First Sample of Dust Attenuation Laws for Supernova Cosmology

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Introduction:

Type Ia supernovae (SN Ia) serve as excellent distance indicators, as their peak luminosity can be standardized by applying some corrections, one of which is based on a color-luminosity relation.

One of the main factors contributing to this particular correction is the effect of interstellar dust on the emitted light, which leads to a reddening of the observed spectrum. This is known as extinction in the case of point sources and attenuation in the case of galaxies.

The parameter controlling the color-luminosity correction is assumed to be universal, despite the fact that it has been shown that dust properties in the Local Universe can vary considerably[1].

Here, we present a novel way of obtaining individual dust properties for a SN Ia from broadband photometric data for its host galaxy. We seek not only to address the problems posed by the SN Ia calibration, but also to offer a new general approach to study attenuation for individual SN Ia.

Data:

We look at data obtained by the Dark Energy Survey (DES). It consists of Global (Kron) and Local (4kpc) aperture broadband photometry in the DECam *griz* filter bands, originally computed by Kelsey (2020)[2] for the host galaxies of 162 spectroscopically confirmed SN Ia and covers a redshift range of $0.077<z<0.58$.

SSP Models:

To recover dust properties, we seek to fit Simple Stellar Population (SSP) models to the photometric data for the host galaxies. While these models result from several complex physical variables, we focus here on the parameters describing dust attenuation.

In our model, the attenuation law will be parametrized by a modified Calzetti curve[3], with the optical depth A_V and the dust attenuation index n acting as free parameters:

$$A(\lambda)=\frac{A_V}{R_{V,0}}[k(\lambda)+D(\lambda)]\left(\frac{\lambda}{\lambda_V}\right)^n$$

k(λ) is the unmodified Calzetti curve, $R_{V,0}$=4.05 the original optical parameter, *D(λ)* a UV bump centered at 2175Å and λ_V=5510Å.

The color-luminosity correction is controlled by *n.*

Bayesian Inference:

To perform the SSP fits, we rely on Bayesian inference. This can be thought of as a process of updating a prior probability distribution function (pdf) for the model parameters θ based on observed data D_{obs}. We call the updated pdf the posterior and it can be obtained from the application of Bayes' Theorem:

$$p(\theta|D_{obs})=\frac{p(D_{obs}|\theta)\,p(\theta)}{p(D_{obs})}$$

To avoid computational drawbacks of Bayesian inference, we sample the posterior distribution, rather than calculating it in full. To do this, we use a Metropolis-Hasting Markov Chain Monte Carlo (M-H MCMC) algorithm[4].

Attenuation for DES galaxies:

The possible correlation between A_V and n is investigated in Fig. 1.

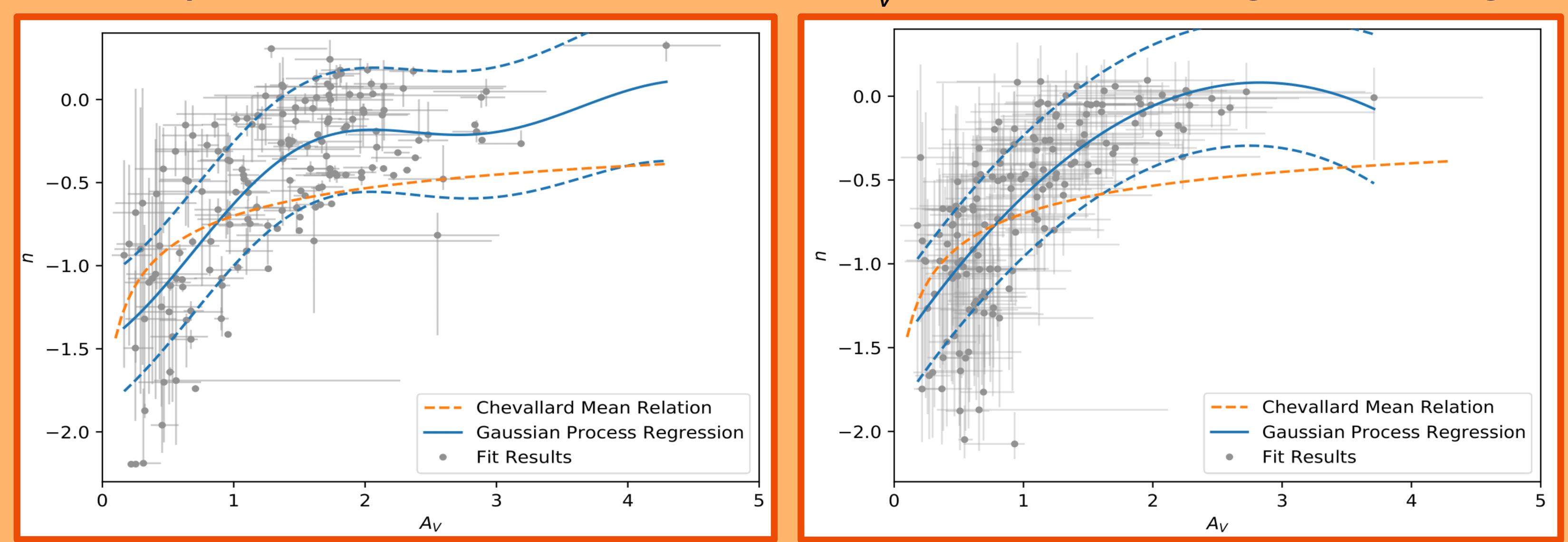

Figure 1: *Best-fit values for n and A_V for the fitted DES galaxies with DECam griz Global (Left) and Local (Right) photometry. A Gaussian Process Regression is shown in solid blue, with dashed blue lines defining a 68% credible interval. The relation found for similar galaxies by Chevallard (2013)[5] is shown in orange.*

Despite some scatter, there is a correlation between A_V and n, which mostly agrees with predictions made by Chevallard (2013)[5].

Cases with small A_V mostly correspond to looking at galaxies face-on. Compared to bluer photons, red photons emitted along the equatorial plane of a galaxy have a higher chance of being scattered away from the plane and escaping before being absorbed. For this reason, in these cases, we see a higher attenuation curve slope and lower values for *n*. For larger A_V, where we have mostly a side view of the galaxies, the radiation emitted from the deepest layers of the galaxy is fully absorbed. The radiation reaching us is dominated by light scattered into the line of sight and emitted by unobscured stars, which leads to a flatter attenuation curve and higher values for *n*.

Dust Properties vs Stellar Mass:

Another relevant question to the study of dust is the way the dust parameters, particularly the dust index *n*, evolve with the Stellar Mass M_* of the host galaxy . The best-fit values for *n* for each galaxy are plotted in Fig. 2 as a function of M_* .

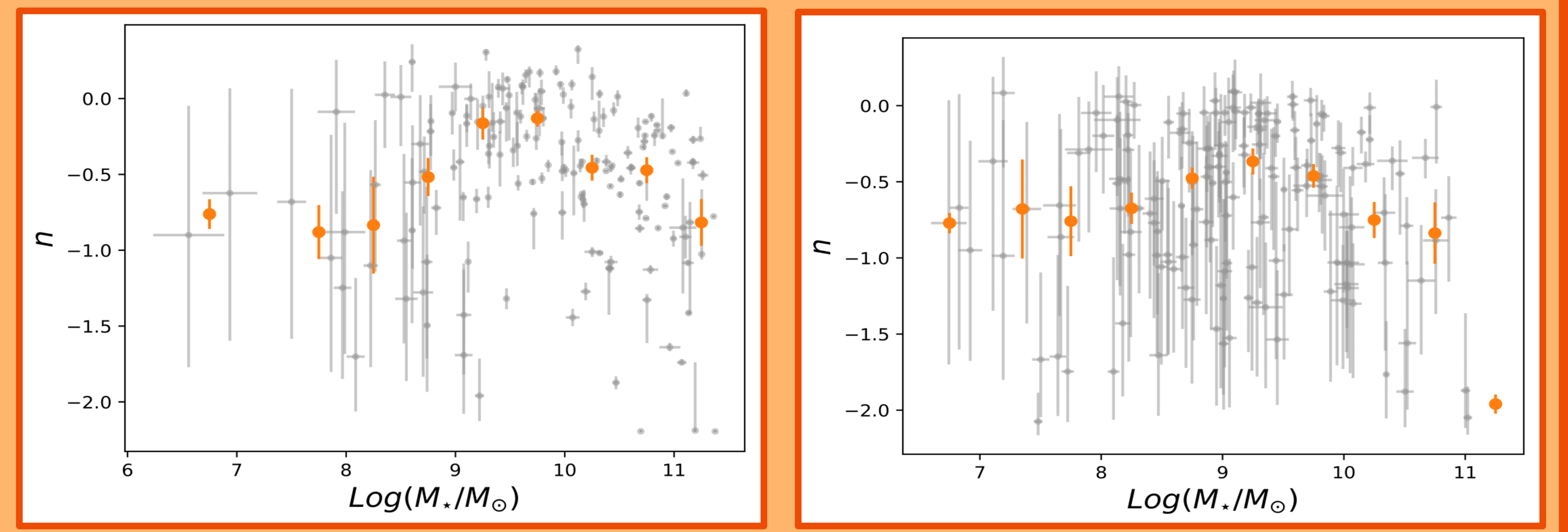

Figure 2: *Best-fit results for n as a function of $Log(M_*/M_\odot)$ for the fitted DES galaxies with DECam griz Global (Left) and Local (Right) photometry. Binned medians for each parameter are shown in orange.*

Despite some scatter, we see that *n* increases with Log($M_*/M_\odot$), up to Log($M_*/M_\odot$) ~ 9.5. This tendency is in agreement with literature data for star-forming galaxies[1]. This data, however, describes a continuous increase in *n*, which does not match our results. This is a consequence of our data set, which most likely includes not only star-forming galaxies, but also quiescent galaxies, whose attenuation curves tend to exhibit steeper slopes[1] and thus lower values for *n*.

Conclusions:

We have explored ways to probe the dust contents of SN Ia host galaxies. We found that, using Bayesian inference and DECam *griz* photometry, we can recover dust properties for host galaxies in a way consistent with literature predictions. Most importantly, we have shown that the values of *n* vary greatly across different galaxies, meaning a universal SN Ia calibration cannot be assumed.

This method not only broadens our ability to probe single SN, but also opens new possibilities for improvements in SN Ia calibration.

References:

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