Predicting Intrinsic MIR to Visible-NIR Flux Ratios for Galaxies of Different Types using Spectral Synthesis Models of Composite Stellar Populations

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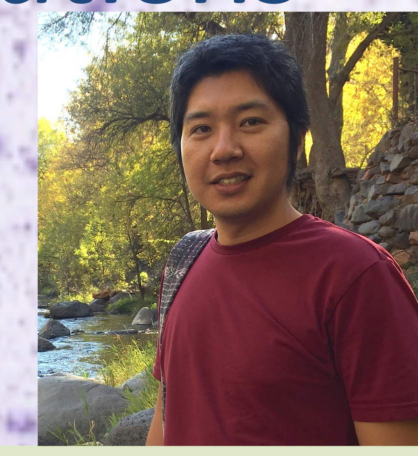
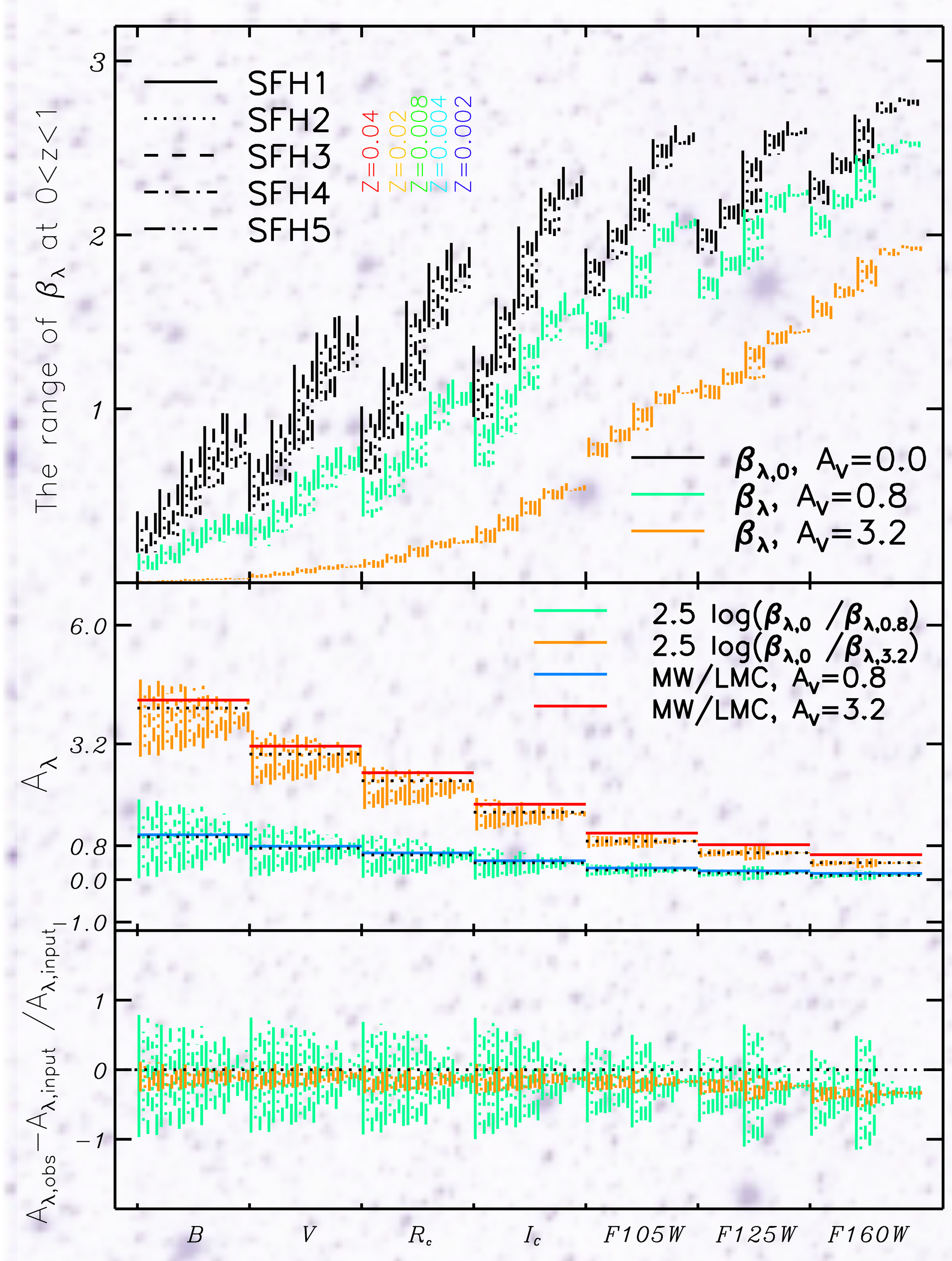


Abstract

We analyze the intrinsic flux ratios of simple and composite stellar populations for various visible–near-infrared filters with respect to 3.5μm (*L*-band), and their dependence on age, metallicity and star formation history. This study is motivated by the fact that light from galaxies is reddened and attenuated by dust via scattering and absorption, where different sightlines across the face of a galaxy suffer various amounts of extinction. Ignoring the effects of this extinction could lead to, e.g., lower inferred stellar mass, SFR or higher inferred metallicity. Tamura et al. (2009) developed an approximate method, dubbed the "β_V" method, which corrects for dust-extinction on a pixel-by-pixel basis, by comparing the observed flux ratio and an empirical estimate of the intrinsic flux ratio of optical and 3.5μm broadband data. Here, we aim to validate and test the limits of the "β_V" method for various filters spanning the visible through near-infrared wavelength range. Through extensive modeling, we test their assumptions for the intrinsic flux ratios for a wide variety of simple and composite stellar populations. We build spectral energy distributions (SEDs) of simple stellar populations (SSPs), by adopting `Starburst99` and `BC03` models for young (<9Myr) and old (>100Myr) stellar populations, respectively, and linear combinations of these for intermediate ages. We then construct composite stellar population (CSP) SEDs by combining SSP SEDs for various realistic star formation histories (SFHs) while taking metallicity evolution into account. We convolve filter response curves of various 0.44–1.65μm filters commonly used for *HST* imaging surveys and mid-IR filters in current (*WISE*, *Spitzer*/IRAC) and near-future use (*JWST*/NIRCam) with each model SED to obtain intrinsic flux ratios ($\beta_{\lambda,0}$) with respect to those mid-IR filters. Unconstrained, due to the prevalence of lower metallicity and younger stellar populations at higher redshifts, the total allowed range of $\beta_{\lambda,0}$ is large. At known redshifts, and in particular at low redshifts (z≅0.1), the $\beta_{\lambda,0}$ values are predicted to span a narrow range, especially for early-type galaxies, and are consistent with observed β_V values. The β_λ method can therefore serve as a 1st order dust correction method for large galaxy surveys that combine *JWST* (rest-frame 3.5μm) and *HST* (rest-frame visible) data.

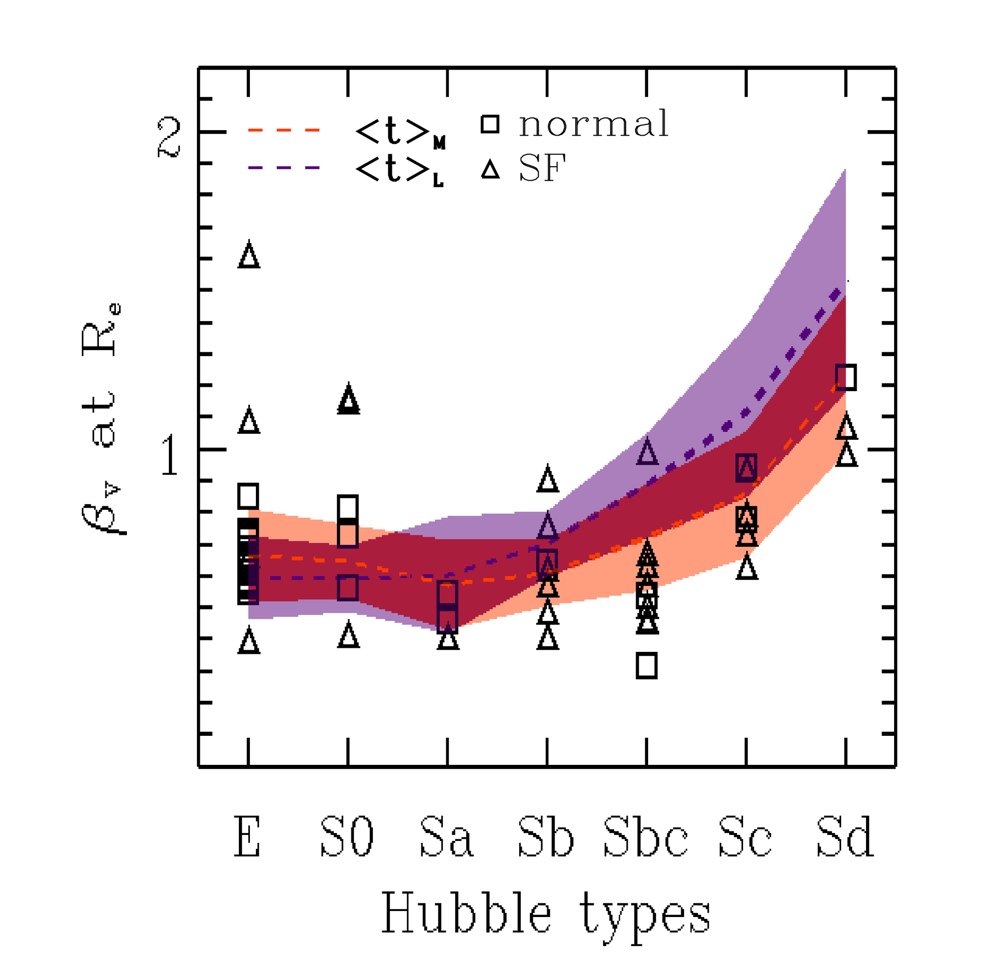


The range of $\beta_{\lambda,0}$ values for galaxies 0<z<1

(*top*) The ranges of $\beta_{\lambda,0}$ values at 0<z<1 with different choice of the optical–near-IR filters for various metallicities, SFHs and dust extinctions.

(*middle*) Comparison between dust extinction values calculated using the ratio of $\beta_{\lambda,0}$ and β_λ values, $A_{V,\mathrm{obs}}$, and dust extinction values at the central wavelengths of the filters using the MW/LMC extinction law, $A_{V,\mathrm{input}}$. Dotted lines are for $A_{V,\mathrm{input}}$ values with -0.05 and -0.19 offset for $A_{V,\mathrm{input}}$ =0.8 and $A_{V,\mathrm{input}}$=3.2, respectively, which are arising from neglecting residual extinction in the *L*-band filter.

(*bottom*) Normalized difference between input and inferred A_V for various assumed SFHs and metallicities, when the redshift is not significantly constrained (worst case).



β_V for different Hubble type of galaxies

The range of expected *V* to *L*-band flux ratios (β_V) as a function of Hubble type using mass-weighted (pale red) and luminosity-weighted (pale violet) ages, adopting typical A_V values at R_e from González Delgado et al. (2015). The mean trends are indicated by the dashed red and blue curves, respectively. The data points represent observed normal quiescent and star-forming nearby galaxies from Brown et al. 2014). Most of the observed β_V values agree well with the predicted values for their Hubble type.

Acknowledgements
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References

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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

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

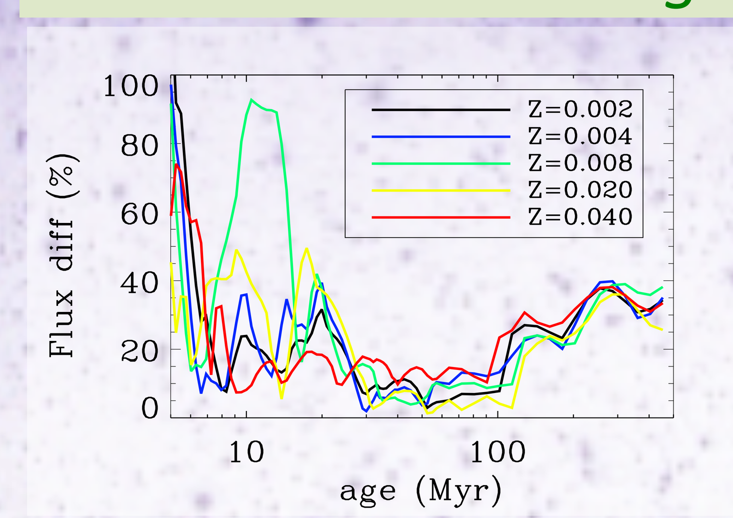
where V is an arbitrary filter at visible wavelengths ≥0.4μm, and both dust extinction and emission by PAHs and silicates reach a minimum near 3.5μm(*L* band). This ratio will be a function of age, t, and metallicity, Z, for a simple stellar population, and will be a function of both the time-dependent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

Combining SB99 & BC03

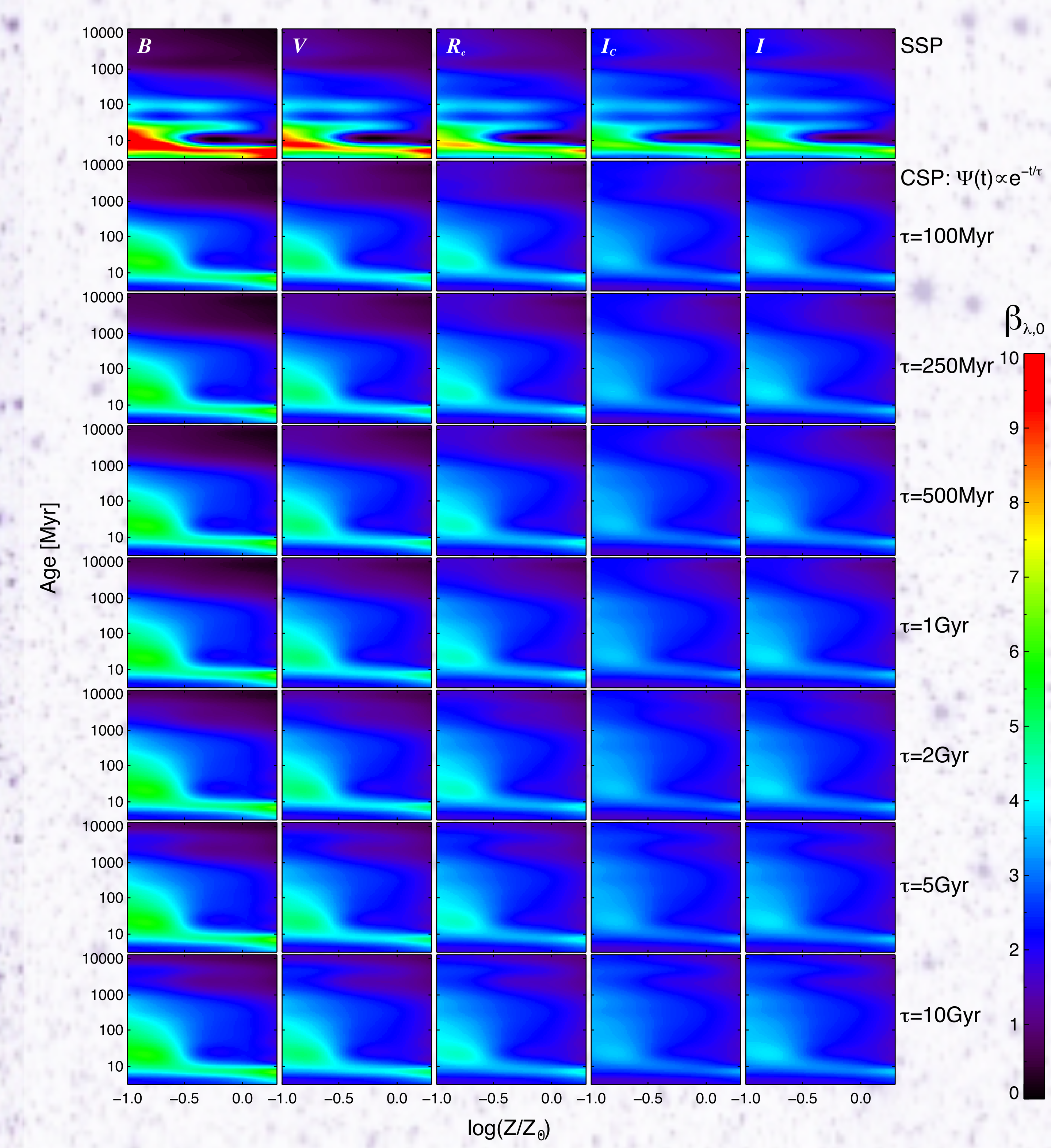


We built SSP SEDs by adopting the Geneva track of `SB99` for young ages and the Padova track of `BC03` for old ages. We scrutinized absolute flux differences between `SB99` and `BC03`, and interpolate between `SB99` and `BC03` SEDs in the intermediate age range.

Composite Stellar Population (CSP) Modeling

We generated CSP SEDs by convolving SSP SEDs as a function of SFH (ψ(t)).

$$F_{\lambda,\mathrm{CSP}}(t',Z') = \sum_{t=t_0}^{t'} F_{\lambda,\mathrm{SSP}}(t, Z(t,Z'))\psi(t)\delta t$$



Maps of $\beta_{\lambda,0}$ values referenced to the Johnson *L*-band filter as a function of metallicity and age of the stellar populations for the (*left to right*) Johnson *B*, *V*, Kron-Cousins *Rc*, *Ic*, and Johnson *I*-band filters for (*top to bottom*) SSP and CSPs resulting from exponentially declining SFHs with τ = 100, 250, 500 Myr, 1, 2, 5, and 10 Gyr.