The Elusive Gas and Dust Properties of Low Metallicity Galaxies Revealed by Herschel

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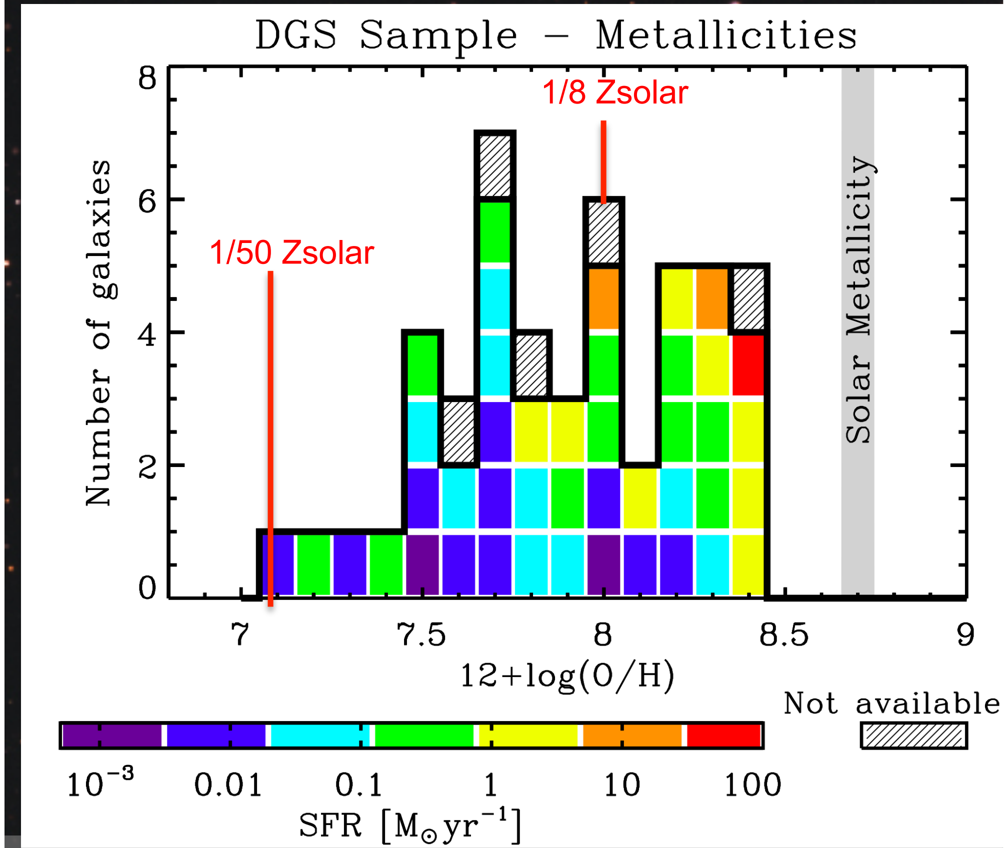
and the SPIRE SAG 2 GT and PACS GT teams

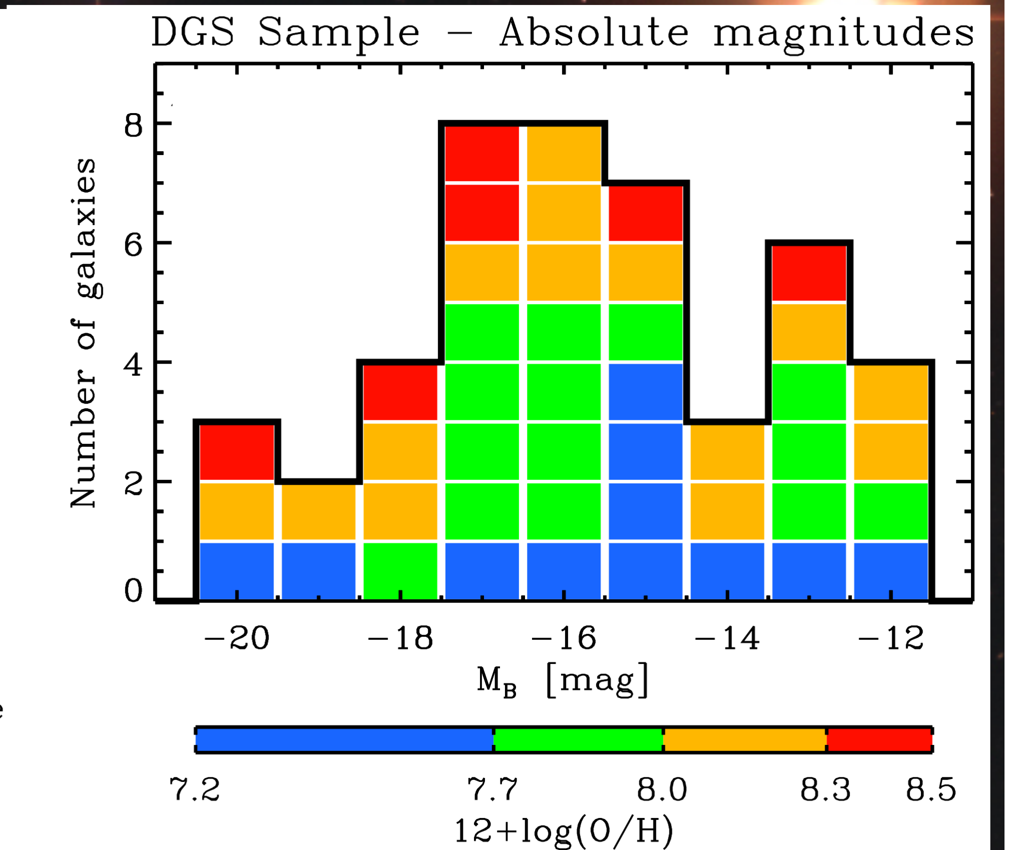
Motivation (in a nutshell)

- Dust and gas properties at decreasing metallicities – early universe templates.
- Evolution of metals: G/D vs metallicity
- Submm excess: before Herschel
- (i.e. Galliano + 03; 05; Lisenfeld et al 2002; Galametz 2009; Zhu + 09)
- Gas phases: PACS f.s. lines what phase is dominating?
- H_2 reservoir? CO challenging. [CII] to trace CO-dark gas
- Use of [CII] and other FIR lines as SFR tracers ?

Herschel Survey of local universe Dwarf Galaxies(DGS)

50 low Z galaxies





PACS (70, 110, 160 mu)
SPIRE (250, 350 500 mu)

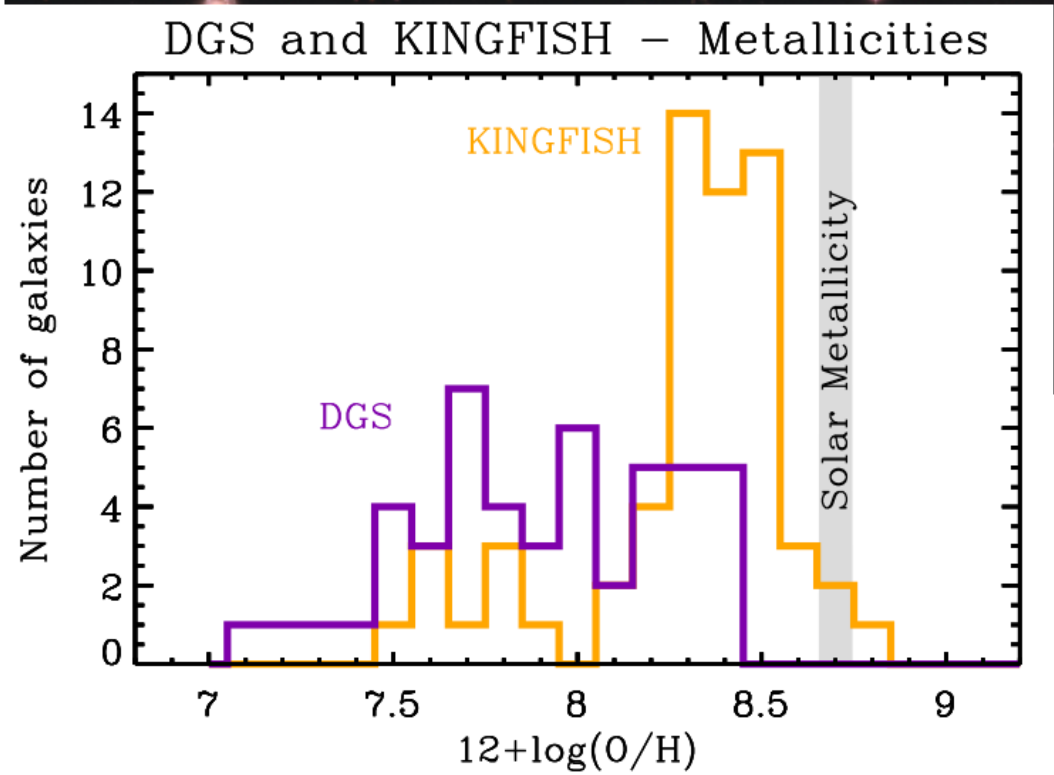
Spitzer MIR photometry
(3 to 160 mu)
Spitzer MIR IRS spectro
(5 to 38 mu)

Madden et al 2013

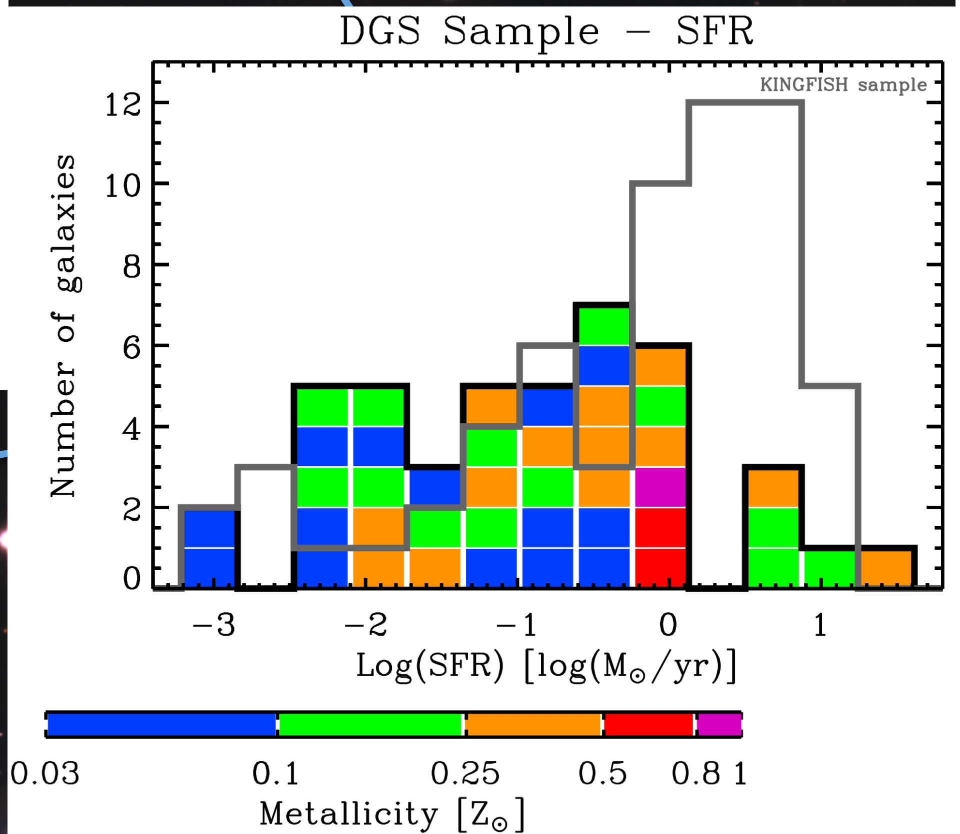
SPIRE submm spectroscopy (200 to 600 mu)
PACS FIR spectroscopy (57 to 205 mu)

PACS: Atomic gas	PACS: Ionized gas
[C II] 158μm	[N II] 122μm
[O I] 63μm	[N II] 205μm
[O I] 145μm	[N III] 57μm
	[O III] 88μm

Dwarf Galaxies vs (mostly) Normal Galaxies (KINGFISH)



KINGFISH: 61 galaxies
mostly normal metallicity
(Kennicutt et al 2011;
Dale et al 2012)
Daniela Calzetti's talk



DGS: 50 Low-metallicity
Dwarf galaxies mapped with Herschel

Dwarfs: Lower L_{FIR}
3×10^{6} to 5×10^{10} Lo

Madden et al 2013;
Remy-Ruyer et al 2013

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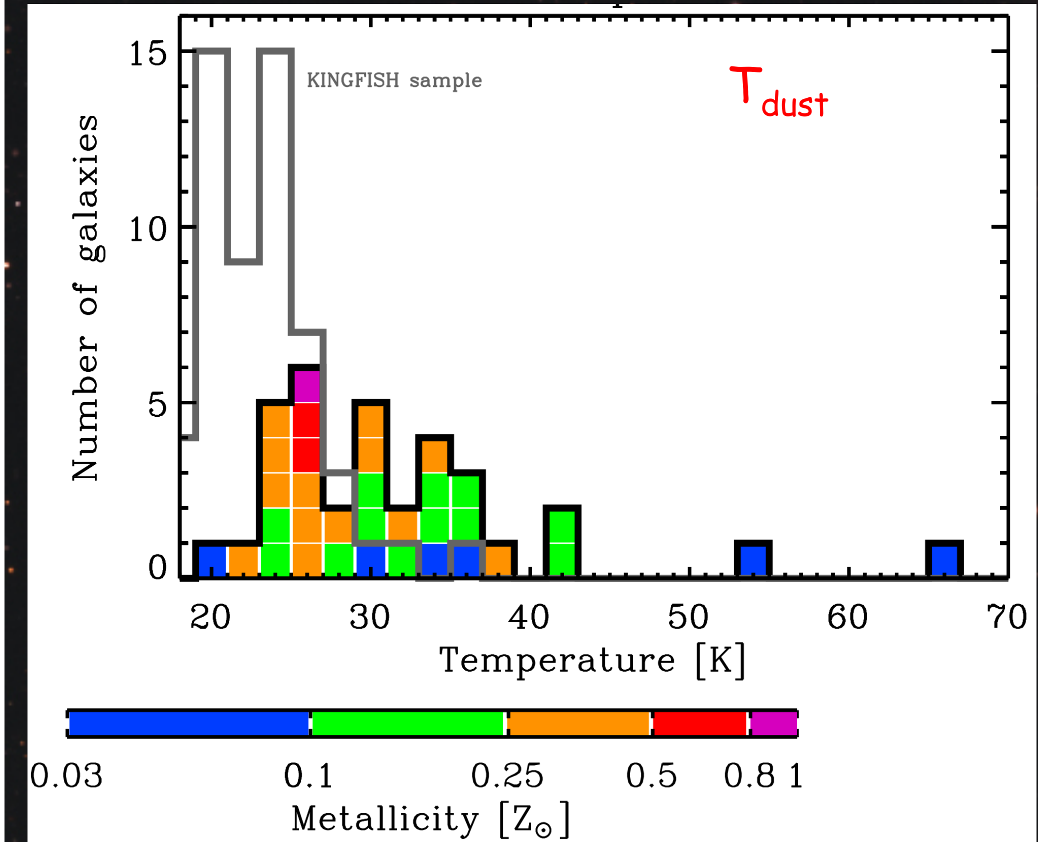
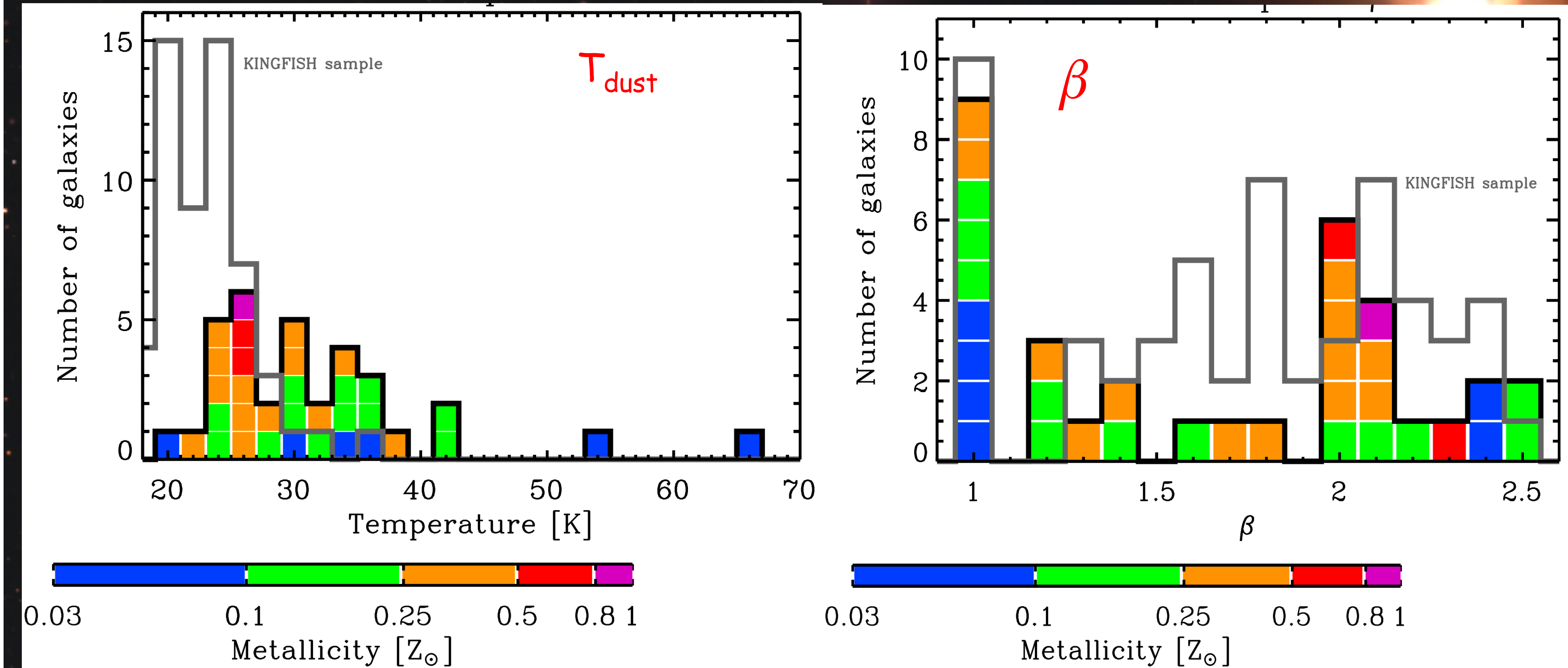


Dwarfs: wide range of
hotter dust T
trend with Z

Dwarfs: T_{med} = 33 K
KINGFISH: T_{med} =23 K

Remy-Ruyer et al 2013a

Dwarf Galaxies vs (mostly) Normal Galaxies (KINGFISH)



Dwarfs: wide range of hotter dust T trend with Z

Dwarfs and KINGFISH: Similarly wide range of β

Dwarfs: T_{med} = 33 K
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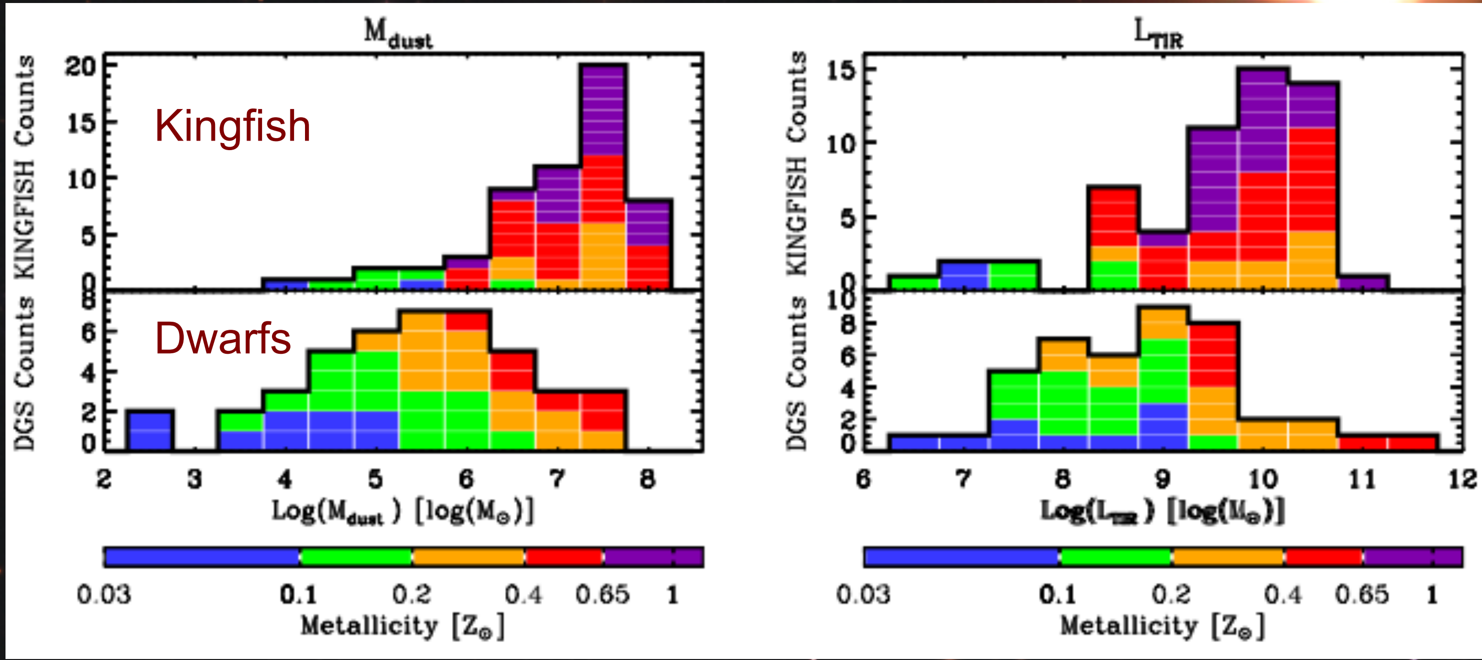
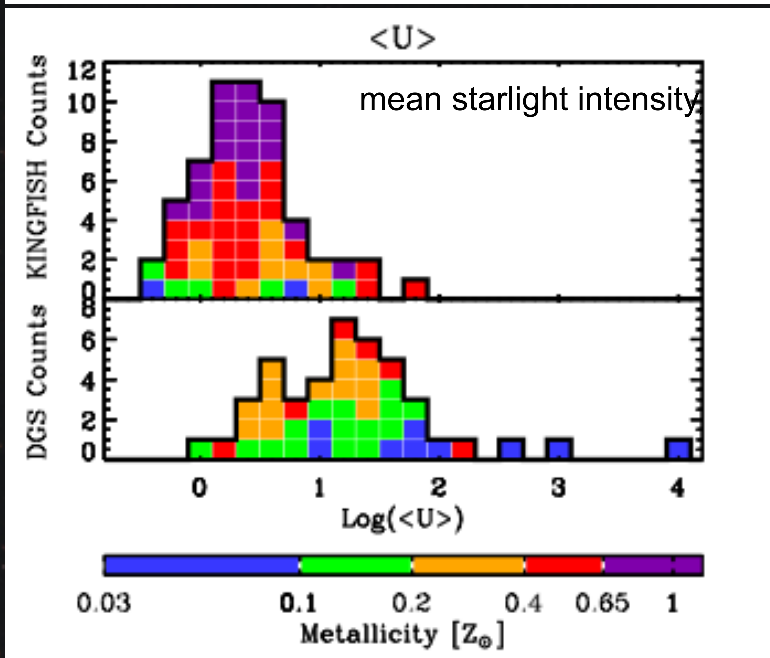
Remy-Ruyer et al 2013a

DGS vs KF: Full SED modeling (Galliano model)





Remy-Ruyer et al 2013c

Trends with Z?

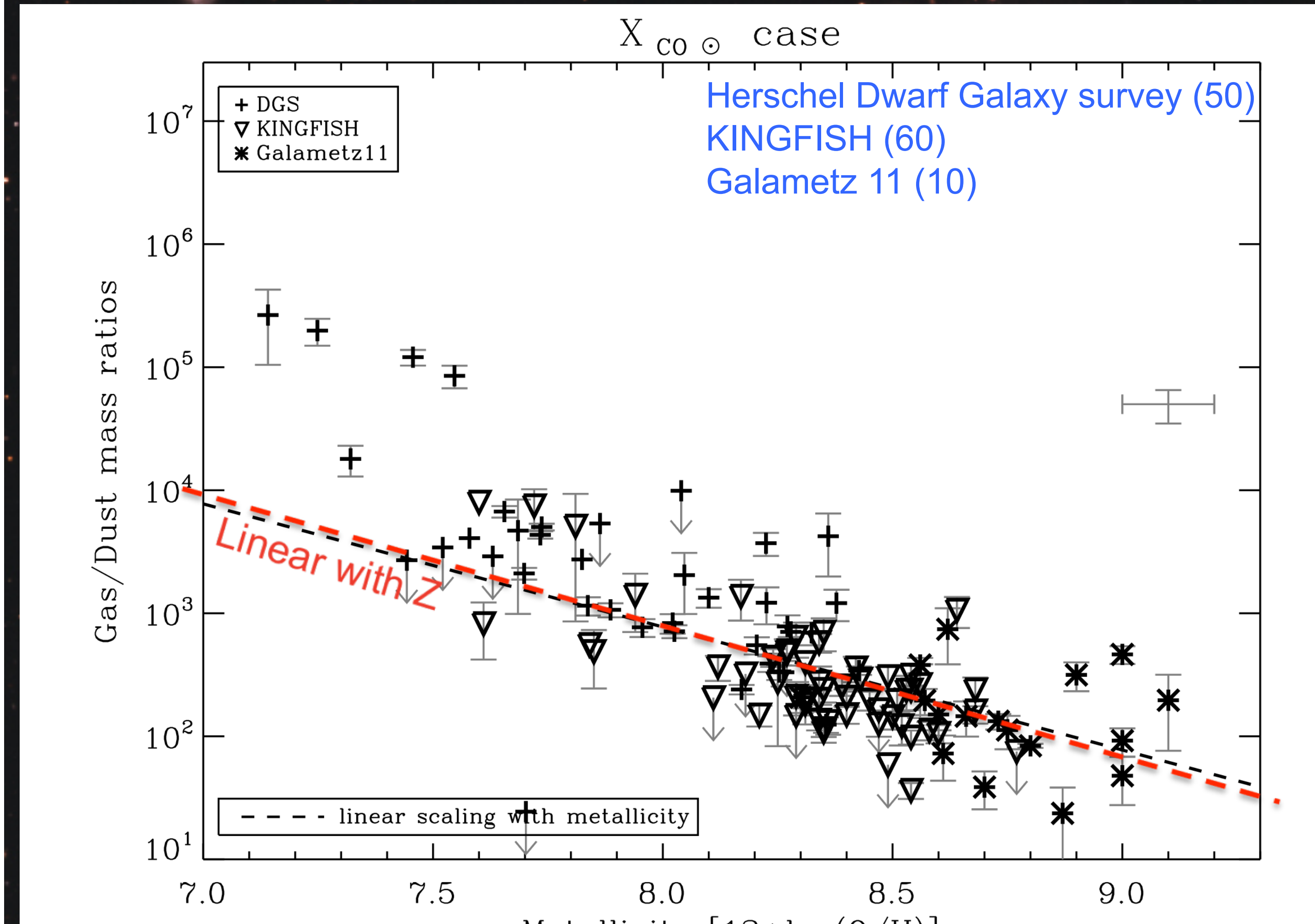
What is the submm excess?

Maud Galametz poster

- Excess emission (~/> 500 mu) above that expected from SED fits
  - All low Z galaxies
- Very cold dust component
  - Large dust mass. D/G ~ sometimes higher than expected for metallicity
  - (Galliano + 2003; 2005; Galametz + 2009 + others)
- Anomalous spinning dust
  - Electric dipole emission of rapidly spinning grains.
  - (Ferrara & Dettmar 1994; Draine &Lazarian 1998; Hoang 2010; Ysard & Verstraete 2010; Bot + 2010.) function of radiation field, grain size, electric dipole moment, gas properties, etc. – the original Galactic 20-40GHz excess (AME)
- Unusual dust emissivity properties
  - Fluctuating very small grains in submm (Lisenfeld + 2001; Zhu + 2009)
  - processes associated with low energy 2-level systems (TLS), i.e. T-dependent emissivity (Meny + 2007; Paradis + 2011)
- Magnetic nanoparticles (Draine & Hensley 2012)

Bottom line: we don't know the origin

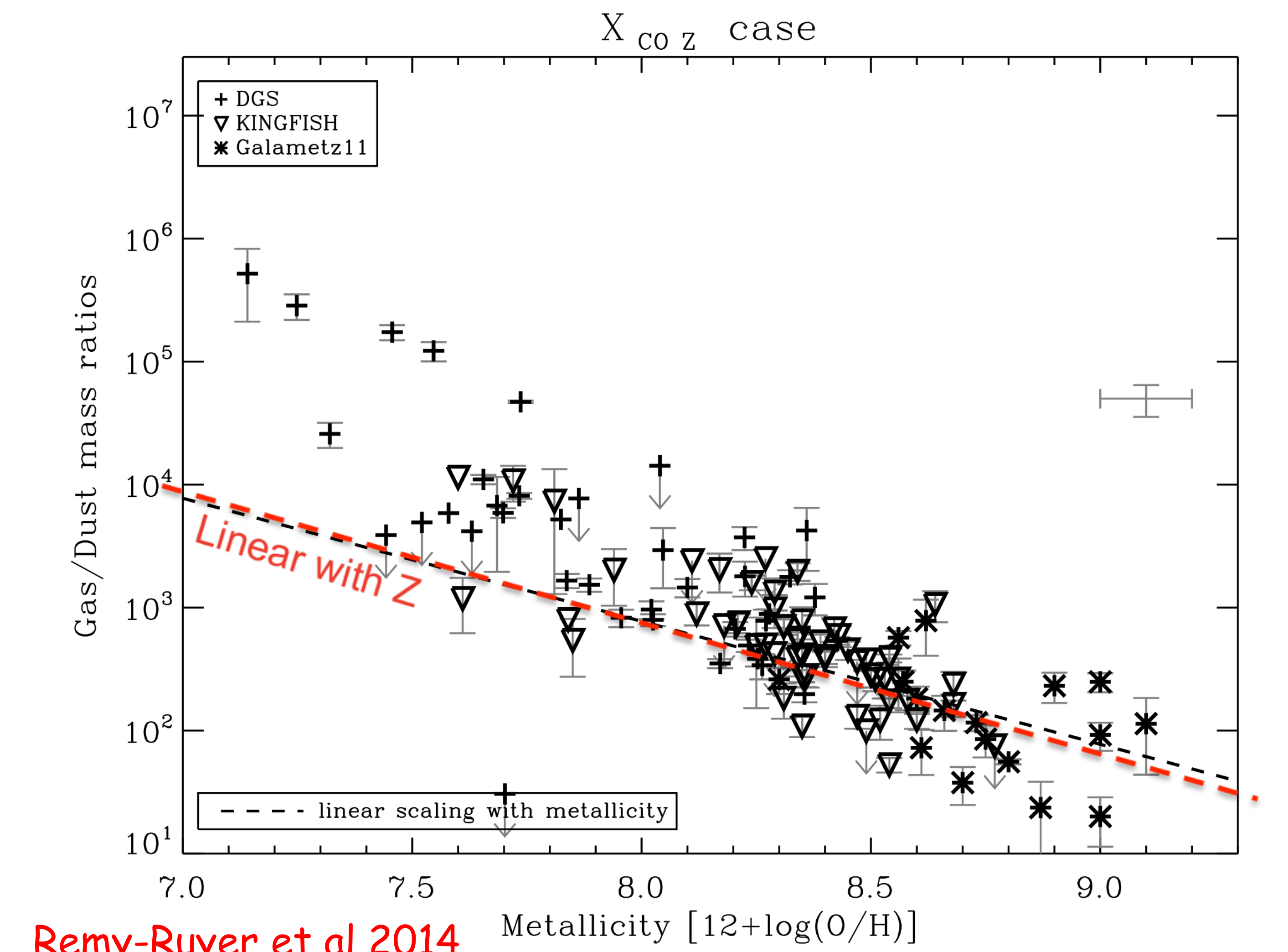
Gas/Dust and Metallicity



Remy-Ruyer et al 2014

- trend with Z
- large G/D scatter for all Z ranges
- what's happening at low Z?
- Dust: full SED mode (Galliano et al model)
- HI and dust in same aperture
- X_{CO} - Galactic

Gas/Dust and Metallicity



Remy-Ruyer et al 2014

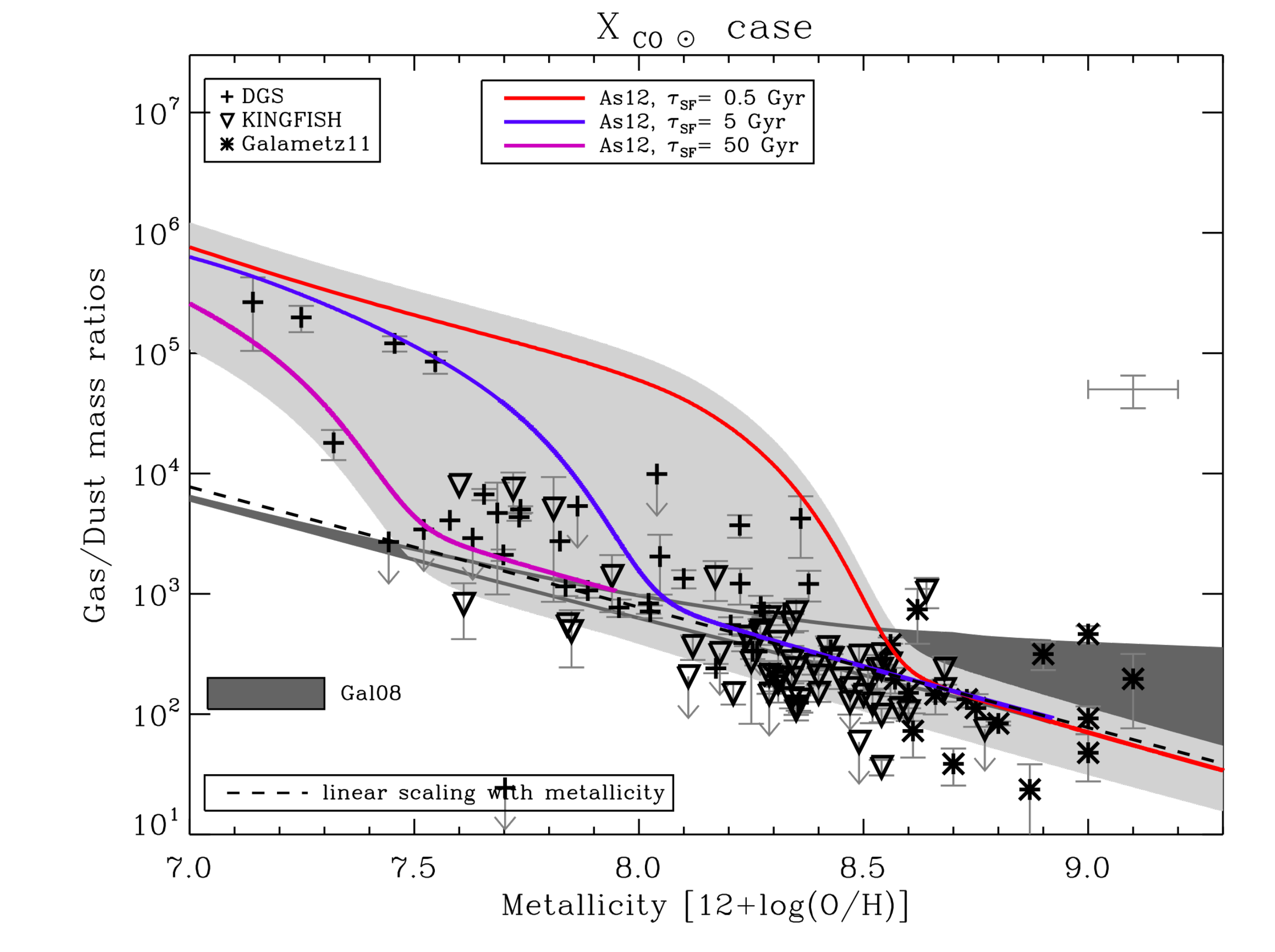
- CO scaled according to Schruba et al 2012

Less dust from the available metals in low-Z ISMs

- ➢ why is grain formation less efficient ?

Chemical Evolution Models: examples

Asano et al 20013



- Metals: SNII & AGBs + Grain growth by mantel accretion

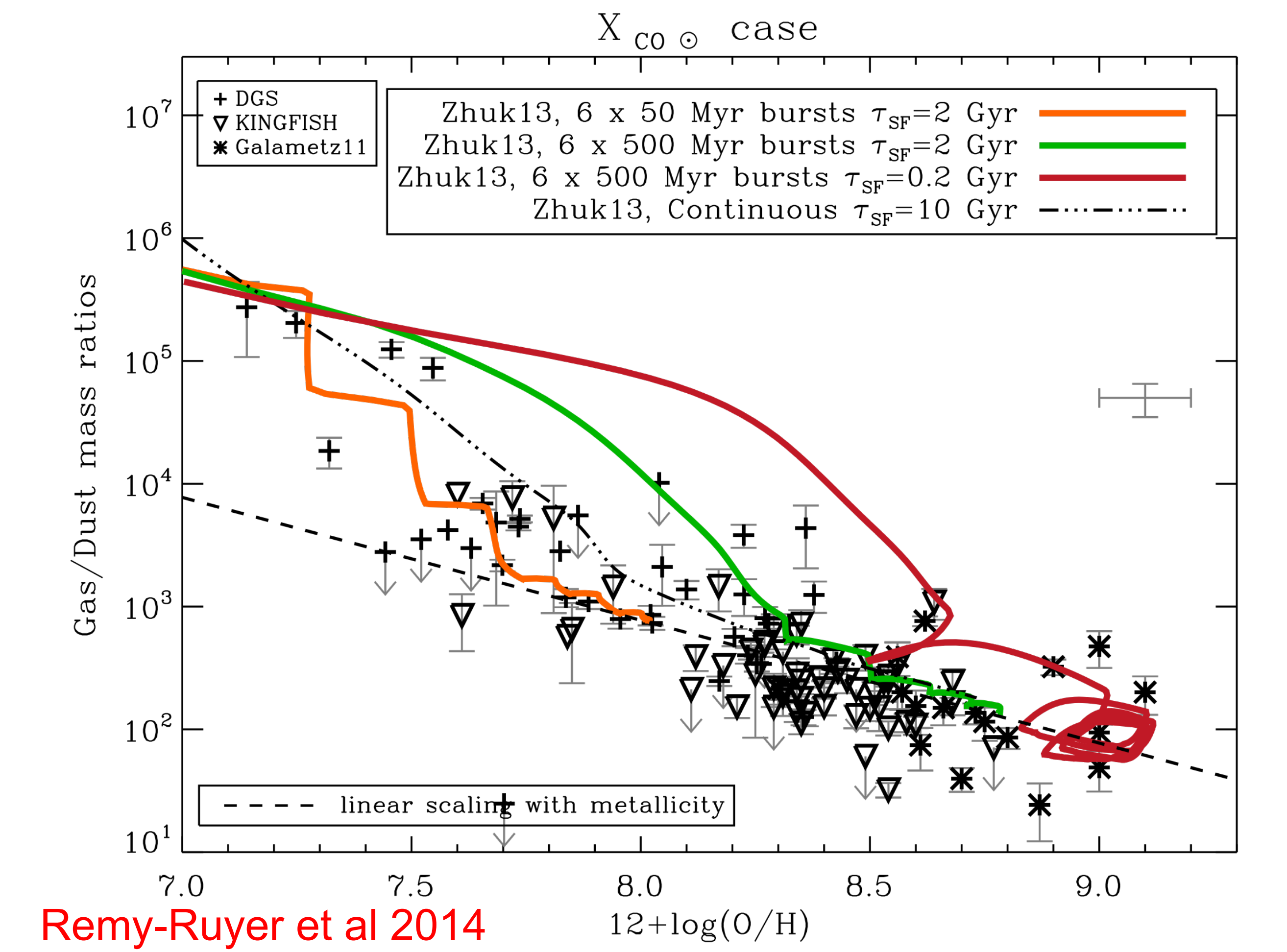
- 2 phase ISM:
- clouds & intercloud
- Clouds with T, n, mass fraction and lifetimes.
-
- Models differ in duration & τ_{SFR}

- episodic SF (likely in dwarfs)

> low Z: SN producing elements, but lack of dense molecular phase to accrete elements-
> grain growth by mantel accretion in dense phase- efficient at higher Z; higher τ_{SFR} (spread)
> low Z galaxies require more time to accumulate metals for efficient grain growth
>

Chemical Evolution Models: examples

See Aurelie Remy-Ruyer's poster



Remy-Ruyer et al 2014

- Metals: SNII & AGBs + Grain growth by mantel accretion

Zhukovska et al 2005, 2013

- 2 phase ISM:
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-

High [CII]/I(CO): PDRs at Low Metallicity

- Normal metallicity clouds – PDR *thin* shell around CO/H2
- Decrease metallicity – lower photon attenuation in cloud:
- CO easily destroyed – deeper PDR shell & smaller CO core
- Very different C+ & CO beam filling factors

H_2 can sef-shild from photodissociation.

•C+ where CO-dark H_2 resides

(i.e Wolfire + 2010; Glover + 2007; Roellig + 2006; Kaufman+ 1999)

Mark Wolfire's talk yesterday

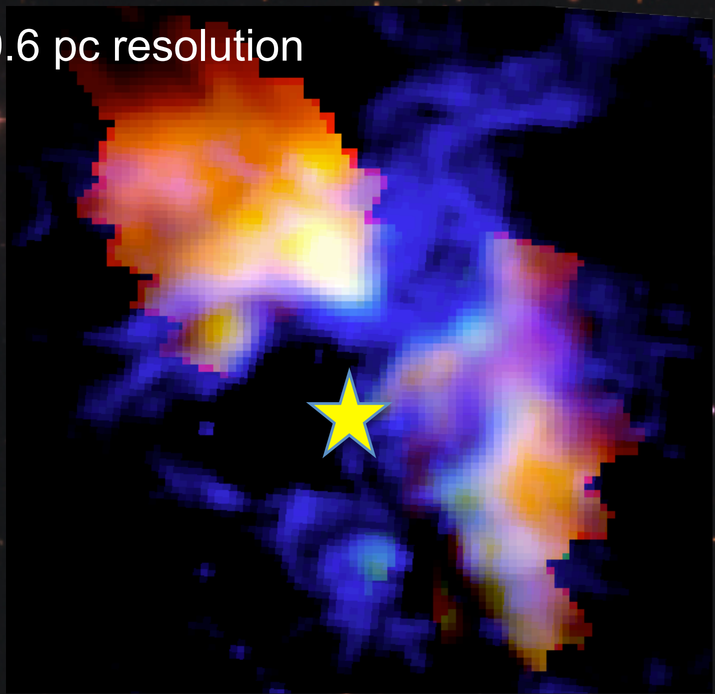
A significant reservoir of H_2 not traced by CO, but traced by [CII] & C^0

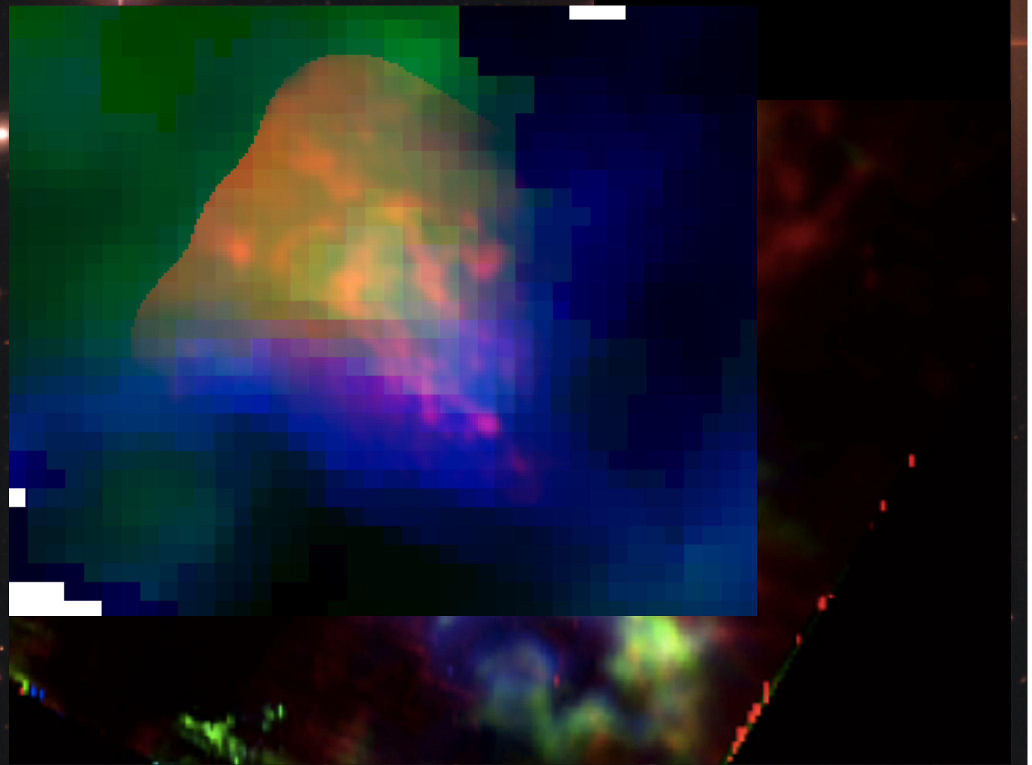
CO - Dark Molecular Gas: 10 to 100x H_2 than that traced by CO(1-0)

[CII] observations of dwarfs with KAO : LMC & IC10: Poglitsch + 1996; Madden +1997, Israel + 1997

30 Dor in LMC - study PDR-Ionization layers

0.4 x 0.6 pc resolution

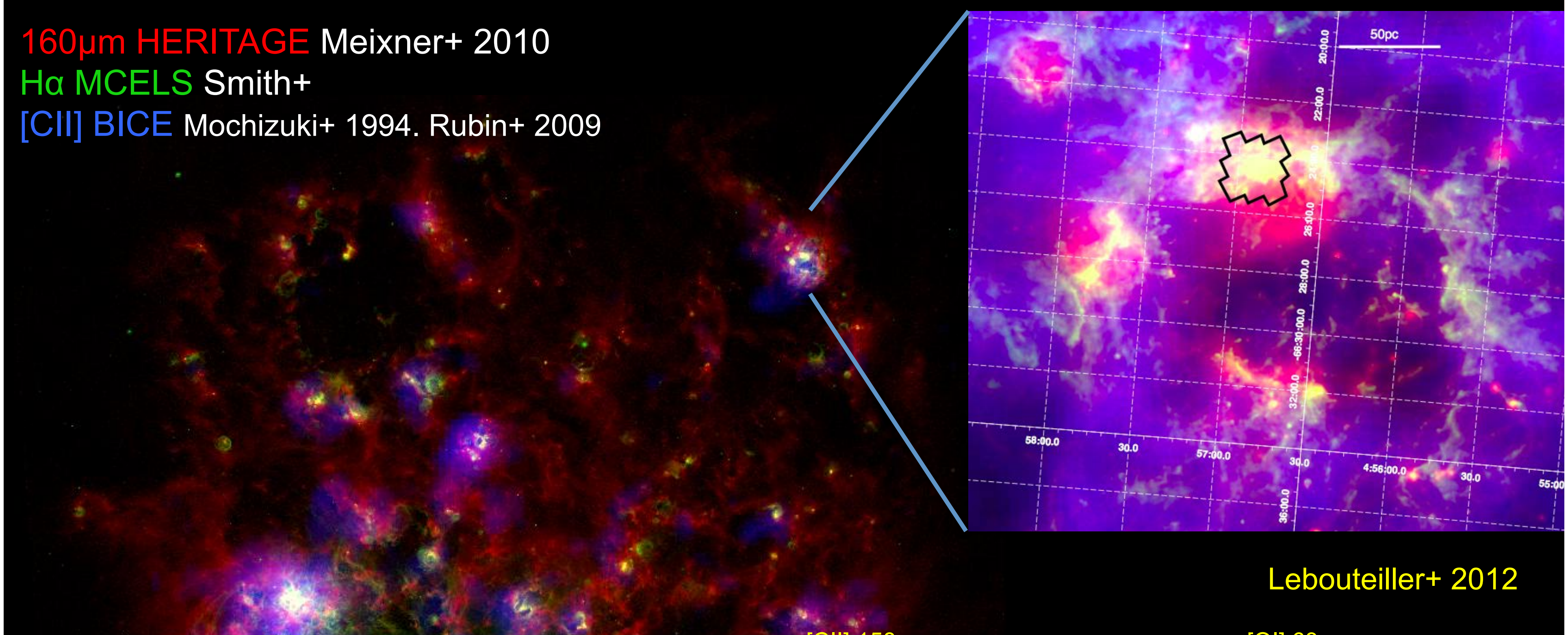


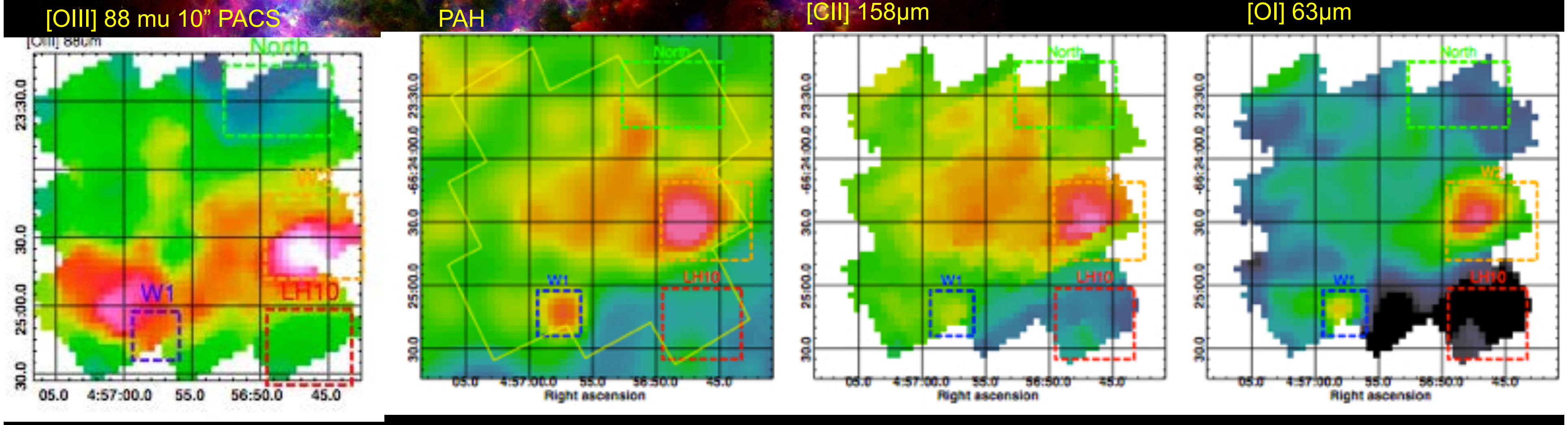


[CII] 158μm Herschel PACS
[OI]63μm Herschel PACS
Hα

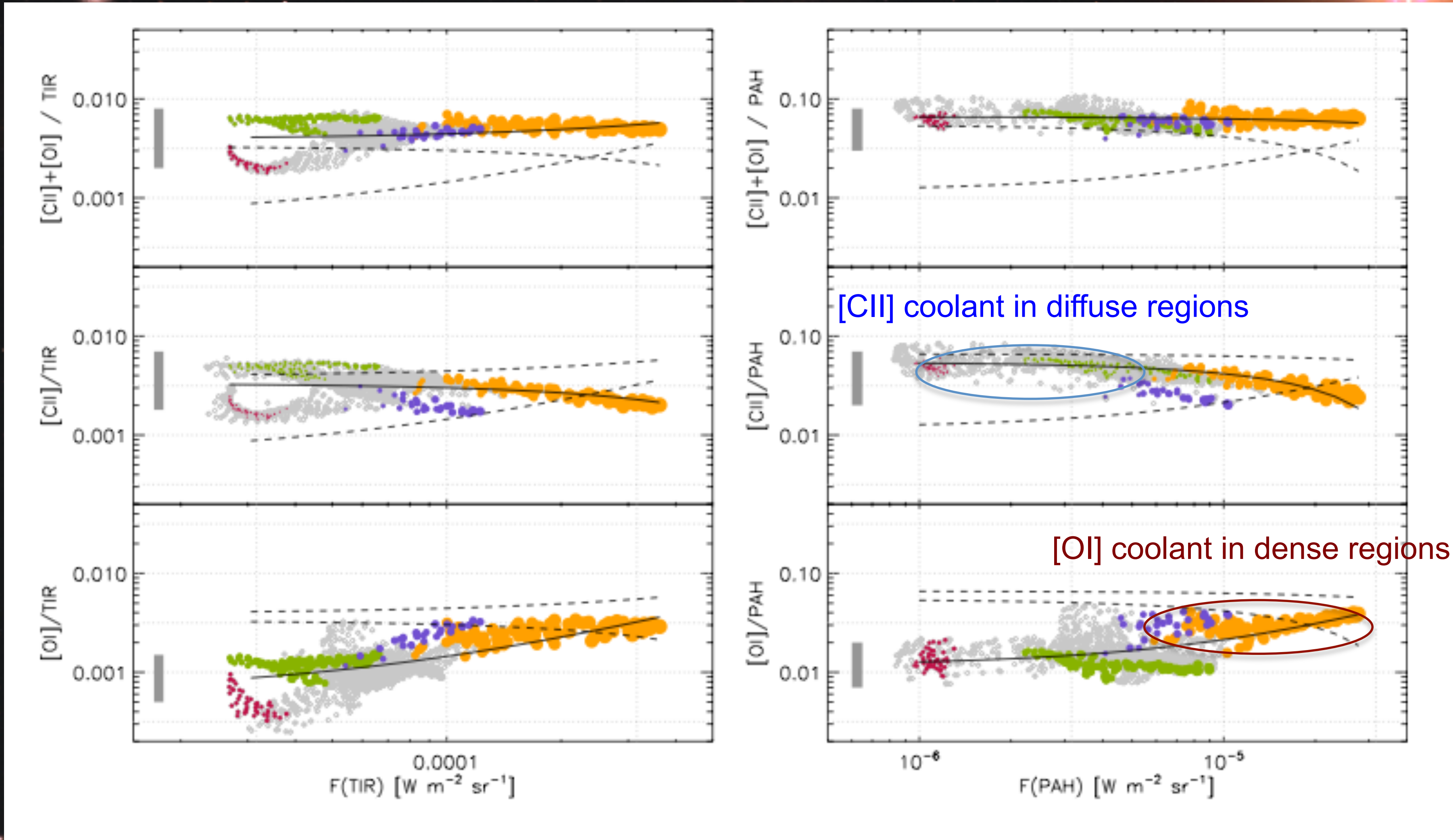
^{12}CO 2-1 ALMA Indebetouw + 2013
[CII] Herschel PACS
[OIII] Herschel PACS

Zoom into N11 PDR Region in LMC



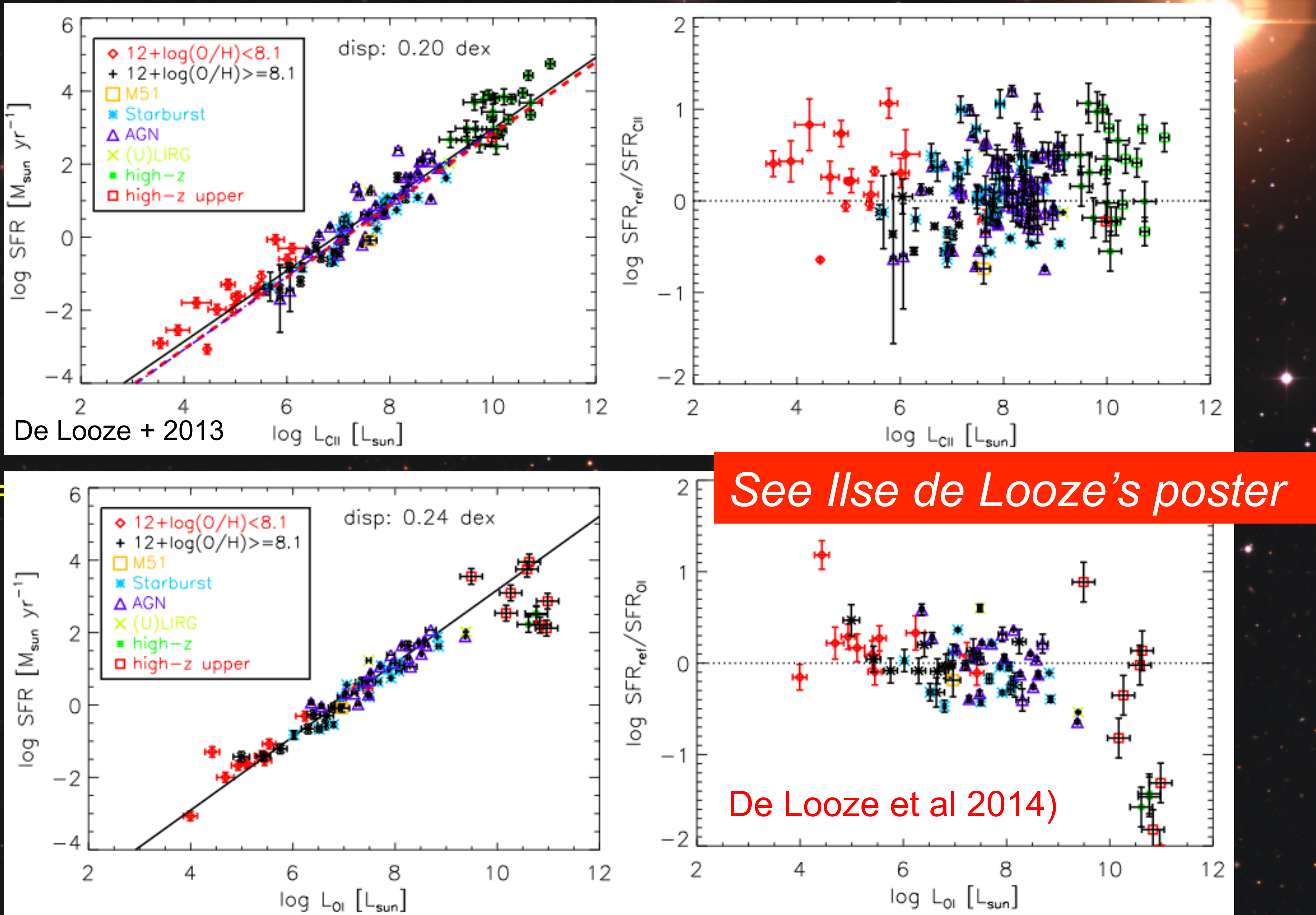


Heating and Cooling in N11B



PAHs dominate the gas heating in PDRs, with a photoelectric efficiency on the order of ~ 7%.

[OI] 63 mu - a universal Star Formation Rate tracer



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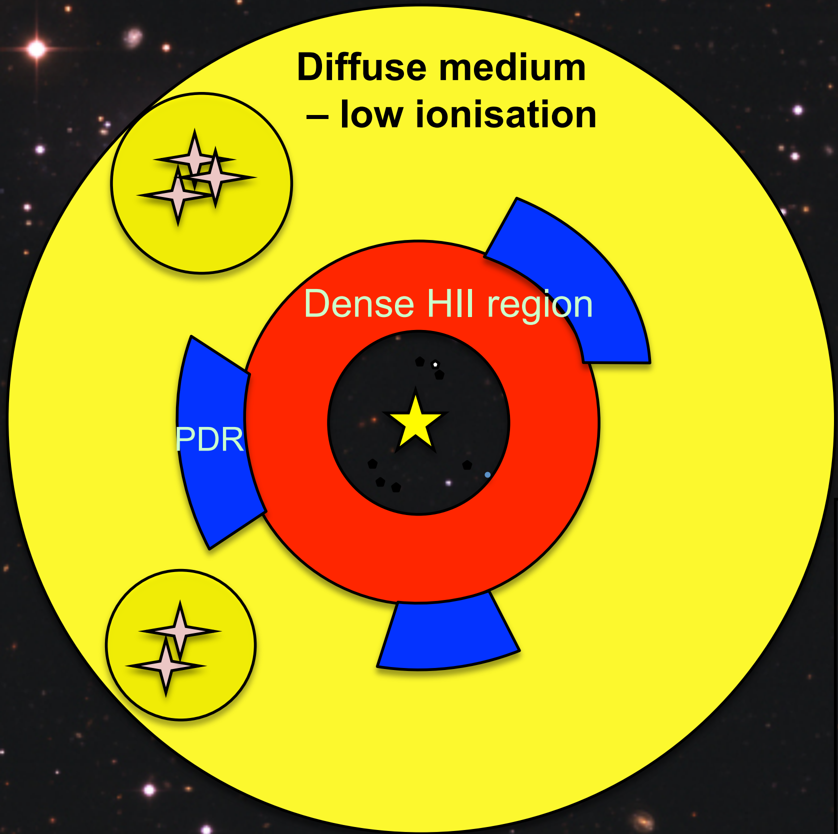
Multiphase Models required – the case of Haro 11

Cormier et al 2012



Model 18 MIR and FIR
fine structure lines - unresolved source

Galaxy wide scale:

at least 50% of the [CII] comes from a diffuse phase – not only dense PDRs.

DIffuse phase is largest fillinfgfactor
PDRs small filling factor

Summary: what we are learning from Herschel

Dust Properties at low metallicities

- The evolution of the G/D vs Z is non-linear and contains large scatter
  - lowest metallicity galaxies incorporate metals into dust less efficiently until Grain-growth improves the efficiency (~ Z~ 1/10 Zo)
  - Caution going from dust mass to total gas mass – wide variations in D/G

- Intense & Hard Radiation Field – galaxy-wide
  - Less dust overall to shield
  - PAH deficit
  - Hot dust: (SED peak ~35 to 60 mu) ….extended cool dust
  - Looks like an HII region

Gas phases at low metallicities:

- [CII] ~ 0.5% to 2% of L_{FIR}
- [CII]/CO enhanced [CII] -> CO-dark H_2 (not CO 1-0)
- [OIII] 88mu - brighter locally and globally in low Z
- Porous ISM - presence of galaxy-wide hard photons
- Ionized gas may be an important phase of the gas mass budget.