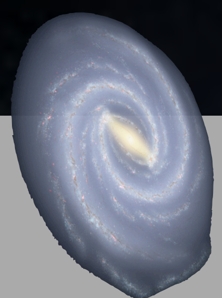
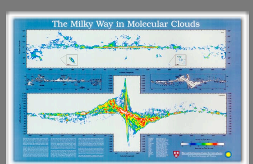
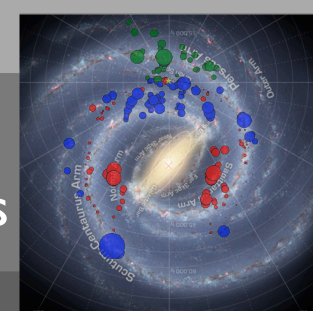
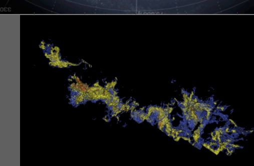
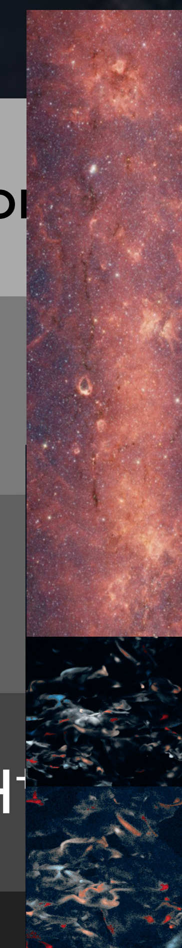
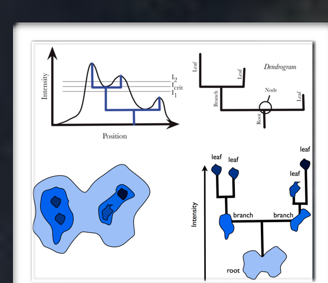
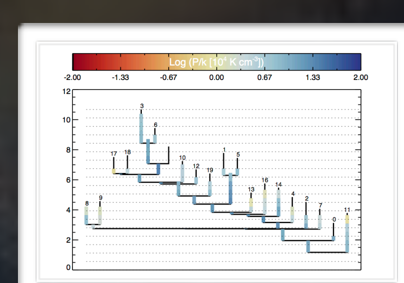
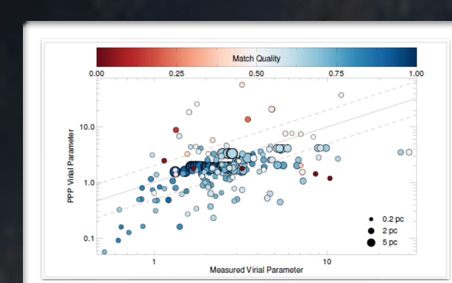
What lies within?

Alyssa A. Goodman
Harvard-Smithsonian Center for Astrophysics

structures	galaxies	dark matter→baryo	ravity, large-scale tructure formation
sub-structures	giant molecular clouds	HI→^{12}CO	ravity, dust formation, hielding
sub-sub-structures	(filamentary) "dark" clouds	^{12}CO→^{13}CO	urbulence" vind drivers?)
sub-sub-sub structures	"coherent" dense cores	^{13}CO→ NH_3, N_2H^+	ssipation of rbulence, gravity
sub-sub-sub-sub structures	filaments within cores	NH_3, N_2H^+ sub structures	(thermal) instabilities

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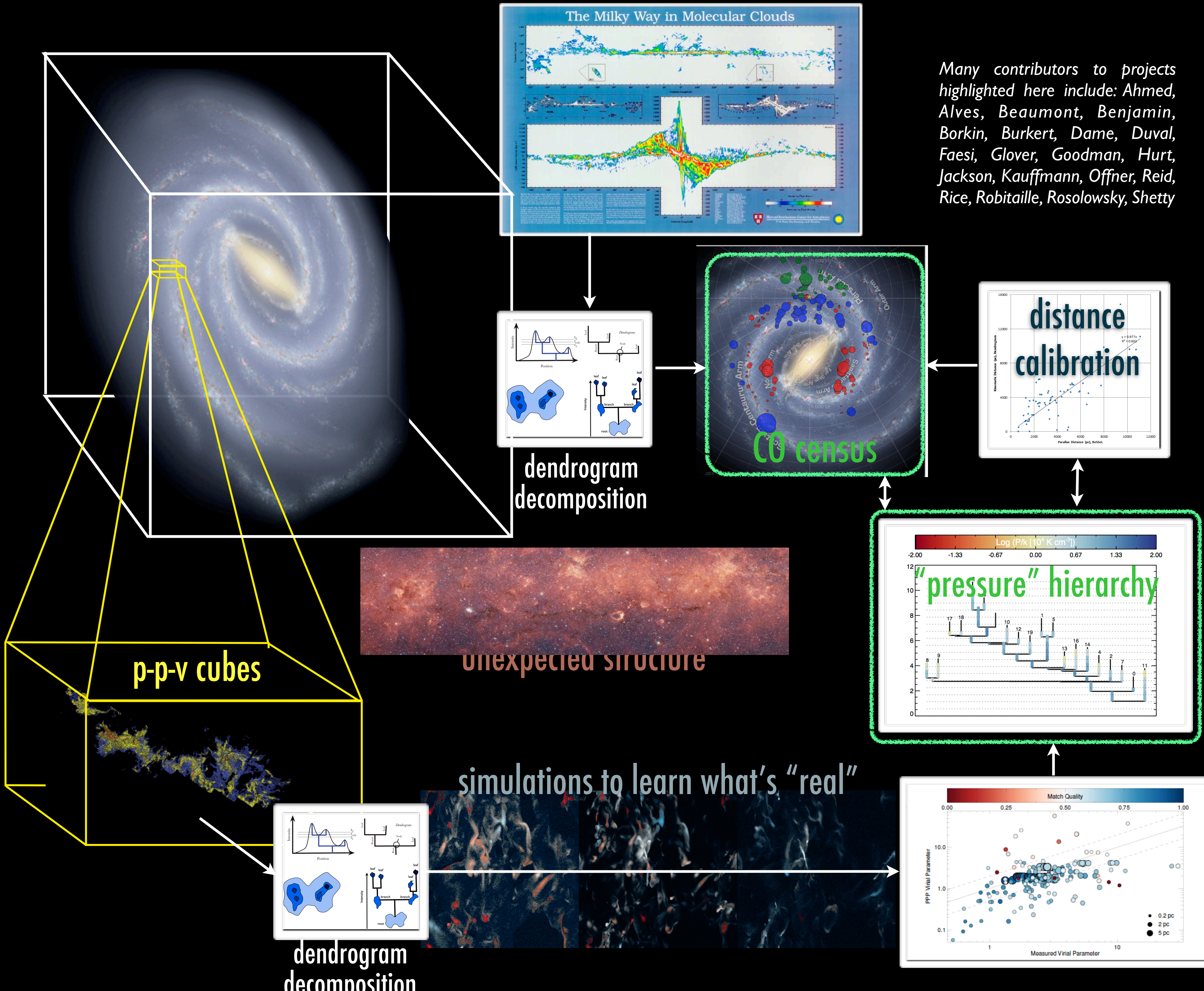
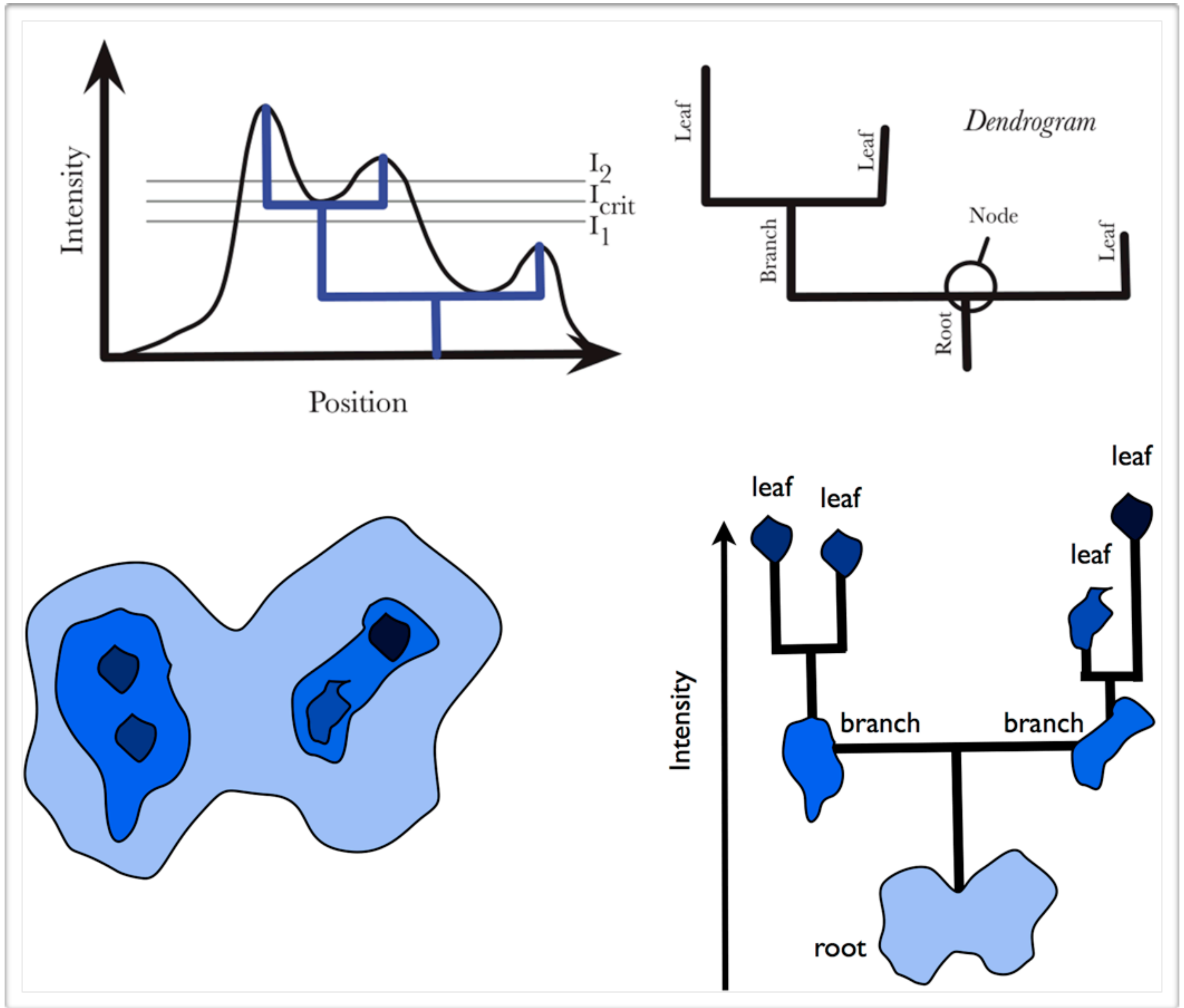


Dendrogram Refresher



from Goodman et al. 2009

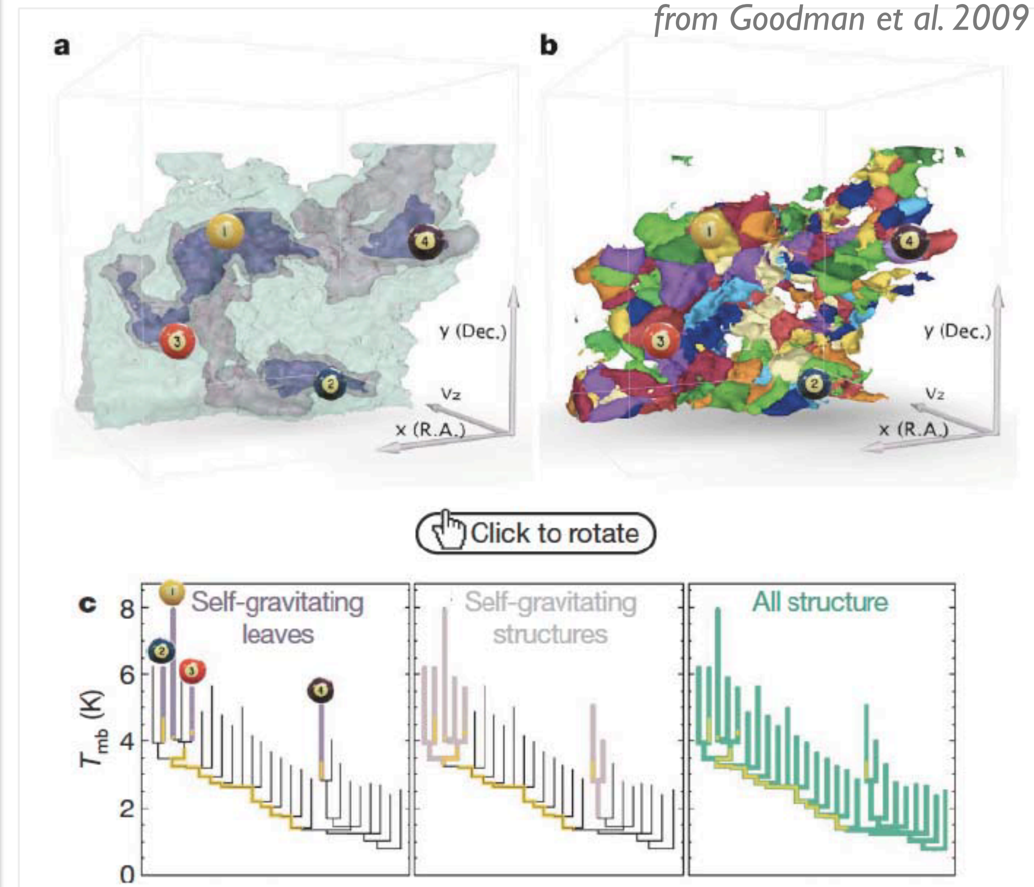
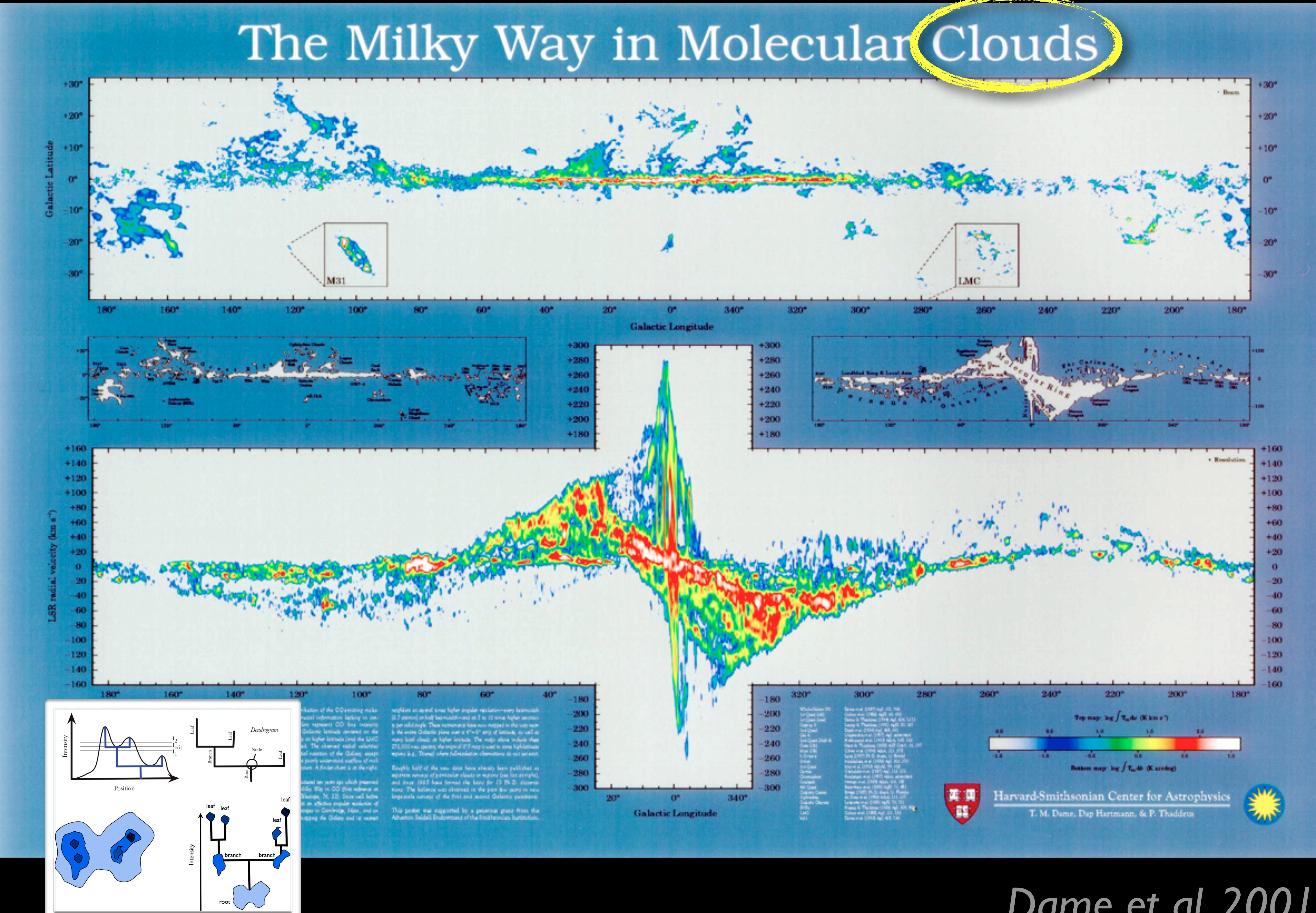


Figure 2 Dendrogram (a) and CLUMPFIND (b) decompositions of ^{13}CO in the L1448 region of Perseus shown in *p-p-v* space. Panels in (c) show dendrograms, colored to match surfaces in (a). Yellow highlights in (c) mark bound regions according to a virial analysis. In the published PDF version of Goodman et al. (2009b), this figure is interactive. Interested readers can download the paper from *Nature*, or visit tinyurl.com/Nature3Dpdf for a video demo.

Hierarchical "Segmentation"

Rosolowsky, Pineda, Kauffmann & Goodman 2008; and see Erik Rosolowsky's talk in a little while!



Dame et al. 2001

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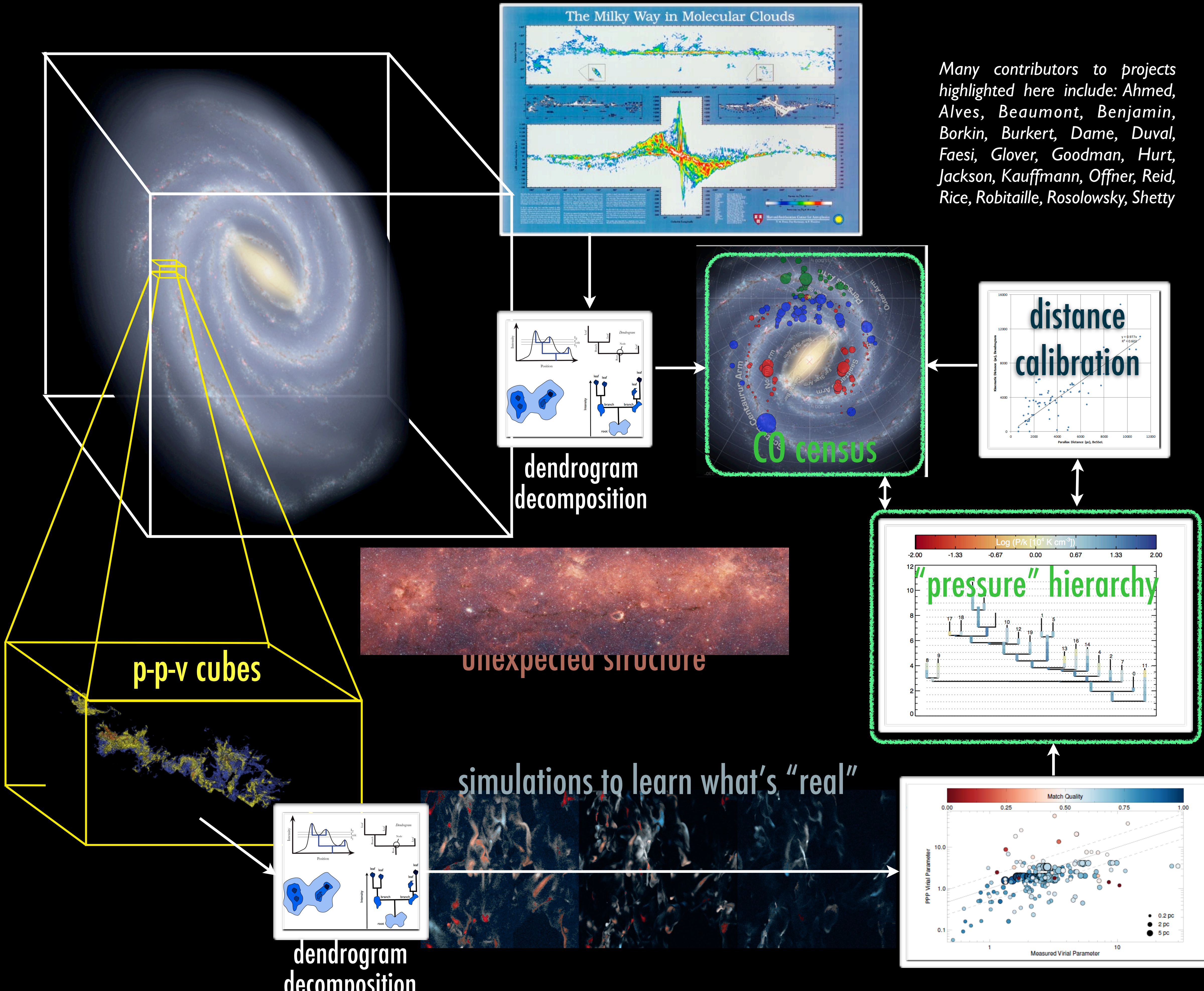

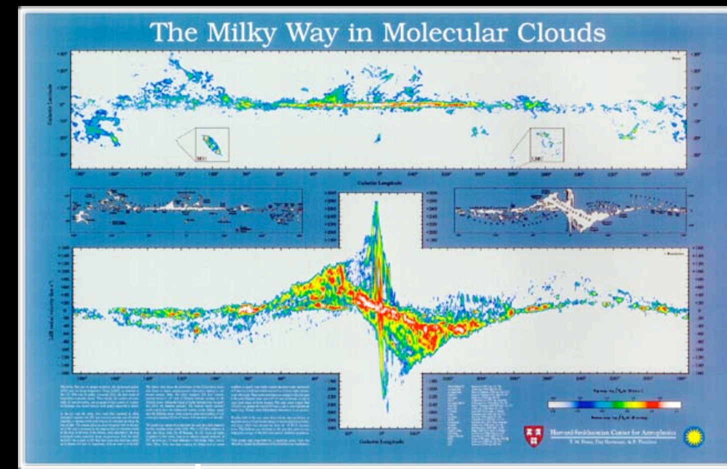

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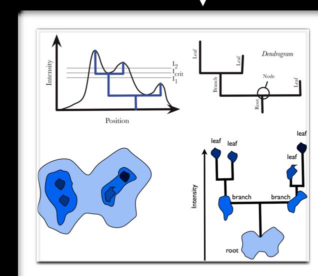
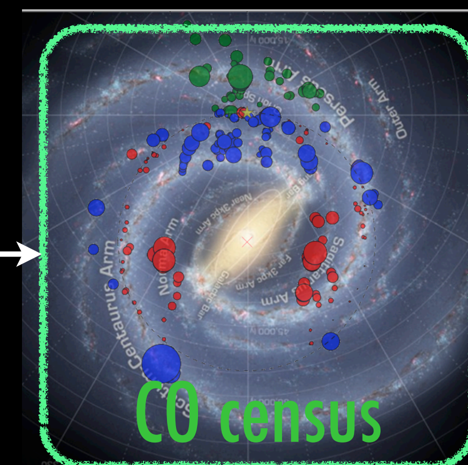
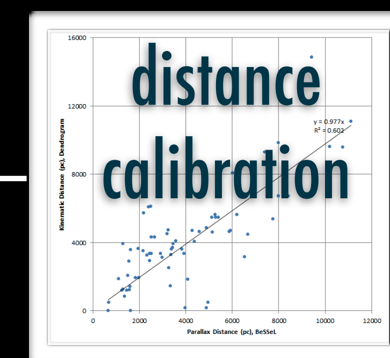
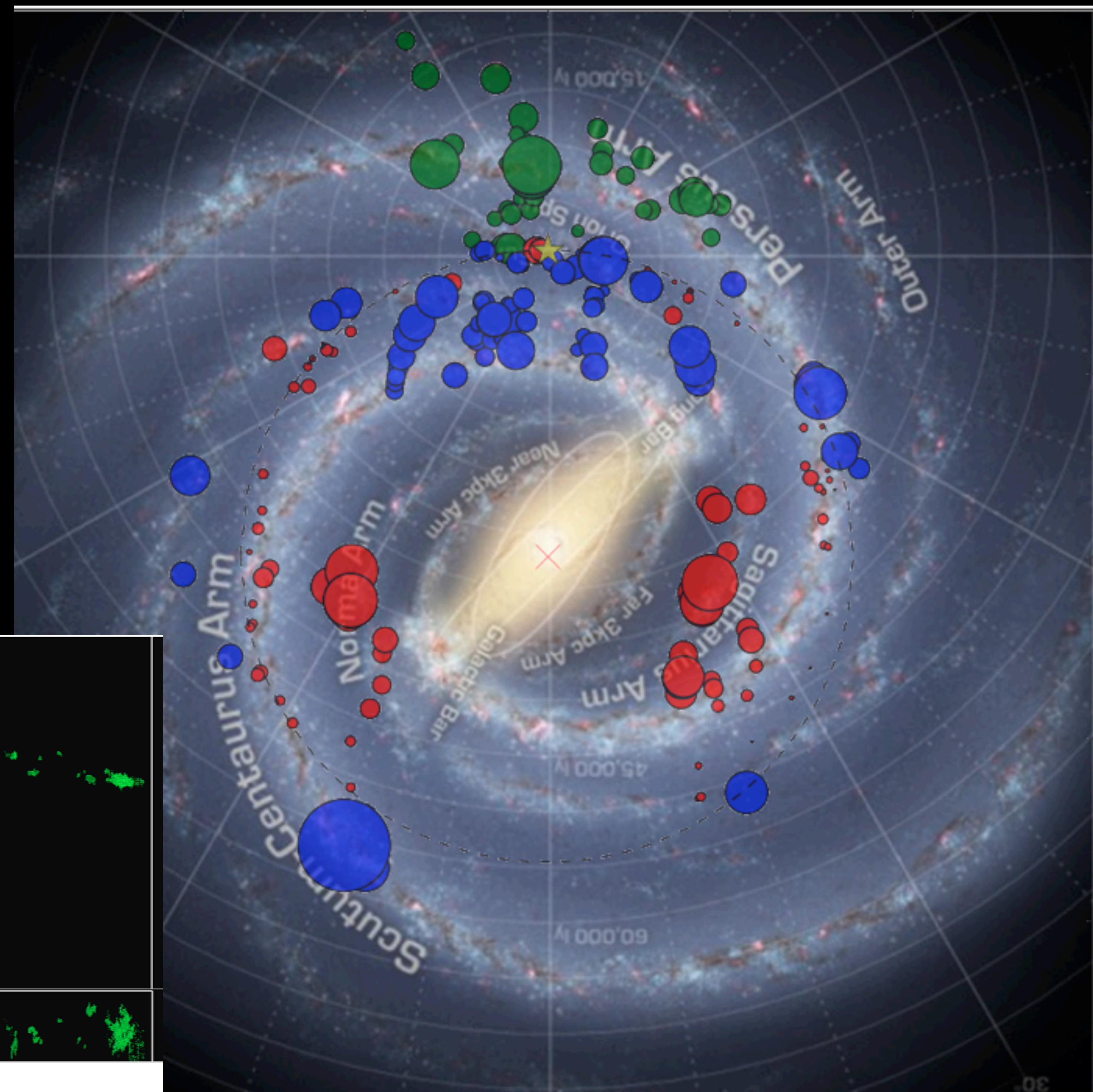


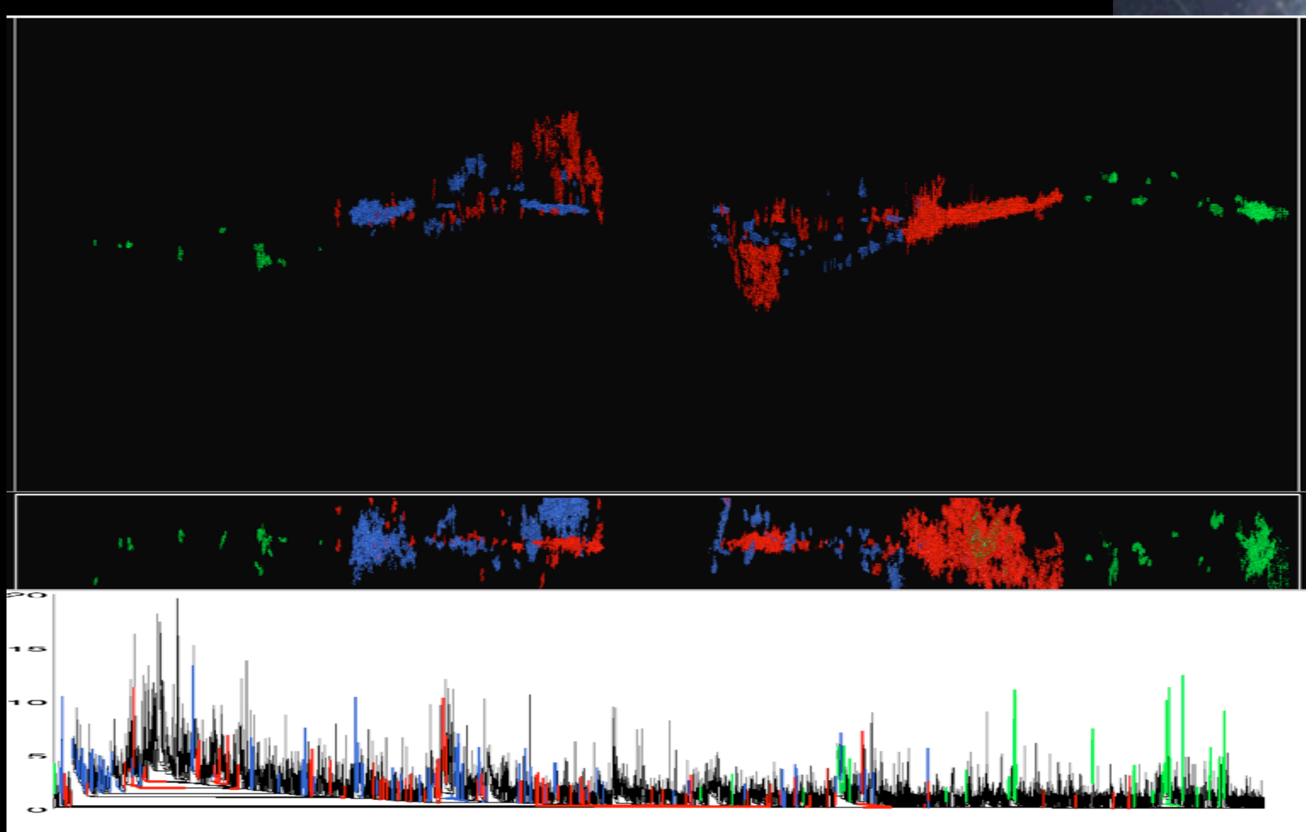
dendrogram decomposition





Preliminary Census of “Bound” Features



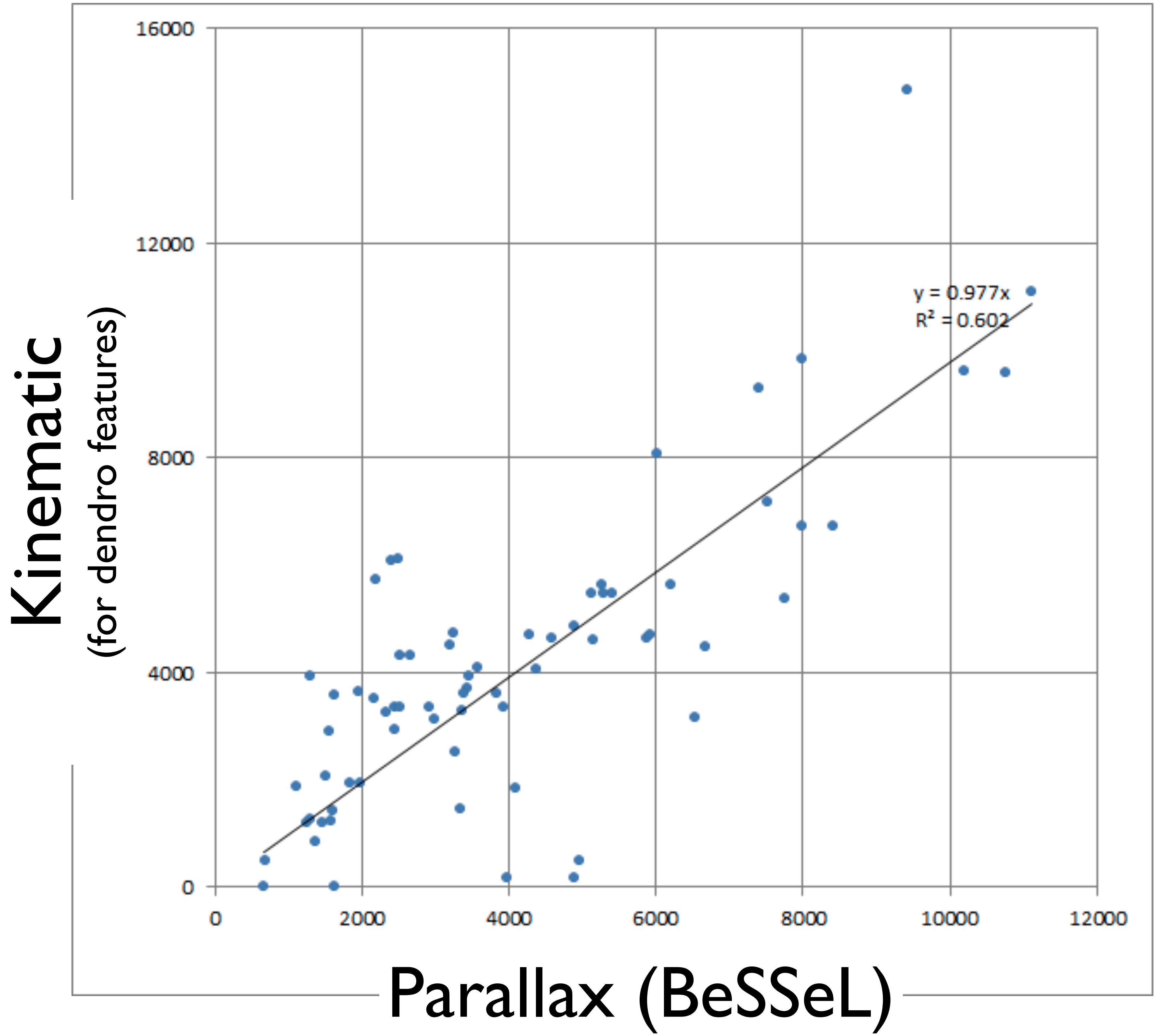


Rice, Beaumont, Dame & Goodman 2014

What does “bound” mean?

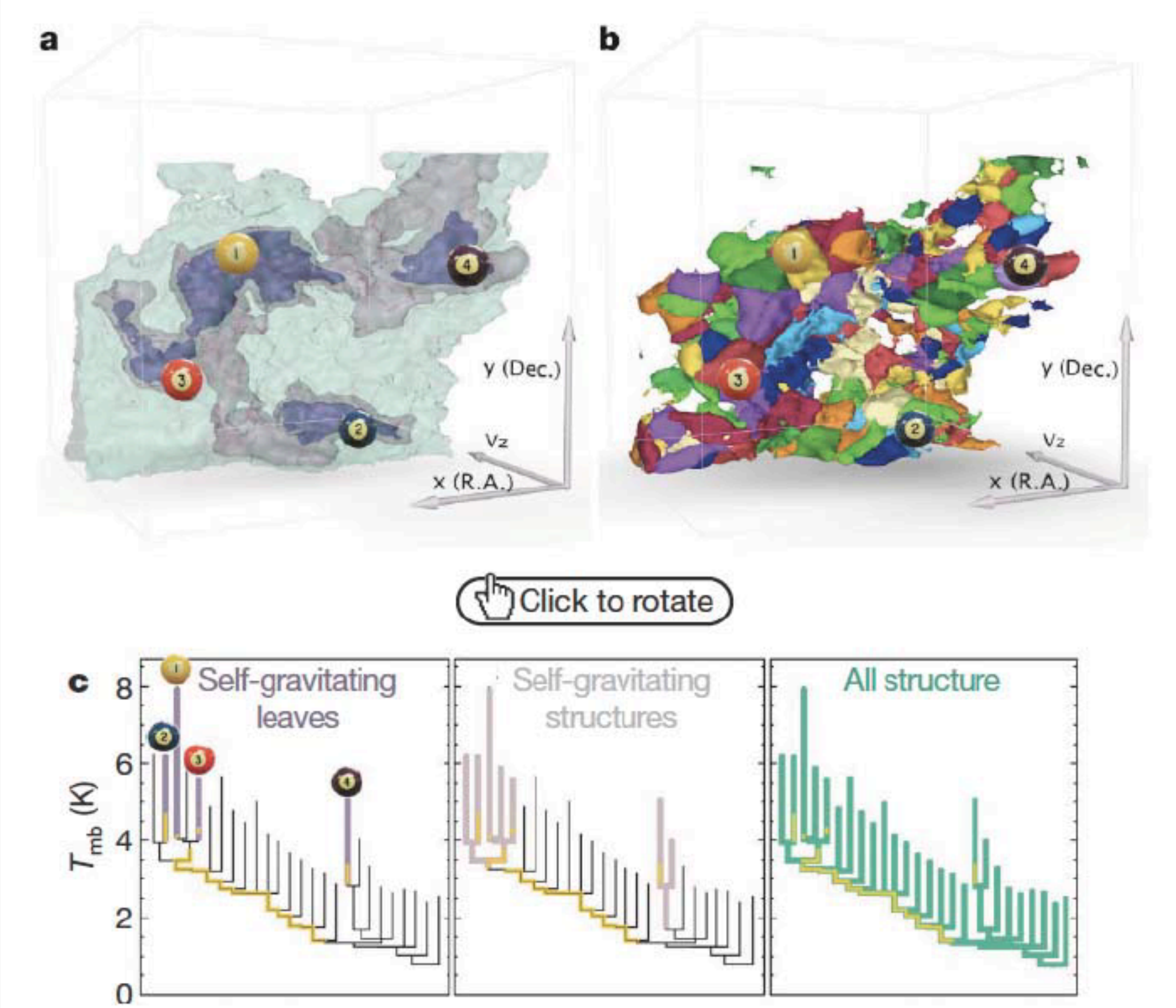
And, how good are distances?

Kinematic distances are OK, but not fantastic...



from Sara Duval's Harvard Junior Thesis with AG, 2013 (thanks to Dame & Reid)

Bound? (2008: Frank Shu asks for a "test of the test")



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Goodman, Rosolowsky, Borkin, Foster, Halle, Kauffmann, Pineda 2009

Yellow highlighting= "self-gravitating"

…where "self-gravitating" just means

$\alpha_{vir}\ (=5\sigma_v^2 R/M_{lum}) < 2$

cf. Bertoldi & McKee 1992

Tests

- *p-p-v* OK for *p-p-p*?
- ignoring all but *gravity* & *random KE* OK?
- ^{13}CO good enough?

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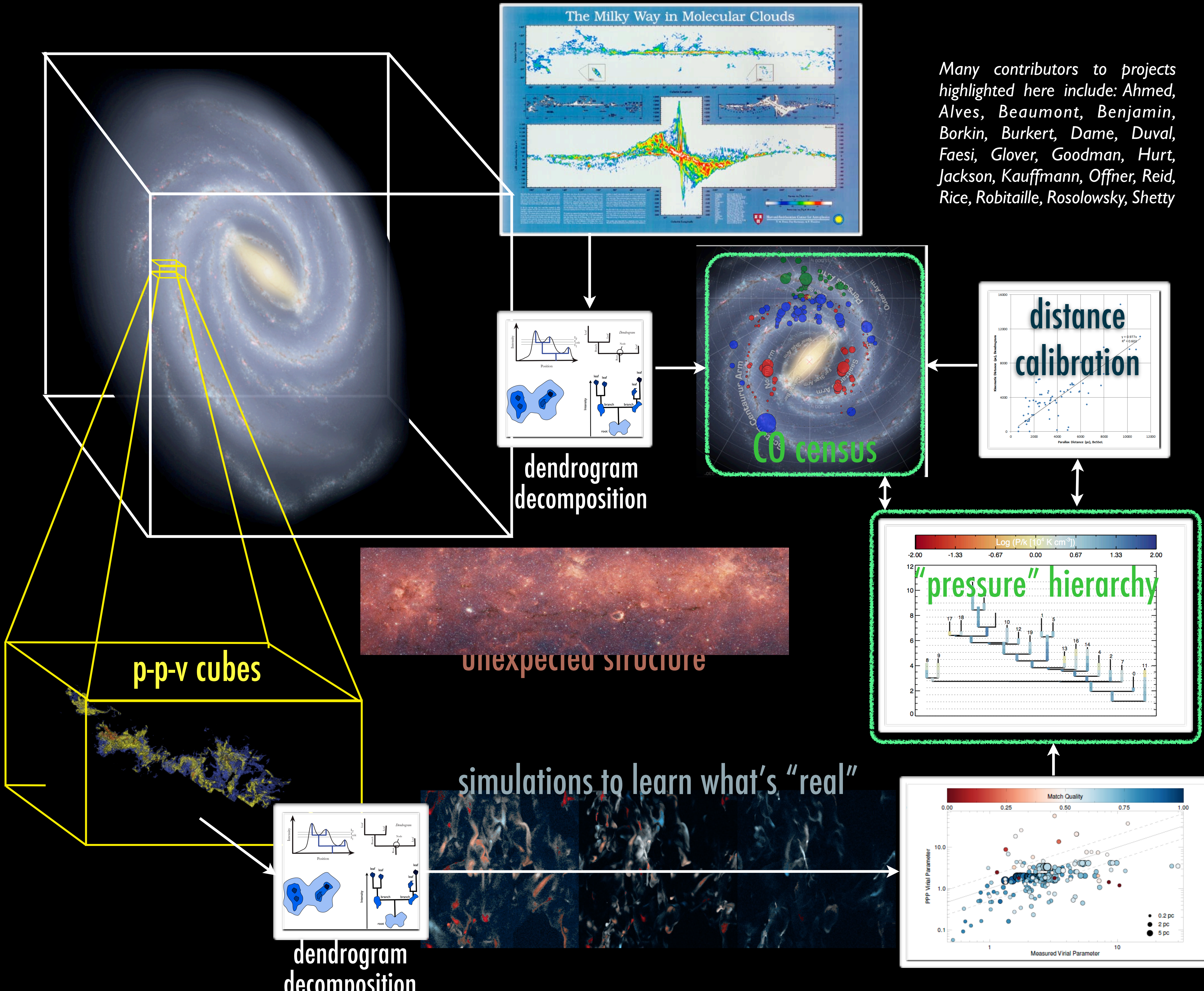

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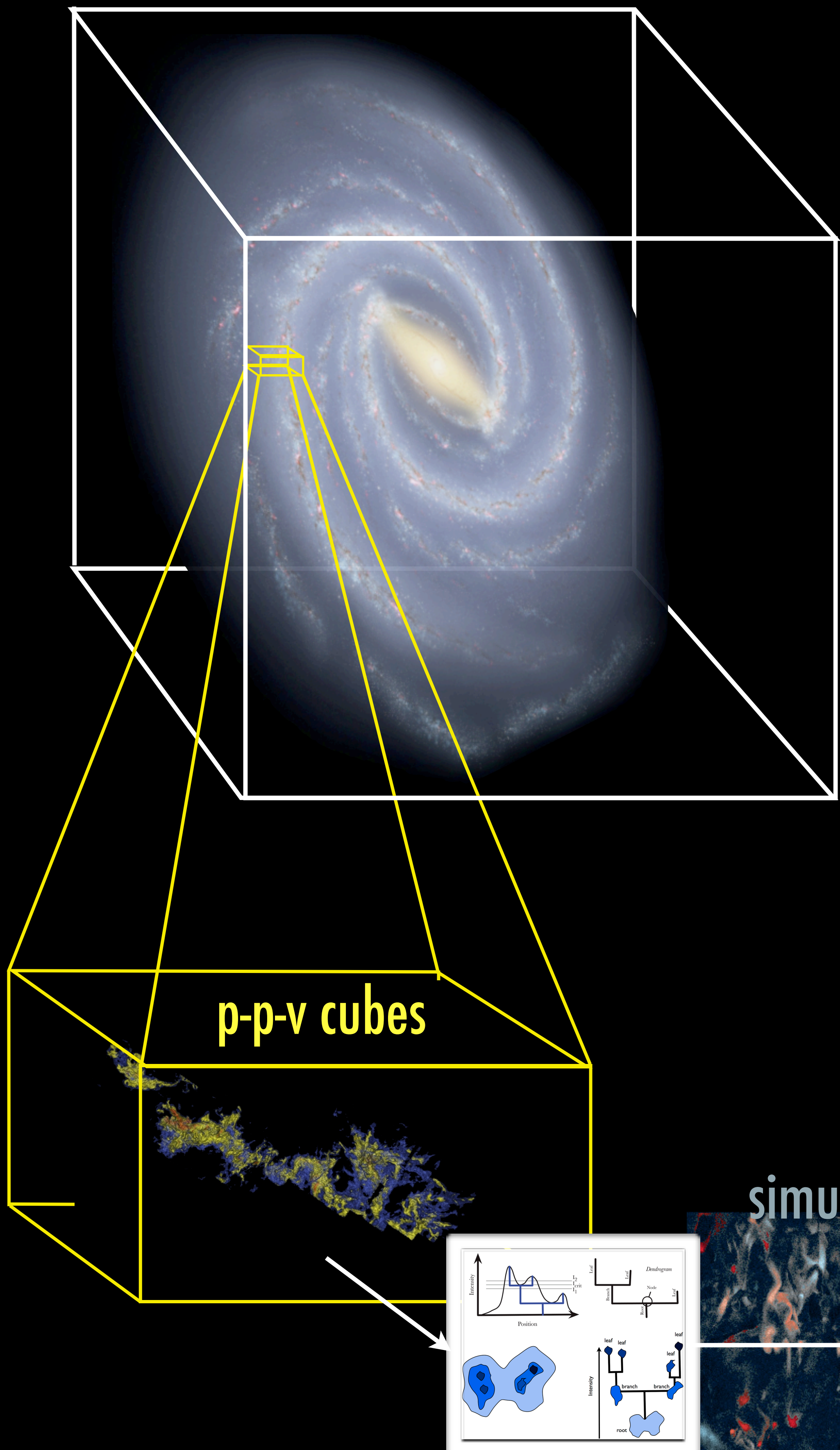
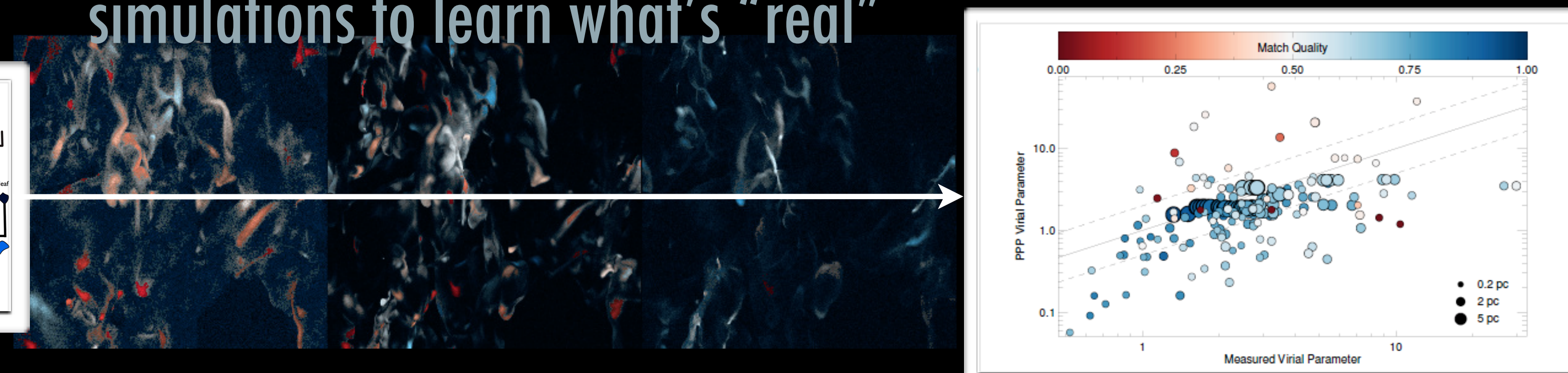
What to believe?

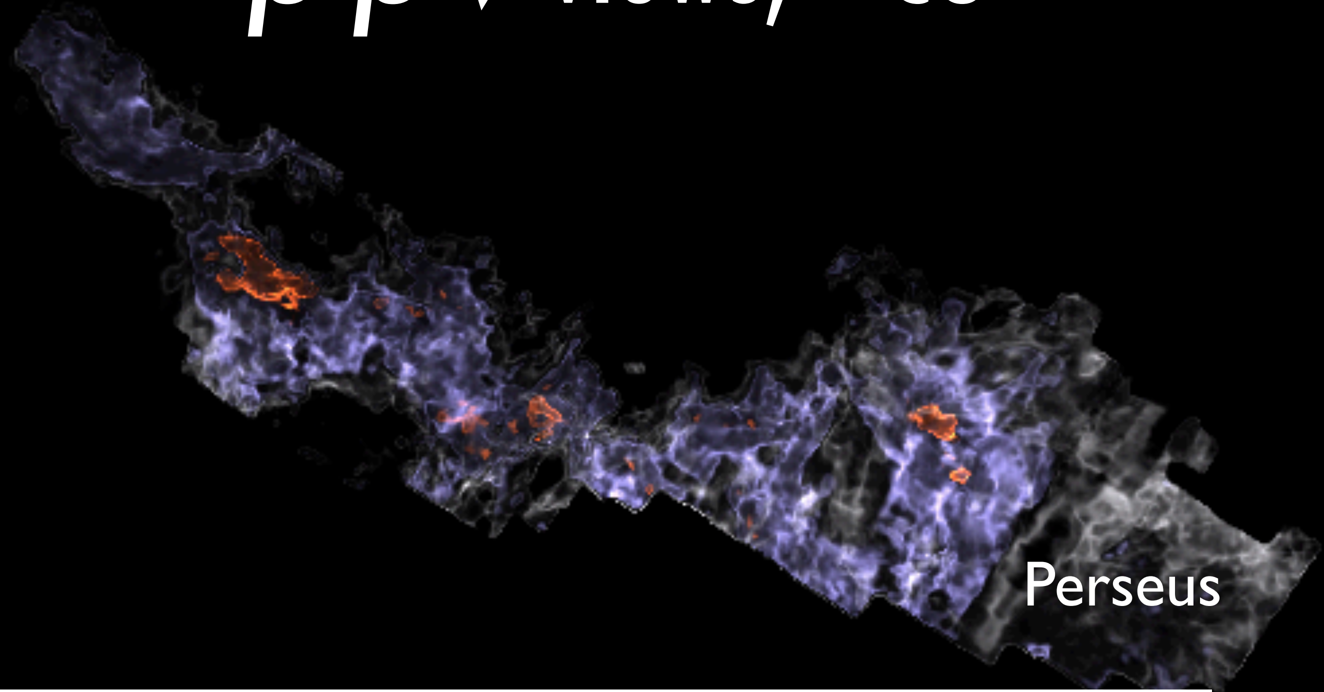




Taste test: Using simulations, and synthetic observations of those simulations, measure "match quality" (indicating *p-p-v* space *overlap* of "<u>real</u>" *p-p-p* dendrogram features projected in to *p-p-v* space, and structures <u>found</u> in *p-p-v* dendrogram).

Beaumont, Offner, Shetty, Glover & Goodman 2013,
cf. prior work of Stella Offner, Rowan Smith, Erik Rosolowsky, Paolo Padoan, Rahul Shetty, et al.

p-p-v views, ^{13}CO



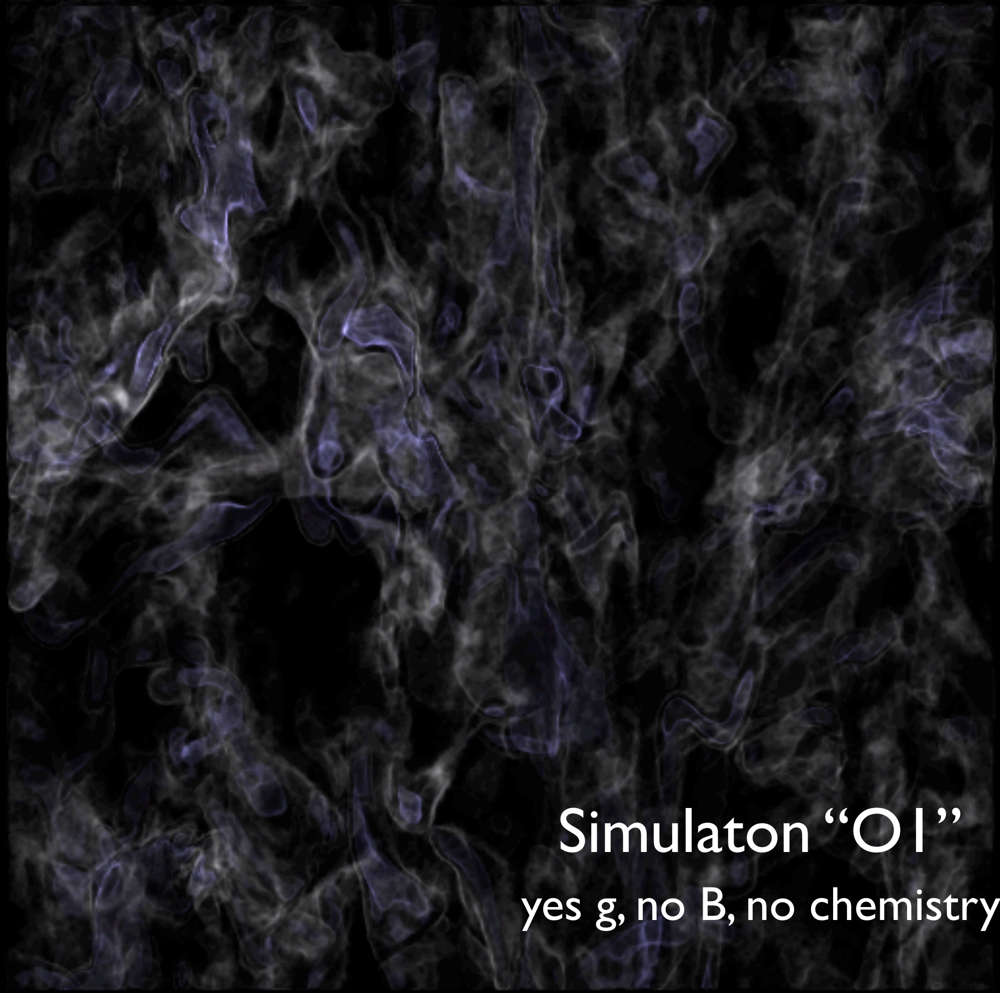


Table 2. Summary of each simulation

	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

Match Quality

good
bad

movies include a noise model, in both cases

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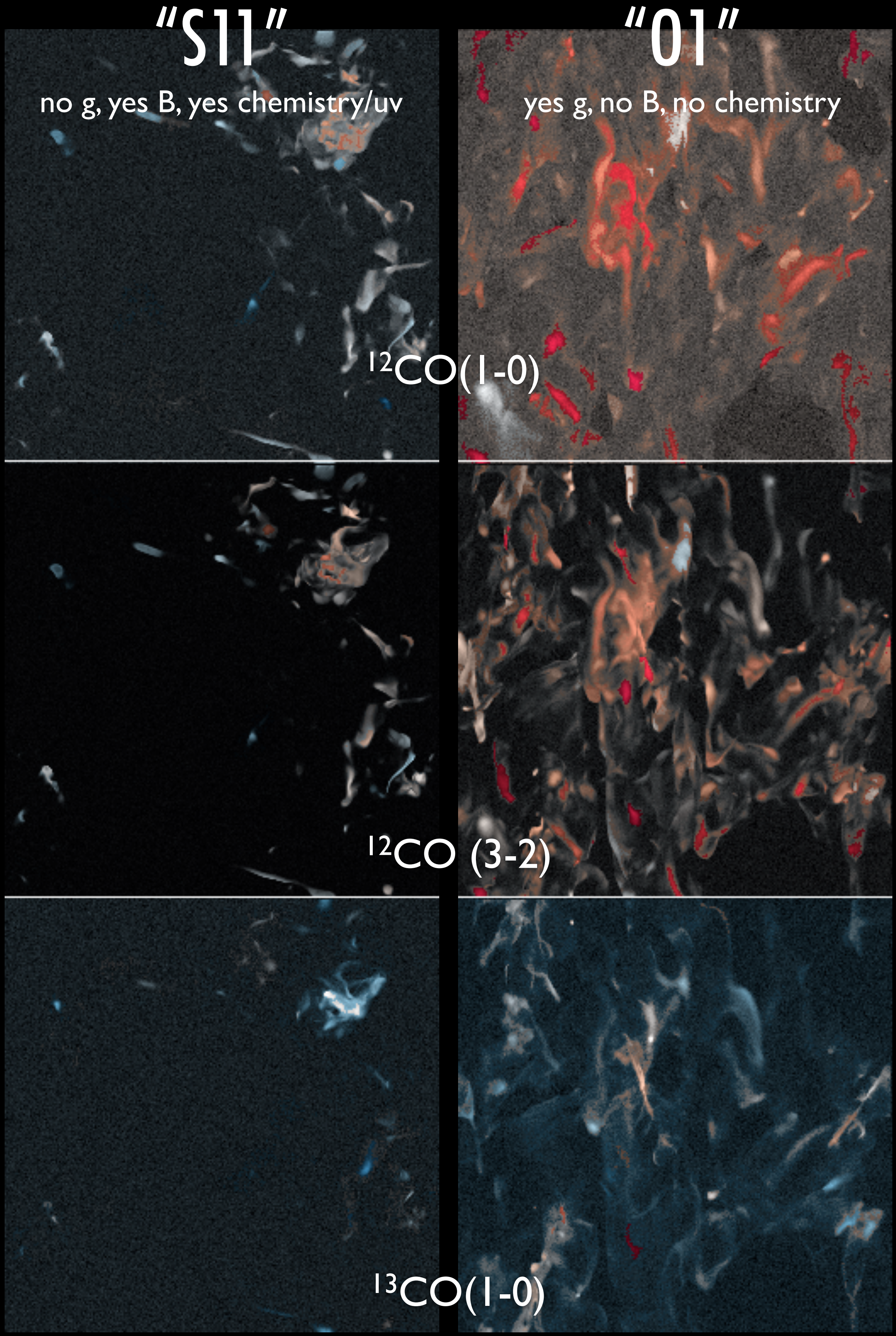
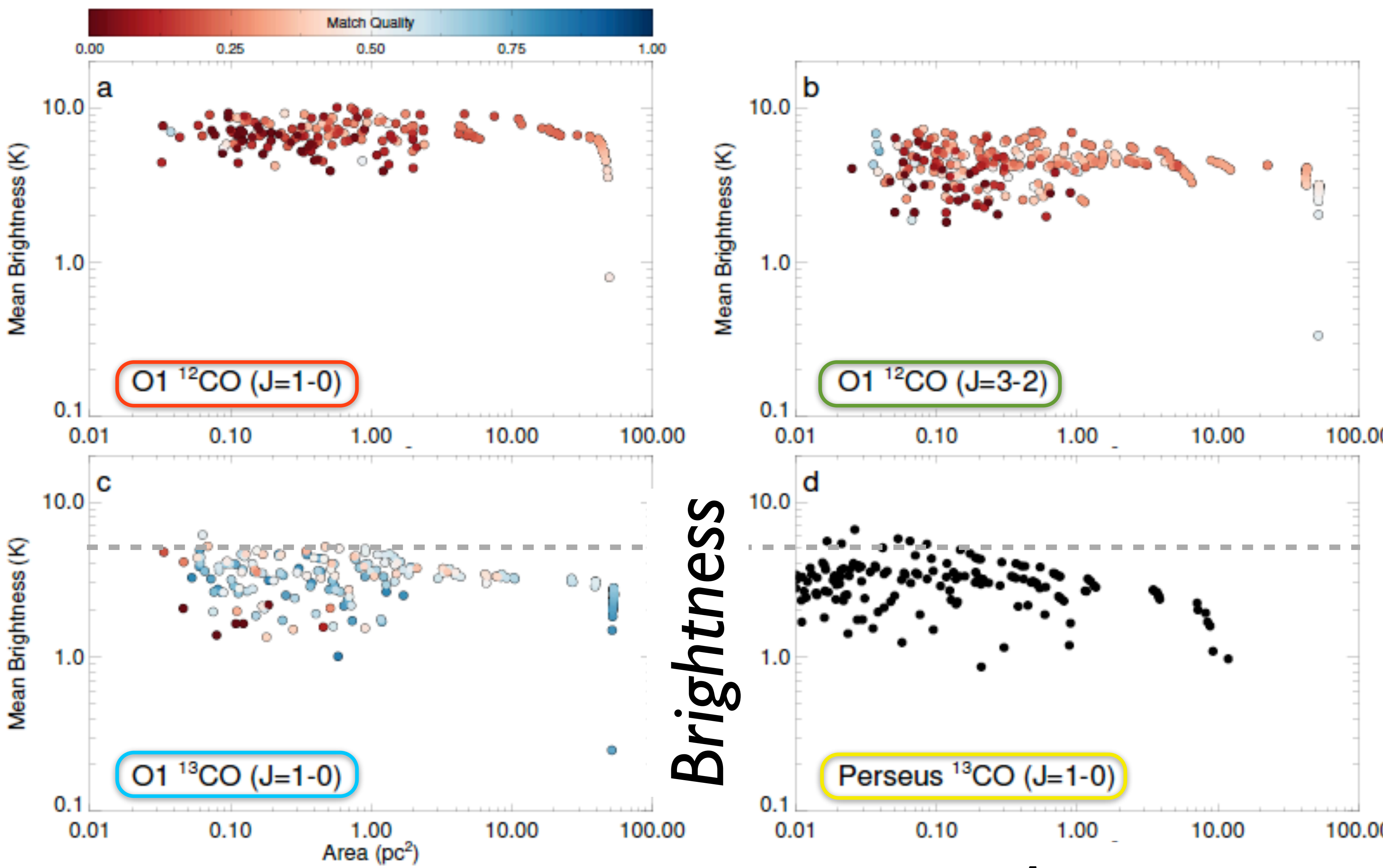


Match Quality

"01"

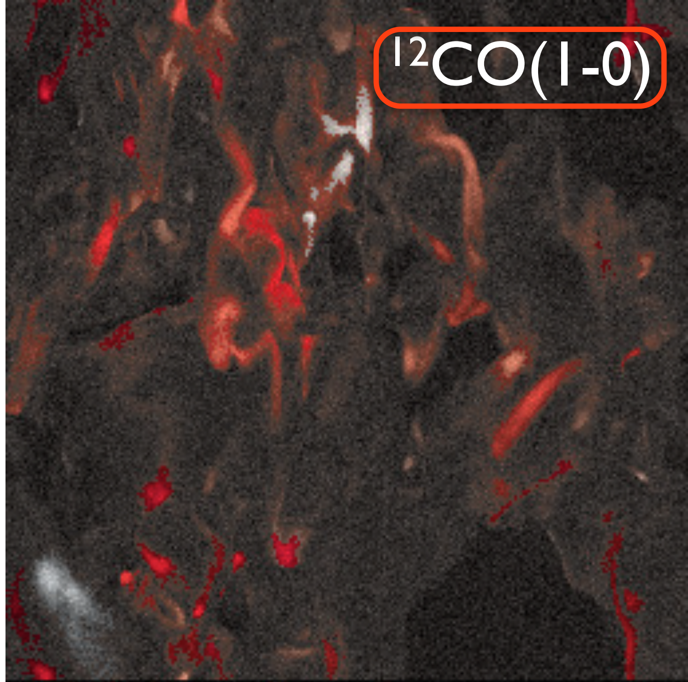
yes g, no B, no chemistry

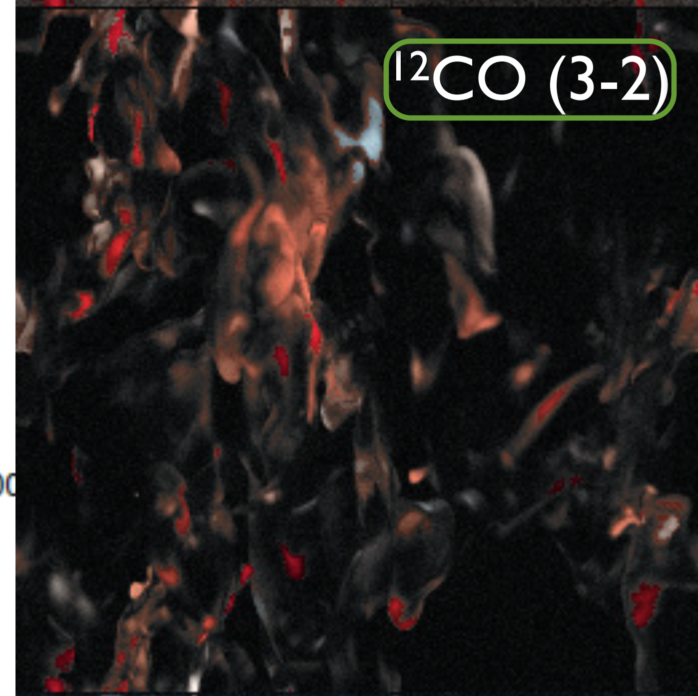
good
bad

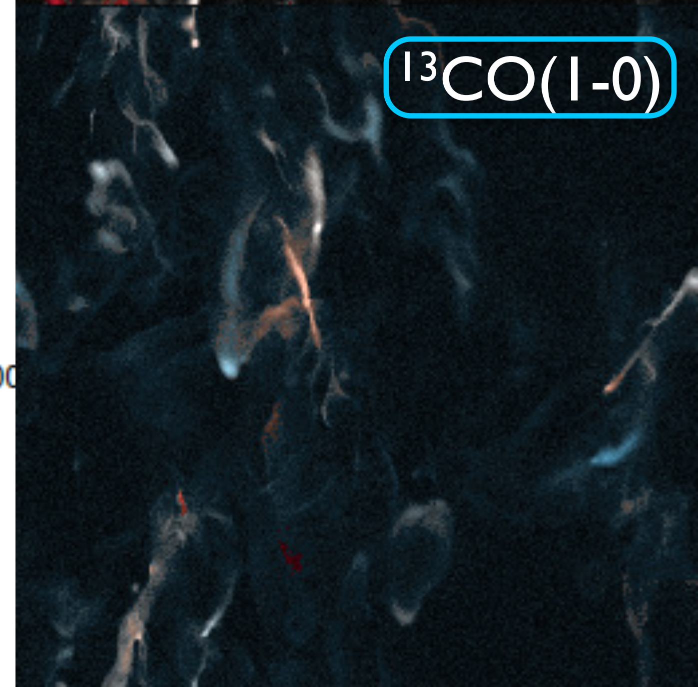


Brightness

Area







Beaumont, Offner, Shetty, Glover & Goodman 2013

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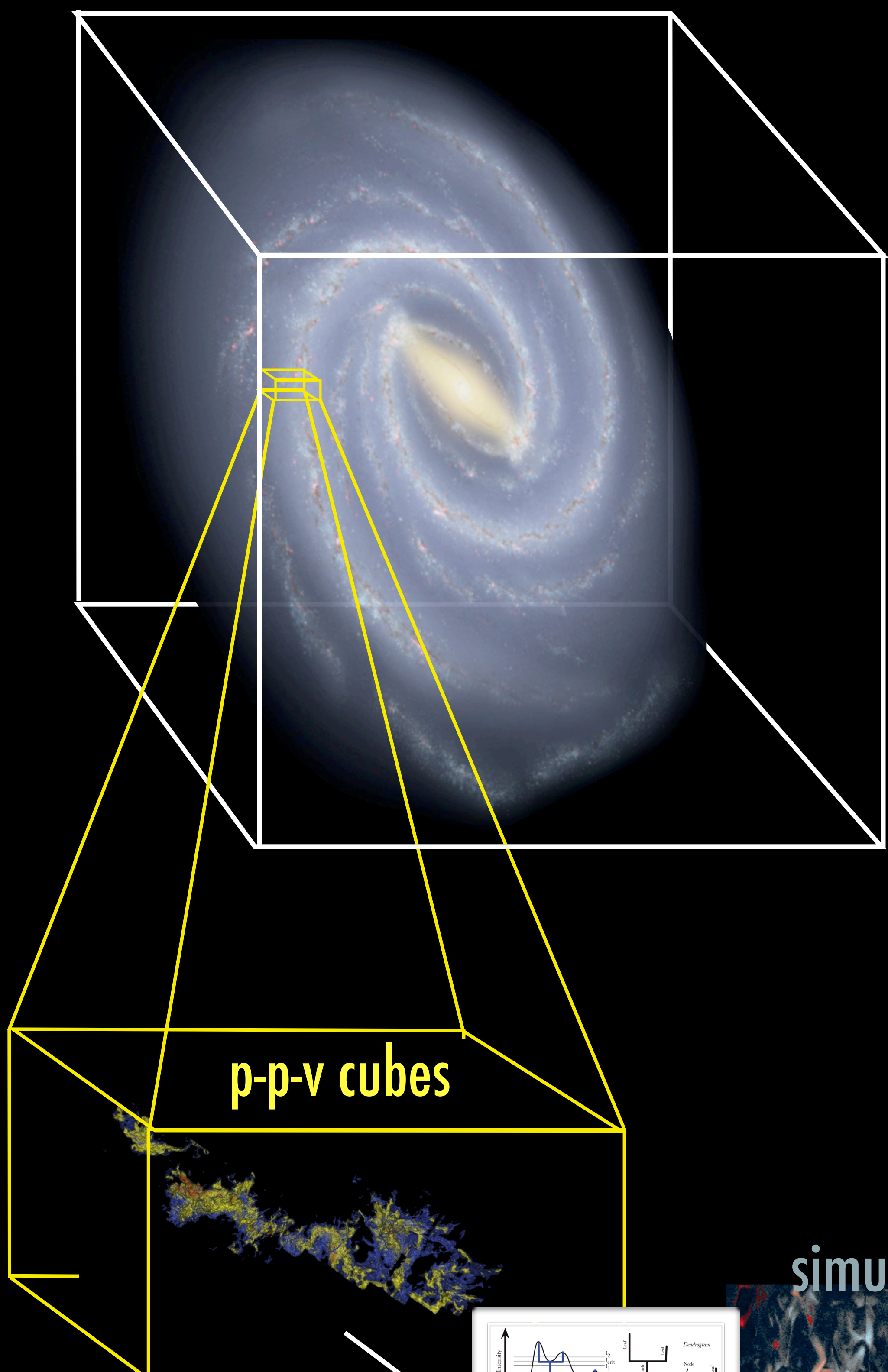
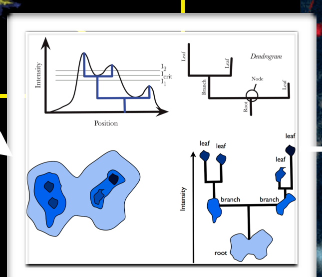
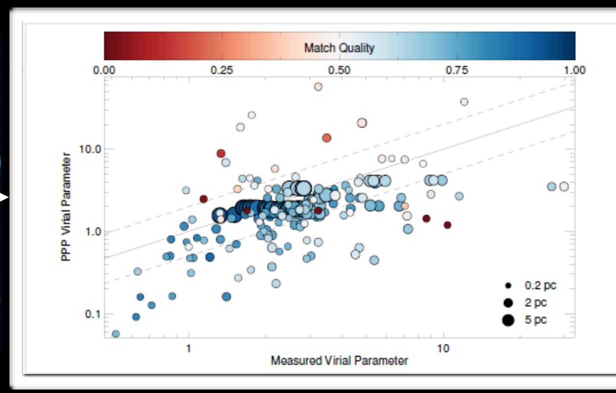


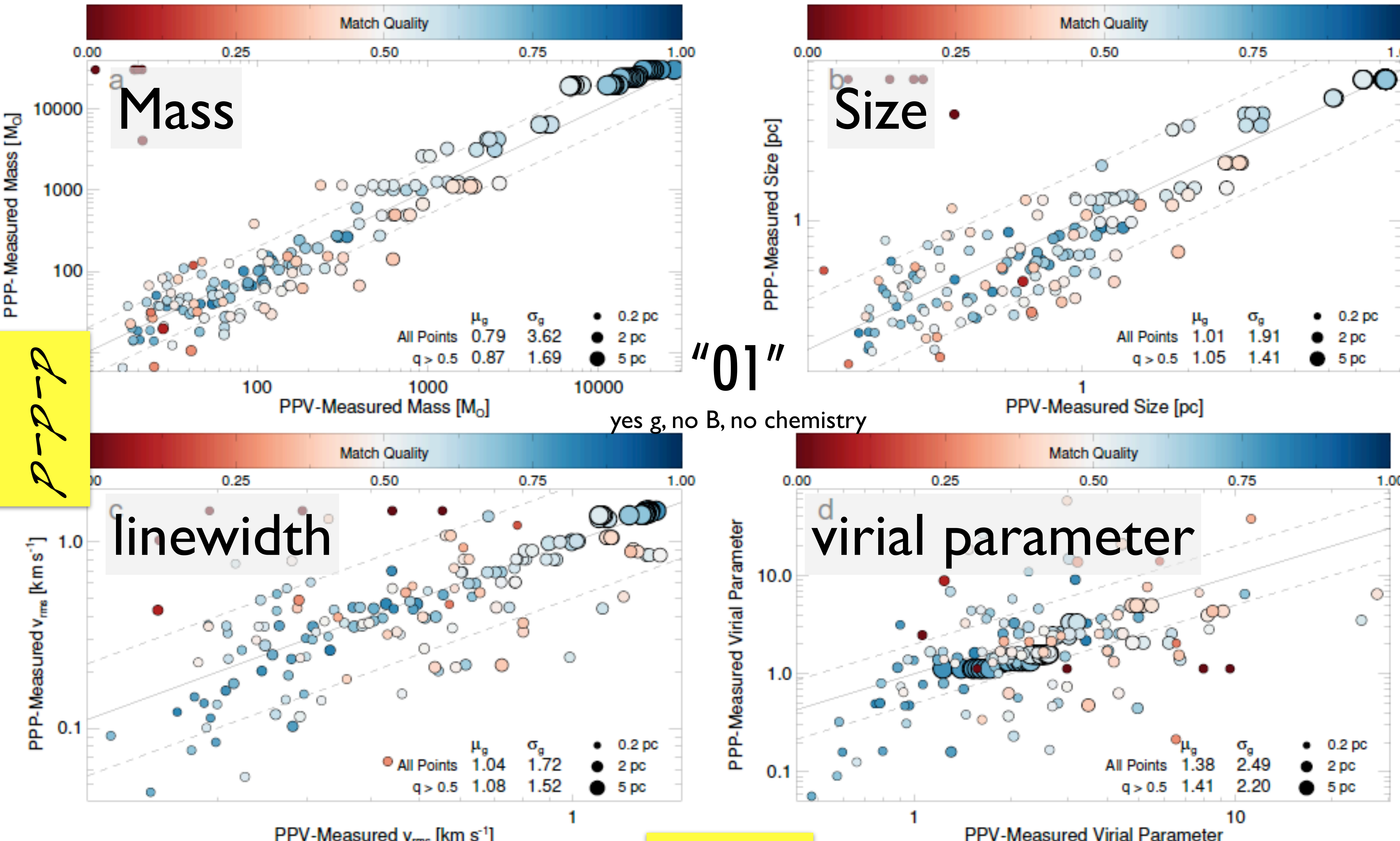




Match Quality

good bad

^{13}CO(1-0)



"01"

yes g, no B, no chemistry

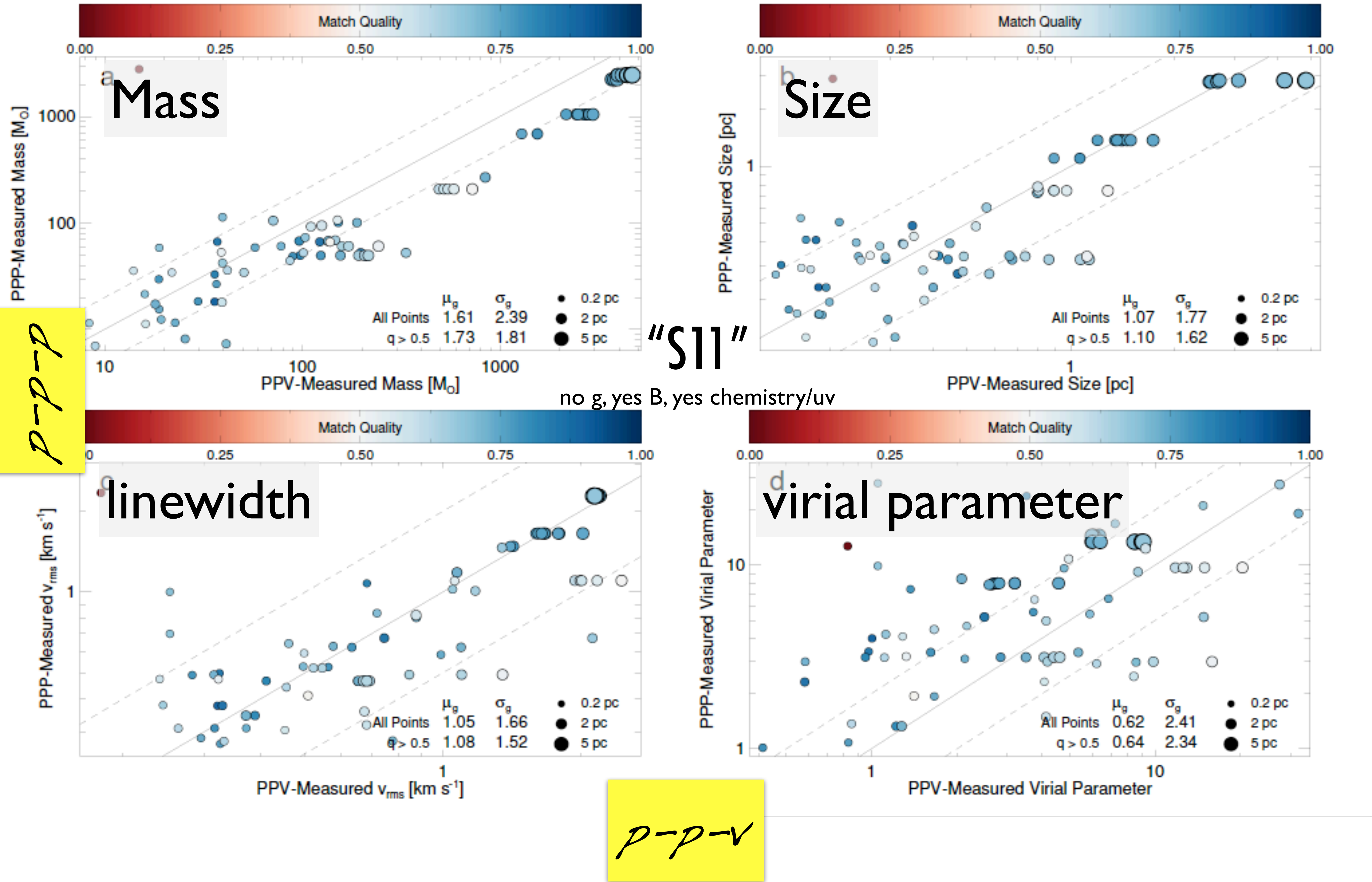
p-p-p

p-p-v

Match Quality

good bad

$^{13}CO(1-0)$



Match Quality

"Larson Relations"

good
bad

"01"

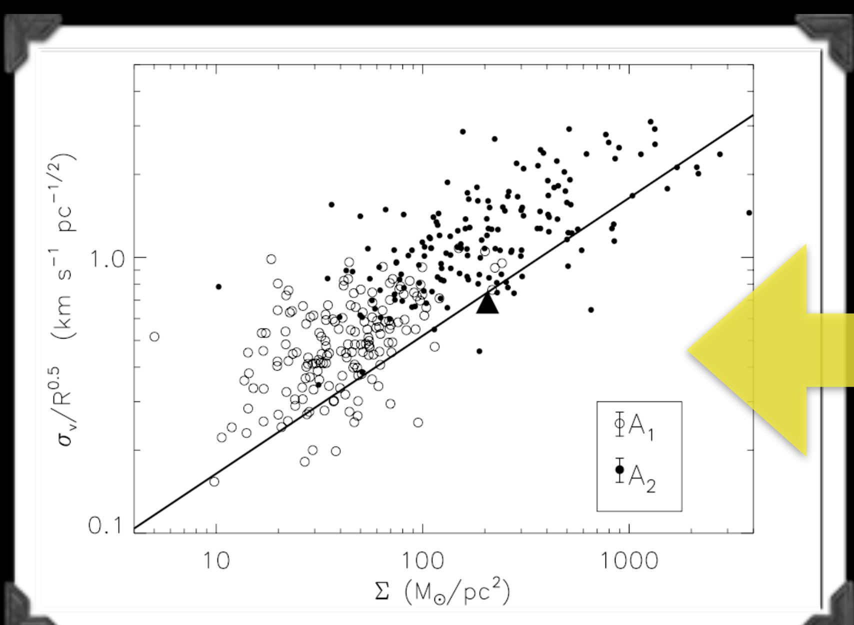
yes g, no B, no chemistry

$^{13}CO(1\text{-}0)$

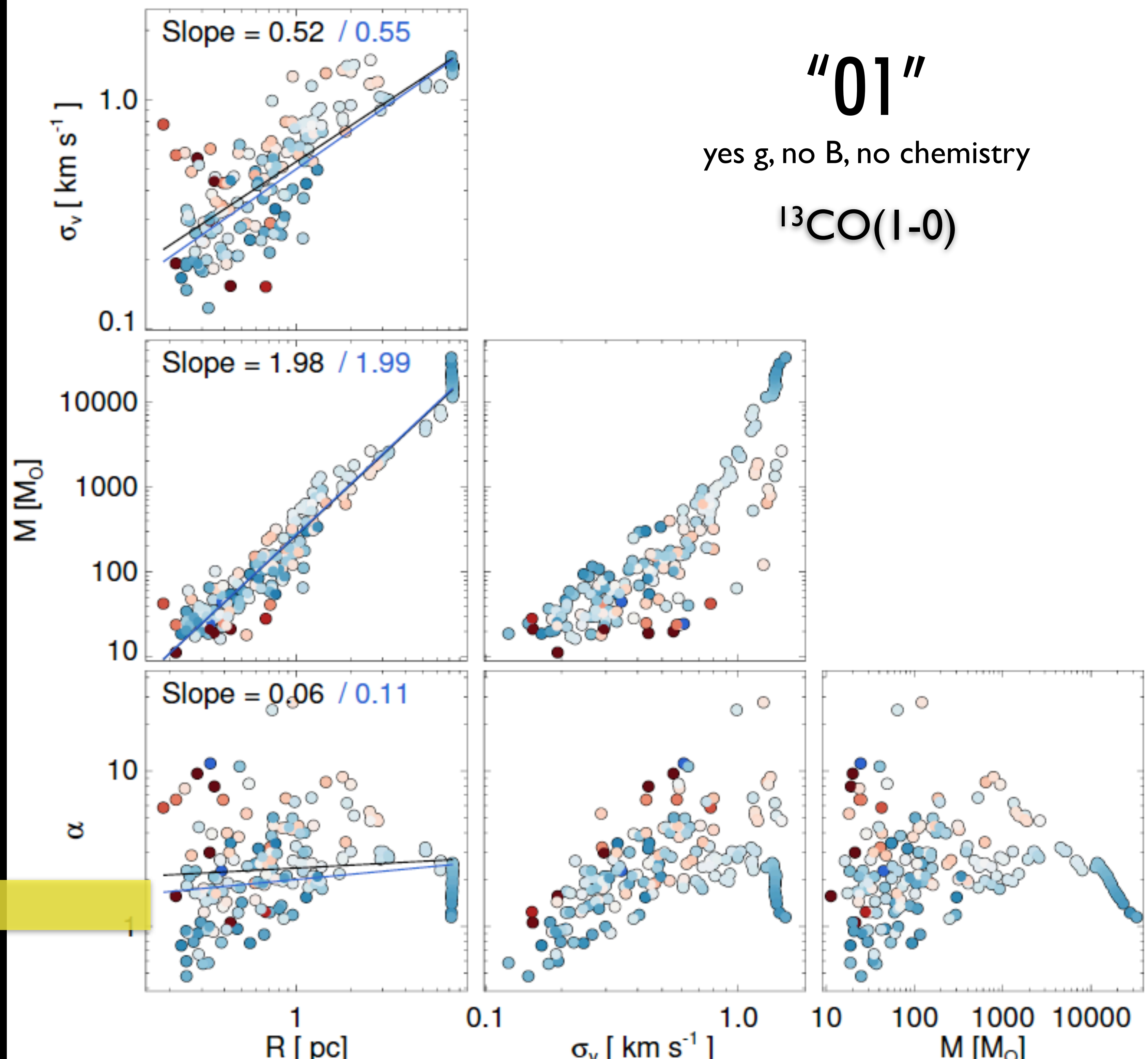
α_{vir} $(=5\sigma_v^2 R/M_{lum})$

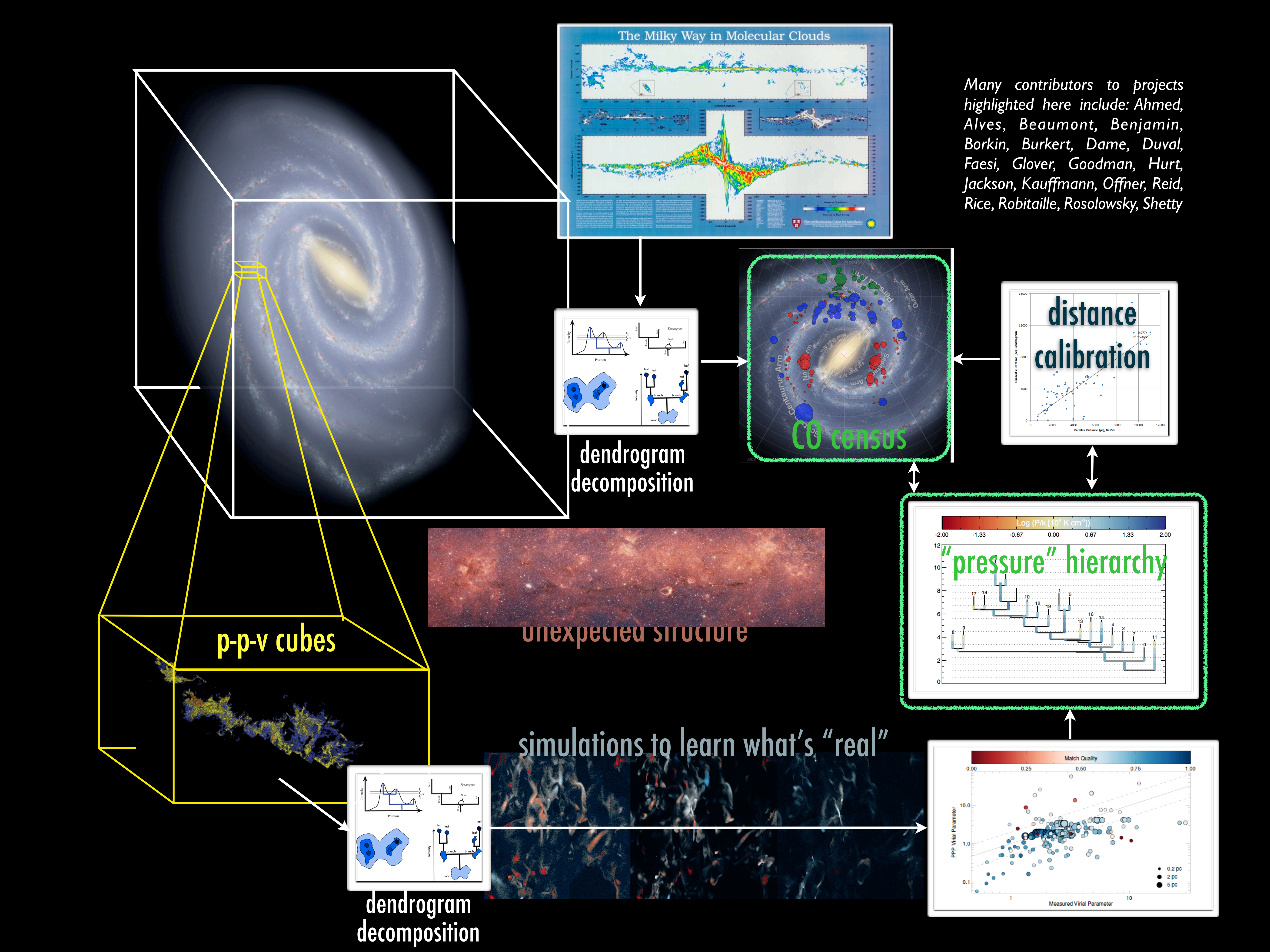
so, note, then if $M \sim R^2$,

$\alpha_{vir} \sim \sigma_v^2/R$



Heyer et al. 2009




The Milky Way in Molecular Clouds
Many contributors to projects highlighted here include: Ahmed, Alves, Beaumont, Benjamin, Borkin, Burkert, Dame, Duval, Faesi, Glover, Goodman, Hurt, Jackson, Kauffmann, Offner, Reid, Rice, Robitaille, Rosolowsky, Shetty
dendrogram decomposition
CO census
distance calibration
"pressure" hierarchy
Log (P/k [10^4 K cm^-3])
p-p-v cubes
unexpected structure
simulations to learn what's "real"
Match Quality
PPP Virial Parameter
Measured Virial Parameter
dendrogram decomposition

Role of Pressure
(..can we measure it?)

Contributors to projects highlighted here include Beaumont, Borkin, Faesi, Glover, Goodman, Offner, Shetty

OBSERVED "Pressure" = $P = \rho\sigma_v^2$

density (ρ) is derived from column density (N), which is derived from CO luminosity & "X-factor" assumptions

1-D **velocity dispersion** (σ_v) is taken to be 2nd moment of velocity along the line of sight. (Can also assume 3D=$3^{1/2}\sigma_v$.)

Operationally

$$\rho = (6.7\mu m_H L X_{CO})/(\sqrt{\pi} * r)^3$$

$$r = 1.91\sqrt{x_{rms} y_{rms}}$$

$$\sigma_v^2 = \sum_i (I_i(v_i - v_0)^2)/(\sum_i I_i)$$

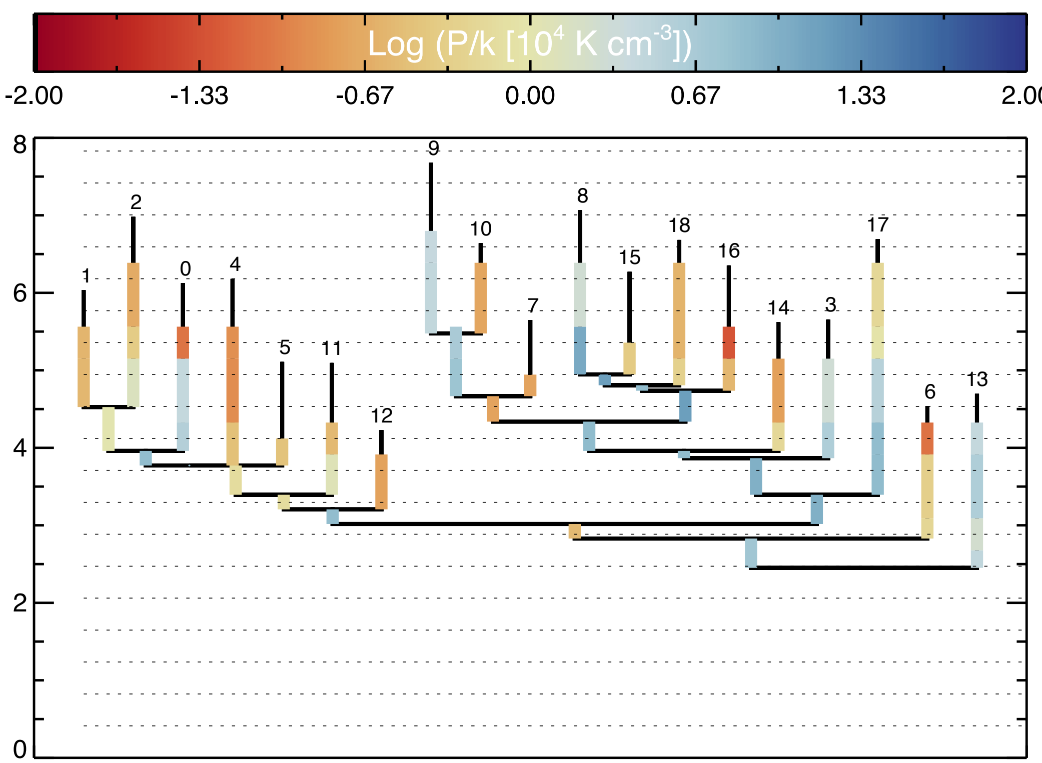
$$\sigma_v = \left[\frac{\sum(I_j v_j^2) - (\sum I_j v_j)^2/\sum(I_j)}{\sum(I_j)}\right]^{1/2}$$

^{13}CO “Pressure”-Encoded Dendrograms

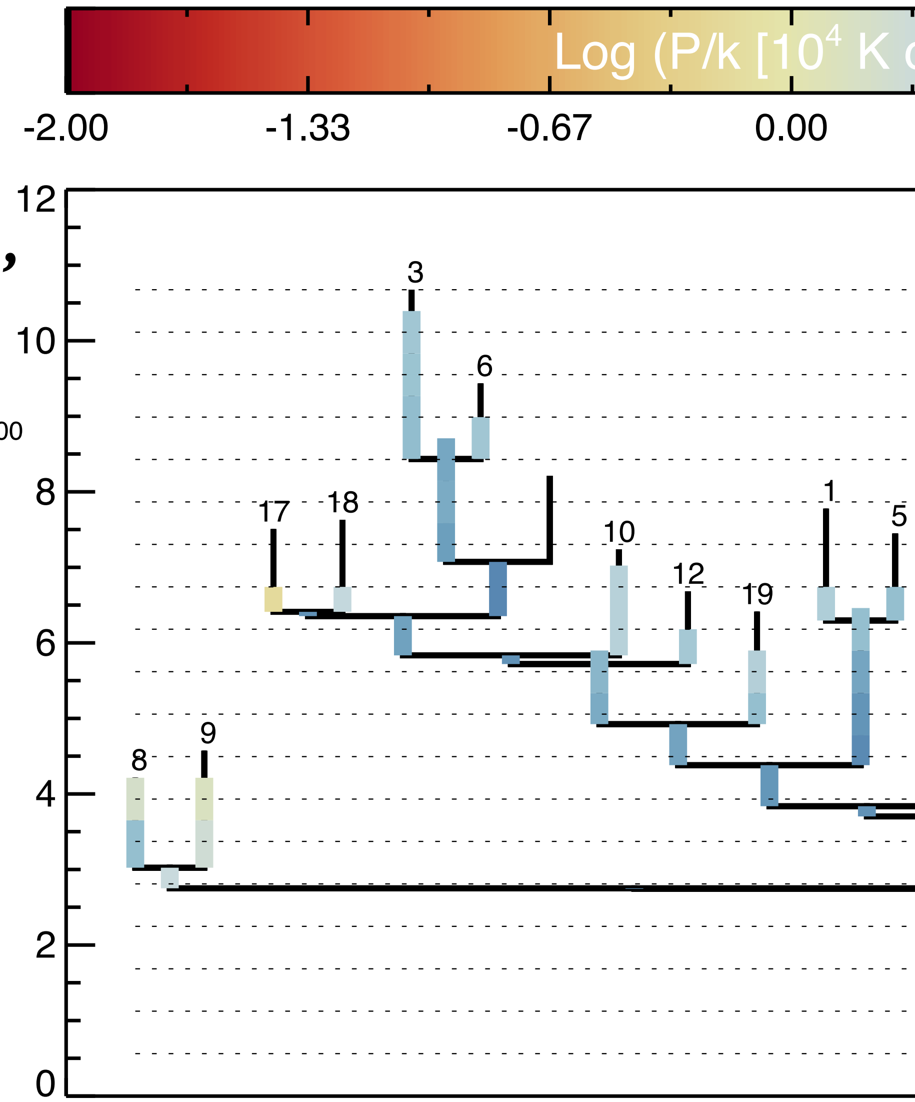
does pressure really “drop” at peaks? (unlikely!)

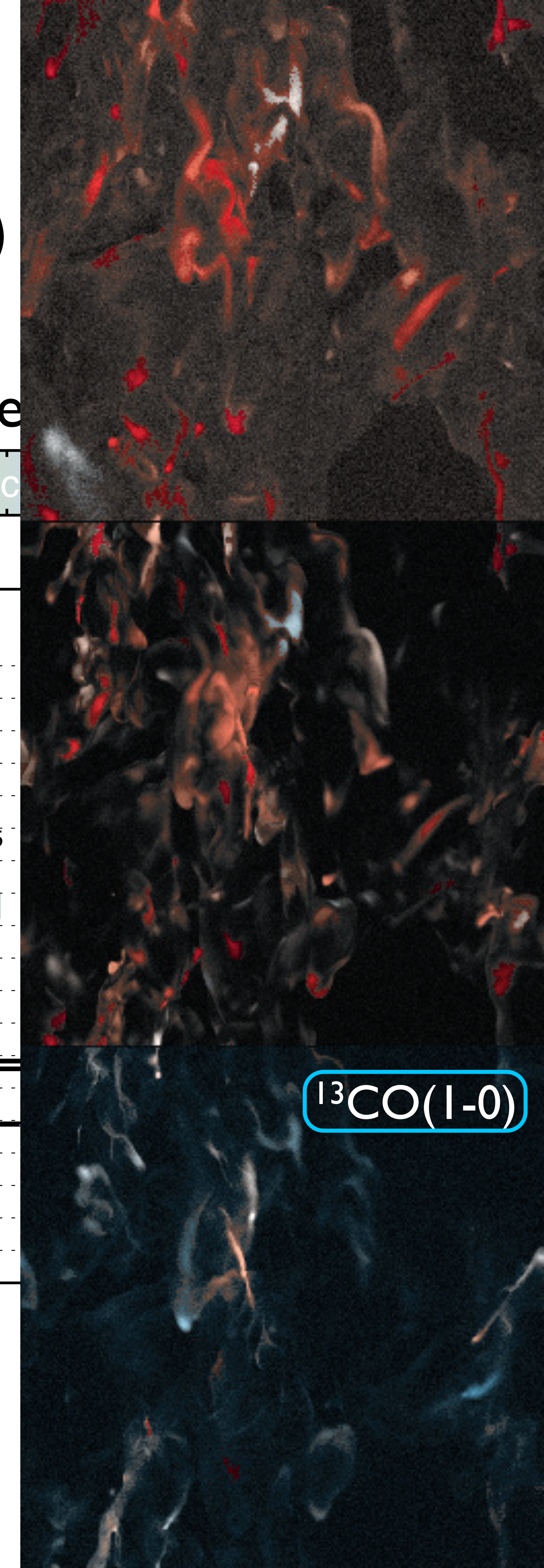
Simulation like “O1”

underluminious, under“pressured”

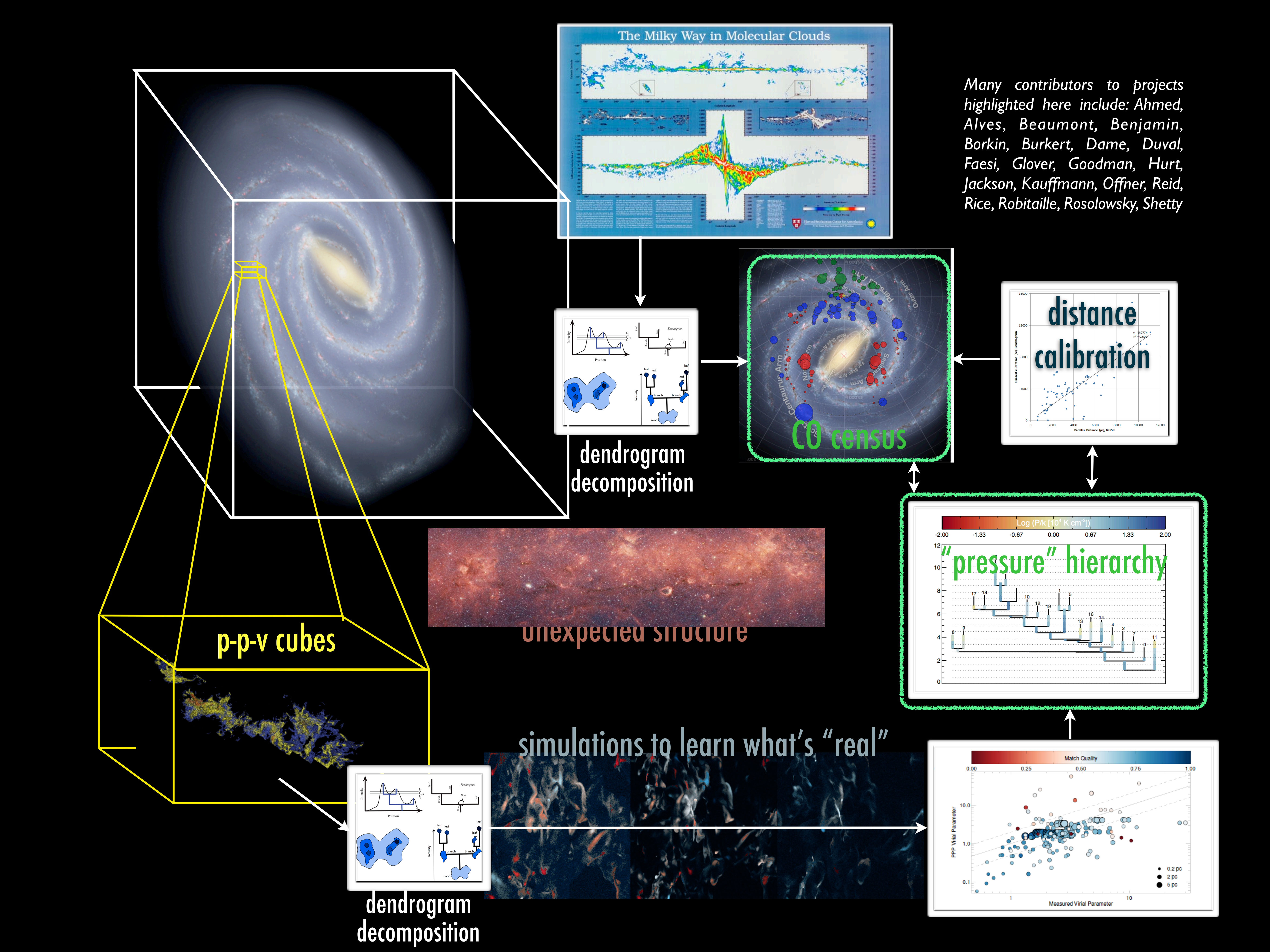


IC348 (cluster-forming re





Faesi, Offner, Beaumont & Goodman 2014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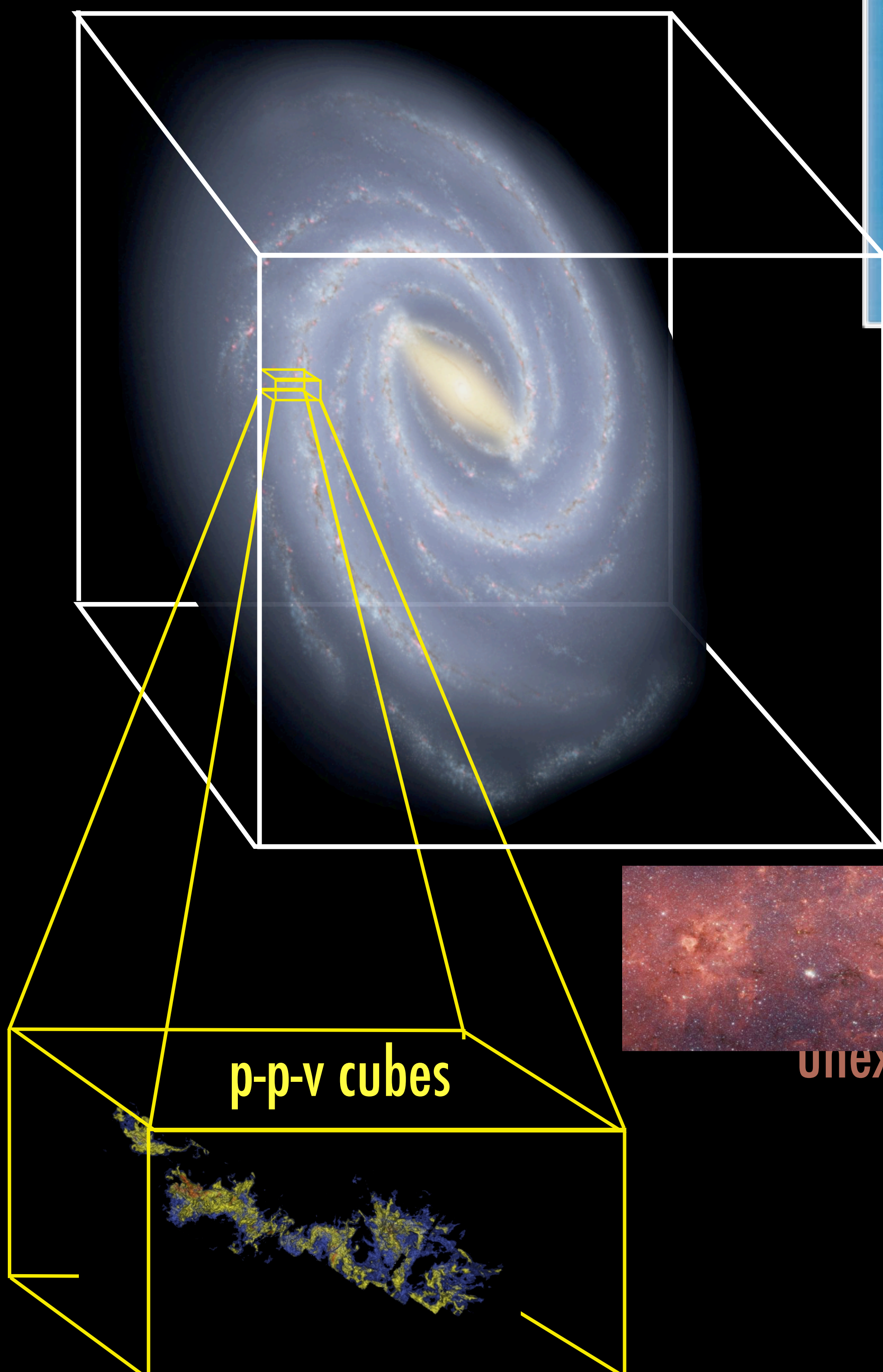

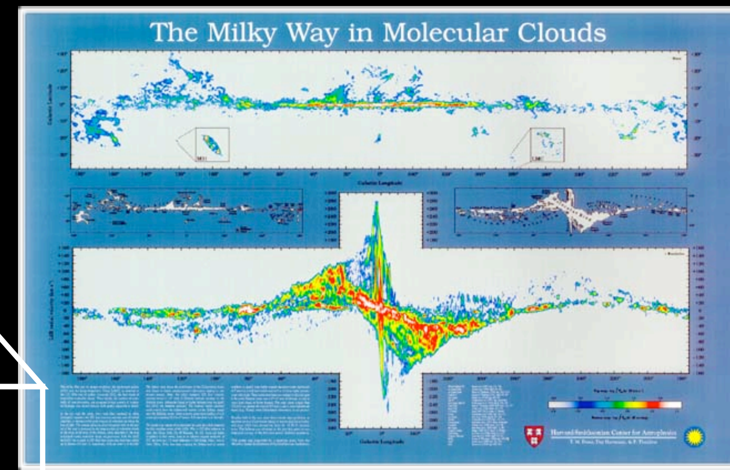

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Unexpected Structure

Authorea

BROWSE ABOUT CONTACT PLANS HELP FEEDBACK ALYSSA GOODMAN

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- Significance
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The Bones of the Milky Way

Alyssa Goodman, Joao Alves, Chris Beaumont, Tom Dame, James Jackson, Jens Kauffmann, Thomas Robitaille, Alberto Pepe, Michelle Borkin, Andreas Burkert, Bob Benjamin

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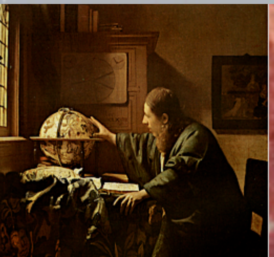
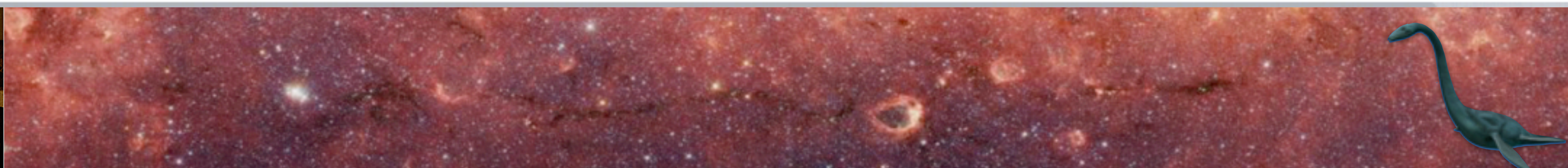
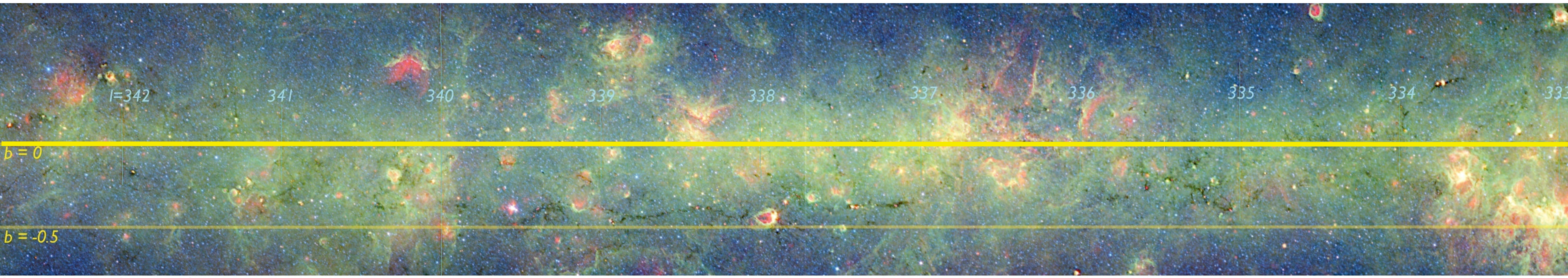
Abstract. The very long, thin infared dark cloud ``Nessie" is even longer than had been previously claimed, and an analysis of its Galactic location suggests that it lies directly in the Milky Way's mid-plane, tracing out a highly elongated bone-like feature within the prominent Scutum-Centaurus spiral arm. Re-analysis of mid-infrared imagery from the Spitzer Space Telescope shows that this IRDC is at least 2, and possibly as many as 8 times longer than had originally been claimed by Nessie's discoverers, Jackson et al. (2010); its aspect ratio is therefore at least 150:1, and possibly as large as 800:1. A careful accounting for both the Sun's offset from the Galactic plane (~ 25 pc) and the Galactic center's offset from the $(l^{II}, b^{II}) = (0,0)$ position defined by the IAU in 1959 shows that the latitude of the true Galactic mid-plane at the 3.1 kpc distance to the Scutum-Centaurus Arm is not $b = 0$, but instead closer to $b = -0.5$, which is the latitude of Nessie to within a few pc. Apparently, Nessie lies *in* the Galactic mid-plane. An analysis of the radial velocities of low-density (CO) and high-density (NH_3) gas associated with the Nessie dust feature suggests that Nessie runs along the Scutum-Centaurus Arm in position-position-velocity space, which means it likely forms a dense 'spine' of the arm in real space as well. No galaxy-scale simulation to date has the spatial resolution to predict a Nessie-like feature, but extant simulations do suggest that highly elongated over-dense filaments should be associated with a galaxy's spiral arms. Nessie is situated in the closest major spiral arm to the Sun toward the inner Galaxy, and appears almost perpendicular to our line of sight, making it the easiest feature of its kind to detect from our location (a shadow of an Arm's bone, illuminated by the Galaxy beyond). Although the Sun's offset from the Galactic plane is not significant compared with the thickness of the plane as traced by Population I objects such as GMCs and HII regions, it may be significant compared with an extremely thin layer that might be traced out by Nessie-like objects. Future high-resolution extinction and molecular line data may therefore allow us to exploit the Sun's position above the plane to gain a small amount of perspective on the Galactic disk.



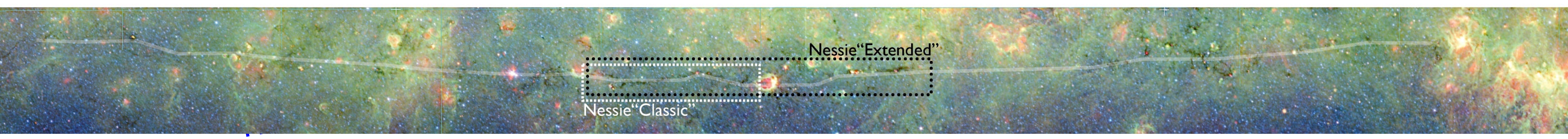


“Is Nessie Parallel to the Galactic Plane?”–A. Burkert, Ringberg 2013

Why b<0?!
Galactic Geometry: 1959 and Now

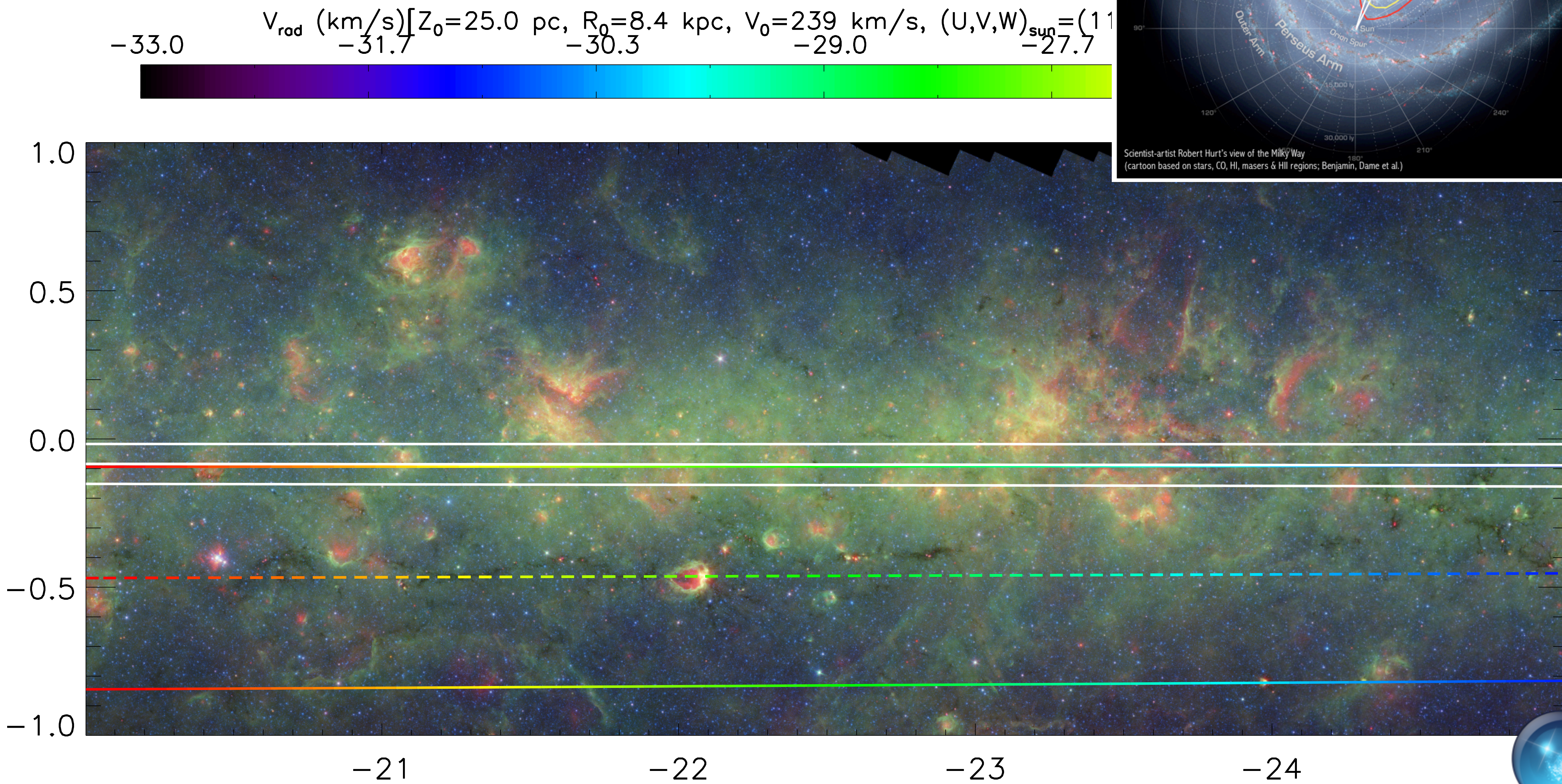


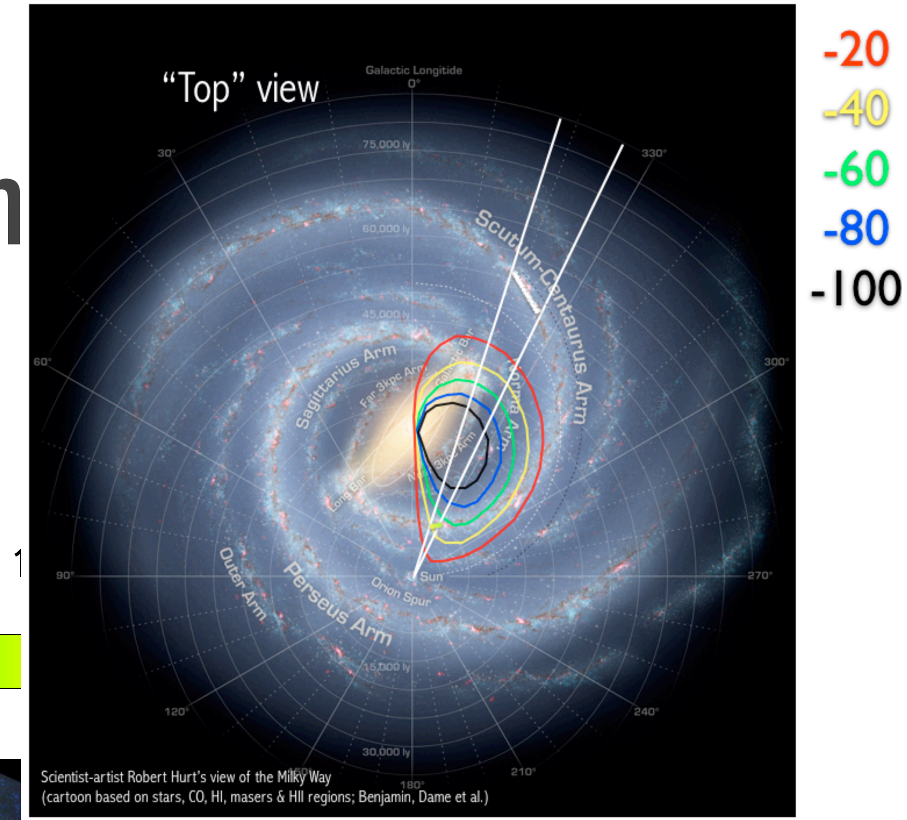
1 degree ~ 60 pc at 3.5 kpc



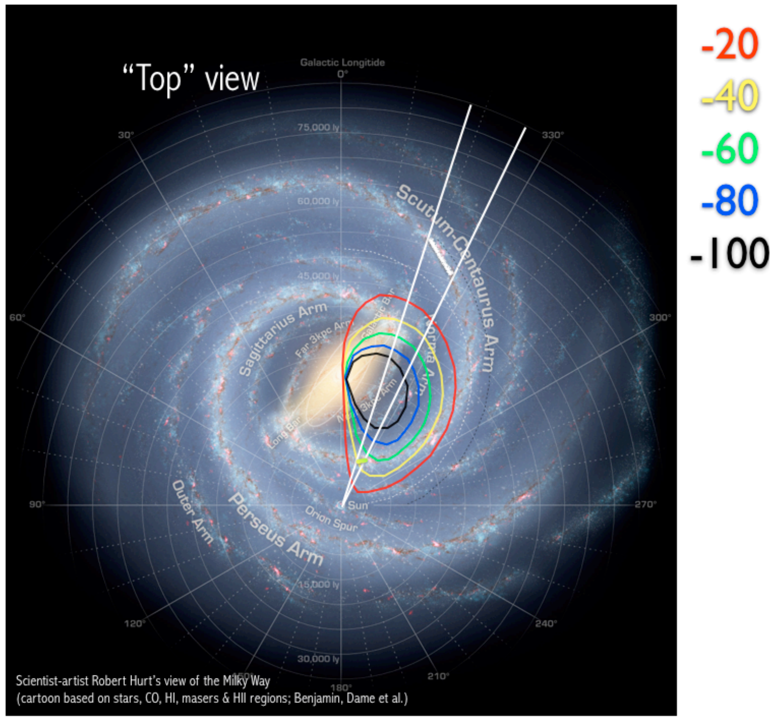
> The equatorial plane of the new co-ordinate system must of necessity pass through the sun. It is a fortunate circumstance that, within the observational uncertainty, both the sun and Sagittarius A lie in the mean plane of the Galaxy as determined from the hydrogen observations. If the sun had not been so placed, points in the mean plane would not lie on the galactic equator.
>
> *[Blaauw et al. 1959]*

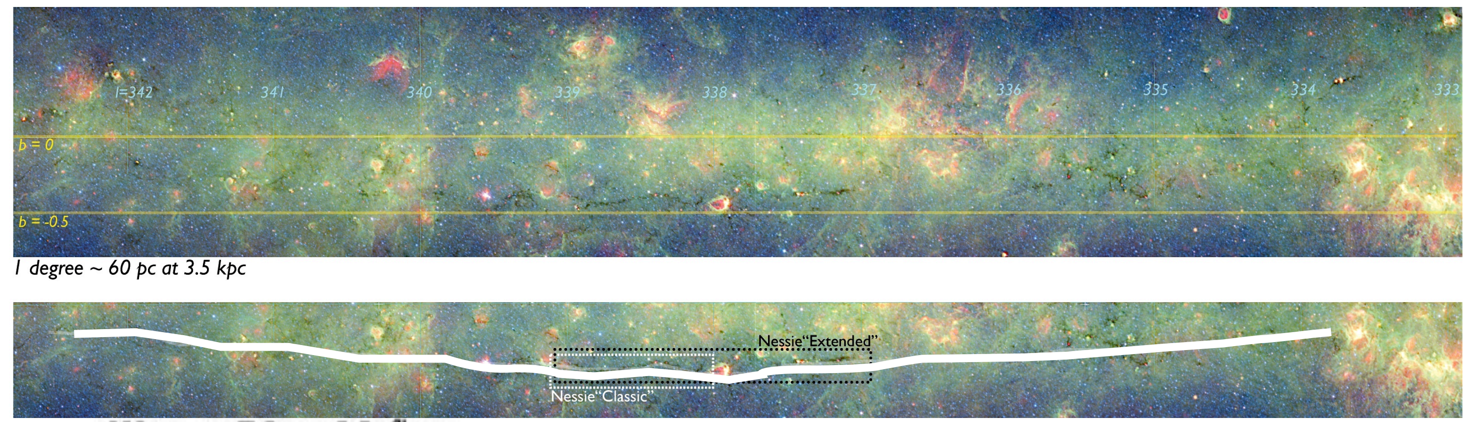
Predicted Near & Far Scutum-Centaurus Arm

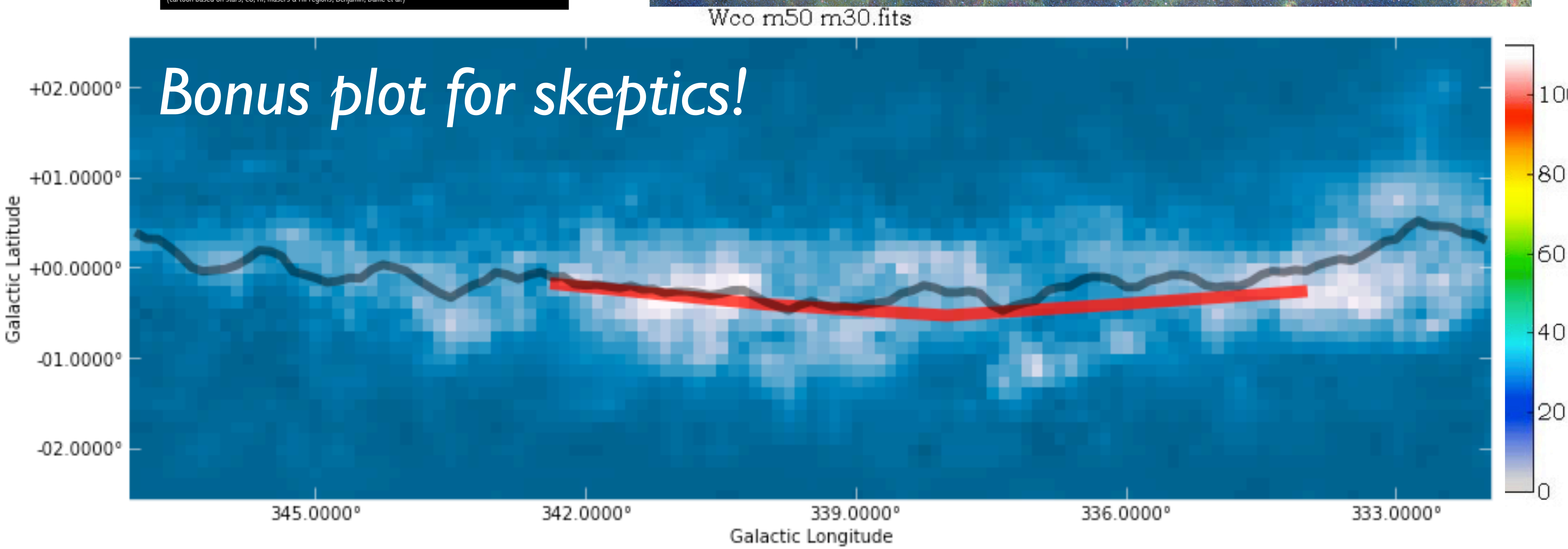




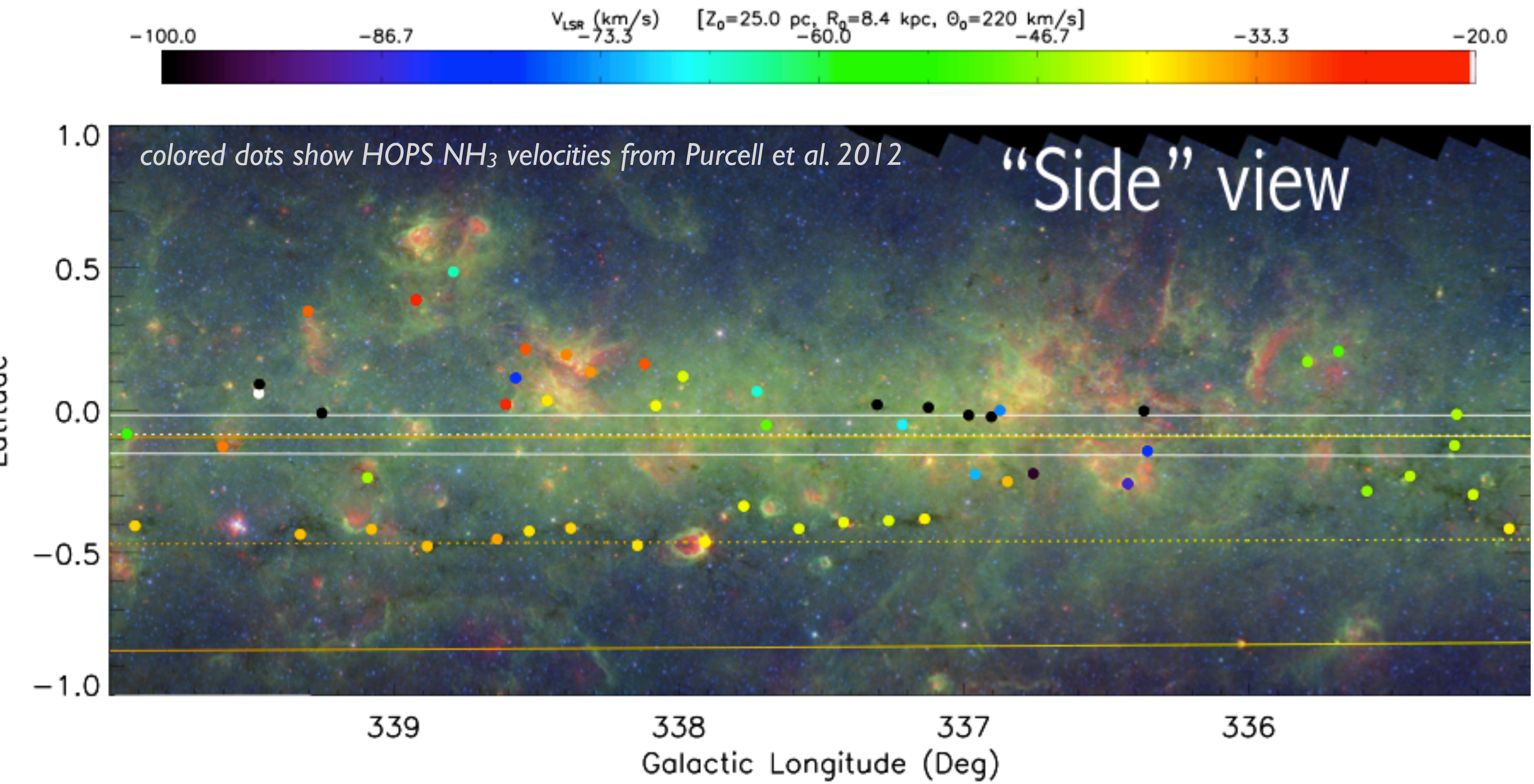
Velocity Constraints



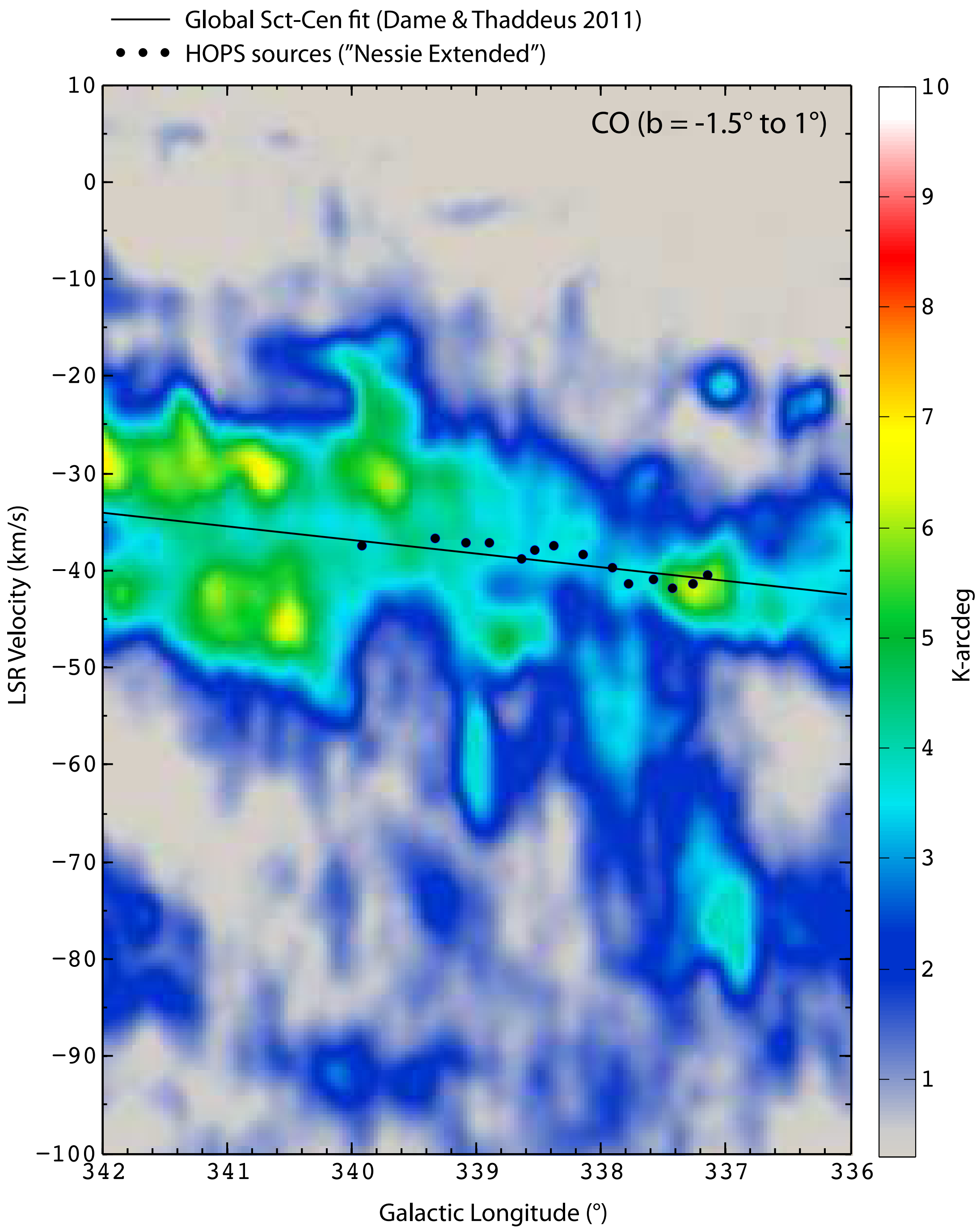




Predicted Velocities match NH_3 Cores in Nessie Perfectly

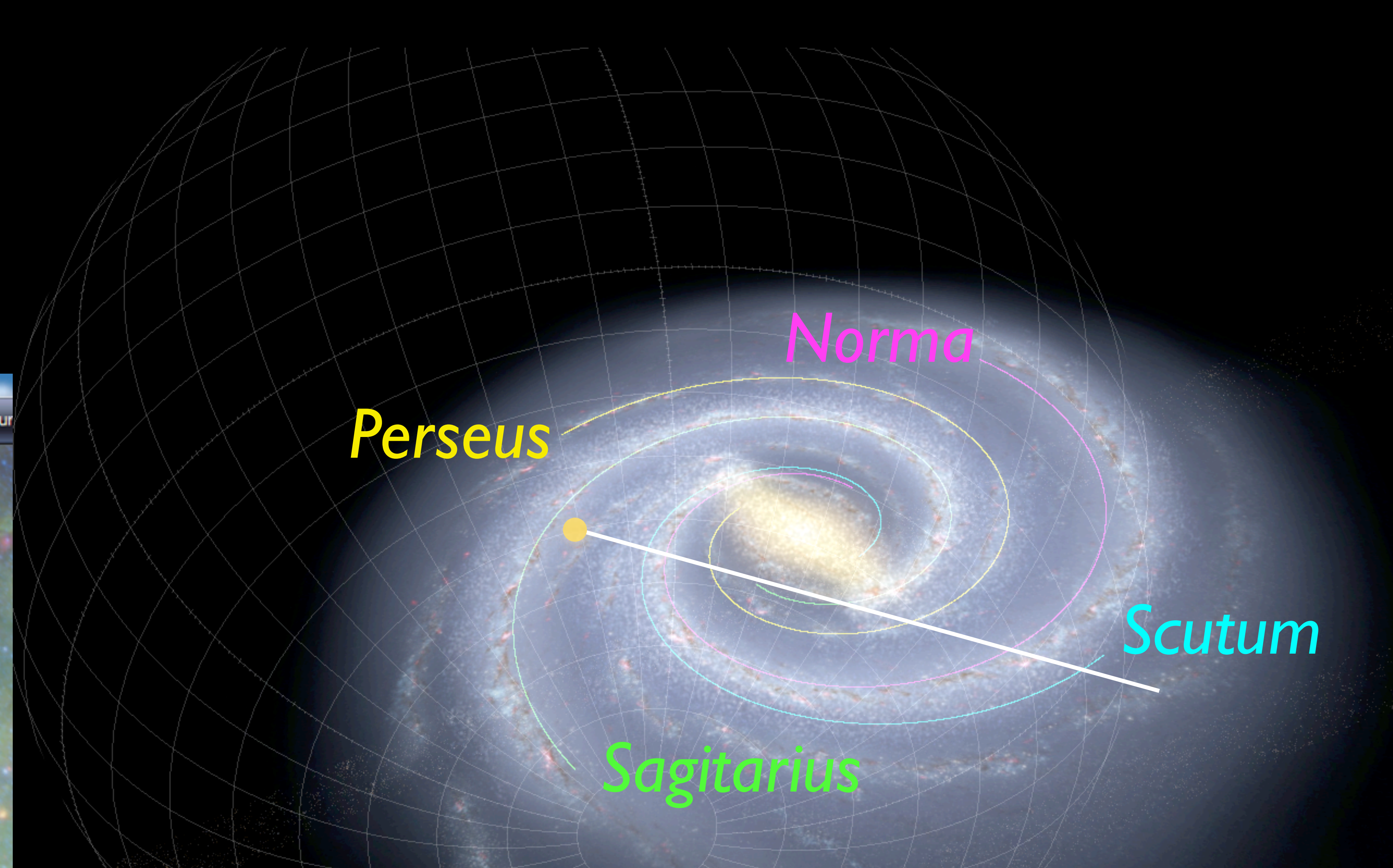


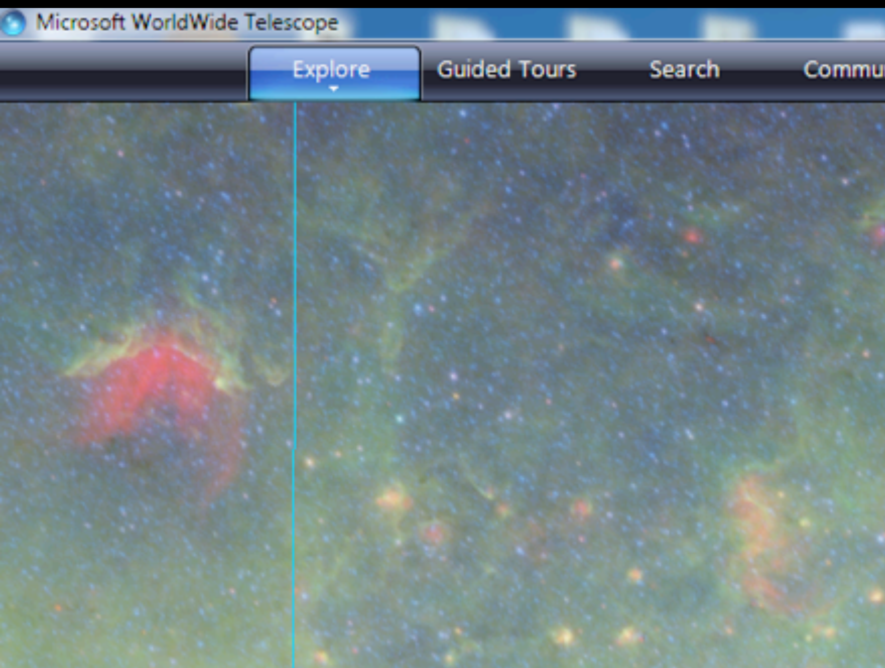
Predicted Velocities match NH_3 Cores in Nessie Perfectly

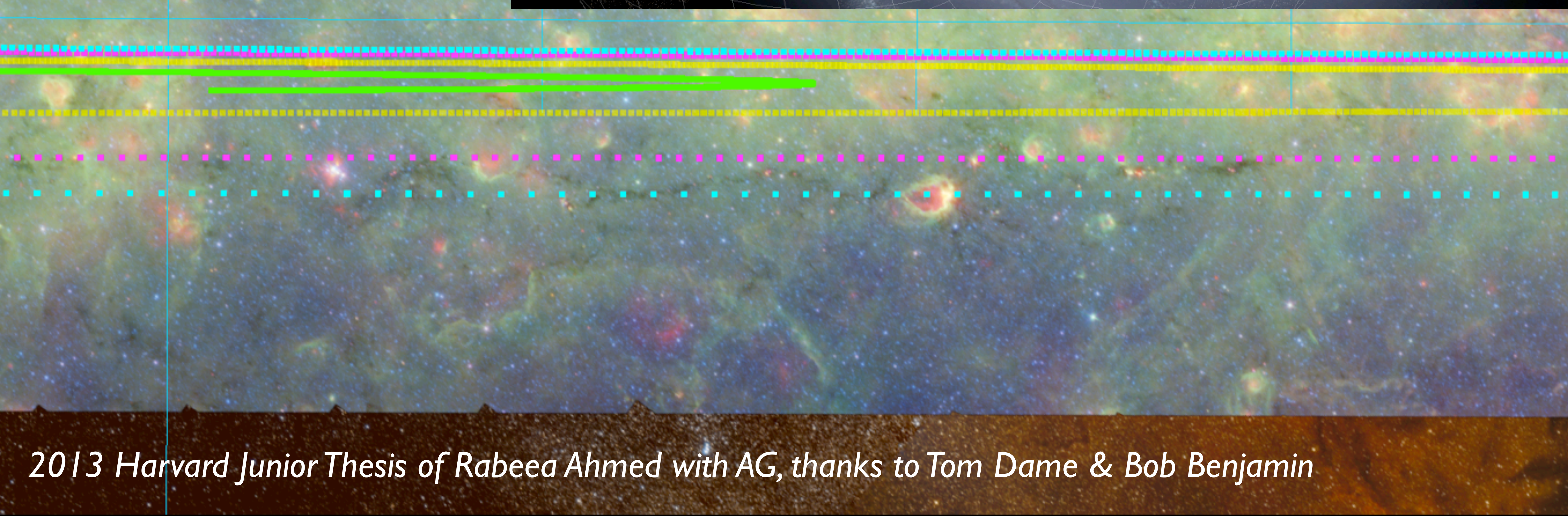


black dots show HOPS NH_3 velocities from Purcell et al. 2012; color is CO; line is log-spiral fit to full Scut-Cen Arm

Other Arms?
Other Nessies?



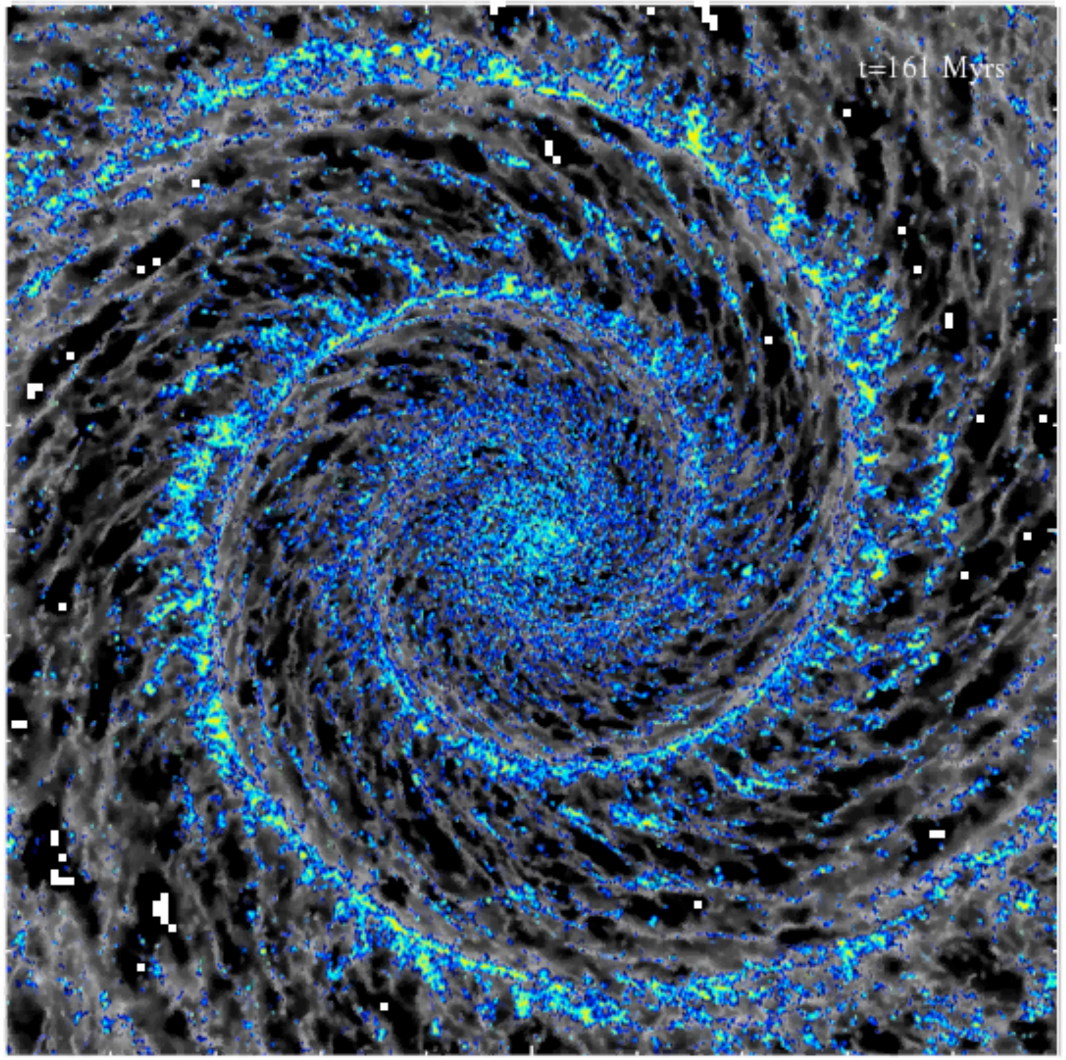


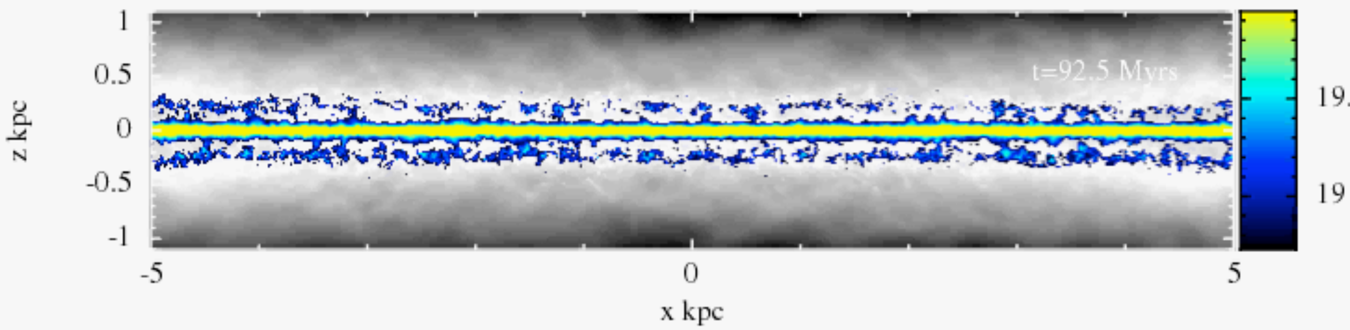


2013 Harvard Junior Thesis of Rabeea Ahmed with AG, thanks to Tom Dame & Bob Benjamin

What's a bone?

(flipped) image of IC342 from Jarrett et al. 2012; WISE Enhanced Resolution Galaxy Atlas



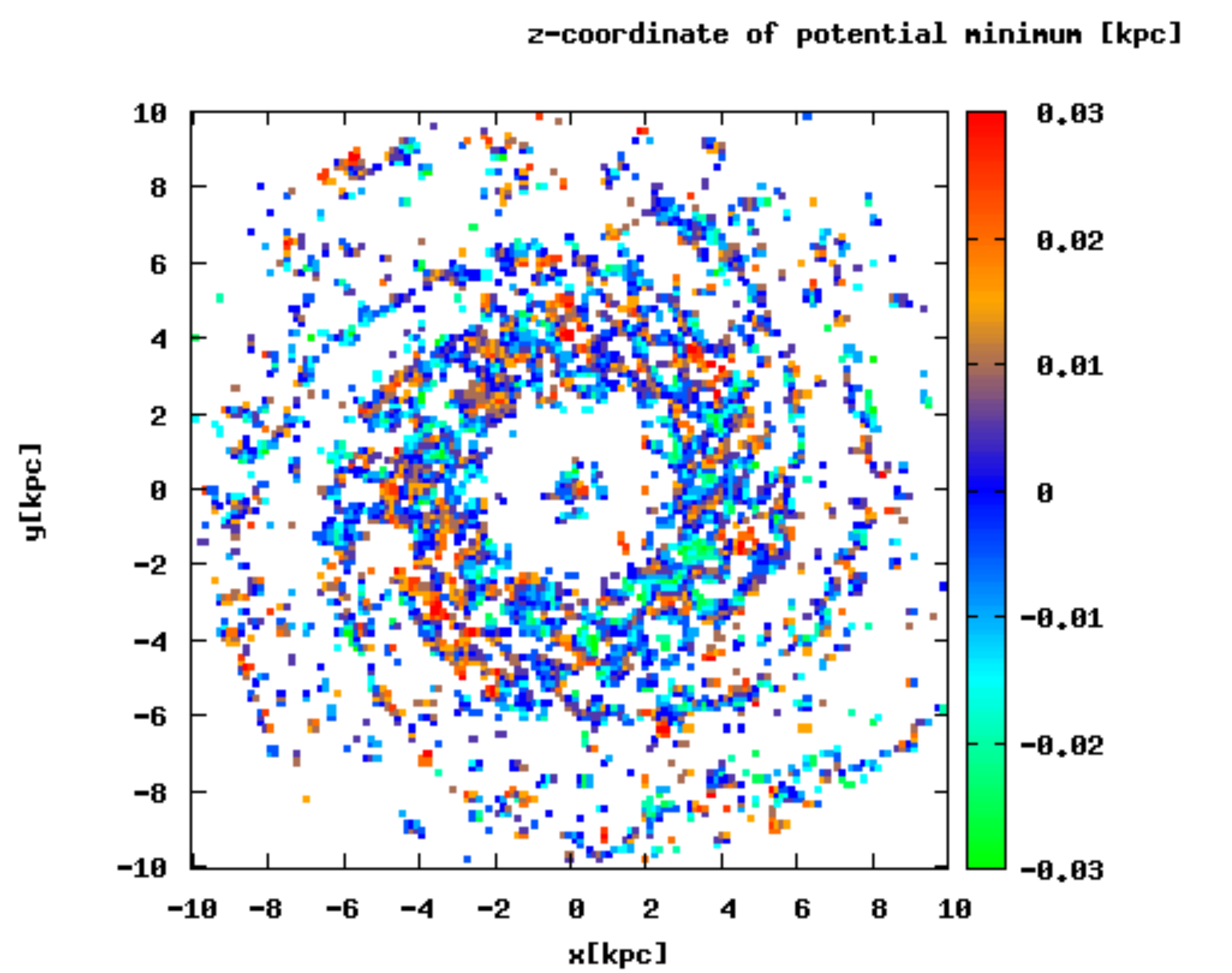


Dobbs & Pringle 2013

What's a bone?

(flipped) image of IC342 from Jarrett et al. 2012; WISE Enhanced Resolution Galaxy Atlas

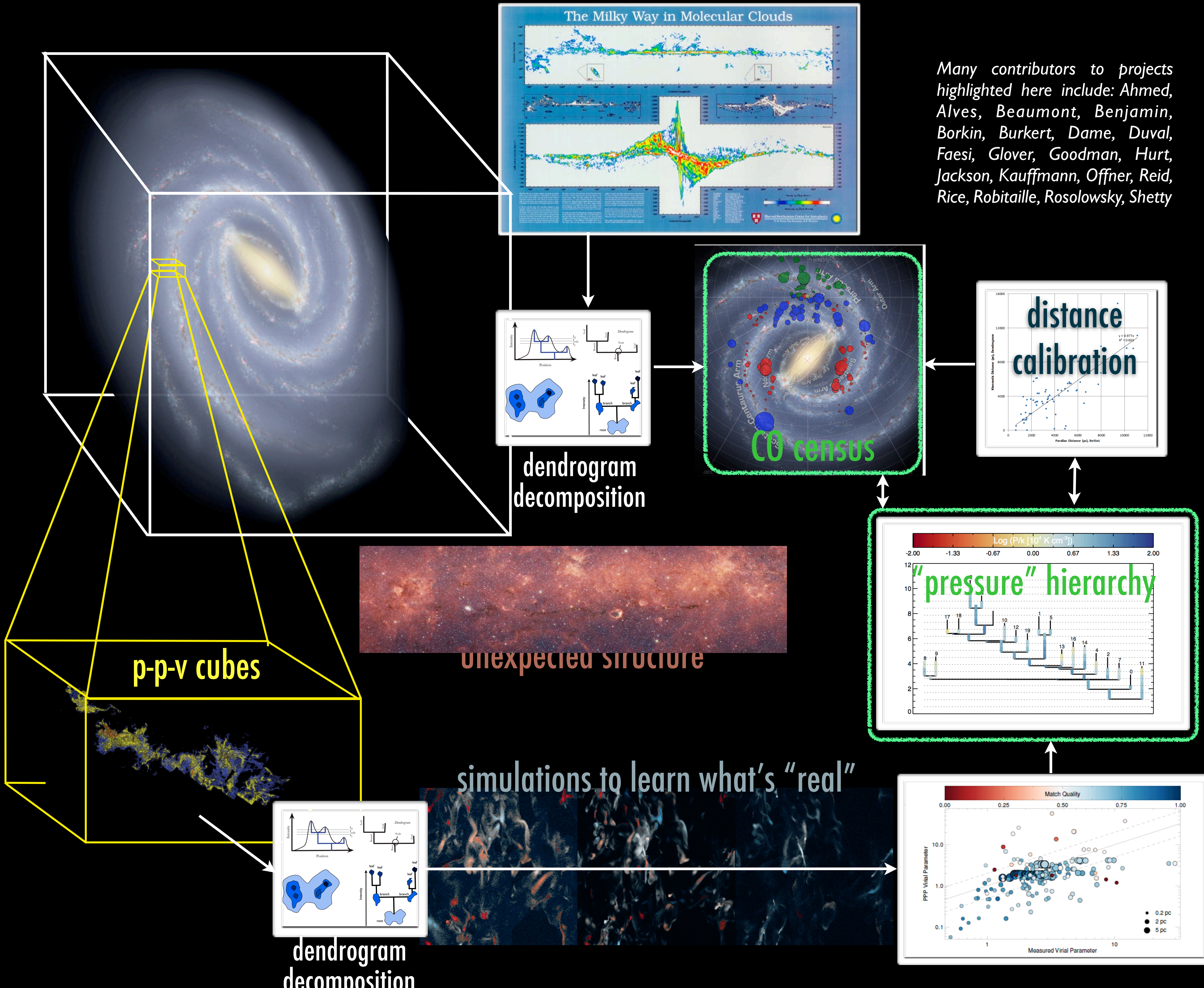
What does Nessie mark?



new (June 2013) simulation by Andi Burkert et al., "inspired" by Nessie, but still not high-enough resolution...

Andi says we need 1 billion particles to see Nessies...ask him tomorrow?!

Many contributors to projects highlighted here include: Ahmed, Alves, Beaumont, Benjamin, Borkin, Burkert, Dame, Duval, Faesi, Glover, Goodman, Hurt, Jackson, Kauffmann, Offner, Reid, Rice, Robitaille, Rosolowsky, Shetty



What lies within?

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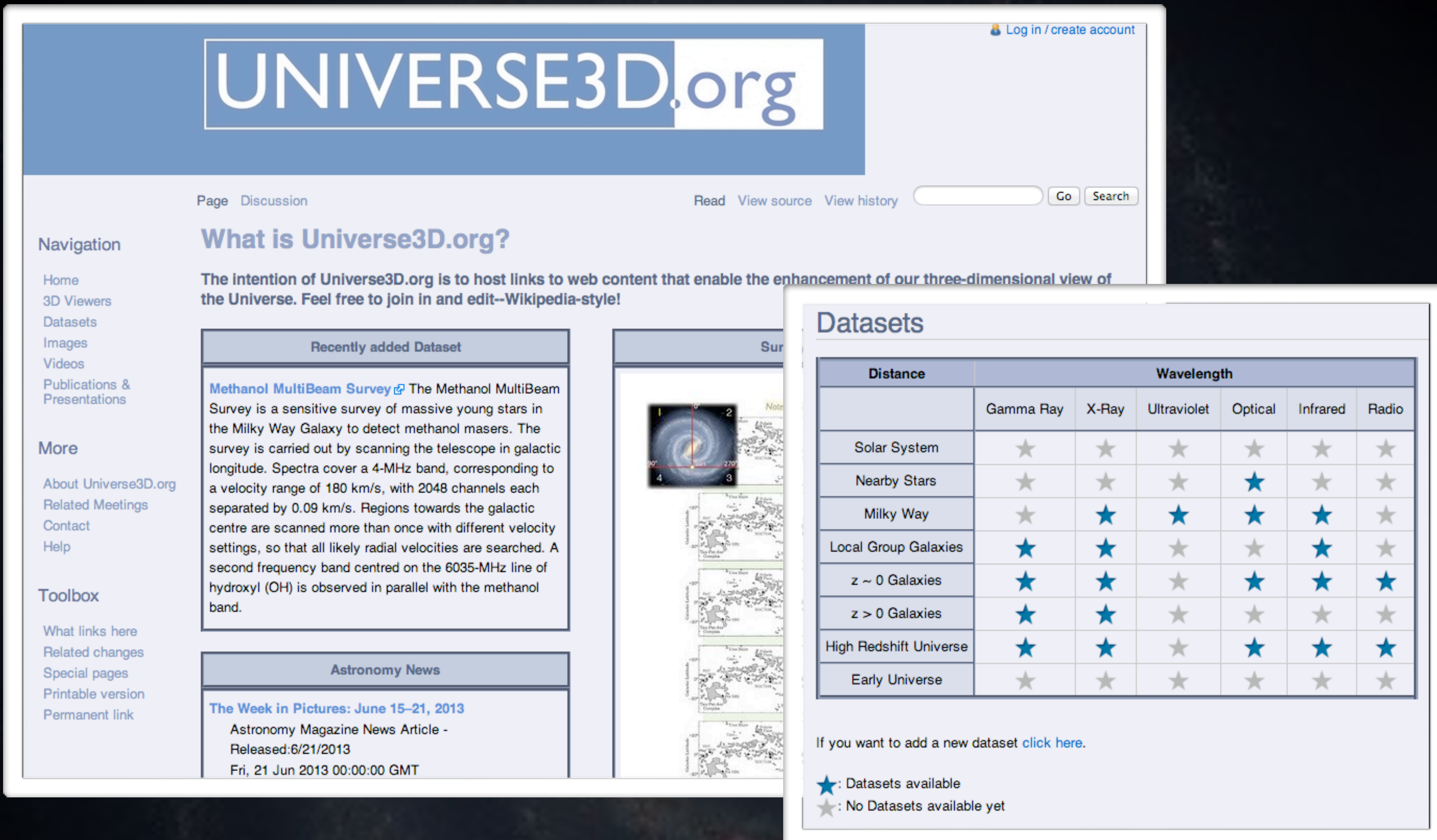

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Recently added Dataset

Methanol MultiBeam Survey The Methanol MultiBeam Survey is a sensitive survey of massive young stars in the Milky Way Galaxy to detect methanol masers. The survey is carried out by scanning the telescope in galactic longitude. Spectra cover a 4-MHz band, corresponding to a velocity range of 180 km/s, with 2048 channels each separated by 0.09 km/s. Regions towards the galactic centre are scanned more than once with different velocity settings, so that all likely radial velocities are searched. A second frequency band centred on the 6035-MHz line of hydroxyl (OH) is observed in parallel with the methanol band.

Astronomy News

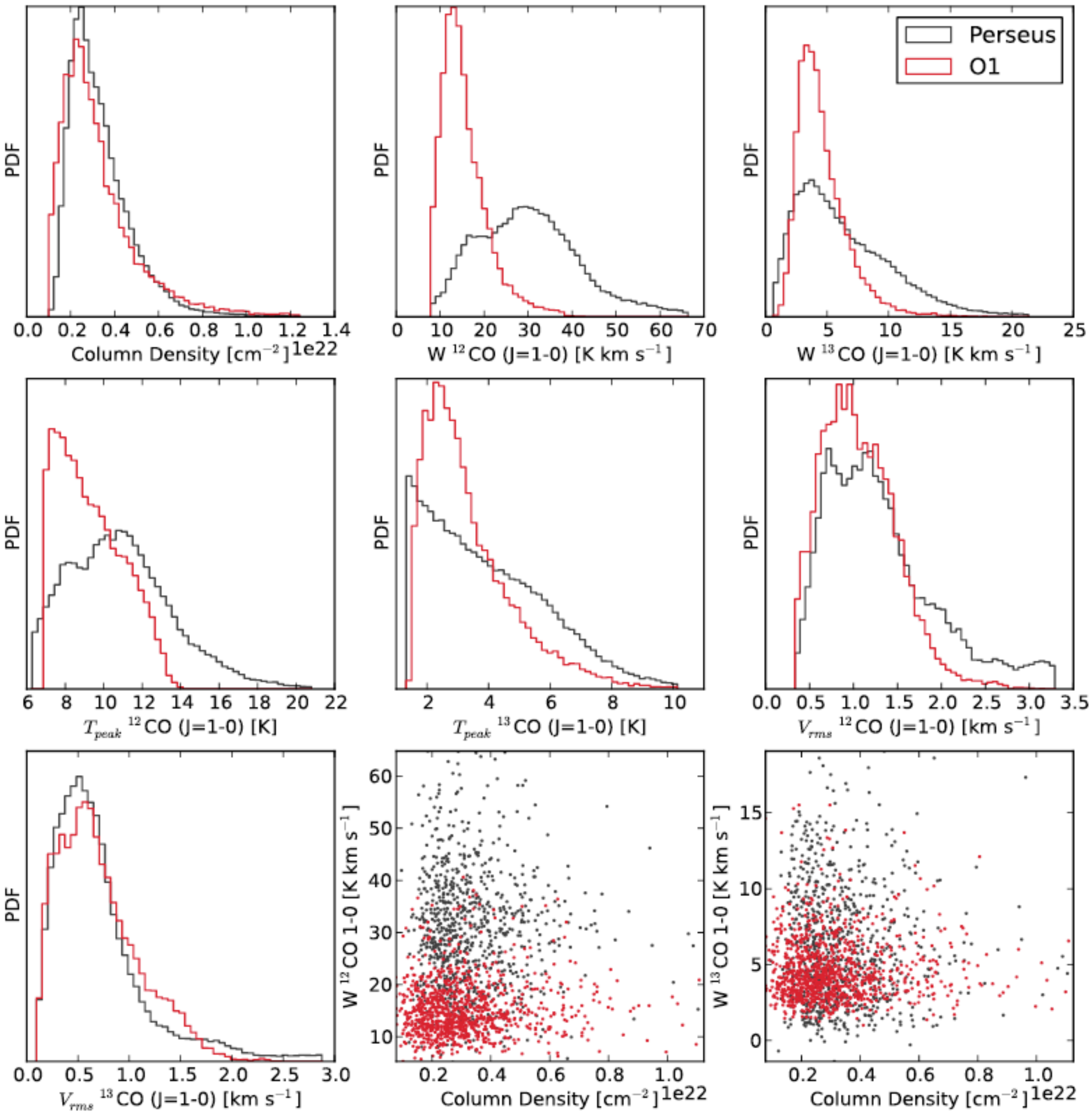
The Week in Pictures: June 15–21, 2013
Astronomy Magazine News Article - Released:6/21/2013
Fri, 21 Jun 2013 00:00:00 GMT

Datasets

Distance	Wavelength					
	Gamma Ray	X-Ray	Ultraviolet	Optical	Infrared	Radio
Solar System	☆	☆	☆	☆	☆	☆
Nearby Stars	☆	☆	☆	★	☆	☆
Milky Way	☆	★	★	★	★	☆
Local Group Galaxies	★	★	☆	☆	★	☆
z ~ 0 Galaxies	★	★	☆	★	★	★
z > 0 Galaxies	★	★	☆	☆	☆	☆
High Redshift Universe	★	★	☆	★	★	★
Early Universe	☆	☆	☆	☆	☆	☆

If you want to add a new dataset click here.

★: Datasets available
☆: No Datasets available yet



Perseus
O1
PDF
Column Density [cm^{-2}] 1e22
W ^{12}CO (J=1-0) [K km s^{-1}]
W ^{13}CO (J=1-0) [K km s^{-1}]
T_{peak} ^{12}CO (J=1-0) [K]
T_{peak} ^{13}CO (J=1-0) [K]
V_{rms} ^{12}CO (J=1-0) [km s^{-1}]
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W ^{12}CO 1-0 [K km s^{-1}]
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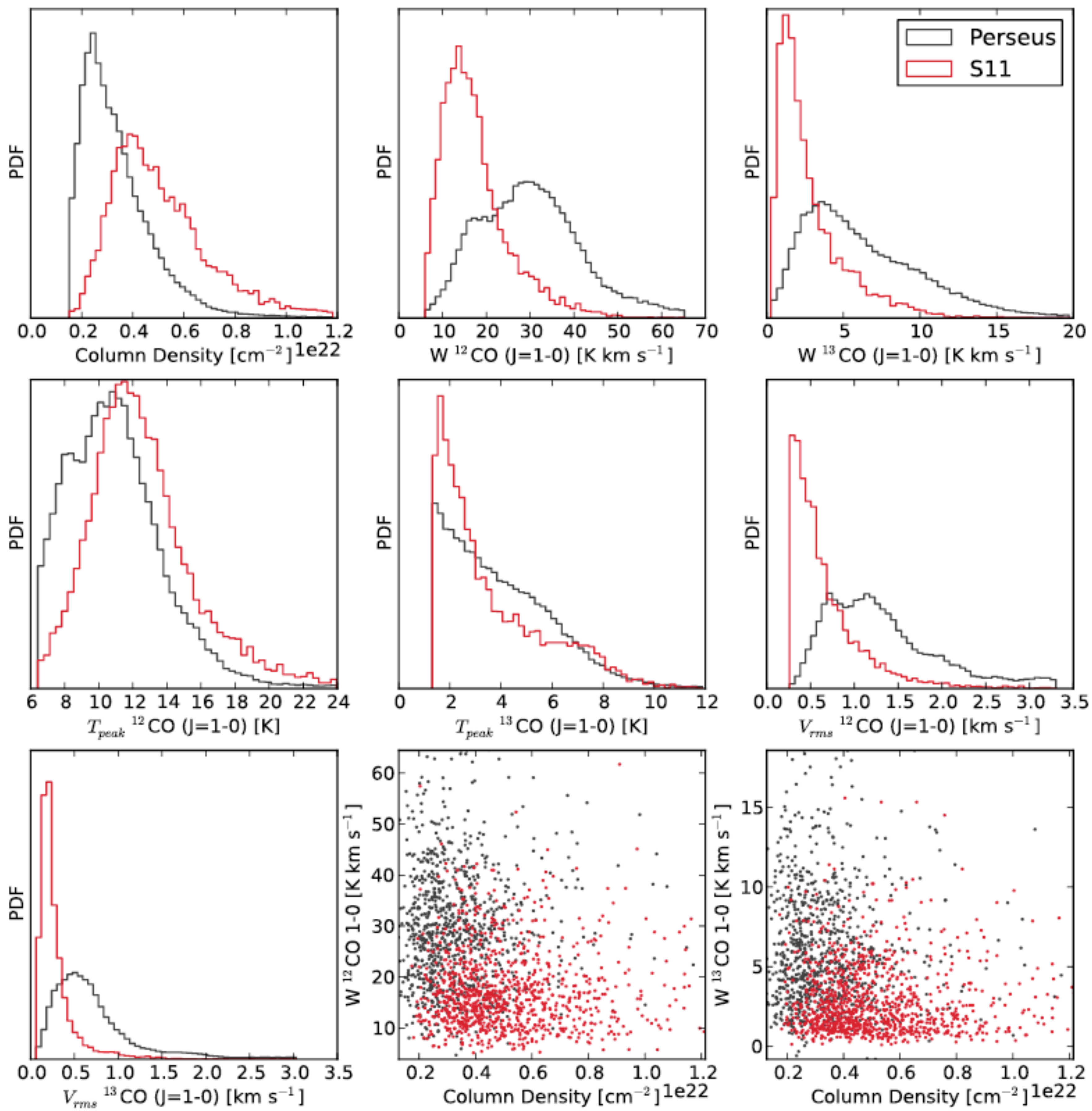

Perseus
S11
PDF
Column Density [cm^{-2}] 1e22
W ^{12}CO (J=1-0) [K km s^{-1}]
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T_{peak} ^{12}CO (J=1-0) [K]
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