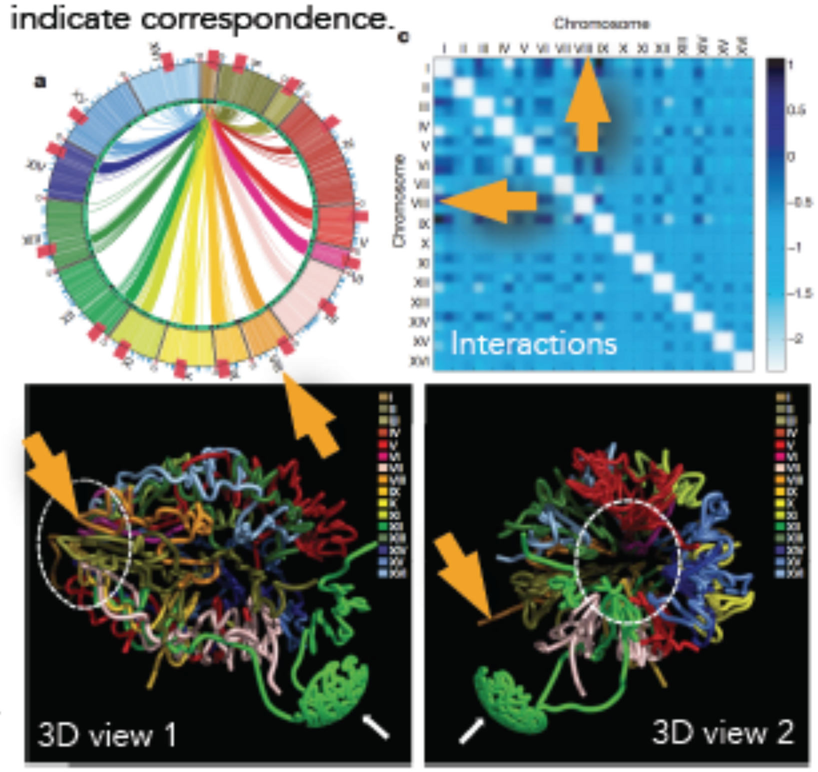
Thanks Alberto!

Question 2: Advancing Methodology, Applications Beyond the Proposal, Open Source

Advancing Methodology Three methodological areas, all related to data science, contribute to the ideas behind Glue3D: linked views; machine learning applied to 3D segmentation and selection; and 3D user-interaction paradigms and tools. Linked views and 3D user interaction are not solved problems by any means, but we are confident that by building on our and others' prior work on linked views, and by employing new commercial devices[5] developed for gaming, and potentially collaborating with their creators, associated challenges will be met. On the other hand, the *smart 3D segmentation* based on crowdsourcing to experts we propose here is a relatively novel approach. Recall that our goal is to offer selection tools that can anticipate what a user seeks, so that 3D interaction devices need only to refine an initial "smart" segmentation. Our recent work (Beaumont et al. 2014, see original submission) on applying a straightforward (random forest) machine learning approach to "smart selection" of 2D views of interstellar bubbles gives us confidence that these ideas will extend to 3D. Current smart segmentation approaches, especially in medical imaging, rely on either pre-defined shapes for organs or sharp gradients in images. Because our training set will be completely empirical in that it is determined by human expert preferences, it will not require such semantic constraints *a priori*. We believe that this is a novel approach to 3D smart segmentation, and that success will represent a significant contribution to visualization, volumetric image analysis, citizen science, and computer science.

Applications Beyond the Proposal Astronomical and Medical data contain information that is inherently (spatially) three-dimensional. Other fields in the physical sciences with similar spatial data include Geology, Geophysics, and Atmospheric Science, and it is easy to see that Glue3D will be immediately useful in such fields, as well is in GIS endeavors. In the Life Sciences and in Chemistry, research today often follows either structural avenues (e.g. protein-folding) or statistical ones (e.g. genomics), and only sometimes both. Members of the Biomedical Engineering group at Drexel University have already begun to contribute to Glue on GitHub, and we envision a future "BioGlue3D" that could extend our work to greater utility in the Life Sciences. A quick example is given at right. The figures in the montage are all extracted from originally separate images in a *Nature* paper[6] that emphasizes the utility of studying the 3D spatial arrangement of chromosomes (*bottom two panels*) in conjunction with the interactions amongst them (*top two panels*). The orange arrows have been added to show which features would be live-linked in BioGlue3D, showing researchers, directly, which structural arrangements map to which interactions. While the matching colors and numerals in the existing figures are helpful, the cognitive load on a user interpreting these data would definitely be reduced by adding linked views and 3D selection to this set of figures.

Matching colors and matching Roman numerals indicate correspondence.



Open Source Products Glue is currently open source, in a code repository on GitHub at github.com/glue-viz/glue, and code for Glue3D will be on GitHub as well. I have recently led a paper entitled *10 Simple Rules for the Care and Feeding of Scientific Data* (see products) which has had over 8K hits in its first two weeks on PLoS. I am also Senior Advisor to the open publishing platform, Authorea.com, founded by my former postdoc Alberto Pepe. Our group's commitment to Open Data, Open Software, and Open Publishing will translate into careful, open, sharing of all the code, data, and research publications produced by this project.

Visualizing the Milky Way across the spectrum

Alyssa A. Goodman
Harvard-Smithsonian Center for Astrophysics

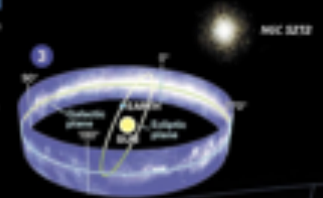

THE MILKY WAY
NATIONAL GEOGRAPHIC
Home galaxy of Earth, the Milky Way is a spiral-shaped system of a few hundred billion stars. Bright regions of recently formed stars highlight its arms, while older stars explode or expel their outer layers as beautiful planetary nebulae, then fade away and die. A thick swarm of orange and red stars marks the galactic bulge, encapsulating the star-packed galactic center. At its core may lie a black hole, a region so dense that not even light can escape its gravitational pull. All objects in the Milky Way orbit the galactic center, much like planets in Earth's solar system revolve around the sun. But the scale is staggering: Light from a star at one edge of the galaxy takes about 100,000 years to reach the opposite side.
GUIDE TO THE GALAXY
A TURBULENT HEART
NORMA ARM
CRUX ARM
CARINA ARM
SCUTUM ARM
SAGITTARIUS ARM
PERSEUS ARM
ORION ARM
OUTER ARM
WE ARE HERE
PLANETARY NEBULA M2-9
LAGOON NEBULA

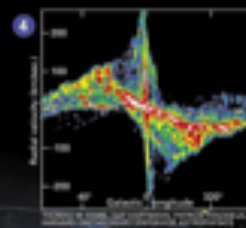
GUIDE TO THE GALAXY

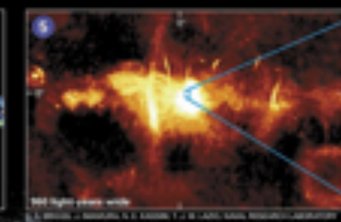
1 Far beyond the galactic disk, yet drawn by its gravity, lone stars and globular clusters wander the galaxy's halo. Regions of dark matter—unseen but felt through its gravitational effects—extend beyond that.

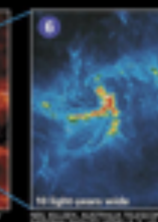
2 Vast clouds of interstellar dust block much of our night sky view of the Milky Way, which from our position in the flat galactic disk appears as a fuzzy band of light. Infrared satellites can see through the dust to reveal the galaxy's structure.

3 Earth's orbit around the sun lies at a severe angle to the galactic plane.









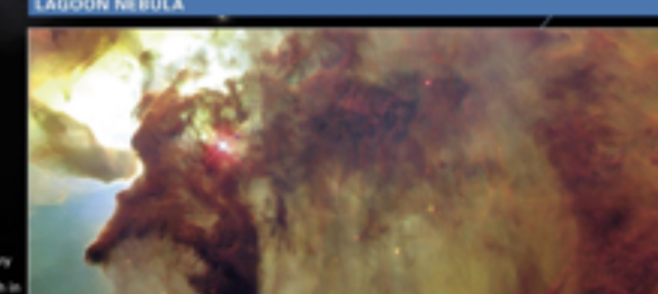
A TURBULENT HEART

4 A graph based on a radio survey reveals the whirlpool motion of molecular gas in the inner part of our galaxy: gas moving away from Earth (top half) and toward Earth (bottom half). The densest gas appears white; least dense, blue.

5 Massive amounts of energy are released near the center of the Milky Way, producing electrons that race along magnetic field lines, illuminating remnants of stellar explosions.

6 Probing even deeper into the core, a radio image details a spiral of hot gas that is falling toward what may be a black hole some 2.6 million times as massive as the sun.

LAGOON NEBULA



…ark nebu- …pic dust …of stars

retirees, however, every star in the cluster is about the

than the sun. They sparkle like an assortment of gems on a jeweler's velvet pad.

In some dark clouds lurk strange

orbit. Light from the hot star is absorbed by and warms the

visible light from the Hubble Space Telescope.

evolving stars may have shaped this surprising pattern.

When a massive star comes to the end

12 In that location today astronomers find the fast-

Earth, clumpy, filamentary clouds of hydrogen gas reveal their stately march in

Images

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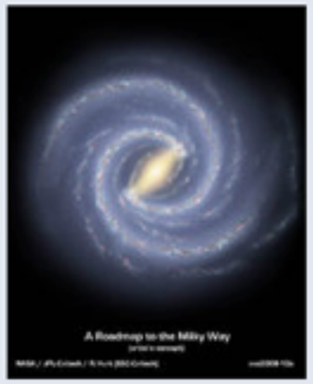
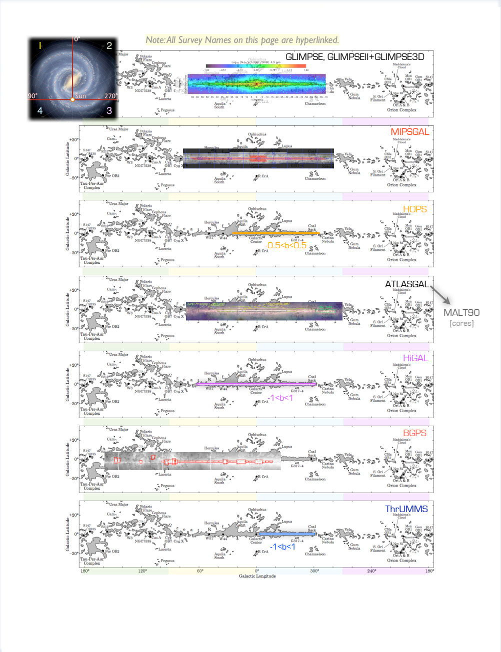


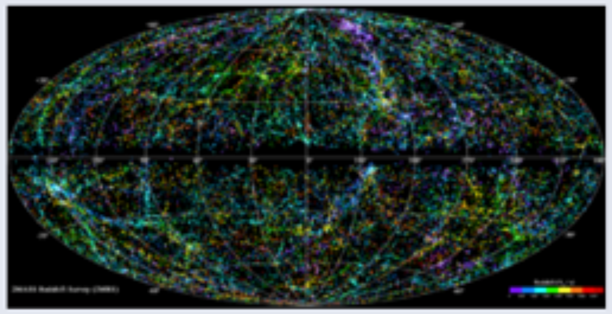
Robert Hurt's Artist's Conception of the Milky Way

He is at the Spitzer Science Center, and he created this "Roadmap to the Milky Way" in 2008.



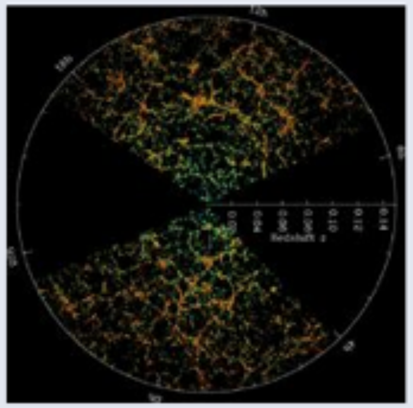
Survey Coverage

A hyperlinked visual summary (pdf) of all ongoing relevant surveys, prepared in conjunction with the NSF proposal, The Hierarchical Structure of Star-Forming Regions in the Milky Way.



The 2MASS Redshift Survey

The most complete map of the local universe to date. For more details see the 2MRS Website.



The SLOAN Digital Sky Survey

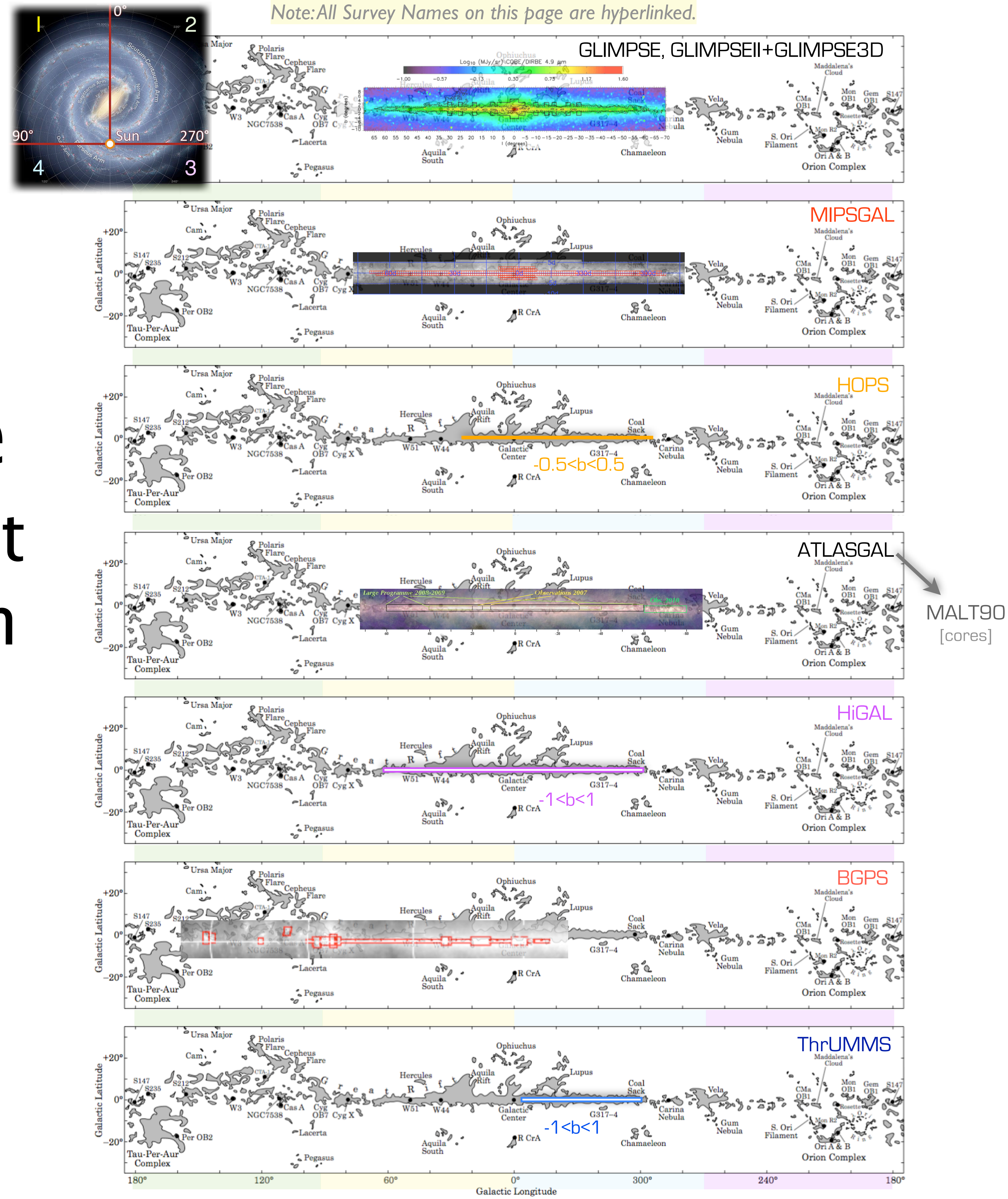
The image shows the "butterfly" of the SDSS a survey of galaxies up to high redshift.

The Milky Way Galaxy Map

Dark Matter

http://universe3d.org/wiki/index.php/Images

Galactic Plane Surveys relevant to Star Formation c. 2012



The Milky Way

The Milky Way
(Artist's Conception)

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Distance	Wavelength					
	Gamma Ray	X-Ray	Ultraviolet	Optical	Infrared	Radio
Solar System	☆	☆	☆	☆	☆	☆
Nearby Stars	☆	☆	☆	★	☆	☆
Milky Way	★	★	★	★	★	★
Local Group Galaxies	★	★	☆	☆	★	★
z ~ 0 Galaxies	★	★	☆	★	★	★
z > 0 Galaxies	★	★	☆	★	★	★
High Redshift Universe	★	★	☆	★	★	★
Early Universe	☆	☆	☆	☆	☆	★

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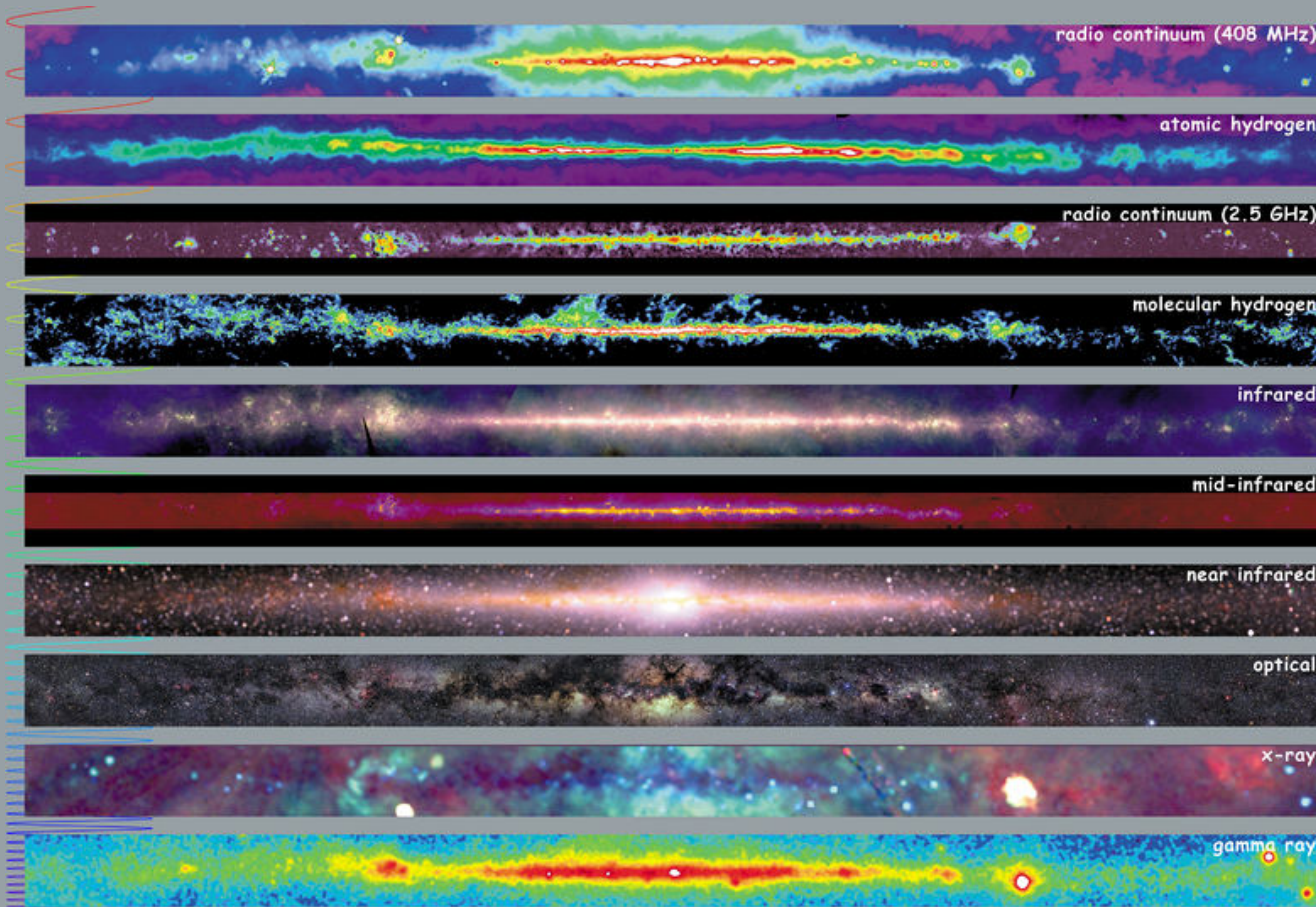
http://universe3d.org/wiki/index.php/Datasets



Multiwavelength Milky Way

http://adc.gsfc.nasa.gov/mw

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World Wide Telescope	✓			✓	✓	✓	✓	✓	✓			✓	✓		
Google Sky	✓		✓	✓	✓	Little	✓		✓			✓			
Partiview	Little	✓	Little		✓	✓	✓	✓	✓			✓			
Celestia	Little	✓	✓			✓	✓	✓				✓	✓	✓	✓
Mintaka															

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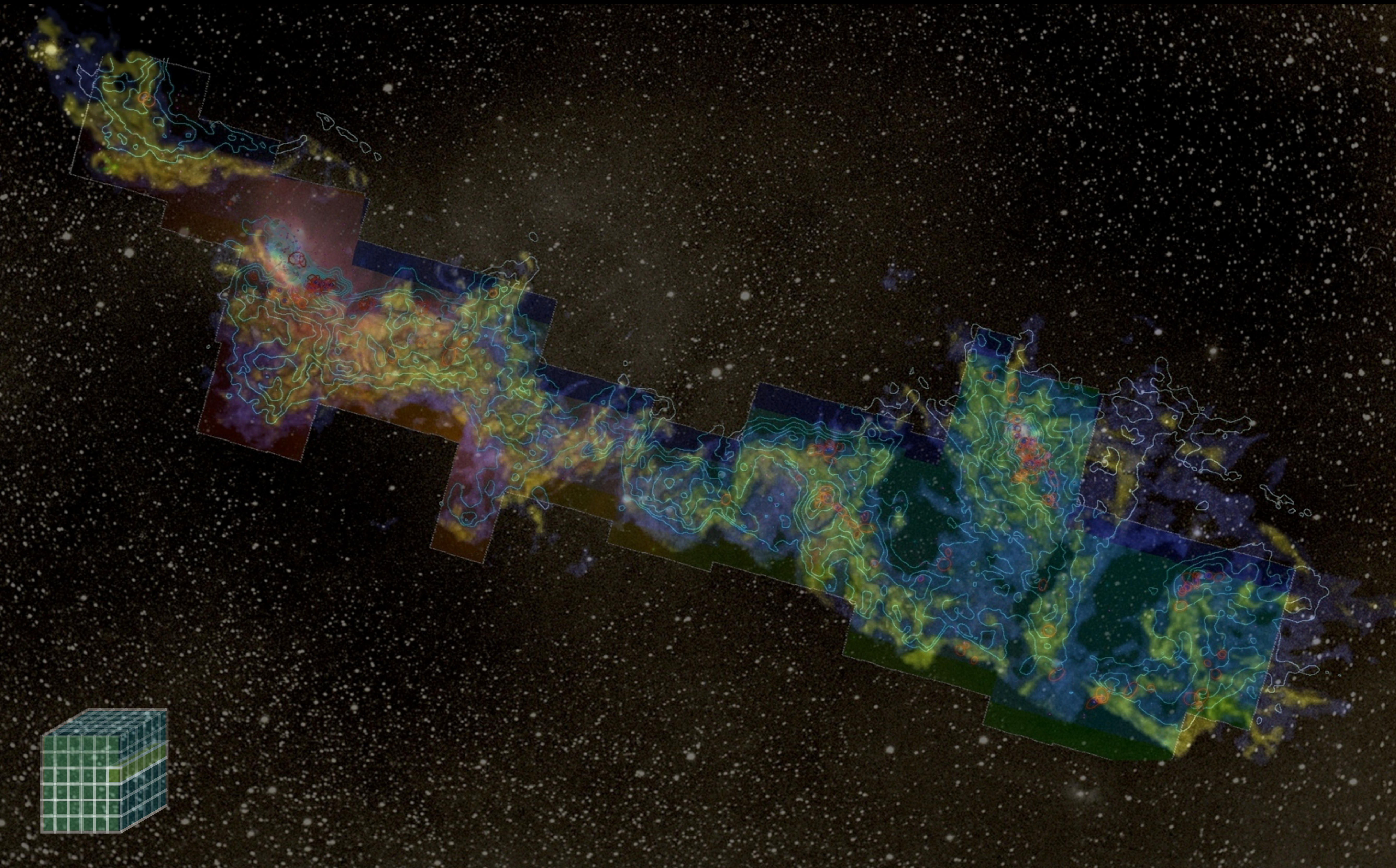


3D Viz made with VolView

AstronomicalMedicine@IIC

COMPLETE

2009

3D PDF

interactivity in a "Paper"

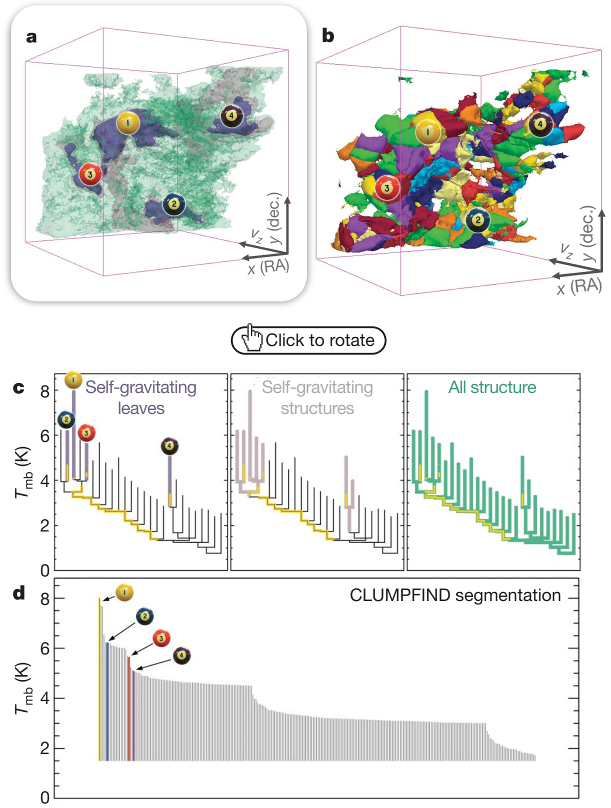


Figure 2 | Comparison of the 'dendrogram' and 'CLUMPFIND' feature-identification algorithms as applied to ^{13}CO emission from the L1448 region of Perseus. a, 3D visualization of the surfaces indicated by colours in the dendrogram shown in **c**. Purple illustrates the smallest scale self-gravitating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

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

Four years before the advent of CLUMPFIND, 'structure trees'[9] were proposed as a way to characterize clouds' hierarchical structure

using 2D maps of column density. With th… …rly 2D work as inspiration, we have developed a structure-id… …rithm that abstracts the hierarchical structure of a… an easily visualized representation calle… well developed in other data-intensive f… application of tree methodologies so fa… and almost exclusively within the ar… 'merger trees' are being used with in…

Figure 3 and its legend explain th… schematically. The dendrogram qua… ima of emission merge with each… explained in Supplementary Meth… determined almost entirely by th… sensitivity to algorithm paramete… possible on paper and 2D screen… data (see Fig. 3 and its legend… cross, which eliminates dimens… preserving all information… Numbered 'billiard ball' labe… features between a 2D map… online) and a sorted dendro…

A dendrogram of a spectr… of key physical properties… surfaces, such as radius (*R*), ve… (*L*). The volumes can have any shape, and in… the significance of the especially elongated features se… (Fig. 2a). The luminosity is an approximate proxy for mass, such that $M_{lum} = X_{13CO} L_{13CO}$, where $X_{13CO} = 8.0 \times 10^{20}\ cm^2\ K^{-1}\ km^{-1}\ s$ (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.

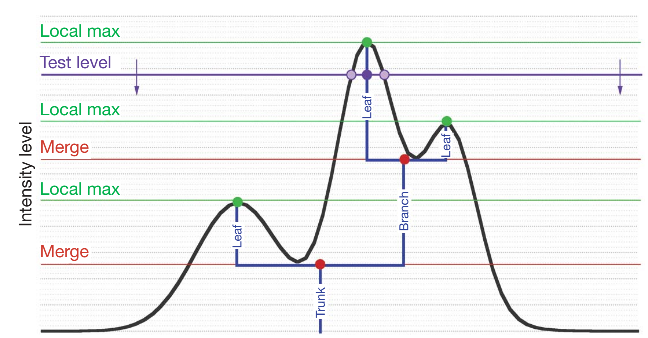
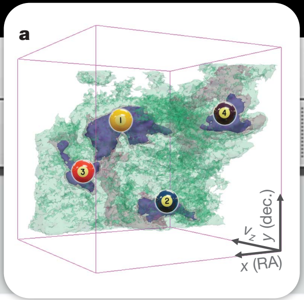


Figure 3 | Schematic illustration of the dendrogram process. Shown is the construction of a dendrogram from a hypothetical one-dimensional emission profile (black). The dendrogram (blue) can be constructed by 'dropping' a test constant emission level (purple) from above in tiny steps (exaggerated in 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. 2009, Nature, cf: Fluke et al. 2009

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



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[1]. 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[2]. 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 ^{13}CO 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 of dust emission[3] are projected on the sky within one of the dendrogram's self-gravitating 'leaves'. As these peaks mark the locations of already-forming stars, or of those probably about to form, a self-gravitating cocoon seems a critical condition for their exist-

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

PAn-STARRS 3D Extinction
Green et al. 2014

determining distance & reddening from large statiscal samples of stellar colors & positions

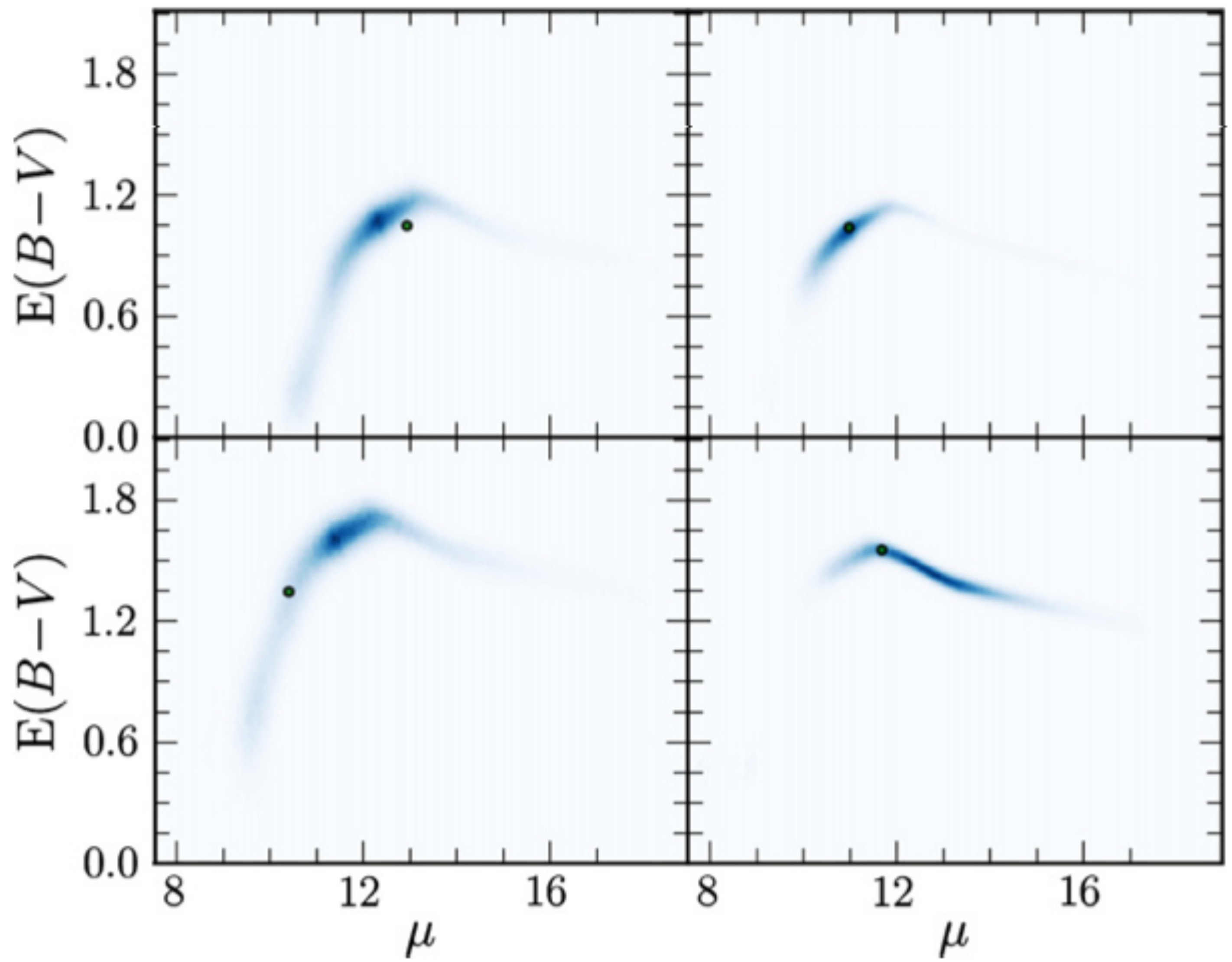


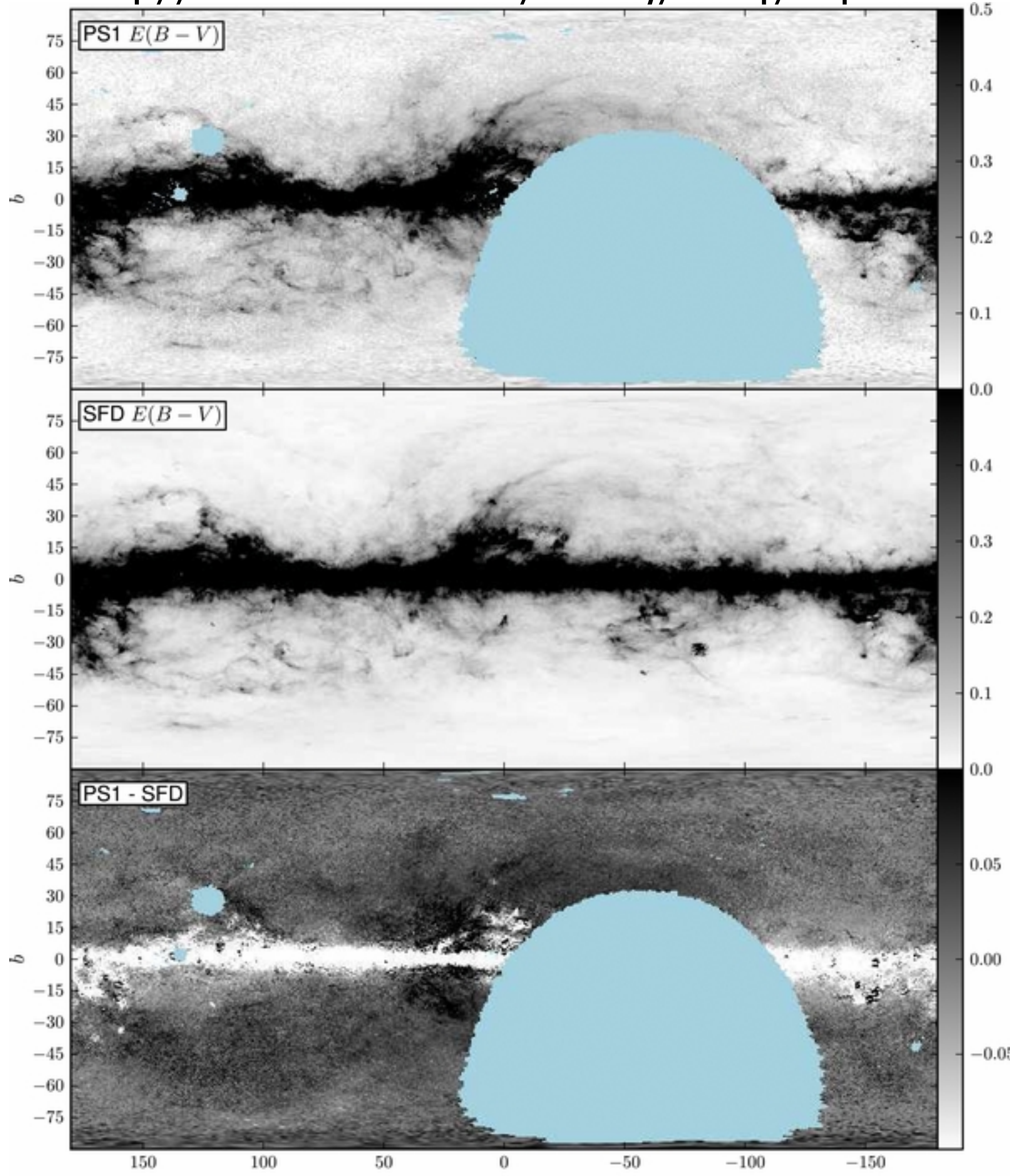
Figure 6. Distance and reddening estimates for four simulated stars. The joint posterior in distance and reddening is shown as a heat map. As this is mock photometry, we know the "true" distances and reddenings for the stars, which are shown as green dots. The true stellar parameters lie in regions of inferred high probability, as expected. The shape of the probability density functions traces that of the stellar locus. The probability density at closer distances corresponds to the main sequence, with increasing reddening compensating for the bluer intrinsic colors as one travels up the stellar locus. The peak in reddening corresponds to the main-sequence turnoff. Distances beyond the turnoff correspond to the giant branch.

http://faun.rc.fas.harvard.edu/eschlafly/2dmap/map.html

PAn-STARRS 3D Extinction

Schlafly et al. 2014b

determining distance & reddening from large statiscal samples of stellar colors & positions

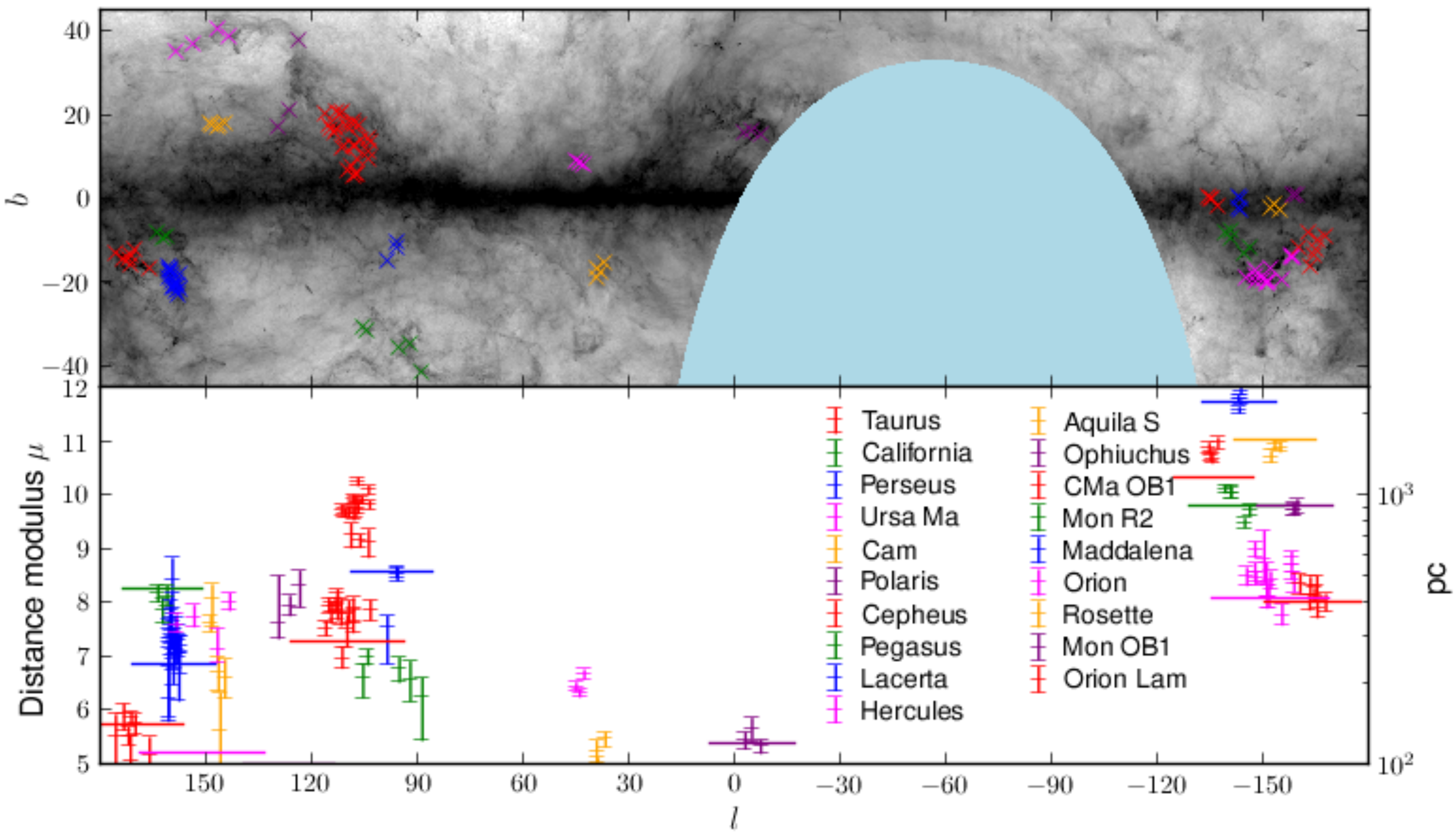


*"As foreseen by Bailer-Jones (2011), **even the photometric component of Gaia** alone is extremely interesting from the perspective of this technique—but the addition of **parallax information will make that mission truly revolutionary** for maps of dust."*

PAn-STARRS 3D Extinction

Schlafly et al. 2014a

determining distance & reddening from large statiscal samples of stellar colors & positions



gaia

esa

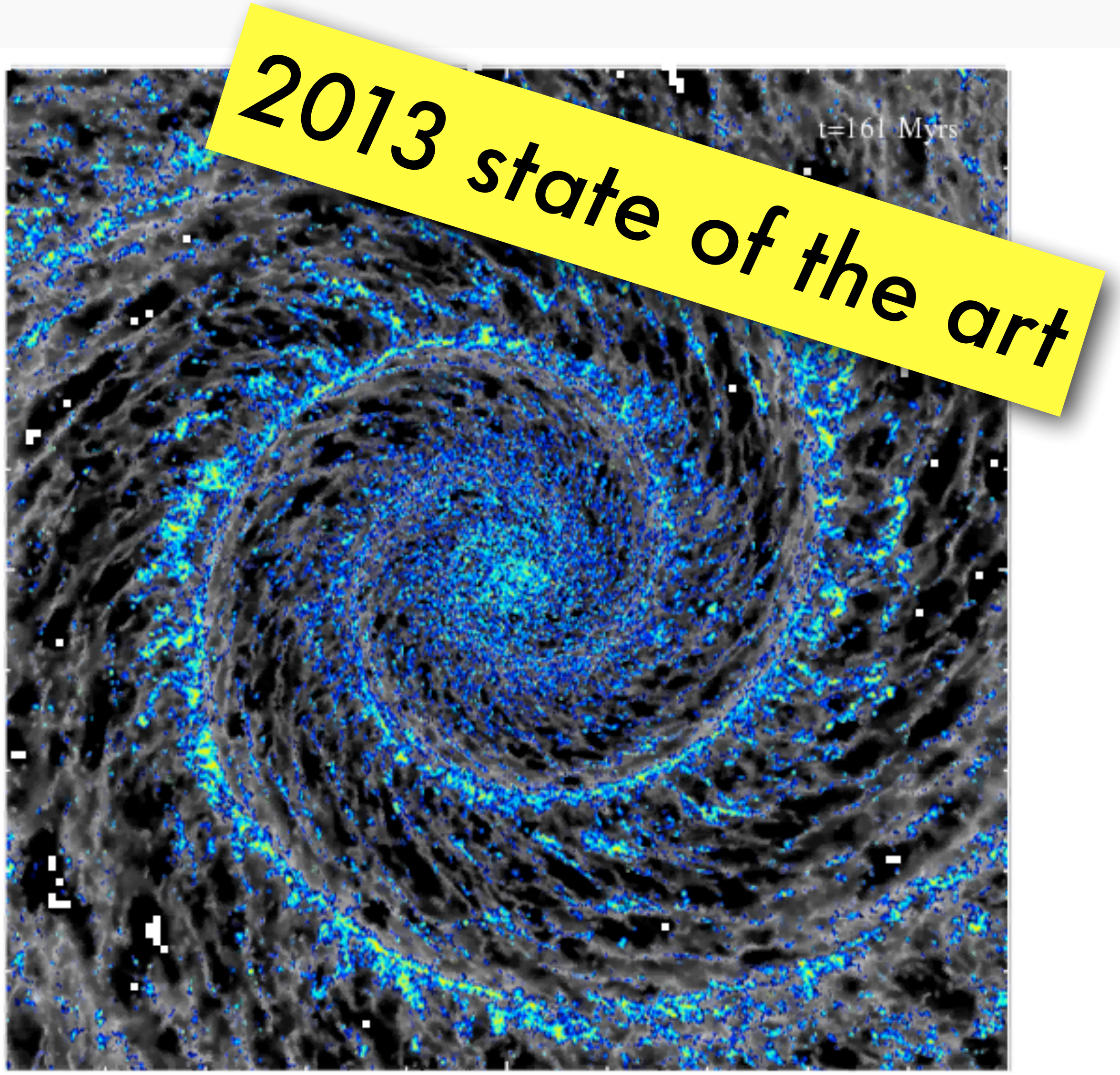
Questions that the Gaia results will be able to help answer are:

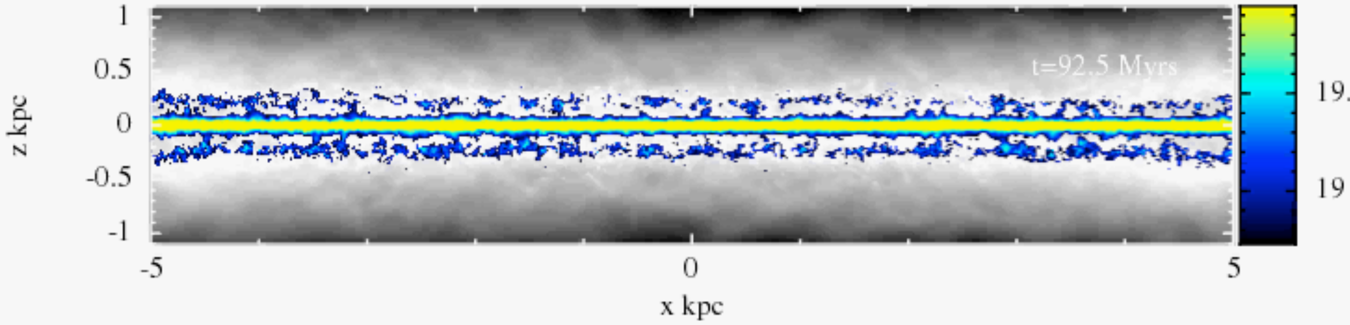
1. Do large galaxies form from accumulation of many sm… which have already initiated star formation?
2. Does star formation begin in a gravit… …ell in which much of the gas is already acc…
3. Does the bulge pre-d… …t contemporaneous with the halo and inner…
4. Is th… …of the early disc and a later major merger?
5. …dial age gradient in the older stars?
6. …the history of star formation relatively smooth or highly episodic?

understanding time-evolution & potentials relies on model comparisons

Galactic Structure

(flipped) image of IC342 from Jarrett et al. 2012; WISE Enhanced Resolution Galaxy Atlas



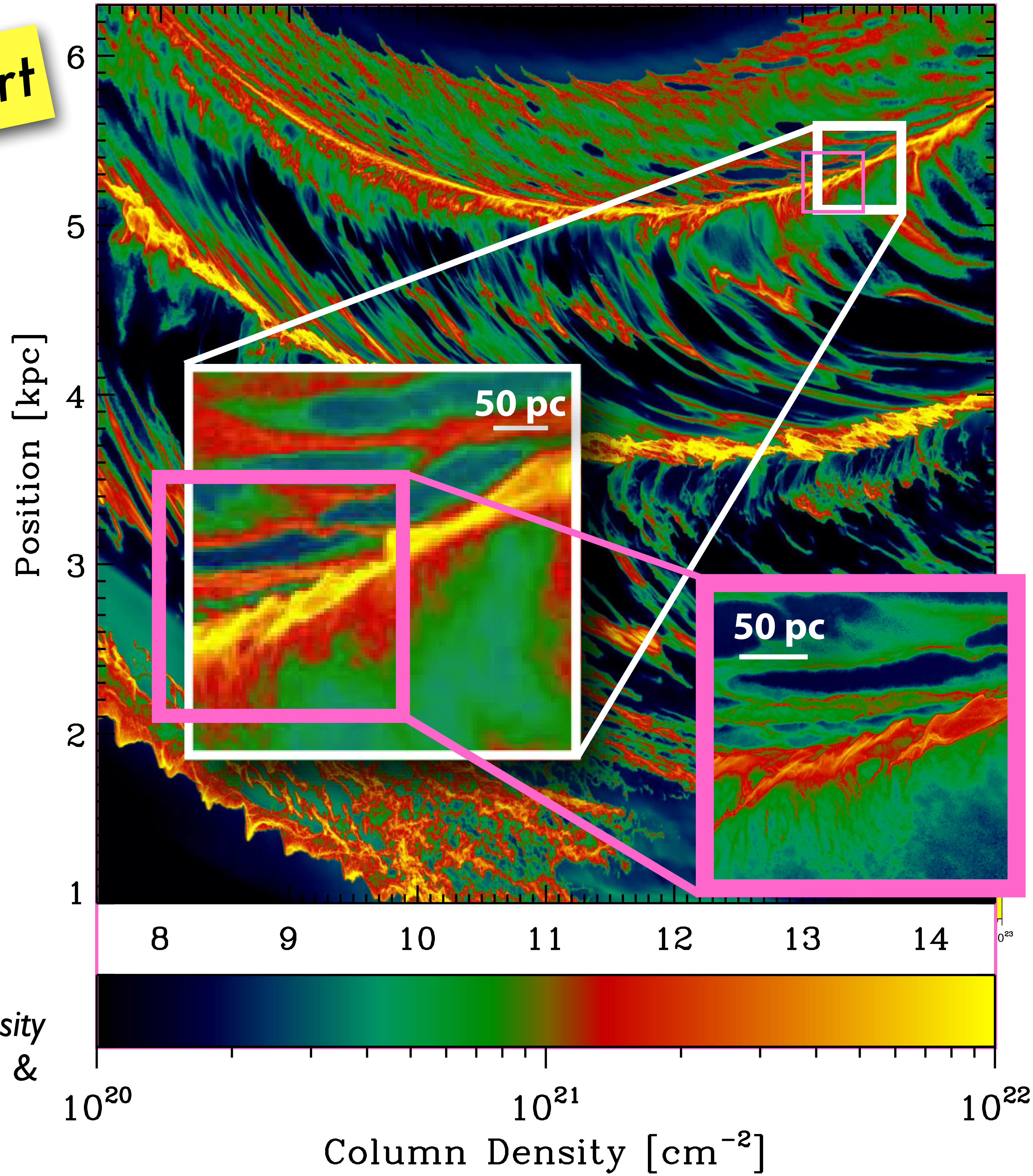


simulations courtesy Clare Dobbs

2014 state of the art

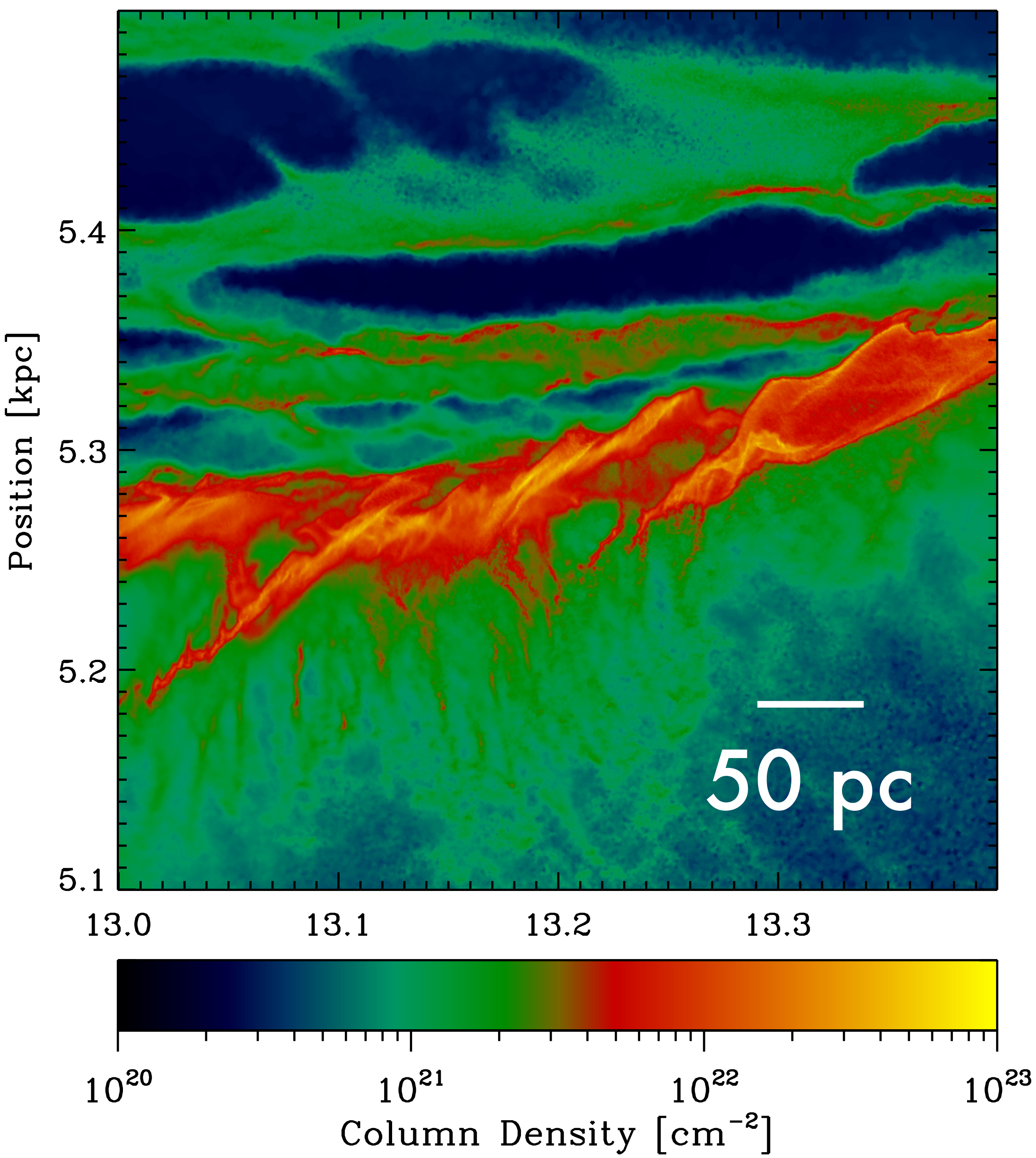
Highest-resolution simulation to date now shows...

Nessies should be there!

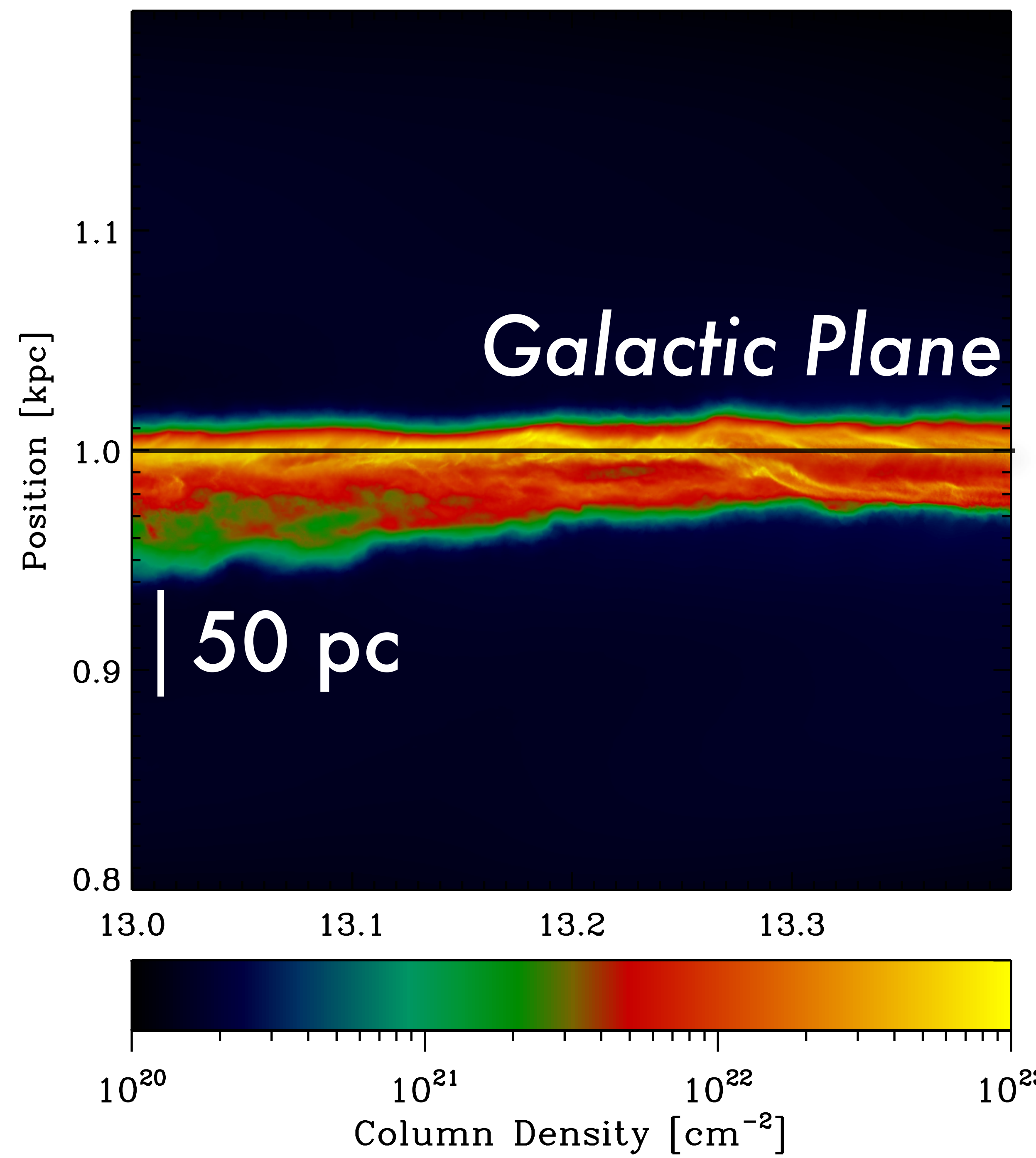


simulation of total H column density from Smith, Glover, Clark, Klessen & Springel 2014

“Top Down”

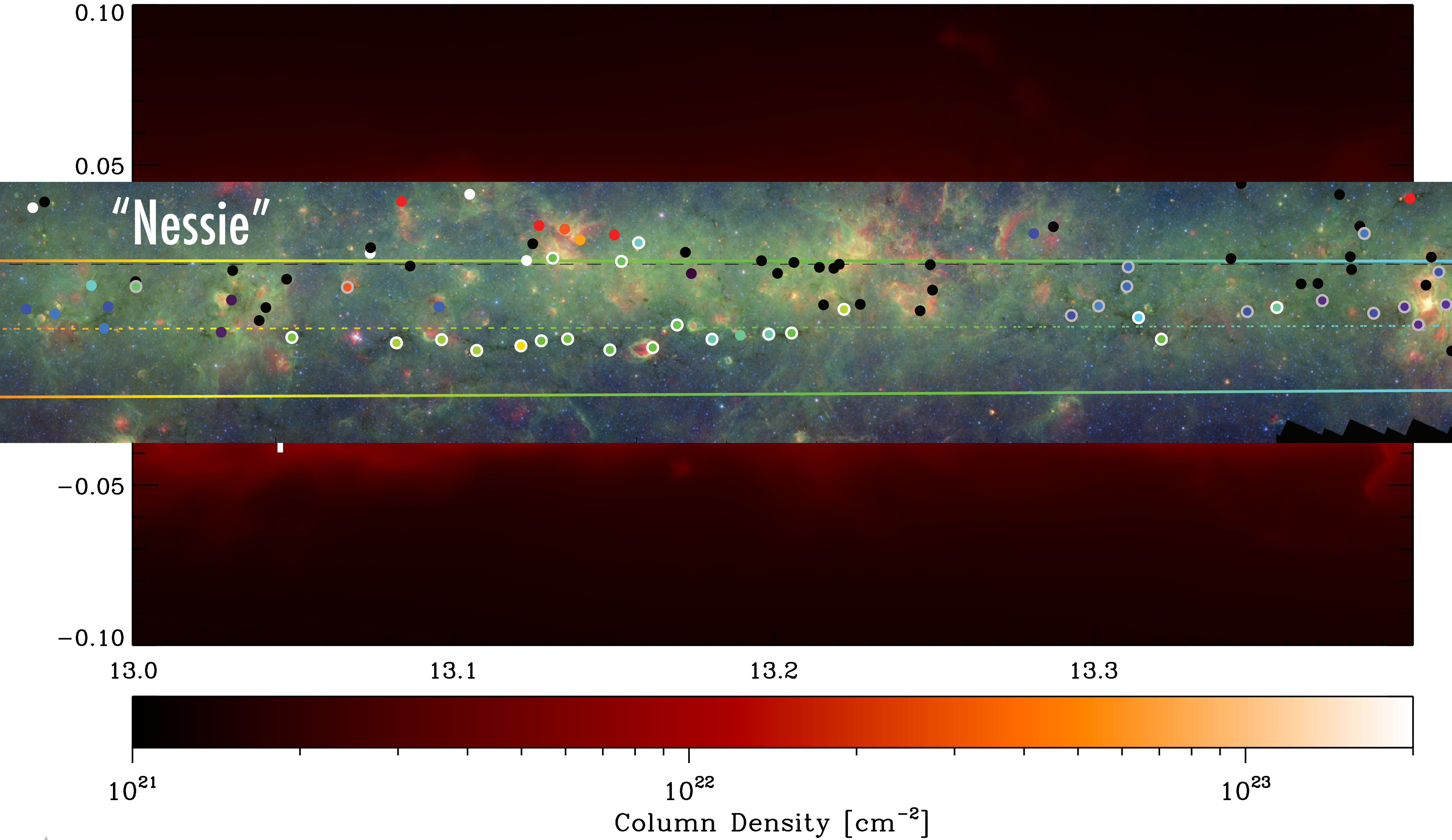


“Edge-On”



simulation of total hydrogen column density from Smith, Glover, Clark, Klessen & Springel 2014

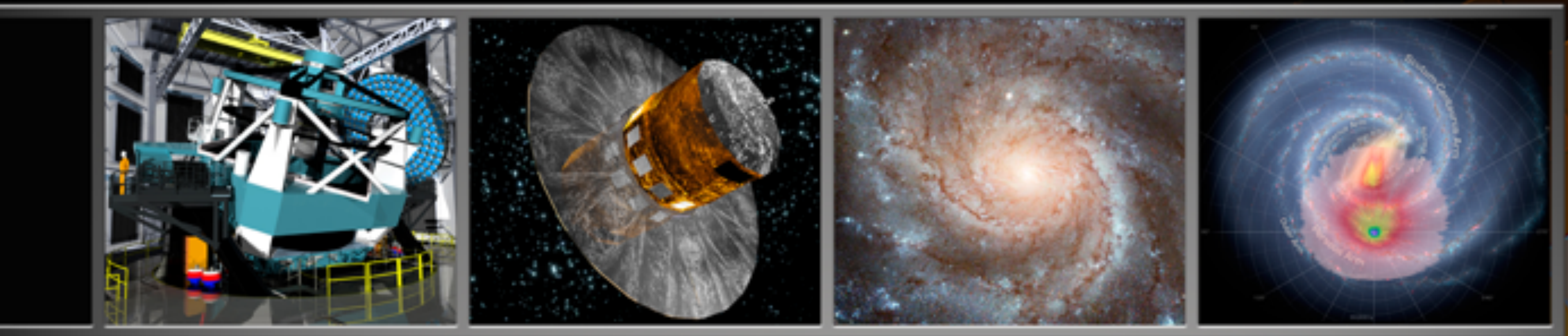
"Edge-On"



cf. Goodman, Beaumont, et al. 2013, 2014

GAIA-LSST Astro-Visualisation School

13-18 Sept 2012 at the University of Washington, Seattle, USA



This workshop is jointly organised by the Gaia GREAT-ITN and GREAT-ESF networks, University of Washington (representing the LSST Consortium) and Microsoft Research. It is tailored to provide a theoretical exploration of the latest data visualisation techniques, and also hands-on practicals illustrating specific data challenges that will be presented by the upcoming Gaia and future LSST missions and telescopes.

The workshop will be limited to 40 student attendees. The workshop will be of interest to PhD and early stage researchers working with the GREAT-ITN network, the wider Gaia- GREAT community, LSST partners, and others interested in Gaia and/or LSST science challenges.

Organising Committee:
Andrew Connolly (co-Chair, University of Washington, USA)
Nicholas Walton (co-Chair, University of Cambridge, UK)
Jonathan Fay (Microsoft Research, Redmond, USA)
Floor van Leeuwen (University of Cambridge, UK)
Zeljko Ivezic (University of Washington, USA)
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Caroline Soubiran (Observatoire de Bordeaux, France)
Yan Xu (Microsoft Research, Redmond, USA)

WEBSITE
http://great.ast.cam.ac.uk/Greatwiki/GreatItn/VizSchoolSep2012

Background image, Seattle Space Needle - Yatharth Gupta (subject to CC licensing)
Image panel left to right: LSST Dome schematic - LSST Corporation
Artist's impression of the GAIA satellite - ESA - C. Carreau
M101 - NASA, ESA, K. Kuntz (JHU), F. Bresolin (University of Hawaii), J. Trauger (Jet Propulsion Lab), J. Mould (NOAO), Y.-H. Chu (University of Illinois, Urbana), and STScI
3-D distribution in the Milky Way of the contents of the GAIA catalogue - X. Luri & the DPAC-CU2. Simulations based on an adaptation for Gaia of the Besançon galaxy model (A. Robin et al.)

GREAT-ITN MARIE CURIE ACTIONS
GREAT
University of Washington
LSST Large Synoptic Survey Telescope
European Science Foundation
Microsoft Research

SkyServer

Szalay et al. (2002)

Also: TOPCAT + Aladin + VisIVO + SAMP + Glue

- SkyServer showed how to deal with multi terabytes of image data
- You precompute images at different resolutions, then scale join and crop appropriate images to give the user what he/she wants.
- WWT works in a similar way it is very scalable.
- So the image part to some extent is solved.

What would you like ?

- SkyServer type tiling is great - want that ! ✔
- CDS Progressive loading for sources - I want to choose on which attribute :)
- For plotting I want wolfram alpha , just type what plot I want and it figures it all out, sends it to the cloud and comes back in a minute.
- For any catalogue I want to visualize it all and interactively add and remove source based on filters instantaneously ✔
- VisIVO is a possible way to go here but then we will all compute grid we go back to shared facility computing
- We have not started to tap multi dimensional visualisation we are barely getting to grips with 3d. ✔
- On Gaia we are computing and maki as we can *while scanning the data.*
- I want it customizable (Connolly e

Conclusion

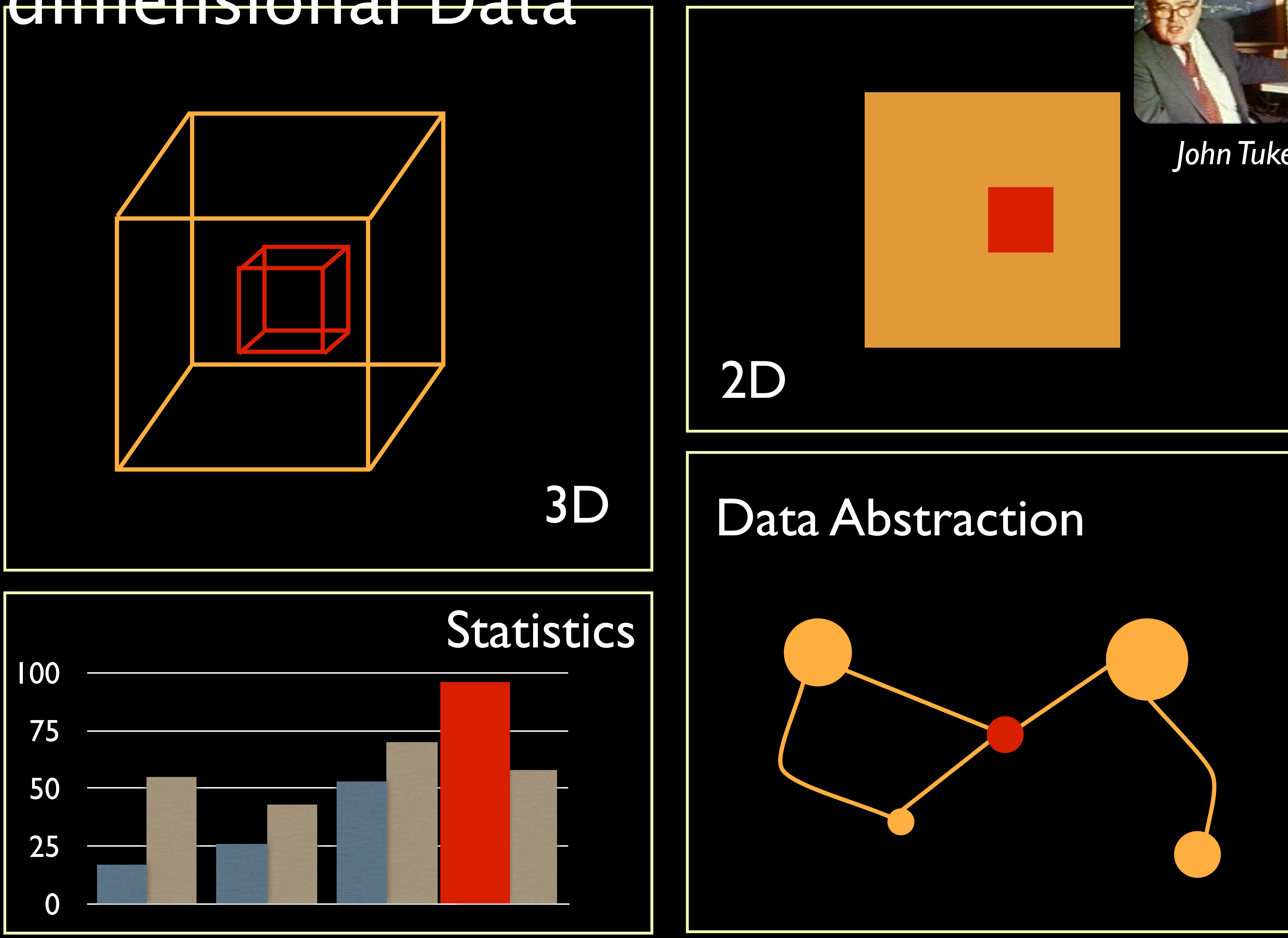
- Soon we will have several *more* multi terabyte, billion object catalogues.
- Gaia brings together many types of data previously dealt with specifically ✔
- Computers are getting better but not faster than the de
- So we will still be faced with finding clever ways to visualize these datasets.
- For now you better consider how you get a subset of Data !
- But it will be fun :)

WorldWide Telescope

[demo]

Now HTML5 compliant.
(e.g. http://adsass.org/wwt)

Linked Views of High-dimensional Data

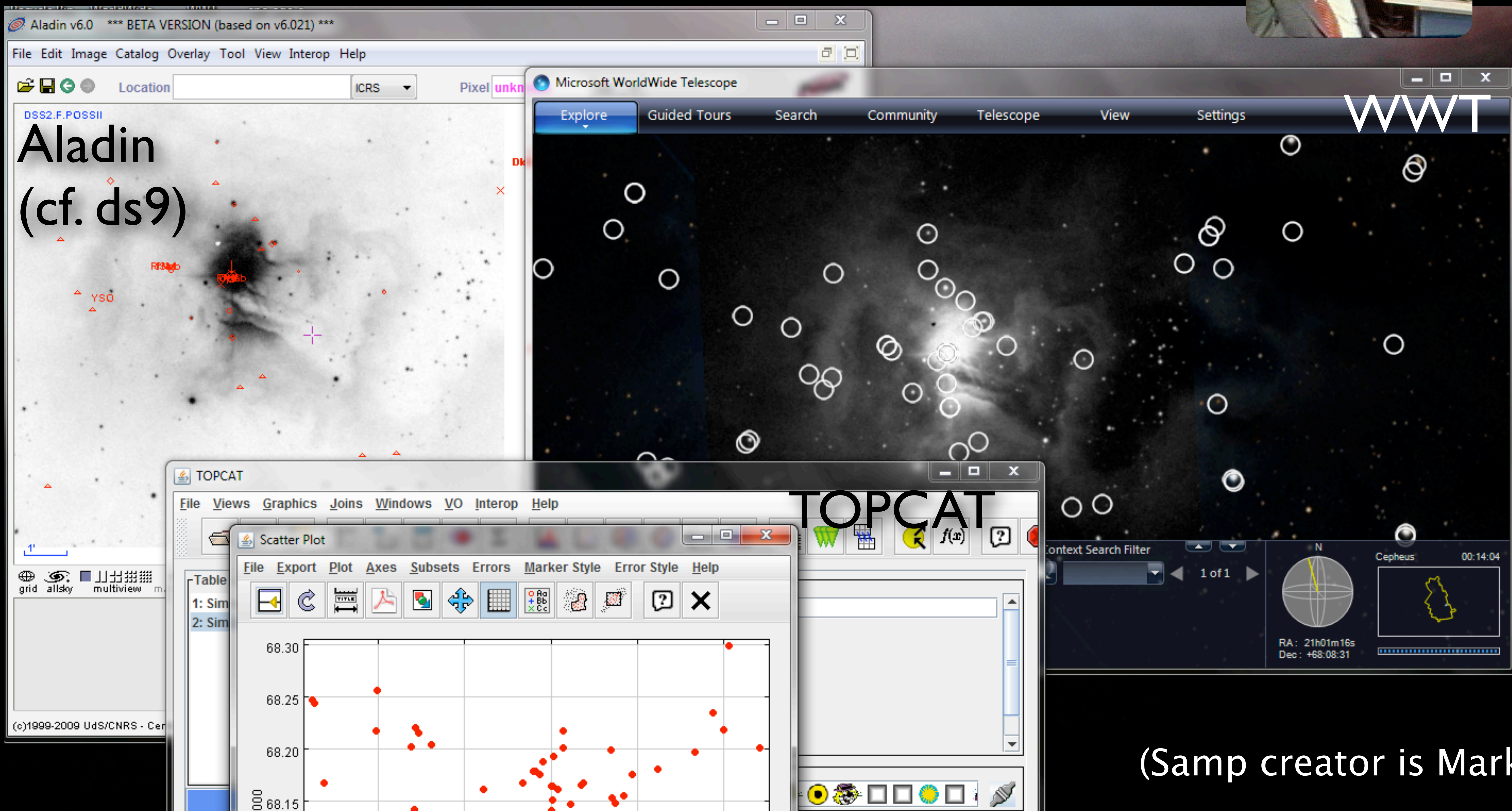


John Tukey

figure, by M. Borkin, reproduced from Goodman 2012, "Principles of High-Dimensional Data Visualization in Astronomy"

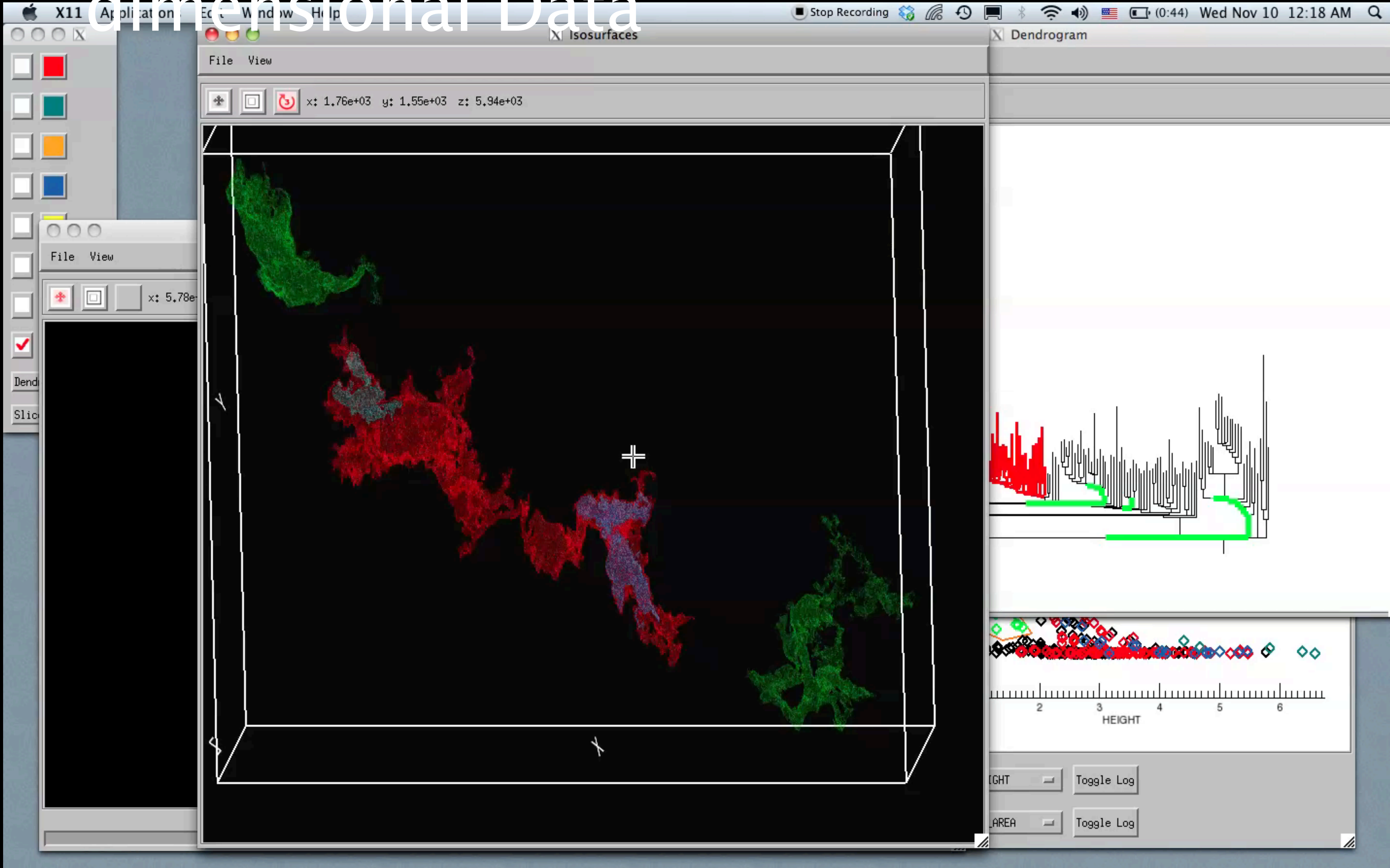
Linked Views of High-dimensional Data

“SAMP”



figure, showing SAMP screenshot, reproduced from Goodman 2012, “Principles of High-Dimensional Data Visualization in Astronomy”

Linked Views of High-dimensional Data



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

Astron. Nachr. / AN **333**, No. 5/6, 505 – 514 (2012) / **DOI** 10.1002/asna.201211705

Principles of high-dimensional data visualization in astronomy

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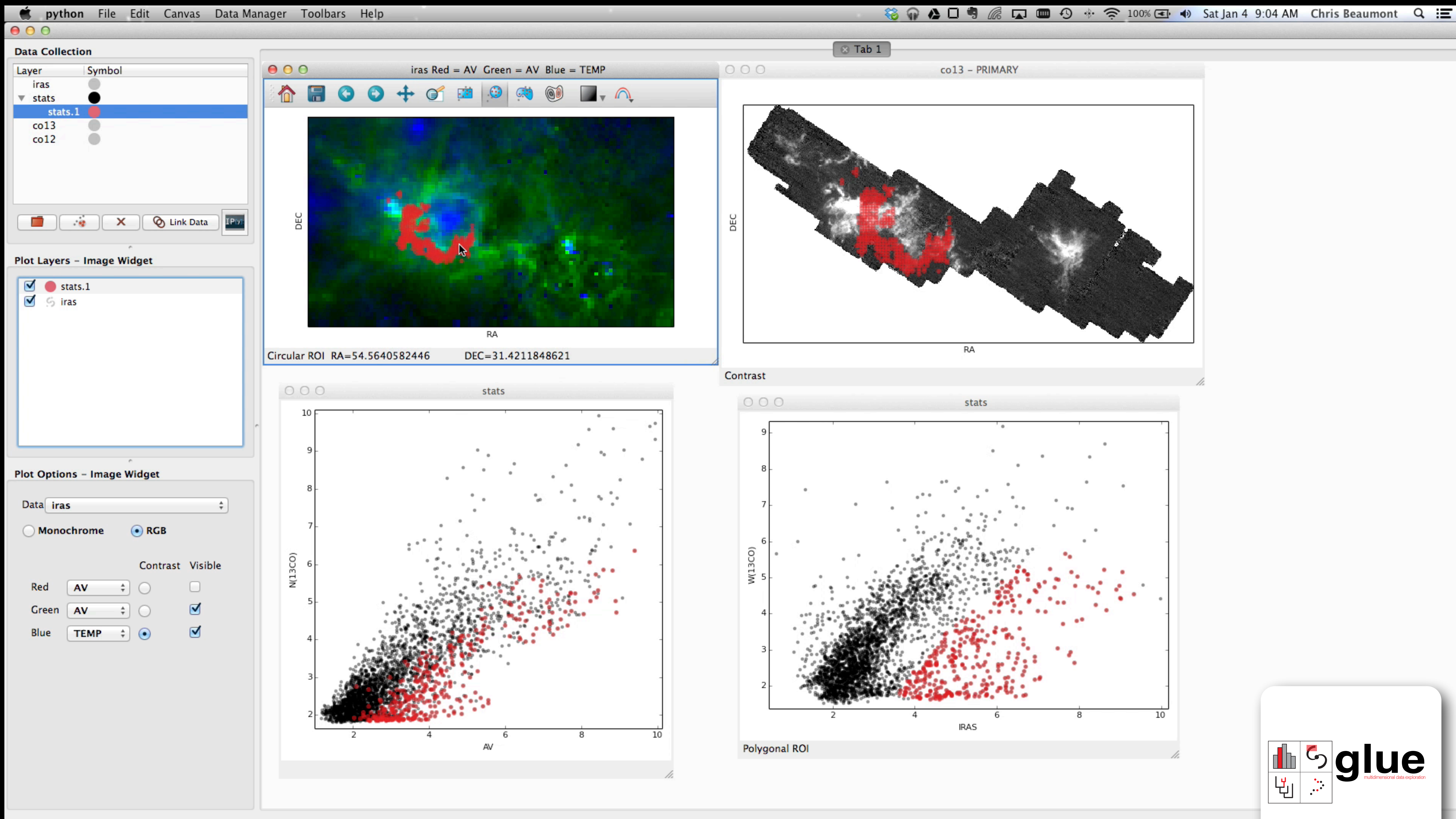
Key words cosmology: large-scale structure – ISM: clouds – methods: data analysis – techniques: image processing – techniques: radial velocities

Astronomical researchers often think of analysis and visualization as separate tasks. In the case of high-dimensional data sets, though, interactive *exploratory data visualization* can give far more insight than an approach where data processing and statistical analysis are followed, rather than accompanied, by visualization. This paper attempts to charts a course toward "linked view" systems, where multiple views of high-dimensional data sets update live as a researcher selects, highlights, or otherwise manipulates, one of several open views. For example, imagine a researcher looking at a 3D volume visualization of simulated or observed data, and simultaneously viewing statistical displays of the data set's properties (such as an x-y plot of temperature vs. velocity, or a histogram of vorticities). Then, imagine that when the researcher selects an interesting group of points in any one of these displays, that the same points become a highlighted subset in all other open displays. Selections can be graphical or algorithmic, and they can be combined, and saved. For tabular (ASCII) data, this kind of analysis has long been possible, even though it has been under-used in astronomy. The bigger issue for astronomy and other "high-dimensional" fields, though, is that no extant system allows for full integration of images and data cubes within a linked-view environment. The paper concludes its history and analysis of the present situation with suggestions that look toward cooperatively-developed open-source modular software as a way to create an evolving, flexible, high-dimensional, linked-view visualization environment useful in astrophysical research.

Linked Views of High-dimensional Data

Glue

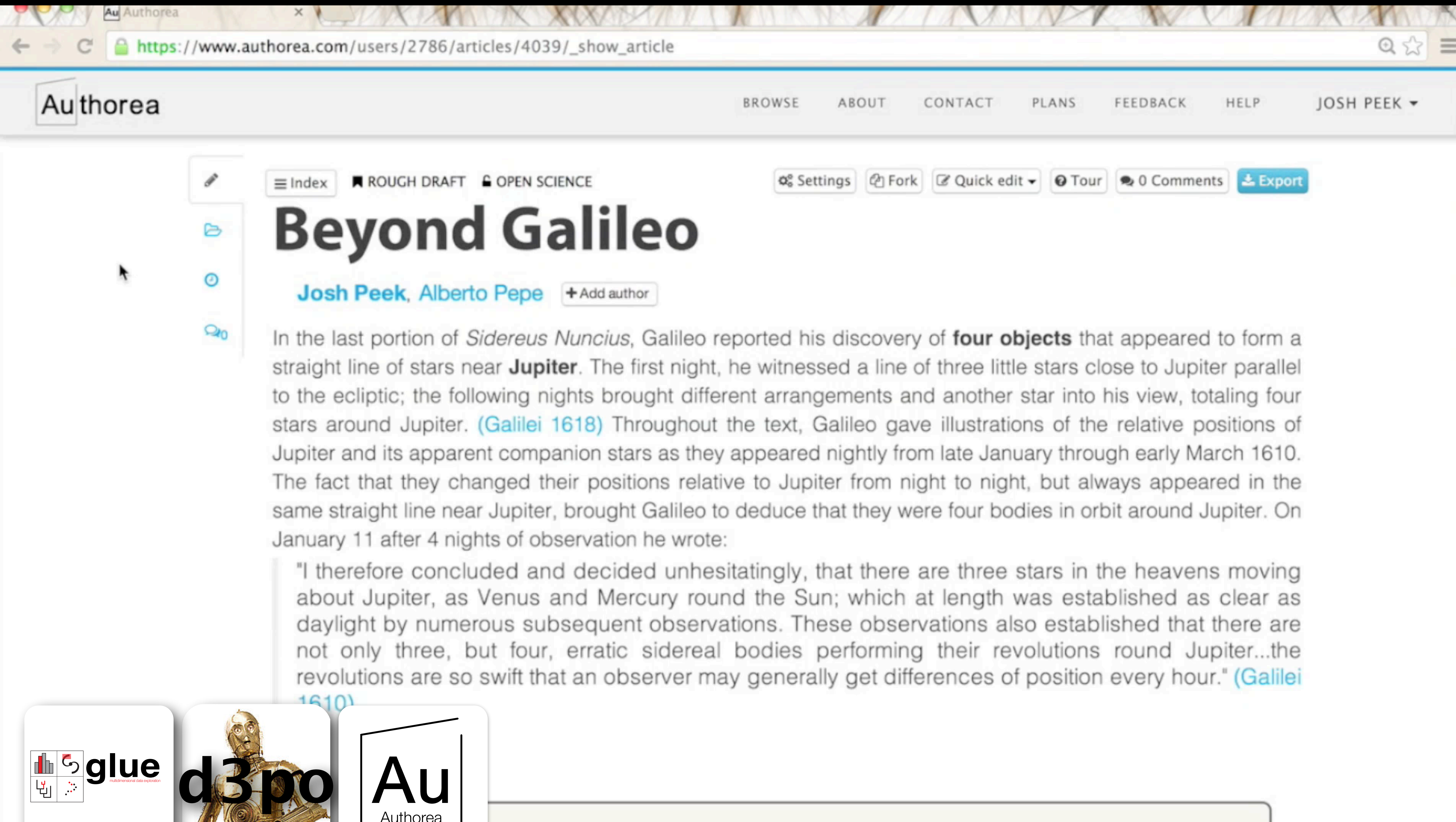


Beaumont, w/Goodman, Robitaille & Borkin

Linked Views of High-dimensional Data

Glue

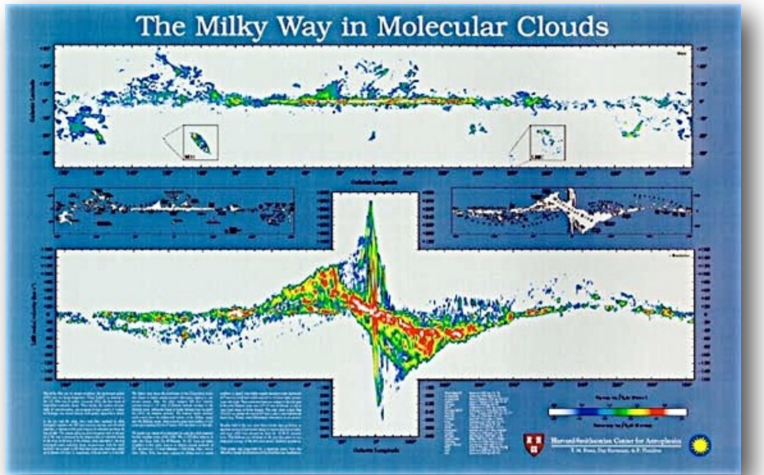
“The Story & the Sandbox” (Glue:D3PO:Authorea)



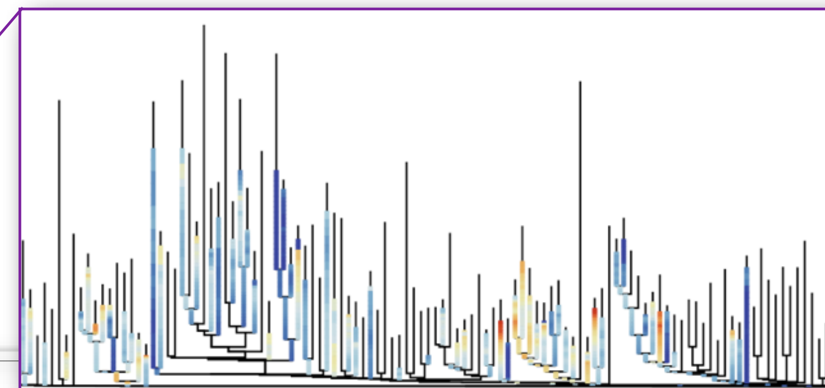
Visualizing the Milky Way across the spectrum

Alyssa A. Goodman
Harvard-Smithsonian Center for Astrophysics

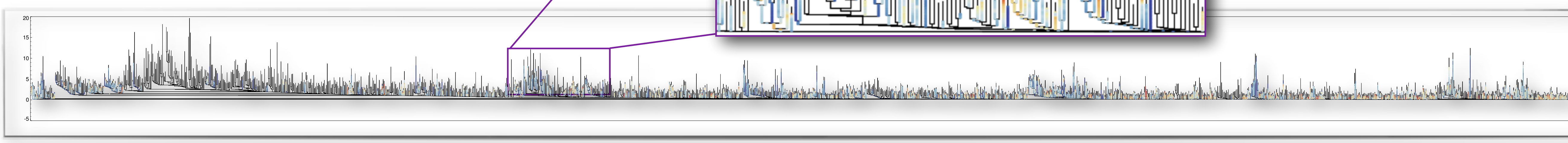
The Grand Plan



CO Map of Milky Way

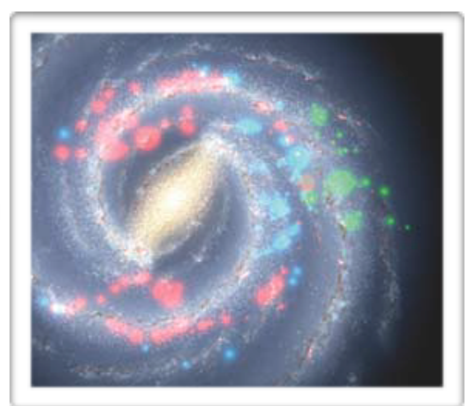


Structure Tree in p-p-v space

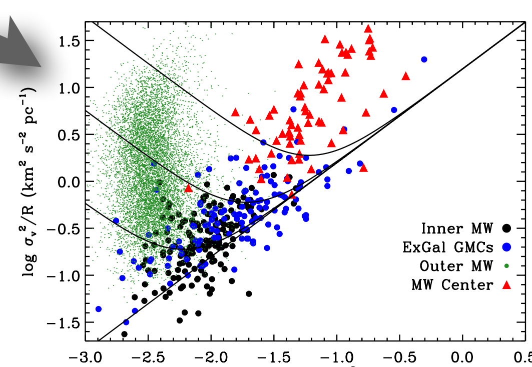


Hierarchical Catalog

distance assignments...



3D Viz



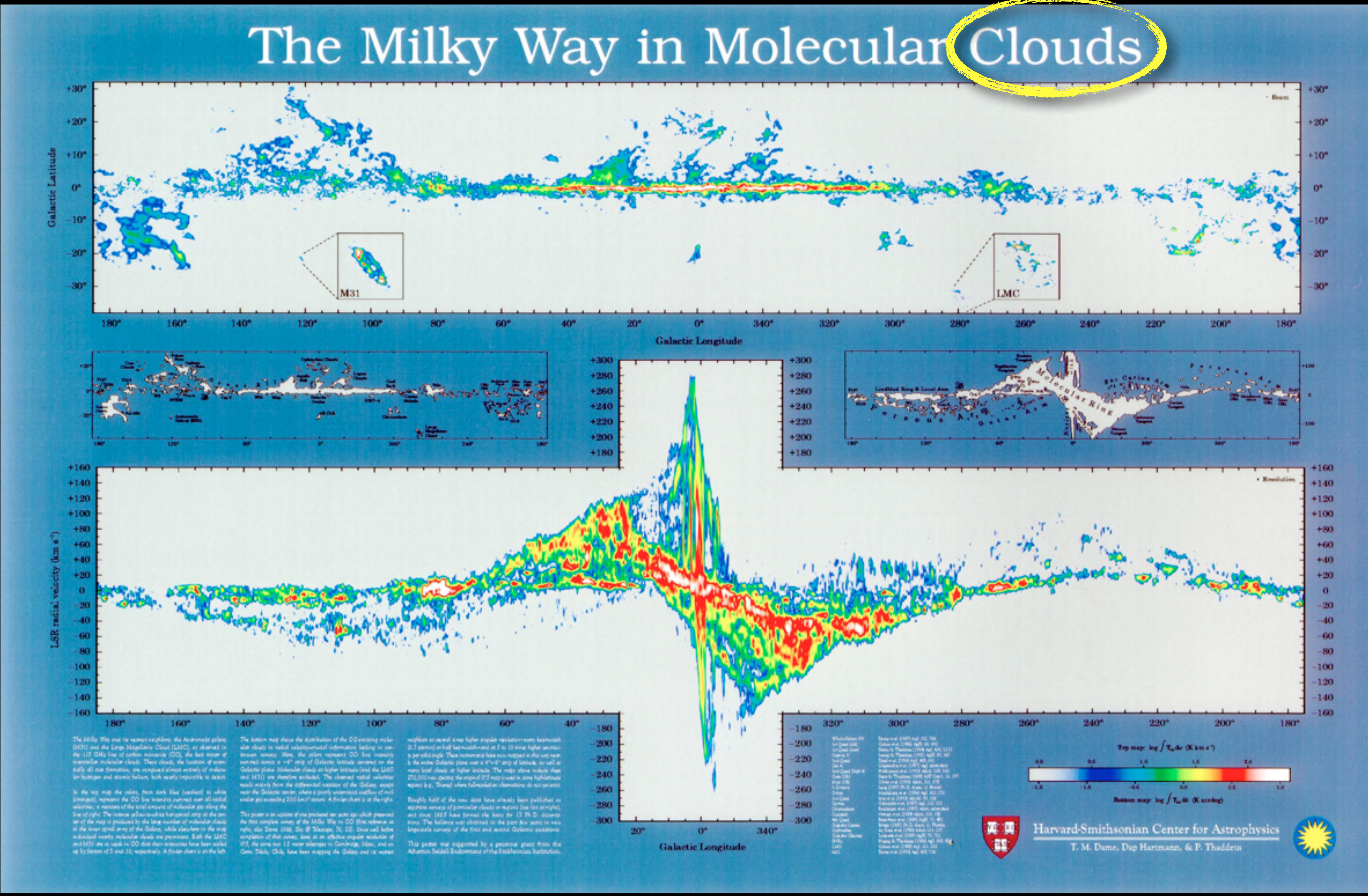
Analysis

e.g. pressure, SFE

open

UNIVERSE3D.org

theastrodata.org



Dame et al. 2001

Dendrograms

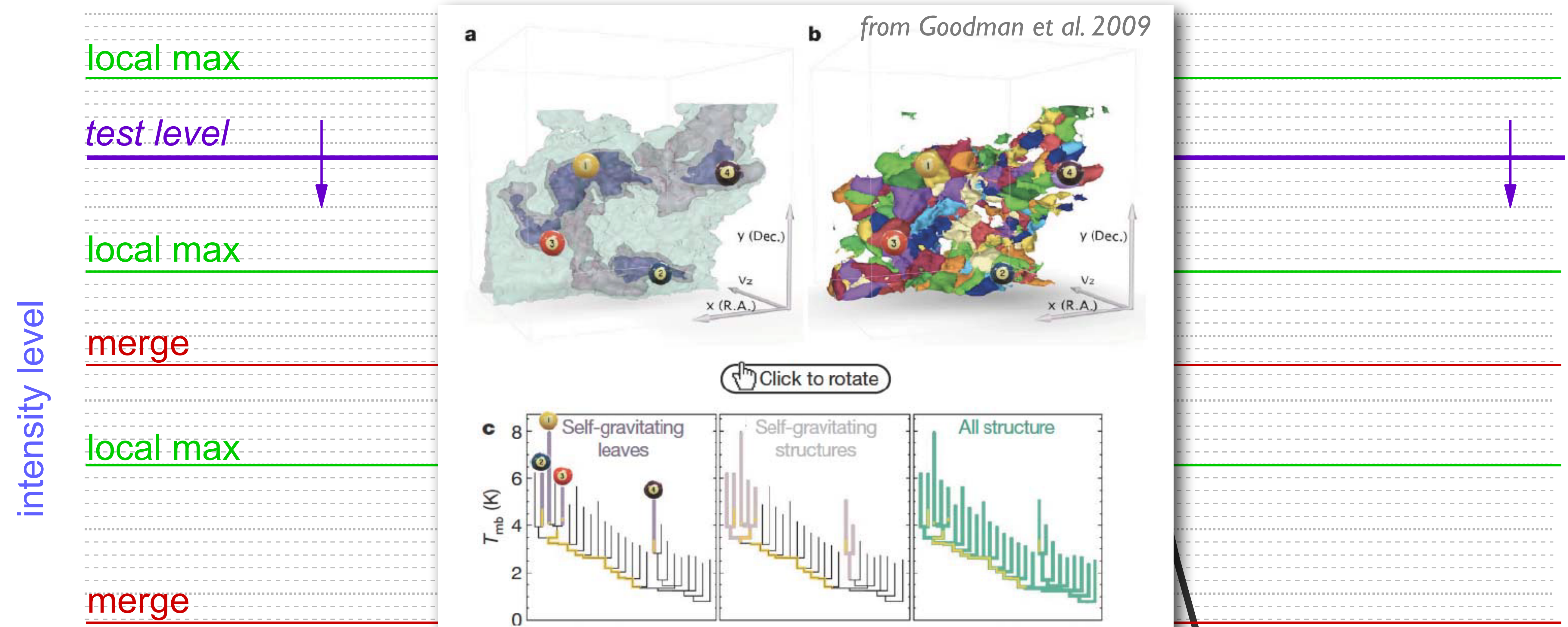
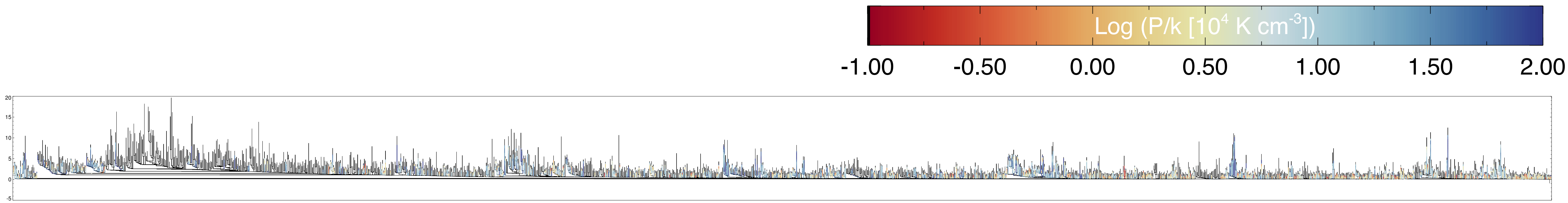


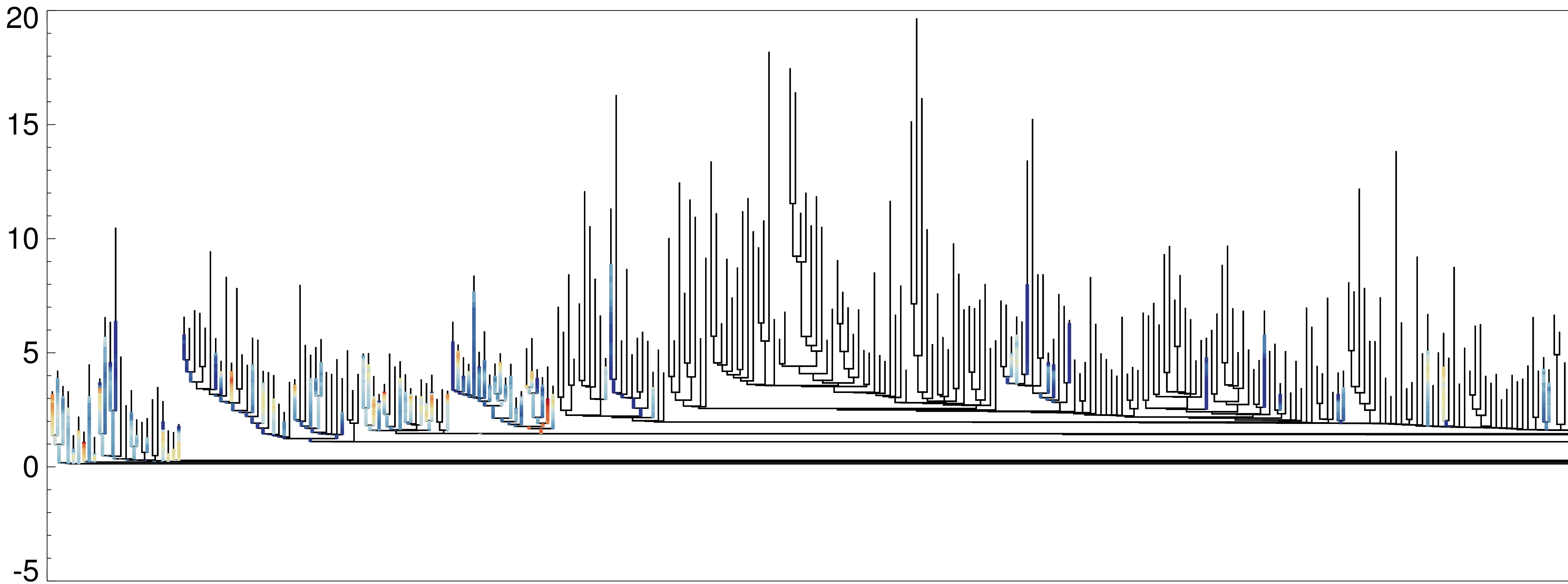
Figure 2 Dendrogram (a) and CLUMPFIND (b) decompositions of ^{13}CO in the L1448 region of Perseus shown in *p-p-v* space. Panels in (c) show dendrograms, colored to match surfaces in (a). Yellow highlights in (c) mark bound regions according to a virial analysis. In the published PDF version of Goodman et al. (2009b), this figure is interactive. Interested readers can download the paper from *Nature*, or visit tinyurl.com/Nature3Dpdf for a video demo.

Hierarchical "Segmentation"

Rosolowsky, Pineda, Kauffmann & Goodman 2008



(Pressure) Structure of Milky Way Clouds



Rice, Alves, Beaumont, Benjamin, Bergin, Dame, Faesi, Goodman, Offner, Reid, Robitaille, Rosolowsky 2014, in prep