A Nearby Galaxy Perspective on Dust Evolution

Frédéric GALLIANO
& the DustPedia collaboration

AIM, CEA/Saclay, France

July 2, 2021
Nearby sources: long-\(\lambda\) opacity; very cold dust distribution; free-free emission. ⇒ cf. talks by S. Katsioli & G. Ejlali.

Distant galaxies: bulk of the dust mass. ⇒ understand its evolution in galaxies.
Dust Content of Galaxies: the Potential of NIKA2

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- **Observed wavelength, $\lambda$ [μm].**
- **Luminosity, $\nu L_\nu / L_{bol}$ at $z=0$.**

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Evidences of Dust Evolution in the Milky Way

Depletion of element X:

\[ \delta X \equiv \log \left( \frac{X_{\text{gas}}}{X_{\text{ref}}} \right) \]

\[ \approx \delta_0 + A_X F^\star \Rightarrow \text{fraction of X locked in dust.} \]

In the Milky Way:

Good correlation between \( F^\star \) and \( \langle n_H \rangle \) \Rightarrow rapid grain growth in ISM.

Rapid destruction by shocks (\( \approx 300 \text{ Myr}; \) e.g. Jones et al., 1994).

\Rightarrow \approx 90\% \text{ of the grains were formed in the ISM (e.g. Tielens, 1998; Draine, 2009)};

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In the Milky Way:

- Good correlation between \( F_* \) and \( \langle n_H \rangle \) \Rightarrow rapid grain growth in ISM.
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The Dust Life Cycle
The Dust Life Cycle

- HII region
- High-mass stars (< 10 Myr)
- SN
- HIM

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The Dust Life Cycle

Low-mass stars
(> 400 Myr)

High-mass stars
(< 10 Myr)

AGB

HII region

SN

HIM
The Dust Life Cycle

Low-mass stars
(> 400 Myr)

High-mass stars
(< 10 Myr)

HII region

SN

AGB

Stardust injection

Condensation

HIM

Grain seeds
The Dust Life Cycle

Diffuse cloud

CNM

WIM & WNM

Low-mass stars

(> 400 Myr)

HII region

High-mass stars

(< 10 Myr)

SN

HIM

Stardust injection

Grain growth (< 1 Myr)

Grain seeds

Condensation

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The Dust Life Cycle

- **Diffuse cloud**
- **CNM**
- **WIM & WNM**

**Condensation**

- **Acreration**

- **Low-mass stars** (> 400 Myr)
- **High-mass stars** (< 10 Myr)
- **SN**
- **AGB**

**Stardust injection**

**Grain growth (< 1 Myr)**

**Grain seeds**
The Dust Life Cycle

Diffuse cloud
CNM
WIM & WNM

Condensation
Acretion

Low-mass stars
(> 400 Myr)

HII region
High-mass stars
(< 10 Myr)

SN

Stardust injection

AGB

Grain growth (< 1 Myr)

Grain seeds

Sputtering & shattering

HIM
The Dust Life Cycle

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Low-mass stars
(> 400 Myr)

High-mass stars
(< 10 Myr)

HII region

SN

Stardust injection

AGB

Diffuse cloud

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Grain growth (< 1 Myr)

Grain seeds

Condensation

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Sputtering & shattering

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Condensation
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Low-mass stars
(> 400 Myr)
AGB

HII region
High-mass stars
(< 10 Myr)
SN

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Grain growth (< 1 Myr)

Grain seeds

Condensation

Acreration

Sputtering

Shattering

Desorption
The Dust Life Cycle

Diffuse cloud → CNM → WIM & WNM → Grain growth (≤ 1 Myr) → Sputtering & shattering → High-mass stars (≤ 10 Myr) → HII region → Low-mass stars (≥ 400 Myr) → AGB → Stardust injection → Grain seeds

Condensation → Accretion → Sputtering → Shattering → Desorption → Sublimation
The Dust Life Cycle

Diffuse cloud

CNM

WIM & WNM

Condensation

Accretion

Sputtering

Shattering

Desorption

Sublimation

Photo-desorption & sublimation

Sputtering & shattering

Cycling (< 30 Myr)

Grain growth (< 1 Myr)

Grain seeds

HII region

Low-mass stars

(> 400 Myr)

High-mass stars

(< 10 Myr)

SN

Stardust injection

AGB

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The Dust Life Cycle

- Molecular cloud
- Diffuse cloud
- CNM
- WIM & WNM
- Low-mass stars
- High-mass stars
- HII region
- AGB
- SN
- Stardust injection
- Condensation
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- Sputtering
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- Desorption
- Sublimation
- Grain growth
- Grain seeds
- Cycling (30 Myr)
- Photo-desorption & sublimation
- Coagulation & icing

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- Icing

Grain growth (< 1 Myr)
Cycling (30 Myr)
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Objectives of the Present Study

1. Dust condensation in SNII ejecta;
2. Grain growth in cold clouds;
3. Dust destruction by SNII blast waves.

The Relevance of Nearby Galaxies

Wider diversity of physical conditions than MW: gas fraction, metallicity ($Z$), SF activity, etc.

Dwarf/Irregular (low $Z$, gas rich)
Spiral/Disk (intermediate)
Elliptical/Lenticular (high $Z$, gas poor)

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How do environmental conditions affect the timescales of the following processes?

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The Merged DustPedia & DGS Sample

Galaxies from DustPedia (Davies et al., 2017):

- 875 DustPedia galaxies observed by Herschel (photometry from Clark et al., 2018).
- 89 galaxies with all IR fluxes flagged.
- 22 AGNs classified by Bianchi et al. (2018).

⇒ 764 DustPedia galaxies.

Galaxies from the Dwarf Galaxy Sample (DGS; Madden et al., 2013):

- 33 galaxies not in DustPedia (photometry from Rémy-Ruyer et al., 2013).

⇒ 798 galaxies in total.

Ancillary Data Used as Prior Dependencies:

- Metallicity by De Vis et al. (2018; PG16S calibration).
- Stellar mass from Nersesian et al. (2019).
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### Galaxies from DustPedia (Davies et al., 2017):
- 875 DustPedia galaxies observed by *Herschel* (photometry from Clark et al., 2018).
- 89 galaxies with all IR fluxes flagged.
- 22 AGNs classified by Bianchi et al. (2018).

⇒ 764 DustPedia galaxies.

### Galaxies from the Dwarf Galaxy Sample (DGS; Madden et al., 2013):
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The Spectral Energy Distribution Model

Grain Properties:

THEMIS dust mixture (Jones et al., 2017); Dale et al. (2001) ISRF prescription.
⇒ infer dust mass, $M_{\text{dust}}$.

Fitting Process:

Using HerBIE (Galliano, 2018):

NIR to mm fit;
Correlated calibration uncertainties;
Color corrections;
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The Derived Scaling Relations

Dust-to-gas mass ratio, $Z_{dust} = M_{dust}/M_{gas}$

Specific gas mass, $sM_{gas} = M_{gas}/M_{star}$

Metallicity, $12 + \log(O/H)$

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Milky Way
Early type
Late type
Irregular

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Modelling Dust Evolution in Galaxies

One-Zone Dust Evolution Model (Rowlands et al., 2014; De Vis et al., 2017):

- **SFH:** delayed (Lee et al., 2010);
- **In/out-flow:** proportional to SFR;
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Fitting the Scaling Relations:

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F. Galliano (AIM)
Observing the mm Universe with NIKA2
July 2, 2021 10/12

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⇒ Low-Z regime crucial to constrain \( \langle Y_{\text{SN}} \rangle \).

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Inference of Dust Evolution Parameters

Accounting for systematics:
\[ \langle Y_{SN} \rangle \lesssim 0.03 \, M_\odot / SN; \]
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\[ m_{\text{dest}} \text{gas} \gtrsim 1200 \, M_\odot / SN. \]

(for a Salpeter IMF).

Sensitivity to IMF:
Consistent results with Chabrier IMF, provided that the SFR and \( M_\star \) are estimated consistently.

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Conclusion: Dust Evolution Timescales

Dust evolution balance:
- Solar metallicity: consistent with what we know of the Milky Way ⇒ rapid growth & destruction.
- Low metallicity: dust formation dominated by SNII.

Take away points:
- Important to fit dust evolution models (not only overlay) ⇒ consistency & eliminate bad solutions;
- Need both low- & high-Z sources ⇒ constrain both production regimes;
- Grain growth realistic for dust at high z ⇒ simply need $Z \gtrsim \frac{1}{5} Z_\odot$.

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Evidence of Thermal Sputtering in Ellipticals

Peculiar trend of ellipticals:
- Dust deficient @ a given gas fraction;
- Their ISM is permeated by X-ray emitting coronal gas;
- Thermal sputtering could dominate (e.g. De Vis et al., 2017).

In our sample:
⇒ correlation w/ X-ray luminosity supports this hypothesis
⇒ exclude ellipticals from dust evolution modelling.

(Galliano et al., 2021)
The Dust-to-Metal Mass Ratio Variations

Dust-to-metal ratio: Fraction of elements locked in dust.

In our sample: Clear variation with $Z$, by 2 orders of magnitude.

Possible biases:
- H I halo $\Rightarrow$ factor $\lesssim 1.5$;
- Grain opacity $\Rightarrow$ factor $\lesssim 2$;
- Size distribution $\Rightarrow$ factor $\lesssim 3$;
- Very cold dust $\Rightarrow$ unlikely.

$\Rightarrow$ factor $\lesssim 4.25 \ll 10^2$.

(Galliano et al., 2021)
Inference of SFH-Related Parameters

(Galliano et al., 2021)