Extinction Curves as a Probe of High-z Metal Enrichment

Hiroyuki Hirashita (Univ. Tsukuba)
T. Nozawa, T. Kozasa (Hokkaido Univ.)
T. T. Takeuchi (Nagoya Univ.)

Abstract: We use high-redshift (high-z) extinction curves to probe the metal enrichment in 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. We theoretically investigate the extinction curve of dust produced in SNe II and PISNe, taking into account the reverse shock destruction induced by collision with ambient interstellar medium. The destruction is significant for small-sized grains, leading to a flat extinction curve in the optical and ultraviolet wavelengths. A high ambient number density with $n > 1$ cm^{-3} produces too flat an extinction curve to be consistent with the observed extinction curve for a quasar at $z = 6.2$. 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. Thus, we are possibly seeing the metal enrichment by SNe at $z > 6$.

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1. Extinction as a Tracer of Metals

Half of metals in interstellar medium are in dust grains.
→Dust formation is important to trace metal enrichment.

Extinction curve:
Wavelength dependence of dust cross section

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Key to understand the dust properties (composition, size distribution etc.)

Pei (1992)

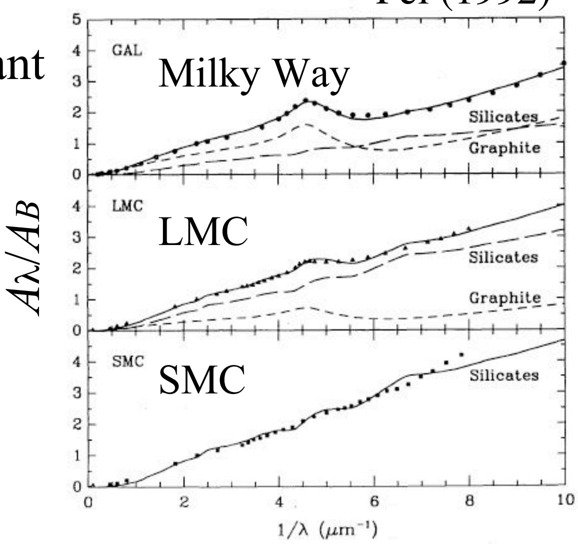
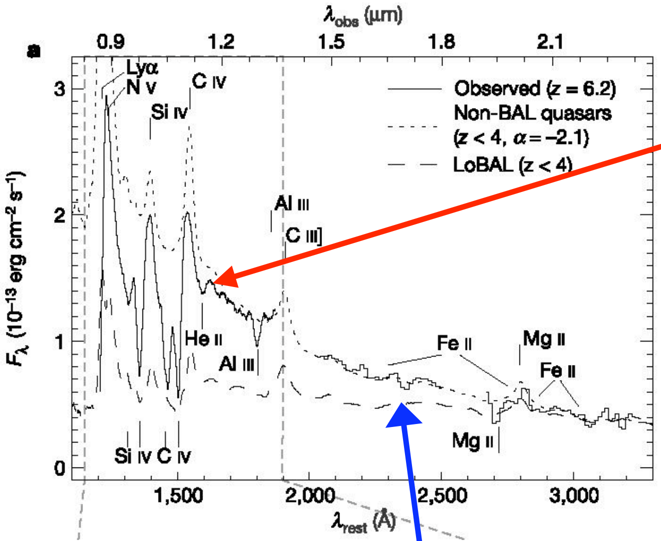


FIG. 5.—Comparisons between the model and empirical extinction curves in the Milky Way, LMC, and SMC. The short and long-dashed lines show, respectively, the relative contributions from graphite and silicate grains, with the sum of the two shown as the solid lines.

2

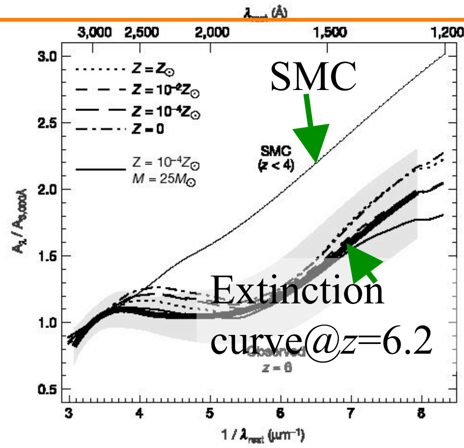
Extinction in a BAL QSO at z = 6.2

Maiolino et al. (2004)



Spectrum of a BAL (SDSS J1048+4637) at redshift z = 6.2

BAL at z < 4: Non-BAL SED + SMC extinction (reddening)



Different dust properties at high z.

Origin of High-z Dust

Young cosmic age at z > 5
→ No dust supply from low-mass stars

Supernovae (SNe) whose progenitors have short lifetimes predominantly supply dust grains.

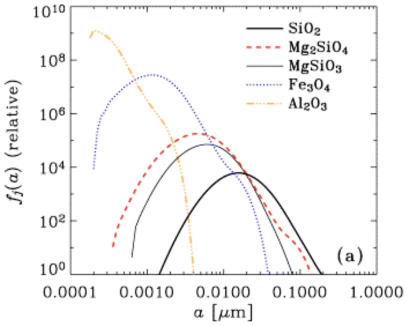
We calculate extinction curves of dust formed in SNe.
→Compared to observations at z = 6.2
to constrain metal production in the early Universe.

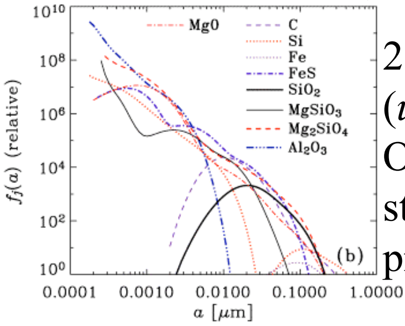
2. Dust Produced in SNe

Grain size distributions of various species produced in SNe

Nozawa et al. (2003)

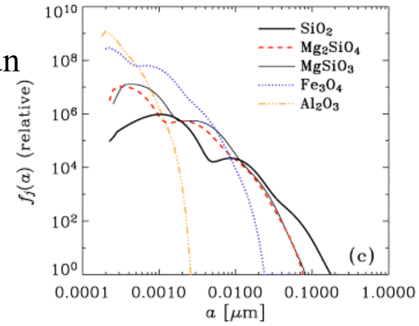
20 Msun (*mixed* within He core)

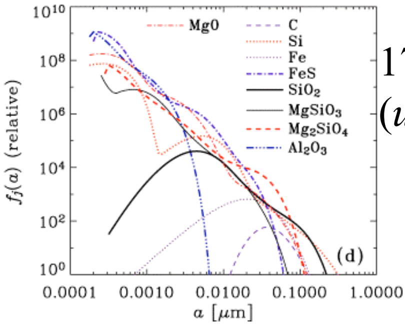




20 Msun (*unmixed*: Onion-like structure is preserved.)

170 Msun (*mixed*)

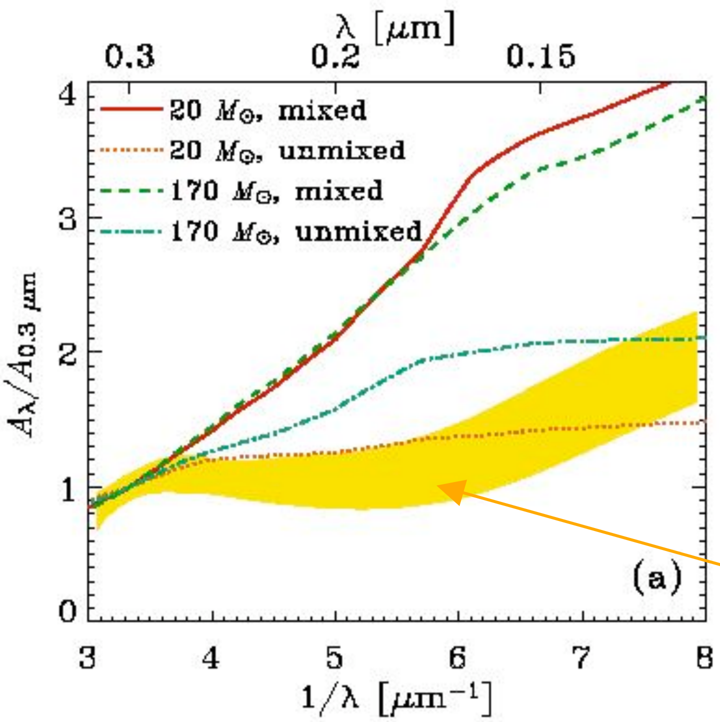




170 Msun (*unmixed*)

Extinction Curves

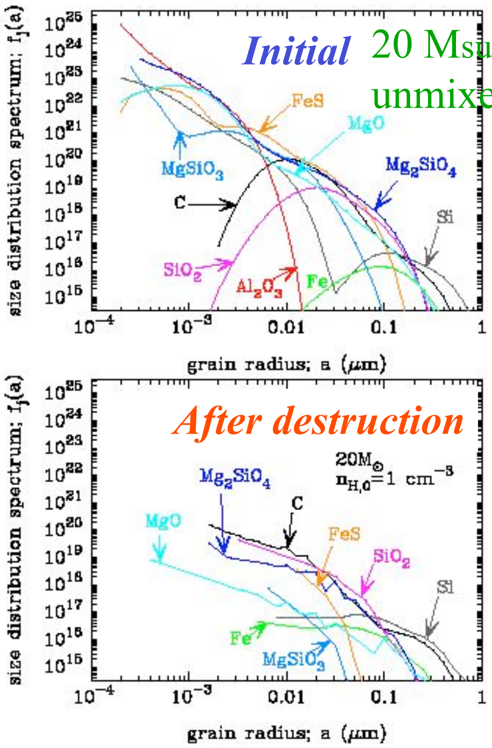
Hirashita et al. (2005)



The extinction curve at $z = 6.2$ is consistent with the dust production by unmixed Type II SNe.

Yellow: Maiolino et al. (2004) for a BAL QSO at $z = 6.2$

Effect of Dust Destruction



Nozawa et al. (2007)

Destruction by reverse shock (sputtering)
→Small grains are destroyed more easily than large grains.

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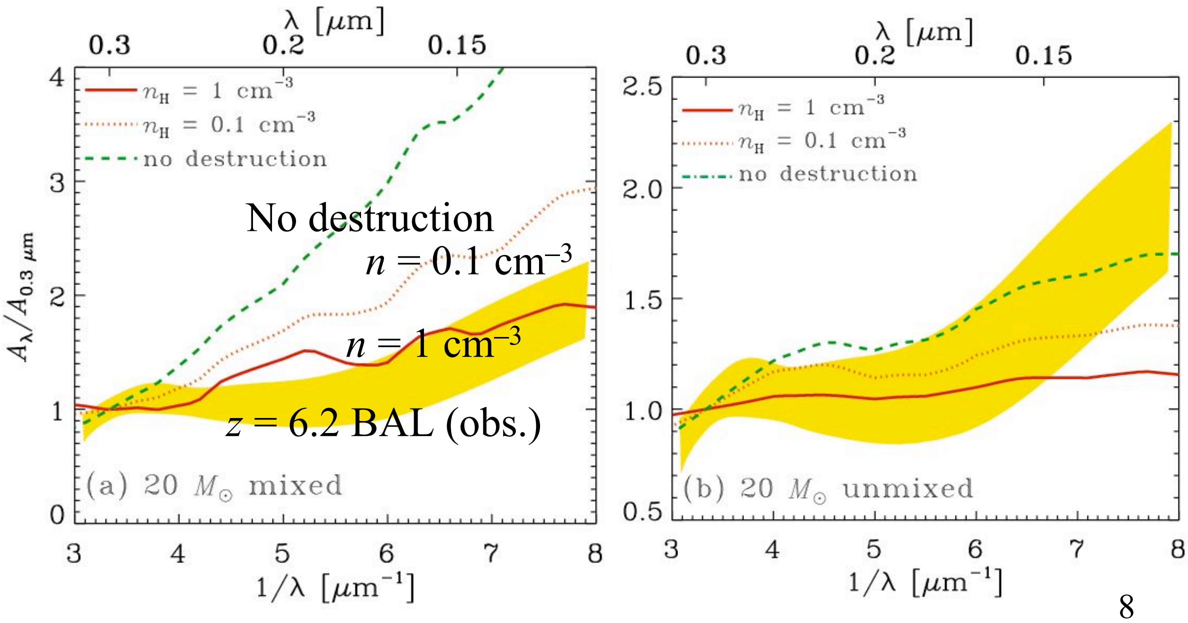
Extinction Curves tend to become flat.

Extinction Curves after Destruction

Hirashita et al. (2007)

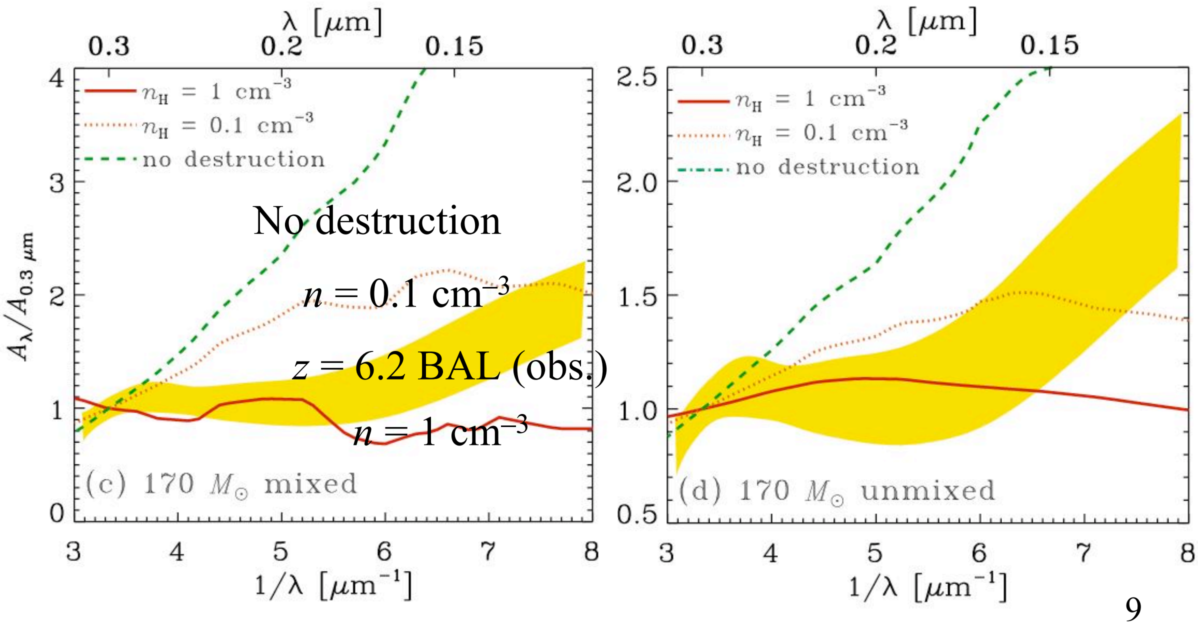
Progenitor mass: 20 Msun



Extinction Curves after Destruction

Hirashita et al. (2007)

170 Msun progenitors



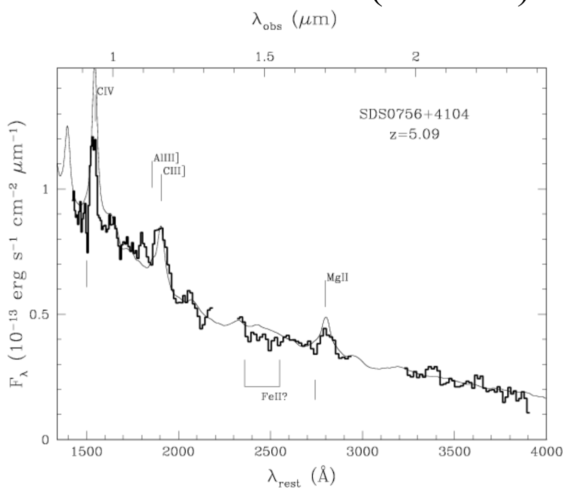
3. Summary and Discussion

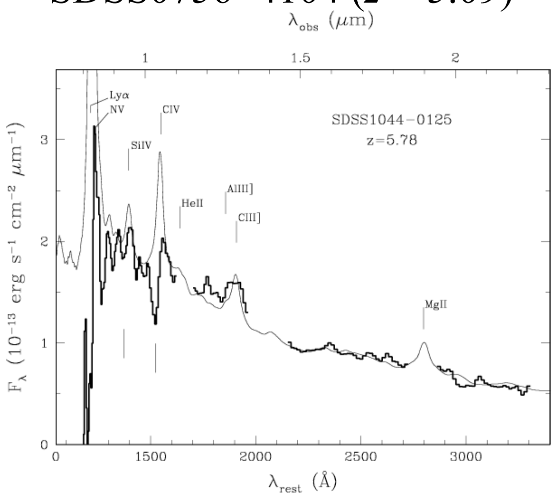
1. Destruction by reverse shocks flatten extinction curves.
2. The extinction curve observed for a $z = 6.2$ BAL can be explained by dust produced in SNe.
3. However, too dense an environment such as $n > 1$ cm^{-3} flatten extinction curves too much.

BALs without Reddening

Maiolino et al. (2004)

SDSS1044–0125 (z = 5.78) SDSS0756+4104 (z = 5.09)





Consistent with non-BAL template ⇒ **no reddening**
But **detected in sub-mm** (**10^8–10^9 Msun dust**: Priddey+03)

Possible Interpretation of High-*z* Dust

Flat extinction curve?

Efficient destruction by reverse shock?

This work implies general importance of flat extinction curve at high redshift.