Molecules and the Kennicutt-Schmidt law at low metallicity

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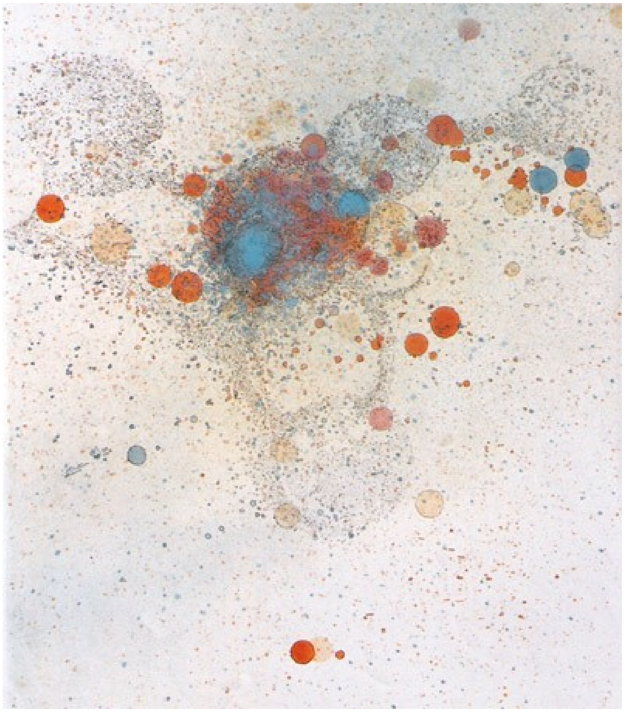
Molecule (2005), Neale Marriott

and the MODULO
(MOlecules and DUst and LOw metallicity)
collaboration

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How can we trace the molecular “cradles” of metal-poor star formation?

H_2 and $^{12}CO(1\text{-}0)$ at low nebular oxygen abundance

- ✔ Blue Compact Dwarf galaxies (BCDs) observed with Spitzer (IRS, IRAC, MIPS) GO program with 12+log(O/H)=7.4-8.2:

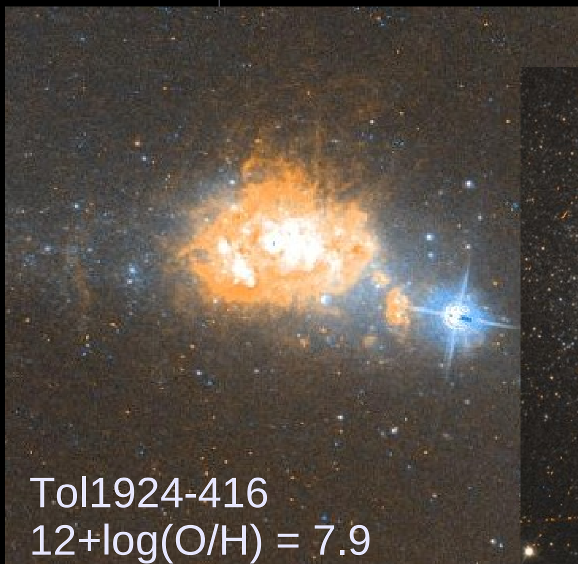
H_2, OH, H_2O

Kennicutt-Schmidt law with H_2

- ✔ BCDs with $^{12}CO(1\text{-}0)$, HI detections from the literature (12+log(O/H)=7.8 (Mrk209), 8.0 – 8.3 :

Kennicutt-Schmidt law with CO → H_2, H_2+HI

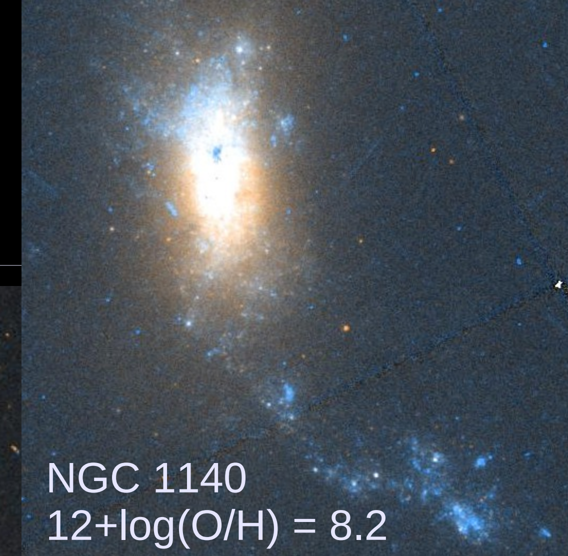
Why Blue Compact Dwarf galaxies?



Tol1924-416
12+log(O/H) = 7.9

Mrk 209
12+log(O/H) = 7.8

SBS1415+437
12+log(O/H) = 7.6

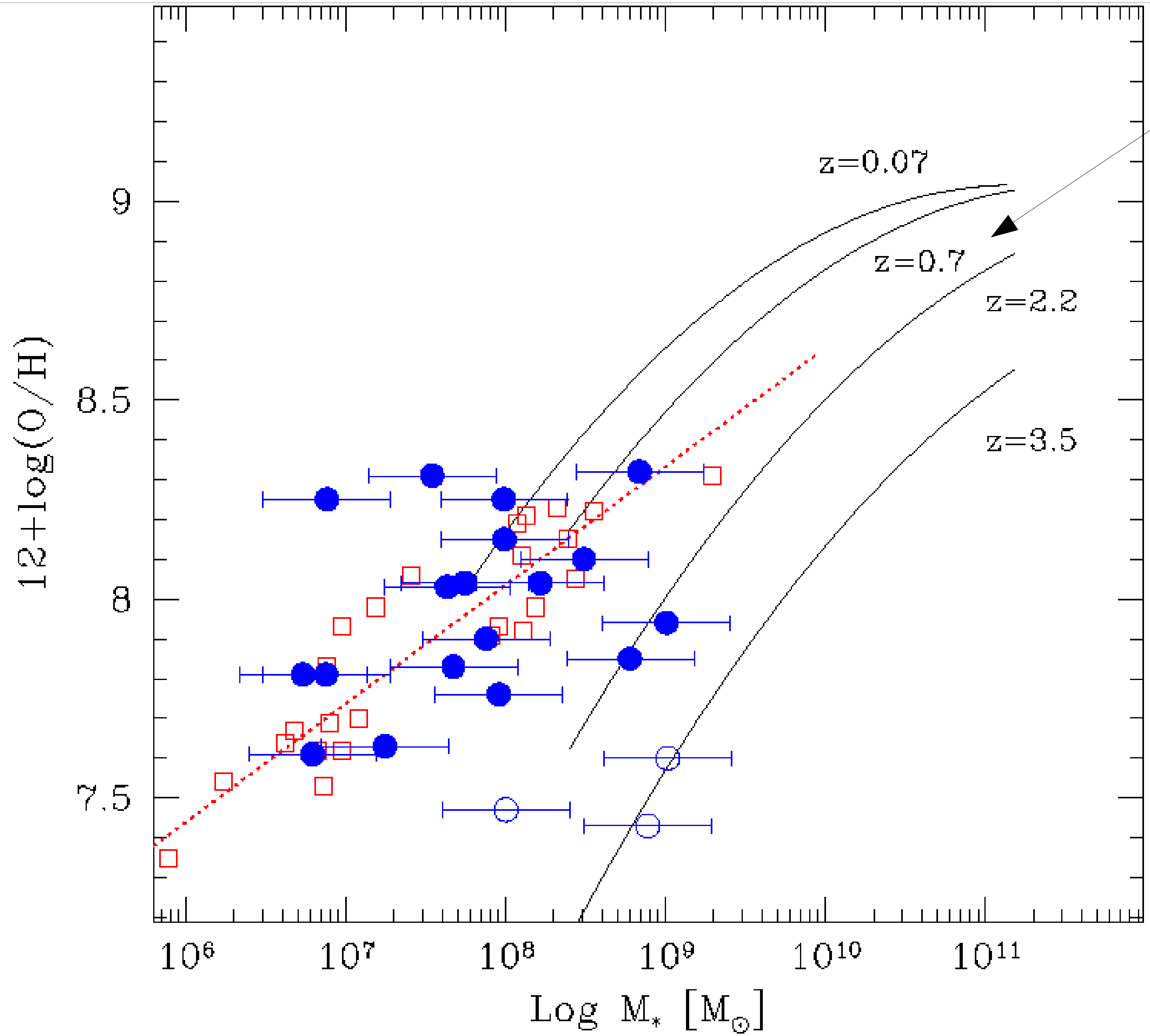


NGC 1140
12+log(O/H) = 8.2

- ✔ Some BCDs have ***high SFR/area,*** therefore c***ompact and dense SF regions.*** Thus promote molecule self-shielding (see Hirashita & Hunt 2004, “active” vs. “passive” modes of star formation)

- ✔ BCDs are ***low mass*** and ***chemically unevolved***, and thus probe the transition from primordial metal-free star formation to metal-rich solar metallicity systems. Also resemble ***“Clump Clusters”*** (Elmegreen & Elmegreen...)

Context: Mass-metallicity relation



Maiolino et al. (2008) AMAZE

BCDs' mass determination from IRAC 4.5µm

(following Lee et al. 2006)

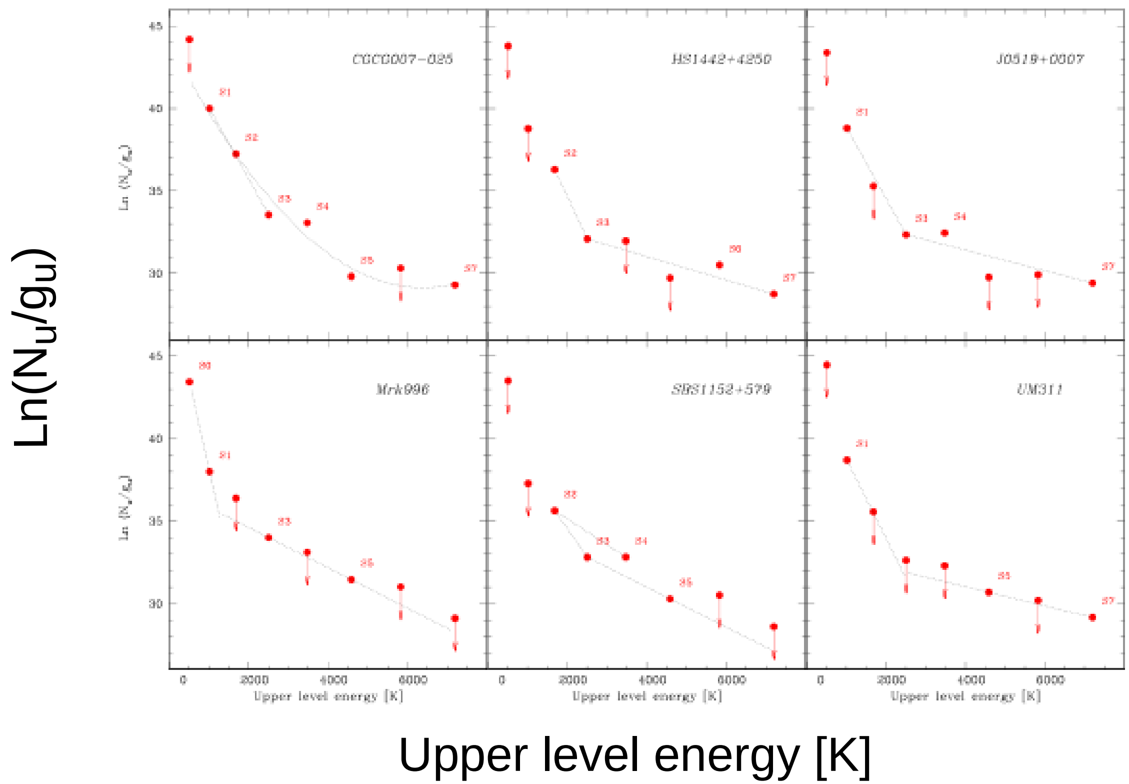
Are there molecules at low metallicity? YES, H_2!

Excitation diagrams of rotational transitions of H_2 :

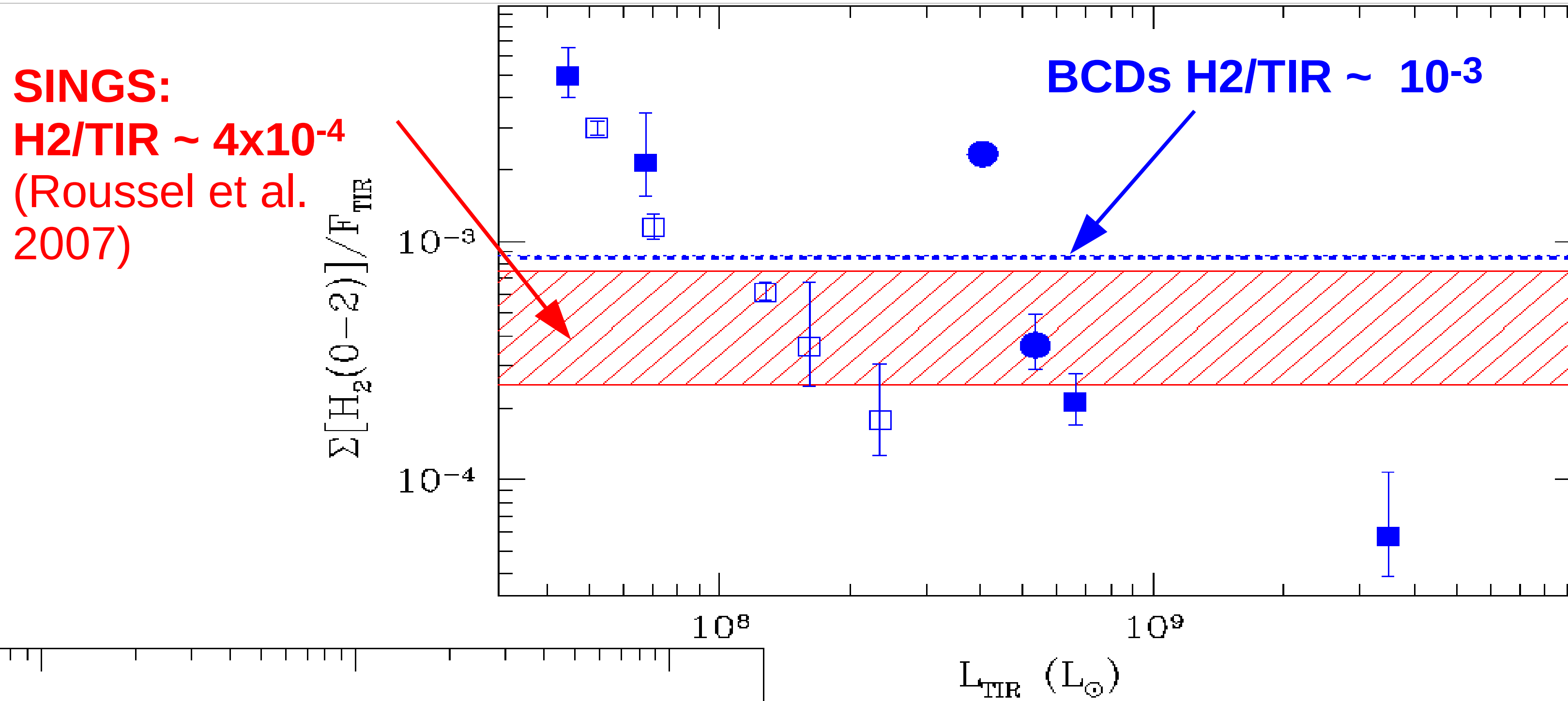
ΔJ=2-0, S(0) 28.2μm, 3-1,S(1) 17.0μm, 4-2, S(2) 12.3μm, ..., 9-7 S(7) 5.5μm

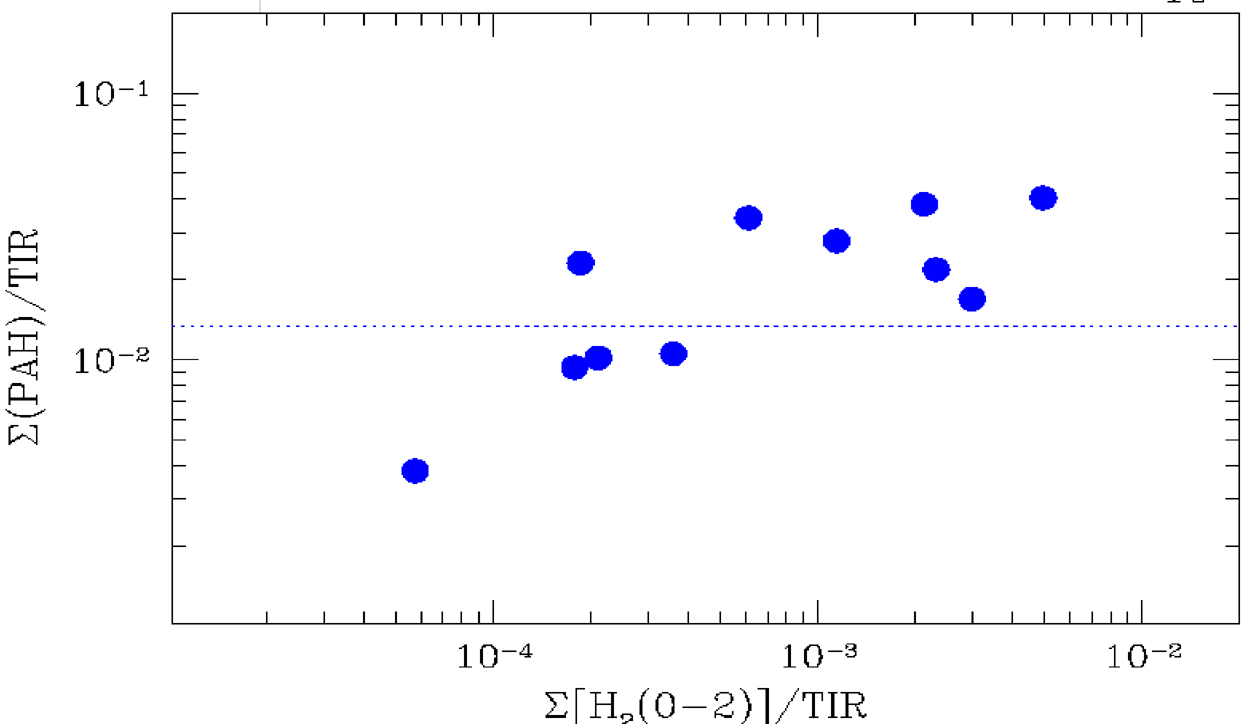
give column densities for warm gas (100-1000K). Inverse slope of excitation diagram gives Tex.

Low n_{crit} means lower-order transitions are likely **thermalized.**



H_2 associated with PAHs, photo-dissociation regions

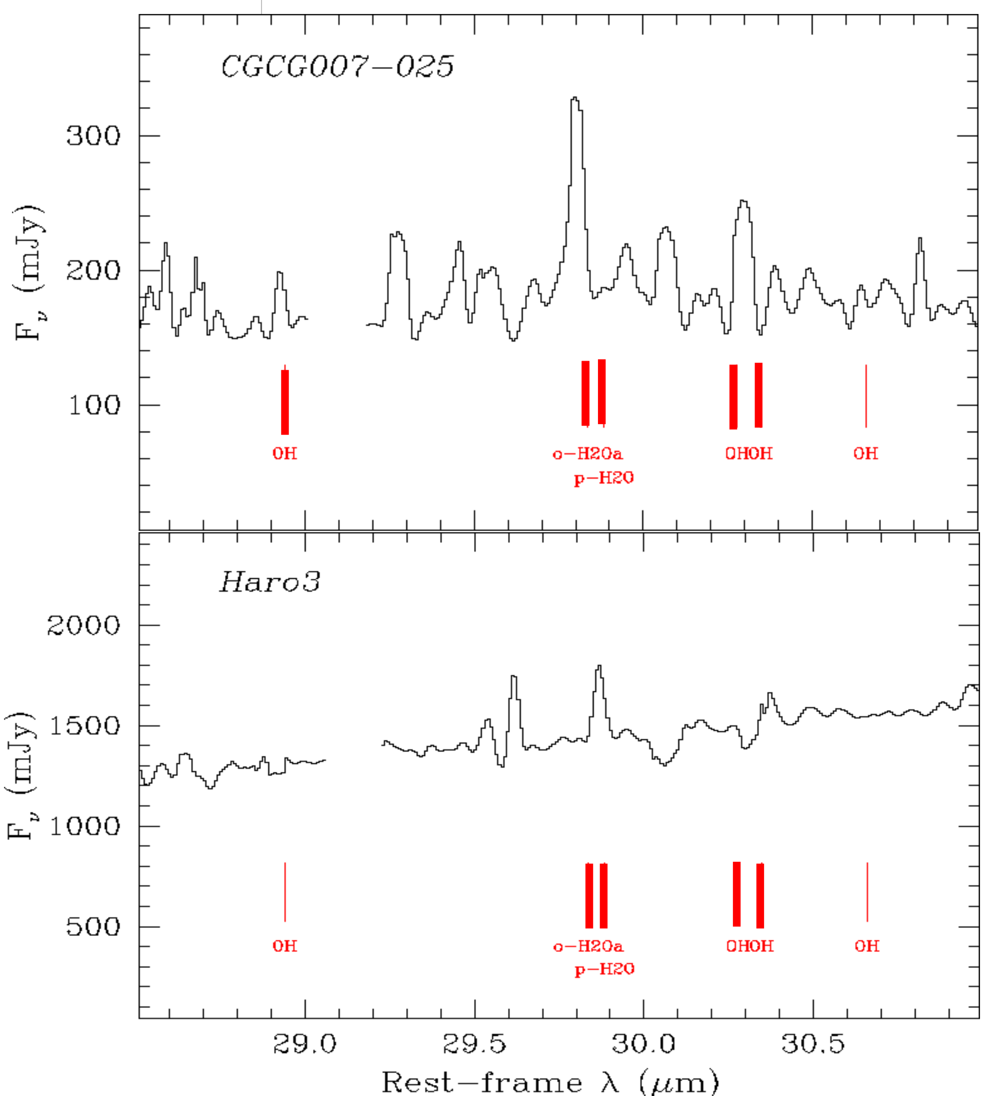




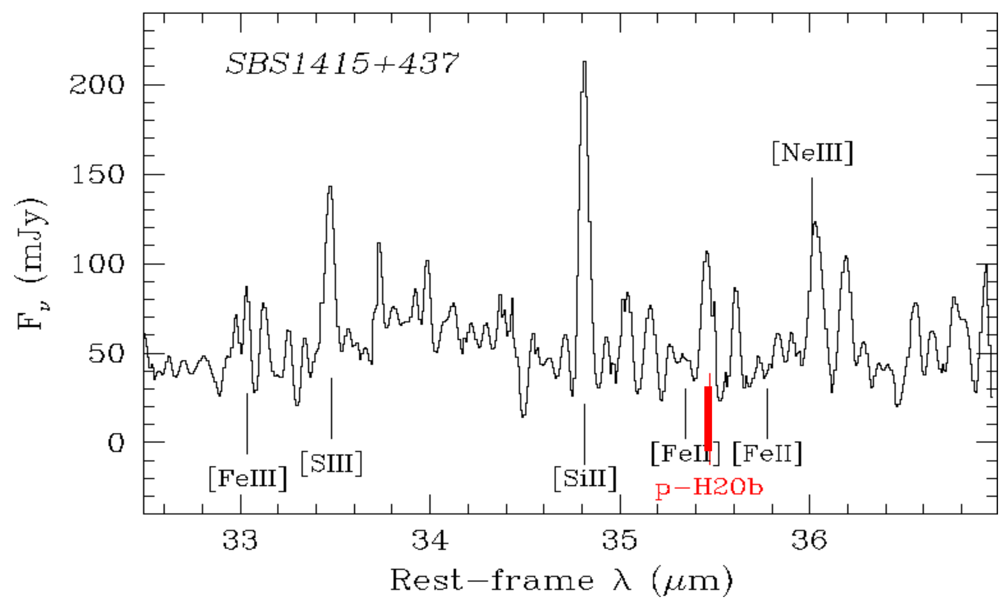
Such a correlation also in SINGS and other samples (Rigopoulou et al. 2002). Not clear whether the association is spatial or energetic...

Tentative evidence also for H_2O ...

Ortho (para) transitions of “hot” H_2O at 7_{25}-6_{16} at 29.84 µm (35.5 µm) are, to our knowledge, the first such (3σ) detections in extragalactic objects.



(Not all marked emission lines are significant detections...)

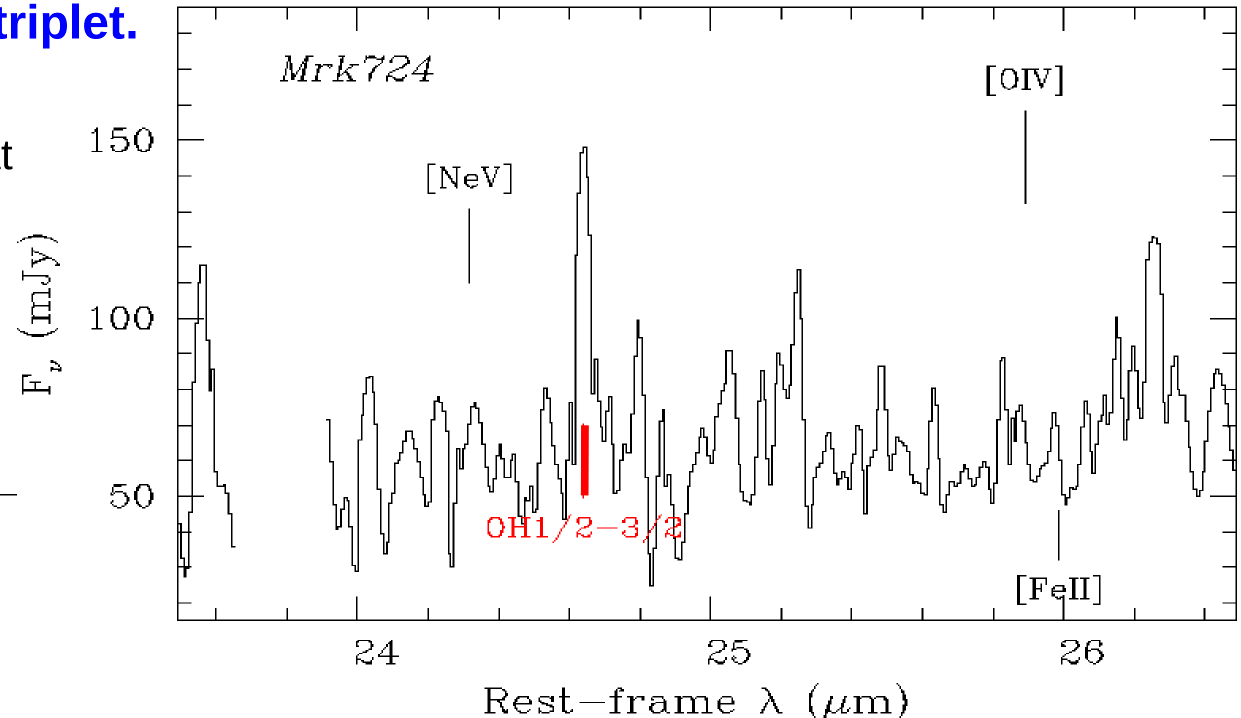


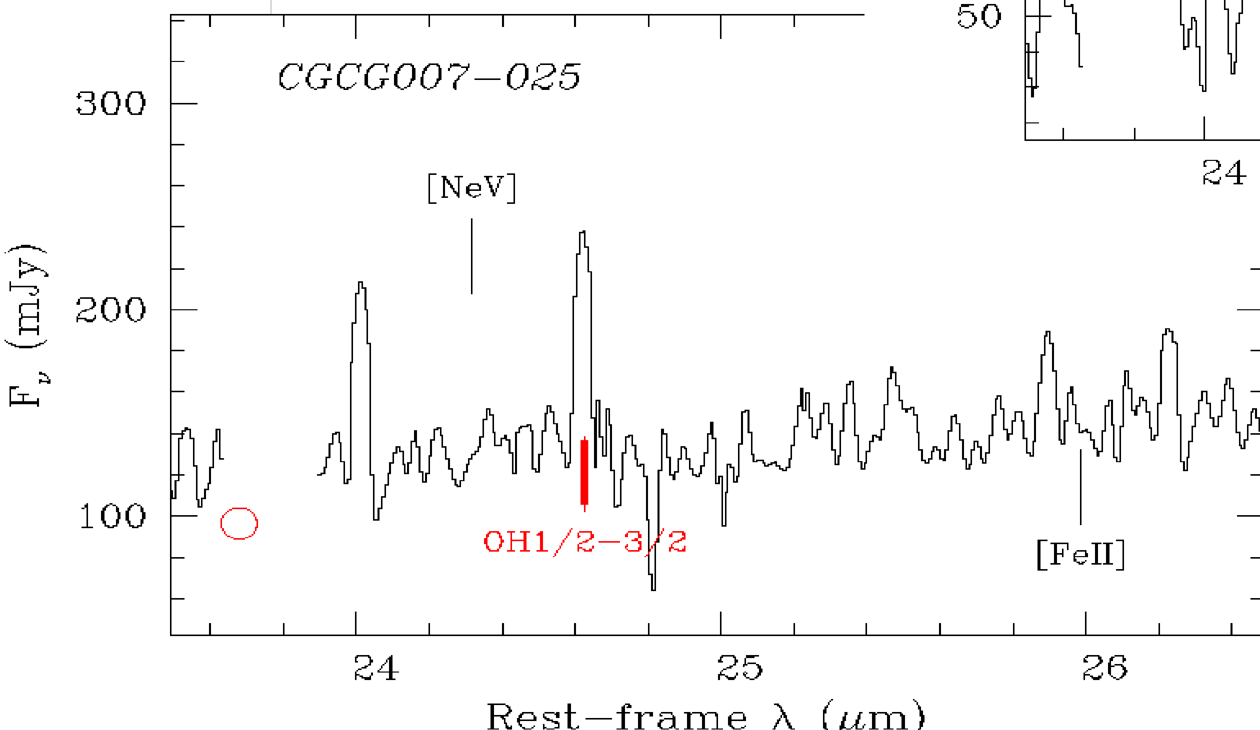
Perhaps caused by slow (non-disocciative, C-type shocks, Draine 1980) which would heat gas to 300K, and subsequently convert all O (not in CO) to H_2O...

... and for OH ...

Tentative 3σ detections of rotationally excited OH at v=0, $2\Pi_{1/2} - 2\Pi_{3/2}$ ΔJ'=0 (9/2-7/2) 24.6 μm triplet.

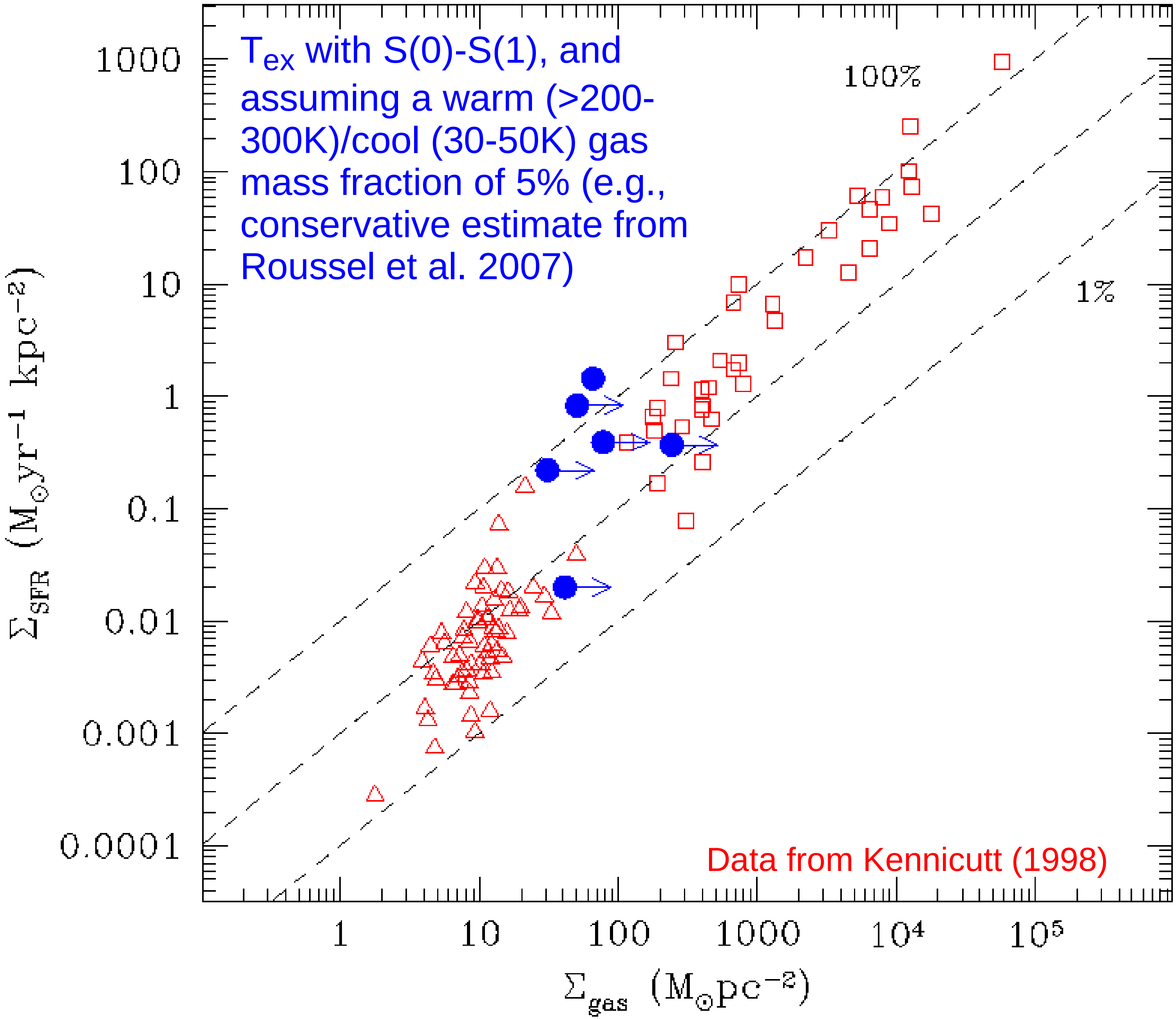
Could be associated with **photodissociation of H_2O** at photon energies ~ 9 eV, similar to what happens in Galactic outflows (Tappe et al. 2008).



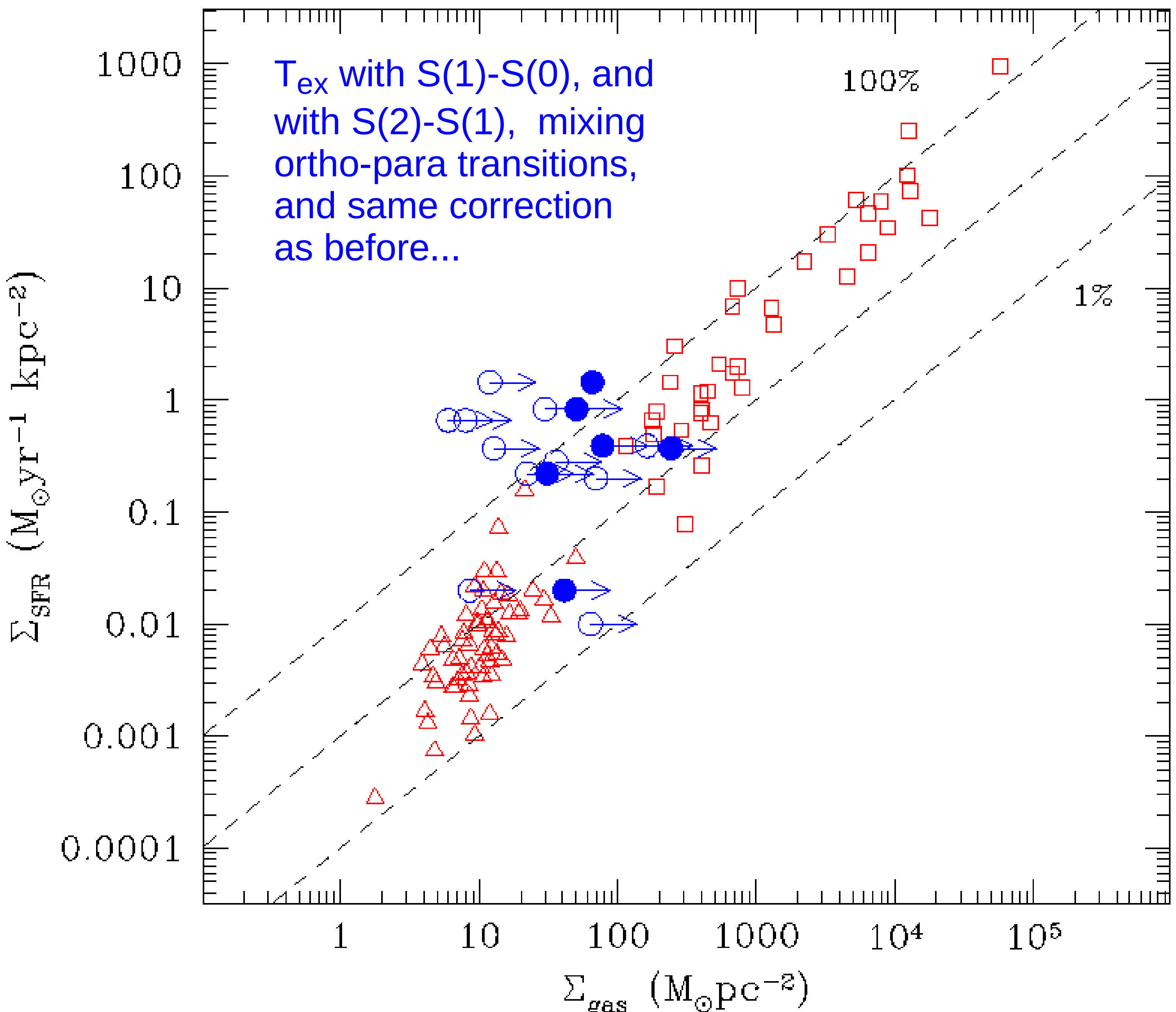


Interestingly, these BCDs also have **high-order H_2 detections** which would imply the present of **hot dense gas** to enable neutral reactions leading to OH and H_2O formation (e.g., Hollenbach & McKee 1979).

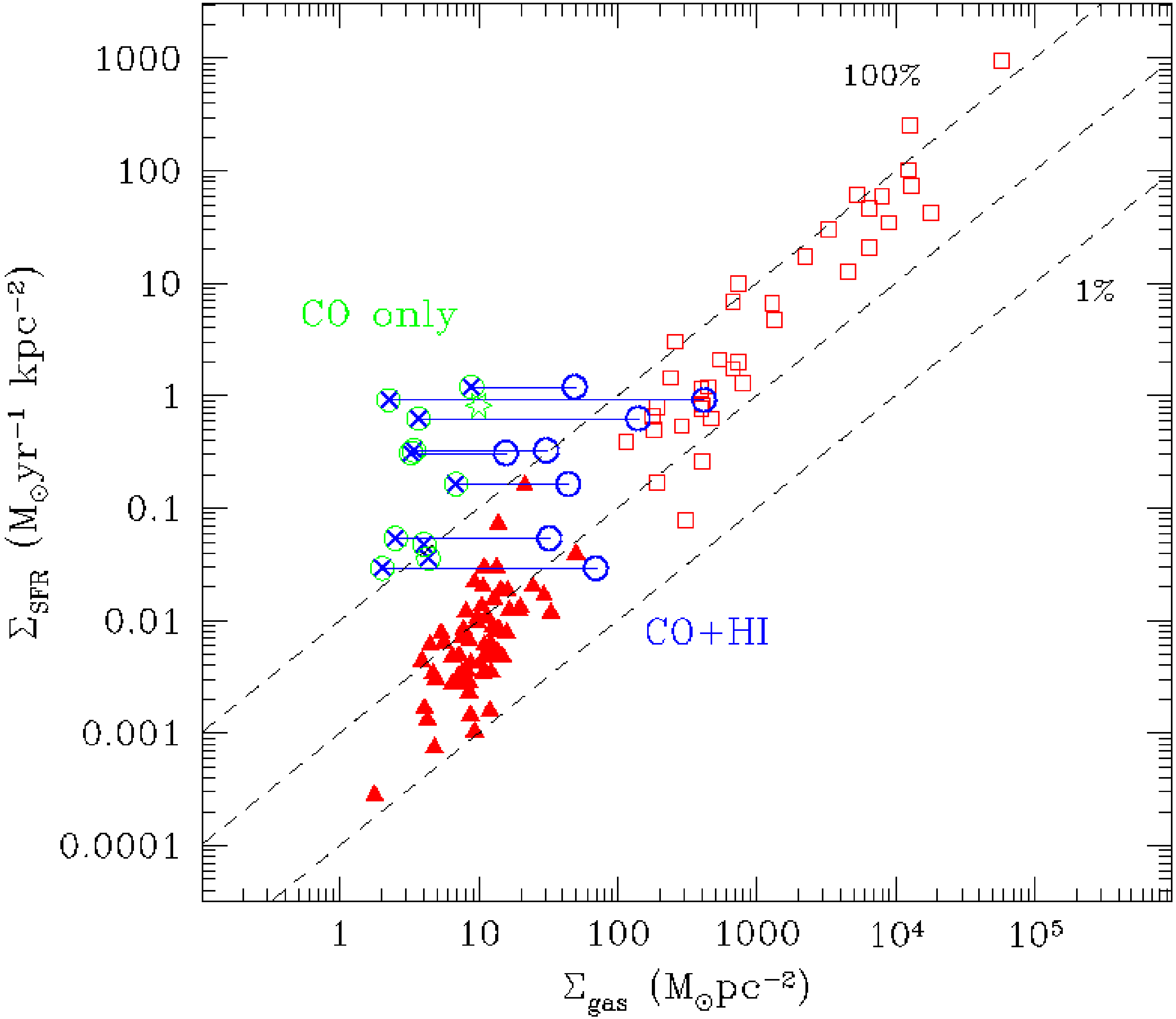
Kennicutt-Schmidt law with H_2



Kennicutt-Schmidt law with H_2



Kennicutt-Schmidt law with ^{12}CO(1-0)



What's going on?

SFR densities Σ_{SFR} in these metal-poor BCDs comparable to circumnuclear starbursts and low-luminosity ULIRGs. H_2 (IRS) by itself *almost* compatible with KS law; adding HI to this would lead to gas excess (at high Σ_{gas}). Adding HI to CO-derived H_2 *almost* compatible with KS law.

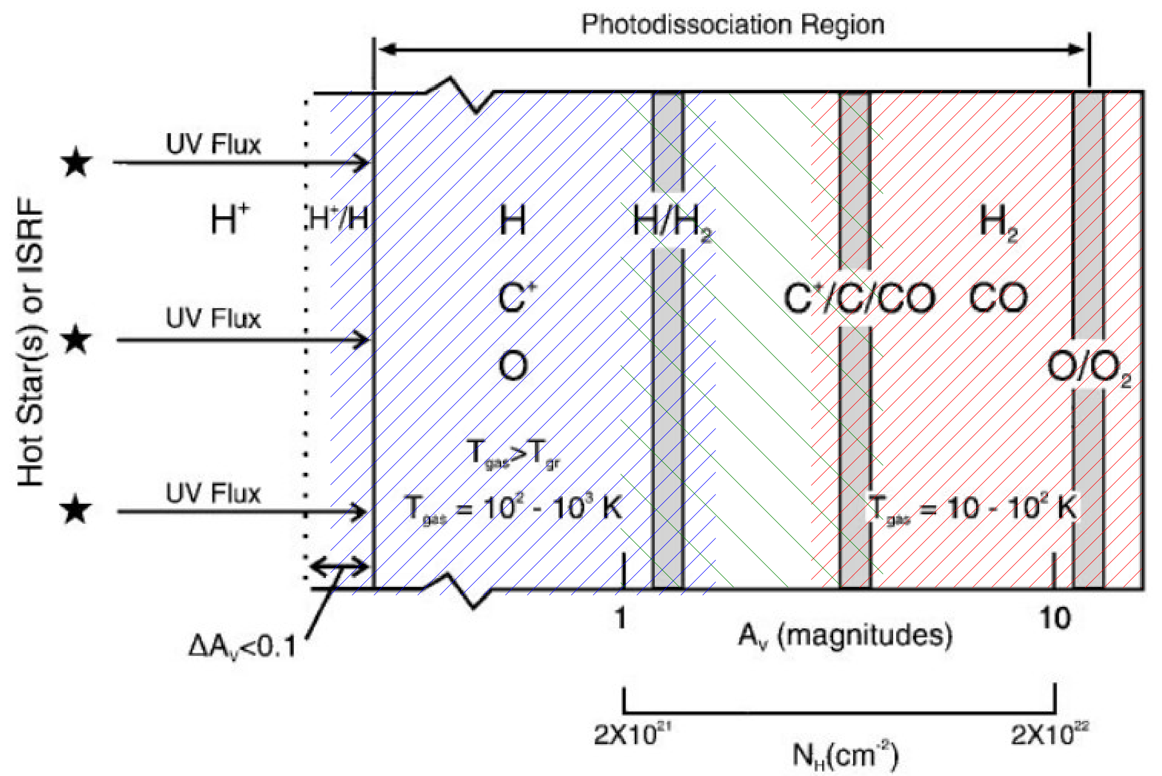
Conversion factor X? Used 2.8 x 10^{20} K km s^{-1} but would need to be increased by an order of magnitude to accommodate CO(1-0) in pure H_2 KS law.

Conversion of H_2 to HI vs metallicity? Σ_{gas} in excess of HI (solar metallicity) saturation threshold. Abundance dependence roughly compatible with Krumholz et al. predictions...

What to do? (Molecular tracers at low metallicity)

- **Warm dense gas tracers** (e.g., higher-order CO, and large-dipole moment molecules such as HCN, HCO+)
- **Molecular PDR tracers** (e.g., CN, CS, HCO+ since could trace less-dense gas on PDR surfaces and thus be more extended, as in the Magellanic Clouds)
- **Atomic gas PDR tracers** (e.g., [CII], [CI], ...)

Hollenbach & Tielens (1997)



...will help understand abundance constraints (raw material) of a metal-poor ISM and assess the effects of its harder and more intense radiation field on the molecular component.