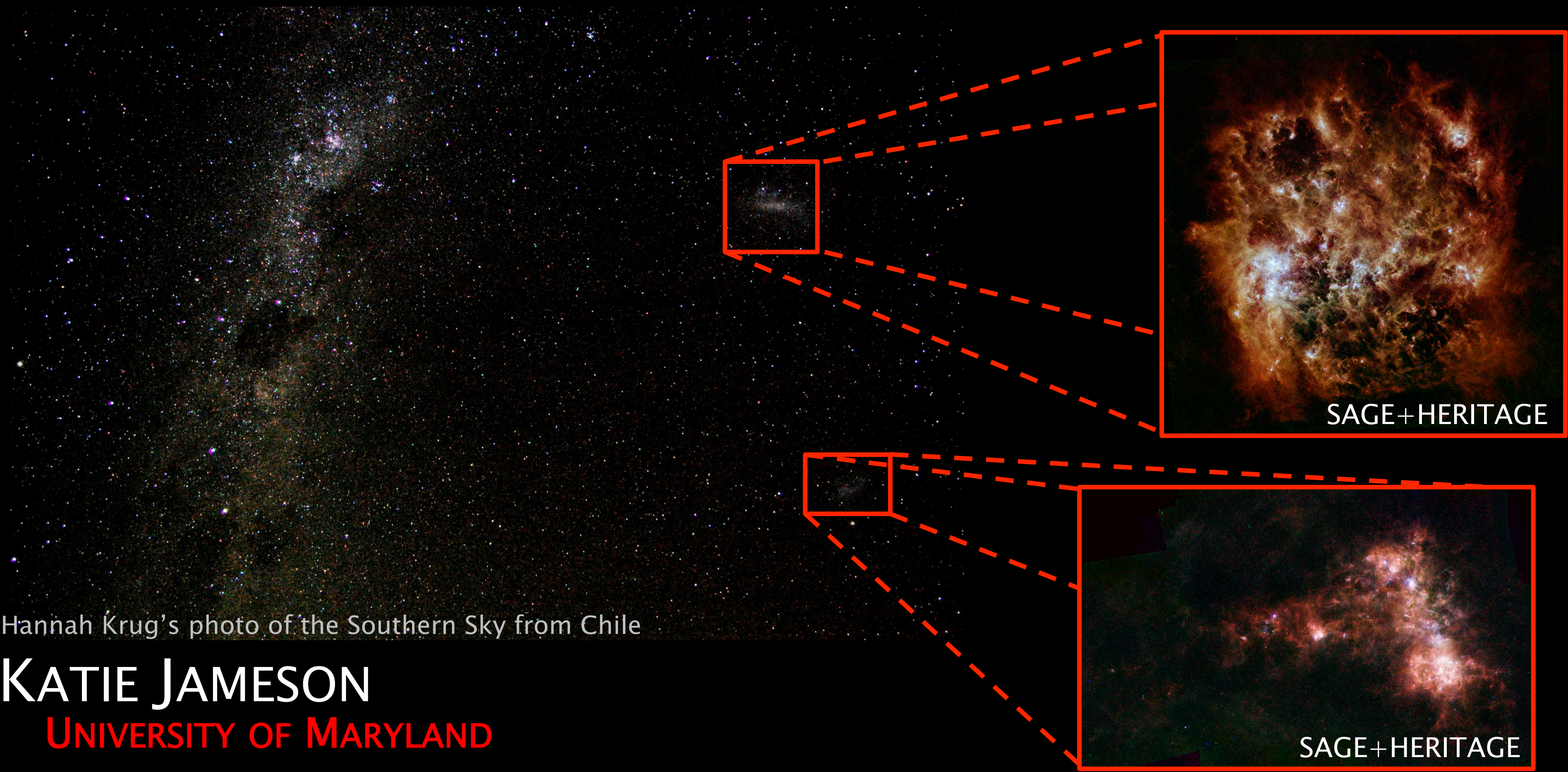
The Effect of Metallicity on Molecular Gas and Star Formation in the Magellanic Clouds

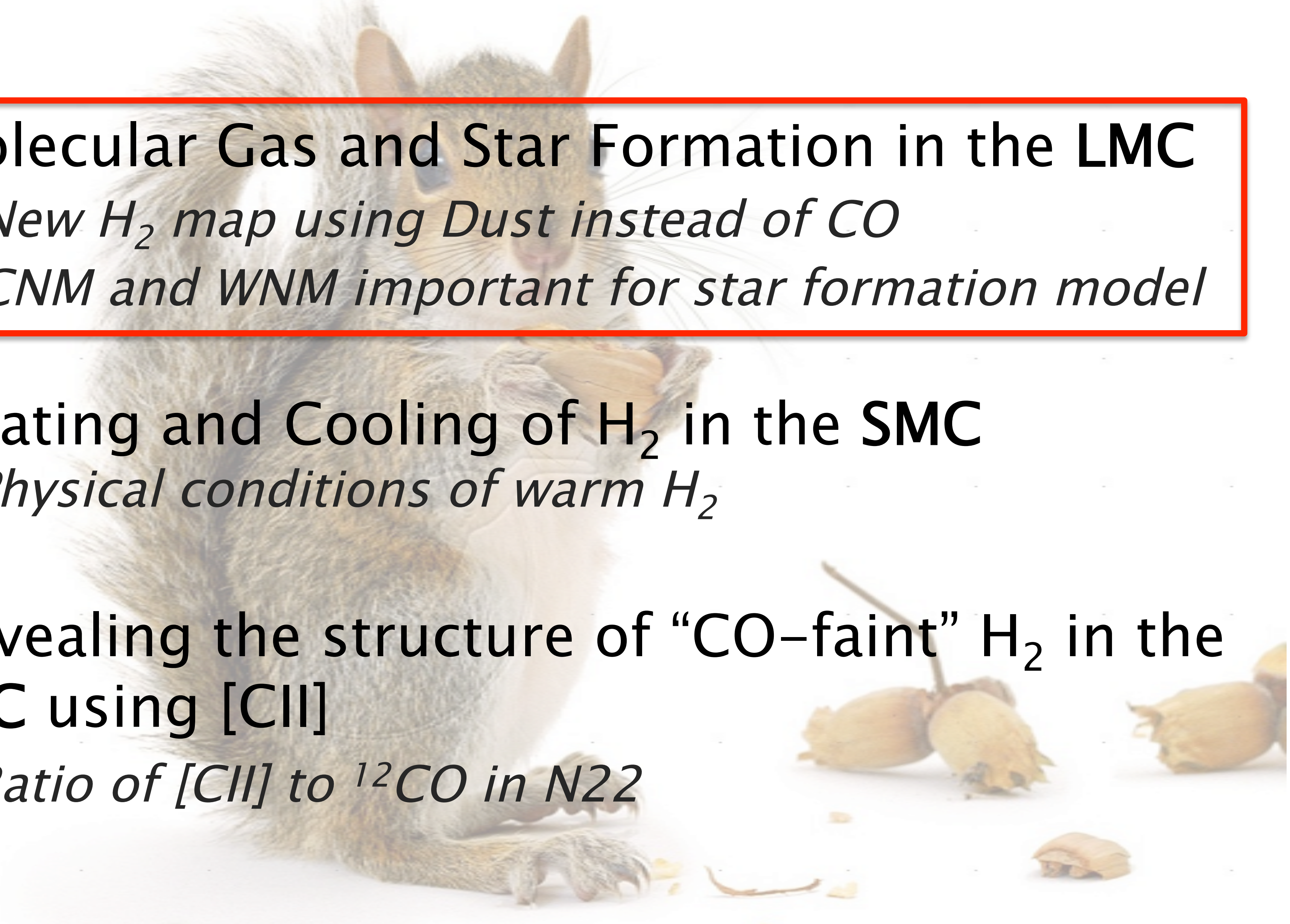


Hannah Krug's photo of the Southern Sky from Chile

Katie Jameson
University of Maryland

Collaborators: Alberto Bolatto (UMD), Adam Leroy (NRAO), Margaret Meixner (STScI), Mark Wolfire (UMD), Karin Sandstrom (MPIA), Julia Roman-Duval (STScI), Karl Gordon (STScI), Annie Hughes (MPIA), Sue Madden (CEA), + HERITAGE Team

THIS TALK IN A NUTSHELL



1. Molecular Gas and Star Formation in the **LMC**
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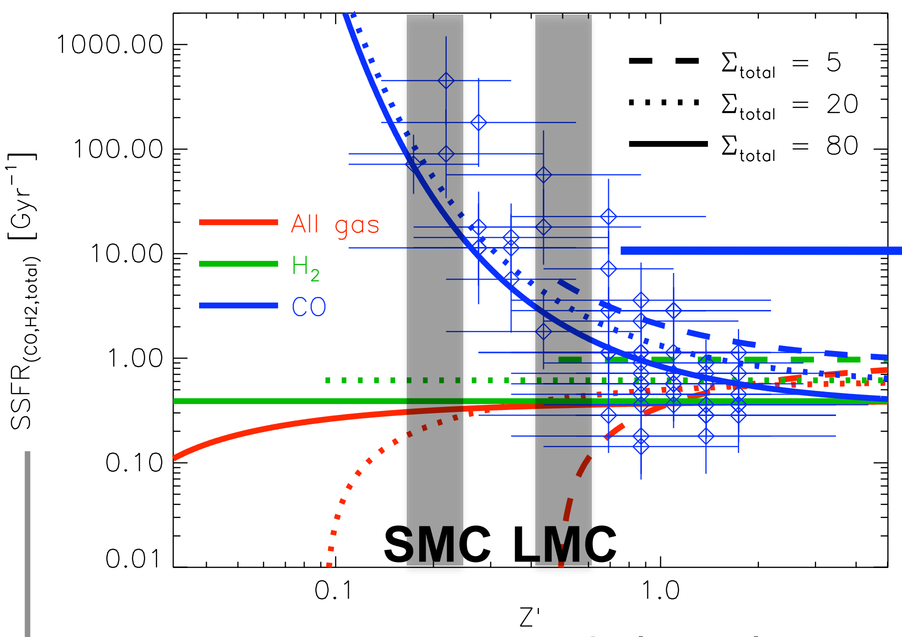
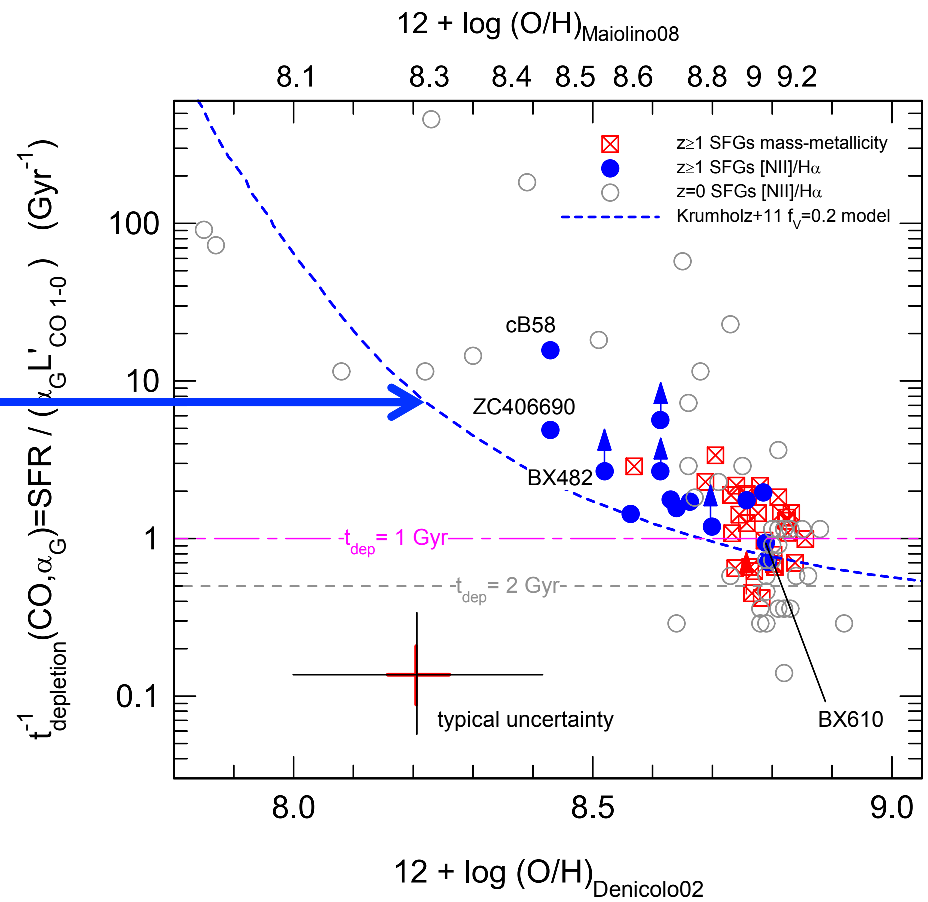
How does star formation efficiency depend on galaxy mass and metallicity?



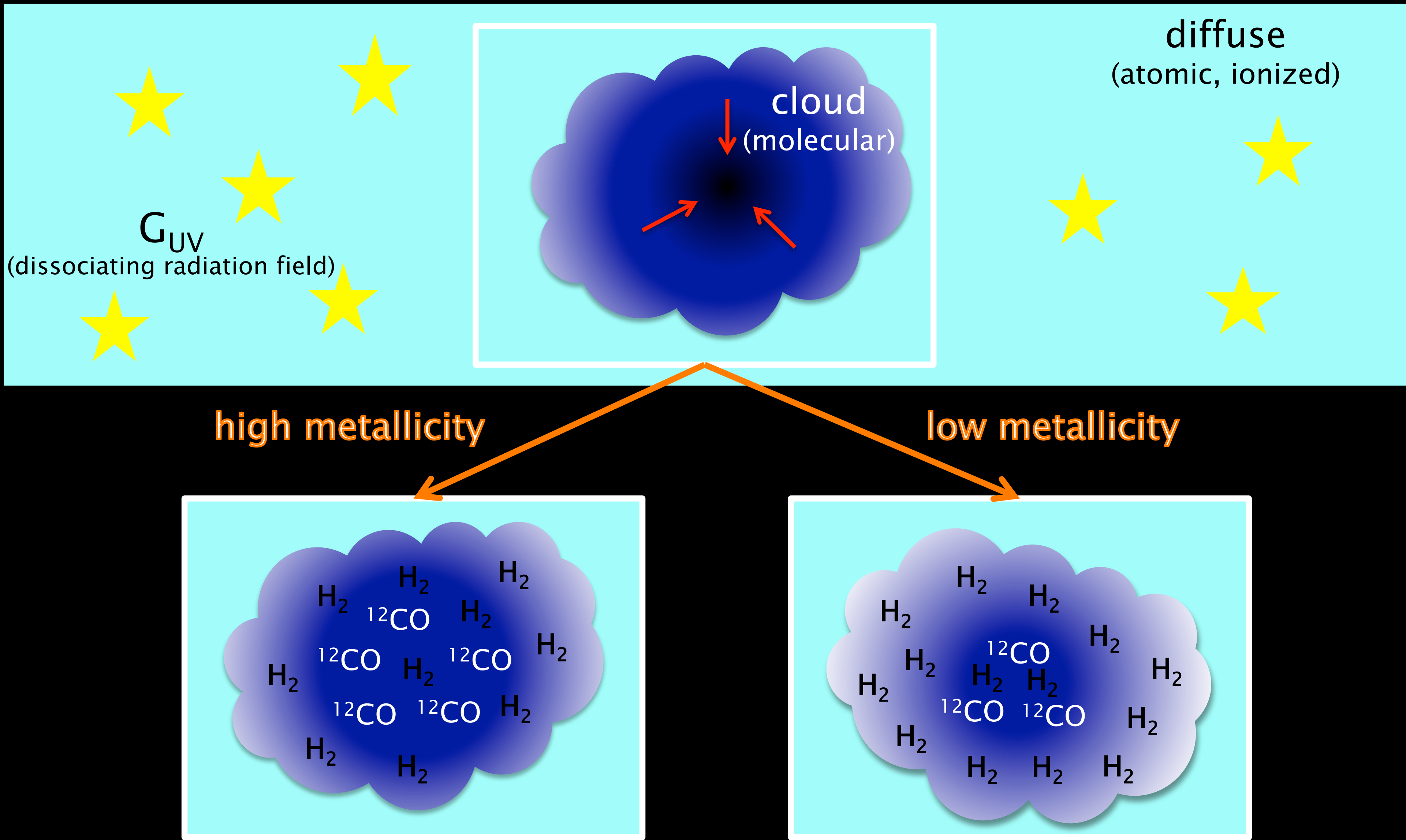
Krumholz et al. (2011)



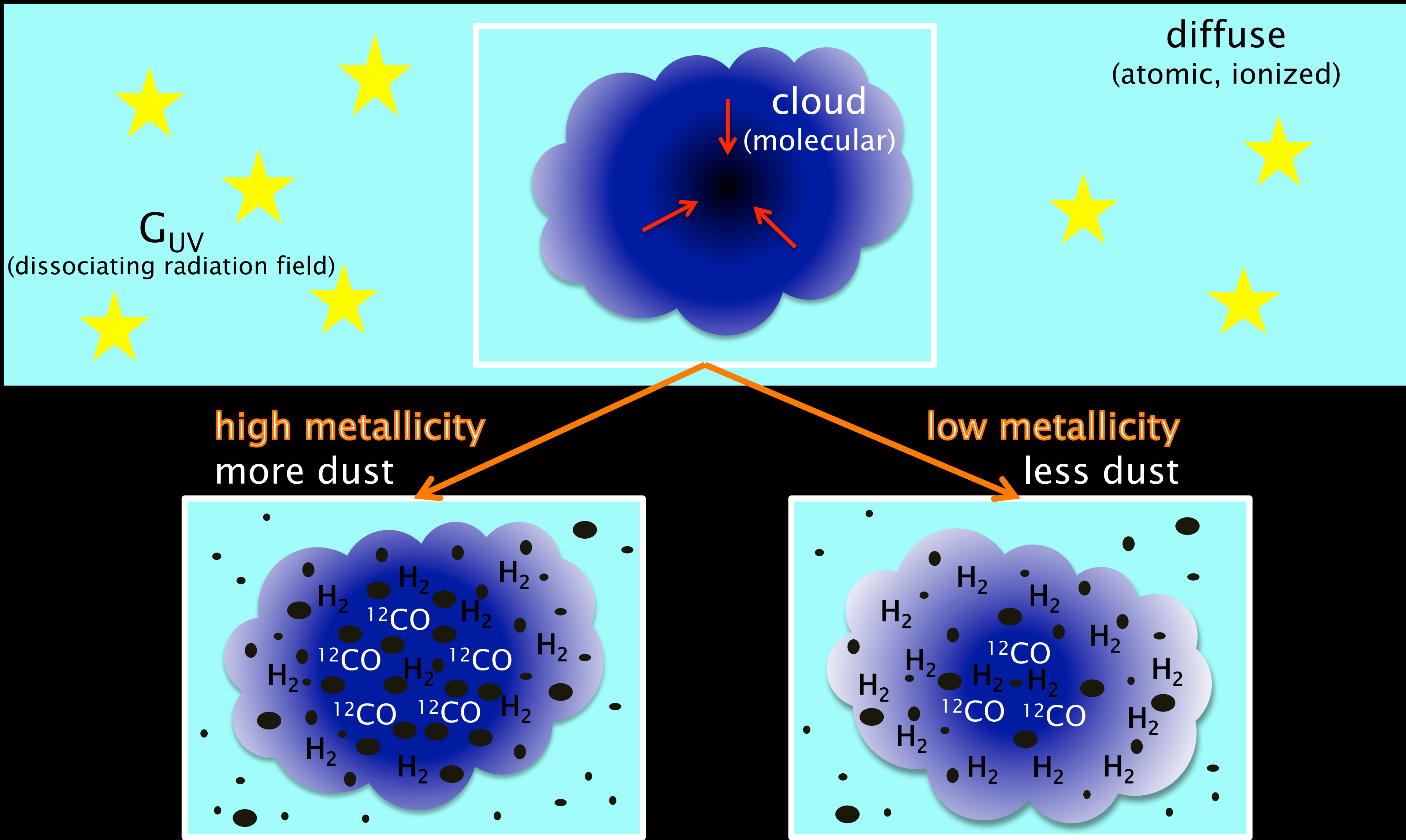
(high-z galaxies; Genzel et al. 2012)

$$\mathrm{SSFR} = \Sigma_{\mathrm{SFR}}/\Sigma_{(\mathrm{CO,H2,total})} = \tau_{dep}^{-1}$$

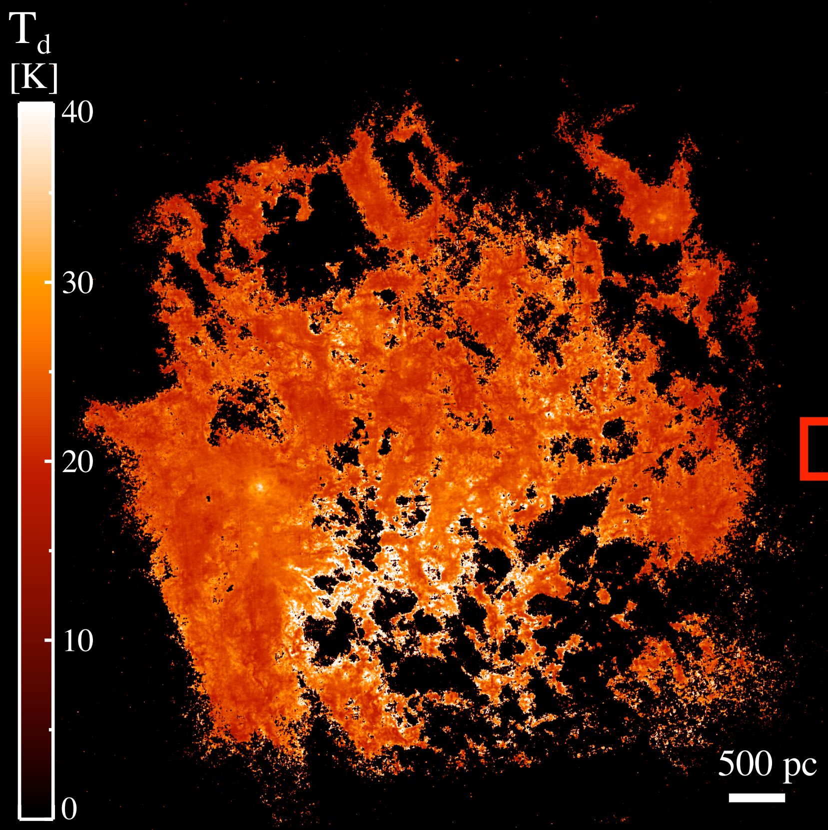
CO traces less H_2 at lower metallicity

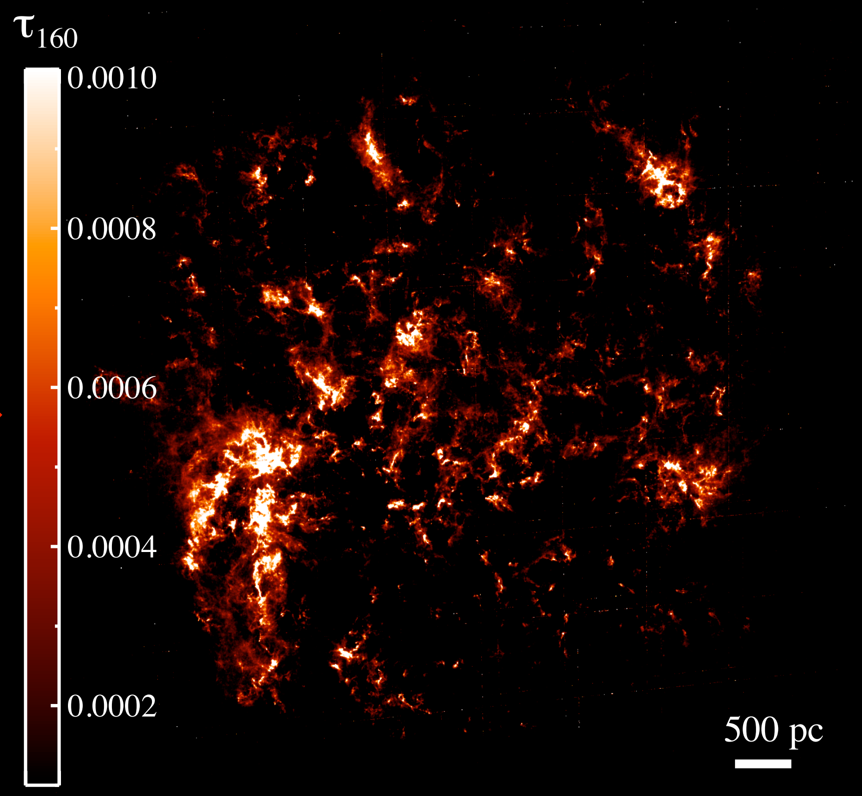


Dust can trace H_2 at low metallicity.



Fit T_d to HERITAGE data and map $\tau_{160\mu m}$





T_d fit modified blackbody with β = 1.8

T_{160} proportional to M_{dust}

Mapping H_2 using dust emission

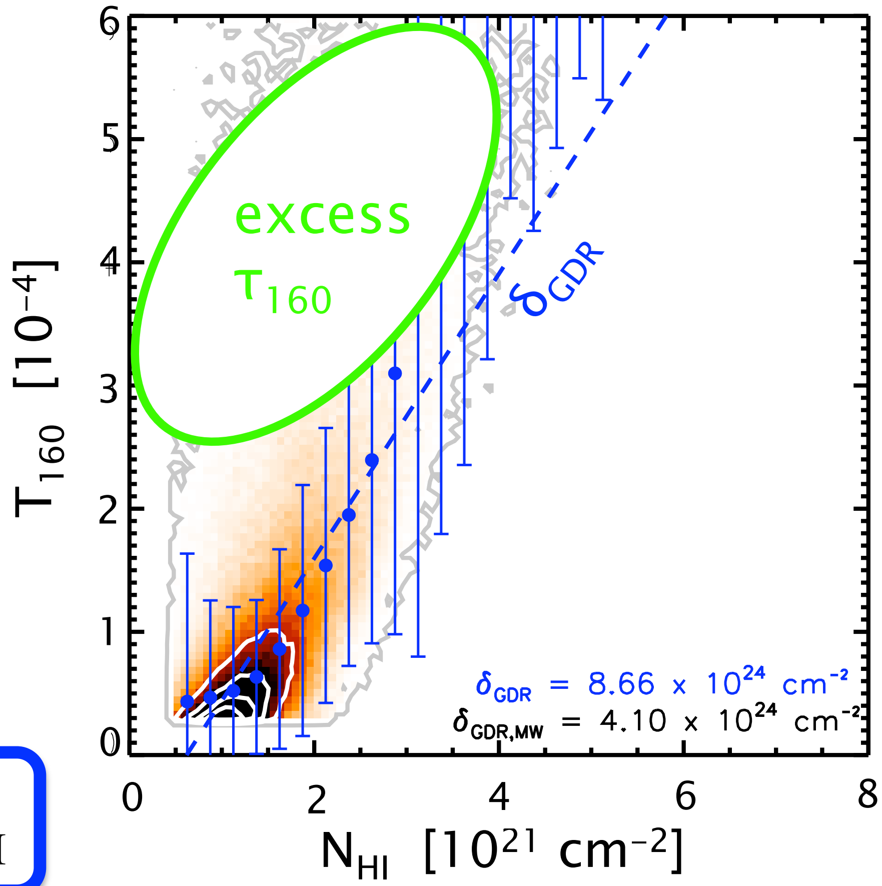
$$\Sigma_{gas} = \Sigma_{HI} + \Sigma_{H_2}$$

$$\Sigma_{dust} \propto \tau_{160\,\mu m}$$

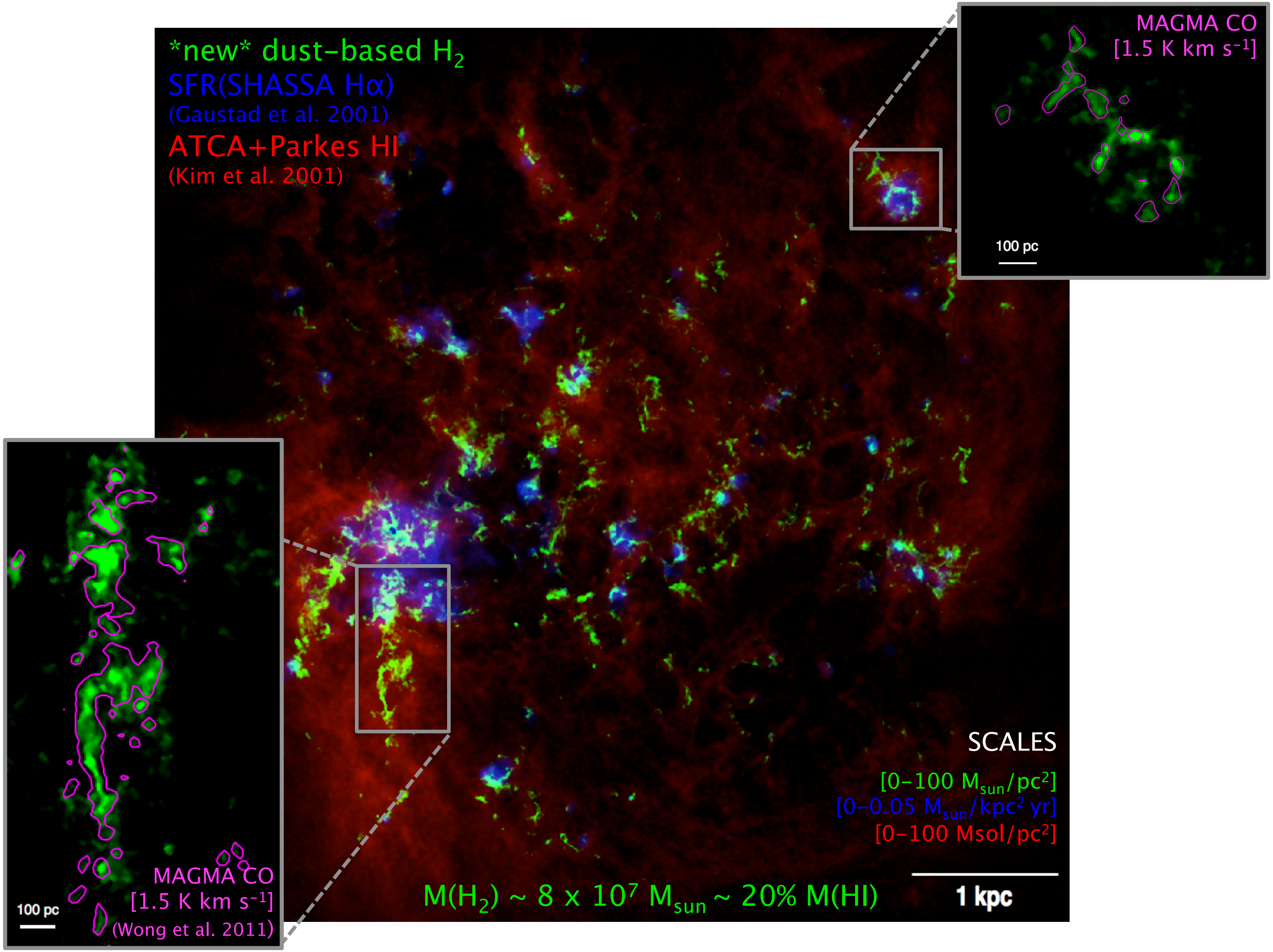
$$\Sigma_{gas} = \delta_{GDR} \times \Sigma_{dust}$$

→ fitted parameter

$$\Sigma_{H_2} = \left(\delta_{GDR} \times \tau_{160\,\mu m}\right) - \Sigma_{HI}$$



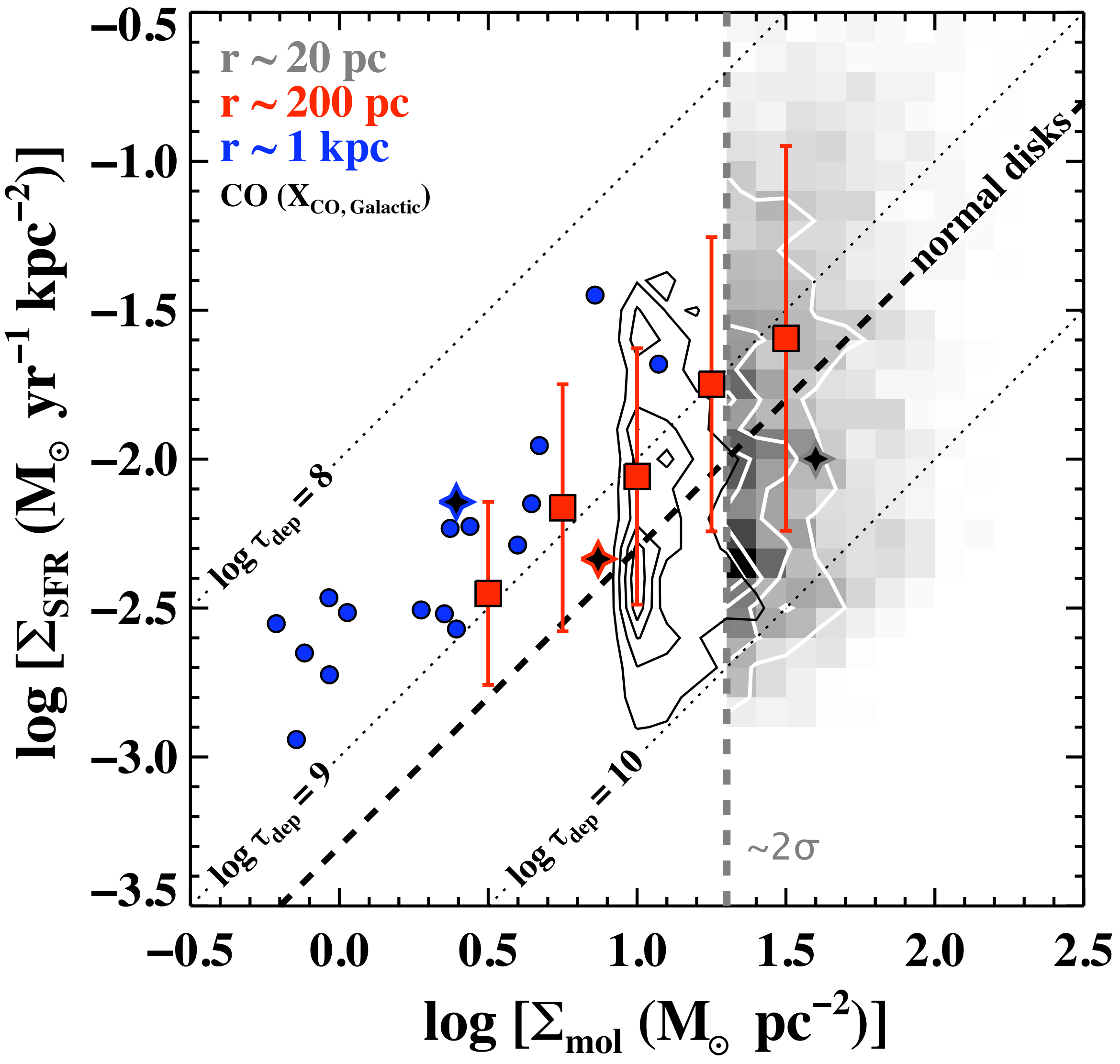
Previous Work:
MCs – Israel (1997); MW – Dame+ (2001);
SMC – Leroy+ (2007); Leroy et al. (2009); Bolatto et al. (2011)


new dust-based H_2
SFR(SHASSA Hα)
(Gaustad et al. 2001)
ATCA+Parkes HI
(Kim et al. 2001)
MAGMA CO
[1.5 K km s^{-1}]
100 pc
MAGMA CO
[1.5 K km s^{-1}]
(Wong et al. 2011)
100 pc
SCALES
[0–100 M_{sun}/pc^2]
[0–0.05 M_{sun}/kpc^2 yr]
[0–100 $Msol/pc^2$]
$M(H_2) \sim 8 \times 10^7 M_{sun} \sim 20\% M(HI)$
1 kpc

How galaxies convert molecular gas to stars does not vary strongly with metallicity.

LMC

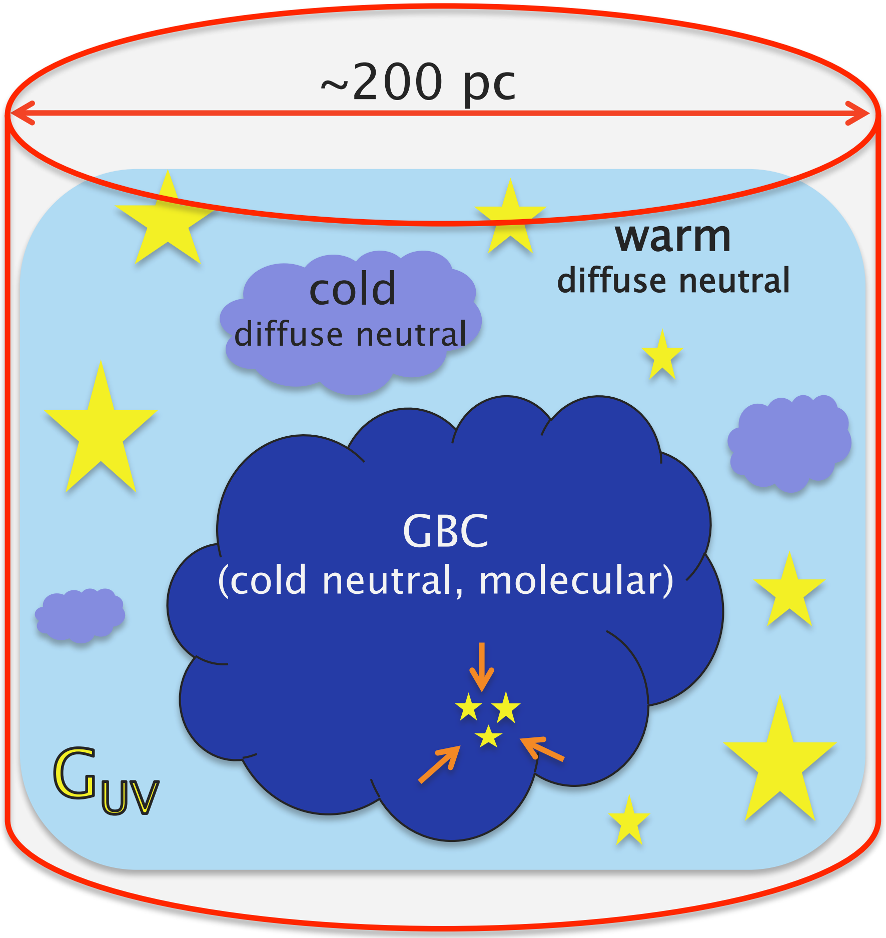
Z'~1/2 Solar



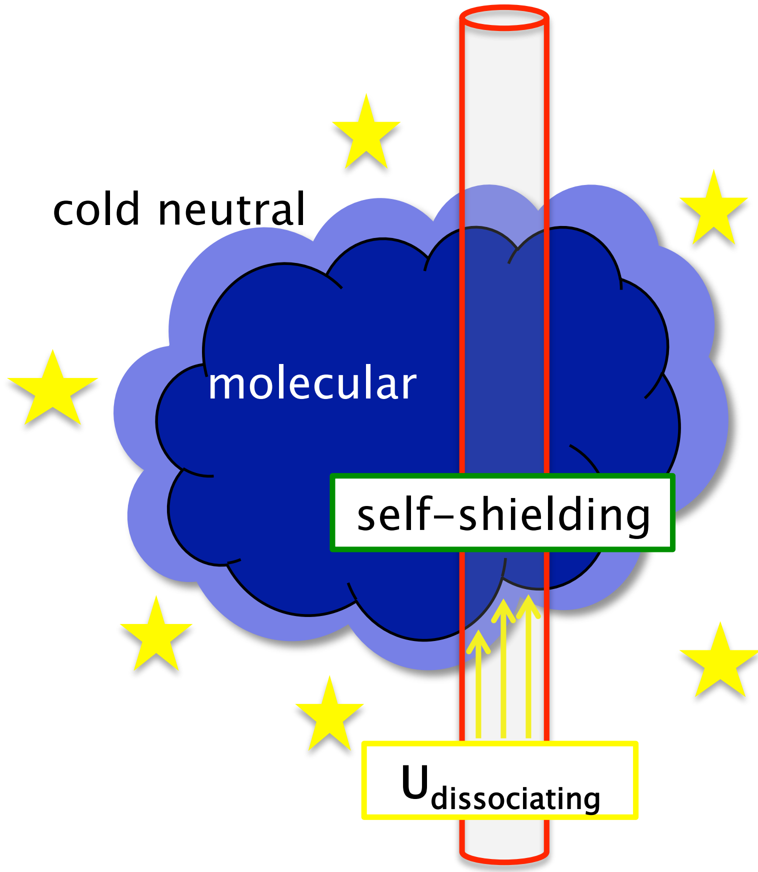
τ_{dep} (200 pc) = 1.6 Gyr

Different approximations of the ISM: pressure-driven vs. shielding

Ostriker, McKee, & Leroy (2010)
(OML10)



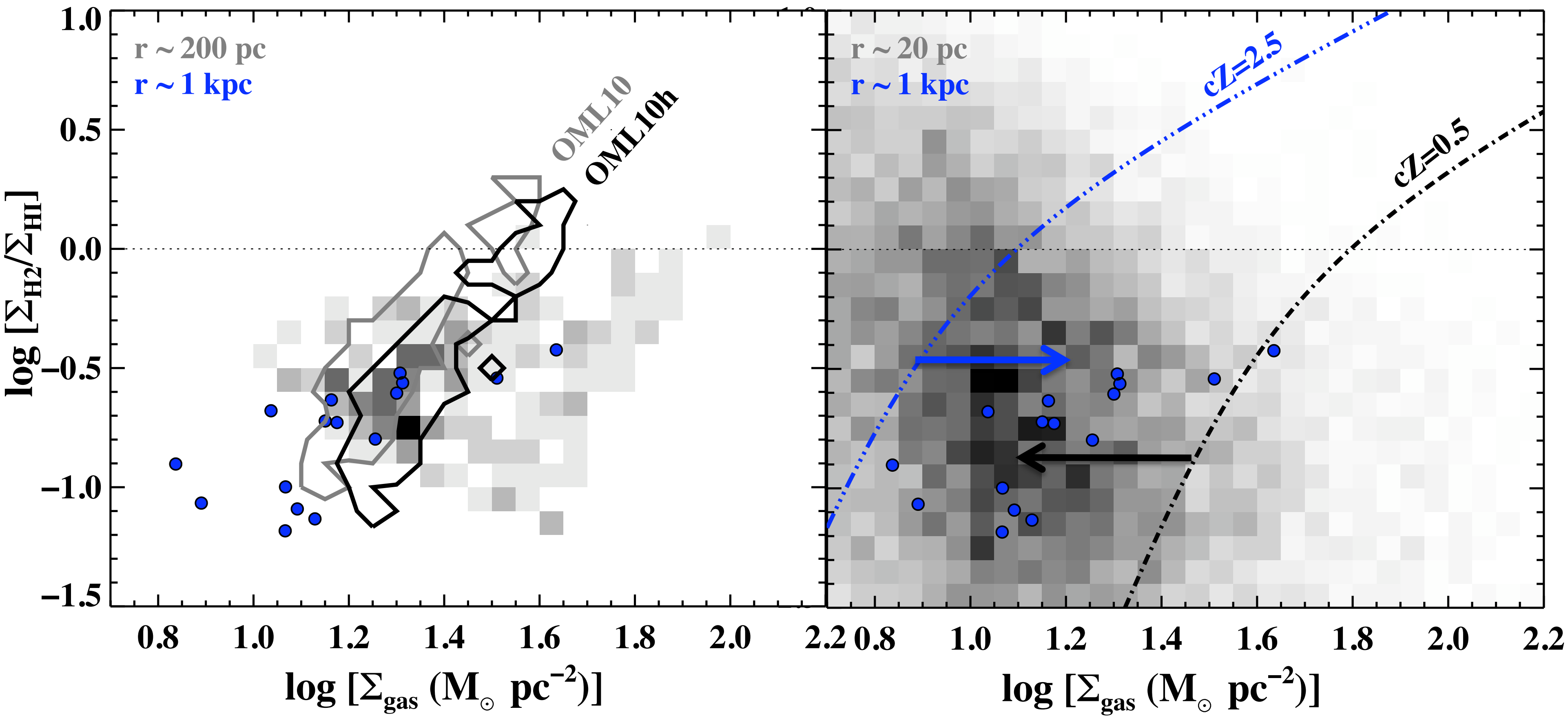
Krumholz, McKee, & Tumlinson (2009)
(KMT09)



How well do the models predict the fraction of molecular gas?

Ostriker, McKee, & Leroy (2010)
(OML10)

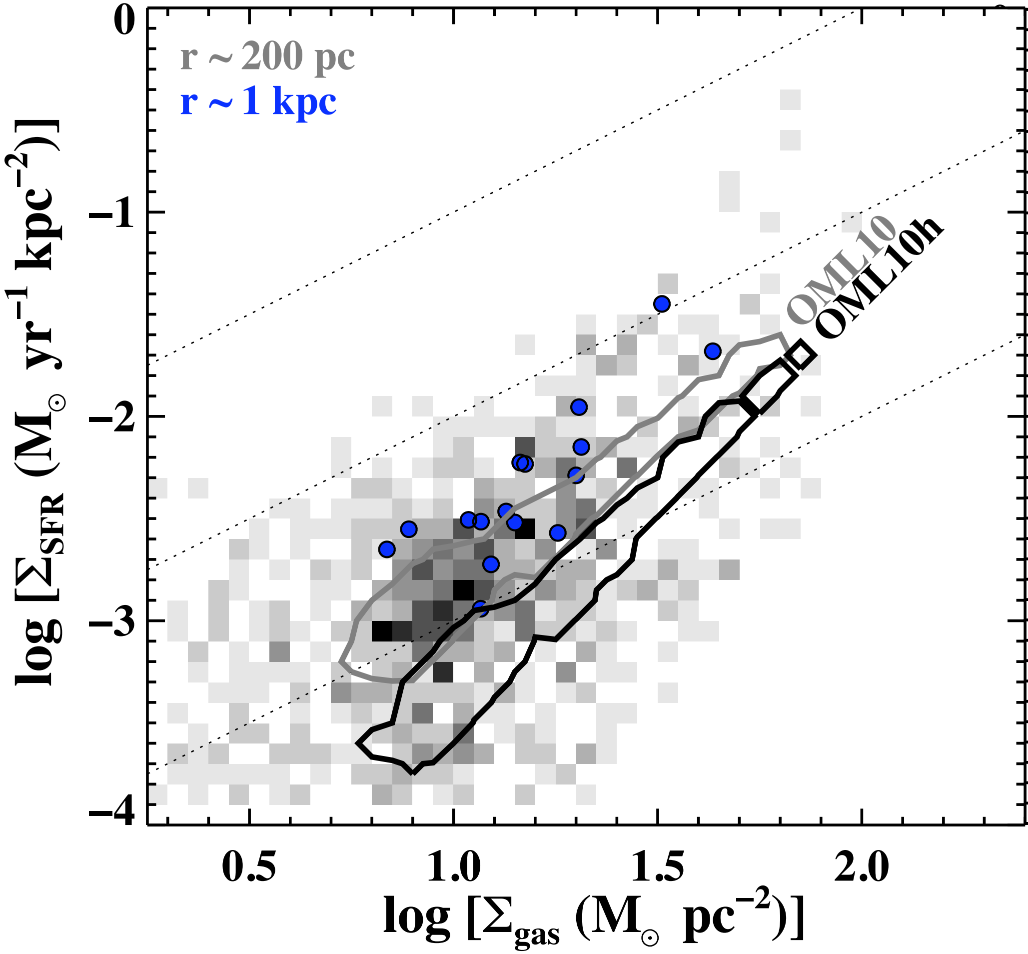
Krumholz, McKee, & Tumlinson (2009)
(KMT09)

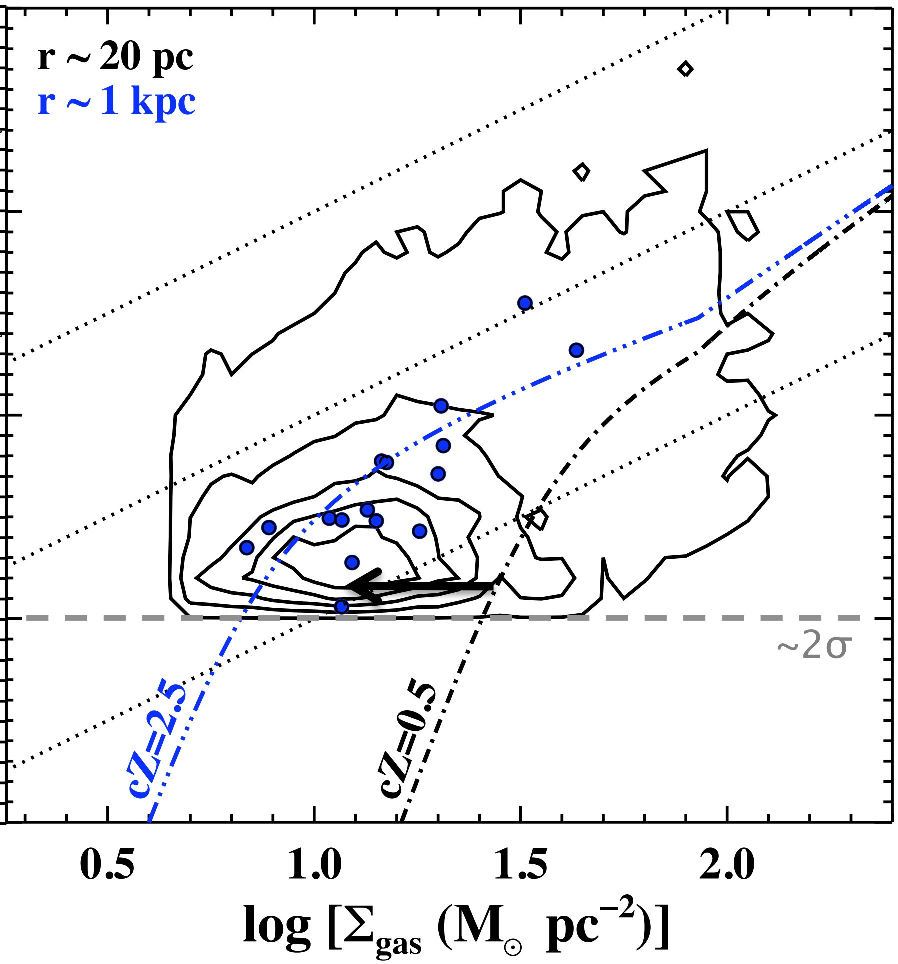


How about predicting star formation rate based on total gas?

Ostriker, McKee, & Leroy (2010)
(OML10)

Krumholz, McKee, & Tumlinson (2009)
(KMT09)





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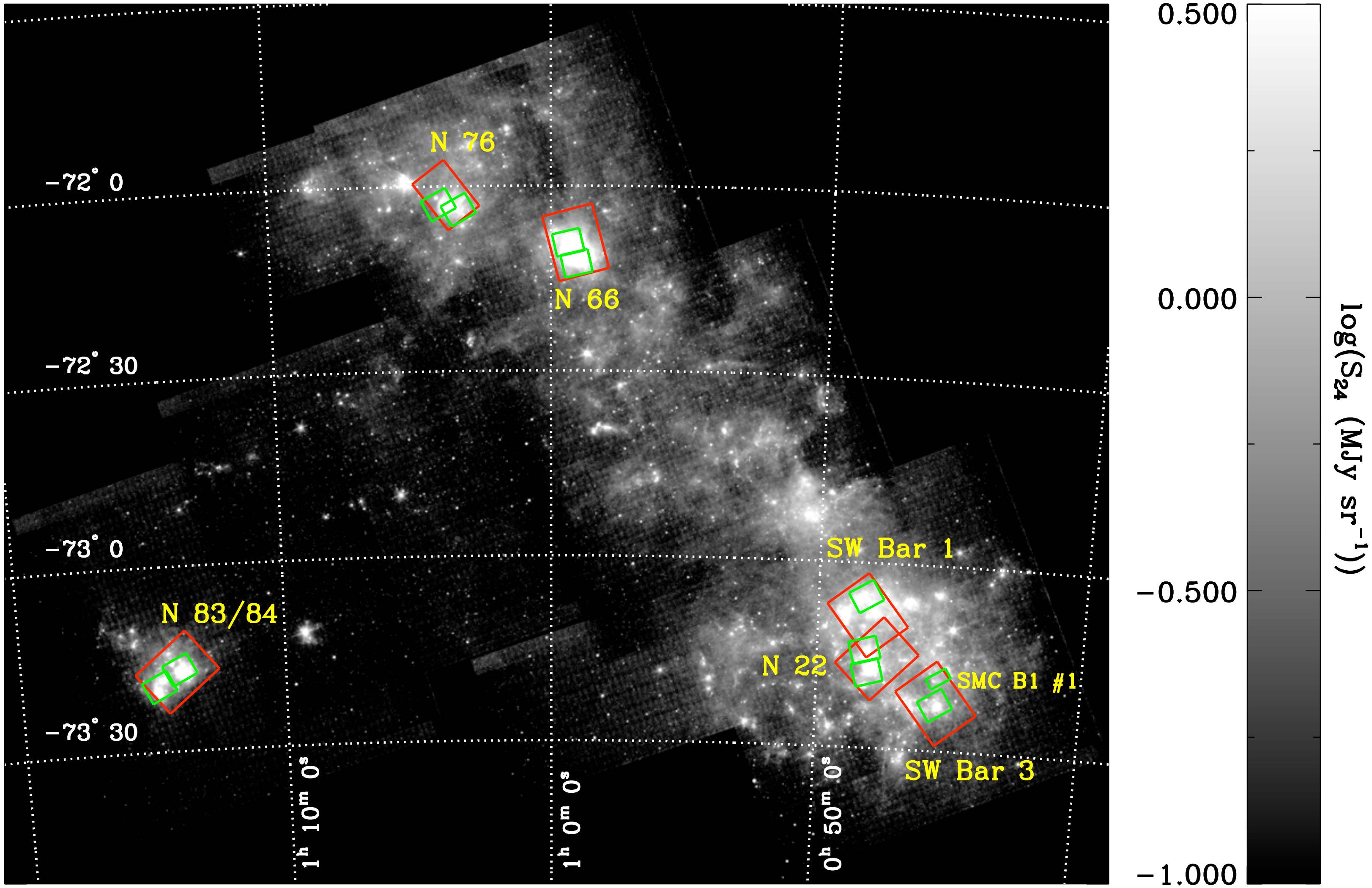
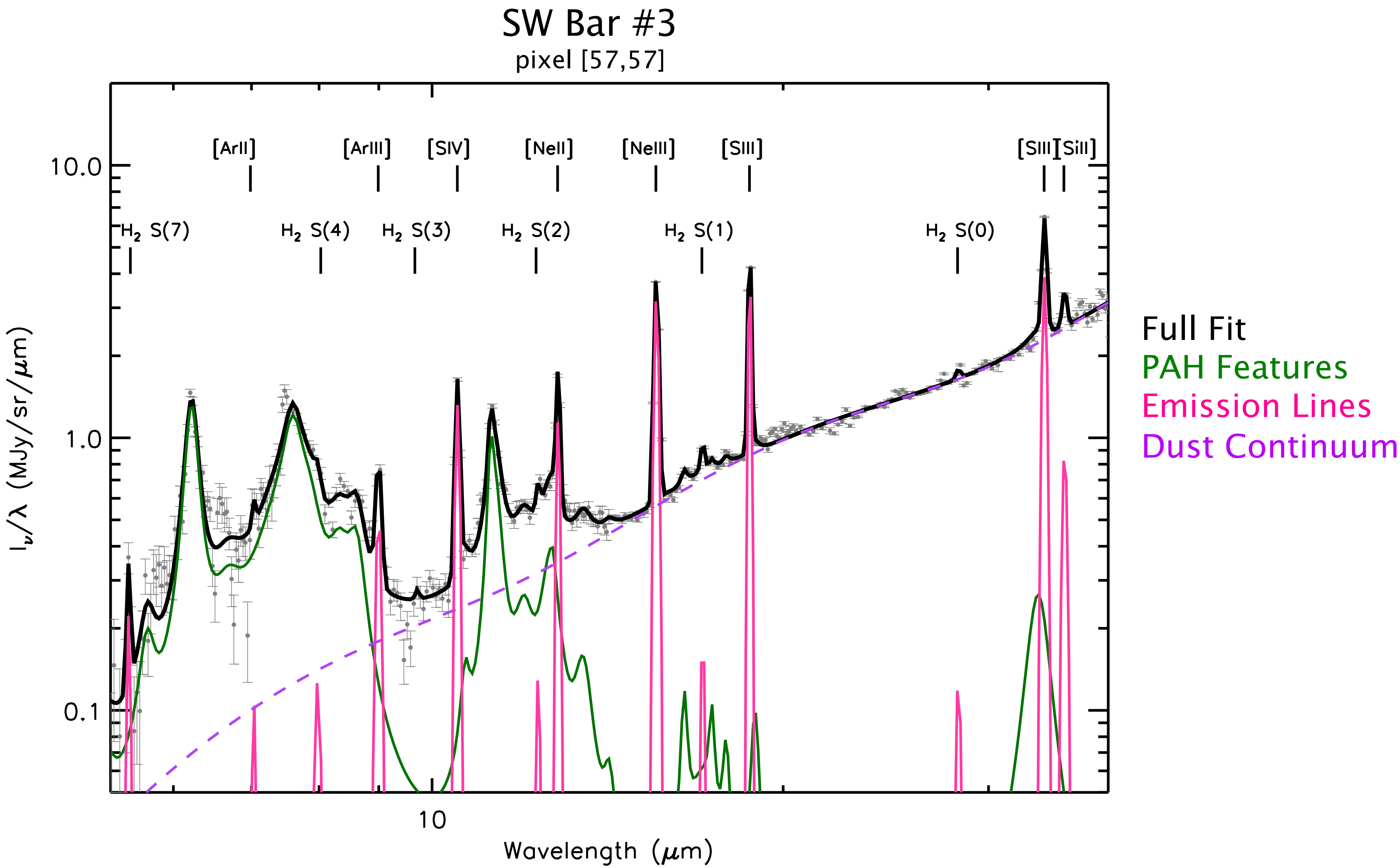
Spitzer Spectroscopic Survey of the SMC (S^4MC)

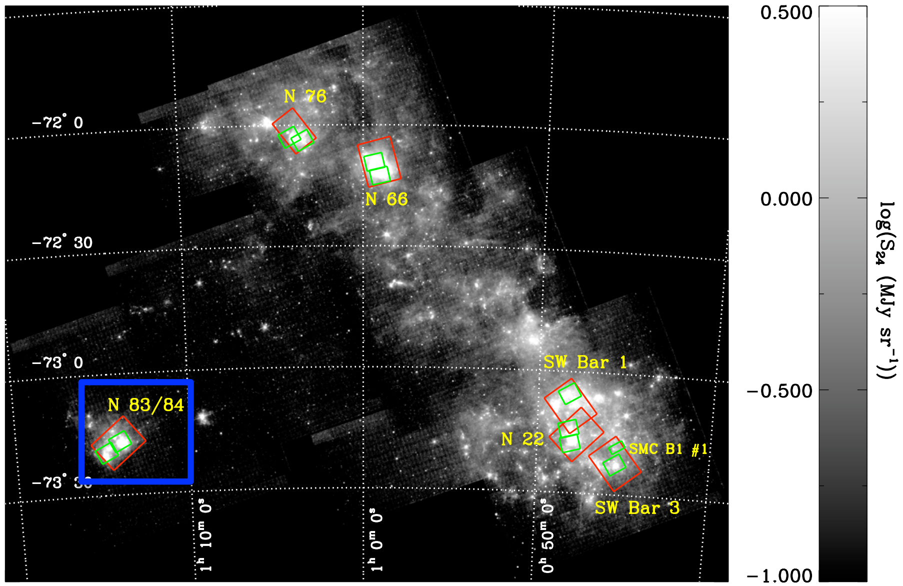


(Sandstrom et al. 2012)

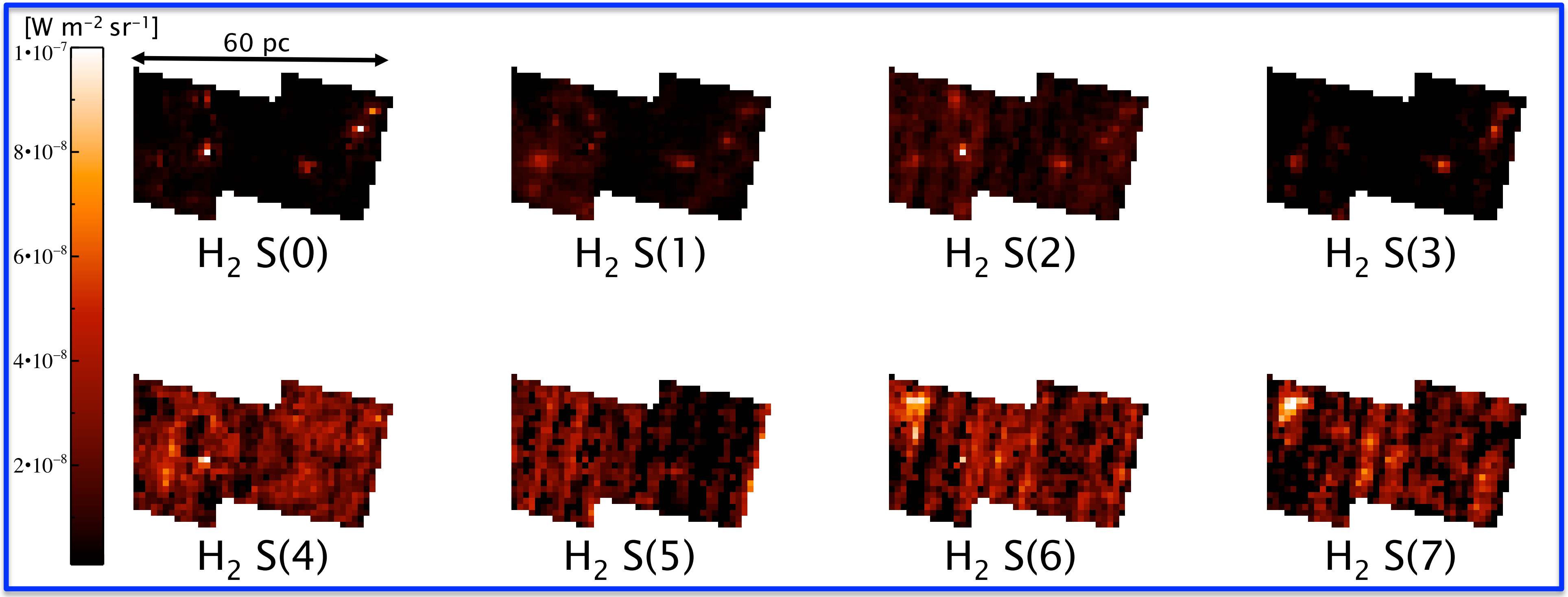
Fitting line emission in the IRS S⁴MC data



Mapping H_2 line emission in the SMC

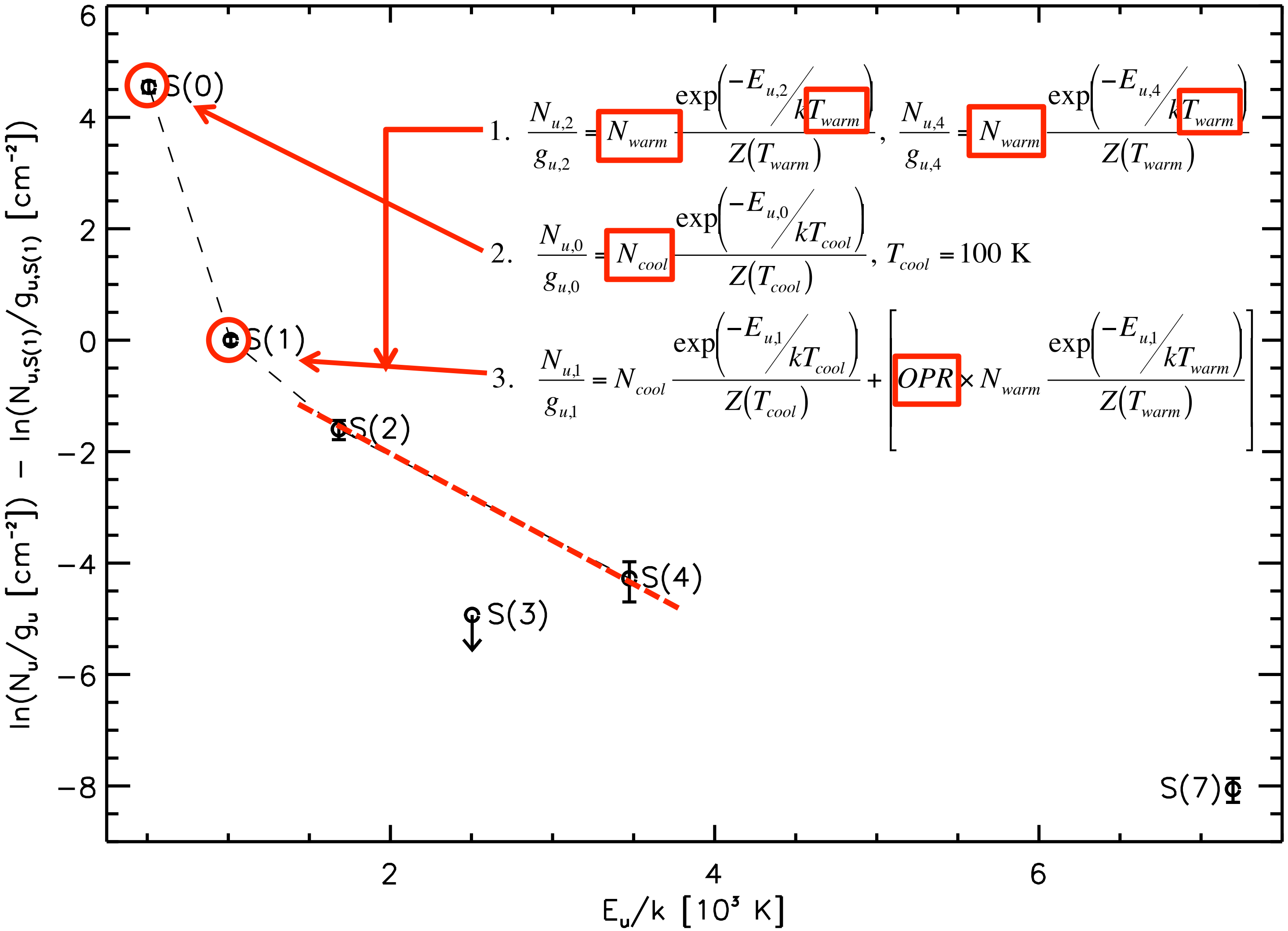


N83/N84



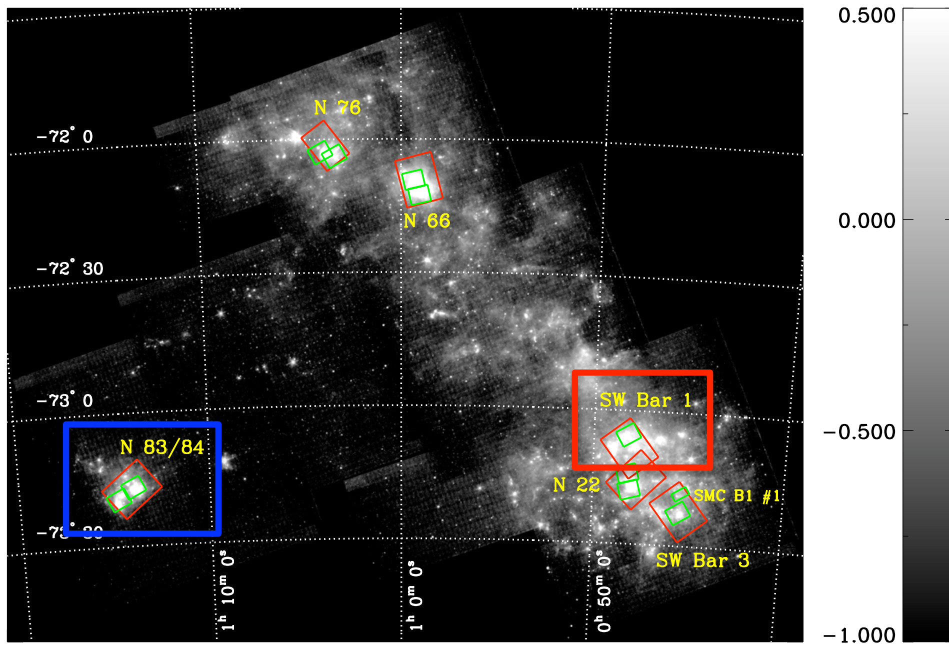
Modeling H_2 line emission

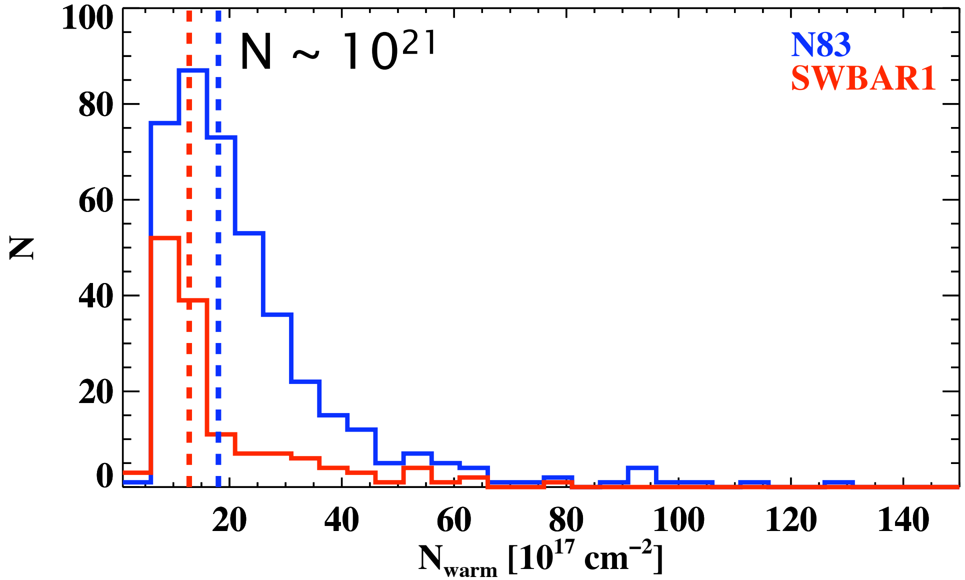
Excitation Diagram
(example pixel)

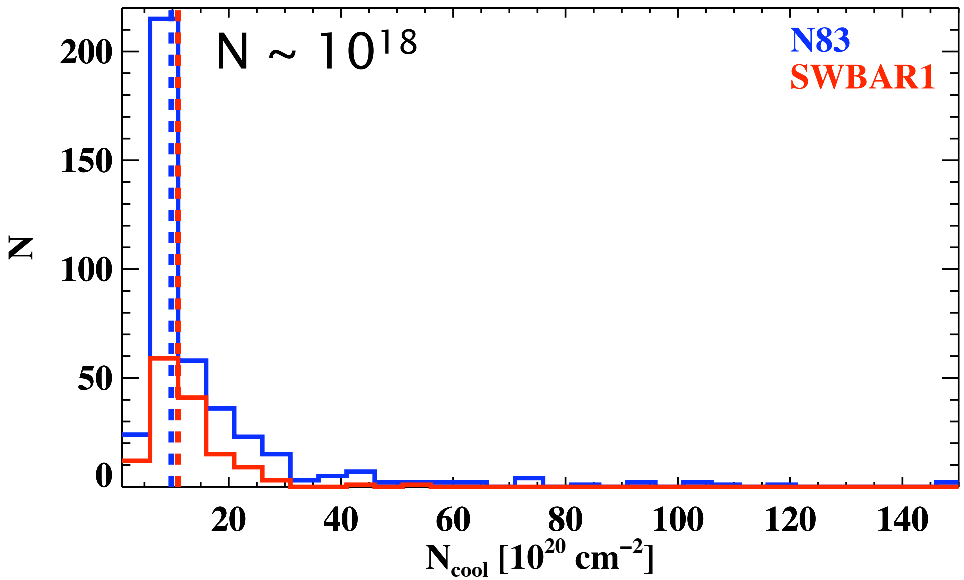


Physical conditions of warm H_2 in the SMC

$f(H_2 > 100K) \sim 10–20\%$







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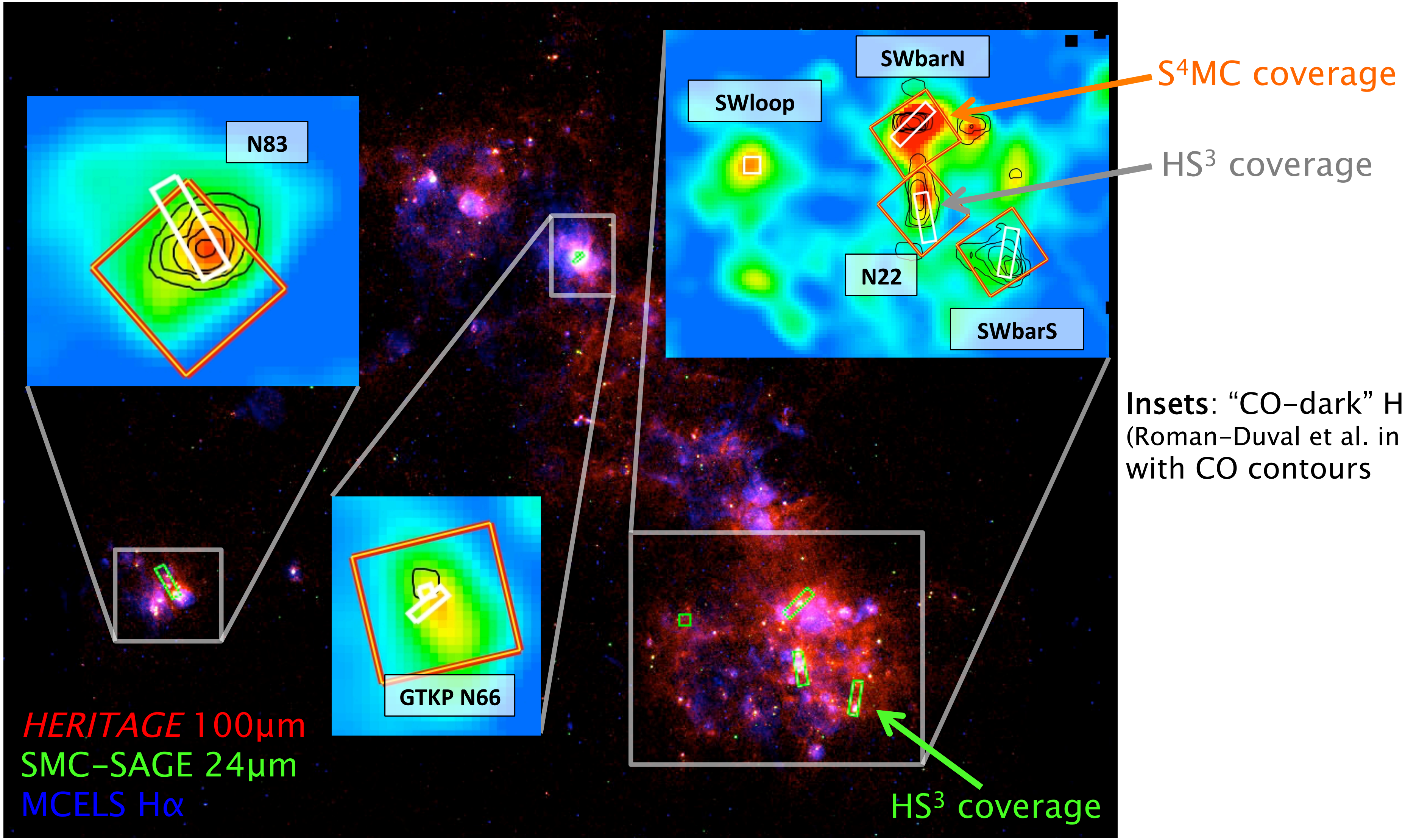
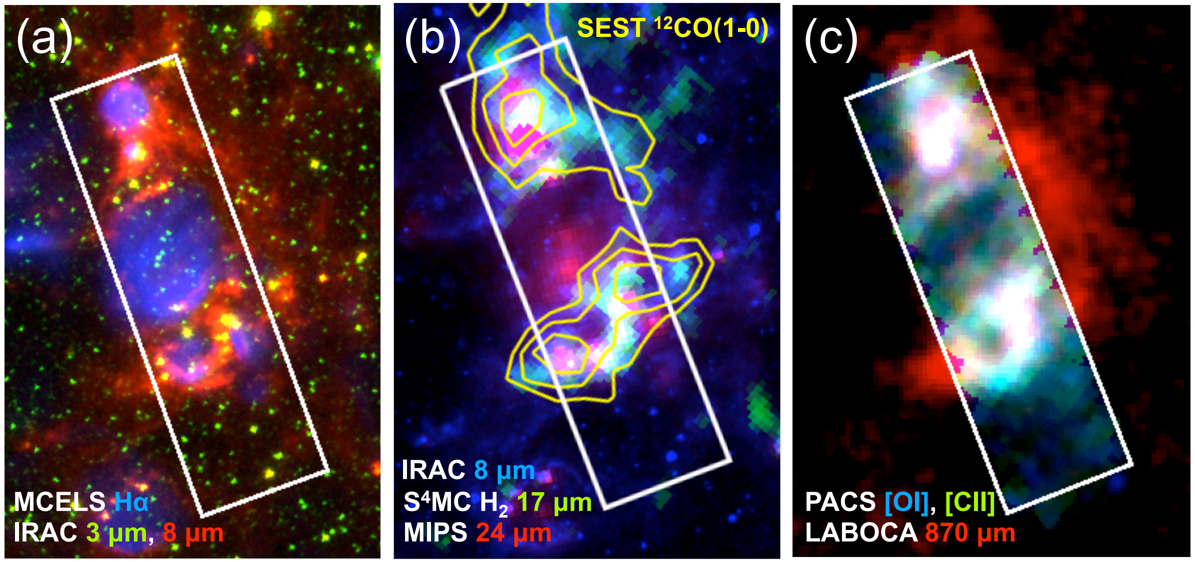
Herschel Spectroscopic Survey of the SMC (HS^3)



Insets: "CO-dark" H_2 map (Roman-Duval et al. in prep) with CO contours

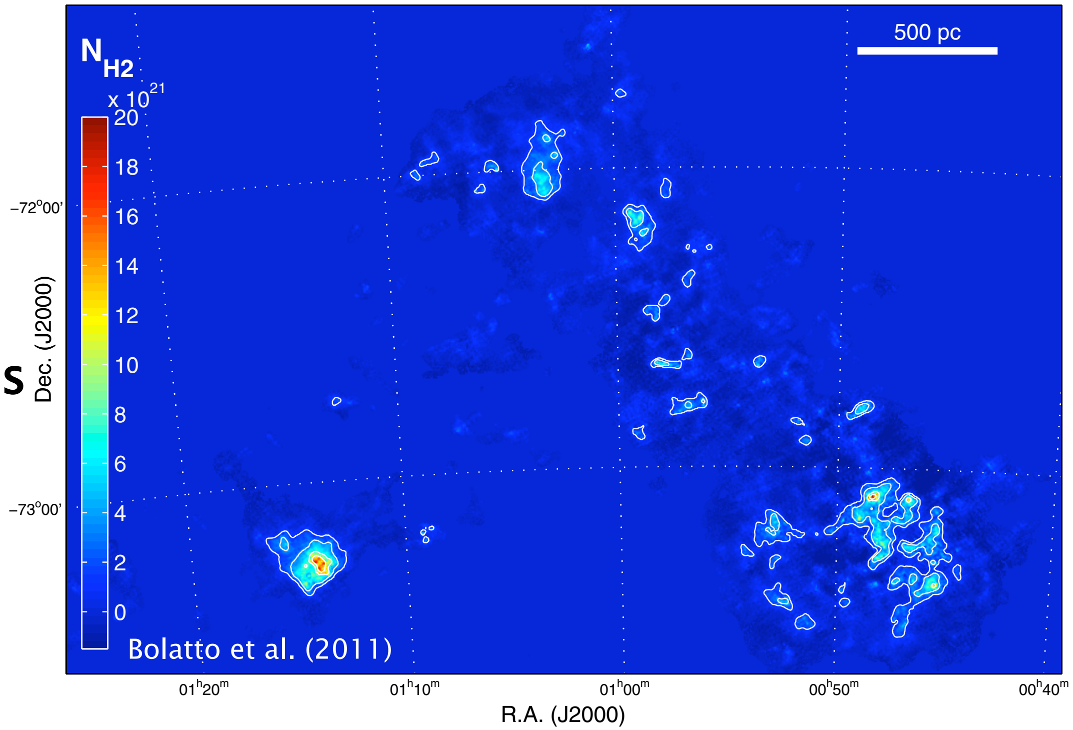
(PI: Bolatto)

Mapping the structure of "CO-dark" H_2 gas

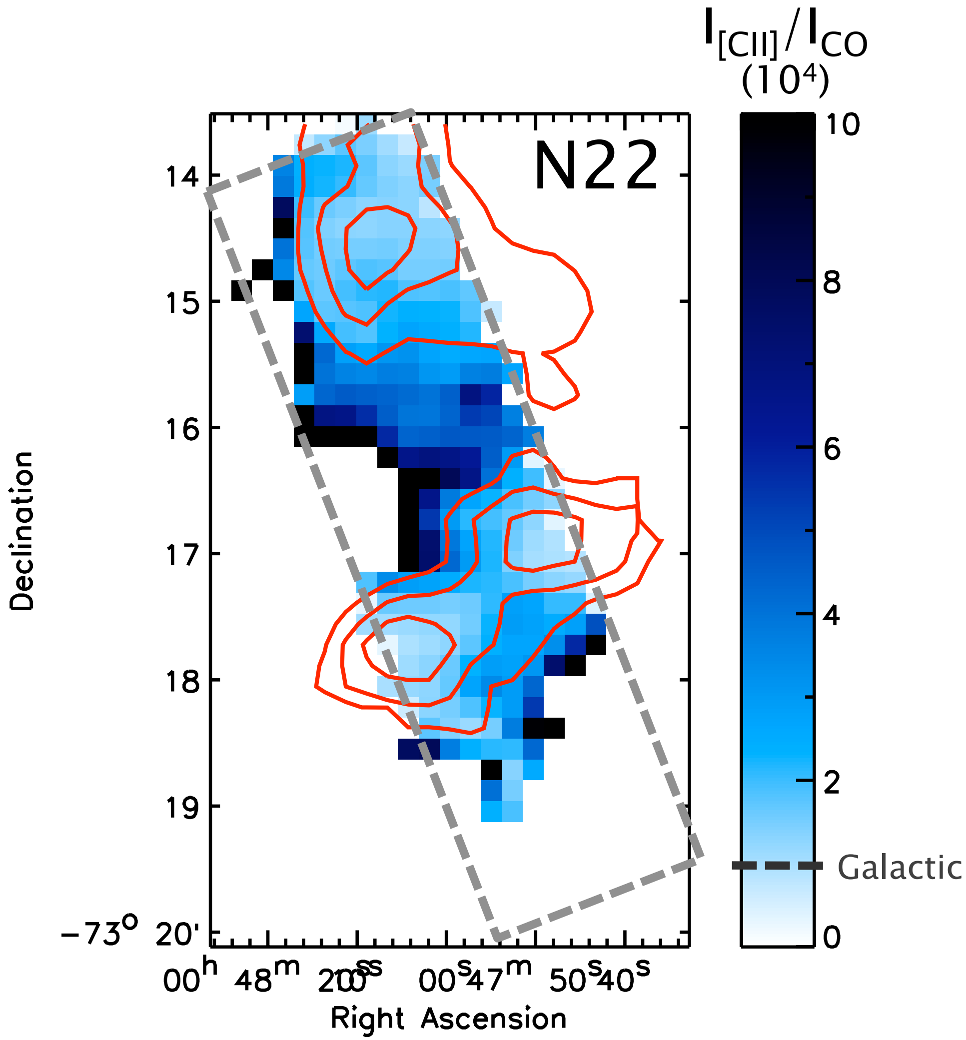


- Map detailed structure

- Anchor the dust-based H_2 estimates

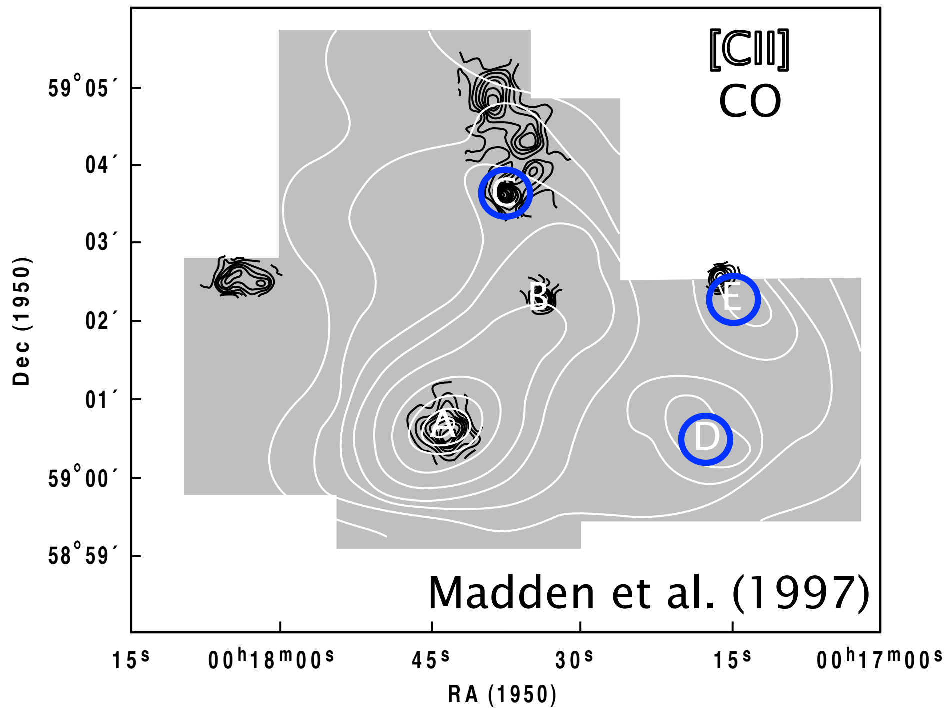


Preliminary results:
Comparing $I_{[CII]}/I_{CO}$ in N22 to IC 10

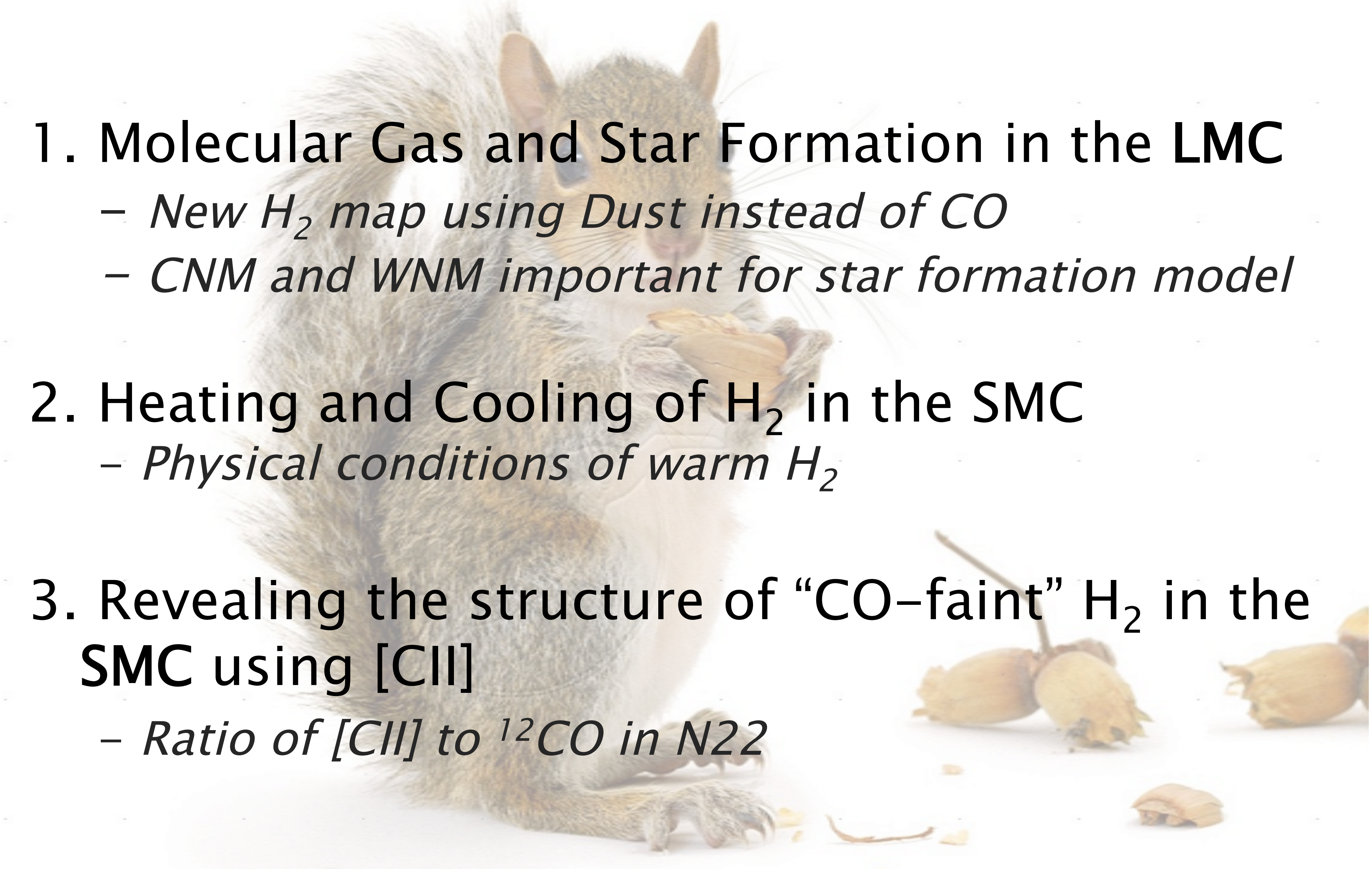


SEST CO(1-0) [1, 2, 3 K]

Position	$I_{[C II]}/I_{CO}$ [e] (10^4)
IC 10A	1.4
IC 10B	4.6
IC 10C	2.0
IC 10D	>8.7
IC 10E	8.7



THIS TALK IN A NUTSHELL



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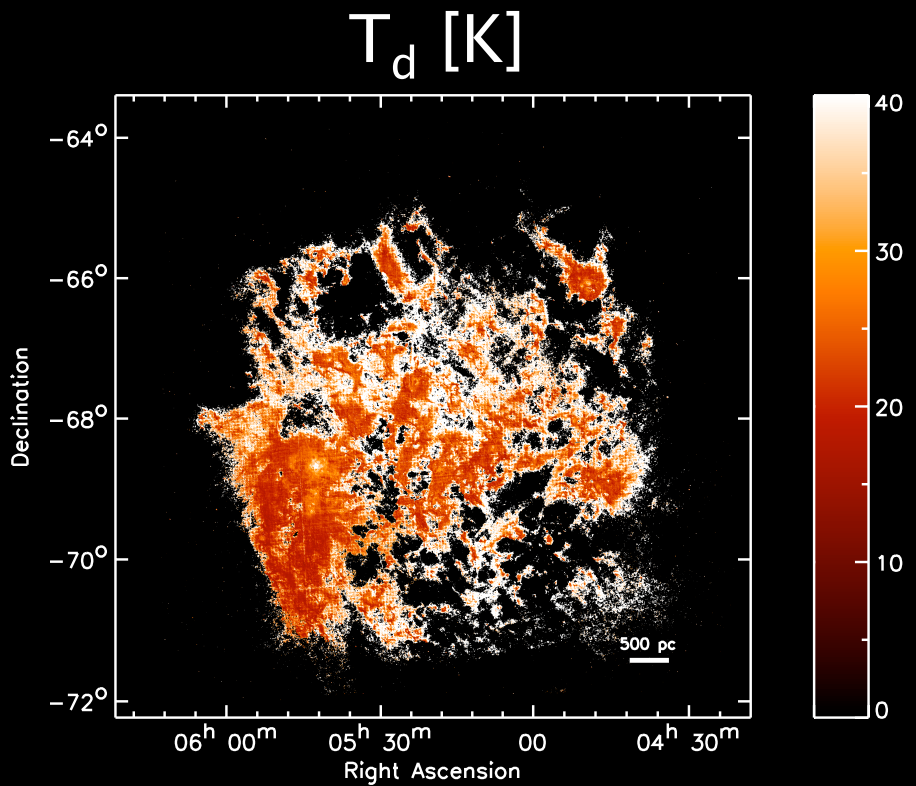
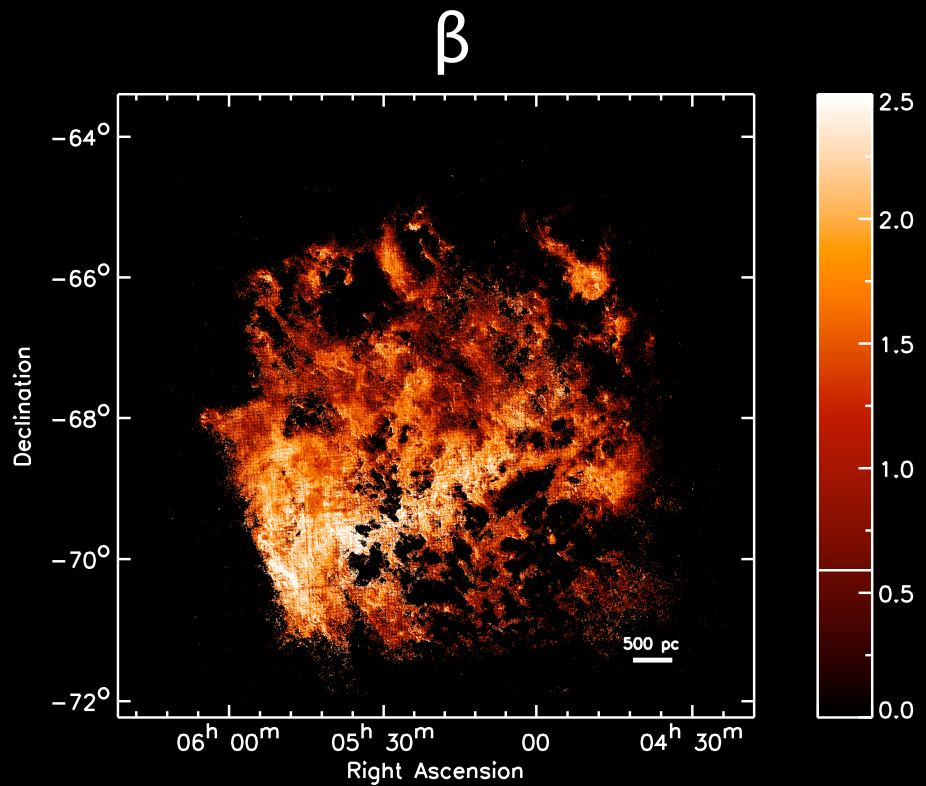
Extra Slides…

T_d and β across the LMC





Map H_2 using dust emission

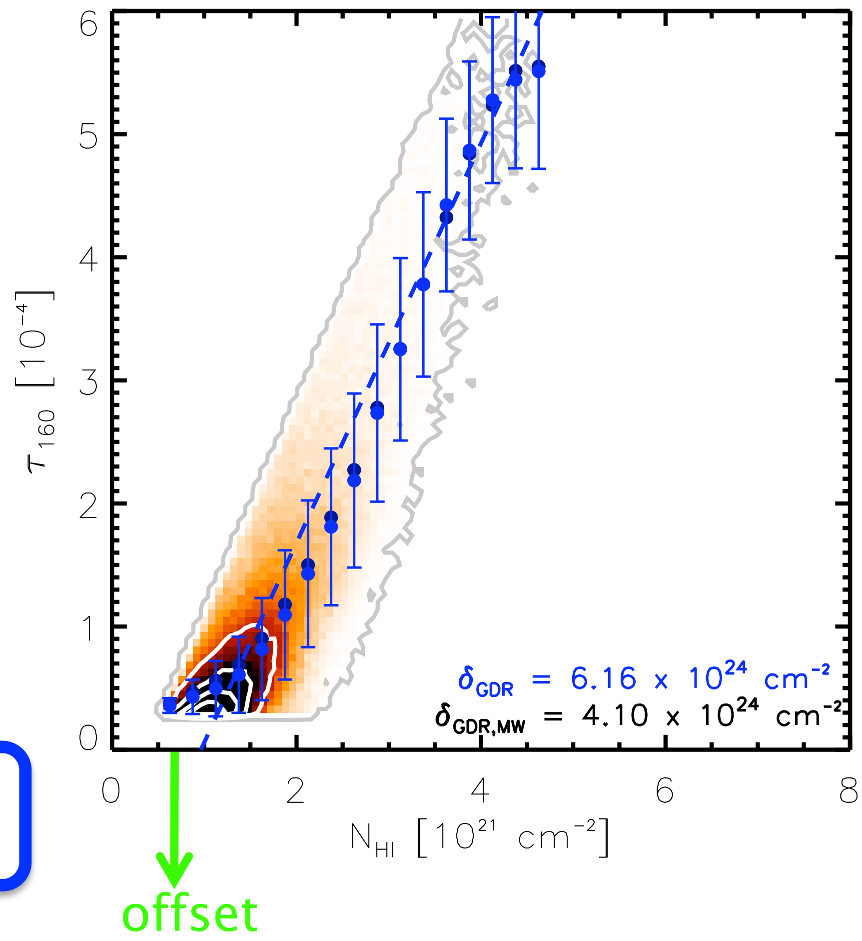
$$\Sigma_{gas} = \Sigma_{HI} + \Sigma_{H_2}$$

$$\Sigma_{dust} \propto \tau_{160\,\mu m}$$

$$\Sigma_{gas} = \boxed{\delta_{GDR}} \times \Sigma_{dust}$$

→ **fitted parameter**

$$\Sigma_{H_2} = \left(\delta_{GDR} \times \tau_{160\,\mu m}\right) - \Sigma_{HI}$$

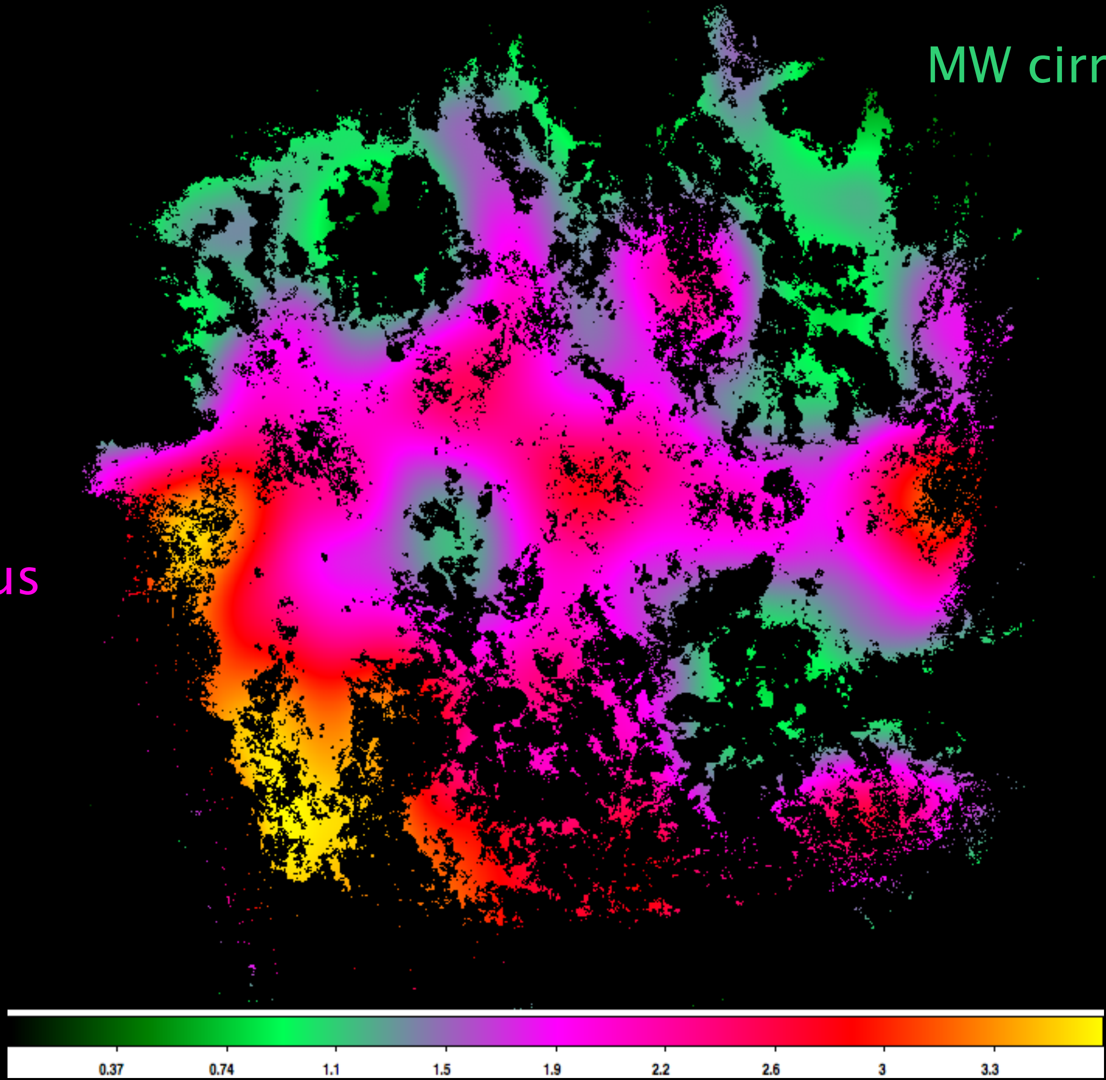


Previous Work:
MCs – Israel (1997); MW – Dame+ (2001);
SMC – Leroy+ (2007); Leroy et al. (2009); Bolatto et al. (2011)

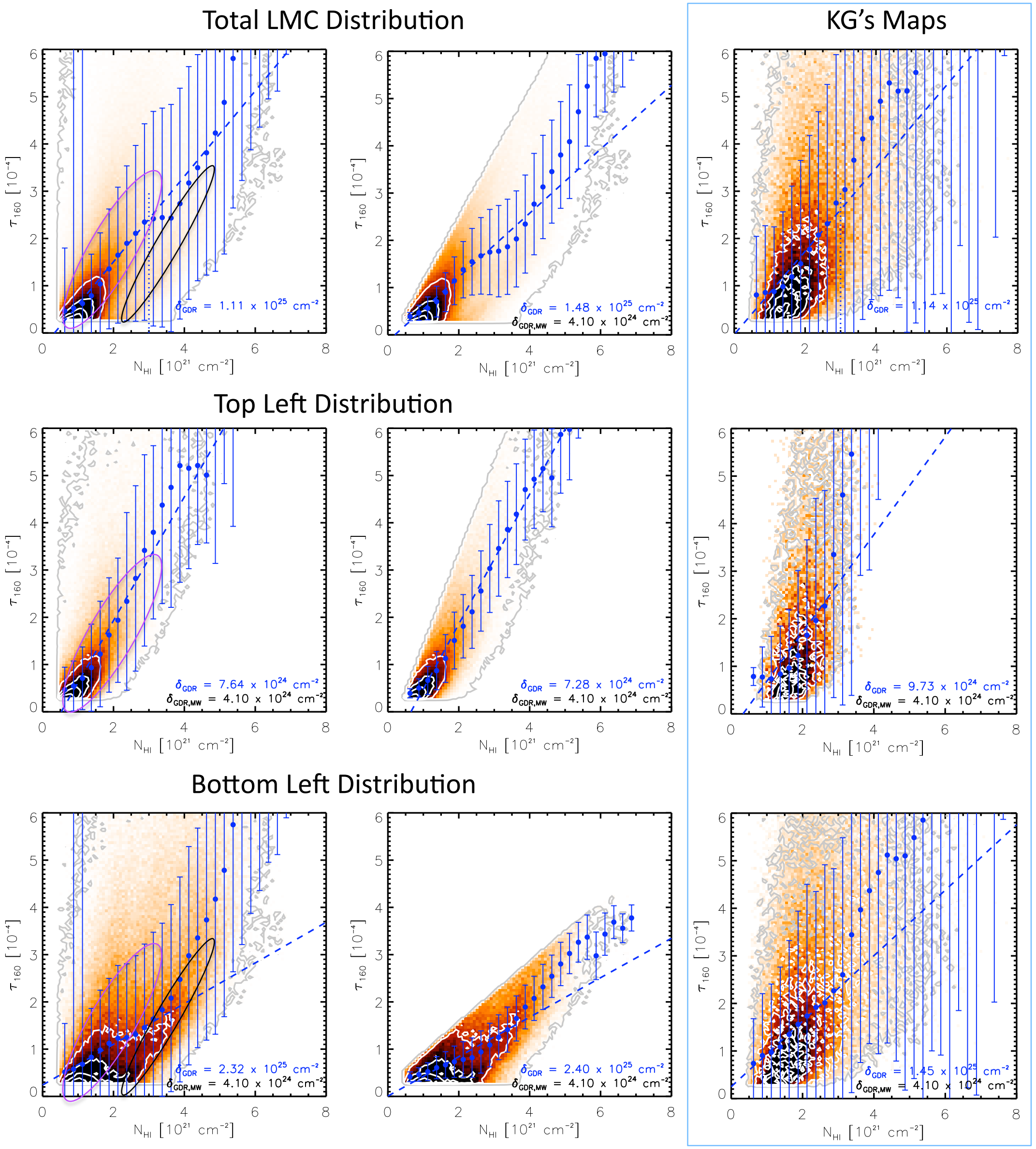
GDR map smoothed to 500 pc (β = 1.8)

MW cirrus value

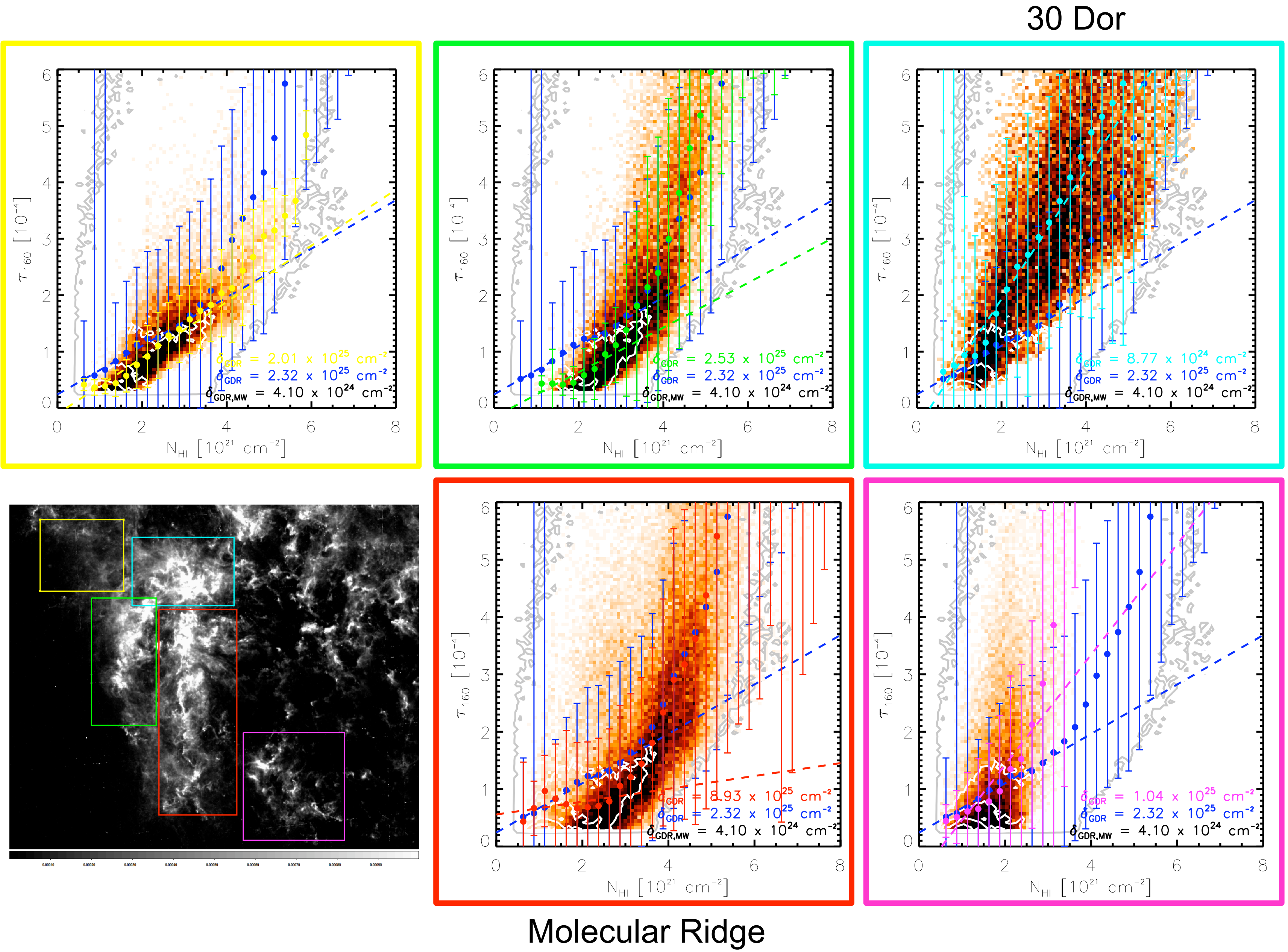
2 x MW cirrus value

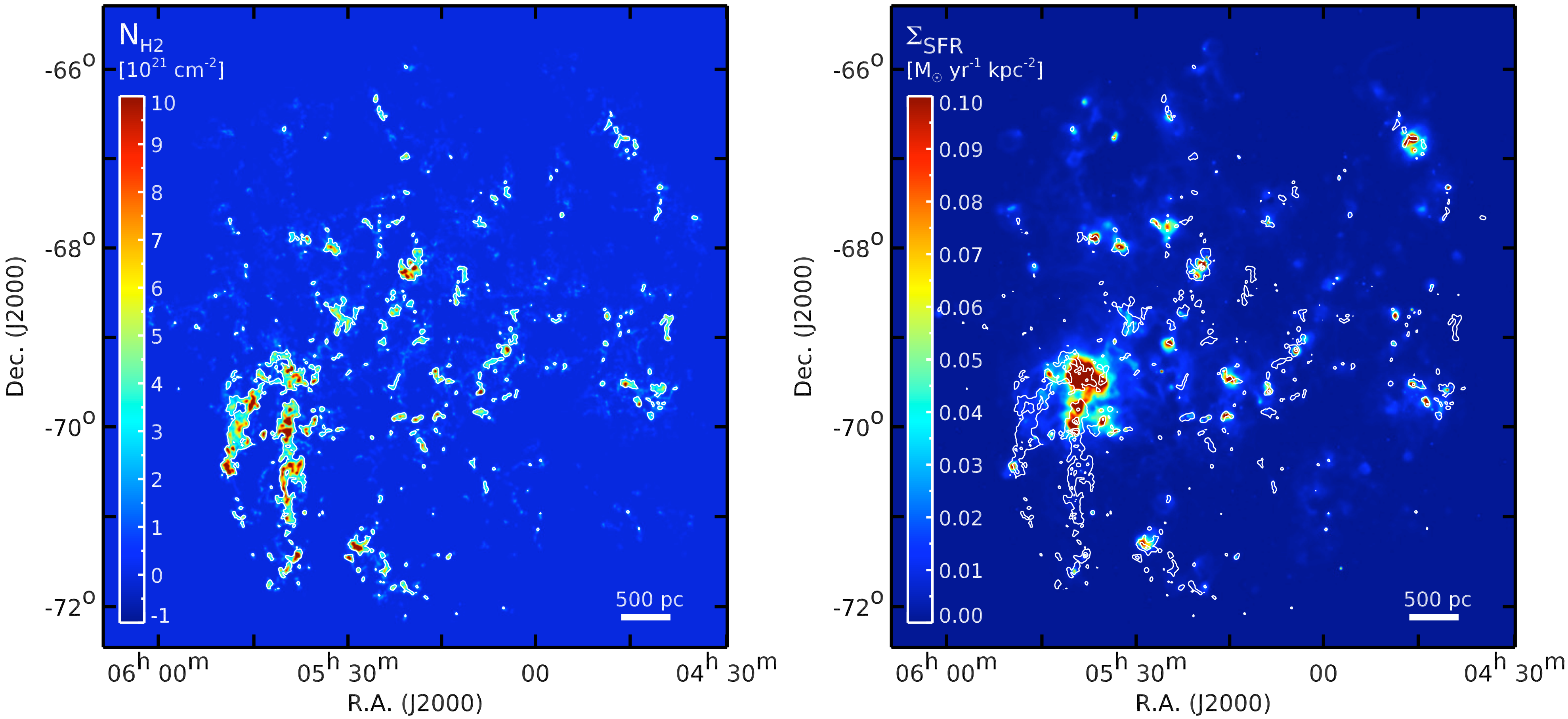


Regional variations in the GDR and N_{HI} offset



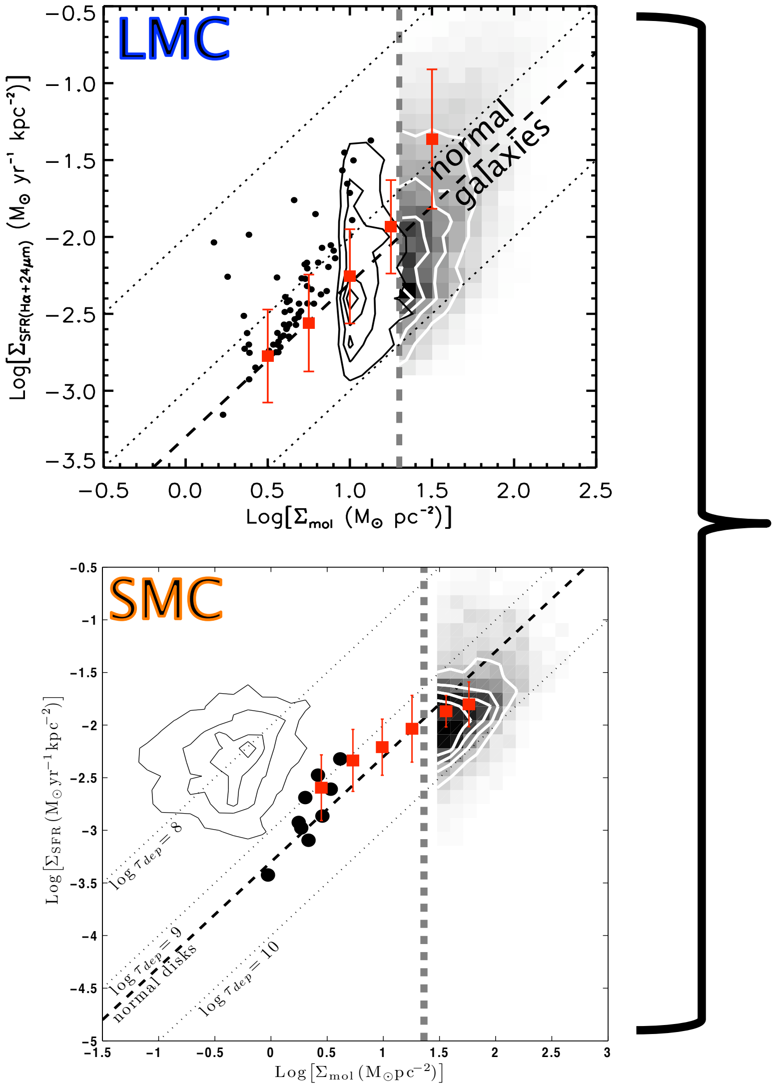
Regional variations in the GDR and N_{HI} offset

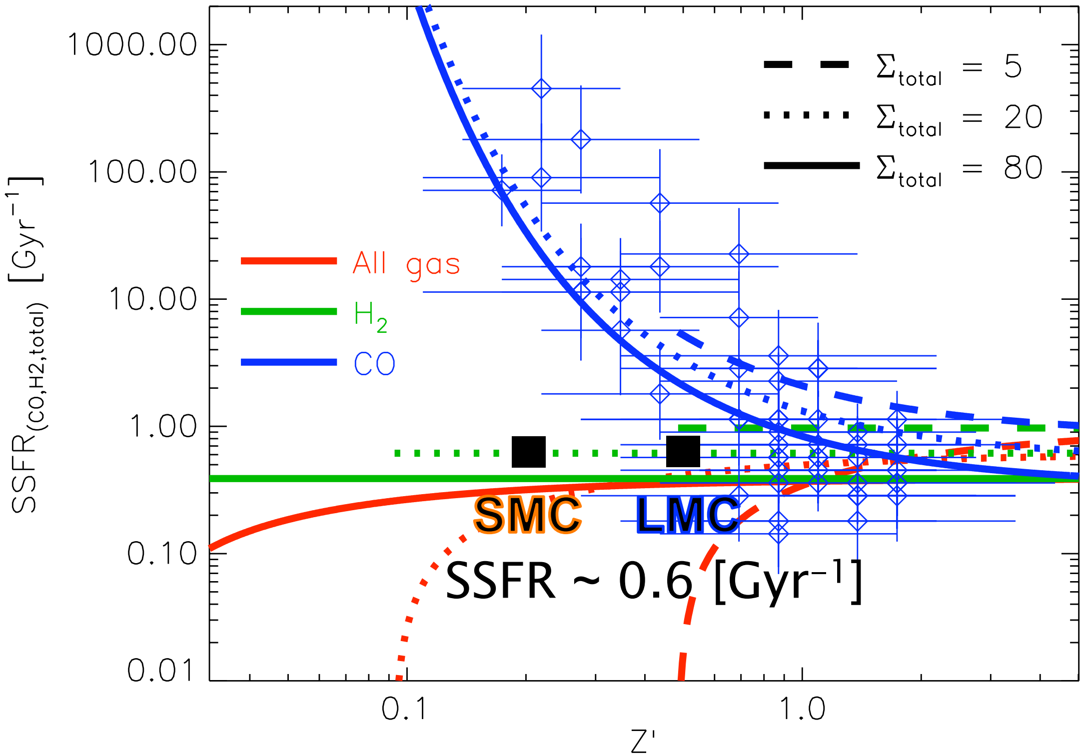




N_H2
[10^21 cm^-2]
10
9
8
7
6
5
4
3
2
1
0
-1
500 pc
-66°
-68°
-70°
-72°
Dec. (J2000)
06h 00m
05h 30m
00
04h 30m
R.A. (J2000)
Σ_SFR
[M☉ yr^-1 kpc^-2]
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
500 pc
-66°
-68°
-70°
-72°
Dec. (J2000)
06h 00m
05h 30m
00
04h 30m
R.A. (J2000)

Constant SSFR with decreasing metallicity

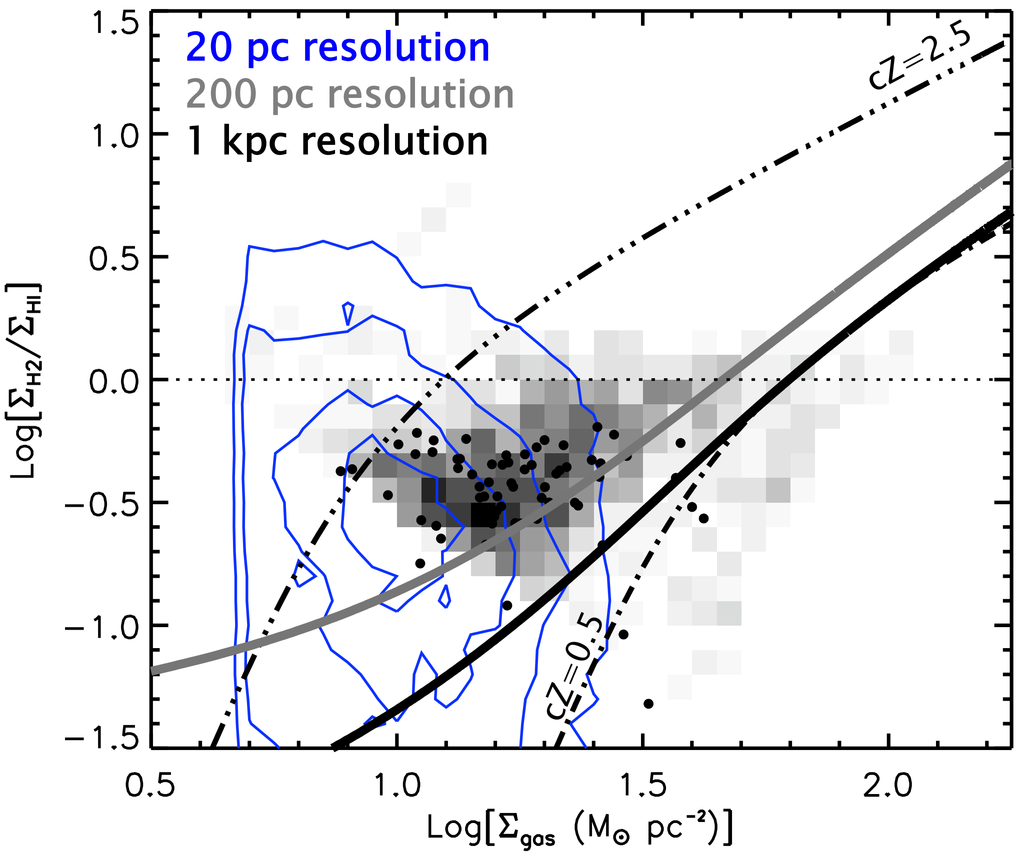




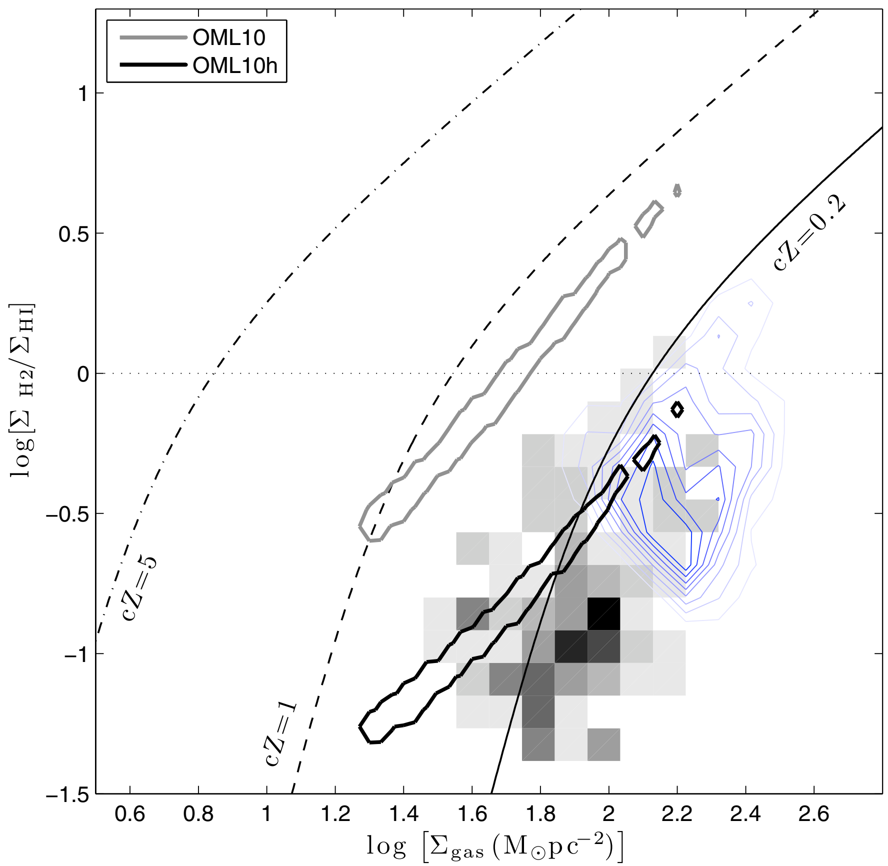
Krumholz et al. (2011)

Fraction of molecular gas as a function of metallicity

LMC

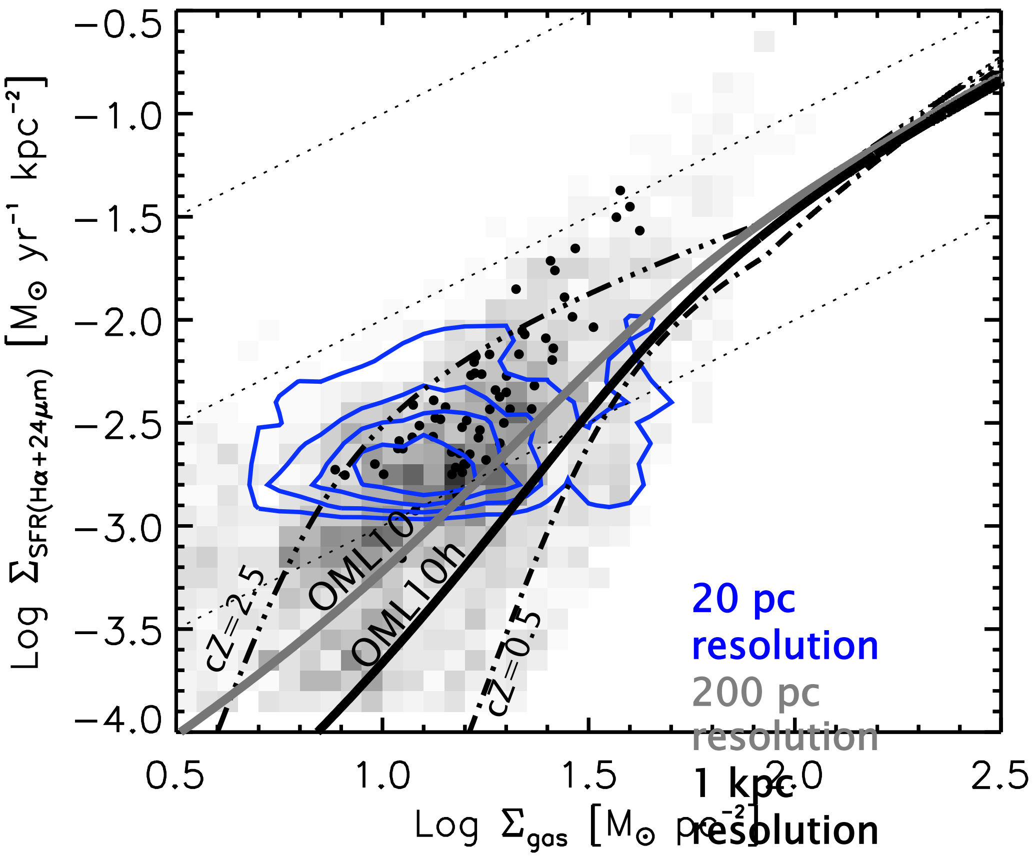


SMC

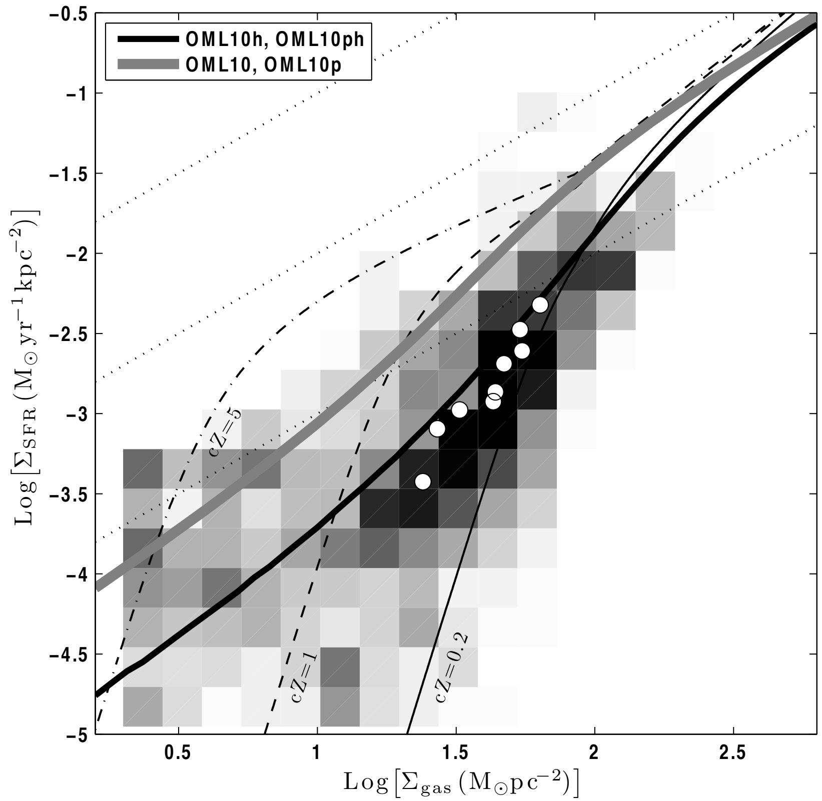


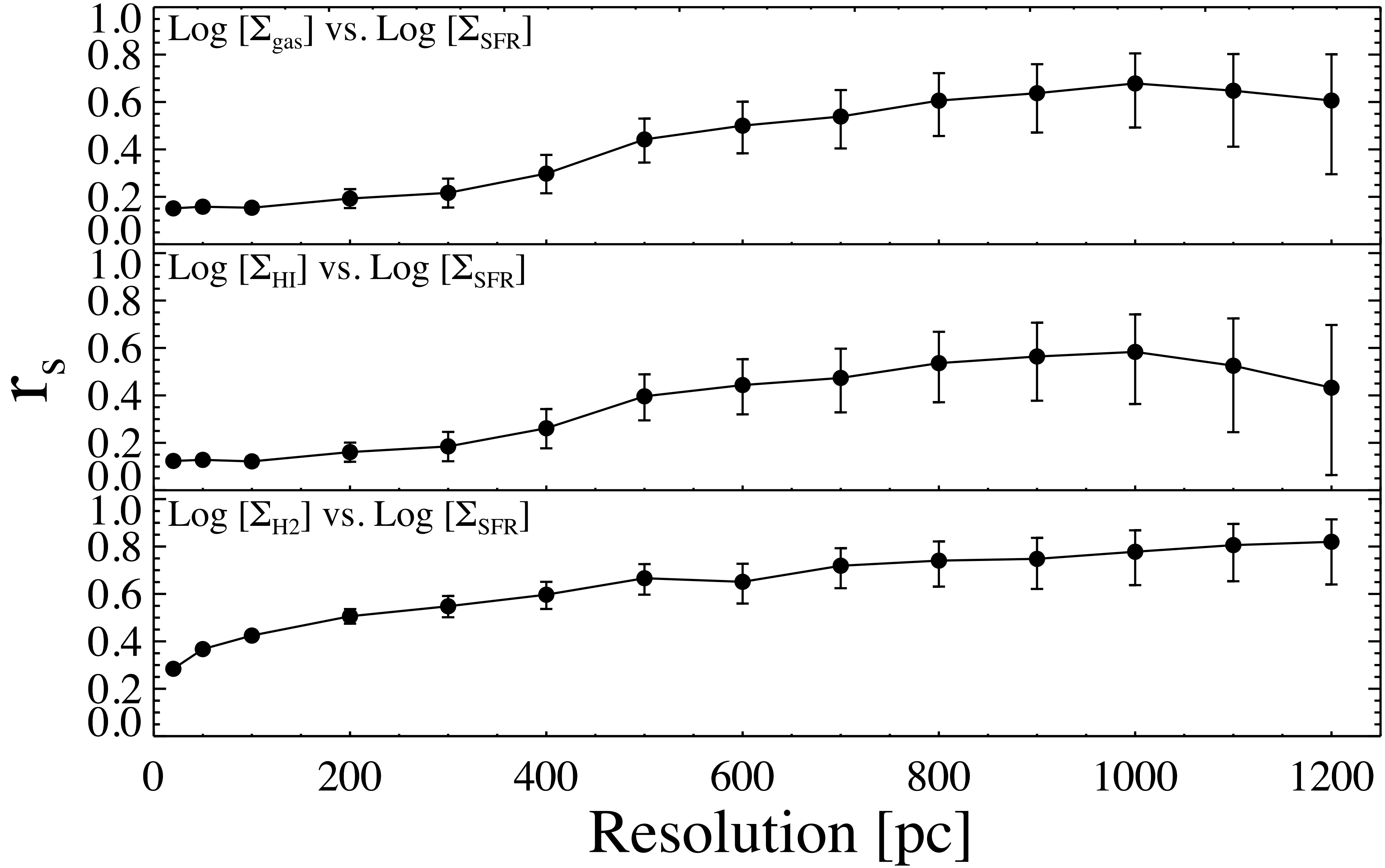
“Star Formation Law” as a function of metallicity

LMC

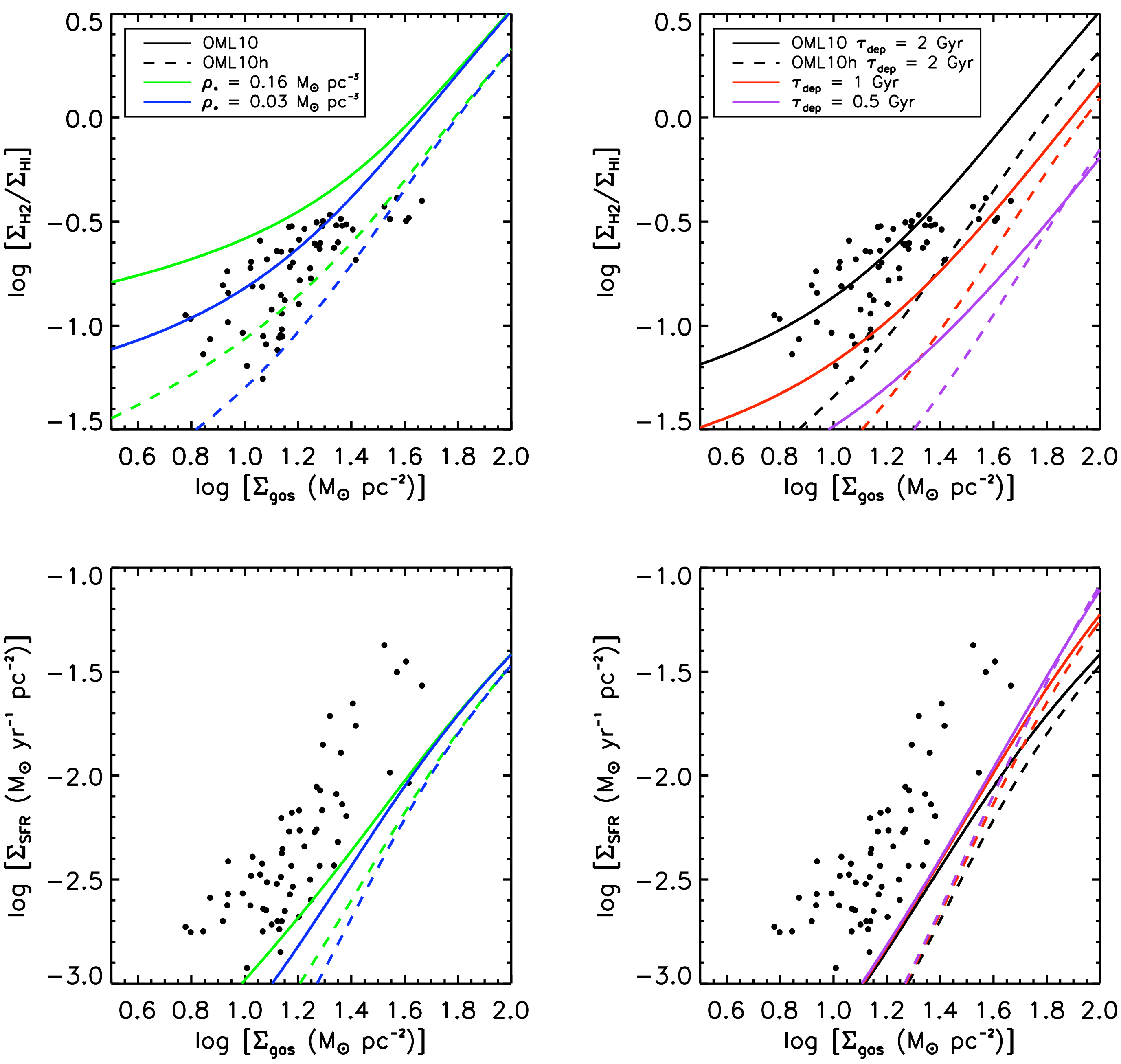


SMC



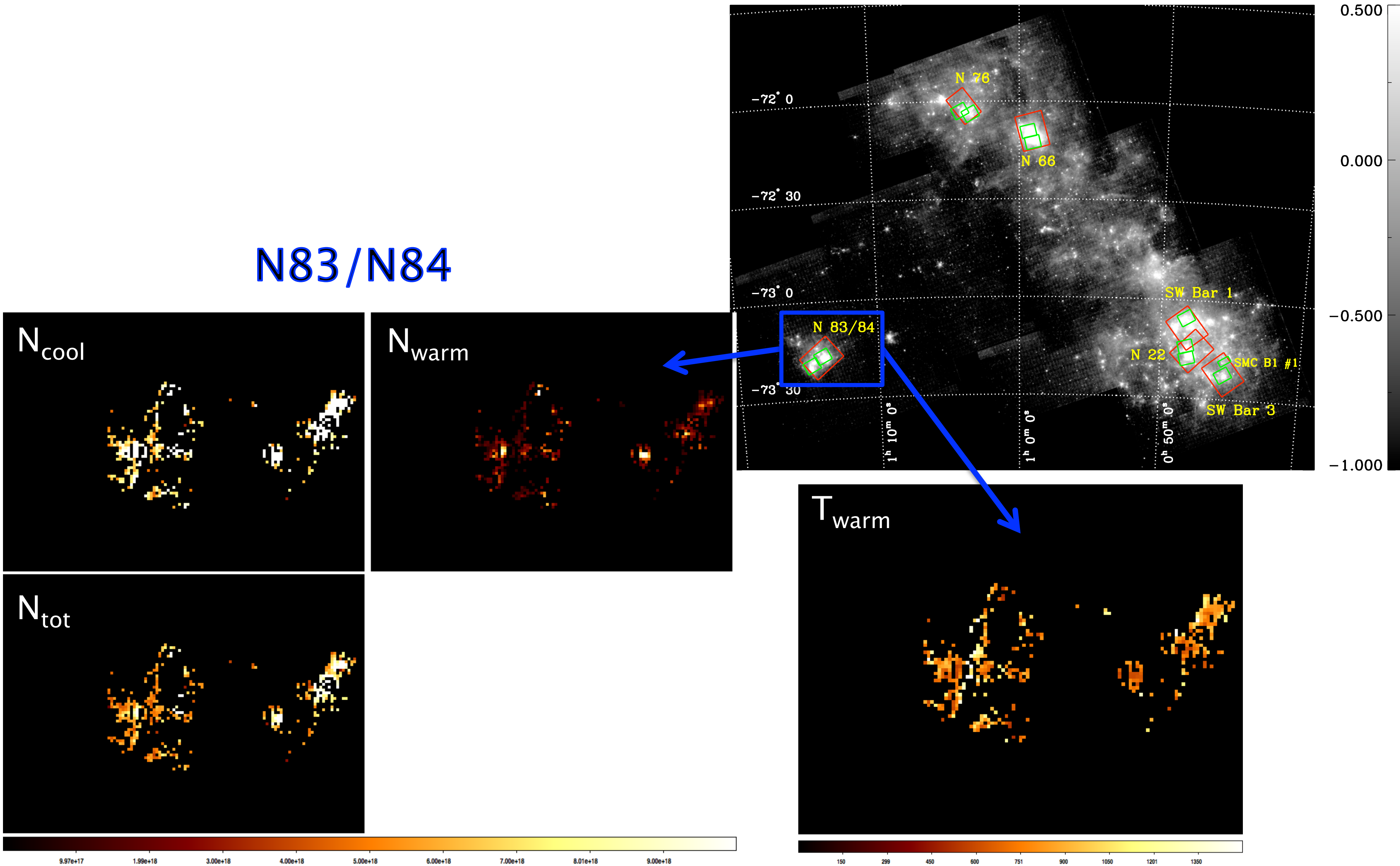


Log [Σgas] vs. Log [ΣSFR]
Log [ΣHI] vs. Log [ΣSFR]
Log [ΣH2] vs. Log [ΣSFR]
rs
Resolution [pc]
0.0
0.2
0.4
0.6
0.8
1.0
0
200
400
600
800
1000
1200

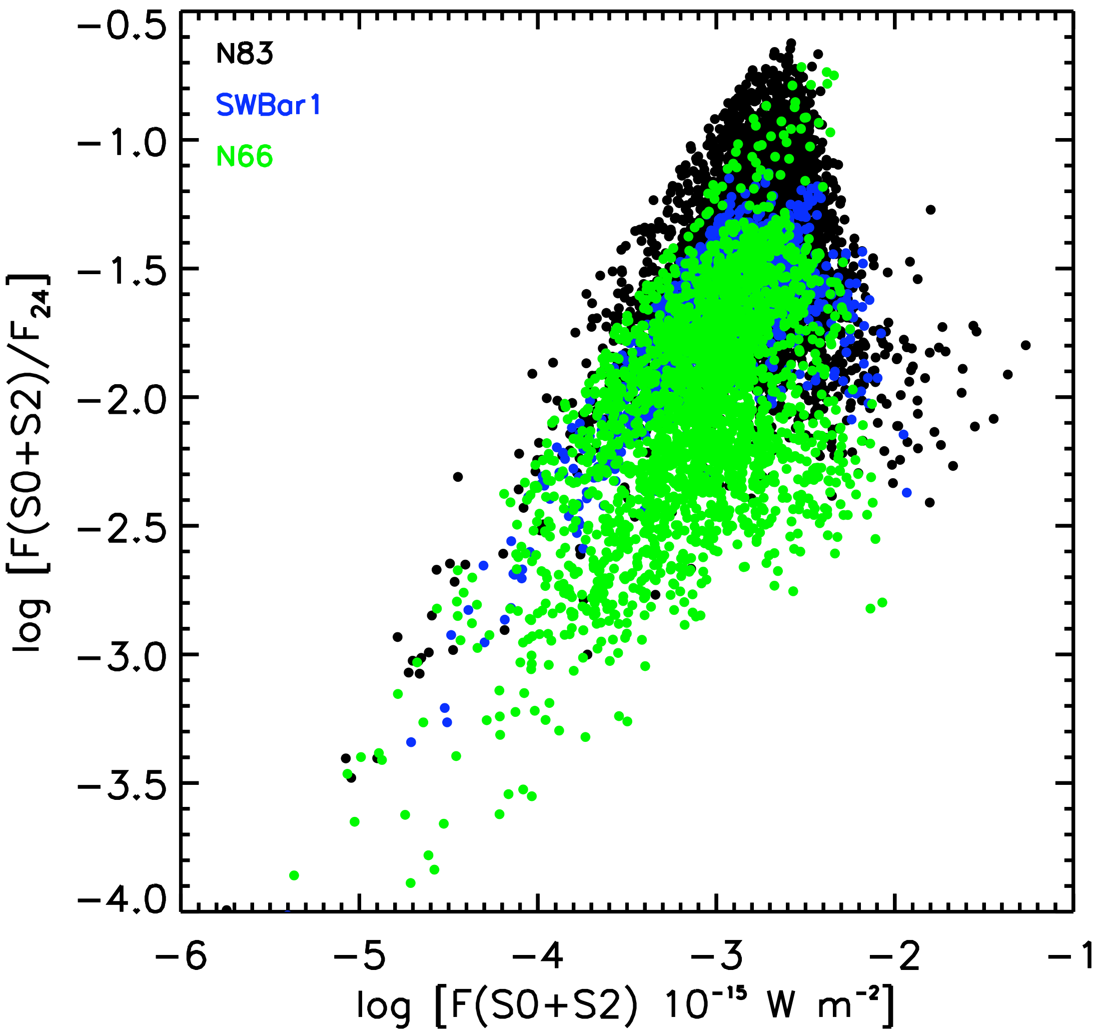


OML10
OML10h
ρ* = 0.16 M⊙ pc⁻³
ρ* = 0.03 M⊙ pc⁻³
log [Σ_H2/Σ_HI]
log [Σ_gas (M⊙ pc⁻²)]
OML10 τ_dep = 2 Gyr
OML10h τ_dep = 2 Gyr
τ_dep = 1 Gyr
τ_dep = 0.5 Gyr
log [Σ_SFR (M⊙ yr⁻¹ pc⁻²)]

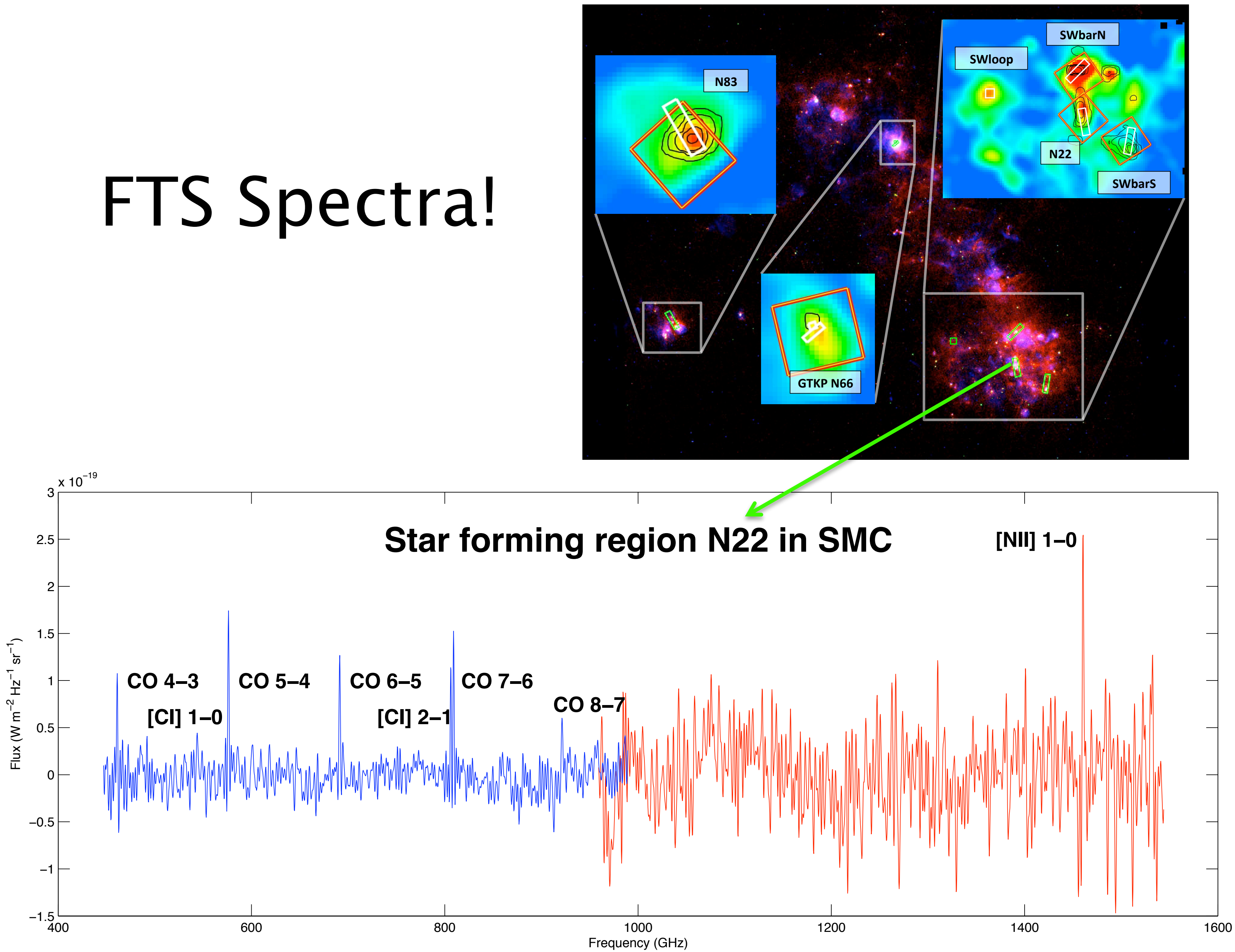
Results from modeling H_2 line emission



Heating and cooling of H_2 in the SMC



FTS Spectra!



N83
SWloop
SWbarN
N22
SWbarS
GTKP N66
Star forming region N22 in SMC
[NII] 1–0
CO 4–3
[CI] 1–0
CO 5–4
CO 6–5
[CI] 2–1
CO 7–6
CO 8–7
x 10^−19
Flux (W m^−2 Hz^−1 sr^−1)
Frequency (GHz)
3
2.5
2
1.5
1
0.5
0
−0.5
−1
−1.5
400
600
800
1000
1200
1400
1600