Galaxy evolution begins at home: GALFA, 21-SPONGE, and GASKAP

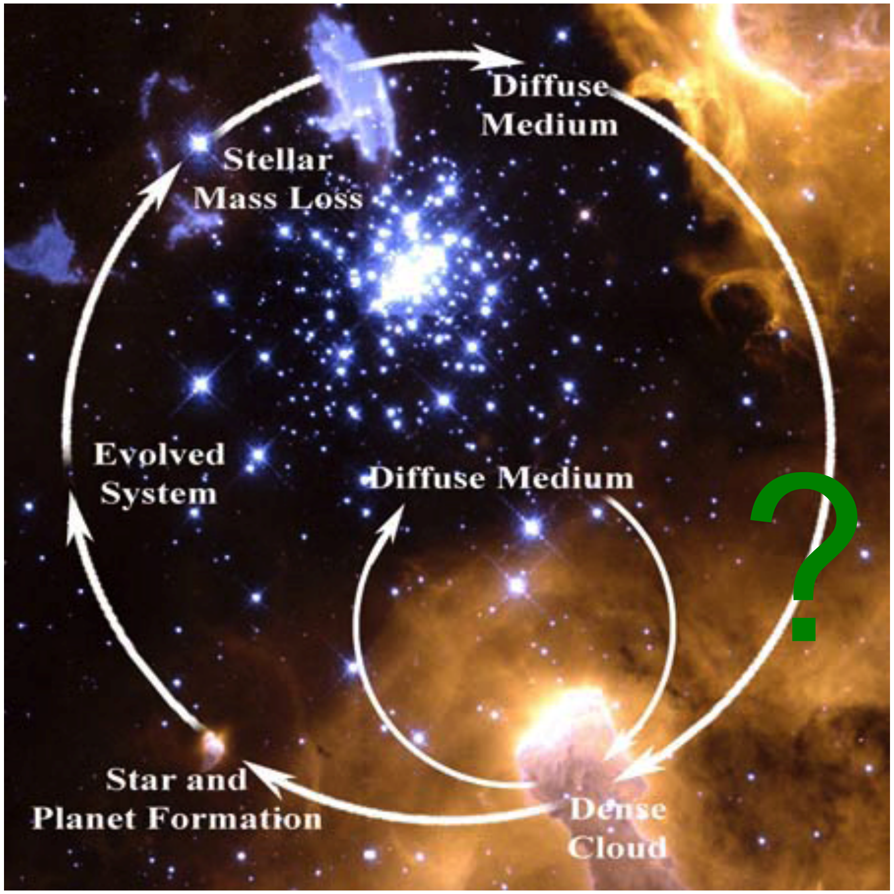
Snežana Stanimirović (UW Madison)

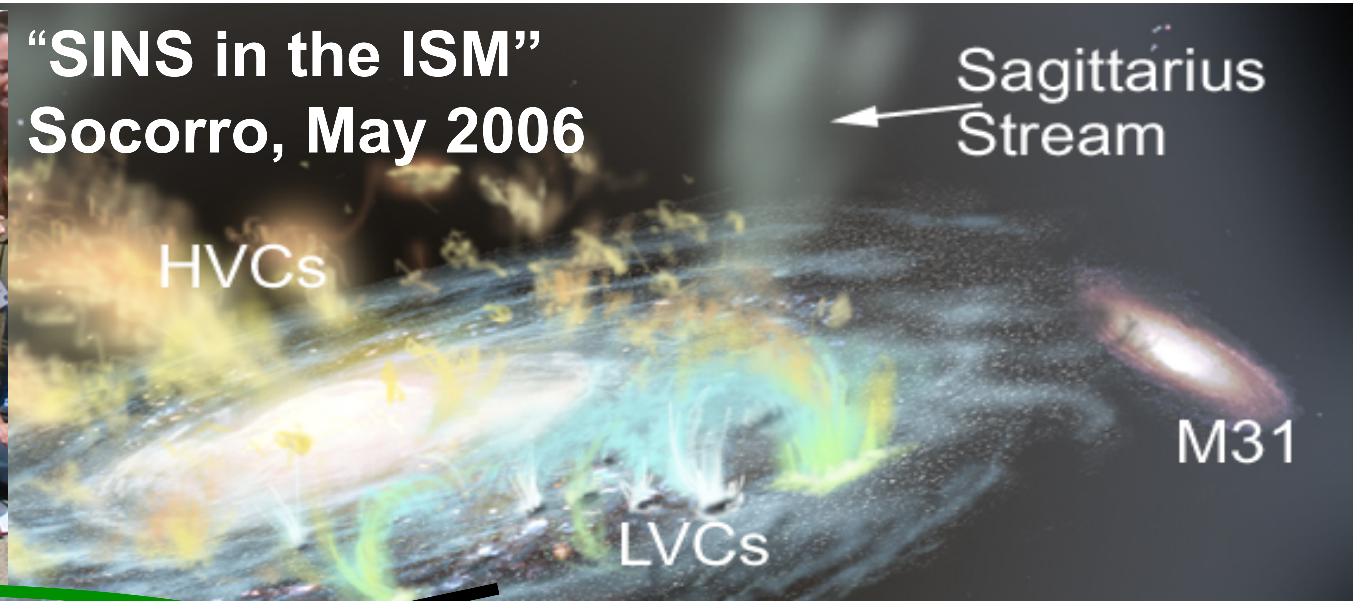
Diffuse interstellar gas = the 1st step in the star formation cycle in galaxies

Properties of the diffuse neutral medium?

ISM structure formation down to AU-scales?

Atomic-to-molecular conversion?



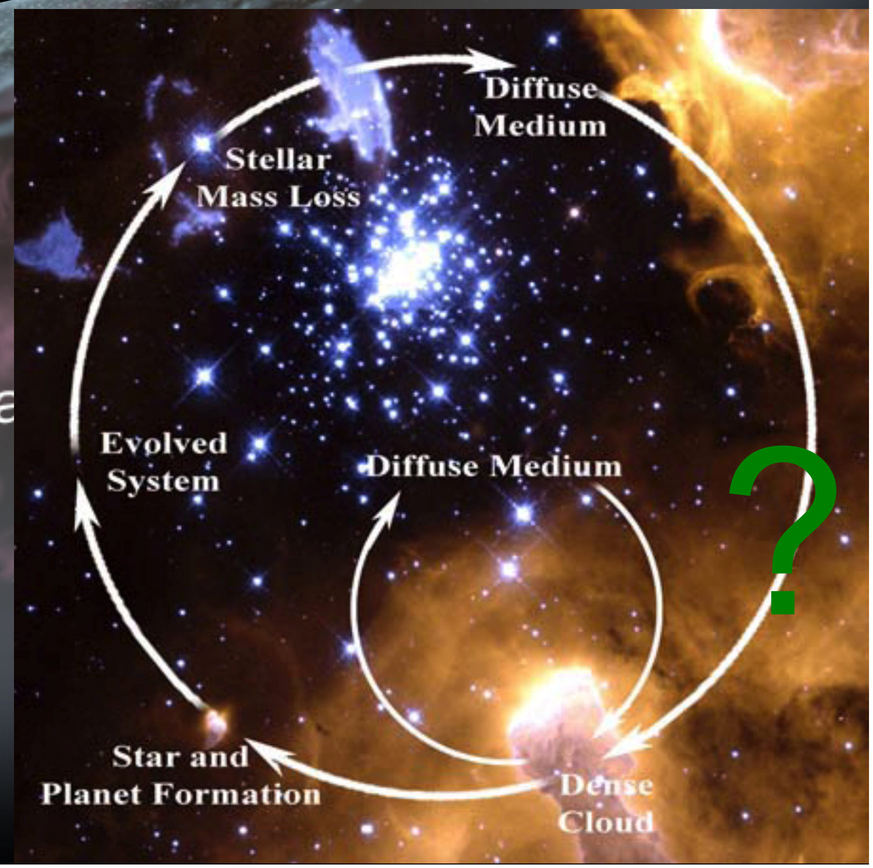


Properties of the diffuse neutral medium?

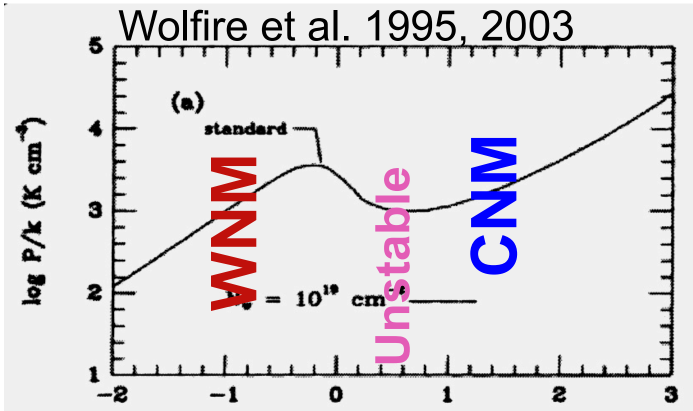
ISM structure formation down to AU-scales?

Atomic-to-molecular conversion?

Fraction & flavor of the accreted diffuse gas?



1. What are the basic physical properties of diffuse neutral clouds (e.g. T)?

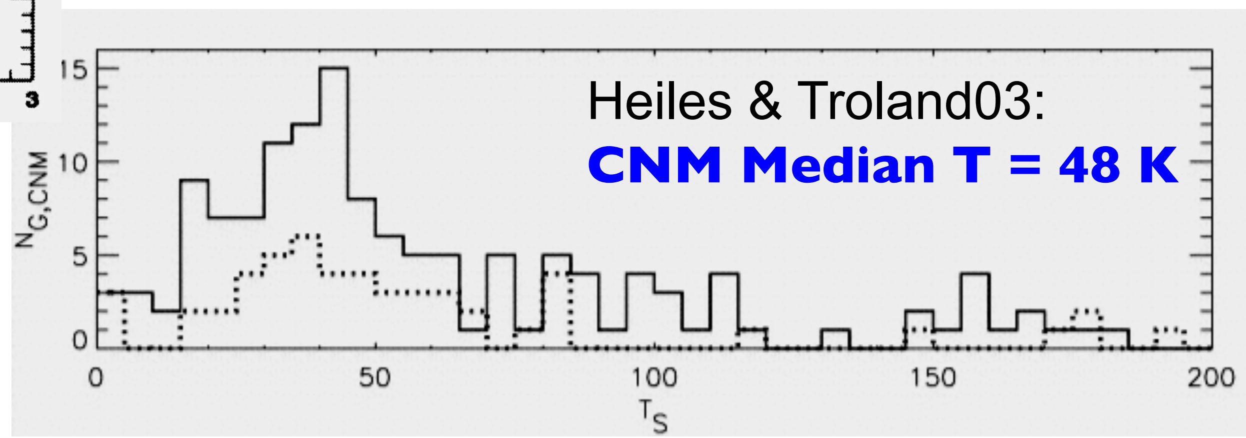


Theory: 2 stable phases.

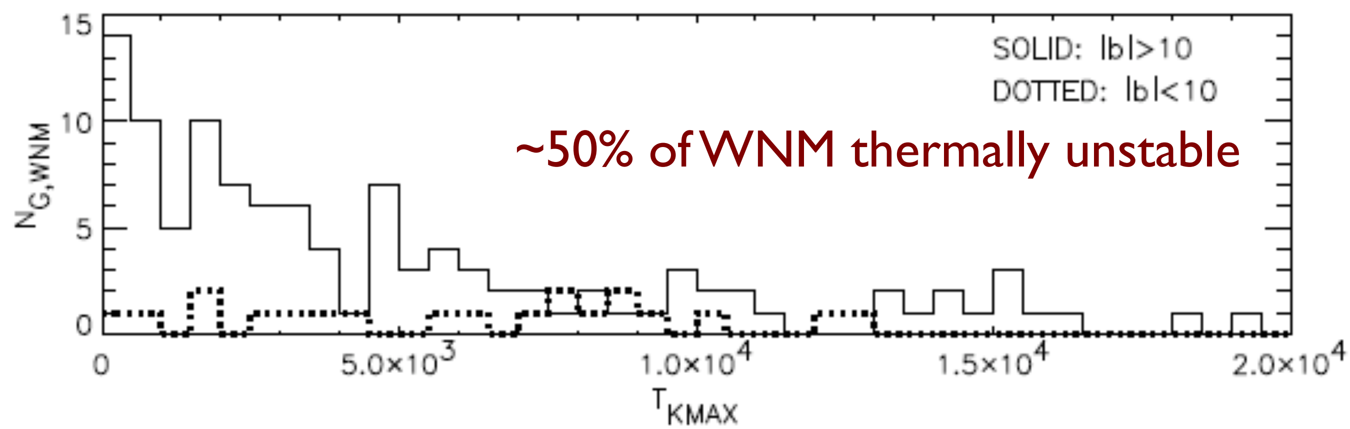
P/k ~ 1700 - 4400 cm^{-3} K

- WNM T ~ 8000 K
- CNM T ~ 50 K

Rad, Goss, Dickey + many others

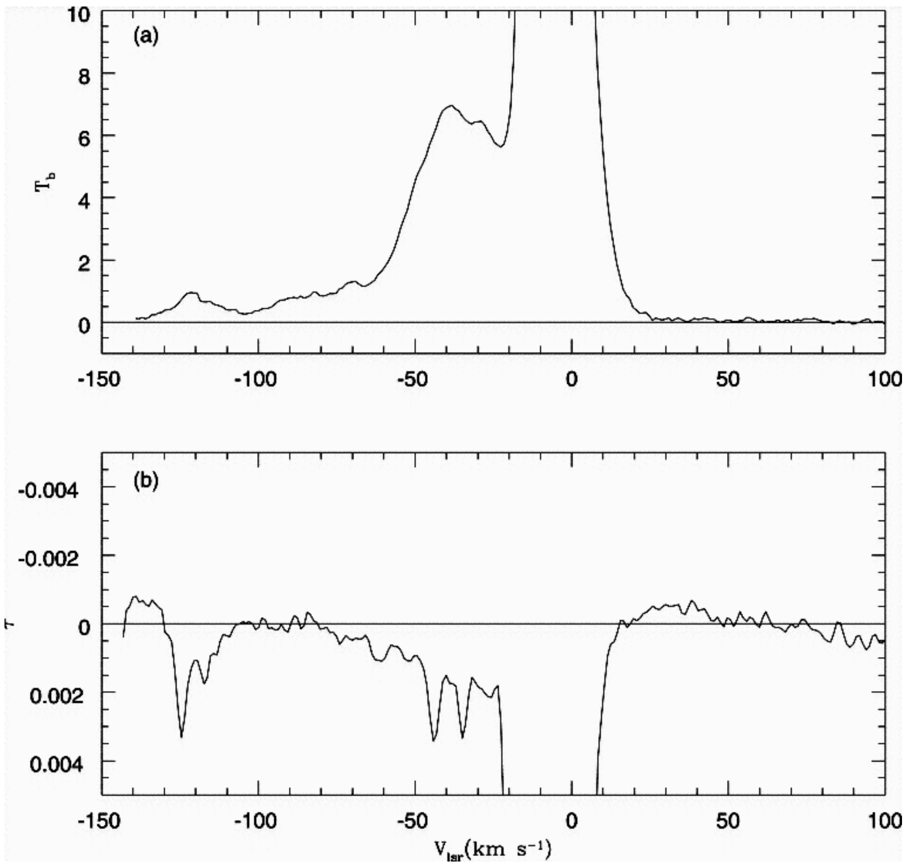


Fraction of thermally unstab
WNM controlled by:
turbulence,
star formation rate?



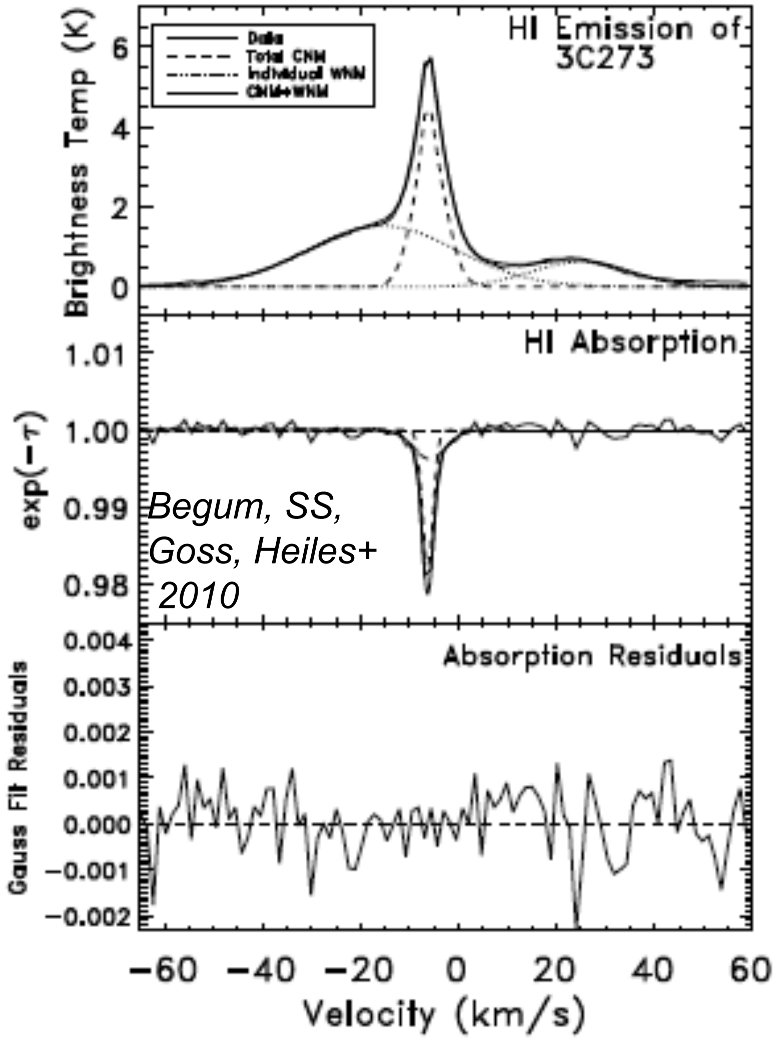
Max. Temperature of the Warm Neutral Medium [K]

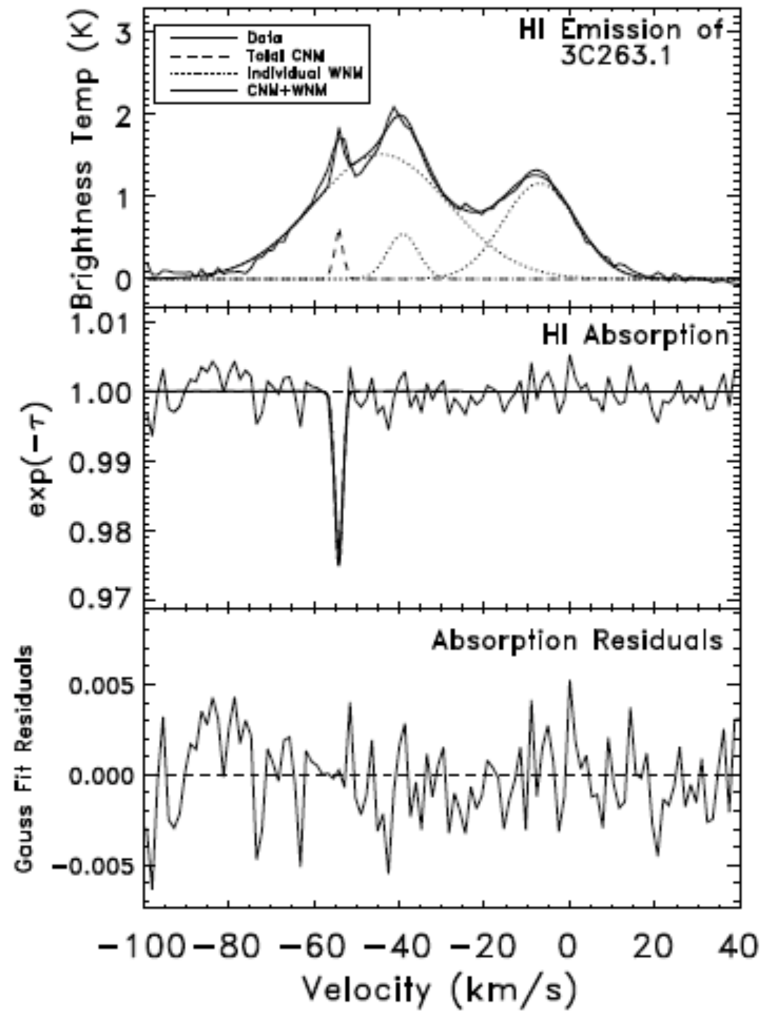
All direct measurements of T(WNM): peak optical depth <10^{-3}, very broad absorption lines



Carilli, Dwarakanath, Goss (1998): T = 6000 +/-1700 K, 4800 +/- 1600 K.
Dwarakanath, Carilli, Goss (2002): T = 3600 +/- 360 K
Kanekar et al. (2003): T = 3127 +/- 300, 3694 +/- 1595, 3500 +/- 1354, 2165 +/- 608 K

Pilot EVLA absorption observations





- VLA ready for the first time to measure WNM in absorption with tau ~10^{-4} !

- Out of 11 detected absorption features: 2 WNM with Ts <1000 K [sen. to <3000 K]; rest CNM with Tk,max < 500 K

21-SPONGE: 21cm Spectral line Observations of Neutral Gas with the EVLA

Deep HI absorption observations with EVLA in the direction of 60 sources to search for WNM in absorption.

GASKAP:

~5000 HI absorption spectra with ASKAP to measure how CNM properties vary with interstellar environments (MW, LMC, SMC).

Also, OH emission!

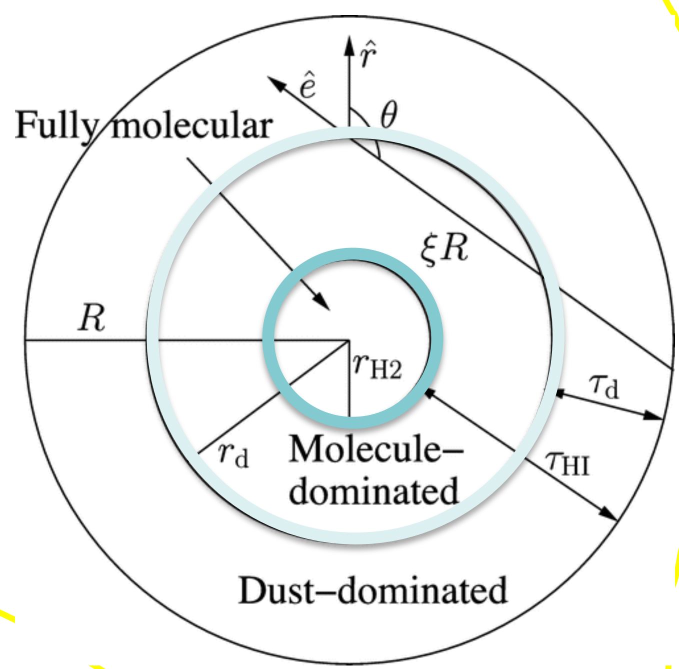
2. What physical processes control the H2 fraction?
What are the observed properties of the atomic-to-molecular transition regions?

Min-Young Lee (PhD student, UW), Rene Plume, Lewis Knee, Kevin Douglas +

GALFA-HI crew

[Mary Putman, Josh Peek, Destry Saul, Jana Grcevich (Columbia), Carl Heiles, Erik Korpela (UCB), Ayesha Begum (UW), Steven Gibson (Western Kentucky)]

Analytical Modelling of the Atomic-to-Molecular transition (Krumholz et al. 2008, 2009)



3D Cloud of finite size embedded in an isotropic radiation field (KMT08)

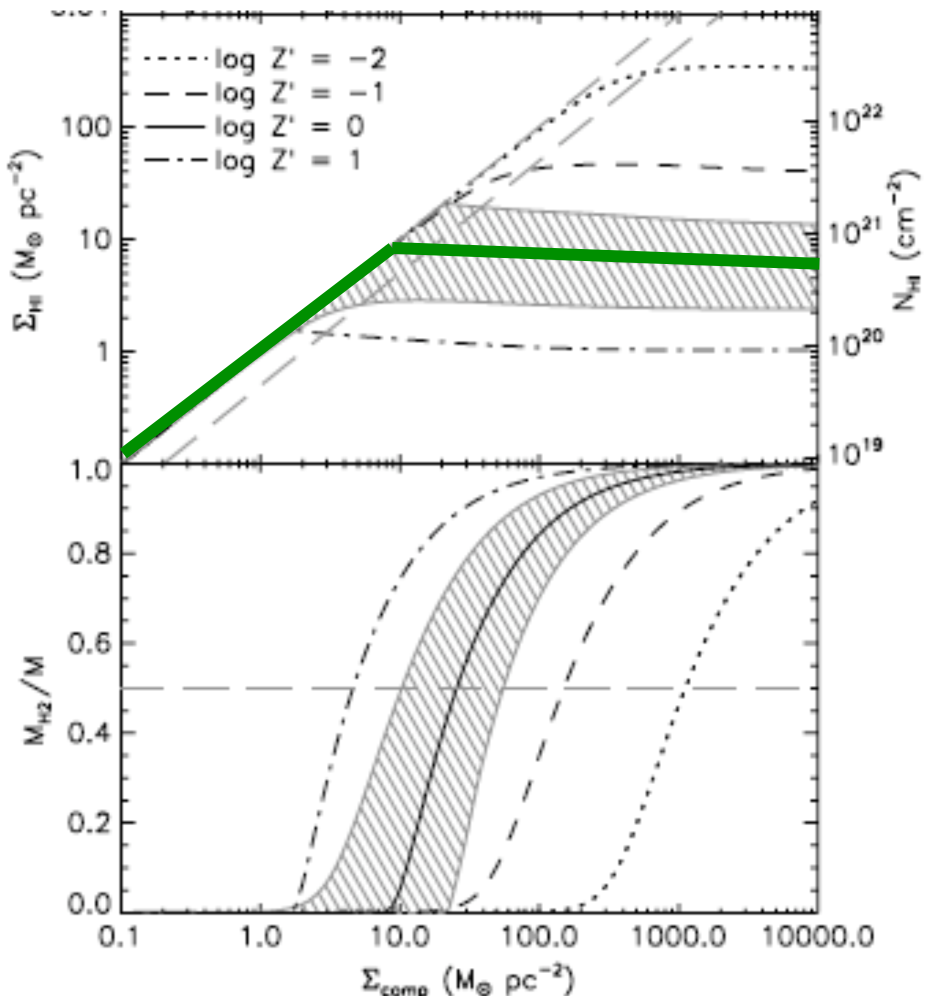
- Motivation = simulate realistic galaxies + turbulent chemistry

- Spherical 3D cloud exposed to an *external* ISRF
- H_2 formation = H_2 photodissociation

- H_2 is formed in the CNM
- CNM and WNM in pressure equilibrium →
- n(CNM) = Φ(CNM) x n_{min}(CNM)
- n_{min}(CNM) depends on metallicity and ISRF

•Approximations:
- Atomic-to-molecular transition as a thin shell
- To solve the transfer-dissociation equation use a 2-zone approximation: molecule vs dust-dominated PDR

Also Ostriker+10, Mac Low & Glover 10



Predictions:

- The location of the atomic-to-molecular transition depends on the photon competition btw dust grains and H_2

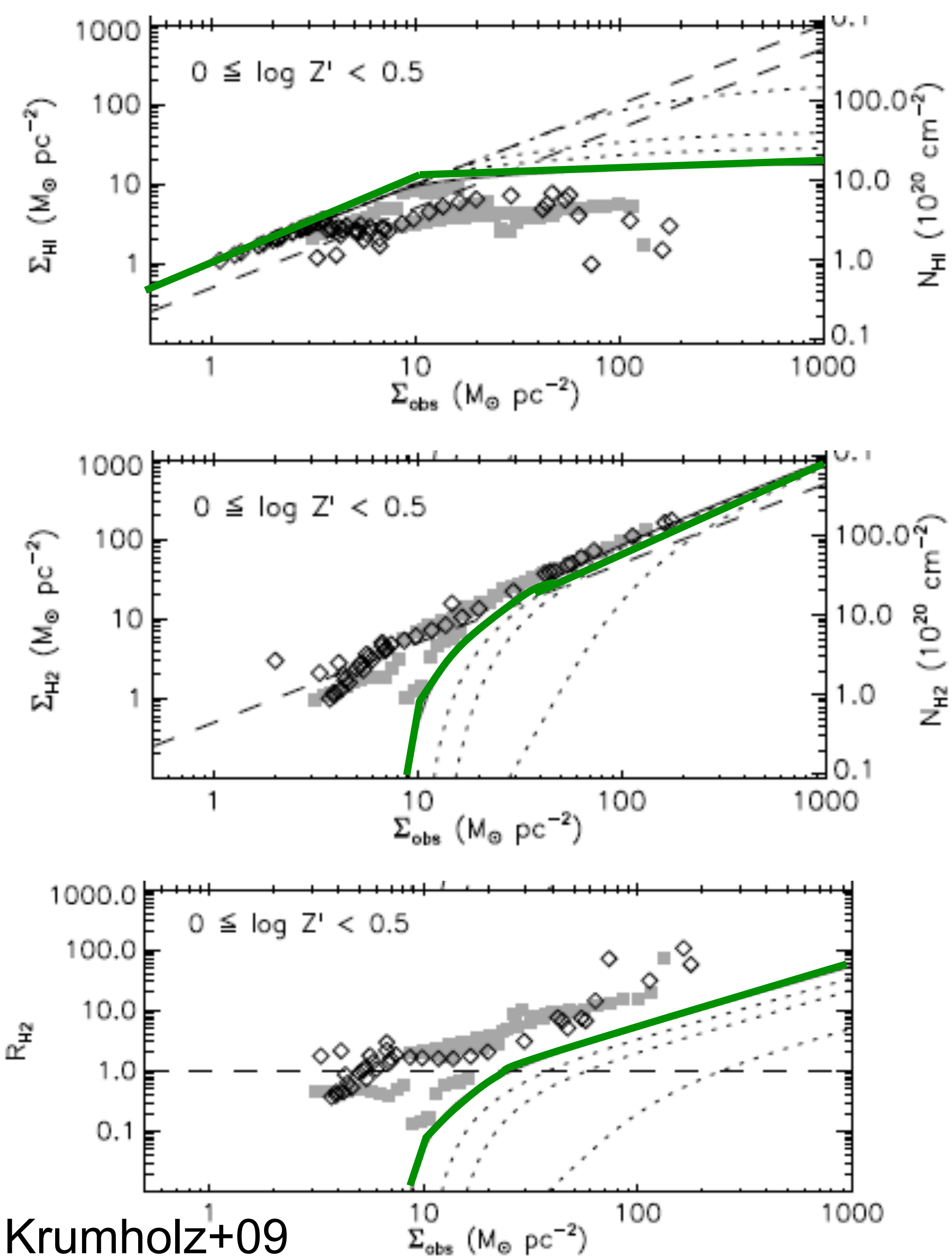
(A)In the MW, about 10 $M_\odot pc^{-2}$ of HI is needed to shield H_2 from photodissociation.

(B) The ratio of molecular-to-atomic gas in galaxies is primarily determined by the gas surface density, secondarily by metallicity, and does not depend on the ISRF.

$$\Sigma_{H2}/\Sigma_{HI} = R_{H_2} = \left[1 + \left(\frac{s}{11}\right)^3 + \left(\frac{125+s}{96+s}\right)^3\right]^{1/3} - 1$$

$$s = \frac{\Sigma_{comp,0} Z'}{\psi}$$

Testing predictions on kpc scales



Krumholz+09

Galaxy samples from Blitz & Rosolowski 04, Leroy+08

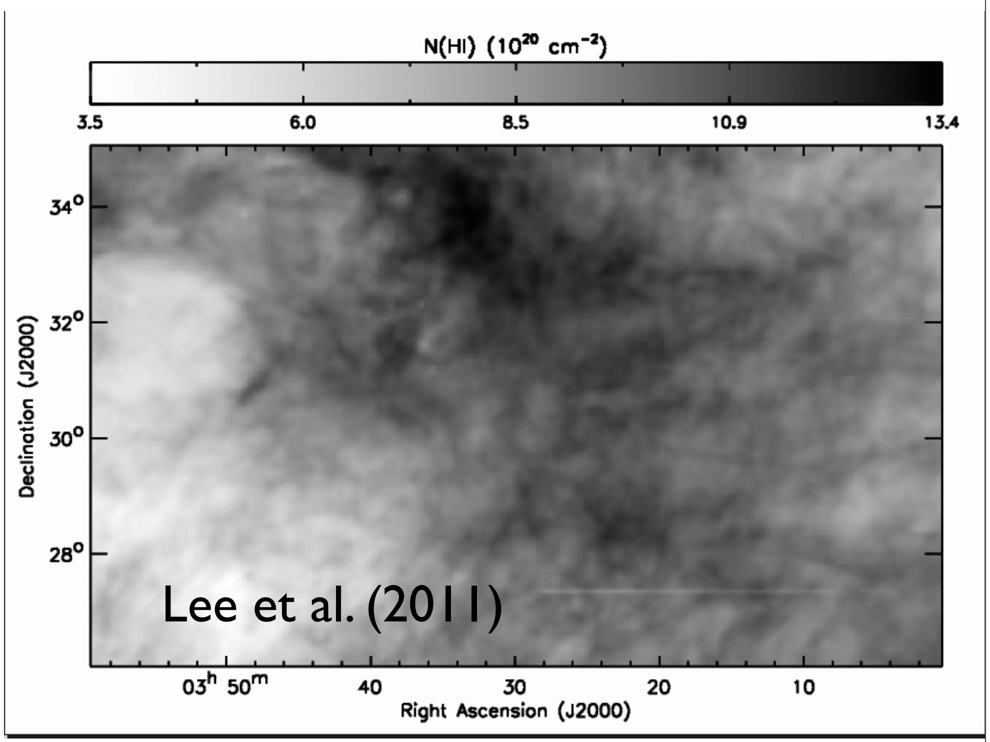
Green = model prediction for the upper/lower envelope of HI, H_2, R_{H2}.

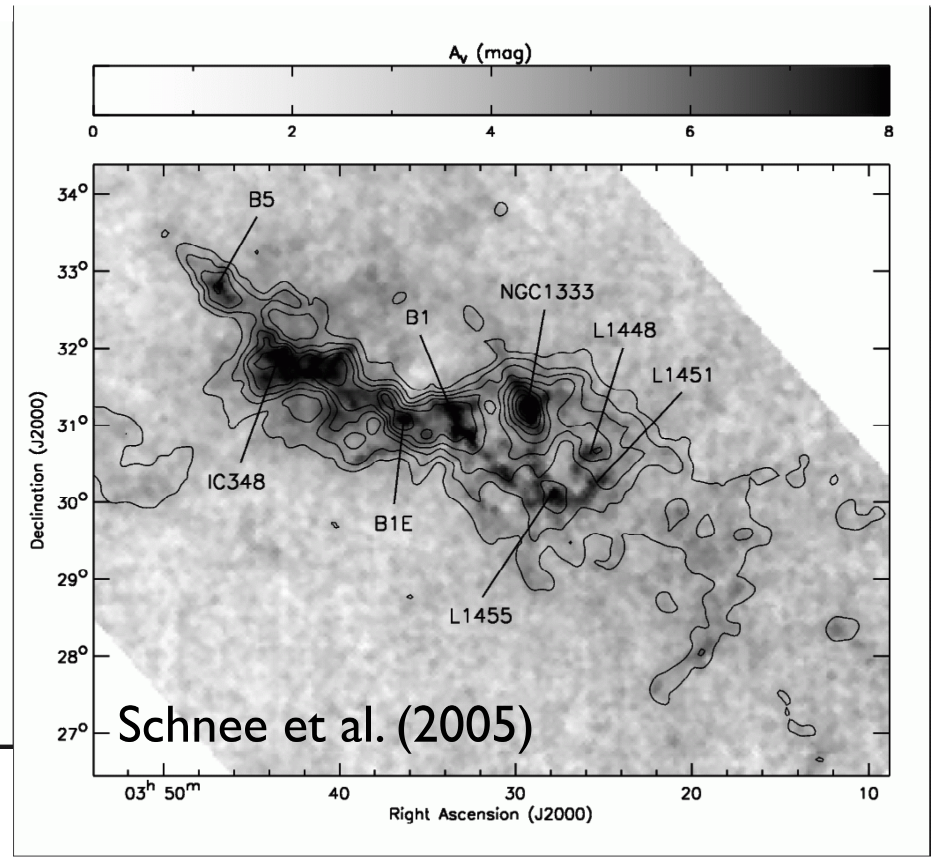
Good agreement, even for varying metallicity.

$R_{H2} = \Sigma_{H2} / \Sigma_{HI}$ for Perseus

(D = 200 – 350 pc → l < 1 pc)

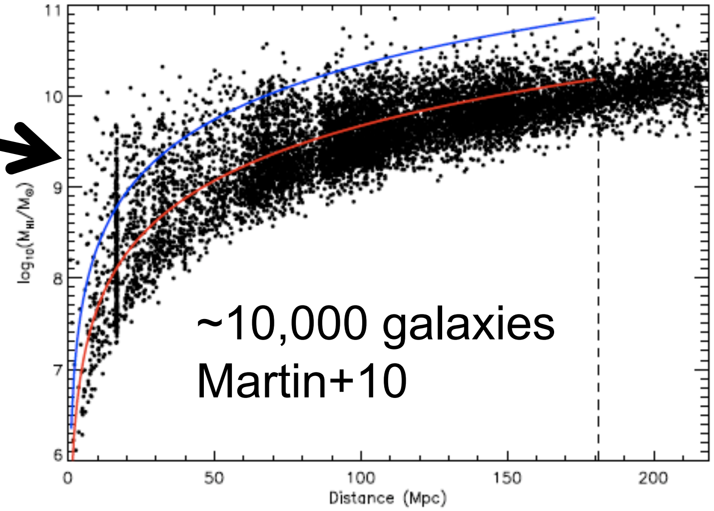
- Σ_{HI} : **GALFA-H I** to reach cloud outskirts
- Σ_{H2} : derived using IRIS 60, 100 μm maps, 2MASS A_V map
  [Schlegel et al. T_{dust} map for calibration]





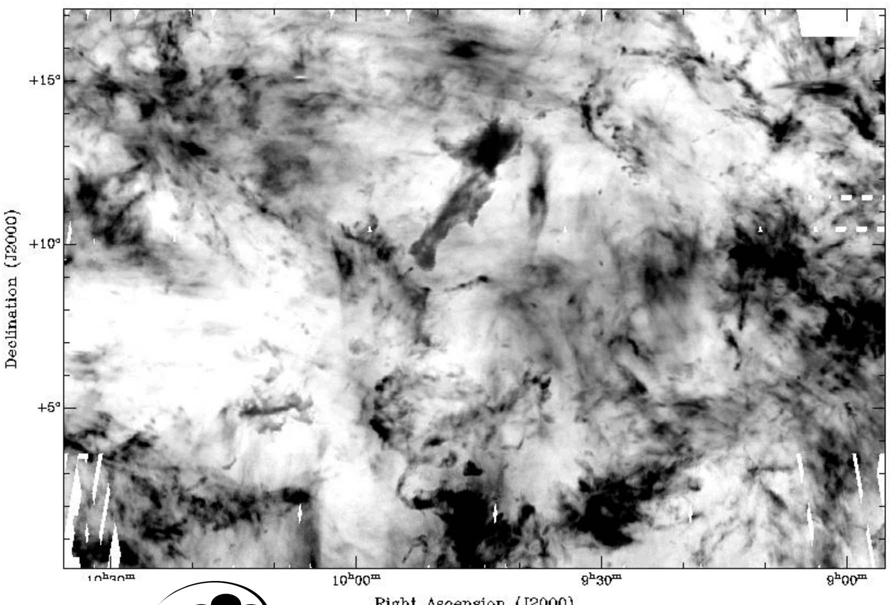
ALFA = Arecibo L-band Feed Array

GALFA-HI = Galactic Science with ALFA

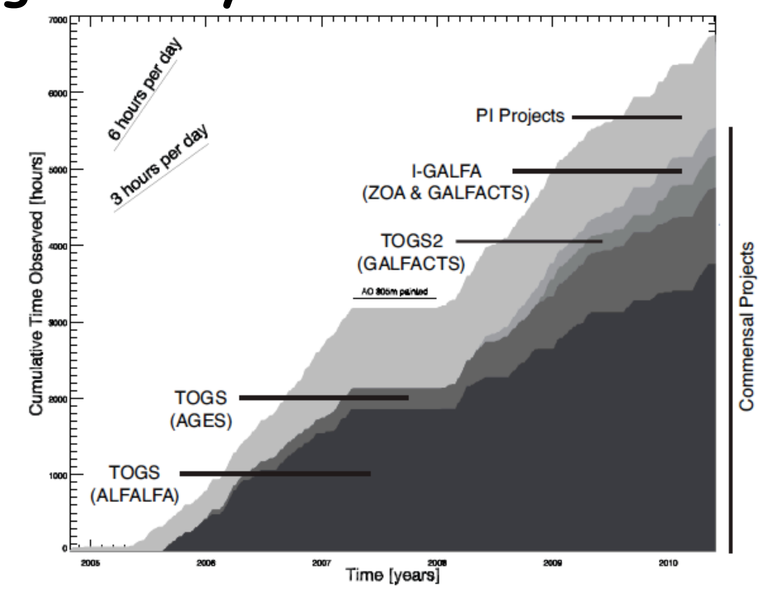


- 12,734 deg^2 @ 3.5’, Δv=0.2 km/s, ΔS~0.08K
- LDS: whole sky @ 36’, Δv=1 km/s, ΔS~0.1K
- Data release: Peek+10

A new way of running large surveys: commensal observing



GALFA-HI



Peek+10

$R_{H2} = \Sigma_{H2} / \Sigma_{HI}$ for Perseus

(D = 200 – 350 pc → l < 1 pc)

- Σ_{HI} : **GALFA-H I**
- Σ_{H2} : derived using IRIS 60, 100 μm maps, 2MASS A_V map [Schlegel et al. T_{dust} map for calibration]

$$\frac{f \times I_{60}}{I_{100}} = \left(\frac{60}{100}\right)^{-(3+\beta)} \frac{\exp(hc/\lambda_{100}kT_{\rm dust})}{\exp(hc/\lambda_{60}kT_{\rm dust})}$$

Calibration to Schlegel et al. T_{dust} map

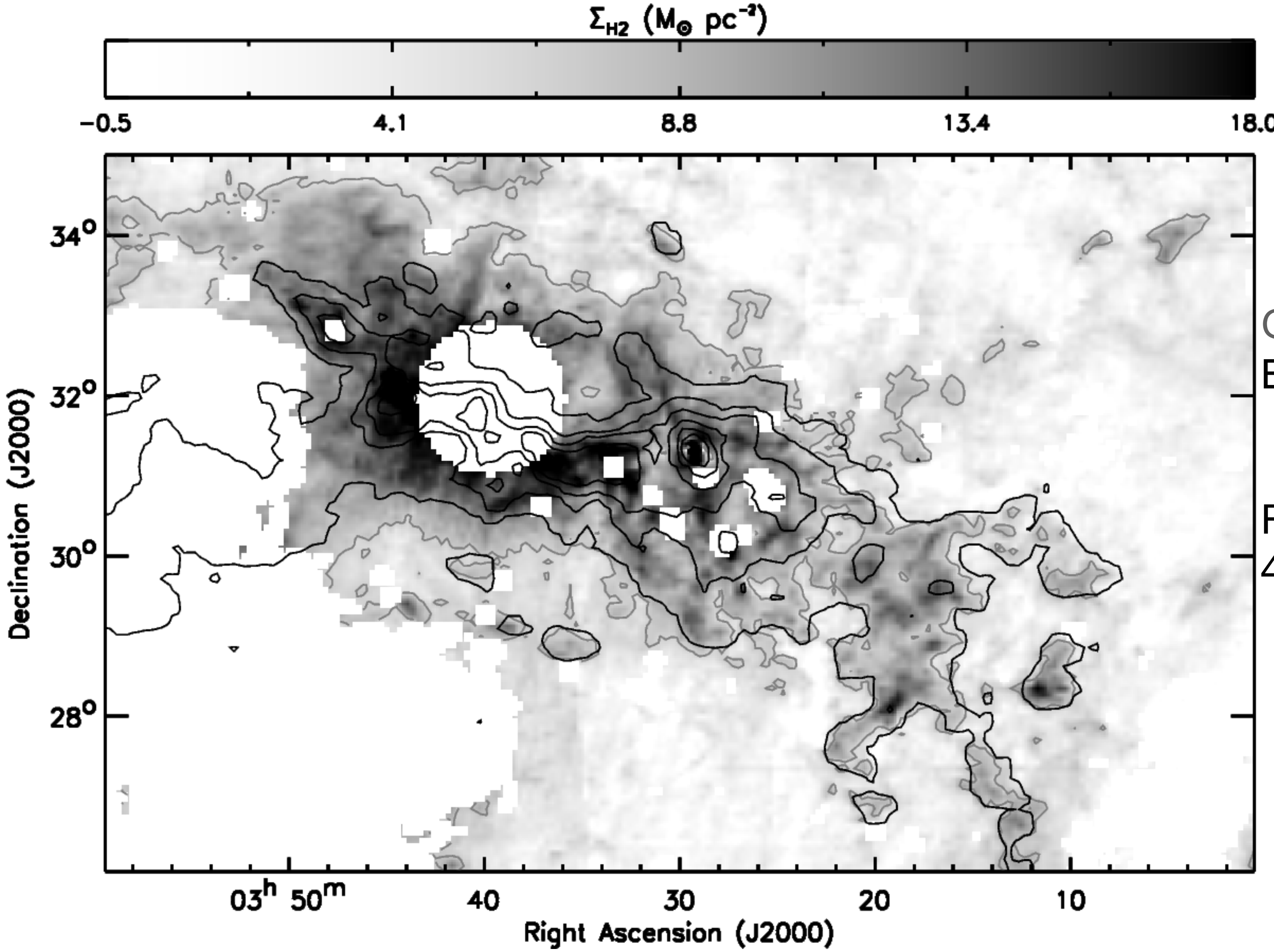
$$\tau_{100} = \frac{I_{100}}{B(T_{\rm dust},\ 100\ \mu{\rm m})}$$

$$A_V = X\tau_{100}$$

Calibration to 2MASS A_V map

$$N({\rm H_2}) = \frac{1}{2}\left(\frac{A_V}{\rm DGR} - N({\rm HI})\right)$$

Result: H_2 distribution across Perseus



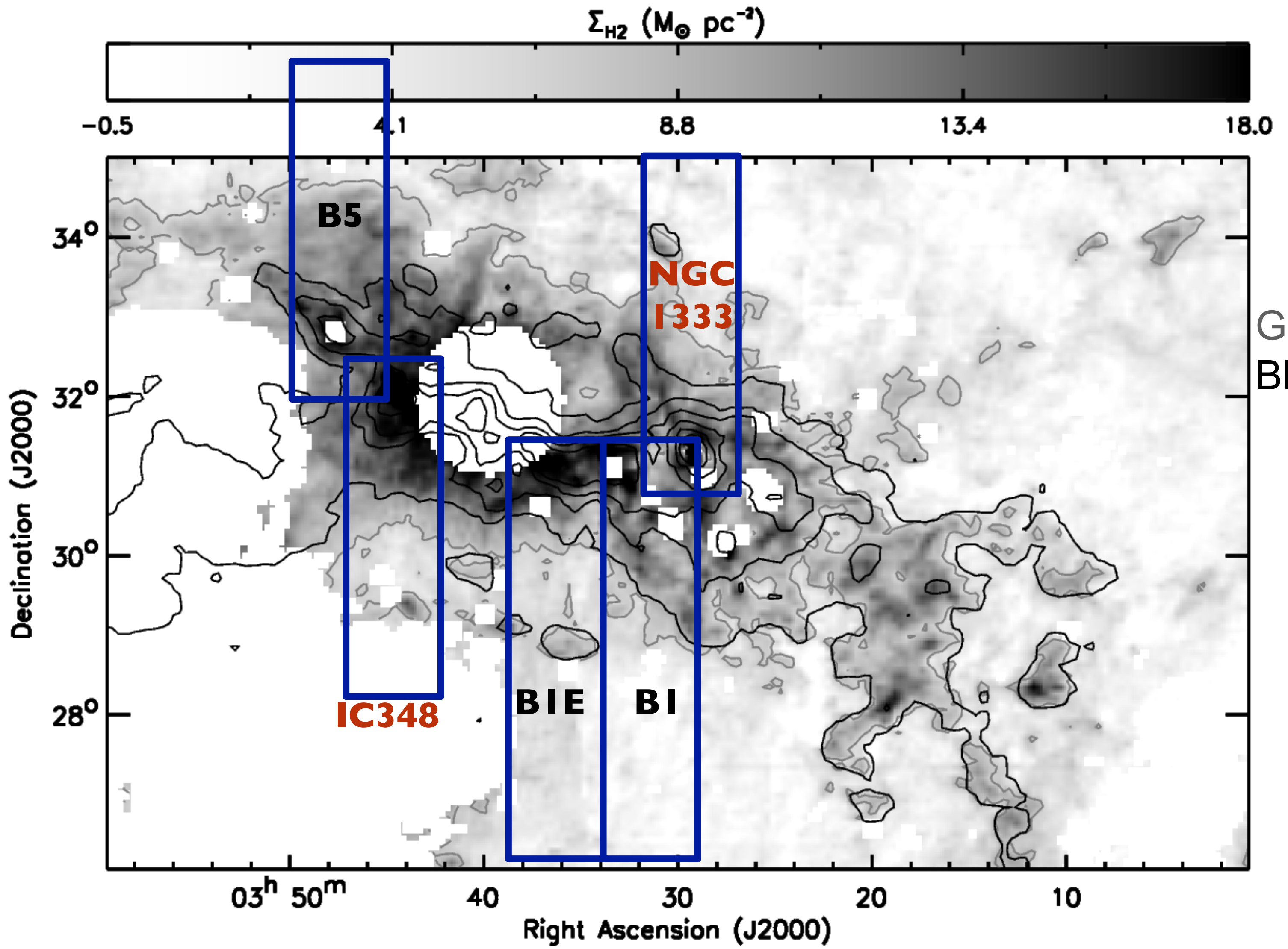
Grey: H2
Black: CfA CO

Resolution: 4.3' or 0.4pc

DGR

5 x 10^{-22} mag cm^2 **10 x 10^{-22}** 15 x 10^{-22} mag cm^2

Result: H_2 distribution across Perseus



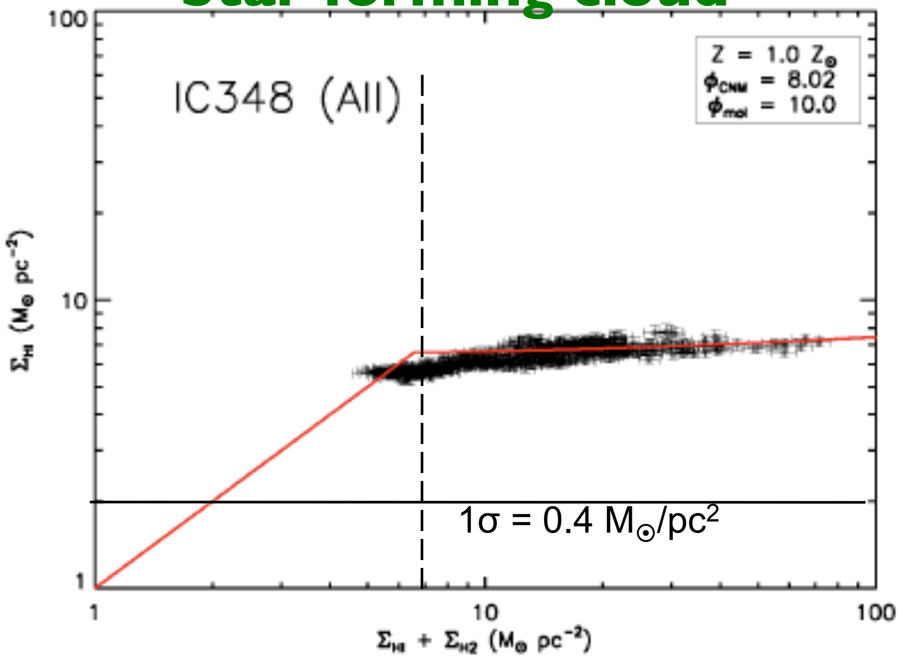
Grey: H2
Black: CfA CO

DGR

5 x 10^{-22} mag cm^2 **10 x 10^{-22}** 15 x 10^{-22} mag cm^2

Σ_{HI} vs. $\Sigma_{HI + H2}$

Star forming cloud



Very narrow range of N(HI).

Evidence for saturation at 6-8 $M_{\odot} pc^{-2}$

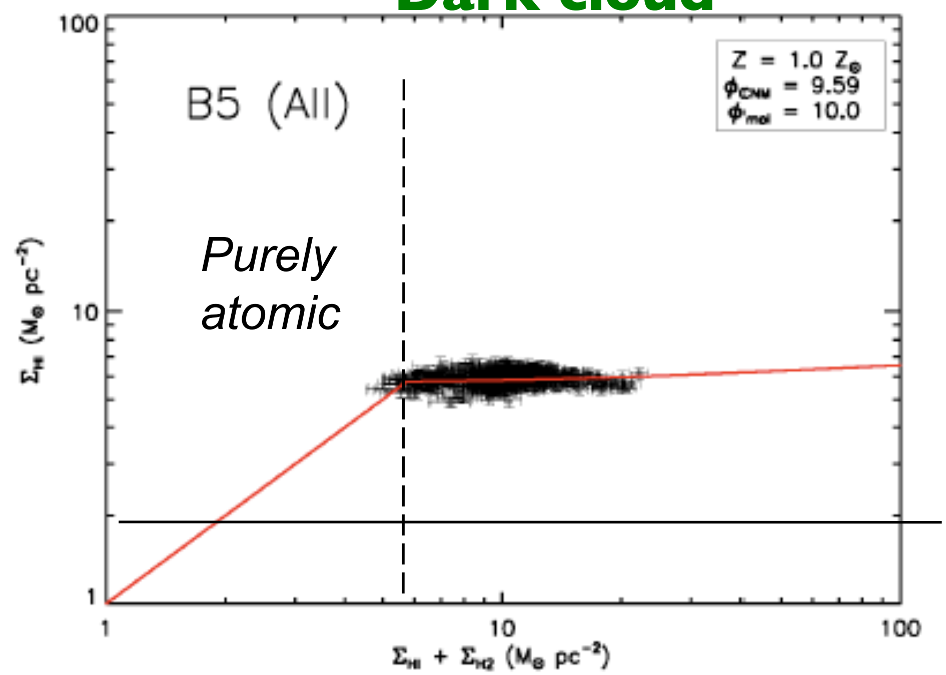
Prediction for 1.0 $Z_{\odot}$ ~ 10 $M_{\odot}$ pc^{-2}

Consistent with the model!

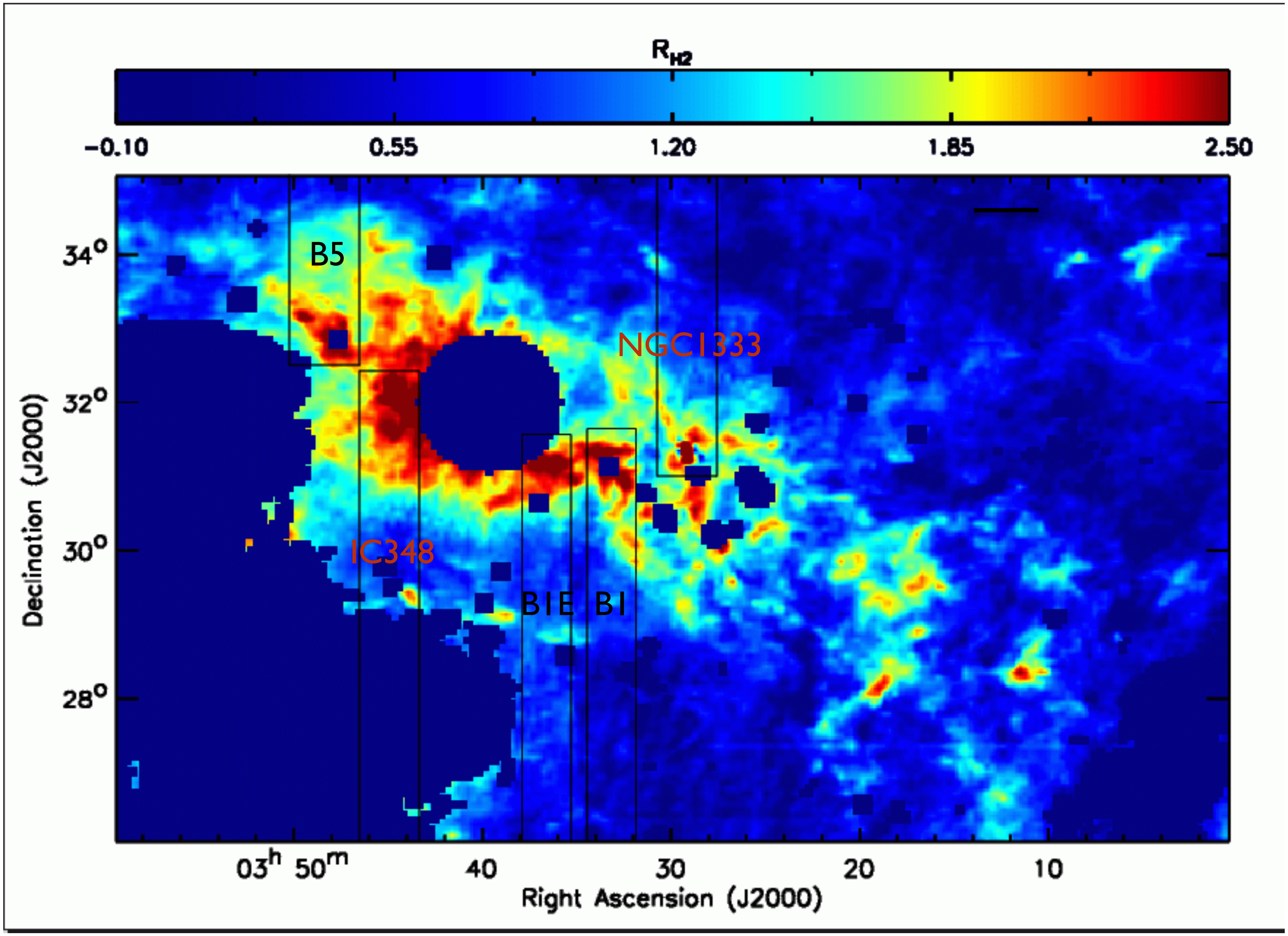
Yet, in most cases no clear turnover.

Has been seen for galaxies on kpc-scales: Blitz & Wong02; Bigiel+08

Dark cloud



R_{H2} map



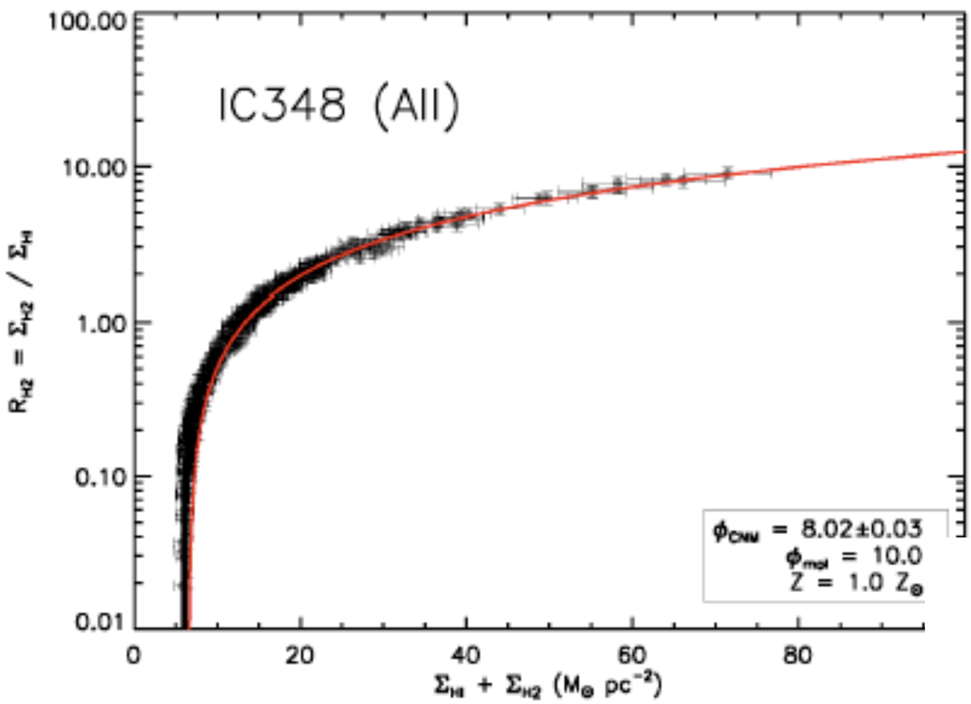
R_{H2}
-0.10
0.55
1.20
1.85
2.50
B5
NGC1333
IC348
B1E
B1
34°
32°
30°
28°
Declination (J2000)
03h 50m
40
30
20
10
Right Ascension (J2000)

R_{H2} vs. $\Sigma_{HI + H2}$

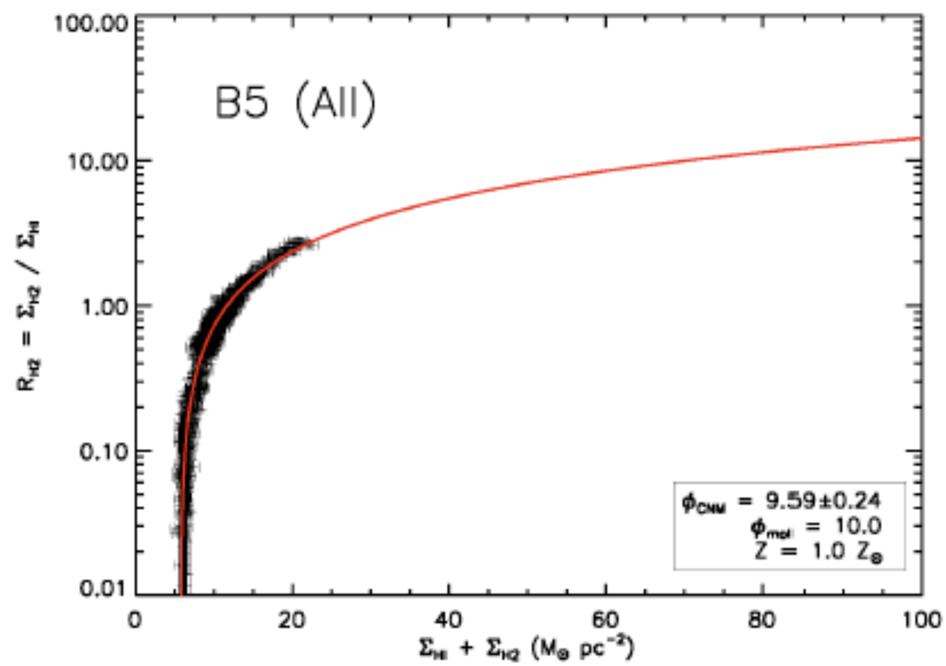
Model Parameters
$Z = 1.0\ Z_\odot$
$\phi_{CNM} = 7.0 \sim 8.0$

$T_{CNM} \sim 70$ K (Heiles & Troland 2003)
$T_{H2} \sim 60 - 80$ K (Savage et al. 1977)

Star forming cloud



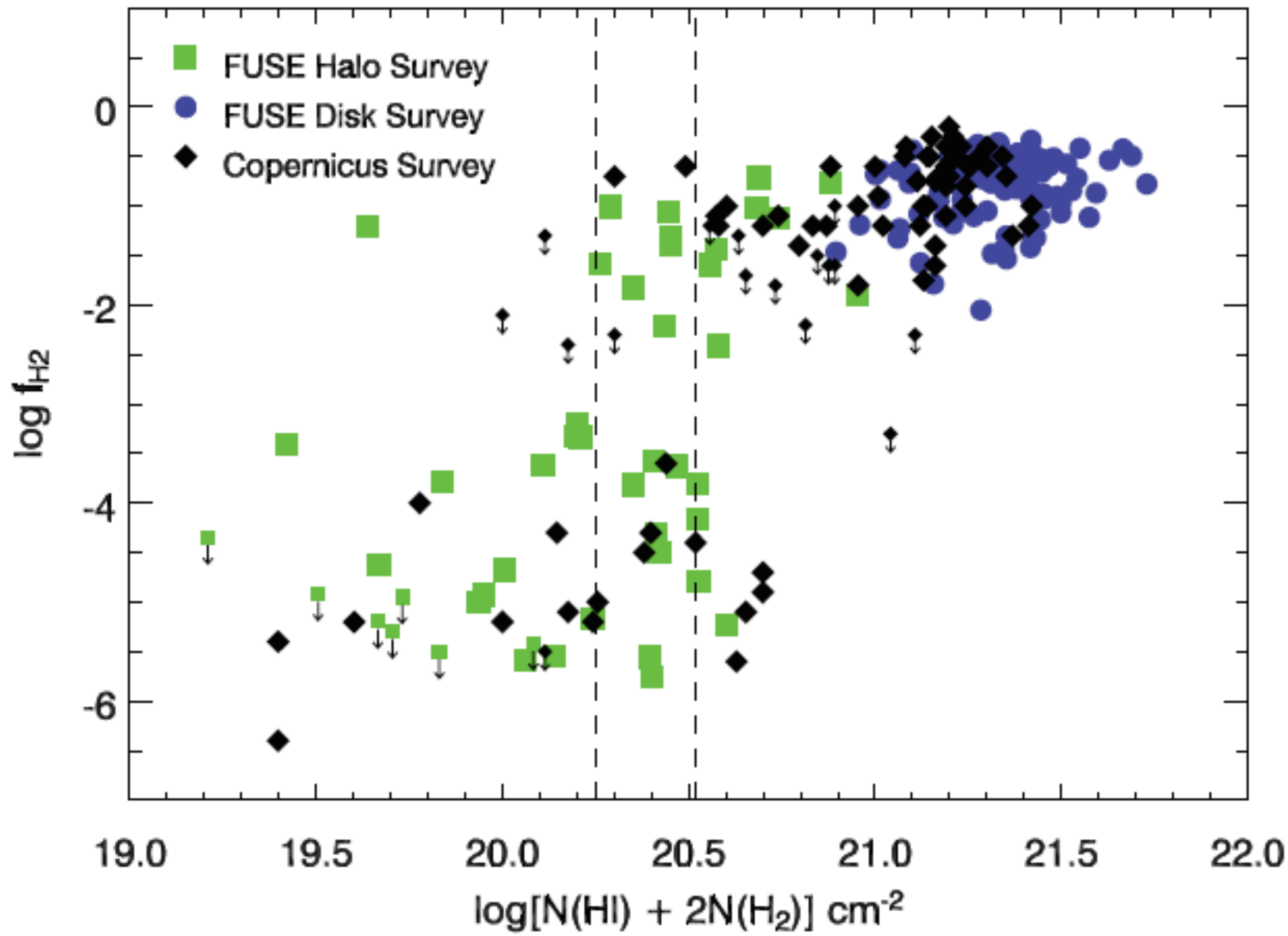
dark cloud



ISRF of IC348 = 2 – 3 ISRF of B5
(if ISRF ~ T_{dust}^6)

Sharp increase of R_{H2}.
→ *KMT model applicable even on sub-parsec scales!*
R~1 at $N_H \sim (1\text{-}2) \times 10^{21}$ cm^{-2}

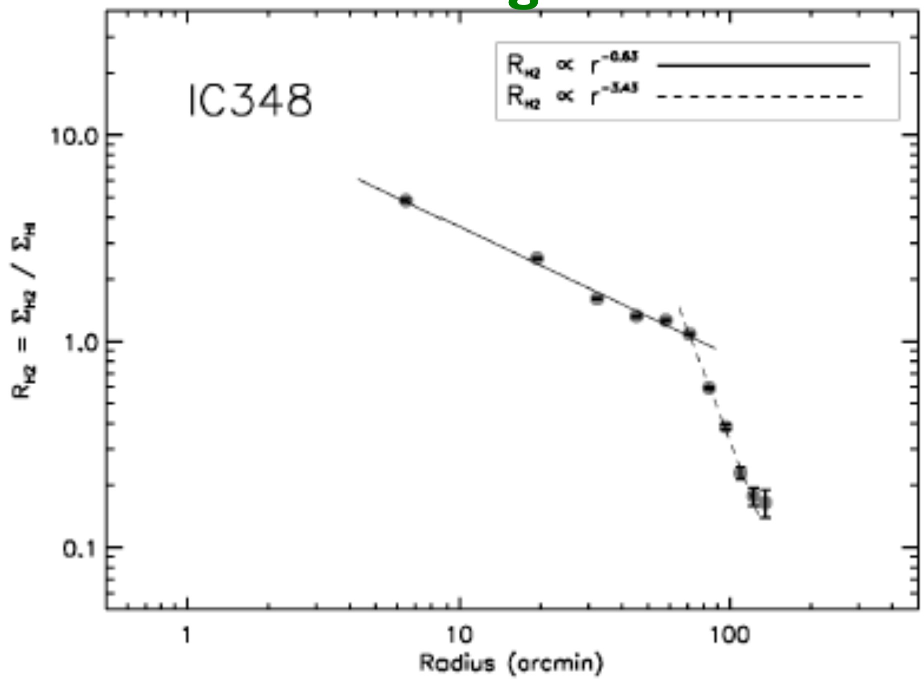
FUSE SURVEY OF INTERSTELLAR H_2 TOWARD AGNs



Gillmon+06

R_{H2}: radial profiles

Star forming cloud

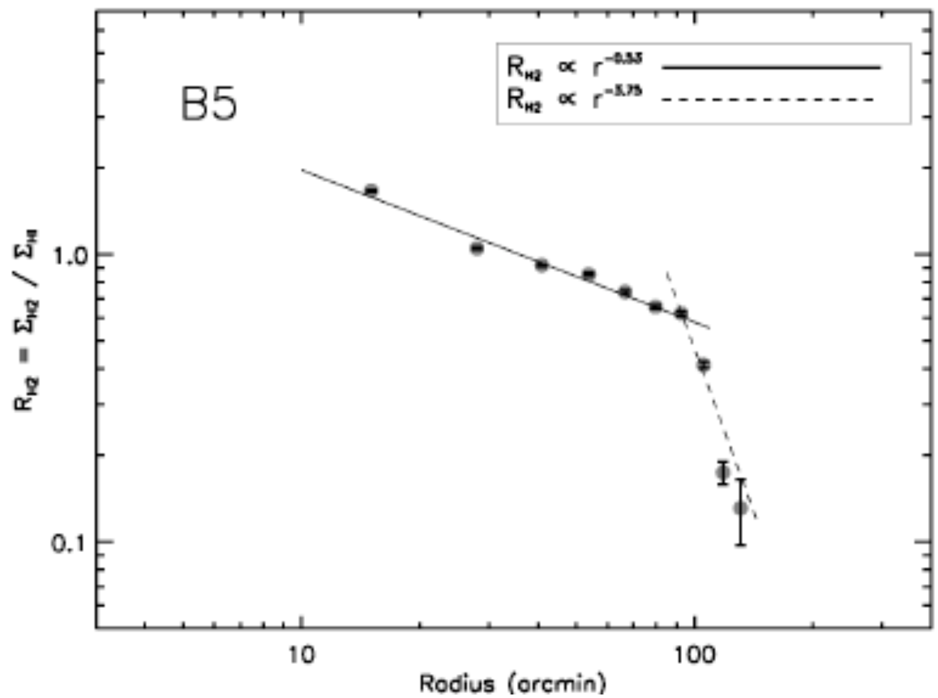


Evidence for sharp change in RH2 profiles.

→*atomic-dominated to molecule-dominated transition thickness ~ 10 pc, while the atomic-dominated "halo" extends to at least 25 pc.*

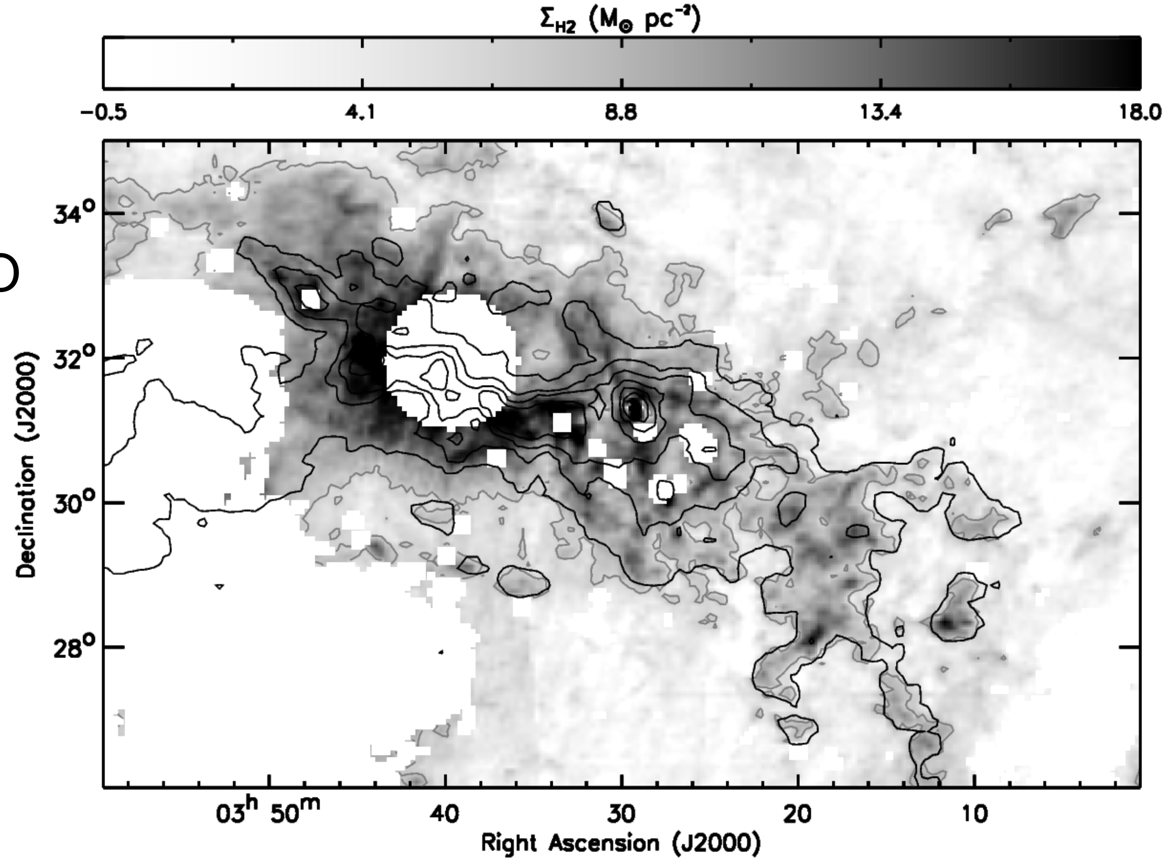
Lee et al., in prep.

dark cloud



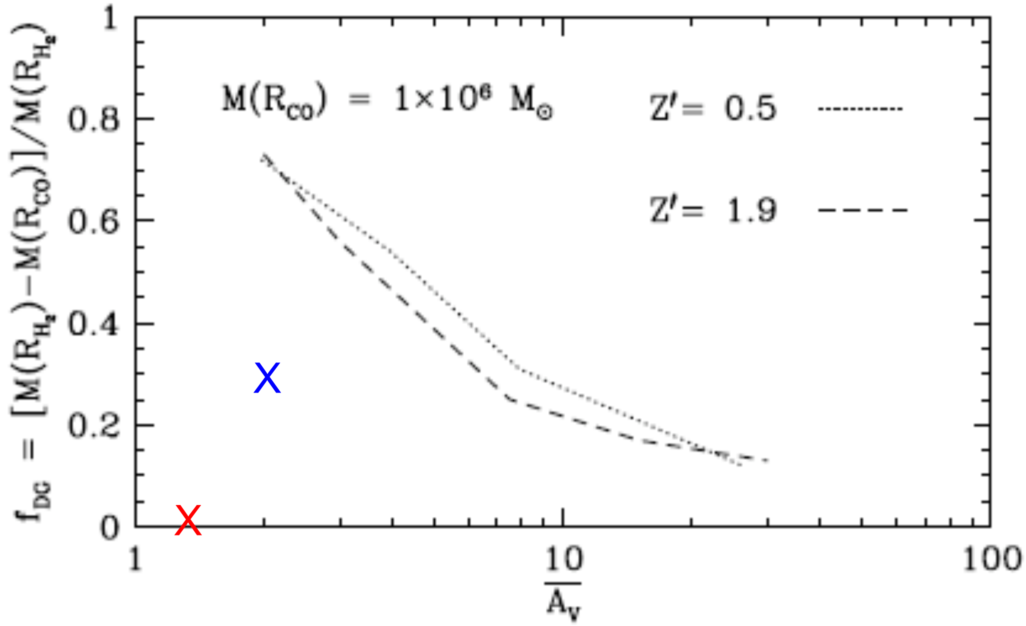
H2 vs CO and “CO-dark” H_2 gas

Grey: H2
Black: CfA CO

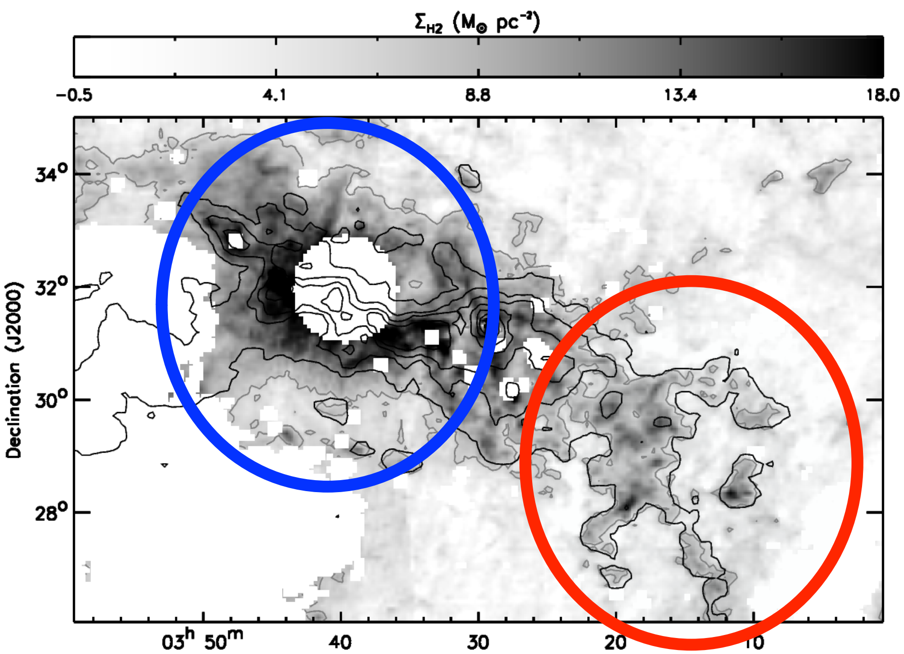


- H_2 found wherever significant CO emission.
- Generally more extended but significant spatial variations.
- Wolfire+10: f_{DG} = M(dark)/M(H_2) does not depend on cloud mass and ISRF, only varies with <Av>. Expected f_{DG}~0.8 for <Av>~1-2.
- **~30% of H_2 is dark in CO.**

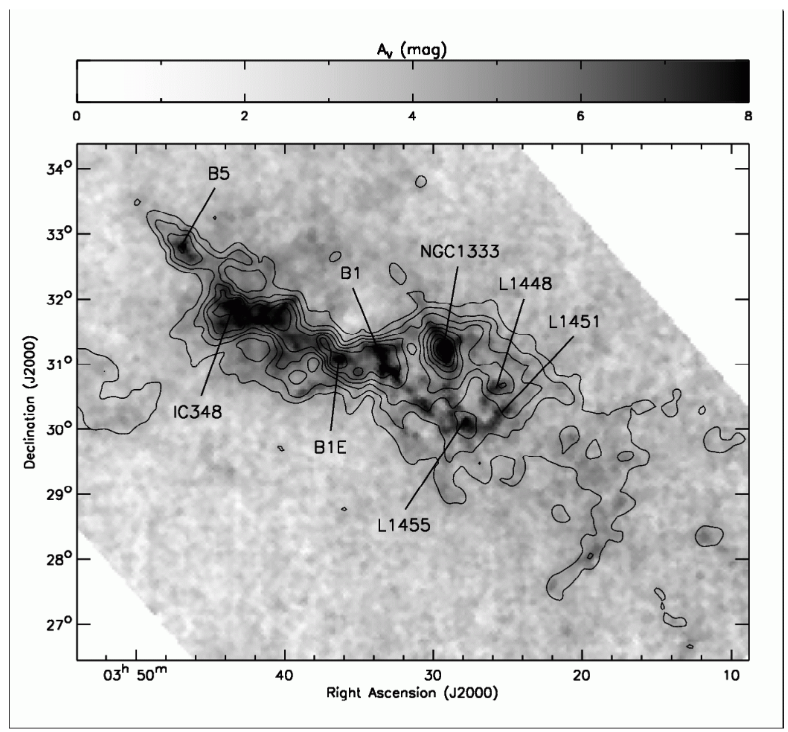
Wolfire+10



$M(R_{CO}) = 1\times10^6\ M_\odot$
$Z' = 0.5$
$Z' = 1.9$
$f_{DG} = [M(R_{H_2}) - M(R_{CO})]/M(R_{H_2})$
X
X
A_V



Σ_{H2} ($M_\odot$ pc^{-2})
−0.5
4.1
8.8
13.4
18.0
Declination (J2000)
Right Ascension (J2000)



A_V (mag)
B5
NGC1333
B1
L1448
L1451
IC348
B1E
L1455
Declination (J2000)
Right Ascension (J2000)

Summary:

- Understanding the star-formation cycle in galaxies requires focus on the very 1^{st} step: diffuse interstellar gas. Nearby Universe offers unprecedented resolution.

- 21-SPONGE and GASKAP: to measure temperature and fraction of the WNM in the MW and Magellanic Clouds.

- Perseus study suggests a threshold HI surface density. Great agreement with the Krumholz+09 predictions for both dark and star forming clouds even on sub-pc scales → ISRF not important.

→ Fundamental assumptions regarding H2 formation and photodissociation work well, no need for additional ingredients (e.g. turbulence).

- The fraction of "CO-dark" H2 gas in Perseus is ~0.3, although significant spatial variations.

Thanks for pushing the limits of radio astronomy Miller, and Happy Birthday!