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Empirical Dust Models

ChangHoon Hahn[1,2,*] and IQ Collaboratory

[1] *Lawrence Berkeley National Laboratory, 1 Cyclotron Rd, Berkeley CA 94720, USA*
[2] *Berkeley Center for Cosmological Physics, University of California, Berkeley CA 94720, USA*

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ABSTRACT

dust

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1. INTRODUCTION

dust is important because....

assumptions on the attenuation curve can dramatically impact the physical properties inferred from SED fitting (*e.g.* Kriek & Conroy 2013; **?**; **?**; Salim & Narayanan 2020).

motivation for an empirical dust attenuation model

attenuation vs extinction. While extinction curves have been derived from observations and theoretically, it's not easy to map this to attenuation curves. Attenuation curves are a product of complicated empirical processes since it accounts for light that gets scattered and star light that is not obscured

This makes modeling them in a complete physically motivated method expensive. People have done it Narayanan et al. (2018); **?**. some detail about the radiative transfer method and such. But besides being expensive they have to make a number of assumptions anyway. e.g. Narayanan et al. (2018) assumes a fixed extinction curve.

Moreover, because the radiative transfer method is expensive it's hard to compare many different simulations. Not only that, observables generated from simulations that take into radative transfer dust models complicates simulation to simulation comparisons. Because you're simultaneously comparing the galaxy formation prescription and all the dust prescription.

Instead, we present a framework using flexible dust empirical models that paints attenuation curves onto galaxies. describe at a high level how we are parameterizing DEMs

talk about the advantages: extremely flexible so it can encompass the wide variety of attenuation curves found in radiative transfer, easy to correlate the attenuation curve with galaxy properties.

Also DEMs make it possible to statistically apply attenuation curves for large galaxy population. Putting this ontop of simulations, we can use them to generate observables and compare them to

* hahn.changhoon@gmail.com

observations to constrain the DEM. This framework allows us to learn about attenuation curves given a model for galaxy formation.

The other way around also works. If you don't care about dust at all, DEM provides a framework to easily marginalize over dust attenuation and treat dust as a nuisance parameter.

In this paper, we do above for multiple simulations.

Starkenburg et la. in prep will use this framework to marginalize over dust and compare galaxy populations predicted by multiple simulations .

2. DATA

2.1. *SDSS*

2.2. *Illustris TNG*

describe what galaxy properties (SFH, ZH, etc) are available TODO

2.3. *SIMBA*

describe what galaxy properties (SFH, ZH, etc) are available TODO

2.4. *Spectral Energy Distributions*

describe how the SED is generated using the SFH and ZHs TODO

2.5. *Forward Modeling SDSS Photometry and Spectra*

3. EMPIRICAL DUST MODELING

$$F_o(\lambda) = F_i(\lambda) 10^{-0.4 A(\lambda)} \tag{1}$$

where F_o is the observed flux, F_i is the intrinsic flux, and $A(\lambda)$ is the attenuation curve.

We normalize the attenuation at the V band,

$$A(\lambda) = A_V \frac{k(\lambda)}{k_V}. \tag{2}$$

Throughout we use the slab model (Somerville & Primack 1999; **?**) for the V band attenuation:

$$A_V = -2.5 \log \left[\frac{1 - e^{-\tau_V \sec i}}{\tau_V \sec i} \right] \tag{3}$$

i is the inclication, which we uniformly sample

3.1. *Naive Model*

We use Calzetti (2001)

$$k_{\rm Cal}(\lambda) = \begin{cases} 2.659(-1.857 + 1.040/\lambda) + R_V, & 6300\mathring{A} \le \lambda \le 22000\mathring{A} \\ 2.659(-2.156 + 1.509/\lambda - 0.198/\lambda^2 + 0.011/\lambda^3) + R_V & 1200\mathring{A} \le \lambda \le 6300\mathring{A} \end{cases}$$

table of free parameters

and

$$\tau_V = m_\tau \log\left(\frac{M_*}{10^{10}M_\odot}\right) + c_\tau \tag{4}$$

We also split the attenuation on the star light and nebular emission

$$F_o(\lambda) = F_i^{\rm star}(\lambda)10^{-0.4A(\lambda)} + F_i^{\rm neb}(\lambda)10^{-0.4A_{\rm neb}(\lambda)} \tag{5}$$

where we parameterize

$$A_{\rm neb}(\lambda) = f_{\rm neb}A(\lambda) \tag{6}$$

3.2. *Less Naive Model*

We use the attenuation curve from Noll et al. (2009)

$$k(\lambda) = (k_{\rm Cal}(\lambda) + D(\lambda))\left(\frac{\lambda}{\lambda_V}\right)^\delta \tag{7}$$

λ_V is the V band wavelength. $D(\lambda)$ is the bump.

$$D(\lambda) = \frac{E_b(\lambda\Delta\lambda)^2}{(\lambda^2-\lambda_0^2)^2+(\lambda\Delta\lambda)^2} \tag{8}$$

we assume fixed $\lambda_0 = 2175\mathring{A}$ and $\Delta\lambda = 350\mathring{A}$. E_b is the strength of the bump. δ, the slope of the attenuation curve, also correlates with galaxy properties. Kriek & Conroy (2013), and **?** more recently with simulations, demonstrated E_b correlates with the slope of the attenuation curve. So we parameterize δ and E_b:

$$\delta(M_*) = m_\delta \log\left(\frac{M_*}{10^{10}M_\odot}\right) + c_\delta \tag{9}$$

$$E_b = m_E\ \delta + c_E \tag{10}$$

3.3. *Less Less Naive Model*

We use the attenuation curve from Noll et al. (2009)

Salim & Narayanan (2020) finds SFR dependence in A_V

$$\tau_V = m_{\tau,1} \log\left(\frac{M_*}{10^{10}M_\odot}\right) + m_{\tau,2}\log{\rm SFR} + c_\tau \tag{11}$$

$$\delta(M_*,{\rm SFR}) = m_{\delta,2} \log\left(\frac{M_*}{10^{10}M_\odot}\right) + m_{\delta,2}\log{\rm SFR} + c_\delta \tag{12}$$

$$E_b = m_E\ \delta + c_E \tag{13}$$

3.4. *Likelihood-Free Inference*

Approximate Bayesian Computation with Population Monte Carlo Hahn et al. (2017), discussion of observables and distance metric Ishida et al. (2015)

4. RESULTS

5. SUMMARY

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APPENDIX

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