Molecular Line Probes of activity In low metallicity Galaxies

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Molecular gas in low metallicity galaxies _

-**Strong UV** fields+**low dust** content change:

-Cloud 'Structure' and 'phase balance' (HI/H_2, H_2/CO, CII/CI/CO)

-Physical parameters (n(H_2), Tk, X(e-),…)

-Chemistry PDRs
SHOCKs ('MDRs')
Hot cores
…

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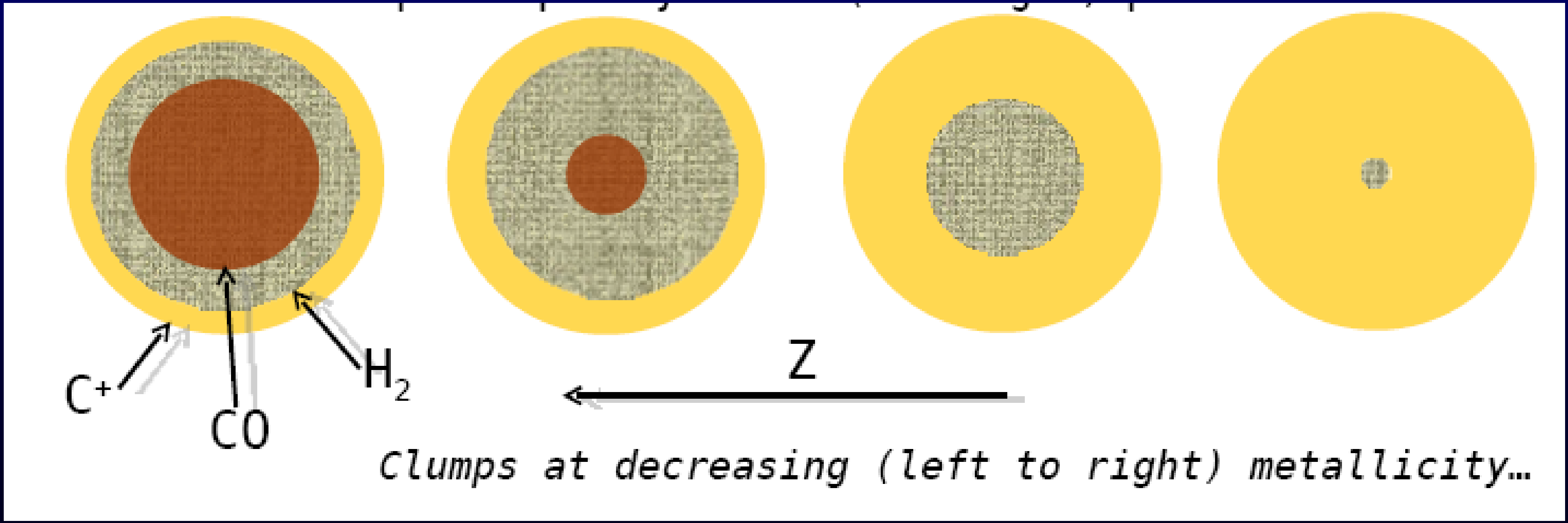
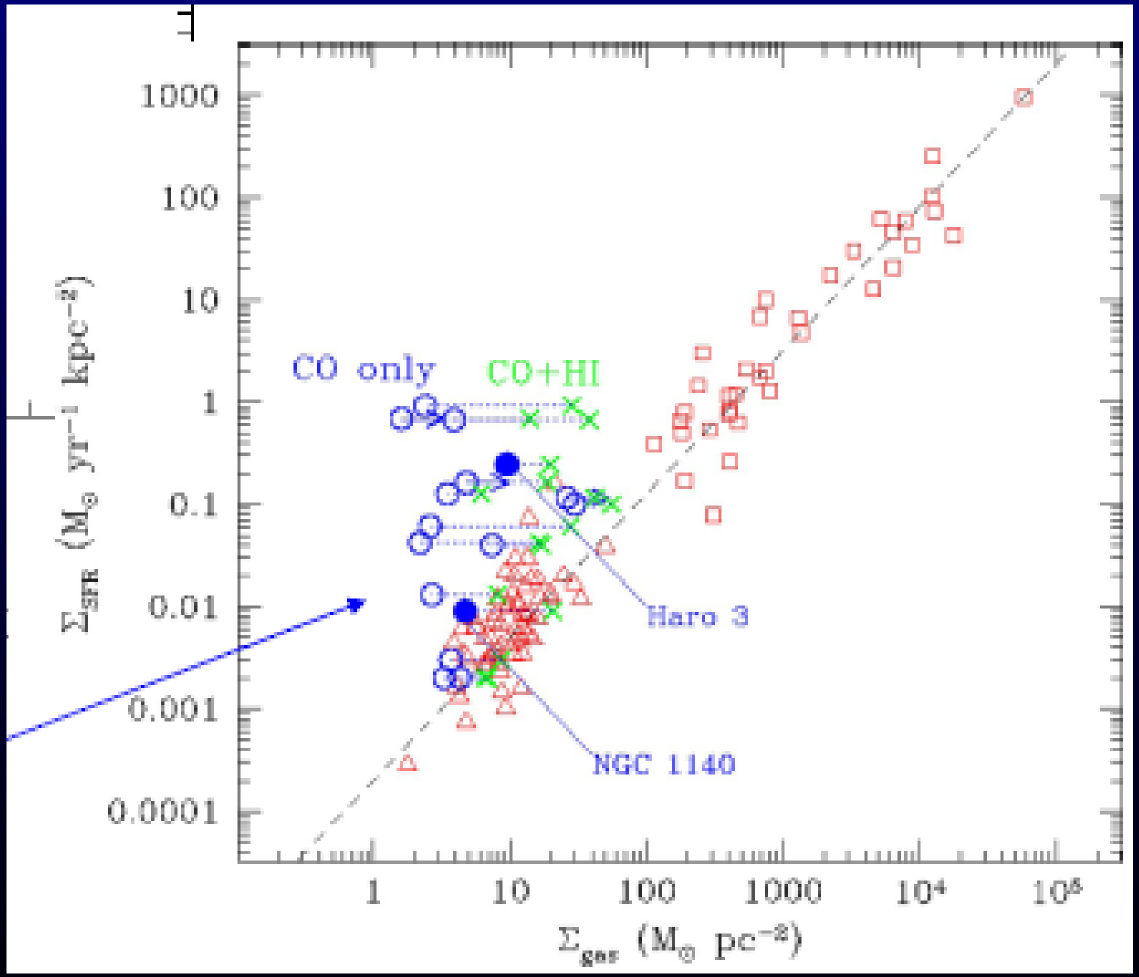
Cloud 'Structure': H_2/CO _

-CO 'deficiency' in low metallicity mol. gas…



CO defficiency in low Z dwarfs



Hunt et al. 2010

CO defficiency in low Z dwarfs

- Dust:gas ratio (DGR) ~ Z

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-[CO] ~ Z ?

- CO conversion factor X_{CO}: CO → H_2

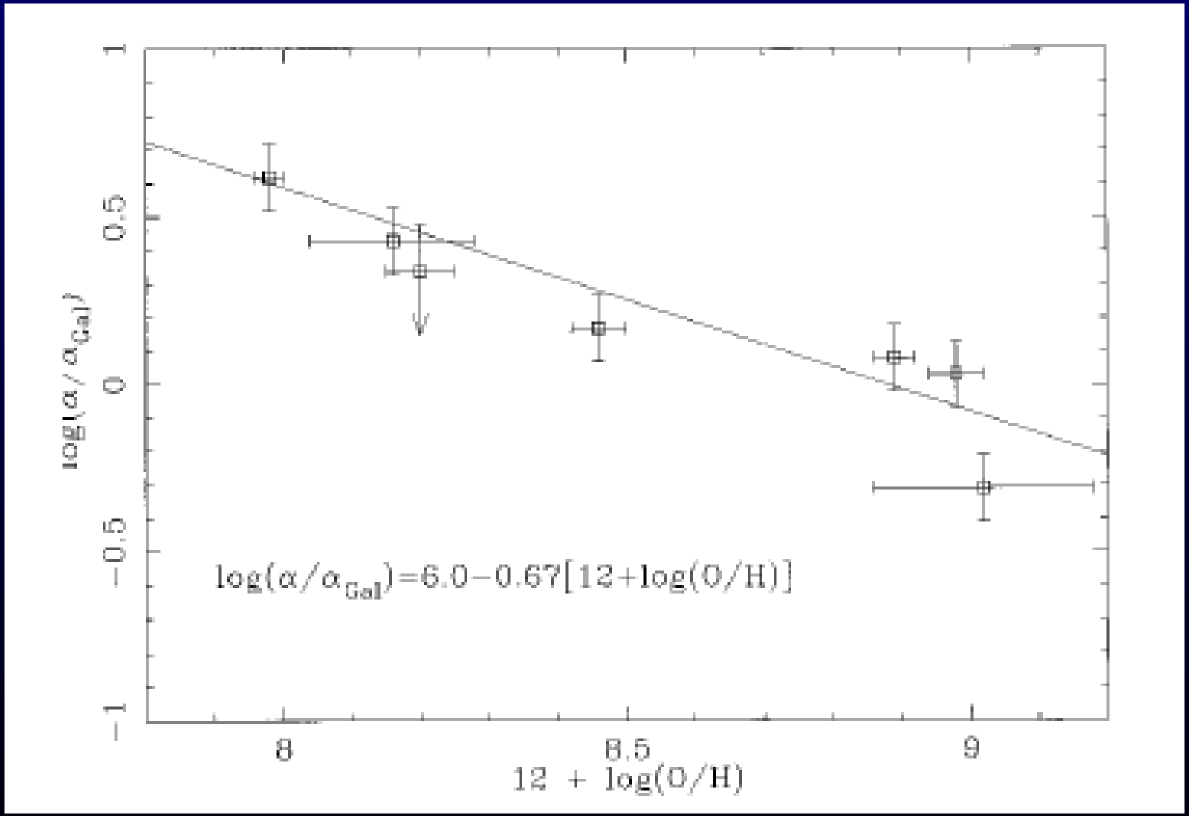
if [CO] ↑ → tau(CO) ↑ → $X_{CO} \neq f(Z)$

if [CO] ↓ → tau(CO) ↓ → $X_{CO} \sim Z^{-1}$

CO conversion factor: CO→H_2

-X_{CO} estimates from virial masses of <u>CO emitting</u> clouds

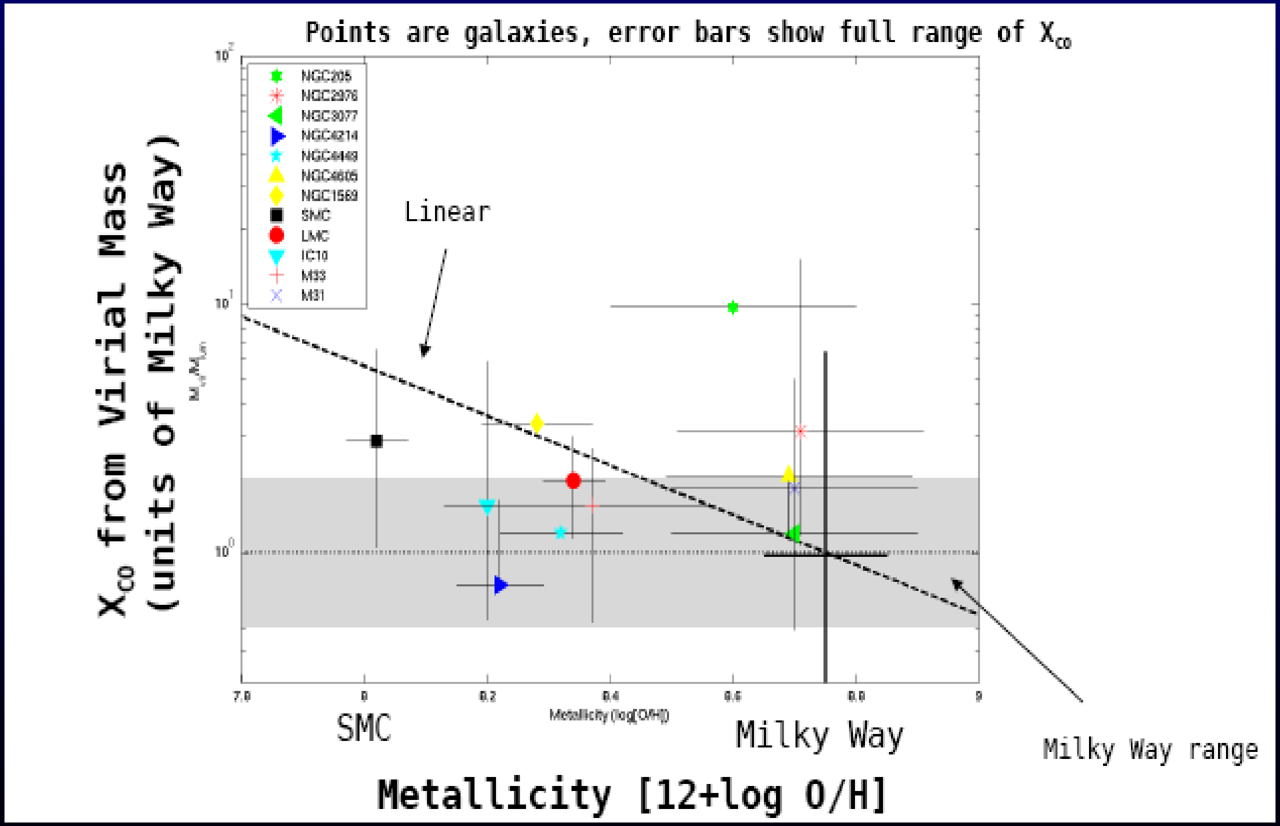
-X_{CO} increases by a factor 5 for a factor 10 decrease in Z



Wilson 1995

CO conversion factor: CO→H_2

- X_{CO} estimates from virial masses of <u>CO emitting</u> clouds
- No clear trend in X_{CO} with Z !



Bolatto et al. 2008

CO conversion factor: CO→H_2

-X_{CO} estimated from FIR data (+ HI): ‘global’ X_{CO}

$$\Sigma_{H2} = (\Sigma_{dust} \times DGR^{-1}) - \Sigma_{HI}$$

*Estimate **dust surface density** from IR (need at least two bands to make a temperature estimate).*

*Measure the **dust-to-gas ratio** from the ratio of dust to atomic gas away from the molecular line emission but near*

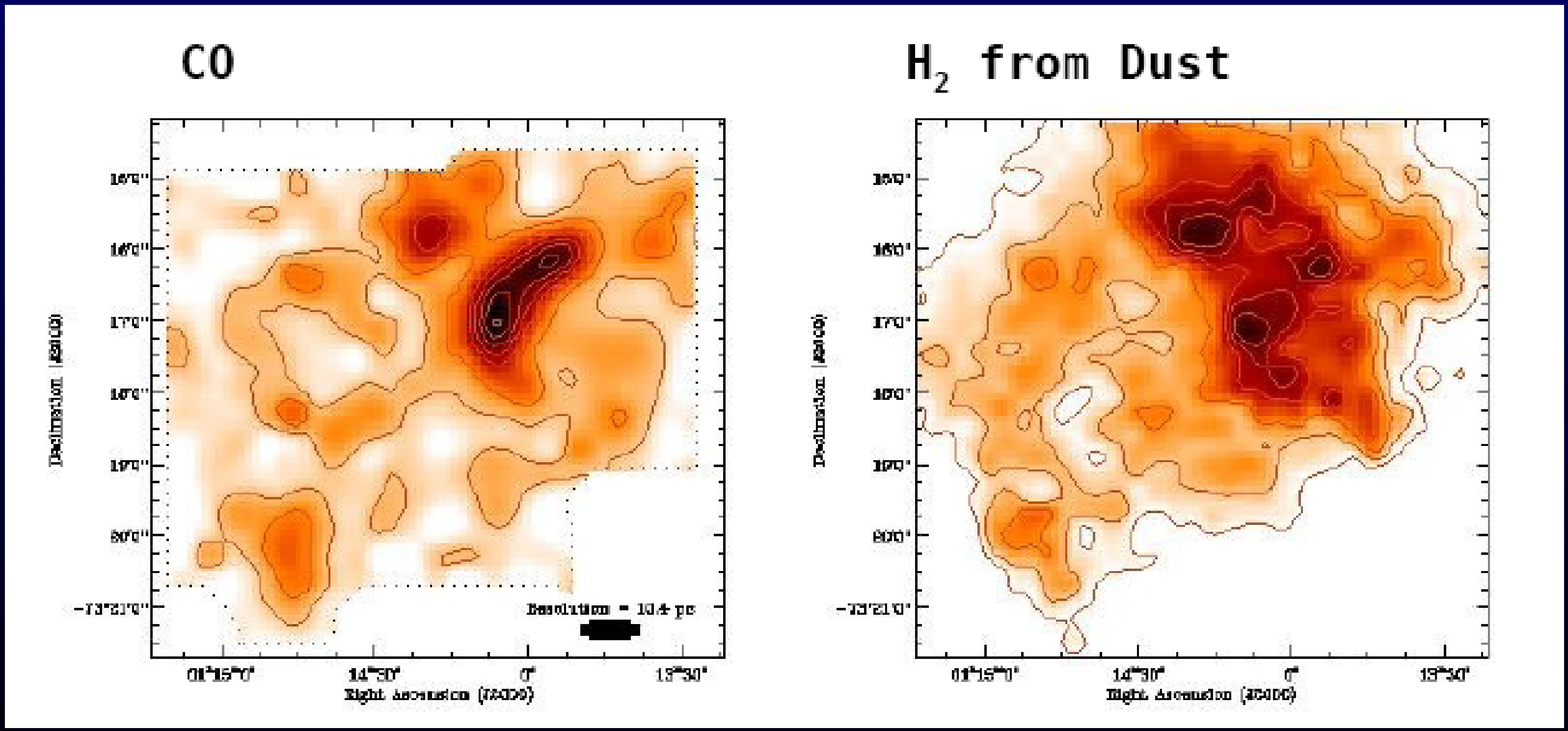
*Subtract the already known distribution of **atomic gas**.*

Leroy et al. 2009

CO conversion factor: CO→H_2

-X_{CO} estimated from FIR data (+ HI): ‘global’ X_{CO}

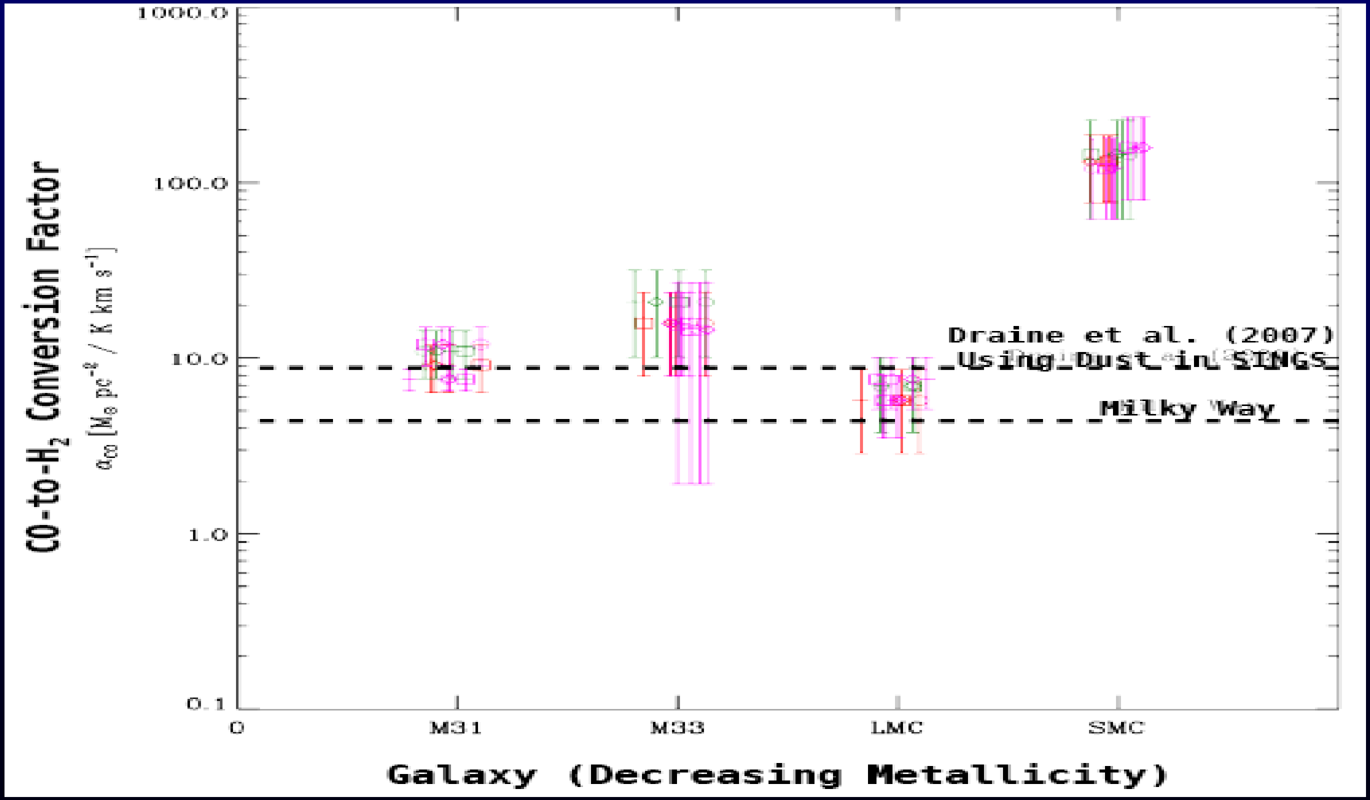
N83 complex in the SMC



Leroy et al. 2009

CO conversion factor: CO→H_2

‘global’ X_{CO} [SMC] ~ 20-30 x X_{CO} [MW]



Leroy et al. 2010

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Physical parameters of mol. clouds in low Z galaxies:

-Multi-species studies of molecular gas in dwarfs

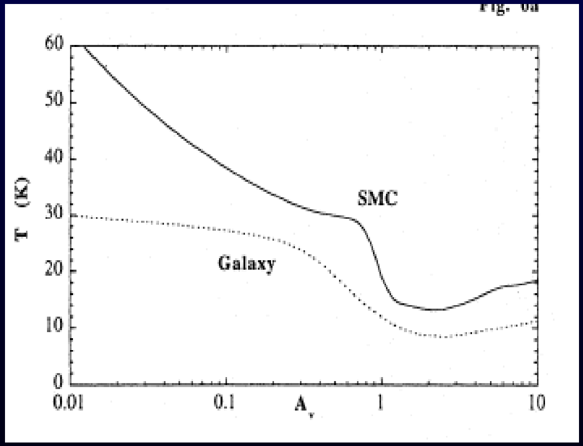
-^{12}CO, ^{13}CO, CI, CII, other molecules…

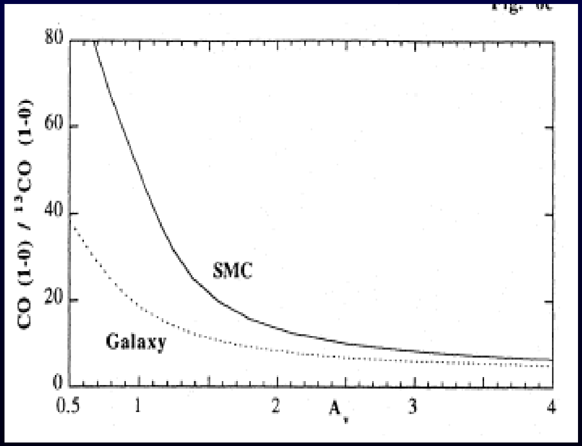
Physical parameters of mol. clouds in low Z galaxies:

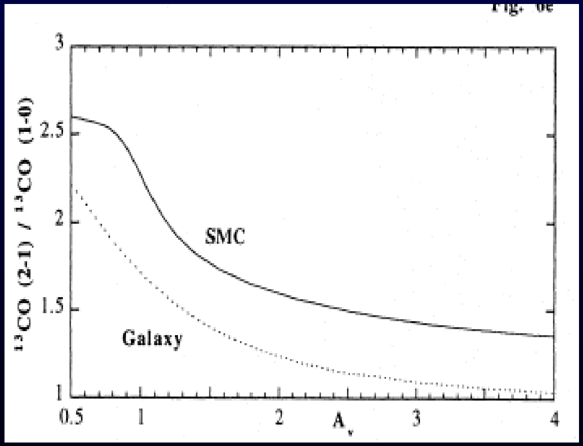
-Multi-species studies of molecular gas in dwarfs

-SF molecular clouds in the SMC *Lequeux et al. 1994*

Modeling of 1-0 and 2-1 ^{12}CO + ^{13}CO ratios @ SMC







T_k (SMC)> T_k (MW)

cloud size (SMC)< cloud size(MW)

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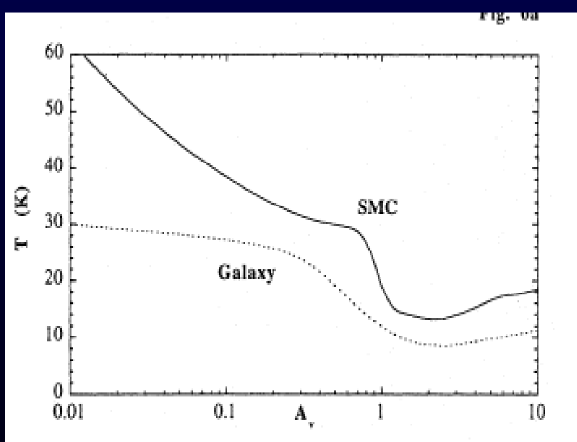

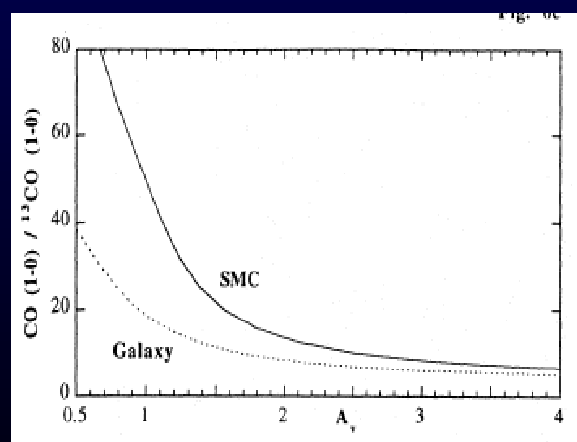

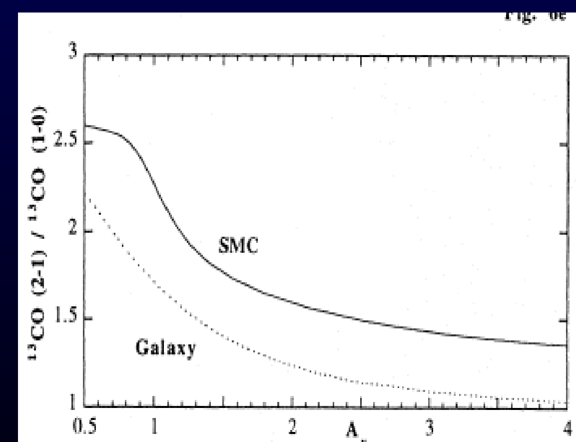

'HOT(ter)' than in MW **'SMALL(er)' than in MW**

Physical parameters of mol. clouds in low Z galaxies:

-Mol. clouds in the SMC + LMC *Bolatto et al. 2005*

Modeling of (1-0, 2-1, 3-2, 4-3) ^{12}CO + (1-0, 2-1) ^{13}CO ratios

	"Cold Dense" Component			"Hot Tenuous" Component	
Source	Kinetic Temperature T_k (K)	Volume Density $n(H_2)$ (cm^{-3})	Column Density $N(CO)/dV$ (cm^{-2} km^{-1} s)	Kinetic Temperature T_k (K)	Volume Density $n(H_2)$ (cm^{-3})
			LMC		
N83A..........	10	10^5	10×10^{17}	100	10^5
	60	10^5	1×10^{17}	150	$(5-10) \times 10^2$
	150	10^5	3×10^{17}	150	10^2
N159W.......	20	10^5	1×10^{17}	100	10^2
N167..........	20	10^4	0.6×10^{17}	30–60	$(1-10) \times 10^2$
			SMC		
N12............	150	10^5	10×10^{17}	150	$(1-5) \times 10^2$
N27............	30	10^5	0.6×10^{17}	60–100	10^2
N66............	20–60	10^4–10^5	6×10^{17}	300	10^4
N83............	10–30	10^4	$(1-2) \times 10^{17}$	100	3×10^3

Two phases

cold (10-30K)+ **dense** ($10^5 cm^{-3}$) and **hot** (100-300K) + **tenuous** (10^2-$10^3 cm^{-3}$)

Physical parameters of mol. clouds in low Z galaxies:

-Mol. clouds in the LMC (N159W region) *Pineda et al. 2008*

Modelling of (1-0, 4-3, 7-6) ^{12}CO + (1-0, 4-3) ^{13}CO + (1-0, 2-1)CI ratios

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One phase modelling (escape probability scheme…)

moderately **dense** ($10^4 cm^{-3}$) and **hot** (80K !!)

…but probably requires more than one phase…

PDRs in low metallicity dwarfs

-Mol. clouds in the LMC **(N159W region)** *Pineda et al. 2008*

Modelling of (1-0, 4-3, 7-6) ^{12}CO + (1-0, 4-3) ^{13}CO + (1-0, 2-1)CI ratios

↓

PDR clumpy modelling

dense ($10^5 cm^{-3}$) and **low mass clumps** (0.1-1Msun !!)

…the upper clump mass cut-off is just 0.1-1Msun

→

a broken up structure of the ISM

PDRs in ´solar´ metallicity SBs

M82

Lord et al. 1996

Mao, Henkel et al 2000

Atomic lines CI, CII, OI

12CO and 13CO lines

PDR models of molecular gas

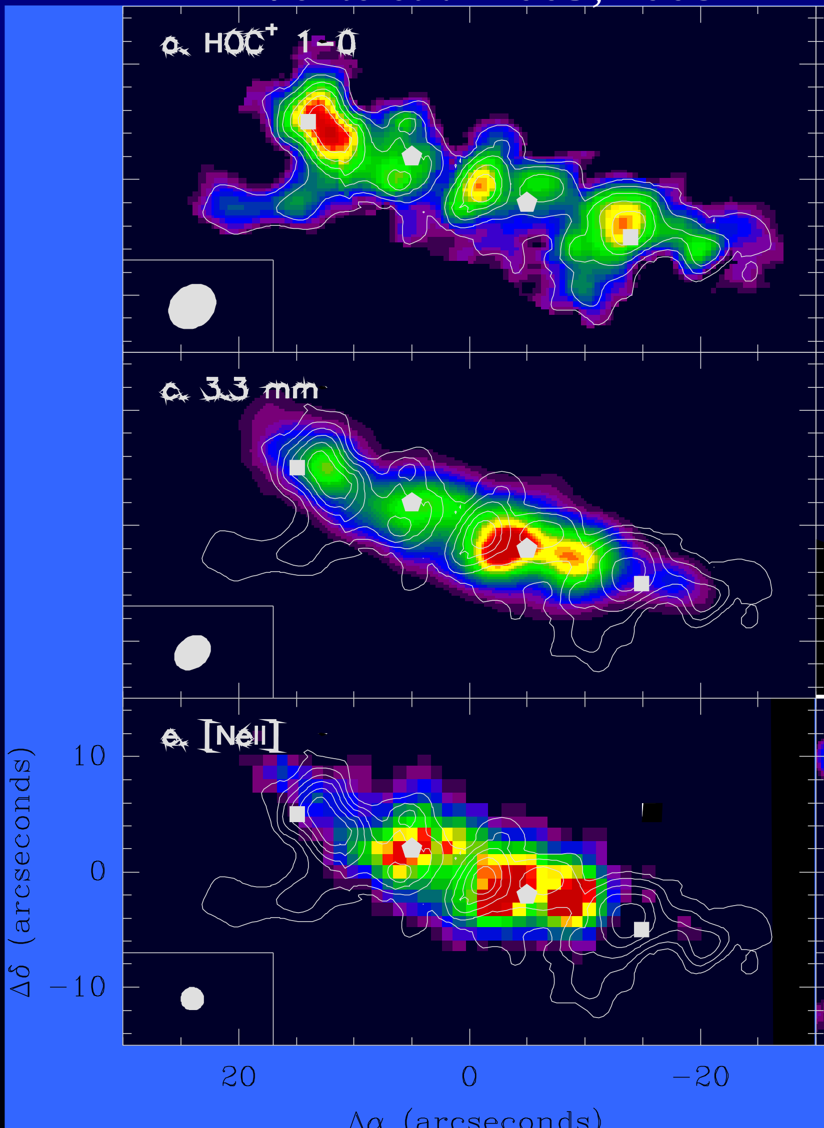
Molecular ´clouds´ are….

- Small (r<<1pc)
- Moderately dense (n_{H2} ~10^{3-4})
- Low mass : 100- 1000 Msun <<M_{GMC}(MW)
- Immersed in intense UV-field $G_0=10^3$

PDRs in ´solar´ metallicity SBs

M82 *Garcia-Burillo et al 2002, 2010*

Fuente et al 2005, 2008



PdBI HOC^+ HCO CN maps

30m CN, CO+, CS…

PDR models of ´dense´ gas

Molecular ´cloud cores´ are….

- Small (r<<1pc)
- Dense (n_{H2} ~10^5)
- Low mass ´filaments´: < 0.01 Msun
- Immersed in intense UV-field $G_0=10^4$
- Highly-ionized: X(e-) > 10^{-5}

PDRs in low metallicity dwarfs

-Mol. clouds in the LMC (N159W region) *Pineda et al. 2008*

⬇

PDR clumpy modelling

dense ($10^5 cm^{-3}$) and **low mass clumps** (0.1Msun !!)

PDRs in low Z dwarfs are pretty extreme compared to M82

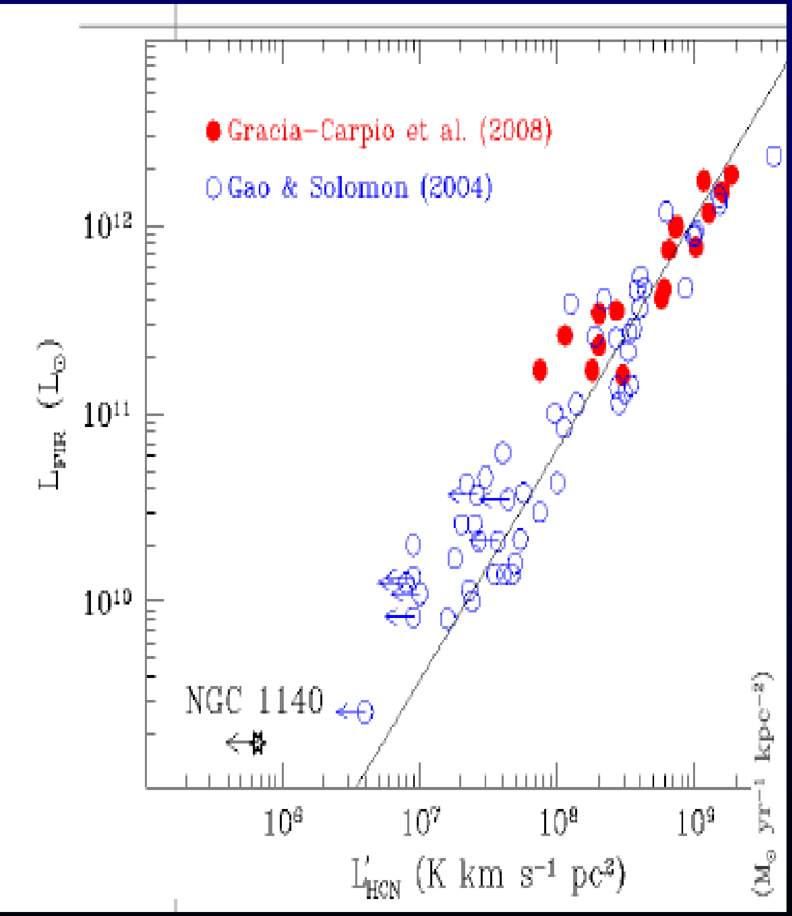
➡

Clumps of much smaller size and smaller masses → can we detect the cores??

PDRs in low metallicity dwarfs: NGC1140

Hunt et al. 2010

-Tracing the dense cloud cores: HCN, HCO+, CN, CS...



- HCN(1-0) not detected! :
  - HCN/CO<0.04 similar to normal SF galaxies, so << ratio in ULIRGs
- NGC1140 clear outlier in HCN/FIR correlation
- [CO] ~ Z, but for **[HCN] is probably 'worse'!!!**
- HCN-M_{dense} conversion factor is ~ 10 times larger?

PDRs in low metallicity dwarfs: SMC & LMC *Chin, Henkel et al. 1997, 1998*

-Tracing the dense cloud cores: HCN, HCO+, CN, CS...

- CO, CS, HCO^+ abundances are ~ 1/10 x MW values

- HCN, HNC and CN are **~ 1/100 x MW values !**

- HCO^+ is the 'best' tracer of the dense phase in low Z PDRs:

I(HCN)/I(CO) [1-0] ~ 0.04 ~ in NGC1140
I(HCO^+)/I(HCN) [1-0] = 1.5-3 !

PDRs in low metallicity dwarfs: models *Bayet et al. 2009*

-What are the 'best' (detectable) tracers?

⬇

$Z \sim 1/10\ Z_\Theta$, $G \sim 10^5 G_o$, $\zeta \sim 10^2\ \zeta_o$, $n(H_2) \sim 10^4 cm^{-3}$

- Very good: **[OH]** ~ 10 x $[OH]_{MW}$!
- Good: **[CO], [H_2O]** and **[HCO^+]** ~ 1/10 x $[CO, H_2O]_{MW}$,but still OK
- Bad: [HCN] ~ 10^{-11}, and [CN], [CS] ~ 1/100 x $[CN, CS]_{MW}$

PDRs in low metallicity dwarfs: models *Bayet et al. 2009*

-What are the 'best' (detectable) tracers?

⬇

- **CO** and **HCO^+** (mm/subm)

- **H_2O** and **OH** (FIR/subm→HERSCHEL)

Hot Cores in low metallicity dwarfs: **models** *Bayet et al. 2008*

-What are the ‘best’ (detectable) tracers?

⬇

$Z \sim 1/5\ Z_{\odot}$, $\zeta \sim \zeta_o$, $n_{final}(H_2) \sim 10^7 cm^{-3}$, $T \sim 300K$

- Good: **[CS], [HCN], [HNC], [H_2S]** $\sim 10^{-8}$
- Bad: [HCO^+] and [CN] $< 10^{-12}$

Hot Cores in low metallicity dwarfs: models *Bayet et al. 2008*

-What are the 'best' (detectable) tracers?

⬇

- **HCN, CS, HNC** and **H_2S** (mm/subm)

- **??** (FIR/subm→HERSCHEL)

Mechanical dominated regions (MDR) in low metallicity dwarfs

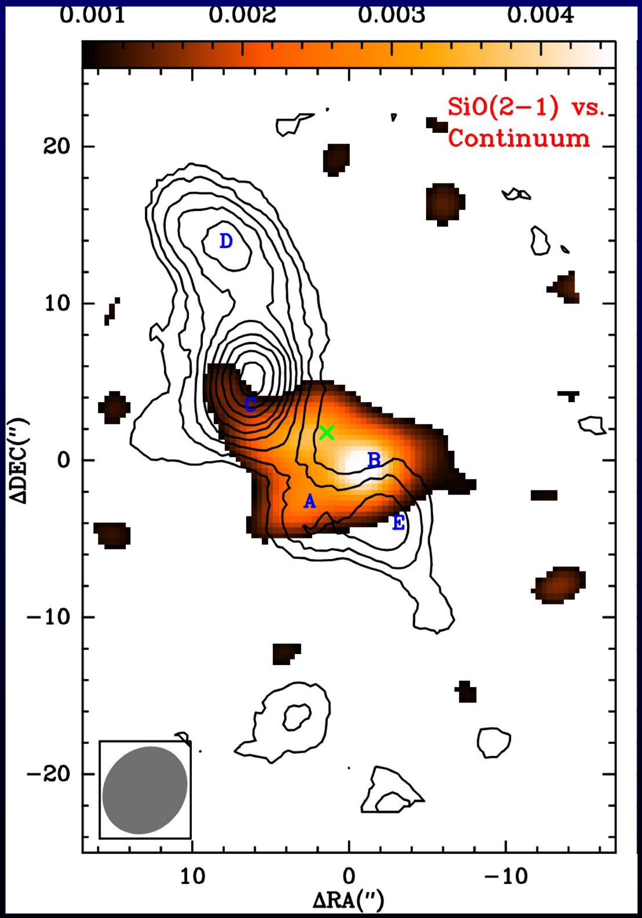
-Molecular shocks in dwarfs?

MDRs in 'normal' SBs: shocks

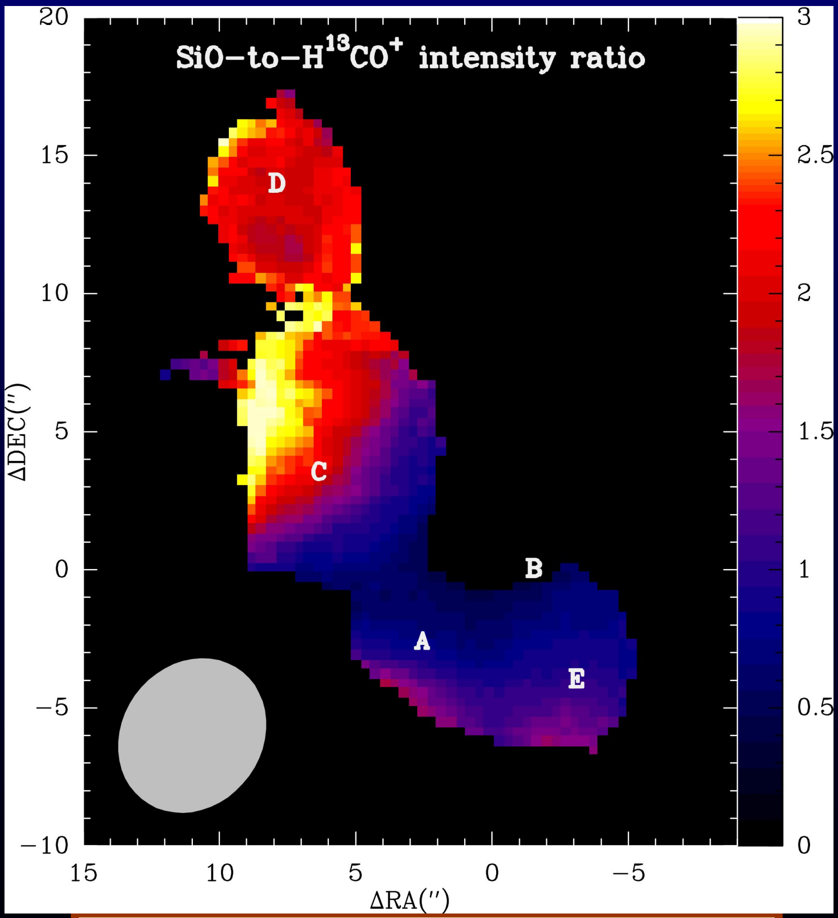
IC342

Usero, Garcia-Burillo et al. 2006

- SiO emission probed by PdBI along spiral structure → gas response to bar
- Shocks not powered by on-going star formation but by density waves



SiO (contours) on 3.5mm RC (color) PdBI maps.



SiO-to- $H^{13}CO^{+}$ integrated intensity ratio.

Mechanical dominated regions (MDR) in low metallicity dwarfs

-Molecular shocks in dwarfs?

• Shallow gravitational potential→no density waves (spiral arms, bars)?

• Bubbles inflated by SN explosions+hot gas→starburst outflows?

• Signature of molecular shocks in dwarfs: OIV and H_2O lines detected by Spitzer…→ *Hunt et al. 2010*

Mechanical dominated regions (MDR) in low metallicity dwarfs

-What are the 'best' (detectable) tracers?

⬇

- **SiO, CH_3OH, HNCO** (mm/subm), likely weak…
- **H_2O** and **OH** lines (FIR/subm→HERSCHEL)

Final Thoughts...

Molecular gas tracers in dwarfs: CO

CO lines need conversion factor (X_{CO}) to get $M(H_2)$

X_{CO}-*virial*

X_{CO}-*LVG/PDR* ⟷ X_{CO}-*global (FIR)*

Final Thoughts…

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X_{CO}-LVG/PDR

↔ *X_{CO}-global (FIR)*

Molecular gas tracers in dwarfs: other molecules

Suitability of tracers depends on prevalent type of chemistry

PDRs, but also hot cores and shocks,…(mm, subm, to Herschel)

'Other molecules' also need X_{other} to get M(H_2)-dense

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Star formation laws in low Z galaxies: models

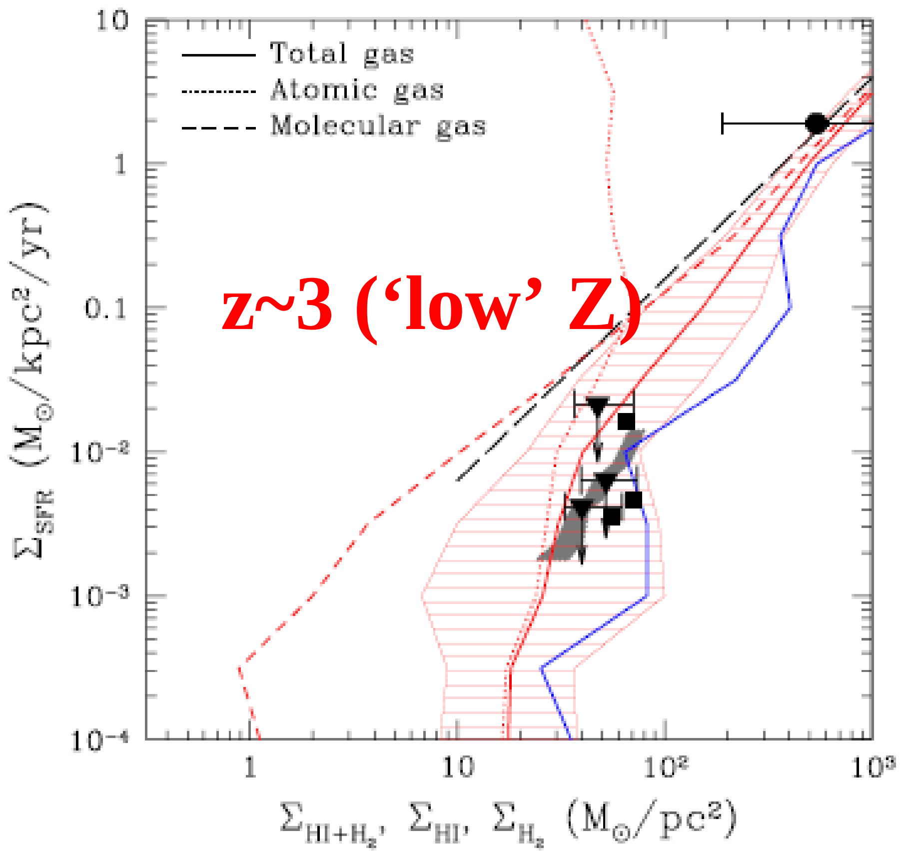
Do we expect to find the same KS law in low Z galaxies?

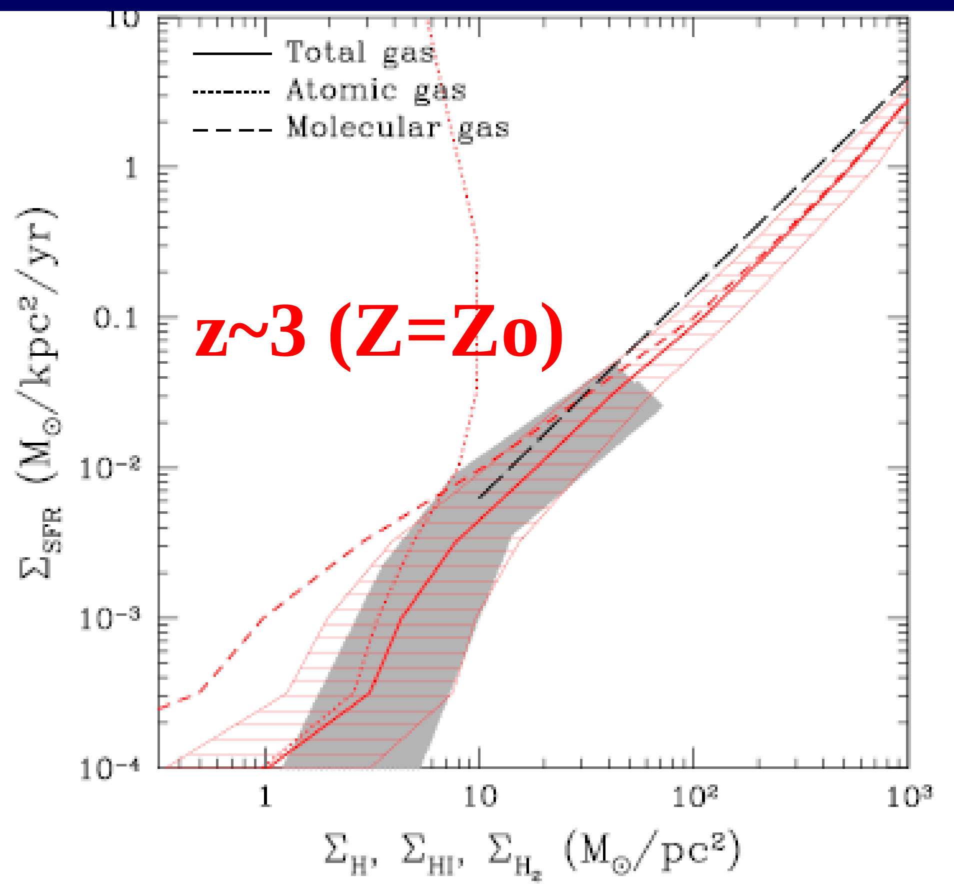
SF laws at low Z + high redshift...

Gnedin and Kravtsov 2009, astro-ph

KS law at low Z and redshift ~ 3

lower amplitude + steeper power law !→metallicity is the key factor!





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