Clouds, Filaments & Fields

Alyssa Goodman
Harvard-Smithsonian Center for Astrophysics

Clouds, Filaments & Fields*

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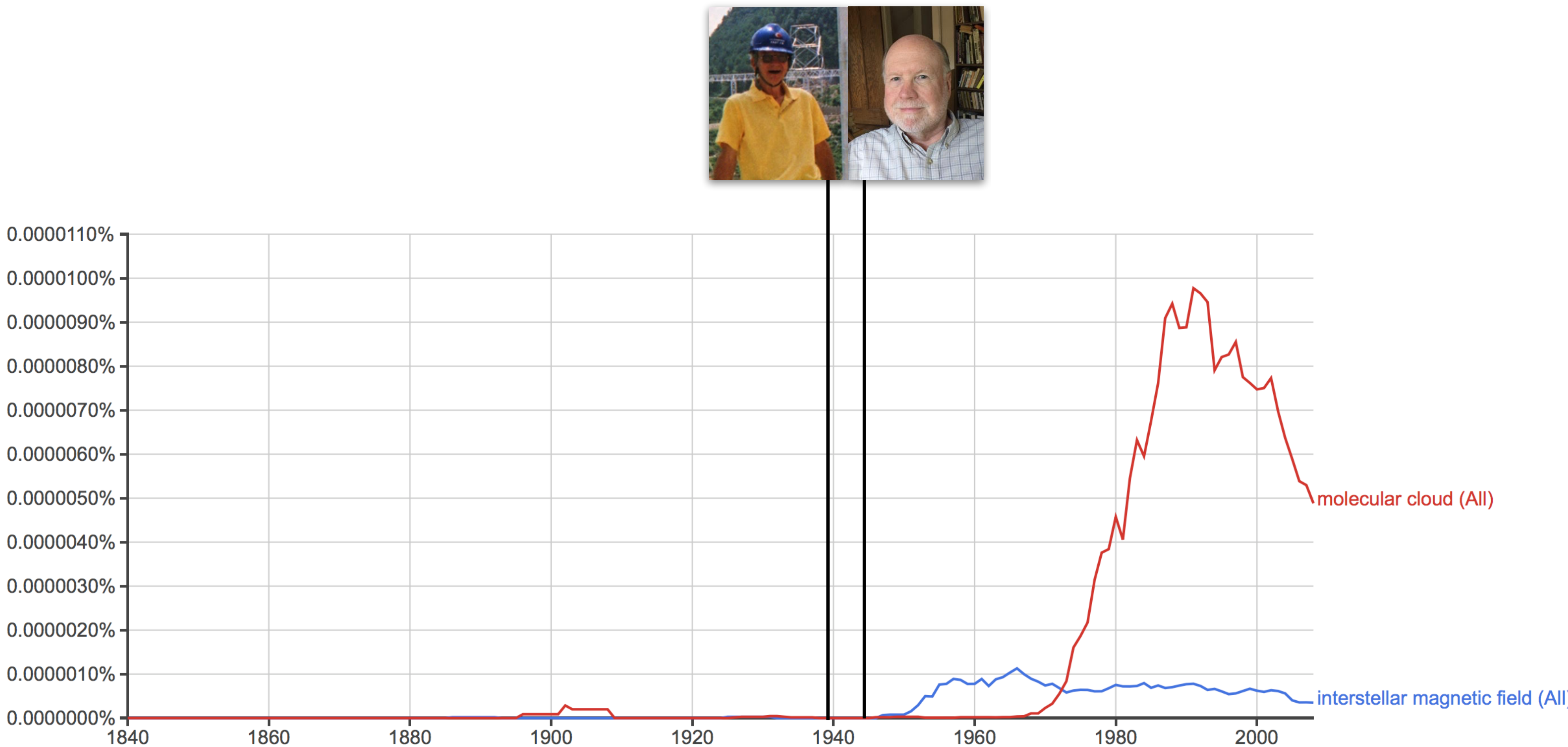
Harvard-Smithsonian Center for Astrophysics

*with special homage to Carl Heiles & Dick Crutcher

Connections (people)

Connections (ISM)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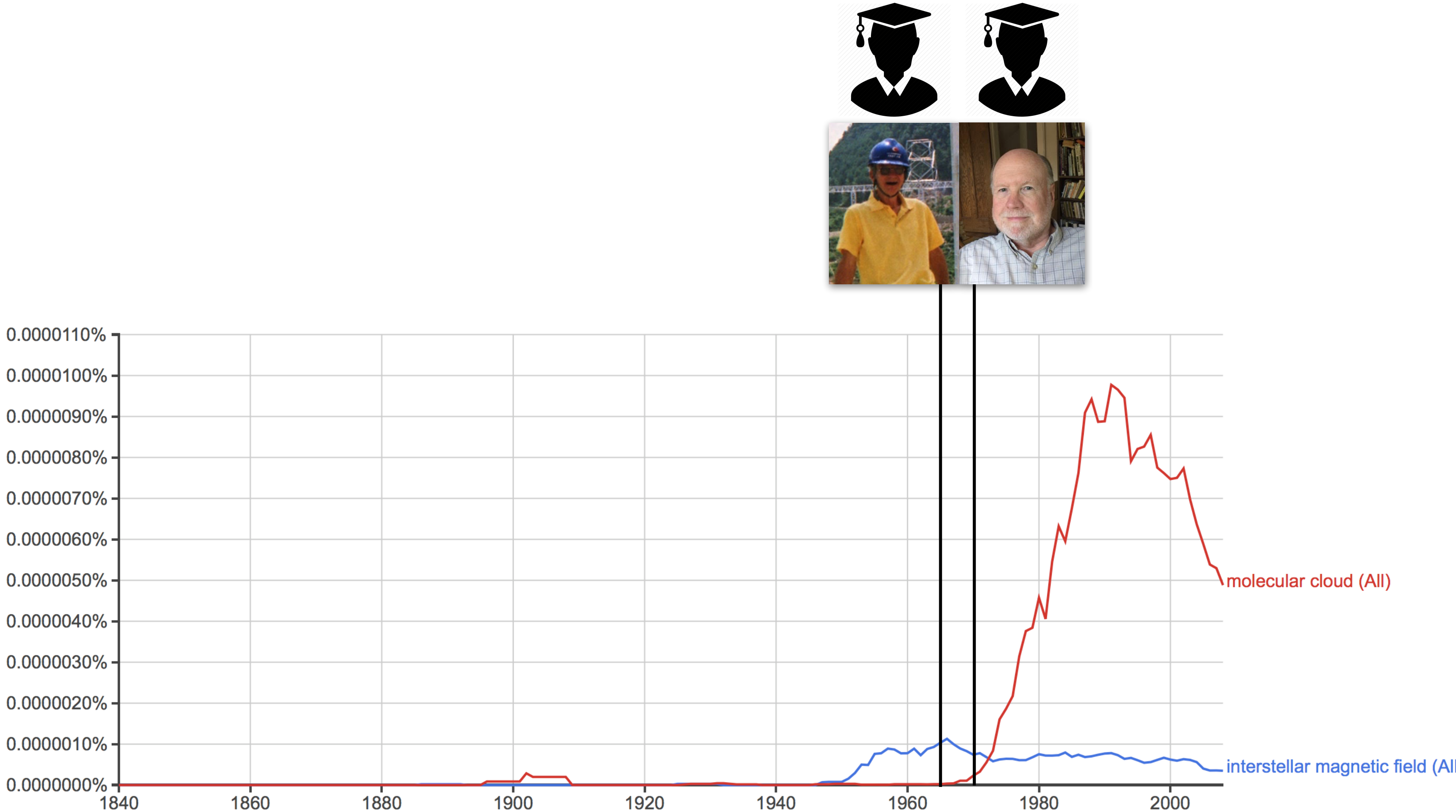
molecular cloud (All)
interstellar magnetic field (All)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molecular cloud (All)
interstellar magnetic field (All)

When did Dick “Go Magnetic”?

1981

THE ASTROPHYSICAL JOURNAL, 249:134–137, 1981 October 1

MAGNETIC FIELDS IN MOLECULAR CLOUDS: OH ZEEMAN OBSERVATIONS

RICHARD M. CRUTCHER
Department of Astronomy, University of Illinois

AND

THOMAS H. TROLAND AND CARL HEILES
Astronomy Department, University of California at Berkeley
Received 1981 February 2; accepted 1981 April 6

ABSTRACT

We have carried out sensitive OH Zeeman observations of the absorption lines produced in interstellar dust clouds toward 3C 133, 3C 123, and W51. Conservative ($3\ \sigma$) upper limits to the magnetic field strengths at each position are 15, 25, and 30 microgauss respectively.
Subject headings: interstellar: magnetic fields — interstellar: molecules — Zeeman effect

1982

THE ASTROPHYSICAL JOURNAL, 254:82–87, 1982 March 1

THE LOCAL INTERSTELLAR MEDIUM

RICHARD M. CRUTCHER
Astronomy Department, University of Illinois; and
Radio Astronomy Laboratory, University of California, Berkeley
Received 1980 September 8; accepted 1981 July 16

ABSTRACT

Analysis of the velocities of optical interstellar lines shows that the Sun is immersed in a coherently moving local interstellar medium whose velocity vector agrees with that of the interstellar wind observed through backscatter of solar H Lyα and He λ584 photons. The local interstellar medium consists of both cool clouds and warm intercloud medium gas, has a mass of perhaps $\sim 30\ M_{\odot}$, does not have severe depletion of trace elements from the gas phase, and appears to be material which has been shocked and accelerated by stellar winds and supernovae associated with the Sco-Oph OB association.
Subject heading: interstellar: matter

1983

Astron. Astrophys. 125, L23–L26 (1983)

ASTRONOMY AND ASTROPHYSICS

Letter to the Editor

The magnetic field of the NGC 2024 molecular cloud: detection of OH line Zeeman splitting

Richard M. Crutcher[1,2] and Ilya Kazès[1]

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[2] Department of Astronomy, University of Illinois, Urbana, IL 61801, USA

Received June 3, accepted July 14, 1983

Summary

Zeeman splitting of the main lines of OH in absorption has been detected for the first time. The derived magnetic field for a clump in the NGC 2024 molecular cloud is -38 ± 1 microgauss.

Key words: magnetic fields – interstellar molecular clouds – Zeeman effect

The antenna feed is a hoghorn (Pippard, 1946) with orthogonal dipoles in a circular waveguide. A noise diode signal may be injected into the horn for calibration. The horizontally and vertically orientated linear polarizations are coupled to unbalanced transmission circuits by folded baluns (Jasik, 1961); the polarization isolation is measured to be in excess of 40 dB. After amplification by cooled paramps or FET's, the linearly polarized signals are combined with the appropriate phases in a hybrid to produce circularly polarized

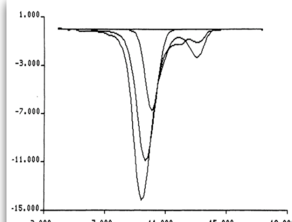


Fig. 1. Spectra of the 1667 (strongest) and 1665 lines observed for $13^h\ 18^m$ toward NGC 2024 (RA/DEC [1950.0] $05^h\ 39^m\ 14^s.3$ / $-01°\ 55'\ 57''$). The weakest line is the assumed gaussian component used for Zeeman analysis.

The abscissa scale in all figures is the same and is given in km s^{-1} relative to the LSR. The ordinate scale in °K antenna temperature is correct except that displacements of zero have been made in most figures.

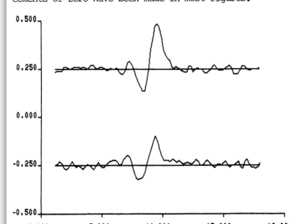
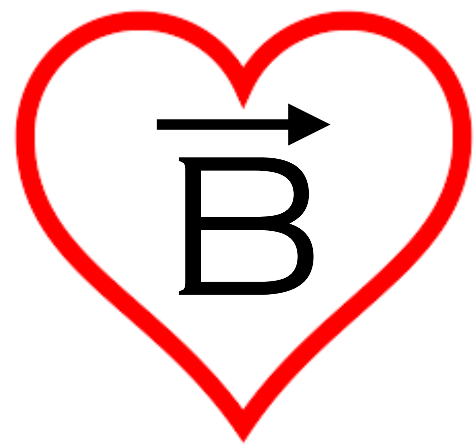
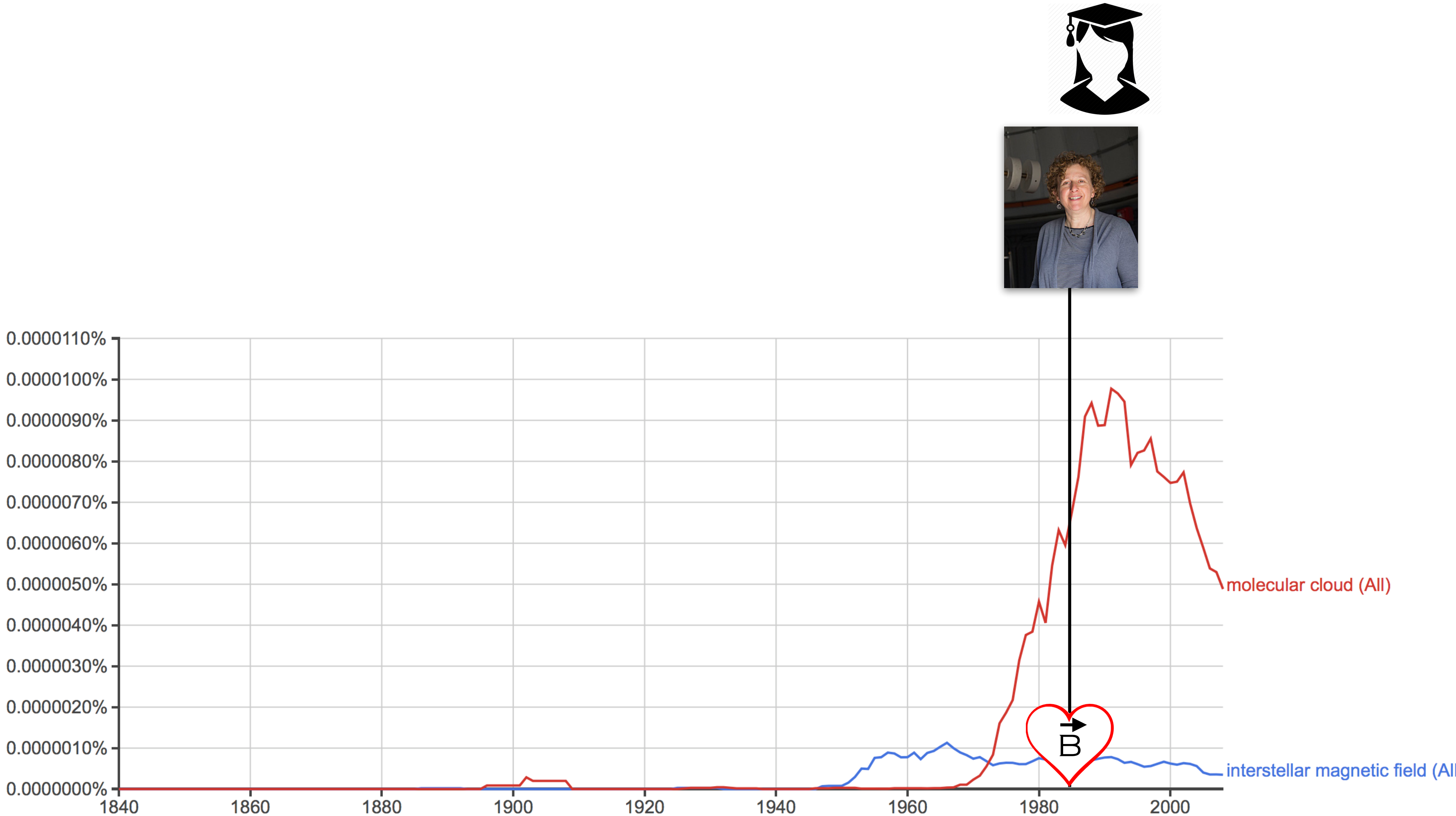


Fig. 2. Stokes V spectra of the 1665 (upper) and 1667 (lower) lines.

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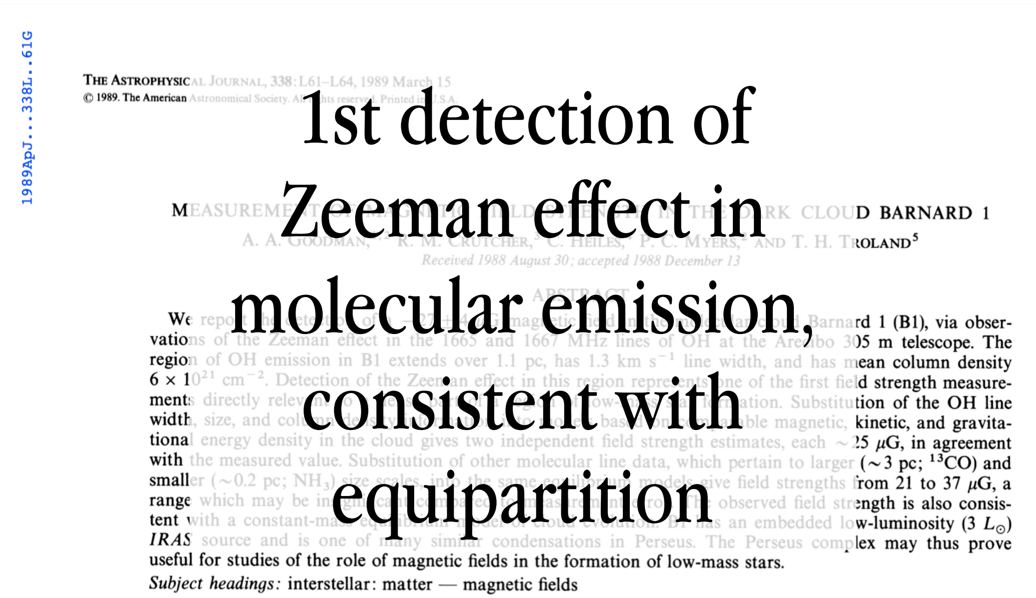
molecular cloud (All)
interstellar magnetic field (All)
B

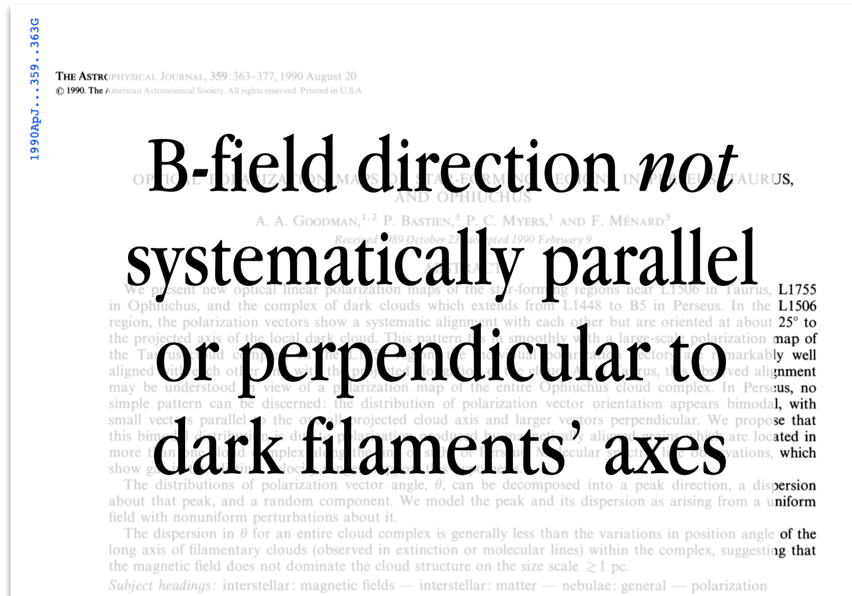
1983 — Thaddeus → Dame* → Maddalena …polarization map of Orion GMC

1984 — Morrison → Alcock

Myers → Strow** → Heyer

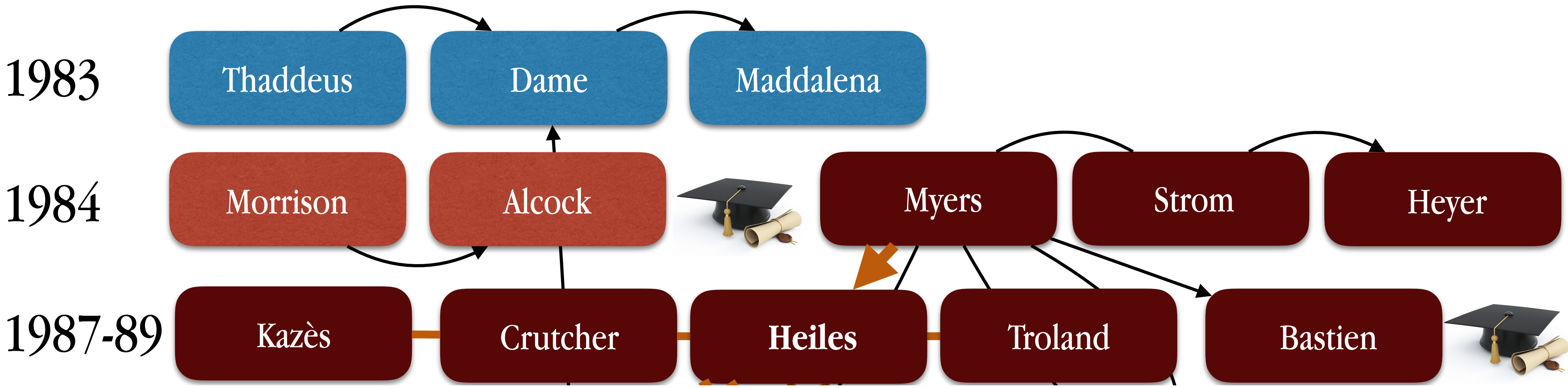
1987-89 — Kazès — Crutcher — **Heiles** — Troland — Bastien





*via Richard Cohen

***B* & outflows…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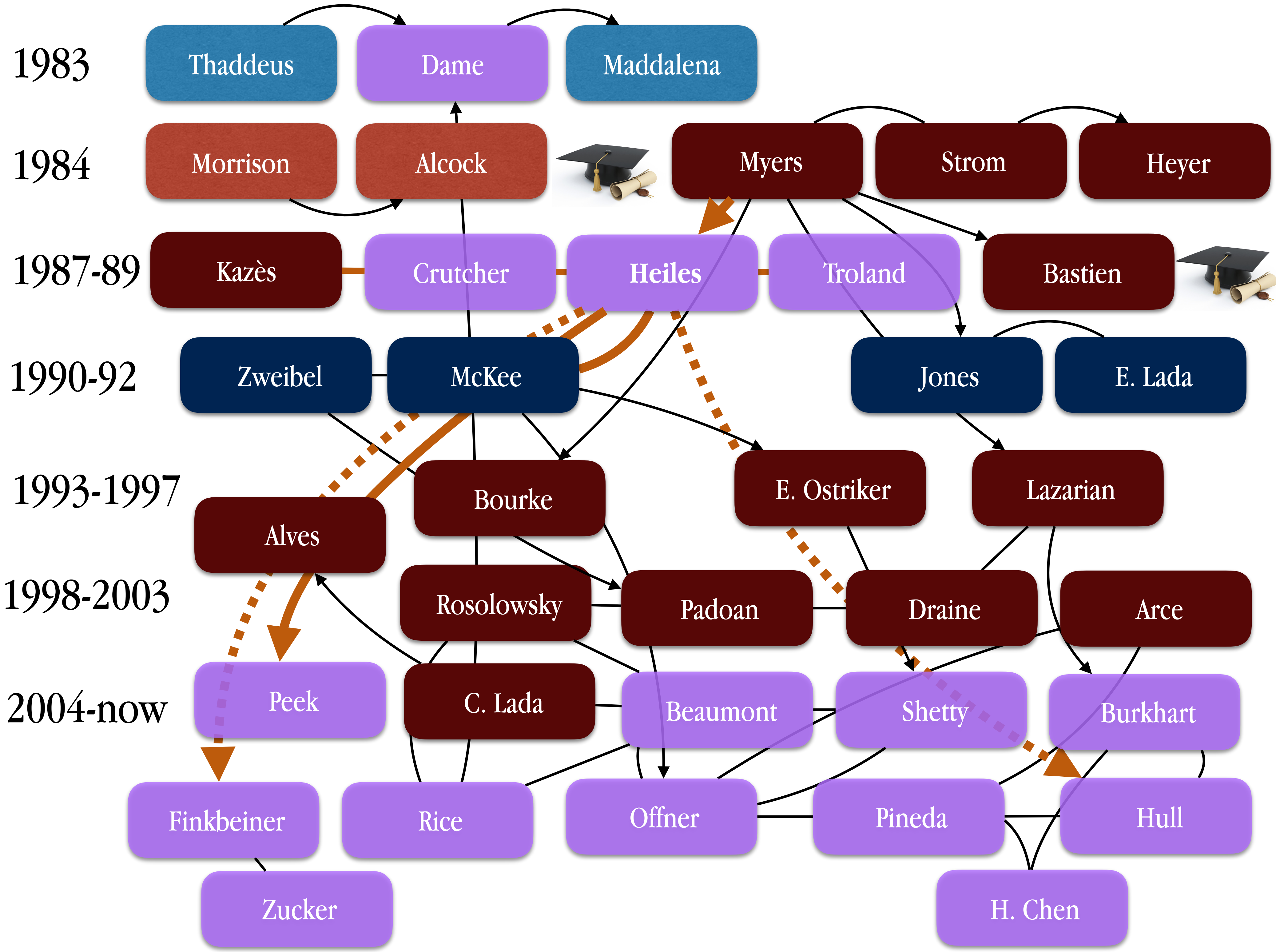
Bastien



1983
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Beaumont
Shetty
Burkhart
Finkbeiner
Rice
Offner
Pineda
Hull
Zucker
H. Chen

The Astrophysical Journal, 768:159 (5pp), 2013 May 10 doi:10.1088/0004-637X/768/2/159

MISALIGNMENT OF MAGNETIC FIELDS AND OUTFLOWS IN PROTOSTELLAR CORES

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[6] Department of Physics & Astronomy, University of Western Ontario, London, ON N6A 3K7, Canada
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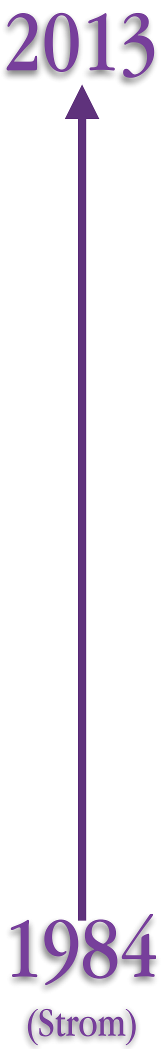
[13] SOFIA Science Center, Universities Space Research Association, NASA Ames Research Center, Moffett Field, CA 94035, USA
[14] Combined Array for Research in Millimeter-wave Astronomy, Owens Valley Radio Observatory, P.O. Box 968, Big Pine, CA 93513, USA
Received 2013 February 22; accepted 2013 March 28; published 2013 April 25



ABSTRACT

We present results of λ1.3 mm dust-polarization observations toward 16 nearby, low-mass protostars, mapped with $\sim$2.″5 resolution at CARMA. The results show that magnetic fields in protostellar cores on scales of $\sim$1000 AU are not tightly aligned with outflows from the protostars. Rather, the data are consistent with scenarios where outflows and magnetic fields are preferentially misaligned (perpendicular), or where they are randomly aligned. If one assumes that outflows emerge along the rotation axes of circumstellar disks, and that the outflows have not disrupted the fields in the surrounding material, then our results imply that the disks are not aligned with the fields in the cores from which they formed.

Key words: ISM: magnetic fields – magnetic fields – polarization – stars: formation – stars: magnetic field – stars: protostars

Online-only material: color figure

A&A 586, A135 (2016)
DOI: 10.1051/0004-6361/201425044

Astronomy & Astrophysics

Planck intermediate results

2016

XXXII. The relative orientation between the magnetic field and structures traced by interstellar dust

Planck Collaboration: R. Adam[68], P. A. R. Ade[79], N. Aghanim[54], M. I. R. Alves[54], M. Arnaud[66], D. Arzoumanian[54], M. Ashdown[63,6], . . .

ABSTRACT

The role of the magnetic field in the formation of the filamentary structures observed in the interstellar medium (ISM) is a debated topic owing to the paucity of relevant observations needed to test existing models. The *Planck* all-sky maps of linearly polarized emission from dust at 353 GHz provide the required combination of imaging and statistics to study the correlation between the structures of the Galactic magnetic field and of interstellar matter over the whole sky, both in the diffuse ISM and in molecular clouds. The data reveal that structures, or ridges, in the intensity map have counterparts in the Stokes Q and/or U maps. We focus our study on structures at intermediate and high Galactic latitudes, which cover two orders of magnitude in column density, from 10^{20} to 10^{22} cm^{-2}. We measure the magnetic field orientation on the plane of the sky from

aligned with the magnetic field measured on the structures. This statistical trend becomes more striking for increasing polarization fraction and decreasing column density. There is no alignment for the highest column density ridges. We interpret the increase in alignment with polarization

aligned with the magnetic field measured on the structures. This statistical trend becomes more striking for increasing polarization fraction and decreasing column density. There is no alignment for the highest column density ridges. We interpret the increase in alignment with polarization fraction as a consequence of projection effects. We present maps to show that the decrease in alignment for high column density is not due to a loss of correlation between the distribution of matter and the geometry of the magnetic field. In molecular complexes, we also observe structures perpendicular to the magnetic field, which, statistically, cannot be accounted for by projection effects. This first statistical study of the relative orientation between the matter structures and the magnetic field in the ISM points out that, at the angular scales probed by *Planck*, the field geometry projected on the plane of the sky is correlated with the distribution of matter. In the diffuse ISM, the structures of matter are usually aligned with the magnetic field, while perpendicular structures appear in molecular clouds. We discuss our results in the context of models and MHD simulations, which attempt to describe the respective roles of turbulence, magnetic field, and self-gravity in the formation of structures in the magnetized ISM.

Key words. ISM: clouds – ISM: magnetic fields – ISM: structure – magnetohydrodynamics (MHD) – polarization – turbulence

A number of studies, using the polarization of background starlight caused by dichroic absorption, have targeted filaments in dark clouds (e.g. Goodman et al. 1990, 1995; Pereyra & Magalhães 2004; Alves et al. 2008; Chapman et al. 2011; Cashman & Clemens 2014), and in the diffuse ISM at lower column densities (McClure-Griffiths et al. 2006; Clark et al. 2014).

1990

2010

THE ASTROPHYSICAL JOURNAL, 725:466–479, 2010 December 10 doi:10.1088/0004-637X/725/1/466

MAGNETIC FIELDS IN INTERSTELLAR CLOUDS FROM ZEEMAN OBSERVATIONS: INFERENCE OF TOTAL FIELD STRENGTHS BY BAYESIAN ANALYSIS

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[2] UPMC Université Paris 06, Institut d'Astrophysique de Paris, 98 bis, boulevard Arago, 75014 Paris, France
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[4] Astronomy Department, University of California, Berkeley, CA 94720, USA
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[6] Physics and Astronomy Department, University of Kentucky, Lexington, KY 40506, USA
Received 2009 October 1; accepted 2010 September 25; published 2010 November 19

ABSTRACT

The only direct measurements of interstellar magnetic field strengths depend on the Zeeman effect, which samples

many fields are so weak that the mass/flux ratio in many clouds must be significantly supercritical. A two-thirds power law comes from isotropic contraction of gas too weakly magnetized for the magnetic field to affect the morphology of the collapse. On the other hand, our study does not rule out some clouds having strong magnetic fields with critical mass/flux ratios.

density. This suggests that diffuse clouds are assembled by flows along magnetic field lines, which would increase the density but not the magnetic field strength. We further find strong evidence for B in molecular clouds being randomly distributed between very small values and a maximum that scales with volume density n as $B \propto n^{0.65}$ for $n > 300\ \mathrm{cm}^{-3}$, with an uncertainty at the 50% level in the power-law exponent of about ±0.05. This break-point density could be interpreted as the average density at which parsec-scale clouds become self-gravitating. Both the uniform PDF of total field strengths and the scaling with density suggest that magnetic fields in molecular clouds are often too weak to dominate the star formation process. The stochasticity of the total field strength B implies that many fields are so weak that the mass/flux ratio in many clouds must be significantly supercritical. A two-thirds power law comes from isotropic contraction of gas too weakly magnetized for the magnetic field to affect the morphology of the collapse. On the other hand, our study does not rule out some clouds having strong magnetic fields with critical mass/flux ratios.

Key words: ISM: magnetic fields – polarization – stars: formation

Online-only material: color figures

1989
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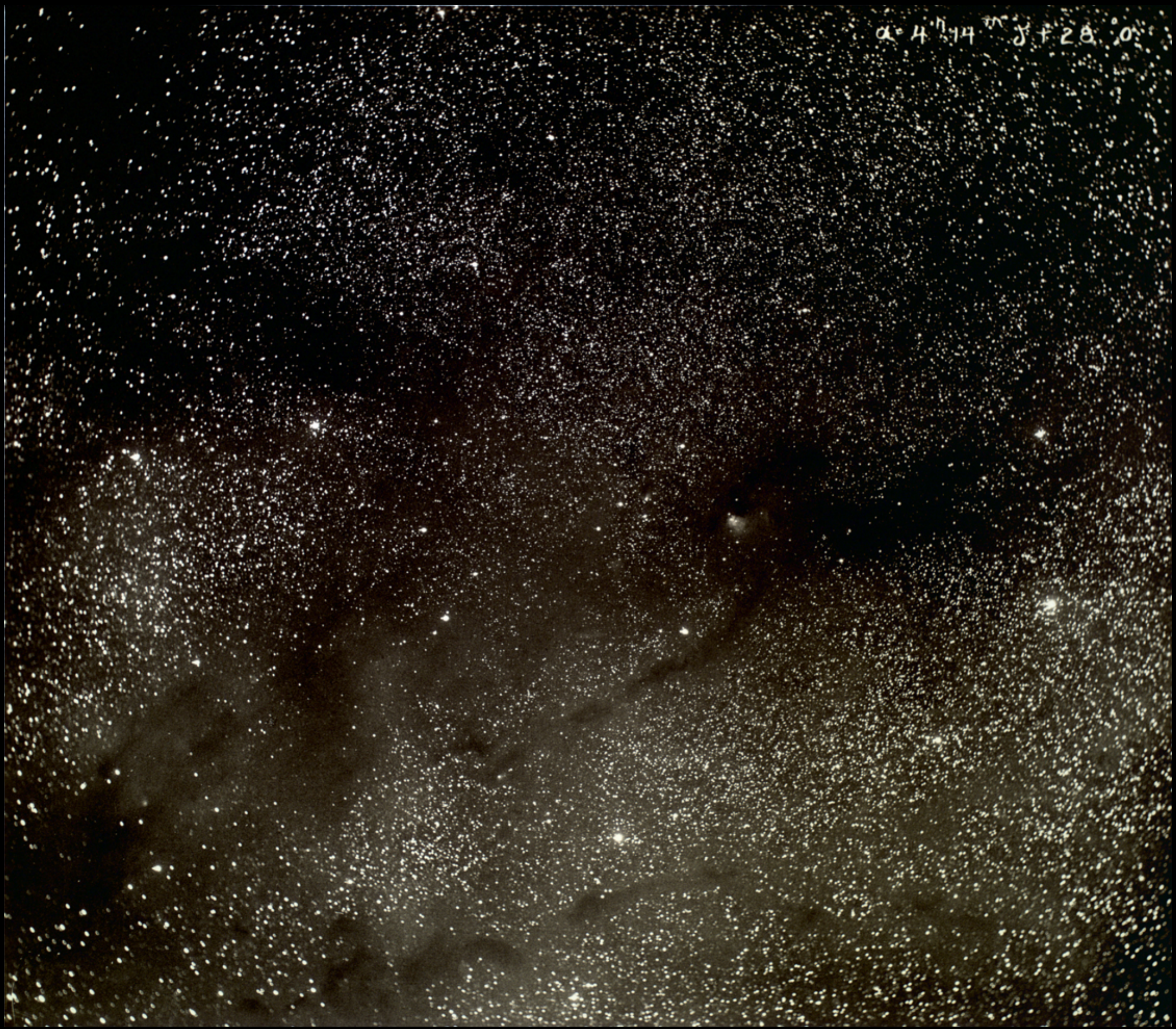
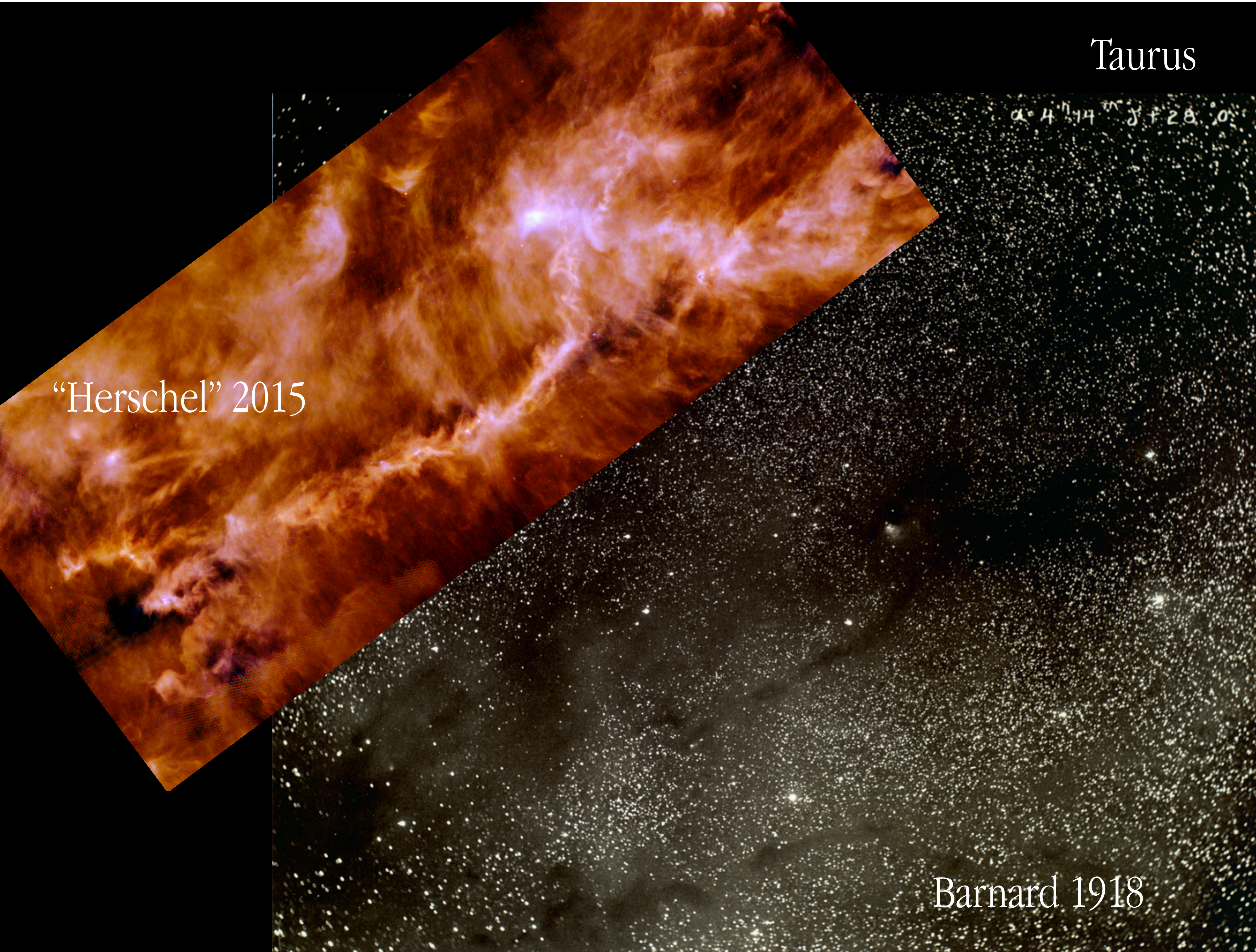
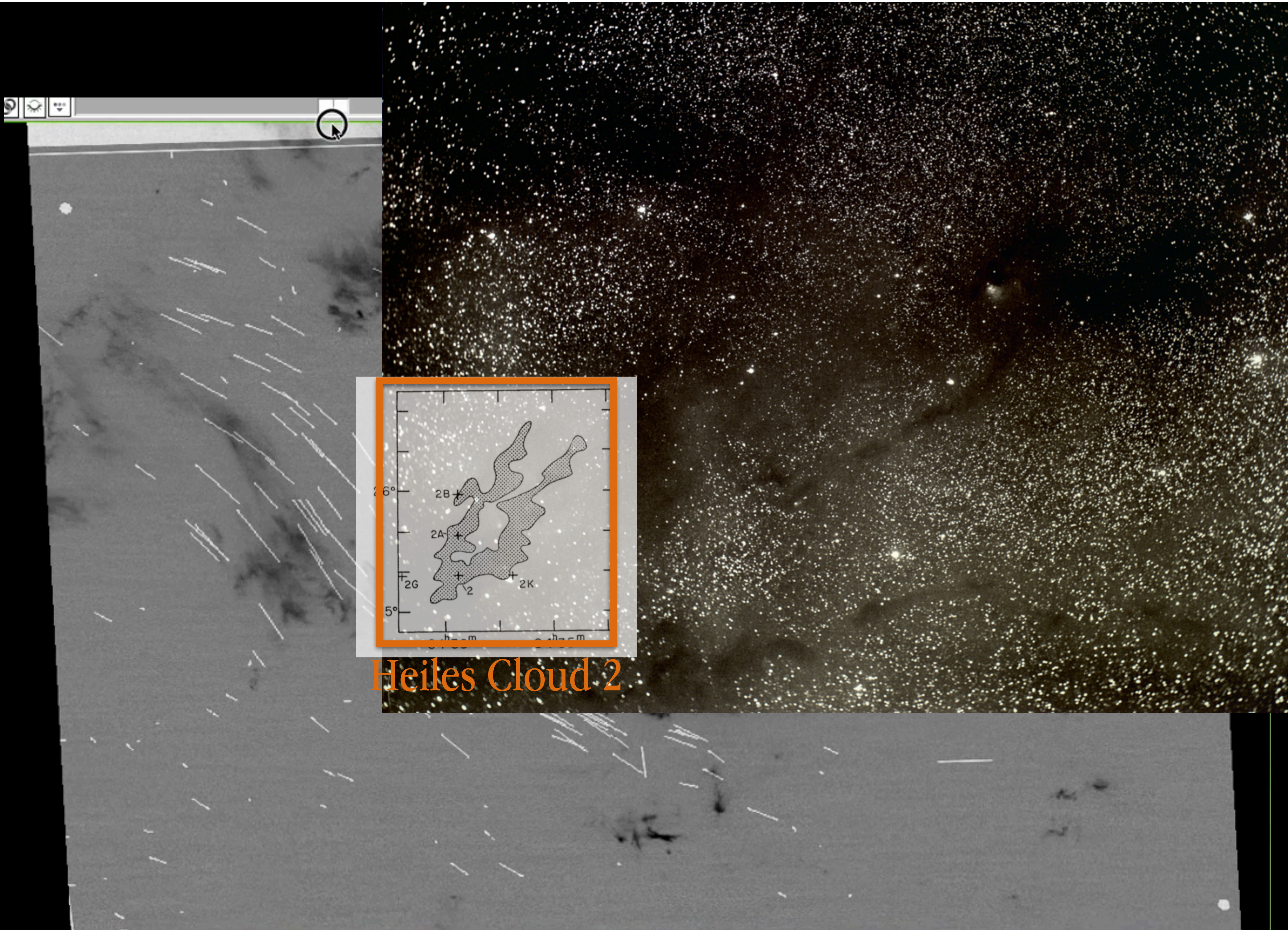


Taurus, Barnard 1918

Connections (ISM)

Taurus





Optical Polarization from Goodman et al. 1990 compilation, on Taurus ^{13}CO from Narayanan et al. 2008
(created for Steve Strom's birthday, 2008… "published" as video: vimeo.com/101109410

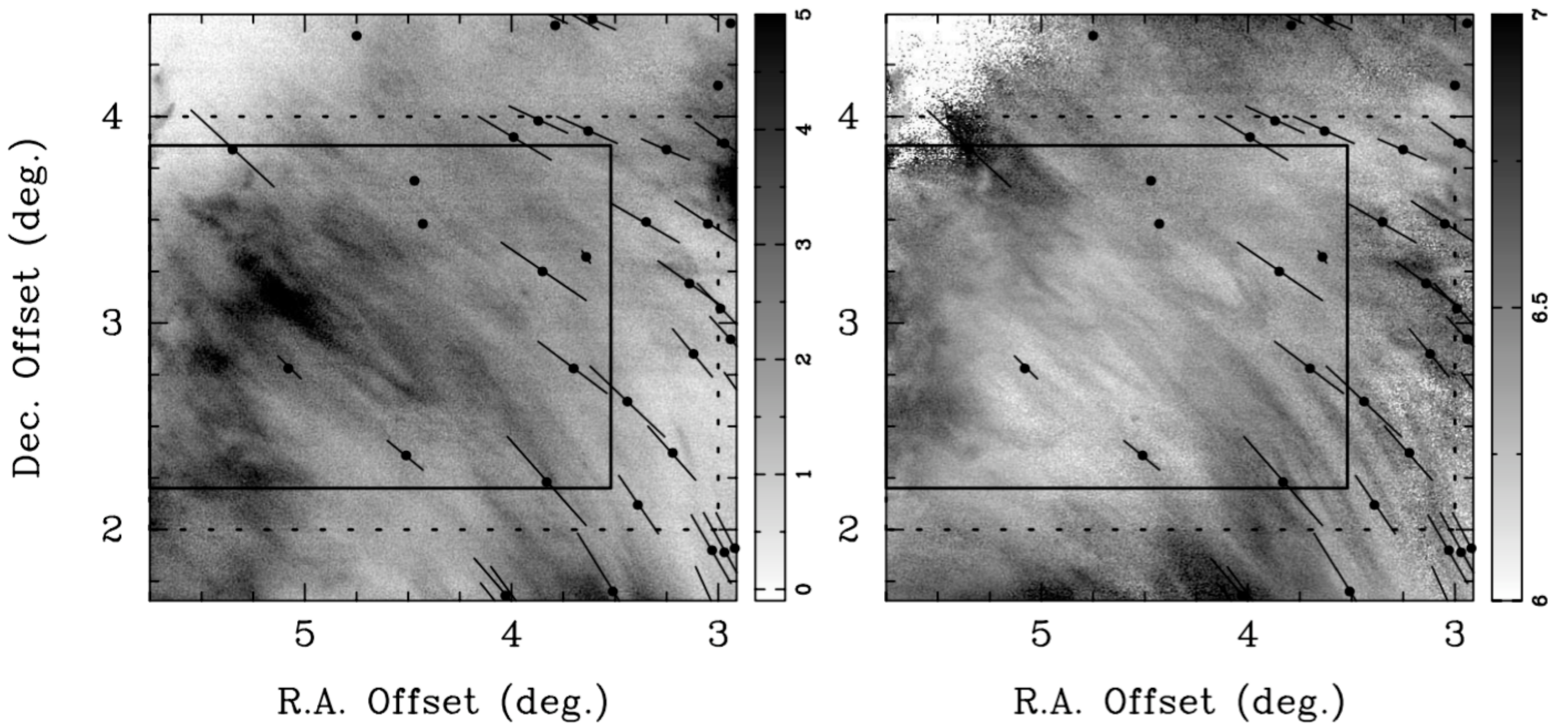
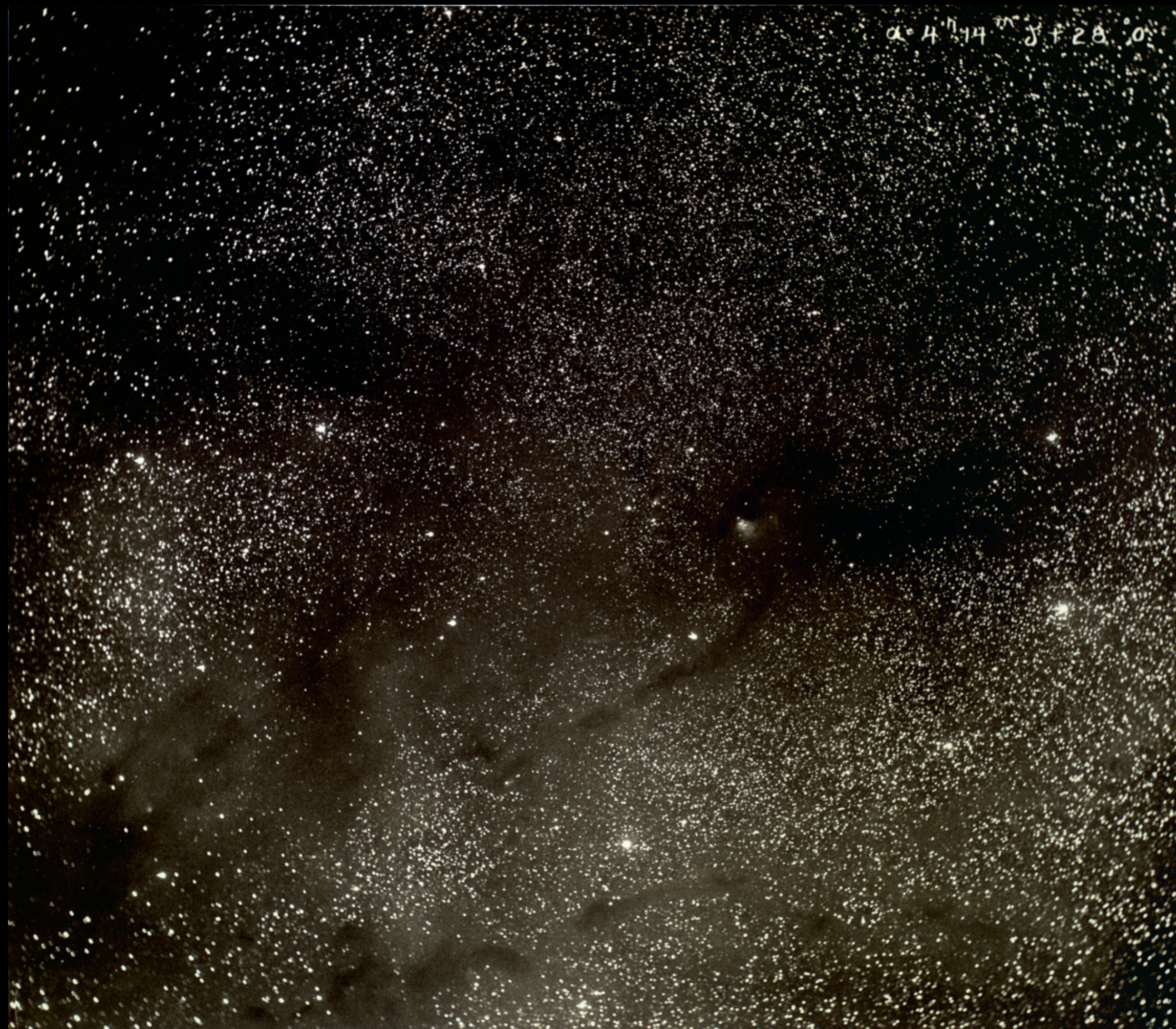


FIG. 3.—(*Left*) Image of ^{12}CO $J = 1-0$ emission of a subfield within the Taurus molecular cloud integrated over the velocity interval 5.5–7.5 km s^{-1} and (*right*) image of ^{12}CO velocity centroid (Narayanan et al. 2008), with overlay of optical polarization vectors from the compilation by Heiles (2000). The molecular line emission and velocities exhibit streaks that are aligned along the local magnetic field direction. The solid line box outlines the area on which the axis-constrained PCA method is applied. The dotted-line box shows the area within which the polarization angles are averaged to estimate the mean magnetic field direction.

Heyer et al. 2008

*[*but we still may not really know **B** in <u>highest</u> density gas…]*

Taurus, Barnard 1918



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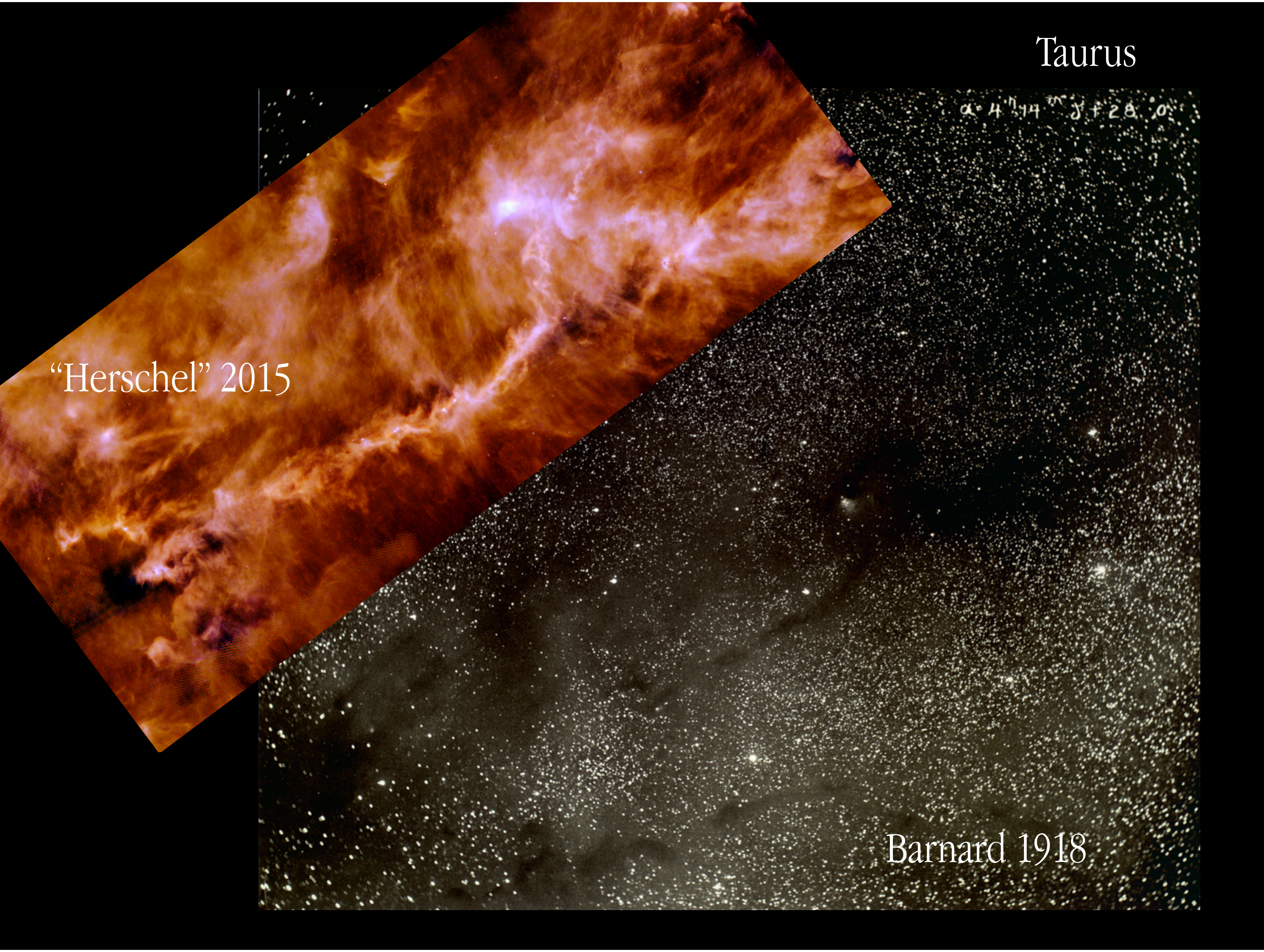
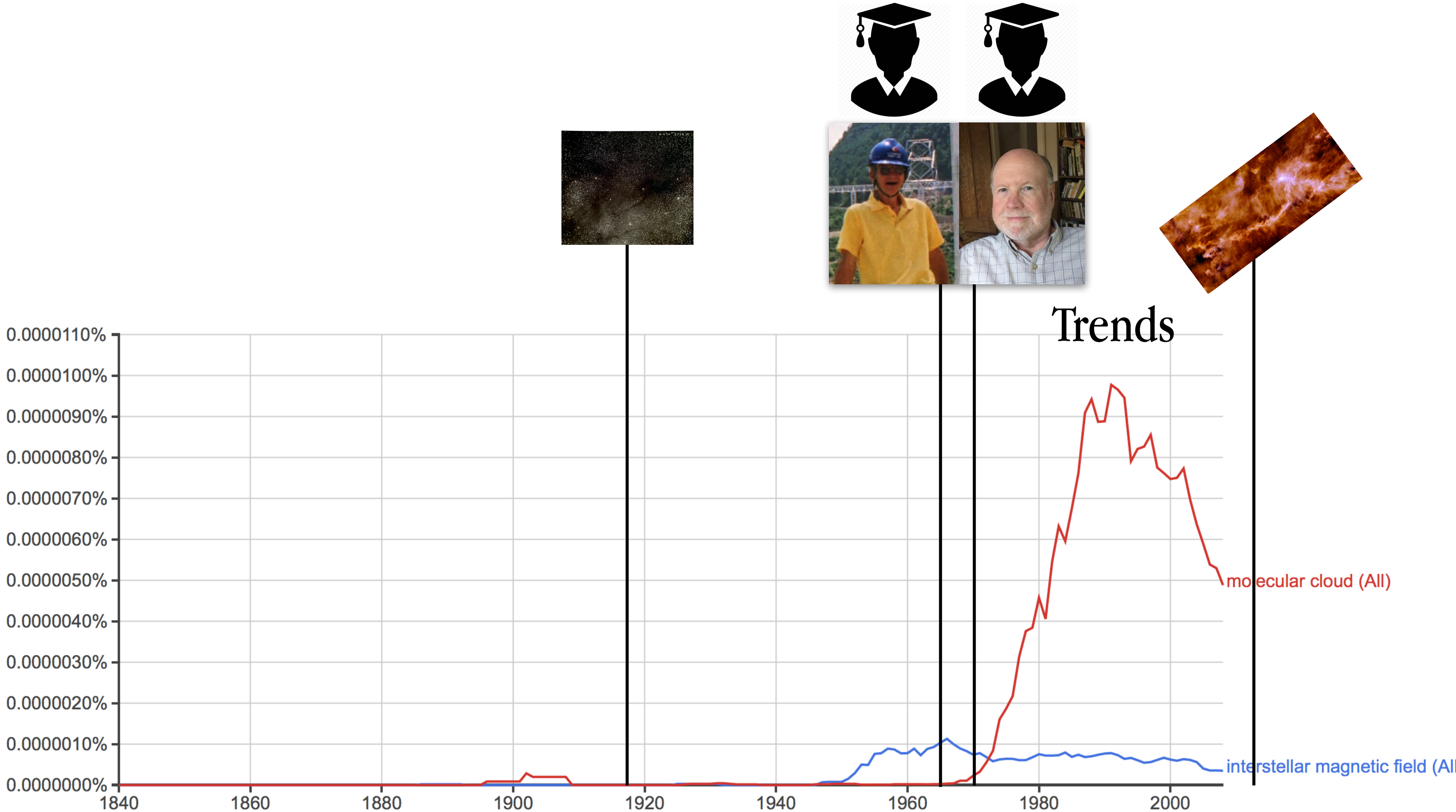

Taurus
“Herschel” 2015
Barnard 1918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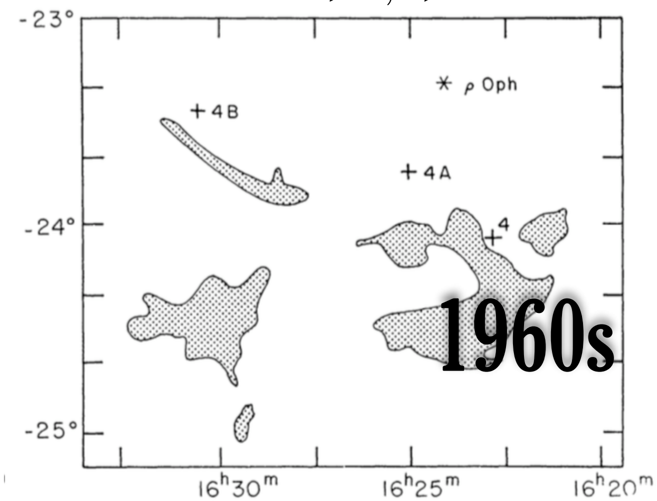
molecular cloud (All)
interstellar magnetic field (All)

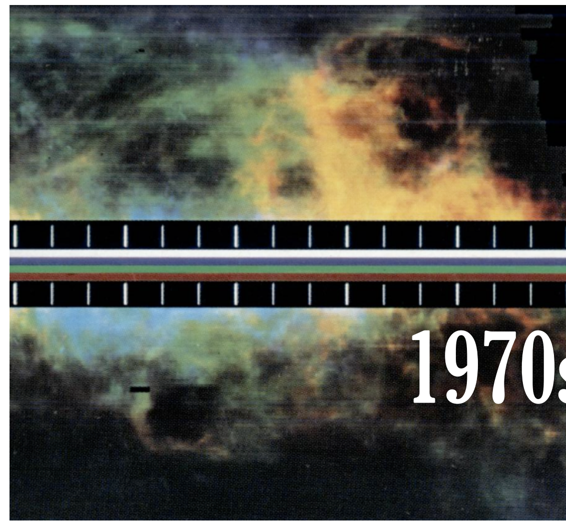
Trends

Heiles 1967, 1968



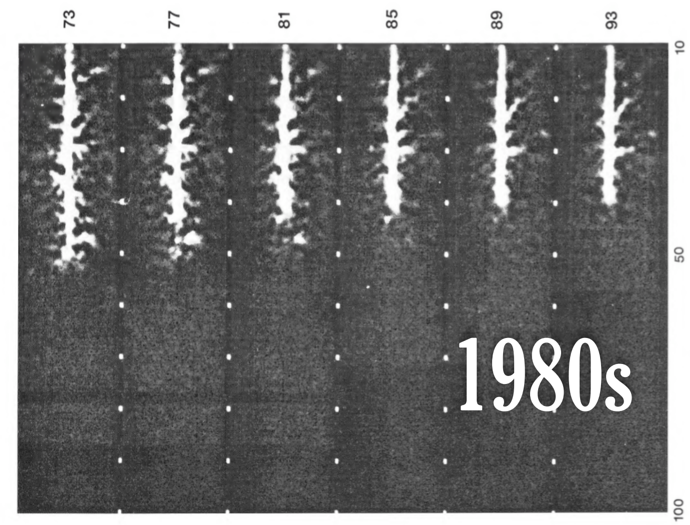
OH in "Dust Clouds"
HI in Sheets & Cloudlets

Heiles & Jenkins 1976
Heiles 1979



Shells & Supershells
Filaments

Heiles 1984



Worms
Aligned B-fields & HI

Heiles 1977

No. 1, 1997 MAGNETIC FIELD IN ERIDANUS/ORION REGION

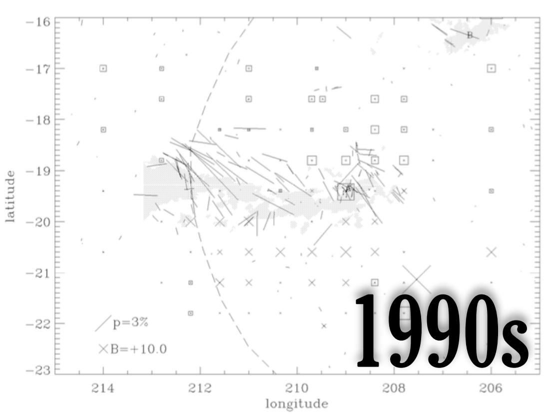


Fig. 24.—Expanded view of stellar polarization and Zeeman splitting results. For the stellar polarization data here, all data from Breger (1976), al. (1994), and VSS are shown instead of just averages. Plotted symbols show Zeeman-splitting detections $B_{\parallel}$ as in Fig. 15: positive fields are repres crosses, and negative fields by squares. Calibrations for both sets of data are shown at the lower left. In contrast to Fig. 15, which shows the ^{12}C boundaries, here the stippled area represents the ^{13}CO molecular clouds from BLL and UFMMIT.

"Tiny Scale" HI Structure
Helical B-Fields?

283 Peek/Heiles/Stanimirovic et al…

2. THE HI SKY AT ARCMIN RESOLUTION

2.1. Sheets and Filaments, Supersonic and Not

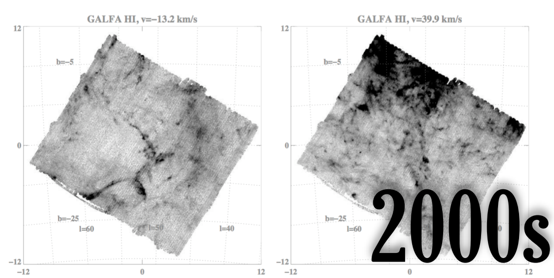
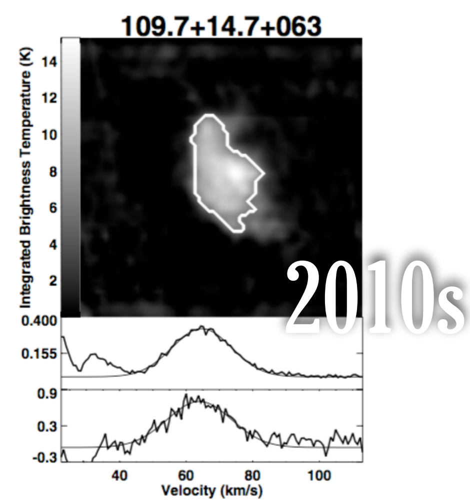


Fig. 1. GALFA maps of a ~ 500 deg^2 area centered near $(\ell, b) = (50°, 0°)$ at two velocities, 13.2 km s^{-1} and +39.9 km s^{-1}. The data are shown in the underappreciated stereographic projection, which is one of the very few projections that is *conformal*, which means that shapes are locally preserved.

Sheets & Filaments (GALFA)

Saul…Heiles et al. 2012

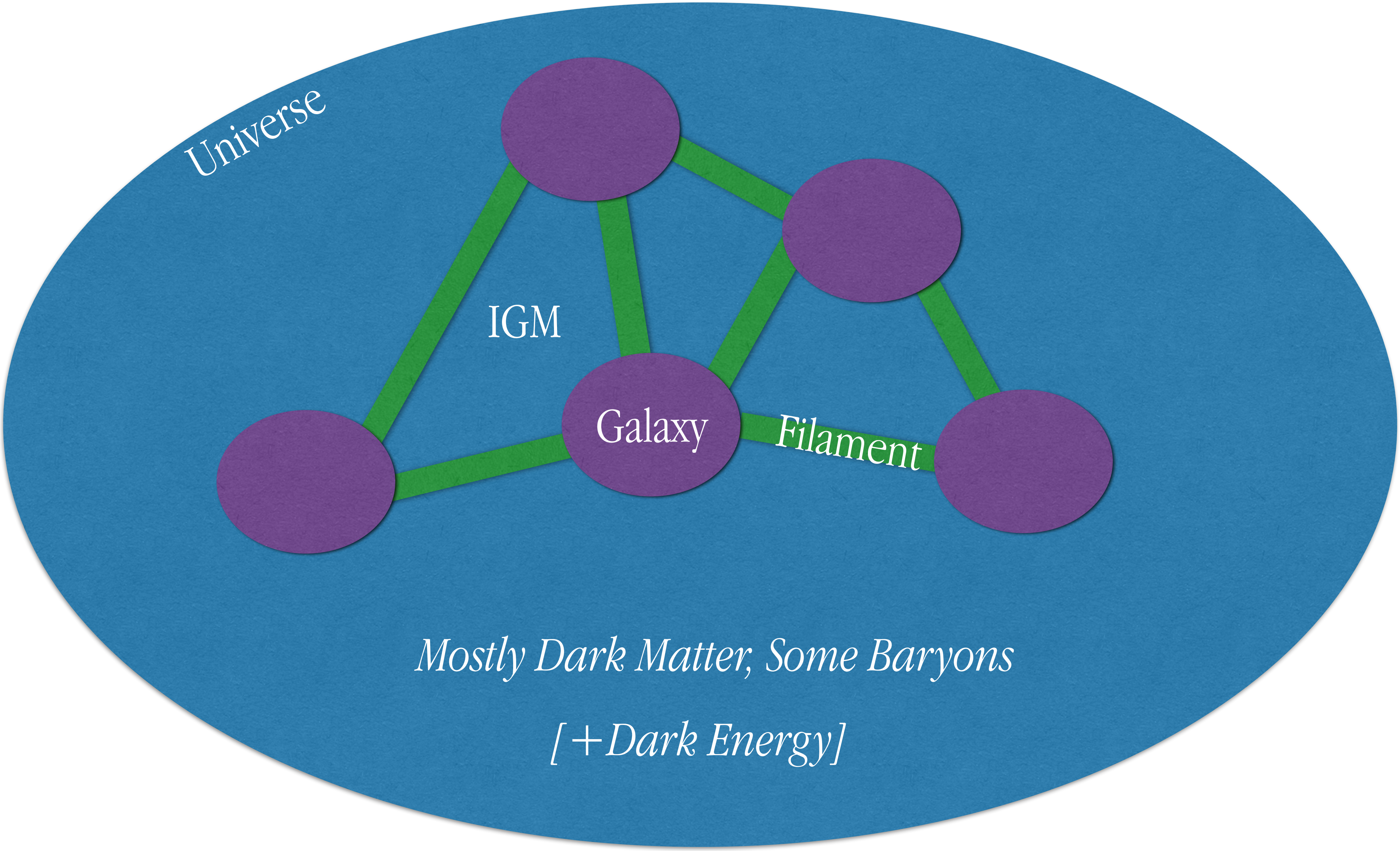


Compact Clouds of HI?!

Meanwhile, in the Theoryverse…

The Theoryverse

[not to scale]



The Theoryverse

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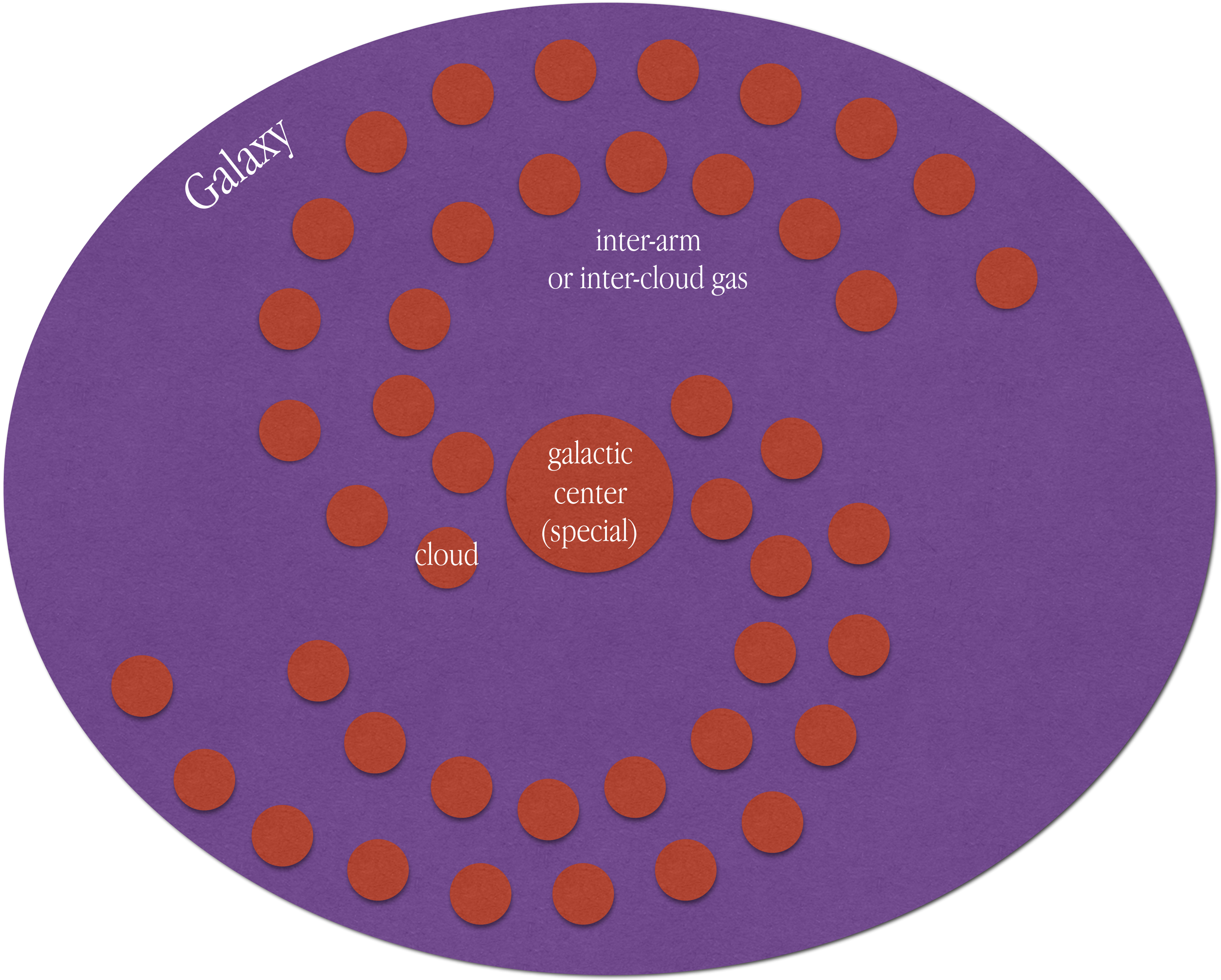
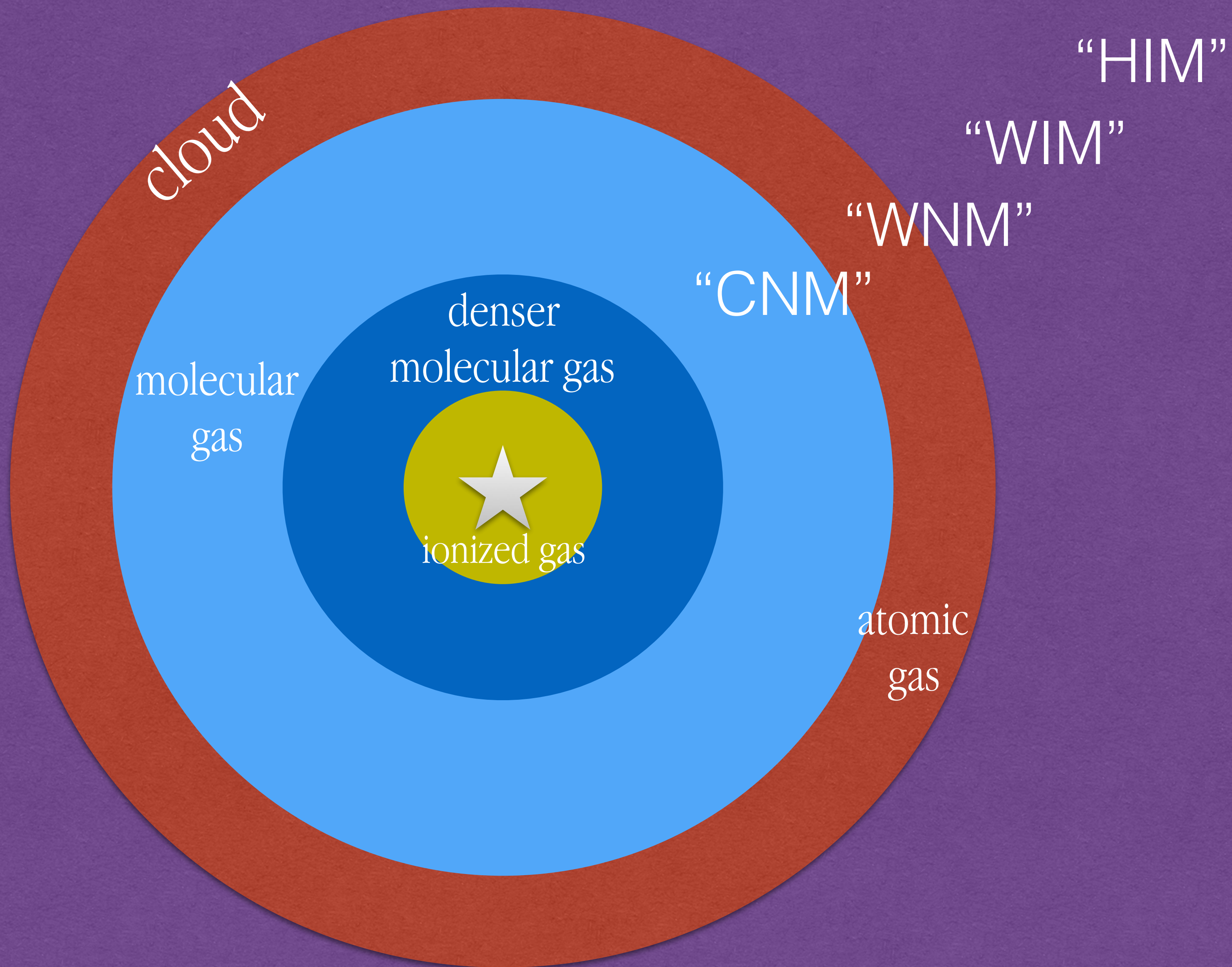


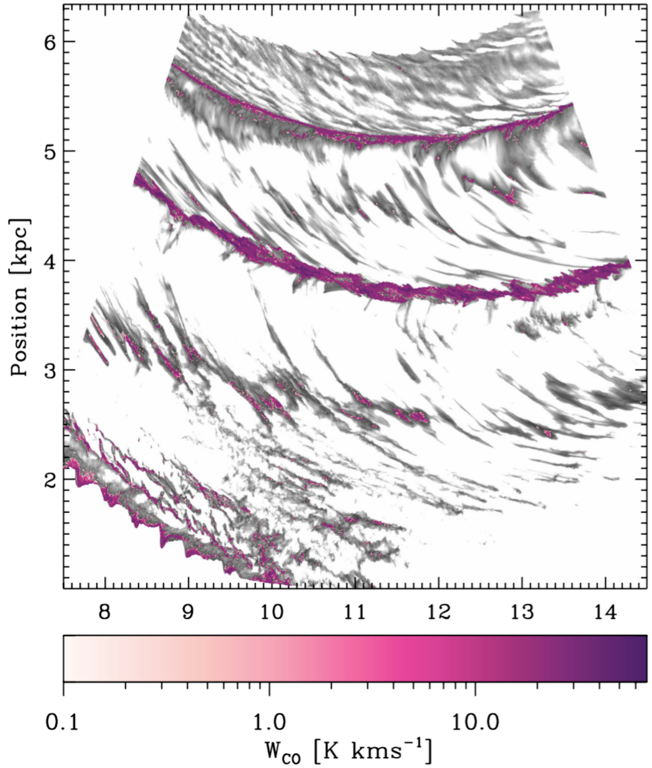
The Theoryverse

[not to scale]



The NEW Theoryverse

[still not right, but gettting much more realistic]



Smith et al. 2014

Figure 7. Morphology of the molecular gas in our Milky Way simulation. The grey-scale background image shows the H_2 column density (cf. Fig. 4), while the purple points show the strength of the CO velocity-integrated intensity, W_{CO}, estimated as described in the text. Many of the clouds in the inter-arm region have no portions with integrated intensities above 0.1 K km s^{-1} and thus would appear entirely 'dark' in CO observations.

Duarte-Cabral & Dobbs 2016

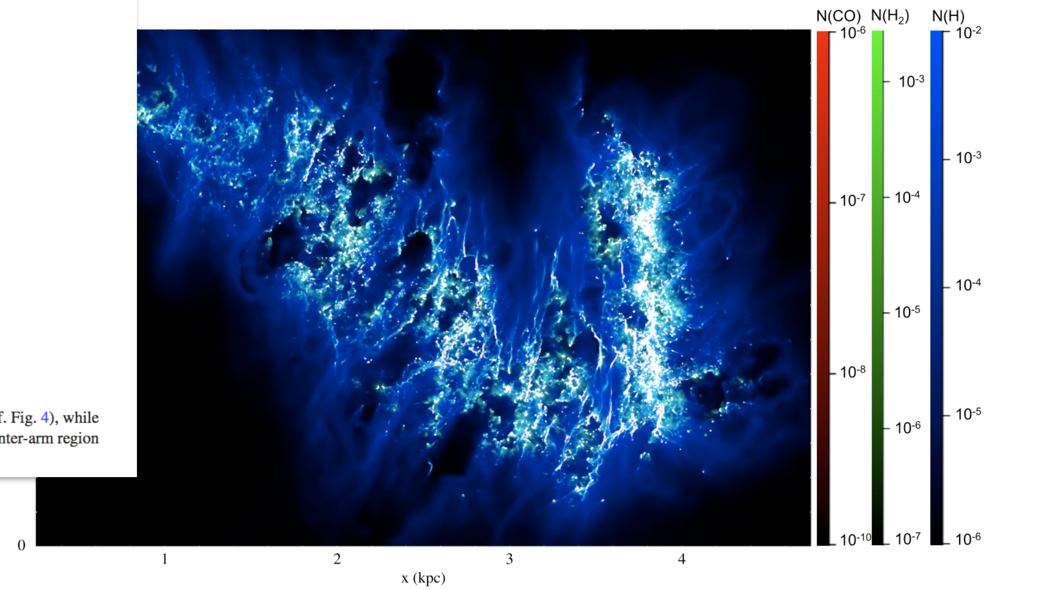
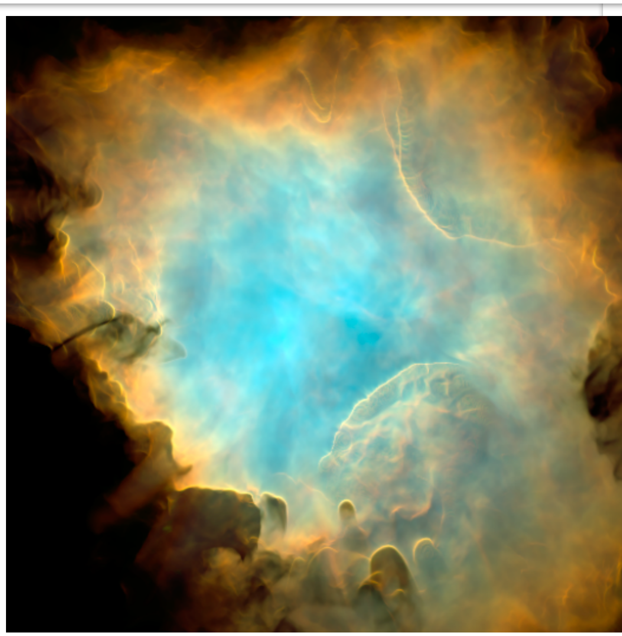


Figure 2. Top-down view of the simulation from Dobbs (2015) used in this work, as a 3-colour (RGB) image of the column densities of CO (red), H_2 (green) and atomic H (blue), in units of g cm^{-2}. For the synthetic observations, we positioned the observer in the top-left corner, at (0,3,0) kpc coordinates.



Mellema et al. 2009

The Carlverse, 1974

A MODERN LOOK AT 'INTERSTELLAR CLOUDS'

CARL HEILES

University of California, Berkeley, Calif., U.S.A.

Abstract. We compare past and present modes of investigation of the structure of the interstellar gas. Many aspects of the interstellar cloud model are invalid.

Interstellar optical absorption lines and H I 21-cm emission lines show a number of very large aggregates with properties similar to those of 'cloud complexes'. At nonzero velocities especially for $b<0°$, exist optical lines which have no H I counterparts. These are almost certainly produced in low-density gas clouds; perhaps the intercloud medium is itself cloudy.

Maps of H I column density taken over large velocity ranges do not reveal much small-scale structure. This fact cannot easily be reconciled with the statistical analyses of interstellar reddening. The maps do reveal large, coherent gas structures which are often filamentary in shape and at least sometimes aligned parallel to the interstellar magnetic field.

Maps of H I column density over small velocity ranges show much small-scale structure, often filamentary in shape. The filaments are almost universally oriented parallel to the interstellar magnetic field and have Doppler velocity gradients along their lengths. In one area the geometry of the field and gas almost exclusively suggests Alfvén-type motions.

The Carlverse, 1974

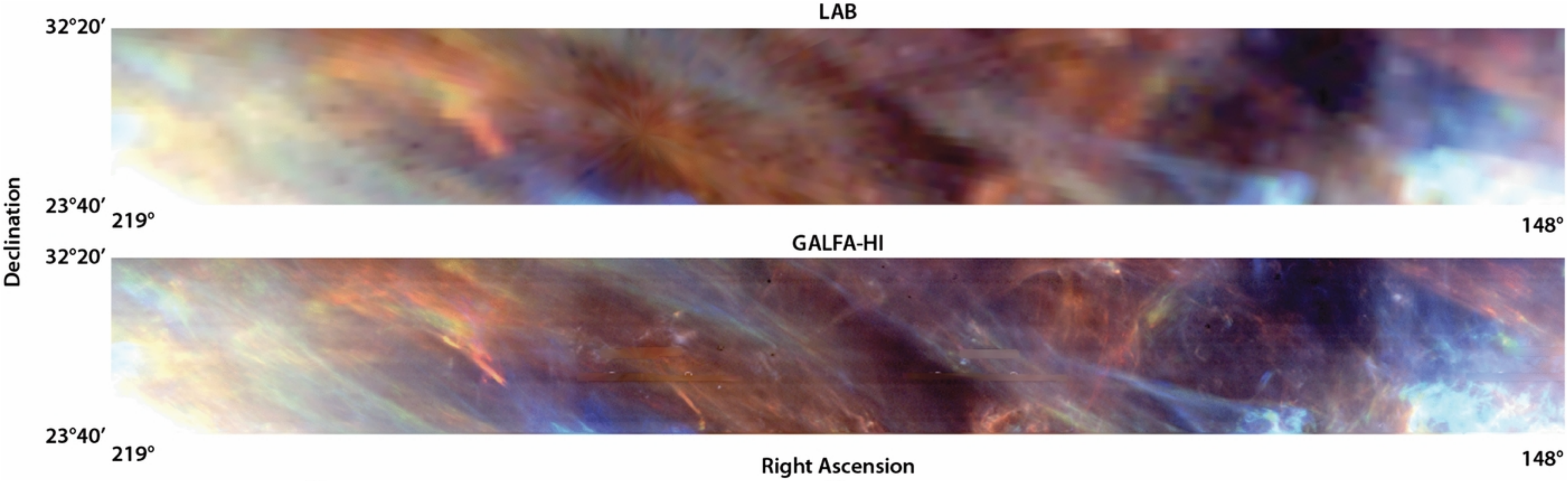
A MODERN LOOK AT 'INTERSTELLAR CLOUDS'

CARL HEILES
University of California, Berkeley, Calif., U.S.A.

Abstract. We compare past and present modes of investigation of the structure of the interstellar gas. Until recently, insufficient data have been available to make such a discussion. We will find that some aspects of the cloud model remain valid. Other aspects, especially the assumptions concerning randomness, are incorrect. Much of the observable gas is affected by the interstellar magnetic field and/or huge explosions. Many large aggregates contain hierarchical structure with non-random shapes and velocities. Outside these aggregates, the gas is often distributed in long, delicate, interconnected filaments rather than clouds.

Yesterday, in the diffuse gas…

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



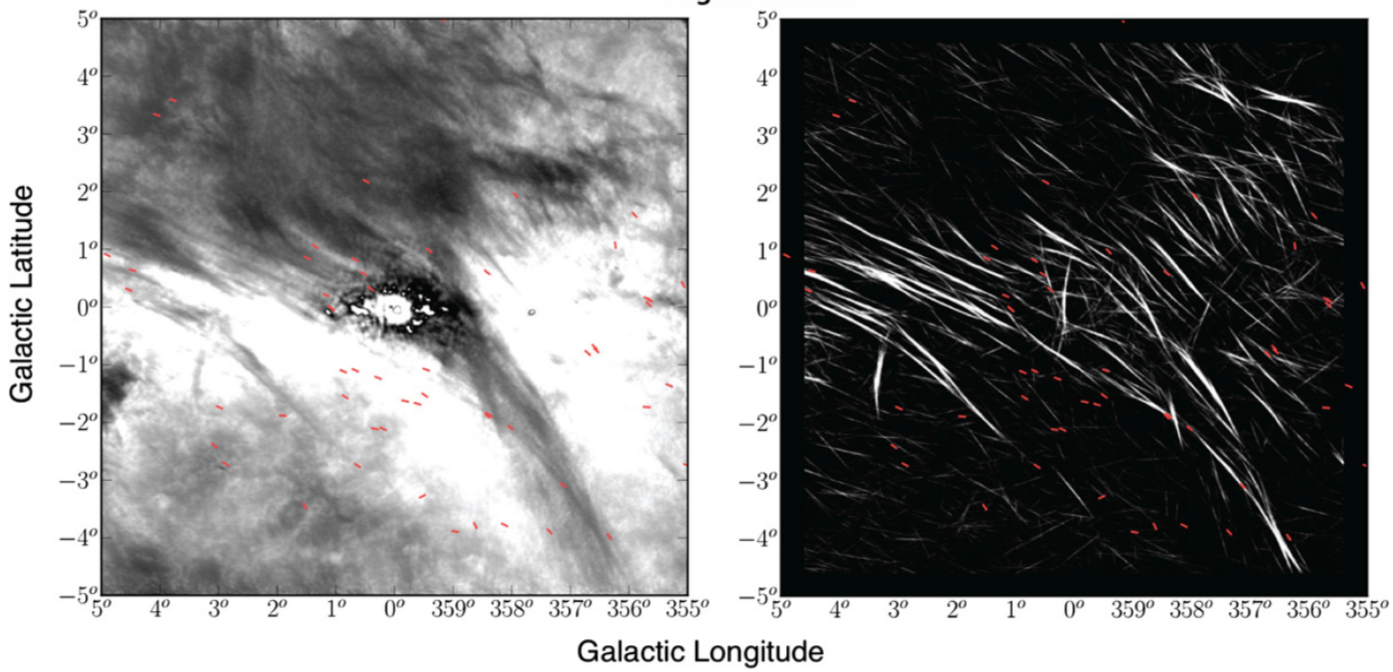
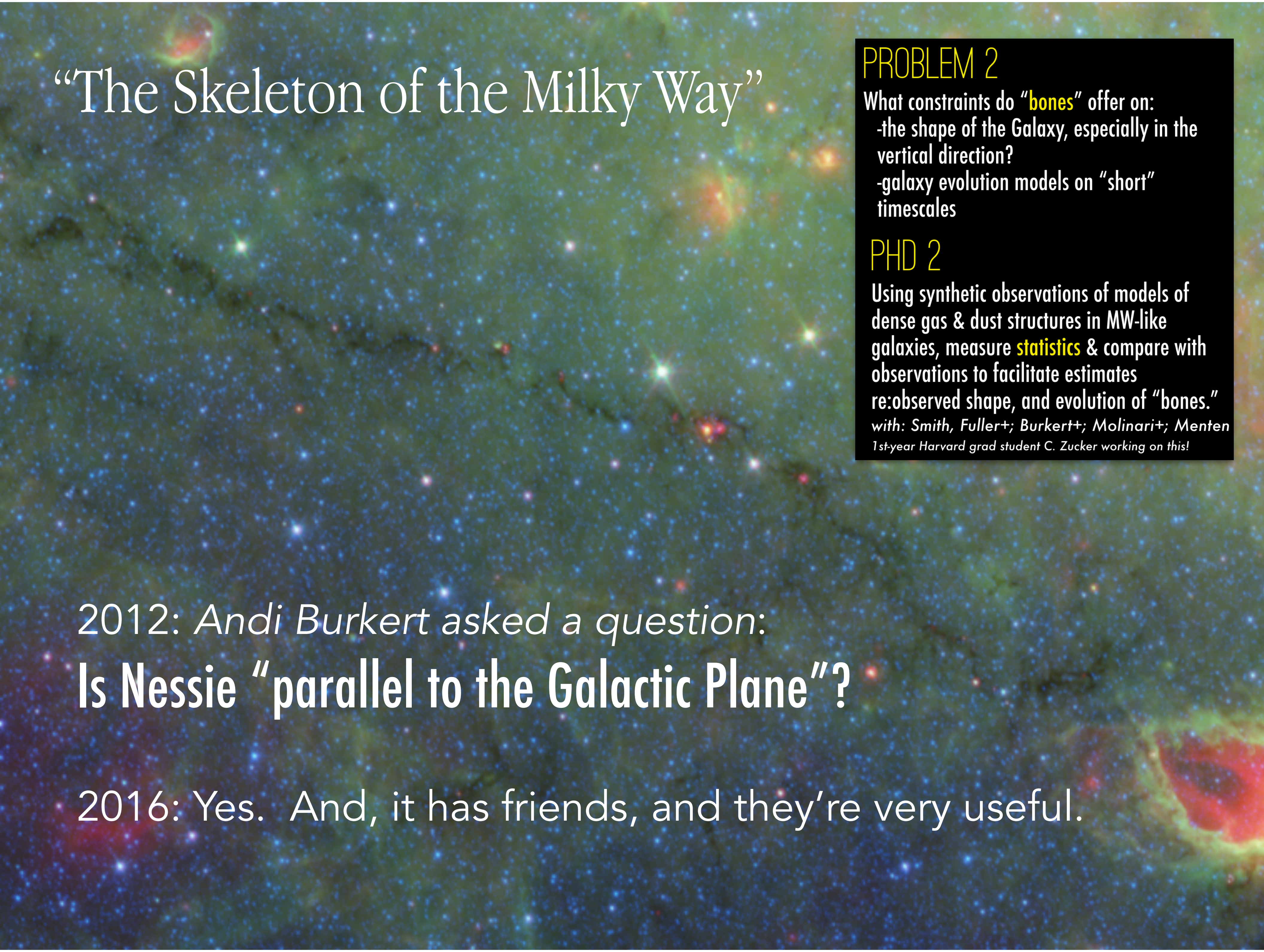


Figure 10. Riegel–Crutcher cloud (Section 6) in H I absorption (left) and RHT backprojection (right). Overlaid pseudovectors represent polarization angle measurements from the Heiles (2000) compilation. In the left panel, the intensity scale is linear from −20 K (white) to −120 K (black).

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

Clark, Peek & Putnam 2014

Last Month, in Dense Gas. . .



"The Skeleton of the Milky Way"

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 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

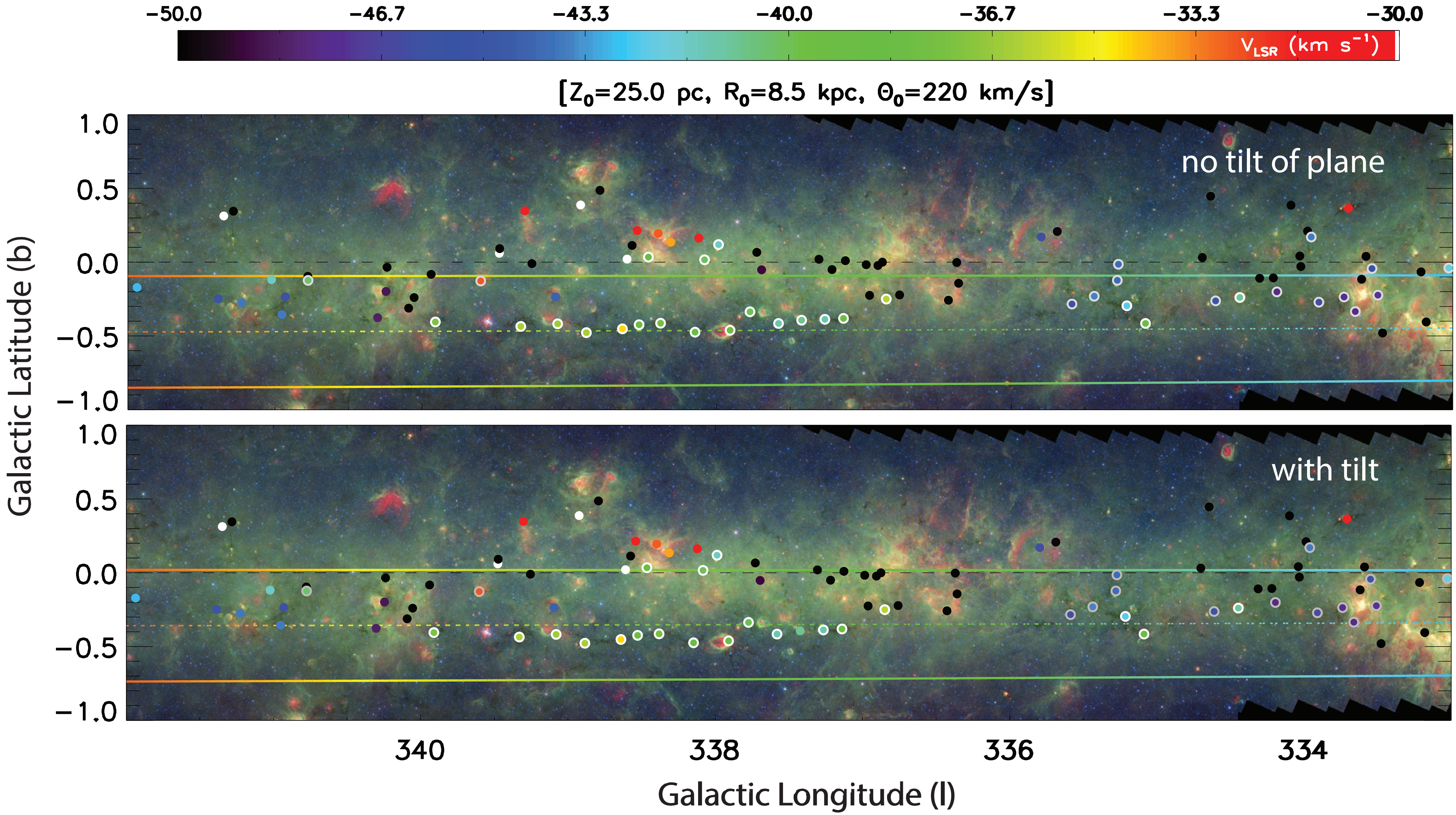
1st-year Harvard grad student C. Zucker working on this!

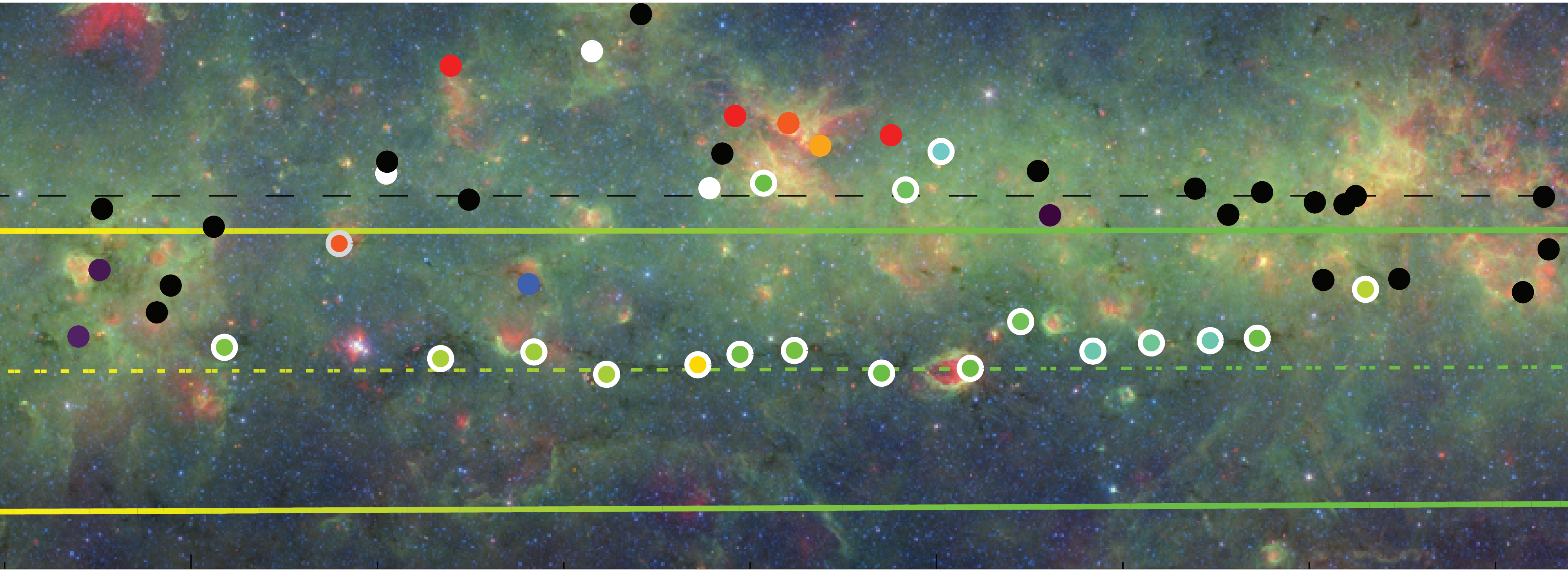
2012: *Andi Burkert asked a question:*

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]
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Received 2015 June 27; accepted 2015 September 21; published 2015 MM DD

ABSTRACT

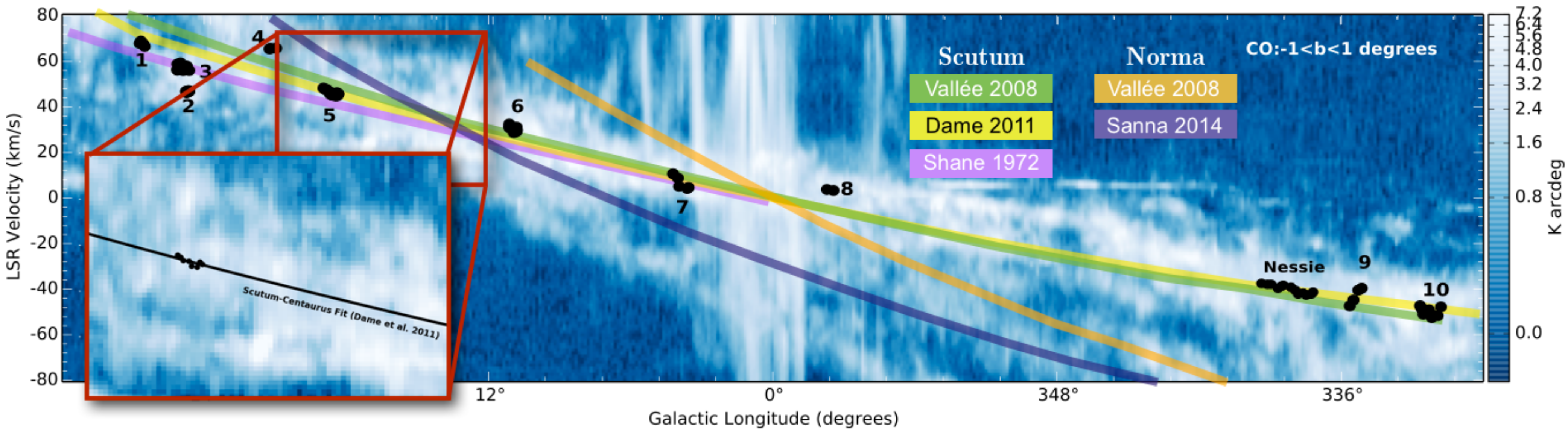
Recently, Goodman et al. argued that the very long, very thin infrared dark cloud "Nessie" lies directly in the Galactic midplane and runs along the Scutum–Centaurus Arm in position–position–velocity (*p–p–v*) space as traced by lower-density CO and higher-density NH_3 gas. Nessie was presented as the 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 ⩾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 ⩾50:1.



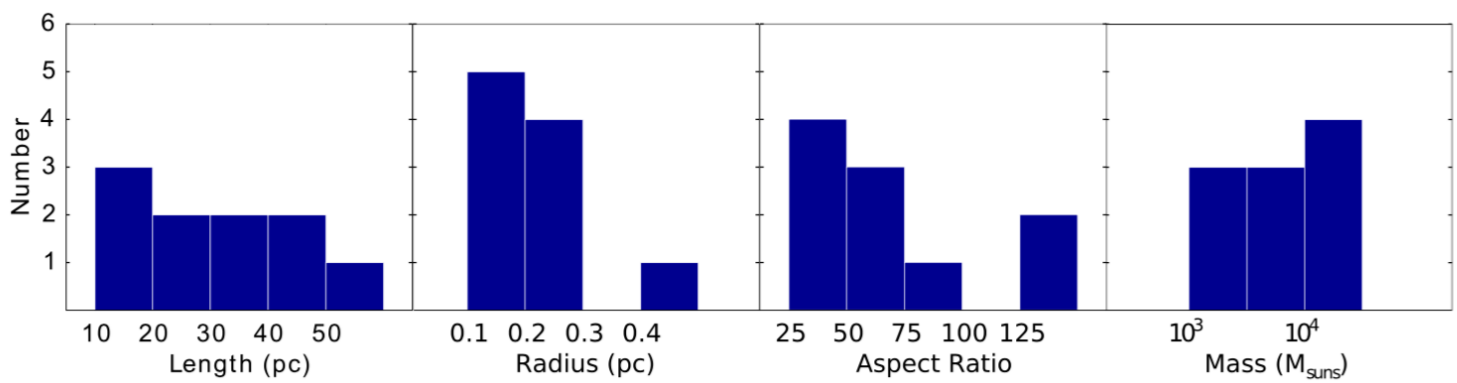
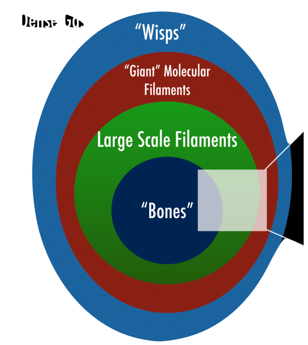


Figure 3. Distributions of length, radius, aspect ratio, and mass for the 10 bone candidates, based on data from Table 2.



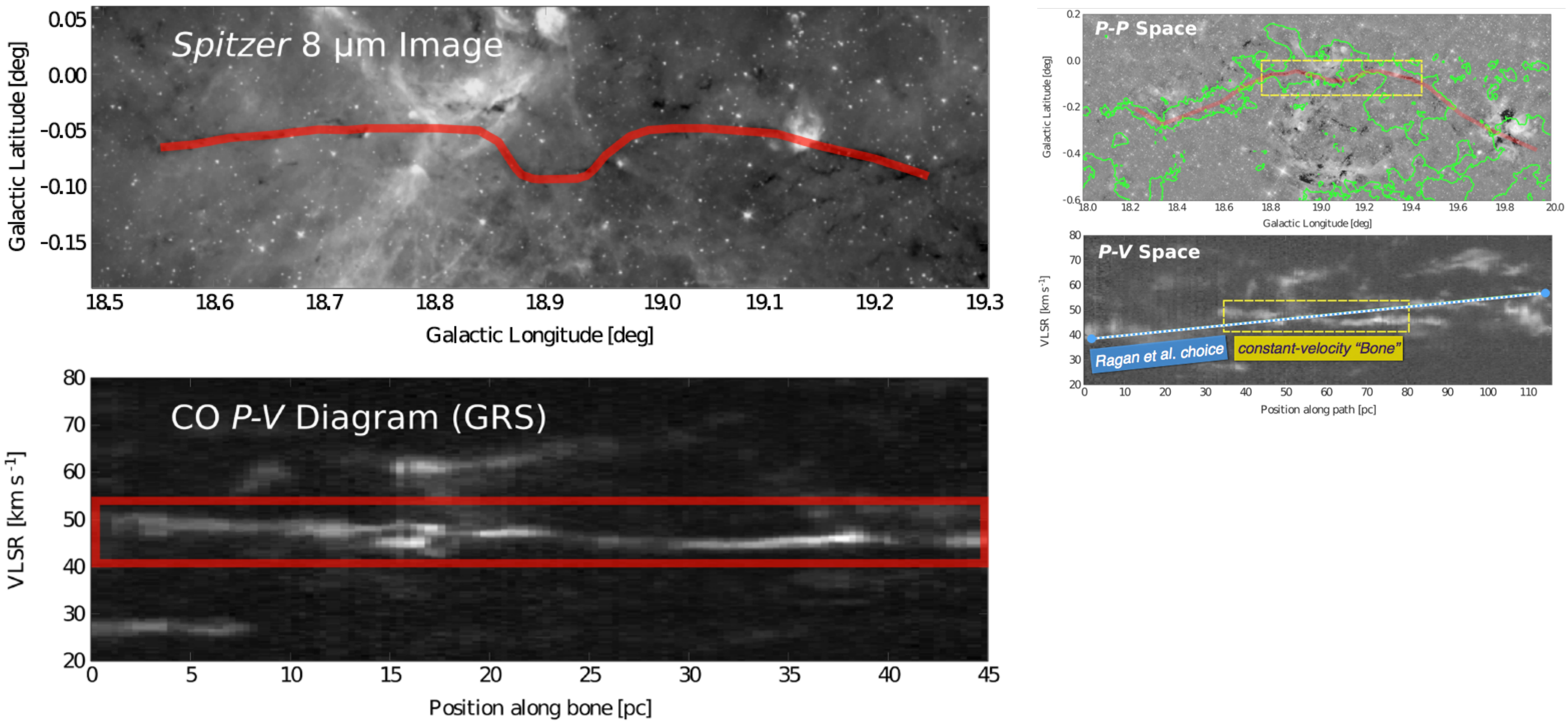


Figure 1. Results of performing a slice extraction along the filamentary extinction feature of our strongest bone candidate, filament 5. The top panel shows a *Spitzer*-GLIMPSE 8 μm image of filament 5, and the red trace indicates the curve (coincident with the extinction feature) along which a *p–v*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

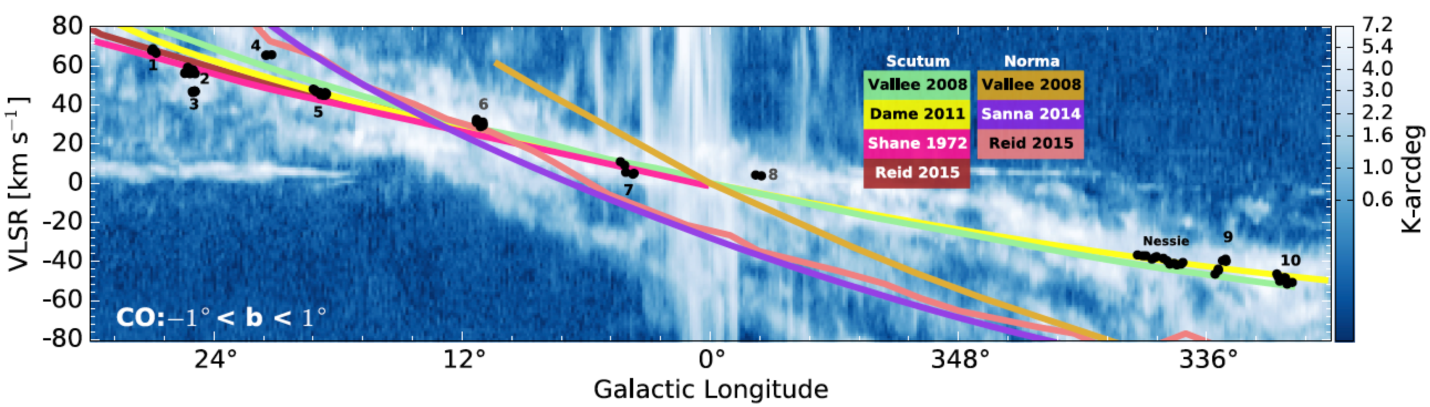
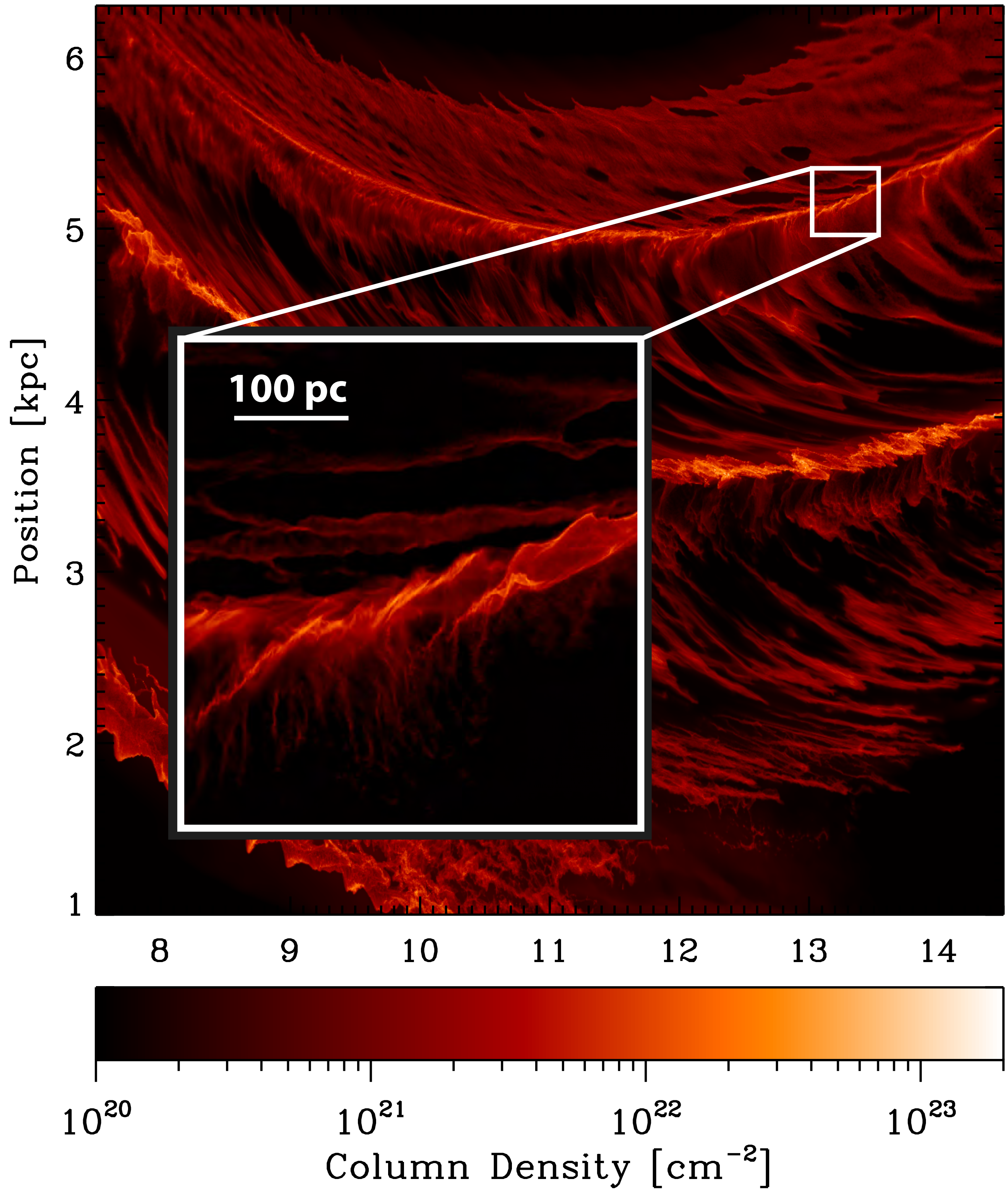


Figure 2. Position–velocity summary of bone candidates and spiral arm models. Blue background shows ^{12}CO emission from Dame et al. (2001), integrated between $-1^\circ < b < 1^\circ$. Black dots show measurements of BGPS-, HOPS-, MALT90-, and GRS-determined velocities, with particular candidate filaments 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).

2014 Simulation



Smith et al. 2014, using AREPO

2014 Simulation

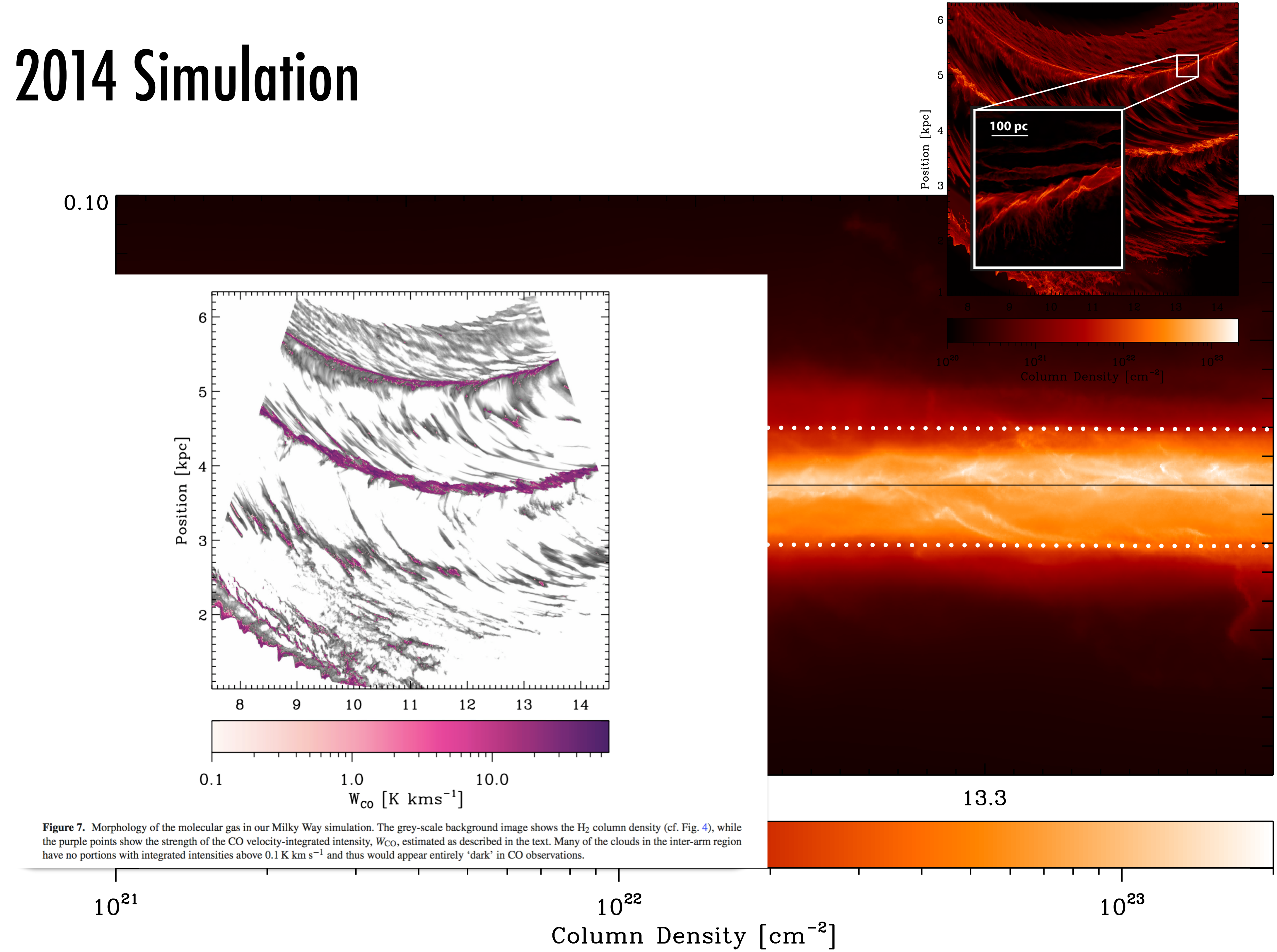


Figure 7. Morphology of the molecular gas in our Milky Way simulation. The grey-scale background image shows the H_2 column density (cf. Fig. 4), while the purple points show the strength of the CO velocity-integrated intensity, W_{CO}, estimated as described in the text. Many of the clouds in the inter-arm region have no portions with integrated intensities above 0.1 K km s^{-1} and thus would appear entirely 'dark' in CO observations.

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

“Core Assembly”

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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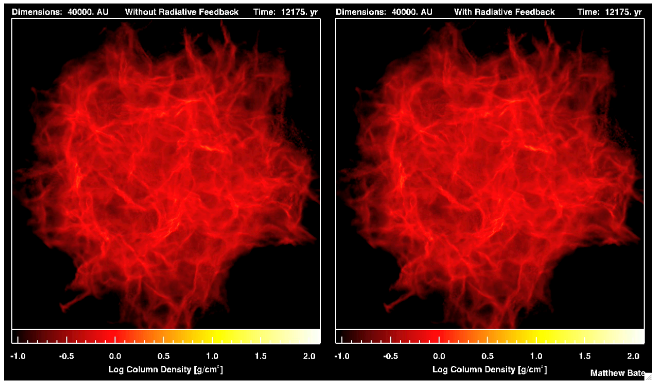

Mon. Not. R. Astron. Soc. 400, 1775–1784 (2009) doi:10.1111/j.1365-2966.2009.15621.x

The simultaneous formation of massive stars and stellar clusters

Rowan J. Smith,[1]★ Steven Longmore[2] and Ian Bonnell[1]
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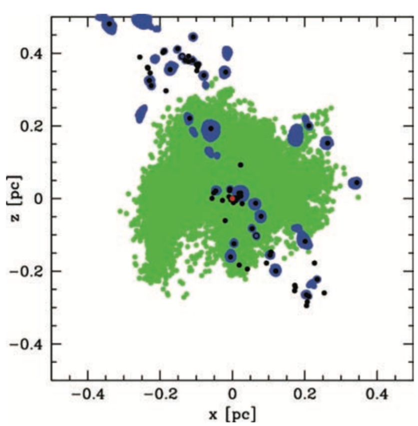

Figure 8. The final fate of the mass within clump Alpha shown at 1 t_{dyn}. The green dots show the positions of gas which will eventually be accreted by the massive sink (red dot). Black dots show the position of sinks and blue dots show the location of material in cores. The gas which will be accreted 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

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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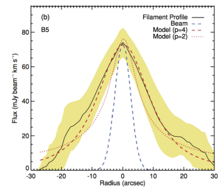
Received 2011 March 29; accepted 2011 June 27; published 2011 August 29



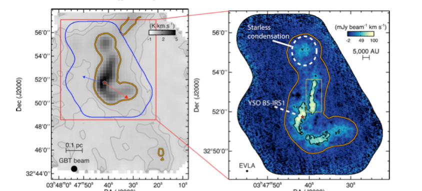


Figure 1. Left panel: integrated intensity map of B5 in NH_3 (1,1) obtained with GBT. Gray contours show the 0.15 and 0.3 K km s^{-1} level in NH_3 (1,1) integrated intensity. The orange contours show the region in the GBT data where the non-thermal velocity dispersion is subsonic. The young star, B5–IRS1, 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

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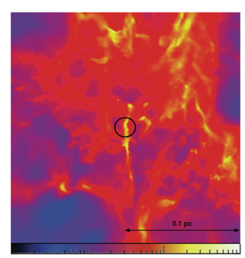
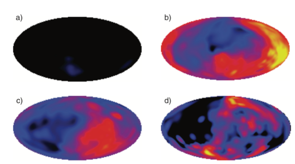


Figure 8. Column density projection in (g cm^{-2}) of the local environment of the filamentary core (d), shown in the circle. There are multiple condensed structures within 0.1 pc of the core.



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 en 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.

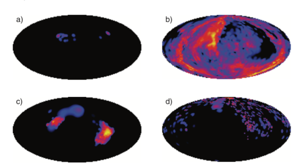


Figure 10. The positions at which accreted material passes through a shell of radius $r = 0.1$ pc around the sink over 20 000 yr. At this larger radius, the accreted material is clearly coming from just a few directions. Core (c) is an obvious example of accretion purely along a filament.

2013

Astronomy & Astrophysics manuscript no. 20090ms
March 12, 2013

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]
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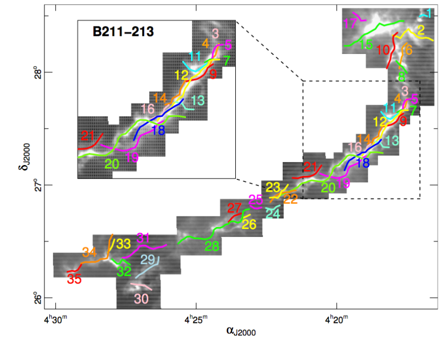
[2] Institute for Astrophysics, University of Vienna, Türkenschanzstrasse 17, 1180 Vienna, Austria.
e-mail: alvaro.hacar@univie.ac.at
[3] Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91109, USA
[4] University of Minnesota, 116 Church St SE, Minneapolis, MN 55414, USA



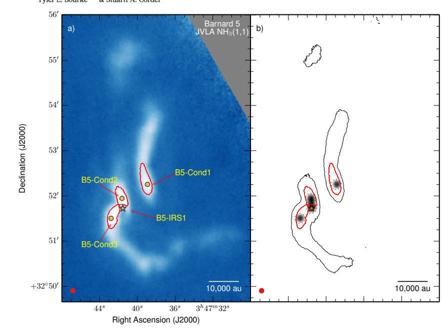
“Now”

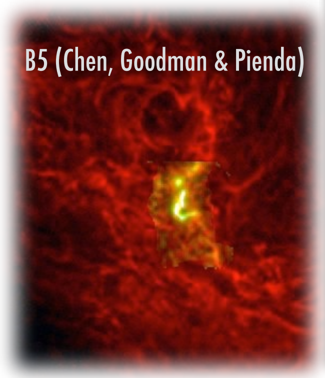
LETTER

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]





PROBLEM 1

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

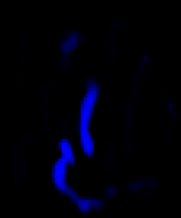
PHD 1

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

“Connections”: 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)



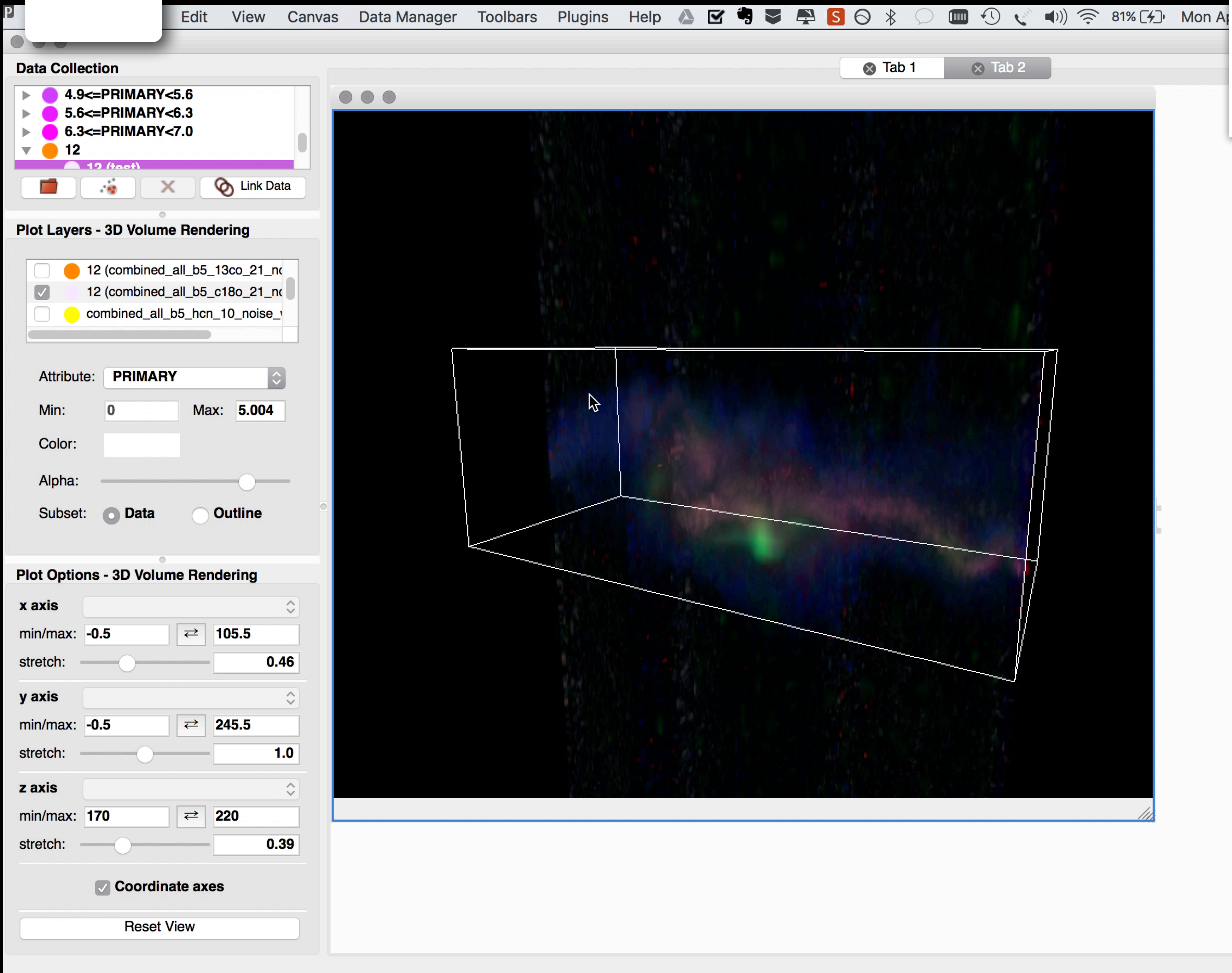
Goodman, Chen, Offner & Pineda 2016 in prep.

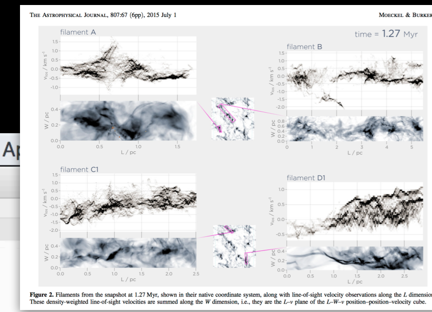
Herschel data from Gould Belt Survey

1998

2008

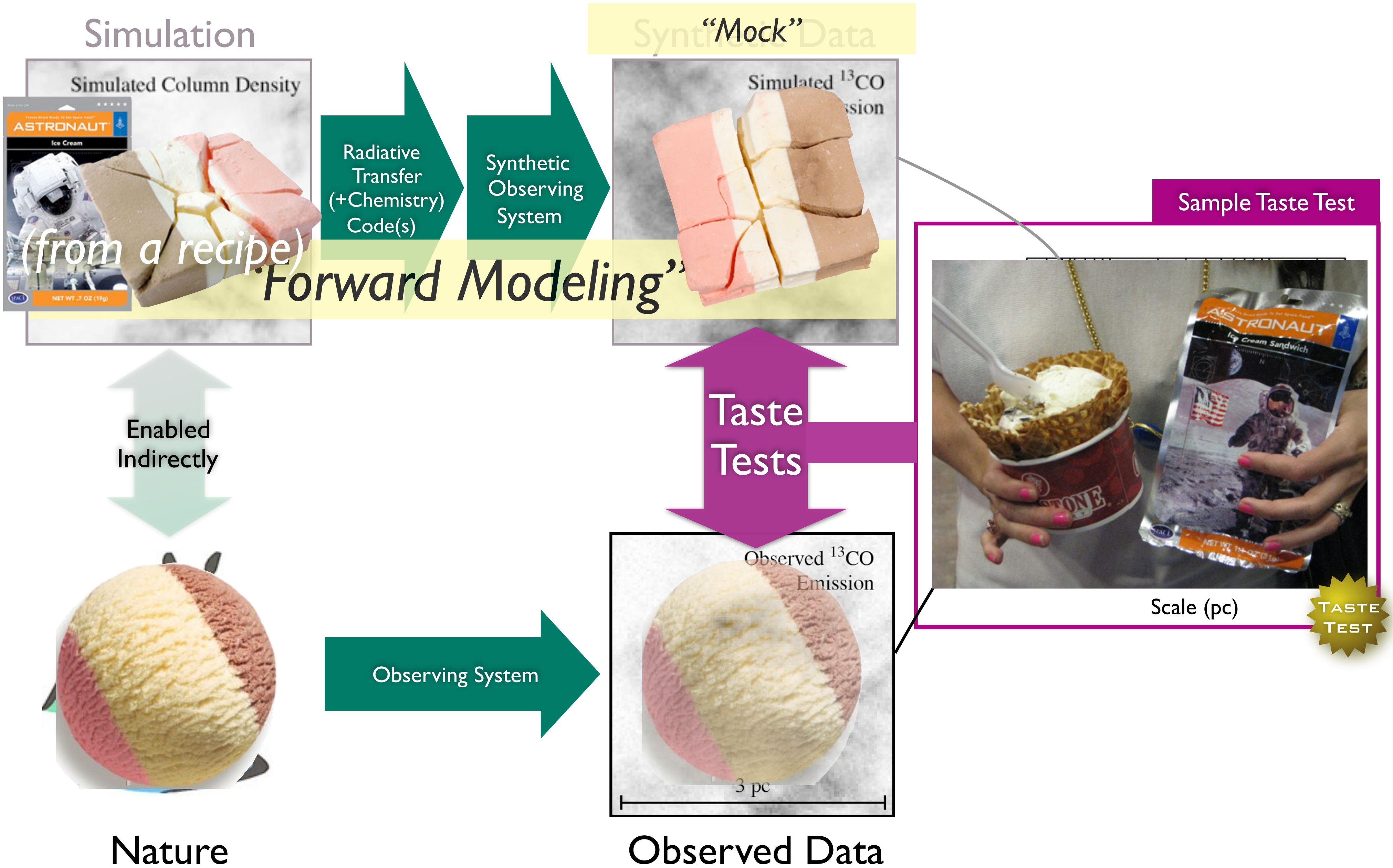
Preview of Carl's Gift





glueviz.org

"Taste-Testing"



Mock Observations + Statistics are the Way Forward.

THE ASTROPHYSICAL JOURNAL, 786:64 (13pp), 2014 May 1

THREE-DIMENSIONAL HYDRODYNAMIC SIMU
WITH STAR FORMATION FEEDBACK. II. SY

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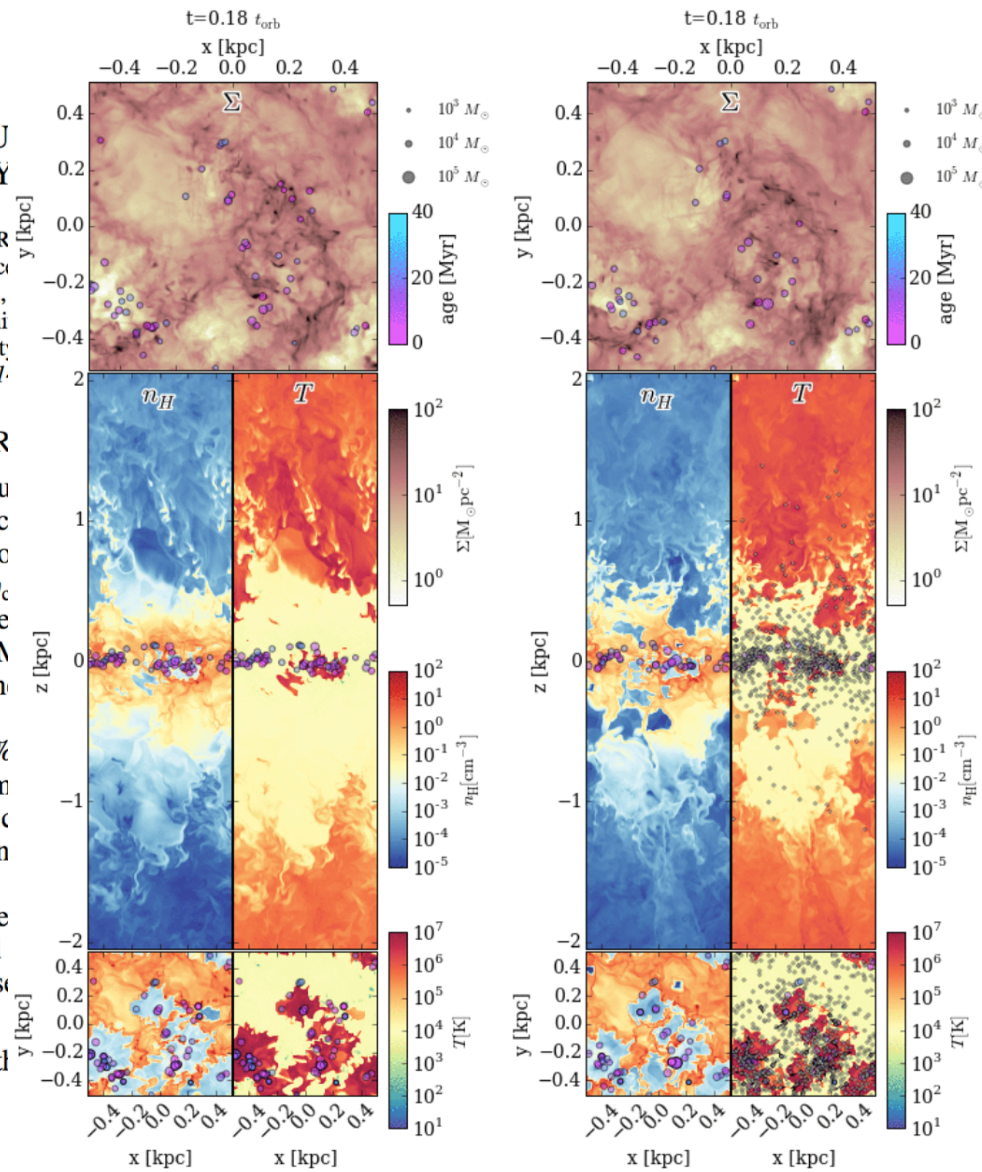
[2] Center for the Exploration of the Origin of the Uni
of Physics & Astronomy, Seoul National Universit
Received 2014 January 2; accepted 201

ABSTR

We use three-dimensional numerical hydrodynamic simu medium (ISM) to construct and analyze synthetic H I 21 c detailed tests of 21 cm observables as physical diagno (1) the "observed" spin temperature, $T_{s,\rm obs}(v_{\rm ch}) \equiv T_B(v_c$ $T_{s,\rm obs}$; (2) the absorption-corrected "observed" column de (3) the "observed" fraction of cold neutral medium (CNM compare each observed parameter with true values obtain Within individual velocity channels, $T_{s,\rm obs}(v_{\rm ch})$ is within consequence, $N_{\rm H,obs}$ and $T_{s,\rm obs}$ are, respectively, within 5% The optically thin approximation significantly underestim accurate observational estimate of the CNM mass fraction c be used to distinguish the relative proportions of warm an of thermally unstable gas can be discerned from 21 cm observations successfully reproduce and explain the obse depth, and spin temperature in Roy et al. The threshold reproduced by our mock observations. We explain this obs in the local Milky Way's ISM disk.

Key words: hydrodynamics – ISM: lines and bands – met

Online-only material: color figures



Mock Observations + Statistics are the Way Forward.

Continuum
Lines (Chemistry)
Synthetic Observatories

PDF
SCF
PCA
Bispectrum
Tsallis
VCS
VCA
2pt CF
3pt CF
…

Observed space is *not* real space

The Astrophysical Journal, 777:173 (20pp), 2013 November 10 doi:10.1088/0004-637X/777/2/173

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

ABSTRACT

The physical properties of molecular clouds are often measured using spectral-line observations, which provide the only probes of the clouds' velocity structure. It is hard, though, to assess whether and to what extent intensity features in position–position–velocity (PPV) space correspond to "real" density structures in position–position–position (PPP) space. In this paper, we create synthetic molecular cloud spectral-line maps of simulated molecular clouds, and present a new technique for measuring the reality of individual PPV structures. Using a dendrogram algorithm, we identify hierarchical structures in both PPP and PPV space. Our procedure projects density structures identified in PPP space into corresponding intensity structures in PPV space and then measures the geometric overlap of the projected structures with structures identified from the synthetic observation. The fractional overlap between a PPP and PPV structure quantifies how well the synthetic observation recovers information about the three-dimensional structure. Applying this machinery to a set of synthetic observations of CO isotopes, we measure how well spectral-line measurements recover mass, size, velocity dispersion, and virial parameter for a simulated star-forming region. By disabling various steps of our analysis, we investigate how much opacity, chemistry, and gravity affect measurements of physical properties extracted from PPV cubes. For the simulations used here, which offer a decent, but not perfect, match to the properties of a star-forming region like Perseus, our results suggest that superposition induces a ~40% uncertainty in masses, sizes, and velocity dispersions derived from ^{13}CO ($J = 1$–0). As would be expected, superposition and confusion is worst in regions where the filling factor of emitting material is large. The virial parameter is most affected by superposition, such that estimates of the virial parameter derived from PPV and PPP information typically disagree by a factor of ~2. This uncertainty makes it particularly difficult to judge whether gravitational or kinetic energy dominate a given region, since the majority of virial parameter measurements fall within a factor of two of the equipartition level $\alpha \sim 2$.

Key words: ISM: clouds – radiative transfer – techniques: image processing – techniques: spectroscopic

Online-only material: color figures

Observed space is *not* real space


THE ASTROPHYSICAL JOURNAL, 777:173 (20pp), 2013 November 10 doi:10.1088/0004-637X/777/2/173

QUANTIFYING OBSERVATIONAL PROJECTION EFFECTS USING MOLECULAR CLOUD SIMULATIONS

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ABSTRACT

The physical properties of molecular clouds are often measured using spectral-line observations, which provide the only probes of the clouds' velocity structure. It is hard, though, to assess whether and to what extent intensity features in position–position–velocity (PPV) space correspond to "real" density structures in position–position–position (PPP) space. In this paper, we create synthetic molecular cloud spectral-line maps of simulated molecular clouds, and present a new technique for measuring the reality of individual PPV structures. Using a dendrogram algorithm, we identify hierarchical structures in both PPP and PPV space. Our procedure projects density structures identified in PPP space into corresponding intensity structures in PPV space and then measures the geometric overlap of the projected structures with structures identified from the synthetic observation. The fractional overlap between a PPP and PPV structure quantifies how well the synthetic observation recovers information about the three-dimensional structure. Applying this machinery to a set of synthetic observations of CO isotopes, we measure how well spectral-line measurements recover mass, size, velocity dispersion, and virial parameter for a simulated star-forming region. By disabling various steps of our analysis, we investigate how much opacity, chemistry, and gravity affect measurements of physical properties extracted from PPV cubes. For the simulations used here, which offer a decent, but not perfect, match to the properties of a star-forming region like Perseus, our results suggest that superposition induces a ~40% uncertainty in masses, sizes, and velocity dispersions derived from ^{13}CO ($J = 1$–0). As would be expected, superposition and confusion is worst in regions where the filling factor of emitting material is large. The virial parameter is most affected by superposition, such that estimates of the virial parameter derived from PPV and PPP information typically disagree by a factor of ~2. This uncertainty makes it particularly difficult to judge whether gravitational or kinetic energy dominate a given region, since the majority of virial parameter measurements fall within a factor of two of the equipartition level $\alpha \sim 2$.

Key words: ISM: clouds – radiative transfer – techniques: image processing – techniques: spectroscopic

Online-only material: color figures

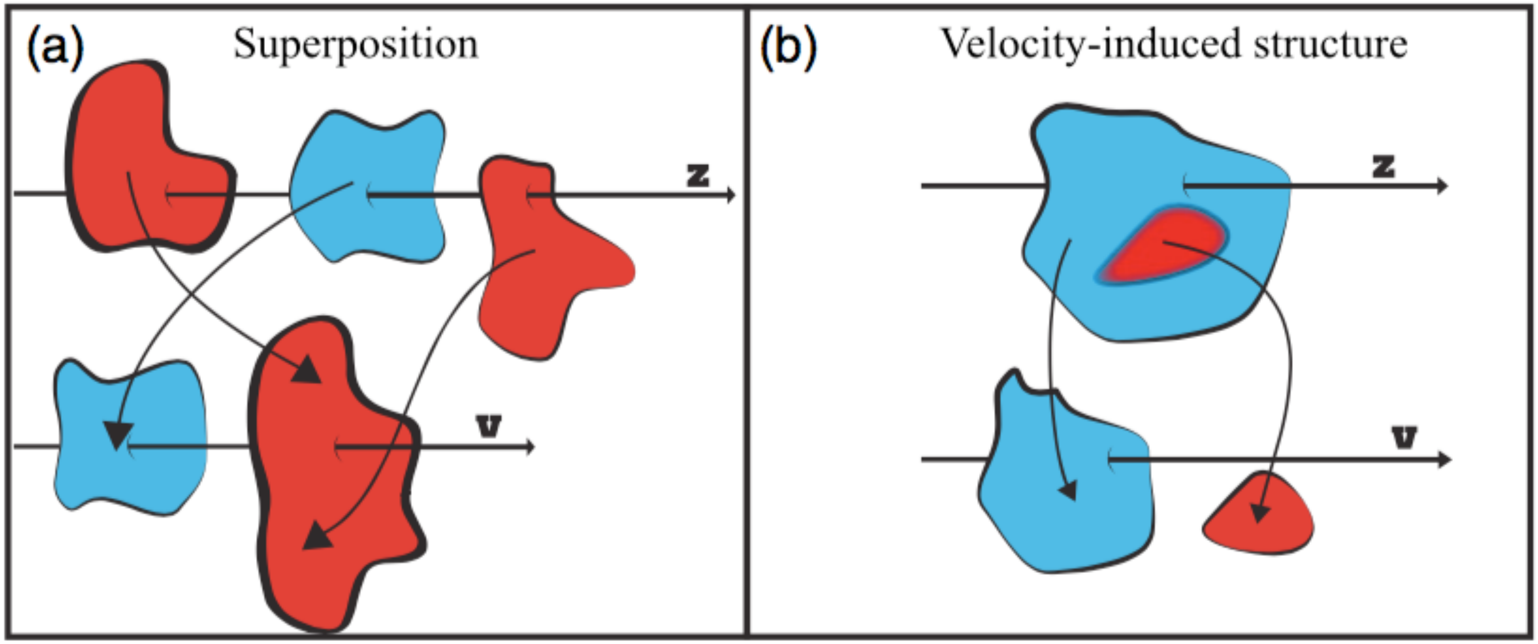


Figure 1. Schematic representation of superposition and velocity-induced structures. Colors indicate velocity. Left: three PPP structures (top) merge into 2 PPV structures (bottom), due to the similar velocity of the front and back structures. Right: a single density structure with internal velocity gradients (top) splits into two PPV structures (bottom).

Observed space is *not* real space

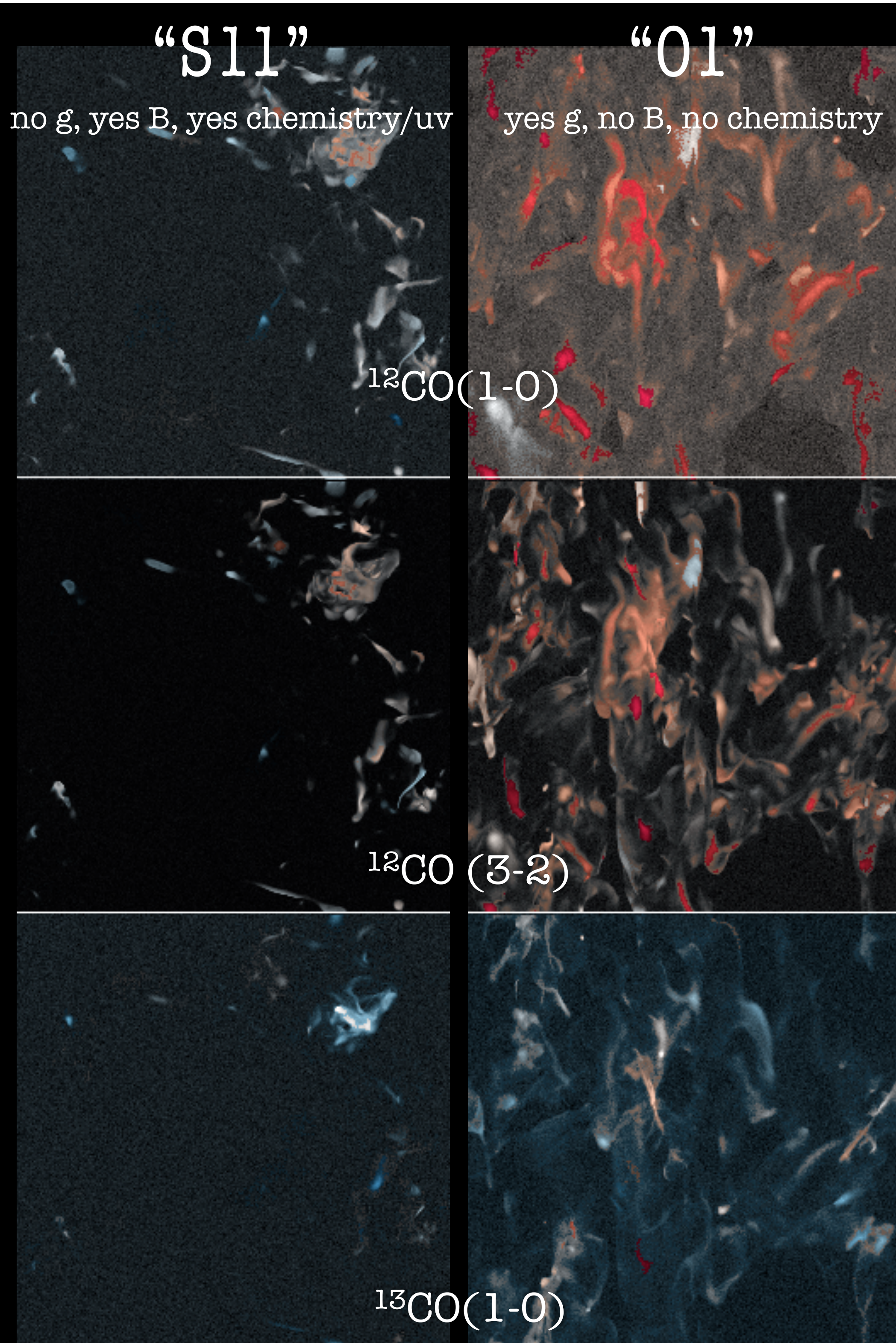
good
bad

movies include a noise model, in both cases

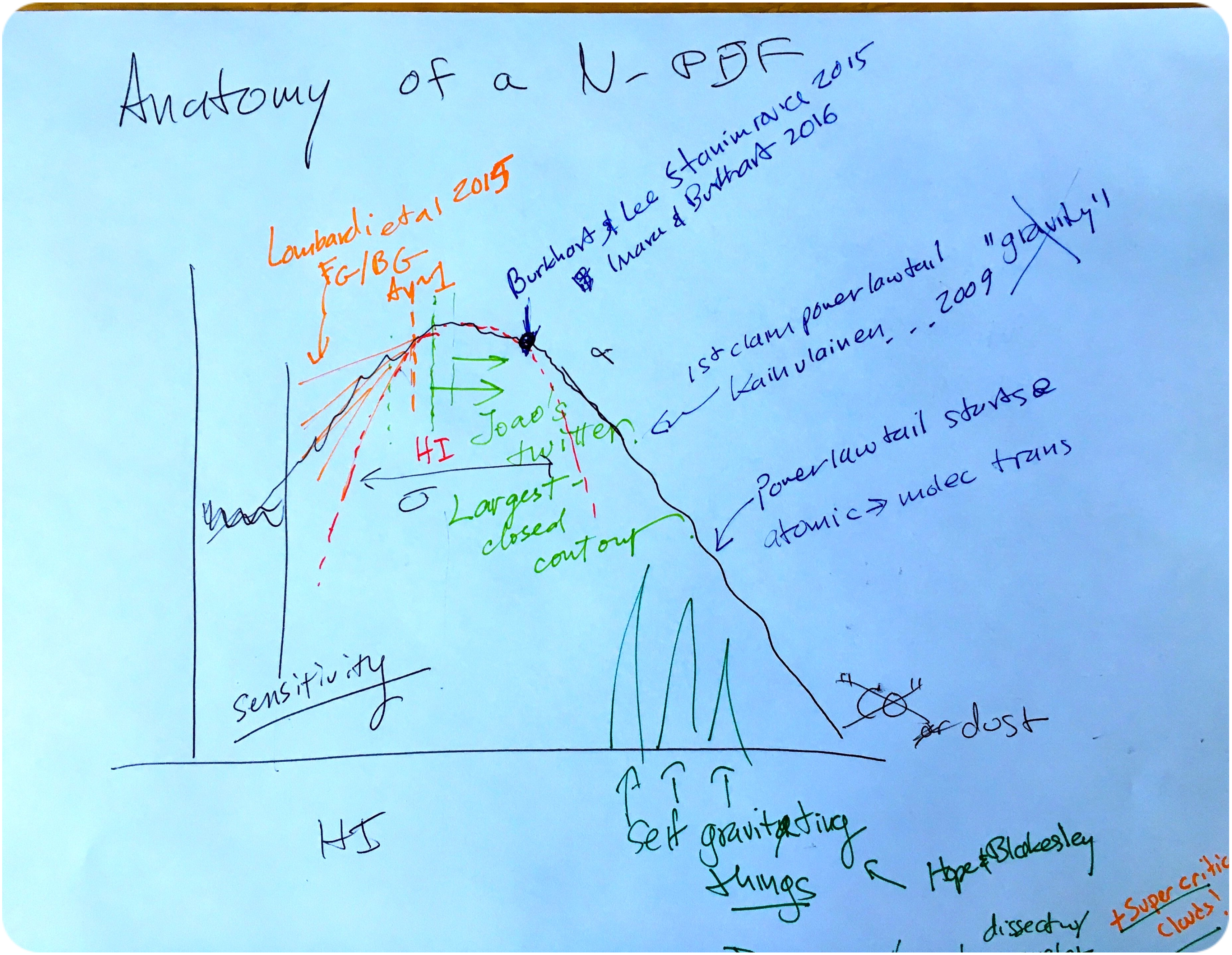
Table 2. Summary of each simulation

	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

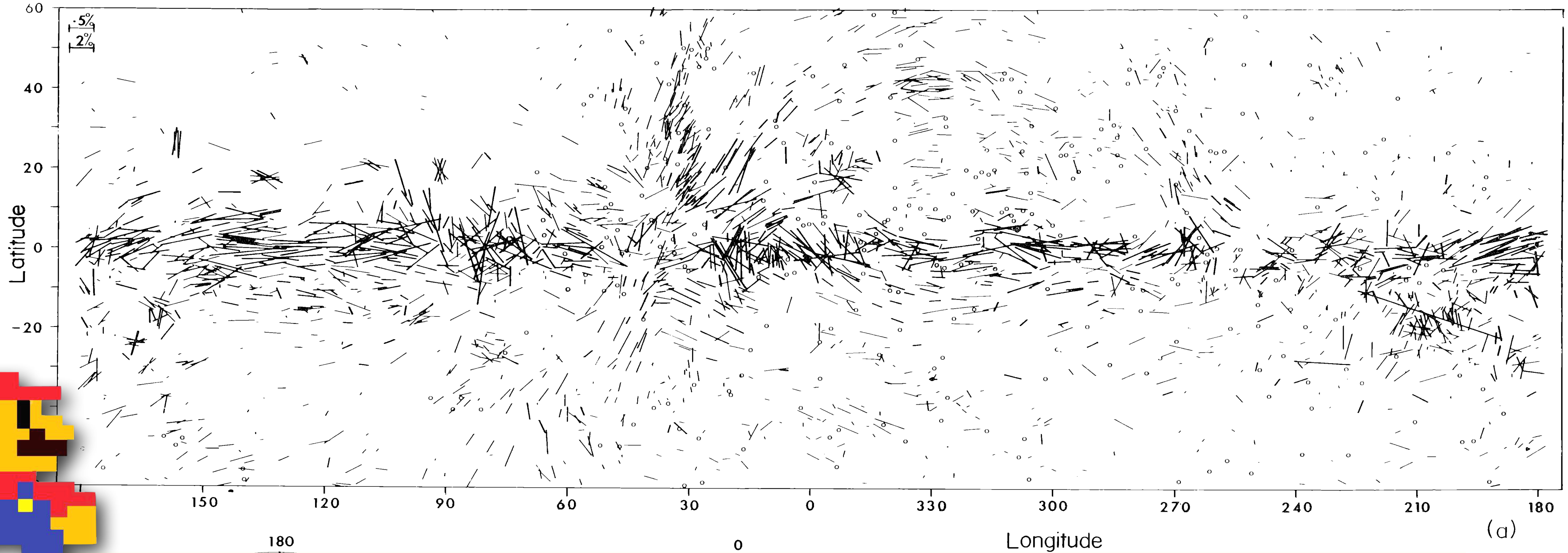


Are N-PDFs a useful test?   Ask Blakesley.



Data, Visualization

1970



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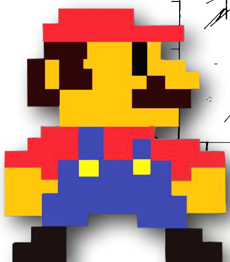
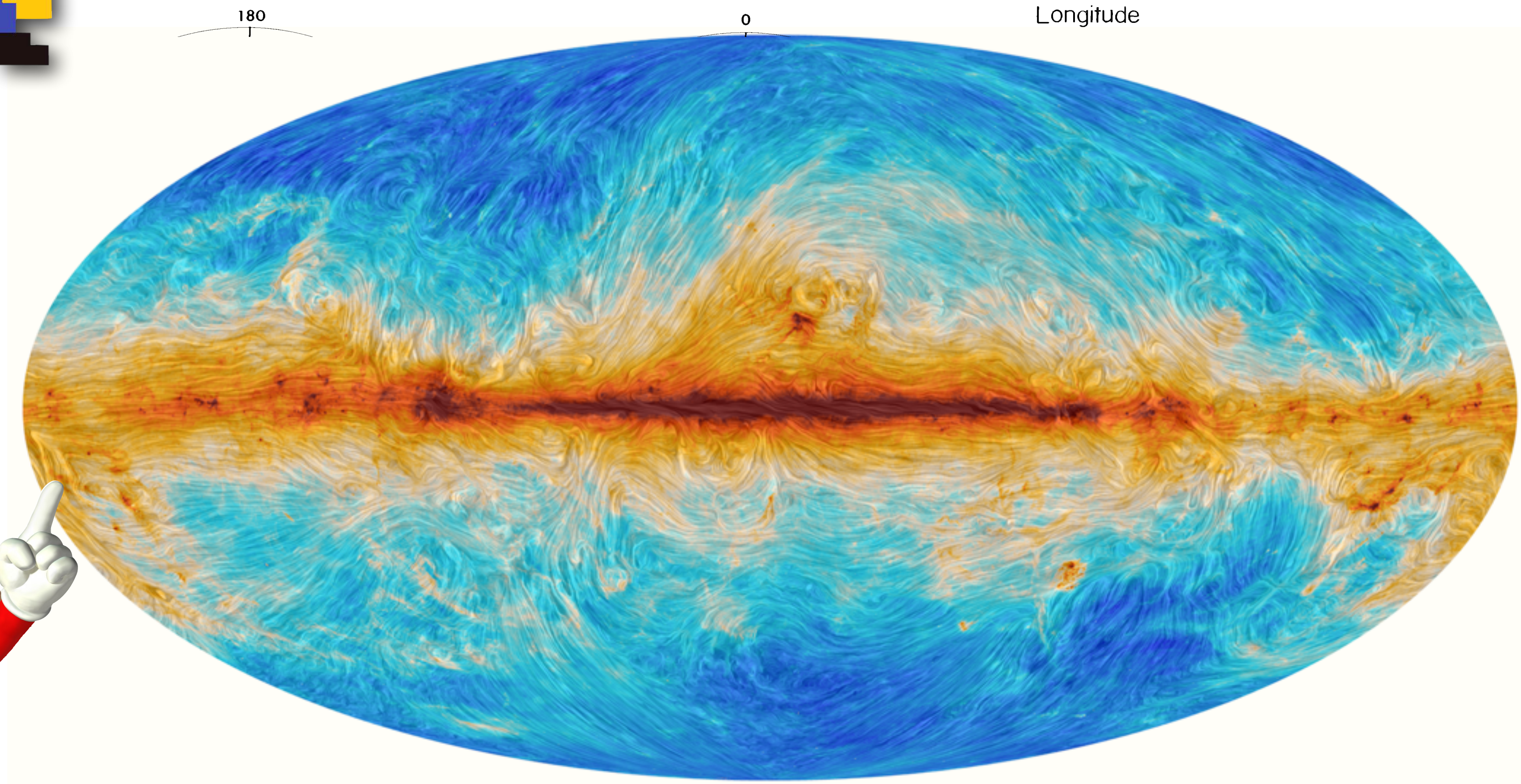


2014



180
0

The Astrophysical Journal, 822:52 (27pp), 2016 May 1

Data

doi:10.3847/0004-637X/822/1/52

CrossMark

A UNIFORM CATALOG OF MOLECULAR CLOUDS IN THE MILKY WAY

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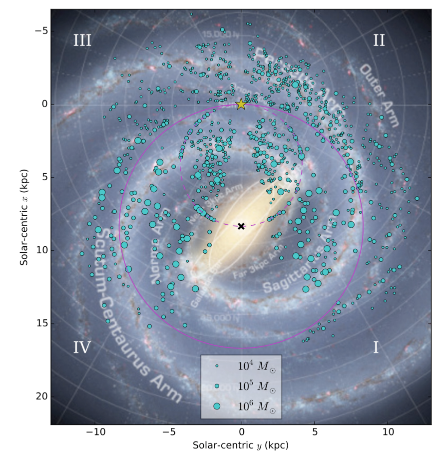
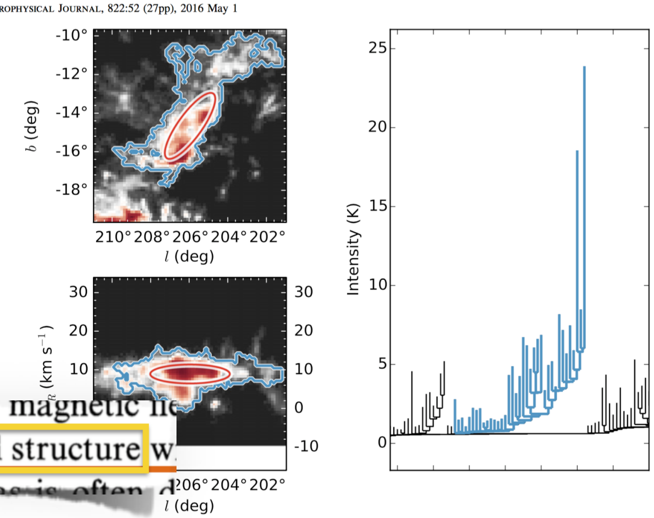
ABSTRACT

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





the interstellar magnetic fie
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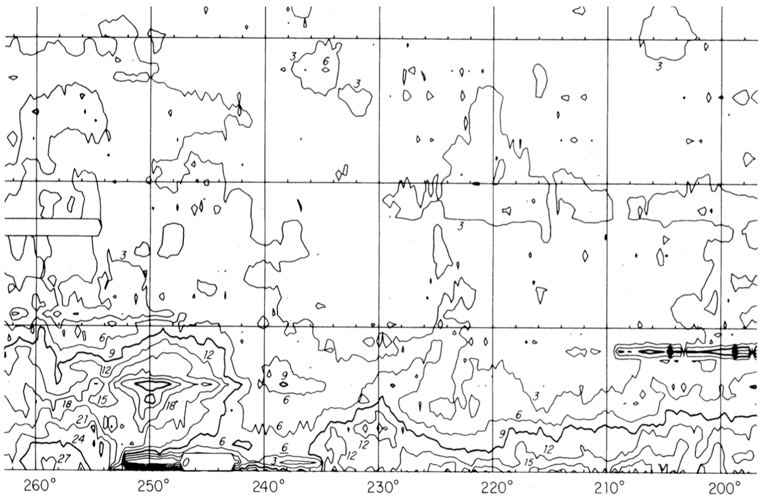
regates the gas is often d

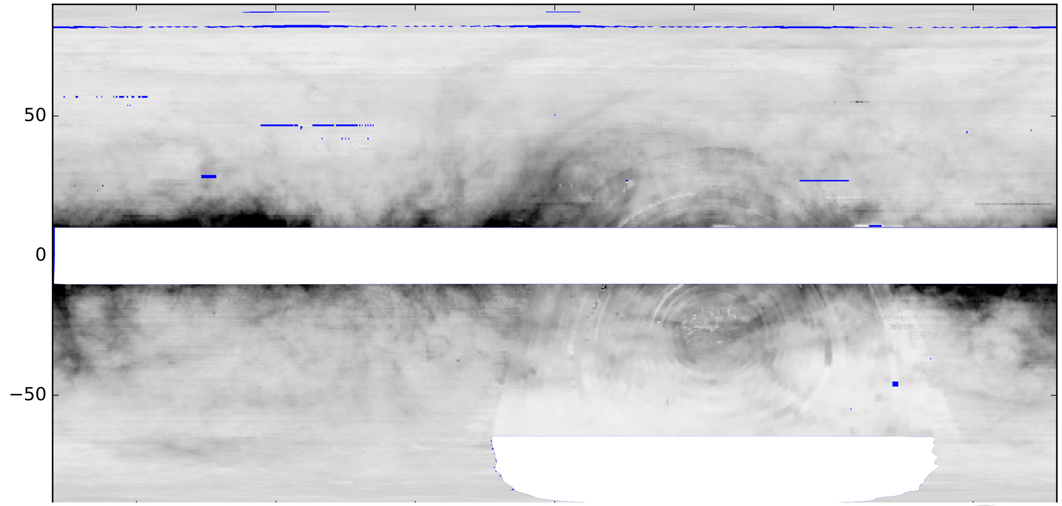
Figure 2. Example dendrogram extraction of Orion B: a nearby, well-studied giant molecular cloud. Top left: (l, b) thumbnail of the cloud and its neighboring region as seen on the sky. Bottom left: (l, v) thumbnail of the same region. Right: dendrogram cutout, with Orion B's structures highlighted in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

Visualization

Video Abstract of Pasquini et al. 2016



Burstein – Heiles (1982)



carl heiles

To: Alyssa Goodman

Cc: Green, Gregory, Catherine Zucker, Doug Finkbeiner, carl heiles, Blakesley Burkhart

Re: history

May 15, 2016 at 9:22 AM

Inbox - goodman.alyssa

hide

CH

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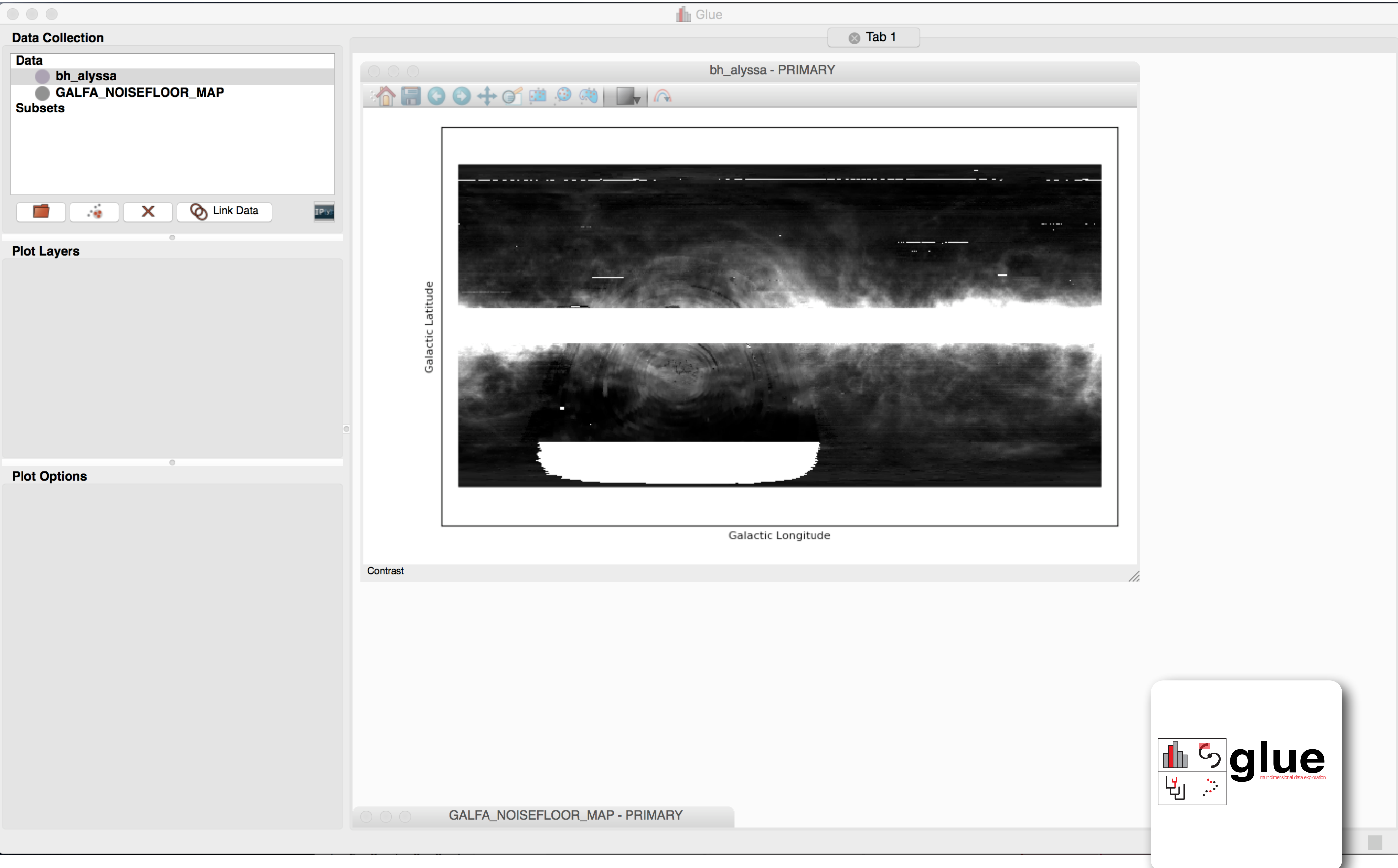
alyssa, you must be dreaming. Healpix in 1981? even fits (i dunno about fits...). i don't recall how i made (i assume it was me, not dave) that contour plot, but back in those days the only way i can imagiine was to use a Calcomp plotter. That's a pen-and-ink plotter that used paper 2 or 3 feet wide on a roll so the length could be arbitrarily long.

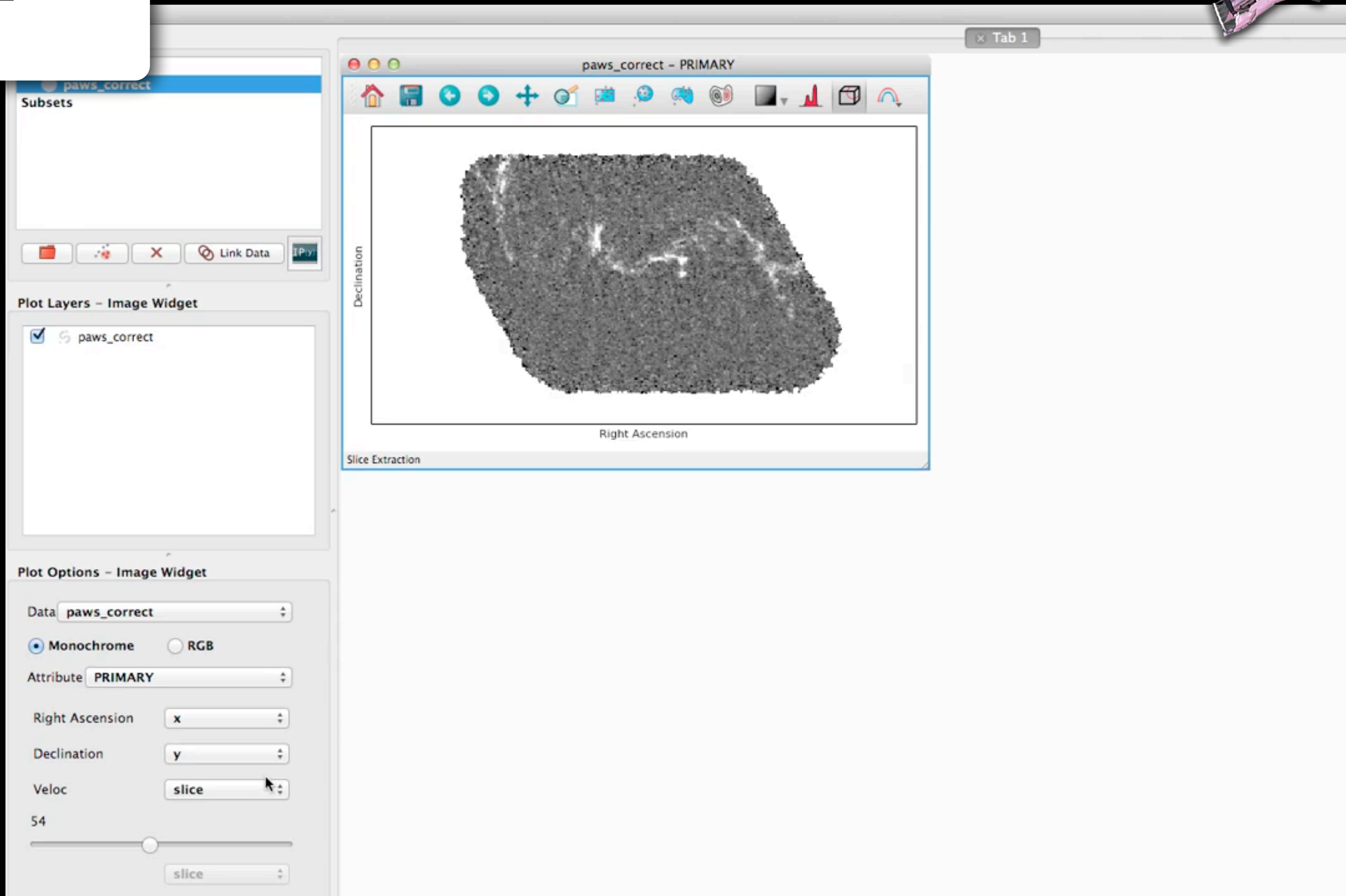
like, the students in my just-given radio astronomy lab class make 21-cm line images of large peices of the sky from their own data with our lab 3.5 m dish and change contrast, etc at will, on our modern-day monitors. one of them dug up some of my old papers with such images that i made in yesteryear. i tell the students what i had to go through to make such images--they were made with a computer controlled laser scanning back and forth on a 3 x 4 inch (i think) glass photographic plate and I would do a set of four on each plate to get four 35 mm slides. i'd do the ones in each set with different laser intensities and stretches, and hope that i'd successfully develop the plates and one would be suitable. and, also, that i'd be succdessful in using a glass cutter to get the four slids from the larger plate without braking anything. and then there were the color images, with color representing velocity, made with ed jenkins. for that we used a modified computer-controlled laseer scanner, originally made for use in magazine publishing, that worked on 12x18 negative plastic, and direct-contact it to make images on photogaphic paper.

anyway, i have no idea where the original files might be--and even if i did, you'd have a tough time finding a Calcomp plotter to go with them!

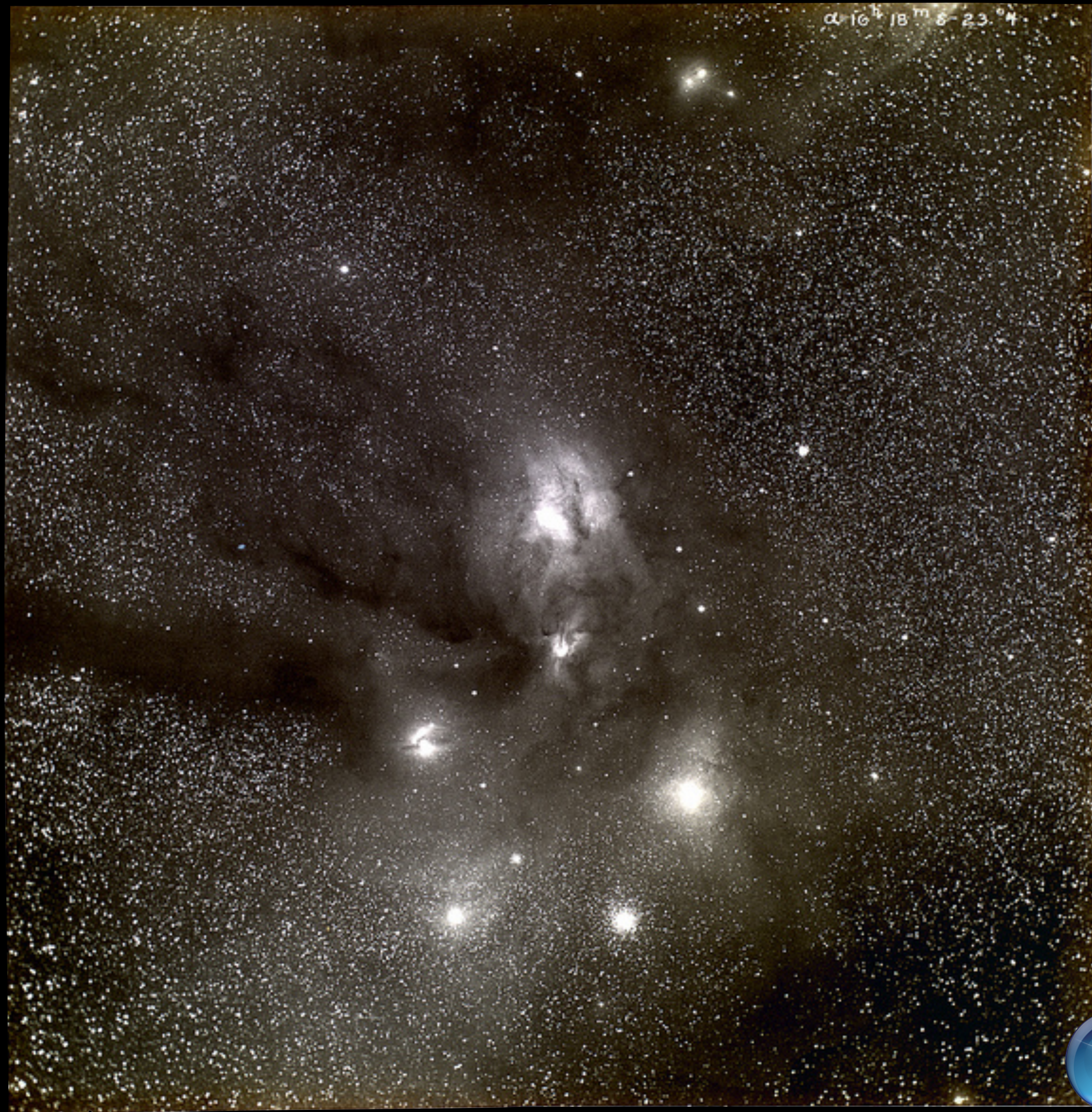
A gift to Carl from Alyssa, Josh, Greg Green, Doug Finkbeiner & Catherine Zucker.



Bonus gift



Beaumont, w/Goodman, Robitaille, Borkin+thanks to Peek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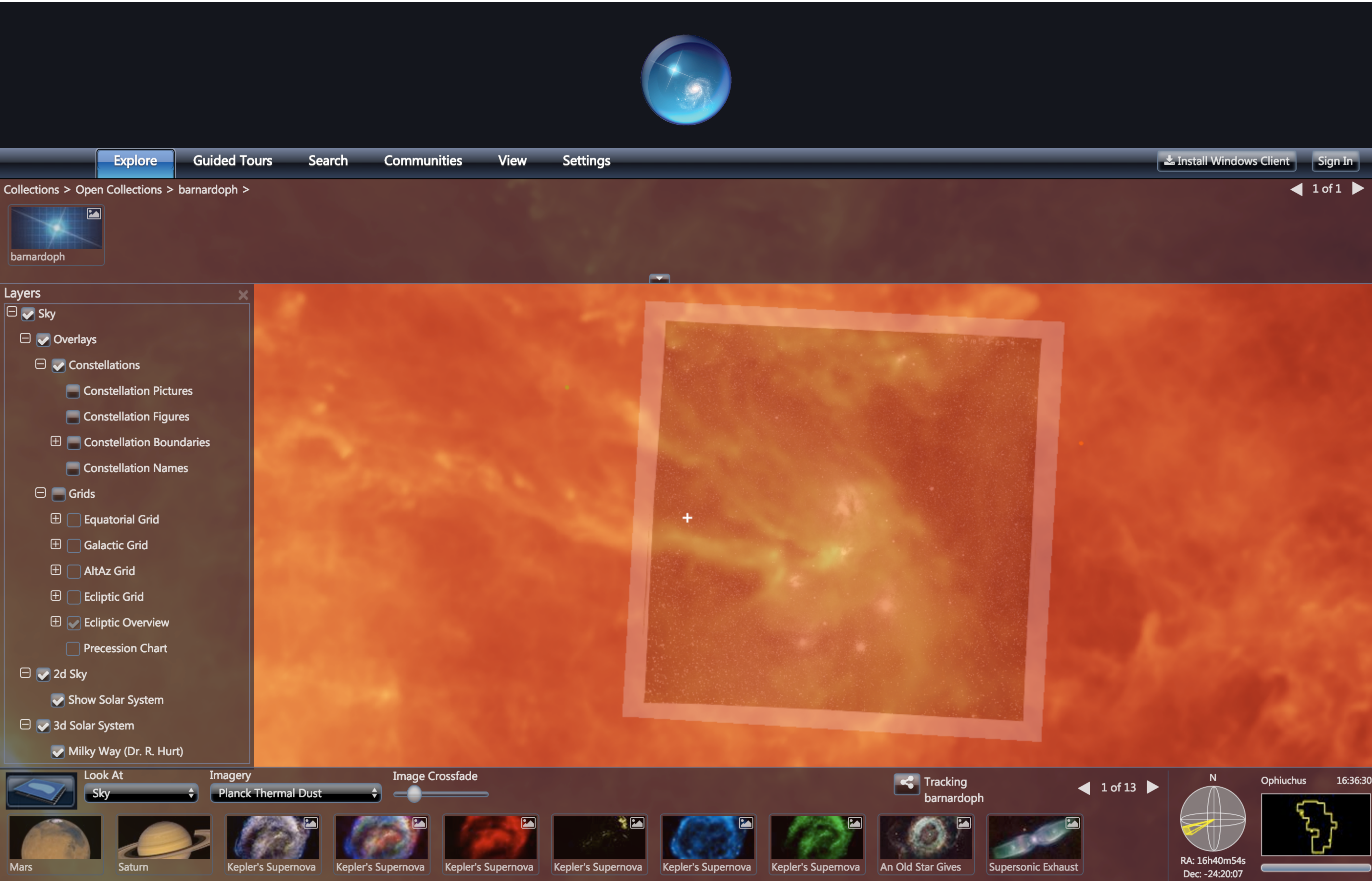
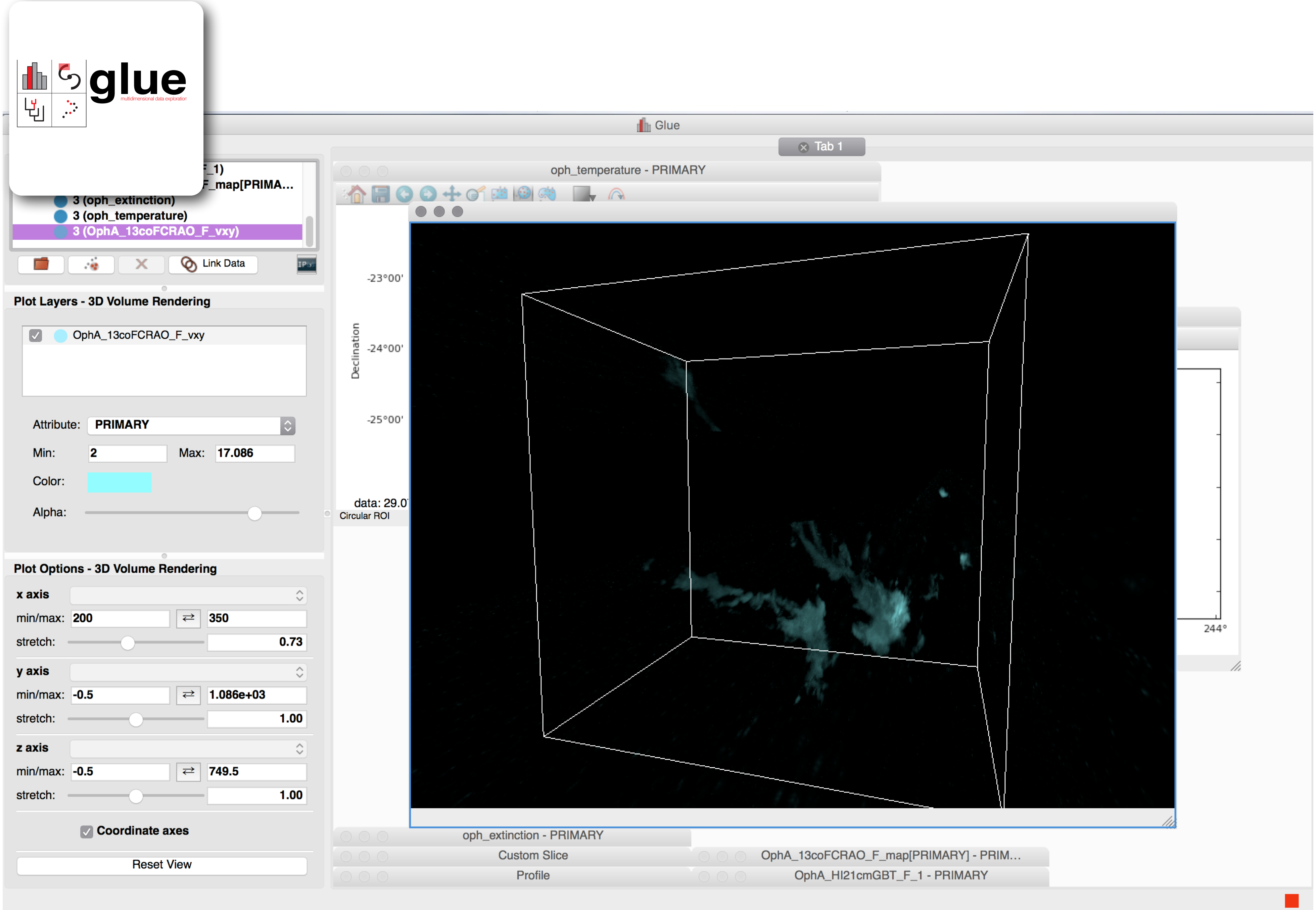


WorldWideTelescope.org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