

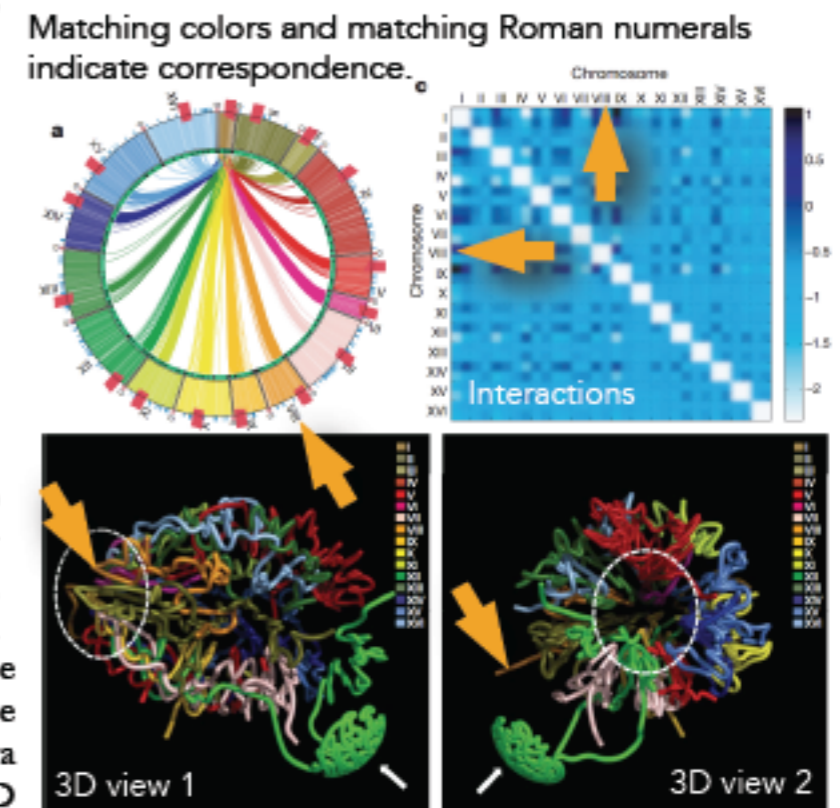
Thanks
Alberto!

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 devices⁵ 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 as 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* paper⁶ 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.

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](https://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

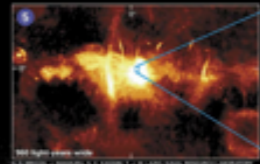
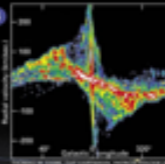
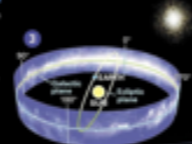


Home galaxy of Earth, the Milky Way is a spiral-shaped system of a few hundred billion stars. Bright regions of recently formed stars highlight its arms, while older stars explode or expel their outer layers as beautiful planetary nebulae, then fade away and die. A thick swarm of orange and red stars marks the galactic bulge, encapsulating the star-packed galactic center. At its core may be 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

- 1 Far beyond the galactic disk, set down by its gravity, lone stars and globular clusters wander the galaxy's halo. Regions of dark matter—invisible but felt through its gravitational effects—extend beyond that.
- 2 Great 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 skewed angle to the galactic plane.



A TURBULENT HEART

1 A graph based on a radio survey reveals the rotational 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.

2 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.

3 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.

This computer-generated image of the Milky Way—one perspective of a 3-D model rarely composed for National Geographic—incorporates the actual positions of hundreds of thousands of stars and nebulae.

- 1 Globular star cluster
 - 2 Interstellar gas and dust
 - 3 Nebulae
 - 4 Younger star region
 - 5 Molecular cloud
 - 6 Galactic bulge of center
- Reference numbers for galaxies, nebulae, and star clusters:
M33, M31, M32, M51, M52, M53, M54, M55, M56, M57, M58, M59, M60, M61, M62, M63, M64, M65, M66, M67, M68, M69, M70, M71, M72, M73, M74, M75, M76, M77, M78, M79, M80, M81, M82, M83, M84, M85, M86, M87, M89, M90, M91, M92, M93, M94, M95, M96, M97, M98, M99, M100, M101, M102, M103, M104, M105, M106, M107, M108, M109, M110, M111, M112, M113, M114, M115, M116, M117, M118, M119, M120, M121, M122, M123, M124, M125, M126, M127, M128, M129, M130, M131, M132, M133, M134, M135, M136, M137, M138, M139, M140, M141, M142, M143, M144, M145, M146, M147, M148, M149, M150, M151, M152, M153, M154, M155, M156, M157, M158, M159, M160, M161, M162, M163, M164, M165, M166, M167, M168, M169, M170, M171, M172, M173, M174, M175, M176, M177, M178, M179, M180, M181, M182, M183, M184, M185, M186, M187, M188, M189, M190, M191, M192, M193, M194, M195, M196, M197, M198, M199, M200, M201, M202, M203, M204, M205, M206, M207, M208, M209, M210, M211, M212, M213, M214, M215, M216, M217, M218, M219, M220, M221, M222, M223, 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PLANETARY NEBULA M2-9



Exotic telescopes of the Milky Way's colorful nebulae and star clusters are found throughout Earth's galaxy. Even a run-of-the-mill star may eventually produce a nebula of surprising beauty. Just as our sun will do in its death throes some five billion years from now, a dying star expanded into a red giant and was transformed into the nebula M2-9 (above). At its center shines a small, hot core, which will cool and fade over time. Its stellar wind, streams of charged particles, rushes outward in opposite directions, like exhaust from back-to-back jet engines. This Dopplerian, revealed by the Hubble Space Telescope, is common among planetary nebulae; ultraviolet light from the star heats M2-9's gases and makes them glow. Other types of nebulae exist in our galaxy, including dark nebulae that block out view of stars beyond. When a star adorns a dark nebula, the dust particles reflect starlight and the black cloud seems to form a silhouette.

The million-plus stars packed into a globular cluster such as Omega Centauri might be some citizens of the Milky Way. Unlike human

retinas, however, every star in the cluster is about the same age, billions of years older than our 4.5-billion-year-old sun. Peering outward toward the central bulge of the Milky Way, the Hubble Space Telescope focused on a rare clear region in the Sagittarius star cloud (above right). These Sagittarius stars, formed at different times, must be older

than the sun. They sparkle like an assortment of gems on a jeweler's velvet pad. In some dark clouds, such as orange OMC-1 (left), detected by a European Southern Observatory telescope in Chile and imaged in infrared light (right), a star 20 times as massive as the sun and 10,000 times brighter, it sports a disk of interstellar dust, shown here in false color, about 20,000 times wider than Earth's

orbit. Light from the hot star is absorbed by and excites the dust, making it glow. As stars cluster—sun-like, they become factories for interstellar dust. Celestial soot—the remnants of its red giant stage—surrounds the tiny hot central star of NGC 7527 (above right). Blown outward, the soot would obscure our view of the center of NGC 7527 were it not for this remarkable composite image in infrared and

visible light from the Hubble Space Telescope. Clouds of interstellar dust (right) stream over huge regions along the galactic plane of the Milky Way, are not thick and smooth but seem as frothy as the head of a glass of beer. Superheated shock waves and stellar wind from

evolving stars may have shaped this surprising pattern. When a massive star comes to the end of its nuclear fuel supply, it collapses and then rebounds in a brief, powerful explosion, or super-nova. The Chinese called these celestial fireworks quiet stars and recorded one such event in the constellation Taurus in July 1054 that was visible in broad daylight.

In that location today, astronomers find the fast-expanding Crab Nebula (left), a supernova remnant. At its heart lies a pulsar—a collapsed star—rotating 30 times a second. Smaller galaxies of the Milky Way host equally remarkable celestial objects (above right), 100,000 light-years from

Earth, clumpy, filamentary clouds of hydrogen gas reveal their stately march in a radio map from the Australia Telescope Compact Array. The inner half of the cloud (left) is rotating toward the Earth with the typical speed of a jet airplane. Streaming away, the spiral arms of the galaxy, bright emission nebulae mark regions where new stars are being born. The Lagoon Nebula (below), 6,500 light-years distant, is easily detected with the naked eye as a hazy spot in the southern constellation Sagittarius. Wide-field images show that it covers more of

the sky than does the full moon. Where there were once only a vast dark cloud, radiation from the brightest and most massive young star in the nebula, Hamal, 36, heats and ionizes the gas across a wide region. Despite the brilliance of the Lagoon Nebula and similar objects like the Ring and Helix, such areas are usually dimmer than hot stars on the banks of giant interstellar clouds.

With new tools, astronomers are unraveling the nature of the Milky Way and measuring distances to stars and nebulae with greater accuracy. Still, they ask, how did the Milky Way form in the first place? How and where did the arms form? How many more planets circle nearby stars besides the 112 already discovered? And the biggest question of all: Do any of them harbor life?

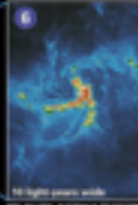
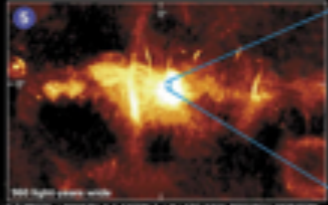
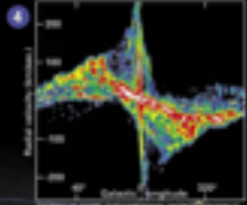
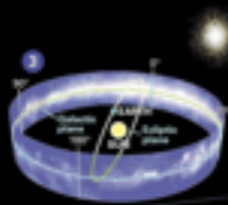
LAGOON NEBULA





GUIDE TO THE GALAXY

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- Visit clouds of interstellar dust block much of our night
- 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.
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A TURBULENT HEART

- 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.
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- electrons that race along magnetic field lines, illuminating remnants of stellar explosions.
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LAGOON NEBULA



...relatives, however, every star in the cluster is about the same size as the sun. They sparkle like an assortment of gems on a jeweler's velvet pad. In some dark clouds lurk strange ...

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

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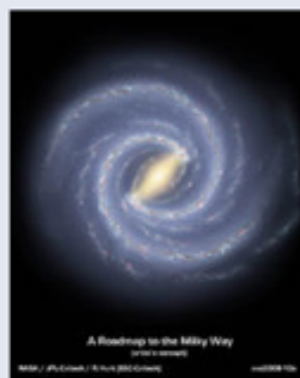
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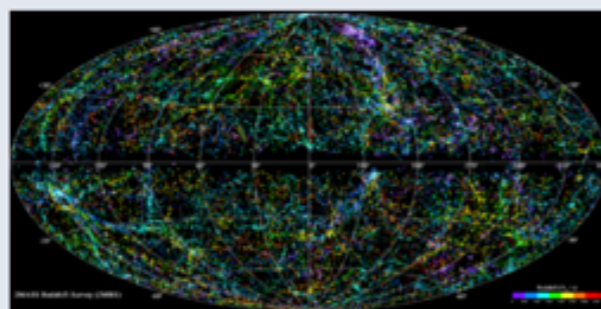
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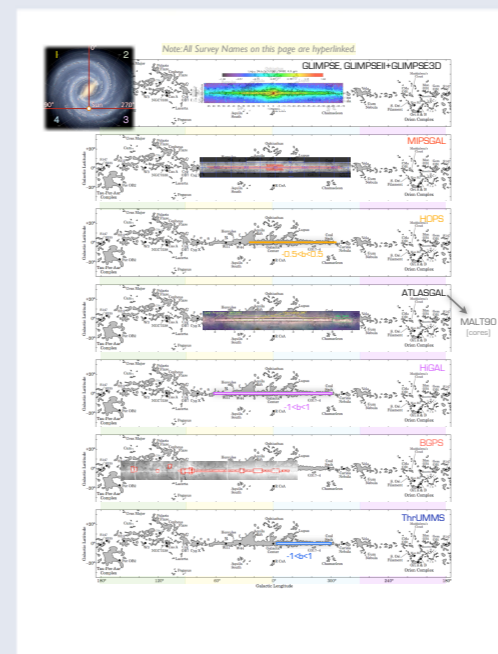
Robert Hurt's Artist's Conception of the Milky Way

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



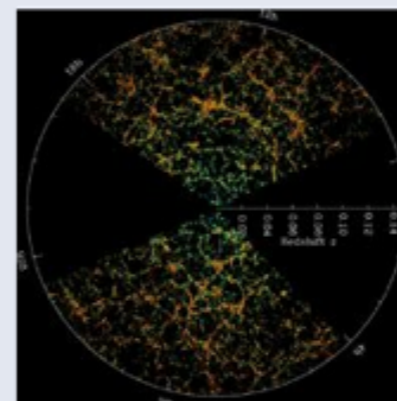
The 2MASS Redshift Survey

The most complete map of the local universe to date. For more details see the [2MRS Website](#).



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 SLOAN Digital Sky Survey

The image shows the "butterfly" of the [SDSS](#) a survey of galaxies up to high redshift.

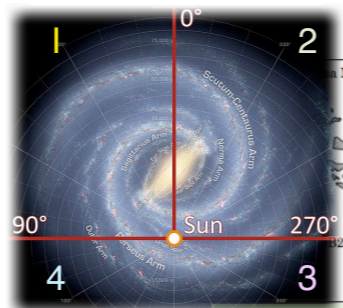


The Milky Way Galaxy Map

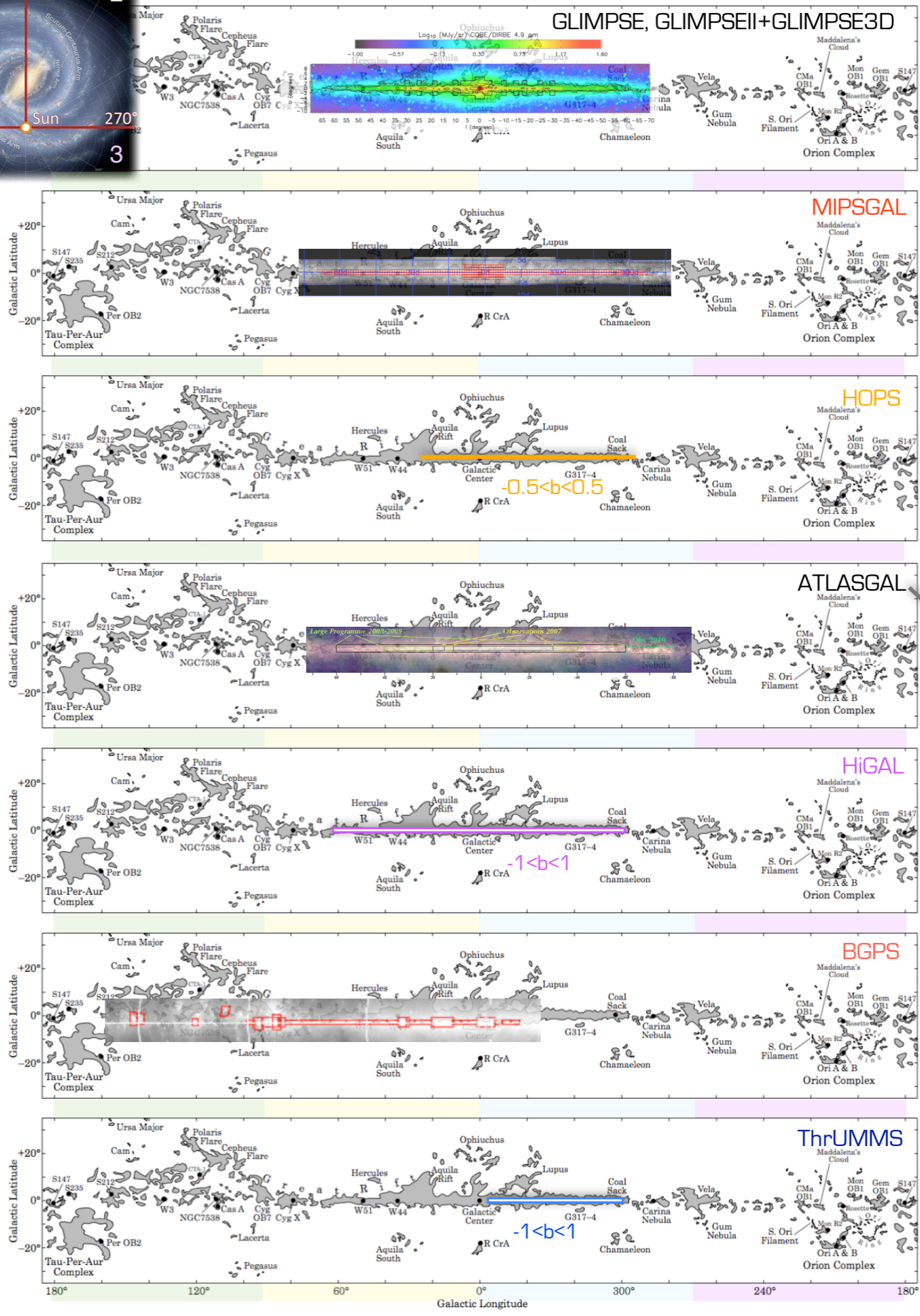


Dark Matter

Galactic Plane Surveys relevant to Star Formation c. 2012



Note: All Survey Names on this page are hyperlinked.

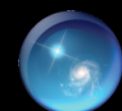


MALT90 [cores]

The Milky Way



The Milky Way
(Artist's Conception)



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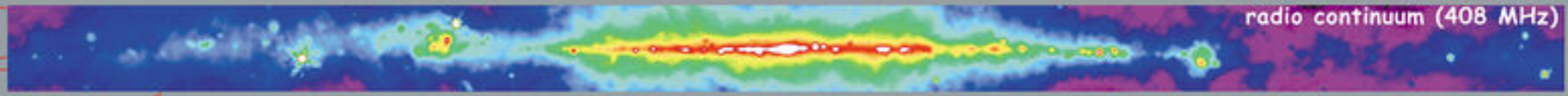
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Distance	Wavelength					
	Gamma Ray	X-Ray	Ultraviolet	Optical	Infrared	Radio
Solar System	★	★	★	★	★	★
Nearby Stars	★	★	★	★	★	★
Milky Way	★	★	★	★	★	★
Local Group Galaxies	★	★	★	★	★	★
$z \sim 0$ Galaxies	★	★	★	★	★	★
$z > 0$ Galaxies	★	★	★	★	★	★
High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

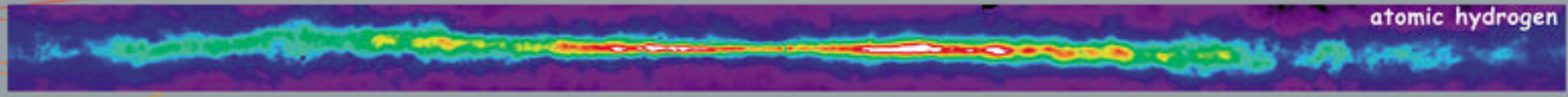
If you want to add a new dataset email us - sblock AT cfa.harvard.edu.

- ★: Datasets available
- ★: No Datasets available yet

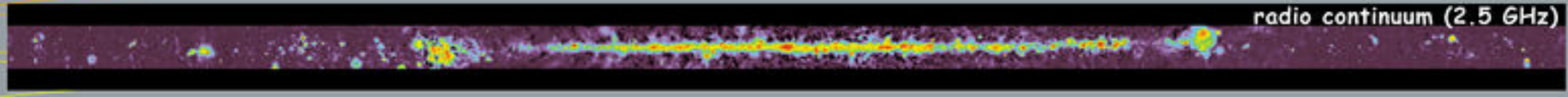
<http://universe3d.org/wiki/index.php/Datasets>



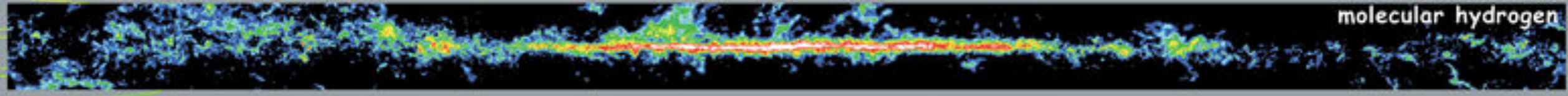
radio continuum (408 MHz)



atomic hydrogen



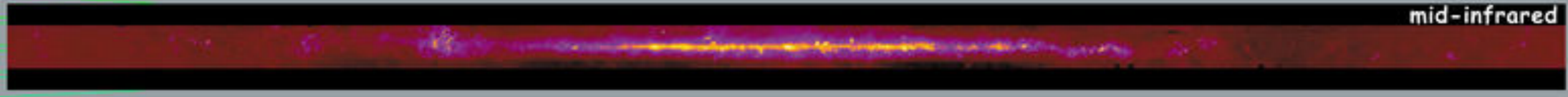
radio continuum (2.5 GHz)



molecular hydrogen



infrared



mid-infrared



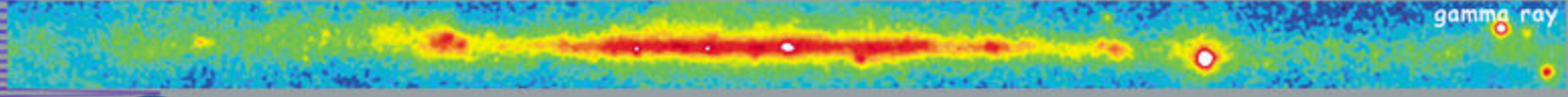
near infrared



optical



x-ray



gamma ray

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



Multiwavelength Milky Way

3D Viewers

Software	Control				Display		Projection		2D Layers			3D Volumes			
	GUI	Command Line	Scriptable	API	2D Sky	3D Universe	Full Sky "Valid"	User-selectable	Pre-loaded Images	Online Image Access	VO-compliant Image Access	Pre-loaded Celestial Objects	User-loaded Celestial Objects	Arbitrary Surfaces	Arbitrary Volumes
World Wide Telescope	✓			✓	✓	✓	✓	✓	✓			✓	✓		
Google Sky	✓		✓	✓	✓	Little	✓		✓			✓			
Partiview	Little	✓	Little		✓	✓	✓	✓	✓			✓			
Celestia	Little	✓	✓			✓	✓	✓				✓	✓	✓	✓
Mintaka															

If you want to add a 3D Viewer please [click here](#) or edit the table directly.

http://universe3d.org/wiki/index.php/3D_Viewers

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- Home
- 3D Viewers
- Datasets
- Images
- Videos
- Publications & Presentations

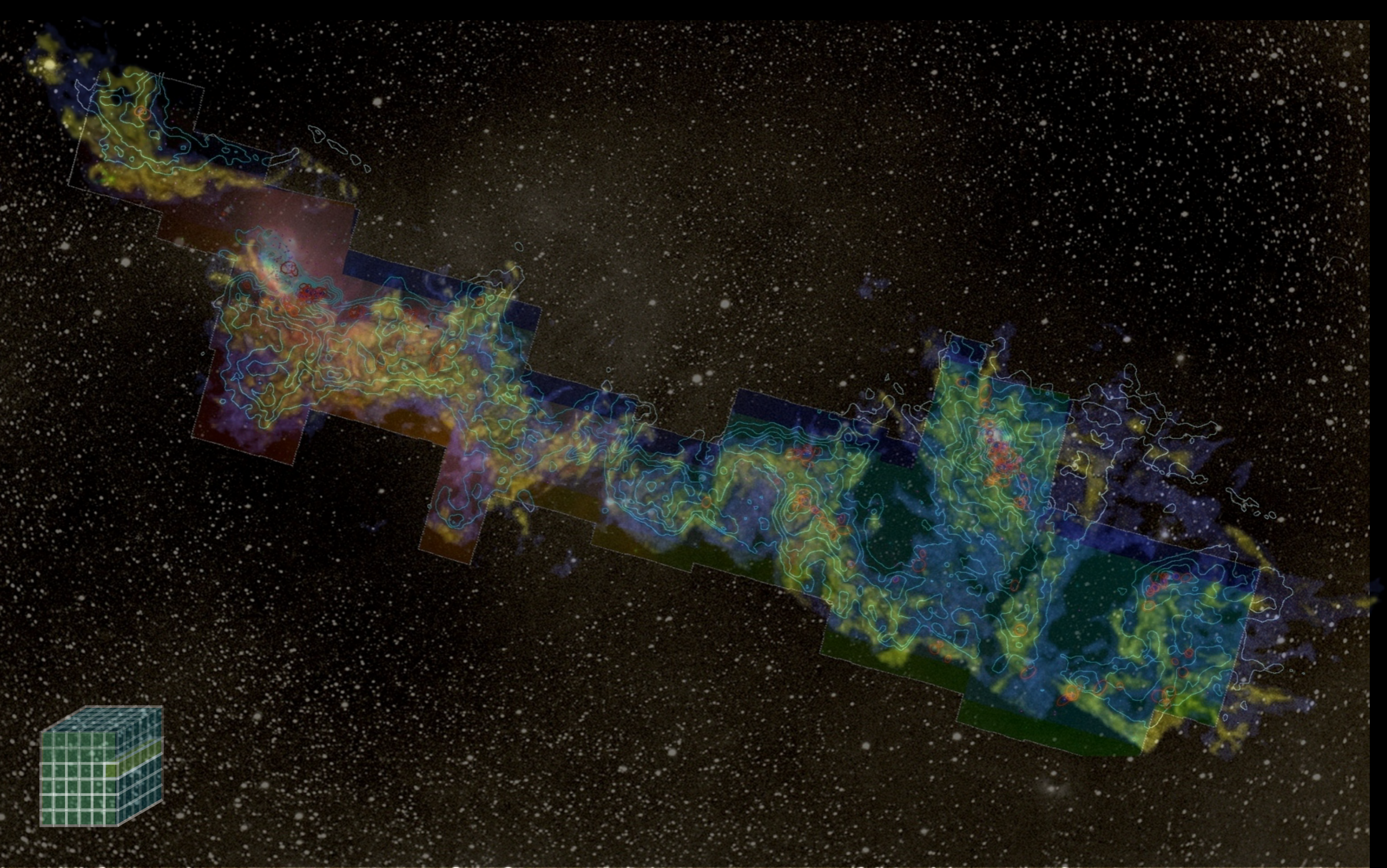
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3D Viz made with VolView

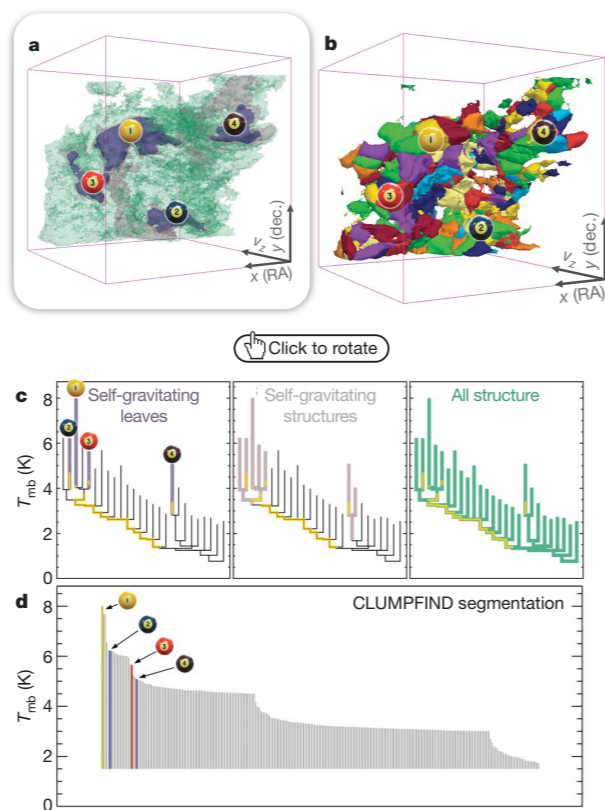


Figure 2 | Comparison of the 'dendrogram' and 'CLUMPFIND' feature-identification algorithms as applied to ^{13}CO emission from the L1448 region of Perseus. **a**, 3D visualization of the surfaces indicated by colours in the dendrogram shown in **c**. Purple illustrates the smallest scale self-gravitating 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 the help of the 2D work as inspiration, we have developed a structure-identification algorithm that abstracts the hierarchical structure of a data set into an easily visualized representation called a dendrogram. This algorithm has been well developed in other data-intensive applications of tree methodologies so far, and almost exclusively within the area of astronomy. 'merger trees' are being used with increasing frequency.

Figure 3 and its legend explain the dendrogram process schematically. The dendrogram was constructed for the data set shown in Fig. 1, and its construction is explained in Supplementary Methods. The dendrogram was determined almost entirely by the data set, and its sensitivity to algorithm parameters was tested as far as possible on paper and 2D screen. The dendrogram was sorted by mass (see Fig. 3 and its legend) and then flattened across, which eliminates dimensions. The dendrogram preserves all information about the hierarchy. Numbered 'billiard ball' labels are used to track features between a 2D map of the sky (see Fig. 1 online) and a sorted dendrogram.

A dendrogram of a spectral line emission cube of key physical properties such as radius (R), luminosity (L), and virial parameter (α_{obs}). The volumes can have any shape, and the virial parameter is defined as $\alpha_{\text{obs}} = 5\sigma_v^2 R / GM_{\text{lum}}$. The luminosity is an approximate proxy for mass, so that $M_{\text{lum}} = X_{13\text{CO}} L_{13\text{CO}}$, where $X_{13\text{CO}} = 8.0 \times 10^{20} \text{ cm}^{-2} \text{ K}^{-1} \text{ s}$ (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.

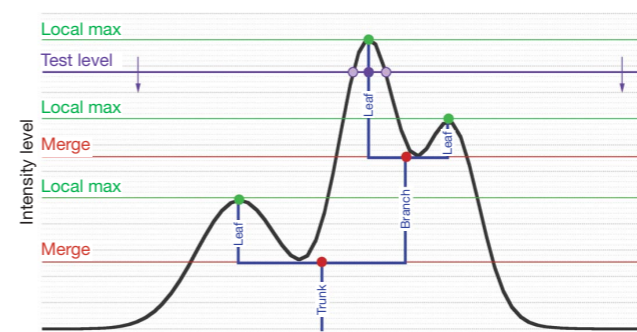


Figure 3 | Schematic illustration of the dendrogram process. Shown is the construction of a dendrogram from a hypothetical one-dimensional emission profile (black). The dendrogram (blue) can be constructed by 'dropping' a test constant emission level (purple) from above in tiny steps (exaggerated in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

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

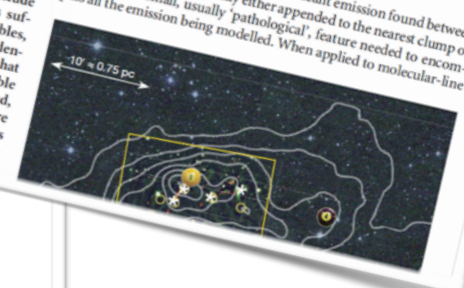
A role for self-gravity at multiple length scales in the process of star formation

Alyssa A. Goodman^{1,2}, Erik W. Rosolowsky^{2,3}, Michelle A. Borkin^{1†}, Jonathan B. Foster², Michael Halle^{1,4}, Jens Kauffmann^{1,2} & Jaime E. Pineda²

LETTERS

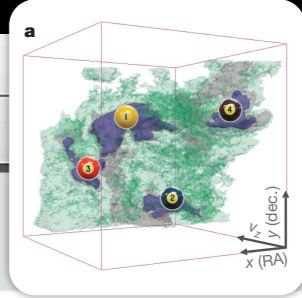
Self-gravity plays a decisive role in the final stages of star formation, where dense cores (size ~ 0.1 parsecs) inside molecular clouds collapse to form star-plus-disk systems. But self-gravity's role at earlier times (and on larger length scales, such as ~ 1 parsec) is unclear; some molecular cloud simulations that do not include self-gravity suggest that 'turbulent fragmentation' alone is sufficient to create a mass distribution of dense cores that resembles 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 ^{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 are projected on the sky within one of the dendrogram's self-gravitating 'leaves'. As these peaks mark the locations of key physical properties such as radius (R), luminosity (L), and virial parameter (α_{obs}), the dendrogram provides a way to track features between a 2D map of the sky (see Fig. 1 online) and a sorted dendrogram.

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



2009
3D PDF
interactivity
in a
"Paper"

Goodman et al. 2009, Nature,
cf. Fluke et al. 2009



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. Foster², Michael Halle^{1,4}, Jens Kauffmann^{1,2} & Jaime E. Pineda²

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 systems¹. 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 function². 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 of dust emission³ 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
statistical samples of stellar colors & positions

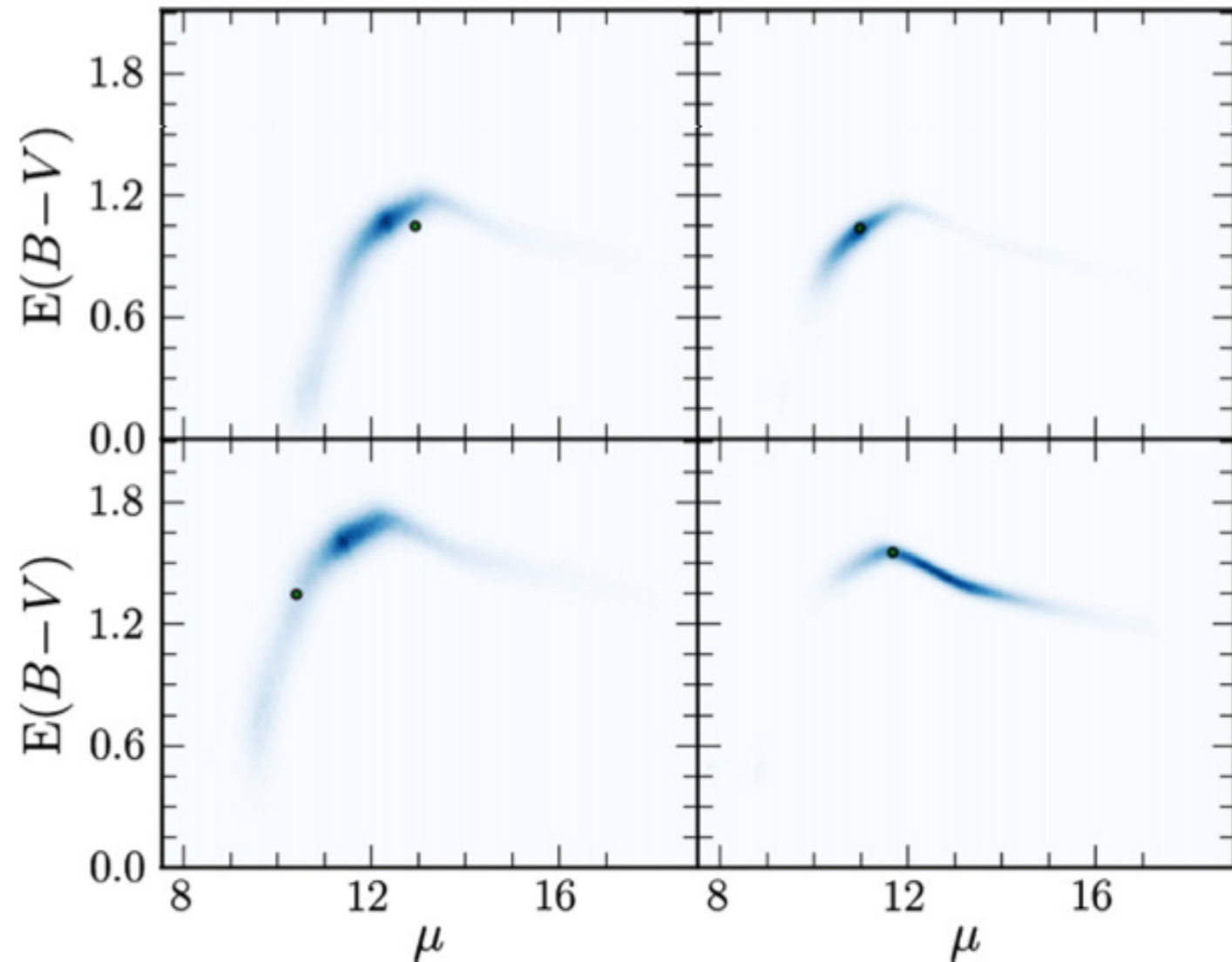
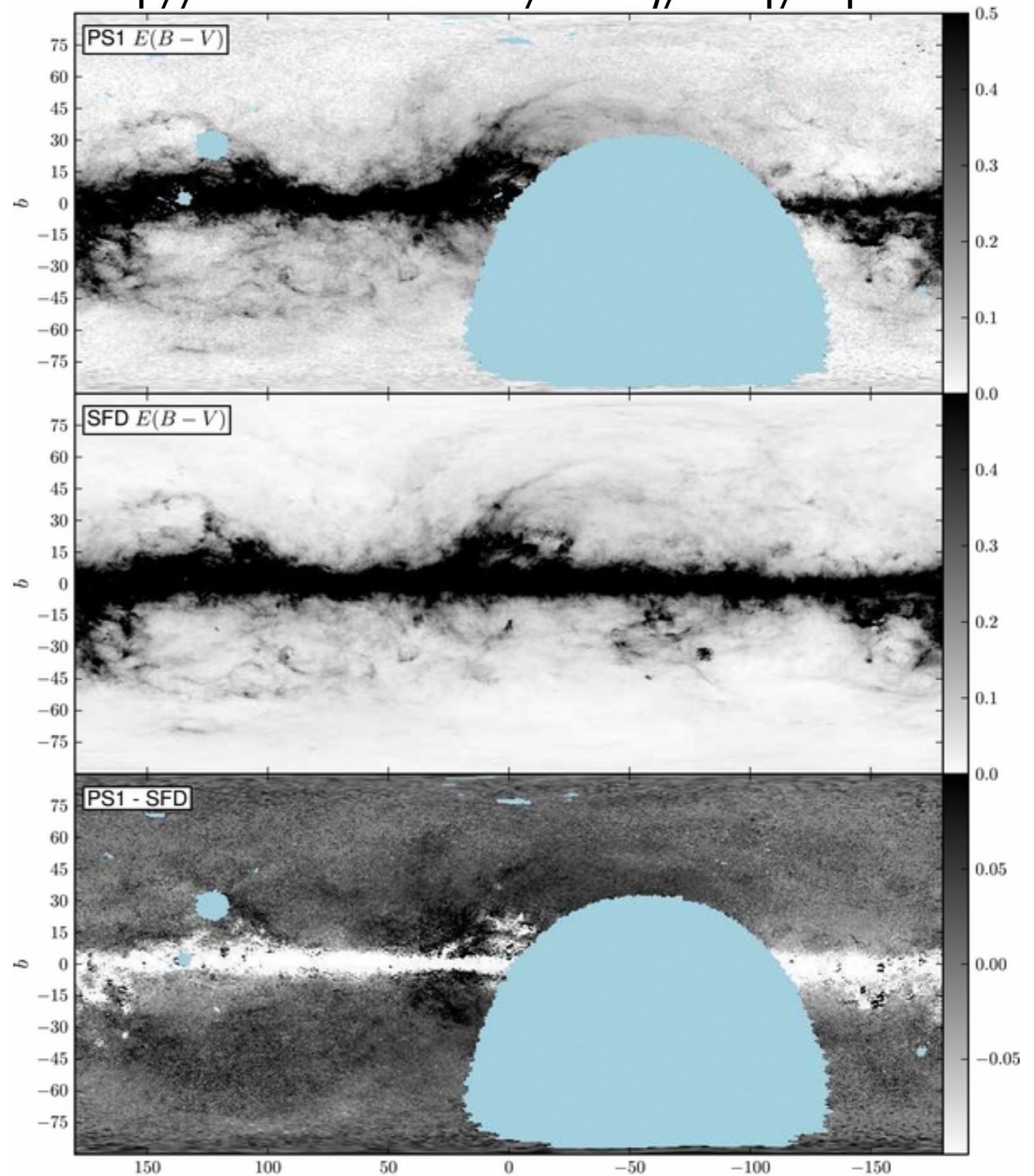


Figure 6. Distance and reddening estimates for four simulated stars. The joint posterior in distance and reddening is shown as a heat map. As this is mock photometry, we know the “true” distances and reddenings for the stars, which are shown as green dots. The true stellar parameters lie in regions of 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.

PAn-STARRS 3D Extinction Schlafly et al. 2014b

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

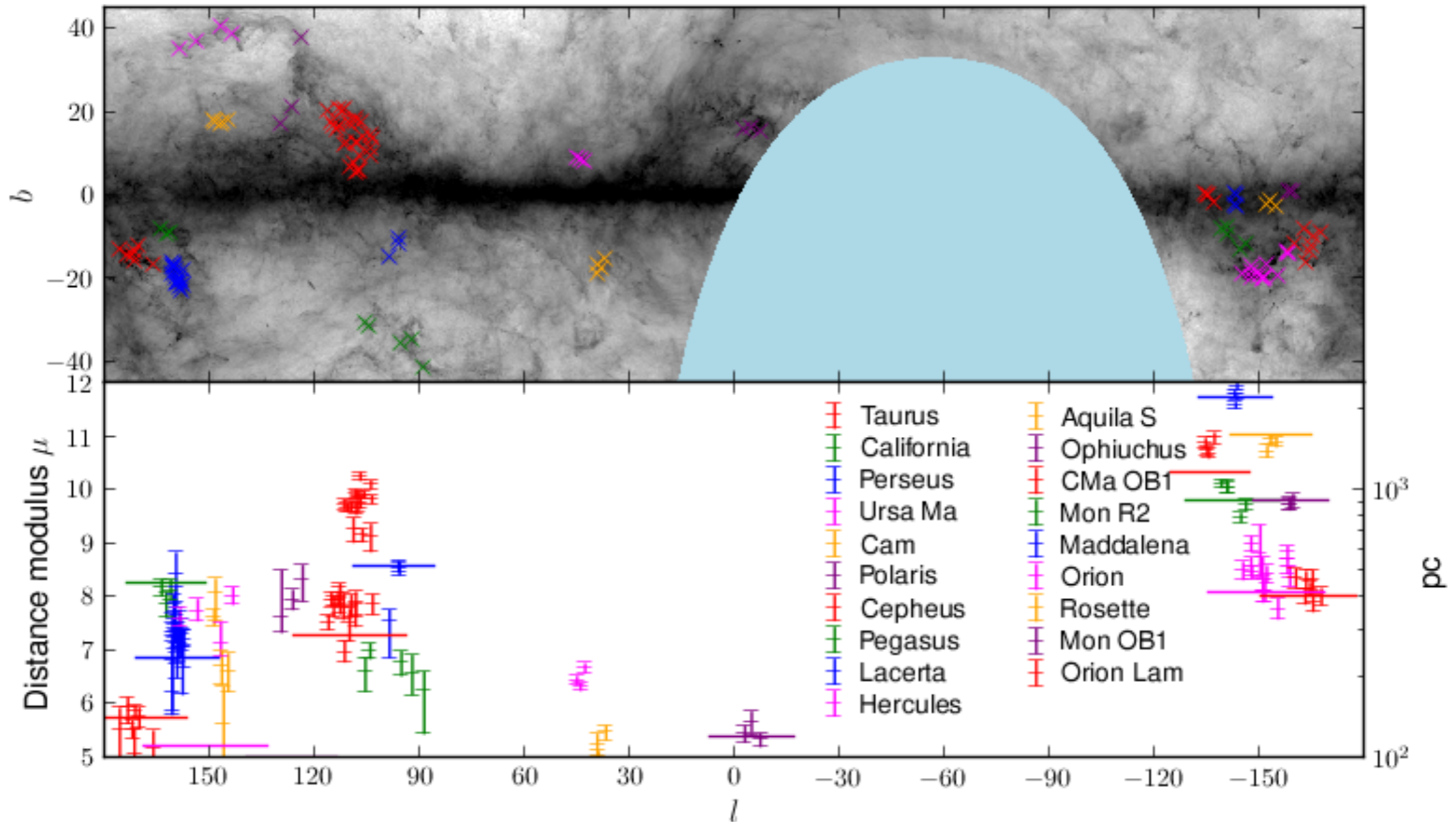


“As foreseen by Bailer-Jones (2011), even the photometric component of Gaia alone is extremely interesting from the perspective of this technique—but the addition of parallax information will make that mission truly revolutionary for maps of dust.”

PAn-STARRS 3D Extinction

Schlafly et al. 2014a

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



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

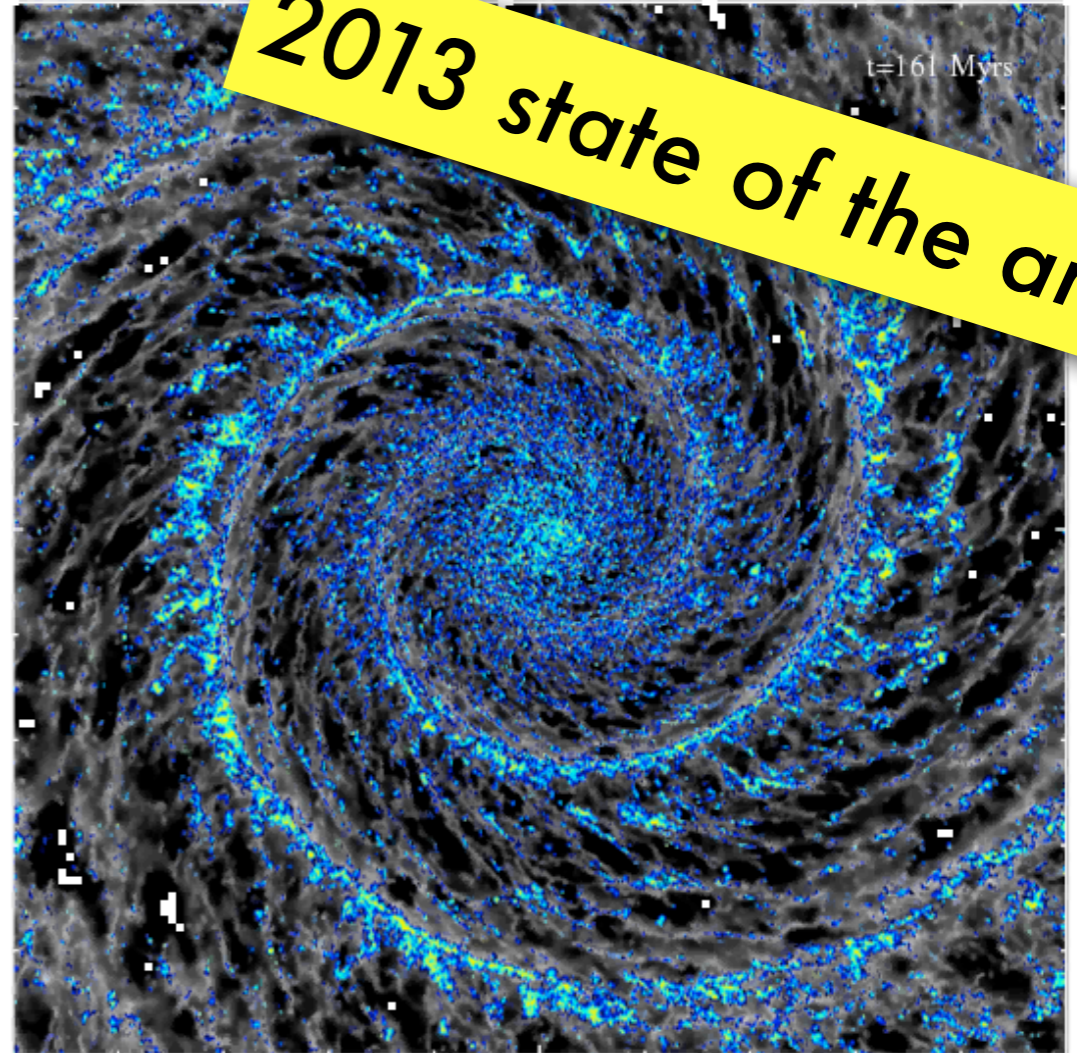
1. Do large **galaxies form** from accumulation of many stars which have already initiated **star formation**?
2. Does star formation begin in a **gravitational well** in which much of the gas is already accumulated?
3. Does the bulge **pre-date** the disc or form contemporaneous with the halo and inner disc?
4. Is the **formation of the early disc and a later major merger** responsible for the **radial age gradient** in the older stars?
5. Was the **history of star formation** relatively smooth or highly episodic?

understanding time-evolution & potentials relies on model comparisons

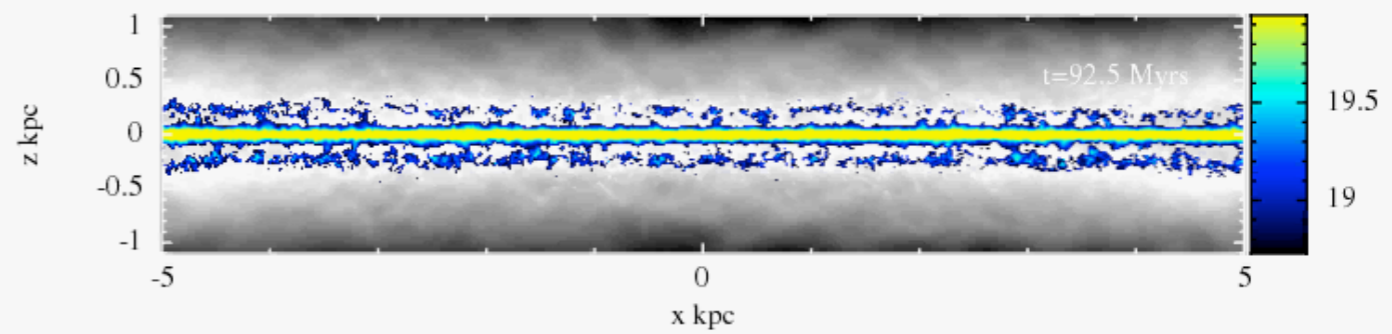
Galactic Structure



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



2013 state of the art

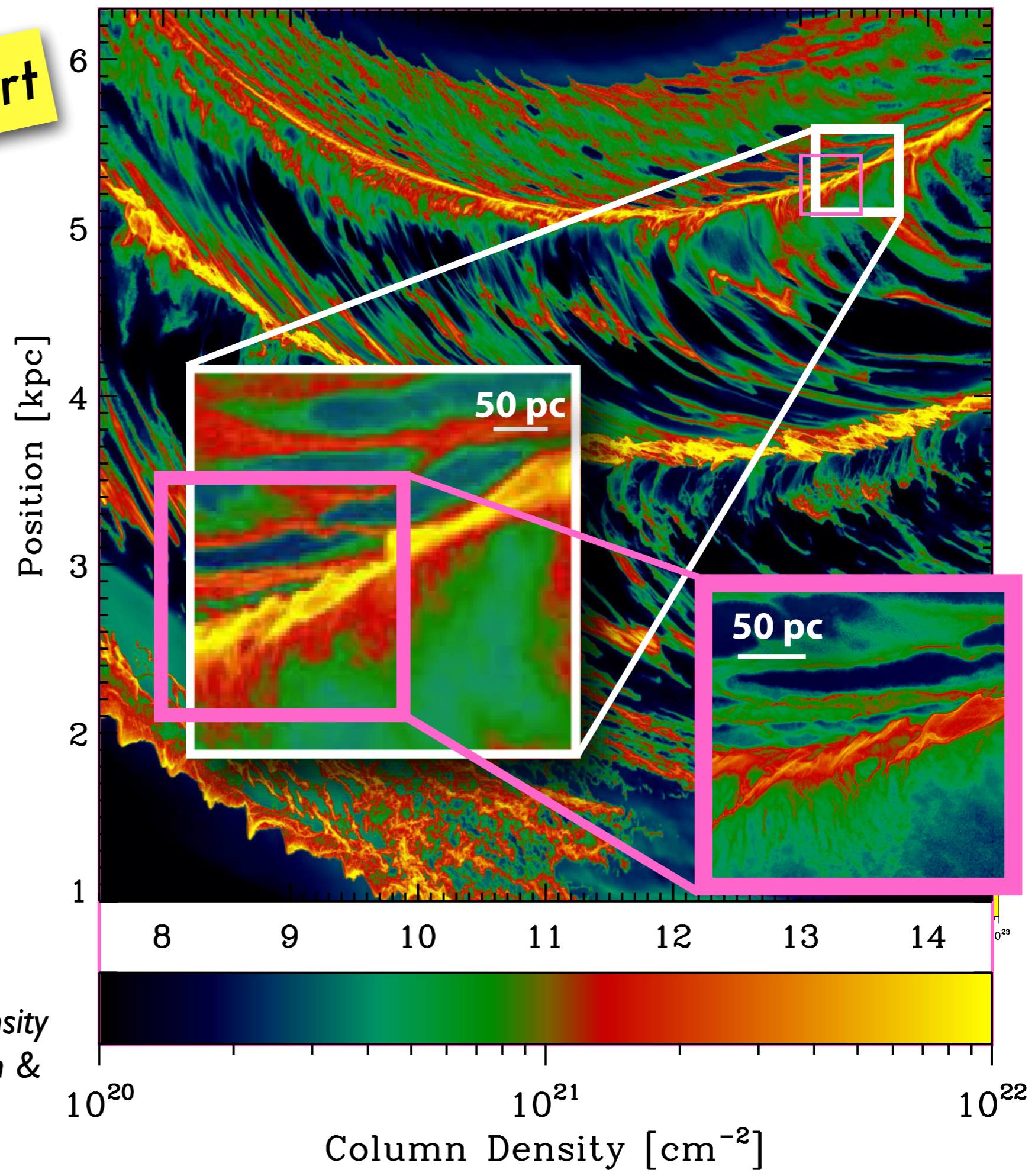


simulations courtesy Clare Dobbs

2014 state of the art

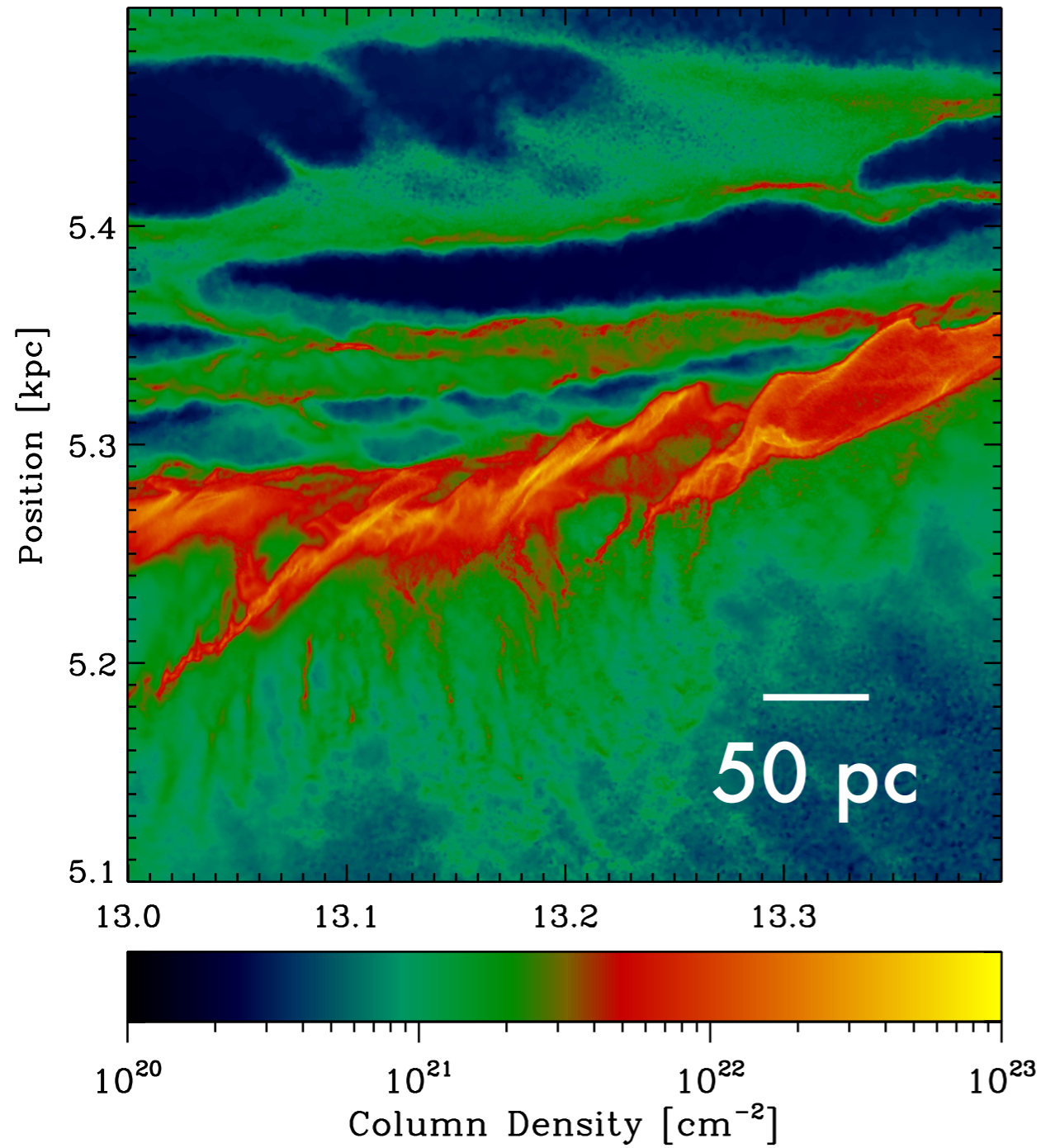
Highest-resolution simulation to date now shows...

Nessies should be there!

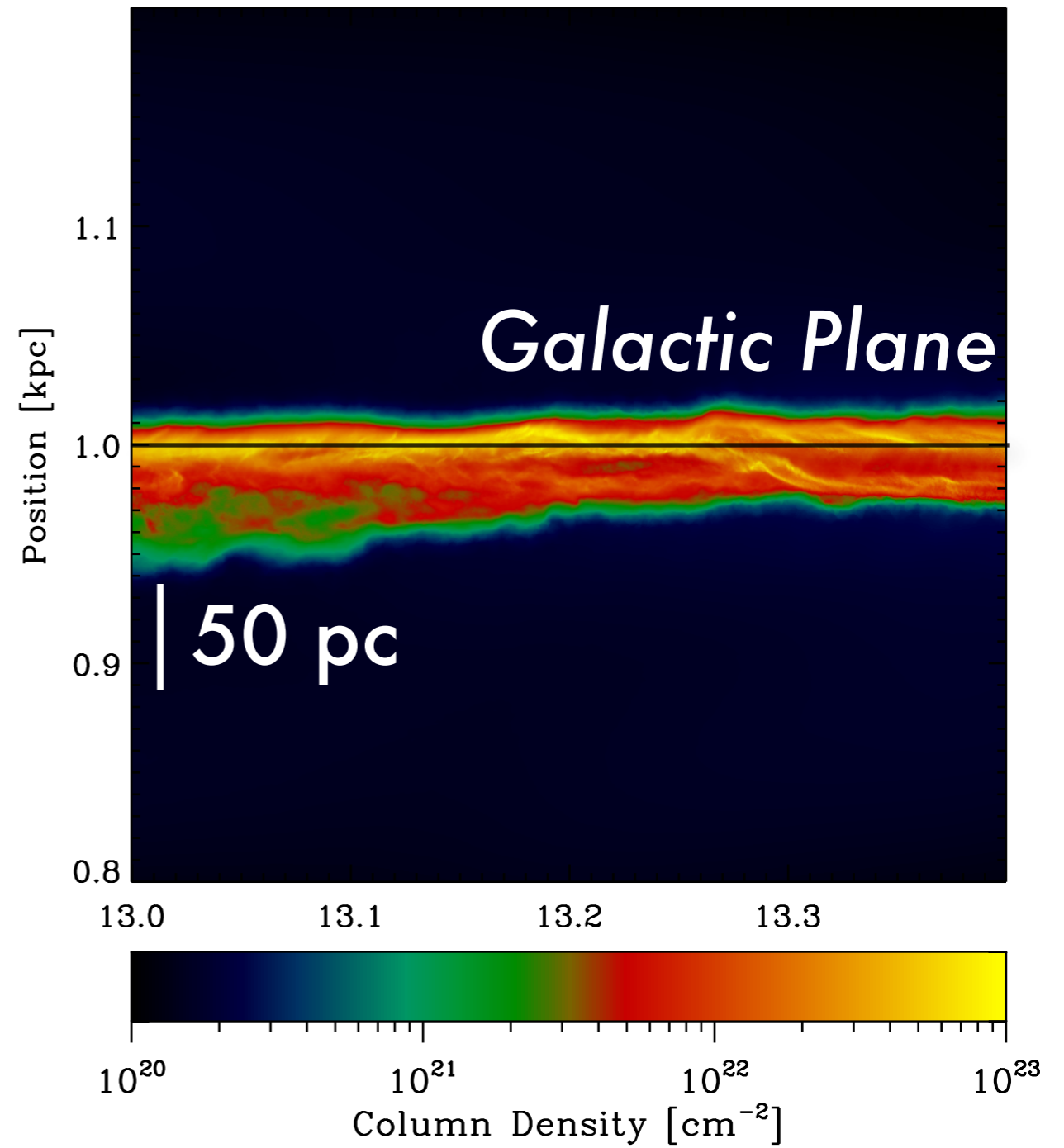


simulation of total H column density from Smith, Glover, Clark, Klessen & Springel 2014

"Top Down"

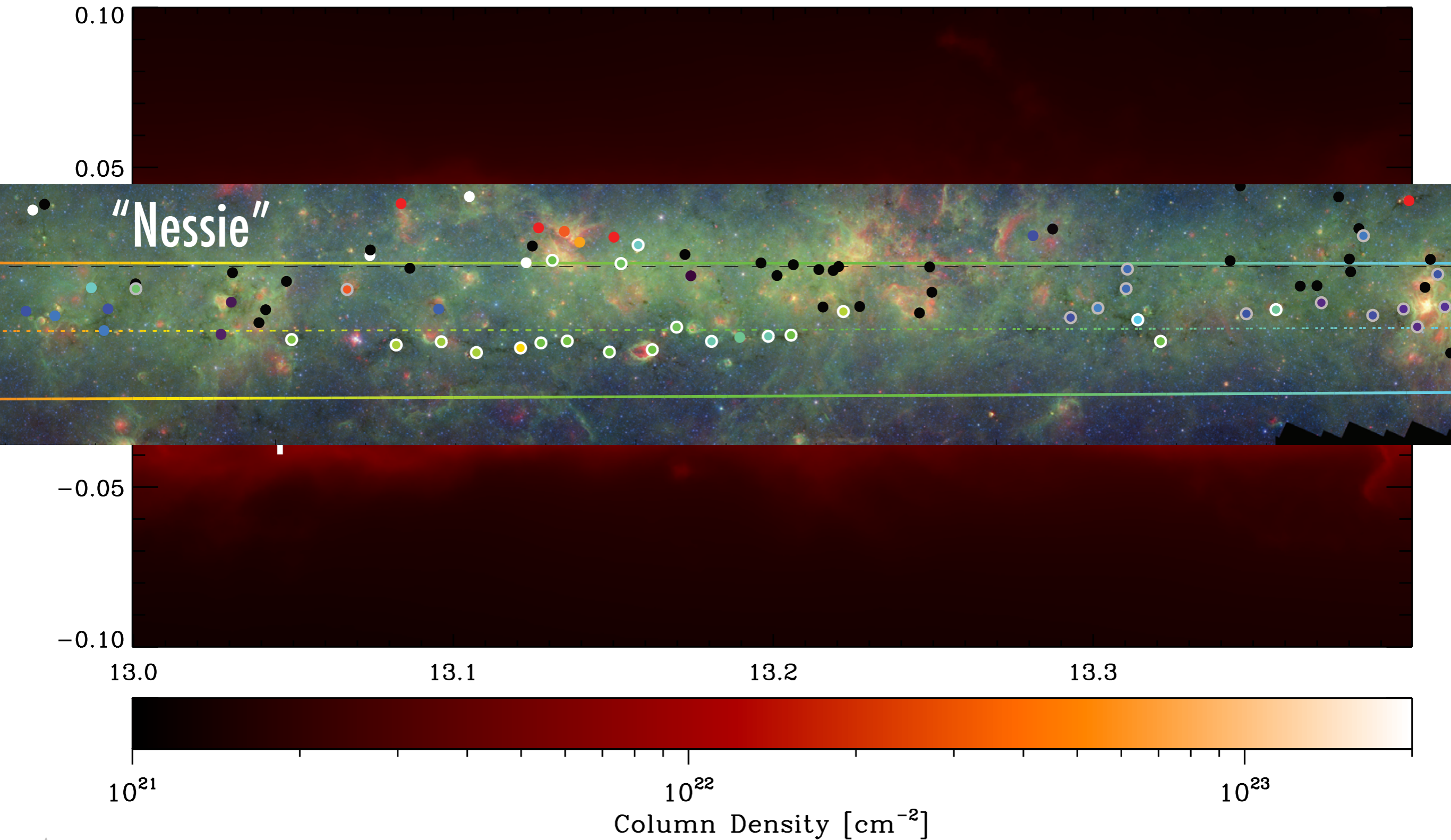


"Edge-On"



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

"Edge-On"

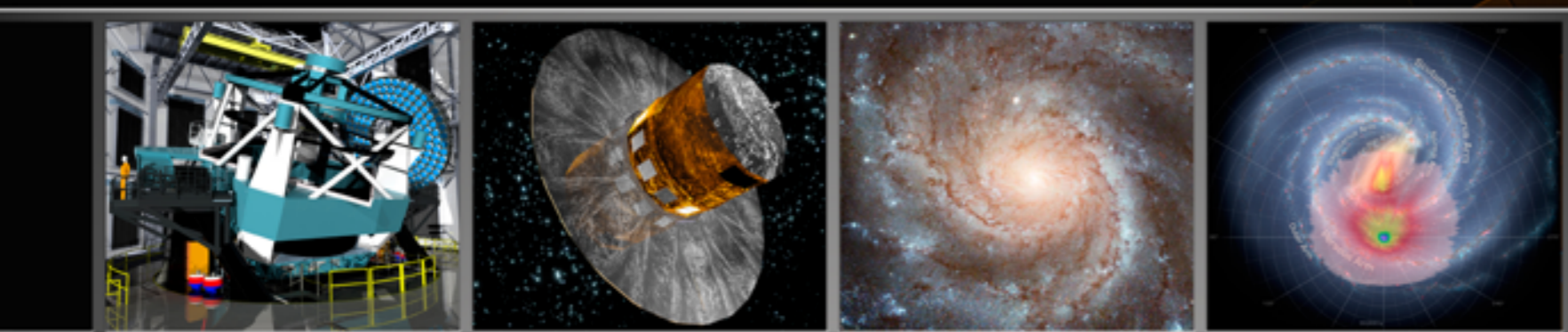


cf. Goodman, Beaumont, et al. 2013, 2014



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)
Xavier Luri (Universitat de Barcelona, Spain)
Ashish Mahabal (Caltech, USA)
William O'Mullane (ESAC, ESA, Spain)
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.)



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 making as we can *while scanning the data.*
- I want it customizable (Connolly et al.)



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 data
- 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 :)



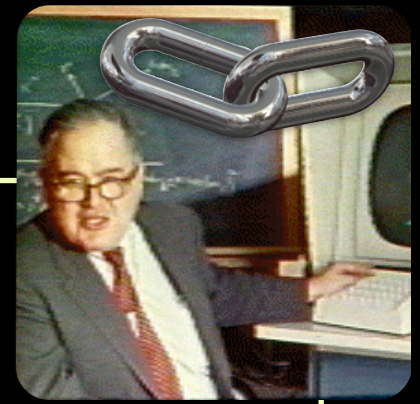
WorldWide Telescope



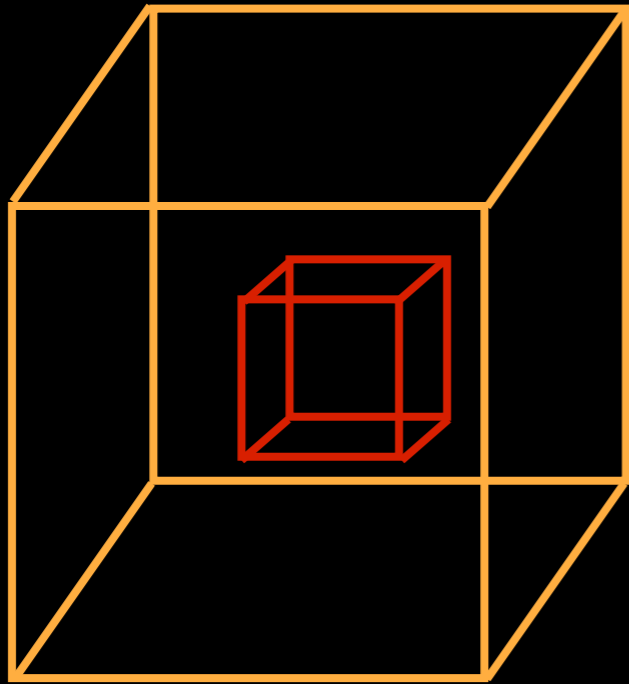
[demo]

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

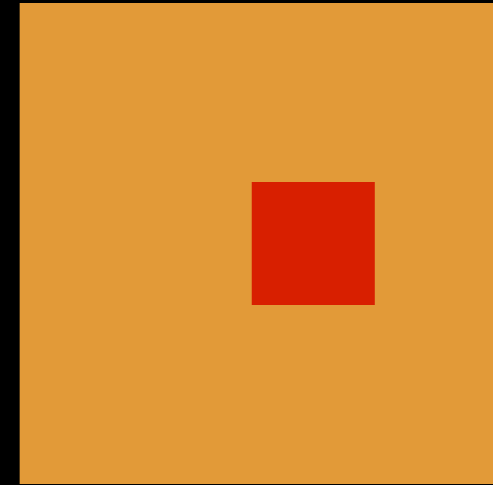
Linked Views of High-dimensional Data



John Tukey

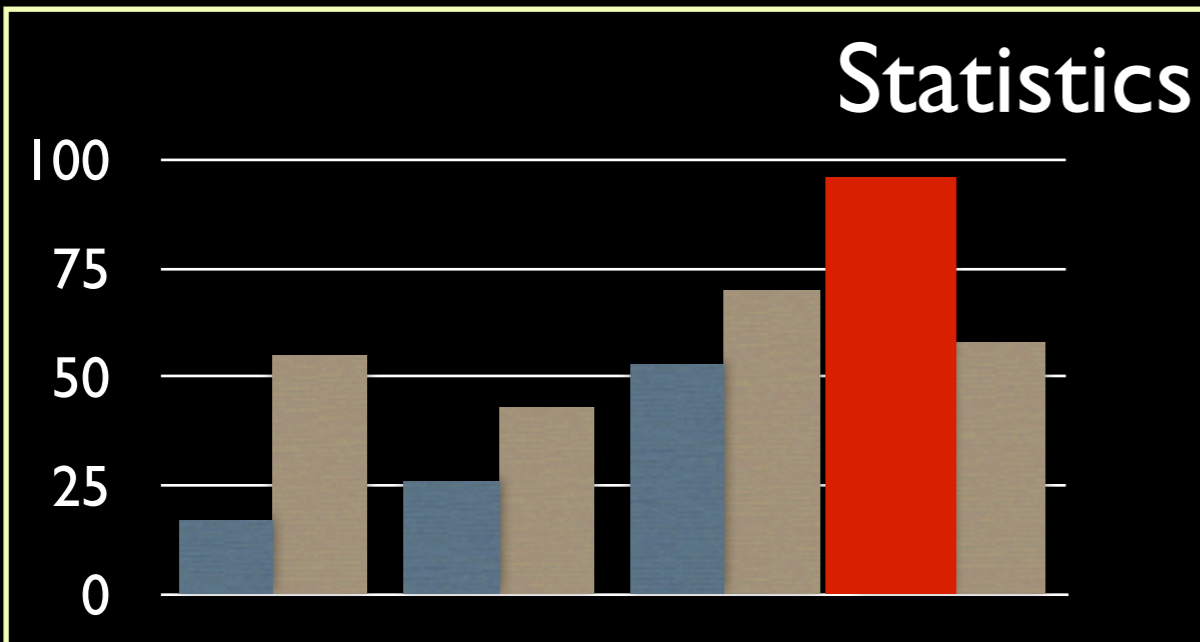
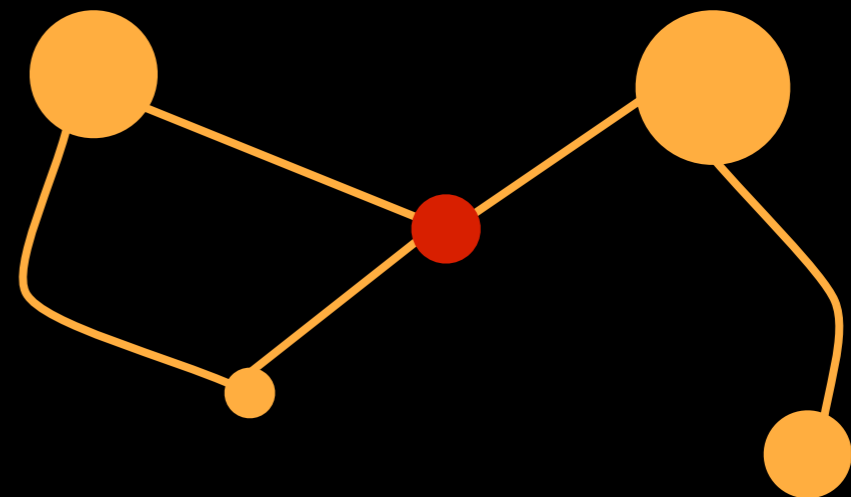


3D

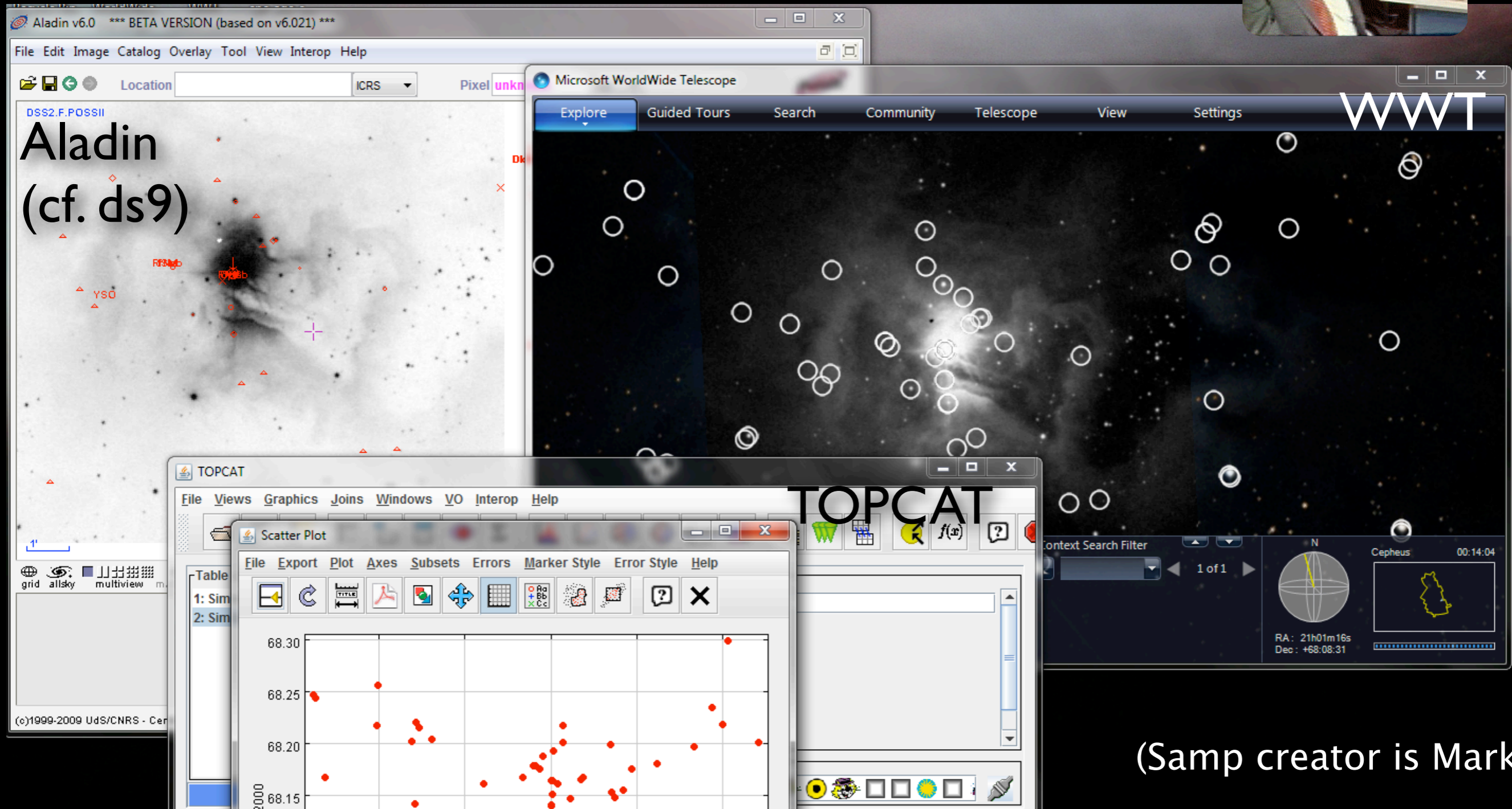


2D

Data Abstraction

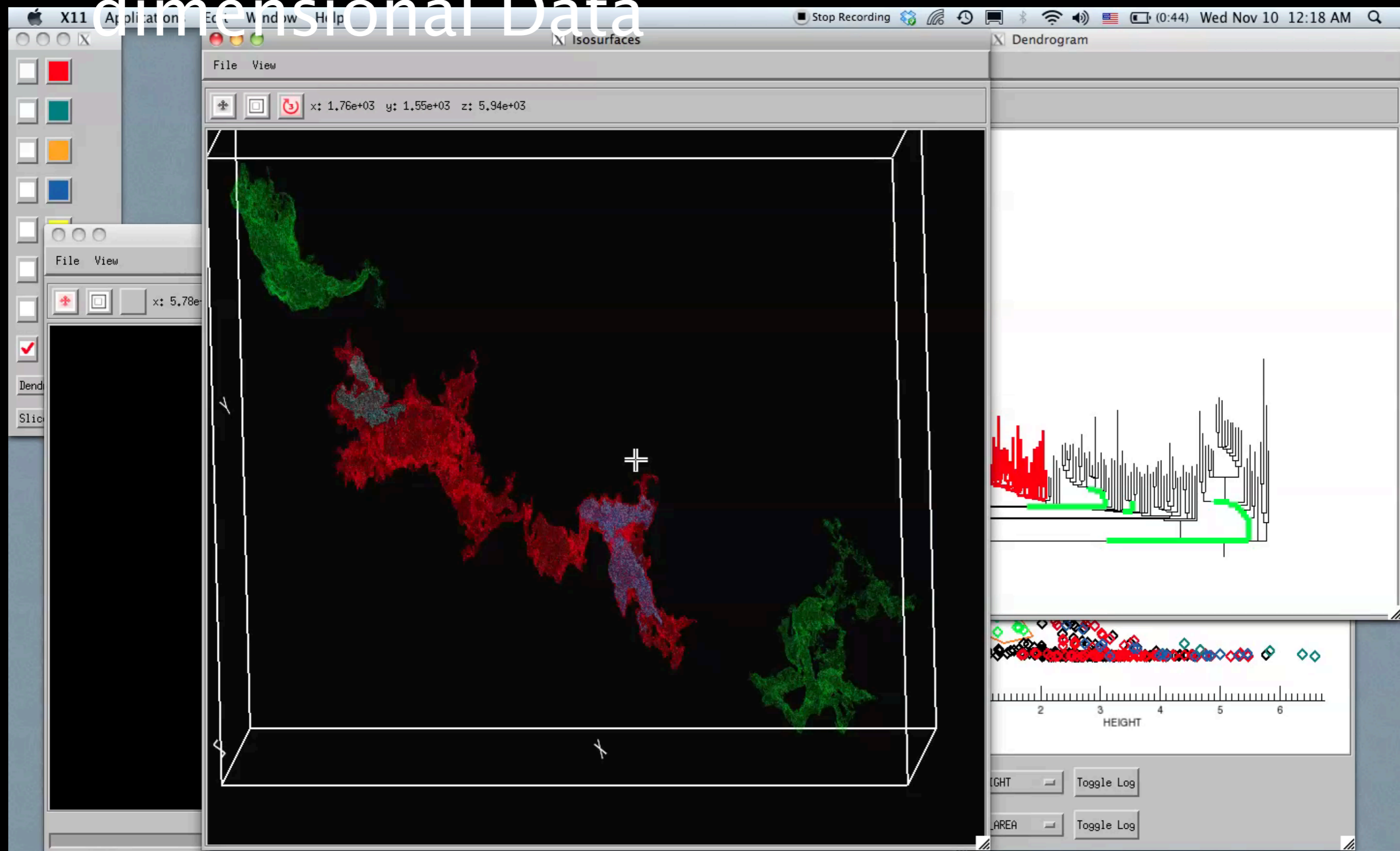


Linked Views of High-dimensional Data

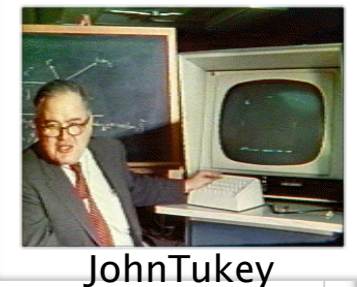


figure, showing SAMP screenshot, reproduced from Goodman 2012, "Principles of High-Dimensional Data Visualization in Astronomy"

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*



JohnTukey

Principles of high-dimensional data visualization in astronomy

A.A. Goodman*

Harvard-Smithsonian Center for Astrophysics, Cambridge, MA, USA

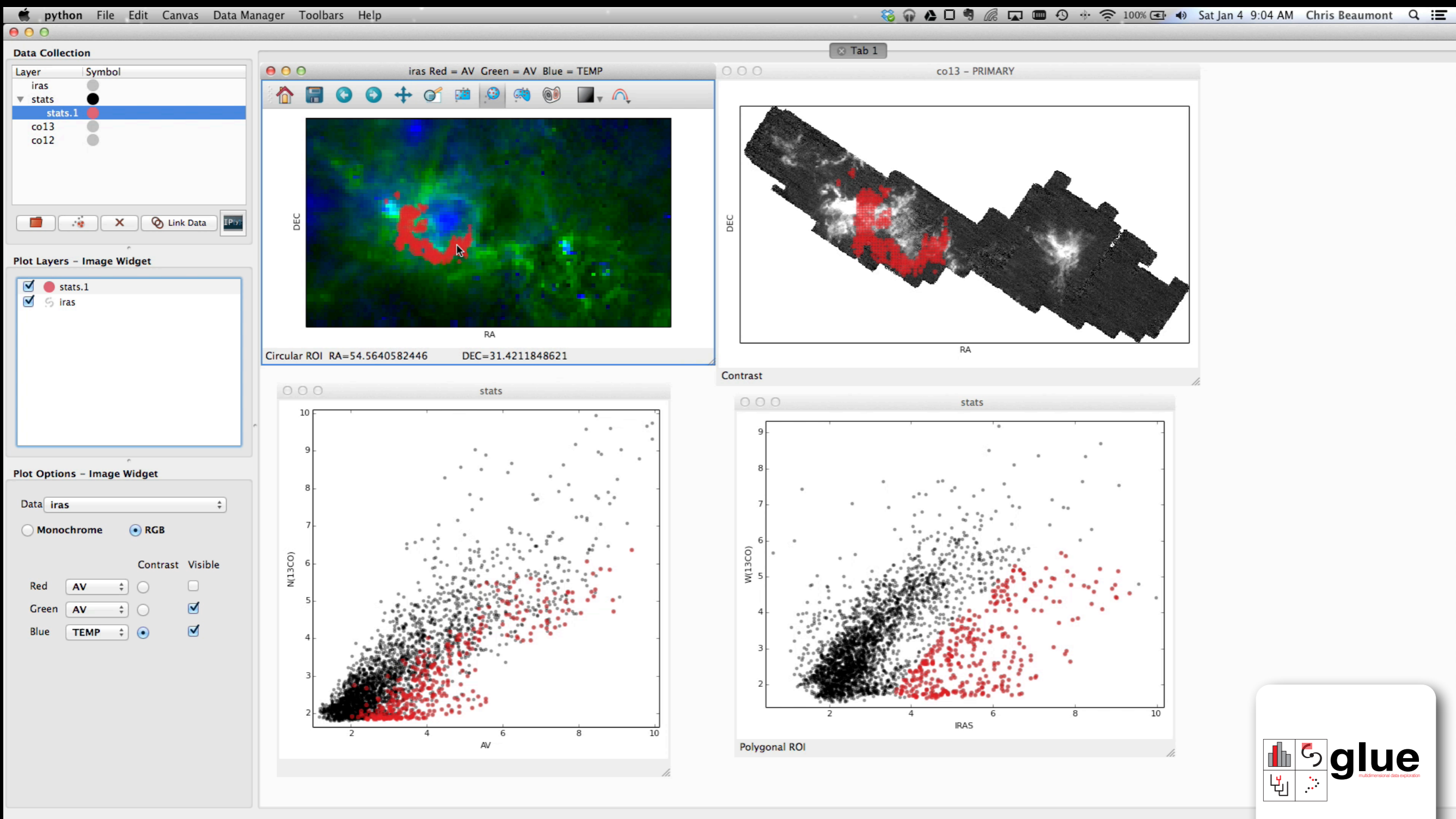
Received 2012 May 3, accepted 2012 May 4

Published online 2012 Jun 15

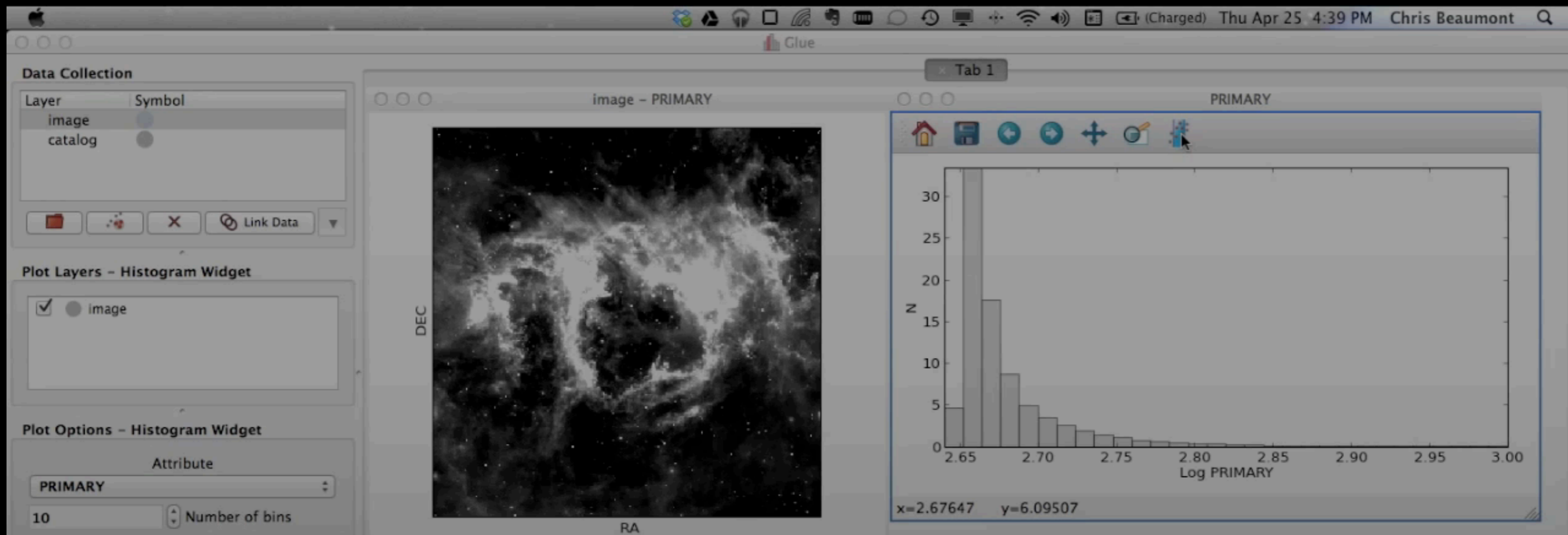
Key words cosmology: large-scale structure – ISM: clouds – methods: data analysis – techniques: image processing – techniques: radial velocities

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 chart 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



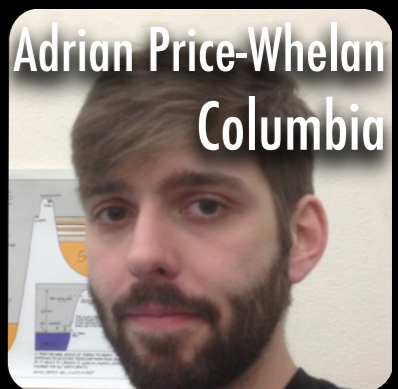
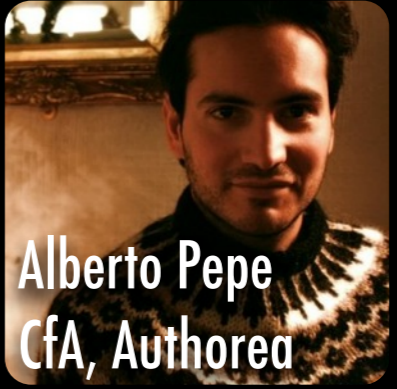
Linked Views of High-dimensional Data Glue



**Many views
per data set**

MANY VIEWS

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



The screenshot shows a web browser displaying an Authorea article. The URL is https://www.authorea.com/users/2786/articles/4039/_show_article. The Authorea logo is in the top left, and navigation links (BROWSE, ABOUT, CONTACT, PLANS, FEEDBACK, HELP) and the user name (JOSH PEEK) are in the top right. The article title is "Beyond Galileo" by Josh Peek and Alberto Pepe. It is marked as a "ROUGH DRAFT" and "OPEN SCIENCE". The article text discusses Galileo's discovery of four objects near Jupiter in 1610. A quote from Galileo's *Sidereus Nuncius* is included: "I therefore concluded and decided unhesitatingly, that there are three stars in the heavens moving about Jupiter, as Venus and Mercury round the Sun; which at length was established as clear as daylight by numerous subsequent observations. These observations also established that there are not only three, but four, erratic sidereal bodies performing their revolutions round Jupiter...the revolutions are so swift that an observer may generally get differences of position every hour." (Galilei 1610)

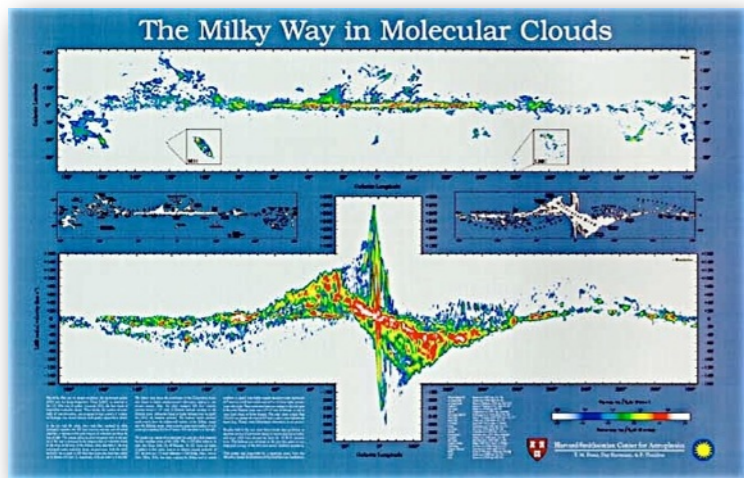


Visualizing the Milky Way across the spectrum



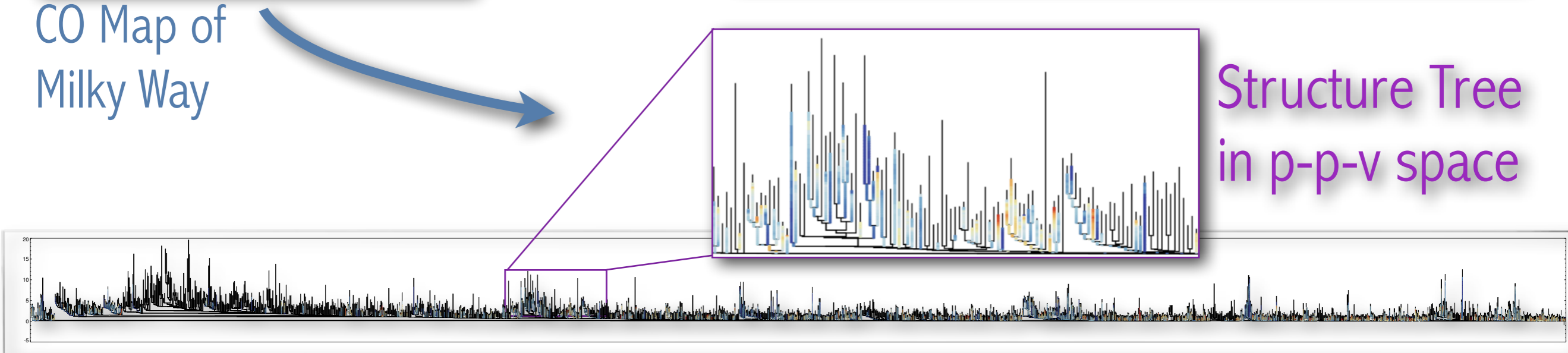
 Alyssa A. Goodman
Harvard-Smithsonian Center for Astrophysics

The Grand Plan



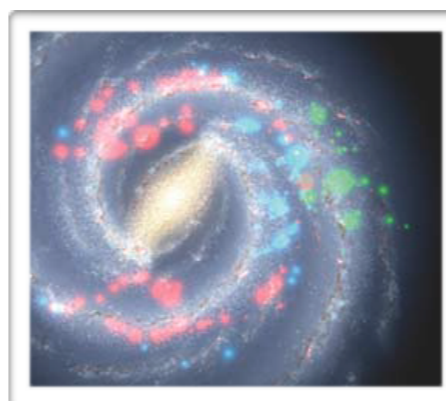
CO Map of Milky Way

Structure Tree in p-p-v space

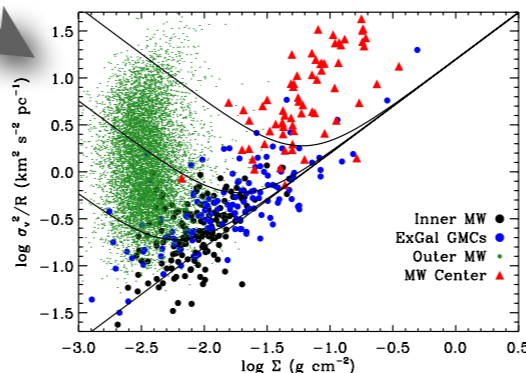


Hierarchical Catalog

distance assignments...



3D Viz



Analysis

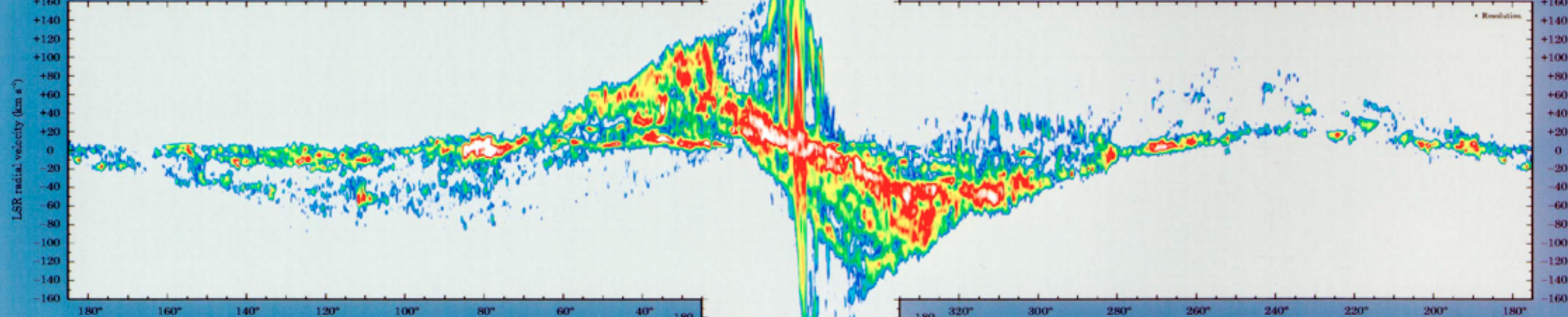
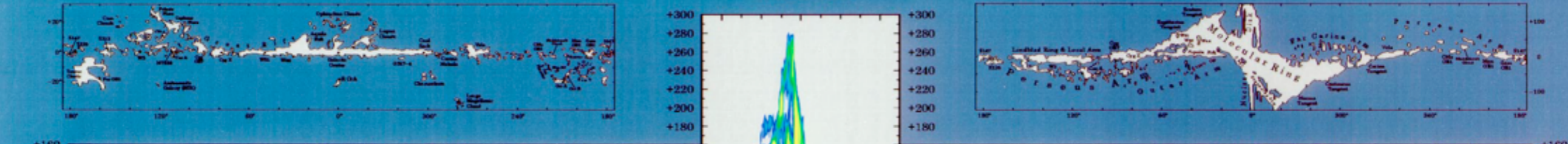
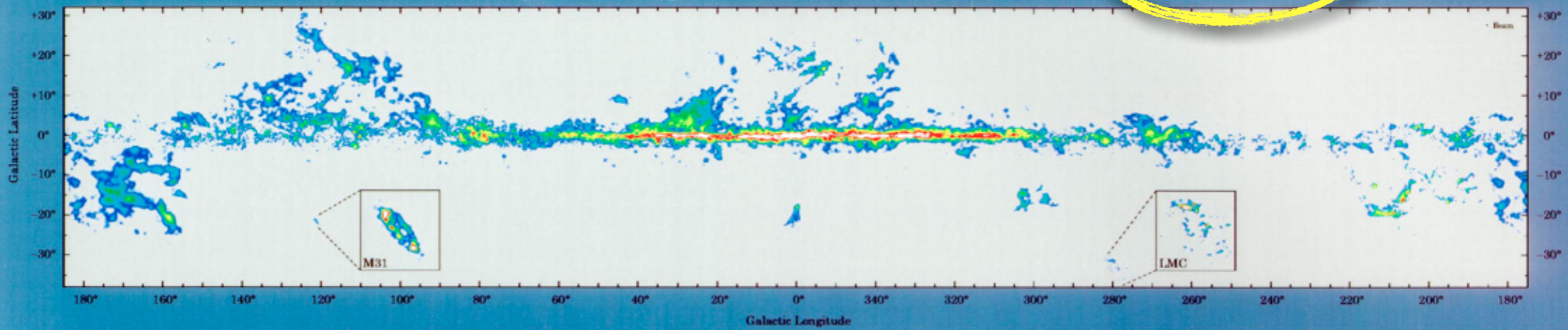
e.g. pressure, **SFE**

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UNIVERSE3D.org

theastrodata.org

The Milky Way in Molecular Clouds



The Milky Way and its nearest neighbors, the Andromeda galaxy (M31) and the Large Magellanic Cloud (LMC), are shown in the 113 GHz line of carbon monoxide (CO), the best tracer of interstellar molecular clouds. These clouds, the factories of essentially all star formation, are composed almost entirely of molecular hydrogen and atomic helium, both nearly impossible to detect.

In the top map the colors, from dark blue (coldest) to white (hottest), represent the CO line intensity summed over all radial velocities, a measure of the total amount of molecular gas along the line of sight. The narrow yellow/orange horizontal strip at the center of the map is produced by the large number of molecular clouds in the inner spiral arm of the Galaxy, which clump in the map without nearby molecular clouds as precursors. Both the LMC and M31 are as weak in CO that their intensity has been added up by beams of 3 and 20, respectively. A finer chart is on the left.

The bottom map shows the distribution of the CO-emitting interstellar clouds in radial velocity-binomial information lacking in conventional surveys. Now, the colors represent CO line intensity summed across a 4" strip of Galactic latitude centered on the Galactic plane. Molecular clouds at higher latitude (and the LMC and M31) are therefore excluded. The observed radial velocity results mainly from the differential rotation of the Galaxy, except near the Galactic center, where a poorly understood outflow of material is producing 200 km/s' flows. A finer chart is on the right.

This figure is an update of one produced six years ago which presented the first complete survey of the Milky Way in CO since release in 1993, also Dame (1998), *Rev. of Space and Time*, 12. Since well before completion of this survey, done at an effective angular resolution of 0.7", the same two 12 meter telescopes in Cambridge, Mass., and in Cas, Table, Okla., have been mapping the Galaxy and its nearest

neighbors at several times higher angular resolution—every beamwidth (3.7 arcmin) or half beamwidth—and at 3 to 20 times higher intensity per solid angle. These improvements have now mapped in the top map the entire Galactic plane over a 4"–6" strip of latitude, as well as many local clouds at higher latitude. The maps above include those 250,000 new spectra the original 0.7" map is used in some high-latitude regions (e.g., Thorne) where full-resolution observations do not exist.

Enough half of the new data have already been published as separate surveys of particular clouds or regions (see list at right), and since 1997 have formed the base for 13 Ph.D. dissertations. The fullness was obtained in the first few years in new long-term surveys of the first and second Galactic quadrants.

This project was supported by a generous grant from the Alabama Seidel Endowment of the Smithsonian Institution.

Whitlock (1997) *ApJ*, 472, 106.
 Dame (1998) *ApJ*, 491, 491.
 Dame & Thaddeus (1998) *ApJ*, 504, 1212.
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 Dame (2000) *ApJ*, 531, 342.
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 Dame et al. (2001) *ApJ*, 553, 797.
 Dame et al. (2002) *ApJ*, 563, 797.
 Dame et al. (2003) *ApJ*, 593, 797.
 Dame et al. (2004) *ApJ*, 603, 797.
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 Dame et al. (2013) *ApJ*, 693, 797.
 Dame et al. (2014) *ApJ*, 703, 797.
 Dame et al. (2015) *ApJ*, 713, 797.
 Dame et al. (2016) *ApJ*, 723, 797.
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 Dame et al. (2019) *ApJ*, 753, 797.
 Dame et al. (2020) *ApJ*, 763, 797.
 Dame et al. (2021) *ApJ*, 773, 797.
 Dame et al. (2022) *ApJ*, 783, 797.
 Dame et al. (2023) *ApJ*, 793, 797.
 Dame et al. (2024) *ApJ*, 803, 797.
 Dame et al. (2025) *ApJ*, 813, 797.

Top map: $\log \int T_{mb} dv$ (K km s⁻¹)
 Bottom map: $\log \int T_{mb} dv$ (K km s⁻¹)

Dendrograms

intensity level

local max

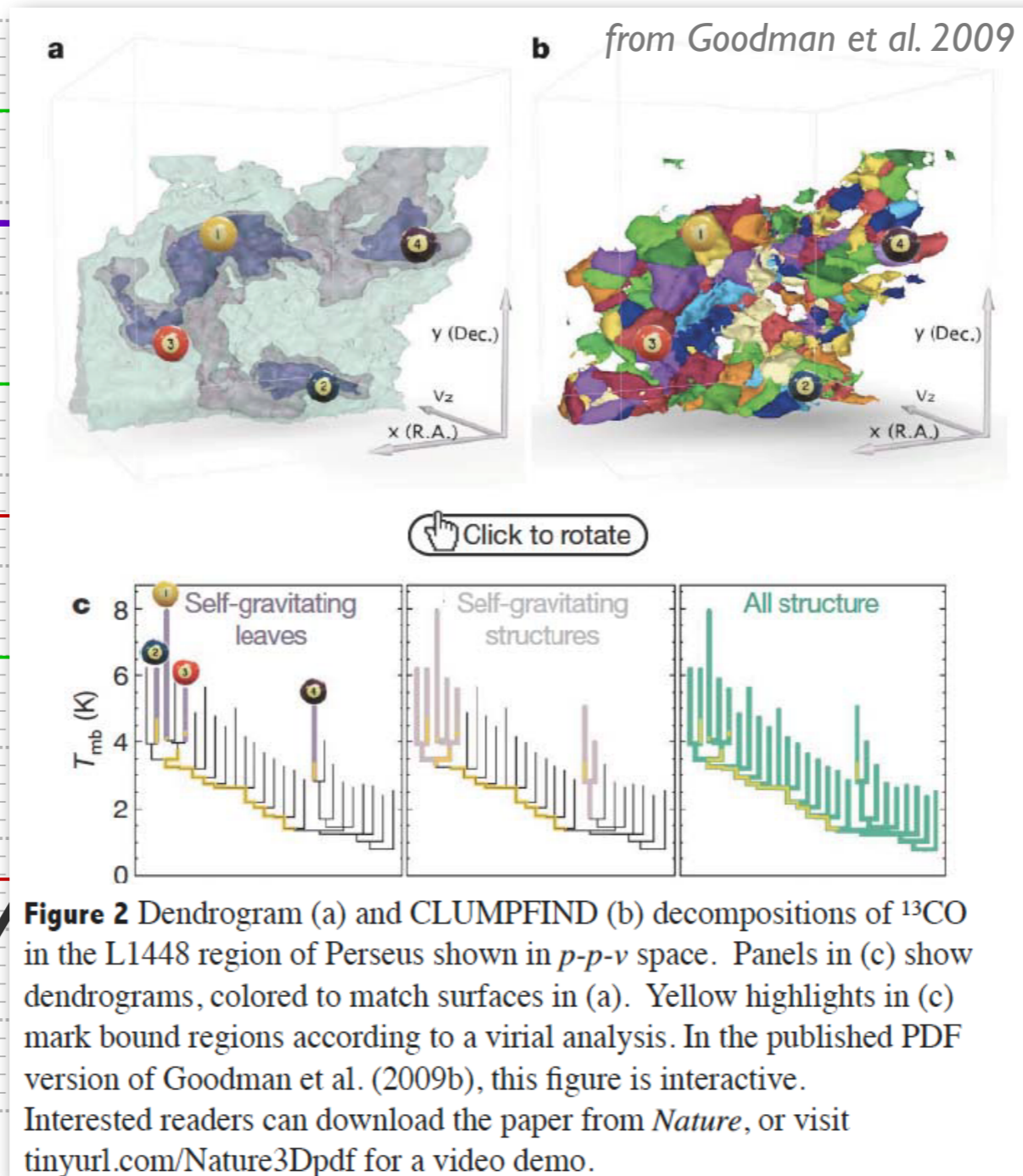
test level

local max

merge

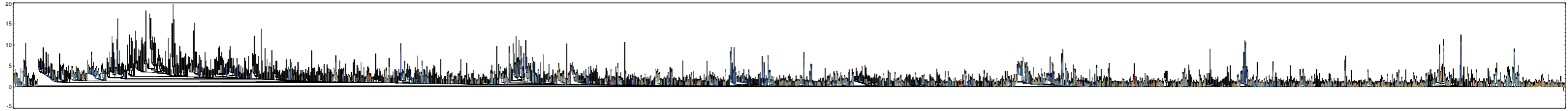
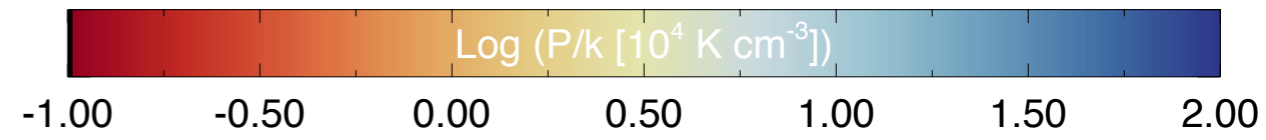
local max

merge



Hierarchical “Segmentation”

Rosolowsky, Pineda, Kauffmann & Goodman 2008



(Pressure) Structure of Milky Way Clouds

