Stellar Continuum Fitting Utilizing Non-uniform Dust Coverage

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Abstract

The far-ultraviolet (FUV) spectra of star-forming galaxies are dominated by young, massive stars and provide key constraints on stellar population properties. However, most continuum-fitting methods assume uniform dust geometry, potentially oversimplifying the complex distribution of dust in galaxies.

We extend FiCUS (Fitting the Continuum of UV Spectra; Saldana-Lopez +2023) to incorporate non-uniform dust covering fractions and apply this framework to FUV spectra from the COS Legacy Archive Spectroscopic Survey (CLASSY; Berg+ 2022). We find that models with partial dust coverage require higher attenuation than uniform-screen models, while inferred stellar population properties remain robust.

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Background

Understanding the UV Continuum

- Understanding the ionizing stellar populations of galaxies is crucial to modeling and interpreting the spectra of galaxies across cosmic time.
- The FUV region (1200-2000 Å) of stellar continuum contains key features, such as stellar winds and spectral slopes, which constrain age, metallicity, and star formation rates.
- **Major constraint**: as stellar light propagates through galaxies, it interacts with dust and gas, causing light to be absorbed and re-emitted at different wavelengths.
  - This process, known as dust attenuation, alters the observed spectra of galaxies.

Research Motivation

- Parker (+2026) fit the FUV stellar continua of CLASSY galaxies using stellar population synthesis (SPS) models, assuming a uniform dust screen.

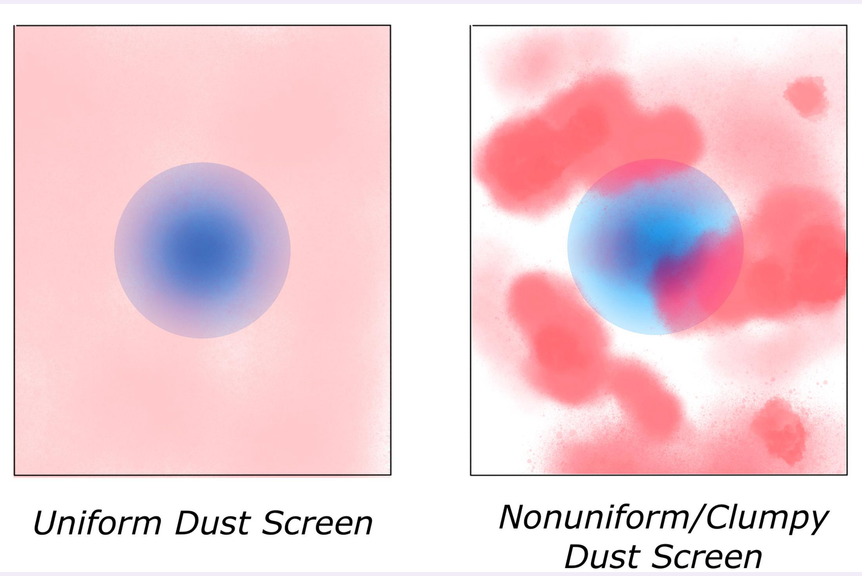

Figure 1. Visual representation of how dust screen configurations obscure the light of a star cluster.

- This method is effective for first-order characterization but does not consider the realistic geometry of dust in star forming regions where young massive stars are located (see Figure 1).
- Non-uniform dust geometry significantly alters spectral slope and dilutes stellar features, impacting inferred quantities.
- Accurately modeling dust geometry and its effects is thus essential for understanding galaxies in the local universe and distant universe.

In this work, we revisit the FUV stellar continuum of the CLASSY galaxies with the FiCUS framework in combination with Starburst99, a SPS model for star forming galaxies, and investigate these effects by implementing non-uniform dust screens with variable covering fraction.

Sample

The CLASSY survey contains the FUV HST/COS spectra of 45 star-forming galaxies at low redshift (z<0.2), exhibiting similar properties to those seen at high redshift. The properties of these galaxies span a wide range of stellar mass, metallicity, ionization, and reddening . The high-resolution spectra of CLASSY strengthens our abilities to infer their properties, including dust geometry.

The previous fittings from Parker (+2026 utilize the extinction model from Reddy (+2016) and assume uniform dust screen.

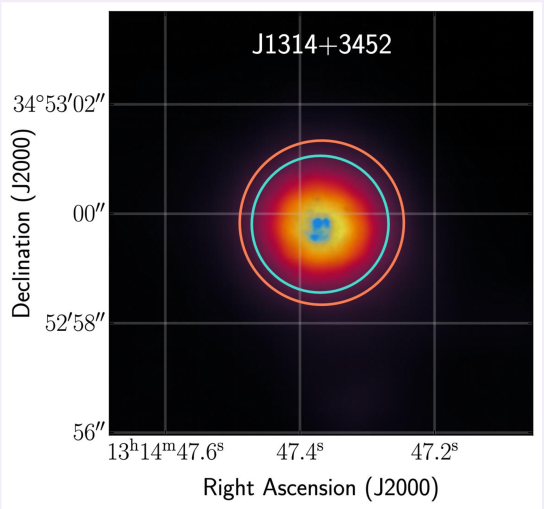

Figure 2. Hα imaging of J1314-3452 . The blue overlay indicates the location of massive stars. The circles enclose FUV HST(blue) and SDSS (orange) spectra apertures.

Methods

Continuum Fitting

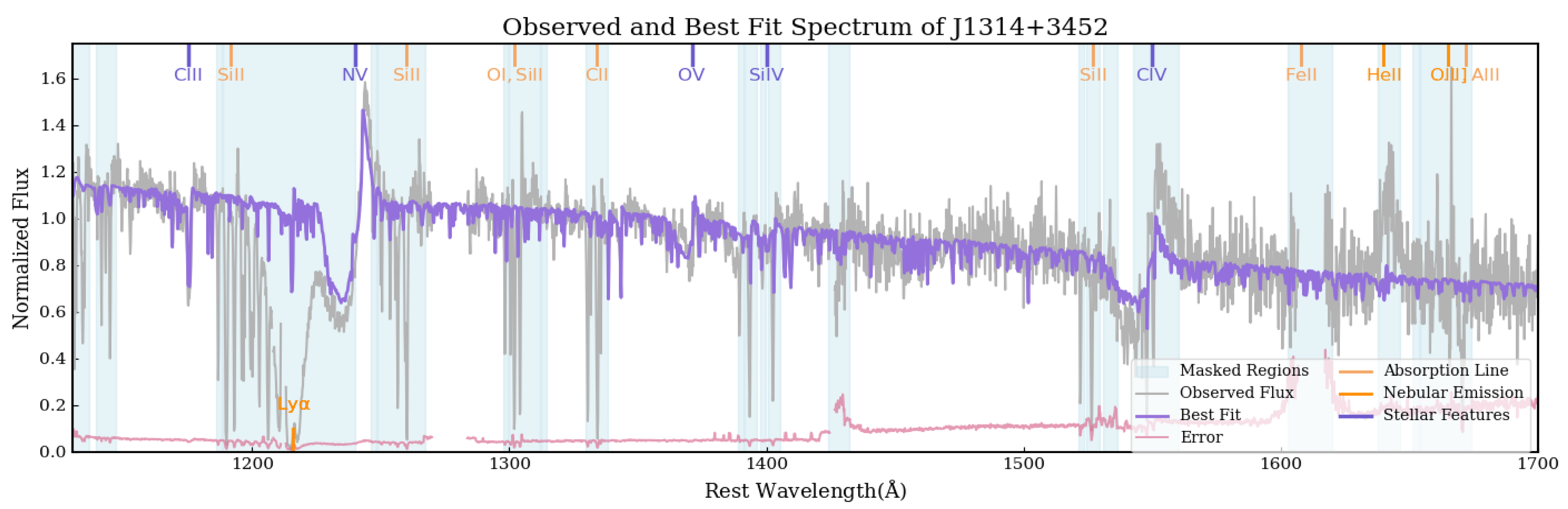

Figure 3. The observed (gray) and best fit (purple) FUV spectrum of J1314+3452. The blue-shaded regions mask contamination from emissions and absorption features. Properties: $Age(Myr) = 3.78 \pm 0.87, Z/Z_{\odot} = 0.18 \pm 0.008,\ \mathrm{E(B-V)} = 0.327 \pm 0.033, c_f = 0.975 \pm 0.003$.

The best-fit stellar continuum model yields the age, metallicity, E(B–V), and covering fraction (c_f), with uncertainties estimated via 300 Monte Carlo realizations per galaxy in which synthetic observed spectra are generated by randomizing fluxes according to their uncertainties and refit.

Implementing Non-uniform Dust as a Parameter

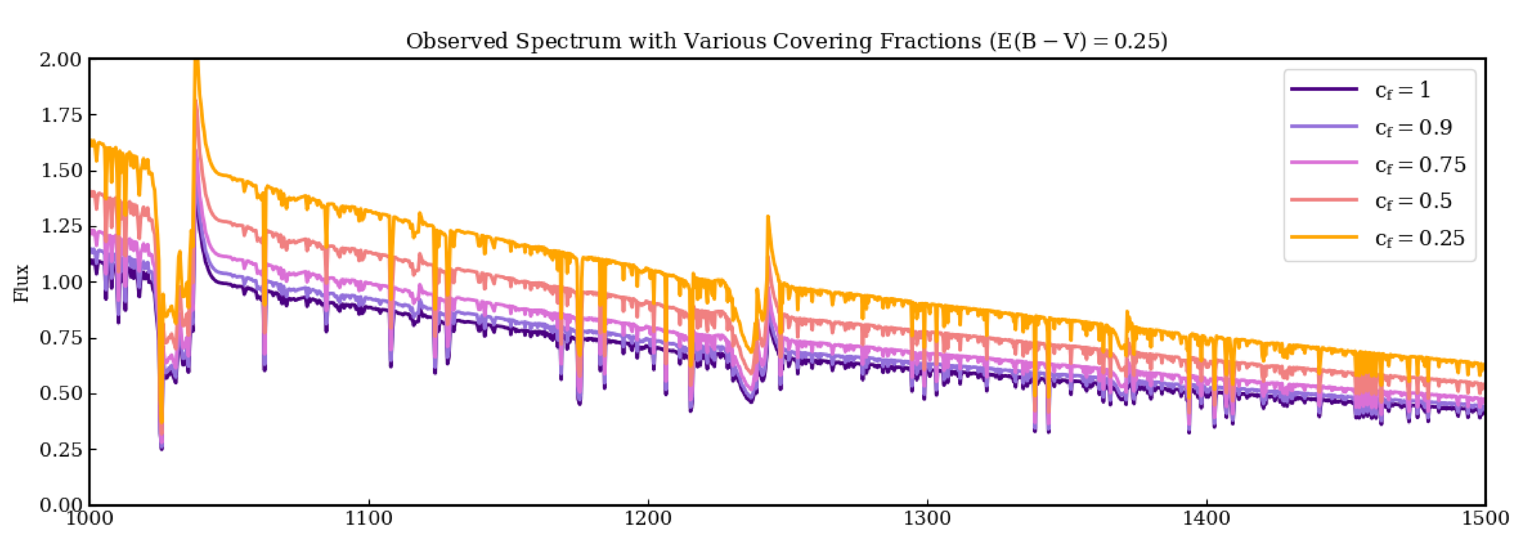

Figure 4. Effects of covering fraction on observed spectrum of a theoretical galaxy from the Starburst99 library

- For uniform dust, observed flux is reddened by a factor of dust relative to intrinsic flux given by: $\mathrm{F_o}(\lambda) = \mathrm{F_i}(\lambda) \times 10^{0.4\mathrm{E(B-V)}k'(\lambda)}$ (Calzetti+1994).
  - $F(\lambda)$ represents the observed or intrinsic flux, $k'^{(\lambda)}$ is the reddening coefficient for the extinction model, and $\mathrm{E(B-V)}$ is the difference in attenuation.
- Accounting for non-uniform dust, we added c_f as a free parameter, allowing it to vary ($0 \le c_f \le 1$)

$$\mathbf{F_o(\lambda) = F_i(\lambda)(1 - c_f + c_f \times 10^{0.4E(B-V)k'(\lambda)})}$$

- Stellar continuum fits were rerun in FiCUS with the *lmfit* python package (Newville +2014) to perform a non-linear least squares minimization to determine the best fit and related uncertainties.
- A limitation of implementing clumpy dust model is the extensive computational time needed to complete simulations. To address this, we parallelized the fitting process so multiple simulations could run simultaneously.

Results

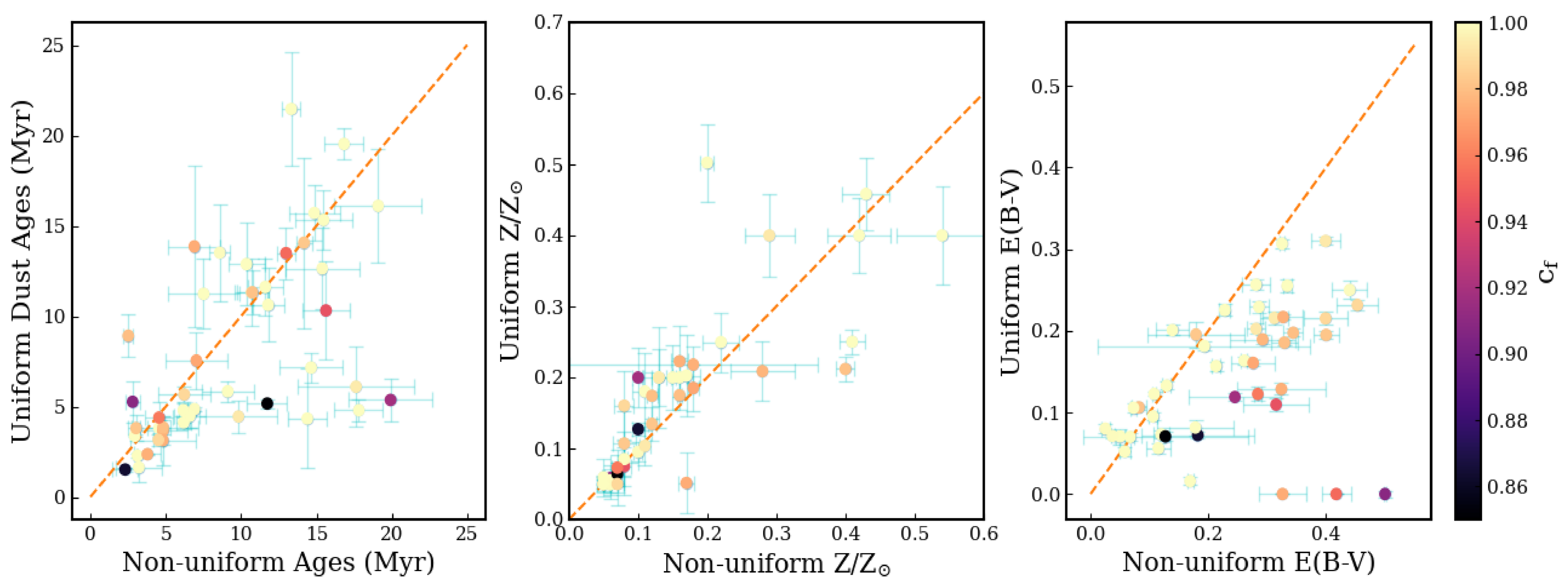

Figure 5. The properties from previous fittings in Parker(+2026) vs new fittings for non-uniform dust covering for attenuation (right), metallicity (center), and stellar ages (left).

We simultaneously recover stellar ages, metallicities, dust attenuation, and covering fraction for each galaxy using FiCUS, allowing us to assess the impact of non-uniform dust geometry:

- Inferred ages and metallicities of the ionizing stellar populations are largely insensitive to the assumed dust covering fraction but remain robust
- Models with partial dust coverage ($c_f < 1$) require higher overall attenuation to reproduce the observed continua, reflecting the reduced effective reddening along unobscured lines of sight (see Figure 5.3)
- The majority of galaxies converge to best-fit covering fraction values near unity($c_f \approx 0.99 - 1$)

Key Result: Stellar ages and metallicities remain stable across dust geometries, while partial covering requires higher attenuation

Discussion

Our results show that the inferred stellar ages and metallicities remain robust and diverse regardless of the assumed dust geometry. This reflects the fact that the covering fraction primarily modifies the slope of the stellar continuum (see Figure 4), while the overall age and metallicity distributions are constrained by broader spectral features that are less sensitive to dust geometry.

Ultimately, these results highlight both the strength of FiCUS in recovering stable stellar population properties and the inherent limitation imposed by our single line-of-sight view of unresolved galaxies.

The constraints on covering fraction highlight the need for additional diagnostics, such as nebular continuum and emission fitting or infrared constraints. Future extensions of FiCUS incorporating emission-line fitting or joint UV–IR analysis may improve constraints on dust geometry.

References

1. Saldana-Lopez, A., Schaerer, D., Chisholm, J., et al. 2023,MNRAS, 522, 6295, doi: 10.1093/mnras/stad1283V
2. Parker, K. S., Berg, D. A., Chisholm, J., et al. 2026, ApJ,997, 98, doi: 10.3847/1538-4357/ae22d9
3. Berg, D. A., James, B. L., King, T., et al. 2022, ApJS, 261,31, doi: 10.3847/1538-4365/ac6c03
4. Reddy, N. A., Steidel, C. C., Pettini, M., & Bogosavljevi ´c,M. 2016, ApJ, 828, 107,doi: 10.3847/0004-637X/828/2/107
5. Calzetti, D., Kinney, A. L., & Storchi-Bergmann, T. 1994,ApJ, 429, 582, doi: 10.1086/174346
6. Newville, M., Stensitzki, T., Allen, D. B., & Ingargiola, A.2014, LMFIT: Non-Linear Least-Square Minimizationand Curve-Fitting for Python, 0.8.0, Zenodo,doi: 10.5281/zenodo.11813