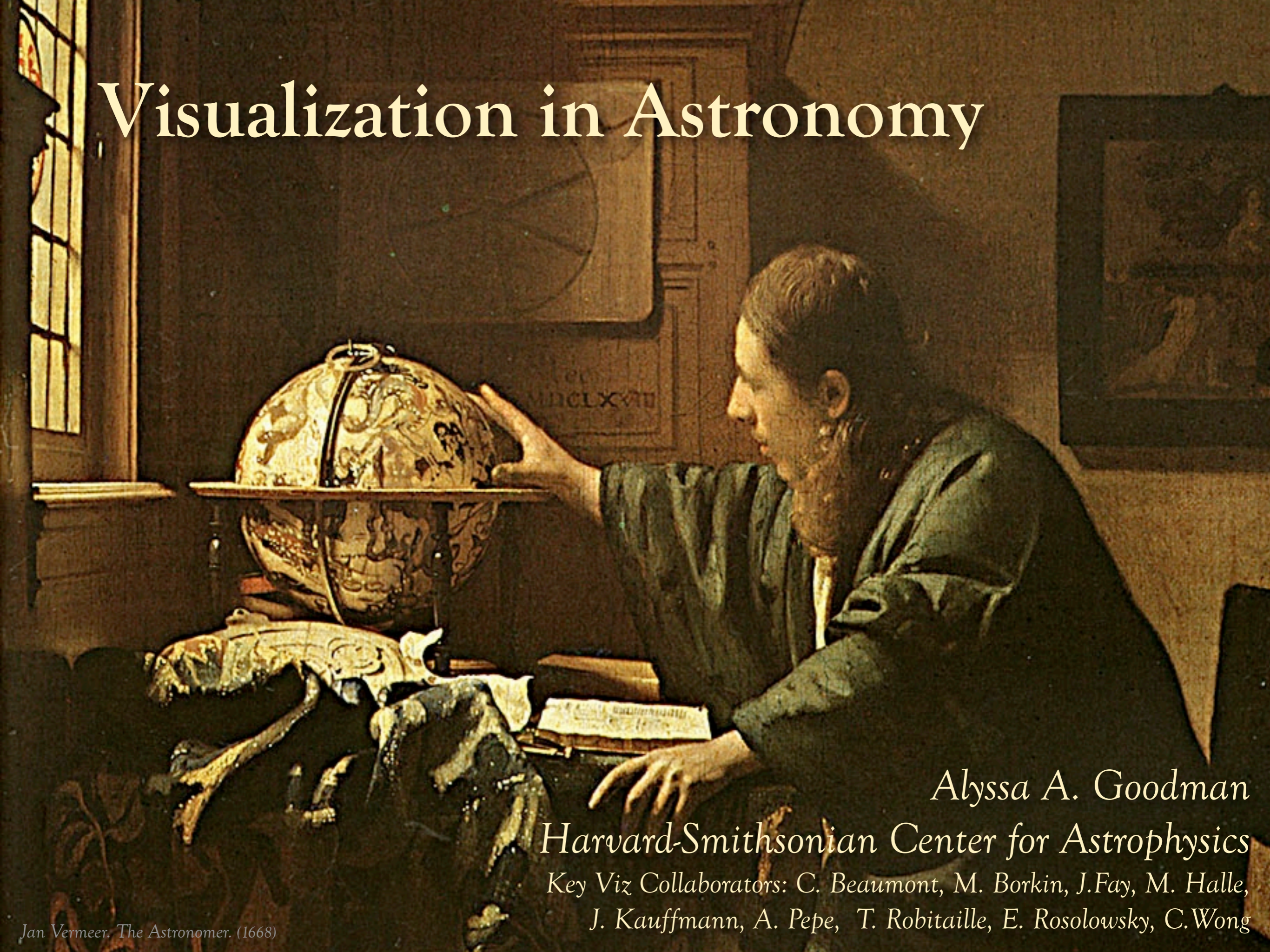


Visualization in Astronomy



Alyssa A. Goodman
Harvard-Smithsonian Center for Astrophysics
Key Viz Collaborators: C. Beaumont, M. Borkin, J. Fay, M. Halle,
J. Kauffmann, A. Pepe, T. Robitaille, E. Rosolowsky, C. Wong

Exploration

Explanation



History of the AG

[http://www.astronomische-gesellschaft.org/](http://www.astronomische-gesellschaft.org/Tagungen_eng.html)

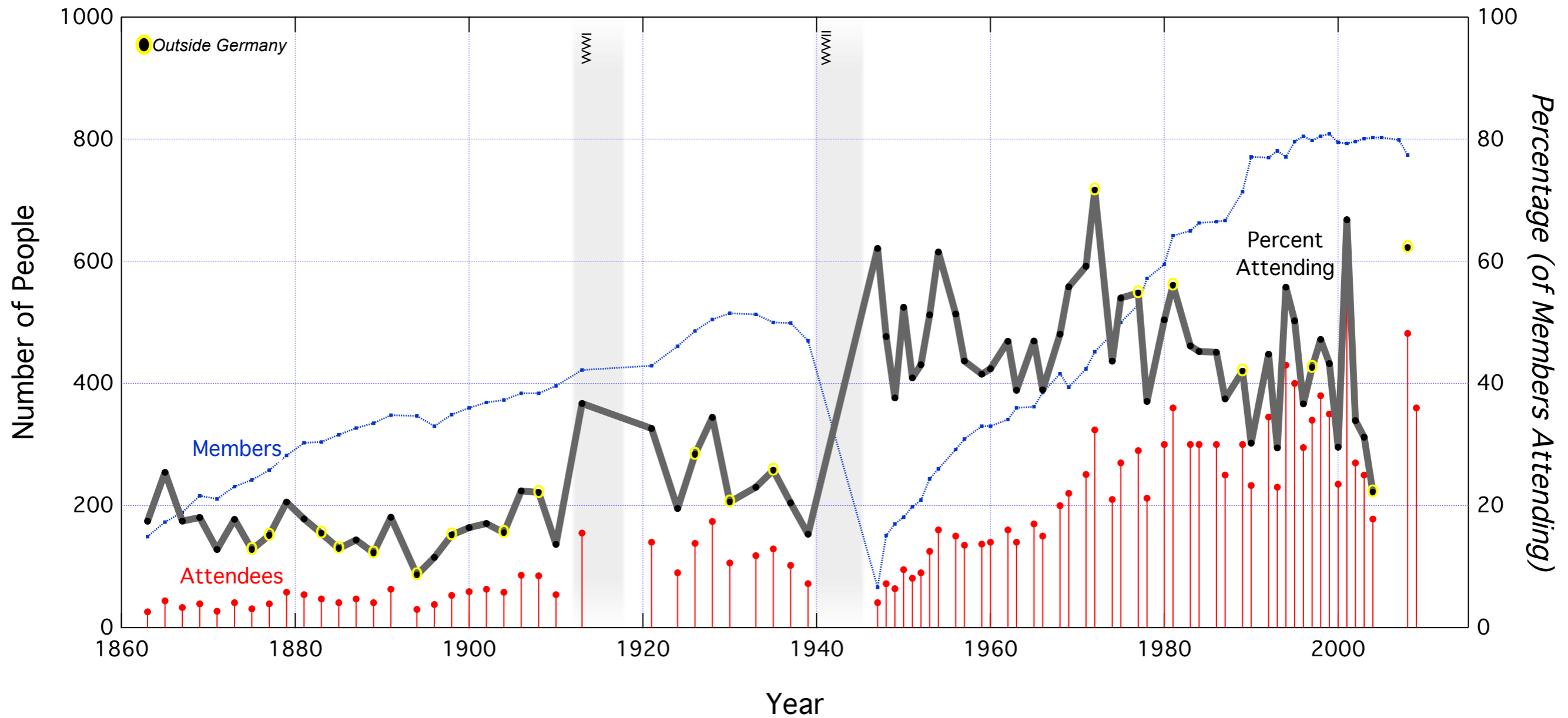
[Tagungen_eng.html](http://www.astronomische-gesellschaft.org/Tagungen_eng.html)

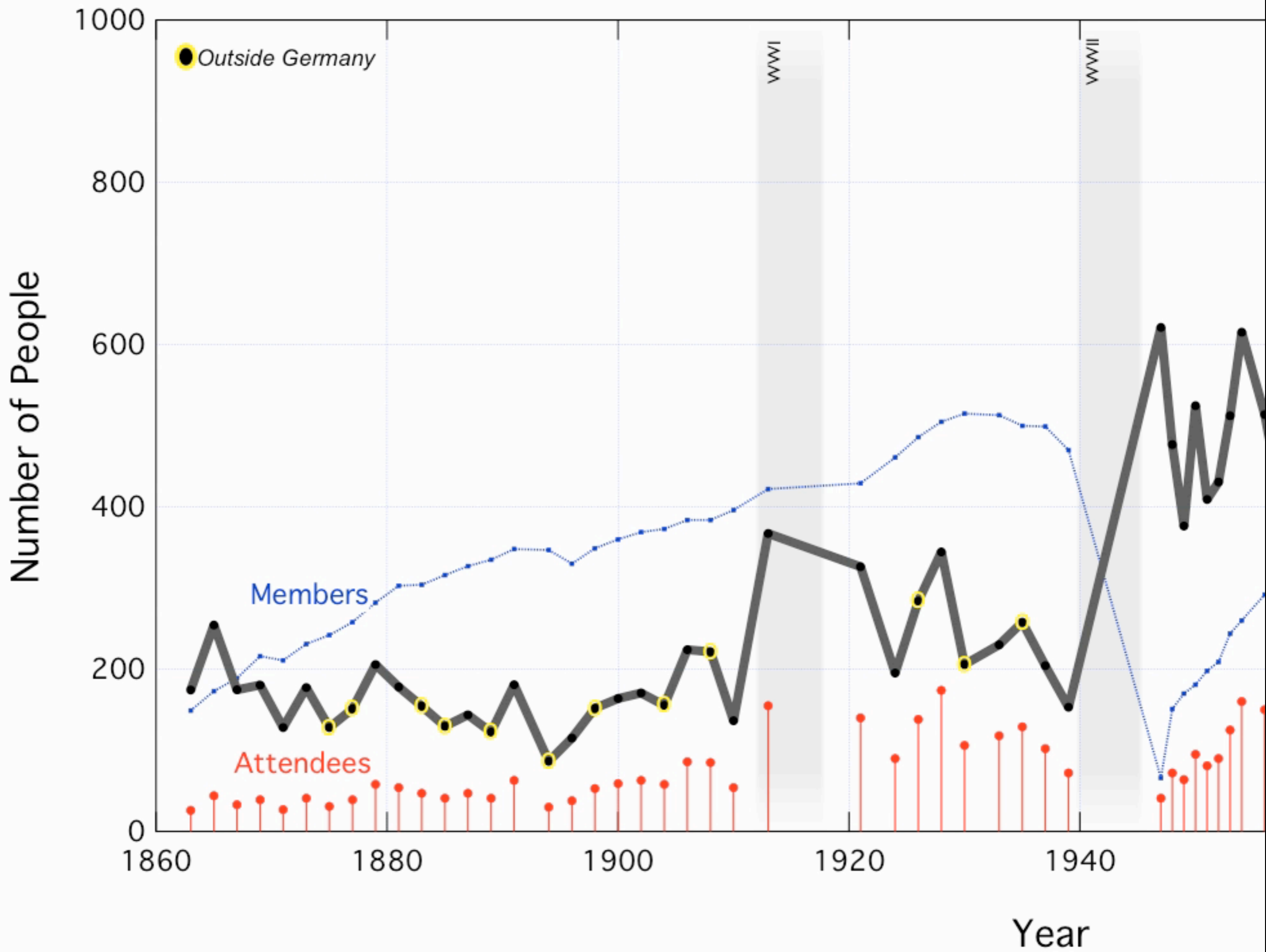
All meetings since 1863:

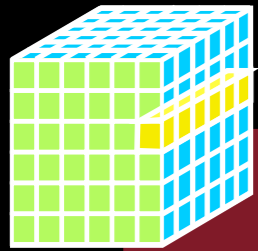
(RGA = regular meeting of the General Assembly)

Year	RGA	City	Date	Members	Attendees	Lectures	Poster
2009	82	Potsdam	Sep. 21-25		360 (138 members, 92 students)	185 (23 plenary talks, 162 splinter talks)	102
2008	81	Vienna (A)	Sep. 07-12	774	482		
2008		<i>Spring:</i> Strasbourg (F)	Mar. 16-20				
2007	80	Würzburg	Sep. 24-28	799			
2005	79	Cologne	Sep.26-Oct.01	803			
2004	78	Prague (CZ)	Sep. 20-25	803	178	107	67
2004		Hamburg	July 05-09				
2003	77	Freiburg	Sep. 15-20	801	250	160	110
2002	76	Berlin	Sep. 23-28	796	270	143	120
2001	75	Munich	Sep. 10-14	793	530	187	180
2000	74	Bremen	Sep. 18-23	795	235	87	110
2000		<i>Spring:</i> Nördlingen	May 16-20				
2000		Heidelberg	Mar. 20-24				
1999	73	Göttingen	Sep. 20-25	809	350	163	125
1998	72	Heidelberg	Sep. 14-19	805	380	184	155
1998		<i>Spring:</i> Gotha	May 11-15				
1997	71	Innsbruck (A)	Sep. 22-27	798	340	155	118
1996	70	Tübingen	Sep. 16-21	805	295	165	98
1995	69	Bonn	Sep. 18-23	796	400	198	116
1994	68	Potsdam	Sep. 26-30	771	430	113	145
1993	67	Dachau	Sep. 27-Oct.01	794	330	140	94

History of the AG,



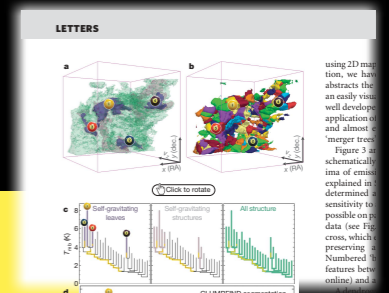




Data
Dimensions
Display



Linked Views



“Taste-Testing”
[Sim:Data]

Seamless
Astronomy
[the future]

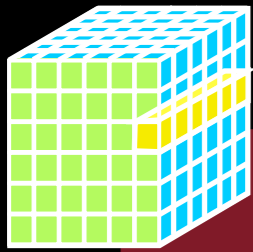


ADS Labs
[info viz]

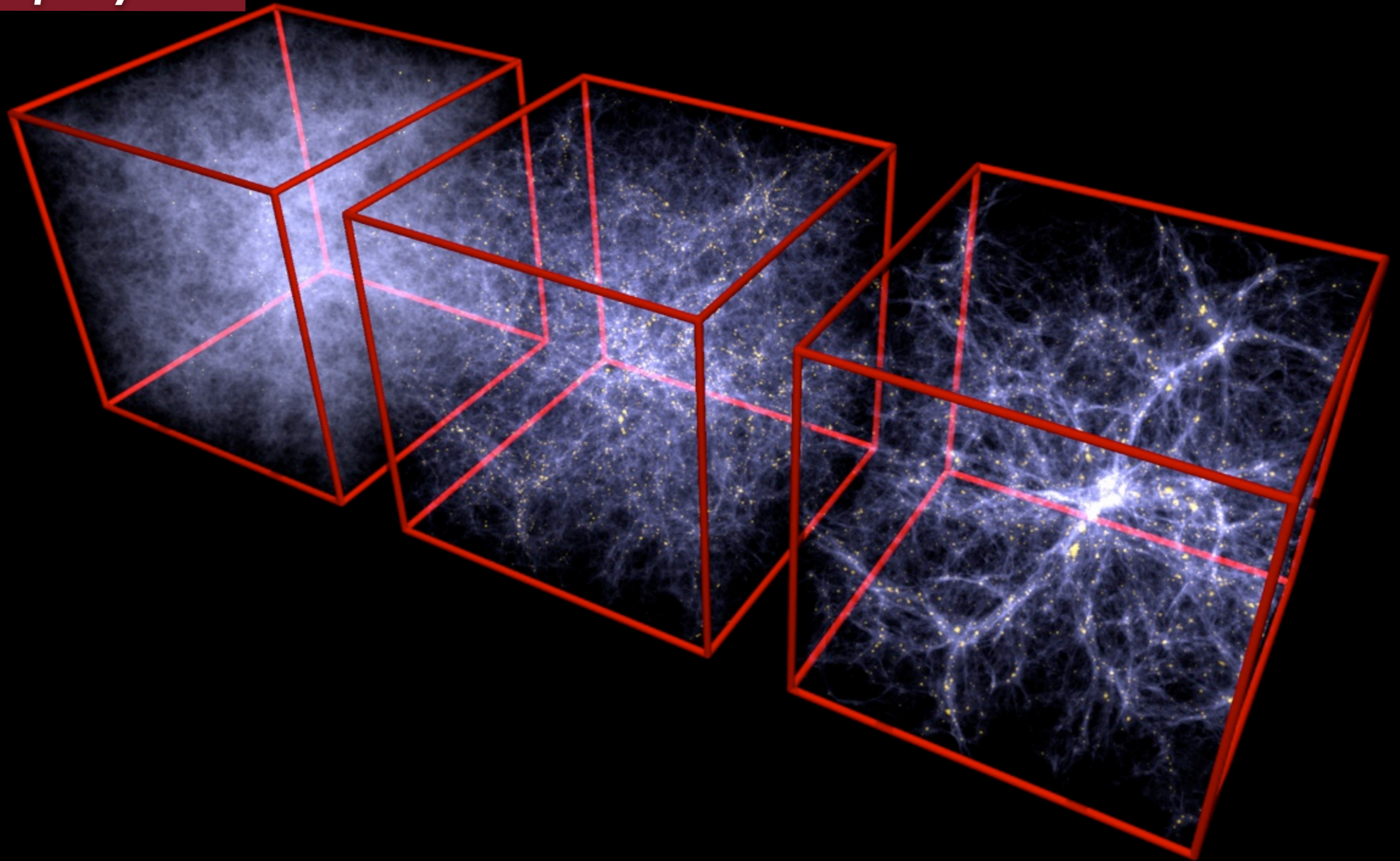


Open Data
Open Tools

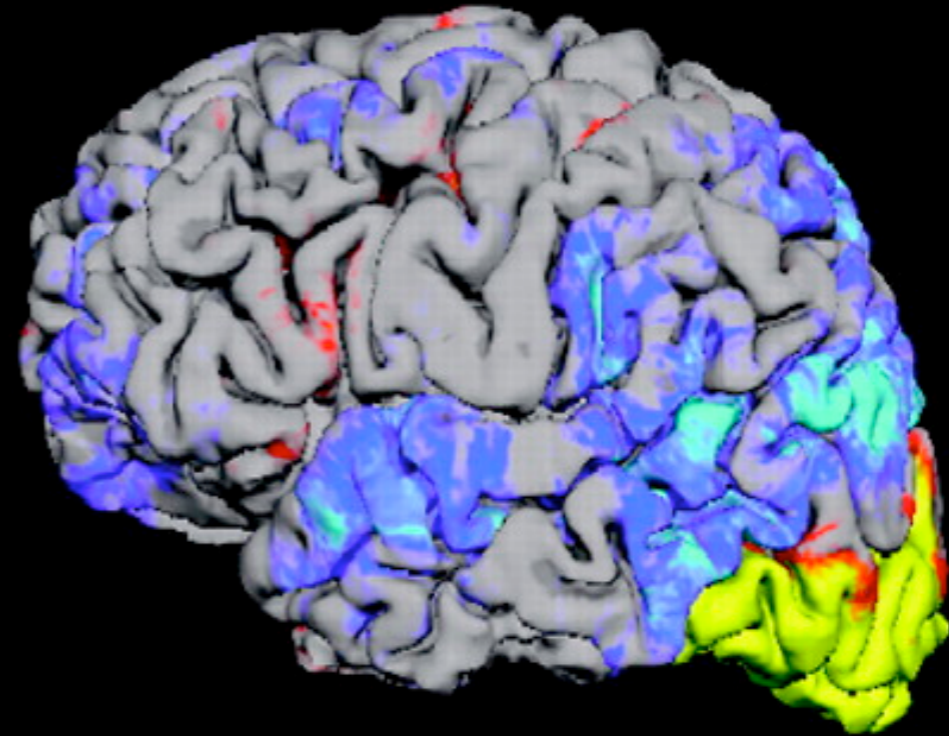
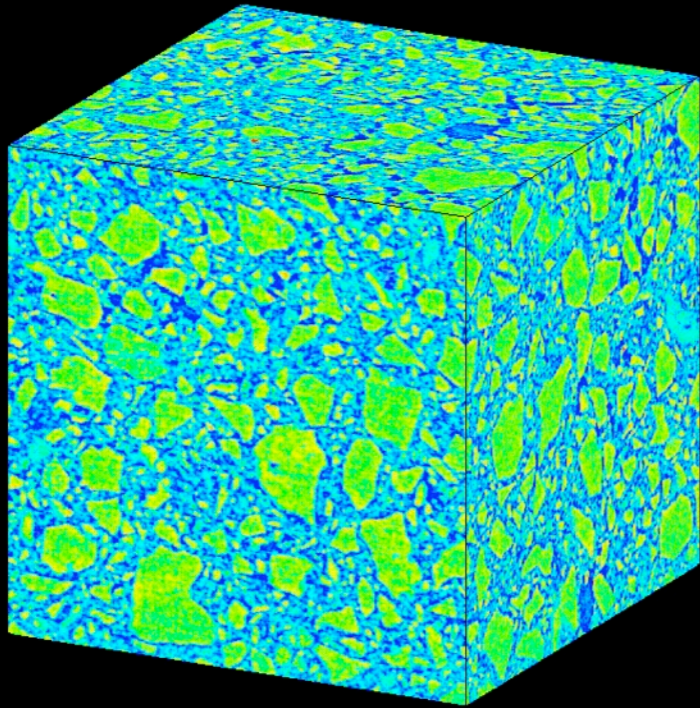




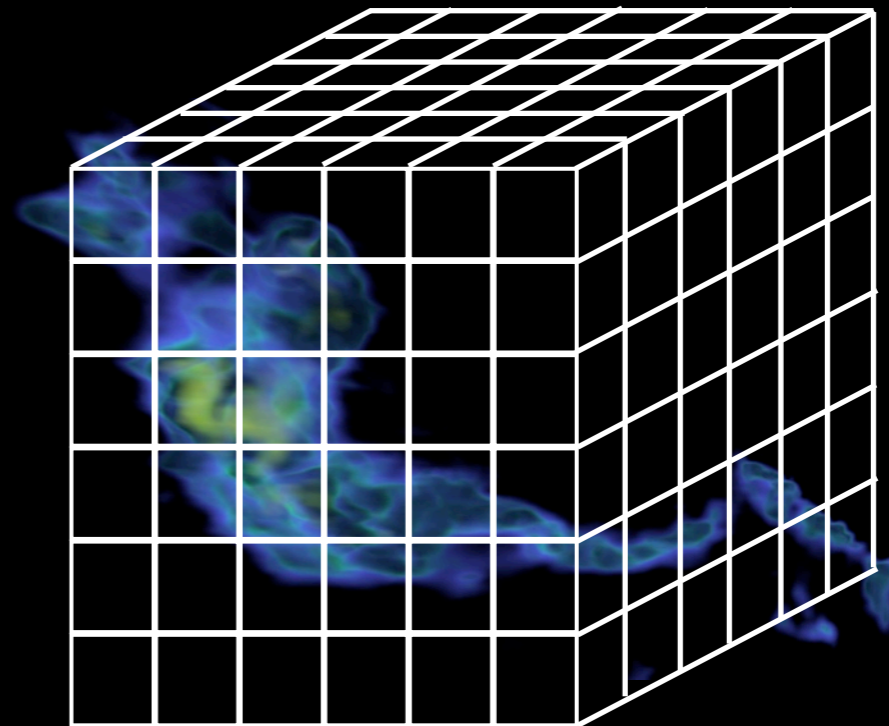
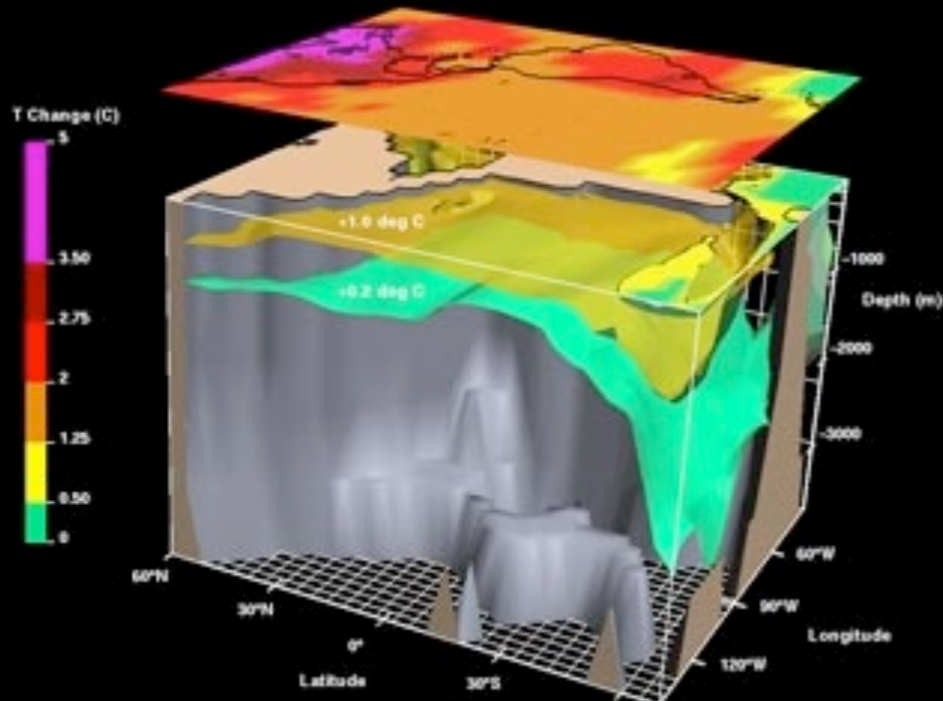
*Data
Dimensions
Display*



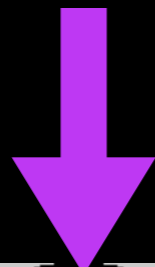
“High-Dimensional” Data



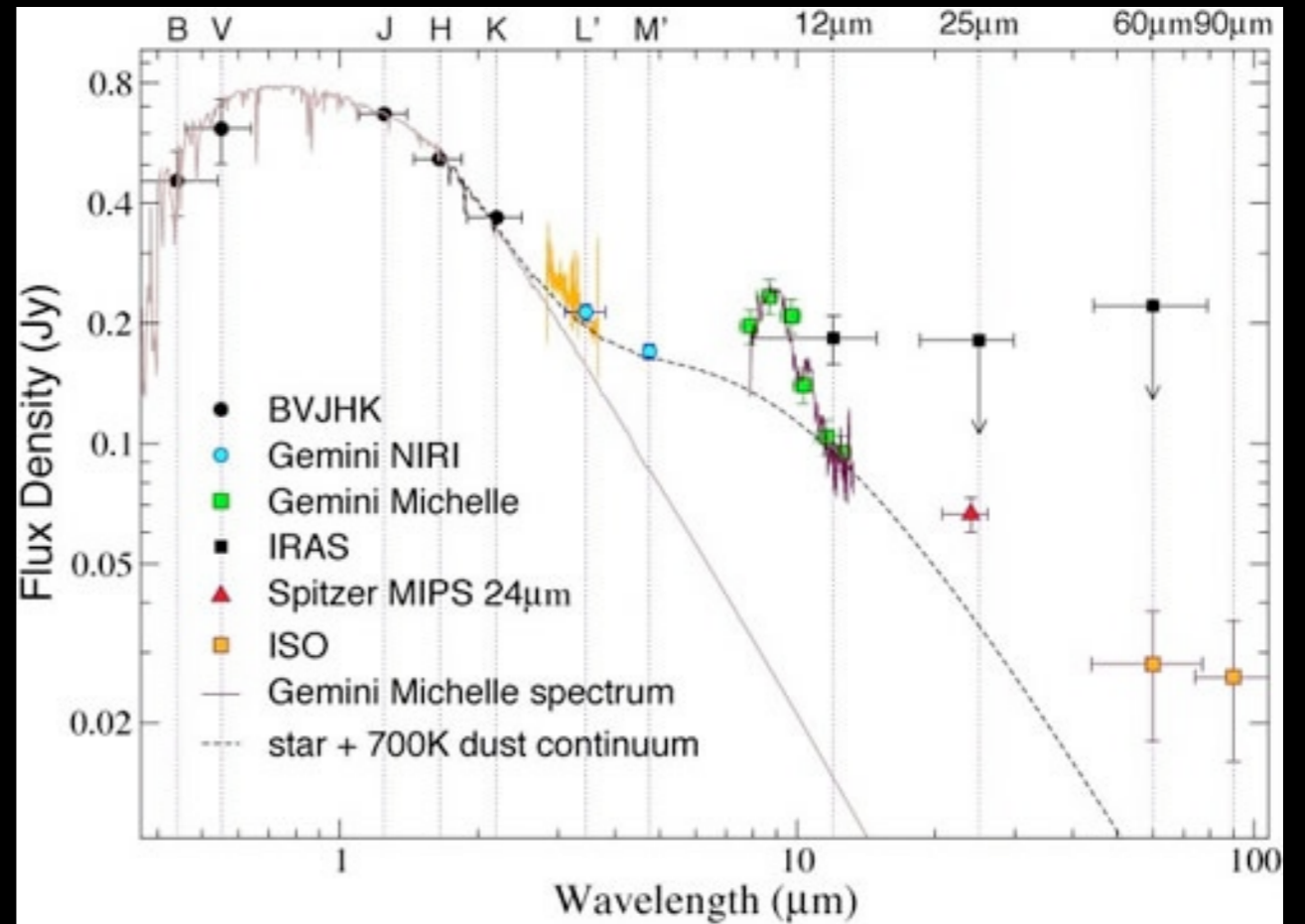
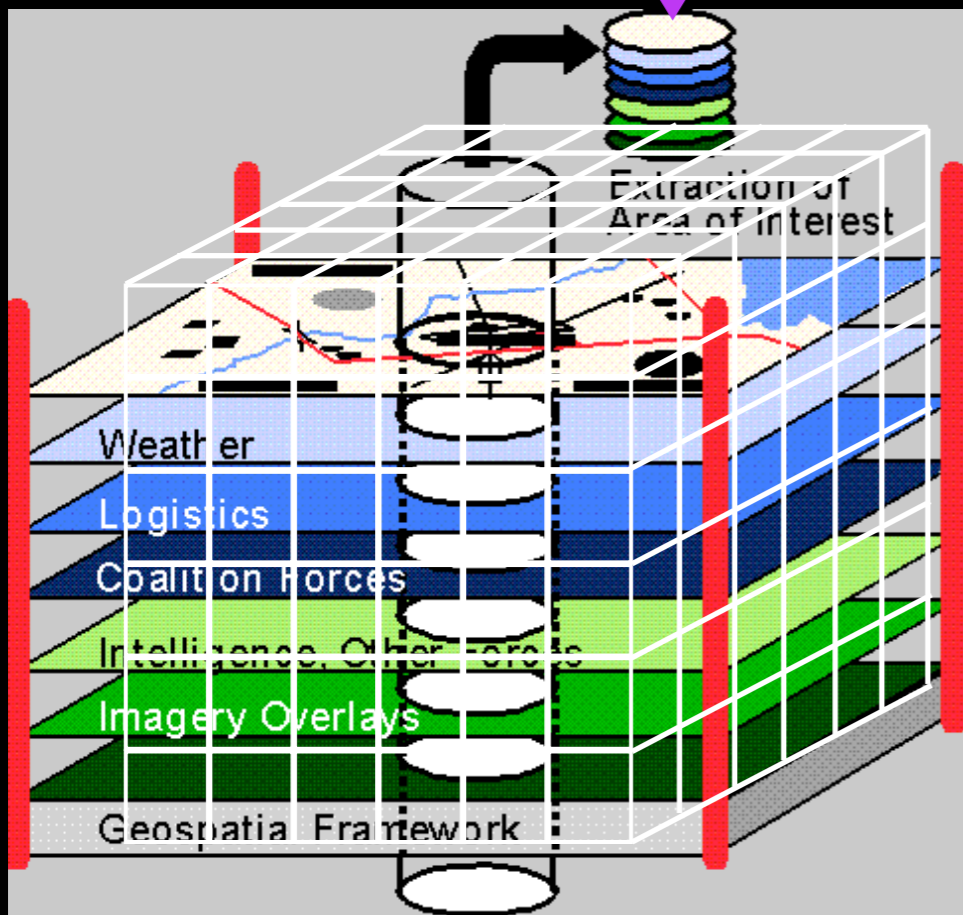
ATMOSPHERIC AND OCEANIC TEMPERATURE CHANGE

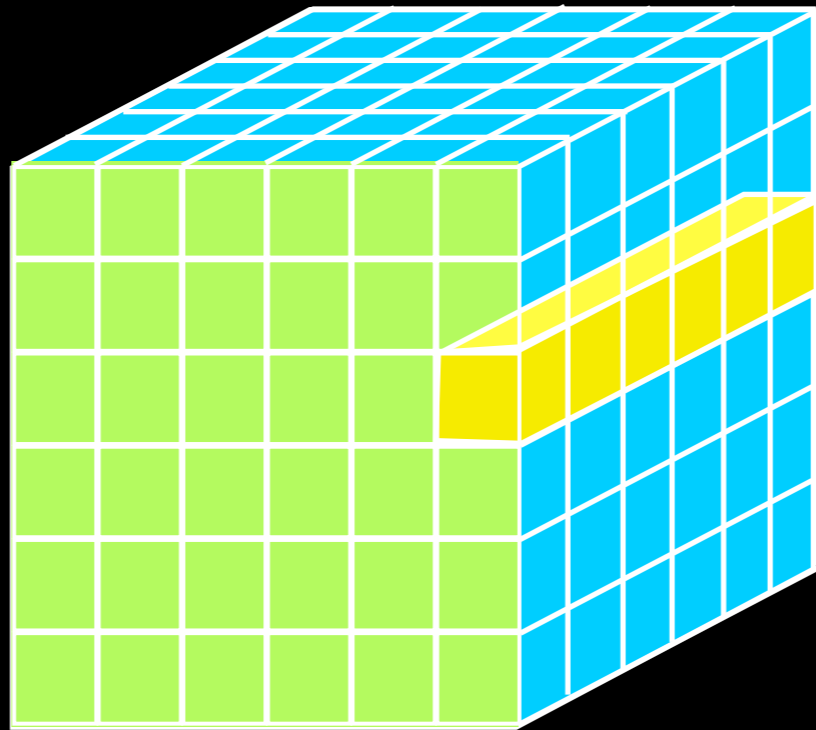


This



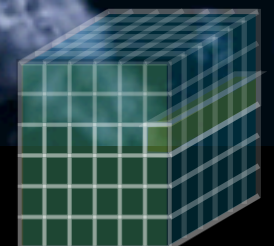
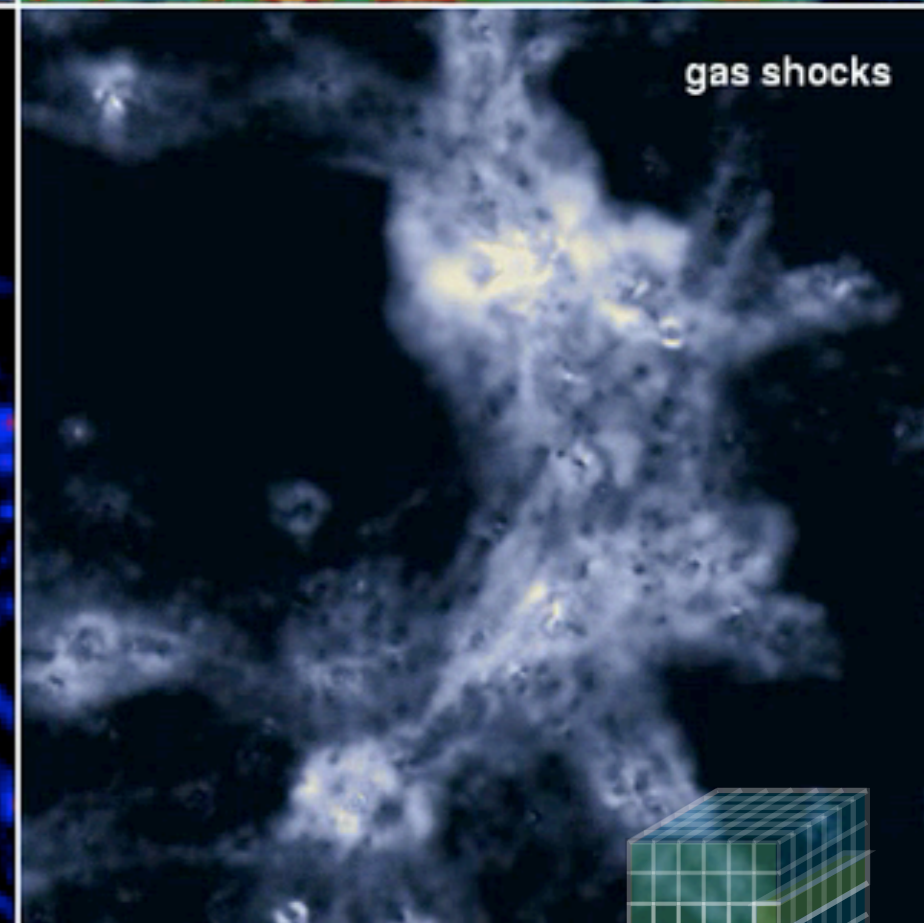
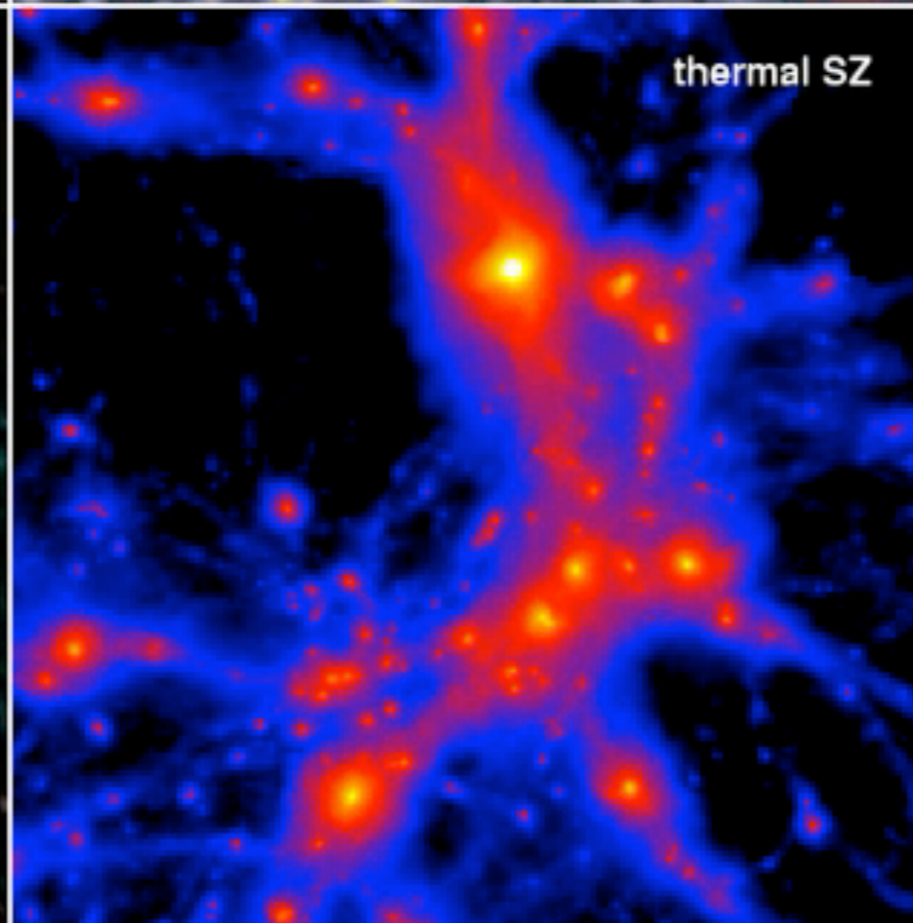
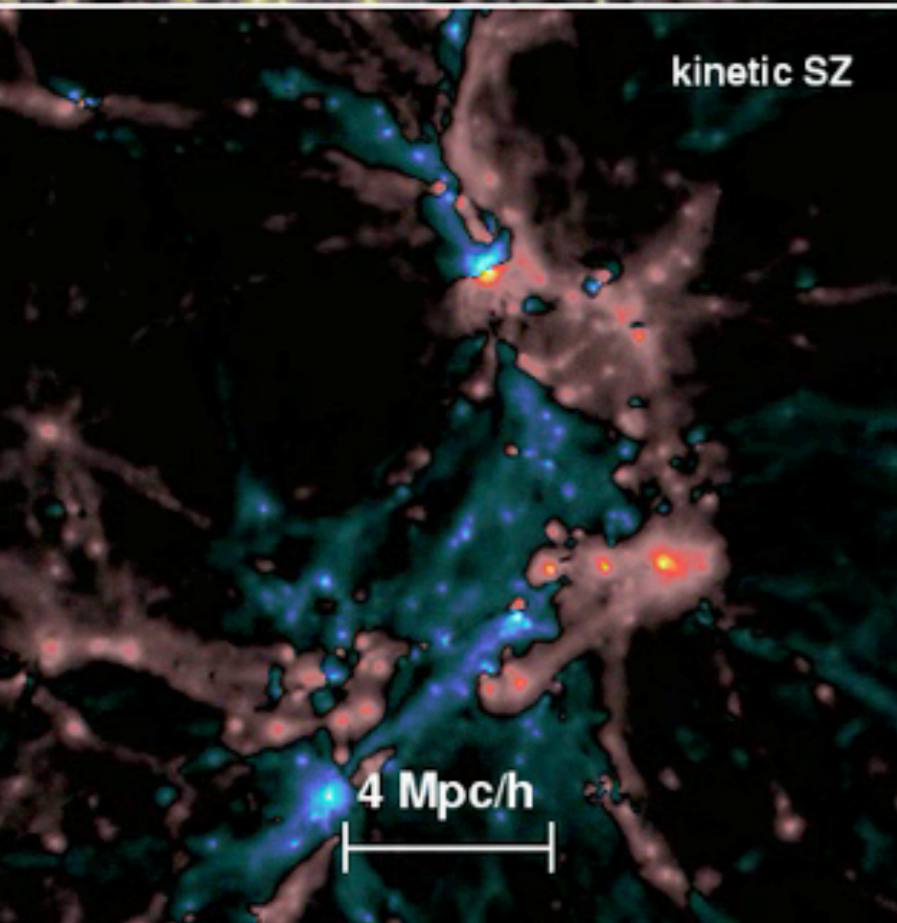
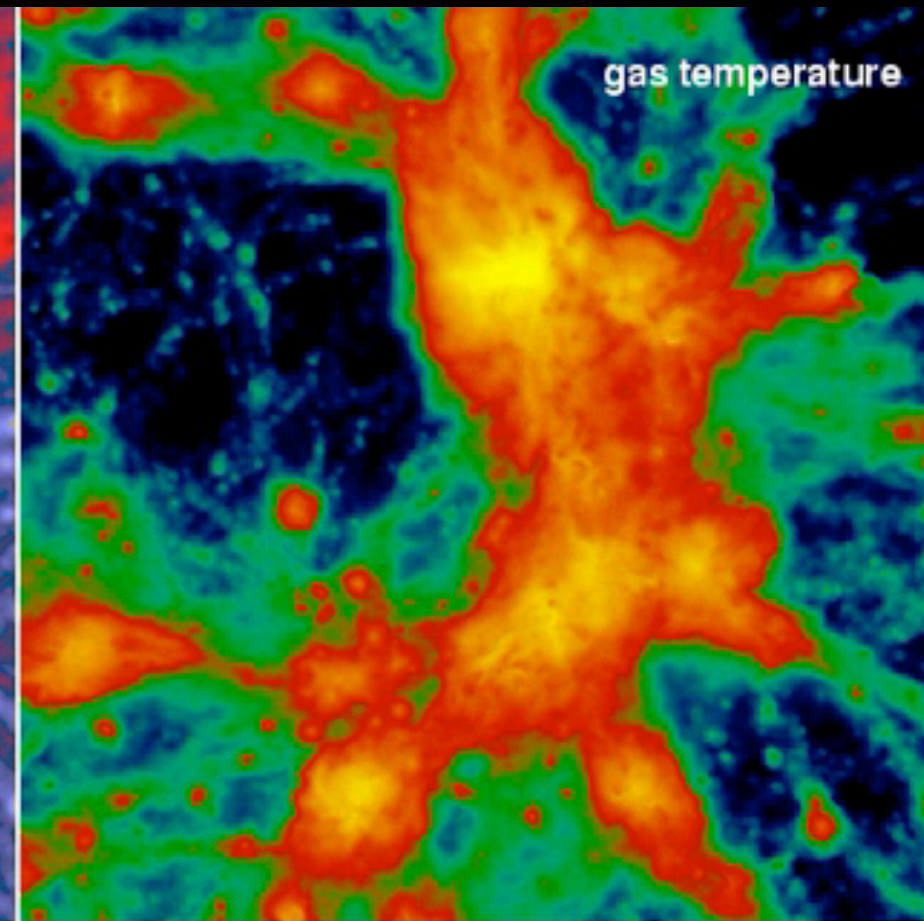
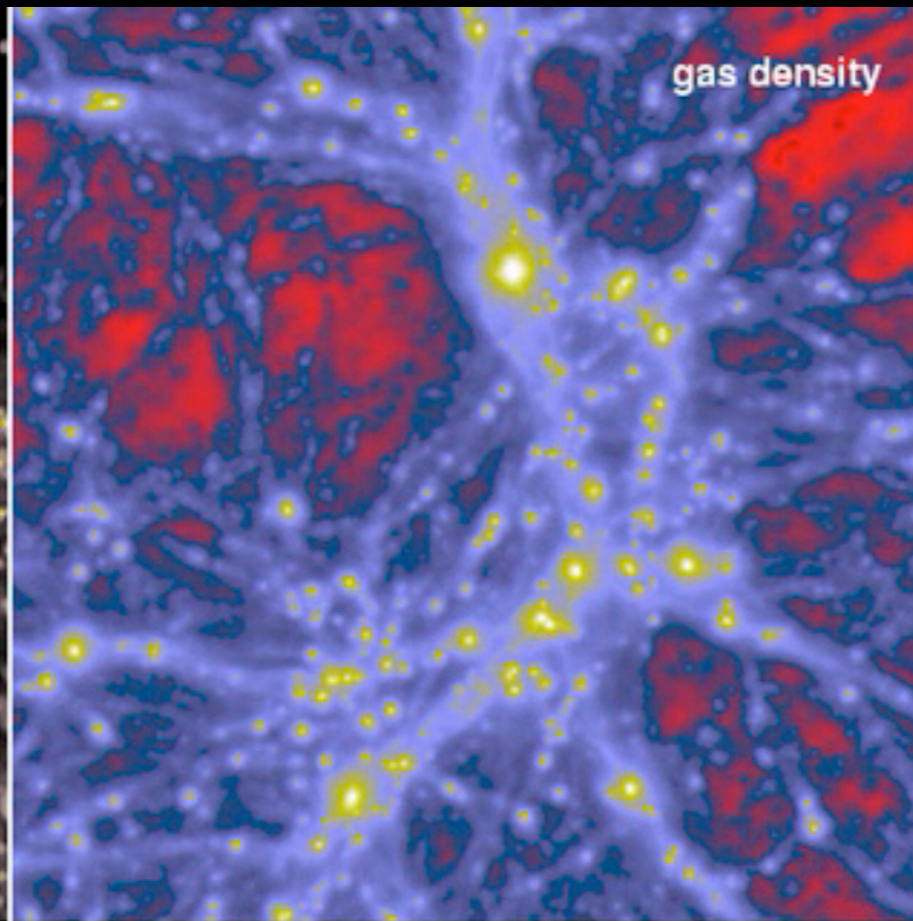
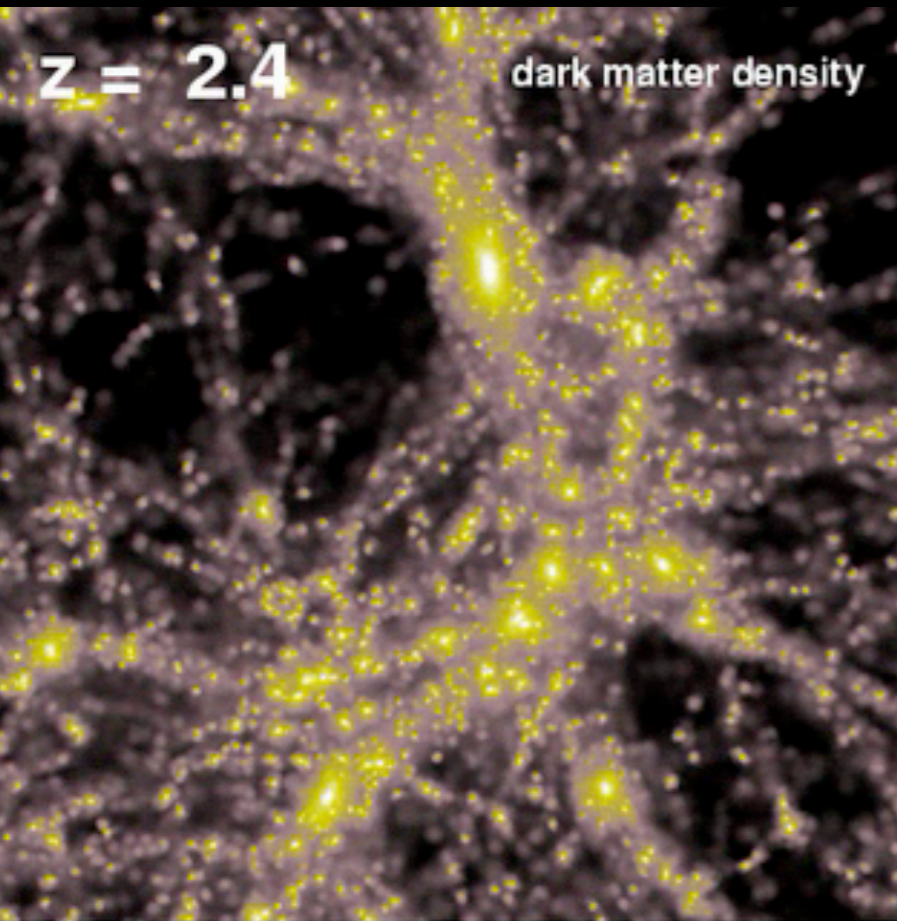
is a “spectral energy distribution”





GENERALLY






- 1D:** Columns = “Spectra”, “SEDs” or “Time Series”
- 2D:** Faces or Slices = “Images”
- 3D:** Volumes = “3D Renderings”, “2D Movies”
- 4D:** Time Series of Volumes = “3D Movies”

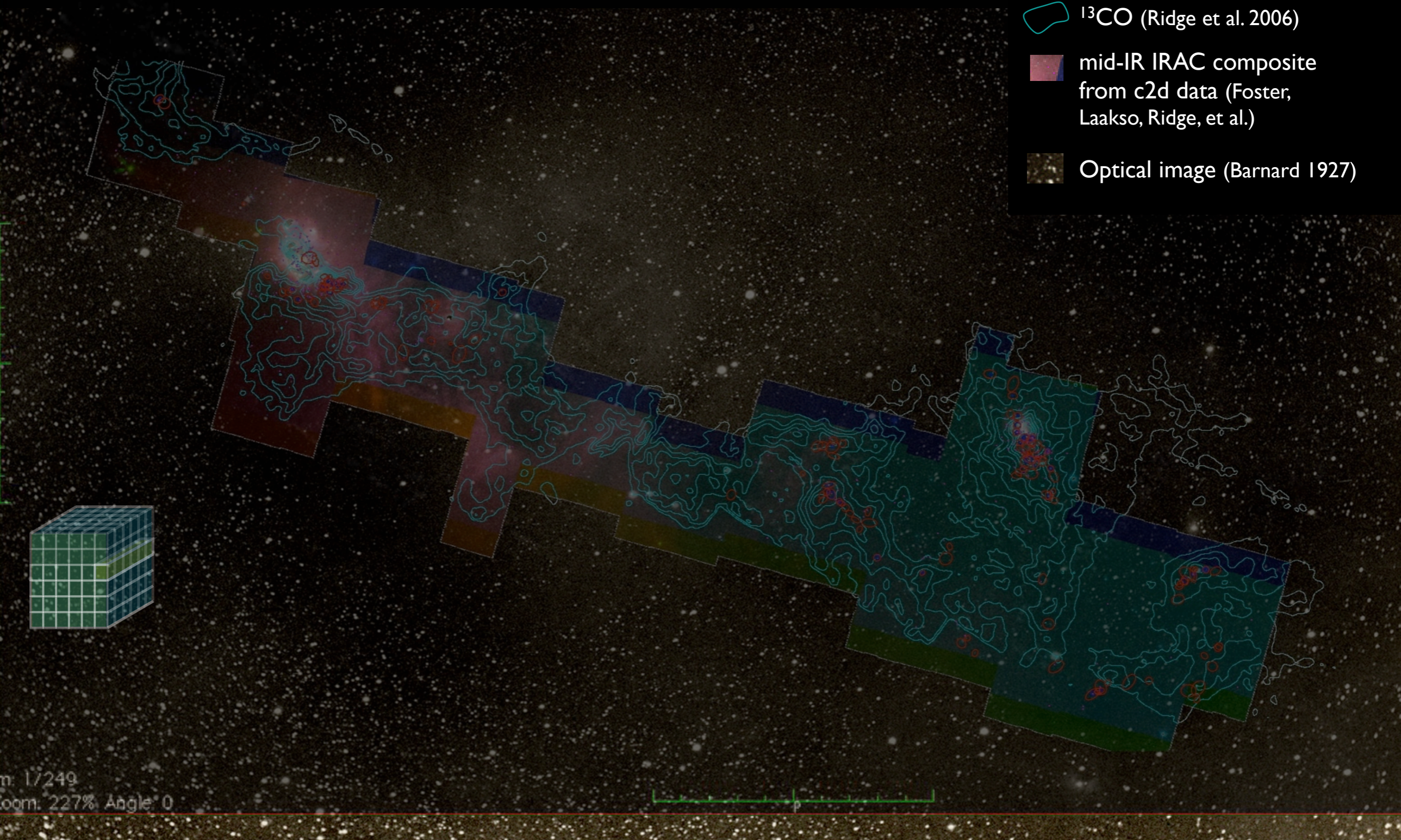


Movie: Volker Springel, formation of a cluster of galaxies

COMPLETE Perseus

Image size: 1305 x 733
WL: 63 WW: 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.)
-  Optical image (Barnard 1927)



m: 17249
Zoom: 227% Angle: 0

“Astronomical Medicine”

“KEITH”



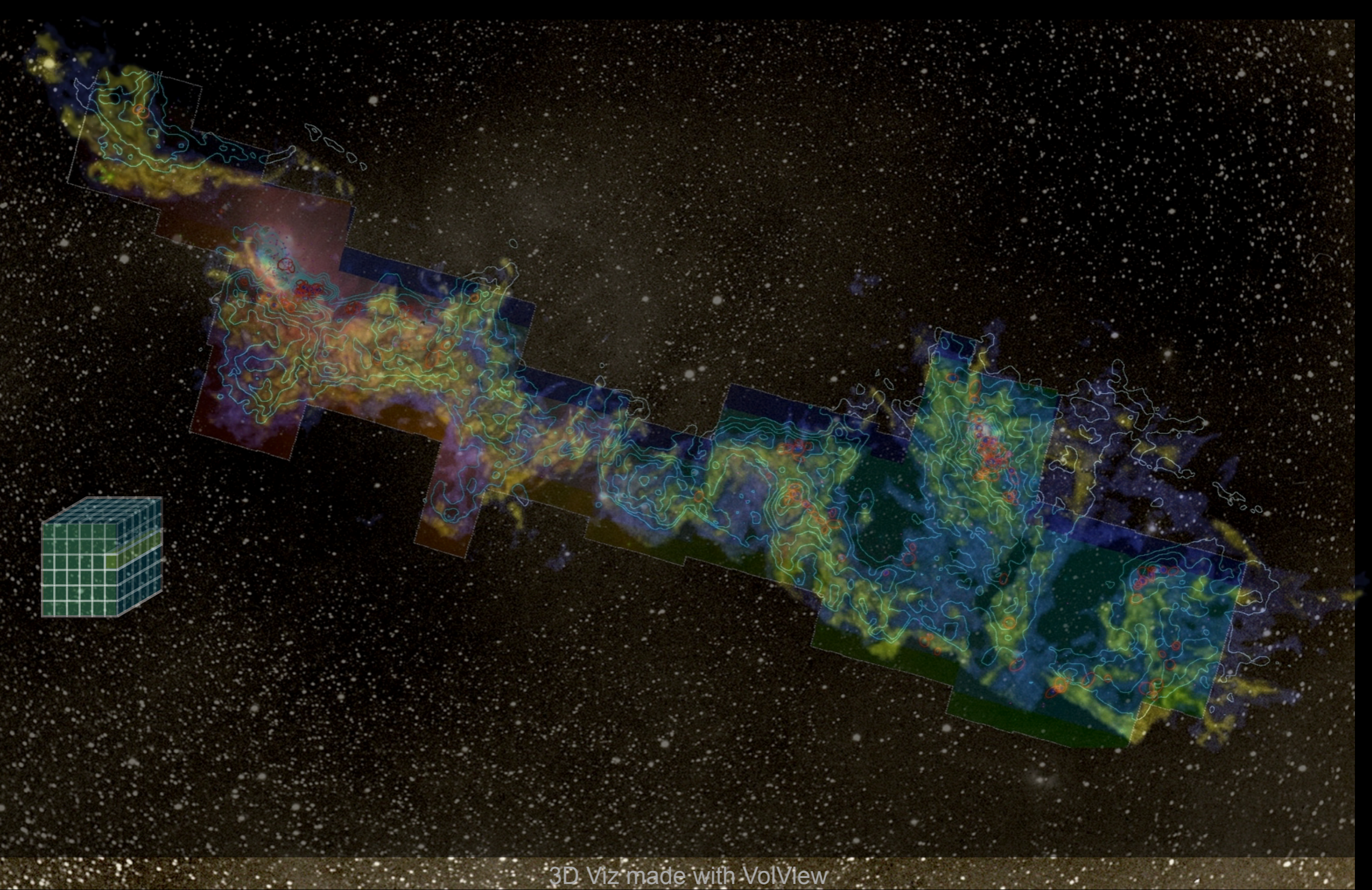
“z” is depth into head

“PERSEUS”

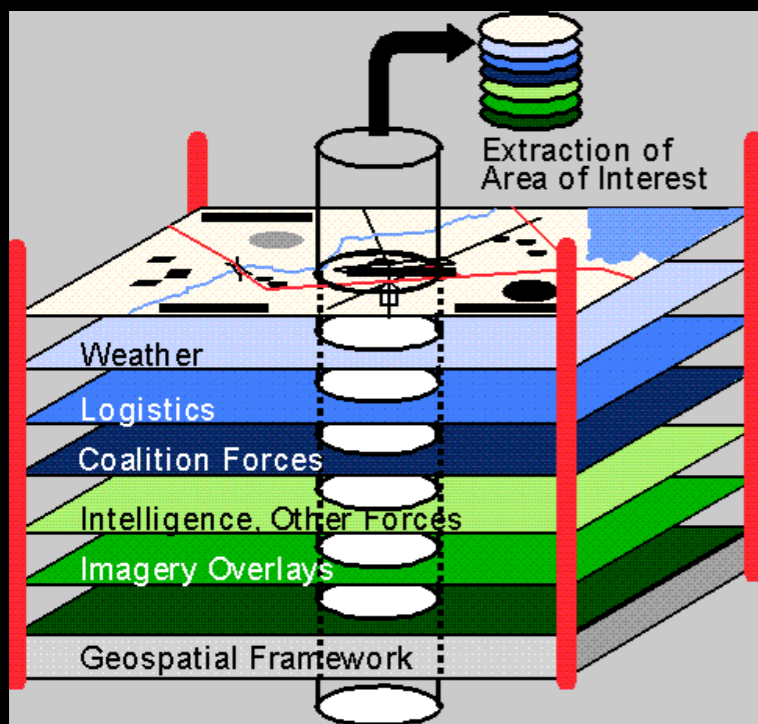


“z” is line-of-sight velocity

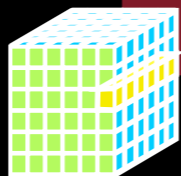
<http://am.iic.harvard.edu/>



3D Viz made with VolView



Data
Dimensions
Display



Open Data
Open Tools



COMPLETE

COMPLETE Data Available

Center on Perseus Center on Ophiuchus Center on Serpens

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

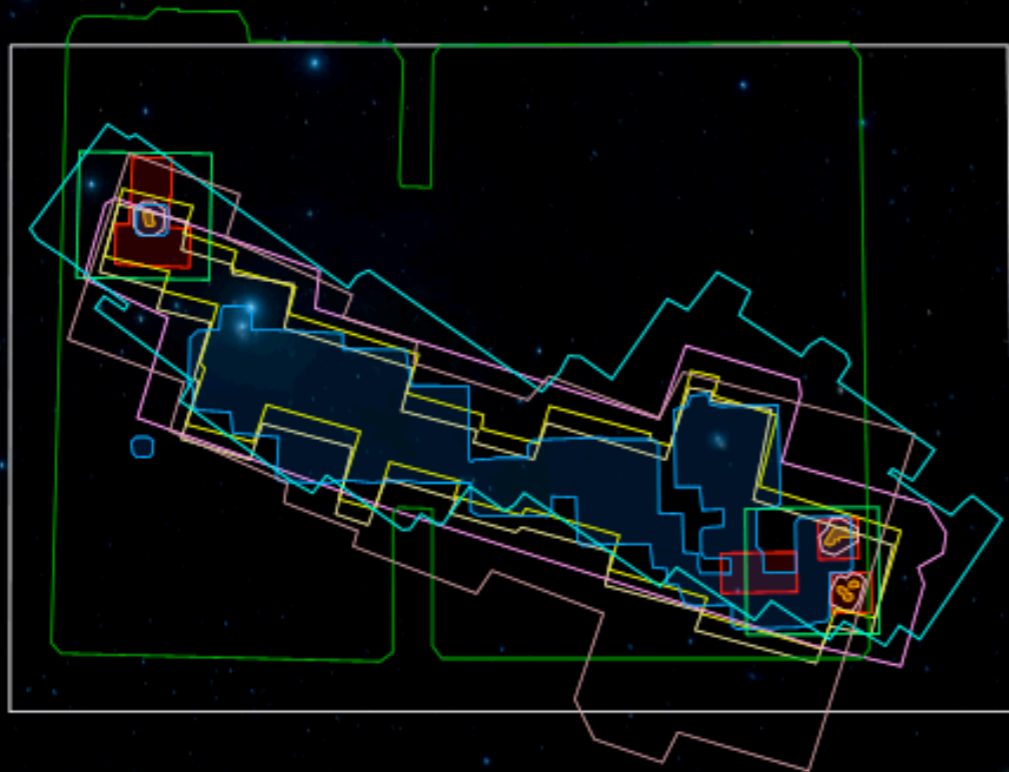
Dataset	Show	Perseus	Ophiuchus	Serpens	Link
GBT: HI Data Cube	<input checked="" type="checkbox"/>	✓	✓	∅	Data
IRAS: Av/Temp Maps	<input checked="" type="checkbox"/>	✓	✓	✓	Data
FCRAO: 12CO	<input checked="" type="checkbox"/>	✓	✓	✓	Data
FCRAO: 13CO	<input checked="" type="checkbox"/>	✓	✓	✓	Data
JCMT: 850 microns	<input checked="" type="checkbox"/>	✓	✓	∅	Data
Spitzer c2d: IRAC 1,3 (3.6,5.8 μm)	<input checked="" type="checkbox"/>	✓	✓	✓	Data
Spitzer c2d: IRAC 2,4 (4.5,8 μm)	<input checked="" type="checkbox"/>	✓	✓	✓	Data
CSO/Bolocam: 1.2-mm	<input checked="" type="checkbox"/>	✓	∅	∅	Data
Spitzer MIPS: Derived Dust Map	<input checked="" type="checkbox"/>	✓	∅	∅	Data

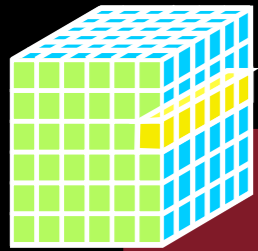
Targeted Regions (Phase II, Some Data Not Yet Available)

CTIO/Calar Alto: NIR (J,H,Ks)	<input checked="" type="checkbox"/>	✓	✓	∅	Data
IRAM 30-m: N2H+ and C18O	<input checked="" type="checkbox"/>	✓	∅	∅	Data
IRAM 30-m: 1.1-mm continuum	<input checked="" type="checkbox"/>	✓	∅	∅	Data
Megacam/MMT: r,i,z images	<input checked="" type="checkbox"/>	✓	∅	∅	Data

Catalogs & Pointed Surveys

NH3 Pointed Survey	<input checked="" type="checkbox"/>	✓	∅	∅	Data
YSO Candidate list (c2d)	<input checked="" type="checkbox"/>	✓	✓	✓	Data





*Data
Dimensions
Display*

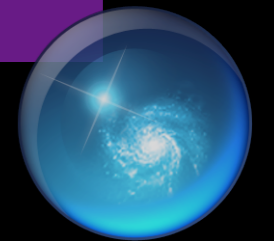
Linked Views

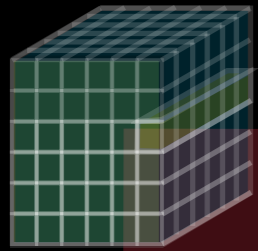
“Taste-Testing”
[Sim:Data]

*Seamless
Astronomy*
[the future]

ADS Labs
[info viz]

*Open Data
Open Tools*





*Data
Dimensions
Display*



Linked Views

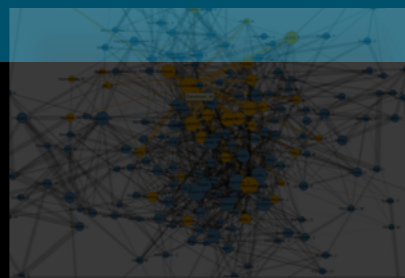


*“Taste-Testing”
[Sim:Data]*

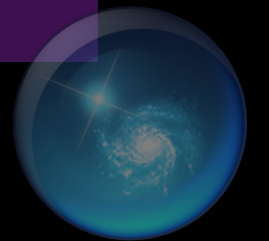
*Seamless
Astronomy
[the future]*



*ADS Labs
[info viz]*



*Open Data
Open Tools*

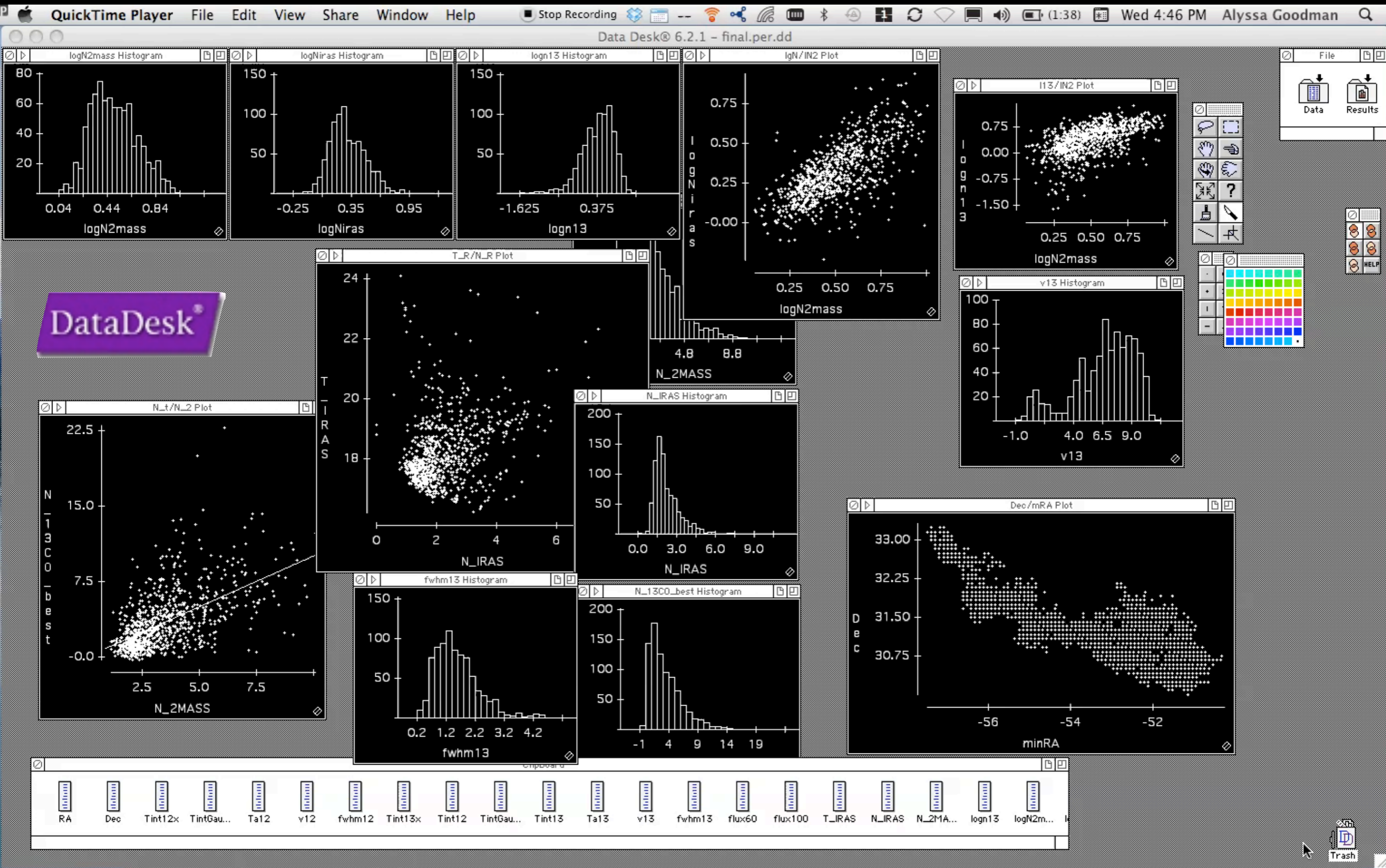


*Contextual,
High-Dimensional
View*

Link

*Flat,
Text-Based
View*

DataDesk (est. 1986)



John Tukey's "Four Essentials" (c.1972)

Picturing

Rotation

Isolation

Masking

Selection

and these *"need to work together"*
in a *"dynamic display"*

Brushing

Linking

Results...

1. for immediate **insight**
2. as visual source of **ideas** for statistical algorithms (...relation to SVM)

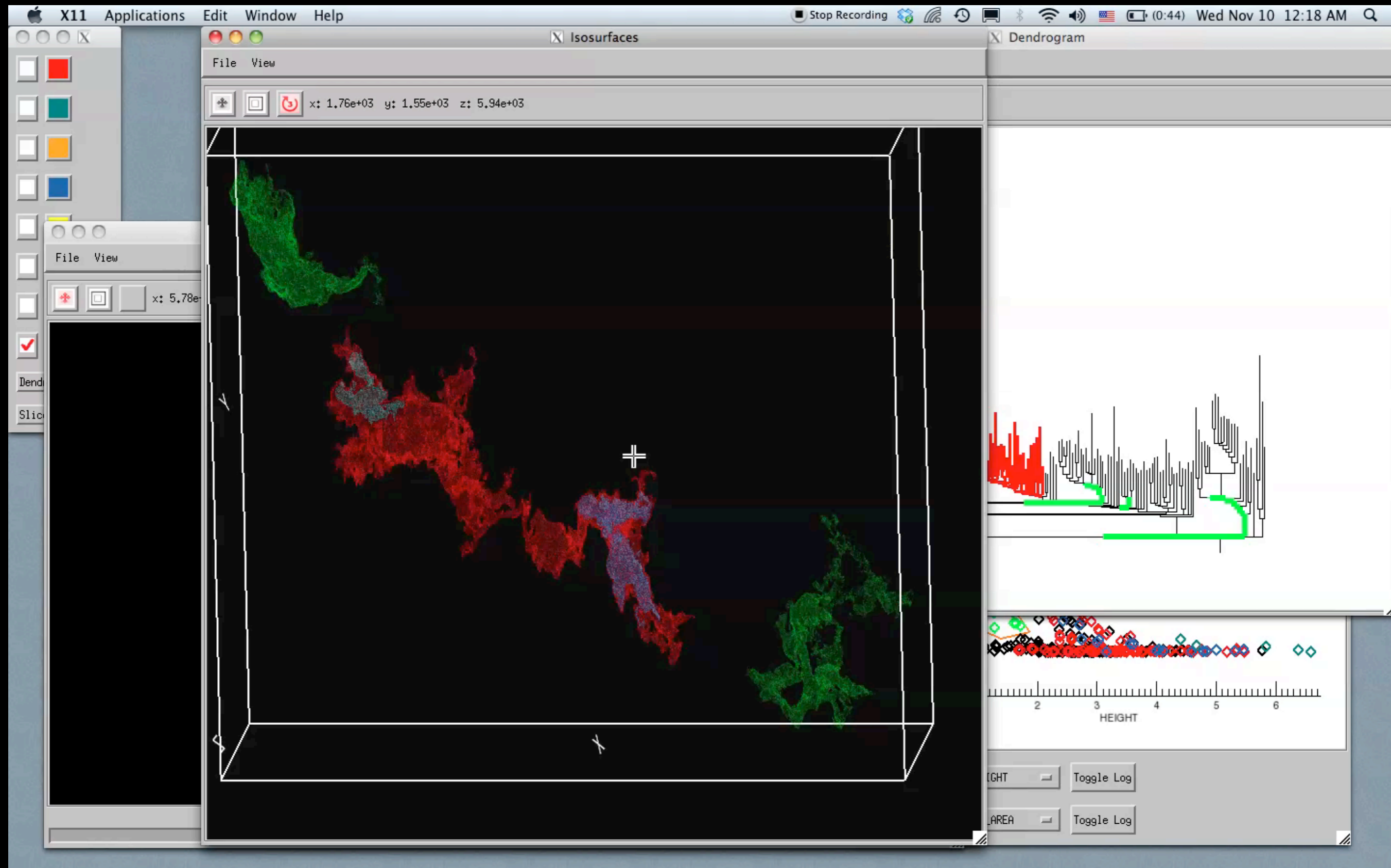
Warning

"details of control can make or break such a system"

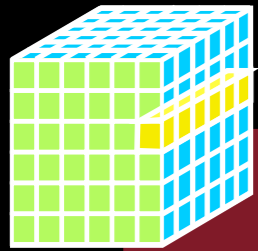
Watch the PRIM-9 video at: <http://stat-graphics.org/movies/prim9.html>



Exemplar: Linked Dendrogram Views in IDL



Video & implementation: Christopher Beaumont, CfA/UHawaii;
inspired by AstroMed work of Douglas Alan, Michelle Borkin, AG, Michael Halle, Erik Rosolowsky



**Data
Dimensions
Display**



Linked Views



**“Taste-Testing”
[Sim:Data]**

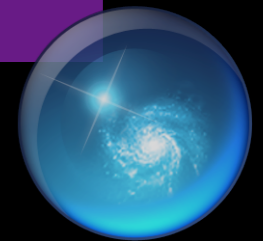
**Seamless
Astronomy
[the future]**

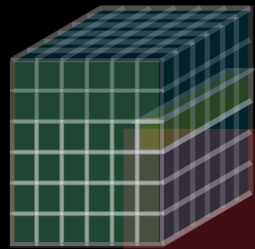


**ADS Labs
[info viz]**



**Open Data
Open Tools**

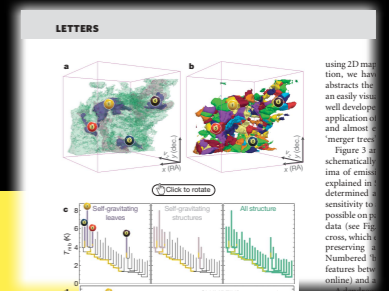




Data
Dimensions
Display



Linked Views



“Taste-Testing”
[Sim:Data]

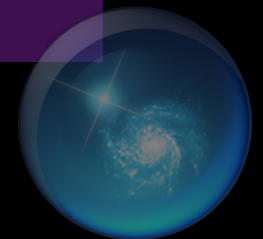
Seamless
Astronomy
[the future]



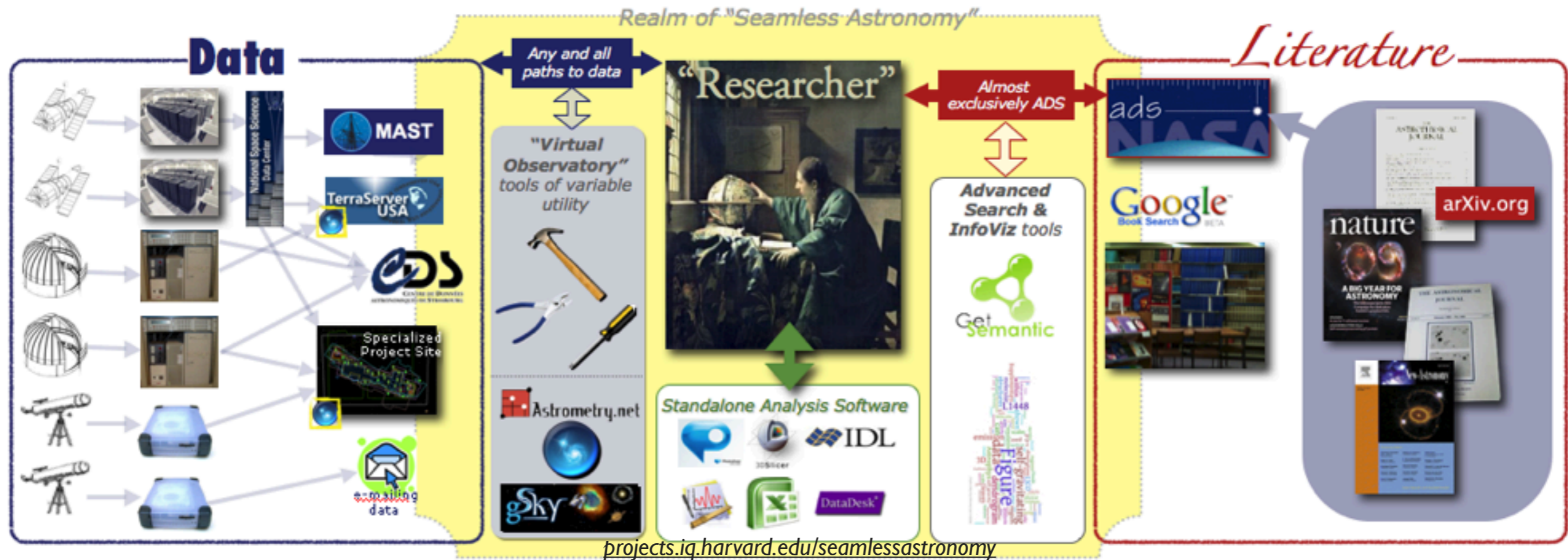
ADS Labs
[info viz]



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Seamless Astronomy [the future]



“3D PDF”

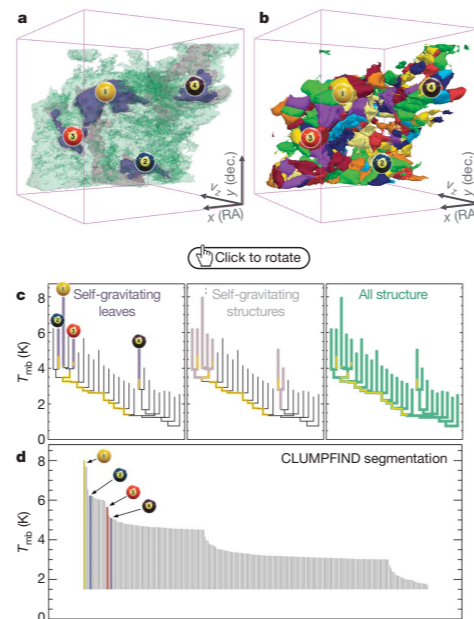


Figure 2 | Comparison of the ‘dendrogram’ and ‘CLUMPFIND’ feature-identification algorithms as applied to ^{13}CO emission from the L1448 region of Perseus. **a**, 3D visualization of the surfaces indicated by colours in the dendrogram shown in **c**. Purple illustrates the smallest scale self-gravitating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

data, CLUMPFIND typically finds features on a limited range of scales, above but close to the physical resolution of the data, and its results can be overly dependent on input parameters. By tuning CLUMPFIND’s two free parameters, the same molecular-line data set⁸ 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 frequency¹³.

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 work¹⁴ 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 $M_{\text{lum}} = X_{13\text{CO}} L_{13\text{CO}}$, where $X_{13\text{CO}} = 8.0 \times 10^{20} \text{ cm}^{-2} \text{ K}^{-1} \text{ km}^{-1} \text{ s}$ (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, $\alpha_{\text{obs}} = 5\sigma_v^2 R/GM_{\text{lum}}$. In principle, extended portions of the tree (Fig. 2, yellow highlighting) where $\alpha_{\text{obs}} < 2$ (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 fields¹⁶, its measured value should only be used as a guide to the longevity (boundedness) of any particular feature.

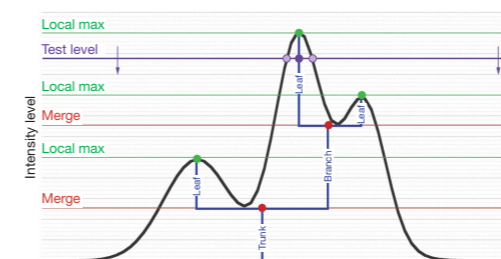
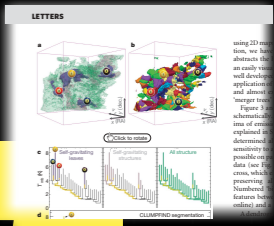


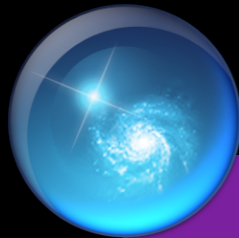
Figure 3 | Schematic illustration of the dendrogram process. Shown is the construction of a dendrogram from a hypothetical one-dimensional emission profile (black). The dendrogram (blue) can be constructed by ‘dropping’ a test constant emission level (purple) from above in tiny steps (exaggerated in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

Seamless
Astronomy
[the future]



“Taste-
Testing”
[Sim:Data]





Open Data Open Tools



Seamless Astronomy [the future]

GERMAN ASTROPHYSICAL
GAVO
VIRTUAL OBSERVATORY

German Astrophysical Virtual Observatory
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The GAVO Data Center is a growing collection of Services, Tools & Archives provided by GAVO. Go there if you are looking for a special GAVO service or if you want to get an overview.



Getting Started

This is the starting point for information on:

- Publishing your data in the VO
- Tutorials & Use cases
- VO Tools & Services
- Acknowledging GAVO



Highlights

Links to some of GAVO's main services:

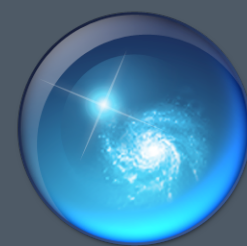
- ROSAT Services
- RAVE
- Millennium Databases
- TheoSSA



Microsoft® Research
WorldWide Telescope

Ambassadors Program





Microscope World



telescope.org

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Seamlessly explore imagery from the best ground and space-based telescopes in the world

Expert led tours of the Universe

Control time to study how the night sky changes

View and compare images from across the electromagnetic spectrum


Much more than "just" the sky at night! 3D features can take you to other planets, stars & galaxies.

Finder Scope links to Wikipedia, publications, and data, so you can learn more

Context bar shows items of interest in current field of view

Context globe shows where you're looking.

[Demo]



John Huchra's Universe

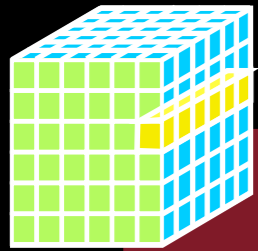
This WorldWide Telescope Tour was created to thank
John Huchra (1948-2010) for the knowledge and cheer he gave us all.

[Demo]

John Huchra's Universe

This WorldWide Telescope Tour was created to thank
John Huchra (1948-2010) for the knowledge and cheer he gave us all.

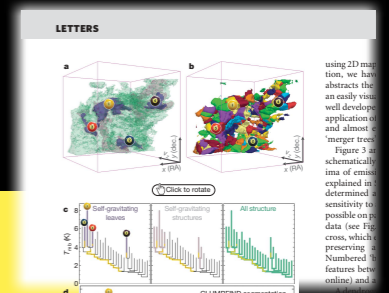
also available on YouTube (search "John Huchra's Universe")



Data Dimensions Display



Linked Views



“Taste-Testing” [Sim:Data]

Seamless Astronomy [the future]

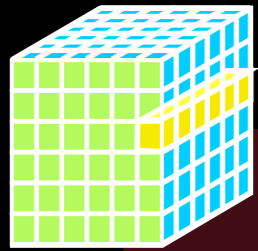


ADS Labs [info viz]



Open Data Open Tools





*Data
Dimensions
Display*



Linked Views



*“Taste-Testing”
[Sim:Data]*

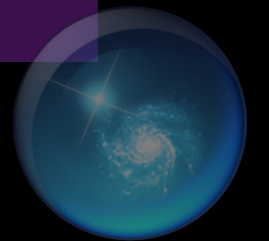
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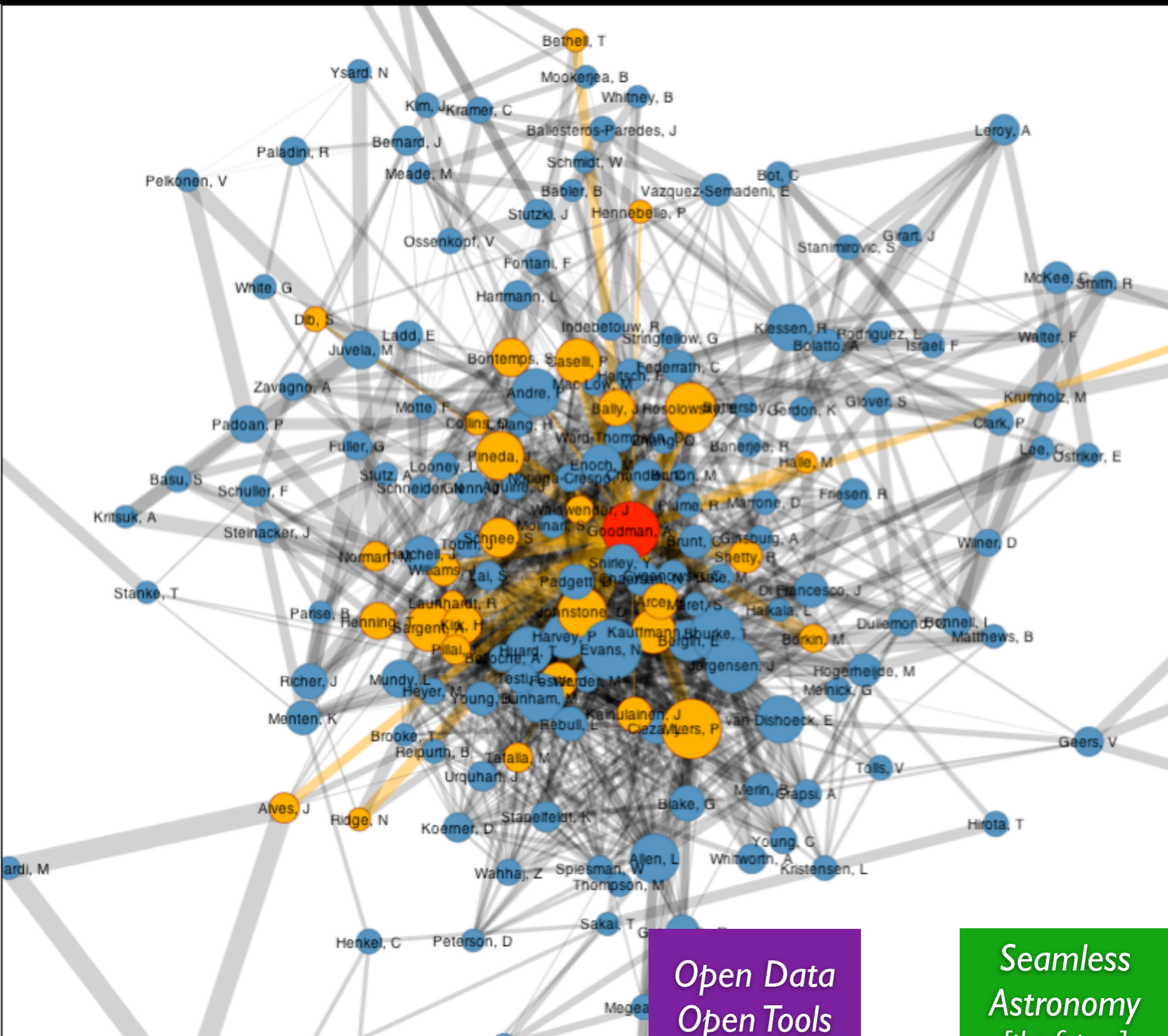
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COMPLETE Citation Network (from ADS Labs)



[Demo]

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“Off the Desktop”



Slideshow: Tabletop Computers *Continued*

By Meredith Ringel Morris

First Published December 2008

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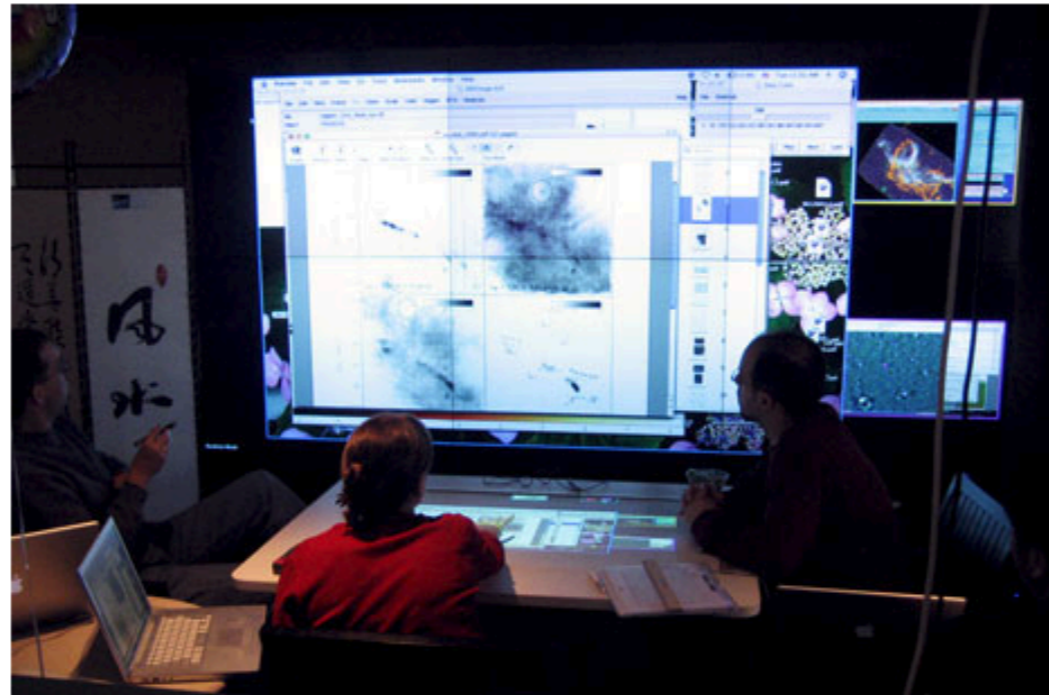


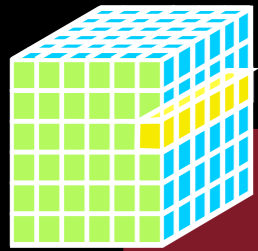
PHOTO: HAO JIANG, DANIEL WIGDOR, CLIFTON FORLINES, AND CHIA SHEN

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.

Linked Views

Seamless
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[the future]

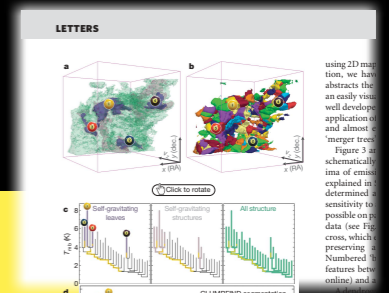
movie courtesy Daniel Wigdor, taken at MERL, Kendall Square, Cambridge, 2007



Data Dimensions Display



Linked Views



“Taste-Testing” [Sim:Data]

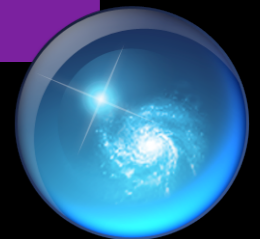
Seamless Astronomy [the future]



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Open Data Open Tools

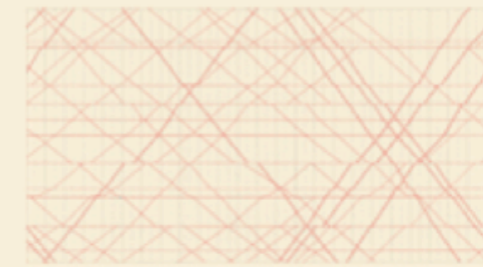


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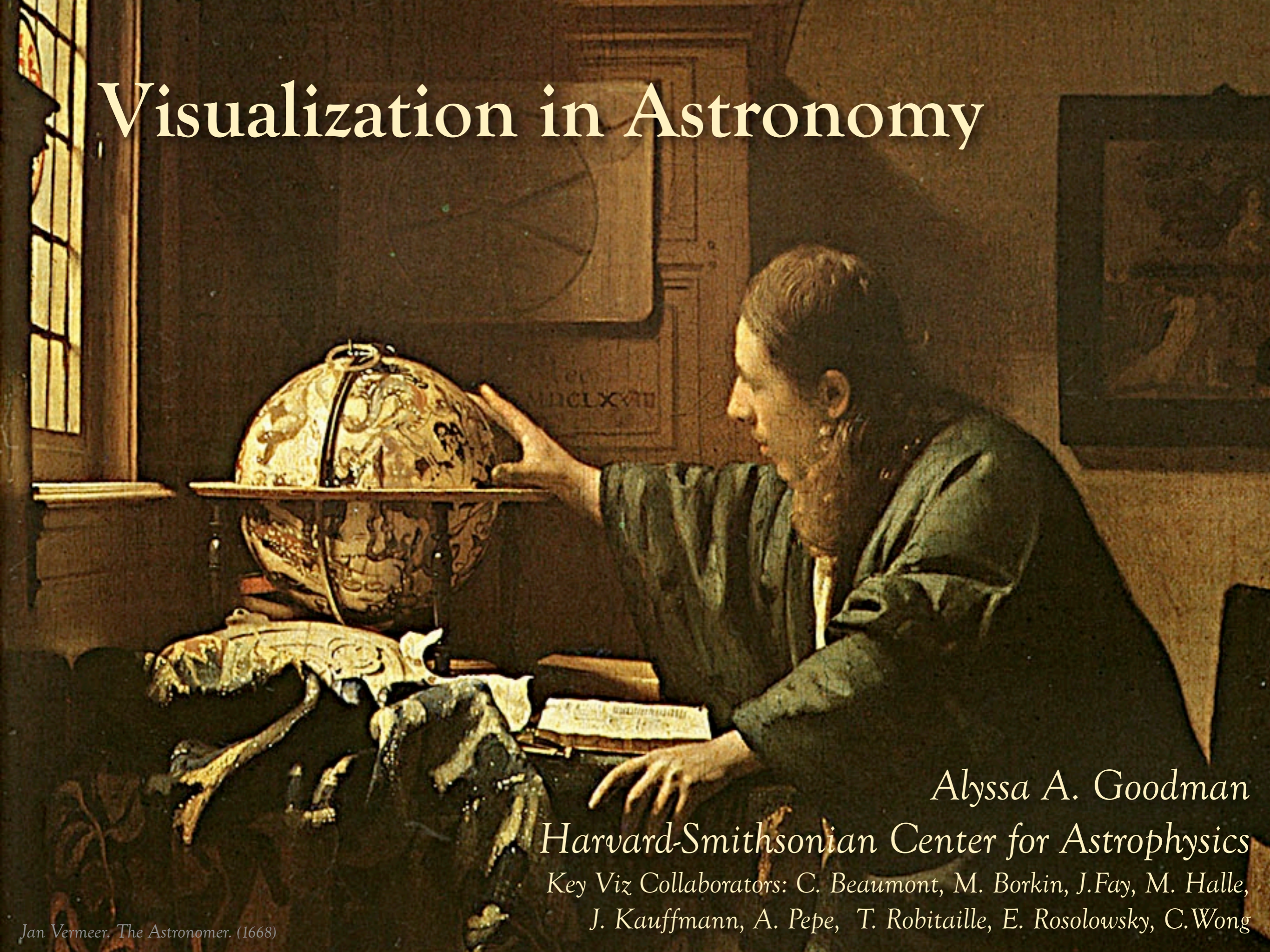
www.cfa.harvard.edu/~agoodman

Software: [projects.iq.harvard.edu/
seamlessastronomy/software](http://projects.iq.harvard.edu/seamlessastronomy/software)

“Everyday” software **blog**...
alyssagoodman.tumblr.com

Frankel & DePace 2011,
Visual Strategies

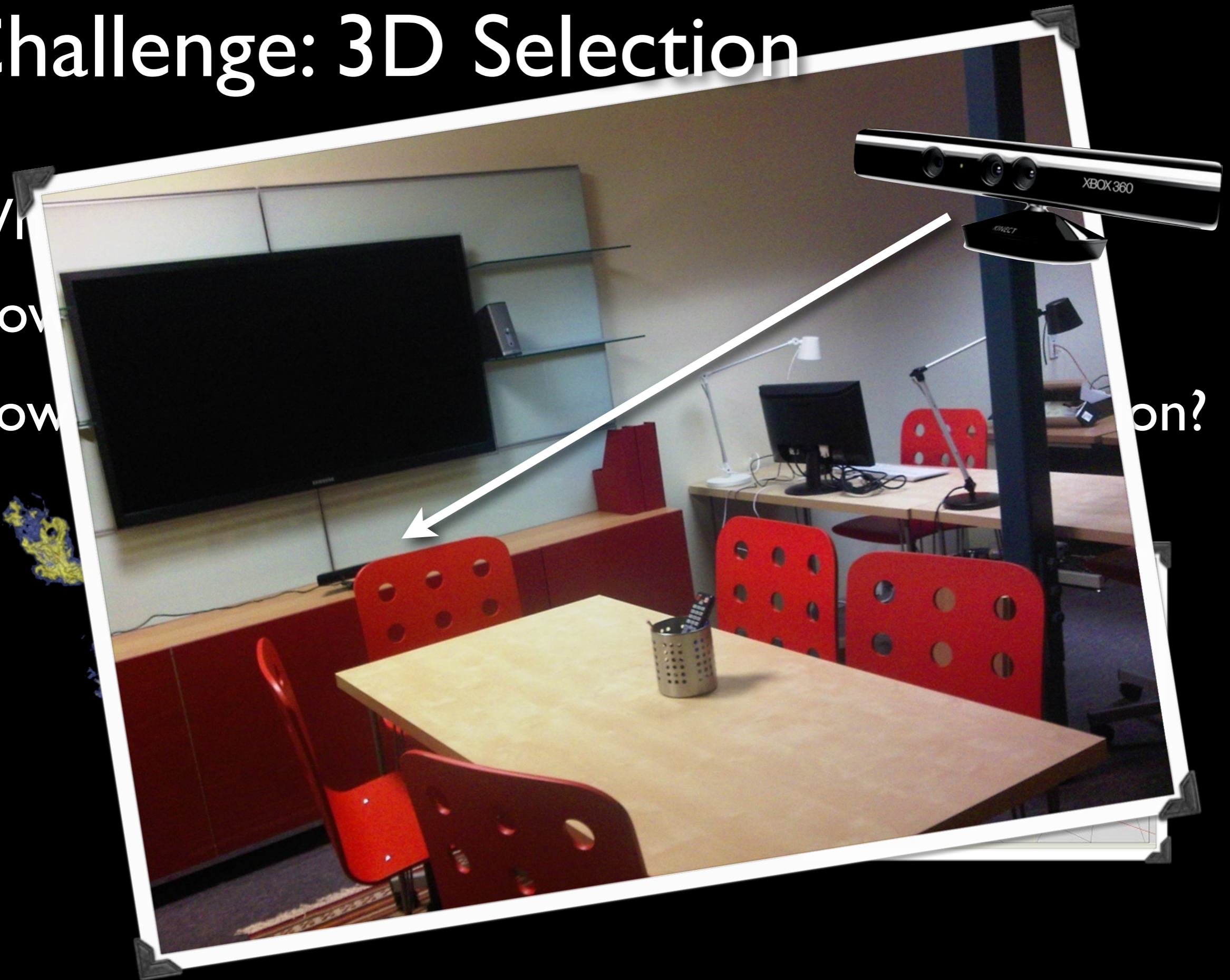
Visualization in Astronomy



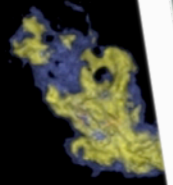
Alyssa A. Goodman
Harvard-Smithsonian Center for Astrophysics
Key Viz Collaborators: C. Beaumont, M. Borkin, J. Fay, M. Halle,
J. Kauffmann, A. Pepe, T. Robitaille, E. Rosolowsky, C. Wong

Challenge: 3D Selection

Why?
How?
How?



on?





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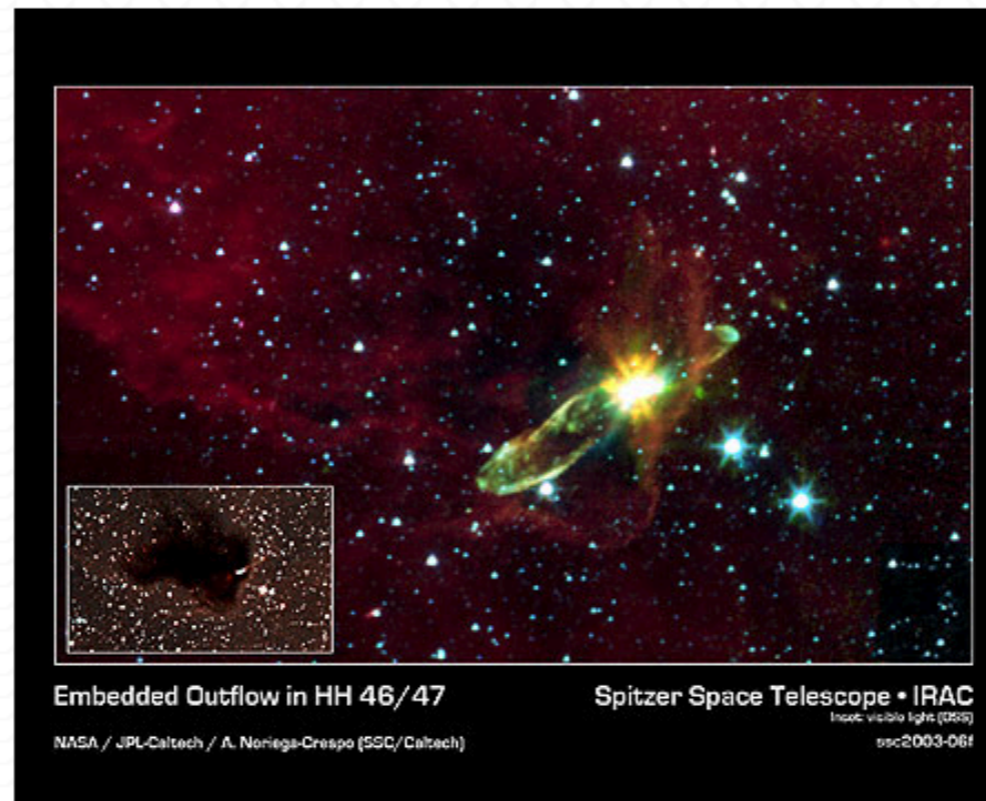
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Embedded Outflow in HH 46/47

Spitzer Space Telescope • IRAC

NASA / JPL-Caltech / A. Noriega-Crespo (SSC/Caltech)

Inset: visible light (DSS)
ssc2003-06f

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

HH4647

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Embedded Outflow in HH 46/47 **Spitzer Space Telescope • IRAC**
Inset: visible light (DSS) bsc2003-06f
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...why we must explain that...

“This is not art.”

