Observations of Hot Stars and Interstellar Dust with Swift/UVOT

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Abstract: We review the contributions of Swift/UVOT to our understanding of interstellar dust and hot stars and young stellar populations in both the Milky Way and other galaxies. These two research areas are closely intertwined: UV-bright objects can only be fully understood when the effects of foreground dust are accounted for, yet those same effects can only be studied by observing the properties of UV-bright sources. UVOT is particularly well-suited to investigate variations in the UV dust attenuation law due to the uvm2 filter that is centered on the 2175 Angstrom "bump" feature (Figure 1) and its ability to resolve nearby stellar populations. When combined with optical and infrared imaging, UVOT provides powerful constraints on the variability of the extinction law, both across different galaxies and within individual galaxies, in addition to providing key insights into the propertiies of young stellar populations. UVOT surveys have spanned the Milky Way, Local Group galaxies, the Local Volume Legacy Survey (LVLS), and two multiwavelength deep fields. These surveys are contributing to the most detailed data to date on the UV dust attenuation law and connecting variations in dust attenuation to underlying physical processes and improve our understanding of the UV characteristics of hot stars and young stellar populations.

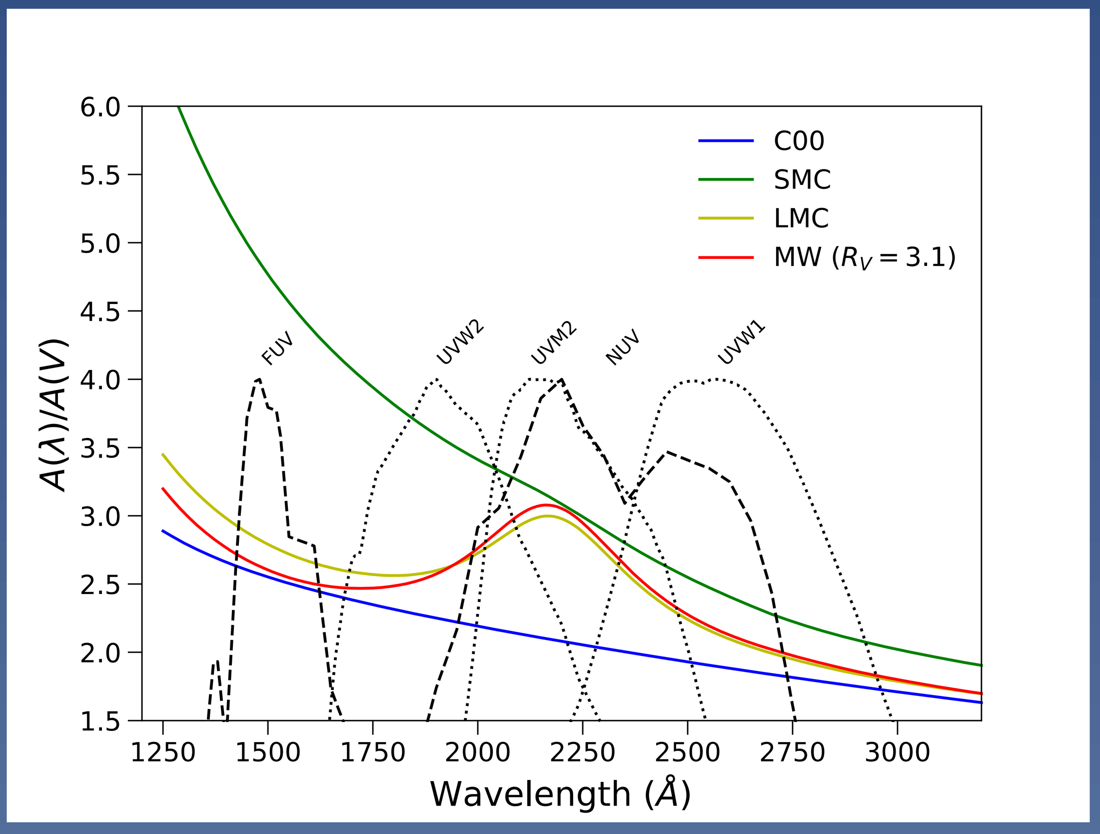


Figure 1: A comparison of several literature dust laws against the filter function of Swift/UVOT and GALEX (which have been scaled for easier comparison). Note the particular sensitivity of the uvm2 filter to the presence or absence of the 2175 Amgstrom dust bump.

Stellar Clusters: Swift/UVOT has observed 103 Galactic open clusters and 101 Galactic globular clusters (Siegel et al. 2019; Siegel et al. 2014). Color magnitude diagrams (CMDs) for the open cluster NGC 2360 and the globular cluster M79 are shown in Figure 2. UVOT's three NUV filters allow for the extinction for open clusters be well constrained with minimal assumptions. UVOT observations of globular clusters allow for the study of blue objects such as RR Lyrae stars and "above the horizontal branch" (AHB) stars naked Post-Asymptotic Giant Branch (PAGB) stars are significant sources of UV radiation, and are likely partially responsible for the UV upturn seen in late-type galaxies. NUV photometry with UVOT also detects extreme horizontal branch stars (EHB) and Asymptotic Giant Branch manque (AGB-M) stars, which represent unusual short-lived paths of stellar evolution.

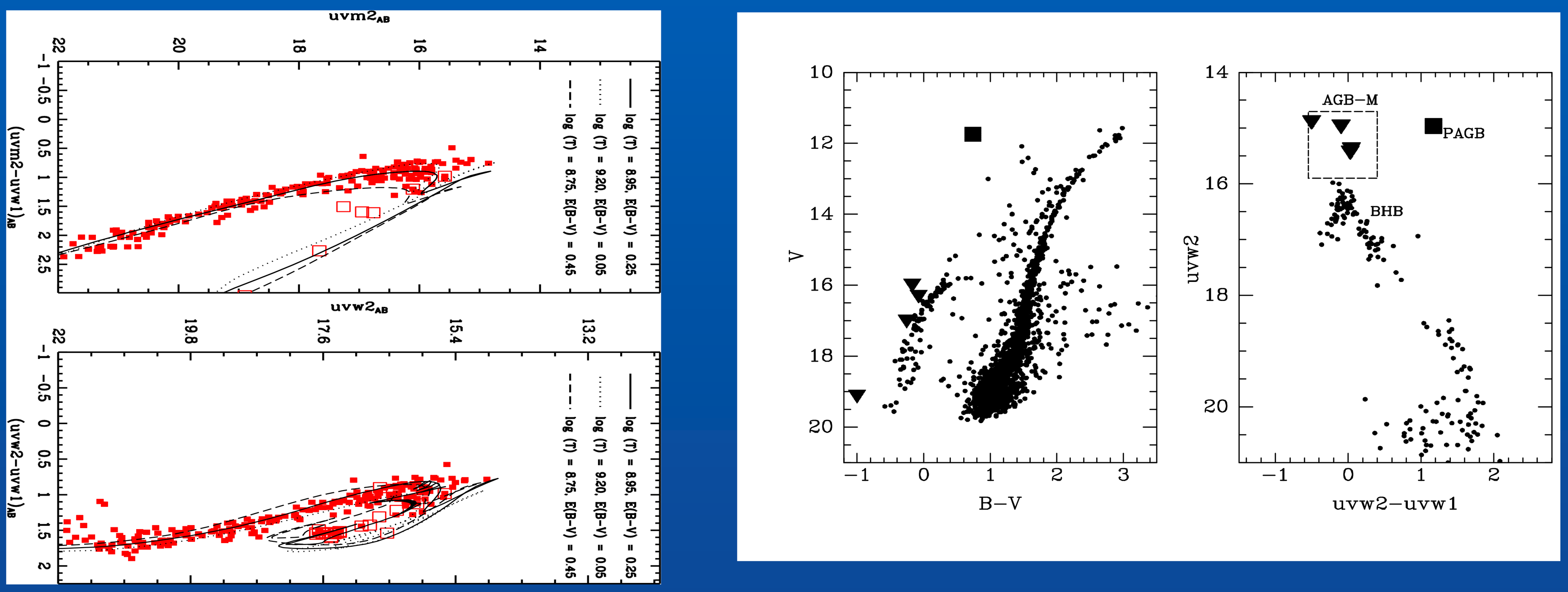
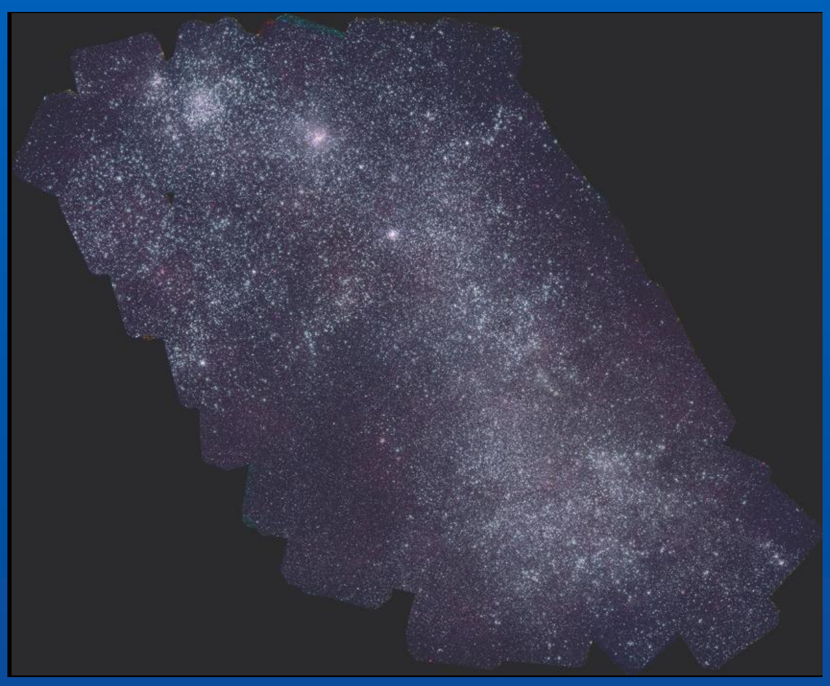


Figure 2: (Left) A comparison of different isochrone fits to the photometry of the open cluster NGC~2360. The three lines are all set at a metallicity of -0.1 and a distance modulus of 10.05. However, they are set at different reddening values, with age adjusted to better match the main sequence turn-off; (Right) M~79 optical and NUV CMDs. In the optical CMD, the post-asymptotic giant branch (PAGB)star is identified with a square while four AGB-Manqe (AGB-M) objects, as identified from Swift/UVOT data, are shown as triangles. In the NUV CMD, the UV-bright stars are labeled. M~79's dominant red giant branch and main sequences are too faint in the UV to be detected by Swift, while the blue horizontal branch (BHB), EHB and AGB-M stars stand out.

Stellar Populations in the Local Group: The galaxies of the Local Group are outstanding areas to study star formation, the properties of hot stars and the effect of interstellar dust on UV light. These galaxies are close enough to be resolved into individual stars, far enough away that a global picture of the galaxy's evolutionary history can be derived and cover a broad range of age, metallicity and UV extinction. UVOT has observed M31, M33, and the Large & Small Magellanic Clouds. Figure 3 shows UVOT images of the LMC & SMC.



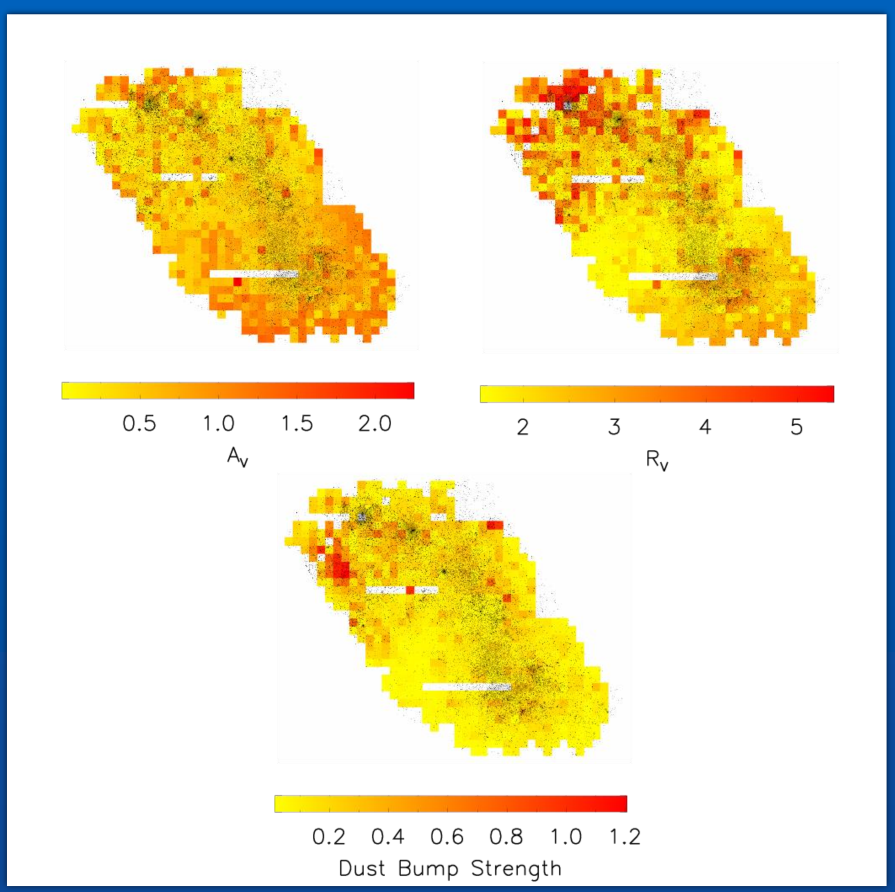


Figure 3: (Left) False color UVOT images of the SMC with *uvw*2 (blue), *uvm*2 (green), and *uvw*1 (red). The image is about 2.3 degrees (2.4 kpc) across. North is to the top and east is to the left. (Right) Pixel-by-pixels maps of reddening within the SMC derived from UVOT observations combined with archival OIR imaging from Hagen et al. 2017. The panels show the overall reddening, the slope of the reddening law and the bump strength. Variations are seen across the face of the galaxy.

Galaxies: Over the course of the mission, Swift/UVOT has extended its survey range into the extragalactic realm with surveys of the SINGS galaxies, the Local Volume Legacy Survey (LVLS) and deep observations of both the Chandra Deep-Field South and the GOODS north field to u~24 mag. These programs, intended to complement both OIR surveys and UV surveys with GALEX, provide a unique window into the star formation history and dust extinction in the local universe and extend the bridge of detailed photometric study toward the most distant objects Swift/UVOT can image within its redshift range (out to $z \sim 1.9$) for the NUV filters. Figure 3 shows images of galaxies from the SINGS/KINGFISH survey imaged in the near-ultraviolet with UVOT.

Figure 4:False color images of select SINGS/KINGFISH galaxies using Swift UVOT (*uvw*2, *uvm*2, and *uvw*1 filters). From left to right, NGC 1566, NGC 3031 (M81), NGC 4594 (M104), NGC 5194 (M51), and NGC 6946.

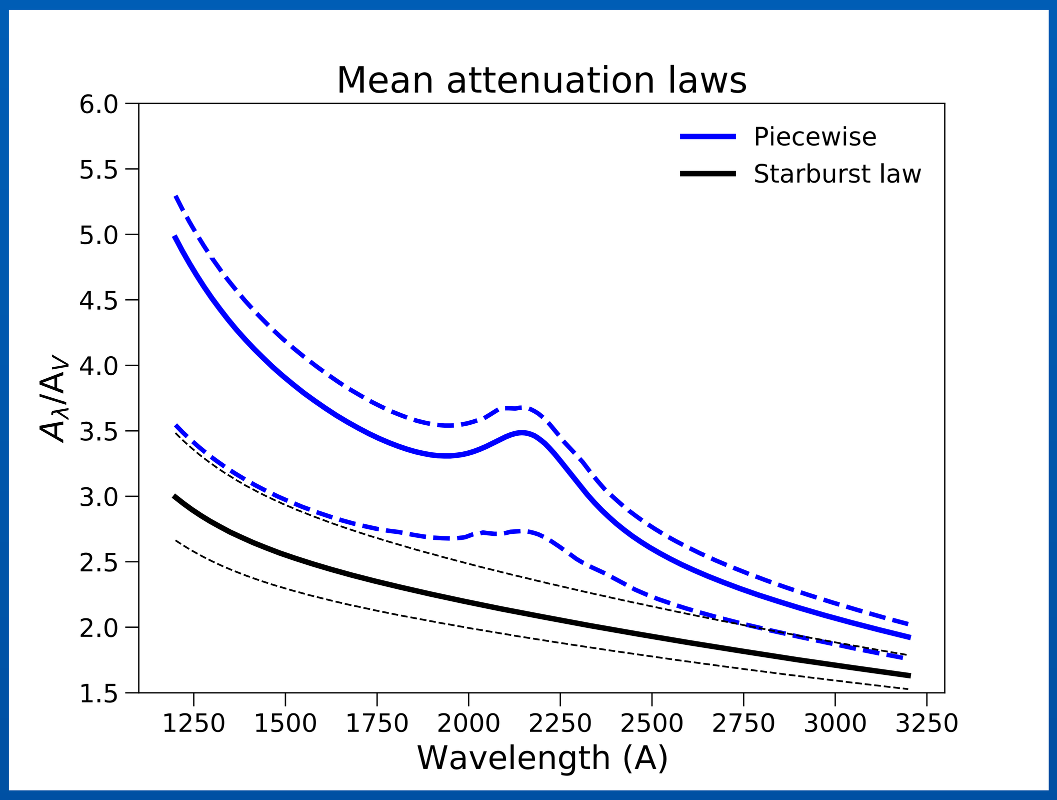


Figure 5: Mean attenuation law for the SINGS/KINGFISH sample from the piecewise star formation history fits compared to the starburst lCalzetti)l aw, excluding galaxies consistent with no dust. The 16th and 84th percentiles are shown for the piecewise SFH result and the Calzetti et al. error in R_V is displayed. We see that the derived attenuation law for each SINGS/KINGFISH galaxy is steeper than the Calzetti law and many show evidence for a 2175 Angstrom bump. From Belles et al. 2023.

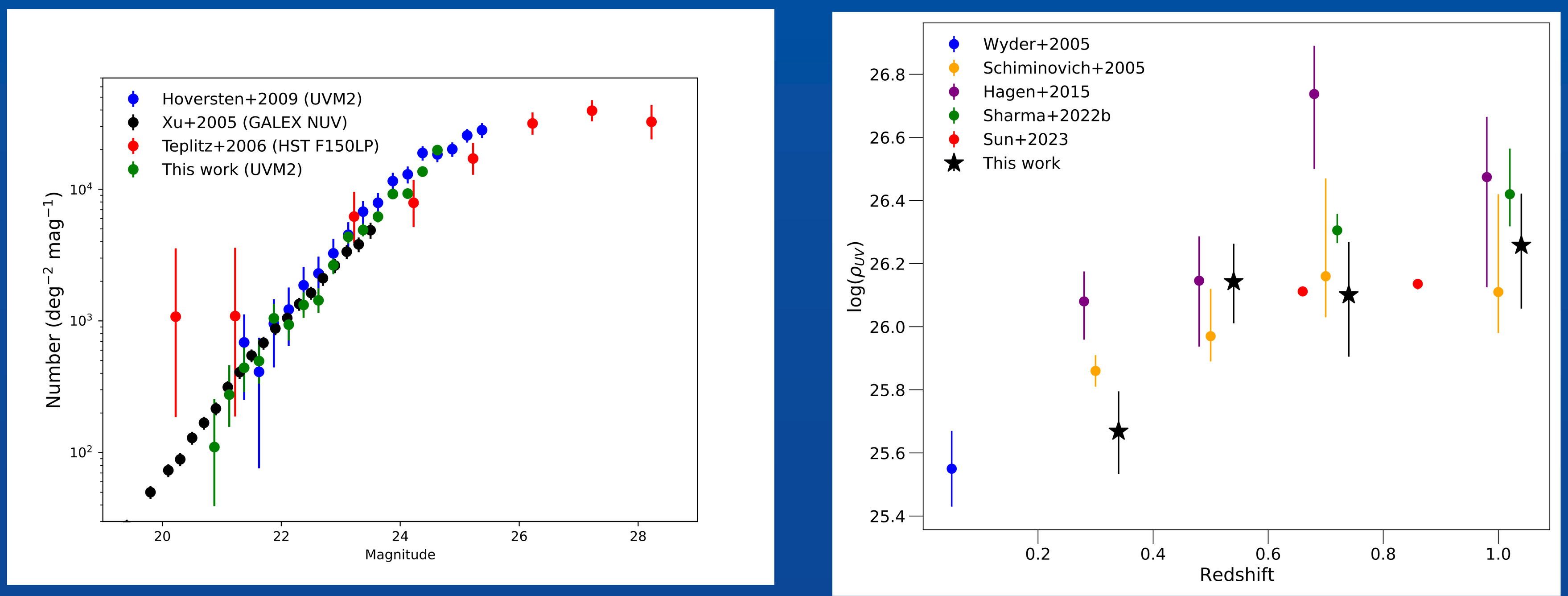


Figure 6: (Left) The *uvm*2 galaxy number counts (green) from our recent (Belles et al. 2025) UVOT observations of GOODS-N compared to previous UVOT observations of CDF-S (Hoversten et al. 2009) and GALEX and HST UV number counts from the literature. We see good agreement and differences can be attributed to survey area and exposure times. (Right) Our observed UV luminosity density (black stars) based on NUV luminosity function from our GOODS-N UVOT observations as a function of redshift compared to values from the literature including our previous deep UVOT observations of CDF-S (Hagen et al. 2015) We see good agreement across all redshift bins. We focus on observed UV luminosity density evolution as a proxy for star formation rate density evolution as the chosen dust attenuation correction and SFR calibrations differ.

References: Belles, A., Decleir, M., Bowman, W. P., et al. 2023, ApJ, 953, 54. 526 ; Belles, A., Gronwall, C., Siegel, M. H., Ciardullo, R. & Page, M., 2025, ApJ, 979, 173; Hagen, L. M. Z., Hoversten, E. A., Gronwall, C., et al. 2015, ApJ, 808, 178; Hagen, L. M. Z., Siegel, M. H., Hoversten, E. A., Gronwall, C., Immler, S. & Hagen, A., 2017, MNRAS, 466, 4540; Hoversten, E. A., Gronwall, C., Vanden Berk, D. E., et al. 2009, ApJ, 705, 1462; Siegel, M.H., LaPorte, S. J., Porterfield, B. L, Hagen, L. M. Z. & Gronwall, C. A., 2019, AJ, 158 35 / Siegel, M. H., Porterfield, B. L., Linevsky, J. S., et al. 2014, AJ, 148, 131

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