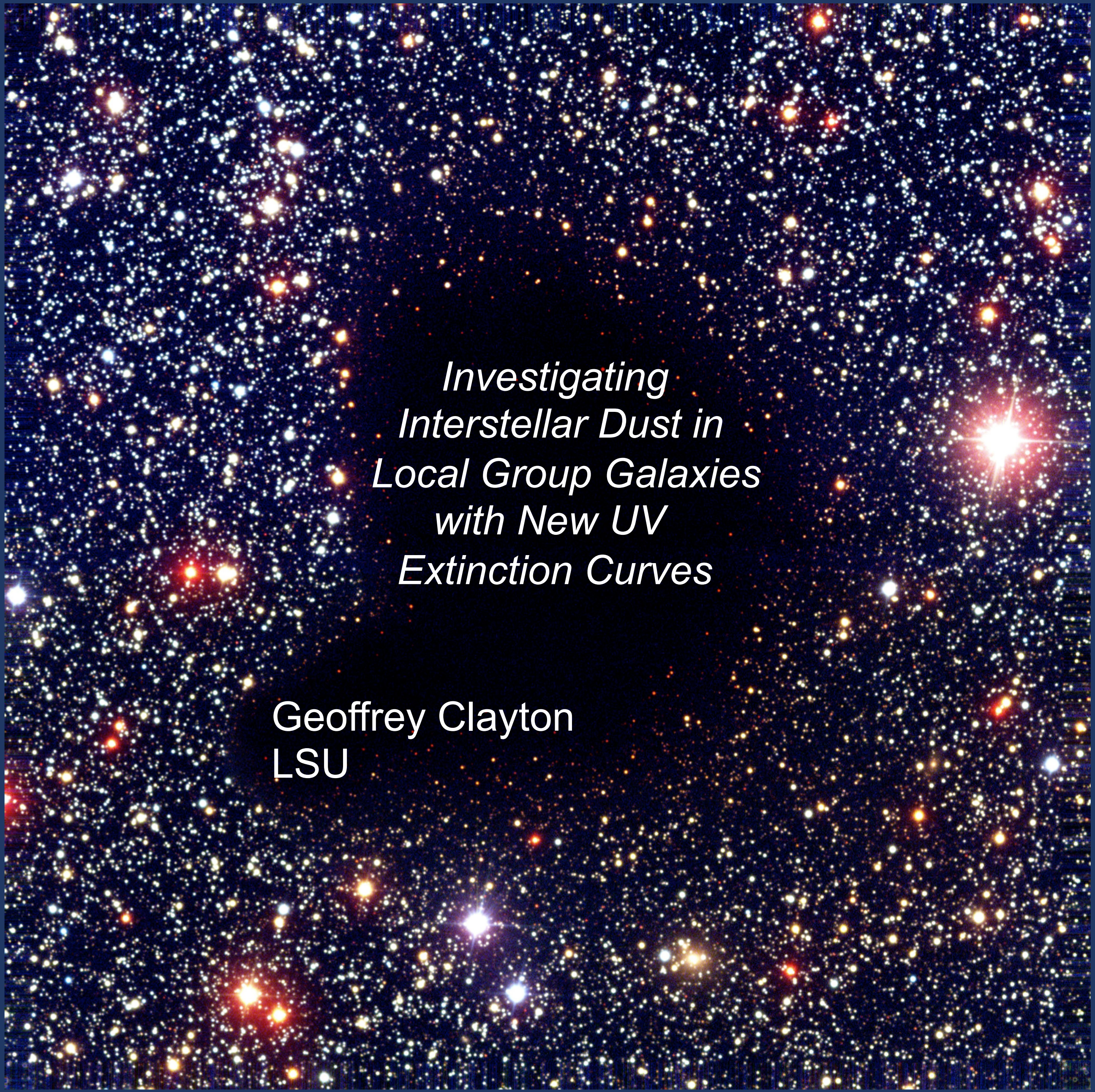

Investigating Interstellar Dust in Local Group Galaxies with New UV Extinction Curves

Geoffrey Clayton
LSU

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THE *HERSCHEL* INVENTORY OF THE AGENTS OF GALAXY EVOLUTION IN THE MAGELLANIC CLOUDS, A *HERSCHEL* OPEN TIME KEY PROGRAM

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Elisabete da Cunha (ANU)
Mark Dickinson (NOAO)
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Cornelia Jäger (FSU-Jena)
Ed Jenkins (Princeton)
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Desika Narayanan (Univ. of Florida)
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1985ApJ...288..558C

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INTERSTELLAR DUST IN THE LARGE MAGELLANIC CLOUD

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ABSTRACT

This paper presents extensive observations of the properties of interstellar dust in a different physical environment than the Galaxy, namely the Large Magellanic Cloud. Extinction and polarization analysis of 12 reddened stars spread across the LMC shows that in the optical and infrared the dust characteristics are remarkably similar to the Galaxy. The wavelength dependence of the polarization and the polarization efficiency, $p/E(B-V)$, are also comparable to Galactic values. On the other hand, along the same lines of sight there are measurable differences from star to star in the ultraviolet. On average, the ultraviolet extinction in the LMC is also different than the Galaxy, having proportionately higher far-ultraviolet extinction and a weaker 2200 Å bump. This confirms and extends previous results based largely on ultraviolet observations of the 30 Dor region. Average extinction curves were calculated for stars outside the 30 Dor region to see if the latter is representative despite the atypical environment. Outside the 30 Dor region the 2200 Å bump is somewhat larger and the amount of far-ultraviolet extinction somewhat less, thus being closer to the Galactic behavior. However, these regional differences are only marginally significant.

The dust-to-gas ratio, $E(B-V)/N_{\rm H}$ in the LMC is several times lower than the Galactic value, which might suggest less net efficiency of dust production in the LMC. However, the amount of dust produced is limited by the abundance of the condensable species. Taking into account the lower CNO abundances found for the LMC, the dust-to-gas ratio, $E(B-V)/N_{\rm CNO}$, is the same within a factor of 2 and the net dust formation efficiency may thus be rather similar in these two galaxies. The lower 2200 Å bump strength in the LMC might similarly reflect a general deficiency of carbon relative to the other heavy elements. A relationship between ultraviolet extinction properties and heavy element abundances in the Galaxy, LMC, and SMC is noted.

Subject headings: galaxies: Magellanic Clouds — interstellar: matter — polarization — ultraviolet: general

I. INTRODUCTION

Observation of the differing physical conditions under which interstellar dust exists provides clues to the mechanisms of formation and destruction of grains because attendant differences in the size, shape, and composition of the grains are manifested in variations in the characteristics of the extinction and polarization produced. Detection of such variations from galaxy to galaxy, or with position in a galaxy, is therefore very important. The LMC environment could well be different than the Galaxy for the evolution of grains.

The first information concerning the nature of the dust came from observations of interstellar polarization and optical reddening. Measurements by Visvanathan (1966), Mathewson and Ford (1970), and Schmidt (1976) of more than 200 LMC stars showed, as far as unfiltered observations could, that the polarization efficiency, $p/E(B-V)$, in the LMC is the same as in the Galaxy. Koornneef (1982), and Morgan and Nandy (1982) both find values of R very close to the Galactic value from *JHK* photometry of LMC supergiants. Observations using the *Netherlands Astronomical Satellite* (*ANS*) suggested that the ultraviolet extinction in the LMC might be anomalous (Borgman, van Duinan, and Koornneef 1975; Koornneef 1977, 1978). This suggestion was confirmed by observations made using *IUE*, which clearly showed that the 2200 Å extinction feature is smaller and the far-ultraviolet extinction higher than is typically seen in the Galaxy (Nandy and Morgan 1978; Nandy *et al.* 1980; Koornneef and Code 1981, hereafter KC; Nandy *et al.* 1981, hereafter NMW).

This previous work in the LMC consists of a number of different types of observation each using a different sample of stars. Often only an average extinction curve is derived for a limited region in the LMC. The present study was undertaken to produce a homogeneous set of observations covering the greatest possible range in wavelength of both extinction and polarization for a large sample of stars spread throughout the LMC. Much care was taken to choose only "normal" stars whose intrinsic characteristics would affect the observations as little as possible. An advantage of this new sample is that it allows direct comparison of the optical and ultraviolet extinction and also the polarization properties along a single line of sight. This permits an investigation of how variations seen in different wavelength regions are related and a search for differences in the dust from place to place in the LMC.

A portion of this study based on measurements of the wavelength dependence of LMC polarization has already been published (Clayton, Martin, and Thompson 1983, hereafter CMT).

II. OBSERVATIONS AND REDUCTIONS

a) The Sample

The stars chosen for this program are normal, mostly B type, supergiants, known to be members of the LMC. A subset consists of unreddened stars of the same spectral types as the reddened members; although it might seem time consuming to collect data on unreddened stars, these are essential to the process of obtaining reliable extinction curves. Known

[1] Guest Observer with the *International Ultraviolet Explorer Satellite* which is sponsored and operated by the National Aeronautics and Space Administration, by the Science Research Council of the United Kingdom, and the European Space Agency.

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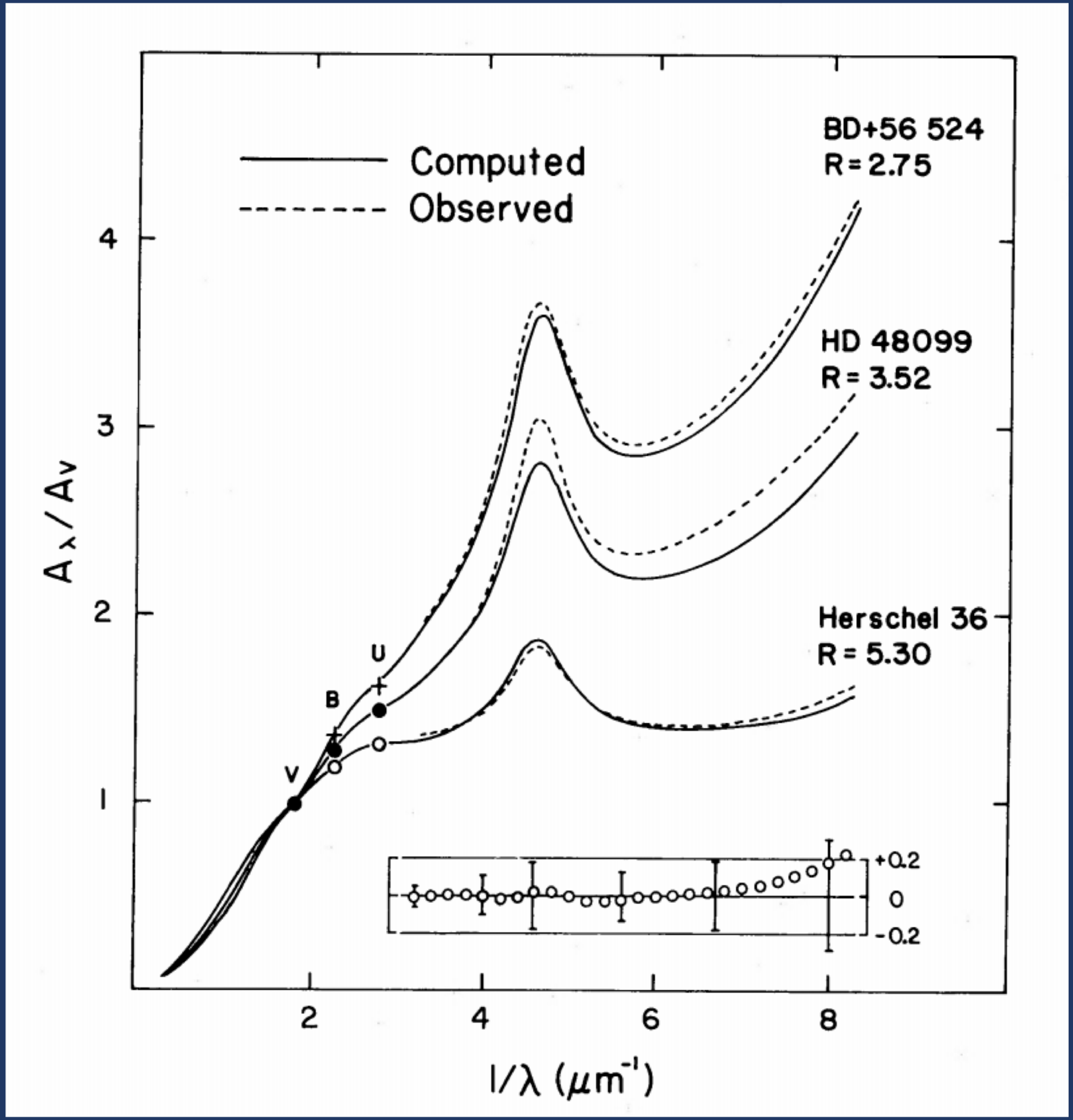
Kathryn Neugent (Lowell Obs.)

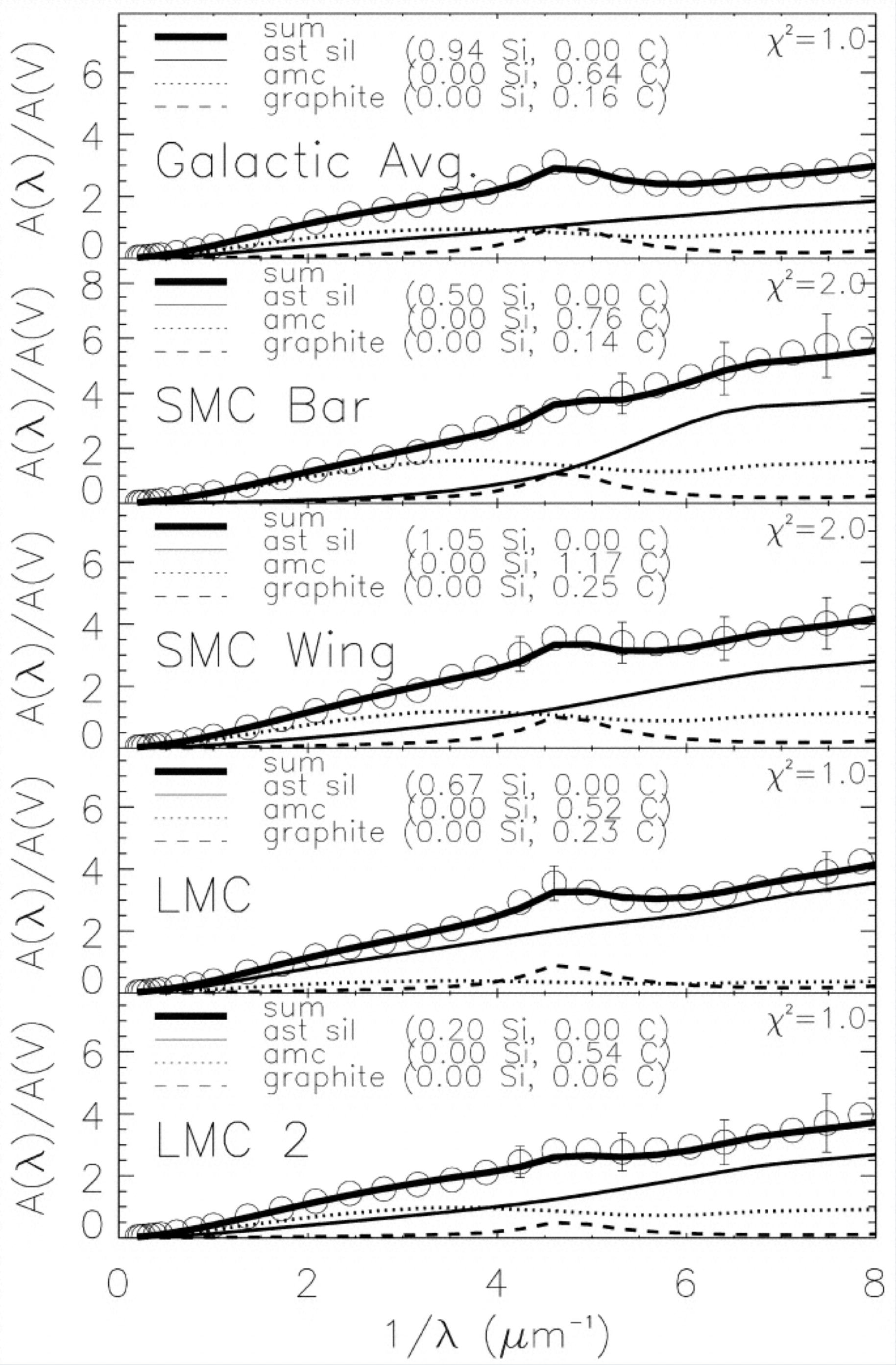
Cardelli, Clayton & Mathis (1989)
CCM

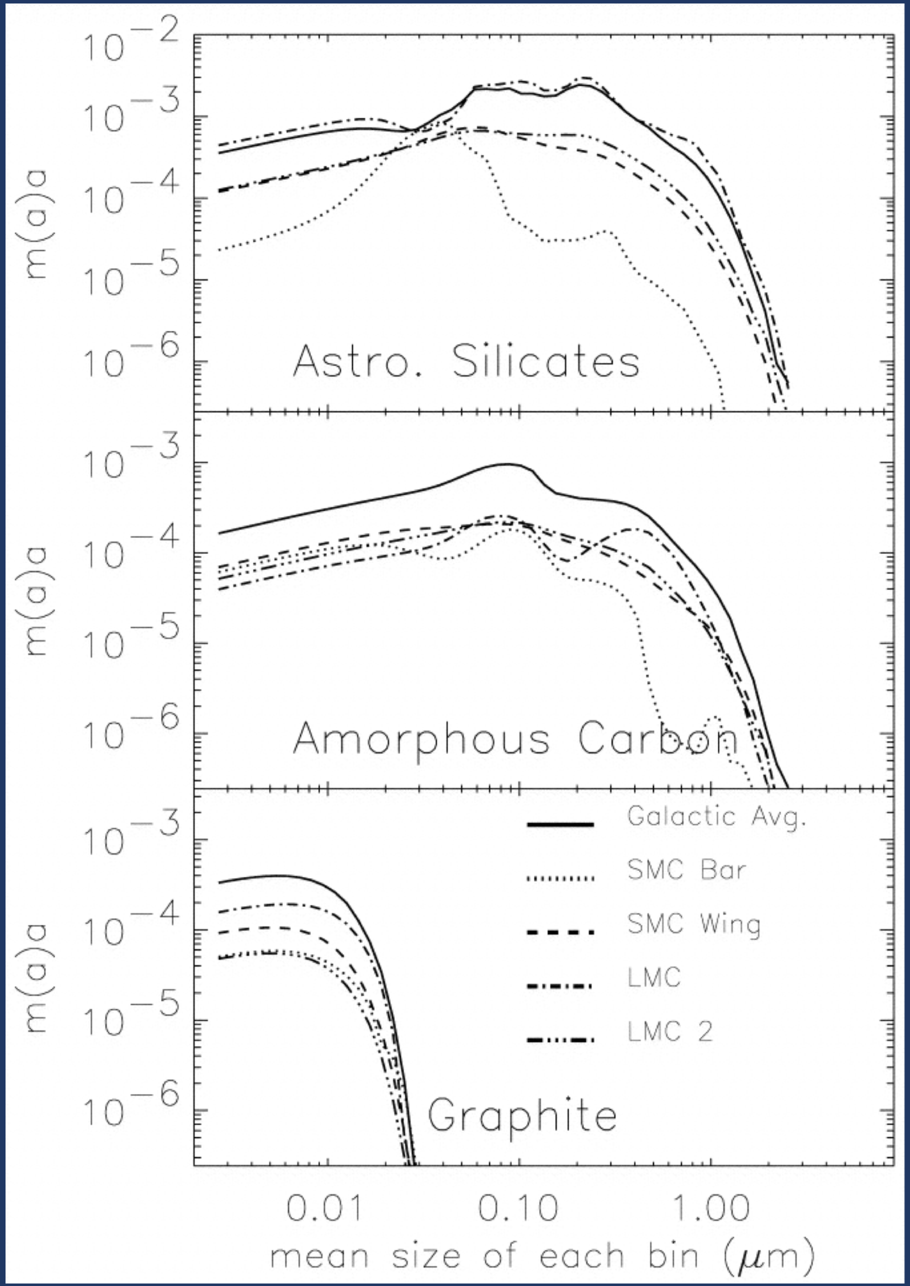
$$R_V \equiv \frac{A_V}{E_{B-V}},$$



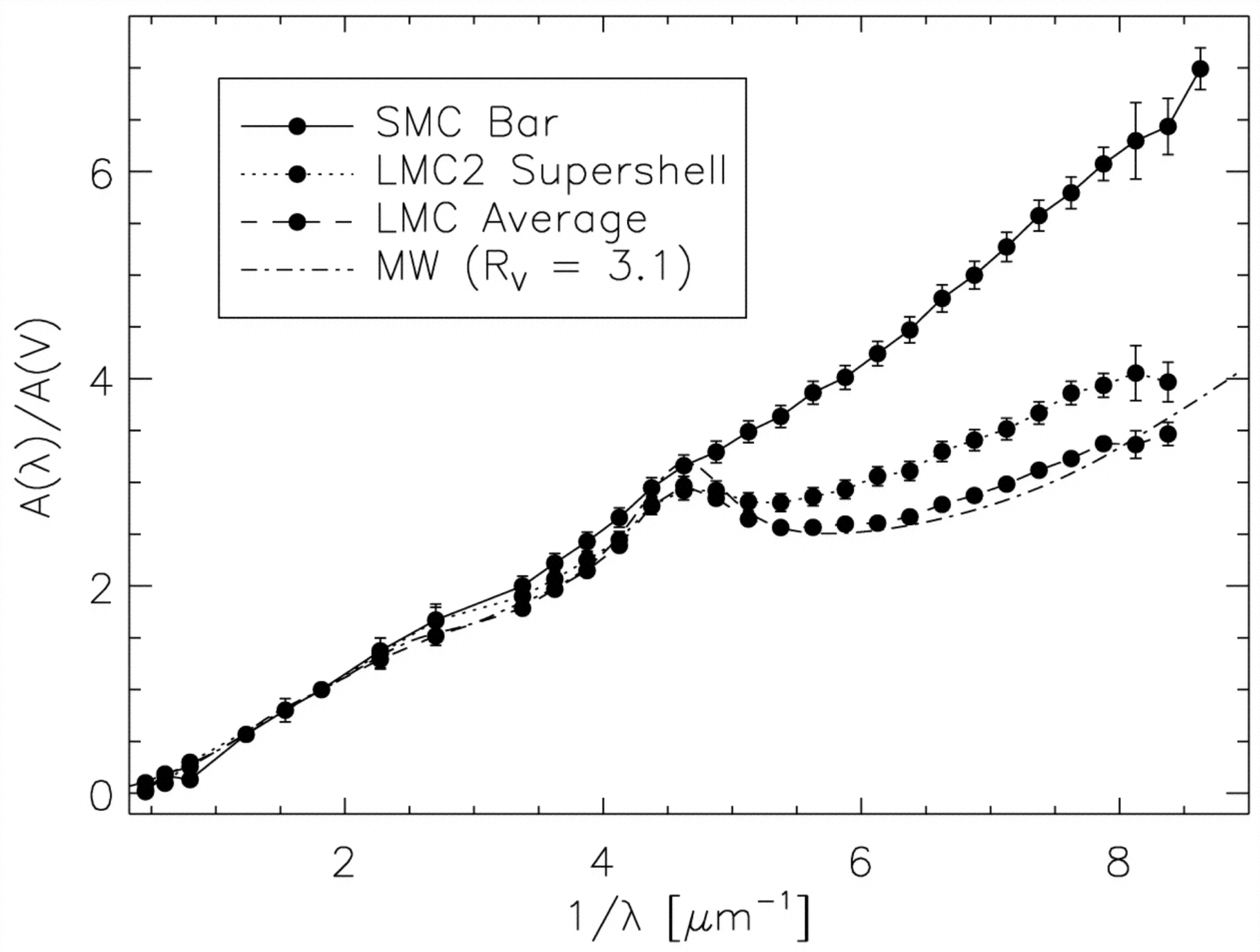
Mathis, Rumpl & Nordsieck (1977)
MRN

$$\propto a^{-3.5}\,, \quad \text{where} \quad a_{\min} \le a \le a_{\max}$$

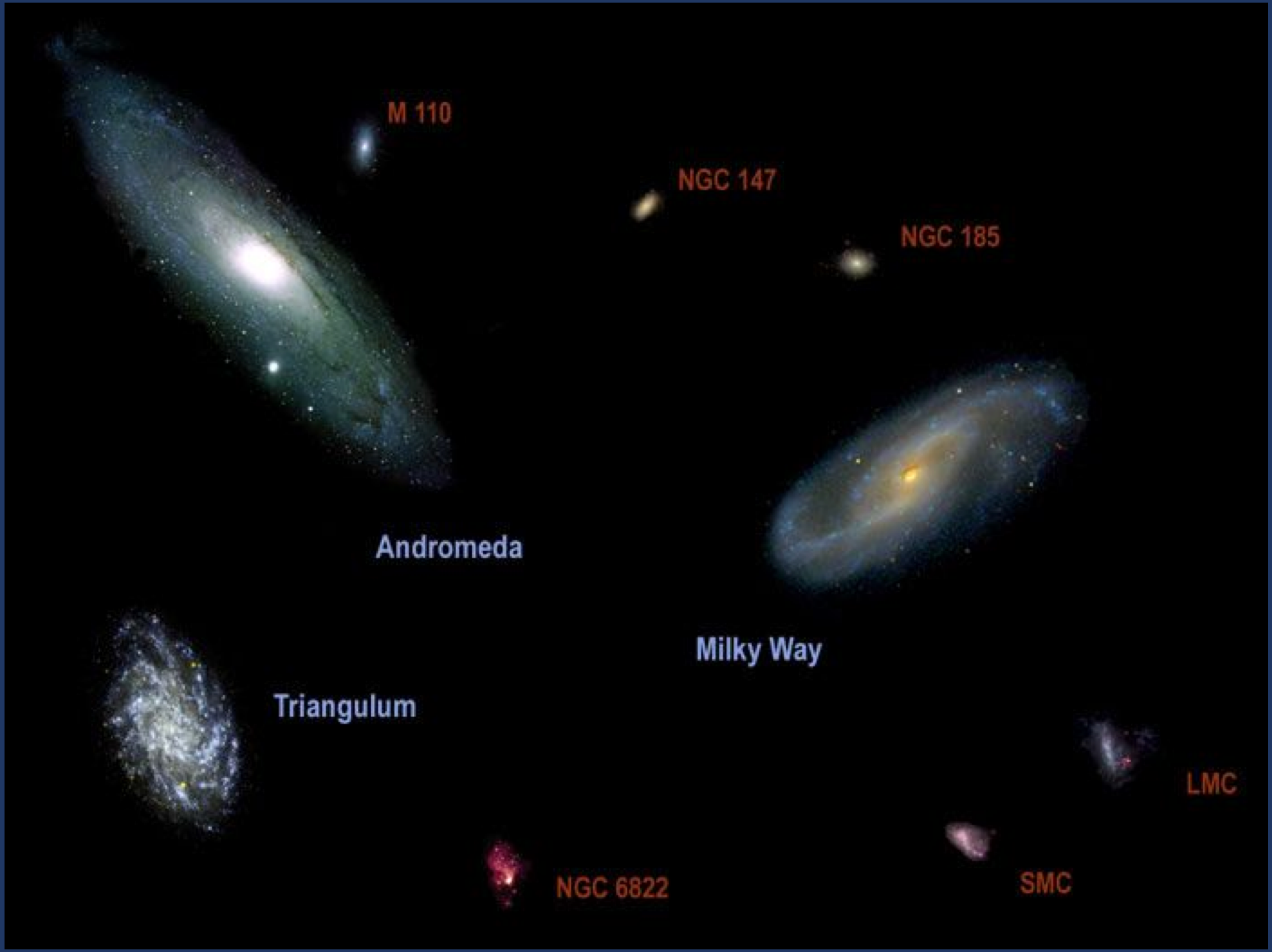


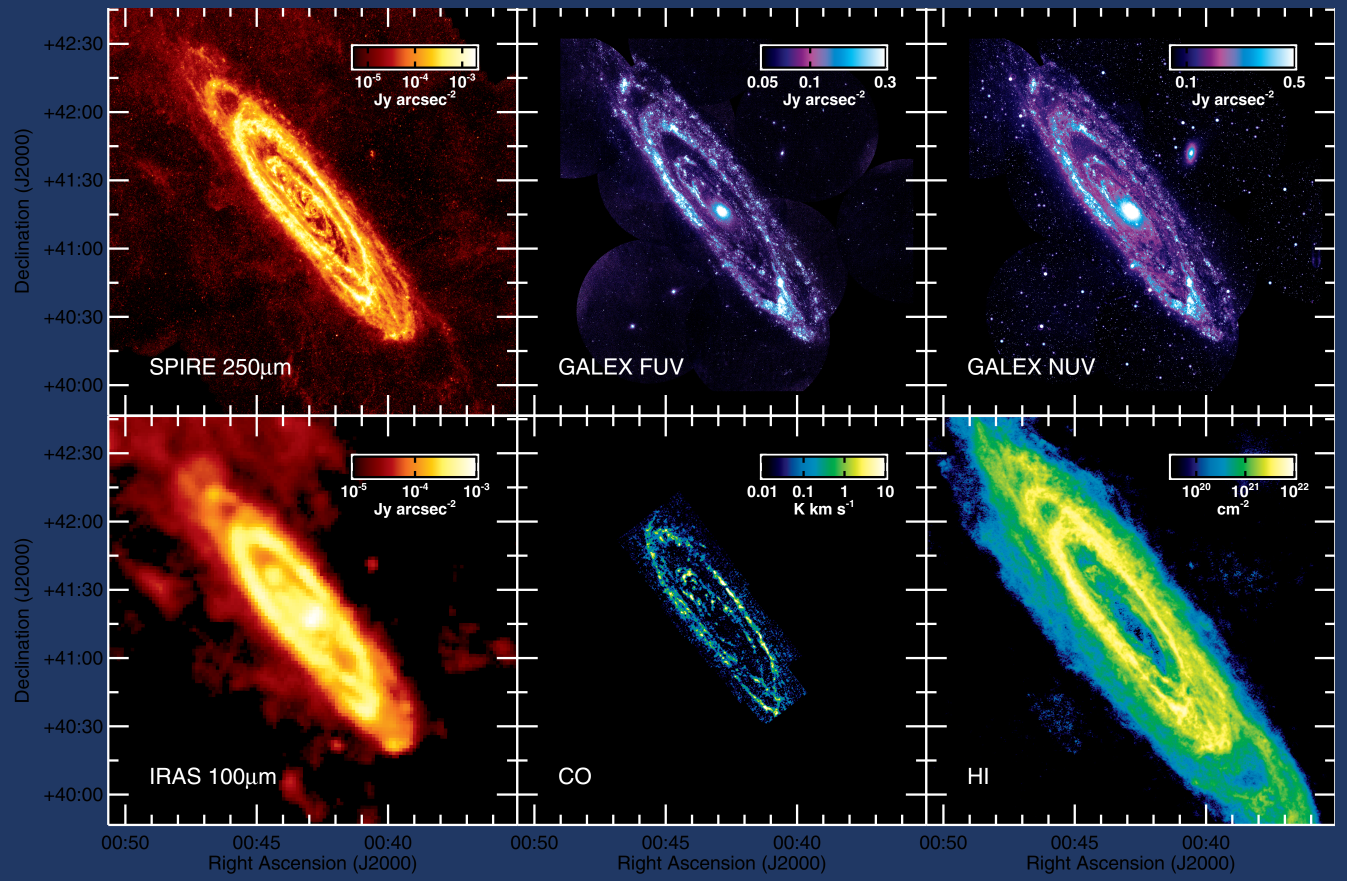


Clayton et al. 2003

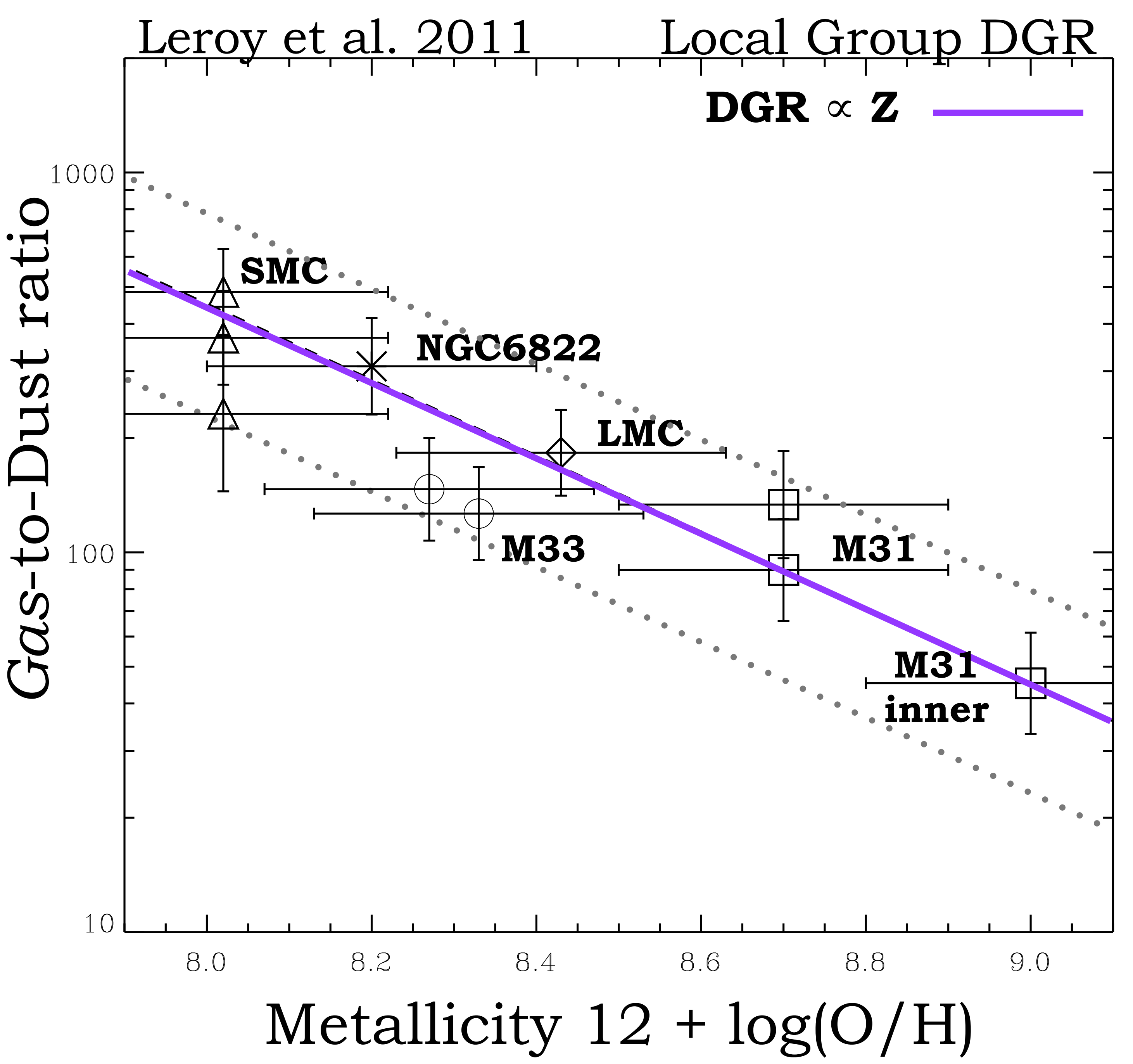


Gordon et al. 2003


M 110
NGC 147
NGC 185
Andromeda
Milky Way
Triangulum
LMC
NGC 6822
SMC

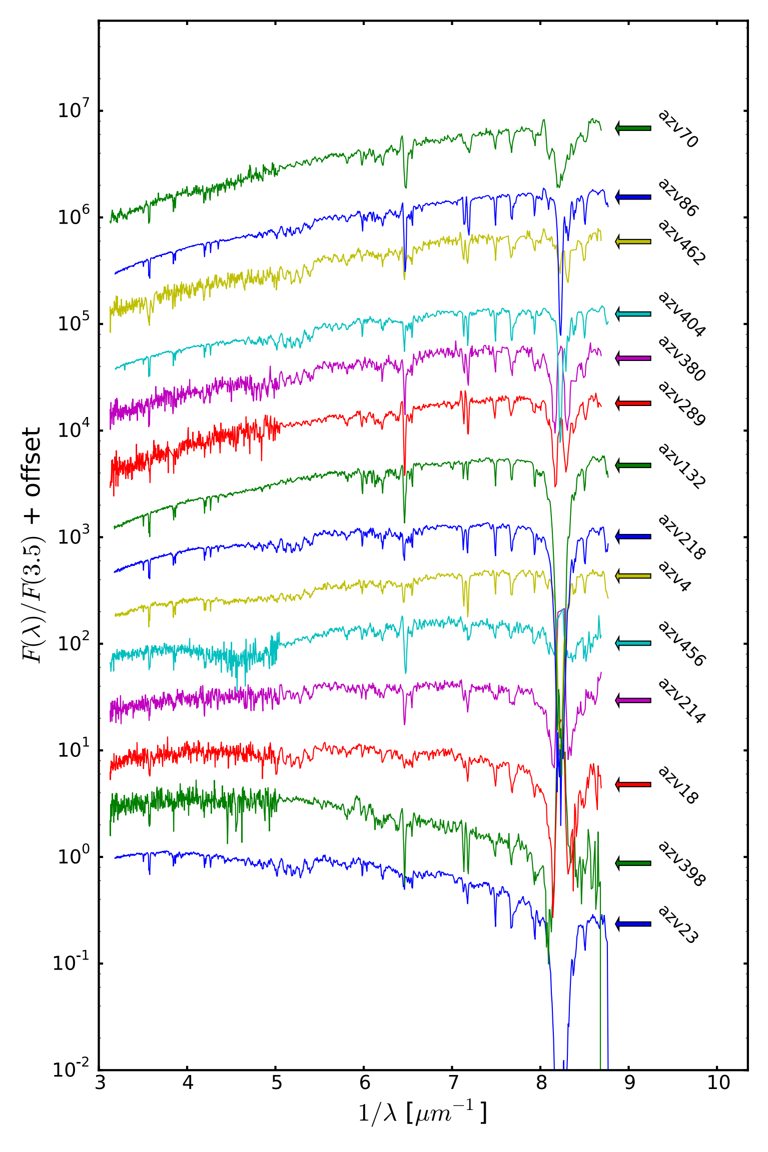


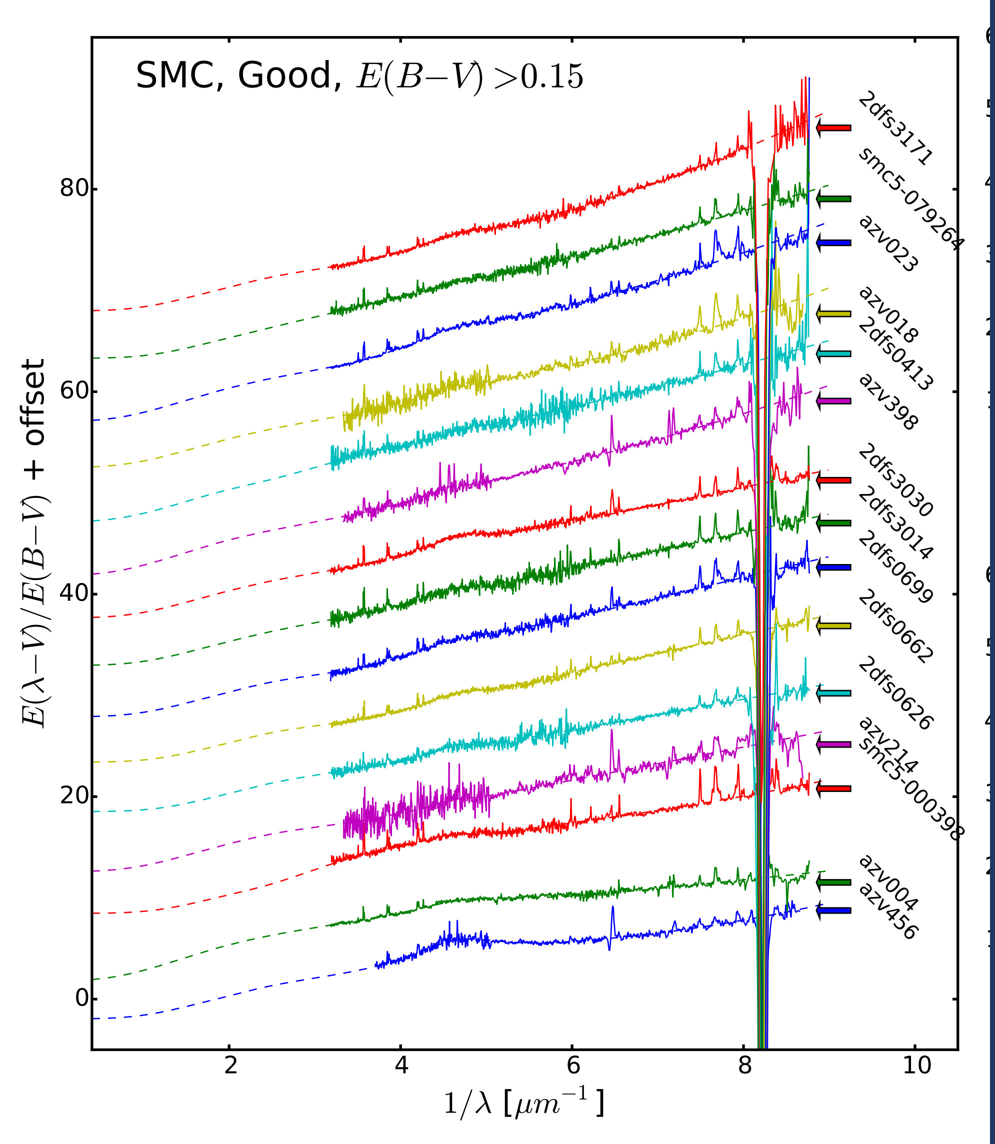
Fritz et al. 2012



Leroy et al. 2011
Local Group DGR
DGR ∝ Z
SMC
NGC6822
LMC
M33
M31
M31
inner
1000
100
10
8.0
8.2
8.4
8.6
8.8
9.0
Gas-to-Dust ratio
Metallicity 12 + log(O/H)

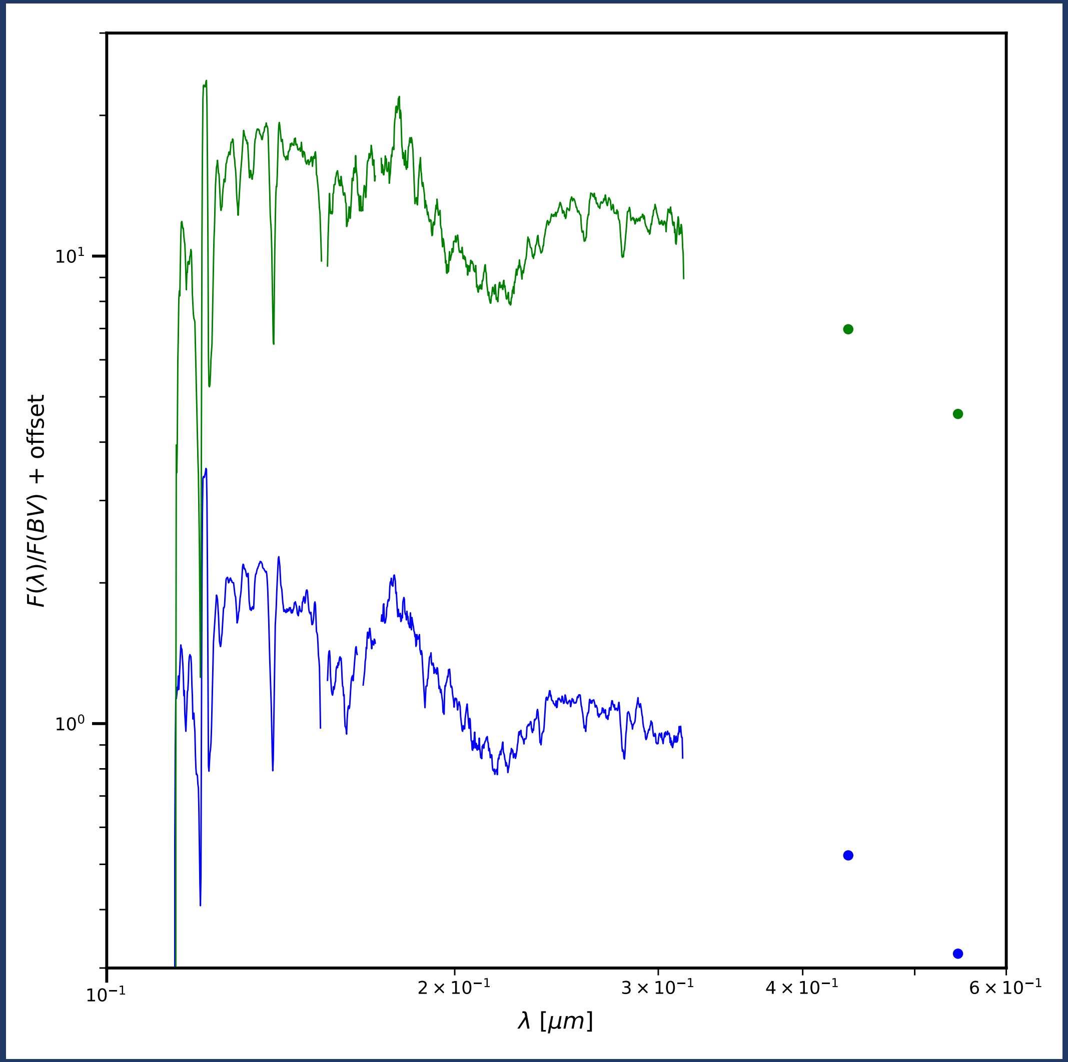
SMC

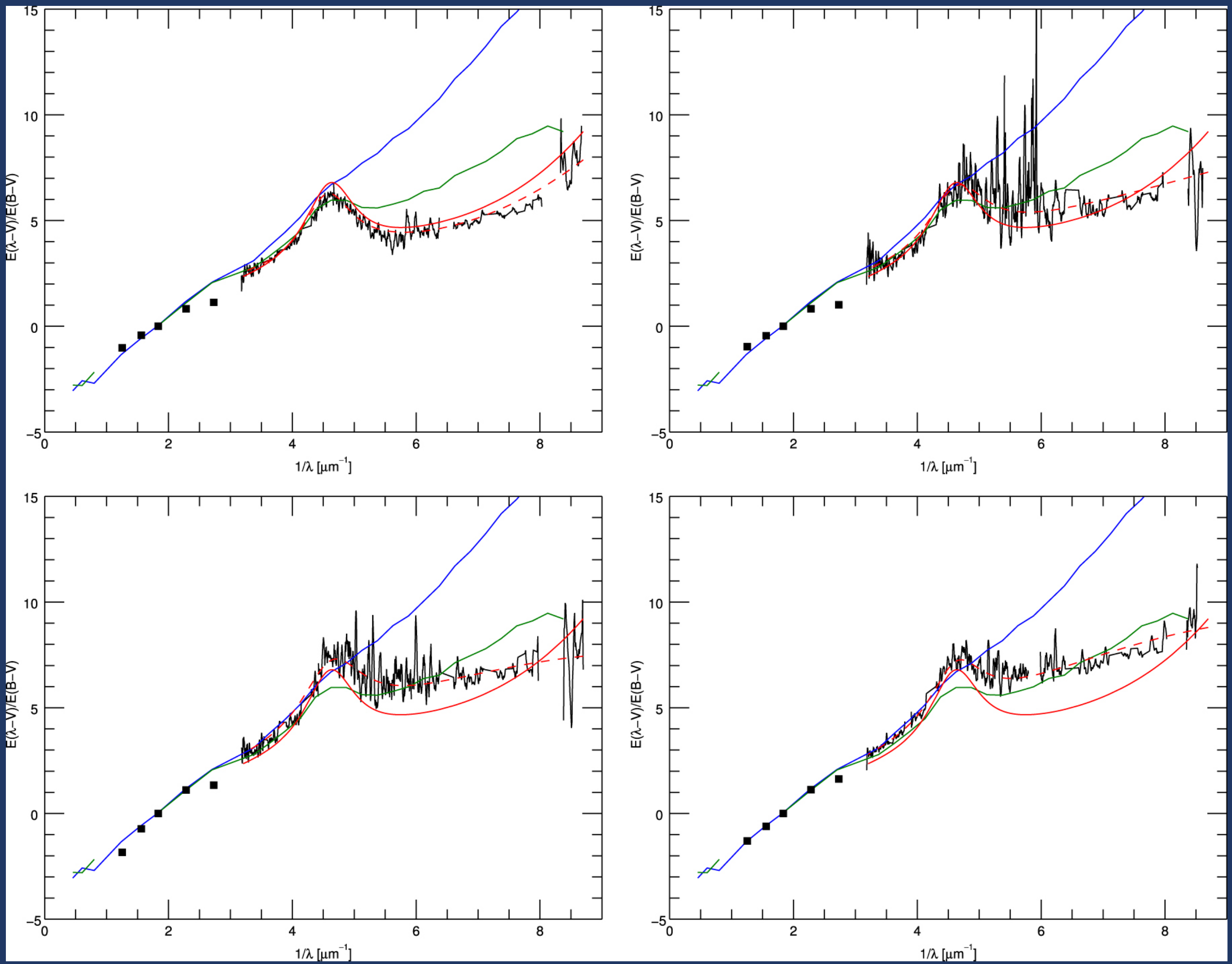




Gordon et al. 2020

M31

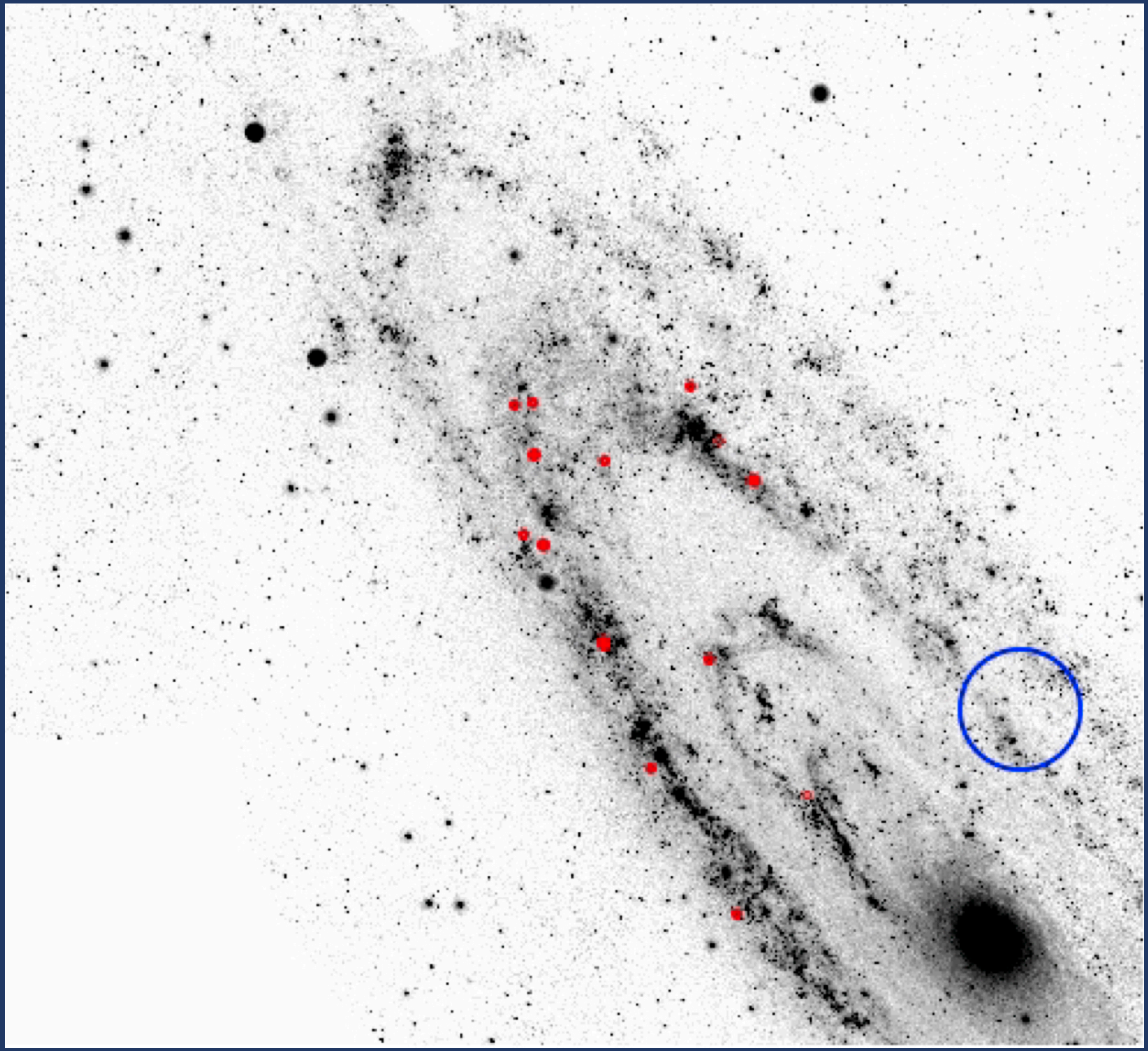




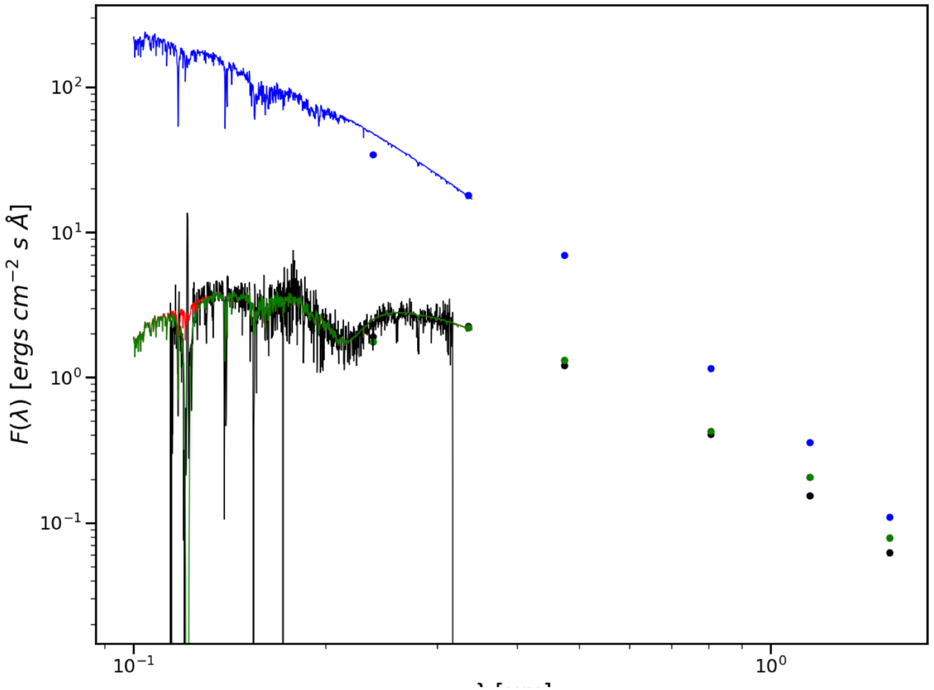
Clayton et al. 2015

M31 (HST Cycle 24)

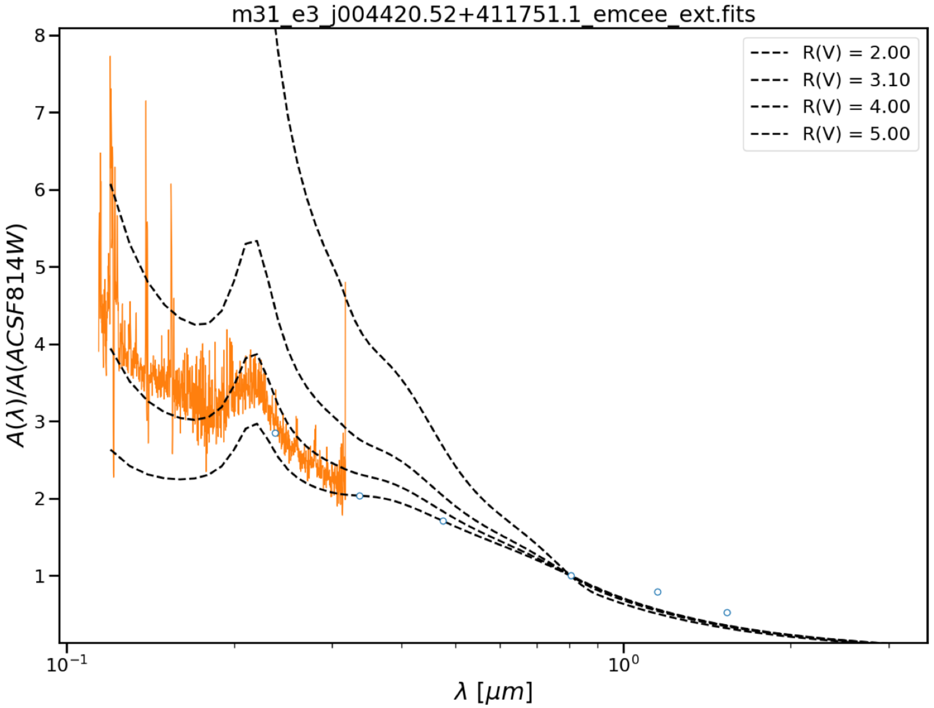
M33 (HST Cycle 25)



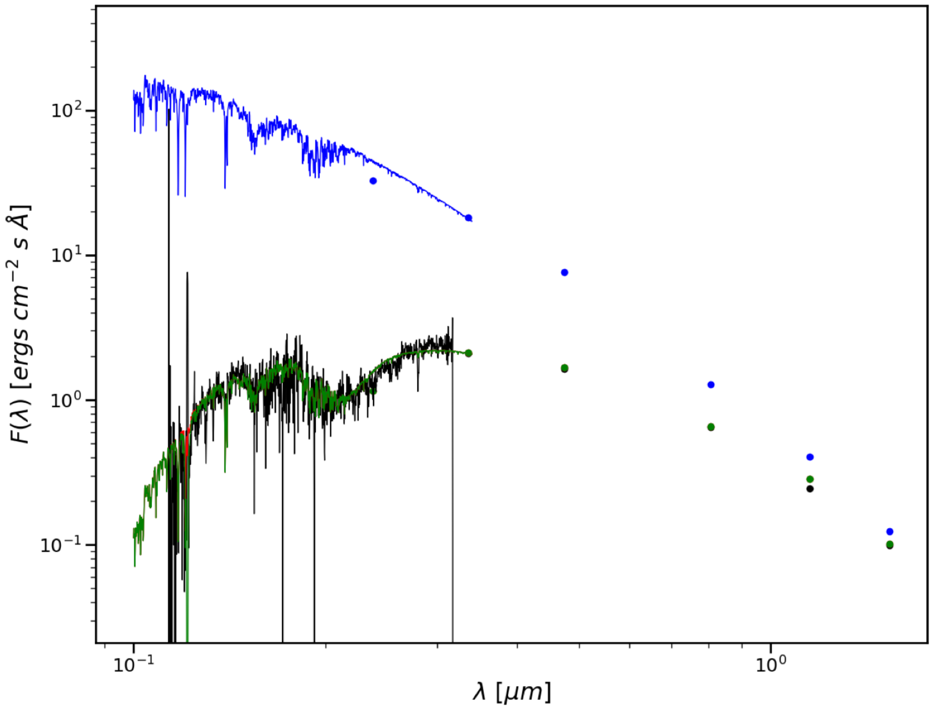
M31



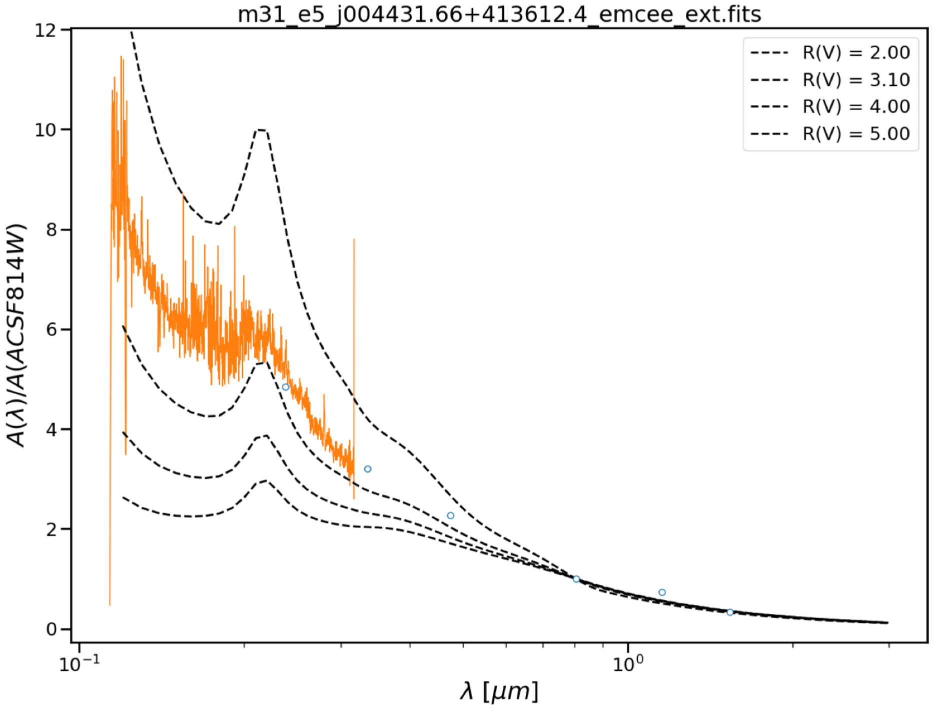
F(λ) [ergs cm⁻² s Å]
λ [μm]



m31_e3_j004420.52+411751.1_emcee_ext.fits
R(V) = 2.00
R(V) = 3.10
R(V) = 4.00
R(V) = 5.00
A(λ)/A(ACSF814W)
λ [μm]



F(λ) [ergs cm⁻² s Å]
λ [μm]



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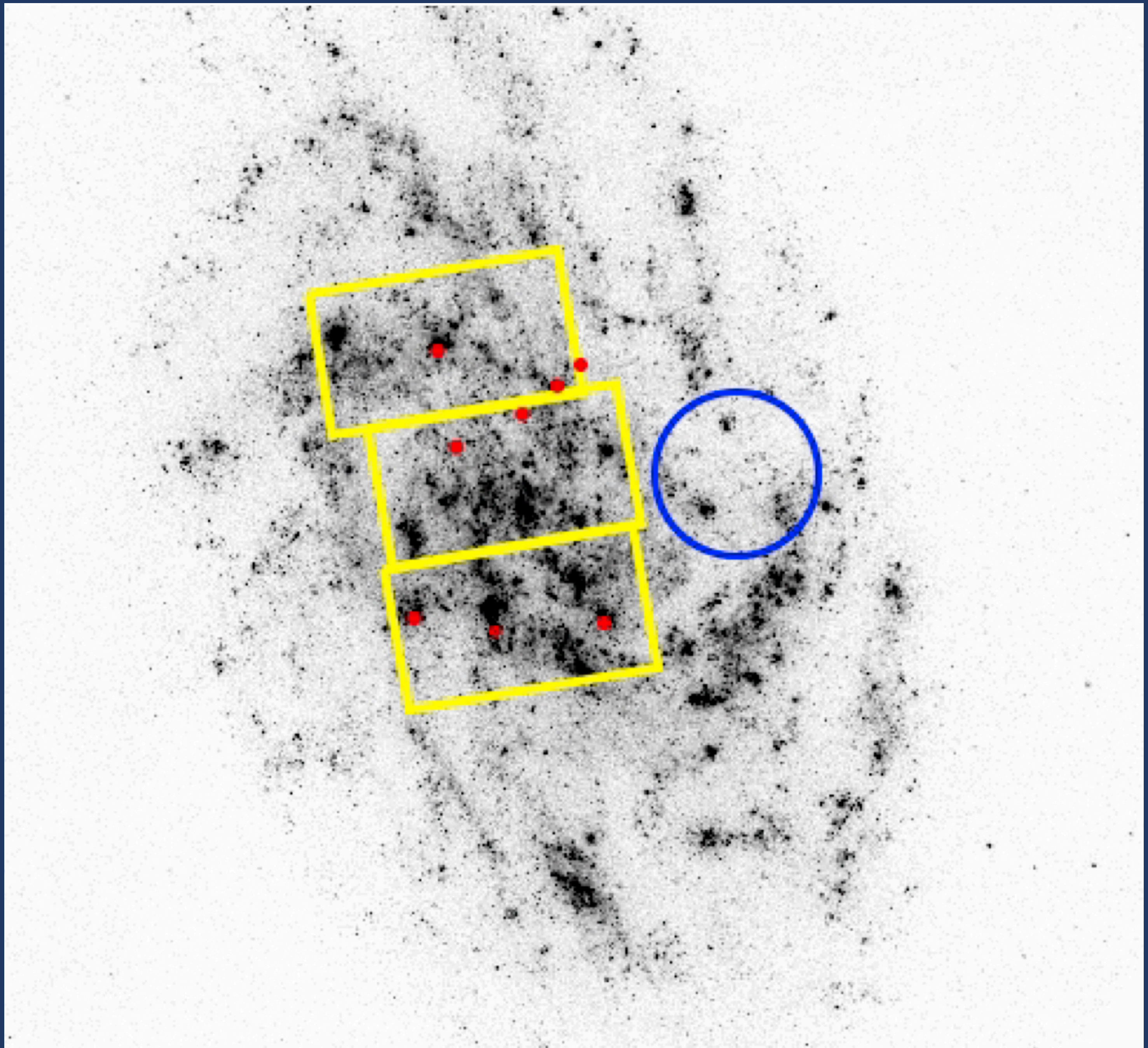
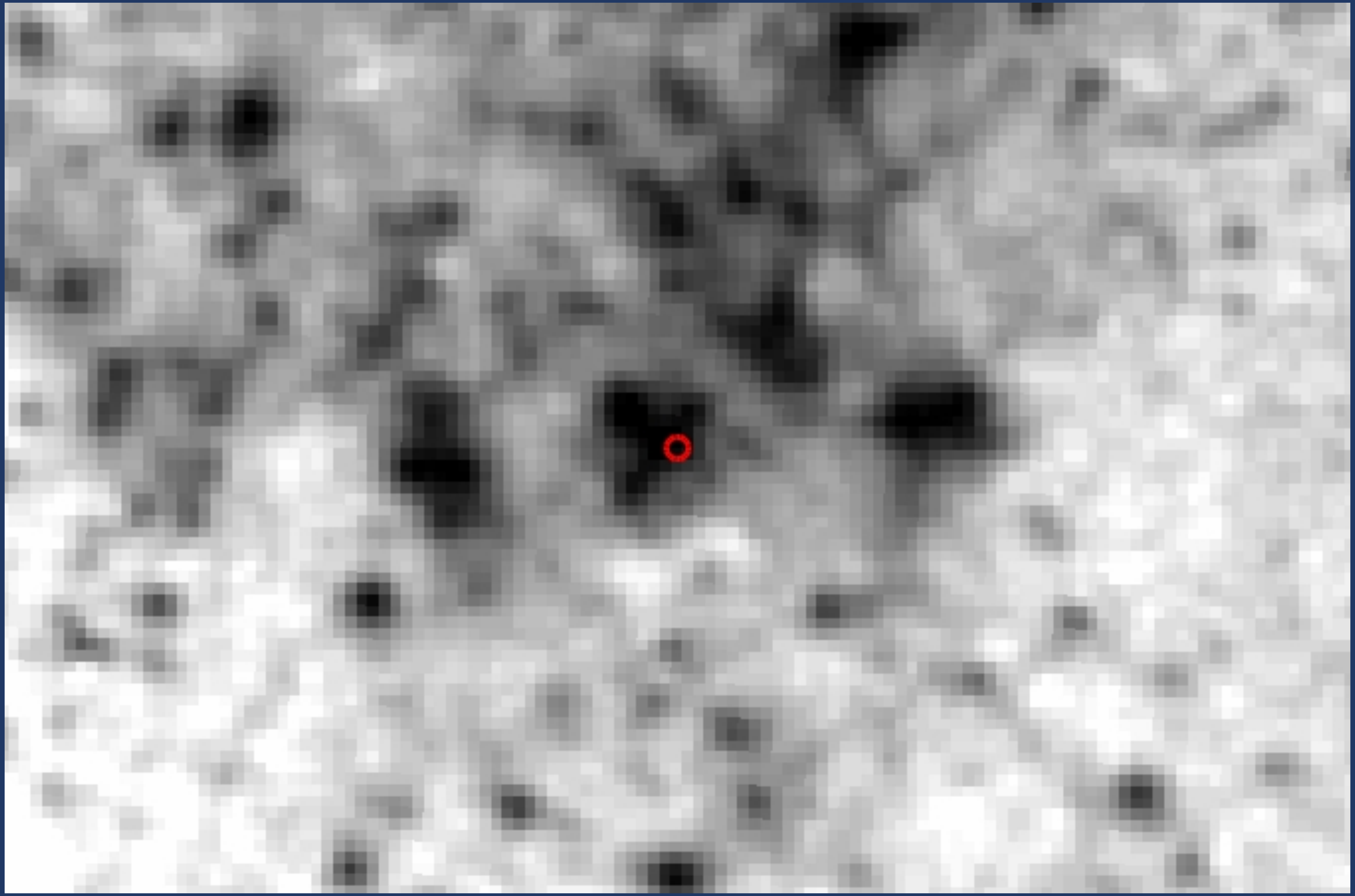
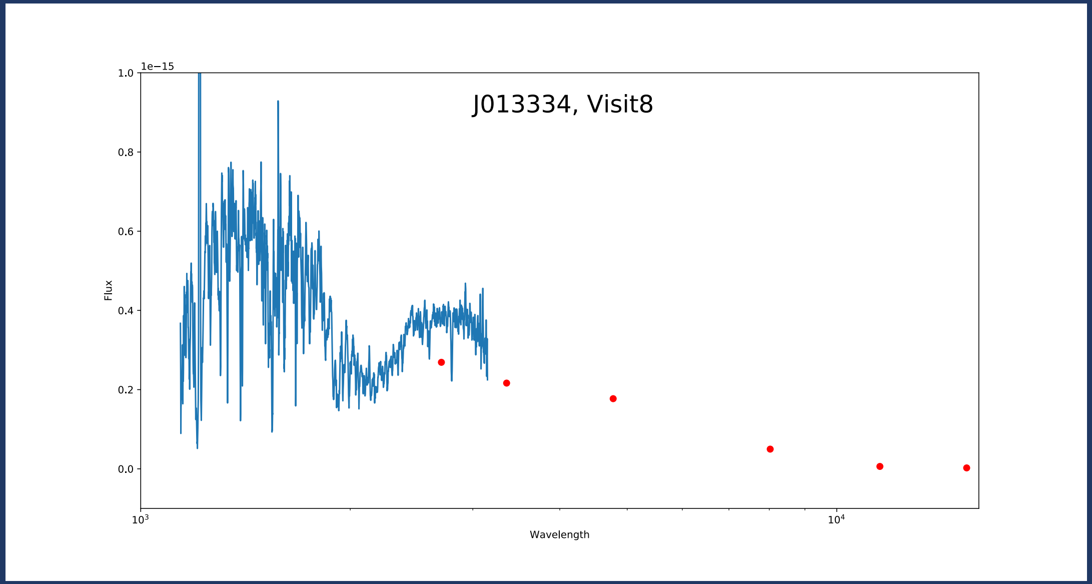
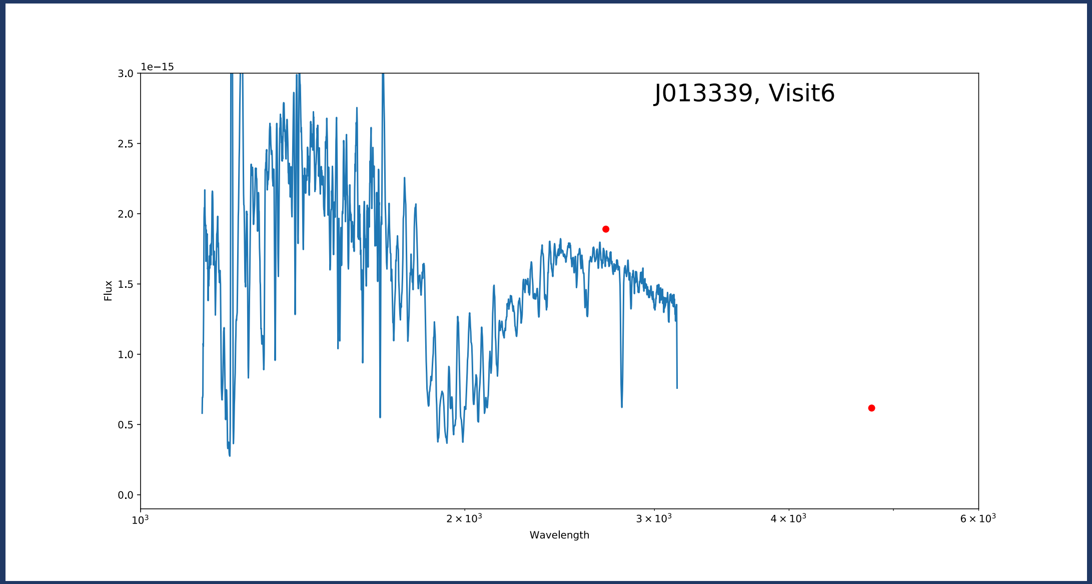
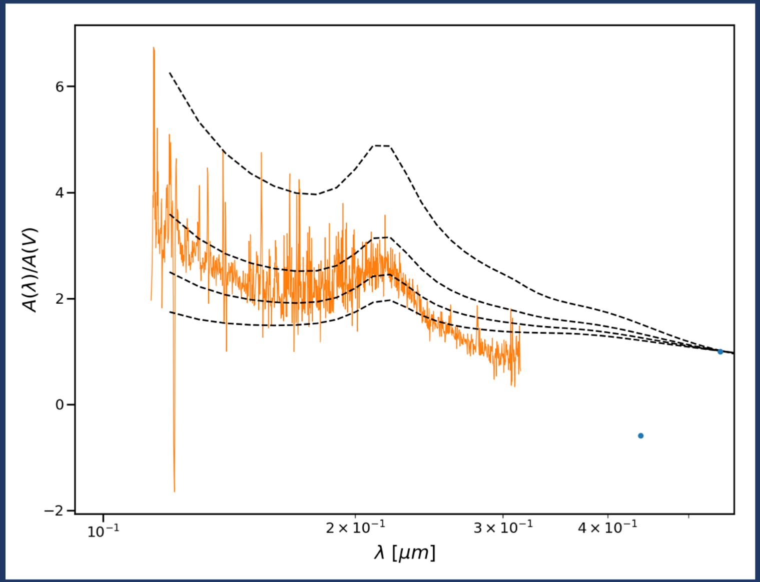
R(V) = 3.10
R(V) = 4.00
R(V) = 5.00
A(λ)/A(ACSF814W)
λ [μm]



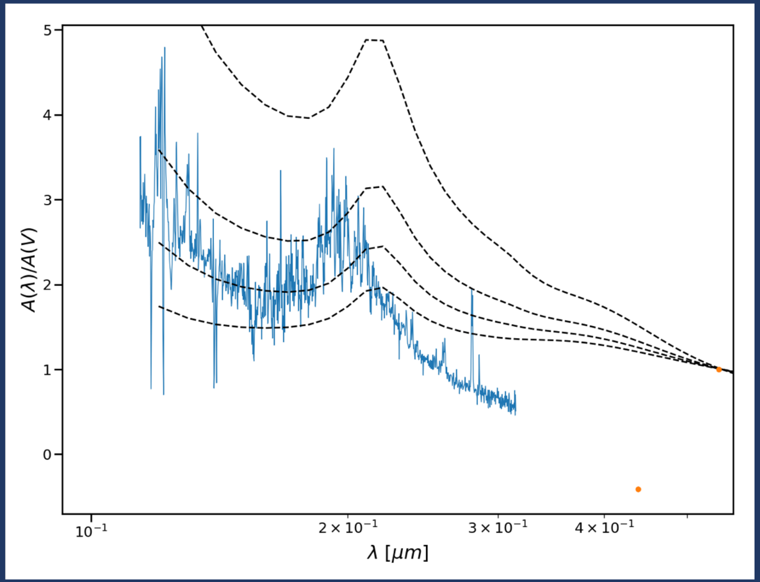



J013334, Visit8
1e−15
Flux
Wavelength


J013339, Visit6
1e−15
Flux
Wavelength


A(λ)/A(V)
λ [μm]

M33


A(λ)/A(V)
λ [μm]

Summary

- MW, LMC, SMC, M31, M33
- Extinction vs Attenuation
- How does UV extinction vary from galaxy to galaxy and across an individual galaxy?
- Different global characteristics such as metallicity and star formation activity.
- Grain components and size distributions for use in RT modeling of other galaxies.