

Isolating the Dependence of Integrated Galaxy SED Flux on Stellar Population Age

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Abstract

The integrated spectral energy distribution (SED) of a galaxy depends on several physical parameters, including stellar population age, metallicity, and dust attenuation, which often exhibit strong degeneracies. In this work, we investigate how the total emergent flux of a galaxy SED varies with stellar population age when other parameters are held fixed. Using simple galaxy SED models generated with the **Prospector** framework, we construct a baseline model and systematically vary the stellar population age over several orders of magnitude. We find that the ratio of the total flux at a given age to that of a reference age is well-described by a power-law relation over a wide age range. We further examine the robustness of this scaling by repeating the analysis for different choices of metallicity and dust attenuation. While the normalization of the relation varies with these parameters, the power-law slope remains relatively stable within the explored parameter space. These results provide a simplified characterization of age-driven flux evolution in galaxy SED models and highlight both its utility and its limitations.

1 Introduction and Motivation

The spectral energy distribution (SED) of a galaxy encodes information about its stellar population, chemical composition, dust content, and star formation history. Interpreting observed galaxy SEDs therefore requires understanding how changes in these physical parameters affect the emergent radiation. In practice, many of these parameters are strongly degenerate: for example, older stellar populations can appear similar to younger but dust-reddened ones, while changes in metallicity can mimic age-related effects over certain wavelength ranges.

A common approach to addressing these degeneracies involves fitting parametric or non-parametric models directly to observed photometric or spectroscopic data. Such methods are powerful and form the backbone of modern galaxy property inference, allowing multiple physical parameters to be constrained simultaneously in a statistically rigorous manner.

At the same time, complementary studies based on simplified models, in which individual parameters are varied in a controlled fashion, can be useful for building physical intuition and understanding qualitative trends. By isolating specific parameters, these controlled experiments help clarify how different physical processes imprint themselves on the spectral energy distribution, thereby providing context for the interpretation of more sophisticated fitting results.

The primary motivation of this work is to isolate and examine the effect of stellar population age on the integrated flux of a galaxy SED in the simplest possible setting. By fixing other physical parameters and systematically varying the stellar population age, we aim to understand whether the resulting flux evolution follows a simple, interpretable scaling relation. Such a characterization can provide insight into how strongly galaxy luminosities evolve with age and how robust this behavior is to changes in other physical properties such as metallicity and dust attenuation.

Rather than attempting to model realistic galaxy populations or perform parameter inference on observational data, this study focuses on controlled numerical experiments using synthetic SEDs. The emphasis is on identifying trends, assessing their stability, and clearly stating the assumptions and limitations under which they arise.

2 Model and Methodology

2.1 Stellar Population Synthesis Framework

In this work, we employ the **Prospector** stellar population synthesis (SPS) framework to generate model galaxy spectral energy distributions (SEDs). **Prospector** combines flexible stellar population models with physically motivated parameterizations of galaxy properties, and is widely used for interpreting galaxy photometric and spectroscopic data.

For the purposes of this study, we intentionally adopt a highly simplified model configuration. Rather than fitting observational data, our goal is to generate synthetic spectra under controlled variations of individual physical parameters, allowing us to isolate and study their qualitative influence on the emergent SED.

The underlying stellar population is modeled using a composite stellar population (CSP) basis, assuming a single stellar population characterized by a uniform age, metallicity, and dust attenuation. Redshift effects are neglected, and all spectra are analyzed in the rest frame.

2.2 Baseline Model Parameters

We define a baseline galaxy model characterized by the following parameters:

- Stellar mass, $M_* = 10^{10} M_\odot$
- Stellar population age, $t_{\text{age}} = 1.0 \text{ Gyr}$
- Metallicity, $\log(Z/Z_\odot) = 0.0$
- Dust attenuation parameter, $\text{dust2} = 0.2$

All parameters are held fixed at these values unless explicitly varied. This baseline model serves as a reference against which changes in the spectral properties induced by varying stellar age are measured.

2.3 Generation of Synthetic Spectra

For a given set of model parameters, **Prospector** generates a rest-frame SED,

$$F_\lambda(\lambda; t_{\text{age}}, Z, \tau_{\text{dust}}), \quad (1)$$

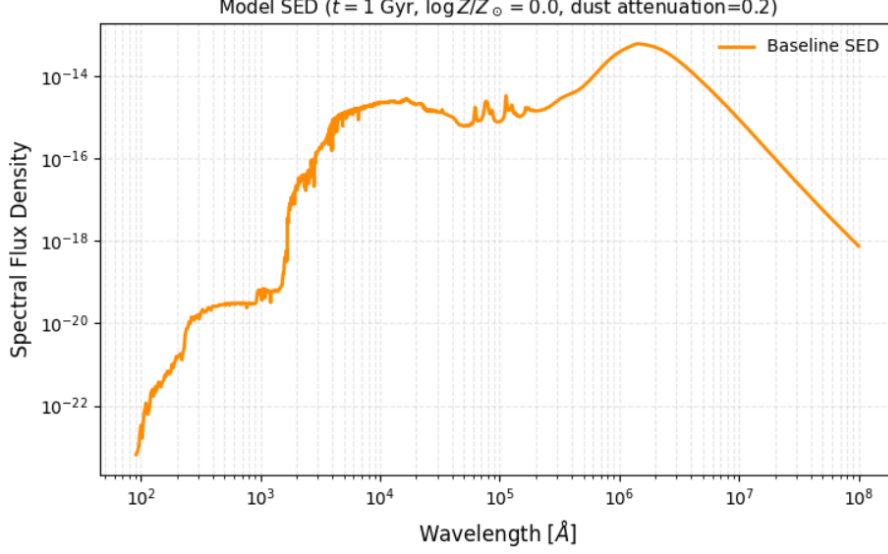


Figure 1: Model SED

sampled over a wavelength range spanning the ultraviolet to mid-infrared. Figure 1 shows the spectral energy distribution generated for a stellar population with fixed mass, age, metallicity, and dust attenuation. To quantify the overall spectral output of the model, we compute the integrated flux,

$$F_{\text{tot}}(t_{\text{age}}) = \int F_{\lambda}(\lambda; t_{\text{age}}) d\lambda, \quad (2)$$

using numerical integration over the full wavelength grid.

2.4 Age Variation and Flux Normalization

To study the dependence of the integrated flux on stellar population age, we vary t_{age} over the range

$$t_{\text{age}} \in [10^{-2}, 10^1] \text{ Gyr}, \quad (3)$$

sampling this interval logarithmically with 6000 points. All other parameters are held fixed.

For each age, we compute the ratio of the integrated flux to that of the baseline model,

$$R(t_{\text{age}}) = \frac{F_{\text{tot}}(t_{\text{age}})}{F_{\text{tot}}(t_{\text{ref}})}, \quad (4)$$

where $t_{\text{ref}} = 1.0$ Gyr denotes the reference age of the baseline model.

This normalization removes trivial scaling effects associated with stellar mass and distances, and enables a direct comparison of how the SED shape evolves with age.

2.5 Power-Law Characterization

Inspection of the normalized flux ratios reveals an approximate power-law dependence on age. We therefore model this behavior as

$$R(t_{\text{age}}) = A t_{\text{age}}^{-\alpha}, \quad (5)$$

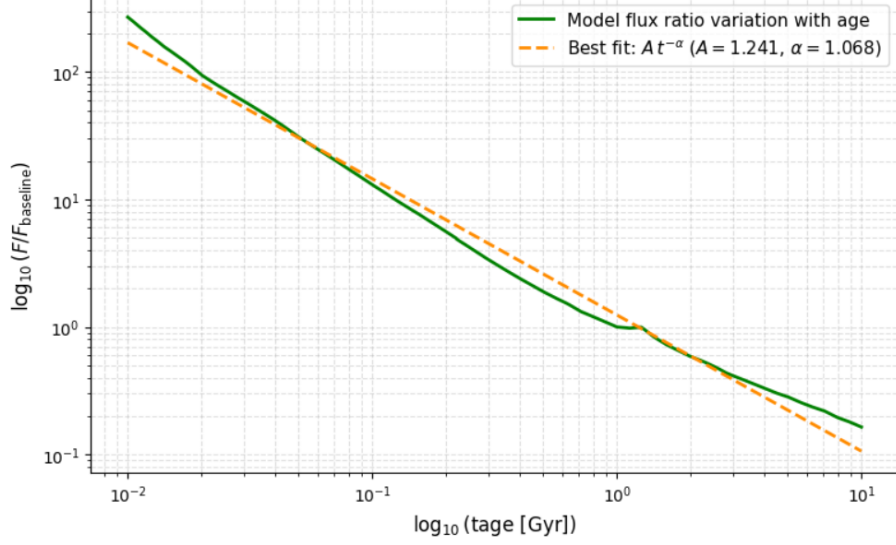


Figure 2: Log–log plot of normalized integrated SED flux as a function of stellar age, showing a clear power-law scaling. The dashed line indicates the best-fit power-law model.

where A is a normalization constant and α characterizes the sensitivity of the integrated flux to stellar age.

To estimate A and α , we perform a linear fit in logarithmic space,

$$\log R = \log A - \alpha \log t_{\text{age}}, \quad (6)$$

using least-squares regression.

In Figure 2 the integrated flux exhibits a clear monotonic decline with increasing stellar age. When plotted in logarithmic space, the relation becomes approximately linear, indicating a power-law dependence of the form

$$\frac{F(t)}{F_{\text{baseline}}} \propto t^{-\alpha}. \quad (7)$$

This motivates the use of a simple power-law model to characterize the age dependence of the integrated spectral energy distribution (SED) flux.

2.6 Robustness of the Age-Flux Scaling

To assess the robustness of the inferred power-law dependence of integrated flux on stellar age, the analysis described above was repeated for a set of alternative baseline models. Rather than fixing a single reference galaxy, the baseline model itself was modified by varying metallicity and dust attenuation independently, while keeping all other parameters unchanged. For each modified baseline model, the stellar age was again varied over the same range, and the normalized integrated flux was re-computed and fitted with a power-law relation of the form

$$\frac{F(t)}{F_{\text{baseline}}} = A t^{-\alpha}. \quad (8)$$

This procedure isolates the influence of individual physical parameters on the fitted power-law coefficients, allowing the sensitivity of the scaling to metallicity and dust attenuation to be examined in a controlled manner.

2.6.1 Dependence on Metallicity

The metallicity of the baseline model was varied over the range $-1.7 \leq \log(Z/Z_\odot) \leq +0.18$, while dust attenuation and stellar mass were held fixed. For each metallicity value, the best-fit power-law parameters (A, α) were determined. The resulting values are summarized in Table 1.

Table 1: Best-fit power-law parameters obtained by varying the metallicity of the baseline model. Here $\log(Z/Z_\odot)$ denotes the stellar metallicity relative to solar, while A and α are defined through $F/F_{\text{baseline}} = A t^{-\alpha}$.

| $\log(Z/Z_\odot)$ | α | A |
|-------------------|----------|-------|
| +0.18 | 1.064 | 1.227 |
| +0.10 | 1.066 | 1.234 |
| -0.40 | 1.070 | 1.190 |
| -0.70 | 1.074 | 1.119 |
| -1.00 | 1.078 | 1.053 |
| -1.40 | 1.078 | 1.108 |
| -1.70 | 1.079 | 1.132 |

Across this metallicity range, the power-law slope α exhibits a weak but systematic dependence on metallicity. Specifically, α increases modestly as metallicity decreases, rising from $\alpha \simeq 1.064$ at $\log(Z/Z_\odot) = +0.18$ to $\alpha \simeq 1.079$ at $\log(Z/Z_\odot) = -1.7$.

Physically, this behavior can be understood in terms of stellar population evolution. Lower-metallicity stellar populations tend to be more luminous at fixed mass and age, particularly at early times, due to reduced line blanketing and higher effective temperatures. As these populations age, their luminosity declines more rapidly relative to the baseline, leading to a slightly steeper age dependence of the integrated flux. Despite this trend, the overall variation in α across nearly two orders of magnitude in metallicity remains small ($\Delta\alpha \lesssim 0.02$), indicating that the power-law slope is remarkably insensitive to metallicity.

2.6.2 Dependence on Dust Attenuation

An analogous analysis was performed by varying the dust attenuation parameter *dust2* over the range $0.3 \leq \textit{dust2} \leq 2.5$, while fixing metallicity at its baseline value. The resulting best-fit parameters are again listed in Table 2.

Table 2: Best-fit power-law parameters obtained by varying the dust attenuation parameter *dust2* of the baseline model, while keeping metallicity fixed.

| <i>dust2</i> | α | A |
|--------------|----------|-------|
| 0.3 | 1.057 | 1.235 |
| 0.6 | 1.029 | 1.194 |
| 1.0 | 0.998 | 1.180 |
| 1.5 | 0.969 | 1.175 |
| 2.5 | 0.940 | 1.154 |

In this case, the power-law slope α shows a clearer monotonic trend, decreasing from $\alpha \simeq 1.057$ at low dust attenuation to $\alpha \simeq 0.940$ at the highest attenuation considered. The normalization A also decreases with increasing dust content.

This behavior reflects the wavelength-dependent suppression of stellar light by dust. At higher attenuation, younger stellar populations---which contribute disproportionately to the ultraviolet and optical flux---are more strongly obscured. As a result, the contrast between young and old populations is reduced, leading to a shallower decline of integrated flux with age and hence a smaller value of α .

2.6.3 Interpretation and Robustness

Taken together, these results demonstrate that the age dependence of the integrated flux is well described by a power-law over a wide range of physical conditions. While both metallicity and dust attenuation influence the normalization A and, to a lesser extent, the slope α , the overall variation in α remains limited. Across all models explored, α lies within the approximate range $0.94 \lesssim \alpha \lesssim 1.08$.

The relative stability of the power-law slope suggests that the decline of integrated stellar light with age is governed primarily by stellar evolutionary effects, with secondary modulation by metallicity and dust. In this sense, α can be regarded as a robust characterization of the age-driven fading of galaxy spectral energy distributions, while A encodes additional dependence on environmental and compositional parameters.

2.6.4 Choice of Parameter Ranges

The adopted metallicity range spans from extremely metal-poor systems ($\log(Z/Z_\odot) \approx -1.7$), characteristic of dwarf galaxies and early-universe stellar populations, to mildly super-solar metallicities typical of massive star-forming galaxies. Similarly, the dust attenuation range $0 \lesssim \text{dust2} \lesssim 2.5$ encompasses values commonly used in stellar population synthesis studies, covering dust-poor systems as well as heavily attenuated star-forming galaxies.

Restricting the analysis to these physically motivated bounds ensures that the inferred trends remain relevant for realistic galaxy populations, while avoiding regimes in which the underlying model assumptions may no longer be reliable.

2.7 Behavior at Zero Dust Attenuation

As an additional test, the case of zero dust attenuation ($\text{dust2} = 0.0$) was examined. While the integrated flux still shows an overall decrease with increasing stellar age, the age--flux relation in this case exhibits noticeable non-smooth variations rather than a clean monotonic trend.

This behavior is not physical in origin but is most plausibly attributed to numerical effects. In the absence of dust, the emergent SED retains sharper spectral features and stronger sensitivity to rapid changes in the contribution of short-lived stellar populations. When the integrated flux is computed over a discrete wavelength grid and evaluated across a finely sampled age sequence, these effects can introduce small irregularities in the flux ratios.

Even modest dust attenuation acts to smooth the spectrum and suppress such high-frequency structure, leading to a more stable and well-behaved power-law relation. For this reason, the $\text{dust2} = 0.0$ case was excluded from the quantitative power-law fitting and robustness analysis presented above. This exclusion ensures that the inferred trends reflect physically meaningful behavior rather than numerical artifacts.

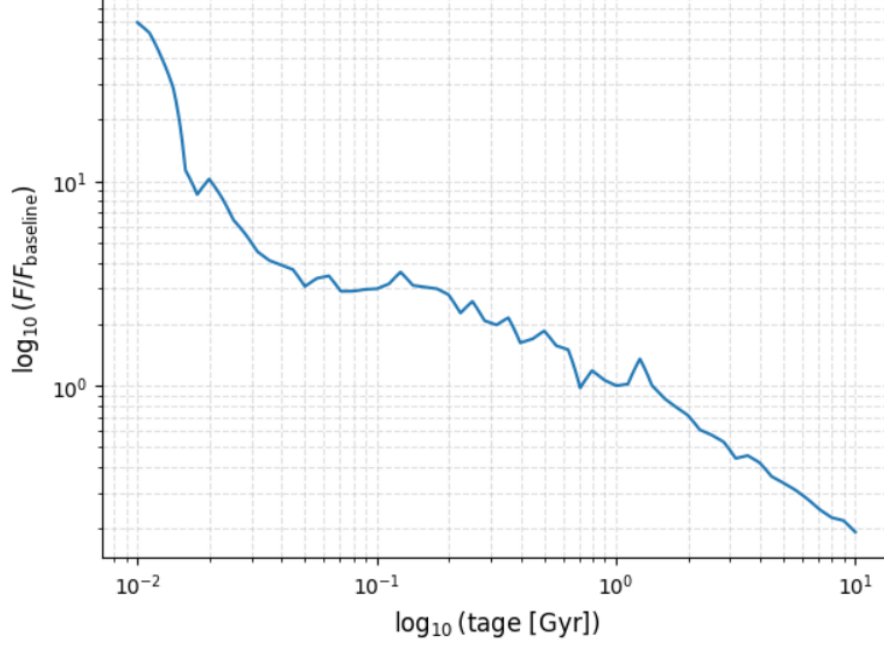


Figure 3: Normalized integrated SED flux as a function of stellar age for different zero value of the dust attenuation parameter. The zero-dust case exhibits increased scatter compared to models with non-zero attenuation.

In Figure 3 we see that while the overall decline of integrated flux with stellar age is preserved, the case of zero dust attenuation shows noticeable non-smooth fluctuations. This behavior contrasts with the smoother, monotonic trends observed for models with non-zero dust attenuation.

3 Conclusions and Limitations

3.1 Summary of Results

In this work, we investigated the dependence of the integrated galaxy spectral energy distribution (SED) flux on stellar population age using simplified stellar population synthesis models generated with the PROSPECTOR framework. By holding stellar mass, metallicity, and dust attenuation fixed and varying the stellar age over several orders of magnitude, we found that the normalized integrated flux declines monotonically with age and is well described by a power-law relation of the form

$$\frac{F(t)}{F_{\text{baseline}}} = A t^{-\alpha}.$$

For the fiducial baseline model, the best-fit power-law slope was found to be $\alpha \simeq 1.07$, indicating a strong and systematic fading of integrated stellar light with increasing age. When the baseline model was modified by varying metallicity or dust attenuation independently, the normalization A showed noticeable variation, while the slope α remained confined to a relatively narrow range ($0.94 \lesssim \alpha \lesssim 1.08$).

These results suggest that the age-driven decline of integrated SED flux is governed primarily by stellar evolutionary effects, with metallicity and dust acting as secondary modifiers rather than dominant drivers of the scaling behavior.

3.2 Physical Interpretation

The approximate universality of the power-law slope reflects the underlying physics of stellar population aging: as massive, short-lived stars evolve off the main sequence, the total emitted luminosity decreases in a predictable manner. Variations in metallicity alter stellar temperatures and lifetimes, while dust attenuation selectively suppresses emission from younger, bluer stars, leading to modest but systematic changes in the inferred scaling parameters.

The emergence of non-smooth behavior in the zero-dust case highlights the role of dust in smoothing spectral contributions across wavelength and age, and emphasizes that even idealized dust-free models may exhibit numerical or population-driven irregularities.

3.3 Limitations and Future Directions

This study intentionally adopts a highly simplified modeling approach. The use of a single-age stellar population neglects extended or complex star formation histories, which are common in real galaxies. Additionally, the analysis focuses on integrated flux rather than wavelength-dependent features, thereby discarding potentially important spectral information.

No observational data were considered, and parameter inference was not performed. As a result, the conclusions drawn here are qualitative in nature and are not intended to directly constrain real galaxy populations.

Future work could extend this analysis by incorporating more realistic star formation histories, exploring wavelength-resolved flux scaling, or testing whether similar power-law behavior emerges in full SED fitting of observational datasets. Such extensions would help clarify the domain of validity and practical usefulness of the simplified scaling relations identified in this study.