Physics 224
The Interstellar Medium

Lecture #13: Neutral Gas, Photodissociation Regions & the HI to H_2 transition

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Outline

- Part I: Neutral Gas
- Part II: HI to H_2 Transition
- Part III: Photodissociation Regions

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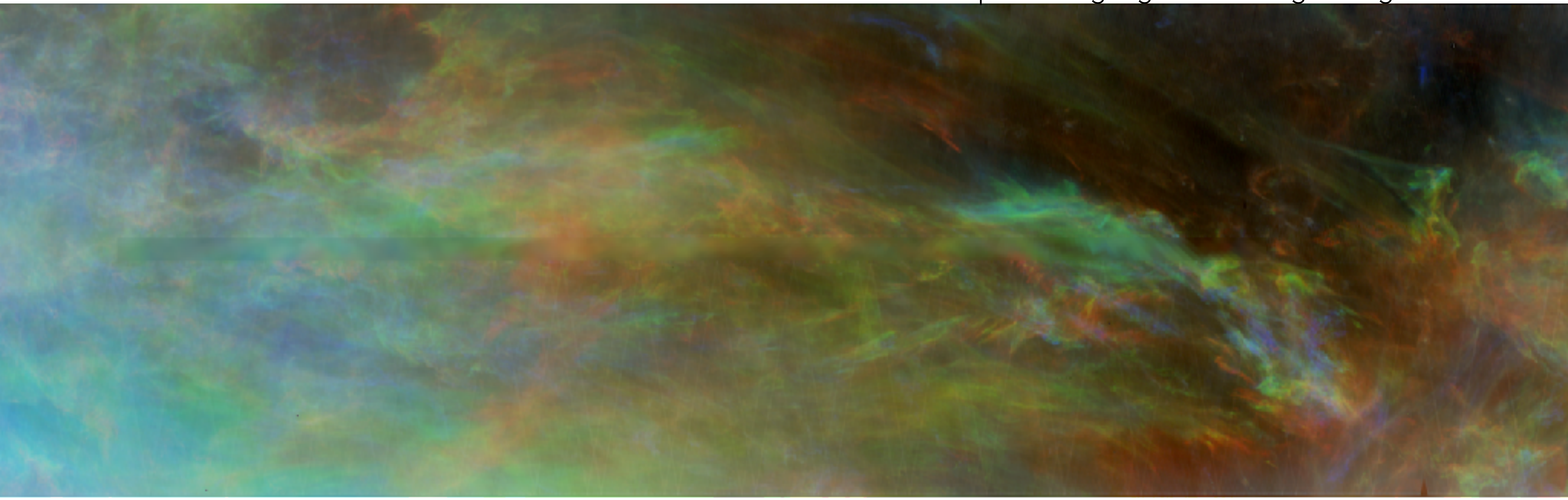
Is the FGH model a good representation of the ISM?

https://sites.google.com/site/galfahi/galfa-hi-science



part of the GALFA HI Survey
colors = different velocity ranges

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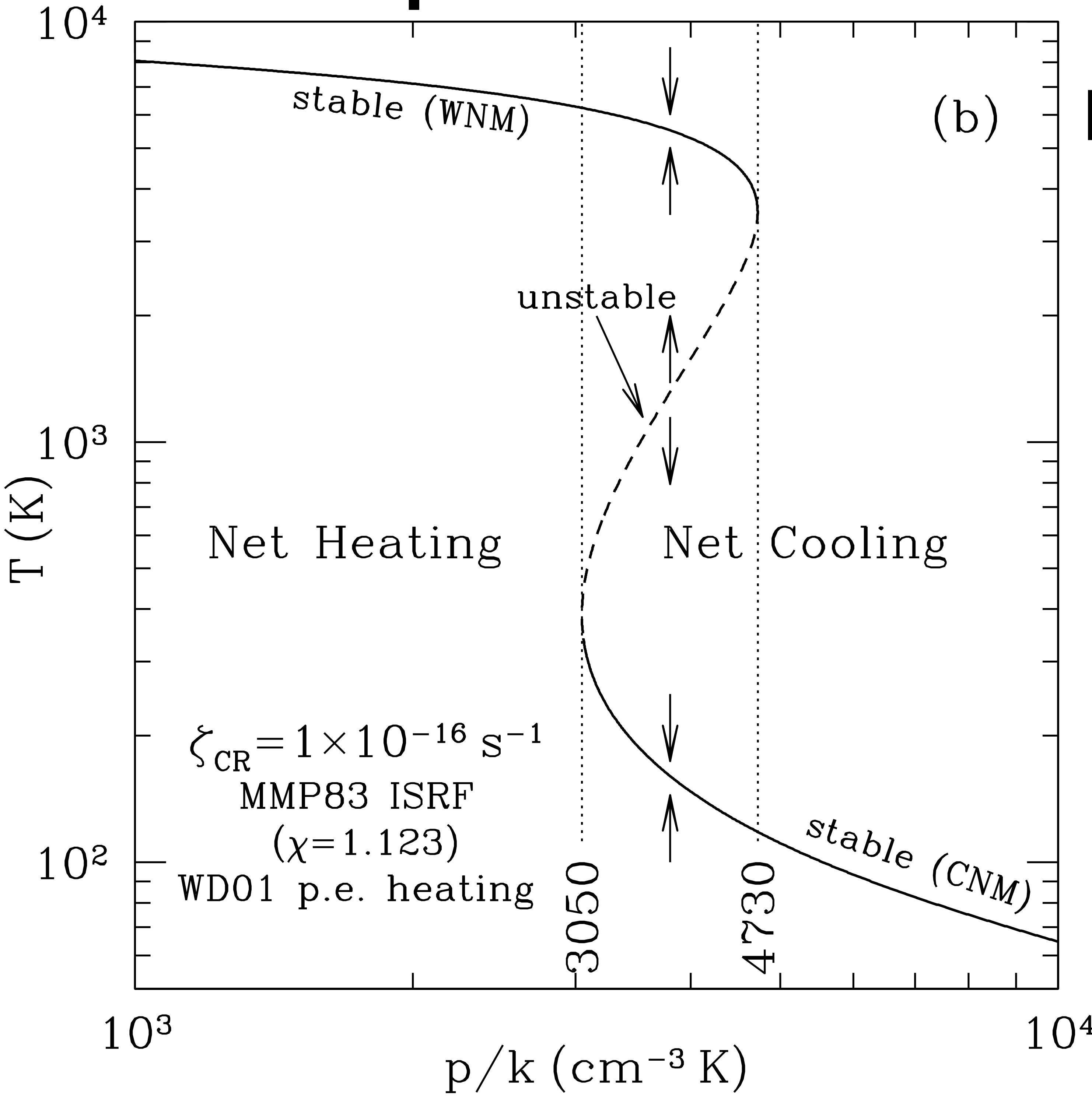
Is the FGH model a good representation of the ISM?



How can we test this model?

Measure the n & T of HI gas and see if it matches the predicted n,T ranges for CNM and WNM stable phases.

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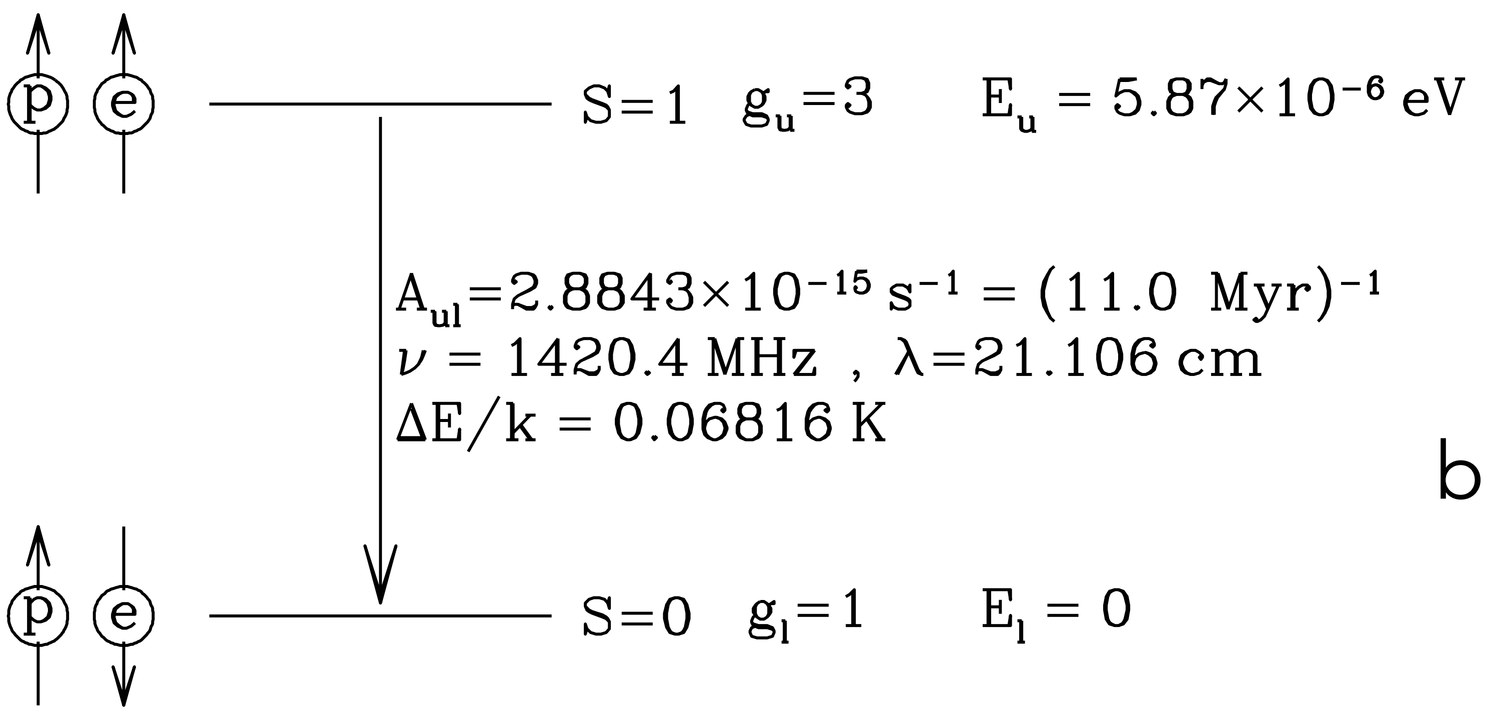
HI Spin Temperature



$T_{exc} \equiv T_{spin} \gg 0.0682$ K

because cosmic microwave background can populate levels

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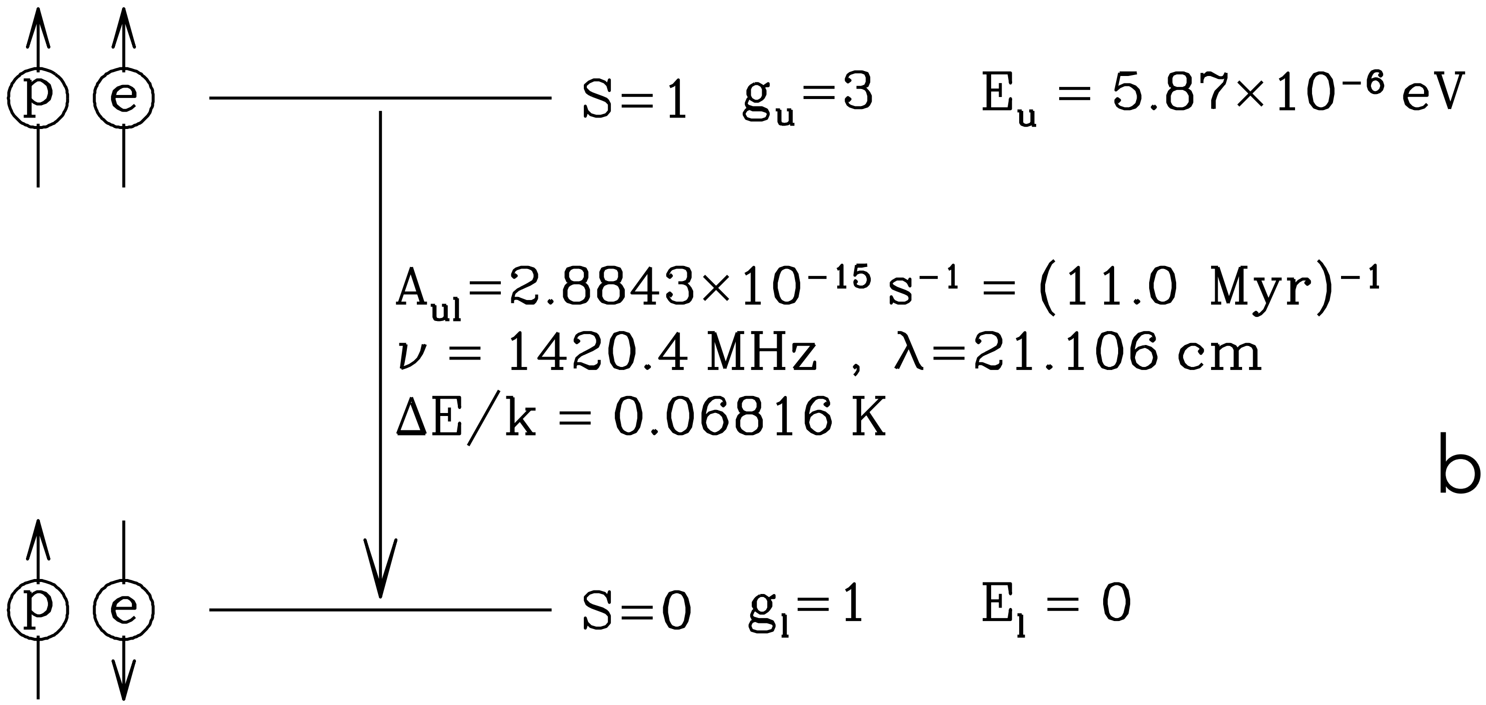
HI Spin Temperature



$T_{exc} \equiv T_{spin} \gg 0.0682$ K because cosmic microwave background can populate levels

Under most ISM conditions, 75% of HI is in upper level. *Emissivity is independent of T_{spin}!!*

$$j_\nu = n_u \frac{A_{ul}}{4\pi} h\nu_{ul}\phi_\nu = \frac{3}{16\pi} A_{ul}\ h\nu_{ul}\ n(\mathrm{H\ I})\ \phi_\nu$$

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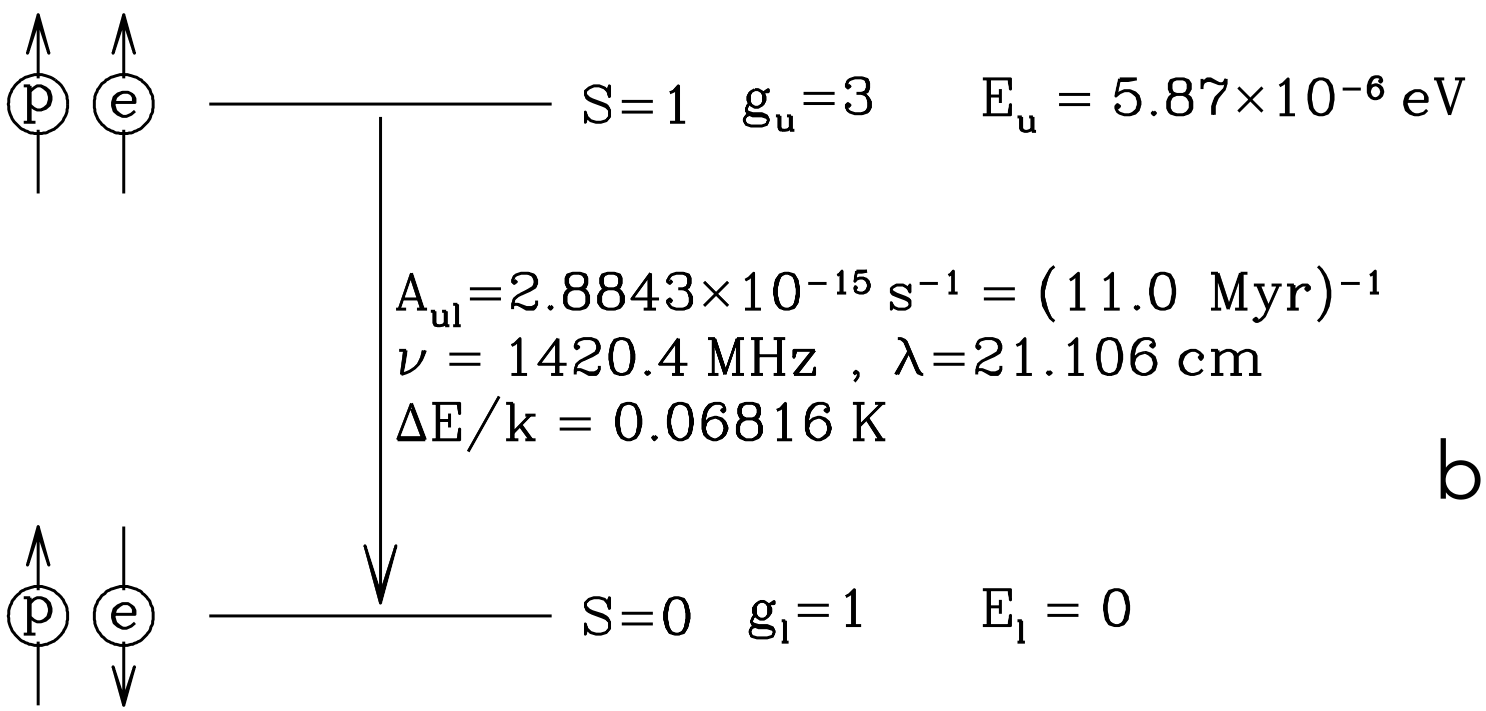
HI Spin Temperature



$T_{exc} \equiv T_{spin} \gg 0.0682$ K
because cosmic microwave background can populate levels

absorption coefficient depends inversely on T_{spin}
as a consequence of stimulated emission not being negligible!

$$\kappa_\nu \approx \frac{3}{32\pi} A_{ul} \frac{hc\lambda_{ul}}{kT_{spin}} n(\mathrm{H\ I})\phi_\nu$$

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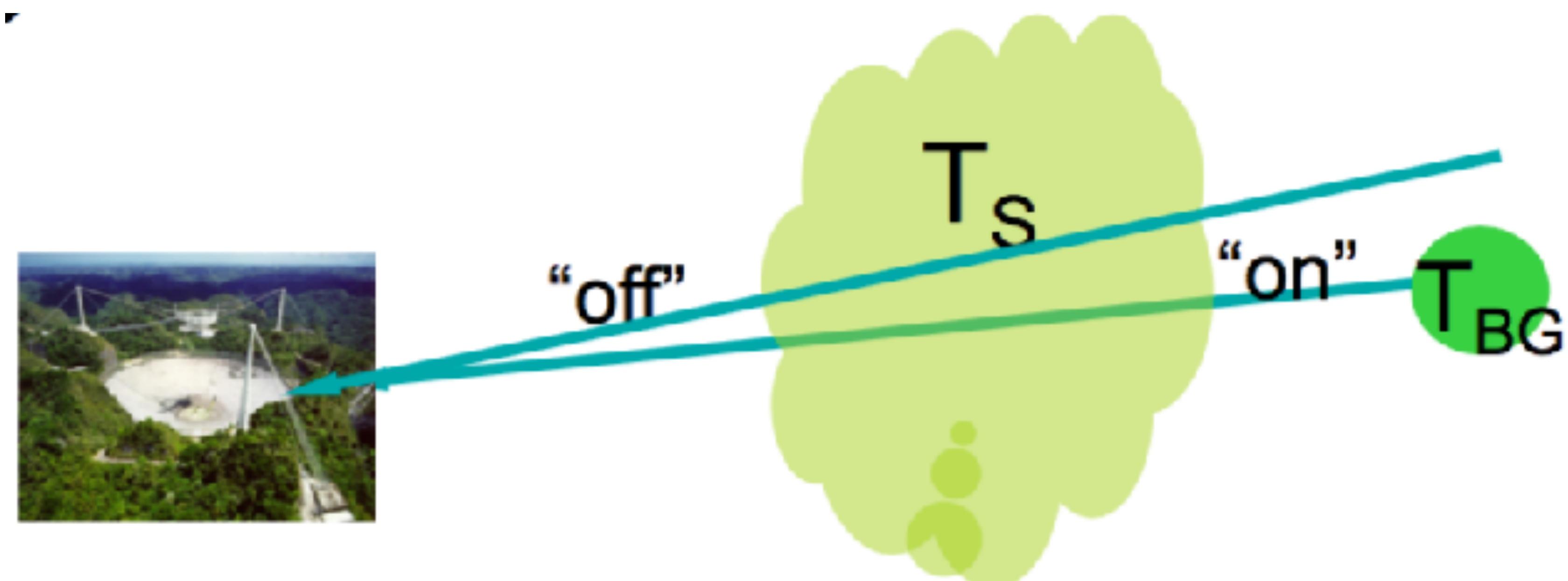
HI Spin Temperature

Measuring spin temperature



$$T_b^{on} = T_{bg} e^{-\tau} + T_s(1 - e^{-\tau})$$
$$T_b^{off} = T_s(1 - e^{-\tau}) \quad (1)$$

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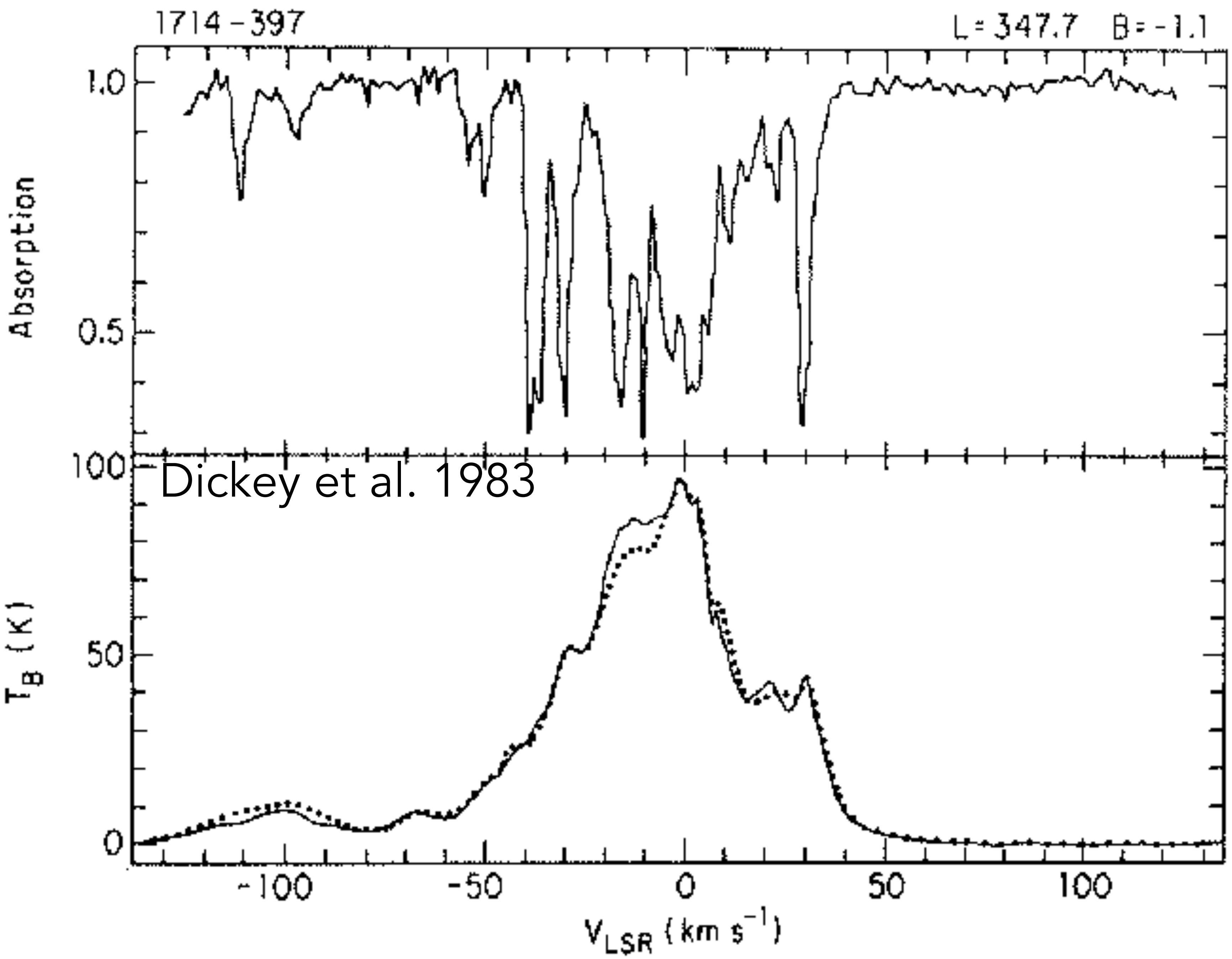
HI Spin Temperature



Absorption - weighted to low T

Emission - independent of T

$\langle T_{spin} \rangle = T_B/(1-e^{-\tau})$

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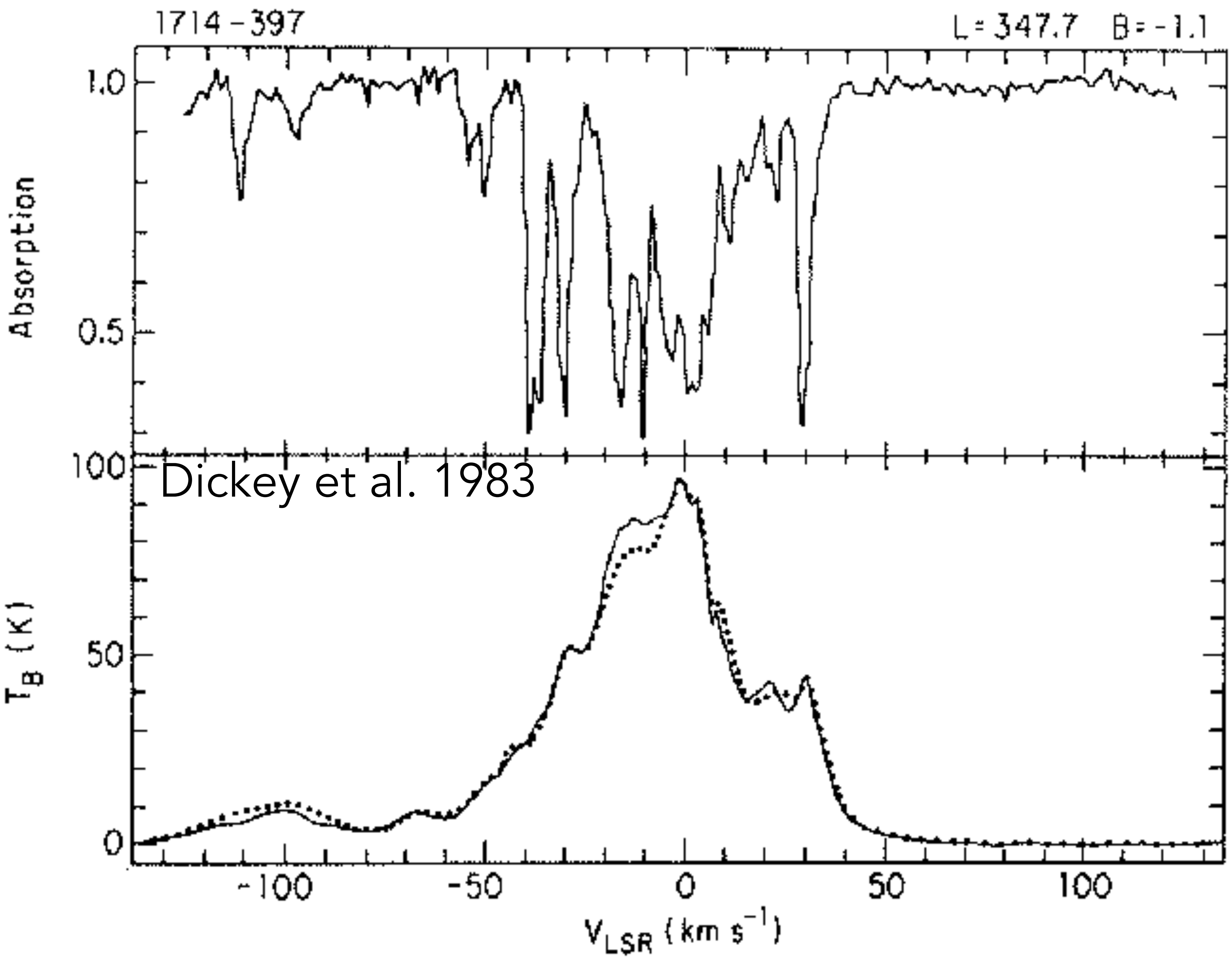
HI Spin Temperature



Assume T_{WNM} is too big to contribute much to the absorption.

$\tau \sim n_{CNM}/T_{CNM}$

$T_B \sim n_{CNM} + n_{WNM}$

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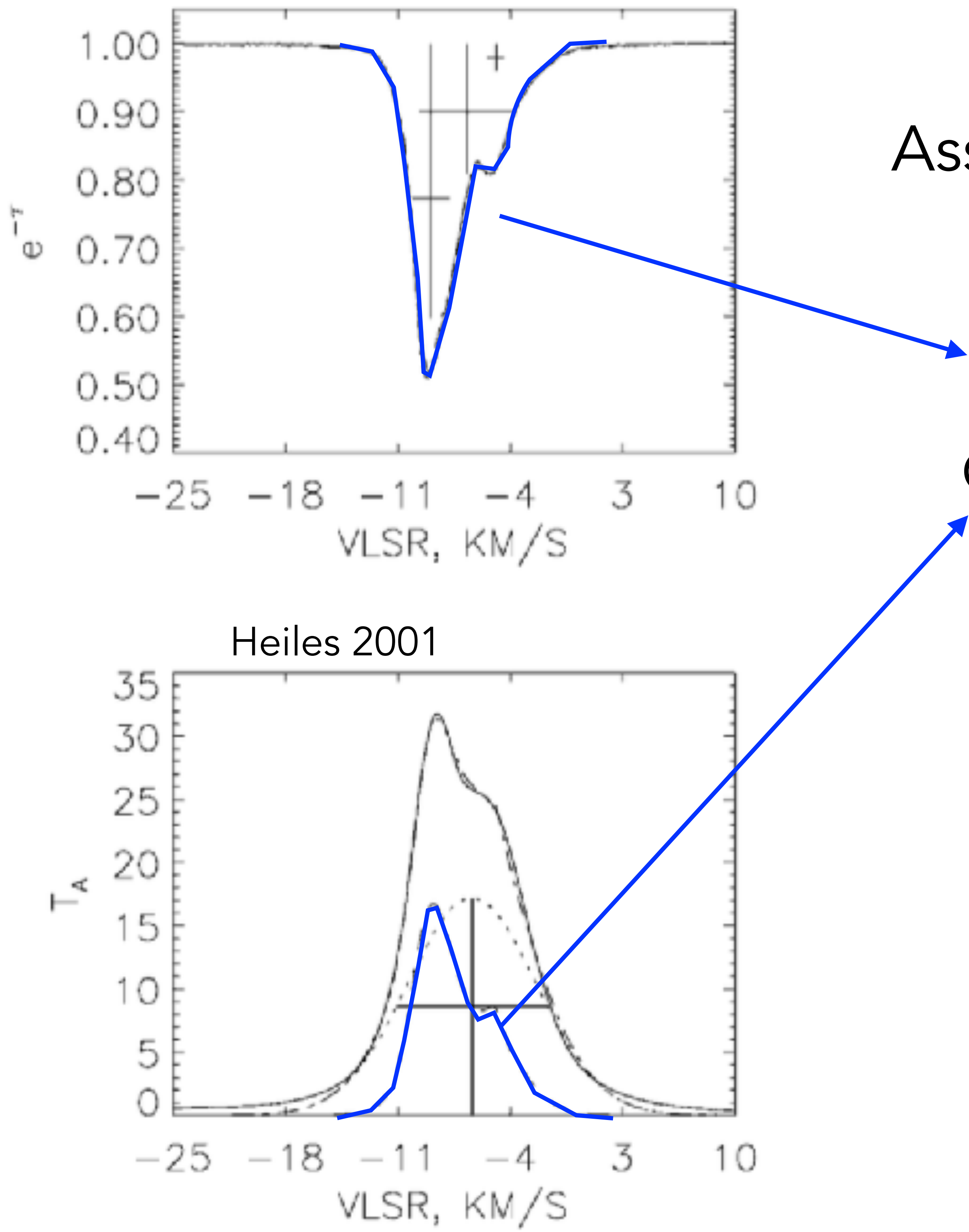
Observed HI Spin Temperature



Assume CNM dominates absorption.

Fit absorption component and emission component with same Gaussian components (σ_V) to get N_{CNM}, T_{CNM}

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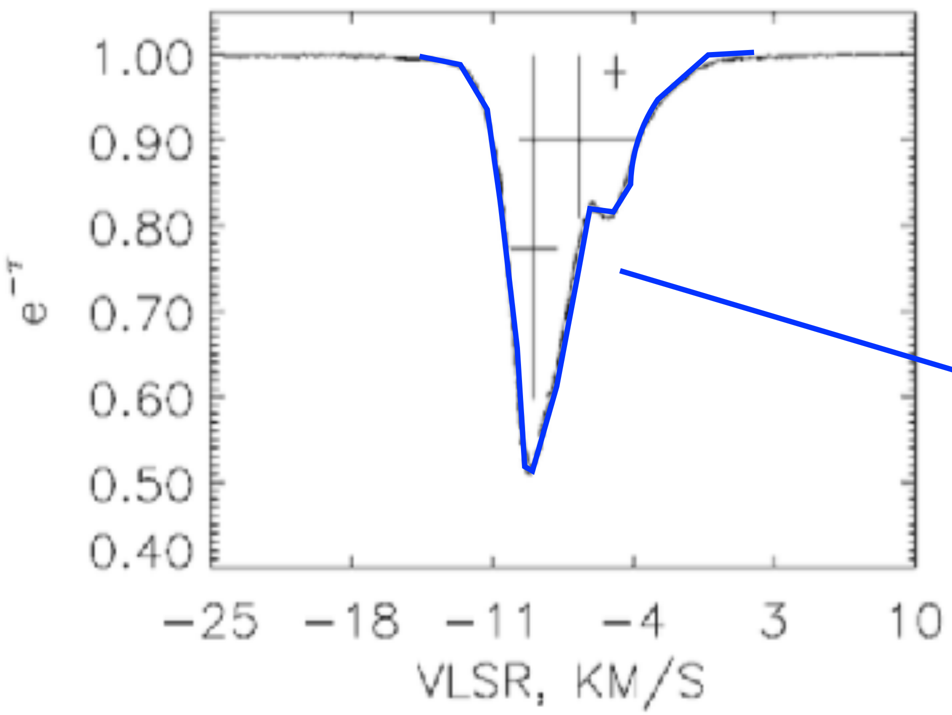
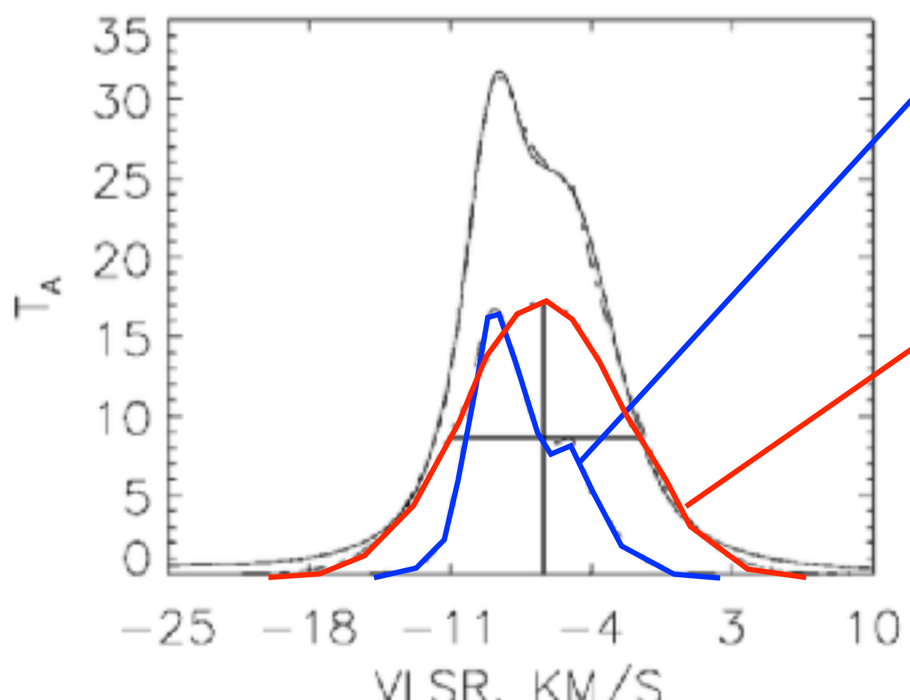
Observed HI Spin Temperature



Heiles 2001



Assume CNM dominates absorption.

Fit absorption component and emission component with same Gaussian components (σ_V) to get N_{CNM}, T_{CNM}

Fit emission component with additional Gaussian and N_{WNM}.

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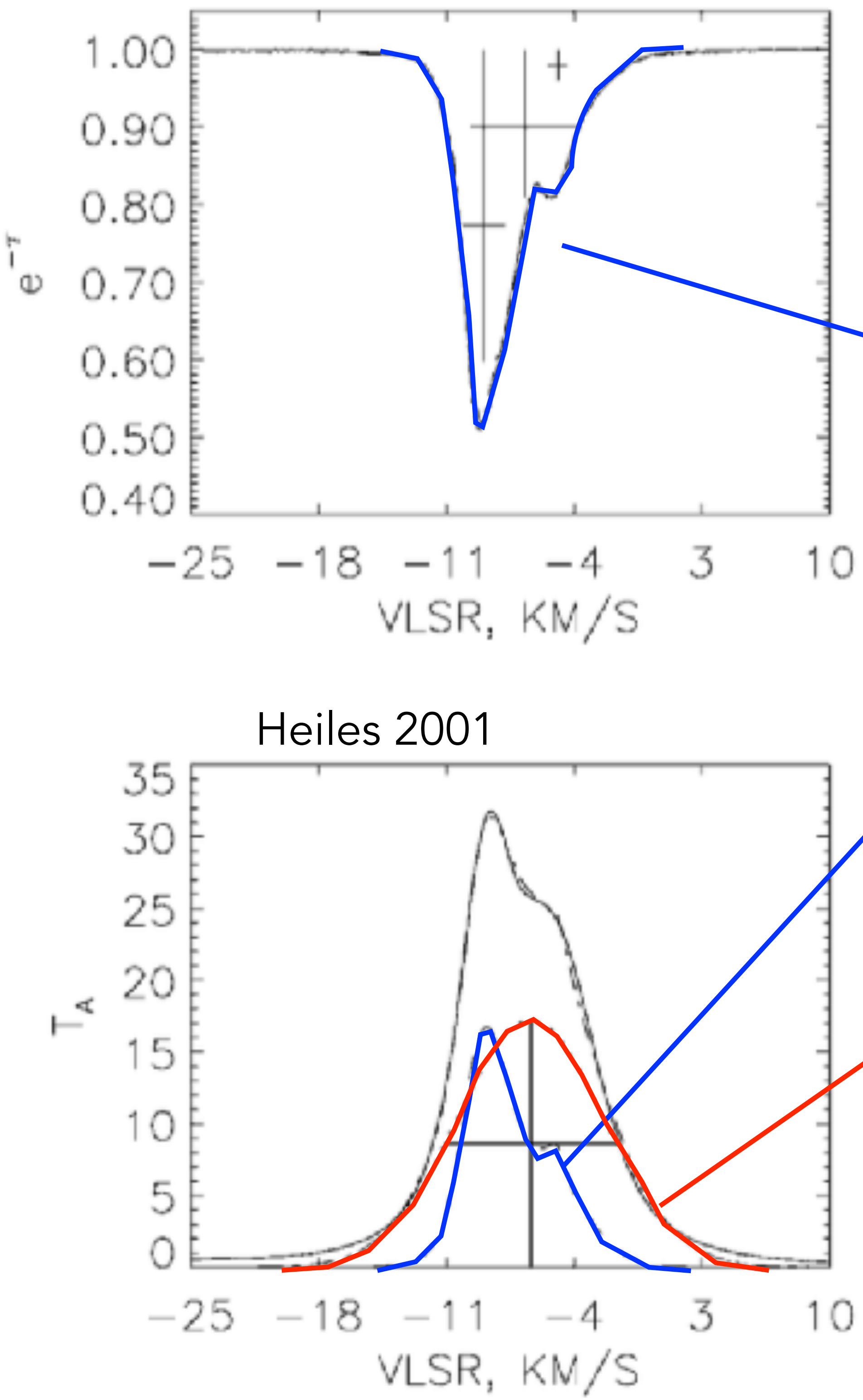
Observed HI Spin Temperature



Assume CNM dominates absorption.

Fit absorption component and emission component with same Gaussian components (σ_V) to get N_{CNM}, T_{CNM}

Fit emission component with additional Gaussian and N_{WNM}.

Get upper limit on T_{WNM} from velocity width (upper limit because of turbulent contribution).

Get lower limit on T_{WNM} from residual absorption.

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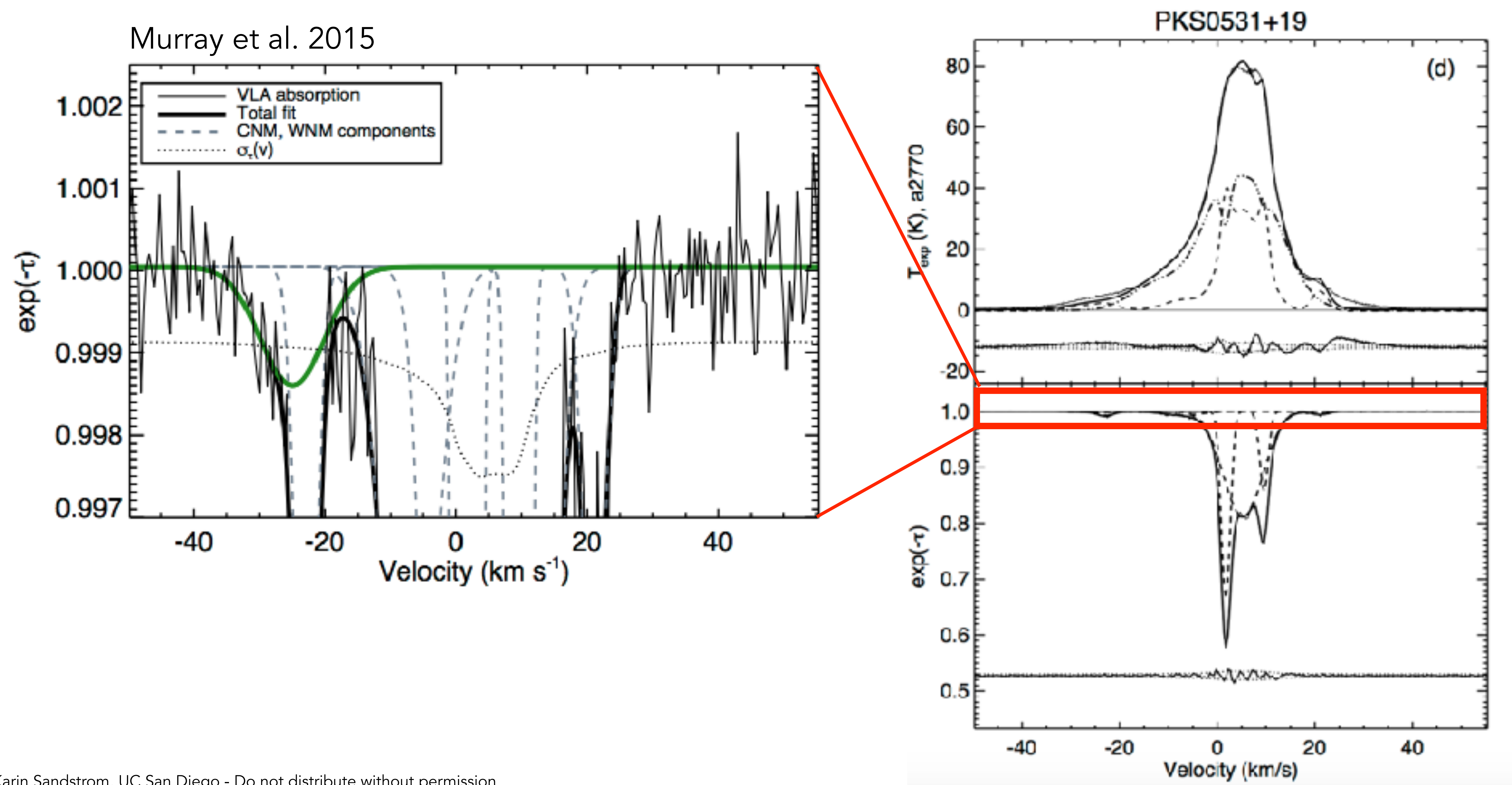
Observed HI Spin Temperature

Measuring absorption from the WNM requires very high S/N measurements.

Murray et al. 2015



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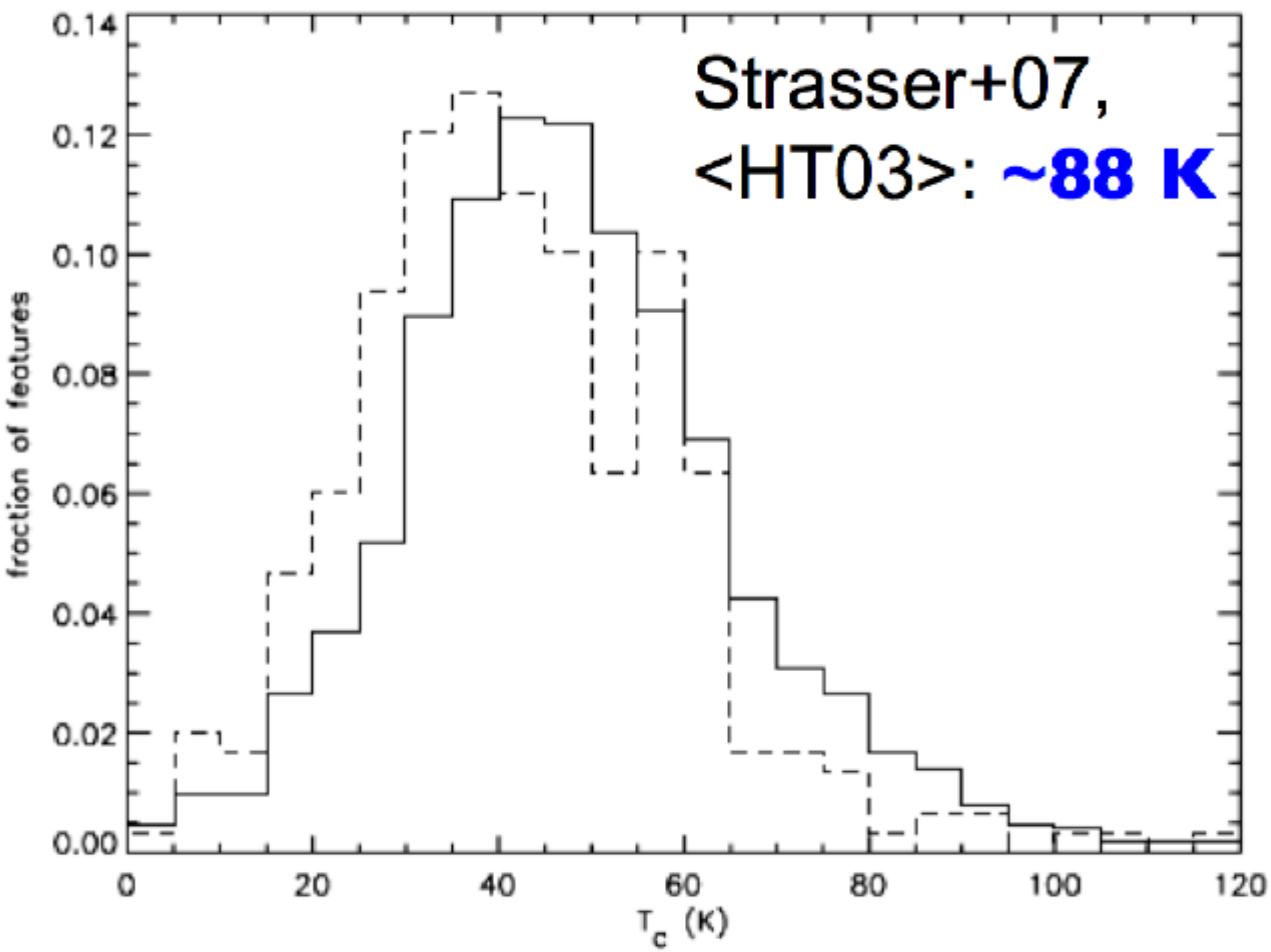
Observed HI Spin Temperature



observed CNM components have T ~ 40-80 K

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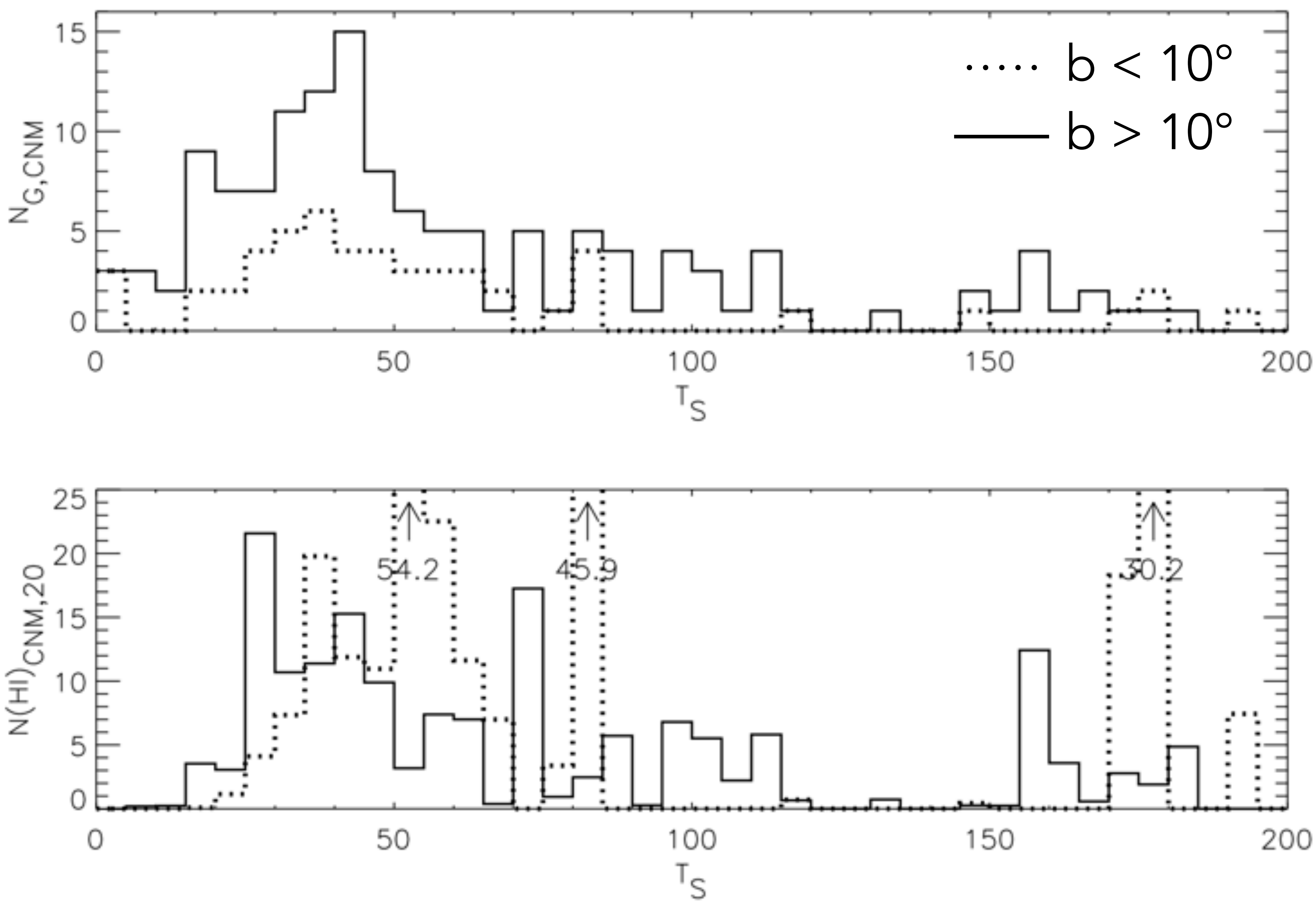
Observed HI Spin Temperature

Heiles & Troland 2003 - The Millennium Arecibo 21-cm Absorption Line Survey



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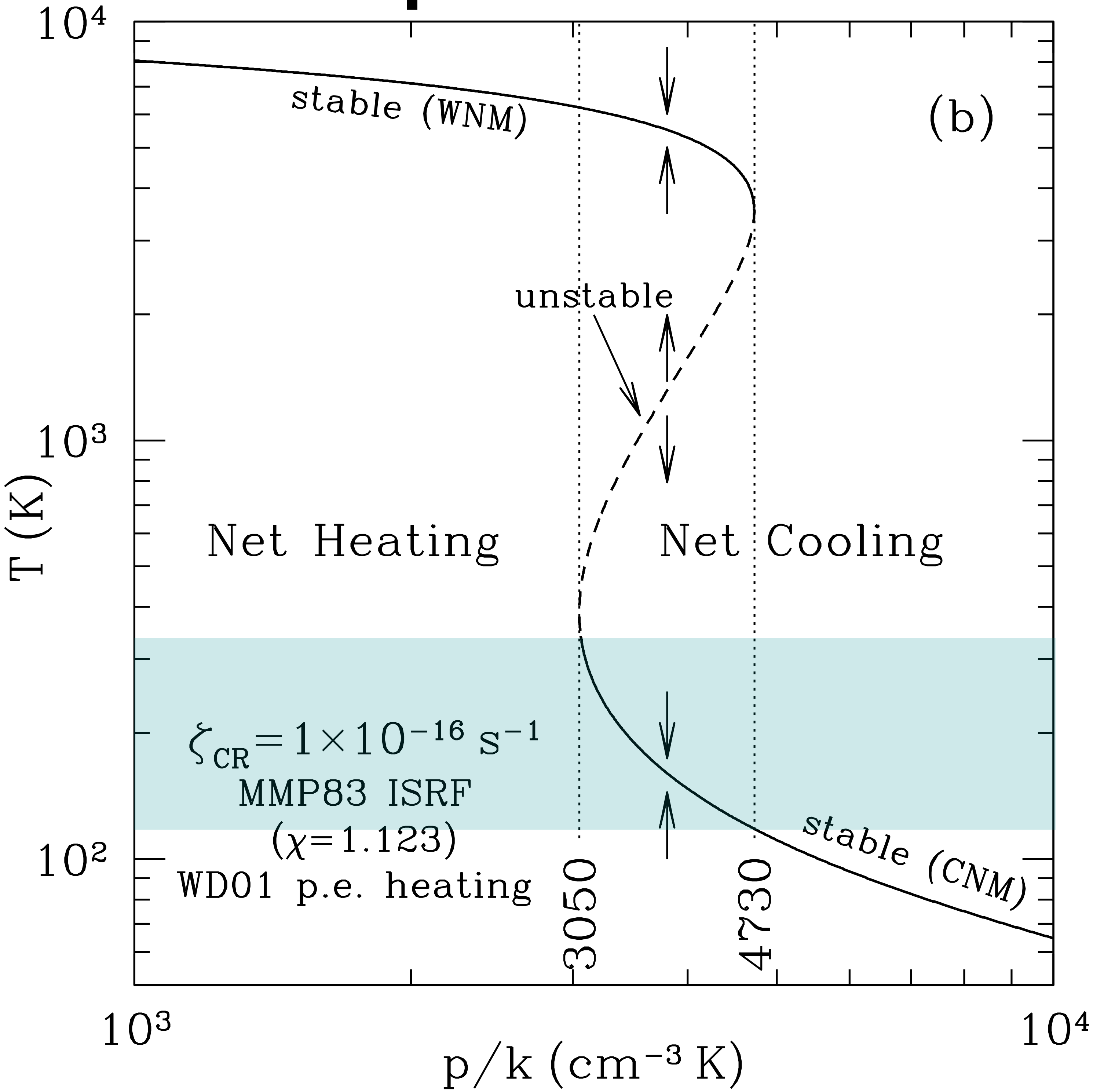
Is the FGH model a good representation of the ISM?



Measured CNM temperature of ~50-100 K is lower than what might be expected for p/k ~ 3000-4000 cm^{-3} K

expected

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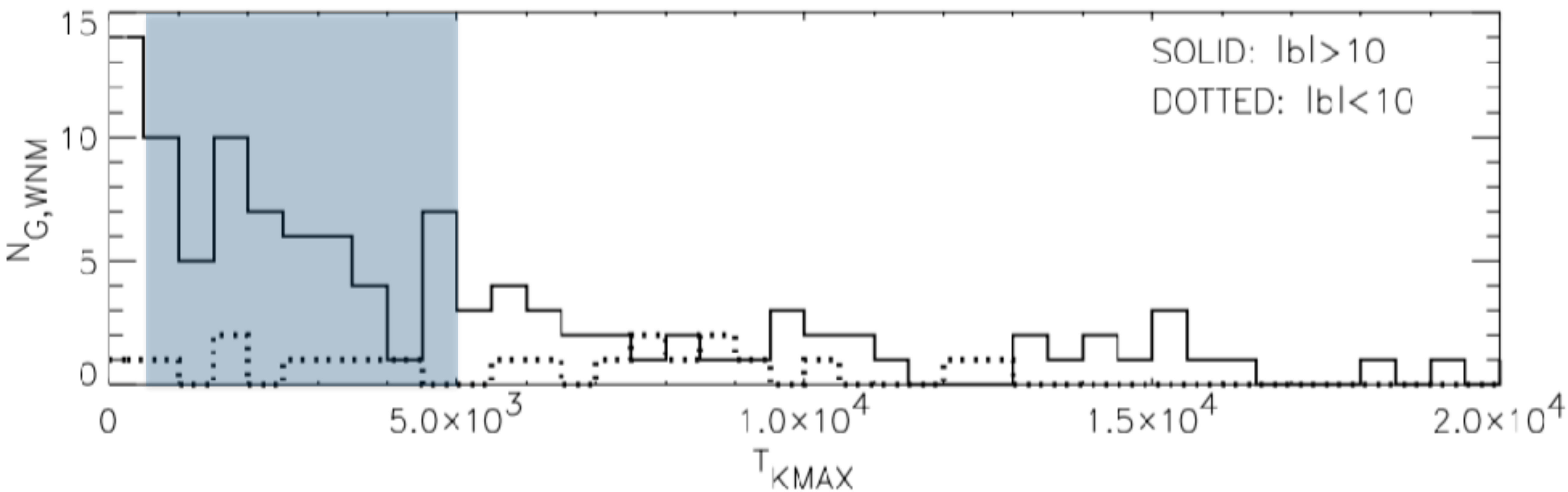
Observed HI Spin Temperature

Evidence for “unstable” phase (500 < T < 5000)

Heiles & Troland 2003



Upper limit on T_{WNM}

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Observed HI Spin Temperature

THE MILLENNIUM ARECIBO 21 CENTIMETER ABSORPTION-LINE SURVEY. II. PROPERTIES OF THE WARM AND COLD NEUTRAL MEDIA

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ABSTRACT

We use the Gaussian fit results of Paper I to investigate the properties of interstellar H I in the solar neighborhood. The warm and cold neutral media (WNM and CNM) are physically distinct components. The CNM spin temperature histogram peaks at about 40 K; its median, weighted by column density, is 70 K. About 60% of all H I is WNM; there is no discernible change in this fraction at $z = 0$. At $z = 0$, we derive a volume filling fraction of about 0.50 for the WNM; this value is very rough. The upper limit WNM temperatures determined from line width range upward from ~500 K; a minimum of about 48% of the WNM lies in the thermally unstable region 500–5000 K. The WNM is a prominent constituent of the interstellar medium, and its properties depend on many factors, requiring global models that include all relevant energy sources, of which there are many. We use principal components analysis, together with a form of

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Observed HI Spin Temperature

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The Phase Structure of the ISM in Galaxies

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The question of phases is not without controversy. A great review article by Vázquez-Semadeni (2009) is entitled "Are there phases in the ISM". Much of the controversy centers on Heiles & Troland (2003) which has turned into a bit of an urban legend. The legend is that 50% of the gas mass is in thermally unstable temperatures and TI plays little role in creating CNM and WNM gas. It appears that most everyone misses that there are two distributions plotted in their Fig. 2. The distribution in temperatures for the in-plane gas shows ∼ 75% of the warm gas within the 7000-9000 K range exactly as expected for TI. Only %25 of the gas is outside this range, and when the CNM is included only ∼ 15% of the gas mass is at thermally unstable temperatures. The out of plane distribution looks nothing like the in-plane distribution with much of the gas outside of 7000-9000 K. I would conclude that the in-plane gas is dominated by TI, while the out of plane is dominated by dynamical processes. Numerical simulations give mixed results showing either no or weak TI (e.g., Gazol *et al.* (2001)) or significant TI (e.g., Koyama & Ostriker (2009)). The results depend on the model resolution, heating rates, cooling rates, and type and amplitude of the turbulence (Gazol *et al.* 2005).

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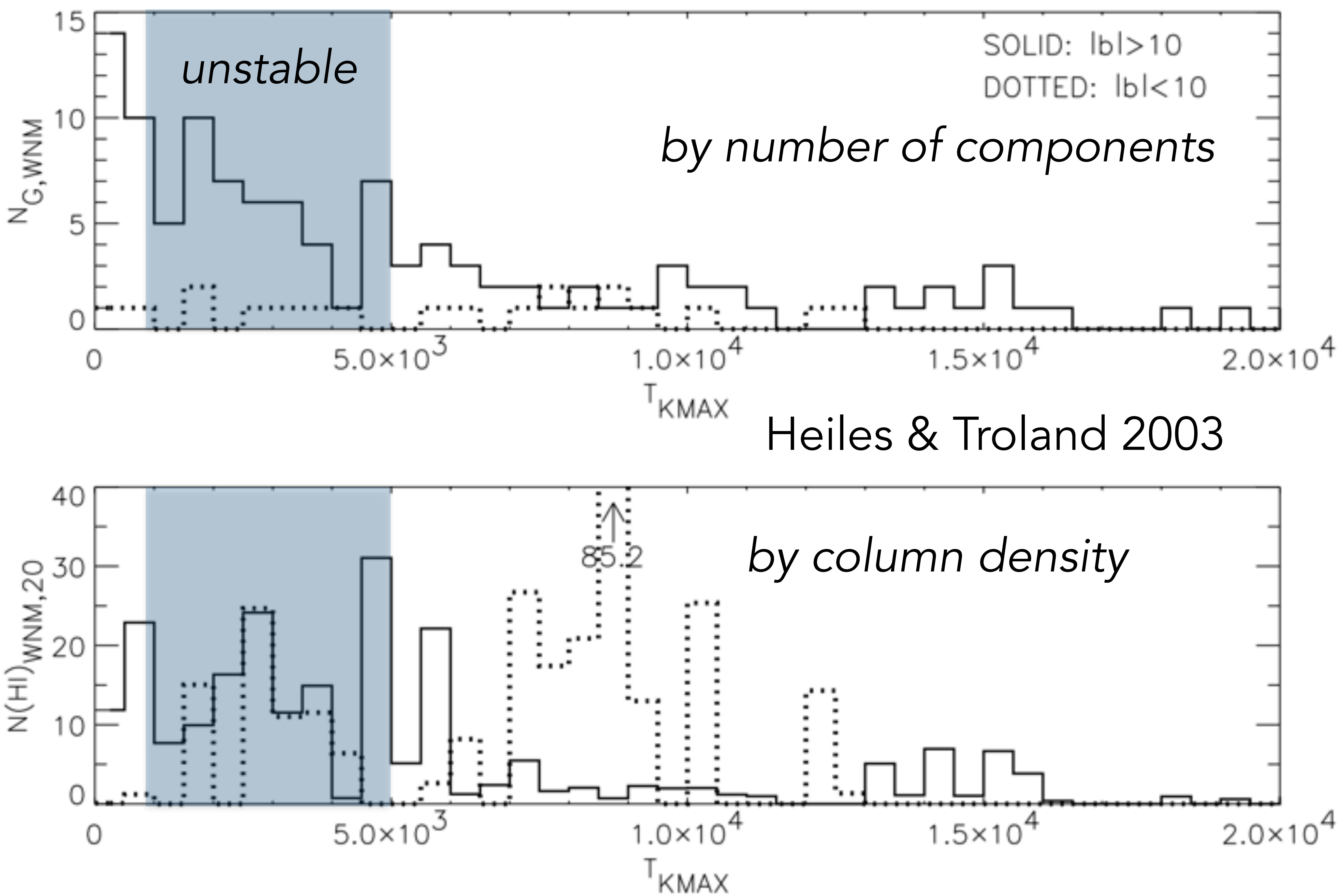
Observed HI Spin Temperature

WNM Temperature



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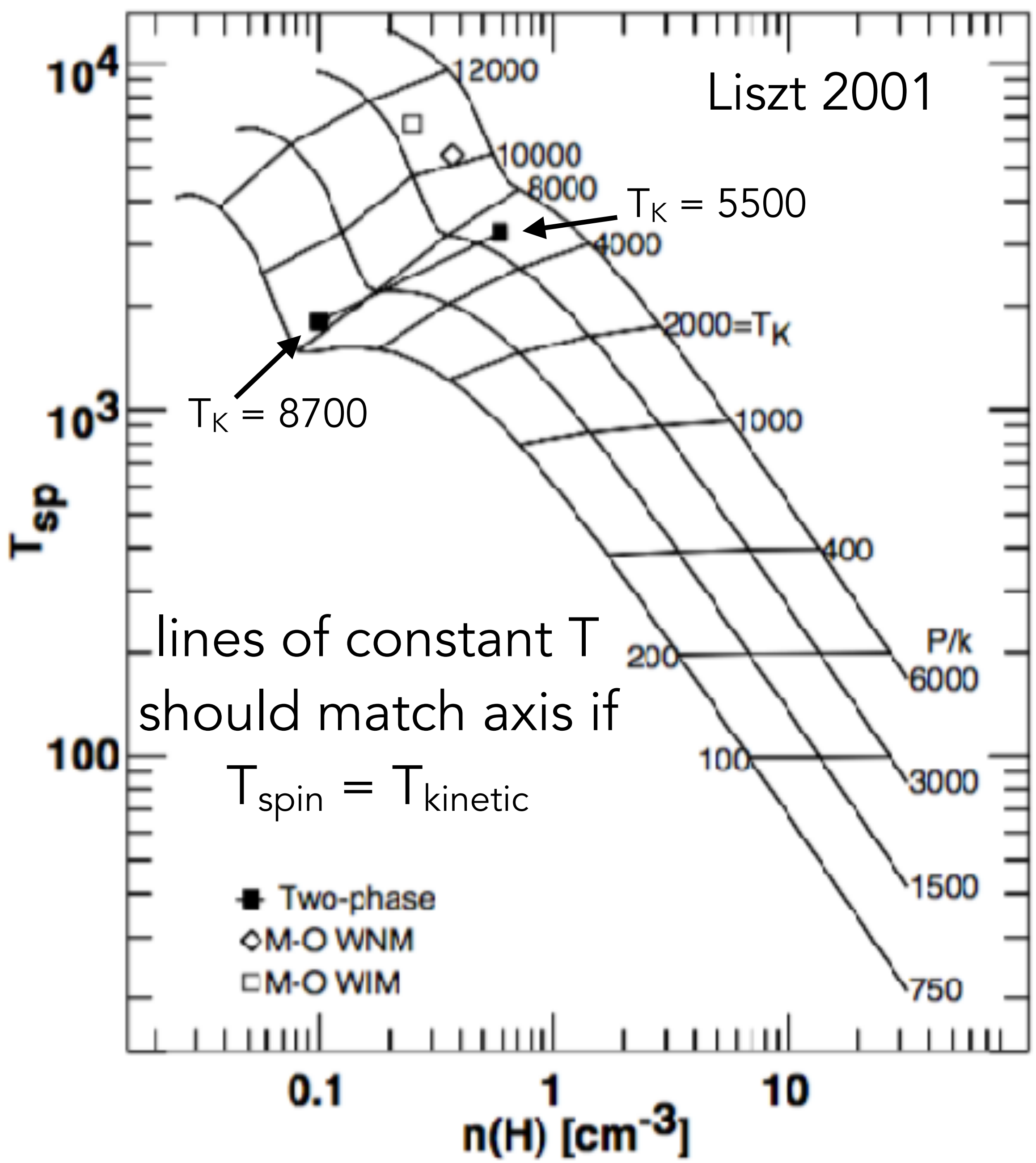
Observed HI Spin Temperature

Important wrinkle: thermalization of HI levels in WNM



Density in the WNM is too low to thermalize levels to predicted WNM temperatures.

However, scattered Lyα radiation can contribute to thermalizing levels as well.

(Liszt 2001)

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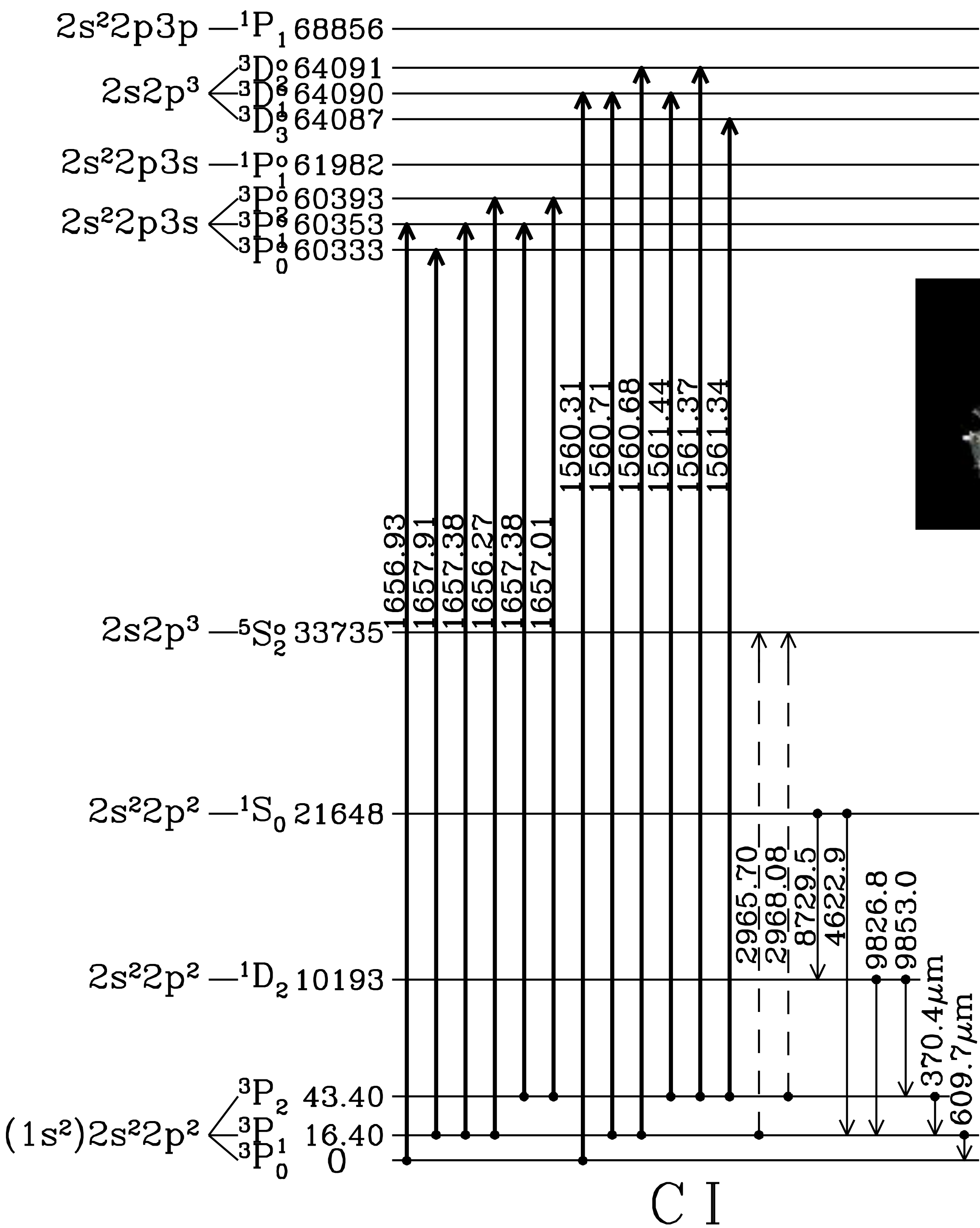
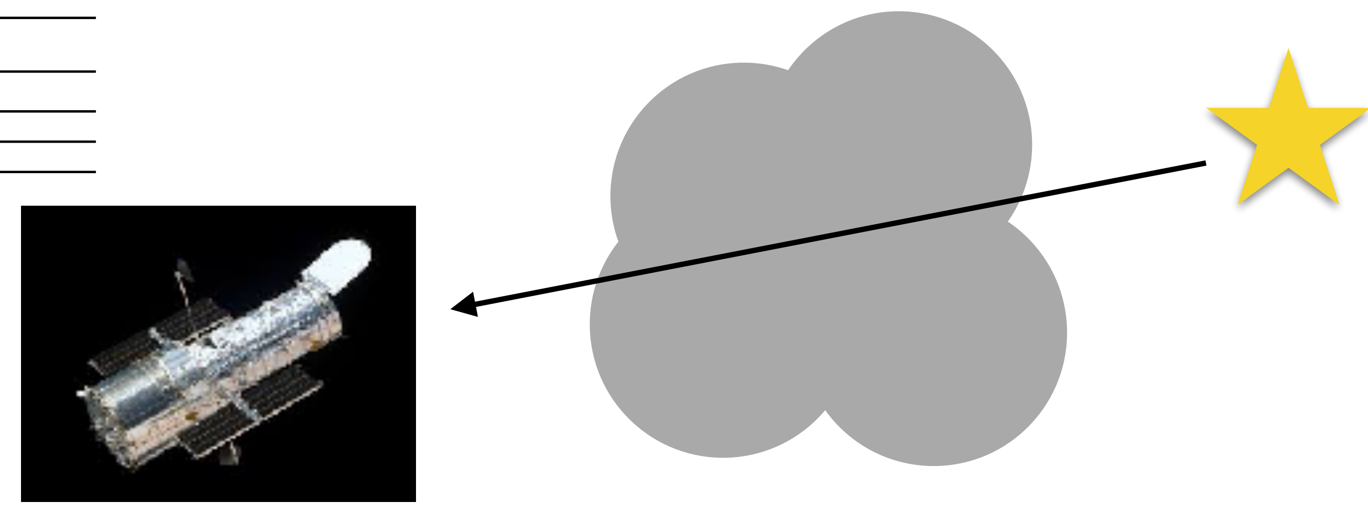
Thermal Pressure from [CI]



Jenkins & Tripp 2001, 2011



Measure UV absorption lines from ground state, collisionally populated fine structure levels of [CI] - populations set by n,T

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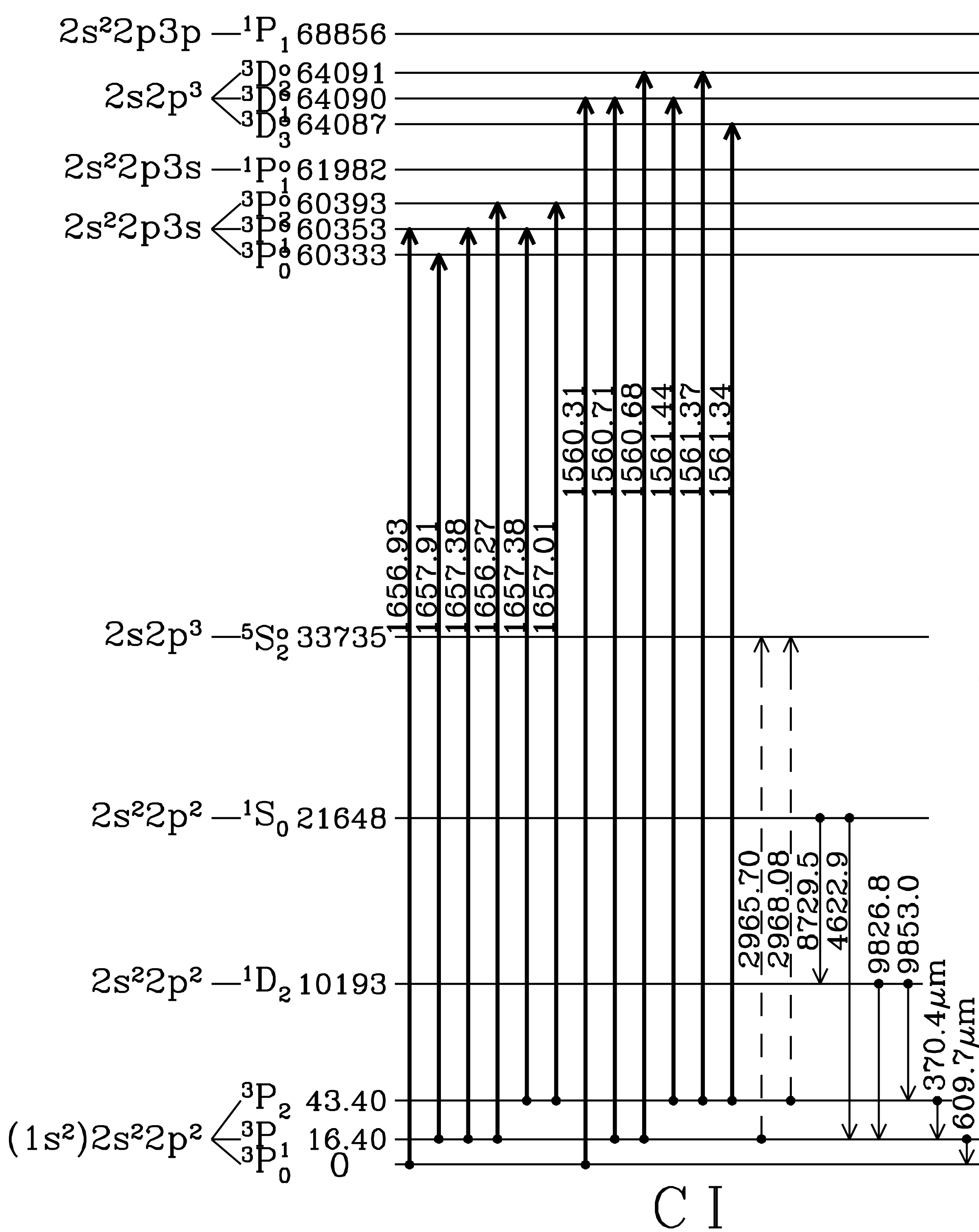
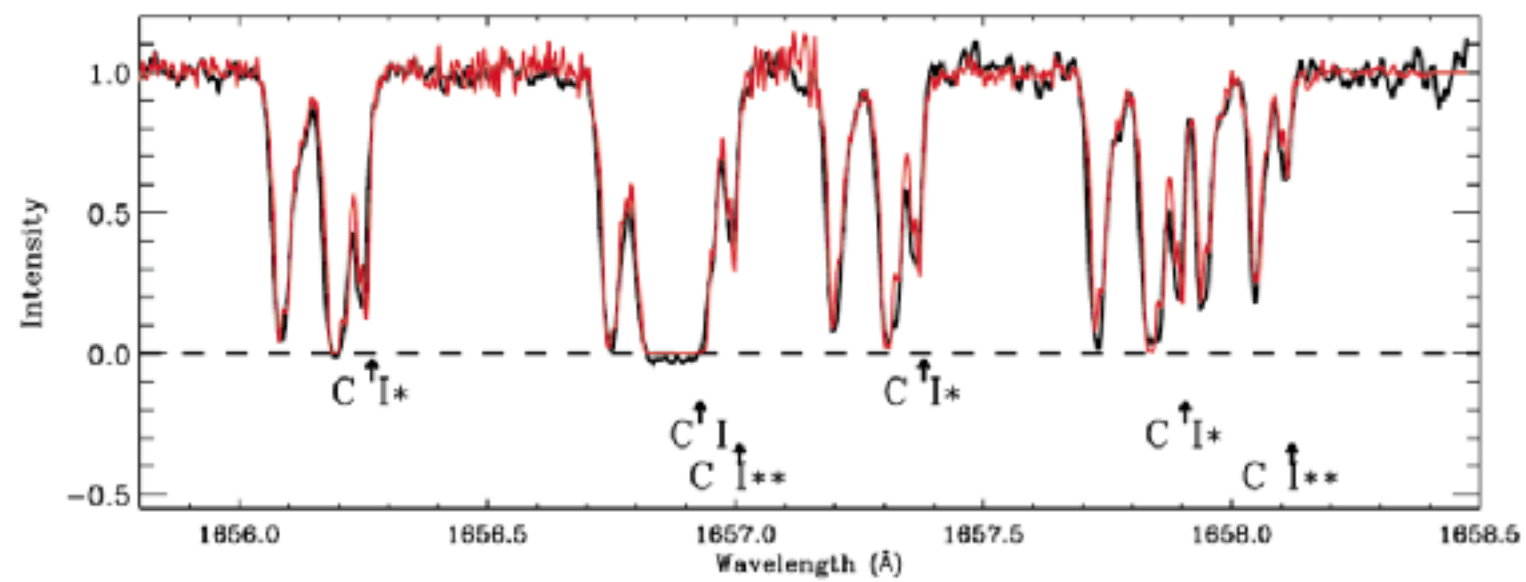
Thermal Pressure from [CI]

Jenkins & Tripp 2001, 2011





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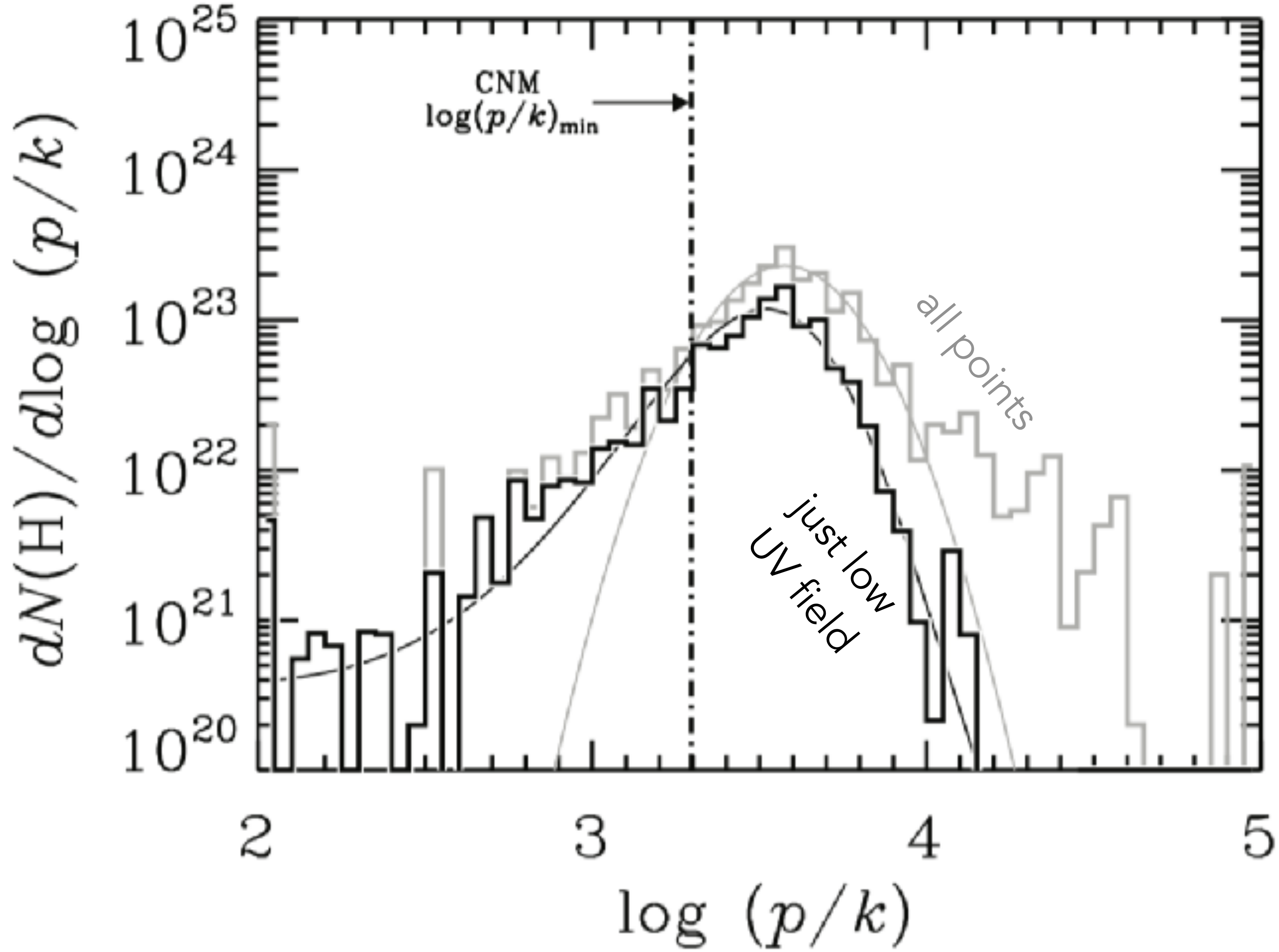

Most gas is at pressures that agree with the FGH picture, but there are tails of low & high pressure that are probably related to turbulence.

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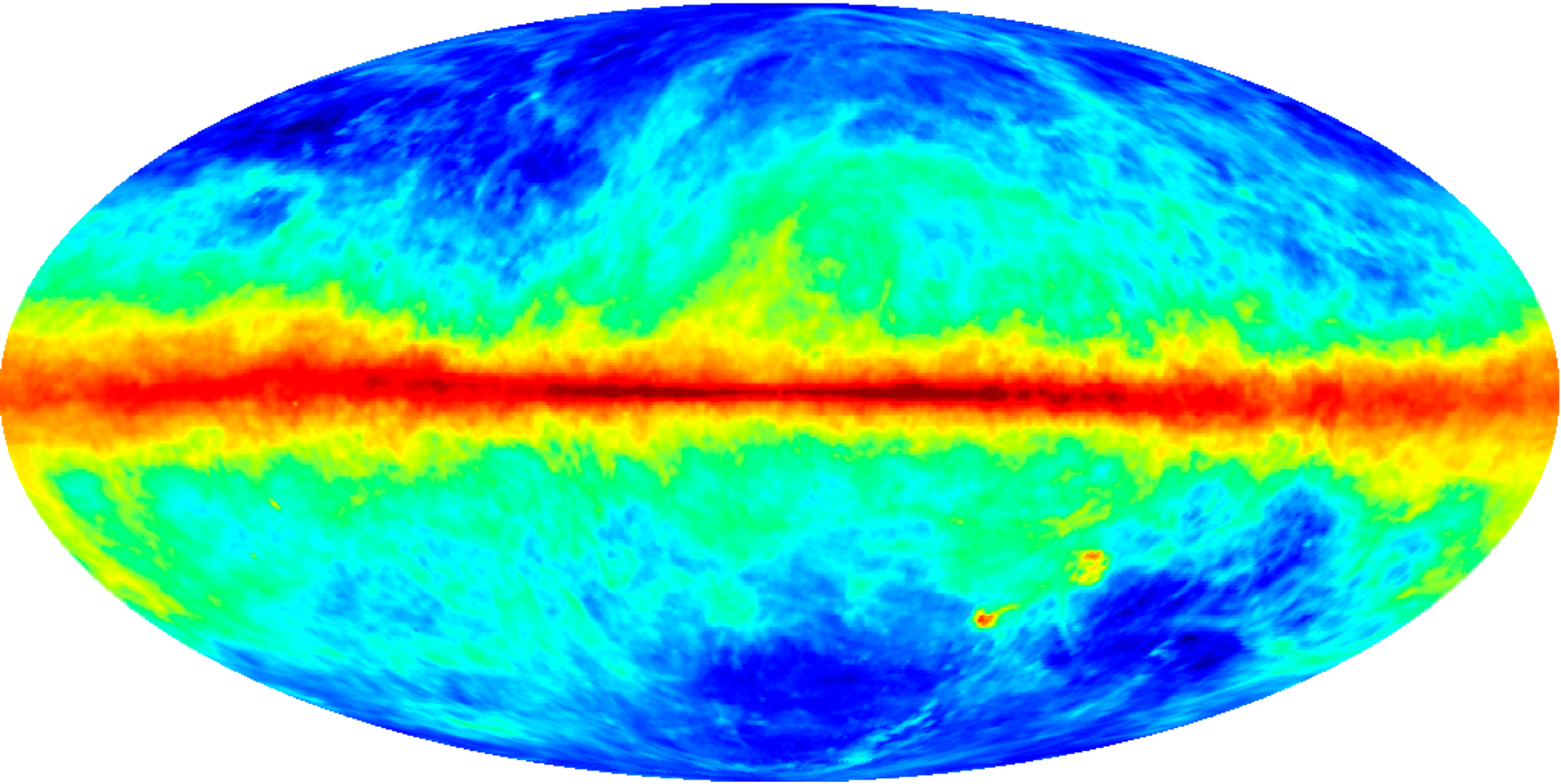
All-Sky Map of N(HI) from the Leiden-Argentine-Bonn Survey (Kalberla et al. 2005)



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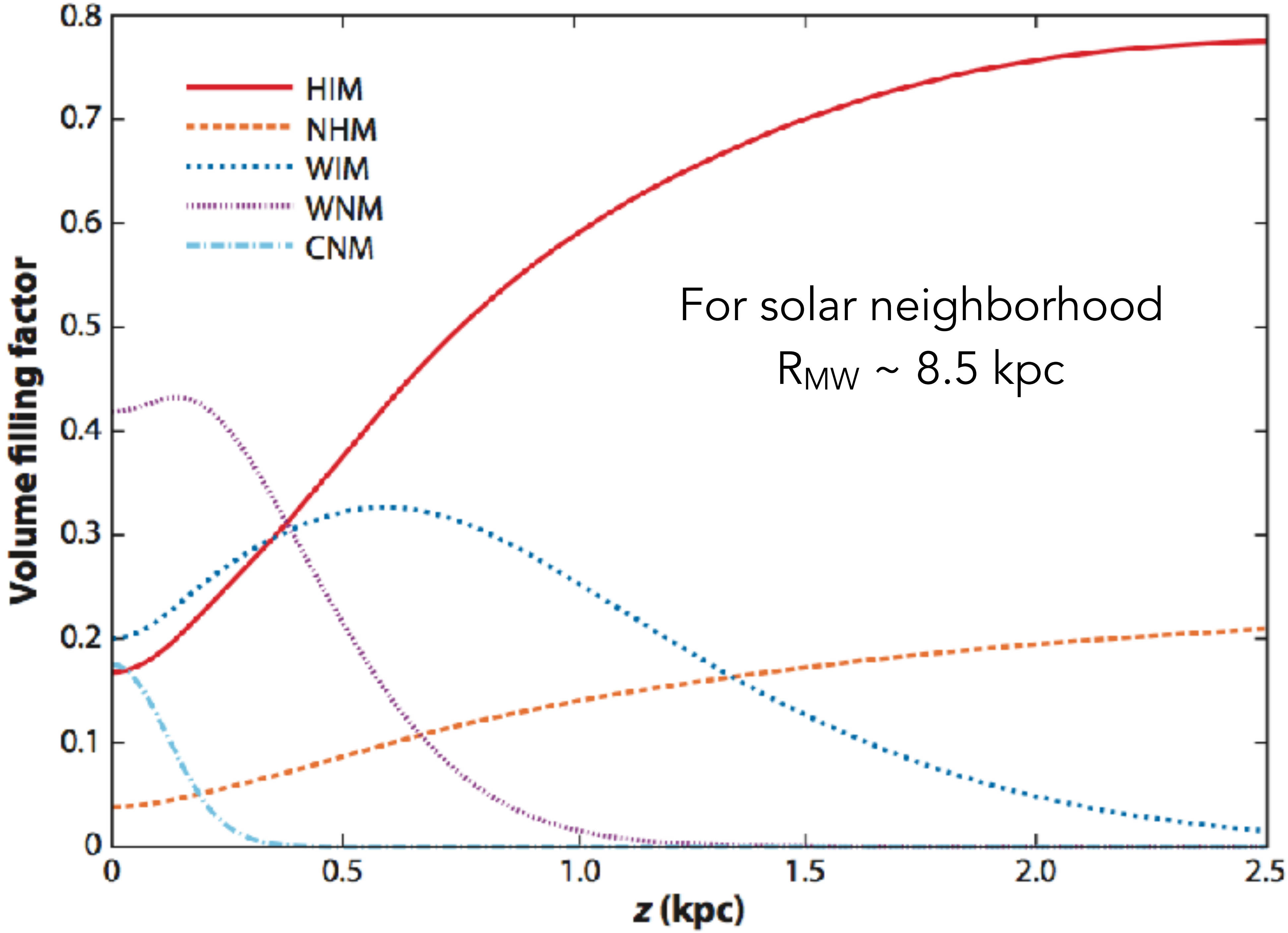
Distribution of HI in the MW

Kalberla & Kerp 2009, ARA&A



height above Galactic midplane

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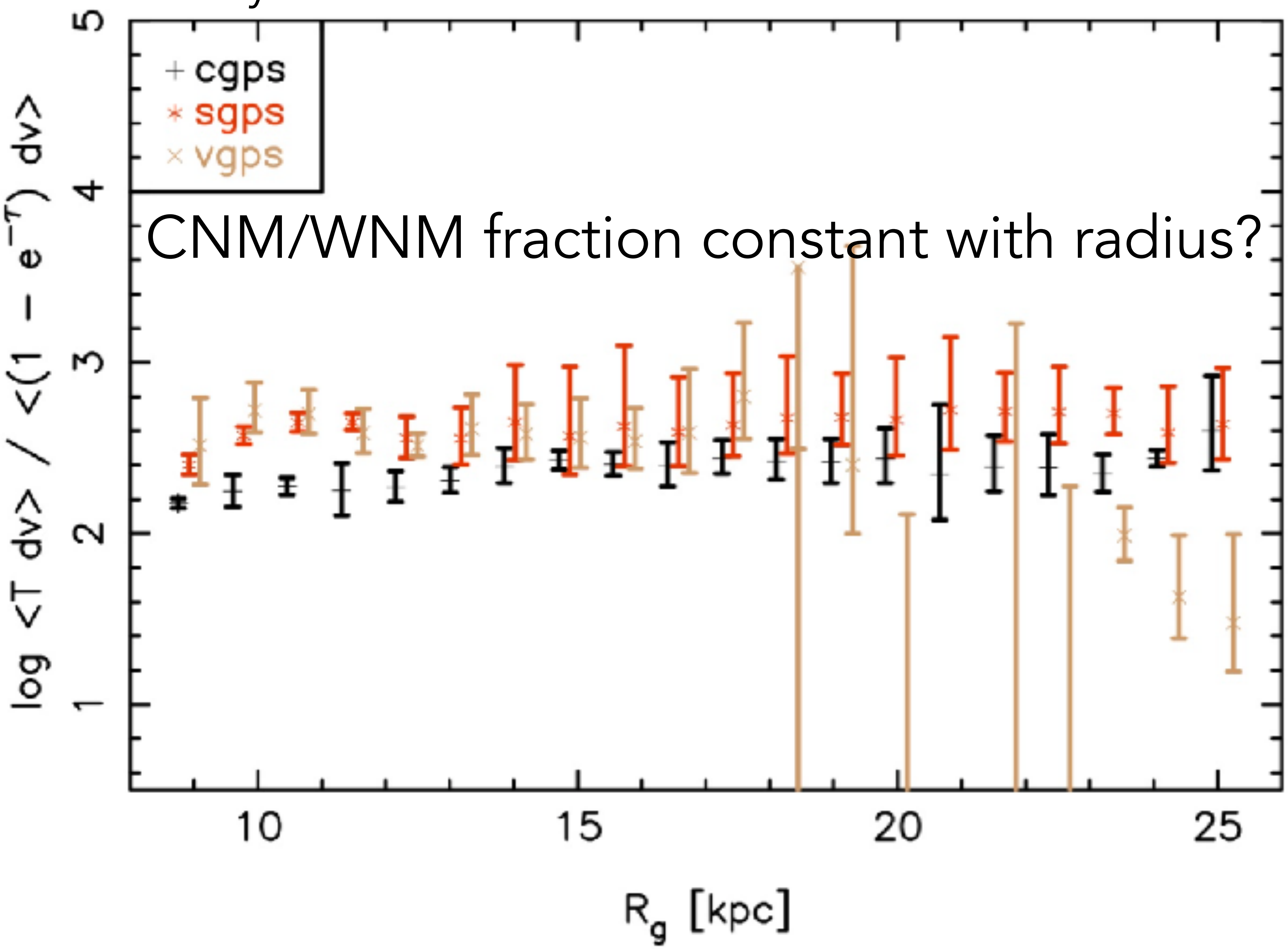
Distribution of HI in the MW

Dickey et al. 2009



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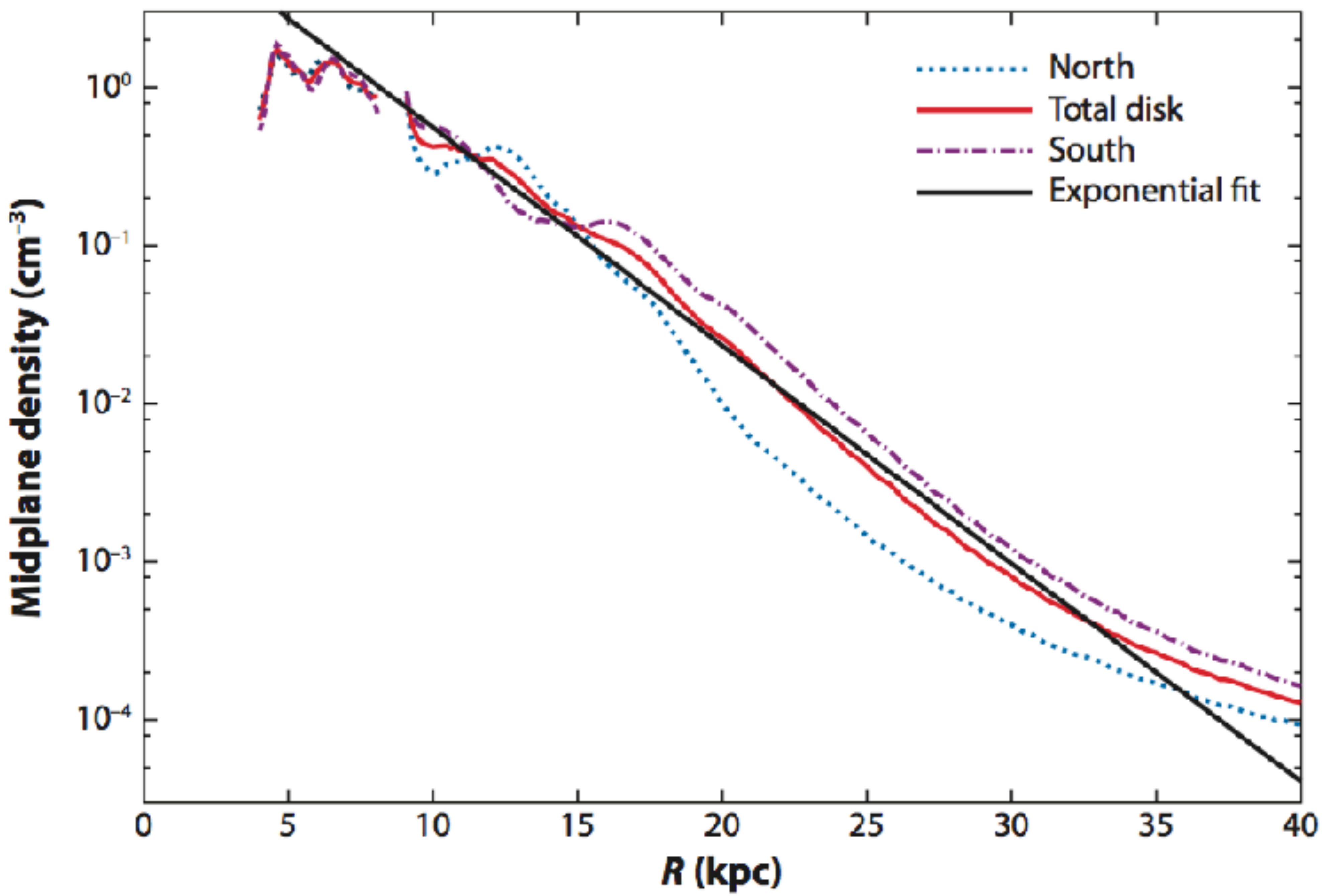
Distribution of HI in the MW

Kalberla & Kerp 2009, ARA&A



distance from Galactic center

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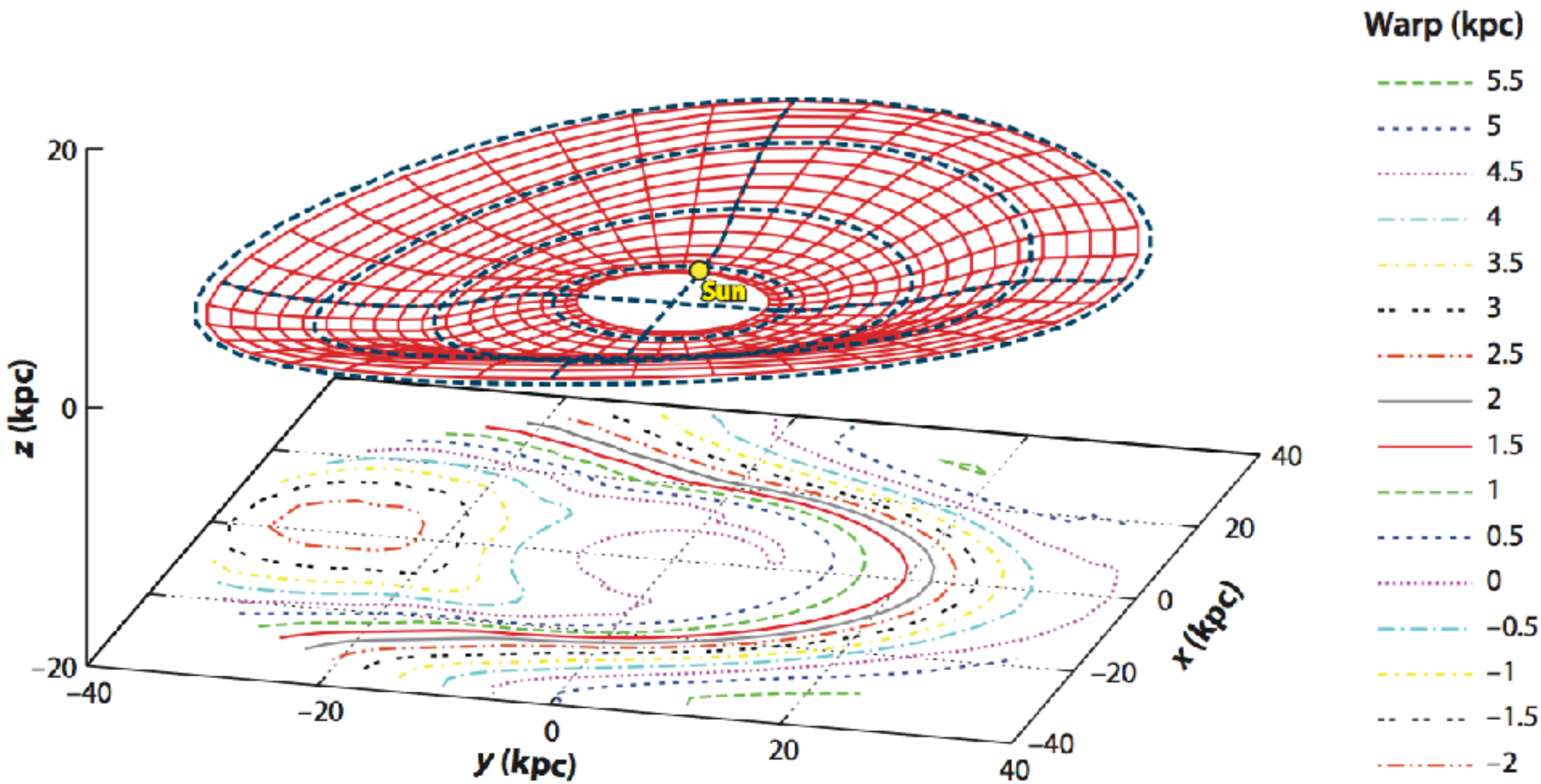
Distribution of HI in the MW

Kalberla & Kerp 2009, ARA&A



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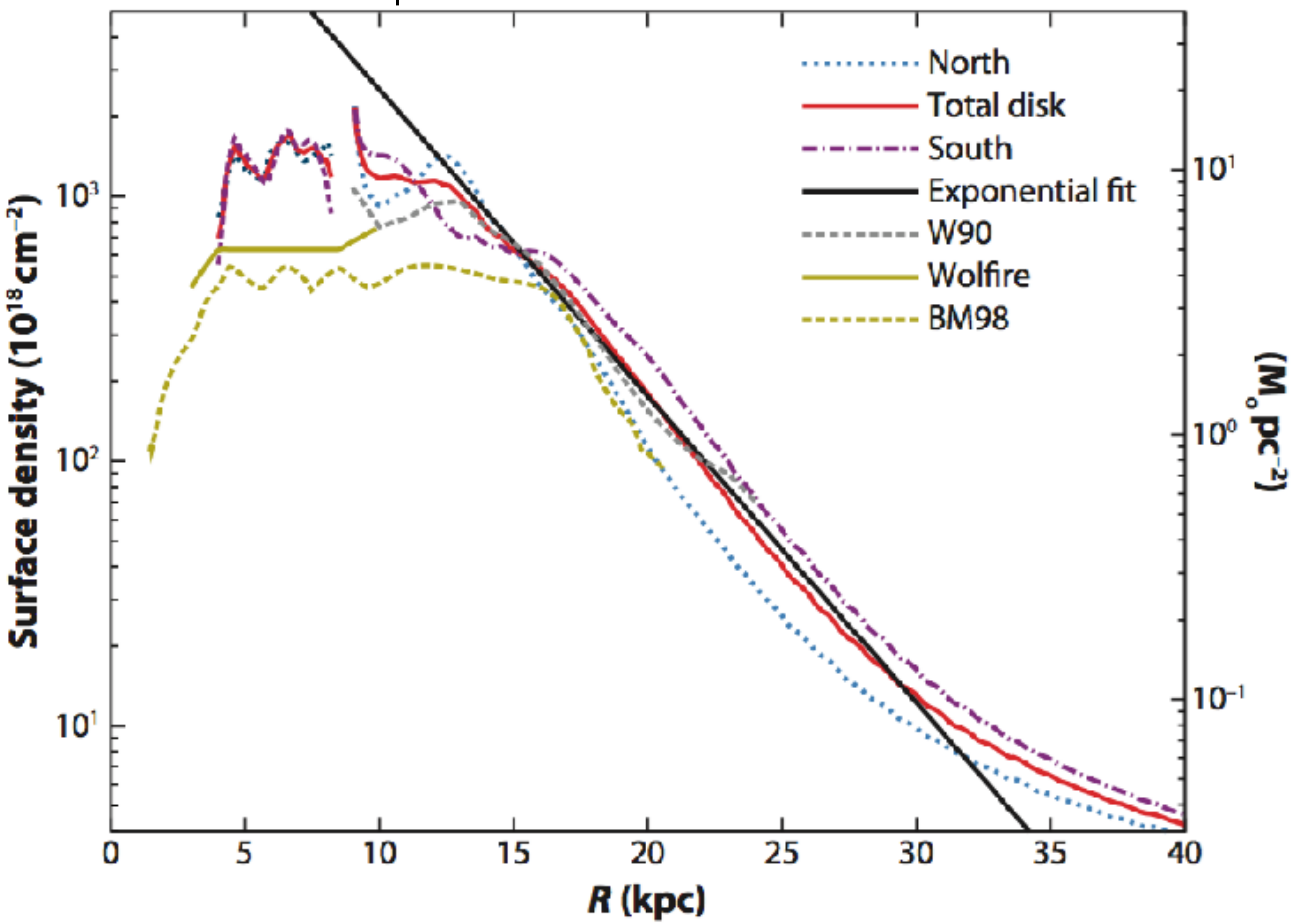

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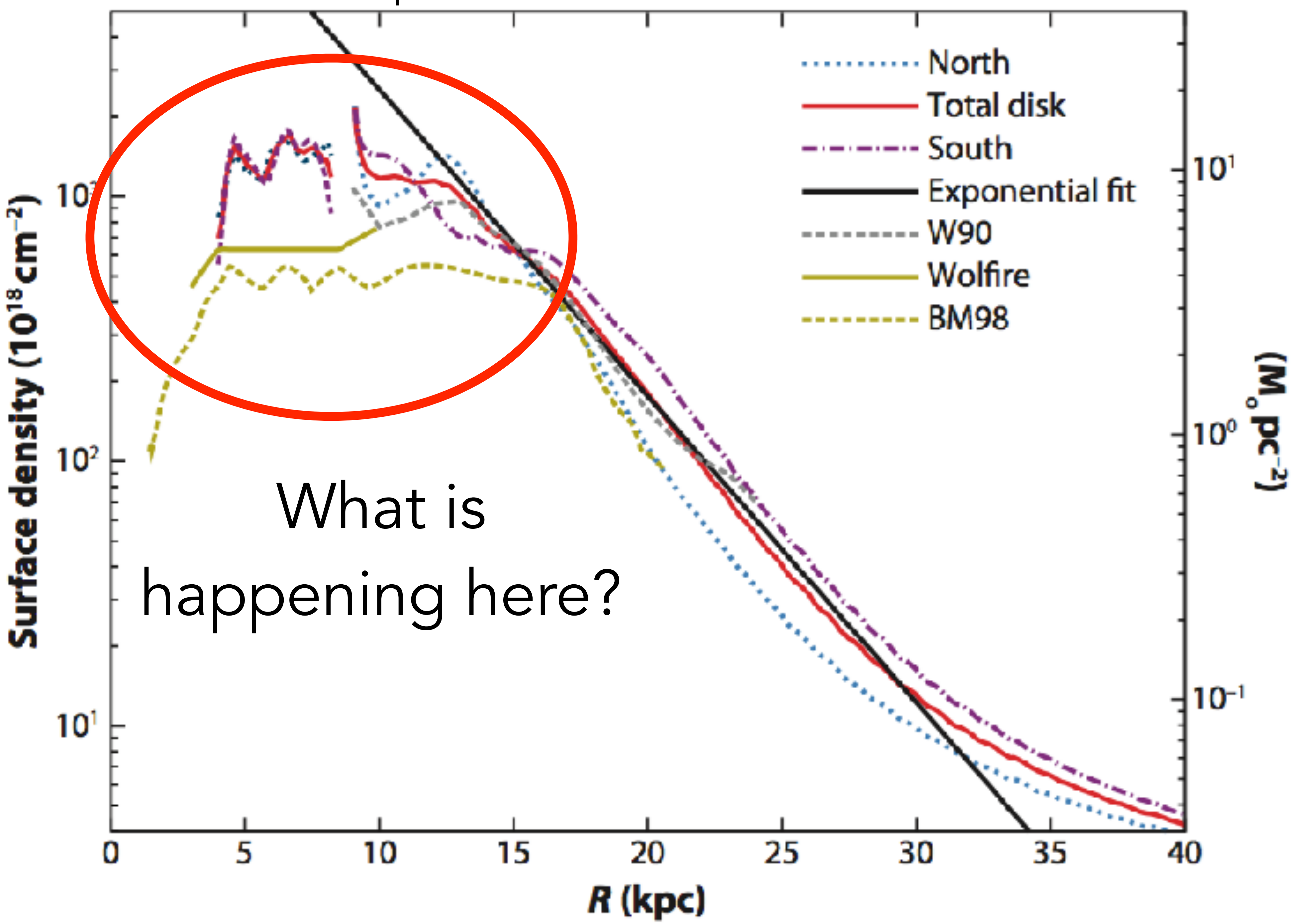

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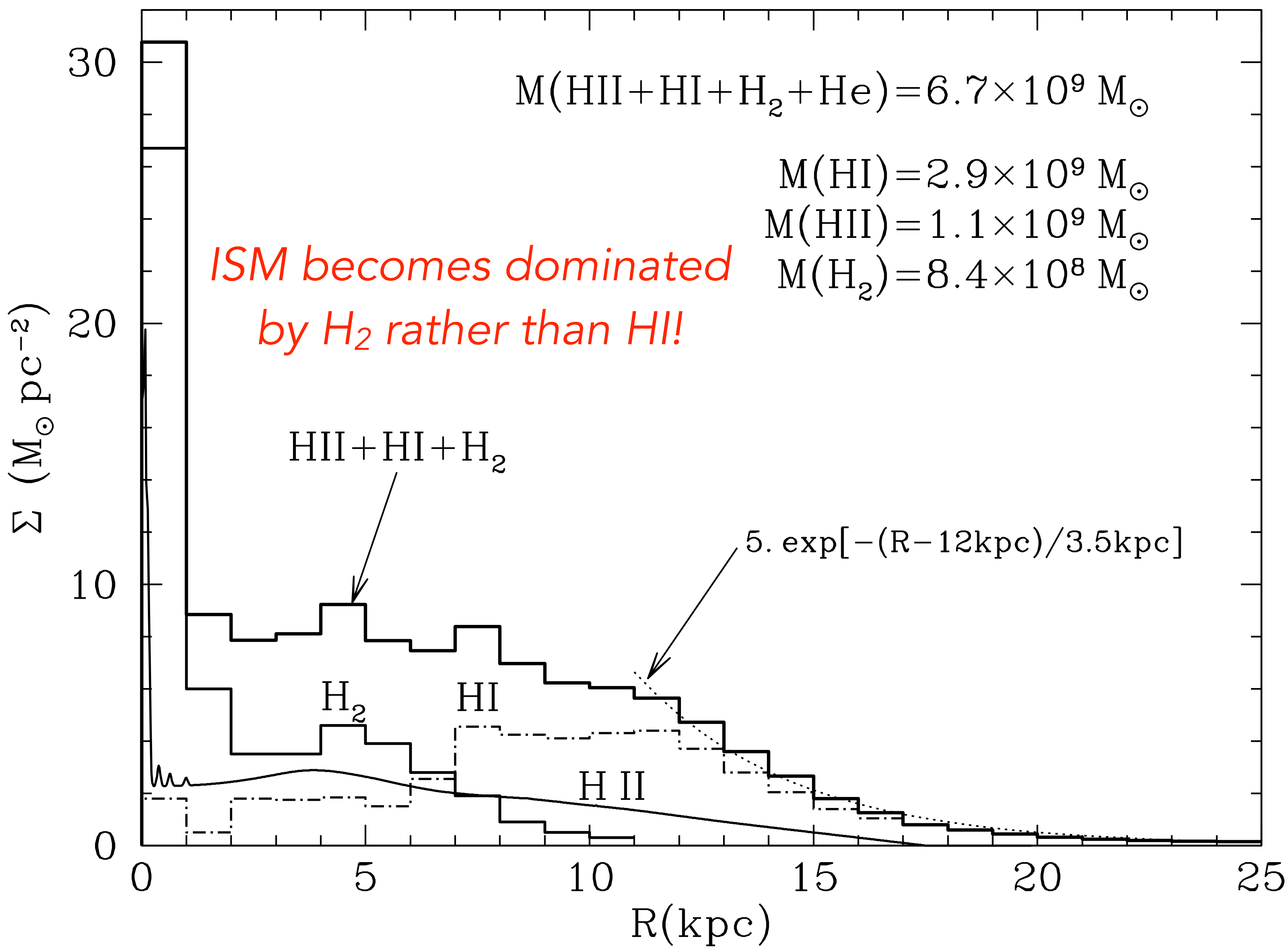
Distribution of HI in the MW



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