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

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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

DGS Sample – Metallicities

1/50 Zsolar

1/8 Zsolar

12+log(O/H) vs Number of galaxies

SFR [M$_\odot$yr$^{-1}$]

Not available

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

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

Madden et al 2013


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

PACS: [O II] 158µm

[O I] 145µm

PACS: Atomic gas

PACS: Ionized gas

Madden et al 2013
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 $L_{\text{FIR}}$ 3x10$^6$ to 5x10$^{10}$ Lo

Madden et al. 2013;
Remy-Ruyer et al. 2013
Dwarfs: wide range of hotter dust $T$

Dwarfs: $T_{\text{med}} = 33$ K

KINGFISH: $T_{\text{med}} = 23$ K

Remy-Ruyer et al 2013a
Dwarfs: wide range of hotter dust $T$ trend with $Z$

Dwarfs: $T_{\text{med}} = 33$ K

KINGFISH: $T_{\text{med}} = 23$ K

Dwarfs and KINGFISH: Similarly wide range of $\beta$

Remy-Ruyer et al 2013a
DGS vs KF: Full SED modeling (Galliano model)

Remy-Ruyer et al 2013c

Trends with Z?

Mean starlight intensity.
What is the submm excess?

**Maud Galametz poster**

- Excess emission (~/> 500 μm) 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

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

Remy-Ruyer et al 2014
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 & $\tau_{SFR}$
  - 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 $\tau_{SFR}$ (spread)
- low Z galaxies require more time to accumulate metals for efficient grain growth
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See Aurelie Remy-Ruyer’s poster
High $[\text{CII}]/I(\text{CO})$: PDRs at Low Metallicity

- Normal metallicity clouds – PDR thin shell around CO/H$_2$
- 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 self-shield 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)

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

160µm HERITAGE Meixner+ 2010
Hα MCELS Smith+

[OIII] 88 µm PACS
PAH
[OII] 158µm
[OI] 63µm

Lebouteiller+ 2012
PAHs dominate the gas heating in PDRs, with a photoelectric efficiency on the order of $\sim 7\%$. 

Heating and Cooling in N11B
[OI] 63 μm - a universal Star Formation Rate tracer

De Looze + 2013

See Ilse de Looze's poster

De Looze et al 2014)
Multiphase Models required - the case of Haro 11

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

- Diffuse phase is largest filling factor
- PDRs small filling factor

Cormier et al 2012

Model 18 MIR and FIR fine structure lines - unresolved source
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 (\(\sim Z \sim 1/10 Zo\))
  - 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 \(\sim 35\) to \(60\) mu) … extended cool dust
  - Looks like an HII region

Gas phases at low metallicities:

- \([\text{CII}]\sim 0.5\%\) to \(2\%\) of \(L_{\text{FIR}}\)
- \([\text{CII}]/\text{CO}\) enhanced \[\text{CII}] \rightarrow \text{CO-dark } H_2\) (not CO 1-0)
- \([\text{OIII}]\) 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.