TOPIC

How Long, and Long-lasting, are Filaments?

EXPERTISE

Profs. A. Goodman, D. Finkbeiner, et al. @ CfA
(obs-sim comparison, stats, viz, software, $\vec{B}$)

PROBLEM 1

On what scale(s) does filamentary structure matter, and when, in the end-game of star-formation?

PROBLEM 2

What constraints do "bones" offer on:
-the shape of the Galaxy, especially in the vertical direction?
-galaxy evolution models on "short" timescales

PHD 1

For synthetic observations best "matching" molecular line & dust data, determine from whence and when bulk of mass gets to forming cores & stars.
Particular focus on timing.

with: Klessen, Glover+; Smith, Fuller+; Caselli, Pineda+; Alves, Lombardi, Hacar, Tafalla+

related to work of 5th-year Harvard grad student H. Chen

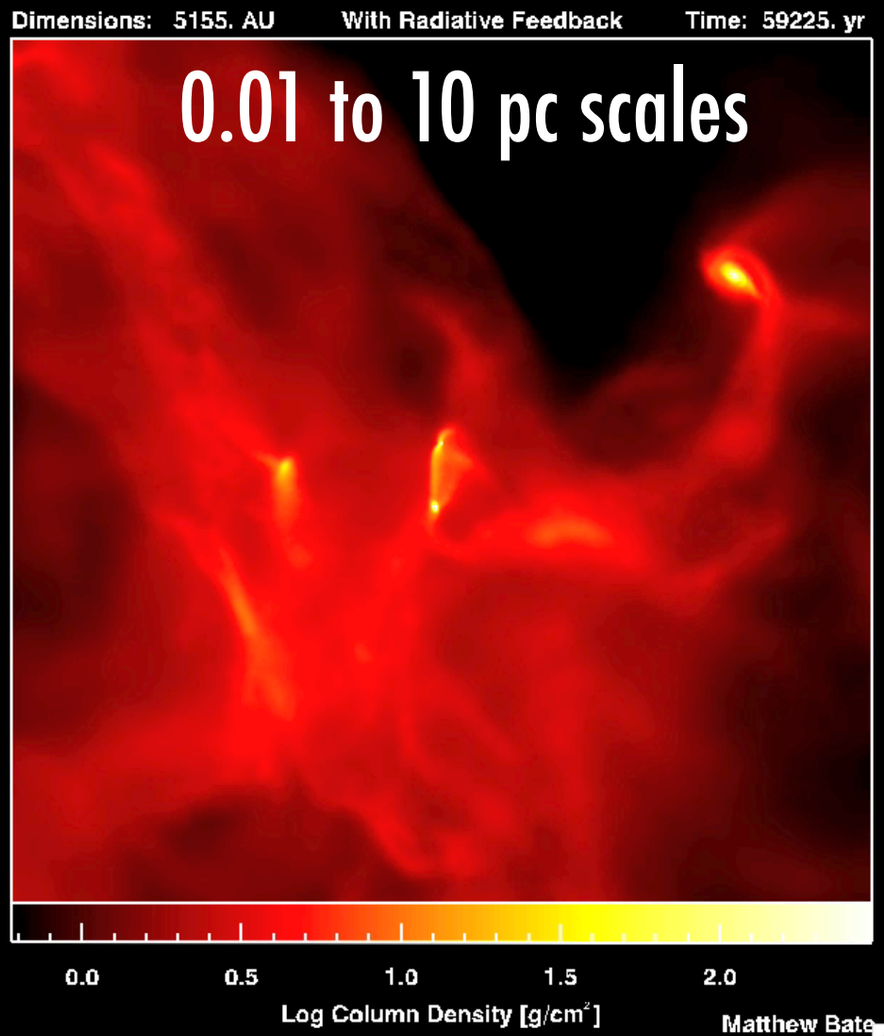
PHD 2

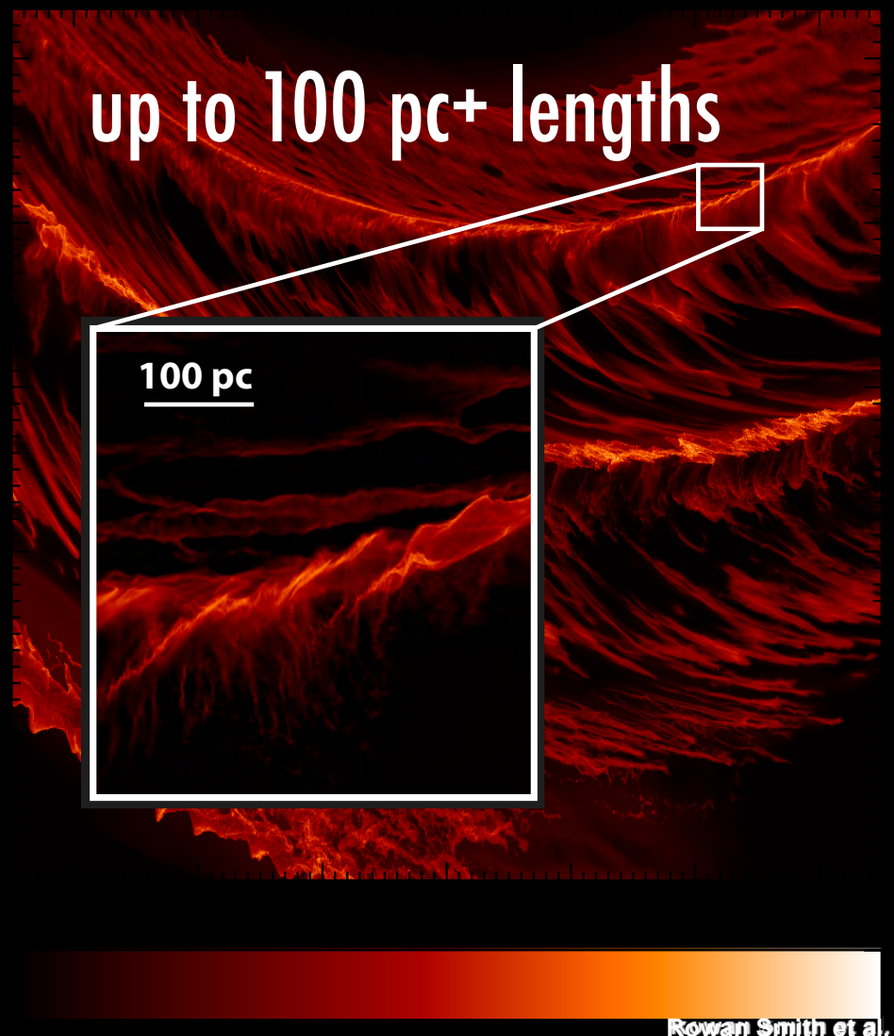
Using synthetic observations of models of dense gas & dust structures in MW-like galaxies, measure statistics & compare with observations to facilitate estimates re:observed shape, and evolution of "bones."

with: Smith, Fuller+; Burkert+; Molinari+; Menten

1st-year Harvard grad student C. Zucker working on this!

FOR ANDI: ARE THESE PROBLEMS CONNECTED?





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"Wisps"

"Giant" Molecular Filaments

Large Scale Filaments

"Bones"

e.g. from "Skeleton of the Milky Way" paper

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.

"Fibers"

"Cores"

"0.1 pc" Filaments

1987

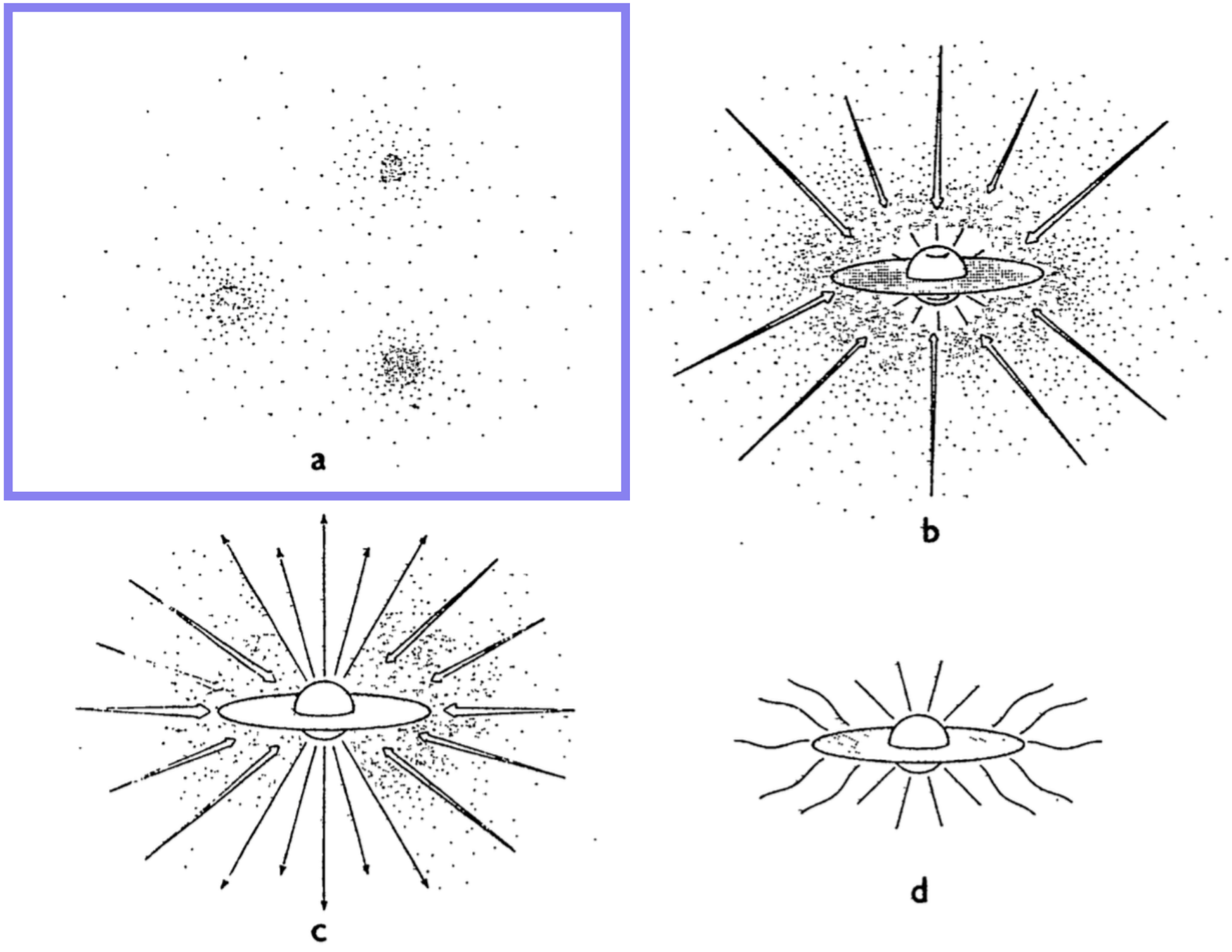

Figure 7 The four stages of star formation. (*a*) Cores form within molecular clouds as magnetic and turbulent support is lost through ambipolar diffusion. (*b*) A protostar with a surrounding nebular disk forms at the center of a cloud core collapsing from inside-out. (*c*) A stellar wind breaks out along the rotational axis of the system, creating a bipolar flow. (*d*) The infall terminates, revealing a newly formed star with a circumstellar disk.

1998

THE ASTROPHYSICAL JOURNAL, 504:223–246, 1998 September 1
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COHERENCE IN DENSE CORES. II. THE TRANSITION TO COHERENCE

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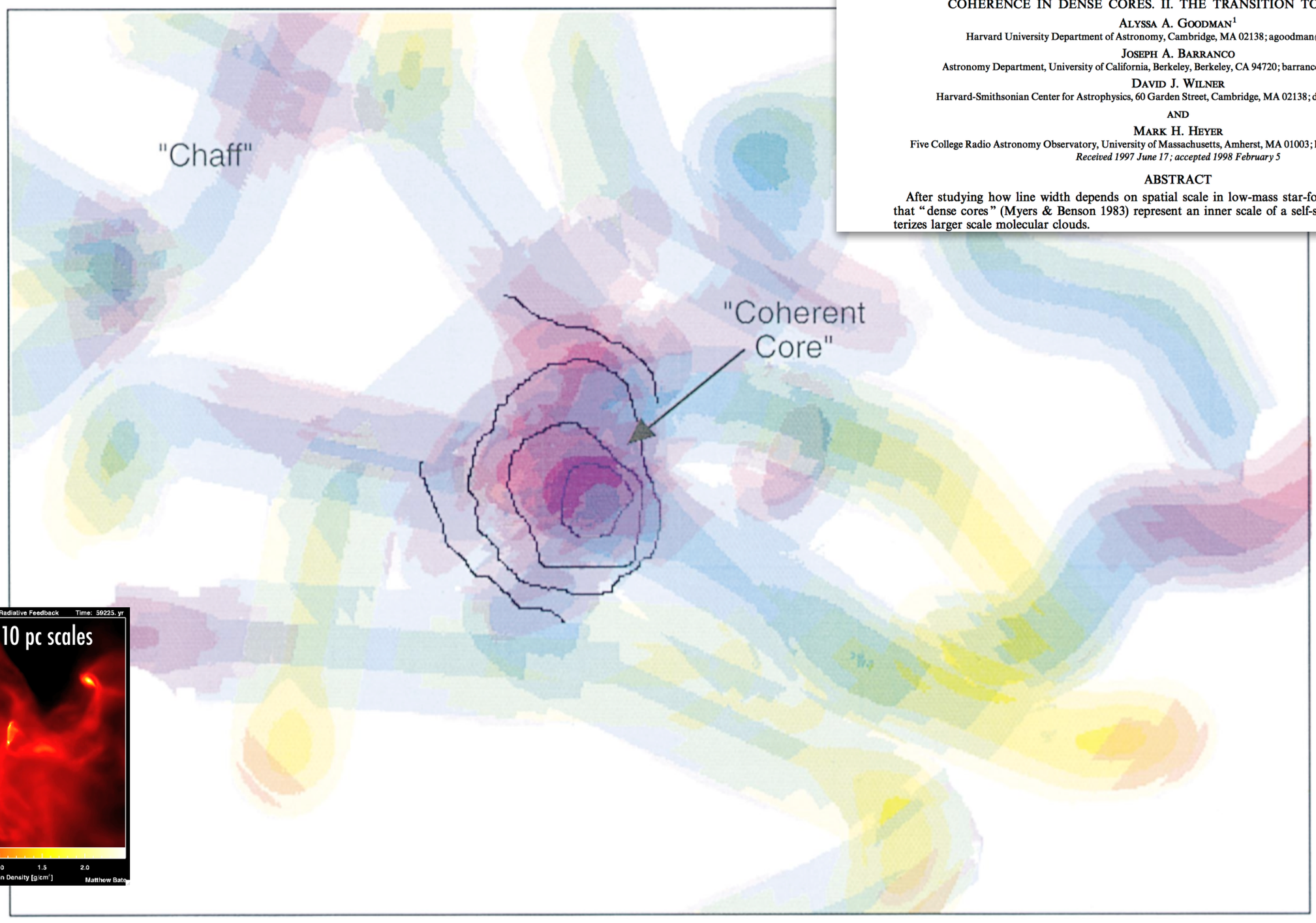
Five College Radio Astronomy Observatory, University of Massachusetts, Amherst, MA 01003; heyer@fcrao1.phast.umass.edu
Received 1997 June 17; accepted 1998 February 5

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.



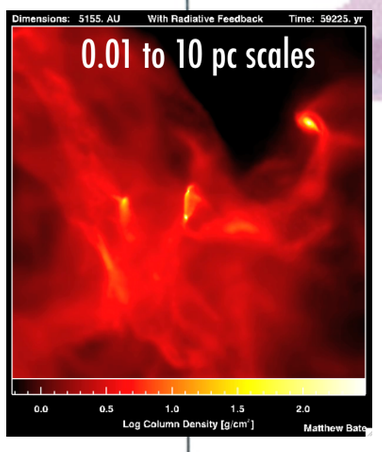


FIG. 10.—An illustration of the transition to coherence. Color and shading schematically represent velocity and density in this figure. On large scales, material (labeled chaff) is distributed in a self-similar fashion, and its filling factor is low. On scales smaller than some fiducial radius, the filling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

?

2009

Mon. Not. R. Astron. Soc. **392,** 1363–1380 (2009) doi:10.1111/j.1365-2966.2008.14165.x

The importance of radiative feedback for the stellar initial mass function

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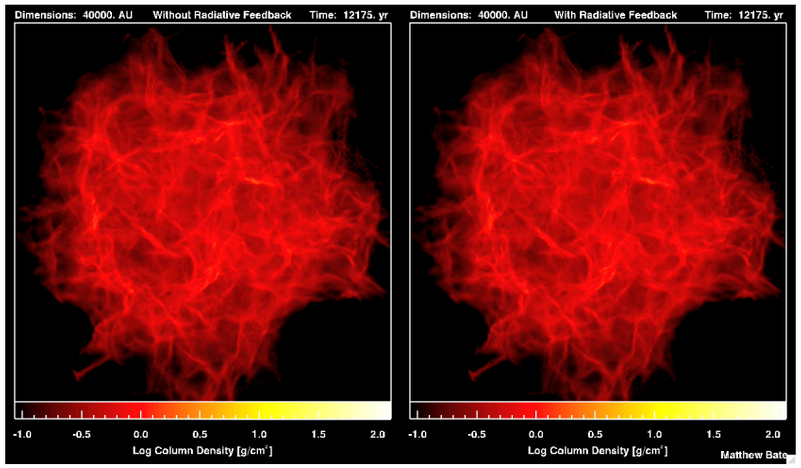
Accepted 2008 October 29. Received 2008 October 24; in original form 2008 October 9



Mon. Not. R. Astron. Soc. **400,** 1775–1784 (2009) doi:10.1111/j.1365-2966.2009.15621.x

The simultaneous formation of massive stars and stellar clusters

Rowan J. Smith,[1]★ Steven Longmore[2] and Ian Bonnell[1]
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[2]*Harvard–Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138, USA*

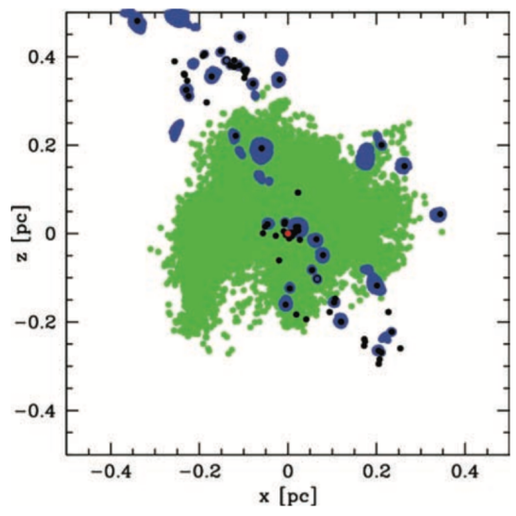

Figure 8. The final fate of the mass within clump Alpha shown at 1 t_{dyn}. The green dots show the positions of gas which will eventually be accreted by the massive sink (red dot). Black dots show the position of sinks and blue dots show the location of material in cores. The gas which will be accreted by the massive sinks is well distributed throughout the clumps, and generally cores within this region will not be disrupted by the massive sink.

2011

The Astrophysical Journal Letters, 739:L2 (5pp), 2011 September 20 doi:10.1088/2041-8205/739/1/L2
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EXPANDED VERY LARGE ARRAY OBSERVATIONS OF THE BARNARD 5 STAR-FORMING CORE: EMBEDDED FILAMENTS REVEALED

Jaime E. Pineda[1,2], Alyssa A. Goodman[3], Héctor G. Arce[4], Paola Caselli[5], Steven Longmore[1], and Stuartt Corder[6,7]
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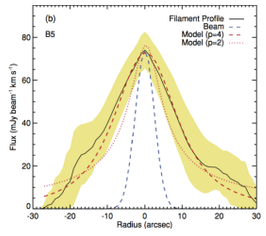
Received 2011 March 29; accepted 2011 June 27; published 2011 August 29



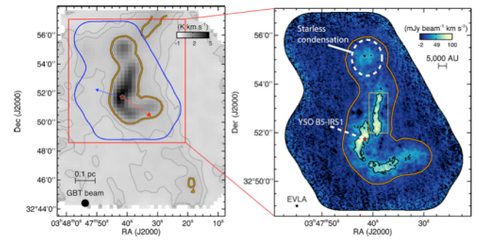


Figure 1. Left panel: integrated intensity map of B5 in NH_3 (1,1) obtained with GBT. Gray contours show the 0.15 and 0.3 K km s^{-1} level in NH_3 (1,1) integrated intensity. The orange contours show the region in the GBT data where the non-thermal velocity dispersion is subsonic. The young star, B5–IRS1, is shown by the star in both panels. The outflow direction is shown by the arrows. The blue contour shows the area observed with the EVLA and the red box shows the area shown in the right panel. Right panel: integrated intensity map of B5 in NH_3 (1,1) obtained combining the EVLA and GBT data. Black contour shows the 50 mJy beam^{-1} km s^{-1} level in NH_3 (1,1) integrated intensity. The yellow box shows the region used in Figure 4. The northern starless condensation is shown by the dashed circle.

Mon. Not. R. Astron. Soc. **411,** 1354–1366 (2011) doi:10.1111/j.1365-2966.2010.17775.x

A quantification of the non-spherical geometry and accretion of collapsing cores

Rowan J. Smith,[1]★ Simon C. O. Glover,[1] Ian A. Bonnell,[2] Paul C. Clark[1] and Ralf S. Klessen[1,3]
[1]*Zentrum für Astronomie der Universität Heidelberg, Institut für Theoretische Astrophysik, Albert-Ueberle-Str. 2, 69120 Heidelberg, Germany*
[2]*SUPA, School of Physics & Astronomy, University of St Andrews, North Haugh, St Andrews, Fife KY16 9SS*
[3]*Kavli Institute for Particle Astrophysics and Cosmology, Stanford University, Menlo Park, CA 94025, USA*

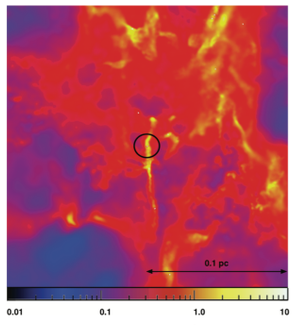
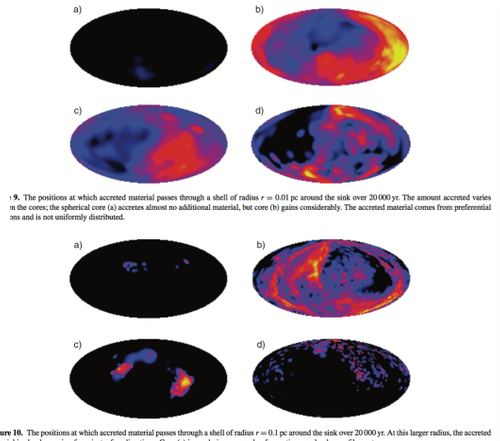


Figure 8. Column density projection in (g cm^{-2}) of the local environment of the filamentary core (d), shown in the circle. There are multiple condensed structures within 0.1 pc of the core.



9. The positions at which accreted material passes through a shell of radius $r = 0.01$ pc around the sink over 20 000 yr. The amount accreted varies n the cores; the spherical core (a) accretes almost no additional material, but core (b) gains considerably. The accreted material comes from preferential ons and is not uniformly distributed.

Figure 10. The positions at which accreted material passes through a shell of radius $r = 0.1$ pc around the sink over 20 000 yr. At this larger radius, the accreted material is clearly coming from just a few directions. Core (c) is an obvious example of accretion purely along a filament.

2013

Astronomy & Astrophysics manuscript no. 20090ms March 12, 2013
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Cores, filaments, and bundles: hierarchical core formation in the L1495/B213 Taurus region ⋆

A. Hacar[1,2], M. Tafalla[1], J. Kauffmann[3], and A. Kovács[4]
[1] Observatorio Astronómico Nacional (IGN), Alfonso XII 3, E-28014 Madrid, Spain
[2] Institute for Astrophysics, University of Vienna, Türkenschanzstrasse 17, 1180 Vienna, Austria.
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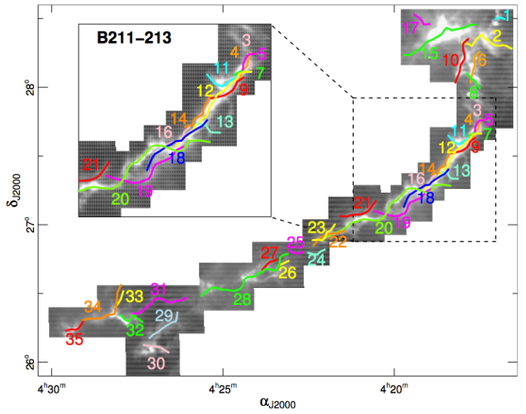
[3] Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91109, USA
[4] University of Minnesota, 116 Church St SE, Minneapolis, MN 55414, USA



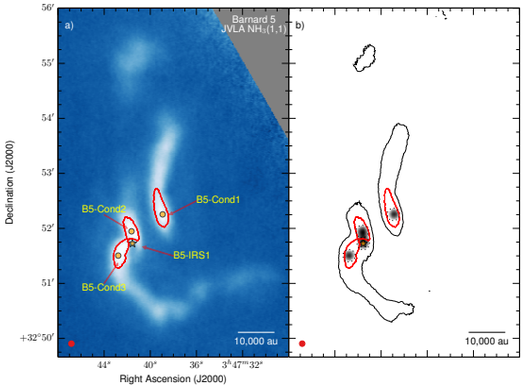
"NOW"

LETTER

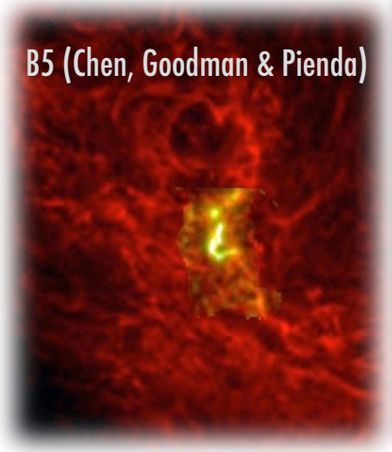
doi:10.1038/nature14166

The formation of a quadruple star system with wide separation

Jaime E. Pineda[1], Stella S. R. Offner[2,3], Richard J. Parker[4], Héctor G. Arce[5], Alyssa A. Goodman[6], Paola Caselli[7], Gary A. Fuller[8], Tyler L. Bourke[9,10] & Stuartt A. Corder[11,12]



B5 (Chen, Goodman & Pienda)



PROBLEM 1

On what scale(s) does filamentary structure matter, and when, in the end-game of star-formation?

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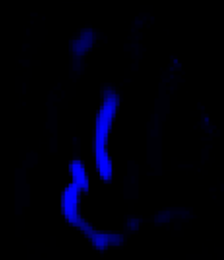
Particular focus on timing.

with: Klessen, Glover+; Smith, Fuller+; Caselli, Pineda+; Alves, Lombardi, Hacar, Tafalla+
related to work of 5th-year Harvard grad student H. Chen

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

Gravity, Observations & "Reality"

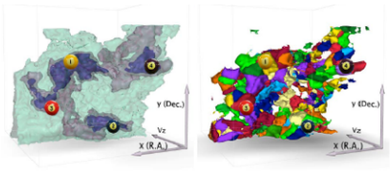
2009

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]



2013

The Astrophysical Journal, 777:173 (20pp), 2013 November 10 doi:10.1088/0004-637X/777/2/173
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QUANTIFYING OBSERVATIONAL PROJECTION EFFECTS USING MOLECULAR CLOUD SIMULATIONS

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[2] Harvard-Smithsonian Center for Astrophysics, 60 Garden St., Cambridge, MA 02138, USA
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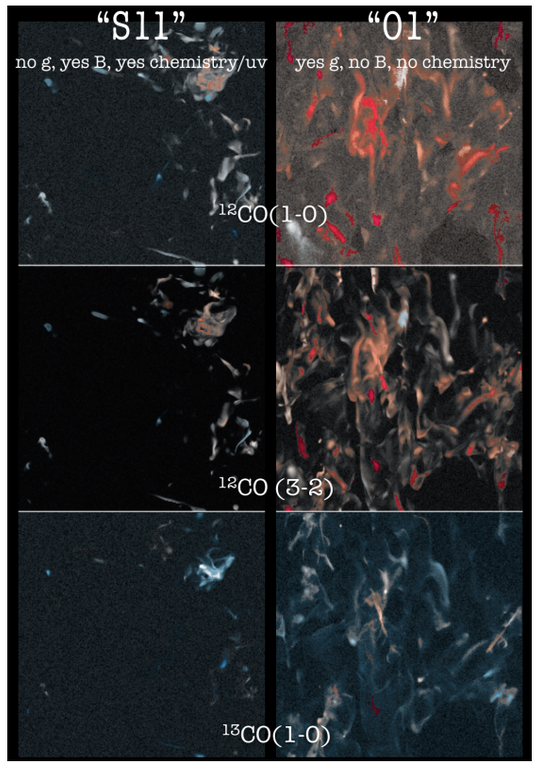
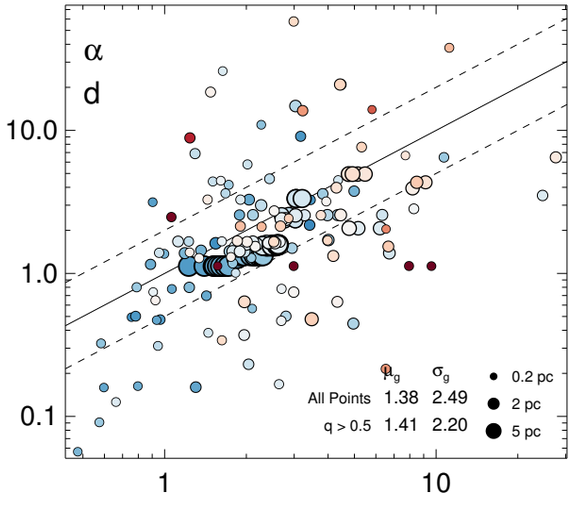
Received 2013 July 11; accepted 2013 September 29; published 2013 October 24





"NOW"

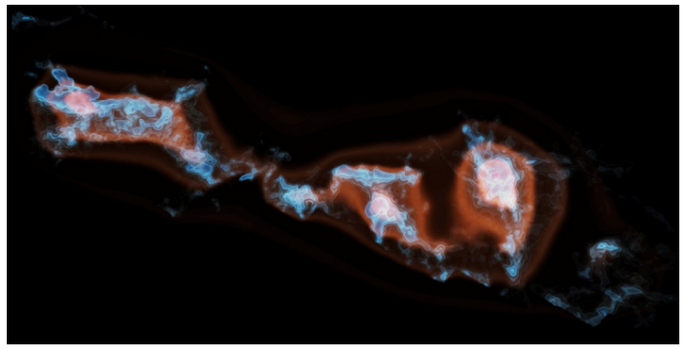
Astronomy & Astrophysics manuscript no. paper_arxiv ©ESO 2016
March 22, 2016

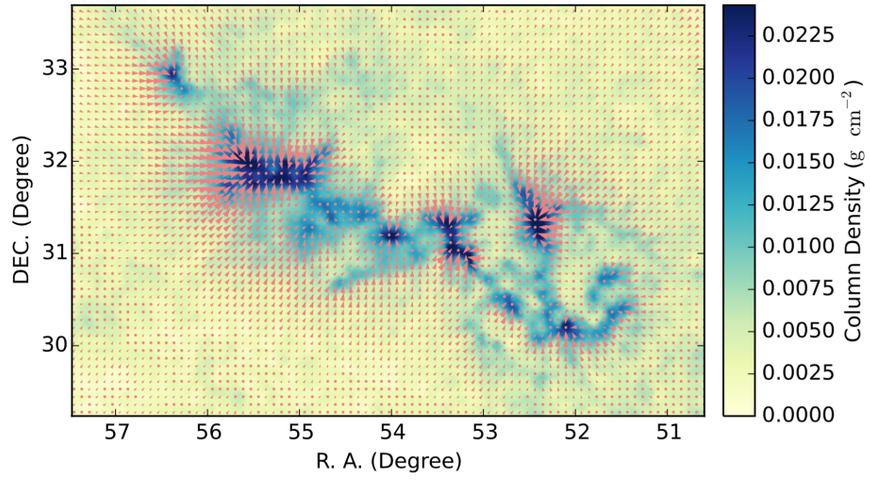
Gravitational acceleration and edge effects in molecular clouds*

Guang-Xing Li[1], Andi Burkert[1,2], Tom Megeath[3], and Friedrich Wyrowski[4]

[1] University Observatory Munich, Scheinerstrasse 1, D-81679 München, Germany
[2] Max-Planck-Fellow, Max-Planck-Institute for Extraterrestrial Physics, Giessenbachstrasse 1, 85758 Garching, Germany
[3] University of Toledo, Ritter Astrophysical Observatory, Department of Physics and Astronomy, Toledo OH 43606 Germany
[4] Max-Planck Institut für Radioastronomie, Auf dem Hügel, 69, 53121 Bonn

March 22, 2016





– In the localized regions, the concentration of acceleration can lead to local collapse. The local collapse can occur in a timescale that is much shorter (e.g. 10^6 yr) than the dynamical timescale of the cloud.

However, a complete picture of gas evolution is yet to be achieved since we need to fully understand the interplay between magnetic field, turbulence and gravity in these these regions. There are ample observational evidences that magnetic fields are important in star-forming regions (Li et al. 2014). Remarkably-ordered magnetic fields have been

Match Quality

good

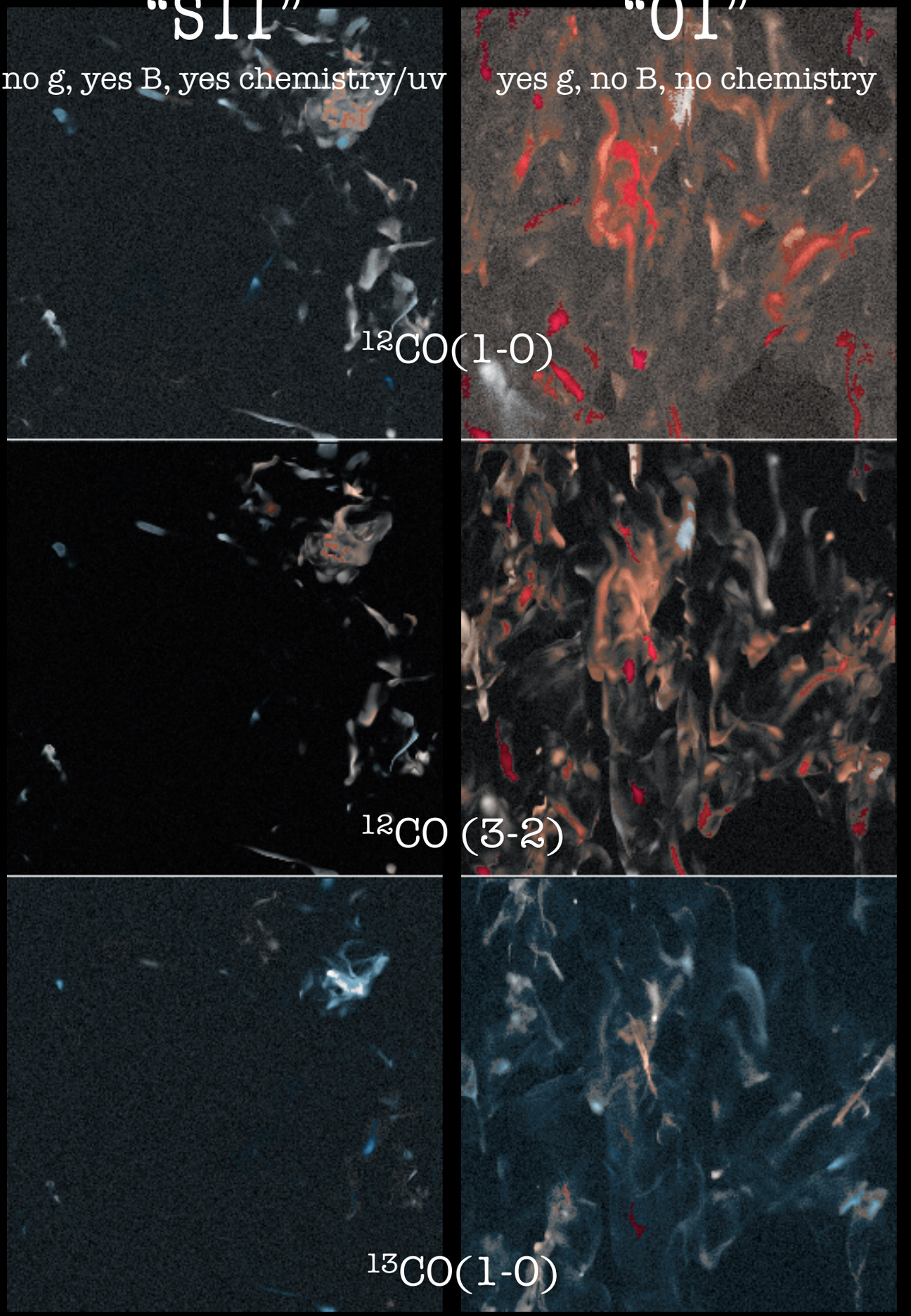
bad

movies include a noise model, in both cases

Table 2. Summary of each simulation

	S11	O1
Box Size	20 pc	25 pc
Simulation Code	Zeus-MP	ORION
Gridding	256^3	256^3 + 4 levels of AMR refinement
Driven Turbulence?	Yes	Yes
Driving Power Spectrum	Uniform $1 < k < 2$	Uniform $1 < k < 2$
Gravity?	No	Yes
B field?	5.85 uG	0
Gas Temperature	Variable (10-200K)	15K
Chemistry	H, O, C	None
Background UV	2.7e-3 erg cm^{-2} s^{-1}	No
Constant CO Abundance	No	1.75 e-4
$^{12}CO/^{13}CO$ abundance	70	70
Radiative Transfer Code	RADMC 3D	RADMC 3D
Microturbulence	0.2 km s^{-1}	0.2 km s^{-1}
Metallicity	Solar	N/A
Mean number density (nH)	100 cm^{-3}	58 cm^{-3}
Mach Number	~ 6	22
Isothermal?	No	Yes
Output time(s)	5.7 Myr	2.5 Myr
Mass in stars	N/A	722 Msun (2.4%)

Beaumont, Offner, Shetty, Glover & Goodman 2013



Simulations "Now" (but we need some lines...)

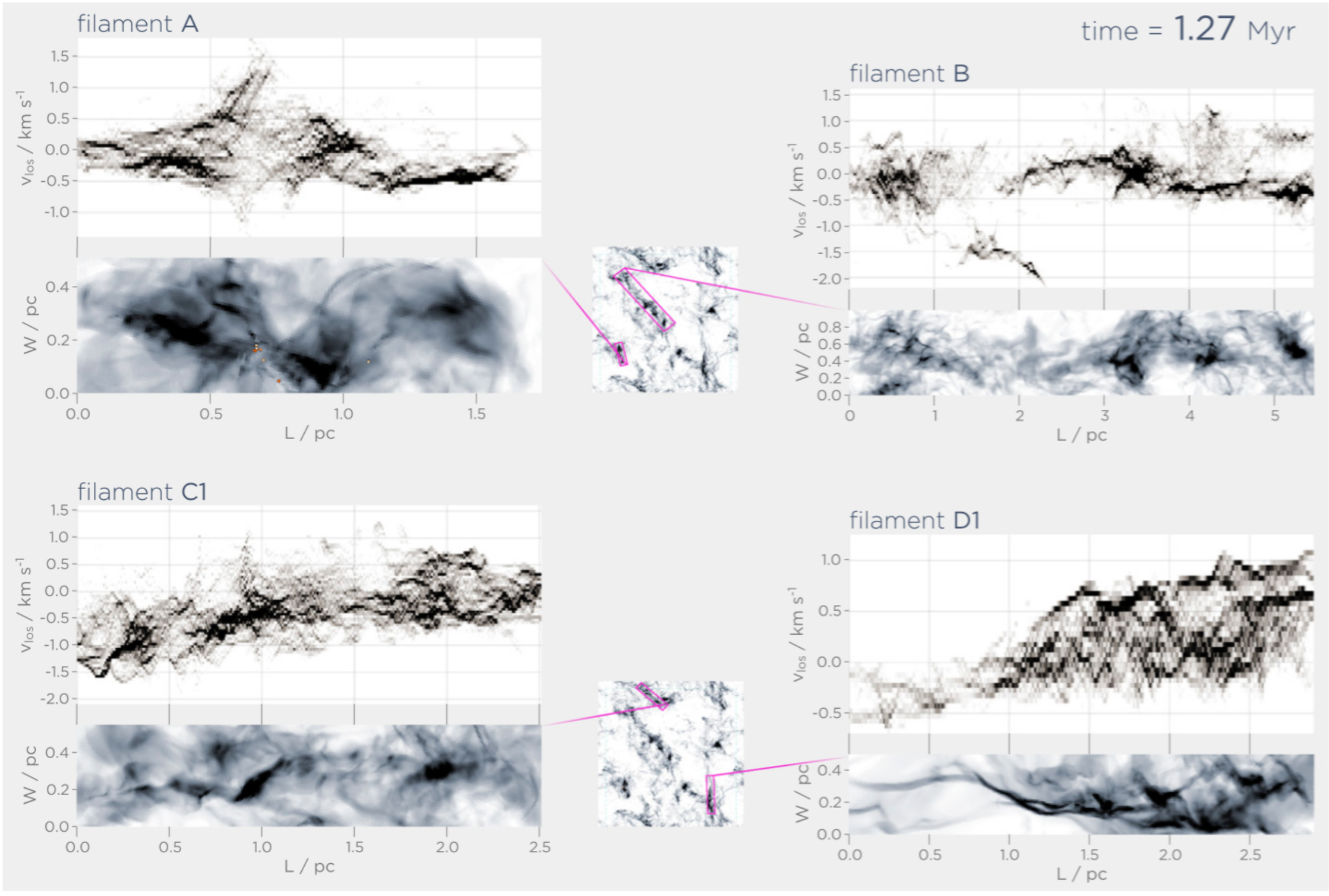
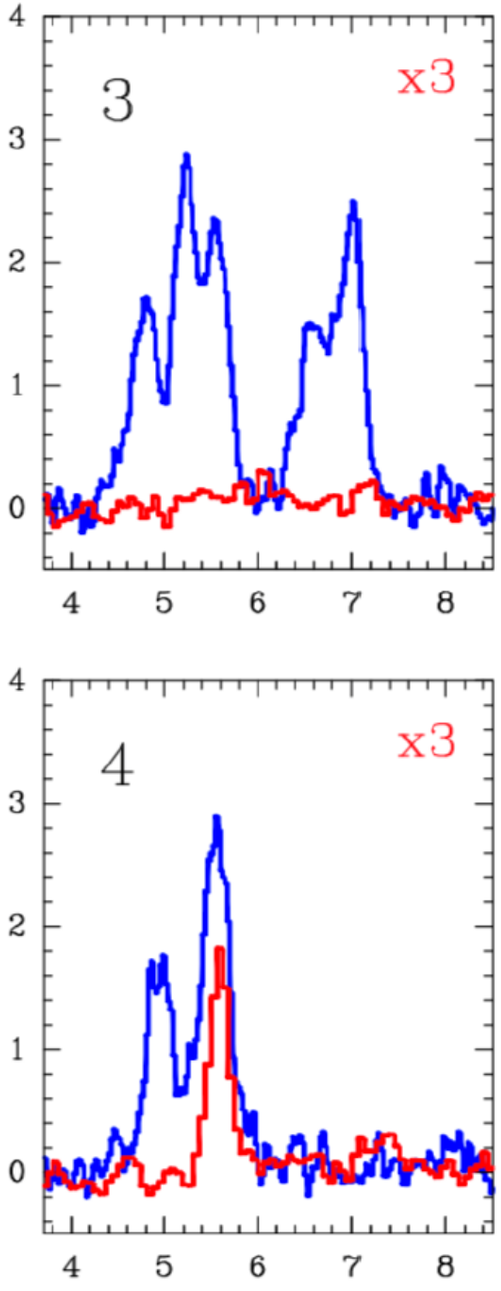


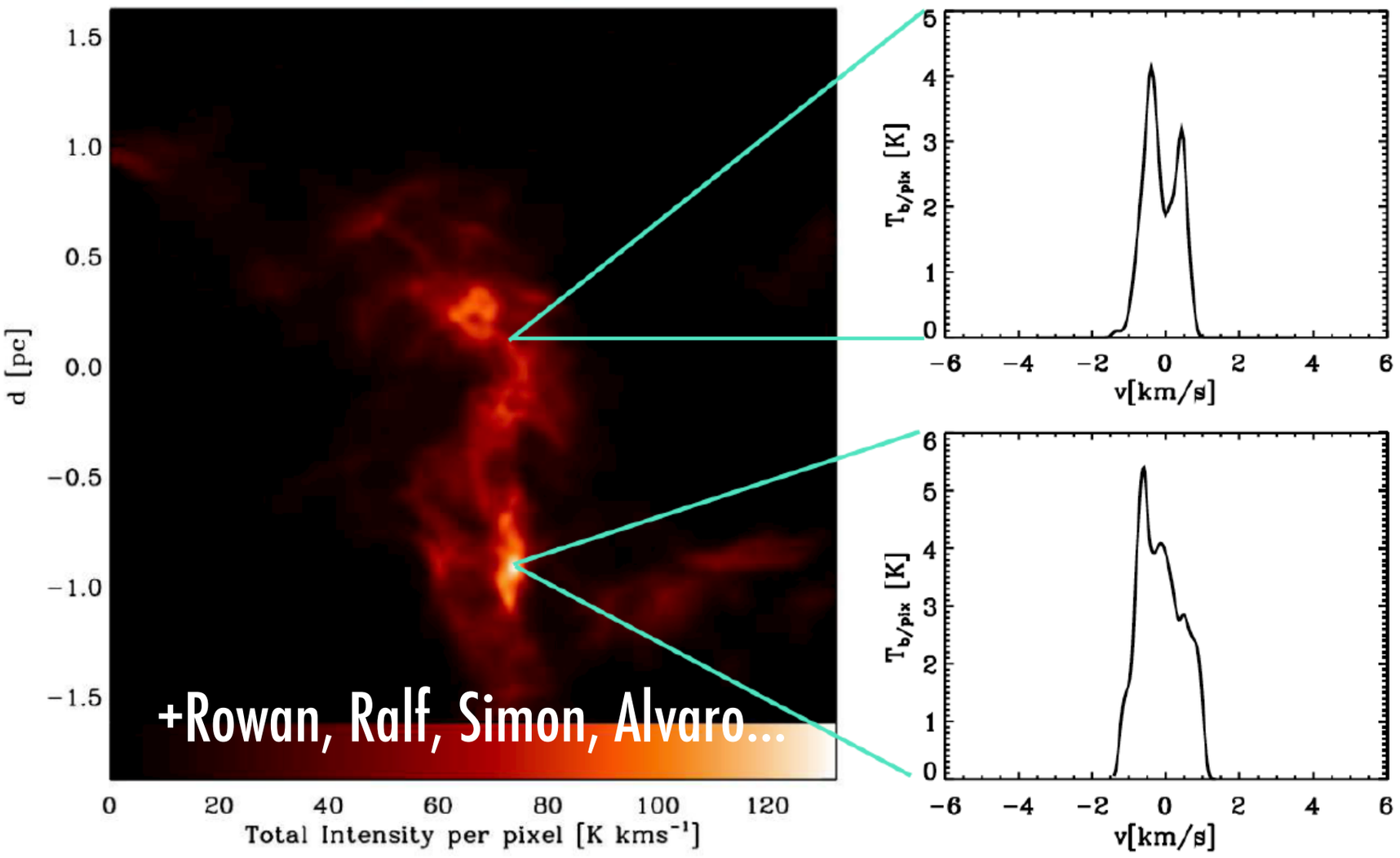
Figure 2. Filaments from the snapshot at 1.27 Myr, shown in their native coordinate system, along with line-of-sight velocity observations along the *L* dimension. These density-weighted line-of-sight velocities are summed along the *W* dimension, i.e., they are the *L*–*v* plane of the *L*–*W*–*v* position–position–velocity cube.

Simulations "Now" (with some 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

GLUE DEMO

Edit View Canvas Data Manager Toolbars Plugins Help

Data Collection

- 4.9<=PRIMARY<5.6
- 5.6<=PRIMARY<6.3
- 6.3<=PRIMARY<7.0
- 12
- 12 (test)

Link Data

Plot Layers - 3D Volume Rendering

- 12 (combined_all_b5_13co_21_nc
- 12 (combined_all_b5_c18o_21_nc
- combined_all_b5_hcn_10_noise_v

Attribute: PRIMARY

Min: 0 Max: 5.004

Color:

Alpha:

Subset: Data Outline

Plot Options - 3D Volume Rendering

x axis

min/max: -0.5 ⇄ 105.5

stretch: 0.46

y axis

min/max: -0.5 ⇄ 245.5

stretch: 1.0

z axis

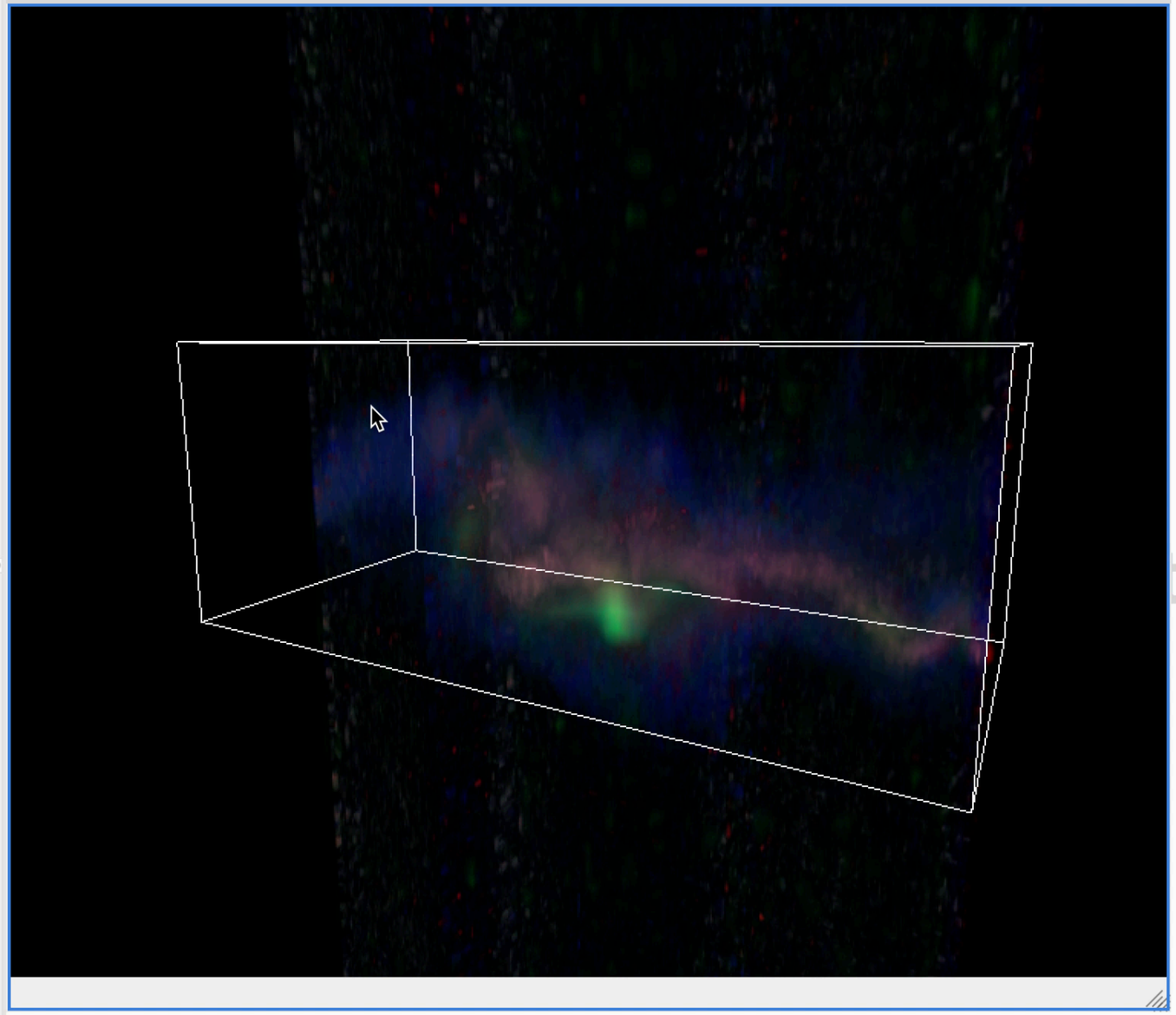
min/max: 170 ⇄ 220

stretch: 0.39

Coordinate axes

Reset View

Tab 1 Tab 2



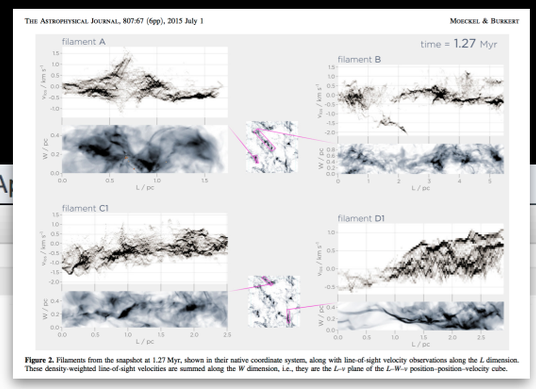


Figure 2. Filaments from the snapshot at 1.27 Myr, shown in their native coordinate system, along with line-of-sight velocity observations along the L dimension. These density-weighted line-of-sight velocities are summed along the W dimension, i.e., they are the L–v plane of the L–W–v position–position–velocity cube.

glueviz.org

TOPIC

How Long, and Long-lasting, are Filaments?

EXPERTISE

Profs. A. Goodman, D. Finkbeiner, et al. @ CfA
(obs-sim comparison, stats, viz, software, $\vec{B}$)

PROBLEM 1

On what scale(s) does filamentary structure matter, and when, in the end-game of star-formation?

PROBLEM 2

What constraints do "bones" offer on:
-the shape of the Galaxy, especially in the vertical direction?
-galaxy evolution models on "short" timescales

PHD 1

For synthetic observations best "matching" molecular line & dust data, determine from whence and when bulk of mass gets to forming cores & stars.
Particular focus on timing.

with: Klessen, Glover+; Smith, Fuller+; Caselli, Pineda+; Alves, Lombardi, Hacar, Tafalla+

related to work of 5th-year Harvard grad student H. Chen

PHD 2

Using synthetic observations of models of dense gas & dust structures in MW-like galaxies, measure statistics & compare with observations to facilitate estimates re:observed shape, and evolution of "bones."

with: Smith, Fuller+; Burkert+; Molinari+; Menten

1st-year Harvard grad student C. Zucker working on this!

PROBLEM 2

What constraints do "bones" offer on:
- -the shape of the Galaxy, especially in the vertical direction?
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PHD 2

Using synthetic observations of models of dense gas & dust structures in MW-like galaxies, measure statistics & compare with observations to facilitate estimates re:observed shape, and evolution of "bones."

with: Smith, Fuller+; Burkert+; Molinari+; Menten

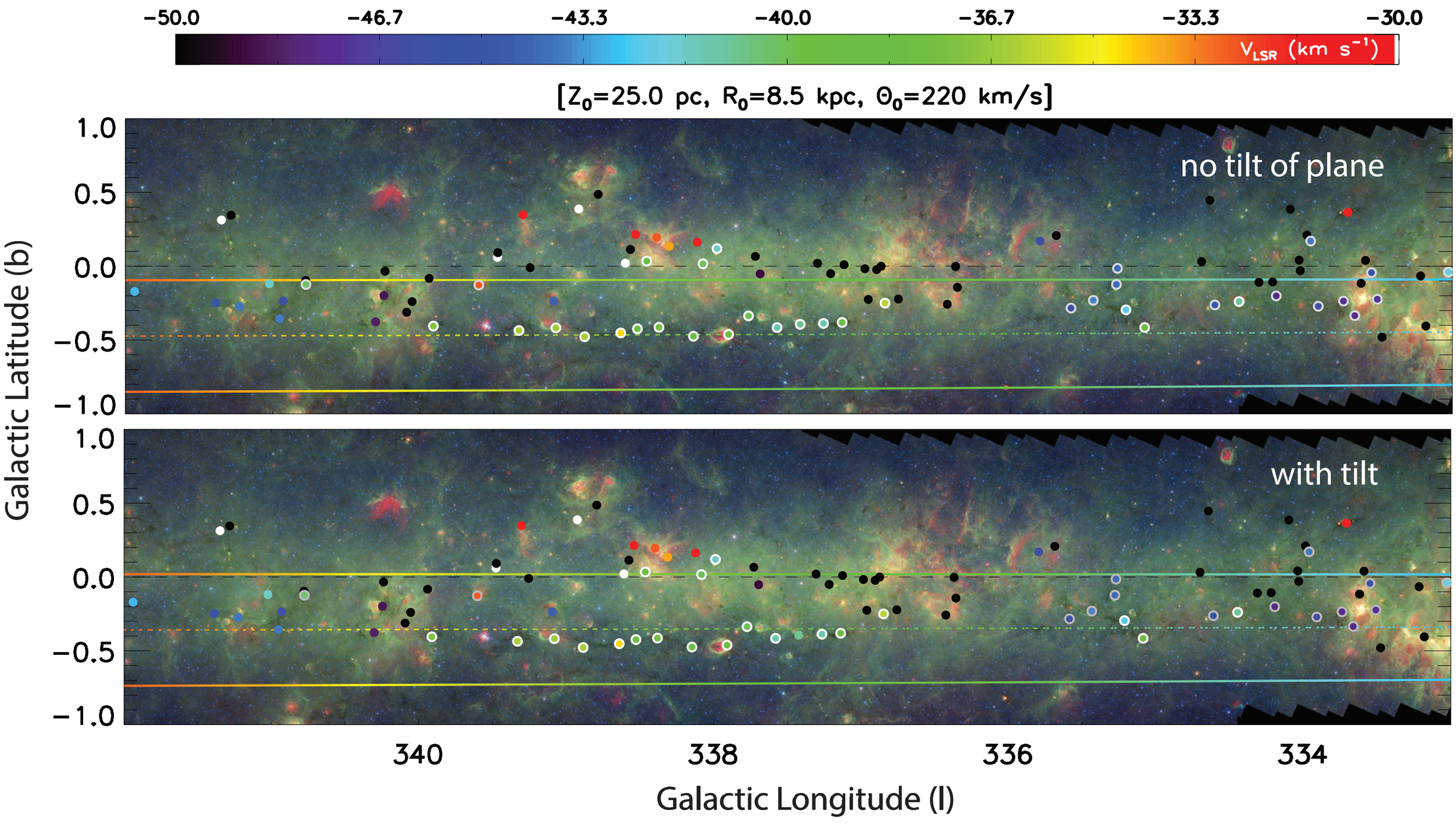
1st-year Harvard grad student C. Zucker working on this!

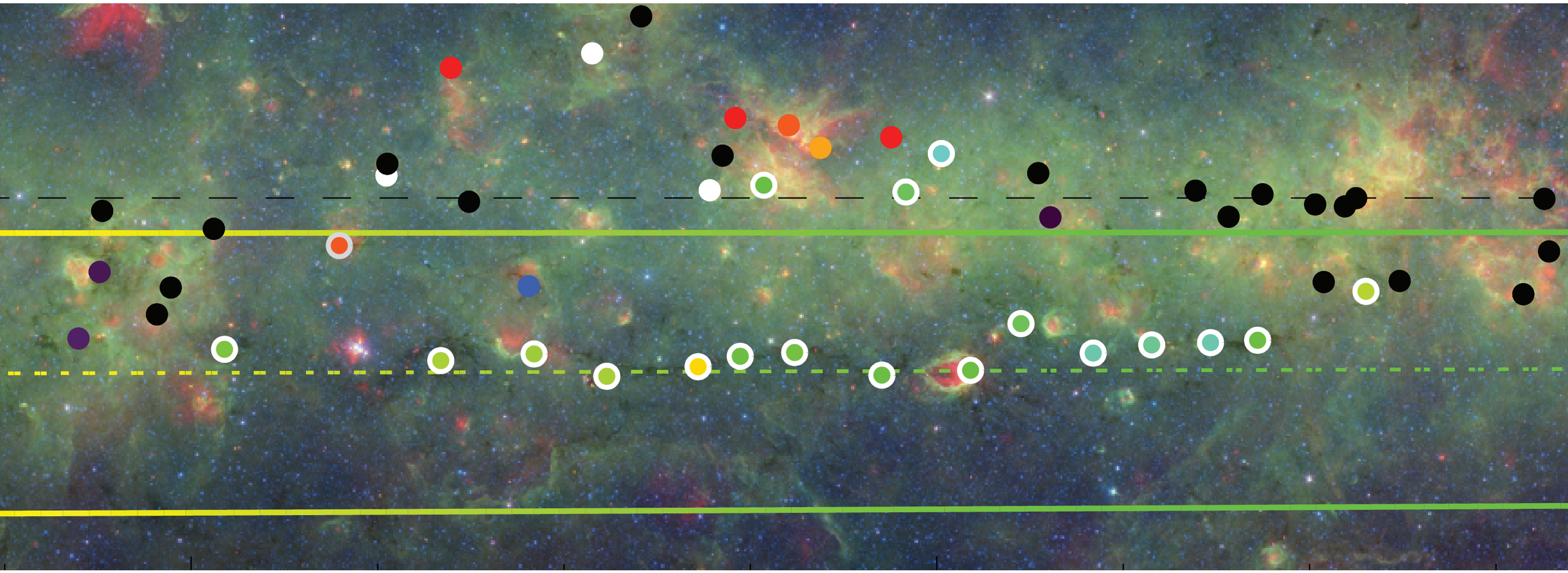
2012: *Andi Burkert asked a question*:

Is Nessie "parallel to the Galactic Plane"?

2016: Yes. And, it has friends, and they're very useful.

In the plane, and at distance of spiral arm!





...eerily precisely...

THE SKELETON OF THE MILKY WAY

Catherine Zucker[1], Cara Battersby[2], and Alyssa Goodman[2]
[1] Astronomy Department, University of Virginia, Charlottesville, VA 22904, USA; catherine.zucker@cfa.harvard.edu
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Received 2015 June 27; accepted 2015 September 21; published 2015 MM DD

ABSTRACT

Recently, Goodman et al. argued that the very long, very thin infrared dark cloud "Nessie" lies directly in the Galactic midplane 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, arguing that Nessie is not a curiosity but one of several filaments that could potentially trace Galactic structure. Our 10 bone candidates are all long, filamentary, mid-infrared extinction features that 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 10 candidates, 6 also have a projected aspect ratio of $\geqslant$50:1; run along, or extremely close to, the Scutum–Centaurus Arm in p–p–v space; *and* exhibit no abrupt shifts in velocity. The evidence presented here suggests that these candidates mark 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.

Key words: Galaxy: kinematics and dynamics – Galaxy: structure – ISM: clouds

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 $\geqslant$50:1.

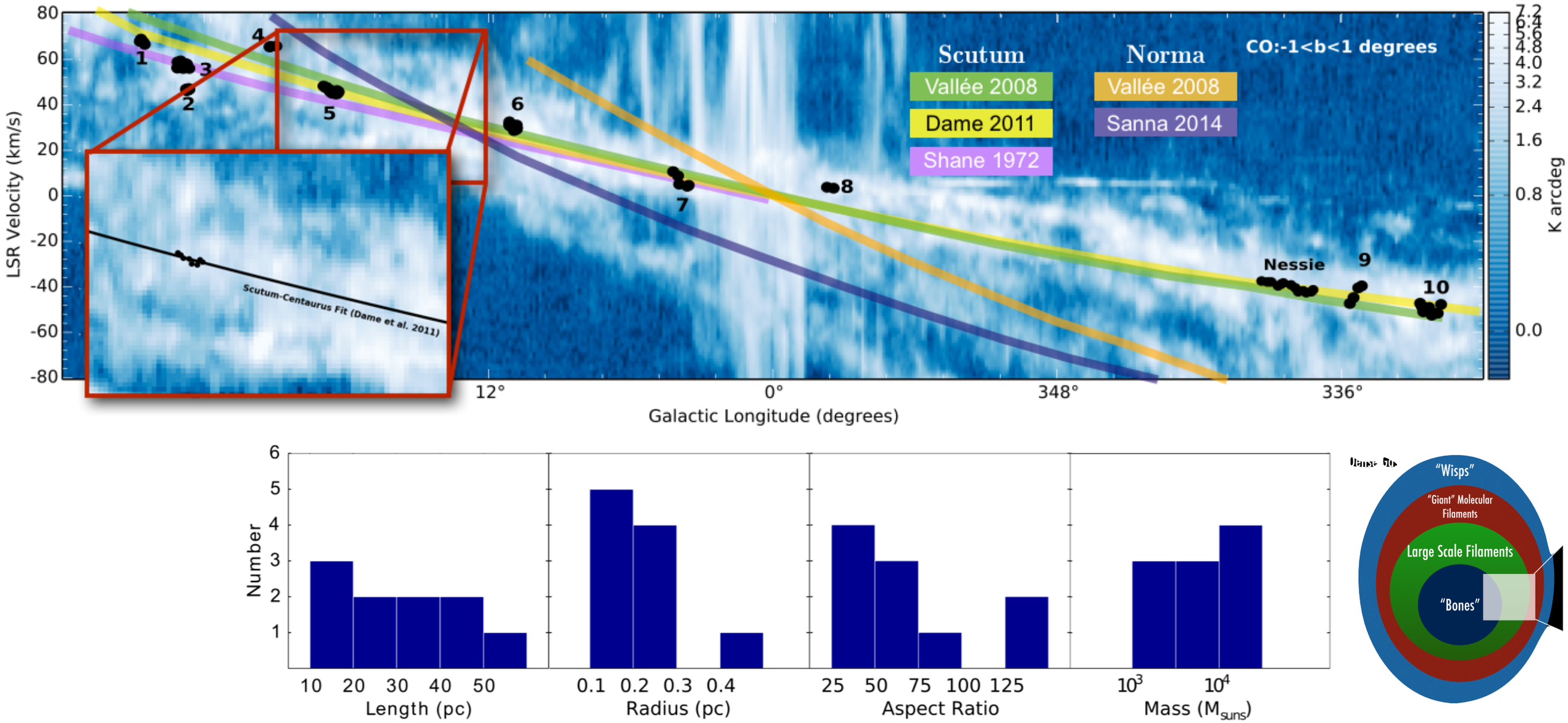


Figure 3. Distributions of length, radius, aspect ratio, and mass for the 10 bone candidates, based on data from Table 2.

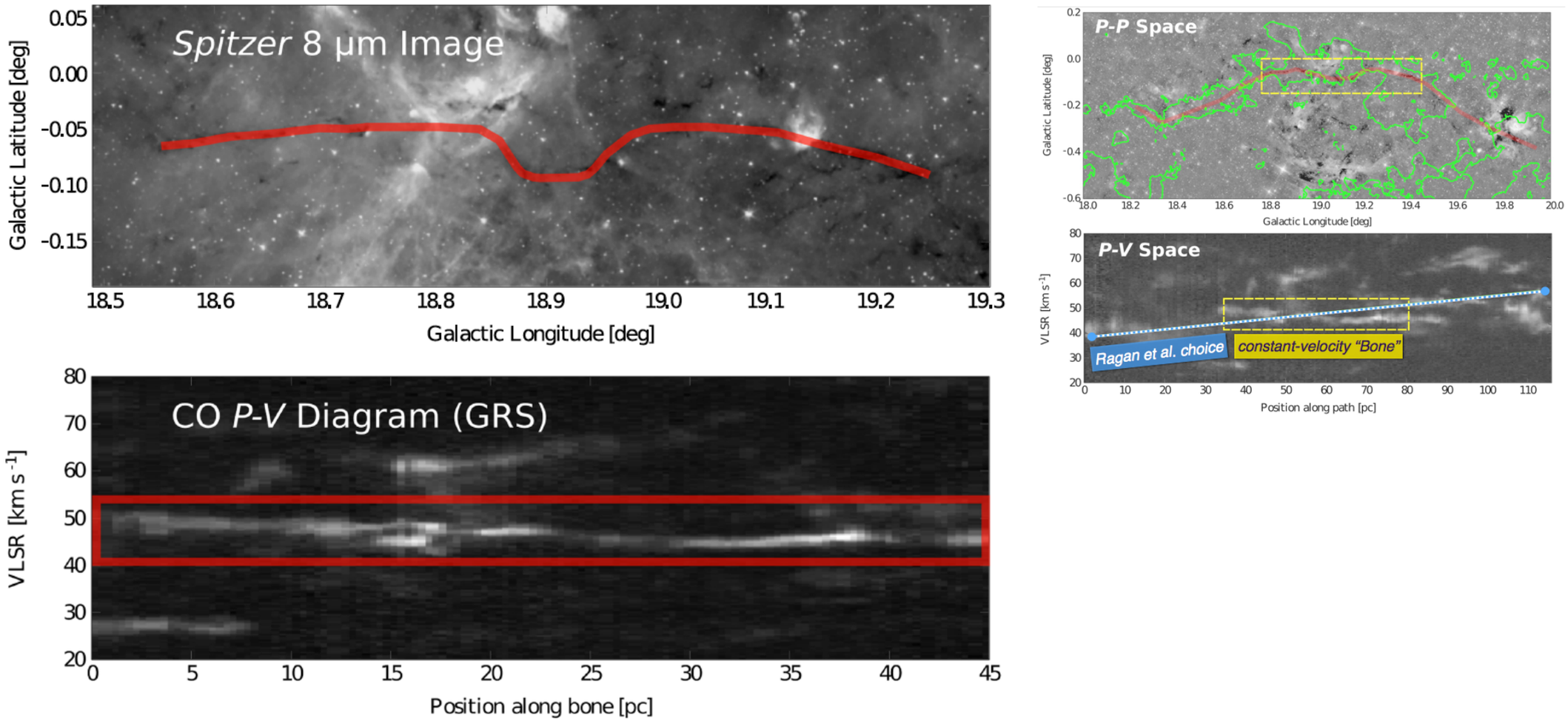


Figure 1. Results of performing a slice extraction along the filamentary extinction feature of our strongest bone candidate, filament 5. The top panel shows a *Spitzer*-GLIMPSE 8 μm image of filament 5, and the red trace indicates the curve (coincident with the extinction feature) along which a *p–v* slice was extracted. The bottom panel shows the *p–v* slice, with the red boxed region indicating the emission corresponding to filament 5.

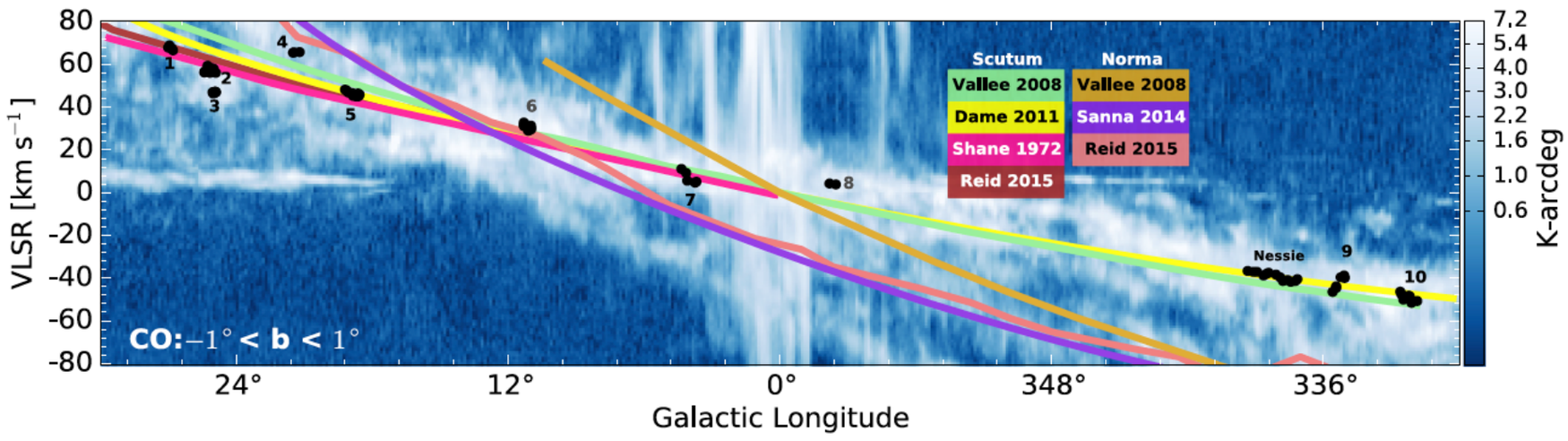
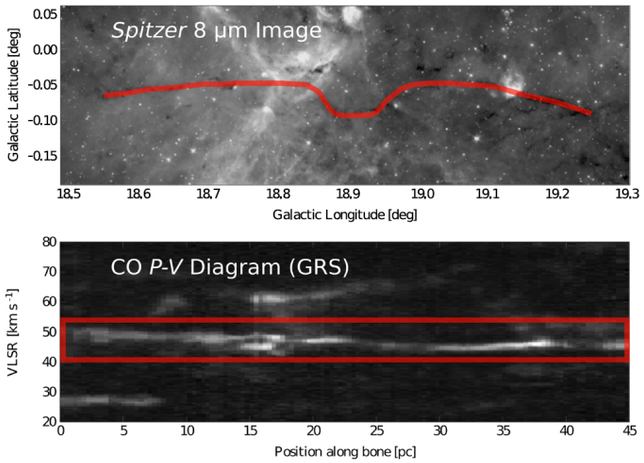


Figure 2. Position–velocity summary of bone candidates and spiral arm models. Blue background shows ^{12}CO emission from Dame et al. (2001), integrated between $-1^\circ < b < 1^\circ$. Black dots show measurements of BGPS-, HOPS-, MALT90-, and GRS-determined velocities, with particular candidate filaments identified by number (see Table 1 for further identification), or, in the case of Nessie, by name. Lines of varying color show predicted *p–v* spiral arm traces from the literature (see text for references).

Zucker, Battersby & Goodman 2015



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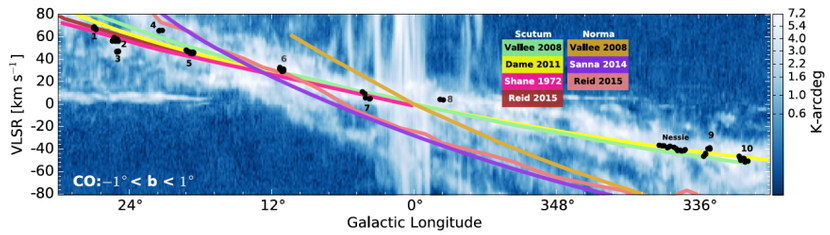

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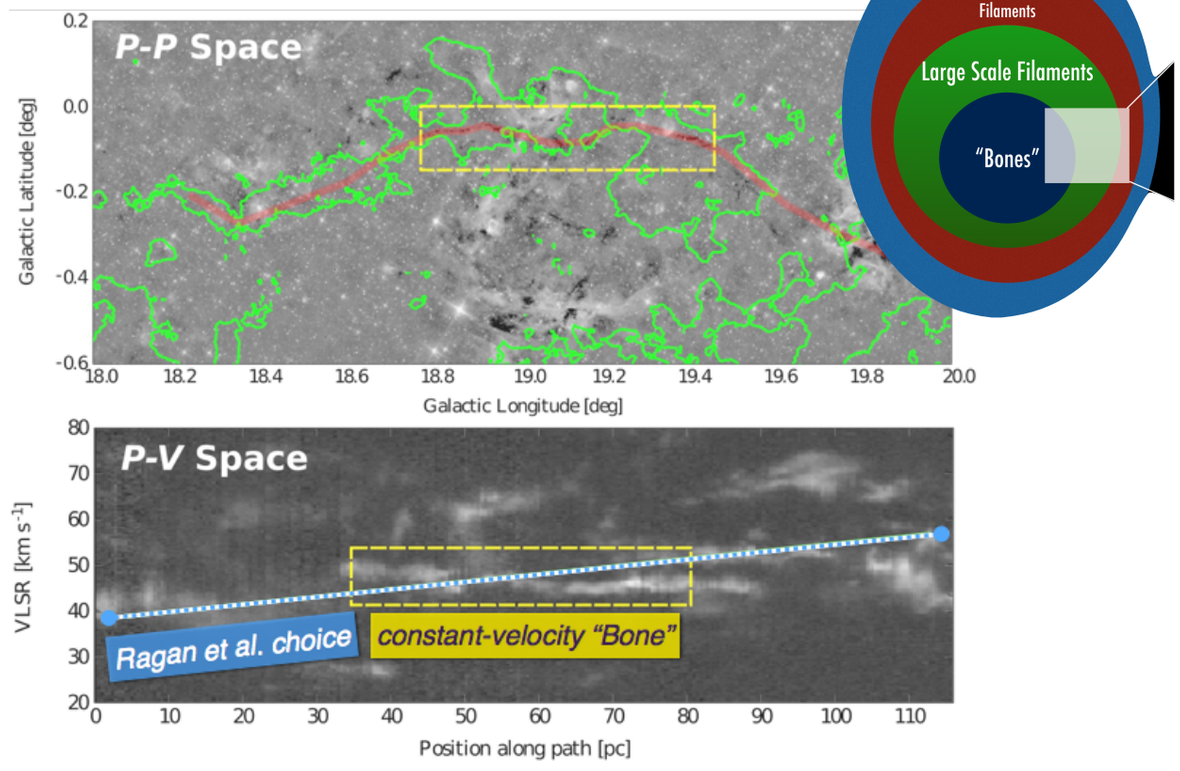


Ragan et al. 2014

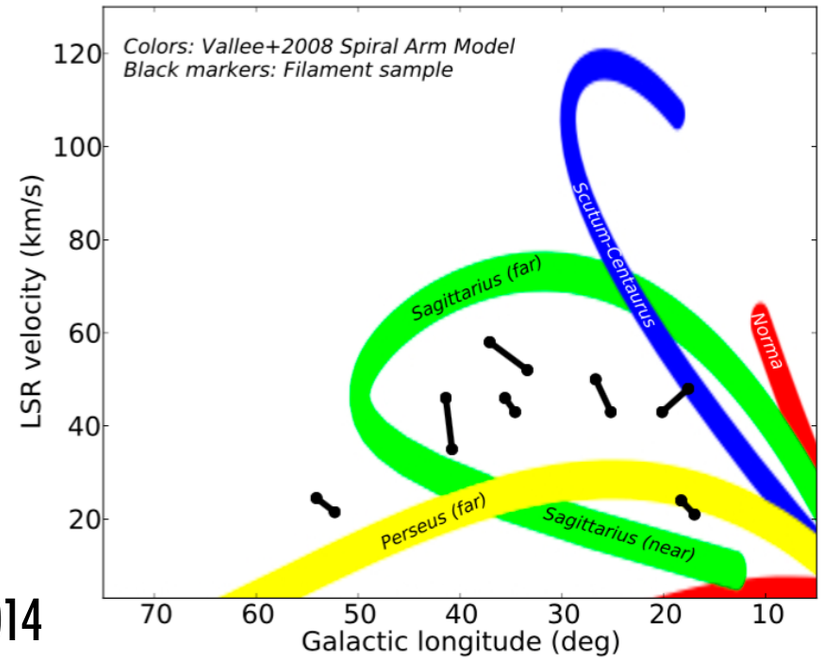


Fig. 4. Illustration of the predicted LSR velocities of the Norma (red), Scutum-Centaurus (blue), Sagittarius-Carina (green), and (far) Perseus (yellow) spiral arms as a function of Galactic longitude in the first quadrant taken from Vallée (2008). Each set of two black circles represent the filament sample, taking approximate values of $v_{\rm lsr}$ from the ends of the filaments.

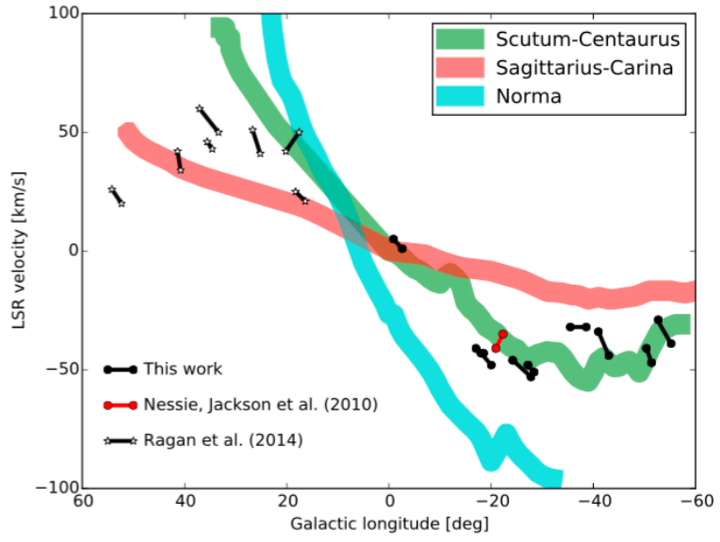
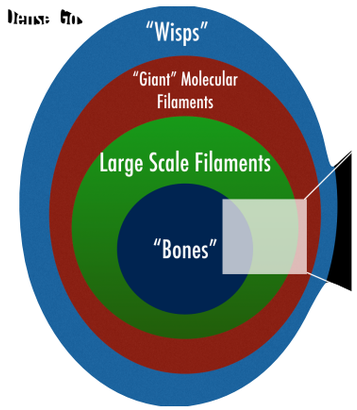
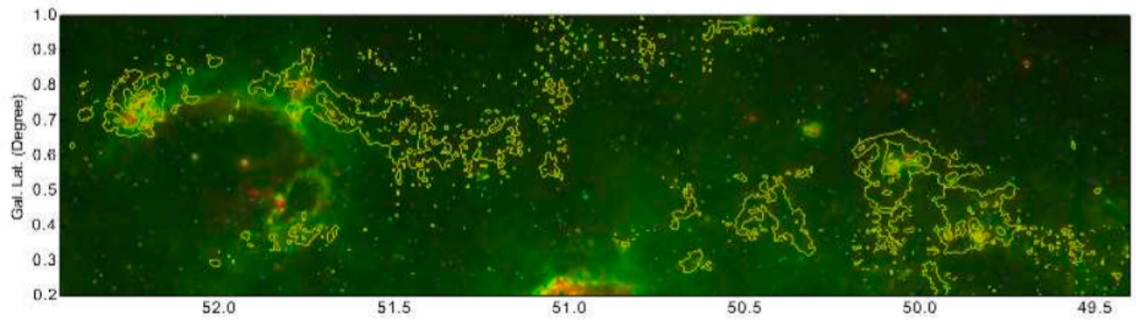
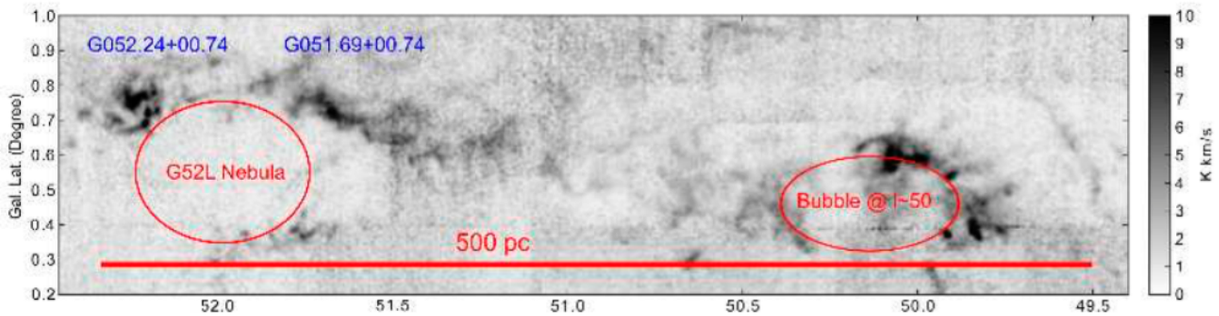


Fig. 1. LSR velocities of the Norma (cyan), Scutum-Centaurus (green) and Sagittarius-Carina (red) spiral arms as function of galactic longitude, as estimated by Reid et al. (2014). The width of the lines, 8 km/s, is equivalent to the spatial width of the filaments from (Reid et al. 2014). For simplicity, we only show the near kinetic distances of the spiral arms. Each line segment represents a GMF, taking the $v_{\rm LSR}$ values from the ends of the filaments. The line segments ended with black circles show GMFs of our sample while those with white stars belong to R14. We also show "Nessie", with a red line ended in red circles.

Abreu-Vicente et al. 2014







Astronomy & Astrophysics manuscript no. paper_filament_bubble
October 14, 2013
©ESO 2013

A 500 pc filamentary gas wisp in the disk of the Milky Way

Guang-Xing Li[1], Friedrich Wyrowski[1], Karl Menten[1], and Arnaud Belloche[1]

Max-Planck Institut für Radioastronomie, Auf dem Hügel, 69, 53121 Bonn, Germany

ABSTRACT

Star formation occurs in molecular gas. In previous studies, the structure of the molecular gas has been studied in terms of molecular clouds, but has been overlooked beyond the cloud scale. We present an observational study of the molecular gas at $49.5^\circ < l < 52.5^\circ$ and -5.0 km s^{-1} $< v_{\rm lsr} <$ 17.4 km s^{-1}. The molecular gas is found in the form of a huge ($\gtrsim$ 500 pc) filamentary gas wisp. This has a large physical extent and a velocity dispersion of $\sim$ 5 km s^{-1}. The eastern part of the filamentary gas wisp is located $\sim$ 130 pc above the Galactic disk (which corresponds to 1.5–4 e-folding scale-heights), and the total mass of the gas wisp is $\gtrsim 1 \times 10^5 M_\odot$. It is composed of two molecular clouds and an expanding bubble. The velocity structure of the gas wisp can be explained as a smooth quiescent component disturbed by the expansion of a bubble. That the length of the gas wisp exceeds by much the thickness of the molecular disk of the Milky Way is consistent with the cloud-formation scenario in which the gas is cold prior to the formation of molecular clouds. Star formation in the filamentary gas wisp occurs at the edge of a bubble (G52L nebula), which is consistent with some models of triggered star formation.

Key words. ISM: clouds –ISM: bubbles–ISM: kinematics and dynamics —ISM: clouds– Stars: formation –Galaxies: structure

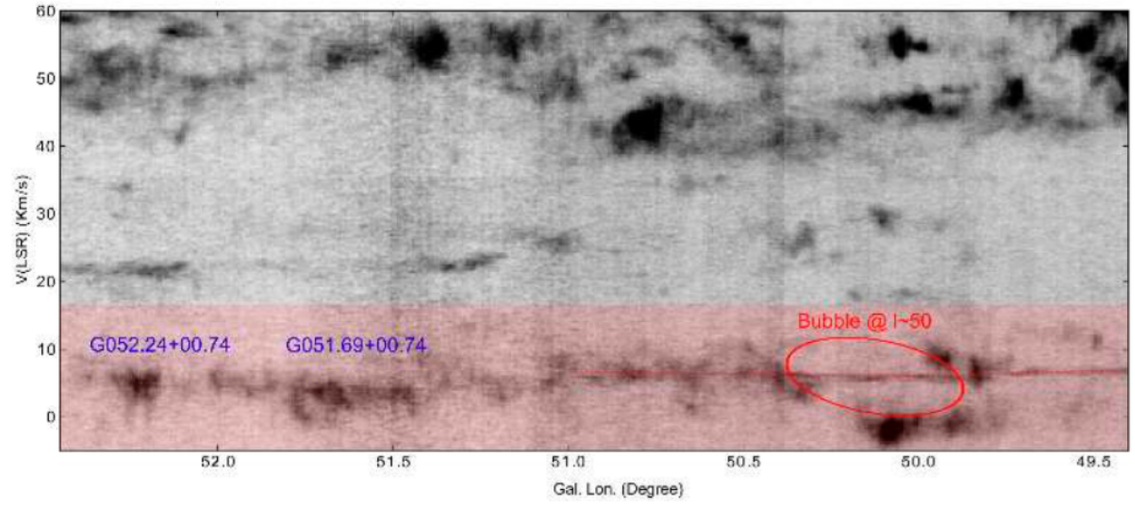
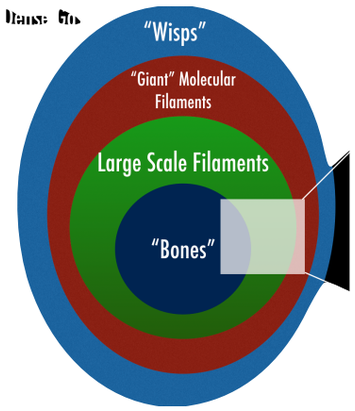


Fig. 1. Top panel: Spitzer GLIMPSE (Benjamin et al. 2003) and MIPSGAL (Carey et al. 2009) three-color image of the region. Red: 24 μm, green: 8 μm, blue: 3.6 μm. Overlaid contours are the velocity-integrated ^{13}CO(1-0) emission (-5.0 km s^{-1} $< v_{\rm lsr} <$ 17.4 km s^{-1}) from the Galactic Ring Survey (Jackson et al. 2006). Contours correspond to 3.5, 7.3, 11.2, 15 K km s^{-1}. **Middle panel:** Velocity-integrated ^{13}CO(1-0) map of the region integrated within -4.95 km s^{-1} $< v_{\rm lsr} <$ 17.36 km s^{-1}. A scale bar of 500 pc is added assuming a kinematic distance of 9.8 kpc. **Bottom panel:** Galactic-latitude-integrated ^{13}CO(1-0) position-velocity map of the region (integrated from $-0.2^\circ < b < 1^\circ$). The clouds G052.24+00.74, G051.69+00.74, the bubble at $l \sim 50^\circ$, and the G52L nebula (Bania et al. 2012) are indicated in the middle and bottom panels. The velocity range we used to produce the ^{13}CO(1-0) integrated intensity map is indicated in the bottom panel as the red shaded region. The emission at 5.2 km s^{-1} $< v_{\rm lsr} <$ 7.2 km s^{-1} is due to contamination from a different molecular cloud, and some of the emission lies on the red dashed line. This component has a smaller line width $\lesssim$ 0.5 km s^{-1}, which implies that the contamination comes from a close-by cloud. This is supported by its apparent diffuse morphology. Channel maps of the region are provided in Appendix A.



Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY

MNRAS **450,** 4043–4049 (2015) doi:10.1093/mnras/stv735

Large-scale filaments associated with Milky Way spiral arms

Ke Wang,[1⋆] Leonardo Testi,[1,2,3] Adam Ginsburg,[1] C. Malcolm Walmsley,[3,4] Sergio Molinari[5] and Eugenio Schisano[5]

[1] *European Southern Observatory (ESO) Headquarters, Karl-Schwarzschild-Str. 2, D-85748 Garching bei München, Germany*
[2] *Excellence Cluster Universe, Boltzmannstr. 2, D-85748 Garching bei München, Germany*
[3] *INAF – Osservatorio astrofisico di Arcetri, Largo E. Fermi 5, I-50125 Firenze, Italy*
[4] *Dublin Institute of Advanced Studies, Fitzwilliam Place 31, Dublin 2, Ireland*
[5] *Istituto di Astrofisica e Planetologia Spaziali – IAPS, Istituto Nazionale di Astrofisica – INAF, via Fosso del Cavaliere 100, I-00133 Roma, Italy*

Accepted 2015 March 31. Received 2015 March 31; in original form 2015 February 1

ABSTRACT

The ubiquity of filamentary structure at various scales throughout the Galaxy has triggered a renewed interest in their formation, evolution, and role in star formation. The largest filaments can reach up to Galactic scale as part of the spiral arm structure. However, such large-scale filaments are hard to identify systematically due to limitations in identifying methodology (i.e. as extinction features). We present a new approach to directly search for the largest, coldest, and densest filaments in the Galaxy, making use of sensitive *Herschel* Hi-GAL (*Herschel* Infrared Galactic Plane Survey) data complemented by spectral line cubes. We present a sample of the nine most prominent *Herschel* filaments, including six identified from a pilot search field plus three from outside the field. These filaments measure 37–99 pc long and 0.6–3.0 pc wide with masses (0.5–8.3) $\times$ 10^4 $M_\odot$, and beam-averaged (28 arcsec, or 0.4–0.7 pc) peak H_2 column densities of (1.7–9.3)$\times$ 10^{22} cm^{-2}. The bulk of the filaments are relatively cold (17–21 K), while some local clumps have a dust temperature up to 25–47 K. All the filaments are located within $\lesssim$60 pc from the Galactic mid-plane. Comparing the filaments to a recent spiral arm model incorporating the latest parallax measurements, we find that 7/9 of them reside within arms, but most are close to arm edges. These filaments are comparable in length to the Galactic scaleheight and therefore are not simply part of a grander turbulent cascade.

Key words: catalogues – stars: formation – ISM: clouds – ISM: structure – Galaxy: structure.

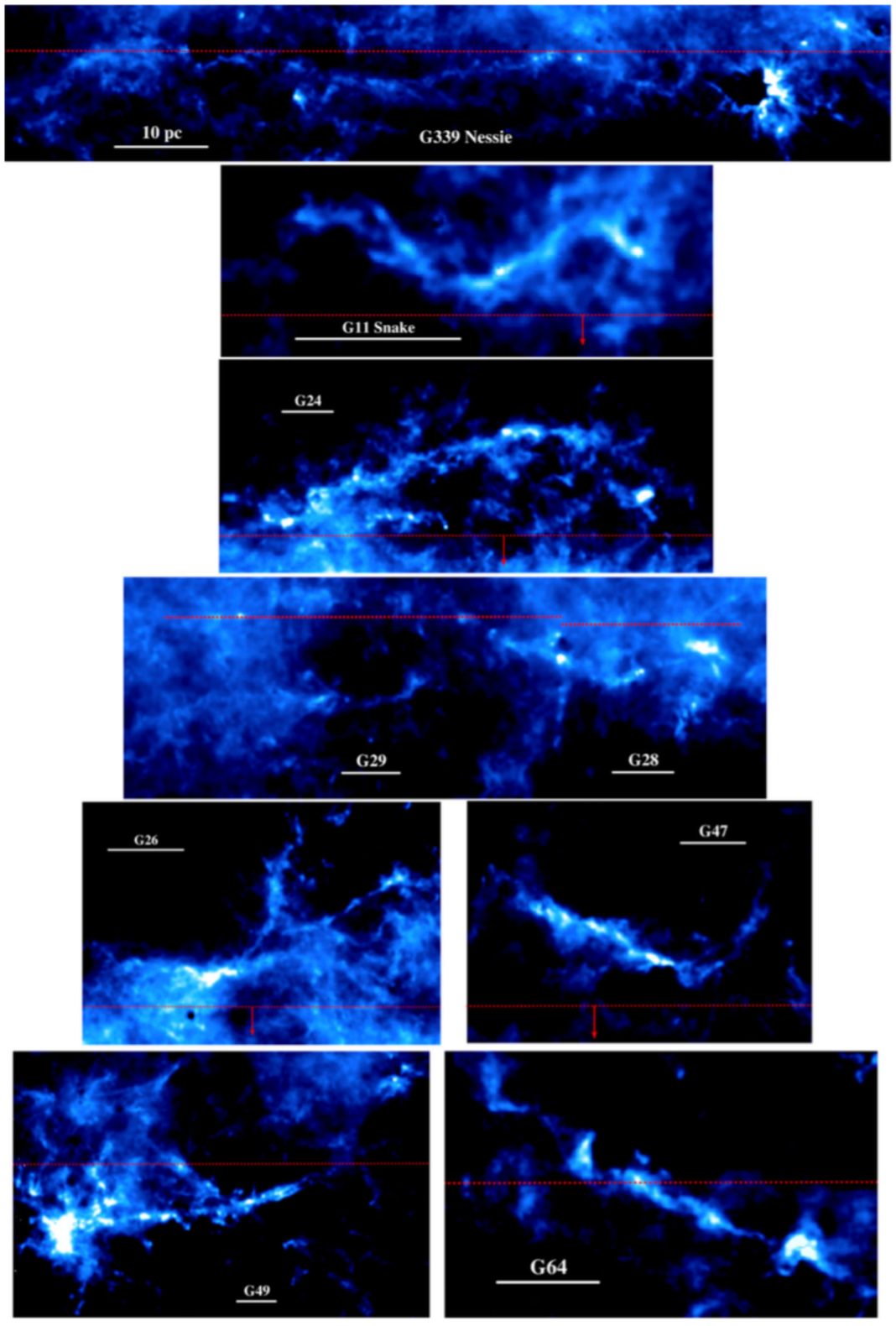
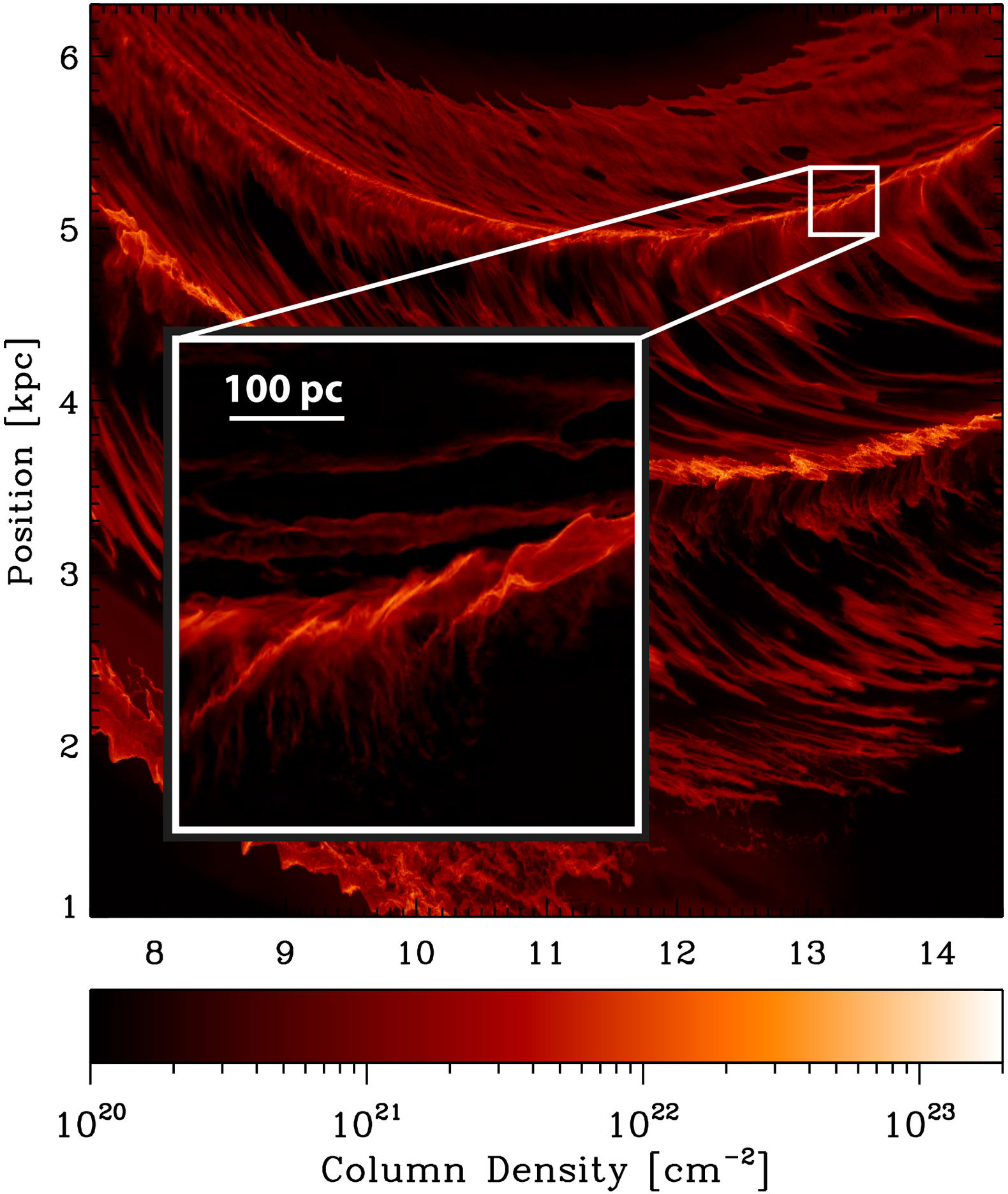


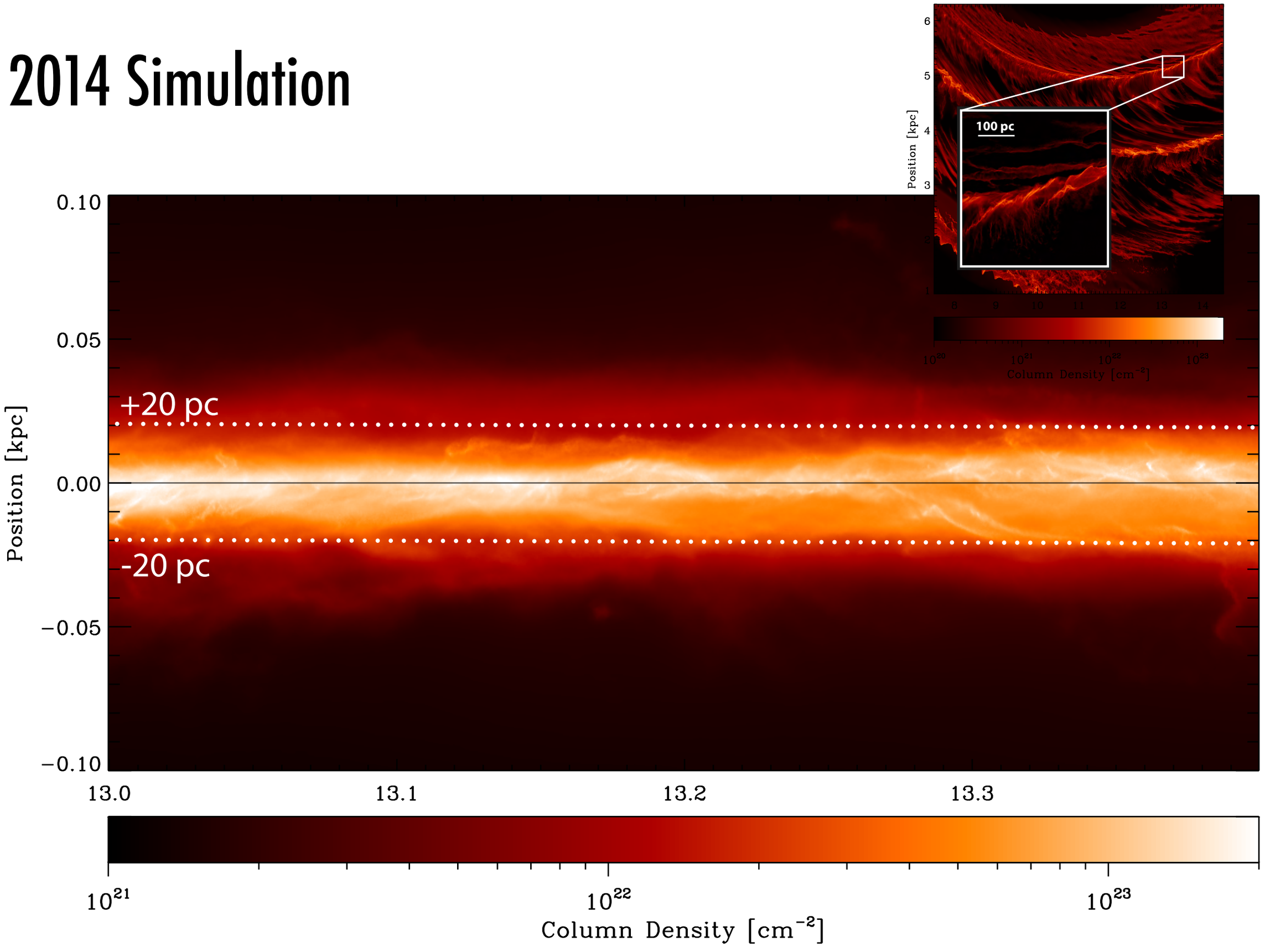
Figure 2. Gallery of the selected filaments: column density maps plotted in logarithmic scale in Galactic coordinates. See peak/mean densities for each filament in Table 1. The scale bars denote 10 pc. The red dotted line depicts Galactic plane at the source distance; when accompanied by a red arrow (G11, G24, G26, and G47), it means that the plane is outside of the plotted area, parallel to the red dotted line, at the direction of the arrow. Table 1 lists distance to Galactic plane for each filament.

2014 Simulation



Smith et al. 2014, using AREPO

2014 Simulation

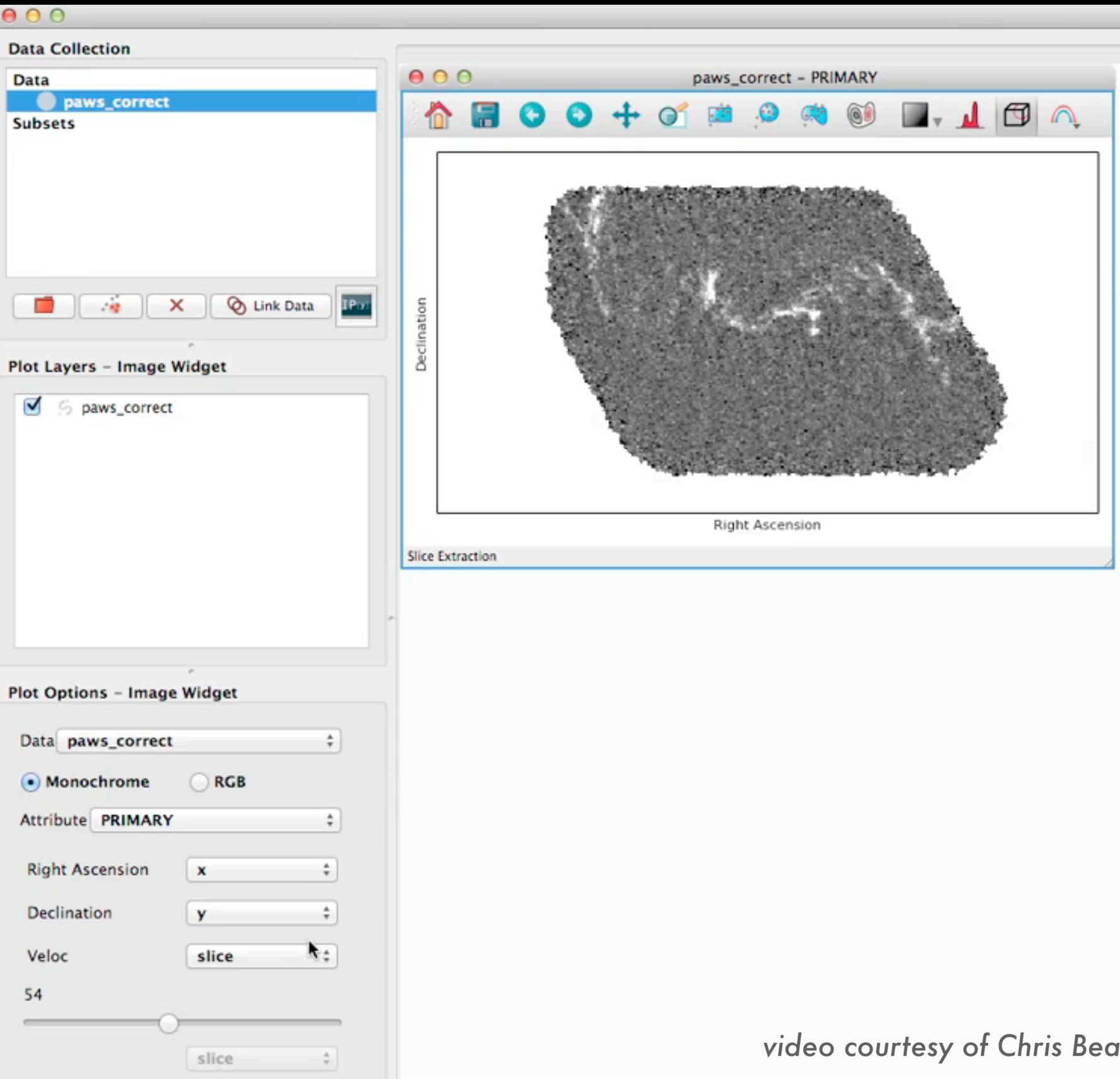


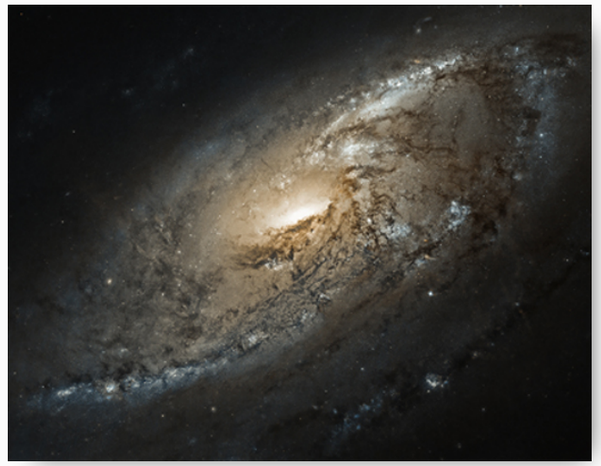
Smith et al. 2014, using AREPO (hydro+chemistry, imposed potential, no B-fields, no local (self-)gravity, no feedback)

Great, but we need synthetic line maps

(Rowan & Ralf both promised
this in person,
in the past 4 days!)

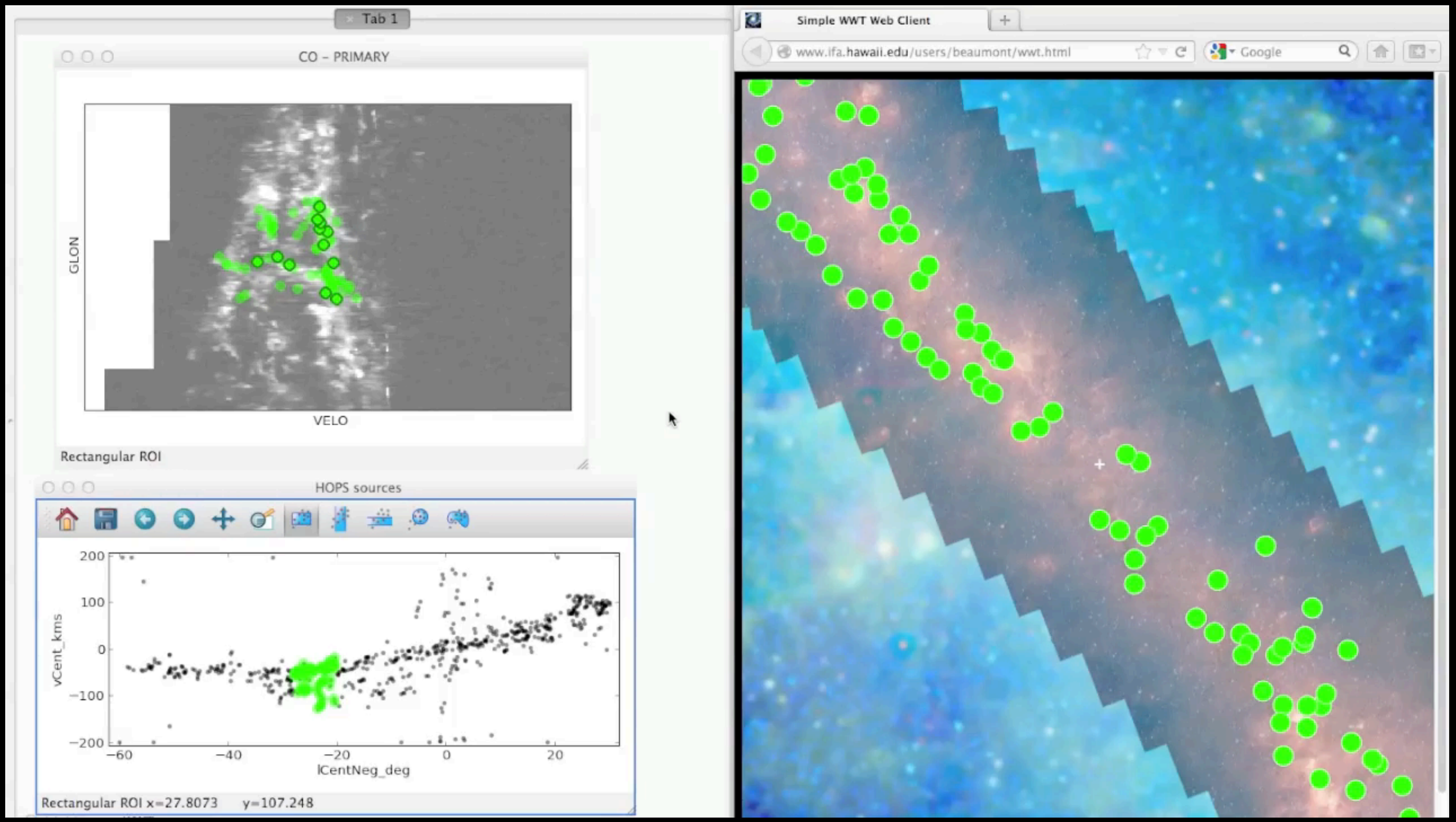
VELOCITY SLICES ON FIDUCIAL "DIMENSIONS"





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

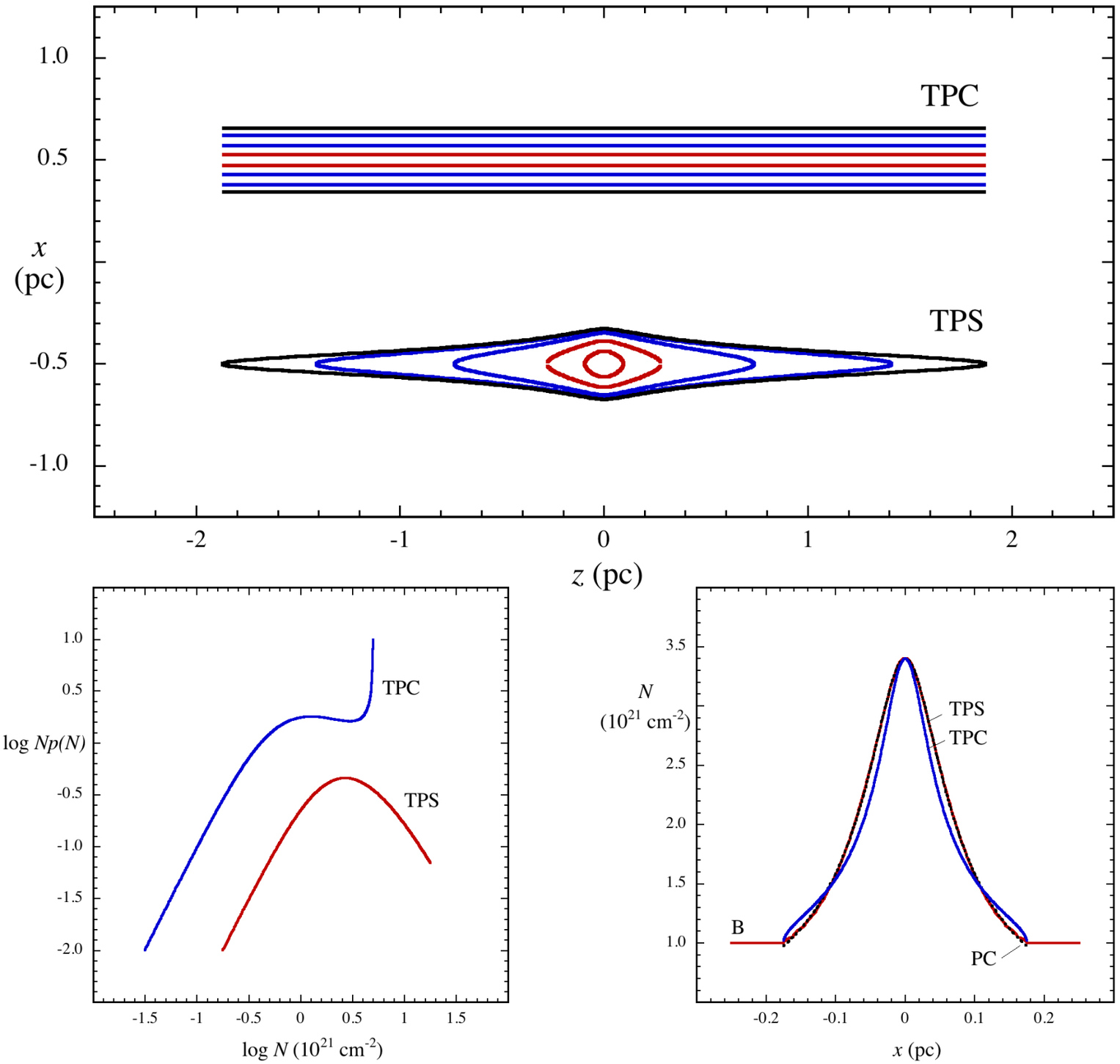
SOFTWARE: GLUE+WWT TOGETHER



Video courtesy of Chris Beaumont

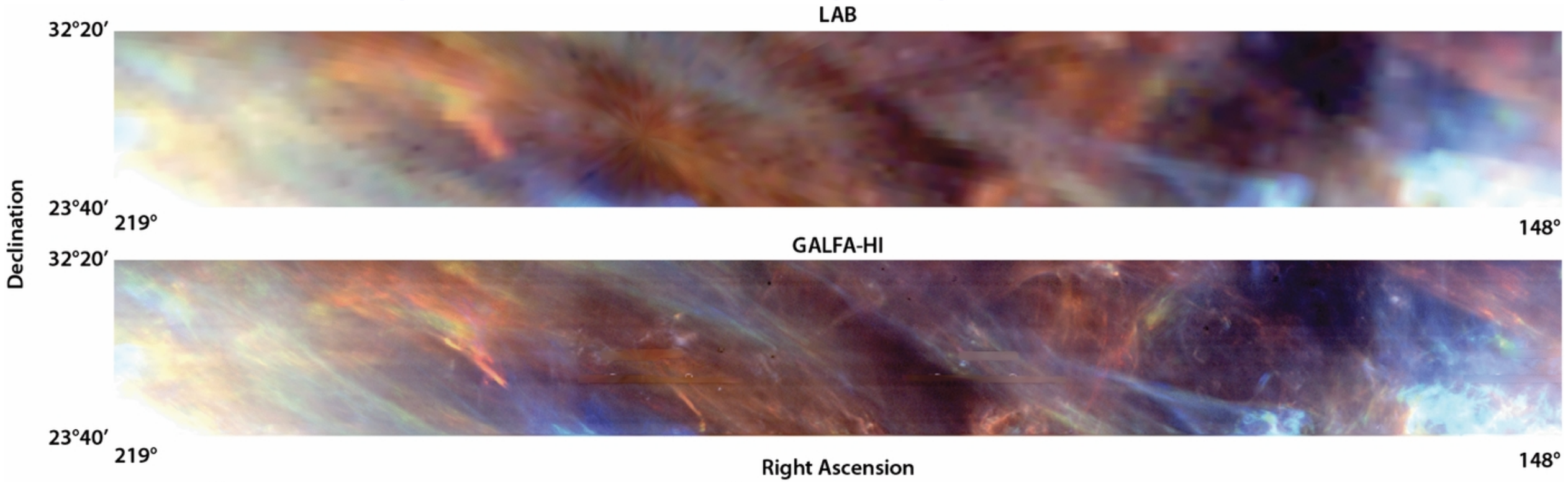
Filament models: truncated Plummer spheroid (TPS) matches observed *N*-maps and *N*-pdfs better than Plummer cylinder, and has similar mean *N*-profile

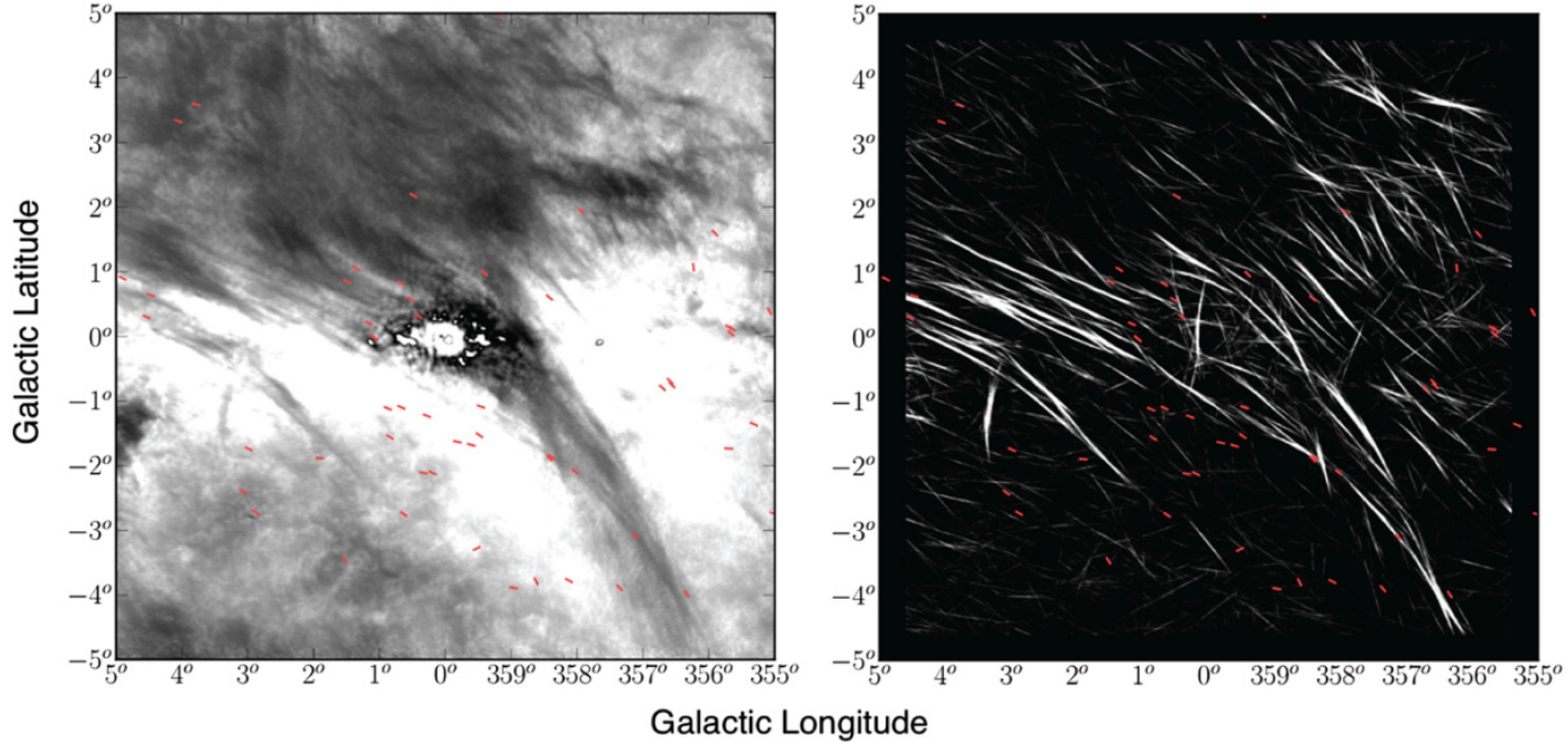
from Phil Myers



TPS and TPC models: $p = 2$, $r_0 = 0.035$ pc, $x_max = 0.175$ pc, $z_max = 2.1$ pc, $M/L = 12.1$ M_Sun/pc. *N*-contours: 0.5, 1, 2, 4, 8 10^21 cm^-2.
TPS model: $n_0 = 6.0$ 10^4 cm^-3, $N_max = 18$ 10^21 cm^-2, $a_in = 1$, $a_out = 12$. TPC model: $n_0 = 1.7$ 10^4 cm^-3, $N_max = 5.0$ 10^21 cm^-2.

HI shows huge filaments/combing, aligned with B....





Clark, Peek & Putnam 2014

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.)

TOPIC

How Long, and Long-lasting, are Filaments?

EXPERTISE

Profs. A. Goodman, D. Finkbeiner, et al. @ CfA
(obs-sim comparison, stats, viz, software, $\vec{B}$)

PROBLEM 1

On what scale(s) does filamentary structure matter, and when, in the end-game of star-formation?

PROBLEM 2

What constraints do "bones" offer on:
-the shape of the Galaxy, especially in the vertical direction?
-galaxy evolution models on "short" timescales

PHD 1

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Particular focus on timing.

with: Klessen, Glover+; Smith, Fuller+; Caselli, Pineda+; Alves, Lombardi, Hacar, Tafalla+

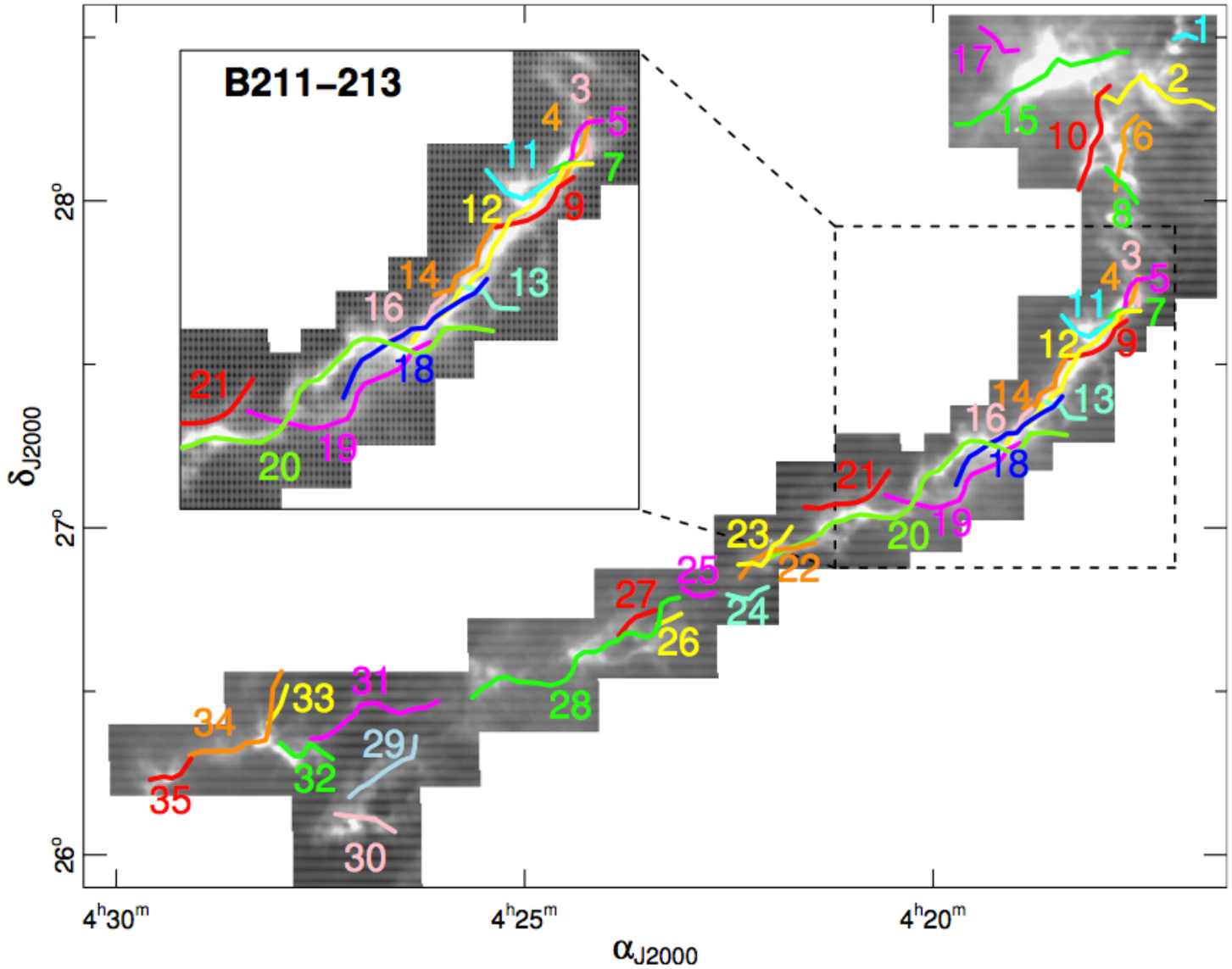
related to work of 5th-year Harvard grad student H. Chen

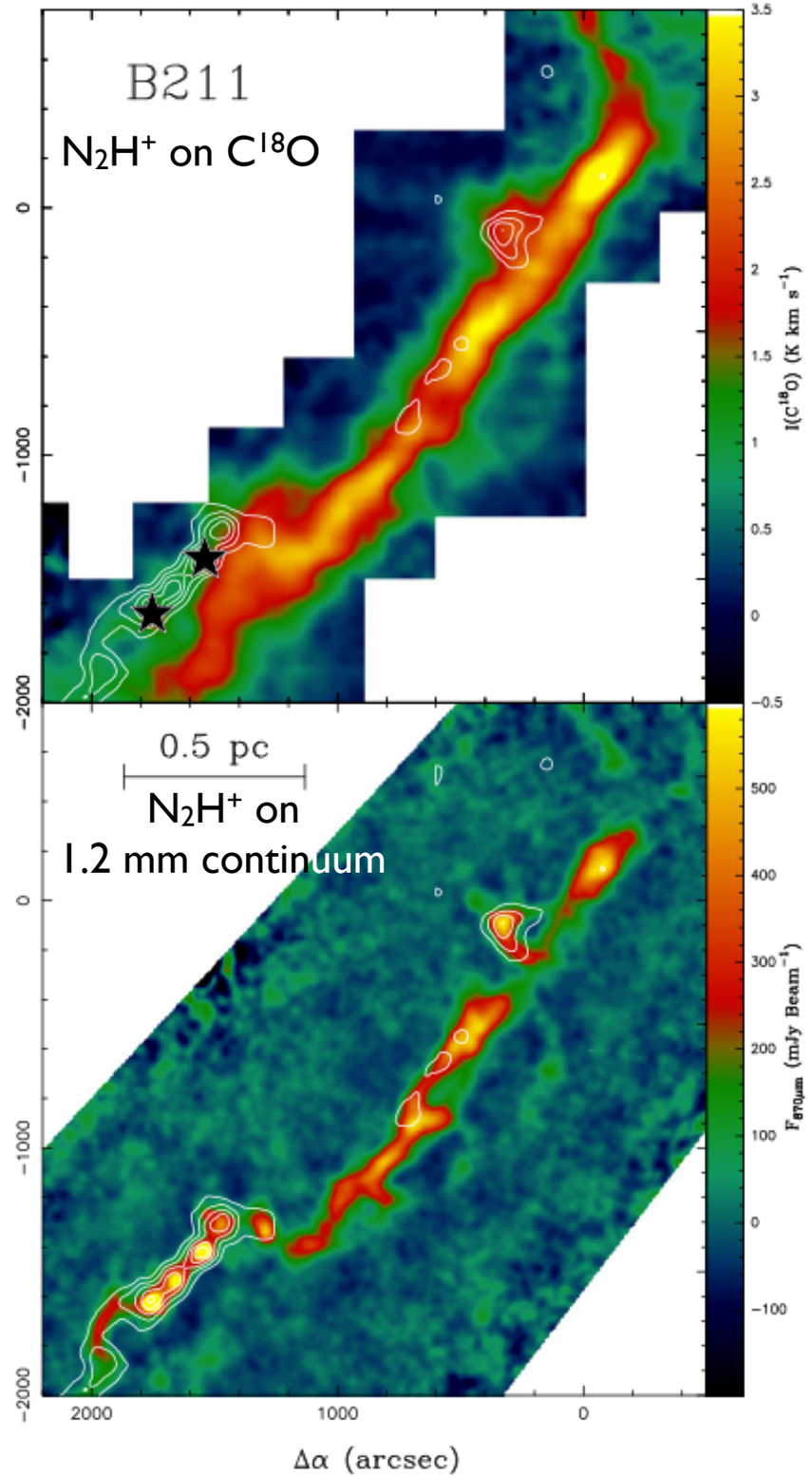
PHD 2

Using synthetic observations of models of dense gas & dust structures in MW-like galaxies, measure statistics & compare with observations to facilitate estimates re:observed shape, and evolution of "bones."

with: Smith, Fuller+; Burkert+; Molinari+; Menten

1st-year Harvard grad student C. Zucker working on this!





Now, we are trying FIVe, from Hacar et al. 2013, and other clustering algorithms, to study "coherent" core-filament relation.

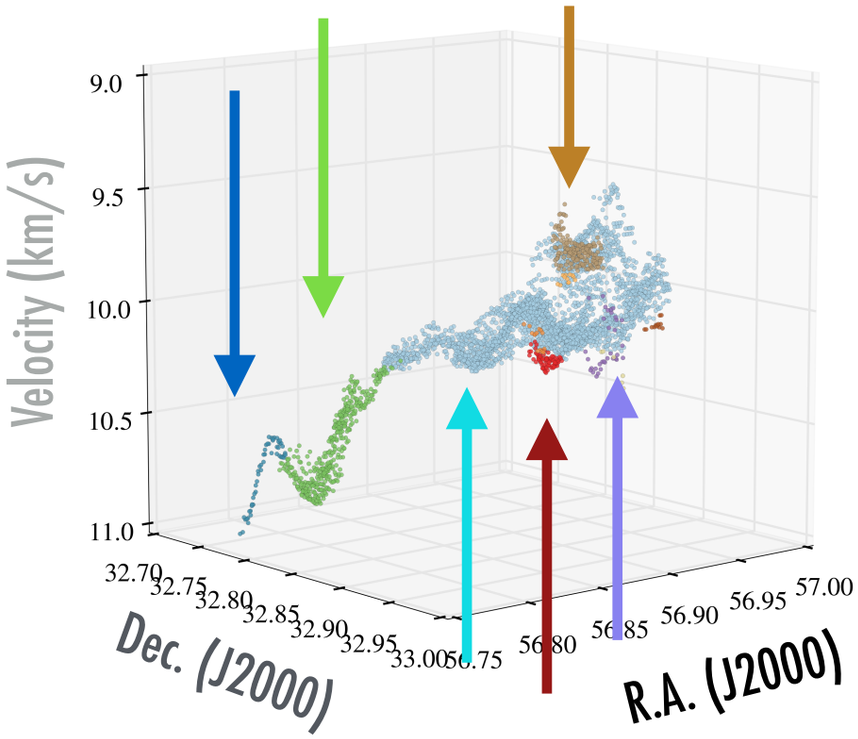
Filaments offer pre-existing density enhancement.

Collapse is rapid enough that aboriginal filament is not erased, even within a "coherent core."

In B5, small bound cluster will form c. 40K years from now.

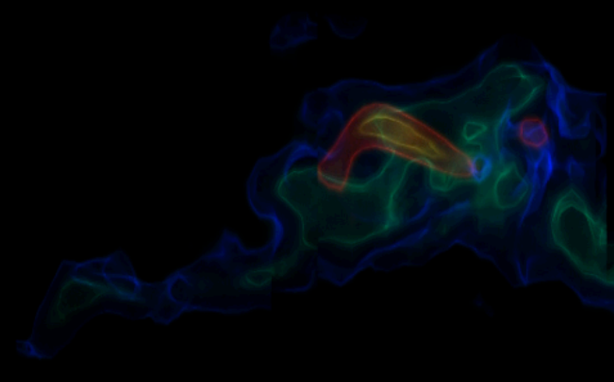
HOT OFF THE PRESS: "FIBERS" WITHIN B5

There are at least three different components in the position-position-velocity space.



And potentially, many more...

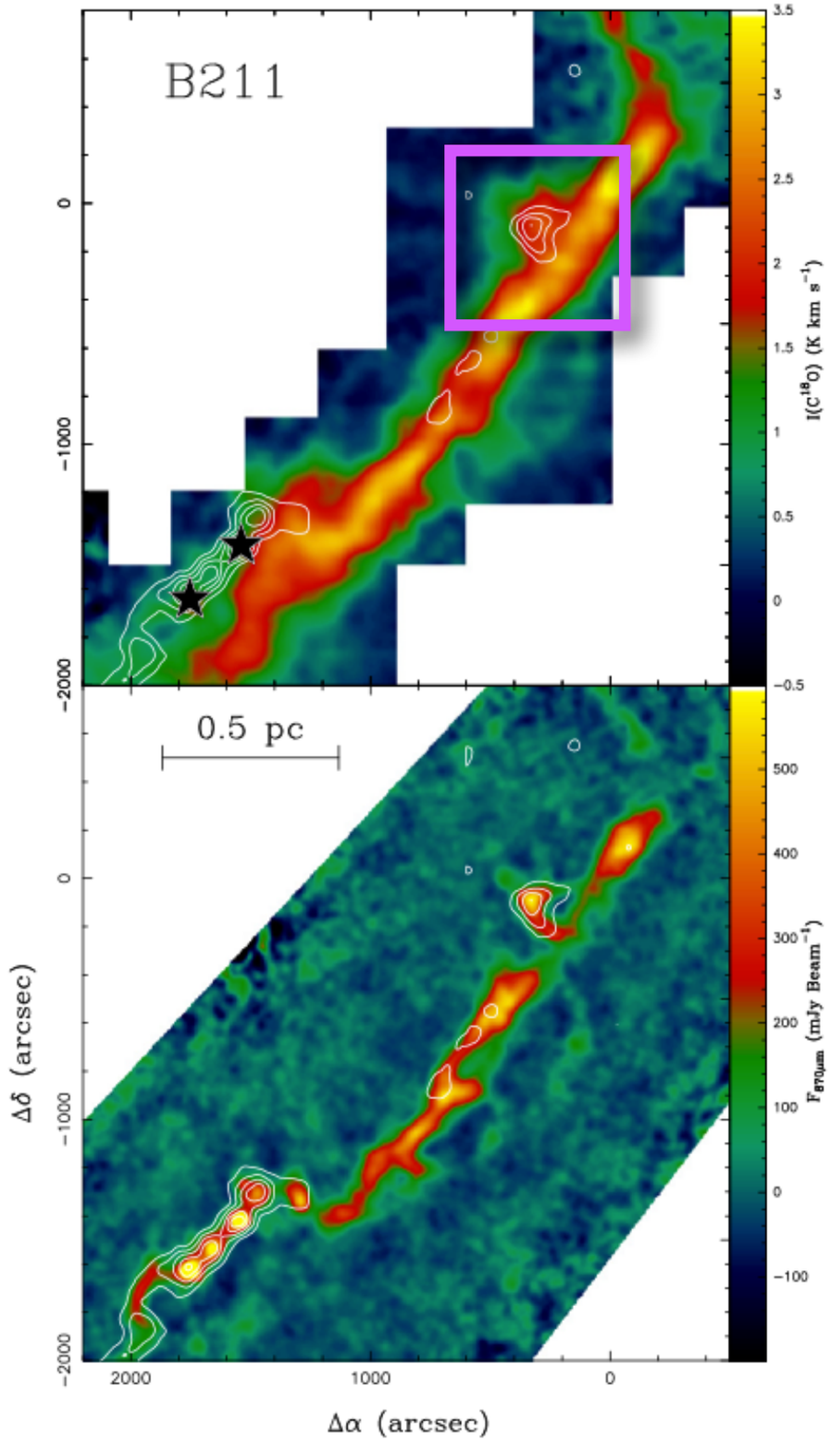
Gaussian fitted C18O (2-1) peaks
with components found using FIVE algorithm (Hacar et al. 2013)



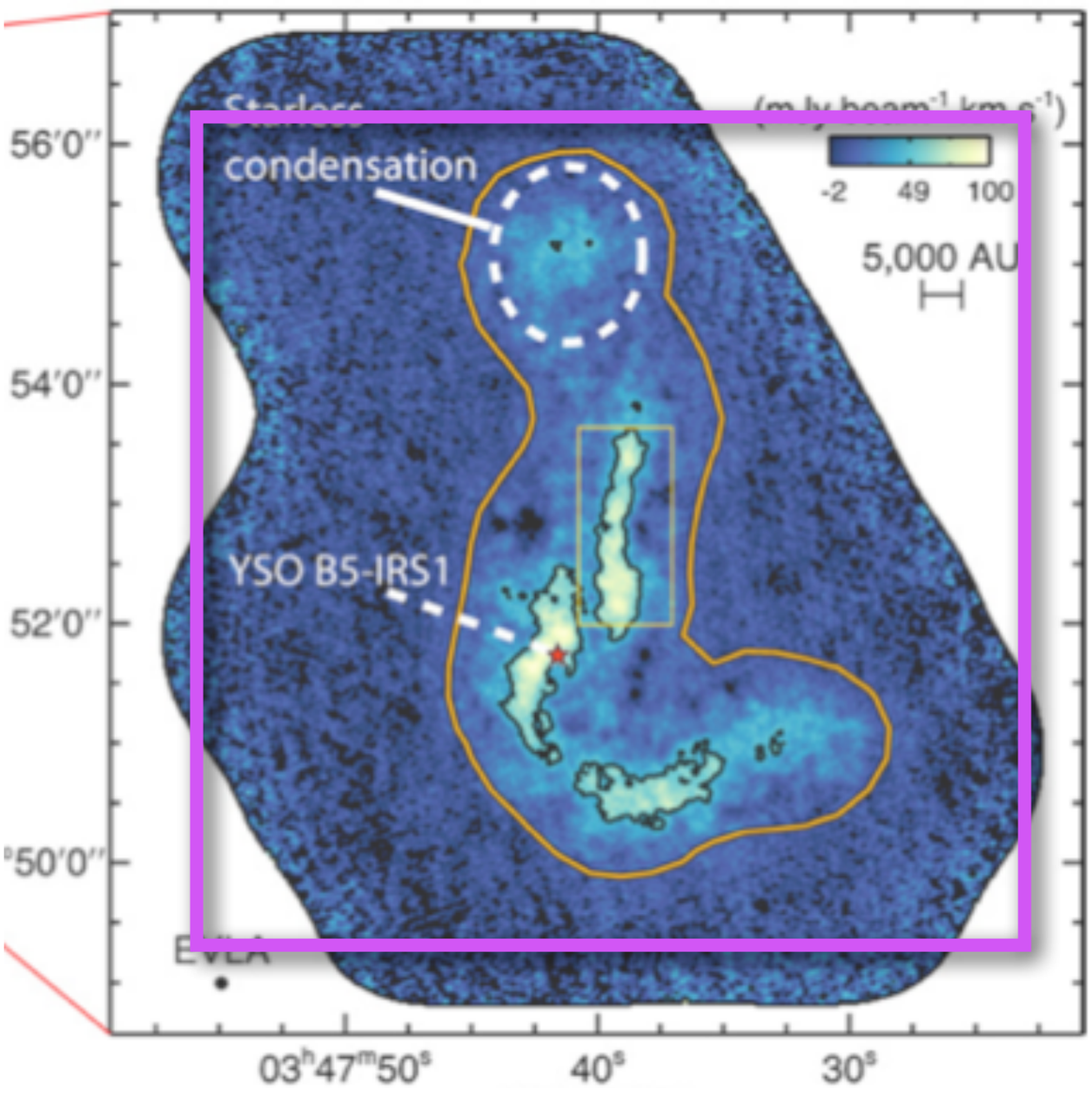
Compact & diffuse C18O (2-1) emission
Compact & diffuse NH3 (1, 1) emission
3D rendering using Python YT

courtesy of Hope Chen

COMPARING SCALES



Taurus (Hacar et al.)



B5 (Pineda et al.)