Galactic Extinction Curves and Interstellar Dust Models

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1. Introduction

Extinction curve: wavelength-dependence of interstellar extinction by dust

- **necessary for correcting the SEDs of stars/galaxies**

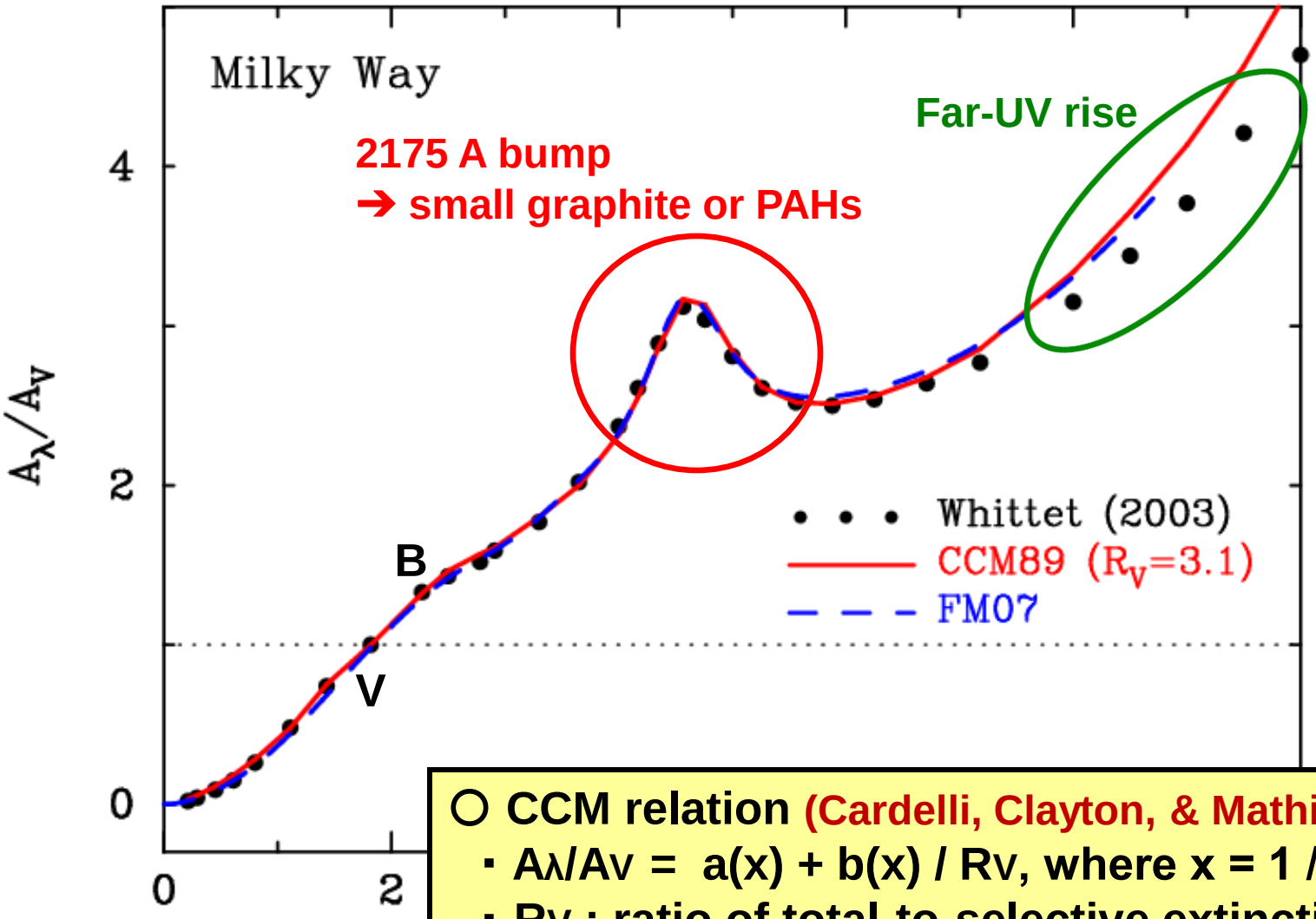
  ➔ **especially, extragalactic objects whose appearances are disturbed by the Galactic interstellar extinction**

- **depends on the physical and optical properties of dust**

  ➔ **provides information on the composition and size distribution of interstellar dust on the line of sight**

  ➔ **holds important clues to the origin and evolution history of interstellar dust**

2. Average interstellar extinction curves in MW



○ CCM relation (Cardelli, Clayton, & Mathis 1989)

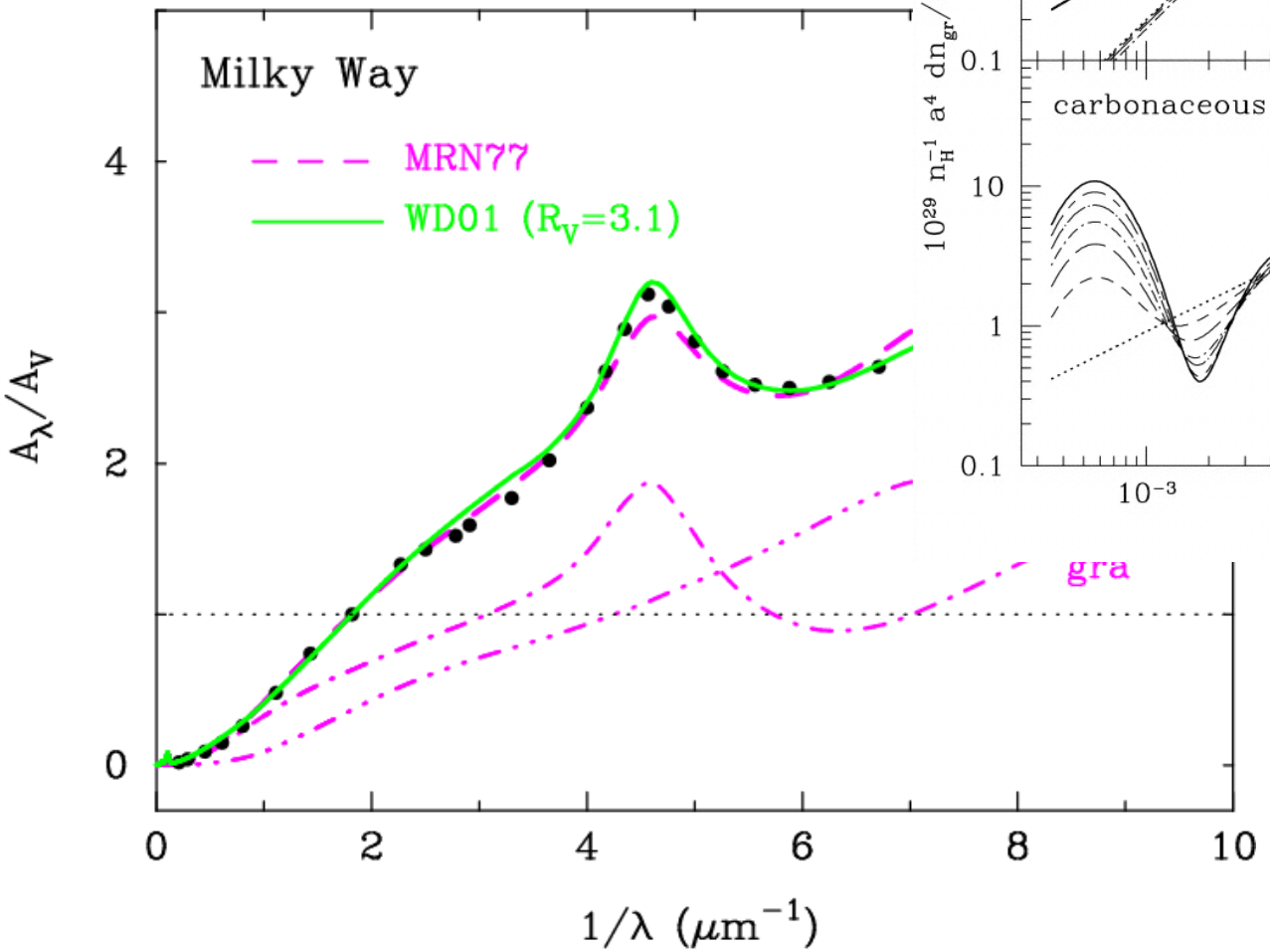
- $A\lambda/AV$ = a(x) + b(x) / Rv, where x = 1 / λ
- Rv : ratio of total-to-selective extinction

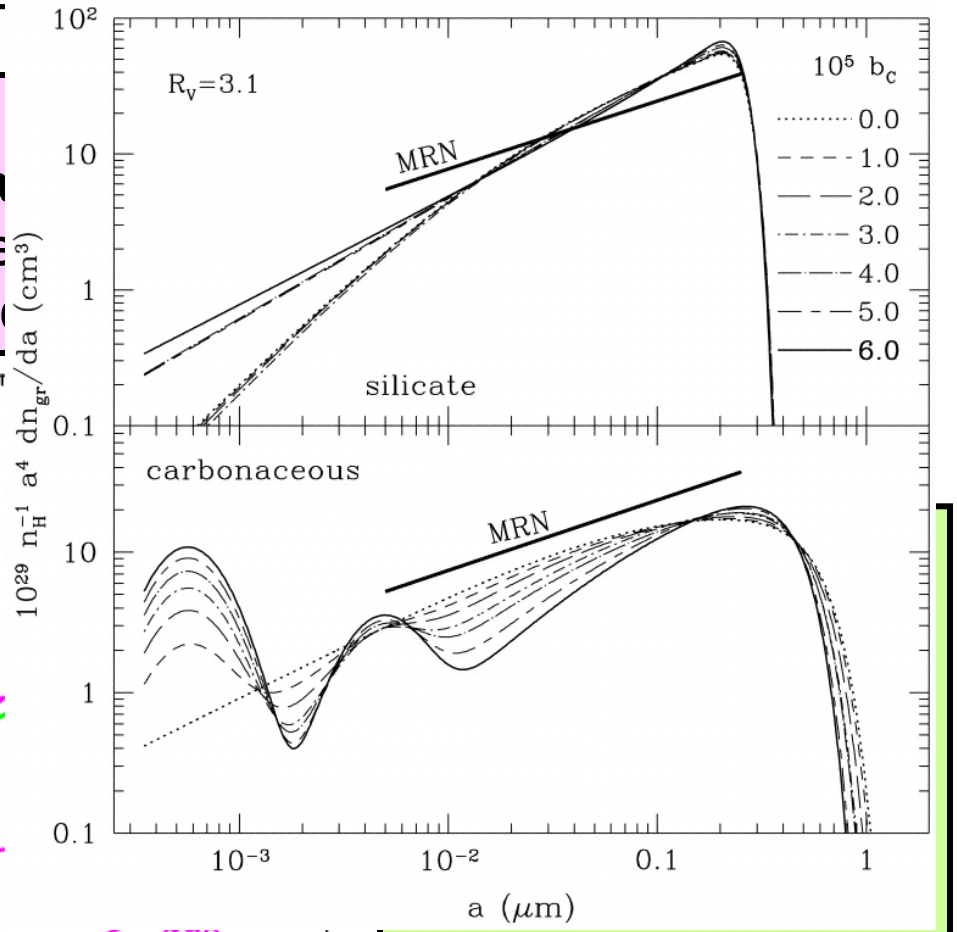
  $Rv = Av / (AB - Av)$ cf. $R_{V,ave}$ = 3.05–3.10

3. Interstellar dust models in MW

○ MRN dust model (Mathis,
- dust composition : silica
- size distribution : powe

n(a)da ∝ a^{-q}da with (





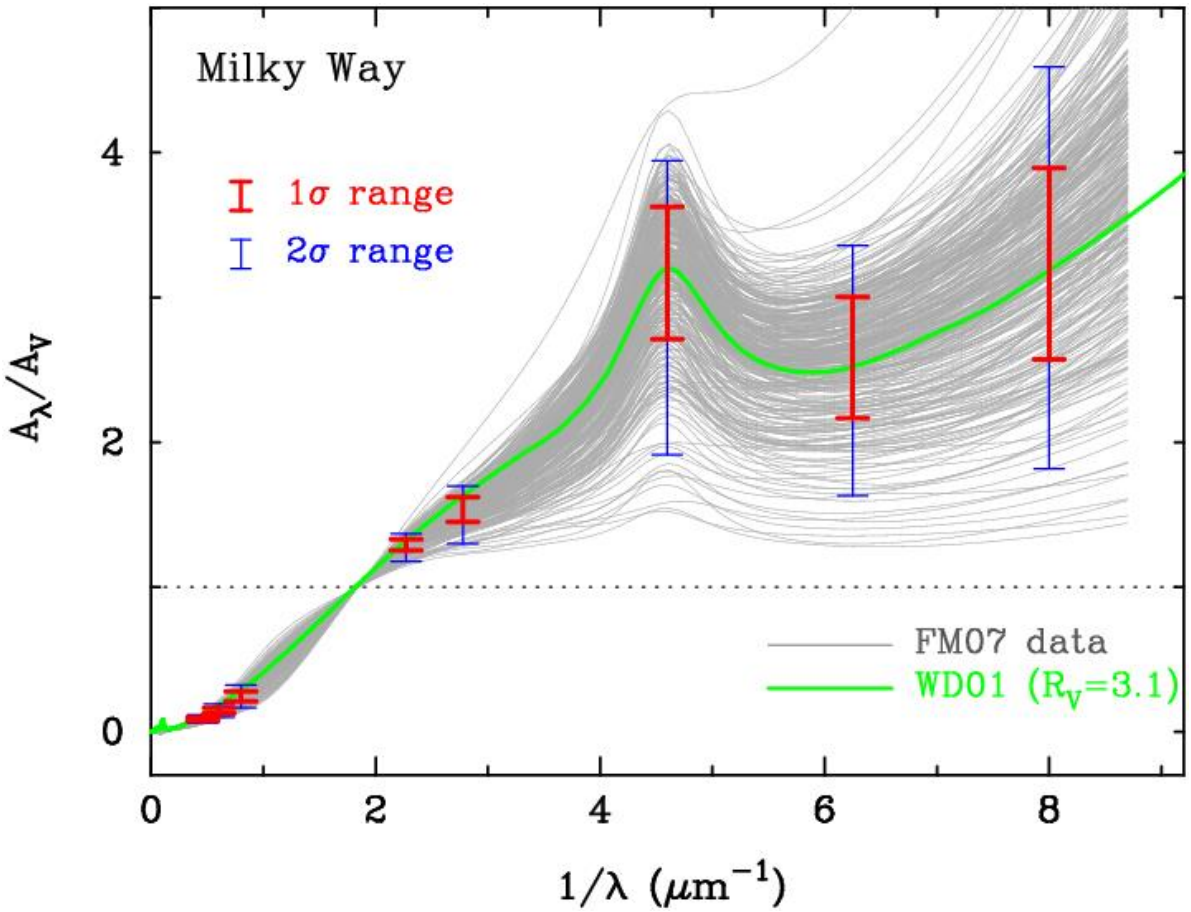
- size distribution : power-law with exponential decay + lognormal

0.3 nm ≤ a ≤ 1 μm

4. Variety of interstellar extinction curves

- There are a large variety of interstellar extinction curves

- How much can the properties of interstellar dust change?



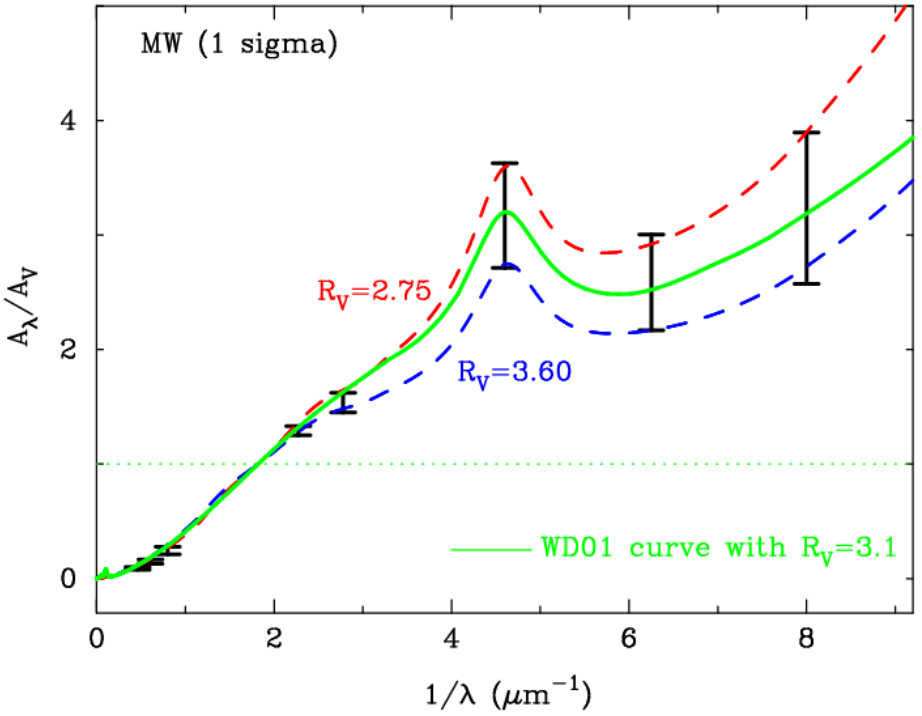
gray curves:
328 extinction curves derived by **Fitzpatrick & Massa (2007)**

red bars:
1σ ranges including 224 data

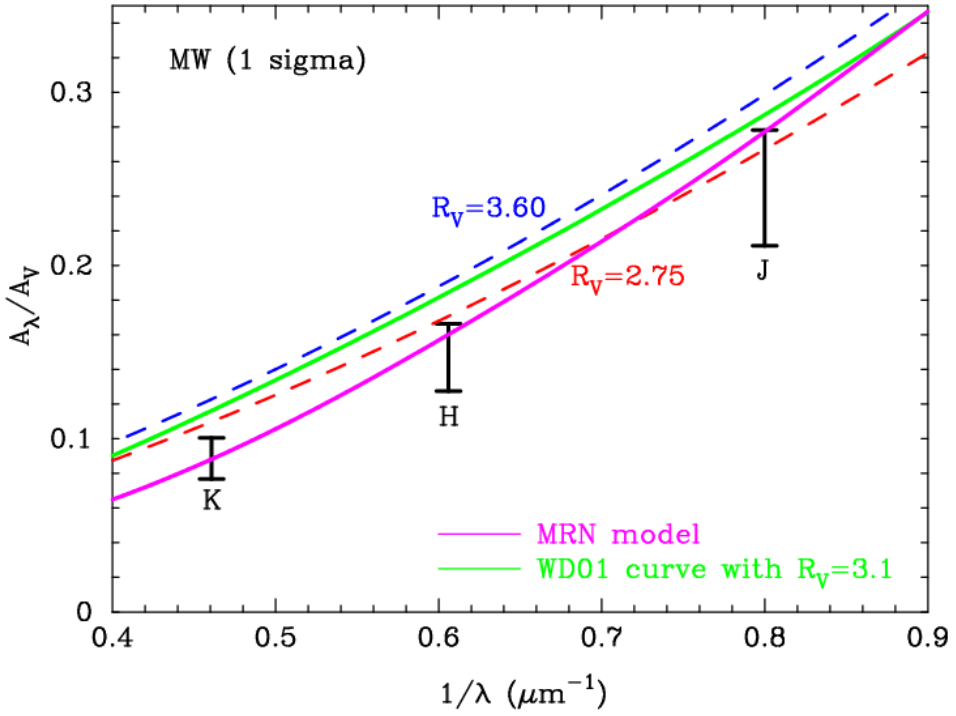
blue bars:
2σ ranges including 312 data

5. Comparison to CCM formula and WD curve

UV-through-IR extinction curves



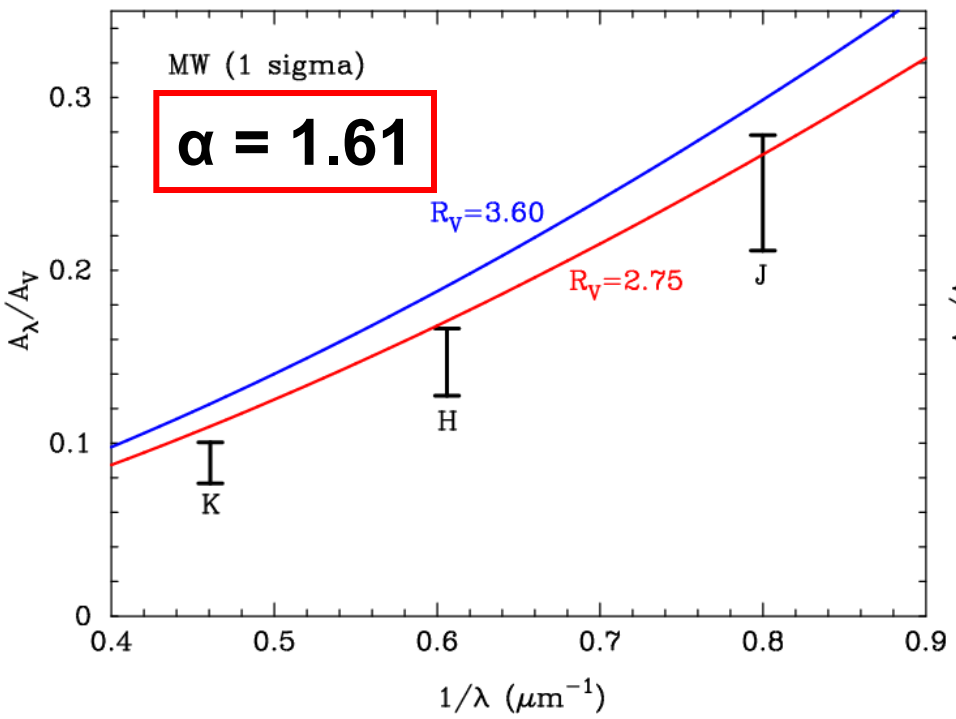
Close-up of IR extinction curves

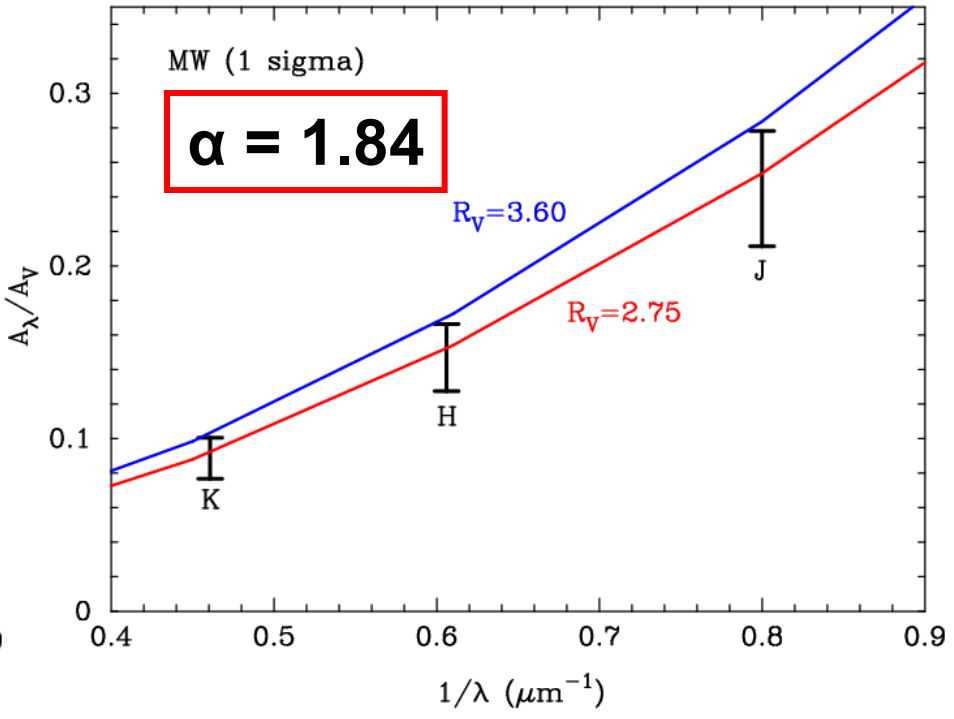


black: 1σ range of the FM07 data
red: CCM curve with Rv = 2.75
blue: CCM curve with Rv = 3.60
green: extinction curve for the case of Rv=3.1 by WD01
fully consistent in UV region

Results from CCM formula with Rv = 2.75-3.60 are 0.02-0.06 mag higher than the 1σ range in JHK
WD01 model is based on results by Fitzpatrick (1999), which are quite similar to the CCM results

6. What causes the difference in IR extinction?





NIR extinction is interpolated by power-law formula Aλ/Av ∝ λ^-α

CCM : α = 1.61
from Rieke & Lebofsky (1985)

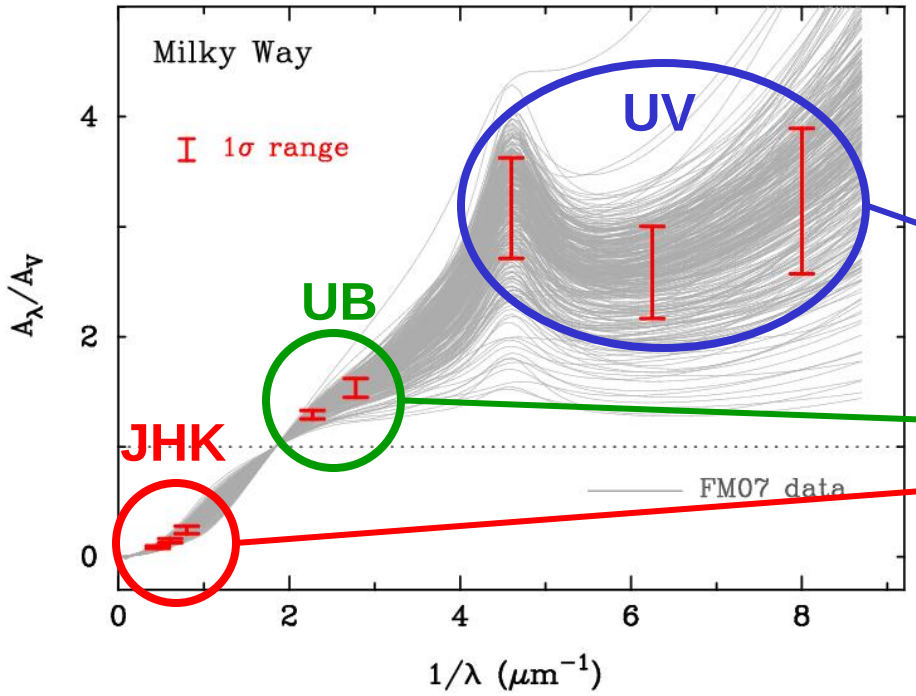
FM07 : α = 1.84
from Martin & Whittet (1990)

the value of α is controversial !!

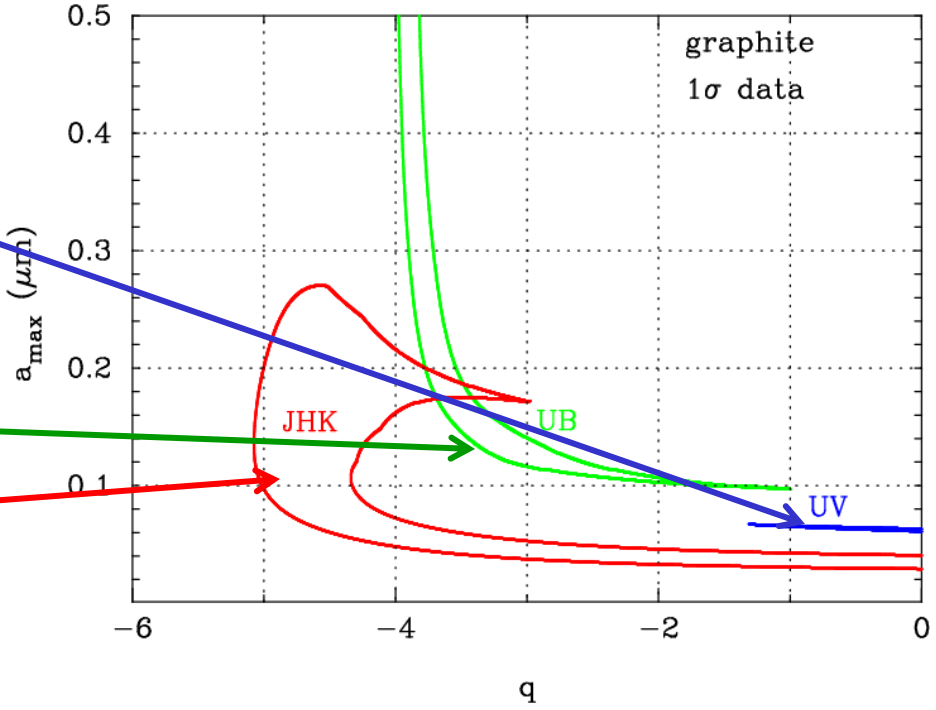
α = 1.7 (He et al. 1995)
α = 1.8 (Froebrich et al. 2007)
α = 2.0 (Nishiyama et al. 2006)
α = 2.3 (Larson & Whittet 2005)
α = 2.6 (Gosling et al. 2009)

7.Demonstration of contour plots

1σ range of FM07 data



Contour plots for graphite

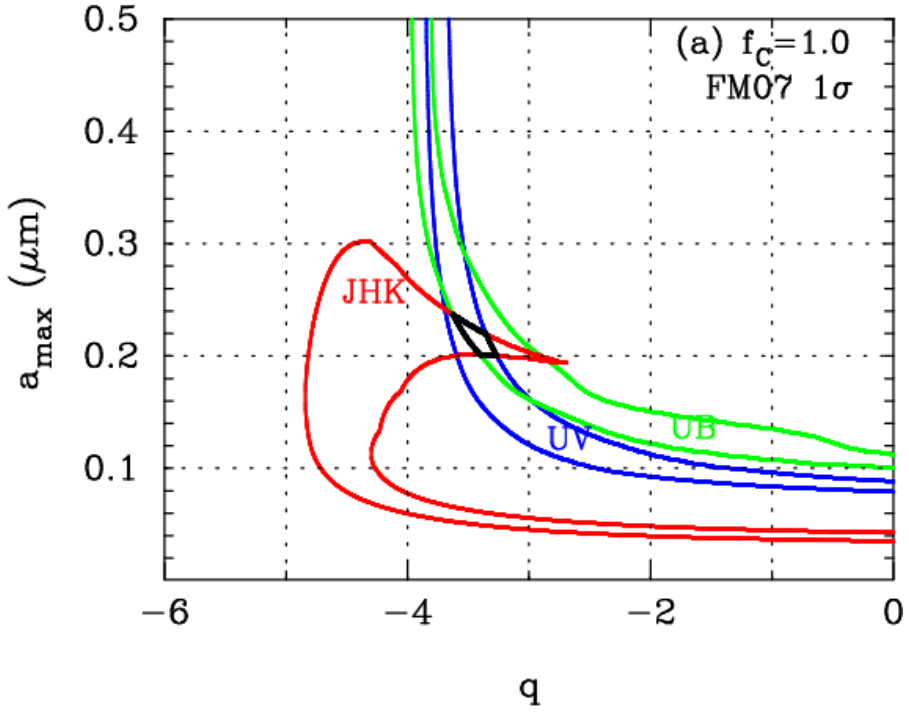


The 1σ ranges from FM07 data are classified into three groups
UV: UV bump (0.22 μm), FUV dip (0.16 μm), FUV rise (0.125 μm)
UB: U band and B band
JHK: J band, H band, K band

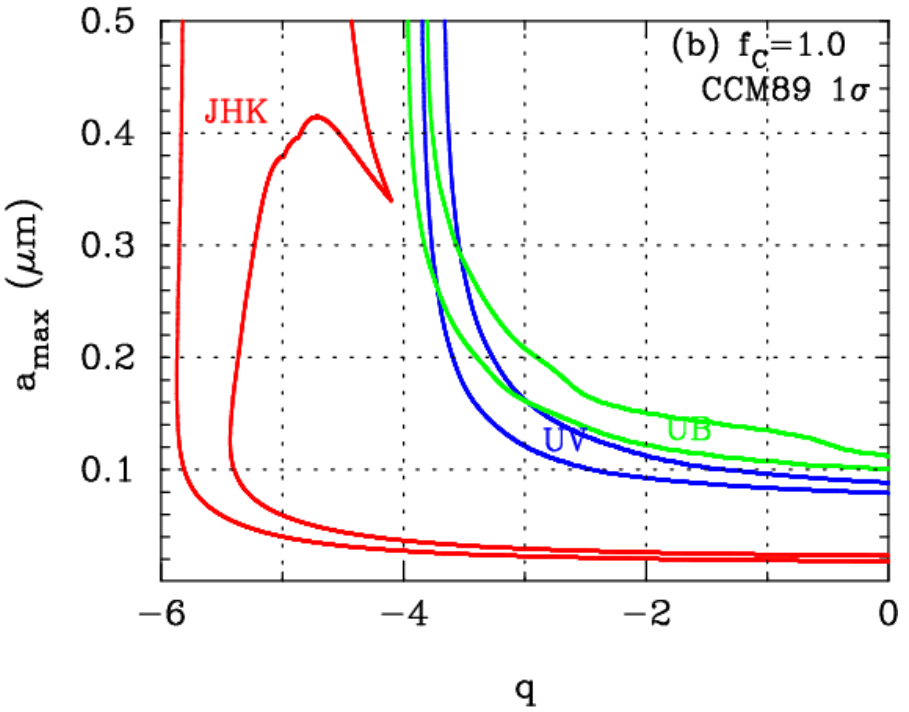
A contour plot is depicted for each of the groups defined in the left panel
blue: constraint from UV/FUV
green: constraint from UB band
red: constraint from JHK band

8-1. Contour plots for f_{gra}/f_{sil} = 1.0

Case of 1σ data, f_{gra}/f_{sil} = 1.0



Case of 1σ data, f_{gra}/f_{sil} = 1.0

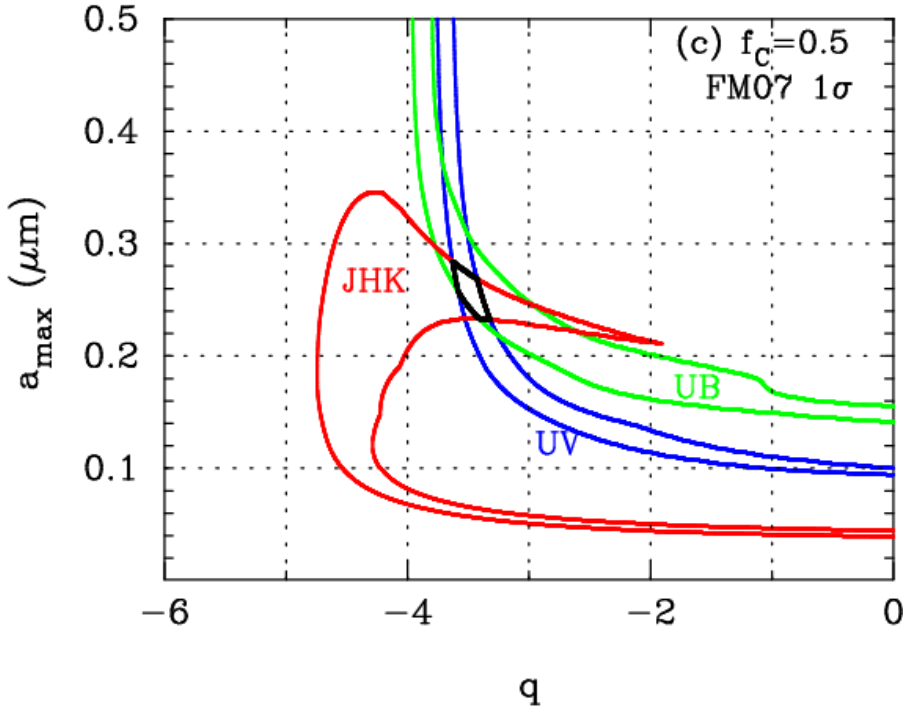


contour plots of a_{max} and q that fulfill the 1σ range of FM07 data for f_{gra}/f_{sil} = 1.0 (M_{gra}/M_{sil} = 0.78)
blue: constraint from UV/FUV
green: constraint from UB band
red: constraint from JHK band

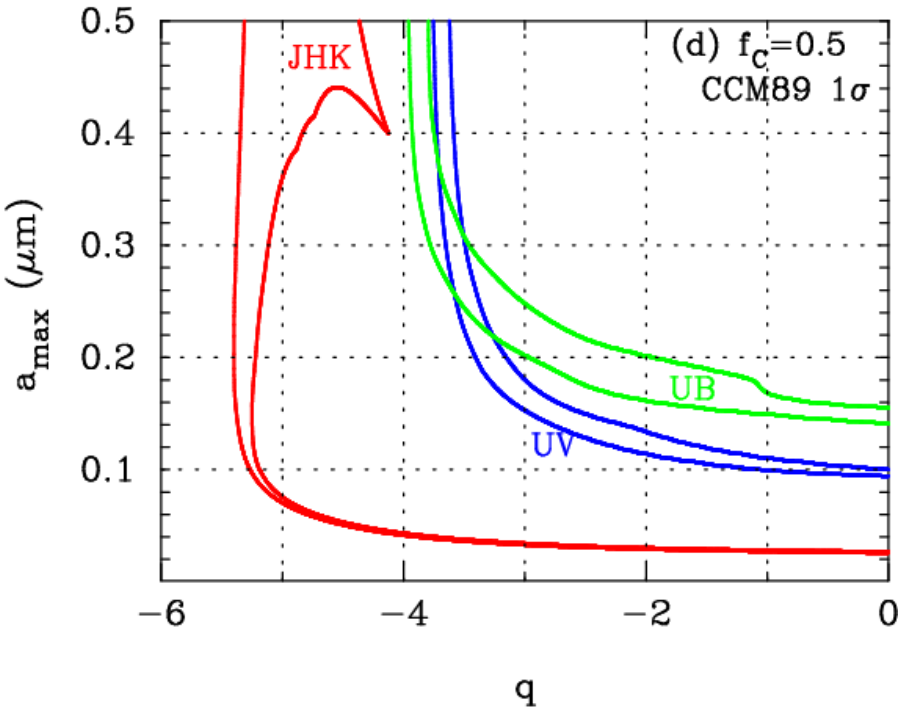
contour plots of a_{max} and q that fulfill the 1σ range of CCM result for f_{gra}/f_{sil} = 1.0 (M_{gra}/M_{sil} = 0.78)
blue: constraint from UV/FUV
green: constraint from UB band
red: constraint from JHK band

8-2. Contour plots for f_{gra}/f_{sil} = 0.5

Case of 1σ data, f_{gra}/f_{sil} = 0.5



Case of 1σ data, f_{gra}/f_{sil} = 0.5

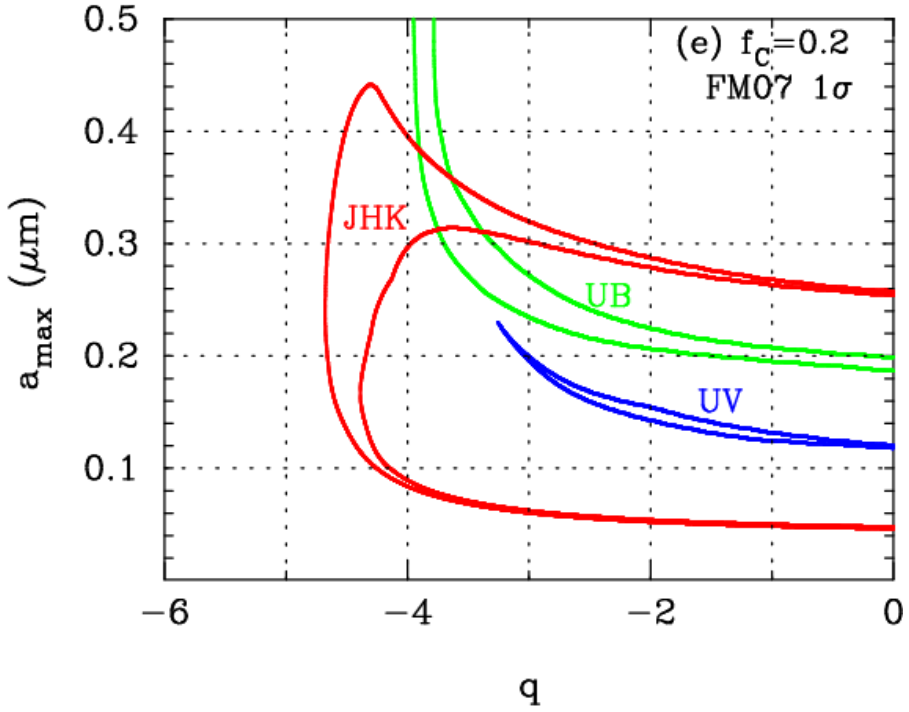


contour plots of a_{max} and q that fulfill the 1σ range of FM07 data for f_{gra}/f_{sil} = 0.5 (M_{gra}/M_{sil} = 0.39)
blue: constraint from UV/FUV
green: constraint from UB band
red: constraint from JHK band

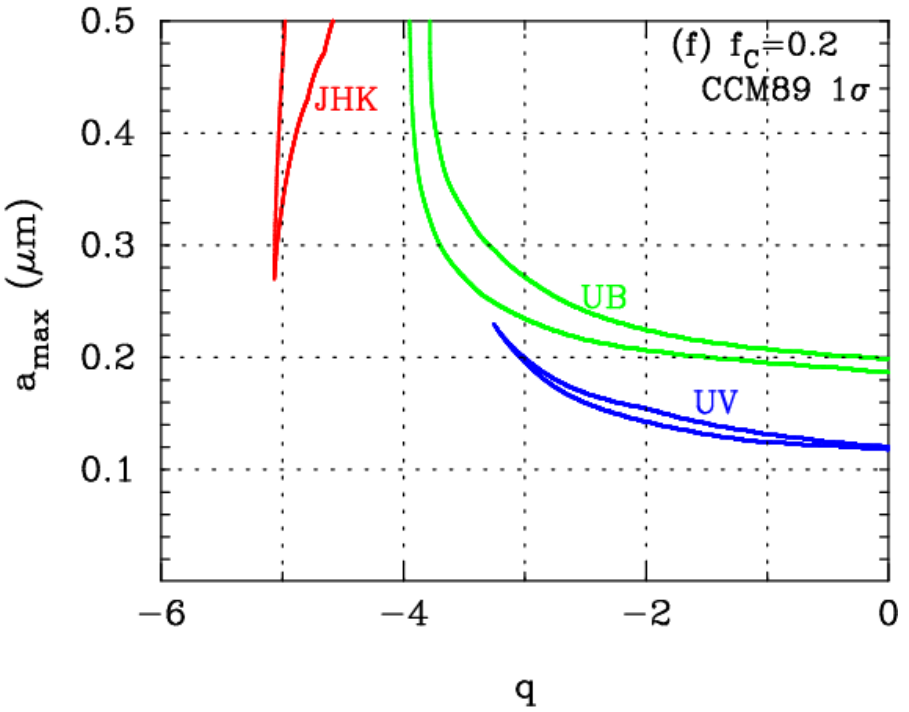
contour plots of a_{max} and q that fulfill the 1σ range of CCM result for f_{gra}/f_{sil} = 0.5 (M_{gra}/M_{sil} = 0.39)
blue: constraint from UV/FUV
green: constraint from UB band
red: constraint from JHK band

8-3. Contour plots for f_{gra}/f_{sil} = 0.2

Case of 1σ data, f_{gra}/f_{sil} = 0.2



Case of 1σ data, f_{gra}/f_{sil} = 0.2



contour plots of a_{max} and q that fulfill the 1σ range of FM07 data for f_{gra}/f_{sil} = 0.2 (M_{gra}/M_{sil} = 0.16)
blue: constraint from UV/FUV
green: constraint from UB band
red: constraint from JHK band

contour plots of a_{max} and q that fulfill the 1σ range of CCM result for f_{gra}/f_{sil} = 0.2 (M_{gra}/M_{sil} = 0.16)
blue: constraint from UV/FUV
green: constraint from UB band
red: constraint from JHK band

9. Summary

- The extinction ranges in UV regions from FM07 are described by the CCM formula with Rv = 2.75-3.60

- The observed range of NIR extinction from FM07 does not match with the results from CCM relation
  difference : 0.02-0.06 mag

  ➔ The average interstellar extinction curve is not necessarily universal

- For the power-law grain-size distribution,
  - The values of q and a_{max} that satisfy the observed 1σ ranges of FM07 are confined to narrow ranges
  - There is no combination of q and a_{max} that satisfy the observed ranges when CCM results are adopted