Mapping $\kappa_d$ in Nearby Galaxies

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Literature Values for $\kappa_d$

- Literature values of $\kappa_{500}$
- James et al. (2002)
- Draine et al. (2003, 2007, 2014)
- Clark et al. (2016)
- THEMIS (Jones et al., 2016)

Mathematical equations:

$$M_d = \frac{S_v D^2}{\kappa_v B_v(T)}$$

$$\kappa_\lambda = \kappa_0 \left( \frac{\lambda_0}{\lambda} \right)^\beta$$
Estimating $\kappa_d$ with the HRS

$$\kappa_\lambda = \frac{D^2}{\xi (M_{HI} + M_{H_2}) \varepsilon_d \bar{f}_Z} \sum_i \left( \frac{S_{\lambda_i}}{B_{\lambda}(T_i)} \right)$$

$\kappa_{500} = 0.051 \text{ m}^2 \text{ kg}^{-1}$

$(\pm 0.24 \text{ dex})$
Literature Values for $\kappa_d$

\[ M_d = \frac{S_v D^2}{\kappa_v B_v(T)} \]

\[ \kappa_\lambda = \kappa_0 \left( \frac{\lambda_0}{\lambda} \right)^\beta \]

- Literature values of $\kappa_{500}$
- James et al. (2002)
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- Clark et al. (2016)
- THEMIS (Jones et al., 2016)

Alton+ (2004); Demyk+ (2013); Köhler+ (2015); Clark+ (2016); Jones+ (2017); Clark+ (2019)
Mapping $\kappa_d$ Within Galaxies

Casasola+ (2017); Clark+ (2018); Casasola+ (in prep.) Clark+ (2019)
The DustPedia Database

• The DustPedia (Davies+, 2017) covers all 875 nearby (D<40 Mpc) extended (1’ < D25 < 1°) galaxies observed by Herschel.

• Standardised imagery & photometry spanning 42 UV–microwave bands (Clark+, 2018).

• Homogenised atomic & molecular gas values for 764 & 255 DustPedia galaxies respectively (Casasola+, in prep.; De Vis+, 2019).

• 10000 consistently-determined gas-phase metallicity datapoints (from IFU, slit, and fibre spectra) for 492 DustPedia galaxies (De Vis+ 2019).
Mapping $\kappa_d$ Within Galaxies

Casasola+ (2017); Clark+ (2018); Casasola+ (in prep.) Clark+ (2019)
Metallicity Data in M74 & M83

De Vis+ (2019); Clark+ (2019)
Gaussian Process Regression

![Graph showing Gaussian Process Regression](image-url)
Gaussian Process Regression

M74 Metallicity Map

M74 Metallicity Uncertainty

De Vis+ (2019); Clark+ (subm.)
Gaussian Process Regression

M83 Metallicity Map

M83 Metallicity Uncertainty
GPR – Works Reliably!

De Vis+ (2019); Clark+ (2019)
All the Necessary Data

Casasola+ (2017); Clark+ (2018); De Vis+ (2010); Casasola+ (in prep.) Clark+ (2019)
Maps of $\kappa_d$ within M73 & M83

Clark+ (2019)
$K_d$ vs ISM Surface Density

Clark+ (2019)
Alternate Model: DTM $\propto$ Density

$\xi_d \propto \Sigma_{ISM}$

M74

$\kappa_{500}$ (m$^2$ kg$^{-1}$)

0.08 0.10 0.12 0.14 0.16

M83

$\kappa_{500}$ (m$^2$ kg$^{-1}$)

0.1 0.2 0.3 0.4 0.5 0.6 0.8

$\xi_d \propto \Sigma_{ISM}$

$\kappa_{500}$ (m$^2$ kg$^{-1}$)

$\Sigma_{ISM}$ (M$_\odot$ pc$^{-2}$)

10$^0$ 10$^1$ 10$^2$ 10$^3$

M74

M83

Clark+ (2019)
Alternate Models

$\varepsilon_d \propto r$

$\varepsilon_d \propto \Sigma_{ISM}$

"Toy" model

DTM $\propto$ radius

DTM $\propto$ ISM density

"Toy" model

$\kappa_{500}$ (m$^2$ kg$^{-1}$)

$\Sigma_{ISM}$ (M$_\odot$ pc$^{-2}$)

$\Sigma_{ISM}$ (M$_\odot$ pc$^{-2}$)

$\Sigma_{ISM}$ (M$_\odot$ pc$^{-2}$)
Alternate Models

DTM $\propto$ radius

DTM $\propto$ ISM density

“Toy” model

CHAOS Z

$\varepsilon_d \propto \kappa_500$ (m$^2$ kg$^{-1}$)

$\varepsilon_d \propto \Sigma_{ISM}$

$Z_{CHAOS}$

M74

M83

Clark+ (2019)
Other Metallicity Prescriptions

Pettini & Pagel (2004); Tremonti+ (2004); Blanc+ (2015); Clark+ (2019)
Results Summary

- Literature values of $\kappa_{500}$
- James et al. (2002)
- Draine et al. (2003, 2007, 2014)
- Clark et al. (2016)
- THEMIS (Jones et al., 2016)
- M74 (90% range, this work)
- M83 (90% range, this work)
Next: the SMC, at All Scales

Herschel only; no faint + large scales

Meixner+ (2014); Roman-Duval+ (2017); Williams+ (2018); Clark+ (in prep.)
So, You Want To Study Dust in the MCs?

- Herschel!
  - *Except faint and large-scale emission all got filtered out.*

- Okay, Planck then!
  - *Planck is great! But its resolution is poor, and it observed at >350um, so can’t constrain dust temperature (and therefore mass).*

- How about Spitzer?
  - *Which has similar background-level problems to Herschel. Plus, severe non-linearity issues at high surface brightness for 160 um.*

- But there’s always IRAS, right?
  - *Unless you want to observe something that is extended and has very high surface brightness. Like the Magellanic Clouds.*

- Urm, I suppose I could try using Akari?
  - *

- Good point. How about JCMT? Or ISO?
  - *Never observed more than tiny parts of the Clouds.*

- I suppose that leaves...
The Only Solid Data is COBE!

Herschel-SPIRE

COBE-DIRBE

Meixner+ (2014); Roman-Duval+ (2017); Clark+ (in prep.)
Combine All The Data

**COBE**
- Far-infrared data, large angular scales

**IRAS**
- Far-infrared data, medium angular scales

**COBE + IRAS**
- FIR data, large and medium angular scales

**Planck**
- Submm data, large & medium angular scales

**COBE + IRAS**
- FIR-submm data, large & medium angular scales

**COBE + IRAS + Planck**

**Herschel**
- FIR-submm data, small angular scales

**COBE + IRAS + Planck + Herschel**
- FIR-submm data, large & medium & small angular scales
Next: the SMC, at All Scales

Herschel only; no faint & large scales  Herschel et al; Fourier-combined

Meixner+ (2014); Roman-Duval+ (2017); Williams+ (2018); Clark+ (in prep.)
Results Summary

1. Literature values of $\kappa_{500}$
2. James et al. (2002)
4. Clark et al. (2016)
5. THEMIS (Jones et al., 2016)
6. M74 (90% range, this work)
7. M83 (90% range, this work)

$\kappa_{500}$ (m$^2$ kg$^{-1}$)

Year of Publication

SED-Fitting Example

Example Pixel

$T_c = 19.00 \text{ K}$, $M_c = 5.24 \log_{10} M_\odot$

$\beta = 2.42$

$\nu_{SPIRE} = -0.00^{+0.03}_{-0.03}$
• Wiseman+ (2016) and De Cia+ (2016) find DTM varies with metallicity, from DLA depletions; but for metallicities of $>0.1 \, Z_\odot$ this variation is less than factor of $\leq 2$.

• Jenkins+ (2009) find Milky Way variation of factor $\leq 2.7$.

Figure 7 from Wiseman+ (2016)

Figure 15 from De Cia+ (2016)
• Popping+ (2017) find DTM varies by factor of \(<4\) at metallicities \(>0.1\) \(Z_\odot\) in semi-analytic models.

• McKinnon+ (2016) find DTM varies by factor of \(\leq 3.5\) at \(z<0.5\) in hydrodynamical zoom-in simulations.
Dust-to-Metals in THEMIS

- Dust-to-metals expected to vary by factor of \(~3.6\) in THEMIS dust model (Jones+ 2017;2018).

Table 3. The gas-to-dust mass ratios (G/D), dust mass relative to hydrogen, dust mass relative to the available metals, carbon and oxygen abundances, [C] and [O], in dust (in parts per million, ppm) and the percentage by volume of carbonaceous matter in dust, \(V_{f,C}\). This is shown as a function of the ISM environment and the corresponding dust model, where: DISM indicates the standard diffuse ISM dust model, C (O) carbon (oxygen) atom accretion from the gas and ice the presence of ice mantles. Fractional variations from the standard diffuse ISM abundances of carbonaceous nano-particles (big grains) \(\frac{1}{n}C_{np}\) or no contribution at all (0×). Low Z indicates sub-solar, low metallicity environments.

<table>
<thead>
<tr>
<th>Environment</th>
<th>(\approx n_H) (cm(^{-3}))</th>
<th>(\approx T_{gas}) (K)</th>
<th>Dust type</th>
<th>G/D</th>
<th>(M_{dust}/m_H)</th>
<th>[C] (ppm)</th>
<th>[O] (ppm)</th>
<th>(V_{f,C}) (%)</th>
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</thead>
<tbody>
<tr>
<td>dense</td>
<td>10^4</td>
<td>15</td>
<td>DISM+C+O+ice</td>
<td>55</td>
<td>0.0184</td>
<td>0.88</td>
<td>406</td>
<td>566</td>
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<tr>
<td>translucent</td>
<td>1500</td>
<td>20</td>
<td>DISM+C+O</td>
<td>81</td>
<td>0.0124</td>
<td>0.60</td>
<td>406</td>
<td>270</td>
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<tr>
<td>translucent</td>
<td>1500</td>
<td>20</td>
<td>DISM+C</td>
<td>102</td>
<td>0.0098</td>
<td>0.47</td>
<td>406</td>
<td>110</td>
</tr>
<tr>
<td>diffuse</td>
<td>50</td>
<td>100</td>
<td>standard DISM</td>
<td>135</td>
<td>0.0074</td>
<td>0.36</td>
<td>206</td>
<td>110</td>
</tr>
<tr>
<td>diffuse</td>
<td>50</td>
<td>100</td>
<td>(\frac{1}{2}C_{np})</td>
<td>153</td>
<td>0.0066</td>
<td>0.32</td>
<td>135</td>
<td>110</td>
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<tr>
<td>diffuse</td>
<td>50</td>
<td>100</td>
<td>(\frac{1}{4}C_{np})</td>
<td>170</td>
<td>0.0059</td>
<td>0.28</td>
<td>77</td>
<td>110</td>
</tr>
<tr>
<td>diffuse</td>
<td>50</td>
<td>100</td>
<td>(\frac{1}{8}C_{np}, \frac{1}{2}C_{bg})</td>
<td>180</td>
<td>0.0056</td>
<td>0.27</td>
<td>52</td>
<td>110</td>
</tr>
<tr>
<td>energetic</td>
<td>0.25</td>
<td>10^4</td>
<td>0\times C_{np}, \frac{1}{2}C_{bg})</td>
<td>185</td>
<td>0.0054</td>
<td>0.26</td>
<td>38</td>
<td>110</td>
</tr>
<tr>
<td>energetic</td>
<td>0.25</td>
<td>10^4</td>
<td>0\times C_{np}, 0\times C_{bg})</td>
<td>196</td>
<td>0.0051</td>
<td>0.25</td>
<td>13</td>
<td>110</td>
</tr>
<tr>
<td>energetic</td>
<td>0.25</td>
<td>10^4</td>
<td>bare a-Sil</td>
<td>202</td>
<td>0.0049</td>
<td>0.24</td>
<td>0</td>
<td>110</td>
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<tr>
<td>low Z/x-ray</td>
<td>0.01</td>
<td>10^6</td>
<td>(\frac{1}{3}) a-Sil</td>
<td>613</td>
<td>0.0016</td>
<td>0.08</td>
<td>0</td>
<td>36</td>
</tr>
<tr>
<td>low Z/x-ray</td>
<td>0.01</td>
<td>10^6</td>
<td>(\frac{1}{30}) a-Sil</td>
<td>6742</td>
<td>0.0002</td>
<td>0.01</td>
<td>0</td>
<td>4</td>
</tr>
</tbody>
</table>

Table 3 from Jones+ (2018)
GPR - Metallicity Residuals

De Vis+ (2019); Clark+ (2019)
GPR - Metallicity Map for M74

M74 Metallicity Map

M74 Metallicity Uncertainty

De Vis+ (2019); Clark+ (2019)

Chris Clark
GPR - Metallicity Map for M83

De Vis+ (2019); Clark+ (2019)