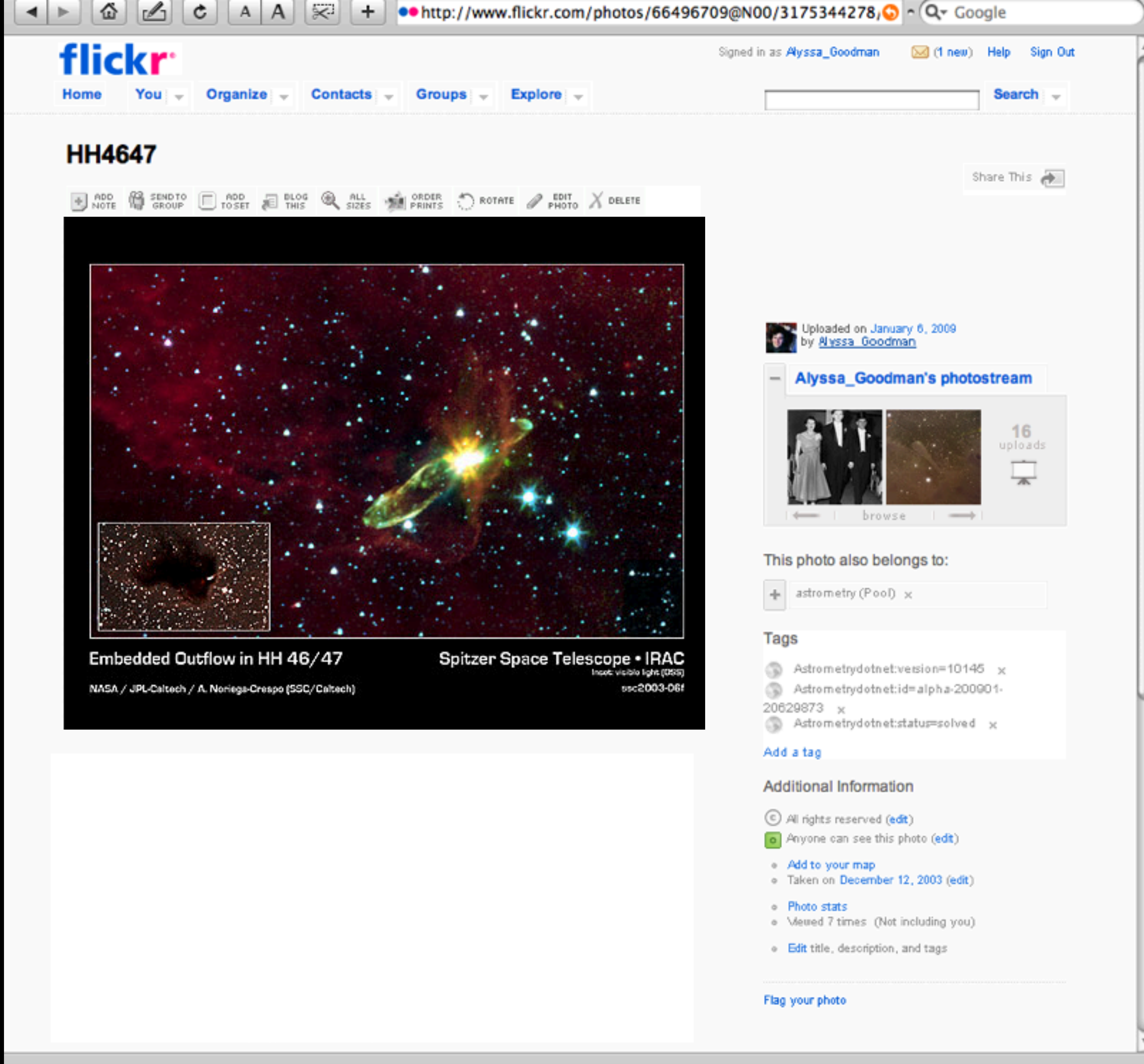
Credit: NASA/JPL-Caltech/A. Noriega-Crespo (SSC/Caltech), Digital Sky Survey

HH46/47

This image from NASA's Spitzer Space Telescope transforms a dark cloud into a silky translucent veil, revealing the molecular outflow from an otherwise hidden newborn star. Using near-infrared light, Spitzer pierces through the dark cloud to detect the embedded outflow in an object called HH 46/47. Herbig-Haro (HH) objects are bright, nebulous regions of gas and dust that are usually buried within dark clouds. They are formed when supersonic gas ejected from a forming protostar, or embryonic star, interacts with the surrounding interstellar medium. These young stars are often detected only in the infrared.

The Spitzer image was obtained with the infrared array camera. Emission at 3.6 microns is shown as blue, emission from 4.5 and 5.8 microns has been combined as green, and 8.0 micron emission is depicted as red.

HH 46/47 is a striking example of a low-mass protostar ejecting a jet and creating a bipolar, or two-sided, outflow. The central



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Embedded Outflow in HH 46/47
Spitzer Space Telescope • IRAC
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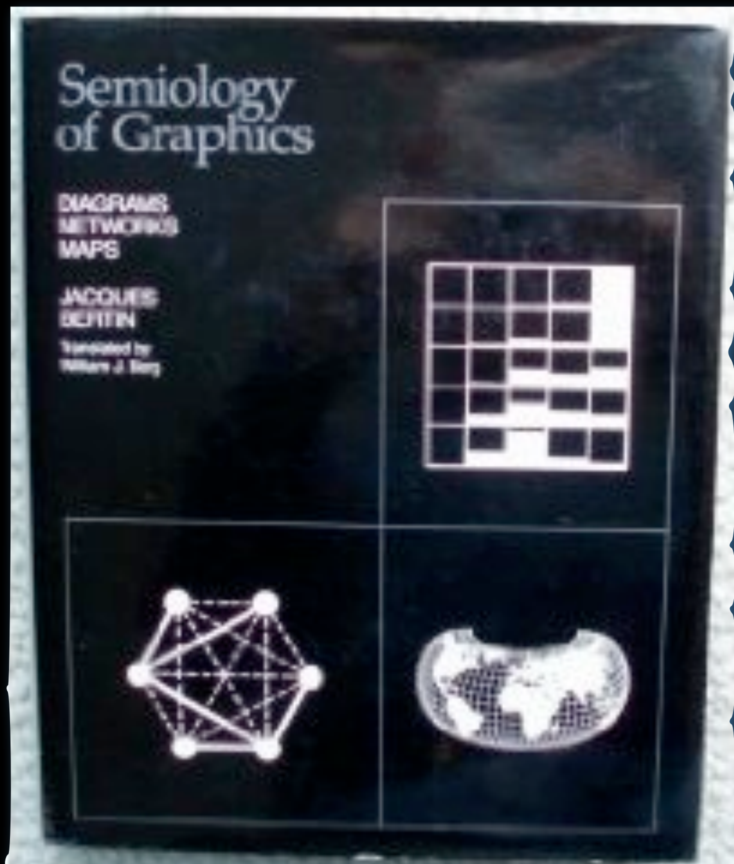
From Baby Pictures to Baby Stars: What Scientists *Can* See

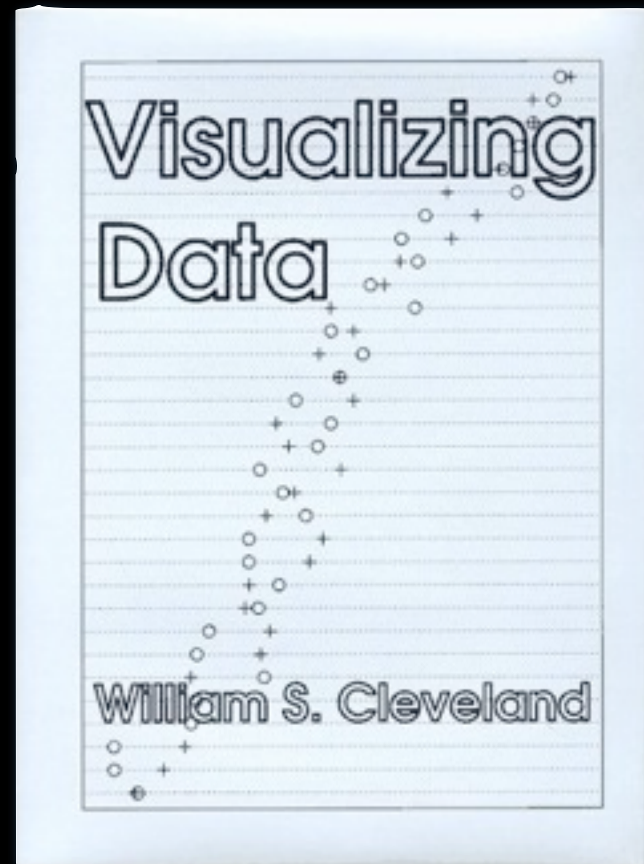
Alyssa A. Goodman
Harvard University (HCO+IIC)
Smithsonian Astrophysical Observatory
Scholar-in-Residence, WGBH

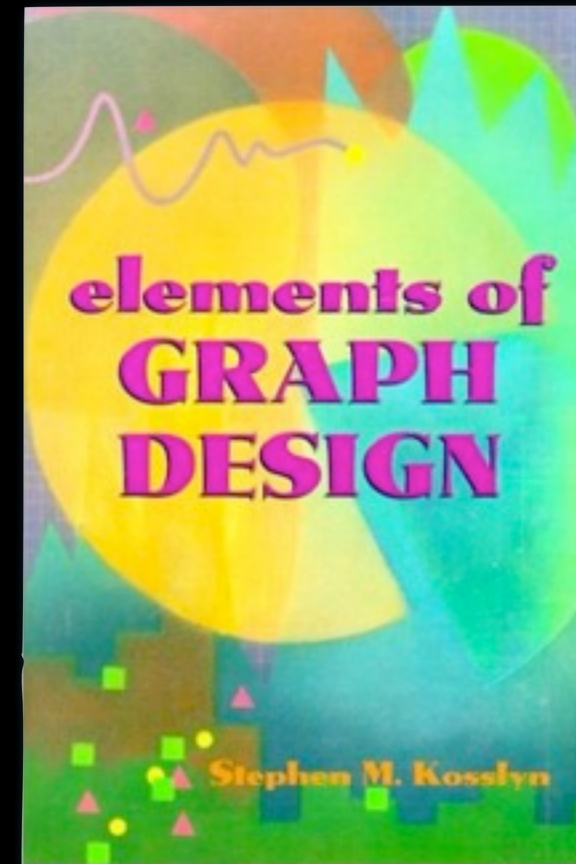
Shall we generalize?...

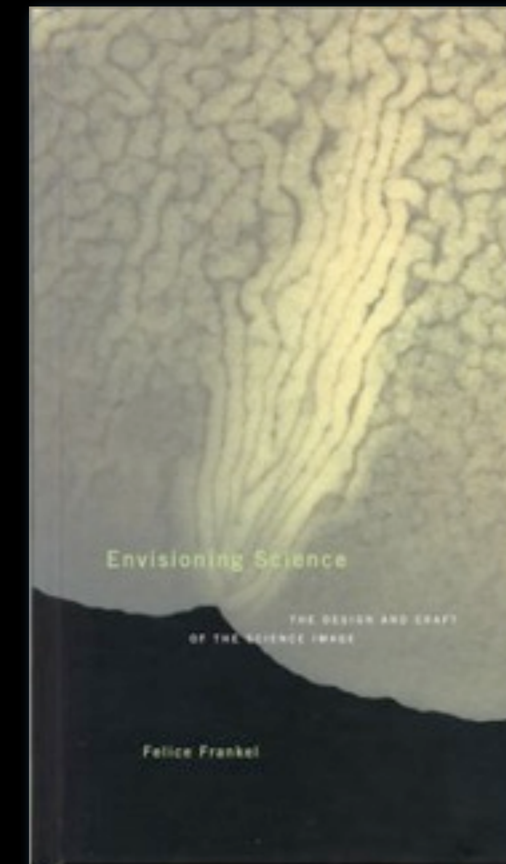
Discussion:

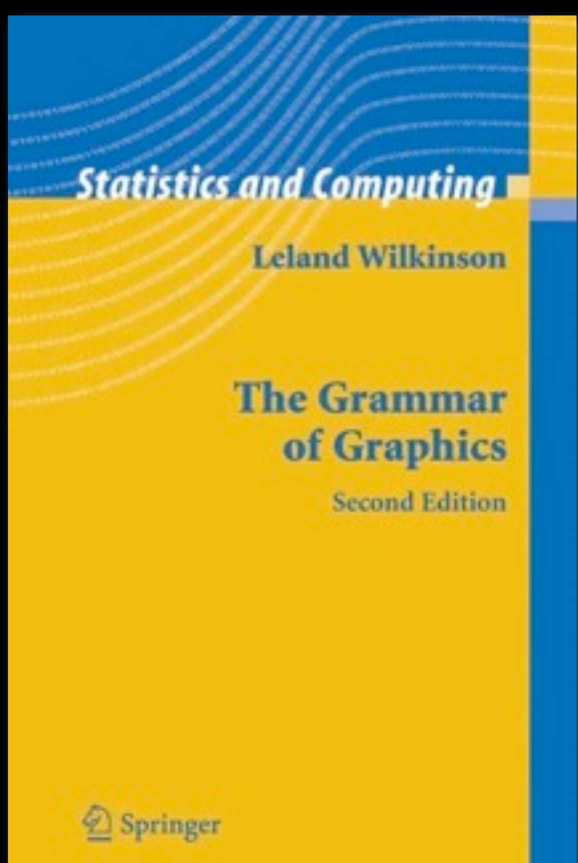
Can this process ever be generalized in a “theory of data graphics”?


Semiology of Graphics
DIAGRAMS
NETWORKS
MAPS
JACQUES BERTIN


Visualizing Data
William S. Cleveland


elements of GRAPH DESIGN
Stephen M. Kosslyn


Envisioning Science
Felice Frankel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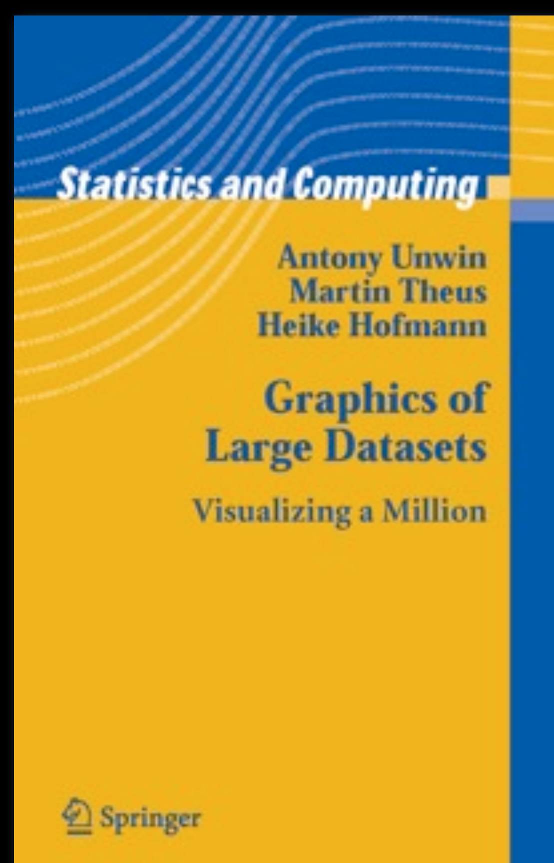
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Graphics of Large Datasets
Visualizing a Million
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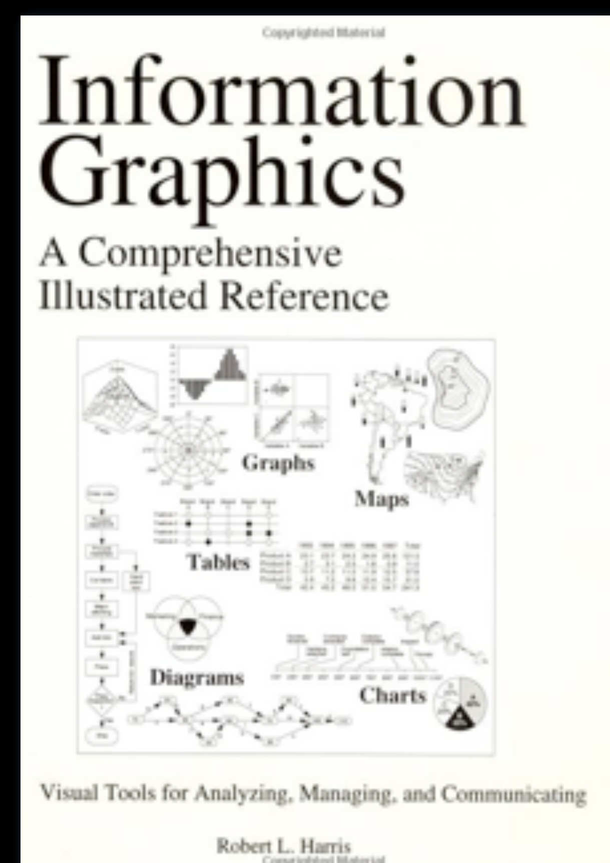
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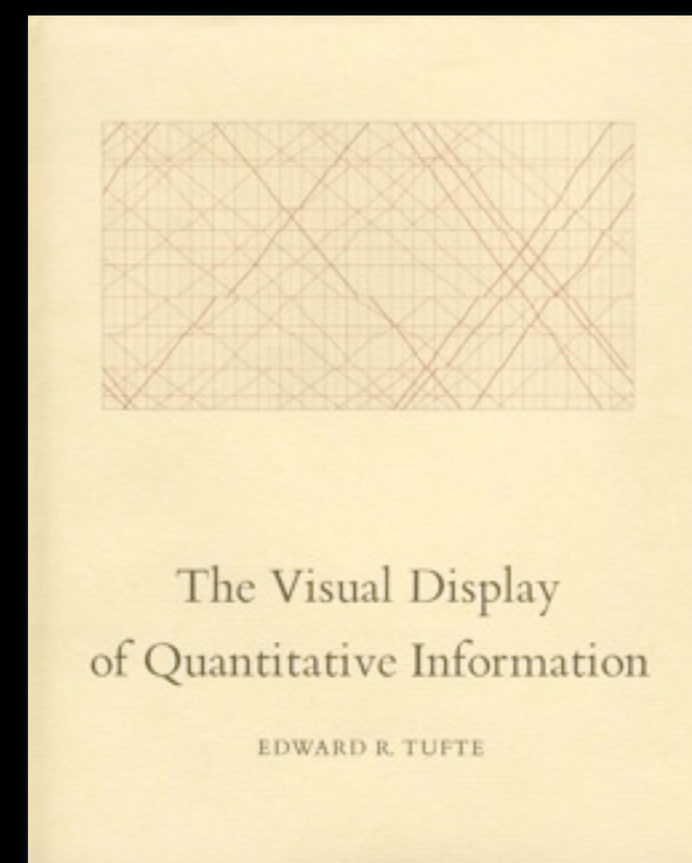
Visual Tools for Analyzing, Managing, and Communicating
Robert L. Harris


The Visual Display of Quantitative Information
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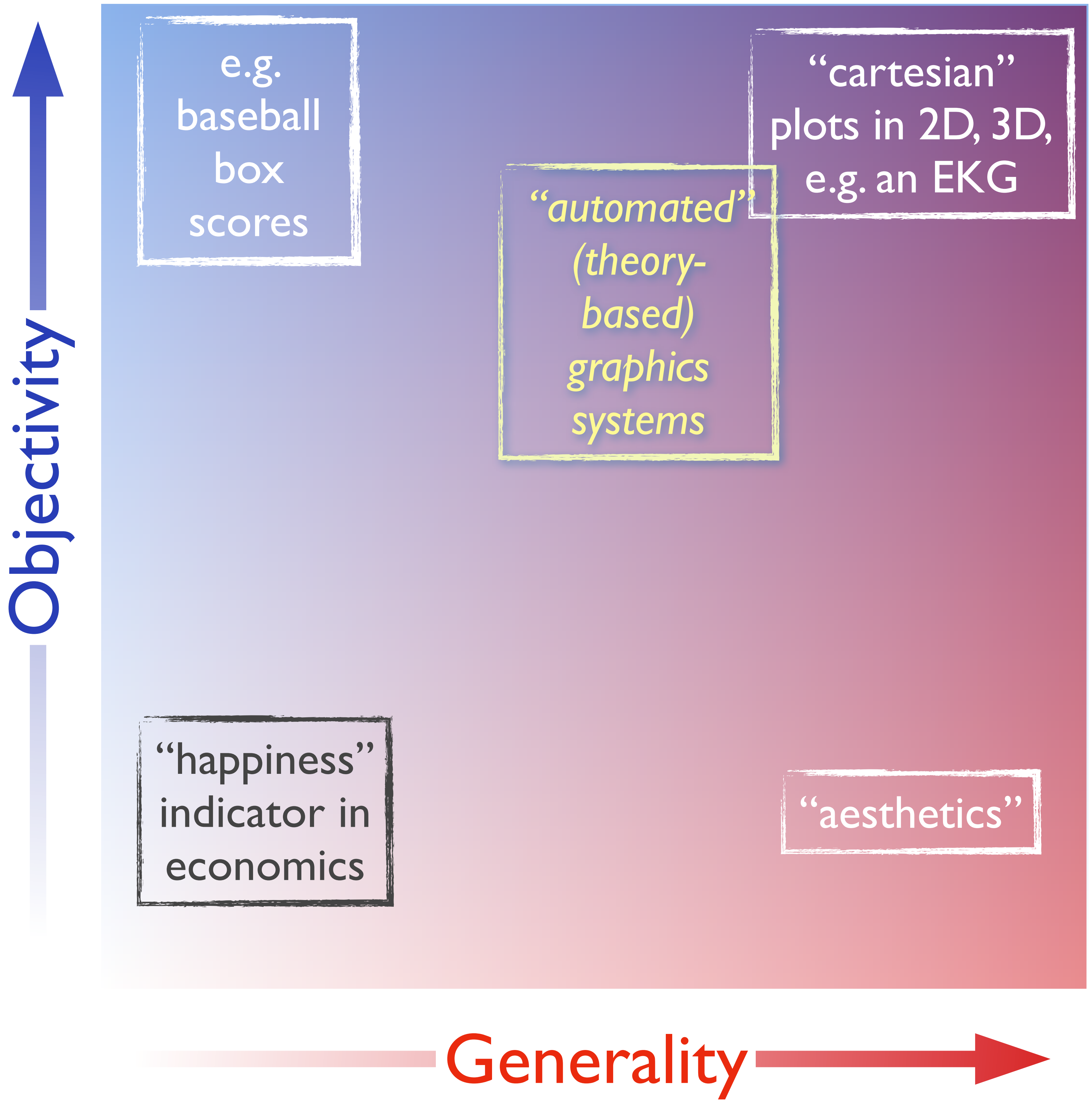
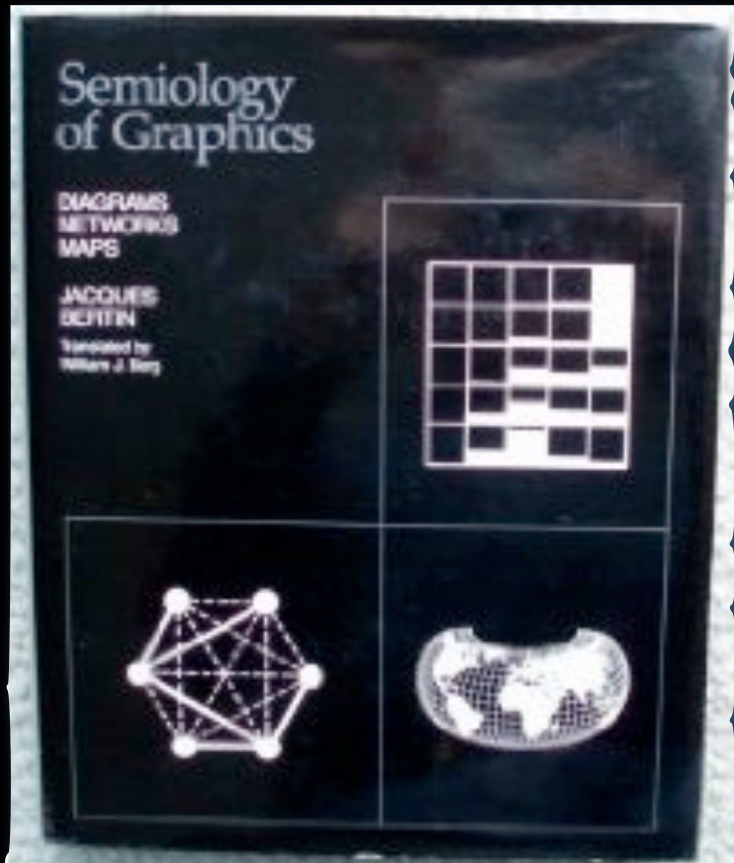

Objectivity
Generality
e.g. baseball box scores
"cartesian" plots in 2D, 3D, e.g. an EKG
"automated" (theory-based) graphics systems
"happiness" indicator in economics
"aesthetics"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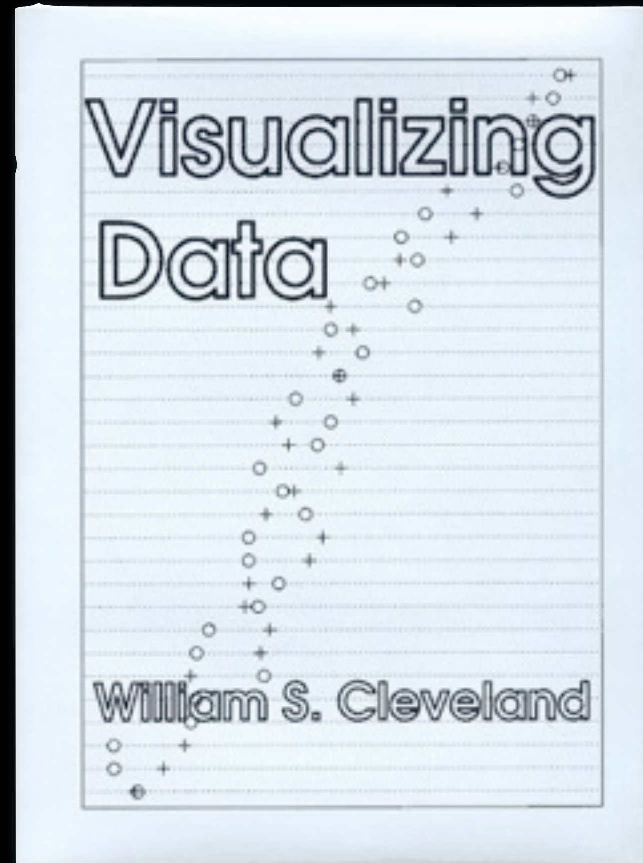
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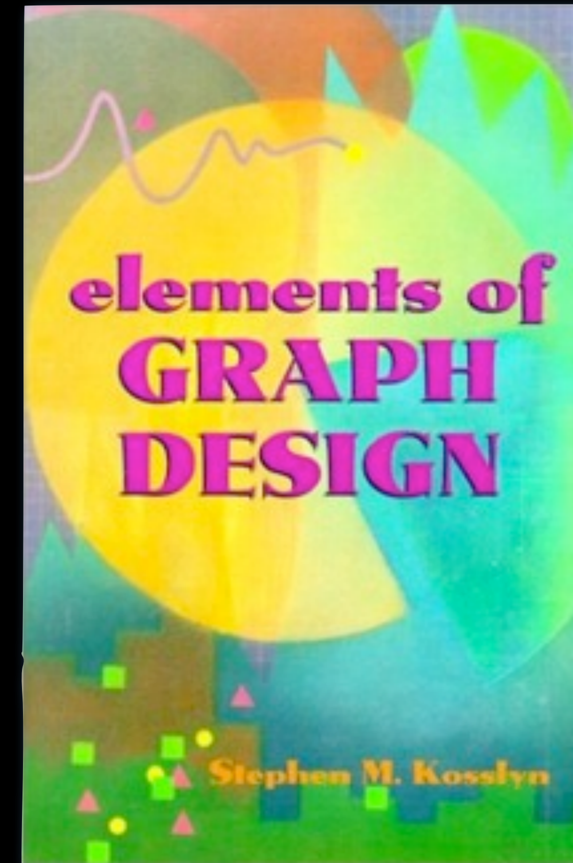
elements of
GRAPH
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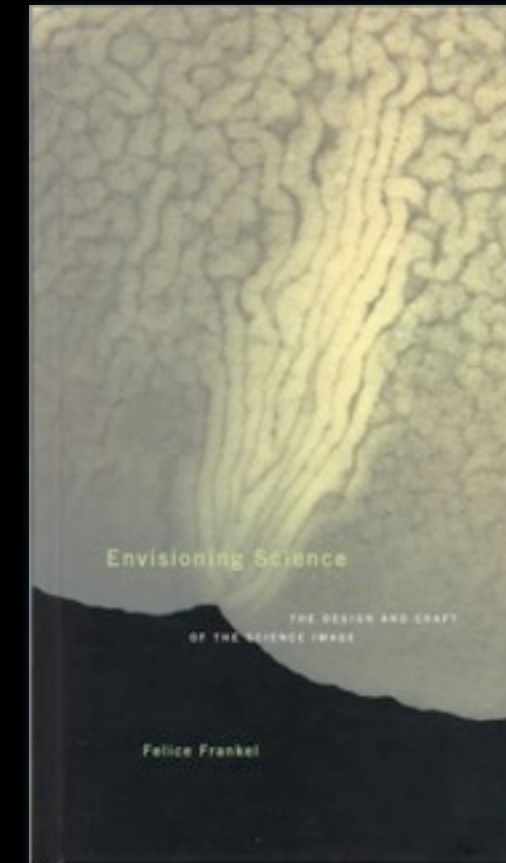
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THE DESIGN AND CRAFT
OF THE SCIENCE IMAGE
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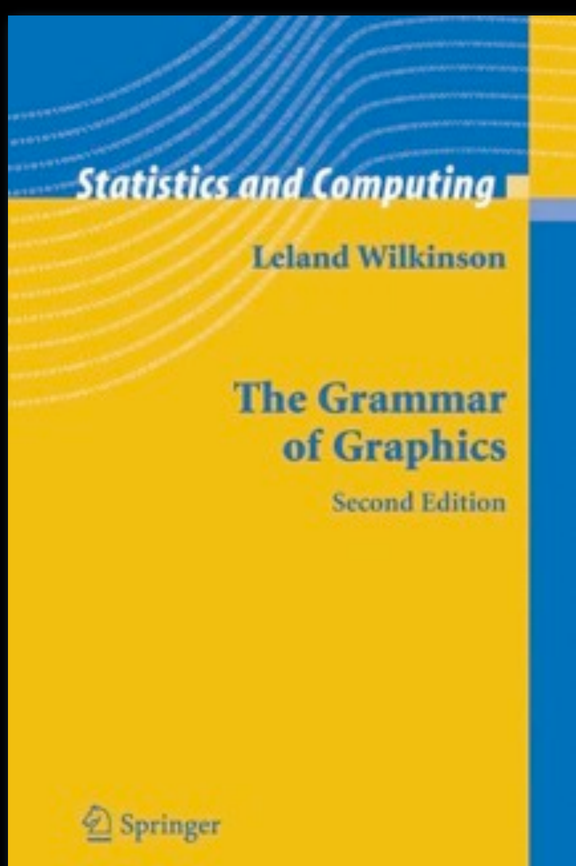
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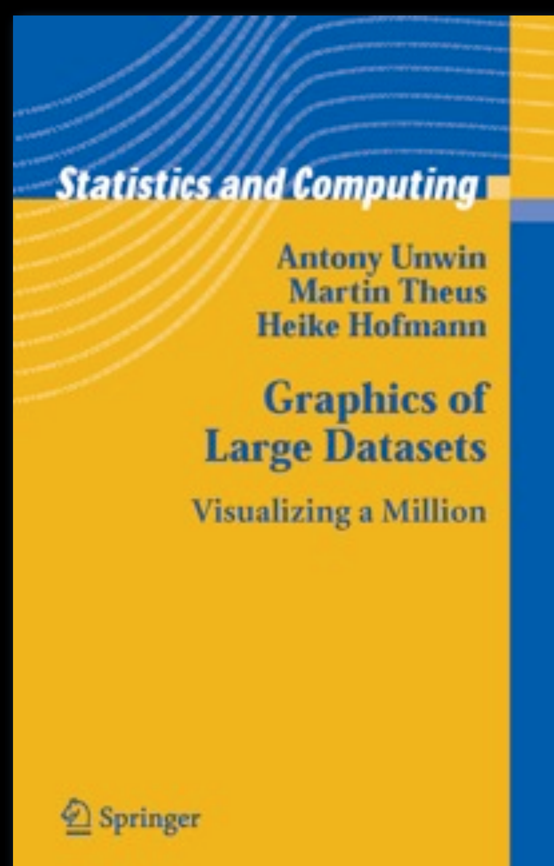
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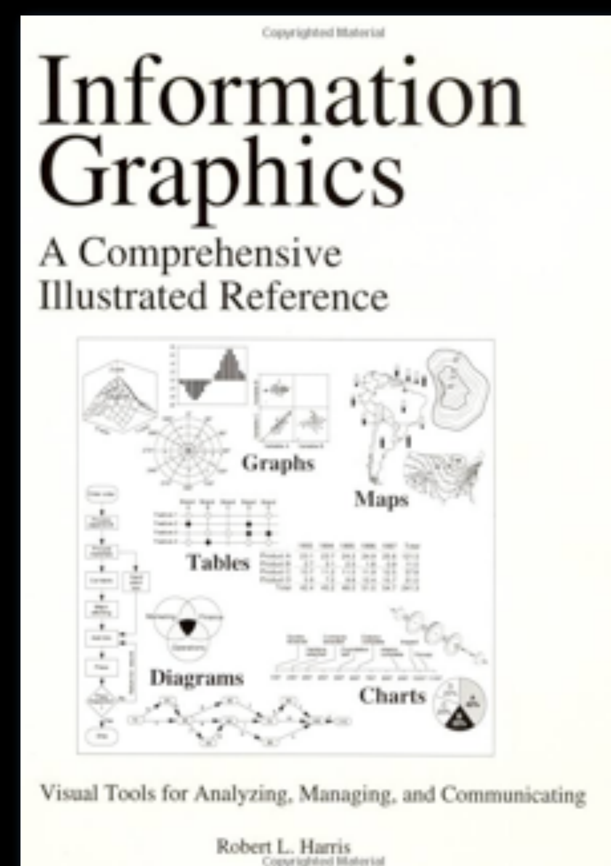
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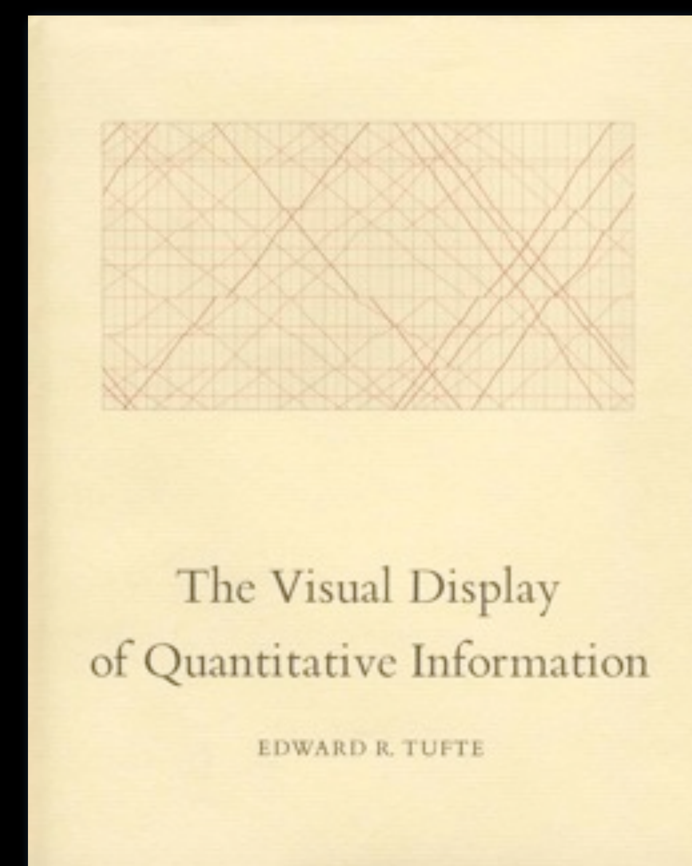
The Visual Display
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Objectivity
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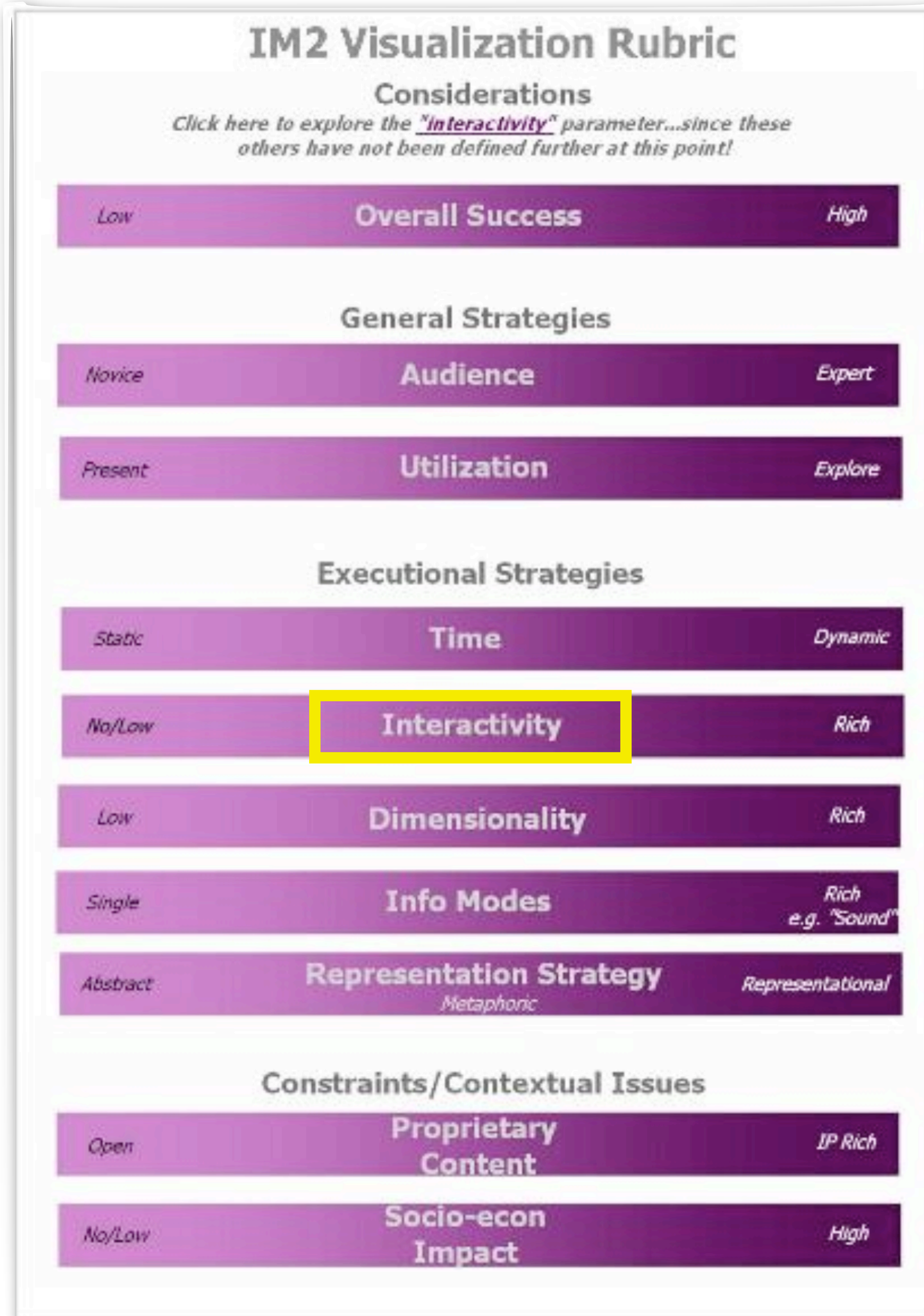
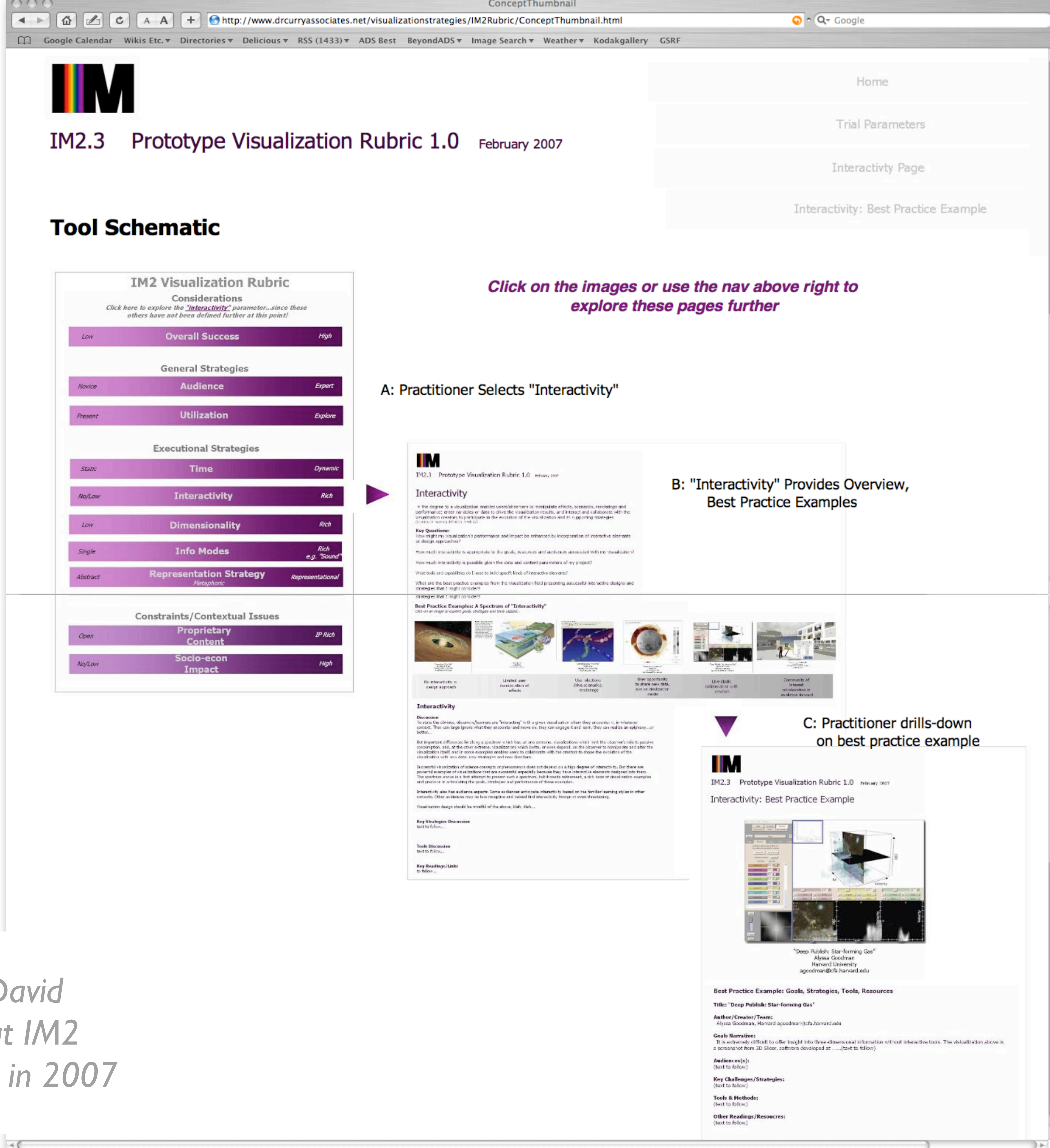
Another approach:
"A Virtual Graphical Collaborative"
a-la-Frankel

(graphics courtesy David Curry, participant at IM2 "Group A" at Apple in 2007)





graphics courtesy David Curry, participant at IM2 "Group A" at Apple in 2007 extra slides

Star Formation + Technology

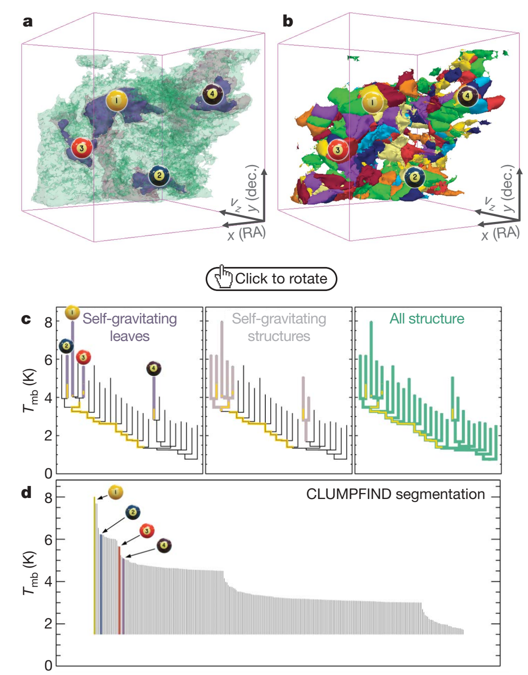


Figure 2 | Comparison of the 'dendrogram' and 'CLUMPFIND' feature-identification algorithms as applied to ^{13}CO emission from the L1448 region of Perseus. a, 3D visualization of the surfaces indicated by colours in the dendrogram shown in **c**. Purple illustrates the smallest scale self-gravitating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

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

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

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

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

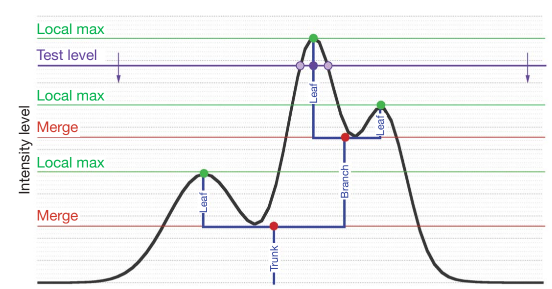
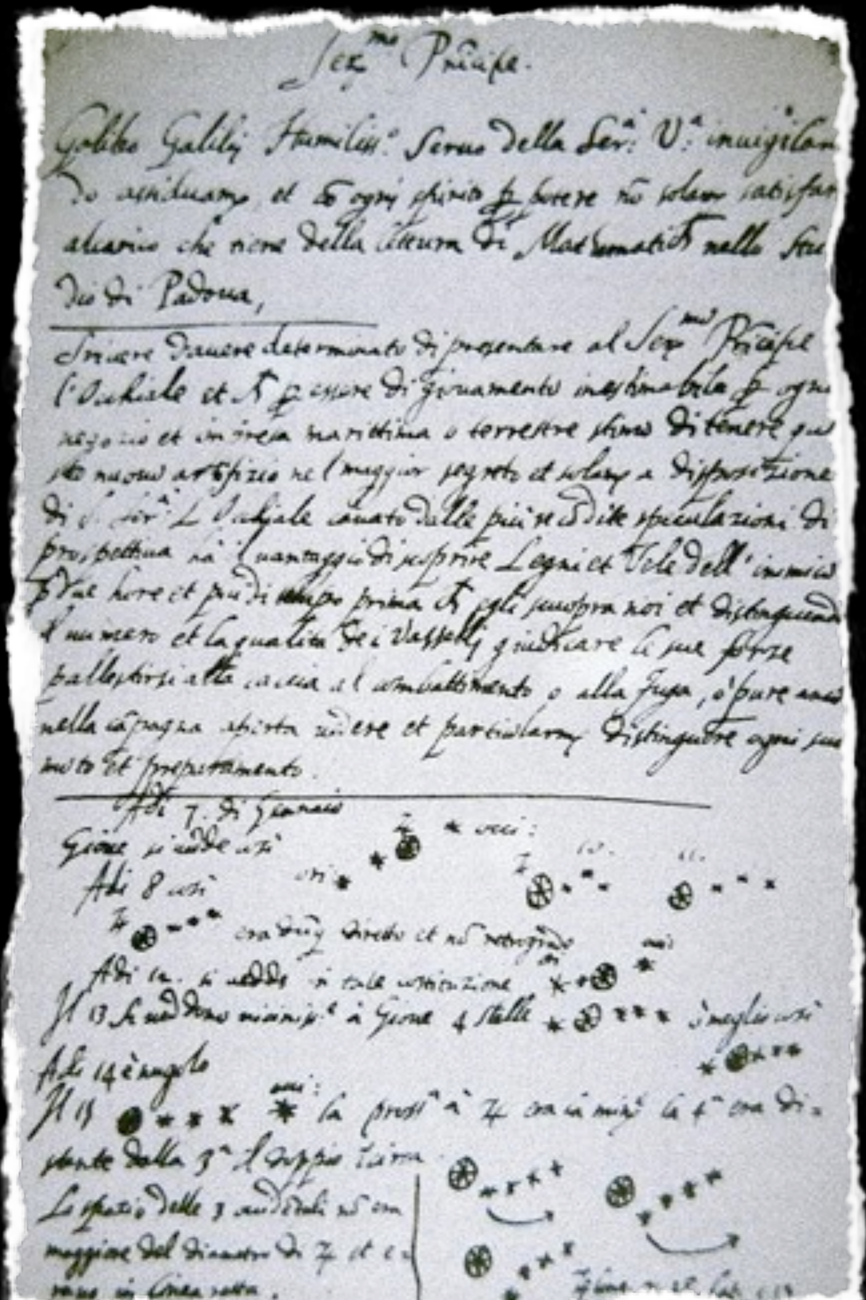
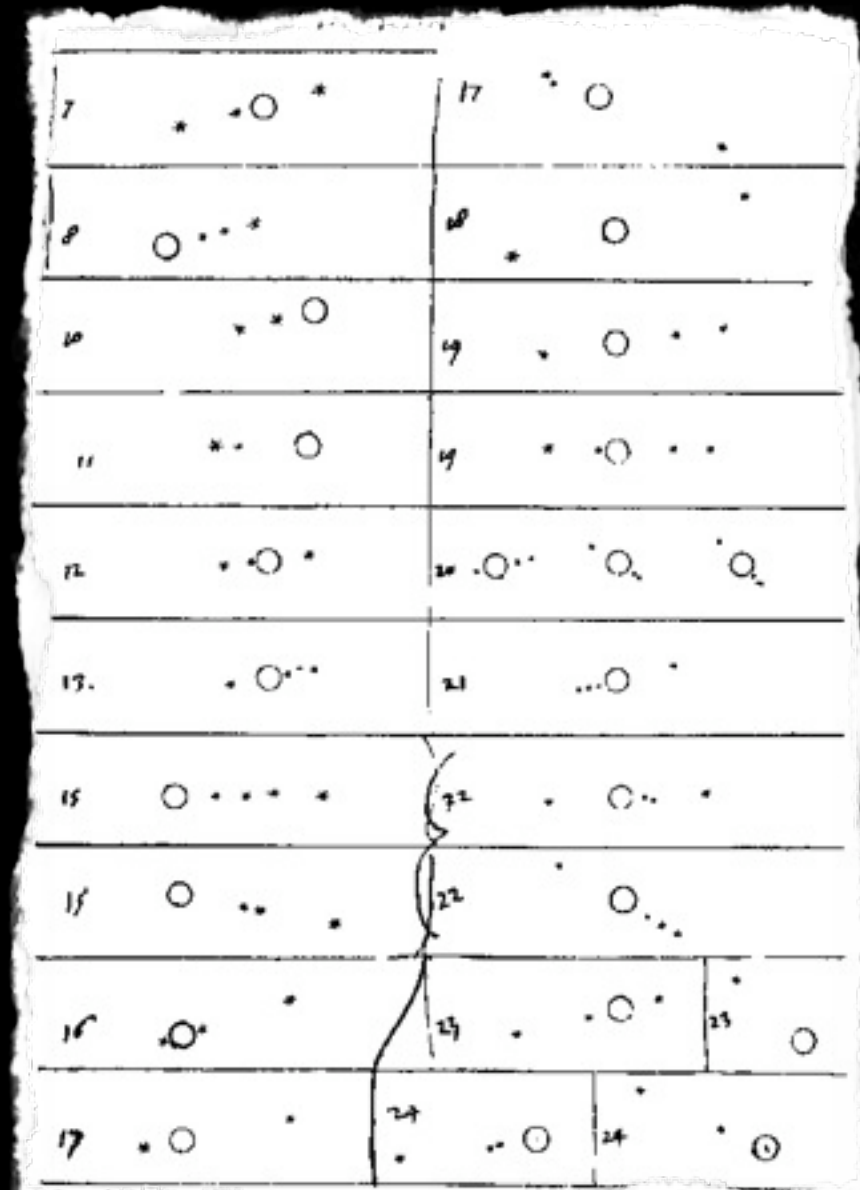
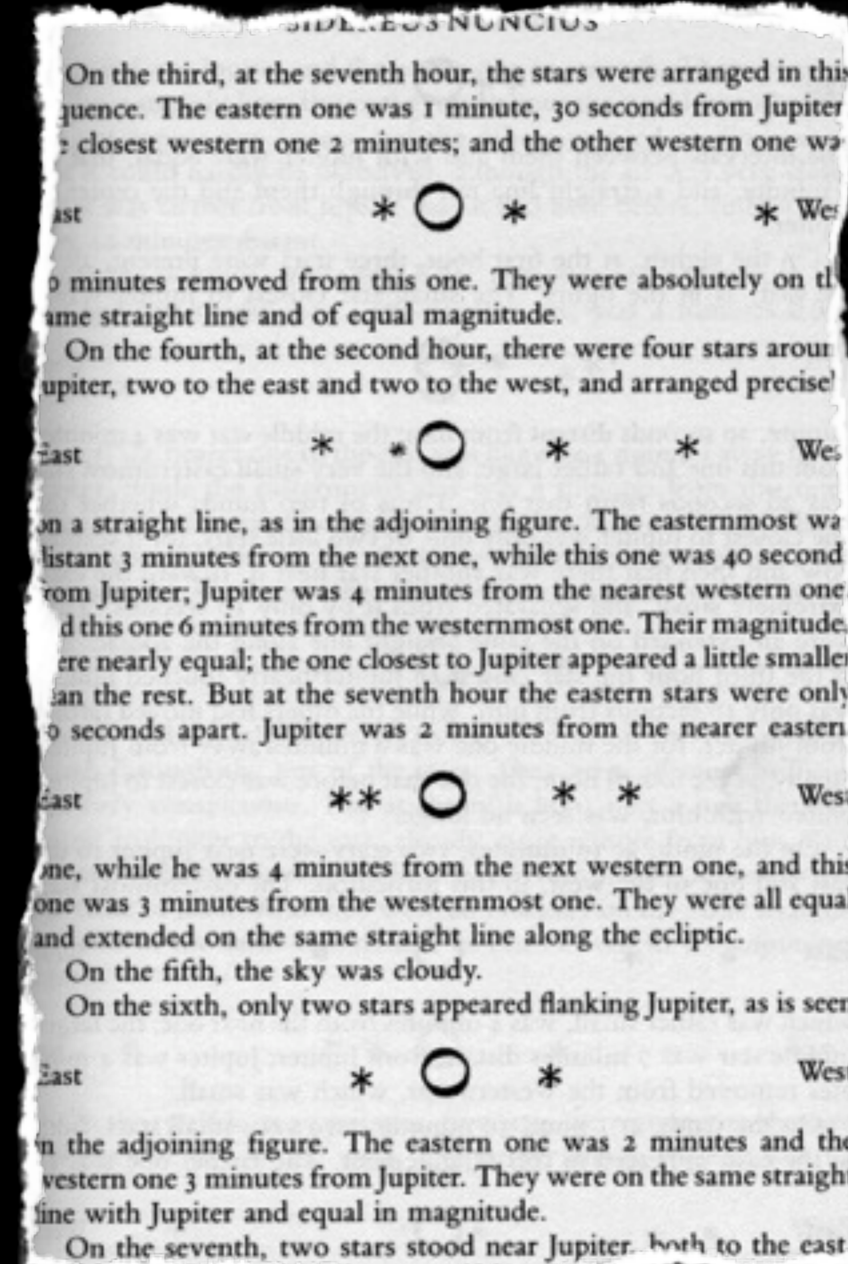


Figure 3 | Schematic illustration of the dendrogram process. Shown is the construction of a dendrogram from a hypothetical one-dimensional emission profile (black). The dendrogram (blue) can be constructed by 'dropping' a test constant emission level (purple) from above in tiny steps (exaggerated in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

Galileo’s Moons + Technology






SIDEREUS NUNCIUS

On the third, at the seventh hour, the stars were arranged in this
quence. The eastern one was 1 minute, 30 seconds from Jupiter
closest western one 2 minutes; and the other western one wa

ast * O * * Wes

minutes removed from this one. They were absolutely on th
ame straight line and of equal magnitude.
On the fourth, at the second hour, there were four stars arou
upiter, two to the east and two to the west, and arranged precise

East * * O * * Wes

n a straight line, as in the adjoining figure. The easternmost wa
istant 3 minutes from the next one, while this one was 40 second
rom Jupiter; Jupiter was 4 minutes from the nearest western one
d this one 6 minutes from the westernmost one. Their magnitude
ere nearly equal; the one closest to Jupiter appeared a little smalle
an the rest. But at the seventh hour the eastern stars were only
seconds apart. Jupiter was 2 minutes from the nearer easter

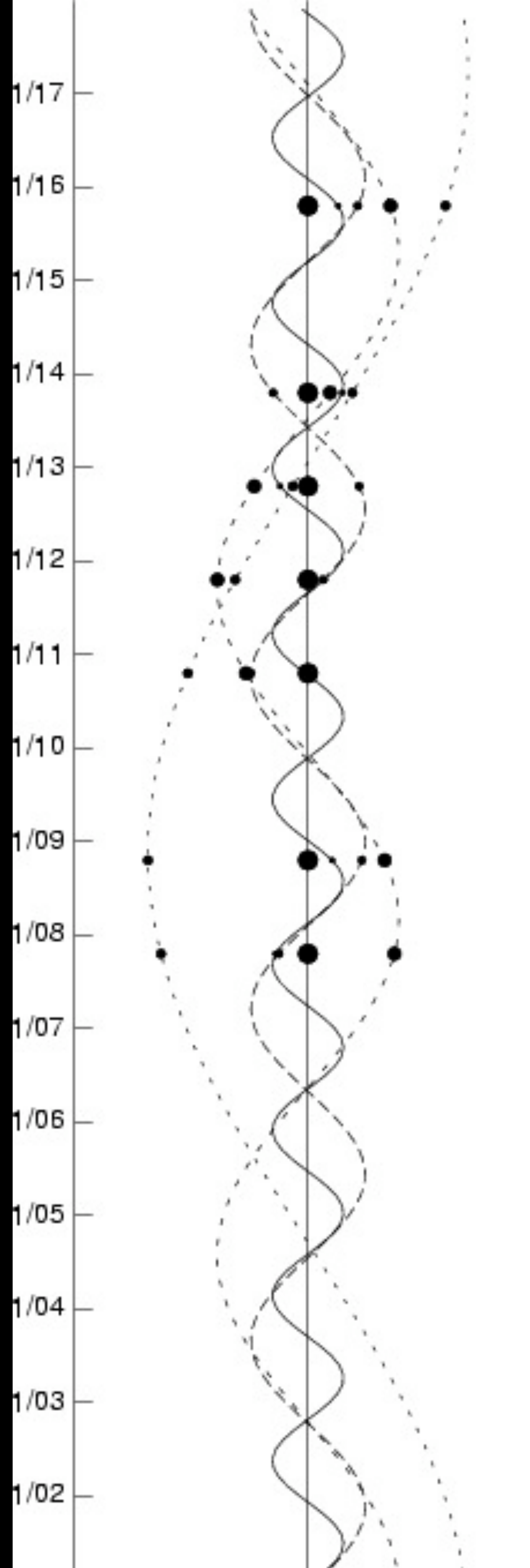
East ** O * * West

ne, while he was 4 minutes from the next western one, and this
one was 3 minutes from the westernmost one. They were all equal
and extended on the same straight line along the ecliptic.
On the fifth, the sky was cloudy.
On the sixth, only two stars appeared flanking Jupiter, as is seen

East * O * West

n the adjoining figure. The eastern one was 2 minutes and the
western one 3 minutes from Jupiter. They were on the same straight
line with Jupiter and equal in magnitude.
On the seventh, two stars stood near Jupiter, both to the east

Notes for & re-productions of Siderius Nuncius (1610)



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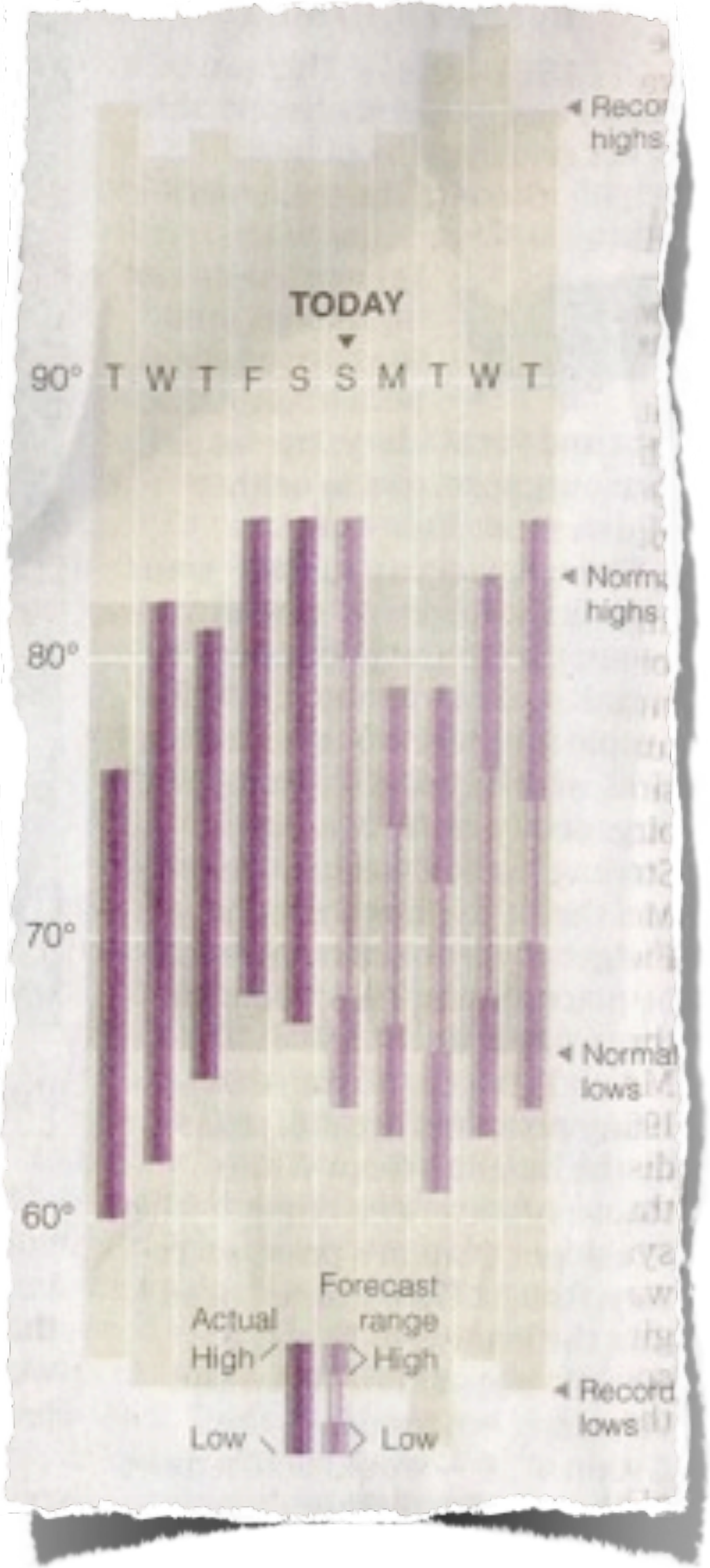
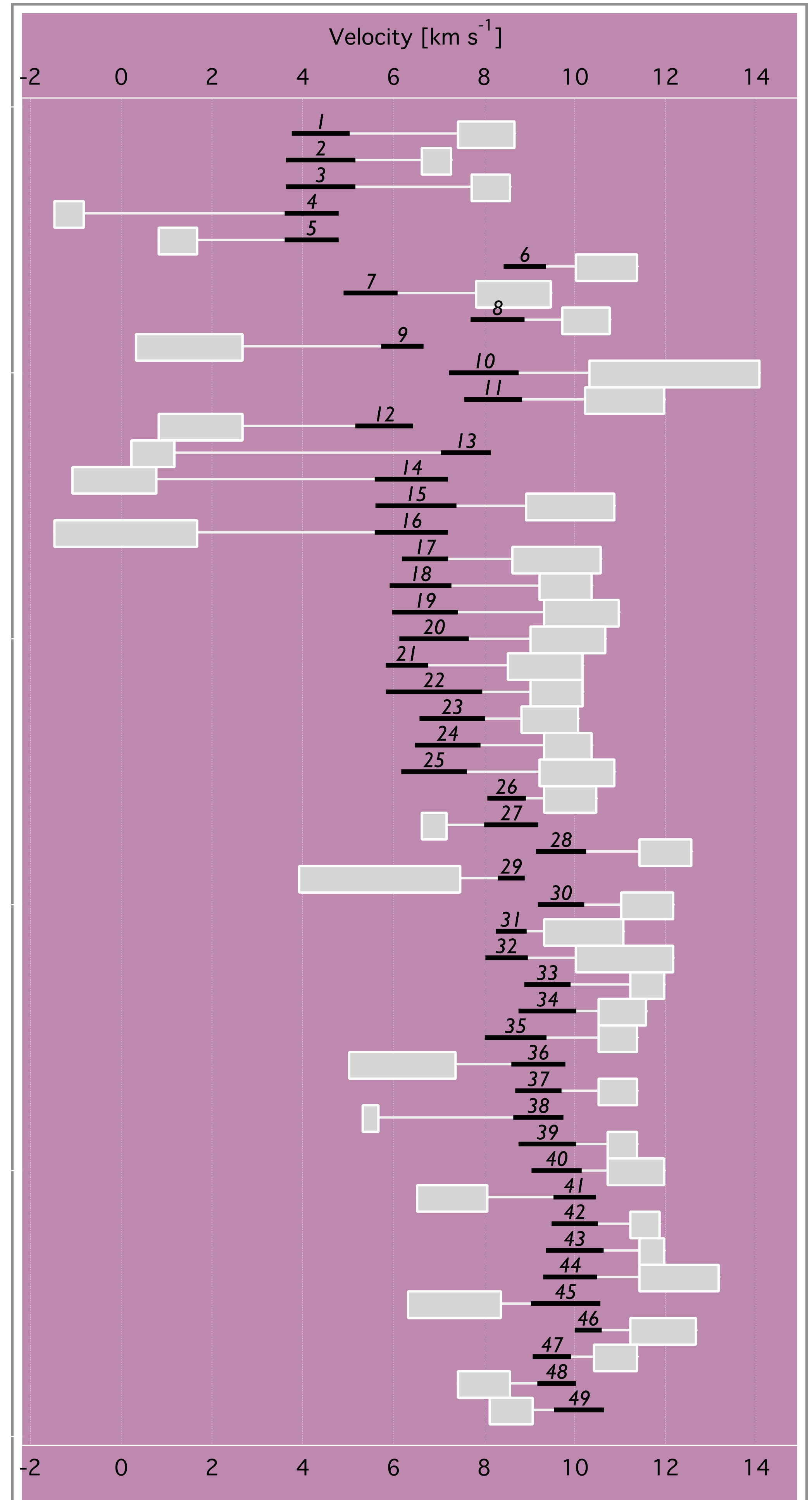
NYT Weather





Young Stellar Outflows