Cosmic molecular rain: evidence for the inflow of gas sustaining the Galactic star-formation rate

Jürgen Kerp[1], ***Tobias Röhser***[1], Daniel Lenz[1,2] and Benjamin Winkel[3]

[1]Argelander-Institut für Astronomie, Universität Bonn

[2]Jet Propulsion Laboratory, NASA, Caltech

[3]Max-Planck-Institut für Radioastronomie

jkerp@uni-bonn.de

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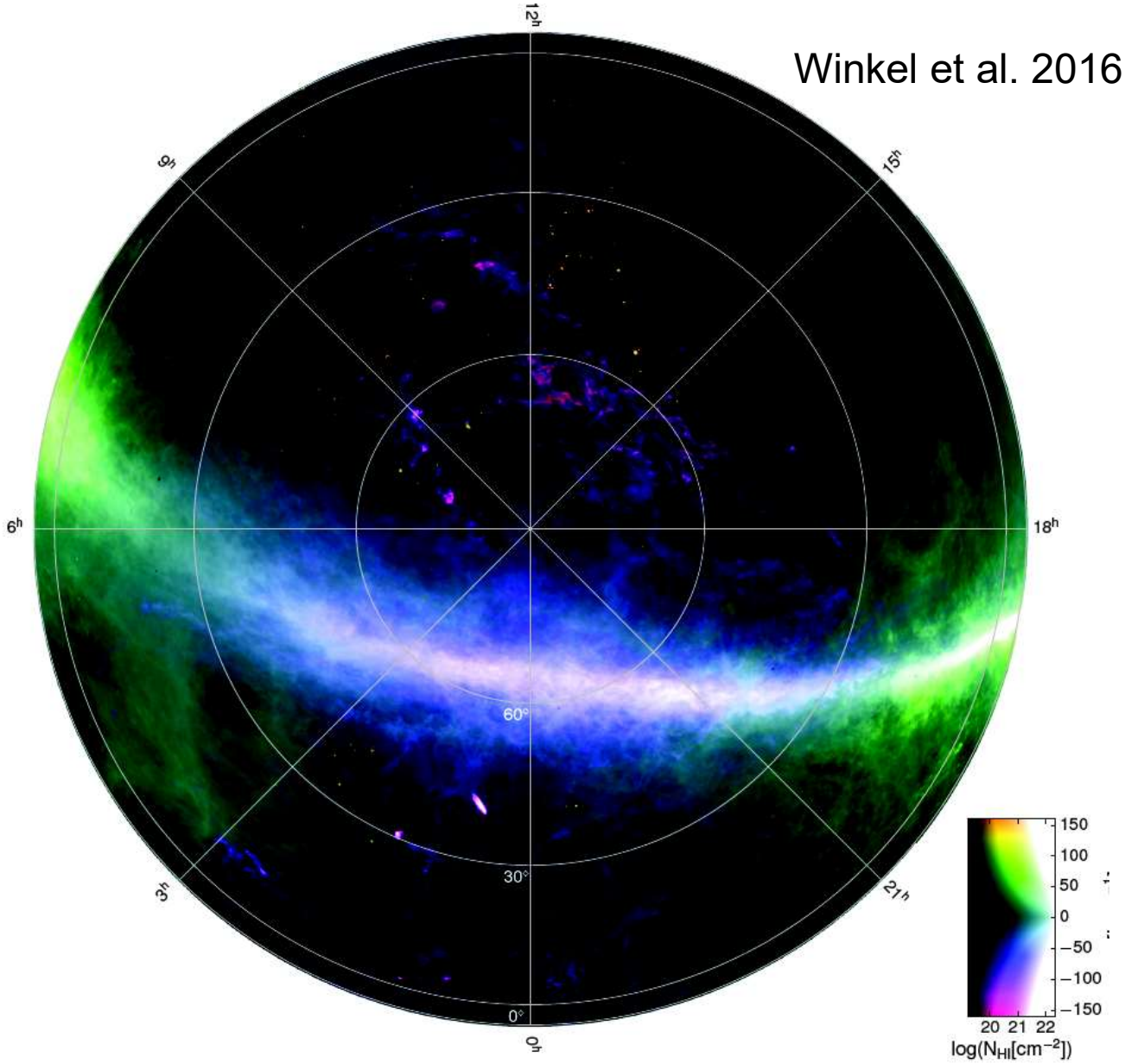
Effelsberg-Bonn HI Survey (EBHIS), Dec 2015

Winkel et al. 2016 A&A 585, A41



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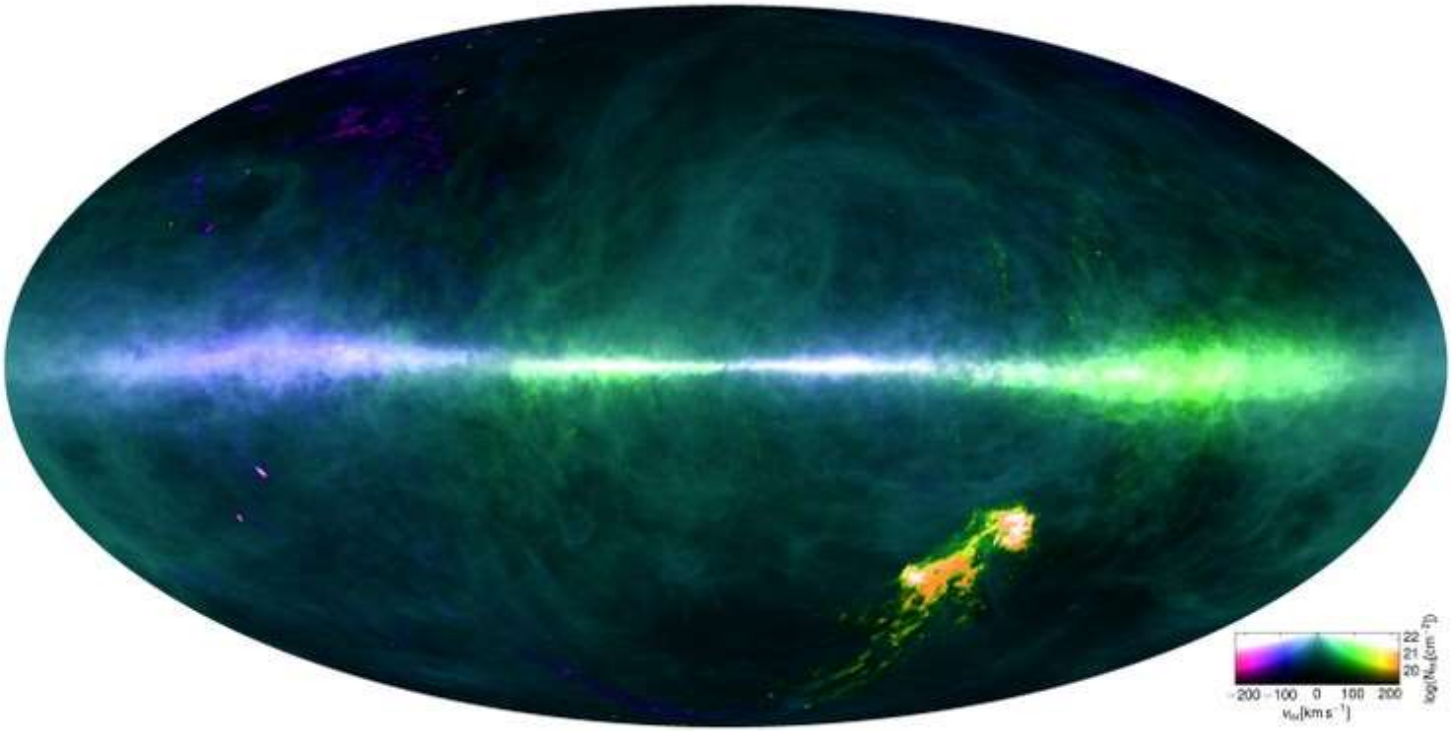
HI4PI, Oct 2016

HI4PI collaboration. 2016 A&A 594, A116



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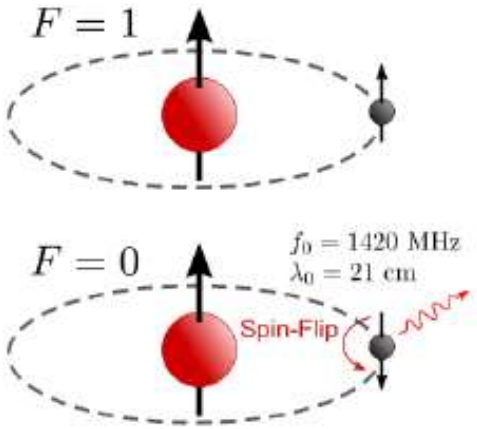
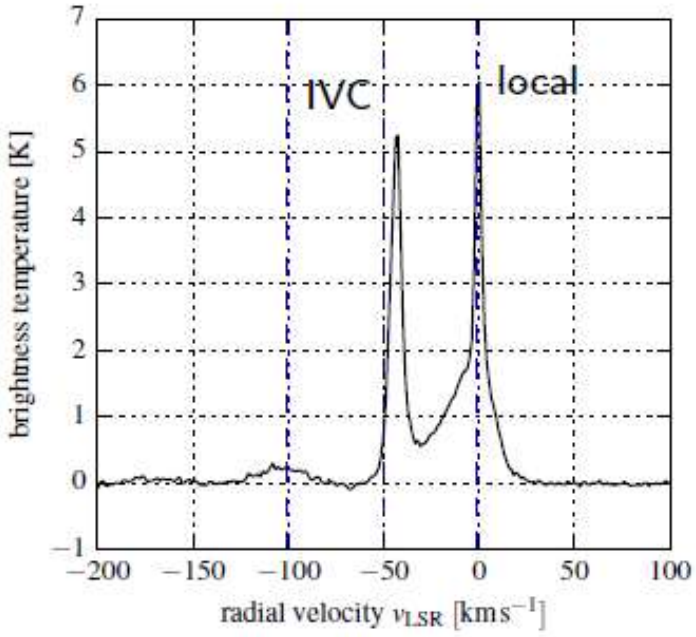
HI 21-cm line data



Wikipedia, Tiltec

- Hyperfine transition:
  1.4 GHz or 21 cm
- Doppler effect: radial velocity
  → spectroscopy
- Data cubes

- Integrated emission:
  H I column density ($N_{\mathrm{H\,I}}$)
- H I line width → gas temperature



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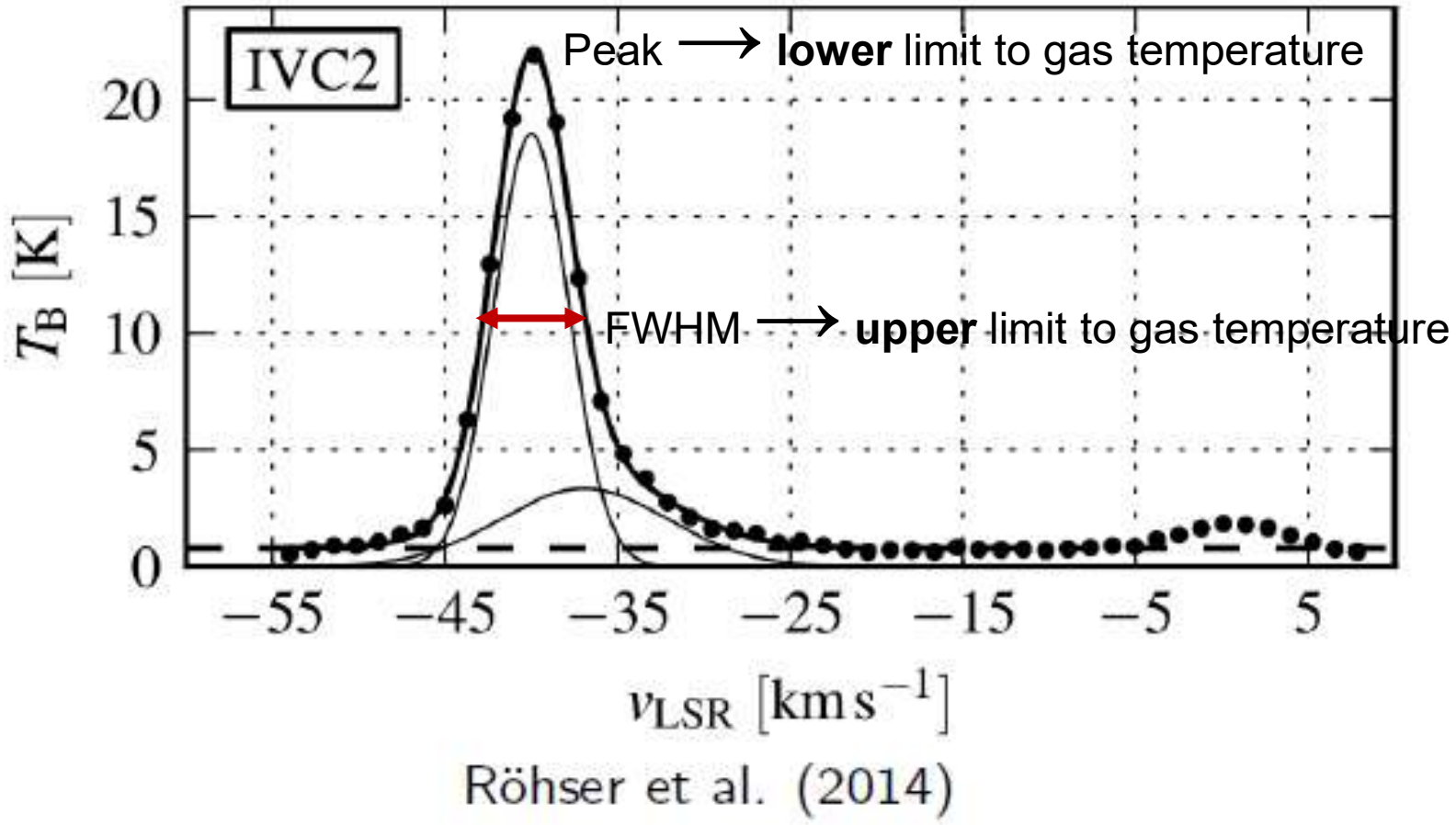

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Molecular hydrogen traced by dust and HI

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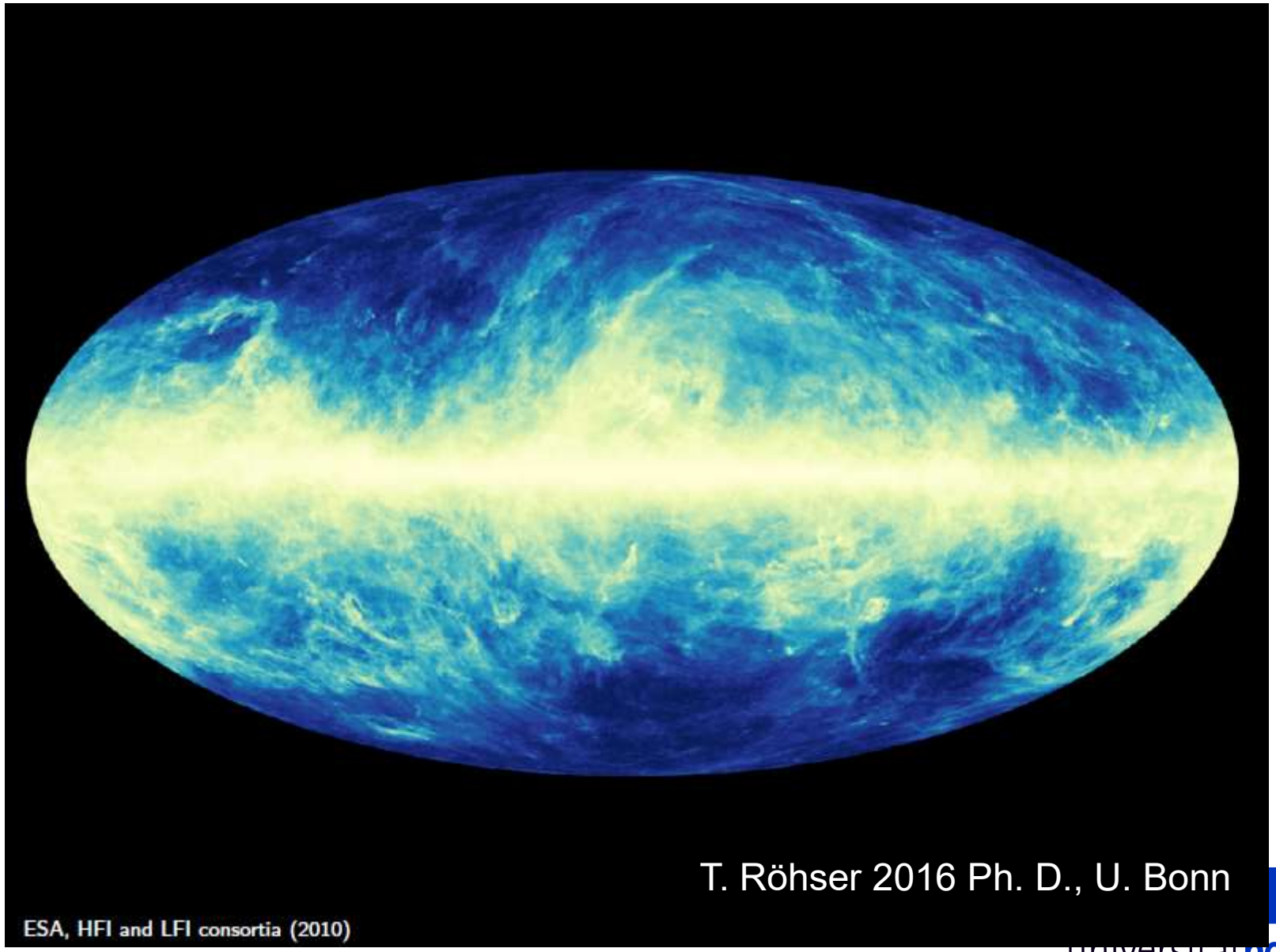

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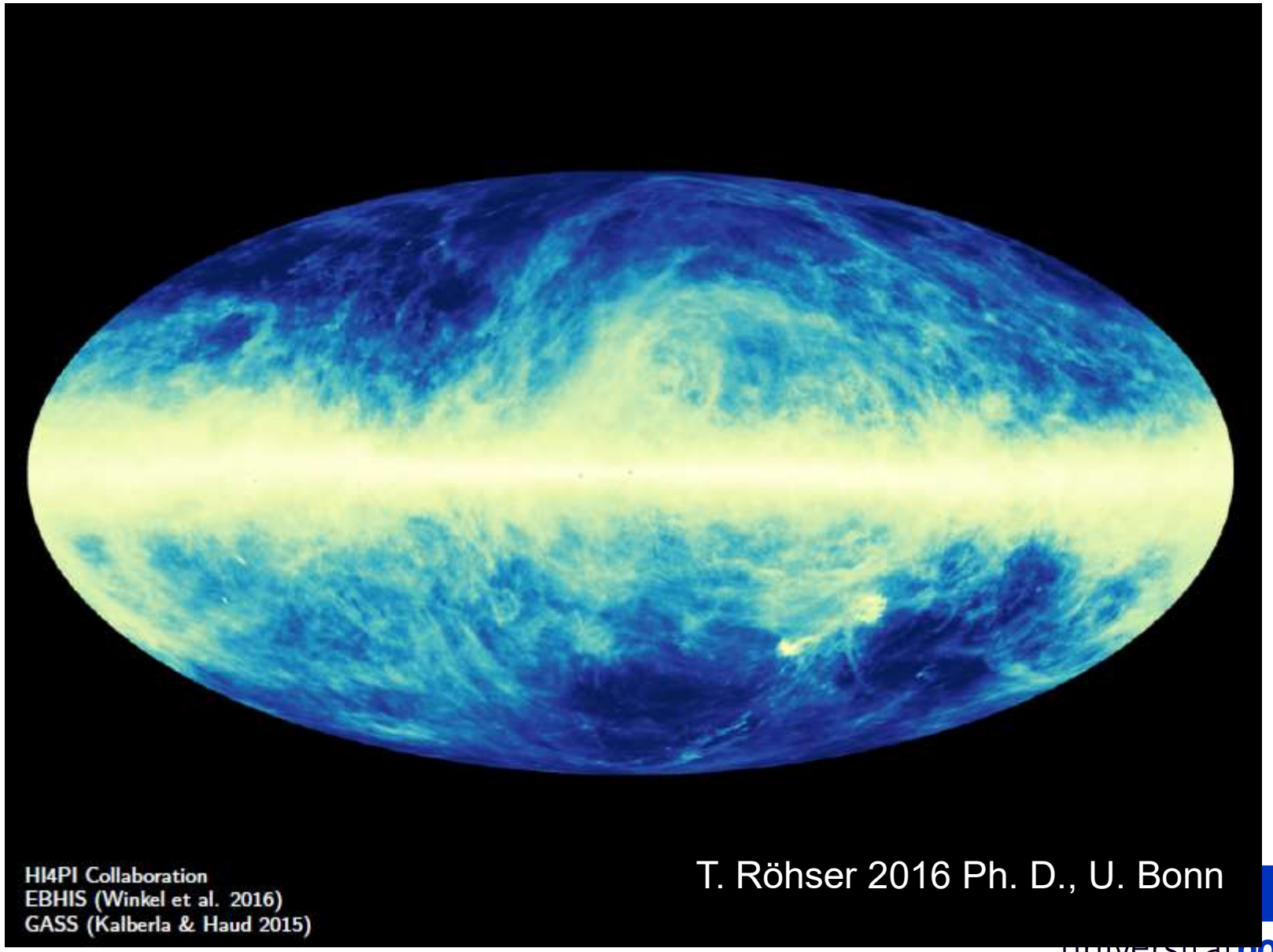

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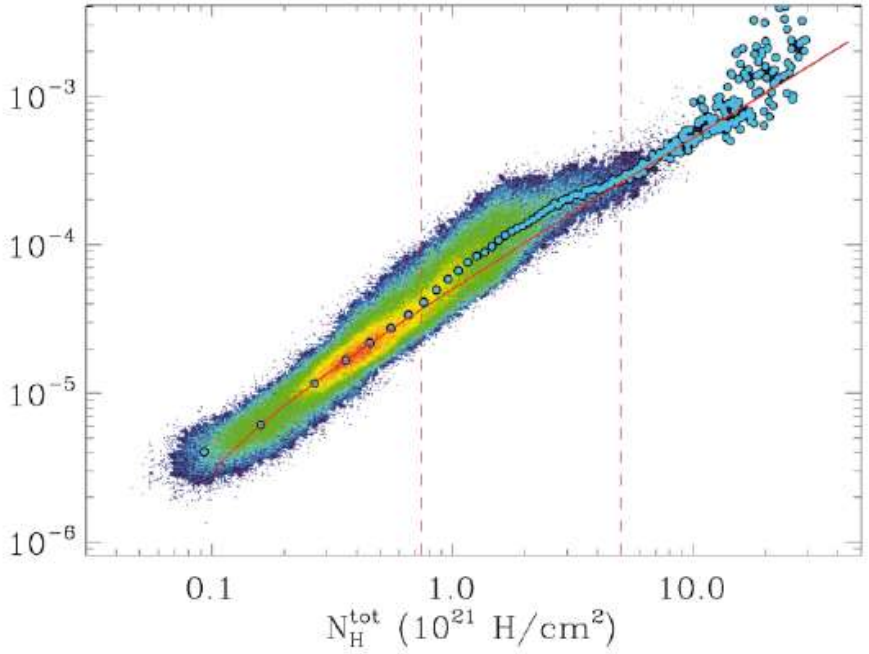
Dust to gas correlation

(e.g. Boulanger & Perault 1988)

$$I_\nu = a_\nu + \epsilon_\nu \times N_{\mathrm{H}}$$



Planck Collaboration XIX (2011)

$$I_\nu = a_\nu + \epsilon_\nu \times (N_{\mathrm{HI}} + 2X_{\mathrm{CO}}W_{\mathrm{CO}})$$

CO-dark H_2 fraction: $\sim 30\%$ (Planck Collaboration XIX 2011, Wolfire et al. 2010)

Dust to gas correlation

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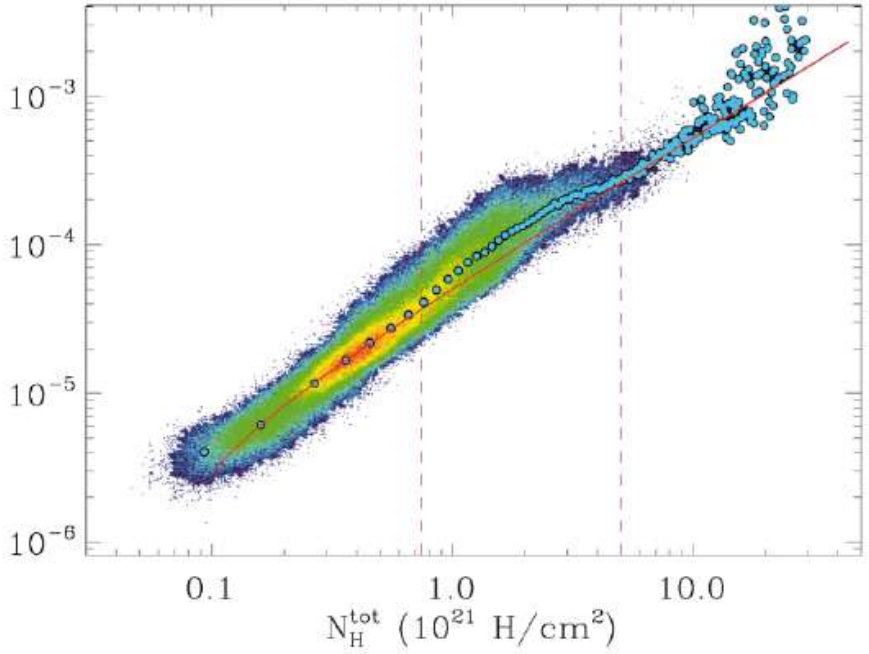

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Dust to HI gas

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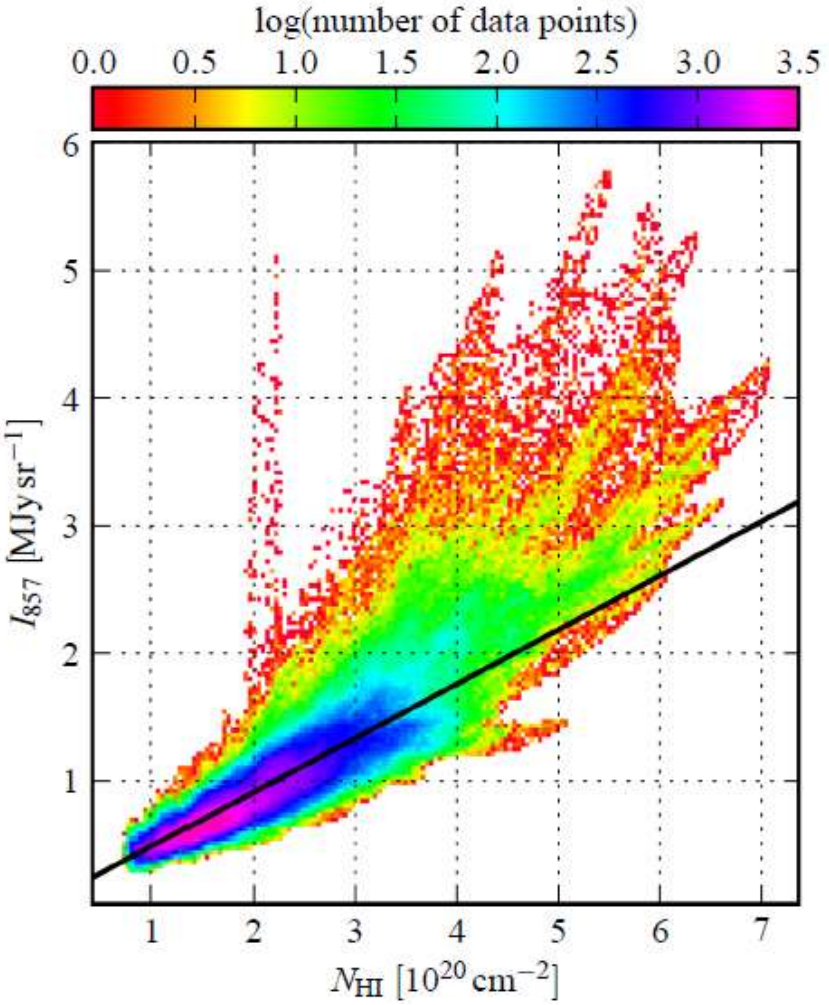

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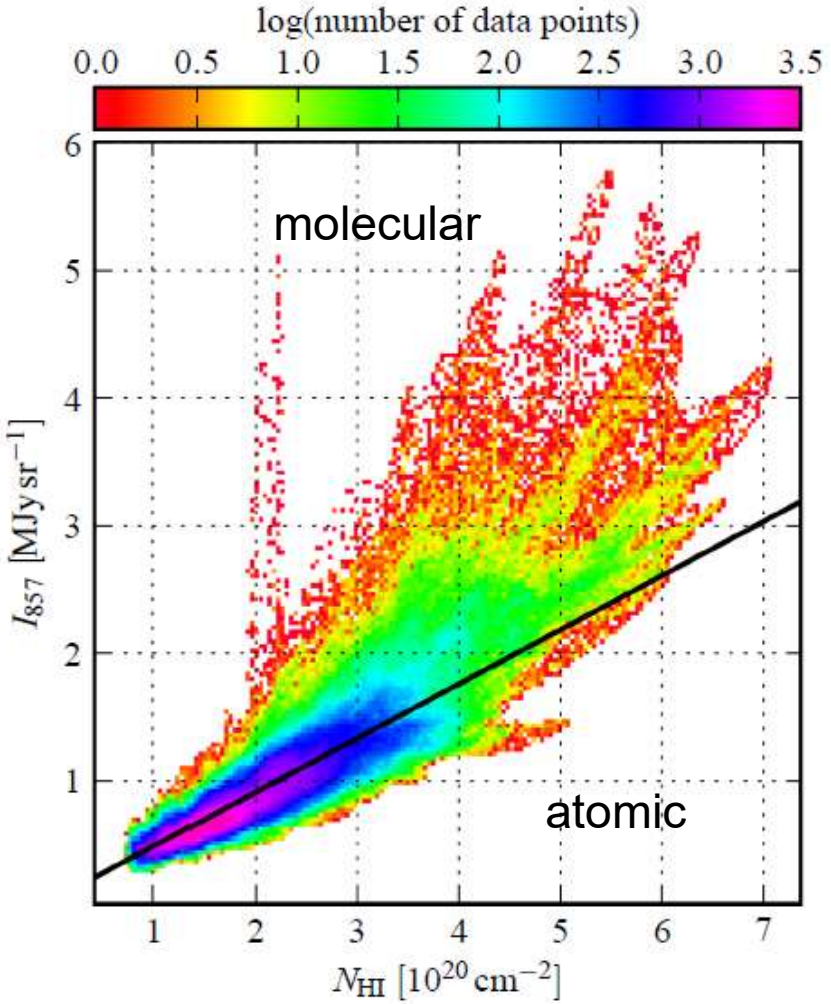
$$I_\nu = a_\nu + \epsilon_\nu \times N_{\rm H}$$

$$I_\nu = a_\nu + \epsilon_\nu \times (N_{\rm H\,I} + 2N_{\rm H_2})$$

- FIR excess: molecular gas → "missing" H I
- H_2 not easily observable
- No tracers (CO) required



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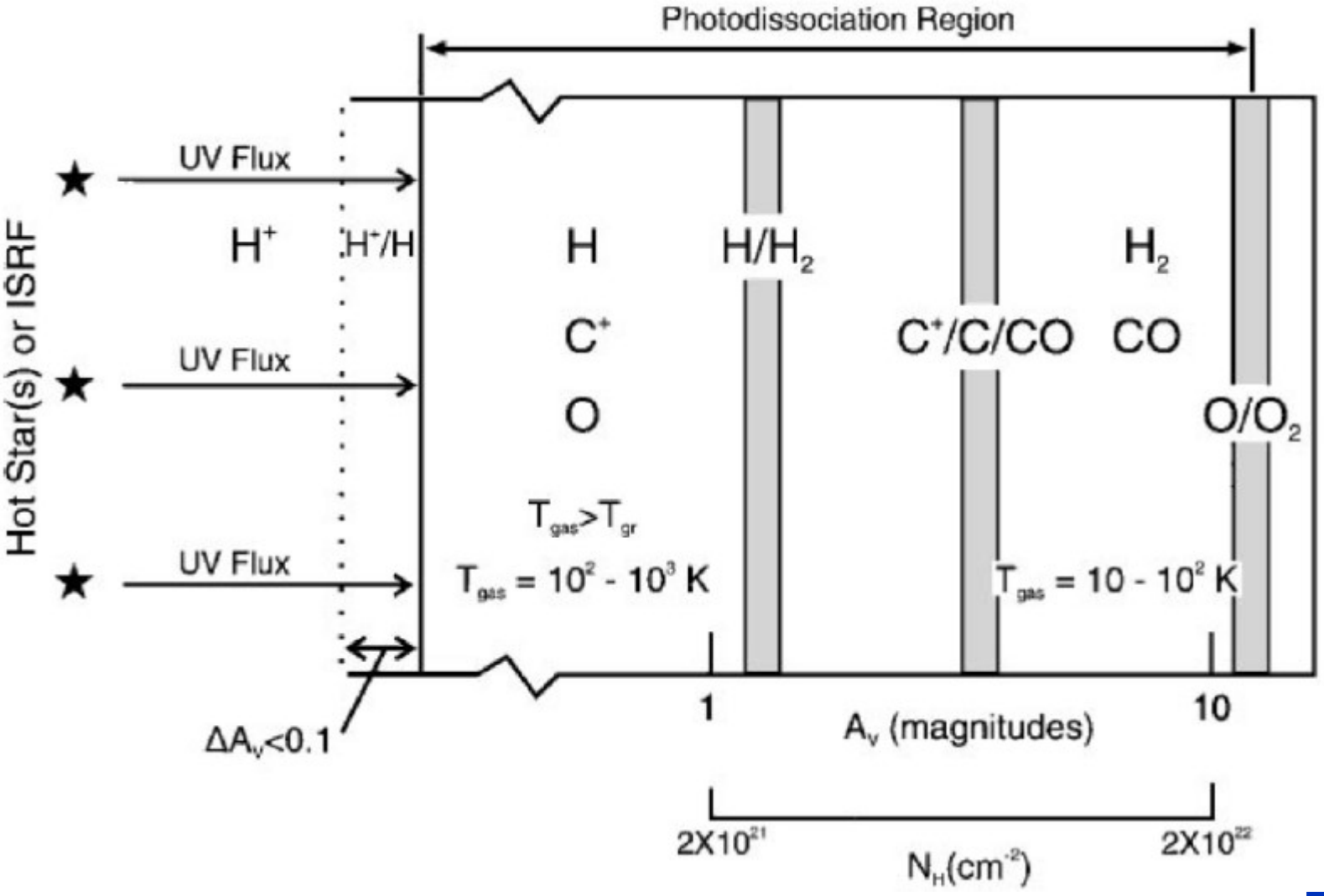
H_2 and its tracer ^{12}CO



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Search for molecular gas: two simple criteria

Narrow HI lines FWHM < 5 kms^{-1}

Bright HI lines T_B > 10 K

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EBHIS vs. *Planck* satellite

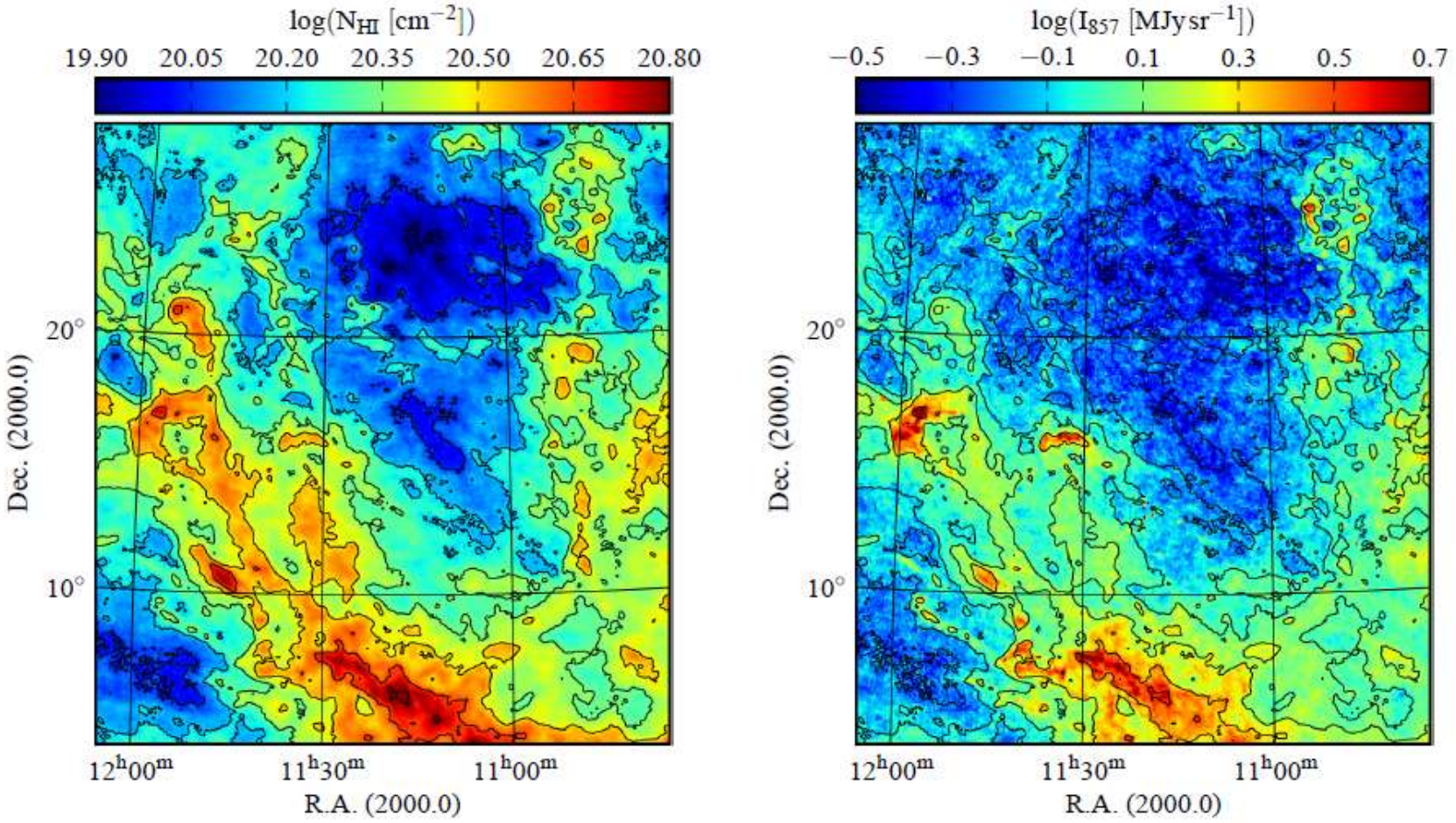

Fig. 1. *Left*: column density map of EBHIS integrated between $-100\,\mathrm{km\,s^{-1}} \leq v_{\mathrm{LSR}} \leq +100\,\mathrm{km\,s^{-1}}$. *Right*: corresponding unsmoothed *Planck* map at 857 GHz. In both figures the black contours mark $N_{\mathrm{H\,I}}$ at the levels of the colour bar tick labels of the column density map.

Röhser et al. 2014, A&A 564, 71

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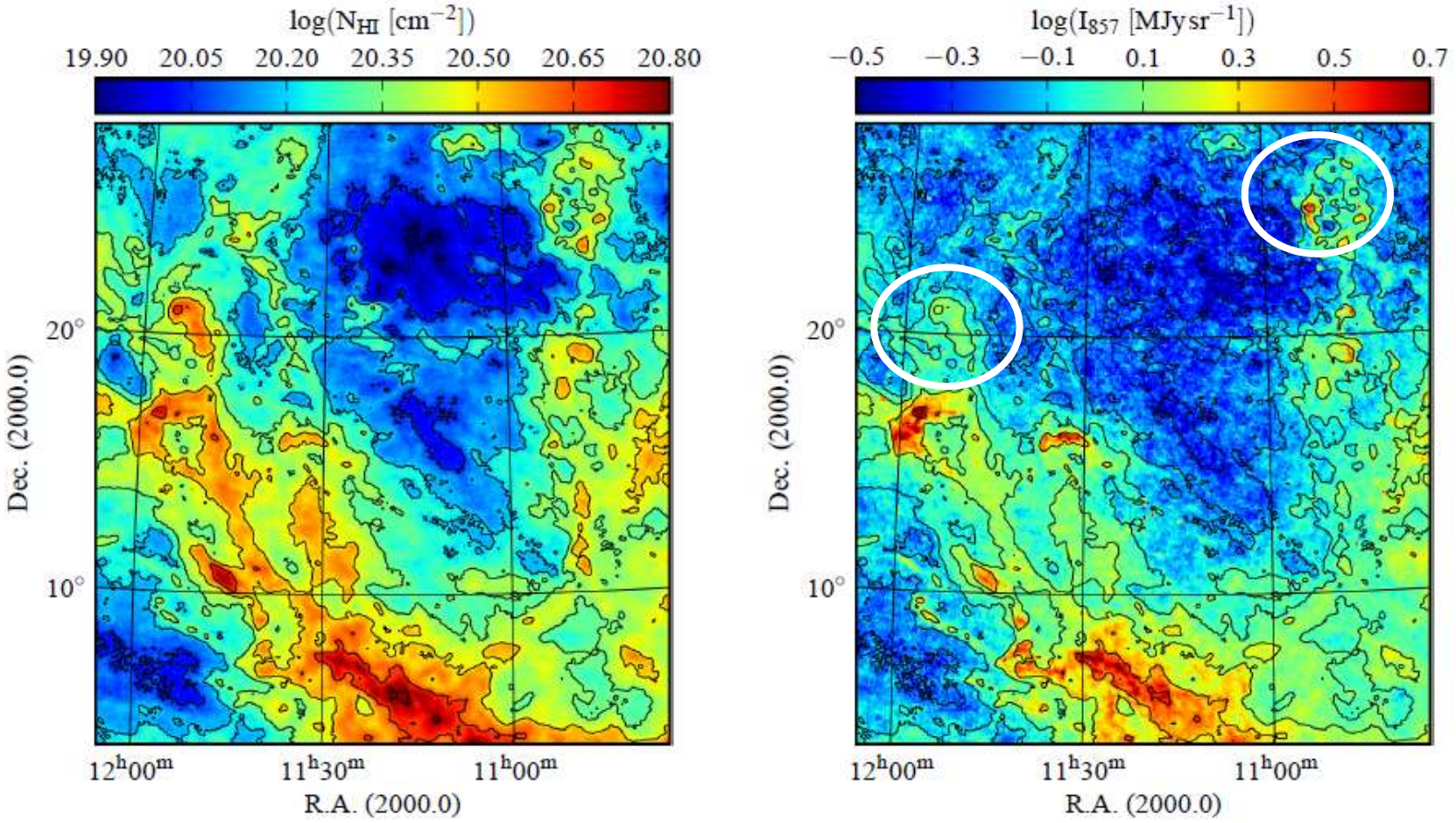

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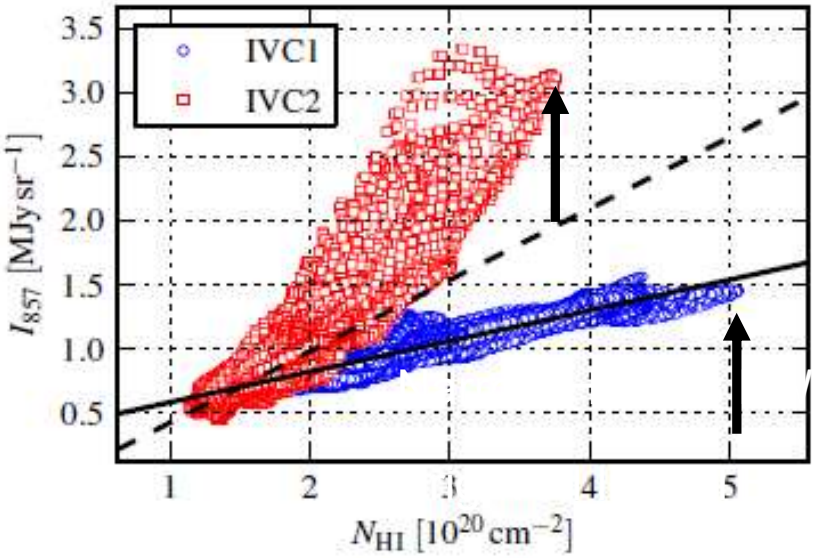

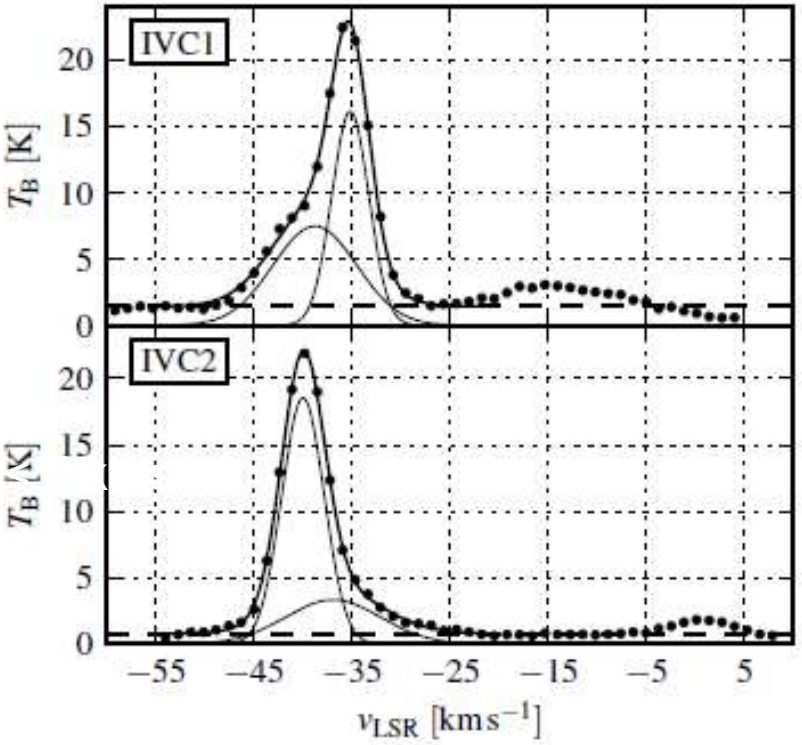

Röhser et al. (2014)

IVC 1: FIR deficient → pure atomic cloud

IVC 2: FIR excess → molecular cloud

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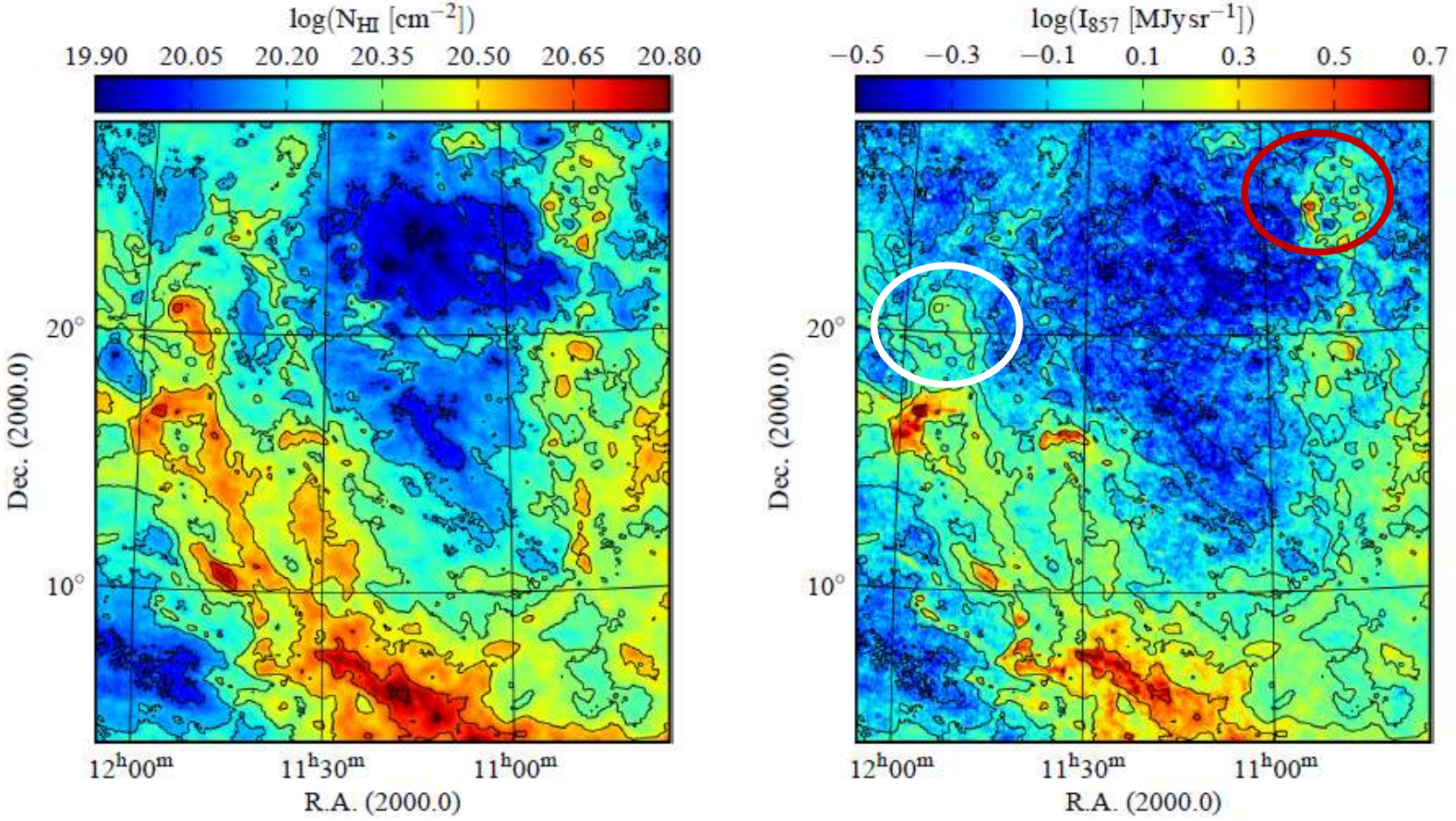
EBHIS vs. *Planck* satellite→molecular gas



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jkerp@uni-bonn.de

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Unexpected intermediate result

Far infared dim cold high HI column density clouds exists

jkerp@uni-bonn.de

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A Galactic census of molecular gas

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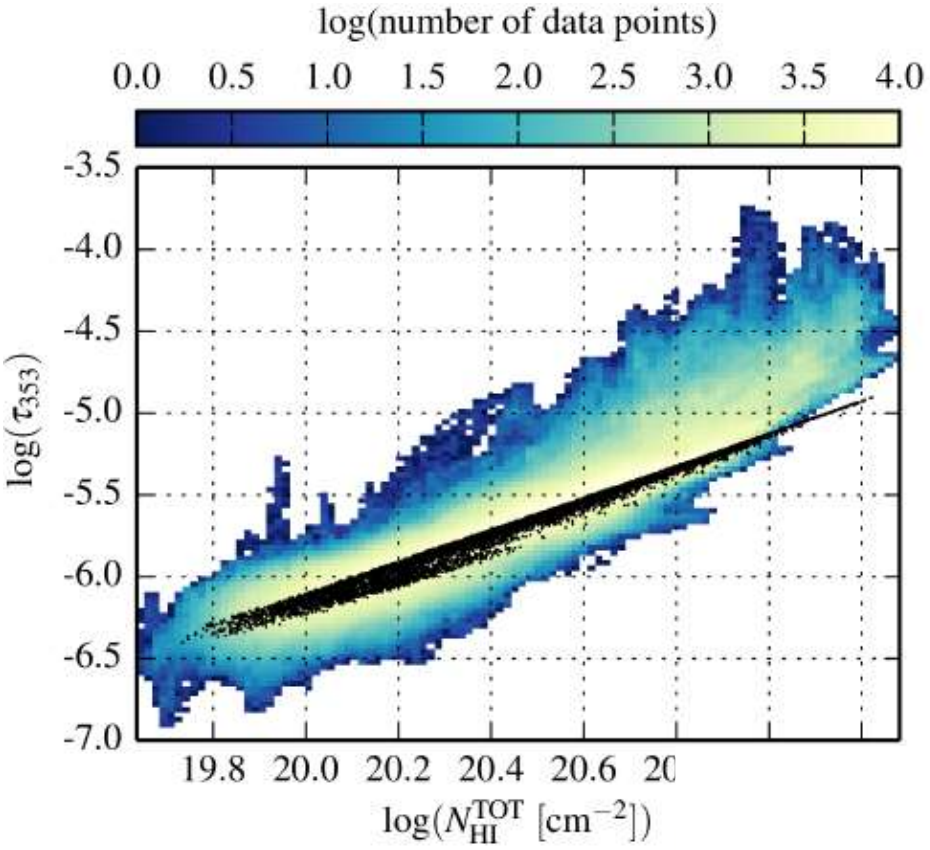
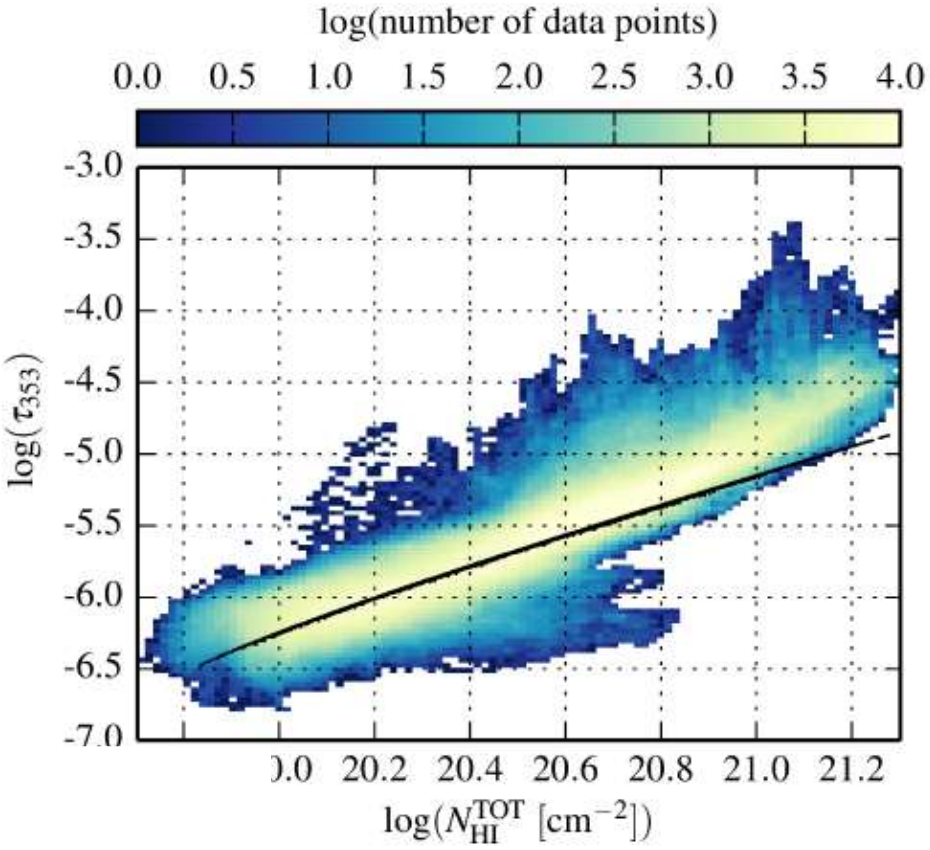
Northern and southern sky fit HI4PI-*Planck*

North



South



Röhser et al. 2016, A&A 596, 94

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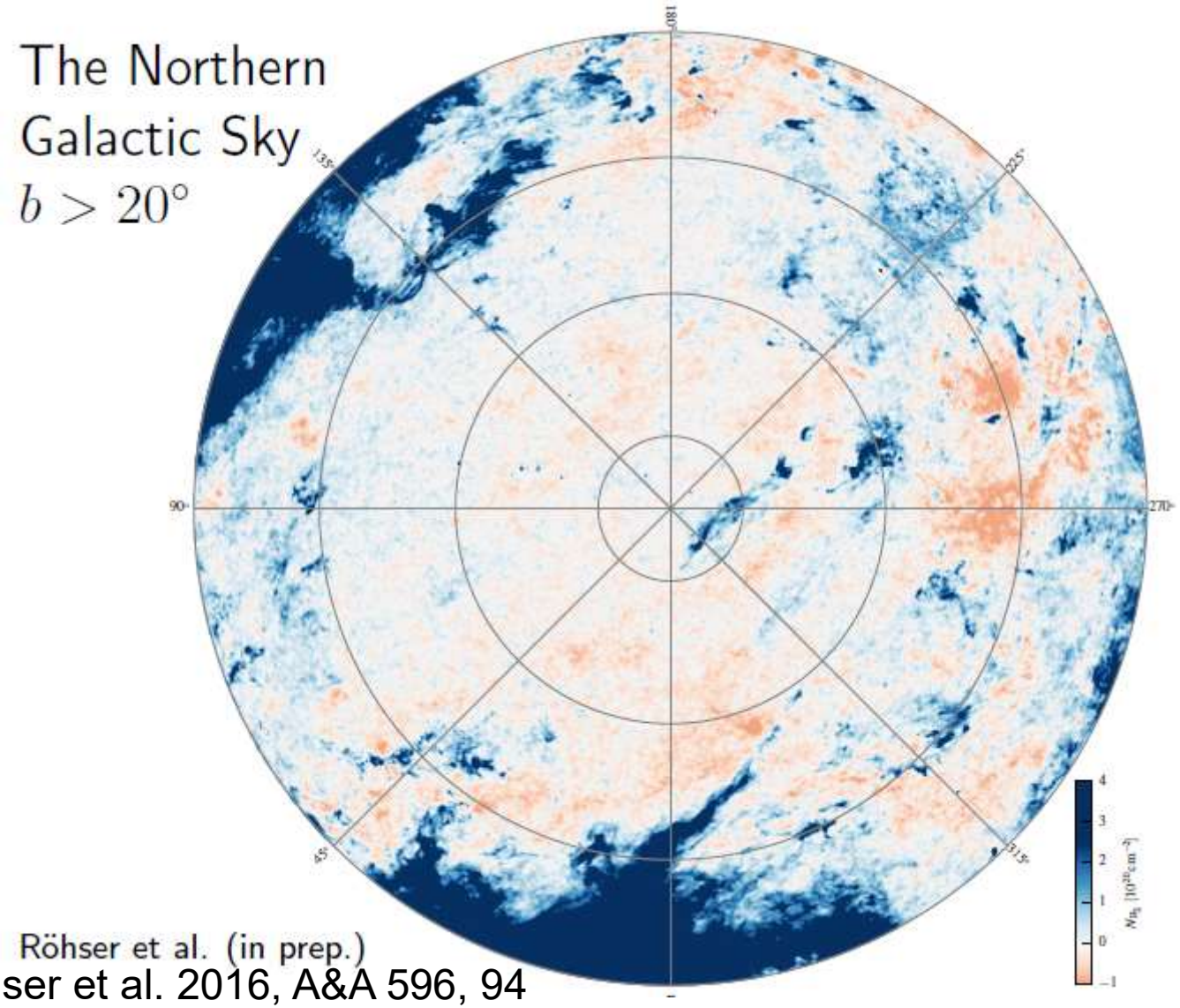
North



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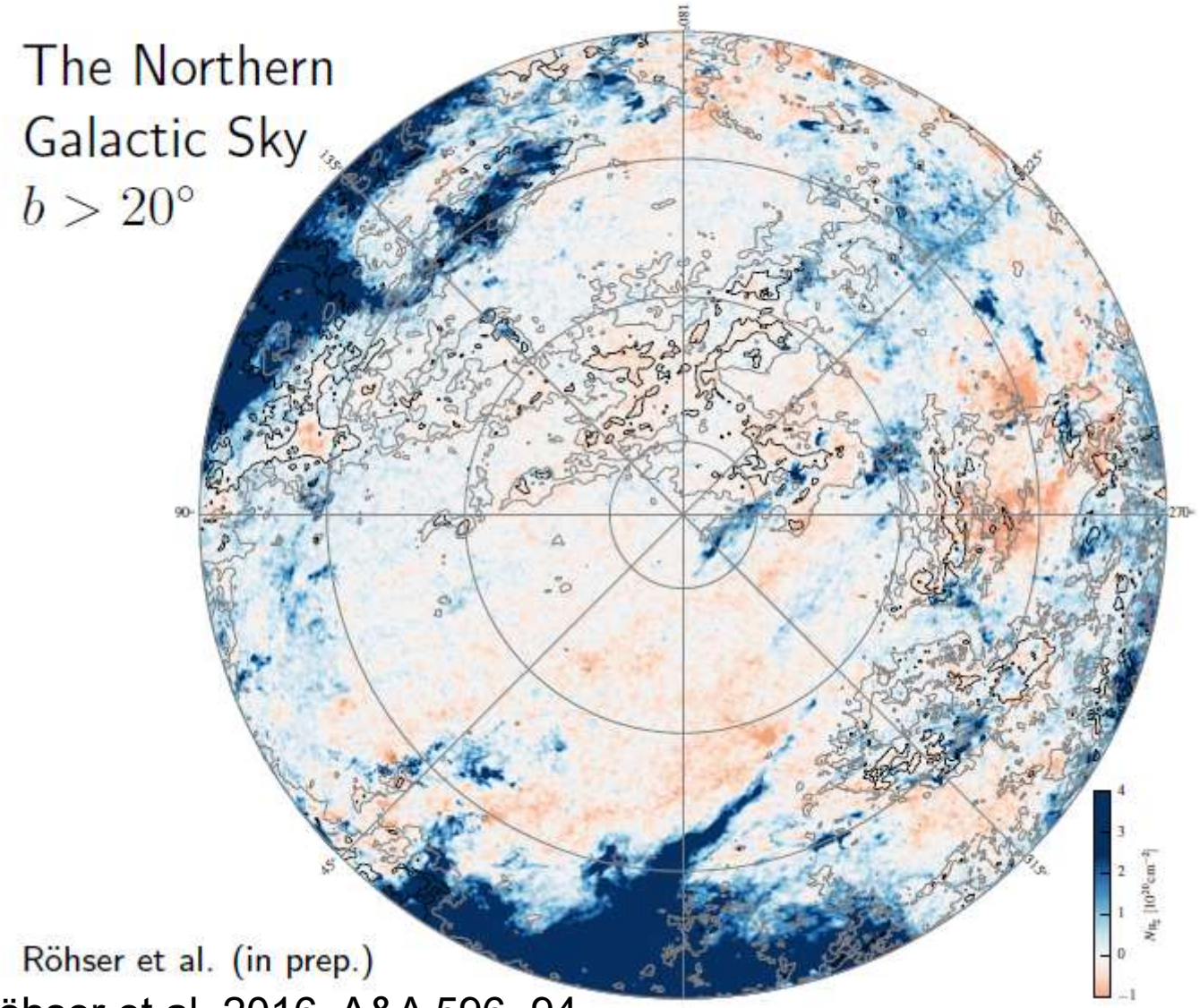
North



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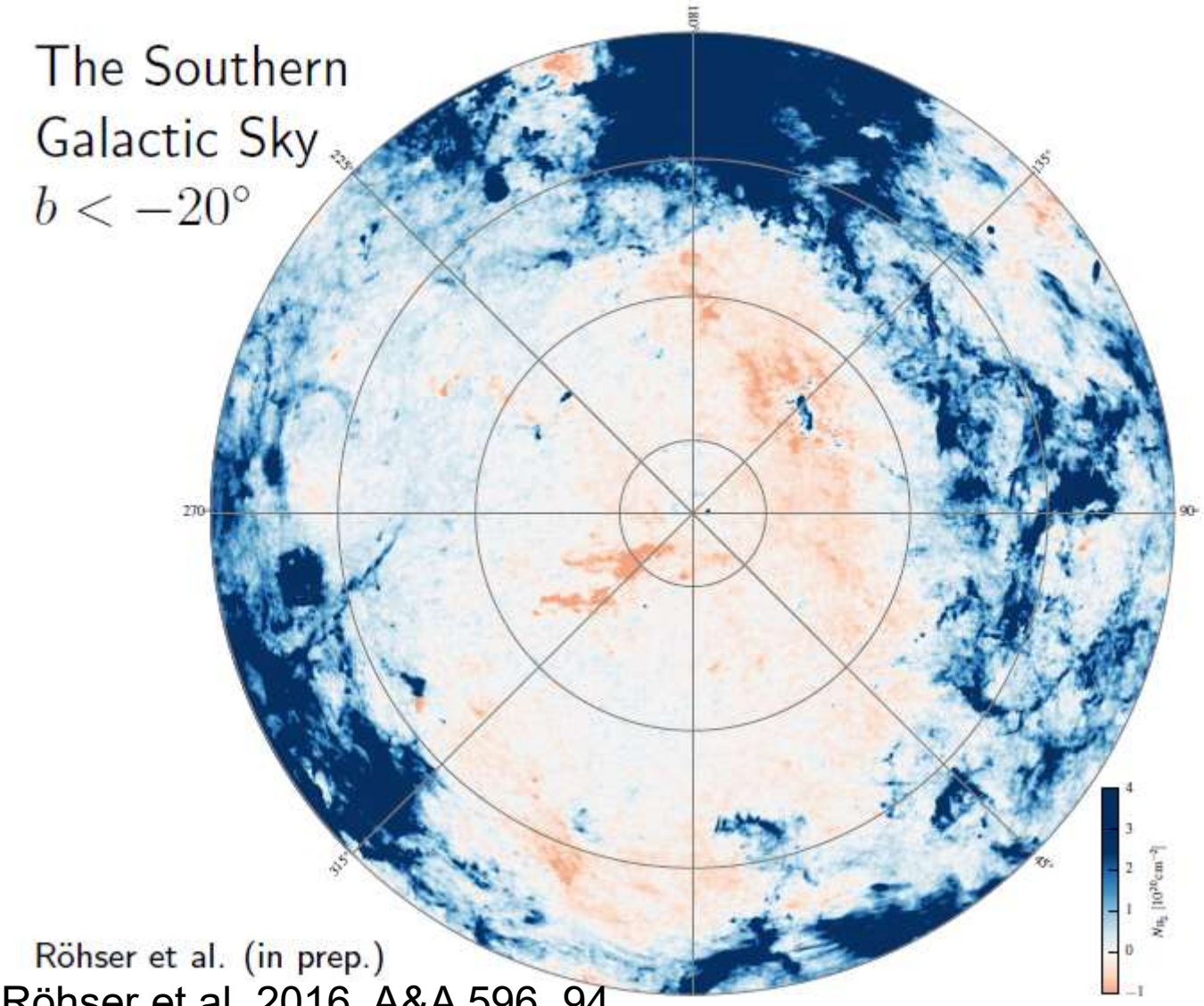
South



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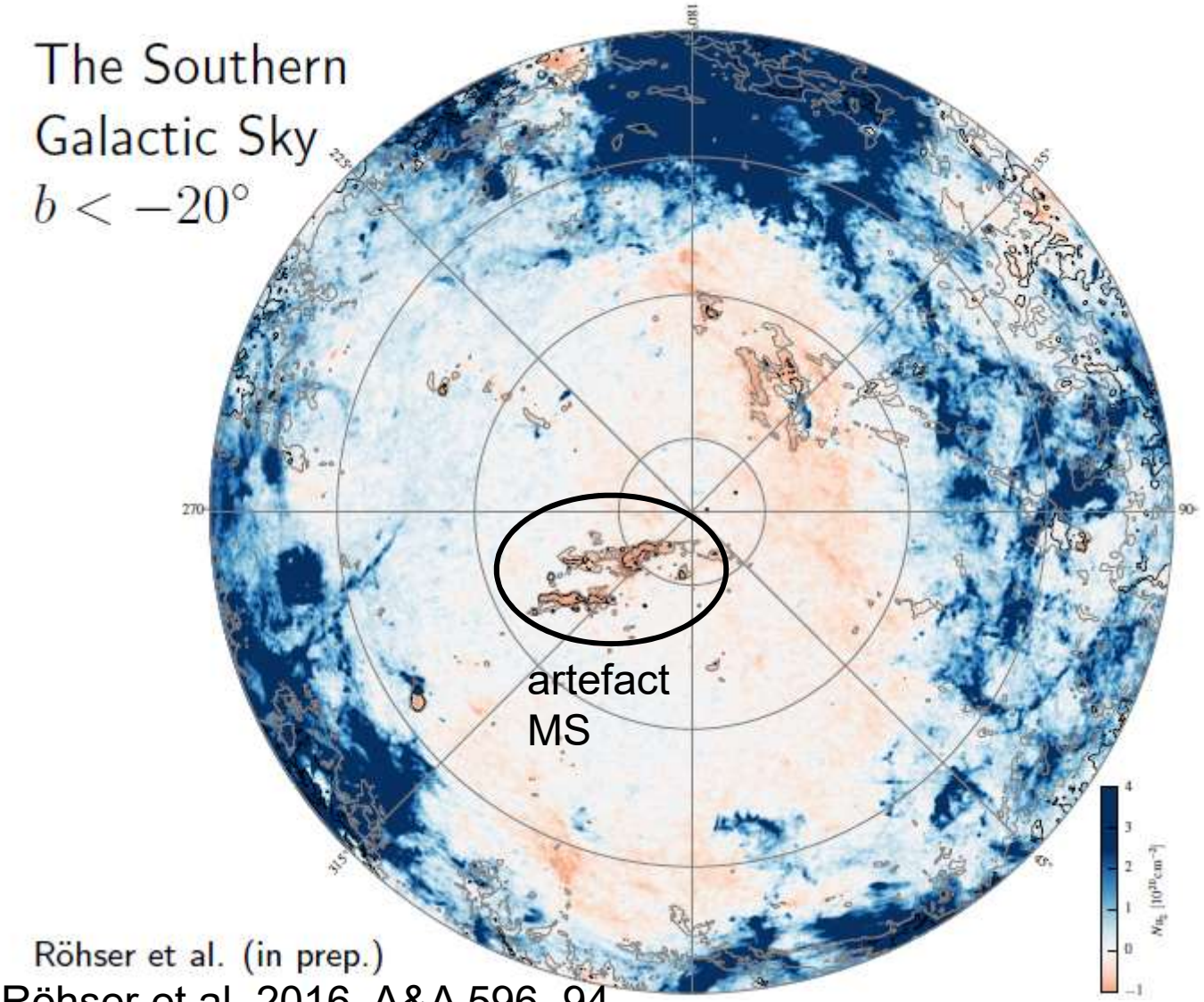
South



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North-south asymmetry

	northern Galactic hemisphere		southern Galactic hemisphere	
	$v_{LSR} < -20\,km\,s^{-1}$	$v_{LSR} > +20\,km\,s^{-1}$	$v_{LSR} < -20\,km\,s^{-1}$	$v_{LSR} > +20\,km\,s^{-1}$
# AIVCs	86	8	23	0
# MIVCs	161	1	24	20
# NIVCs	288	22	31	5

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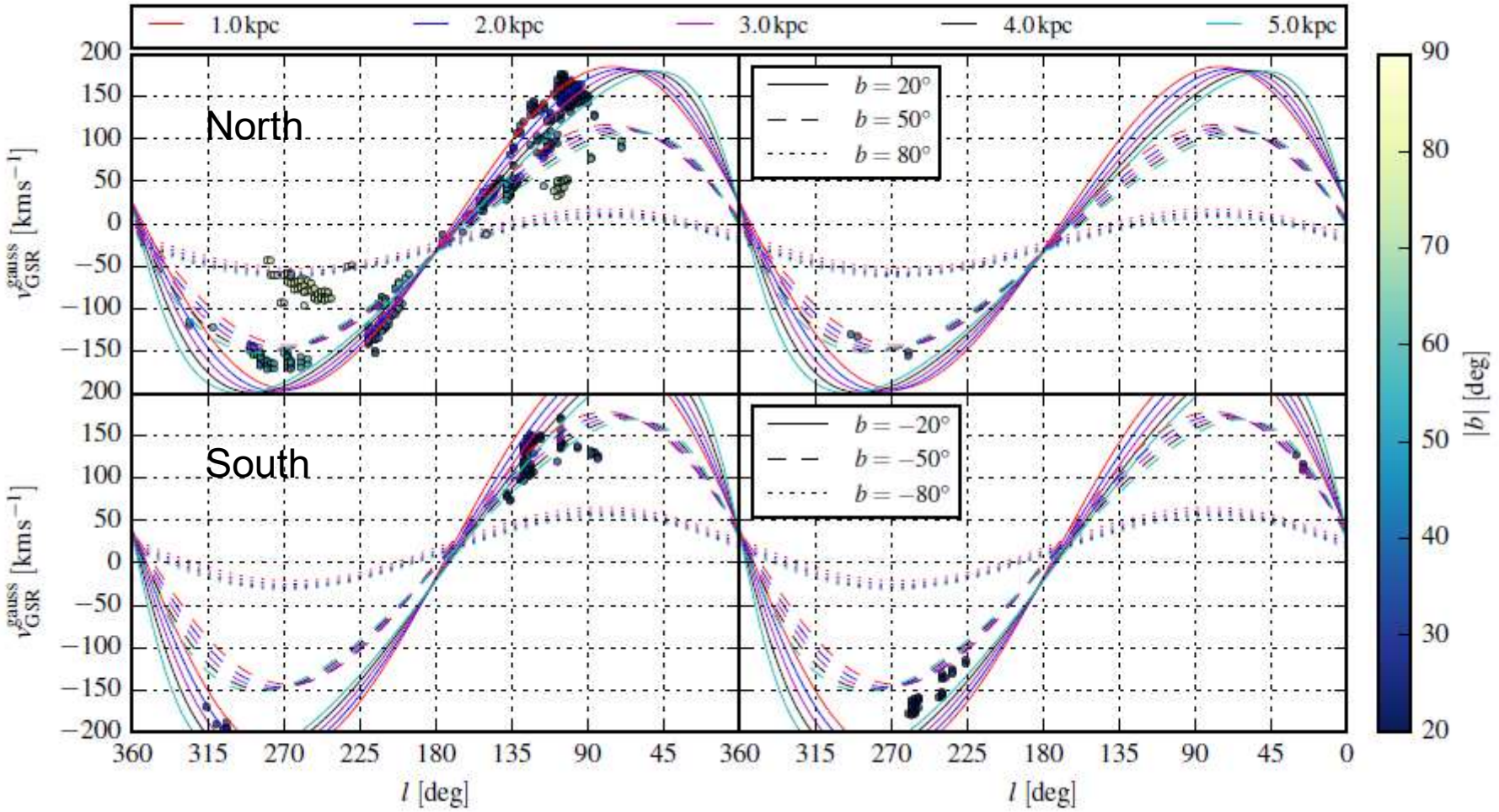
Co-rotation



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MIVCs: tiny extent and mass

	d [pc]	$T_{\rm kin}$ [K]	$n_{\rm HI}$ [$\rm cm^{-3}$]	$p/k_{\rm B}$ [$\rm K\,cm^{-3}$]	$f_{\rm mol}$	$M_{\rm HI}$ [$M_\odot$]	$M_{\rm H}$ [$M_\odot$]
northern MIVCs$^-$	6.2	412	4.7	1766	0.51	33	67
southern MIVCs$^-$	10.2	440	7.2	2920	0.37	165	300
southern MIVCs$^+$	13.3	388	3.2	980	0.57	170	400

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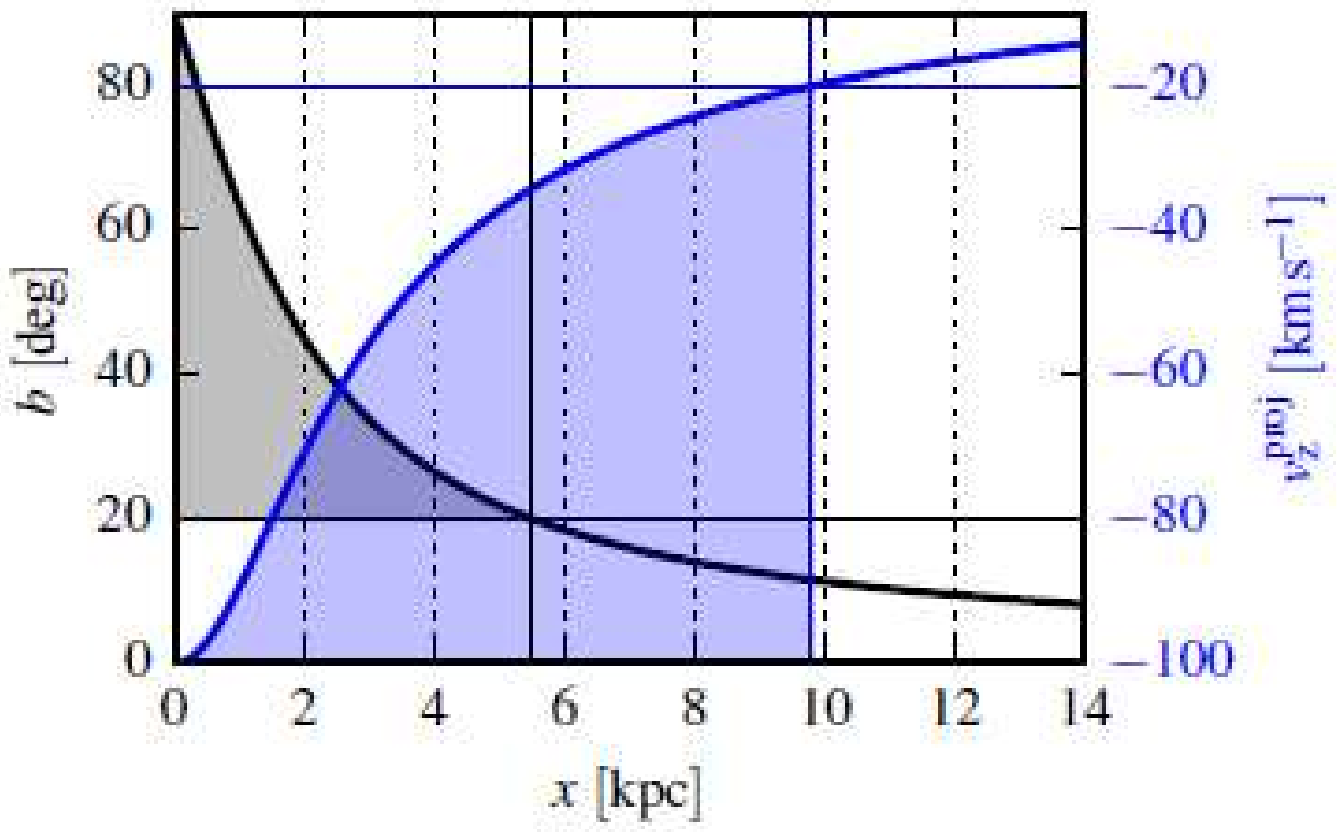
Probed parameter space



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Extrapolation to the whole Milky Way Galaxy

	M_{H1} [$M_\odot$]	M_{H_2} [$M_\odot$]	M_H [$M_\odot$]
		$\Omega \geq \Omega_{GASS}$	
			MIVC$^-$
north	$7.0 \cdot 10^4$	$1.8 \cdot 10^5$	$2.5 \cdot 10^5$
south	$3.6 \cdot 10^4$	$3.0 \cdot 10^4$	$6.6 \cdot 10^4$
			MIVC$^+$
north	$8.8 \cdot 10^1$	$3.5 \cdot 10^1$	$1.2 \cdot 10^2$
south	$2.6 \cdot 10^4$	$3.1 \cdot 10^4$	$5.7 \cdot 10^4$

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How to form molecules in translucent MIVCs?

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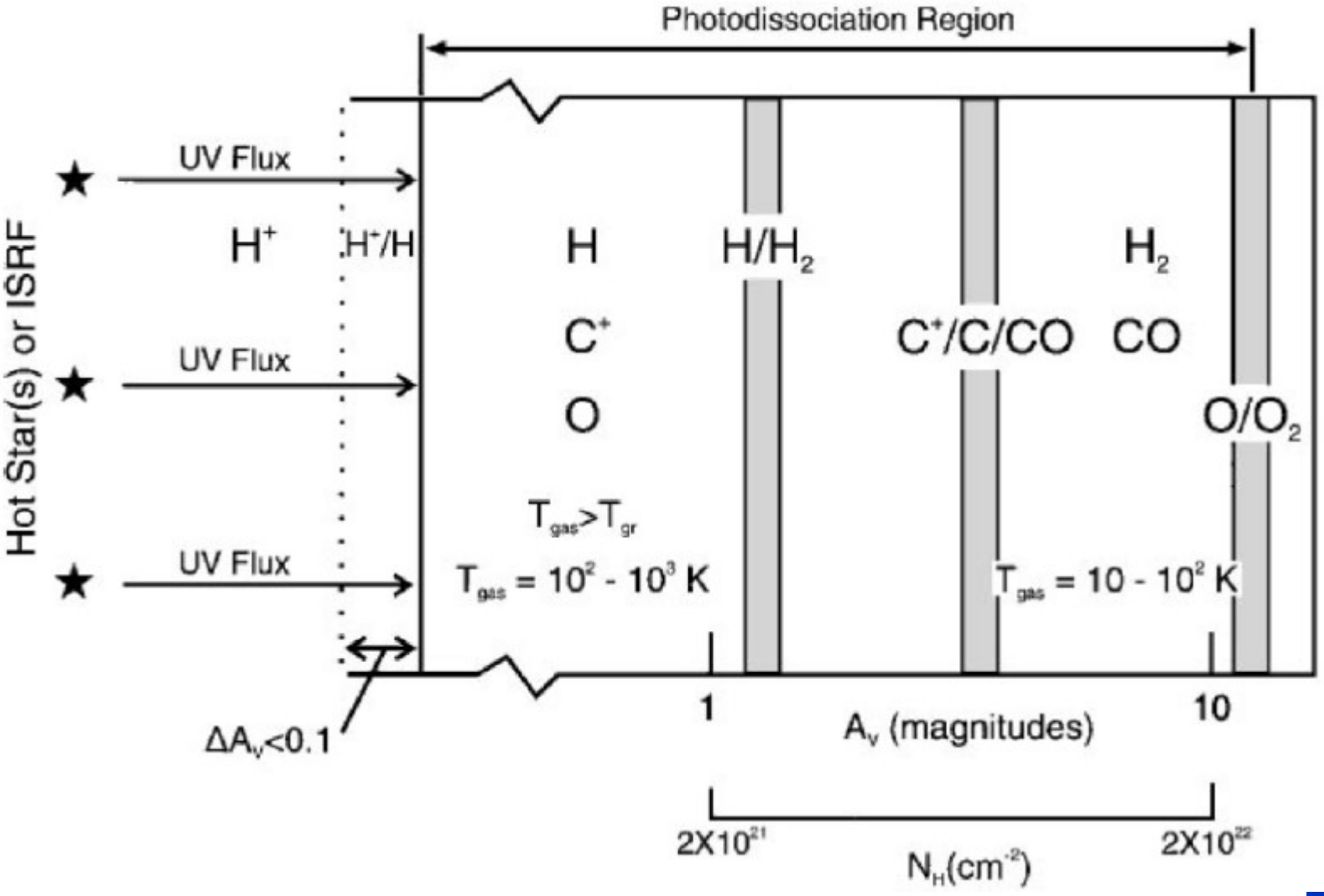
H_2 and its tracer ^{12}CO



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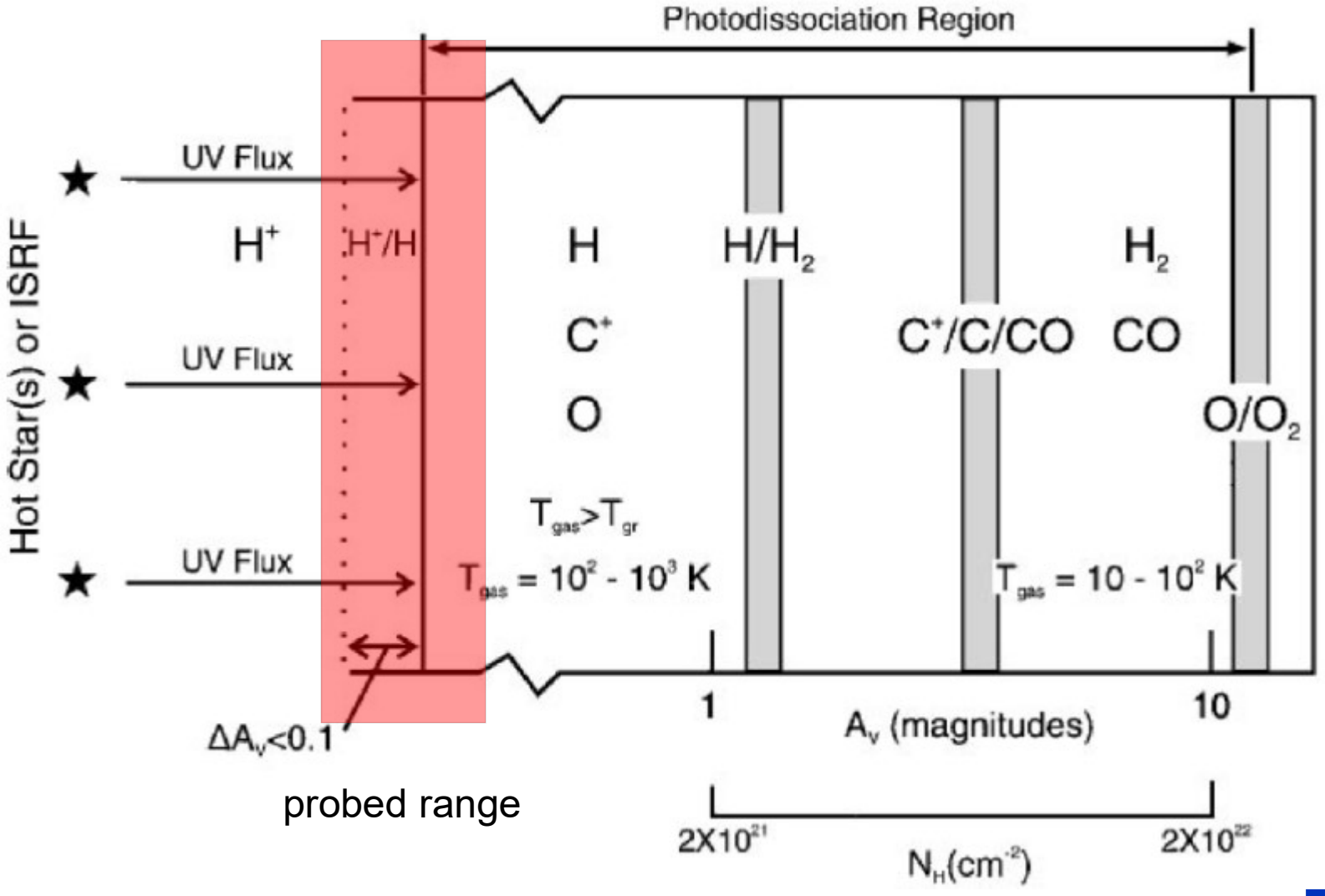
Probing only the atomic/ionized gas range



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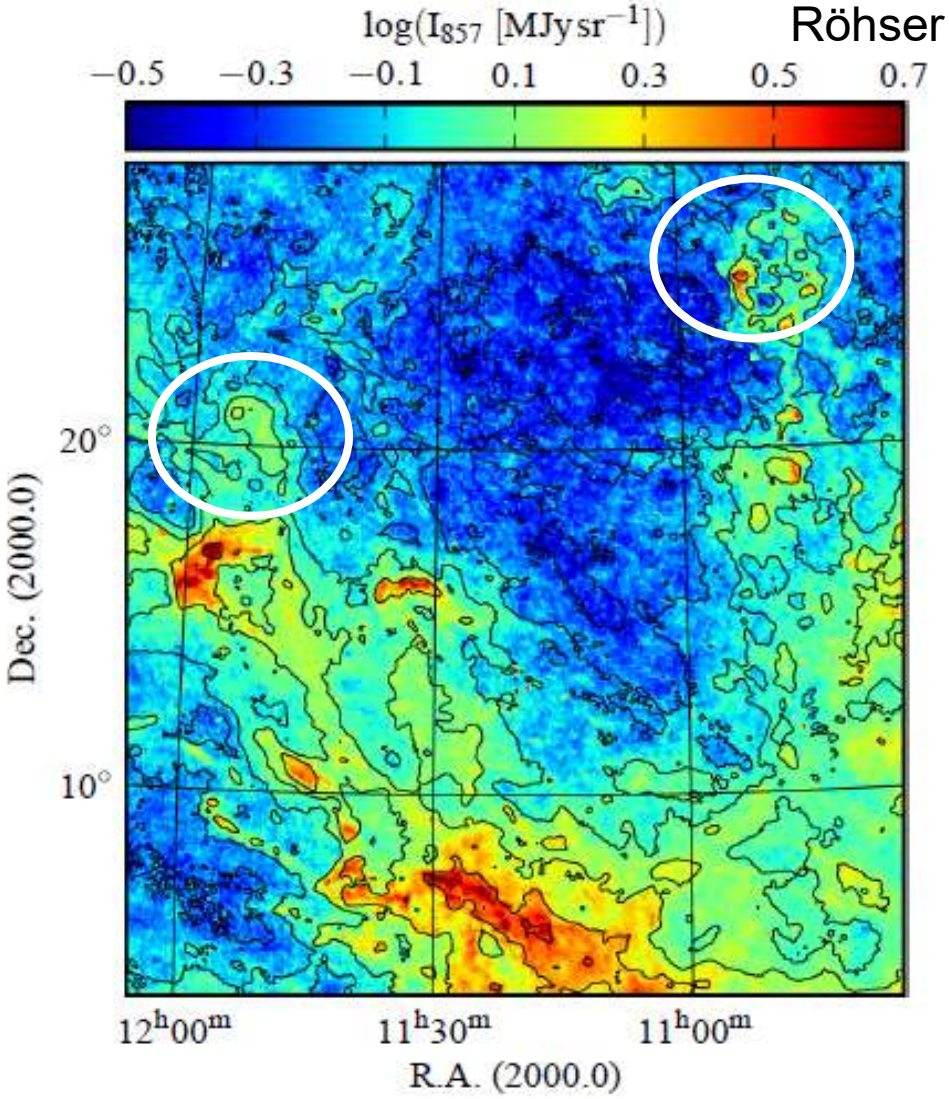
EBHIS vs. *Planck* satellite



Röhser et al. 2014, A&A 564, 71

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Westerbork Synthesis Radio Telescope (WSRT)

- 14 dishes with 25 m diameter
- Maximum separation ∼3 km
- Angular resolution for H I:
  ∼49″ × 18″
  ∼75″ × 23″
- Channel width ∼1.0 km s^{-1}

Credit: ASTRON

IRAM 30 m telescope

- ^{12}CO(1→0) at 115.27 GHz
- Angular resolution ∼23″
- Channel width 0.53 km s^{-1}

Credit: IRAM

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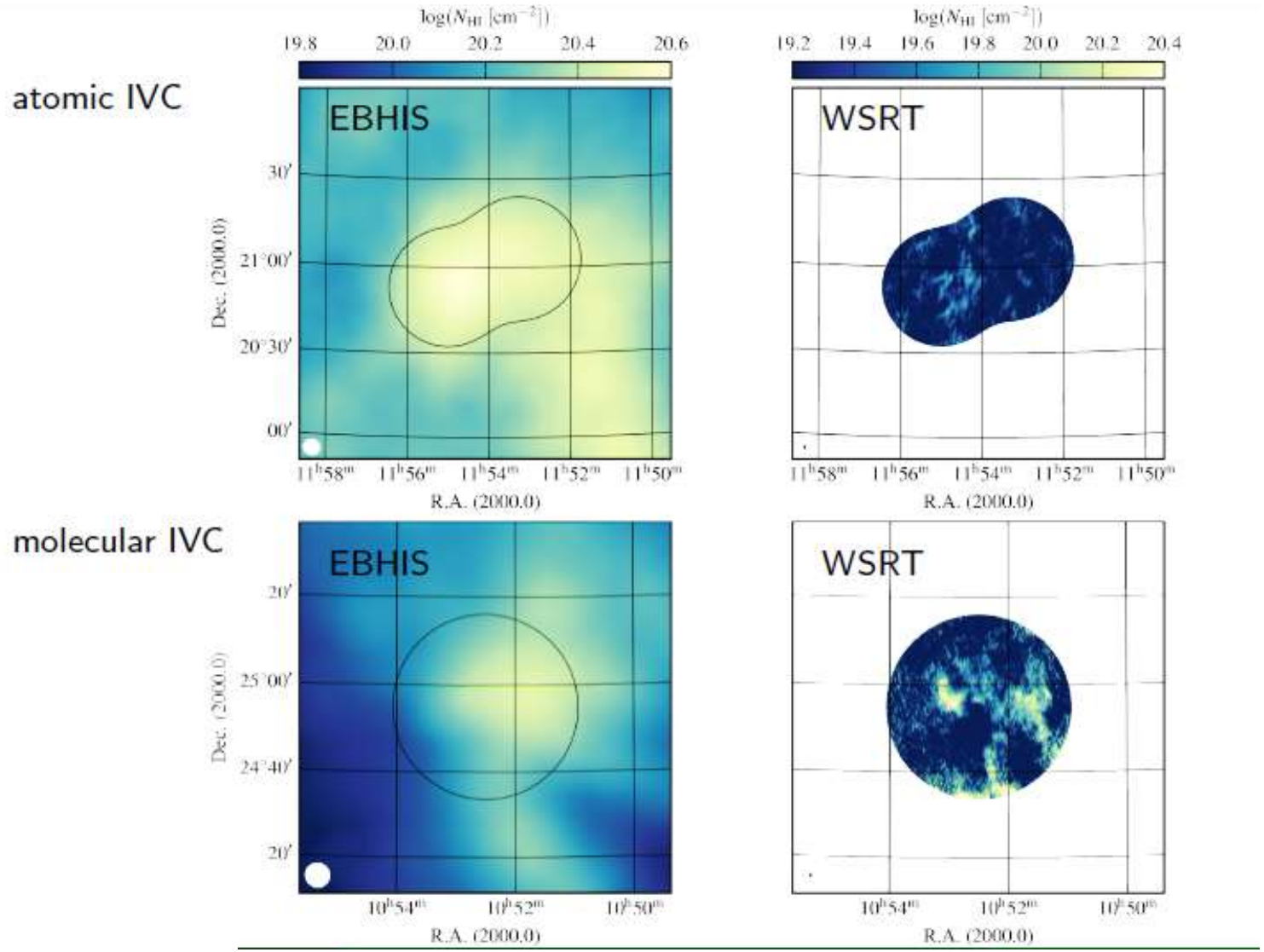
EBHIS vs. WSRT

Röhser et al. 2016, A&A 592, 142



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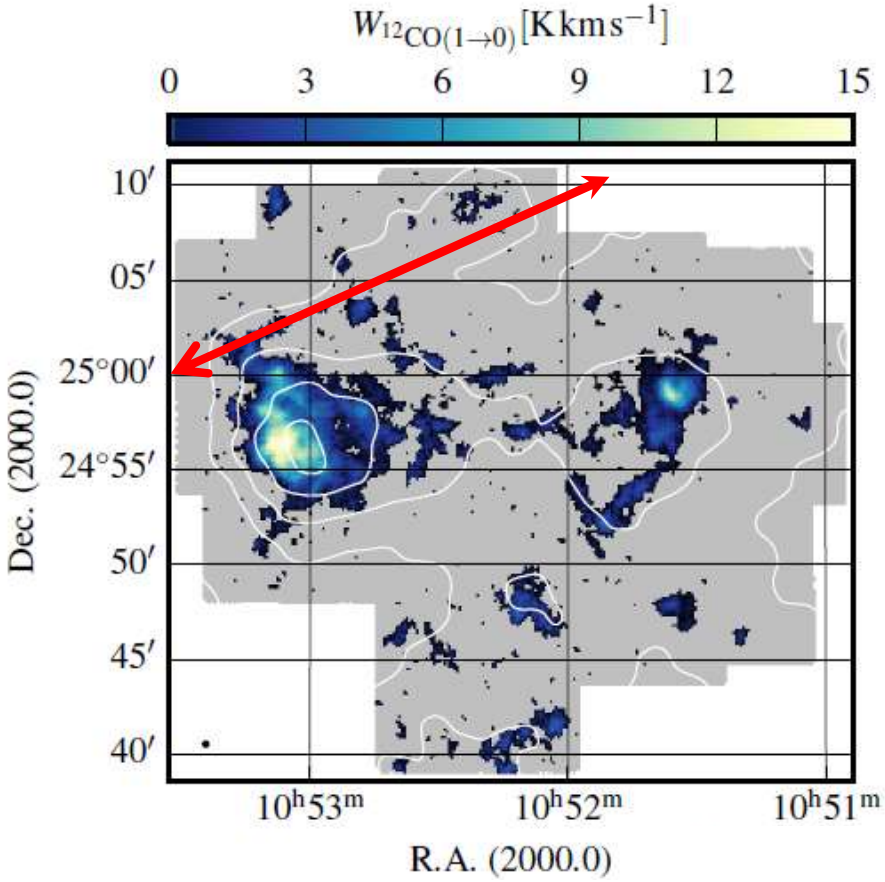
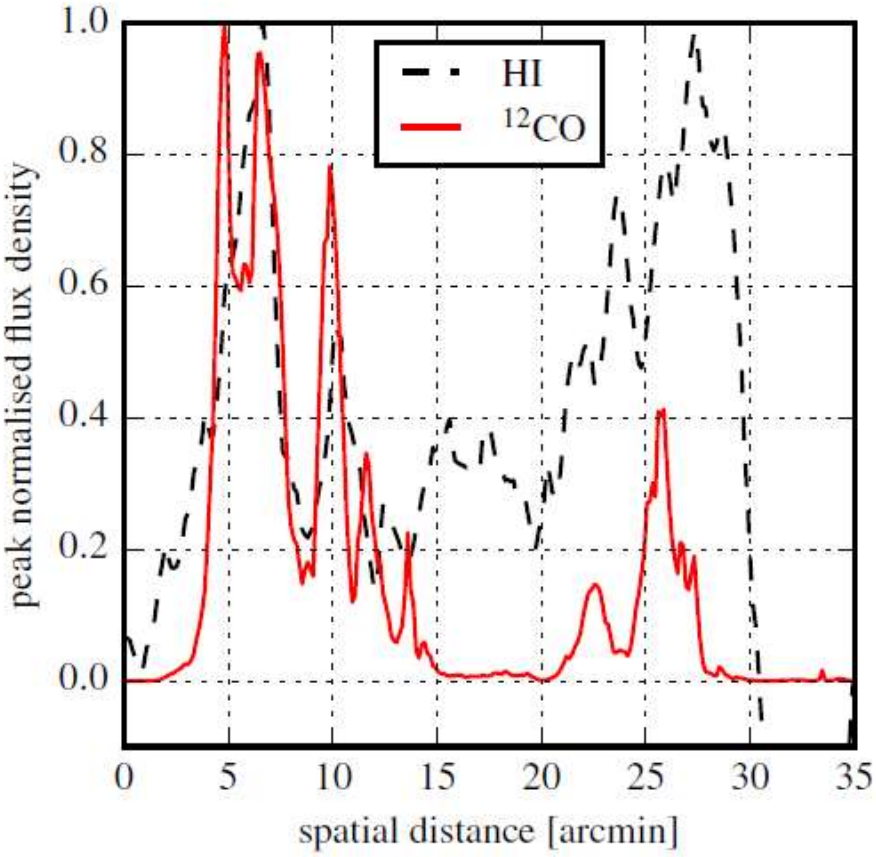
^{12}CO Pico Veleta

Röhser et al. 2016, A&A 592, 142





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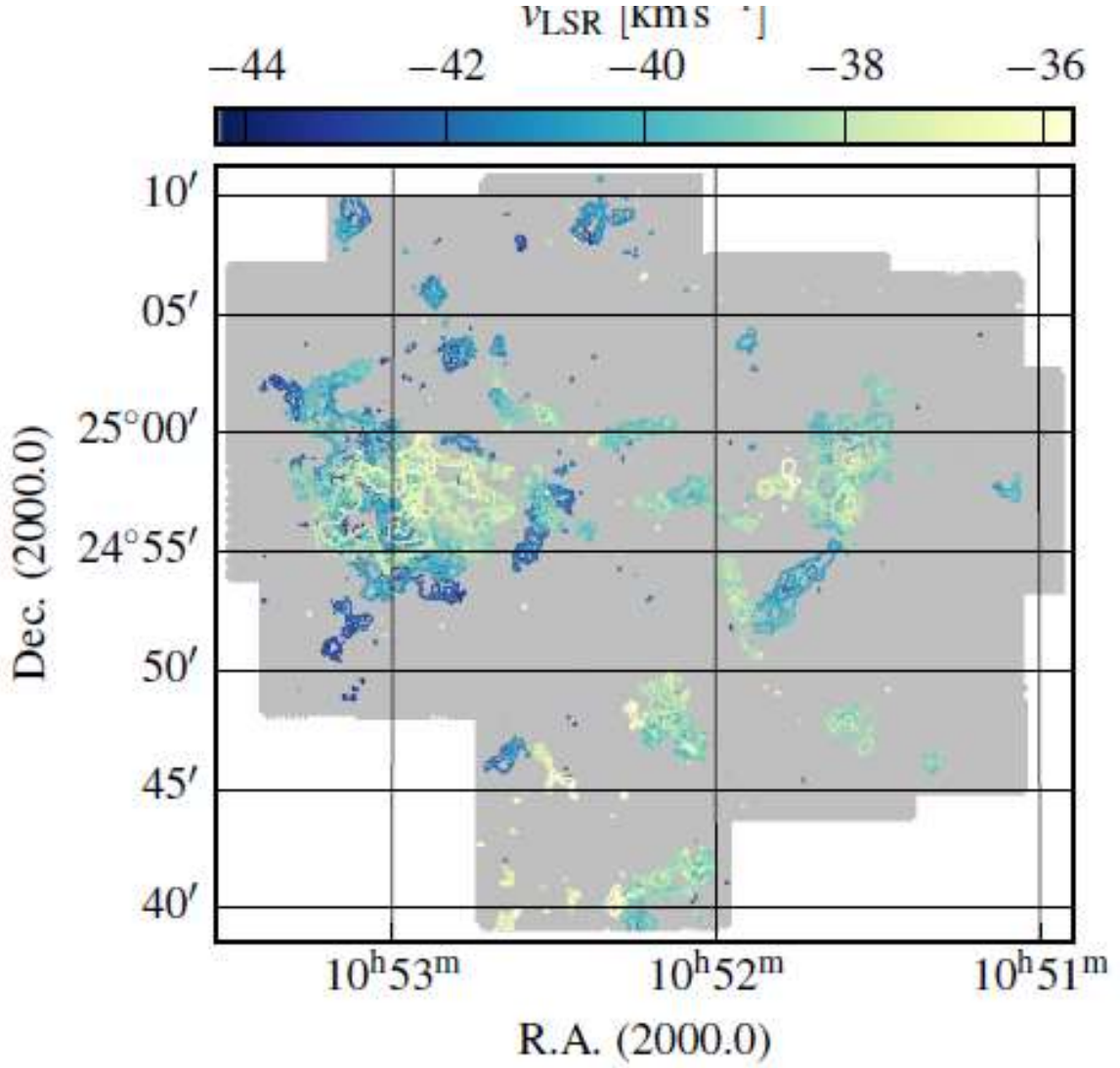
Turbulent ^{12}CO velocity field

Röhser et al. 2016, A&A 592, 142



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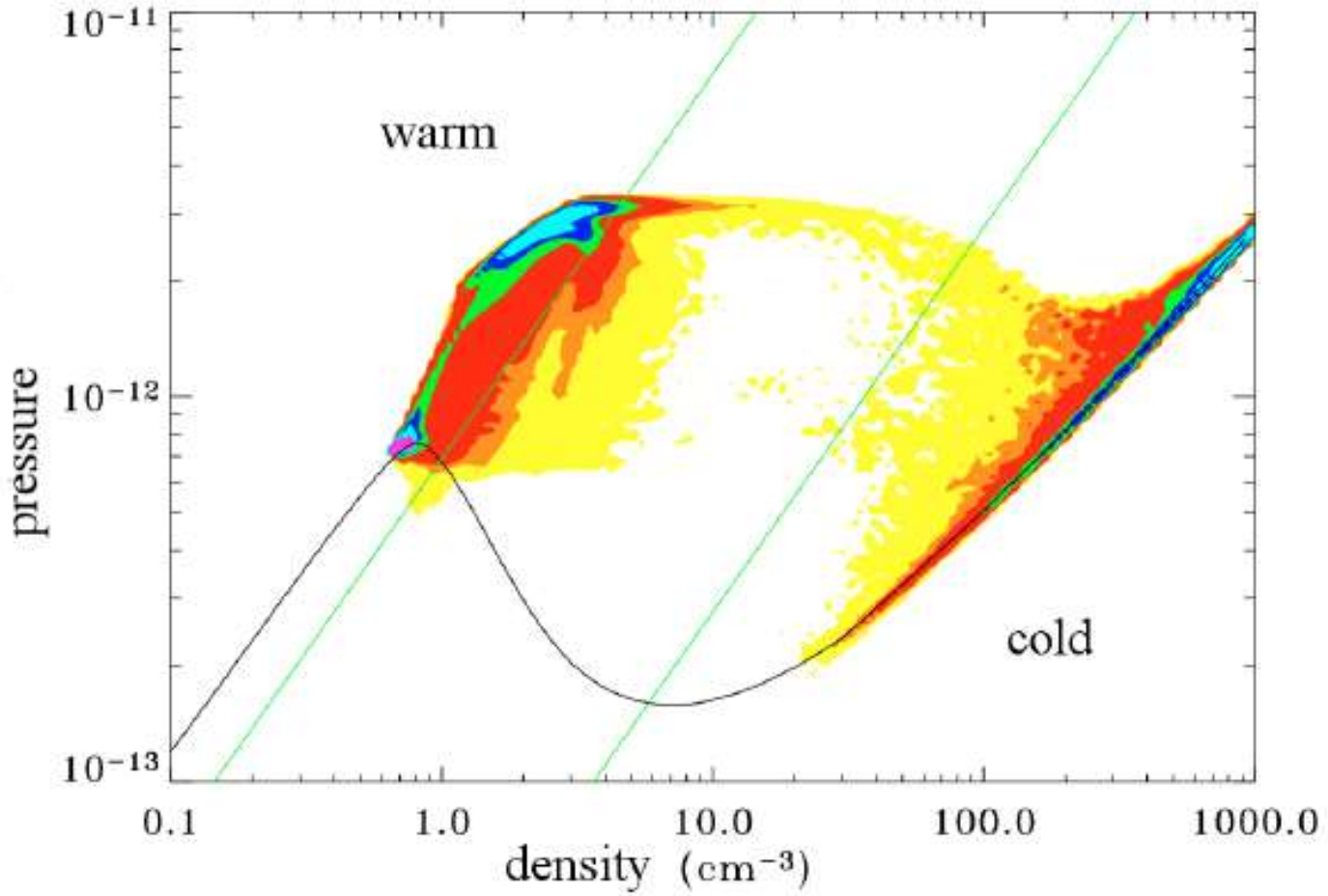
Dynamical triggered transition



Audit & Hennebelle (2005)

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Summary

Probing the **intermediate velocity cloud regime** only

Toward high galactic latitude → local ISM

239 molecular IVCs discovered, about a factor of four more than previously known.

Strong asymmetry between

northern and southern sky

187 vs. 52

descending and ascending northern MIVCs

184(neg.) vs. 3 (pos.)

descending and ascending southern MIVCs

31(neg.) vs. 21(pos.)

Evidence for non-equilibrium conditions caused by dynamical interaction

Mass inflow rate: $0.54 M_{Sun}\ yr^{-1}$ (0.5 kpc) to $4.3 M_{Sun}\ yr^{-1}$ (1.6 kpc)

Objects are too tiny and too light to be detectable in external galaxies

cosmic molecular rain.

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