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Ia型超新星の特異な減光則から探る系外銀河のダスト特性

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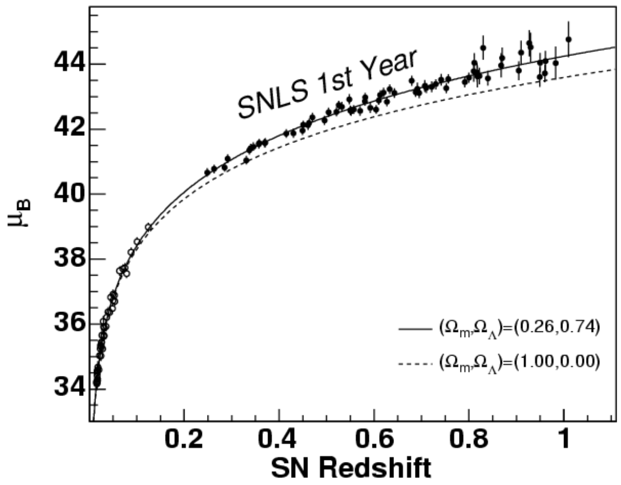
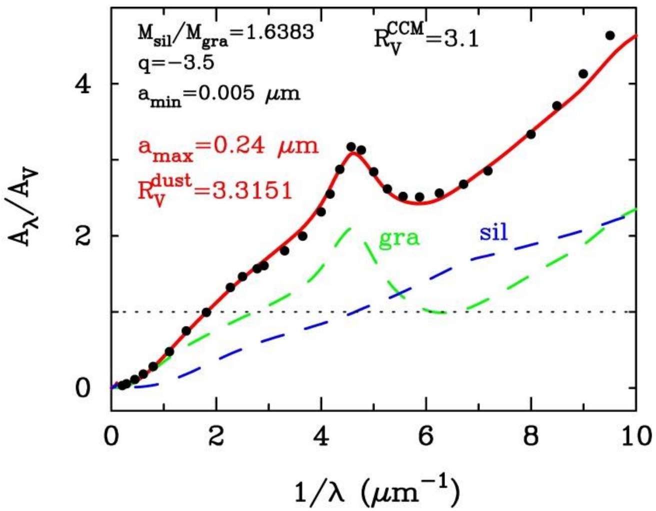
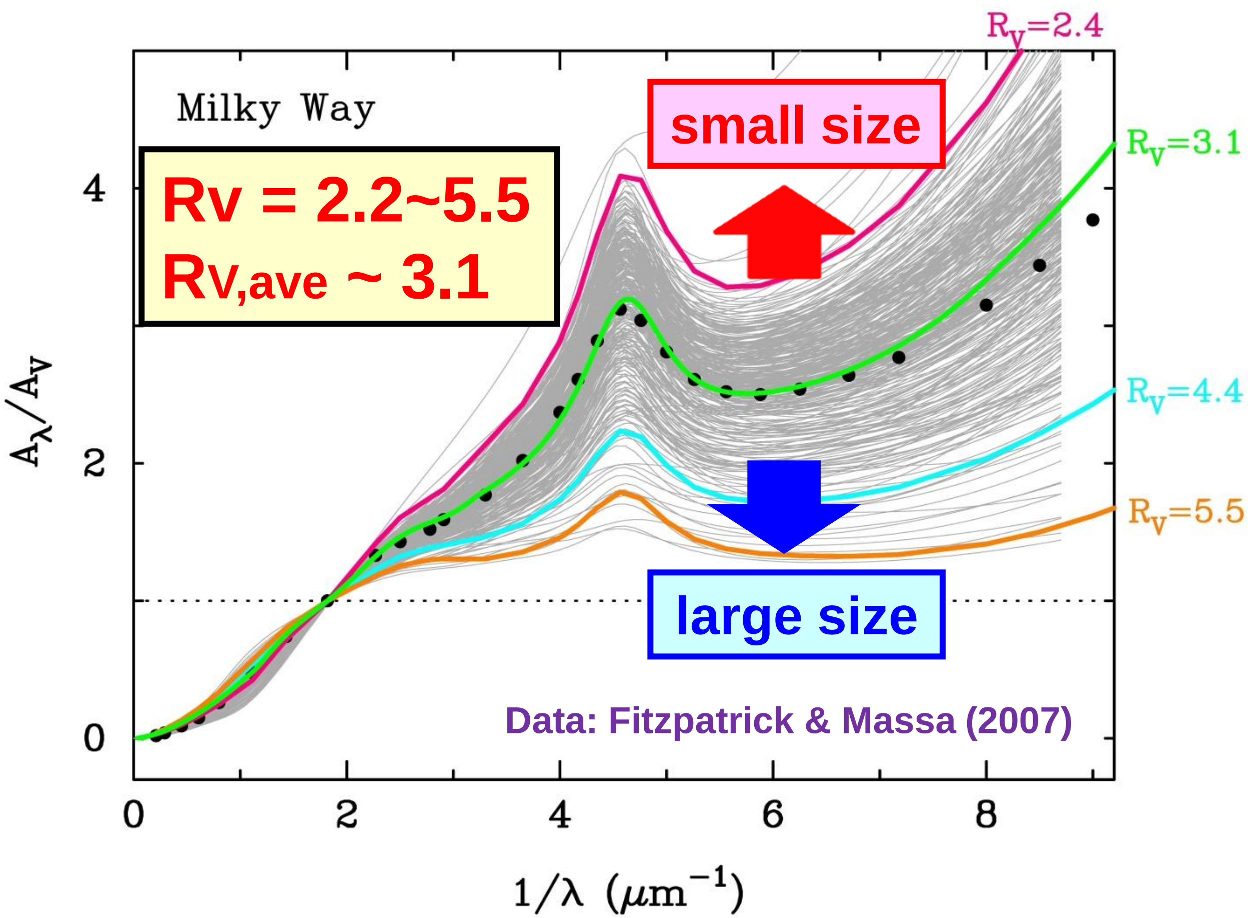




1-1. MW extinction curve and CCM relation



○ CCM relation

(Cardelli, Clayton, Mathis 1989)

Rv : ratio of total-to-selective extinction

$$R_V = A_V / E(B - V) = A_V / (A_B - A_V)$$

↓

$$A_\lambda / A_V = a(x) + b(x) / R_V$$

where $x = 1 / \lambda$

- **steeper** extinction curve (**lower** Rv) ➜ **smaller** grains
- **flatter** extinction curve (**higher** Rv) ➜ **larger** grains

1-2. Extinction law towards Type Ia SNe

○ Type Ia supernovae (SNe)

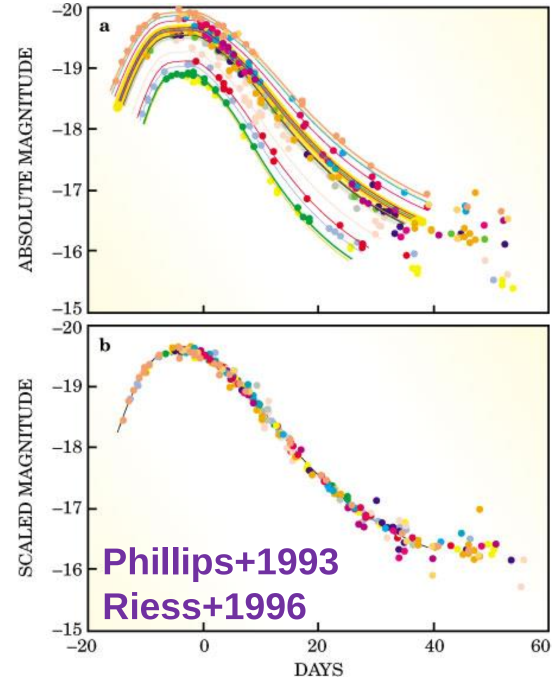
- thermonuclear explosion of WD
  - single-degenerate scenario (WD + MS)
  - double-degenerate scenario (WD +WD)
- main sources of cosmic Fe
  - M_{Fe} ~ 0.7 M_{sun} (cf. M_{Fe} ~ 0.07 M_{sun} in CCSNe)
- discovered in all types of galaxies
  - star-forming, elliptical, irregular, etc …
- cosmic standard candles

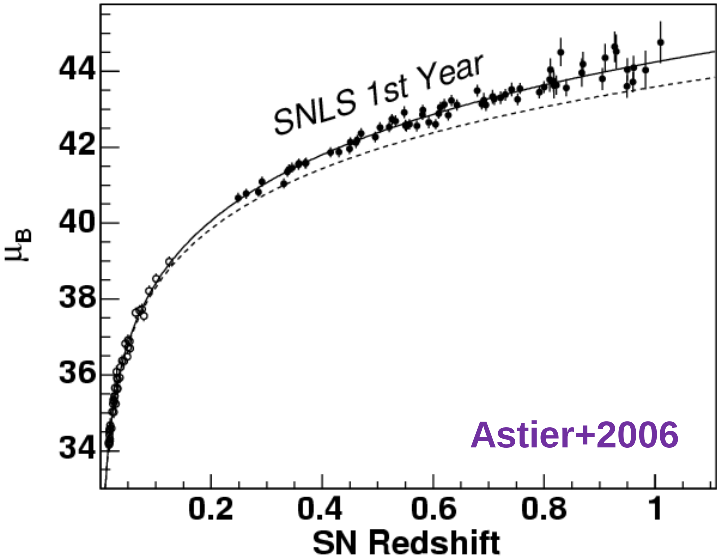
$$M_B = m_B - 5 \log_{10}(D_L) - A_B - 5$$

➜ $R_V = 1.0 \sim 2.5$

to minimize the dispersion of Hubble diagram

(e.g., Tripp+1998; Conley+2007; Phillips+2013)





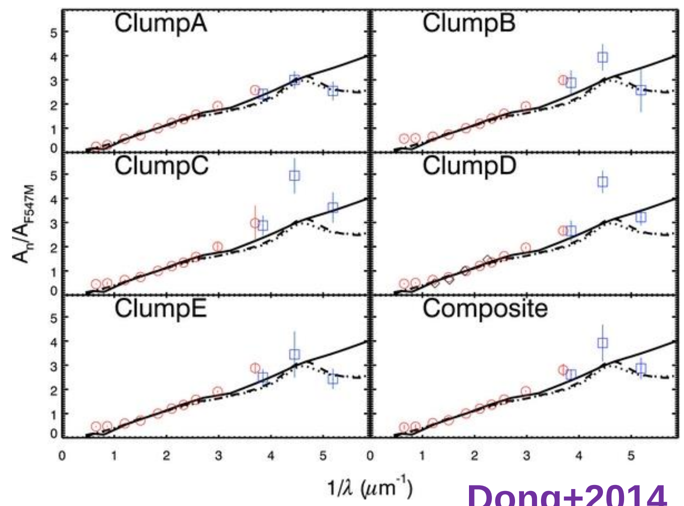
1-3. Other examples of extinction in galaxies

○ Extinction of individual SNe

- from the observed colors of SNe Ia

  Rv ~ 3.2, similar to the Galactic value

  - a few outliers (SN 2005A, SN 2006X) with Rv ~ 1.7 (Folatelli+2010)



Dong+2014

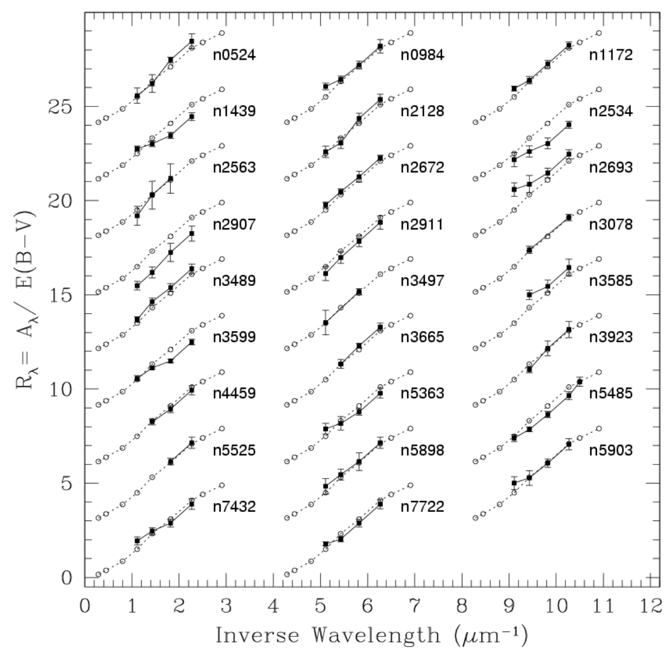
○ Extinction of nearby galaxies

- M 31 (Andromeda Galaxy)
  - disk region: Rv ~ 3.1 (Bianchi+1996)
  - dusty complex: Rv ~ 2.1 (Melchior+2000)
  - central parts: Rv ~ 2.4-2.5 (Dong+2014)

- elliptical galaxies (Patil+2007)

  Rv = 2.0-3.5 (with the average of Rv = 3.0)

➜ Rv is moderately low or normal

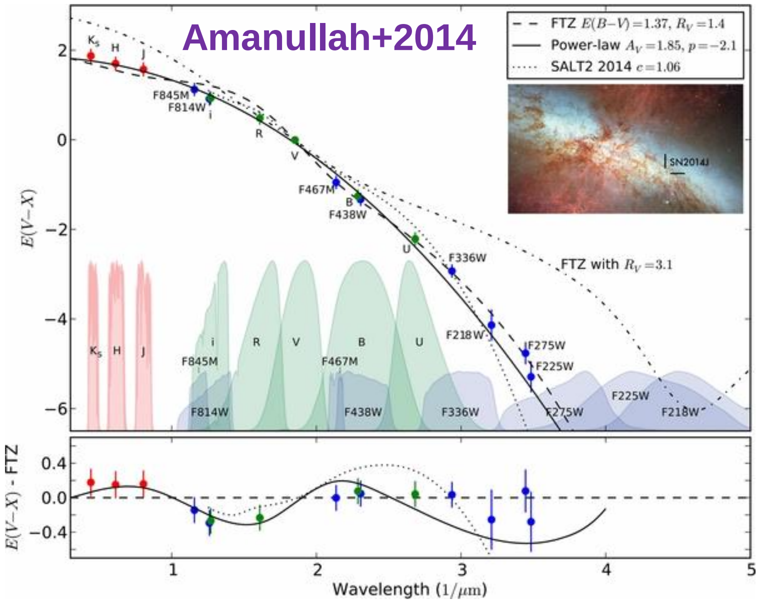


Patil+2007

1-4. Peculiar extinction towards SN 2014J

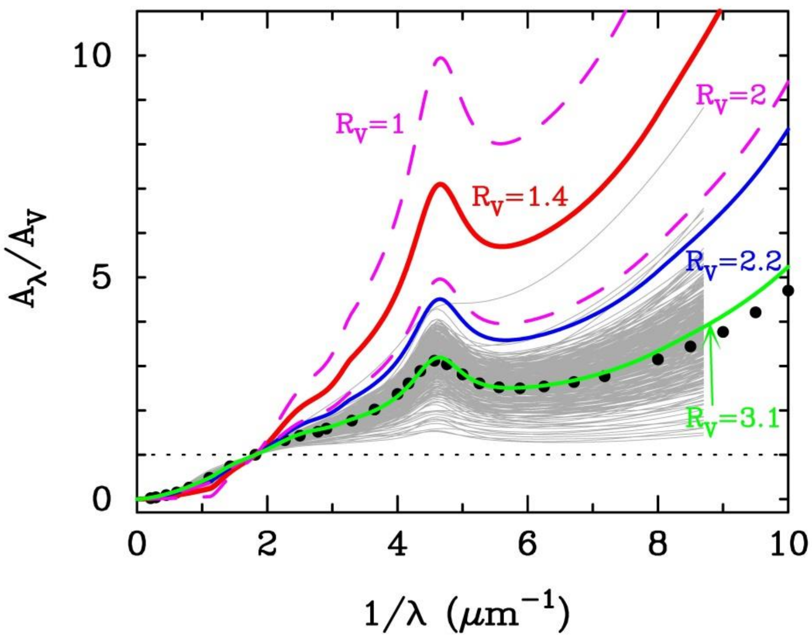
○ Type Ia SN 2014J

- discovered in M 82 (D ~ 3.5±0.3 Mpc)
  - closest SN Ia in the last thirty years
  - highly reddened (Av ~ 2.0 mag)
- reddening law is reproduced by CCM relation with **Rv ~ 1.4** (Ammanullah+2014)



○ Origin of peculiar extinction

- odd properties of interstellar dust
  (Kawabata+2014; Foley+2014)
- circumstellar dust (multiple scattering)
  (Wang 2005; Goobar+2008)
  ➜ this scenario is unlikely
  (Maeda+2015; Johansson+2015)

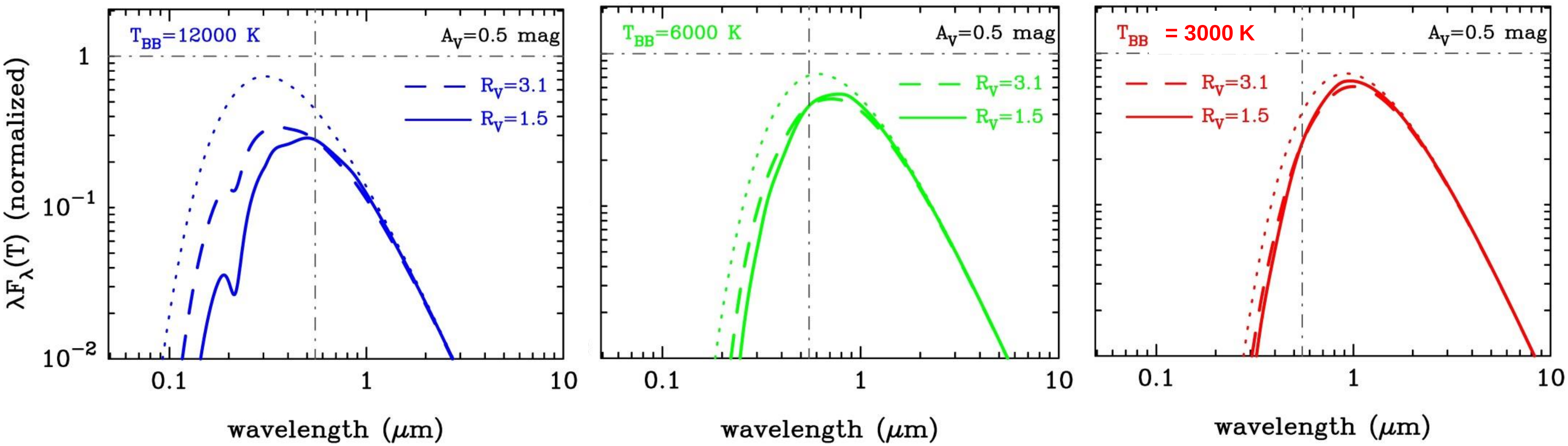


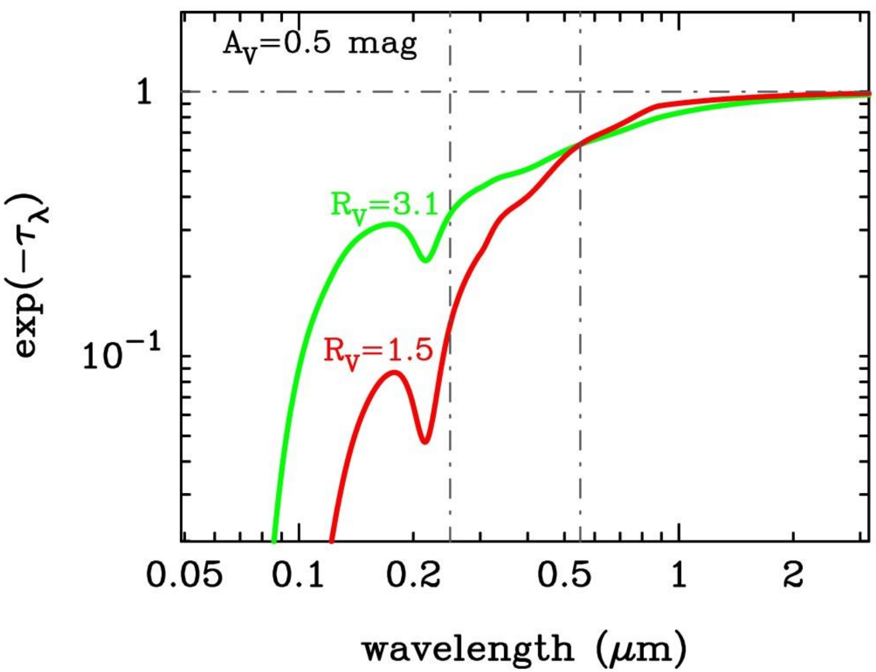
1-5. Aims of this talk

1. もし本当にRv~1.5であったならば、銀河のSEDはどう影響されるか？

2. Rv~1.5を再現するような星間ダストモデルはあるのか？

2-1. Effects of low Rv on the SEDs



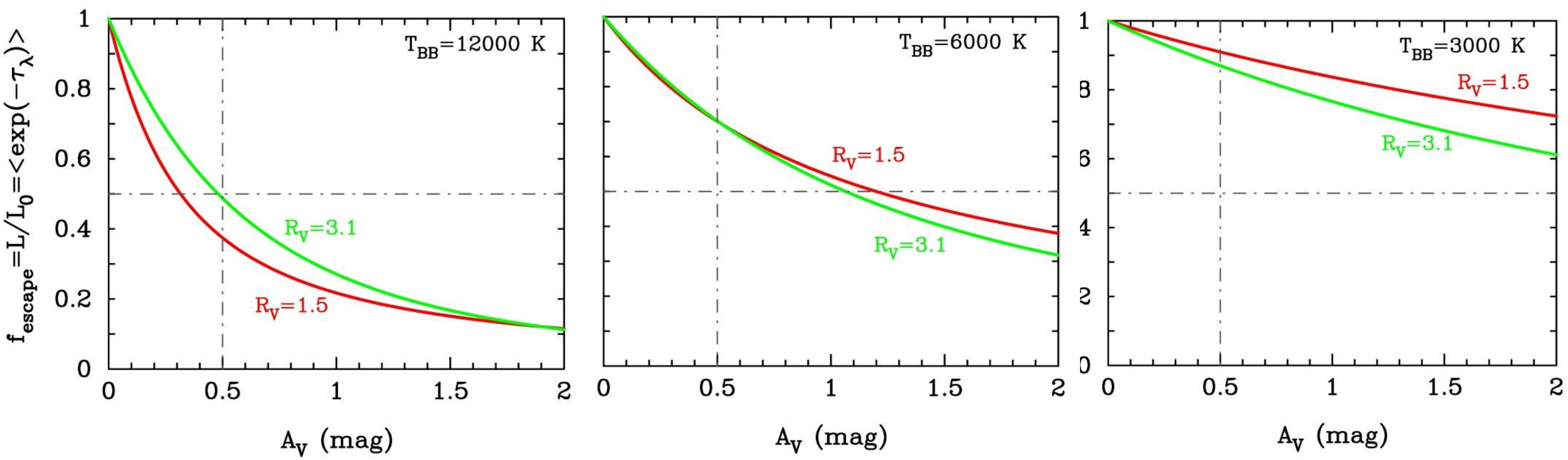


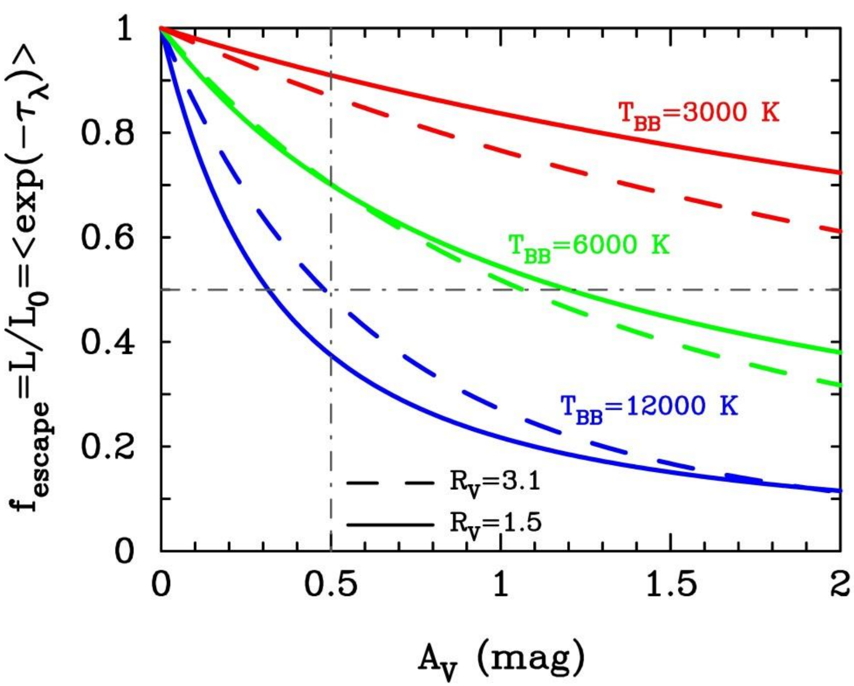
- if Rv = 1.5, the SED for high T_{BB} (T_{BB} > 10000 K) is highly affected

- (A_{2500A} / Av) for Rv = 1.5 ~ 3 (A_{2500A} / Av) for Rv = 3.1

- (A_{1600A} / Av) for Rv = 1.5 ~ 3.5 (A_{1600A} / Av) for Rv = 3.1

2-2. Dependence of absorbed luminosity on Rv



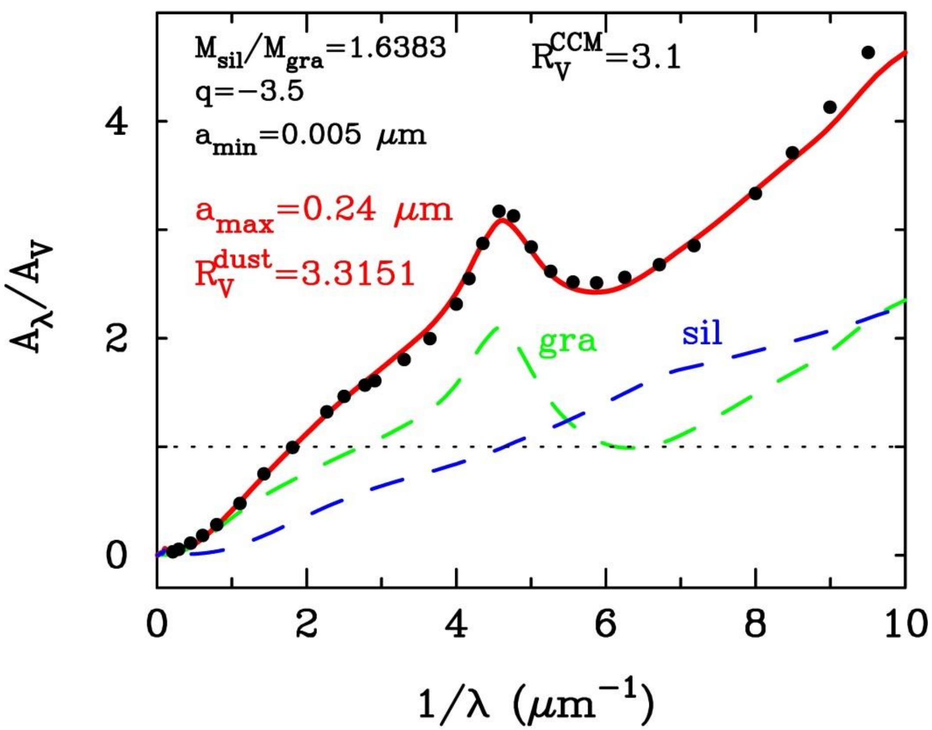


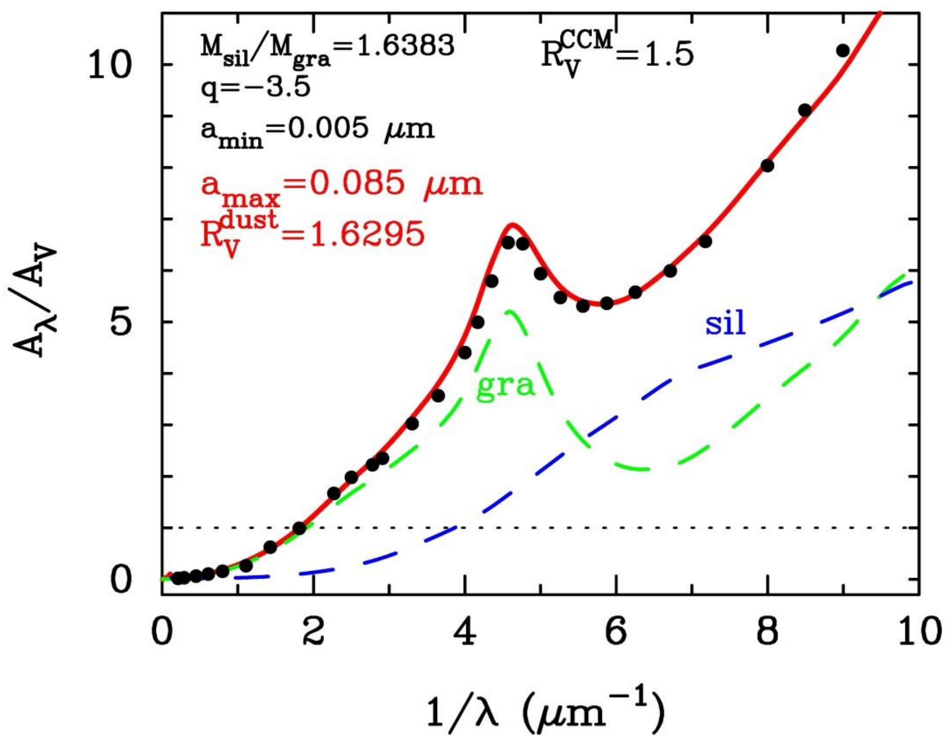
- for T_{BB} > 6000 K, Rv = 1.5 absorb stellar lights than Rv = 3.1

- for T_{BB} < 6000 K, Rv = 3.1 absorb stellar lights than Rv = 1.5

➜ Rv=1.5 curve is steeper than Rv=3.1 curve at 0.5-1.0 μm

3-1. Dust model for Rv = 1.5 CCM curve





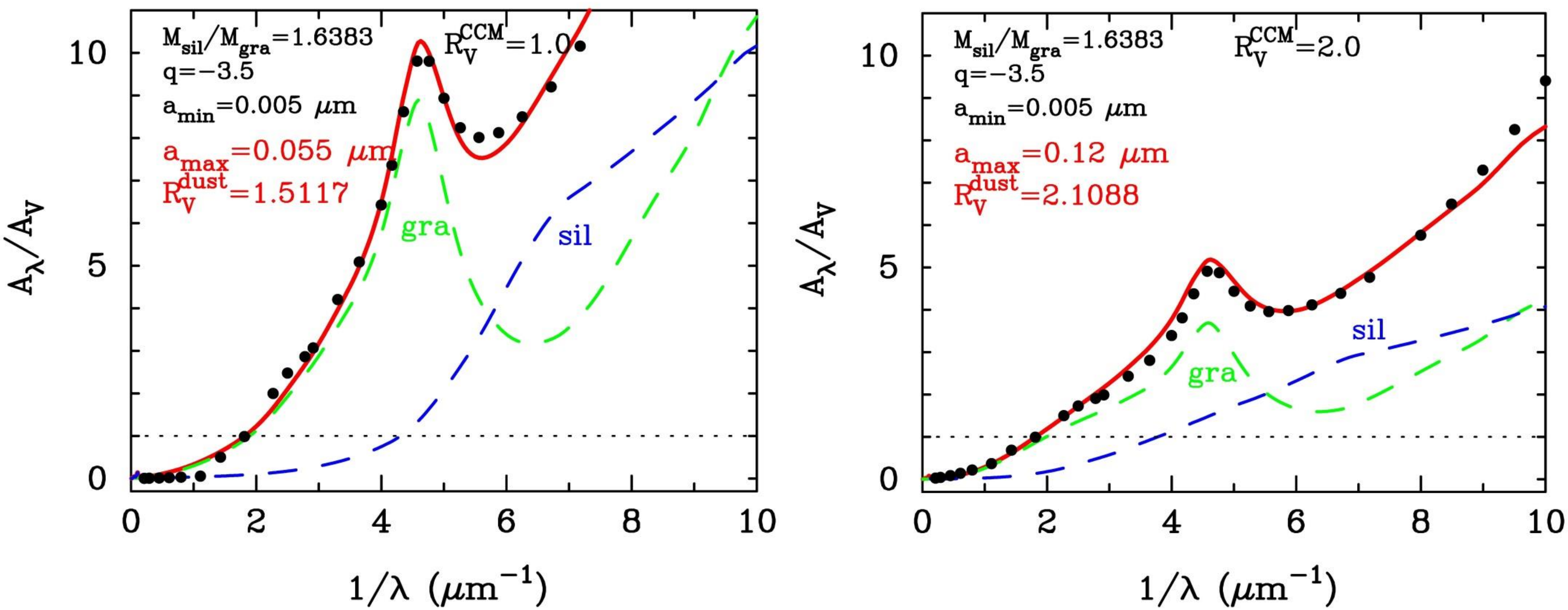
○ MRN dust model (Mathis, Rumpl, & Nordsieck 1977)

- dust composition : silicate ($MgFeSiO_4$) & graphite (C)
- size distribution : power-law distribution

  $n(a) \propto a^{-q}$ with q=3.5, a_{max} = 0.25 μm, a_{min} = 0.005 μm

Rv = 1.5 curve ➜ a_{max} = 0.085 μm, a_{min} = 0.005 μm

3-2. Dust models for Rv = 1.0 and 2.0 curve



Rv = 1.0 curve ➜ a_{max} = 0.055 μm, a_{min} = 0.005 μm

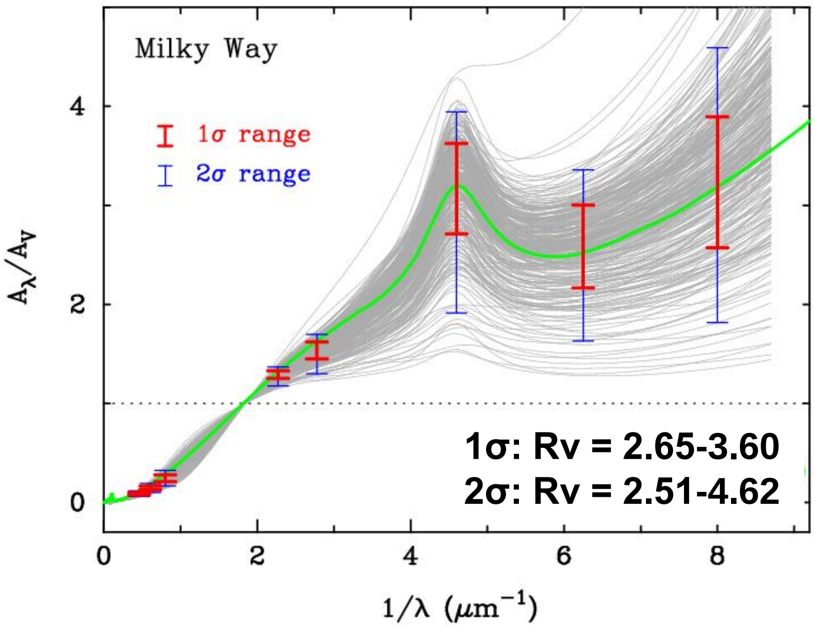
Rv = 2.0 curve ➜ a_{max} = 0.12 μm, a_{min} = 0.005 μm

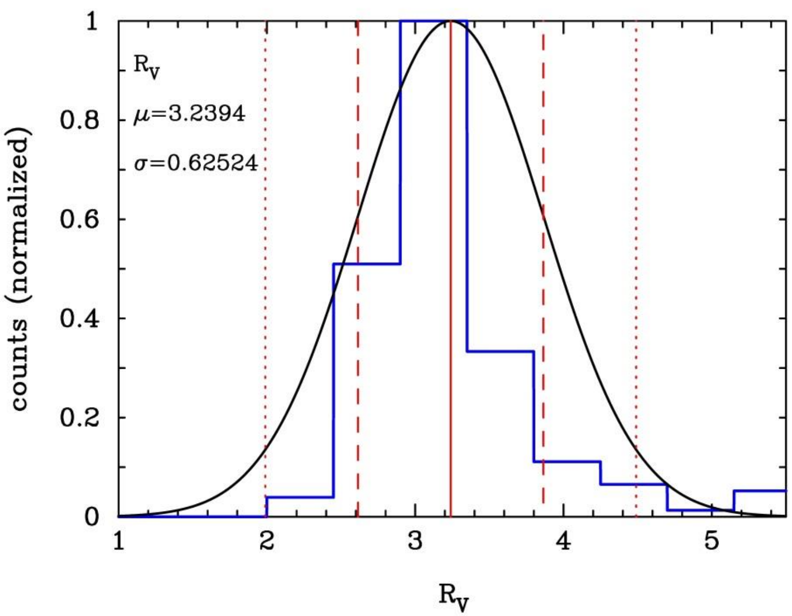
But, the values of Rv based on the MRN dust model are higher than Rv used for the CCM relation

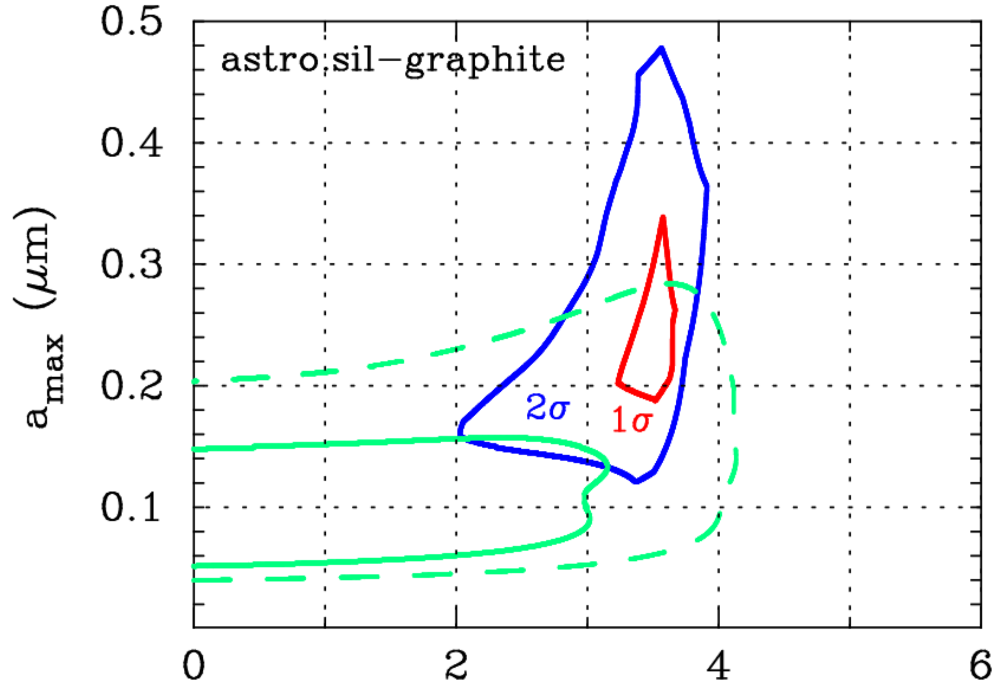
$R_{V,CCM}$ = 1.0 curve ➜ $R_{V,\ dust}$ = 1.5

$R_{V,CCM}$ = 2.0 curve ➜ $R_{V,\ dust}$ = 2.1

3-3. Range of a_{max} from variation of MW ECs







Nozawa & Fukugita (2013)

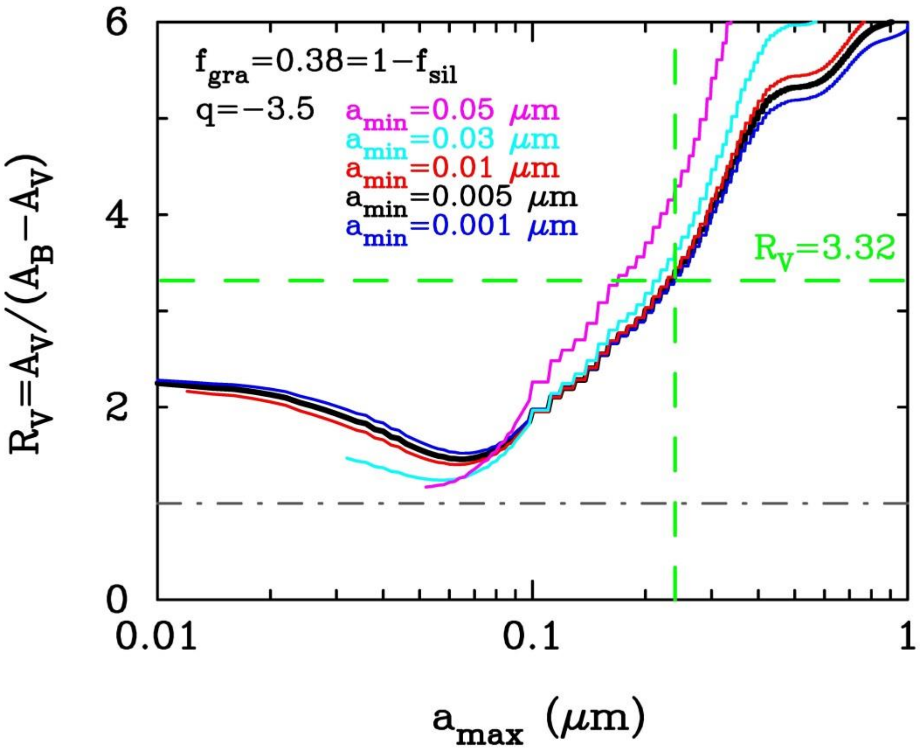
q

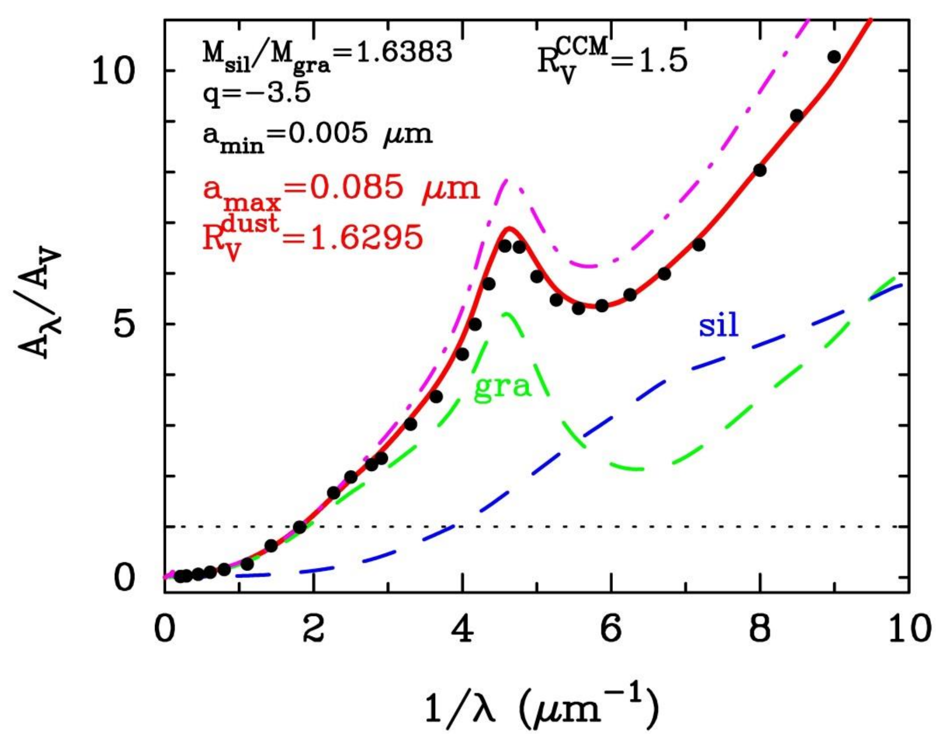
Ranges of q and a_{max} that meet the 1σ range of FM07 data are confined to be narrow ranges of

$3.2 < q < 3.7$

$0.19\ \mu m < a_{max} < 0.34\ \mu m$

3-4. Dependence of extinction on grain size





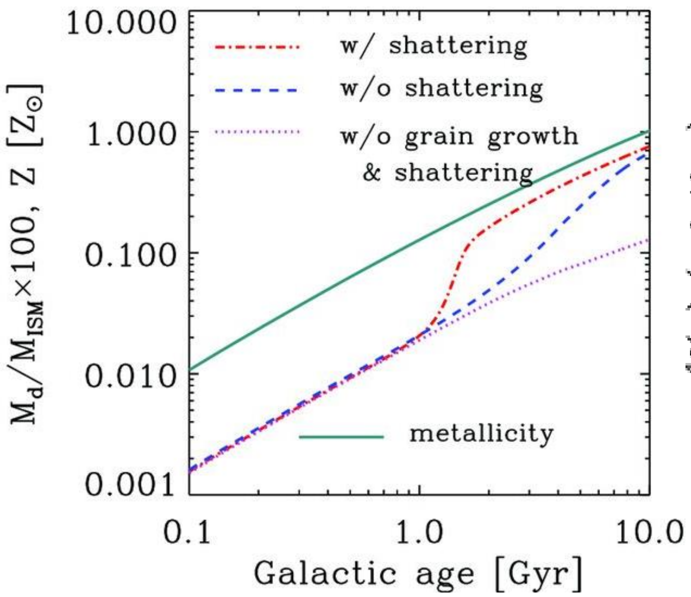
- **Low values of Rv = 1.5-2.0 can be reproduced by the MRN dust model with a_{max} = 0.055-0.12 μm**

- **Rv < 1.4 is unlikely to be realized with the MRN dust model**

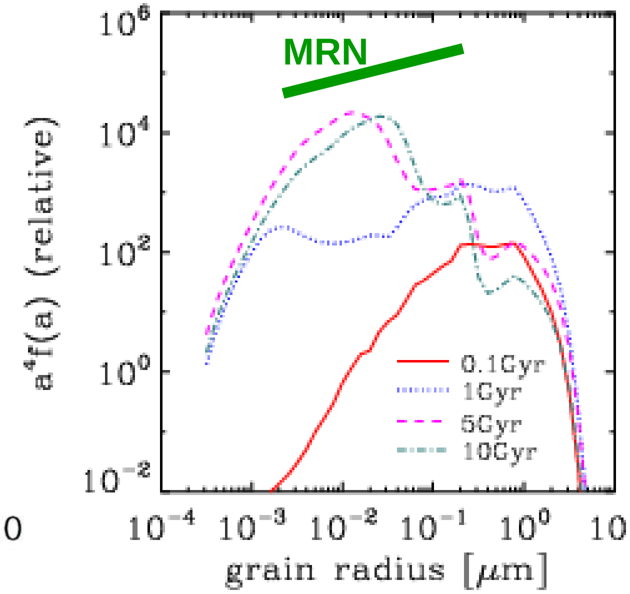
- **Rv, as well as the shape of extinction curve, does not depend on a_{min} as long as a_{min} < 0.01 μm**

4-1. Implication from dust evolution in galaxies

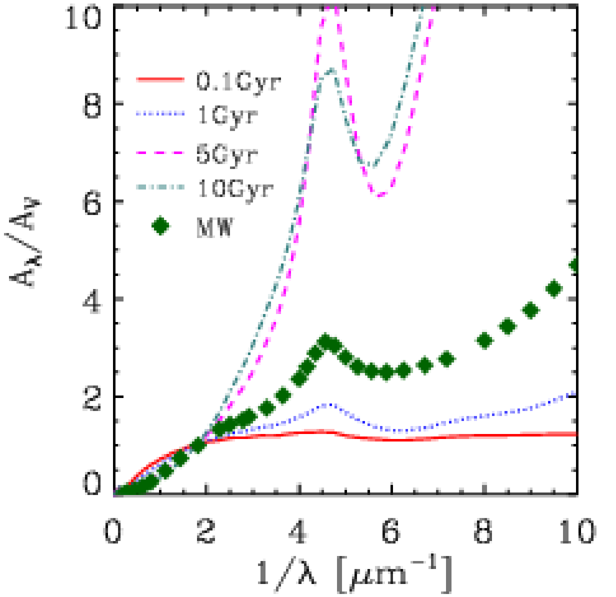
dust amount



grain size distribution

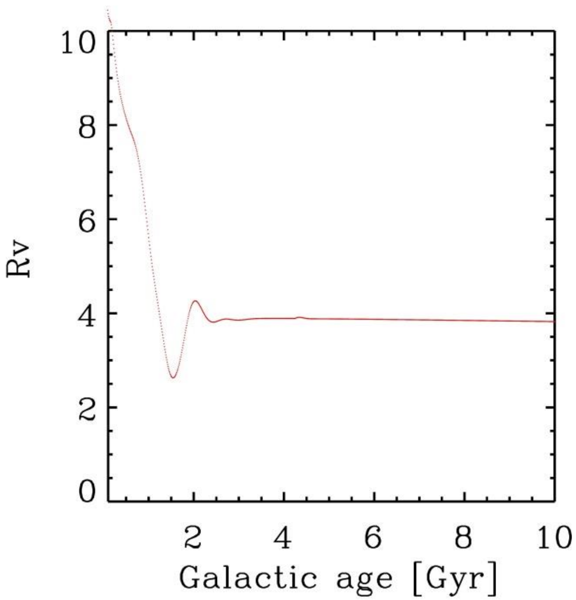


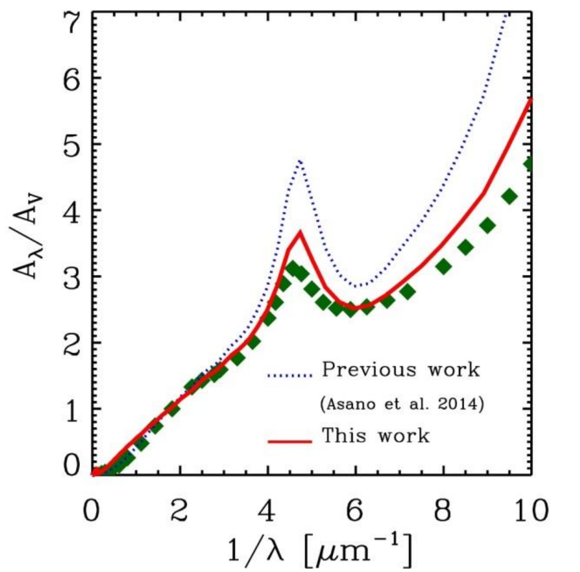
extinction curve



Asano+2013, 2014; Nozawa+2015

Dust evolution model predicts that there may be a phase of a steep extinction curve
(but, the calculated Rv is not necessarily low)





5. Summary of this talk

We explore the interstellar dust model to reproduce extinction curve with low Rv as suggested for SNe Ia

1) Some studies (mainly SNe Ia cosmology) suggest that the Rv value towards SNe Ia is generally low (Rv < 2.5)

2) The CCM curves with Rv = 1-2 can be fitted by the MRN dust model (graphite & silicate) with a_{max} = 0.05-0.15 μm (instead of amax = 0.25 for Rv = 3.1)

3) Within the framework of the MRN dust model, the low values of Rv < 1.5 are not likely to be achieved