A&A manuscript no.
(will be inserted by hand later)

Your thesaurus codes are:
05 (09.03.1; 09.04.1; 11.05.2; 11.09.4; 19.53.1)

ASTRONOMY AND ASTROPHYSICS

Dust-to-Gas Ratio and Phase Transition of Interstellar Medium

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Received March 4, 1999; accepted March 17, 1999

Abstract. We discuss the time evolution of dust-to-gas mass ratio in the context of multi-phase model of interstellar medium. Phase transition of interstellar gas is considered to occur on a timescale of $\sim 10^{7-8}$ yr, according to a nonlinear open system model of interstellar medium. Since the phase transition changes the dust formation and destruction rates, the dust-to-gas ratio also fluctuates on the same timescale. This explains the scatter of the dust-to-gas ratios of spiral galaxies quantitatively, though we should note the large observational uncertainty.

Key words: ISM: clouds – dust, extinction – galaxies: evolution – galaxies: ISM — galaxies: spiral

1. Introduction

Recent chemical evolution models of galaxies including the dust content are successful in explaining the dust amount of nearby galaxies (Wang 1991; Lisenfeld & Ferrara 1998; Dwek 1998; Hirashita 1999a, hereafter H99; see also Takagi, Arimoto, & Vansevičius 1999). Supernovae (SNe) are the dominant source of the formation of dust grains (Dwek & Scalo 1980), and SN shocks destroy grains (Jones et al. 1994; Borkowski & Dwek 1995). Thus, in those models are dust content connected with star formation histories.

In our previous work, H99, the dust-to-gas ratio was expressed as a function of metallicity (see also Lisenfeld & Ferrara 1998), which is also related to star formation histories. It confirmed the suggestion proposed by Dwek (1998) that the accretion process onto preexisting dust grains is efficient in spiral galaxies. However, since the accretion is effective in cold clouds, the global efficiency of the accretion depends on the fraction of the gas in cold phase (Seab 1987; McKee 1989; Draine 1990). Thus, the efficiency varies on a timescale of $\sim 10^{7-8}$ yr by the phase transition of the ISM (Ikeuchi 1988; McKee 1989).

In this Letter, we combine the framework of H99 with a theoretical work on multiphase ISM by Ikeuchi & Tomita (1983), whose limit-cycle model of the ISM phase transition is applied to the result in Tomita, Tomita, & Saitō (1996) by Kamaya & Takeuchi (1997; hereafter KT97). In the limit-cycle model, mass fraction of each phase oscillates continuously because of mass exchange among the components of the phases. The timescale of the phase transition in the model is determined by a few parameters intrinsic to a spiral galaxy; sweeping rate of SN shocks, evaporation rate of the cold gas, and the cooling rate of the gas heated by SN shocks. Actually, a static solution as well as the limit-cycle solution for the filling factors of the three components is possible depending on the parameters. However, the oscillatory behaviour (i.e., the limit-cycle model) of the filling factors is supported observationally. Indeed, the observed scatter of the far-infrared-to-optical flux ratios of spiral galaxies (Tomita, Tomita, & Saitō 1996) is interpreted through the limit-cycle model in KT97. KT97 suggested that the fraction of the gas mass (i.e., the mass filling factor) in the cold phase changes in the range of 0.1 to 0.7 (or more) on the timescale of 10^{7-8} yr (see also Korchagin, Ryabtsev, & Vorobyov 1994).

This Letter is organized as follows. In §2, we investigate the variation of the dust-to-gas ratio due to the phase transition of ISM in spiral galaxies. Finally, we discuss the result in §3.

2. Grain growth in multiphase interstellar medium

The ISM in a spiral galaxy is composed of multiphase gas. McKee & Ostriker (1977) constructed the model of the ISM with three components in a pressure equilibrium: the cold phase ($T \sim 10^2$ K and $n \sim 10$ cm^{-3}), the warm phase ($T \sim 10^4$ K and $n \sim 10^{-1}$ cm^{-3}), and the hot phase ($T \sim 10^6$ K and $n \sim 10^{-3}$ cm^{-3}). Since the mass of the hot component is negligible in a galactic disc compared with the others, we only consider the warm and the cold gas.

Dwek (1998) and H99 showed that the accretion of heavy elements onto preexisting dust grains is the dominant process for the growth of the dust content in spiral

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