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Extinction Curves as a Probe of High-Redshift Metal Enrichment

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Abstract. We use extinction curves of high-z ($z > 5$) galaxies to probe the metal enrichment in the early universe. Since at high z (> 5), low-mass stars cannot be dominant sources for dust grains, Type II supernovae (SNe II) and pair instability supernovae (PISNe), whose progenitors are massive stars with short lifetimes, should govern the dust production. Here, we investigate the theoretical extinction curves of dust produced in SNe II and PISNe. We find that the hypothesis that the dust is predominantly formed by SNe at $z = 6$ is still allowed by the current observational constraints.

1. Introduction

It is expected that at high redshift ($z > 5$) at the cosmic age < 1 Gyr, the main sources of dust grains are Type II supernovae (SNe II) and pair instability supernovae (PISNe). In general, extinction curves can be used to investigate the dust properties. By using a sample of broad absorption line (BAL) quasars, Maiolino et al. (2004a) show that the extinction properties of the low-z ($z < 4$) sample are different from those of the high-z ($z > 4.9$) sample, suggesting a change in the dust production mechanism in the course of galaxy evolution. Maiolino et al. (2004b) show that the extinction curve of SDSS J1048+4637 at $z = 6.2$ is in agreement with the SN II dust models by Todini & Ferrara (2001). Bianchi & Schneider (2007) consider dust destruction by reverse shock in SNe, suggesting that 2–20% of the initial dust mass survives, and that the extinction curve after the destruction is still consistent with that of SDSS J1048+4637.

We have written other theoretical papers on the extinction curves of high-z objects (Hirashita et al. 2005, 2008), based on the dust production models by Nozawa et al. (2003, 2007). We summarize our results below. See those papers for details.

2. Results

Here, we show our theoretical results for the extinction curves of dust produced by SNe. In Figure 1a, we show the results without reverse shock destruction. We observe that the observed extinction curve at $z = 6.2$ is consistent with the model prediction. The effect of the reverse shock destruction is shown in Figure 1b. We find that the extinction curve is sensitive to the ambient gas density around SNe. The destruction is significant for small-sized grains, leading to a flat extinction curve in the optical and ultraviolet wavelengths. Although the extinction curve is highly sensitive to the ambient density, the hypothesis that the dust is predominantly formed by SNe at $z = 6$ is still allowed by the current observational constraints. Finally, it is worth noting that the reverse shock destruction tends to modify extinction curves to a flat shape, which may explain some unreddened BAL quasars at $z > 5$ in Maiolino et al. (2004a).

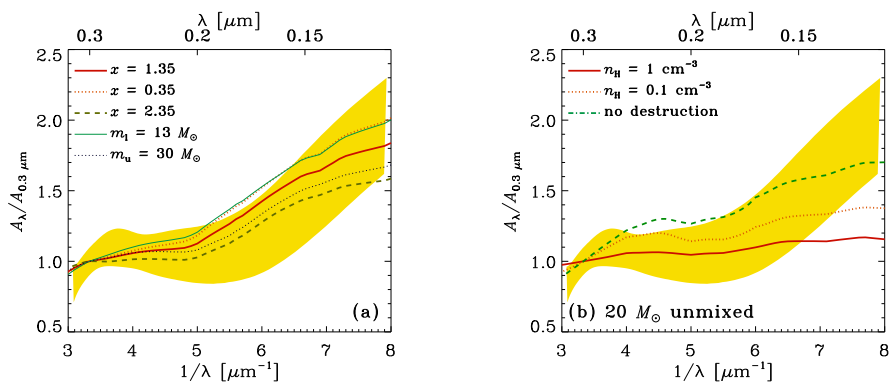

Figure 1. Extinction curves normalized to the extinction at a wavelength $\lambda = 0.3$ μm. The range observationally derived by Maiolino et al. (2004b) for SDSS 1048+4637 is shown by the shaded area in each figure. The helium core is assumed to be unmixed. (a) Averaged extinction curves of dust produced by SNe II (without reverse shock destruction). Various lines correspond to various stellar initial mass function adopted for the averages (see Hirashita et al. 2005). (b) Extinction curves with reverse shock destruction ($20M_\odot$ progenitor) for various ambient hydrogen number densities ($n_{\rm H} = 1$ and 0.1 cm^{-3}). The case without the reverse shock destruction is also shown.

References

Bianchi, S., & Schneider, R. (2007), MNRAS, 378, 973
Hirashita, H., et al. 2005, MNRAS, 357, 1077
Hirashita, H., Nozawa, T., Takeuchi, T. T., & Kozasa, T. 2008, MNRAS, in press
Maiolino, R., et al. 2004a, A&A, 420, 889
Maiolino, R., et al. 2004b, Nat, 431, 533
Nozawa, T., Kozasa, T., Umeda, H., Maeda, K., & Nomoto, K. 2003, ApJ, 598, 785
Nozawa, T., et al. 2007, ApJ, 666, 955
Todini, P., & Ferrara, A. (2001), MNRAS, 325, 726