DustEM User's Guide

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DustEM is a numerical tool in fortran 95 jointly developed by IAS and IRAP to compute the extinction and the emission of interstellar dust grains heated by photons. The dust emission is calculated in the optically thin limit (no radiative transfer) and the default spectral range is 40 to 10^8 nm. The code has been designed so that dust properties can easily be changed and mixed and to allow for the inclusion of new grain physics (Compiègne et al., 2011). The grain temperature distribution dP/dT is derived with the formalism of Désert et al. (1986), assuming that the grain cooling is continuous. To correctly describe the long wavelength emission of dust, the initial algorithm has been revised to cover the low temperature part of dP/dT. The current stable version of DustEM is available at `http://www.ias.u-psud.fr/DUSTEM`. The fortran files are in `/src`, data files in `/oprop, /hcap, /data` and output files are in `/out`. All data files have headers (where each line begins with #) that document their content. IDL routines useful to generate or visualize DustEM files can be found in `/pro`[1].
After a few words on how to set up DustEM, we detail below the way to control DustEM as well as the files it needs or produces.

1 Getting started

After downloading the tar ball from the DustEM website:

1. unpack the archive:

   ```
   tar xvzf dustem.tar.gz
   ```

   this will generate the `dustem` directory which should contain the following subdirectories: `data`, `hcap`, `oprop`, `out`, `pro` and `src`.

2. Go in `src` and edit the file `DM_constants.f90`. Then define the string `data_path` as the absolute path to the DustEM directory you just created. If you are running DustEM coupled to the Meudon PDR code, you must also define the string `dir_PDR` as the absolute path to the `/PDR/data` directory, where specific output files (used by PDR) will be written.

3. Edit `Makefile` and set up the standard commands corresponding to your fortran compiler (`gfortran`, `g95` and `ifort` have been tested[2]), *e.g.*:

   ```
   FC = gfortran
   FFLAGS = -O2 -fno-second-underscore
   ```

4. Type `make` to compile possibly preceded by `make clean`, if a former attempt went wrong. A successful compilation will end with `That's it !`. The executable is called `dustem`

5. Running: `./src/dustem`. This runs the model of (Compiègne et al., 2011) and should take a few seconds CPU on current computers.

6. After running `dustem`, you can check your run by using `show_dustem.pro` in `pro`.

[1] Documentation on the routine `rname` is usually obtained by typing `rname` (`tt=rname()`) in case of a procedure (function) respectively.

[2] `ifort` is about twice as fast as the others.

2 Input files

The main input file for `DustEM` is `GRAIN.DAT` and must be located in the directory `/data`. This file contains the main parameters and keywords that define a dust model. Each dust *population* is defined by its grain *type* noted `tt` and its size distribution as set in `GRAIN.DAT`. For a given type, `DustEM` requires the files `/oprop/Q_tt.DAT` and `/hcap/C_tt.DAT` containing the optical properties and heat capacities of grain of type `tt`, respectively[3]. These files are described in section 2.5. `DustEM` can handle an arbitrary number of dust populations.

2.1 Defining a dust model

Within `DustEM`, a dust model is defined by the control input file `GRAIN.DAT`. We show below a typical example of this file (as in Compiègne et al. (2011)).

```
    # DUSTEM: definition of grain populations
#
# run keywords
# G0 scaling factor for radiation field
# grain type, nsize, population keywords, Mdust/MH, rho, amin, amax, alpha/a0 [, at, ac, gamma (ED)] [, au, zeta, eta (CV)]
# cgs units
#
 sdist
 1.00
 PAH0_MC10      10 logn-chrg-zm    7.80E-04 2.24E+00 3.50E-08 1.20E-07  6.40E-08   1.00E-01
 PAH1_MC10      10 logn-zm         7.80E-04 2.24E+00 3.50E-08 1.20E-07  6.40E-08   1.00E-01
 amCBEx         15 logn            1.65E-04 1.81E+00 6.00E-08 2.00E-06  2.00E-07   3.50E-01
 amCBEx         25 plaw-ed         1.45E-03 1.81E+00 4.00E-07 2.00E-04 -2.80E+00 1.50E-05 1.50E-05 2.00E+00
 aSil           25 plaw-ed         7.80E-03 3.50E+00 4.00E-07 2.00E-04 -3.40E+00 2.00E-05 2.00E-05 2.00E+00
```

After some documentation lines (starting with #) come the run keywords (`sdist` in the above example), then a scaling factor on the intensity of the radiation field (1.00). The next lines define the dust populations. From left to right we have: grain type (e.g. `PAH0_MC10`), number of sizes (`nsize`), the population keywords, the dust-to-gas mass ratio (M_i/M_H), the grain mass density (ρ in g/cm^3), the minimum (a_{min}) and maximum (a_{max}) sizes in cm and other parameters for the size distribution. As seen in this example for `amCBEx`, several dust *populations* can make use of the the same grain *type*.
Keywords are important to control `DustEM`. They can be written in uppercase or lowercase characters. The *run keywords* control the way `DustEM` is executed and the output files it produces. If multiple run keywords are used, they must be separated by blanks. The available run keywords are

- **none:** if no run kyword required,
- **quiet:** sets the verbose mode off at runtime,
- **res_a:** writes output for each grain size (see section 3)
- **sdist:** for each grain size and type, writes the size distribution in the file `/out/SDIST.DAT`,
- **zdist:** for each grain size and type, writes the charge distribution in the file `/out/ZDIST.DAT`,

[3] In general, a type of grain has a well defined composition (bulk material), structure (porosity, mass density) and shape (spherical or spheroidal). All these properties are taken into account while generating the grain data (section 2.5).

- **temp:** for each grain size and type, writes the temperature distribution in the file `/out/TEMP.DAT`,
- **pdr:** writes a summary of `DustEM` output in `/out/EXTINCTION_DUSTEM.DAT`. To be set when `DustEM` is used coupled to the Meudon PDR code (`http://pdr.obspm.fr/PDRcode.html`). Requires `G_tt.DAT` files in `/data` (see section 2.5).

The *population keyword* (e.g., `logn`, `plaw`) define the size distribution and the physical processes included in `DustEM` for each grain population. Population keywords can also be multiple, they are then separated by a dash. The population keywords defining the size distribution are described in section 2.3 and those defining the grain physics in section 2.4

2.2 Template dust models

Several dust models are widely used and constitute reference dust models. The control input files for the following reference models are included in the current `DustEM` distribution:

- **GRAIN_DBP90.DAT:** for the model of Désert et al. (1990),
- **GRAIN_DL07.DAT:** for the model of Draine & Li (2007) (see section A).
- **GRAIN_MC10:** for the model of Compiègne et al. (2011).

To be used, these files must be renamed to `GRAIN.DAT` in `/data`.

2.3 The size distribution

When the population keyword `size` is not set, the size distribution is defined from the parameters in `GRAIN.DAT`. The size grid has `nsize` points and is defined over the interval $[a_{min}, a_{max}]$ with a constant logarithmic step. For each grain of mass density ρ, the radius a is defined as that of an equivalent sphere of same mass $m = \rho\, 4\pi a^3/3$. The shape of the size distribution dn/da (the number of grains whose radius is included in $[a,\, a + da]$) is then defined by the following population keywords and parameters:

- **logn:** defines a log-normal size distribution with $dn/d\log a \propto \exp\left(-\frac{1}{2}\,(\log(a/a_0)/\sigma)^2\right)$. The centroid a_0 (in cm) and the width σ are given after a_{max} in `GRAIN.DAT`.
- **plaw:** defines a power-law size distribution $dn/da \propto a^\alpha$. The index α is given after a_{max} in `GRAIN.DAT`.
- **ed:** applies an exponential decay to a power law size distribution multiplying dn/da by the function

$$D(a) = \begin{array}{ll} 1 & a \le a_t \\ \exp(-\,[(a-a_t)/a_c]^\gamma) & a > a_t. \end{array} \qquad (1)$$

  The parameters a_t, a_c and γ are given in this order after α in `GRAIN.DAT`.
- **cv:** applies a curvature term to a power law size distribution multiplying dn/da by the function

$$C(a) \;=\; [\,1 + |\zeta|\,(a/a_u)^\eta\,]^{\mathrm{sgn}(\zeta)} \qquad (2)$$

  If `ed` is set with `cv` the parameters a_u, ζ and η are given in this order after γ in `GRAIN.DAT`. Otherwise they are given after α.

The keywords `ed` and `cv` allow to use a size distribution similar to that of Weingartner & Draine (2001a).
Alternatively, the size distribution of a given grain population can be read from a file. When the population keyword `size` is set the size distribution and the size grid are read from the file

`/data/SIZE_tt.DAT` which must have the following format (not including the #-lines):

```
    # Size distribution of grain species
#
# shape (t-matrix code, 0:spheres, -1:spheroids) eps (b/a, eps>1:oblate, eps<1: prolate)
# Nbr of bulk materials
# Name of bulks
# Bulk densities in g/cm3
# Mass fractions for each bulk
# Nbr of size bins
# [ a (cm), dloga, a^4*dn/da, rho_eff, fv ]
# fv: volume fraction of bulks, rho_eff: volume mean density
#
0 1.00E+00
1
Gra
2.2500E+00
1.0000E+00
46
8.0876E-08 2.0939E-01 7.1858E-02 2.2500E+00 1.0000E+00
....
```

The `SIZE_tt.DAT` file can be generated with the IDL routine `/pro/create_vdist.pro` or taken from the `DustEV` output (Guillet *et al.* 2011, in preparation). Size dependent composite grains can be handled this way.

2.4 Grain physics

Physical processes affecting the grain properties are taken into account in `DustEM` thanks to population keywords often associated with data files where parameters are passed. Below is the list of population keywords for the processes included in dustem:

- **mix:** apply a size dependent weighting factor f_{mix} when computing the contribution of the dust population to the extinction and emission. For each population `tt` featuring the `mix` keyword, a file `/data/MIX_tt.DAT` must be given containing a single column with weighting factors for each point of the size grid. The contribution to the emission and extinction of each size bin is then weighted by f_{mix}, allowing to perform a size dependent mixing of several dust types. For each size, the weighting factors must verify $\sum_{tt} f_{mix}(tt) = 1$. In the example `GRAIN.DAT` shown above neutral (`PAH0_MC10`) and ionized PAHs (`PAH1_MC10`) are mixed size by size in the model. The weighing factors (in the `MIX_tt.DAT` files) then corresponds to the fraction of neutral and ionized PAHs. In a coarser way, species can also be mixed with the mass fraction.

- **beta:** applies a correction to Q_{abs} to introduce a temperature dependence, namely:

$$Q_{abs}(a,\nu) = Q_0(a,\nu)\ (\nu/\nu_t)^{\delta(T)\,H(\nu_t/\nu)} \tag{3}$$

  where Q_0 is the grain emissivity without the temperature dependence, $\nu_t = c/\lambda_t$ is the frequency threshold and $\delta(T) = \beta(T) - \beta_0$ is the index correction with respect to β_0 some reference value. The threshold function in frequency is $H(x) = 0.5\,(1 + 4\tanh(x)/s)$ where $x = \log(\lambda/\lambda_t)$ and s controls the stiffness of the transition (the width Δx is proportional to s) from 0 to 1: for instance for $s = 1$ $H(x)$ rises from 0 to 1 for x between 0.5 to 1.5 and $\Delta x = 1$. Parameters for this correction are in `/data/BETA_tt.DAT`:

```
# DUSTEM: parameters for BETA(T) behaviour of Qabs
# first DBETA correction to standard index beta0
# then lambda threshold to apply BETA(T)
#
# beta0 a g bmax
# lthresh(microns) lstiff (dlambda=lthresh/lstiff)
# nbetav (nr of beta values if 0 uses formula)
# tbeta betav (if nbetav >= 0)
#
2.11E+00 1.15E+01 -6.60E-01 5.00E+00
```

```
3.00E+01 1.00E+00
13
1.00E+00 1.55E+00
...
```

where $lthresh$ and $lstiff$ stand for the above λ_t and s. If $nbetav = 0$ then $\beta(T) = a\,T^g$ (Désert et al., 2008) and we take $\beta = \min(\beta, bmax)$. If $nbetav > 0$ the $\beta(T)$-values must be given below $nbetav$ in two columns T and β

- **chrg:** if set the equilibrium charge distribution of grains per grain size and type will be computed using the Weingartner & Draine (2001b) formalism with the van Hoof et al. (2004) modification for the photodetachment (see also Weingartner et al. (2006)). Requires the following data: the gas state in the file `/data/GAS.DAT` (see 2.6) and the quantities for grain charging in the file `/data/CHRG_tt.DAT`:

```
# DUSTEM : Constants for charge distribution
#
# Wf(eV) p_ea(2)(nm) for IP and EA
# s_ea(2) for EA cross-section: f and dE(eV)
# le(Å) p_y(3) for PE yield
# p_uait(3) for Uait
# m1mass molecular mass in grain (g)
# nr of Ebg values (if 1 Ebg constant equal to 1st value)
# Ebg(eV)
#
4.4 4.0 7.0
0.5 3.0
10.0 9.0e-03 3.7e-02 5.0
3.9 0.12 2.0
12.01
1
0.0
...
```

  The bandgap E_{bg} can be made size-dependent: in that case values must be provided in one column with as many lines as the number of sizes for the given grain type. When E_{bg} has a single value (one line), this value is applied for all sizes. The grain charge distribution is sensitive to the electron sticking coefficient s_e which by default is that of the Weingartner & Draine (2001b) model. The case of the Bakes & Tielens (1994) model ($s_e = 1$) can also be used by using the composed keyword `chrg-bt`[4].

  The charge distribution of small grains ($a \leq 10$ nm) is computed on a charge grid around Z_{eq}, the charge value corresponding to zero current, i.e., $J_{pe} + J_{ion} = J_e$ (see Weingartner & Draine (2001b) for notations). The number of charge points is MIN($Z_{max} - Z_{min} + 1, nz\_max$) with nz_max=30 by default. In the case of larger grains the charge distribution is strongly peaked around Z_{eq} and the charge grid has nz_min around Z_{eq} (nz_min=20 by default).

- **zm:** allows to mix populations of neutral and charged grains with fractions given by the charge distribution $f_Z(Z)$. Must be set for two subsequent grain populations in `GRAIN.DAT` (see section 2.1). For the first population (neutral grains) `zm` must be set with `chrg` and a weighting factor $f_{mix} = f_Z(0)$ is applied per size to the grain emission and extinction. For the second population (charged grains), `zm` is set alone and the weighting factor per size is then $f_{mix} = \sum_{|Z|>0} f_Z(Z) = 1 - f_Z(0)$. This mixing can be applied to any grain population and does not require any `MIX_tt.DAT` file. It is particularly useful to compute the emission and extinction of neutral and charged PAHs.

- **dtls:** adds the low temperature opacities of amorphous grains as described in Meny et al. (2007). Uses the file `/data/DTLS_tt.DAT`:

```
# DUSTEM: constants for the DCD and TLS effects
# a_dtl lc(nm) c_delta
```

[4]The Bakes & Tielens (1994) model has also been widely used in astrophysical modeling and this prescription for s_e has noticeable consequences (Verstraete, 2011).

```
# vt(cm/s) P*mub2 gamma_e(eV)
# omega_m(s-1) tauO(s-1) Vo(erg) Vmin(erg) Vm(erg)
# ldtresh(microns)
#
5.00e-02 2.00e-02 1.30e+01 1.87e+03
3.00e+05 1.40e-03 1.00e+00
2.69e+12 1.00e-13 5.70e-14 6.90e-15 7.60e-14
1.00e+02
```

where all parameters are as in Meny et al. (2007) with a_{dtls} the relative weight of the DCD to TLS effects and $ldtresh$ is the threshold above which the correction is applied (scaled to the current Q value at wavelength $ldtresh$). The absorption efficiency per grain type and size thus reads:

$$Q_{abs}(\lambda \geq ldtresh) = Q_0 \ (a_{dtls} Q_{DCD} + Q_{TLS}) \tag{4}$$

where Q_0 is the absorption efficiency at $ldtresh$ read in the Q_tt.DAT file (see sec. 2.5).

- **pol:** turns on the computation of the polarized emission and extinction. Requires `Q1_tt.DAT`, `Q2_tt.DAT` and `Q3_tt.DAT` files to be in `/oprop`. A picket fence model is used with a size dependent alignment function f_p (Draine & Fraisse, 2009). This function is controlled by the file `/data/POL_tt.DAT`.

```
# DUSTEM: polarization parameters
# for f_pol and cos(theta0)
#
# atresh pstiff plev
# cteta0
# npol
#
1.00E-01 0.60E+00 0.80E+00
0.00E+00
20
1.00E-01
...
```

If $npol = 0$ then $f_p(x) = 0.5\, p_{max}\, (1 + 4 \tanh(x)/s)$ where $x = \log(a/a_t)$ with a_t (or $atresh$) the size threshold (in cm), s (or $pstiff$) the stiffness parameter controlling the transition width and p_{lev} the maximum fraction of linear polarization. If $npol > 0$ the f_p-values are given below $npol$ in one column (assuming the size grid defined in sec. 2.3). The $cteta0$ parameter gives the cosine of the angle between the direction of the magnetic field and the line-of-sight ($\cos\theta_0$ in Draine & Fraisse (2009)).

- **spin:** turns on the emission of spinning PAHs following **?** for the gas-grain interactions and using the emission as derived in `DustEM` for the radiative IR excitation rates. The permanent electric dipole moment is assumed to be $\mu = m\, a^{3/2}$ and m is given in `/data/SPIN_tt.dAT`. The gas parameters are given in `/data/GAS.DAT` (see sec. 2.6). Requires the charge distribution of each grain to be computed.

2.5 Grain data

For a given type of grain `tt`, dust grain properties are provided depending on the size a in data files, namely: `Q_tt.DAT` files for the absorption and scattering efficiencies, $Q(a, \lambda)$, and `C_tt.DAT` files for the heat capacity per unit volume, $C(a, T)$. The Q and C values are provided over the broadest possible size range (usually 0.3 to 10^4 nm). A grain type can be used once these Q and C-files exist in the `DustEM` data file set, in the optical properties `/oprop` and heat capacity `/hcap` directories respectively. Sizes requested in `GRAIN.DAT` or `SIZE_tt.DAT` have to fit into those of the above files (i.e. extrapolation is not allowed). When `DustEM` is coupled to radiative transfer codes (e.g. `PDR`), g-factors[5] are required at all wavelengths and sizes: they are given

[5]The anisotropy factor for scattering defined as $< \cos\theta >$ where θ is the scattering angle.

in `/oprop/G_tt.DAT`. In the case of spherical grains, the Q and G files are generated with the Mie theory (`bhmie` Bohren & Huffman 1983) while for spheroidal grains the T-matrix method is used (Mischenko & Travis, 1998). We briefly outline below the format of these files.

The Q-files are as follows:

```
    # QABS and QSCA to be used by DUSTEM
#
# nsize (number of sampled sizes in this file)
# sizes (microns)
50
3.0000E-04 3.7104E-04 4.5891E-04 5.6759E-04 7.0200E-04 8.6824E-04 1.0738E-03 1.3281E-03 ...
#
#### QABS ####
1.3461E-03 1.6642E-03 2.0571E-03 2.5419E-03 3.1398E-03 3.8762E-03 4.7819E-03 5.8952E-03 ...
...
#### QSCA ####
5.0179E-07 1.1650E-06 2.6935E-06 6.1884E-06 1.4083E-05 3.1594E-05 6.9380E-05 1.4766E-04 ...
```

The first uncommented line gives the number of sizes present in the file. The line next gives the sizes (in microns). Then comes for each grain size (one column per size) the absorption Q_{abs} and scattering Q_{sca} efficiencies. The G-files are as Q-files with the QABS field replaced by $g(a, \lambda)$ and no QSCA field. The Q and G-files are all generated with a common wavelength grid given in `/oprop/LAMBDA.DAT`.

The C-files look like:

```
    # DUSTEM heat capacity
#
# nr of sizes ns
# sizes (microns)
# nr of T-values
# log T(K) log C_1...log C_ns (erg/K/cm3)
50
3.0000E-04 3.7104E-04 4.5891E-04 5.6759E-04 7.0200E-04 8.6824E-04 1.0738E-03 1.3281E-03 ...
30
-1.0000E+00 4.8983E-01 4.8983E-01 4.8983E-01 4.8983E-01 4.8983E-01 4.8983E-01 4.8983E-01 4.8983E-01 ...
```

The first uncommented line gives the number of sizes present in the file and the second line gives the sizes in microns. The third line gives the number of points in the temperature grid. Then comes the $\log_{10}$ of temperatures (in Kelvin, column 1) and the $\log_{10}$ of heat capacities (one column for each size) in unit of erg/K/cm3 . The same temperature grid (30 points from 0.1 to 5,000 K with a constant log step) is used for all Cles. This temperature grid is given in `/hcap/TEMP.DAT`.

The grain data can be batch generated with the `dustprop` IDL package (not included in `pro`). We list below the grain types for which Q and C files are available in the current `DustEM` distribution:

- **PAH0_MC10, PAH1_MC10:** PAHs as defined in Compiègne et al. (2011) for neutral and singly charged PAHs, respectively,
- **PAH0_DL07, PAH1_DL07:** PAHs as defined in Draine & Li (2007) for neutral and singly charged PAHs, respectively. It takes into account the transition to graphite (Gra_Dr03) optical properties for $a > 50\,\text{Å}$,
- **PAH1_MC08:** PAHs described in Compiègne et al. (2008),
- **Gra:** graphite grains. The Q-values have been generated with the Mie method for spherical particles. The refractive index and heat capacity are as described in Draine & Li (2001); Li & Draine (2001),
- **Gra_Dr03:** graphite grains, same as `Gra` but with the changes of Draine (2003) at short wavelengths.

- **amCBEx:** Amorphous carbon grains. The Q-values have been generated with the Mie method. The refractive index is from **?** and the Q_{abs} have been extrapolated above 0.9 mm (see Compiègne et al., 2011). The heat capacity is the same as that of graphite.
- **aSil:** Silicate (olivine type) grains. The Q-values have been generated with the Mie method. The refractive index and heat capacity are as in Draine & Li (2007) (originally from Draine & Lee, 1984).
- **BG_MC08:** big grain as defined in Désert et al. (1990), modified by Compiègne et al. (2008).

Data files for the Désert et al. (1990) model are also available corresponding to the grain types **PAH0_DBP90, PAH1_DBP90, VSG_DBP90** and **BG_DBP90**.

In the case of more complex grain types with size-dependent properties (composition, porosity) the Q, C and G files are generated with the information in the `SIZE_tt.DAT` file.

2.6 Astrophysical data

The radiation field used by `DustEM` is in `/data/ISRF.DAT`. This file contains 2 columns, the wavelength (microns) and the flux $4\pi I_\nu$ in erg/s/cm^2/Hz. The wavelength range must be included in that of the Q-file. It can be generated with the `create_rfield.pro` routine in `/pro`. The current distribution includes `ISRF_MATHIS.DAT`, the standard radiation field of Mathis et al. (1983) and `ISRF_CMB.DAT` where the CMB contribution has been added to the Mathis field.

Parameters for the gas are given in `/data/GAS.DAT` as:

```
    # DUSTEM : Gas quantities
#
# Gas temperature (K), hydrogen density, H2 density
# number of charge type (electrons, H+, C+, ...)
# ion density (cm-3), mass (amu), charge, polarizability (A^3)
# >>>>> 1st line is electron <<<<<<<
#
1.00E+02 3.00E+01 0.00E+00 4.50E-02
3
4.50E-02 5.4858E-04 -1.00 0.00
3.60E-02 1.00794 1.00 0.67
9.00E-03 12.0107 1.00 1.54
```

3 Output files

Output files produced by `DustEM` are stored in `/out`. They give essentially the emission and extinction of dust grains. Each file begins with documentation lines (first character is #). Any `DustEM` run will produce the 2 following files:

- **SED.RES:** contains the emission per proton of each dust population $4\pi\nu I_\nu/N_H$ in erg/s/H as a function of wavelength (N_H is the proton column density). The last column is the total of all previous columns.
- **EXT.RES:** contains the extinction cross-section of the grain populations per gram of dust type.

If the run keywords `temp`, `zdist` or `sdist` are used, `TEMP.DAT`, `ZDIST.RES` or `SDIST.RES` will be written containing respectively the temperature, charge or the size distribution of the dust populations. Each of these files has a header with documentation.
Using population keywords `pol` or `spin` will generate the following files:

- **SED_POL.RES:** contains the polarized emission of grains with the same format as `SED.RES`.
- **SPIN.RES:** contains the emission of spinning grains with the same format as `SED.RES`.

Using the run keyword `res_a` will generate the files `SED_A.RES`, `SED_POL_A.RES` and `SPIN_A.RES` which contains the same information, namely, the emission per grain in size bin $[a, a + da]$ or $4\pi\nu I_\nu / N_d(a)$ in erg/s/grain ($N_d(a)$ is the column density of grains of size a).

References

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A Comparison to other models

Figure 1 shows the comparison between the Draine & Li (2007) model as tabulated and retrieved on the B.T. Draine webpage[6] and the `DustEM` output obtained using the input file `GRAIN_DL07.DAT`.

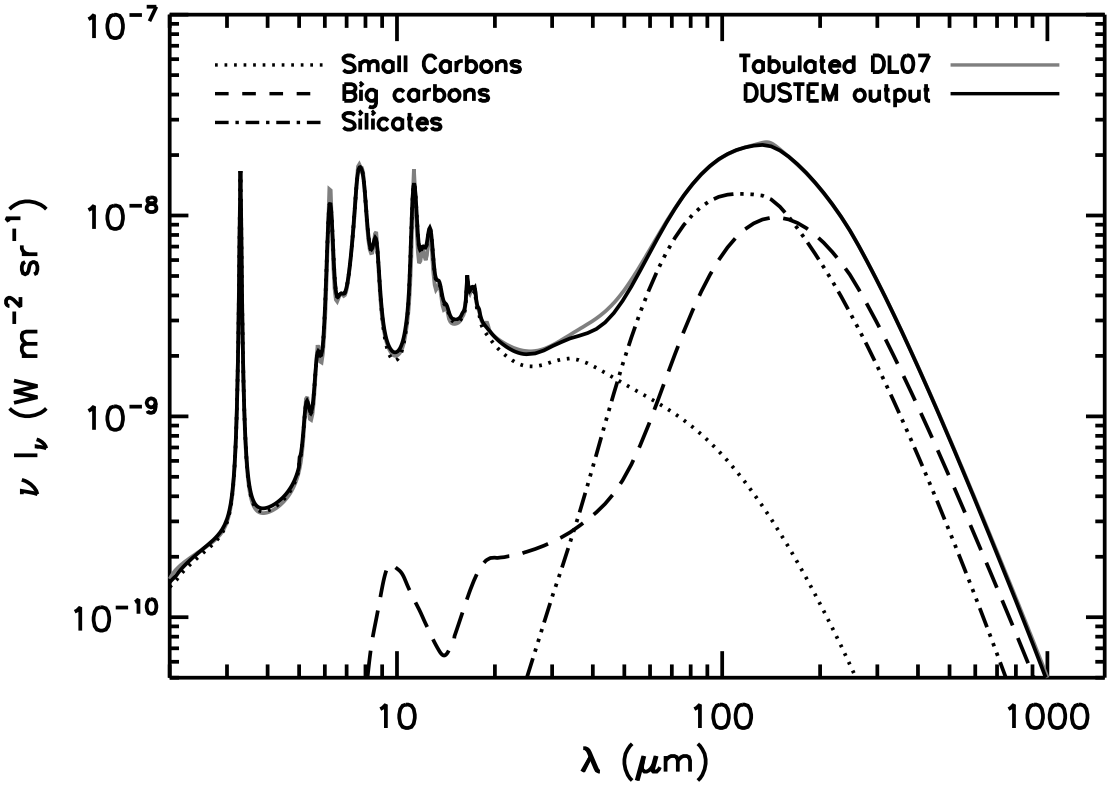

Figure 1: Comparison between the tabulated version and the output of `DustEM` for the Draine & Li (2007) model.

[6] `http://www.astro.princeton.edu/~draine/`