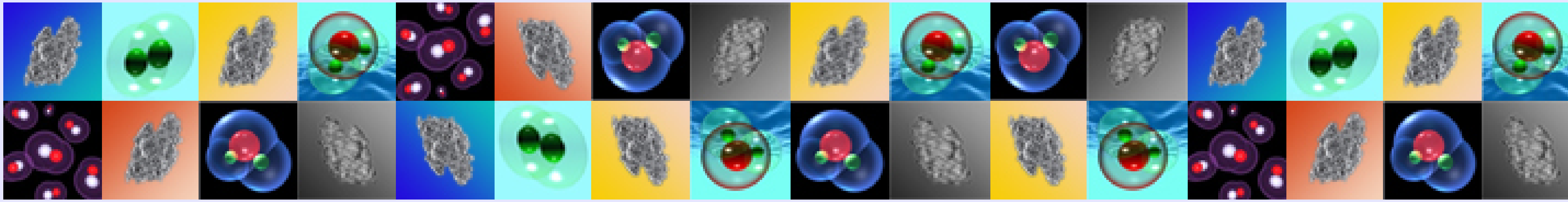
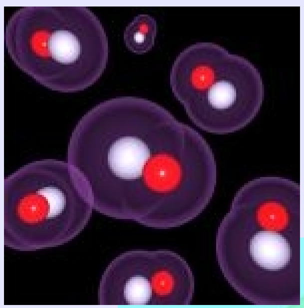
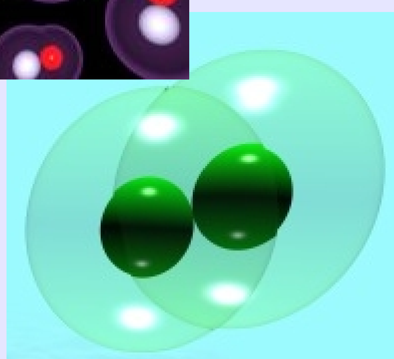
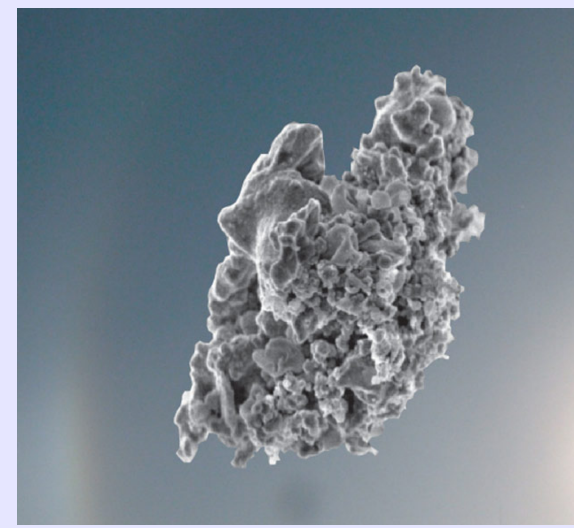


MOlecules and DUst at LOw metallicity

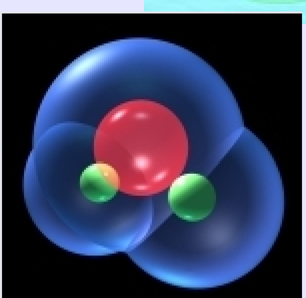


(1) Relation of gas and star-formation density (Kennicutt-Schmidt, KS law)





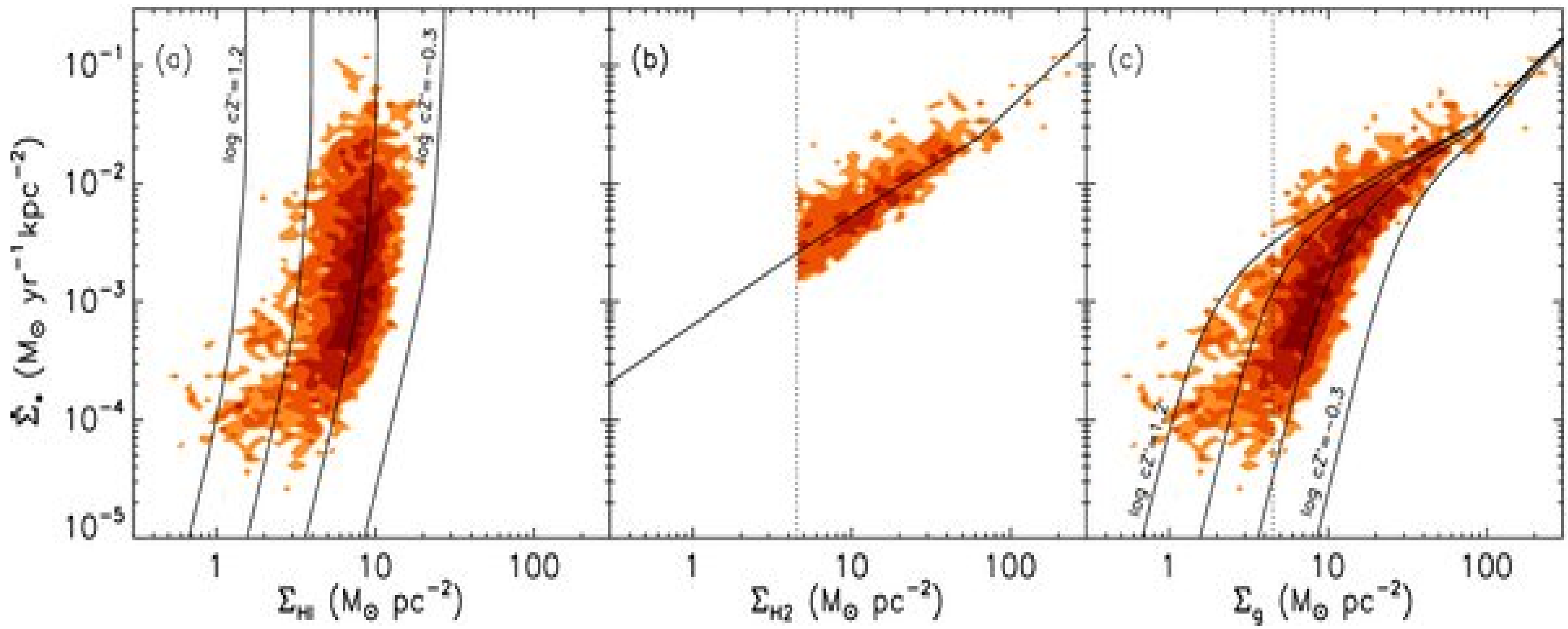
(2) Focus on galaxies with high Σ_{SFR} but low Σ_{H2}. These are a sub-class of the metal-poor Blue Compact Dwarf galaxies (BCDs), but *SFR independent of metallicity O/H.*



(3) Identify the properties of these BCDs, and try to understand what makes them form stars so effectively with (apparently) few molecules.

(1) The Kennicutt-Schmidt law:
Star-formation vs. gas surface density

KMT models and the Kennicutt-Schmidt law (1)



Left panel: Σ_{SFR} vs. Σ_{HI}

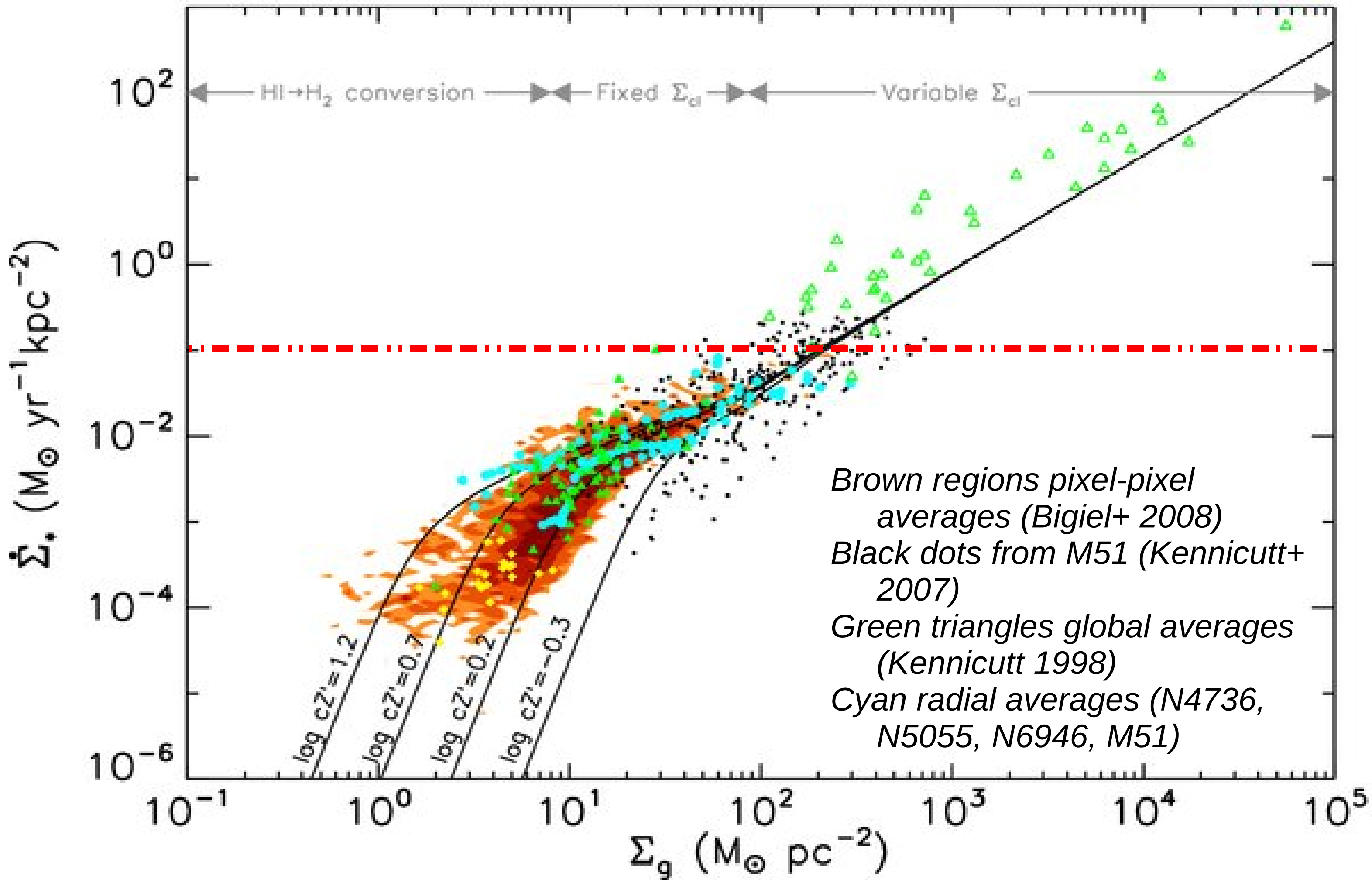
Middle panel: Σ_{SFR} vs. Σ_{H2}

Data from Bigiel+ (2008)

Right panel: Σ_{SFR} vs. Σ_{HI+H2}

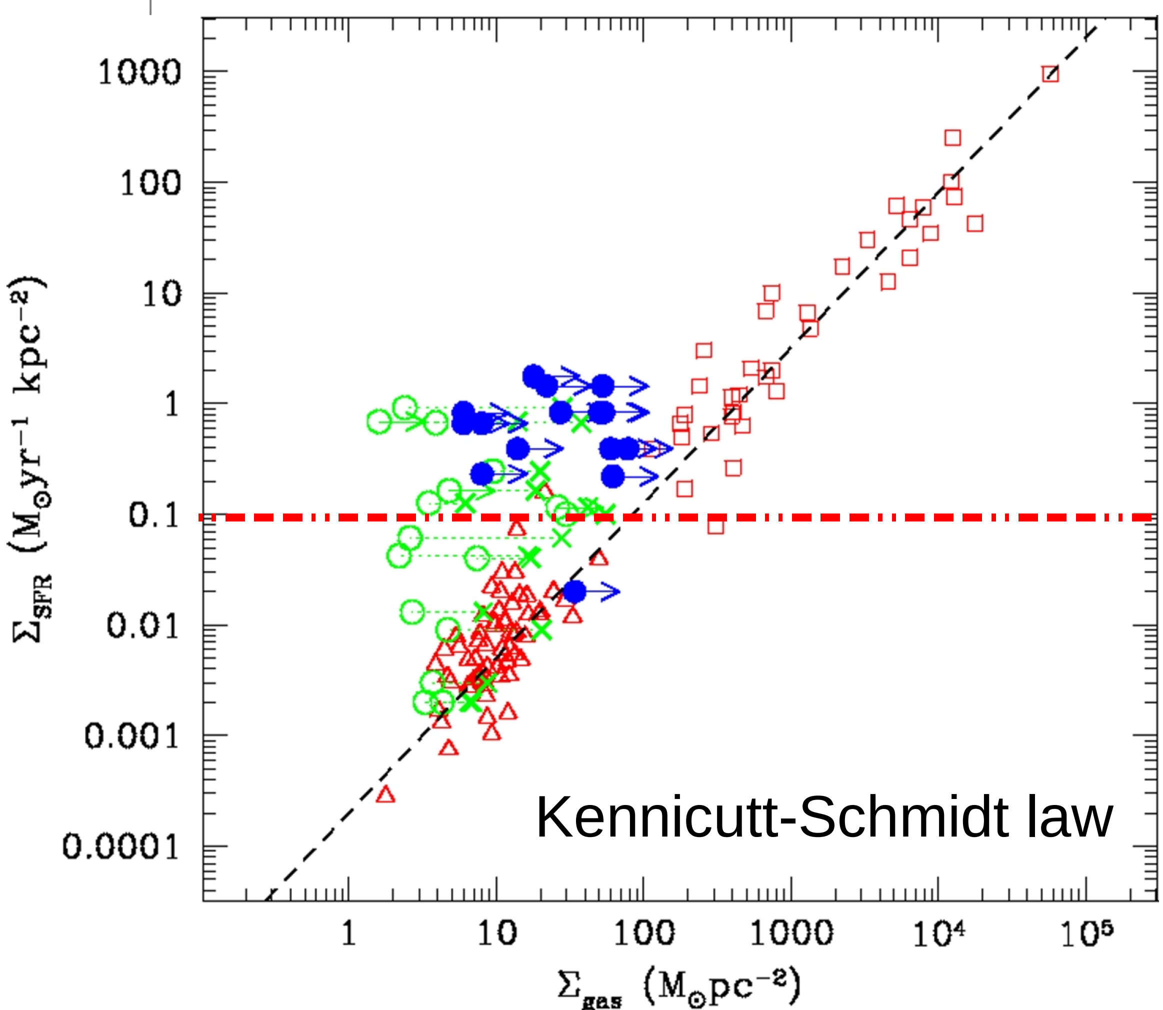
Model curves derived by assuming that H2 fraction in a 100pc SF complex depends on gas surface density and to 2^{nd} order on ***metallicity*** ** clumping factor (Krumholz, McKee, Tumlinson 2009)*

KMT models and the Kennicutt-Schmidt law (2)



Metallicity assumed to govern UV field and dust content, thus self-shielding *(taken from Krumholz, McKee, Tumlinson 2009)*

SFR surface density and gas content in BCDs



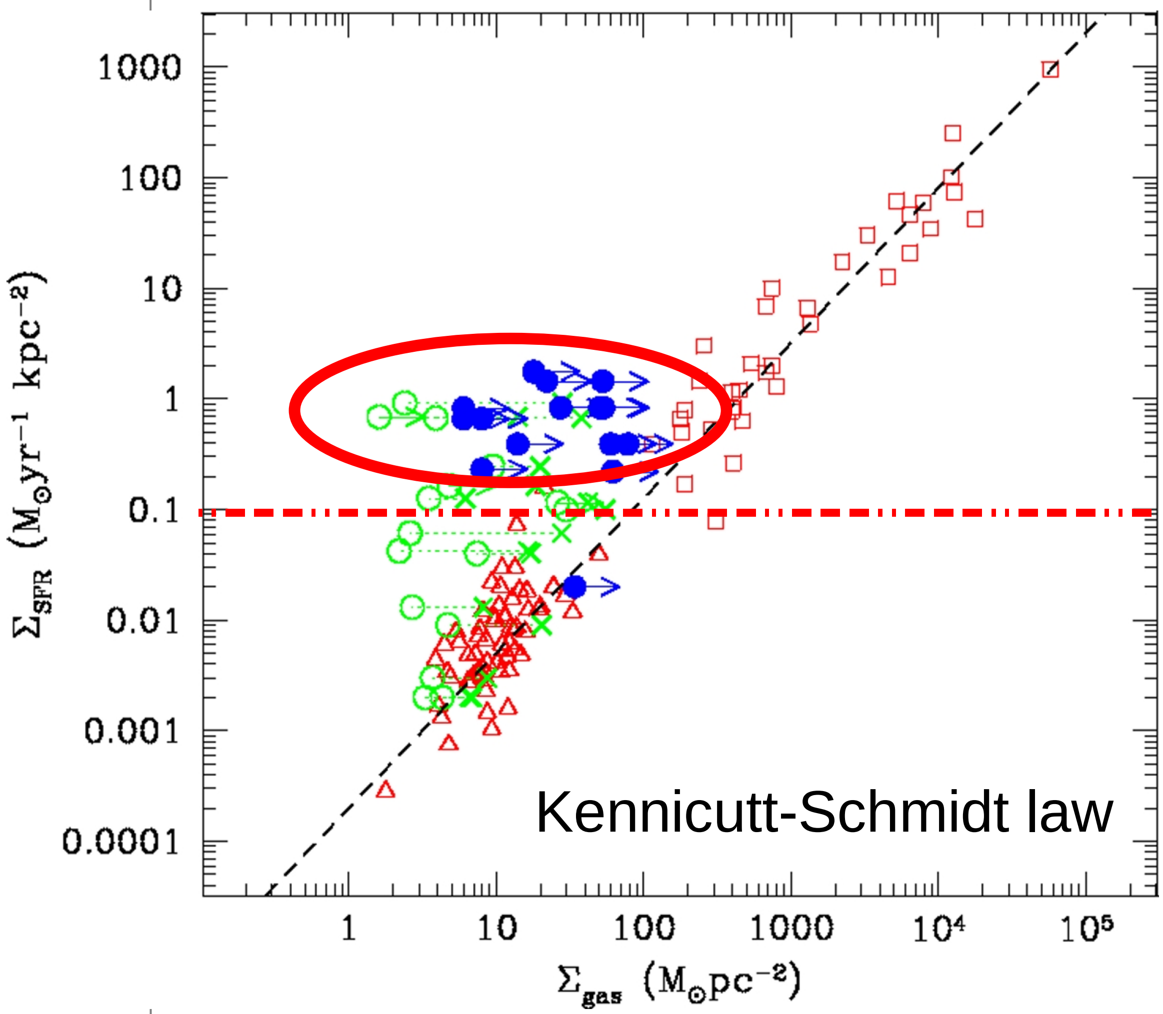
Data and regression from Kennicutt (1998). Gas densities are global averages, and include CO +HI for spirals (triangles), but CO only for circumnuclear starbursts and ULIRGs (squares).

BCDs from Hunt+ (2010); (filled circles) with S(0), S(1), S(2) transitions detected (shown with right arrows), assuming **warm/cold molecular gas fraction = 0.05** (as in Roussel et al. 2007, normal star-forming galaxies).

BCDs (open circles, X) with CO +HI

Some BCDs are forming stars as almost as violently as ULIRGs; these the active BCDs

SFR surface density and gas content in BCDs



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(2) BCDs: "Active" and "Passive" modes of star formation (at the same metallicity)

I Zw 18: A “passive” BCD

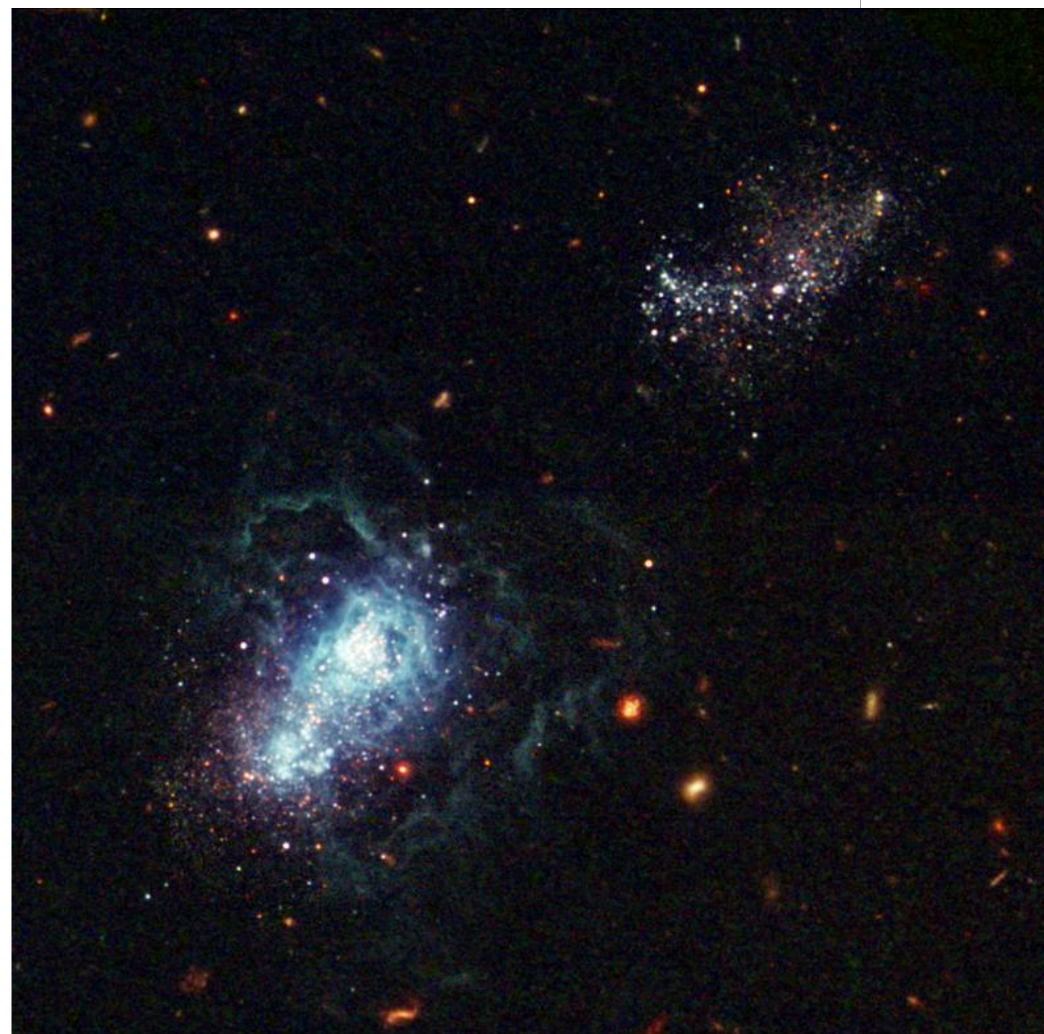
12+logO/H=7.19

~1150 O stars in mainly two clusters in the main body

star clusters >~ 100 pc in diameter

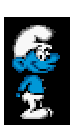
n_e ~ 100 cm^{-3}

SFR ~ 0.04-0.1 M_{sun}/yr



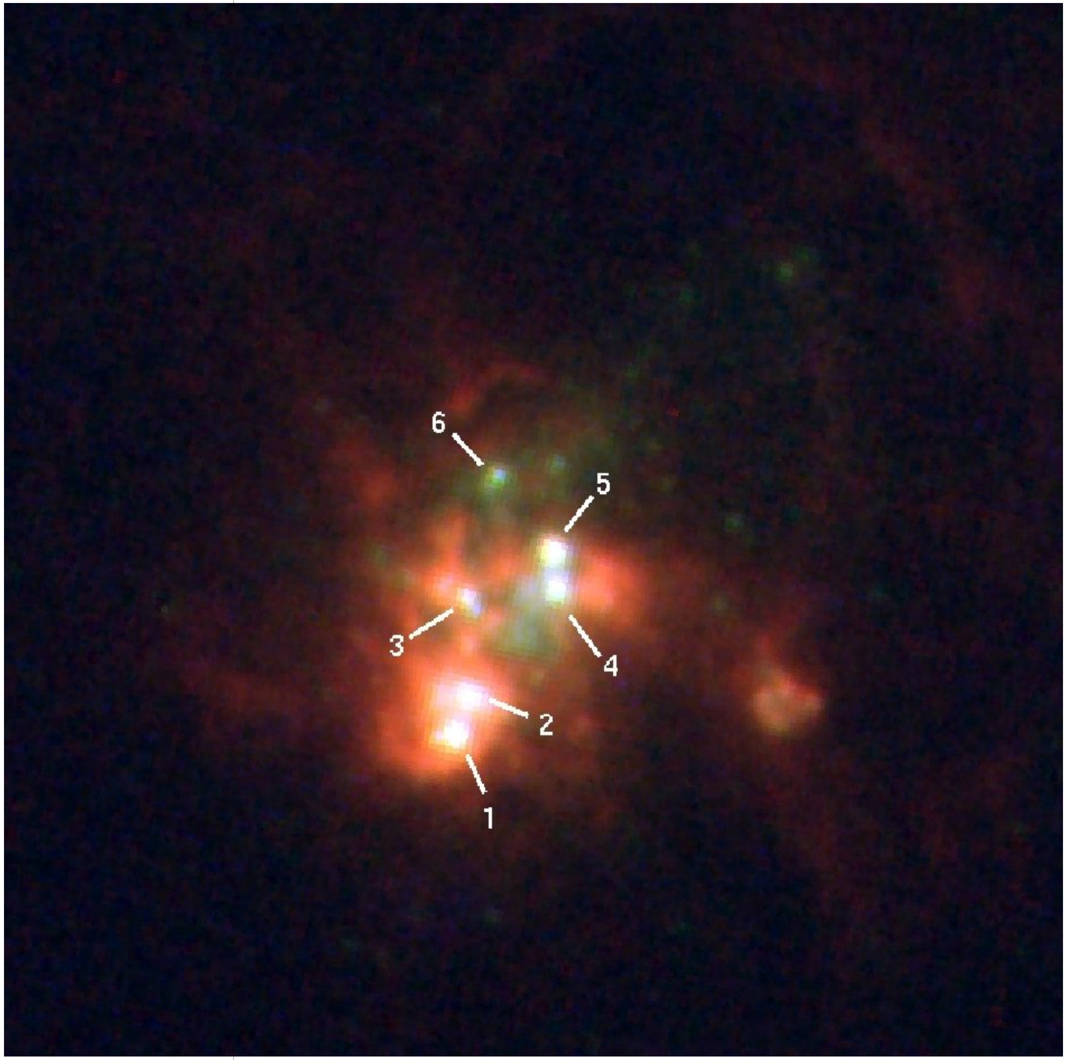
Thuan & Izotov 2004

passive



DIFFUSE LOW-DENSITY STAR-FORMING REGIONS

SBS0335-052E: An "active" BCD



Reines, Johnson & Hunt 2008

12+logO/H=7.23

~9400 O stars in mainly two SSCs

star clusters < 50 pc in diameter (not resolved by HST/WFPC2)

n_e >~ 600 cm^{-3}

Star formation rate (SFR) ~ 1 M_{sun}/yr

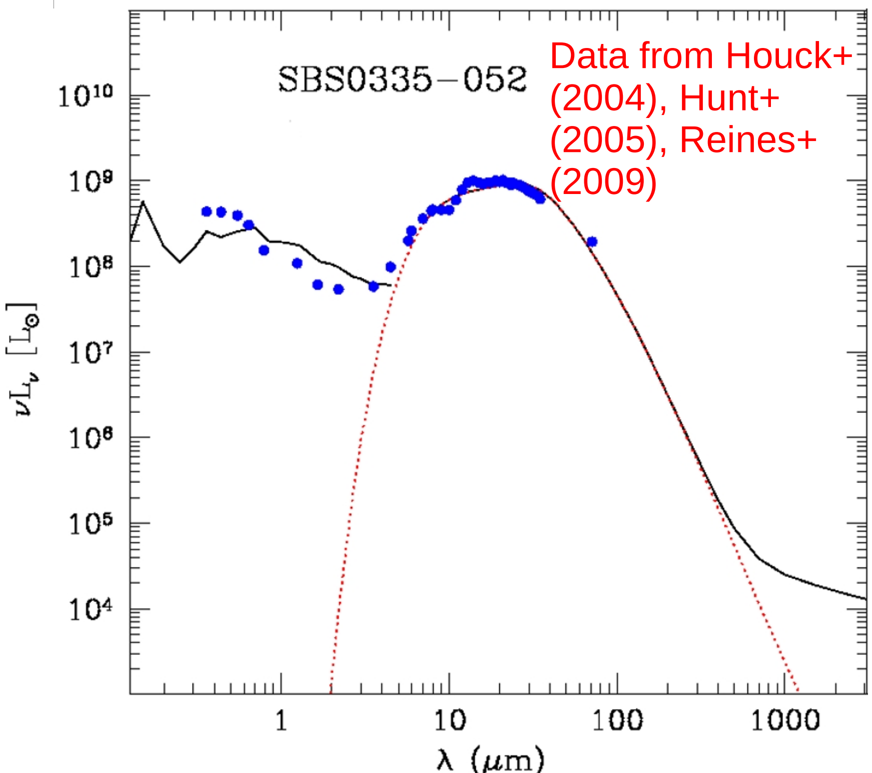
COMPACT DENSE STAR-FORMING REGIONS

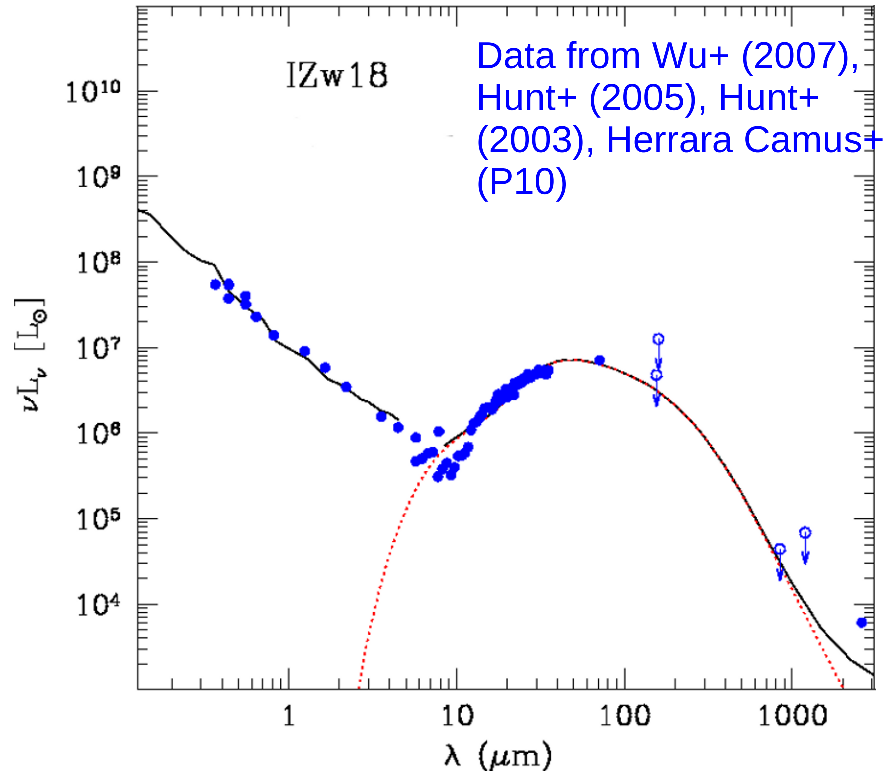
active

DUSTY fits to global SEDs of active/passive prototypes

12+logO/H=7.23 (1/26 Zsun)
L_{IR} = 1.4 10^9 L_{sun}

12+logO/H=7.19 (1/29 Zsun)
L_{IR} = 3.6 10^7 L_{sun}





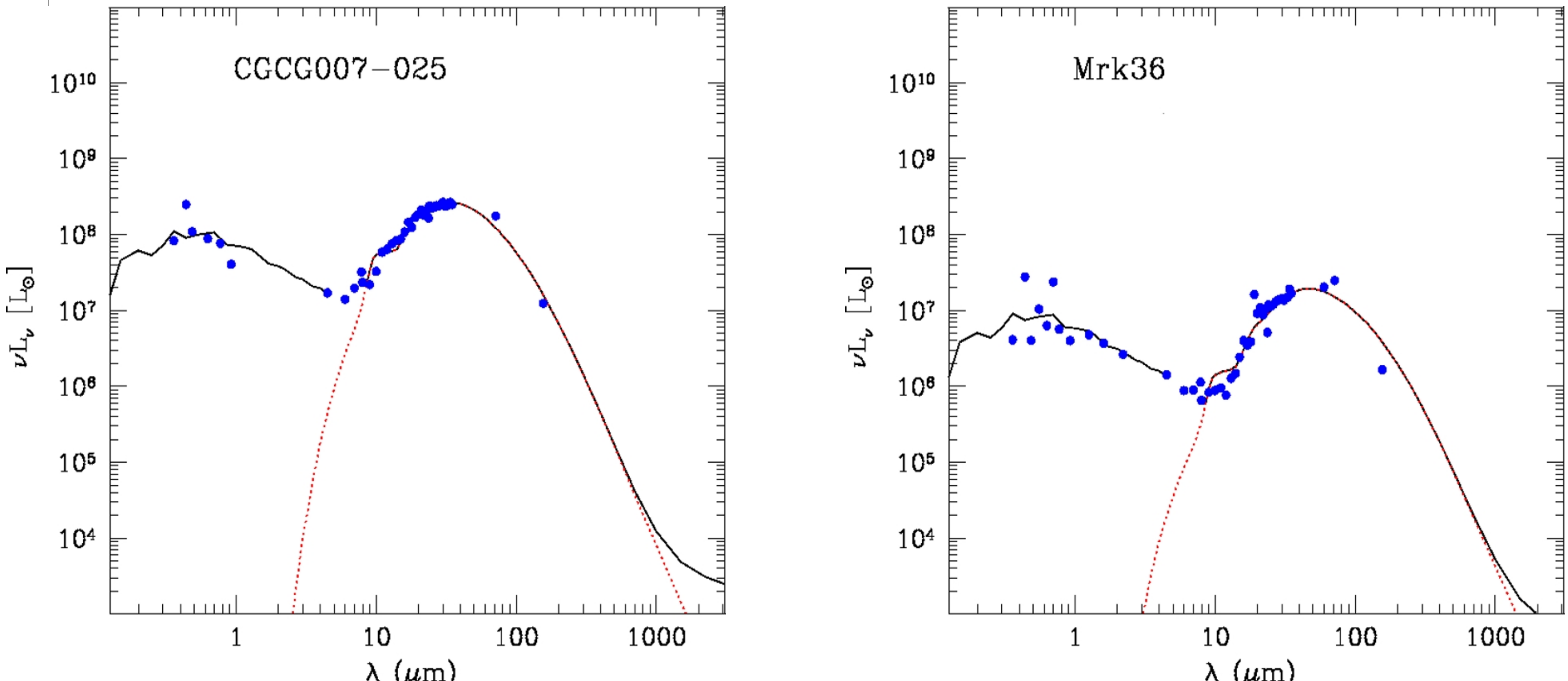
Stars more luminous than IR in IZw18, but not in SBS0335-052

SED peaks at longer wavelengths (cooler dust) in IZw18 than in SBS0335-052; factor of 40 in IR luminosity at same O/H

SEDs (with DUSTY fits) of active/passive BCDs

12+logO/H=7.76 (~3.5 times SBS0335-052)
SFR = 0.2 M_{sun}/yr
L_{IR} = 4.1 10^8 L_{sun}

12+logO/H=7.81
SFR = 0.04 M_{sun}/yr
L_{IR} = 3.1 10^7 L_{sun}



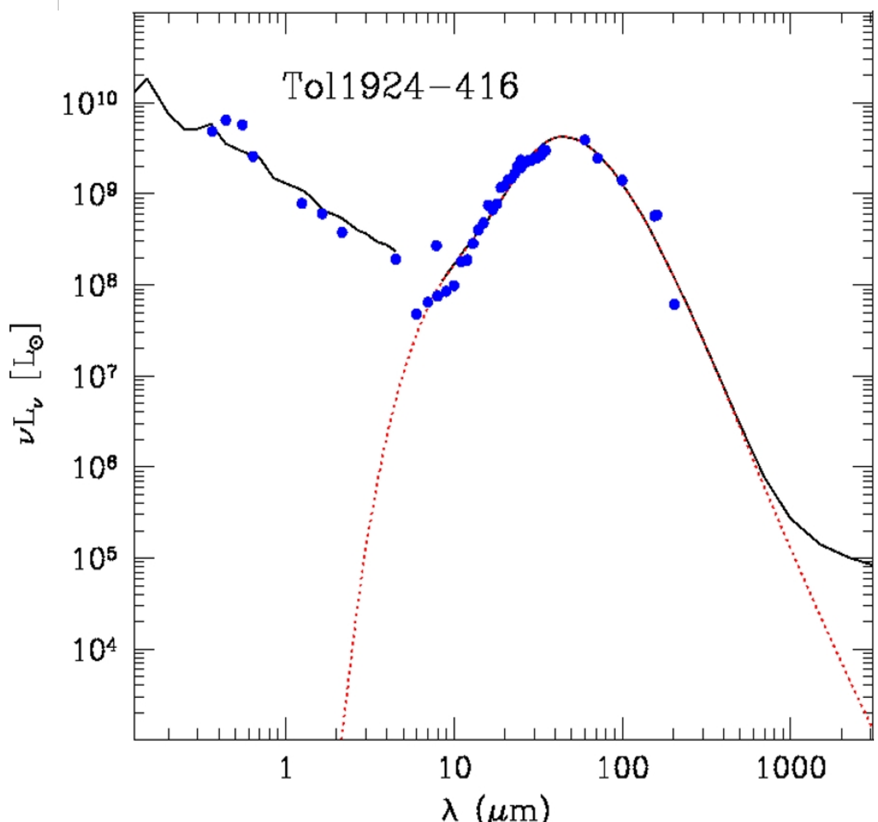
BCDs paired according to similarity of nebular oxygen abundance, but also the largest difference in Σ_{SFR}...

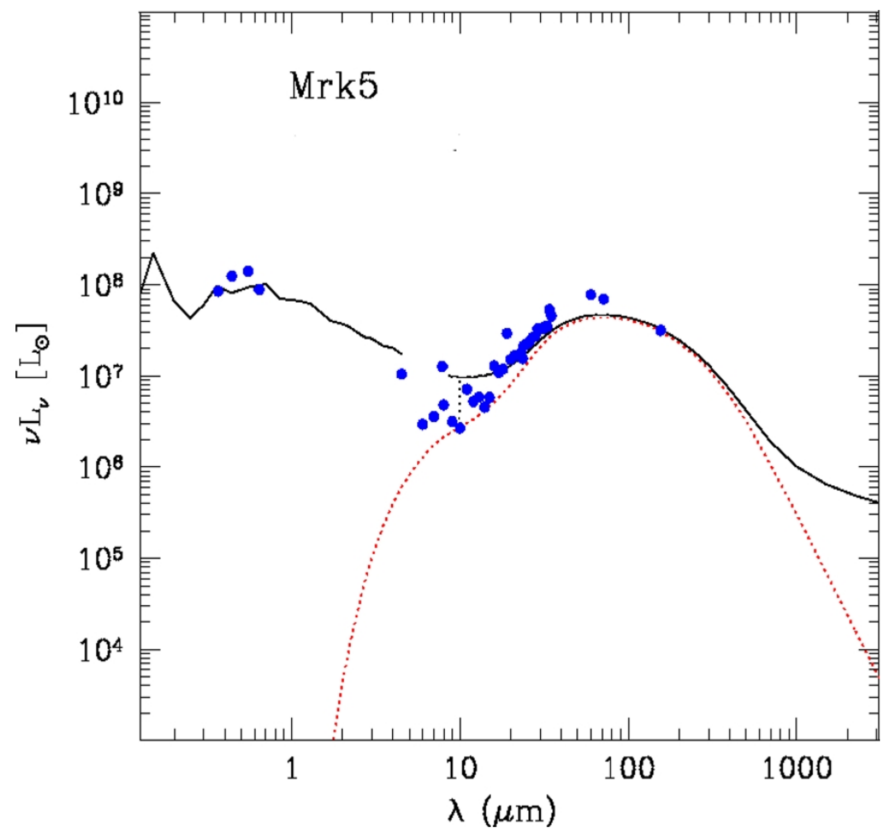
L_{IR} can vary widely even at a given metallicity!

More SEDs of active/passive BCDs

12+logO/H=7.94 (~6 times SBS0335-052)
SFR = 6.2 M_{sun}/yr
L_{IR} =5.6 10^9 L_{sun}

12+logO/H=8.04
SFR =0.1 M_{sun}/yr
L_{IR} = 9.3 10^7 L_{sun}



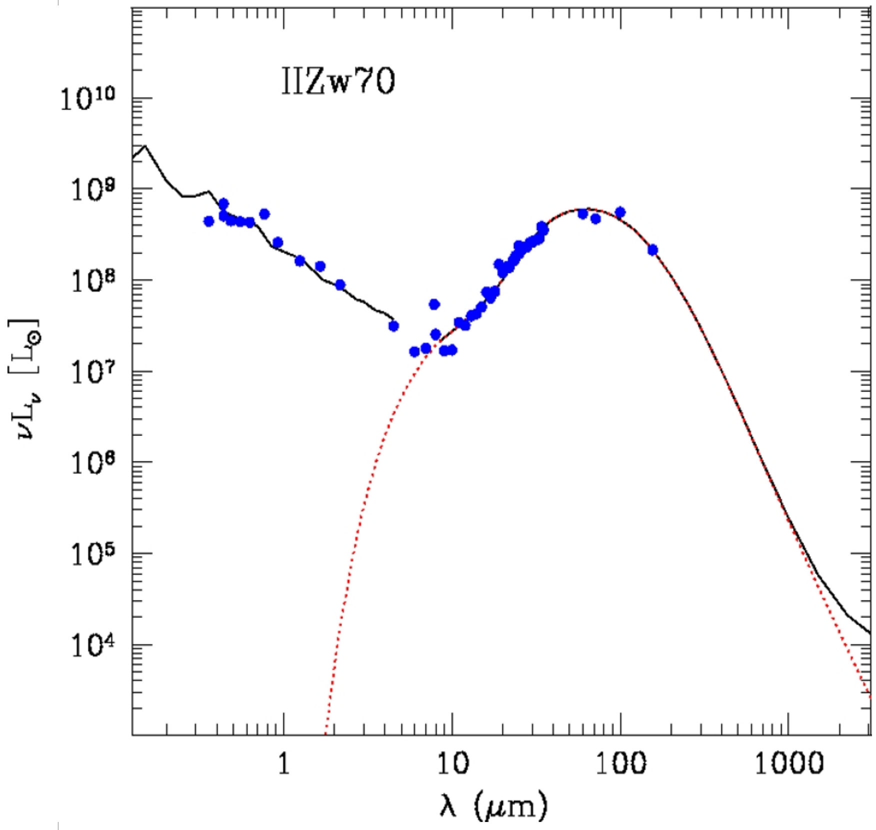


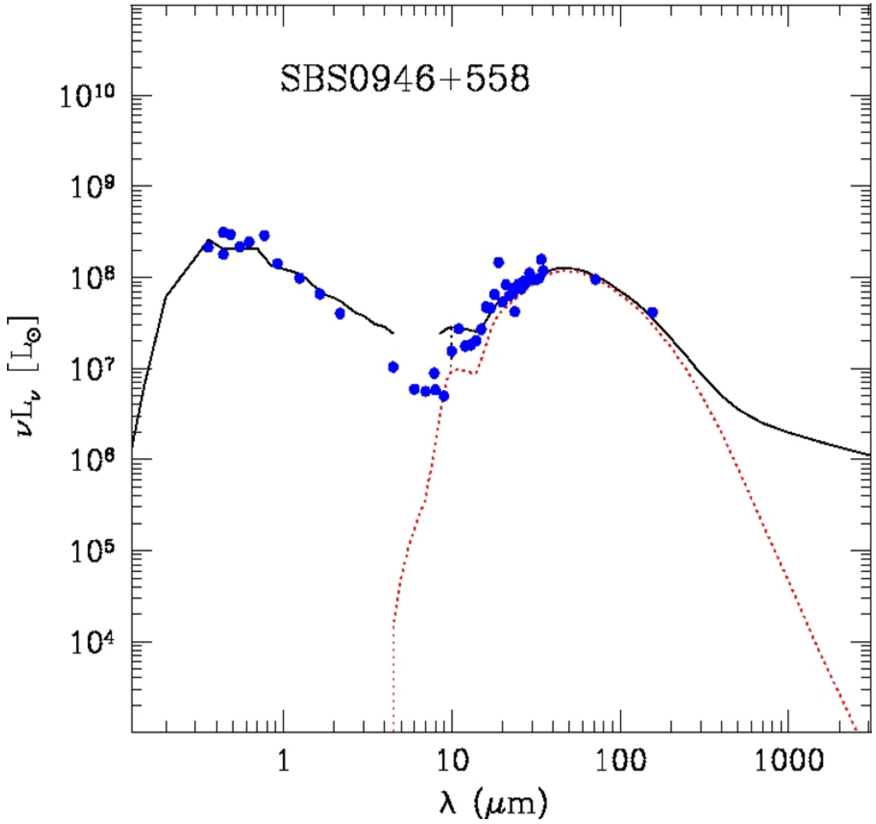
L_{IR} differs by a factor of ~50

Yet more SEDs of active/passive BCDs

12+logO/H=8.04 (~7 times SBS0335-052)
SFR = 0.5 M_{sun}/yr
L_{IR} =1.0 10^9 L_{sun}

12+logO/H=8.04
SFR = 0.1 M_{sun}/yr
L_{IR} =2.0 10^8 L_{sun}

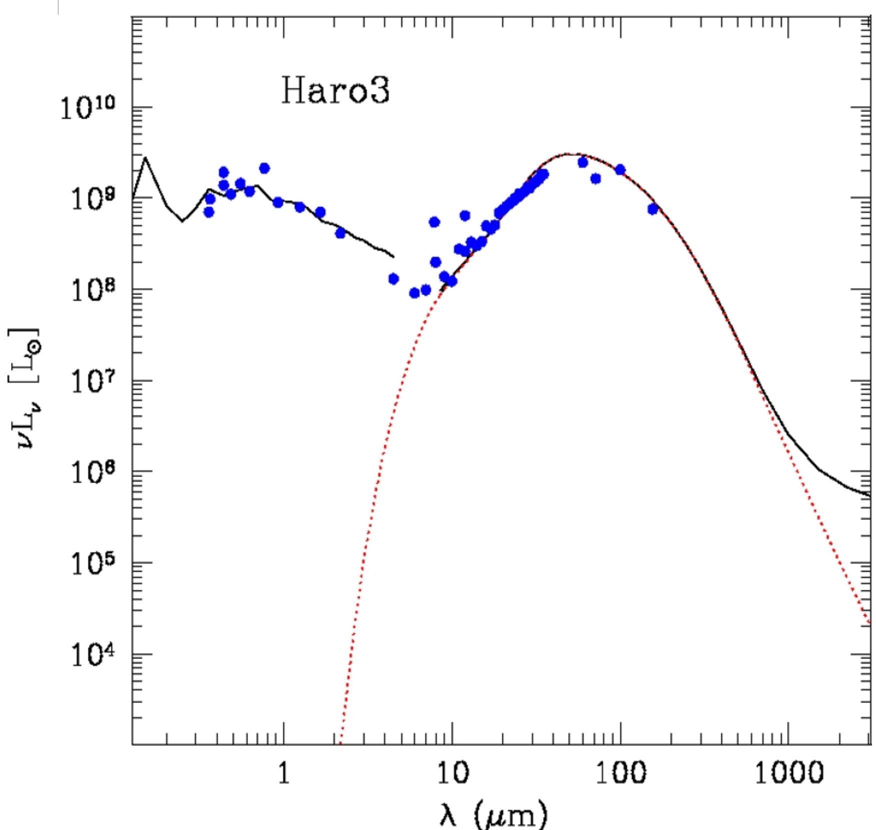




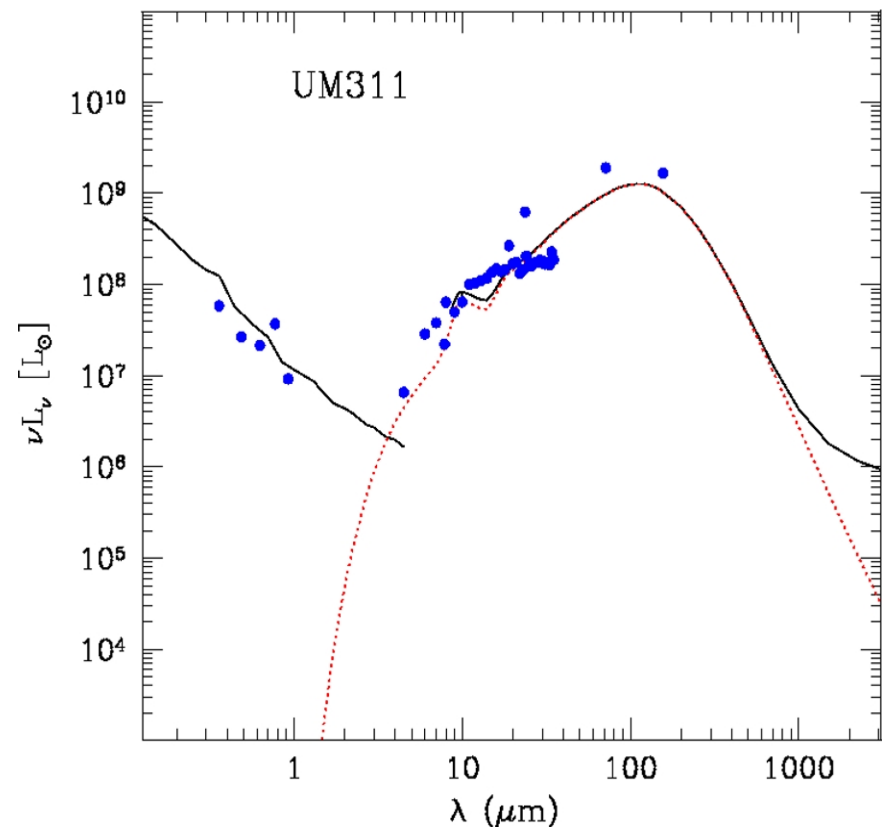
L_{IR} differs in this case only by a factor of ~5

Last of SEDs of active/passive BCDs

12+logO/H=8.32 (~14 times SBS0335-052)
SFR = 1.2 M_{sun}/yr
L_{IR} =5.0 10^9 L_{sun}



12+logO/H=8.31
SFR = 1.3 M_{sun}/yr
L_{IR} = 2.5 10^9 L_{sun}



L_{IR} varies by ~50-100, roughly independently of O/H!

(3) Why are some BCDs "active"?
Compact/dense vs. extended/diffuse

Modeling the IR luminosity in simple starbursts

Star formation rate. Stars form as a result of the gravitational collapse of a gas cloud. Thus assume constant ***SFR*** over a ***free-fall timescale*** of the gas (e.g. Elmegreen 2000, Tan & Krumholz 2007):

$$t_{\rm ff} = \sqrt{\frac{3\pi}{32 G\rho}} \simeq \frac{4.35\times 10^7}{\sqrt{n_{\rm H}}}\ {\rm yr}$$

$$\psi(t) = \frac{\epsilon_{\rm SF} M_{\rm gas}}{t_{\rm ff}} f(t) \simeq 0.230 \left(\frac{\epsilon_{\rm SF}}{0.1}\right) \left(\frac{M_{\rm gas}}{10^7\ M_\odot}\right) \left(\frac{n_{\rm H0}}{100\ {\rm cm}^{-3}}\right)^{1/2} \times\ f(t)\ M_\odot\ {\rm yr}^{-1}$$

Number density n_{H0} related to initially fixed ***gas mass***:

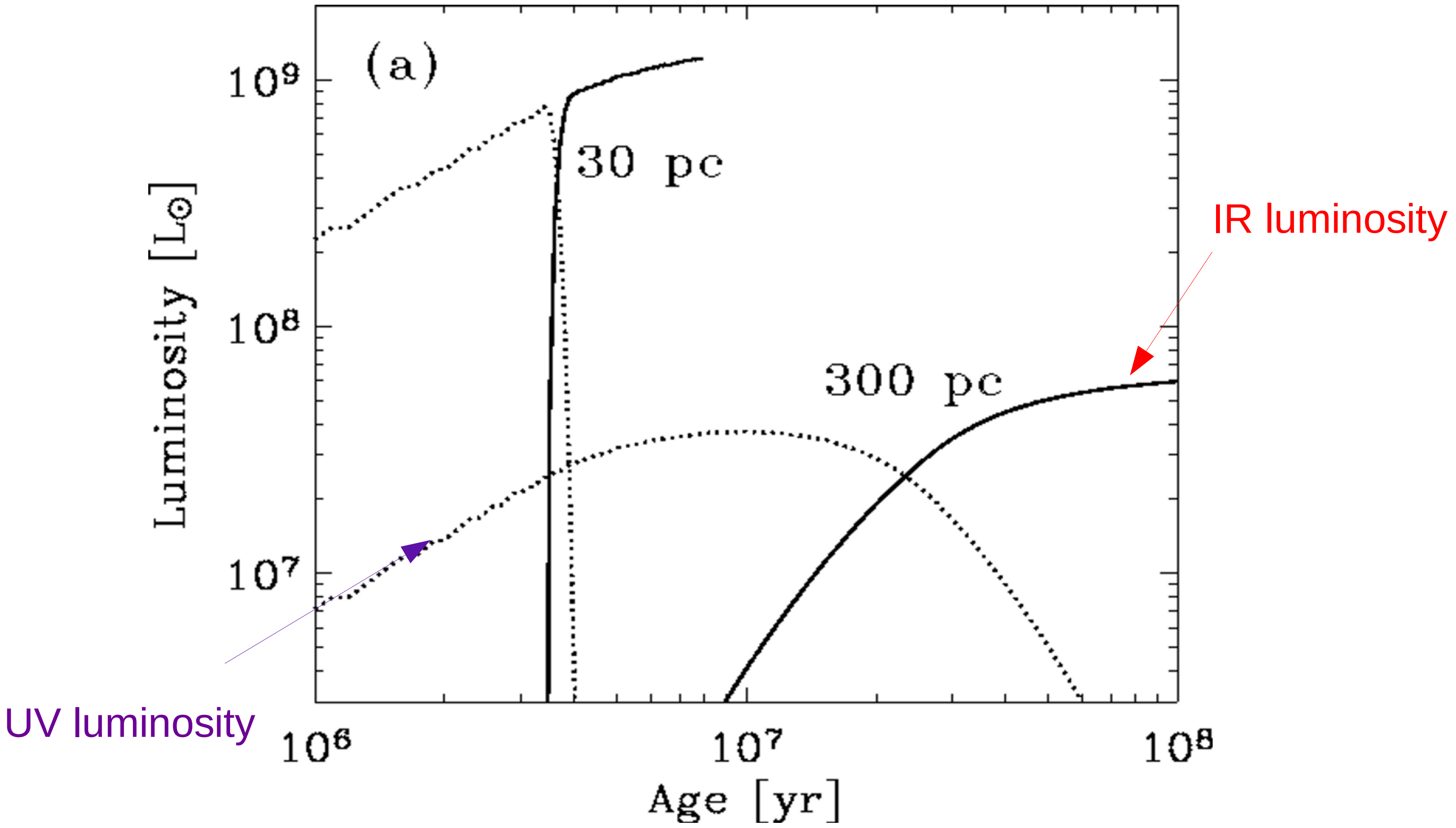
$$n_{\rm H0} \simeq 69 \left(\frac{r_{\rm SF}}{100\ {\rm pc}}\right)^{-3} \left(\frac{M_{\rm gas}}{10^7\ M_\odot}\right)\ {\rm cm}^{-3}$$

Dust production related to ***SFR*** through ***Type II SNe rate Y*** (Todini & Ferrara 2001; Schneider et al. 2004: Bianchi & Schneider 2007):

Hirashita & Hunt (2004, 2006):
Hunt & Hirashita (2009)

$$\gamma(t) = \int_{8\ M_\odot}^{\infty} \psi(t-\tau_m)\,\phi(m)\,dm$$

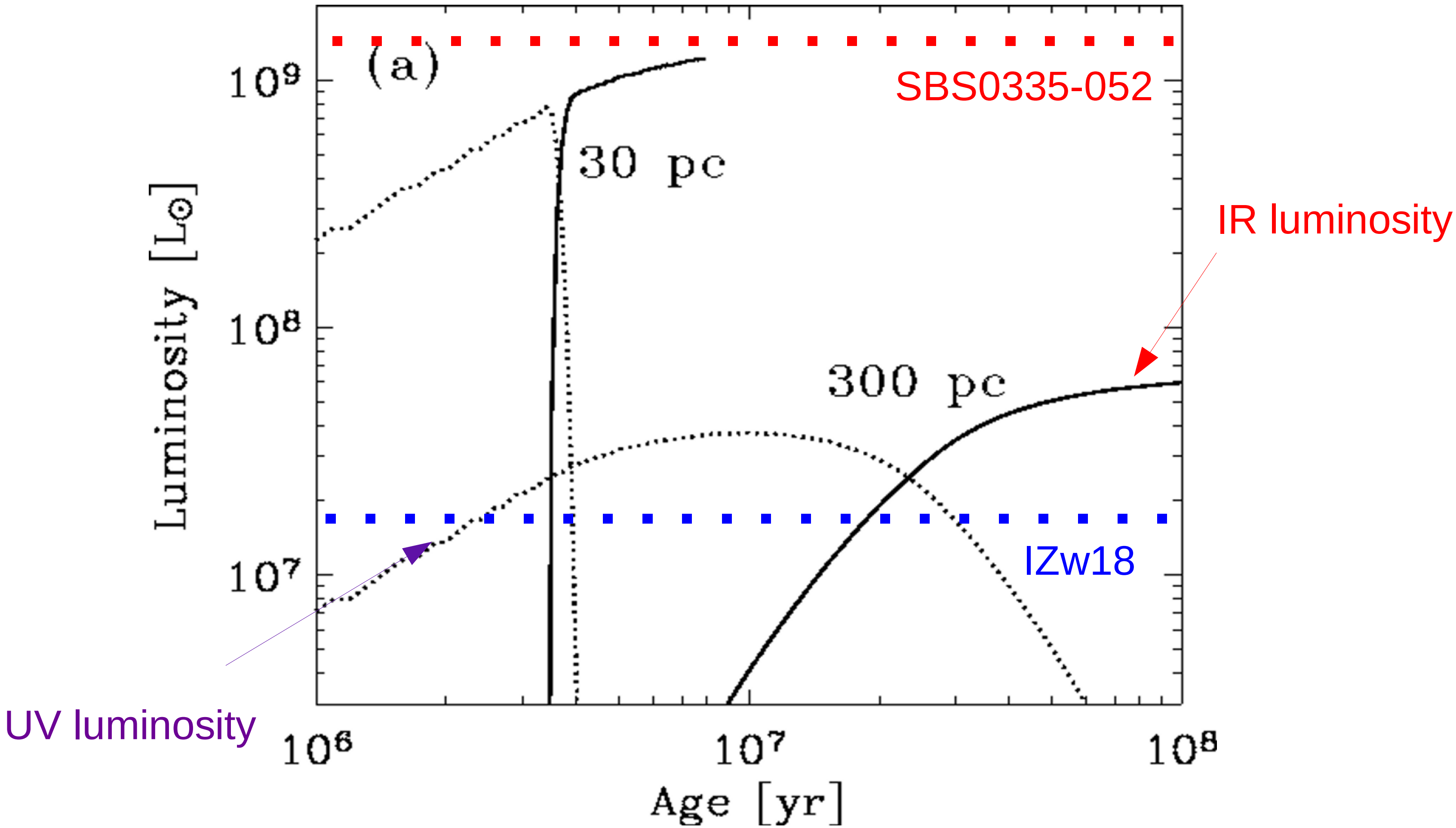
Predictions for UV and IR luminosity



For a given gas and stellar mass, *smaller denser HII regions* are *more IR luminous* than *larger more diffuse ones* (essentially a question of evolutionary time scale and SFR) ...

Hirashita & Hunt (2004)

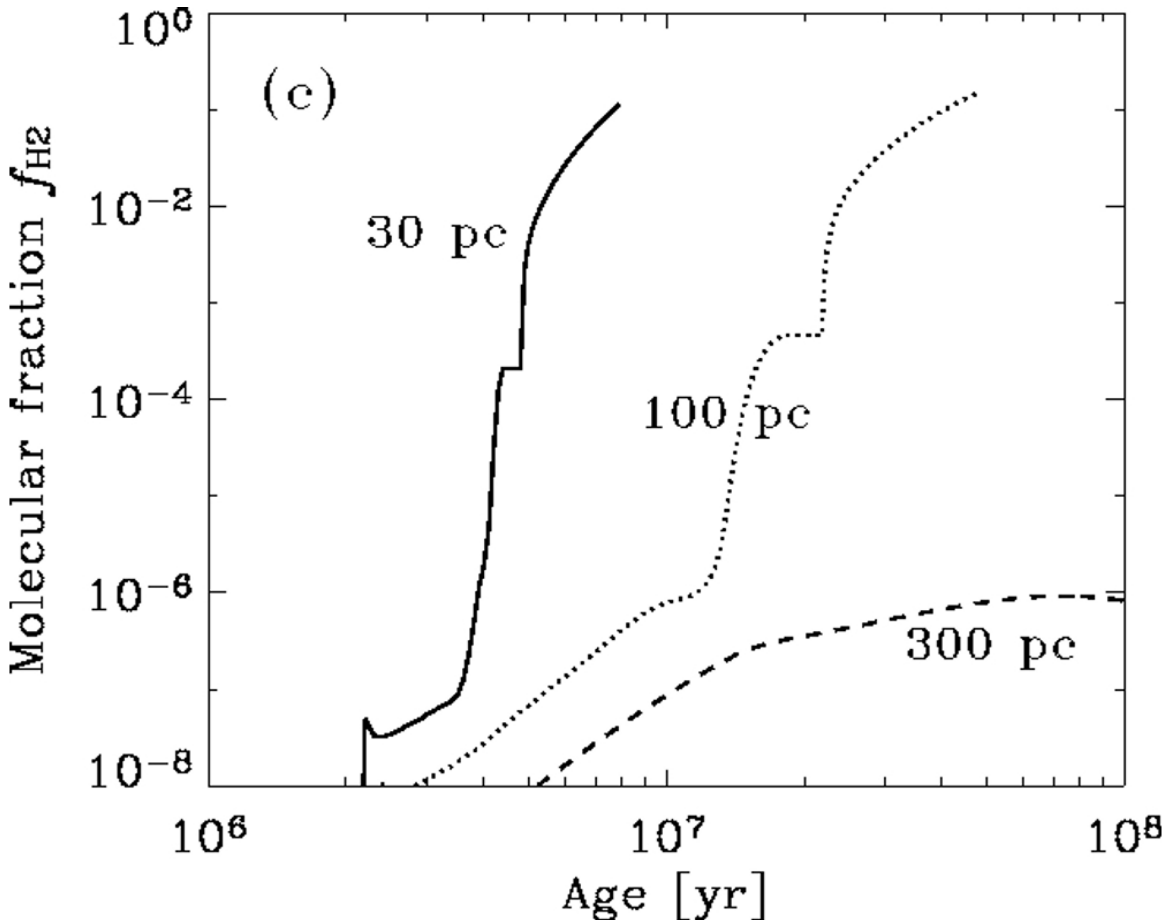
Predictions for UV and IR luminosity (before *Spitzer*)



For a given gas and stellar mass, *smaller denser HII regions* are *more IR luminous* than *larger more diffuse ones* (essentially a question of evolutionary time scale and SFR) ...

Plante & Sauvage(2002); Hunt, Bianchi, Maiolino (2005); Wu et al. (2007)

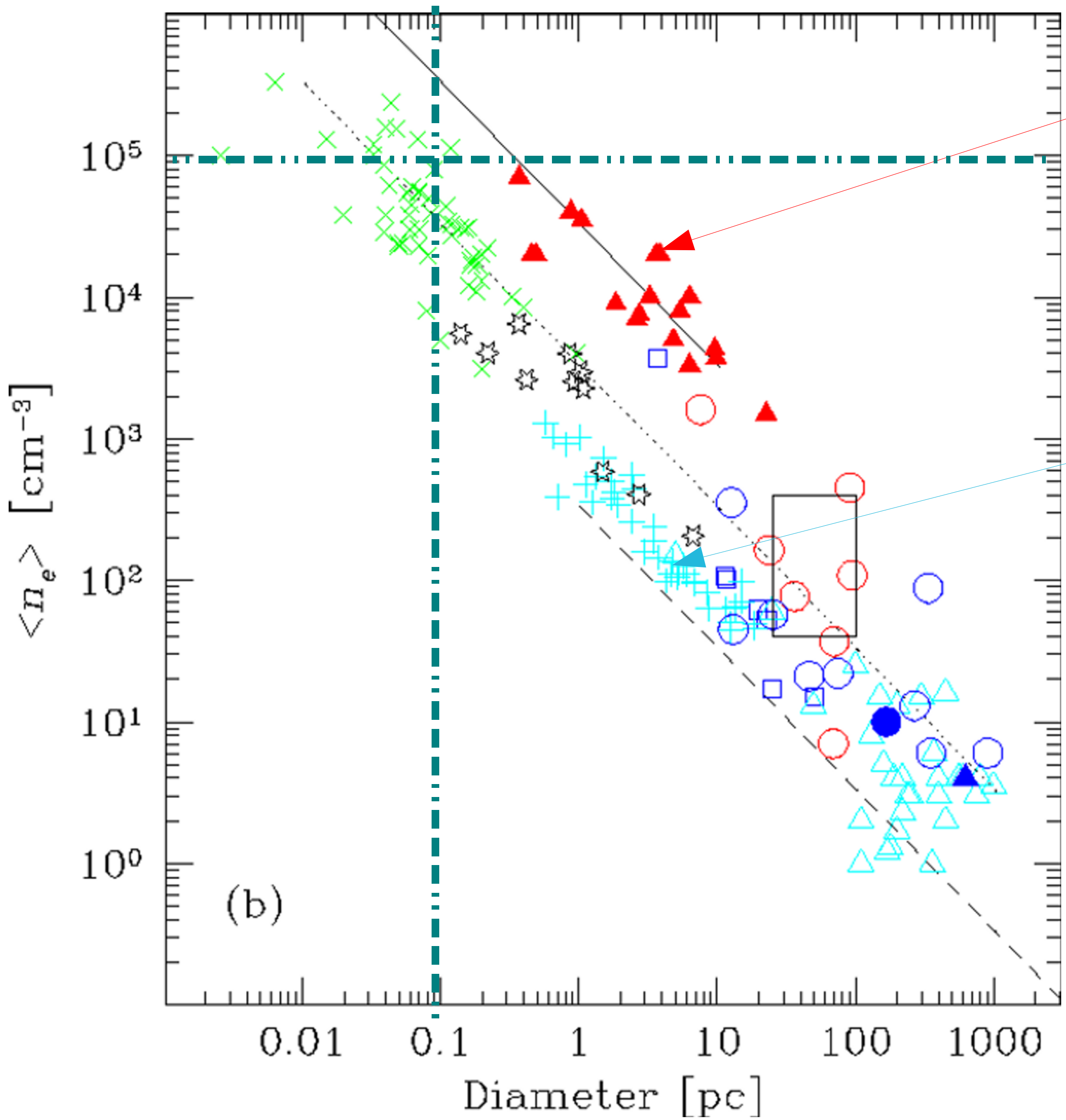
Predictions for molecular fraction



For a given gas and stellar mass, *smaller denser HII regions* are *more molecular rich (sooner)* than *larger more diffuse ones* ...

Compact regions tend to be **more self-shielding**, suppressing UV dissociation of H2.

Size and density inversely correlated in Galactic and extragalactic HII regions (BCDs): slope ~-1



BCDs from highν high-resolution radio continuum observations *(Beck et al. 2000, Beck et al. 2002, Johnson et al. 2001, Turner et al. 2000)*

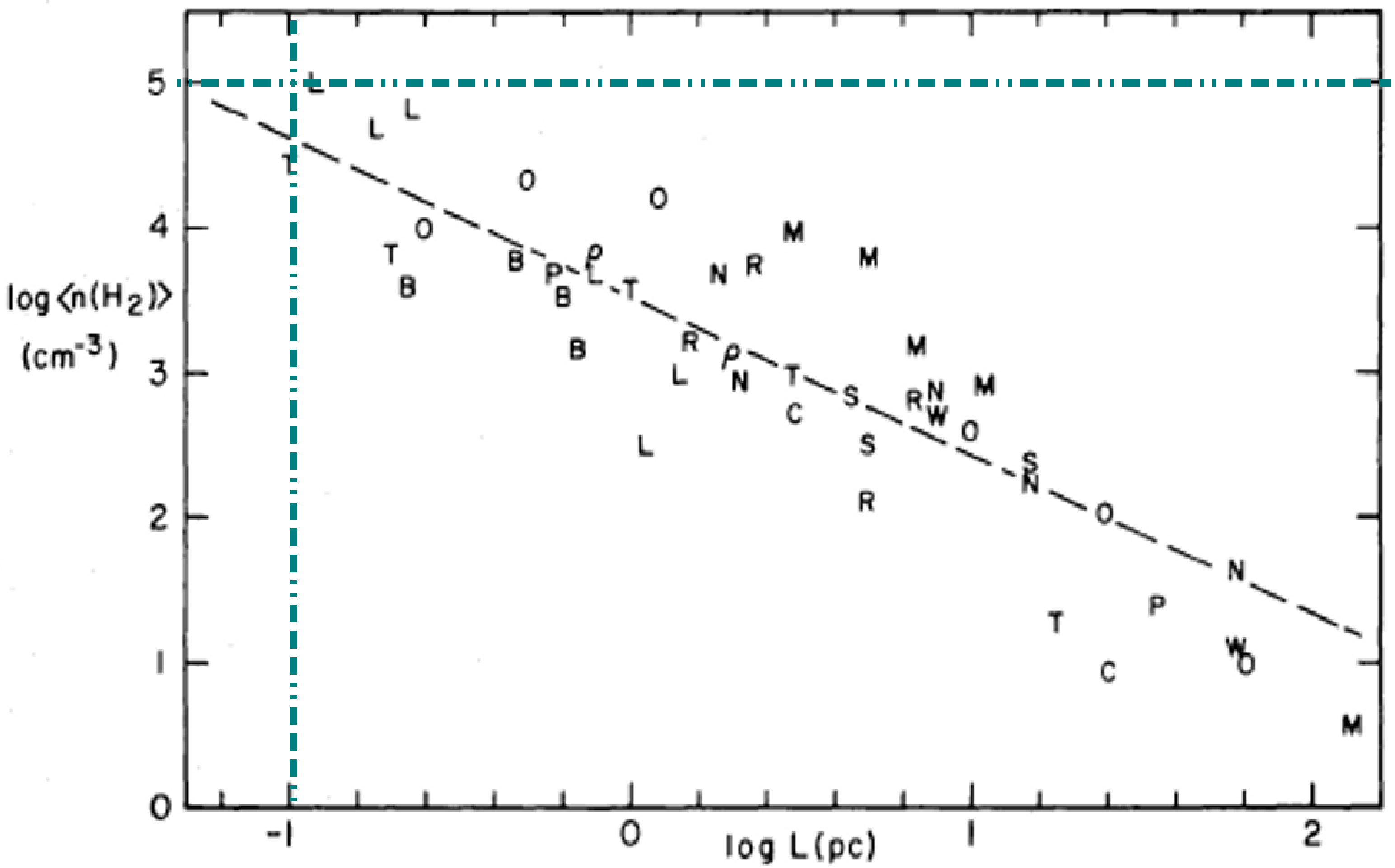
HII regions in the Milky Way and SMC measured from radio observations *(+, X: Garay & Lizano 1999, Kim & Koo 2002, Martin-Hernandez et al. 2005)* + HII regions in spiral disks *(open triangles: Kennicutt 1998)*

HII regions in the LMC, SMC (open stars), M33 (open squares)

Star-forming regions in BCDs from *HST* images + rms densities from Hβ emission measures (open circles, taken from Hunt & Hirashita, 2009)

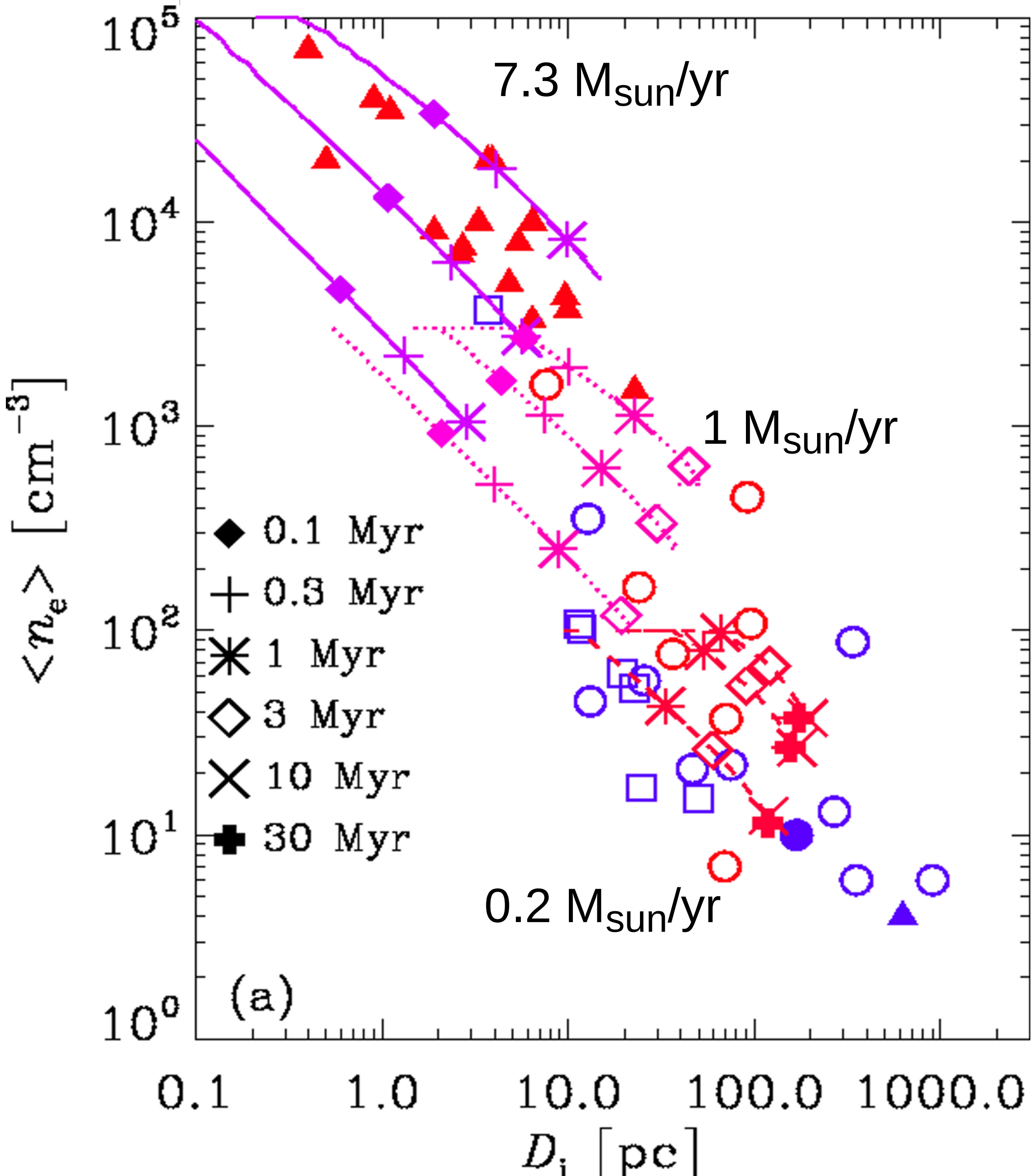
Lines correspond to constant dust τ with varying dust filling factor

Size and density inversely correlated in Galactic giant molecular clouds: slope ~-1



From Larson (1981): n_{H2} (cm^{-3}) = 3400 L(pc)$^{-1.1}$

Evolving HII region models for the size-density relation



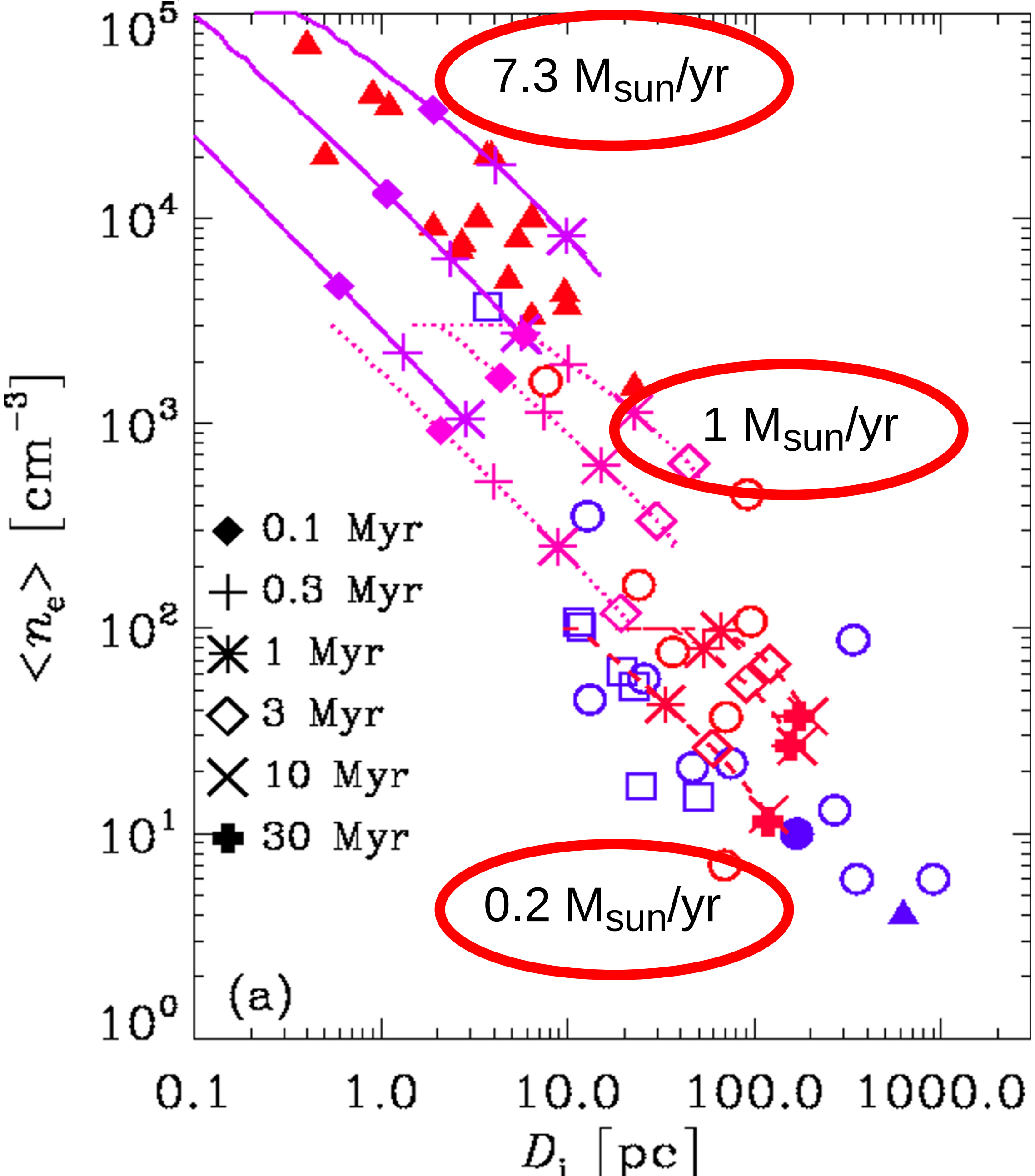
One-zone models which consider HII region expansion, gas consumption, and *dust intermixed with ionized gas* can be divided into two basic regimes:

Dense + compact ("active")

Diffuse ("passive")

Hunt & Hirashita (2009), although see Dopita et al. (2006) for an alternative explanation of the size-density relation that involves radiation pressure compression of ionized gas front

Evolving HII region models for the size-density relation



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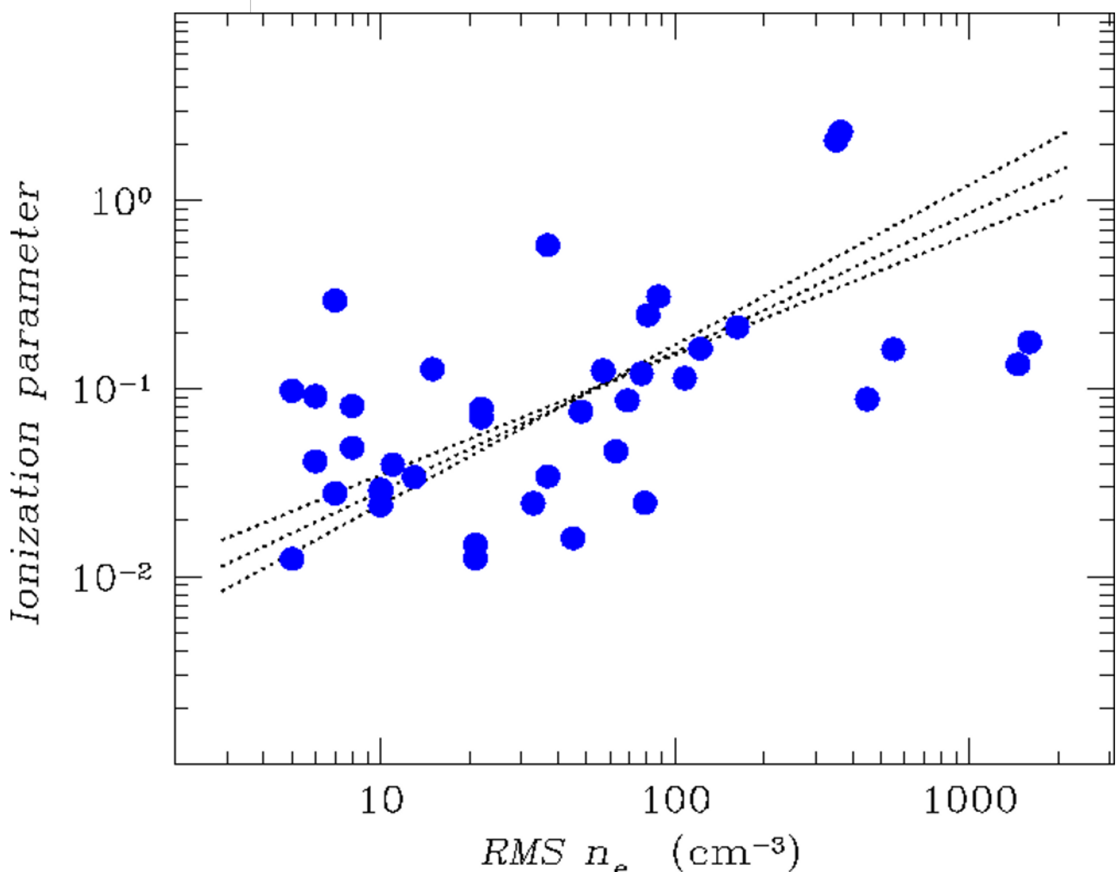
Size, density, and the ionization parameter



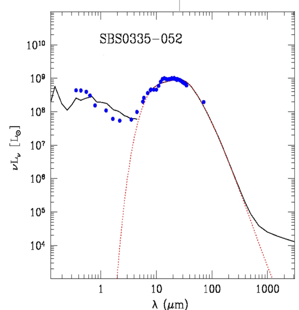
Ionization parameter U for the BCDs in the size-density relation

High density and compact size coupled through the size-density relation of HII regions.

Compact dense BCDs (shown in the size-density plot) have high SFR surface density, and also high U, as there is a weak correlation between U and n_e.

High U found for some high-redshift (z~1-3) populations, and usually attributed to high densities when possible to measure them directly (Brinchmann+ 2008, Liu+ 2008). High U also associated with high SFR surface density (Liu+ 2008).

The bottom line



Local samples of low-metallicity BCDs show variations in SED shapes and IR luminosity that are decoupled from changes in metal abundance. These BCDs also lie in the starburst region of the KS relation.

Simple models suggest that the variations in the IR SED and molecular fraction are due to variations in the size and density of the HII regions responsible for heating the dust, independently of the metallicity.

Compact and dense conditions in HII regions give rise to a high ionization parameter, which is observed locally in "active BCDs" and in high redshift populations, and associated with high SFR surface density.

Perhaps size and density are more important than metallicity in shaping molecular content (and galaxy evolution)

KEYWORDS: *size, density, UV field, self-shielding*