"Toward True Topology"

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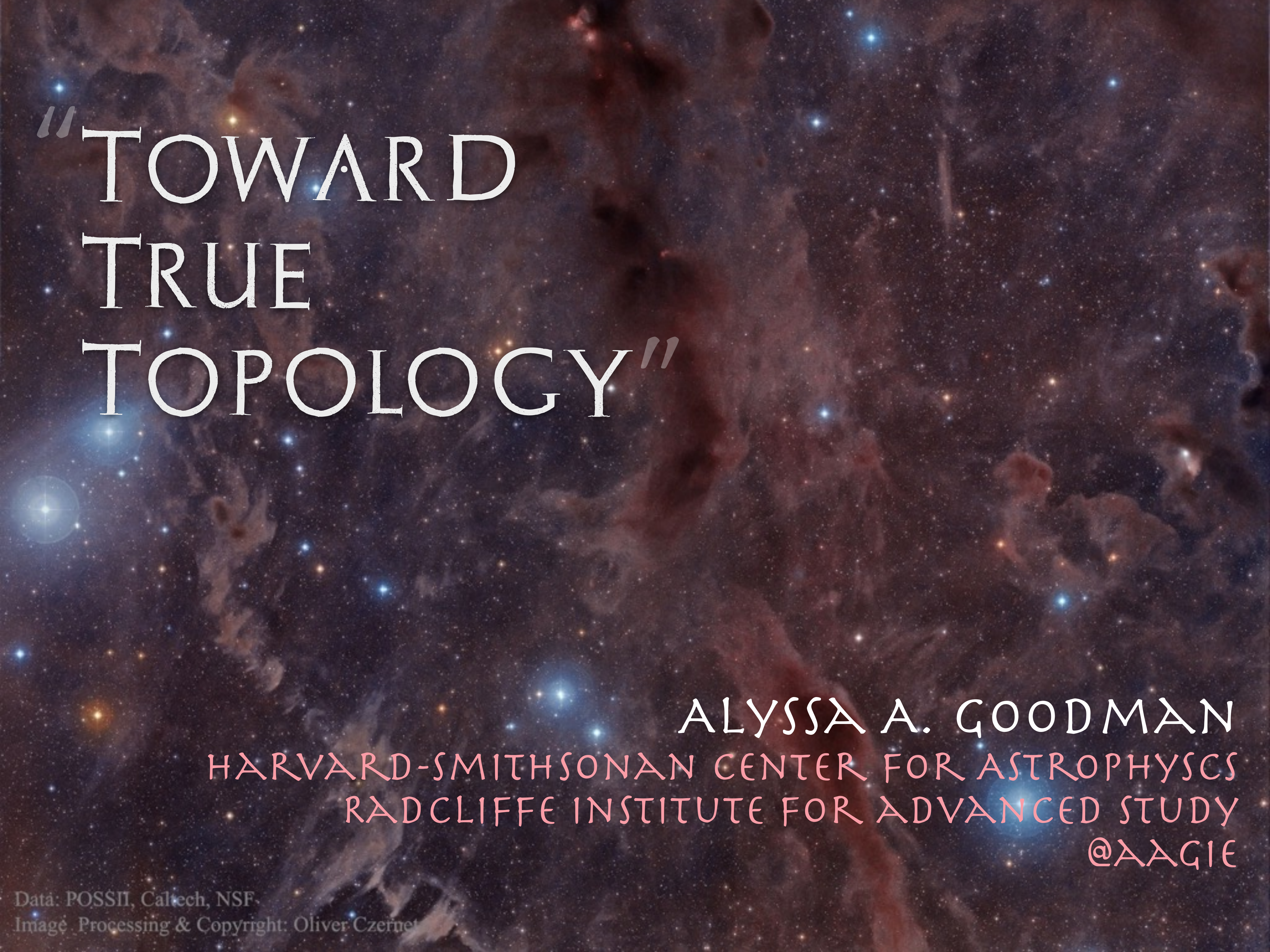
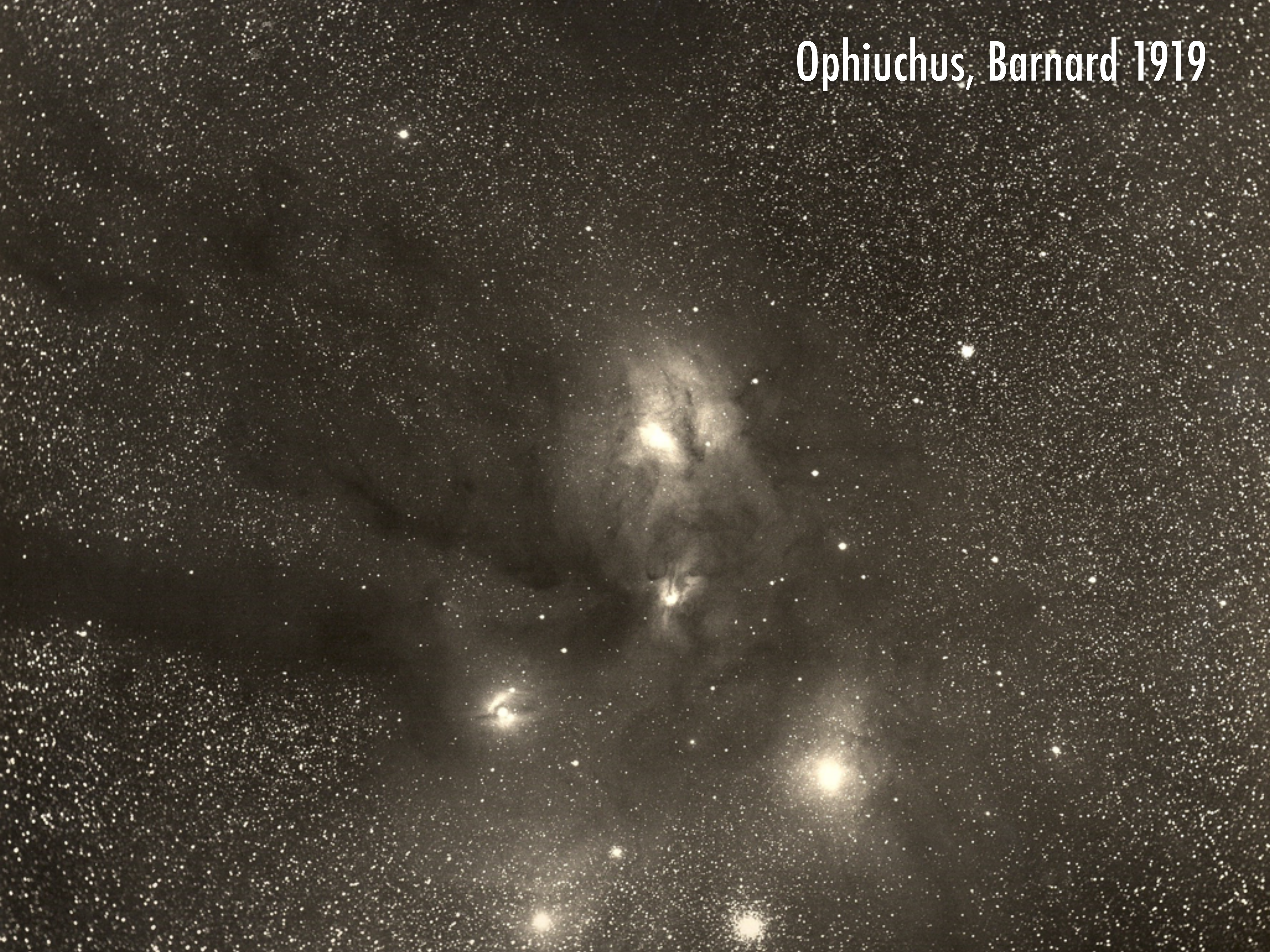
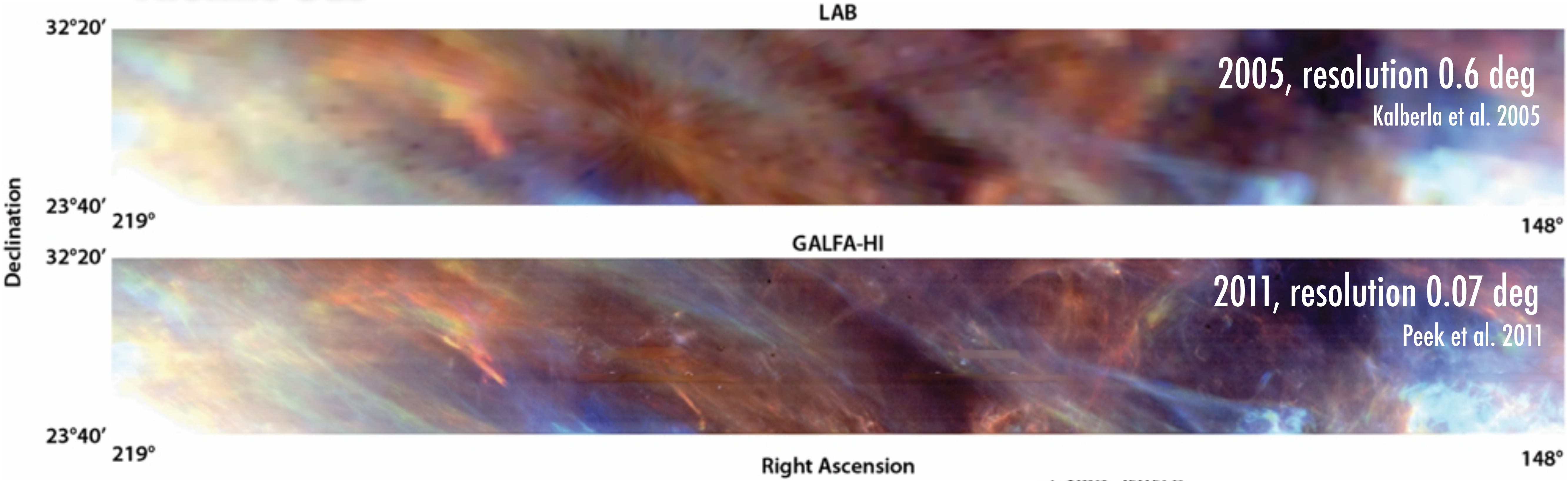


Data: POSSII, Caltech, NSF
Image Processing & Copyright: Oliver Czernetz


Ophiuchus, Barnard 1919

Atomic Gas



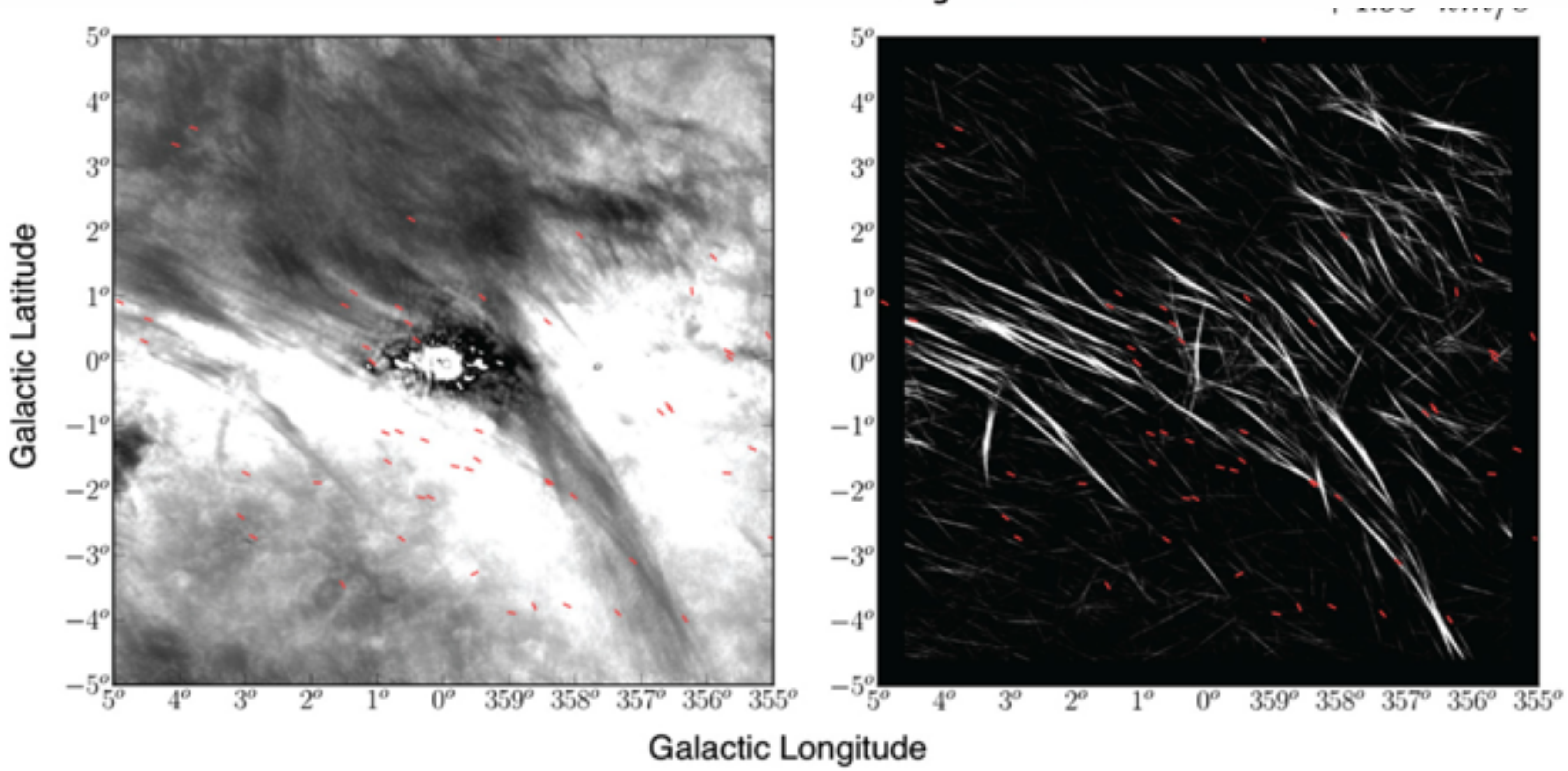


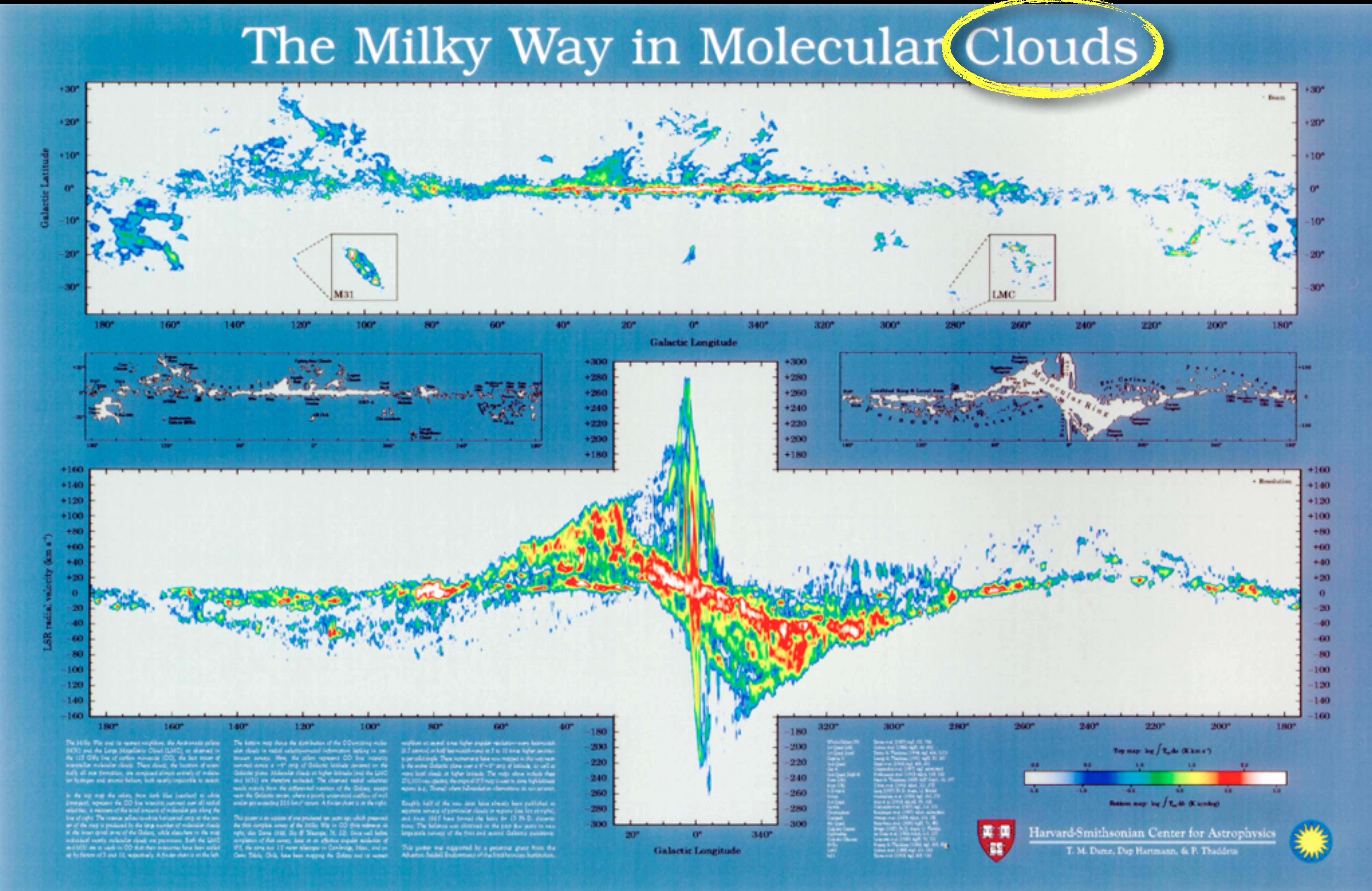
Figure 10. Riegel–Crutcher cloud (Section 6) in H I absorption (left) and RHT backprojection (right). Overlaid pseudovectors represent polarization angle measurements from the Heiles (2000) compilation. In the left panel, the intensity scale is linear from −20 K (white) to −120 K (black).

(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

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

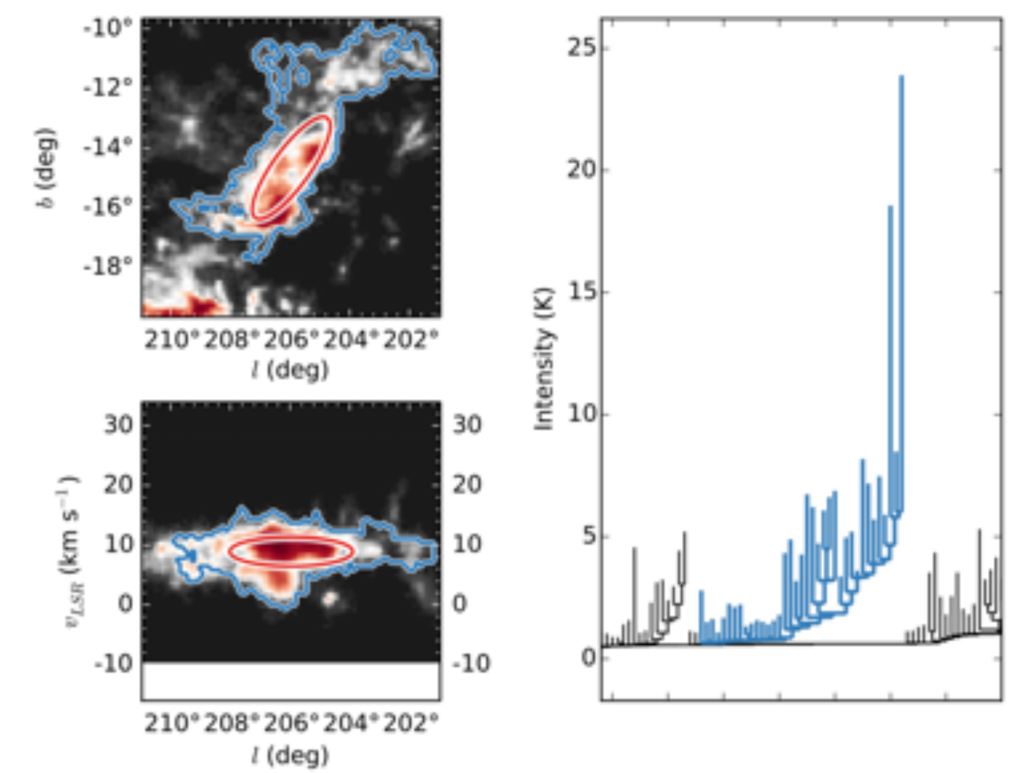
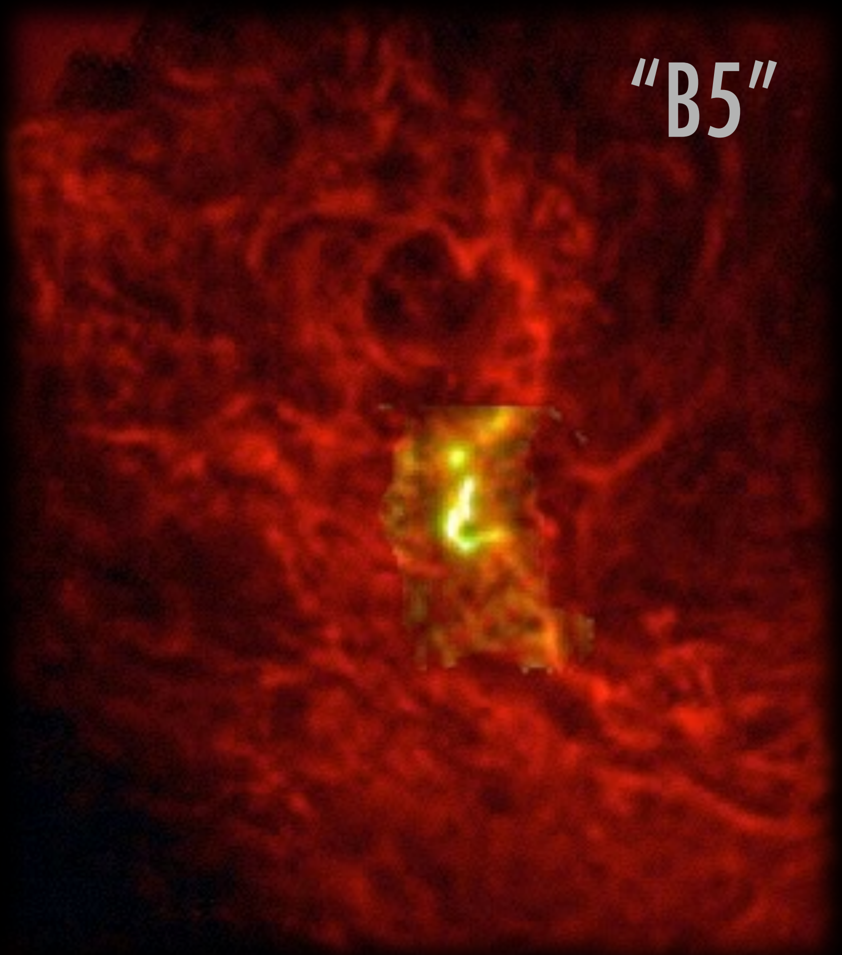


Figure 2. Example dendrogram extraction of Orion B: a nearby, well-studied giant molecular cloud. Top left: (l, b) thumbnail of the cloud and its neighboring region as seen on the sky. Bottom left: (l, v) thumbnail of the same region. Right: dendrogram cutout, with Orion B's structures highlighted in 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...
BONES, PERSISTENT FILAMENTS & PDFS...



~0.01 to 10 pc

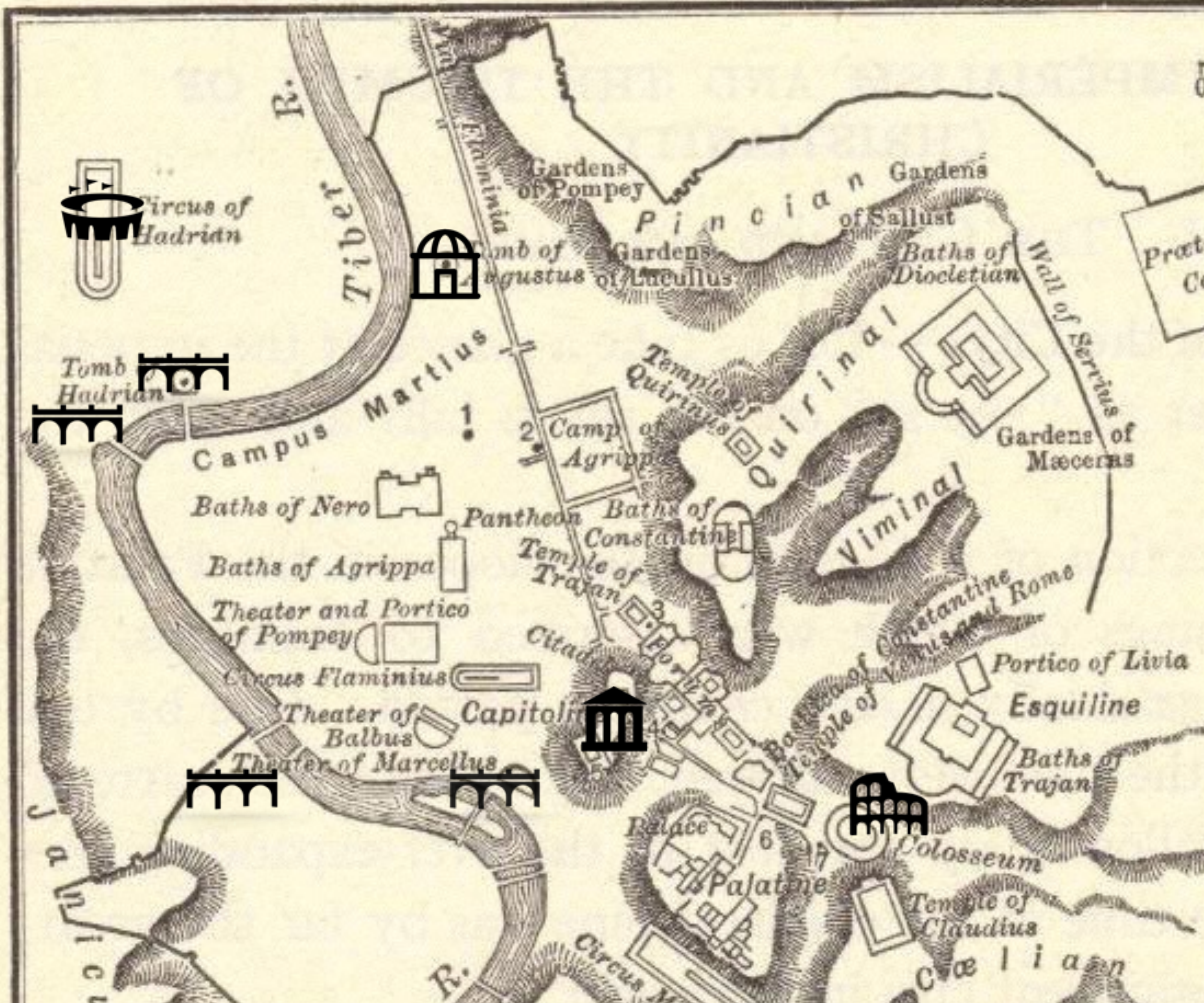
>100 pc

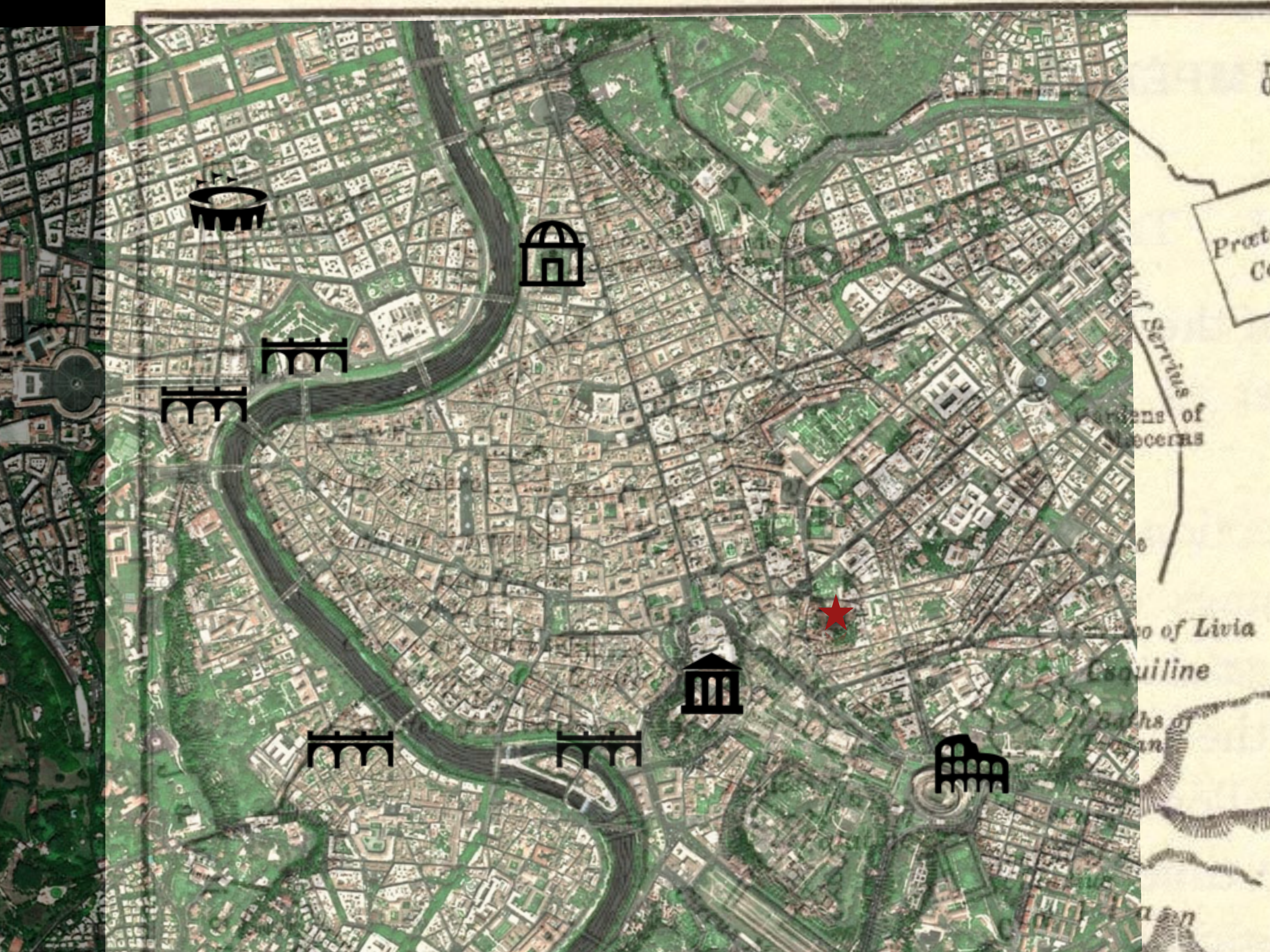
BUT FIRST...


ROME
2016 AD

2000 YEARS AGO…

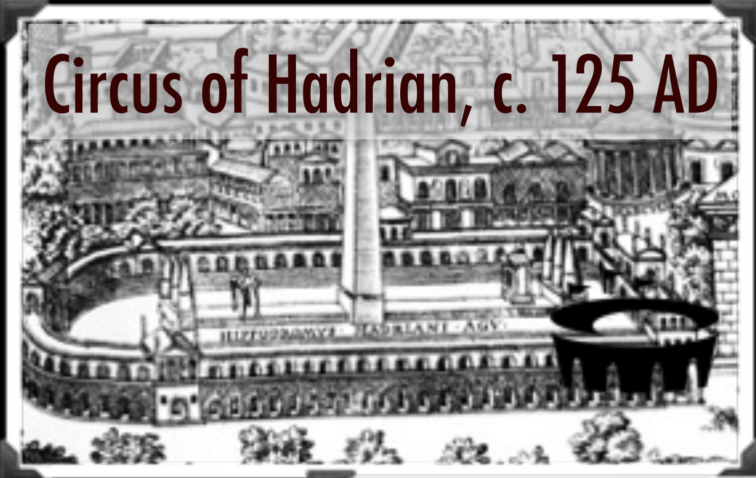
2000 YEARS AGO…





of Servius
of Livia
Esquiline

All Stone
All in Rome


Circus of Hadrian, c. 125 AD


Mausoleum of Augustus, 28 BC


Ponte Sant'Angelo, 134 (Hadrian)


Pons Neronianus, c. 50 AD,
under Ponte Sant'Angelo


Capitoline Hill
Citadel → Piazza Venezia
500 BC → 1540 AD


Pons Fabricus, 62 BC
(oldest in Rome)

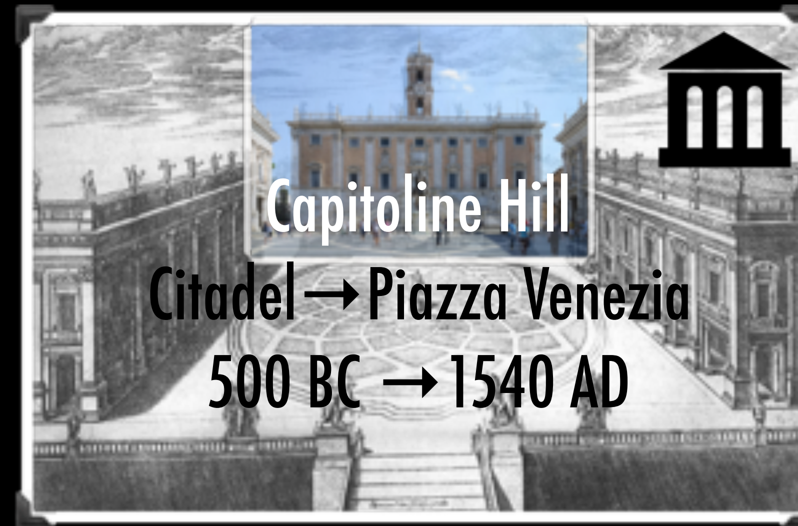

Ponte Vittorio Emanuele II, 1886


Colosseum, 90 AD

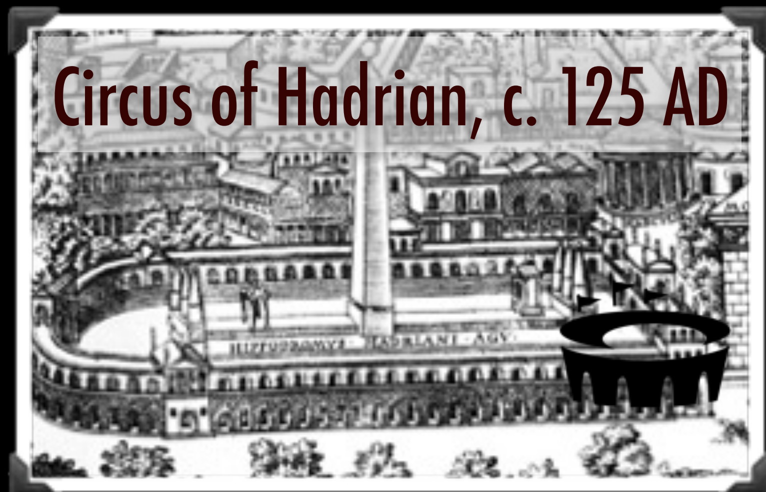
 ≠  ≠  ≠  ≠ 

A SEQUENCE…
BUT NOT OF TIME
…OR OF TYPE

~~Replaced~~



Erased



Extant

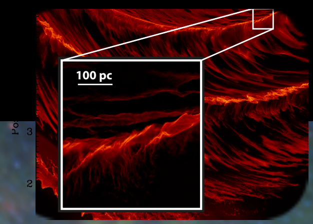
Disappearing

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?

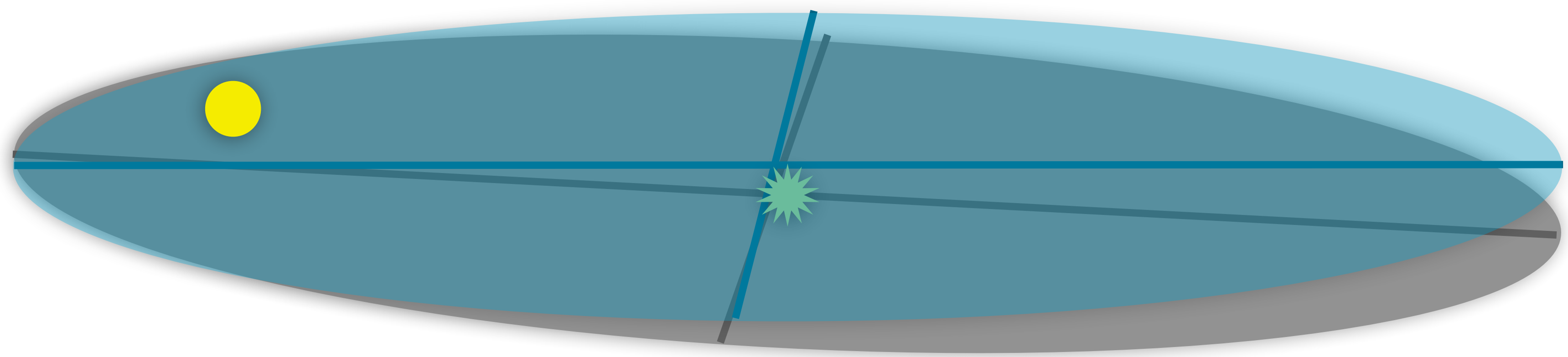
How do "influences" change what is special?

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

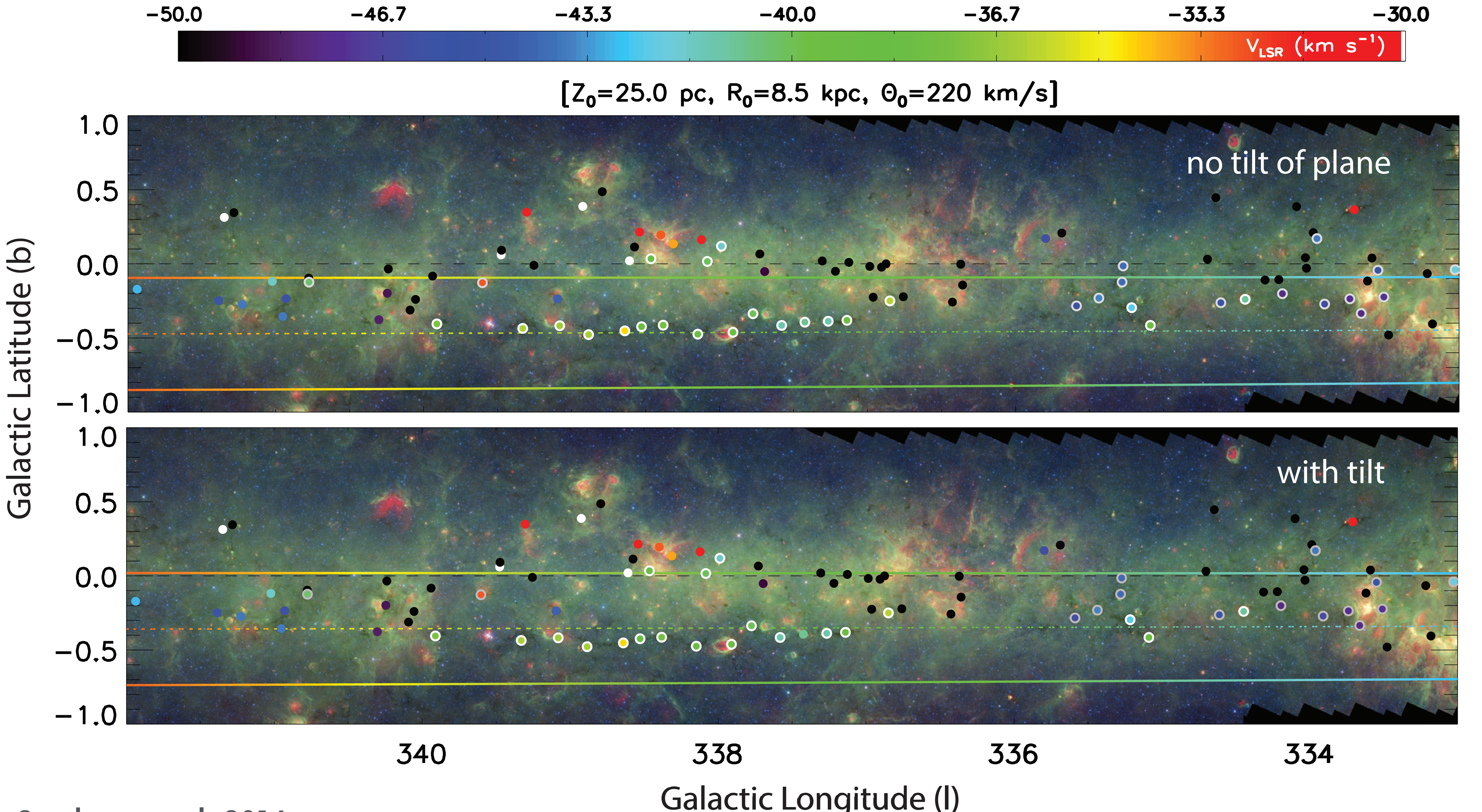
+

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

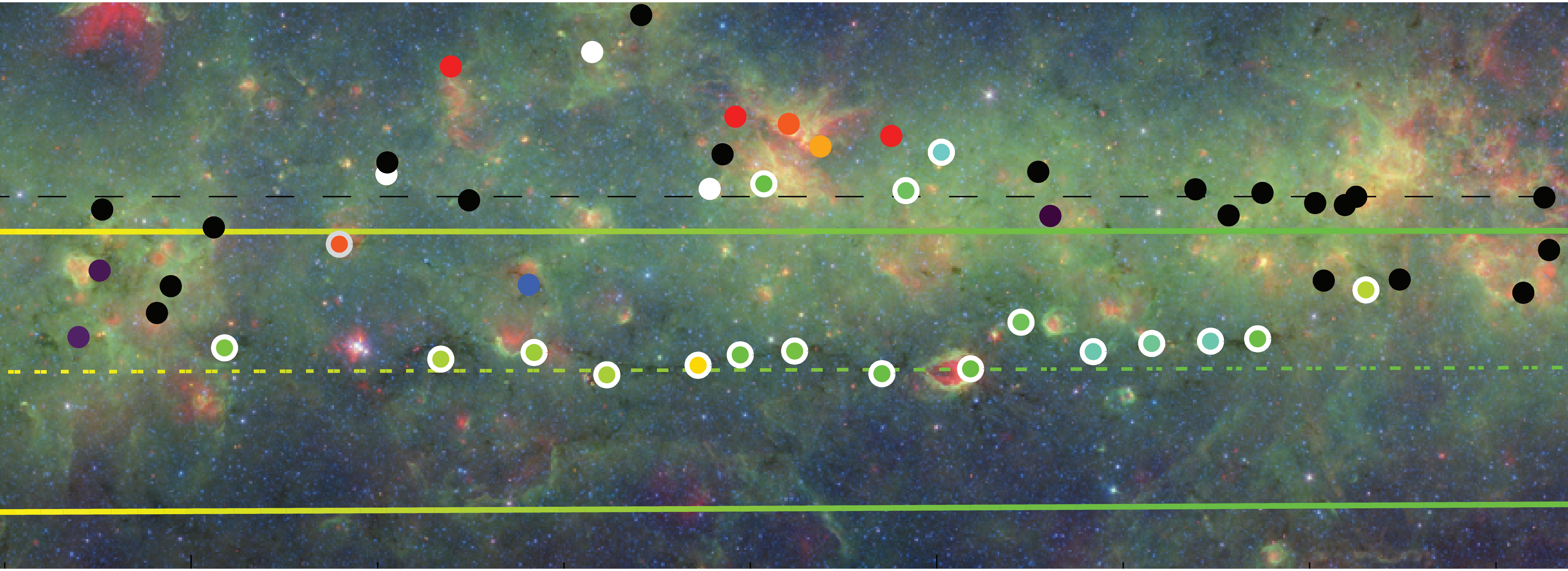
=

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!



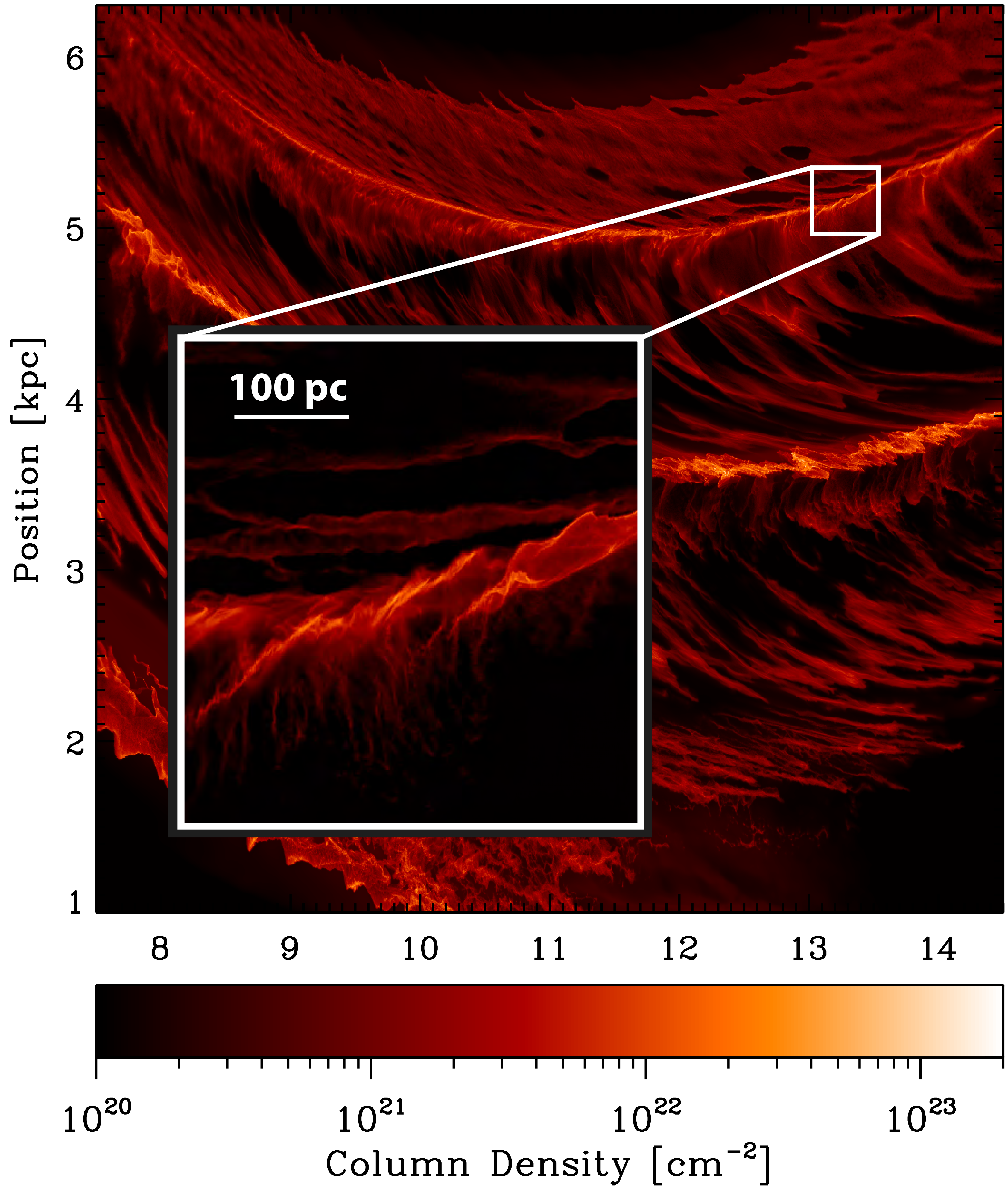
Goodman et al. 2014



...eerily precisely...

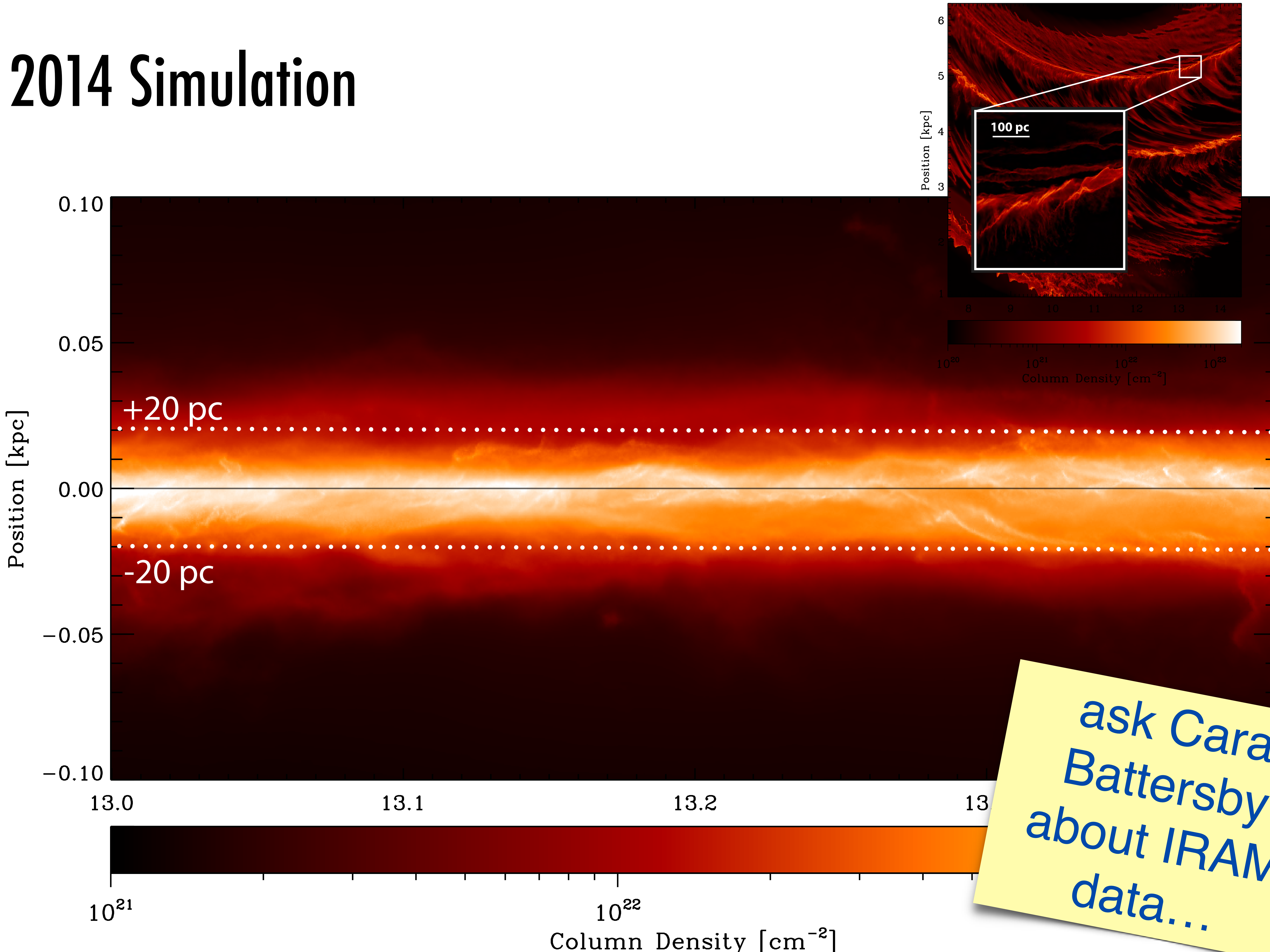
Goodman et al. 2014

2014 Simulation



Smith et al. 2014, using AREPO

2014 Simulation



ask Cara Battersby about IRAM data...

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

#48

The Physical Properties of Large-Scale Galactic Filaments

Catherine Zucker, Alyssa Goodman, Cara Battersby

Harvard-Smithsonian Center for Astrophysics

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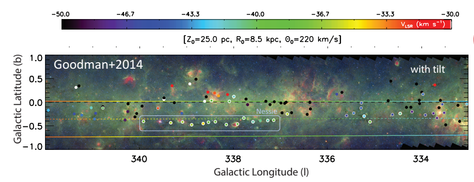
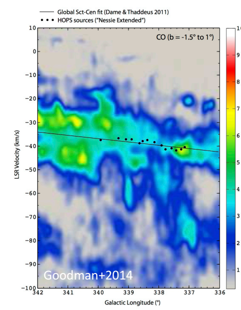
Nessie is a "Bone" of the Milky Way

(1) The infrared dark cloud "Nessie" seen in extinction. Its length (160+ pc) and aspect ratio (>300:1) suggests its formation is due to the global spiral potential of the Galaxy.

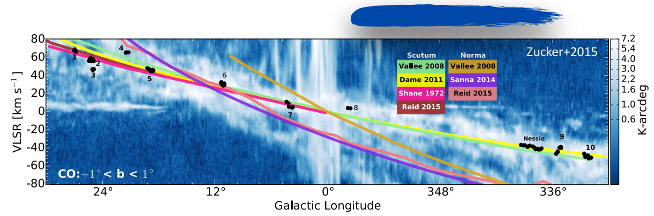


(2) Nessie lies within 3 pc of the physical Galactic midplane (dashed colored line), at d=3.1 kpc



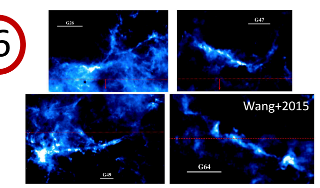
(3) Nessie's velocity gradient *exactly* matches the global-log spiral fit to the Scutum Centaurus Arm in p-v space

And it may have friends!

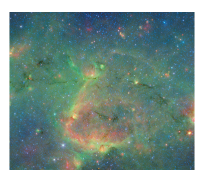


Large-Scale Herschel Filaments: Dense, cold filaments (aspect ratios >>10) chosen through visual inspection of Hi-GAL images. Confirmed velocity contiguous through ^{13}CO GRS data (Wang+2015)

(6)



(4) **Milky Way Bones**: Ultra-dense, high aspect ratio Nessie analogs that may form the "Skeleton" of the Milky Way. Analogs must satisfy quantitative Bone criteria (Zucker+2015)

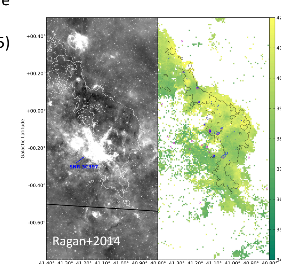


Nessie Analog from Zucker+2015

2.3. Establishing "Bone" Criteria

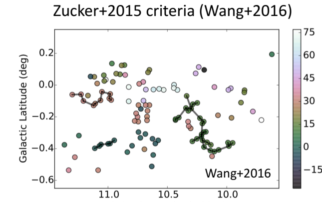
After narrowing down our list to 10 filaments with kinematic structure consistent with existing spiral arm models, we develop a set of criteria for an object to be called a "bone":

1. Largely continuous mid-infrared extinction feature
2. Parallel to the Galactic plane, to within 30°
3. Within 20 pc of the physical Galactic mid-plane, assuming a flat galaxy
4. Within 10 km s^{-1} of the global-log spiral fit to any Milky Way arm
5. No abrupt shifts in velocity (of more than 3 km s^{-1} per 10 pc) within extinction feature
6. Projected aspect ratio ⩾50:1.



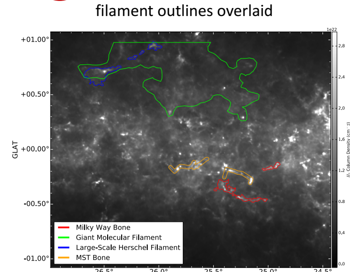
(5) **Giant Molecular Filaments**: 70+ pc lower density filaments traced mainly by ^{13}CO, with typical aspect ratios between 5:1-10:1 (Ragan+2014, Abreu-Vicente+2016)

(7) **MST Bones**: Filaments created by connecting dense BGPS $N_2H+/HCO+$ sources in p-p-v space using Minimum Spanning Tree algorithm. Must also satisfy additional Bone criteria based on Zucker+2015 criteria (Wang+2016)

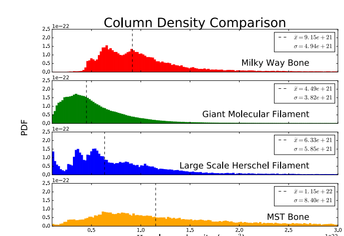


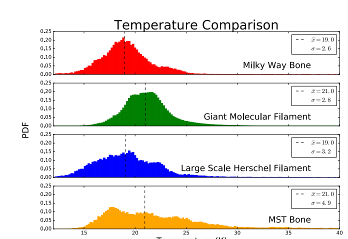
But they have different properties and utility in tracing spiral structure

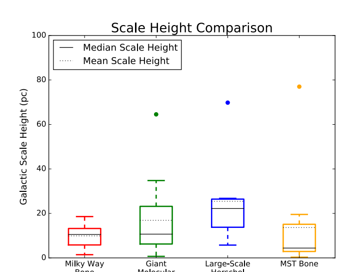
(8) Size Scale Comparison of Large-Scale Filament Catalogs: Herschel column density map with filament outlines overlaid

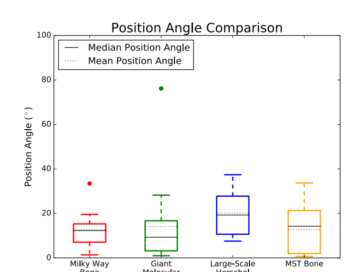


(10) Systematic offsets in column density (top left), temperature (top right), scale height (bottom left) and position angle (bottom right) among different classes





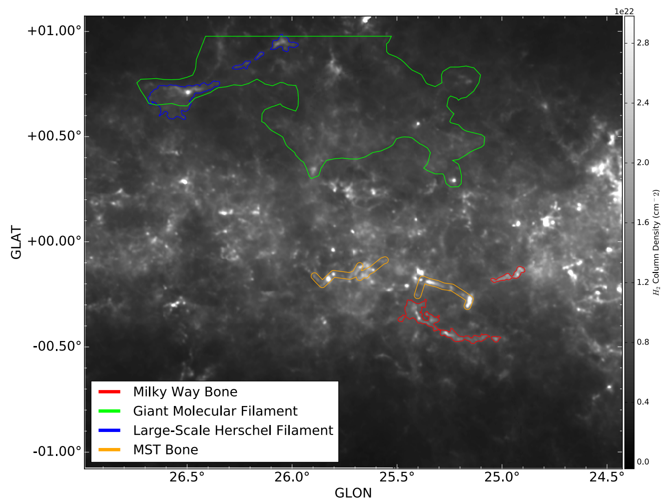




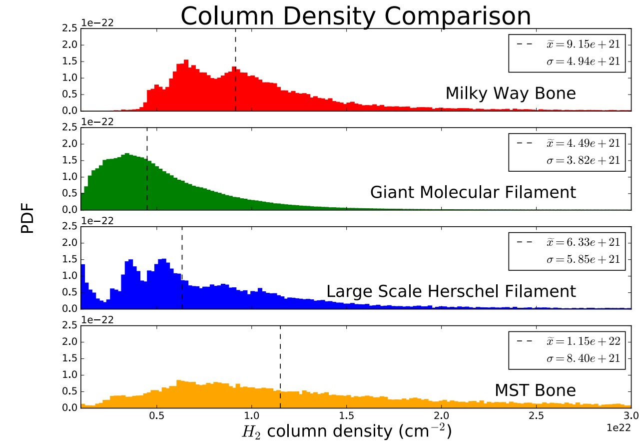
(9) Filament Venn Diagram: Only 18% of large-scale filaments share any overlap with other large-scale filament catalogs

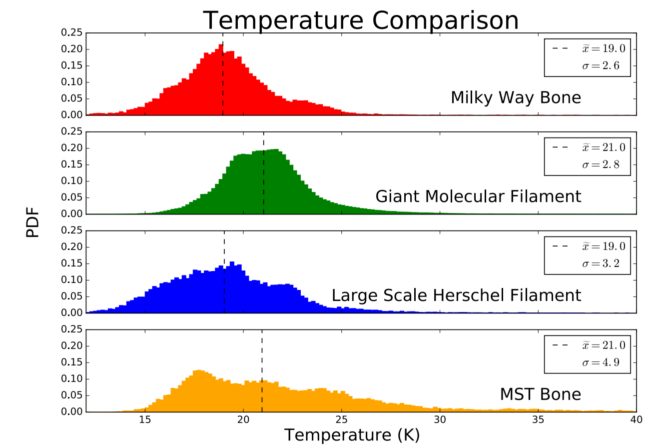
But they have different properties and utility in tracing spiral structure

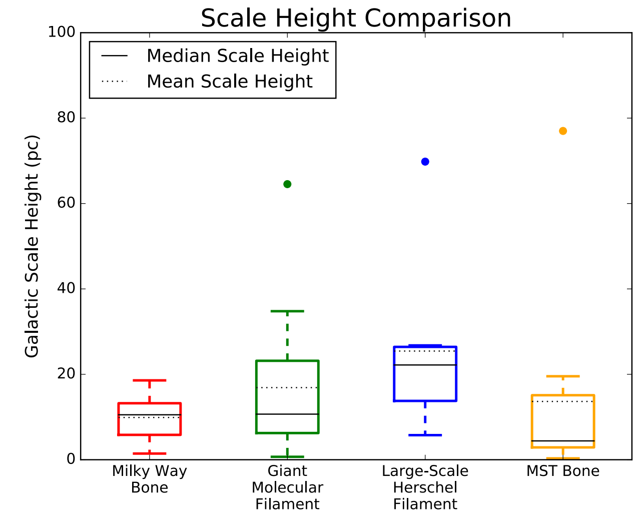
8 **Size Scale Comparison** of Large-Scale Filament Catalogs: Herschel column density map with filament outlines overlaid

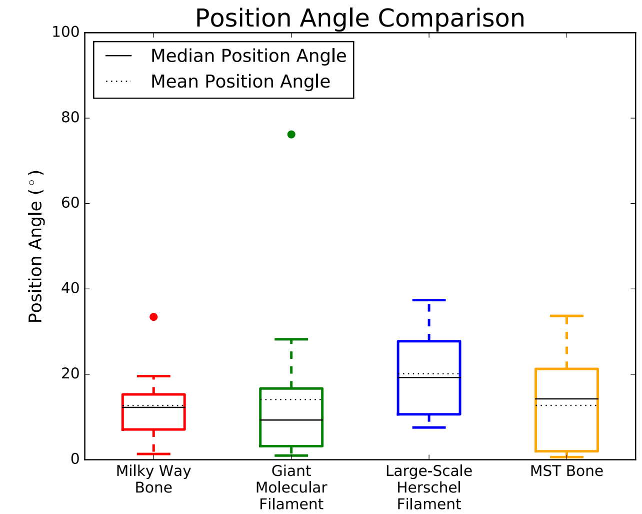


10 **Systematic offsets** in column density (top left), temperature (top right), scale height (bottom left) and position angle (bottom right) among different classes

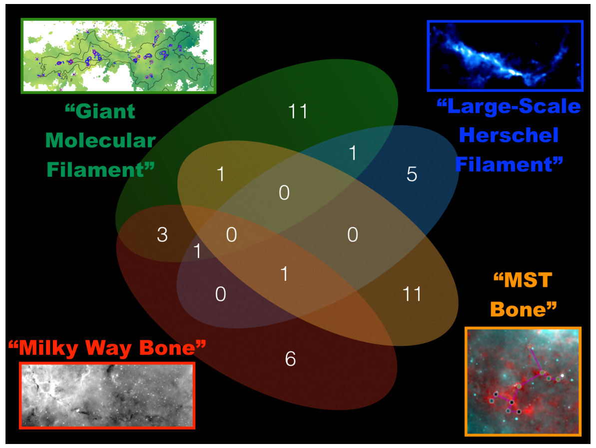




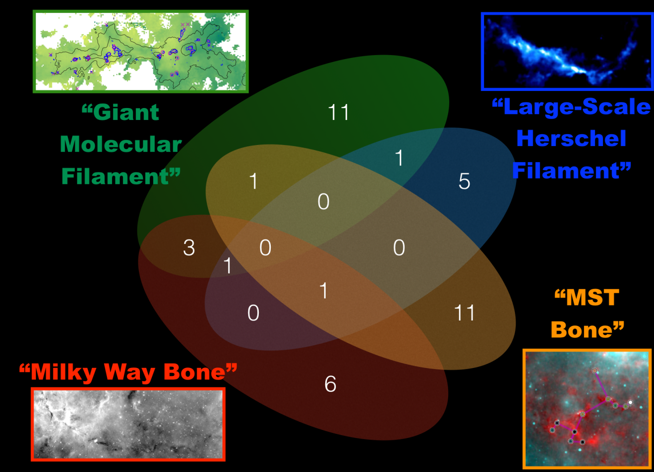




9 **Filament Venn Diagram:** Only 18% of large-scale filaments share any overlap with other large-scale filament catalogs



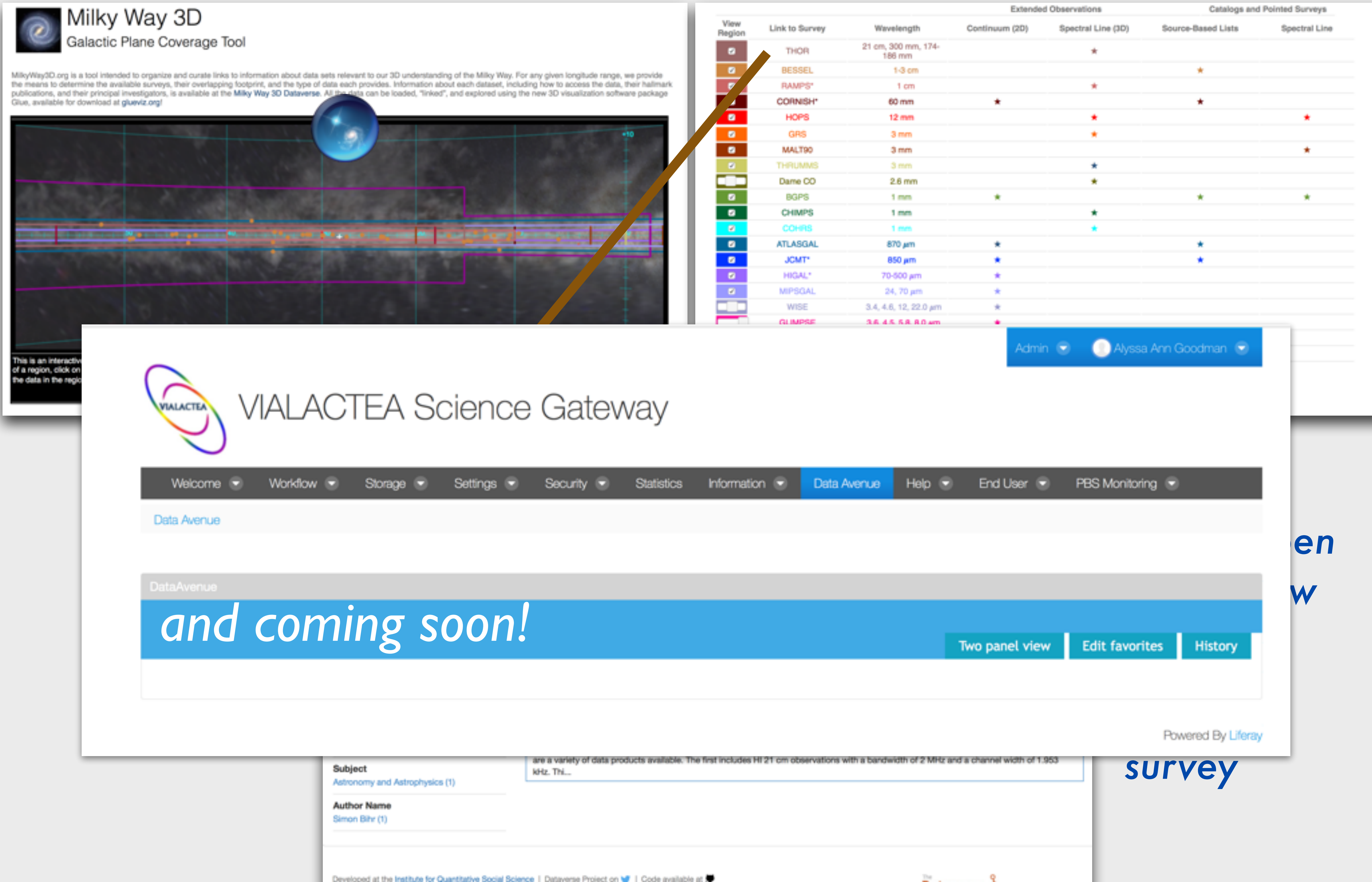
"Bones" tend to be closest to mid-plane, closest to "horizontal," coldest, and densest.



see Catherine Zucker (poster #48) for details

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	…tion 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$_2$H+, 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$_2$H+, 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$_2$H+, 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

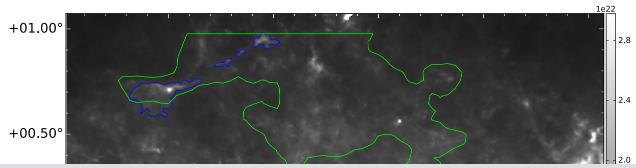
milkyway3d.org



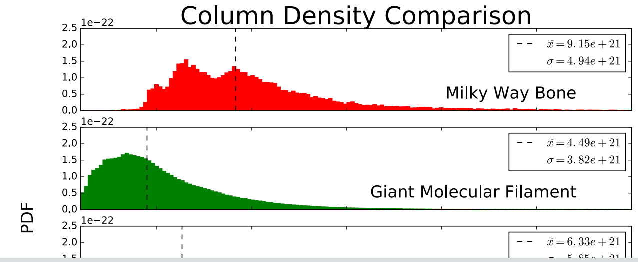
en
w
survey

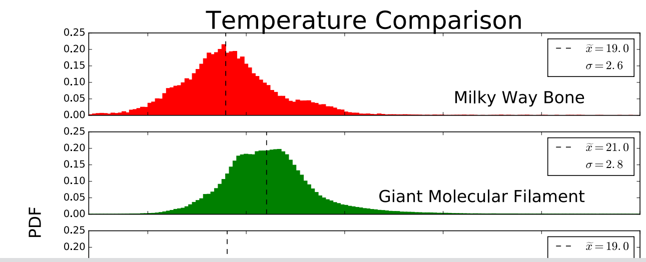
But they have different properties and utility in tracing spiral structure

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

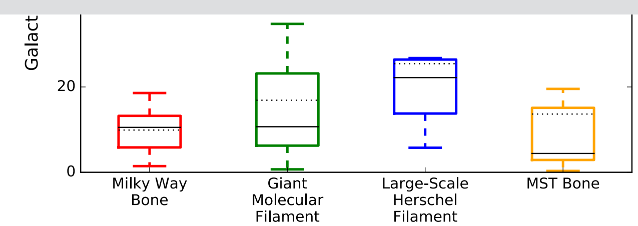


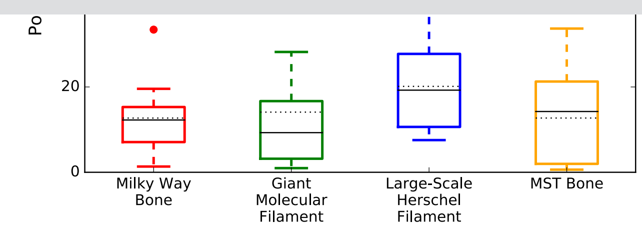
10 Systematic offsets in column density (top left), temperature (top





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

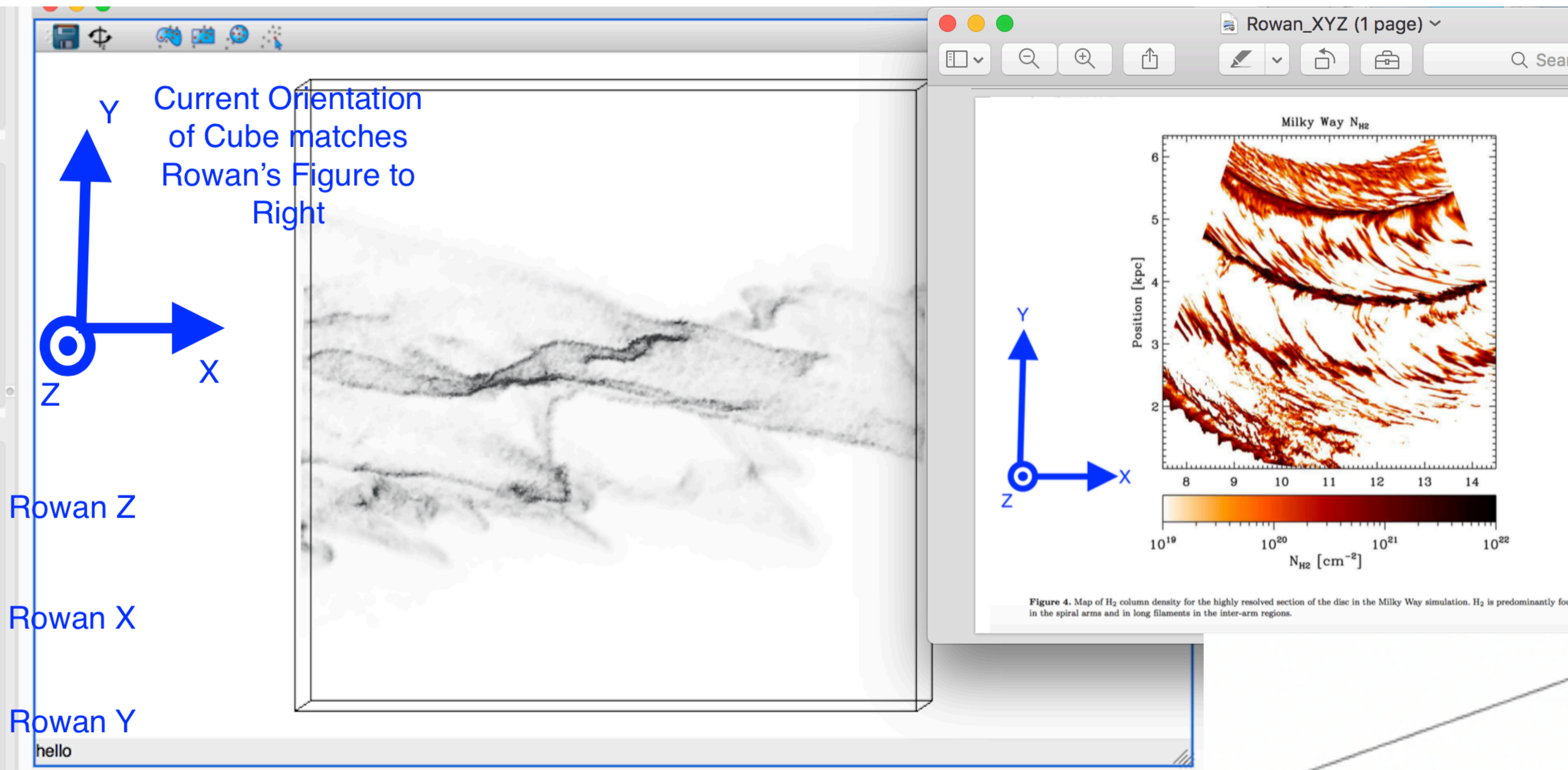




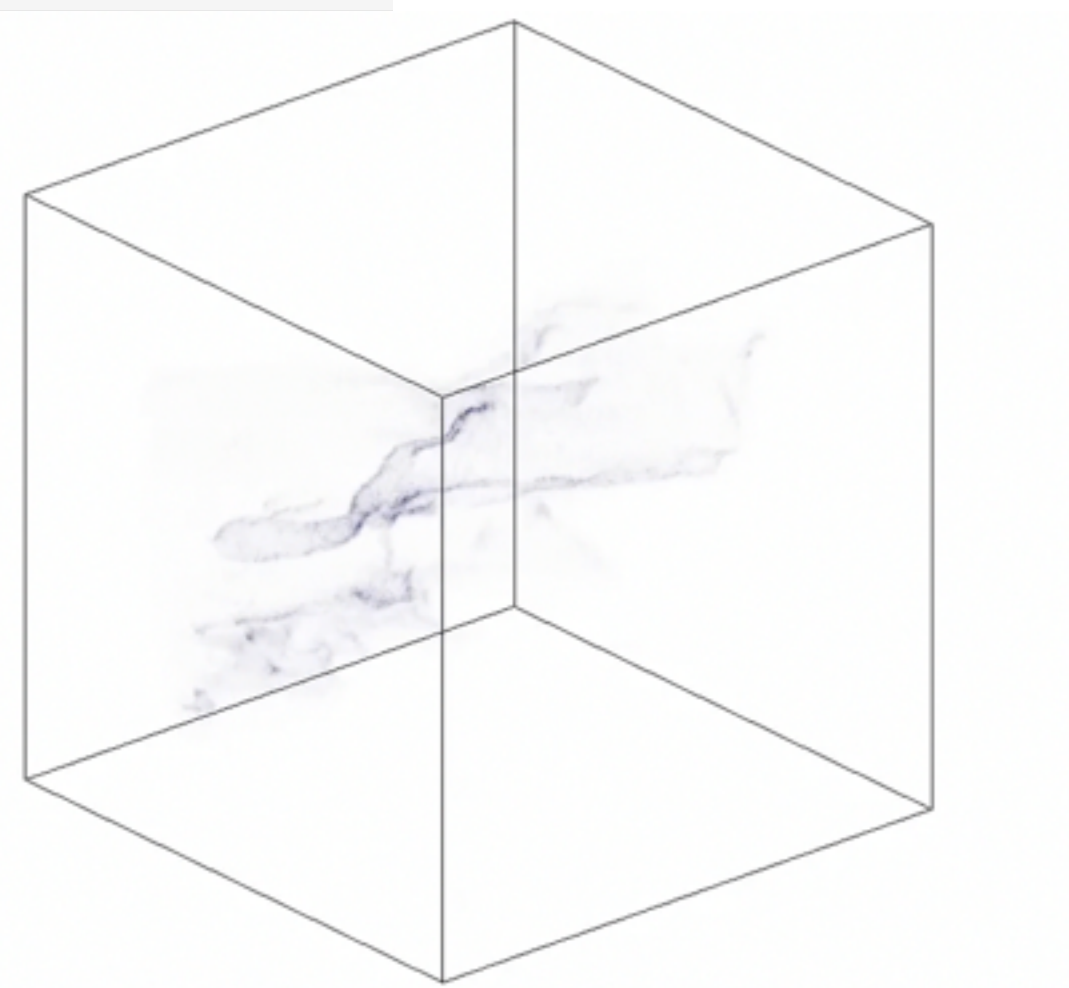
"Bones" are most likely to trace structure in/of the Galaxy's plane.

But what creates the Bones we observe?

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

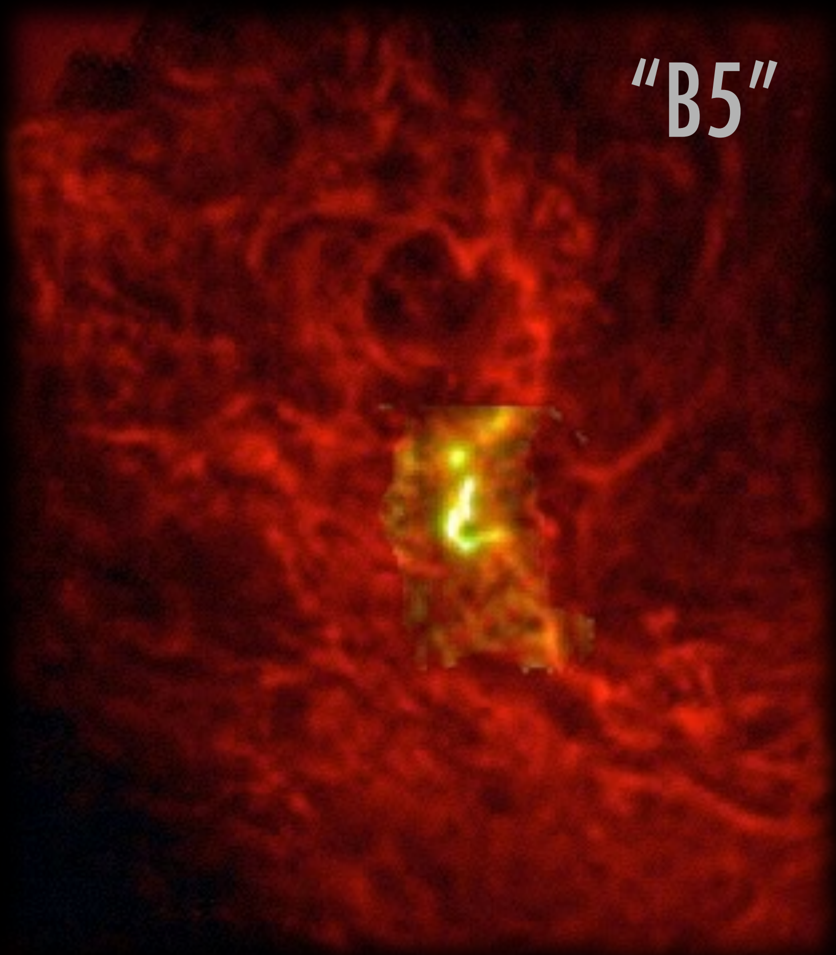


glue
multidimensional data exploration



cf. simulation work by Moeckl & Burkert 2015, Duarte-Cabral & Dobbs 2016; + AREPO MHD simulation -ALMA polarimetry comparison from Hull, Mocz, Burkhart, Goodman, Hernquist, Springel et al., submitted, & more…

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

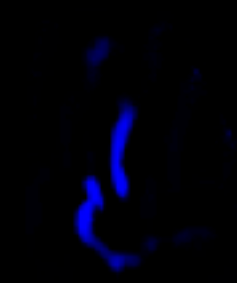


~0.01 to 10 pc

>100 pc

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)



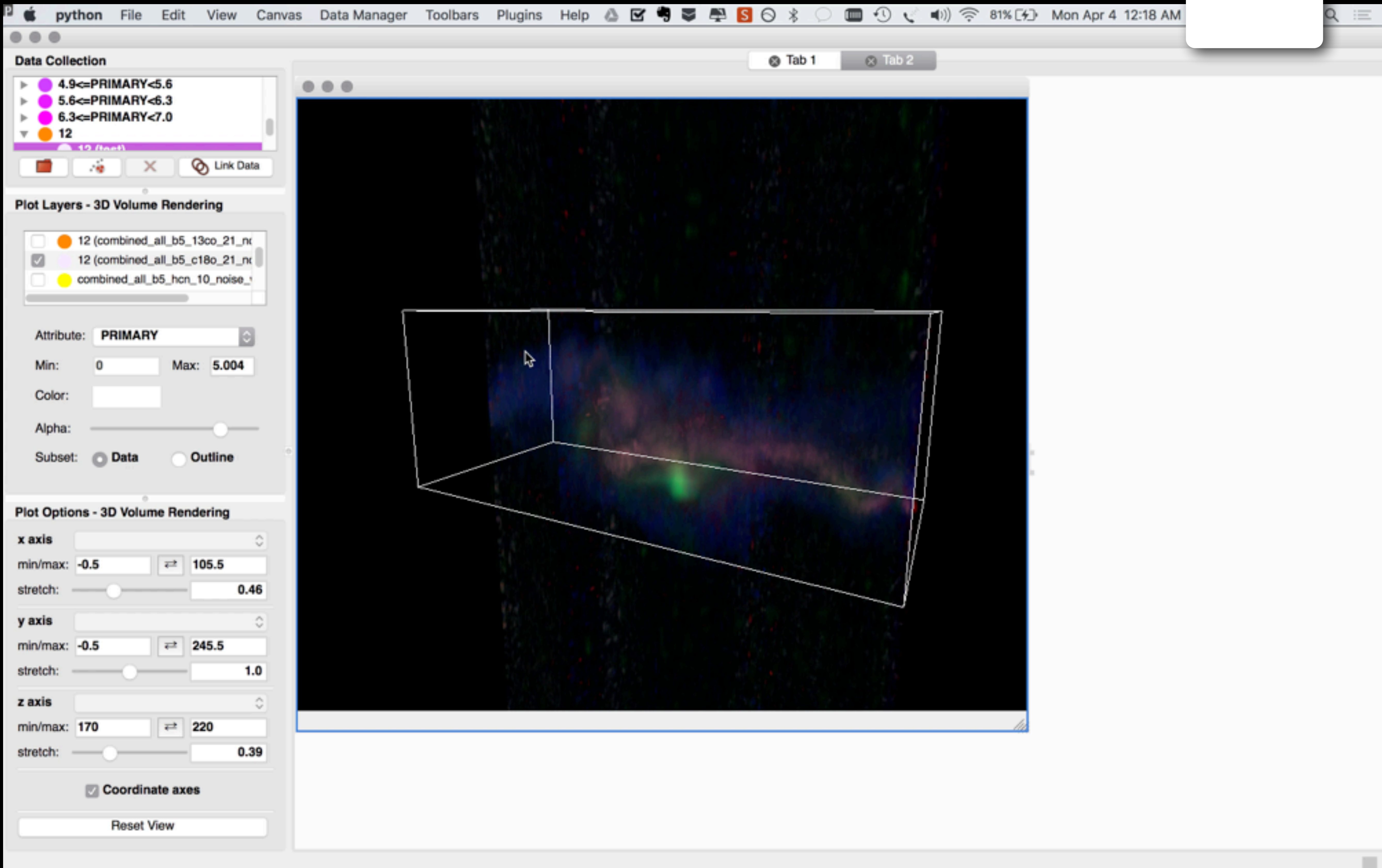
Goodman, Chen, Offner & Pineda 2016 in prep.

Herschel data from Gould Belt Survey


1998


2008

B5/GLUE DEMO (NEW IRAM 30-M DATA)

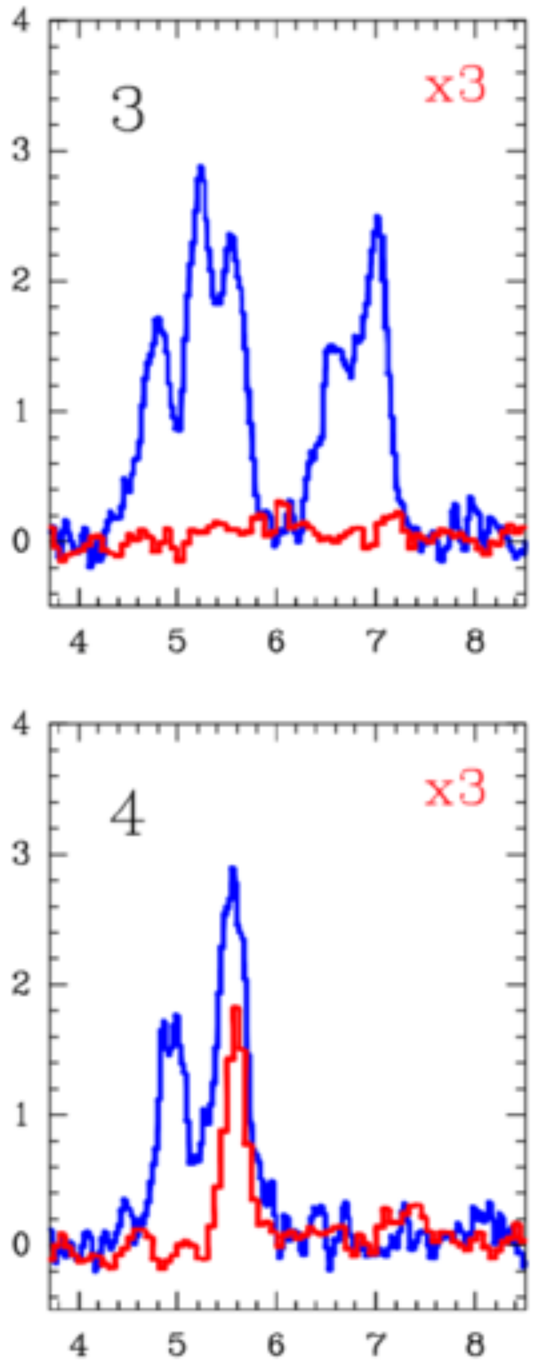


Chen, Offner, Pineda & Goodman 2016 in prep.

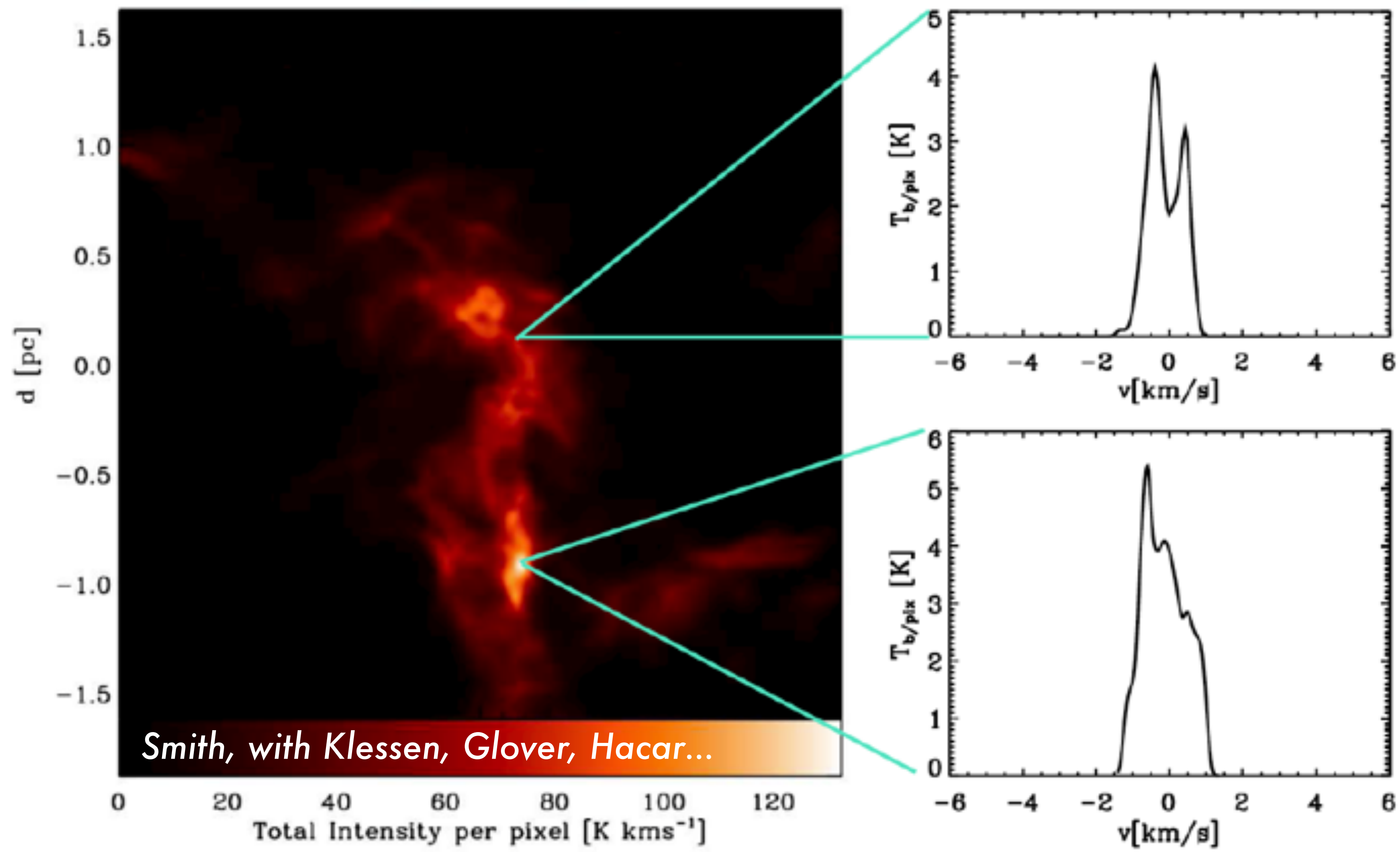
glueviz.org

Simulators are almost observing enough lines...

Filaments in Filaments



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

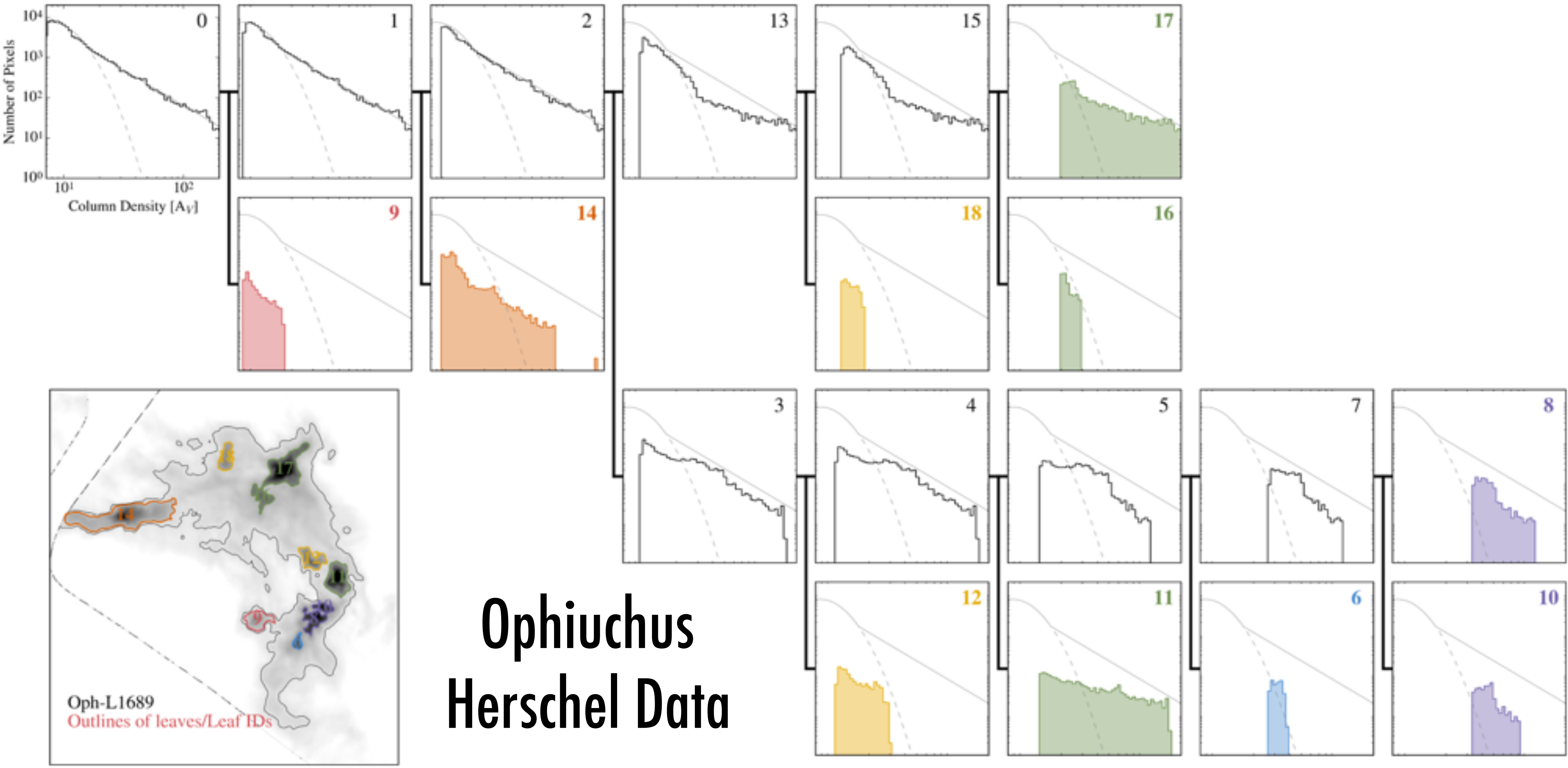


Synthetic observation of $C^{18}O$ emission from our time-dependent chemical model post-processed with radmc-3d

slide courtesy of Rowan Smith, from CfA-ITC talk, March 31, 2016

cf. work of Hacar et al...

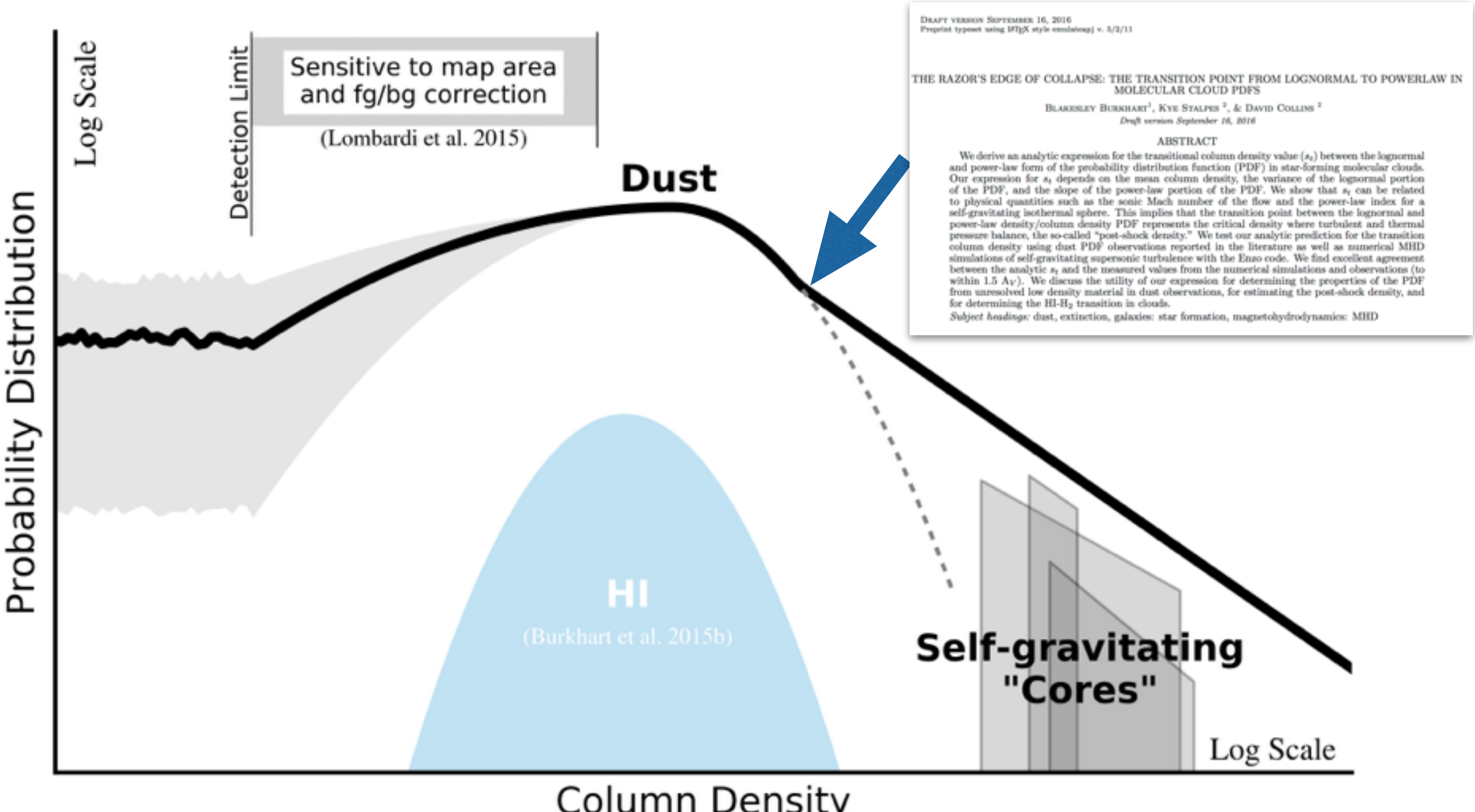
Bonus: Let's use dendrograms to put "topology" into the context of PDFs.



Ophiuchus
Herschel Data

Chen, Burkhart & Goodman 2016, draft online.

Why would we do that?
Consider the anatomy of a PDF...



DRAFT VERSION SEPTEMBER 16, 2016
Preprint typeset using LaTeX style emulateapj v. 5/2/11

THE RAZOR'S EDGE OF COLLAPSE: THE TRANSITION POINT FROM LOGNORMAL TO POWERLAW IN MOLECULAR CLOUD PDFS

BLAKESLEY BURKHART[1], KYE STALPES [2], & DAVID COLLINS [2]

Draft version September 16, 2016

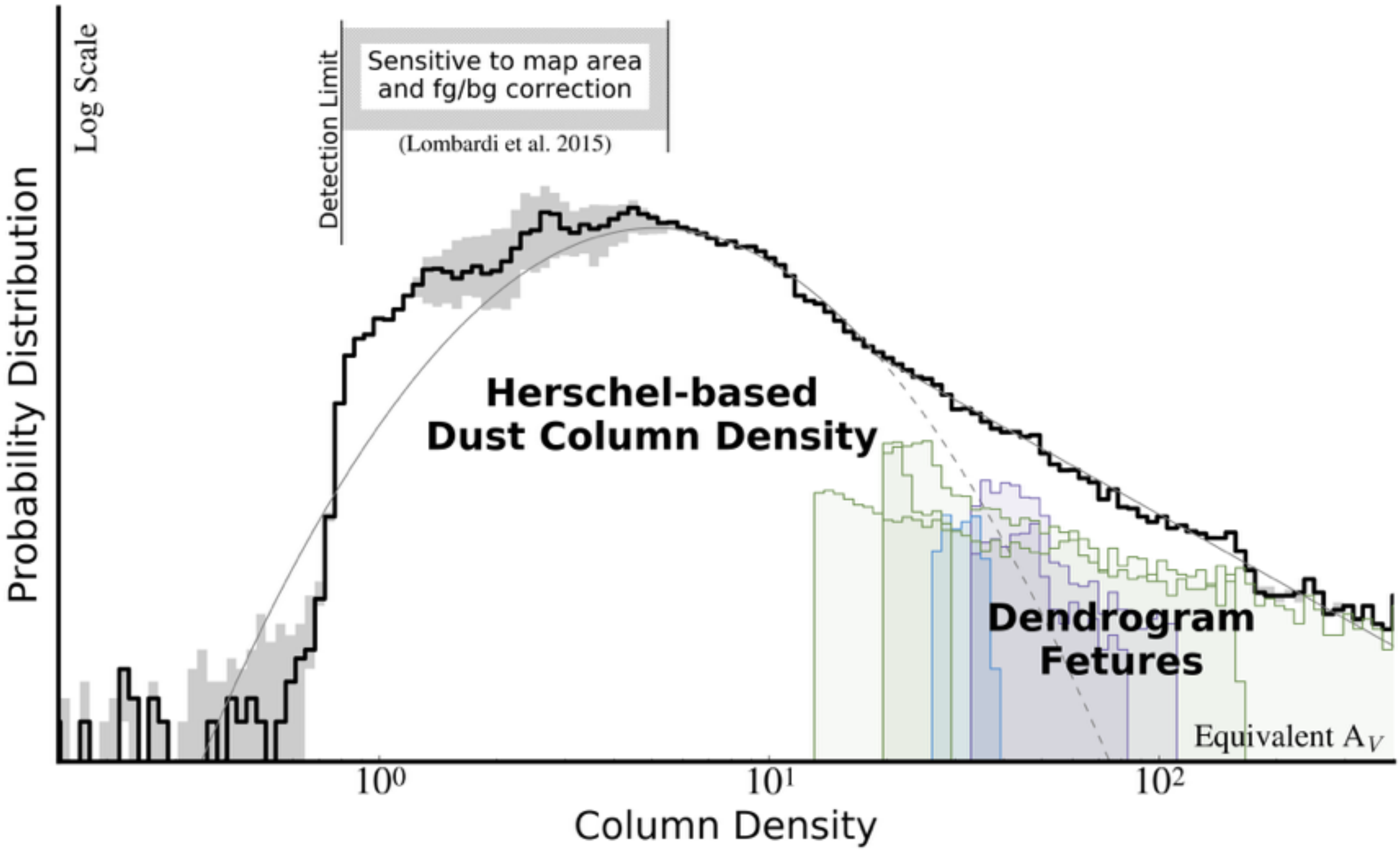
ABSTRACT

We derive an analytic expression for the transitional column density value (s_t) between the lognormal and power-law form of the probability distribution function (PDF) in star-forming molecular clouds. Our expression for s_t depends on the mean column density, the variance of the lognormal portion of the PDF, and the slope of the power-law portion of the PDF. We show that s_t can be related to physical quantities such as the sonic Mach number of the flow and the power-law index for a self-gravitating isothermal sphere. This implies that the transition point between the lognormal and power-law density/column density PDF represents the critical density where turbulent and thermal pressure balance, the so-called "post-shock density." We test our analytic prediction for the transition column density using dust PDF observations reported in the literature as well as numerical MHD simulations of self-gravitating supersonic turbulence with the Enzo code. We find excellent agreement between the analytic s_t and the measured values from the numerical simulations and observations (to within 1.5 A_V). We discuss the utility of our expression for determining the properties of the PDF from unresolved low density material in dust observations, for estimating the post-shock density, and for determining the HI-H_2 transition in clouds.

Subject headings: dust, extinction, galaxies: star formation, magnetohydrodynamics: MHD

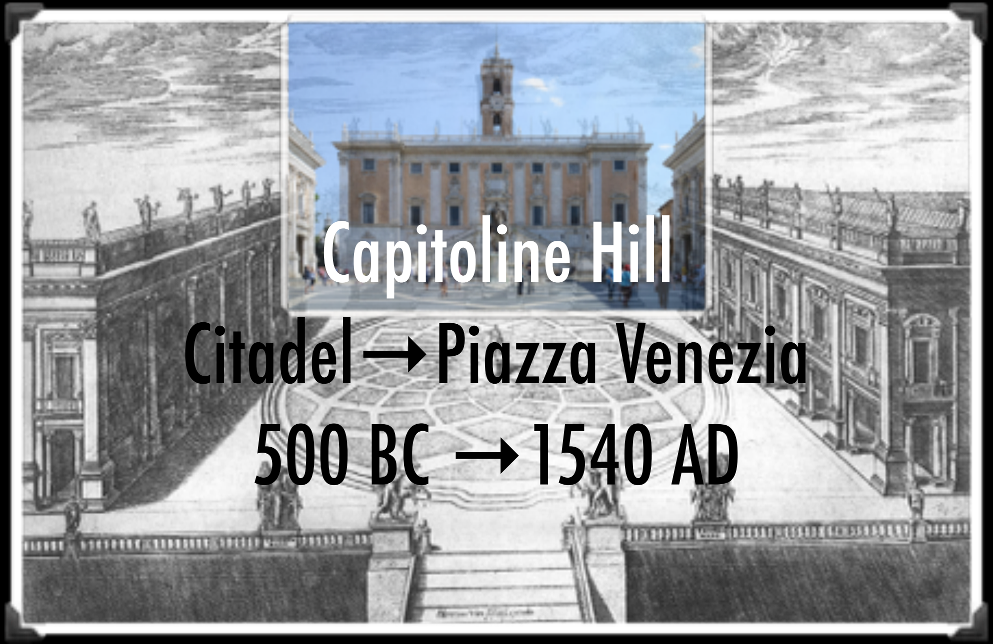
Chen, Burkhart & Goodman 2016, draft online.

Ophiuchus Herschel Data
Yes, power law is all from “cores” (leaves).



Chen, Burkhart & Goodman 2016, draft online.

SOME PLACES ARE SPECIAL



+ this afternoon's "debate"?

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

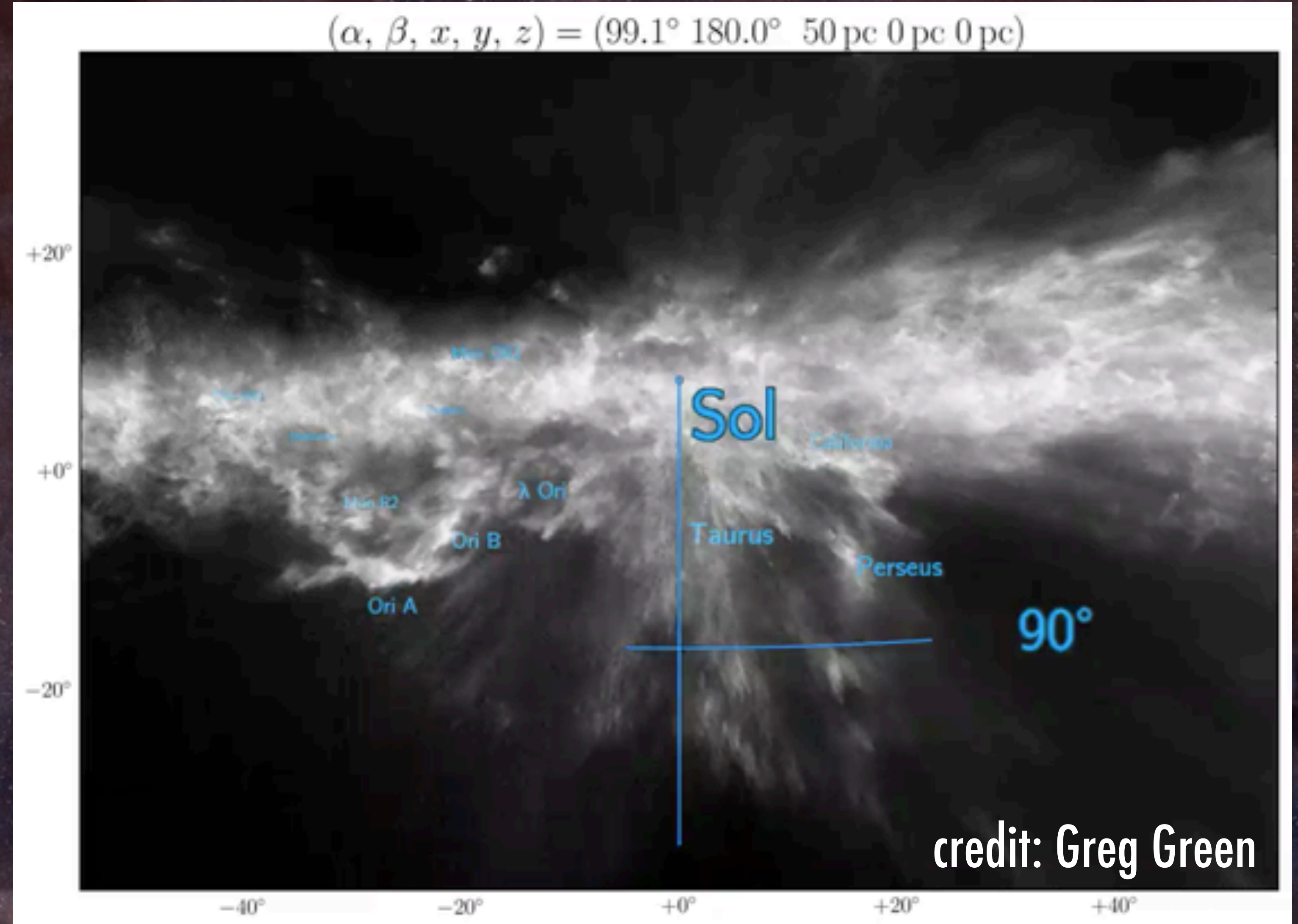
- galactic plane, Bones
- filaments' influence may last into cores–how long, and when, simulators?

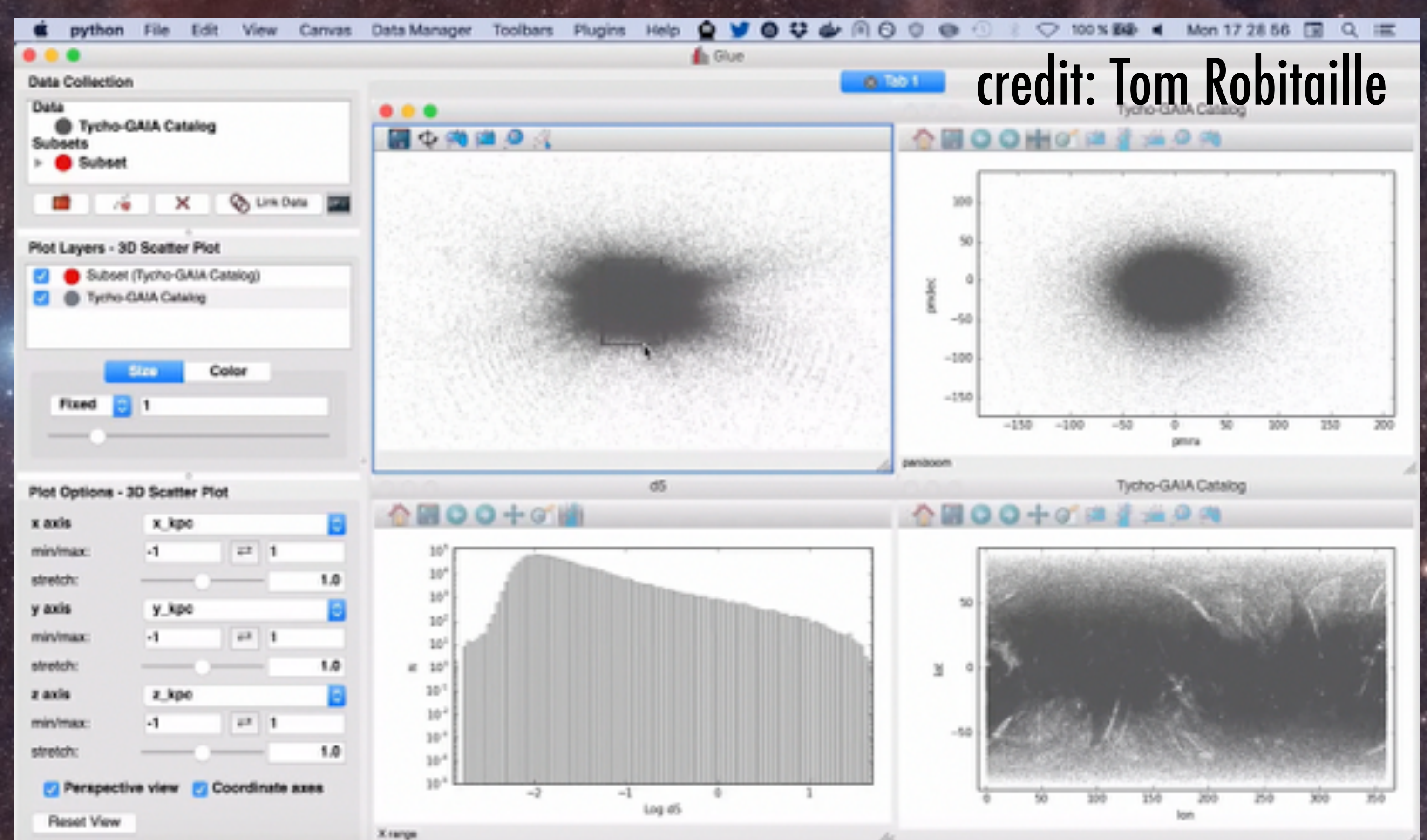
How do "influences" change what is special?

- magnetic fields, feedback, "collisions," but when, how & where, simulators?

Toward True Topology

...ask about Gaia, 3D dust & glue...

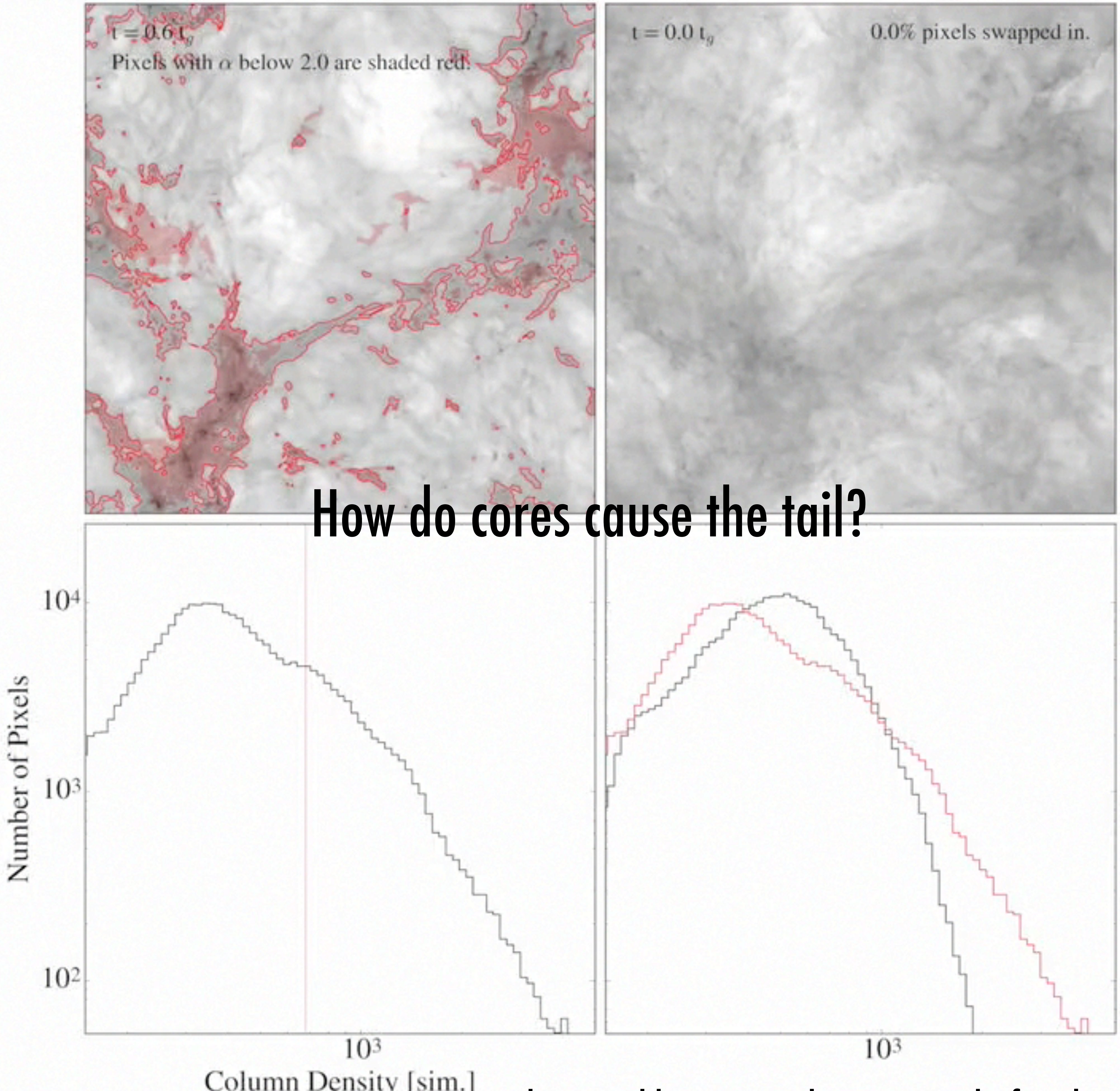




3D dust: http://argonaut.skymaps.info

glue: http://glueviz.org

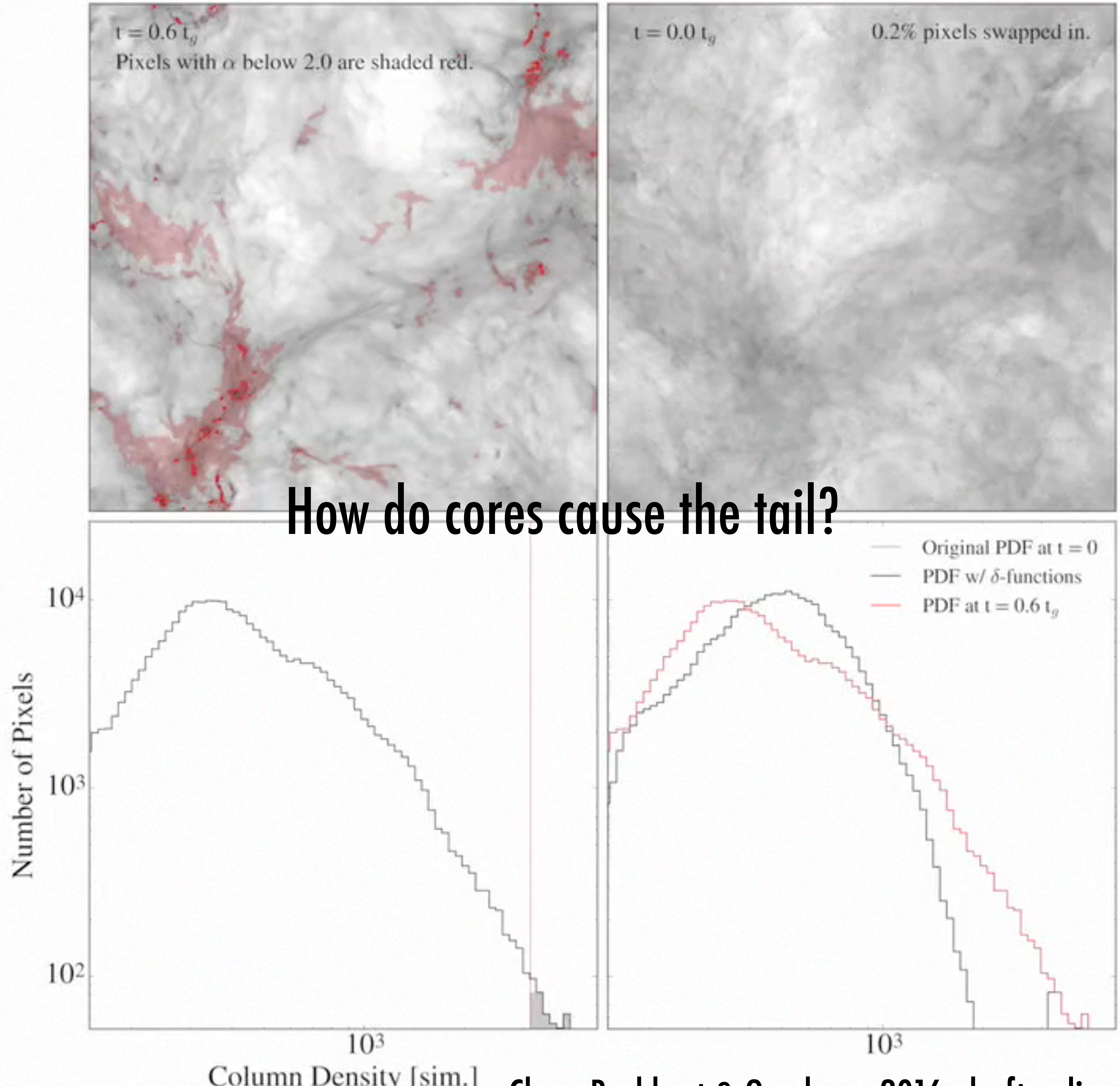
extra slides



How do cores cause the tail?

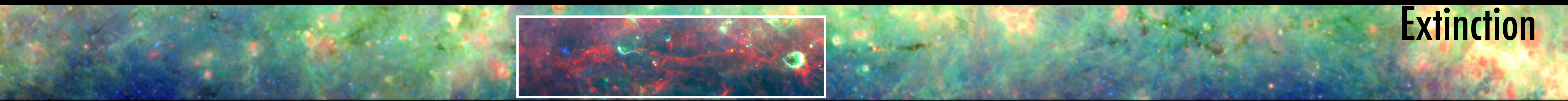
Chen, Burkhart & Goodman 2016, draft online.

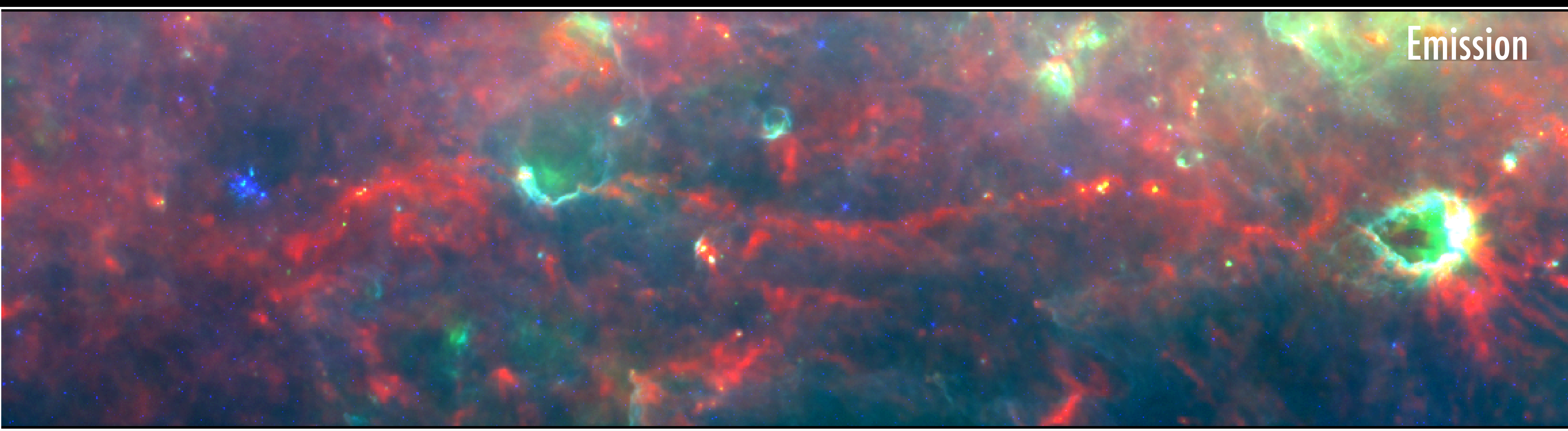
How do cores cause the tail?



Chen, Burkhart & Goodman 2016, draft online.

NESSIE

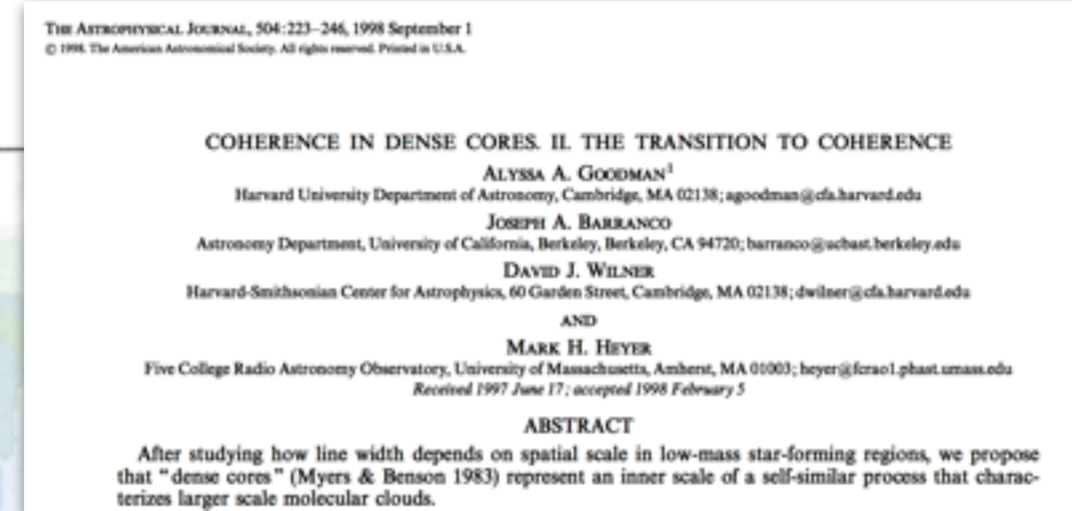




Bottom panel: Red=column density from Herschel, green=70 micron data from Herschel, and blue= 8 micron data

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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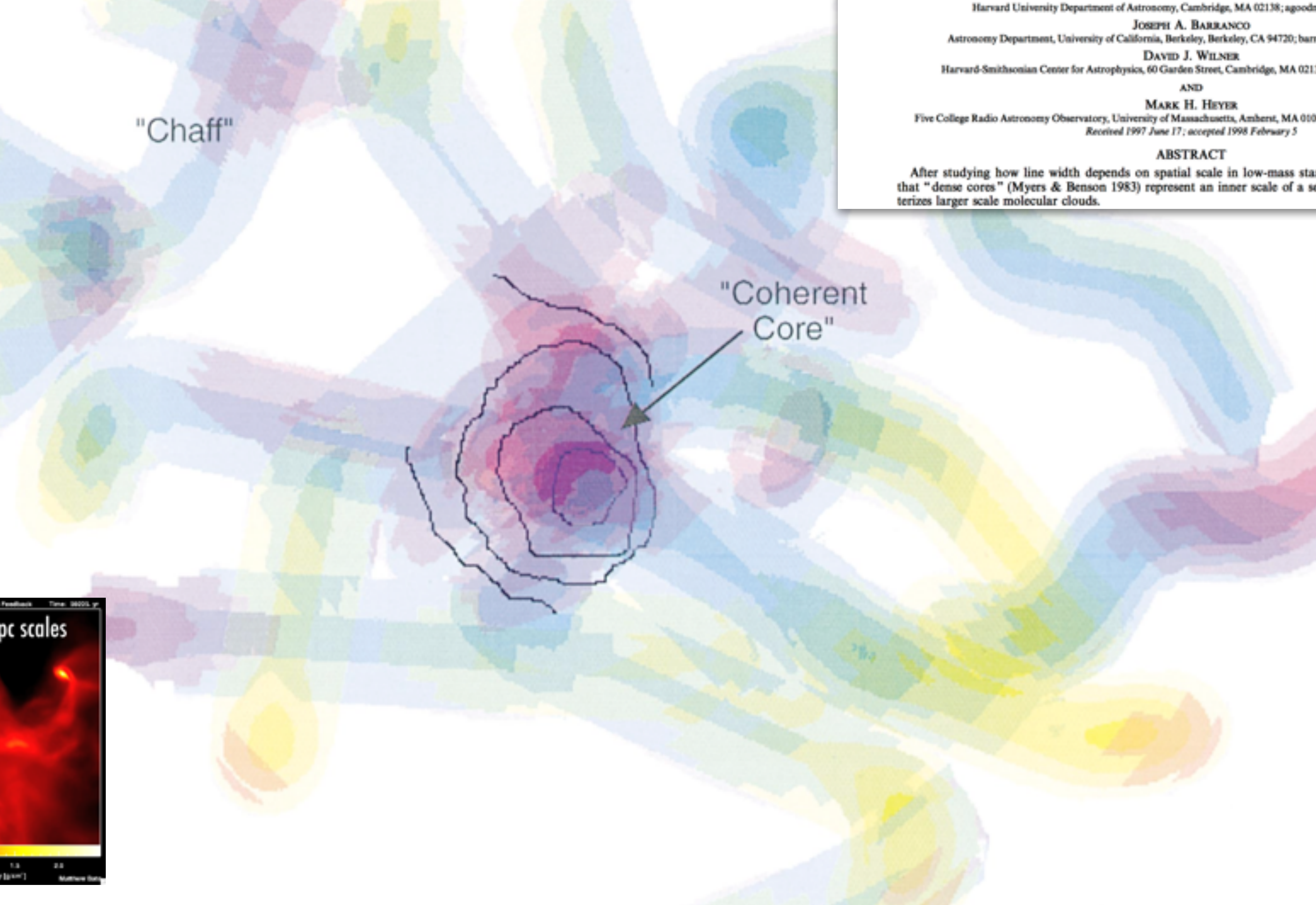
ABSTRACT

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.



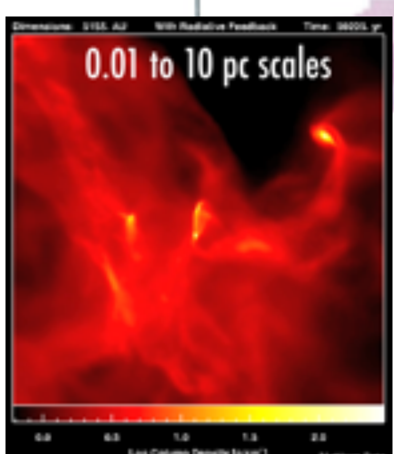


FIG. 10.—An illustration of the transition to coherence. Color and shading schematically represent velocity and density in this figure. On large scales, material (labeled chaff) is distributed in a self-similar fashion, and its filling factor is low. On scales smaller than some fiducial radius, the filling 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.

?