The Life Cycle of Dust in the Magellanic Clouds: Insights from Spitzer and Herschel

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http://sage.stsci.edu/
The Large Magellanic Cloud
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Why does this galaxy have dust?
Life Cycle of Dust in Galaxies

Dwek, Zhkovska
Magellanic Clouds

• Proximity:
  ~50 kpc Large Magellanic Cloud (LMC) (Schaefer 2008)
  ~60 kpc Small Magellanic Cloud (SMC) (Szewczyk et al. 2009)
• Inclination of LMC ~23° –37° (Subramanain & Subramanain)
• Stepping stone between galactic and extragalactic studies.
• Mean metallicity: (Russel & Dopita 1992; Asplund et al. 2004)
  – LMC: Z~0.5 x Z☉
  – SMC: Z~0.2 x Z☉
  – ISM during Universe’s peak star formation epoch (z~1.5 Pei et al 1999)
  – Dust content (dust-to-gas ratio) lower: LMC~0.5xMW, SMC~0.1xMW
• Long History of Studies => rich context for interpretation:
  – Ideal Case study for a galaxy dust evolution (Bekki & Chiba 2005)
Spitzer Surveying the Agents of Galaxy Evolution (SAGE) & HERschel Inventory of The Agents of Galaxy Evolution (HERITAGE)

Galliano 2008
LMC Dust Mass: $7.3 \pm 1.0 \times 10^5$ M$_\odot$

Gordon et al. 2014
Roman-Duval et al. 2014
SMC Dust Mass: $8.3 \pm 1.0 \times 10^4 M_\odot$

Gordon et al. 2014
Roman-Duval et al. 2014
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Evolved Star Classification

Boyer et al. 2011,
Blum et al. 2006
GRAMS:
Grid of Red supergiant and Asymptotic giant branch star ModelS:

Oxygen Rich Dust:
Amorphous Silicates
Size distribution:
KMH, 0.01-0.1µm

Star:
5088 L☉
2.0×10⁻⁹ M☉ yr⁻¹

Sargent et al. (2010)
Carbon Rich Dust:

Amorphous Carbon

SiC

Size distribution:

KMH, 0.01-1μm

Star:

5670 L⊙

2.6×10⁻⁹ M⊙ yr⁻¹

Srinivasan et al. 2010
GRAMS:
Grid of Red supergiant and Asymptotic giant branch star Models:

~68,000 O-rich models: AGB & RSGs
~12,000 C-rich models: AGB only
GRAMS applied to LMC & SMC

GRAMS applied to LMC & SMC

LMC: Riebel et al. 2012
Total = 2.1 (±0.1) ×10^{-5} M_☉ yr^{-1}

Total = 8.9 (±0.1) ×10^{-7} M_☉ yr^{-1}

GRAMS applied to LMC & SMC

LMC: Riebel et al. 2012
Total = 2.1 \(\pm 0.1\) \(\times 10^{-5}\) M\(_{\odot}\)yr\(^{-1}\)
65% is C-rich
35% is O-rich

Total = 8.9 \(\pm 0.1\) \(\times 10^{-7}\) M\(_{\odot}\)yr\(^{-1}\)
50% is C-rich
50% is O-rich

GRAMS applied to LMC & SMC

LMC: Riebel et al. 2012
Total = 2.1 ($\pm$0.1) \times 10^{-5} M_\odot yr^{-1}
65% is C-rich
35% is O-rich
9% RSG
26% AGB

Total = 8.9 ($\pm$0.1) \times 10^{-7} M_\odot yr^{-1}
50% is C-rich
50% is O-rich
25% RSG
25% AGB

LMC Luminous Blue Variable, R71
Dust mass: $8 \times 10^{-7} \, \text{M}_\odot \, \text{yr}^{-1}$

**Spectral dust features of R71**

- **Spitzer IRS**
- **Spitzer MIPS**

**Guha et al. 2014**
Herschel Finds Enormous Stores of Dust in Supernova 1987A

ESA/NASA-JPL/Caltech/UCL/STScI
Images of SN1987A

HST

Chandra

Challis, Kirshner

Burrows et al. 2000

ejecta

ring
Far-IR detection of SN 1987A: $\sim0.4-0.8\,M_\odot$
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Supernova Remnants (SNRs) in LMC

Badenes, Maoz, & Draine (2010), Temim et al. (2015)
Dust Destroyed by SNRs in LMC

Temim et al. 2015
Average lifetime of a dust grain in ISM

\[ \tau_d = \frac{M_d(LMC)}{\langle m_{\text{dest}} \rangle R_{SN}} \]

LMC:
silicates: 26 – 42 Myr
carbon: 34 – 57 Myr

Temim et al. 2015
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Fig. 11.—Map of the gas-to-dust ratio in the LMC at 1′ resolution. \[ X_{\text{CO}} = 2 \times 10^{20} \text{cm}^{-2} \text{K}^{-1} \text{km}^{-1} \text{s} \] is assumed. The typical error on the apparent GDR is 100. The black contours show the 0.04, 0.07, 0.1, 0.3 \( \text{M}_\odot \text{pc}^{-2} \) levels of the dust surface density. The blue contours show the 1.2 K km s\(^{-1}\) level of the CO integrated intensity. The apparent GDR is only calculated in pixels with a dust surface density determination and with H I and CO coverage.
Fig. 12.—Map of the gas-to-dust ratio in the SMC at 2.6′ resolution. $X_{\text{CO}} = 2 \times 10^{20} \text{cm}^{-2} K^{-1} \text{km}^{-1} \text{s}$ is assumed. The typical error on the apparent GDR is 50. The black contours show the 0.01-0.05 $M_{\odot} \text{pc}^{-2}$ in steps of 0.01 $M_{\odot} \text{pc}^{-2}$ levels of the dust surface density. The blue contours show the 0.5 and 0.8 K km s$^{-1}$ level of the CO integrated intensity. The apparent GDR is only calculated in pixels with a dust surface density determination and with H I and CO coverage.

Fig. 13.—Histogram of the GDR in the LMC (left) and SMC (right), only including pixels with dust surface densities determined at S/N = 2 or better. $X_{\text{CO}} = 2 \times 10^{20} \text{cm}^{-2} K^{-1} \text{km}^{-1} \text{s}$ is assumed. The black line corresponds to pixels with no significant CO detection, and the red line only includes pixels with CO integrated intensities greater than the $3\sigma$ sensitivity. The median values in each case are indicated in the panels.

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SAGE/SMC: YSO Candidates

Boyer et al. (2011)
Bonanos et al. (2010)

Bolatto et al. (2007)
Simon et al. (2007)
Carlson et al. (2011)

Robitaille et al. (2006)

Sewilo et al. (2013)
SAGE/SMC: ~1100 YSO Candidates

Sewilo et al. 2013
HERITAGE/SMC: YSOs and Dust Clumps

Hα

SMC

N84

N66

SPIRE 250μm

SMC

Band–Matched Catalog Sources

SMC

~7500

Prob/Pos YSO Cand

Prob/Pos Dust Clump Cand

Pos Galaxy Cand

~660

~110

~5100

Seale et al. 2014
SMC: YSO properties
Star Formation Rate (SFR)

Histogram of Stellar Mass

Luminosity Histogram

SFR $\sim 0.06 \, M_\odot / \text{year}$

Sewilo et al. (2013)
### MCs inventory of dust

<table>
<thead>
<tr>
<th>Item</th>
<th>LMC Value</th>
<th>SMC Value</th>
</tr>
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<tbody>
<tr>
<td>ISM Dust mass</td>
<td>$7.3 \times 10^5 \ M_\odot$</td>
<td>$8.3 \times 10^4 \ M_\odot$</td>
</tr>
<tr>
<td>RSG &amp; AGB &amp; LBV Mass Loss return</td>
<td>$2.5 \times 10^{-5} \ M_\odot \ yr^{-1}$</td>
<td>$4.2 \times 10^{-6} \ M_\odot \ yr^{-1}$</td>
</tr>
<tr>
<td>Supernovae Dust production</td>
<td>$\sim 2 \times 10^{-3} \ M_\odot \ yr^{-1}$</td>
<td>$\sim 1 \times 10^{-3} \ M_\odot \ yr^{-1}$</td>
</tr>
<tr>
<td>Dust destruction by SNe</td>
<td>$\sim 2 \times 10^{-2} \ M_\odot \ yr^{-1}$</td>
<td>$\sim 1 \times 10^{-2} \ M_\odot \ yr^{-1}$</td>
</tr>
<tr>
<td>Star formation rate -stellar astration of dust</td>
<td>$\sim 0.1 \ M_\odot \ yr^{-1}$</td>
<td>$\sim 0.06 \ M_\odot \ yr^{-1}$</td>
</tr>
<tr>
<td></td>
<td>$\sim 2 \times 10^{-4} \ M_\odot \ yr^{-1}$</td>
<td>$\sim 5 \times 10^{-5} \ M_\odot \ yr^{-1}$</td>
</tr>
<tr>
<td>Net Loss of Dust Dust growth rate in ISM?</td>
<td>$\sim 1.8 \times 10^{-2} \ M_\odot \ yr^{-1}$</td>
<td>$\sim 9.0 \times 10^{-3} \ M_\odot \ yr^{-1}$</td>
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</tbody>
</table>
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