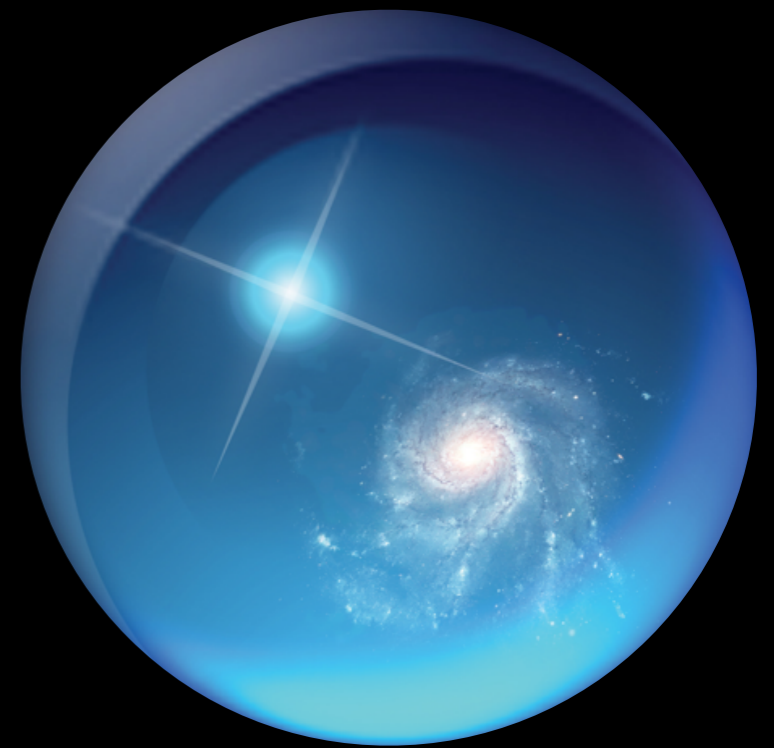


Orion in Context

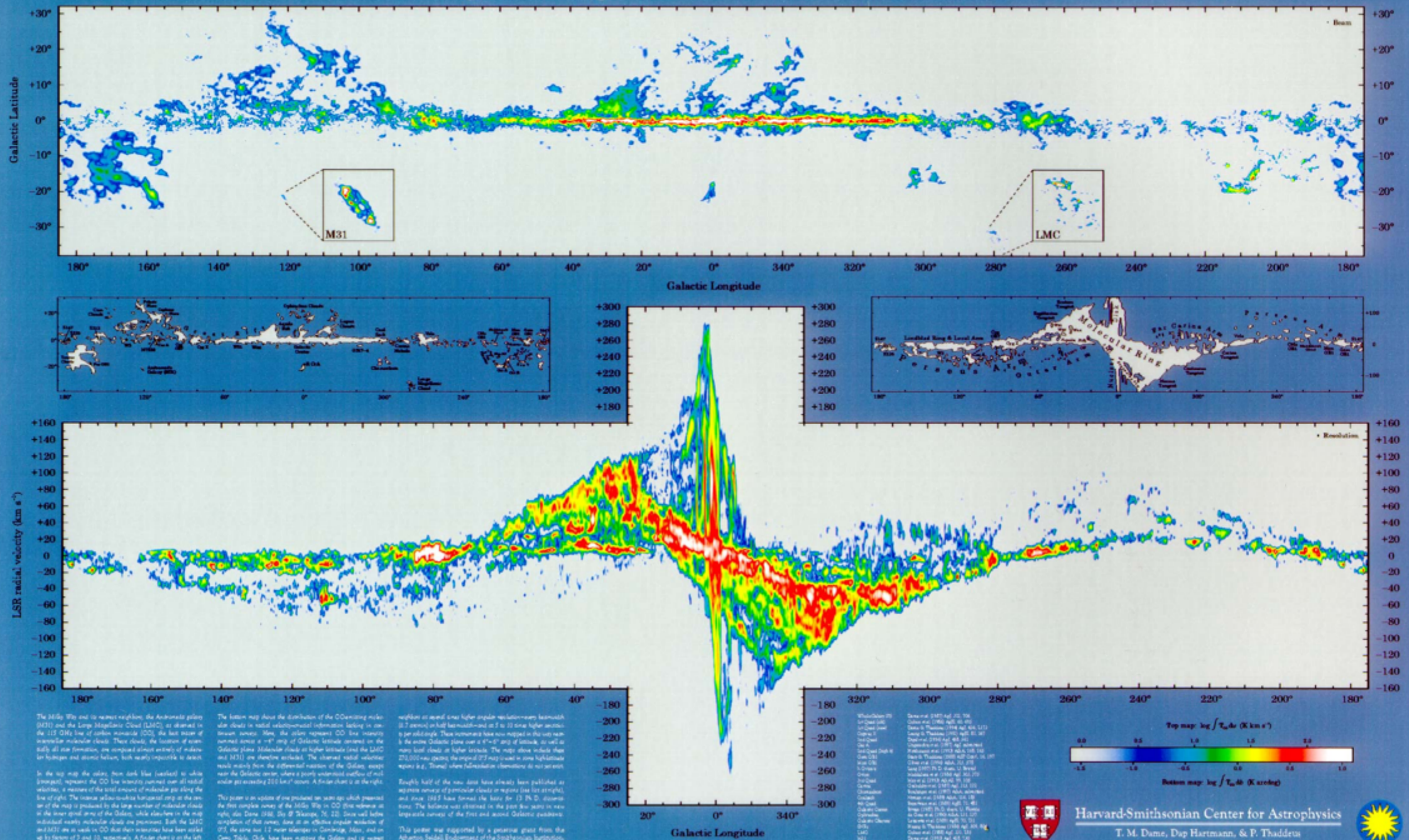
Alyssa A. Goodman
Harvard-Smithsonian
Center for Astrophysics



Please join me at the unplugged part of the meeting for (more) exploration of **Orion** in context using **WorldWide Telescope...** (or visit worldwidetelescope.org)



The Milky Way in Molecular Clouds



The Milky Way and its nearest neighbors, the Andromeda galaxy (M31) and the Large Magellanic Cloud (LMC), are observed in the 115 GHz line of carbon monoxide (CO), the best tracer of interstellar molecular clouds. These clouds, the factories of essentially all star formation, are composed almost entirely of molecules for hydrogen and helium, both nearly impossible to detect.

In the top map the colors, from dark blue (weakest) to white (strongest), represent the CO line intensity summed over all radial velocities, a measure of the total amount of molecular gas along the line of sight. The lowest radial-velocity horizontal strip at the center of the map is produced by the large number of molecular clouds in the inner spiral arm of the Galaxy, while elsewhere in the map individual nearby molecular clouds are prominent. Both the LMC and M31 are as weak in CO that their locations have been worked up by means of H and H₂, respectively. A further check is on the left.

The bottom map shows the distribution of the CO-emitting molecular clouds in radial-velocity-bin resolution lacking in conventional surveys. Here, the colors represent CO line intensity summed across a 10³ km/s range of Galactic longitude centered on the Galactic plane. Molecular clouds at higher latitudes (and the LMC and M31) are therefore excluded. The observed radial-velocity shift results mainly from the differential rotation of the Galaxy, except near the Galactic center, where a poorly understood outflow of molecular gas exceeding 100 km/s occurs. A further check is on the right.

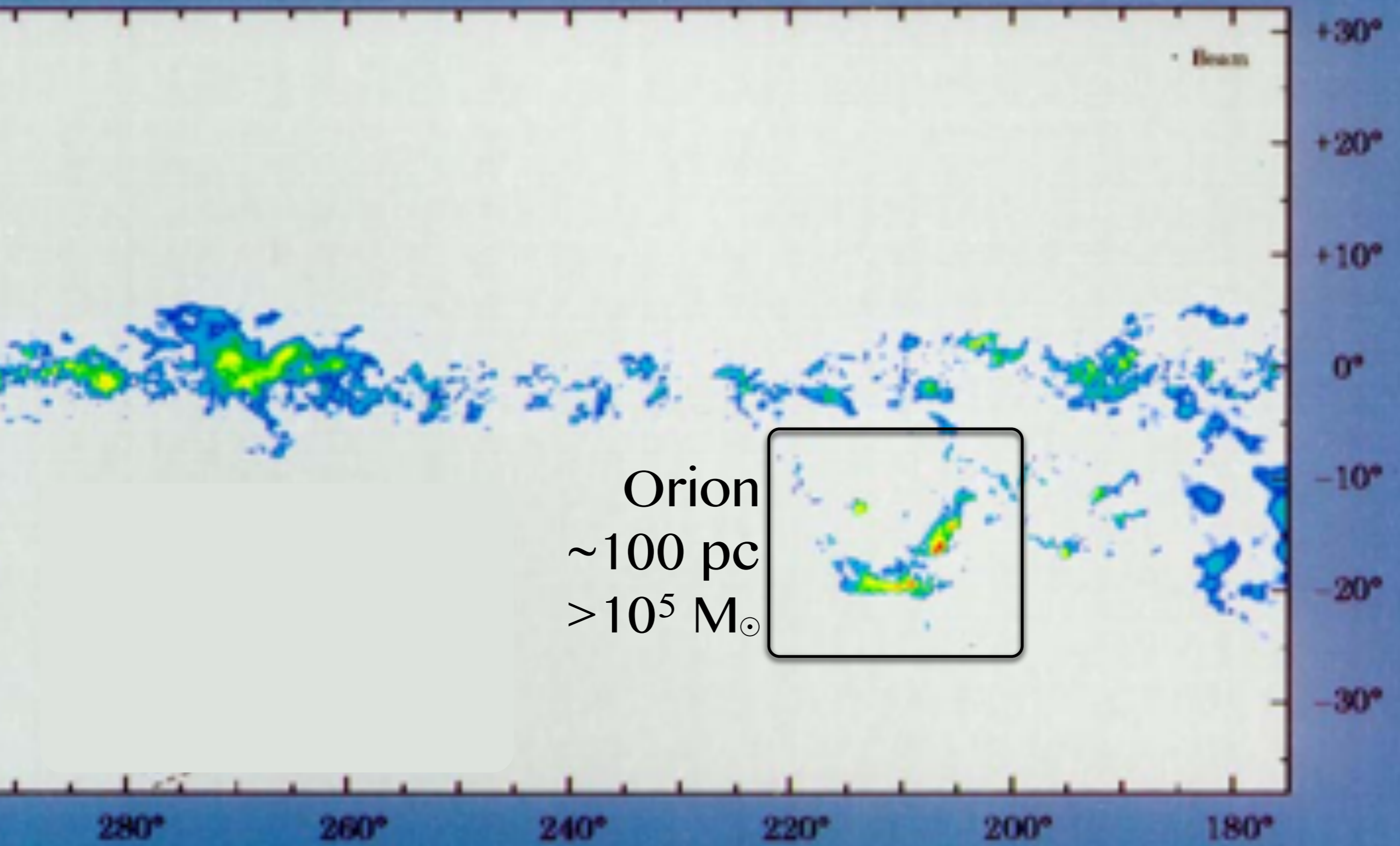
This paper is an update of one produced on warm up which presented the first complete survey of the Milky Way in CO since reference is made, also Dame (1986), De & Shklovski, 76, 23. Since well before completion of that survey, done at an effective angular resolution of 0.5', the same has 12 more telescopes in Cambridge, Mass., and on Ohio State, Ohio, have been mapping the Galaxy and its nearest

neighbors at several times higher angular resolution—many beamwidths (0.7 arcmin) or half beamwidth—and at 2 to 10 times higher resolution in per resolution. These improvements have now mapped in the very near to the entire Galactic plane over a 4°–4° strip of latitude, as well as many local clouds at higher latitudes. The maps above include those 250,000 new spectra, the original 257 maps used in some high-latitude regions (e.g., Throner) where full-resolution observations do not exist.

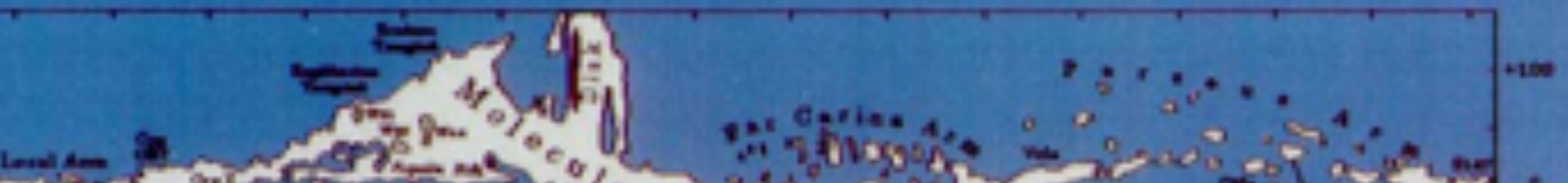
Enough half of the new data have already been published as separate surveys of particular clouds or regions (see list attached), and since 1985 have formed the basis for (1) 2% D. distance survey. The distance was obtained in the past few years in new large-scale surveys of the first and second Galactic quadrants.

This project was supported by a generous grant from the Atlantic Seaboard Endowment of the Smithsonian Institution.

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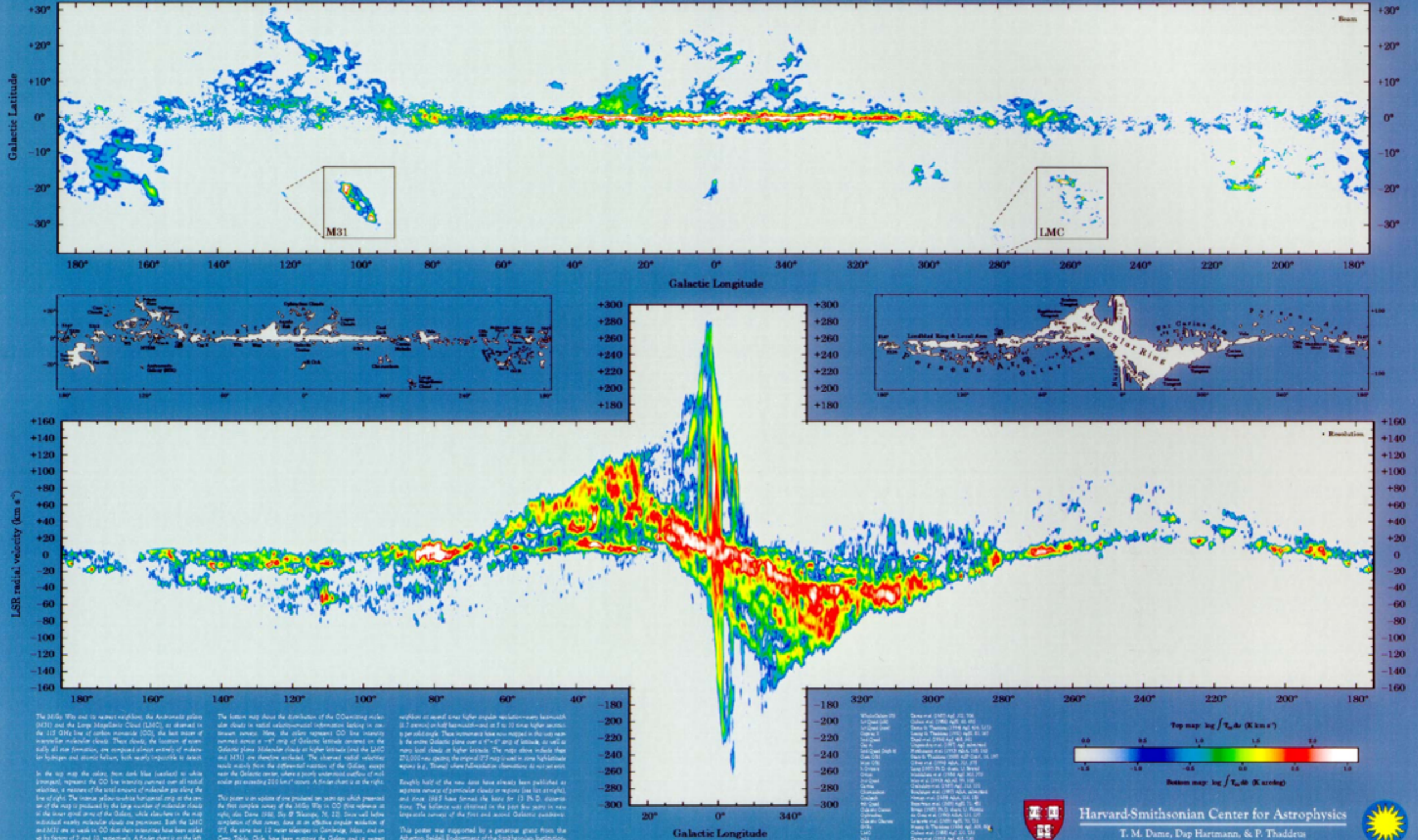
Orion
~100 pc
> 10⁵ M_⊙



Dendrogramming the Milky Way

cf. Rice, Goodman, Bergin, Beaumont & Dame 2015

The Milky Way in Molecular Clouds



The Milky Way and its nearest neighbors, the Andromeda galaxy (M31) and the Large Magellanic Cloud (LMC), are shown in the top map. The color scale represents CO line intensity summed over all radial velocities. The color scale represents CO line intensity summed over a $\pm 10^\circ$ range of Galactic latitude centered on the Galactic plane. Molecular clouds at higher latitude (and the LMC and M31) are therefore excluded. The observed radial velocity results mainly from the differential rotation of the Galaxy, except near the Galactic center, where a poorly understood outflow of high velocity gas exceeding 200 km s⁻¹ occurs. A further chart is at the right.

This paper is an update of one published on-line ago, which presented the first complete survey of the Milky Way in CO (the reference is right, also Dame 1988, 89 & 1990, 91, 92). Since we had better resolution of our survey, data at an effective angular resolution of 0.5', the same size 1.2 meter telescope in Cambridge, Mass., and on Cerro Tololo, Chile, have been mapping the Galaxy and its nearest

neighbors at several times higher angular resolution—over beamwidth 0.7' (shown on half beamwidth—) and at 20 times higher resolution in per solid angle. These improvements have now mapped in the map near to the entire Galactic plane over a 4° – 6° range of latitude, as well as many local clouds at higher latitude. The map also includes about 250,000 new objects, the original 0.7' map included in some high-latitude regions (e.g., Thaddeus) where follow-up observations do not exist.

Enough half of the new data have already been published as separate surveys of particular clouds or regions (see list at right), and since 1987 have formed the basis for 13 Ph.D. dissertations. The follow-up was obtained in the past few years in new longer-wavelength surveys of the first and second Galactic quadrants.

This paper was supported by a generous grant from the Albertus Feldt Endowment of the Smithsonian Institution.

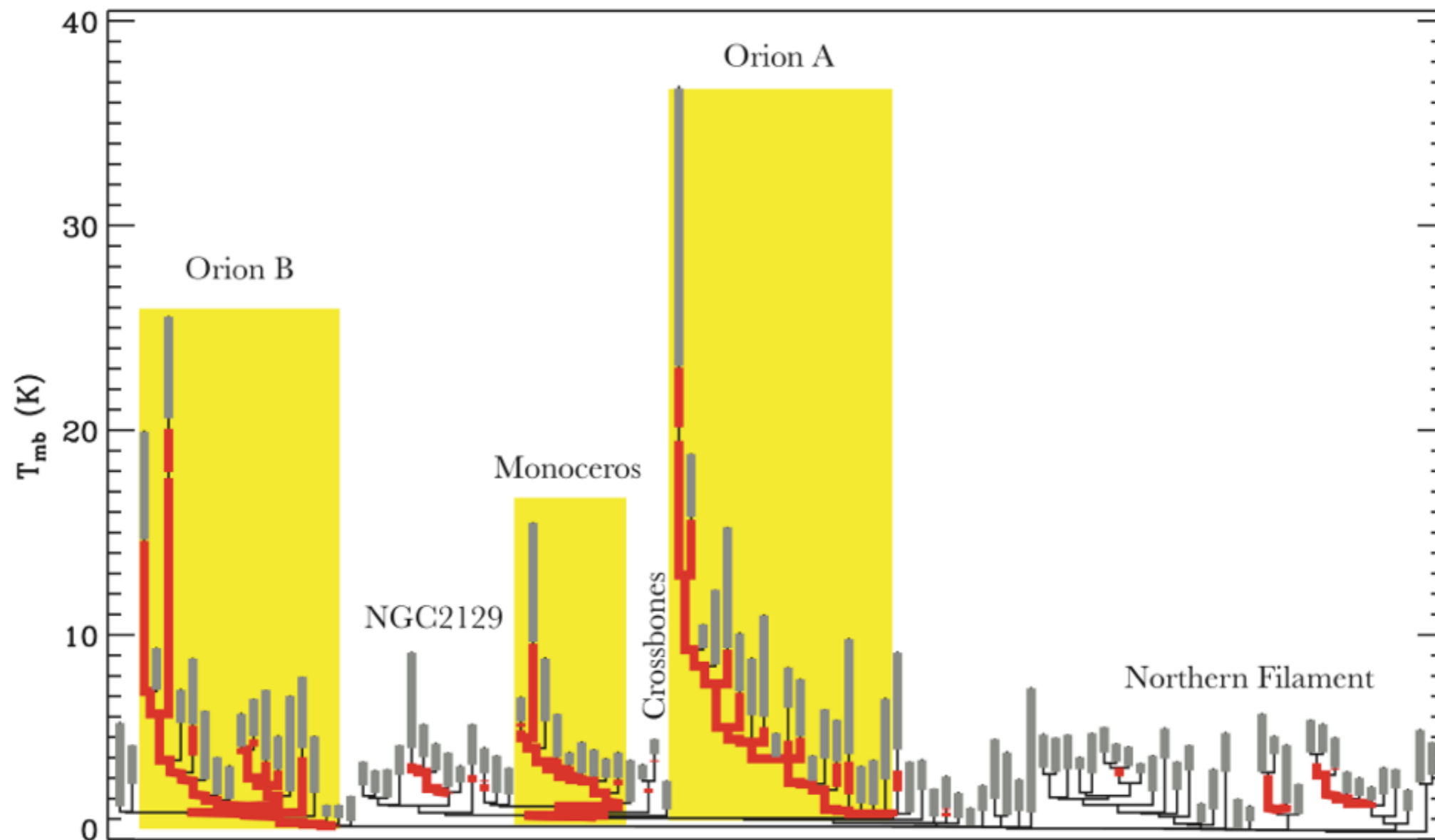


FIG. 15.—Dendrogram of the Orion-Monoceros region. Branches of the dendrogram corresponding to self-gravitating structures are highlighted in red. Regions where the quality of the data prohibit accurate estimation of the virial parameter are shown in gray. The GMCs within the data cube are identified as the largest scale objects that are self-gravitating but not bound to each other. Regions of the dendrogram corresponding to specific objects are labeled and the sections of the dendrogram corresponding to GMCs are shaded in yellow.

A Catalog of Molecular Clouds in the Entire Galactic Plane

Thomas S. Rice¹, Alyssa A. Goodman², Edwin A. Bergin¹,
Christopher Beaumont³, and T. M. Dame²,

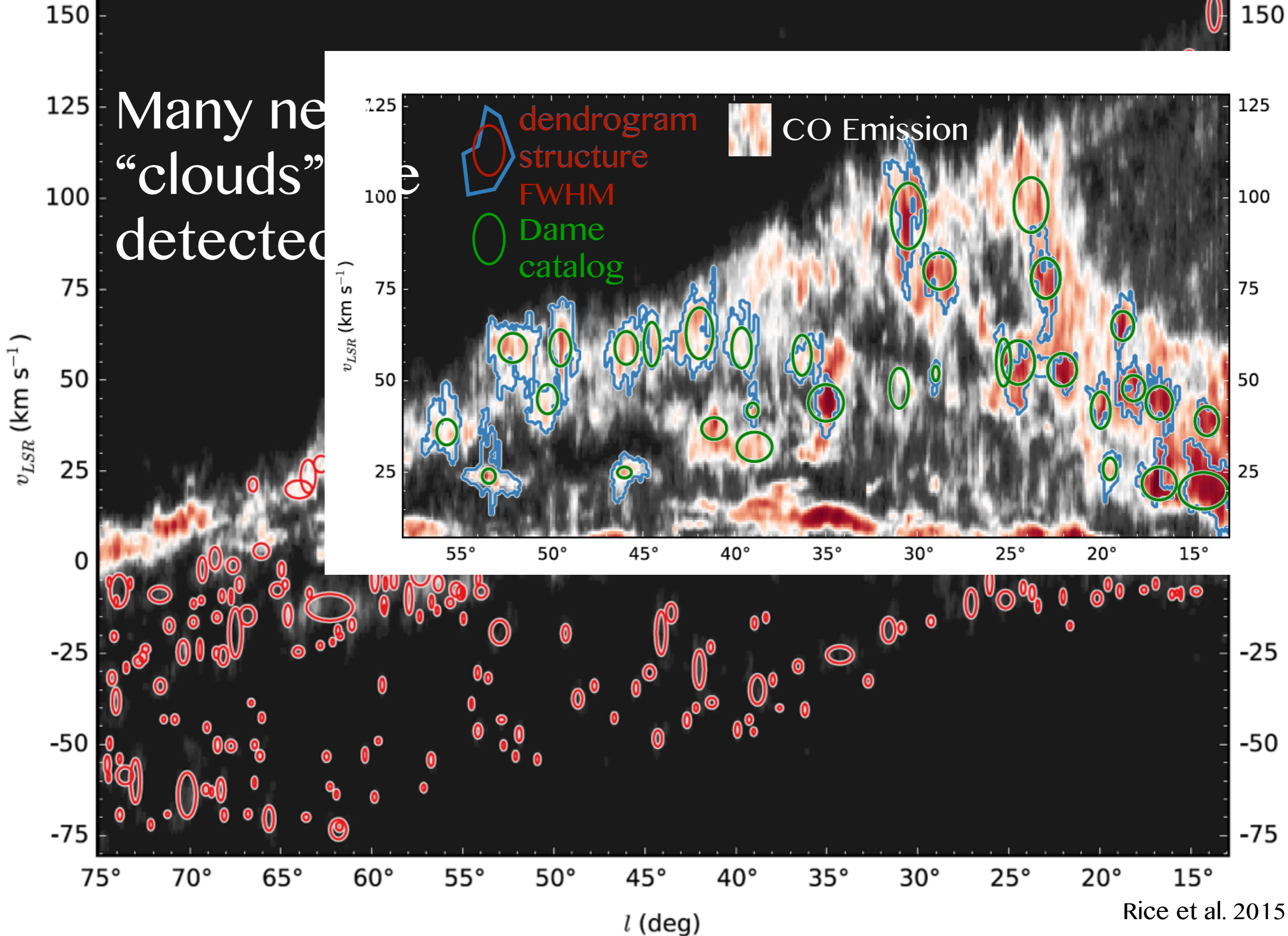
1: Department of Astronomy, University of Michigan, 311 West Hall, 1085 South University Avenue, Ann Arbor, MI 48109, USA; tsrice@umich.edu

2: Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138, USA

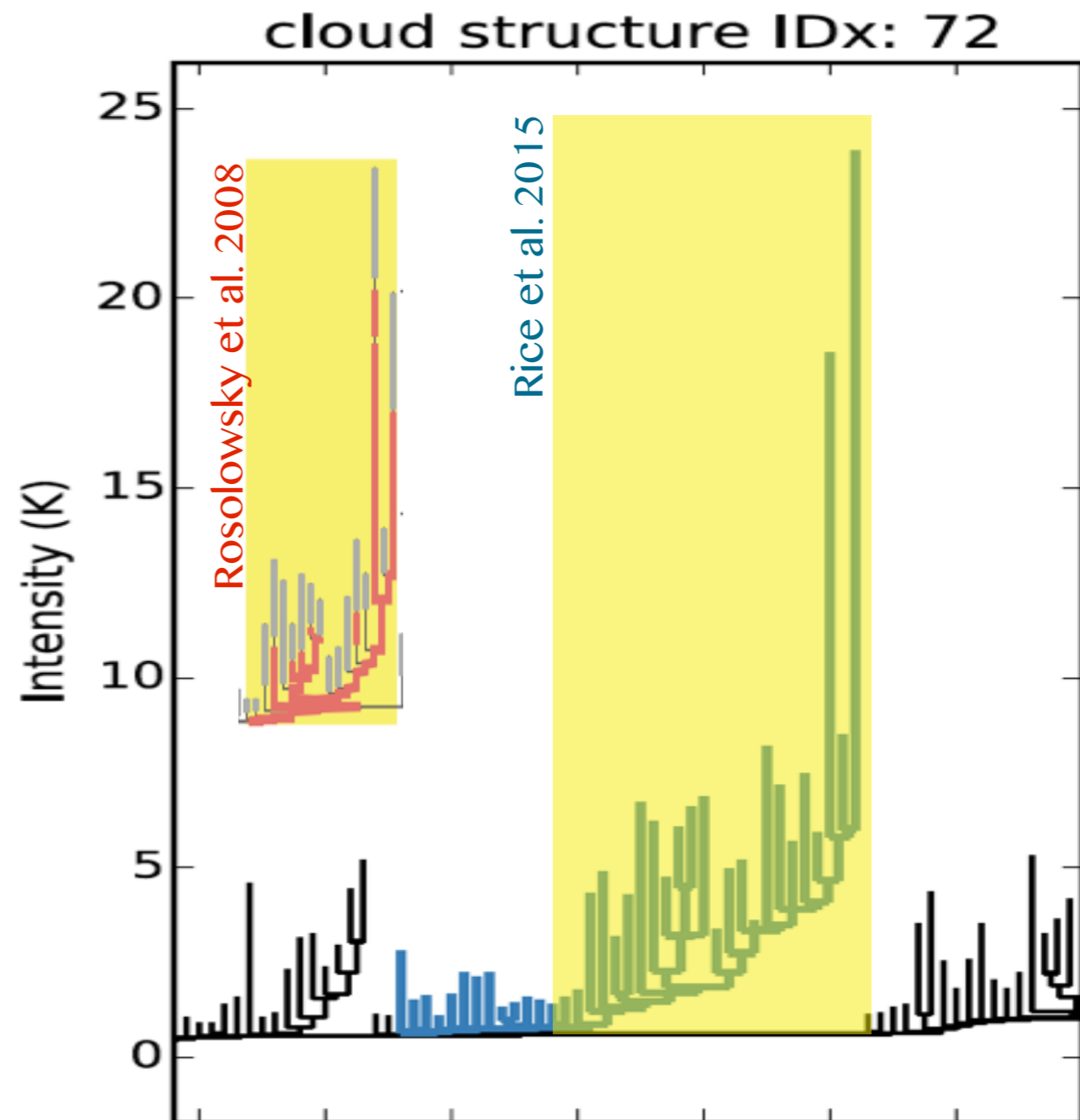
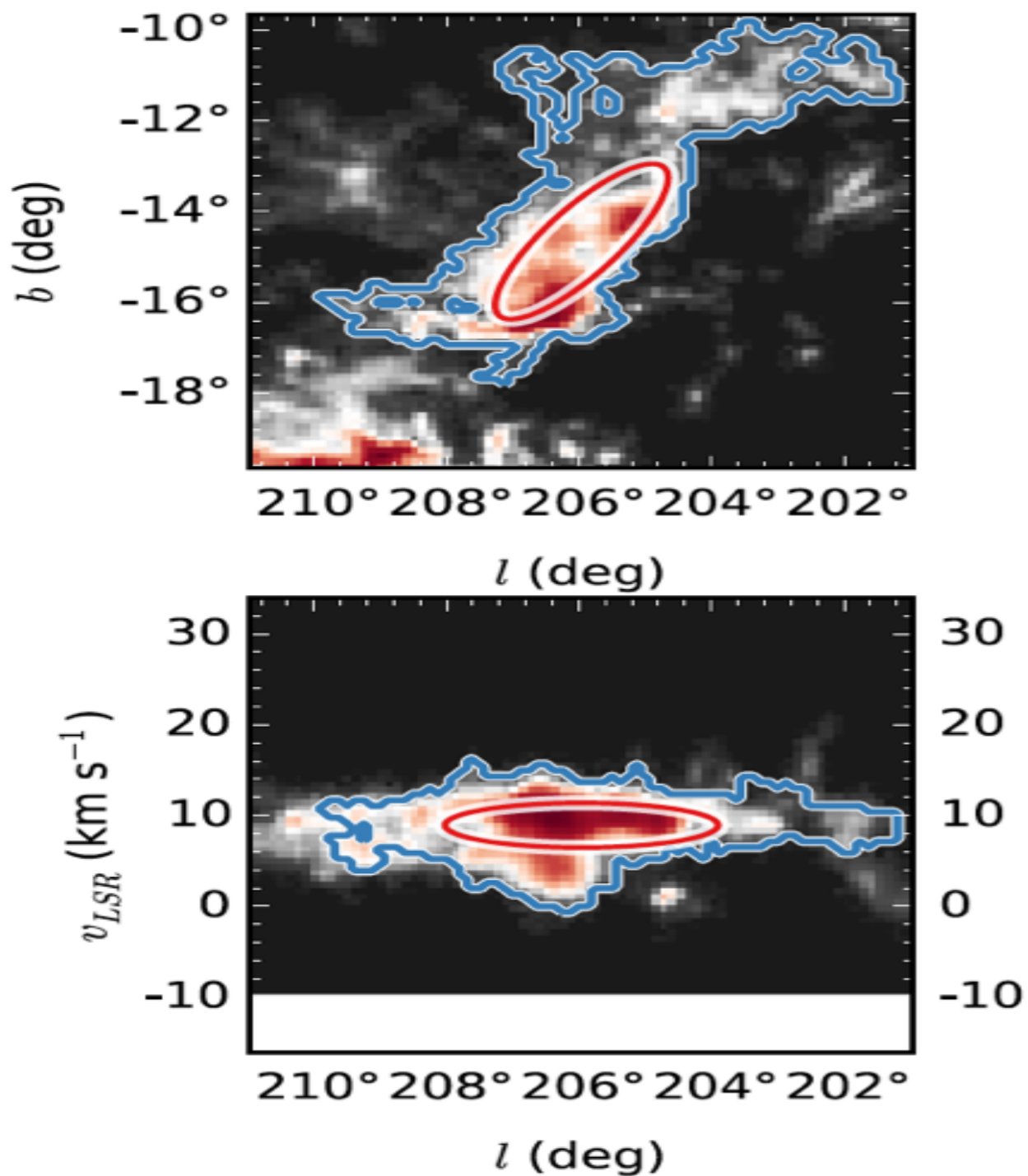
Coming very soon to astro-ph!

Here we present a systematically produced catalog of 1058 massive molecular clouds throughout the entire Galactic plane, with a total of 2.5×10^8 solar masses, or $25_{-5.8}^{+10.7}\%$ of the Milky Way's estimated H_2 mass, of which $1.96 \times 10^8 M_\odot$ is located within the solar circle. A number of prominent spiral arms, including the Sagittarius, Perseus, Outer, Carina, and Scutum arms are traced in this catalog; some are tracked through multiple quadrants. We find that the power index of Larson's first law, the size-linewidth relation, is consistent with 0.5 in all regions, but that clouds in the inner Galaxy systematically have significantly higher linewidths at a given size, suggesting that their linewidths are set in part by pressure confinement. The slope of the mass spectrum is similar in all regions, but the truncation mass in the inner Galaxy ($\sim 10^7 M_\odot$) is more than an order of magnitude higher than that in the outer Galaxy ($\sim 5 \times 10^5 M_\odot$), indicating that the inner Galaxy is able to form and host substantially more massive GMCs than the outer Galaxy. Using the luminosities and x, y positions of the clouds in this catalog, we have produced simulated CO images of how the Milky Way would appear to an extragalactic observer in CO at different angular resolutions, which can be compared to current and future CO maps of other galaxies.

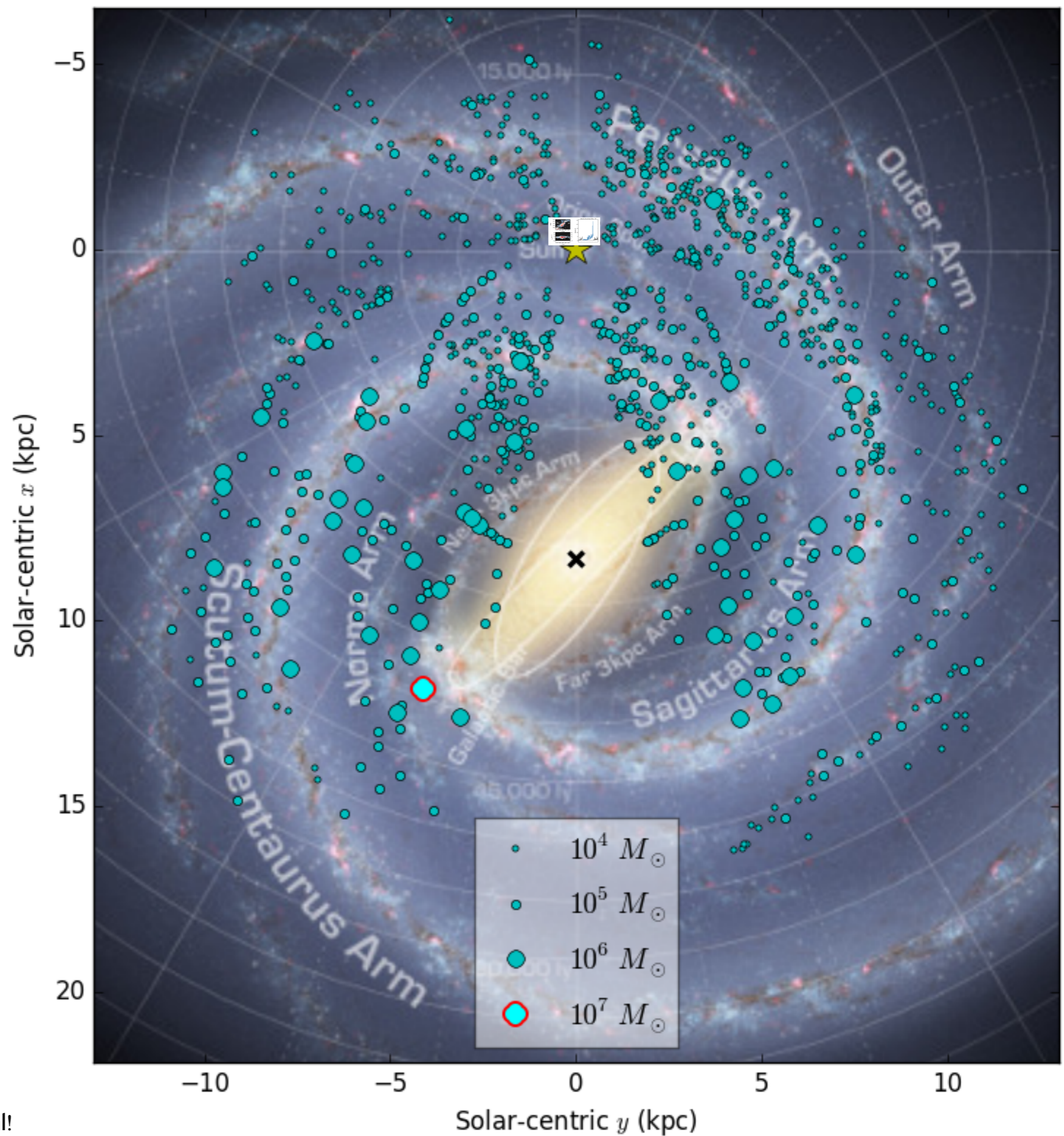
Many new
“clouds”
detected



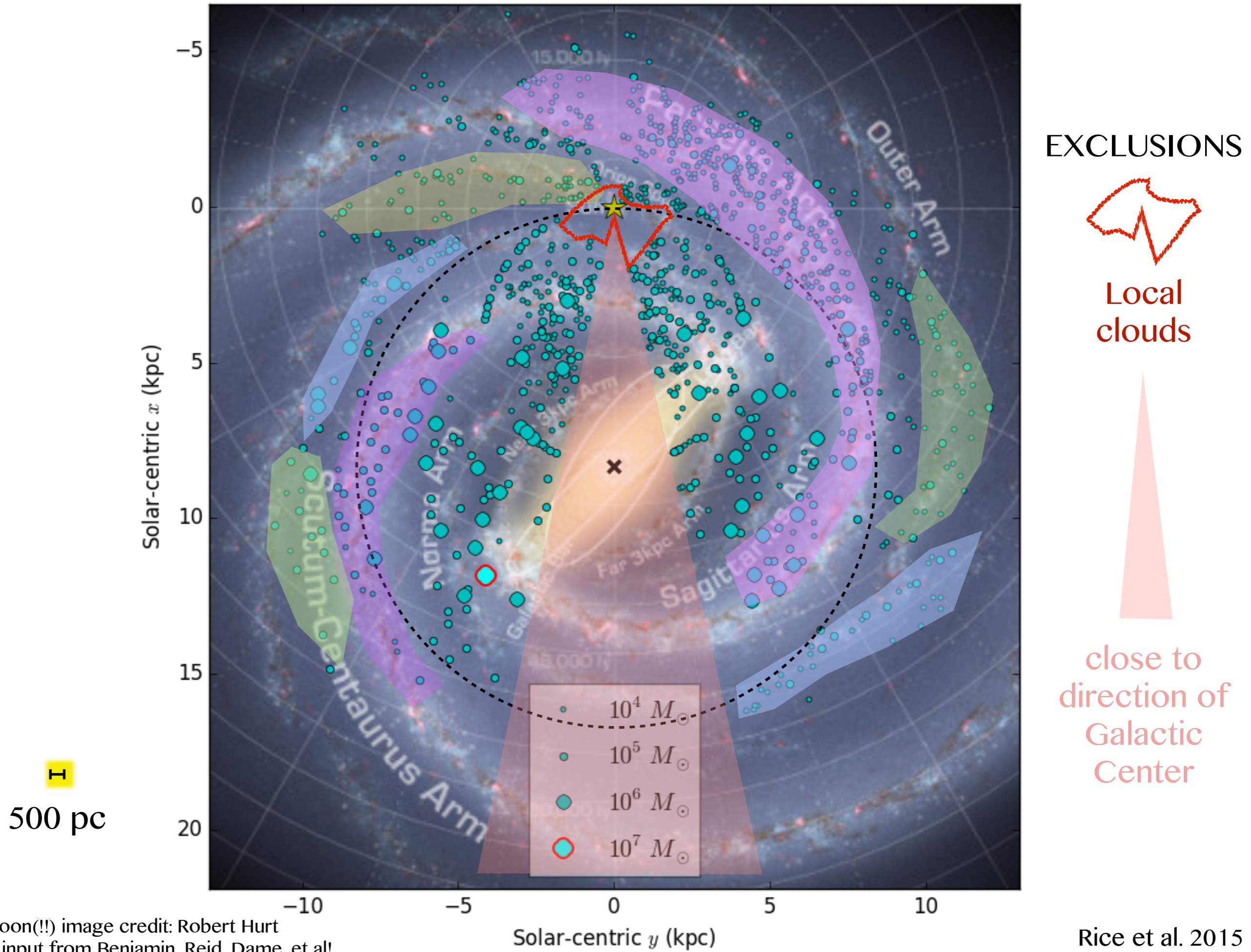
Dendrogramming Orion B



“Orion in Context”



Cartoon(!) image credit: Robert Hurt
with input from Benjamin, Reid, Dame, et al!

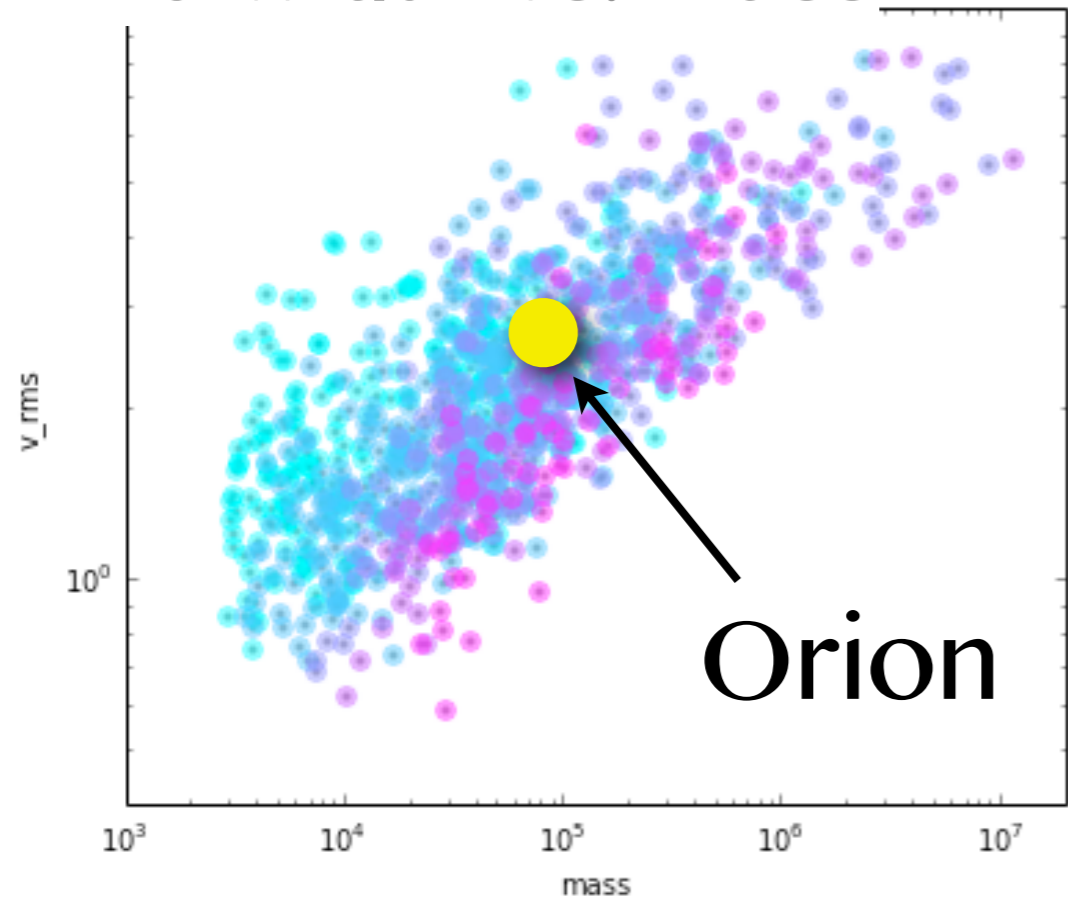


How biased?

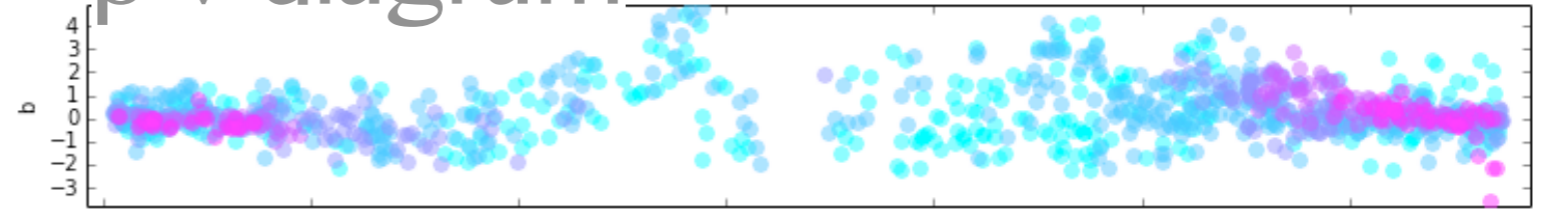
color-code shows distance bins



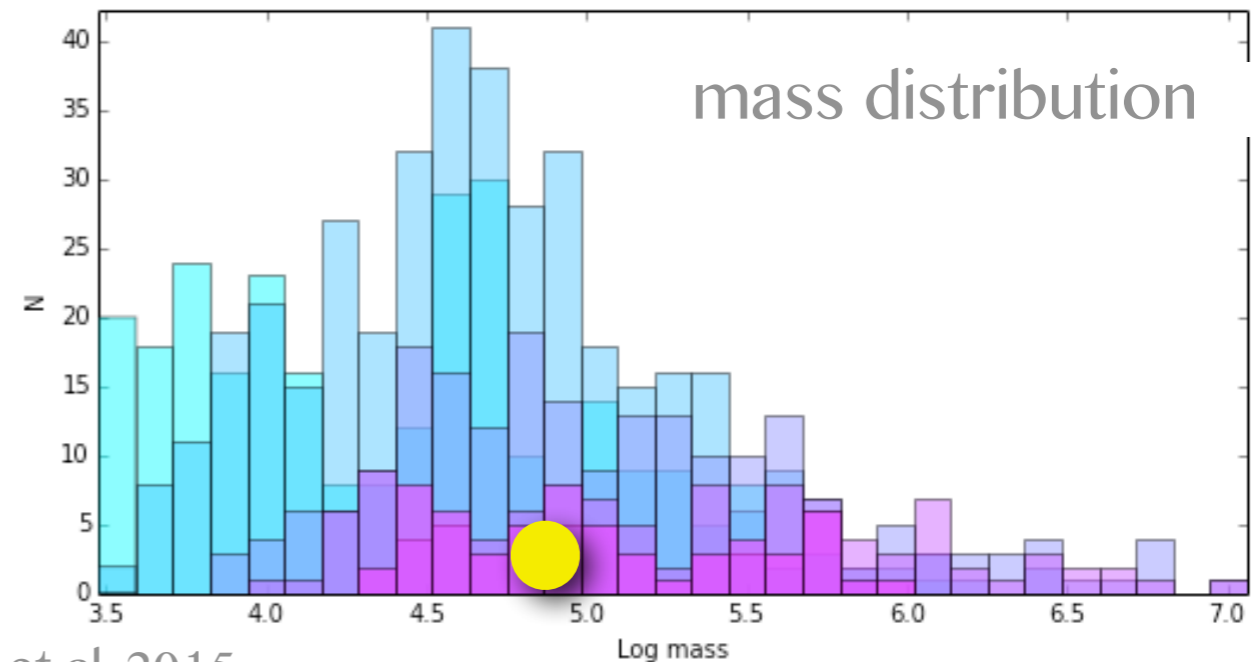
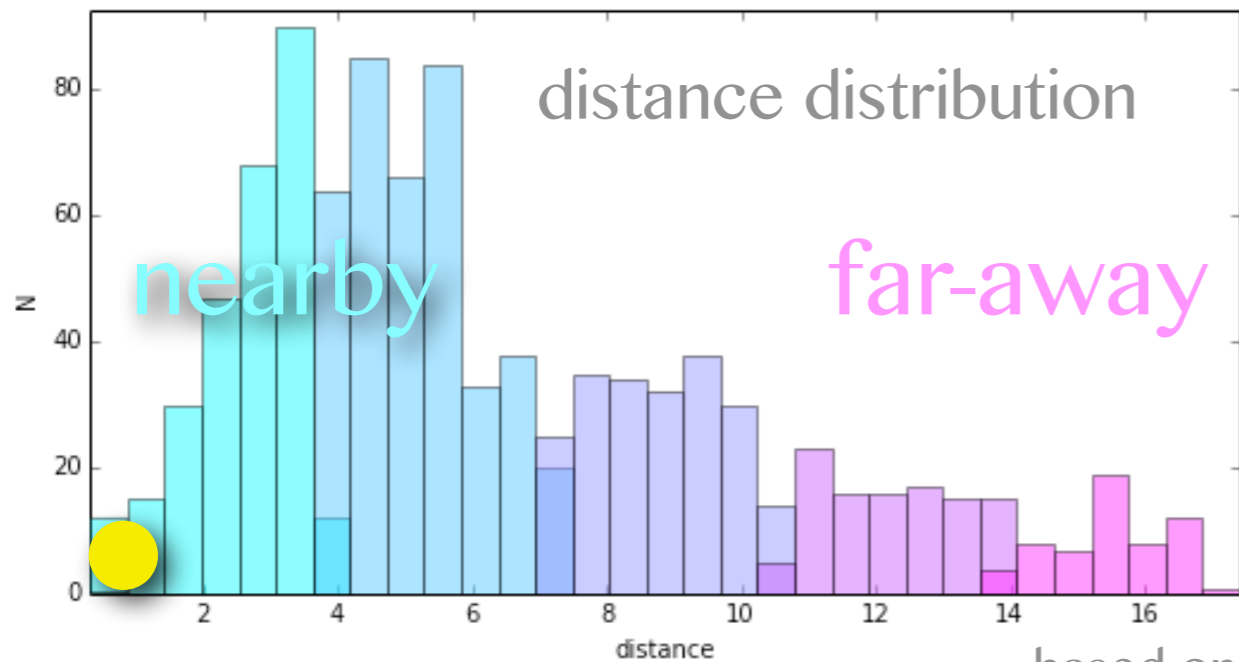
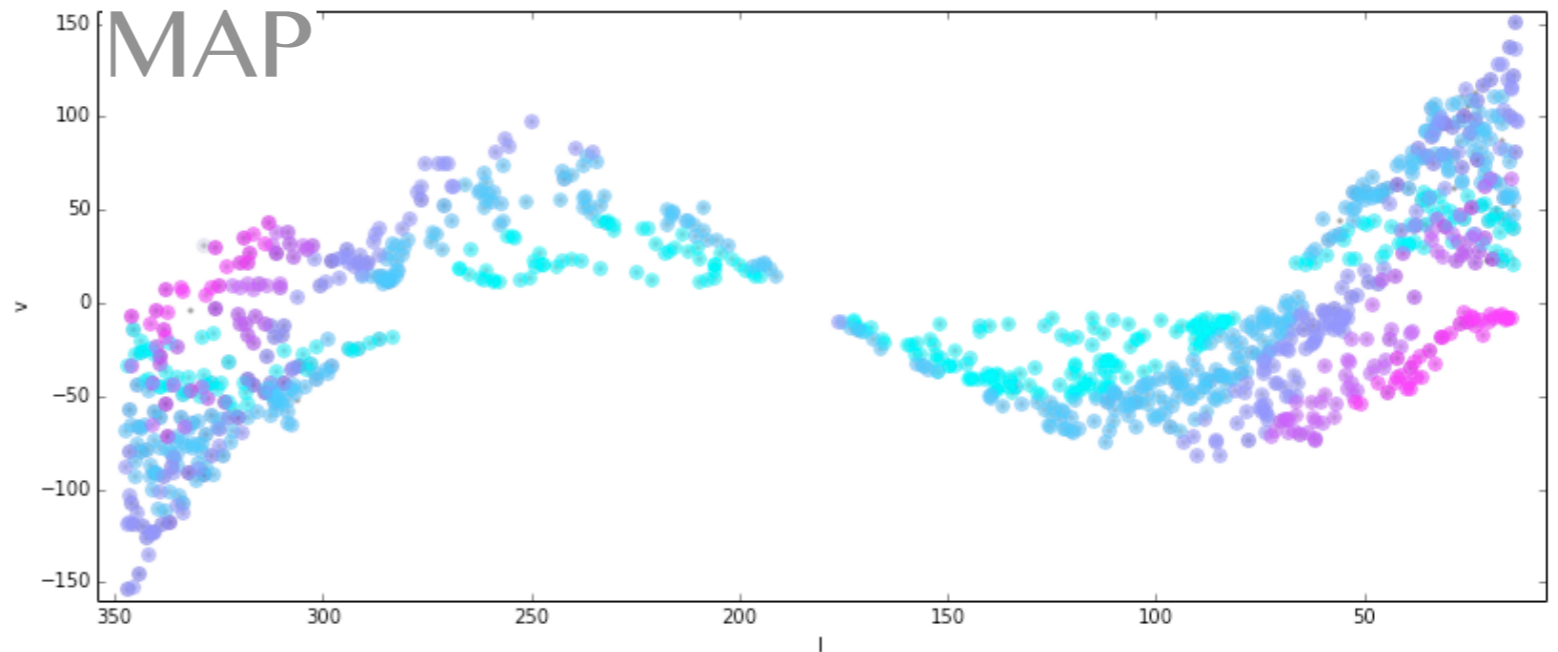
line width vs. mass



p-v diagram

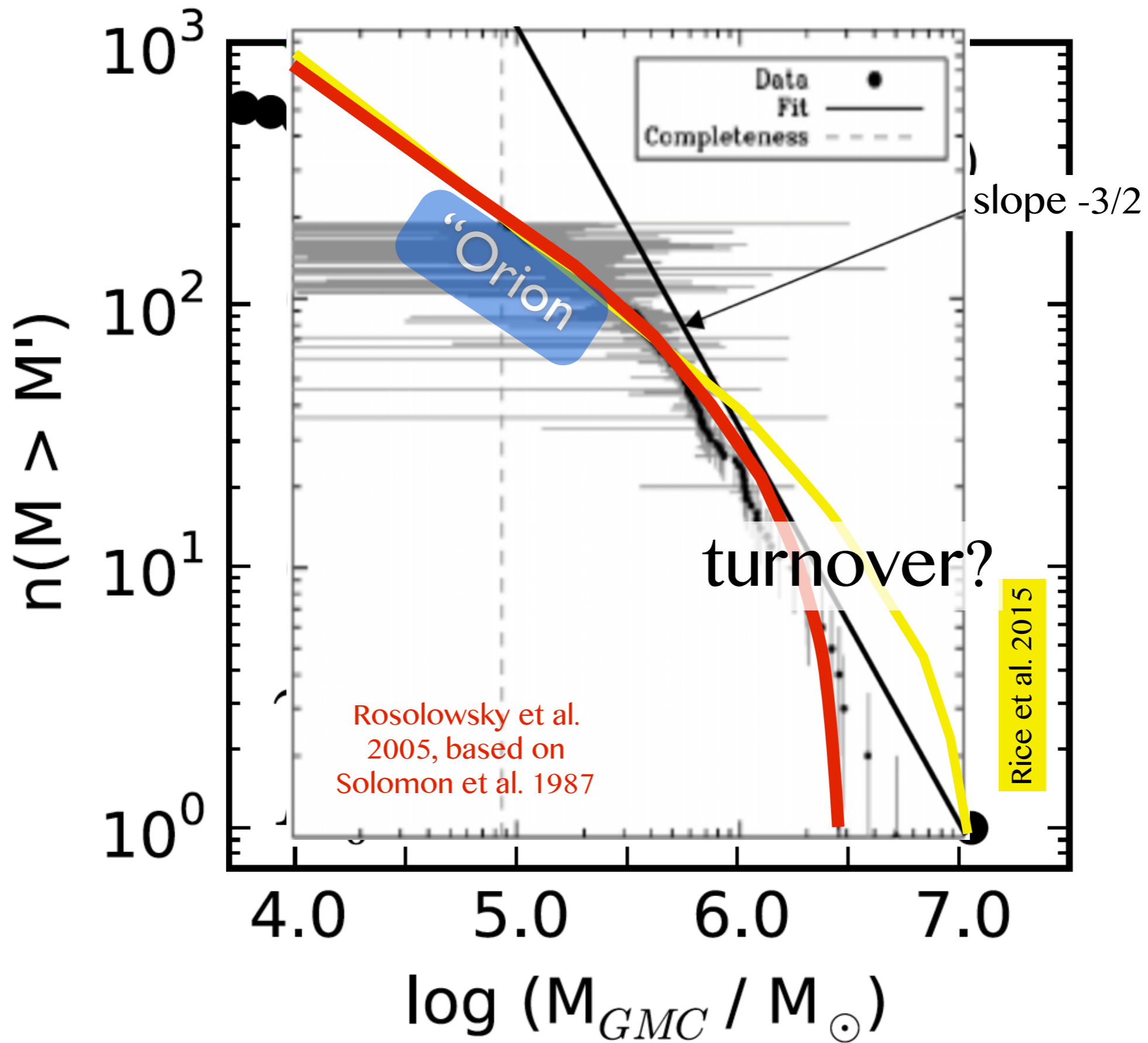


MAP



based on Rice et al. 2015

“Cloud Mass Function”



The Milky Way from M51

M51 from the Milky Way

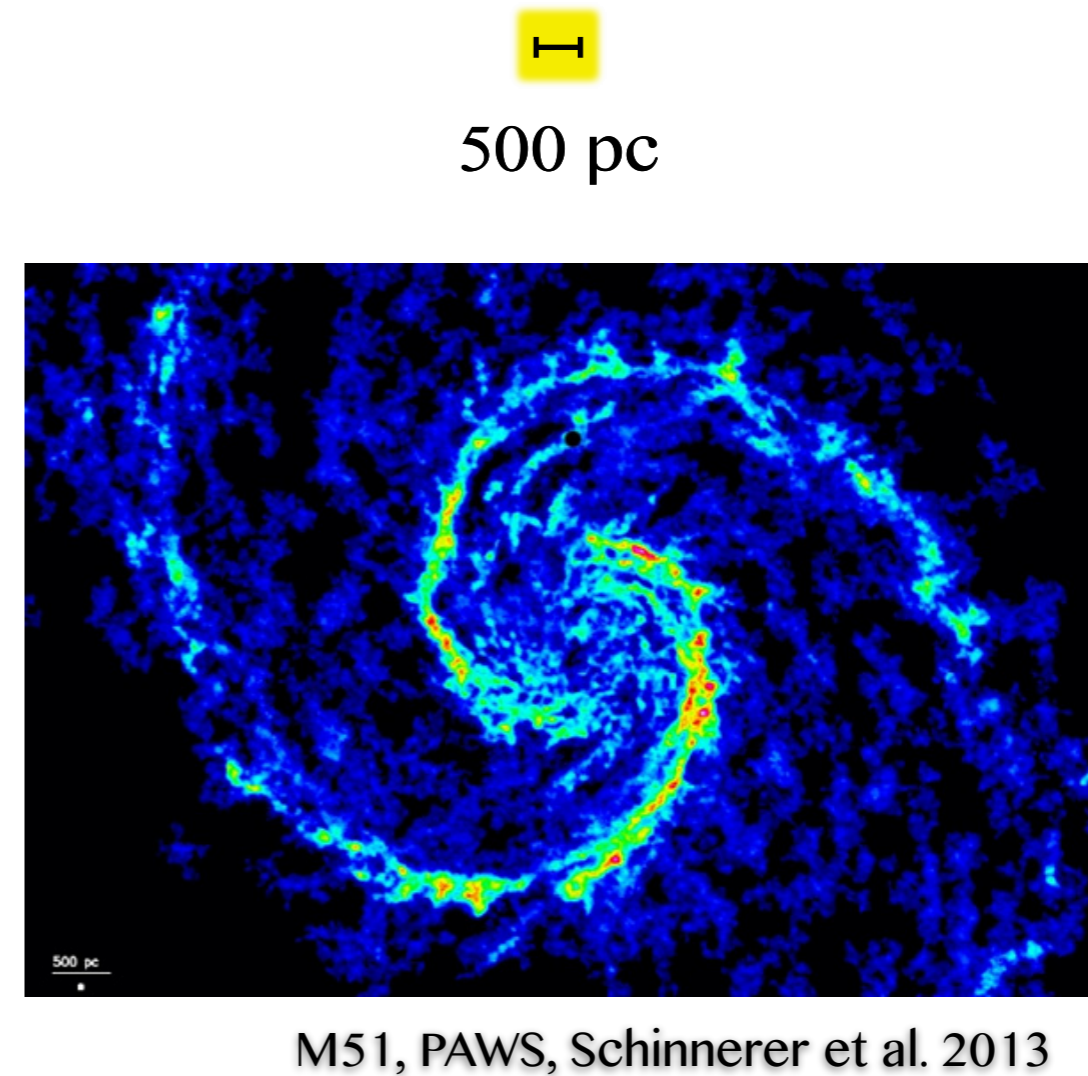
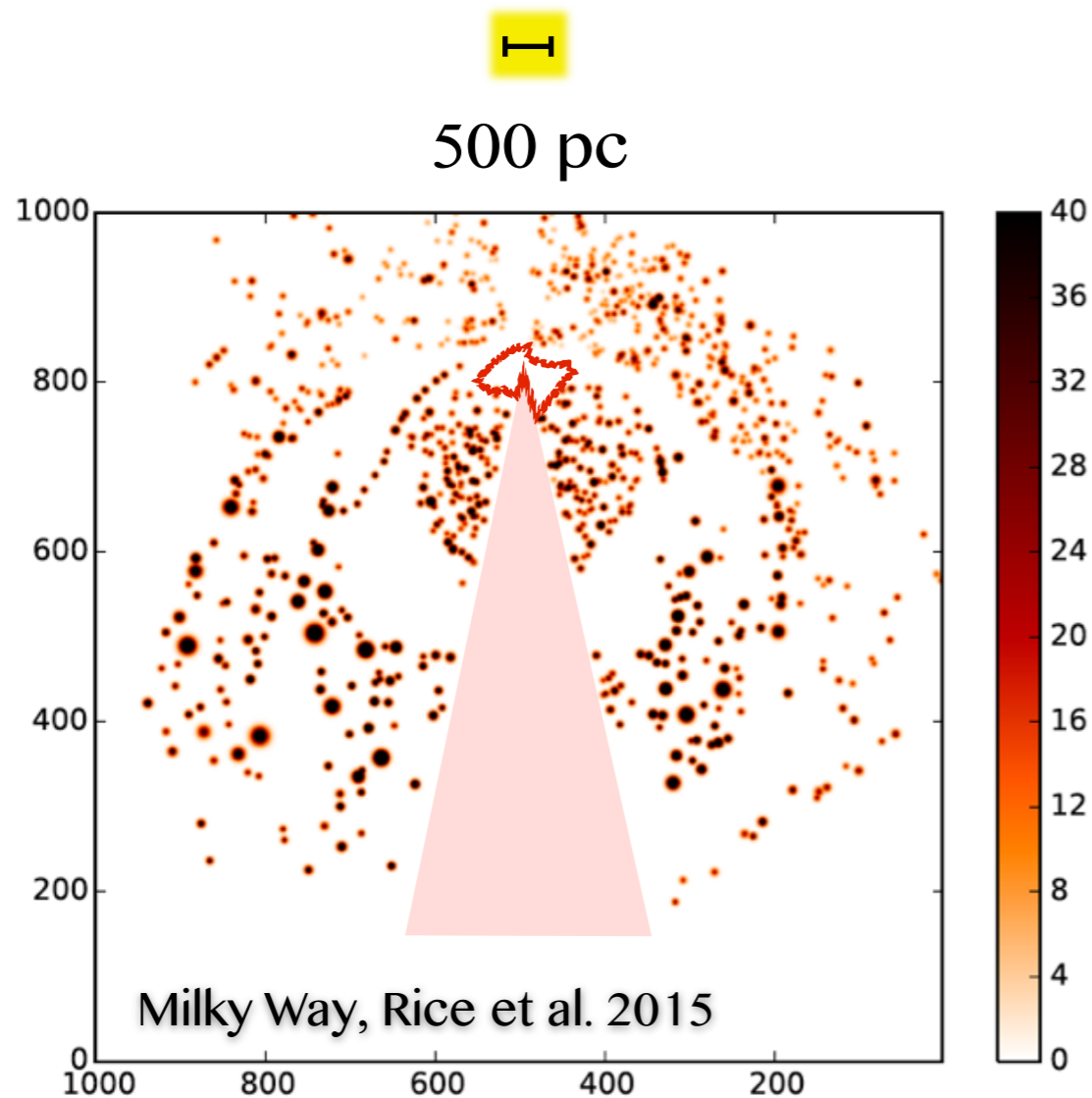


Fig. 16.— Face-on “simulated” CO image of the Milky Way based on the clouds in this catalog, as seen by two hypothetical extragalactic observers: *Left*: with 40 pc resolution, matching the PAWS survey of M51 (Schinnerer et al. 2013). *Right*: with 400 pc resolution, simulating a galaxy 10 times further than M51. Each image is displayed with a square root intensity scale.

The Milky Way from M51

...and from 10x farther than M51 (400 pc resolution)

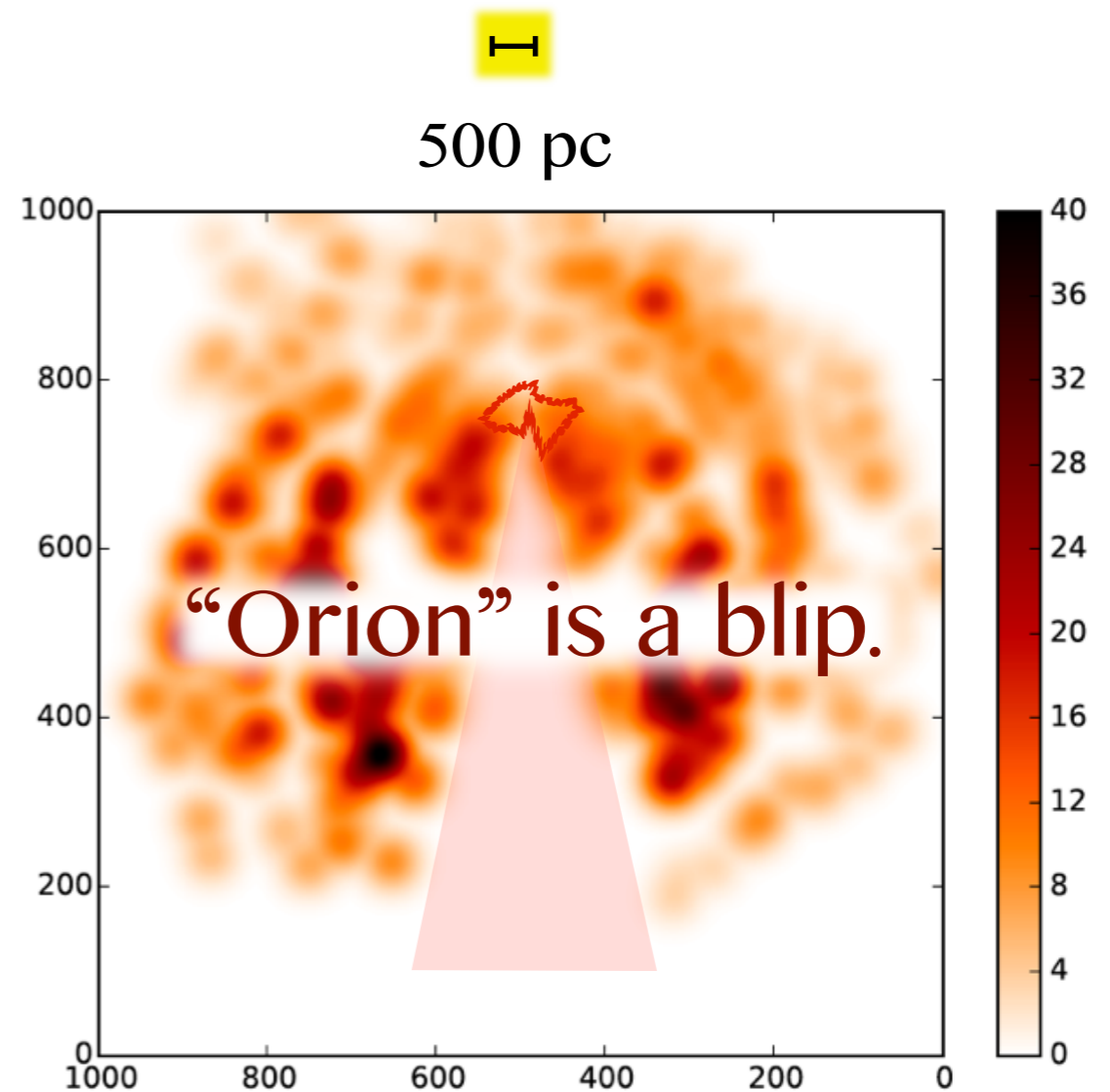
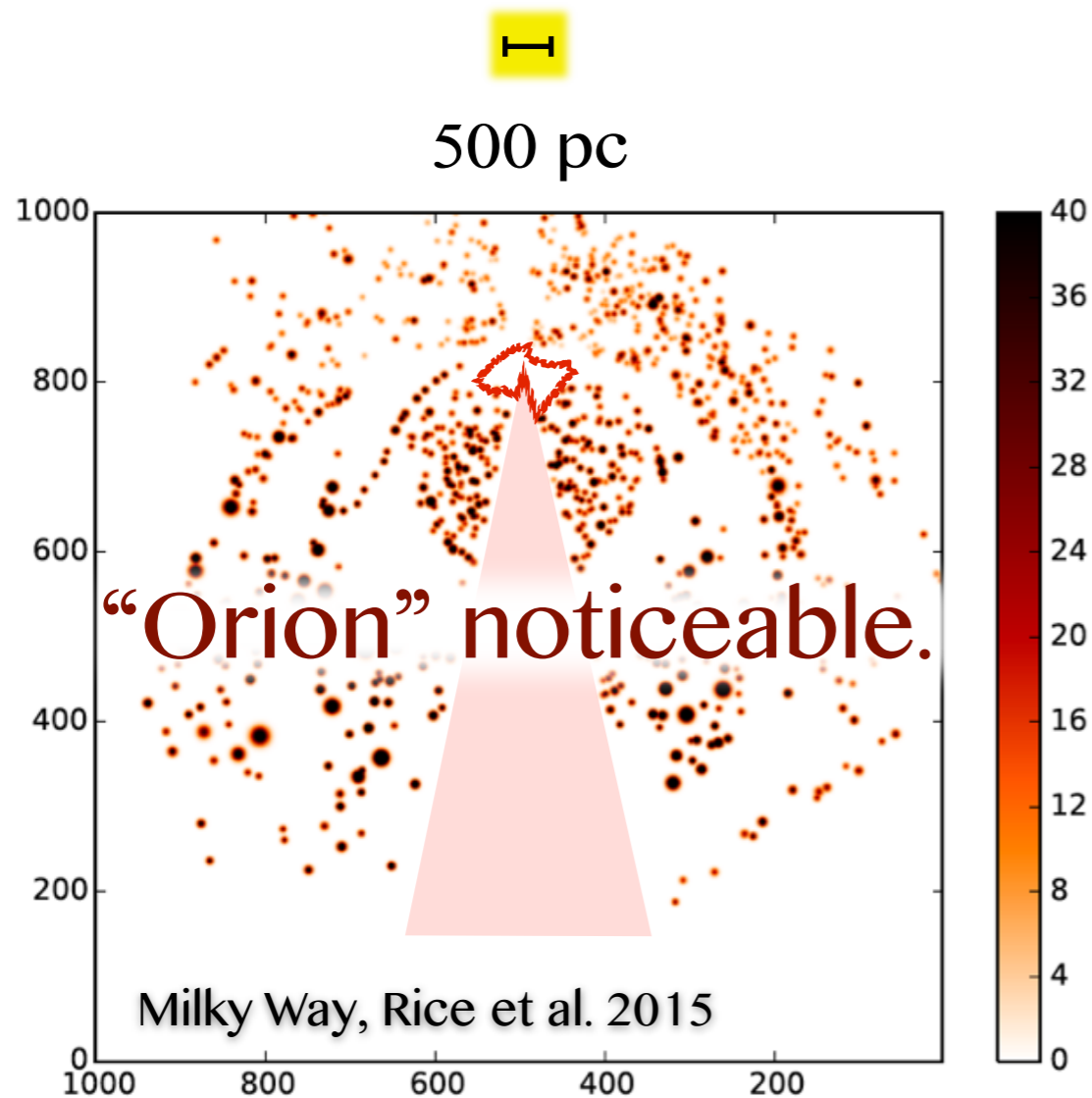


Fig. 16.— Face-on “simulated” CO image of the Milky Way based on the clouds in this catalog, as seen by two hypothetical extragalactic observers: *Left*: with 40 pc resolution, matching the PAWS survey of M51 (Schinnerer et al. 2013). *Right*: with 400 pc resolution, simulating a galaxy 10 times further than M51. Each image is displayed with a square root intensity scale.

Orion in Context

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Center for Astrophysics

