

Full-sky ultraviolet maps from harmonised *GALEX*, *Swift*-UVOT, FIMS/SPEAR, TD-1 and *Gaia* data

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Draft, October 2026

Abstract

We present arcminute-sampled all-sky HEALPix maps of the total surface brightness in the *GALEX* far- and near-ultraviolet bands, with per-pixel provenance weights and uncertainties. The *GALEX* GR6/7 mosaics are cleaned in two steps—a cell-wise airglow and zodiacal foreground removal against the UV-BKGD diffuse maps of Murthy (2014a), from which the zero point is inherited (systematic $\lesssim 100$ CU), and a per-tile background equalisation in which 38 000 tile offsets and field-edge rims are fitted to neighbour differences and the scattered light of avoided bright stars is modelled, removing 60/77 per cent (FUV/NUV) of the excess tile-edge step while leaving the isotropic level, the degree-scale sky and point-source photometry unchanged. The cleaned *GALEX* layer is combined with an NUV-informed FUV layer (imaged NUV times a learned diffuse colour, plus catalogue stars), cross-calibrated *Swift*-UVOT imaging and the FIMS/SPEAR starless map. Sky without ultraviolet imaging is filled by a 90-feature gradient-boosted prediction of the diffuse component from dust, H α , starlight and positional templates, trained on the star-subtracted *GALEX* sky, plus a full-depth *Gaia* DR3 source layer of 1.19×10^8 stars with measured or predicted ultraviolet fluxes, galaxies and globular clusters; all layers are gain-harmonised to *GALEX* and blended by priority-nested feathering. *GALEX* imaging sets three fifths of the FUV and three quarters of the NUV sky and is reproduced to 0.003 dex; over a quarter of each band the sub-degree morphology is predicted and flagged by the weight maps. The gap-matched, spatially held-out scatter of the diffuse prediction is 0.047/0.057 dex (FUV/NUV; 0.052/0.058 dex for prediction plus stars against the total sky), rising to 0.08 dex several degrees from data; where *GALEX* never observed, the maps agree with FIMS/SPEAR and UVOT to 0.2 dex; stars in filled sky are complete to $G \simeq 17$ and isolated UVOT point sources are half recovered at UVM2 $\simeq 19.3$. The uncertainty is a calibrated function of pixel class, distance from data and dust column (held-out coverage 0.68; heavy tails, 95.4 per cent at 2.5σ). Both bands are also published partitioned into resolved sources and diffuse light. We discuss the inherited isotropic level, the FUV-H α slope, a FUV-only high-latitude excess, and what each pixel class supports.

1 Introduction

The appearance of the sky between the Lyman limit and the atmospheric cut-off is set by a small number of physical components: hot-star photospheres, dust-scattered starlight, line and continuum emission from ionised and molecular gas, and an extragalactic background. The far-ultraviolet interstellar radiation field controls heating, ionisation balance and chemistry of the diffuse interstellar medium (Habing 1968; Draine 1978; Mathis et al. 1983); dust-scattered starlight constrains grain albedo and phase function (Witt et al. 1997; Draine 2003b; Murthy 2016; Hamden et al. 2013); fluorescent molecular hydrogen traces illuminated molecular-cloud surfaces (Jo et al. 2017); two-photon and line emission trace the warm and hot ionised media (Kulkarni 2022); and the residual isotropic component bounds the ultraviolet extragalactic background (Henry et al. 2015; Akshaya et al. 2018, 2019; Chiang et al. 2019). The ultraviolet sky is also a foreground: intensity mapping and clustering-redshift tomography (Ménard et al. 2013; Chiang & Ménard 2019; Chiang et al. 2019) cross-correlate diffuse

ultraviolet maps with galaxy catalogues and require a well-characterised Galactic component. Finally, current and planned wide-field missions—SPHEREx (Doré et al. 2014; Crill et al. 2020), ULTRASAT (Shvartzvald et al. 2024), UVEX (Kulkarni et al. 2021), CSST (Zhan 2021), UVIT (Tandon et al. 2017) and CASTOR (Côté et al. 2019)—need realistic all-sky ultraviolet surface-brightness estimates for planning.

Despite this breadth of applications there is no ultraviolet image of the *entire* sky. The *Galaxy Evolution Explorer* (*GALEX*; Martin et al. 2005; Morrissey et al. 2007) imaged roughly two thirds of the sky in its FUV (1350–1750 Å) band and three quarters in the NUV (1750–2800 Å), but detector safety limits excluded the Galactic plane and ultraviolet-bright stars (Bianchi et al. 2014, 2017). The FIMS/SPEAR spectro-imager on *STSAT-1* (Edelstein et al. 2006) observed 80 per cent of the sky in the FUV (Seon et al. 2011; Jo et al. 2017), and Jo et al. (2021) filled its gaps with a convolutional network. Diffuse-background analyses of the *GALEX* archive (Murthy et al. 2010; Murthy 2014a; Hamden et al. 2013; Akshaya et al. 2018, 2019) have released

Full-sky far-UV (1350–1750 Å)

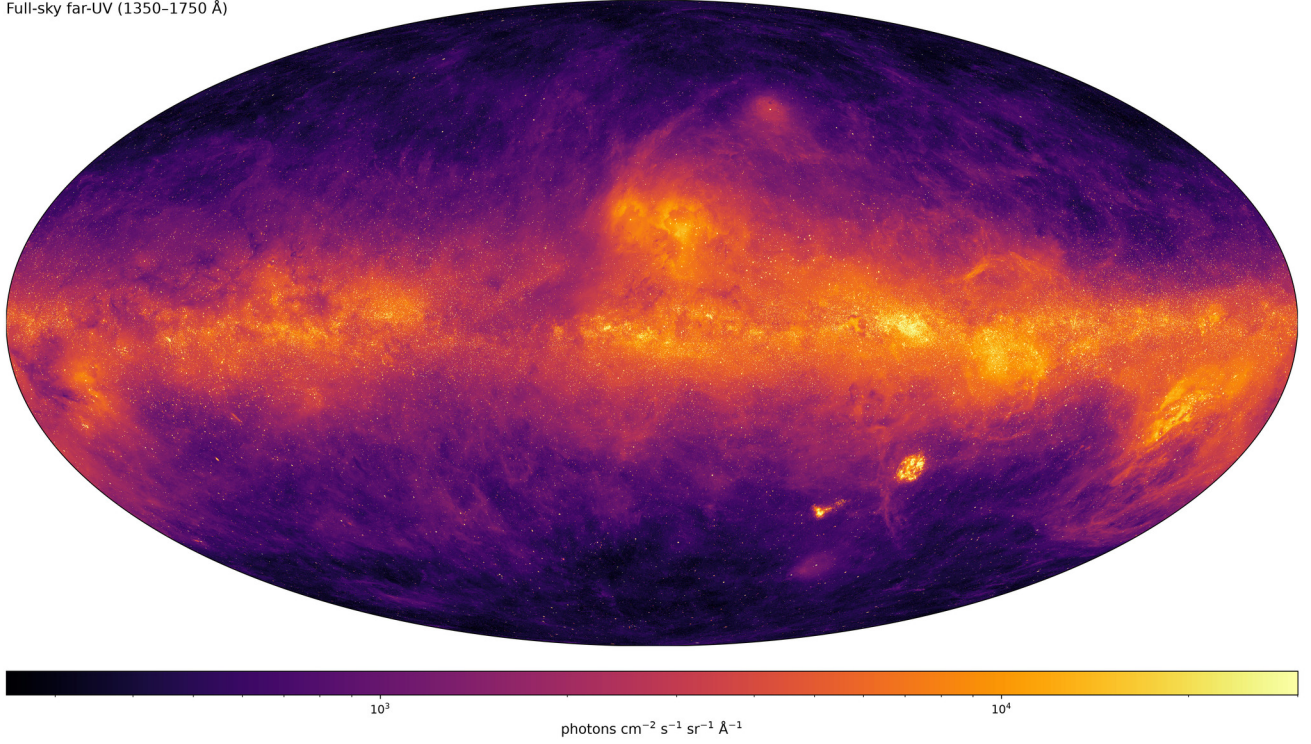


Figure 1: The published all-sky FUV (1350–1750 Å) map: destriped and artefact-repaired *GALEX* FUV with censored bright stars restored, the NUV-informed FUV layer where *GALEX* imaged only the NUV, mapped *Swift*-UVOT, and the FIMS/SPEAR-constrained, gain-harmonised model layer of equation (6), blended with the priority-nested feathered weights of equations (8)–(9). Galactic Mollweide projection centred on the Galactic Centre, l increasing to the left; logarithmic colour scale in $\text{photons cm}^{-2} \text{s}^{-1} \text{sr}^{-1} \text{Å}^{-1}$. The Sco–Oph complex above the Galactic Centre, Orion–Eridanus at lower right, the Magellanic Clouds and the Gum/Vela region are prominent; the dark high-latitude sky reaches $\sim 300\text{--}400$ CU. Fig. 8(a) shows which of these pixels are imaging and which are predicted.

Full-sky near-UV (1750–2800 Å)

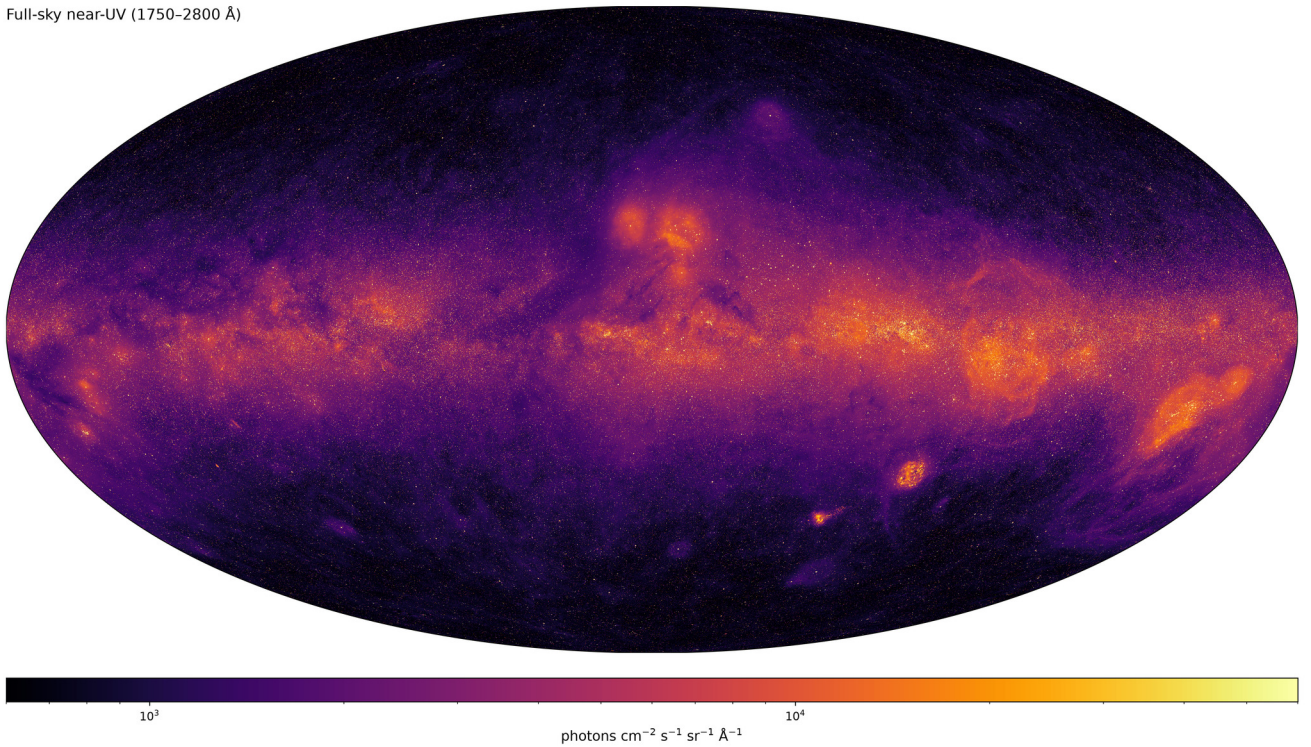


Figure 2: As Fig. 1 for the NUV (1750–2800 Å). No wide-field imager has covered the Galactic plane in the NUV, so the low-latitude band (26.5 per cent of the sky by dominant weight) is the harmonised diffuse prediction plus the full-depth *Gaia* DR3 stellar layer (Section 3.5) and the galaxy layer; the grainier texture of the star-rich NUV sky continues without change of character into the filled plane, where it is synthetic.

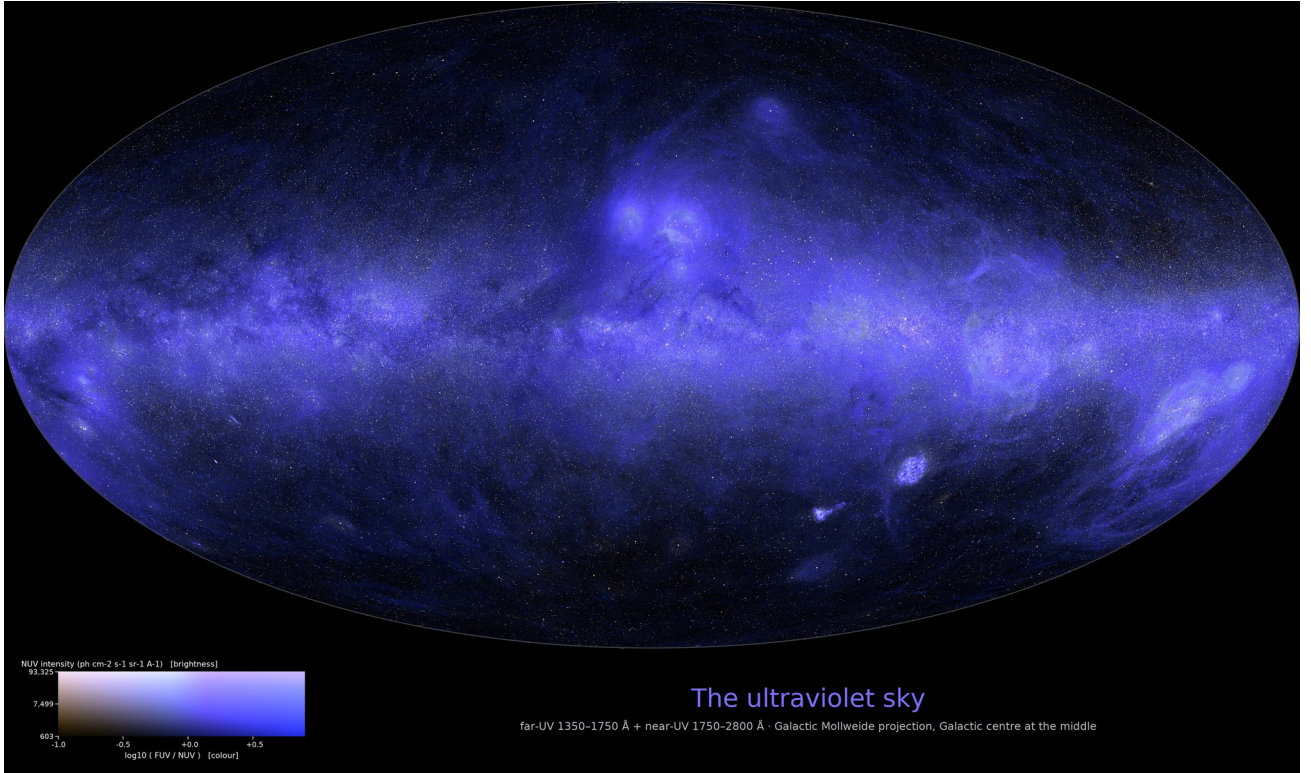


Figure 3: Two-band colour composite of the published maps. Brightness follows an asinh stretch of the FUV and NUV intensities; hue encodes the band ratio $\log_{10}(\text{FUV}/\text{NUV})$, from pale gold where the NUV dominates, through blue, to violet where the FUV dominates (colour key below the map, rendered through the same transfer function; the hue axis is offset by 0.24 dex so that the typical diffuse sky, $\log_{10}(\text{FUV}/\text{NUV}) \simeq -0.3$, is blue). Violet-blue regions are dominated by dust-scattered light from hot stars and by OB associations (Sco-Cen above the Galactic Centre, Orion-Eridanus, the Gum/Vela region, the Magellanic Clouds); gold-white regions by cooler stellar populations (the bulge, M31, and field stars at intermediate latitude).

foreground-subtracted *diffuse*-background maps over the *GALEX* footprint. No map of the *total* ultraviolet surface brightness has been available over the full sky in both *GALEX* bands, at arcminute sampling, with the instruments photometrically harmonised, the *GALEX* gaps filled by data-constrained layers, and per-pixel provenance and uncertainty, with the qualification that where no ultraviolet imaging exists, 28 (FUV) and 27 per cent (NUV) of the sky, the sub-degree morphology of such a map is template-predicted rather than observed.

This paper presents an all-sky FUV/NUV surface-brightness map built by destriping and per-tile equalising the *GALEX* mosaic against the [Murthy \(2014a\)](#) foreground reference, filling its gaps with a template-trained gap-fill predictor, a full-depth *Gaia* DR3 stellar and galaxy layer, and a NUV-informed FUV layer, and combining every layer with *Swift*-UVOT and FIMS/SPEAR by priority-nested feathering. Where calibrated imaging exists we use it; elsewhere we predict the ultraviolet surface brightness from all-sky templates—thermal dust, $\text{H}\alpha$, and *Gaia* integrated starlight—via a gradient-boosted regression trained on the *GALEX* sky, tie it to surrounding data via a smooth gain field and, in the FUV, to FIMS/SPEAR, add catalogue stars and galaxies, and feather the layers together. Blending weights are published per pixel. The main contributions of this work are (i) multi-instrument harmonisation and per-pixel provenance; (ii) filling *GALEX* gaps with template predictions and a synthetic stellar layer; (iii) an empir-

ical, spatially resolved error model for the filled sky; and (iv) a full-depth *Gaia* DR3 stellar layer with an explicit resolved-source/diffuse partition of both bands (Sections 3.5–3.7). Within the *GALEX* footprint the map inherits the established zero point.

Section 2 describes the input data; Section 3 the method, in pipeline order, and published pixel classes; Section 4 the validation of the published maps; Section 5 the physical content and absolute level; Section 6 the limitations; Section 7 the data products, code and reproducibility; and Section 8 a summary. Appendices give the gap-fill benchmark (A), statistical details and sources of every headline number (B), additional validation (C) and a list of enabled measurements (D). Surface brightnesses are in continuum units, $1 \text{ CU} = 1 \text{ photons cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1} \text{ Å}^{-1}$, at effective wavelengths 1539 and 2316 Å; 1 CU corresponds to $I_{\lambda} = 1.29 \times 10^{-11}$ (FUV) and 8.58×10^{-12} (NUV) $\text{erg cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1} \text{ Å}^{-1}$, and $\nu I_{\nu} = 1 \text{ nW m}^{-2} \text{ sr}^{-1}$ corresponds to 50.3 CU at any wavelength. Intensities are observed (attenuated) values, not corrected for Galactic extinction ($A_{\text{FUV}}/E(B-V) \simeq 8$); logarithms are decimal; maps are in Galactic coordinates on the HEALPix NESTED grid ([Górski et al. 2005](#)); weight names follow FITS column names (W_{GALEX} , W_{NUVX} , W_{UVOT} , W_{FIMS} , W_{MODEL}).

1.1 Relation to previous wide-area ultraviolet background products

Table 1 places this work among earlier wide-area measurements, including the pre-*GALEX* experiments (TD-1, *Voyager* UVS, FAUST and NUVIEWS) that established the correlation of diffuse Galactic light with column density, the forward-scattering phase function and a few-hundred-CU high-latitude floor (reviewed by Bowyer 1991; Murthy et al. 2019). Two choices define this work relative to them. First, every product with an absolute level either fits a constant term jointly with a scattering model (FAUST, NUVIEWS, Hamden et al. 2013) or subtracts an empirical per-observation foreground (Murthy et al. 2010; Murthy 2014a; FIMS/SPEAR removes airglow spectrally); we do the second by inheritance. The closest antecedent is the UV-BKGD product of Murthy (2014a,b), tabulating the foreground-subtracted diffuse background of every GR6/7 visit; because our destripping ties the 14'-cell diffuse level of the mosaics to exactly these values (Section 3.2), the two share a zero point by construction—agreeing to a median of -4 (FUV) and -6 CU (NUV) with 0.008/0.006 dex scatter (Fig. 4)—so our contribution to the isotropic-background problem is spatial rather than absolute (Section 5). The published total map is brighter than the UV-BKGD diffuse map by a median of 45 CU (FUV) and 225 CU (NUV), the resolved-source light. The GR4/5 compilation of Murthy et al. (2010) agrees with our diffuse estimate to $+26$ CU in the FUV but is 256 CU lower in the NUV, illustrating the sensitivity of any NUV level to the adopted zodiacal model. Second, every previous product is either blank or degree-resolution outside the *GALEX* footprint: the FIMS/SPEAR continuum survey (Seon et al. 2011), the only previous FUV map with plane coverage, has $\sim 1^\circ$ resolution and is an input here (median *GALEX*/FIMS/SPEAR ratio 0.97, scatter 0.13 dex at $55'$), and Jo et al. (2021) inpainted its gaps with a network trained on $H\alpha$, $E(B-V)$, N_{HI} , soft X-rays and position—conceptually close to our gap filling, but at 1° , one band, without a stellar layer or blocked validation. The tomographic maps of Chiang et al. (2019), over the SDSS footprint, give an extragalactic monopole a factor of three below our inherited diffuse zero points, confirming that most of the isotropic term in any *GALEX*-based map is Galactic or foreground. The present maps are thus the first product to provide both bands over 4π at a common sampling with per-pixel provenance, at the price that a documented quarter of their pixels carry predicted rather than observed sub-degree structure (Section 3.10).

2 Input data

Table 2 lists the input data sets with their wavelength coverage, resolution as used, sky fraction and role. All are public (Section 7). Ultraviolet imaging enters as *data layers*; the remaining sets are calibration references, *discrete-source supplements* or *predictor templates*.

GALEX. *GALEX* imaged the sky simultaneously in

the FUV ($\lambda_{\text{eff}} = 1539 \text{ \AA}$) and NUV ($\lambda_{\text{eff}} = 2316 \text{ \AA}$) with a 1.2° field and $4.5\text{--}5.5''$ resolution (Morrissey et al. 2007). We use the background-inclusive intensity images of GR6/GR7 as served by the CDS in HiPS format (Fernique et al. 2015)—the GR6/7 HiPS supplemented by the GR6 AIS HiPS where the former is empty—reading every order-3 tile, whose pixels map one-to-one onto HEALPix $N_{\text{side}} = 4096$ ($0.86'$). The valid footprint after masking covers 64.1 per cent of the sky in the FUV and 75.9 per cent in the NUV; 11.9 per cent has NUV but no FUV. Count rates are converted to photon continuum units with the Morrissey et al. (2007) unit responses and the $1.5''$ pixel solid angle $\Omega_{\text{pix}} = 5.29 \times 10^{-11} \text{ sr}$:

$$I[\text{CU}] = K r_{\text{pix}}, \quad K = \frac{f_{\lambda}^{(1 \text{ cps})} \lambda_{\text{eff}}}{hc \Omega_{\text{pix}}}, \quad (1)$$

$$K_{\text{FUV}} = 2.05 \times 10^6, \quad K_{\text{NUV}} = 4.54 \times 10^5$$

in units of CU (cps pixel $^{-1}$) $^{-1}$.

An $N_{\text{side}} = 2048$ pixel contains 4720 *GALEX* pixels and collects $a = 2.30 \times 10^{-3}$ (FUV) and 1.04×10^{-2} (NUV) counts s $^{-1}$ CU $^{-1}$, so that at AIS depth ($\simeq 100$ s) and high-latitude raw levels the photon noise per $1.7'$ pixel is $\simeq 44$ CU (FUV) and 33 CU (NUV). No colour correction is applied.

Swift-UVOT. Summed count and exposure HiPS of the full UVOT archive (Romig et al. 2005; Poole et al. 2008) in UVW2 ($\lambda_c \simeq 1930 \text{ \AA}$), UVM2 ($\simeq 2250 \text{ \AA}$) and UVW1 ($\simeq 2600 \text{ \AA}$) are distributed by HEASARC through *SkyView*. Rate maps formed where exposure exceeds 100 s cover about 3.5 per cent of the sky. Conversion to *GALEX*-equivalent intensities is empirical (Section 3.6); the FUV estimate receives reduced weight.

FIMS/SPEAR. The L-band (1350–1750 $\text{\AA}$) continuum HEALPix maps of the FIMS/SPEAR survey (Edelstein et al. 2006; Seon et al. 2011; Jo et al. 2017), at exposure-adaptive $N_{\text{side}} = 64\text{--}256$, cover 80.7 per cent of the sky. Their information content is degree-scale: the template autocorrelation half-width is $35'$ and the coherence with *GALEX* falls below 0.5 at scales under $137'$. FIMS/SPEAR is used as a large-scale ($> 4^\circ$) constraint on the FUV model layer where *GALEX* support is weak, and for validation elsewhere; it is never a predictor feature.

Diffuse-background reference. Murthy (2014a) reprocessed the *GALEX* visit-level archive into point-source-masked diffuse background maps, subtracting an airglow term and a zodiacal term (the Leinert et al. 1998 distribution; Murthy 2014b). Since this uses geometry and epoch information lost in the co-added HiPS, we adopt the UV-BKGD maps as the foreground-free reference level (Section 3.2).

Discrete sources. The TD-1 catalogue (Thompson et al. 1978) supplies absolutely calibrated fluxes of 31 215 stars at 1565, 1965, 2365 and 2740 $\text{\AA}$; the FUV flux is F_{1565} and the NUV flux the combination $0.25F_{1965} + 0.45F_{2365} + 0.30F_{2740}$, rendered as $3'$ -FWHM Gaussians (per-star accuracy ~ 0.1 dex, set by the TD-1/*IUE* scale offsets and the unvalidated NUV synthesis). The full-depth source layer draws on *Gaia* DR3 (Gaia Collaboration 2023): 1.19×10^8 stars ($G < 16.5$

Table 1: Wide-area maps and compilations of the diffuse ultraviolet sky. ‘Diffuse’ products mask point sources; the maps presented here are total intensity with a derivable diffuse estimate. Zero point: how the absolute level at zero dust column is set. All *GALEX*-based products share the GR6/7 photometric calibration (Morrissey et al. 2007).

Product	Reference	Bands (Å)	Coverage	Resolution	Foreground treatment	Zero point (FUV/NUV, CU)	Public format
TD-1 S2/68 sky background	Morgan et al. (1976) ^a	1565, 1965, 2365, 2740	near all-sky	$\sim 2^\circ$ scans	none (bright limits only)	upper limits	printed tables
<i>Voyager</i> UVS	Murthy et al. (1999) ^a	500–1700 (spectra)	several hundred sight lines	$0.1^\circ \times 0.87^\circ$	interplanetary $\text{Ly}\alpha/\text{Ly}\beta$ lines fitted; no airglow (heliocentric >5 au)	darkest $\lesssim 100\text{--}300$ at 1100 Å	tables
FAUST	Bowyer et al. (1993) ^a ; Witt et al. (1997)	1400–1800	21 fields, ~ 5 per cent of sky	8° FOV, $4'$	constant airglow+EBL term fitted per field	model-separated	images (NSSDC)
NUVIEWS rocket	Schiminovich et al. (2001)	1450, 1550, 1610, 1740 (narrow)	~ 25 per cent	$5\text{--}10'$; 6.25° bins	night-time rocket; stellar halos removed	fitted with DGL model	not released
<i>GALEX</i> GR4/5 tile medians	Murthy et al. (2010)	1530, 2310	$\simeq 75$ per cent	$\sim 1^\circ$ (per tile)	per-tile airglow + zodiacal model subtracted	coscant fits; NUV 250 below UV-BKGD	VizieR table
FIMS/SPEAR L-band continuum	Seon et al. (2011); Jo et al. (2017)	1370–1710 (spectral, $\sim 1\text{ Å}$)	$\sim 76\text{--}80$ per cent	HEALPix $N_{\text{side}} = 64$ ($\sim 1^\circ$)	O I 1356 excluded spectrally; no zodiacal term	$\simeq 270$ at $N_{\text{HI}} \rightarrow 0$	HEALPix FITS (KASI/MAST)
<i>GALEX</i> AIS diffuse FUV	Hamden et al. (2013)	1344–1786	65 per cent	HEALPix $N_{\text{side}} = 1024$	none per visit; airglow scatter ± 50	300 isotropic (fits vs $100\text{ }\mu\text{m}$, N_{HI} , $\text{H}\alpha$)	not released
UV-BKGD HLSP	Murthy (2014a,b)	1539, 2316	61 / 72 per cent (FUV/NUV)	$2'$ per visit; $6'$ Aitoff maps	per-visit airglow (Sun angle, local time) + zodiacal (Leinert $\times 0.65$ colour)	$\simeq 300$ / $\simeq 600$ polar	ASCII per visit + FITS maps (MAST)
<i>GALEX</i> polar caps	Akshaya et al. (2018, 2019)	1539, 2316	$ b \gtrsim 70^\circ$	$2\text{--}6'$	UV-BKGD model	230–290 / 480–580; 240 ± 18 / 394 ± 37 at $E(B-V) = 0$	none
<i>GALEX</i> tomographic maps	Chiang et al. (2019)	1539, 2316	5500 deg^2 (SDSS)	$N_{\text{side}} = 4096$ sampling of $2'$ data	UV-BKGD model; monopole not needed	EBL 89^{+28}_{-16} / 172^{+40}_{-21}	analysis product
FIMS/SPEAR + CNN inpainting	Jo et al. (2021)	1370–1710	100 per cent (24 per cent predicted)	$N_{\text{side}} = 64$	as Seon et al. (2011)	as FIMS/SPEAR	HEALPix FITS
This work	—	1350–1750, 1750–2800	100 per cent (61.9 / 73.3 imaging; rest NUV-informed, UVOT, FIMS/SPEAR-constrained or predicted)	HEALPix $N_{\text{side}} = 2048$ ($1.7'$); effective $2.5'\text{--}1^\circ$ by class	UV-BKGD per-visit model transferred by $14'$ additive destriping; identity to $\pm 4\text{ CU}$	inherited: 264 / 579 diffuse, 291 / 727 total ($\pm 50\text{--}100$ syst.)	HEALPix FITS: intensity, 5 weights, uncertainty, provenance; Galactic + equatorial

^a Pre-*GALEX* entries are included for completeness; see Bowyer (1991) and Murthy et al. (2019) for reviews of the earlier measurements.

over the whole sky, blue and hot sources to $G = 19$, plus white-dwarf, hot-subdwarf and ESP-HS catalogues), with the flux of each star taken from a hierarchy TD-1 (where available) > a Yale Bright Star Catalogue (BSC; Hoffleit & Jaschek 1991) model > GUVcat AIS photometry (Bianchi et al. 2017) (unsaturated, clean) > a hot/degenerate-star model > a main-sequence model, validated blind against *Swift* UVOTSSC, XMM-OM SUSS, UVIT and TD-1 photometry (Section 3.5). Integrated *GALEX* photometry of 14 283 nearby galaxies (Leroy et al. 2019; Bai et al. 2015; Gil de Paz et al. 2007; de Vaucouleurs et al. 1991) and 146 globular clusters (Dalessandro et al. 2012; Harris 2010) supplies the galaxy layer (Section 3.5). A small completion outside the imaged footprint—bright BSC stars (306 FUV / 368 NUV), a cool-star patch (56 / 11 stars) and Canopus—is added after fusion.

Predictor templates. The learned prediction uses templates that trace, at other wavelengths, the physical components of the ultraviolet sky: the *Planck* 2013 thermal dust model ($E(B-V)$, τ_{353} , radiance $\mathcal{R}$; Planck Collaboration XI 2014), which sets the scattering mate-

rial and, through the radiance, the illuminating field; the Finkbeiner (2003) $\text{H}\alpha$ composite of WHAM, VTSS and SHASSA, tracing the warm ionised medium and hence two-photon and free-bound continua and ionising stars; the CDS *Gaia* DR3 HiPS of integrated G_{BP} and G_{RP} flux and source density (Gaia Collaboration 2016, 2023), predictors of starlight; and Galactic and ecliptic coordinates, absorbing residual zodiacal structure. Templates at lower N_{side} are upsampled by nearest neighbour, adequate because the regression works at $N_{\text{side}} = 512$.

3 Method

3.1 Overview

All layers and products are full-sky HEALPix arrays at $N_{\text{side}} = 2048$ ($1.7'$ pixels), NESTED ordering, Galactic coordinates, in continuum units (CU, photons $\text{cm}^{-2} \text{s}^{-1} \text{sr}^{-1} \text{Å}^{-1}$) with airglow and zodiacal light removed and no correction for extinction. Figure 6 shows the data flow and Fig. 5 the corresponding stages on the sky for the NUV. The *GALEX* mosaics G are destriped

Table 2: Input data sets. ‘Resolution’ is the effective angular resolution as used here (not necessarily the native instrumental value); f_{sky} is the fraction of the $N_{\text{side}} = 2048$ sky with valid data after masking. Roles: D = ultraviolet data layer entering the fused map; R = photometric/foreground reference; S = discrete-source supplement; P = predictor template (base templates from which the 90 features of Section 3.7 are derived; templates marked $\dagger$ also enter the uncertainty model of Section 4.6); V = validation only. Acronyms: AIS, All-sky Imaging Survey; HiPS, Hierarchical Progressive Survey; MCCM, MAST Mission Community-Contributed Models; HLSP, high-level science product; UV-BKGD, the *GALEX* diffuse-background HLSP of Murthy (2014a).

Data set	Band / wavelength	Resolution	f_{sky}	Role	Ref.
<i>GALEX</i> GR6/7 + AIS	FUV 1350–1750 Å	$\sim 5''$ (used at 1.7')	0.641	D	1, 2, 3
HiPS	NUV 1750–2800 Å	$\sim 5''$ (used at 1.7')	0.759	D (also FUV via colour)	
<i>Swift</i> -UVOT summed-image HiPS	UVW2, UVM2, UVW1 (1900–2600 Å)	$\sim 2.5''$ (used at 1.7')	0.035	D	4, 5
FIMS/SPEAR L-band (MAST MCCM)	1360–1710 Å; ‘starry’ and ‘starless’	14'–55' (N_{side} 256/128/64)	0.807	D ($> 4^\circ$), V	6, 7, 8
<i>GALEX</i> diffuse background HLSP (UV-BKGD)	FUV, NUV, foreground-subtracted	2' bins, per visit	(<i>GALEX</i>)	R	9
TD-1 stellar catalogue	F1565, F1965, F2365, F2740	31 215 stars, rendered at 3' FWHM	1.00	S	10
Yale Bright Star Catalogue (BSC)	FUV, NUV (TD-1 or modelled); cool-star FUV (empirical <i>GALEX</i> relation)	bright-star completion 306 (FUV) / 368 (NUV) stars; cool-star patch 56 (FUV) / 11 (NUV) stars; 1618 stars in the hierarchy	1.00	S	23
<i>Gaia</i> DR3 full-depth stellar layer: $G < 16.5$ all-sky, blue/hot to $G < 19$, white dwarfs, hot subdwarfs, ESP-HS	measured (TD-1, GUVcat) or predicted FUV, NUV	1.189×10^8 stars + 160 099 extragalactic points; 2' FWHM outside imaging, map-matched PSF inside	1.00	S	10, 16, 17, 26, 27
UVOTSSC, XMM-SUSS, UVIT point-source photometry	UVW2/UVM2/UVW1; F148W–N263M	4.2×10^6 / 5.1×10^6 / 2.9×10^5 <i>Gaia</i> matches	—	V (stellar predictors)	24, 25, 28
Galaxies, globular clusters	integrated FUV, NUV	14 283 + 146 objects, 2' FWHM	1.00	S	18–22
<i>Planck</i> 2013 thermal dust model †	$E(B-V)$, τ_{353} , radiance	5'	1.00	P	11
H α composite (WHAM, VTSS, SHASSA) †	6563 Å	6' ($N_{\text{side}} = 512$)	1.00	P	14
<i>Gaia</i> DR3 flux and density HiPS †	G_{BP} , G_{RP} integrated flux; source density	$\sim 1'$	1.00	P	15, 16
Position †	$\sin b$, $ b $, $\cos l$, $\sin l$; $ \beta $, $\sin \lambda$, $\cos \lambda$	—	1.00	P	—

References: (1) Martin et al. (2005); (2) Morrissey et al. (2007); (3) Bianchi et al. (2017); (4) Roming et al. (2005); (5) Poole et al. (2008); (6) Edelstein et al. (2006); (7) Seon et al. (2011); (8) Jo et al. (2017); (9) Murthy (2014a); (10) Thompson et al. (1978); (11) Planck Collaboration XI (2014); (12, 13) unused; (14) Finkbeiner (2003); (15) Gaia Collaboration (2016); (16) Gaia Collaboration (2023); (17) Bianchi et al. (2017) (GUVcat training photometry); (18) Leroy et al. (2019); (19) Bai et al. (2015); (20) Gil de Paz et al. (2007); (21) de Vaucouleurs et al. (1991); (22) Harris (2010), Dalessandro et al. (2012); (23) Hoffleit & Jaschek (1991); (24) Yershov (2014), Page et al. (2014); (25) Page et al. (2012); (26) Gentile Fusillo et al. (2021); (27) Culpan et al. (2022); (28) Tandon et al. (2017). HiPS: Fernique et al. (2015).

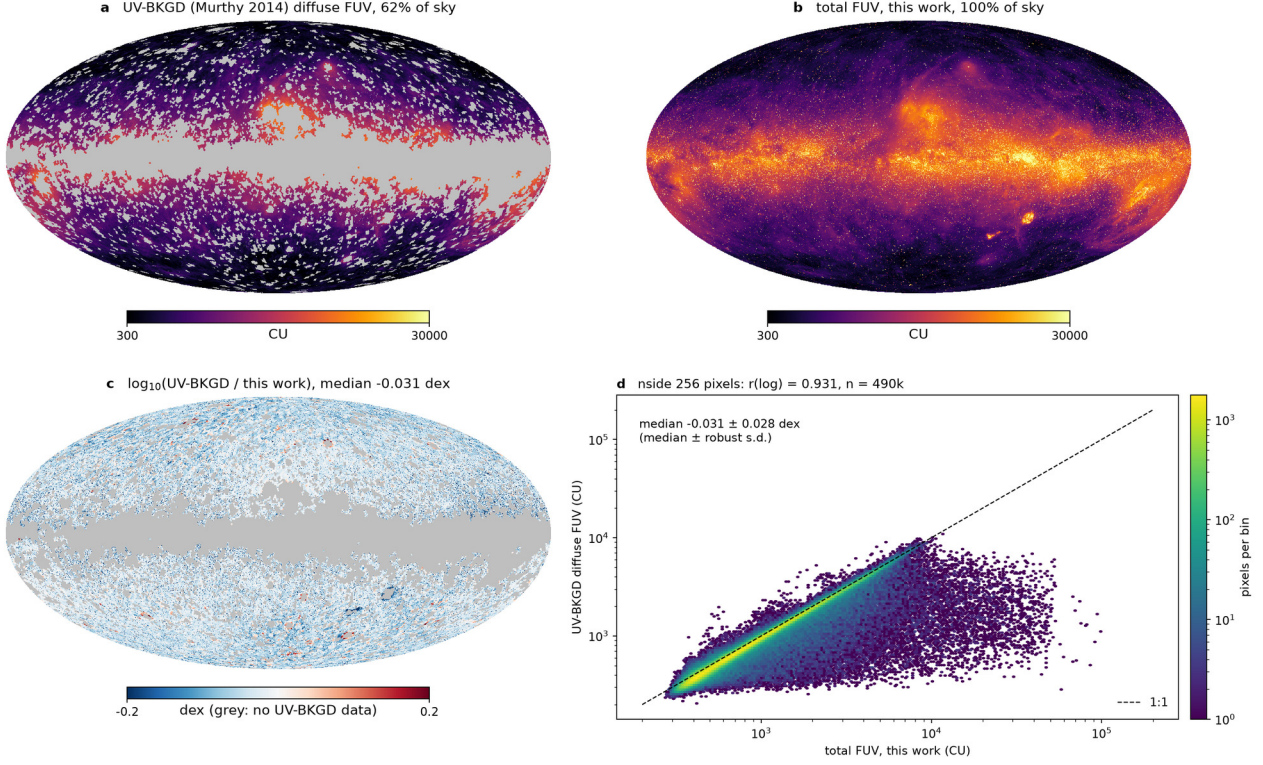


Figure 4: Map-level comparison with the *GALEX* UV-BKGD diffuse FUV map of Murthy (2014a), regidded to $N_{\text{side}} = 256$. (a) UV-BKGD diffuse FUV (62 per cent of the sky at $N_{\text{side}} = 256$). (b) Total FUV, this work. (c) $\log_{10}(\text{UV-BKGD}/\text{this work})$; grey, no UV-BKGD data. (d) Pixel-by-pixel comparison; the one-sided offset (median -0.031 dex) is the resolved-source light present in the total map and masked in UV-BKGD. Against our *diffuse* estimate the agreement is -0.002 dex with 0.008 dex scatter, by construction of the destriping.

cell by cell against UV-BKGD, giving G' (Section 3.2), and equalised tile by tile, giving the *GALEX* layer g (Section 3.3); residual instrumental features in g define weight multipliers, and bright stars censored by *GALEX* are topped up from TD-1 (Section 3.4). A source layer $S = S_{\star} + E + L_{\text{gal}}$ —*Gaia* DR3 stars, extragalactic point sources, and galaxies and globular clusters—is rendered on the same grid from catalogues, using the ultraviolet imaging only for training photometry and the point-spread function (Section 3.5). UVOT is cross-calibrated onto g and the FIMS/SPEAR scale is verified (Section 3.6). The star-subtracted *GALEX* sky $g - S$ is the training truth of a 90-feature gradient-boosted predictor of the diffuse intensity, P_D (Section 3.7), and, in the FUV, of a diffuse colour model that converts NUV-only *GALEX* imaging into an NUV-informed FUV layer I_X (Section 3.8). The fusion (Section 3.9) gain-harmonises $P_D + S$ to g on degree scales, constrains its large-scale FUV level with the FIMS/SPEAR starless map far from *GALEX*, and feathers the layers in the priority order *GALEX* > NUV-informed FUV > UVOT > FIMS/SPEAR-constrained model > model, with weights W_{GALEX} , W_{NUVX} , W_{UVOT} , W_{FIMS} and W_{MODEL} that sum to unity in every pixel. A small set of post-fusion edits and the derived products—weights, provenance, data-only maps, the source/diffuse partition and the uncertainty maps—complete the chain (Section 3.10). The two bands are processed identically except that FIMS/SPEAR and I_X exist only in the FUV.

Table 9 in Appendix B collects the notation.

3.2 *GALEX* assembly and foreground destriping

Assembly. HiPS tiles sample the sky on the NESTED grid of $N_{\text{side}} = 512 \times 2^k$ at order k . *GALEX* and *Gaia* order-3 tiles are placed into an equatorial $N_{\text{side}} = 4096$ array, rotated to Galactic coordinates by nearest-neighbour lookup and averaged over the four children of each $N_{\text{side}} = 2048$ pixel, conserving surface brightness and introducing scatter of at most $0.43'$; *GALEX* count rates are converted to CU. Equatorial copies are produced by bilinear resampling of $\log I$; quantitative work should use the Galactic files.

Destriping. The co-added *GALEX* mosaics contain airglow and zodiacal light whose level varies from visit to visit (Murthy 2014b), appearing as tile-to-tile offsets of tens (FUV) to hundreds (NUV) of CU superposed on a smooth zodiacal gradient in the NUV. We remove them as an *additive* offset field on the $N_{\text{side}} = 256$ grid ($14'$ cells). For each cell c ,

$$F_c = \mathcal{P}_{30}\{G_p : p \in c\} - \text{med}\{M_q : q \in c\}, \quad (2)$$

$$G'_p = G_p - F(\hat{\mathbf{n}}_p),$$

where G_p are the *GALEX* intensities of the $N_{\text{side}} = 2048$ children of the cell, $\mathcal{P}_{30}$ denotes the 30th percentile, and M_q are the UV-BKGD diffuse intensities in the cell. Where UV-BKGD has no data (9.4 per cent of *GALEX*

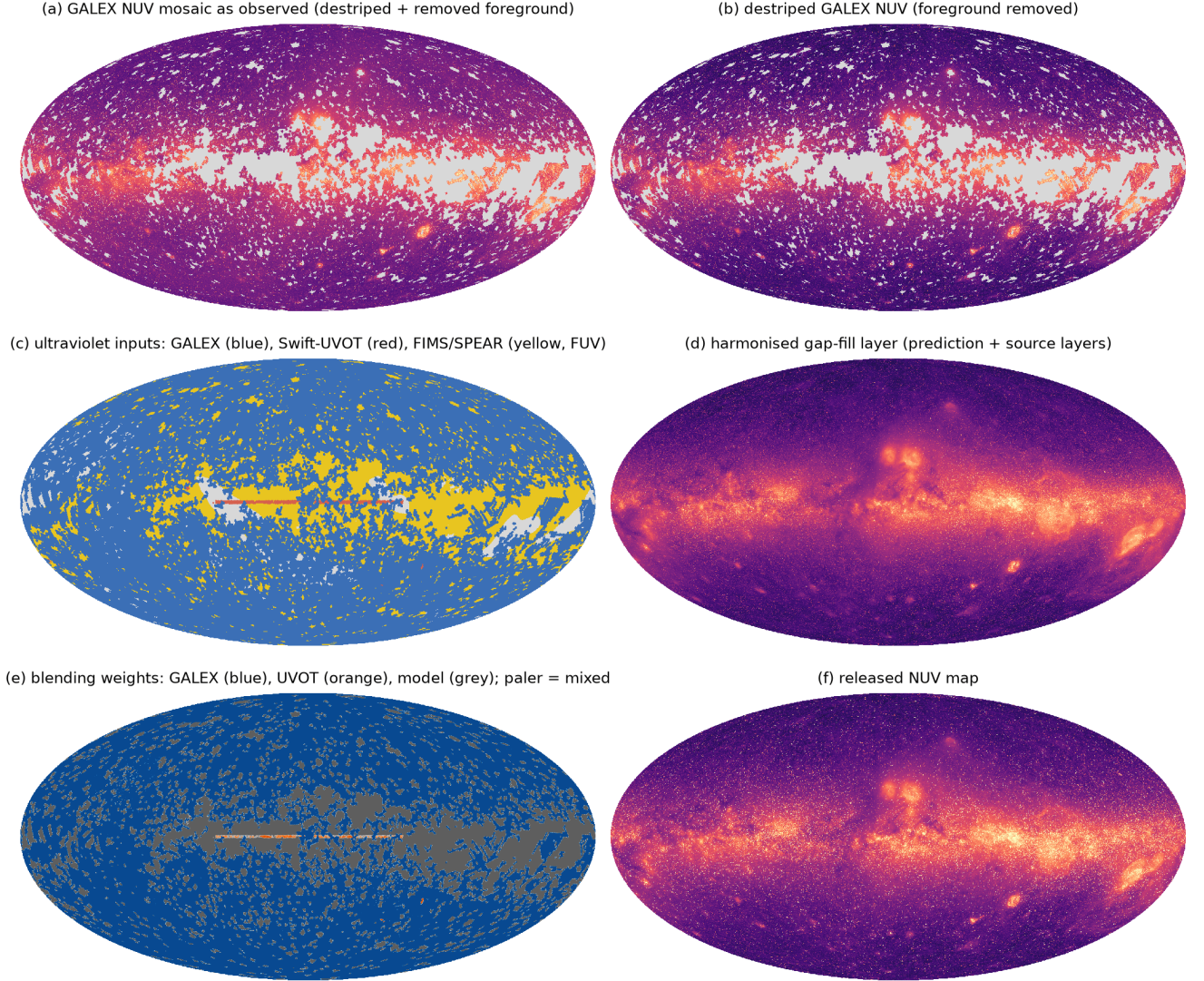


Figure 5: Pipeline stages on the sky for the NUV band, rendered from the published files at $N_{\text{side}} = 256$ (Galactic Mollweide centred on $l = 0$, l increasing to the left; grey denotes no data). (a) *GALEX* NUV mosaic as observed, i.e. the destriped layer plus the removed foreground field F (76 per cent of the sky). (b) The destriped mosaic G' after subtraction of the per-cell airglow-plus-zodiacal foreground tied to [Murthy \(2014a\)](#) (Section 3.2). (c) Footprints of the ultraviolet inputs: *GALEX* (blue), *Swift*-UVOT (red) and FIMS/SPEAR (yellow, FUV only). (d) The harmonised gap-fill layer: 90-feature diffuse prediction plus stellar and galaxy source layers (Sections 3.5 and 3.7). (e) Dominant blending weight: *GALEX* (blue), UVOT (orange), model (grey), paler where mixed. (f) The published NUV map. Panels (a), (b), (d) and (f) share a logarithmic colour scale ($300\text{--}3 \times 10^4$ CU).

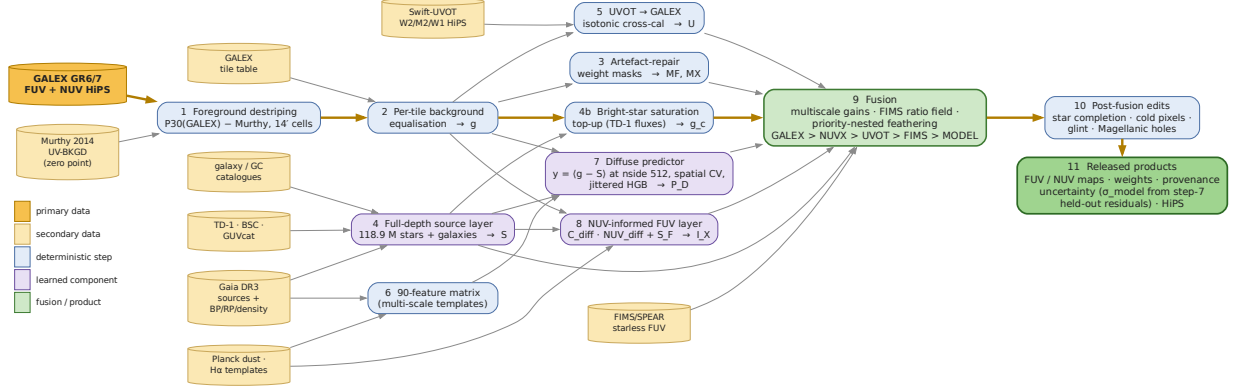


Figure 6: Data flow of the pipeline, left to right. Cylinders are public inputs, drawn where they first enter (dark: the primary *GALEX* imaging; light: secondary data); blue boxes are deterministic steps, purple boxes learned components (the source-layer flux models, the diffuse predictor and the diffuse colour model of the NUV-informed FUV layer), green boxes the fusion and the published products. The thick line is the *GALEX* spine: HiPS mosaic → foreground destriping (Section 3.2) → per-tile equalisation, g (Section 3.3) → bright-star top-up, g_c (Section 3.4) → fusion (Section 3.9) → post-fusion edits and products (Section 3.10). Every other layer—UVOT (Section 3.6), the source layer (Section 3.5), the diffuse prediction (Section 3.7) and the NUV-informed FUV layer (Section 3.8)—is calibrated or trained against g and enters only at the fusion. Numbers in the boxes are the step numbers used in the text.

FUV cells and 8.2 per cent of NUV cells at $N_{\text{side}} = 256$) F is inpainted by mask-normalised Gaussian smoothing (1.5° , then 8°). F is evaluated at every $N_{\text{side}} = 2048$ pixel by bilinear interpolation and subtracted; the offset fields are published. The pixel-weighted median offset removed is 46 CU (FUV) and 480 CU (NUV), with 5–95 per cent ranges of -13 to 188 and 322 to 704 CU. A handful of under-exposed rim pixels (faint pixels lying more than 0.5 dex below their eight-neighbour median) are replaced by that median, so that no non-positive pixel remains.

Equation (2) transfers the zero point of the UV-BKGD maps to the mosaics cell by cell, leaving structure below $14'$ and all sources untouched; it inherits a foreground rather than determining one. Any error in the Murthy (2014a) airglow-plus-zodiacal model propagates unchanged into our maps: agreement with UV-BKGD to $-4/-6$ CU demonstrates identity, not accuracy. We adopt an additive systematic of ± 50 – 100 CU on the absolute level of both bands, plus two smaller structured terms: a *GALEX*-depth-dependent $+13$ CU term from the order-statistic bias of $\mathcal{P}_{30}$, and a possible foreground share, bounded to $\lesssim 30$ CU. None is included in the multiplicative per-pixel uncertainty maps; they dominate the error budget of the darkest high-latitude sky ($\simeq 300$ CU FUV).

The $\mathcal{P}_{30}$ estimator. For photon noise σ_{pix} per $N_{\text{side}} = 2048$ child, the 30th percentile of a cell lies $0.52\sigma_{\text{pix}}$ (Poisson) to $0.33\sigma_{\text{pix}}$ (measured) below the diffuse mean. Because F is solved with $\mathcal{P}_{30}$ on the noisy mosaic but the median on UV-BKGD, destriped total intensities are high relative to UV-BKGD by $+0.34 \pm 0.01 \sigma_{\text{pix}}$ (FUV) and $+0.35 \pm 0.05 \sigma_{\text{pix}}$ (NUV), i.e. $+13$ CU at high latitude, with steps of $\simeq 10$ CU (0.010 dex FUV, 0.005 dex NUV) at deep-field boundaries. In crowded low-latitude cells $\mathcal{P}_{30}$ is biased high by faint stars, absorbing unresolved stellar light into F ; the effect is small

and covered by plane systematics (Section 6).

3.3 Per-tile background equalisation

At high latitude the destriped mosaics still show the survey tiling: 1.2° discs whose level differs by a few per cent from their neighbours, with bright or dark rims at $\rho \simeq 0.55$ – 0.60° from the tile centre, most conspicuously in faint fields such as Coma and the Galactic poles (Fig. 7). They are per-visit residual backgrounds (time-variable airglow and detector background of the short AIS visits against deeper MIS/DIS coadds) that the $N_{\text{side}} = 256$ destriping cannot remove at the single-tile level: the per-tile scatter shows no trend with ecliptic latitude and falls with exposure time. We remove them with an explicit per-tile model. The tile list is the *GALEX* GR6/7 image inventory at MAST (79 164 image products; co-pointed visits within $3'$ merged), giving 31 449 FUV and 38 473 NUV tiles with centre, exposure and survey; the effective field radius measured from the coverage edge of isolated tiles is $R_{\text{eff}} = 0.595^\circ$ (attribution radius 0.665° with an exposure-weighted soft edge).

Working at $N_{\text{side}} = 1024$ on the relative residual $r = (G' - S')/S'$ of the destriped map against a robust local sky S' (the 2.5° -FWHM smoothing of the source-masked $N_{\text{side}} = 256$ block median plus a locally regressed sub- 2.5° dust term, so that cirrus does not enter r), each tile t carries a constant offset o_t , a rim amplitude a_t multiplying a stacked empirical radial template $R(\rho)$, and—for the 2–4 per cent of tiles whose residual shows a straight internal step (partial or multi-epoch coadds) or whose coverage is chord-cut—a split into two pseudo-tiles along the fitted chord, plus per-tile gradients for flagged outliers; boundary tiles use their measured footprints. The basis is fitted not to r itself but to all $N_{\text{side}} = 1024$ neighbour-pair differences

$r_i - r_j$ inside the footprint (3.7×10^7 rows per band), which are insensitive to any smooth real sky, with weak level rows and ridge priors ($\tau_o = 0.30$; $\tau_a = 0.30$ about the survey-level stacked rim amplitude, 0.05–0.08 FUV and 0.10–0.12 NUV), solved by sparse LSQR inside a Huber ($c = 2.5$) iteratively reweighted loop and iterated with S' , the source mask and $R(\rho)$ re-estimated. Tiles with $|o_t| > 0.25$, or with a significant residual edge step together with an interior offset of the same sign (2.3 per cent), are refit without the ridge with their discs masked from S' , and flattened non-parametrically at 0.35° inside the disc unless they lie on bright H α ($> 3R$) or $E(B-V) > 0.15$, where sub-degree residuals may be nebular. Two targeted passes then treat the tiles that still show a disc. The first addresses short visits adjacent to coverage holes or inside clusters of offset tiles, which bias their own local reference S' and so escape the interior criterion, and pointings on catalogued galaxies smaller than the field: every tile whose residual step at the tile radius exceeds 0.04 at $> 4.5\sigma$ with a disc-minus-surroundings contrast of the same sign, or whose disc contrast exceeds 0.04 at $> 6\sigma$ with an interior offset above 0.08 (S' re-estimated with the candidate discs masked), receives a jointly fitted constant over its full footprint, clipped to 1.25 times the measured contrast and accepted only if it reduces that tile's edge step (or its disc contrast by 30 per cent without raising the step) and does not move the tile's interior more than 0.02 further from the model reference introduced below—without this guard the step between a levelled scattered-light tile and its clean neighbour is 'repaired' by darkening the neighbour—followed by the same in-disc flattening outside protected regions and nebular tiles; 3.1/2.1 per cent of FUV/NUV tiles receive such a constant, and their median edge step falls from 0.060/0.070 to 0.027/0.028. The second addresses light scattered into the field by ultraviolet-bright stars that *GALEX* itself avoided, for which a neighbour reference either does not exist or is itself contaminated, and for which a per-tile flag necessarily stops at the first ring of tiles while the scattered light does not. A census of every tile within 2.5° of an avoided TD-1 star compares its 0.5° interior with its 0.7° – 1.7° surroundings and with the gap-fill prediction and identifies 30 FUV and 74 NUV stars (Magellanic fields excluded) with at least one tile whose excess is above 0.15 dex, or above 0.08 dex with a gradient > 0.15 dex directed at the star. Around each such star the correction is rebuilt on all tiles within 3.6° (2.9/6.8 per cent of FUV/NUV tiles) against a neutral template, the gain-harmonised gap-fill prediction of Section 3.9 with its stellar layer subtracted, T : with $y = (g - S)/T$ on source-free pixels, the local clean level $k(r, \phi)$ is the median of y over tiles that are neither census-flagged nor inside the current scattered-light footprint, in $0.2^\circ \times 30^\circ$ polar bins about the star (empty bins inherit the nearest outer bin of their sector); the scattered light is modelled as a smooth non-negative field $E(r, \phi)$, the binned median of $y - k$ over all observed pixels, Gaussian-smoothed by one bin and truncated at the outermost radius where the sector

still exceeds 0.01, plus per-tile constant and tangent-plane gradient terms fitted jointly (exposure-weighted tile footprints, ridge-damped, 2.5σ -clipped) to the residual and kept only where significant ($|c_t| > 0.03$ at $> 4\sigma$; gradients > 0.03 across the tile at $> 3\sigma$). Positive tile terms are allowed anywhere inside the footprint of E , negative ones only on tiles the neighbour-pair rounds had altered, so that a tile is returned to the local clean level k rather than below it and no untouched clean tile is changed; footprint, clean set, k , E and tile terms are iterated three times. The smooth field carries a third of the removed light (median peak amplitude 0.03/0.04 of the template, up to 0.12/0.28 at the worst stars); the tile terms (94/367 constants, 208/617 gradients; median $|c_t| = 0.06/0.07$) carry the visit-to-visit remainder. Tiles whose modelled excess exceeds 0.5 of the template, or 0.10 with residual $14'$ structure above 0.10 rms after the fit, are dominated by scattered light rather than sky and are removed from the mosaic (5 FUV and 49 NUV tiles, $4.2/49.0 \text{ deg}^2$), to be filled by the fusion like any other gap. Measured as the ratio of corrected to neighbouring uncorrected pixels, both divided by T , per 45° sector within 3° of each star, the tiles so treated sat at a median of 1.04–1.06 (up to 1.2–2.4 in individual sectors) before the correction and at 1.00–1.01 after it, with 22/125 (FUV) and 63/422 (NUV) sectors outside ± 3 per cent and 4/17 outside ± 5 per cent, against 66/231 before. Together the targeted passes change 2.2/4.1 per cent of the *GALEX* pixels of each band by more than 1 per cent; the removed pattern carries 0.04–0.1 (FUV) and 0.5–1.2 per cent (NUV) of the mosaic's power at $\ell = 30$ –150 and is uncorrelated with $E(B-V)$ and H α ($|r| \leq 0.05$ in the 1° – 3° band), the band-passed correlation of the mosaic itself with both templates rising slightly at each pass. Two constraints protect the astrophysical content: the component of the offset map $O = S'm$ on scales $> 2.5^\circ$ is projected out and its footprint mean set to zero, so the isotropic level and the degree-scale sky are untouched by construction; and O is replaced by a local constant inside $r = 0.75 D_{25} + 0.42^\circ$ of 315 galaxies with $D_{25} > 5'$, generous LMC/SMC/M31/M33 ellipses and 0.4° of 147 globular clusters, while inside 21 bright-star ultraviolet scattering haloes (e.g. Spica) the ridged solution is kept so that the halo, whatever its nature, is left as observed. The *GALEX* layer is $g = G' - O$ (files `galex_{fuv,nuv}_equalised`); O , the per-tile table (including the scattered-light and removal flags) and the tile footprints are published. The rms of O over *GALEX* pixels is 60 CU (FUV) and 157 CU (NUV) outside the bright-star scattered-light regions (70 and 202 CU with them); the equalisation reduces the excess step at exposed tile edges of the mosaics by 60 per cent (FUV) and 77 per cent (NUV) and the number of tiles with a residual disc contrast above 0.05 at $> 5\sigma$ to 4.3/5.1 per cent of tiles, two fifths of which lie on nebular/dusty tiles or in protected regions where the correction is withheld by design; injection–recovery of synthetic offsets and rims through the full procedure returns slopes of 0.94/0.94 (offsets) and 0.89/0.92 (rims).

NUV, 2.5°-high-pass relative residual of destriped GALEX: before (g-S)/S | removed per-tile offset+rim model O/S' | after (g-O-S)/S' (colour ± 0.12 ; sources white)

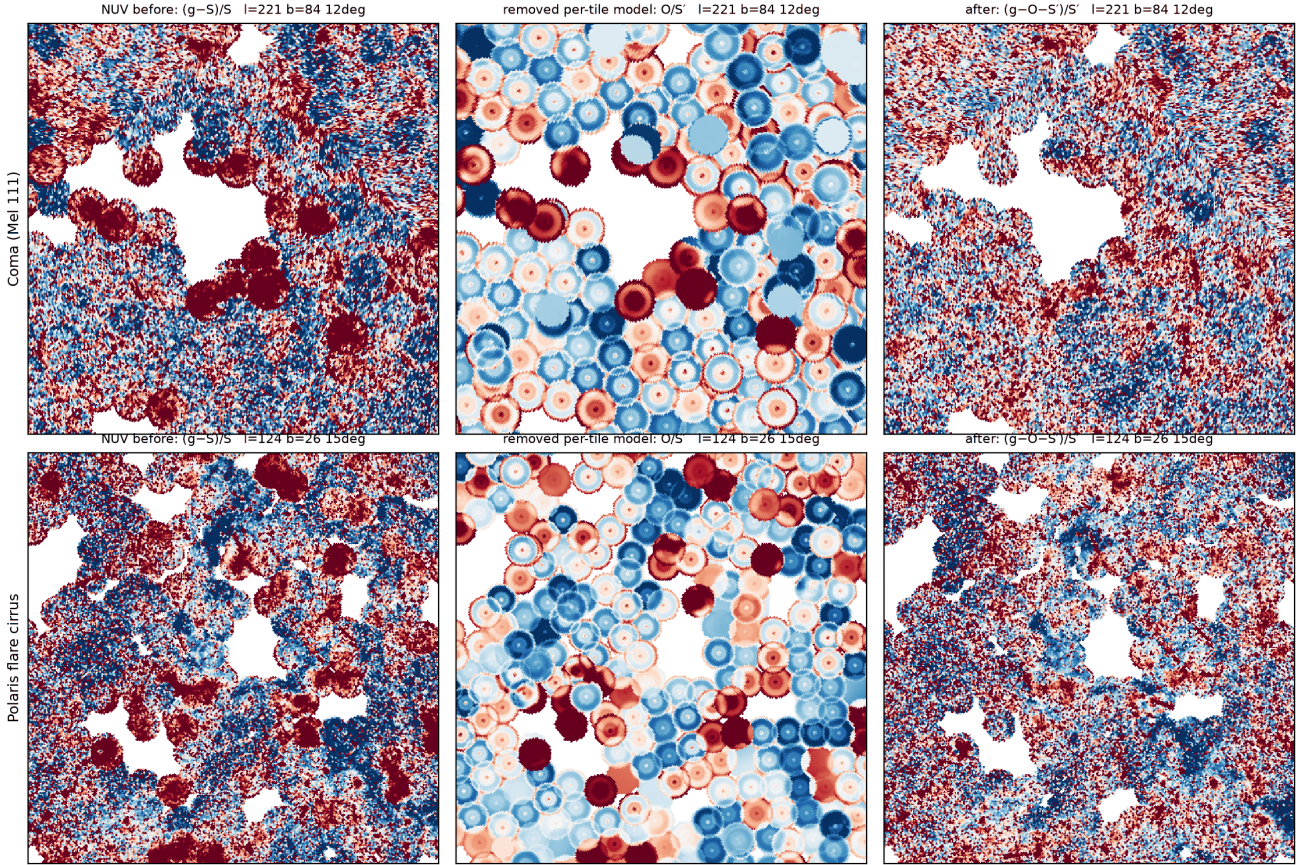


Figure 7: Per-tile background equalisation in two NUV fields (top: Coma, $l, b = 221^\circ, +84^\circ, 12^\circ$ across; bottom: Polaris-flare cirrus, $124^\circ, +26^\circ, 15^\circ$): 2.5°-high-pass relative residual of the destriped *GALEX* mosaic before (left), the fitted per-tile offset+rim+chord model O/S' that is removed (middle), and the residual after (right), on a common ± 0.12 stretch (sources masked white). The model consists of discs, rims and chords only; the cirrus of the Polaris field is absent from it and unchanged in the corrected residual. The discs that remain in the Coma field are pointings on NGC 4565, NGC 4559 and their neighbours, inside protected galaxy regions where O is held at a local constant.

3.4 Artefact masks and bright-star saturation top-up

Artefact masks. Residual instrumental features of the *GALEX* layer are down-weighted, never edited. Cells at $N_{\text{side}} = 512$ where $|\log_{10}(g/\bar{P}_{\text{loc}})| > 0.2$ dex against the local harmonised prediction are grouped into 8-connected components; a component is classed as instrumental if extended (≥ 3 cells), a positive excess within $12'$ of a $V < 5$ star, or touching the coverage edge, and not coincident with an RC3 galaxy, globular cluster or planetary nebula. A multiplier M_A , zero inside each of the 642 (FUV) and 433 (NUV) components and rising to unity over $15'$, multiplies the *GALEX* confidence factor in the fusion so that the affected $123/119 \text{ deg}^2$ are filled by lower-priority layers; the NUV multiplier also multiplies the confidence of the NUV-informed FUV layer, which inherits the NUV artefacts (Section 3.9). Maps and flags are published.

TD-1 top-up of censored stars. Bright stars above *GALEX*'s count-rate limits are absent or masked by $6'$ holes. For TD-1 stars with $f_\lambda > 2 \times 10^{-11} \text{ erg cm}^{-2} \text{ s}^{-1} \text{ \AA}^{-1}$ inside the footprint whose $6'$ *GALEX* aperture is deficient, the missing fraction of

the TD-1 flux is deposited with the TD-1 point-spread function into g (and into the imaged NUV used by the NUV-informed FUV layer, Section 3.8); the median $\log_{10}(\text{aperture}/\text{TD-1})$ of TD-1-bright stars changes from -1.09 to 0.00 dex. The *GALEX* fusion layer I_1 is g plus this top-up, undefined outside the footprint.

3.5 The source layer: stars, galaxies and extragalactic points

At $1.7'$ individual stars dominate the local intensity over much of the sky, and no full-sky template localises them. Discrete sources therefore enter the filled sky through a catalogue-based source layer $S = S_\star + E + L_{\text{gal}}$ built from the full depth of *Gaia* DR3, which also partitions both maps into resolved sources and a diffuse remainder. Validation figures are collected in Appendix C.2; the photometric behaviour of sources in the published map is tested in Section 4.5.

Gaia harvest and ultraviolet photometry. All 1.116×10^8 *Gaia* DR3 sources with $G < 16.5$ and the 7.2×10^6 blue or hot sources ($\text{BP} - \text{RP} < 0.6$ or GSP-Phot $T_{\text{eff}} > 7500 \text{ K}$) with $16.5 \leq G < 19$ were retrieved in HEALPix-ordered chunks whose row counts were

verified against server-side counts, with the ESP-HS hot-star parameters (2.4×10^6 stars), the white-dwarf catalogue of Gentile Fusillo et al. (2021) (3.6×10^5 , $P_{\text{WD}} > 0.75$) and the hot-subdwarf lists of Culpán et al. (2022) (6.8×10^4). Ultraviolet photometry for training and validation is GUVcat AIS (83.0 million rows, 3.1×10^7 matched to *Gaia* within $3''$; Bianchi et al. 2017), the *Swift* UVOTSSC and XMM-OM SUSS catalogues (4.2×10^6 and 5.1×10^6 *Gaia* matches, 56 and 67 per cent outside the *GALEX* FUV footprint; Yershov 2014; Page et al. 2012), UVIT DR1, SMC and M31 photometry (Tandon et al. 2017)—never used in training—and TD-1.

Per-star predictors. For normal stars the *GALEX*-system AB magnitude is a physical backbone—synthetic photometry of ATLAS9 spectra (Castelli & Kurucz 2003) at the GSP-Phot T_{eff} , $\log g$, $[M/H]$ and A_0 , anchored to G —corrected by a histogram gradient-boosted regression of the GUVcat residual on *Gaia* colours, M_G , parallax quality, RUWE, flux excess, *Planck* $E(B-V)$ and latitude (84 per cent of stars; a colour-only regression otherwise). GUVcat is NUV-selected and only 5 per cent of clean training stars have an FUV detection, so the FUV regression is a censoring-aware (Tobit-type) expectation–maximisation fit in which non-detections in FUV-exposed tiles enter as limits at the local 50 per cent completeness magnitude, $17.6 + 1.6 \log_{10}(t_{\text{FUV}}/\text{s})$; out of fold it places 99.8 per cent of 8.1×10^6 non-detections fainter than that limit, where a detections-only fit is biased bright by 1.3–2.5 mag at $0.3 < \text{BP} - \text{RP} < 1.4$. White dwarfs (Koester DA grid), hot subdwarfs and ESP-HS O/B/A stars (ATLAS9) use an analogous physical-plus-residual quantile regression, the physical value alone being adopted brightward of the *GALEX* non-linearity limit. In five-fold cross-validation blocked on 7.3° cells the out-of-fold robust scatter for 8.6×10^6 normal stars is 0.16 mag in the NUV (0.10 at $G = 11\text{--}13$, 0.27 at $17\text{--}19$; median offsets within ± 0.02 mag in every G , $|b|$ and $E(B-V)$ bin) and 0.38 mag in the FUV for depth-complete detections (0.35 at $\text{BP} - \text{RP} < 0.3$); for ESP-HS B/A stars it is 0.13/0.10 (NUV) and 0.27/0.32 mag (FUV), for white dwarfs 0.25/0.44 and for known hot subdwarfs 0.13/0.22, with 63–71 per cent of residuals inside the predicted $\pm 1\sigma$. Blind tests outside the *GALEX* footprint, where the layer is used, give for normal stars NUV–UVM2 medians of -0.02 (UVOT, 1.07×10^5 stars) and $+0.02$ mag (XMM-OM, 6.7×10^4) with robust scatter 0.26/0.22 mag and no plane bias beyond ± 0.07 mag up to line-of-sight $E(B-V) > 3$, and FUV–UVIT F148W/F154W of $+0.06$ (0.45) and -0.03 (0.33) mag; for hot stars, FUV/NUV–TD-1 of -0.04 (0.25) / -0.10 (0.29) mag at $G \lesssim 10$, FUV–UVIT F148W of -0.06 (0.24) mag in Magellanic and plane fields, and an NUV scatter against UVOT of 0.17–0.18 mag at $|b| < 10^\circ$ (0.20 at $E(B-V) > 1$).

Flux hierarchy and flux scale. Each of the 118 932 137 stellar sources takes, per band, the first available of: TD-1 at $S/N \geq 5$, multiplied by 1.047 onto the *GALEX* AB scale (17 757 FUV / 25 539 NUV stars, 79/72 per cent of the summed layer flux); a Bright Star Catalogue

model flux for *GALEX*-saturated stars without TD-1 (992/538), from a gradient-boosted model trained on 4577/5256 TD-1-matched BSC stars that predicts unmatched stars with a held-out scatter of 0.06–0.10 dex for O–B stars; the measured GUVcat magnitude where unsaturated and clean (7.7×10^5 / 1.17×10^7); the hot/degenerate prediction (2.5×10^6 / 2.1×10^6); and the normal-star prediction (1.16×10^8 / 1.05×10^8). A per-source σ and flux origin are recorded. The summed stellar flux is 1.107×10^5 (FUV) and 9.04×10^4 (NUV) photons $\text{cm}^{-2} \text{s}^{-1} \text{\AA}^{-1}$; stars fainter than $G = 13$ carry 1.1/2.2 per cent of it over the sky but 91 per cent (FUV; hot subdwarfs and white dwarfs) and 31 per cent (NUV) of the stellar flux of a median $N_{\text{side}} = 256$ cell at $|b| > 30^\circ$. The 160 099 *Gaia* quasar and galaxy candidates without stellar astrometry form the extragalactic point-source layer E ($8.9/8.6$ photons $\text{cm}^{-2} \text{s}^{-1} \text{\AA}^{-1}$ in total).

Galaxies and globular clusters L_{gal} . The integrated light of 14 283 nearby galaxies (171 magnitudes predicted with 0.85/0.63 mag rms) and 146 globular clusters (104 predicted with 0.69/0.41 mag rms) is rendered as exponential discs of scale length $D_{25}/6.4$ truncated at $1.2R_{25}$ and as Plummer profiles, respectively; M31, M33 and the Magellanic Clouds, which are imaged, are excluded. Against D_{25} photometry of 605 isolated galaxies the layer gives median *GALEX*/layer ratios of 0.94 in the FUV and 1.16 in the NUV. Its all-sky mean is 1.35/1.63 CU; inside $W_{\text{GALEX}} > 0.5$ its contribution is zero.

Rendering. Outside ultraviolet imaging sources are deposited flux-conservingly as $2.0'$ Gaussians ($3.0'$ for TD-1/BSC stars, with 10 per cent in a $6'$ wing for the brightest). Inside imaging the point-source response of the published map, measured on 5854 isolated GUVcat stars, is a pixel-limited core ($\sigma = 0.20'$) with 12.5 per cent of the flux in a $6'$ -FWHM wing; aperture photometry of the map at GUVcat stars gives map/catalogue flux ratios $\kappa = 1.205$ (FUV) and 1.213 (NUV), applied to catalogue- and prediction-tier sources in the subtracted (‘map-matched’) layer, TD-1/BSC stars entering unscaled. Per-pixel 1σ maps σ_{stars} are propagated from lognormal per-star errors. In the Magellanic Clouds ($8^\circ/5^\circ$ discs) the Galactic-calibrated predictions of $\sim 10^6$ members exceed the *GALEX* surface photometry, so the stellar input to the fusion is capped cell-wise at a reference level consistent with the surrounding imaging (62 deg^2 , the LMC bar and SMC body; Section 3.10). Inside the footprint, stellar content follows the *GALEX* mosaics, with *GALEX* non-linearity for $\text{NUV} \lesssim 15$ stars inherited unflagged; very bright cool stars are the population the hierarchy serves least well (Section 6).

Partition and completeness. The published diffuse maps are the total minus the map-matched stellar layer, E and L_{gal} , provenance-weighted so that outside imaging they equal the harmonised diffuse prediction exactly (all-sky medians 1063/1140 CU; files `diffuse_{fb}`). Stacked residuals at the positions of 14–18 mag layer stars are $-4/-3$ per cent (FUV/NUV) of the star flux inside imaging and $+12/-1.5$ per cent outside, the FUV excess being FIMS/SPEAR-resolution

starlight. Outside the Clouds 0.25 per cent (FUV) and 1.42 per cent (NUV) of $N_{\text{side}} = 2048$ pixels lie below $-2\sigma_{\text{stars}}$ (0.43/1.73 per cent negative at all; model-class pixels 0.00–0.02 per cent), the NUV rate reflecting GU-Vcat magnitude errors smaller than the true per-star map/catalogue scatter; inside the Clouds 24 per cent are negative and the region must be masked in diffuse analyses. Ninety-nine per cent of the layer flux of a median $N_{\text{side}} = 256$ cell is reached at $G = 17.25$ (FUV) / 16.5 (NUV), i.e. FUV 23.3 / NUV 21.8 AB; a power-law extrapolation of the differential source flux to $m = 23$ leaves an unresolved stellar remainder, published at $N_{\text{side}} = 64$, of median 4.2/14 CU over the sky, 2.8/5.5 CU at $|b| > 30^\circ$ (≤ 0.7 per cent of the diffuse level) and 13/242 CU at $|b| < 10^\circ$, so that only in the NUV plane can unresolved starlight reach ~ 10 per cent of the diffuse map.

3.6 Cross-calibration of UVOT and FIMS/SPEAR

UVOT. Count and exposure maps give a rate per filter, and both UVOT and *GALEX* are smoothed to $1.7''$. For each UVOT filter and each *GALEX* band we fit an isotonic regression of $\log g$ on $\log r_{\text{UVOT}}$ over 0.7–0.9 million common $N_{\text{side}} = 2048$ pixels, with robust scatter of 0.11 dex for the closest filter–band pairs and 0.25 dex for the FUV mapping. The transformation is colour dependent: $\log(g_{\text{FUV}}/\text{UVOT}_{\text{FUV}})$ drifts by 0.51 ± 0.01 dex per decade of $E(B-V)$ above $E(B-V) = 0.03$ (Section 4.4). UVOT therefore receives a capped weight ($c_3 = 0.8$), is gain-matched regionally (Section 3.9), and is treated as a validation reference of 0.1–0.2 dex precision; overlapping filter estimates are combined with inverse-variance weights into the mapped UVOT layer.

FIMS/SPEAR. Averaged to the local FIMS/SPEAR resolution, g_{FUV} and the FIMS/SPEAR starry map have a median ratio of 0.97–1.08 by resolution tier with 0.13 dex robust scatter at $55''$, and the ratio is flat in $E(B-V)$ to ± 0.04 dex over $0.01 < E(B-V) < 1.2$ (Section 4.4); no rescaling is applied beyond an empirical global factor of 0.97 on the starless map. Because its resolution is 10–30 times coarser than our grid, FIMS/SPEAR is not injected as an image layer but constrains the large-scale level of the FUV model layer far from *GALEX*; the constraint is built in the fusion from the *starless* map plus our own source layer, so that a bright star inside the FIMS/SPEAR beam is not represented twice (Section 3.9). The TD-1 scale is tied to the same *OAO-2/IUE*-era flux scale as *GALEX* through white-dwarf standards and enters through the factor 1.047 of Section 3.5.

3.7 The diffuse predictor

Where no ultraviolet imaging exists we require an estimate of the diffuse surface brightness that is unbiased, retains true small-scale structure, and carries an empirical error model; discrete sources are added separately

through S . We cast this as supervised regression with the star-subtracted *GALEX* sky as the training set, using histogram-based gradient-boosted regression trees (HGB; Friedman 2001; Ke et al. 2017) in SCIKIT-LEARN (Pedregosa et al. 2011), minimising the squared error of $\log_{10} I$. Trees were preferred over convolutional models because the mapping from dust, gas and starlight tracers to ultraviolet intensity is local and non-linear, and trees handle missing features natively and are cheap to retrain for cross-validation. Their inability to extrapolate beyond the training feature range is relevant to the inner Galactic plane (Section 4.2).

Features. The predictor uses the 90 features of Table 3: pixel values of the dust, $\text{H}\alpha$, starlight and positional templates, plus features encoding each pixel’s *neighbourhood*—Gaussian-smoothed templates at six scales with their high-pass residuals, gradient amplitudes, texture, coarser-scale source density, τ_{353} , colour, and ecliptic coordinates. The physical motivation is that ultraviolet intensity depends on the illuminating field, set by sources and dust over degrees around it. All features derive from full-sky templates; none uses the target or ultraviolet data.

Target. The target y is defined at $N_{\text{side}} = 512$ as the mean of $g - S$ (with S the map-matched source layer of Section 3.5) over the fully imaged children of each cell ($W_{\text{GALEX}} \geq 0.99$; children below $-5\sigma_{\text{stars}}$ dropped), with the Magellanic Clouds masked and cells flagged as non-positive, bright-star artefact or noisy removed, leaving $\simeq 2 \times 10^6$ cells per band. The explicit subtraction makes the target the diffuse light as partitioned in the published maps, rather than an order-statistic proxy for it.

Training and cross-validation. All performance figures are out-of-fold values from a six-fold spatial block cross-validation, folds being unions of $N_{\text{side}} = 8$ super-pixels (7.3°) assigned by a fixed permutation (151/121/122/120/130/124 super-pixels per fold); the median held-out-to-training distance is 1.27° (90th percentile 2.85° ; tail to 7.8°). Held-out *GALEX* pixels are re-weighted to the $(E(B-V), |b|)$ distribution of the filled sky (‘gap-matched’) for both training and scoring. Each cross-validation model is trained on 5×10^5 pixels per fold; the deployed model, which uses all folds, is trained on 4×10^5 pixels entered three times, with sample weights $0.3 + 0.7 \text{ clip}(\sqrt{w/\bar{w}}, 0, 10)$. Hyper-parameters (800 iterations, learning rate 0.05, ≤ 127 leaves, ≥ 40 samples per leaf, L2 regularisation 1) were chosen on the out-of-fold scatter, with tuning gain $\simeq 0.002$ (FUV) and 0.003 dex (NUV) (Appendix B). The benchmark file, with targets, folds and gap-matching weights, is published for identical scoring of alternative models (Appendix A); the same out-of-fold residuals feed the uncertainty model (Section 4.6).

Jitter-regularised positional features. Axis-aligned splits on coordinates can produce discontinuities along coordinate lines. Each training pixel is entered with its true templates plus two copies perturbed by Gaussian jitter ($\sigma_b = 2^\circ$, $\sigma_l = 2.5^\circ / \cos b$), and predictions are averaged over six jittered draws. Across $b = 0$ the de-

Table 3: Features of the gap-fill predictor (90 in total), all evaluated from full-sky templates at $N_{\text{side}} = 512$ for training and $N_{\text{side}} = 1024$ for prediction. $\mathcal{S}_\theta$ denotes Gaussian smoothing of FWHM θ ; ‘high-pass’ is pixel value minus $\mathcal{S}_\theta$. Logarithms of $\text{H}\alpha$ and *Gaia* source density are floored at -1 (0.1 R and 0.1 stars per pixel) and those of the *Gaia* fluxes at 0; the dust templates are strictly positive and need no floor (the published feature matrix records the values used). The six templates marked $\dagger$ plus distance to data are the inputs of the uncertainty model (Section 4.6).

Group	Features
Base (12)	$\log E(B-V)^\dagger$, $\log \tau_{353}$, $\log \mathcal{R}$ (Planck Collaboration XI 2014); $\log I_{\text{H}\alpha}^\dagger$ (Finkbeiner 2003); $\log F_{\text{BP}}^\dagger$, $\log F_{\text{RP}}$, $\log(F_{\text{BP}}/F_{\text{RP}})$, $\log n_\star^\dagger$ (Gaia Collaboration 2023); $\sin b$, $ b ^\dagger$, $\cos l$, $\sin l$ (jittered)
Multi-scale (48)	$\mathcal{S}_\theta[x]$ and $x - \mathcal{S}_\theta[x]$ for $x \in \{\log E(B-V), \log \mathcal{R}, \log I_{\text{H}\alpha}, \log F_{\text{BP}}\}$ and $\theta = 0.5^\circ, 1^\circ, 2^\circ, 4^\circ, 8^\circ, 16^\circ$
Gradients, texture (10)	$ \nabla \mathcal{S}_\theta[x] $ for $x \in \{\log E(B-V), \log \mathcal{R}, \log I_{\text{H}\alpha}\}$, $\theta = 0.5^\circ, 2^\circ$; standard deviation of the eight neighbours of $\log E(B-V)$, $\log \mathcal{R}$, $\log I_{\text{H}\alpha}$, $\log F_{\text{BP}}$
Secondary scales (15)	$\mathcal{S}_\theta$ and high-pass of $\log n_\star$ and $\log \tau_{353}$ at $\theta = 1^\circ, 4^\circ, 16^\circ$, and $\mathcal{S}_\theta$ of BP/RP colour at $1^\circ, 4^\circ$ (plus high-pass at 1°)
Ratios (2)	$\log \mathcal{R} - \log \tau_{353}$ (dust temperature proxy), $\log E(B-V) - \log \tau_{353}$
Ecliptic (3)	$ \beta $, $\sin \lambda$, $\cos \lambda$

ployed prediction steps by $-0.002/-0.003$ dex between the $\pm 0.125^\circ$ bins and by $0.030/0.041$ dex rms over eighteen longitude sectors, against 0.111 dex for the *Planck* radiance itself: no seam. The cost in held-out scatter is $+0.0018 \pm 0.0003$ dex (NUV, significant); we accept it for removal of coordinate-aligned steps.

Accuracy and deployment. In the six-fold block cross-validation the predictor scores an area-weighted/gap-matched robust scatter of $0.037/0.047$ dex (FUV) and $0.047/0.057$ dex (NUV) on the diffuse target, and $0.041/0.052$ and $0.047/0.058$ dex for prediction plus S against the total g ; part of this scatter is noise in the target rather than prediction error (Section 4.2). Predictions are evaluated at $N_{\text{side}} = 1024$ and interpolated bilinearly in $\log I$ to $N_{\text{side}} = 2048$, giving the diffuse prediction P_D .

3.8 The NUV-informed FUV layer

In the 11.9 per cent of the sky imaged by *GALEX* in the NUV only, a $5''$ ultraviolet image exists in the neighbouring band, and the FUV/NUV colour of the diffuse sky is a smooth, predictable function of dust column, latitude and stellar content (Section 5). Stars, by contrast, span colours from $10^c \ll 1$ to NUV fluxes 10–60 times their FUV flux and cannot be transferred with the diffuse colour. We therefore predict the *diffuse* colour,

$$c_d = \log_{10} \left(\frac{\widehat{g_{\text{FUV}}} - S_{\text{FUV}}}{g_{\text{NUV}} - S_{\text{NUV}}} \right), \quad (3)$$

with an HGB regressor on the twelve base templates of Table 3 plus $\log g_{\text{NUV}}$, trained on the star-subtracted

GALEX FUV and NUV at $N_{\text{side}} = 512$ (six-fold cross-validation robust scatter 0.0351 dex, $R^2 = 0.966$), evaluated at $N_{\text{side}} = 1024$ and interpolated in $\log$ to $N_{\text{side}} = 2048$, and define wherever *GALEX* NUV exists

$$I_X = (g_{\text{NUV}} - S_{\text{NUV}})_L \times 10^{c_d} + S_{\text{FUV}}, \quad (4)$$

where S_{NUV} and S_{FUV} are the stellar layer $S_\star$ of Section 3.5 in the two bands (catalogue fluxes deposited with the model PSF), g_{NUV} is the imaged NUV without the TD-1 top-up, and the subscript L denotes that star cores (S_{NUV} above the local star-free level L , the $N_{\text{side}} = 512$ median of the imaged NUV over pixels with $S_{\text{NUV}} < 0.05L$) and over-subtracted wings (residual $< 0.5L$ where $S_{\text{NUV}} > 0.02L$; together 6.6 per cent of the NUV-imaged FUV-gap pixels) are replaced by L . Stars in NUV-informed sky therefore enter the FUV map with their catalogue (or predicted) FUV flux, exactly as in model sky, while the diffuse morphology is that recorded by the NUV detector. Star-adjacent cold pixels (> 0.3 dex below their eight-neighbour median, two passes) are replaced by that median, reducing the fraction of NUV point sources with an adjacent FUV hole from 30.6 to 3.7 per cent.

Stacks of isolated catalogue stars in the layer alone are colour-flat (aperture/catalogue $0.86/0.86/0.85/0.91/1.10$ at 15–17 mag and $0.90/0.87/0.91/0.93/0.98$ at 12–15 mag for FUV–NUV < -0.5 / -0.5 – 0.5 / 0.5 – 1.5 / 1.5 – 3 / > 3 , i.e. the 0.89 of the model PSF held by a $2'$ aperture), the diffuse level of the layer against *GALEX* FUV (30th percentile of $N_{\text{side}} = 256$ cells in the overlap) is -0.003 dex ($-0.008/-0.007/+0.002$ at $|b| = 0$ – $20/20$ – $40/40$ – 90°), and bright-star wings show no moats

((layer− S_{FUV})/background 1.55/1.35/1.06/1.04 at 0–2/5–6/8–10/10–14', the residual being the imaged *GALEX* halo beyond the model PSF wing). In the published FUV map, stacks of isolated stars in NUV-informed-class sky read 1.00 (4–8 mag), 0.92 (8–12), 0.97 (12–15; blue/mid/red 0.91/0.97/1.02) and 1.10 (15–17; 1.20 at $|b| < 10^\circ$ where faint imaged neighbours fill the aperture, 1.10 above) of the catalogue flux, against 0.92–0.97 for the model and FIMS/SPEAR classes, which deposit the same PSF; TD-1 stars in that sky read +0.006 dex against the catalogue (8' apertures) and +0.04 dex against TD-1 itself, the adopted *Gaia*-based fluxes of these B/A stars lying 0.027 dex above TD-1 in a direct star-by-star comparison of the two flux scales. I_X enters the fusion as a survey-like layer with its own feather ($\theta_2 = 1.2^\circ$) and confidence cap $c_2 = 0.9$, below *GALEX* FUV and above UVOT; it has non-zero weight over 19 per cent of the sphere and is dominant over 9.7 per cent of the FUV sky. Its status is dual: every structure was recorded by the NUV detector, but its FUV intensity is a prediction, and FUV/NUV colours or FUV-only physics cannot be taken from it (Section 3.10). Inside the Magellanic Clouds, where the layer carries the capped stellar layer of Section 3.5, the median step to adjacent *GALEX* FUV pixels is +0.036 (LMC) and +0.031 dex (SMC); UVOT cannot arbitrate there (coincidence loss), and the Clouds remain excluded from quantitative use (Section 6).

3.9 Fusion: gain harmonisation, the FIMS/SPEAR ratio field and priority-nested feathering

Gain harmonisation and the model layer. Even an unbiased regression has spatially correlated residuals at the 0.02–0.04 dex level on degree scales (Section 4.6), which if uncorrected would produce steps where the prediction meets the data. We therefore multiply the diffuse prediction by a smooth multi-scale gain field estimated from the data/model ratio and extrapolated a short distance into the gaps:

$$\tilde{P}_D = 10^\gamma P_D, \quad \gamma = \sum_{j=1}^4 \zeta_j \gamma_j, \quad (5)$$

$$\gamma_j = \mathcal{S}_{\vartheta_j} \left[\text{med}_{c \in \text{cells}_j} (\log I_1 - \log P) \right],$$

where the ratio is formed between the *GALEX* layer I_1 and the complete model of the total intensity, $P = P_D + S$, and the hierarchy consists of medians in $N_{\text{side}} = 128$ cells smoothed with $\vartheta_1 = 1.2^\circ$, medians in $N_{\text{side}} = 64$ cells smoothed with $\vartheta_2 = 4^\circ$, a $\vartheta_3 = 15^\circ$ smoothing, and the global median log ratio γ_4 (within 2 per cent of unity in both bands). Cell medians require at least 30 ($N_{\text{side}} = 128$) and 20 per cent ($N_{\text{side}} = 64$) valid *GALEX* children and are clipped to a factor of 3. The coefficients $\zeta_j(\hat{\mathbf{n}})$, $\sum_j \zeta_j = 1$, select the finest level with adequate *GALEX* support, the 1.2° level rising from zero to unity between kernel-weighted valid

fractions of 0.3 and 0.7, the 4° level between 0.03 and 0.23. By construction γ has no structure below 1.2° and cannot imprint *GALEX* noise on the prediction. Inside *enclosed* coverage holes (bright-star avoidance zones and missing tiles; every non-*GALEX* component smaller than 150 deg^2 , 1316/1397 in FUV/NUV totalling $4400/4160 \text{ deg}^2$, i.e. everything except the Galactic-plane gap) the harmonised diffuse prediction is additionally anchored to the rim: the logarithm of the ratio of the measured star-subtracted *GALEX* intensity to $\tilde{P}_D$ is evaluated on 14' cells around each hole (artefact-masked cells excluded, 0.25° smoothing), continued into the hole as the harmonic (Laplace) interpolant of its rim values—which carries the rim's mean level and its dipole (tilt) across the hole—plus, for the first degree inward, a linear continuation of the radial gradient fitted to the rim cells within 1° of the boundary (median $|\text{d log } C/\text{d } r| = 0.005 \text{ dex deg}^{-1}$ over the large holes, 0.03 at Spica in the FUV), and applied as a multiplicative correction C to $\tilde{P}_D$ inside the hole and, tapering to unity between 0.6° and 1.2° , on its surroundings, so that the fill continues the measured brightness and its trend across the coverage boundary in every direction rather than only on the 1.2° average of γ . The correction has median $|C - 1| = 0.015$ and exceeds 8 per cent in 1–2 per cent of hole pixels; without it the extrapolation of the predictor to the extreme stellar-density features at the centres of bright-star holes leaves rim discontinuities of 5–15 per cent (e.g. around Spica and Achernar). The mapped UVOT intensity is harmonised in the same way against *GALEX* where available and against the model layer elsewhere (global gains $\simeq 1.7$ FUV, $\simeq 0.9$ NUV). An island consistency test gives small isolated *GALEX* regions (regional support below 20 per cent) whose level disagrees with the harmonised model by more than 0.10–0.25 dex a confidence multiplier falling from unity to zero, preventing anomalous AIS tiles from being propagated into the gaps.

Because no template localises individual stars, a regression of the total intensity is smooth on arcminute scales and recovers only 15–50 per cent of the flux of catalogued 11–15 mag sources. The model layer separates what the regression can and cannot predict:

$$\mathcal{M} = 10^\gamma P_D + S_\star + E + L_{\text{gal}}, \quad (6)$$

with P_D the diffuse prediction and $S_\star$, E and L_{gal} the stellar, extragalactic point-source and galaxy/globular-cluster layers of Section 3.5. $\mathcal{M}$ receives weight where the data layers do not, so nothing is double counted inside the *GALEX*, NUV-informed and UVOT footprints; it is published over the full sky as the gap-fill layer.

The FIMS/SPEAR-constrained layer. In the FUV we form the ratio of $0.97 I_{\text{FIMS,starless}} + S$ to $\mathcal{M}$ in $N_{\text{side}} = 32$ (1.8°) cells, excluding zones around the 76 stars brighter than $150 \text{ photons cm}^{-2} \text{ s}^{-1} \text{ \AA}^{-1}$ whose FIMS/SPEAR scattered-light haloes would raise it, smooth it above 4° , clip it to $[1/2, 2]$, taper it, and multiply the *diffuse*

component of the model layer alone:

$$\begin{aligned} I_F &= C_F 10^{\gamma} P_D + [\mathcal{M} - 10^{\gamma} P_D], \\ C_F &= \text{clip}(R, \frac{1}{2}, 2)^{\eta_F(\hat{\mathbf{n}}) t(d)}, \\ R &= \mathcal{S}_4 \left[\frac{\langle 0.97 I_{\text{FIMS,starless}} + S \rangle_{32}}{\langle \mathcal{M} \rangle_{32}} \right], \end{aligned} \quad (7)$$

where $\mathcal{S}_\theta$ is mask-normalised Gaussian smoothing of FWHM θ , $\eta_F \in [0, 1]$ is a support taper, unity where the smoothed ratio field is well supported and regional *GALEX* support is weak, falling linearly to zero as the support weight drops from 0.65 to 0.3 and as regional *GALEX* coverage rises from 15 to 60 per cent, and $t(d)$ is a distance taper, zero within 2° of the nearest valid *GALEX* FUV pixel and rising linearly to unity at 6° . The distance taper reflects a measured property of the constraint (Section 4.3): near *GALEX* the multi-scale gain field already fixes the prediction level, and the $N_{\text{side}} = 32$ FIMS/SPEAR/prediction ratio there is dominated by FIMS/SPEAR noise and residual stellar structure rather than prediction error, so applying it increases the blind mock-gap error (68th percentile 0.067–0.077 versus 0.054–0.058 dex at 1° – 4°); only beyond $\simeq 6^\circ$ and at $|b| < 10^\circ$ does the ratio improve on the harmonised prediction. With the taper the gap-matched blind mock-gap error of the FIMS/SPEAR-constrained layer is 0.068 dex instead of 0.081 dex and is nowhere worse. Before clipping, the $N_{\text{side}} = 32$ log-ratio has 5–95 per cent range -0.14 to $+0.19$ dex; 1.4 per cent of supported cells sit at the upper clip and 0.55 per cent at the lower, the W_{FIMS} -weighted upper-clipped cells forming three compact groups in Vela/Gum, Carina–Crux and Upper Sco where residual FIMS/SPEAR stellar haloes survive the star mask; without the clip the map there would be up to 0.16 dex brighter, elsewhere unchanged ($|\Delta| = 0.003$ dex). I_F thus carries the measured diffuse FUV level above 4° far from *GALEX*, the template-predicted morphology below that scale, and catalogue sources at their catalogue fluxes. In the *GALEX*-free plane the published map reproduces the constraint quantity to a median of 0.99 with 0.07 dex scatter and $r = 0.95$ at $13.7'$; its ratio to the FIMS/SPEAR *starry* map is resolution dependent (Section 4.4).

Priority-nested feathering. The layers are combined pixel by pixel as a convex combination; in decreasing priority they are $k = 1$, *GALEX* (I_1 , i.e. g with the TD-1 top-up); $k = 2$, the NUV-informed FUV layer I_X (FUV only); $k = 3$, the harmonised mapped UVOT intensity; $k = 4$, the FIMS/SPEAR-constrained model layer I_F (FUV only); and finally the model layer $\mathcal{M}$. The fused intensity is

$$\begin{aligned} I(\hat{\mathbf{n}}) &= \sum_{k=1}^4 w_k(\hat{\mathbf{n}}) I_k(\hat{\mathbf{n}}) + w_M(\hat{\mathbf{n}}) \mathcal{M}(\hat{\mathbf{n}}), \\ w_M &= 1 - \sum_{k=1}^4 w_k \geq 0, \end{aligned} \quad (8)$$

with priority-nested weights

$$\begin{aligned} w_k(\hat{\mathbf{n}}) &= c_k(\hat{\mathbf{n}}) f_k(\hat{\mathbf{n}}) \left(1 - \sum_{j < k} w_j(\hat{\mathbf{n}}) \right)_+, \\ f_k &= m_k \rho \left(\frac{\mathcal{S}_{\theta_k}[m_k] - \rho_0}{\rho_1 - \rho_0} \right), \quad \rho(x) = \text{clip}(x, 0, 1), \end{aligned} \quad (9)$$

where $m_k \in \{0, 1\}$ is the validity mask of layer k and $\mathcal{S}_{\theta_k}[m_k]$ its coverage fraction smoothed with FWHM θ_k , so that f_k vanishes where the local smoothed coverage is below ρ_0 and reaches unity above ρ_1 , and $c_k \leq 1$ is a confidence factor. For *GALEX* we adopt $\theta_1 = 0.3^\circ$ with $(\rho_0, \rho_1) = (0.45, 0.95)$; for the NUV-informed layer, UVOT and FIMS/SPEAR $\theta_k = 1.2^\circ$, 0.7° and 2.5° with $(\rho_0, \rho_1) = (0.5, 0.95)$. The confidence factors are $c_1 = M_A$, the artefact multiplier of Section 3.4, times the island multiplier; $c_2 = 0.9$ times the NUV artefact multiplier, since I_X inherits the NUV artefacts; $c_3 = 0.8$; and c_4 a factor that is unity where the regional *GALEX* coverage is below 20 per cent and falls to zero where it is complete. The factors c_2 and c_3 encode the larger calibration-transfer uncertainty of the colour-scaled NUV image and of UVOT relative to *GALEX*; the source layer enters only through I_X , I_F and $\mathcal{M}$, because stars and galaxies inside the *GALEX* and UVOT footprints are already present there. The factor $(1 - \sum_{j < k} w_j)_+$ nests the weights by priority, so they sum to unity by construction and a fully feathered-in *GALEX* pixel ($f_1 = c_1 = 1$) has $w_1 = 1$ exactly; $\max W_{\text{GALEX}} = 1$ in the published files. The *GALEX* feather scale $\theta_1 = 0.3^\circ$ balances fidelity to *GALEX* against seam roughness: the 90th percentile of $|\log_{10}(\text{map}/g)|$ over the footprint is 0.0024 dex (FUV) and 87 per cent of imaged pixels have $W_{\text{GALEX}} > 0.99$. In the FUV *GALEX* dominates 61.9 per cent of the sky, the NUV-informed layer 9.7, UVOT 0.2, the FIMS/SPEAR-constrained model 23.7 and the model 4.5 per cent; in the NUV *GALEX* dominates 73.3, UVOT 0.2 and the model 26.5 per cent. Pixels with $W_{\text{GALEX}} + W_{\text{NUVX}} + W_{\text{UVOT}} \geq 0.5$ cover 72.0/73.5 per cent of the sky.

3.10 Post-fusion edits, products and pixel classes

Post-fusion edits. Four local edits are applied to the fused maps. (i) Ultraviolet-bright stars that lack a valid TD-1 flux and are censored in the imaging receive the Bright Star Catalogue model deficit as a $2'$ Gaussian (BSC stars earlier than F5; 306 FUV, 368 NUV stars), and 56 (FUV) and 11 (NUV) very bright cool stars plus Canopus receive an additive completion patch; all are deposited with weight $1 - W_{\text{FIMS}} - W_{\text{MODEL}} - W_{\text{NUVX}}$, i.e. only where the source layer does not already carry them. (ii) Cold pixels (> 0.3 dex below their eight-neighbour median, two passes) are replaced by that median in FIMS/SPEAR-dominated FUV sky and in a handful of *GALEX* and NUV pixels. (iii) One *GALEX* NUV edge-reflection glint of ν And (0.4 deg^2 , peak 10^5 CU), which the NUV-informed layer would copy into the FUV, is re-

moved from both bands by harmonic inpainting of $\log I$ from the boundary of a grown mask (915 pixels) with compact sources protected and the original high-pass texture retained; the boundary step after repair is 0.000 (NUV) and -0.010 dex (FUV). (iv) Inside the LMC (8°) and SMC (5°) discs, pixels with $W_{\text{MODEL}} + W_{\text{FIMS}} > 0.5$ are tied to the capped reference level of Section 3.5 through a smooth boundary-matching factor field, so that un-imaged holes in the Clouds do not inherit the over-predicted member starlight.

Products. The published files (Section 7, Table 7) are the two maps; the five weight columns $W_k \equiv w_k$ per band; an integer provenance code (the dominant layer, Fig. 8); a ‘data-only’ variant in which pixels with $W_{\text{GALEX}} + W_{\text{NUVX}} + W_{\text{UVOT}} < 0.5$ are blanked; $N_{\text{side}} = 512$ means of the sixteen children; the gap-fill layer $\mathcal{M}$ (and I_{F}) over the full sky; every source layer separately, with the stellar, extragalactic, diffuse and unresolved-remainder partition of Section 3.5 and its per-source catalogue; and two-column uncertainty maps. The per-pixel uncertainty of $\log_{10} I$ (column SIGMA, equation 10) is the weight-quadrature sum of per-class terms—*GALEX* pixel noise, the colour-model scatter for I_{X} , an intensity-dependent UVOT term, an empirical model term from a quantile regression of the absolute out-of-fold residuals of Section 3.7 on the six templates marked in Table 3 and distance to data, a FIMS/SPEAR term from mock gaps, and the stellar-layer σ_{stars} —with a separate systematic column SIGMA_SYS; its construction and calibration are given in Section 4.6.

Pixel classes: what the map is and is not. The maps combine direct imaging with template-based prediction constrained by coarser data where imaging is absent, fused seamlessly so that a pixel’s supported science depends on its class rather than appearance. Table 4 gives the taxonomy: direct *GALEX* imaging sets 61.9 per cent of the FUV and 73.3 per cent of the NUV sky, while predicted sub-degree morphology covers 28.0 per cent (FUV) and 26.5 per cent (NUV).

Two of these classes need a sharper statement. First, the NUV-informed FUV layer is imaging-derived—every diffuse structure in it was recorded by the *GALEX* NUV detector—but its FUV *intensity* is the star-subtracted NUV intensity multiplied by a learned colour plus catalogue stars, so it is a prediction conditioned on an image. Whether it counts as ‘data’ depends on the question: for position and shape it does; for the FUV/NUV ratio, H_2 fluorescence, or any FUV-specific quantity it does not, by construction. We recommend a strictly data-only FUV analysis select $W_{\text{GALEX}} + W_{\text{UVOT}} \geq 0.5$ ($\simeq 62$ per cent of the sky) rather than $W_{\text{GALEX}} + W_{\text{NUVX}} + W_{\text{UVOT}} \geq 0.5$ (72.0 per cent) used for the published ‘data-only’ file; the header (SELECT) and Table 7 state it includes 9.7 per cent of sky whose FUV level and colour are transferred from the NUV. Second, in the FIMS/SPEAR-constrained class the constraint is coarse: FIMS/SPEAR fixes the mean level over $\gtrsim 4^\circ$ (coherence falls below 0.5 at scales $< 137'$), while below a degree is template prediction plus catalogue stars. Over the full 28 per cent

of the FUV sky in these classes, sub-degree morphology is predicted, not observed.

The practical rules by science case are as follows (Appendix D). Photometry and morphology of diffuse structure, structure functions and small-scale power: $W_{\text{GALEX}} > 0.99$ only. Cross-correlation with extragalactic tracers, EBL and offset studies: $W_{\text{GALEX}} > 0.99$, and remember the monopole is inherited (Section 5). FUV/NUV colours and FUV-only physics: both bands *GALEX*-dominated. Degree-scale level of the FUV sky in the plane and in the *GALEX* gaps: all classes, with the published uncertainty (0.05–0.10 dex per $7'$ in W_{MODEL} and W_{FIMS} sky from column SIGMA, plus the 0.10 dex coherent plane systematic of column SIGMA_SYS; Section 4.6). Bright-source avoidance: all classes, noting that outside *GALEX* the stellar content is the *Gaia*-based layer of Section 3.5, complete in flux to $G \simeq 17$ but with predicted rather than measured ultraviolet fluxes for most stars (0.16–0.4 mag per star). What no filled pixel can provide is new small-scale interstellar physics: a filament, shell or cloud edge seen only in $W_{\text{FIMS}}/W_{\text{MODEL}}$ sky is templates re-projected through the regression, with contrast biased low by the conditional-mean nature of the predictor (Section 4.7).

4 Validation of the published maps

This section establishes, on the published files, (i) how faithfully the fused map reproduces *GALEX* inside the footprint; (ii) how well the diffuse predictor reproduces *GALEX* where withheld, weighted as the sky actually filled; (iii) how the complete fusion recovers mock gaps; (iv) how the maps compare with independent instruments in sky *GALEX* never observed; (v) how discrete sources behave by pixel class; (vi) whether the published uncertainty is calibrated; and (vii) what fraction of the angular power the filled sky retains. We reserve *validation* for tests against withheld *GALEX*, independent instruments (FIMS/SPEAR, UVOT, TD-1) and catalogues; comparisons with dust, $\text{H}\alpha$ and H I are *consistency checks* (Section 5, Appendix C). UVOT and FIMS/SPEAR were never training features but were consulted during design. Every benchmark scatter quoted for a single model carries a spatial block-bootstrap uncertainty of ± 0.002 dex (FUV) and ± 0.001 dex (NUV) (Appendix B). Table 11 in Appendix B lists the source of every headline number.

4.1 Fidelity to *GALEX* and seams

Where $W_{\text{GALEX}} \geq 0.99$ the map equals the destriped, tile-equalised *GALEX* layer g identically. Over all pixels with valid *GALEX* data, $|\log_{10}(\text{map}/g)|$ has a 90th percentile of 0.0023 dex (FUV) and 0.0004 dex (NUV) and a 99th percentile of 0.064 and 0.073 dex. $W_{\text{GALEX}} > 0.99$ for 87.0/89.3 per cent of valid pixels and $W_{\text{GALEX}} < 0.5$ for 4.1/3.4 per cent. In $W_{\text{GALEX}} > 0.9$ sky the fusion alters the *GALEX* angular power spectrum by at most

(a) FUV dominant layer: GALEX / NUV-informed / UVOT / FIMS-constrained / model

(b) NUV dominant layer (same colours)

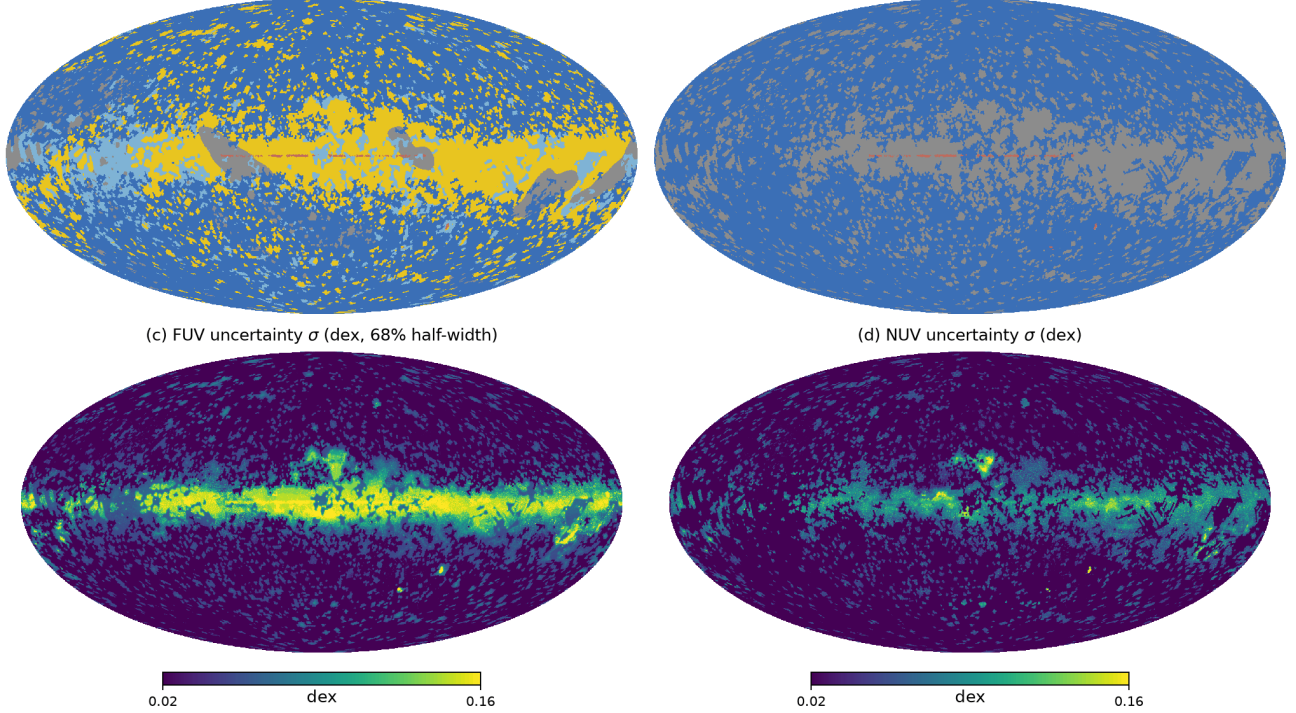


Figure 8: Provenance and uncertainty of the published maps ($N_{\text{side}} = 256$ rendering of the published weight and uncertainty files). (a) FUV dominant layer: *GALEX* (blue), NUV-informed FUV (light blue), UVOT (red), FIMS/SPEAR-constrained model (yellow), model (grey). (b) NUV dominant layer, same colours. (c, d) The published 1σ (68 per cent half-width) uncertainty of $\log_{10} I$, column **SIGMA** of equation (10), FUV and NUV, on a common 0.02–0.16 dex scale; the systematic column **SIGMA_SYS** (0.10 dex in the FIMS/SPEAR-constrained plane) is not shown.

Table 4: Pixel classes of the published maps (dominant weight), their sky fractions, what is measured and what is predicted in each, and the uses each supports. ‘Level’ means the $\gtrsim 1^\circ$ mean intensity; ‘morphology’ means structure below that scale.

Class (dominant weight)	FUV (%)	NUV (%)	Content	Supports / does not support
<i>GALEX</i> imaging (W_{GALEX})	61.9	73.3	Destriped GR6/7 mosaic; level tied to UV-BKGD per $14'$ cell; native $\simeq 2.5\text{--}3'$ structure and all sources	All uses: photometry of diffuse structure ($W_{\text{GALEX}} > 0.99$), power spectra and cross-correlations, stacking, point sources. Not: an independent monopole (inherited zero point).
NUV-informed FUV (W_{NUVX})	9.7	—	star-subtracted <i>GALEX</i> NUV image $\times$ predicted diffuse FUV/NUV colour below $6.9'$, plus catalogue FUV stars (equation 4); level from the colour model	NUV-traced diffuse morphology at full resolution, source positions, large-scale FUV level to ~ 0.1 dex, stellar fluxes at the catalogue (predicted) level as in model sky. Not: FUV/NUV colours, FUV-only physics (H_2 , C IV, two-photon), measured FUV photometry of individual sources.
<i>Swift</i> -UVOT (W_{UVOT})	0.2	0.2	UVOT UVM2/UVW2 imaging transformed to the <i>GALEX</i> bands (0.11–0.25 dex)	Level and morphology in small deep fields, mostly in the plane. Not: precise colours (filter transformation, red leak).
FIMS/SPEAR-constrained prediction (W_{FIMS})	23.7	—	Template prediction + catalogue stars, rescaled to the FIMS/SPEAR starless map on $> 4^\circ$ scales ($\simeq 1^\circ$ data, 0.15–0.20 dex absolute)	Degree-scale FUV level in the <i>GALEX</i> -free sky including the plane; mission background planning; boundary conditions for RT models at $\gtrsim 1^\circ$. Not: sub-degree ISM morphology, filament contrasts, small-scale power, new point sources.
Pure prediction (W_{MODEL})	4.5	26.5	Gradient-boosted diffuse prediction from dust, $\text{H}\alpha$, starlight and position templates + <i>Gaia</i> /TD-1/galaxy source layers	Expected background level (0.05–0.10 dex per $7'$) for planning and as a prior; continuity of all-sky statistics. Not: any measurement of ISM structure independent of the templates; EBL or offset studies; discovery of sources.

1 per cent at any $\ell \leq 1536$ (Section 4.7).

Seams are measured with the coverage-boundary stack of Appendix B: the median of $\log(\text{map}/\mathcal{S}_{2^\circ}[\text{map}])$ in integer-pixel rings from the *GALEX* edge, the step being the mean over rings +1 to +3 minus rings −1 to −3. The sky-averaged step is +0.0031 dex (FUV) and +0.0033 dex (NUV) at $N_{\text{side}} = 2048$; across implementations differing in boundary-pixel selection it stays below 0.005 dex (FUV) and below 0.015 dex (NUV), while its statistical error is ± 0.0005 dex (block bootstrap), so the range is definitional, not statistical. Locally, in 3.7° boundary segments, the step has an rms of 0.022 (FUV) and 0.026 dex (NUV) against 0.012/0.013 dex for the same estimator on random great circles inside the footprint, i.e. an intrinsic local seam amplitude of $\simeq 0.02$ dex rms, with 3–4 per cent of segments beyond 0.05 dex. A matched filter for coherent steps across internal HEALPix cell boundaries ($N_{\text{side}} = 8\text{--}256$) finds no excess over control lines in any pixel class (e.g. 0.0074 versus 0.0073 dex at $N_{\text{side}} = 32$ in FUV model sky), and a small-circle ring test finds no great-circle stripe (Appendix C).

4.2 Gap-fill accuracy: benchmark, distance to data and covariate shift

Headline. Scored on the published benchmark (six-fold 7.3° -block spatial cross-validation at $N_{\text{side}} = 512$; Appendix A) with importance weights matching held-out pixels to the $(E(B-V), |b|)$ distribution of the filled sky, the out-of-fold diffuse prediction reproduces the withheld star-subtracted *GALEX* intensity with a robust scatter of 0.037/0.047 dex (FUV, area-weighted/gap-matched) and 0.047/0.057 dex (NUV) per $6.9'$ element, with 11/18 per cent of matched pixels beyond 0.1 dex; prediction plus source layer scored against the *GALEX* total gives 0.057/0.060 dex (matched, FUV/NUV). Re-weighted to the $(E(B-V), |b|)$ distribution of the sky actually filled by each layer the scatter is 0.050–0.052 (FUV) and 0.061 dex (NUV). By column density it is 0.035–0.045 dex for $E(B-V) < 0.2$, 0.049/0.059 at 0.2–0.4, 0.065/0.074 at 0.4–0.8 and 0.095/0.088 dex at 0.8–1.6 mag (FUV/NUV).

Baselines and the un-jittered variant. Table 5 and Fig. 9 compare the adopted predictor with featureless baselines on the same folds, scored on the total intensity against the destriped layer G' before tile equalisation; on that truth the adopted predictor has a robust scatter of 0.060 ± 0.002 dex (FUV) and 0.060 ± 0.001 dex (NUV) (block bootstrap; fold-to-fold range 0.056–0.061 and 0.054–0.062), with 16 per cent of pixels beyond 0.1 dex and a bias of +0.009/+0.010 dex. Tile equalisation of the withheld *GALEX* lowers the diffuse-target scatter by 0.004–0.007 dex, all but ≤ 0.001 dex of which is the removal of tile-offset noise from the truth itself, and leaves the total-intensity scores unchanged within the bootstrap error. Featureless interpolation is competitive only near data: the nearest *GALEX* pixel scores 0.042 dex within 0.5° but 0.17 dex beyond 3° , and harmonic inpainting of $\log G'$ scores 0.064/0.085 dex overall. The

same model without coordinate jitter scores marginally *better* in the NUV (-0.0017 ± 0.0002 dex); we publish the jittered model nonetheless, for $b = 0$ continuity and reproducibility, and state its NUV cost, 0.0017 dex in 0.060, here and in Section 6.

Distance to data. Spatial blocking guarantees a minimum separation, not one representative of the real gaps. Held-out pixels lie at a median of 1.27° from training data, whereas FUV gap pixels lie at a median of 1.1° from *GALEX* but with a long tail: 25.5 per cent of the filled FUV sky is beyond 3.65° , 17.9 per cent beyond 5° and 5 per cent beyond 8° ; the NUV gaps are benign (median 0.50°). Because smoothed features carry information across block edges, accuracy degrades with distance (Fig. 9c,d): the matched scatter of the adopted predictor is 0.048 ± 0.001 dex within 0.25° , 0.053 ± 0.002 at $0.5^\circ\text{--}1^\circ$, 0.063 ± 0.003 at $1.5^\circ\text{--}2^\circ$, 0.070 ± 0.005 at $3^\circ\text{--}4^\circ$ and 0.08 ± 0.02 dex at $5^\circ\text{--}8^\circ$ (FUV), and 0.054, 0.070 and 0.08 ± 0.02 dex in the NUV, i.e. slopes of $+0.0066 \pm 0.0008$ and $+0.0048 \pm 0.0004$ dex deg^{-1} over $0^\circ\text{--}5^\circ$; beyond 5° the benchmark has no statistical power. Two direct measurements reach farther: blind mock gaps through the published FUV fusion out to 8.6° (Section 4.3) give a 68th-percentile error of 0.046–0.057 dex within 3° , 0.068 at $3^\circ\text{--}5^\circ$ and 0.093 dex at $6^\circ\text{--}9^\circ$, and a 29.3° -block cross-validation re-weighted to the far FUV gap gives 0.11 dex beyond 3.65° and 0.16 dex beyond 8° . We therefore state the accuracy of the gap fill as 0.060 ± 0.002 dex for the 97 per cent of the filled NUV sky within 3.65° of data and for the three quarters of the filled FUV sky within $\simeq 3.7^\circ$ of *GALEX*; 0.07–0.10 dex for the quarter beyond; and 0.10–0.16 dex, poorly determined, for the innermost 5 per cent beyond 8° , where the map is checked against FIMS/SPEAR and UVOT at their own 0.1–0.2 dex precision (Section 4.4). The published uncertainty carries this distance dependence explicitly (Section 4.6).

Column-density regime and the limits of matching. Above $E(B-V) = 1.6$ only 110 held-out FUV pixels exist, and of the filled FUV sky ($W_{\text{MODEL}} + W_{\text{FIMS}} > 0.5$) 8.2 per cent lies at $E(B-V) > 1.6$ with no held-out *GALEX* FUV analogue, where histogram trees return edge-bin values set by FIMS/SPEAR. The importance weighting is poorly conditioned in the FUV: its Kish effective sample size is 4.5×10^4 of 2.0×10^6 pixels (2.2 per cent; NUV 46 per cent), and the top 1 per cent of held-out pixels carry 23 per cent of the weight. Matching on $(E(B-V), |b|)$ does not make held-out and filled pixels exchangeable: a classifier two-sample test on the eight non-positional templates separates matched held-out from $W_{\text{MODEL}} > 0.5$ pixels with AUC = 0.83 (FUV) and 0.66 (NUV), driven by $H\alpha$, *Gaia* starlight and source density, higher in the filled sky. Re-weighting on the classifier score raises the matched scatter from 0.060 to 0.064–0.067 dex in the NUV and to 0.07–0.10 dex for the 4.5 per cent model-filled FUV sky. We adopt 0.065 dex as the shift-corrected NUV figure.

Table 5: Gap-fill benchmark (Appendix A): out-of-fold performance of the adopted predictor, its un-jittered variant and featureless baselines in the six-fold 7.3°-block cross-validation at $N_{\text{side}} = 512$, total-intensity target scored against the destriped *GALEX* layer G' (before tile equalisation), with importance weights matching held-out pixels to the $(E(B-V), |b|)$ distribution of the filled sky (‘matched’) and area-weighted. σ : robust scatter ($1.4826 \times$ weighted MAD) of $\log_{10}(\text{pred}/G')$; $f_{0.1}$: fraction beyond ± 0.1 dex. Block-bootstrap 1σ errors on single-model matched σ are 0.002–0.004 (FUV) and 0.001 (NUV). The last columns give the matched σ by distance to the nearest training pixel (the $> 3^\circ$ bin holds 1–2 per cent of the weight).

Model	matched σ		matched $f_{0.1}$		area σ FUV/NUV	FUV/NUV $< 0.5^\circ$	matched σ by distance	
	FUV	NUV	FUV	NUV			$1^\circ\text{--}2^\circ$	$> 3^\circ$
<i>Featureless baselines</i>								
<i>Planck</i> -radiance power law per $ b $ band	0.160	0.167	0.56	0.57	0.103/0.117	0.153/–	–	0.141/–
Nearest observed <i>GALEX</i> pixel	0.083	0.117	0.29	0.42	0.072/0.106	0.042/–	–	0.169/–
Harmonic inpainting of $\log G'$ ($N_{\text{side}} = 128$)	0.064	0.085	0.20	0.34	0.059/0.075	0.048/–	–	0.112/–
<i>Learned models</i>								
90 features, HGB, no jitter	0.059	0.058	0.17	0.15	0.048/0.052	0.047/0.051	0.060/0.058	0.069/0.070
Adopted predictor (90 features, jitter, test-time averaging)	0.060	0.060	0.16	0.16	0.049/0.053	0.050/0.054	0.061/0.060	0.071/0.071

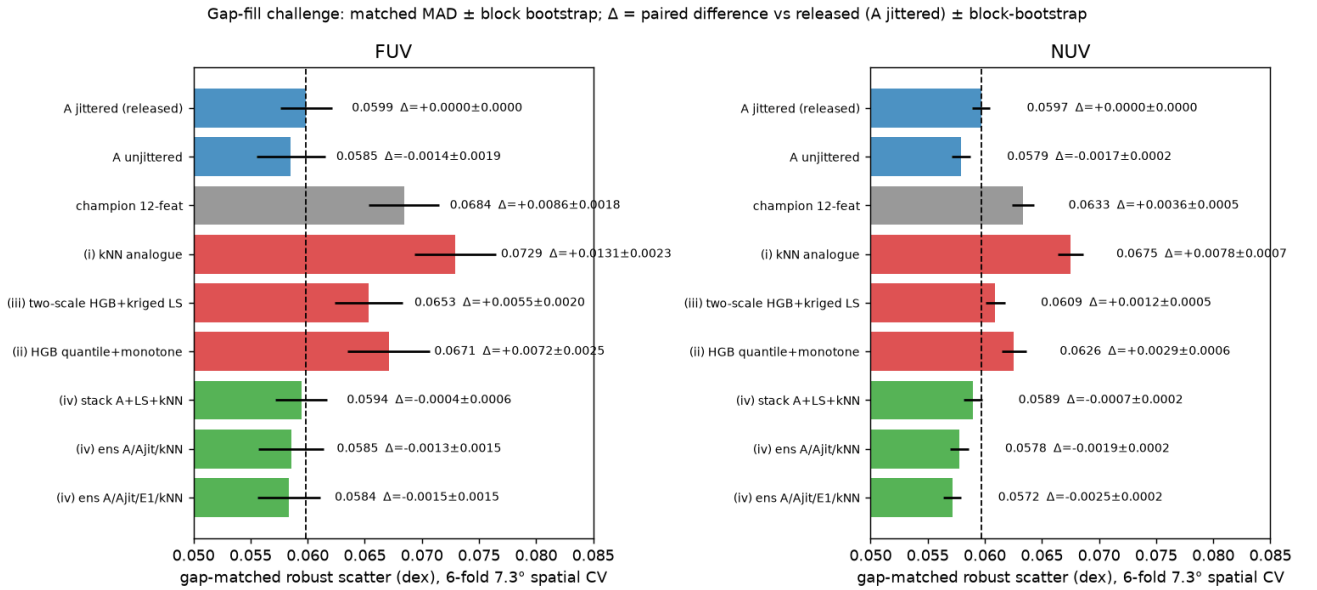


Figure 9: Gap-fill benchmark scores of the adopted predictor, its un-jittered variant and alternative learners tested on the same benchmark (Appendix A). (a) Gap-matched robust scatter with $N_{\text{side}} = 8$ block-bootstrap errors, FUV and NUV. (b) Matched scatter by $E(B-V)$ regime. (c, d) Matched scatter versus distance to the nearest training pixel, FUV and NUV; all learned models share the same rise with distance.

4.3 End-to-end test: mock gaps through the production fusion

The benchmark tests the regression; the published map is the output of the whole fusion. We hid forty $N_{\text{side}} = 8$ super-pixels (5.2 per cent of the sky) from the *GALEX* input and re-ran the production fusion code, re-estimating every gain field, the FIMS/SPEAR ratio field and the island penalty without the hidden data. Inside the hidden blocks the diffuse prediction was replaced by the adopted predictor’s spatial-block out-of-fold prediction, so neither the fusion nor the regression had seen the hidden pixels. Against the destriped *GALEX* truth (Fig. 10) the reconstruction has, at $N_{\text{side}} = 512$, a robust scatter of 0.049 dex (FUV) and 0.047 dex (NUV), medians of -0.009 and $+0.007$ dex, and 8.3/10.6 per cent of cells beyond 0.1 dex (against the tile-equalised truth g , 0.046/0.043 dex); at $N_{\text{side}} = 2048$ the scatter is 0.059/0.062 dex with 0.8/3.6 per cent of pixels be-

yond 0.3 dex. The block-to-block scatter of the forty median offsets is 0.023 (FUV) and 0.011 dex (NUV). The FUV error grows from 0.032 dex at the block edge to 0.055 dex more than 2° inside; keeping the NUV-informed layer flattens the profile to 0.037–0.038 dex ($|\text{median}| \leq 0.004$ dex), and the NUV profile is flat at 0.042–0.046 dex. Intra-block structure is recovered with a Pearson correlation of 0.80 (FUV) and 0.78 (NUV) at $1.7'$, rising to 0.90/0.93 at $27'$. Model-only $N_{\text{side}} = 512$ hindcasts of the six spatial folds (each sixth of the *GALEX* sky rebuilt from the out-of-fold prediction, re-estimated gain field and source layers, no ultraviolet data inside) give 0.038/0.039 dex robust scatter against g , medians $+0.001/-0.005$ dex, $0.030 \rightarrow 0.042$ dex from the fold edge to $> 2^\circ$ inside, block-to-block scatter 0.019/0.017 dex and intra-block structure correlations of 0.86/0.86 at $6.9'$ rising to 0.94/0.88 at 2° . Using the in-sample prediction instead of the out-of-fold one changes the $N_{\text{side}} = 512$ scatter by only 0.004/0.002 dex,

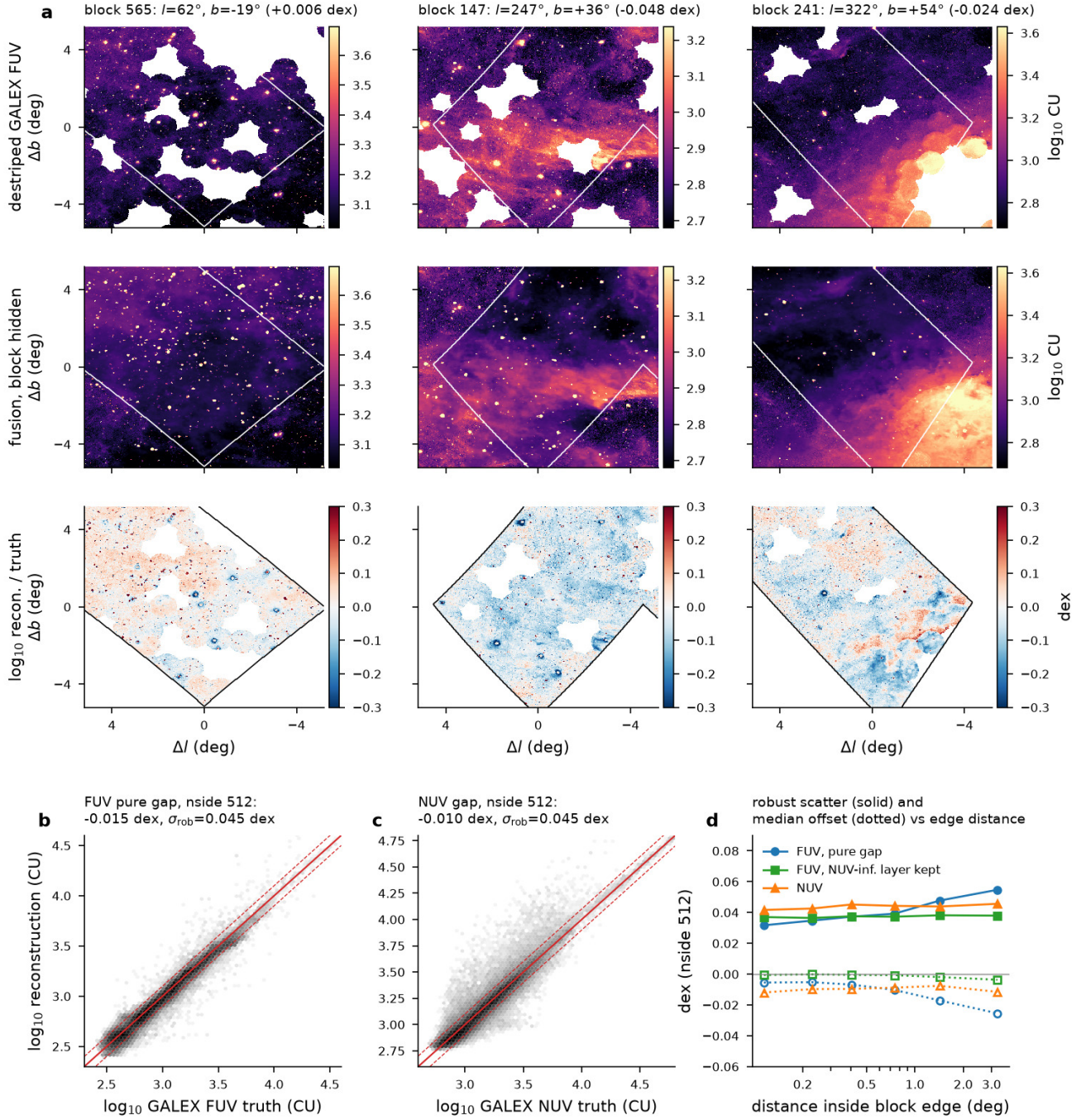


Figure 10: Mock-gap test of the production fusion. (a) Three of the forty hidden 7.3° blocks (one per $|b|$ stratum; outline, hidden super-pixel; blank, no *GALEX*): destriped *GALEX* FUV truth, the production fusion re-run with the block hidden, and $\log_{10}(\text{reconstruction}/\text{truth})$ on ± 0.3 dex, with the per-block median offset. (b, c) Reconstruction versus truth at $N_{\text{side}} = 512$ for all hidden FUV and NUV pixels; dashed, ± 0.1 dex. (d) Robust scatter (solid) and median offset (dotted) versus distance inside the block edge for the FUV pure gap, the FUV gap with the NUV-informed layer kept, and the NUV.

so the moderate column density of the hidden blocks, not training-set membership, makes mock gaps easy (no hidden block exceeds $E(B-V) = 0.5$). A larger blind experiment on the FIMS/SPEAR-constrained layer alone (2.25 million hidden pixels, distances to 8.6°) gives 68th-percentile errors of 0.046, 0.051, 0.054, 0.057, 0.068 and 0.093 dex from 0° to 9° , U-shaped in $E(B-V)$ (0.078 at $E(B-V) < 0.02$, 0.058 at 0.06–0.2, 0.10–0.13 dex above 0.4).

4.4 Independent instruments in the *GALEX*-free sky

All preceding tests use *GALEX* as truth and cannot reach the high-column plane. Two instruments observed it (Fig. 11). *FUV versus FIMS/SPEAR*. In strictly *GALEX*-free $27.5'$ pixels ($n = 45\,354$, median $|b| = 8.7^\circ$, median $E(B-V) = 0.36$) the published map has a median ratio to the FIMS/SPEAR *starry* map of 0.92 with 0.19 dex robust scatter and $r = 0.80$ in $\log I$, against 1.05, 0.15 dex and $r = 0.83$ for destriped *GALEX* itself versus FIMS/SPEAR *starry* where both observed: the filled FUV sky agrees with FIMS/SPEAR to within 1.3 times the scatter that *GALEX* shows, at a level slightly below the *GALEX*/FIMS/SPEAR scale. This comparison is not independent of FIMS/SPEAR above 4° in W_{FIMS} sky, but the sub- 4° structure (4° -high-pass $r = 0.67$) is untouched by the ratio field, and the reference differs from the constraint quantity (*starry* versus $0.97 \times \text{starless}$ plus catalogue stars, which the map matches to 0.99, 0.07 dex, $r = 0.95$). Against FIMS/SPEAR *starless* the *diffuse* prediction with no ultraviolet input has, in the same sky, a median ratio of 0.86 with 0.135 dex scatter and $r = 0.84$ —as high a correlation as between the two instruments where both observed—and a genuine low bias reaching 20 per cent in the mid-plane, which is what the FIMS/SPEAR constraint corrects. *NUV versus UVOT*. In $13.7'$ pixels with no *GALEX* NUV ($n = 5362$, median $|b| = 0.7^\circ$, median $E(B-V) = 5.2$) the published NUV map has a median ratio to UVM2-calibrated UVOT of 1.005 with 0.146 dex scatter and $r = 0.77$ (1.03, 0.12 dex at $|b| < 1^\circ$; 1.01, 0.21 dex in pixels with $W_{\text{UVOT}} < 0.05$, which are strictly independent).

The FUV plane bracket. In the same *GALEX*-free plane the published FUV map is 1.37/1.41/1.23 times the UVOT-derived FUV at $|b| = 0^\circ$ – 5° , 5° – 10° and 10° – 20° , while it is 0.87–0.95 times FIMS/SPEAR: the two references bracket the adopted level by $\simeq 0.2$ dex either side (Fig. 12). We adopt the FIMS/SPEAR-based level: FIMS/SPEAR measures the 1350–1710 Å band directly and its ratio to *GALEX* is flat to ± 0.04 dex over $0.01 < E(B-V) < 1.2$, whereas the UVOT ‘FUV’ is an extrapolation from 1930–2250 Å across the steepest part of the extinction curve, whose ratio to *GALEX* drifts by 0.51 ± 0.01 dex per decade of $E(B-V)$. Half the bracket, 0.10 dex, equal also to the FIMS/SPEAR absolute calibration uncertainty (Seon et al. 2011), is recorded as the coherent systematic **SIGMA_SYS** of the FIMS/SPEAR-constrained plane (Section 4.6).

4.5 Discrete sources by pixel class

Aperture photometry of GUVcat, XMM-SUSS and UVOT serendipitous-source stars recovers catalogue fluxes with a median ratio of 0.98 in *GALEX*-dominated pixels (Appendix C). In *GALEX*-free, model-filled NUV sky, aperture photometry ($r < 2'$) of 3191 isolated *Swift* UVOTSSC sources recovers half the UVM2 flux at $\text{UVM2} \simeq 19.3$, within a factor of two for 0.57 of sources at 17–18 mag and 0.42 at 18–19, with an NMAD of the ratio of 0.18–0.43 at 13–17 mag; beyond $\text{UVM2} \simeq 19$ a $2'$ aperture on a $\sim 10^3$ CU background has $S/N < 1$ and the test loses power. TD-1 stars outside the *GALEX* FUV footprint ($n = 2828$) return a median $\log(\text{ap}/1.047 \text{ TD1})$ of $+0.008$ dex (Section 3.6; 24 stars at $|b| < 11^\circ$ read > 0.3 dex high because *Gaia* neighbours enter the $6'$ aperture, and $+0.006$ dex against the catalogue in NUV-informed sky), and every $V < 4.5$ hot BSC star ($n = 209$) is reproduced to within 1 dex. A stack of 143 154 Milliquas quasars, each referenced to a matched control position, detects them at $+13.1 \pm 0.5$ CU (FUV) and $+26$ CU (NUV) in *GALEX* pixels. These catalogued quasars are inputs of the extragalactic point layer and are recovered in every filled class as well ($+13.0 \pm 1.1$ CU FUV over all filled pixels; $+10.6 \pm 0.9$ FIMS/SPEAR-, $+17 \pm 6$ NUV-informed- and $+17 \pm 7$ CU model-dominated), so the null test is made with 98 513 fainter quasars ($19.8 < R < 21.5$) absent from every input layer: they are detected at $+1.1 \pm 0.5$ CU in *GALEX* FUV pixels and give -0.5 ± 1.1 CU over filled FUV sky (0.0 ± 0.8 FIMS/SPEAR-dominated, -6 ± 5 model-dominated, $+6 \pm 6$ CU NUV-informed, where NUV imaging legitimately carries them): objects absent from the inputs leave no imprint, as required (Appendix C). Stacked 15–17 mag input stars return 0.99–1.09 (median) of their catalogue flux within $2'$ in *GALEX*-, FIMS/SPEAR- and model-dominated sky; in NUV-informed FUV sky ($W_{\text{NUVX}} > 0.5$) stacks return 1.00, 0.92, 0.97 and 1.10 of the catalogue flux at 4–8, 8–12, 12–15 and 15–17 mag, colour-flat (0.91/0.97/1.02 for blue/intermediate/red stars at 12–15 mag; Section 3.8).

4.6 Uncertainty model and its calibration

The published uncertainty file carries two columns per $N_{\text{side}} = 512$ pixel. **SIGMA** is the half-width u of the central 68 per cent interval of $\log_{10} I$,

$$u^2 = \frac{\sum_k W_k \sigma_k^2}{\sum_k W_k} + (W_{\text{FIMS}} + W_{\text{MODEL}} + W_{\text{NUVX}}) \sigma_\star^2, \\ \sigma_G = \sigma_G(I, t_{\text{exp}}), \quad \sigma_U = \sigma_U(I), \\ \sigma_X = \sigma_X(E(B-V), |b|, I_{\text{NUV}}), \\ \sigma_M = \sigma_M(\hat{\mathbf{n}}), \\ \sigma_F = \max[S(d, E(B-V)), \sigma_M, 0.046], \quad (10)$$

in dex, with $u \geq 0.02$ and the weights of the fusion. σ_G is the empirical $6.9'$ noise of g , a monotone quantile-0.68 regression of the eight-neighbour scatter of the star-subtracted diffuse map on intensity and effective

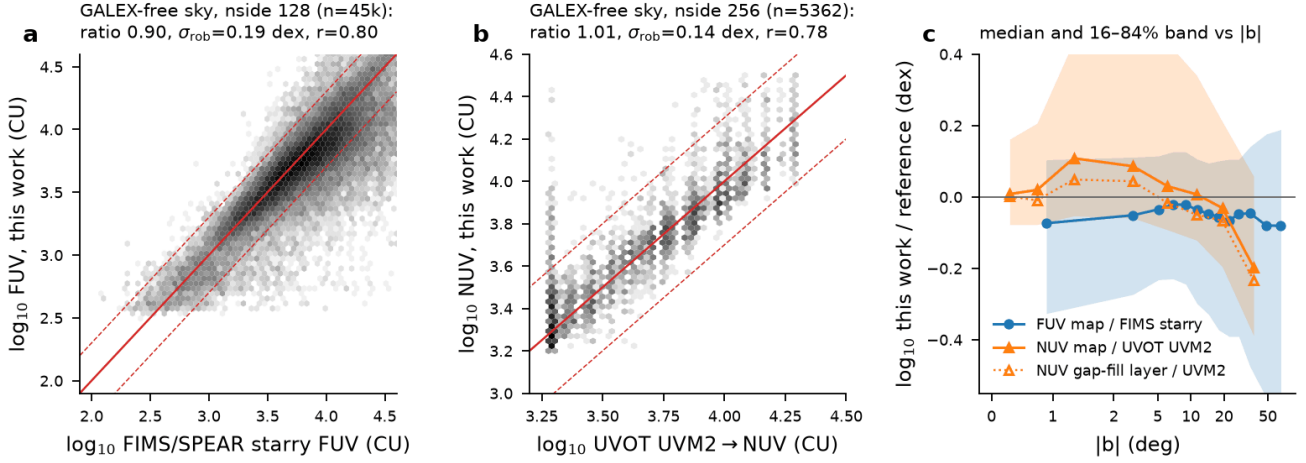


Figure 11: The published maps against independent instruments in sky with no *GALEX* coverage in the band concerned. (a) Published FUV versus the FIMS/SPEAR starry map in $27.5'$ pixels ($n = 45\,354$, median $|b| = 8.7^\circ$). (b) Published NUV versus *Swift*-UVOT UVM2, calibrated to CU on *GALEX*-covered $E(B-V) > 0.1$ pixels, in $13.7'$ pixels ($n = 5362$, median $|b| = 0.7^\circ$, median $E(B-V) = 5.2$). Dashed, factor of two. (c) Median and 16–84 per cent band of $\log(\text{map}/\text{reference})$ versus $|b|$; dotted, the NUV gap-fill layer alone.

exposure (FUV 0.019 dex in AIS tiles below 120 s to 0.008 dex above 5 ks, at the 0.02 floor over 80 per cent of *GALEX* sky; NUV 0.029/0.020/0.011 dex at < 120 s, 120–200 s and 0.4–1.5 ks, median 0.026). The model term σ_M is a quantile-0.68 gradient-boosted regression of the adopted predictor’s out-of-fold $|\log_{10}(\text{pred}/g)|$ on the total intensity ($1.75 \times 10^6/2.12 \times 10^6$ pixels; held-out p68 0.044/0.053 dex) on $\log E(B-V)$, $|b|$, $\log I_{H\alpha}$, $\log n_*$, $\log F_{BP}$ and distance to training data, the latter recomputed per fold and capped at 5° , the range the 7.3° blocks can represent; it is evaluated all-sky with the distance-to-*GALEX* map and extended linearly beyond: $+0.0825 \text{ dex deg}^{-1}$ from 5° to 6° (which brings the 2500 held-out FUV pixels at 5° – 8° , p68 0.113 dex, from a coverage of 0.43 to 0.71) and $+0.0133 \text{ dex deg}^{-1}$ beyond (the weighted slope of the held-out p68 over 3° – 7°) in the FUV, $+0.0056 \text{ dex deg}^{-1}$ beyond 5° in the NUV. σ_X is a quantile-0.68 regression of the diffuse colour model’s cross-validation residuals (p68 0.036 dex; Section 3.8) on $E(B-V)$, $|b|$ and NUV intensity (median 0.046 dex in $W_{\text{NUVX}} > 0.5$ sky, 90th percentile 0.121); σ_U is the measured scatter of the UVOT layer against g after removal of 3.7° medians, interpolated in intensity (0.077/0.107/0.188 dex FUV and 0.056/0.090/0.114 dex NUV at $\log I = 2.5/3.25/3.75$). The FIMS/SPEAR term σ_F is the quantile-0.68 surface S of the blind mock-gap error of Section 4.3 on distance to *GALEX* and $\log E(B-V)$, monotone non-decreasing in distance (Fig. 13): 0.040–0.066 dex at $E(B-V) < 0.2$ within 1° , 0.048–0.069 at 1.5° , 0.049–0.084 at 3° , and 0.106–0.134 dex for $E(B-V) \geq 0.6$ beyond 1.5° , saturating at 0.134 dex beyond 5° ; the floor 0.046 dex is the measured error within 0.5° of data. The stellar-layer term is $\sigma_* = \log_{10}(1 + s_{512}/I)$ from the per-pixel 1σ map of the source layer (`stars_sigma`; median 0.013/0.006 dex in filled sky, raising u by more than 10 per cent in 11/7 per cent of filled pixels). In FIMS/SPEAR-dominated sky the median u is 0.052, 0.076 and 0.113 dex at 0° – 1° , 1 – 2° and 2° – 4° from *GALEX*, and 0.19 dex (90th percentile

0.27) in the 4.5 per cent of the sky that is FUV-filled more than 6° from *GALEX*; beyond 8° (1.8 per cent of the sky) σ_M is a linear extrapolation without held-out support. In NUV model sky the medians are 0.058, 0.084 and 0.100 dex at 0° – 1° , 1 – 2° and 2° – 4° . All-sky, *SIGMA* has 10th/50th/90th percentiles of 0.020/0.022/0.118 (FUV) and 0.021/0.029/0.083 dex (NUV); by provenance the medians are 0.020/0.026 (*GALEX*), 0.058 (NUV-informed FUV), 0.068 (FIMS/SPEAR), 0.072/0.065 (model) and 0.19/0.11 dex (UVOT). *SIGMA_SYS* is 0.10 dex where $W_{\text{FIMS}} > 0$ at $|b| < 10^\circ$ (13.0 per cent of the sky) and 0.05 dex where $W_{\text{UVOT}} > 0.5$, flagged in both bands; it is not to be added in quadrature per pixel nor divided by $\sqrt{N}$ when averaging. The per-tile offsets removed by the tile equalisation amount to p68 0.018/0.021 dex over *GALEX* pixels and are recovered with slope 0.947 in injection tests, so the un-removed tile residual is $\simeq 0.001$ dex (keyword `TILESYS`) and is not added; the inherited additive foreground zero point is in neither column.

Calibration. In cross-half validation the coverage of $|r| < \sigma_M$ on held-out pixels is 0.677/0.678 area-weighted and 0.656/0.675 gap-matched (FUV/NUV), 0.67–0.69 in every distance bin to 8° (FUV, with the far extension; NUV to 6°), 0.65–0.68 in every $E(B-V)$ bin below 0.8 mag, and 0.52/0.66 at $E(B-V) = 0.8$ – 1.6 (2600/36 000 pixels), where FUV users should inflate *SIGMA* by $\simeq 1.6$. The held-out coverage of σ_X is 0.684/0.671. On the test half of the 2.25 million blind mock-gap pixels σ_F covers 0.71 overall, 0.70–0.73 by distance, 0.69–0.77 by $E(B-V)$ and 0.68–0.74 by $|b|$, where a flat 0.10 dex would cover 0.90 overall but 0.63–0.73 at $E(B-V) > 0.4$ (Table 10, Appendix B). The residuals are heavy-tailed and mildly skewed: $|r|/\sigma_M$ has 95.45th/99.73rd percentiles of 2.52/15.3 (FUV) and 2.46/19.2 (NUV) area-weighted, 2.69/7.1 and 2.49/13.3 gap-matched (2.23/5.24 for the NUV-informed term; header keywords `MULT954`, `MULT997`, `MULT954G`, `MULT997G`), and 92 per cent of residuals lie within $2u$

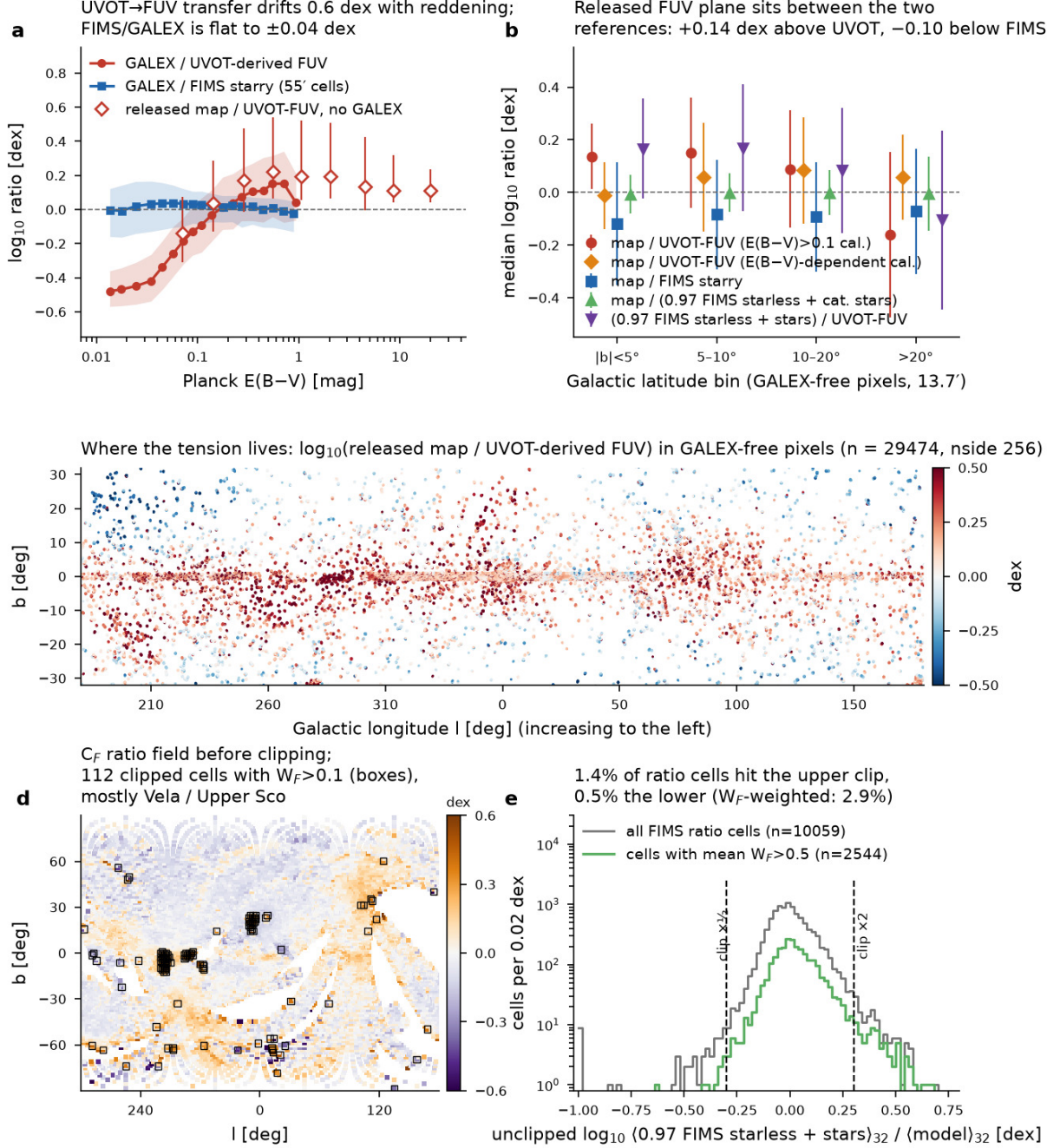


Figure 12: The FUV Galactic-plane level bracket. (a) Ratio of the published FUV map to the UVOT-derived FUV and to the FIMS/SPEAR starry map in *GALEX*-free $13.7'$ pixels versus $|b|$, for the dust-matched UVOT gain and for an $E(B-V)$ -dependent gain. (b) $\log(G'_{\text{FUV}}/\text{UVOT}_{\text{FUV}})$ and $\log(G'_{\text{FUV}}/\text{FIMS})$ versus $E(B-V)$ in *GALEX*-covered pixels: the UVOT transfer drifts by 0.5 dex per decade of $E(B-V)$, the FIMS/SPEAR ratio is flat. (c) Sky distribution of the map/UVOT ratio in the *GALEX*-free plane.

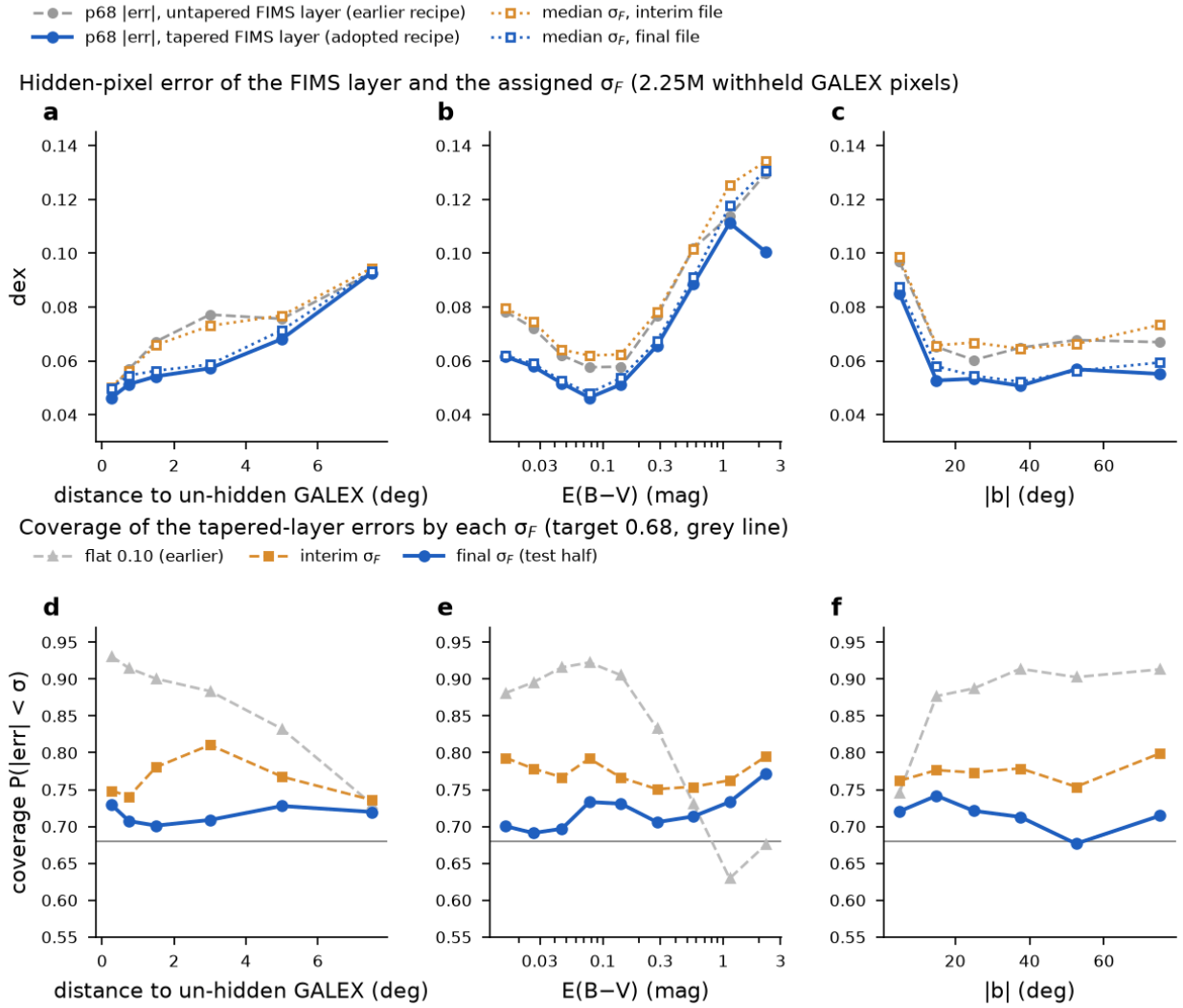


Figure 13: The empirical error of the FIMS/SPEAR-constrained FUV layer from 2.25 million blind mock-gap pixels (withheld *GALEX*), and the published uncertainty. (a–c) 68th-percentile absolute error at $6.9'$ of the published, distance-tapered layer (solid) and of an untapered variant (dashed grey) versus distance to the nearest un-hidden *GALEX* pixel, $E(B-V)$ and $|b|$, with the median assigned σ_F (open squares). (d–f) Coverage of the tapered-layer errors by a flat 0.10 dex, by a surface calibrated on the untapered variant, and by the published σ_F (test half; target 0.68, grey line).

and 97 per cent within $3u$, so 95.4 or 99.7 per cent intervals need these multipliers rather than $2u$ and $3u$. Residuals are spatially correlated on $\gtrsim 1^\circ$ scales and between bands ($r = 0.52$ for block-mean residuals), so u must not be divided by $\sqrt{N}$ when averaging.

4.7 Angular power spectra and small-scale power by pixel class

On *GALEX* pixels with $W_{\text{GALEX}} > 0.9$, the pseudo- C_ℓ of $\log_{10} I$ of the published map is within 1.00–1.01 of that of the *GALEX* layer at every $\ell \leq 1536$ (Fig. 14d,e). The gap-fill layer (harmonised prediction plus source layer) evaluated on the same pixels retains the large scales ($r_\ell > 0.99$ at $\ell < 100$) and 0.87/0.86/0.80 (FUV, $|b| = 20^\circ\text{--}40^\circ/40^\circ\text{--}60^\circ/60^\circ\text{--}90^\circ$) and 1.03/1.09/1.12 (NUV) of the log-power over $\ell = 100\text{--}1500$, with $r_\ell = 0.87\text{--}0.94$ averaged over that range (Fig. 14f): a conditional-mean predictor built from $5'\text{--}6'$ templates is necessarily smoother than the truth, and the *diffuse* prediction

retains 0.75, 0.54 and 0.36 of the true diffuse power at $\ell \simeq 100, 300$ and 700 , while the discrete-source layer restores the small-scale power of the *total* intensity to within $\simeq 20$ per cent of *GALEX* on identical pixels. Users of filled pixels for diffuse structure statistics should treat filament contrasts, structure functions and small-scale power there as lower limits, smoothed by 13–40 per cent between $\ell = 100$ and 700 (Section 6). Within the *GALEX* footprint itself the tile equalisation removes the tile-diameter bump at $\ell \simeq 150\text{--}400$ (Section 3.3); users comparing power spectra with un-equalised *GALEX* mosaics should expect this difference.

5 Physical content and absolute level

We do not perform component separation of the ultra-violet sky, but the reported zero points, dust and H α slopes, and colours have a physical reading, and users

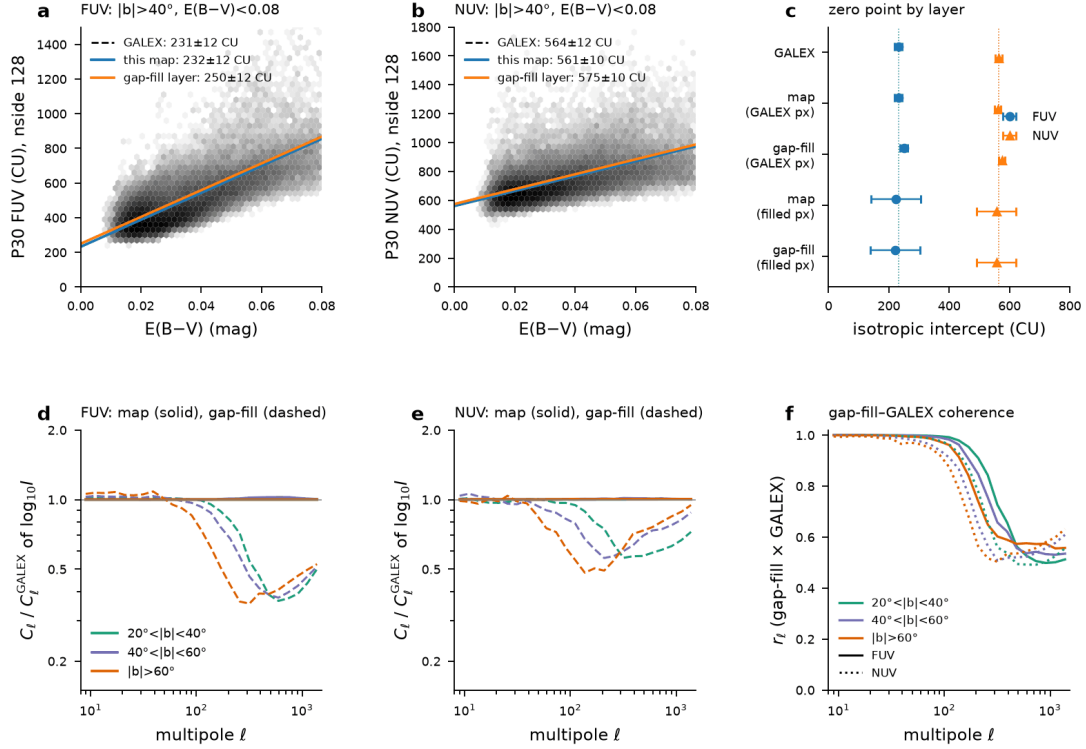


Figure 14: Zero point and angular power spectra of the published maps and of the gap-fill layer on identical *GALEX* pixels. (a, b) $\mathcal{P}_{30}$ intensity in $N_{\text{side}} = 128$ cells versus *Planck* $E(B-V)$ at $|b| > 40^\circ$, $E(B-V) < 0.08$ (hexbin, destriped *GALEX*) with the least-squares lines of *GALEX*, the published map and the gap-fill layer, FUV and NUV. (c) Intercepts by layer and pixel set (dotted, the *GALEX* value). (d, e) Ratio of the pseudo- C_ℓ of $\log_{10} I$ to that of destriped *GALEX* for the published map (solid, $\simeq 1$) and for the gap-fill layer (dashed) in three $|b|$ bands, $N_{\text{side}} = 1024$, $W_{\text{GALEX}} > 0.9$ pixels, 1° -apodised masks. (f) Cross-correlation coefficient r_ℓ of the gap-fill layer with *GALEX*.

must know which emission processes each band integrates before comparing the maps with models. This section summarises the physical content of the two bands from the literature before placing our measurements in context. A line of intensity $10^4 \text{ photons cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$ (LU) inside the *GALEX* FUV band contributes $\simeq 25$ –40 CU of band-averaged intensity, depending on where it falls in the response (Morrissey et al. 2007).

5.1 What the FUV and NUV bands contain

Dust-scattered starlight. Away from resolved stars the dominant signal in both bands is the diffuse Galactic light (DGL), starlight from O and B stars scattered by interstellar grains. Its intensity scales with dust column in the optically thin regime and saturates at $\tau \gtrsim 1$ –2. Radiative-transfer analyses of wide-field FUV data give a moderate albedo and strongly forward-throwing phase function: $a = 0.45 \pm 0.05$, $g = 0.68 \pm 0.10$ (Witt et al. 1997); $a = 0.55 \pm 0.10$, $g = 0.75 \pm 0.10$ (Schiminovich et al. 2001); $a = 0.62 \pm 0.04$, $g = 0.78 \pm 0.05$ (Hamden et al. 2013); $0.3 < a < 0.5$, $g < 0.6$ (Murthy 2016); and $a = 0.4 \pm 0.1$, $g = 0.8 \pm 0.1$ (FUV), 0.5 ± 0.1 (NUV) (Akshaya et al. 2019), bracketing $a \simeq 0.4$, $g \simeq 0.6$ –0.7 (Weingartner & Draine 2001; Draine 2003b), though a and g are degenerate for any single geometry. Two model-independent facts matter: the albedo minimum across the 2175 Å feature, inside the *GALEX* NUV band,

means scattered light should be at least as blue as the illuminating field even though $A_{\text{FUV}} \simeq A_{\text{NUV}}$ per unit $E(B-V)$; and turbulence enhances scattered intensity on low-density and suppresses it on high-density sight lines relative to column (Seon & Witt 2013), limiting pixel-by-pixel DGL prediction (Section 4.7).

Molecular-hydrogen fluorescence (FUV only). Lyman- and Werner-band fluorescence of H_2 pumped by 912–1108 Å photons emits a forest of lines between 1350 and 1700 Å, within the *GALEX* FUV and FIMS/SPEAR L bands and absent from the NUV. The FIMS/SPEAR all-sky map (Jo et al. 2017) shows fluorescence correlated with $E(B-V)$, reaching ~ 10 per cent of total FUV intensity in Taurus–Perseus–Auriga (Lim et al. 2013), up to 30–50 per cent in the Sandage nebulosity (Sujatha et al. 2009), and detectable at the Galactic poles (Akshaya et al. 2018): a dust-correlated, FUV-only excess of a few per cent at high latitude to 10–40 per cent on illuminated surfaces.

Atomic and ionic lines (mostly FUV). FIMS/SPEAR detects C IV $\lambda 1549$, Si IV $\lambda 1398$, Si II* $\lambda 1533$, He II $\lambda 1640$, O III] $\lambda 1663$ and Al II $\lambda 1671$ from the warm and hot ionised media at high latitude (Welsh et al. 2007; Korpela et al. 2006; Edelman et al. 2006). Their summed intensity is of order 10^4 LU, a few tens of CU, or $\lesssim 10$ per cent of the darkest FUV sky, larger towards superbubble walls. The strongest line in raw *GALEX* FUV data is geocoronal O I $\lambda 1356$, not interstellar. The NUV band contains only weak interstellar lines (C III] $\lambda 1909$,

[O II] $\lambda 2470$).

Two-photon continuum. Every population of the hydrogen $2s$ level decays by two-photon emission, peaking at $\simeq 1480$ Å and extending through the NUV. In photoionised gas a fraction $P_{2s} \simeq 0.32$ of case-B recombinations passes through $2s$, so the continuum scales with $H\alpha$. Integrating the $2s \rightarrow 1s$ distribution of Nussbaumer & Schmutz (1984) with the case-B $H\alpha$ emissivity (Draine 2011) yields 57 CUR^{-1} (FUV, 1350–1750 Å) and 34 CUR^{-1} (NUV, 1750–2800 Å) per Rayleigh of in-situ $H\alpha$ at $T = 8000$ K, FUV/NUV ratio 1.67. At the Galactic poles ($I_{H\alpha} \simeq 0.4$ – 0.6 R; Finkbeiner 2003) this yields $\simeq 25$ – 35 CU in the FUV and 15 – 20 CU in the NUV.

Extragalactic background. The integrated light of galaxies (IGL) from *GALEX*, *HST* and ground-based counts converges to 1.45 ± 0.27 (FUV) and $3.15 \pm 0.45 \text{ nW m}^{-2} \text{ sr}^{-1}$ (NUV), i.e. 60–87 and 136–181 CU (Xu et al. 2005; Driver et al. 2016). The tomographic measurement of Chiang et al. (2019) gives 89^{+28}_{-16} (FUV) and 172^{+40}_{-21} CU (NUV), consistent with the IGL, leaving little room for a diffuse component. In a $1.7'$ -pixel map most IGL is unresolved, residing in the ‘diffuse’ level.

The isotropic ‘offset’. Every *GALEX* and FIMS/SPEAR analysis finds the DGL regression against dust extrapolates to $\simeq 230$ – 300 CU in the FUV and $\simeq 400$ – 600 CU in the NUV at zero column (Hamden et al. 2013; Murthy 2016; Akshaya et al. 2018, 2019). Henry et al. (2015) argue the FUV remainder is a genuine ‘mystery’ component, while Kulkarni (2022) shows two thirds, arguably all, can be supplied by conventional sources. Murthy (2016)’s model requires offsets of 100 (FUV) and 200 CU (NUV) at the poles rising to 200–400 CU at lower latitude—probably not isotropic.

Zodiacal light (NUV only). Sunlight scattered by interplanetary dust is negligible shortward of 2000 Å but the largest term in the NUV sky. Murthy (2014b) finds the *GALEX* NUV zodiacal signal proportional to the Leinert et al. (1998) visible-light distribution with a UV/optical colour of 0.65, subtracted by UV-BKGD and hence here. The $\simeq 330$ CU pole-to-plane amplitude implies $\simeq 140$ – 270 CU subtracted at the poles; a 30 per cent colour error maps onto ± 40 – 80 CU. The 250 CU difference between Murthy et al. (2010) and Murthy (2014a) NUV levels matches this size.

Airglow (both bands, FUV-dominated). From low Earth orbit the FUV band receives geocoronal/thermospheric emission (OI $\lambda\lambda 1304, 1356$, N_2 Lyman–Birge–Hopfield bands, Lyman- β -pumped two-photon continuum). In *GALEX* data airglow separates into a Sun-angle-dependent baseline and a component depending only on time from local midnight, tens to $\simeq 200$ CU per visit in the FUV (Murthy 2014b,a). This visit-dependent term produces tile striping and is what the destriping transfers (median 46 CU FUV, 480 CU NUV; Section 3.2).

5.2 Our measurements in this context

Zero points of the published maps. At $N_{\text{side}} = 256$, $|b| > 40^\circ$, $E(B-V) < 0.08$, a linear fit of intensity against *Planck* $E(B-V)$ gives, for the destriped *GALEX* pixels, total-intensity intercepts of 301 ± 24 (FUV) and 727 ± 16 CU (NUV) and diffuse ($\mathcal{P}_{30}$) intercepts of 264 ± 24 and 579 ± 11 CU; the Murthy (2014a) maps fitted identically give 262 ± 23 and 573 ± 11 CU, i.e. our diffuse level differs by $+2/+4$ CU. Alternative estimators move the intercept by 30–40 CU, less than the inherited systematic. The published map reproduces the *GALEX* intercept to $+0.2 \pm 0.2/-3 \pm 3$ CU; *GALEX*-free pixels give $223 \pm 82/557 \pm 65$ CU ($\mathcal{P}_{30}$ estimator on $27'$ cells: *GALEX* $233 \pm 12/567 \pm 10$ CU with slopes $7.8/5.2 \text{ kCU mag}^{-1}$, map–*GALEX* on identical cells $+0.4 \pm 0.2/-0.5 \pm 0.5$ CU, gap-fill–*GALEX* $+11.9 \pm 0.4/+1.4 \pm 0.7$ CU, *GALEX*-free cells $232 \pm 62/552 \pm 43$ CU) (Fig. 14a–c). The excess of total over diffuse intercept, 37 ± 34 (FUV) and 148 ± 19 CU (NUV), is resolved-source light at $1.7'$, consistent with galaxy counts (Xu et al. 2005; Driver et al. 2016) plus field stars, less the $\mathcal{P}_{30}$ order-statistic offset. Users comparing with diffuse-background work should use the published diffuse prediction or subtract the total-minus-diffuse increment; no constant has been subtracted from either band.

The isotropic level is inherited, and what it would contain. These intercepts are not a measurement of the extragalactic or ‘offset’ background. Equation (2) ties the $14'$ diffuse level of every cell to the UV-BKGD per-visit foreground model, so the monopole of our maps is the monopole of Murthy (2014a) and carries that model’s airglow and zodiacal-colour systematics unchanged; we add only the total-minus-diffuse increment and the spatial structure of the residual. In the FUV (Table 6, Section 5.1), identified terms (IGL 60–87, two-photon continuum 25–35, interstellar lines 20–40, faint stars $\lesssim 10$ CU) sum to $\simeq 105$ – 170 CU against a diffuse intercept of 230–265 CU, leaving 60–160 CU shared between DGL, residual airglow, and any extragalactic term; this is the 120–180 CU ‘unidentified’ component of Akshaya et al. (2018). In the NUV, identified terms leave 340–430 CU of the 560–580 CU diffuse intercept unexplained, as found by Akshaya et al. (2018). The diffuse FUV/NUV ratio, $264/579 = 0.46$, equals that of the IGL (0.44–0.48) and the tomographic EBL (0.52); the ratio of the unexplained parts, $\simeq 0.15$ – 0.45 , is redder than the IGL and any Galactic diffuse process—only a zodiacal or extragalactic spectrum is that red. A NUV foreground residual at 100–200 CU is thus the most economical reading, and it cannot be settled with any *GALEX*-based product.

The structure of the offset is new information. The monopole is inherited, but its anisotropy is measured: after linear $E(B-V)$ detrending, the $|b| > 30^\circ$ sky retains a dipole of 0.042 dex (FUV) and 0.038 dex (NUV) towards $(l, b) \simeq (290^\circ\text{--}310^\circ, -26^\circ)$, a Galactic quadrupole, and the northern hemisphere 6 per cent fainter than the southern at fixed $E(B-V)$. At $|b| > 50^\circ$, $E(B-V) < 0.03$, the FUV diffuse residual rises by $\simeq 130$ CU from the ecliptic plane to $|\beta| = 70^\circ$

Table 6: Illustrative budget of the isotropic (zero-dust, $|b| > 40^\circ$) diffuse intensity. Our intercepts are inherited from the [Murthy \(2014a\)](#) foreground model and carry a common ± 50 – 100 CU additive systematic; component estimates are from the literature cited in Section 5.1 except the two-photon term (this work, case B, $T = 8000$ K, $I_{\text{H}\alpha} = 0.4$ – 0.6 R).

Term [CU]	FUV	NUV
Diffuse intercept, this work ($\mathcal{P}_{30}$; estimator range)	230–265	560–580
Total-intensity intercept, this work (Huber)	291 ± 8	742 ± 9
Integrated galaxy light (Xu et al. 2005 ; Driver et al. 2016) (tomographic EBL, Chiang et al. 2019)	60–87 (89^{+28}_{-16})	136–181 (172^{+40}_{-21})
WIM two-photon continuum (recombination)	25–35	15–20
Interstellar line emission (C IV, Si II*, ...)	20–40	< 10
Unresolved Galactic stars below $\mathcal{P}_{30}$	$\lesssim 10$	$\lesssim 20$
Sum of identified terms	105–170	150–230
Remainder (DGL at zero template column, residual airglow/near-Earth two-photon, zodiacal colour, diffuse EBL)	60–160	340–430
of which dust-template zero level (± 5 mmag)	∓ 35	∓ 25
of which zodiacal model at 30 per cent	—	± 40 – 180

($+1.82 \pm 0.14$ CU deg $^{-1}$), with an NUV counterpart consistent with zero ($+0.00 \pm 0.12$ CU deg $^{-1}$). The FUV pattern appears at $+4.1 \pm 0.4$ CU deg $^{-1}$ in the independent FIMS/SPEAR starless map, matching low-order Galactic harmonics as well as ecliptic latitude and the polar asymmetries of [Akshaya et al. \(2018, 2019\)](#) and the [Henry et al. \(2015\)](#) component, pointing to the FUV-specific terms of Section 5.1. Users fitting isotropic backgrounds to these maps must model this $\ell \leq 2$ FUV structure; a template is distributed for characterisation.

The FUV–H α slope and two-photon emission. The diffuse FUV of *GALEX*-dominated pixels rises with H α , but H α and $E(B-V)$ are correlated. Regressing the $N_{\text{side}} = 512$ intensity on both gives partial H α slopes of 86 ± 3 (FUV) and 75 ± 3 CUR $^{-1}$ (NUV) at $|b| > 25^\circ$ and $68 \pm 3 / 53 \pm 3$ CUR $^{-1}$ at $|b| > 40^\circ$. The recombination two-photon expectation of 57 (FUV) and 34 CUR $^{-1}$ (NUV) supplies 65–85 per cent of the H α -correlated FUV and 45–65 per cent of the H α -correlated NUV; the remainder is plausibly scattered starlight and WIM line emission. The measured slope is thus largely accounted for by WIM two-photon emission, without requiring an additional H α -correlated source. Two corollaries follow: the sub-linear scaling $I_{\text{FUV}} \propto I_{\text{H}\alpha}^{0.4}$ (Appendix C) reflects a transition from dust-dominated to two-photon-plus-dust regimes, and H α -bright filled pixels inherit a physically motivated FUV excess via the H α feature of the predictor.

The FUV/NUV colour– $E(B-V)$ relation. Three regimes of the FUV/NUV colour– $E(B-V)$ relation map onto the components above. (1) The red plateau, FUV/NUV = 0.58 at $E(B-V) < 0.02$ (0.46 for the diffuse intercepts), is the colour of the isotropic term of Table 6 and carries no information on grains. (2) The blueing between $E(B-V) = 0.02$ and 0.3 at $d \log(\text{FUV/NUV}) / d \log E(B-V) \simeq 0.30$ reflects the growing weight of the DGL, whose photon colour is set by the dust slope ratio, $7760/4720 = 1.64$ at $|b| > 40^\circ$. In the optically thin, single-scattering limit $dI_\lambda / dE(B-V) \propto a_\lambda (\tau_\lambda / E(B-V)) \Phi_\lambda(g) J_\lambda$, so the

DGL colour measures $(a\Phi)_{\text{FUV}} / (a\Phi)_{\text{NUV}}$ times the illuminating field colour (1.0–1.2 for the map’s own stellar layers, $\simeq 1.8$ for the [Draine \(1978\)](#) field), giving $(a\Phi)_{\text{FUV}} / (a\Phi)_{\text{NUV}} \simeq 0.9$ – 1.6 : equal albedos or a lower NUV albedo are admitted, as expected if the 2175 Å feature is pure absorption ([Draine 2003b](#)), disfavoured a scattering population markedly more reflective at 2300 than at 1500 Å. Since H $_2$ fluorescence and FUV lines are dust-correlated and FUV-only, 5–15 per cent of the FUV dust slope may be fluorescence; the FUV-blue excursions of Upper Sco/Ophiuchus and Orion–Eridanus are equally consistent with a harder field, enhanced H $_2$ fluorescence ([Jo et al. 2017](#); [Lim et al. 2013](#)), or C IV/two-photon emission ([Kregenow et al. 2006](#); [Jo et al. 2012](#)). (3) The turnover at $E(B-V) = 0.38 \pm 0.06$ ($\tau_{\text{FUV}} \simeq 2.8$) marks saturation of scattered intensity plus decline of H $_2$ fluorescence; the higher peak colour (1.27) than the toy model’s (1.1) is expected near OB associations dominating the $E(B-V) \simeq 0.3$ – 1 sky.

Albedo and phase function: what can and cannot be inferred. The high-latitude dust slope constrains only a combination of a and g . For a thin layer illuminated by the [Draine \(1978\)](#) field, single scattering with a Henyey–Greenstein phase function reproduces $S_{\text{FUV}} = 7760$ CU mag $^{-1}$ for $(a, g) = (0.26, 0.6)$, $(0.39, 0.7)$ or $(0.65, 0.8)$. Breaking the degeneracy requires the anisotropy of the radiation field, multiple scattering and the three-dimensional dust distribution, via a Monte-Carlo transfer calculation as in [Witt et al. \(1997\)](#), [Murthy \(2016\)](#) and [Akshaya et al. \(2019\)](#). Such a fit—embedding the observer in a three-dimensional *Gaia*-based dust map illuminated by the full-depth stellar source layer with measured or calibrated ultraviolet fluxes and parallax distances, and fitting the albedo and phase-function asymmetry in both bands to the point-source-free *GALEX* sky together with isotropic and H α terms—is left to future work; here we quote only model-independent slopes and colours, not grain constants.

5.3 Foreground residuals: a UV-blind test and the FUV high-latitude structure

The foreground field F removed from the NUV mosaic follows ecliptic geometry, its median falling from $\simeq 650$ CU on the ecliptic to $\simeq 360$ CU at $|\beta| \simeq 60^\circ$, with anomalous airglow tiles superposed; a two-component model (airglow term plus [Leinert et al. 1998](#) template) explains 77 per cent of its variance. The FUV term (46 CU median) instead rises towards the ecliptic poles by $+1.08 \pm 0.08$ CU deg $^{-1}$.

A test of the residual that does not use the trained prediction as reference is available and decisive. At $|b| > 50^\circ$, $E(B-V) < 0.03$ we regress the diffuse level on $E(B-V)$ alone and bin the residual in $|\beta|$ (Fig. 15). In the NUV the destriped residual slope is $+0.25 \pm 0.12$ CU deg $^{-1}$ ($+0.00 \pm 0.12$ with a $\csc |b|$ term) where the raw mosaic gives -3.2 ± 0.3 : the zodiacal removal is complete to < 10 CU over 70° of ecliptic latitude. In the FUV the destriped residual is *not* flat: it rises by $+1.82 \pm 0.14$ CU deg $^{-1}$, $\simeq 130$ CU from the ecliptic to $|\beta| = 70^\circ$, in both Galactic hemispheres. Four facts identify this as sky rather than foreground. (i) The same estimator on the FIMS/SPEAR starless map gives $+4.1 \pm 0.4$ CU deg $^{-1}$, steeper, and the FIMS/SPEAR and *GALEX* residual fields correlate at $r = 0.74$. (ii) The trend is present in the raw mosaic ($+2.5 \pm 0.2$) and destriping *reduced* it; a zodiacal residual would have the opposite sign and be ≥ 10 times larger in the NUV. (iii) The residual has no dependence on *GALEX* depth at fixed sky ($+0.02 \pm 0.05$ CU per CU of pixel noise). (iv) The published diffuse prediction, which contains no ultraviolet data, reproduces 81 per cent of the trend ($+1.48 \pm 0.12$), so the prediction-referenced variant of this test returns $+0.05$ CU deg $^{-1}$ and must not be quoted as a foreground bound. Ecliptic latitude is moreover degenerate with Galactic longitude at $|b| > 50^\circ$: adding harmonics in β and λ plus $\csc |b|$ and $H\alpha$ reverses the sign of the partial $|\beta|$ slope (-0.9 ± 0.5 *GALEX*, -3.2 ± 1.2 FIMS/SPEAR). The removed FUV foreground correlates with *GALEX* depth (-90 ± 5 CU per decade of fractional pixel noise) more than with $|\beta|$ ($+1.0$ CU deg $^{-1}$), accounting for its polewards rise; the amplitude matches the FUV-only isotropic-component variations discussed by [Henry et al. \(2015\)](#) and [Akshaya et al. \(2018\)](#). We therefore make no correction; the possible foreground share is $\lesssim 0.4$ CU deg $^{-1}$ ($\lesssim 30$ CU over 70°) and is listed among the additive systematics of Section 3.2.

6 Limitations

The fused maps are heterogeneous by construction; the weight and uncertainty maps are the primary tools for using them responsibly (Section 3.10). The specific limitations, each with its measured size, are as follows.

(i) *The FUV inner Galactic plane is an extrapolation constrained only by FIMS/SPEAR and UVOT.* No *GALEX* FUV pixel exists above $E(B-V) = 1.6$ (8.2

per cent of the filled FUV sky), and 25 per cent of that sky is farther from *GALEX* than 3.65° . Above 4° scales the level is set by FIMS/SPEAR and is 1.4–1.6 times the UVOT-derived FUV, a 0.2 dex instrument bracket, half of which is recorded as `SIGMA_SYS` = 0.10 dex. The filled sky is brighter in $H\alpha$ and starlight than held-out sky, inflating error of the 4.5 per cent pure-model FUV sky to 0.07–0.10 dex. Near γ^2 Vel and δ/β Sco the FIMS/SPEAR-calibrated level lies 0.25–0.3 dex above the unconstrained prediction and 0.5–0.65 dex below the FIMS/SPEAR starry map.

(ii) *The NUV plane is validated over less than 3 per cent of its area.* 26.5 per cent of the NUV sky is model layer, validated against held-out *GALEX* NUV to 0.060 ± 0.001 dex (0.065 dex after correcting for the $H\alpha$ /starlight covariate shift), with narrow gaps (median 0.5°). The only imaging test, against *Swift*-UVOT (map/UVOT = 1.01, 0.14 dex), covers 0.8 per cent of the sky with a non-random pointing distribution.

(iii) *Sub-degree diffuse structure in filled sky is reduced in amplitude* by 13, 27 and 40 per cent at $\ell \simeq 100, 300$ and 700 (Section 4.7). The effective beam of predicted diffuse structure is $\simeq 4'$, FIMS/SPEAR information enters only above $\simeq 1^\circ$, and a residual 20–30 per cent excess of pixel differences across $N_{\text{side}} = 1024$ cell edges remains. A scale-dependent structure-amplification (de-bias) correction is available but is not applied to the published maps.

(iv) *Dependence on positional features.* Removing position raises the gap-matched scatter by $+0.017/+0.010$ dex, as the model captures the regional *GALEX* sky level via smooth functions of coordinates and $\geq 4^\circ$ -smoothed templates, with error growing with distance ($+0.0066 \pm 0.0008 / +0.0048 \pm 0.0004$ dex deg $^{-1}$). The UV-blind test of Section 5.3 bounds such residuals in the NUV but not the FUV beyond $\lesssim 30$ CU.

(v) *The adopted predictor is not the best-scoring configuration of its own benchmark.* The un-jittered model and a four-model ensemble score 3–4 per cent better in the NUV (-0.0017 ± 0.0002 and -0.0025 ± 0.0002 dex); the single jittered model is adopted for $b = 0$ continuity and simplicity (Section 4.2). Hyper-parameters were tuned on the reporting folds, and UVOT, FIMS/SPEAR and the folds were consulted during development: there is no blind test.

(vi) *Stellar content of the filled sky.* Outside ultraviolet imaging every *Gaia* DR3 source to $G = 16.5$ (blue and hot sources to $G = 19$, plus catalogued white dwarfs and hot subdwarfs) is individually present, and 99 per cent of the stellar flux of a median $N_{\text{side}} = 256$ cell is reached at $G = 17.25/16.5$ (FUV/NUV 23.3/21.8 AB; per-cell limits are published); but for 97 per cent (FUV) / 88 per cent (NUV) of these stars the flux is a prediction with a per-star uncertainty of 0.16 mag (NUV) to 0.4 mag (FUV, hot stars) and $\gtrsim 1$ mag for the chromospheric FUV of cool dwarfs, so individual filled-sky sources are expectations, not measurements, and 8.9 per cent of TD-1 stars at $|b| < 11^\circ$ read > 0.3 dex high in a $6'$ aperture because of predicted neighbours. The unresolved remainder below the layer limit is 3–6 CU at

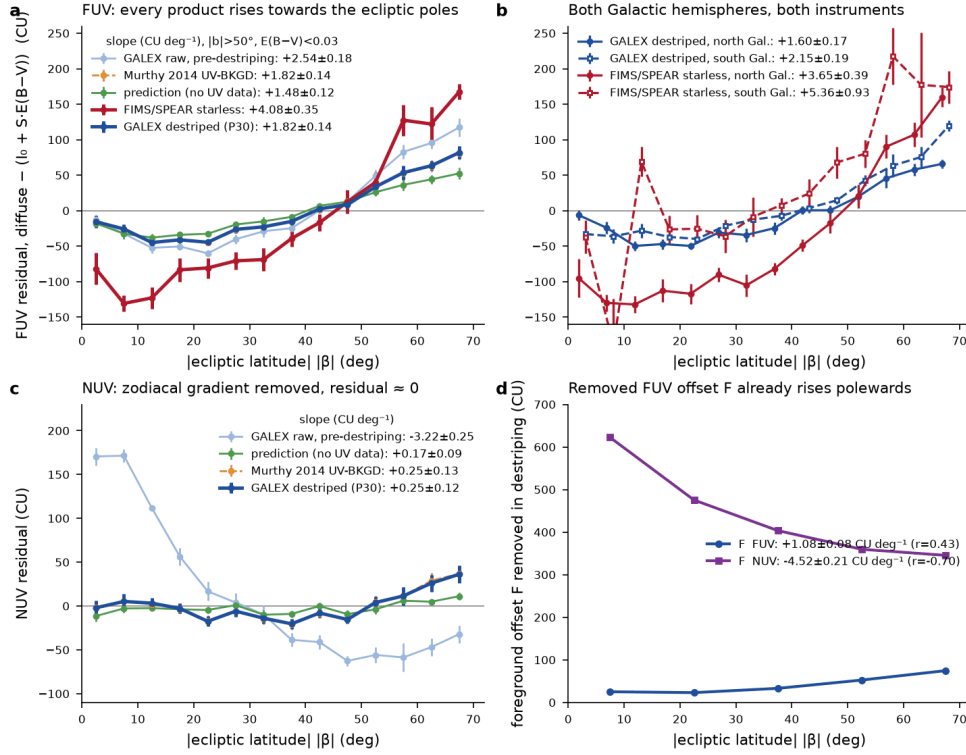


Figure 15: A UV-blind foreground-residual test at $|b| > 50^\circ$, $E(B-V) < 0.03$ ($N_{\text{side}} = 256$ cells): the diffuse intensity minus a linear dust regression $I_0 + S E(B-V)$, binned in ecliptic latitude $|\beta|$, for the destriped *GALEX* FUV and NUV, the raw (foreground-inclusive) mosaics, the removed [Murthy \(2014a\)](#) foreground itself, the independent FIMS/SPEAR starless FUV map, and the published diffuse prediction (no ultraviolet input). Slopes with 7.3° block-bootstrap errors are given in the legend. The FUV trend is steeper in FIMS/SPEAR than in *GALEX* and absent in the NUV: it is celestial.

$|b| > 30^\circ$ but $\simeq 240$ CU (up to ~ 800 CU if extrapolated to $m = 25$) in the NUV plane, i.e. up to 10–25 per cent of the NUV diffuse partition at $|b| < 10^\circ$ can still be starlight. Three specific caveats apply. (a) In the most crowded inner-plane *Swift*-UVOT tiles ($|b| < 5^\circ$) the model layer is 1.47/1.42 times the UVOT-derived intensity; the published map there is UVOT itself and no edge step results, but the level of the surrounding filled plane may be 0.06–0.08 dex high if the *Gaia*-based fluxes rather than the UVM2 photometry are at fault. (b) In the Magellanic Clouds the Galactic-calibrated stellar predictions are inconsistent with the *GALEX* surface photometry: the stellar input is capped, so un-imaged holes in the LMC bar and SMC core ($12.7/10.9 \text{ deg}^2$) retain a fixed intensity level, 24 per cent of diffuse-partition pixels within the discs are negative, and the Clouds must be masked in any use of the partition. (c) Very bright cool stars: the hierarchy adopts TD-1 F_{2365} alone for the NUV, which is within ± 0.25 dex of an unsaturated-*GALEX* calibration for 14 of 18 test stars, and it had no FUV tier for a few $V < 2$ G/K stars; 56 FUV and 11 NUV stars (among them Arcturus, Dubhe, Polaris, Pollux, α Cen and the B9 star HD 225132 in a *GALEX* mask hole) therefore received additive completion deposits totalling $32/6.9 \text{ photons cm}^{-2} \text{ s}^{-1} \text{ \AA}^{-1}$ (FUV/NUV, summed over the patched stars) so that no BSC $V < 4.5$ star outside imaging reads below half its expected flux, at the price of $\simeq 0.5$ dex-uncertain typical rather than measured cool-star FUV fluxes. In-

side the footprint the *GALEX* bright-star non-linearity (NUV $\lesssim 15$) is inherited unflagged, the layer restates the resolved sources of *GALEX* itself ($\kappa = 1.21$ aperture scale), and $G < 8$ stars are over-subtracted by 7–11 per cent in the diffuse partition.

Zero point and foreground. The absolute level is inherited from [Murthy \(2014a\)](#) with a ± 50 – 100 CU additive systematic, plus a $+13$ CU order-statistic term and a possible $\lesssim 30$ CU ecliptic FUV term, none in the uncertainty maps (Sections 3.2, 5.3); the total-intensity NUV zero point (727 ± 16 CU) exceeds the diffuse one (579 ± 11 CU); the diffuse NUV level contains a 340–430 CU unexplained component; and the high-latitude FUV sky carries $\simeq 130$ CU of structure not traced by dust. Intensities are observed, not extinction-corrected.

(viii) *Residual GALEX artefacts.* Bright-star ghosts and halos, edge reflections and inconsistent AIS tiles survive below repair thresholds (0.2 dex, three cells); light scattered into the field by avoided ultraviolet-bright stars is modelled around 30 FUV and 74 NUV stars and 5/49 tiles are discarded (Section 3.3), leaving the treated tiles within ± 3 per cent of their untouched neighbours in five sectors out of six, but scattered light around stars below the census thresholds, visit-to-visit structure finer than a tile gradient, and sub-tile structure on H α -bright tiles where flattening is withheld (e.g. 6 per cent in the NUV 3° south of Spica), remain; inside bright-star holes the fill is tied to the rim level and gradient (Section 3.9) and is continuous with the

adjacent observed mosaic to 5–10 per cent per 30° sector, but the interior is an extrapolation: a genuine dust-scattered halo of the avoided star (cf. [Murthy 2014a](#)) rising inside the rim, or residual instrumental scattered light in the rim tiles that sets the continued gradient, cannot be distinguished there; the artefact census flags $|\log(\textit{GALEX}/\text{prediction})| > 0.25$ dex in 0.30/0.90 per cent of covered cells. Edge-reflection glints of $V \lesssim 5$ stars are propagated into the FUV by the NUV-informed layer; one (ν And, 0.4 deg²) was removed, others may remain.

(ix) *Colour of filled pixels and the NUV-informed FUV level.* The FUV/NUV ratio of model-dominated pixels falls 0.1–0.3 below the *GALEX* locus at $E(B-V) \gtrsim 0.2$ (Appendix C); in NUV-informed FUV sky (9.7 per cent) the diffuse colour is the predicted one below 6.9', the absolute FUV level is uncertain at ~ 0.1 dex (0.06 dex median SIGMA) and point sources carry their catalogue-predicted FUV fluxes (Section 3.8); 15–17 mag stacks in that sky still read 1.1–1.2 at $|b| < 10^\circ$ from imaged faint neighbours; FUV boundaries facing that sky step by -0.02 dex.

(x) *Products not provided.* The uncertainty is valid at $N_{\text{side}} \leq 512$ only and is heavy-tailed (95.4 per cent at $\simeq 2.5u$, 99.7 per cent at 7–19 u), rests on a mock-gap calibration for the FIMS/SPEAR term and on a linear extrapolation beyond 8° from *GALEX* (Section 4.6); no exposure or photon-noise map is provided, no provenance window function beyond the transfer function of Fig. 14, and no dust-template alternative: only the *Planck* 2013 model has been used, with cosmic-infrared-background leakage ([Chiang & Ménard 2019](#)) entering filled high-latitude sky with positive sign at $\lesssim$ few per cent of $E(B-V)$ at $E(B-V) < 0.02$. A residual dipole of 0.04 dex remains at $|b| > 30^\circ$ after $E(B-V)$ detrending. The UVOT contribution to the FUV is capped at weight 0.8 (0.2 per cent of the sky). Ultraviolet inputs span 1972–2017, with variable sources at an ill-defined mean epoch. Equatorial copies are bilinearly resampled in $\log I$; stellar photometry should use the Galactic files.

7 Data products, code and reproducibility

Figures 1–3 show the published maps and Table 7 lists the principal files by their distributed names; the complete manifest (`manifest.json`, with SHA-256 checksums, HEALPix metadata and per-file descriptions) and a browsable landing page accompany them. All maps are HEALPix NESTED, Galactic, single precision, in CU; missing data are IEEE NaN in the destriped *GALEX* layers and the data-only maps; the fused maps have no missing or non-positive pixel (medians 1120/1359 CU; all-sky means 10 590/8726 CU). Every FITS header carries BAND, the HEALPix keywords and, for the data-only and provenance files, SELECT, BADVAL and the class fractions; the numerical constants of the pipeline (unit conversions of equation 1, global gains, feather param-

eters, FIMS/SPEAR constants, jitter, TD-1 cap, the ordered feature list, the uncertainty recipe and its interval multipliers) are tabulated in `header_addendum.json` distributed with the maps and are written as HIERARCH cards by the published script `add_header_keywords.py`. The uncertainty files carry the model description and the 2.4 u /9–13 u multipliers as header comments. HiPS tile trees for the published maps and derived products, for use in Aladin/ipyaladin, are built by `hips_lib.py`.

Code and reproducibility. The data set is accompanied by `pipeline_code.tar.gz` and `PIPELINE.md`, which states what can and cannot be re-run from the distributed material. Two stages are fully scripted and reproduce the published files from published inputs: the diffuse predictor (feature construction given the template matrices, cross-validation, training, prediction; `challengerA_gapfill.py`) and the fusion (`fusion.py`, run as `run_fusion_fuv.py` for the FUV and `run_fusion_nuv.py` for the NUV, with the configuration file, the fusion input archives `fusein_FUV.npz/fusein_NUV.npz` and the FIMS/SPEAR star mask; a re-run reproduces the published weights bit for bit, Section 4.3). The stellar layer is scripted end to end: the *Gaia* harvest (`gaia_harvest_code.tar.gz`), the two per-source predictors with their trained models and inference code, the rendering and partition, and the training of the diffuse predictor (`run_cv.py`, `run_full.py`); the two post-fusion patches (Magellanic holes, bright cool stars) are published as additive/multiplicative layers with their scripts. The artefact repair is partly scripted. HiPS ingestion, template regridding, destriping, cross-calibration, the source layer, the NUV-informed layer and the derived products are produced interactively; for these the algorithms are specified in this paper and in `PIPELINE.md` to the level of every constant, and their *outputs* (offset fields, cross-calibration curves, every source layer with its per-object catalogue, I_X , multipliers) are published, so every downstream stage can be re-run and every upstream stage checked against its product, but not regenerated from raw HiPS tiles by a single command. The gap-fill benchmark (`gapfill_benchmark_nside512.npz`; the out-of-fold predictions `oof_challengerA_jit_{FUV,NUV}_{total,diffuse}.npz`; the scorer `score_benchmark.py`) allows any alternative gap-fill model to be scored under the rules of Table 5. `validation_statistics.json` tabulates the headline numbers of this paper with their provenance (Table 11).

Licence, citation and archive. The data products are distributed under CC-BY-4.0 and the code under the MIT licence (`LICENCE.md`); `CITATION.cff` gives the citation and `ACKNOWLEDGEMENTS.md` the acknowledgements inherited from the public input archives: *GALEX* GR6/7 and the UV-BKGD high-level science product (<https://archive.stsci.edu/prepds/uv-bkgd/>; no DOI is registered) from MAST; *GALEX* and *Gaia* DR3 HiPS from the CDS; *Swift*-UVOT images from HEASARC *SkyView*; FIMS/SPEAR maps from the MAST MCCM collection; the *Planck* 2013 dust model from the Planck Legacy Archive; the H α composite from

Table 7: Principal published files, by their distributed names (`{b}` stands for `fuv` or `nuv`). The complete list with checksums is `manifest.json`.

File	Content
<i>Primary products</i>	
<code>{b}_total_n2048_gal.fits</code>	Fused, foreground-subtracted total surface brightness, equations (8)–(9), combining the tile-equalised <i>GALEX</i> layer with the model layer (full-depth stellar layer plus diffuse prediction) and, in the FUV, the NUV-informed layer of equation (4); Magellanic-hole and bright-cool-star patches; full sky; processing recorded in <code>HISTORY</code> . Also at $N_{\text{side}} = 512$ (<code>_n512_</code> , exact 16:1 mean).
<code>{b}_weights_n2048_gal.fits</code>	Blending weights W_{GALEX} , W_{NUVX} , W_{UVOT} , W_{FIMS} , W_{MODEL} as five columns (W_{NUVX} , W_{FIMS} zero in the NUV); sum unity to 1.2×10^{-7} .
<code>{b}_uncertainty_dex_n512_gal.fits</code>	Calibration combining <i>GALEX</i> , model, NUV-informed, UVOT and stellar-layer terms (held-out coverage keywords <code>COVAREA</code> , <code>COVGAPM</code> , <code>COVNUVX</code>). Two columns: <code>SIGMA</code> , the 68 per cent half-width of $\log_{10} I$, equation (10); <code>SIGMA_SYS</code> , the coherent systematic (0.10 dex FUV where $W_{\text{FIMS}} > 0$ at $ b < 10^\circ$; 0.05 dex NUV where $W_{\text{UVOT}} > 0.5$). Header keywords <code>MULT954/MULT997</code> (2.51/15.2 FUV, 2.45/19.2 NUV; gap-matched <code>MULT954G/MULT997G</code> 2.73/7.0, 2.47/13.2) give the multipliers for 95.4/99.7 per cent intervals; <code>DKNEE</code> , <code>DSLOPE1/2</code> , <code>DBREAK</code> the far-distance extension and <code>TILESYS</code> the un-added tile residual. Neither column includes photon noise or the additive zero-point systematic.
<code>{b}_provenance_n2048_gal.fits</code>	Dominant-layer code (uint8: 0 <i>GALEX</i> , 1 NUV-informed FUV, 2 UVOT, 3 FIMS/SPEAR-constrained model, 4 model; 61.9/9.7/0.2/23.7/4.5 per cent FUV, 73.2/0/0.2/0/26.6 per cent NUV; keywords <code>CODE0-4</code> , <code>FRAC0-4</code>).
<code>{b}_dataonly_n2048_gal.fits</code> , <code>fuv_dataonly_strict_n2048_gal.fits</code>	Fused map where $W_{\text{GALEX}} + W_{\text{NUVX}} + W_{\text{UVOT}} \geq 0.5$, NaN elsewhere (72.0/73.4 per cent kept; header <code>SELECT</code>). The FUV file <i>includes</i> the 9.7 per cent of sky whose FUV level and colour are transferred from NUV imaging; the <code>strict</code> file keeps $W_{\text{GALEX}} + W_{\text{UVOT}} \geq 0.5$ only (61.6 per cent).
<code>tile_offset_map_{b}_n2048_gal.fits</code> , <code>tile_offsets_{b}.parquet</code> , <code>gallex_{b}_equalised_n2048_gal.fits</code> , <code>scattered_light_model_{b}_n2048_gal.fits</code> , <code>scattered_light_census_tiles.csv</code> , <code>{b}_model_prediction_n2048_gal.fits</code> , <code>hole_anchor_{b}_n2048_gal.fits</code> , <code>nuvx_fuv_from_nuv_n2048_gal.fits</code> , <code>nuvx_colour_log10_fuvdiff_over_nuvdiff_-n1024_gal.fits</code> , <code>crosscal.json</code> , <code>gapfill_benchmark_nside512.npz</code> , <code>y_targets_nside512.npz</code> , <code>gallex_{b}_destriped_n2048_gal.fits</code>	Per-tile <i>GALEX</i> background model O (CU; zero outside the footprint; includes the scattered-light model), the per-tile table (offset, rim, gradient, chord, flags, scattered-light terms, interior residuals), the bright-star scattered-light model $T(E + c_t + \dots)$ on its own, the census and the corrected destriped <i>GALEX</i> layer g on which the fusion is based (Section 3.3).
<code>stars_all_{b}_n2048_gal.fits</code> , <code>stars_sigma_{b}_n2048_gal.fits</code> , <code>stars_count_n2048_gal.fits</code> , <code>extragalactic_points_{b}_n2048_gal.fits</code> , <code>diffuse_{b}_n2048_gal.fits</code> , <code>diffuse_negfrac_n256_gal.fits</code>	Component layers used in the fusion: the gap-fill layer prediction (rim-anchored) and its hole-anchor field C (<code>EXTNAME = GAPFILL</code>); the full-depth stellar, extragalactic and galaxy layers plus the diffuse prediction), the NUV-informed FUV layer and its colour model, the UVOT cross-calibration, and the gap-fill benchmark on the tile-equalised targets (out-of-fold predictions; scorer <code>score_benchmark.py</code>).
<code>unresolved_remainder_n64_gal.fits</code> , <code>stellar_layer_aux_n256_gal.fits</code> , <code>stellar_layer<chunk>.parquet</code> (27 files), <code>stellar_layer_catalogue_manifest.json</code>	Destriped <i>GALEX</i> GR6/7 layer with TD-1 top-up (g_c); NaN outside the footprint (<code>BADVAL</code>). Stellar and source layer, and diffuse partition (Section 3.5) Full-depth stellar layer (118 932 137 sources at catalogue scale, CU), its propagated 1σ , and source counts per pixel; <code>stars_mapmatched_{b}</code> is the κ -scaled variant subtracted in the diffuse partition. The 160 099 <i>Gaia</i> quasar/galaxy candidates, and the diffuse partition (fused map minus the κ -scaled map-matched stars, extragalactic points and L_{gal} inside imaging, minus the fusion's deposited source layer outside imaging, weighted by $w = W_{\text{GALEX}} + W_{\text{NUVX}} + W_{\text{UVOT}}$; equal to the diffuse prediction outside imaging); pixels below $-2\kappa\sigma_{\text{stars}}$ masked (0.25/1.42 per cent, per-cell fractions in the <code>negfrac</code> file), as are the Magellanic discs. Extrapolated unresolved stellar surface brightness below the layer limit (<code>SB_MISSING</code> , <code>_L0/_HI</code> , <code>_T025</code>); per-cell counts, G_{99}/G_{90} completeness magnitudes and negative-pixel fractions. Per-source catalogue: <i>Gaia</i> <code>source_id</code> , position, adopted FUV/NUV flux and σ , <code>fuv_-origin/nuv_origin</code> tier code, population, flags; predictor tables <code>uvpred_ms_gaia_*.parquet</code> , <code>uvpred_hot_predictions.parquet</code> with models and inference code (<code>uvpred_ms_model.pkl</code> , <code>uvpred_-hot_models.pkl</code> , <code>uvpred_{ms,hot}_infer.py</code> , <code>stellar_uv_model.py</code>).
<code>brightstar_completion_{b}_patch_n2048_gal.fits</code> , <code>brightstar_completion.csv</code> , <code>oof_{FUV,NUV}_diffuse.npz</code> , <code>y_targets_nside512.npz</code> , <code>model_{FUV,NUV}_diffuse.pkl</code> , <code>cv_scores.csv</code>	Additive bright-cool-star completion patch of Section 6 (56/11 stars) and its 5001-row candidate table with expectations, origins and deposits. Diffuse-predictor target, out-of-fold predictions, fitted models and cross-validation scores (Section 3.7).

Table 7: – *continued*: component layers, benchmark, code and documentation.

File	Content
<i>Component layers and auxiliary maps</i>	
<code>gallex_nuv_informed_fuv_n2048_gal.fits</code>	The NUV-informed FUV layer I_X of equation (3), with top-up, cold-pixel repair and glint removal.
<code>gallex_artefact_repair_mult_{b}_n2048_gal.fits</code>	Artefact-repair multiplier M_A ($1 = GALEX$ untouched, $0 =$ replaced); <code>{b}_qualityflags_n512_gal.fits</code> , artefact-census flags.
<code>galgc_layer_{b}_n2048_gal.fits</code>	L_{gal} , the galaxy/globular-cluster layer, with <code>galgc_layer_catalogue.csv</code> .
<code>foreground_offset_{b}_n256_gal.fits</code>	Additive foreground field F of equation (2) at its native $N_{side} = 256$, with the UV-BKGD coverage (inpainting) flag.
<code>fims_fuv_starless_n2048_gal.fits</code> , <code>fims_exposure_n2048_gal.fits</code> , <code>fims_ratio_starmask.npy</code>	The FIMS/SPEAR starless input and exposure map, and the bright-star exclusion mask of equation (7).
<code>uvot_{uvw2,uvw1}_{rate,coverage}_n2048_gal.fits</code> , <code>uvot_galex_crossscal.json</code>	UVOT rate maps and the isotonic cross-calibration curves.
<code>gallex_{b}_n{2048,4096}_gal.fits</code> , <code>murthy_{b}_diffuse_n2048_gal.fits</code> , <code>ebv_planck2013_n2048_gal.fits</code> , <code>templates_gaia_halpha_n2048.npz</code>	Raw <i>GALEX</i> mosaics, regridded UV-BKGD reference and predictor templates as used.
<i>Benchmark, code and documentation</i>	
<code>gapfill_benchmark_nside512.npz</code> , <code>oof_challengerA_jit_{FUV,NUV}_{total,diffuse}.npy</code> , <code>score_benchmark.py</code> , <code>challengerA_gapfill.py</code>	The gap-fill benchmark of Appendix A: features, fold assignment, targets, gap-matching weights; out-of-fold predictions of the diffuse predictor; the scorer; the predictor code.
<code>fusion.py</code> , <code>run_fusion_fuv.py</code> , <code>run_fusion_nuv.py</code> , <code>config/</code>	Fusion code (FUV/NUV entry points) and its configuration.
<code>pipeline_code.tar.gz</code> , <code>PIPELINE.md</code>	All project scripts and the stage-by-stage pipeline specification with its scripted/not-scripted statement.
<code>header_addendum.json</code> , <code>add_header_keywords.py</code>	Pipeline constants as keyword tables and the script that writes them as HIERARCH cards.
<code>DATAMODEL.md</code> , <code>README.md</code> , <code>manifest.json</code> , <code>validation_statistics.json</code> , <code>CITATION.cff</code> , <code>LICENCE.md</code> , <code>ACKNOWLEDGEMENTS.md</code> , <code>index.html</code>	Column-level data model with an executable worked example; user guide; manifest; headline numbers with provenance; citation; licences; inherited acknowledgements; landing page.

LAMBDA; HI4PI, TD-1, Bright Star Catalogue, GUVcat and galaxy and globular-cluster catalogues (Bai et al. 2015; Gil de Paz et al. 2007; de Vaucouleurs et al. 1991; Harris 2010; Dalessandro et al. 2012) from VizieR; *Gaia* DR3 photometry from the *Gaia* archive; and z0MGS from IRSA.

8 Summary

This work provides HEALPix $N_{side} = 2048$ maps of the total FUV and NUV surface brightness over the full sky, built from a destriped and tile-equalised *GALEX* GR6/7 layer whose foreground and zero point are inherited from Murthy (2014a), an NUV-informed FUV layer, *Swift*-UVOT, a FIMS/SPEAR large-scale constraint, a full-depth *Gaia* DR3 stellar layer of 1.19×10^8 sources with measured (TD-1, GUVcat) or predicted ultraviolet fluxes and nearby galaxies, and—where no ultraviolet imaging exists—a 90-feature gradient-boosted prediction of the diffuse light from dust, $H\alpha$, starlight and position, trained on the star-subtracted *GALEX* sky, harmonised to the data and feathered into it with published per-pixel weights; both bands are also published partitioned into resolved sources and diffuse light. Direct *GALEX* imaging sets 61.9/73.2 per cent of the FUV/NUV sky and is reproduced to < 0.003 dex over 90 per cent of the footprint; predicted sub-degree morphology covers 28.0/26.5 per cent. The gap fill is accurate to 0.052/0.058 dex (FUV/NUV, prediction plus stars) and 0.047/0.057 dex (diffuse partition) per $7'$ in gap-matched block cross-validation against the tile-equalised *GALEX* sky, degrading to 0.07–0.10 dex several degrees

from data and in the pure-model FUV sky; blind mock gaps through the fusion are recovered to 0.05 dex. In the *GALEX*-free plane the maps agree with FIMS/SPEAR (0.90, 0.19 dex) and UVOT (1.01, 0.14 dex). In filled sky stars are individually present to $G \simeq 17$ and isolated UVOT sources are half recovered at $UVM2 = 19.3$. The published two-column uncertainty is empirical in every pixel class and calibrated to 0.68–0.71 coverage, with heavy-tail multipliers of 2.3–2.4 u and 9–13 u . The isotropic level (264/579 CU) is inherited, not measured; its FUV- $H\alpha$ slope is largely two-photon emission, its colour- $E(B-V)$ relation reflects the changing mix of a red isotropic term and blue scattered light, and a 130 CU FUV-only high-latitude structure shared by FIMS/SPEAR is celestial. The principal limitations are the weakly constrained FUV inner plane, the sparsely tested NUV plane, the 13–40 per cent amplitude deficit of sub-degree diffuse structure in predicted sky, the positional-feature dependence, the inherited zero point, the predicted (not measured) fluxes of most filled-sky stars, a heavy-tailed uncertainty whose FIMS/SPEAR term rests on mock-gap experiments, and the Magellanic Clouds, where the stellar layer is capped and the partition invalid.

These maps are likely to remain the only full-sky FUV-plus-NUV surface-brightness product until the deeper full-sky UVEX survey (Kulkarni et al. 2021) becomes available; until then they supply the background, confusion and stellar environment needed by SPHEREx (Doré et al. 2014; Crill et al. 2020), ULTRASAT (Shvartzvald et al. 2024), the CSST survey camera (Zhan 2021), UVIT (Tandon et al. 2017), CASTOR (Côté et al. 2019)

and UVEX planning itself. The scientifically richest interim uses are those needing 4π rather than depth (Appendix D): full-sky radiative-transfer fits of the DGL with *Gaia*-based three-dimensional dust, a direction-resolved empirical FUV radiation field, the anisotropy of the high-latitude offset, and clustering-redshift tomography over two to three times the sky now usable for such analyses. In every application the weight and uncertainty maps should be consulted first.

Acknowledgements

This work is based on observations made with the NASA *Galaxy Evolution Explorer*; *GALEX* was operated for NASA by the California Institute of Technology under NASA contract NAS5-98034, and its data were obtained from the Mikulski Archive for Space Telescopes (MAST) at the Space Telescope Science Institute, operated by the Association of Universities for Research in Astronomy, Inc., under NASA contract NAS5-26555; the UV-BKGD and FIMS-SPEAR high-level science products were likewise obtained from MAST. We acknowledge the use of public data from the *Swift* data archive and of NASA’s HEASARC; we acknowledge the use of NASA’s *SkyView* facility (<http://skyview.gsfc.nasa.gov>) located at NASA Goddard Space Flight Center. This research made use of the HiPS and MOC services (*hips2fits*, MocServer, Aladin) and of the VizieR catalogue access tool (DOI: 10.26093/cds/vizier) of the Centre de Données astronomiques de Strasbourg (Fernique et al. 2015; Boch & Fernique 2014), of ESASky, developed by the ESAC Science Data Centre, of the NASA/IPAC Infrared Science Archive, which is funded by NASA and operated by the California Institute of Technology, and of the HyperLEDA database. Based on observations obtained with *Planck* (<http://www.esa.int/Planck>), an ESA science mission with instruments and contributions directly funded by ESA Member States, NASA and Canada. This work has made use of data from the European Space Agency mission *Gaia* (<https://www.cosmos.esa.int/gaia>), processed by the *Gaia* Data Processing and Analysis Consortium (DPAC); funding for the DPAC has been provided by national institutions, in particular those participating in the *Gaia* Multilateral Agreement. HI4PI is based on observations with the 100-m telescope of the MPIfR at Effelsberg and the Parkes Radio Telescope, part of the Australia Telescope National Facility funded by the Commonwealth of Australia for operation as a National Facility managed by CSIRO. We acknowledge the use of the Legacy Archive for Microwave Background Data Analysis (LAMBDA), part of the High Energy Astrophysics Science Archive Center (HEASARC), a service of the Astrophysics Science Division at NASA Goddard Space Flight Center. The Wisconsin H-Alpha Mapper, the Virginia Tech Spectral-Line Survey and the Southern H-Alpha Sky Survey Atlas are supported by the National Science Foundation. FIMS/SPEAR was a joint project of the Korea Astronomy and Space Science Institute, the Korea Advanced Institute of Science and

Technology and the University of California, Berkeley, supported by the Korean Ministry of Science and Technology and NASA. This research made use of HEALPY and HEALPix (Górski et al. 2005; Zonca et al. 2019), NAMASTER (Alonso et al. 2019), NUMPY (Harris et al. 2020), SCIPY (Virtanen et al. 2020), ASTROPY (Astropy Collaboration 2022), MATPLOTLIB (Hunter 2007) and SCIKIT-LEARN (Pedregosa et al. 2011).

Data availability

The maps, code bundle, benchmark and documentation described in Section 7 are available at menard.pha.jhu.edu/uvmap. All inputs are public (Section 7).

A The gap-fill benchmark, baselines and feature ablation

Benchmark definition. The published benchmark (`gapfill_benchmark_nside512.npz`) contains, at $N_{\text{side}} = 512$: the feature matrix (the twelve base features plus, for reference, the withdrawn FIMS/SPEAR and *AKARI* columns; the adopted predictor uses the columns listed in `clean_cols` and derives its remaining 78 features from the published templates with `challengerA_gapfill.py`); the fold assignment (six folds, unions of $N_{\text{side}} = 8$ super-pixels assigned by a fixed pseudo-random permutation, 151/121/122/120/130/124 super-pixels); the total and diffuse targets (destriped *GALEX* at $N_{\text{side}} = 512$; NaN where no *GALEX*); the importance weights `weight_matched_{FUV,NUV}` that match held-out pixels to the $(E(B-V), |b|)$ distribution of the filled sky in 10×6 cells ($E(B-V)$ edges 0, 0.02, 0.035, 0.06, 0.1, 0.2, 0.4, 0.8, 1.6, 3.2; $|b|$ edges 0, 10, 20, 30, 45, 60, 90°; cells with fewer than 50 held-out pixels unused; the FUV target population is the no-*GALEX* mask, the NUV target the $W_{\text{MODEL}} > 0.5$ sky at $N_{\text{side}} = 2048$); $E(B-V)$, $|b|$, l ; and the out-of-fold predictions of the adopted predictor (`oof_challengerA_jit_*`). The scorer computes the weighted robust scatter as 1.4826 times the weighted median absolute deviation of $\log_{10}(\text{pred}/G')$, the weighted median taking the lower sample at ties (which shifts the matched scatter by $\simeq 10^{-4}$ dex relative to an interpolating quantile). Table 5 in the main text gives all scores; Table 8 here gives a single-fold feature ablation.

Feature ablation. Table 8 retrains the adopted feature set on held-out fold 0. Permutation and retrain-ablation importances agree that *Planck* dust features dominate the FUV prediction and *Gaia* starlight the NUV, that position is the second most valuable group (+0.017/+0.010 dex gap-matched scatter when removed from the published set), and that H α is worth $\simeq 0.002$ dex.

B Statistical details and sources of the headline numbers

Block bootstrap and paired comparisons. Residuals are spatially correlated on $\geq 1^\circ$ scales and the FUV importance weights concentrate on few super-pixels, so pixel-level bootstrap errors ($\pm 0.0003/\pm 0.0001$ dex) understate the uncertainty of the matched scatter by a factor of 6–8. Resampling the 708 (FUV) and 765 (NUV) $N_{\text{side}} = 8$ super-pixels that carry held-out data (1000 resamples) gives ± 0.0023 and ± 0.0009 dex (95 per cent intervals 0.055–0.064 and 0.058–0.062); resampling $N_{\text{side}} = 16$ super-pixels $\pm 0.0018/\pm 0.0006$; the fold-to-fold range is 0.056–0.061 and 0.054–0.062 dex. Paired differences between models scored on identical pixels with the same resamples are determined to ± 0.0015 –0.002 (FUV) and ± 0.0002 –0.0005 dex (NUV); single-fold ablation differences below $\simeq 0.004$ (FUV) and 0.002 dex (NUV), including the individual rows of Table 8 and

Table 8: Retrain ablation of the adopted feature set on held-out fold 0 (gap-matched robust scatter, dex; single fold; paired differences below $\simeq 0.004$ dex FUV and 0.002 dex NUV are not significant, Appendix B). ‘Base’ is the twelve-feature set of the earlier predictor; ‘full’ the 89-feature development set including *AKARI*; the published 90-feature set equals ‘full–*AKARI*’ plus the 16° scale and the secondary-scale block, and scores 0.0597/0.0597 (FUV/NUV) on the same fold, 0.0575/0.0589 with the importance-based sample weights.

Feature set	n_{feat}	FUV	NUV
base	12	0.0641	0.0616
base + multi-scale	61	0.0637	0.0611
base + ecliptic	15	0.0645	0.0611
base + ratios	14	0.0634	0.0624
base + <i>AKARI</i>	35	0.0676	0.0632
full	89	0.0611	0.0606
full – <i>AKARI</i>	66	0.0612	0.0606
full – multi-scale	40	0.0672	0.0620
full – ecliptic	86	0.0614	0.0614
full – position	82	0.0781	0.0706

Table 9: Notation.

Symbol	Meaning
G, G'	raw and destriped <i>GALEX</i> intensity ($N_{\text{side}} = 2048$)
F	additive foreground offset field, equation (2)
M	UV-BKGD diffuse intensity (Murthy 2014a)
$\mathcal{P}_{30}$	30th percentile of the $N_{\text{side}} = 2048$ children of a cell (diffuse proxy)
P_D, P	diffuse prediction; complete model of the total used for the gain
$g, g_j, \zeta_j, \vartheta_j$	gain field, its levels, mixing coefficients and smoothing scales, equation (5)
$\mathcal{M}$	model layer, equation (6)
I_X, c	NUV-informed FUV layer and predicted colour, equation (3)
$I_F, C_F, \eta_F, t(d)$	FIMS/SPEAR-constrained layer, ratio field, support and distance tapers, equation (7)
$w_k \equiv W_k, f_k, c_k, m_k, \theta_k, \rho_{0,1}$	weights, feather, confidence, mask, feather scale and thresholds, equation (9)
M_A	artefact-repair multiplier
$u, \sigma_k, S(d, E(B-V))$	published SIGMA, per-layer terms and the FIMS/SPEAR mock-gap surface, equation (10)
σ (benchmark)	robust scatter, $1.4826 \times$ weighted MAD of $\log_{10}(\text{pred}/G')$

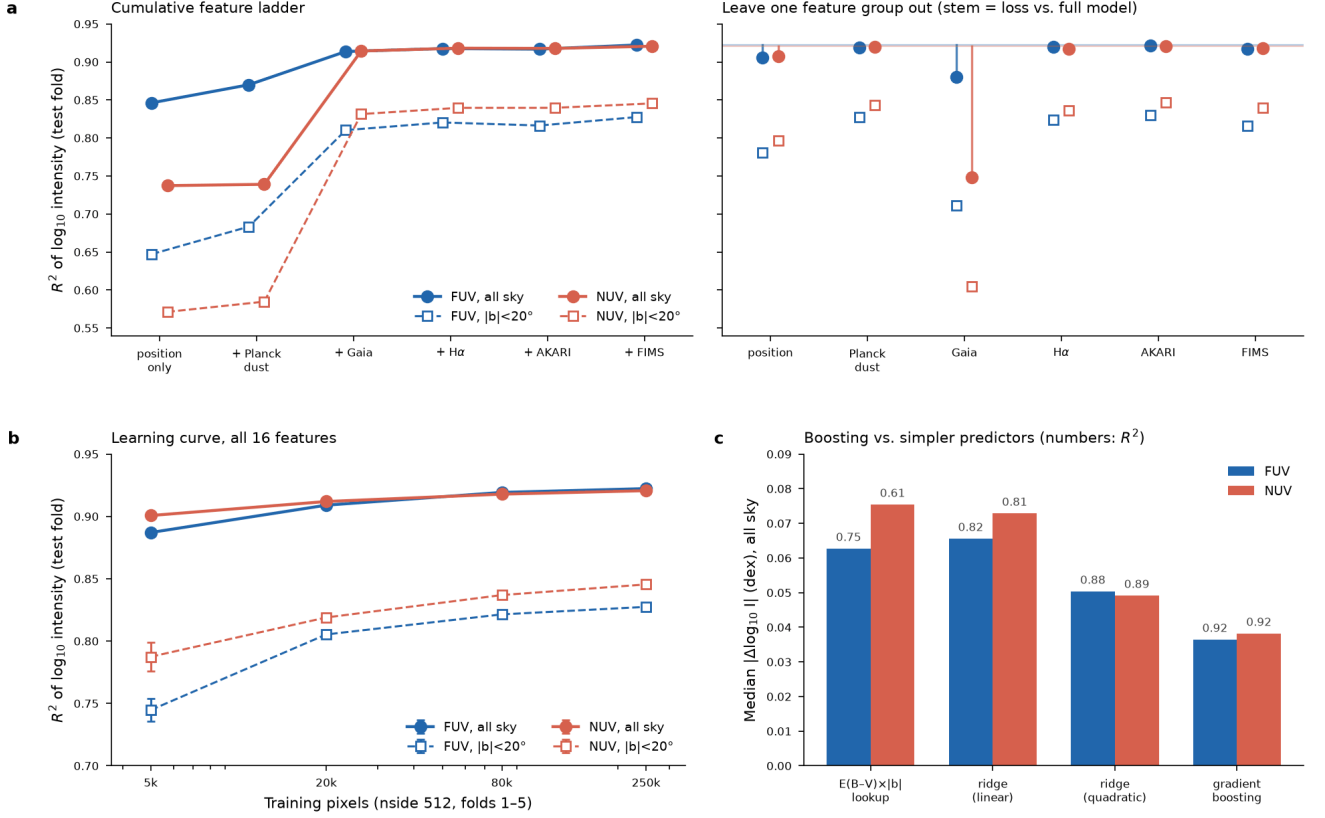


Figure 16: Feature ablation on the held-out spatial fold (7.3° blocks; 4.0×10^5 FUV and 4.9×10^5 NUV test pixels at $N_{\text{side}} = 512$, 2.5×10^5 training pixels), using the sixteen-feature development model so that the withdrawn groups can be assessed. (a) Left: cumulative feature ladder, $R^2(\log_{10} I)$ on the test fold as groups are added in the order position, *Planck* dust, *Gaia*, H α , *AKARI*, FIMS/SPEAR, for all sky (filled) and $|b| < 20^\circ$ (open); right: leave-one-group-out R^2 (stems show the loss relative to the full model). (b) Learning curve: test-fold R^2 versus number of training pixels. (c) Median absolute log residual of the gradient-boosted model compared with an $E(B-V) \times |b|$ median lookup table, linear ridge and quadratic ridge regression on the same features; numbers above the bars are R^2 .

statements such as ‘ecliptic and ratio features are worth ≤ 0.001 dex each’, are not significant. Hyper-parameters were tuned on the reporting folds; the tuning gain available within the fold-to-fold standard deviation is $\simeq 0.002$ (FUV) and 0.003 dex (NUV), which bounds the resulting optimism.

Importance weights and covariate shift. Kish effective sample sizes, weight concentration, the sensitivity of the matched scatter to the cell definition (± 0.0015 dex FUV, up to $+0.002$ dex NUV) and the classifier two-sample test (HGB classifier on eight non-positional templates, 200k versus 200k pixels, two-fold cross-fitted with the split on $N_{\text{side}} = 16$ super-pixels; AUC 0.83/0.66; single-feature AUCs $\log I_{\text{H}\alpha}$ 0.64, $\log F_{\text{BP}}$ 0.63, $\sin b$ 0.63, $\log n_\star$ 0.58, $E(B-V)$ 0.54 in the FUV) are those quoted in Section 4.2. Between 15 and 49 per cent of model-filled FUV pixels have a classifier score above the 99th percentile of held-out scores, i.e. essentially no analogue; the three shift-inflation estimators (top-decile scatter, density-ratio re-weighting with weights capped at the 99th percentile, linear extrapolation of $|r|$ on score) give 0.065–0.086, 0.097 ± 0.020 (effective sample 2 per cent) and $+2$ to $+6$ per cent for the FUV and 0.073, 0.064 ± 0.001 and $+2$ to $+6$ per cent for the NUV.

Seam estimator and its null. The stacked step is the mean of the ring medians of $\log(\text{map}/S_{2^\circ}[\text{map}])$ at $+1$ to $+3$ pixels outside the *GALEX* coverage edge

minus that at -1 to -3 inside. Placed on random great circles through pure-*GALEX* sky the estimator returns 0.0000 ± 0.0024 (FUV) and $+0.0002 \pm 0.0021$ dex per circle and a white-noise floor of ± 0.0002 dex at the length of the real boundary; block bootstrap of the real-boundary statistic gives $\pm 0.0005/\pm 0.0006$ dex. Three implementations (published code at $N_{\text{side}} = 2048$: $+0.0011/+0.0054$; an independent pair-selection variant: $0.003\text{--}0.004/0.015\text{--}0.016$; a re-implementation at $N_{\text{side}} = 512$ with the benchmark coverage: $+0.0041 \pm 0.0005/+0.0138 \pm 0.0006$ dex) span the ranges quoted in Section 4.1. Per 3.7° segment (≥ 100 ring pixels each side; 1601/1548 segments) the local step has rms 0.022/0.026 dex, 90th percentile of $|\text{step}|$ 0.031/0.039 and 2.6/3.6 per cent of segments beyond 0.05 dex; the great-circle null gives rms 0.012/0.013, 90th percentile 0.021 and 0.0/0.3 per cent.

Uncertainty calibration by stratum. Table 10 gives the coverage of $\pm u$, $\pm 2u$ and $\pm 3u$ by $E(B-V)$, distance and latitude stratum for the model term (benchmark, cross-half) and the FIMS/SPEAR term (blind mock gaps, test half), with the conventions stated in the caption.

Table 10: Coverage of the published uncertainty on withheld data (target 0.68 for $\pm 1u$). Model term σ_M : cross-half validation on the benchmark, adopted predictor’s out-of-fold residuals, area-weighted (gap-matched in parentheses). FIMS/SPEAR term σ_F : test half of the 2.25 million blind mock-gap pixels. Multipliers: percentiles of $|r|/\sigma$ (model term: with the far-distance extension applied).

Stratum	σ_M FUV	σ_M NUV	σ_F FUV
All	0.68 (0.66)	0.68 (0.68)	0.71 (0.73)
$E(B-V) < 0.1$ / 0.1–0.4 / 0.4–0.8	0.66–0.68	0.67–0.68	0.69–0.73 / 0.71–0.73 / 0.71
$E(B-V)$ 0.8–1.6 / > 1.6	0.54 / 0.81	0.66 / 0.67	0.73 / 0.77
$d < 1^\circ$ / 1–3 / 3–5 / 5°–9°	0.68 / 0.68 / 0.67 / 0.71	0.68 / 0.68 / 0.67 / 0.67	0.71–0.73 / 0.70–0.71 / 0.73 / 0.72
$ b < 10^\circ$ / 10–30 / $> 30^\circ$	—	—	0.72 / 0.72–0.74 / 0.68–0.72
σ -decile range	0.65–0.72	0.66–0.70	—
within $\pm 2u$ / $\pm 3u$	0.921 / 0.968	0.925 / 0.971	0.937 / 0.972
$ r /\sigma$ at 95.45 / 99.73 per cent	2.51 / 15.2	2.45 / 19.2	2.29 / 13.5

Table 11: Sources of the quantitative claims of the abstract and summary. ‘File’ entries are published maps from which the number is recomputed by the recipe given; named `.json/.csv` files are published tables (also collected in `validation_statistics.json`); ‘Table’ entries point to this paper.

Claim	Value	Source
Dominant-layer sky fractions	61.9/9.7/0.2/23.7/4.5; 73.3/0.2/26.5 per cent	File: <code>argmax</code> over columns of <code>{b}_weights_n2048_gal.fits</code> ; header FRACO-4 of the provenance files
Stellar layer size and completeness	1.189×10^8 stars; $G_{99} = 17.25/16.5$	<code>stellar_layer_key_numbers.json</code> ; <code>stellar_layer_aux_n256_gal.fits</code>
Predicted sub-degree morphology	28.0/26.5 per cent	File: $W_{\text{FIMS}} + W_{\text{MODEL}}$ dominant; equivalently NaN fraction of the data-only files
<i>GALEX</i> fidelity	$p_{90} \log(\text{map}/G') = 0.0024/0.0005$ dex; $W_{\text{GALEX}} > 0.99$ on 87.0/89.3 per cent	File: fused map versus <code>gallex_{b}_destriped_n2048_gal.fits</code> on its non-NaN pixels; weight file
Sky-averaged seam step	+0.0011 dex FUV; < 0.005/0.005–0.015 across implementations	File + <code>seam_metrics.py</code> ; <code>S5_seam_null_test.csv</code> ; Appendix B
Local seam rms	0.022/0.026 versus null 0.012/0.013 dex	<code>S5_seam_null_test.csv</code> ; Appendix B
Gap-matched CV scatter	0.060 ± 0.002 / 0.060 ± 0.001 dex	File: <code>score_benchmark.py</code> on <code>gapfill_benchmark_nside512.npz</code> with <code>oof_challengerA_jit_{b}_total.npz</code> ; bootstrap over $N_{\text{side}} = 8$ super-pixels (<code>S1_bootstrap_matchedMAD_CIs.csv</code>)
Shift-corrected NUV scatter	0.065 dex	<code>S3_covariate_shift_c2st.csv</code> , <code>S3b_shift_reweighted_uncertainty.csv</code>
Distance dependence	0.048→0.08 (FUV), 0.053→0.08 dex (NUV) at < $0.25^\circ \rightarrow 5\text{--}8^\circ$	File: <code>benchmark + dist_to_training_champion_folds_{b}.npz</code> ; <code>S6_distance_binned_MAD_v26.csv</code>
Far-gap fractions	25.5 per cent of filled FUV sky beyond 3.65° ; 5 per cent beyond 8°	File: <code>dist_gap_to_galex_FUV.npz</code> (any-valid-child rule, $N_{\text{side}} = 512$)
Mock-gap recovery	0.049/0.047 dex at $N_{\text{side}} = 512$; structure $r = 0.80\text{--}0.93$	<code>e2e_validation_v26.json</code> (T1, variant C); <code>fusion_v35.py</code>
Blind FIMS/SPEAR-layer mock gaps	p_{68} 0.046→0.093 dex with distance; gap-matched 0.068	<code>fims_mockgap_error_table.csv</code> , <code>fims_sky_uncertainty.json</code>
FUV versus FIMS/SPEAR (<i>GALEX</i> -free)	0.90, 0.19 dex, $r = 0.80$; 0.87–0.95 by $ b $	File: fused FUV versus <code>fims_fuv_starry_n2048_gal.fits</code> at $N_{\text{side}} = 128$, zero <i>GALEX</i> children; <code>e2e_validation_v26.json</code> (T2)
NUV versus UVOT (<i>GALEX</i> -free)	1.01, 0.14 dex, $r = 0.78$	File: fused NUV versus <code>uvot_uvm2_rate</code> calibrated by <code>uvot_galex_crosscal.json</code> ; <code>e2e_validation_v26.json</code> (T2)
Uncertainty coverage	0.68/0.68 (σ_M); 0.70 (σ_F); multipliers 2.4, 9–12	<code>model_term_v27_calibration.csv</code> , <code>fims_sky_uncertainty.json</code> ; Table 10; FITS header comments
Zero points	291/742 (Huber, total); 301/727 and 264/579 CU (jackknife, total/diffuse)	File: destriped <i>GALEX</i> + <code>ebv_planck2013</code> at $N_{\text{side}} = 256$, $ b > 40^\circ$, $E(B-V) < 0.08$; <code>nuv_zeropoint_key_numbers.json</code> , <code>e2e_validation_v26.json</code> (T3)
Identity to UV-BKGD	+2/+4 CU (fit); −4/−6 CU (pixel median)	File: <code>murthy_{b}_diffuse_n2048_gal.fits</code> versus $\mathcal{P}_{30}$ of G'
FUV–H α partial slope	86 ± 3 / 68 ± 3 CU R $^{-1}$	<code>halpha_partial_slopes.json</code> ; two-photon 57/34 CU R $^{-1}$ computed from Nussbaumer & Schmutz (1984)
FUV high-latitude $ \beta $ structure	$+1.82 \pm 0.14$ (<i>GALEX</i>), $+4.1 \pm 0.4$ (FIMS/SPEAR), $+0.25 \pm 0.12$ CU deg $^{-1}$ (NUV)	File: G' , FIMS/SPEAR starless, $E(B-V)$ at $N_{\text{side}} = 256$, $ b > 50^\circ$, $E(B-V) < 0.03$; <code>eciptic_residual_numbers.json</code> ; template file header
$\mathcal{P}_{30}$ depth term	$+0.34 \pm 0.01 \sigma_{\text{pix}}$; +13 CU median	<code>p30_bias_results.json</code> ; raw $N_{\text{side}} = 4096$ mosaics
Power retained by gap fill	C_ℓ ratio 0.47–0.60/0.68–0.70 at $\ell = 100\text{--}1500$; diffuse 0.75/0.54/0.36	<code>e2e_validation_v26.json</code> (T4), <code>structure_amplitude_heldout_v26.csv</code> ; Fig. 14
Foreground removed	median 46/480 CU; inpainted cells 9.4/8.2 per cent	File: <code>foreground_offset_{b}_n256_gal.fits</code> weighted by <i>GALEX</i> pixel counts; UV-BKGD coverage at $N_{\text{side}} = 256$
Map extrema and medians	min 107/254 CU; medians 1120/1359 CU	File: fused maps (<code>audit_key_numbers.json</code> , <code>integrity</code>)

C Additional validation

This appendix collects validation material that supports statements of the main text but is not required to follow it: a quasar null test by fusion-layer provenance, recovery of stellar and galaxy photometry, and further internal-consistency checks on the published maps.

C.1 Quasar null test and point-source photometry

Extragalactic point sources test for spurious extended signal and for the degree to which the diffuse predictor imprints extragalactic objects through its templates, independently of which layer supplies the flux at a given pixel. Figure 17 stacks Milliquas quasars (Flesch 2023) on the published maps, split by the provenance of the pixel: the point-source term is detected where the pixel is *GALEX*-dominated and where the FUV is NUV-informed (both carry real NUV imaging), and is null where the FUV is FIMS/SPEAR-constrained or model-filled, i.e. the predictor does not synthesise a spurious quasar signal where no ultraviolet photon has been measured.

The map is trained on, and represents, total surface brightness; whether individual sources are photometrically preserved depends on provenance. In *GALEX*-dominated pixels ($W_{\text{GALEX}} > 0.9$) stellar flux is recovered essentially one to one: $r = 3'$ aperture photometry with a $6' - 10'$ median-annulus background at the positions of 27 110 isolated GUVcat AIS stars (Bianchi et al. 2017) with $\text{NUV} < 14$ (8126 with $\text{FUV} < 14.5$) gives median recovered/catalogue photon-flux ratios of 1.13 (16–84 per cent range 1.03–1.29, robust scatter 0.025 dex, $n = 1098$) in FUV and 1.15 (0.84–1.45, 0.08 dex, $n = 19910$) in NUV, flat with magnitude and identical in the destriped *GALEX*-only map, the 13–15 per cent excess being consistent with PSF wings and blends entering the aperture relative to the GUVcat Kron-type magnitudes. Ratios above unity for stars brighter than $\text{NUV} \simeq 14$ reflect the known non-linearity of *GALEX* bright-star photometry, which the map inherits; an independent check with isolated $12 < \text{NUV} < 16.5$ AIS stars gives destriped-*GALEX* $4'$ -aperture flux/catalogue ratios of $+0.02$ to $+0.08$ dex, i.e. the CU scale of the *GALEX* layer is correct to $\lesssim 20$ per cent for unsaturated stars. Brighter still, the stars censored by *GALEX* are restored from TD-1 and the BSC (Section 3.5): TD-1-bright stars inside the footprint have a median map/TD-1 aperture ratio of 0.00 dex in both bands.

C.2 Galaxy and globular-cluster layer validation

The galaxy and globular-cluster layer L_{gal} has galaxy fluxes validated directly against *GALEX* aperture photometry to 0.94 (FUV) and 1.16 (NUV) with 0.08–0.09 dex scatter (Fig. 18); for the 104 globular clusters without measured integrated ultraviolet magnitudes the

predicted FUV flux carries a 0.7 mag uncertainty, and their cores should be regarded as recovered only partially.

C.3 Further consistency checks

A matched filter for coherent steps across HEALPix $N_{\text{side}} = 8 - 256$ cell boundaries of the published maps, compared with identical control lines offset by half a cell, finds no excess at any scale in any provenance class (median $|\text{step}|$ along boundary segments equal to control to < 0.001 dex; e.g. FUV model-class $N_{\text{side}} = 32$ boundaries 0.0074 versus 0.0073 dex, FIMS/SPEAR-class $N_{\text{side}} = 16$ 0.0064 versus 0.0063). A Hough-style ring test (mean 1° -high-pass along 0.23° -wide small circles about 6144 poles) is dominated by the Galactic plane for all poles; at $|b| > 25^\circ$ the maximum over 400 poles is 13.6/16.3 against a smooth distribution of mean $11.2 \pm 0.8/13.1 \pm 0.8$, i.e. no outlier pole and no great-circle stripe.

D Measurements enabled by a full-sky two-band ultraviolet map

We list, without elaboration, measurements that the published maps make newly possible or substantially easier, with the pixel class each requires (Section 3.10). *Diffuse Galactic light and dust* — full-sky Monte-Carlo radiative-transfer fits of the DGL with *Gaia*-based three-dimensional dust and the resolved hot-star census as sources, closing the albedo- g degeneracy that single-geometry fits leave open (W_{GALEX} sky as data, filled sky as boundary condition); a direction-resolved empirical FUV interstellar radiation field at the cloud surfaces mapped by *Planck*; the FUV/NUV colour of the DGL as a function of environment (W_{GALEX} in both bands); H_2 -fluorescence and two-photon excesses as FUV-only residuals against dust and $\text{H}\alpha$ (W_{GALEX}). *The isotropic component* — the anisotropy (dipole, quadrupole, hemispheric asymmetry, the $\ell \leq 2$ FUV structure of Section 5.3) of the high-latitude offset over twice the sky now usable, and its cross-correlation with H I velocity components, soft X-rays and synchrotron templates (W_{GALEX} ; monopole inherited). *Extragalactic* — clustering-redshift tomography and broadband intensity mapping (Chiang et al. 2019) over the full *GALEX* footprint with a characterised Galactic component and transfer function; cross-correlation with CMB lensing and the cosmic infrared background; stacking on clusters, filaments and quasar sightlines for halo ultraviolet light and circumgalactic dust ($W_{\text{GALEX}} > 0.99$, transfer function of Fig. 14 for anything else). *Mission planning and calibration* — background, confusion and bright-object maps over 4π for ULTRASAT, UVEX, CSST, UVIT and CASTOR field selection and exposure-time calculators (all classes, with SIGMA and SIGMA_SYS); inter-mission zero-point cross-checks (the harmonisation gains are themselves measurements: UVOT $\rightarrow$ *GALEX*

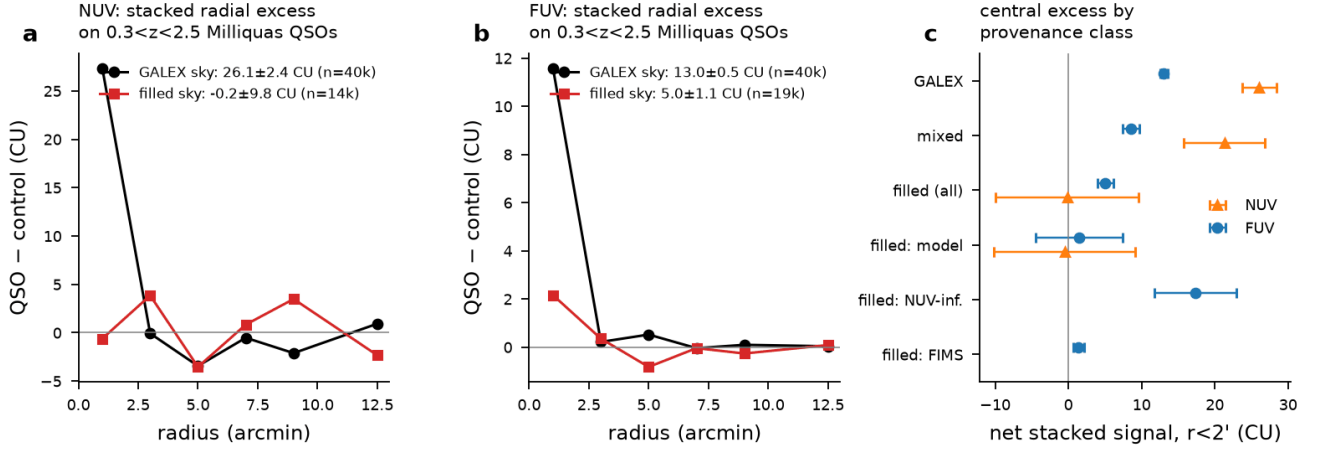


Figure 17: Quasar null test on the published maps by provenance class (143 154 Milliquas quasars, $0.3 < z < 2.5$, $R < 19.5$; each object referenced to a control position of the same class $0.4^\circ - 2^\circ$ away). (a, b) Stacked radial excess in *GALEX*-dominated and in filled pixels of the published NUV and FUV maps. (c) Net $r < 2'$ excess by class: detected in *GALEX* pixels and in NUV-informed FUV pixels (which are NUV imaging), null in FIMS/SPEAR-constrained and model-filled sky.

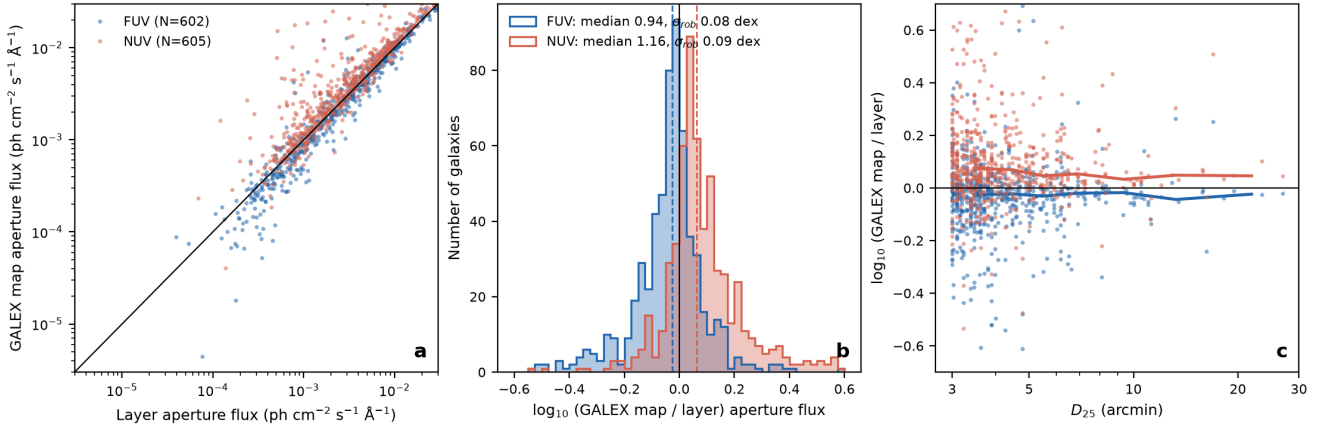


Figure 18: Validation of the galaxy and globular-cluster layer L_{gal} against D_{25} -aperture photometry of the destriped *GALEX* maps for 605 isolated galaxies with $3' \leq D_{25} \leq 30'$ at $|b| > 20^\circ$ and full *GALEX* coverage (aperture $1.2R_{25} + 1.5'$, background from a $1.6-2.5R_{25}$ annulus). (a) *GALEX* aperture flux versus layer aperture flux, FUV (blue) and NUV (red). (b) Distribution of $\log_{10}(\text{GALEX}/\text{layer})$ with medians and robust scatters. (c) The same ratio versus D_{25} with running medians.

NUV 0.88, FIMS/SPEAR/*GALEX* FUV 0.97–1.05); a reference background for transient searches in archival *GALEX*/UVOT data. *Foreground by-products* — the zodiacal ultraviolet colour and ecliptic profile at $2300 \text{ \AA}$ and airglow statistics versus orbital geometry from the published per-cell offsets. *Stellar populations* — an all-sky ultraviolet-bright star census cross-matched to *Gaia* including the plane (imaging classes only; filled-sky stellar fluxes are predictions), and integrated photometry of objects larger than a *GALEX* tile on a uniform background. *Methodological* — the frozen public gap-fill benchmark, on which any inpainting method can be scored under identical rules, and the priority-nested feathering with per-pixel provenance and empirical uncertainty as a template for other multi-mission sky fusions.

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