The Dark Milky Way: Probing our Galaxy's Hidden Gas

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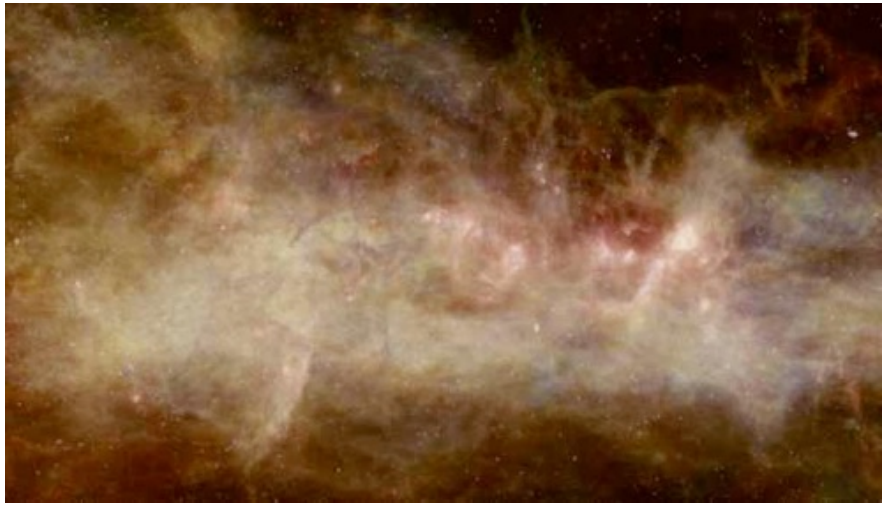
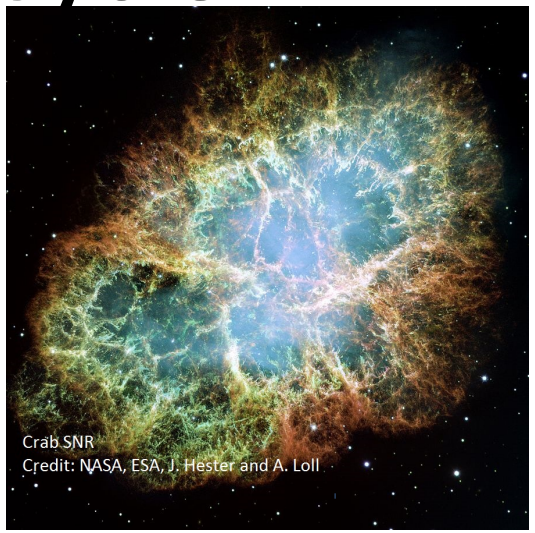


Nordita, May 2017

Outlines

- “Dark” gas – Introduction
- Results from HI data
- Results from OH data
- Results from Dust data (τ_{353}, E(B-V), Radiance R)

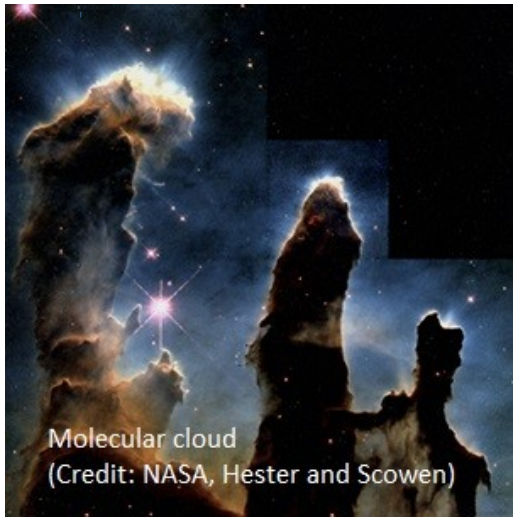
Star-gas-star Cycle



Supernova Remnant

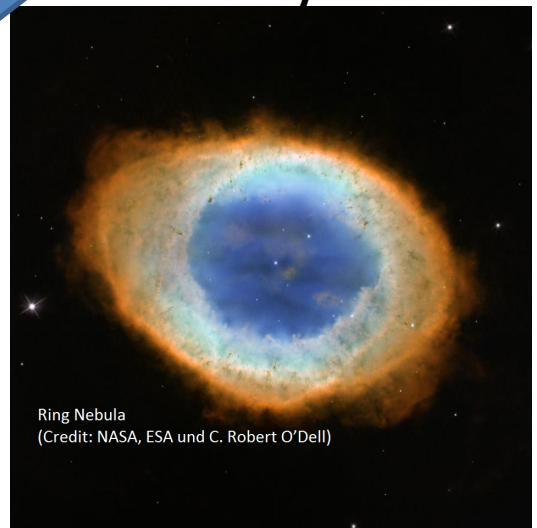
Diffuse gas

Molecular Cloud

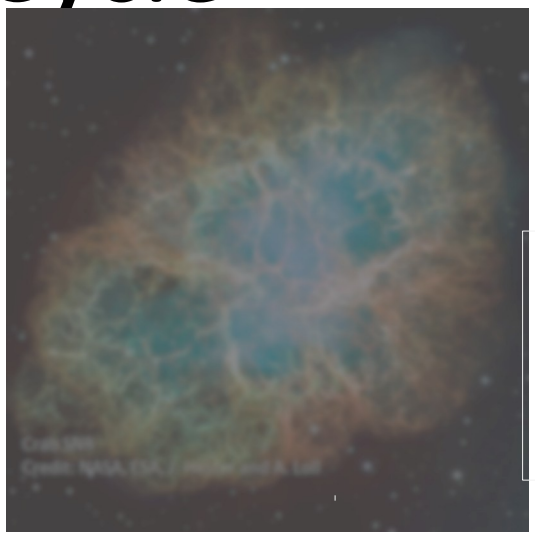


Stars

Planetary Nebula



Star-gas-star Cycle



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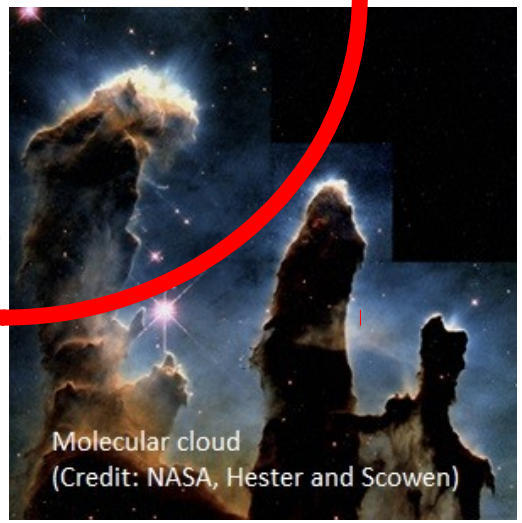
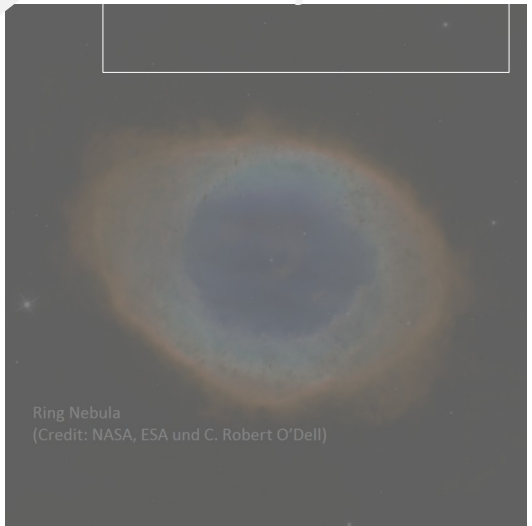


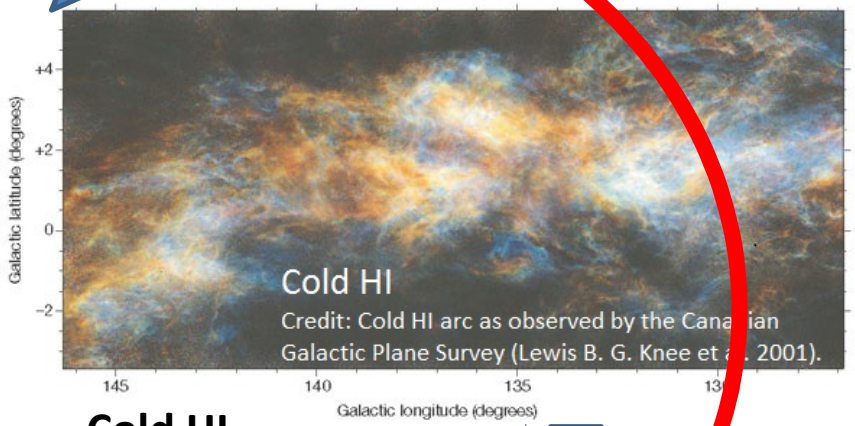
I'm studying this stage

Stars

Planetary Nebula

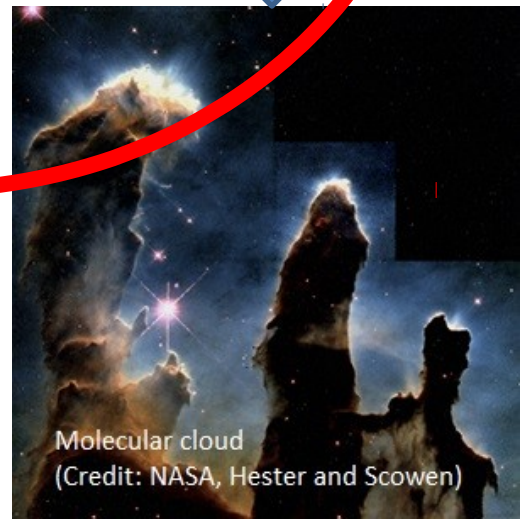


Diffuse gas



Cold HI

Molecular Cloud



Tracing the conversion from HI to H_2 through the "Dark" phase

“Dark Gas”

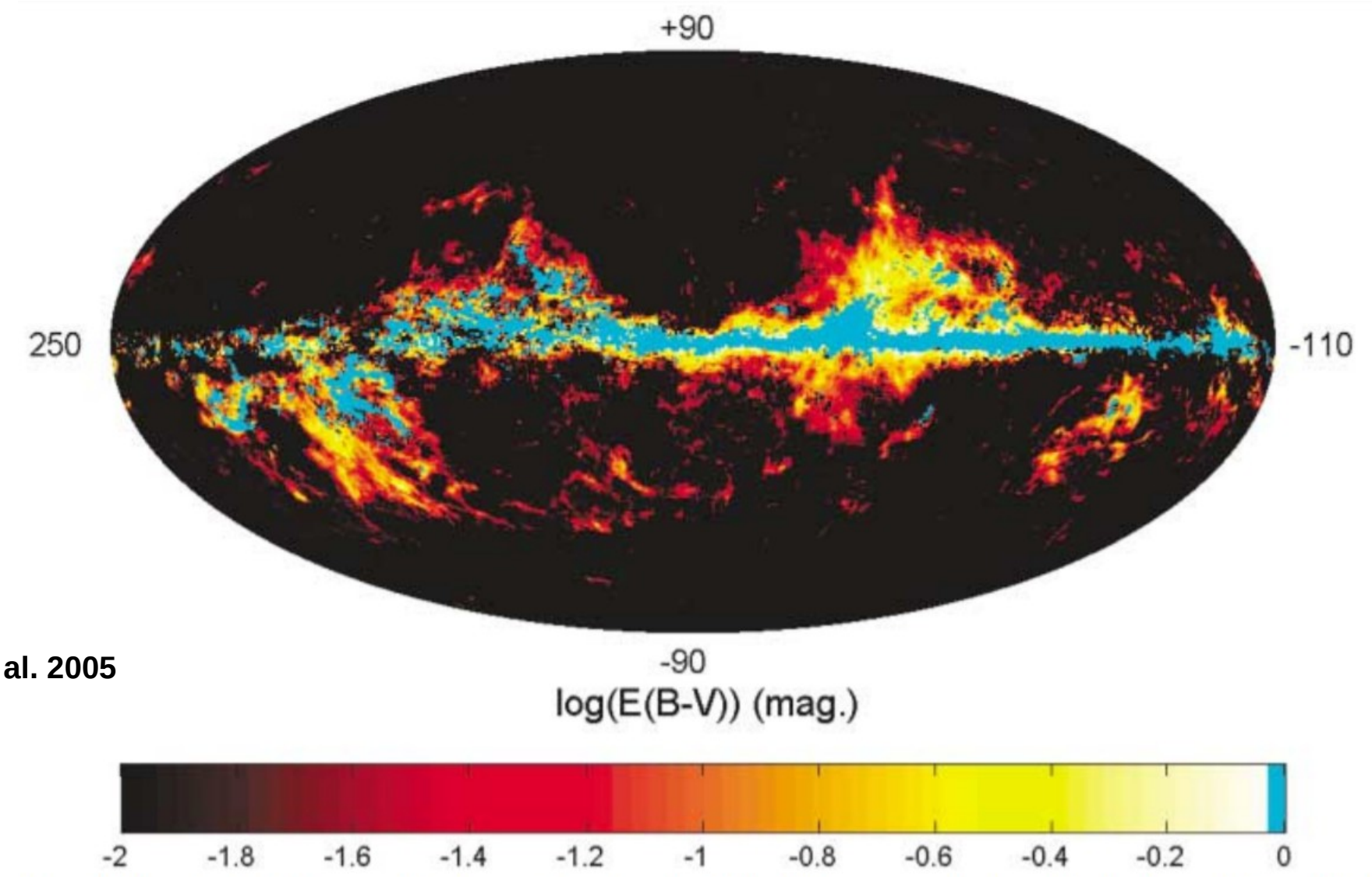
What is “Dark gas”?

Gas component **NOT** detected by traditional radio emissions:

- Atomic hydrogen (HI 21cm line) and
- Carbon monoxide (CO) molecules (~2.6 mm lines)

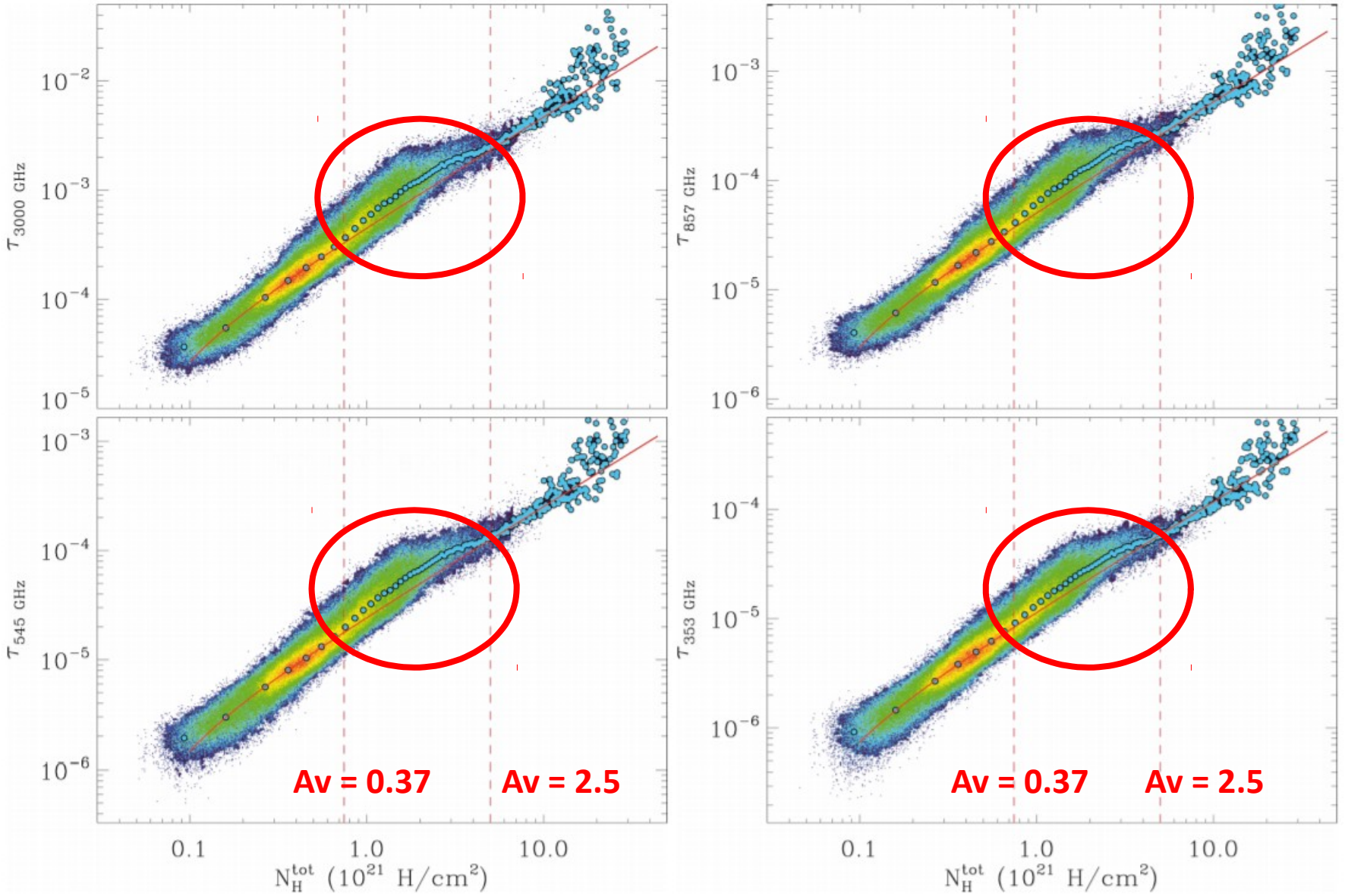
But can be seen from...

Excess of **Dust Reddening E(B-V)** found above the linear correlation with **N(H)**



Grenier et al. 2005

Fig. 1. Map, in Galactic coordinates centered on $l = 70°$, of the excess dust reddening found above that linearly correlated with the integrated HI and CO line intensities.



Excess of **Dust optical depth τ** above the linear correlation with **N(H)**

(Planck collaboration 2011).

“Dark Gas”

Where?

- In the Galactic plane

- In the Molecular clouds

- Else where?

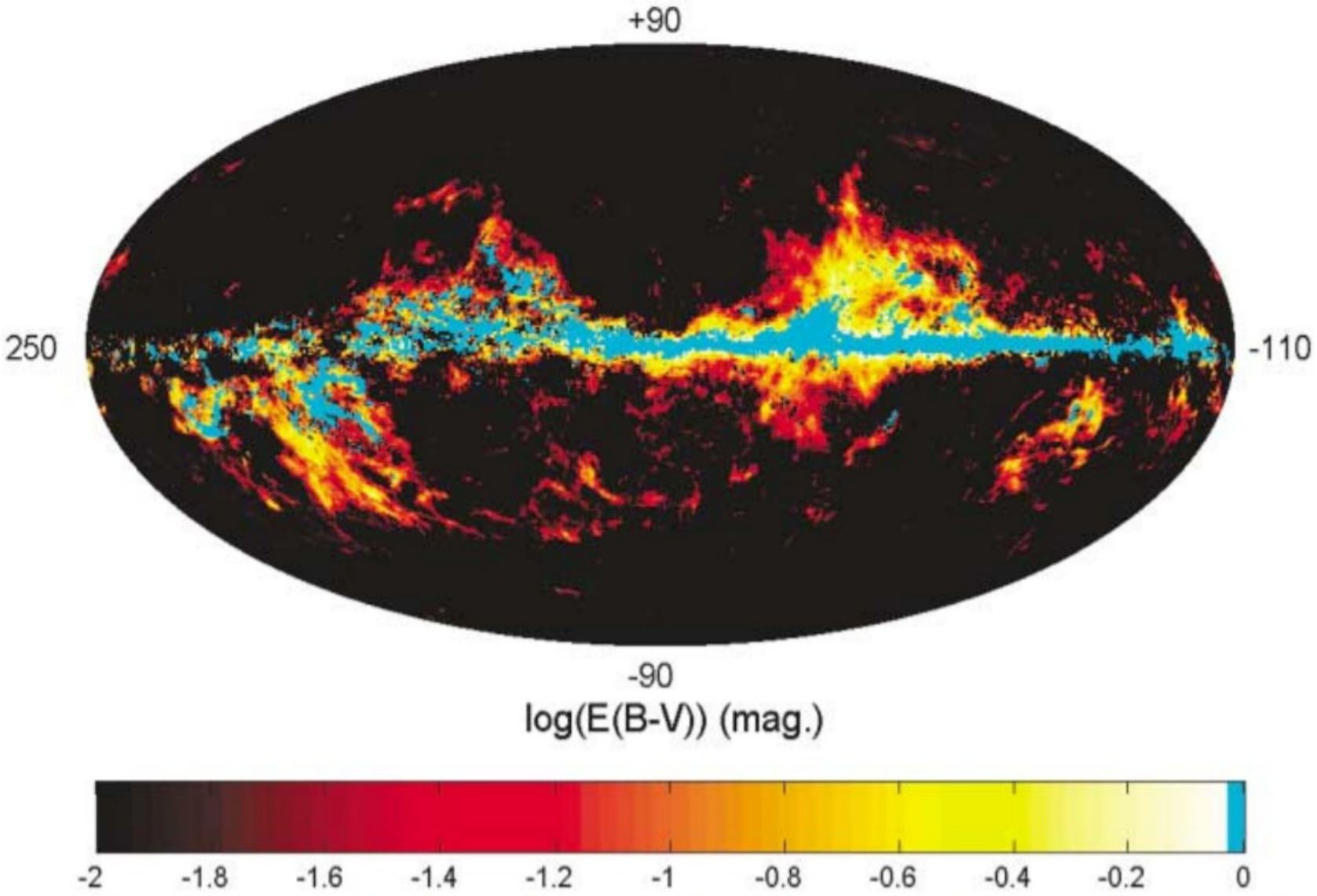


Fig. 1. Map, in Galactic coordinates centered on $l = 70°$, of the excess dust reddening found above that linearly correlated with the integrated HI and CO line intensities.

“Dark Gas”

How much?

20 - 50% of the measured mass of HI (Grenier et al. 2005, Planck collab. 2011)

Still poorly understood

Nature of “Dark Gas”?

- **Cold HI** (Fukui et al 2014) or
- **Molecular H_2** or **both** (Lee et al. 2015)?

Also poorly understood

Not much evidence for Dark Gas in my analysis

Data

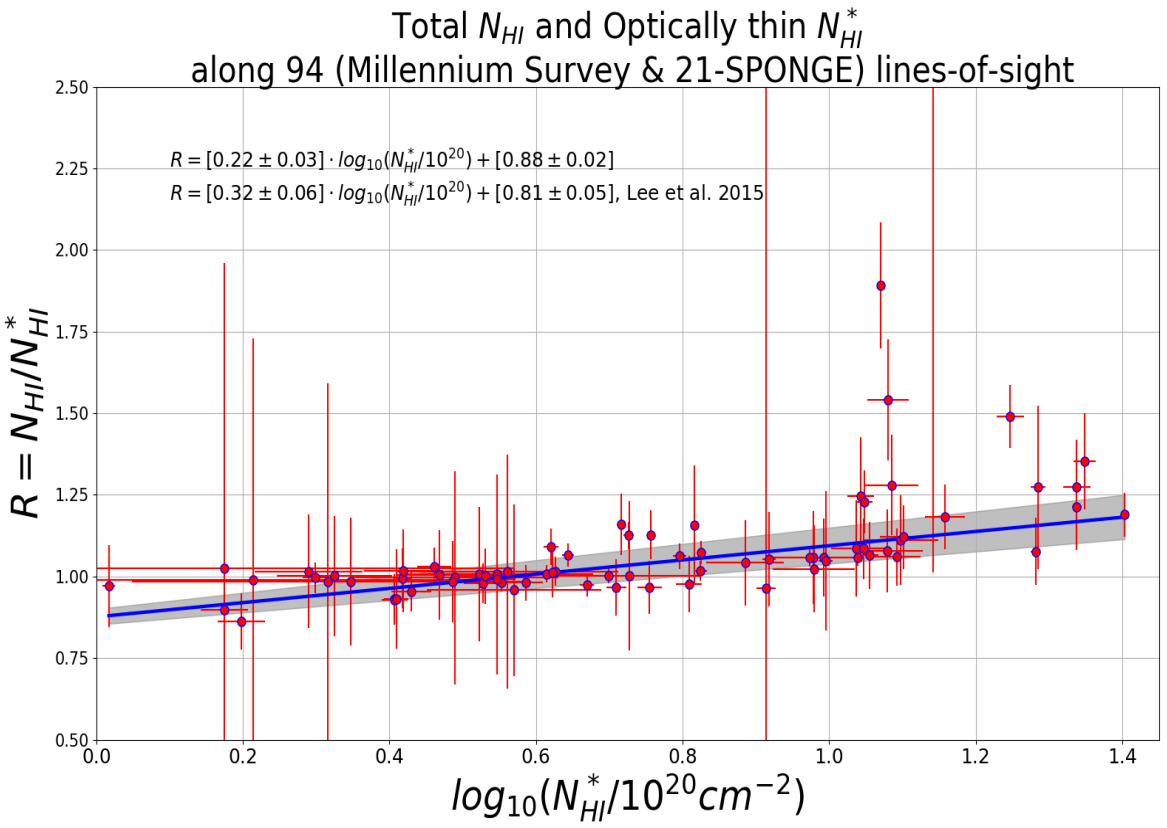
1. HI and OH:
Arecibo Telescope (Millennium Survey) and 21-SPONGE survey

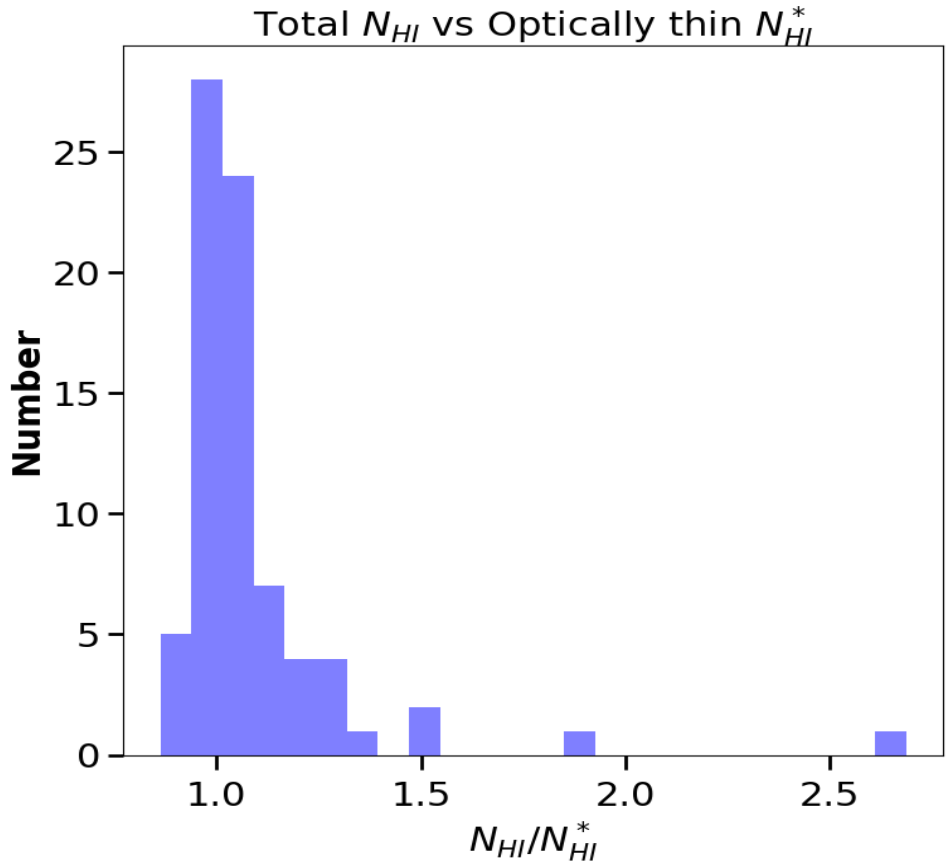
2. CO:
Delingha 14m telescope (China)

3. Dust optical depth τ_{353}, dust radiance *R*:
Planck data (Plack collaboration 2013)

4. Reddening E(B-V):
Sloan Digital Sky Survey Stellar Spectra (Schlafly et al. 2011)

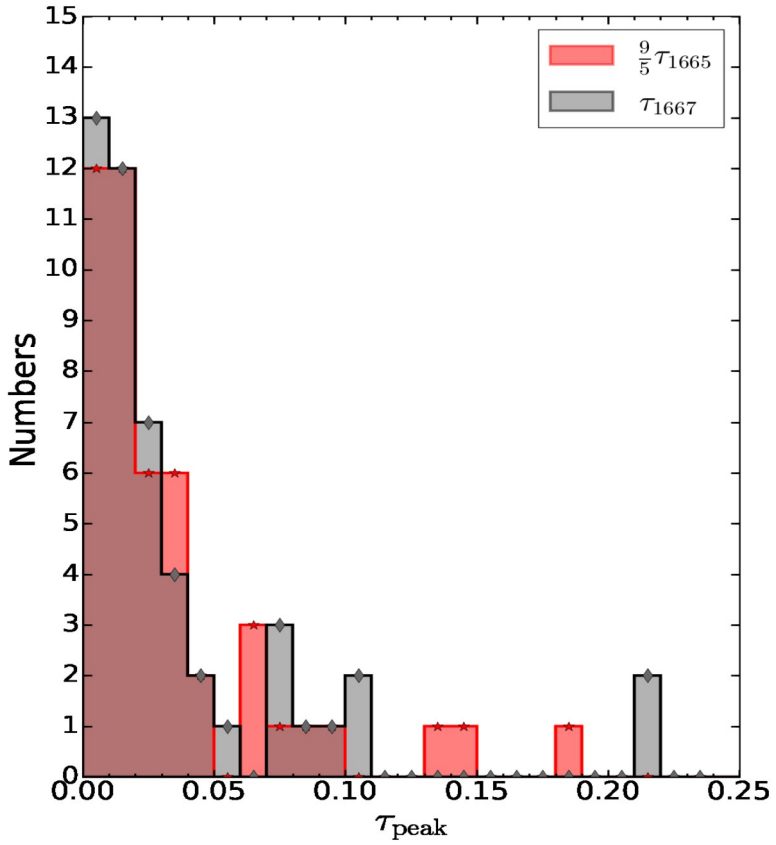
1. Results from HI data



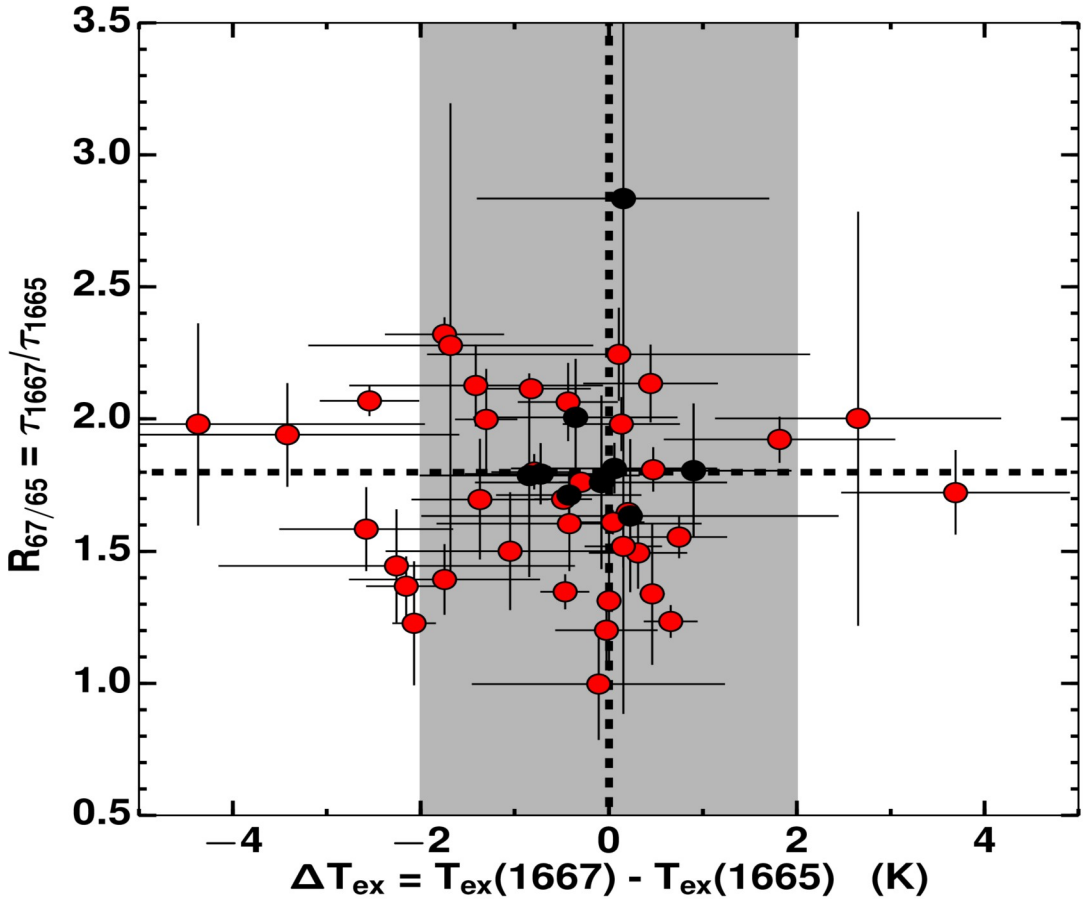


HI mass increases by ~10% compared to optically thin assumption.

2. Results from OH data



Main lines LTE conditions:
- Optical depth: τ_{1667}/τ_{1665} = 9/5
- Excitation temperature: Tex_{1667} = Tex_{1665}



Optical depth τ<0.25: OH main lines are optically thin

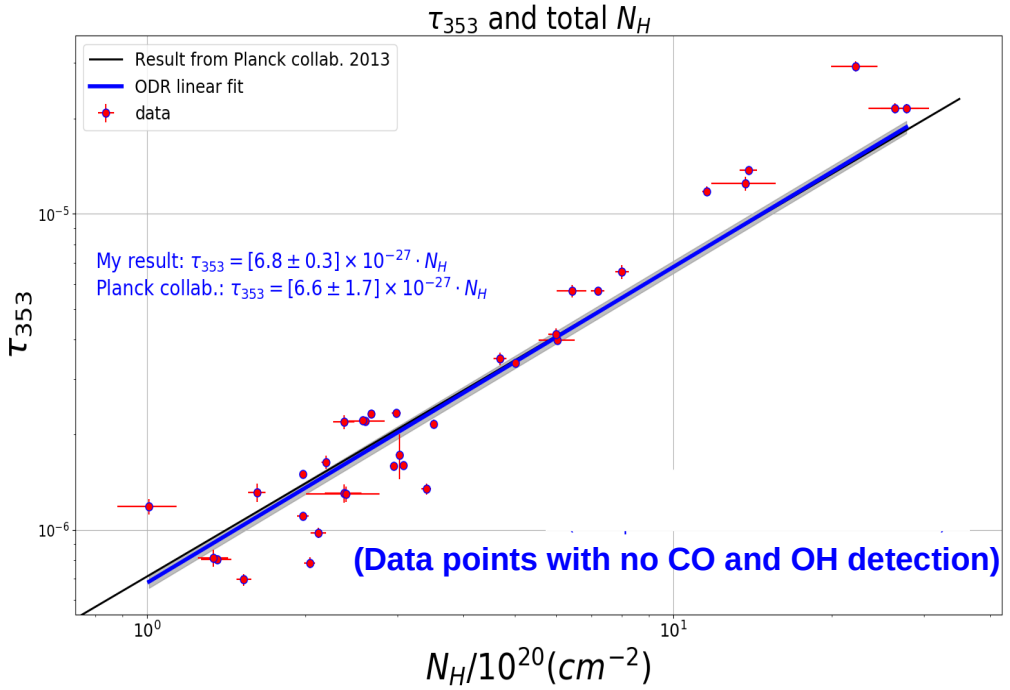
Only 9/48 OH components having:

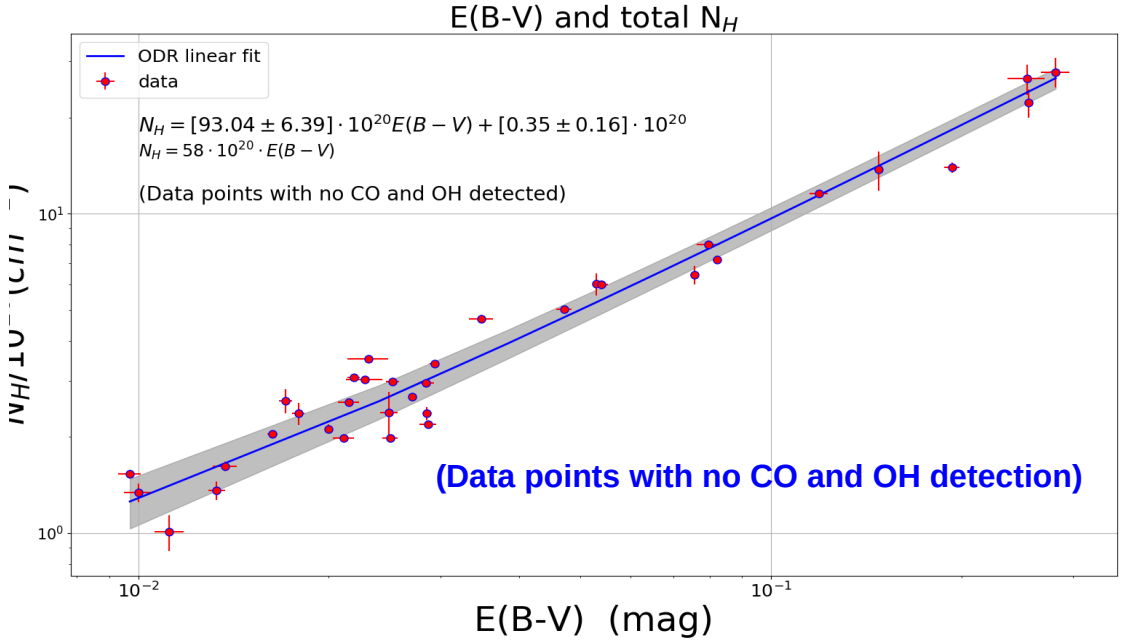
τ_{1667}/τ_{1665} = 9/5 (within the error-bar)

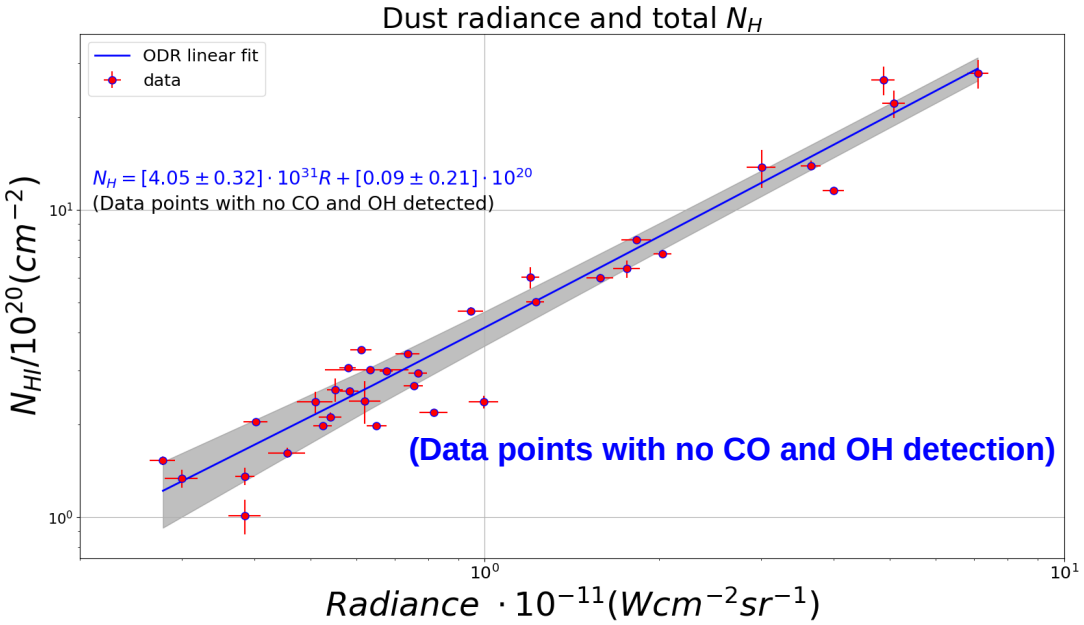
Tex_{1667} = Tex_{1665} (within the error-bar)

=> In general, OH main lines are not in LTE
(Dangerous to assume LTE)

3. Results from dust, CO and HI data







Linear correlations:

1) Dust optical depth τ and total N_H
2) Reddening *E(B-V)* and total N_H
3) Dust radiance *R* and total N_H

OH abundance ratio: $X_{OH} = N_{OH}/N_{H2}$

1) N_H derived from $\tau 353$, $E(B\text{-}V)$ and *Radiance*

2) $N_{H2} = \frac{1}{2}(N_H - N_{HI})$, N_{HI} *from Arecibo MS survey*

3) N_{OH} derived from Arecibo MS survey

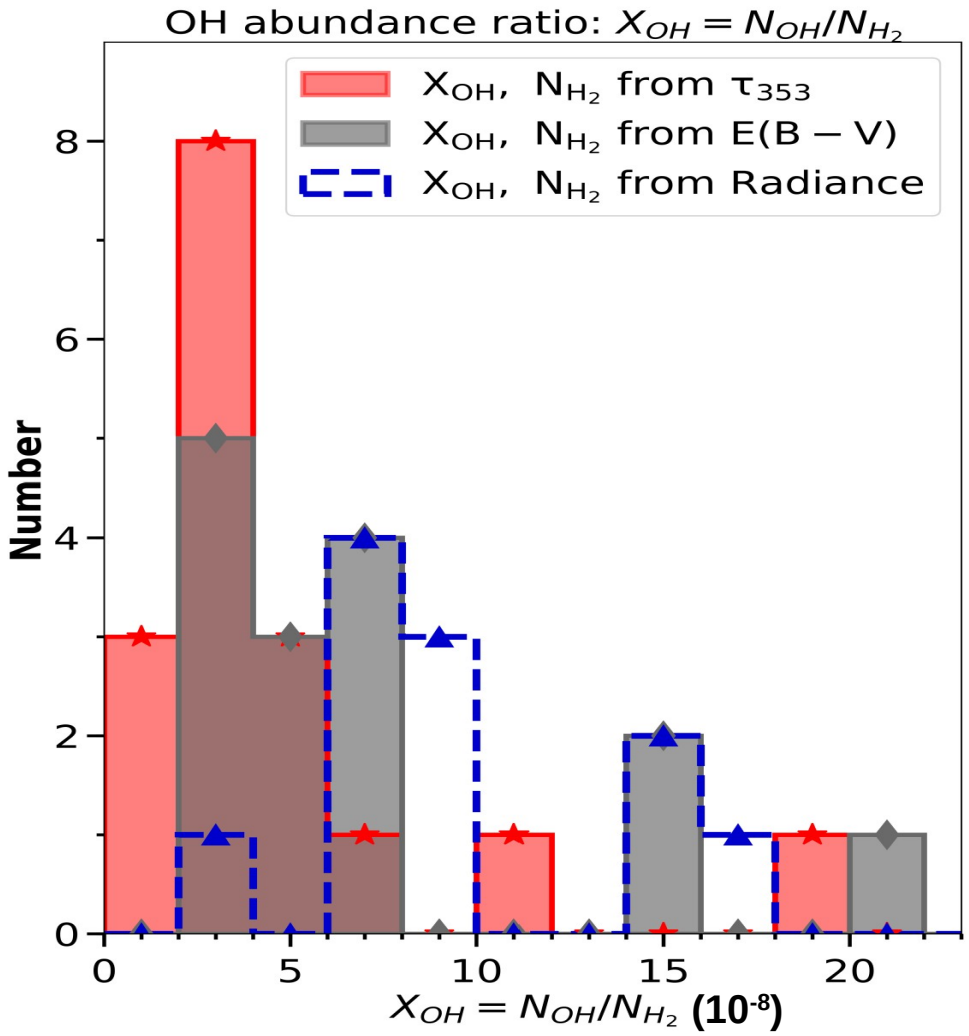
4) Then $X_{OH} = N_{OH}/N_{H2}$

OH abundance ratio from 3 different proxies of N_H are consistent:

$$X_{OH} \sim 5.0 \times 10^{-8}$$

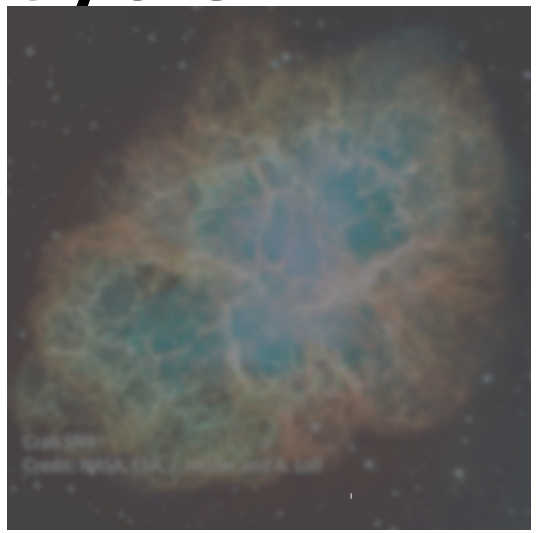
From Liszt et al. 1979:

$$X_{OH} \sim 10^{-7}$$



Thank you !

Star-gas-star Cycle



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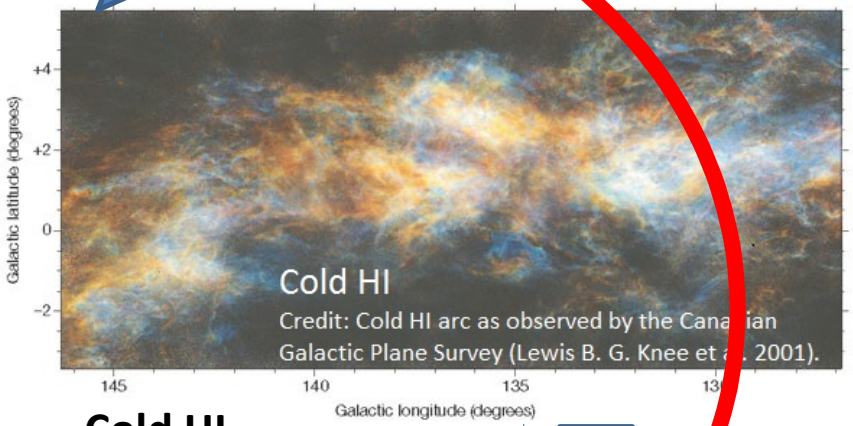
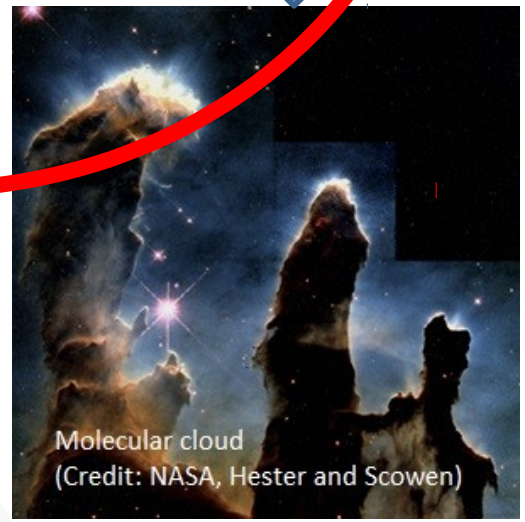


Cold HI

Molecular Cloud



Stars

Planetary Nebula