Physics 224
The Interstellar Medium

Lecture #16: Observations of Molecular Gas

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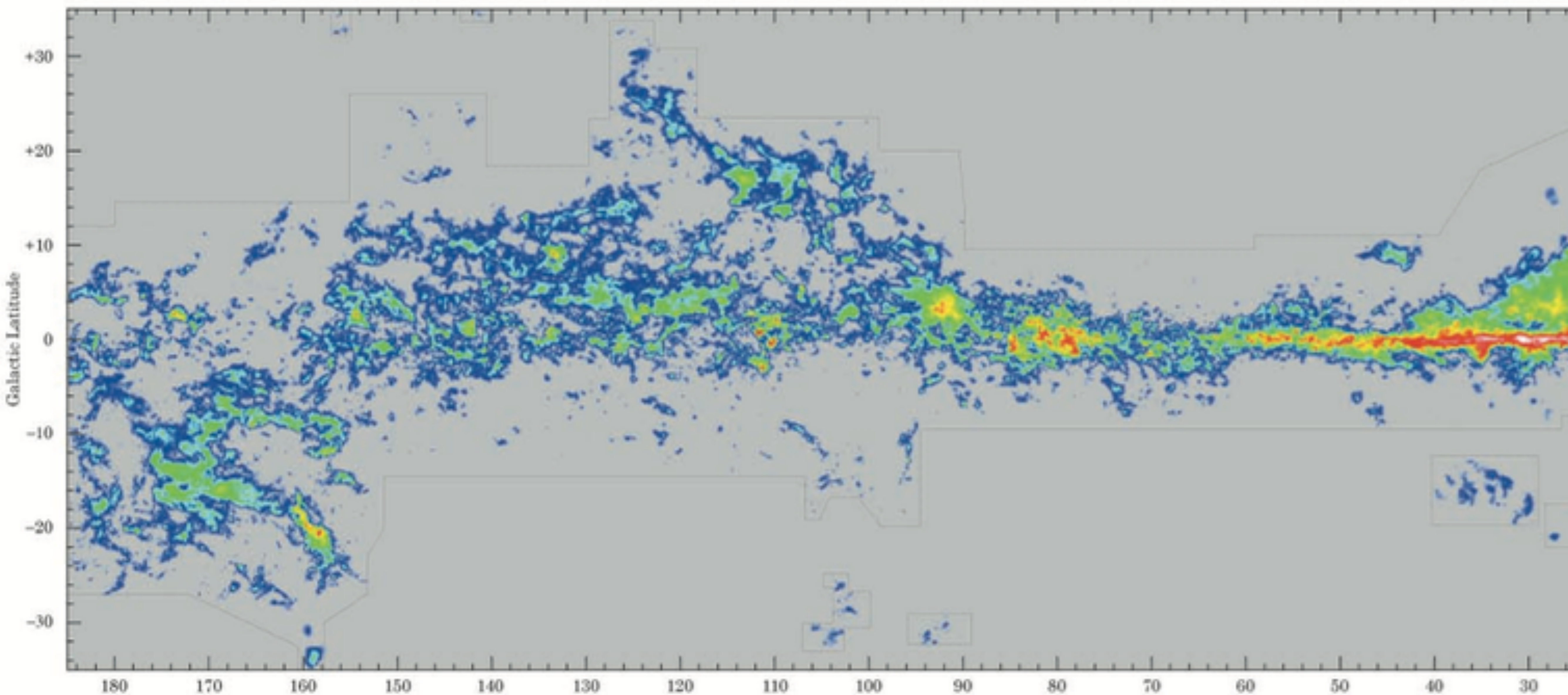
Observations of Molecular Gas

Distribution of Molecular Gas in the Milky Way:



Dame et al. 2001

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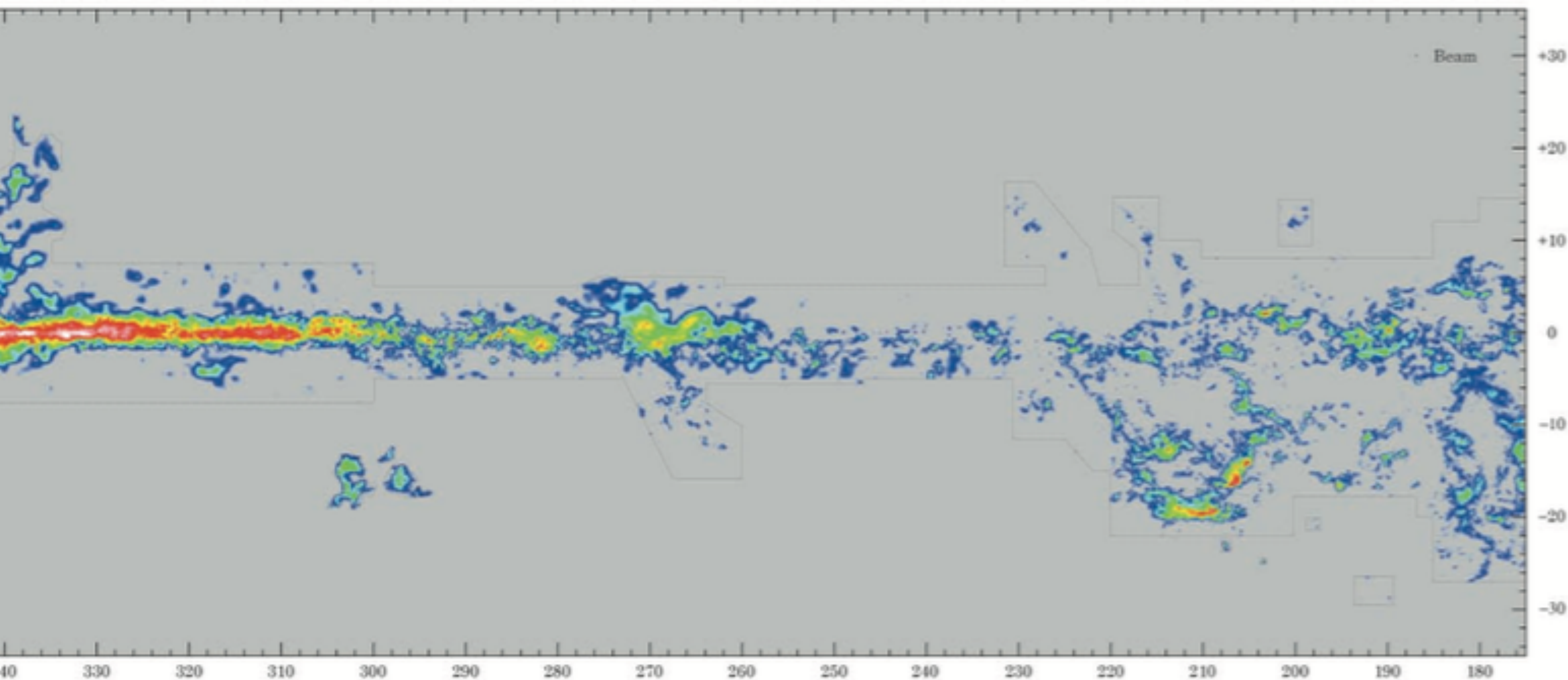

Dame et al. 2001

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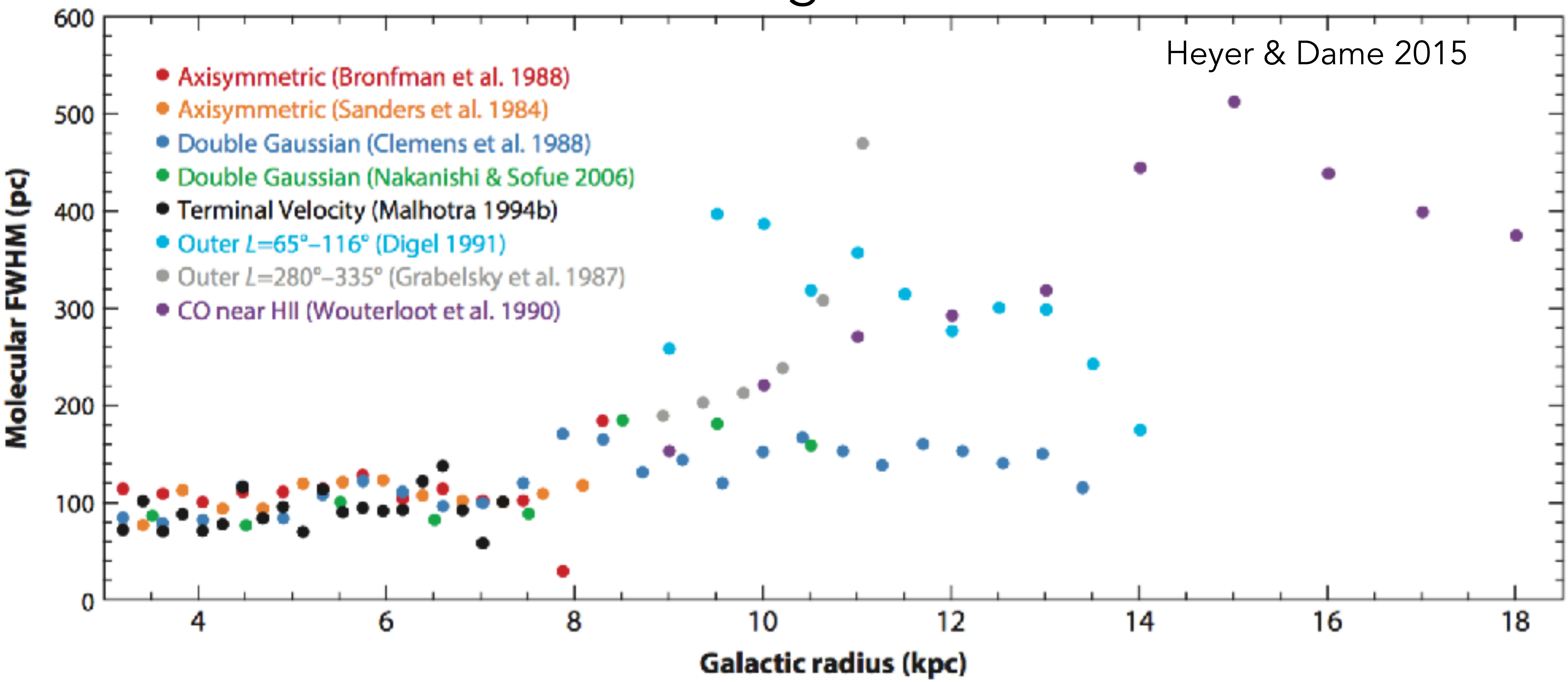
Observations of Molecular Gas

Distribution of Molecular Gas in the Milky Way:

Scale Height of CO



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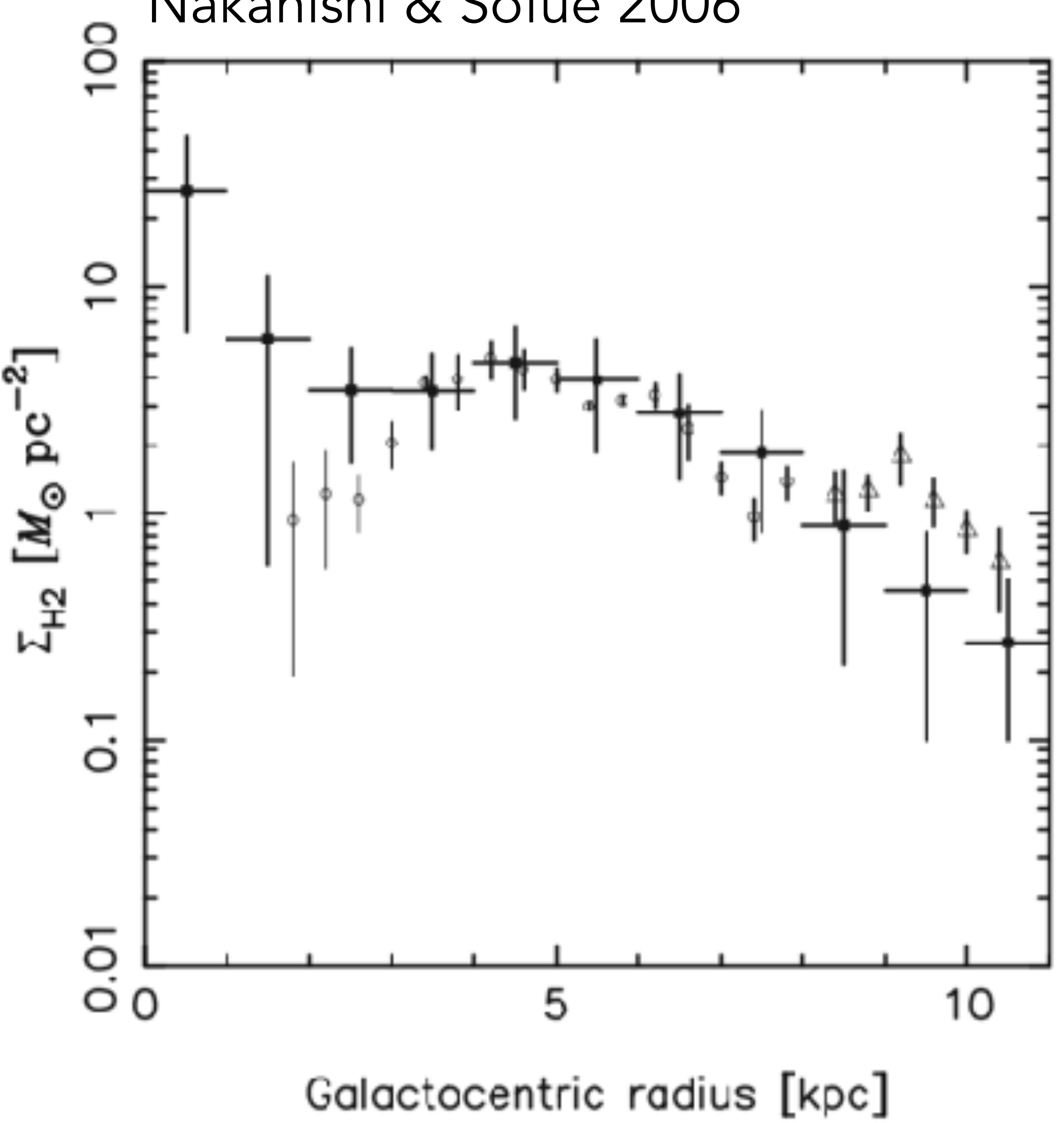
Observations of Molecular Gas

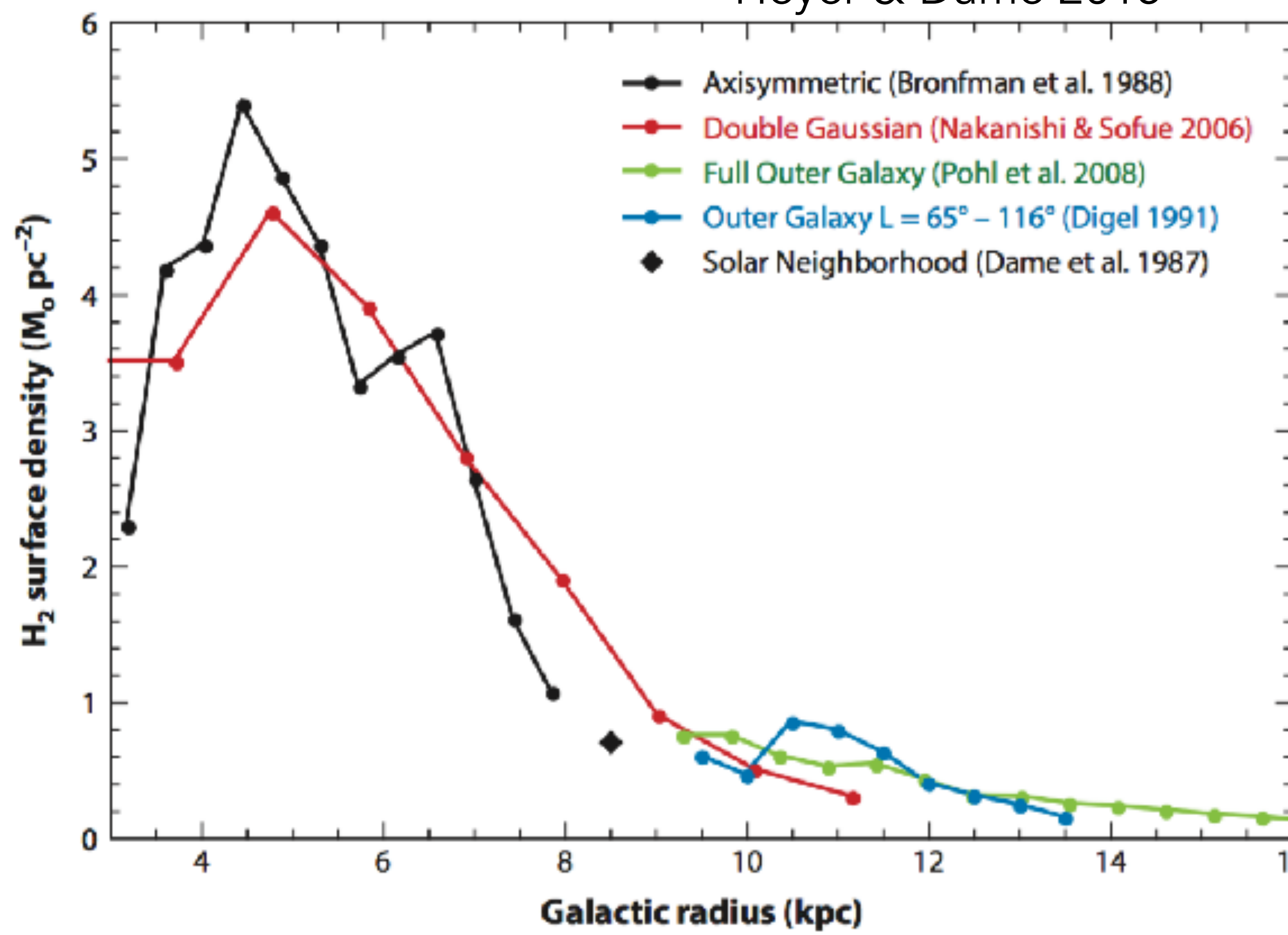
Distribution of Molecular Gas in the Milky Way:

Surface Density

Nakanishi & Sofue 2006



Heyer & Dame 2015



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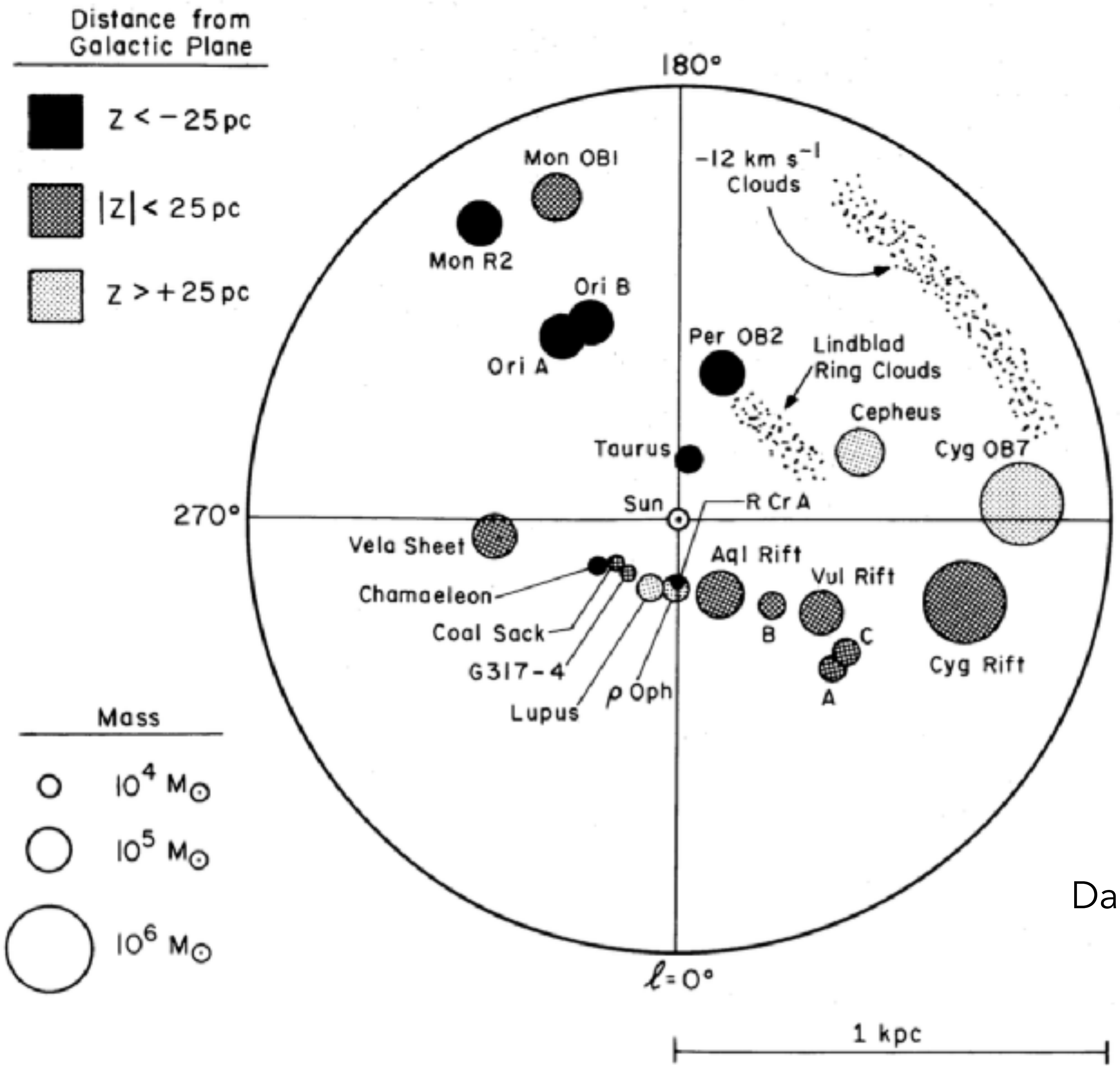

Dame et al. 1987

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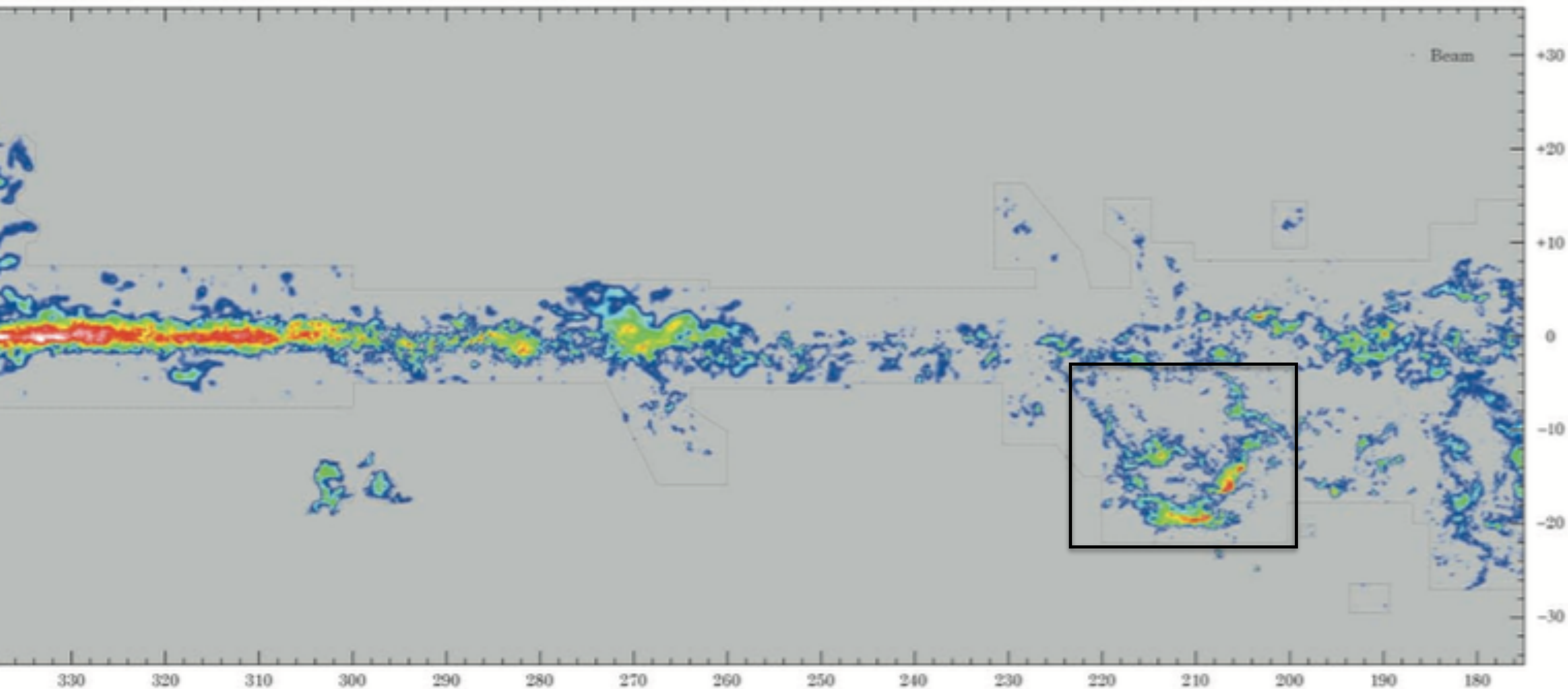
Observations of Molecular Gas

"Molecular Clouds"



Dame et al. 2001

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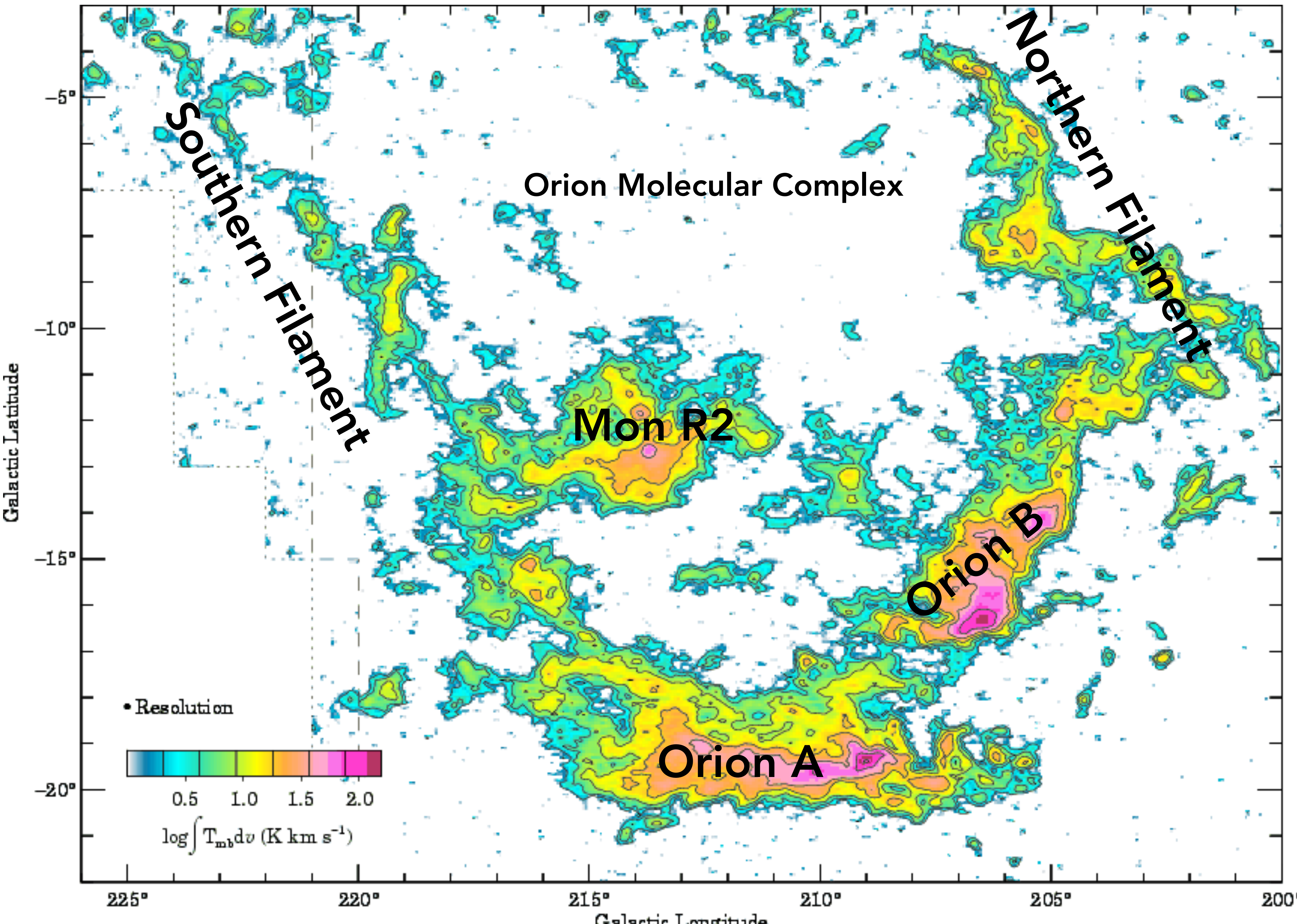
Wilson et al. 2005



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Molecular Clouds

- Observational definition: Discrete regions of CO emission in position-position-velocity space.

MOPRA Galactic Plane Survey ^{12}CO ppv - Braiding et al. 2015

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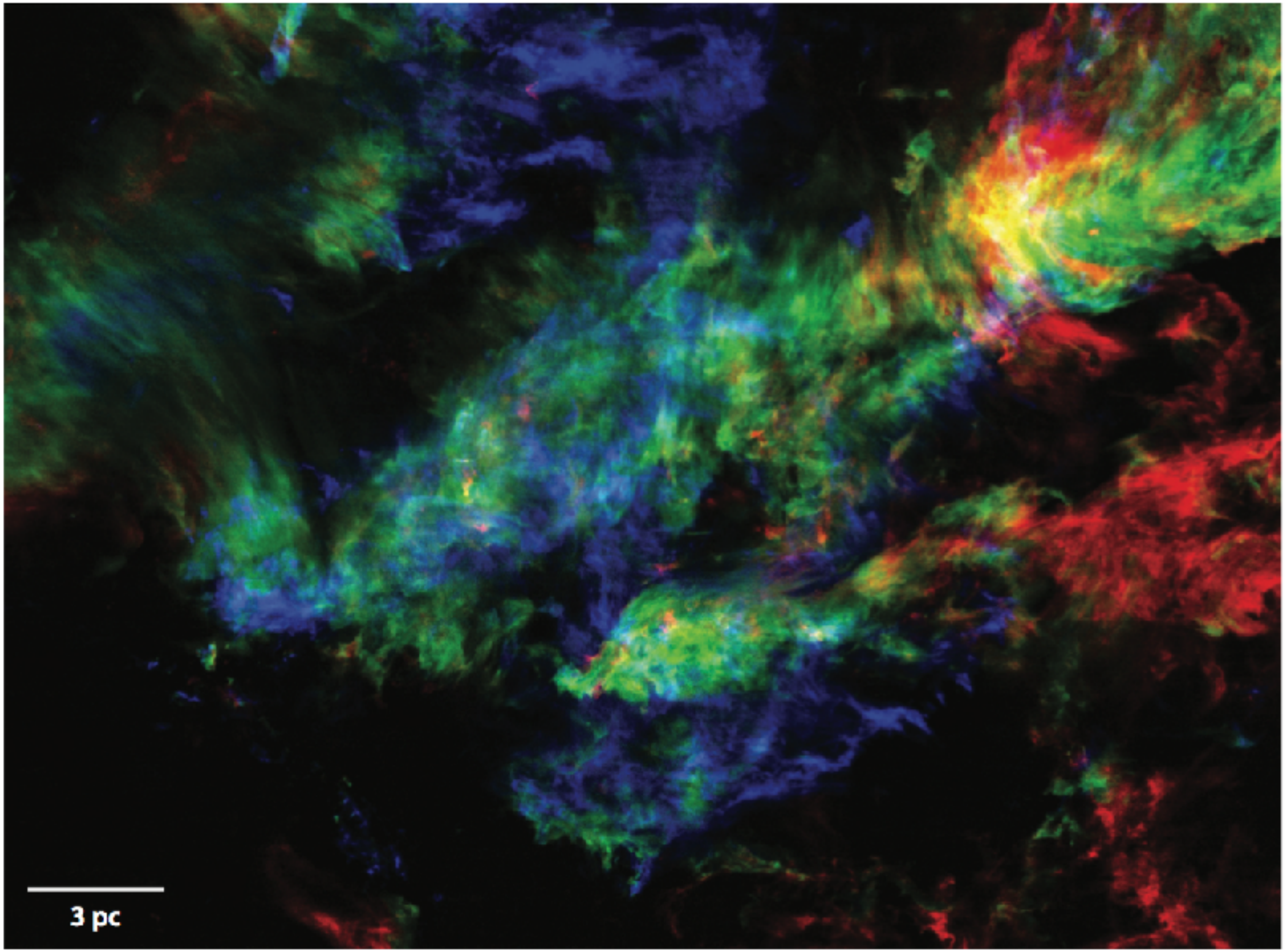

Taurus Molecular cloud Heyer & Dame 2015

Figure 10

An image of ^{12}CO $J = 1$–0 emission from the Taurus molecular cloud integrated over v_{LSR} intervals 0–5 km s^{-1} (*blue*), 5–7.5 km s^{-1} (*green*), and 7.5–12 km s^{-1} (*red*), illustrating the intricate surface brightness distribution and complex velocity field of the Taurus cloud. The data are from Narayanan et al. (2008). Adapted from figure 12 of Goldsmith et al. (2008) and reproduced with permission from AAS.

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Molecular Clouds

- Observational definition: Discrete regions of CO emission in position-position-velocity space.

<u>Giant Molecular Clouds (GMC):</u>

> It is rather amazing that 15 yr since the identification of giant molecular clouds, there is no generally accepted definition of what a GMC is. There seems to be little disagreement about the classification of the largest clouds as GMCs, but an all inclusive definition of what a GMC is has proven elusive. A large part of the problem is that the various studies of the mass spectrum of molecular clouds indicate that the spectrum is well fit by a power law (see below) and there is consequently no natural size or mass scale for molecular clouds. What we call a GMC is therefore largely a question of taste. For the

Blitz 1993 - review for Protostars & Planets

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Giant Molecular Clouds (GMC):

Masses ~10^3 - 10^6 $M_\odot$

Size ~ 10^1 - 10^2 pc

GMC is the largest unit, it can have substructure & more than one can be clustered together in a "GMC complex".

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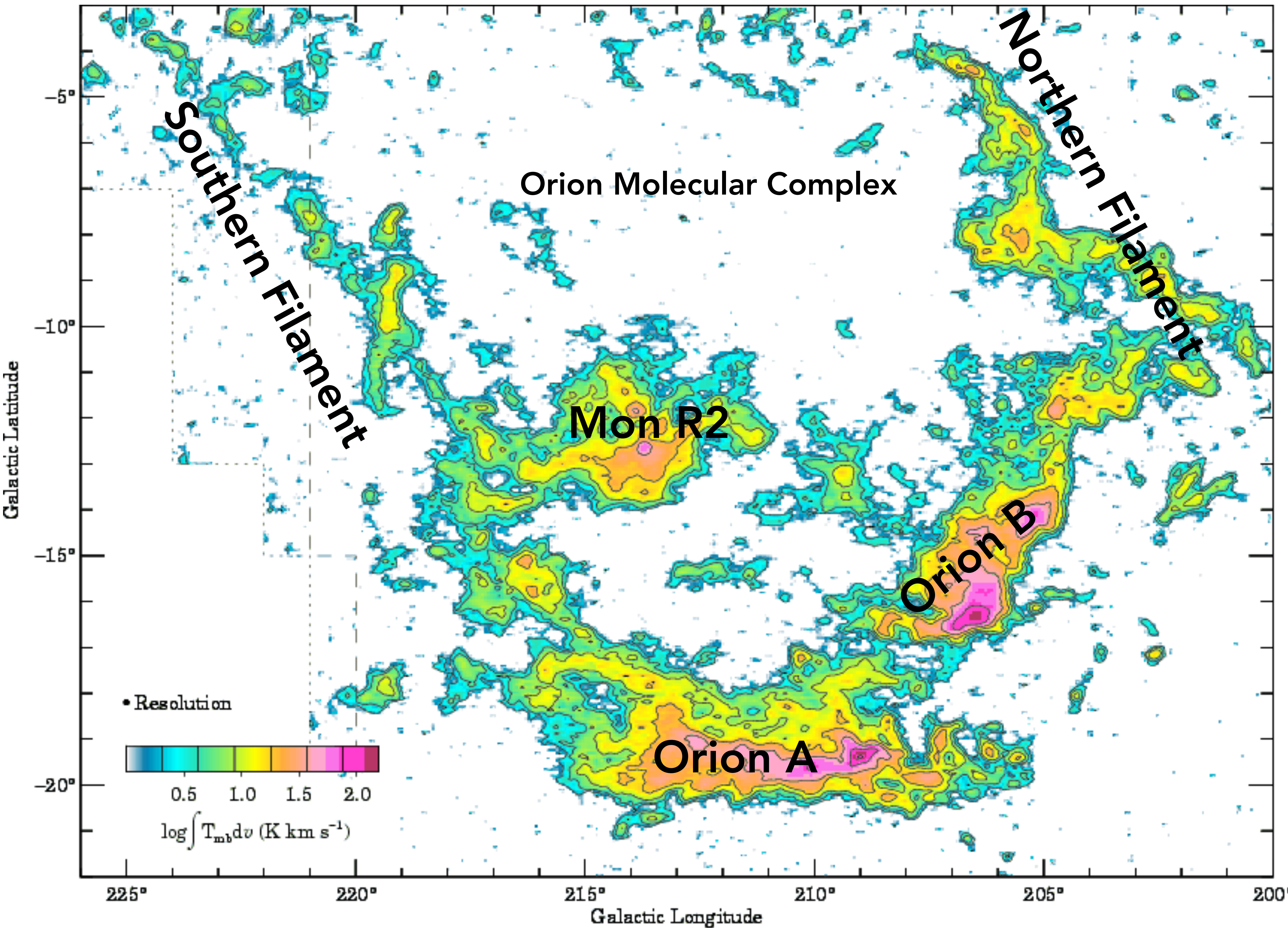
Wilson et al. 2005



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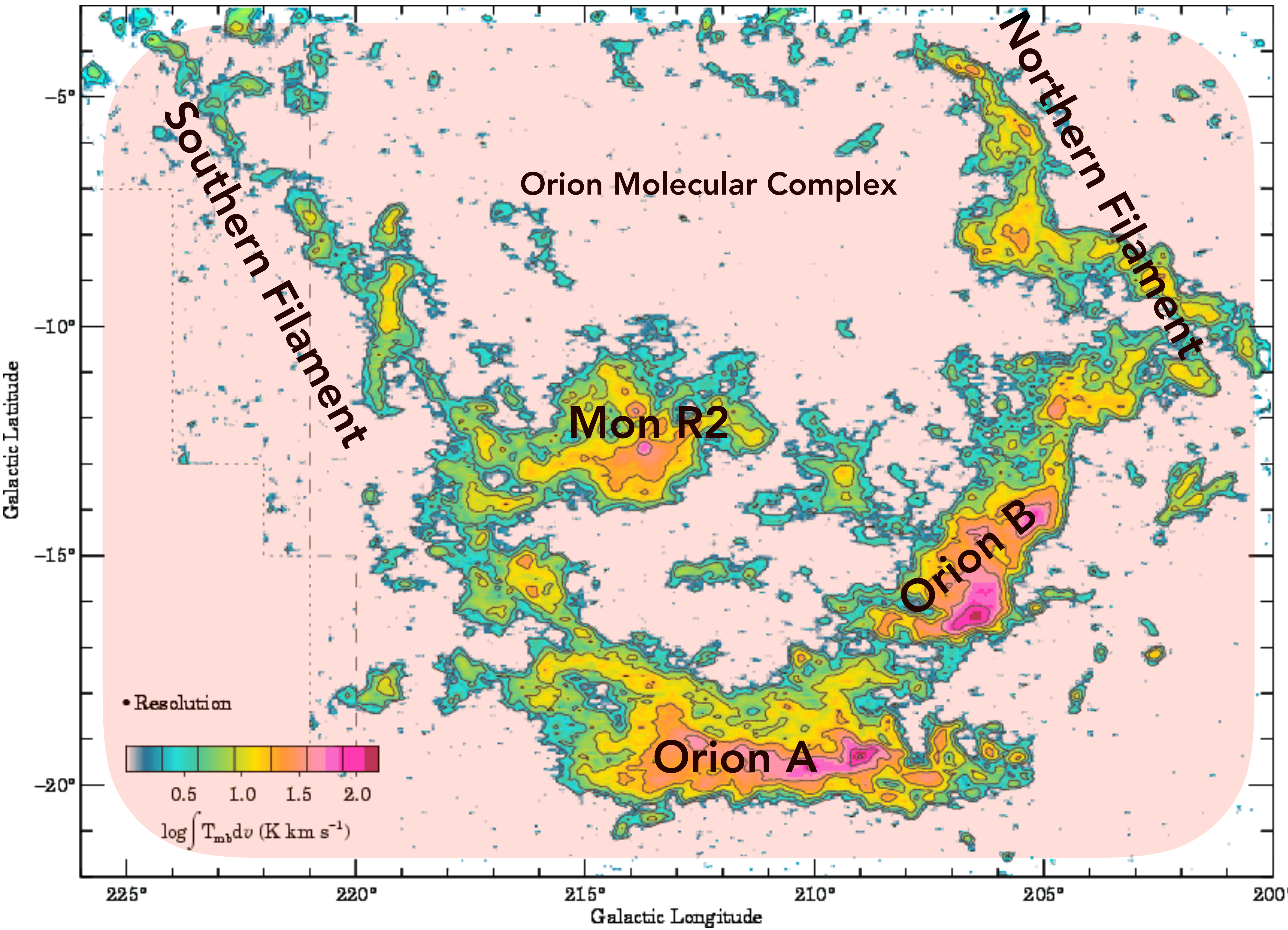
Wilson et al. 2005



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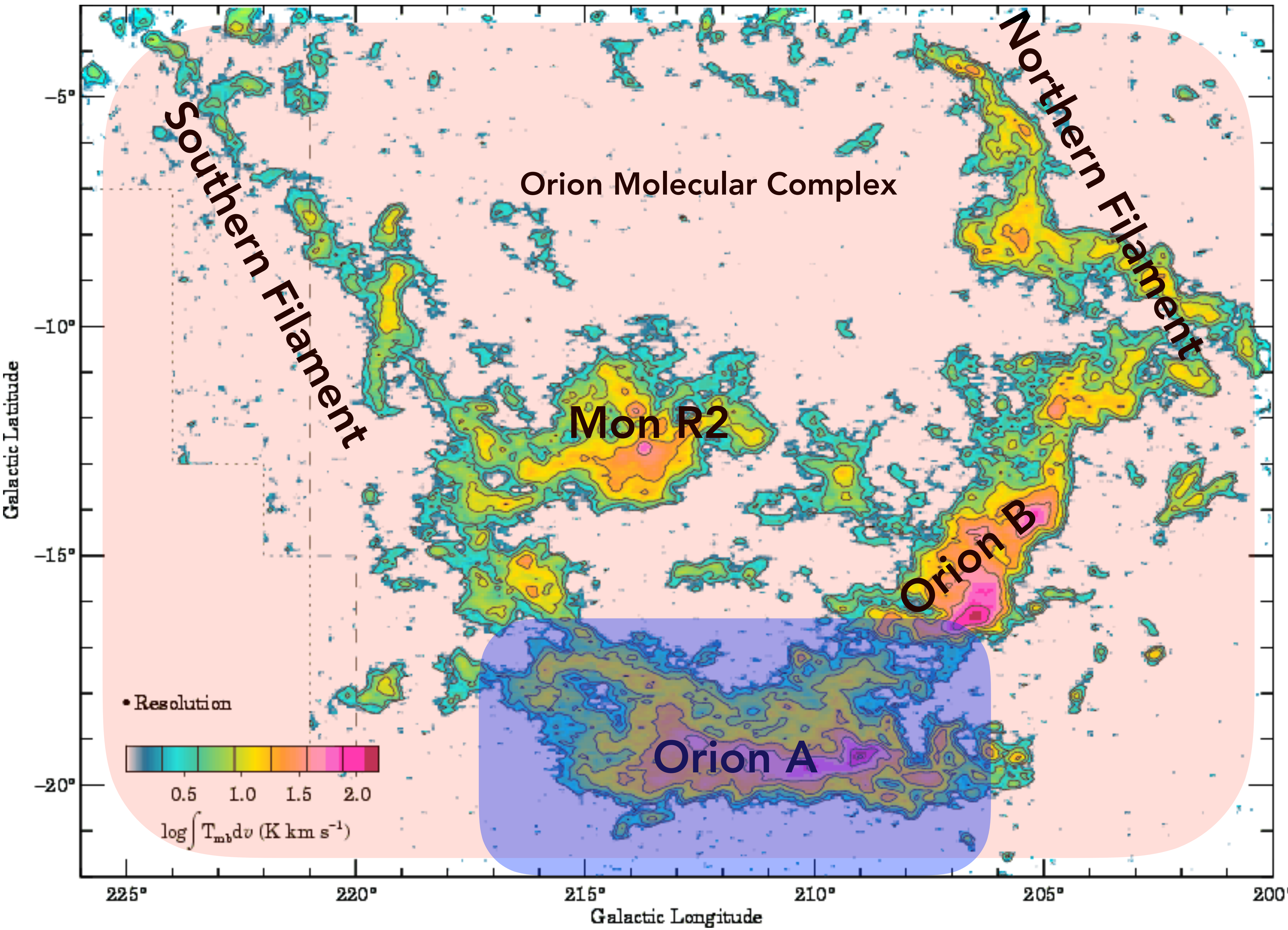
Wilson et al. 2005



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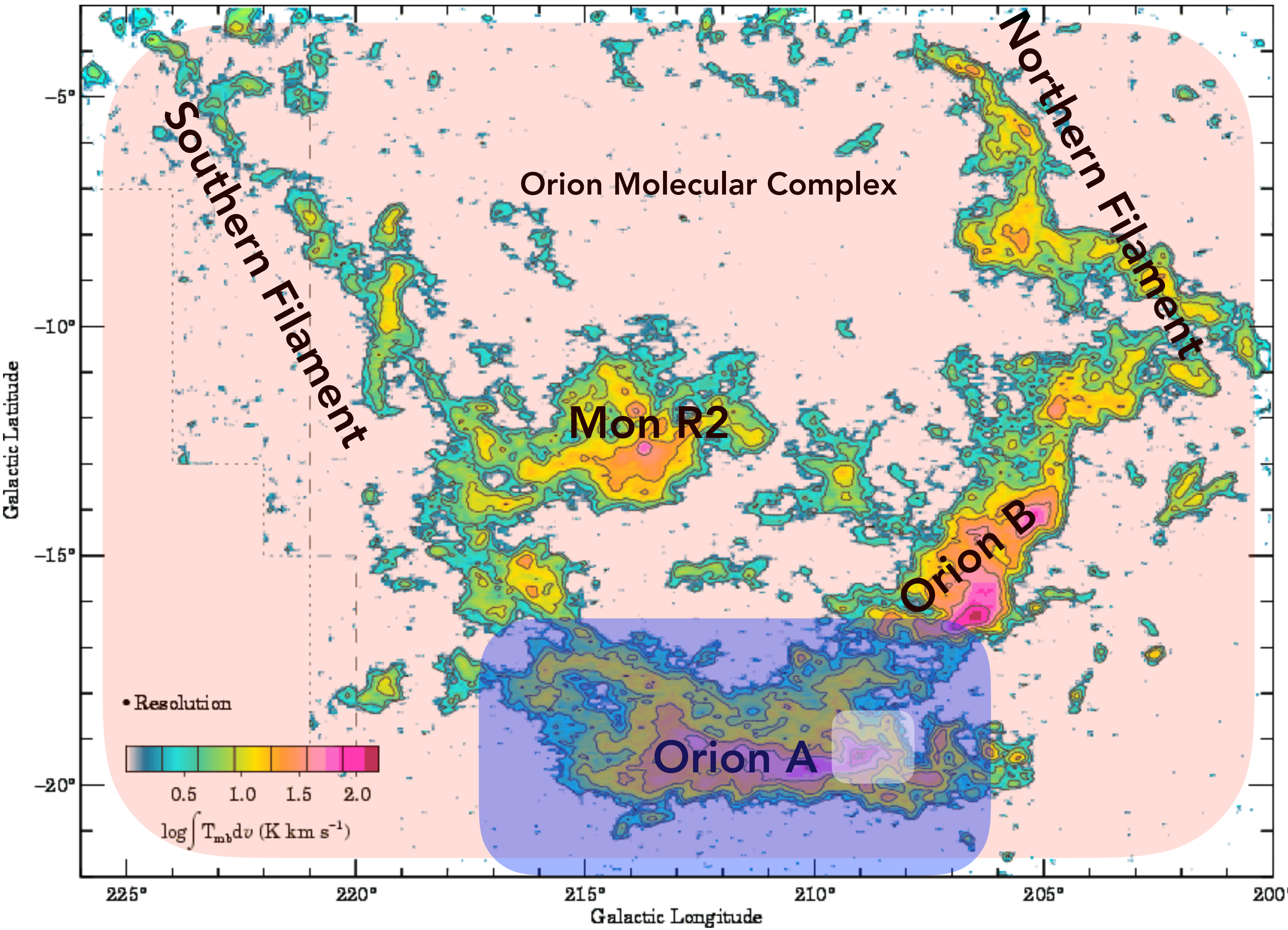

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Molecular Clouds

Observed Characteristics

- Self-Gravity
- Turbulence
- Substructure
- Magnetic Fields
- Mass Spectrum
- Lifetimes
- Star Formation

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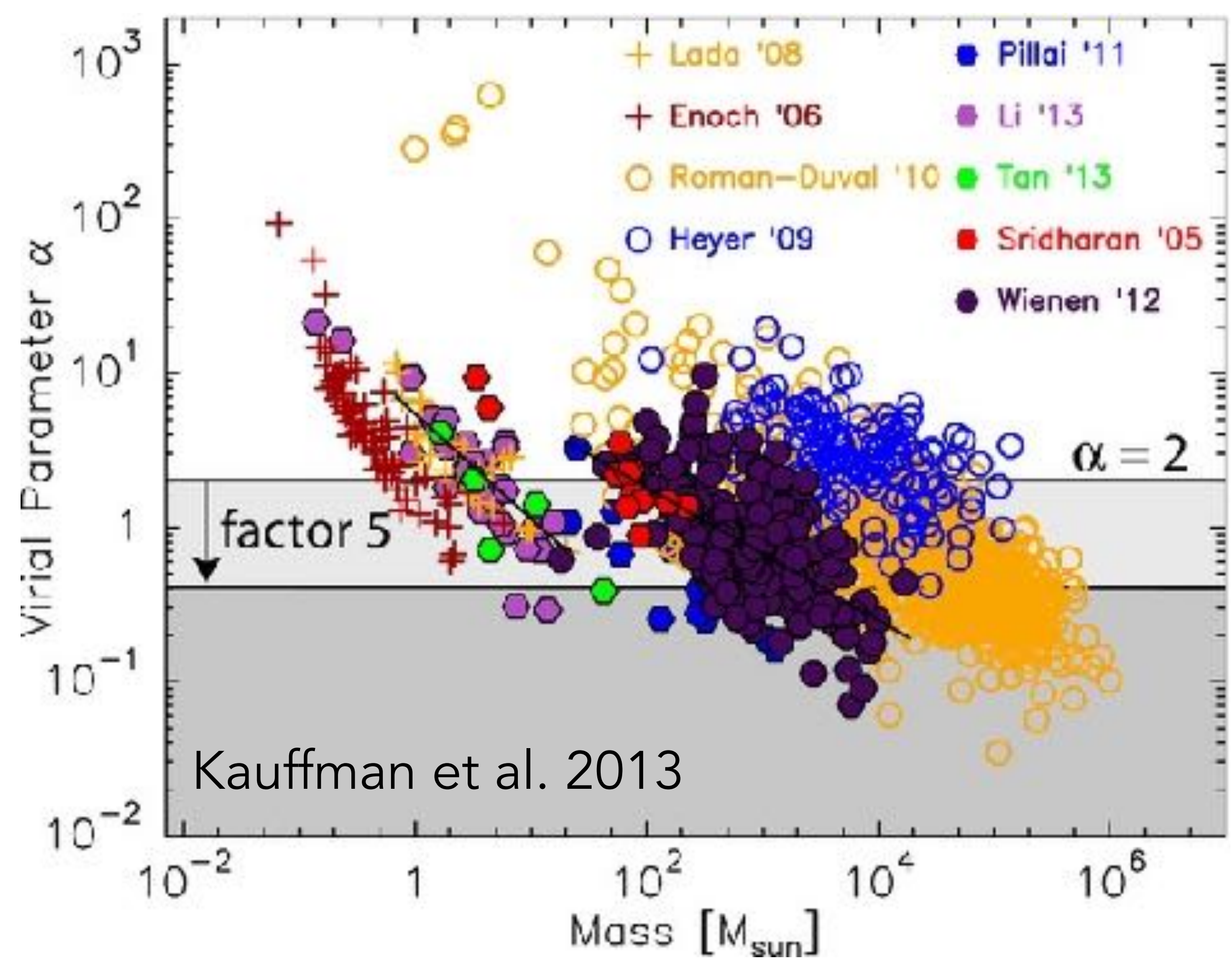
Continuing controversy over whether GMCs are gravitationally bound. Regardless, $\alpha_{vir} = 5\sigma_v R/GM$ ~ order unity



Kauffman et al. 2013

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Also note that GMCs are "over-pressurized" wrt diffuse ISM:

WNM/CNM: P ~ 3800 cm^{-3} K

GMC (T=10, n=10^4): P ~ 10^5 cm^{-3} K

Without self-gravity, GMCs would be transient.

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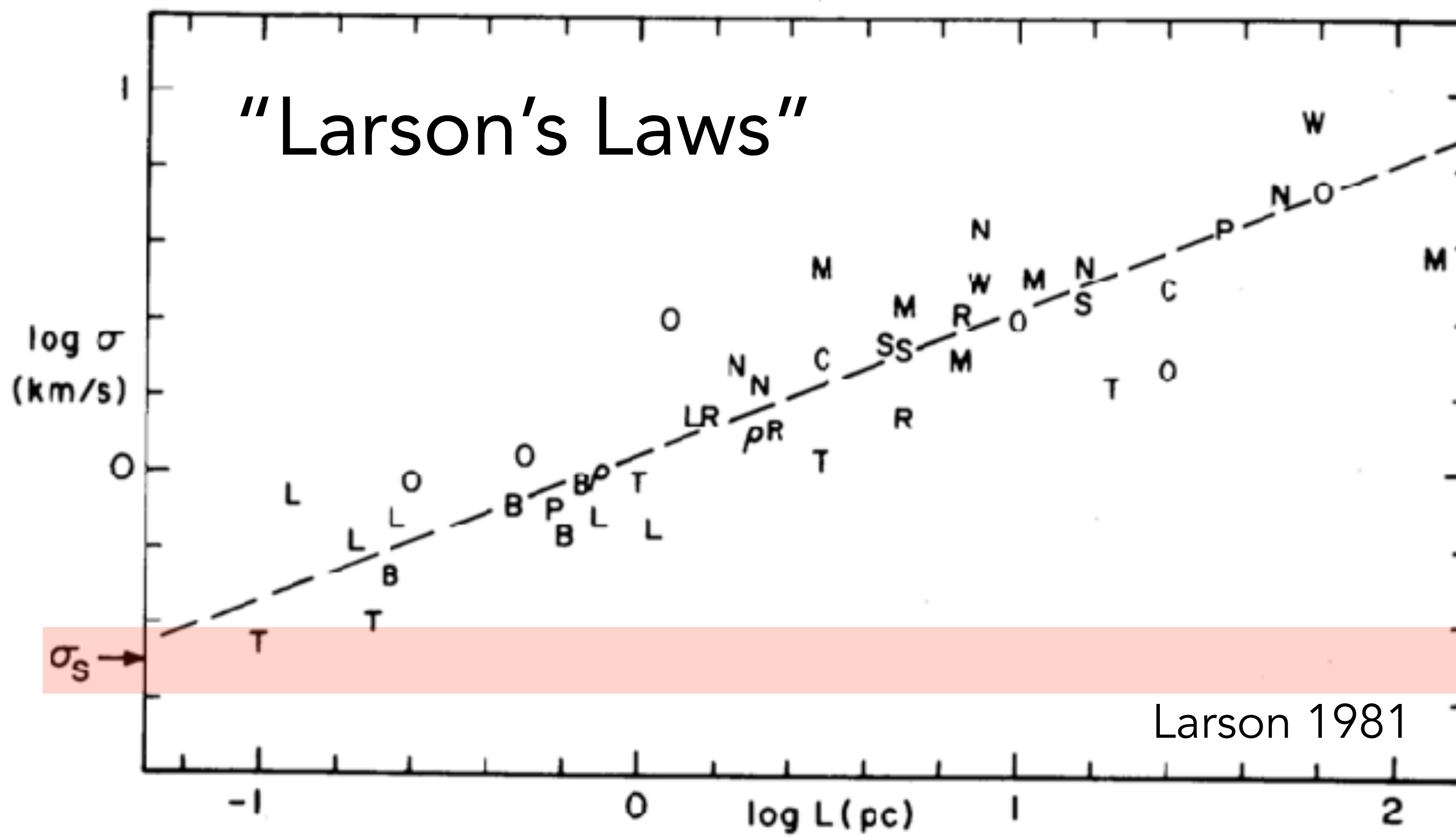

Velocity dispersion is >> sound speed, supersonic turbulence provides support against gravity.

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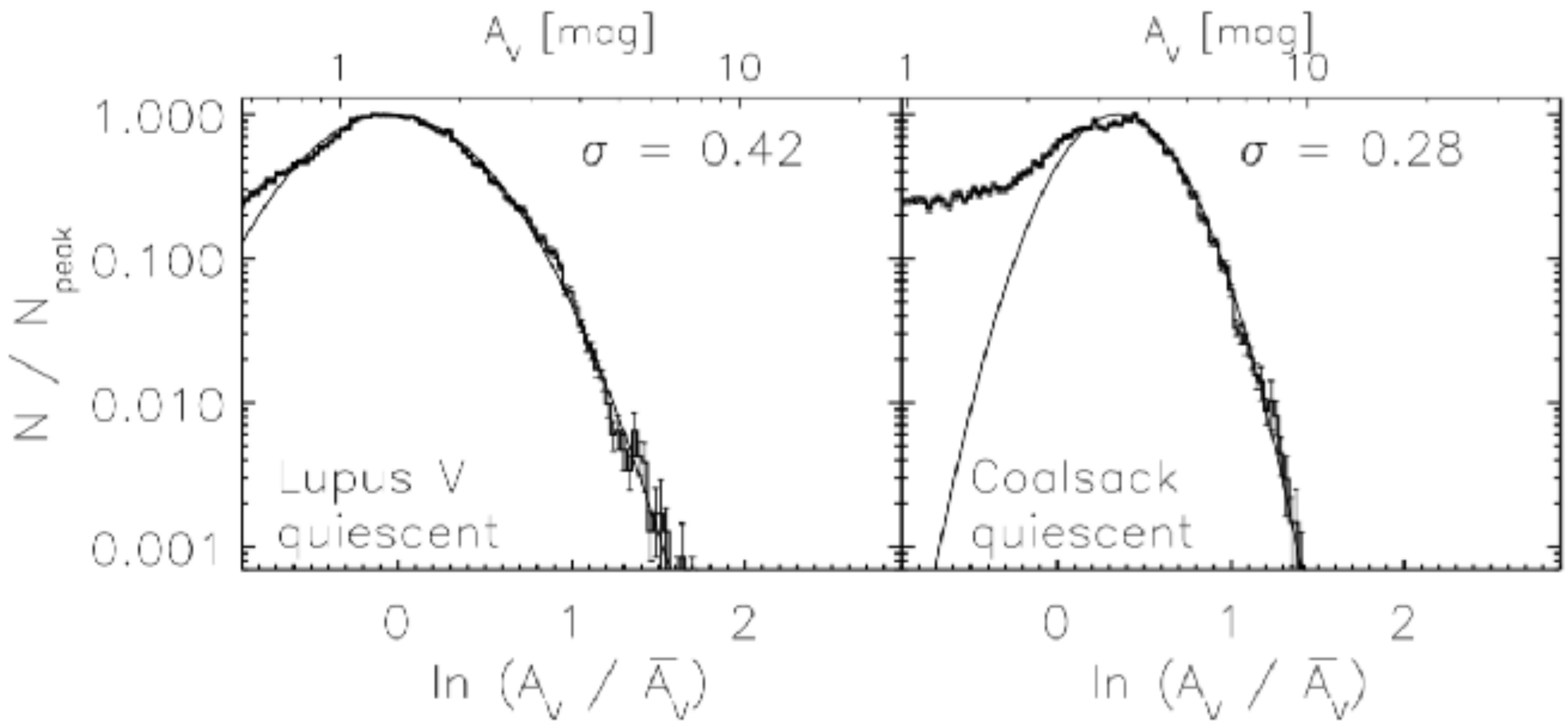

Kainulainen et al. 2009

Log-Normal PDF of column density observed in molecular clouds.

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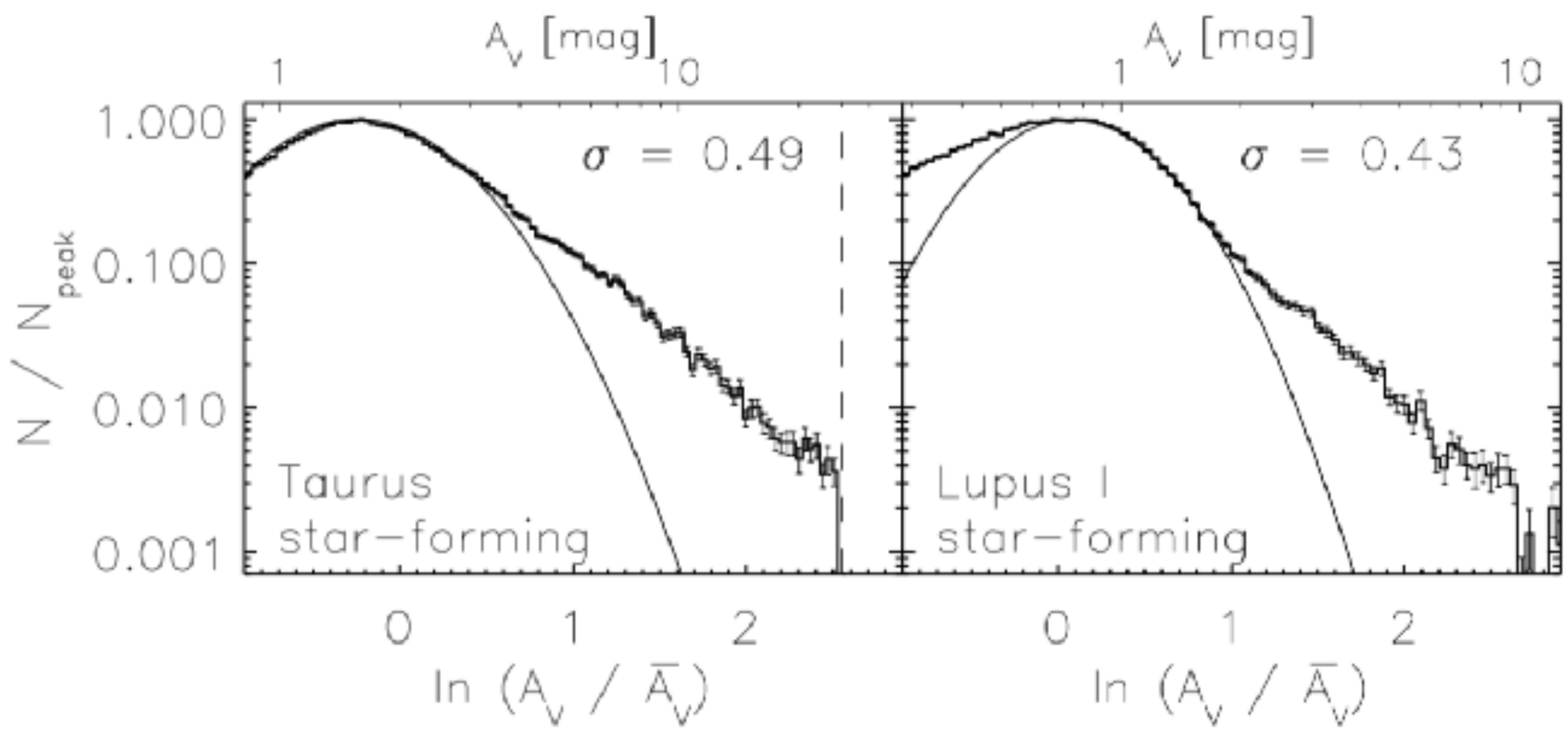

Kainulainen et al. 2009

Actively star-forming clouds show power-law tail at high column.

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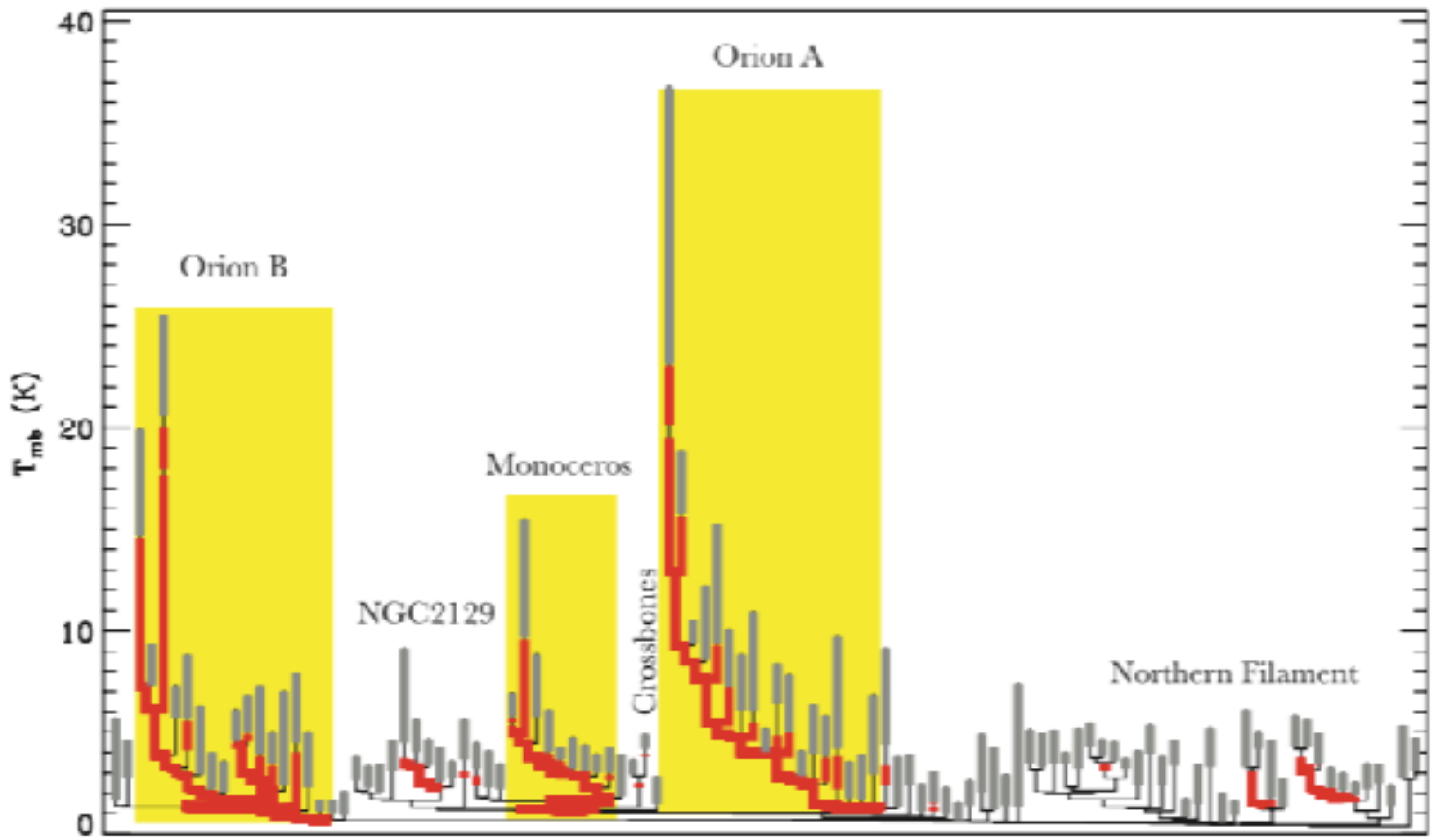
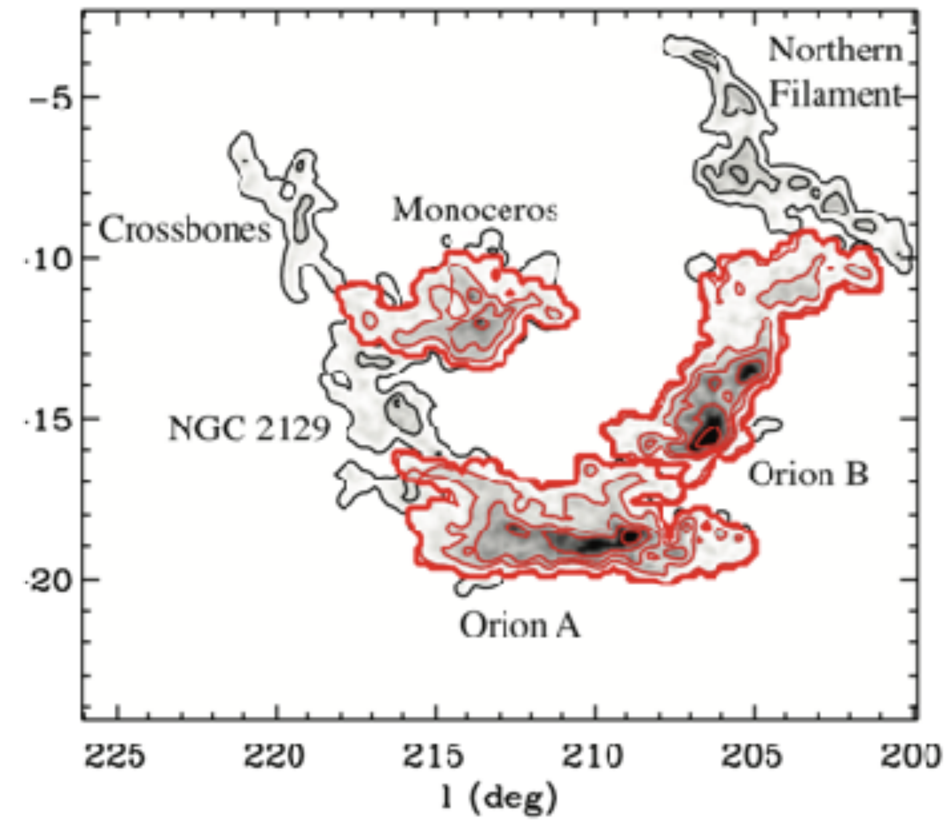
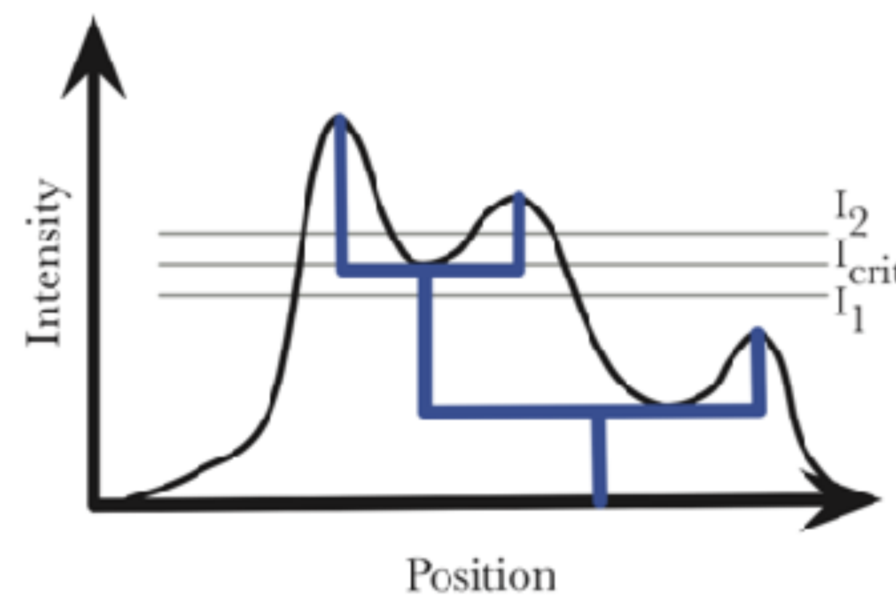


FIG. 15.—Dendrogram of the Orion-Monoceros region. Branches of the dendrogram corresponding to self-gravitating structures are highlighted in red. Regions where the quality of the data prohibit accurate estimation of the virial parameter are shown in gray. The GMCs within the data cube are identified 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.





Ways to quantify substructure in GMCs: dendrograms
(Rosolowsky et al. 2008)

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Molecular Clouds

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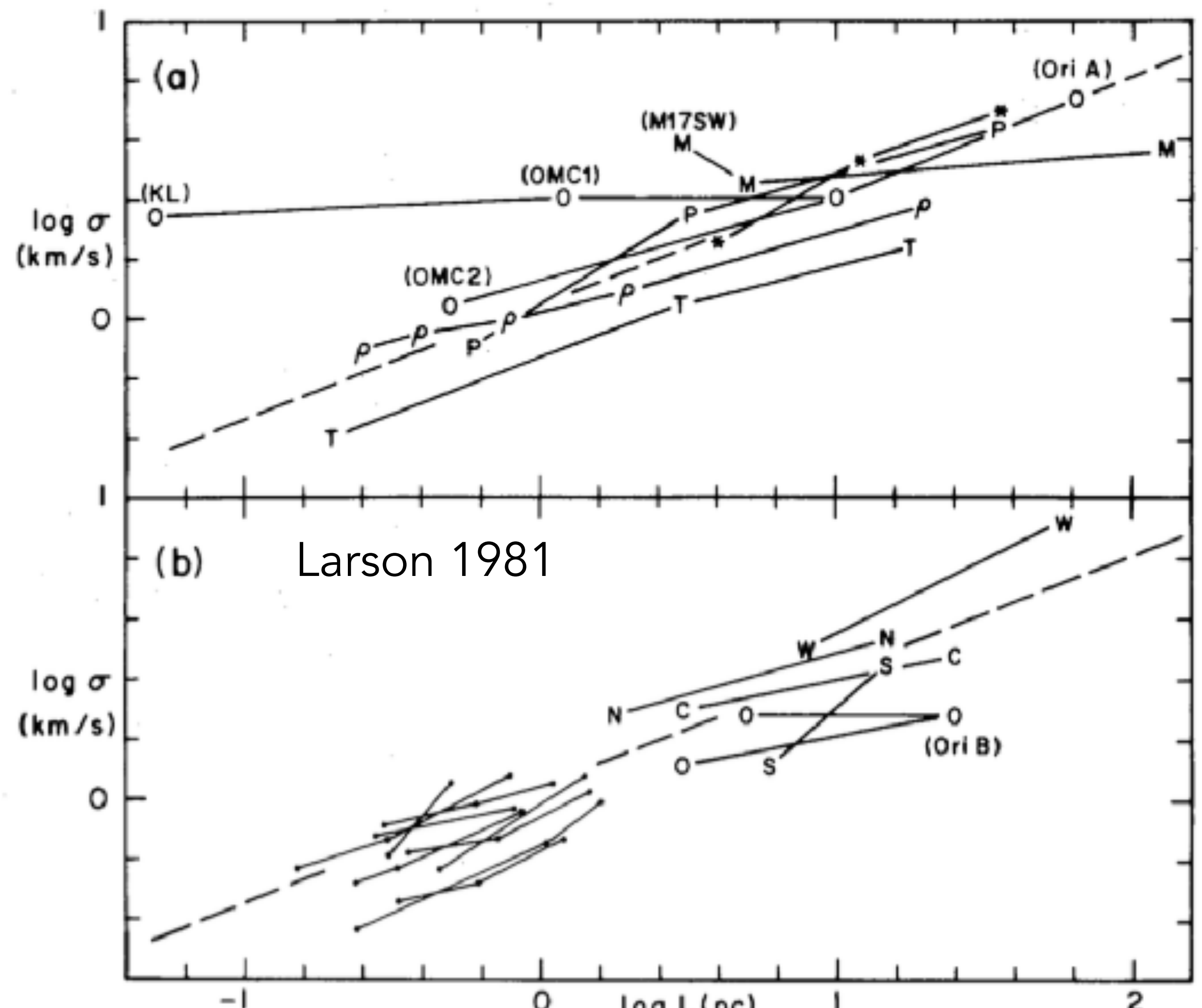
Sub-structures show scaling of L, σ_v, M.



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Molecular Clouds

Observed Characteristics

Leroy et al. 2015

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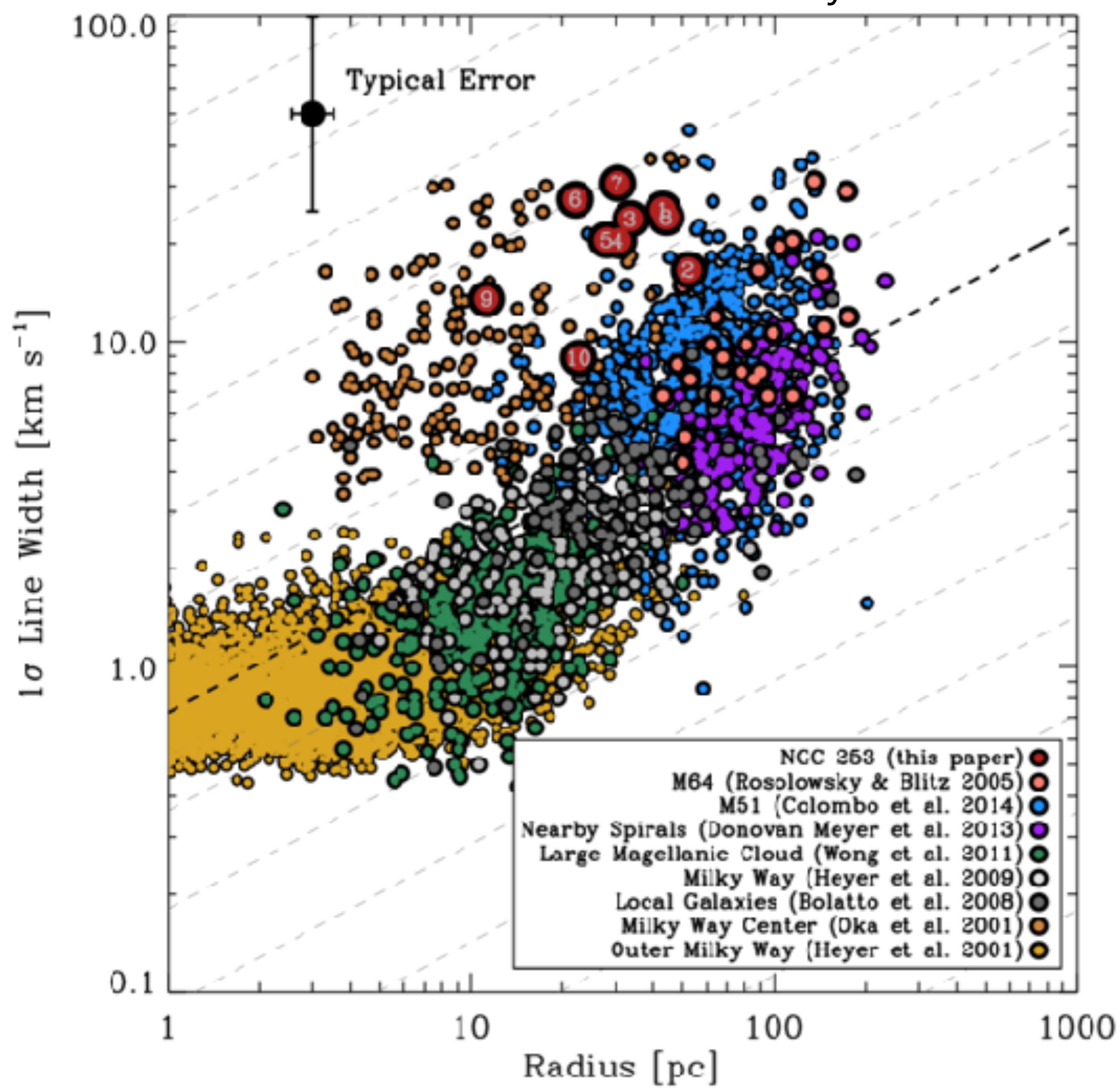

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Magnetic Fields in the ISM

Observational Tracers:

- Synchrotron emission - from charged particles interacting with the magnetic field.
- Faraday Rotation - different phase velocities of right & left circularly polarized light in the presence of B-field leads to rotation of polarization angle
- Polarization - of starlight due to dust grains aligned along B-field or of dust emission from aligned grains
- Zeeman splitting - splitting of fine structure levels in atoms/ molecules due to interaction of electron magnetic moment and B-field

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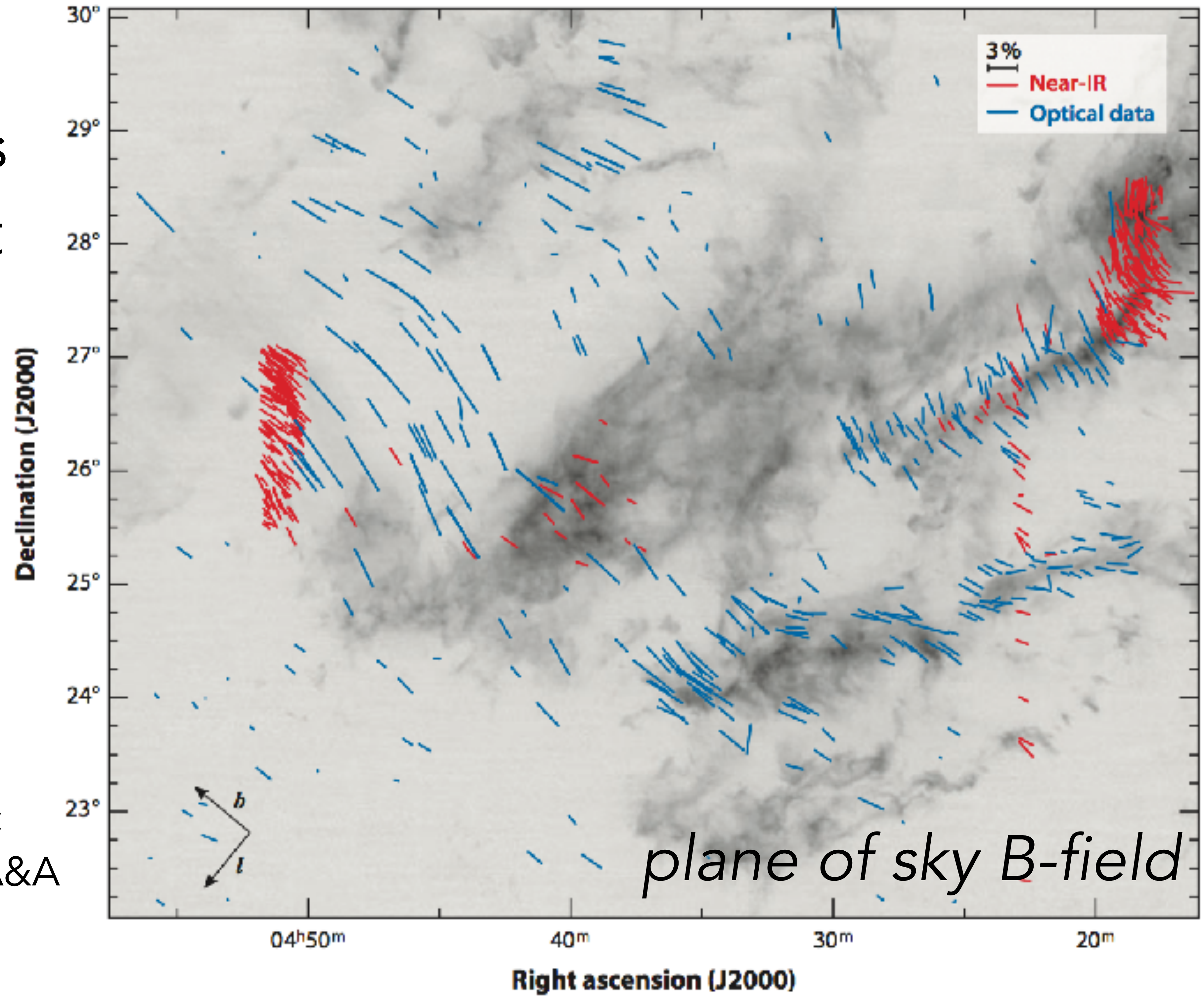
Magnetic Fields in the ISM

Crutcher 2012



Polarization of starlight in Taurus due to alignment of dust grains with the B-field.

Magnetic fields review: Crutcher 2012 ARA&A

Grain alignment review: Andersson et al. 2015 ARA&A

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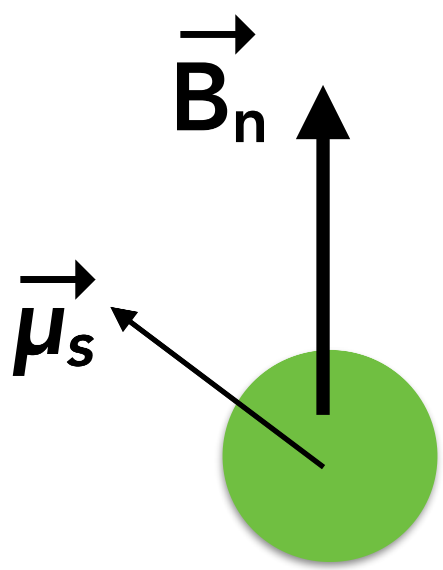
Hyperfine Transitions

Classical non-relativistic atom



spin magnetic moment of electron interacts with B-field from nuclear spin

"hyperfine structure" transitions

interaction between magnetic moments of nucleus and e-

$E \sim 13.6 \text{ eV } (m_e/m_n)(\alpha^2 Z^4/n^5)$

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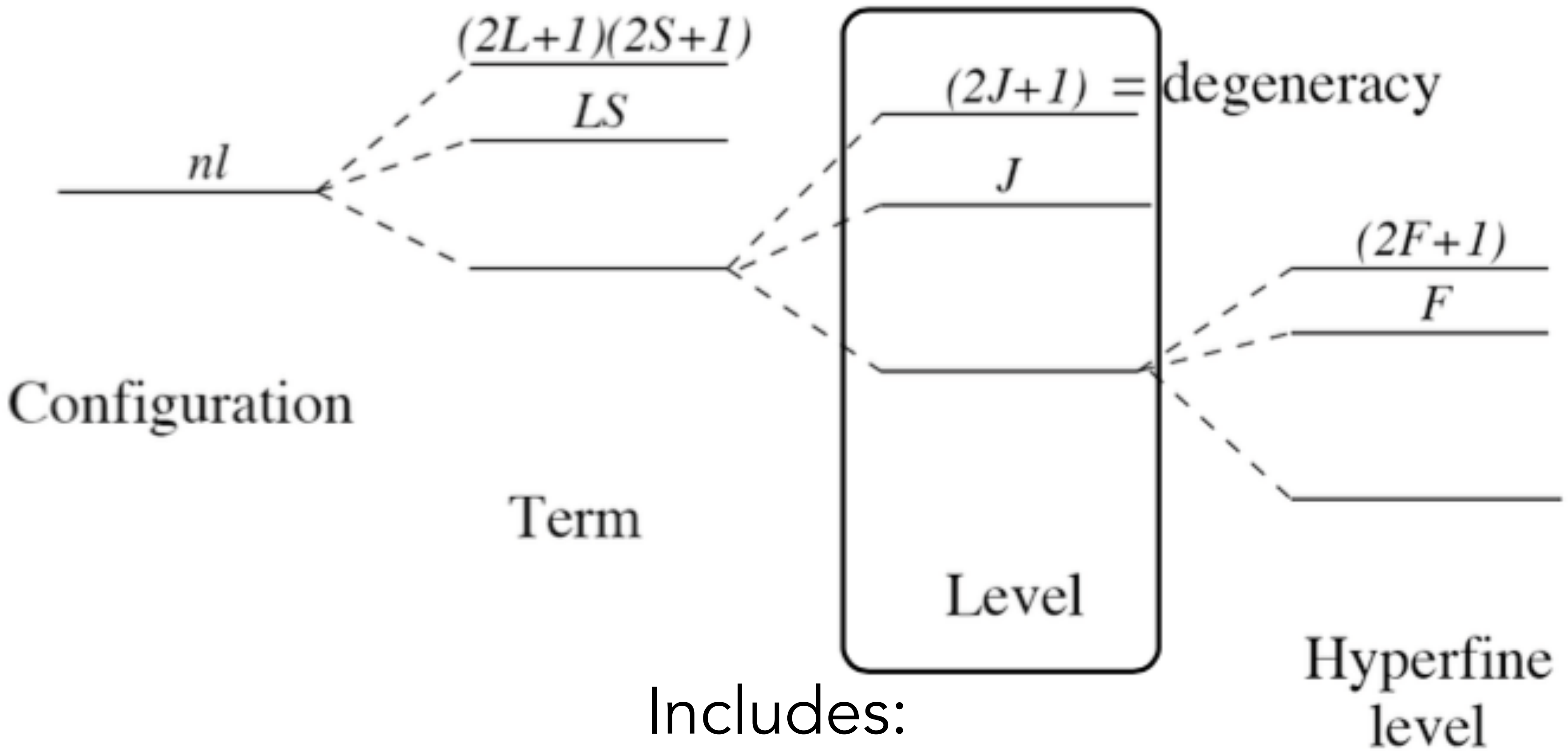
Hyperfine Transitions



Fine & Hyperfine are "forbidden"
parity doesn't change
$\Delta S \neq 0$

Includes:

-fine structure transitions (transitions within a term, e.g. $^2P_{1/2}$ - $^2P_{3/2}$ 158μm line of [CII] within ^2P term)

-hyperfine structure transitions (transitions within a given level of a term caused by splitting due to interaction of electron & nuclear spin, e.g. HI 21 cm spin-flip transition)

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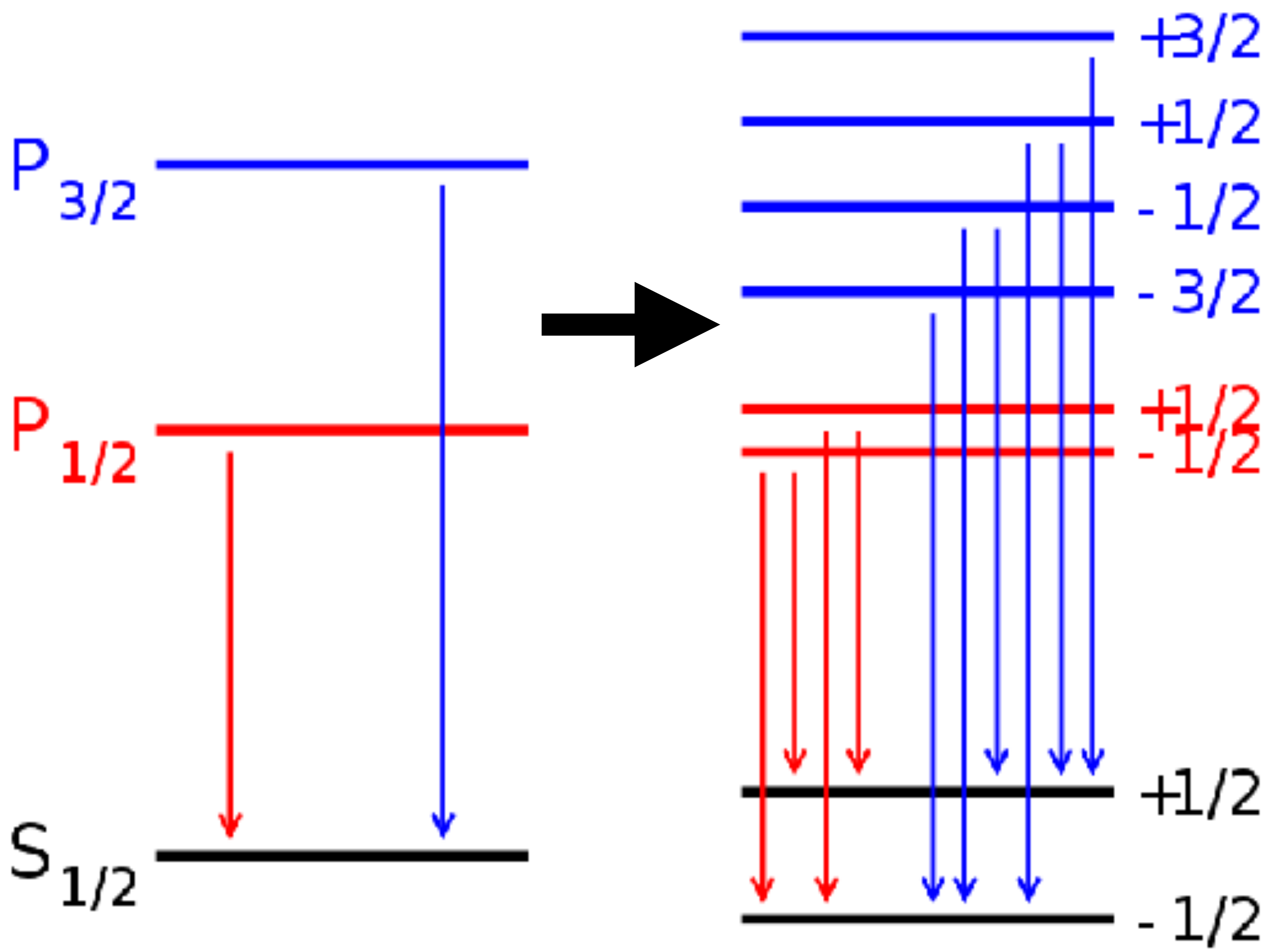
Magnetic Fields in Molecular Gas

Zeeman Effect



Zeeman splitting is largest when there is an unpaired electron in outer shell: e.g. HI, OH, CN, CH, CCS, SO, and O_2

Even then, energy shift is small.

But, shifted levels produce different circular polarizations.

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