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AN UNBOUND UNIVERSE?*

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Received 1974 June 28

ABSTRACT

A variety of arguments strongly suggest that the density of the universe is no more than a tenth of the value required for closure. Loopholes in this reasoning may exist, but if so, they are primordial and invisible, or perhaps just black.

Subject heading: cosmology

Desist from thrusting out reasoning from your mind because of its disconcerting novelty. Weigh it, rather, with a discerning judgment. Then, if it seems to you true, give in. If it is false, gird yourself to oppose it. For the mind wants to discover by reasoning what exists in the infinity of space that lies out there, beyond the ramparts of this world. . . . Here, then, is my first point. In all dimensions alike, on this side or that, upward or downward through the universe, there is no end.

[LUCRETIUS]

I. PARAMETERS

and is related to the mean density of matter

$$\rho_0 = \frac{3H_0^2}{4\pi G} q_0 . \tag{3}$$

It is useful to define a critical density ρ_c and a dimensionless density parameter Ω, by

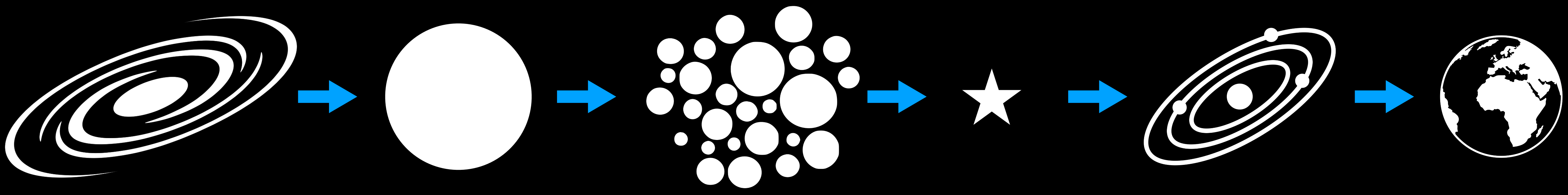
$$\rho_c = \frac{3H_0^2}{8\pi G} , \qquad \Omega = \frac{\rho_0}{\rho_c} = \frac{8\pi G \rho_0}{3H_0^2} , \tag{4}$$

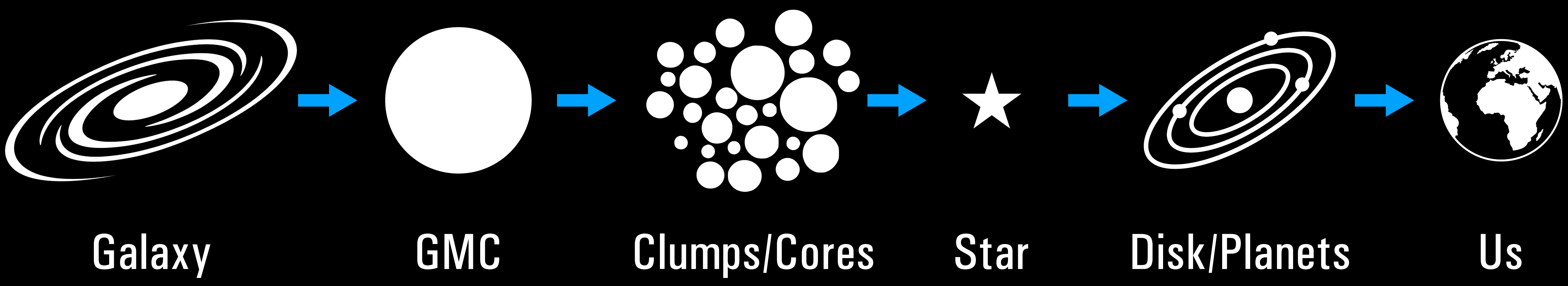
so that

Star Formation Unbound

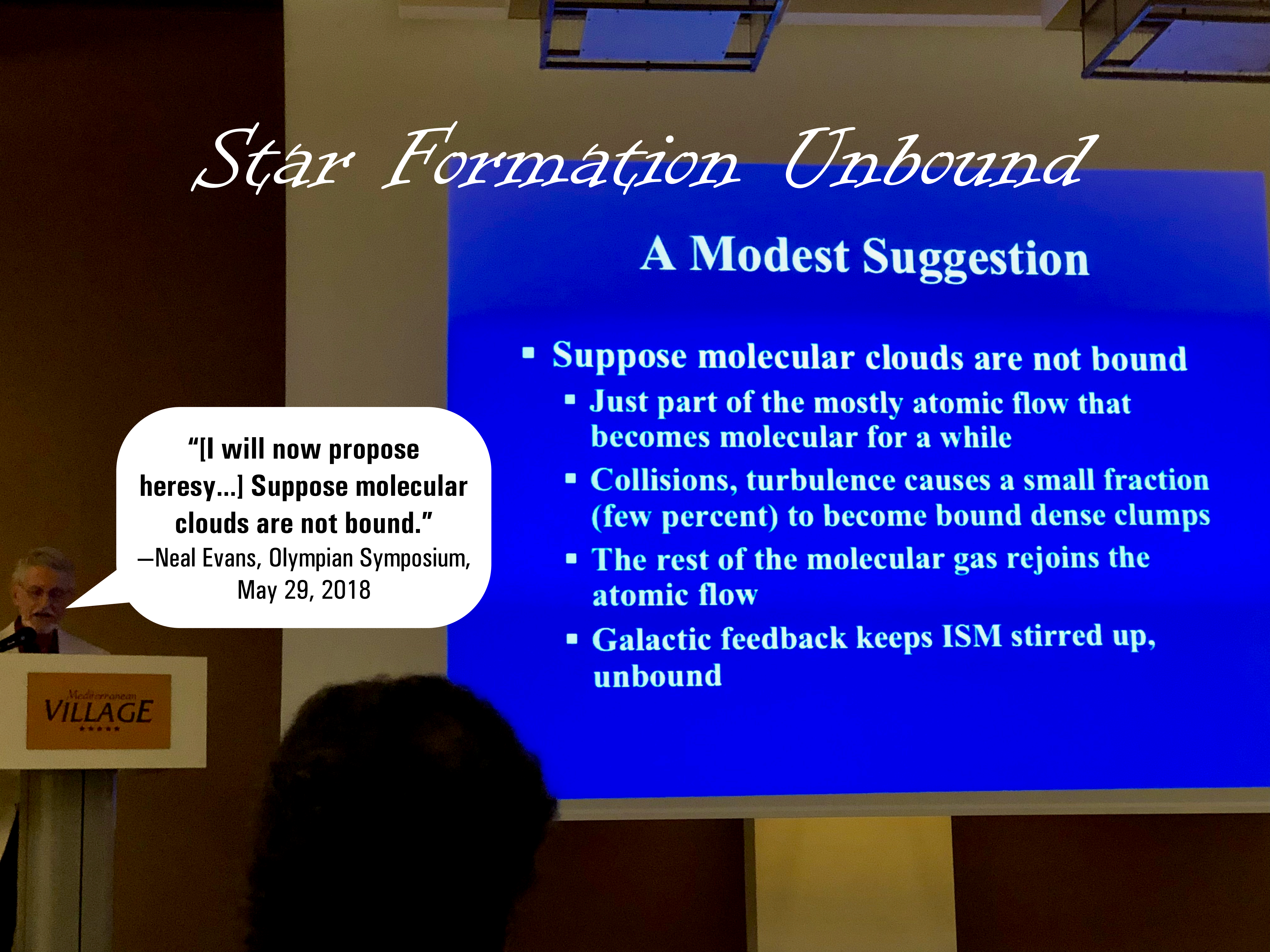
Alyssa A. Goodman
Harvard-Smithsonian Center for Astrophysics
& Radcliffe Insitute for Advanced Study

With many thanks to: Joao Alves, Andi Burkert, Cara Battersby, Hope Chen, Chat Hull, Mike Dunham, Phil Myers, Stella Offner, Jaime Pineda, Anna Rosen, Catherine Zucker




Galaxy
GMC
Clumps/Cores
Star
Disk/Planets
Us

At what scales does gravity truly play the key role in the story of star formation?


Star Formation Unbound
A Modest Suggestion
Suppose molecular clouds are not bound
Just part of the mostly atomic flow that becomes molecular for a while
Collisions, turbulence causes a small fraction (few percent) to become bound dense clumps
The rest of the molecular gas rejoins the atomic flow
Galactic feedback keeps ISM stirred up, unbound
"[I will now propose heresy...] Suppose molecular clouds are not bound."
—Neal Evans, Olympian Symposium, May 29, 2018
Mediterranean
VILLAGE

The story I told in 1998

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COHERENCE IN DENSE CORES. II. THE TRANSITION TO COHERENCE

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Received 1997 June 17; accepted 1998 February 5

ABSTRACT

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

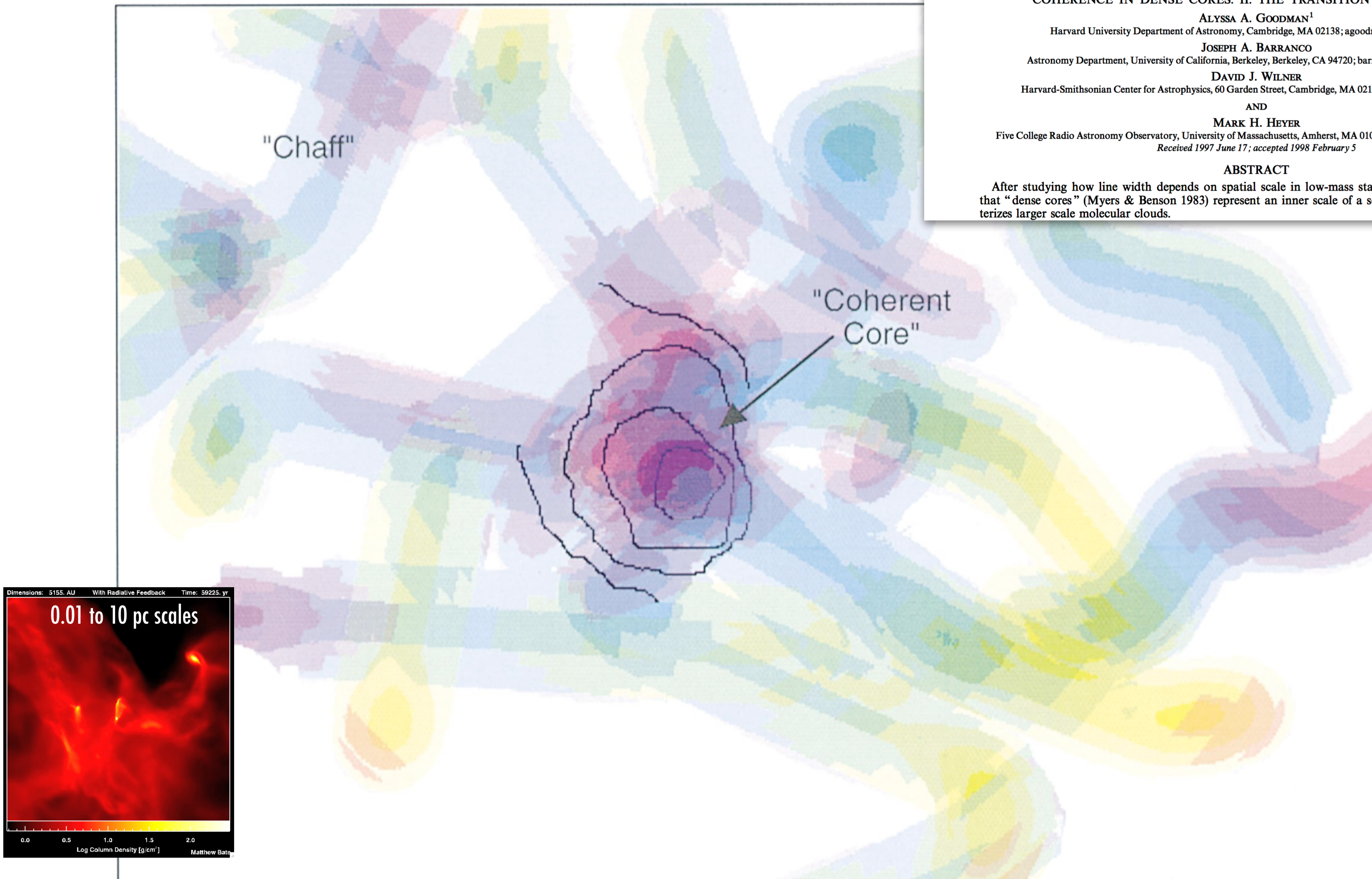

FIG. 10.—An illustration of the transition to coherence. Color and shading schematically represent velocity and density in this figure. On large scales, material (labeled chaff) is distributed in a self-similar fashion, and its filling factor is low. On scales smaller than some fiducial radius, the filling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

The story I want to think about today…

land

MDPI

Article

Spatial and Temporal Characteristics of Road Networks and Urban Expansion

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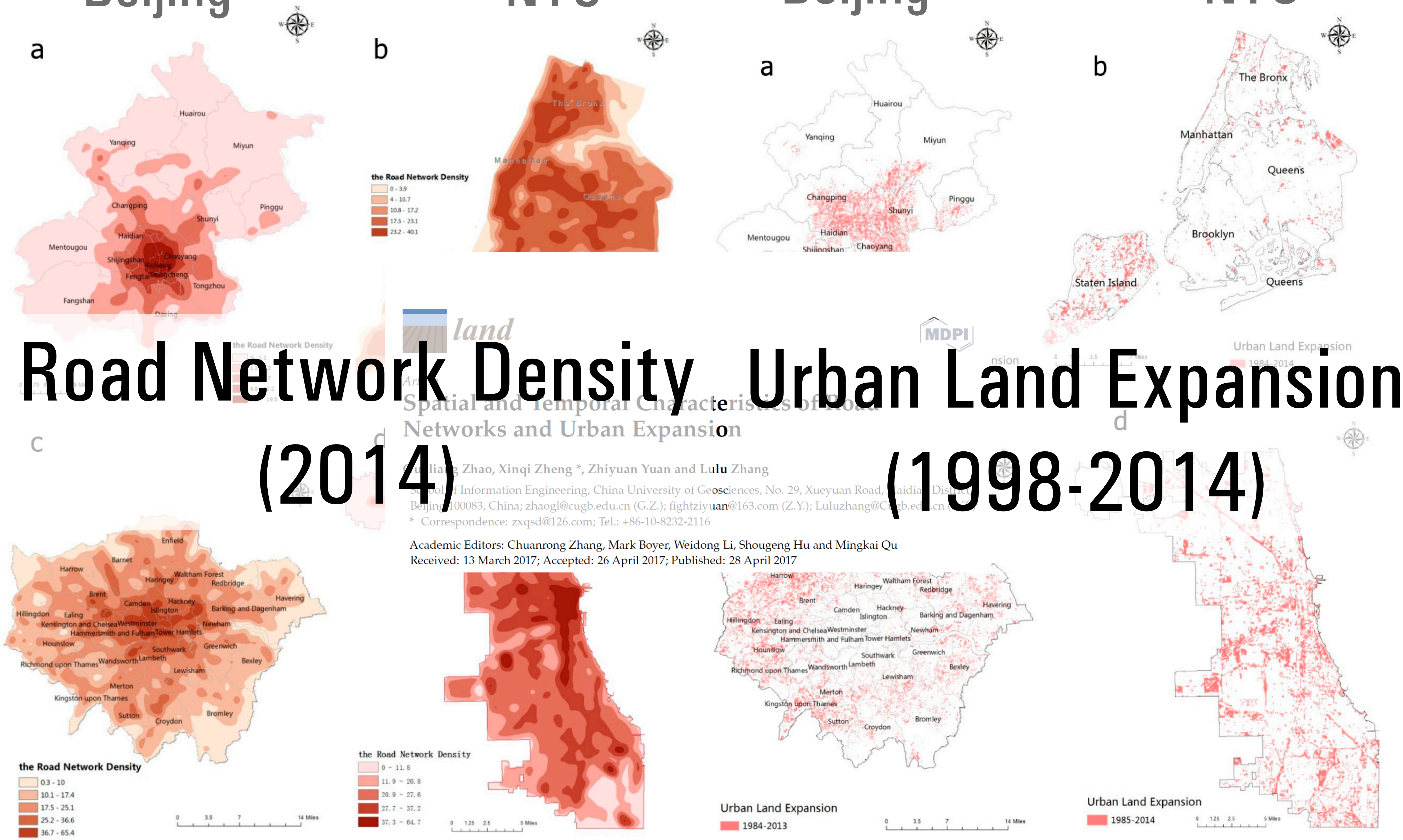
Zhao et al. 2017

Beijing | NYC | Beijing | NYC

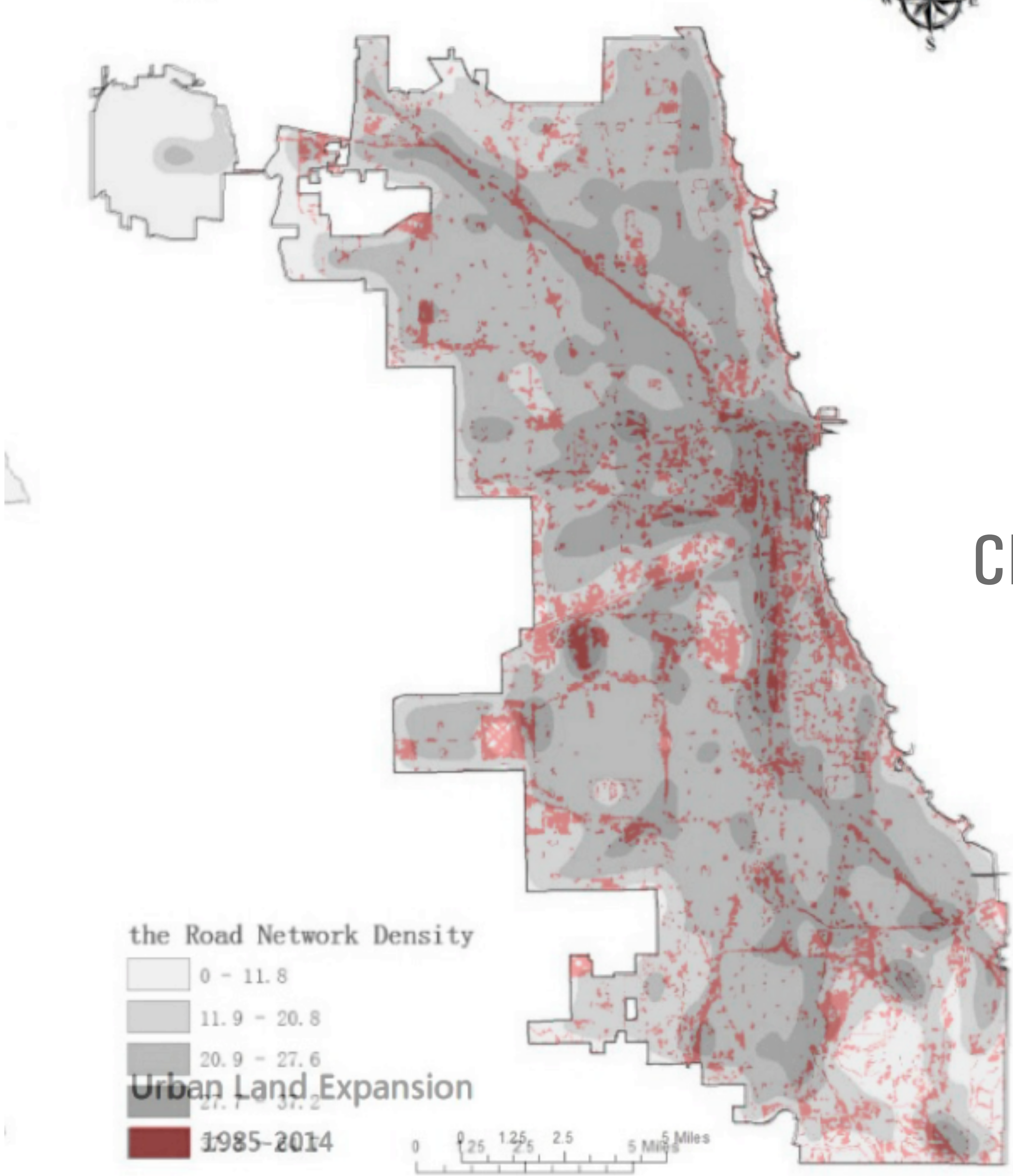
Road Network Density (2014)

Urban Land Expansion (1998-2014)



London | Chicago | London | Chicago

Zhao et al. 2017



Chicago

Zhao et al. 2017

Chicago

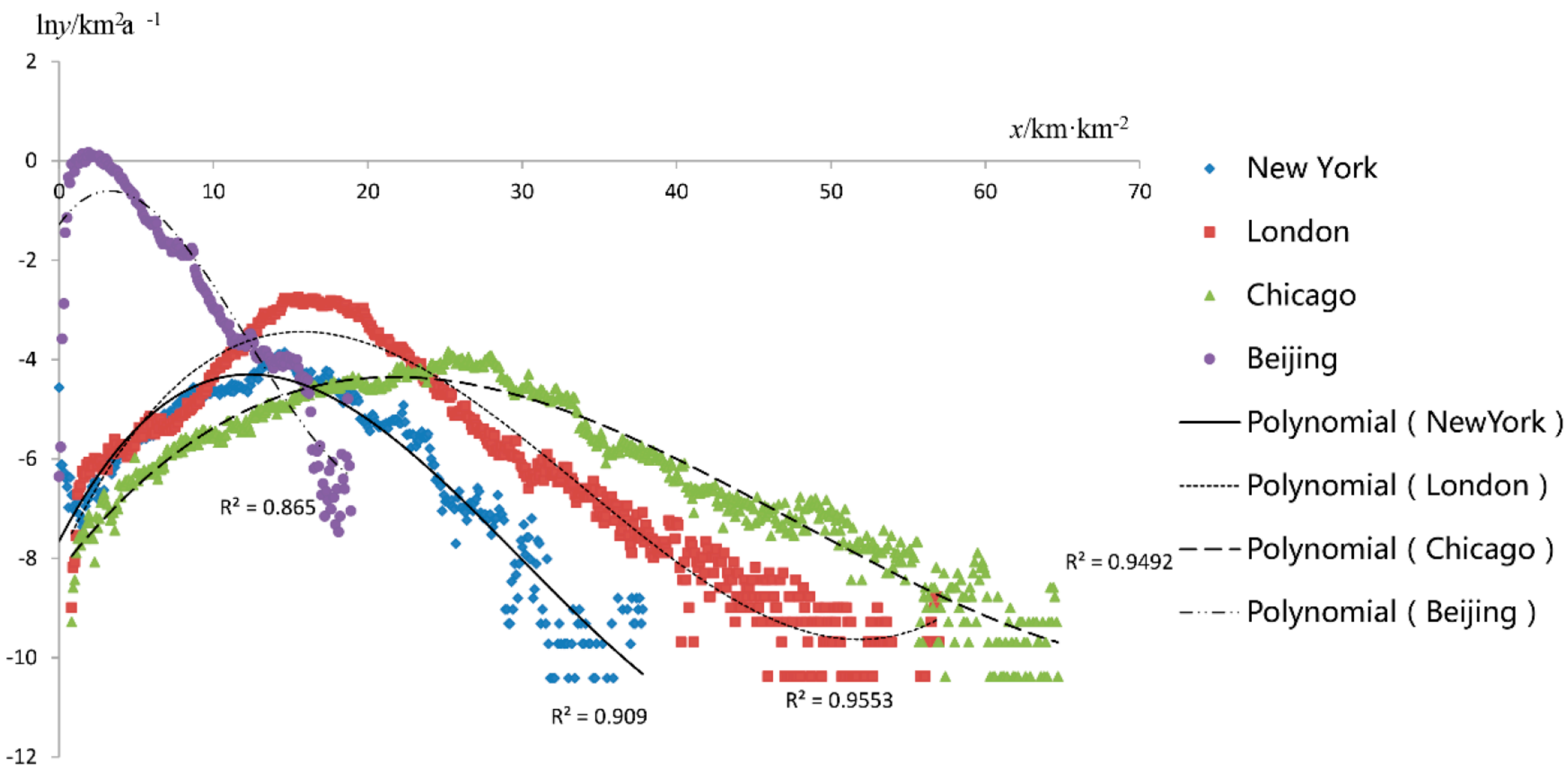
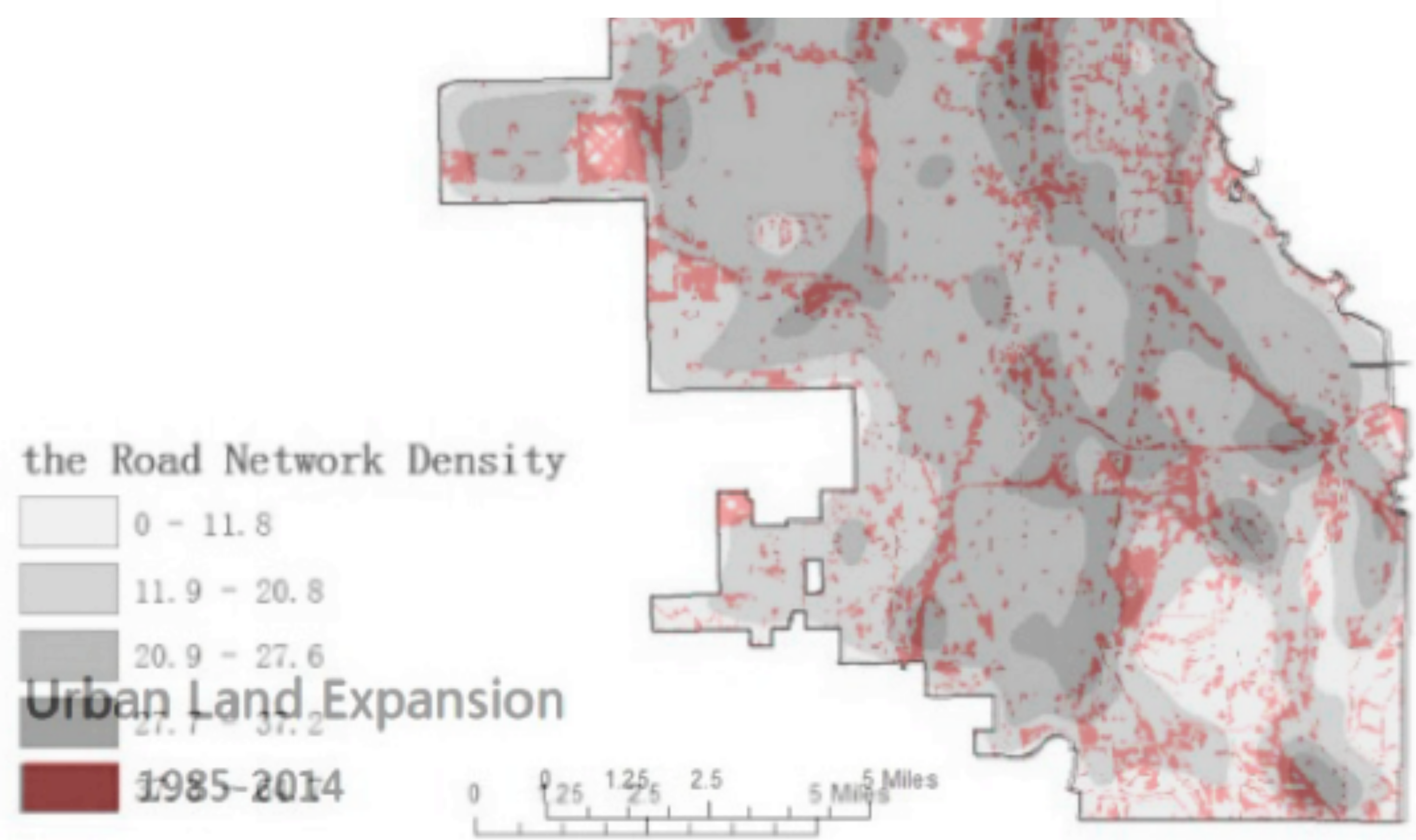


Figure 5. Fitting curves of the urban expansion and road network density.



Zhao et al. 2017

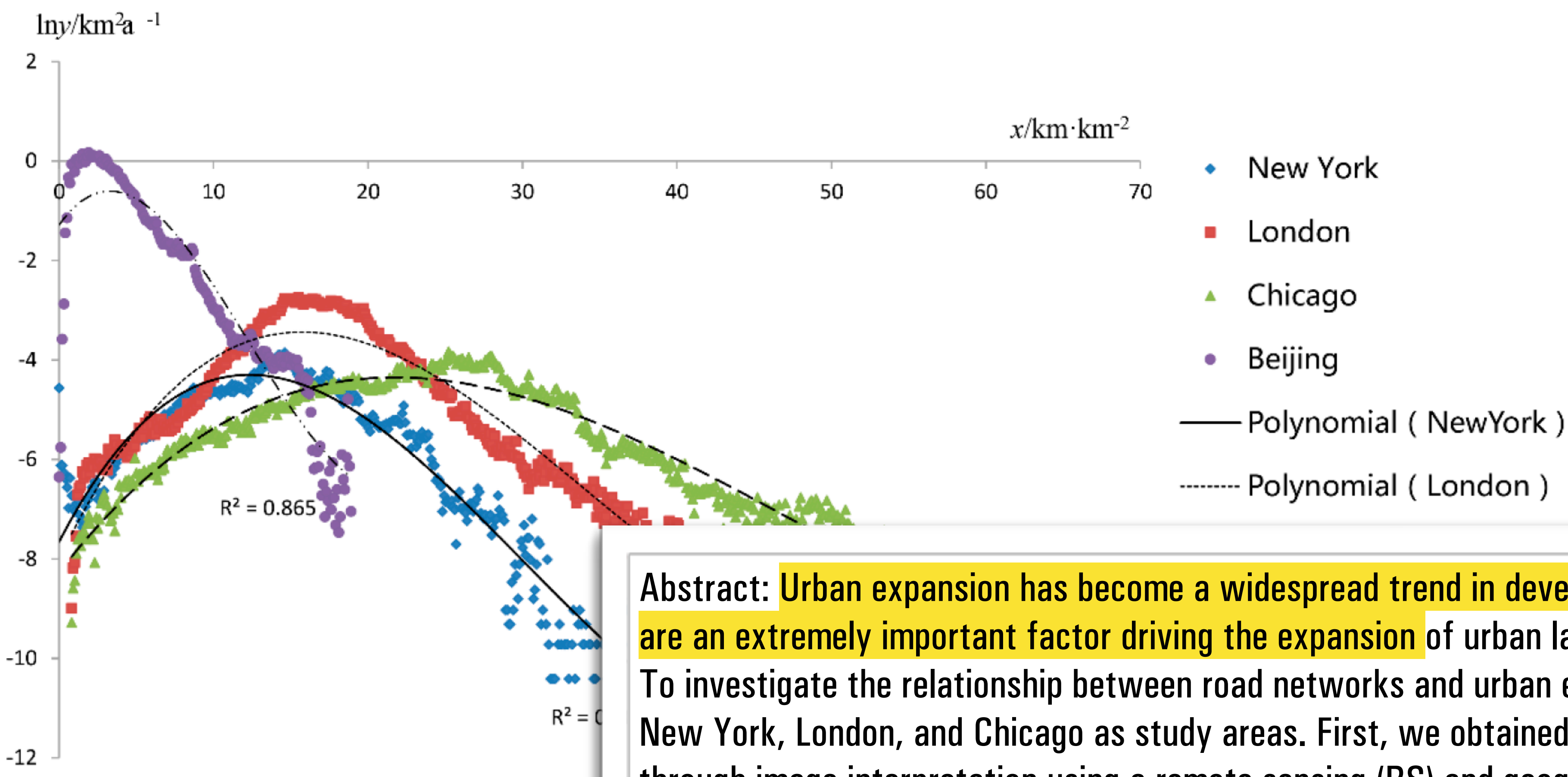
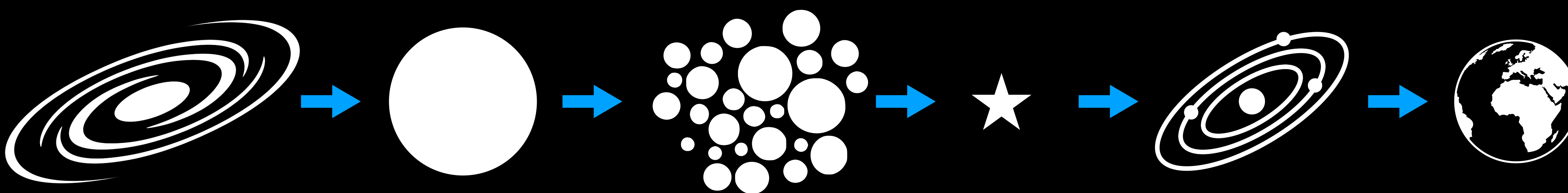


Figure 5. Fitting curves o

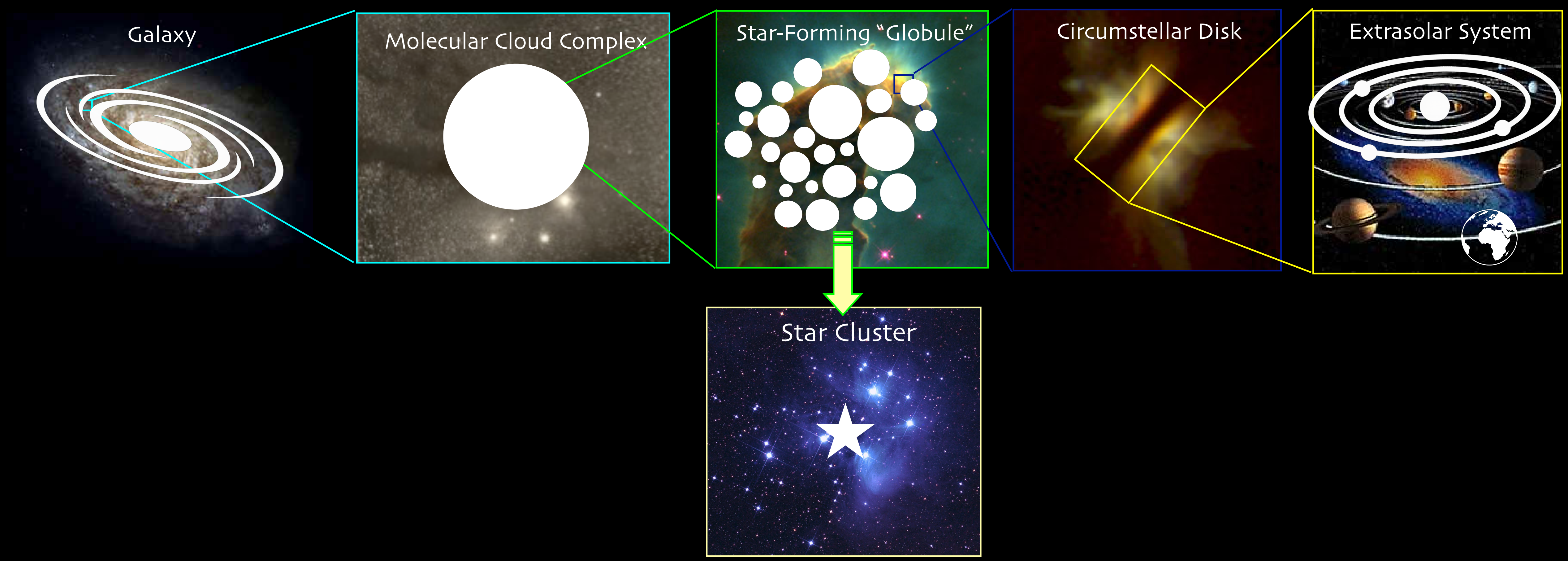
Abstract: Urban expansion has become a widespread trend in developing countries. Road networks are an extremely important factor driving the expansion of urban land and require further study.
To investigate the relationship between road networks and urban expansion, we selected Beijing, New York, London, and Chicago as study areas. First, we obtained urban land use vector data through image interpretation using a remote sensing (RS) and geographic information systems (GIS) platform and then used overlay analysis to extract information on urban expansion. A road network density map was generated using the density analysis tool. Finally, we conducted a spatial statistical analysis between road networks and urban expansion and then systematically analyzed their distribution features. In addition, the Urban Expansion-Road Network Density Model was established based on regression analysis. The results indicate that (1) the road network density thresholds of Beijing, New York, London, and Chicago are 18.9 km/km2, 37.8 km/km2, 57.0 km/km2, and 64.7 km/km2, respectively, and urban expansion has an inverted U-curve relationship with road networks when the road network density does not exceed the threshold; (2) the calculated turning points for urban expansion indicate that urban expansion initially accelerates with increasing road network density but then decreases after the turning point is reached; and (3) when the road density exceeds the threshold, urban areas cease to expand. The correlation between urban expansion and road network features provides an important reference for the future development of global cities. Understanding road network density offers some predictive capabilities for urban land expansion, facilitates the avoidance of irregular expansion, and provides new ideas for addressing the inefficient utilization of land.
Keywords: geography; regression analysis; urban expansion; road networks

Zhao et al. 2017

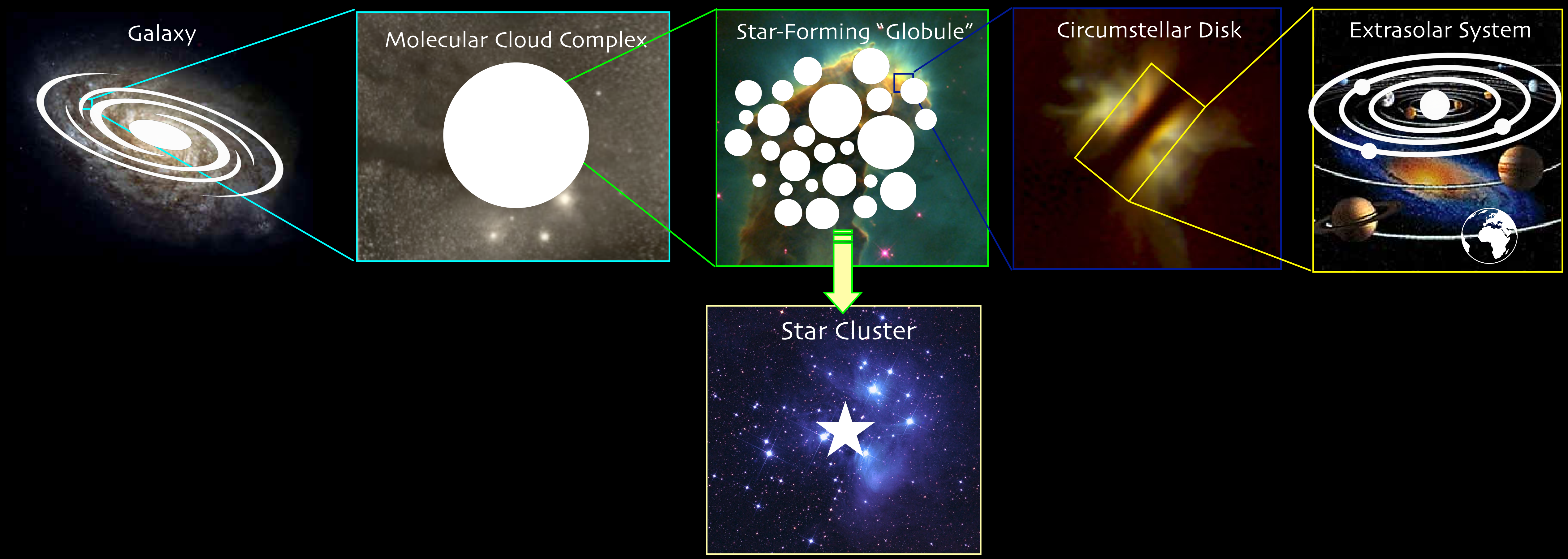
The Story



The Story

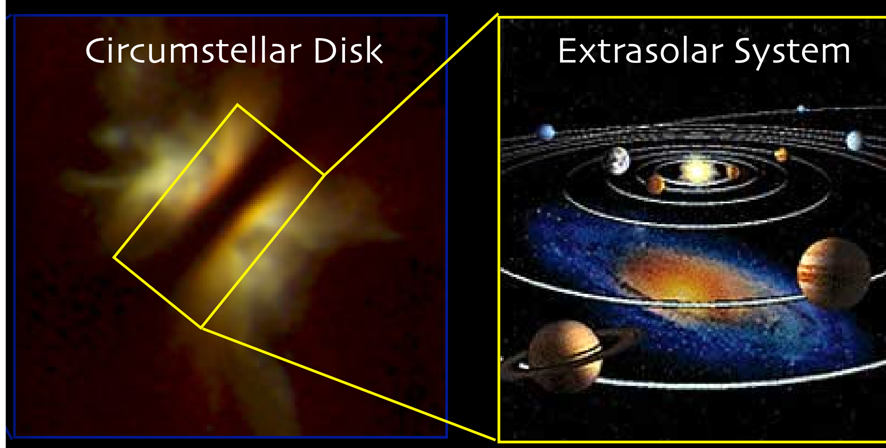

Galaxy
Molecular Cloud Complex
Star-Forming "Globule"
Circumstellar Disk
Extrasolar System
Star Cluster

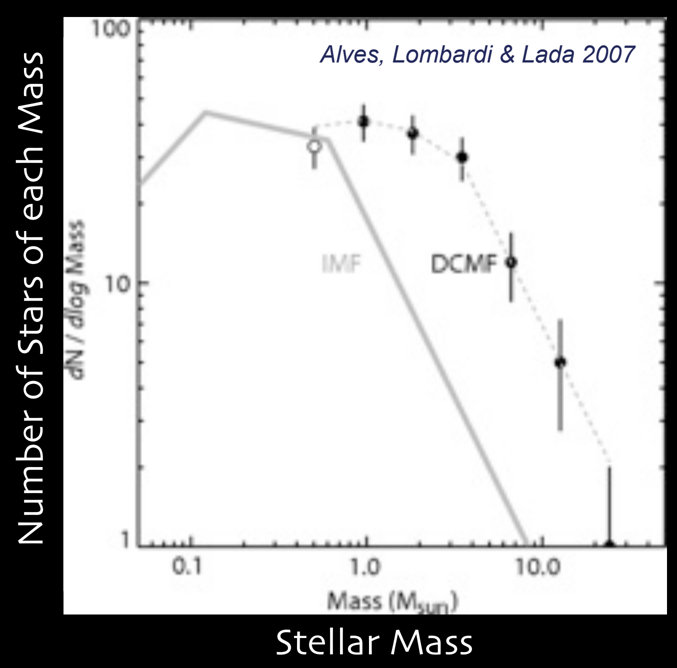
The Story


Galaxy
Molecular Cloud Complex
Star-Forming "Globule"
Circumstellar Disk
Extrasolar System
Star Cluster

The Story


Galaxy
Star-Forming "Globule"
Star Cluster
Today: what's (really) happening here?


Circumstellar Disk
Extrasolar System


Alves, Lombardi & Lada 2007
Number of Stars of each Mass
dN / dlog Mass
100
10
1
IMF
DCMF
0.1
1.0
10.0
Mass (M_sun)
Stellar Mass

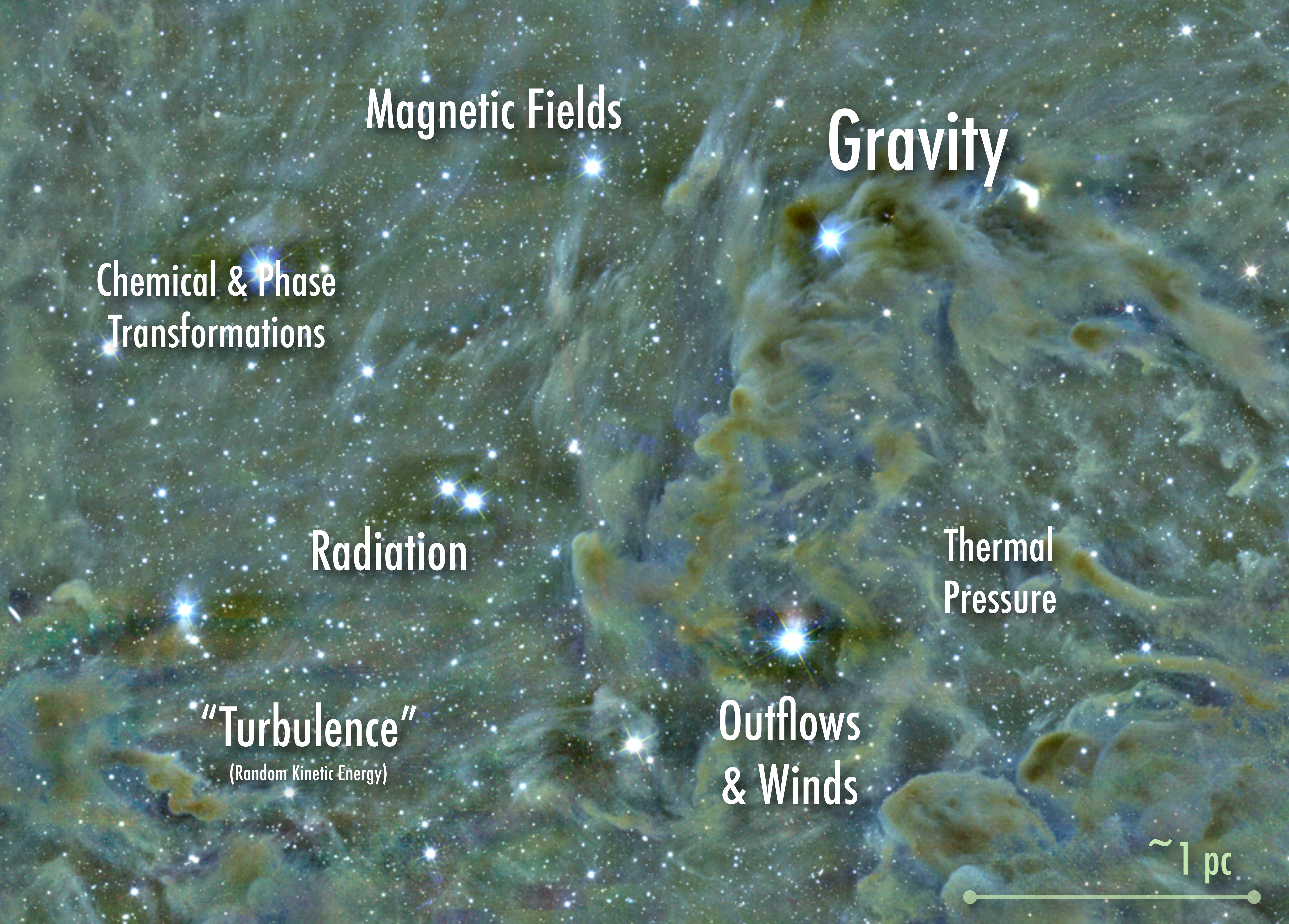
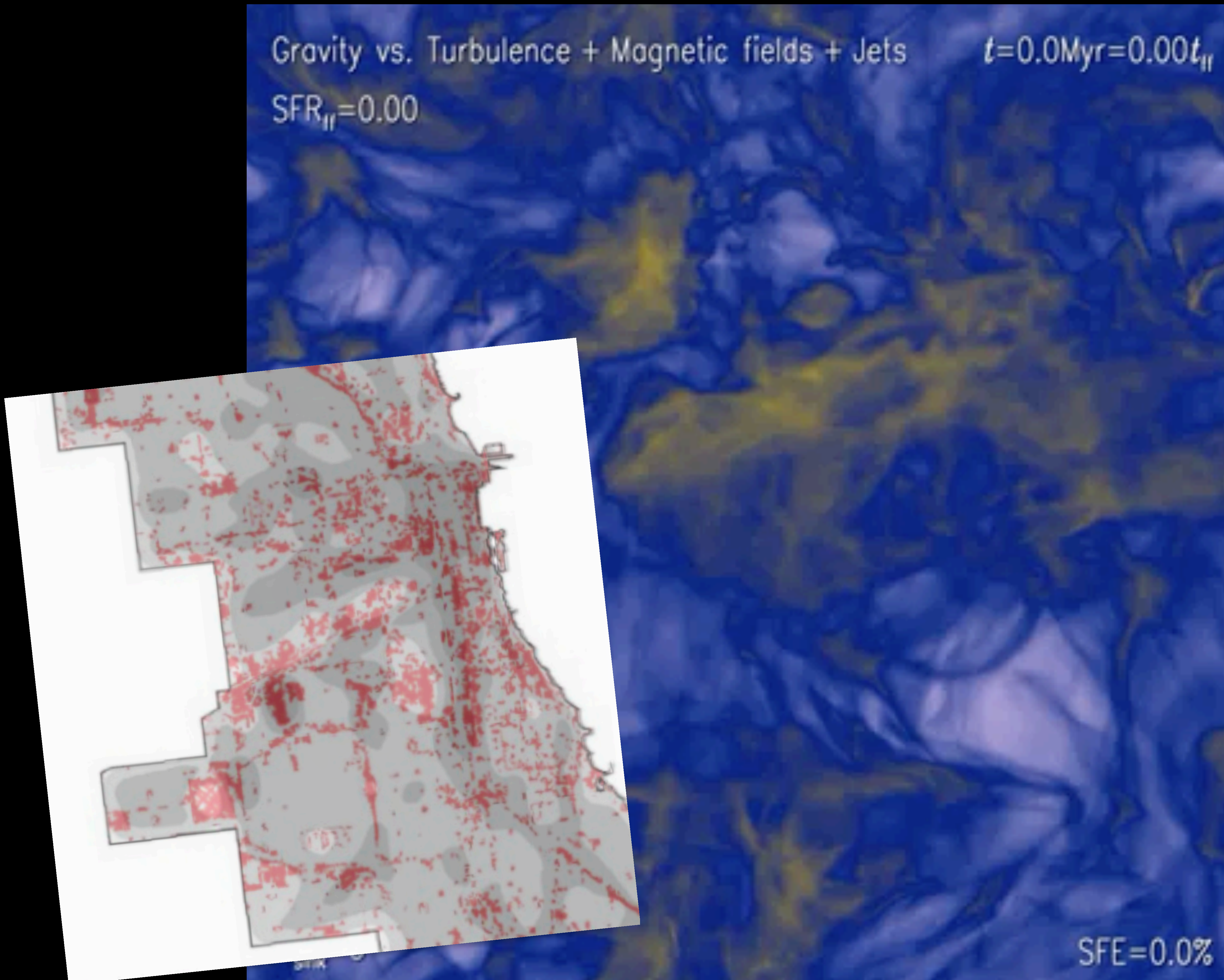


Image Credit: Jonathan Foster & Jaime Pineda CfA/COMPLETE Deep Megacam Mosaic of West End of Perseus

Gravity++



“Inefficient star formation through turbulence, magnetic fields and feedback” (Federrath 2015)

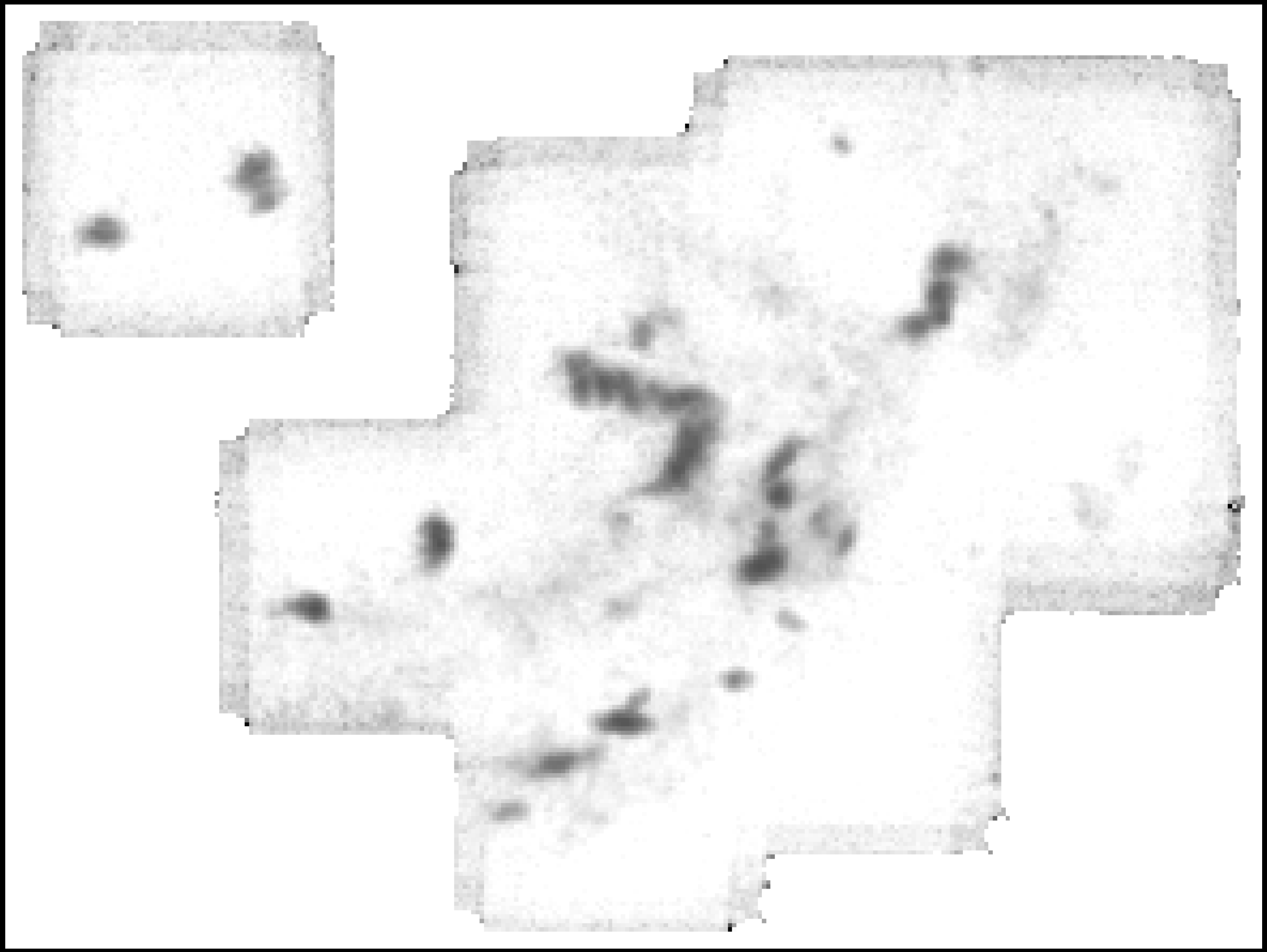
Stella Offner says…

"In terms of your analogy of migration to cities I have work in progress with Kaitlin Kratter, Rachel Smullen (U of AZ grad student) and Aaron Lee (post-doc with me here), where we track the formation and evolution of cores in MHD simulations using dendrograms. Basically, we're finding that some cities have very volatile population growth while others carry on quietly with no rapid migration from the outside."


"Taste-Testing"

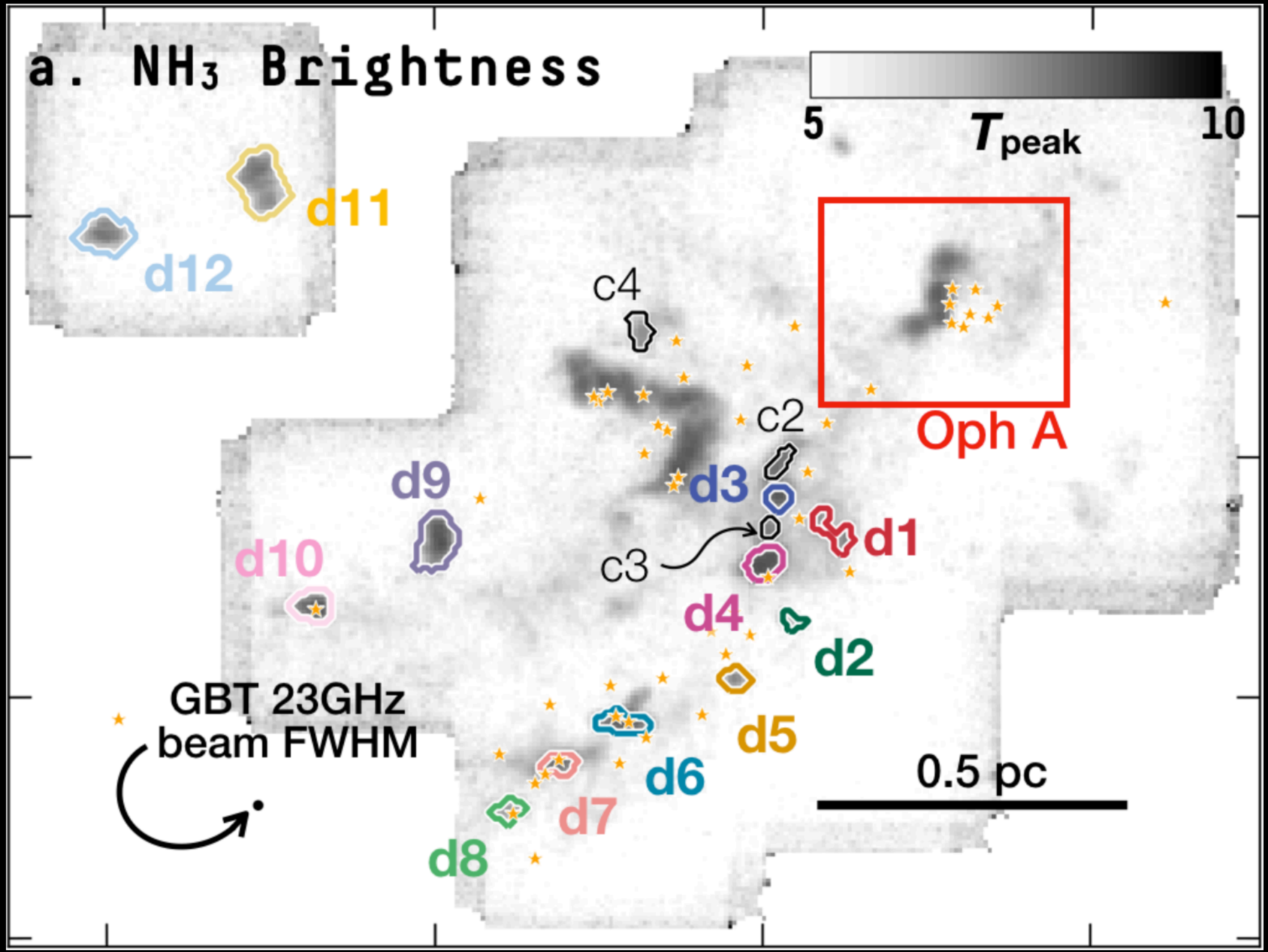
The Story We See

Ophiuchus

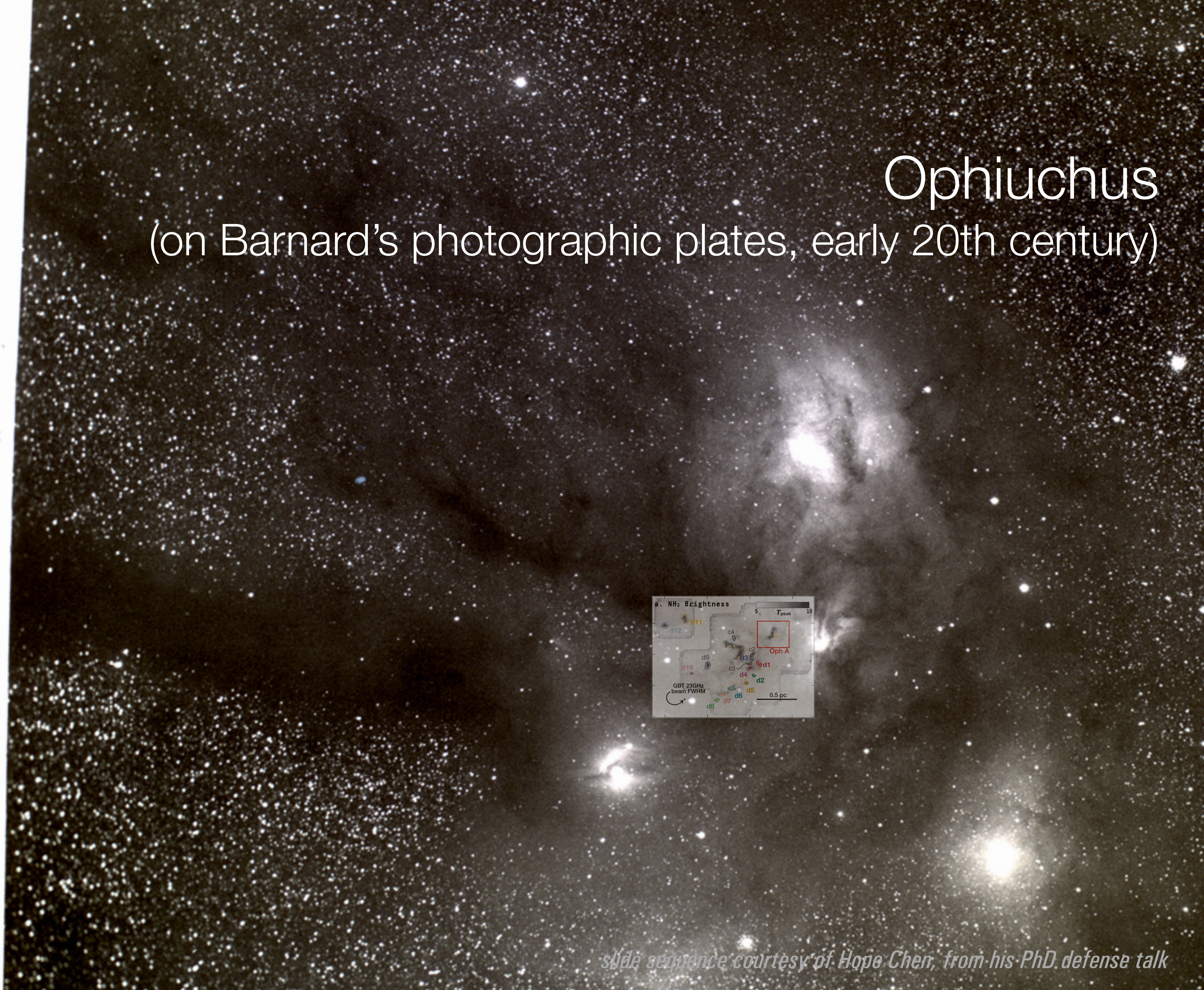


slide sequence courtesy of Hope Chen, from his PhD defense talk

Many Cores in Ophiuchus



slide sequence courtesy of Hope Chen, from his PhD defense talk

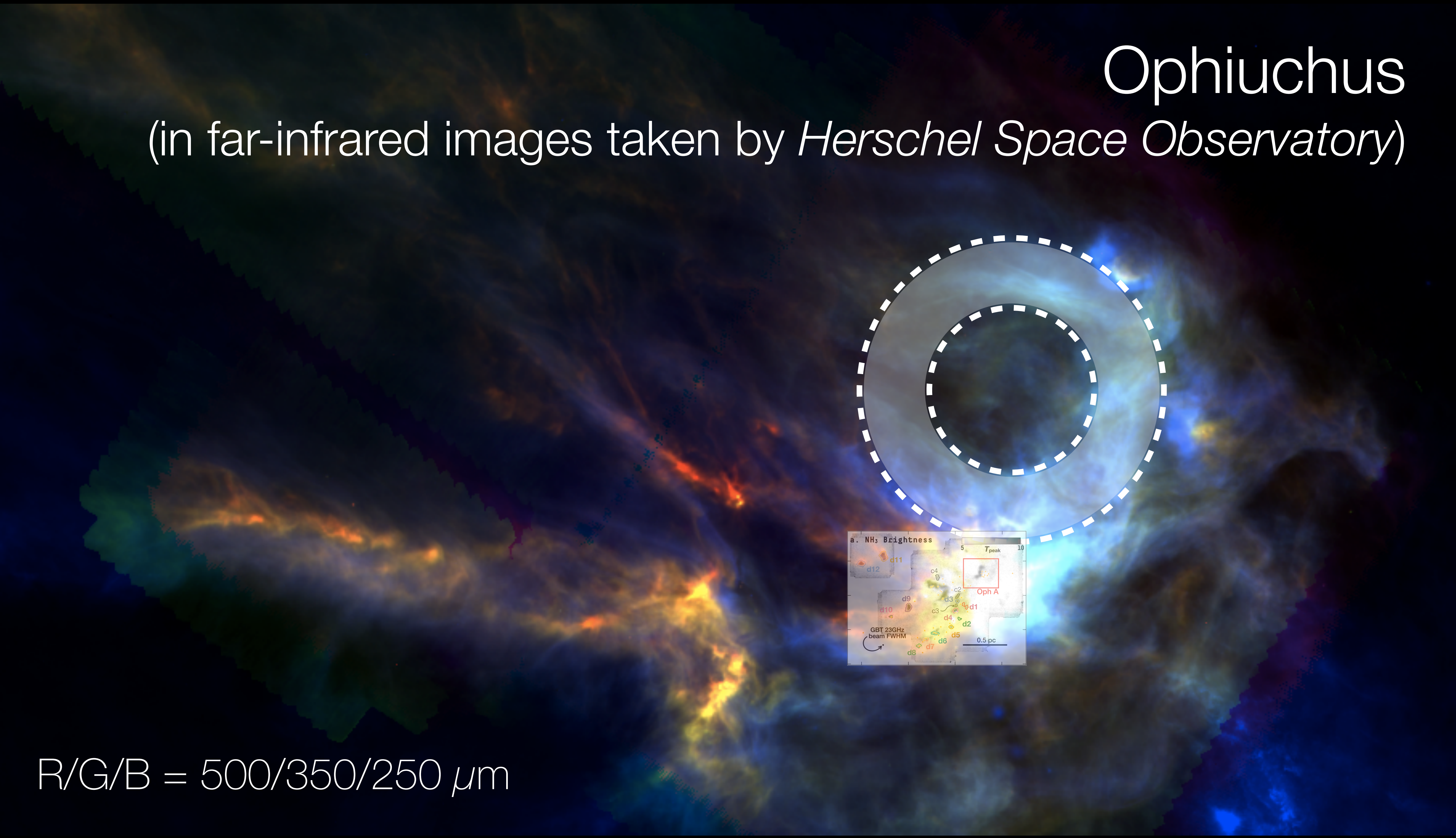

Ophiuchus
(on Barnard's photographic plates, early 20th century)
a. NH3 Brightness
5
Tpeak
10
d11
d12
c4
Oph A
c2
d9
d3
d1
d10
c3
d4
d2
GBT 23GHz
beam FWHM
d5
d6
0.5 pc
d7
d8
slide sequence courtesy of Hope Chen, from his PhD defense talk

Ophiuchus

(in an amateur astronomer's picture, early 21st century)

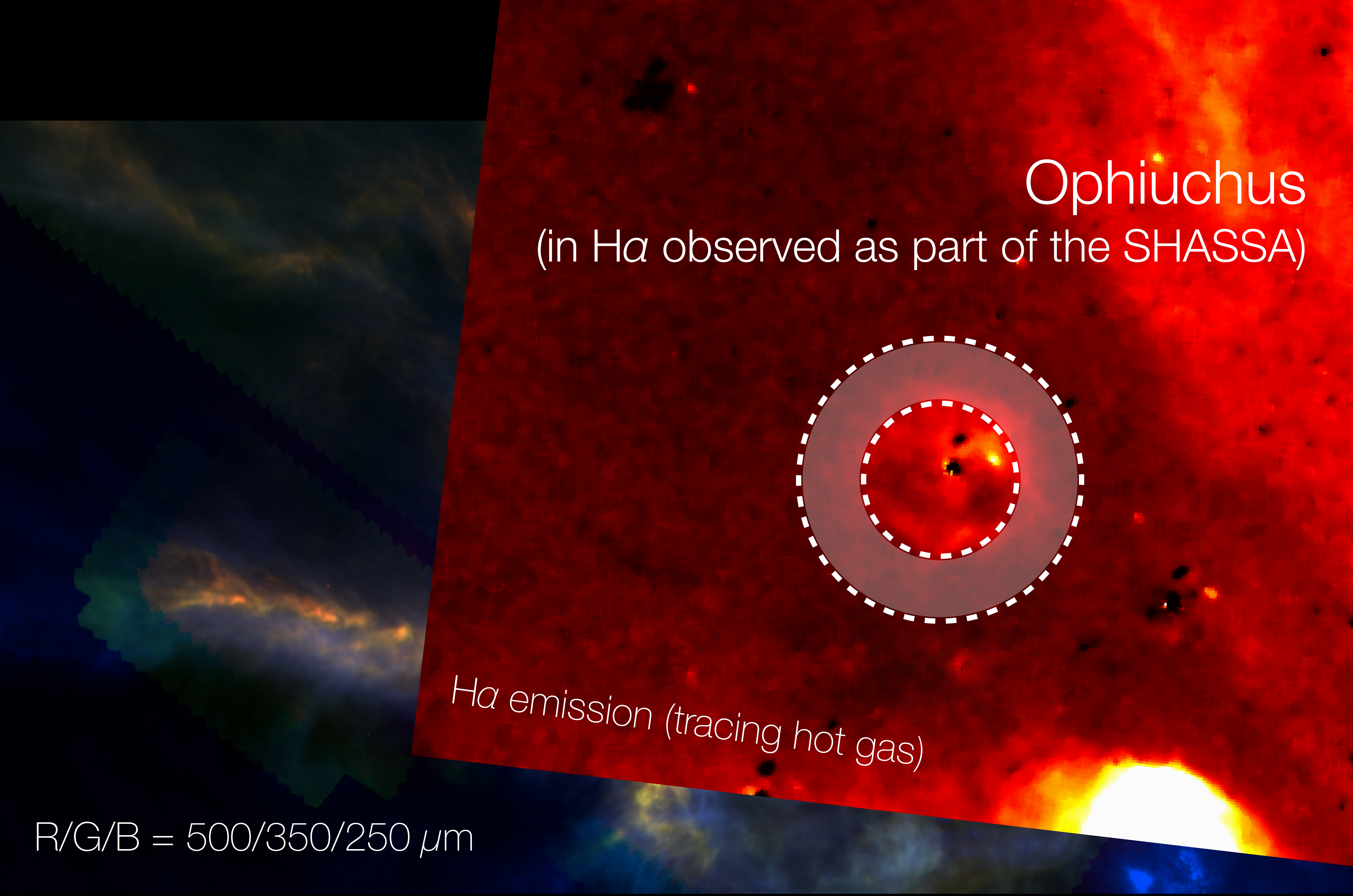
Ophiuchus

(in far-infrared images taken by *Herschel Space Observatory*)



R/G/B = 500/350/250 μm

slide sequence courtesy of Hope Chen, from his PhD defense talk



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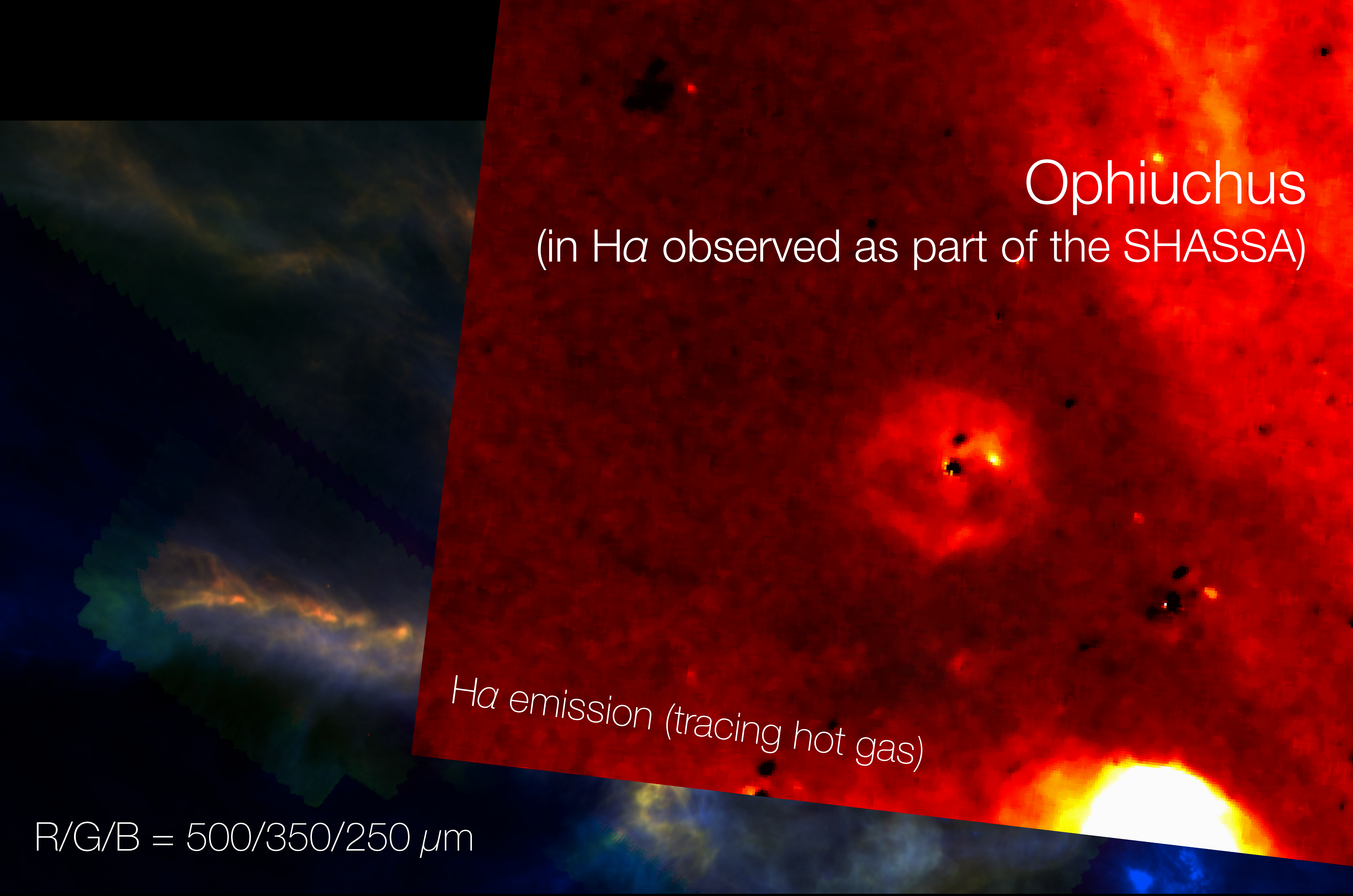

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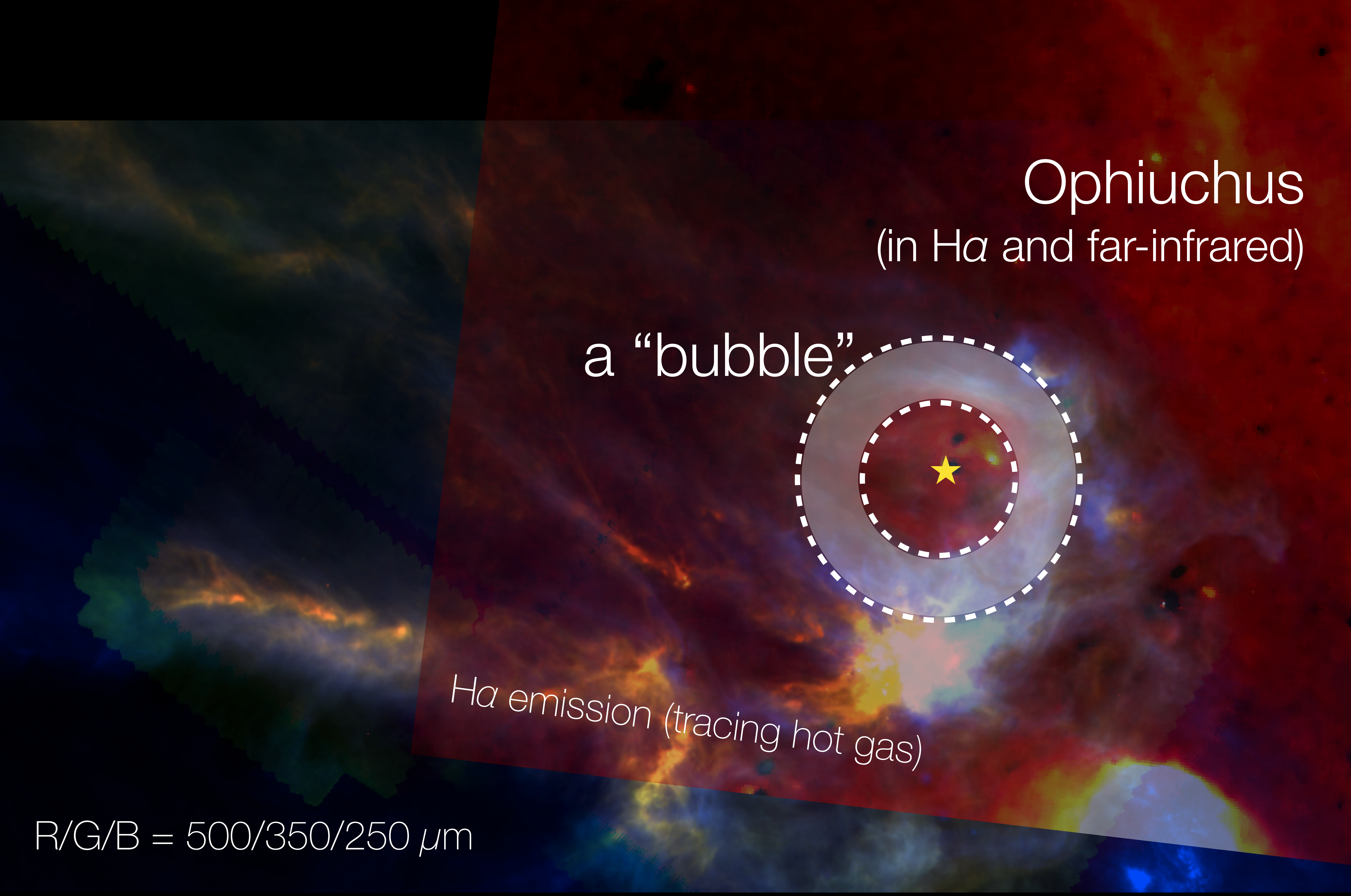
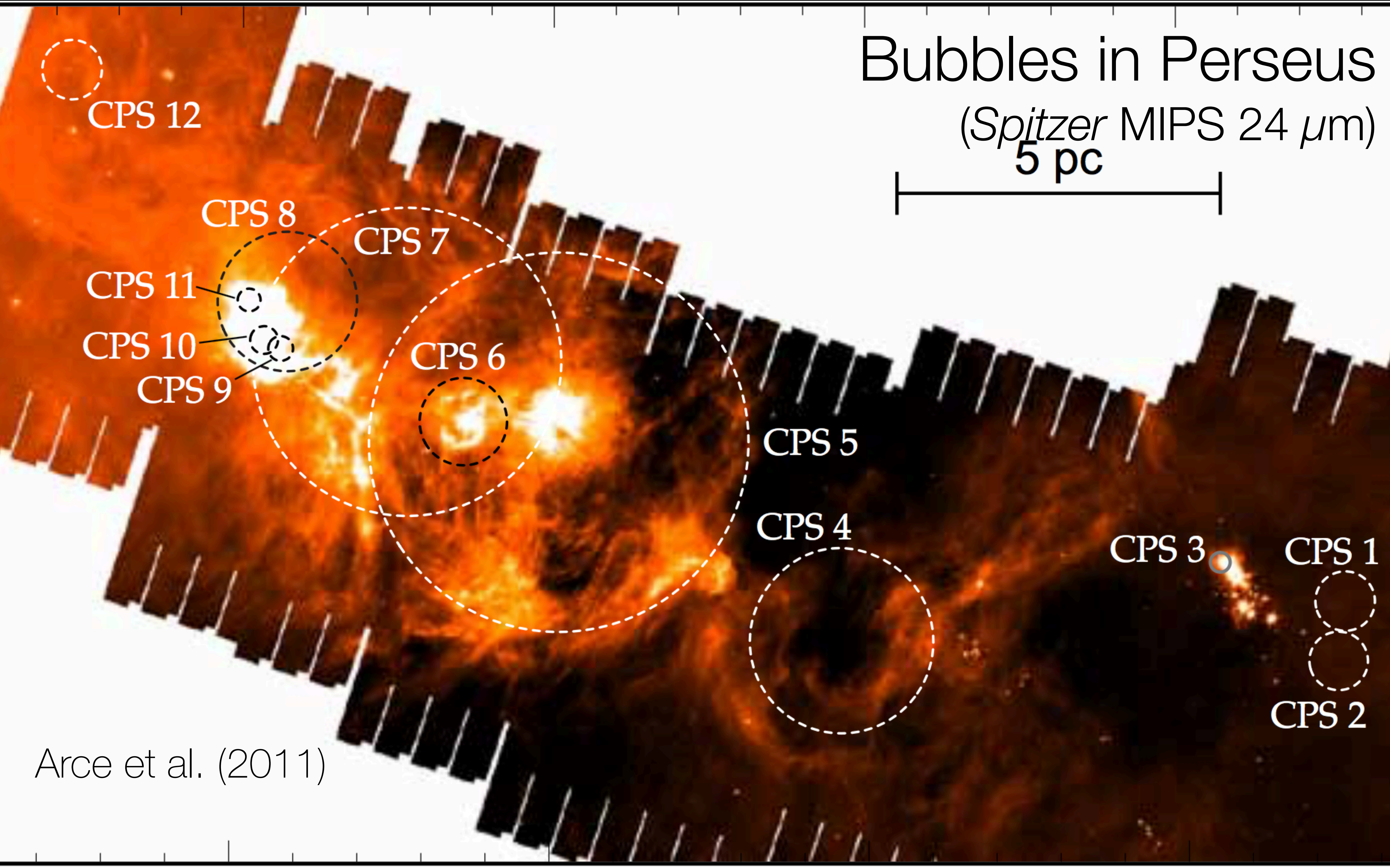


slide sequence courtesy of Hope Chen, from his PhD defense talk

Bubbles in Perseus

(*Spitzer* MIPS 24 μm)



Arce et al. (2011)

slide sequence courtesy of Hope Chen, from his PhD defense talk

Bubbles in Perseus

Measuring “Feedback”

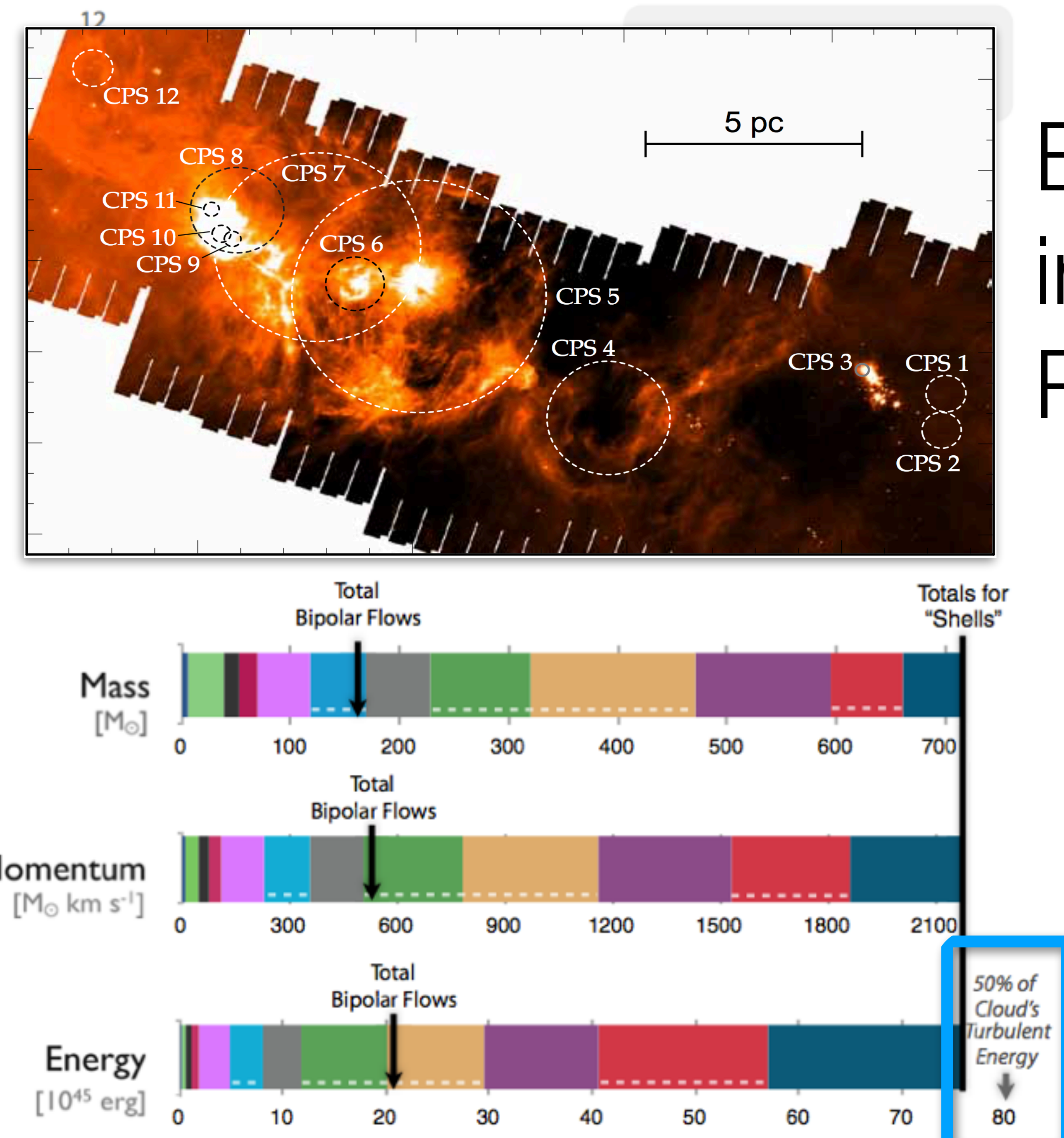


Figure 30. Schematic picture of size, mass, momentum, and energy distribution of shells in Perseus. The radius of each circle (and position) are proportional to the radius (and location) of the shell in the cloud, while the ring thickness is proportional to the expansion velocity (see the legend on the upper right corner). Shells with a confidence level of 3 or less (from Table 4) are indicated by a dashed white line. Candidate powering sources with a B5 spectral type or later are shown as white star symbols, while those with earlier spectral type (i.e., high-mass stars) are shown as black (filled) star symbols. Candidate sources with no known spectral type (but known α) are shown as red stars. The relative mass, momentum, and kinetic energy of the shells are shown in the three horizontal bars (where the colors indicate the value for each shell). The total outflow mass, momentum, and kinetic energy of the molecular outflows in Perseus (from Arce et al. 2010) are shown for comparison.

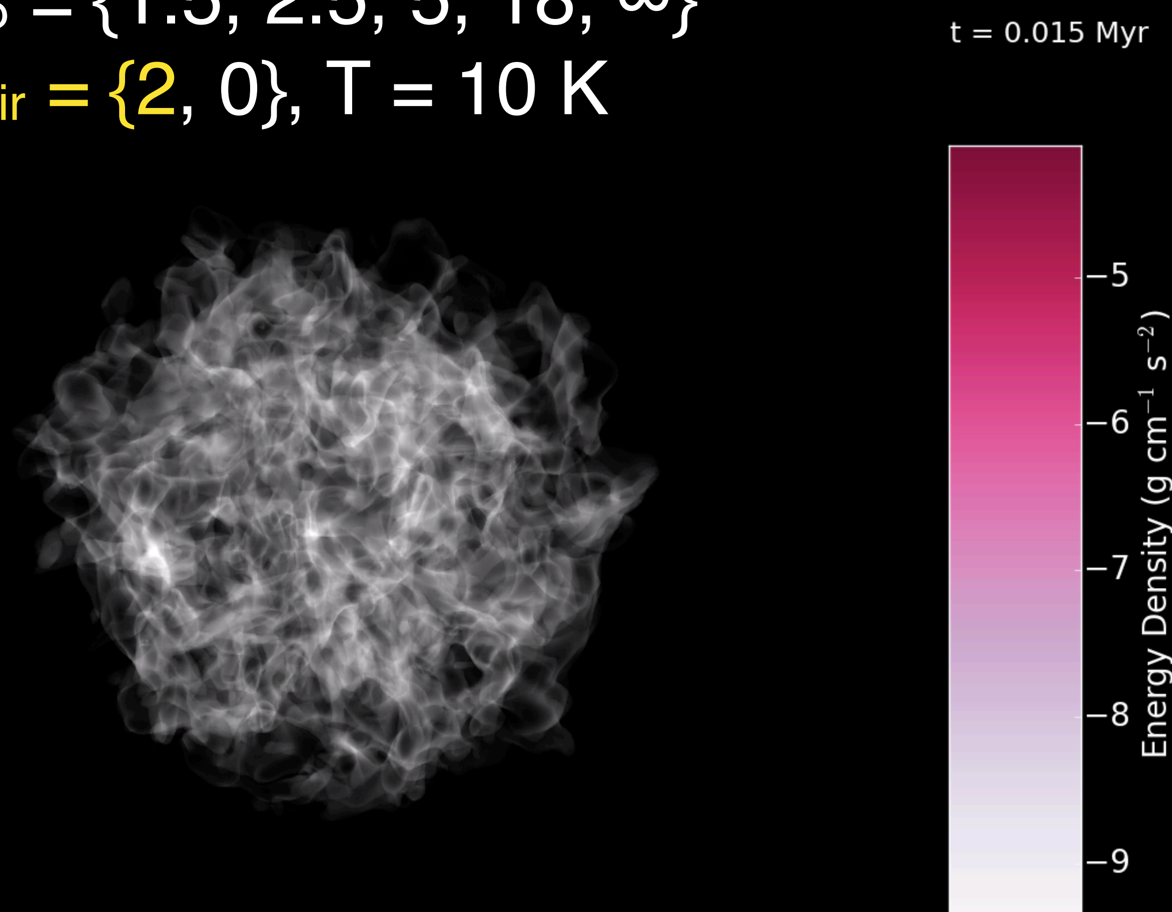
Arce et al. 2011

Simulating “Feedback”

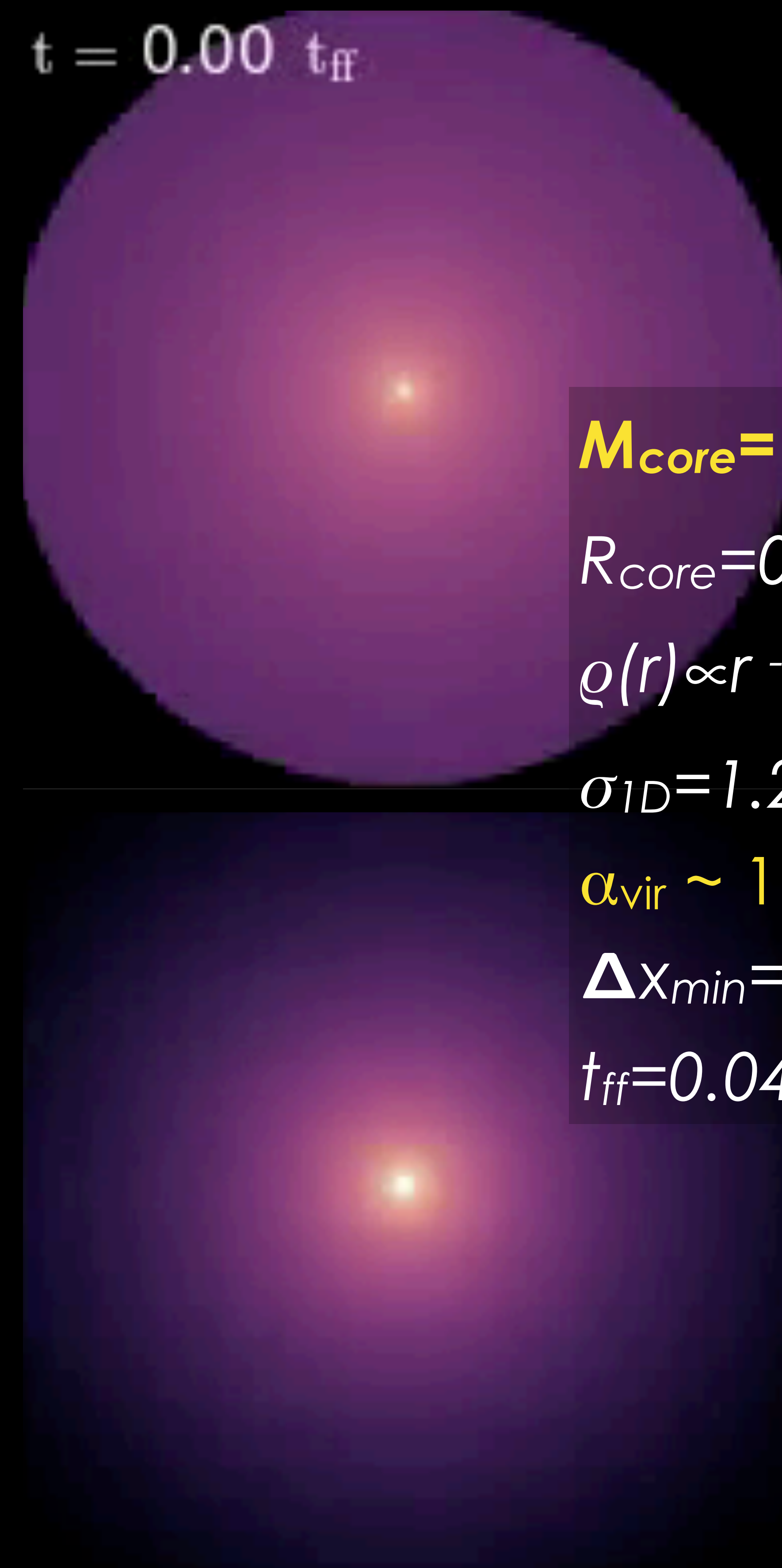
$M_{core} = \{4,6,8\}\ M_\odot$

$\mu_\Phi = \{1.5, 2.5, 5, 18, \infty\}$

$\alpha_{vir} = \{2, 0\}$, $T = 10$ K



Offner & Chabon 2017
Lee, Hull & Offner 2017



M_{core}=150 $M_\odot$

R_{core}=0.1 pc

$\rho(r) \propto r^{-3/2}$

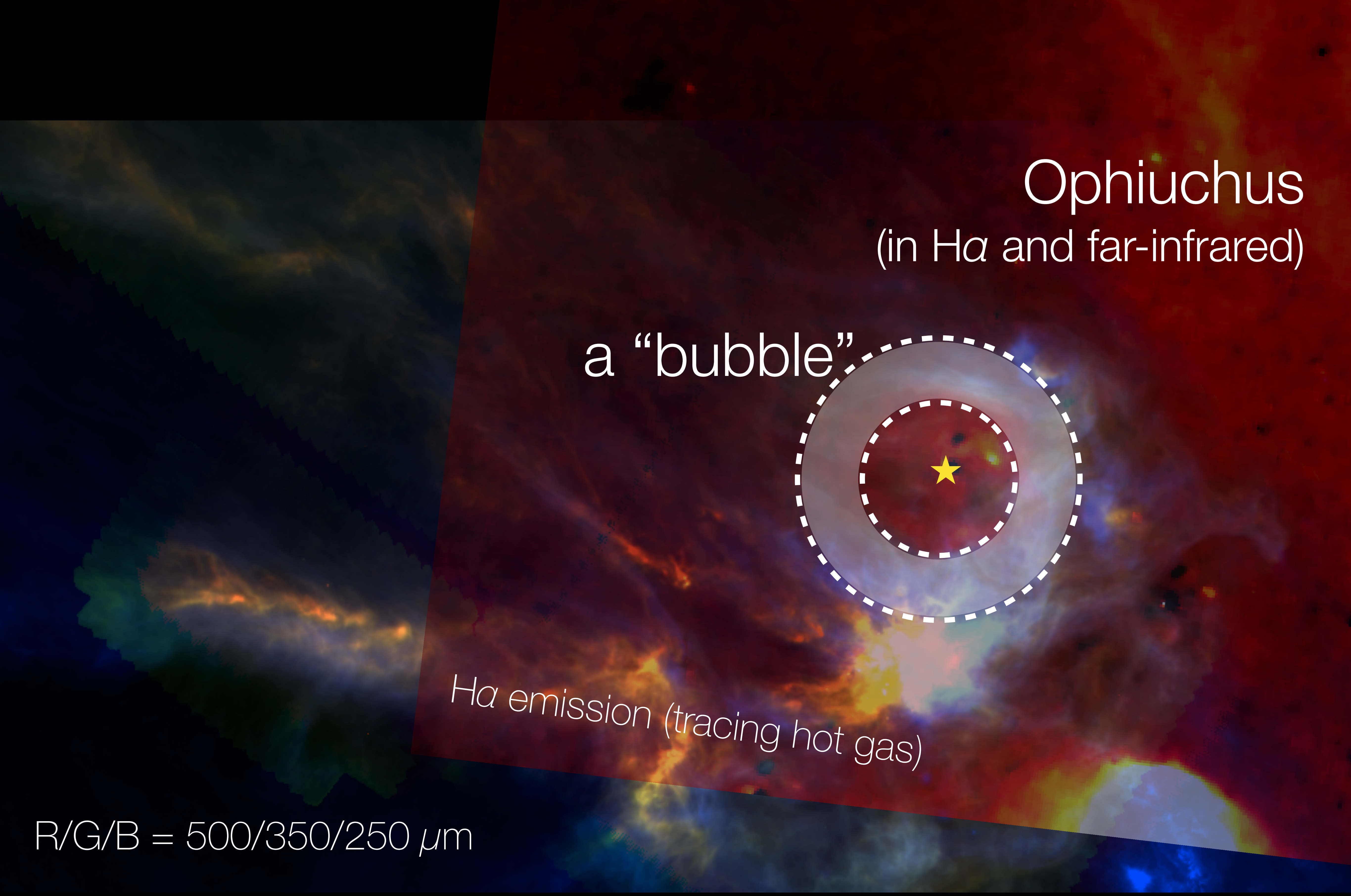
σ_{1D}=1.2 km s^{-1}

$\alpha_{vir} \sim 1$

Δx_{min}=20 AU

t_{ff}=0.04 Myr

Rosen et al. 2018, in prep



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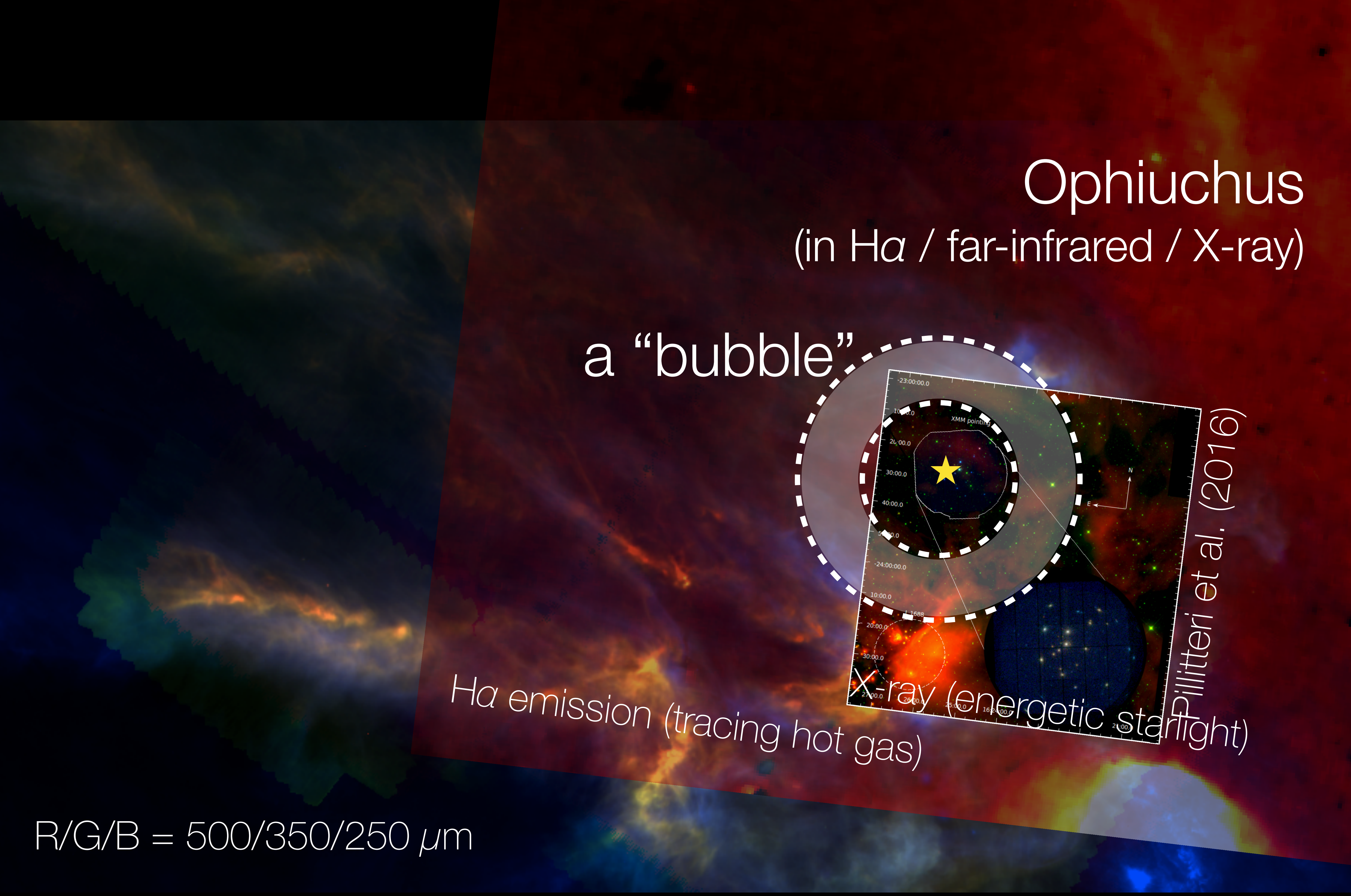

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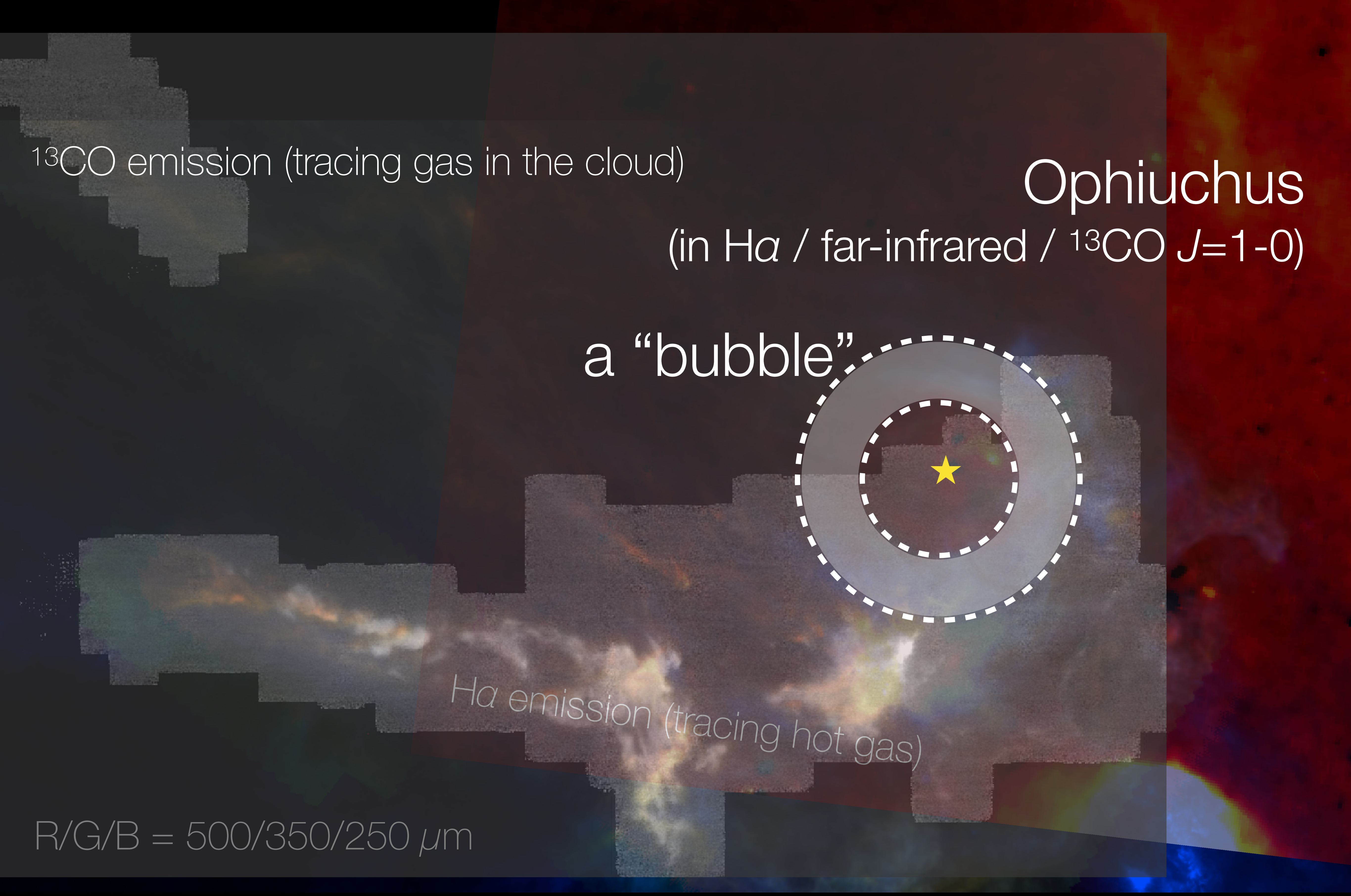

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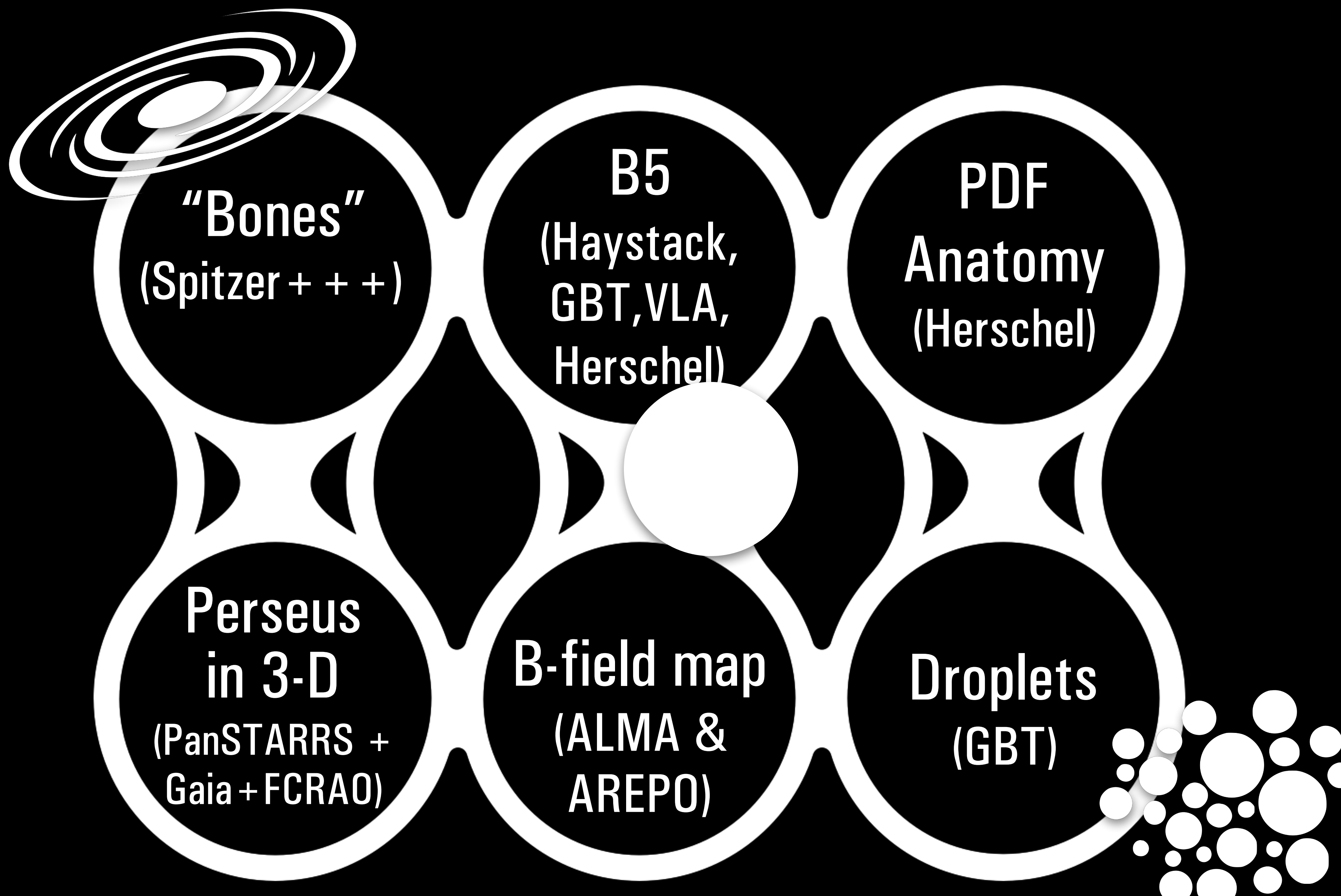
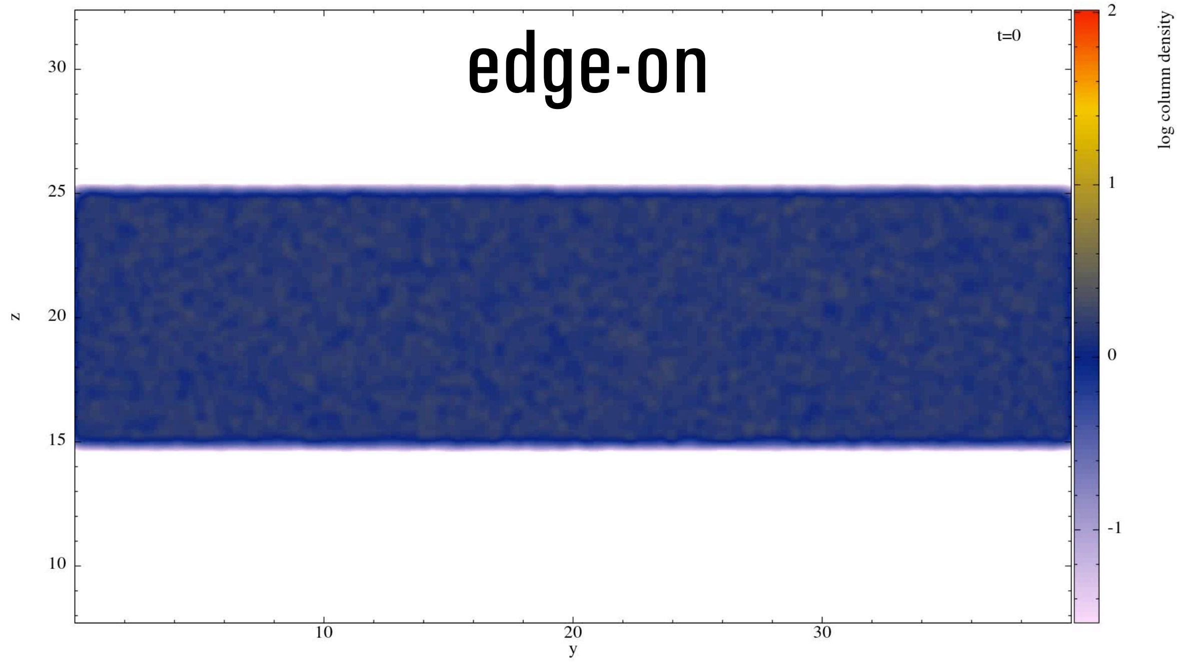
The Story We See

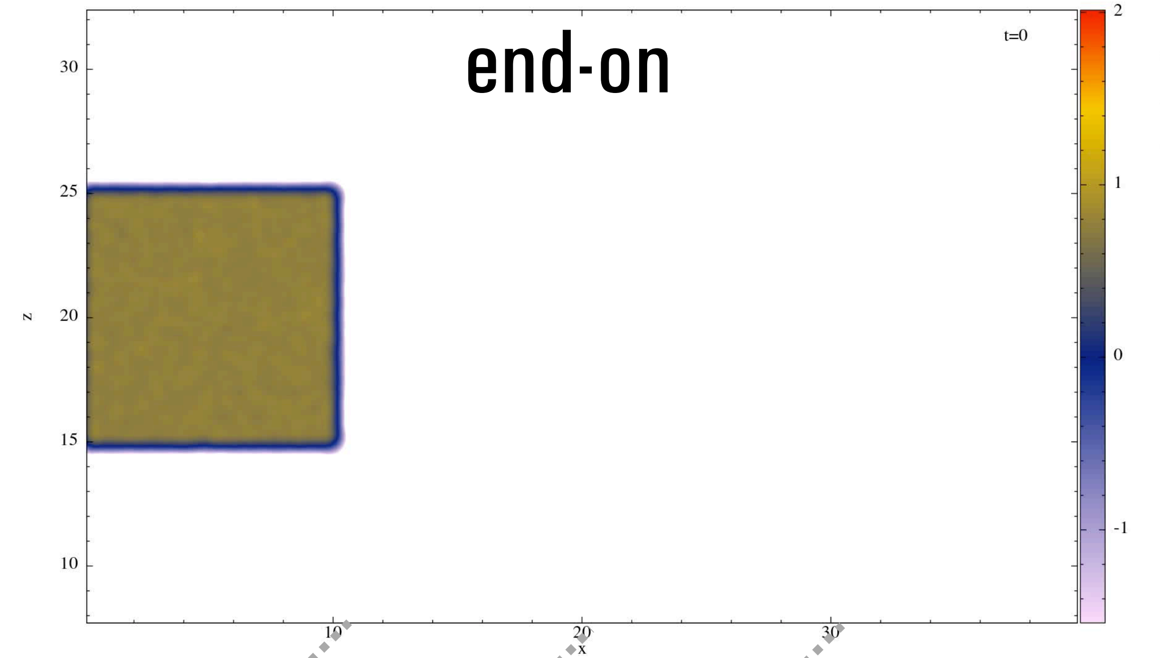
(A Six-Pack Sampler of Surprises)

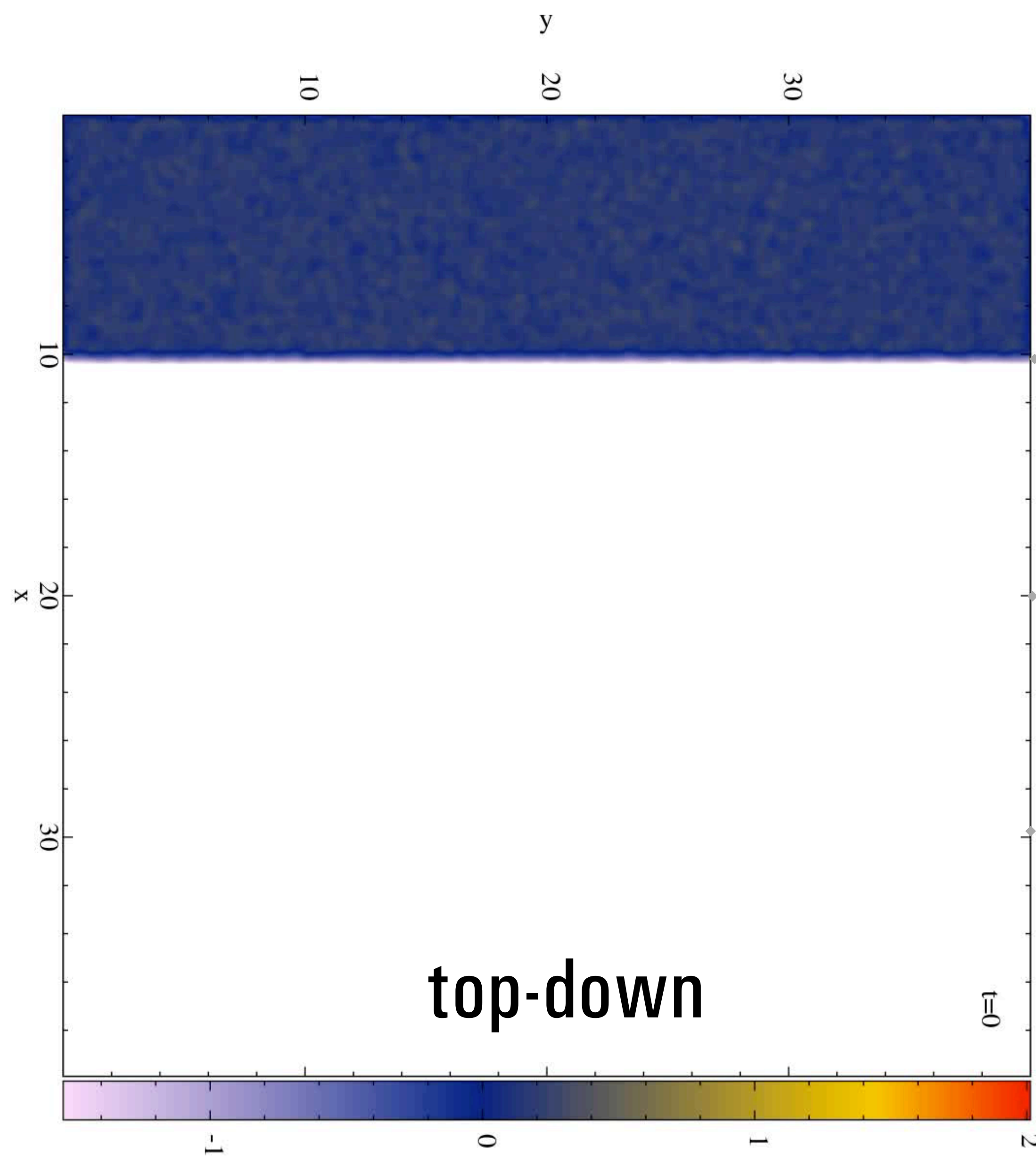


The Physical Properties of Observed (and Synthetic!) Large-Scale Galactic Filaments

Catherine Zucker (Harvard-Smithsonian Center for Astrophysics)
with…
Cara Battersby (University of Connecticut)
Alyssa Goodman (Harvard-Smithsonian Center for Astrophysics)
Rowan Smith (Jodrell Bank Centre for Astrophysics)





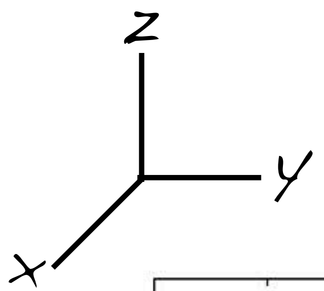


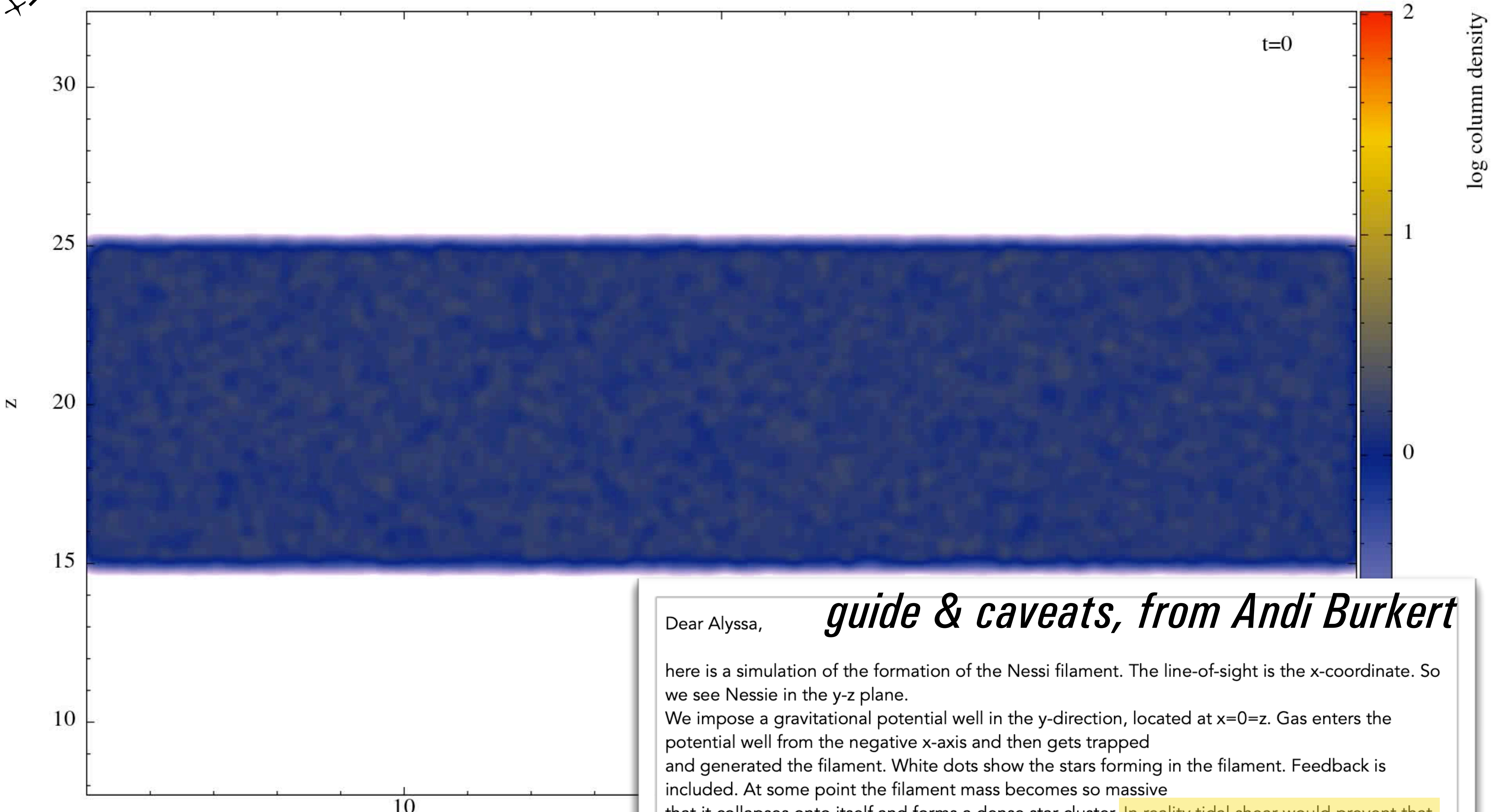
Last week in Germany...

A “numerical experiment”

(from Alig & Burkert, in prep 2018)

edge-on





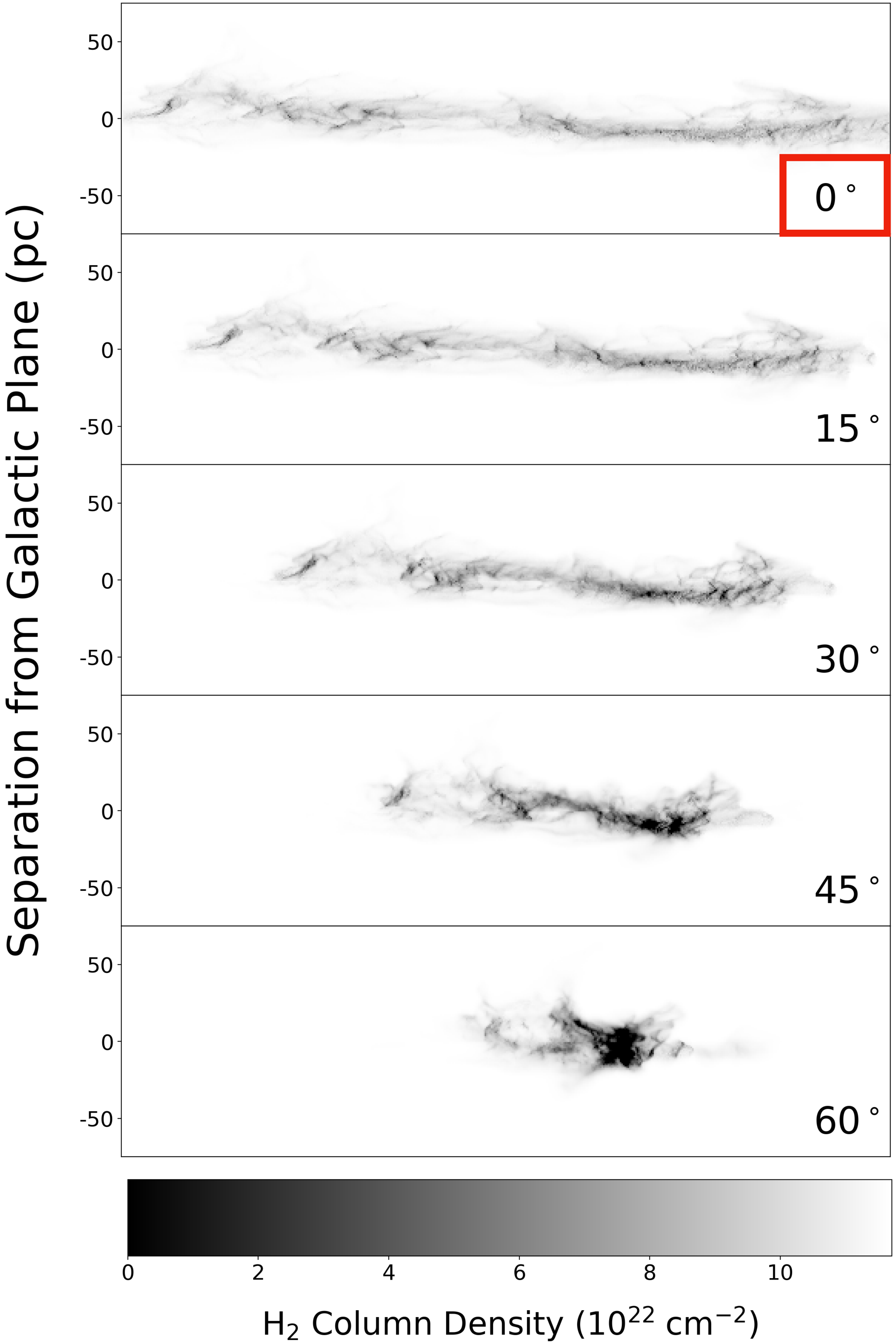
guide & caveats, from Andi Burkert

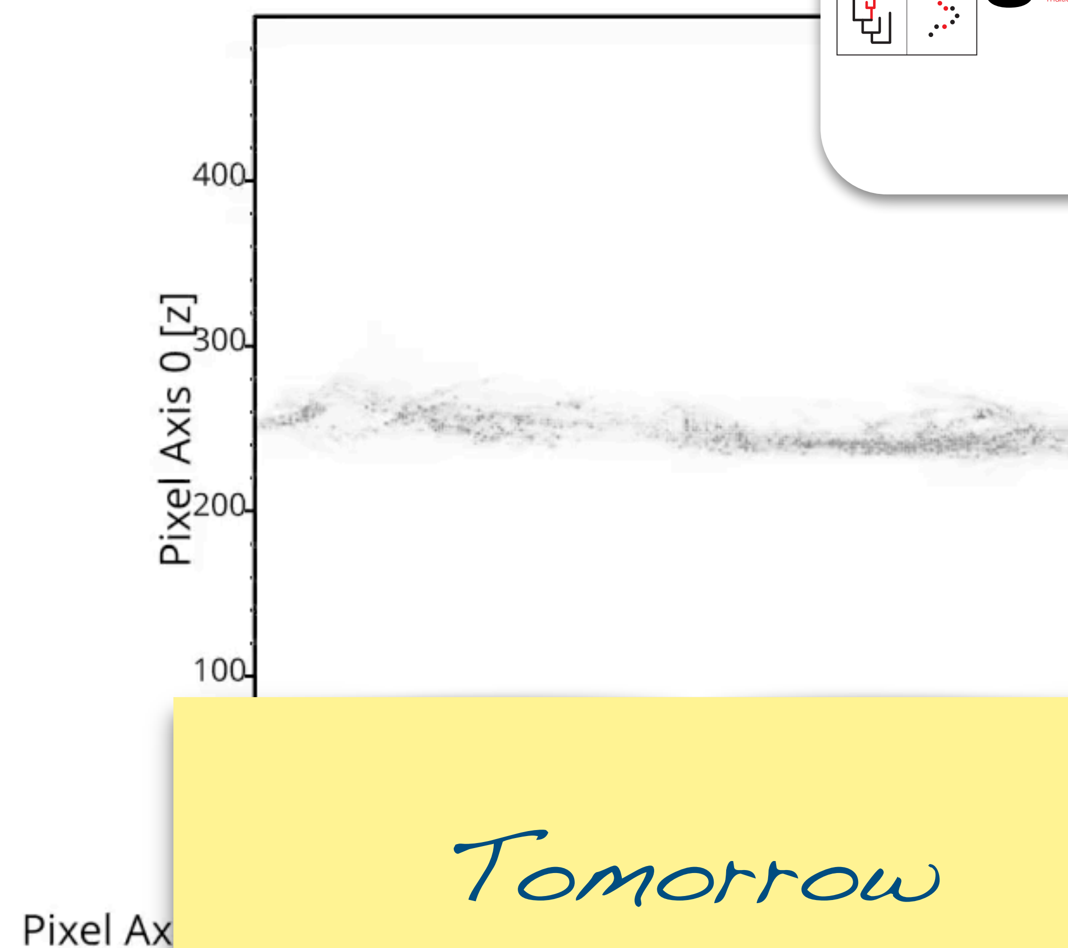
Dear Alyssa,

here is a simulation of the formation of the Nessi filament. The line-of-sight is the x-coordinate. So we see Nessie in the y-z plane.
We impose a gravitational potential well in the y-direction, located at x=0=z. Gas enters the potential well from the negative x-axis and then gets trapped
and generated the filament. White dots show the stars forming in the filament. Feedback is included. At some point the filament mass becomes so massive
that it collapses onto itself and forms a dense star cluster. In reality tidal shear would prevent that from happening.

The 3 movies show the gas and stars in x-y, x-z and y-z projection. As the movies are too large to send via email, here is a link where you can download them:


"Taste-Testing"



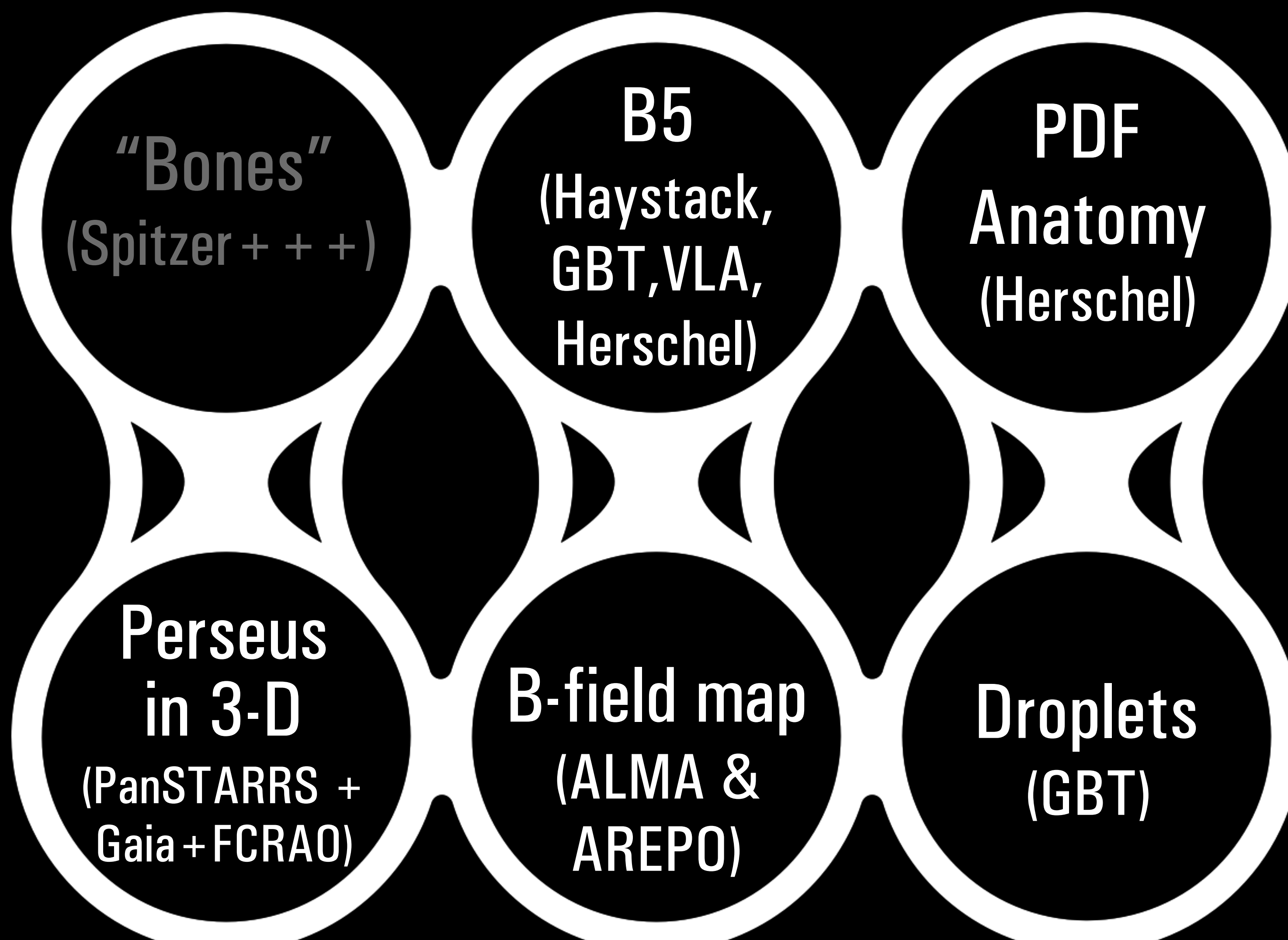


Tomorrow
(is about how–
today is about why).

Slide courtesy of Catherine Zucker,
from Zucker, Smith & Goodman 2018, in prep

The Story We See

(A Six-Pack Sampler of Surprises)



The story I told in 1998

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COHERENCE IN DENSE CORES. II. THE TRANSITION TO COHERENCE

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Received 1997 June 17; accepted 1998 February 5

ABSTRACT

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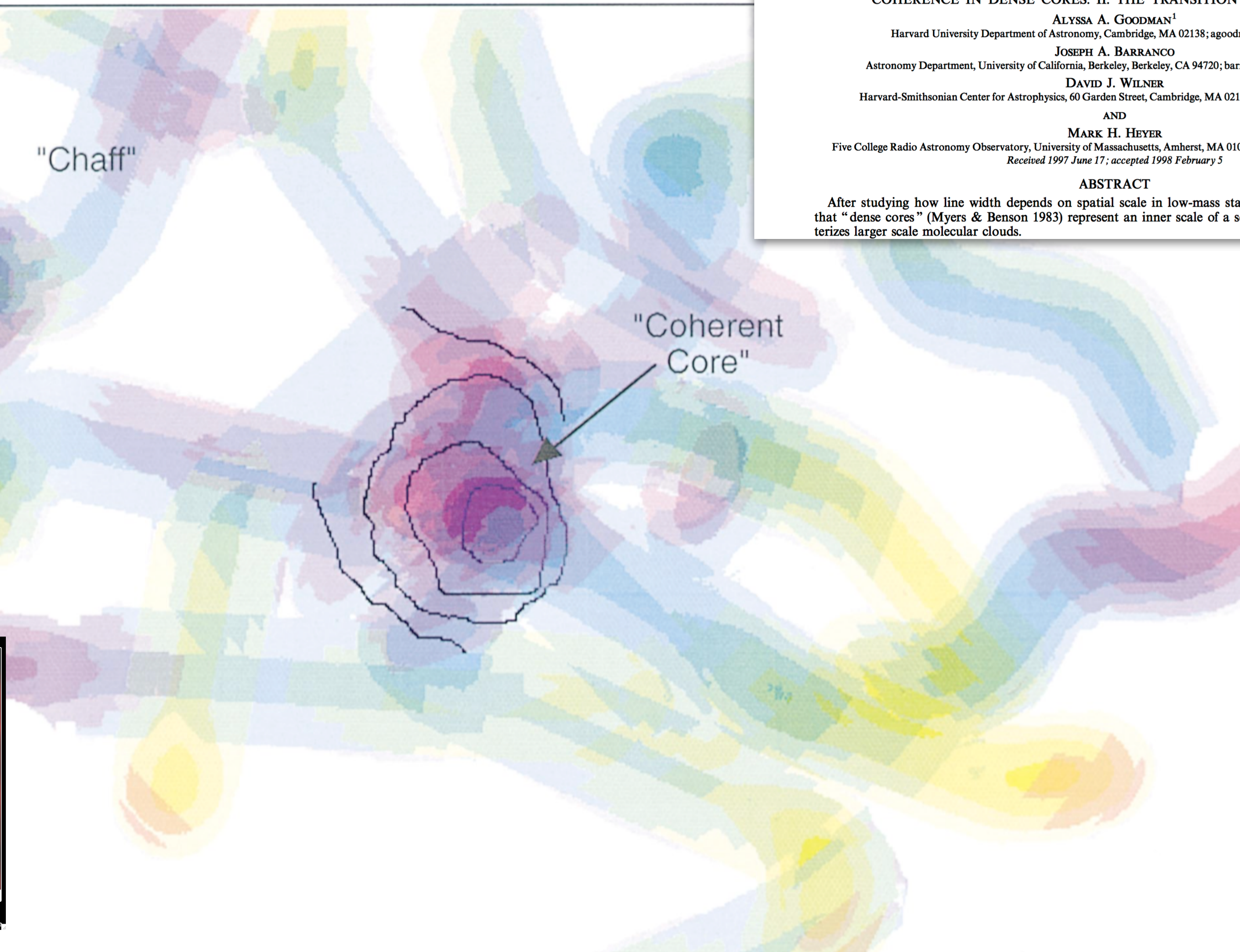


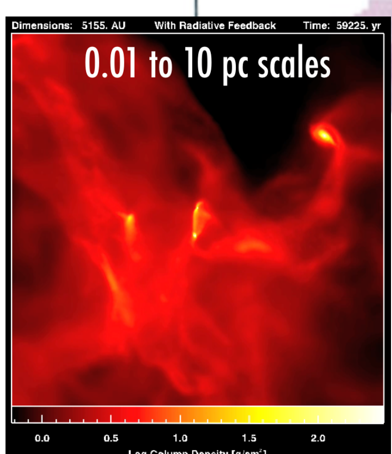
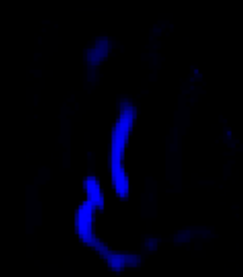


Fig. 10.—An illustration of the transition to coherence. Color and shading schematically represent velocity and density in this figure. On large scales, material (labeled chaff) is distributed in a self-similar fashion, and its filling factor is low. On scales smaller than some fiducial radius, the filling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

WHAT IF FILAMENTS CONTINUE ACROSS "CORE" BOUNDARIES?!

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

B5
(Haystack,
GBT,VLA,
Herschel)

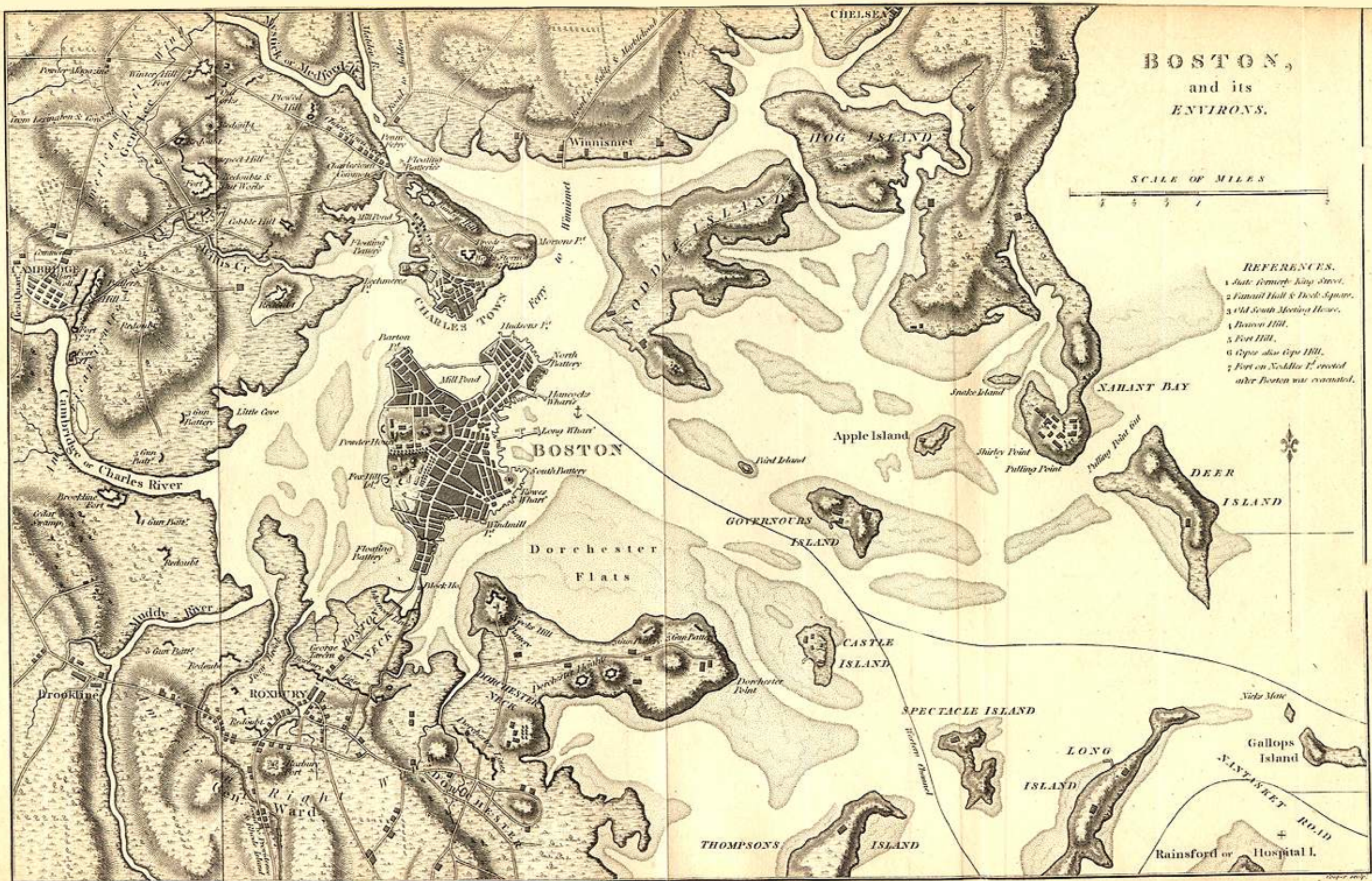


Goodman, Chen, Offner & Pineda 2018 in prep.

Herschel data from Gould Belt Survey

1998

2008

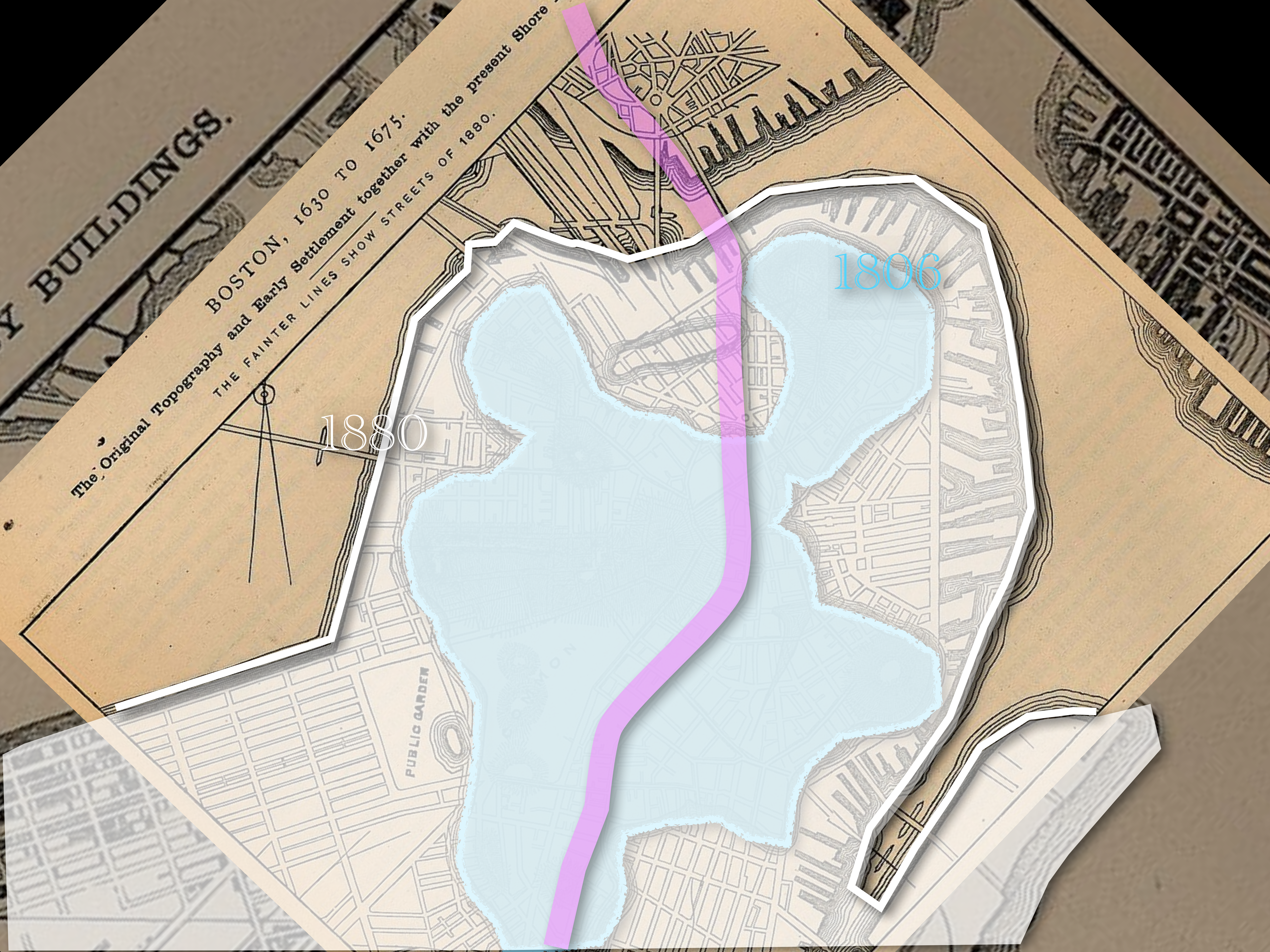

BOSTON,
and its
ENVIRONS.
SCALE OF MILES
REFERENCES.
2 Fanueil Hall & Dock Square.
3 Old South Meeting House.
5 Fort Hill.
CHELSEA
HOG ISLAND
NODDLES ISLAND
Winnisimet
CHARLES TOWN
CAMBRIDGE
Cambridge or Charles River
Muddy River
BOSTON
Mill Pond
North Battery
South Battery
Long Wharf
Dorchester Flats
BOSTON NECK
ROXBURY
Brookline
DORCHESTER NECK
Dorchester Point
DORCHESTER
Apple Island
Bird Island
Snake Island
Shirley Point
Pulling Point
NAHANT BAY
DEER ISLAND
GOVERNOURS ISLAND
CASTLE ISLAND
SPECTACLE ISLAND
THOMPSONS ISLAND
LONG ISLAND
Gallops Island
NANTASKET ROAD
Rainsford or Hospital I.
Little Cove
Cobble Hill
Winter Hill Fort
Ploughed Hill
Lechmere Pt.
Barton Pt.
Hudsons Pt.
Windmill Pt.
Floating Battery
Powder House
Fox Hill
Brookline Fort
Redoubt
Right Wing

Boston 1806

Boston 1880

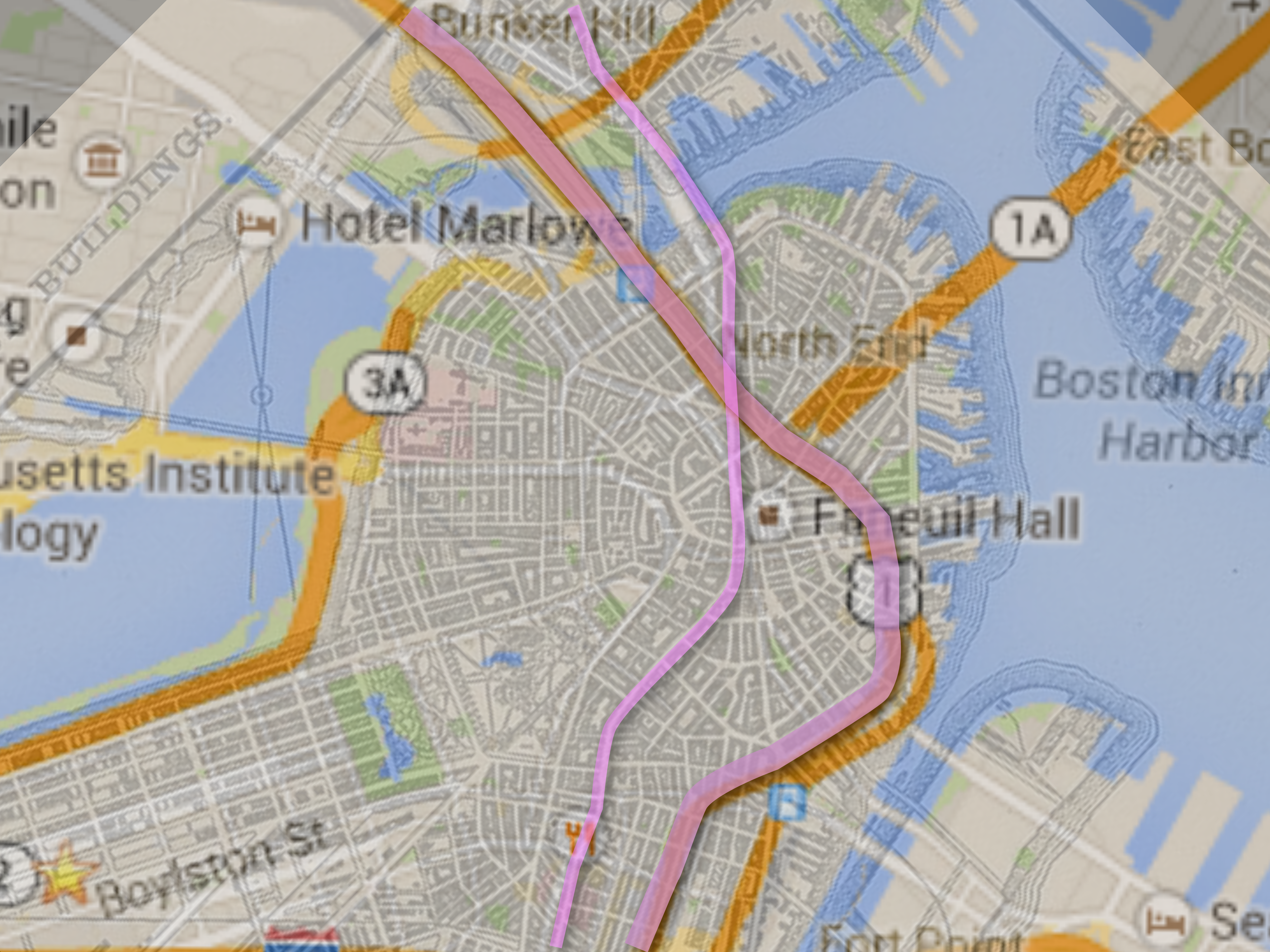
Boston 1806

Boston
1880

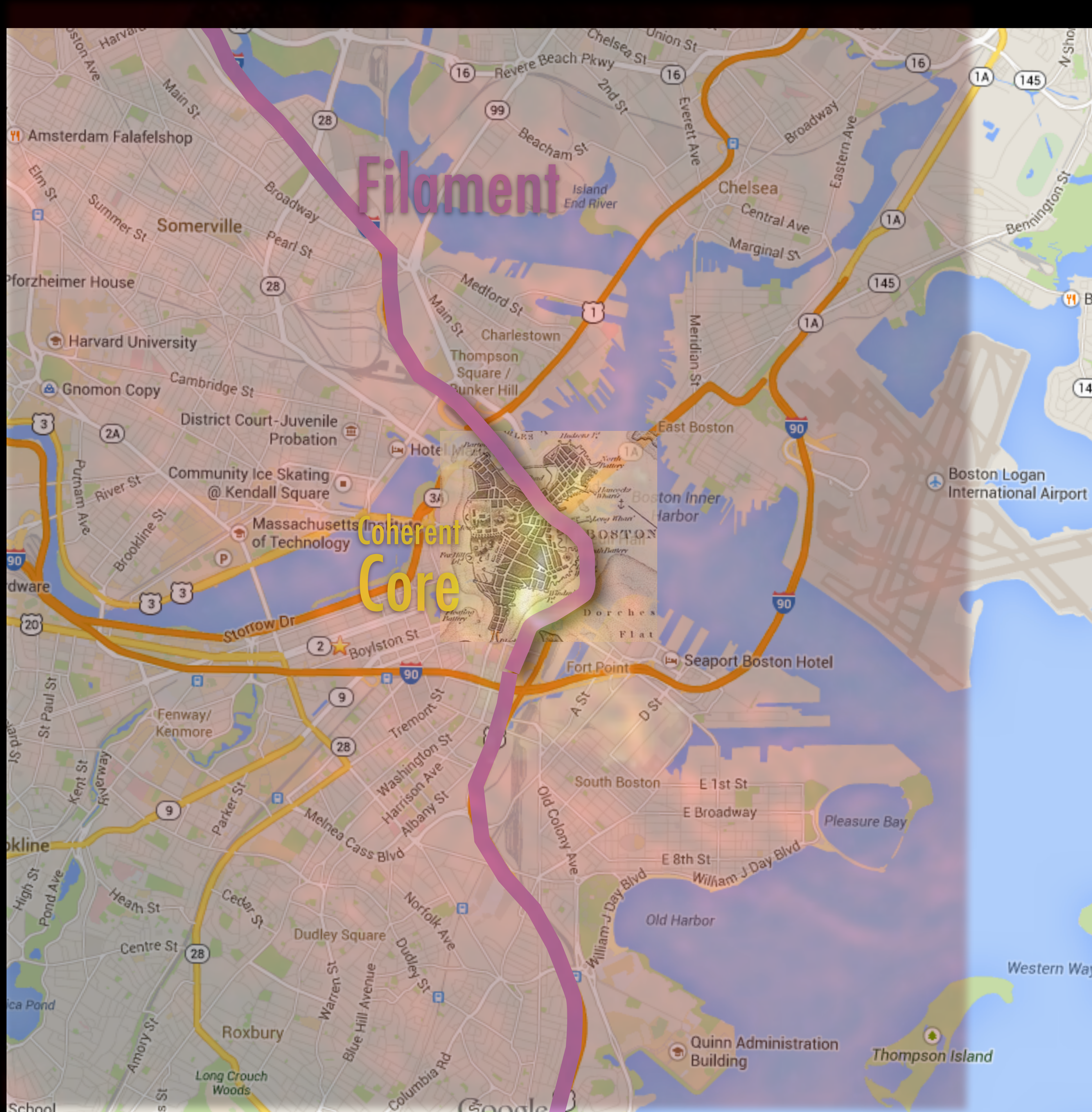

Y BUILDINGS.
BOSTON, 1630 TO 1675.
The Original Topography and Early Settlement together with the present Shore
THE FAINTER LINES SHOW STREETS OF 1880.
1880
1806
PUBLIC GARDEN


BOSTON, 1630 TO 1675.
The Original Topography and Early Settlement
with the present Shore
THE FAINTER LINES SHOW
STREETS OF 1880.
1880
1806
Mill Pond
North Battery
Long Wharf
BOST
South Battery
Dorc

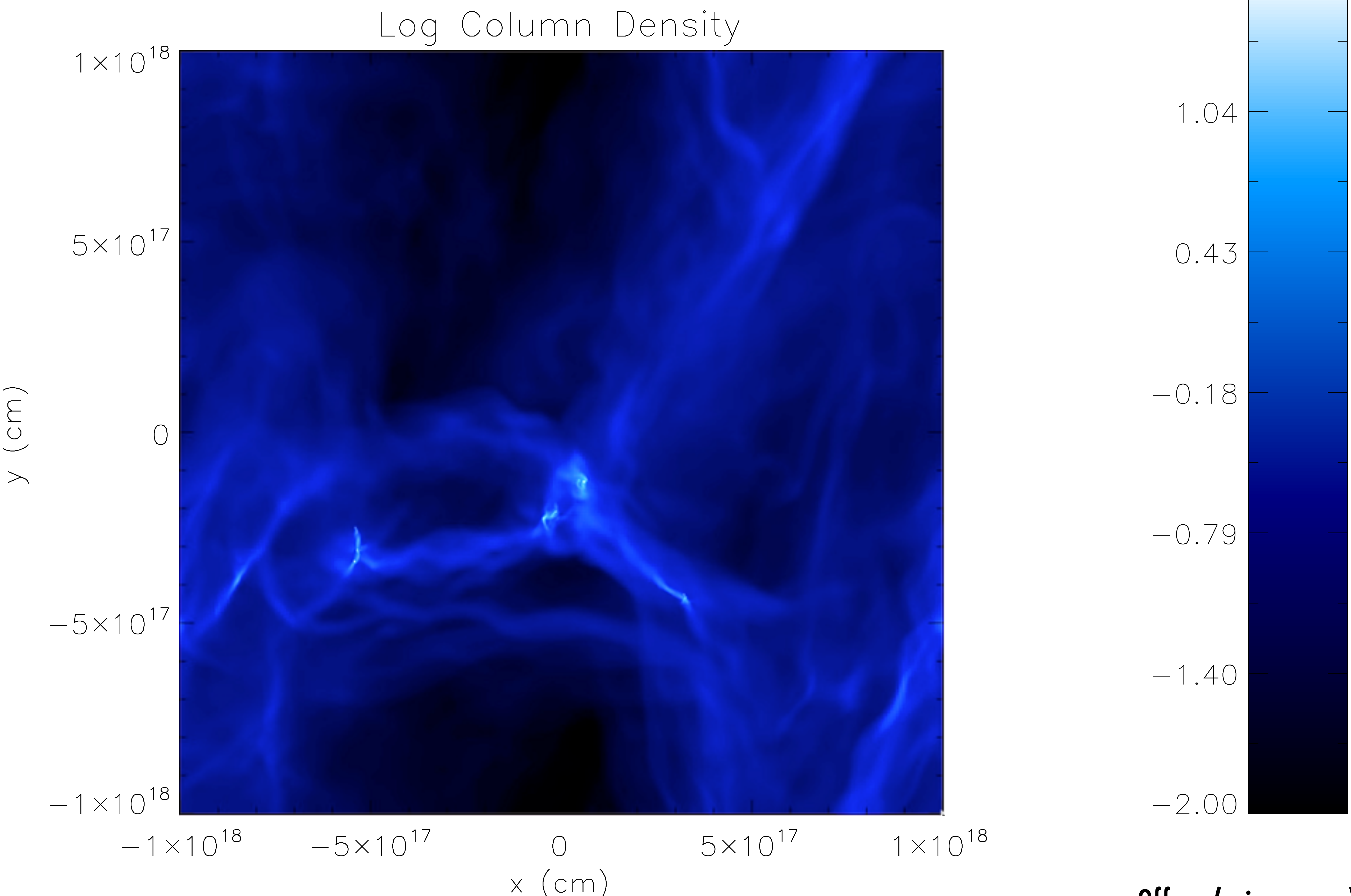

Y BUILDINGS.



BUILDINGS
Hotel Marlowe
3A
1A
North End
Faneuil Hall
1
Boylston St

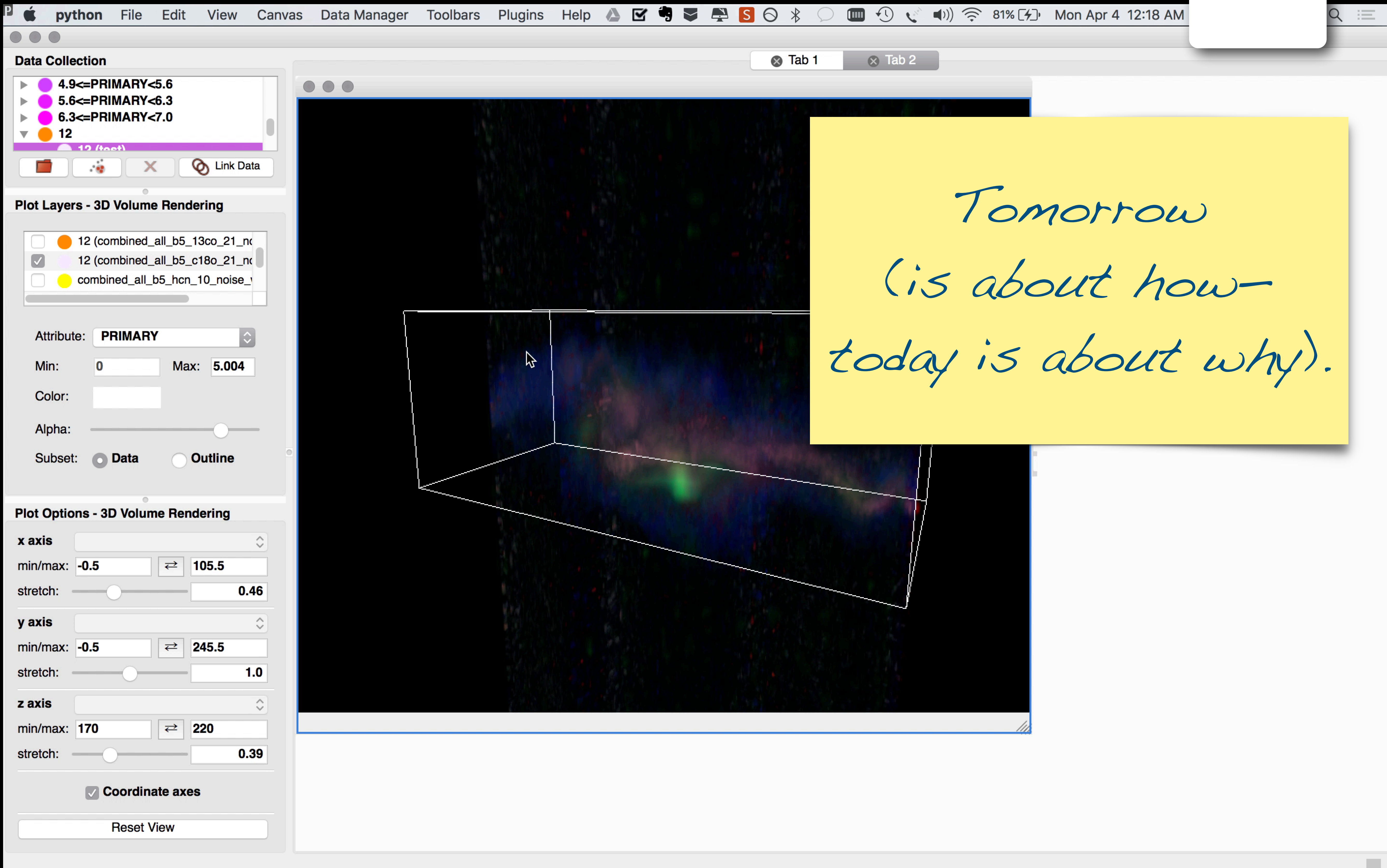

Filament
Coherent
Core
Somerville
Harvard University
Gnomon Copy
Amsterdam Falafelshop
Pforzheimer House
District Court-Juvenile Probation
Community Ice Skating @ Kendall Square
Massachusetts Institute of Technology
Charlestown
Thompson Square / Bunker Hill
Island End River
Chelsea
East Boston
Boston Inner Harbor
Boston Logan International Airport
Seaport Boston Hotel
Fort Point
Fenway/ Kenmore
South Boston
Pleasure Bay
Old Harbor
Dudley Square
Roxbury
Long Crouch Woods
Quinn Administration Building
Thompson Island
Western Way
Storrow Dr
Boylston St
Cambridge St
Melnea Cass Blvd
Old Colony Ave
E Broadway
William J Day Blvd
Google

B5-ISH SIMULATION (NO MAGNETIC FIELD)



Offner (priv. comm.)

B5/GLUE (NEW IRAM 30-M DATA)



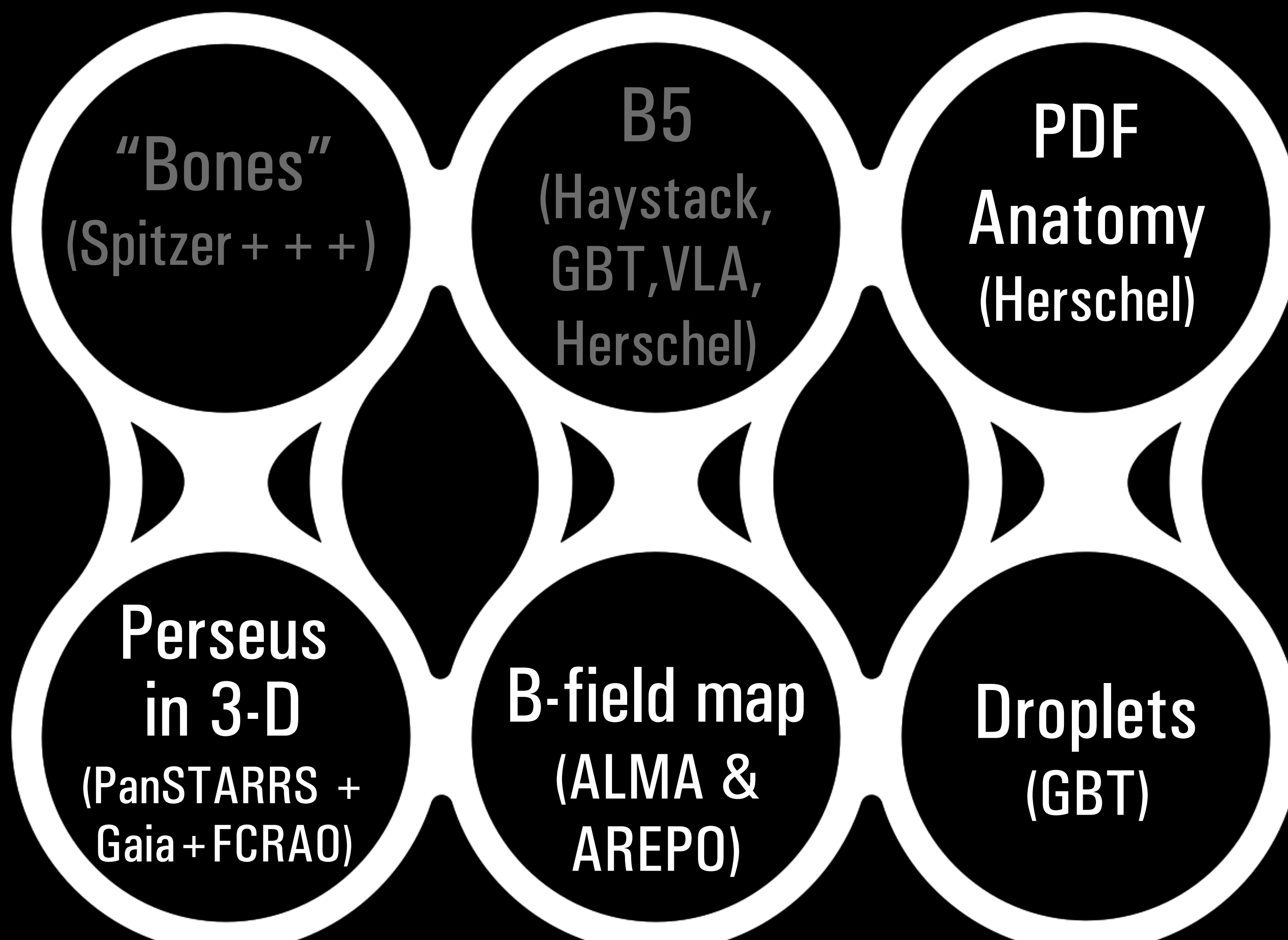
Tomorrow
(is about how—
today is about why).

Goodman, Chen, Offner & Pineda 2018 in prep.

glueviz.org

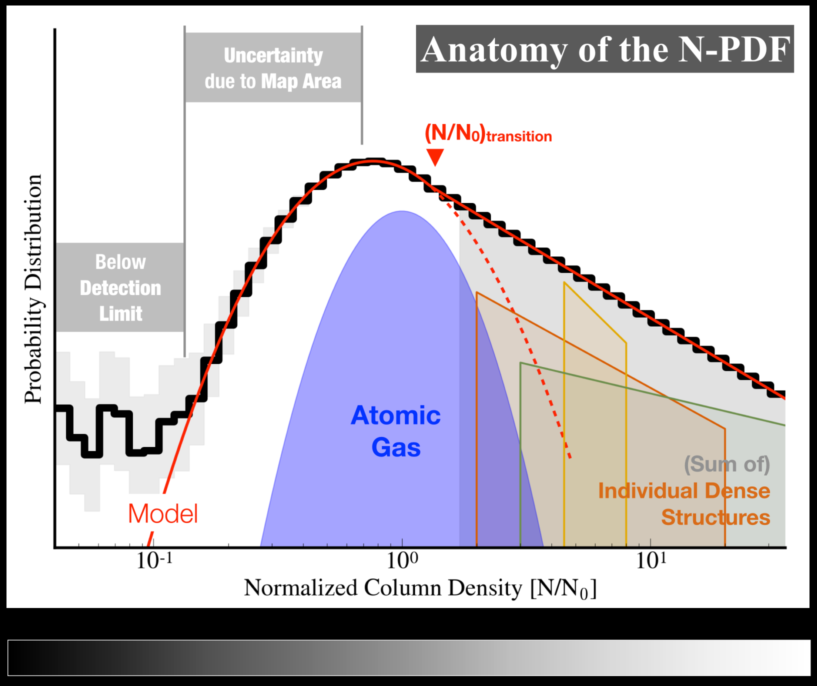
The Story We See

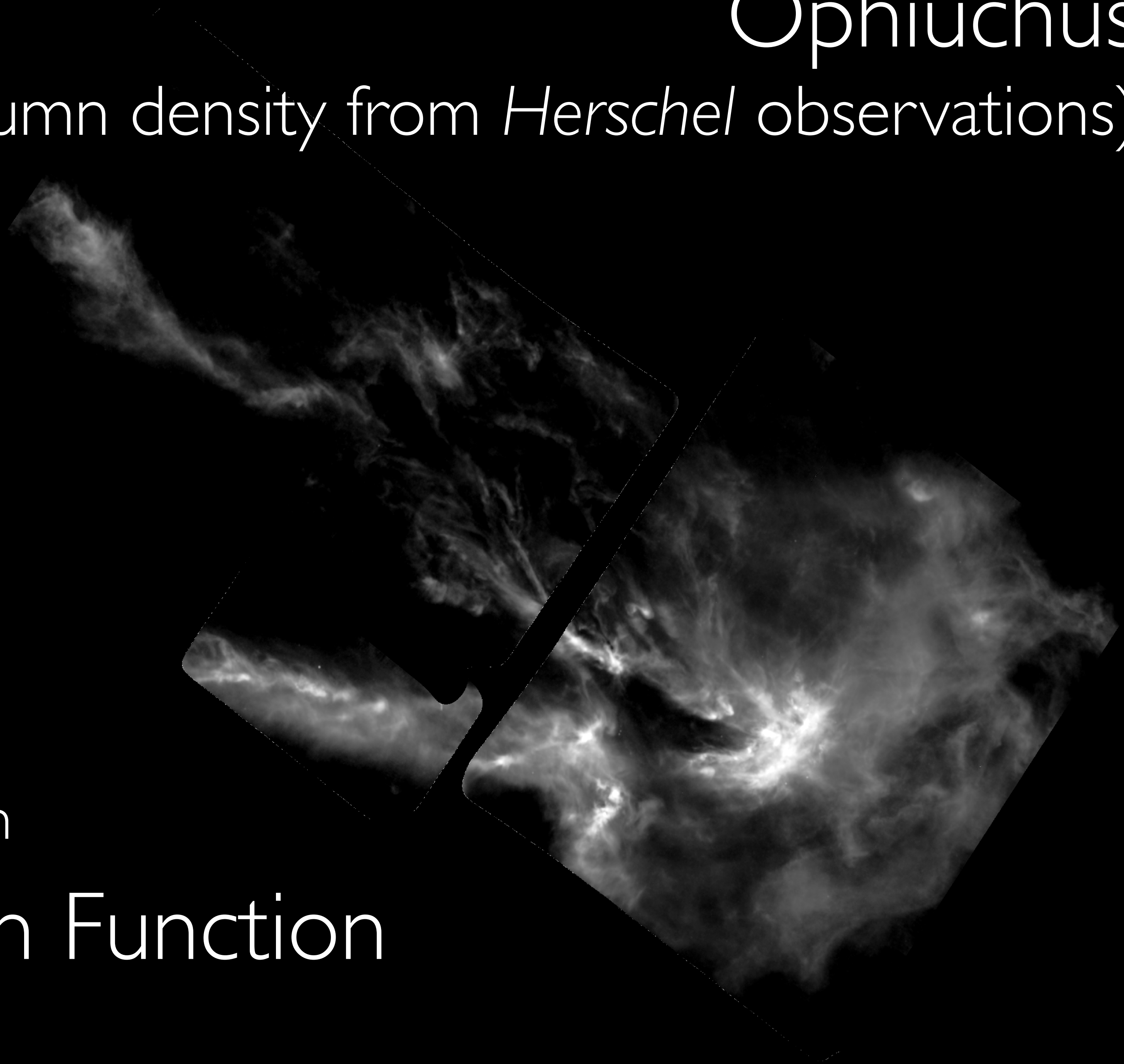
(A Six-Pack Sampler of Surprises)



PDF
Anatomy
(Herschel)

Ophiuchus
(column density from *Herschel* observations)

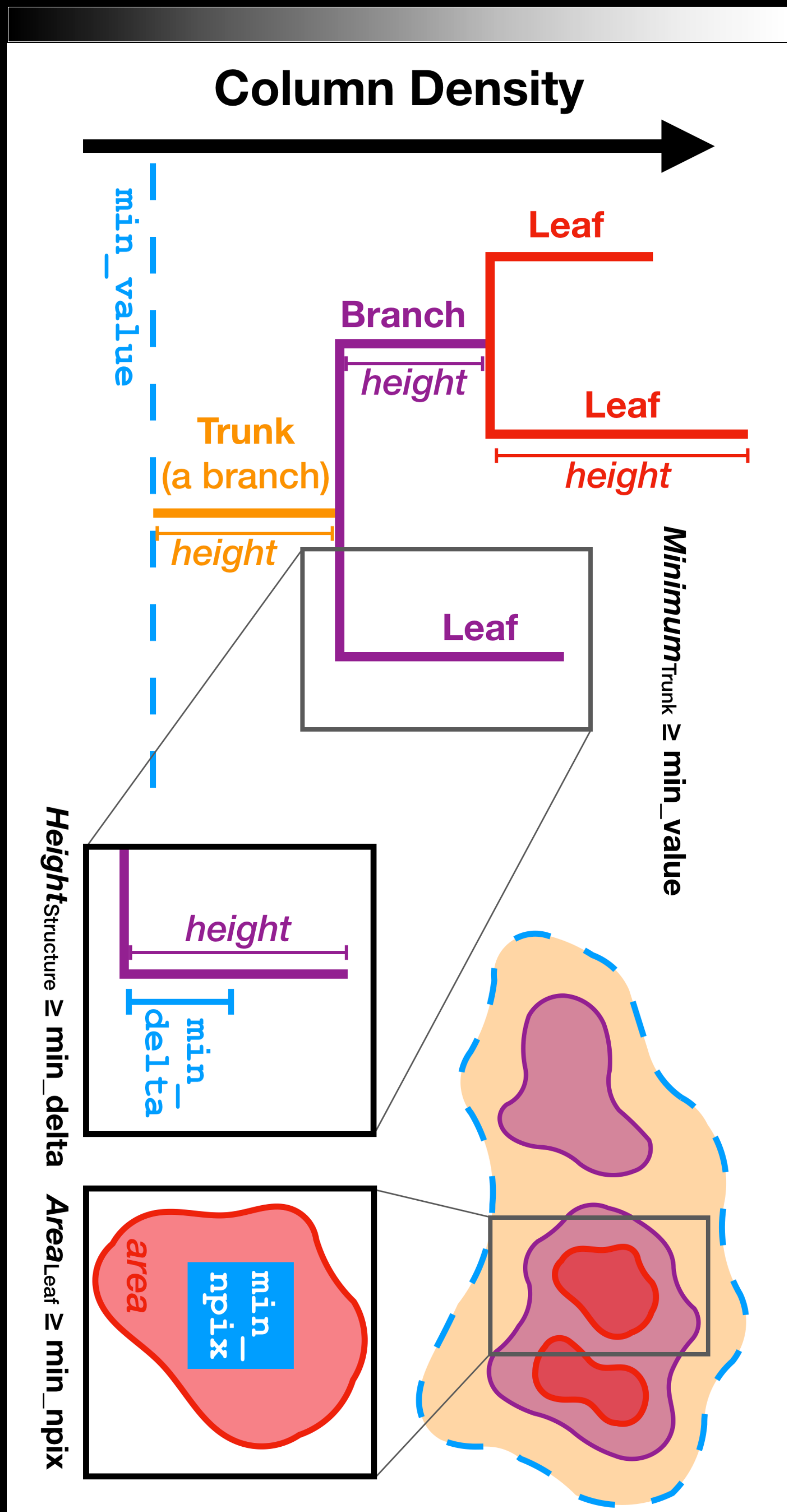




Probability Distribution Function
(N-PDF)

slide sequence courtesy of Hope Chen, from his PhD defense talk

low



high

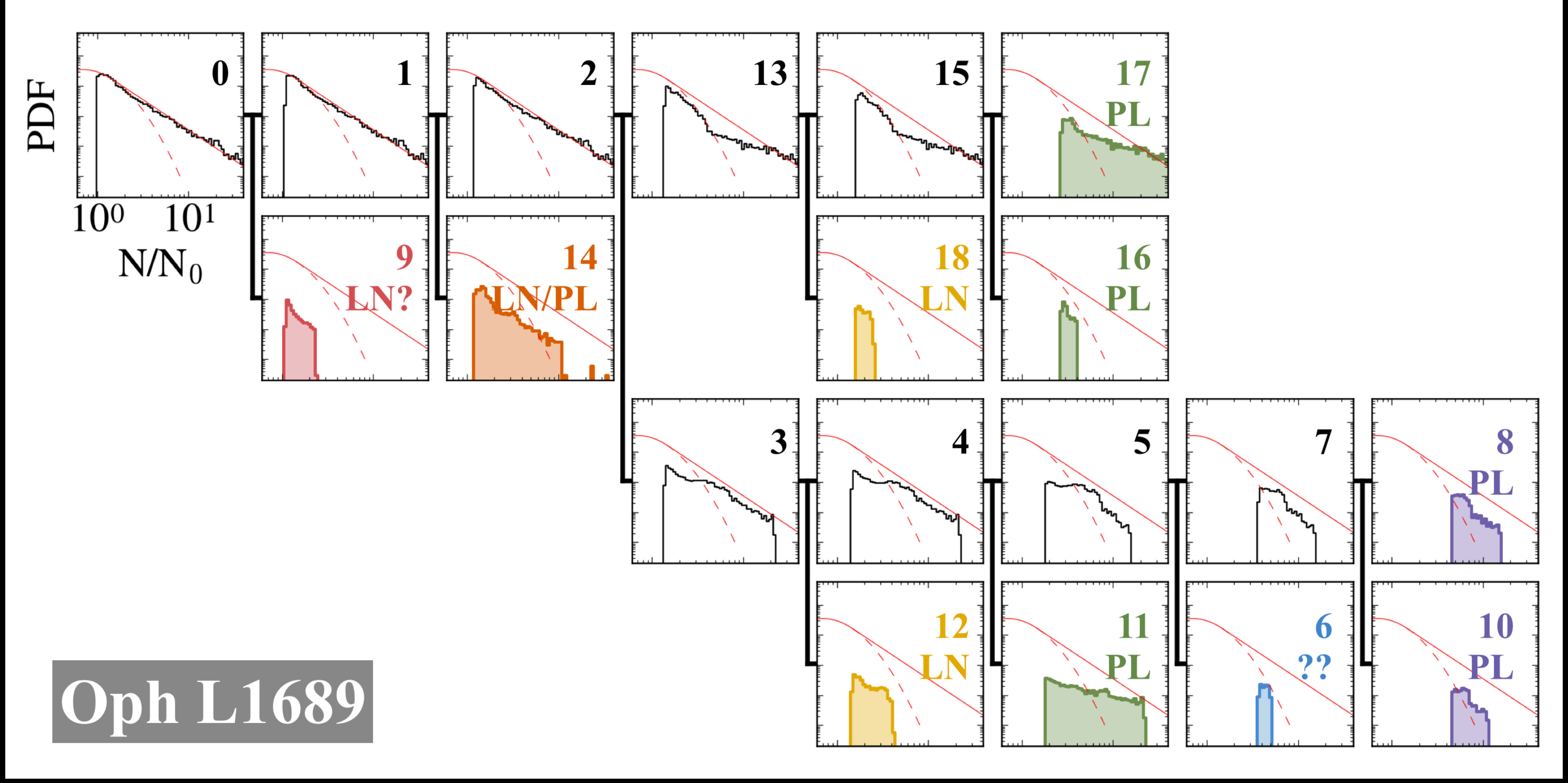
Ophiuchus

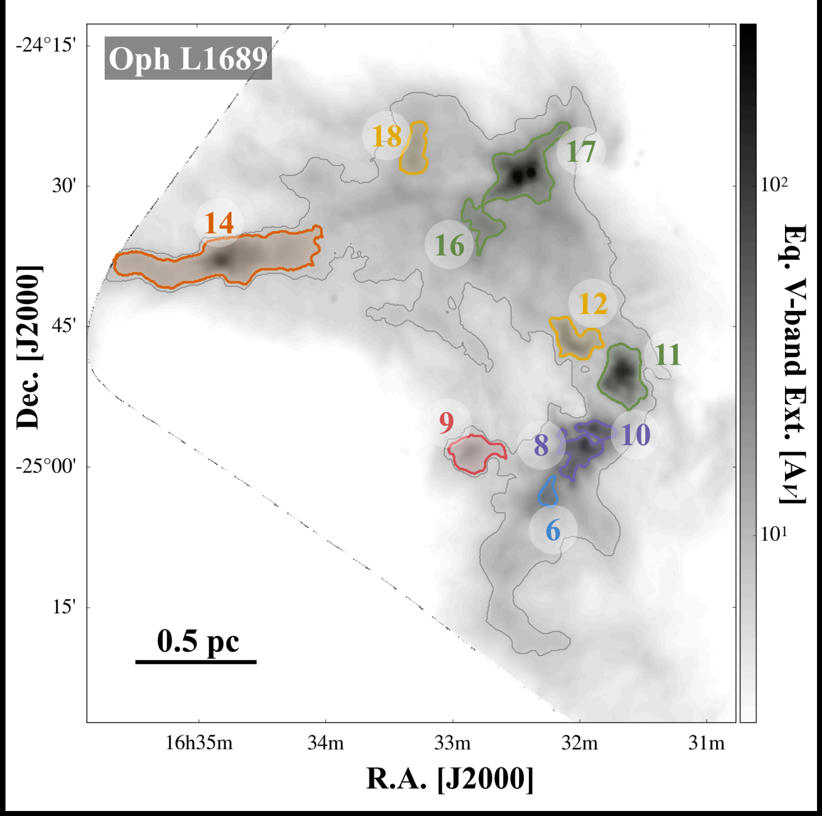
(column density from *Herschel* observations)

Dendrogram

slide sequence courtesy of Hope Chen, from his PhD defense talk

Ophiuchus
(column density from *Herschel* observations)

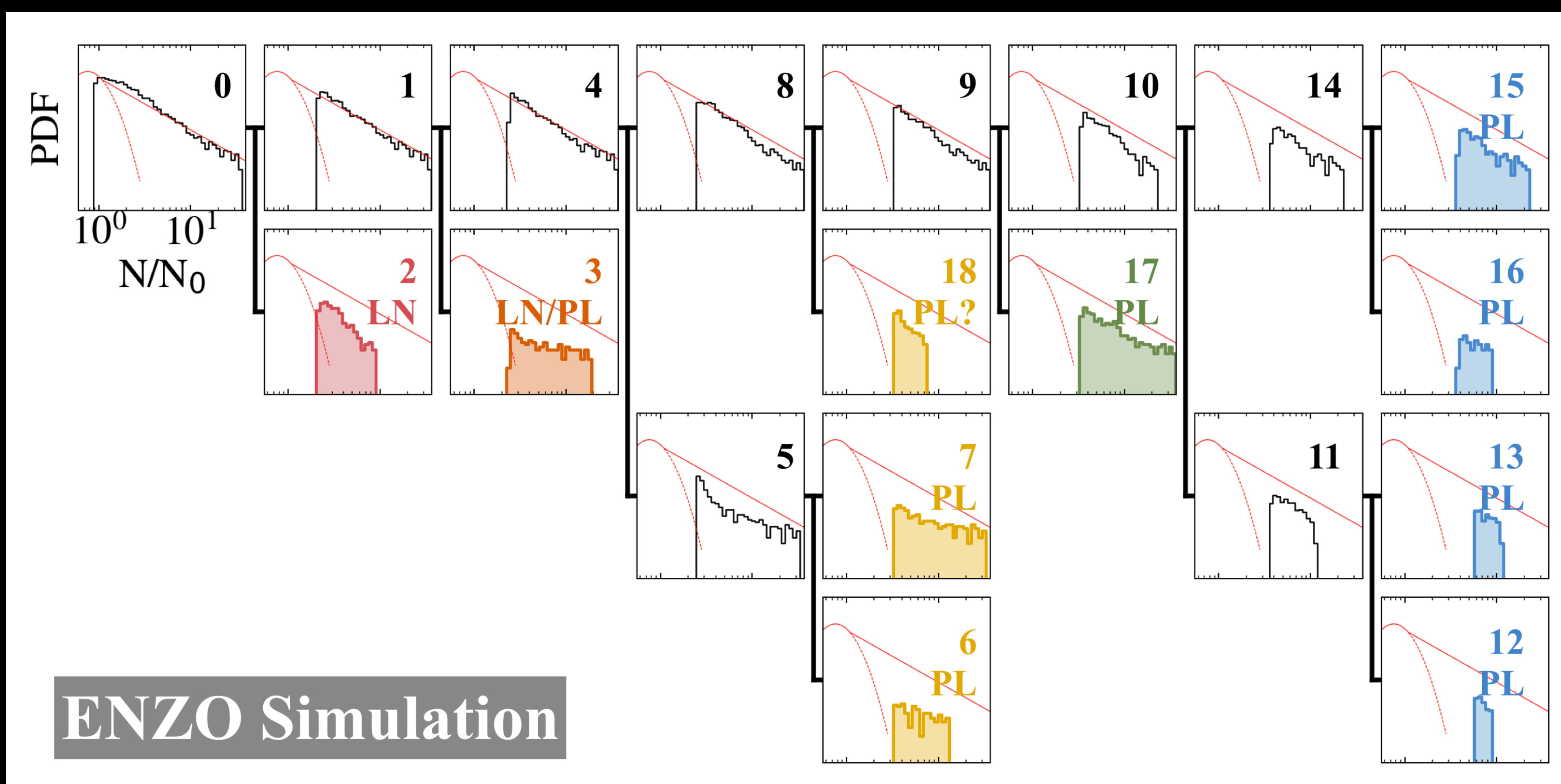


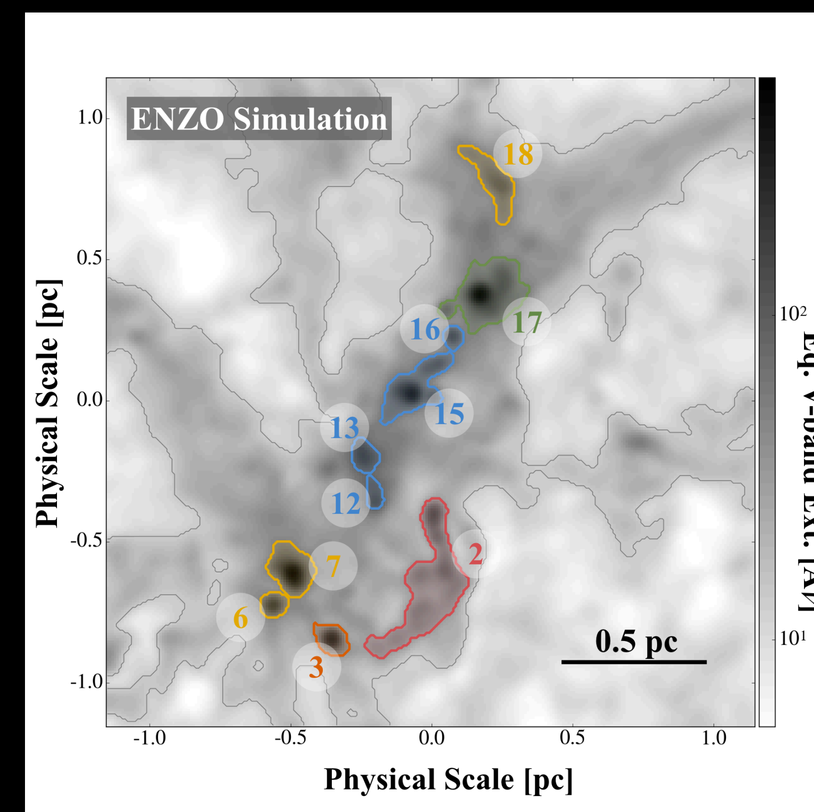


slide sequence courtesy of Hope Chen, from his PhD defense talk

Simulation

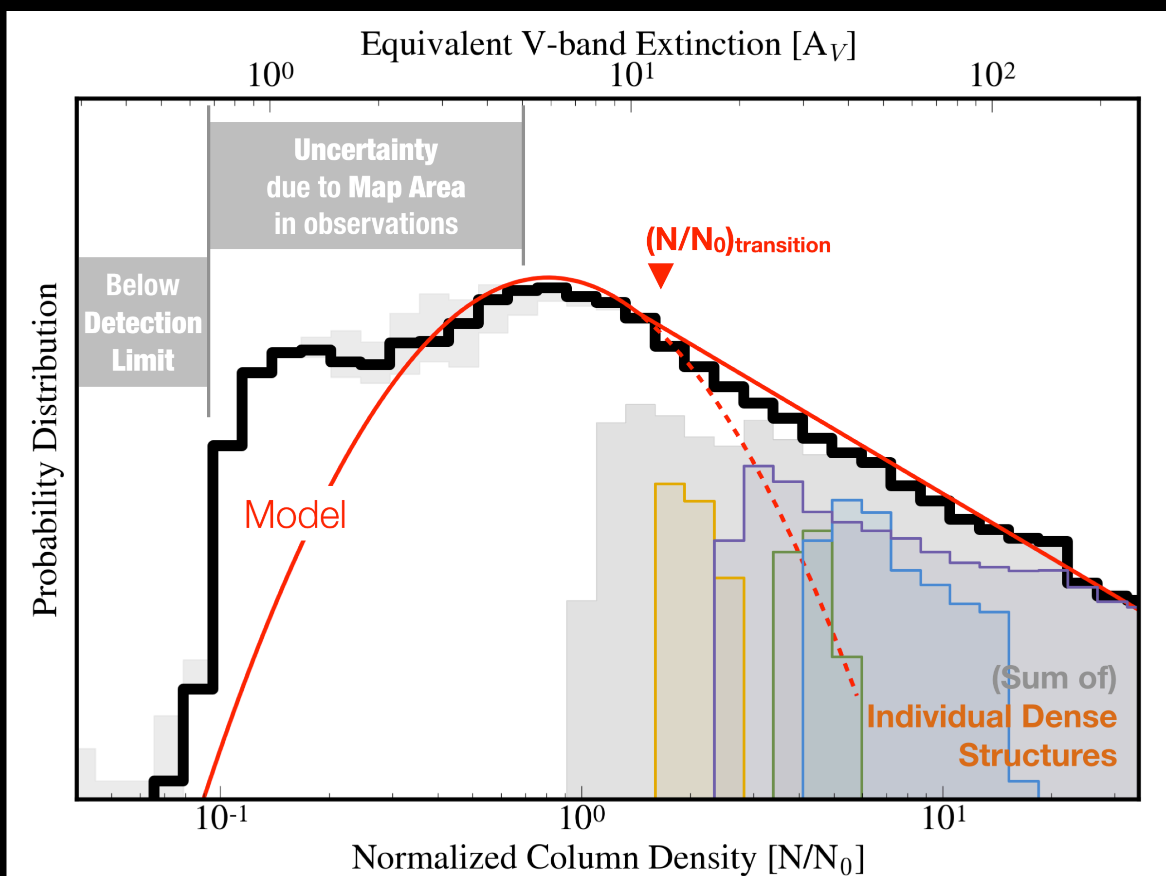
(mimicking column density derived from dust emission)





slide sequence courtesy of Hope Chen, from his PhD defense talk

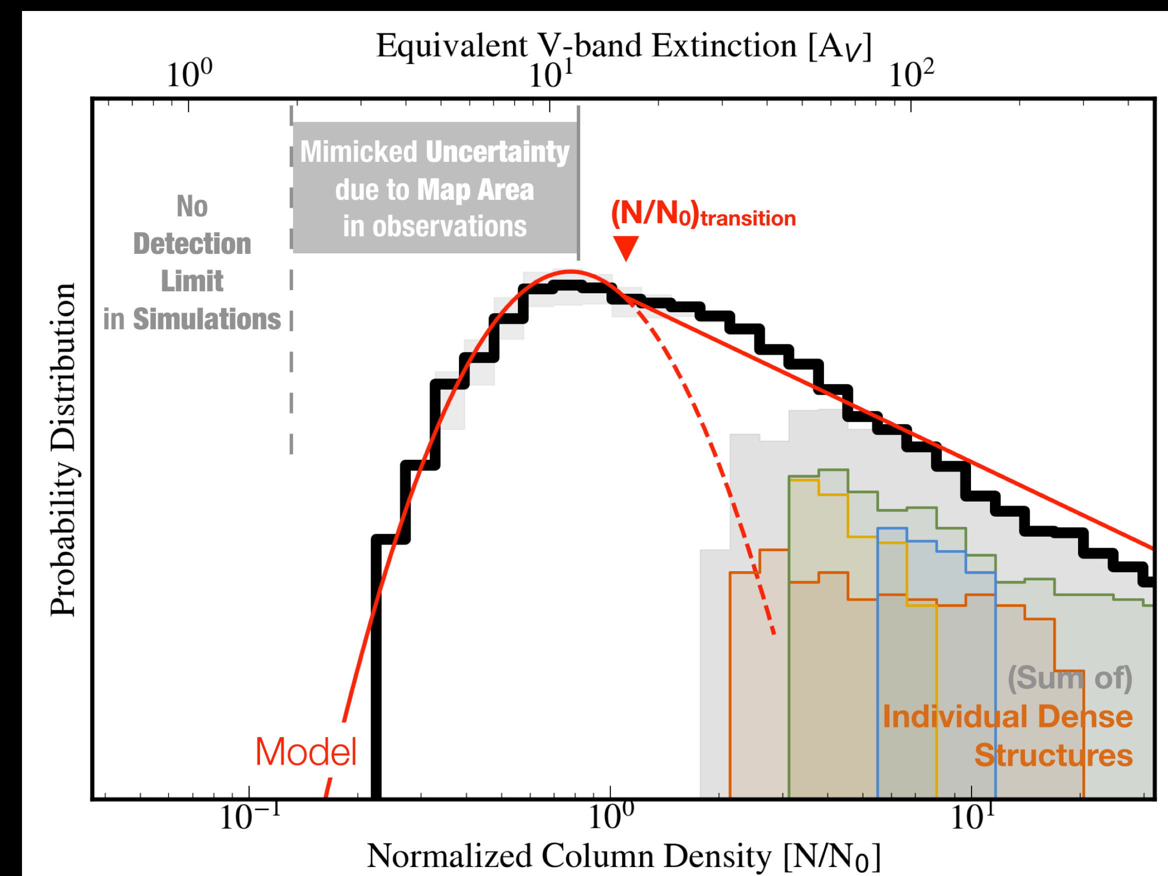
Observation
(Ophiuchus)



high

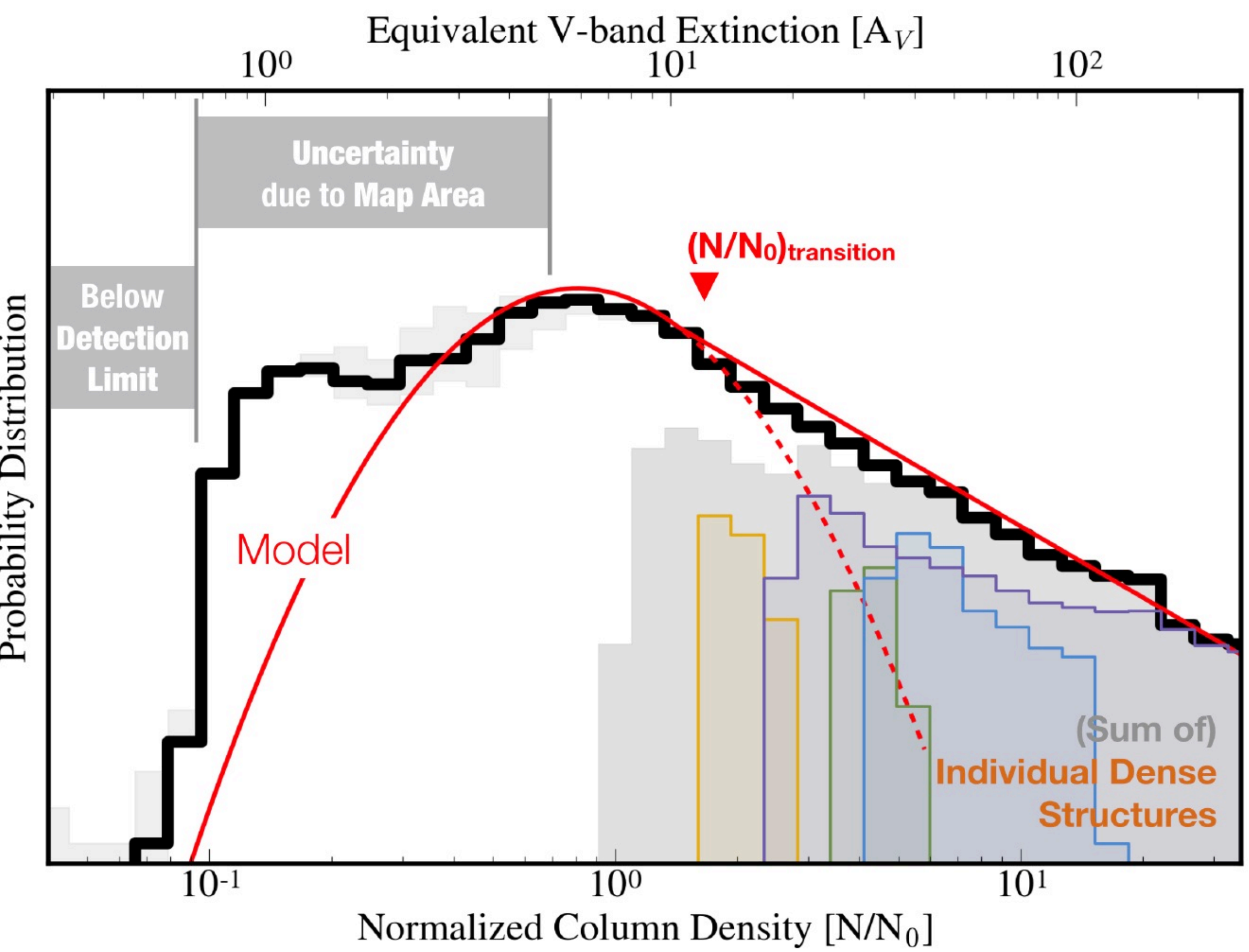
low

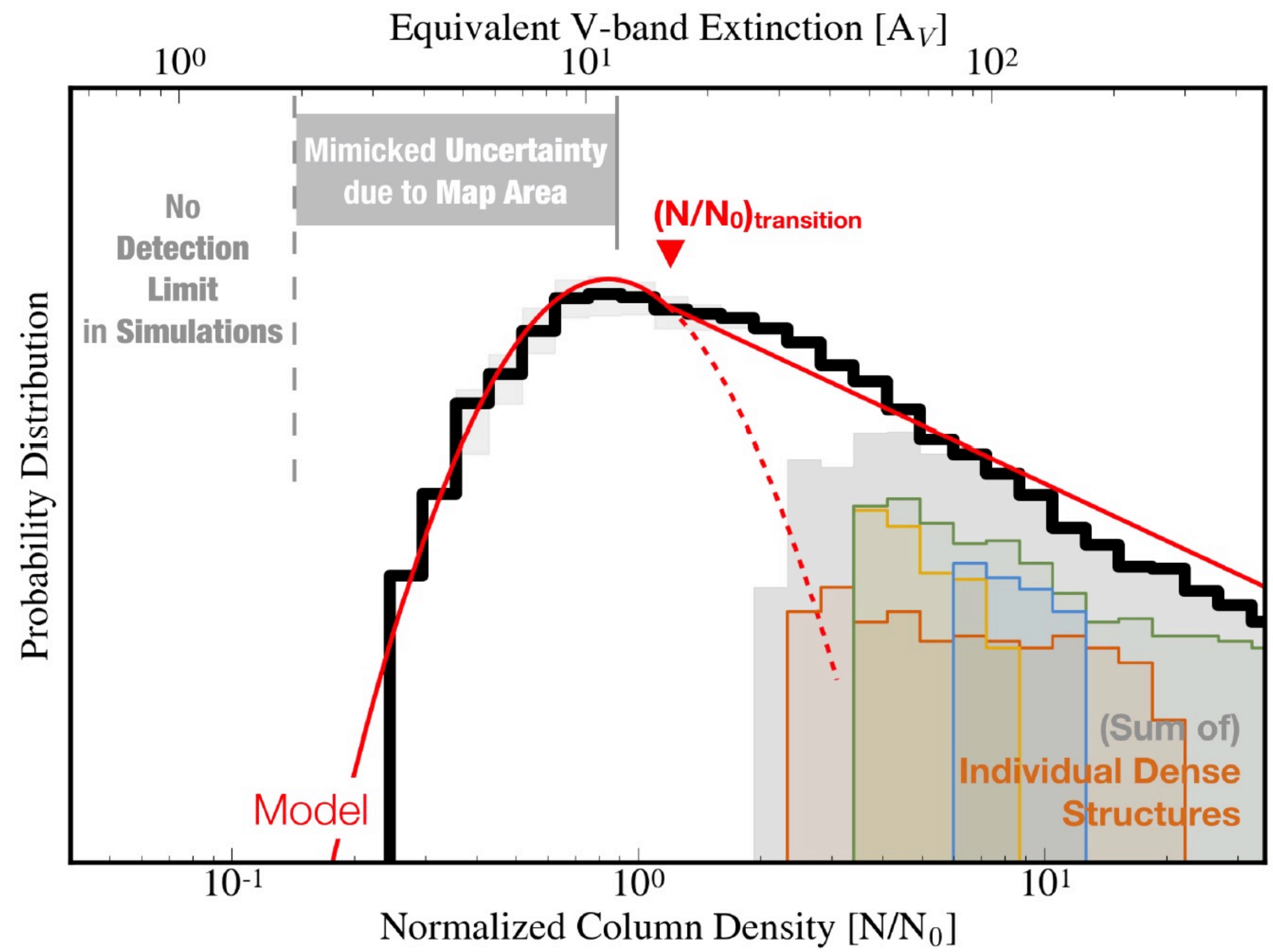
Simulation
(Collins et al. 2012)

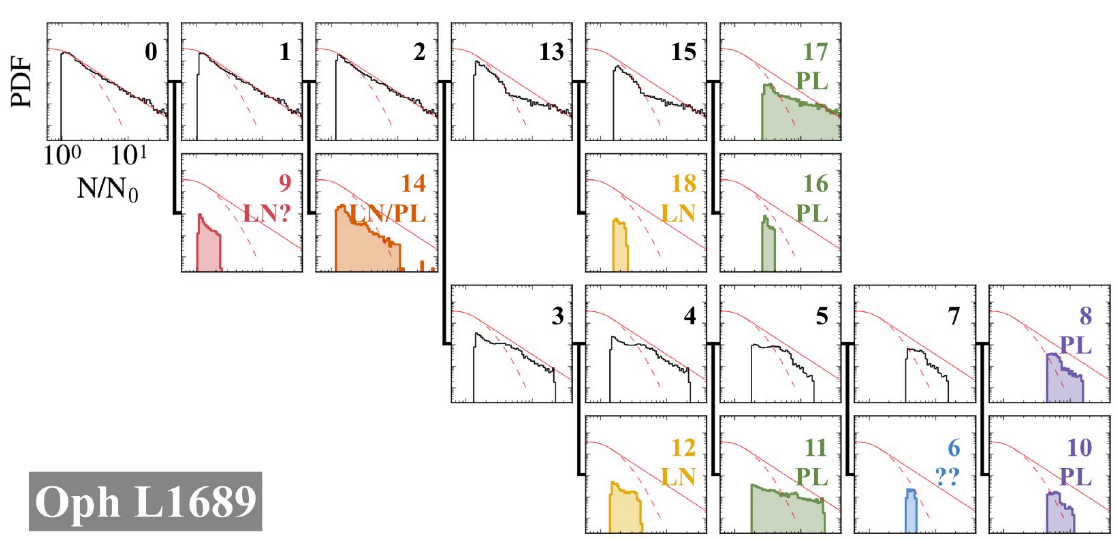


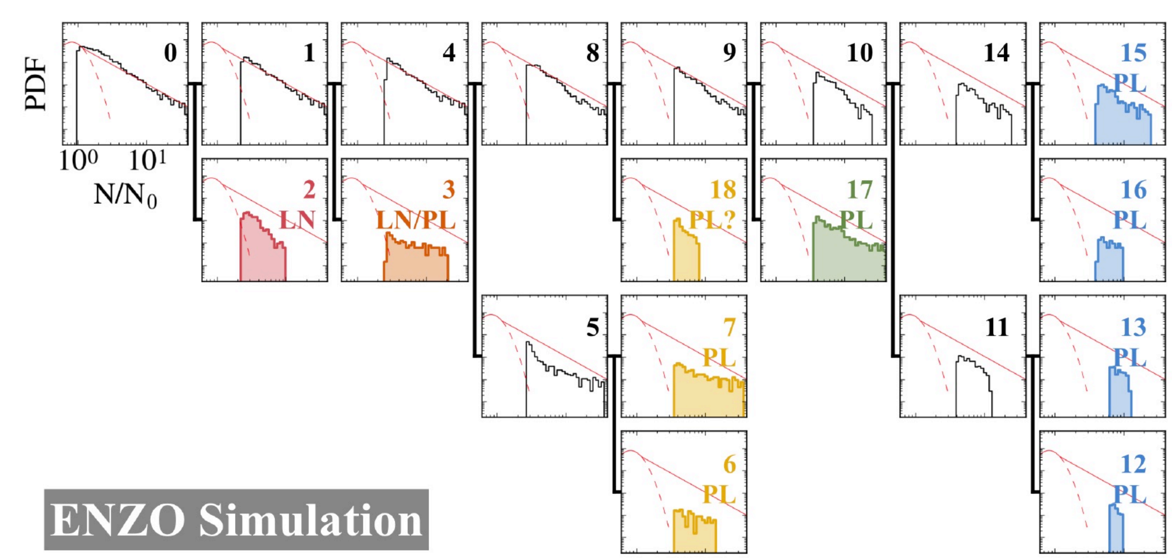
slide sequence courtesy of Hope Chen, from his PhD defense talk

Are the dense structures “cores”? Are they gravitationally bound?



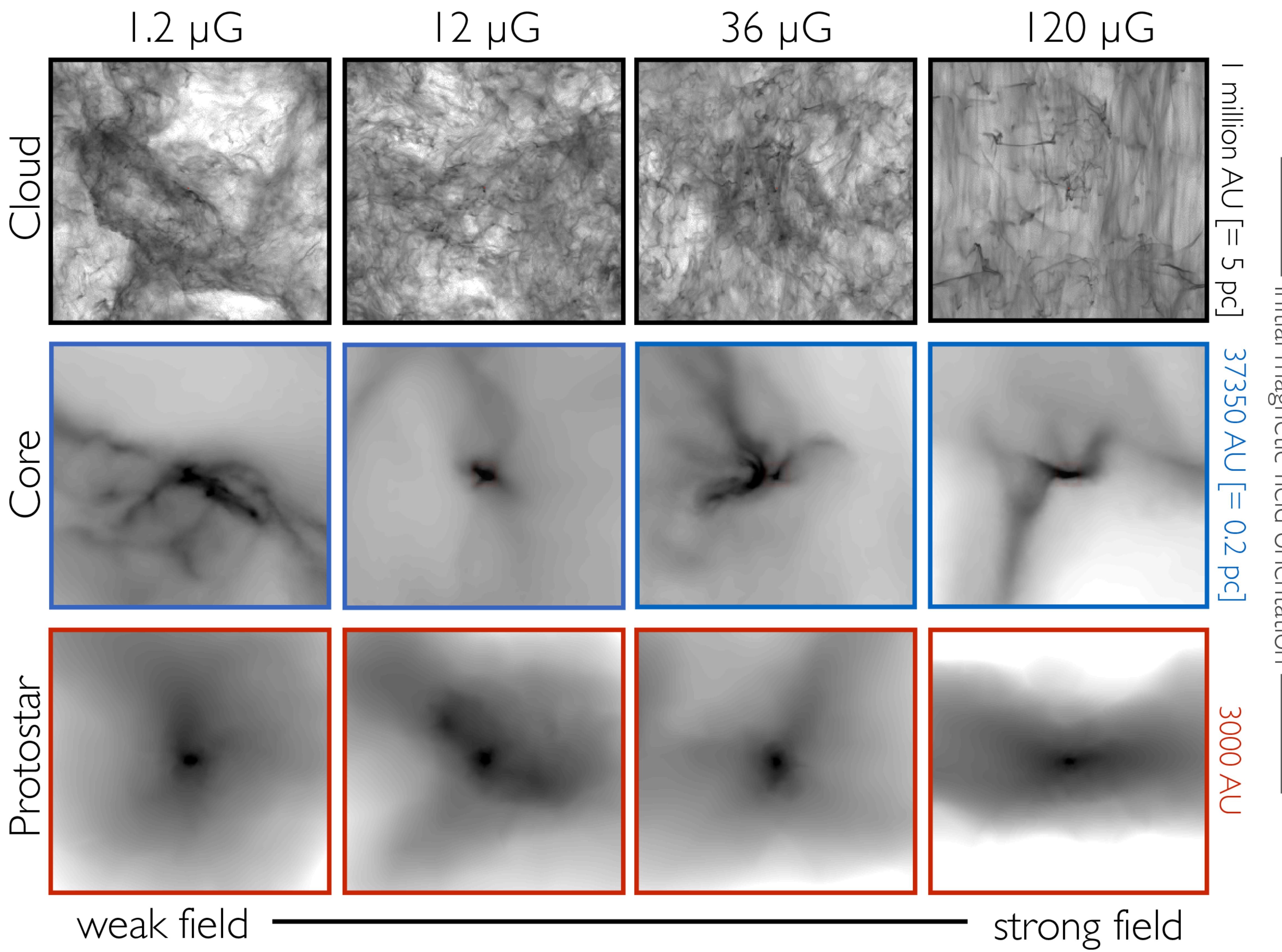






Chen, Burkhart, Goodman & Collins 2017

What, really, is a "dense core?"



Hull, Mocz, Burkhart, Goodman, Girart, Cortes, Hernquist, Springel, Li & Lai 2017.

The Story We See

(A Six-Pack Sampler of Surprises)

"Bones"
(Spitzer+++)

B5
(Haystack, GBT,VLA, Herschel)

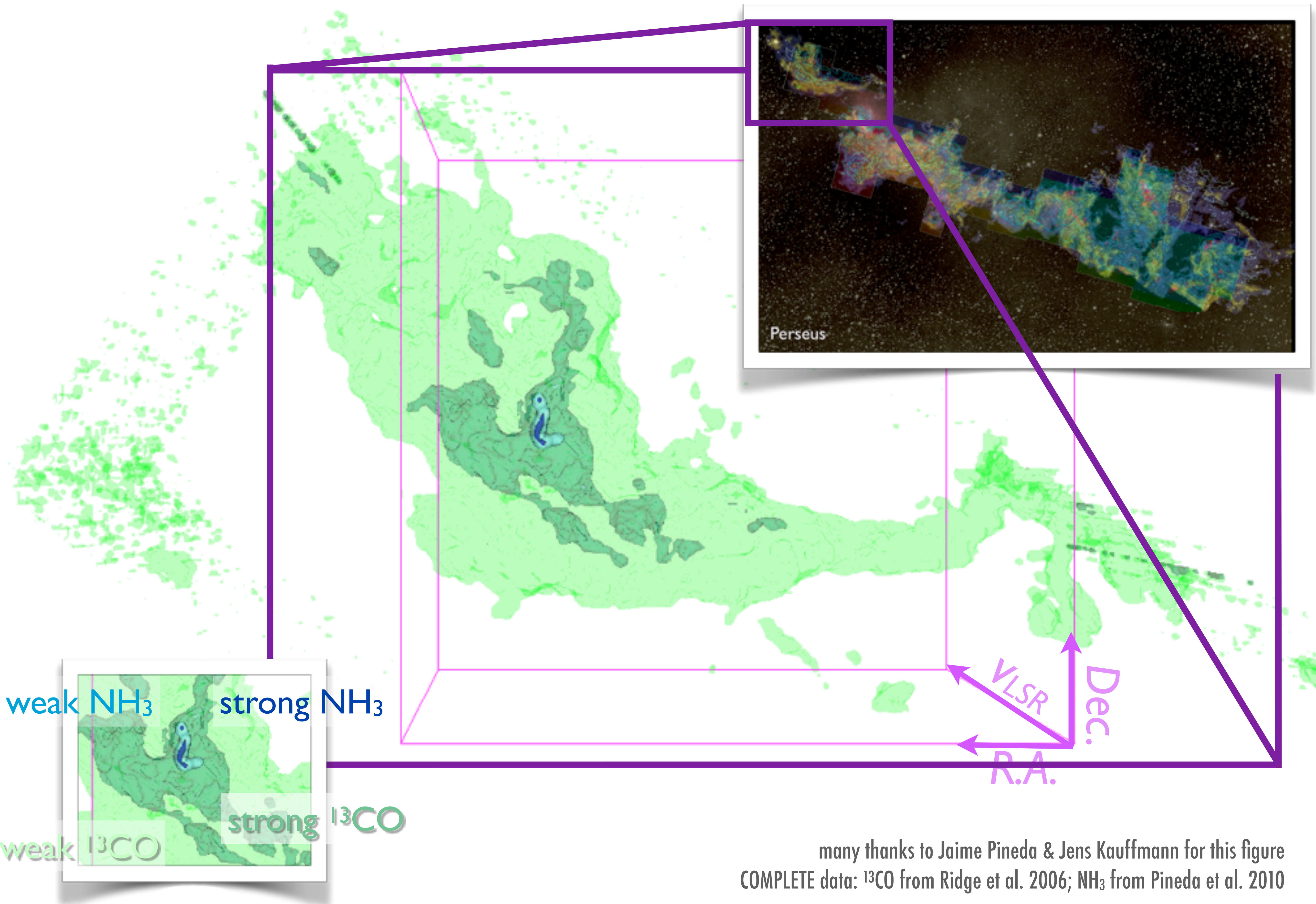
PDF Anatomy
(Herschel)

Perseus in 3-D
(PanSTARRS + Gaia+FCRAO)

B-field map
(ALMA & AREPO)

Droplets
(GBT)

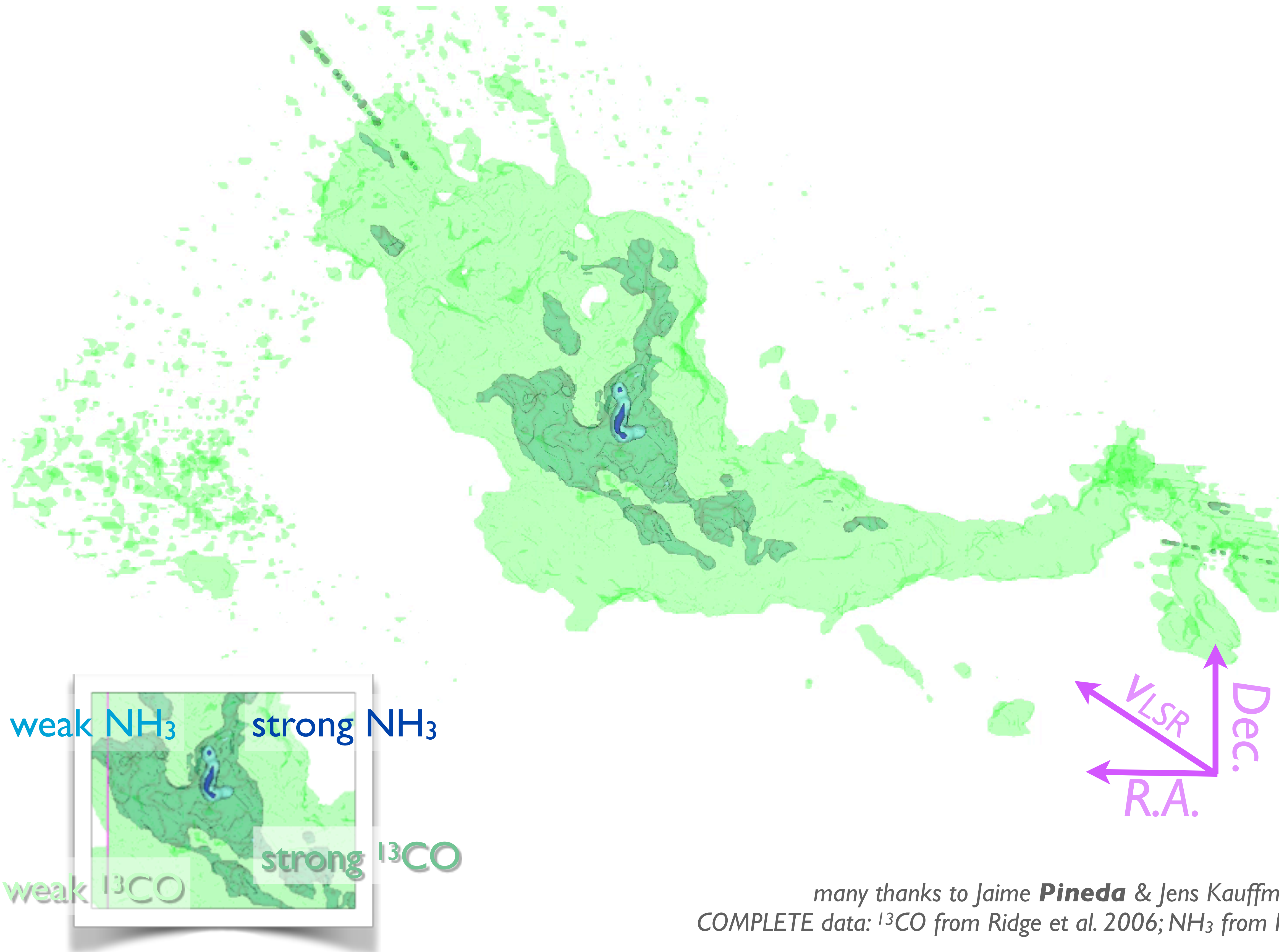
POSITION-VELOCITY STRUCTURE OF THE B5 REGION IN PERSEUS



many thanks to Jaime Pineda & Jens Kauffmann for this figure

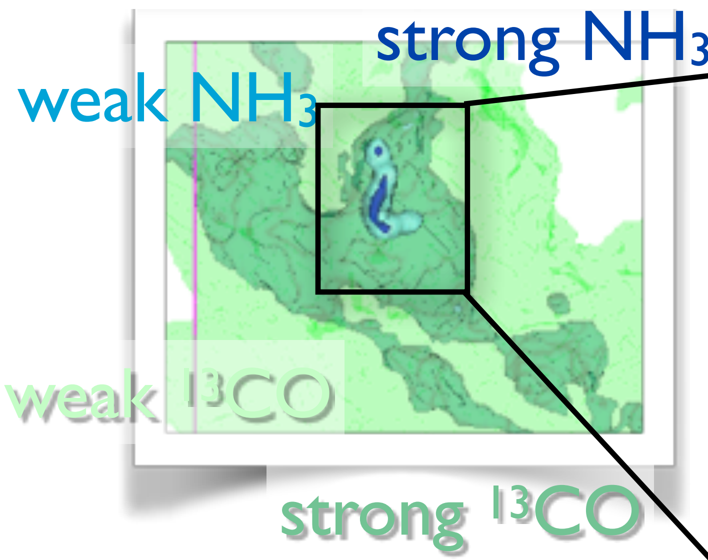
COMPLETE data: ^{13}CO from Ridge et al. 2006; NH_3 from Pineda et al. 2010

POSITION-VELOCITY STRUCTURE OF THE B5 REGION IN PERSEUS

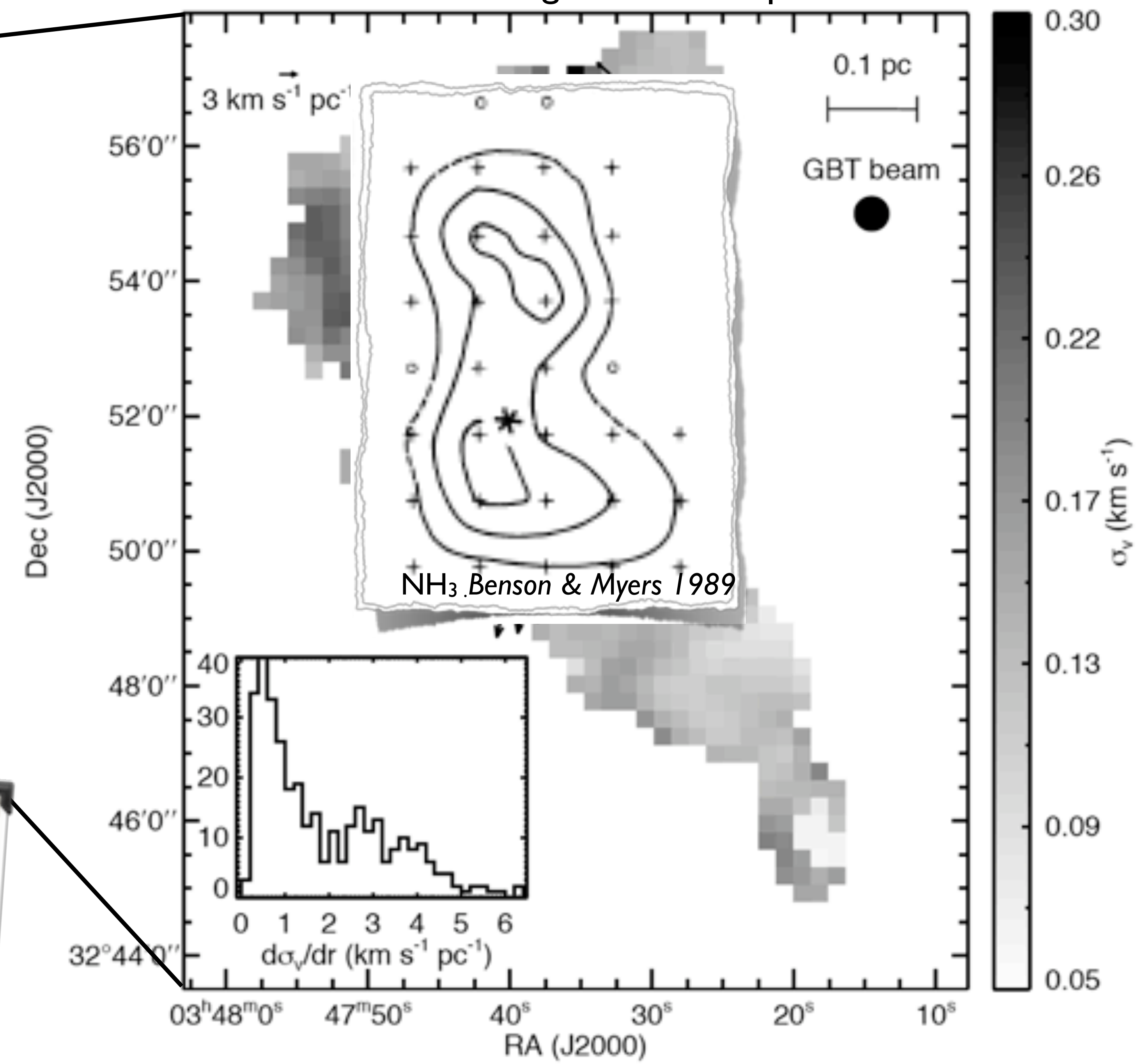


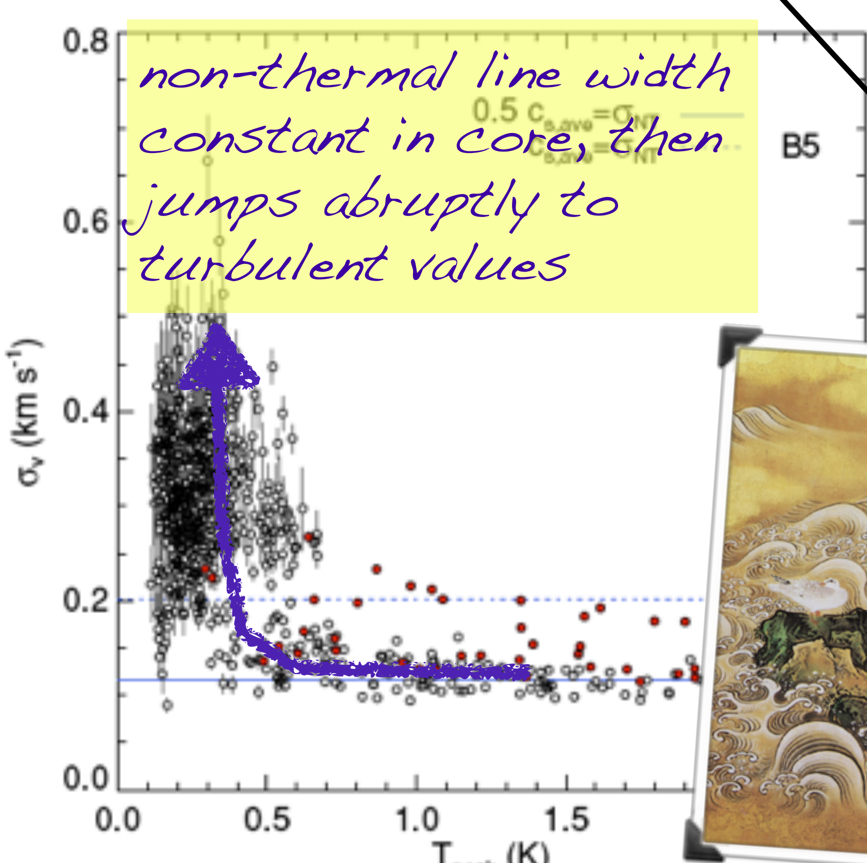
*many thanks to Jaime **Pineda** & Jens Kauffmann for this figure*
COMPLETE data: ^{13}CO from Ridge et al. 2006; NH_3 from Pineda et al. 2010

STRONG EVIDENCE FOR "VELOCITY COHERENCE" IN DENSE CORES



greyscale shows NH_3 velocity dispersion,
arrows show gradient in dispersion

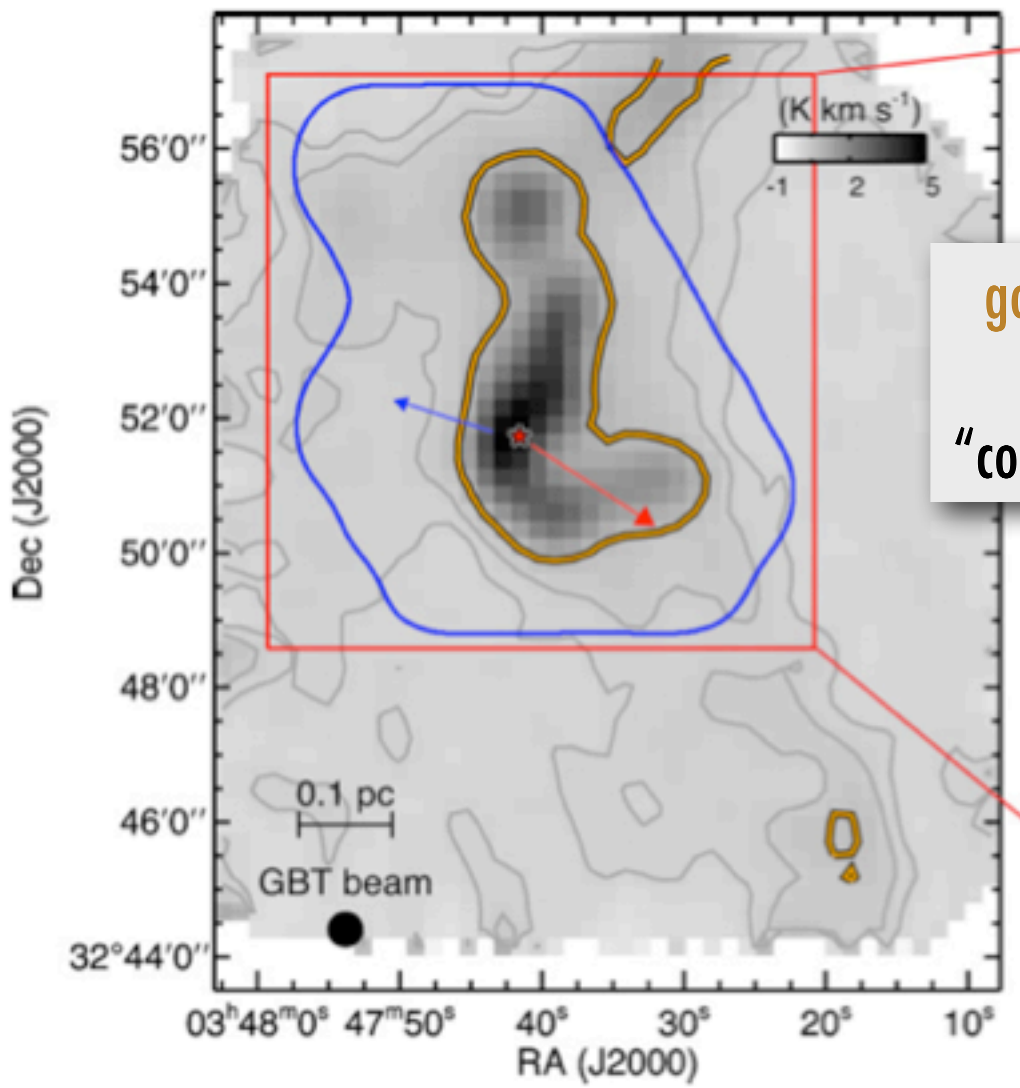




GBT NH_3 observations of the B5 core (Pineda et al. 2010)

BUT THEN... WE FOUND SUB-STRUCTURE

THE ASTROPHYSICAL JOURNAL LETTERS, 739:L2 (5pp), 2011 September 20 PINEDA ET AL.



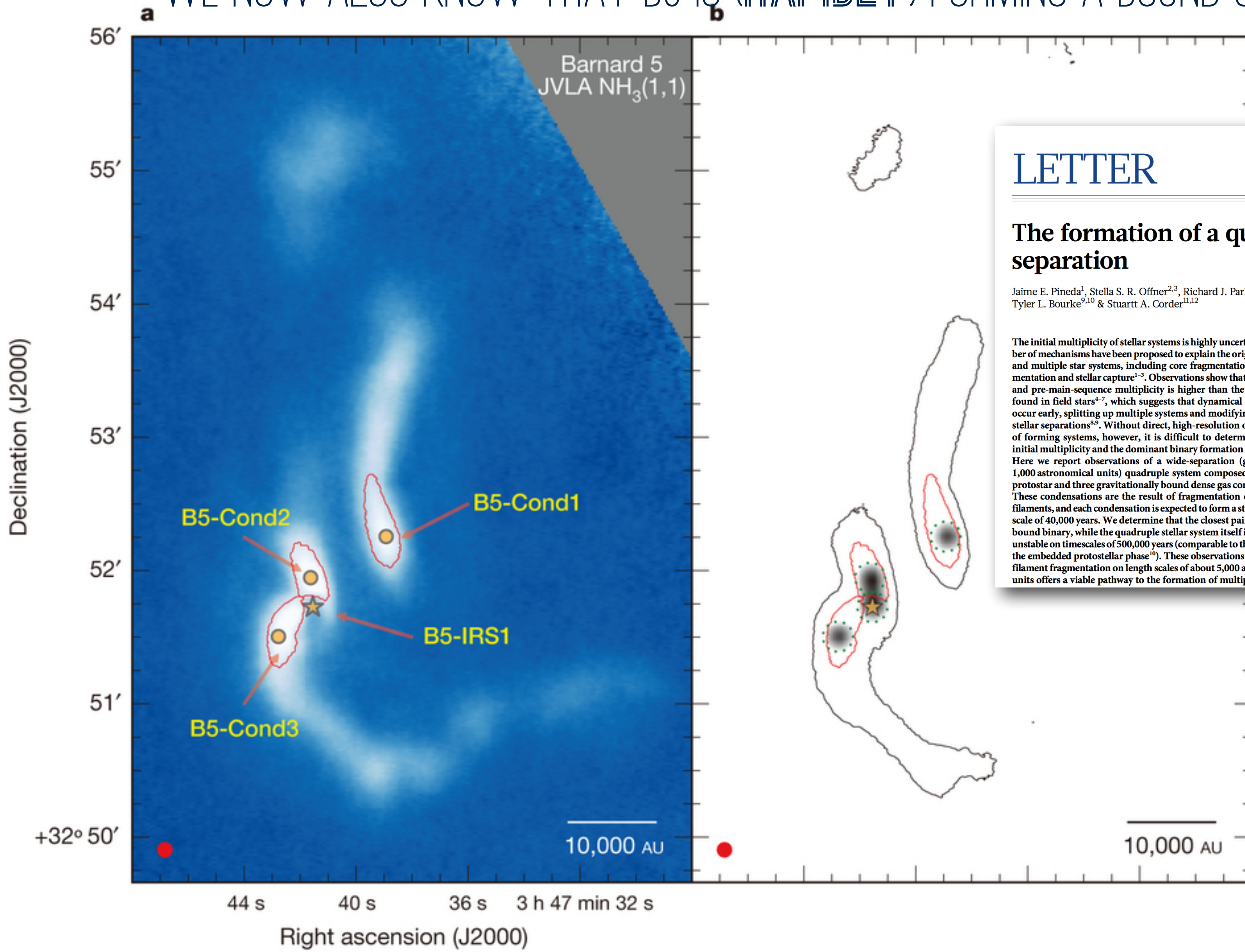
gold contour shows "coherent" core

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.

Pineda et al. 2011

AND SUB-SUB STRUCTURE

WE NOW ALSO KNOW THAT B5 IS (**RAPIDLY**) FORMING A BOUND CLUSTER



LETTER

doi:10.1038/nature14166

The formation of a quadruple star system with wide separation

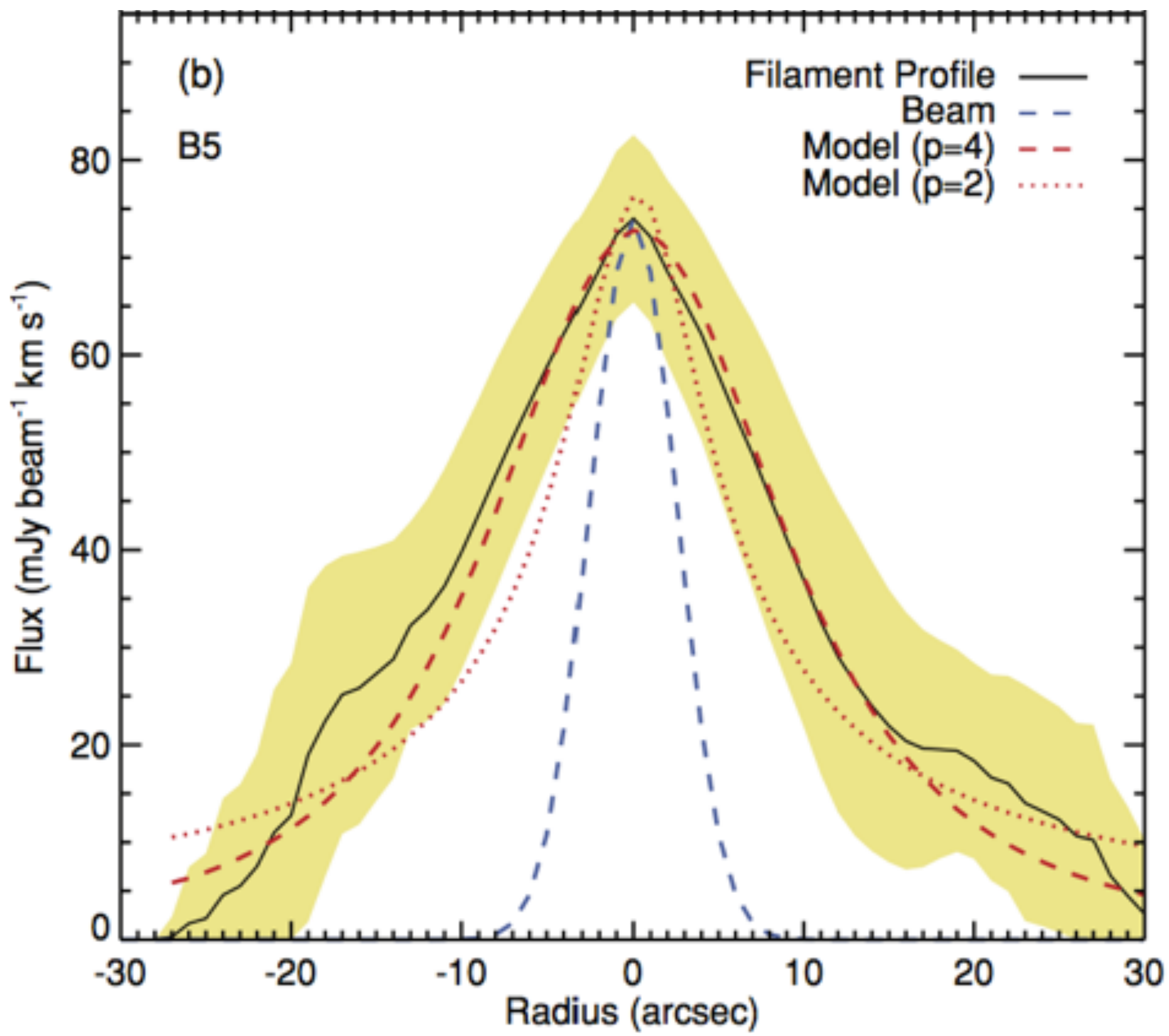
Jaime E. Pineda[1], Stella S. R. Offner[2,3], Richard J. Parker[4], Héctor G. Arce[5], Alyssa A. Goodman[6], Paola Caselli[7], Gary A. Fuller[8], Tyler L. Bourke[9,10] & Stuartt A. Corder[11,12]

The initial multiplicity of stellar systems is highly uncertain. A number of mechanisms have been proposed to explain the origin of binary and multiple star systems, including core fragmentation, disk fragmentation and stellar capture[1–3]. Observations show that protostellar and pre-main-sequence multiplicity is higher than the multiplicity found in field stars[4–7], which suggests that dynamical interactions occur early, splitting up multiple systems and modifying the initial stellar separations[8,9]. Without direct, high-resolution observations of forming systems, however, it is difficult to determine the true initial multiplicity and the dominant binary formation mechanism. Here we report observations of a wide-separation (greater than 1,000 astronomical units) quadruple system composed of a young protostar and three gravitationally bound dense gas condensations. These condensations are the result of fragmentation of dense gas filaments, and each condensation is expected to form a star on a timescale of 40,000 years. We determine that the closest pair will form a bound binary, while the quadruple stellar system itself is bound but unstable on timescales of 500,000 years (comparable to the lifetime of the embedded protostellar phase[10]). These observations suggest that filament fragmentation on length scales of about 5,000 astronomical units offers a viable pathway to the formation of multiple systems.

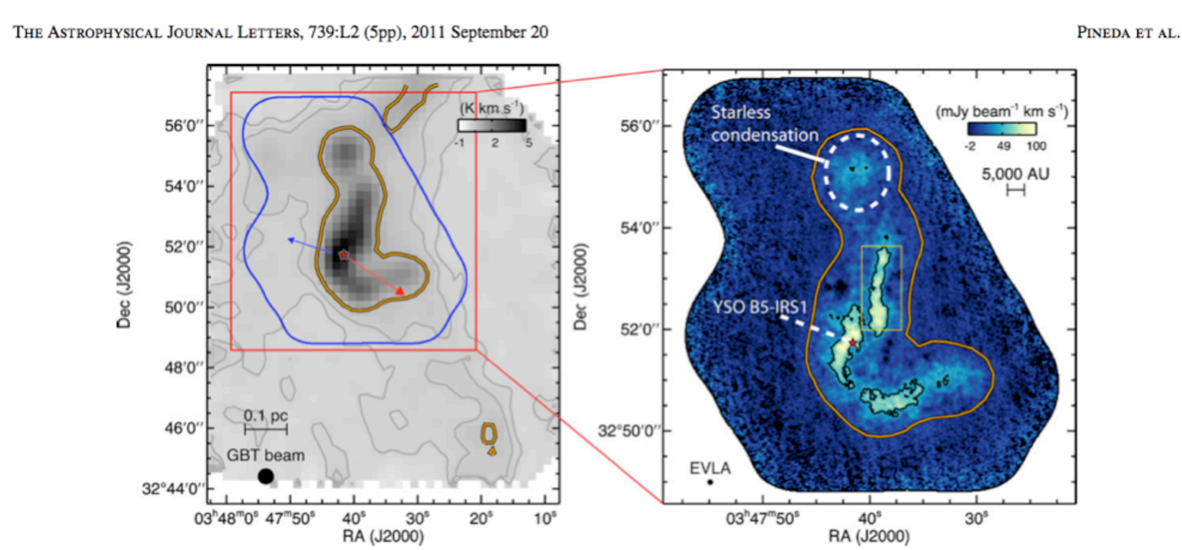
Detailed knowledge of the underlying distribution of dense gas is the key to determining which structures will go on to form stars. Here we identify the dense gas structures that are most likely to form stars using the dendrogram technique[21]. Dendrogram analysis is a hierarchical structure decomposition that uses isocontours to identify individual features, while also determining where these contours merge with adjacent structures to create a new parental structure. We refer to the smallest scale (and brightest) structures in the dendrogram as condensations. These are the most likely places for an individual star to form. Figure 1a shows the B5 region as seen in dense gas (number density of H_2, $n_{H_2} \gtrsim 10^4$ cm^{-3}), with the protostar and the identified gas condensations shown by a star and circles, respectively. The mass of the well known protostar B5-IRS1 is 0.1 solar masses (M_{Sun}; ref. 22), while the masses of condensations B5-Cond1, B5-Cond2 and B5-Cond3 are 0.36 ± 0.09 M_{Sun}, 0.26 ± 0.12 M_{Sun} and 0.30 ± 0.13 M_{Sun}, respectively. Uncertainty in these masses is dominated by the uncertainty in the temperature used to convert measured fluxes to masses. The radii of the three condensations are respectively 2,800 AU, 2,300 AU and 2,500 AU, while the projected separations between the same three condensations and the protostar are 3,300 AU, 5,100 AU and 11,400 AU (see Methods). The half-mass radii of the condensations are about half the condensation radii. This, combined with

Pineda, Offner, Parker, Arce, Goodman, Caselli, Fuller, Bourke & Corder 2015

BUT MAYBE IT'S DIFFERENT?



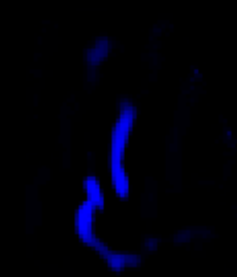
isothermal, hydrostatic filaments, not turbulent ones?



Pineda et al. 2011

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)

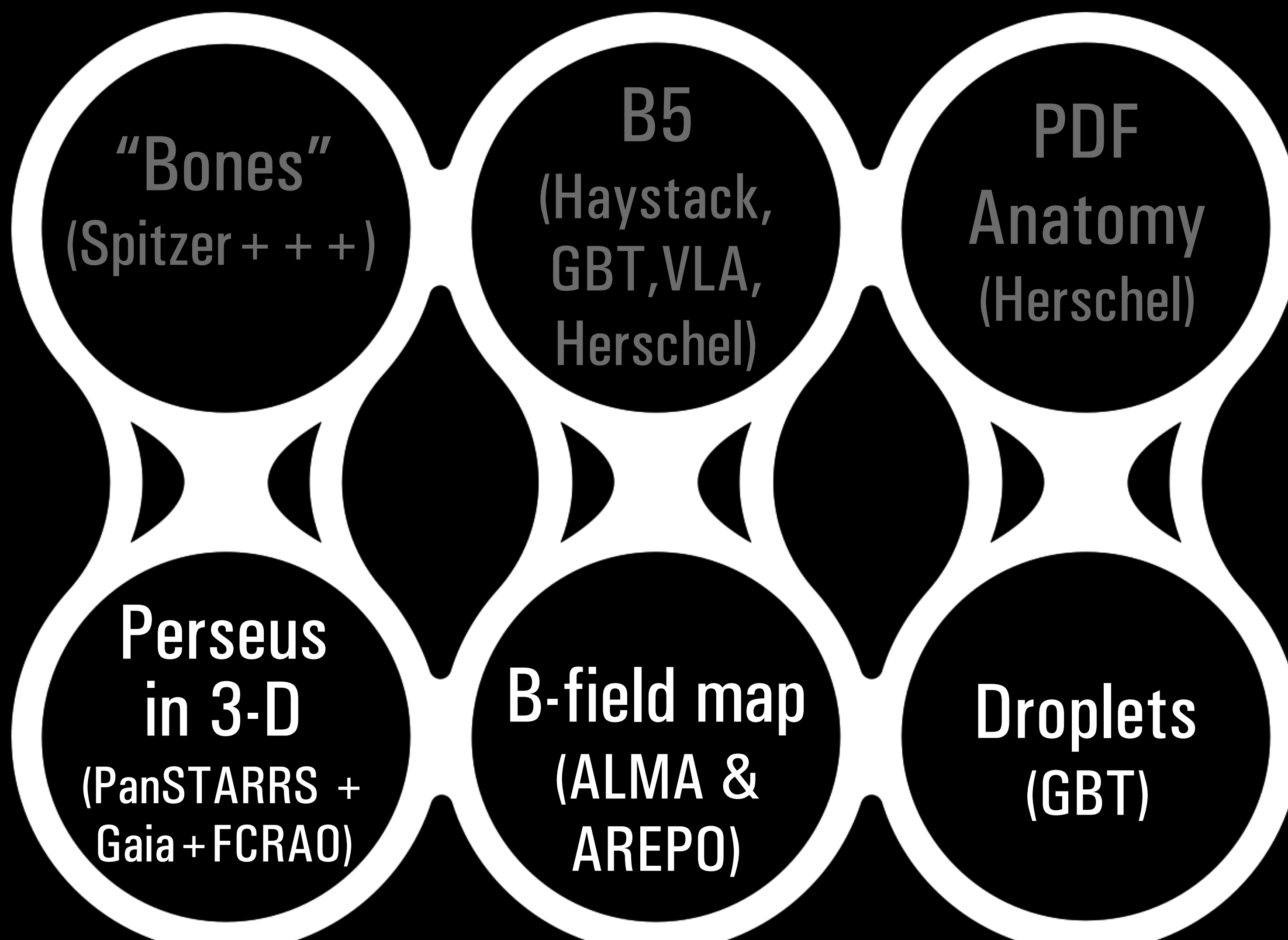


Goodman, Chen, Offner & Pineda 2018 in prep.

Herschel data from Gould Belt Survey

The Story We See

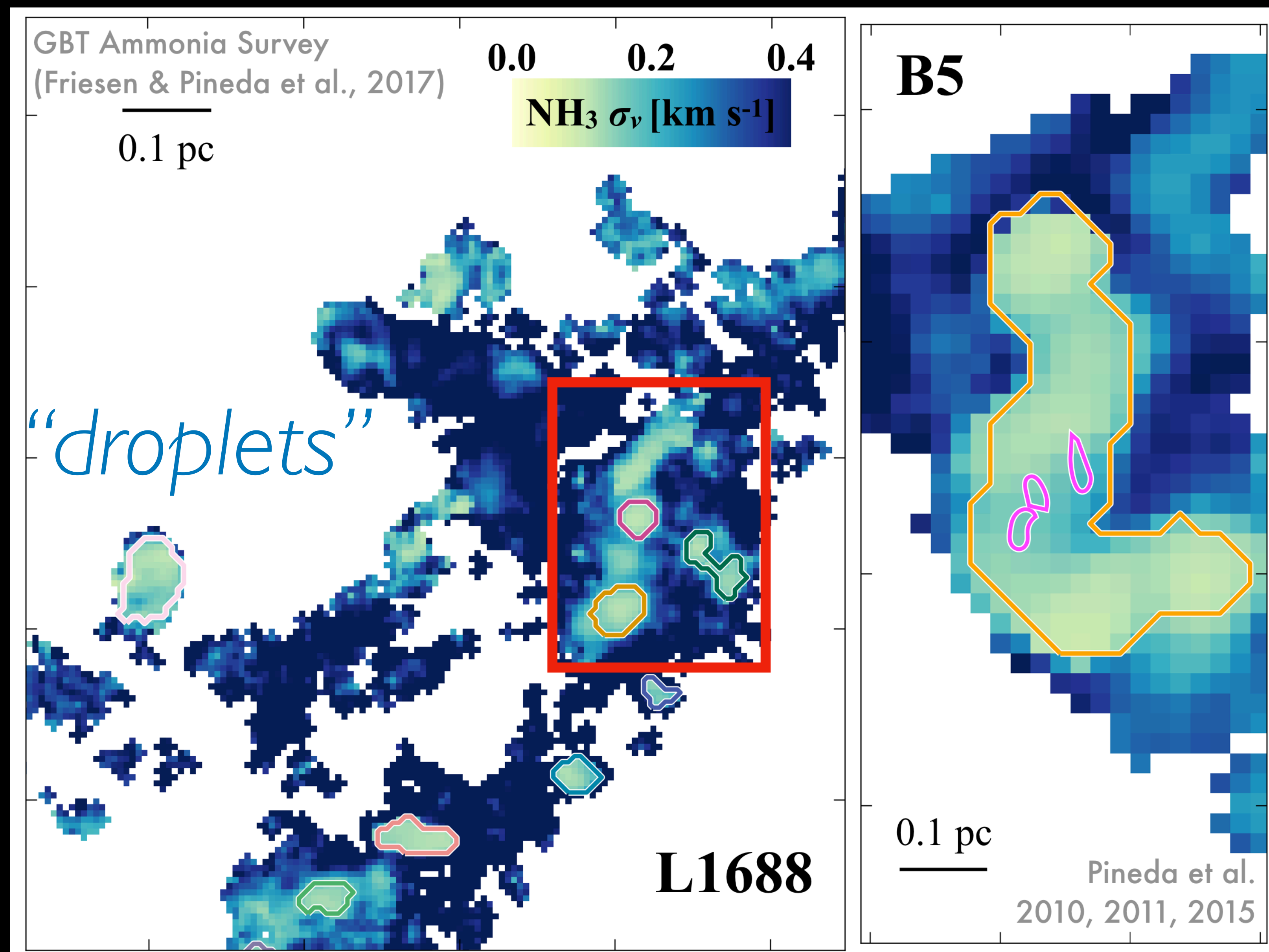
(A Six-Pack Sampler of Surprises)



Friesen et al. (2017; GAS)
Chen et al. 2018

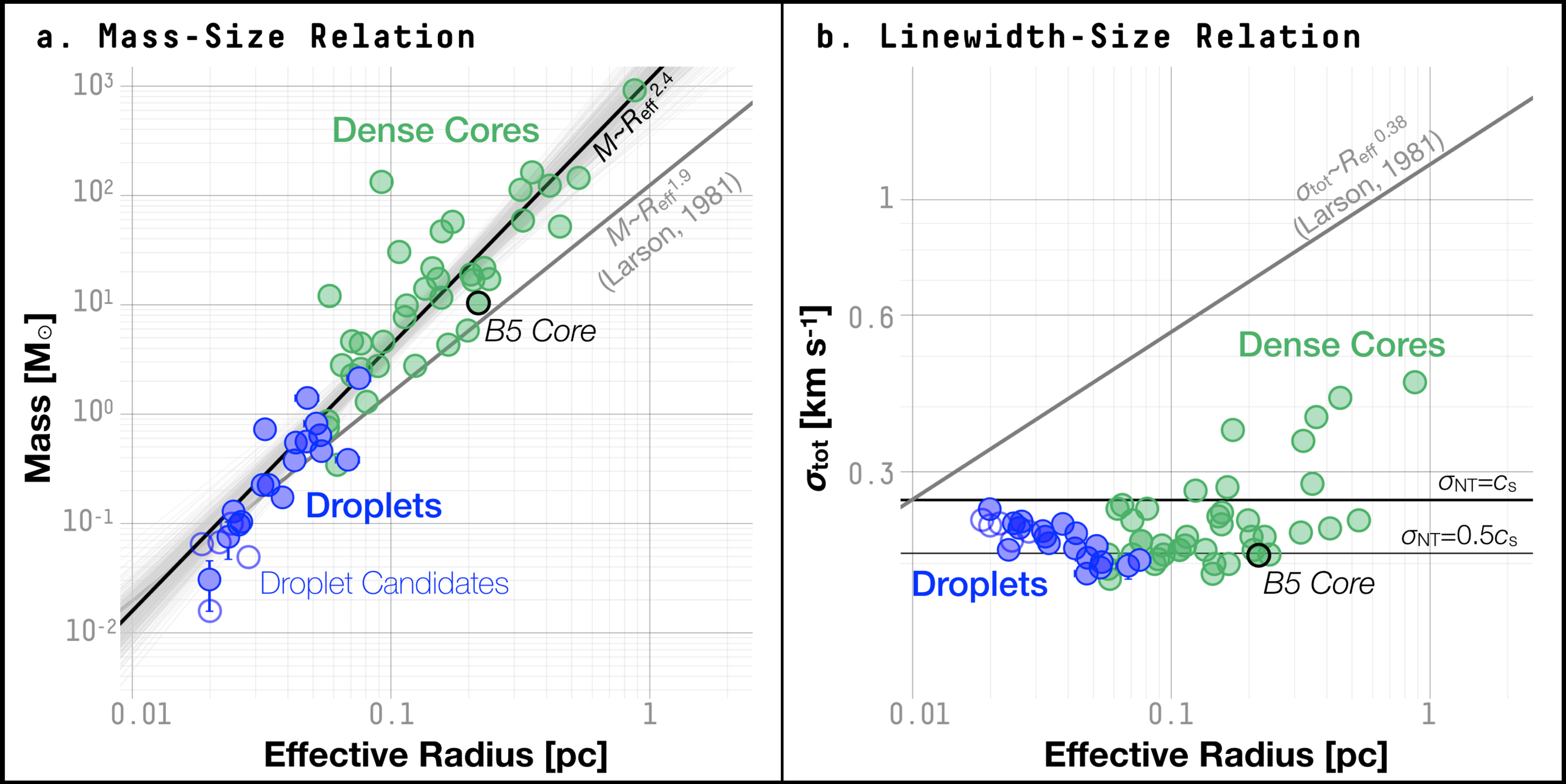
Droplets
(GBT)

Coherent Core



slide sequence courtesy of Hope Chen, from his PhD defense talk

Ophiuchus & Taurus



Dense Cores: Fuller & Myers (1992)/Goodman et al. (1993)

B5 Core: Pineda et al. (2010)

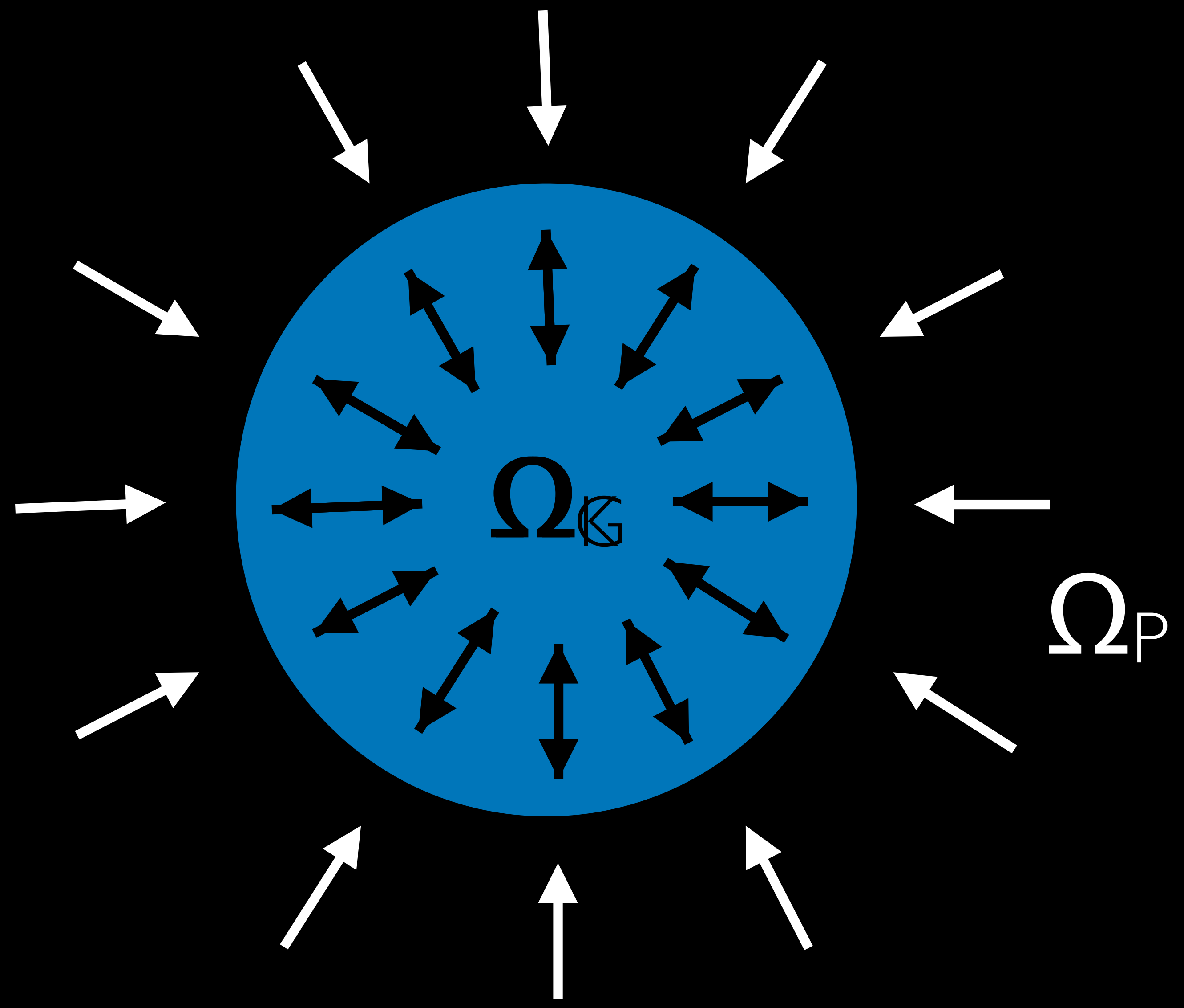
slide sequence courtesy of Hope Chen, from his PhD defense talk

At what scales does gravity truly play the key role in the story of star formation?

Virial Theorem

$$2\Omega_K = -(\Omega_G + \Omega_P)$$

dispersing confining



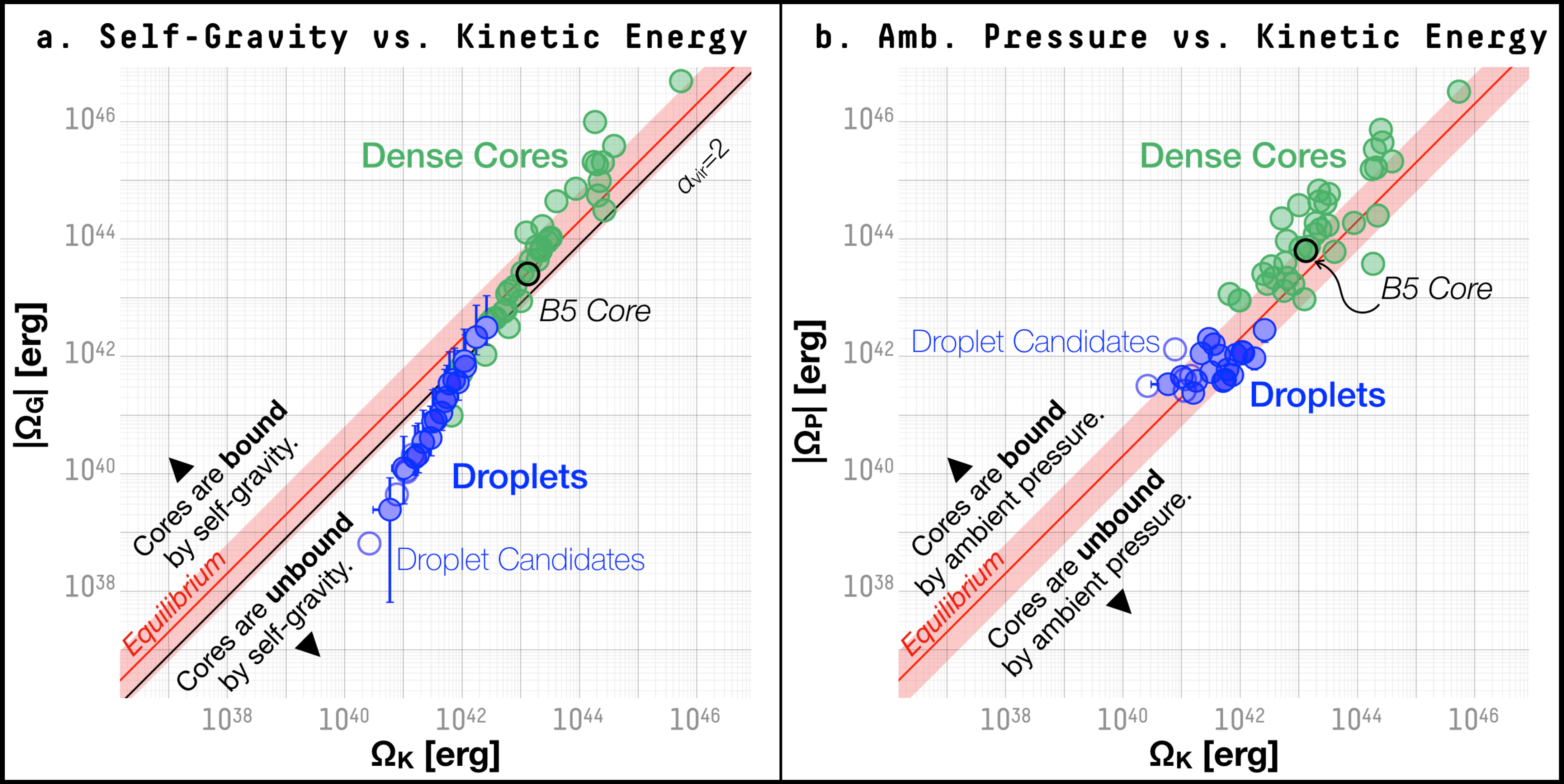
slide sequence courtesy of Hope Chen, from his PhD defense talk

Virial Theorem

$$2\Omega_K = -(\Omega_G + \Omega_P)$$

dispersing — confining

Ophiuchus & Taurus



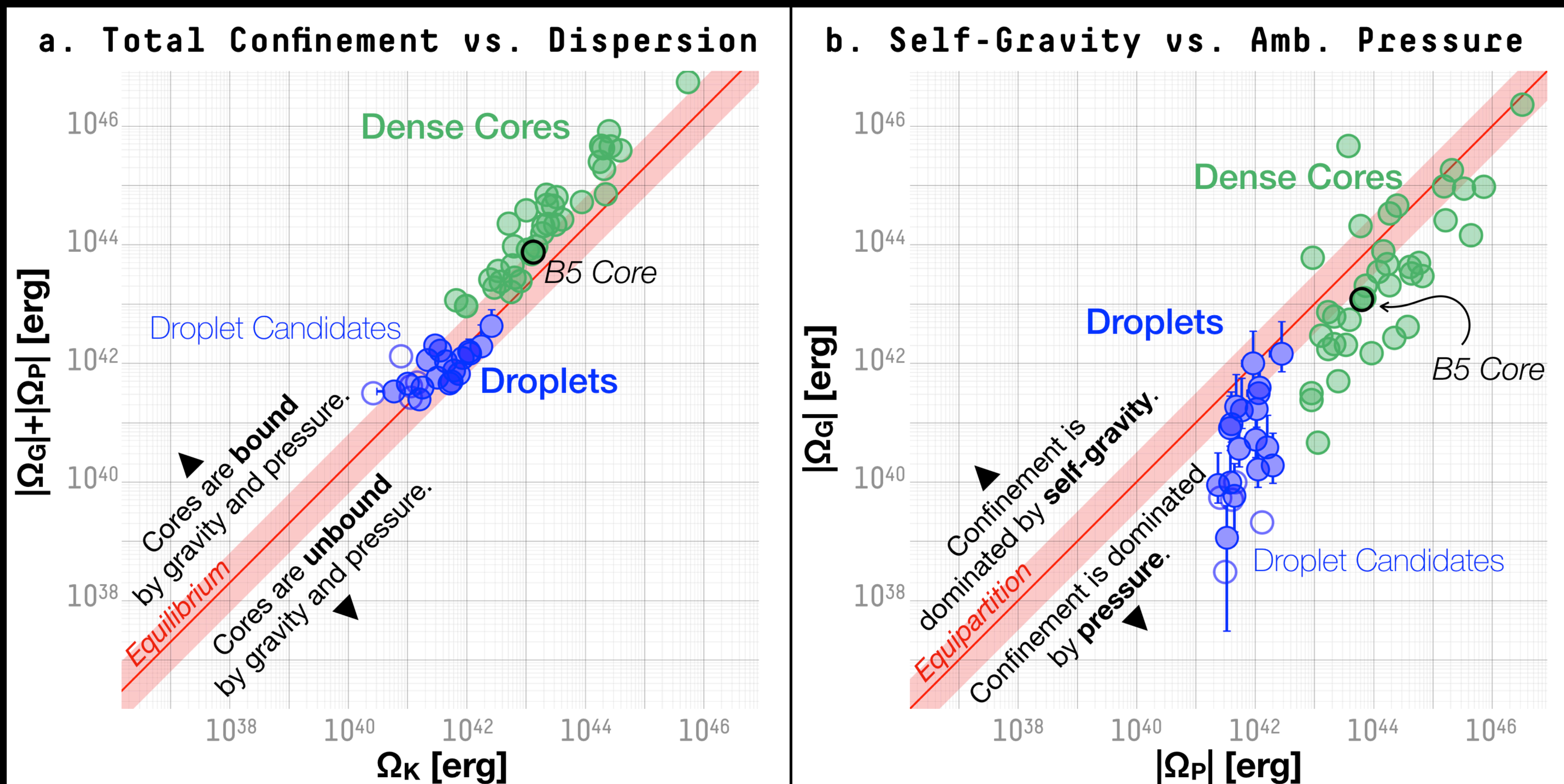
slide sequence courtesy of Hope Chen, from his PhD defense talk

Virial Theorem

$$2\Omega_K = -(\Omega_G + \Omega_P)$$

dispersing confining

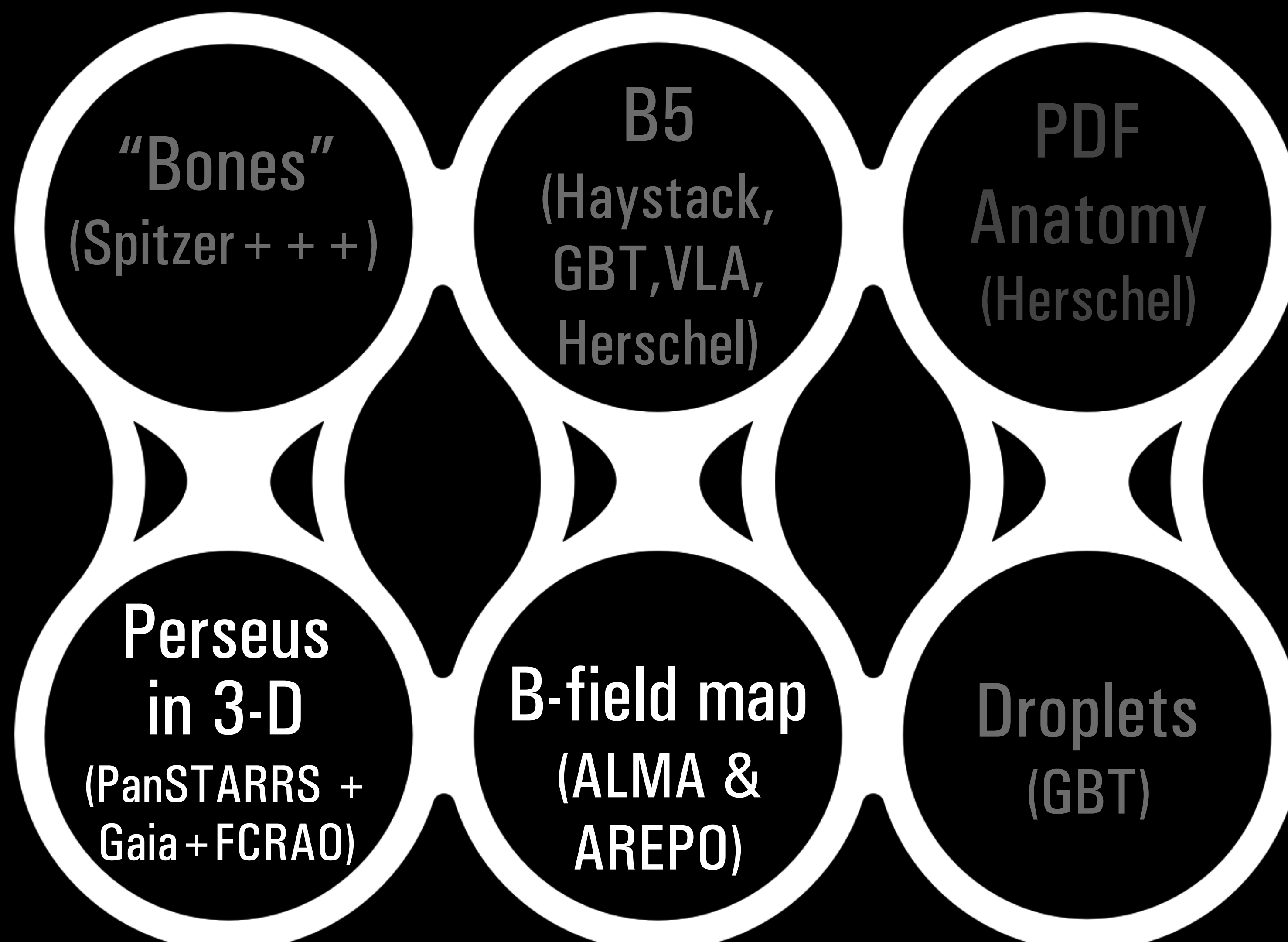
Ophiuchus & Taurus



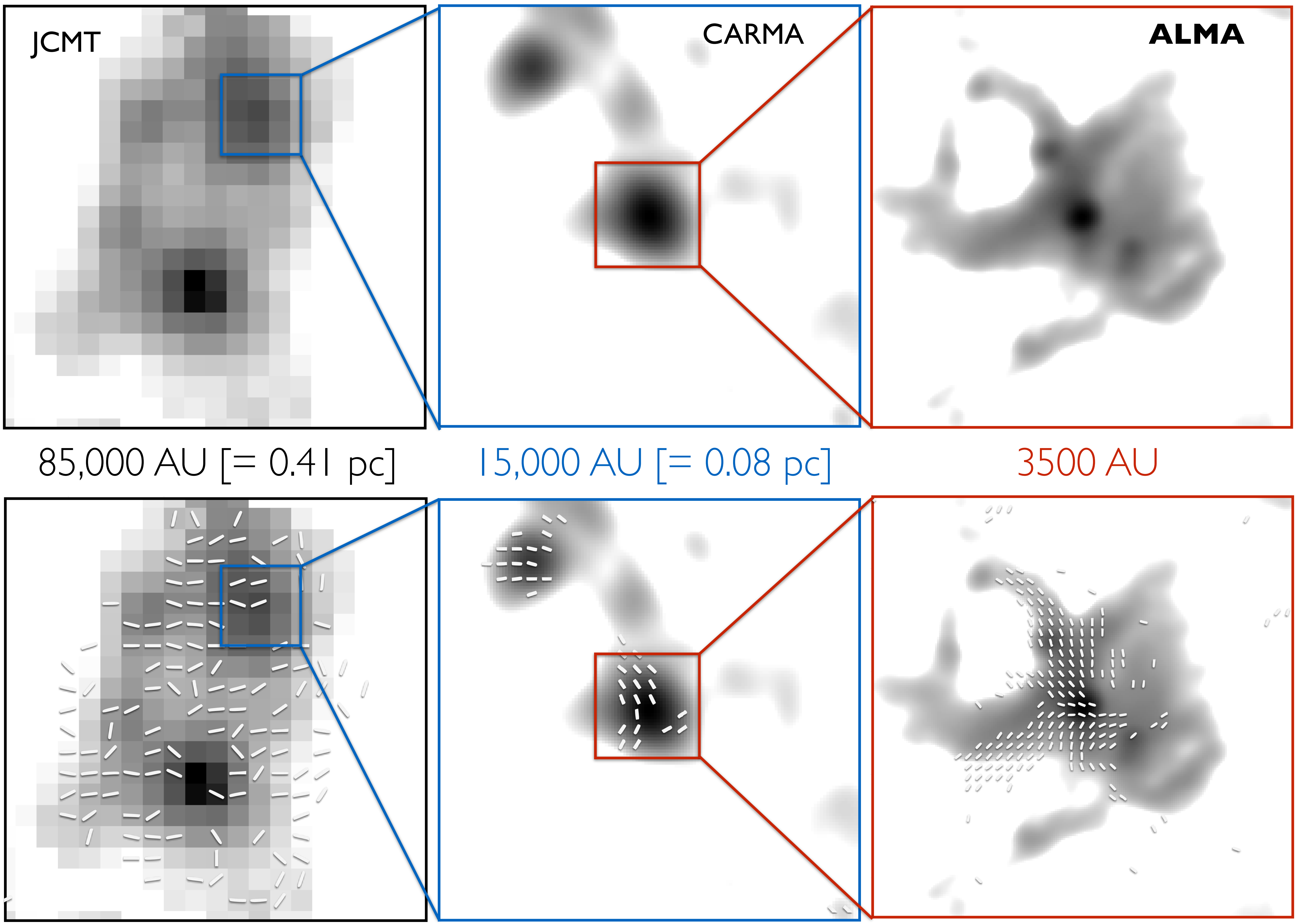
slide sequence courtesy of Hope Chen, from his PhD defense talk

The Story We See

(A Six-Pack Sampler of Surprises)

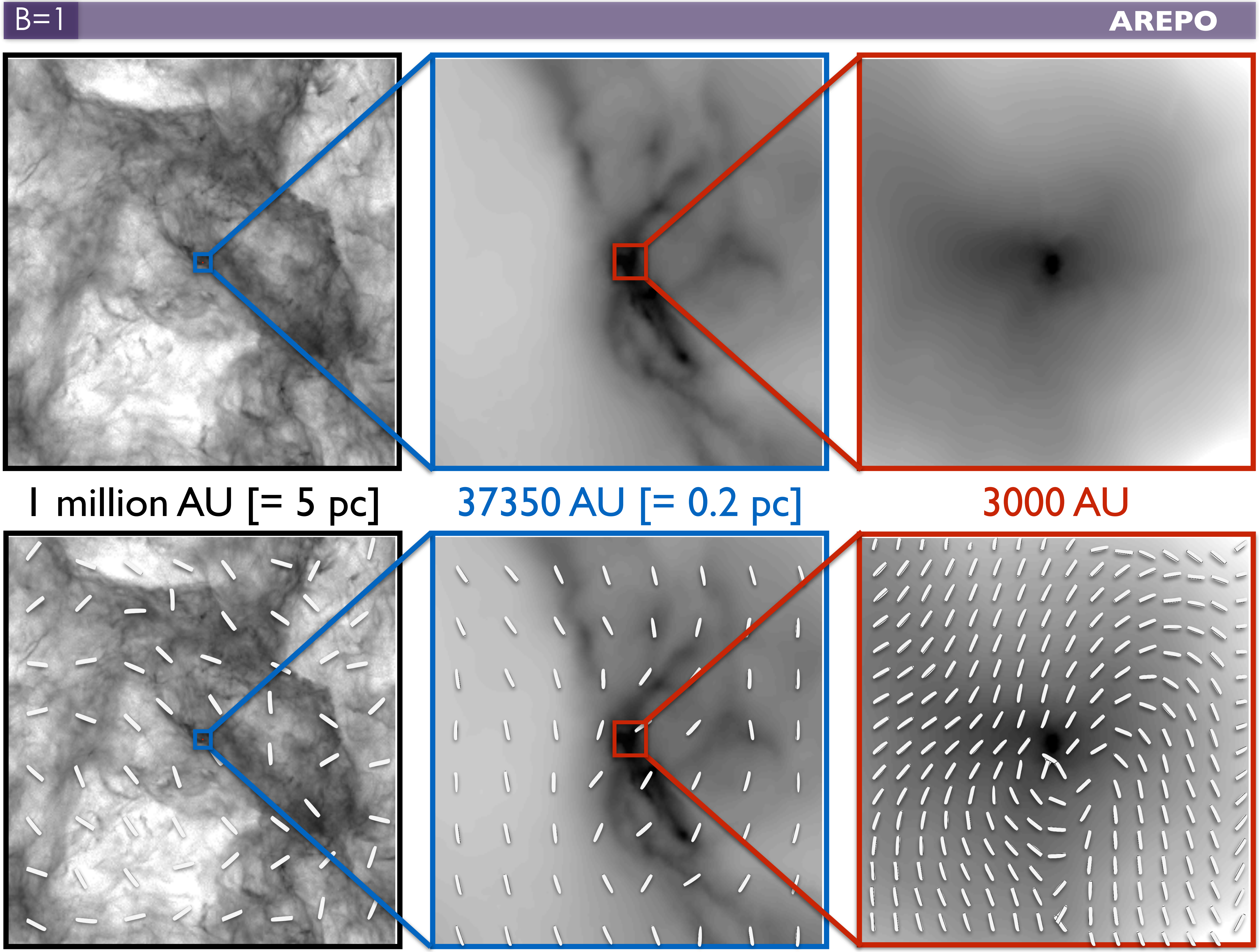



ALMA
B-field map
(ALMA &
AREPO)
Photo credit: C. Hull



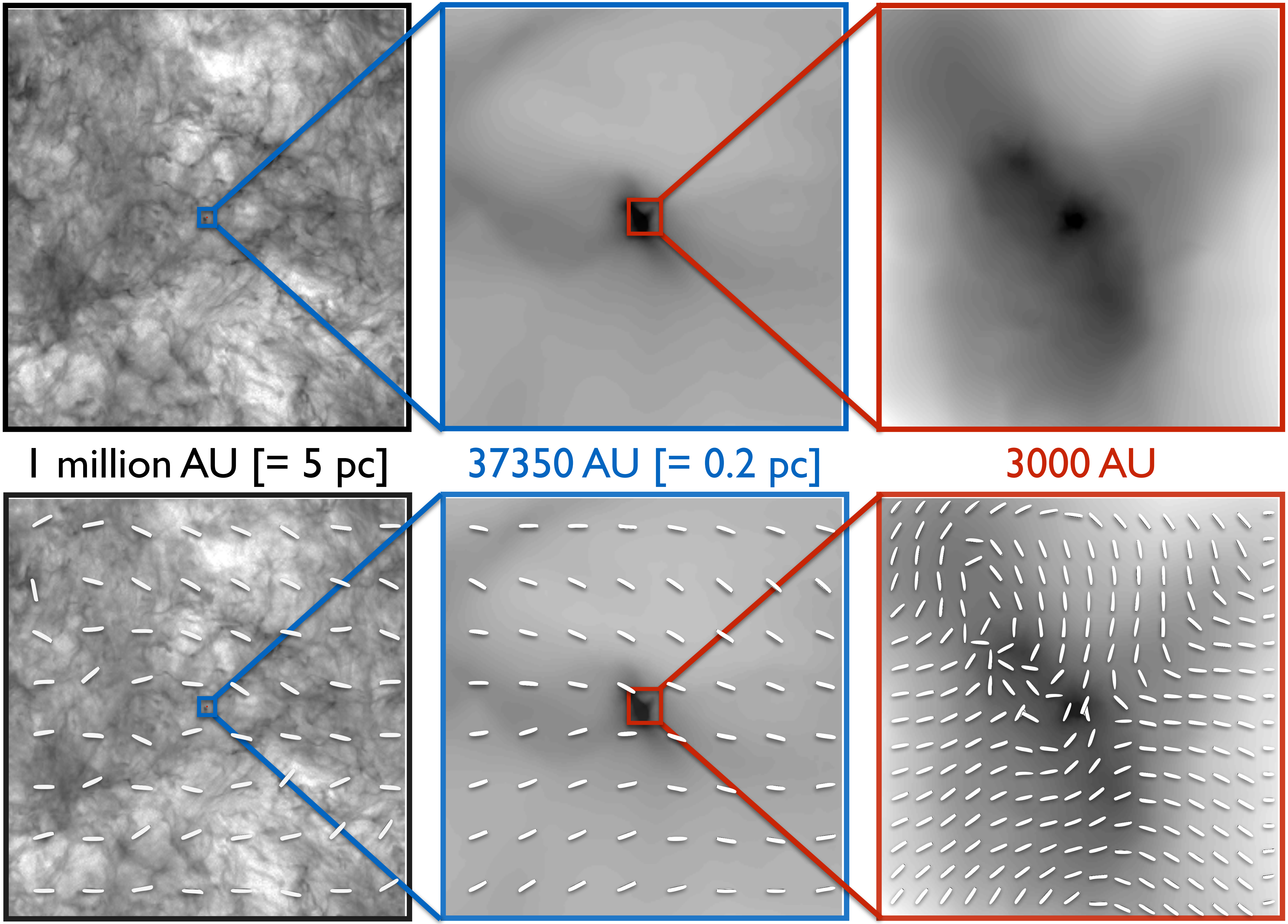
Hull+2017a


"Taste-Testing"



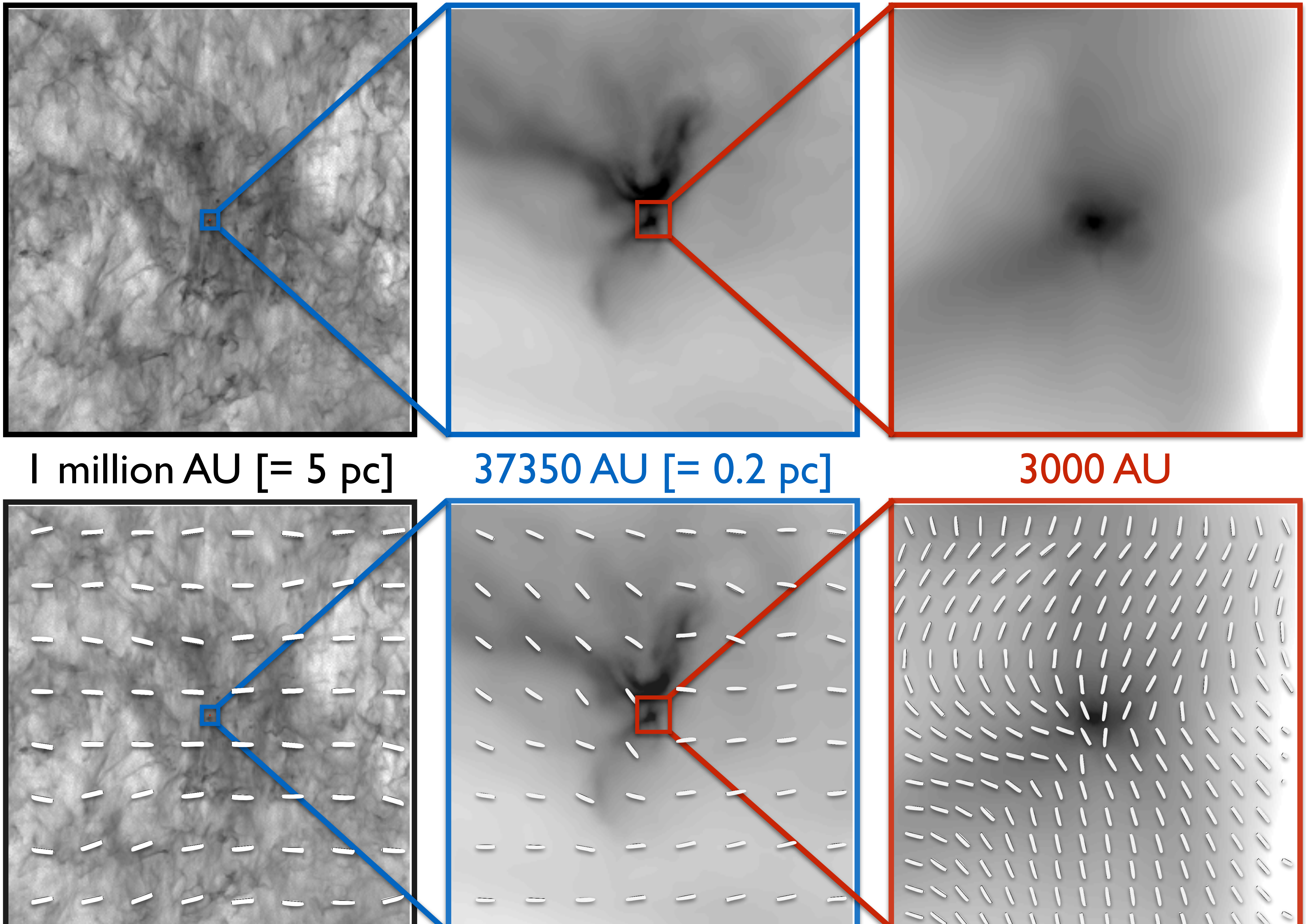
Hull+2017a

B=10



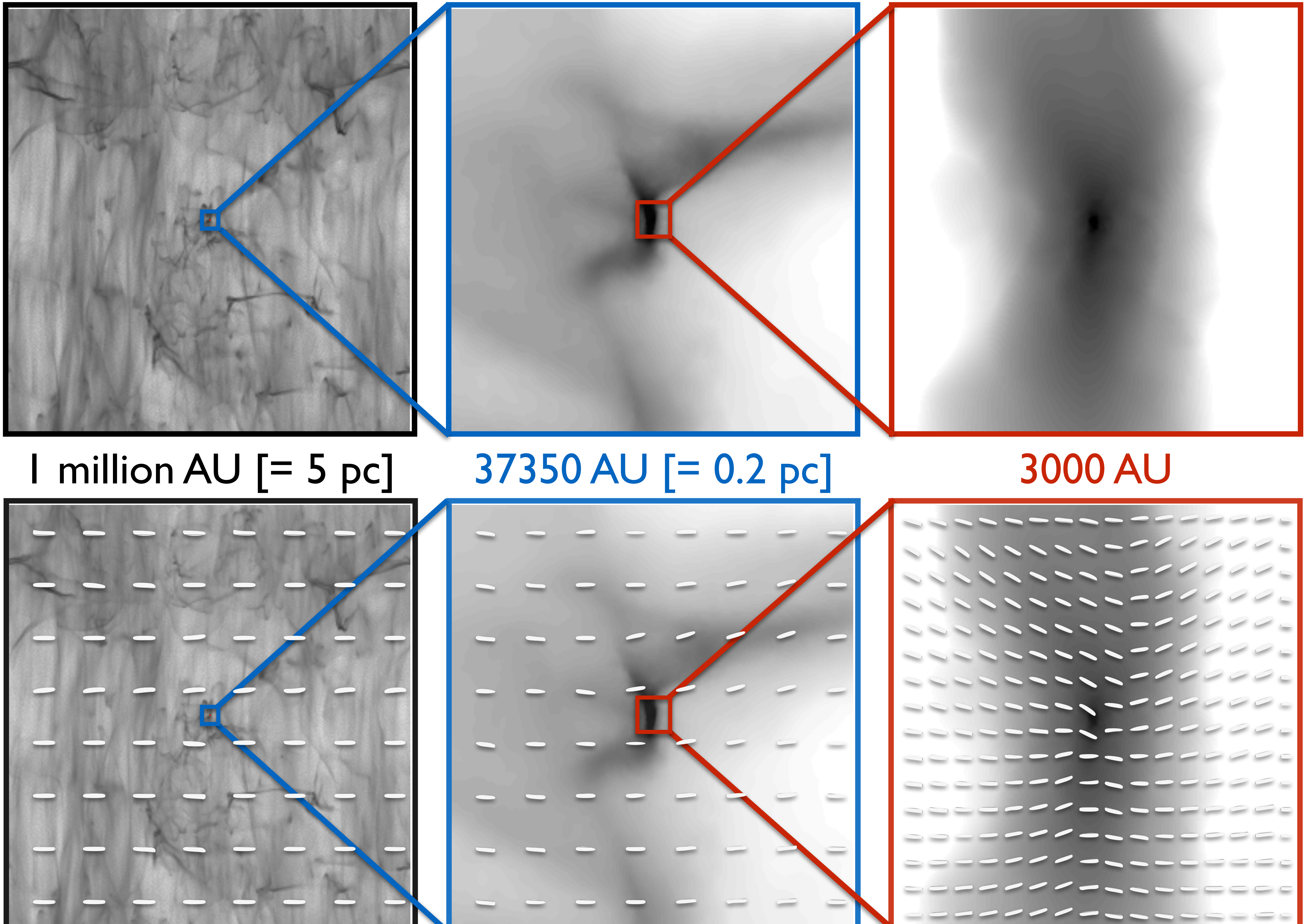
Hull+2017a

B=30



Hull+2017a

B=100



Hull+2017a

The Story We See
(A Six-Pack Sampler of Surprises)

Perseus in 3-D

(PanSTARRS + Gaia+FCRAO)

DRAFT VERSION OCTOBER 18, 2018
Typeset using LATEX **preprint** style in AASTeX61

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MAPPING DISTANCES ACROSS THE PERSEUS MOLECULAR CLOUD USING CO OBSERVATIONS, STELLAR PHOTOMETRY, AND GAIA DR2 PARALLAX MEASUREMENTS

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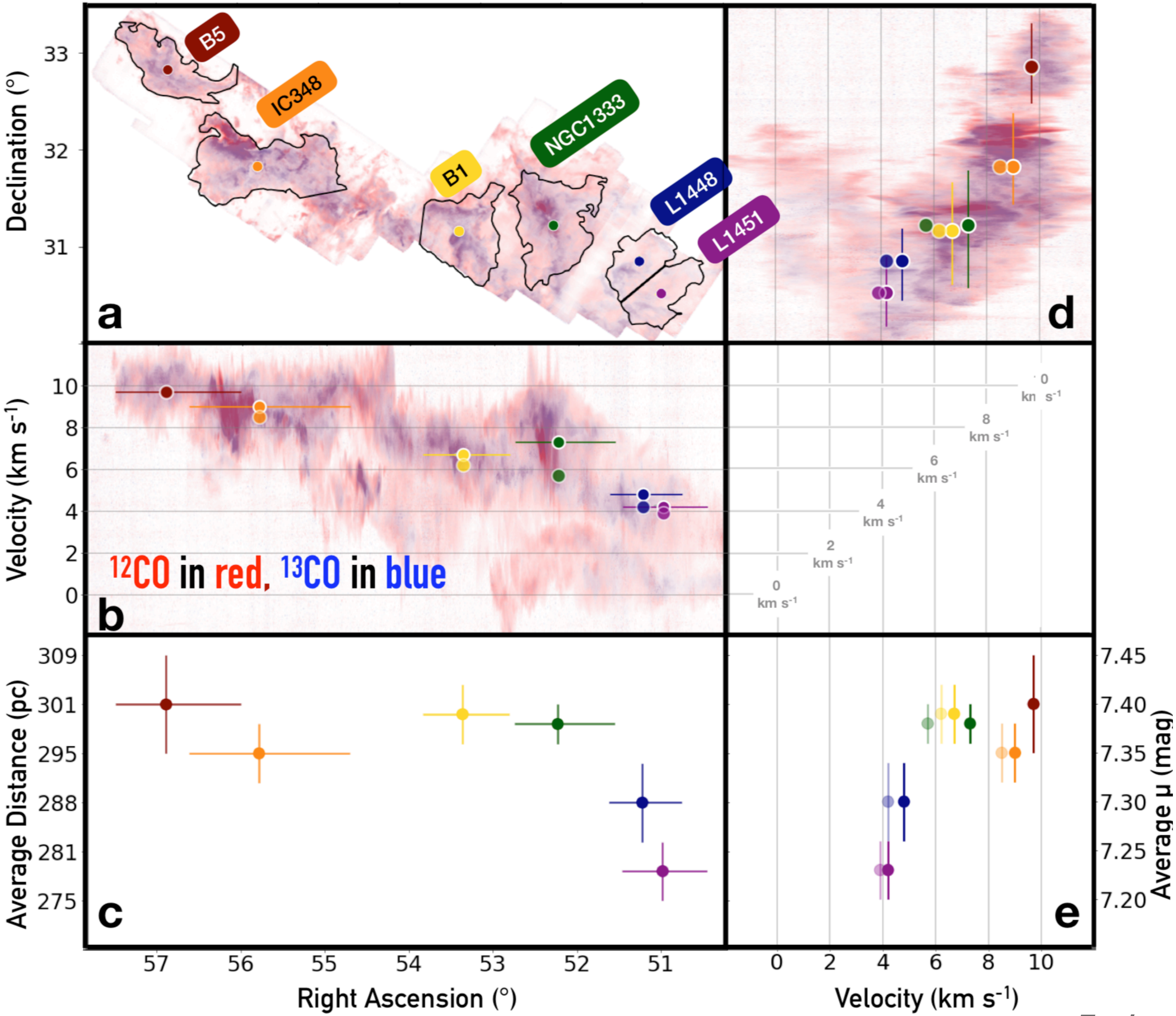
Abstract

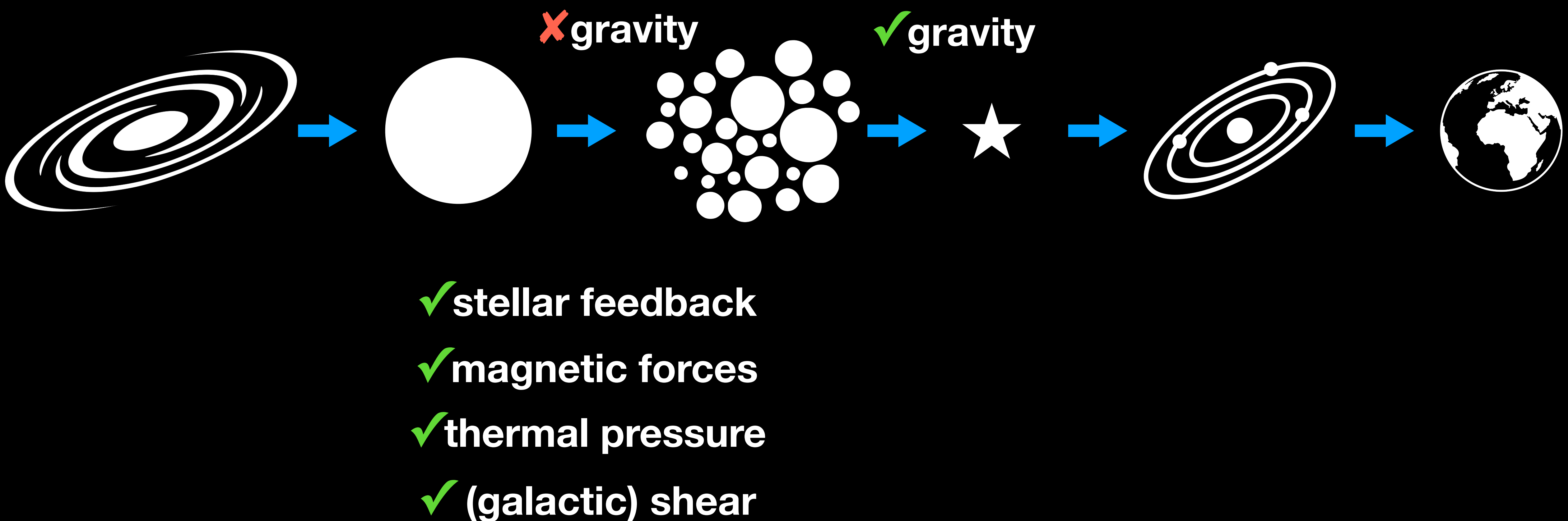
We present a new technique to determine distances to major star-forming regions across the Perseus Molecular Cloud, using a combination of stellar photometry, astrometric data, and ^{12}CO spectral-line maps. Incorporating the Gaia DR2 parallax measurements when available, we start by inferring the distance and reddening to stars from their Pan-STARRS1 and 2MASS photometry, based on a technique presented in Green et al. (2014, 2015) and implemented in their 3D "Bayestar" dust map of three-quarters of the sky. We then refine the Green et al. technique by using the velocity slices of a CO spectral cube as dust templates and modeling the cumulative distribution of dust along the line of sight towards these stars as a linear combination of the emission in the slices. Using a nested sampling algorithm, we fit these per-star distance-reddening measurements to find the distances to the CO velocity slices towards each star-forming region. This results in distance estimates explicitly tied to the velocity structure of the molecular gas. We determine distances to the B5, IC348, B1, NGC1333, L1448, and L1451 star-forming regions and find that individual clouds are located between $\approx 275 - 300$ pc, with typical combined uncertainties of $\approx 5\%$. We find that the velocity gradient across Perseus corresponds to a distance gradient of about 25 pc, with the eastern portion of the cloud farther away than the western portion. We determine an average distance to the complex of 294 ± 17 pc, about 60 pc higher than the distance derived to the western portion of the cloud using

Perseus in True 3D (actually 4D)

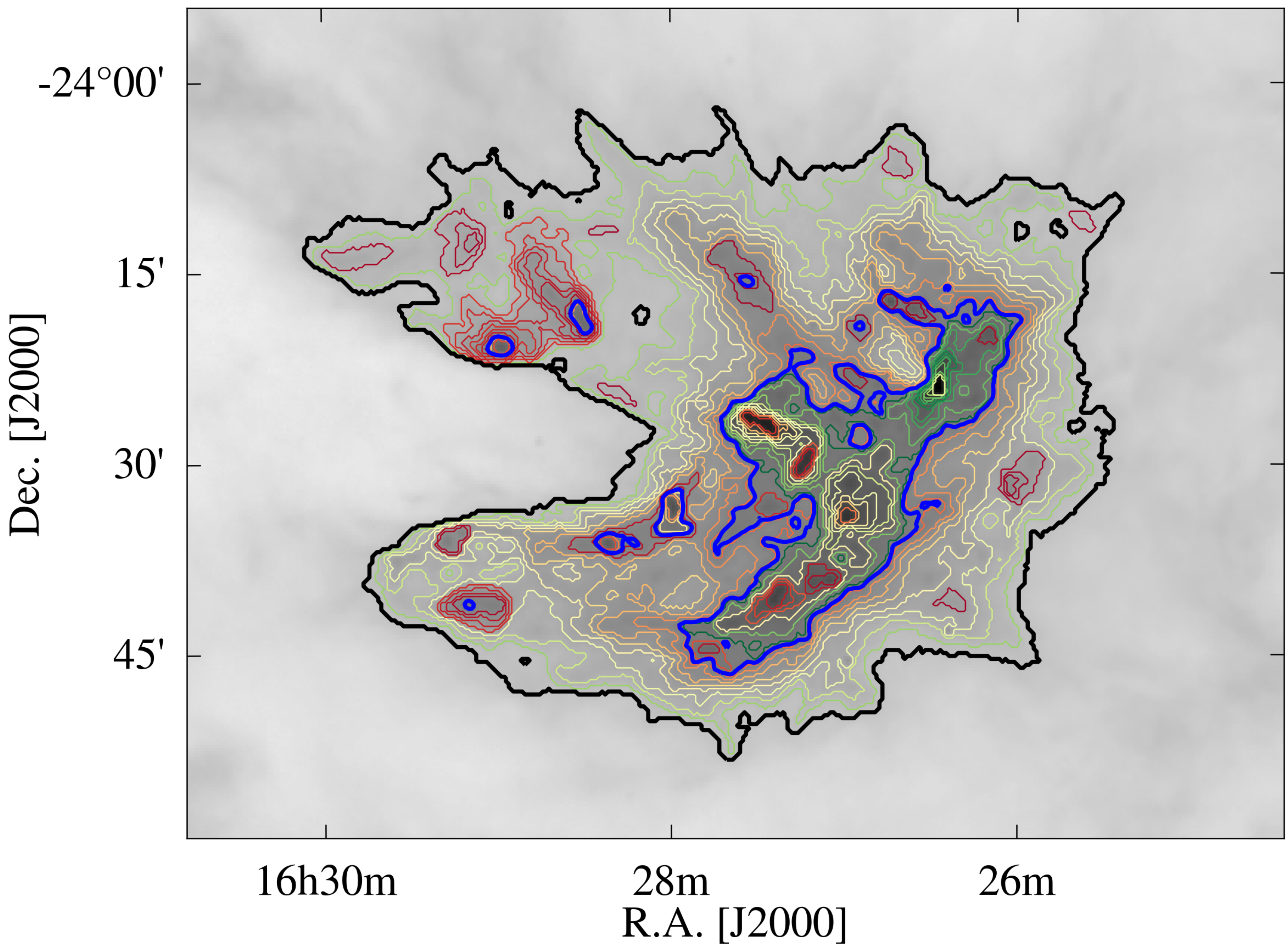


Zucker et al. 2018

At what scales does gravity truly play the key role in the story of star formation?


✗gravity
✓gravity
✓stellar feedback
✓magnetic forces
✓thermal pressure
✓ (galactic) shear

Hot off the press! Chen et al. 2019...Unbound droplets & star formation in bound clumps!



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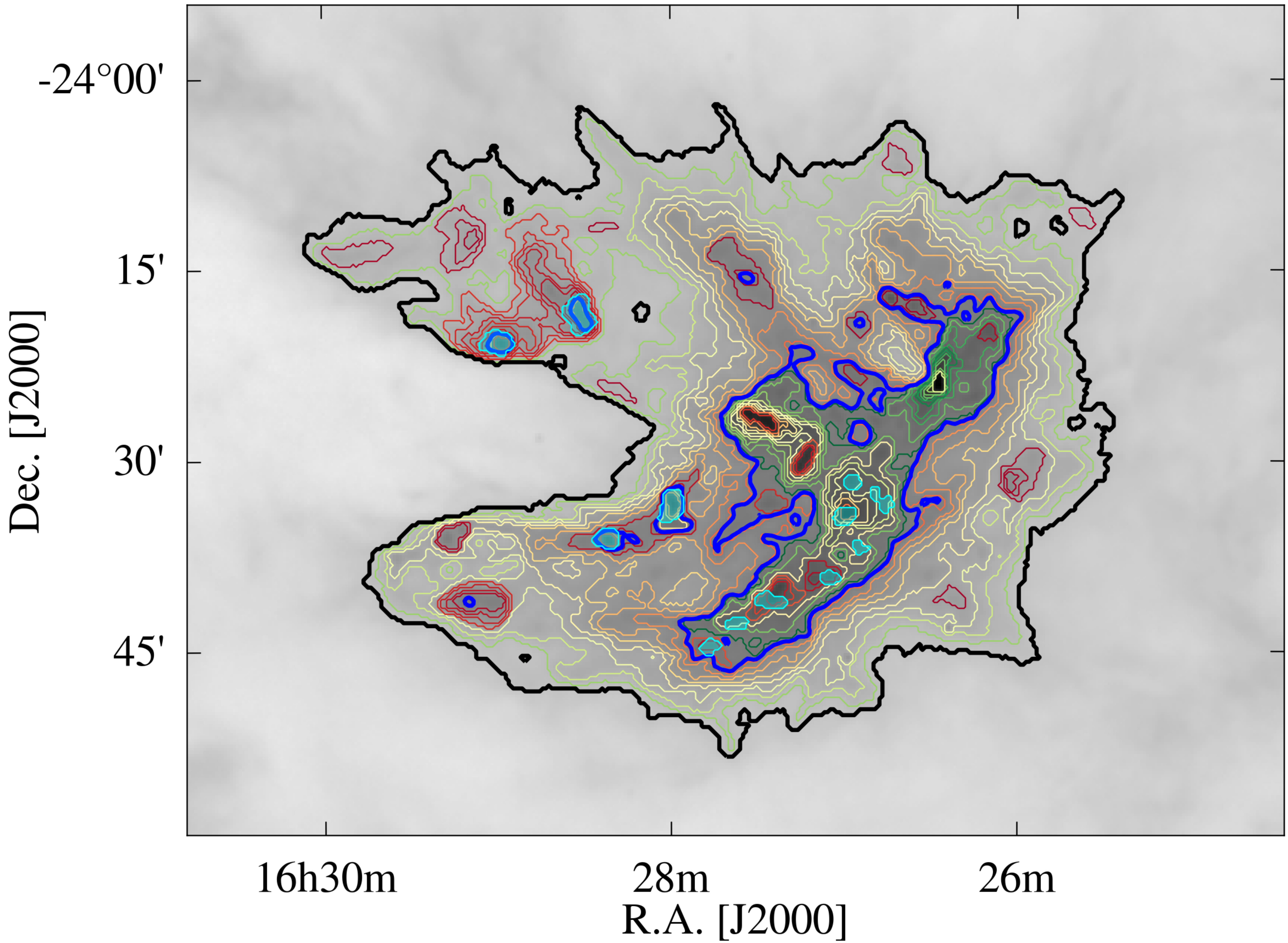

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