Mapping the Spatial Distribution of Dust Extinction within NGC 0959

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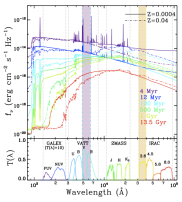
Abstract

Using broadband optical *V* and mid-IR (MIR) 3.6 μm images combined with a pixel-based analysis, we present a method to map the detailed spatial distribution of dust extinction within a late-type spiral galaxy, NGC 0959. This is accomplished by comparing the observed *V*-to-3.6 μm flux ratio, β_V, to the theoretical one, $\beta_{V,0}$, which is determined statistically instead of from SSP models due to mixing of light. We show that we can estimate the deficiency of *V*-band flux and infer the pixel-averaged dust extinction, A_V.

Theory

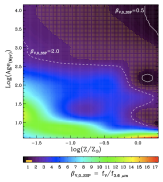
Selection of Filters

- Optical *V*-band
  - Significant dust extinction
  - Minimum metallicity effect
- MIR 3.6 μm
  - Minimum/No dust extinction
    - Fazio et al. (2004)
  - Used as stellar distribution tracer
    - Kennicutt et al. (2003), Helou et al. (2004)



Comparing the observed to theoretical *V*-to-3.6 μm flux ratios lets us estimate the amount of missing *V*-band flux. From this missing flux, we are then able to calculate the amount of dust extinction.

Theoretical Flux Ratio ($\beta_{V,0\_SSP}$) Map



- Created from an Spectral Energy Distribution (SED) library
  - Simple Stellar Populations (SSPs)
  - Padova Isochrones
  - Scalo IMF
    - Anders & Fritze-von Albensleben (2003)
- Old stellar populations
  - t > 500 Myr, or log(t_{Myr}) > 2.7
  - Relatively flat flux ratio:
    - $0.5 < \beta_{V,0\_SSP} < 2.0$
- Young Stellar populations
  - Two distinct flux ratios:
    - Extremely young: t < 10—100 Myr → $9 < \beta_{V,0\_SSP} < 13$
    - Young: 10—100 Myr < t < 500 Myr → $5 < \beta_{V,0\_SSP} < 7$

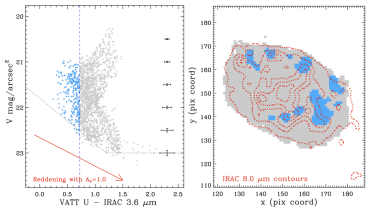
Estimating Dust Extinction, A_V

$$A_V = m_V - [\,-2.5 \log(\beta_{V,0} \times f_{3.6\,\mu m}) - V_{zp}]$$

- m_V – Observed *V*-band magnitude
- $f_{3.6\,\mu m}$ – Observed MIR 3.6 μm flux
- V_{zp} – *V*-band zero-point magnitude

Application: A Pixel-based Analysis of NGC 0959

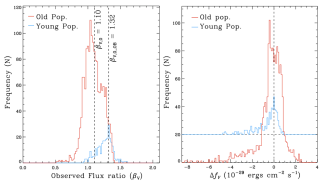
Using a pixel-based analysis (e.g., Bothun 1986, Eskridge et al. 2003, Lanyon-Foster et al. 2007), we treat the light in each pixel as dominated by a single stellar population. However, due to the distance (9.9 ± 0.7 Mpc) to NGC 0959, a large pixel scale (1.5" pix^{-1}), and even larger point spread function (PSF: ~5.5" FWHM), the light accumulated in a single pixel is a mixture of light from underlying and neighboring stellar populations. As a result, the theoretical $\beta_{V,0}$ cannot be selected from the SED library of SSPs directly, but it has to be selected statistically from the observed β_V distribution.



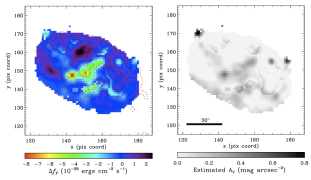
Selection of Pixels Dominated by Young/Old Stars

- *Left figure*: Pixel Color-Magnitude Diagram (pCMD)
  - Selection based on the shape/branching of distribution
  - Different slopes for branches on bluer/redder side of (U – 3.6 μm) ≈ 0.72 mag arcsec^{-2}
  - Young stellar populations: (U – 3.6 μm) < 0.72
    - Usually associated with dust → slopes along reddening vector
- *Right figure*: Spatial distribution of young and old stellar populations
  - Young stellar populations dominate contiguous regions

Selection of $\beta_{V,0}$ and Calculation of Δf_V

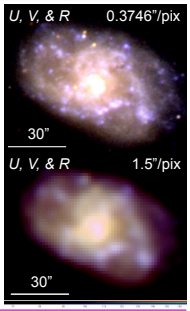


- *Left figure*: Observed *V*-to-3.6 μm flux ratio (β_V) distributions
  - Old stellar pop.: $\beta_{V,0}$ = 1.10 – within the range of expected values
  - Young Stellar pop.: $\beta_{V,0\_OB}$ = 1.32 – much lower than SSP model range
    - Due to the mixture of light from underlying and neighboring old stellar populations
- *Right figure*: Estimated missing *V*-band flux (Δf_V)
  - Larger tails on negative side of Δf_V – due to dust extinction



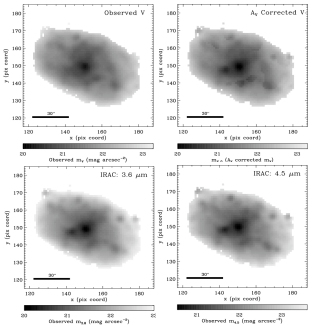
Distributions of Δf_V and A_V

- *Left (color) figure*: Distribution of Δf_V
  - Large-valued "negative Δf_V" pixels follows galactic structures: Star formation regions, spiral arms, and the bulge—where dust commonly exists in large amounts
  - Regions without visible structures have near-zero to positive Δf_V's
- *Right (gray-scale) figure*: Distribution of A_V
  - Distribution of A_V follows these galactic structures
  - More complicated than a simple 1-D, or radial, profile: Not a simple distribution pattern
  - Highest A_V regions at the disk edge: Likely contamination by background objects
  - Low extinction region at the bottom of galaxy disk: Due to dust lanes along a spiral arm



Conclusions

Using the *V*-to-3.6 μm flux ratio with a pixel-based analysis, we are able to trace the detailed distribution of dust extinction in late-type spiral NGC 0959. Our extinction corrected *V*-band image shows a similar light distribution as the MIR 3.6 and 4.5 μm images, which trace stellar populations. An important result from our method is that the distribution of dust and A_V can be traced, even though the dust features are not readily apparent. Requiring only two filters, our method will be a powerful tool to correct the images of higher redshift galaxies, as observed with the *HST*/WFC3 and JWST, for dust extinction.



Acknowledgements

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References

Anders P., & Fritze-von Alvensleben, U., A&A, 401, 1063

Bthun, G. D., 1986, AJ, 91, 507

Eskridge, P. B., Frogel, J. A., Taylor, V. A., et al., 2003, ApJ, 586, 923

Fazio, G. G., Hora, J. L., Allen, L. E., et al., 2004, ApJS, 154, 10

Helou, G., Roussel, H., Appleton, P., et al, 2004, ApJS, 154, 253

Kennicutt, R. C., Armus, L., Bendo, G., et al., 2003, PASP, 115, 928

Lanyon-Foster, M. M., Conselice, C. J., & Merrifield, M. R., 2007, MNRAS, 380, 571