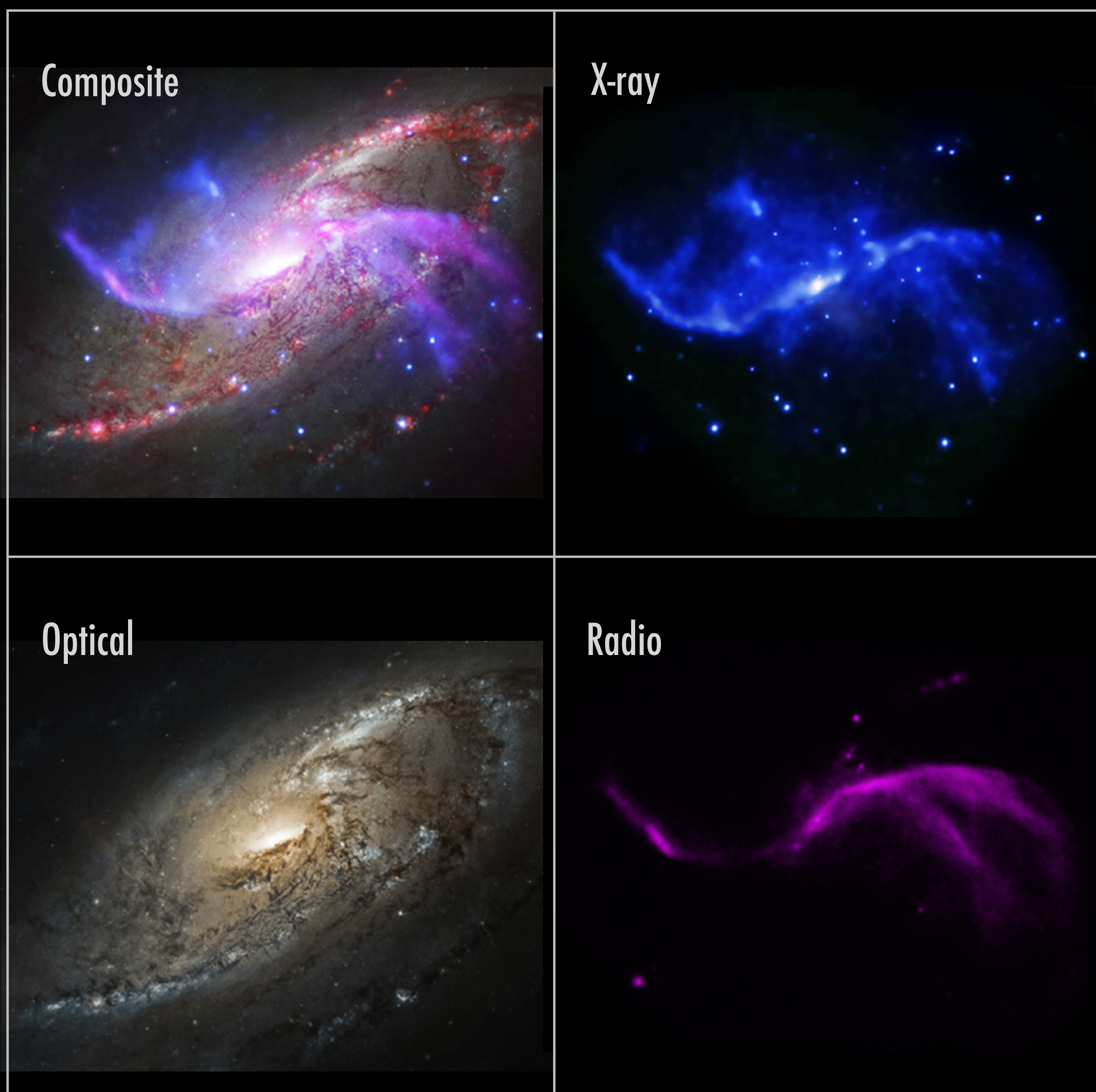
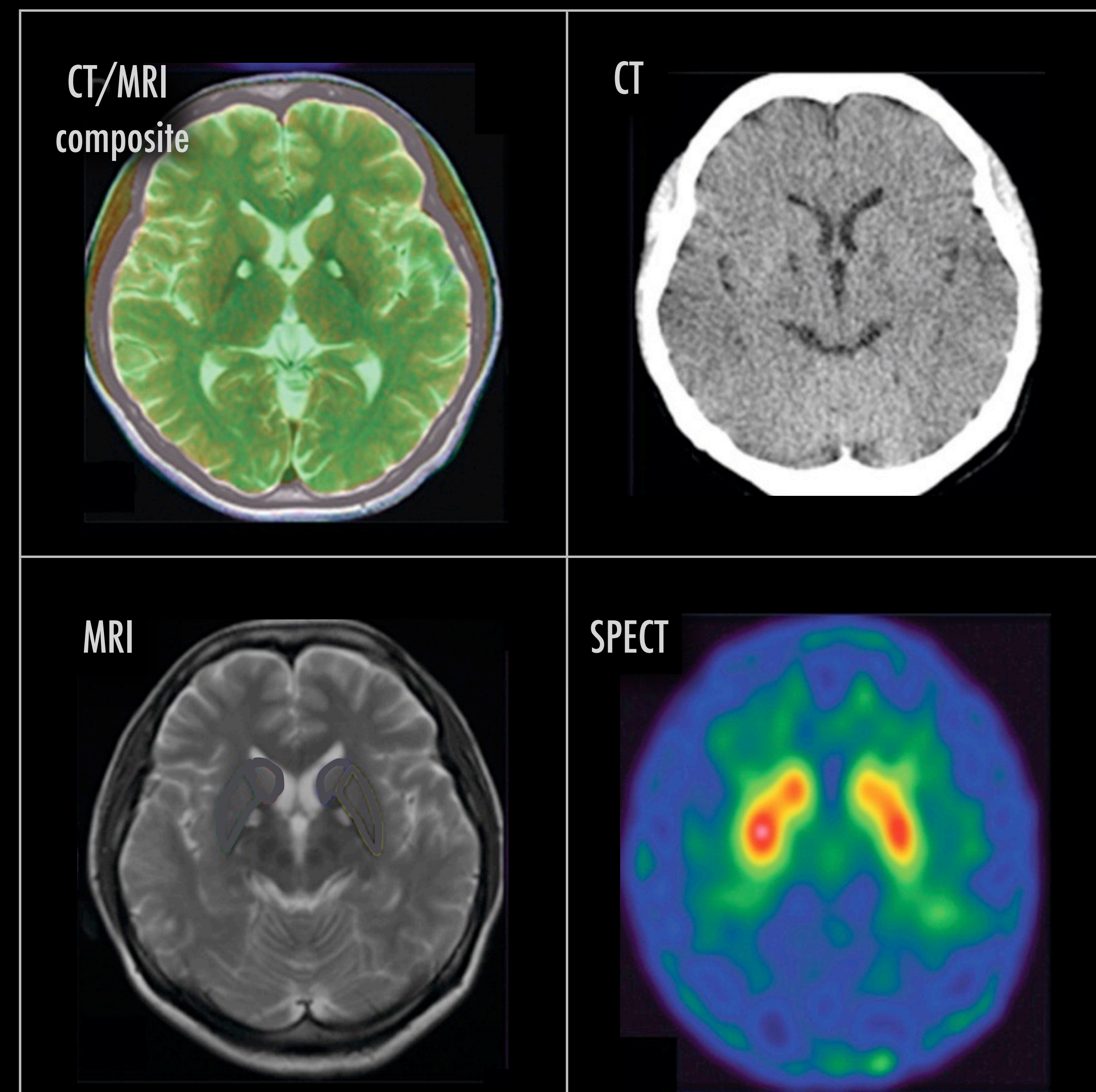
ASTRONOMY, MEDICINE, AND THE FUTURE

ALYSSA A. GOODMAN, HARVARD-SMITHSONIAN CENTER FOR ASTROPHYSICS



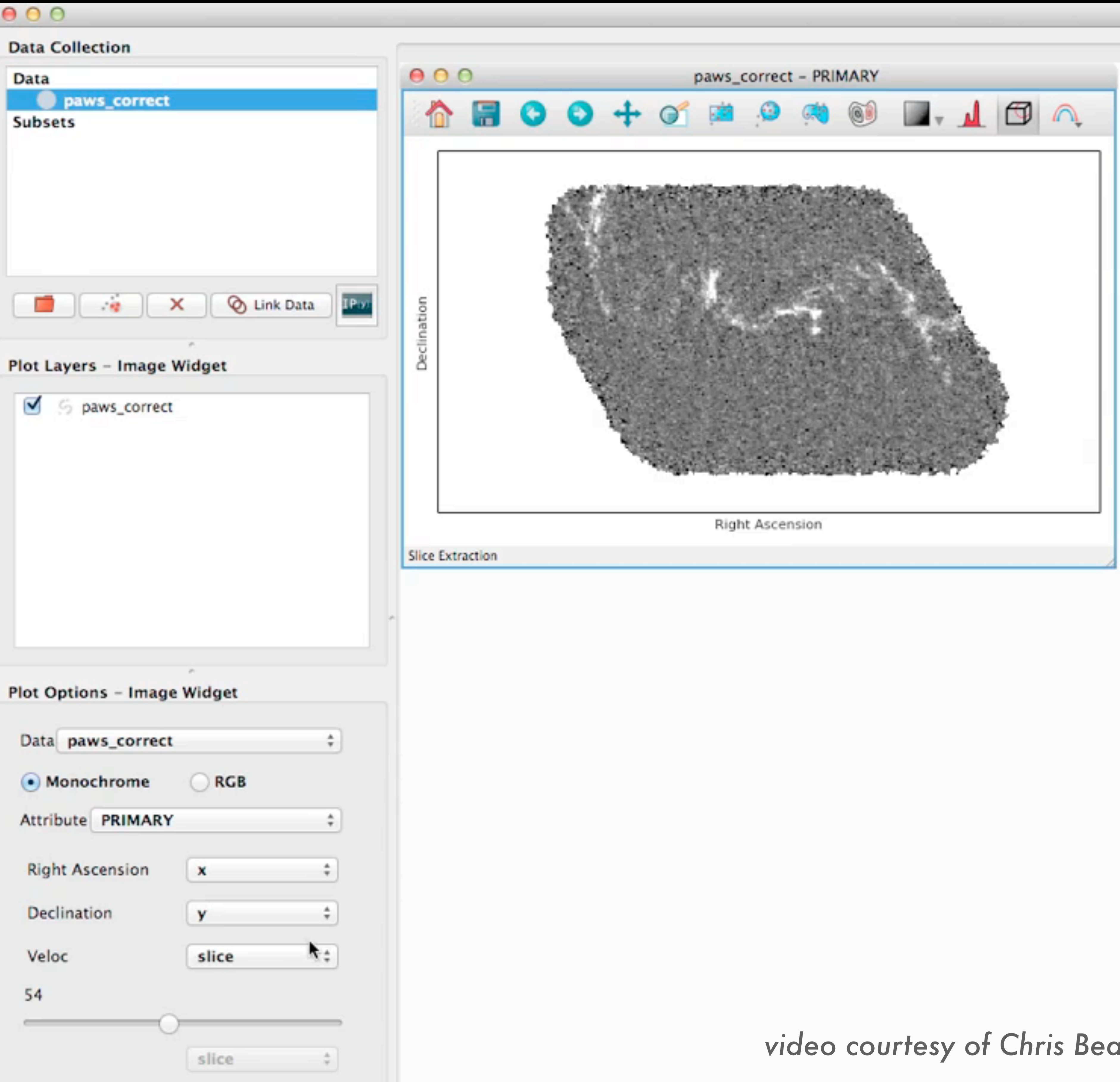
chandra.harvard.edu/photo/2014/m106/



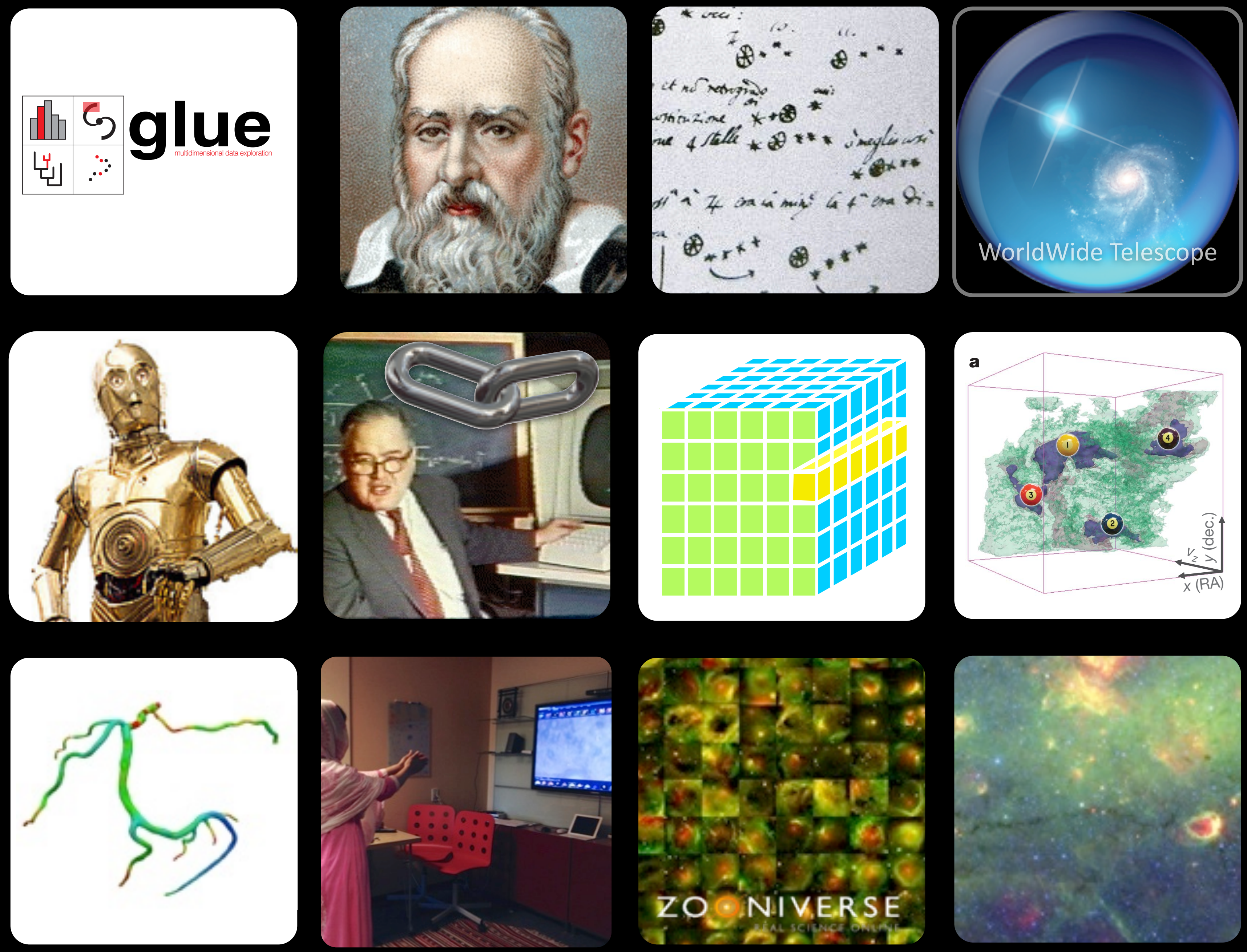
Chang, et al. 2011, brain.oxfordjournals.org/content/134/12/3632

@aagie

THIS WILL MAKE PERFECT SENSE, SOON...



video courtesy of Chris Beaumont, lead glue developer 2012-14


glue
multidimensional data exploration
WorldWide Telescope
a
y (dec.)
x (RA)
ZOONIVERSE
REAL SCIENCE ONLINE

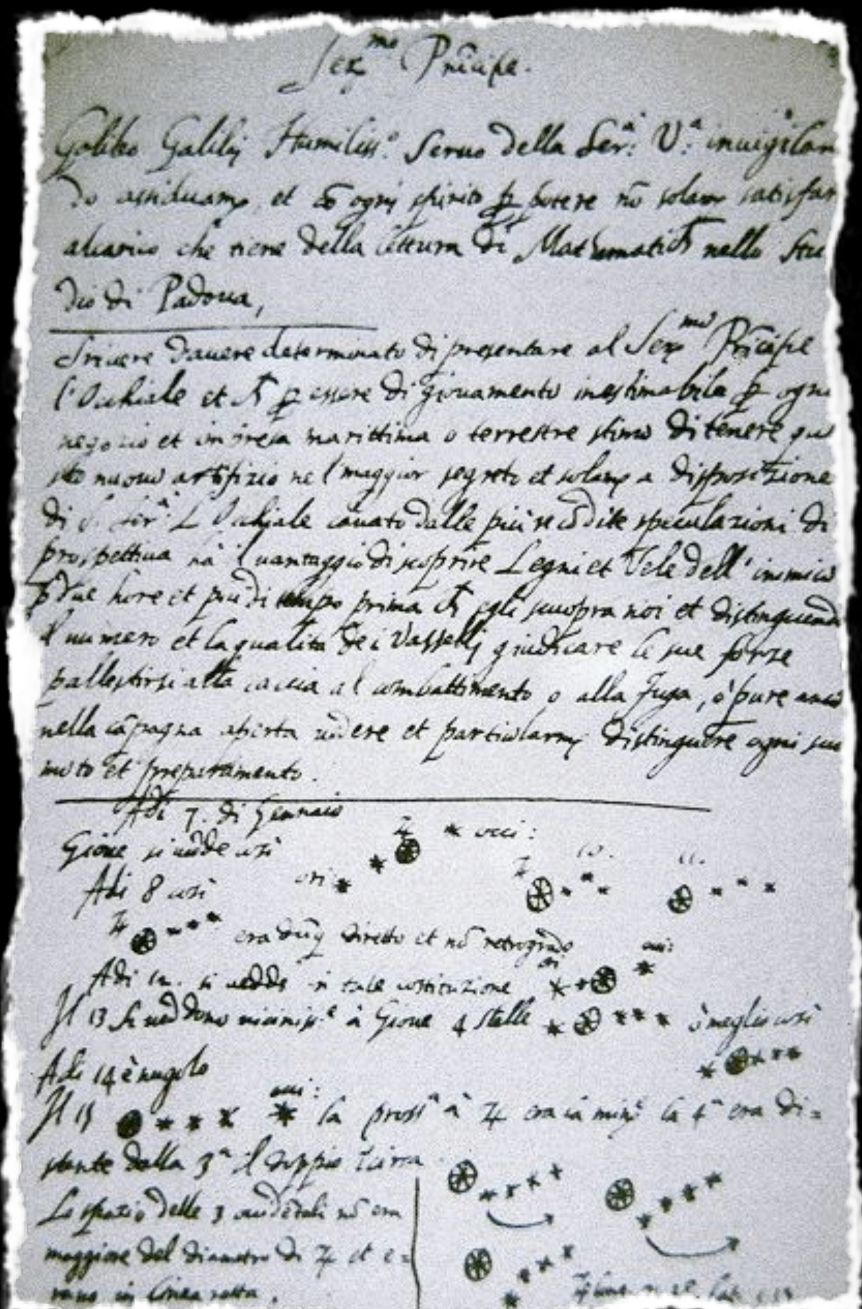
RELATIVE STRENGTHS

Pattern Recognition
Creativity

Calculations

GALILEO GALILEI

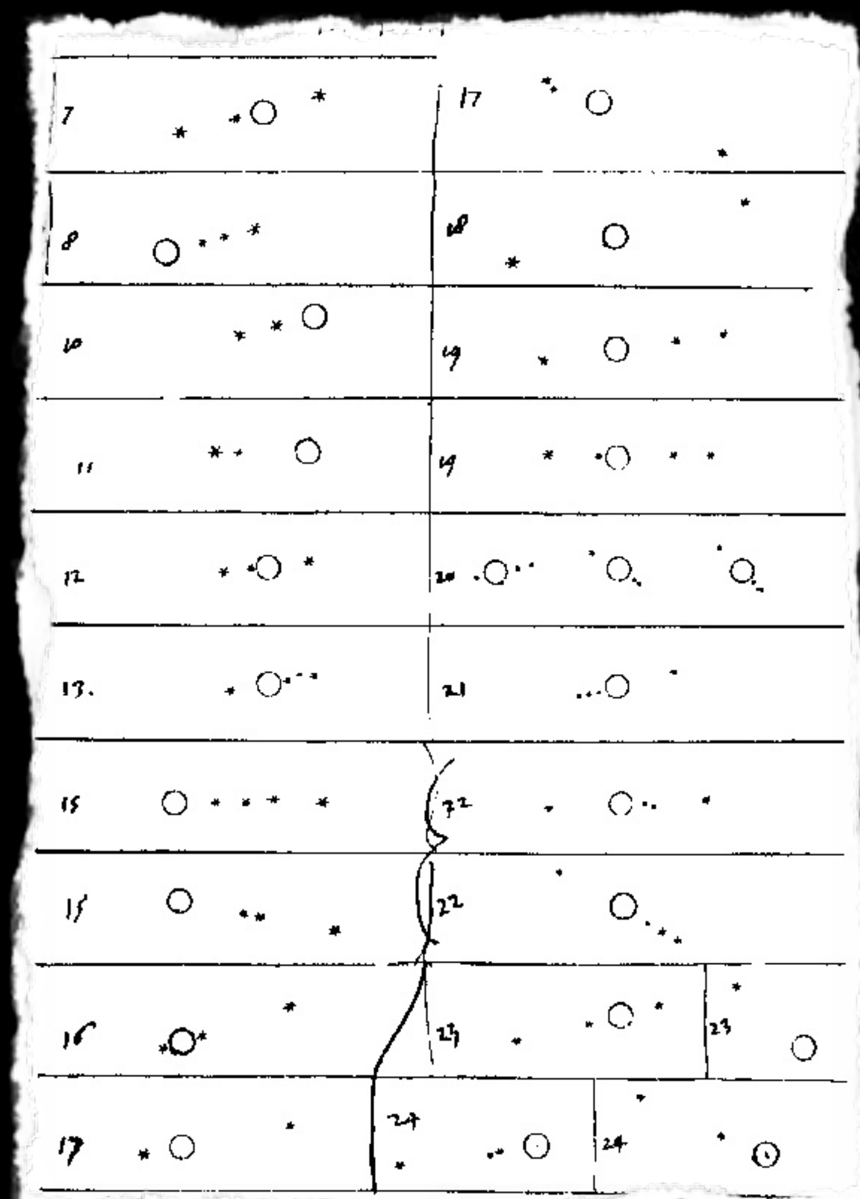
(1564–1642)

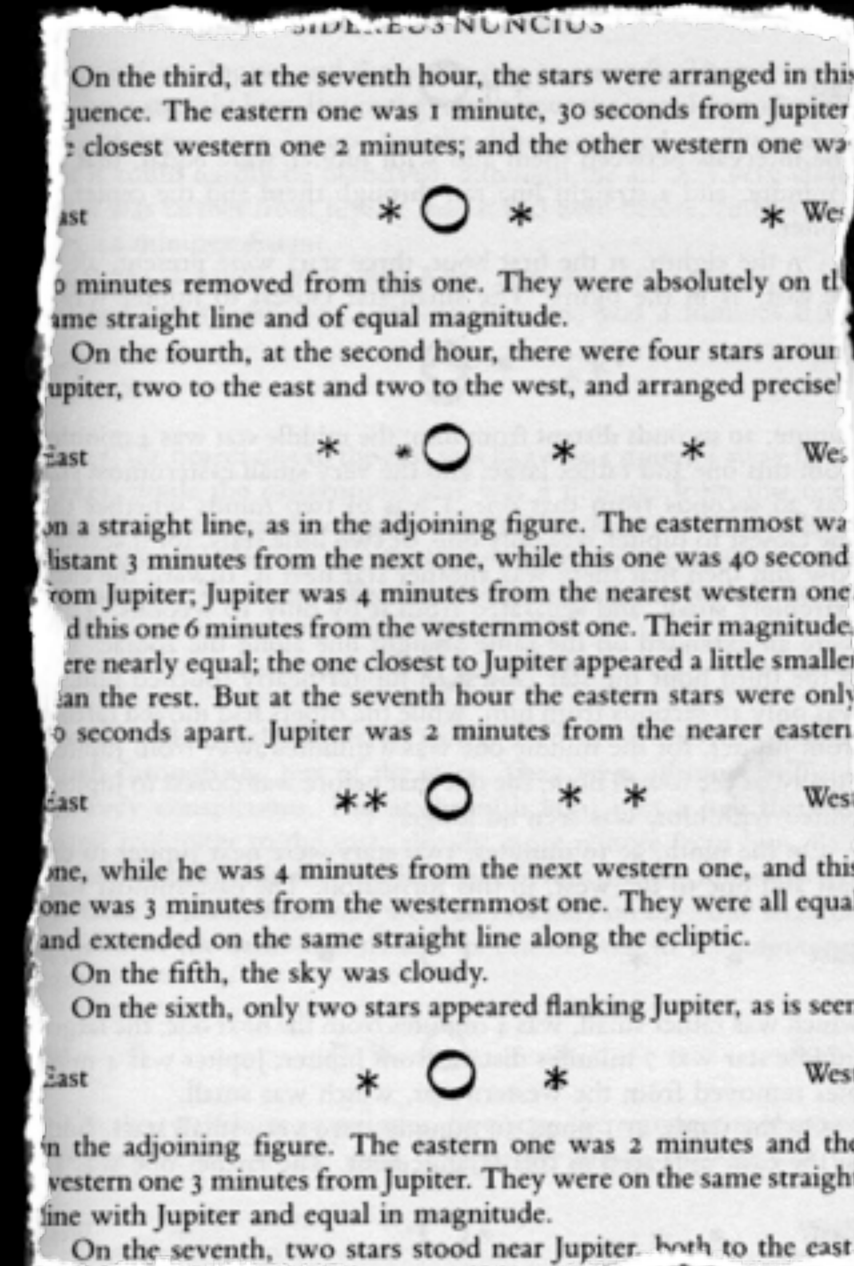


Ser.mo Principe.

Galileo Galilei Humiliss.o Servo della Ser.tà V.a

di Padova,





SIDEREUS NUNCIUS

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

East * O * * Wes

0 minutes removed from this one. They were absolutely on th ame straight line and of equal magnitude.

On the fourth, at the second hour, there were four stars arour upiter, two to the east and two to the west, and arranged precise

East * * O * * Wes

on a straight line, as in the adjoining figure. The easternmost wa listant 3 minutes from the next one, while this one was 40 second rom Jupiter; Jupiter was 4 minutes from the nearest western one d this one 6 minutes from the westernmost one. Their magnitude ere nearly equal; the one closest to Jupiter appeared a little smalle an the rest. But at the seventh hour the eastern stars were only 0 seconds apart. Jupiter was 2 minutes from the nearer eastern

East ** O * * West

one, while he was 4 minutes from the next western one, and this one was 3 minutes from the westernmost one. They were all equal and extended on the same straight line along the ecliptic.

On the fifth, the sky was cloudy.

On the sixth, only two stars appeared flanking Jupiter, as is seen

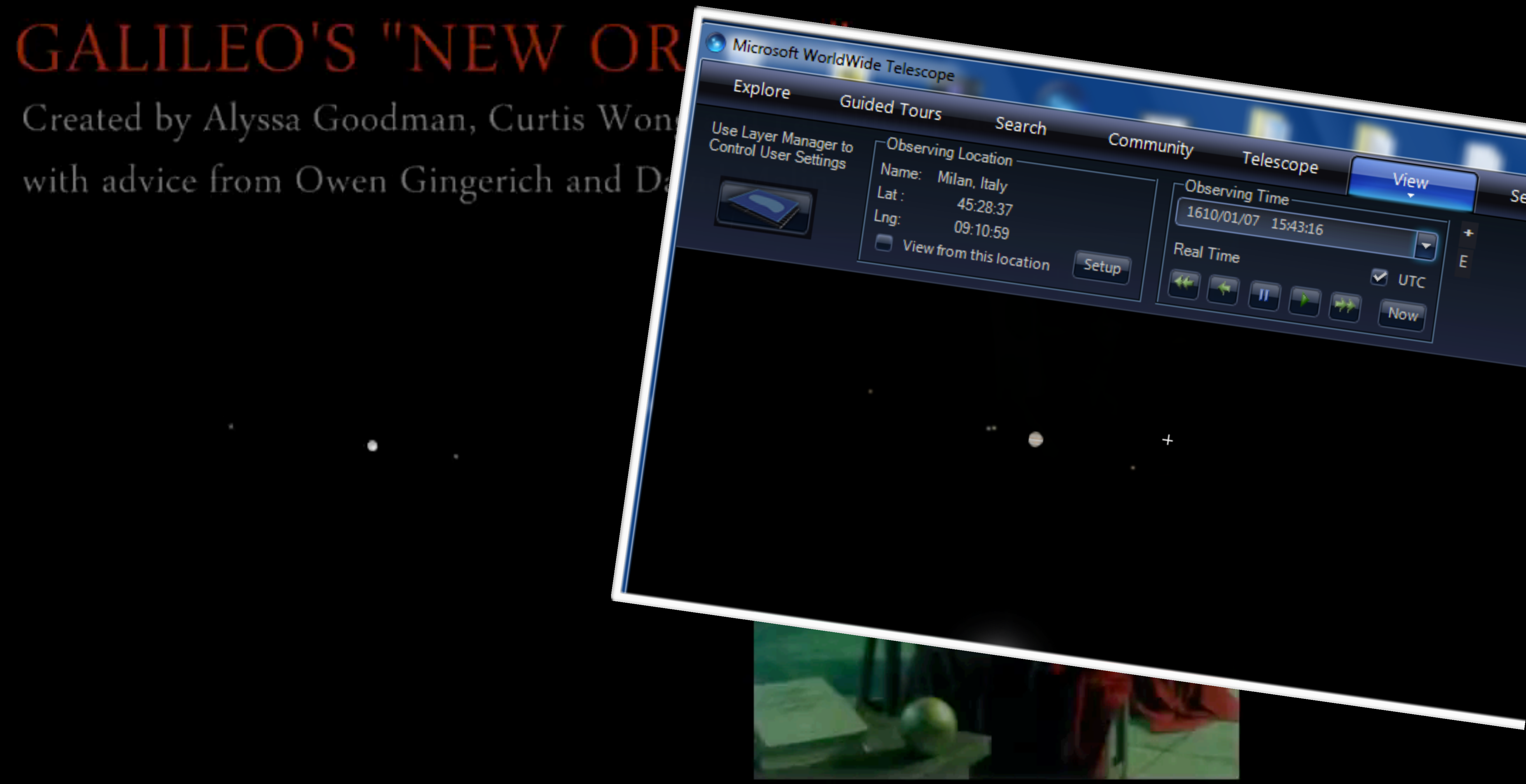
East * O * West

in the adjoining figure. The eastern one was 2 minutes and the western one 3 minutes from Jupiter. They were on the same straight line with Jupiter and equal in magnitude.

On the seventh, two stars stood near Jupiter, both to the east

Notes for & re-productions of Siderius Nuncius

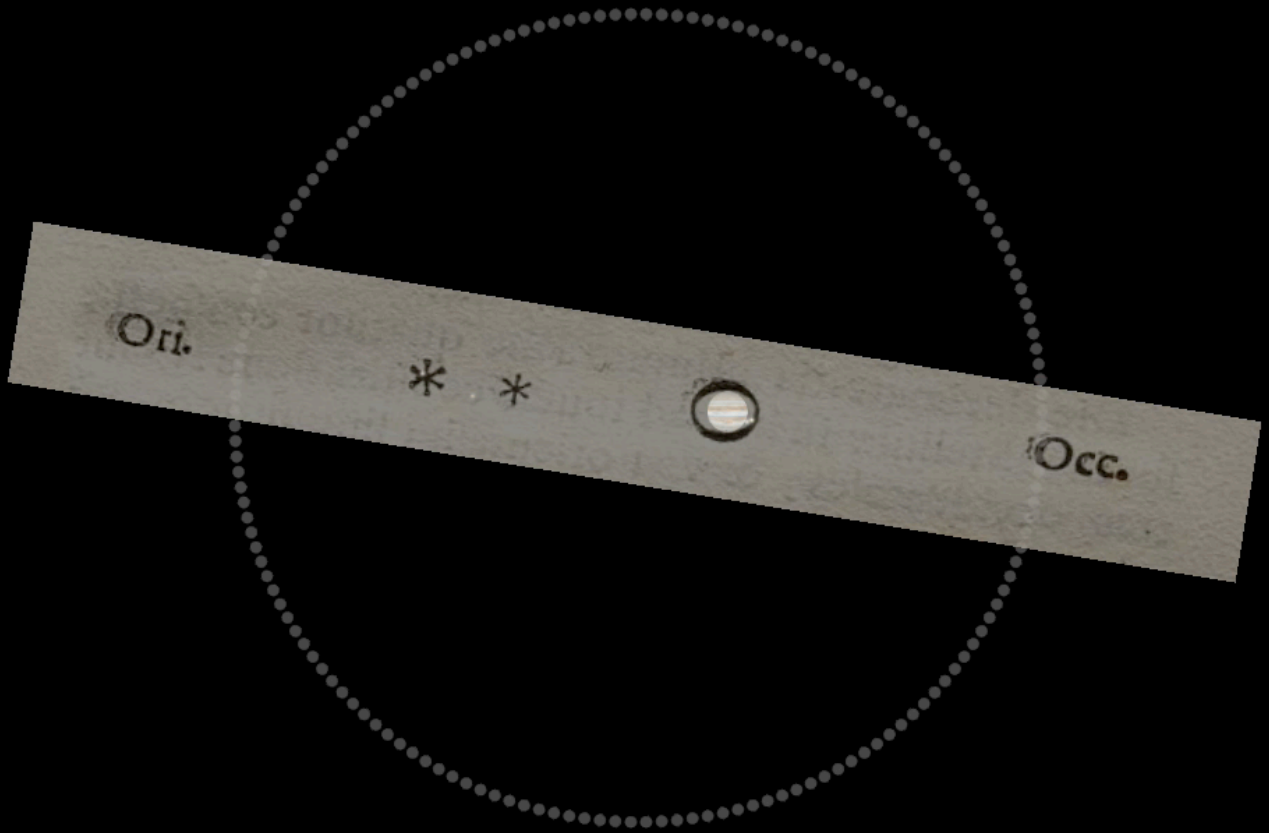
"REMOTE SENSING"



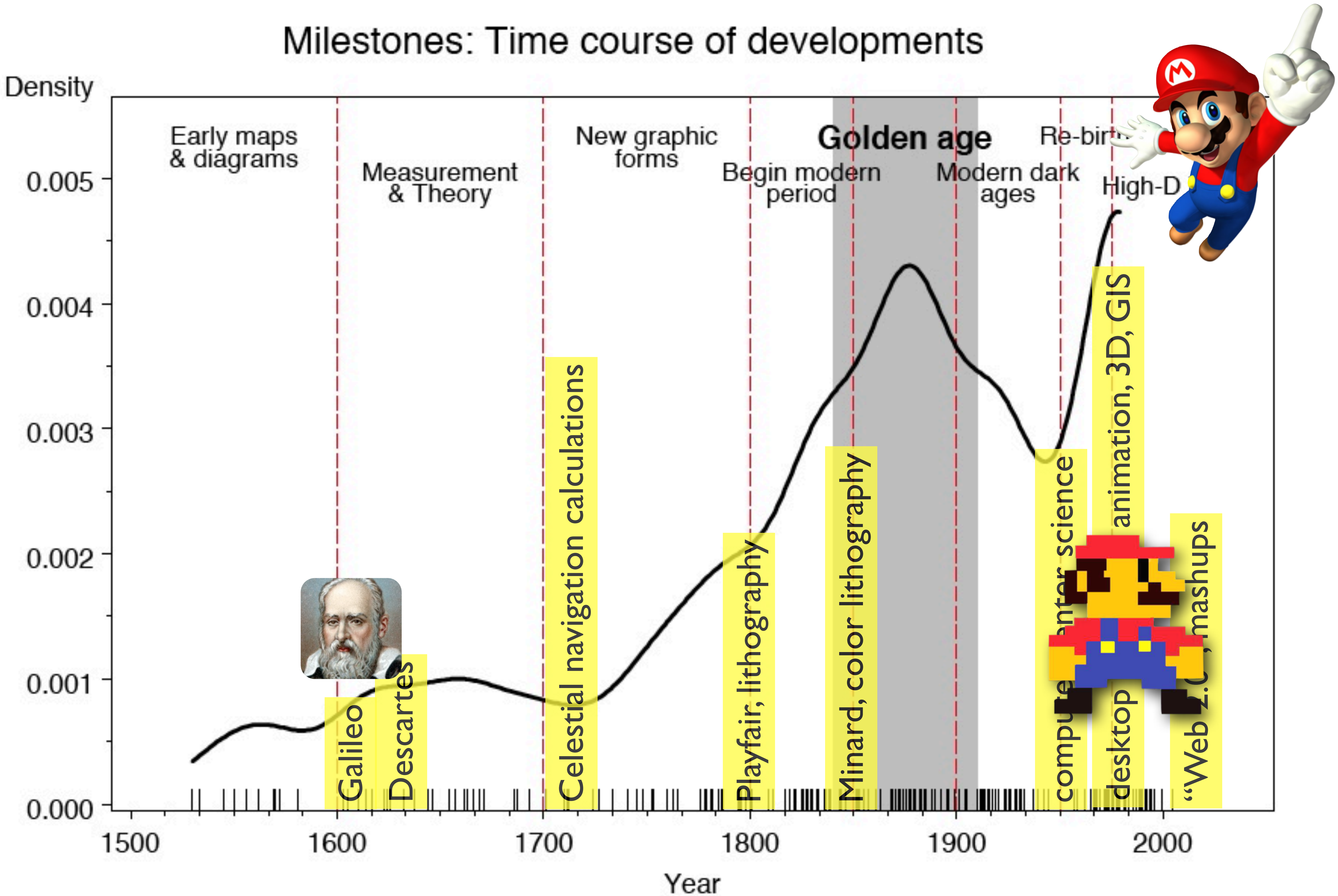
Galileo's New Order, A WorldWide Telescope Tour by Goodman, Wong & Udomprasert 2010
Microsoft Research WWT Software (~now "OpenWWT"): Wong (inventor), Fay (architect), et al.

REMOTE SENSING
+ 3D MODELLING

January 11, 1610



Galileo's New Order, A WorldWide Telescope Tour by Goodman, Wong & Udomprasert 2010
Microsoft Research WWT Software (~now "OpenWWT"): Wong (inventor), Fay (architect), et al.



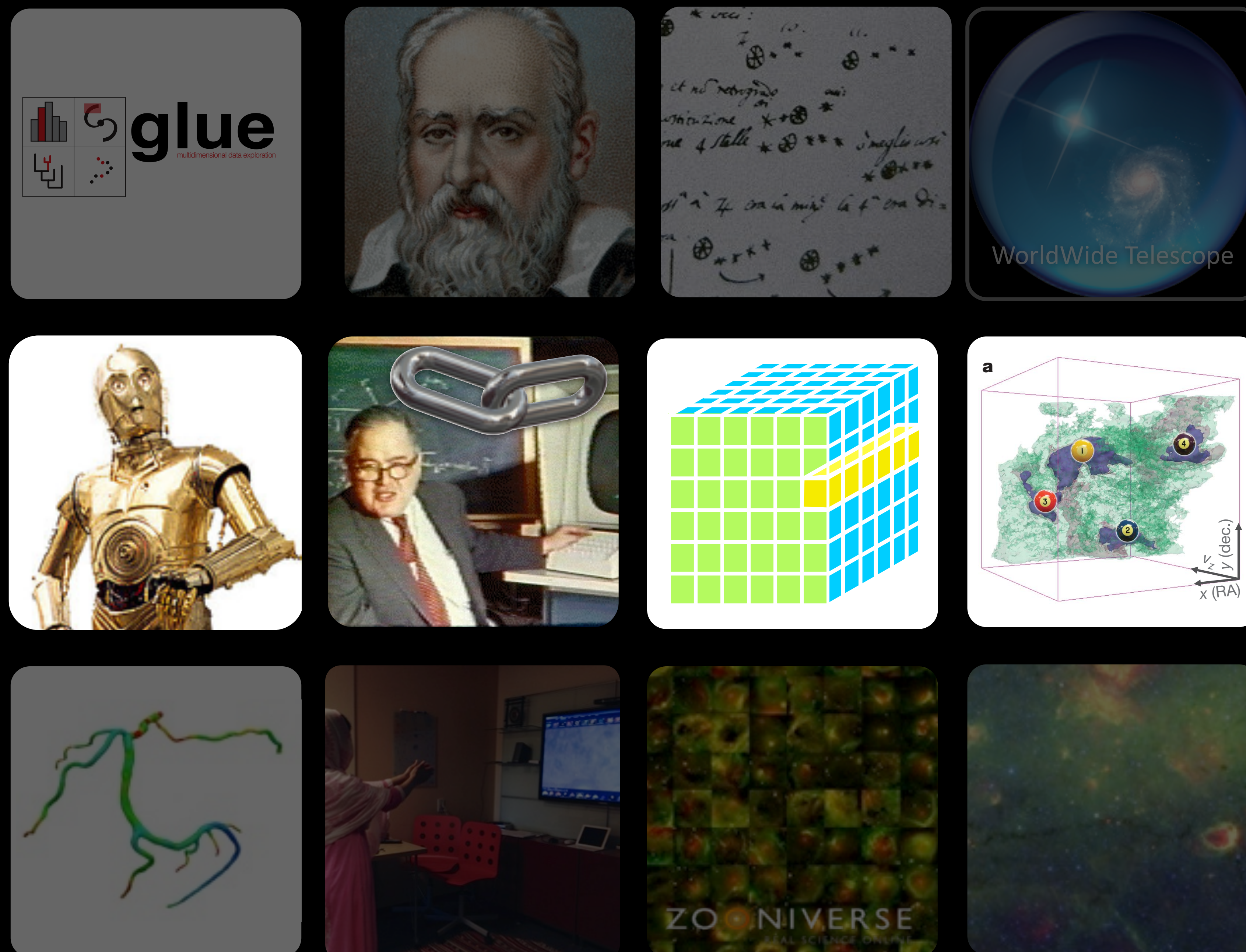
adapted from Friendly, "The Golden Age of Statistical Graphics," *Statistical Science*, 2009

1992

Super Mario Kart: Rainbow Road (1992)

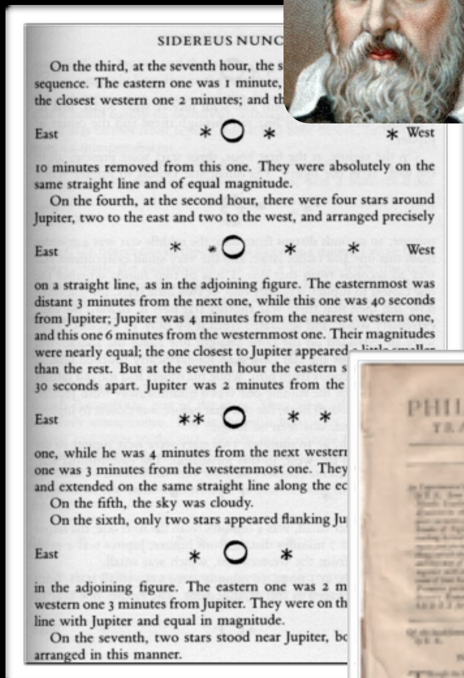
2014

Mario Kart 8: Rainbow Road (2014)


glue
WorldWide Telescope
a
y (dec.)
x (RA)
ZOONIVERSE

SCHOLARLY COMMUNICATION

1610


SIDEREUS NUNC

On the third, at the seventh hour, the s sequence. The eastern one was 1 minute, the closest western one 2 minutes; and th

East * ○ * * West

10 minutes removed from this one. They were absolutely on the same straight line and of equal magnitude.

On the fourth, at the second hour, there were four stars around Jupiter, two to the east and two to the west, and arranged precisely

East * ·○ * * West

on a straight line, as in the adjoining figure. The easternmost was distant 3 minutes from the next one, while this one was 40 seconds from Jupiter; Jupiter was 4 minutes from the nearest western one, and this one 6 minutes from the westernmost one. Their magnitudes were nearly equal; the one closest to Jupiter appeared a little smaller than the rest. But at the seventh hour the eastern s 30 seconds apart. Jupiter was 2 minutes from the

East ** ○ * *

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On the fifth, the sky was cloudy.

On the sixth, only two stars appeared flanking Ju

East * ○ *

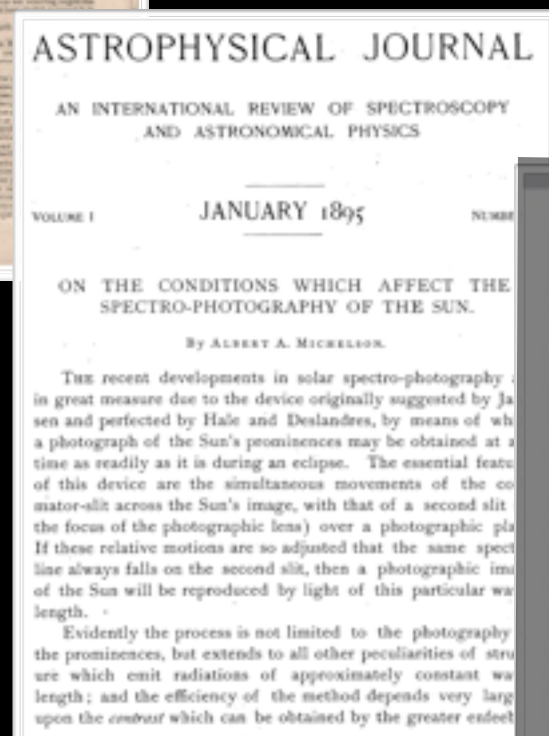
in the adjoining figure. The eastern one was 2 m western one 3 minutes from Jupiter. They were on th line with Jupiter and equal in magnitude.

On the seventh, two stars stood near Jupiter, bo arranged in this manner.

1665


PHILOSOPHICAL TRANSACTIONS

1895


ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY AND ASTRONOMICAL PHYSICS

VOLUME I JANUARY 1895 NUMBE

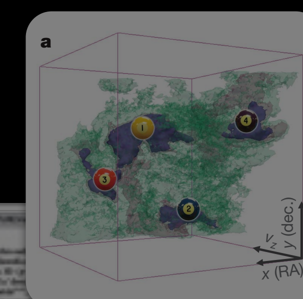
ON THE CONDITIONS WHICH AFFECT THE SPECTRO-PHOTOGRAPHY OF THE SUN.

By Albert A. Michelson.

The recent developments in solar spectro-photography in great measure due to the device originally suggested by Ja sen and perfected by Hale and Deslandres, by means of wh a photograph of the Sun's prominences may be obtained at a time as readily as it is during an eclipse. The essential featu of this device are the simultaneous movements of the co mator-slit across the Sun's image, with that of a second slit the focus of the photographic lens) over a photographic pla If these relative motions are so adjusted that the same spect line always falls on the second slit, then a photographic ima of the Sun will be reproduced by light of this particular wa length.

Evidently the process is not limited to the photography the prominences, but extends to all other peculiarities of stru ure which emit radiations of approximately constant wa length; and the efficiency of the method depends very larg upon the *contrast* which can be obtained by the greater enfeet

2009



2015


Authorea

The "Paper" of the Future

Alyssa Goodman, Josh Peek, Alberto Accomazzi, Chris Beaumont, Christine L. Borgman, How-Huan Hope Chen, Merce Crosas, Christopher Erdmann, August Muench, Alberto Pepe, Curtis Wong

A 5-minute video demonstration of this paper is available at this YouTube link.

1 Preamble

A variety of research on human cognition demonstrates that humans learn and communicate best when more than one processing system (e.g. visual, auditory, touch) is used. And, related research also shows that, no matter how technical the material, most humans also retain and process information best when they can put a narrative "story" to it. So, when considering the future of scholarly communication, we should be careful not to do blithely away with the linear narrative format that articles and books have followed for centuries: instead, we should enrich it.

Much more than text is used to commuicate in Science. Figures, which include images, diagrams, graphs, charts, and more, have enriched scholarly articles since the time of Galileo, and ever-growing volumes of data underpin most scientific papers. When scientists communicate face-to-face, as in talks or small discussions, these figures are often the focus of the conversation. In the best discussions, scientists have the ability to manipulate the figures, and to access underlying data, in real-time, so as to test out various what-if scenarios, and to explain findings more clearly. **This short article explains—and shows with demonstrations—how scholarly "papers" can morph into long-lasting rich records of scientific discourse,** enriched with deep data and code linkages, interactive figures, audio, video, and commenting.

WorldWide Telescope

glue

Au
Authorea

Au Authorea

FEATURED ARTICLES ABOUT PLANS BLOG FEEDBACK HELP ALYSSA GOODMAN

PUBLIC ROUGH DRAFT Index Settings Fork Quickedit Word Count 42 Comments Export Unfollow

The "Paper" of the Future

3

Alyssa Goodman, Josh Peek, Alberto Accomazzi, Chris Beaumont, Christine L. Borgman, How-Huan Hope Chen, Merce Crosas, Christopher Erdmann, August Muench, Alberto Pepe, Curtis Wong + Add author Re-arrange authors

A 5-minute video demonsration of this paper is available at this YouTube link.

2

1 Preamble

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0

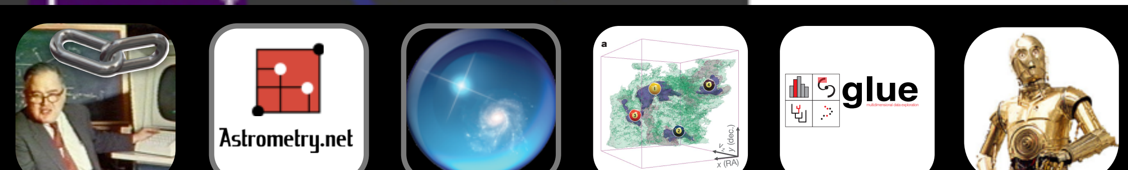
Konrad Hinsen 3 days ago · Public
Many good suggestions, but if the goal is "long-lasting rich records of scientific discourse", a more careful and critical attitude towards electronic artifacts is appropriate. I do see it concerning videos, but not a word on the much more critical situation in software. Archiving source code is not sufficient: all the dependencies, plus the complete build environment, would have to be conserved as well to make things work a few years from now. An "executable figure" in the form of an IPython notebook wil...
more

Merce Crosas 3 days ago · Public
Konrad, good points; this has been a concern for the community working on reproducibility. Regarding data repositories, Dataverse handles long-term preservation and access of data files in the following way: 1) for some data files that the repository recognizes (such as R Data, SPSS, STATA), which depend on a statistical package, the system converts them into a preservation format (such as a tab/CSV format). Even though the original format is also saved and can be accessed, the new preservation format gua...
more

Konrad Hinsen 1 day ago · Public
That sounds good. I hope more repositories will follow the example of Dataverse. Figshare in particular has a very different attitude, encouraging researchers to deposit as much as possible. That's perhaps a good strategy to change habits, but in the long run it could well backfire when people find out in a few years that 90% of those deposits have become useless.

Christine L. Borgman 4 months ago · Private
"publications"

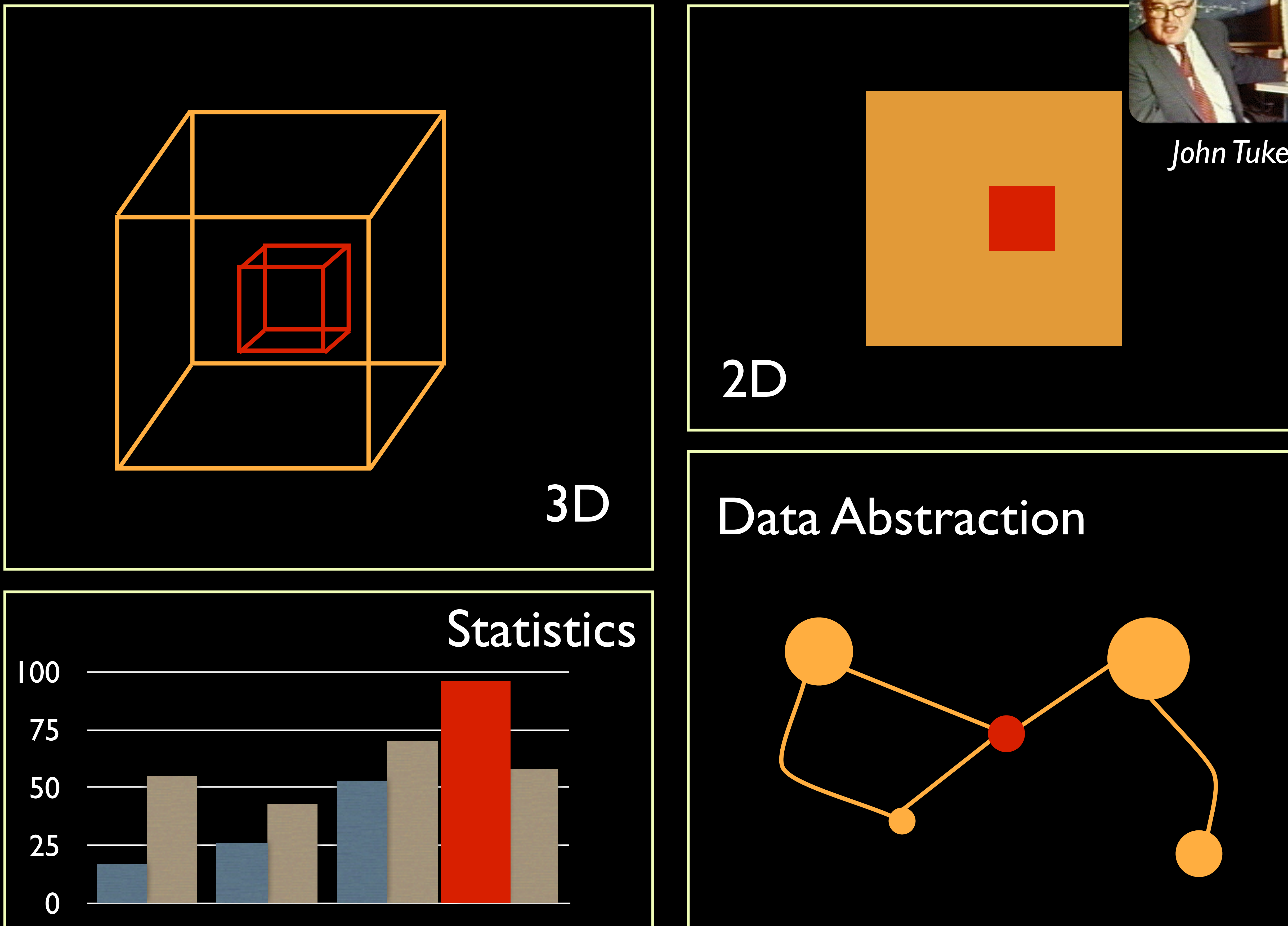
d3po/Authorea: Peek, Price-Whelan, Pepe, Beaumont, Borkin, Newton; PoF: Goodman, Peek; WWT: Wong, Fay et al.; Astrometry.net: Hogg, Lang, Roweis et al.



[video, demos]

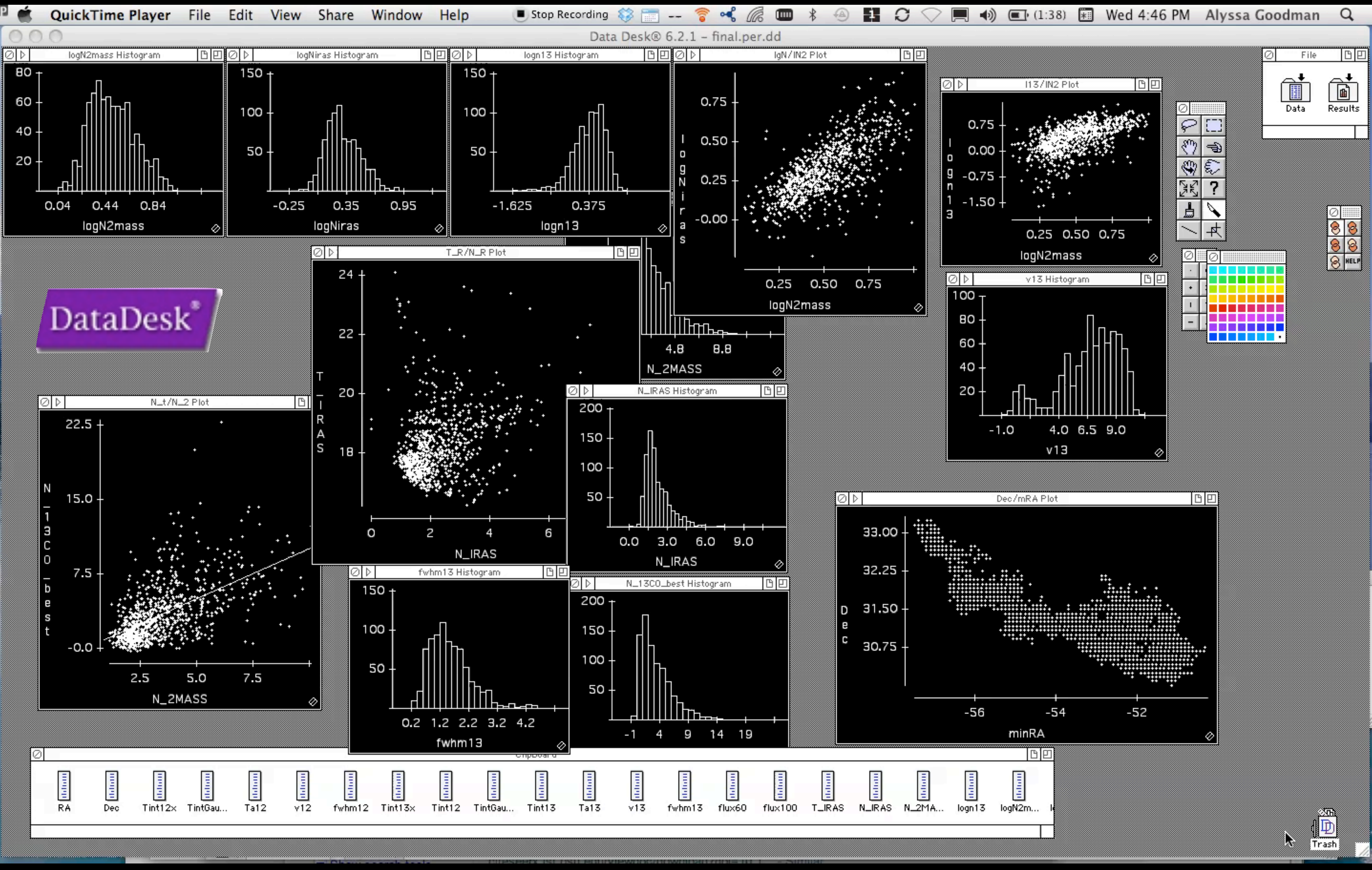
LINKED VIEWS OF HIGH-DIMENSIONAL DATA

John Tukey



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

DATADESK (EST. 1986)



JOHN TUKEY'S LEGACY

PRIM-9 → DataDesk →

PRIM-H

glue

XGobi → GGobi →

RGGobi

Spotfire →

Polaris → tableau software

1970 1980 1990 2000 2010

DATADESK + "STANDARD" 2D POLYGONS

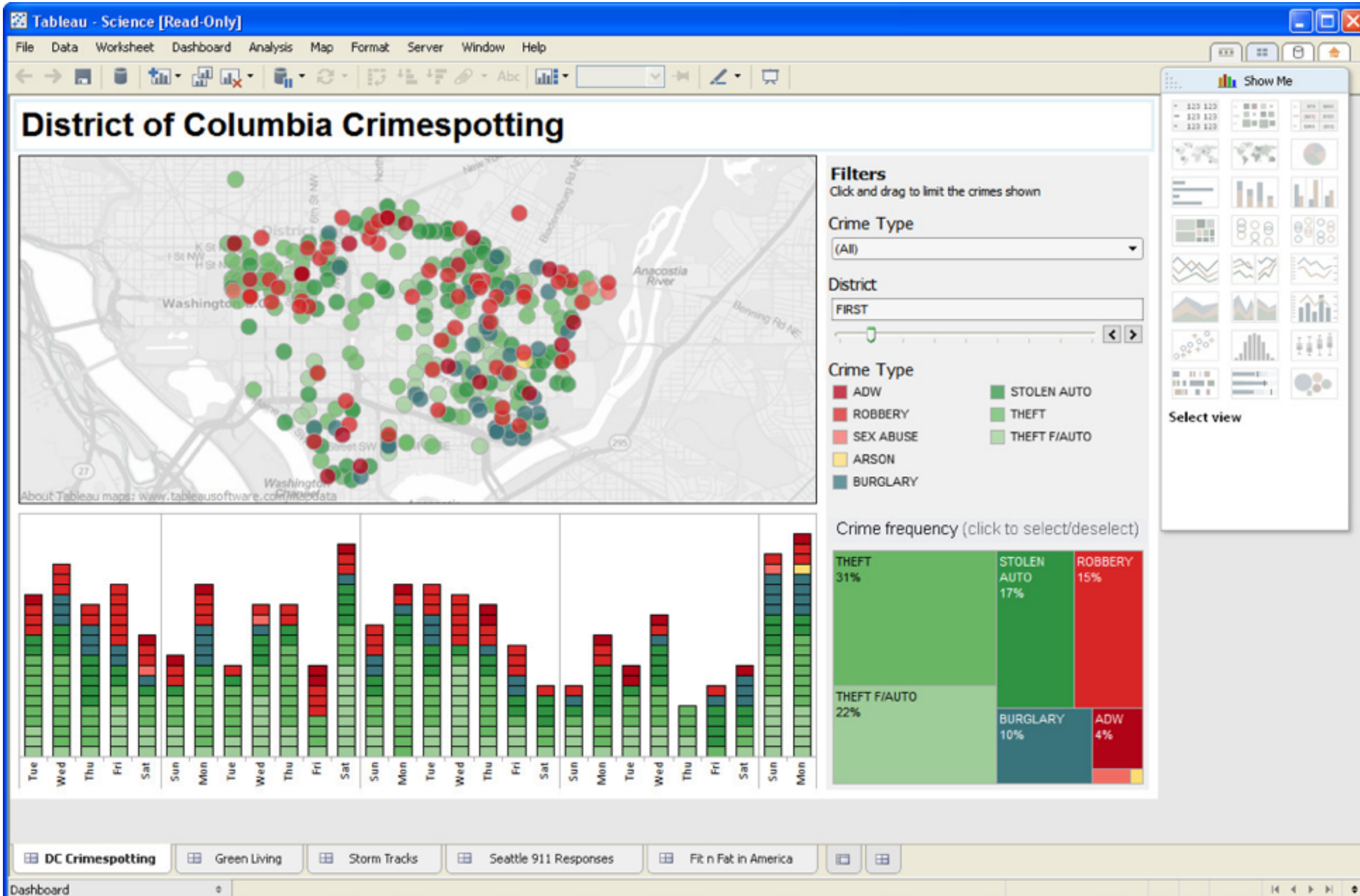
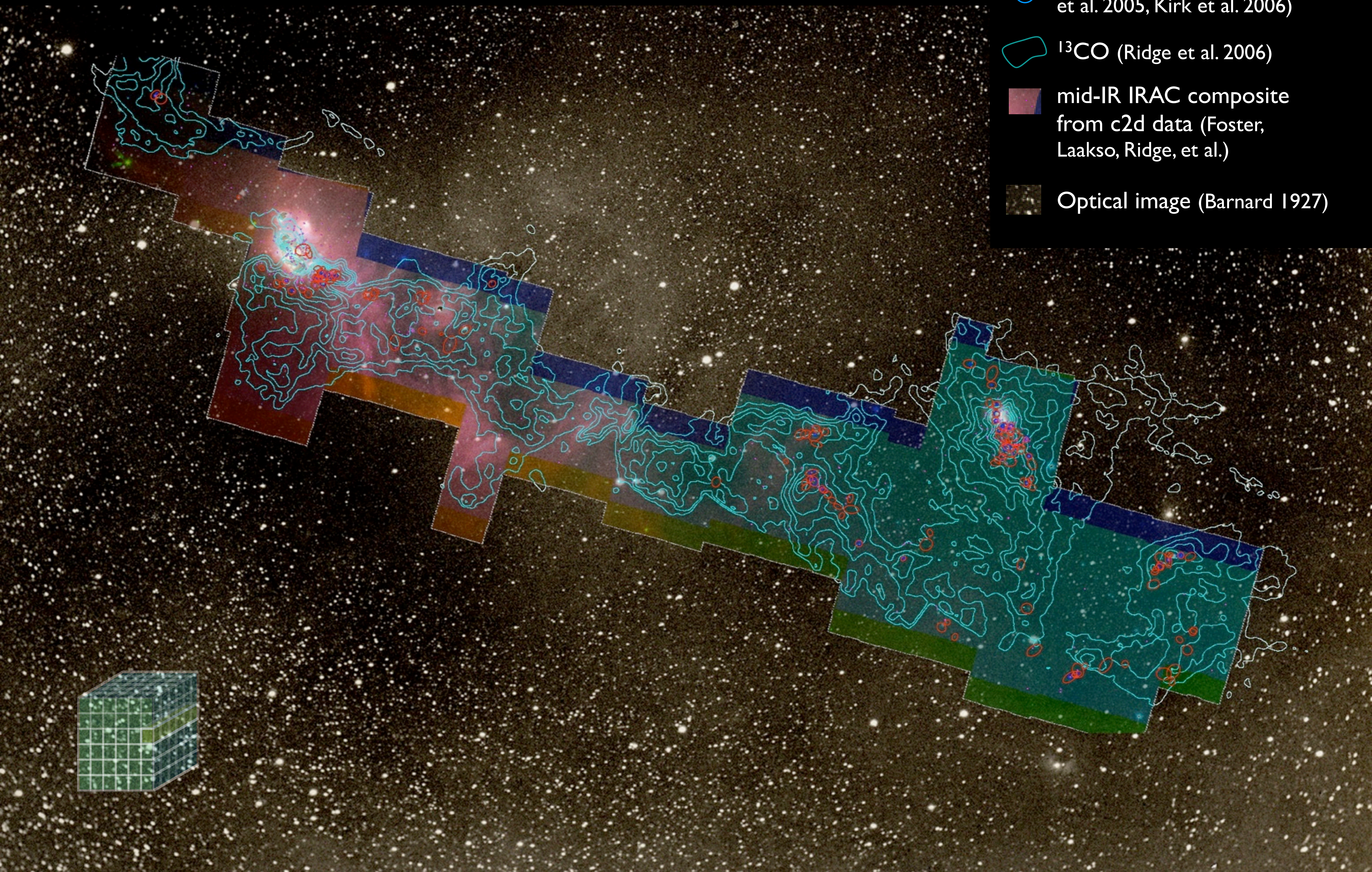


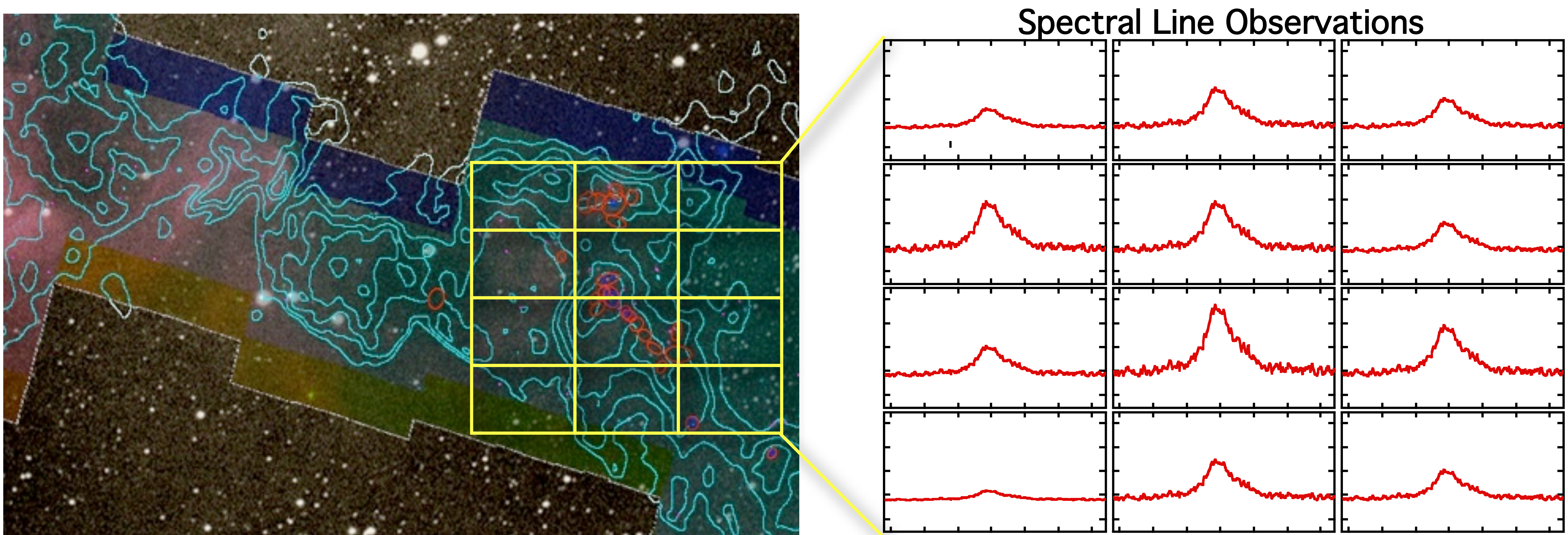
image credit: htableau-32-bit.software.informer.com/screenshot/432751/

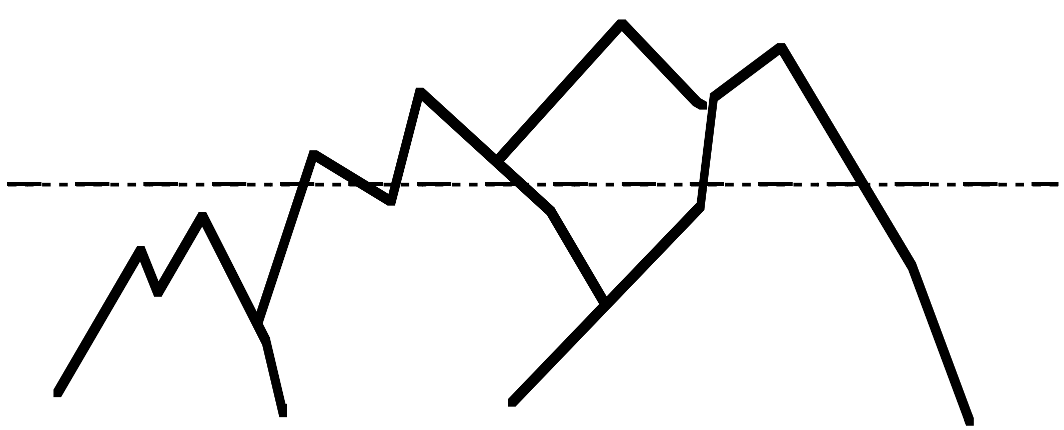
WIDE DATA

COMPLETE

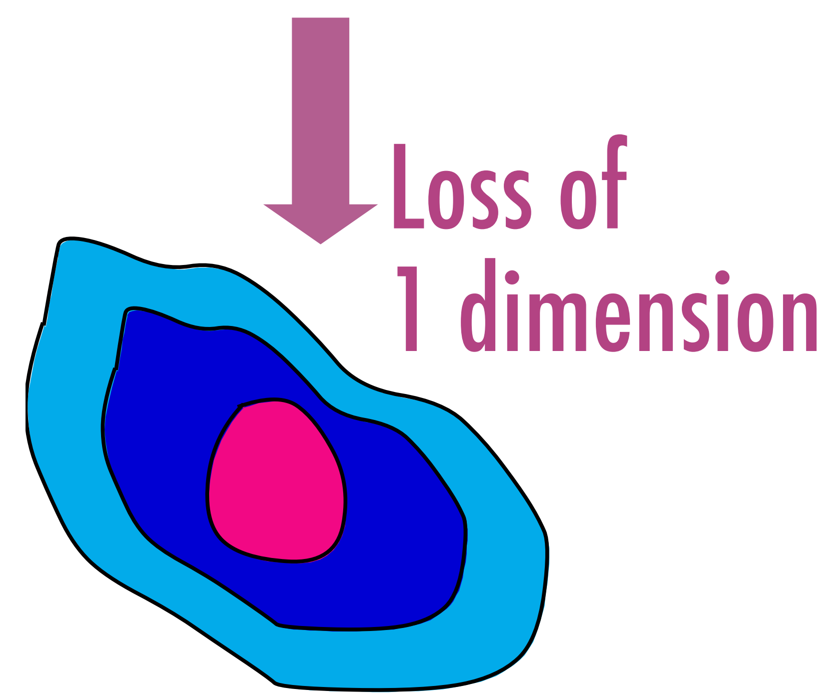


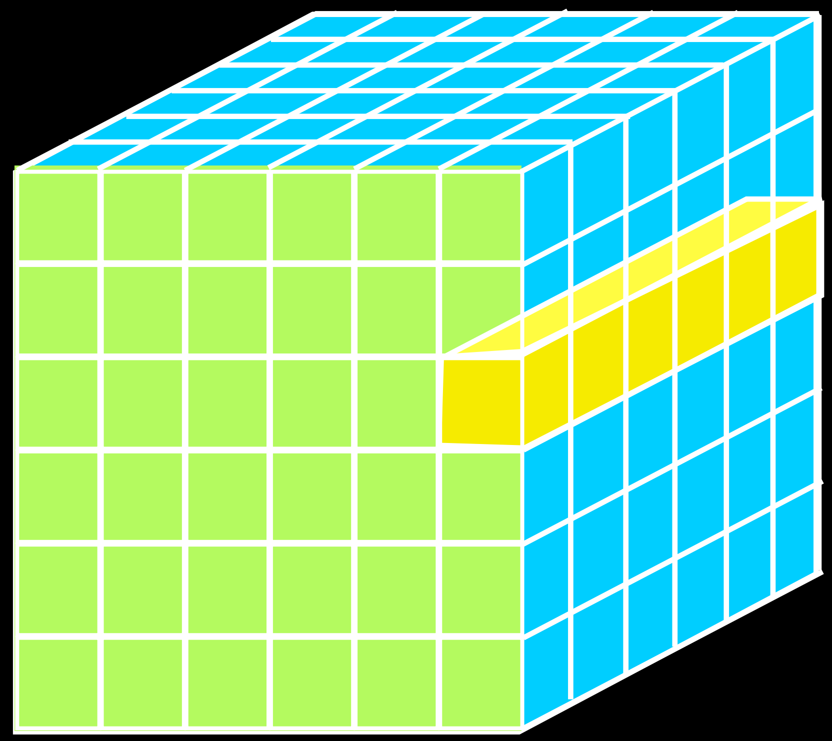
HIDDEN "3D" IN ASTRONOMY





No loss of information

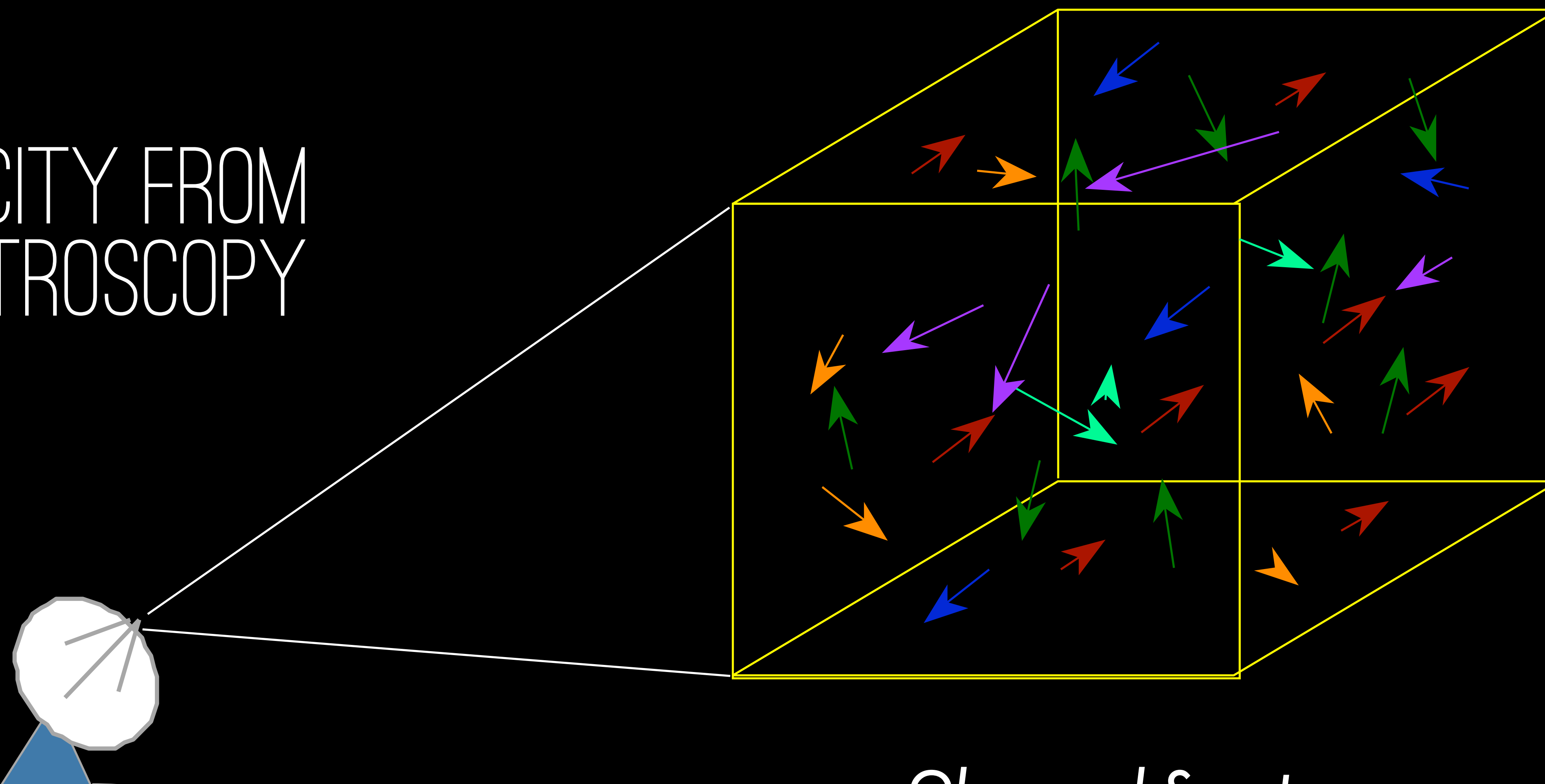




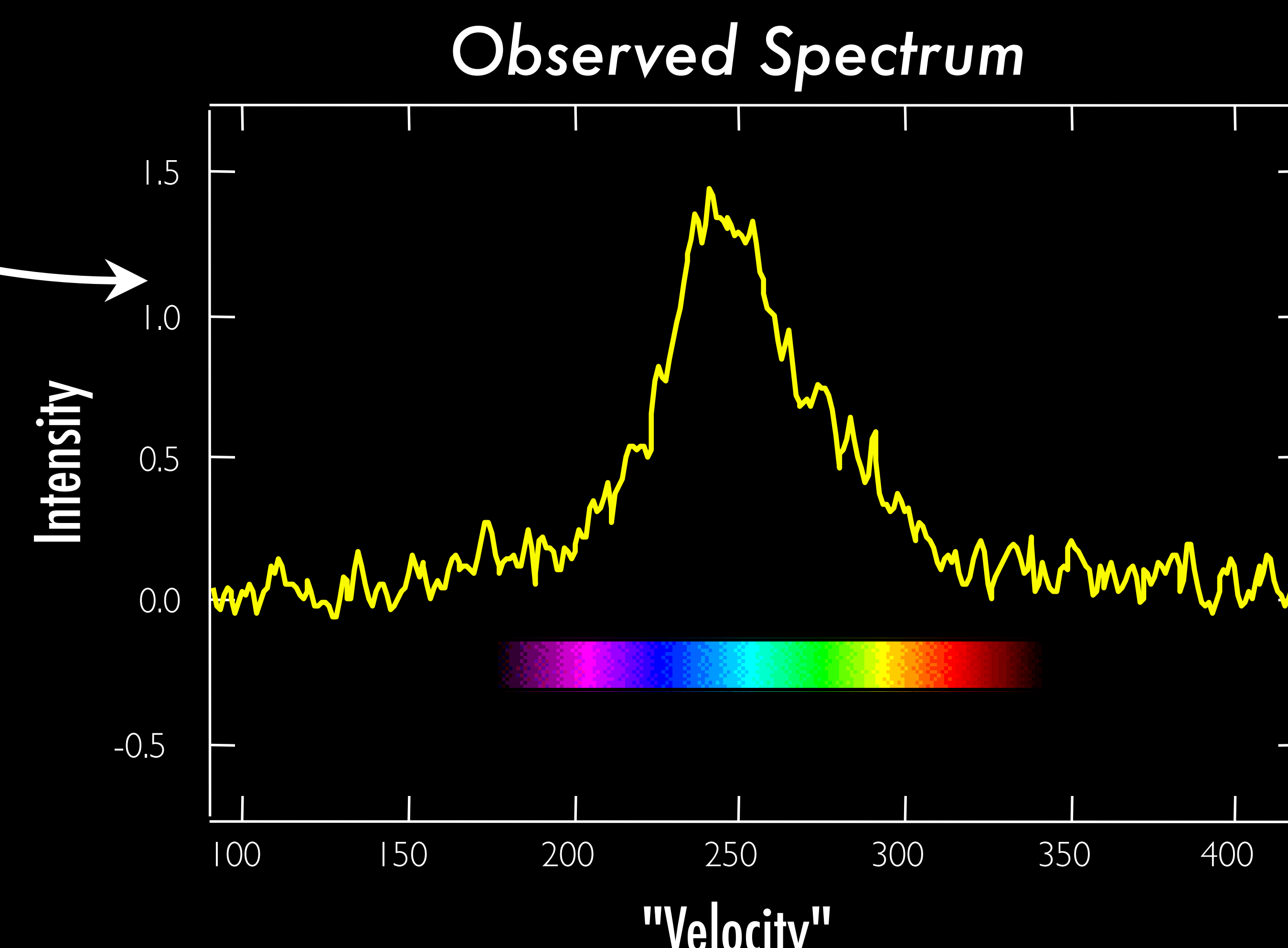
THINKING ABOUT DIMENSIONS

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

VELOCITY FROM SPECTROSCOPY



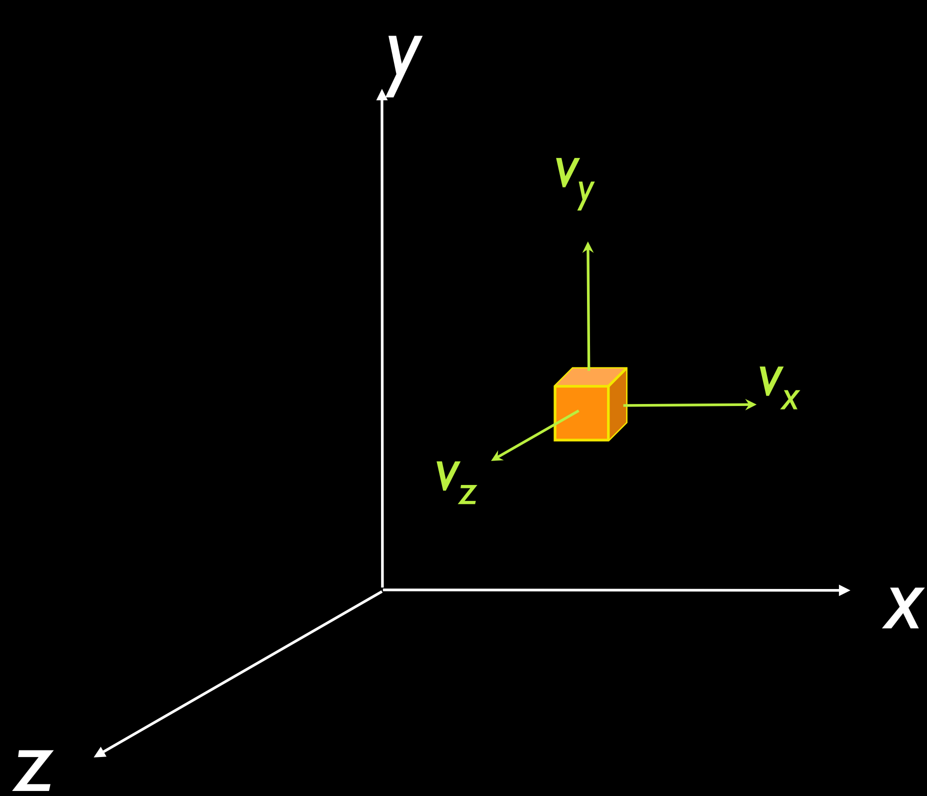
Telescope + Spectrometer

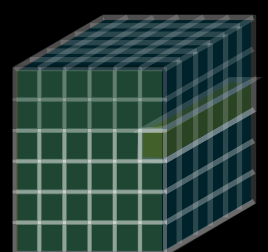


All thanks to Doppler

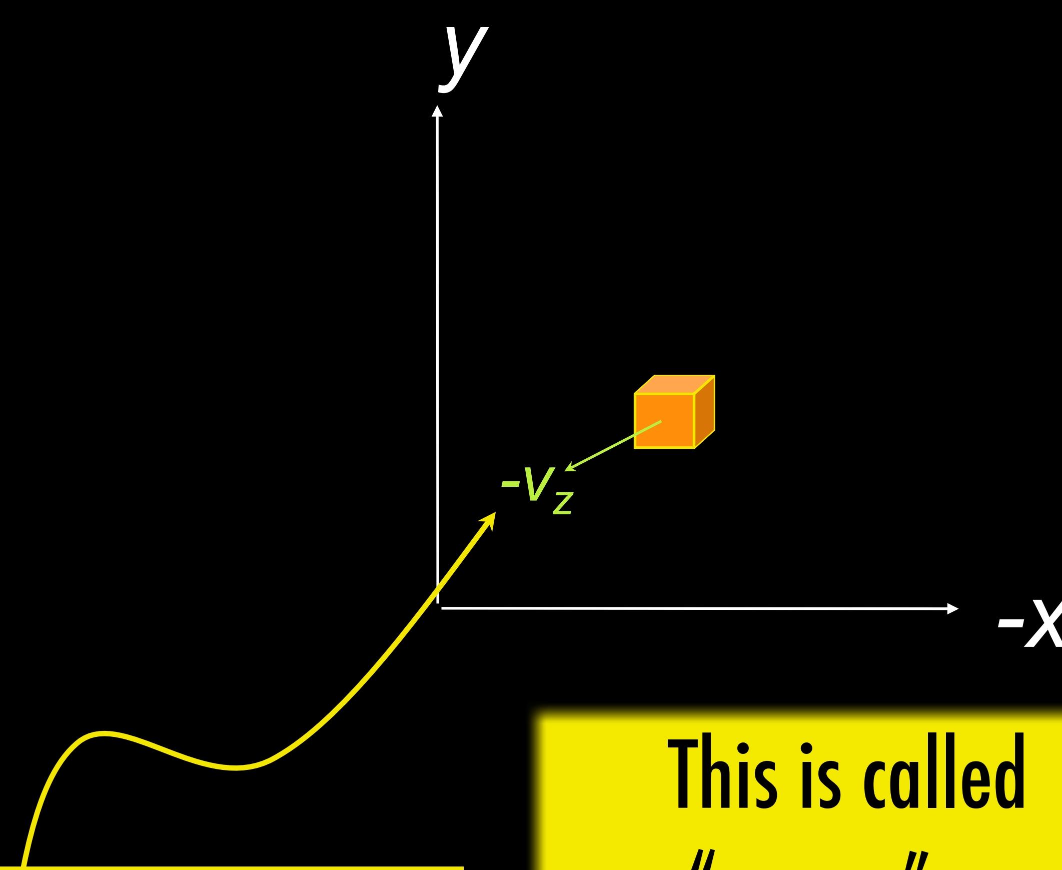
SPECTRAL-LINE MAPPING GIVES A "THIRD" DIMENSION

We wish we could measure...





But we can measure...

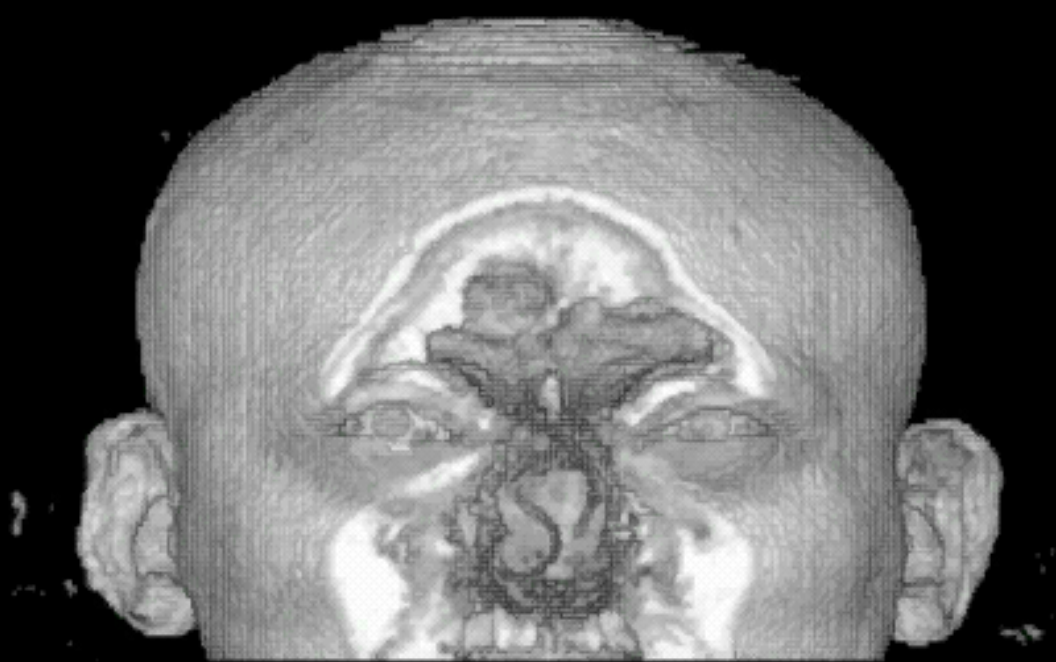


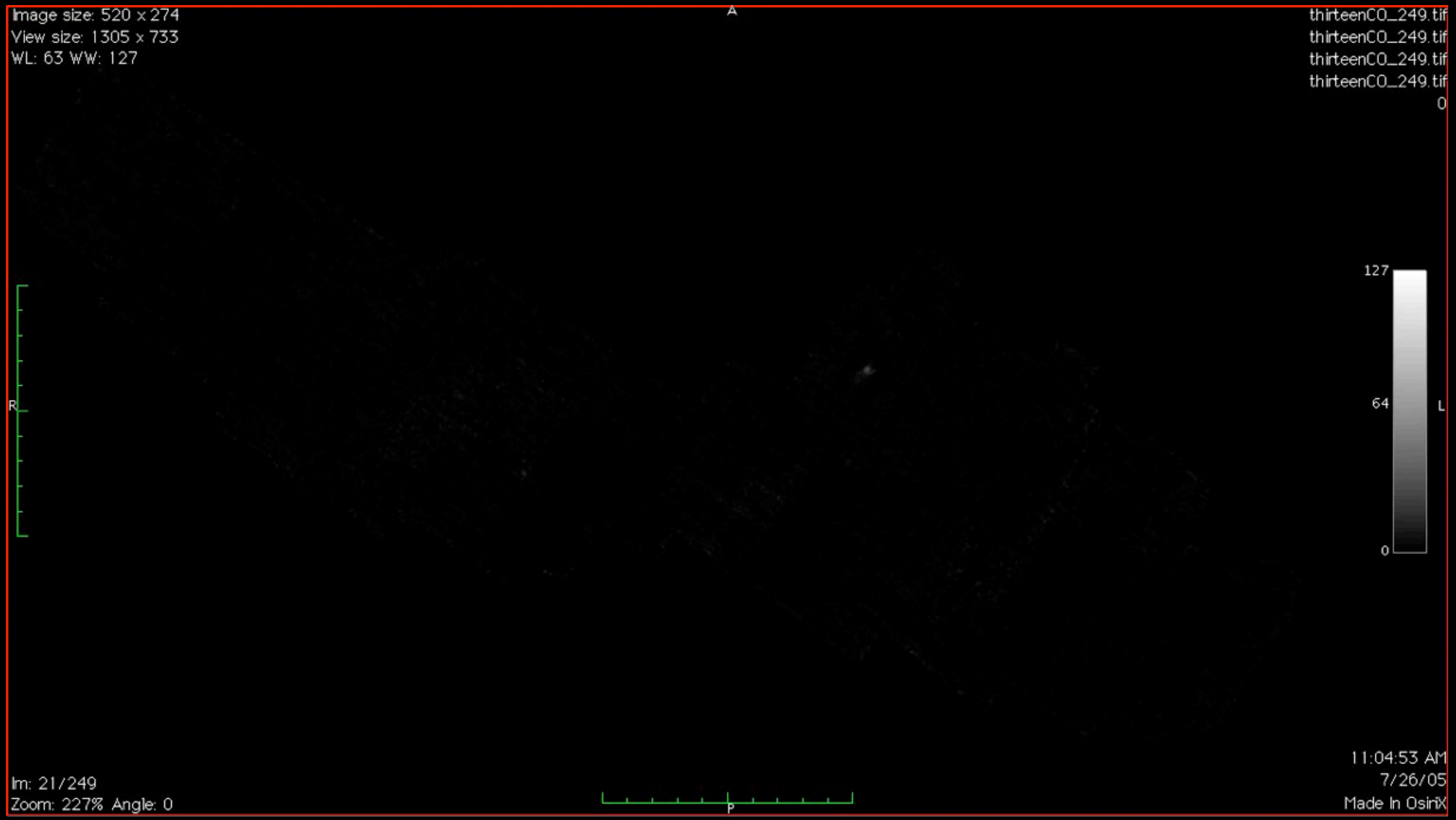
v_z only
from
"spectral-line maps"

This is called
"*p-p-v*" or
"position-position-velocity" space.

AstronomicalMedicine@IIC

“KEITH”	“PERSEUS”





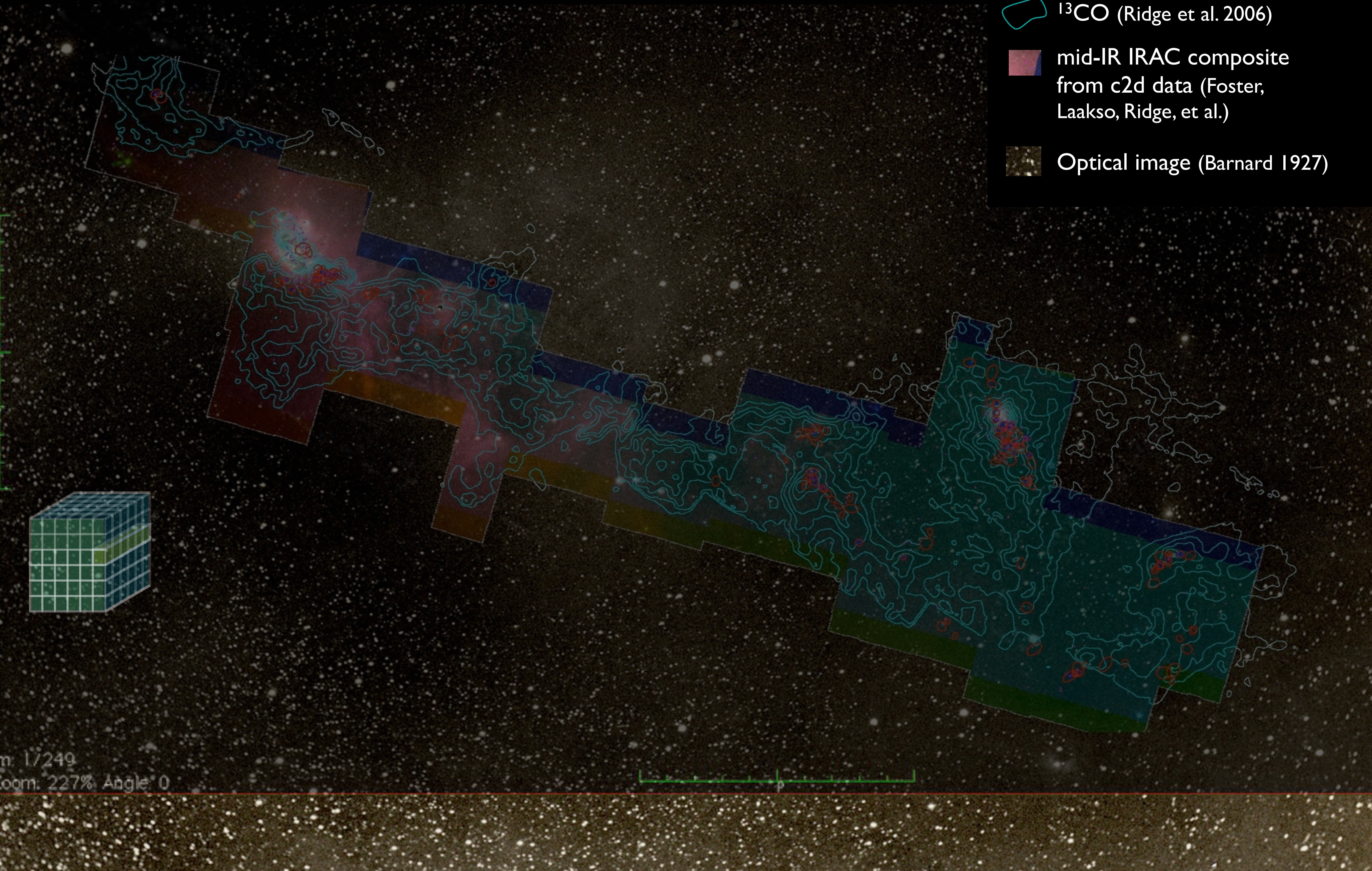
“z” is depth into head

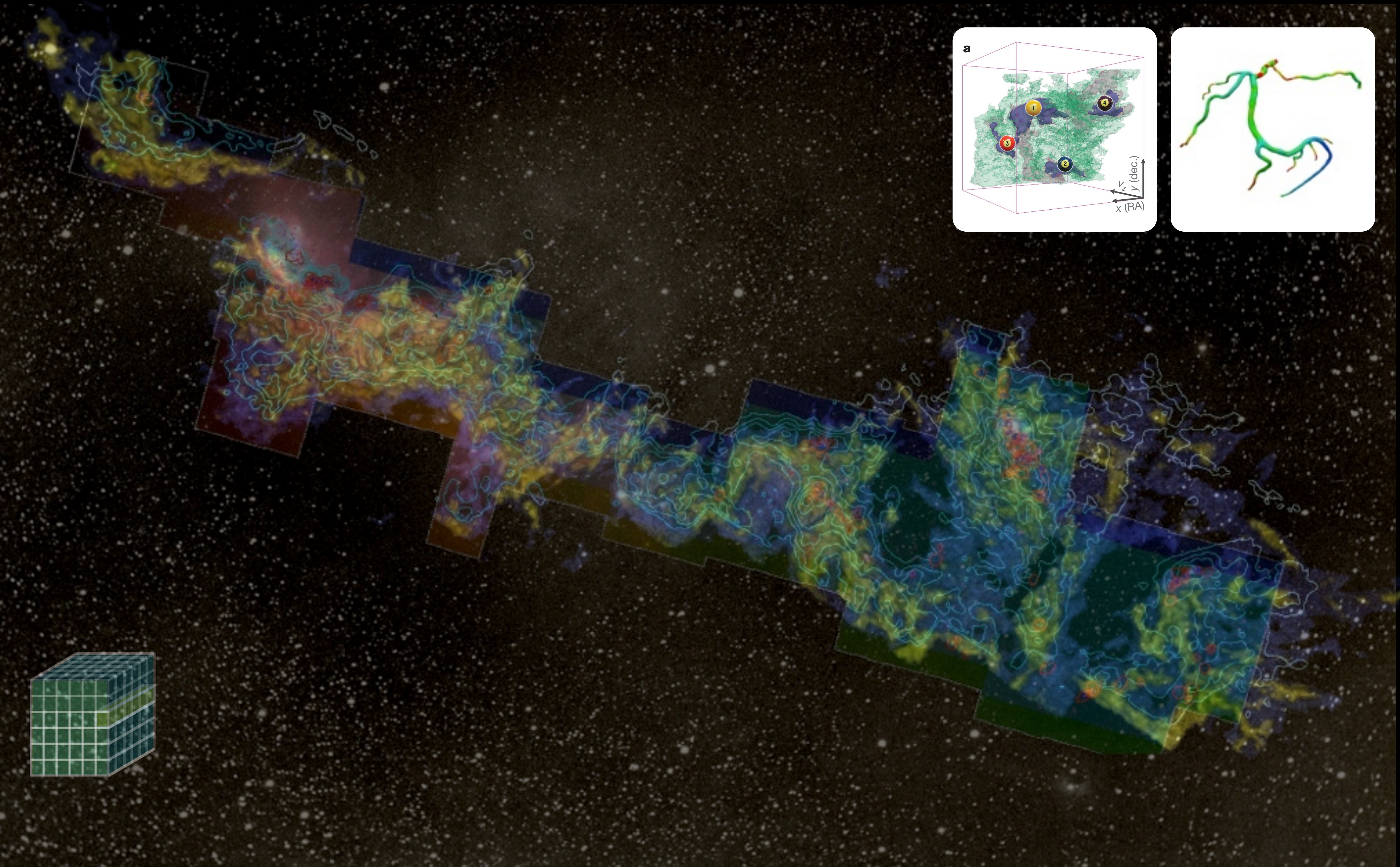
“z” is line-of-sight velocity

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

WIDE DATA, "IN 3D"

- 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)





3D Viz made with VolView

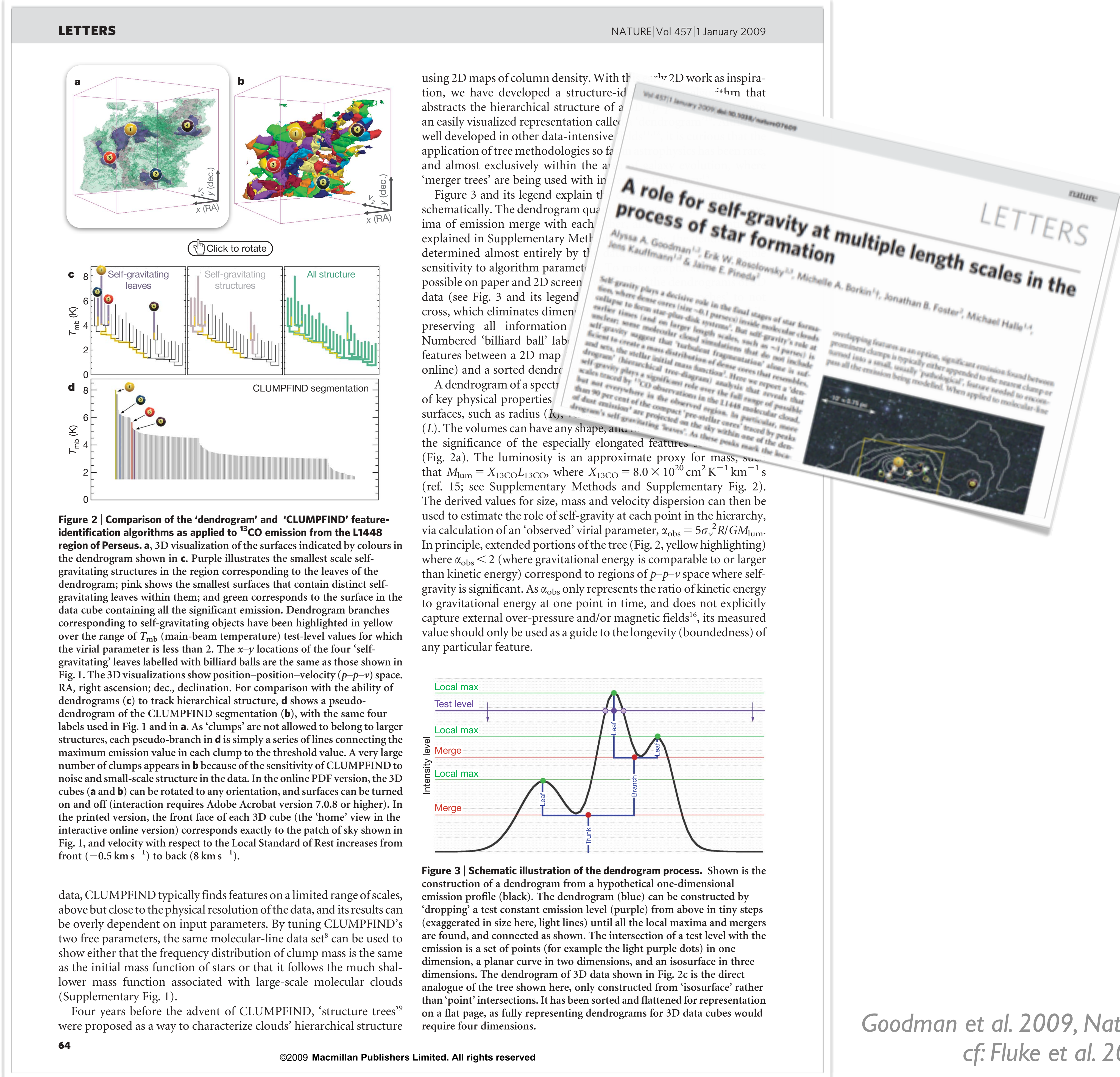
AstronomicalMedicine@IIC

COMPLETE

2009

3D PDF

INTERACTIVITY IN A "PAPER"



Click to rotate

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[...]ly 2D work as inspiration, we have developed a structure-id[...]ithm that abstracts the hierarchical structure of a[...] an easily visualized representation calle[...] well developed in other data-intensive[...] application of tree methodologies so fa[...] and almost exclusively within the a[...] '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 paramet[...] possible on paper and 2D screen[...] data (see Fig. 3 and its legend[...] cross, which eliminates dimen[...] preserving all information[...] Numbered 'billiard ball' lab[...] features between a 2D map[...] online) and a sorted dendro[...]

A dendrogram of a spectr[...] of key physical properties[...] surfaces, such as radius (R),[...] (L). The volumes can have any shape, and[...] the significance of the especially elongated features[...] (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, $\alpha_{obs} = 5\sigma_v^2 R / G M_{lum}$. 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.

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

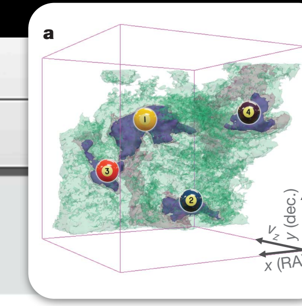
nature

LETTERS

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

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

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



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

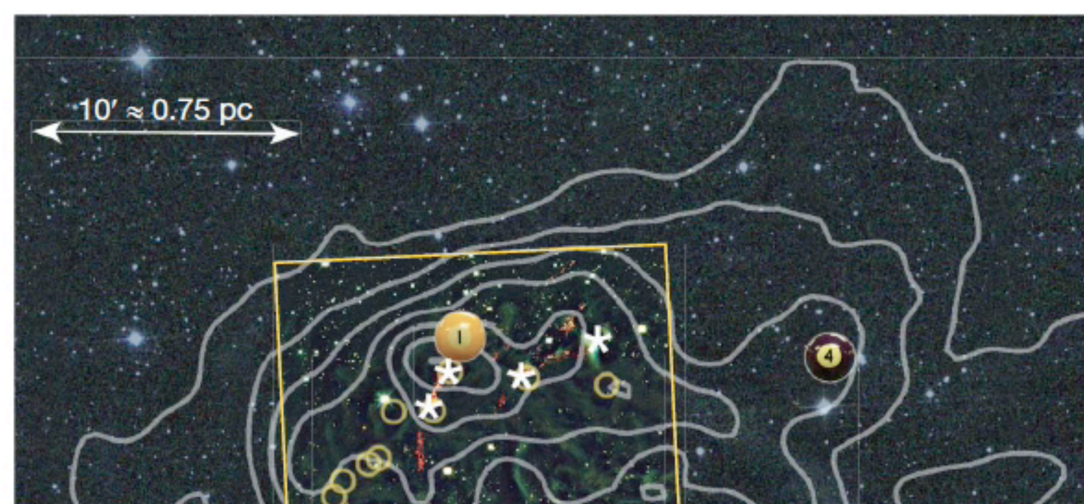
LETTERS

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

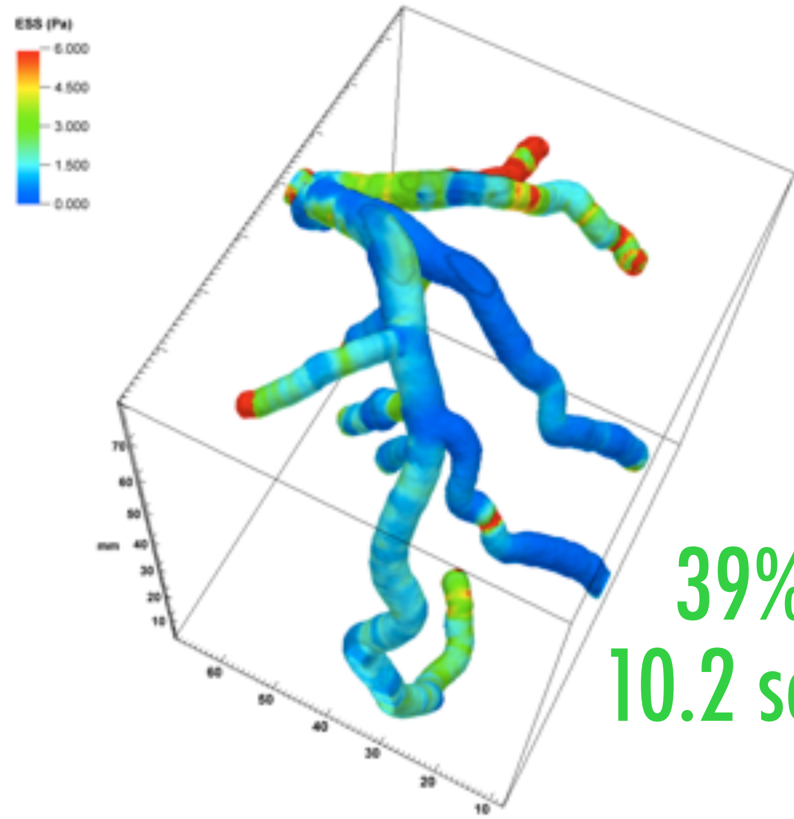
Alyssa A. Goodman[1,2], Erik W. Rosolowsky[2,3], Michelle A. Borkin[1]†, Jonathan B. Foster[2], Michael Halle[1,4], Jens Kauffmann[1,2] & Jaime E. Pineda[2]

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-

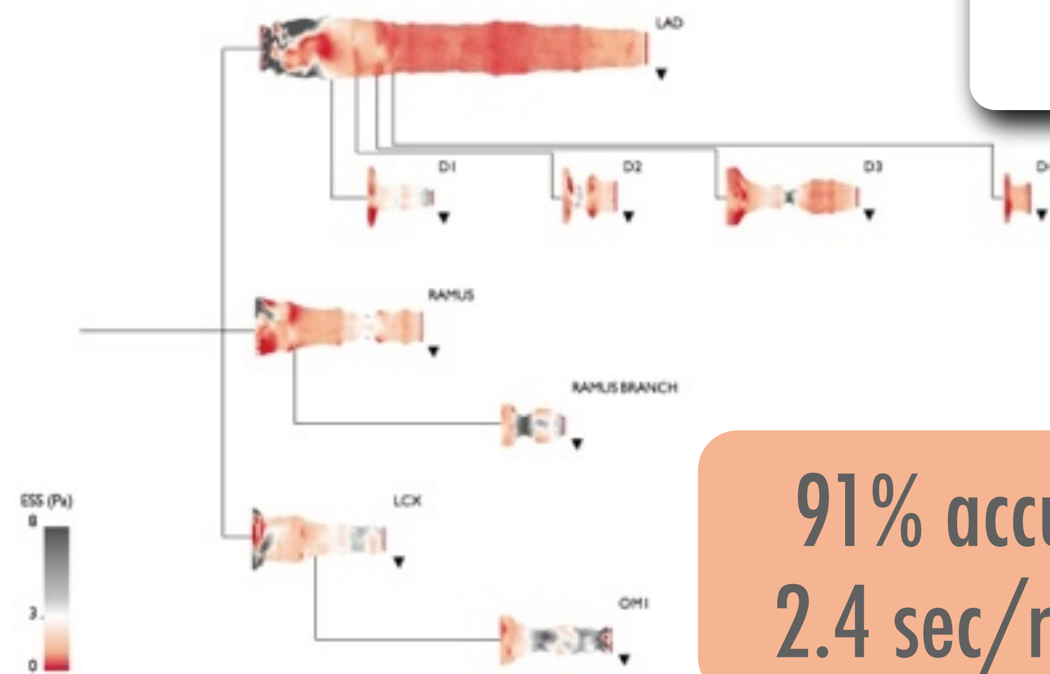
overlapping features as an option, significant emission found between prominent clumps is typically either appended to the nearest clump or turned into a small, usually 'pathological', feature needed to encompass all the emission being modelled. When applied to molecular-line



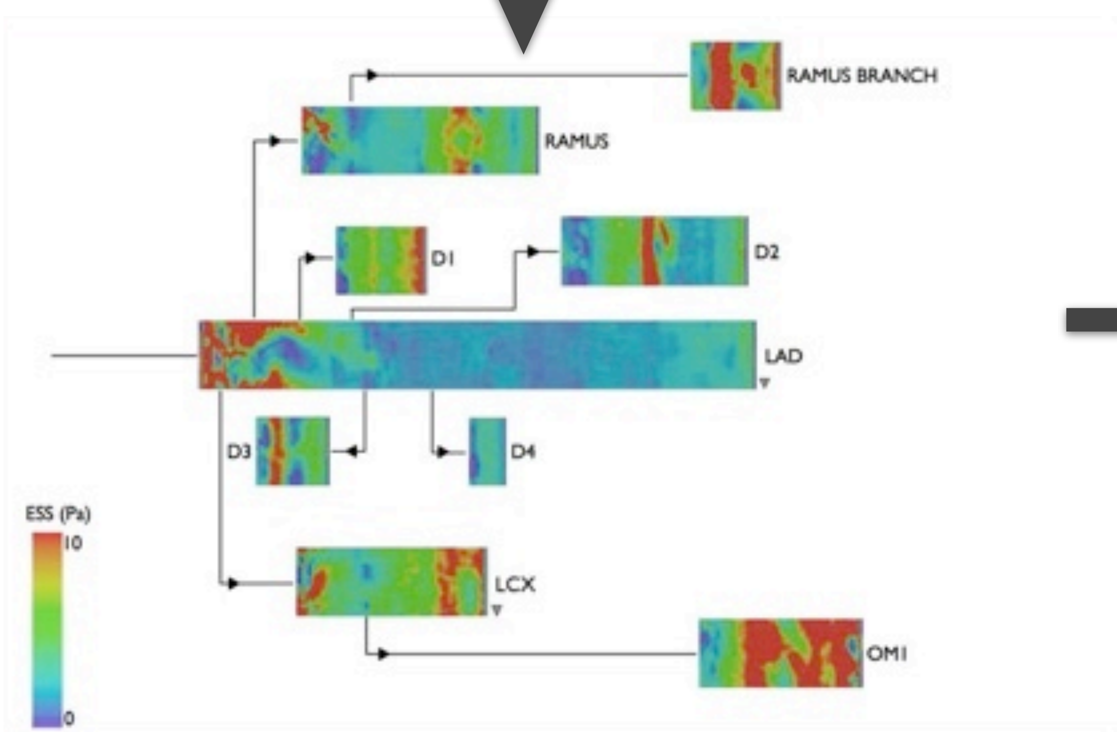
"DENDROGRAMS" IN MEDICINE

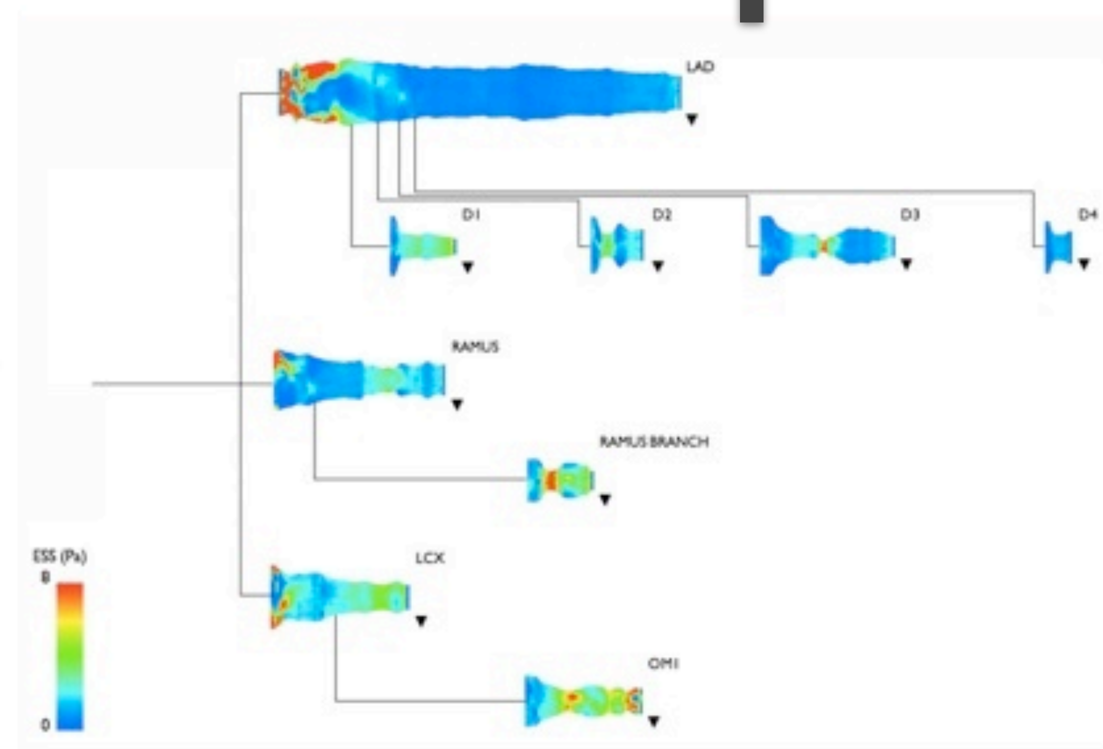


39% accurate
10.2 sec/region



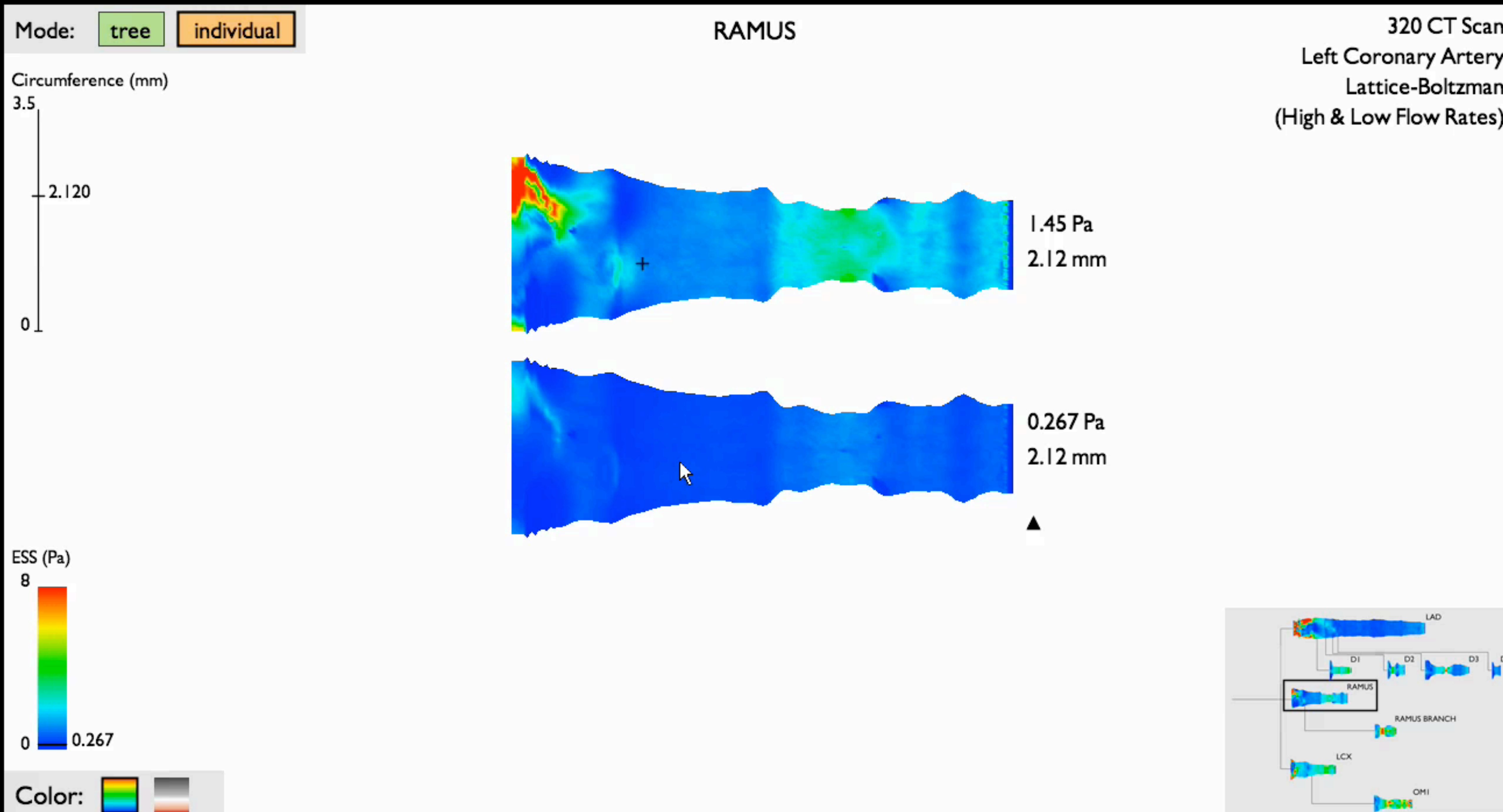
91% accurate
2.4 sec/region





Borkin et al. 2011
cf. colorbrewer2.org

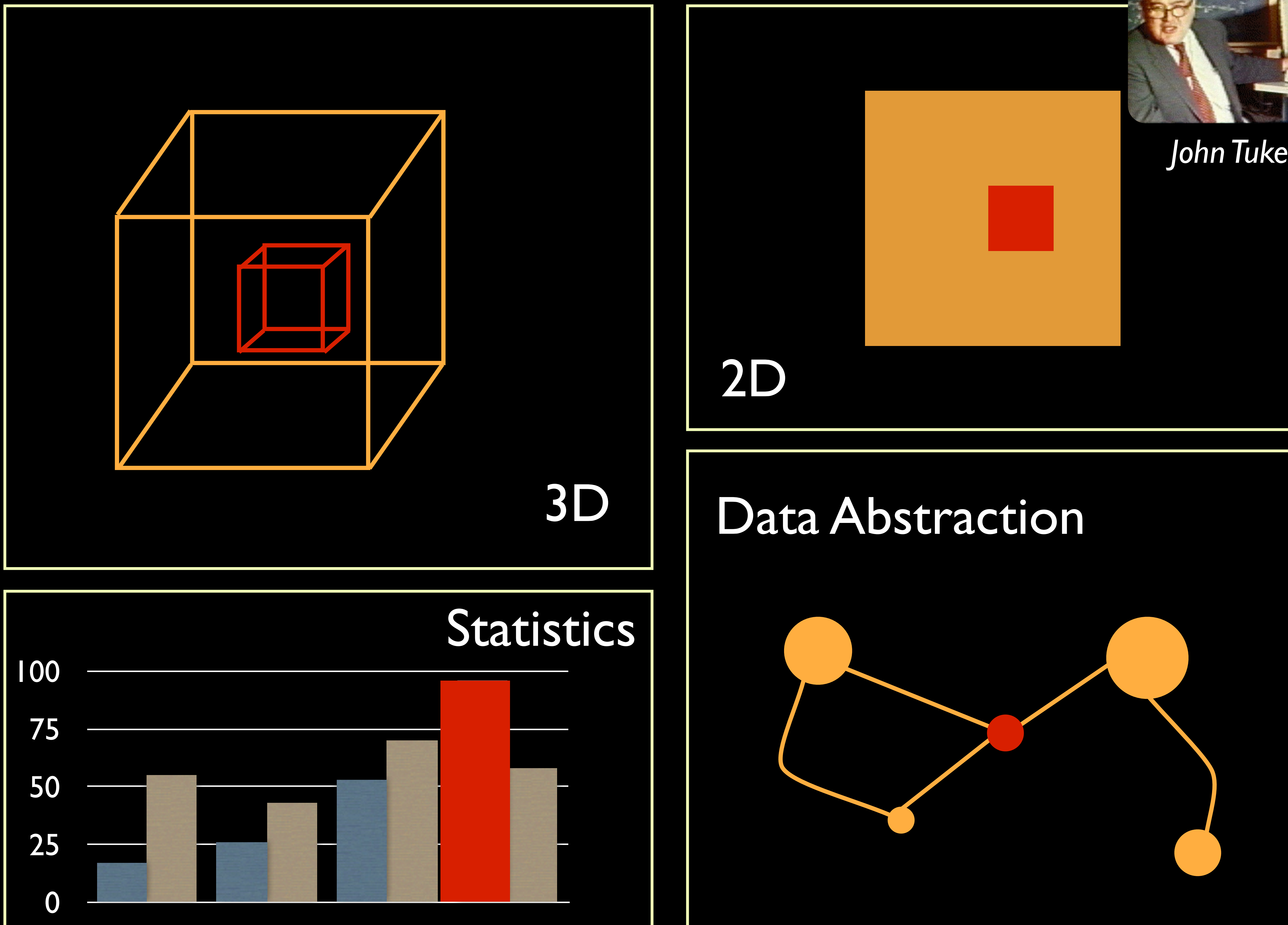
INTERACTIVE (LINKED) VIEW



Borkin et al. 2011

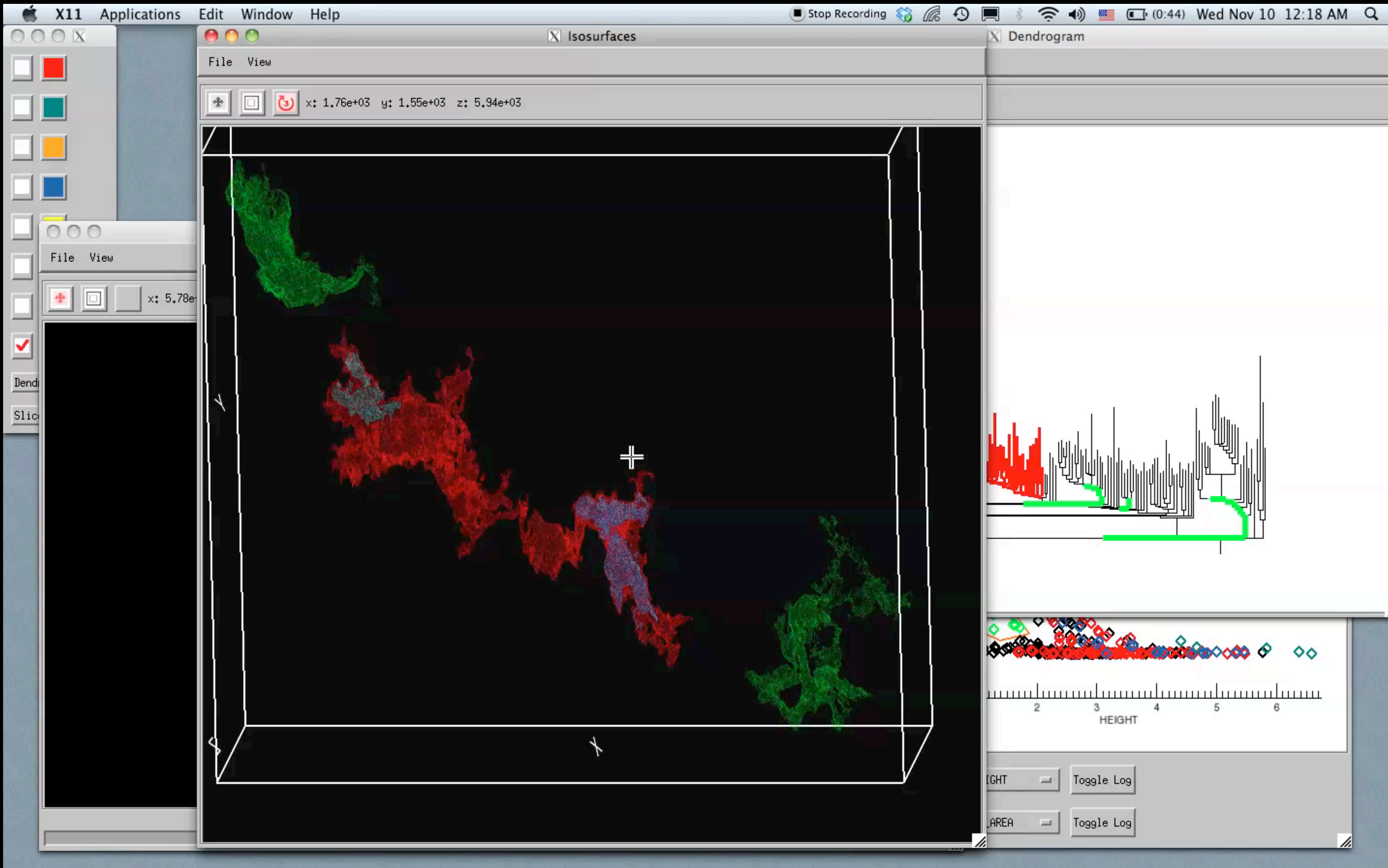
LINKED VIEWS OF HIGH-DIMENSIONAL DATA

John Tukey



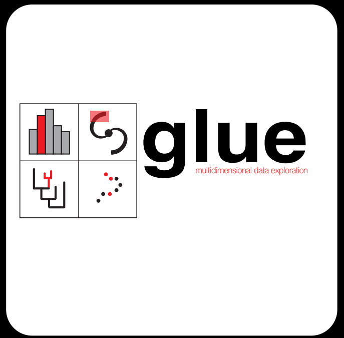
figure, by M. Borkin, reproduced from Goodman 2012, "Principles of High-Dimensional Data Visualization in Astronomy"

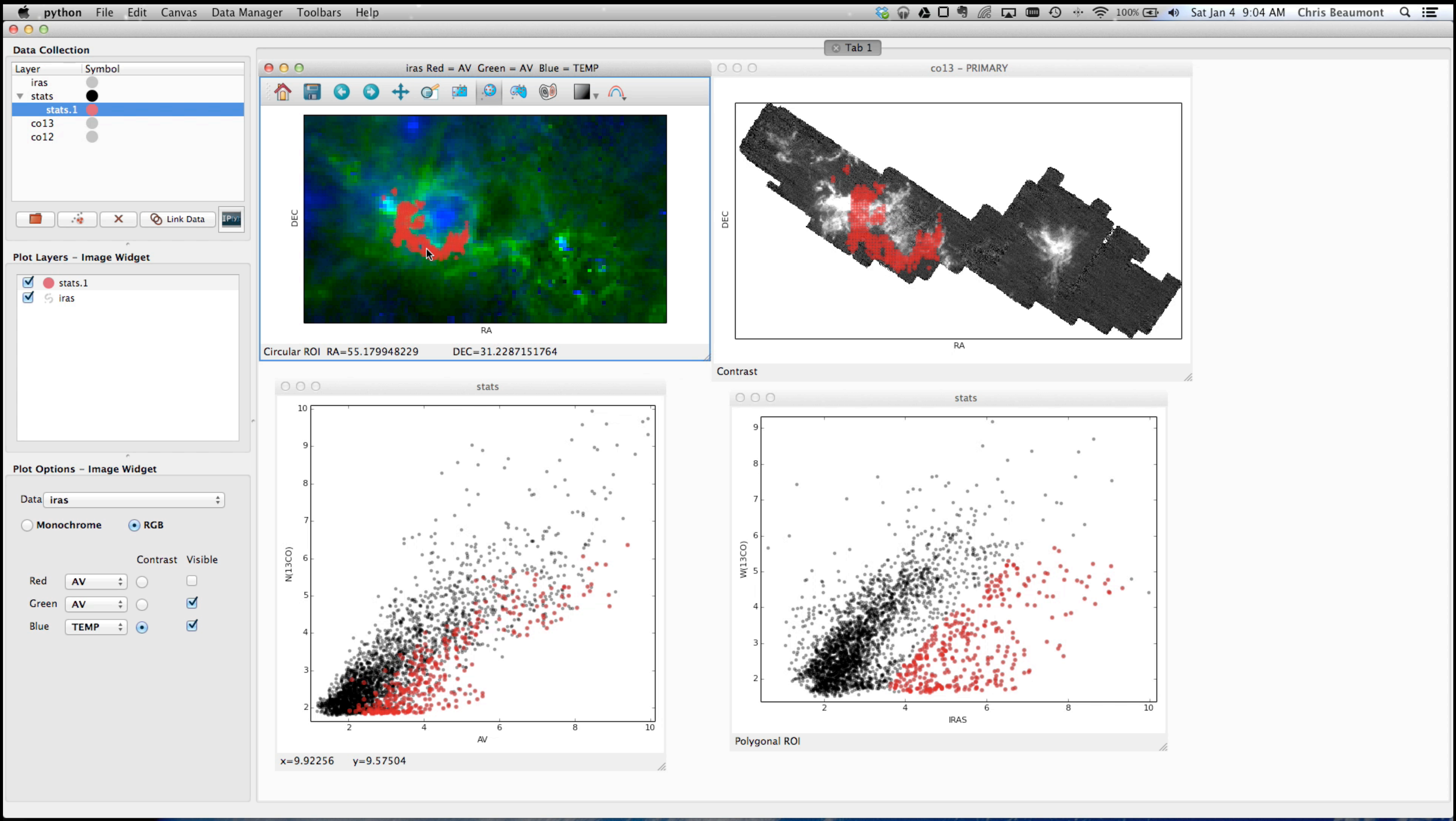
LINKED VIEWS OF HIGH-DIMENSIONAL DATA



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

LINKED VIEWS OF HIGH-DIMENSIONAL DATA (IN PYTHON)
GLUE



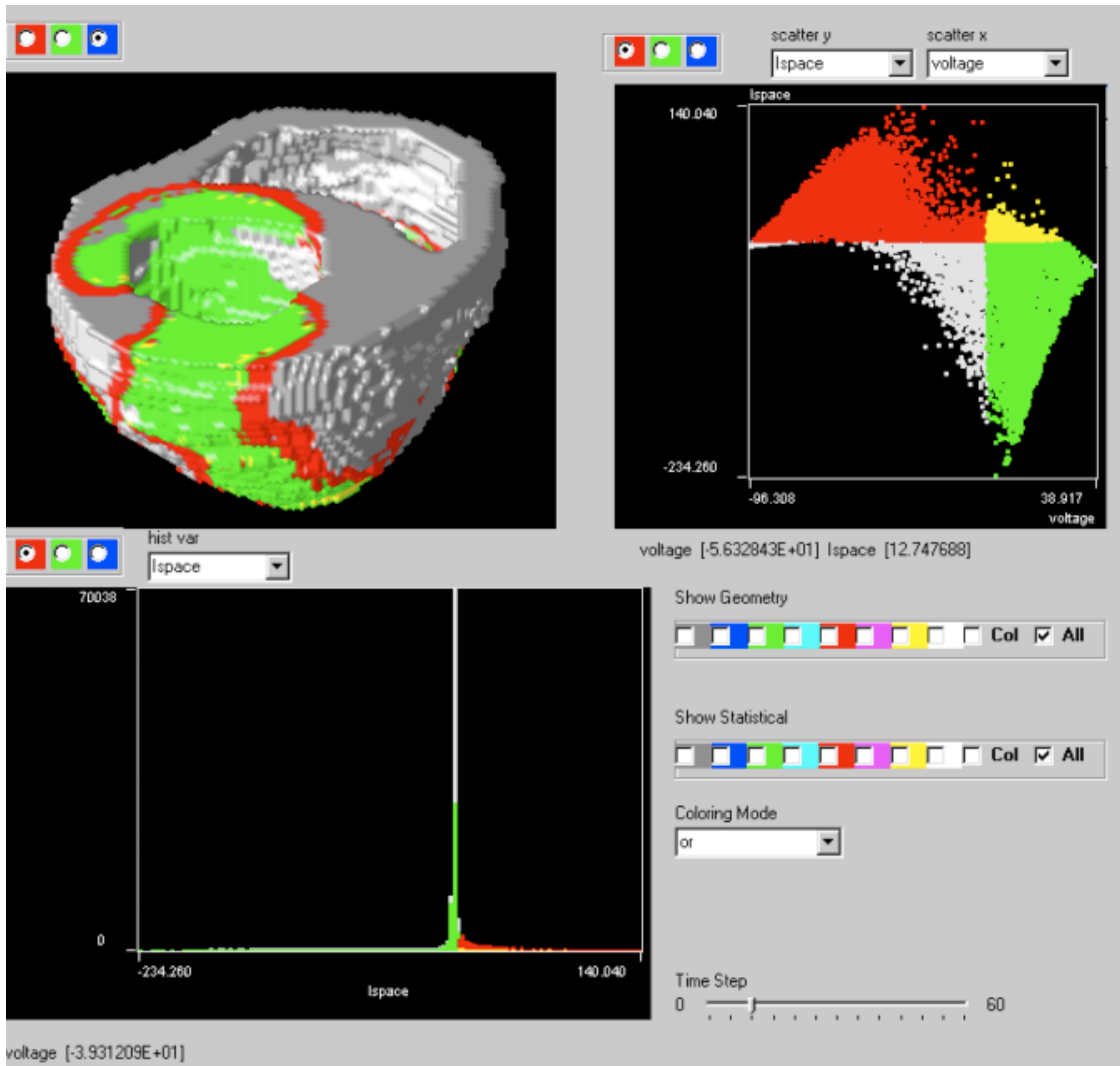


Christopher Beaumont, w/A. Goodman, T. Robitaille & M. Borkin

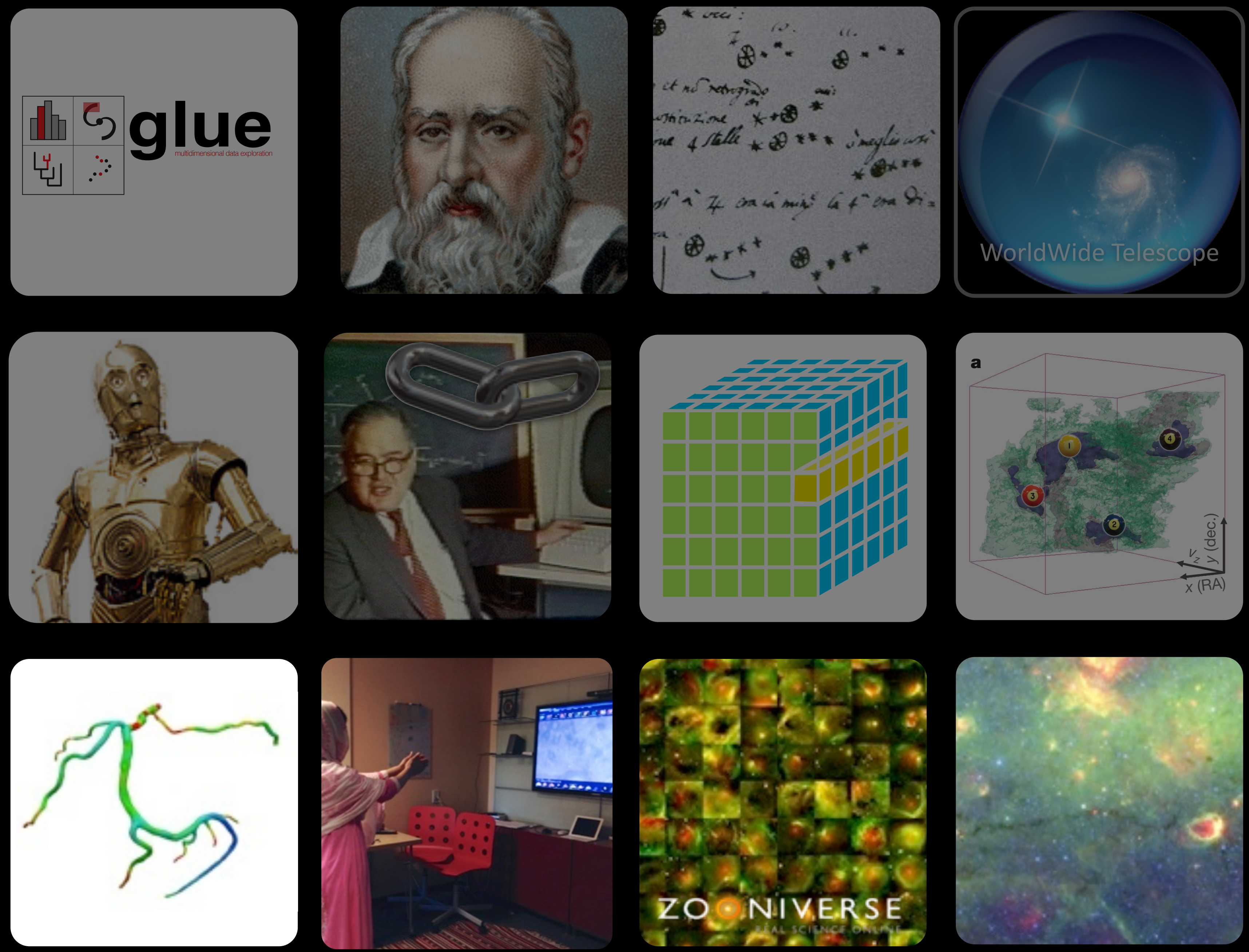
WEAVE: A System for Visually Linking 3-D and Statistical Visualizations, Applied to Cardiac Simulation and Measurement Data

D.L. Gresh and B.E. Rogowitz*
IBM T.J. Watson Research Center

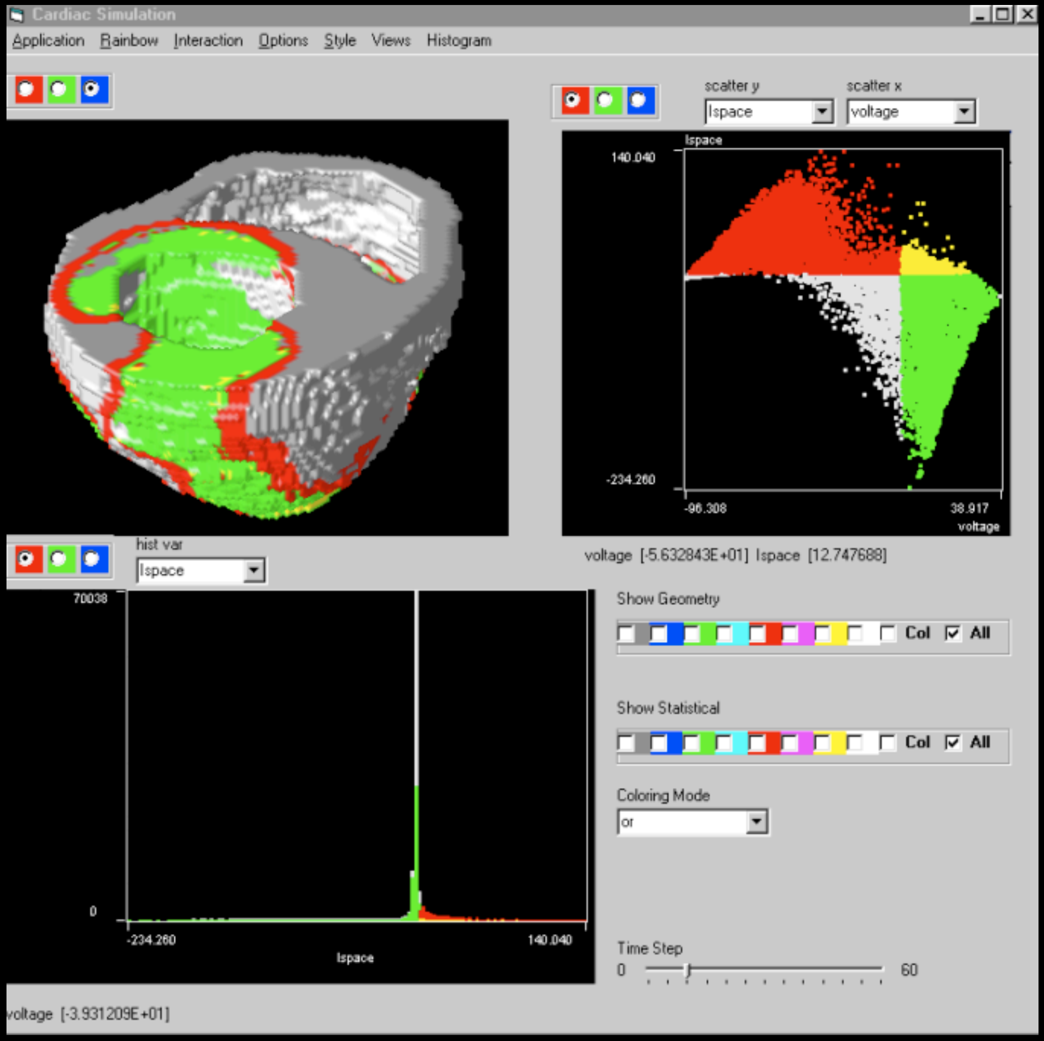
R.L. Winslow, D.F. Scollan, and C.K. Yung †
Department of Biomedical Engineering, Johns Hopkins University School of Medicine

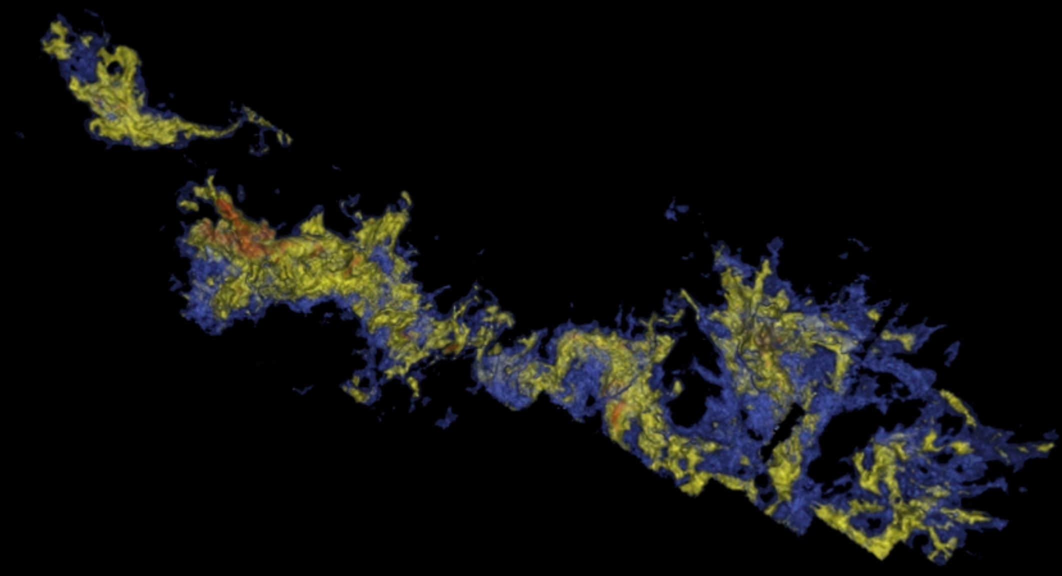


screenshot from Gresh et al. 2000; reproduced as shown in Goodman 2012

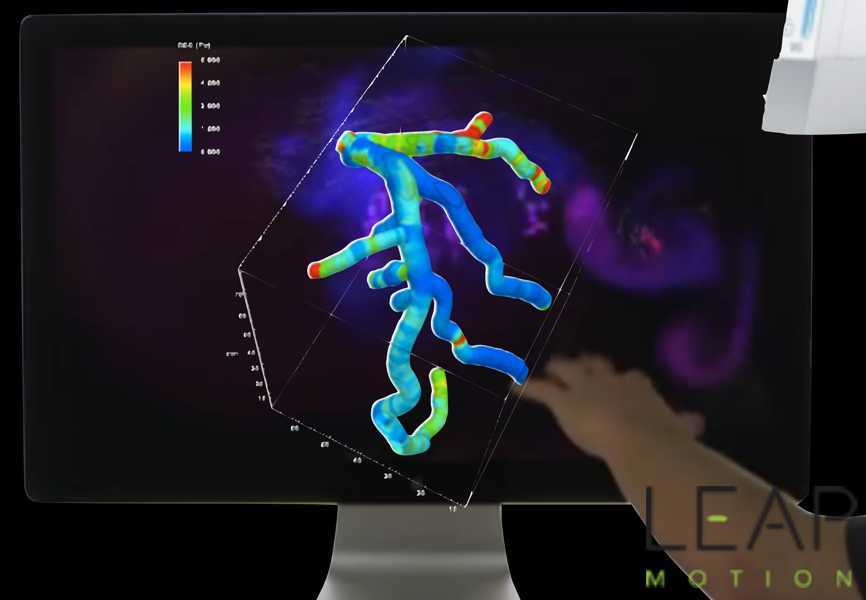

glue
WorldWide Telescope
a
y (dec.)
x (RA)
ZOONIVERSE

SELECTION IN 3D IS AN UNSOLVED PROBLEM





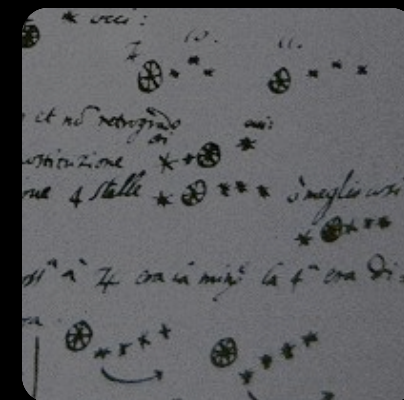
SELECTION IN 3D IS AN UNSOLVED PROBLEM

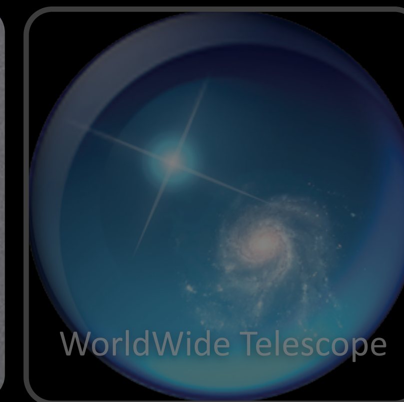


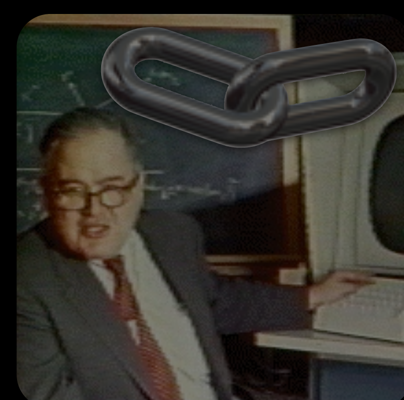
John Tukey's warning:
"details of control can
make or break such a system"

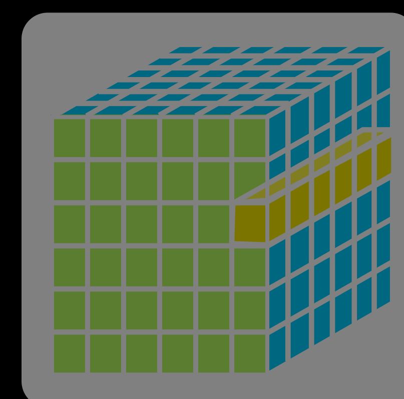
Microsoft
HoloLens

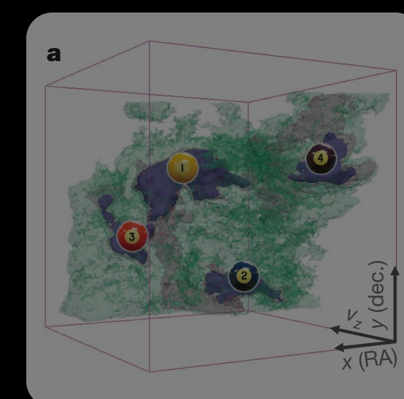
glue
multidimensional data exploration

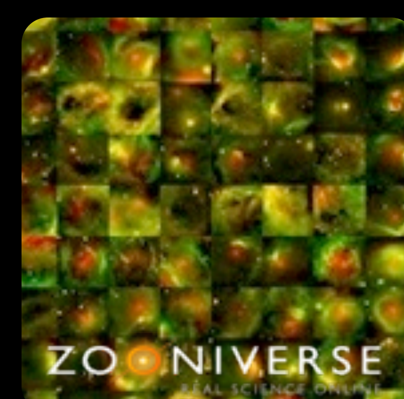


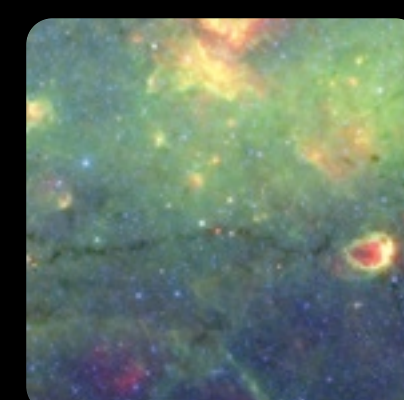


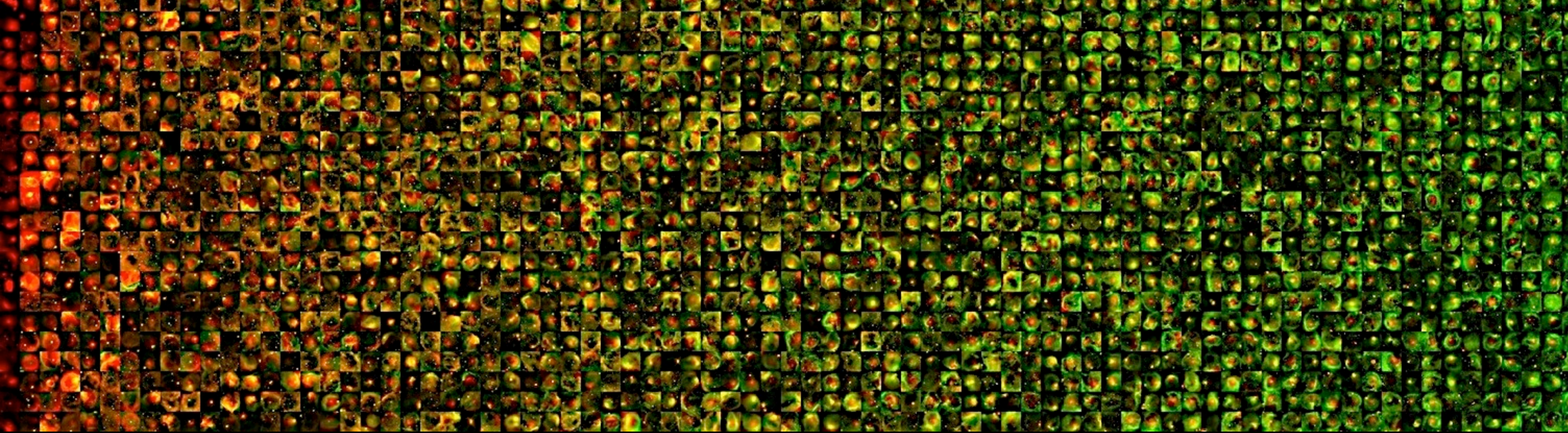




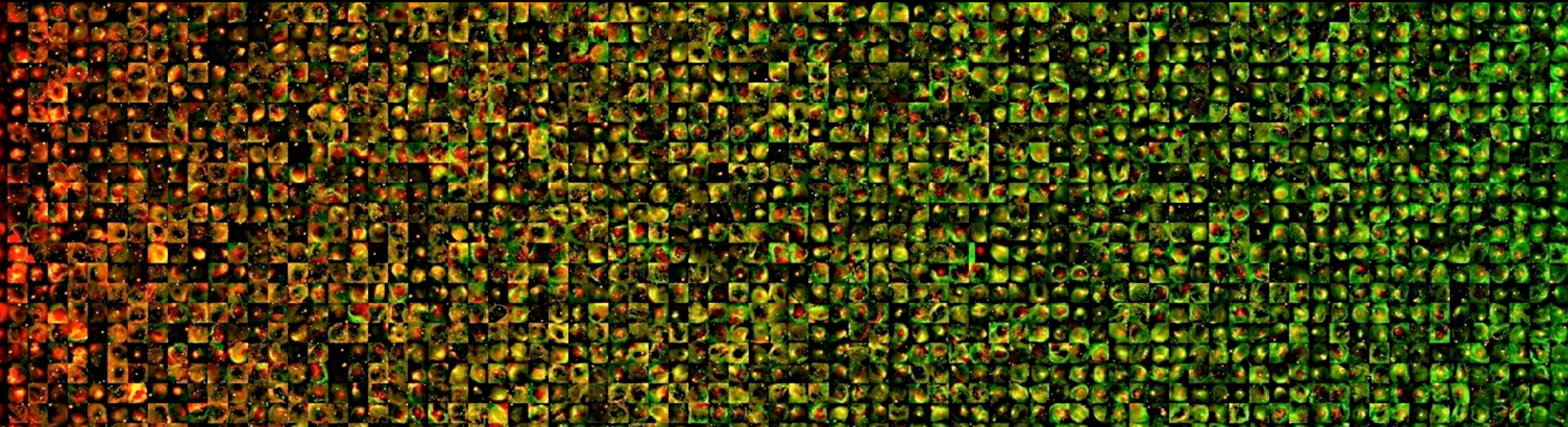


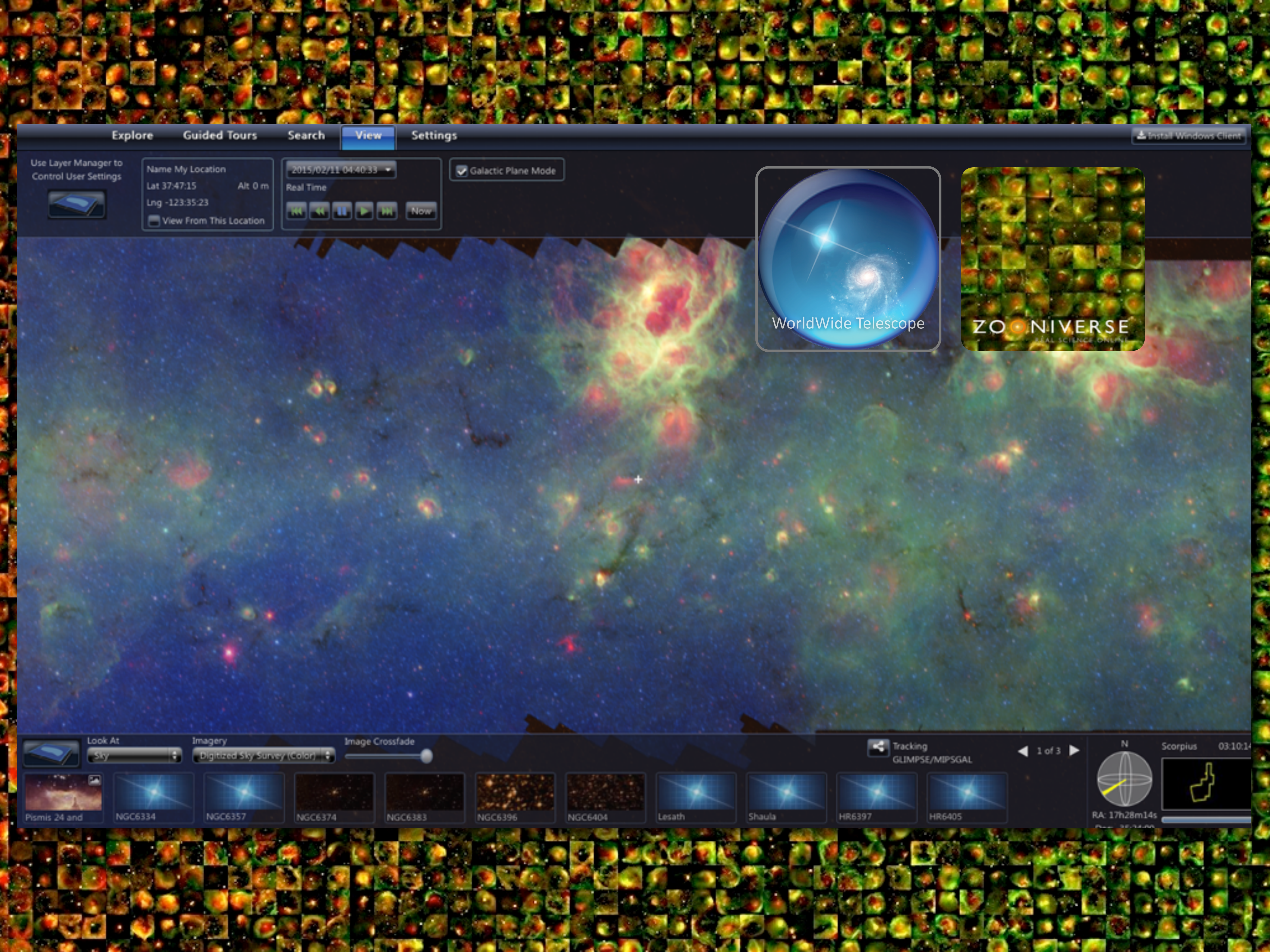






BIG DATA, WIDE DATA




Explore
Guided Tours
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Use Layer Manager to Control User Settings
Name My Location
Lat 37:47:15
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Lng -123:35:23
View From This Location
Real Time
Now
Galactic Plane Mode
WorldWide Telescope
ZOONIVERSE
Look At
Imagery
Image Crossfade
Tracking
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Scorpius
Pismis 24 and
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NGC6357
NGC6374
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Shaula
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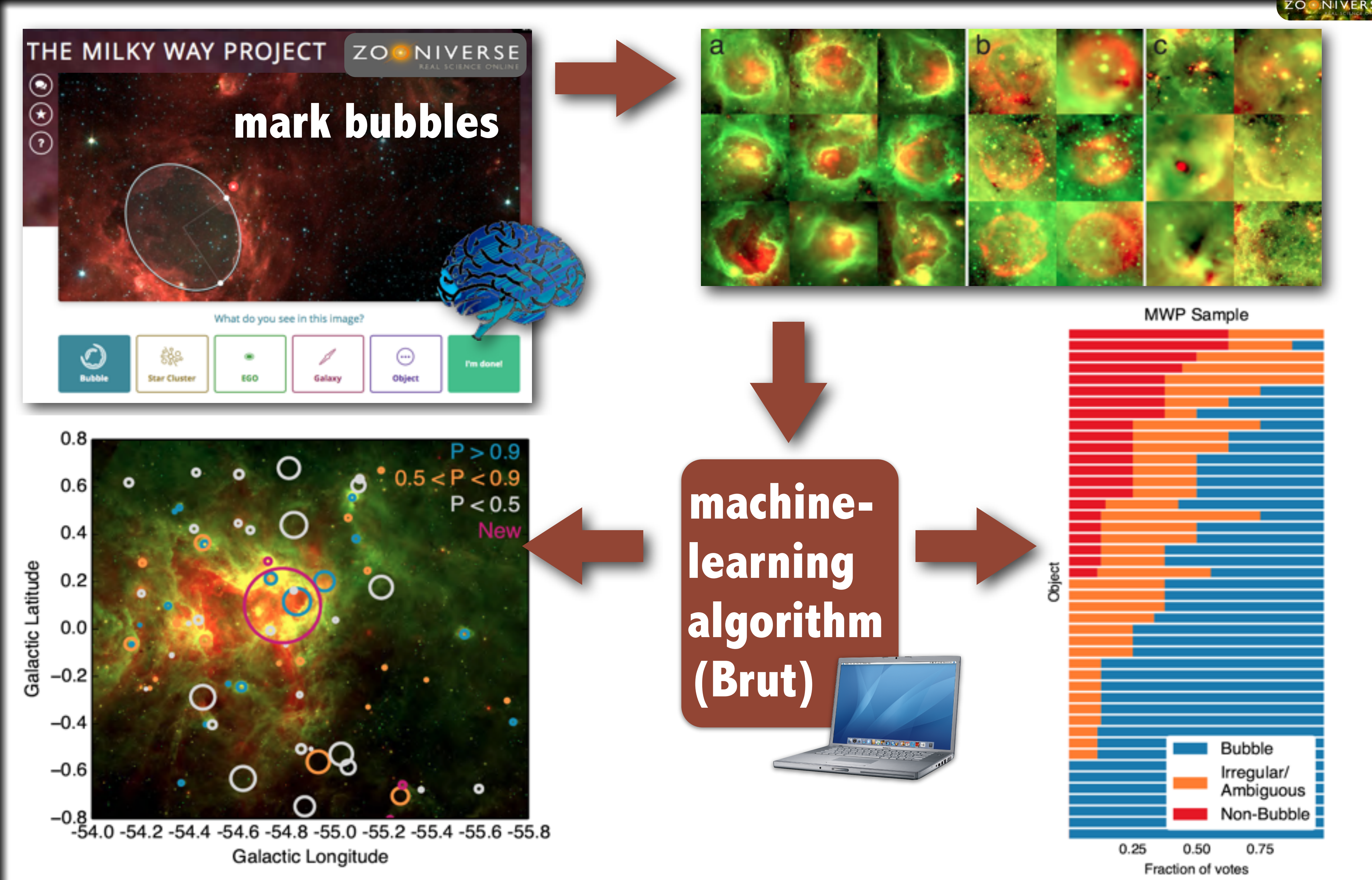
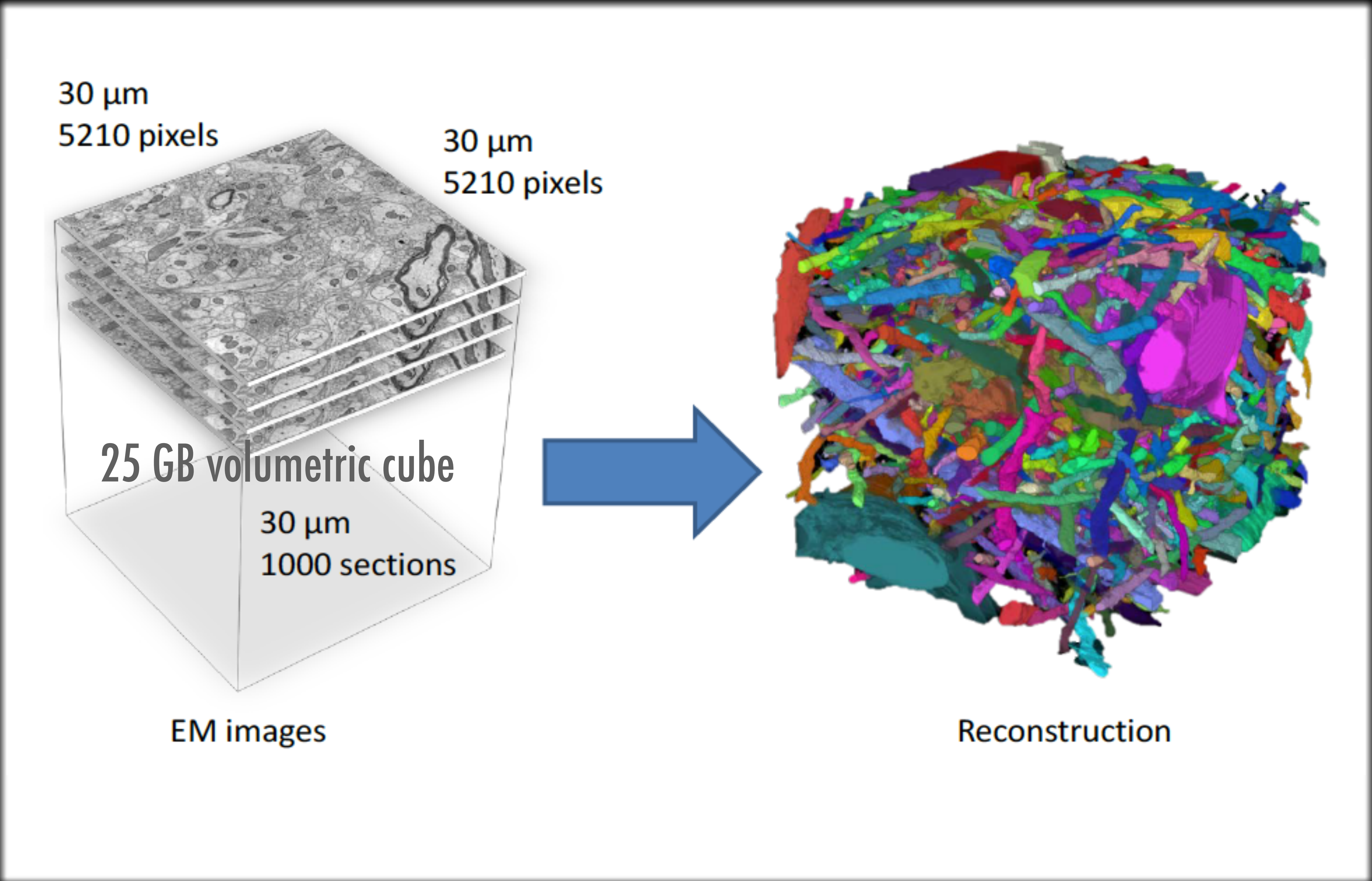
HR6405
RA: 17h28m14s

BIG DATA AND "HUMAN-AIDED COMPUTING"



example here from: ***Beaumont****, Goodman, Kendrew, Williams & Simpson 2014; based on* ***Milky Way Project*** *catalog (Simpson et al. 2013), which came from* ***Spitzer/GLIMPSE*** *(Churchwell et al. 2009, Benjamin et al. 2003), cf. Shenoy & Tan 2008 for discussion of HAC;* ***astroml.org*** *for machine learning advice/tools*

BIG DATA AND "HUMAN-AIDED COMPUTING"



example here from: Kaynig...Lichtman...Pfister et al. 2013, "Large-Scale Automatic Reconstruction of Neuronal Processes from Electron Microscopy Images"; cf. Shenoy & Tan 2008 for discussion of HAC; ***astroml.org*** *for machine learning advice/tools*

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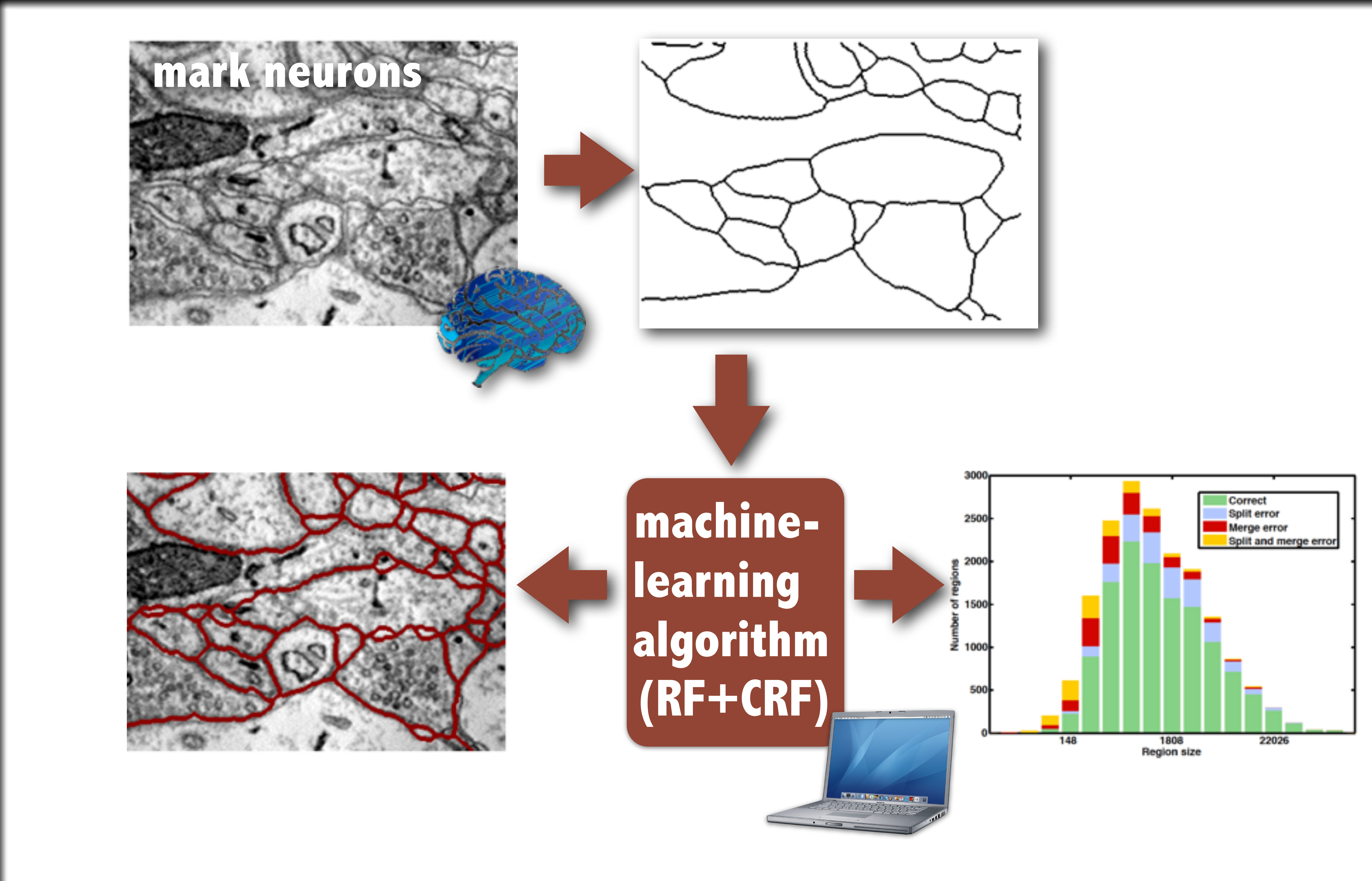
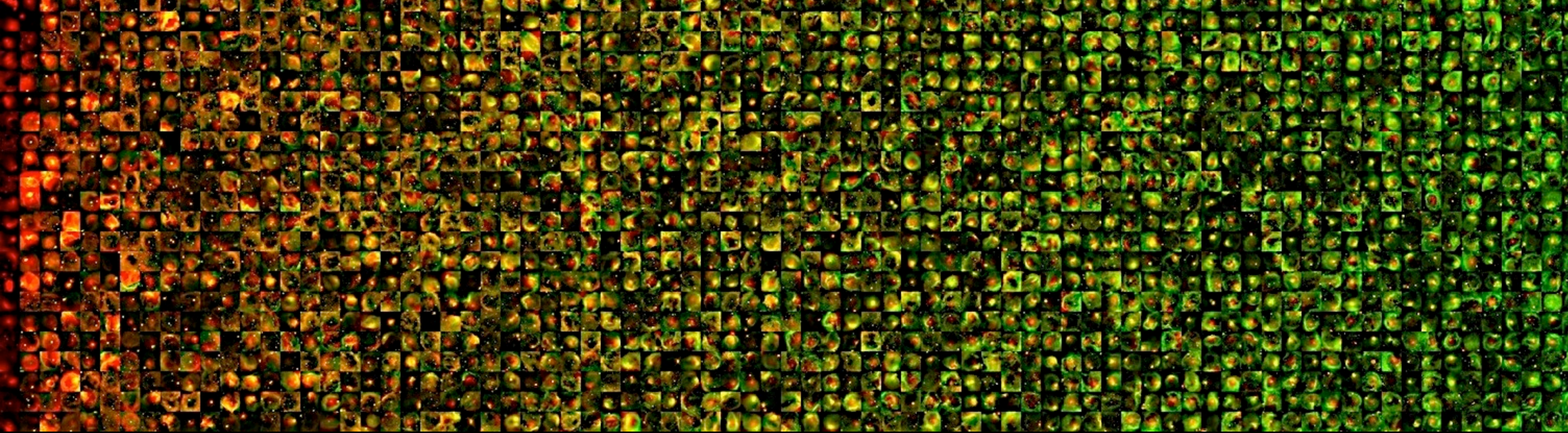
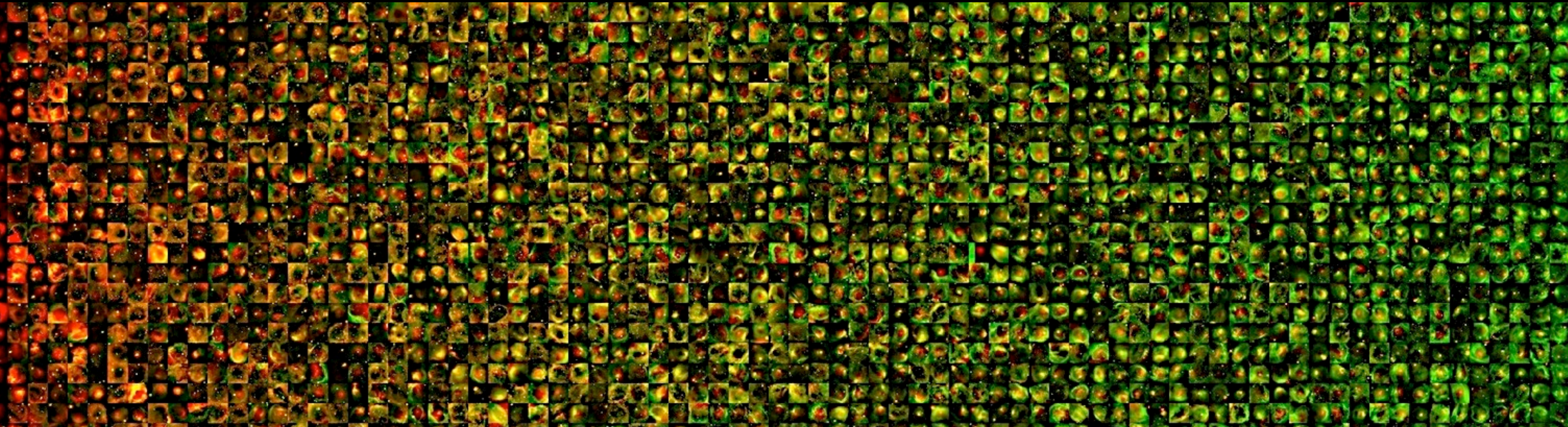


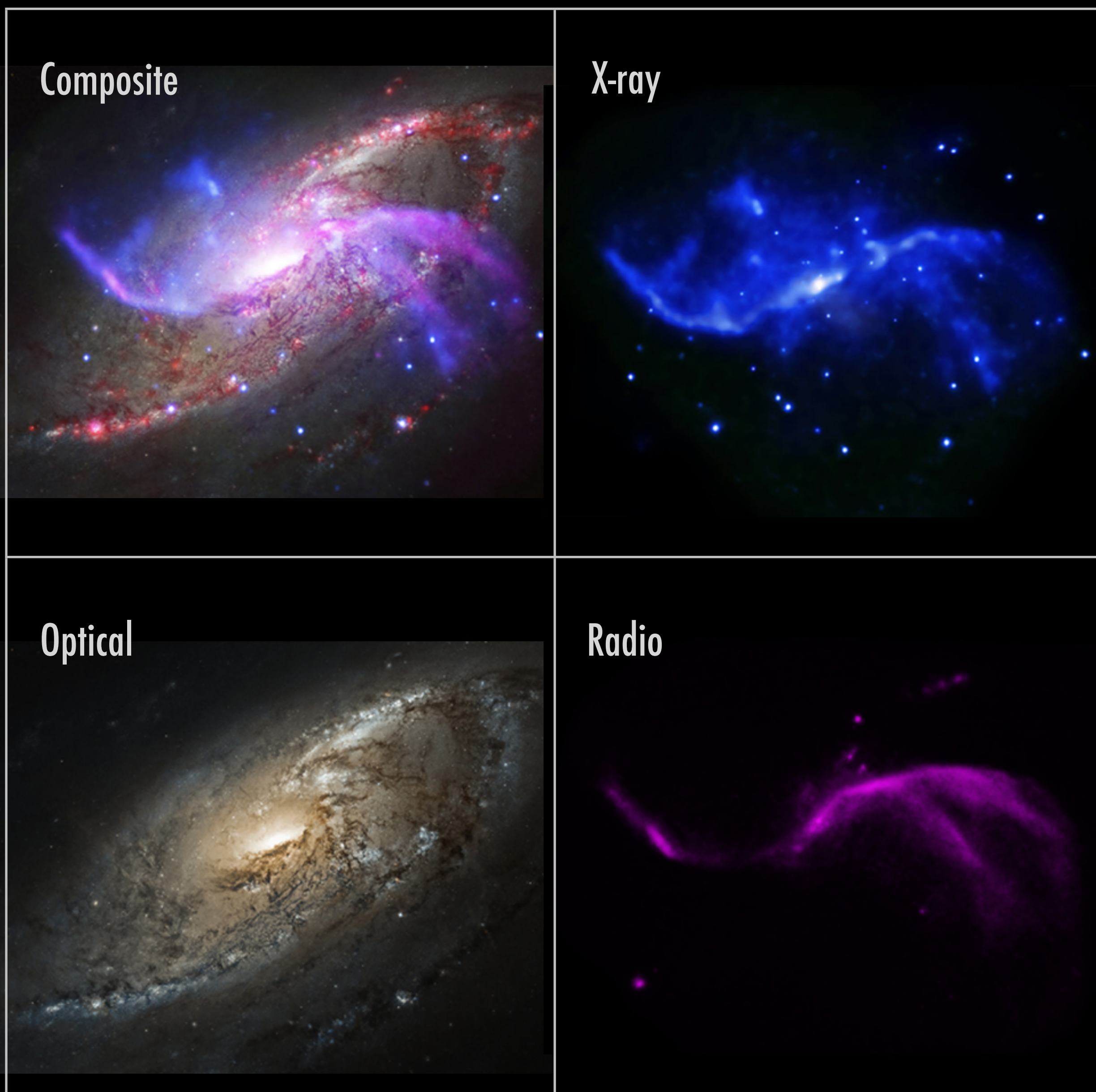
example here from: Kaynig...Lichtman...Pfister et al. 2013, "Large-Scale Automatic Reconstruction of Neuronal Processes from Electron Microscopy Images"; cf. Shenoy & Tan 2008 for discussion of HAC; ***astroml.org*** *for machine learning advice/tools (Note: RF=Random Forest; CRF=Conditional Random Fields.)*



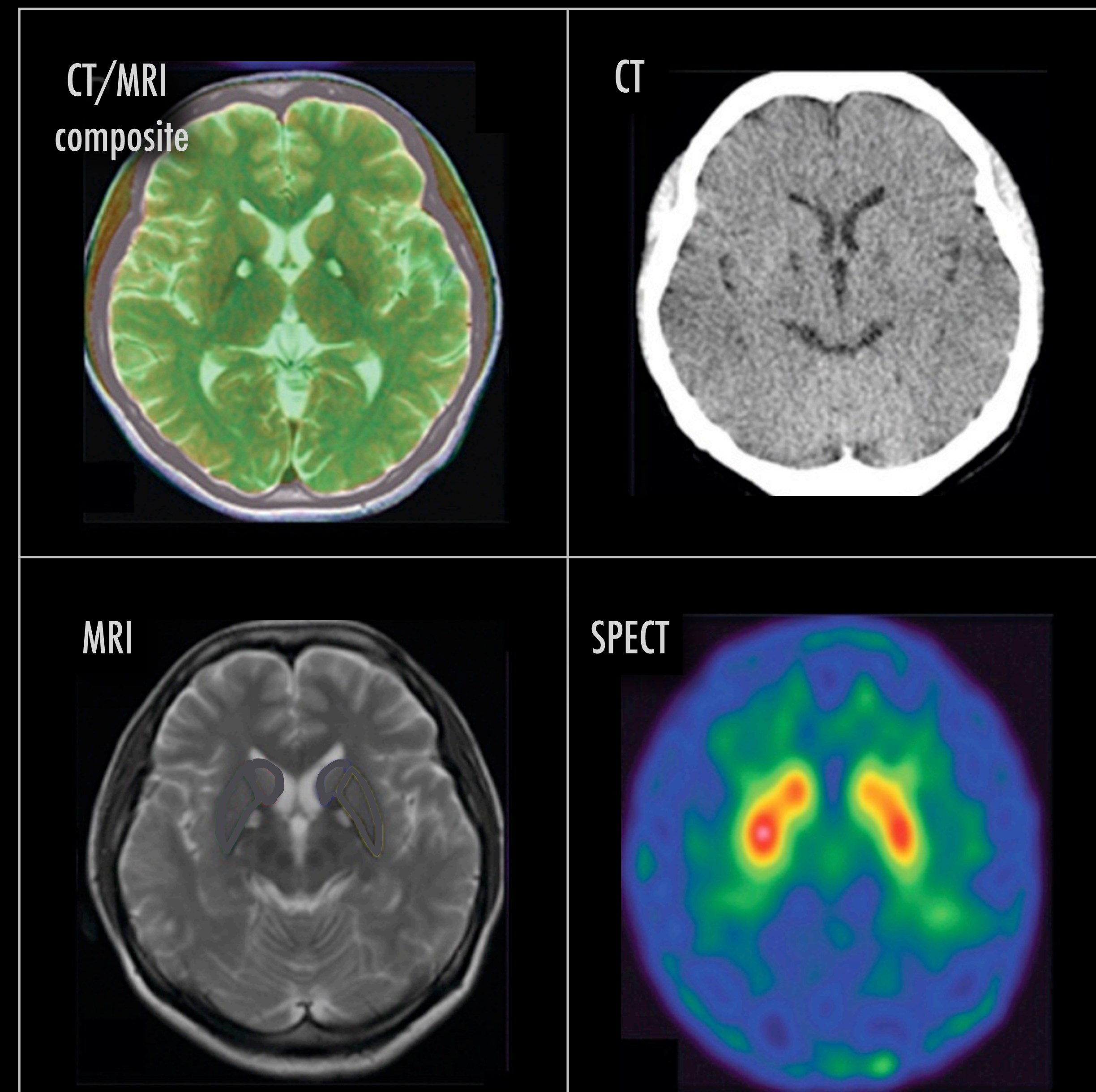
BIG DATA, WIDE DATA



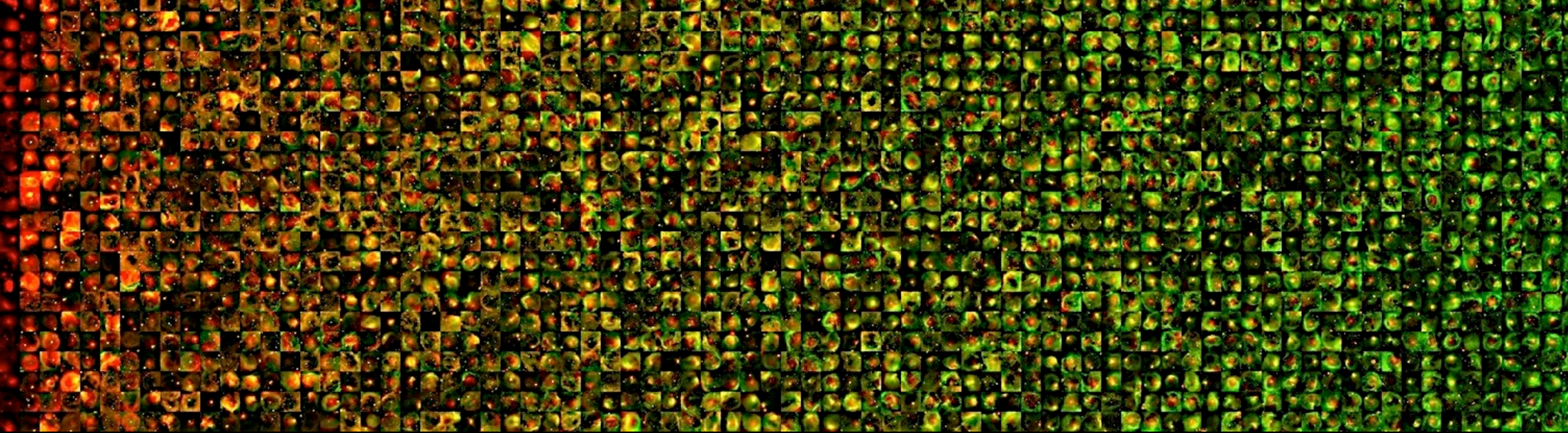
WIDE DATA



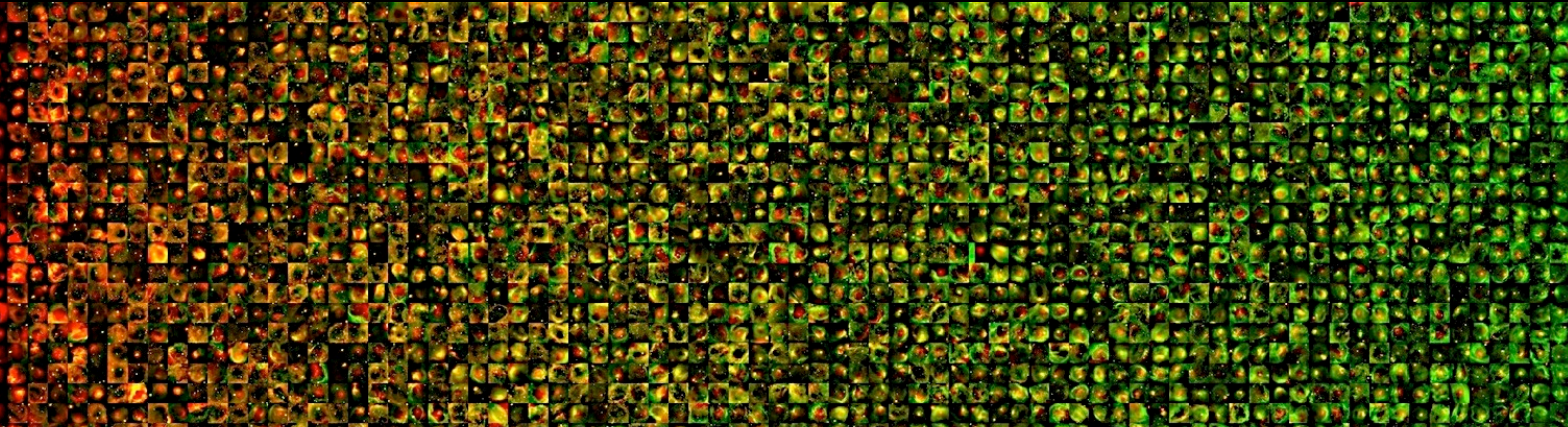
chandra.harvard.edu/photo/2014/m106/

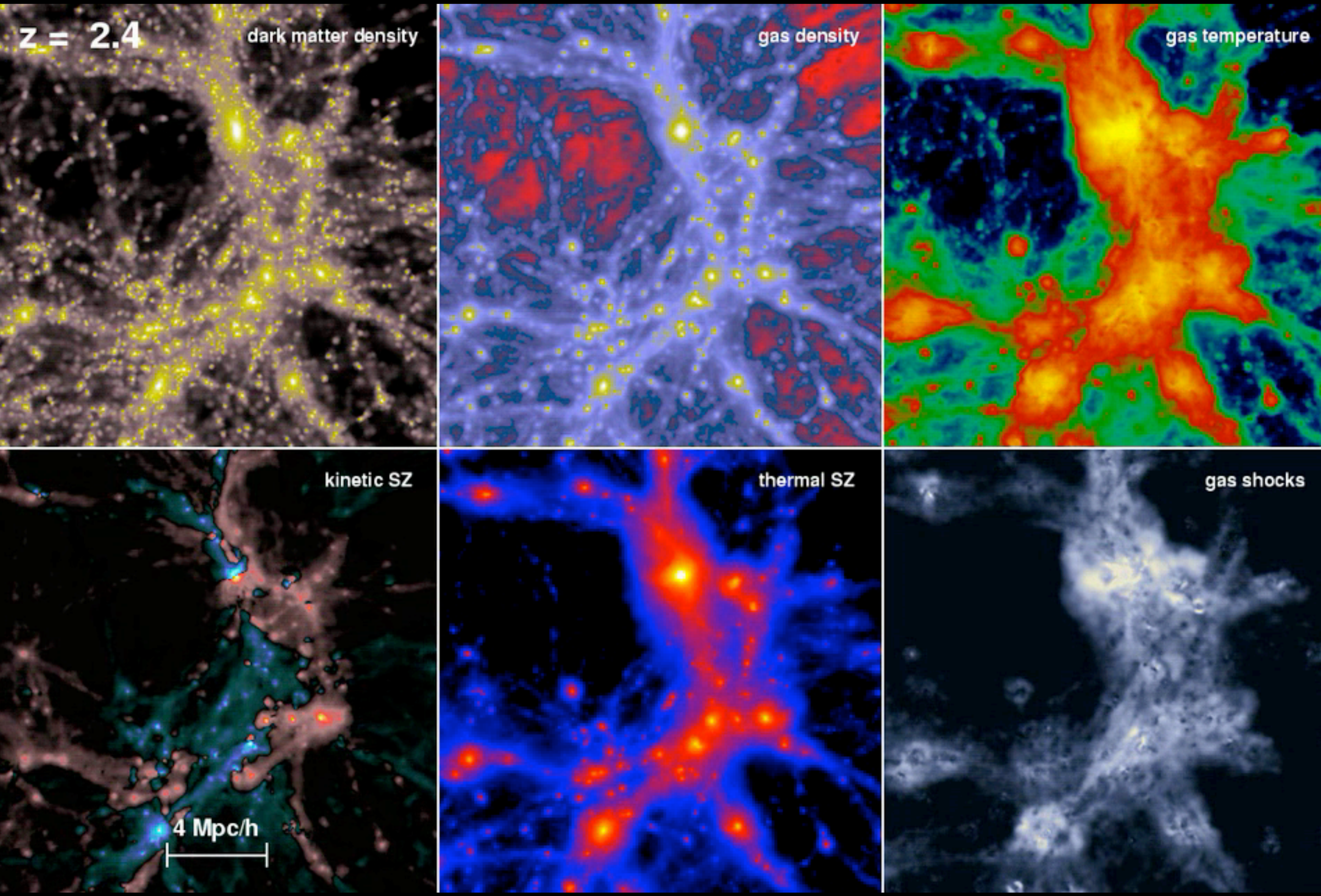


Chang, et al. 2011, brain.oxfordjournals.org/content/134/12/3632

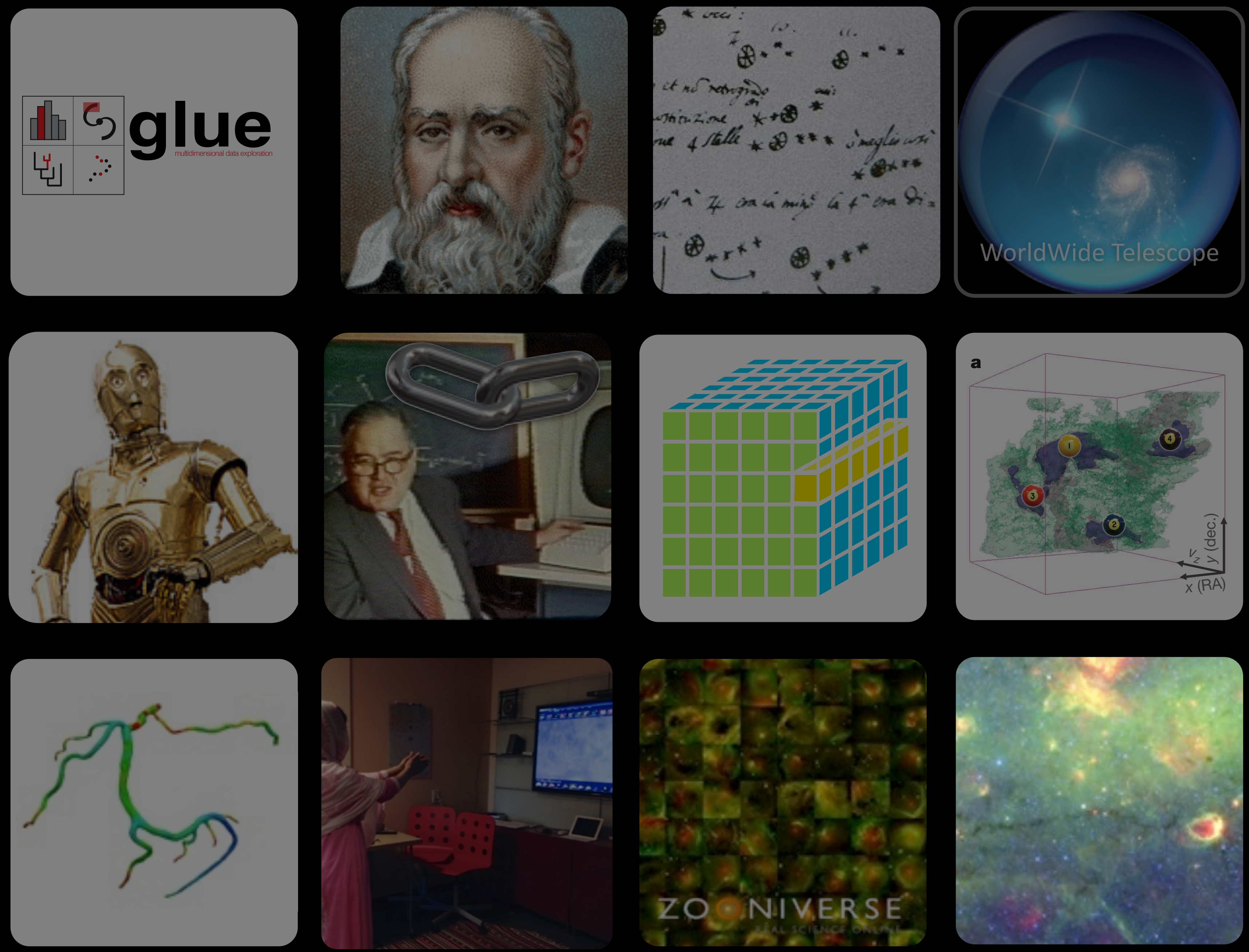


BIG AND WIDE DATA

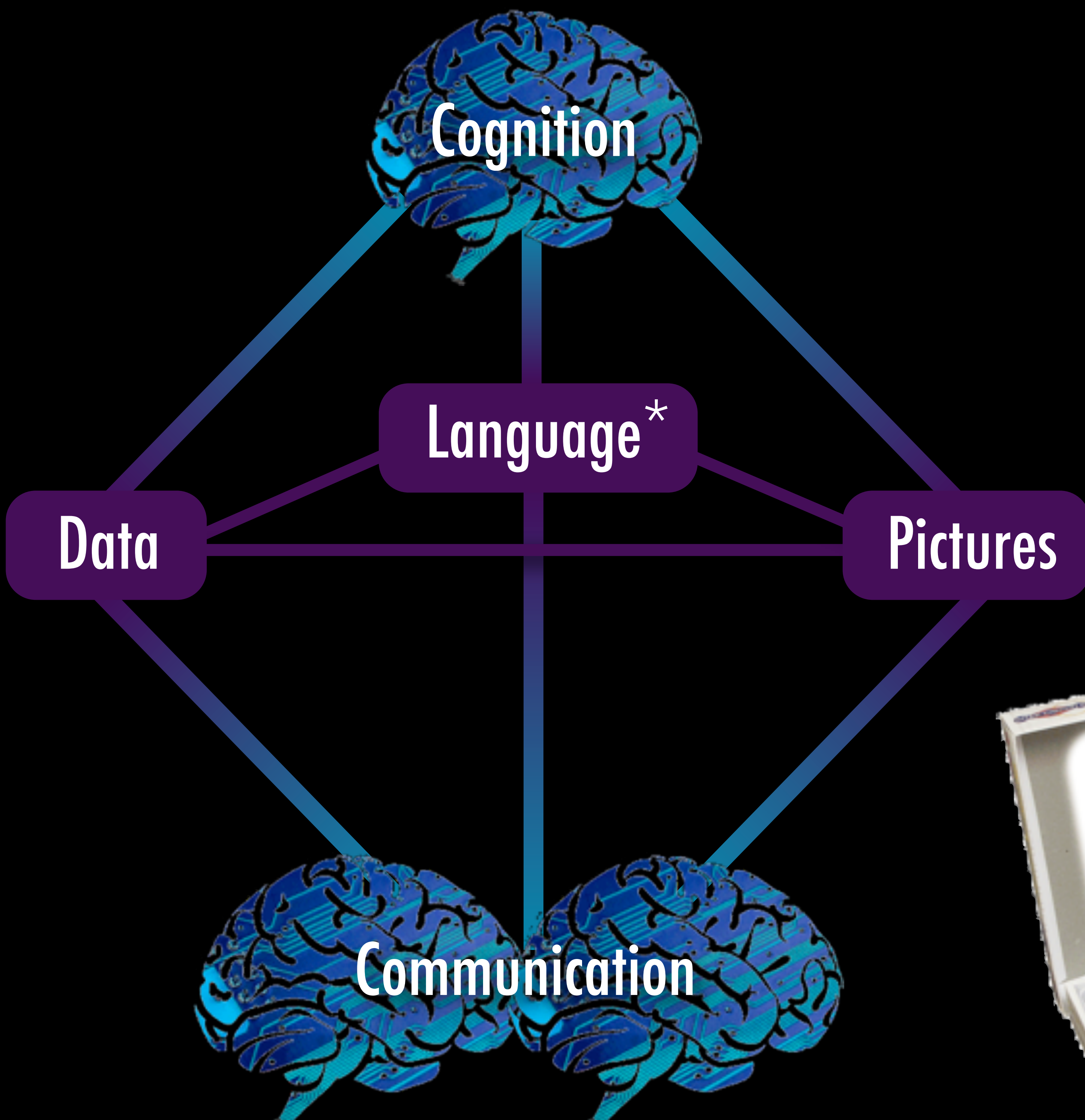




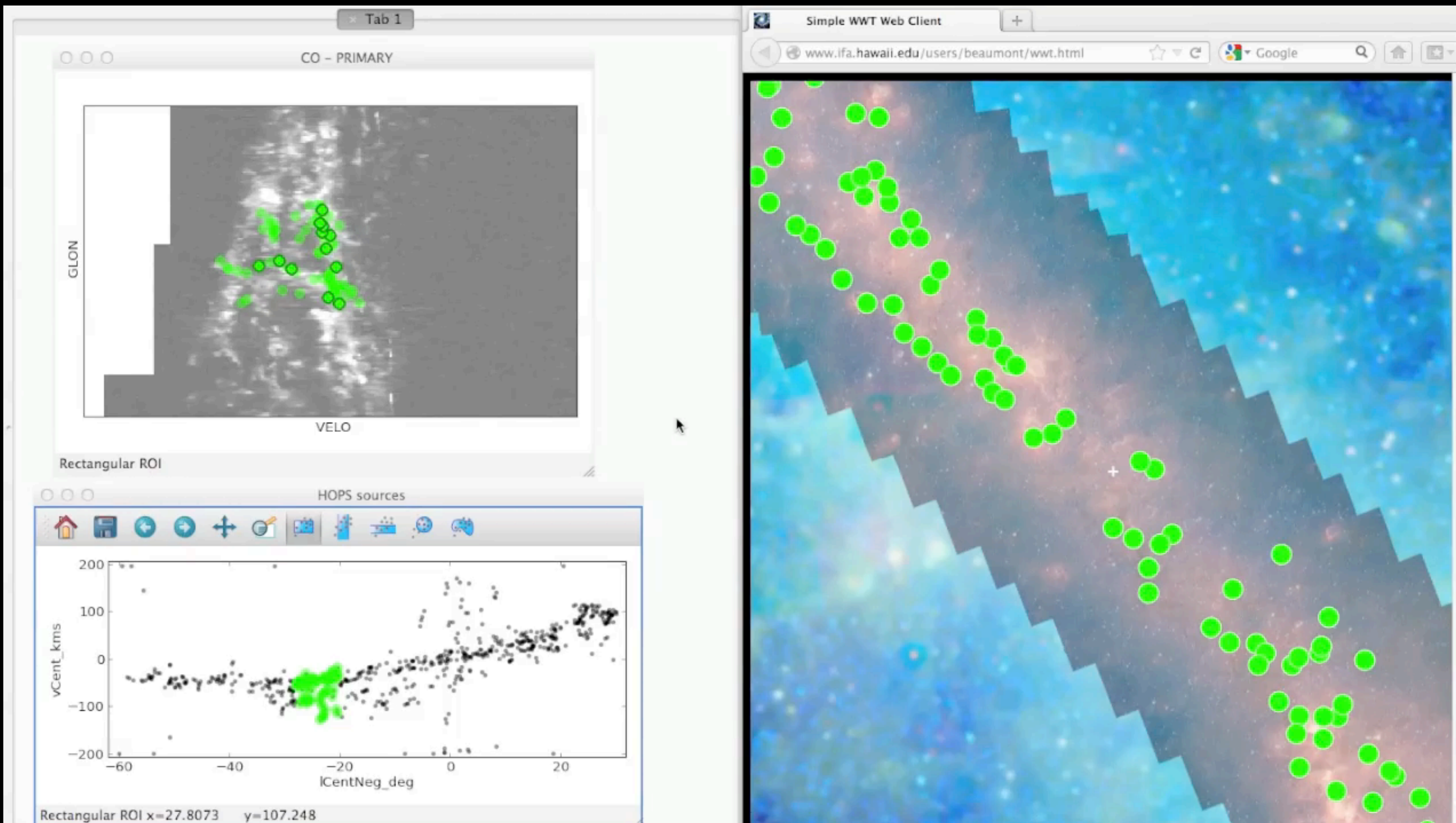
Movie: Volker Springel, formation of a cluster of galaxies. Millenium Simulation requires 25TB for output.


glue
multidimensional data exploration
WorldWide Telescope
a
y (dec.)
x (RA)

THE FUTURE IS ABOUT **INTEGRATION**



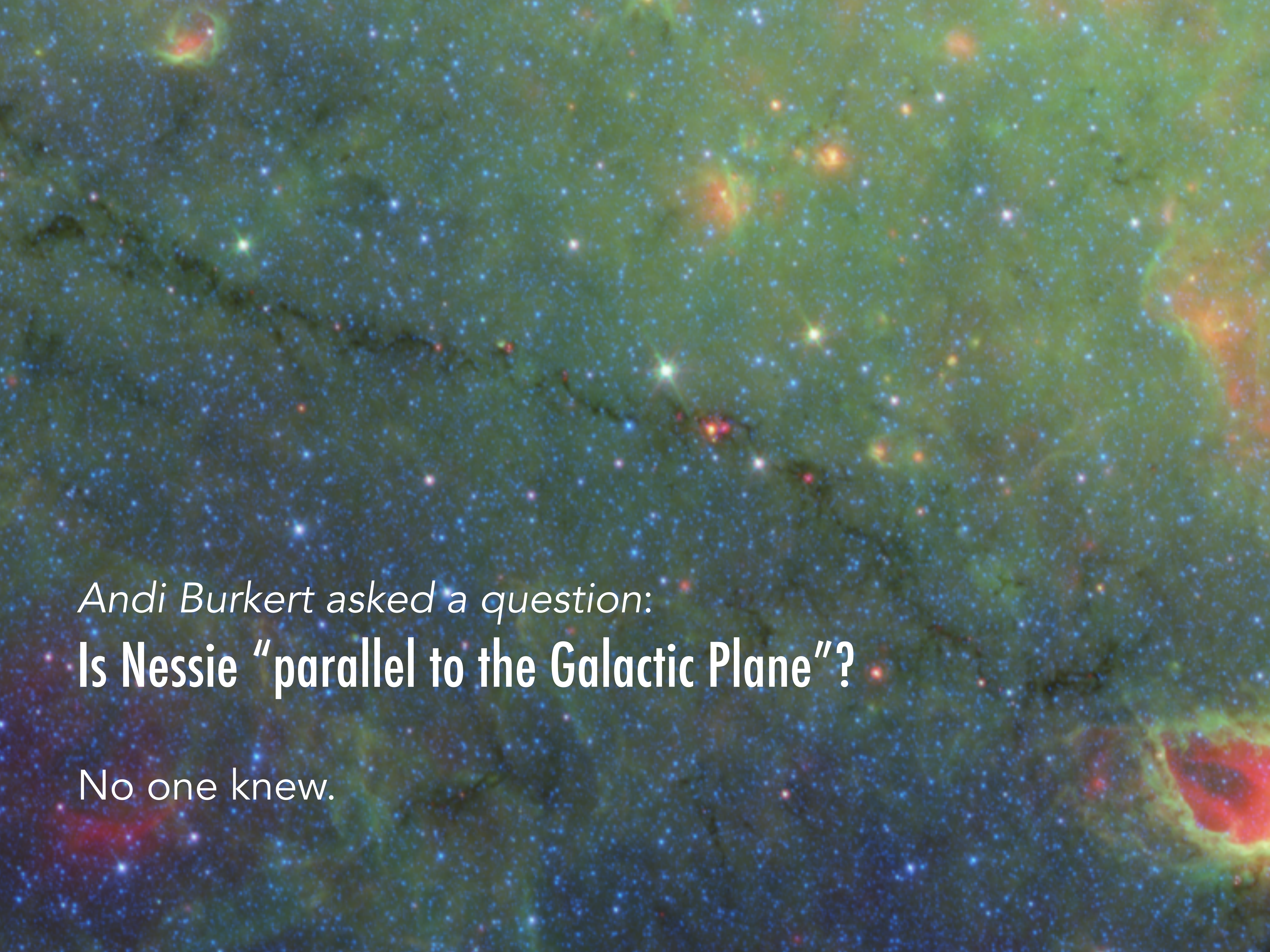
python™
SciPy
IP[y]: IPython Interactive Computing
astropy A Community Python Library for Astronomy
JavaScript
d3.js
plotly
HTML



Video courtesy of Chris Beaumont, Lead Glue Architect

Once upon a time (2012), in an enchanted castle (in Bavaria)

...at a conference about
“The Early Phases of Star Foration”


Andi Burkert asked a question:
Is Nessie "parallel to the Galactic Plane"?
No one knew.

THE MILKY WAY

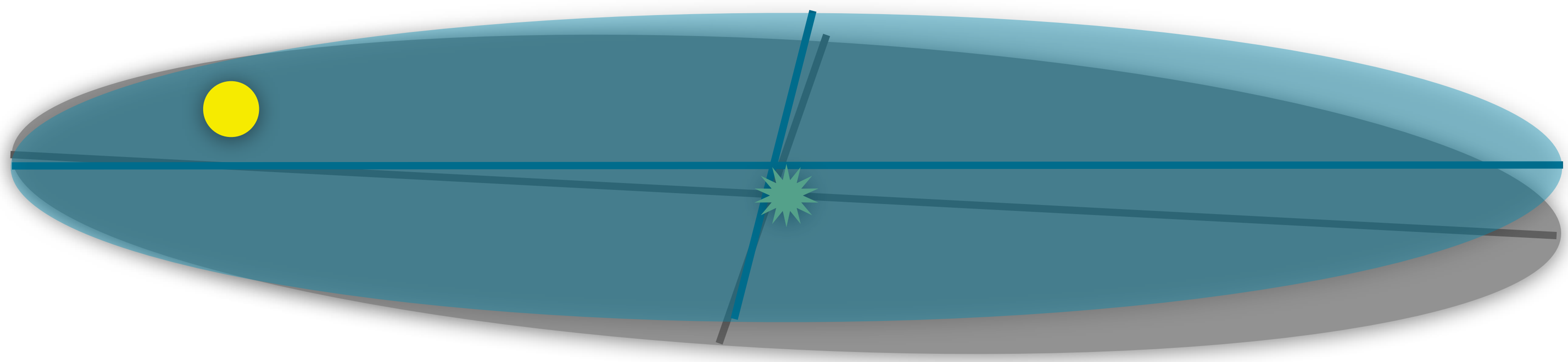
“Galactic Plane”

The Milky Way
(Artist's Conception)

“Is Nessie Parallel to the Galactic Plane?”

Where are we, really?

"IAU Milky Way", est. 1959



True Milky Way, modern

> The equatorial plane of the new co-ordinate system must of necessity pass through the sun. It is a fortunate circumstance that, within the observational uncertainty, both the sun and Sagittarius A lie in the mean plane of the Galaxy as determined from the hydrogen observations. If the sun had not been so placed, points in the mean plane would not lie on the galactic equator.
>
> *[Blaauw et al. 1959]*

Sun is ~75 light years "above" the IAU Milky Way Plane

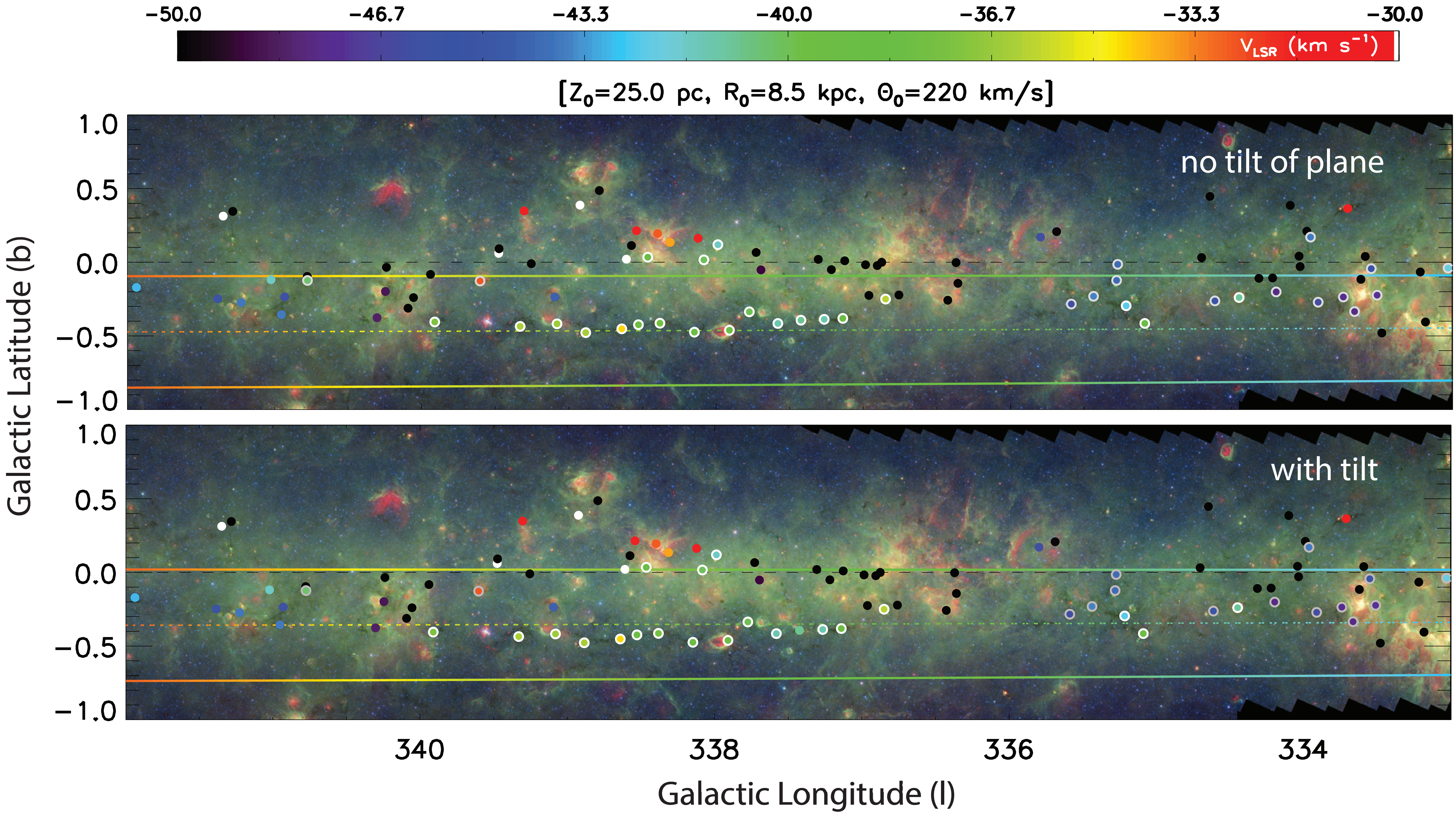
\+

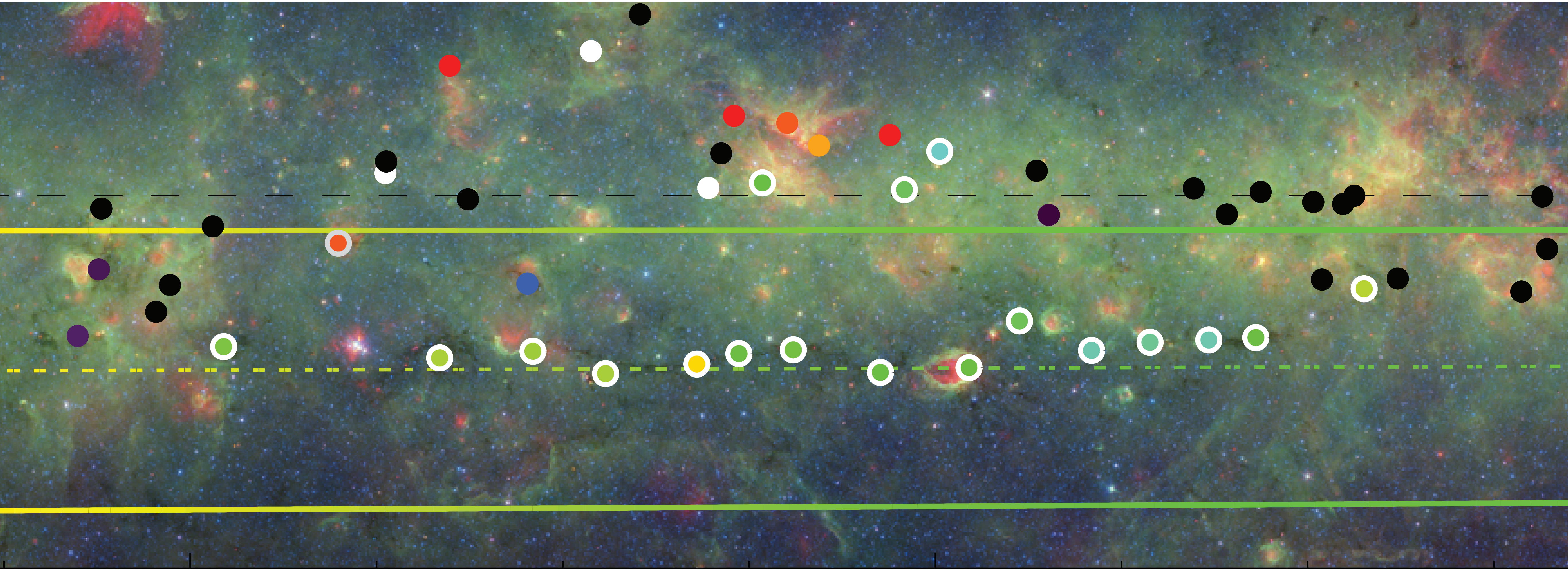
Galactic Center is ~20 light years offset from the IAU Milky Way Center

=

The **Galactic Plane is not quite where you'd think it is** when you look at the sky

In the plane! And at distance of spiral arm!

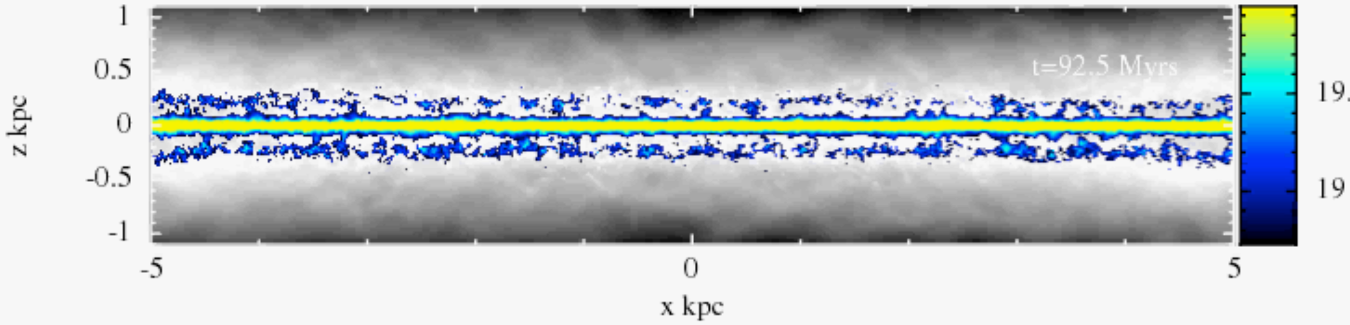




...eerily precisely...

How do we know the velocities?

A full 3D skeleton?

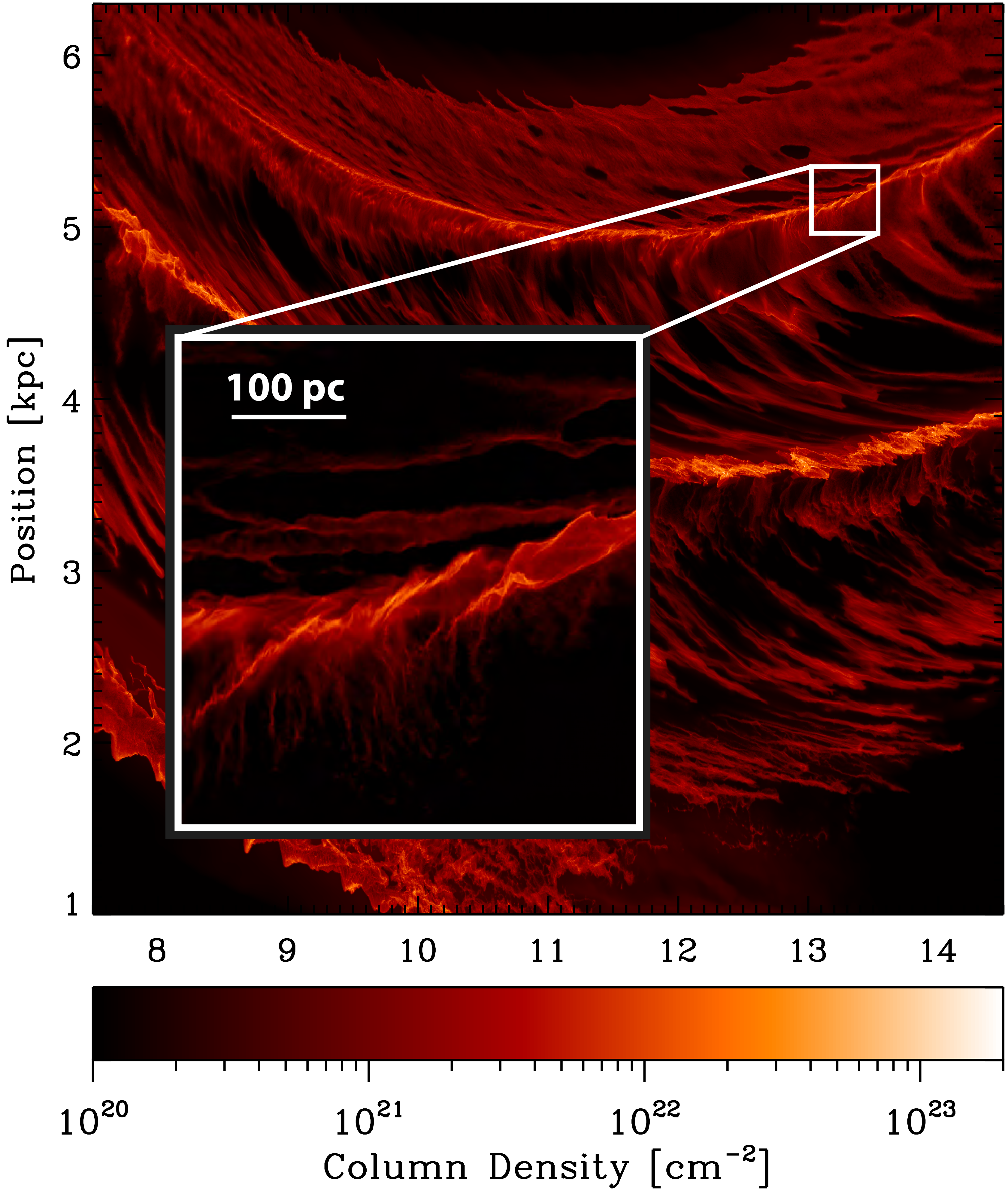


(flipped) image of IC342 from Jarrett et al. 2012; WISE Enhanced Resolution Galaxy Atlas

simulations courtesy Clare Dobbs

New!

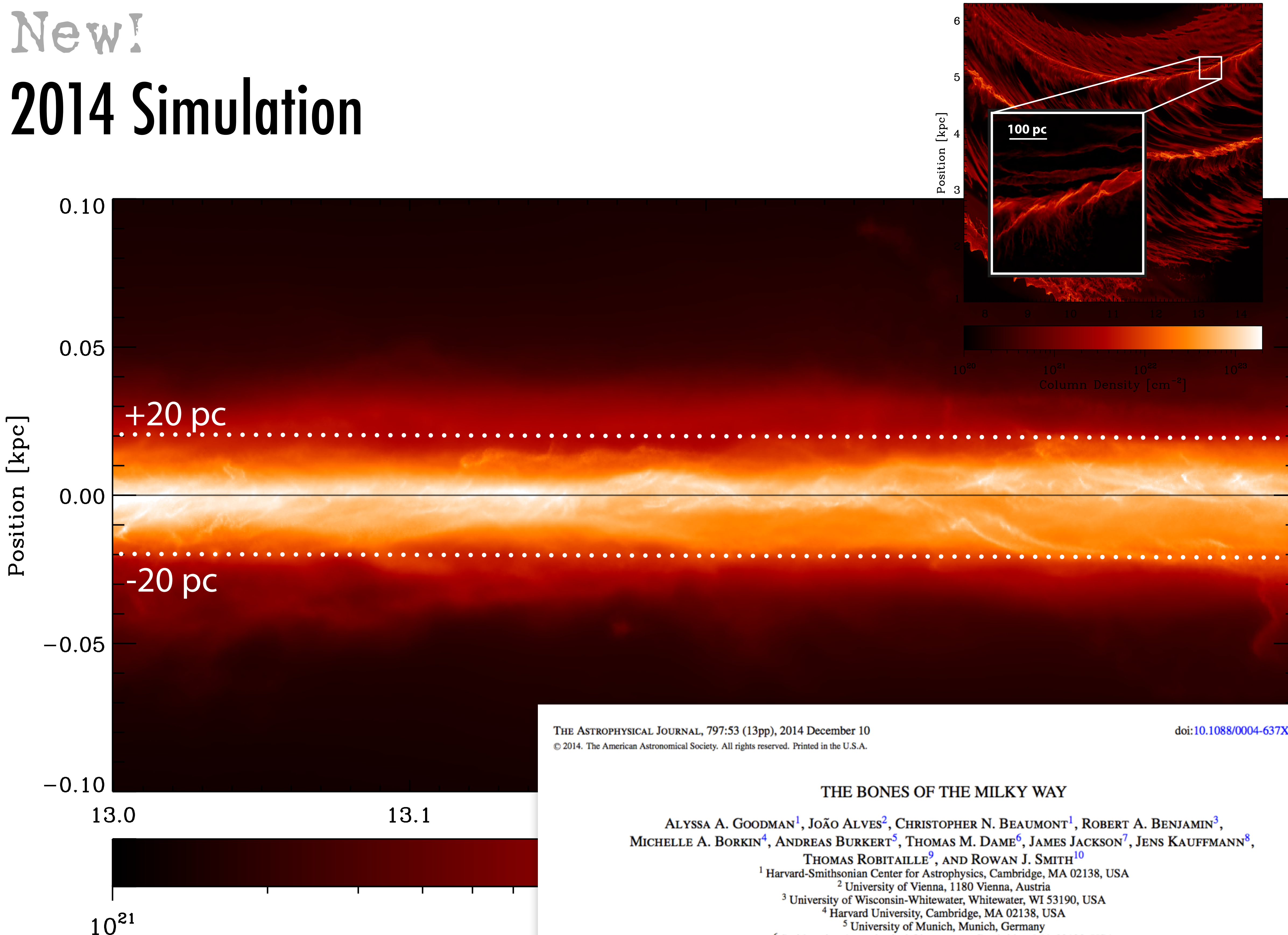
2014 Simulation



Smith et al. 2014, using AREPO

New!

2014 Simulation



THE ASTROPHYSICAL JOURNAL, 797:53 (13pp), 2014 December 10
doi:10.1088/0004-637X/797/1/53

THE BONES OF THE MILKY WAY

ALYSSA A. GOODMAN[1], JOÃO ALVES[2], CHRISTOPHER N. BEAUMONT[1], ROBERT A. BENJAMIN[3], MICHELLE A. BORKIN[4], ANDREAS BURKERT[5], THOMAS M. DAME[6], JAMES JACKSON[7], JENS KAUFFMANN[8], THOMAS ROBITAILLE[9], AND ROWAN J. SMITH[10]
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[2] University of Vienna, 1180 Vienna, Austria
[3] University of Wisconsin-Whitewater, Whitewater, WI 53190, USA
[4] Harvard University, Cambridge, MA 02138, USA
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[8] California Institute of Technology, Pasadena, CA 91125, USA
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Received 2013 December 16; accepted 2014 July 30; published 2014 November 25

Smith et al. 2014, using AREPO

Authorea

INSTITUTIONS ARTICLES ABOUT PLANS BLOG HELP FORUM ALYSSA GOODMAN

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The Skeleton of the Milky Way

Catherine Zucker, Alyssa Goodman, Cara Battersby

Abstract

Recently, Goodman
directly in the Gala
velocity (p-p-v) spa
presented as the firs
can be used to map
Milky Way Galaxy, a
potentially trace Gal
extinction features w
midplane. We use C
candidates in p-p-v
$\geq 50:1$, run along,
abrupt shifts in velo
mark the location of
strongly. As molecu
resolution and sensit
to the Galaxy's spiral

arXiv.org > astro-ph > arXiv:1506.08807

Search or Article

Astrophysics > Astrophysics of Galaxies

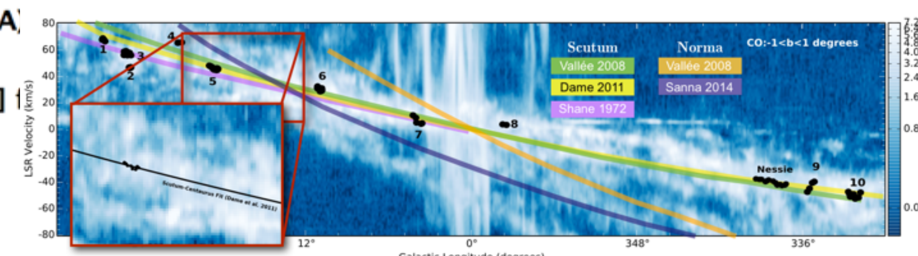
The Skeleton of the Milky Way

Catherine Zucker, Cara Battersby, Alyssa Goodman

(Submitted on 29 Jun 2015)

Recently, Goodman et al. (2014) argued that the very long, very thin infrared dark cloud "Nessie" lies directly in the Galactic mid-plane and runs along the Scutum-Centaurus arm in position-position-velocity ($p-p-v$) space as traced by lower density CO and higher density NH_3 gas. Nessie was presented as the first "bone" of the Milky Way, an extraordinarily long, thin, high-contrast filament that can be used to map our Galaxy's "skeleton." Here, we present evidence for additional bones in the Milky Way Galaxy, arguing that Nessie is not a curiosity but one of several filaments that could potentially trace Galactic structure. Our ten bone candidates are all long, filamentary, mid-infrared extinction features which lie parallel to, and no more than 20 pc from, the physical Galactic mid-plane. We use CO, N_2H^+, HCO^+, and NH_3 radial velocity data to establish the three-dimensional location of the candidates in $p-p-v$ space. Of the ten candidates, six also: have a projected aspect ratio of $\gtrsim$50:1; run along, or extremely close to, the Scutum-Centaurus arm in p-p-v space; and exhibit no abrupt shifts in velocity. Evidence suggests that these candidates are marking the locations of significant spiral features, with the bone called filament 5 ("BC_18.88-0.09") being a close analog to Nessie in the Northern Sky. As molecular spectral-line and extinction maps cover more of the sky at increasing resolution and sensitivity, it should be possible to find more bones in future studies, ultimately to create a global-fit to the Galaxy's spiral arms by piecing together individual skeletal features.

Comments: Submitted to The Astrophysical Journal
Subjects: Astrophysics of Galaxies (astro-ph.GA)
Cite as: arXiv:1506.08807 [astro-ph.GA]
(or arXiv:1506.08807v1 [astro-ph.GA]



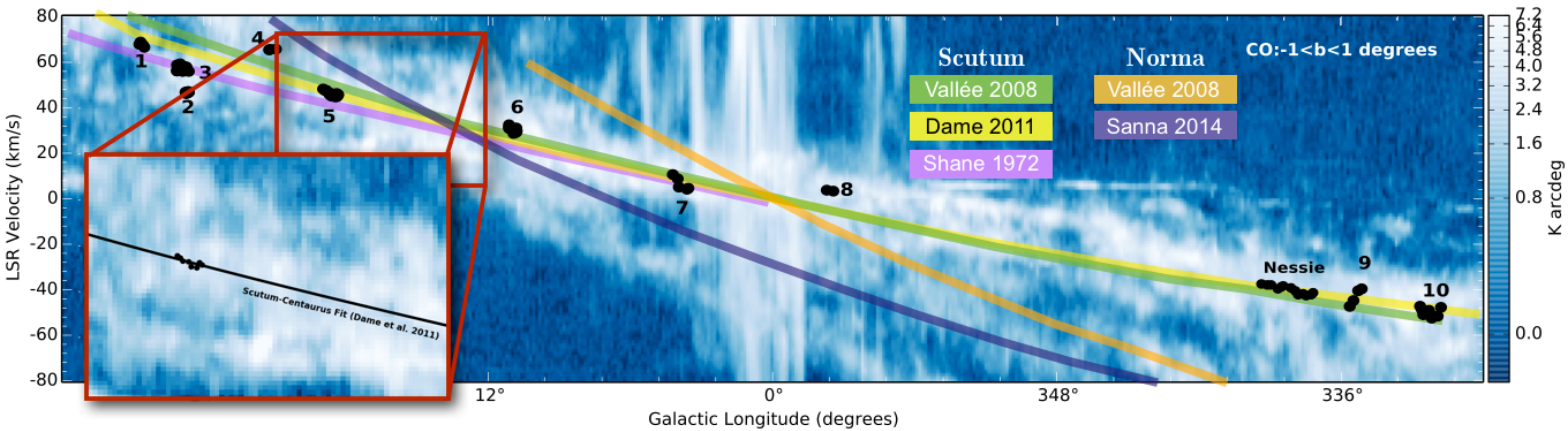
Submission history

From: Catherine Zucker [view email]
[v1] Mon, 29 Jun 2015 19:58:53 GMT (7267kb,D)

2015

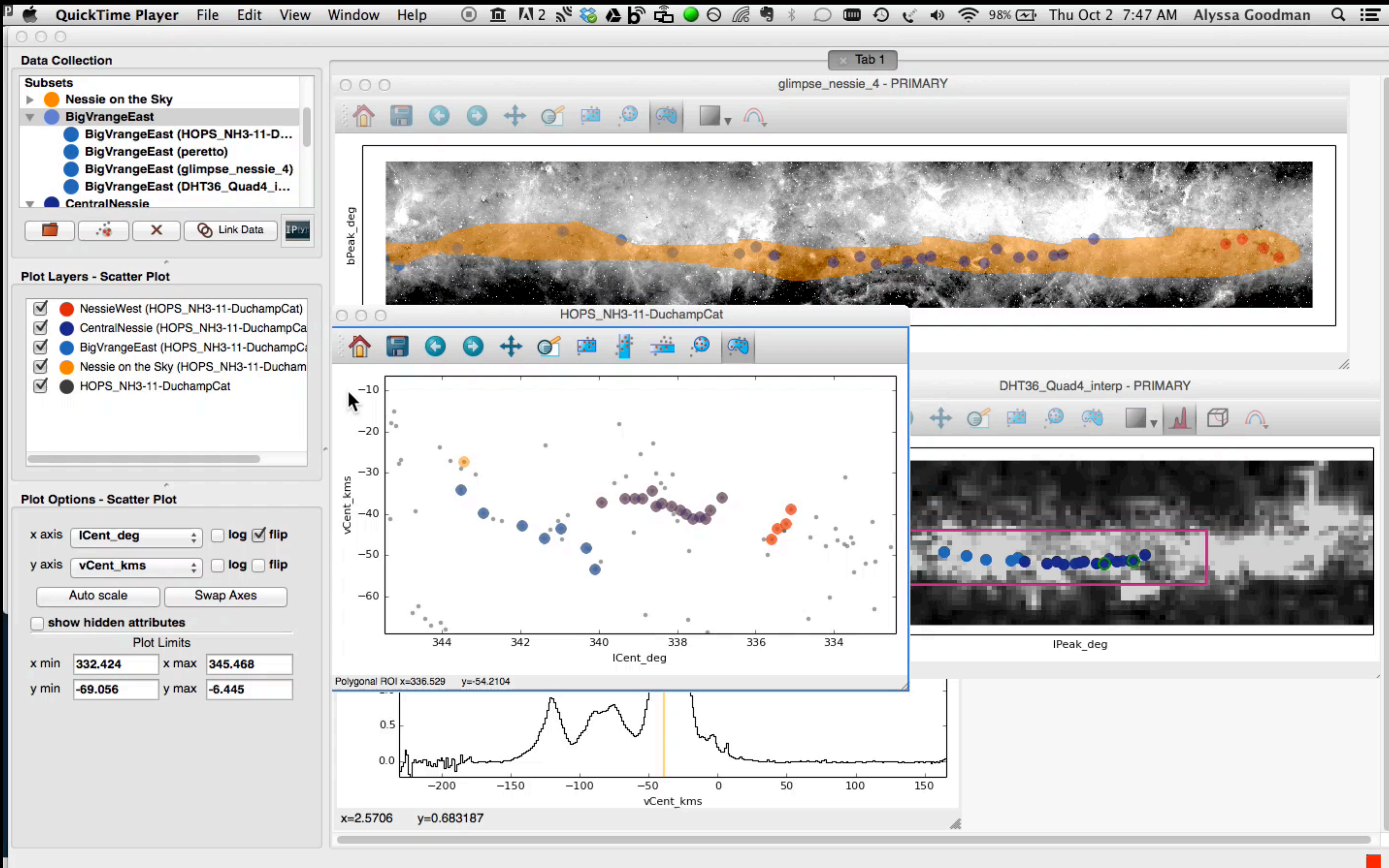
6 OUT OF 10 BONE CANDIDATES LOOK EXCELLENT IN "3D"

(POSITON-POSITION-VELOCITY SPACE)



Blue image in the background shows CO position-velocity diagram based on Dame et al. 2001

NESSIE IN GLUE



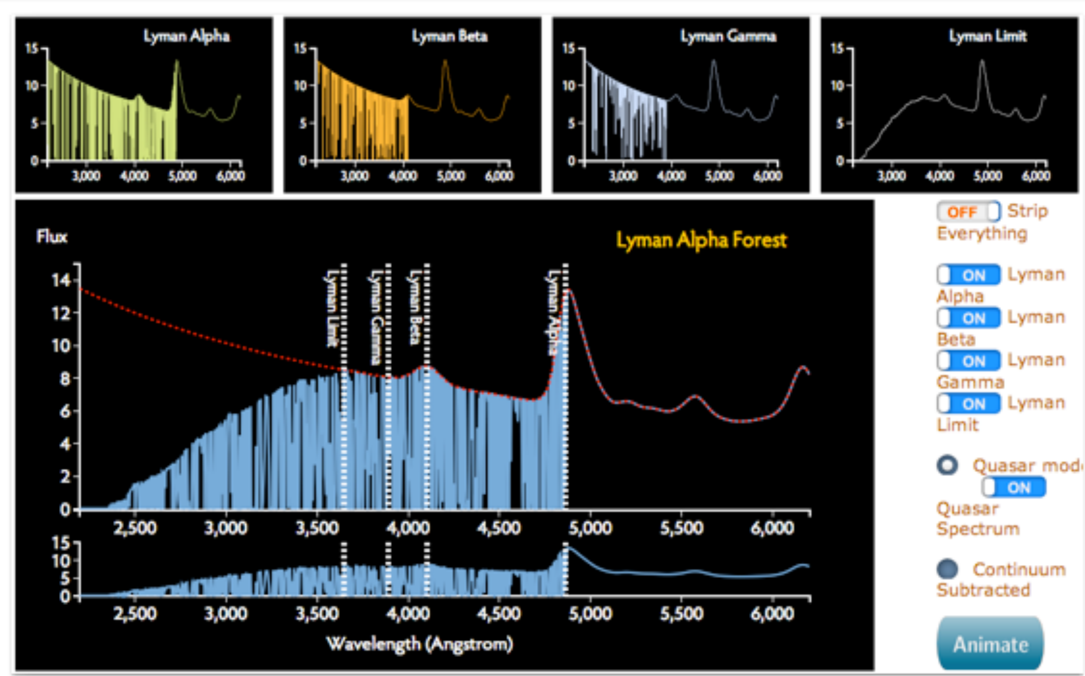
EDUCATION, 2015+

Stephen

all lines SII 6716/6731 Å Hα 6563 Å OIII 5007 Å

Yuan-Sen Ting

Interstellar Absorption and the Lyman Alpha Forest



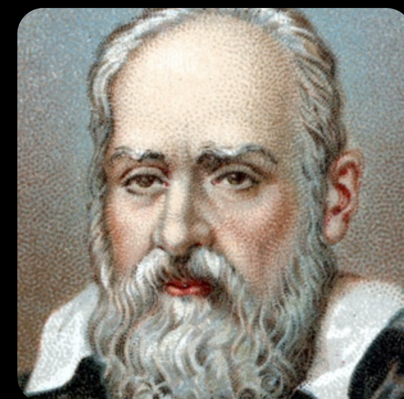
JavaScript https://www.cfa.harvard.edu/~yuan-sen.ting/lyman_alpha.html

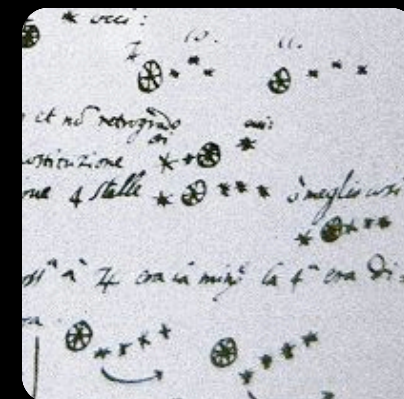
JavaScript http://portillo.ca/nebula/

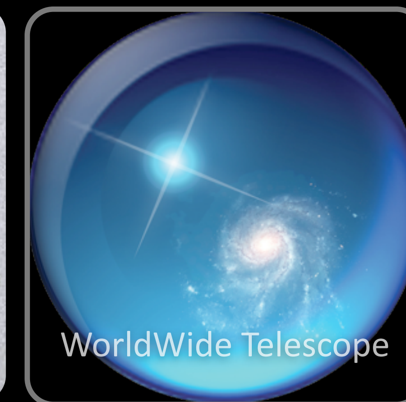
online learning

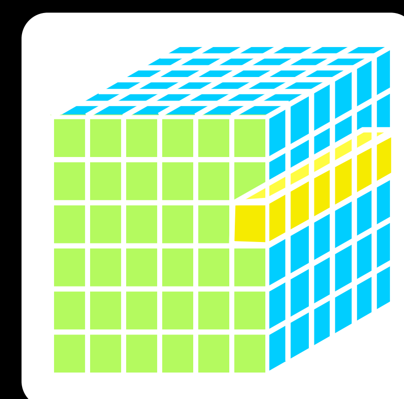
WWT Ambassadors

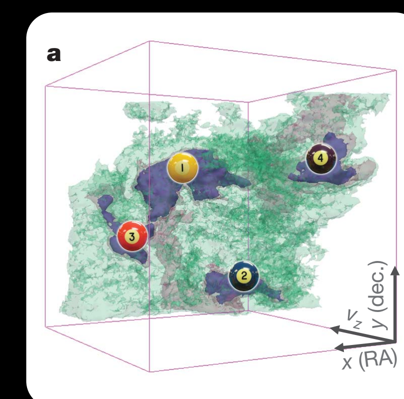
see: A New Approach to Developing Interactive Software Modules through Graduate Education, Sanders, Faesi & Goodman 2013

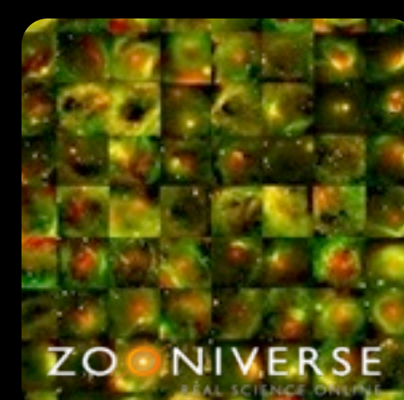


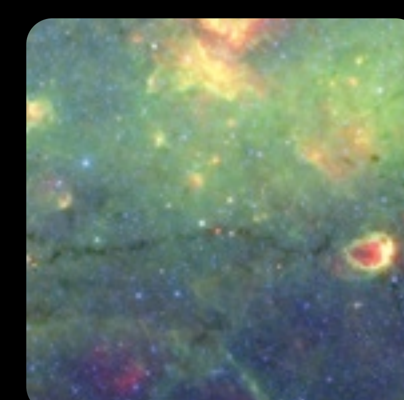



WorldWide Telescope



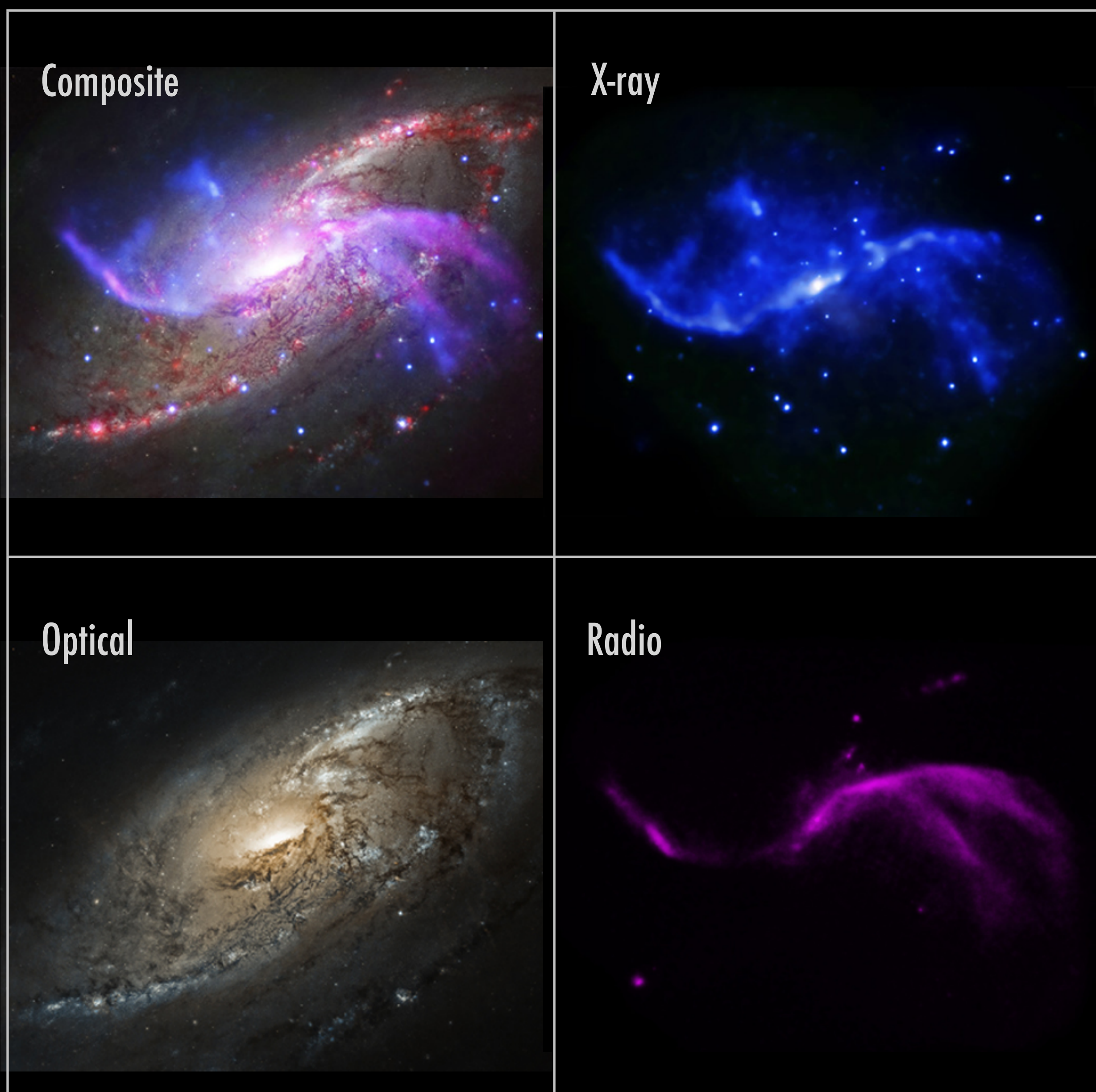

a
x (RA)
y (dec.)


ZOONIVERSE
REAL SCIENCE ONLINE

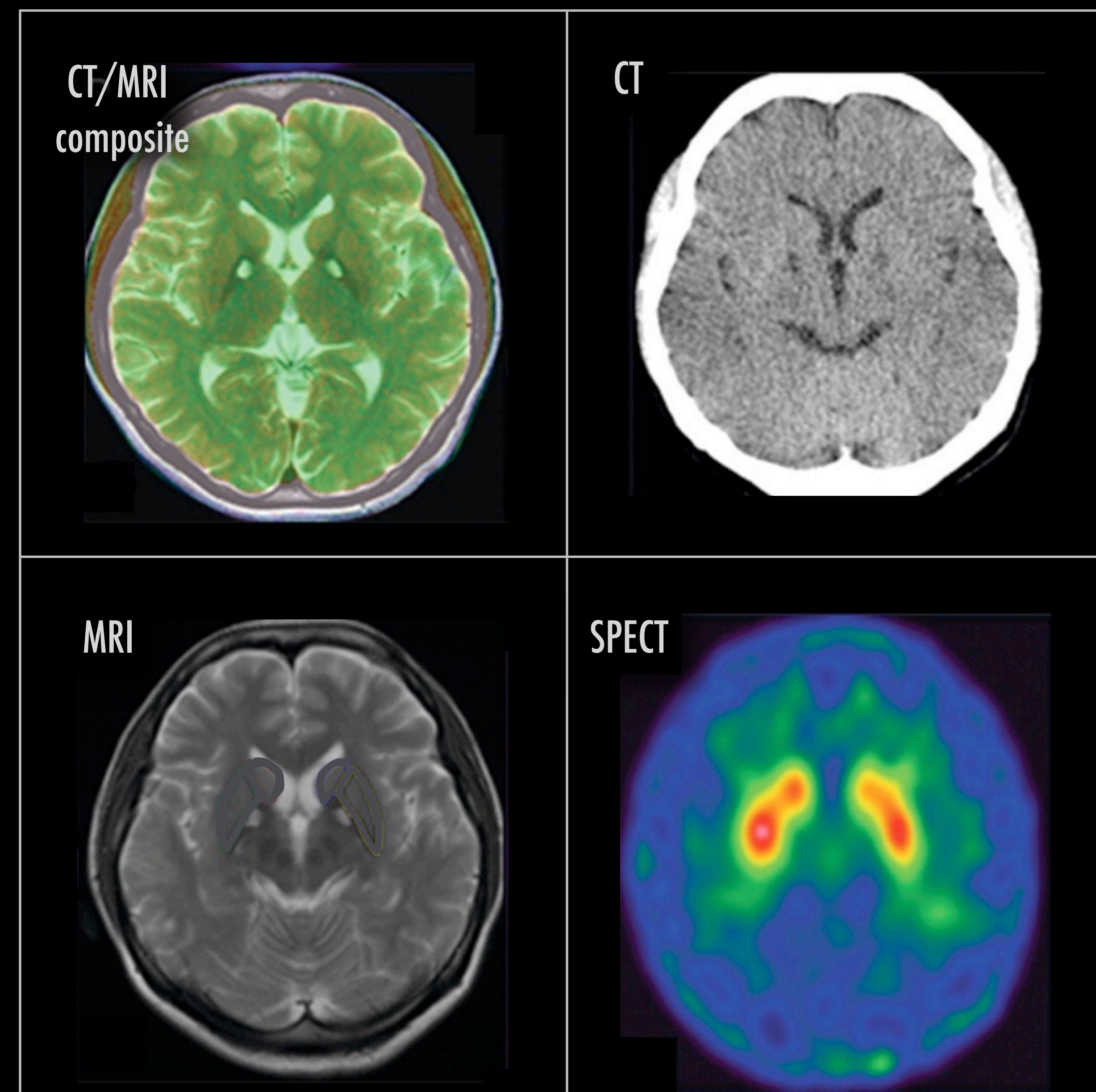


ASTRONOMY, MEDICINE, AND THE FUTURE

ALYSSA A. GOODMAN, HARVARD-SMITHSONIAN CENTER FOR ASTROPHYSICS



chandra.harvard.edu/photo/2014/m106/



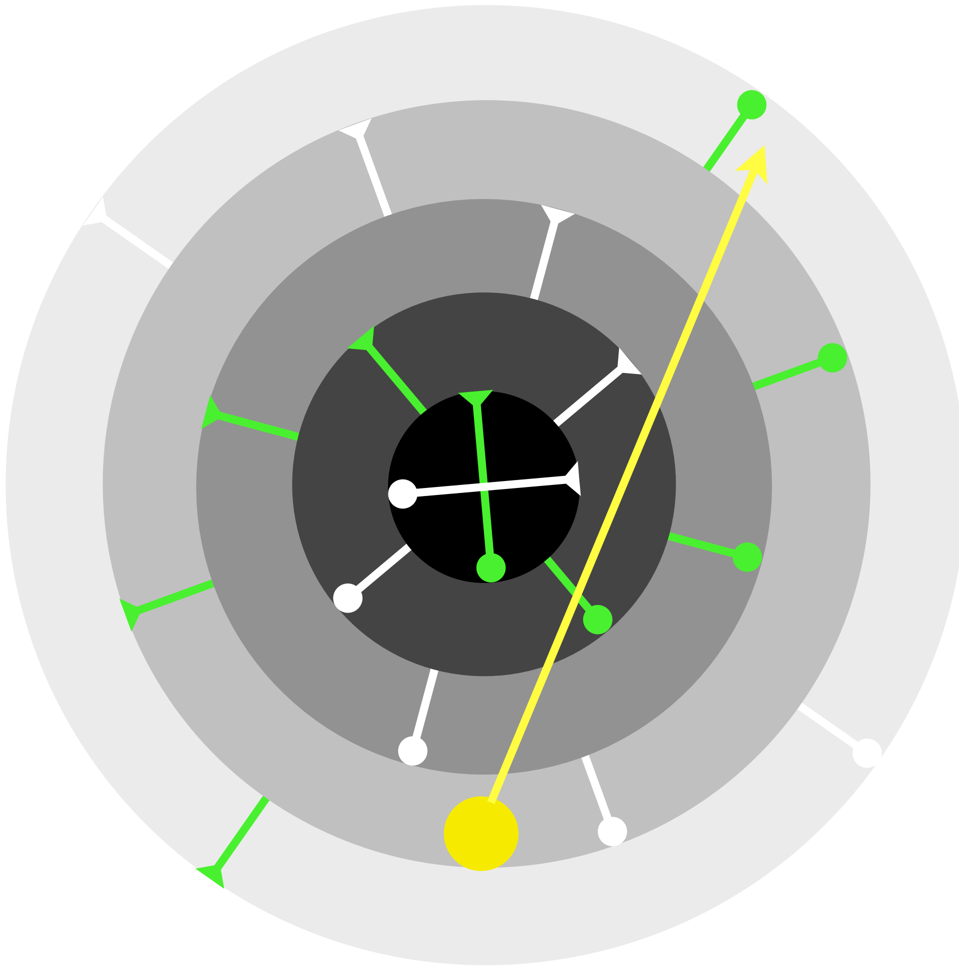
Chang, et al. 2011, brain.oxfordjournals.org/content/134/12/3632

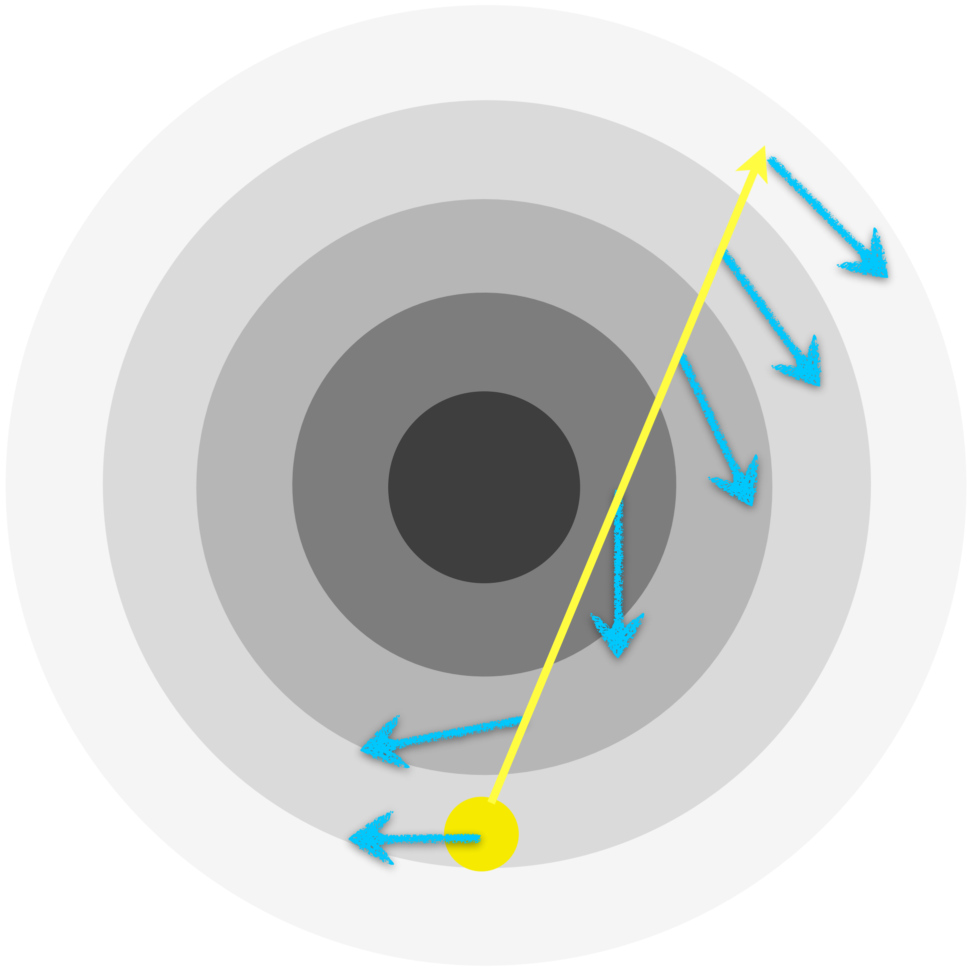
@aagie

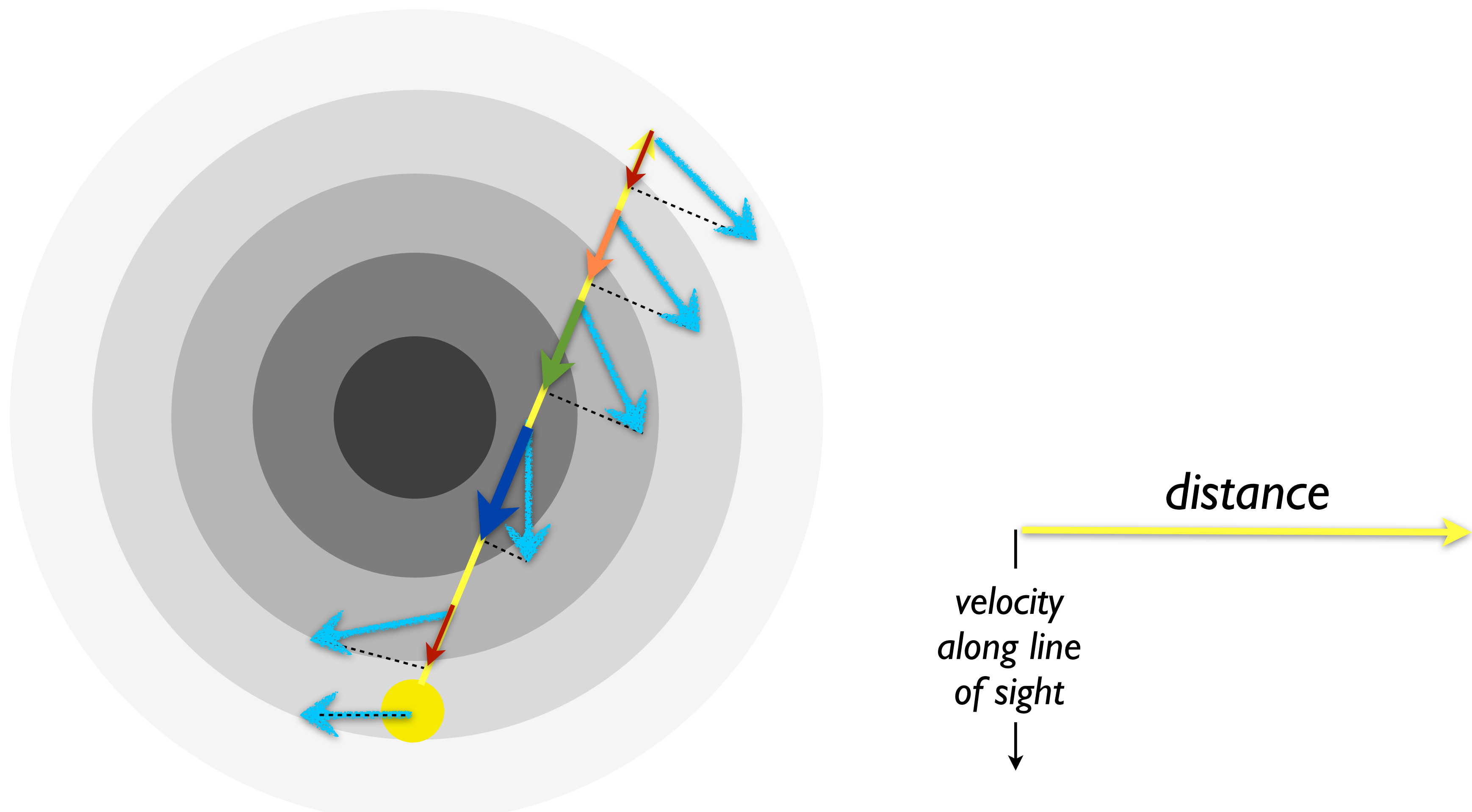
MORE?

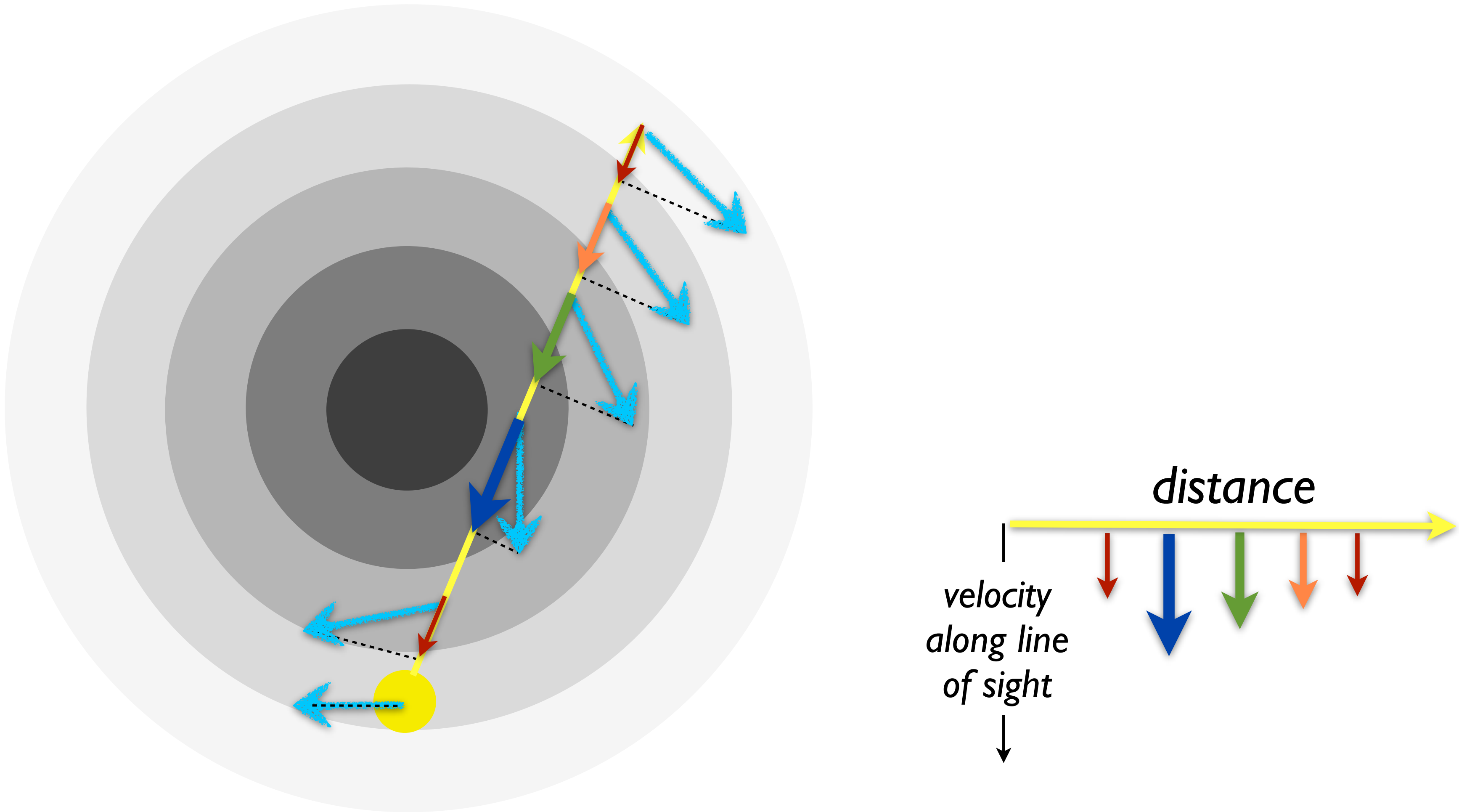
projects.iq.harvard.edu/seamlessastronomy/presentations

A Rotating (Spiral) Galaxy Observed from its Outskirts...






distance
velocity
along line
of sight



back