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DUST MASS IN SIMULATIONS OF GALAXIES

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Abstract. We have designed a model to compute dust abundances in chemodynamical N-body+SPH simulations. It includes the production by Asymptotic Giant Branch (AGB) stars, supernovae (SNe, type I and II), the destruction by shock induced by SNe and the growth of dust grains in the interstellar medium (ISM). The model takes advantage of the self-consistent chemodynamical code to compute the evolution of the dust mass: the two ISM phases, evolving stellar populations, and metal enrichment. We show that our model is able to reproduce the abundances of dust and its linear relation with the metallicity of the ISM, provided all dust processes are included. Moreover, some low-metallicity galaxies that are under-abundant in dust could be explained by our simulations as being dominated by the dust destruction in SNe shocks.

Keywords: dust, galaxies: evolution, methods: numerical

1 Introduction

Despite its low mass fraction the dust provides powerful clues for the chemical and physical description of the ISM (Savage & Sembach 1996; Jenkins 2009), and recently for constraining galactic evolution (Dwek et al. 2011).

To understand the life-cycle of dust in ISM, semi-analytic models of galactic evolution have been extensively used (Lisenfeld & Ferrara 1998; Tielens 1998; Hirashita et al. 2002; Morgan & Edmunds 2003; Zhukovska et al. 2008; Dwek & Cherchneff 2011). We present hereafter a model for dust production and destruction mechanisms, specially designed for self-consistent chemodynamical simulations of galaxies. The results obtained in simulation of a massive galaxy are discussed in section 3.

2 The Model

The evolution of a galaxy is simulated using PM+SPH code described in Michel-Dansac & Wozniak (2004). Wozniak et al. (2011) have updated the star formation recipes and the chemical evolution to take the stellar population evolution as well as the multiphase nature of the ISM into account. The new chemodynamical prescription includes star formation based on the local Jeans instability. Stellar populations have various metallicities and evolve over $\sim$10 Gyr injecting energy and gas into ISM. The ISM has two gaseous phases. One represents the cold neutral medium with a fixed temperature (10^2 K). The second has a variable temperature ranging from 10^2 to 10^8 K, determined by solving the energy equilibrium. The cooling function is metallicity dependent. Heating from stars is also included. Phases exchange mass by condensation and evaporation mechanisms.

Our model (see Fig. 1, left) computes the dust mass with recipes adapted from semi-analytic models. The main difference is the local nature of our model. Indeed, contrary to the global galactic computation of semi-analytic models, our recipes computes dust mass for each SPH particles having a resolution varying from 10 pc (in the nucleus) to 1 kpc (in the outskirts). All assumptions of classical semi-analytic models of dust evolution have been adapted to the local conditions in simulations. A second difference comes from the physically motivated distinction of two ISM phases (the cold and the warm/hot). Our model takes advantage of this, providing dust mass separately for both phases.

We have performed simulations with different combinations of three basic processes: the production of dust by stars, the accretion in interstellar medium, and the destruction by SNe. The “stardust” is mainly produced by

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AGB stars and SNe (Cherchneff & Dwek 2010; Morgan & Edmunds 2003), we make use of data from Zhukovska et al. (2008) with metallicity dependent populations of stars, injecting dust in the two phases of our ISM as proportional to their respective volume. The production by growth of grains in ISM must be included to balance the low lifetime of dust (Draine et al. 2007). In our simulations, it is activated in cold phase above a threshold density of $n_H = 10^4$ cm^{-3}. Our accretion recipe uses a simple assumption based on the collision rate between grains and particles of the gaseous phase, leading to:

$$\rho_d(t) = \frac{\rho_d(0)}{(1 - \rho_d(0)/\rho_M)\, e^{-t/\tau} + \rho_d(0)/\rho_M}, \tag{2.1}$$

where ρ_d is the local density of the dust component, ρ_M its maximal density which is the density of the accreting metal C, O, Mg, Si, Fe (Savage & Sembach 1996; Draine et al. 2007), and τ^{-1} the rate of accretion (proportional to the accreting metal density too). The destruction of dust occurs mainly in shocks produced by SNe. We use the destruction efficiency computed by Jones et al. (1994, 1996) and the shocked mass from Hirashita et al. (2002), to get a formula of destroyed mass of dust, proportional to the energy released by the SNe.

3 Discussion

We have performed four simulations with various combinations of active processes. The global evolution of simulations is plotted in Fig. 1 (right). Our simulations agree well with the observations from Lisenfeld & Ferrara (1998), Draine et al. (2007), and Engelbracht et al. (2008). The trend for the simulations, apart from the simulation with stardust and destruction only, is linear as predicted by the expected relation:

$$\frac{\mathrm{M_{dust}}}{\mathrm{M_H}} \approx 0.01 \frac{(O/H)}{(O/H)_{\mathrm{MW}}}, \tag{3.1}$$

scaled from local Milky-Way models (see Draine et al. 2007). If destruction is activated and accretion is not, we obtain lower dust abundances conforming with the low-metallicity galaxies which are dust under-abundant.

We have shown that only the simulation which includes all the three creation and destruction mechanisms is able to reproduce the observed dust mass ratio as a function of metallicity (see Fig. 2). Especially, because of the lack of free parameters for destruction, we need to include accretion to obtain a reasonable mass of dust when the destruction process is activated. Moreover, it is noteworthy that the destruction has a visible effect in low metallicity region of our simulation with the full dust physics. This dust fraction, lower than that predicted by the linear relation, suggests that low-metallicity irregular dwarves could be dominated by the dust destruction. This will be checked by full self-consistent simulations of dwarf galaxies.

References

Cherchneff, I. & Dwek, E. 2010, ApJ, 713, 1

Draine, B. T., Dale, D. A., Bendo, G., et al. 2007, ApJ, 663, 866

Dwek, E. & Cherchneff, I. 2011, ApJ, 727, 63

Dwek, E., Staguhn, J. G., Arendt, R. G., et al. 2011, ApJ, 738, 36

Engelbracht, C. W., Rieke, G. H., Gordon, K. D., et al. 2008, ApJ, 678, 804

Hirashita, H., Tajiri, Y. Y., & Kamaya, H. 2002, A&A, 388, 439

Jenkins, E. B. 2009, ApJ, 700, 1299

Jones, A. P., Tielens, A. G. G. M., & Hollenbach, D. J. 1996, ApJ, 469, 740

Jones, A. P., Tielens, A. G. G. M., Hollenbach, D. J., & McKee, C. F. 1994, ApJ, 433, 797

Lisenfeld, U. & Ferrara, A. 1998, ApJ, 496, 145

Michel-Dansac, L. & Wozniak, H. 2004, A&A, 421, 863

Morgan, H. L. & Edmunds, M. G. 2003, MNRAS, 343, 427

Savage, B. D. & Sembach, K. R. 1996, ARA&A, 34, 279

Tielens, A. G. G. M. 1998, ApJ, 499, 267

Wozniak, H., Champavert, N., & Feldner, H. 2011, in EAS Publications Series, Vol. 44, EAS Publications Series, ed. H. Wozniak & G. Hensler, 41–42

Zhukovska, S., Gail, H.-P., & Trieloff, M. 2008, A&A, 479, 453

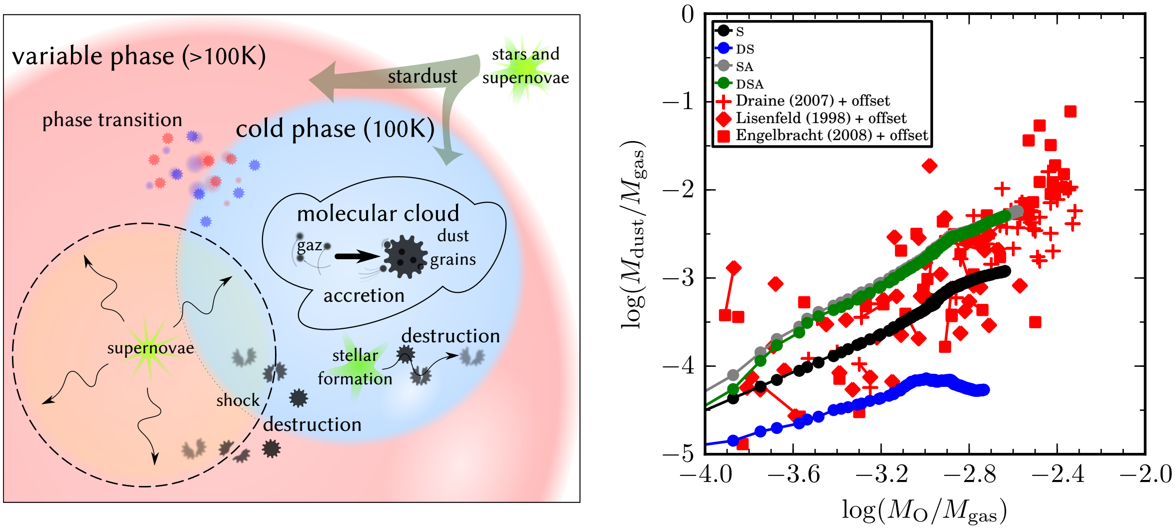

Fig. 1. Left: Sketch of physical processes involved to compute the evolution of the dust mass. **Right:** Evolution of our 4 simulations, snapshots every $\sim$25 Myr. Simulations are labelled with the active processes: S for stardust, D for destruction, A for accretion. Data from observations (Lisenfeld & Ferrara 1998; Draine et al. 2007; Engelbracht et al. 2008), in red, have been homogenized applying an offset.

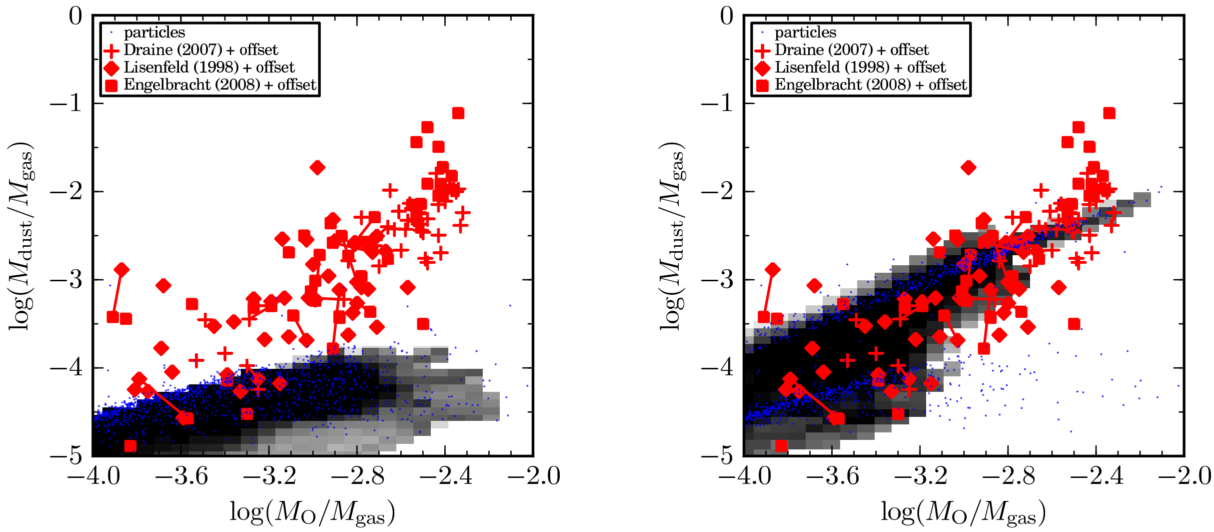

Fig. 2. 2D histograms of snapshots. **Left:** Simulation with stardust, SNe shock destruction, but without accretion. The observed dust abundance for high-metallicity galaxies is higher than the simulated value. All snapshots show similar behavior, we show here snapshot at $t = 264$ Myr. **Right:** Simulation with all the three dust processing active: destruction, stardust, and accretion. We take the snapshot at $t = 264$ Myr, few Myrs after the star formation rate maximum to have high dust destruction rate from SNe shocks.