Tracing the total dust and gas Reservoirs in Low Metallicity Galaxies

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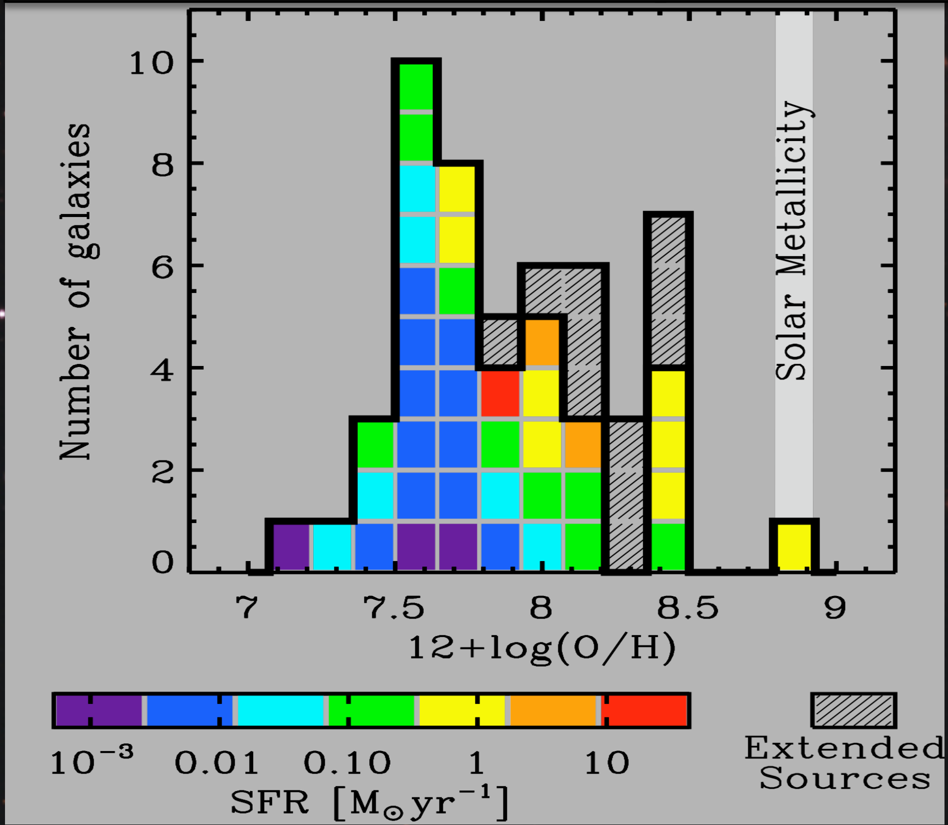
With the Herschel & SPIRE (SAG2) & PACS teams

Especially Maud Galametz, Diane Cormier, Vianney Lebouteiller, Frederic Galliano, Sacha Hony

Herschel & low metallicity galaxies

Herschel Dwarf Galaxy Survey



~50 galaxies

Extremely low metallicity galaxies: 1/50 to 1/20

All targets: Herschel FIR & submm photometry and FIR spectroscopy
All targets: Spitzer MIR

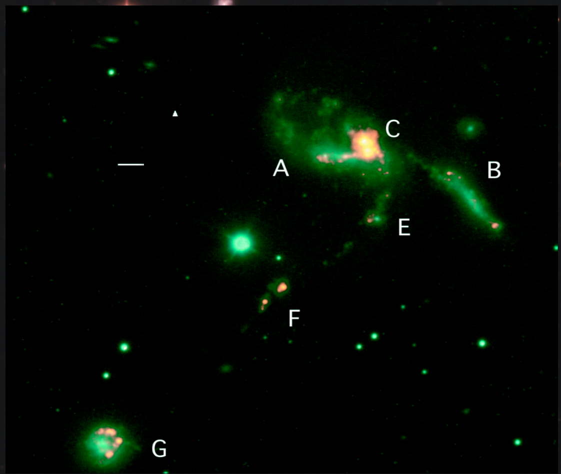
Galaxy Evolution issues:

- *How do galaxies accumulate their metals?*
- *How does the enrichment effect star formation processes?*

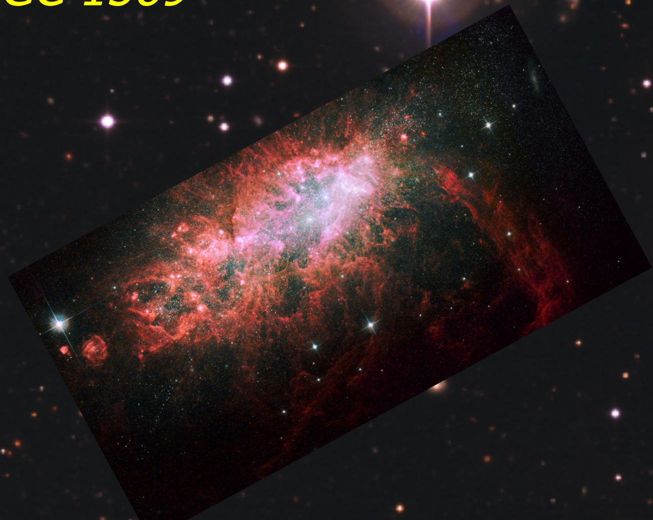
Zoo of dwarf galaxies in the local Universe

Optical view of a sample of the Herschel dwarfs

Mkn 1089

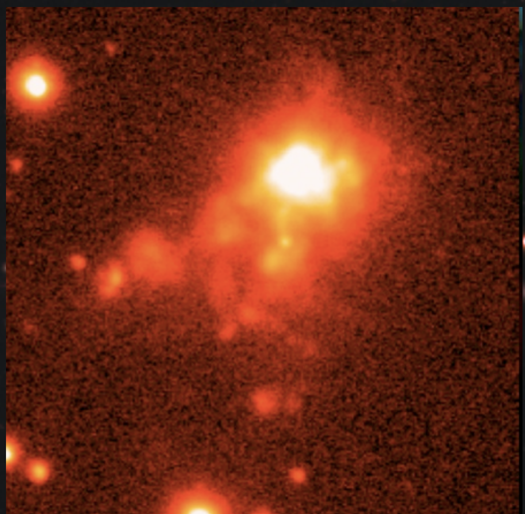


NGC 1569



NGC 1705

II Zw 40

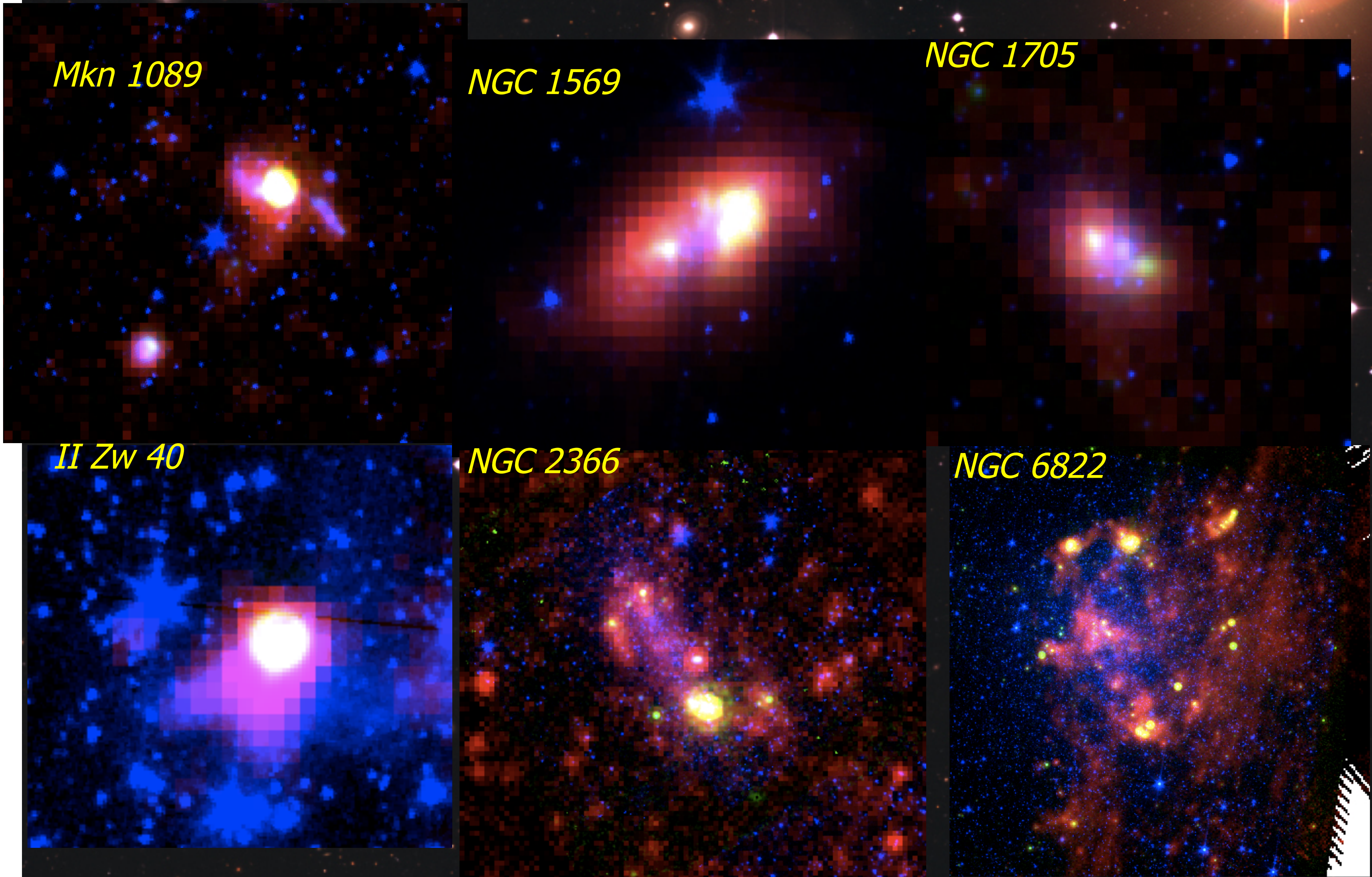


NGC 2366

NGC 6822

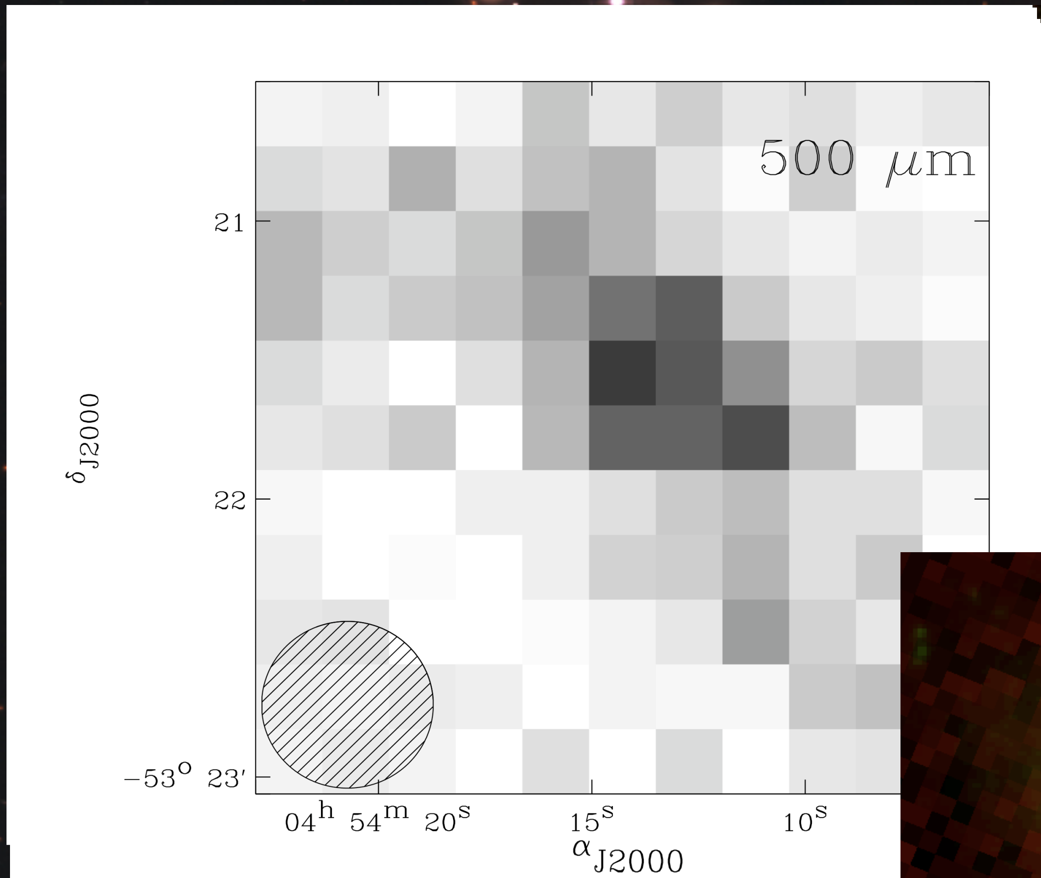
Dwarf Galaxies: Herschel-Spitzer 3-color images

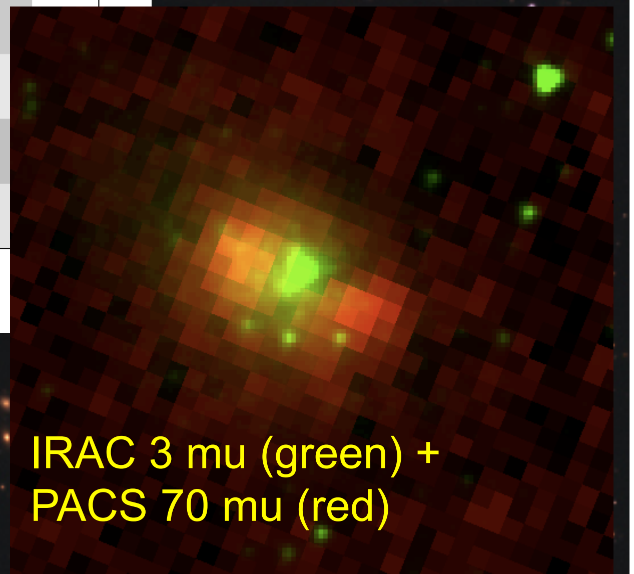
Blue: 3.6 mu(stars) green: 24 mu (hot dust) red: 250 mu (cold dust)



NGC 1705 *Herschel + Spitzer* D = 5 Mpc Z = 1/3 Zsolar

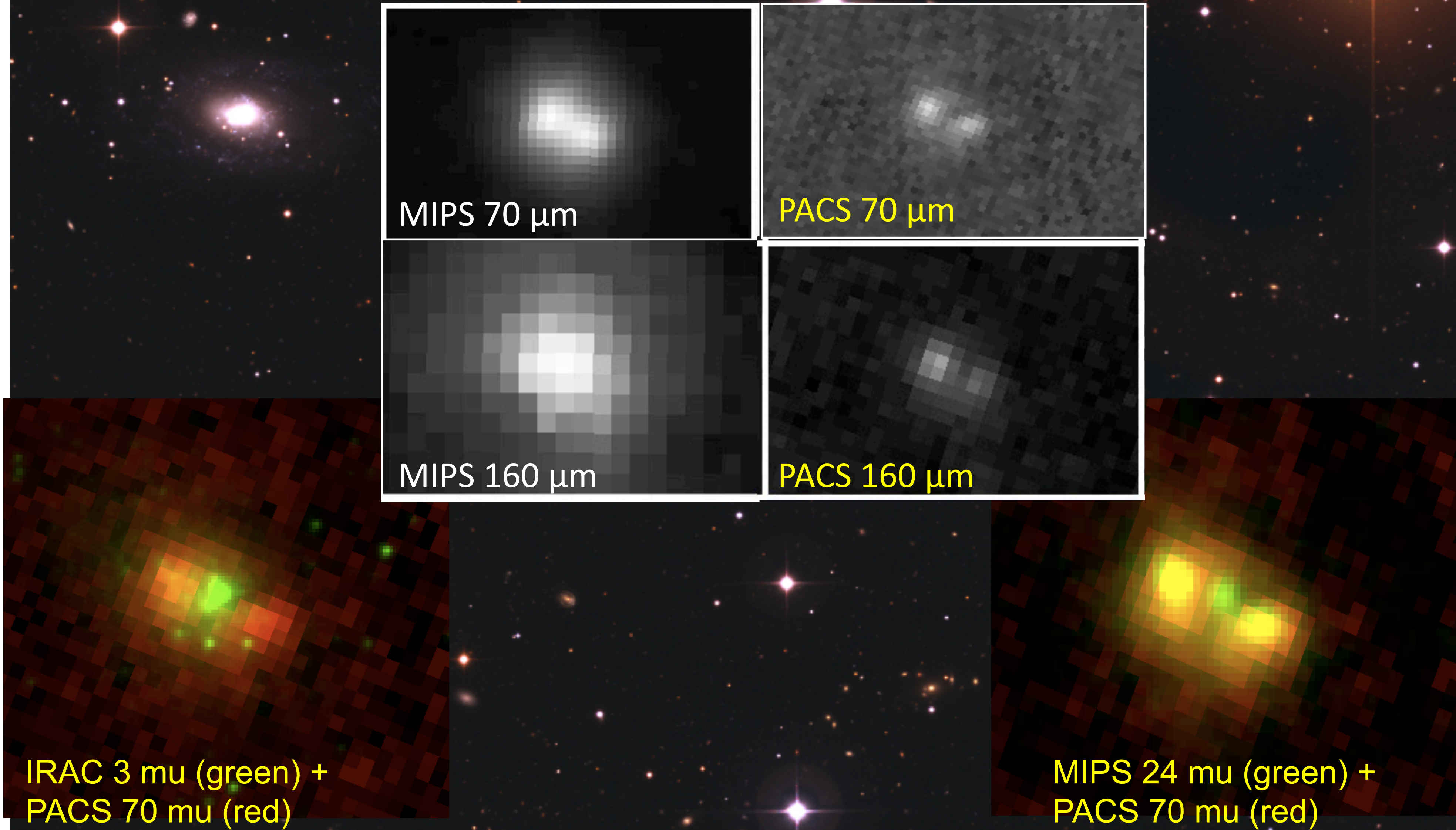
O'Halloran et al 2010





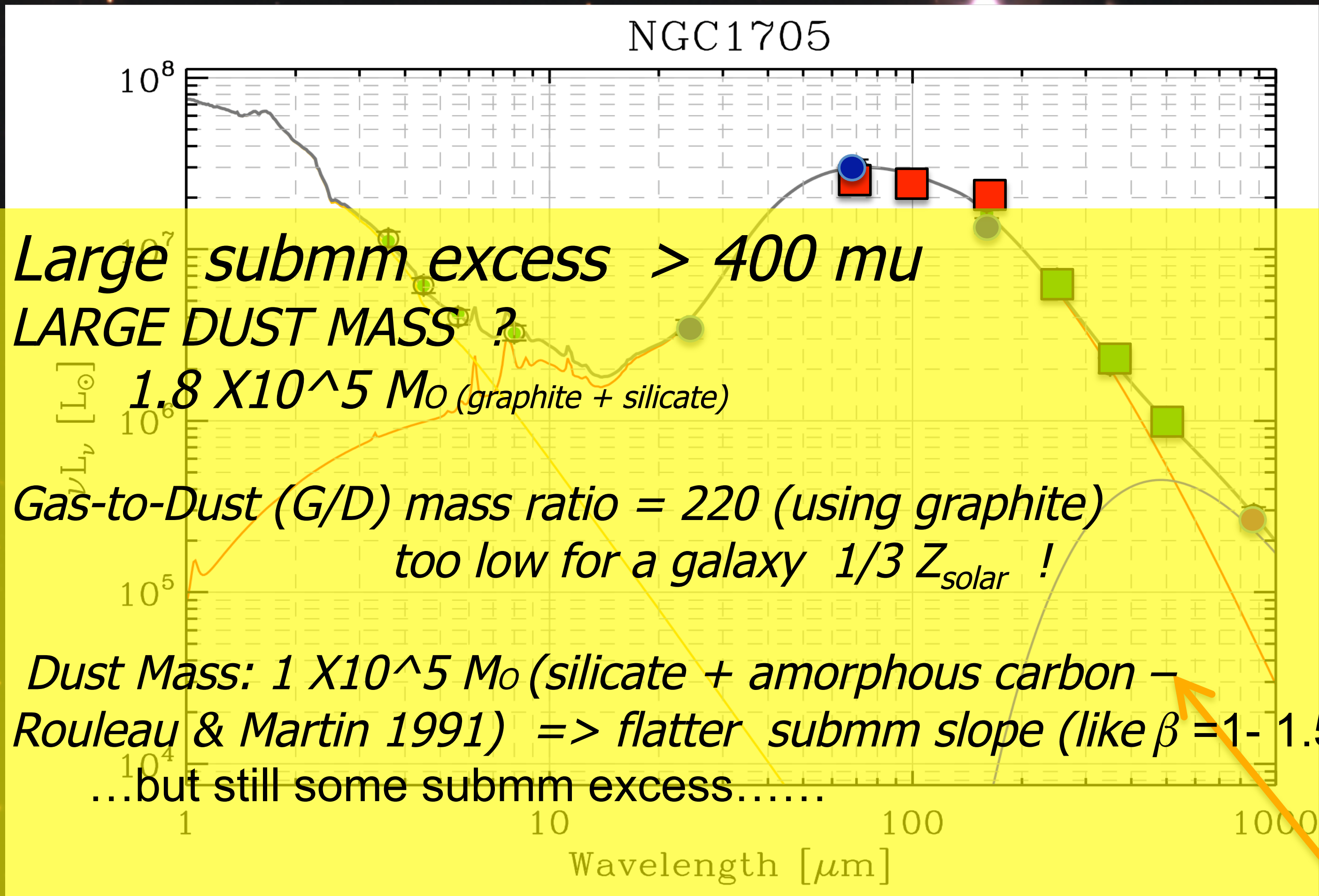
The Super Star Cluster dominates at short λ
but disappears > 24 $\mu\upsilon$
PACS isolates the 2 other clusters

NGC1705: the Improved Spatial Resolution of Herschel



NGC 1705 Herschel confirms submm excess

IRAC + MIPS + PACS + SPIRE + Laboca 870 mu



- MIPS
- PACS
- SPIRE
- LABOCA

Large submm excess > 400 mu

LARGE DUST MASS ?

1.8 X10^5 Mo (graphite + silicate)

Gas-to-Dust (G/D) mass ratio = 220 (using graphite)
too low for a galaxy 1/3 Z_{solar} !

Dust Mass: 1 X10^5 Mo (silicate + amorphous carbon – Rouleau & Martin 1991) => flatter submm slope (like β =1- 1.5)
…but still some submm excess……

(G/D) mass ratio = 400 ~ 3 X Galactic G/D

Very cold dust component:

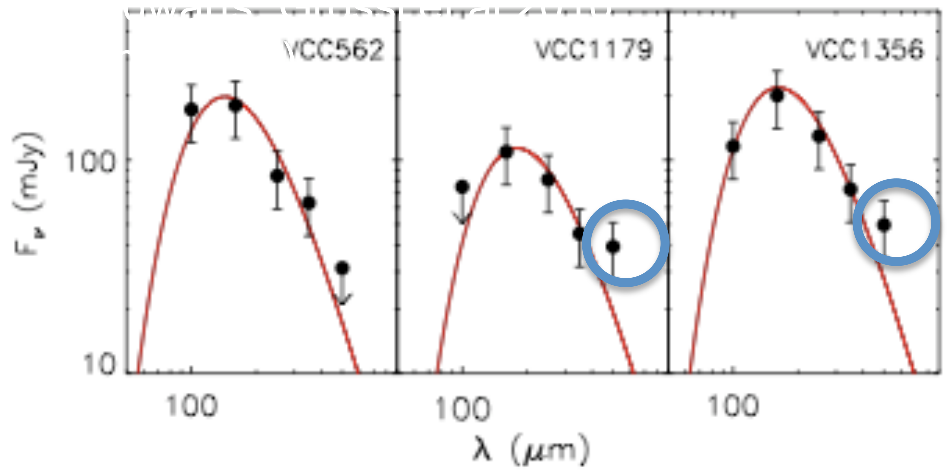
T dust ~ 10 K
β = 1.0

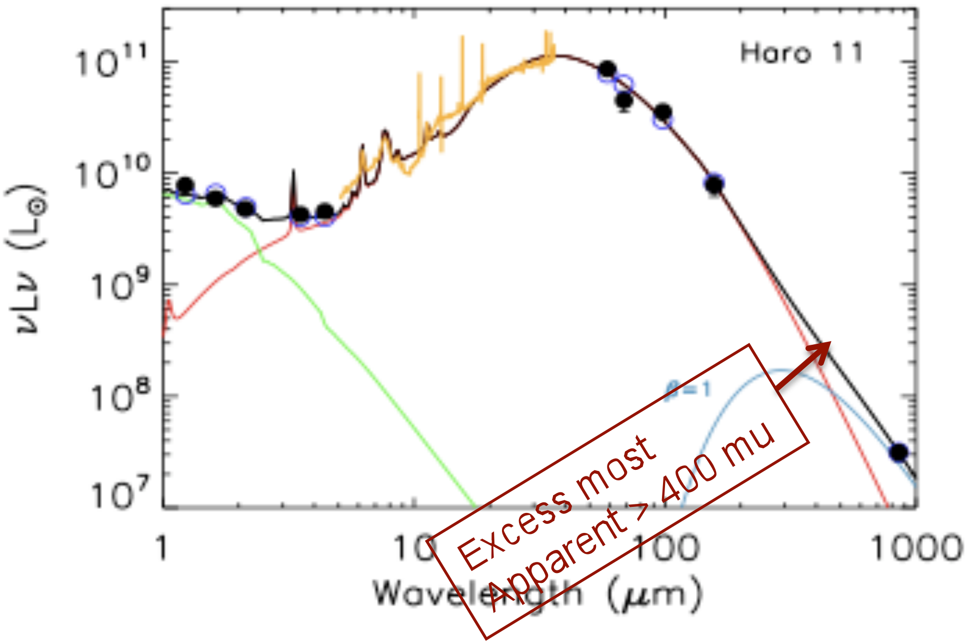
O'Halloran et al 2010; SED model Galliano et al & Galametz et al 2009

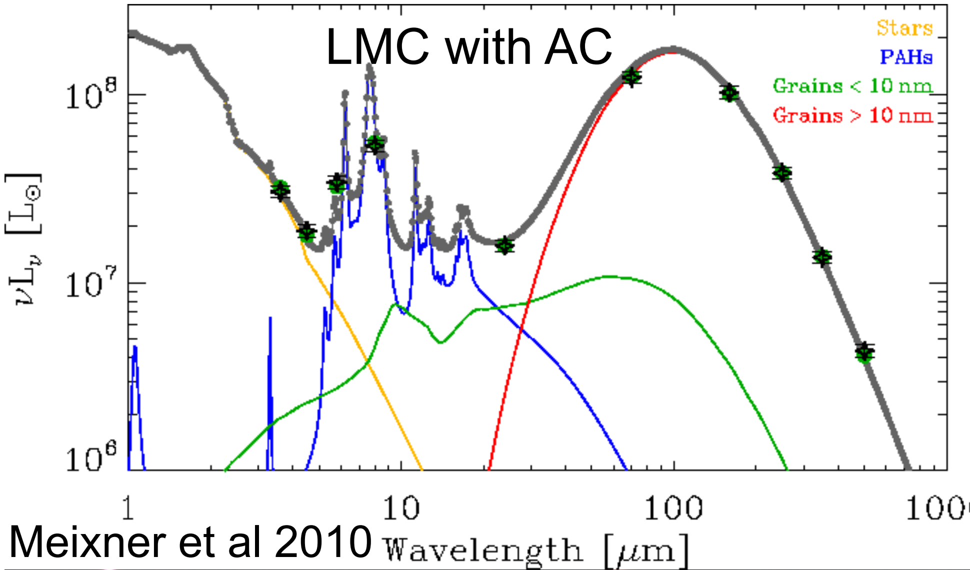
Dwarf Galaxies often show submm excess

Virgo dwarfs: Grossi et al 2010

Haro 11 Galametz et al 2009







Meixner et al 2010

500 mu excess in the LMC w/graphite -
Excess gone with amorphous carbon

graphite -> amorphous carbon
(but often still excess + extra cold dust comonent)

Some other possibilities: Lisenfeld et al hot fluctuating small grains (2001)
Modified optical properties Inverse T – beta relationshp : (Meny et al 2007)
Spinning dust (Draine &Lazarian 1998; Hoang 2010; Ysard & Verstraete 2010; Bot et al 2010.)

Such large dust masses giving low G/D not plausible for low metallicity galaxies

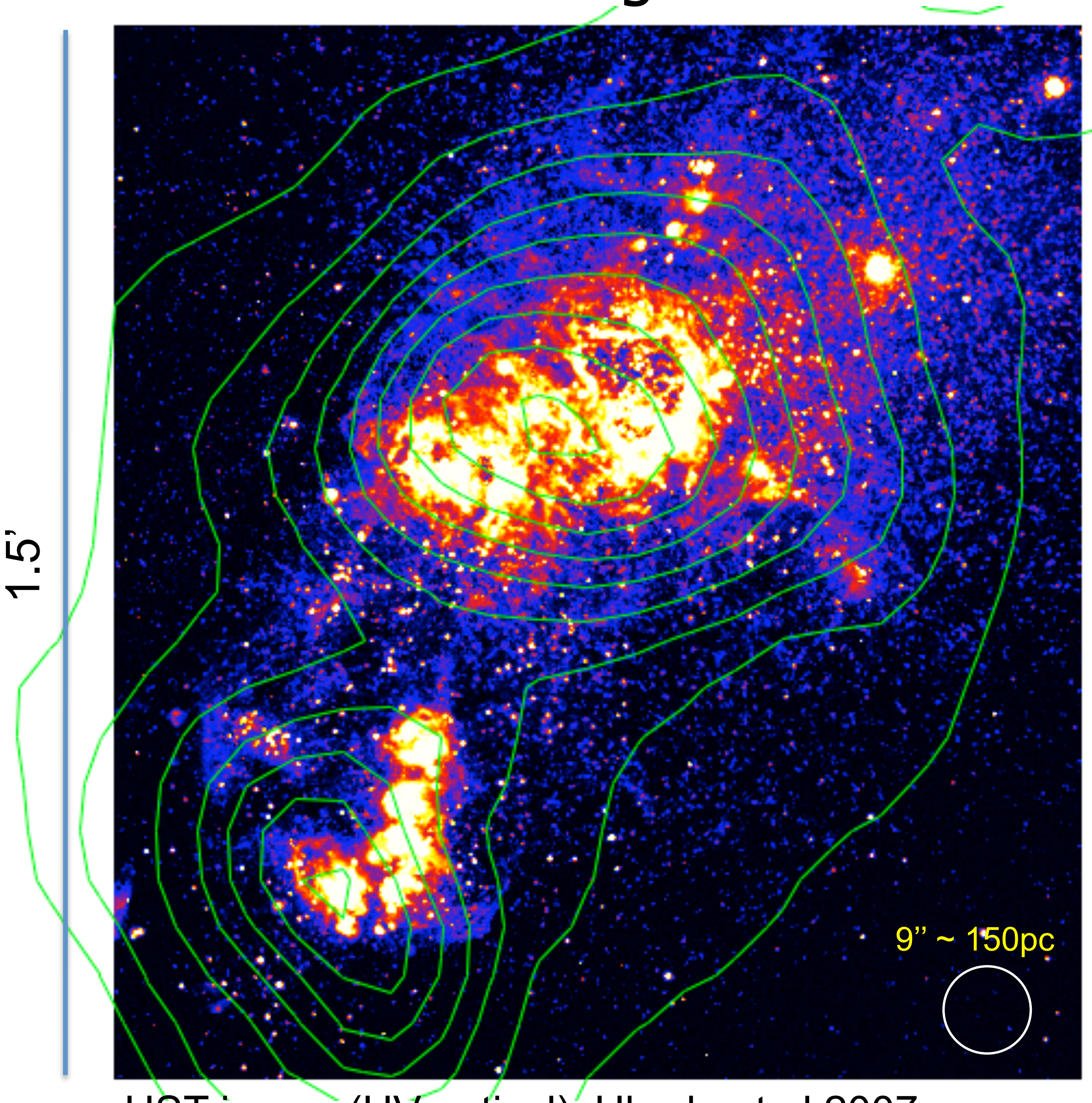
BUT

Do we know the total gas reservoirs in dwarfs?

NGC 4214 HST image + PACS CII contours

D=3 Mpc

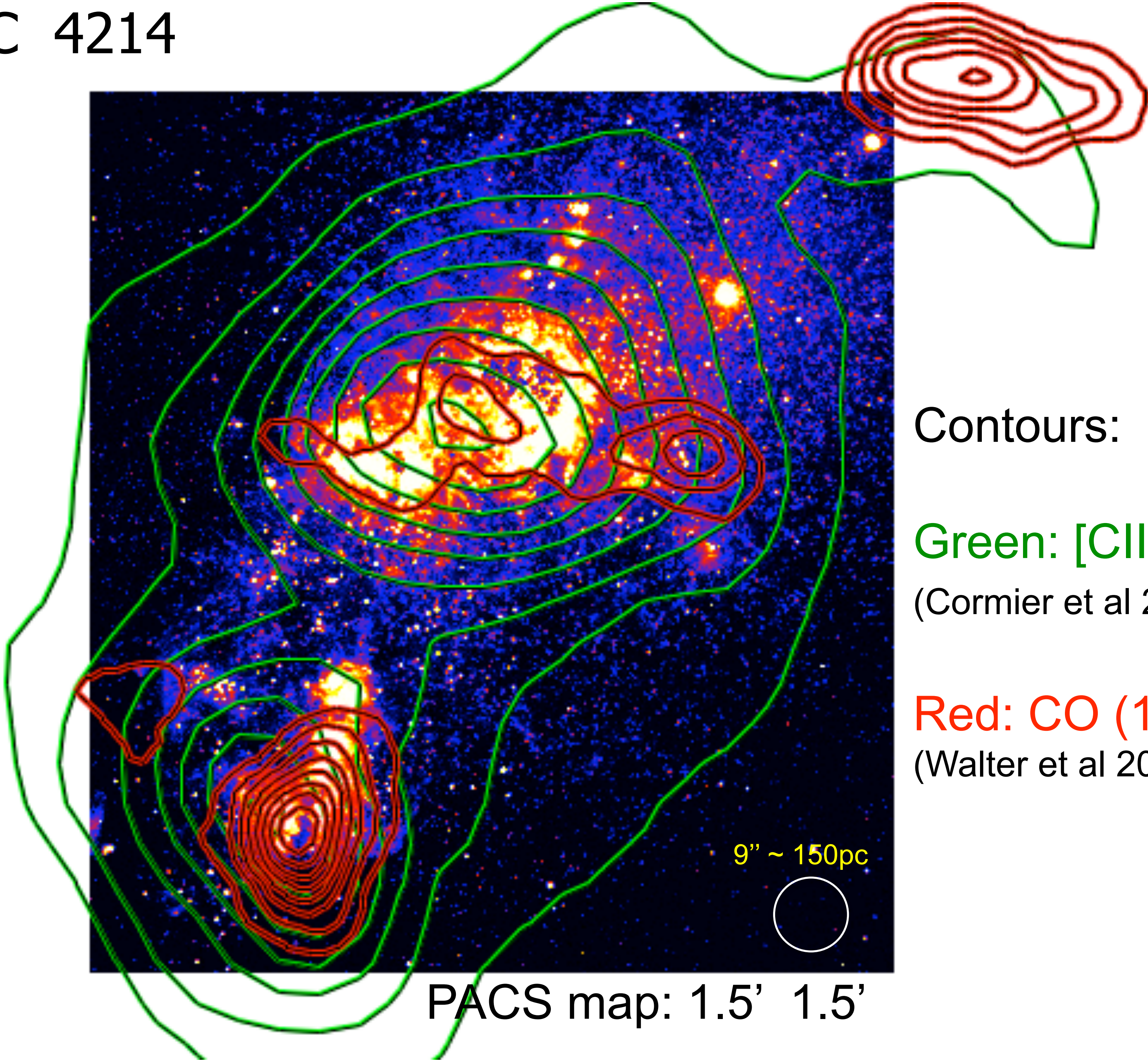
Z = 30% Z_{solar}



HST image (UV-optical): Ubeda et al 2007

158 mu [CII] map: Cormier et al 2010

NGC 4214



Contours:

Green: [CII]

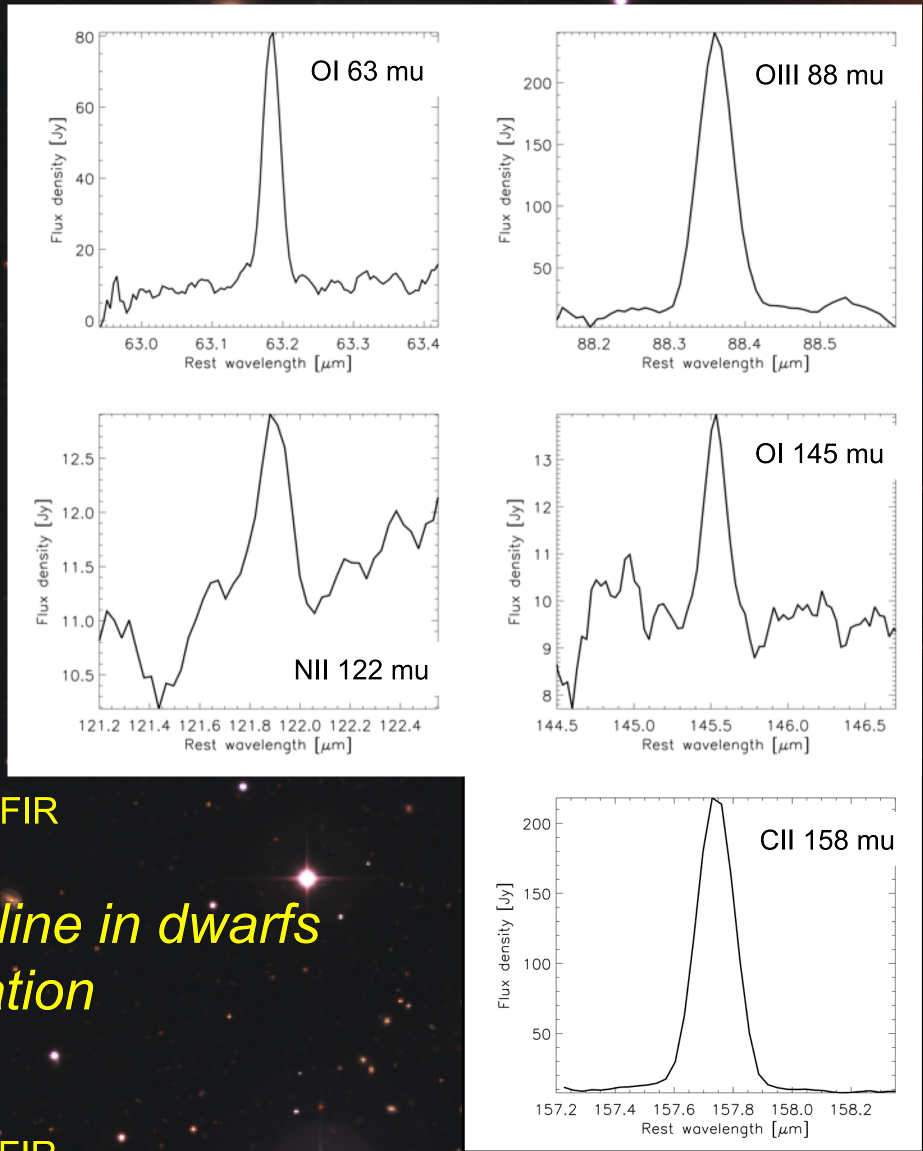
(Cormier et al 2010)

Red: CO (1-0)

(Walter et al 2001)

NGC 4214 d=3 Mpc $Z = 30\% \, Z_{solar}$

5 FIR lines mapped:



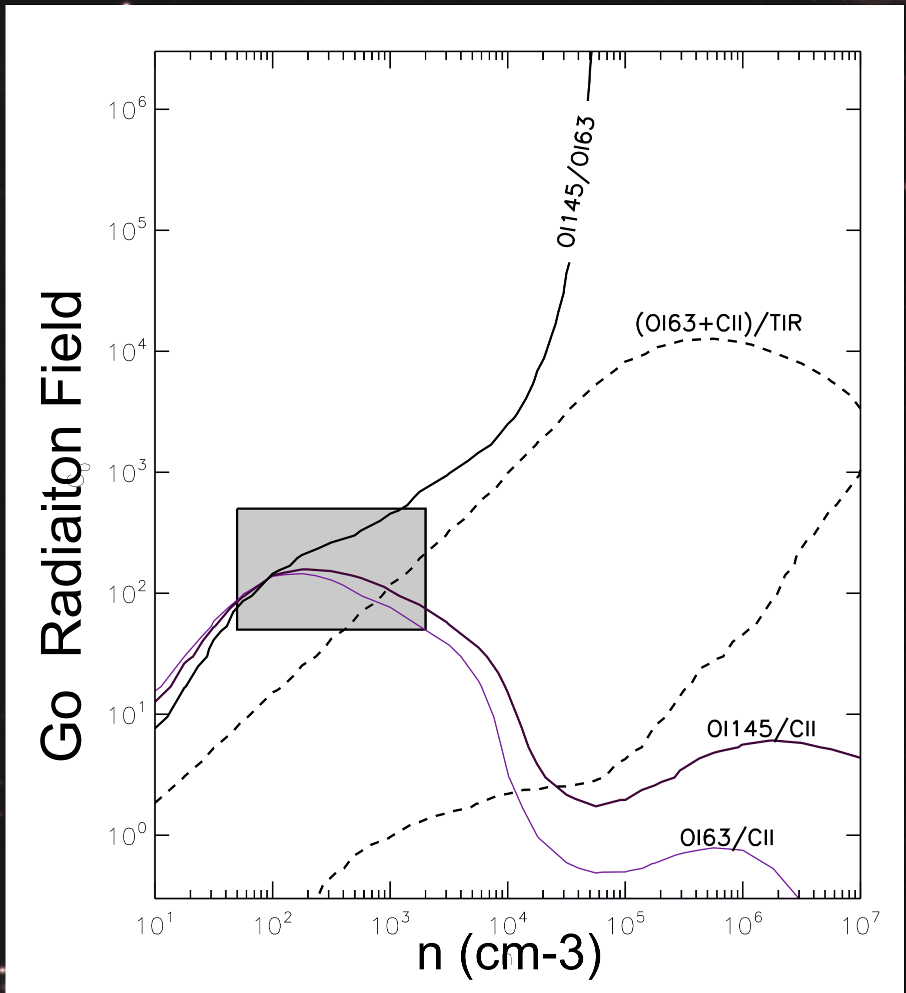
[CII] is 1% to 1.5 % of the L_{FIR}

[OIII] 88 mu line - brightest line in dwarfs – traces the source of ionisation

All FIR lines ~ 2 to 4 % of L_{FIR}

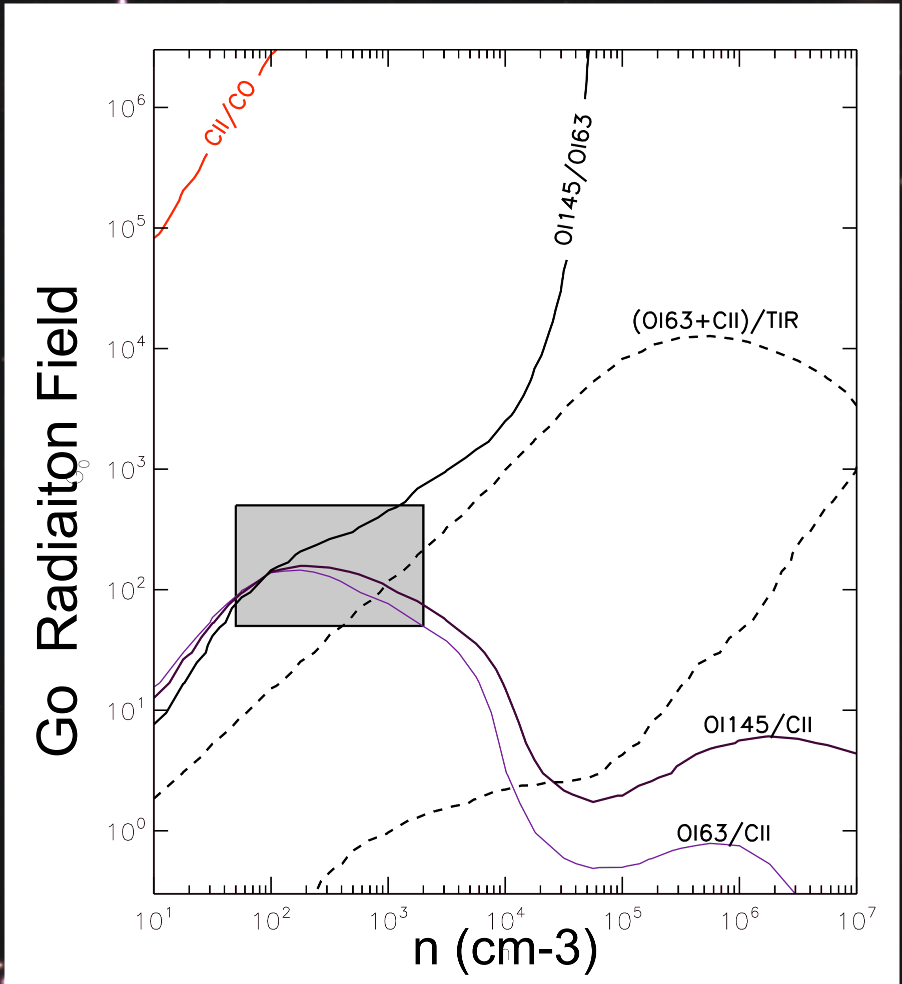
NGC 4214 d=3 Mpc Z = 30% Z_{solar}

Kaufman et al PDR plots



NGC 4214 d=3 Mpc $Z = 30\% Z_{solar}$

Kaufman et al PDR plots



[CII]/CO = 4 000 to 75 000
(galaxy average: 30 000)

'Hidden' molecular gas traced by C+ (CO-free zone)

'CO-Dark' molecular gas (Wolfire et al 2010)

Also: Stacey et al 1991; Poglitsch et al 1995; Madden et al 1997; Bolatto et al 1997; Madden et al 2000; Models: Roellig et al 2006; Wolfire et al 2010

Solar metallicity

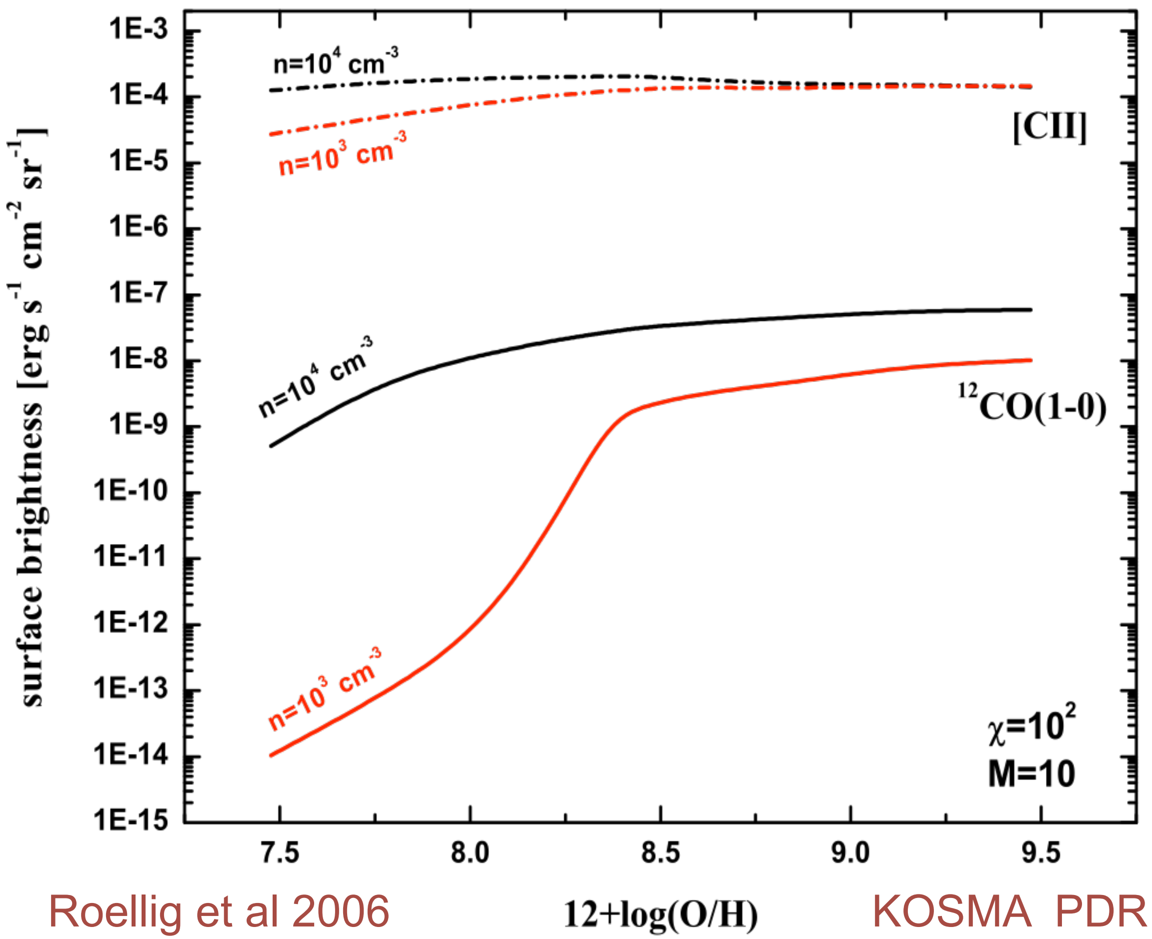
Low metallicity

high I[CII]/I(CO) - decrease in metallicity
Normal metallicity clouds – PDR a *thin* shell around H2
Decreased in metallicity – decrease in dust – lower photon attenuation in cloud -> CO more easily destroyed – deeper PDR around smaller CO core

Total N(C^+) the same ; N(H_2) might not be less (self-shielding of H_2)

Low Z dwarf IC10: ***'hidden' H_2 factors of*** up to 50 to 100 times more H_2 than traced with CO (Madden et al 1997)

PDR modeling and Metallicity



Roellig et al 2006 KOSMA PDR

"The Dark Molecular Gas": Grenier et al 2005
Wolfire et al 2010

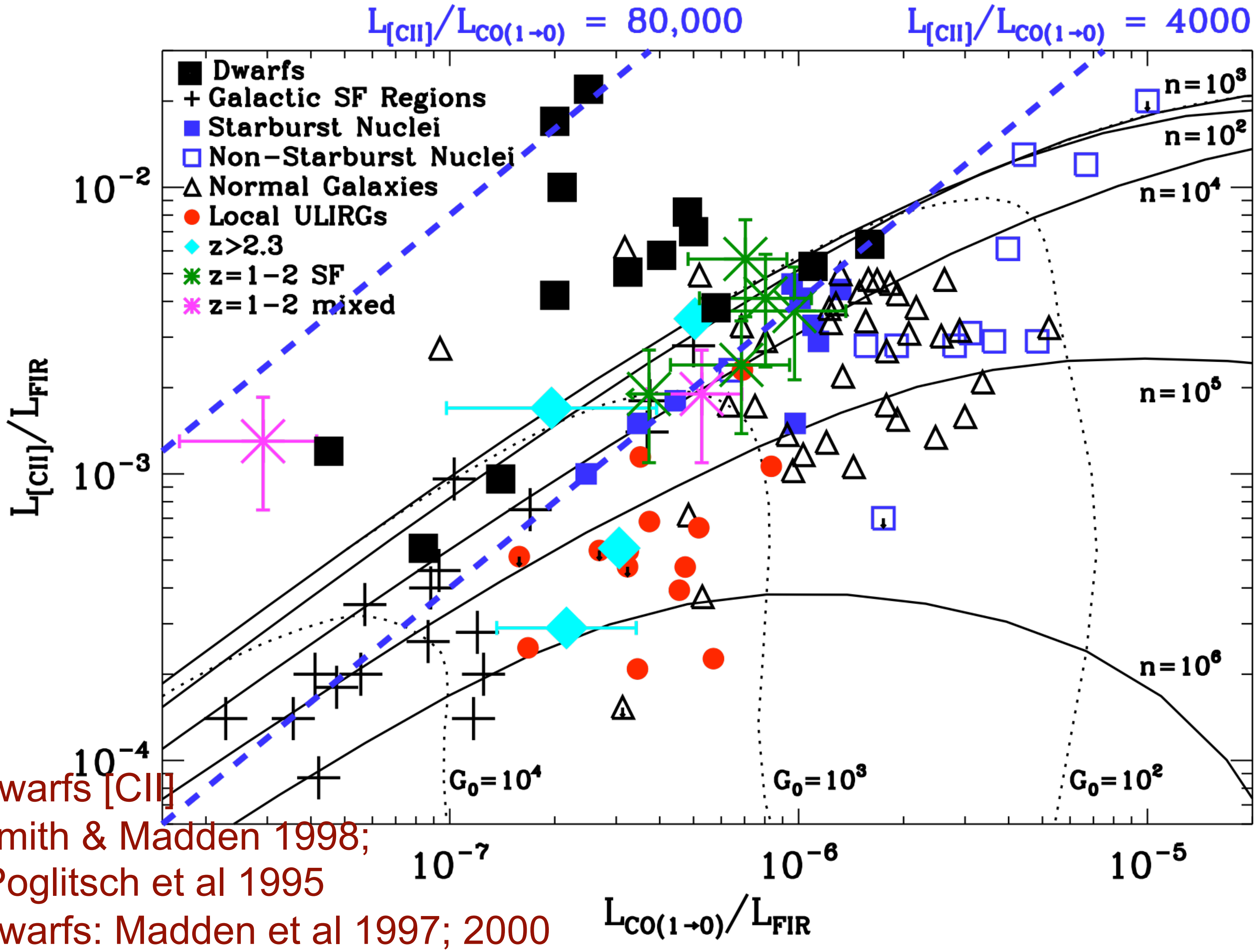
CO-free zone
H2- dark zone
Traced by [CII]

Critical parameter:
Shielding of H2 determines HI/H2 transition - depends on
Go/n vs
dust extinction of FUV

Close to the clump surface?
Or close to the
C+/C/CO interface?

More Herschel spectroscopy
To come….

[CII]/FIR & [CII]/CO in Galaxies - local and high-z



Dwarfs [CII]
Smith & Madden 1998;
Poglitsch et al 1995
Dwarfs: Madden et al 1997; 2000
Cormier et al 2010

Non-dwarfs from : Hailey-Dunsheath et al 2010
Stacey et al 1991; Stacey et al 2010

Summary (take home the yellow points)

- *Submm excess observed in dwarf galaxies*
  - Is this due to a v. large cold dust mass?
  - Using amorphous carbons instead of graphite can ameliorate this
  - Can still find large dust masses sometimes - *low gas-to-dust mass ratio*
- *'Missing' Molecular Gas in low metallicity galaxies?*
  - *L([CII]/L(CO) >> than dusty star burst galaxies - tracing the H_2 gas not traced by CO*
  - [CII] widely distributed throughout low metallicity galaxies – very clumpy?
  - L([CII]/LFIR 0.5% to 2%
  - OIII/CII > 2 on galactic scale (like giant HII regions). OIII may be a workhorse diagnostic for high z, low Z galaxies with ALMA

Molecular reservoir:

([CII] + CO) -to-H_2 conversion factor

The total dust mass issue - needs the gas inventory