FILAMENTS: FAD OR FUNDAMENTAL?

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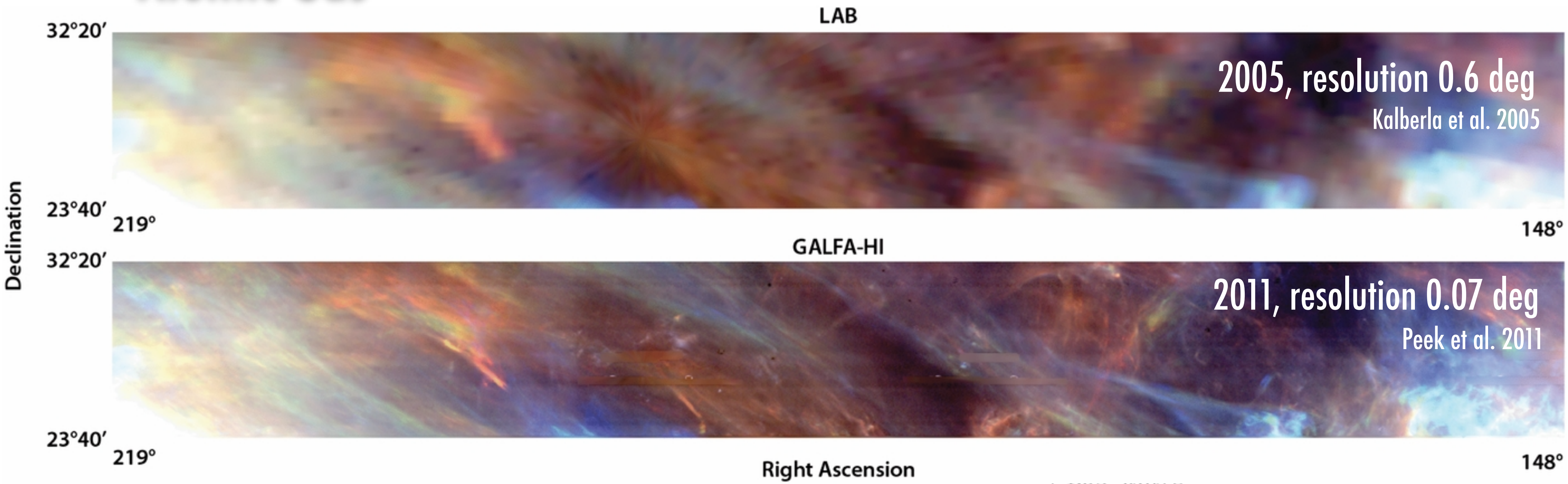
Ophiuchus, Barnard 1919

Ophiuchus, Barnard 1919

Atomic Gas



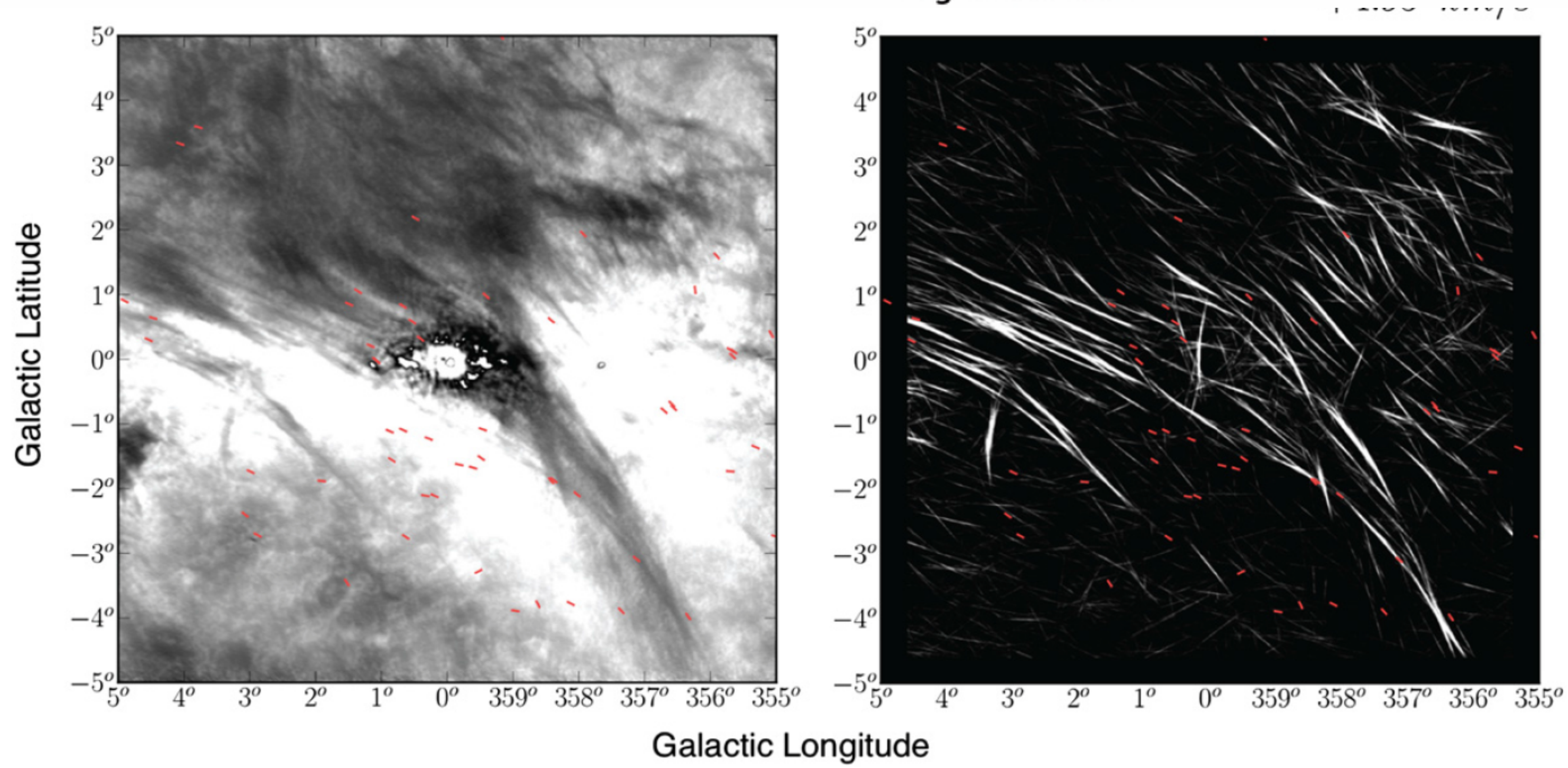


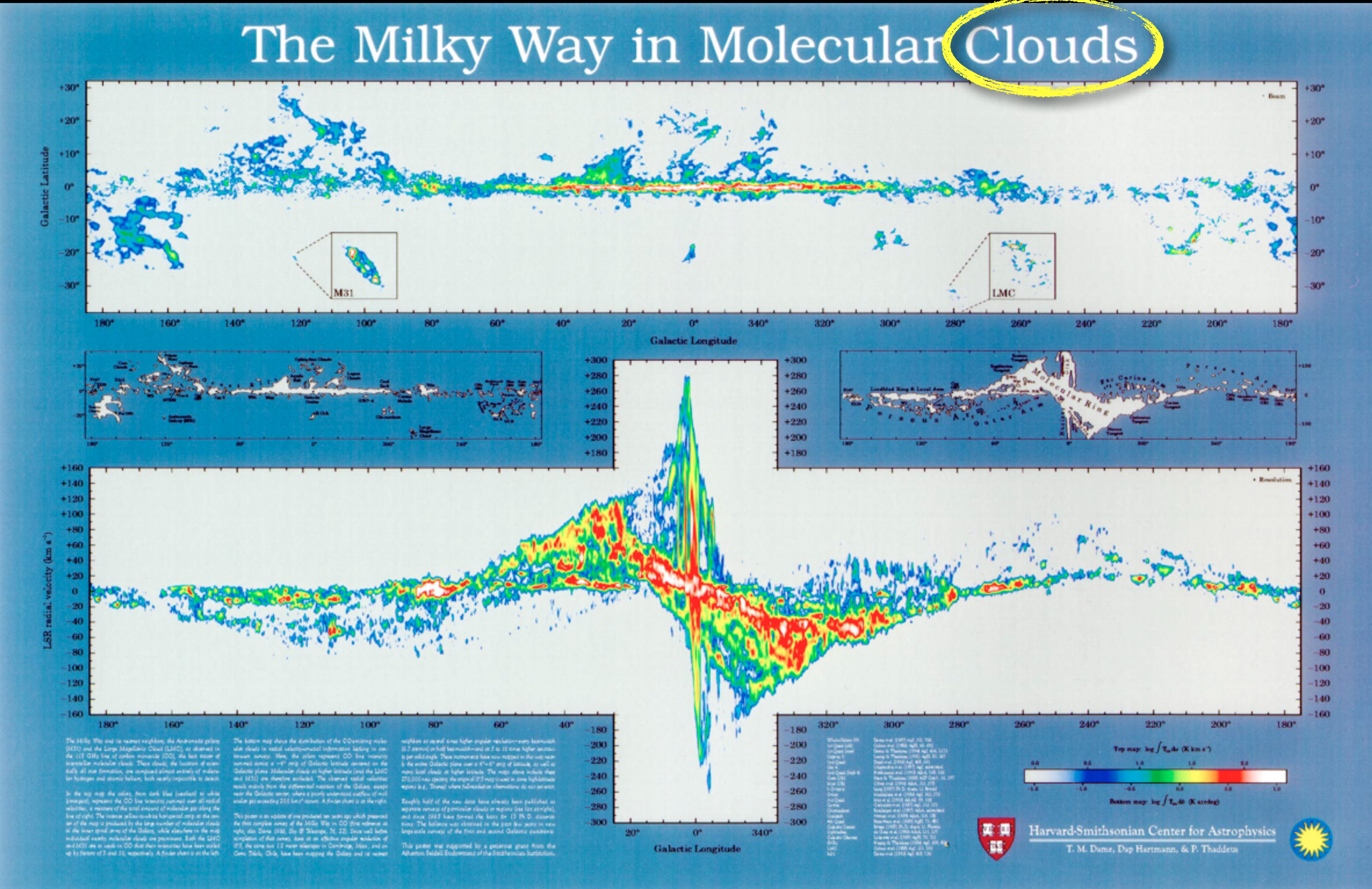
Figure 10. Riegel–Crutcher cloud (Section 6) in H I absorption (left) and RHT backprojection (right). Overlaid pseudovectors represent polarization angle measurements from the Heiles (2000) compilation. In the left panel, the intensity scale is linear from −20 K (white) to −120 K (black).

(A color version of this figure is available in the online journal.)

Clark, Peek & Putnam 2014

Molecular Gas

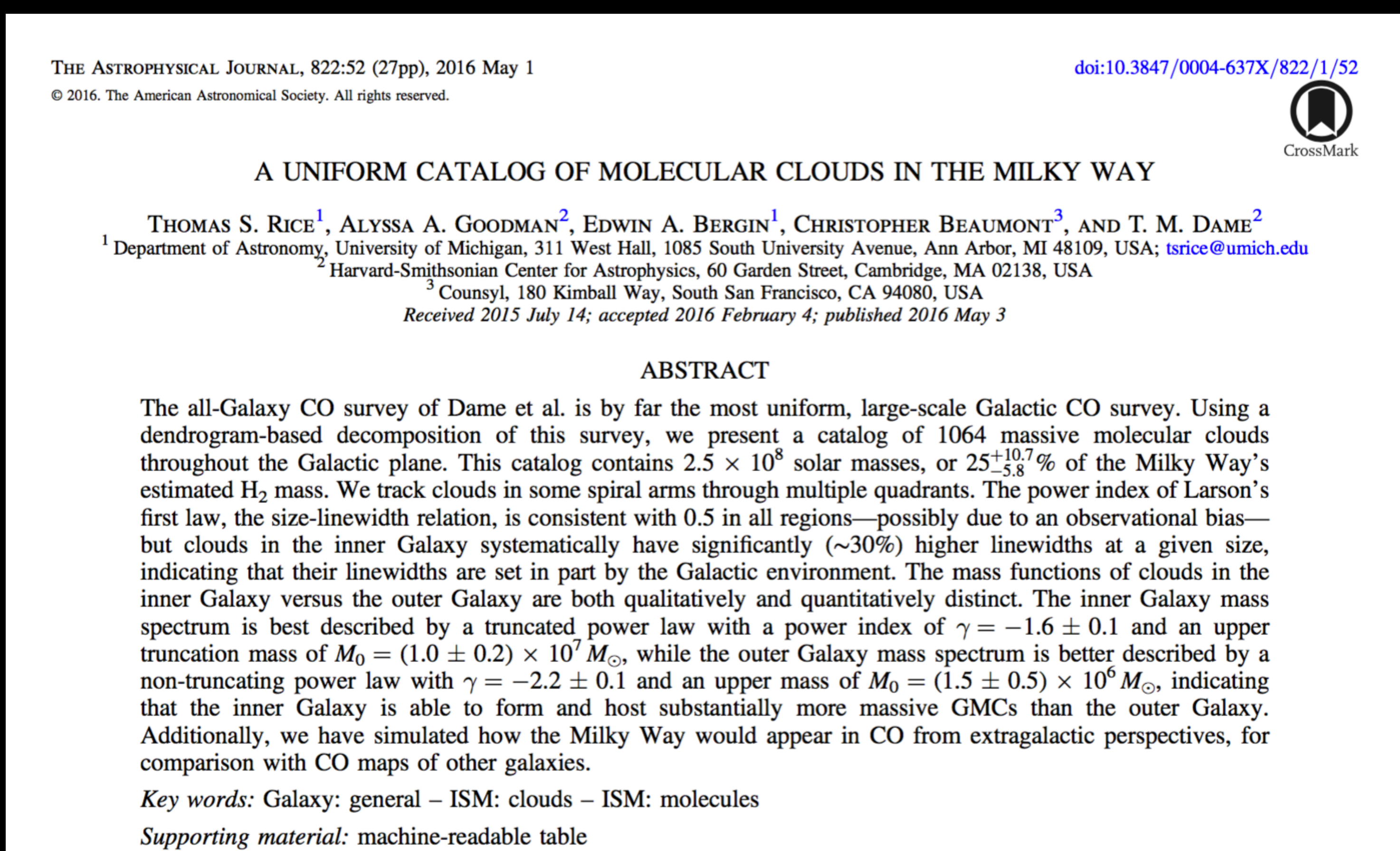
Dame et al. 2001



Molecular Gas "Clouds"

Rice et al. 2016

video: Matt Pasquini



The Astrophysical Journal, 822:52 (27pp), 2016 May 1
doi:10.3847/0004-637X/822/1/52

CrossMark

A UNIFORM CATALOG OF MOLECULAR CLOUDS IN THE MILKY WAY

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ABSTRACT

The all-Galaxy CO survey of Dame et al. is by far the most uniform, large-scale Galactic CO survey. Using a dendrogram-based decomposition of this survey, we present a catalog of 1064 massive molecular clouds throughout the Galactic plane. This catalog contains 2.5×10^8 solar masses, or $25^{+10.7}_{-5.8}\%$ of the Milky Way's estimated H_2 mass. We track clouds in some spiral arms through multiple quadrants. The power index of Larson's first law, the size-linewidth relation, is consistent with 0.5 in all regions—possibly due to an observational bias—but clouds in the inner Galaxy systematically have significantly (~30%) higher linewidths at a given size, indicating that their linewidths are set in part by the Galactic environment. The mass functions of clouds in the inner Galaxy versus the outer Galaxy are both qualitatively and quantitatively distinct. The inner Galaxy mass spectrum is best described by a truncated power law with a power index of $\gamma = -1.6 \pm 0.1$ and an upper truncation mass of $M_0 = (1.0 \pm 0.2) \times 10^7\,M_\odot$, while the outer Galaxy mass spectrum is better described by a non-truncating power law with $\gamma = -2.2 \pm 0.1$ and an upper mass of $M_0 = (1.5 \pm 0.5) \times 10^6\,M_\odot$, indicating that the inner Galaxy is able to form and host substantially more massive GMCs than the outer Galaxy. Additionally, we have simulated how the Milky Way would appear in CO from extragalactic perspectives, for comparison with CO maps of other galaxies.

Key words: Galaxy: general – ISM: clouds – ISM: molecules

Supporting material: machine-readable table

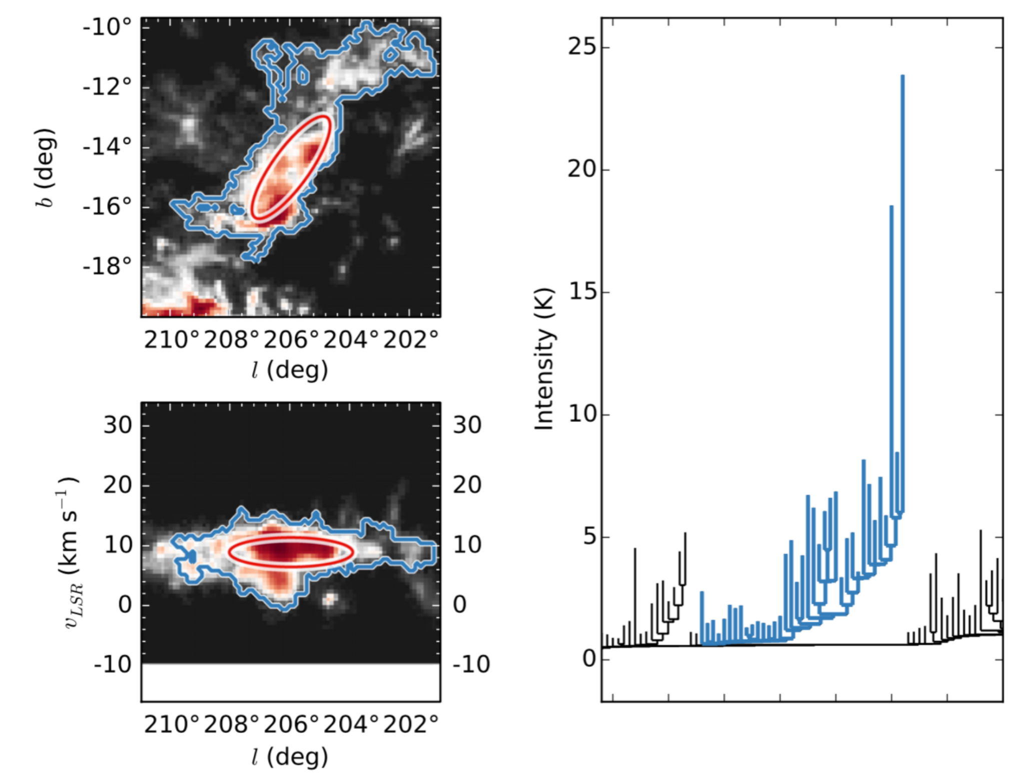
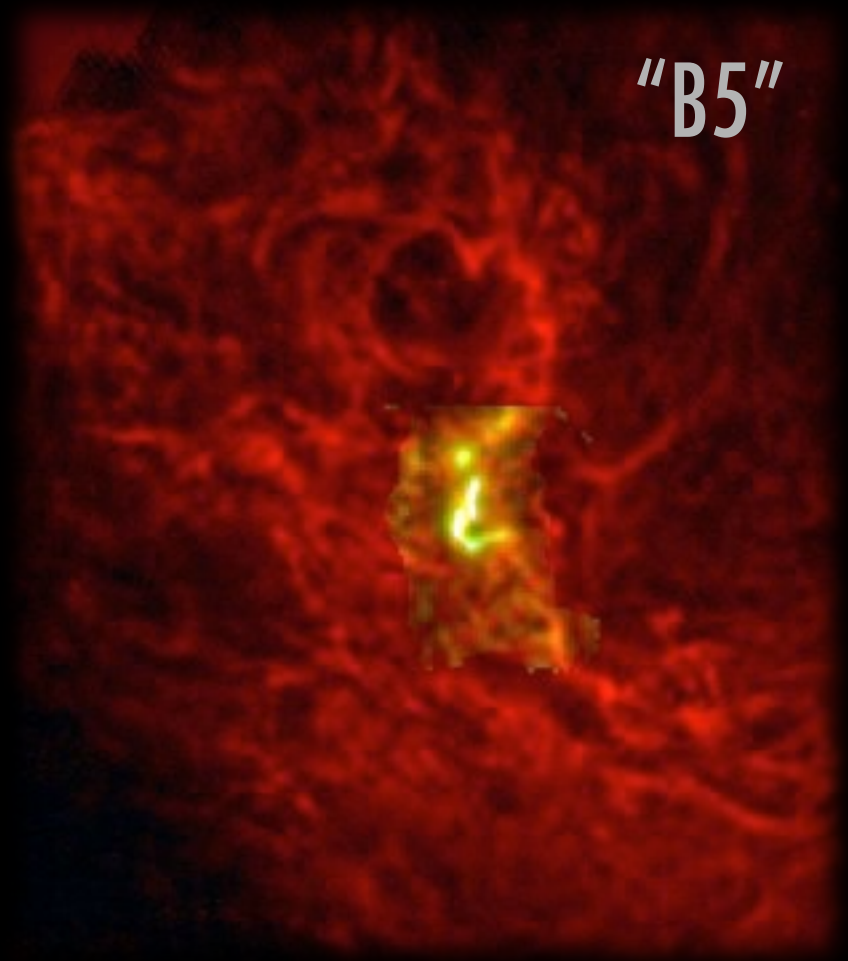


Figure 2. Example dendrogram extraction of Orion B: a nearby, well-studied giant molecular cloud. Top left: (*l*, *b*) thumbnail of the cloud and its neighboring region as seen on the sky. Bottom left: (*l*, *v*) thumbnail of the same region. Right: dendrogram cutout, with Orion B's structures highlighted in blue. The pixels corresponding to the highlighted dendrogram structures are outlined in the blue contour (in projection); a representative ellipse is drawn in red, with semimajor axis length equal to the second moment along each relevant dimension (as calculated in Section 2.2). Data come from DHT Survey #27 (the Orion complex).

IN A FEW MINUTES...



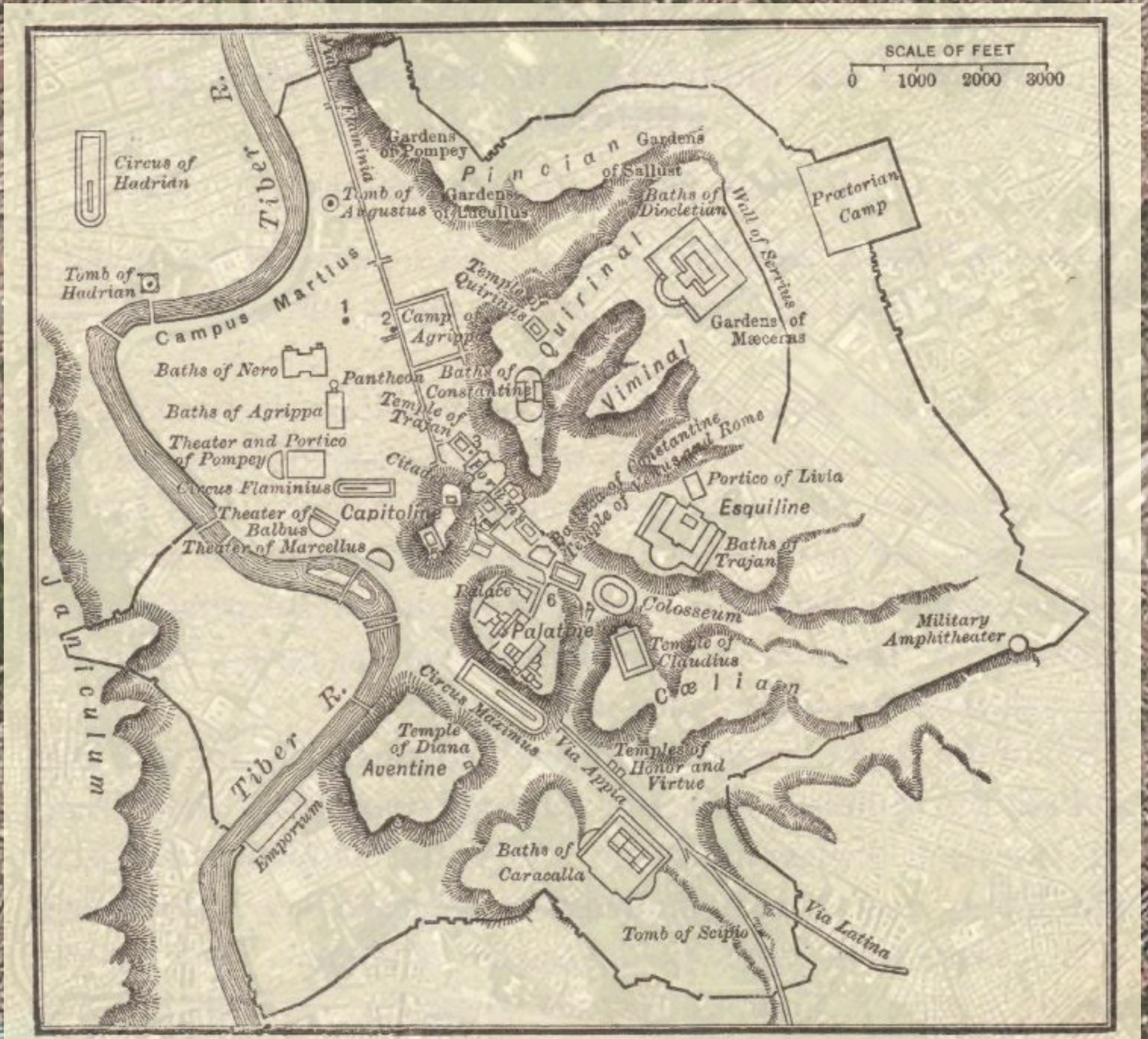
~0.01 to 10 pc

>100 pc

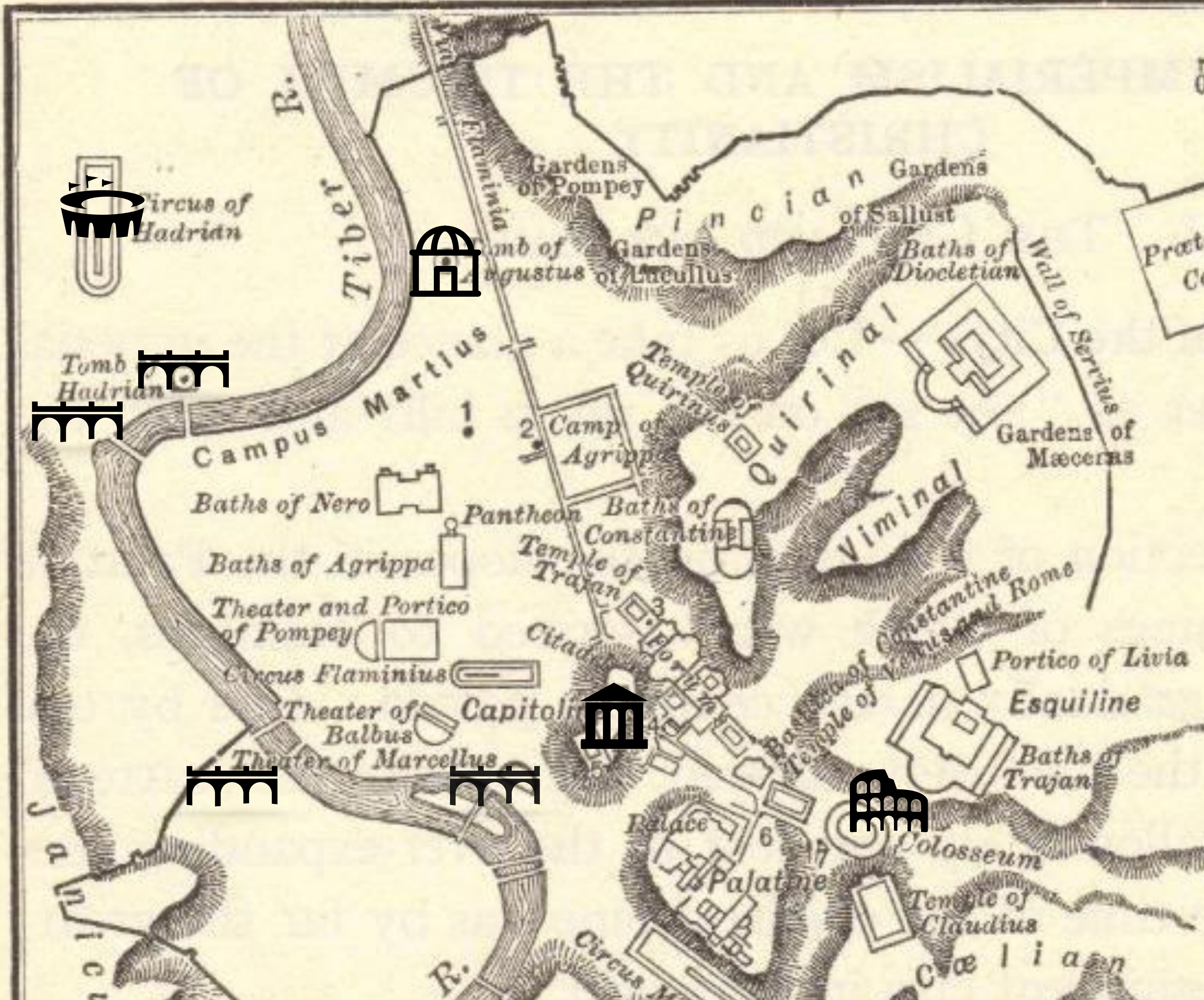
BUT FIRST...

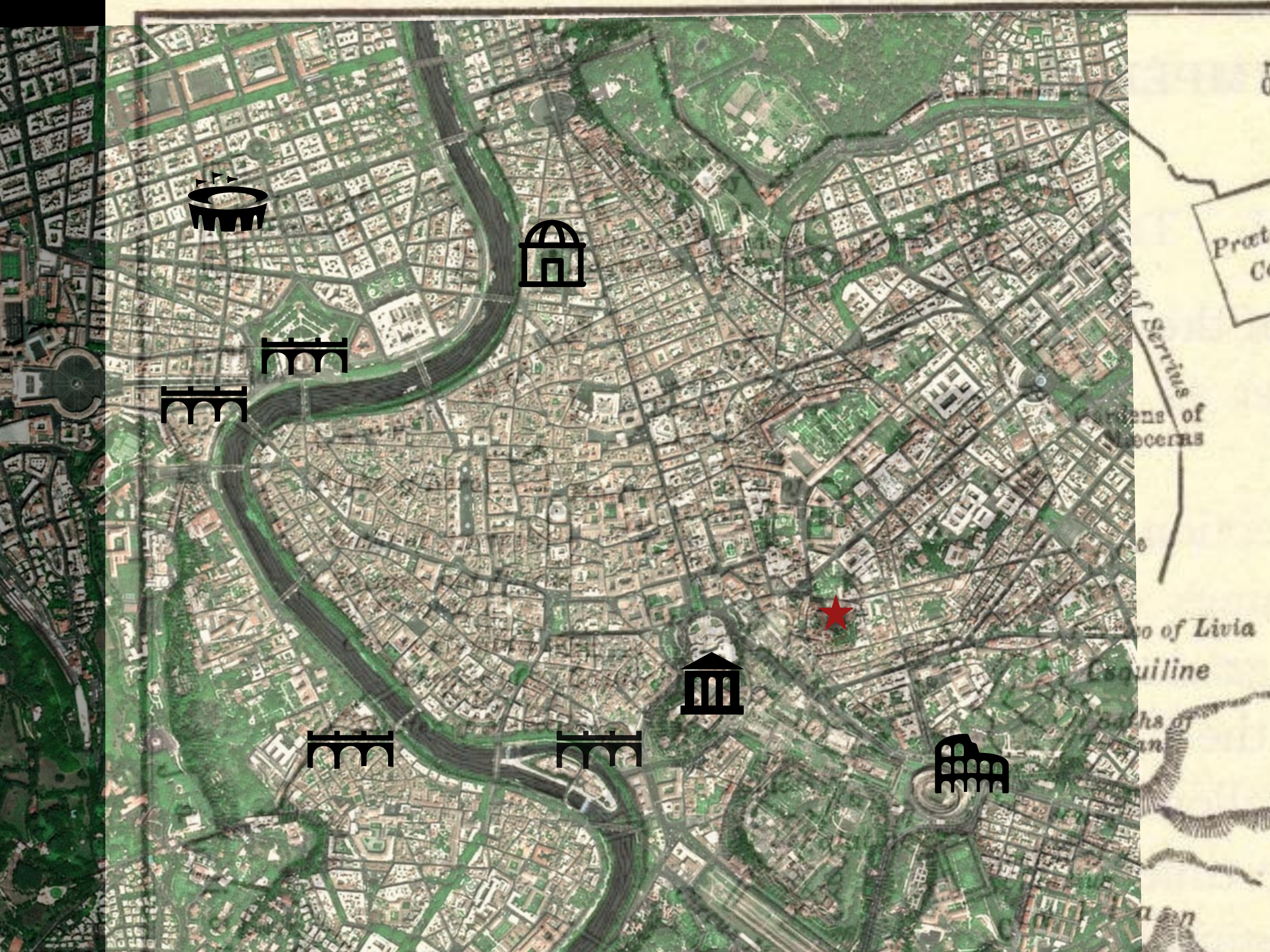

ROME
2016 AD
VIALACTEA

2000 YEARS AGO...

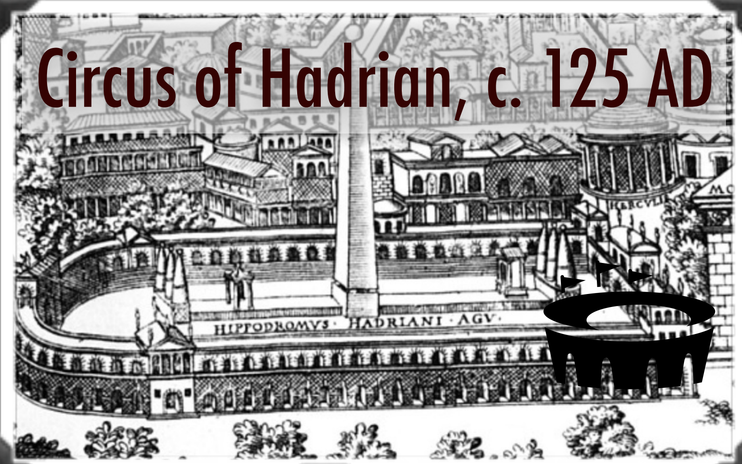


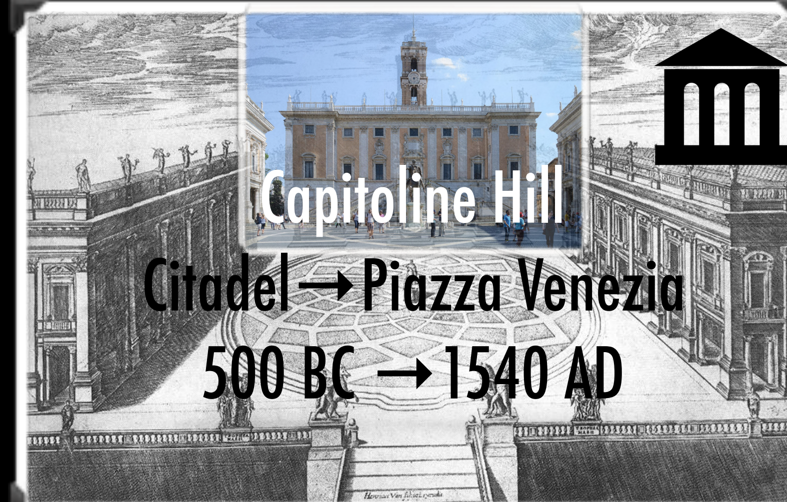
2000 YEARS AGO…

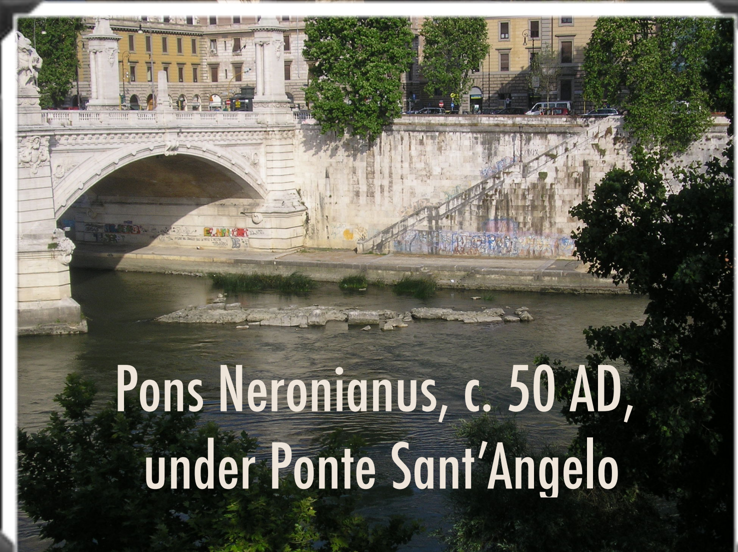


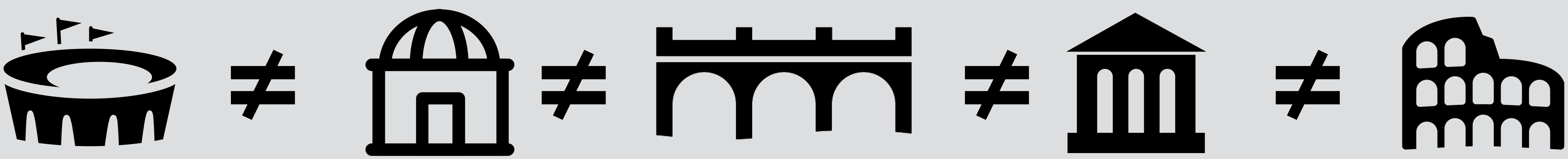

of Servius
of Livia
Esquiline

All Stone
All in Rome





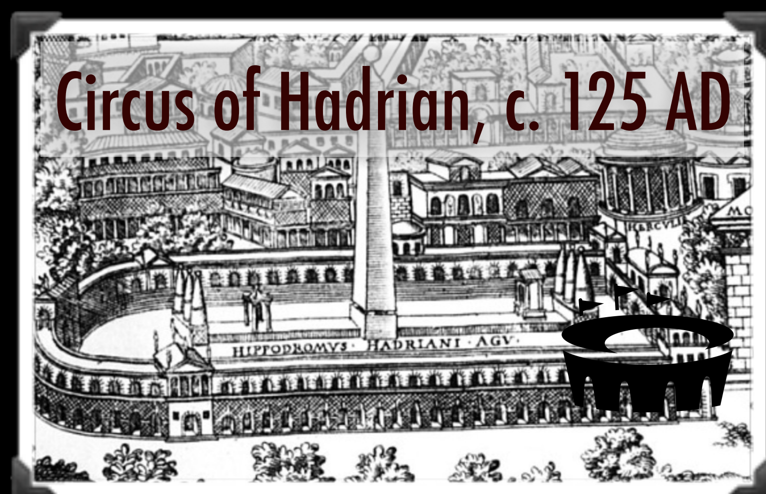




A SEQUENCE…
BUT NOT OF TIME
…OR OF TYPE

~~Replaced~~

Erased



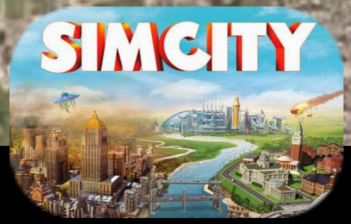
Extant

Disappearing

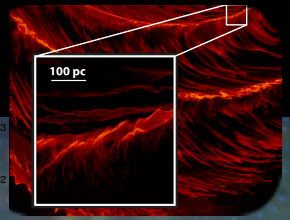
New

ROME

is a mixture of



Erased   Disappearing   ~~Replaced~~*   Extant   New



and so is

THE STAR-FORMING ISM

*~~Recycled?~~

What are the destructive/constructive forces?

Any structure’s longevity is affected by which influences govern it.

How (long) do structures live?

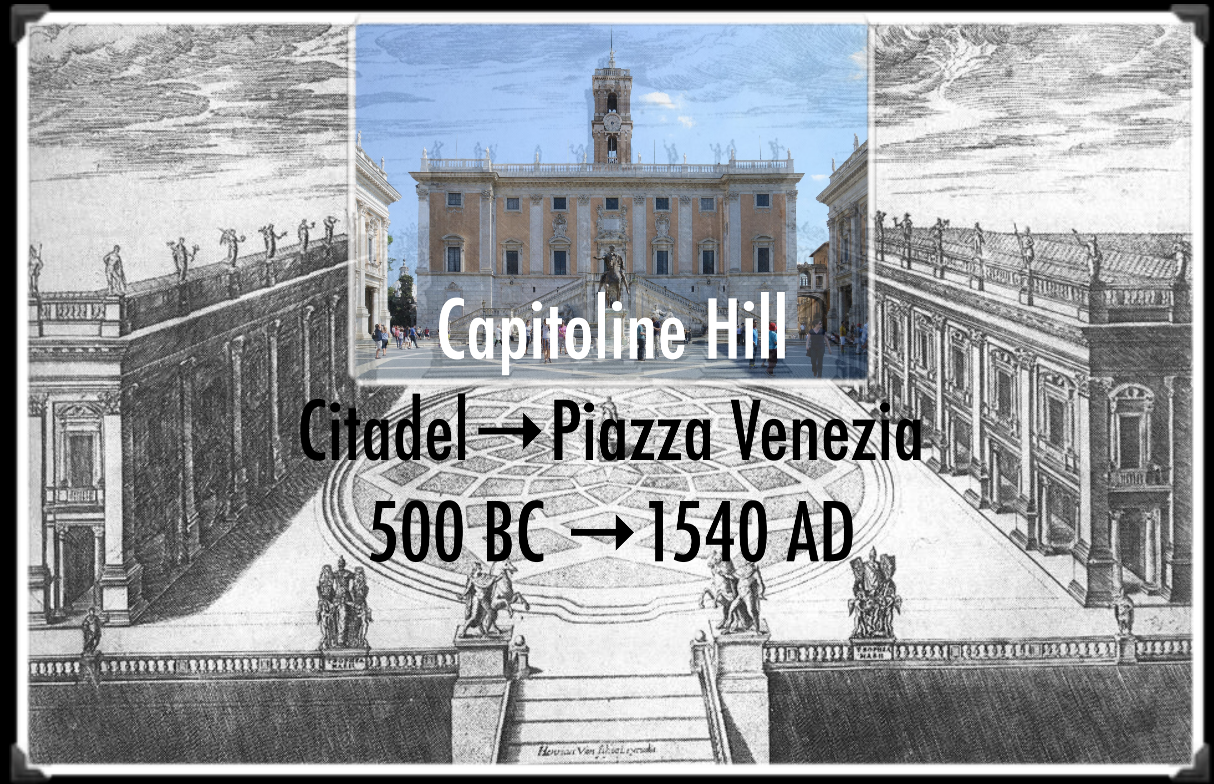
ONLY SIMULATIONS ALLOW US TO BUILD, DESTROY & TIME TRAVEL

C. 80 AD

2016

+"observed" simulations are best

ARE SOME PLACES SPECIAL?



What are “special” places in ISM & how long do they last?

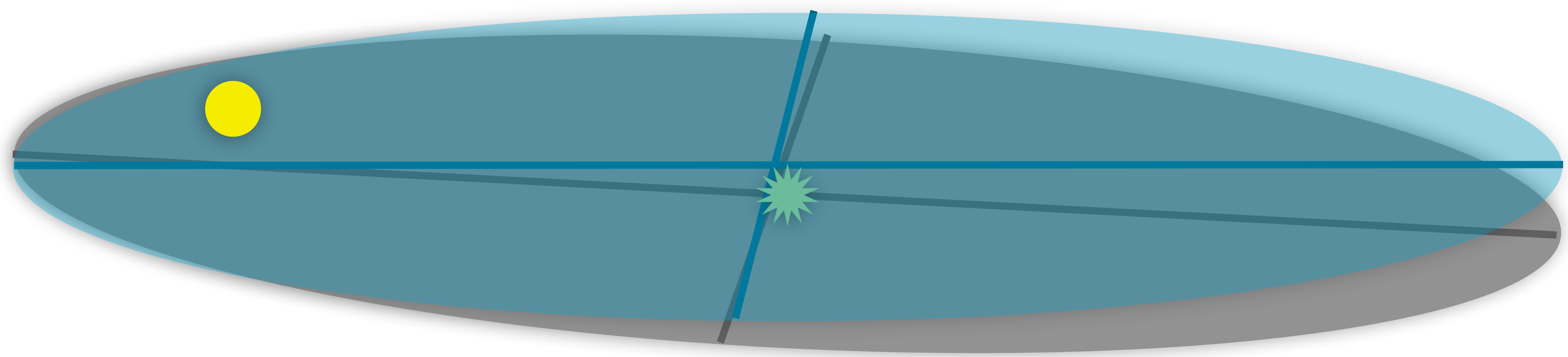
How do “influences” change what is special?

The mid-plane of a spiral galaxy is a special place.

"Is Nessie Parallel to the Galactic Plane?" *-A. Burkert, 2012*

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 ~25 pc "above" the IAU Milky Way Plane

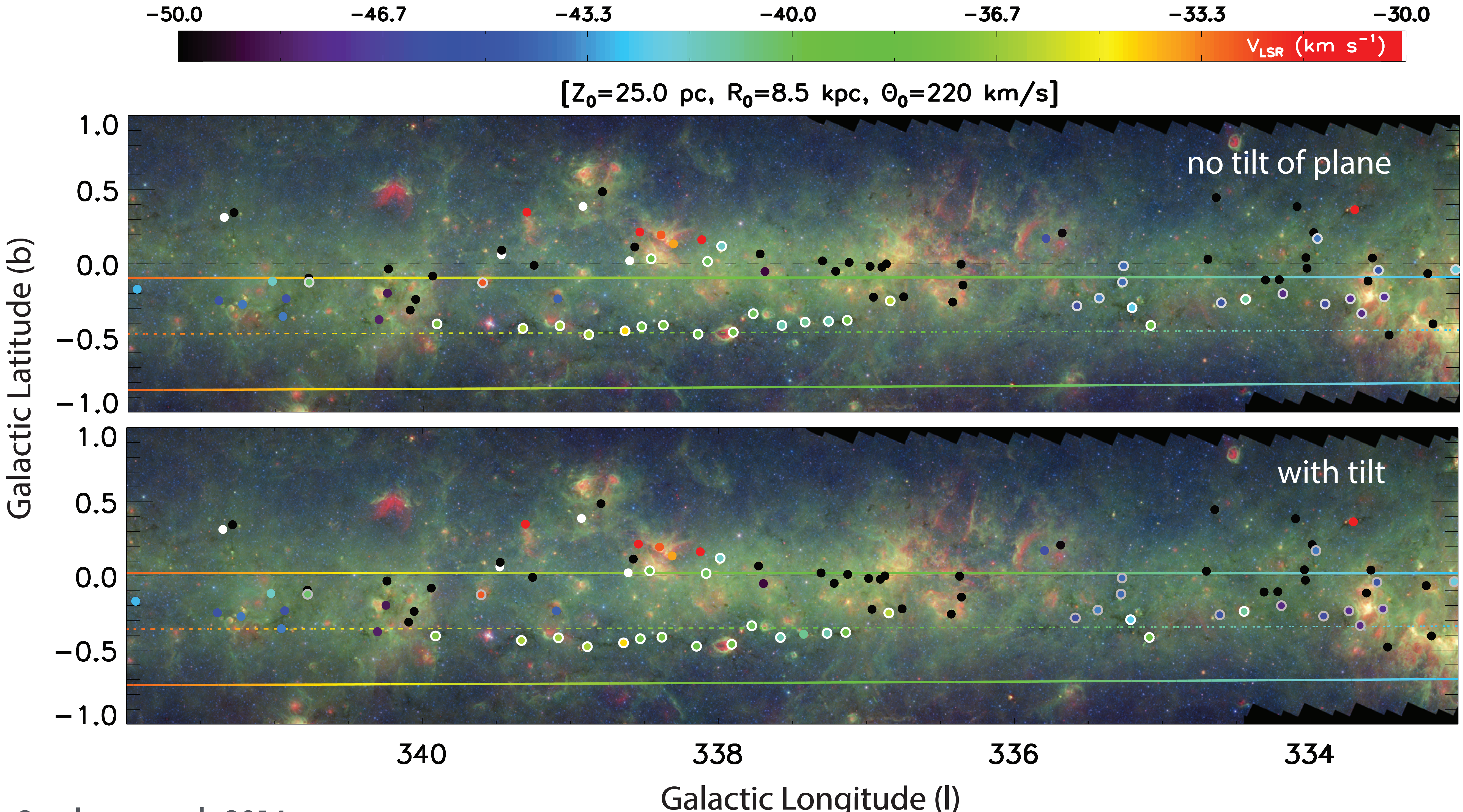
+

Galactic Center is ~7 pc offset from the IAU Milky Way Center

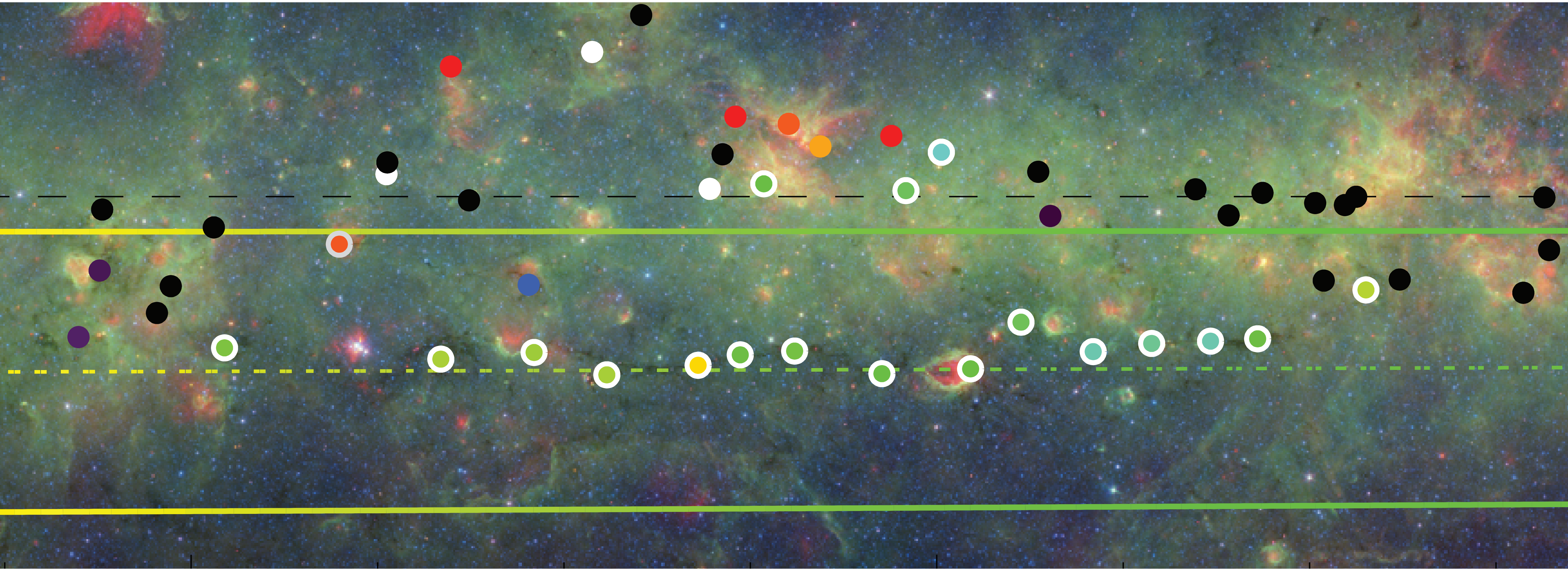
=

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!



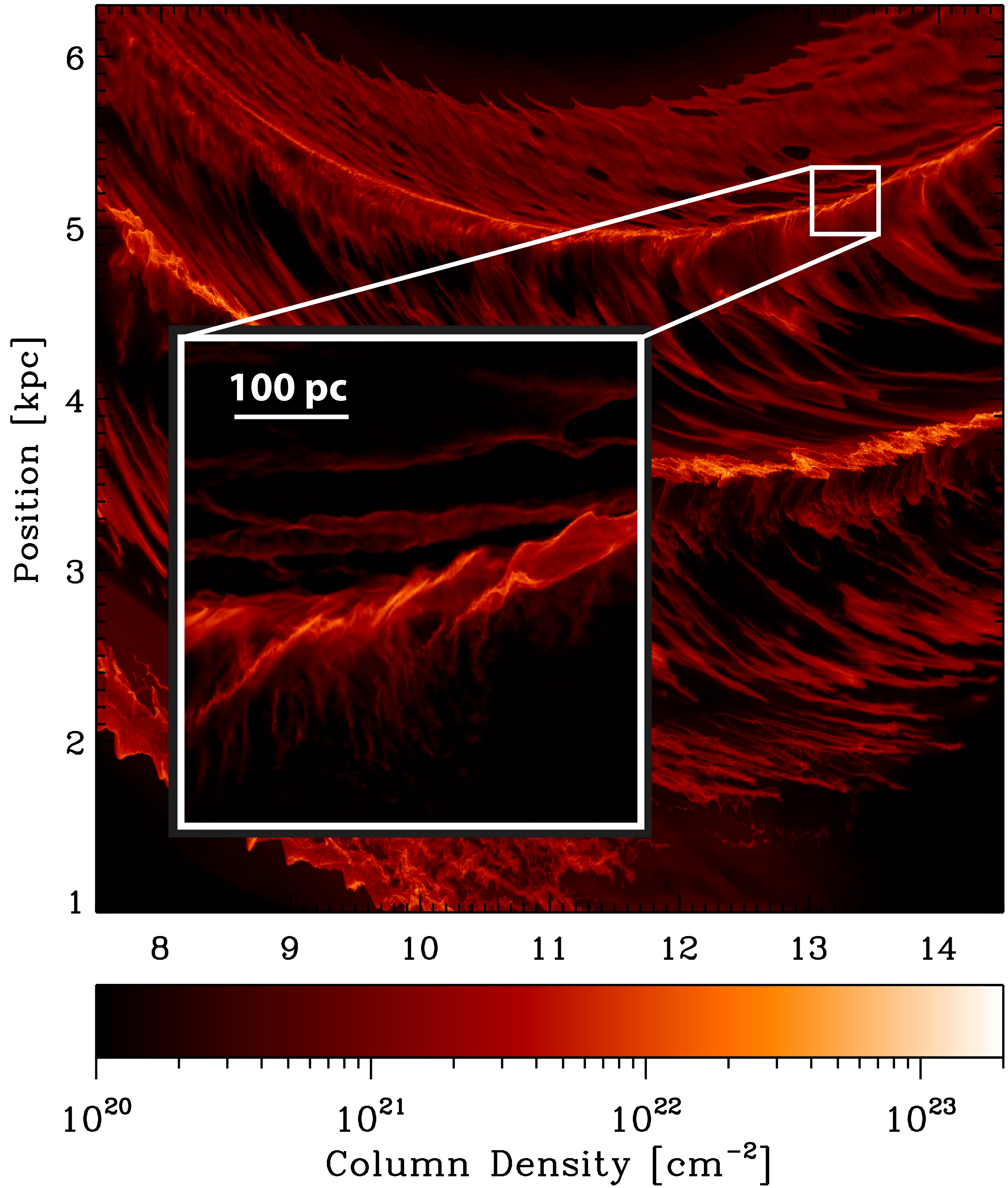
Goodman et al. 2014



...eerily precisely...

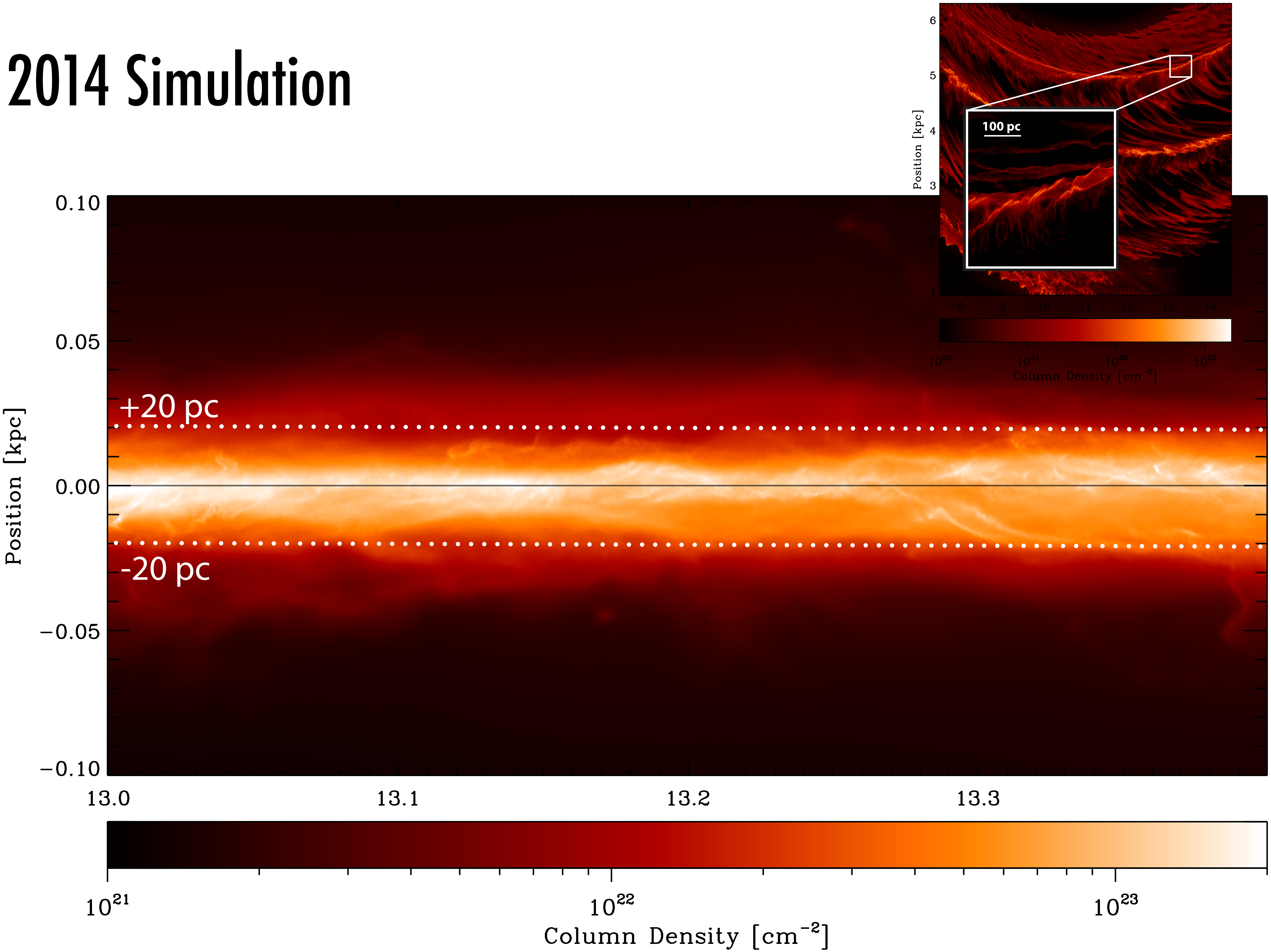
Goodman et al. 2014

2014 Simulation



Smith et al. 2014, using AREPO

2014 Simulation



Smith et al. 2014, using AREPO (hydro+chemistry, imposed potential, no B-fields, no local (self-)gravity, no feedback)

The Physical Properties of Large-Scale Galactic Filaments

Catherine Zucker, Alyssa Goodman, Cara Battersby

Harvard-Smithsonian Center for Astrophysics

catherine.zucker@cfa.harvard.edu

Nessie is a "Bone" of the Milky Way

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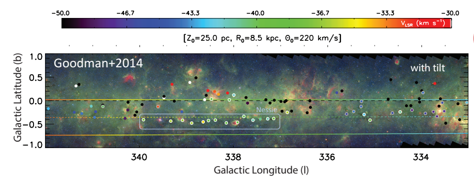

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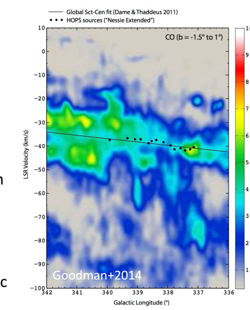

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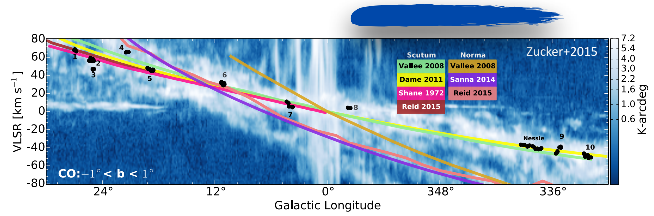
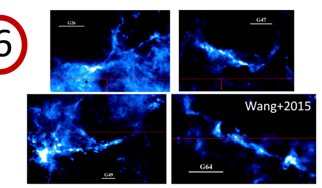
And it may have friends!



Large-Scale Herschel Filaments: Dense, cold filaments (aspect ratios >>10) chosen through visual inspection of Hi-GAL images. Confirmed velocity contiguous through ^{13}CO GRS data (Wang+2015)

6



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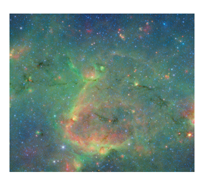

Nessie Analog from Zucker+2015

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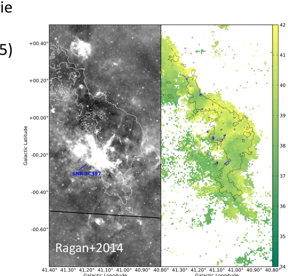

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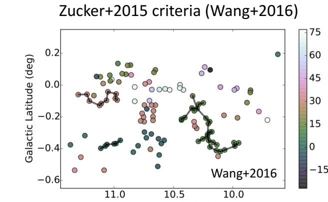

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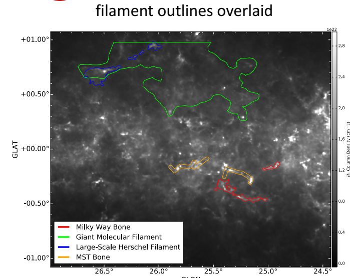
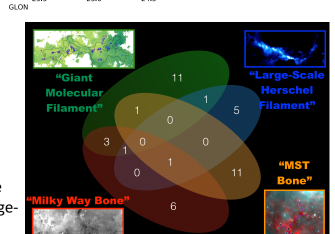
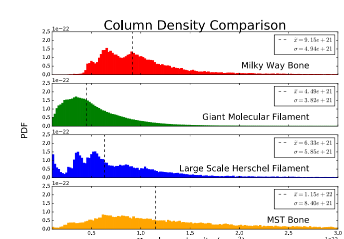
8 **Size Scale Comparison** of Large-Scale Filament Catalogs: Herschel column density map with filament outlines overlaid

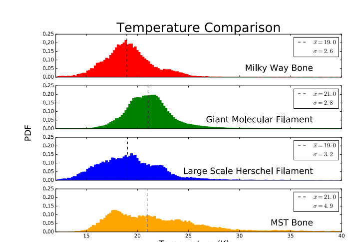


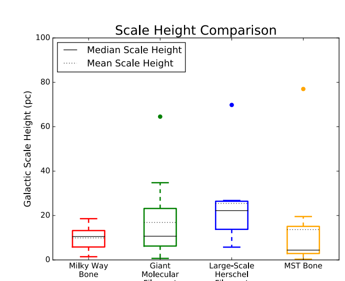
9 **Filament Venn Diagram**: Only 18% of large-scale filaments share any overlap with other large-scale filament catalogs

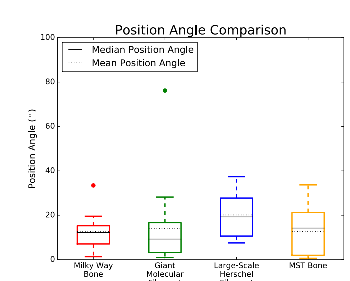


10 **Systematic offsets** in column density (top left), temperature (top right), scale height (bottom left) and position angle (bottom right) among different classes









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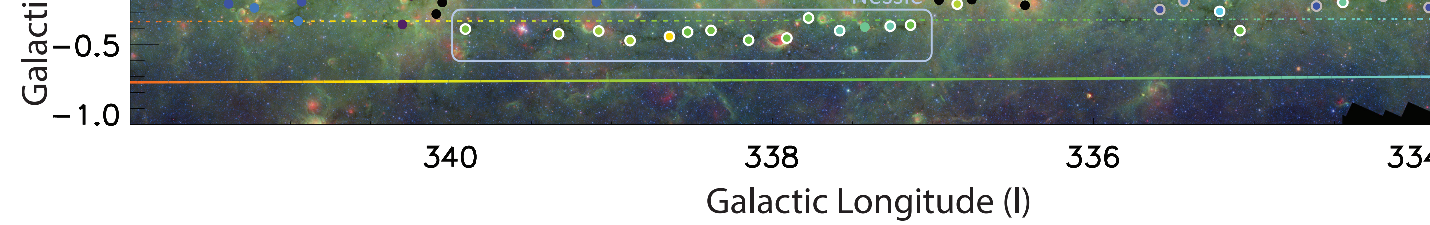

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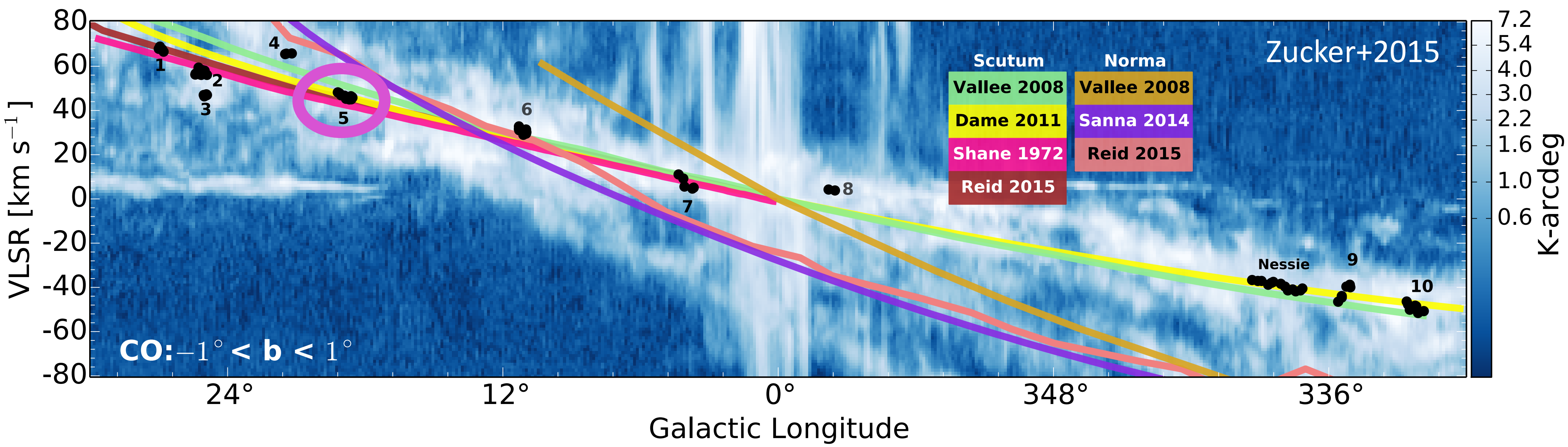

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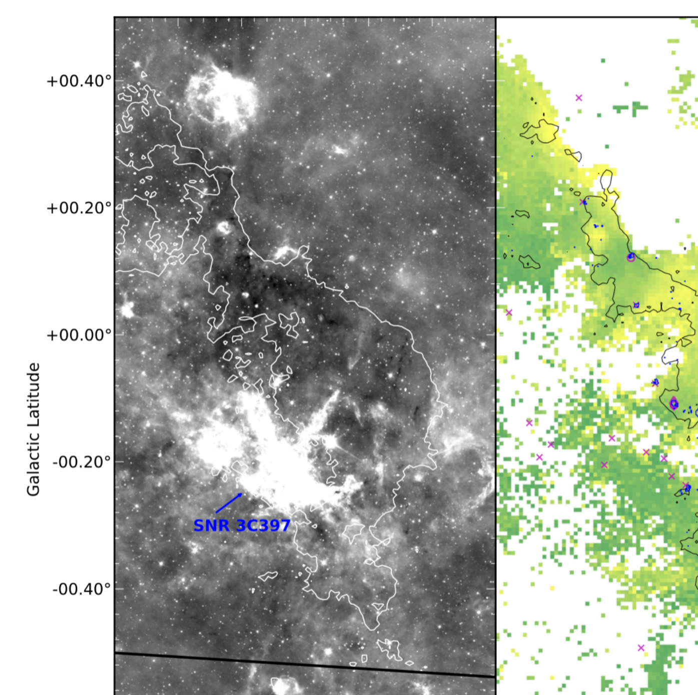
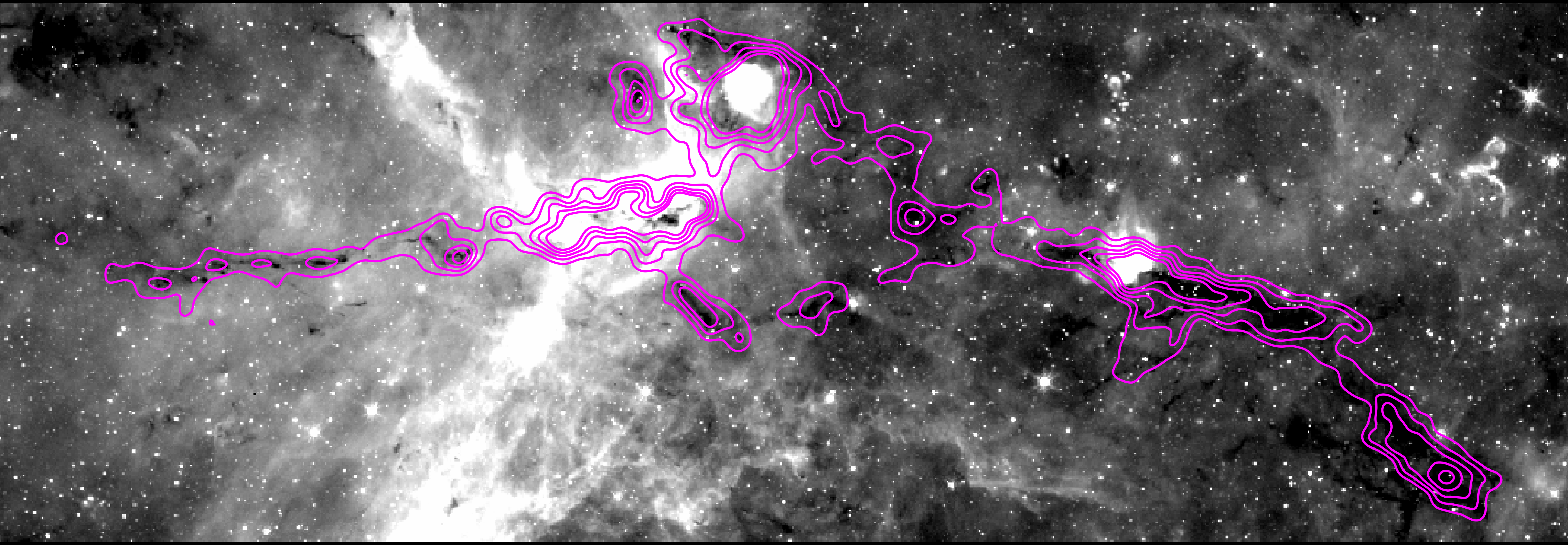


"FILAMENT 5"

Battersby, Goodman, Zucker et al. in prep.

"FILAMENT 5" WITH THE 30-M



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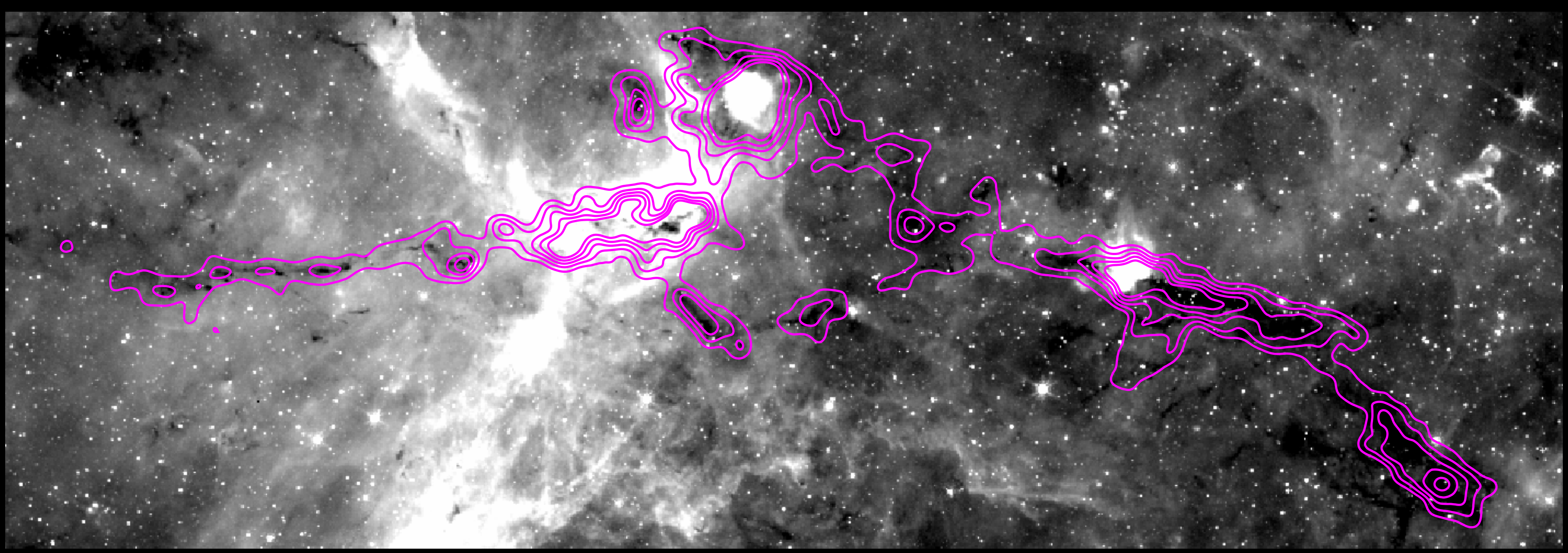

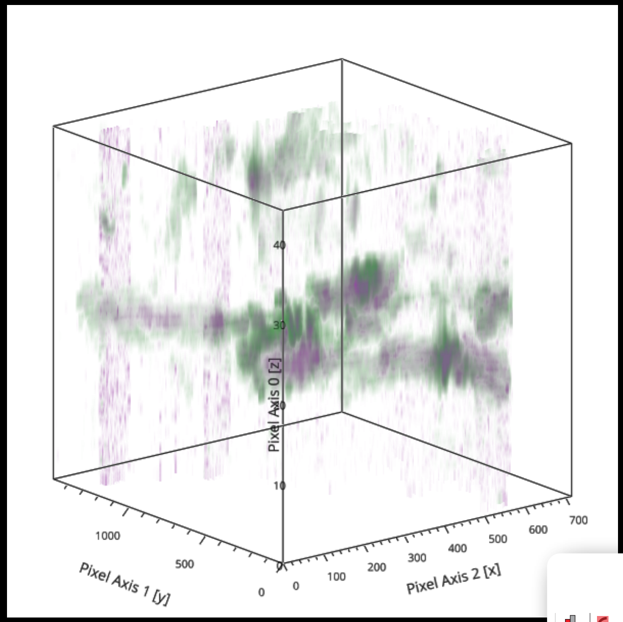

glue 3-D volume rendering of ^{13}CO and $C^{18}O$

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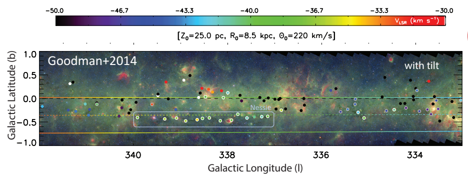

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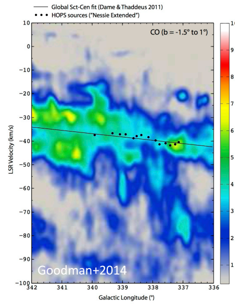

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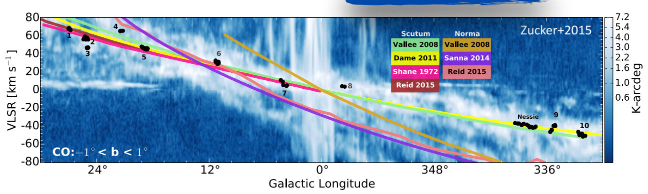

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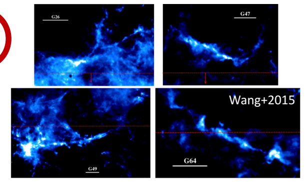

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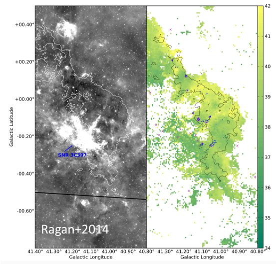

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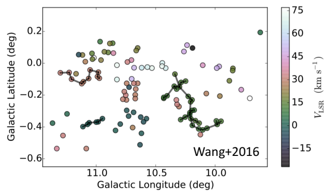

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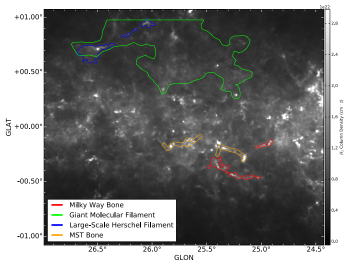
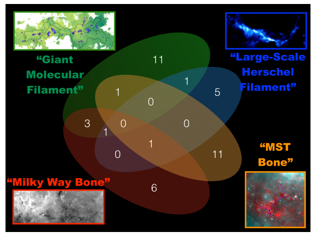
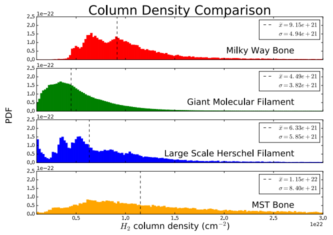
(8) Size Scale Comparison of Large-Scale Filament Catalogs: Herschel column density map with filament outlines overlaid

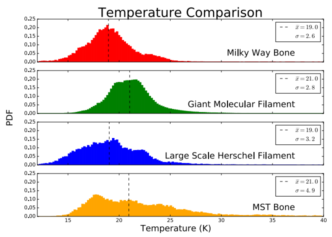


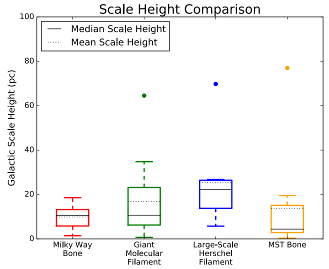
(9) Filament Venn Diagram: Only 18% of large-scale filaments share any overlap with other large-scale filament catalogs

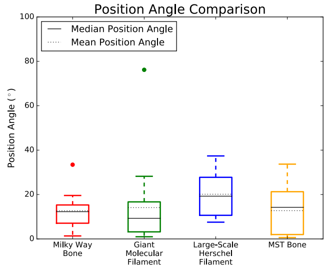


(10) Systematic offsets in column density (top left), temperature (top right), scale height (bottom left) and position angle (bottom right) among different classes



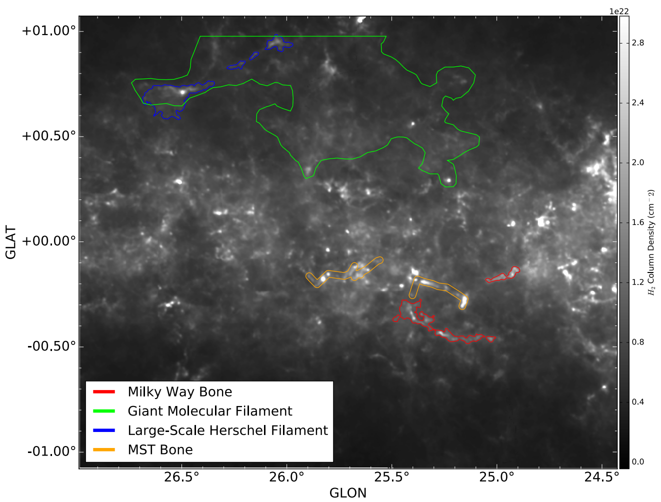




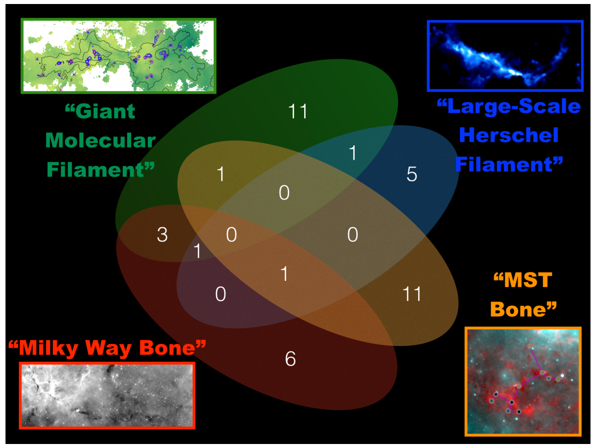


But they have different properties and utility in tracing spiral structure

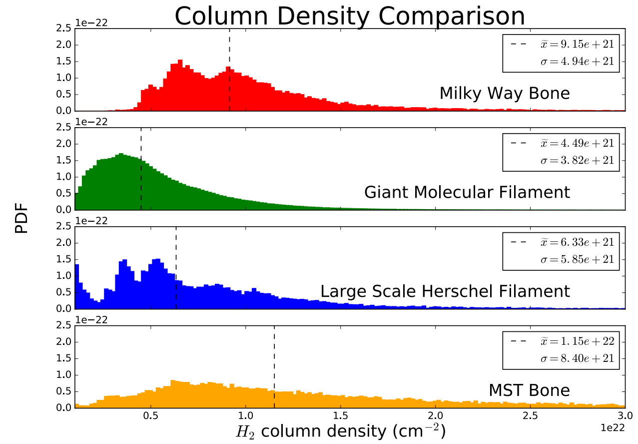
8 Size Scale Comparison of Large-Scale Filament Catalogs: Herschel column density map with filament outlines overlaid

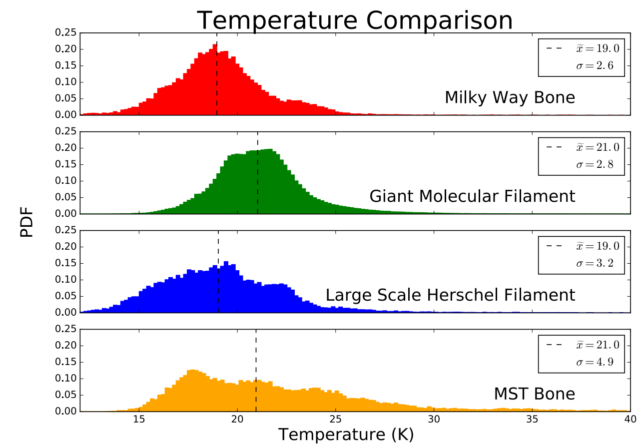


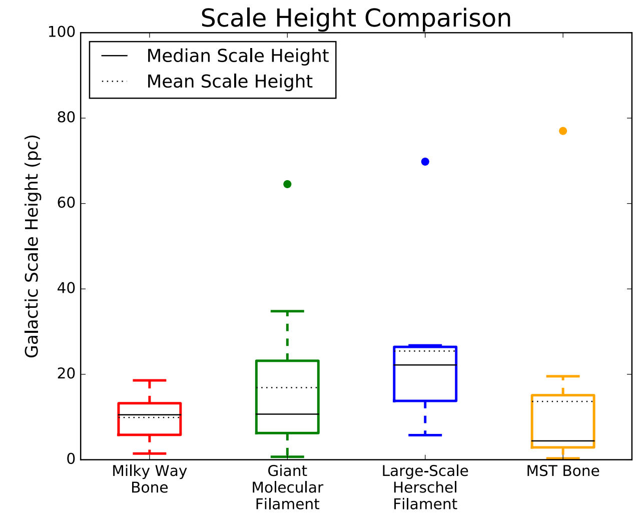
9 Filament Venn Diagram: Only 18% of large-scale filaments share any overlap with other large-scale filament catalogs

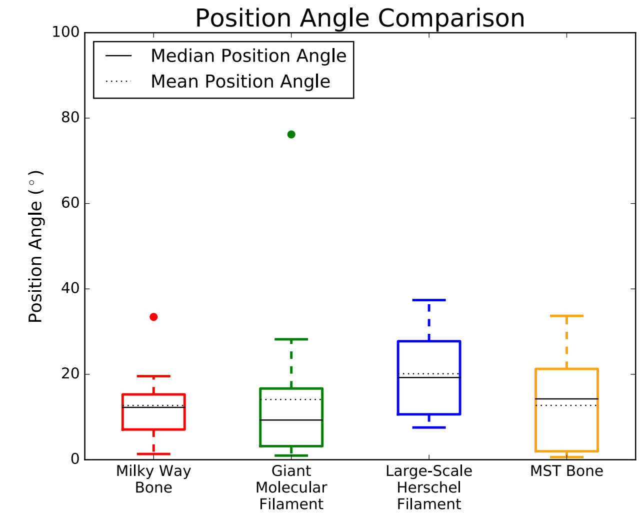


10 Systematic offsets in column density (top left), temperature (top right), scale height (bottom left) and position angle (bottom right) among different classes

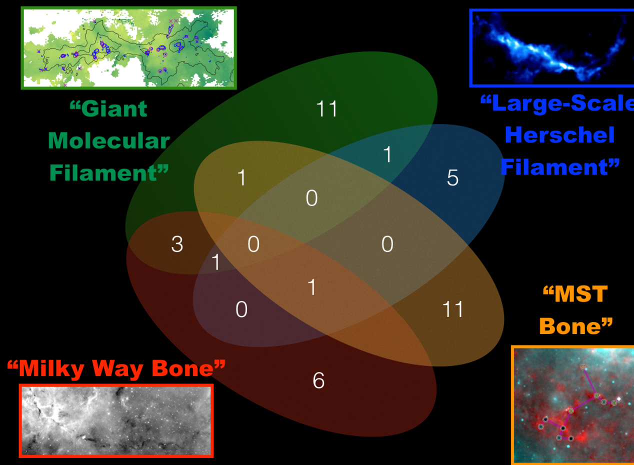






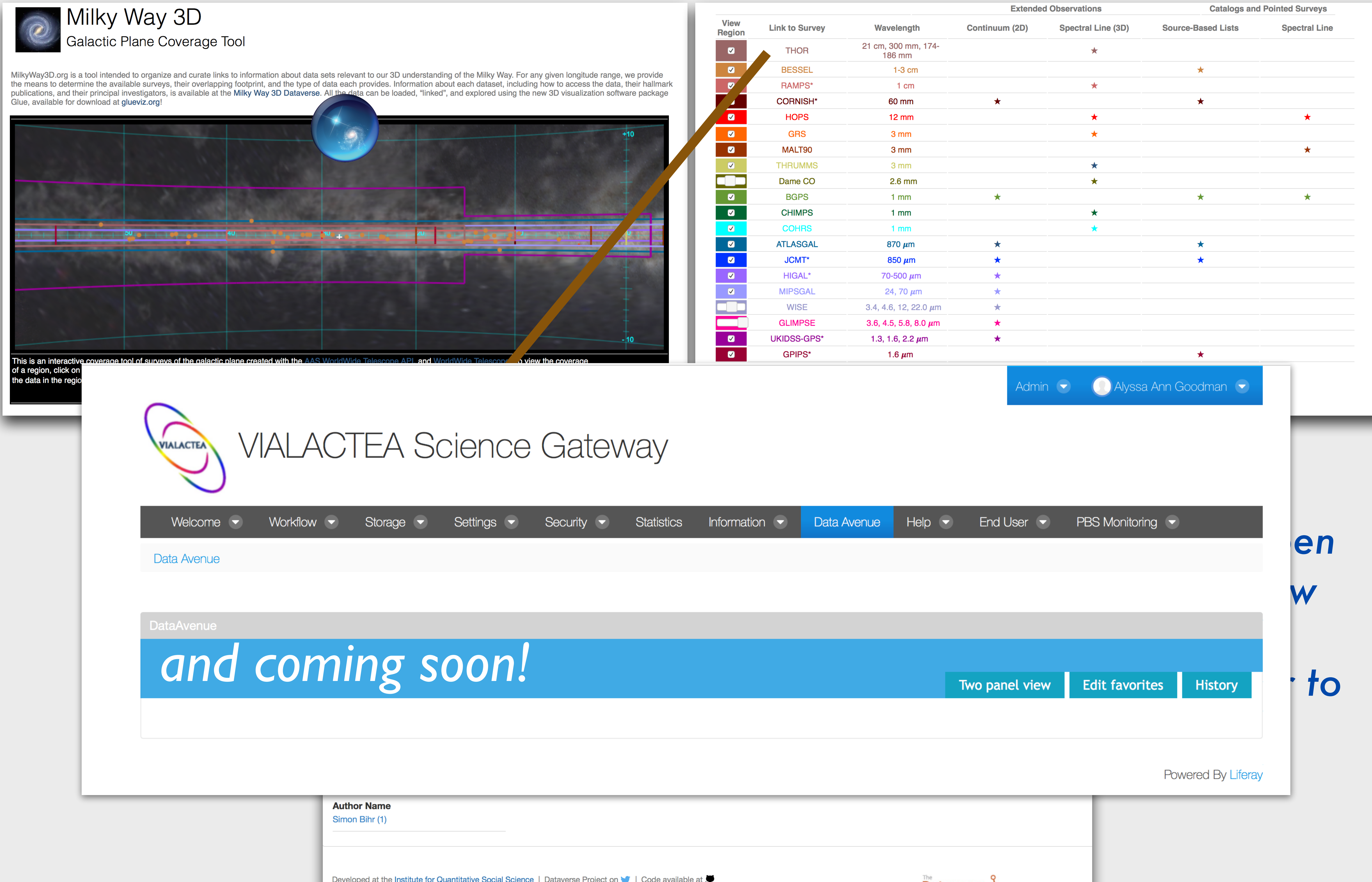


"Bones" tend to be closest to mid-plane, closest to "horizontal," coldest, and densest.



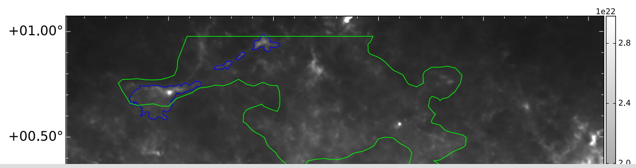
Filament Class	References	λ of Initial Detection	Velocity Reference	Spectral Lines	Velocity Contiguity Criterion	Aspect Ratio or Linearity Criterion	Min. Length	Spiral Arm Association Criterion	Spiral Arm Reference	Galactic scale height criterion	Position angle criterion
GMF	Ragan et al. 2014, Abreu-Vicente et	Mid-IR, Near-IR	GRS, ThrUMMS	^{13}CO	"Continuous" velocity gradient		1°	Intersects *p-v* fit within arm errors	Vallee 2008, Reid et al. 2014		
Herschel	Wang et al. 2015	Far-IR	GRS	^{13}CO	"Continuous, not broken" emission in p-v diagram	>>10		Intersects *p-p* fit within arm/	Reid et al. 2014		
Bone	Goodman et al. 2014, Zucker et	Mid-IR	HOPS, MALT90, BGPS, GRS,	NH_3, N_2H+, HCO+, ^{13}CO	Δv < 3 km/s per 10 pc	>50:1		Within 10 km/s of *p-v* fit	Dame et al. 2011, Reid et al. 2016	<20 pc	<30° from midplane
ATLASGAL	Li et al. 2016	Submm	HOPS, MALT90, BGPS, COHRS,	NH_3, N_2H+, HCO+, ^{13}CO,	Std. Dev. of clumps < 10 km/s	>3:1		Within 10 km/s of *p-v* fit	Taylor & Cordes 1993		
MST	Wang et al. 2016	Radio	BGPS	N_2H+, HCO+	Δv < 2 km/s between connected clumps	$\sigma_{major}/\sigma_{minor}$ > 1.5	10 pc	Within 5 km/s of *p-v* fit	Reid et al. 2016	<20 pc	< 30° from midplane

milkyway3d.org

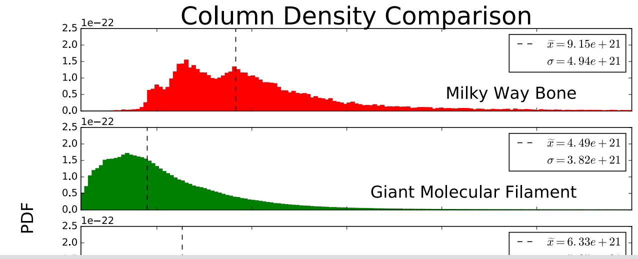


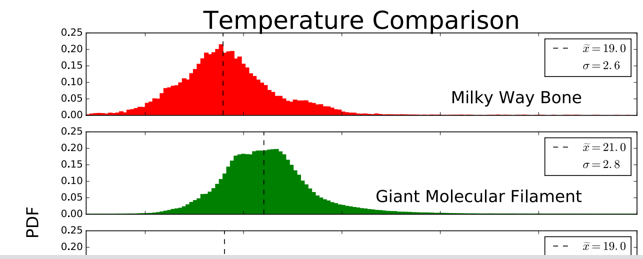
But they have different properties and utility in tracing spiral structure

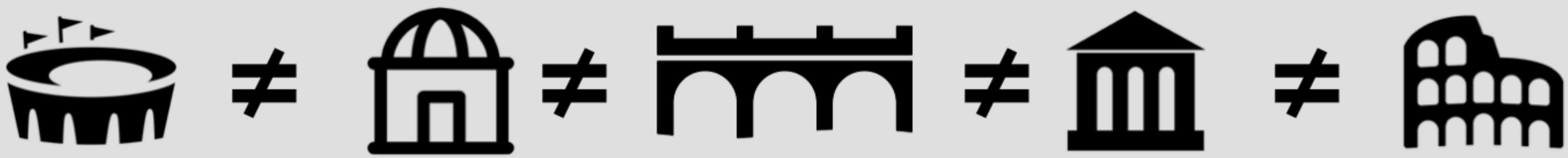
8 Size Scale Comparison of Large-Scale Filament Catalogs: Herschel column density map with filament outlines overlaid



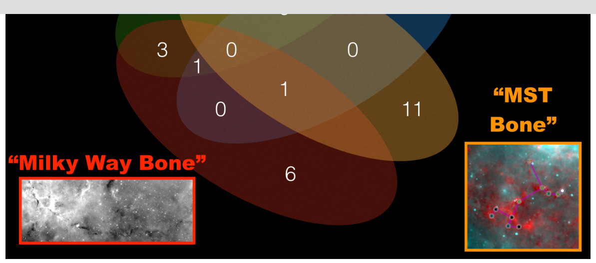
10 Systematic offsets in column density (top left), temperature (top

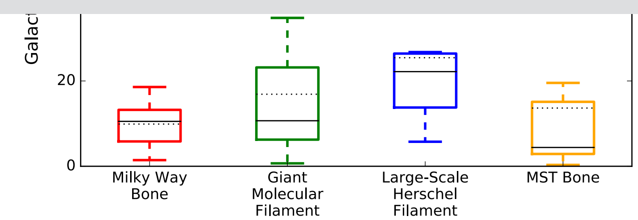


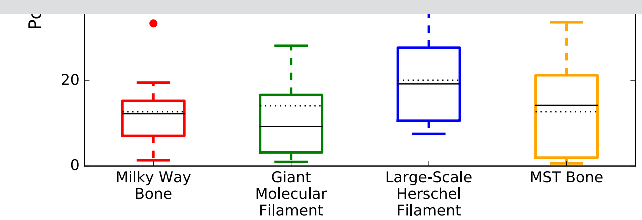




Filament Venn Diagram: Only 18% of large-scale filaments share any overlap with other large-scale filament catalogs



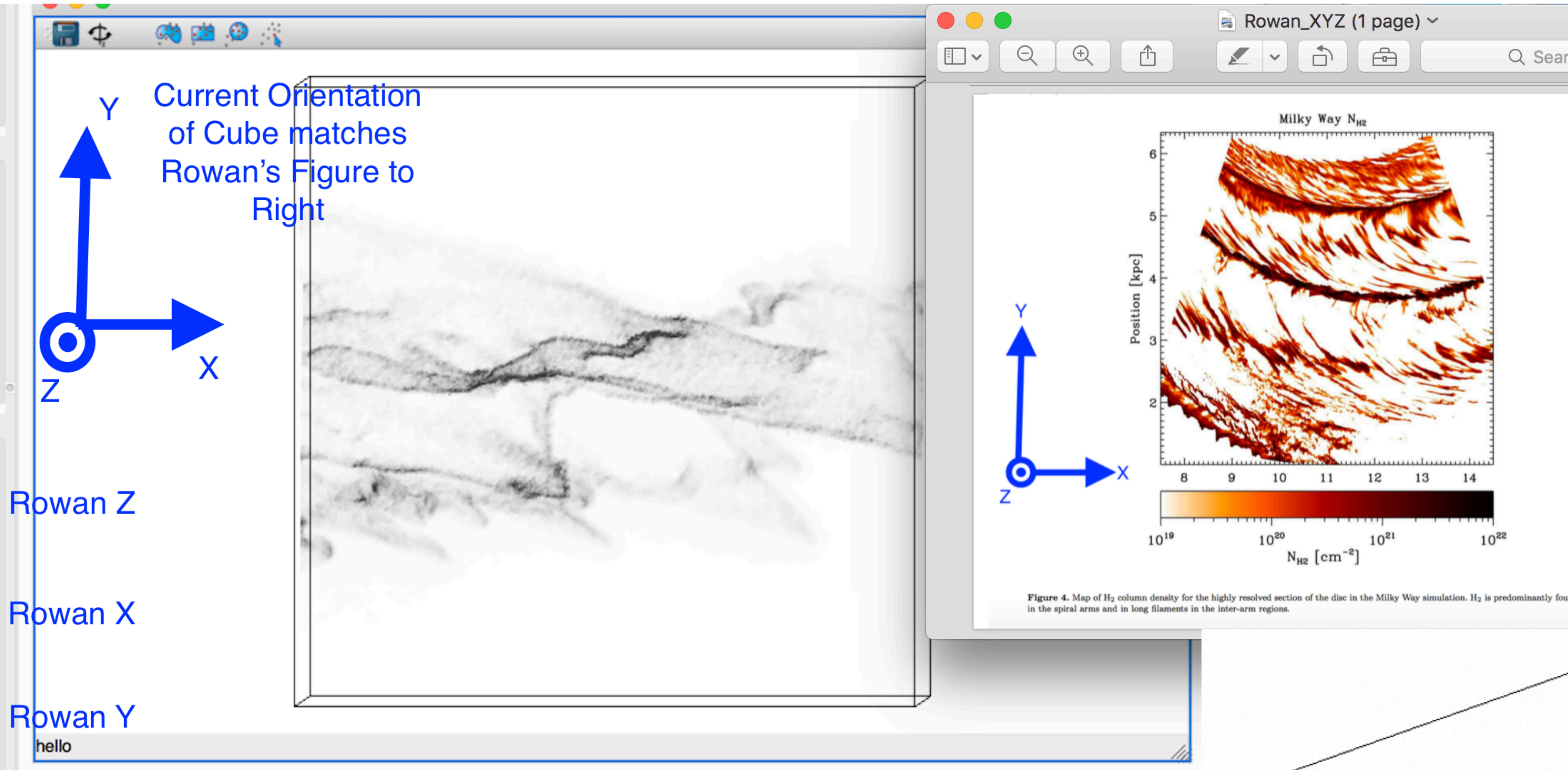




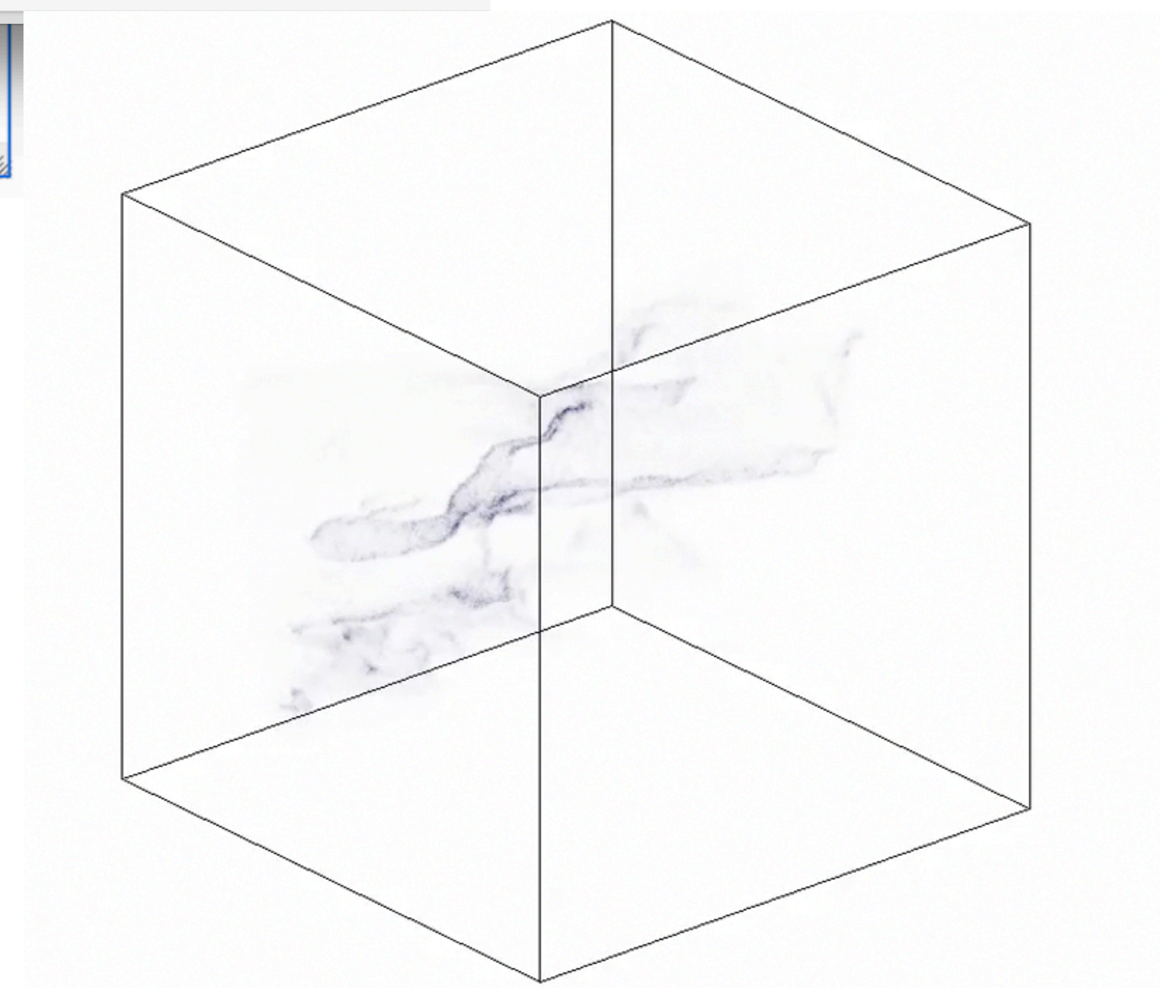
"Bones" are most likely to trace structure in/of the Galaxy's plane.

But what creates the Bones we observe?

brand new AREPO work...look for Zucker, Smith, Battersby, Goodman 2017

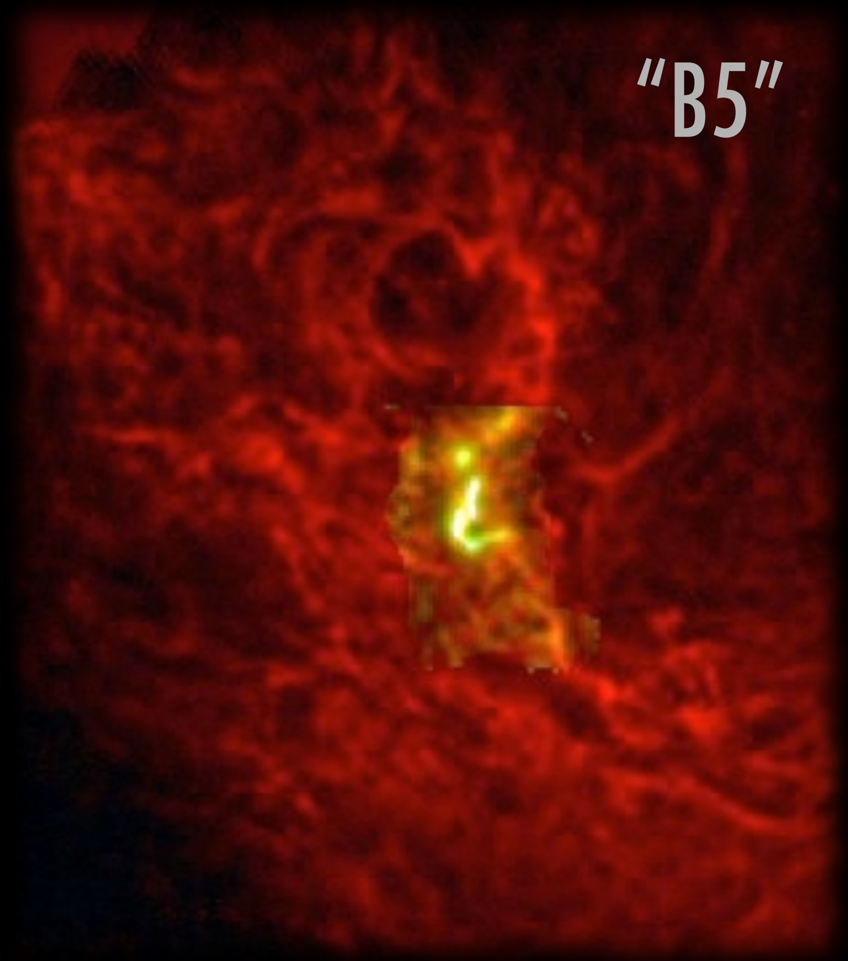


glue
multidimensional data exploration



cf. simulation work by Moeckl & Burkert 2015, Duarte-Cabral & Dobbs 2016; + AREPO MHD simulation -ALMA polarimetry comparison from Hull et al. 2016, more...

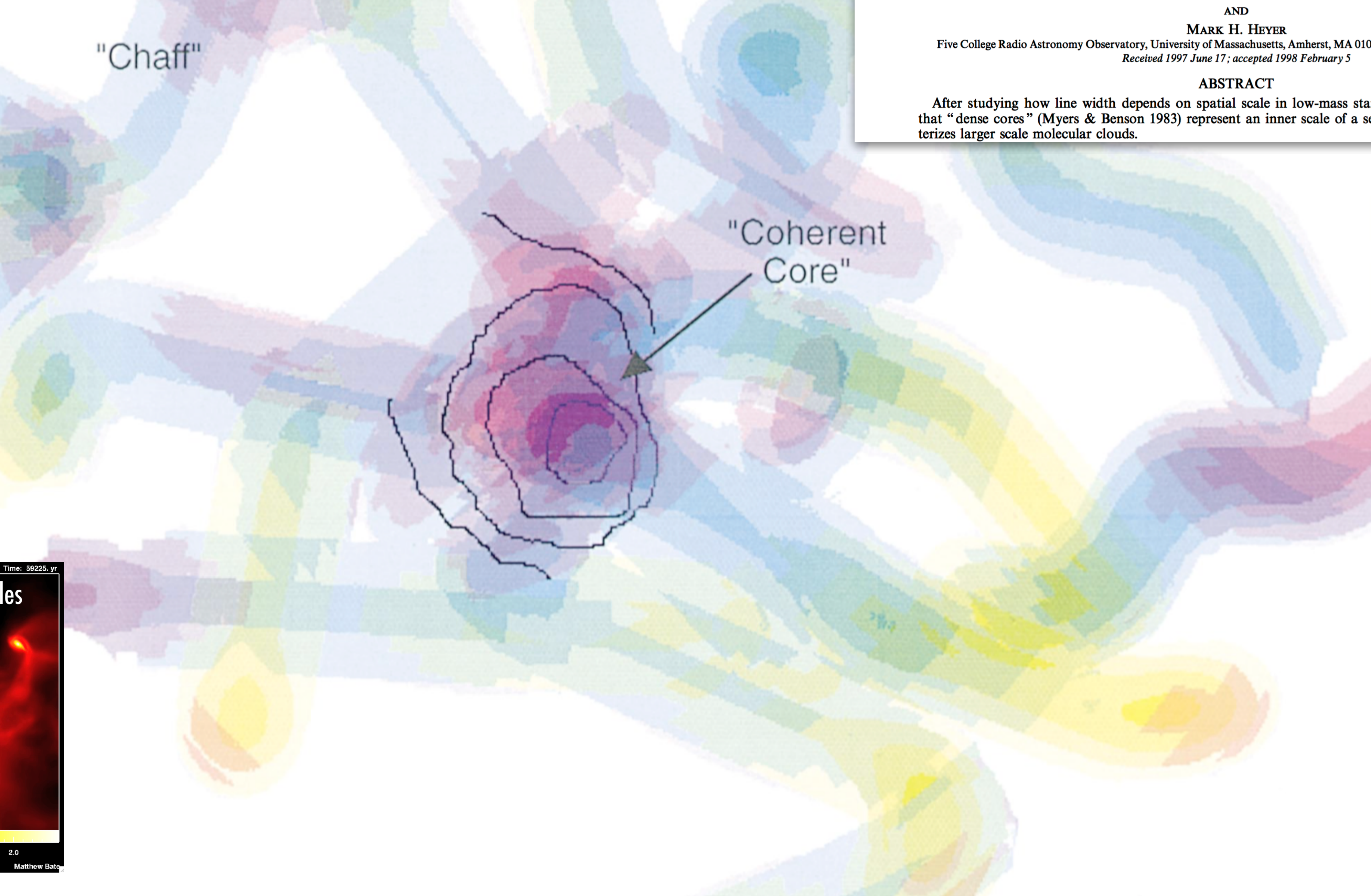
AS PROMISED: B5, AND A LITTLE MORE "GLUE"

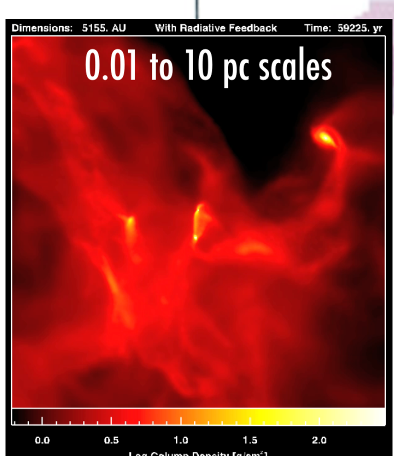


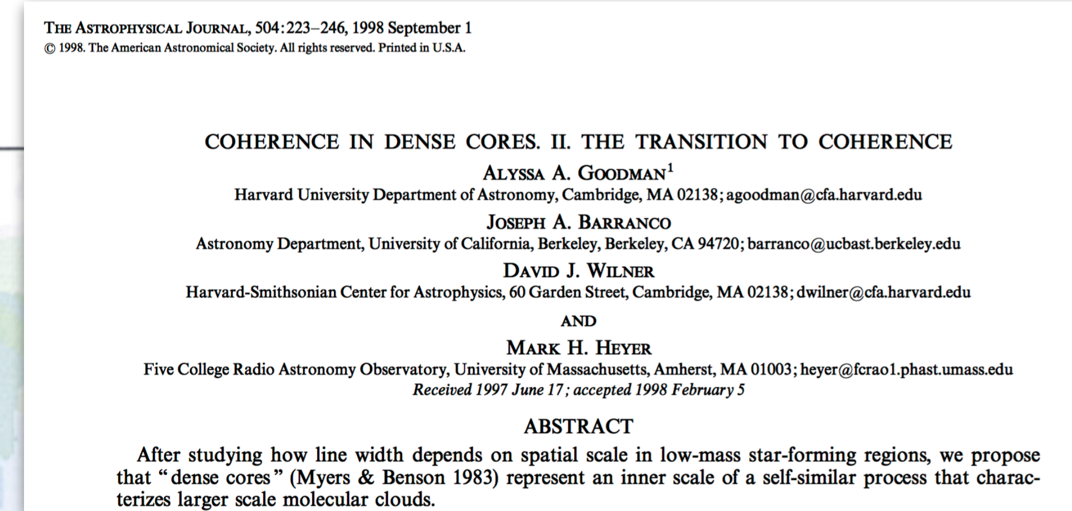
~0.01 to 10 pc

>100 pc

1998






The Astrophysical Journal, 504:223–246, 1998 September 1

COHERENCE IN DENSE CORES. II. THE TRANSITION TO COHERENCE

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Received 1997 June 17; accepted 1998 February 5

ABSTRACT

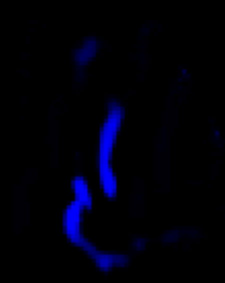
After studying how line width depends on spatial scale in low-mass star-forming regions, we propose that "dense cores" (Myers & Benson 1983) represent an inner scale of a self-similar process that characterizes larger scale molecular clouds.

Fig. 10.—An illustration of the transition to coherence. Color and shading schematically represent velocity and density in this figure. On large scales, material (labeled chaff) is distributed in a self-similar fashion, and its filling factor is low. On scales smaller than some fiducial radius, the filling factor of gas increases substantially, and a coherent dense core, which is not self-similar, is formed. Due to limitations in the authors' drawing ability, the figure emphasizes a particular size scale in the chaff, which should actually exhibit self-similar structure on all scales ranging from the size of an entire molecular cloud complex down to a coherent core.

?

WHAT IF FILAMENTS CONTINUE ACROSS "CORE" BOUNDARIES?!

blue =VLA ammonia (high-density gas); green=GBT ammonia (lower-res high-density gas); red=Herschel 250 micron continuum (dust)



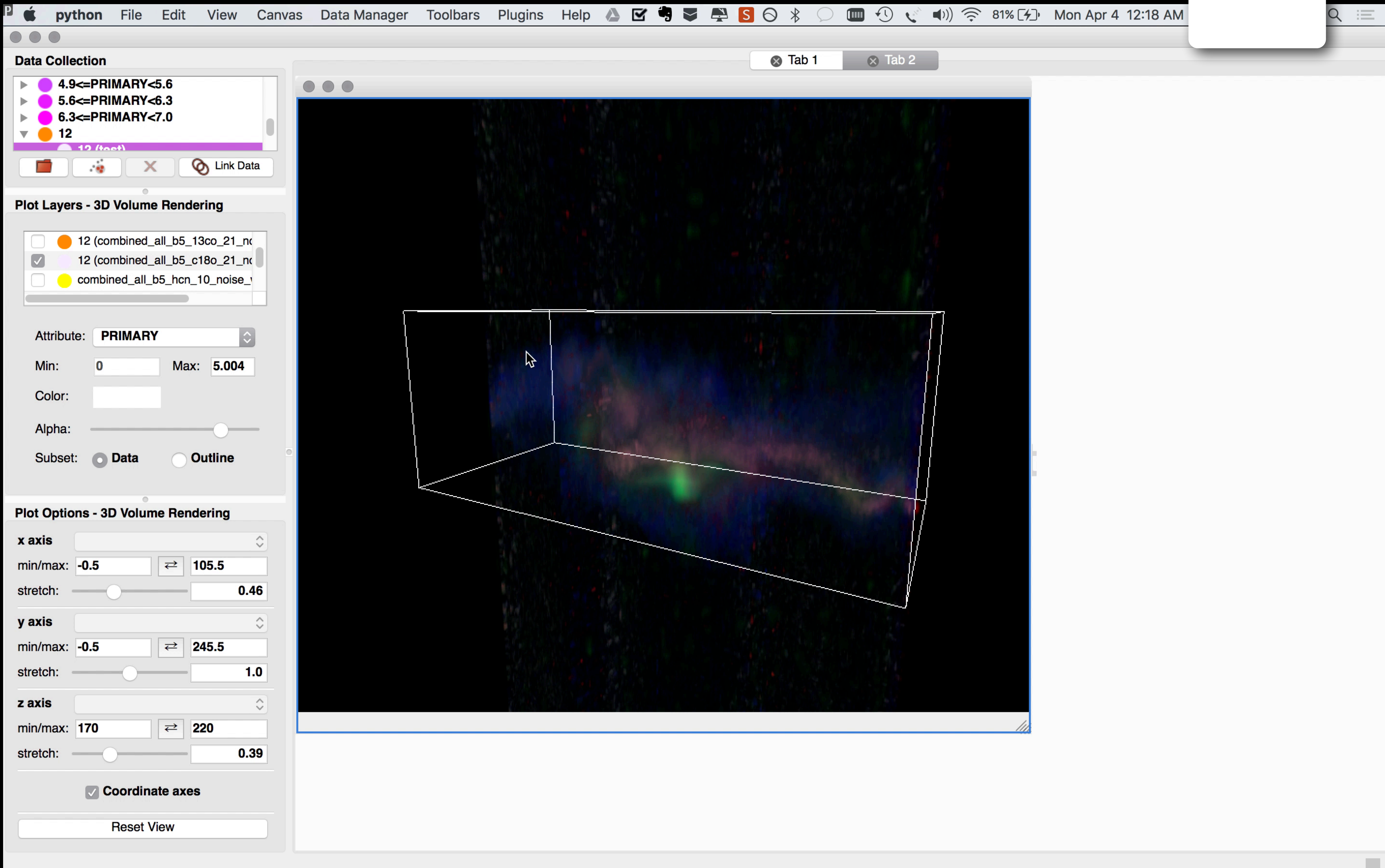
Goodman, Chen, Offner & Pineda 2016 in prep.

Herschel data from Gould Belt Survey

1998

2008

B5/GLUE (NEW IRAM 30-M DATA)

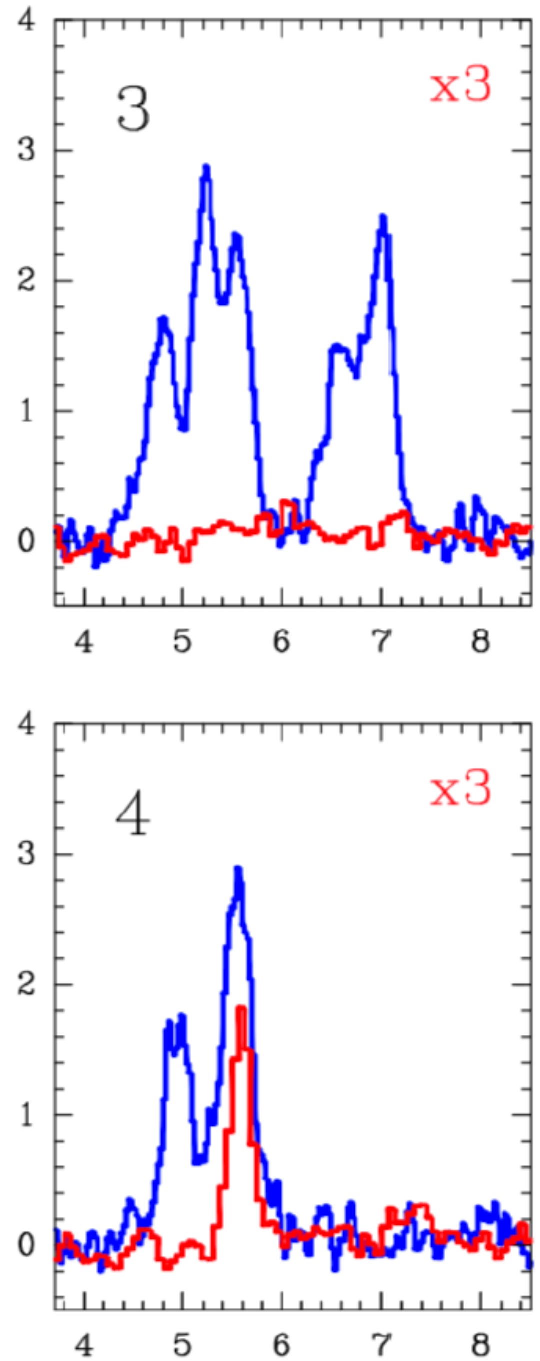


Chen, Offner, Pineda & Goodman 2016 in prep.

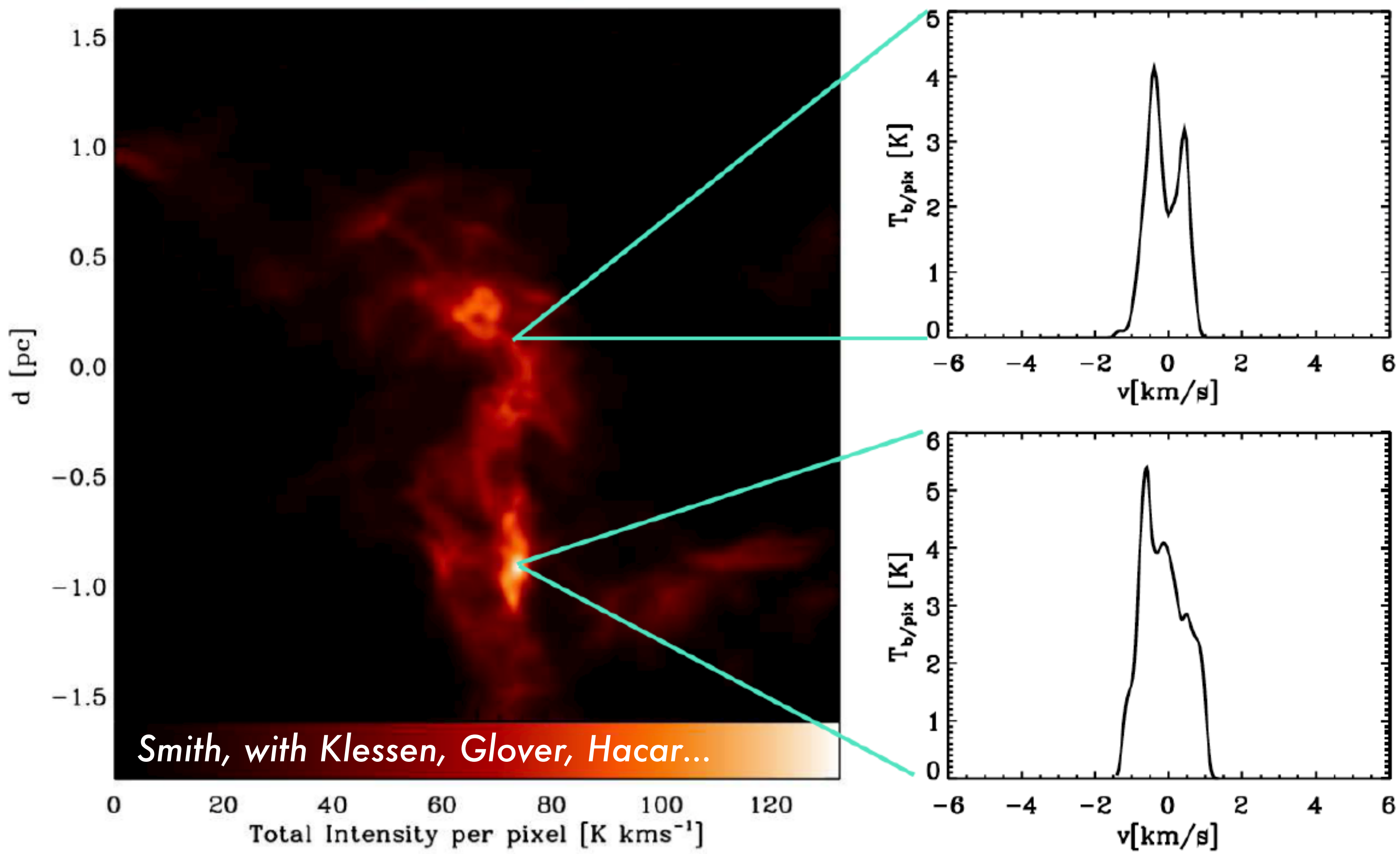
glueviz.org

Simulators are almost observing enough lines...

Filaments in Filaments



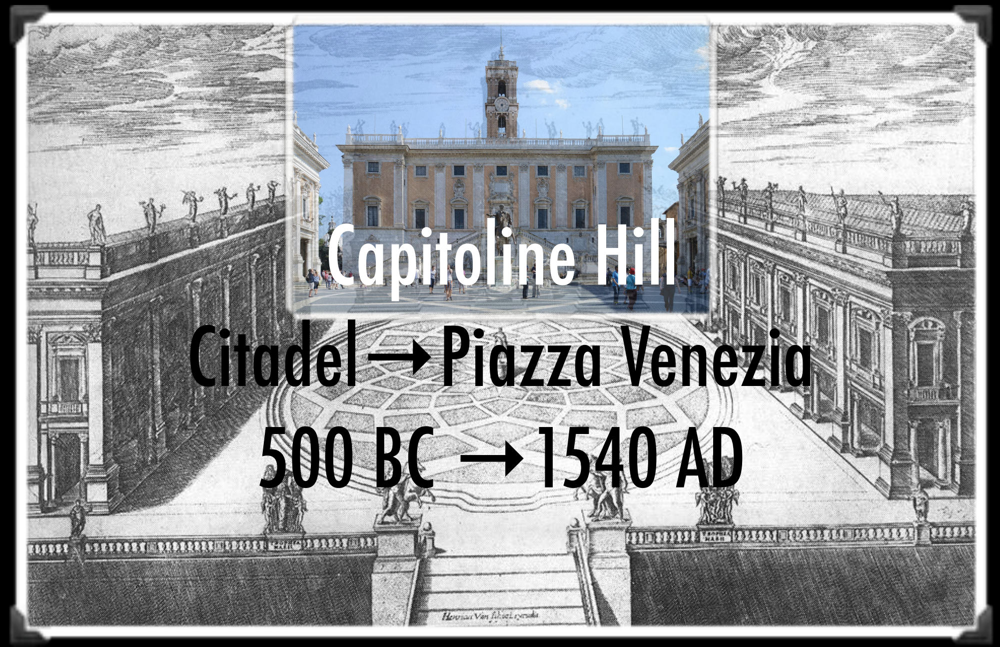
Observed $C^{18}O$ emission in blue.



Synthetic observation of $C^{18}O$ emission from our time-dependent chemical model post-processed with radmc-3d

slide courtesy of Rowan Smith, from CfA-ITC talk, March 31, 2016
cf. Moeckl & Burkert 2015, work of Hacar et al...

SOME PLACES ARE SPECIAL



What are “special” places in ISM & how long do they last?

–galactic plane, Bones

–filaments’ influence may last into cores–how long, and when, simulators?

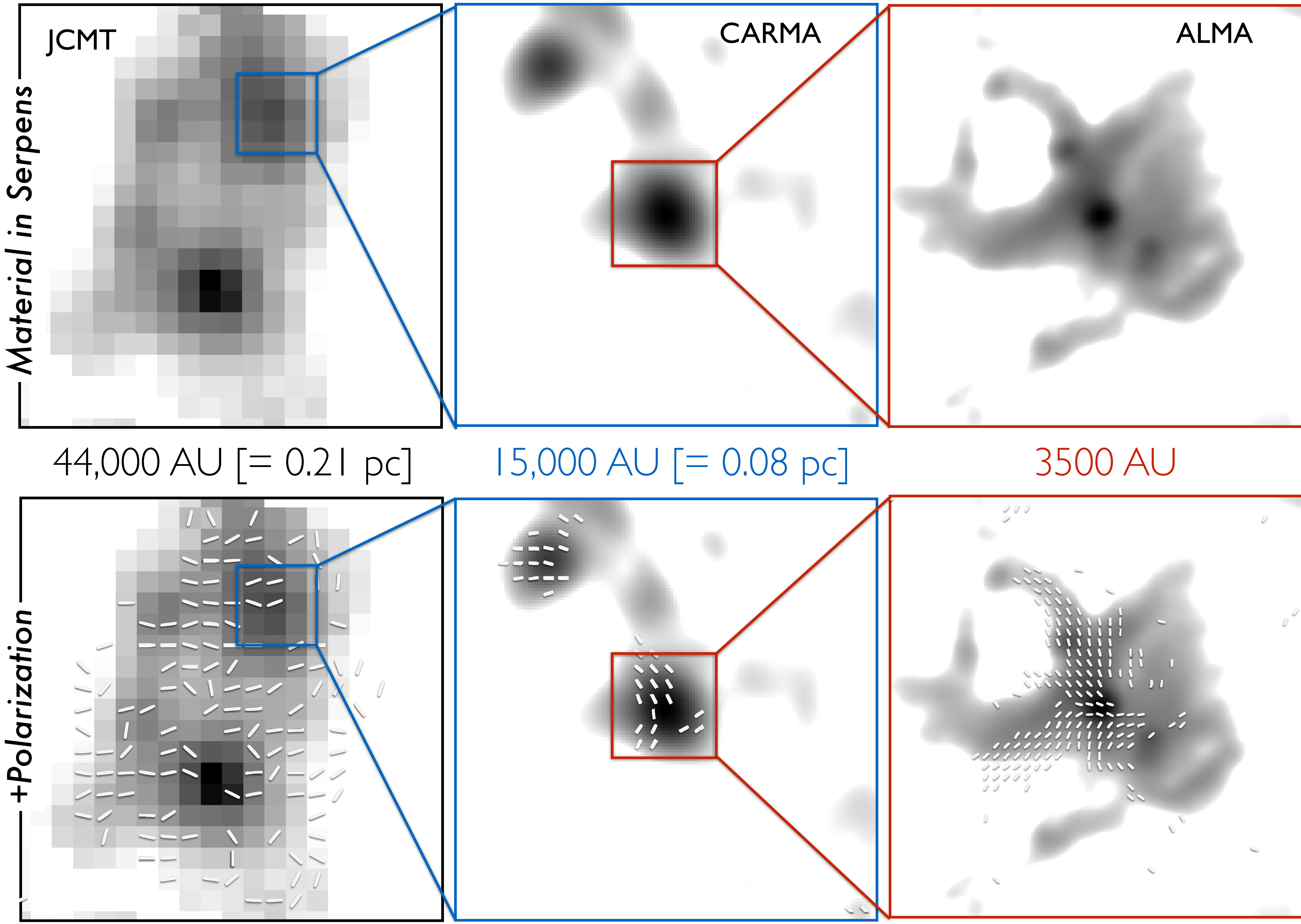
How do “influences” change what is special?

–magnetic fields, feedback, “collisions,” but when, how & where, simulators?

Sneak Preview of ALMA+AREPO B-field insights...

Hull, Mocz, Burkhart, Goodman, Girart, Cortes, Hernquist, Lai, Li, Springel 2016, *Nature*, under review.

Hull, Mocz, Burkhart, Goodman, Girart, Cortes, Hernquist, Lai, Li, Springel 2016, *Nature*, under review.



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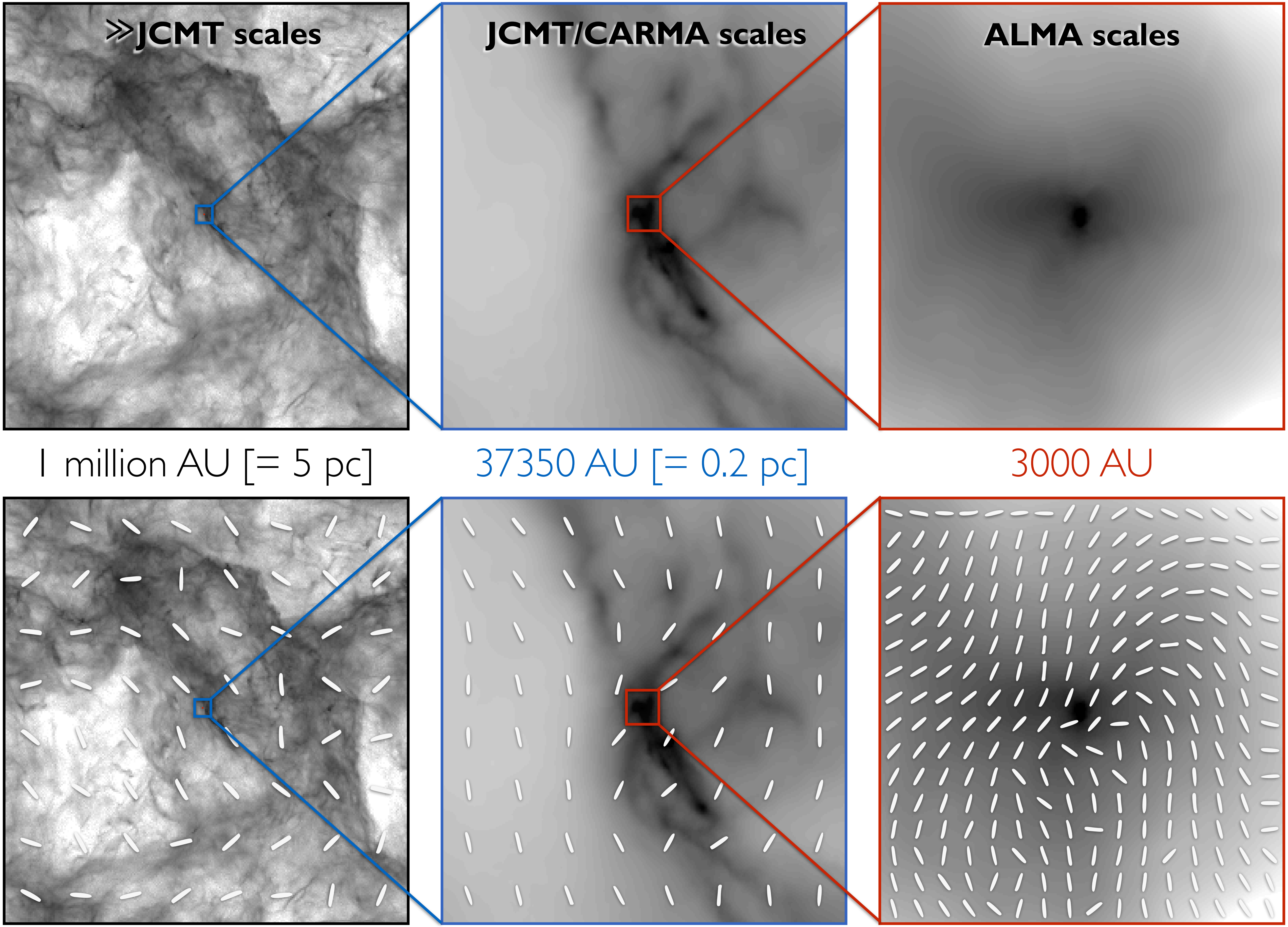
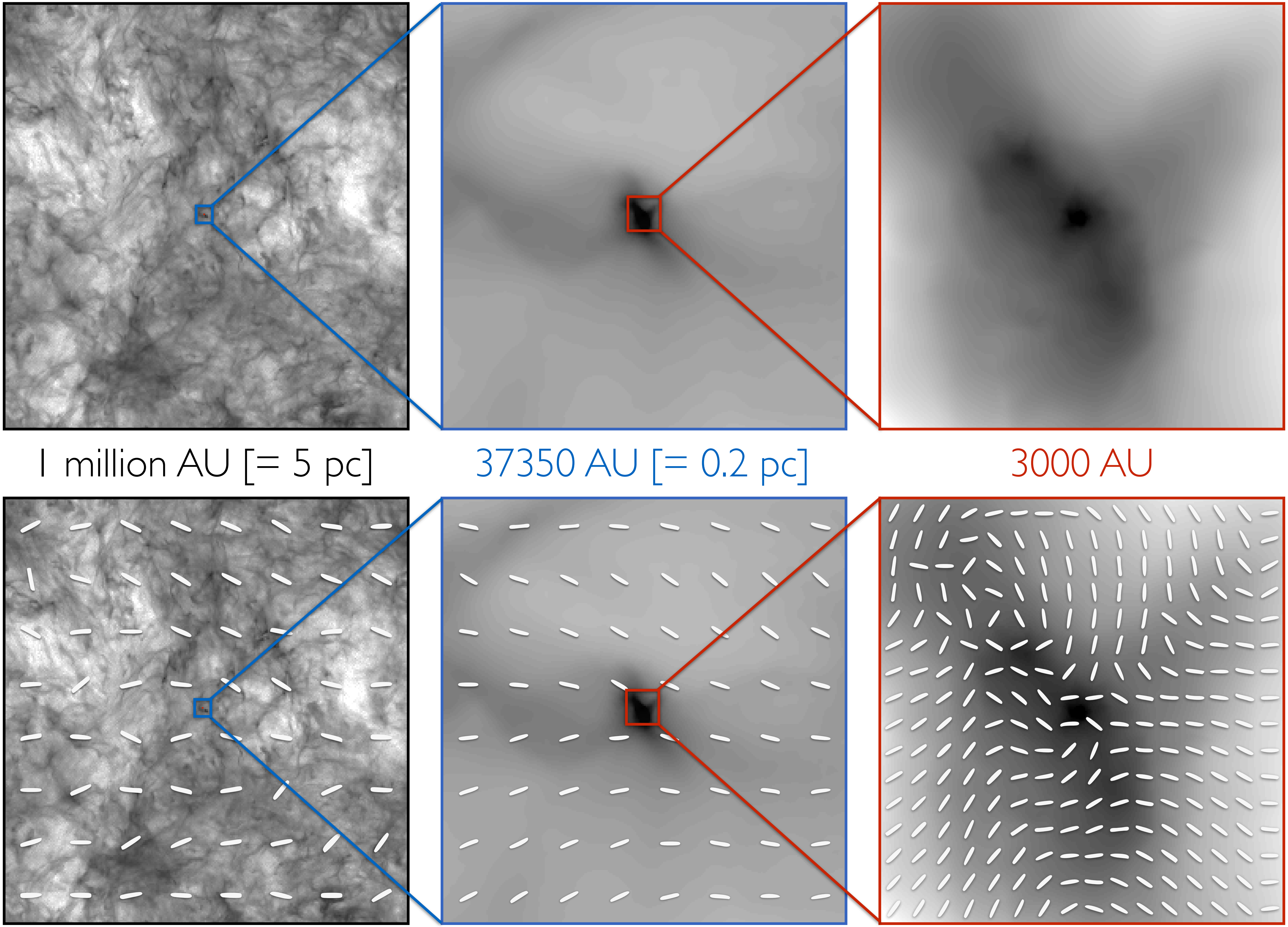
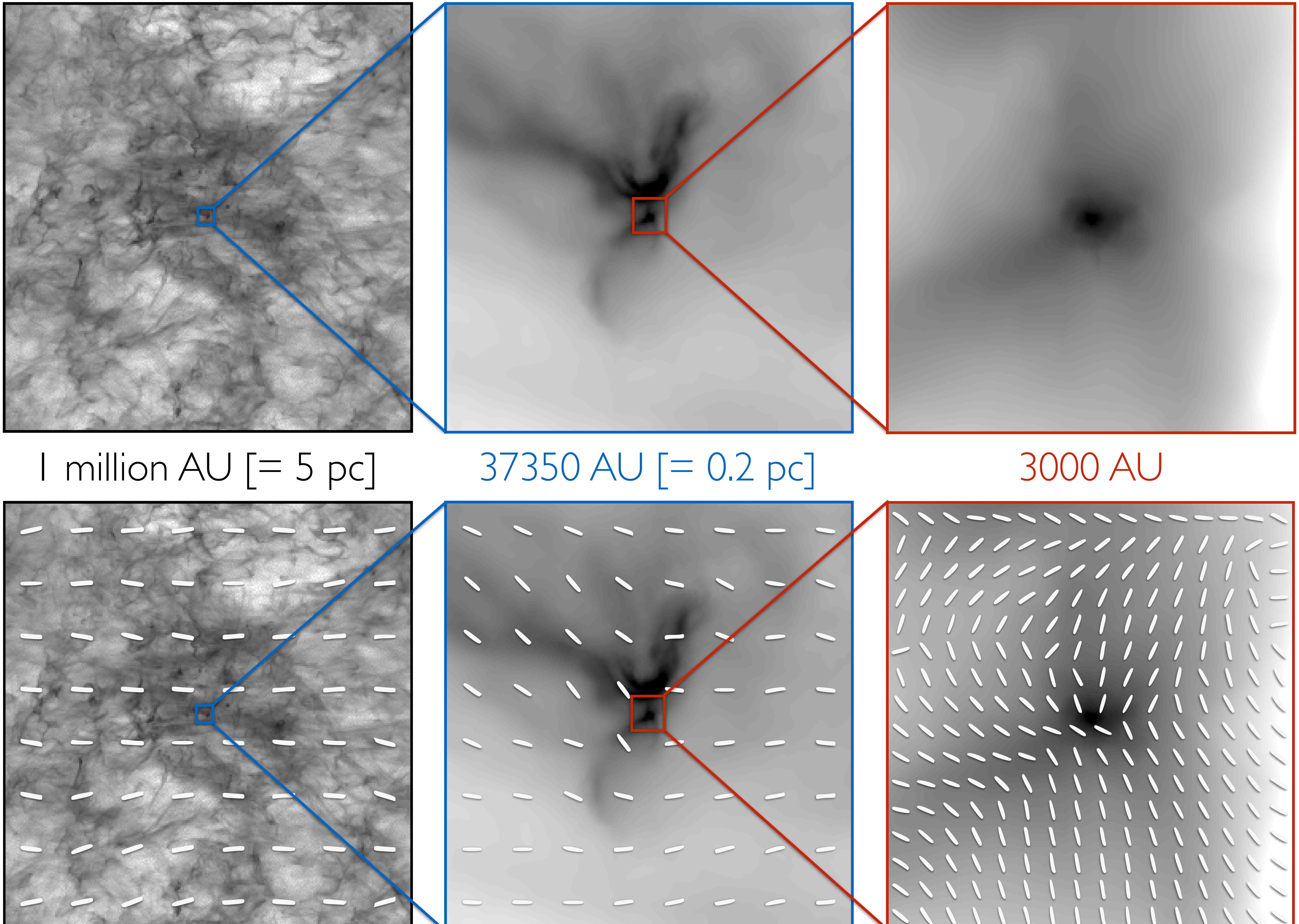
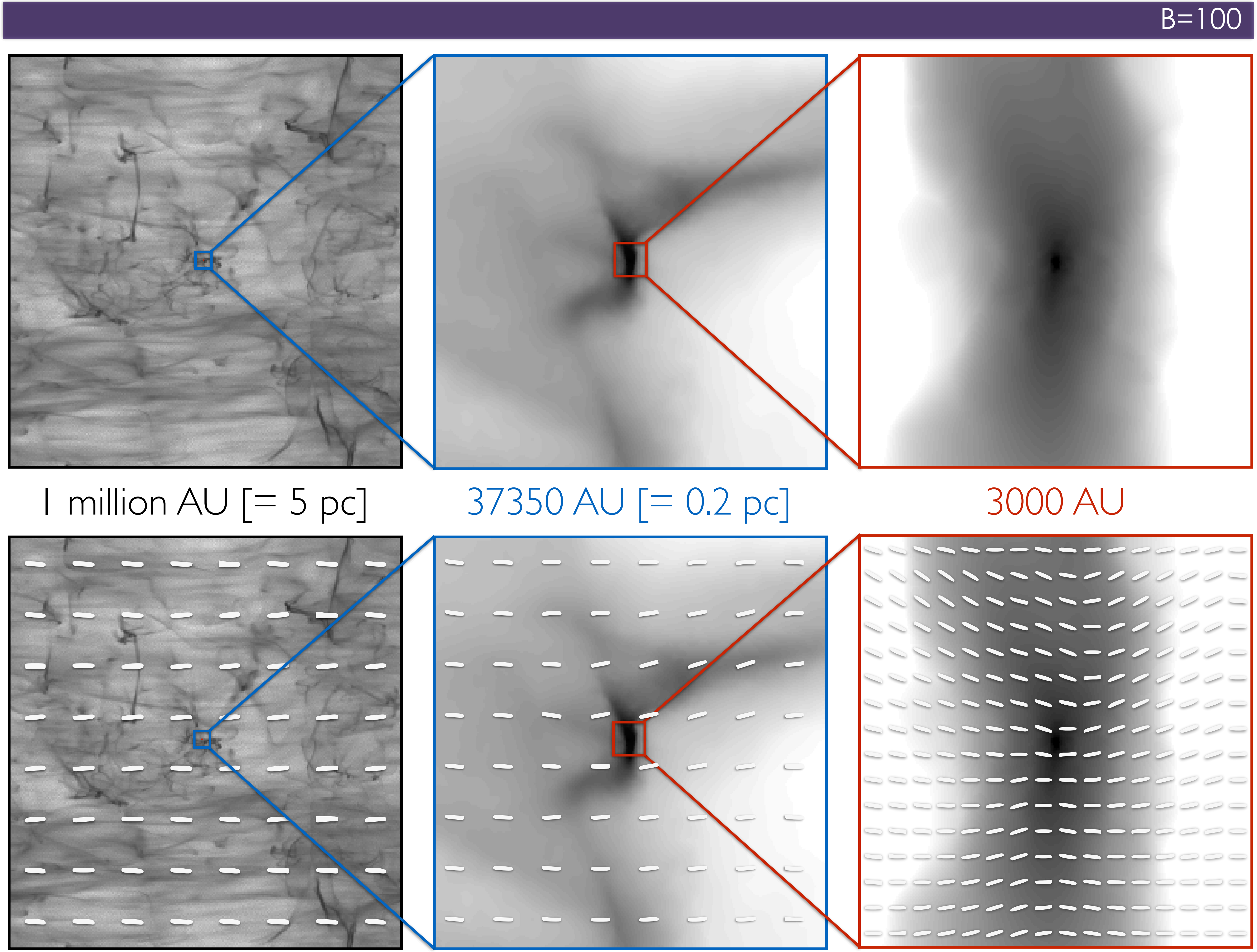

≫JCMT scales
JCMT/CARMA scales
ALMA scales
1 million AU [= 5 pc]
37350 AU [= 0.2 pc]
3000 AU

B=10




1 million AU [= 5 pc]
37350 AU [= 0.2 pc]
3000 AU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37350 AU [= 0.2 pc]
3000 AU

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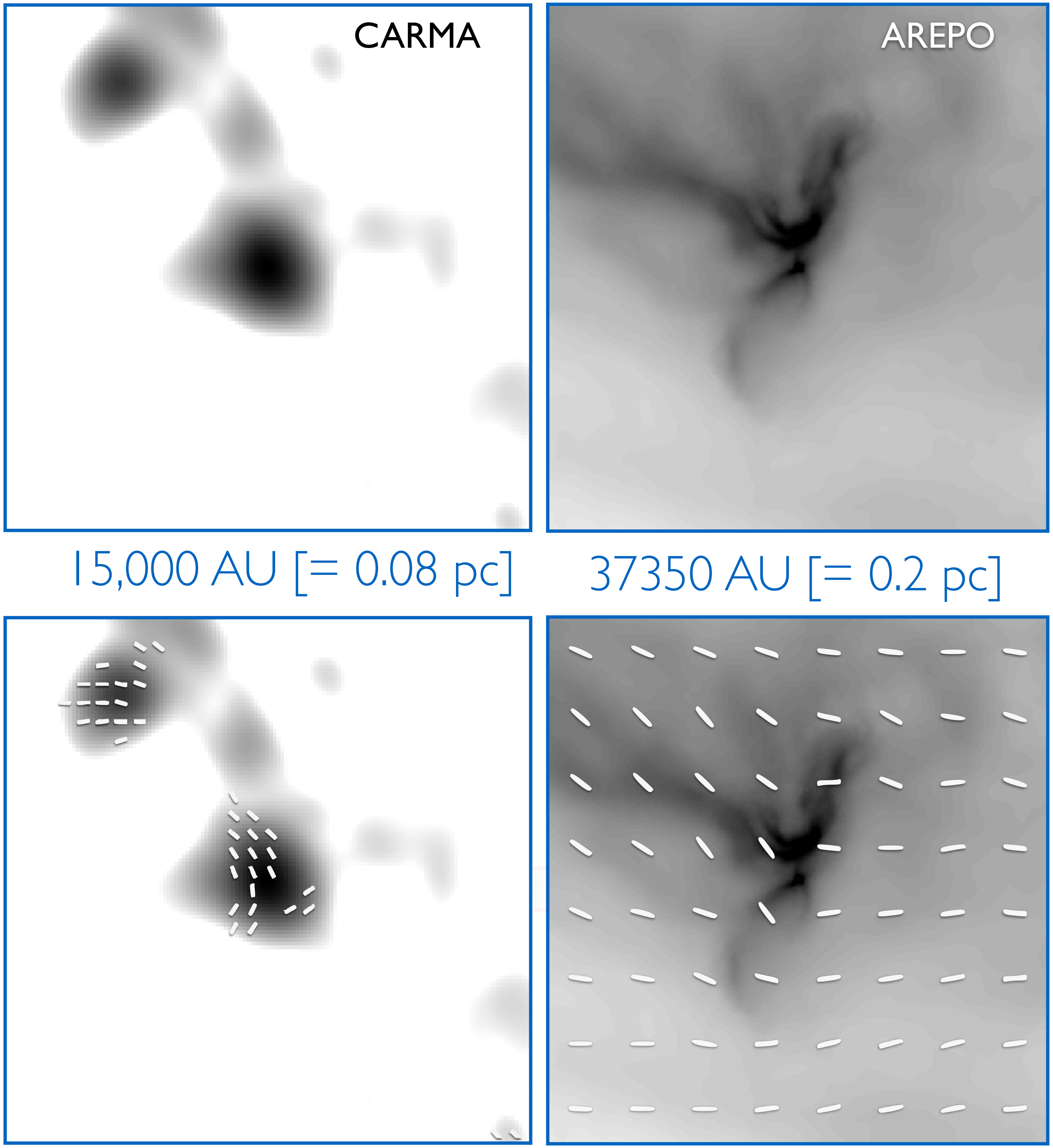

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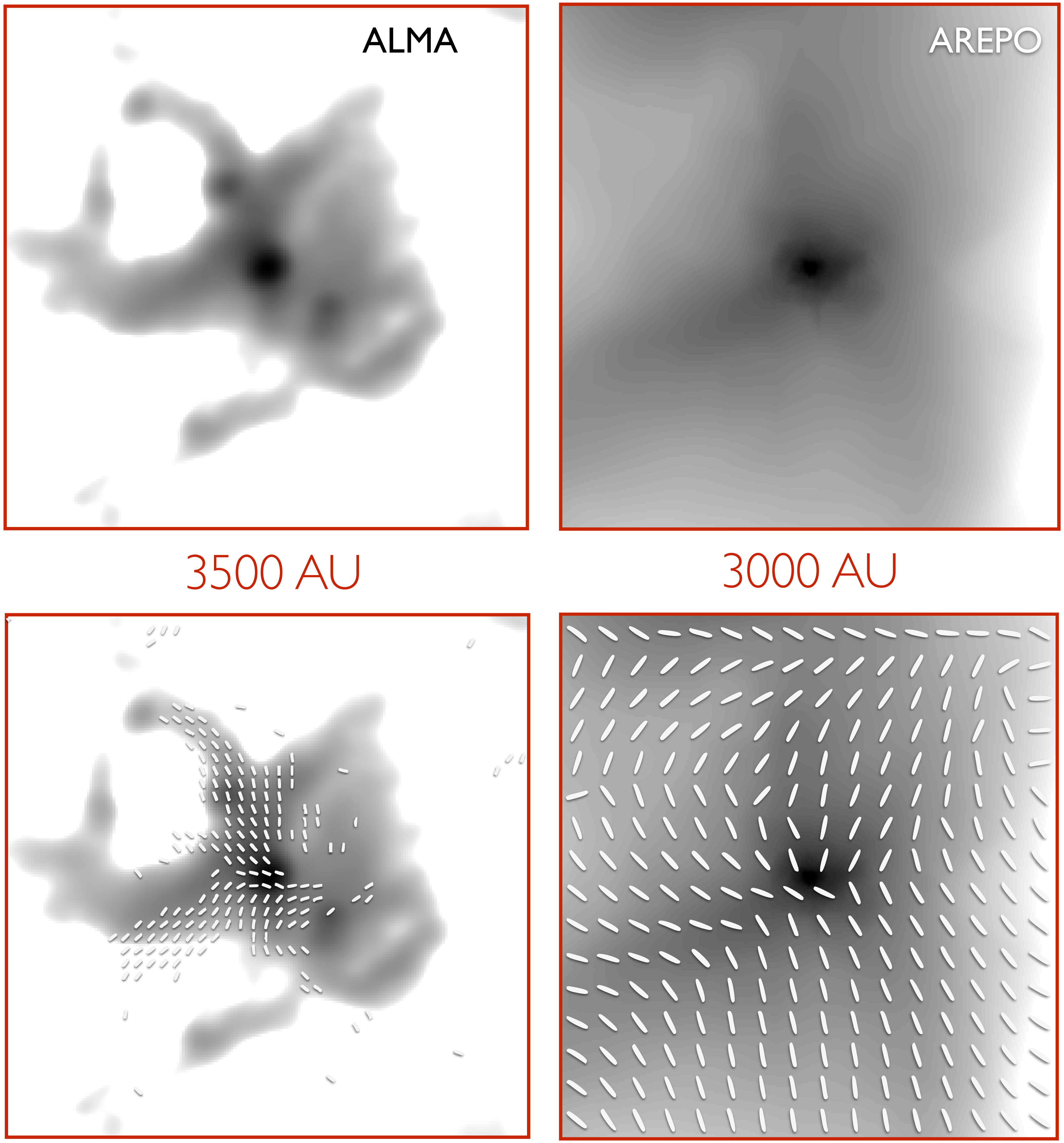
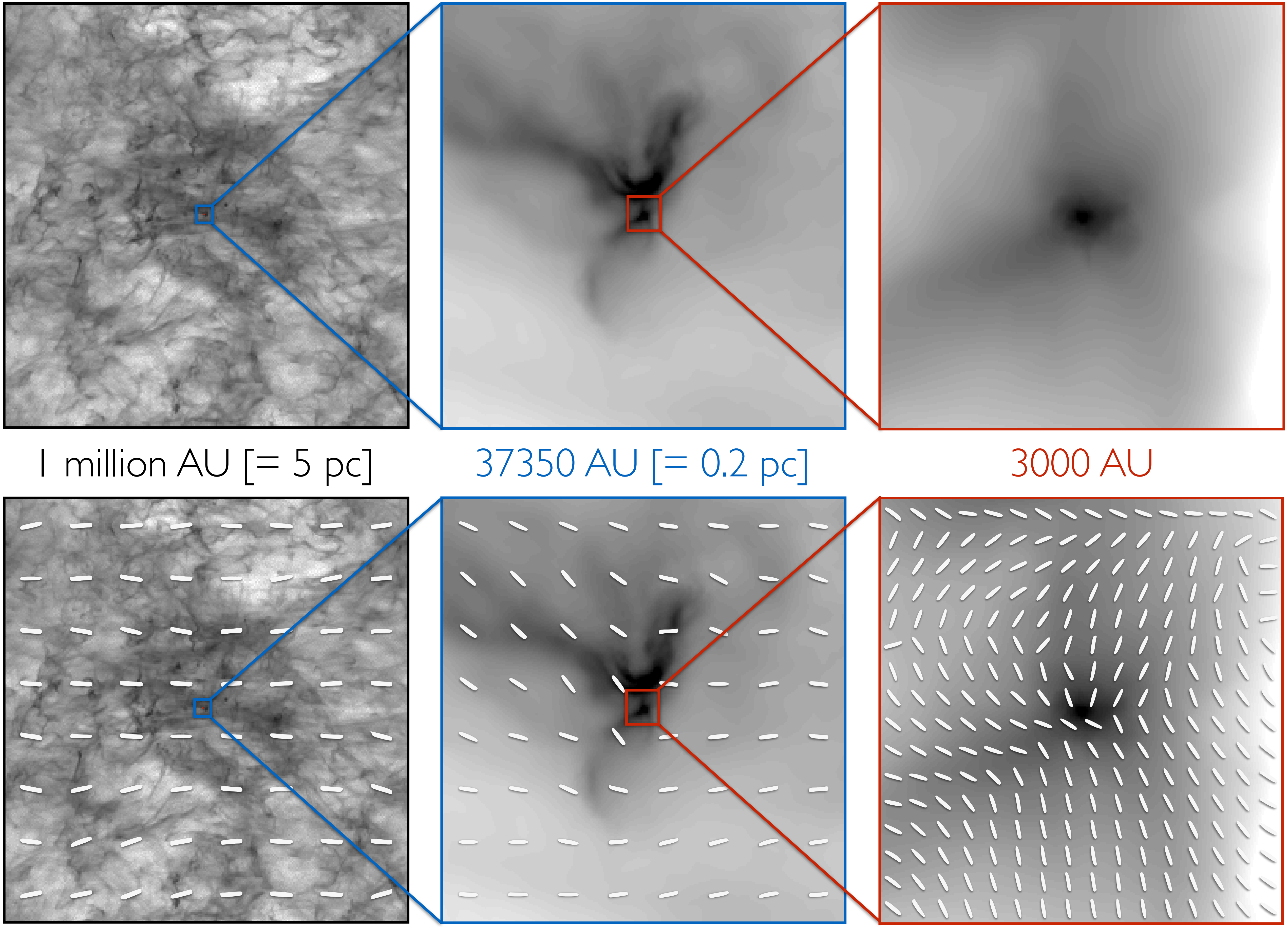


Please do not distribute

B=30



FILAMENTS: FAD OR FUNDAMENTAL?

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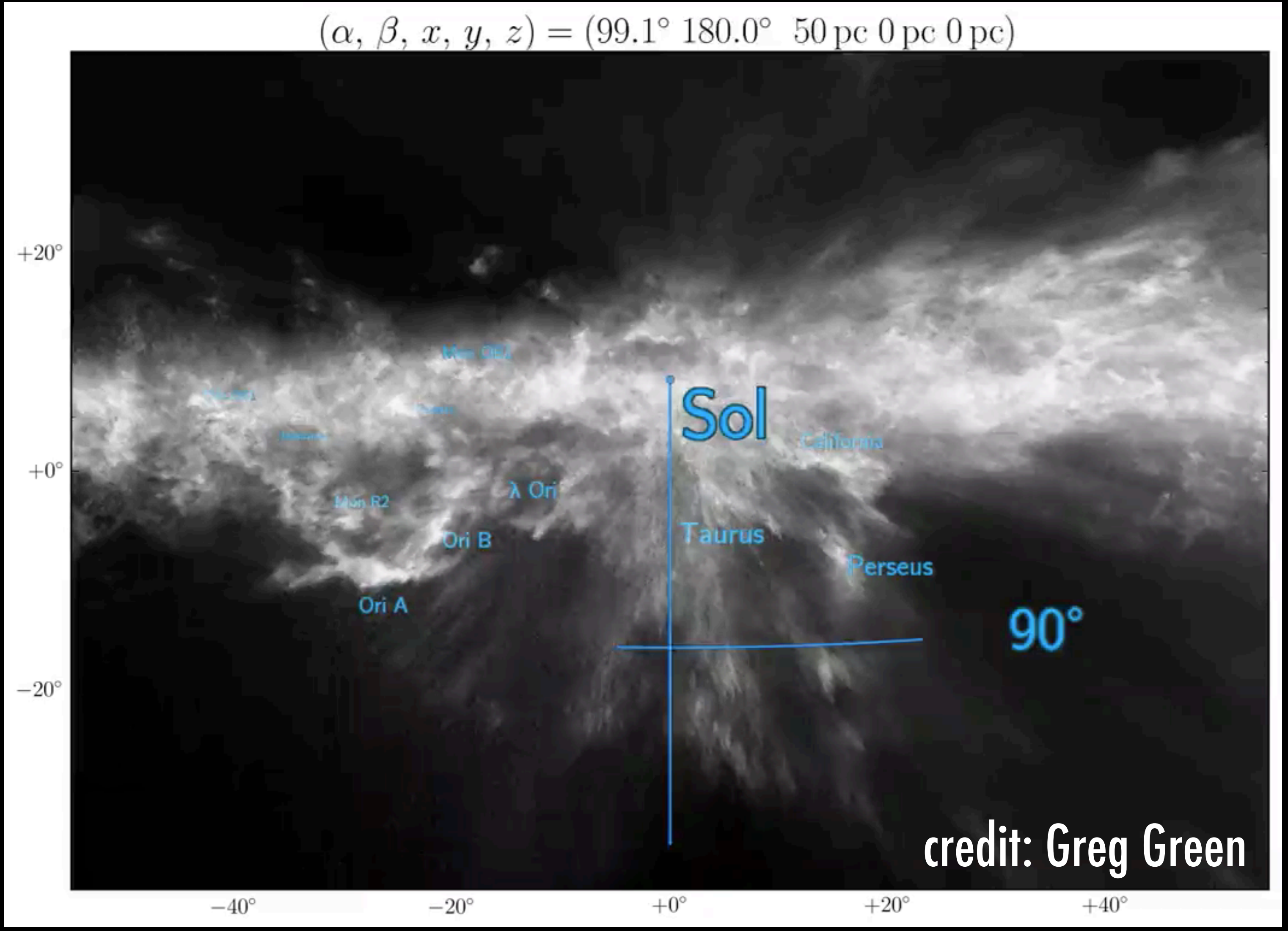
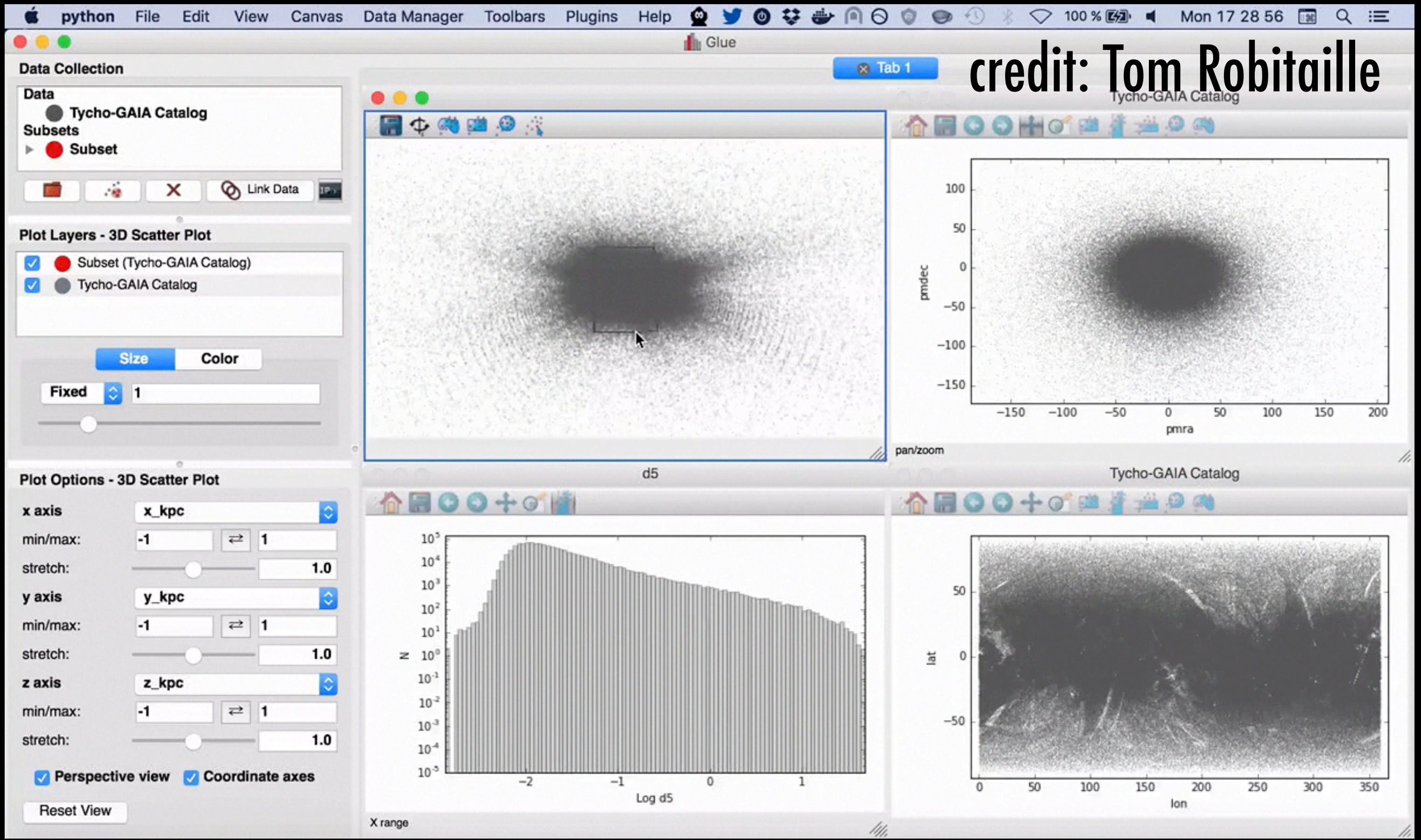
Radcliffe Institute for Advanced Study
@aagie

Ophiuchus, Barnard 1919

3D dust: http://argonaut.skymaps.info

Gaia 3D dust & glue





glue: http://glueviz.org

2011

Astronomische Gesellschaft
German Astronomical Society

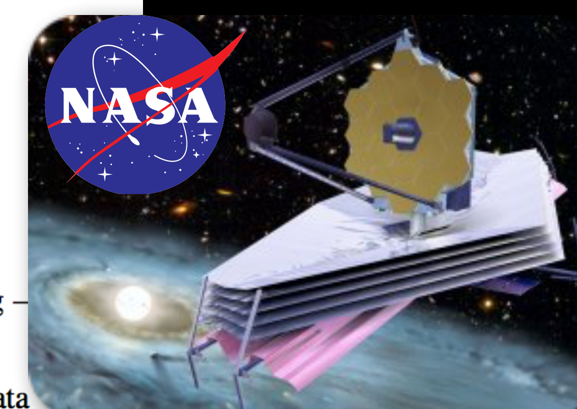
Astron. Nachr. / AN **333**, No. 5/6, 505 – 514 (2012) / **DOI** 10.1002/asna.201211705

glue

Principles of high-dimensional data visualization in astronomy

A.A. Goodman[*]

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

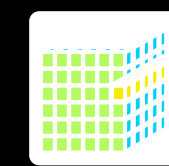


Received 2012 May 3, accepted 2012 May 4
Published online 2012 Jun 15

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

MSDSE
Moore - Sloan
Data Science Environments

LINKED-VIEW  VISUALIZATION OF HIGH-DIMENSIONAL DATA  IN GLUE

Alyssa A. Goodman

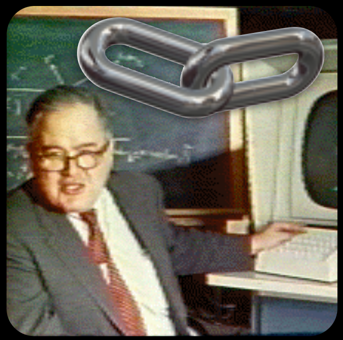
Harvard-Smithsonian Center for Astrophysics & Radcliffe Institute

with Chris Beaumont, Michelle Borkin, Penny Qian & Tom Robitaille

@aagie
@glueviz
@astrofrog

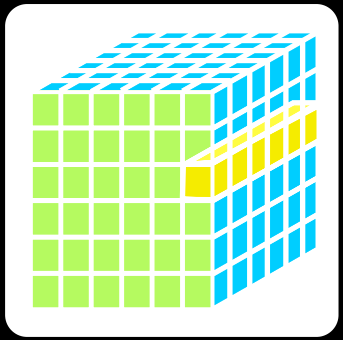
glueviz.org
github.com/glue-viz
Tom Robitaille, lead developer

James Webb
Space Telescope



"Linked Views"

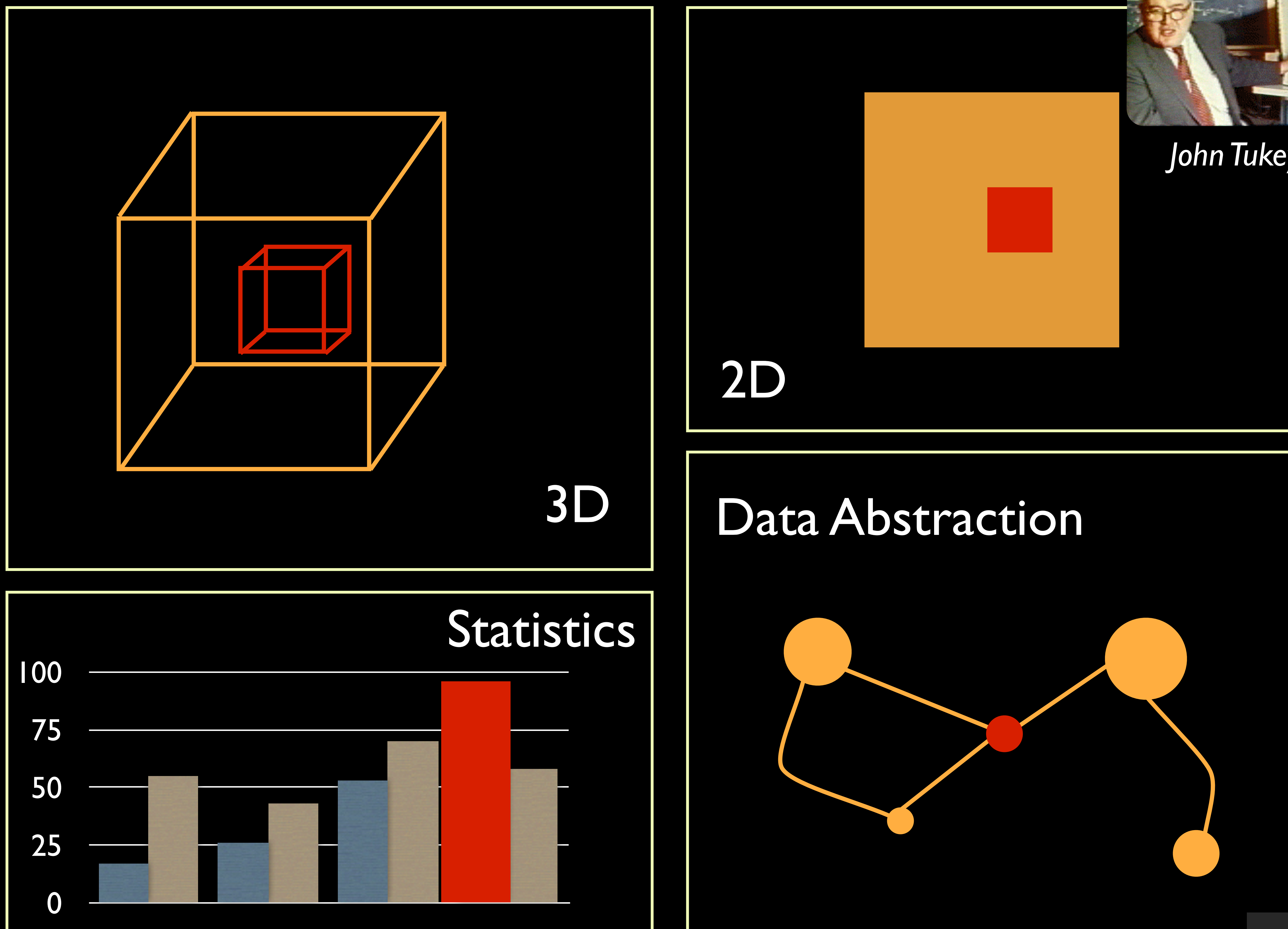
Open Source Python, on GitHub



3D+

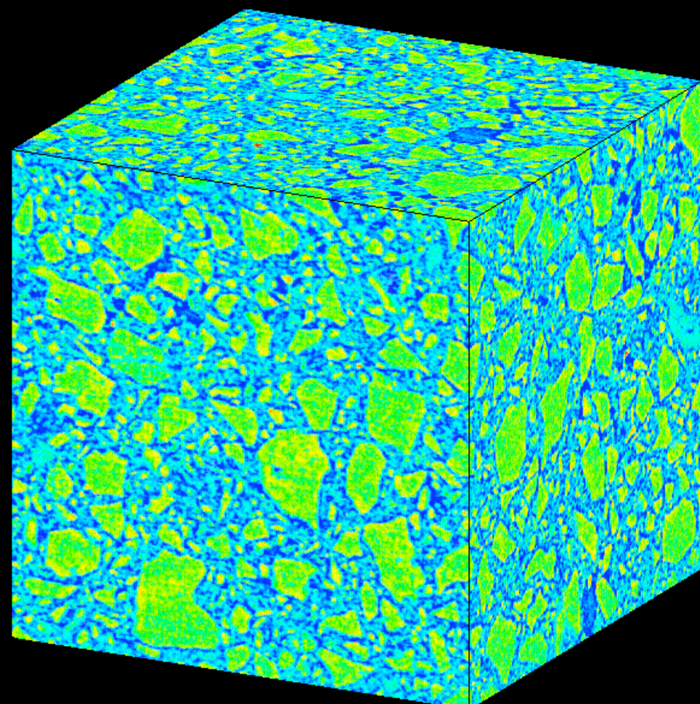
LINKED VIEWS OF HIGH-DIMENSIONAL DATA

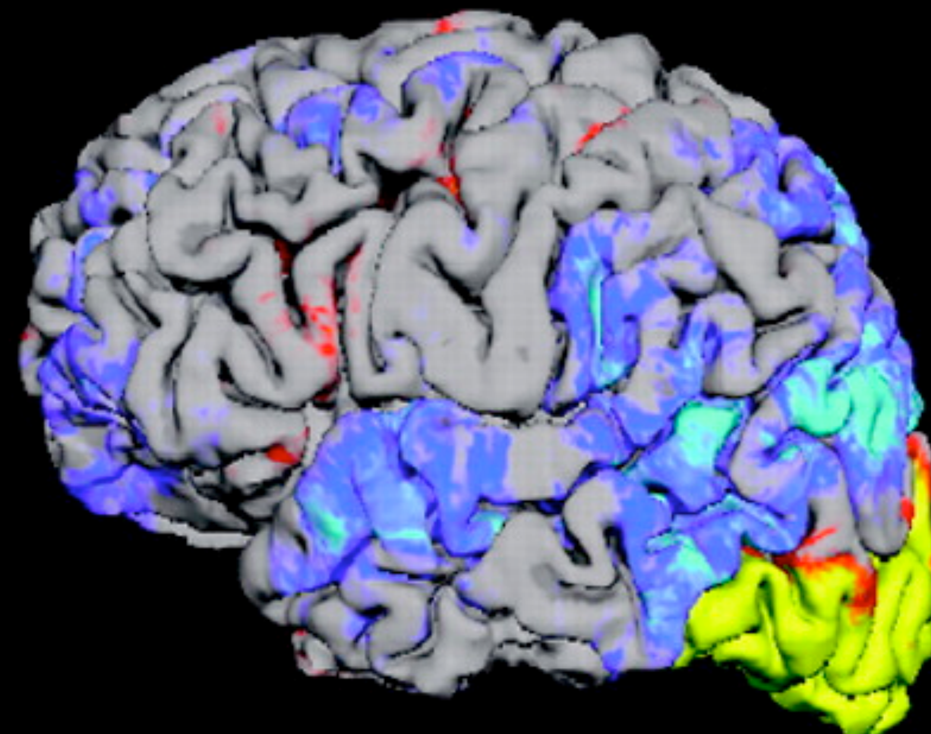
John Tukey

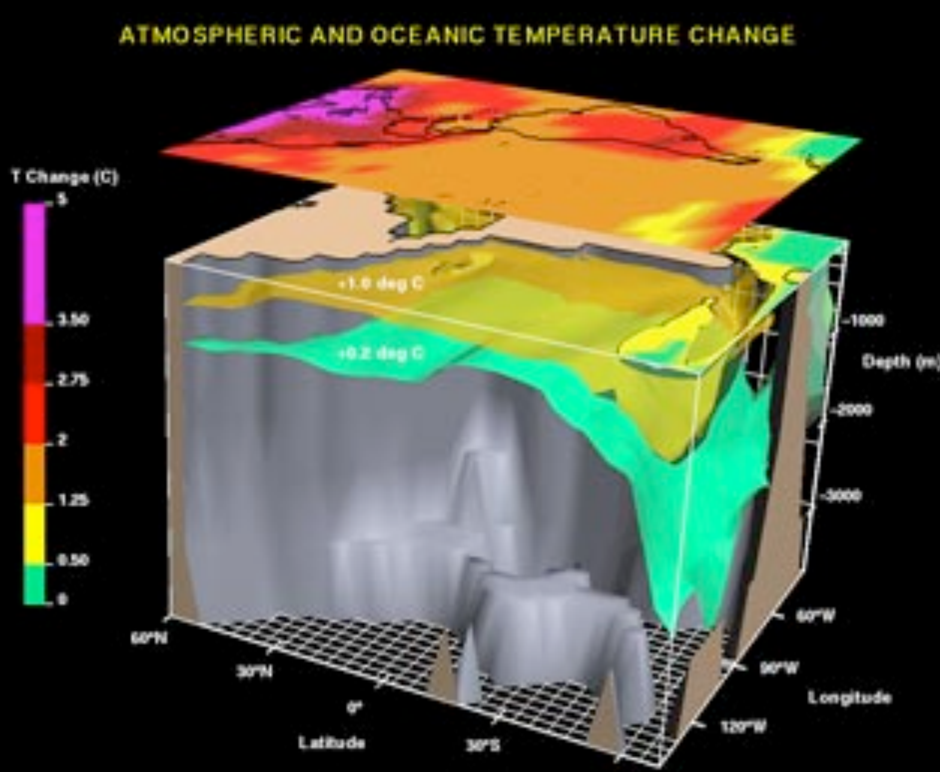


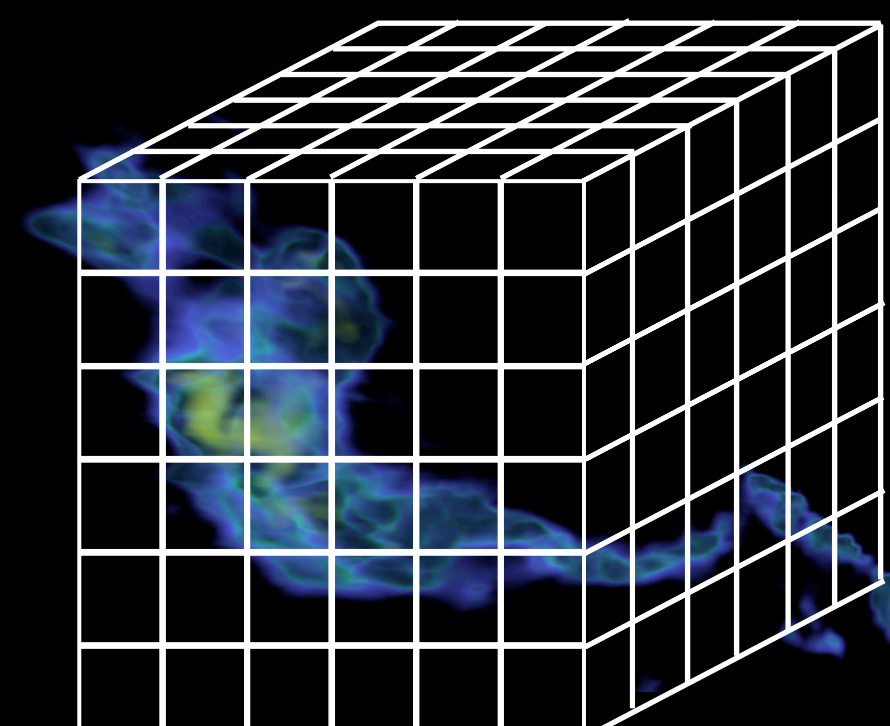
figure, by M. Borkin, reproduced from Goodman 2012, "Principles of High-Dimensional Data Visualization in Astronomy"

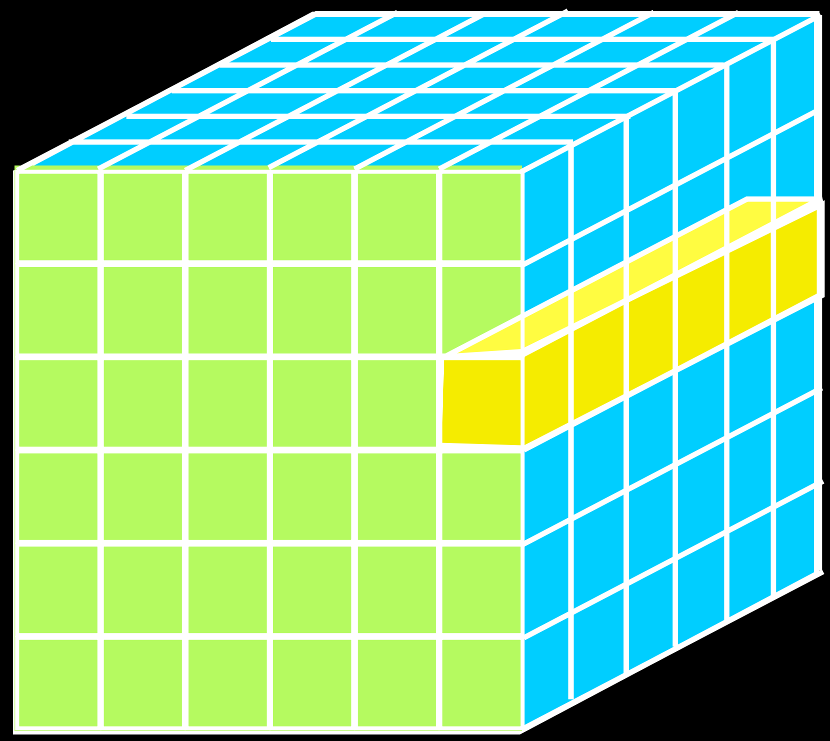
"HIGH-DIMENSIONAL" DATA







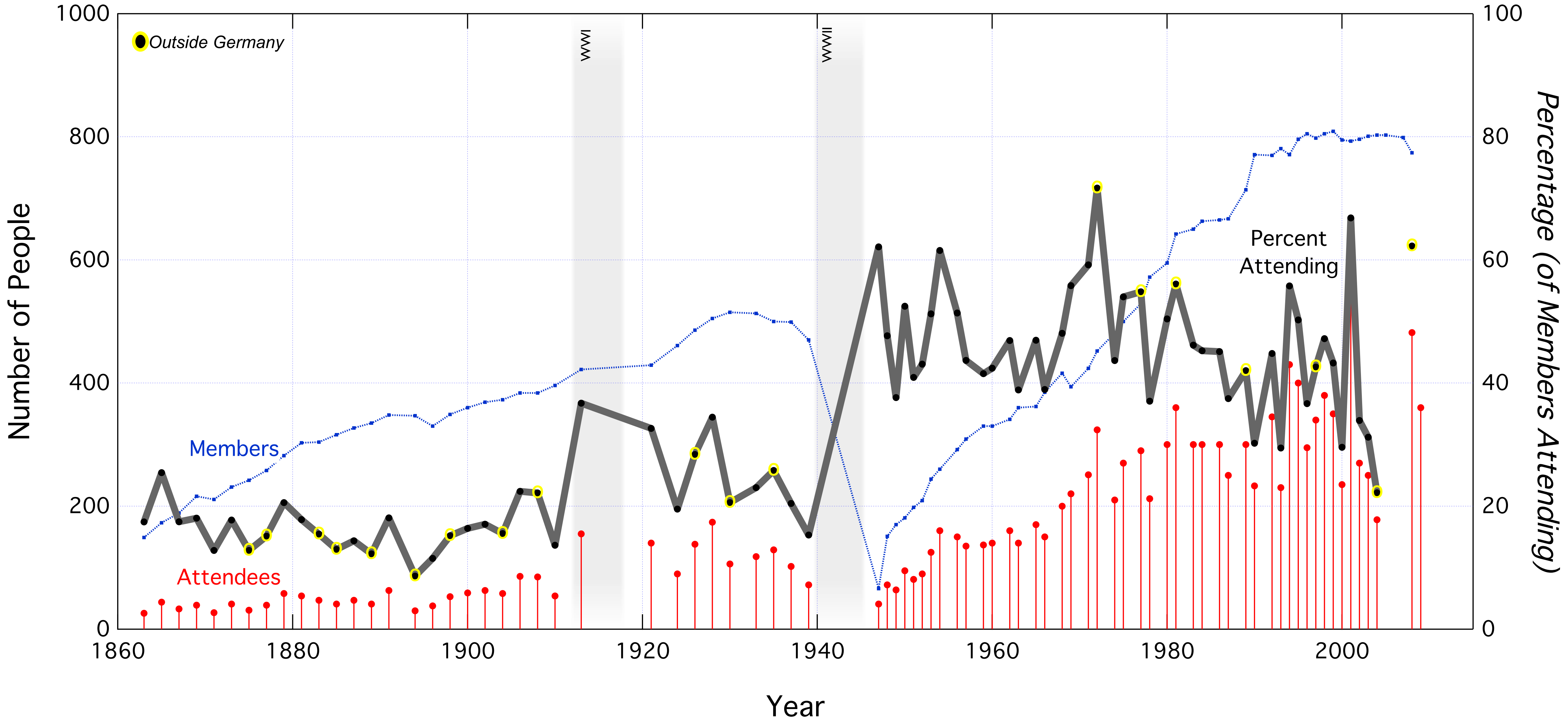


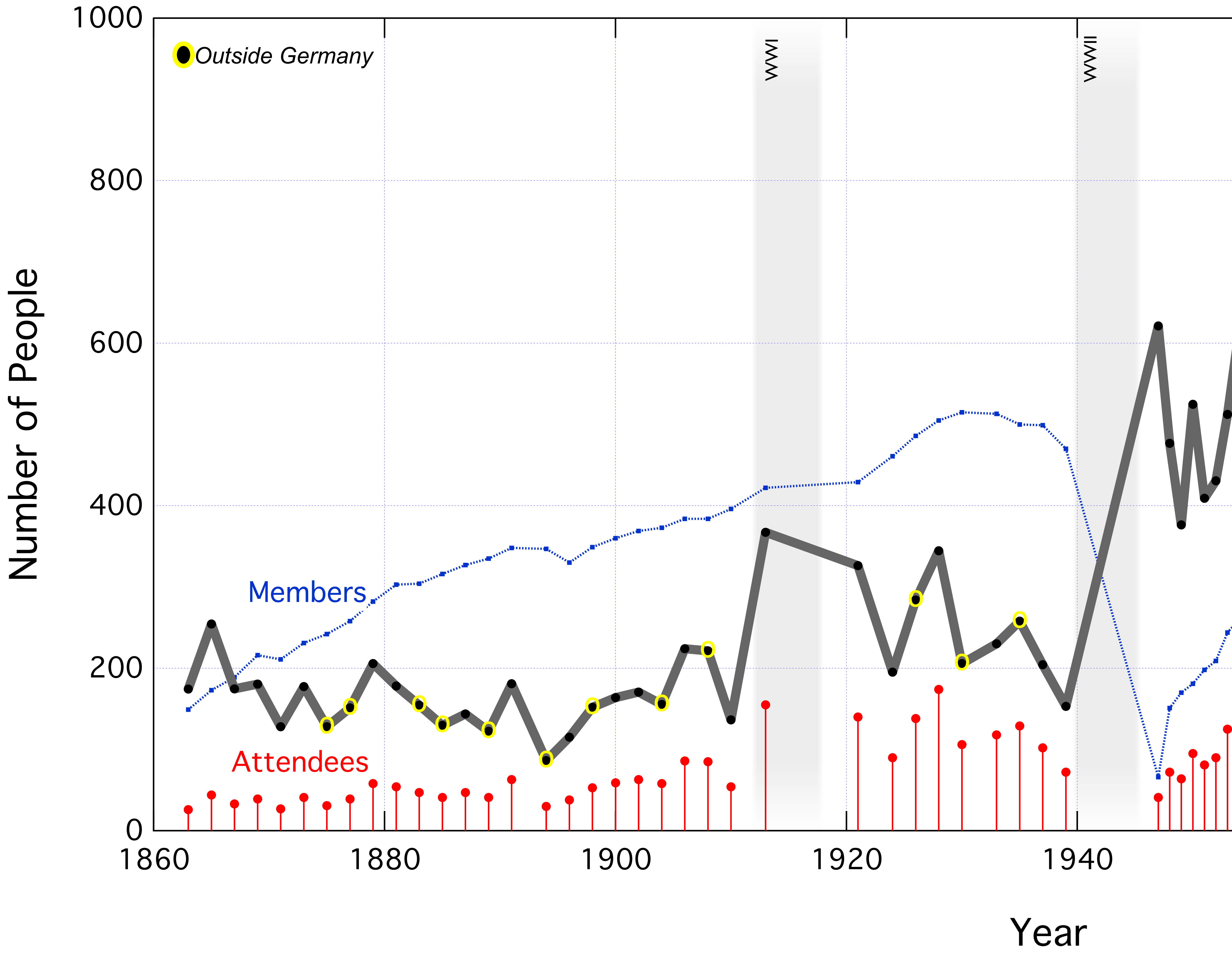


DATA–DIMENSIONS–DISPLAY

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”

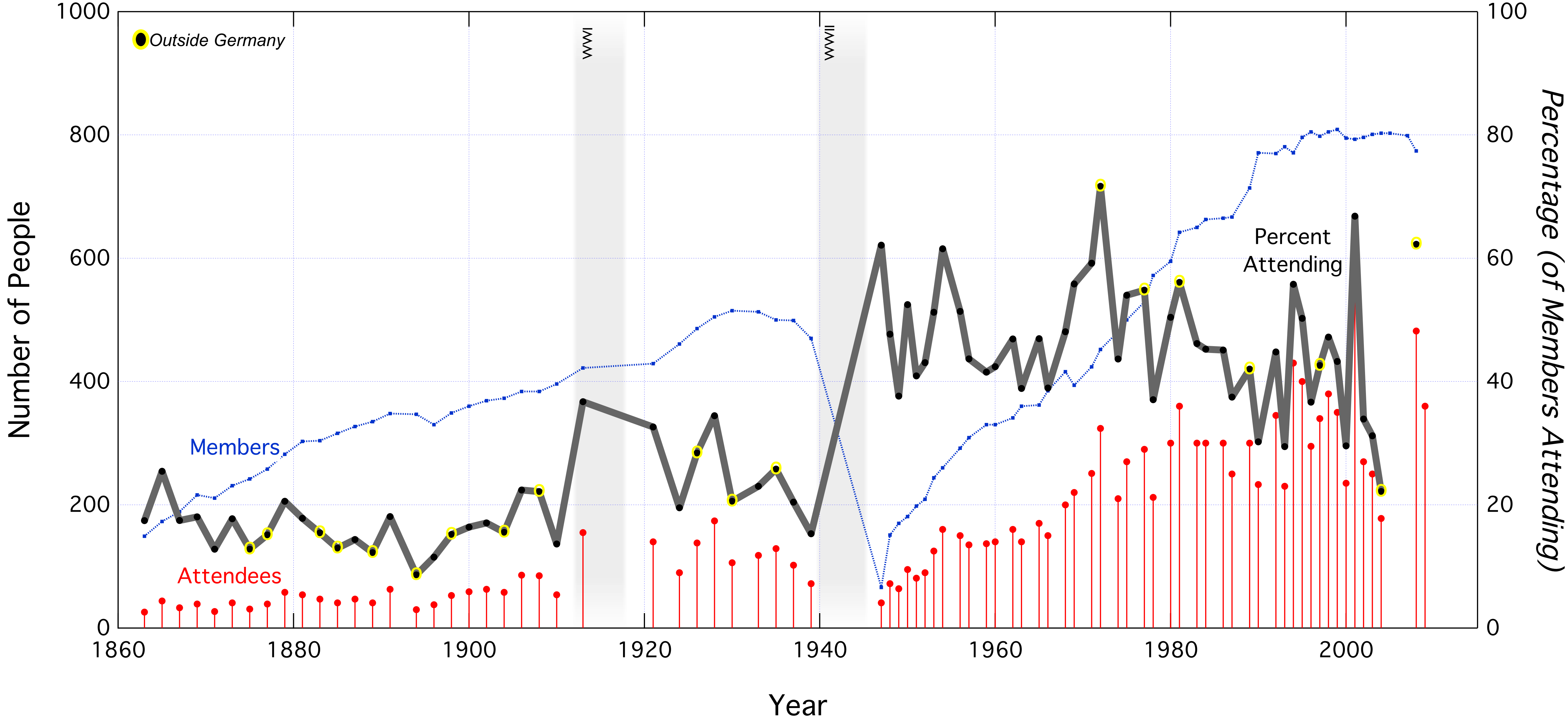
"Time Series" History of the AG, 1860-2009



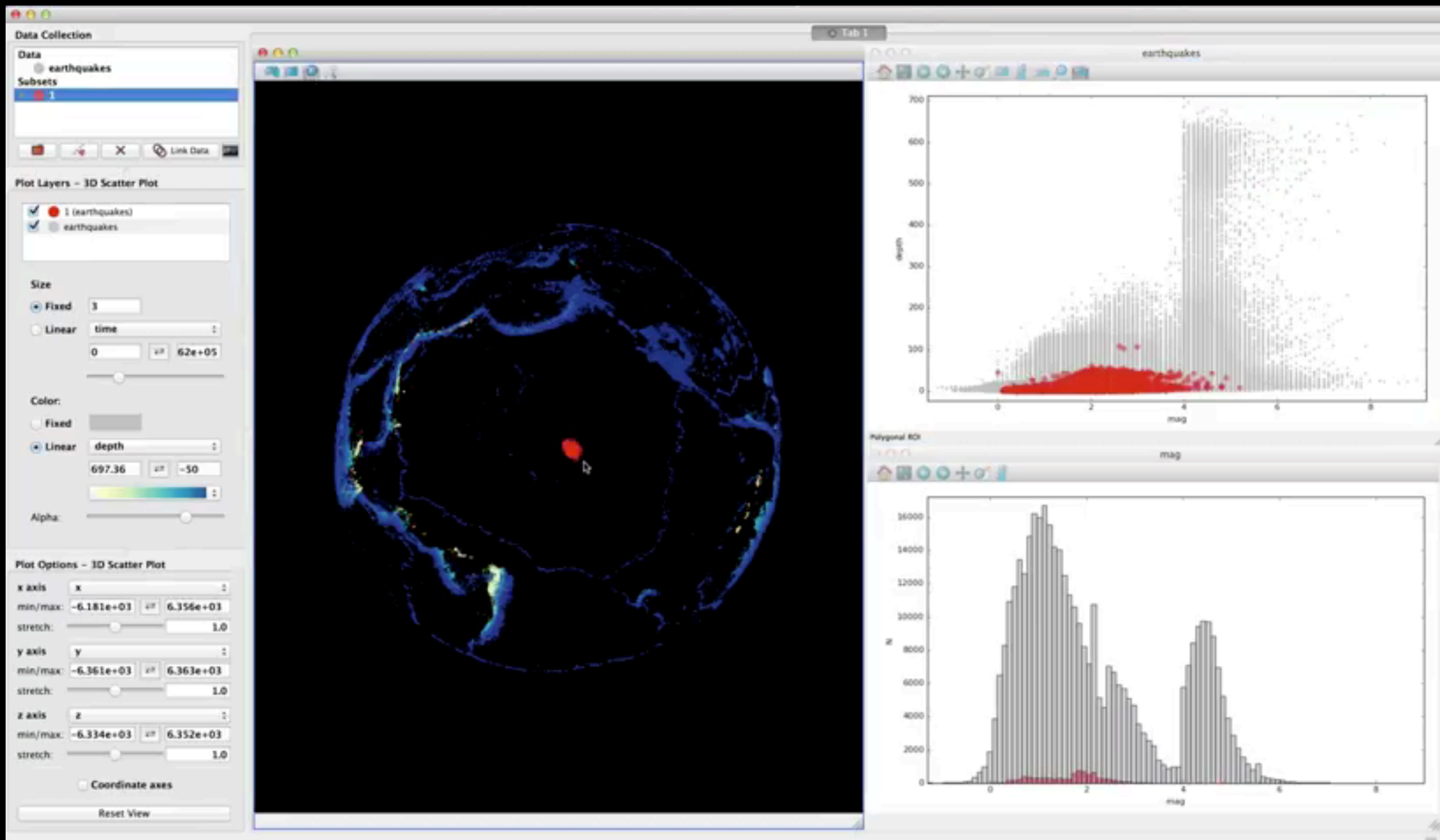


1000
800
600
400
200
0
Outside Germany
WWI
WWII
Members
Attendees
Number of People
1860
1880
1900
1920
1940
Year

History of the AG, 1860-2009



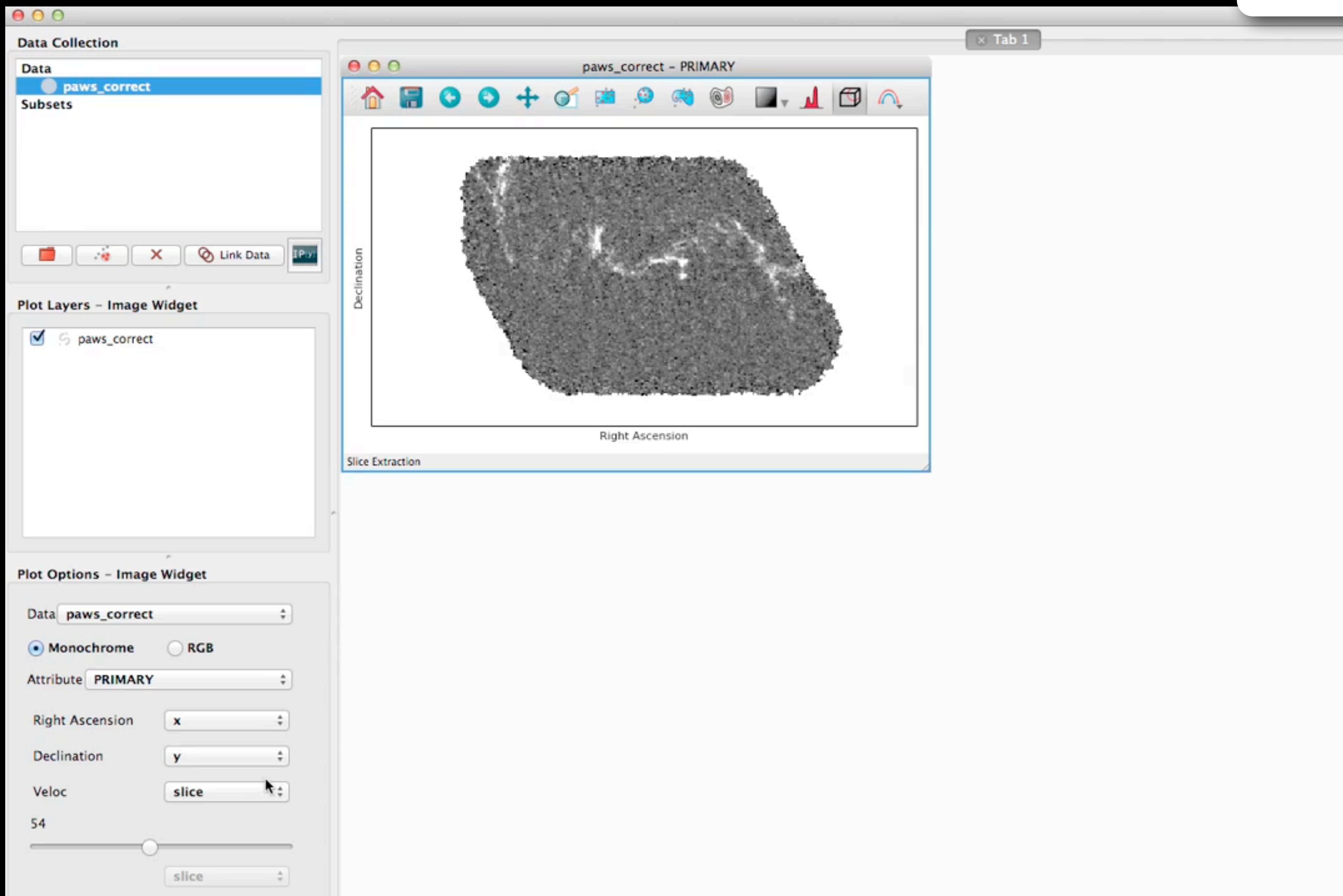
LINKED VIEWS OF HIGH-DIMENSIONAL DATA (IN PYTHON)
GLUE



video by Tom Robitaille, lead glue developer
glue created by: C. Beaumont, M. Borkin, P. Qian, T. Robitaille, and A. Goodman, PI

LINKED VIEWS OF HIGH-DIMENSIONAL DATA (IN PYTHON)

GLUE



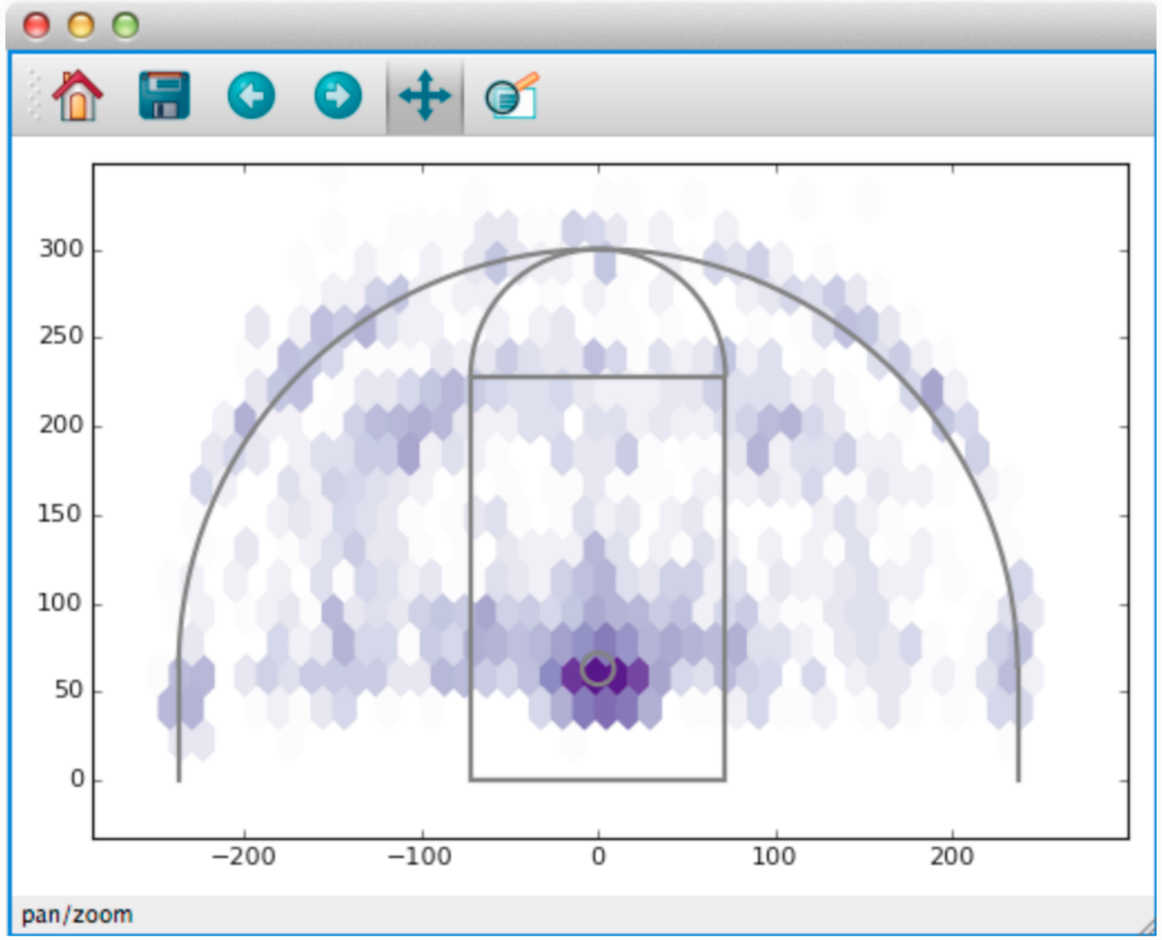
video by Chris Beaumont, glue developer

glue created by: C. Beaumont, M. Borkin, P. Qian, T. Robitaille, and A. Goodman, PI

"BUT WAIT, THERE'S MORE..."

dollars logo - Google Search | Building Custom Data Viewers — Glue 0.9.0 documentation | balzer82.g

Building Custom Data Viewers



Glue's standard data viewers (scatter plots, images, histograms) are useful in a wide variety of data exploration settings. However, they represent a *tiny* fraction of the ways to view a particular dataset. For this reason, Glue provides a simple mechanism for creating custom visualizations using matplotlib.

Creating a `custom data viewer` requires writing a little bit of Matplotlib code but involves little to no GUI programming. The next several sections illustrate how to build a custom data viewer by

"BUT WAIT, THERE'S MORE..."

"cuts" along arbitrary paths

flood-fill selection (2D, 3D)

export to d3po, plotly

custom viewers (e.g. GIS, WorldWide Telescope, Super Mario)

plot manipulation/customization (via Matplotlib)

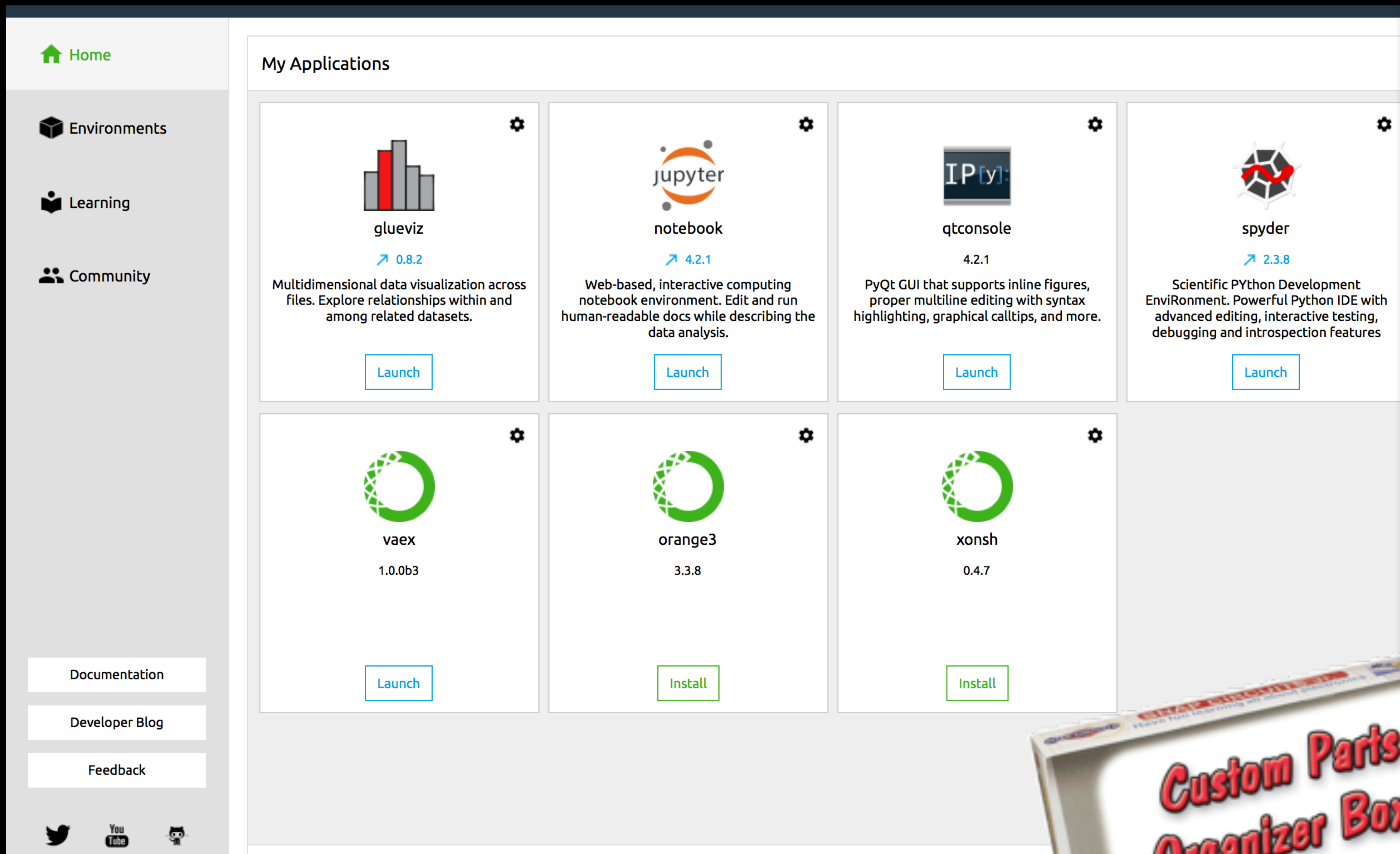
flexible import/export

saved sessions (.glu)

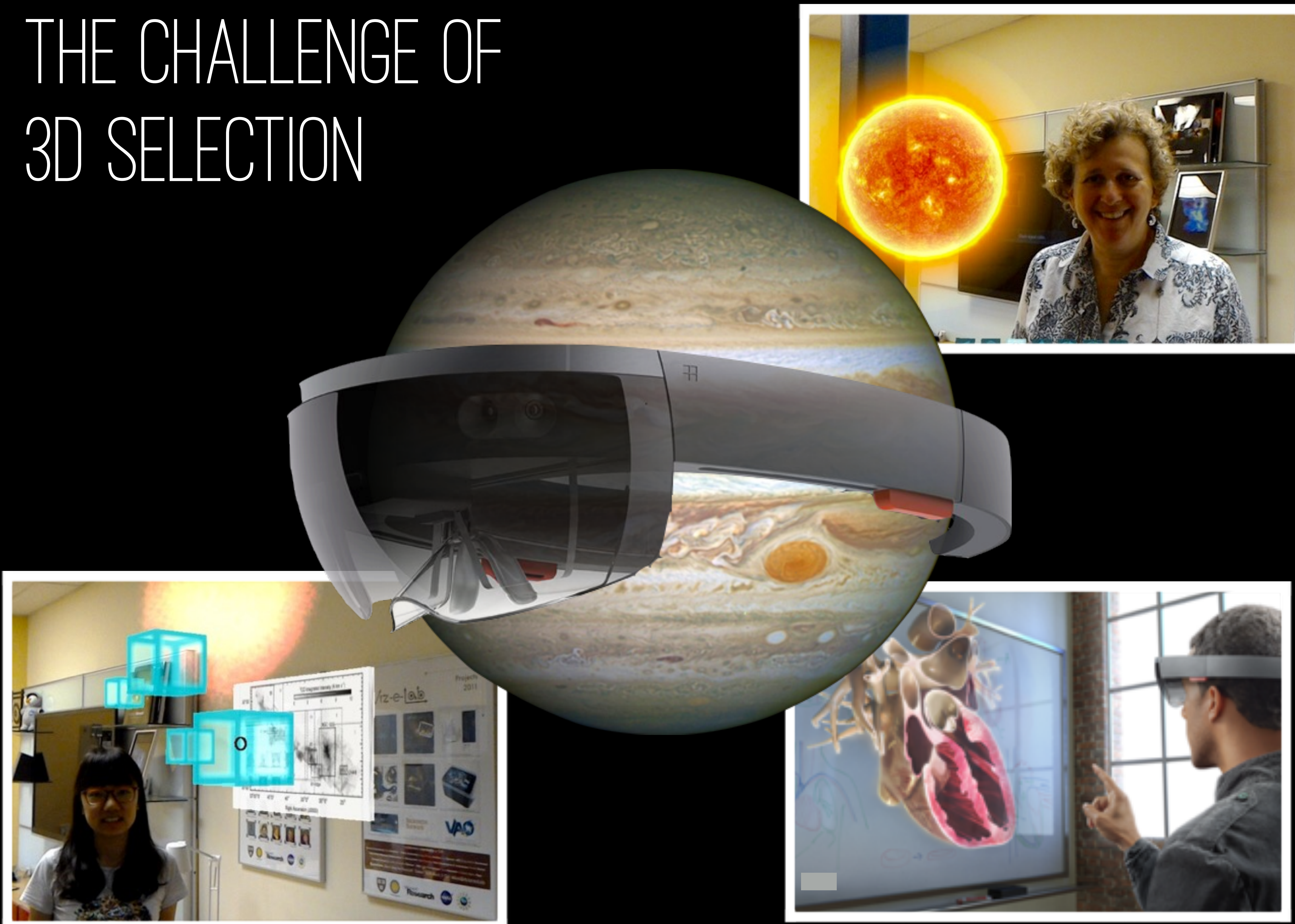
Anaconda Navigator install/upgrade

Yes, please do go start adding code now, at github.com/glue-viz.

INTEGRATION



THE CHALLENGE OF 3D SELECTION



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

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.

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

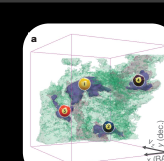
Merce Crosas 3 days ago · Public
Konrad, good points; this has been a concern for the community working on reproducibility. Regarding data repositories, Dataverse handles long-term preservation and access of data files in the following way: 1) for some data files that the repository recognizes (such 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.

Astrometry.net



glue

[video, demos]

LINKED-VIEW  VISUALIZATION OF HIGH-DIMENSIONAL DATA  IN GLUE

Alyssa A. Goodman

Harvard-Smithsonian Center for Astrophysics & Radcliffe Institute

with Chris Beaumont, Michelle Borkin, Penny Qian & Tom Robitaille

@aagie
@glueviz
@astrofrog

glueviz.org
github.com/glue-viz
Tom Robitaille, lead developer

James Webb
Space Telescope

extra slides

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

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

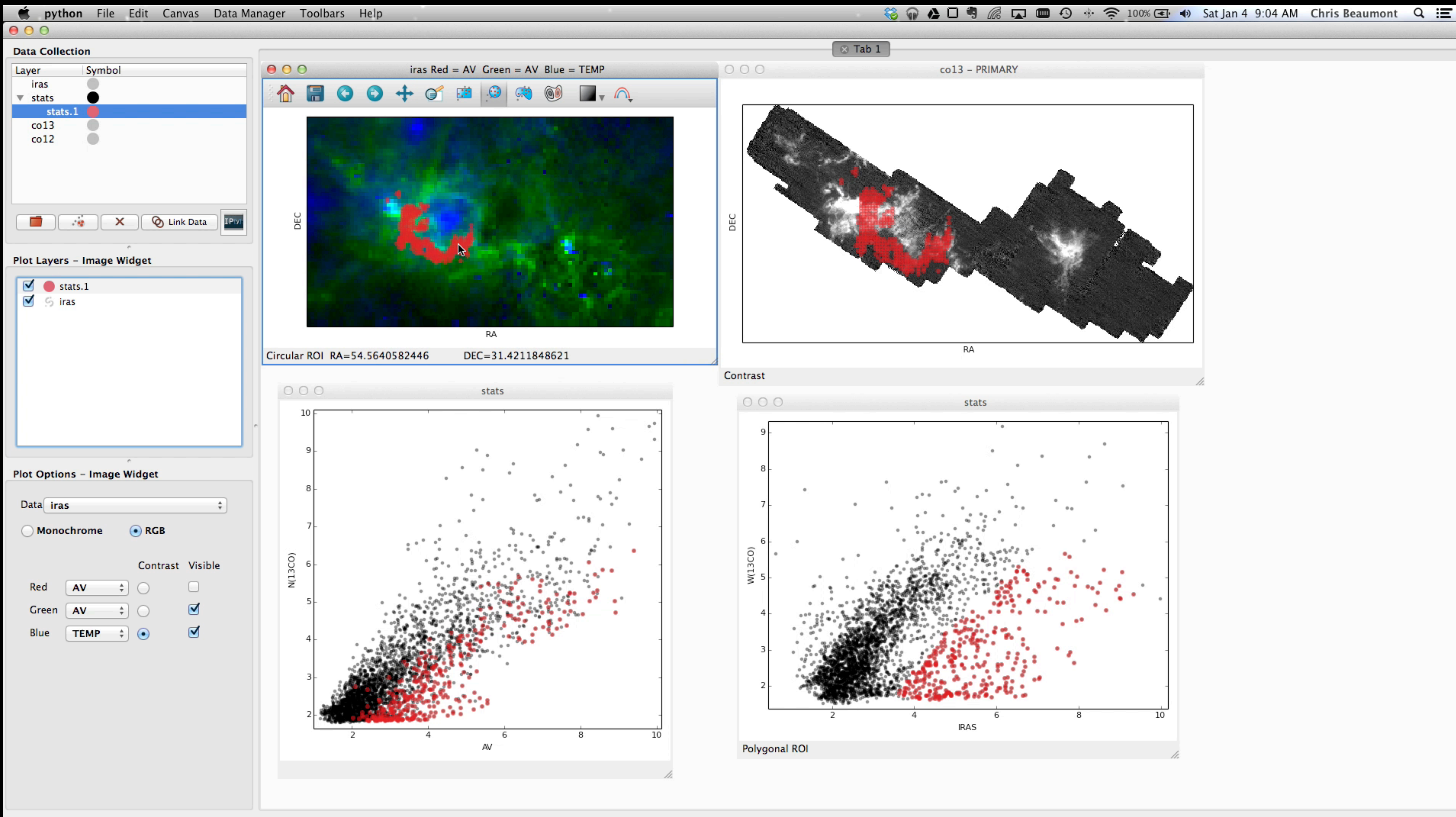
Key words cosmology: large-scale structure – ISM: clouds – methods: data analysis – techniques: image processing – techniques: radial velocities

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 insi
and statistical analysis are followed, rather than accompanied, by visualiza
toward "linked view" systems, where multiple views of high-dimensional
highlights, or otherwise manipulates, one of several open views. For example,
visualization of simulated or observed data, and simultaneously viewing st
(such as an x-y plot of temperature vs. velocity, or a histogram of vorticiti
selects an interesting group of points in any one of these displays, that the sa
other open displays. Selections can be graphical or algorithmic, and they can
data, this kind of analysis has long been possible, even though it has been
for astronomy and other "high-dimensional" fields, though, is that no extant
and data cubes within a linked-view environment. The paper concludes its
with suggestions that look toward cooperatively-developed open-source mod
flexible, high-dimensional, linked-view visualization environment useful in a

#	Bibcode / Authors	Cites / Title	Date	List of Links / Access Control Help
1	2016A&C....15...50N Naiman, J. P.	1.000 AstroBlend: An astrophysical visualization package for Blender	04/2016	A Z E L X R C U
2	2015A&A...584A..26B Bouy, H.; Alves, J.	1.000 Cosmography of OB stars in the solar neighbourhood	12/2015	A Z E F L D R C S O U
3	2015ASPC..495..121R Rosolowsky, E.; Kern, J.; Federl, P.; Jacobs, J.; Loveland, S.; Taylor, J.; Sivakoff, G.; Taylor, R.	1.000 The Cube Analysis and Rendering Tool for Astronomy	09/2015	A Z E L T R U
4	2015ASPC..495..101B Beaumont, C.; Goodman, A.; Greenfield, P.	1.000 Hackable User Interfaces In Astronomy with Glue	09/2015	A Z E L T R U
5	2015A&C....12...86P Punzo, D.; van der Hulst, J. M.; Roerdink, J. B. T. M.; Oosterloo, T. A.; Ramatsoku, M.; Verheijen, M. A. W.	1.000 The role of 3-D interactive visualization in blind surveys of H I in galaxies	09/2015	A Z E L X R C U
6	2015arXiv150604621T Taylor, Rhys	1.000 Comment on 'The role of 3-D interactive visualization in blind surveys of HI in galaxies'	06/2015	A Z X R C U
7	2013arXiv1307.0712B Burton, Michael; Crocker, Roland; Dickey, John; Filipovic, Miroslav; Purcell, Cormac; Rathborne, Jill; Rowell, Gavin; Tothill, Nick; Walsh, Andrew	1.000 The Interstellar Medium White Paper	07/2013	A Z X R U
8	2013PASP..125..731K Kent, Brian R.	1.000 Visualizing Astronomical Data with Blender	06/2013	A Z E F L X R C S U
9	2013arXiv1304.6615C Cavuoti, Stefano	1.000 Data-rich astronomy: mining synoptic sky surveys	04/2013	A Z X R U

LINKED VIEWS OF HIGH-DIMENSIONAL DATA (IN PYTHON)

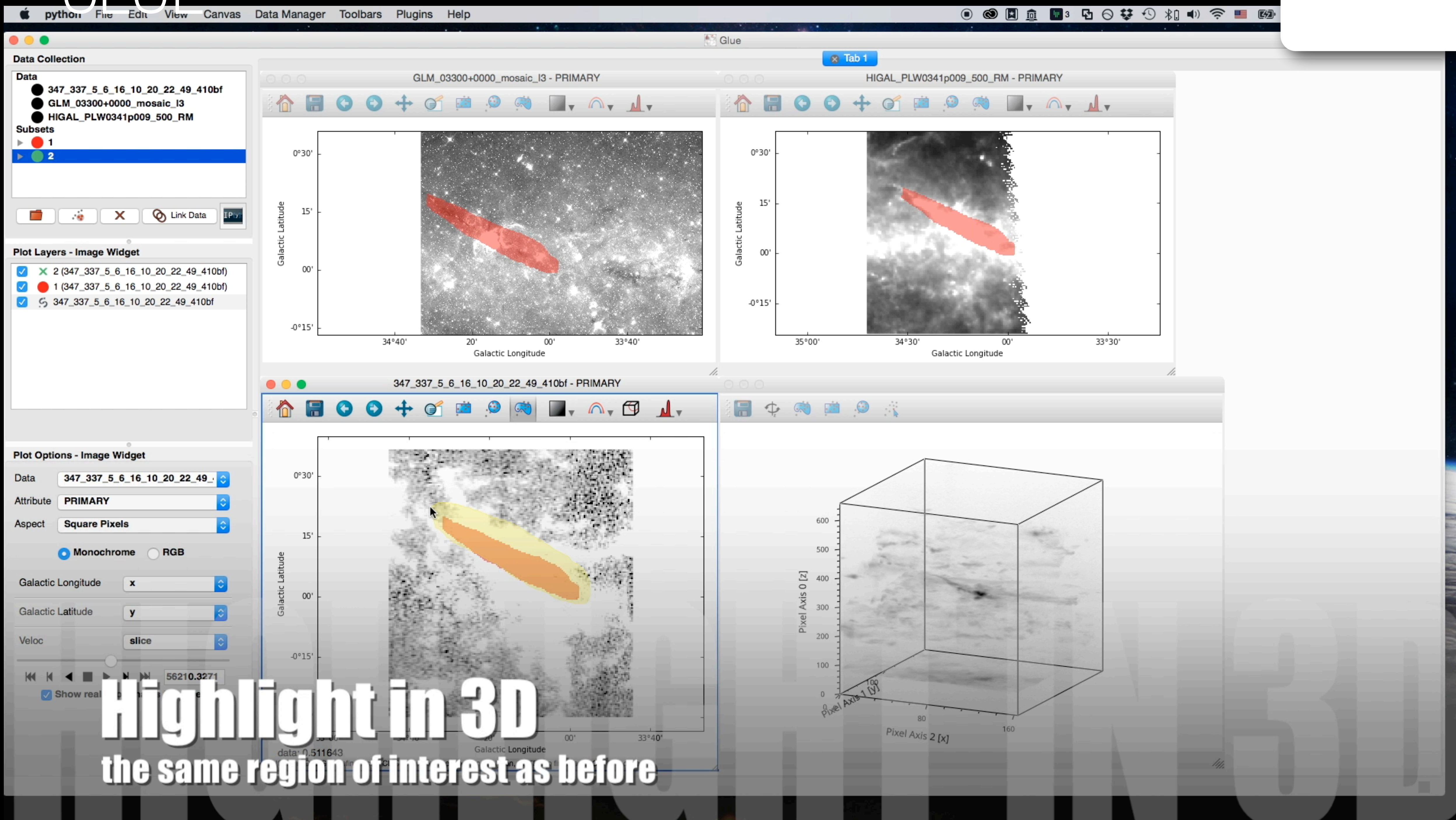
GLUE



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

LINKED VIEWS OF HIGH-DIMENSIONAL DATA (IN PYTHON)

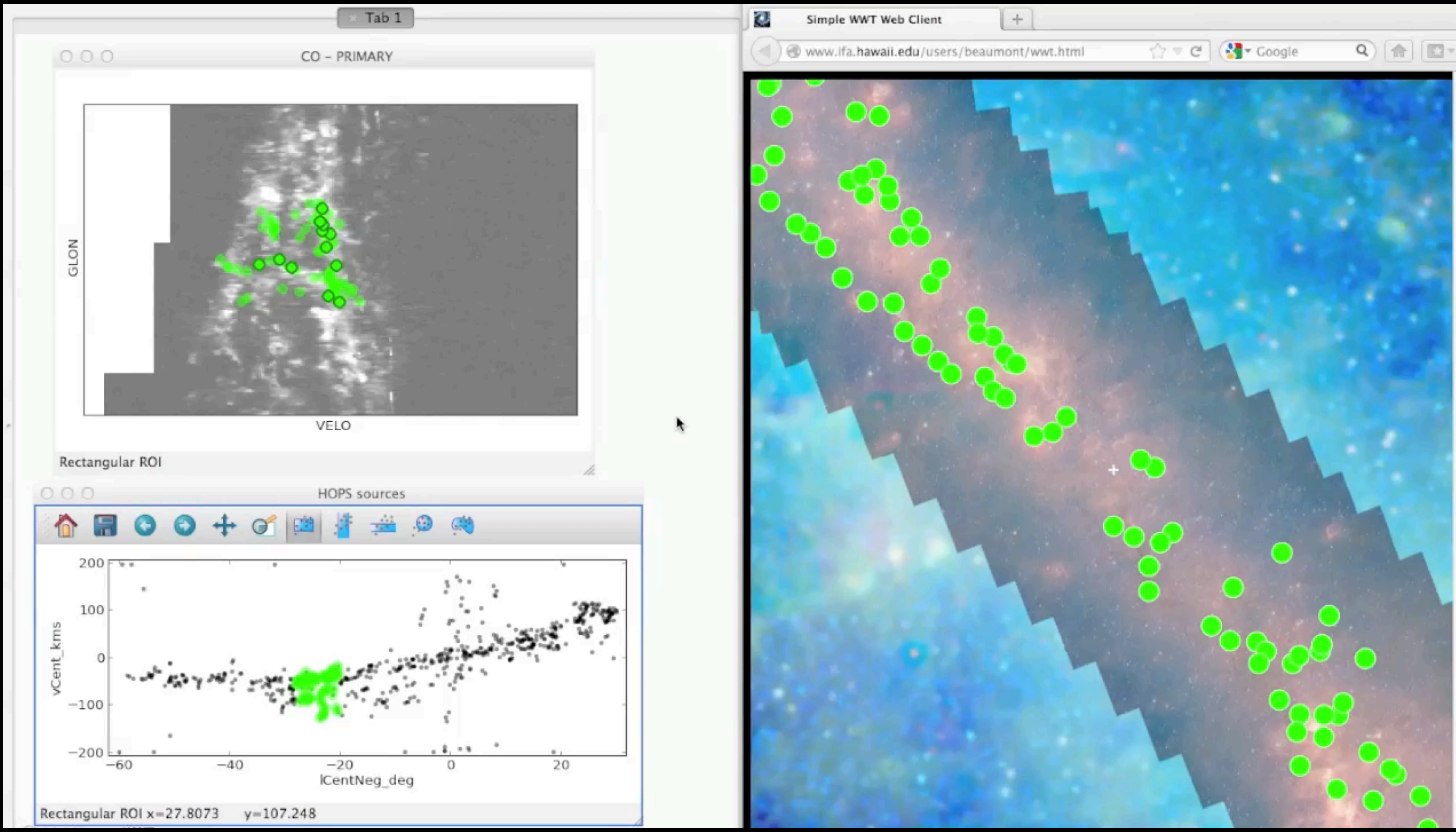
GLUE



video by Penny Qian, wth Catherine Zucker, graduate students
glue created by: C. Beaumont, M. Borkin, P. Qian, T. Robitaille, and A. Goodman, PI

glue

WorldWide Telescope

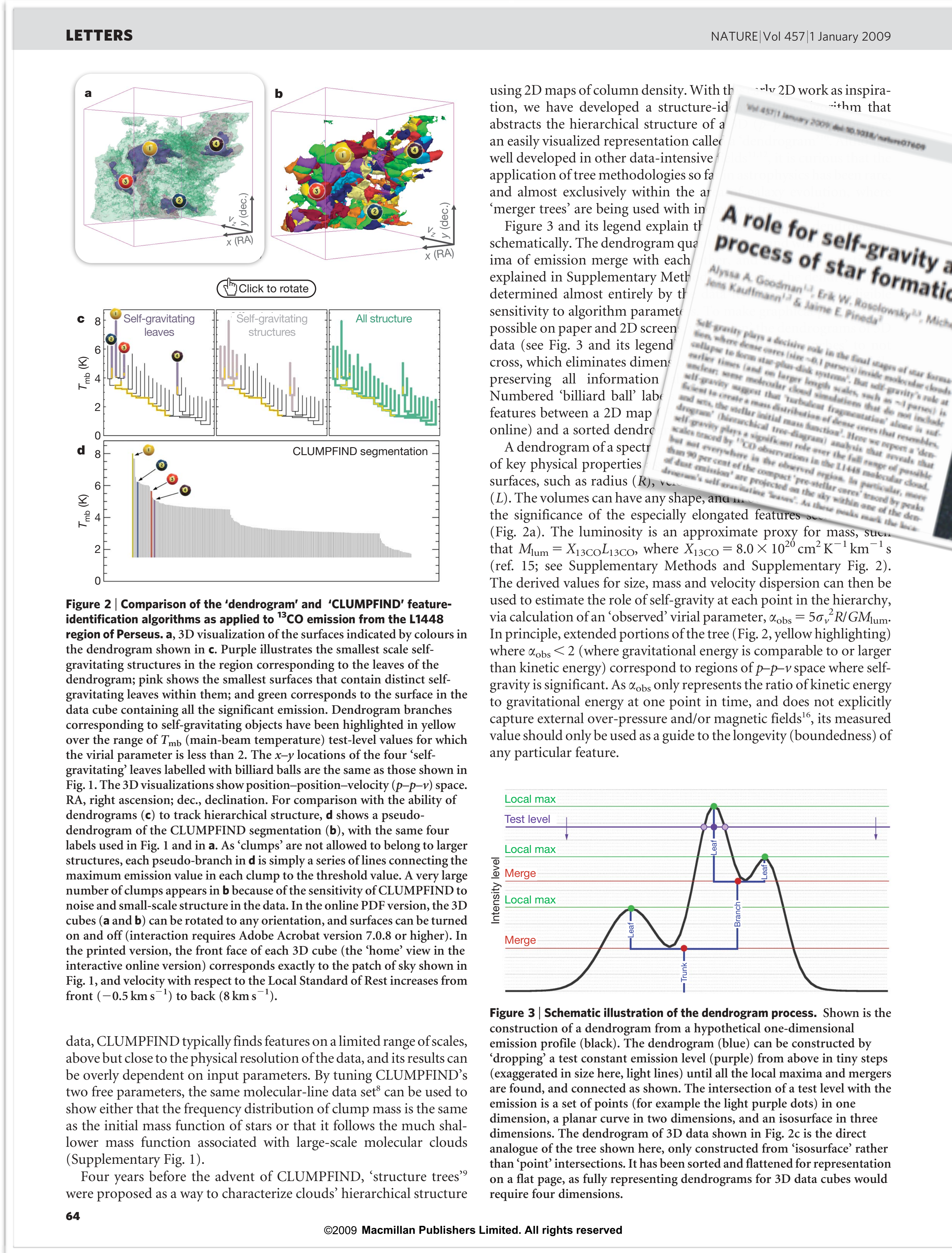


Video courtesy of Chris Beaumont

2009

3D PDF

HIGH-DIMENSIONAL DATA 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 ($-0.5\ \mathrm{km\,s^{-1}}$) to back ($8\ \mathrm{km\,s^{-1}}$).

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

Four years before the advent of CLUMPFIND, 'structure trees'[9] were proposed as a way to characterize clouds' hierarchical structure using 2D maps of column density. With th[…]rly 2D work as inspiration, we have developed a structure-id[…]rithm that abstracts the hierarchical structure of a […] an easily visualized representation calle[…] well developed in other data-intensive […] 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 t[…] schematically. The dendrogram qua[…] ima of emission merge with each […] explained in Supplementary Meth[…] determined almost entirely by t[…] 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' labe[…] features between a 2D map […] online) and a sorted dendro[…]

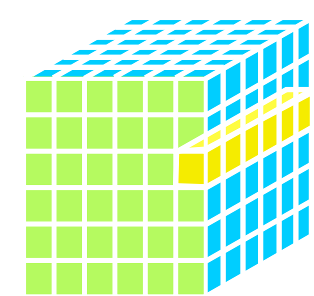
A dendrogram of a spectr[…] of key physical properties […] surfaces, such as radius (R), ve[…] (L). The volumes can have any shape, and i[…] the significance of the especially elongated features se[…] (Fig. 2a). The luminosity is an approximate proxy for mass, such that $M_{lum} = X_{13CO} L_{13CO}$,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

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

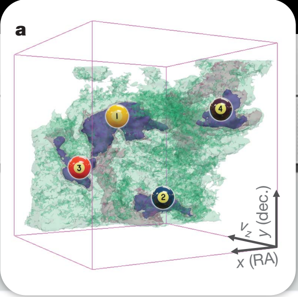
LETTERS

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

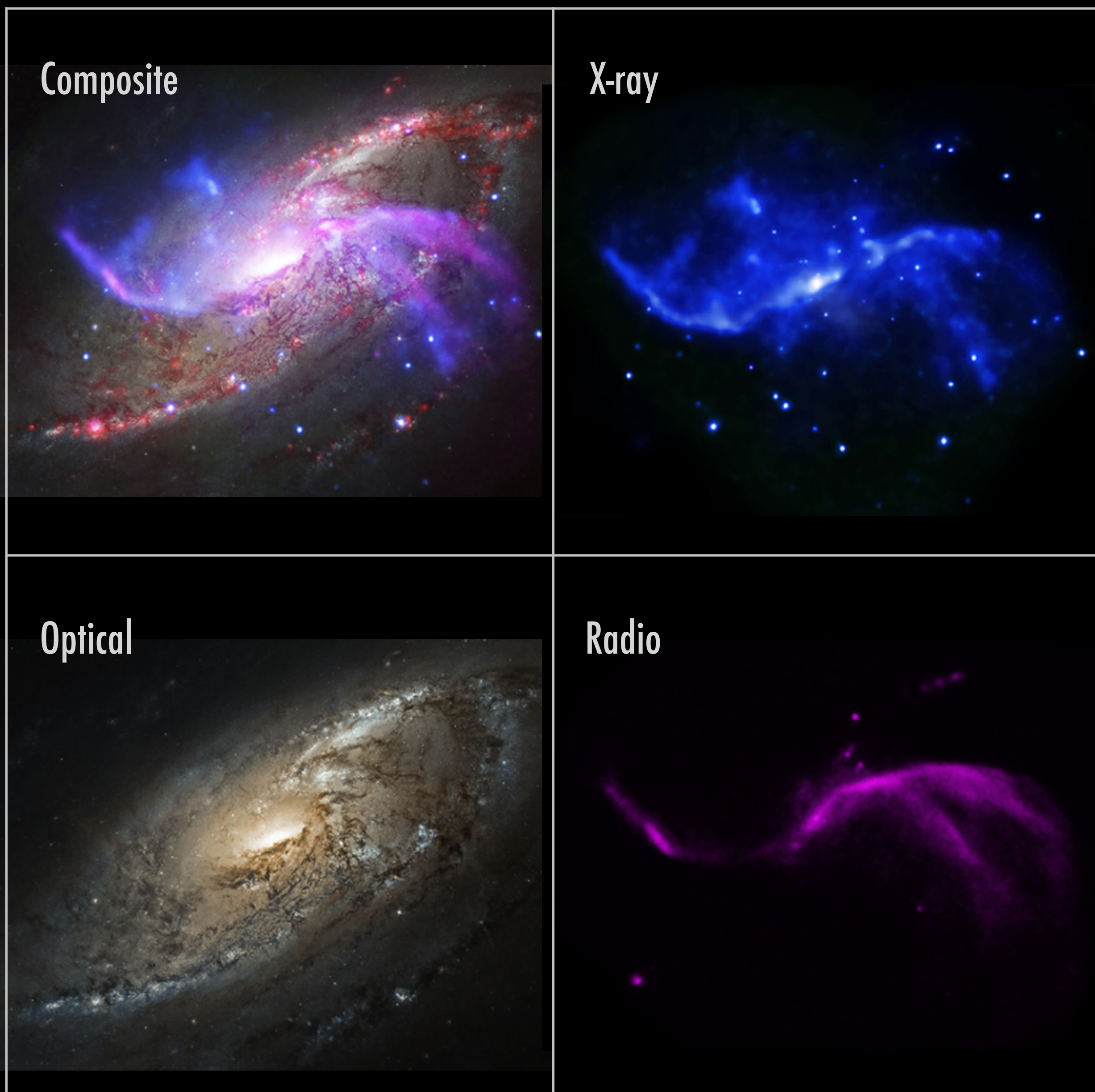
A role for self-gravity at multiple length scales in the process of star formation

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]

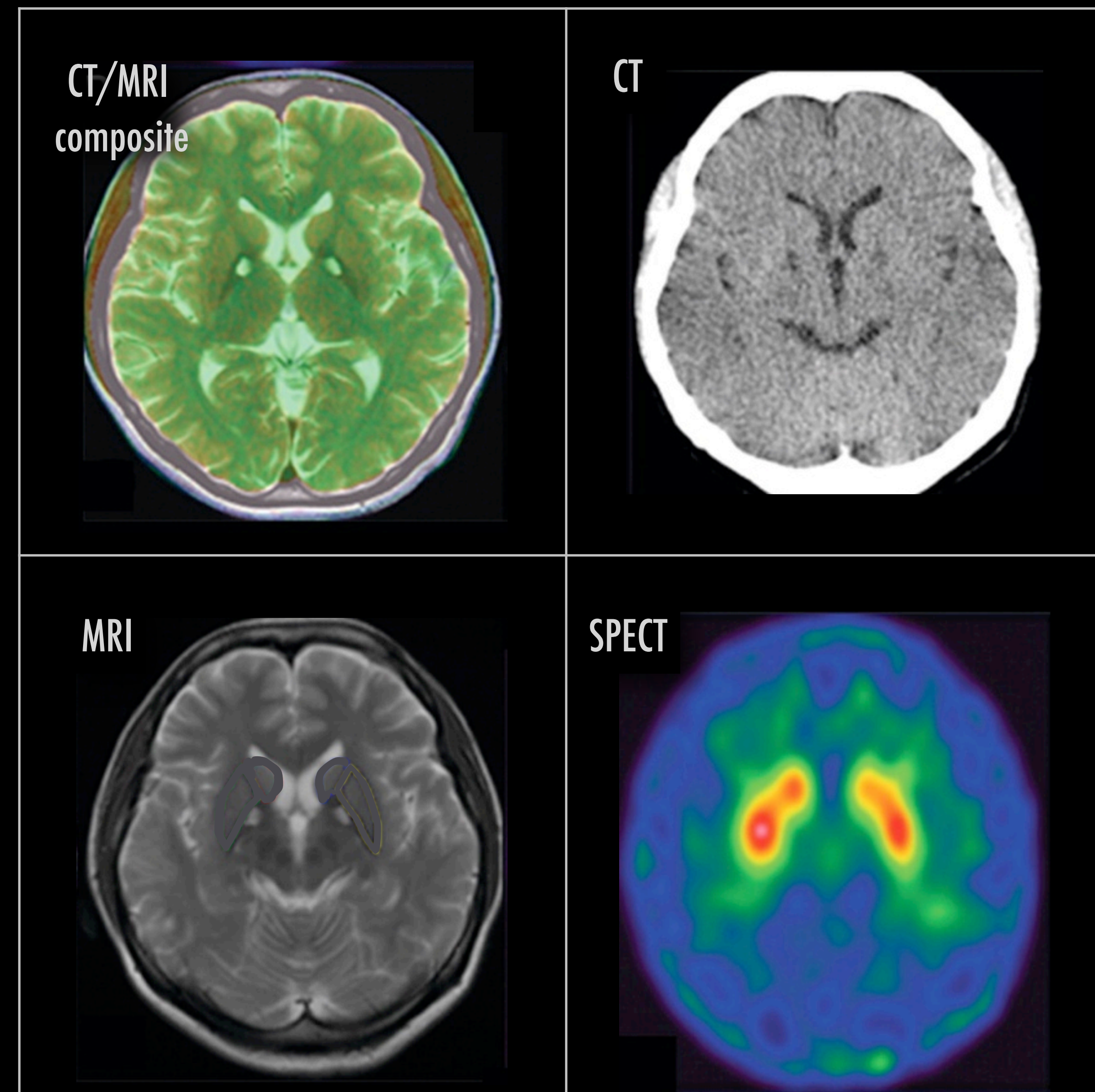
Self-gravity plays a decisive role in the final stages of star formation, where dense cores (size ~0.1 parsecs) inside molecular clouds collapse to form star-plus-disk systems[1]. But self-gravity's role at earlier times (and on larger length scales, such as ~1 parsec) is unclear; some molecular cloud 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

ASTRONOMICAL MEDICINE



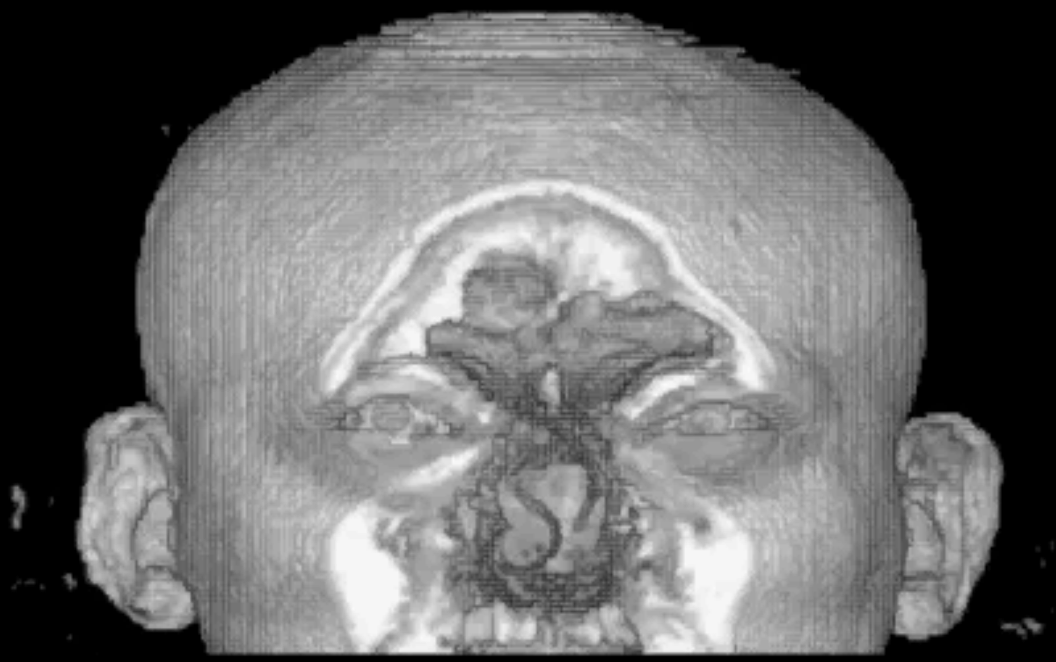
chandra.harvard.edu/photo/2014/m106/



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

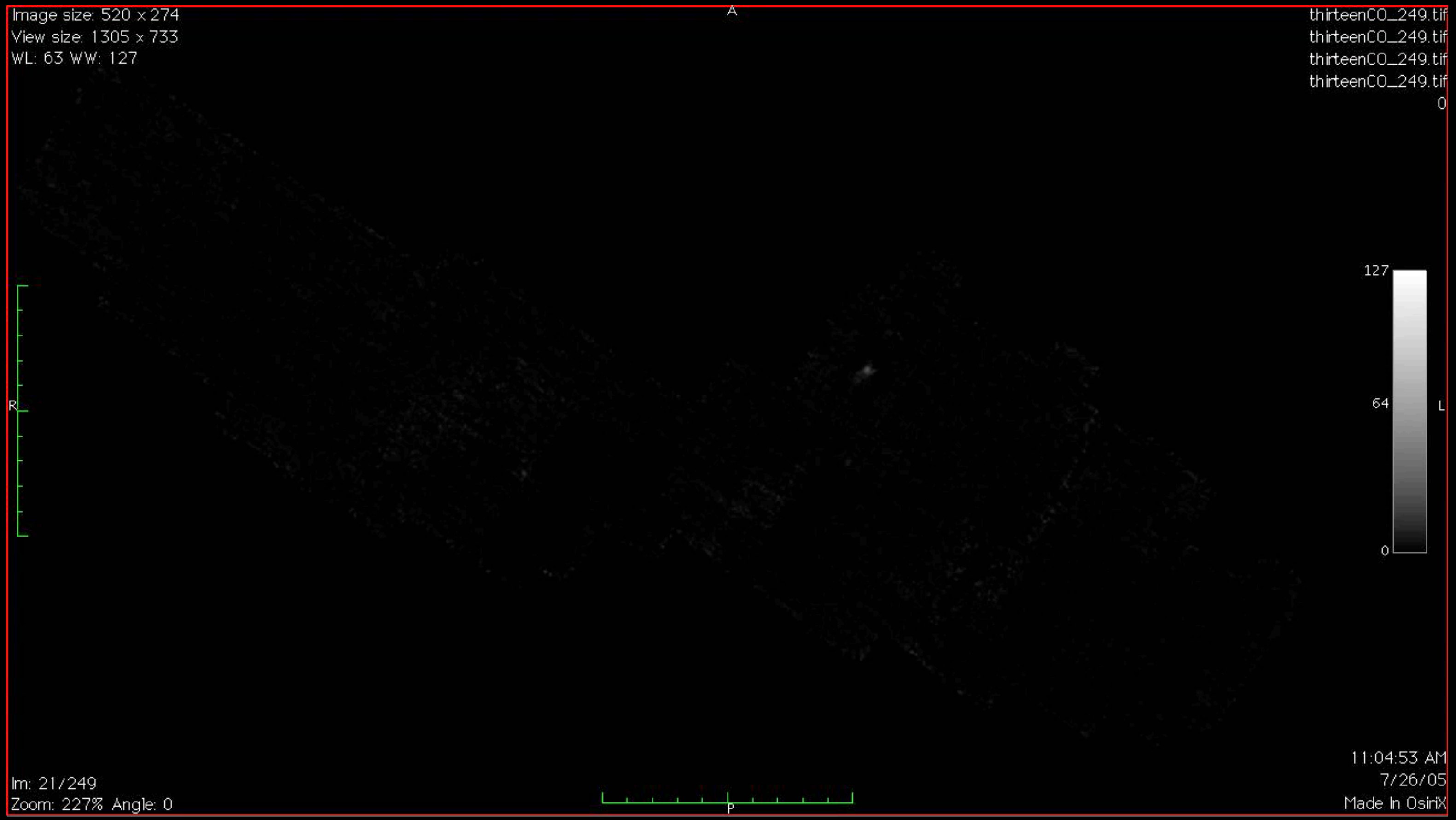
ASTRONOMICAL MEDICINE

"KEITH"



"z" is depth into head

"PERSEUS"



"z" is line-of-sight velocity

ASTRONOMICAL MEDICINE

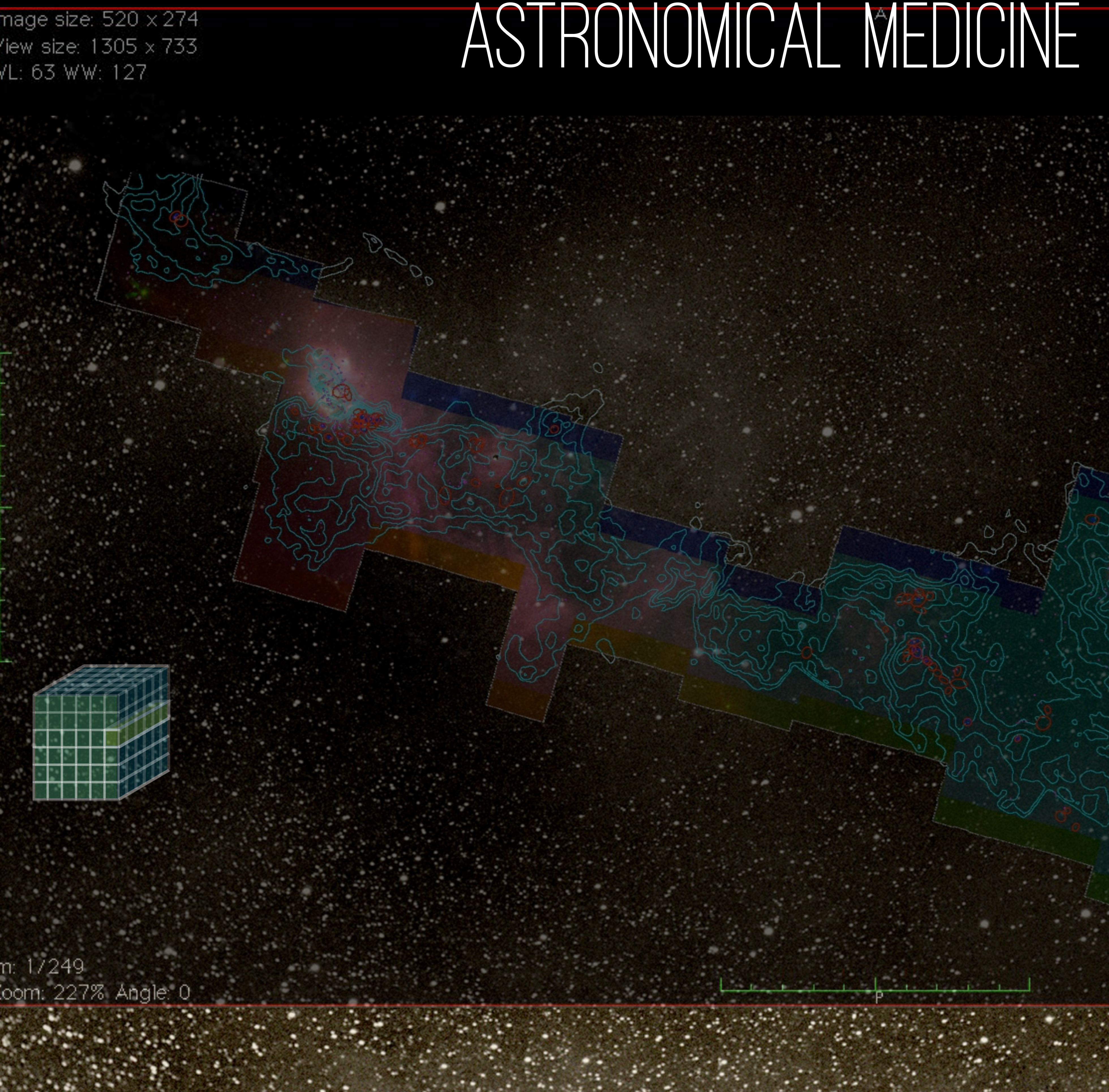
mm peak (Enoch et al. 2006)

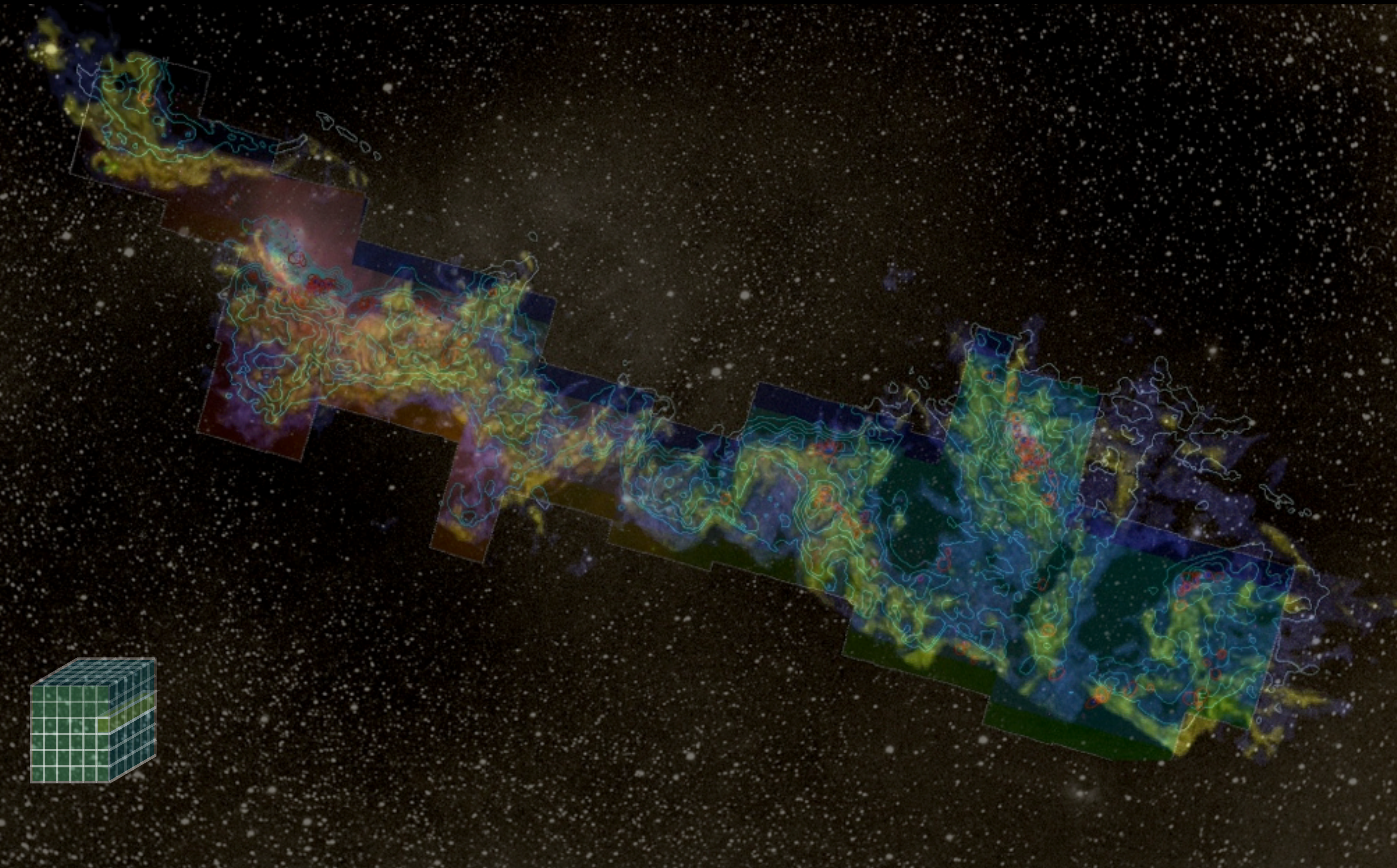
sub-mm peak (Hatchell et al. 2005, Kirk et al. 2006)

^{13}CO (Ridge et al. 2006)

mid-IR IRAC composite from c2d data (Foster, Laakso, Ridge, et al.)

Optical image (Barnard 1927)

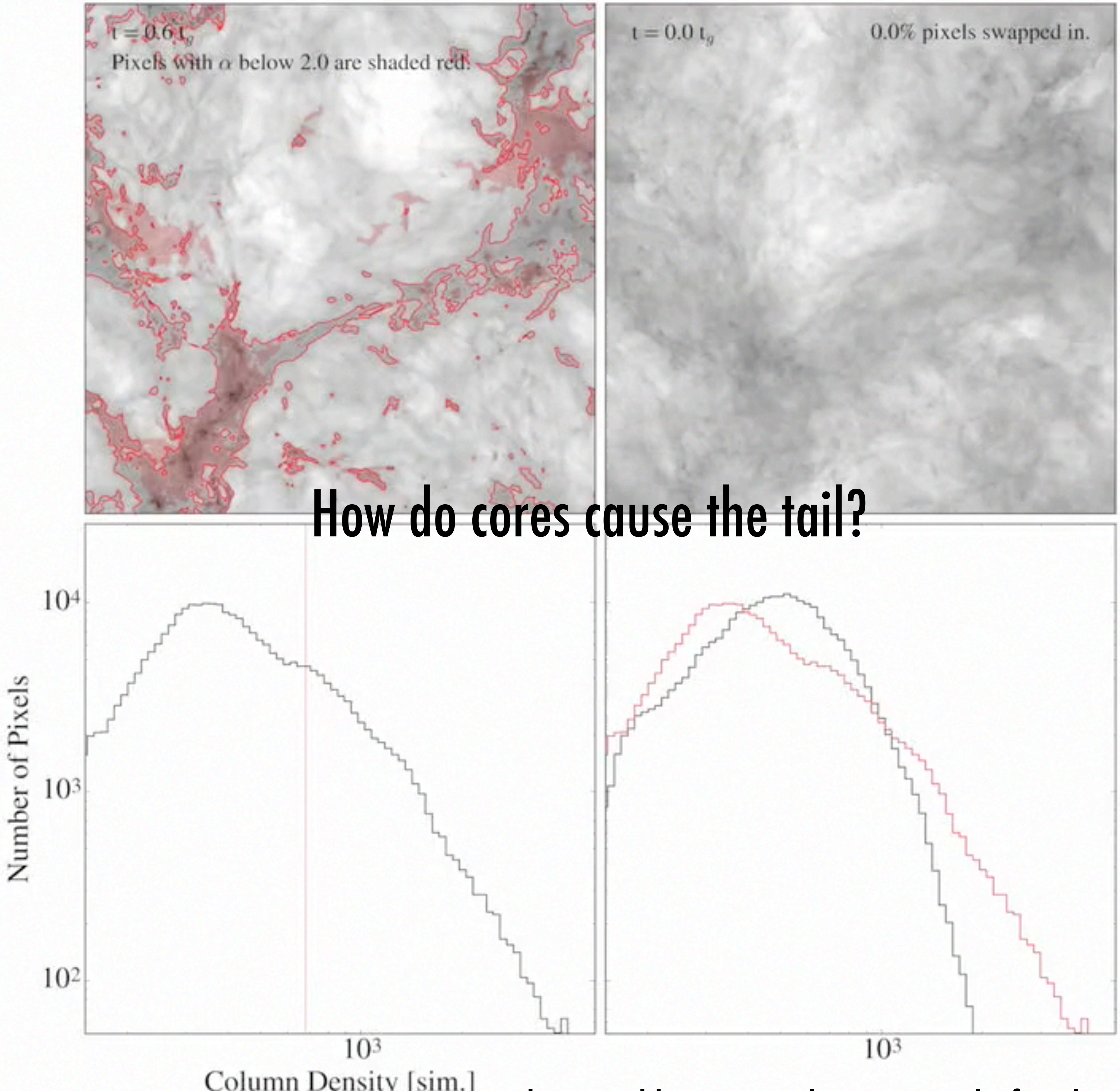




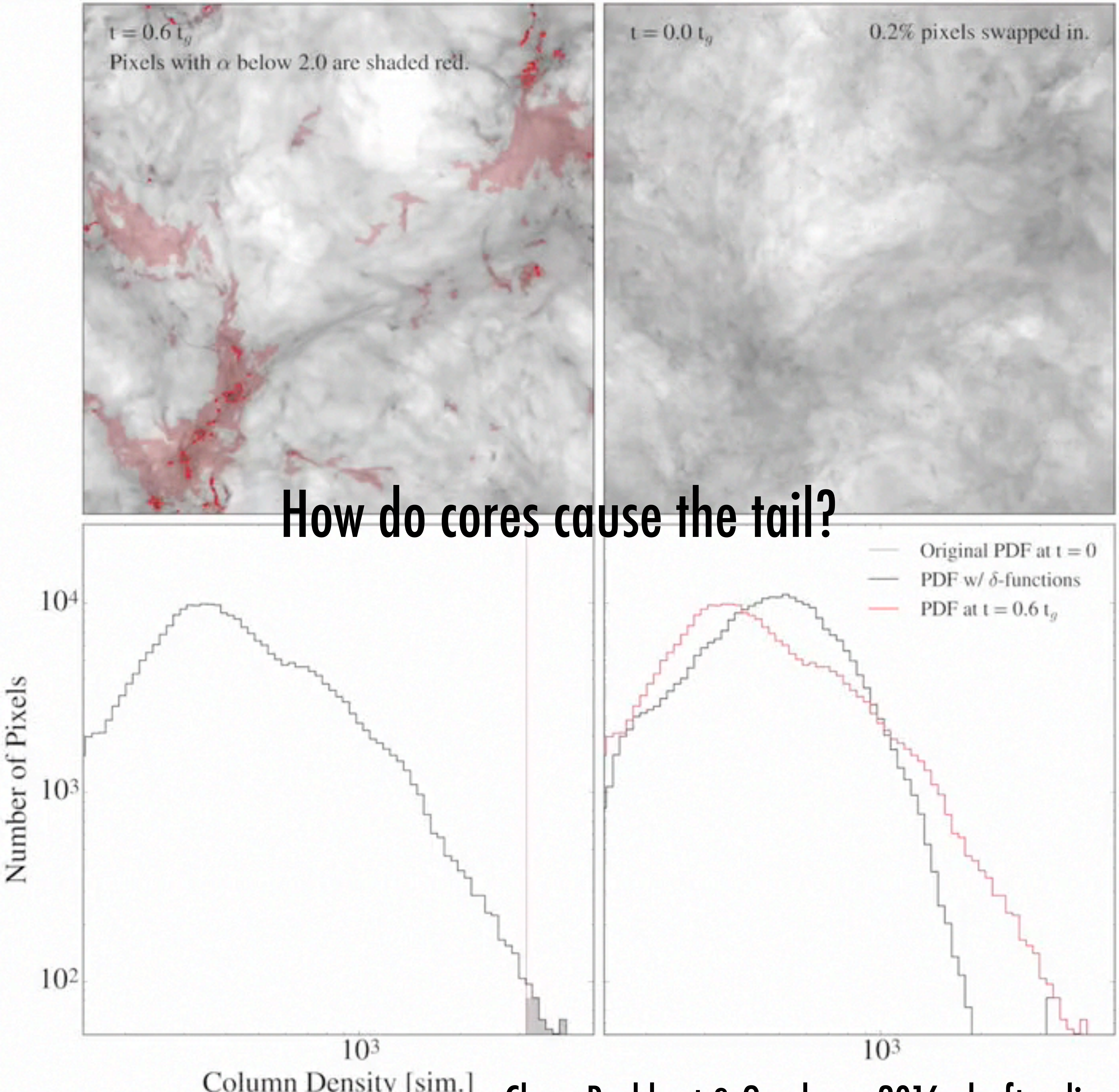
3D Viz made with VolView

COMPLETE

How do cores cause the tail?



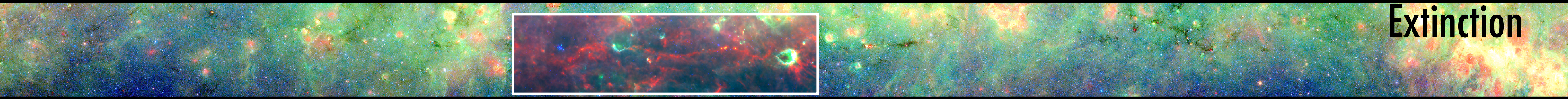
Chen, Burkhart & Goodman 2016, draft online.

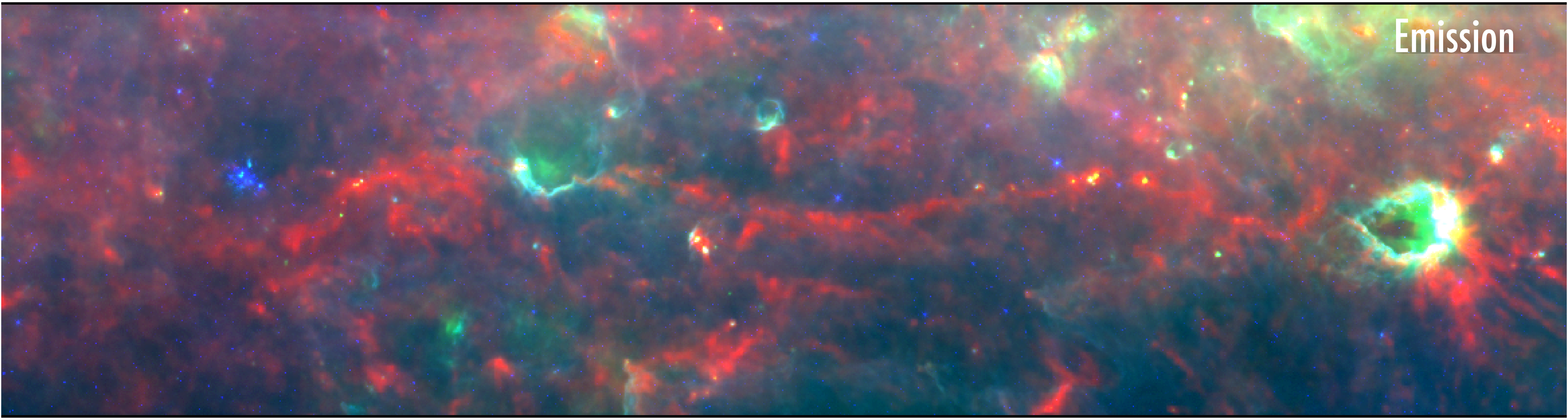


How do cores cause the tail?

Chen, Burkhart & Goodman 2016, draft online.

NESSIE





Bottom panel: Red=column density from Herschel, green=70 micron data from Herschel, and blue= 8 micron data

image courtesy of Cara Battersby

1998

The Astrophysical Journal, 504:223–246, 1998 September 1

COHERENCE IN DENSE CORES. II. THE TRANSITION TO COHERENCE

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Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138; dwilner@cfa.harvard.edu
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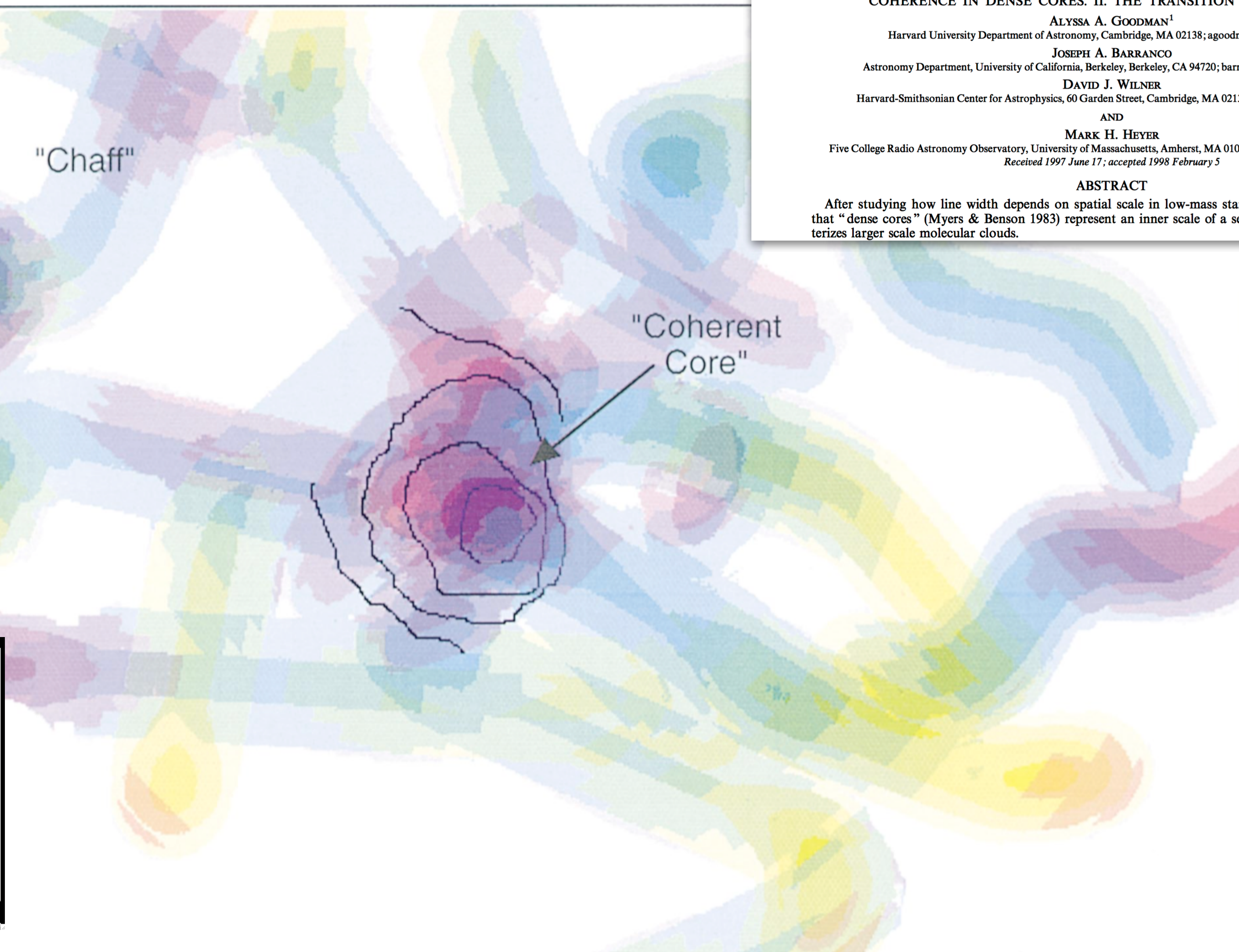
Received 1997 June 17; accepted 1998 February 5

ABSTRACT

After studying how line width depends on spatial scale in low-mass star-forming regions, we propose that "dense cores" (Myers & Benson 1983) represent an inner scale of a self-similar process that characterizes larger scale molecular clouds.



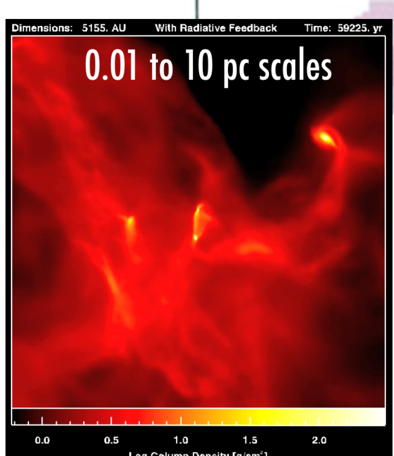


Fig. 10.—An illustration of the transition to coherence. Color and shading schematically represent velocity and density in this figure. On large scales, material (labeled chaff) is distributed in a self-similar fashion, and its filling factor is low. On scales smaller than some fiducial radius, the filling factor of gas increases substantially, and a coherent dense core, which is not self-similar, is formed. Due to limitations in the authors' drawing ability, the figure emphasizes a particular size scale in the chaff, which should actually exhibit self-similar structure on all scales ranging from the size of an entire molecular cloud complex down to a coherent core.

?