2016/11/14

Peculiar Extinction Laws observed for Type Ia Supernovae

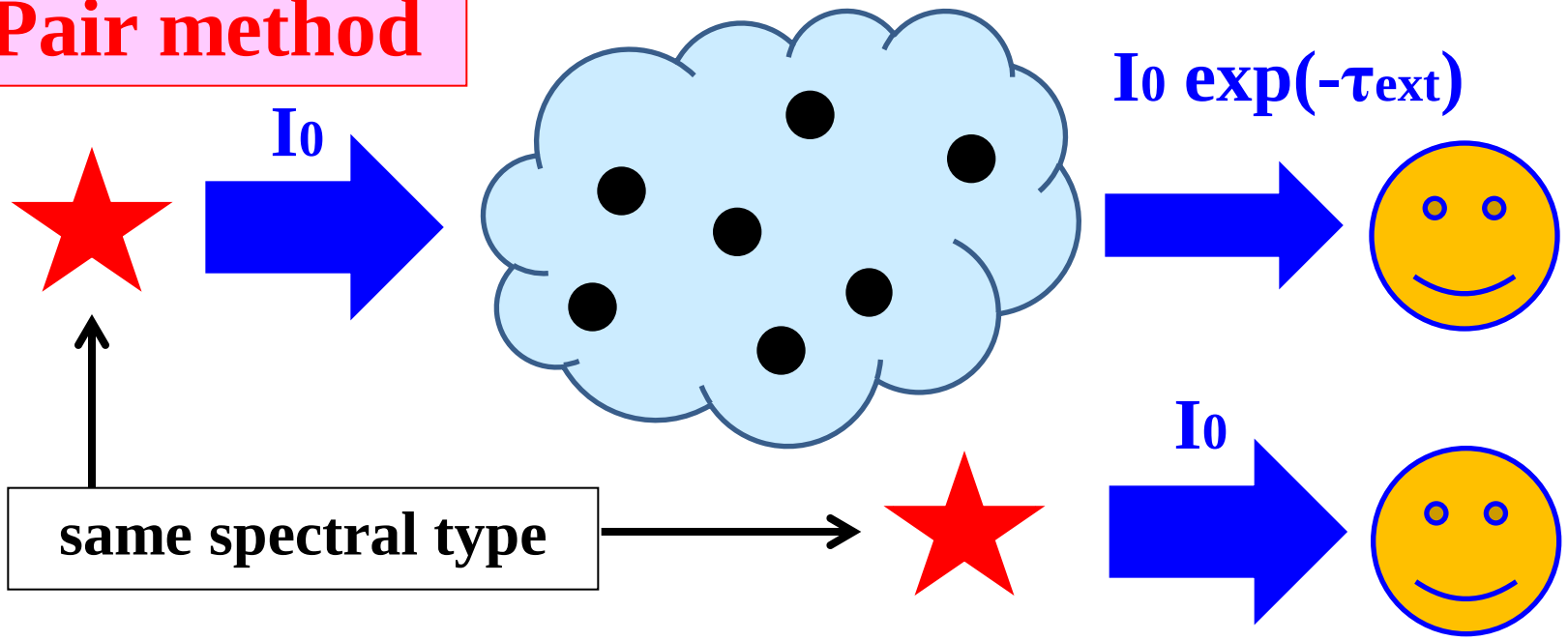
Takaya Nozawa
(National Astronomical Observatory of Japan)

SN 2014J in M82 © NASA/ESA Foley & McCully

To be appeared in Planetary and Space Science
arXiv: 1608.06689, doi: 10.1016/j.pss.2016.08.006

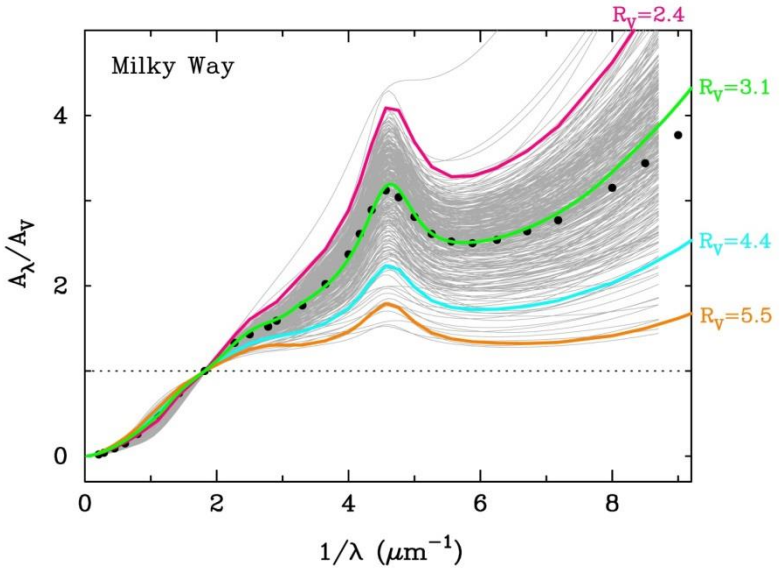
1-1. Deriving extinction curves in the MW

Pair method



○ Light sources: OB stars (or RGs)

- luminous (~ 10^5 Lsun)
  - ➜ we can see a large volume
- UV (or IR) bright
  - ➜ variation of extinction curves at UV wavelengths



1-2. Applicability of OB stars in pair method

- **OB stars can be used only for MW, LMC, SMC, (M31)**
  - ➜ **OB stars are too faint to be observed in external galaxies**
  - ➜ **Extinction curves in external galaxies are poorly known**

- **QSOs and GRB afterglows**
  - ➜ **good light sources to extract the extinction curves at z = 0-6.5**

However …

- **intrinsic SEDs are not always established**
- **local dust may also contribute the extinction**

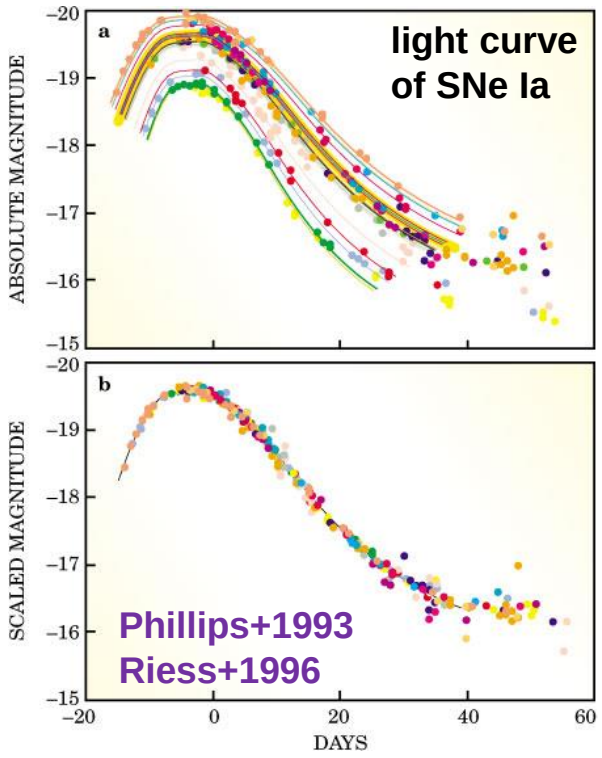
Type Ia supernovae (SNe Ia) could be a good target to derive the extinction curve in external galaxies

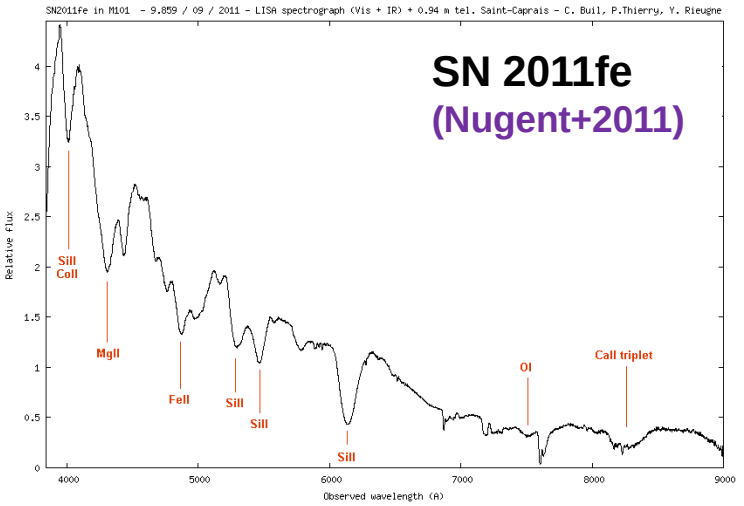
2-1. Type Ia SNe as standard light sources

○ Type Ia supernovae (SNe Ia)

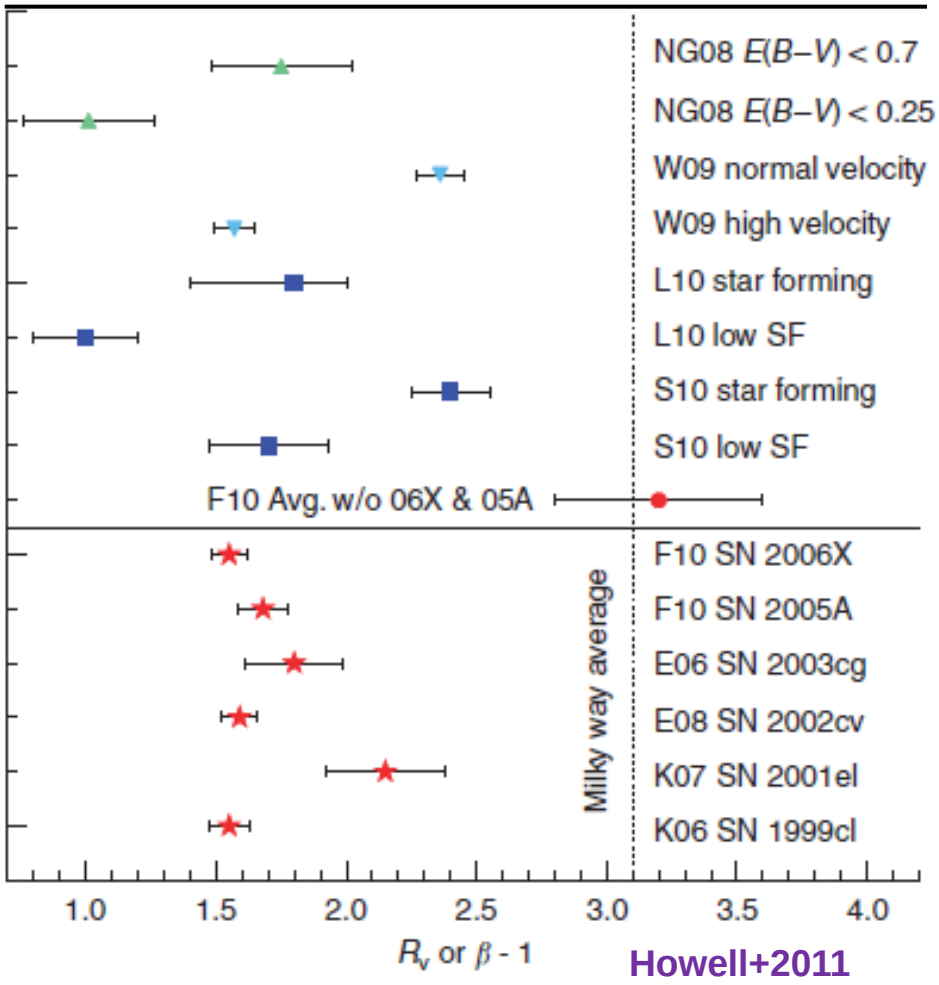
- thermonuclear explosion of a WD
- highly luminous ($L_{peak} \sim 3 \times 10^9 L_{sun}$)
  - ➜ homogeneous peak luminosity
  - ➜ used as standard candles
- intrinsic opt/IR spectral established
  - ➜ SN 2011fe as an unreddened template
- discovered in all types of galaxies
  - ➜ star-forming, elliptical, spiral etc…

good targets to probe the extinction (dust) properties in external galaxies

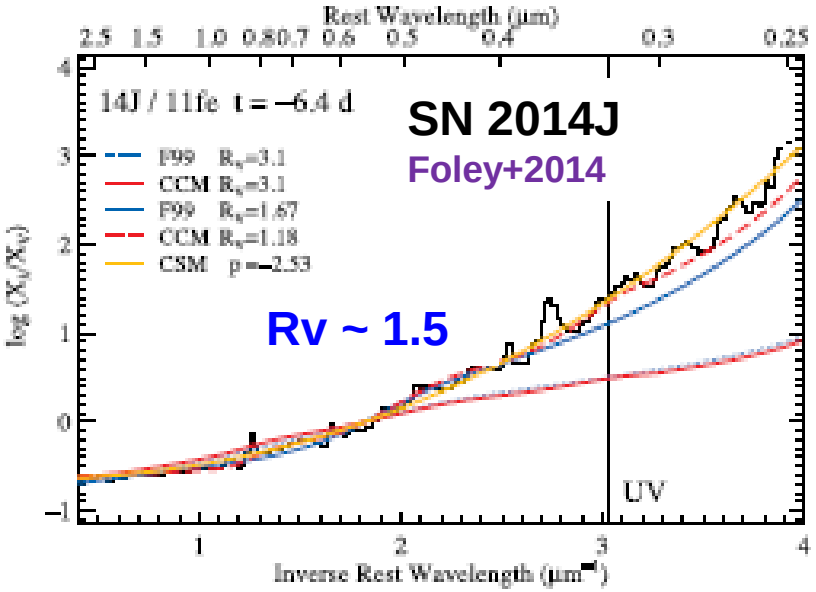


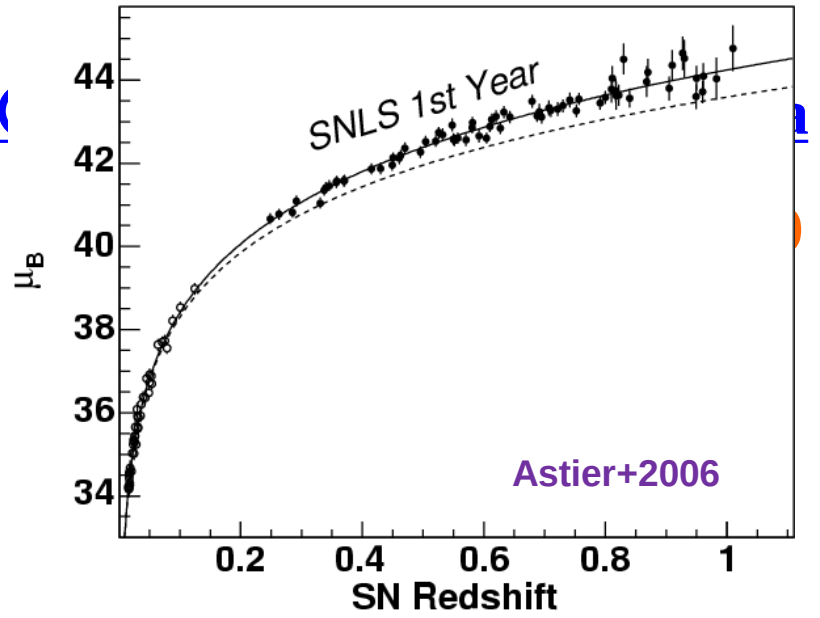


2-2. Extinction laws measured for SNe Ia



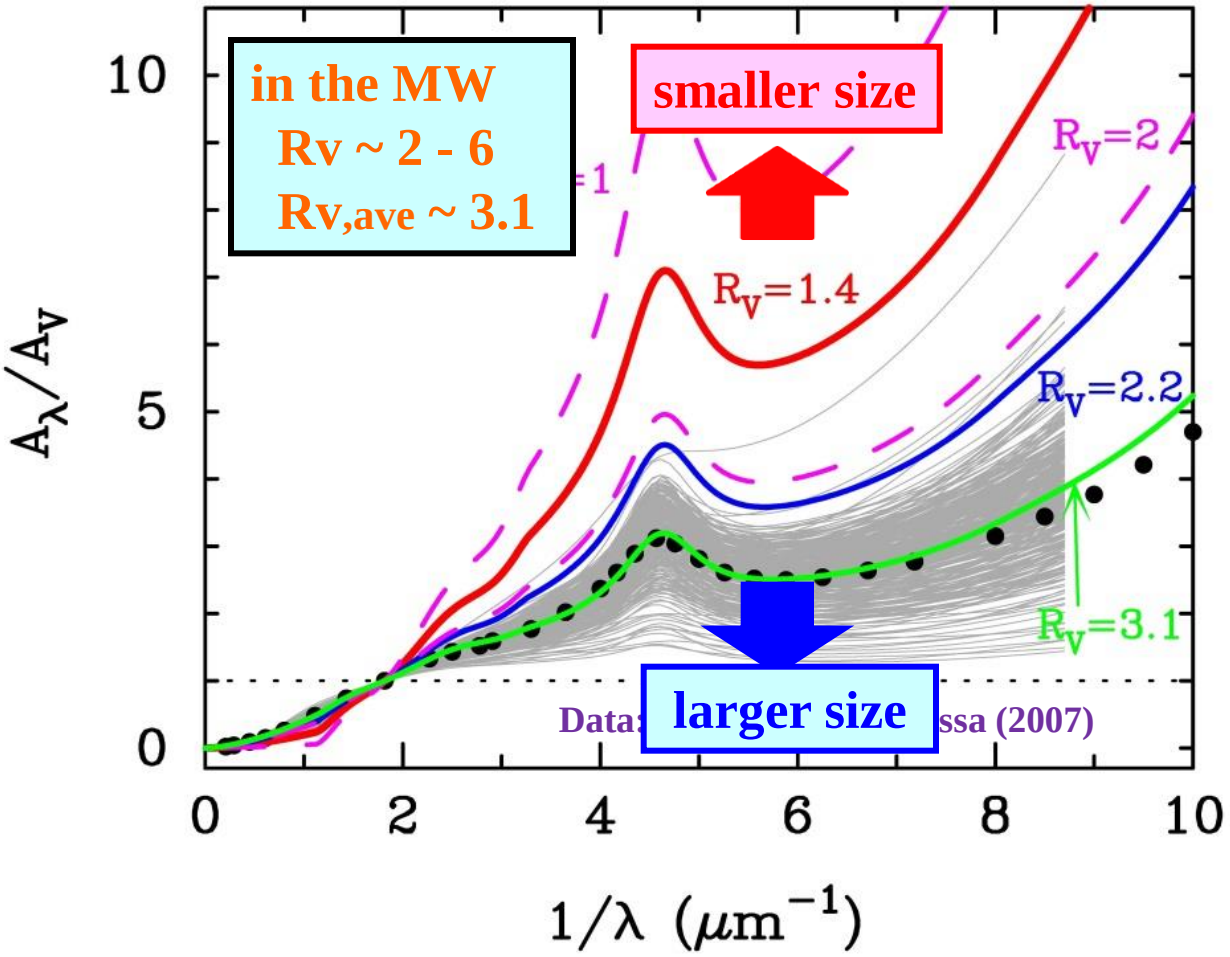
Howell+2011





Rv values measured for SNe Ia are unusually low (Rv ~ 1.0-2.5)

2-3. How peculiar is SNe Ia extinction curves?



○ CCM relation

(Cardelli, Clayton, Mathis 1989)

Rv : total-to-selective extinction ratio

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

$= A_V / (A_B - A_V)$

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

where $x = 1 / \lambda$

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

3-1. Fitting to CCM curves with Rv = 1-2

What properties of dust cause steep extinction curves?

○ Data on extinction curves to be fitted

CCM extinction curves with Rv = 2.0, 1.5, 1.0 at representative photometric bands

○ Interstellar dust model

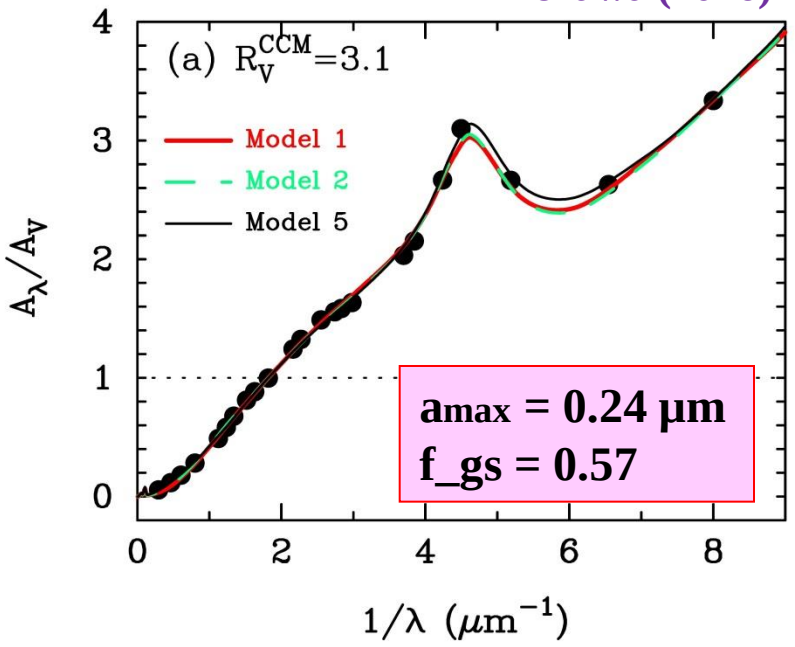
(e.g., Mathis+1977, Draine & Lee 1984)

- **graphite & astronomical silicate**
- **power-law grain size distribution**
- **Model 1 (simplest model)**
  same size distribution with q = -3.5 and
  amin = 0.005 μm for two grain species

parameters:

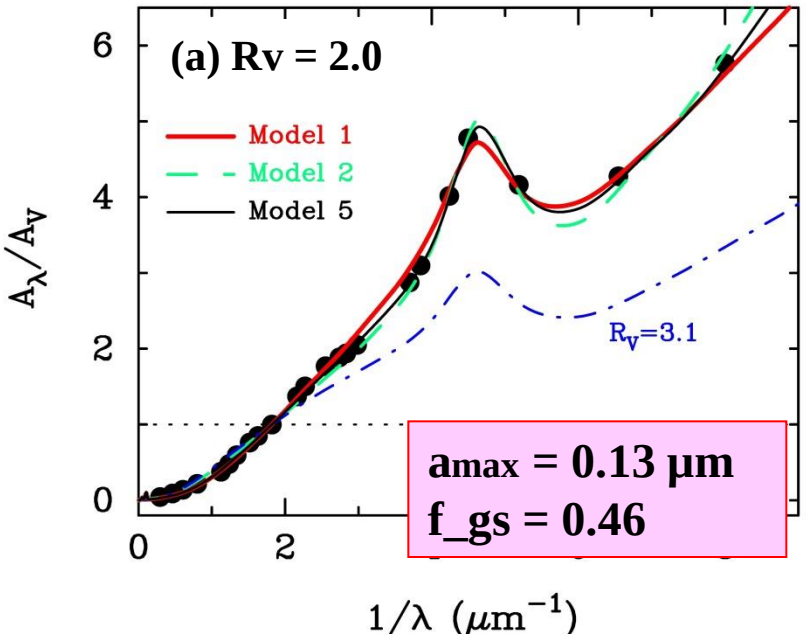
- **amax (upper cutoff radius)**
- **f_gs (graphite-to-silicate mass ratio)**

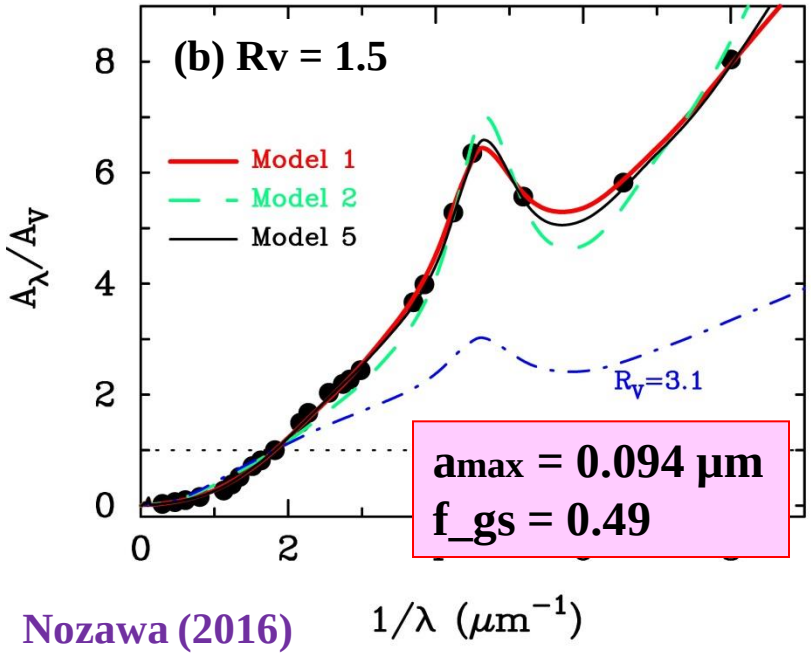
Nozawa (2016)



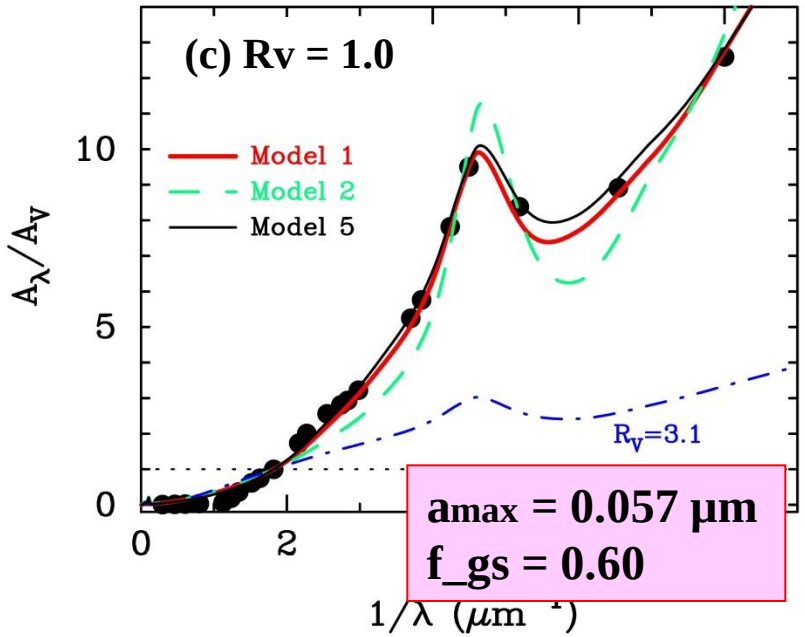
black dots : data of extinction Aλi/Av derived from the CCM formula at photometric bands

3-2. Results of fitting calculations





Nozawa (2016)



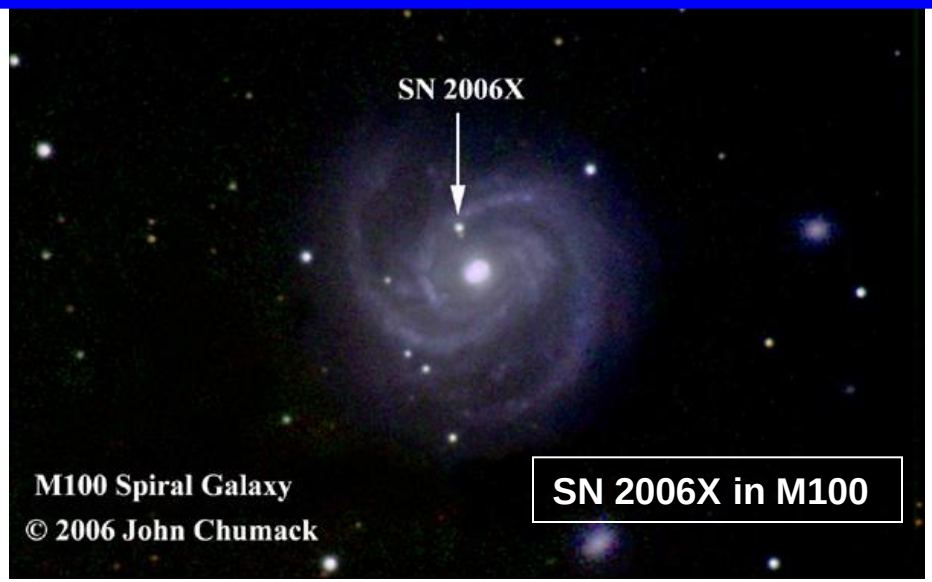
- steep extinction curves with Rv=1-2 can be described by the power-law grain model

- f_gs = 0.45-0.6
  ➜ Mgra/Mtotal = 0.3-0.4

cf. f_gs = 0.3-0.7 in the MW
(Nozawa & Fukugita 2013)

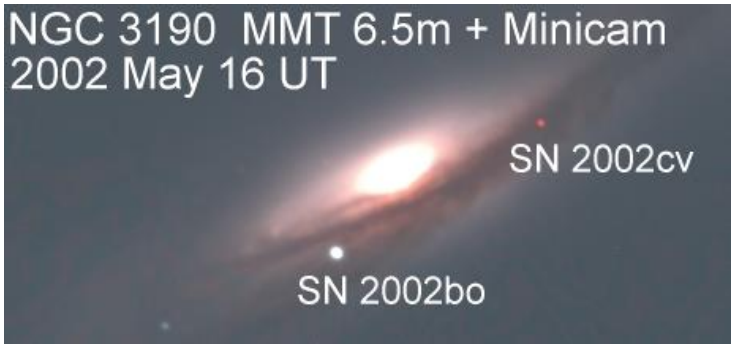
3-3. Unusual dust properties: Selection bias?

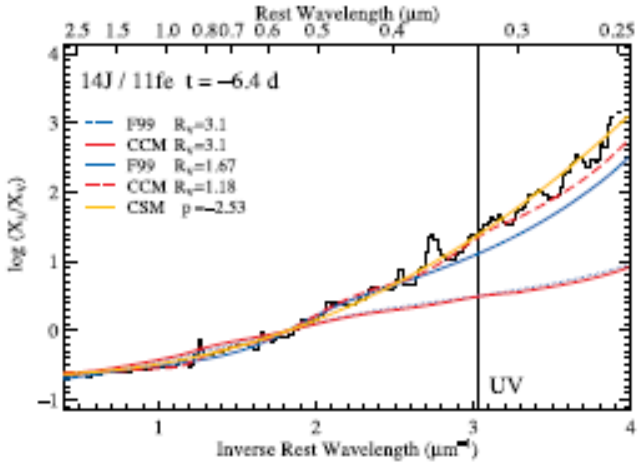
SNe Ia appear in any type of galaxies!



4. Summary of this talk

1) SNe Ia are good targets to derive the extinction curve in external galaxies





2) Many studies suggest that Rv values toward SNe Ia are very low (Rv = 1-2), compared with Rv = 3.1. in the MW

3) The CCM curves with Rv = 1-2 can be nicely fitted by power-law grain size distributions with a_{max} = 0.05-0.15 μm