Magellanic Clues to Spatially-resolved Extinction Corrections for Distant Galaxies in the *HST/JWST* Era

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Extinction by dust hampers and possibly biases our understanding of galaxies at all redshifts. Moreover, extinction is not constant within or across the face of a galaxy, nor from galaxy to galaxy. We are testing an approximate spatially-resolved correction method for use with future JWST and existing HST imagery.

Project Overview

In Tamura et al. (2009), we presented an empirical method to correct galaxy images for extinction due to interstellar dust embedded within those galaxies (interspersed with their stellar populations) on a pixel by pixel basis, using only rest-frame 3.6 and 0.55 μm (V-band) images. While this "β_V" method is approximate in nature, in its first application to a nearby late-type spiral galaxy we produced extinction maps and revealed hidden coherent galaxy structures like a stellar bar and ridges of dust (Tamura et al. 2010), while anomalous inferred central extinctions in several earlier-type disk galaxies proved powerful tracers of hidden AGN, independent of radio, optical spectroscopic, of X-ray observations (Tamura 2009). This method is particularly promising for deep mid-IR imaging surveys with the *James Webb Space Telescope* (*JWST*) in fields already covered (or soon to be covered) by the *Hubble Space Telescope* (*HST*) in visible and near-IR light, since their resolutions will be well-matched. Here we report on our follow-up investigation to explore the applicability, robustness, and fidelity of the β_V method on linear size scales from pc to kpc and in regions of varying star formation histories, metallicities, and dust content/distribution. We can do so by combining *WISE* 3.4 μm (or *Spitzer*/IRAC 3.6 μm) images of both Magellanic Clouds —the nearest astrophysical laboratories with a range of sub-solar metallicities— with ground-based 2MASS (Skrutskie et al. 2006) JHK_s and OGLE-III (Udalski et al. 2008) multi-year V and I reference images and catalogs. The proximity of the LMC and SMC and wealth of archival space- and ground-based data provide for the overconstrained boundary conditions needed to perform such analysis. We assess at $\sim 1''$ ($\sim$0.25–0.35 pc) resolution the properties of the stellar populations that contribute to the flux in each *WISE* (or IRAC) resolution element using the 2MASS and OGLE-III data. That allows us to measure the observed, and derive through modelling the inherent, V-to-3.4(3.6) μm flux ratio per *WISE* (IRAC) resolution element. Subsequent resampling and PSF-matching at geometrically increasing scales from pc to kpc resolution elements allows us to assess the accuracy and fidelity of the method as a multi-variate function of the resolution, underlying stellar population mixture, physical environments, and projected distribution of dust. The resulting graphs and tables of biases, corrections, and predicted $\beta_{\lambda,0}$ will serve as calibrations in the application of the spatially-resolved extinction correction method to galaxies at all redshifts, or those redshifts or conditions where the method is proved reliable.

The "β_V" Method

If we have knowledge of the intrinsic SED of a simple or composite stellar population, then we know the intrinsic flux ratio

$$\beta_{V,0} = f_{V,0}/f_{L,0} \ ,$$

where V is an arbitrary filter at visible wavelengths $\geq$0.4μm, and both dust extinction and emission by PAHs and silicates reach a minimum near 3.5μm(L band). This ratio will be a function of age, t, and metallicity, Z, for a simple stellar population, and will be a function of both the time-dependent star formation rate SFR(t) and metallicity $Z(t)$ for a composite one.

If the variation of $\beta_{V,0}$ is small, or if we can estimate t and Z, comparing the intrinsic ($\beta_{V,0}$) and observed (β_V) flux ratios therefore allows one to infer the missing flux in the V band.

The extinction in magnitudes is given by $A_V = (m_V - m_{V,0})$, which can be rewritten as:

$$A_V \simeq m_V - [-2.5 \log(\beta_{V,0} \times f_L) - V_{zp}] \ ,$$

where V_{zp} is the zeropoint magnitude for the V filter. The above equation, applicable on a pixel-by-pixel basis, is referred to by Tamura et al. (2009) as the "β_V"-method.

Modeling $\beta_{\lambda,0}$

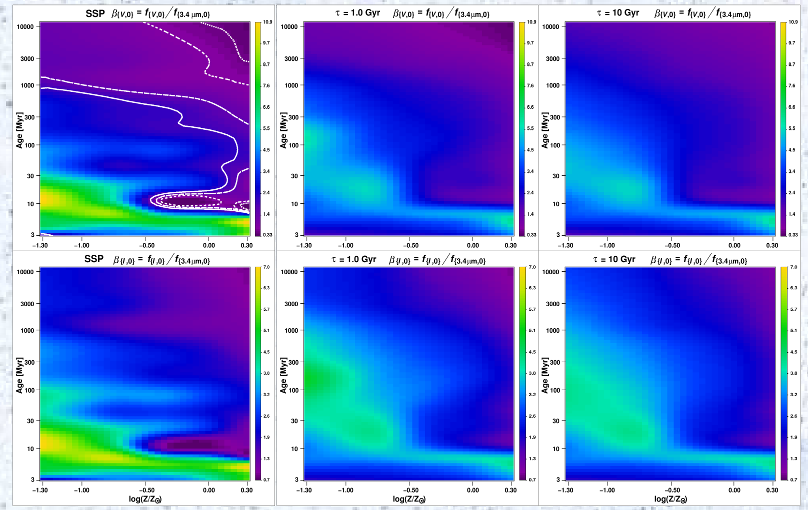


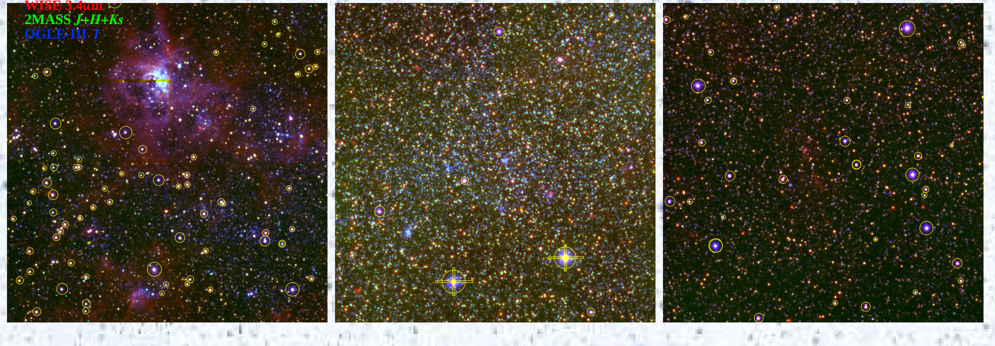
Fig. 1 — Modeled *intrinsic* values of β_λ (i.e., extinction-free $\beta_{\lambda,0}$) for [*top 3 panels*] the V filter ($\lambda_c \simeq$ 5470Å) and [*bottom 3 panels*] the I filter ($\lambda_c \simeq$ 7900Å), both with respect to the *WISE* 3.4μm passband. Shown are $\beta_{\lambda,0}$ as a function of metallicity (Z) and age (t) for [*left*] a passively evolving single stellar population (SSP); [*middle*] a composite stellar population representative of an exponentially declining star formation rate (SFR) with an e-folding time τ = 1 Gyr; and [*right*] a composite stellar population representative of continuous star formation (τ = 10 Gyr).

For more prolonged star formation episodes and, hence, mixed stellar populations, as would be observed in actual galaxy regions, sharp features visible in the SSP graphs —associated with the rapid evolution of massive stars— tend to be smoothed out toward older ages, and the total range in $\beta_{\lambda,0}$ is significantly reduced (e.g., from $\beta_{V,0}$=[0.33–10.9] for SSPs to [0.38–6.03] and [0.62–6.02] for declining SFRs with τ=1.0 and 10 Gyr).

We adopt the stellar population models of Bruzual & Charlot (2003) for older ages and `Starburst99` (Leitherer et al. 1999; Vazquez & Leitherer 2005) for young ages, and a smooth transition between the two for ages in the 25–95 Myr range. The contours in the upper left panel allow a direct comparison with Fig. 2 of Tamura et al. (2009), who used the SED library of Anders & Fritze-von Alvensleben (2003), and correspond to $\beta_{V,0}$ = 0.50 (*dotted*), 0.75 (*short dashed*), 1.50 (*long dashed*), and 2.00 (*solid*). We similarly model $\beta_{\lambda,0}(Z,t)$ for other common passbands in the visible range, and with respect to the *Spitzer* IRAC 3.6μm and ground-based L (3.5μm) passbands, and for more complex star formation histories (Jansen et al. 2014). For display purposes, the renditions here oversample our coarser native grid of metallicities and ages.

Observed β_λ in the LMC & SMC

Fig. 2 — Color composites of three 35′×35′ regions within the Large Magellanic Cloud, resampled to the 3.4μm image resolution. Shown are regions [*left*] around 30 Doradus, [*middle*] within the bar, and [*right*] in the outer disk. Yellow circles mark regions where the OGLE I data is affected by bright (mostly Galactic foreground) stars, and (small) cyan ellipses mark extended background objects seen through the LMC. Analysis of the stellar populations within regions with sizes from (a few tens of) pc to kpc using the multi-band observational data allows us to assess the age, metallicity and effective extinction within each region, and to compare the extinction with that inferred from β_λ to test the robustness of our approximate extinction correction method. Our analysis extends to the entire OGLE-III footprint in both Clouds, sampling regions with varied star formation histories, sub-solar metallicities, and suffering a large range in extinction by dust.



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