Extended far-ultraviolet emission in distant dwarf galaxies

The formation and growth of blue compact dwarf (BCD) galaxies are challenging to observe directly because these galaxies are too small to resolve at high redshift and too faint to reveal their outer regions in the local Universe. Far-ultraviolet observations at intermediate redshifts are necessary to show star formation in their outer disks while they are still growing. For this purpose, we use a sample of 14 BCDs with deep observations by the Ultra-Violet Imaging Telescope (UVIT) in the GOODS South field. Two of the BCDs, GS3 (redshift \(z = 0.1\)) and GS6 (\(z = 0.21\)), are shown in Fig. 1, with the other nine BCDs shown in Methods. Most have extended far-ultraviolet (hereafter, XUV) emission beyond their optical disks, which are well resolved with the Hubble Space Telescope (HST). To our knowledge, this is the first time such large far-ultraviolet (FUV) disks have been observed in distant dwarfs. There are also large FUV clumps of magnitude 25.3 (C3A) and 25.46 (C3B), and 26.8 (C6A) in the XUV regions of GS3 and GS6, respectively. Nine clumps in the other nine BCDs are listed in Extended Data Table 4. Most clumps were detected using automated software with the constraint of a minimum area of 5 pixels. Some clumps had to be separated from the main galaxy by eye (see ‘Clump significance’ for clump detection significance). All magnitudes discussed in this paper are corrected from the main galaxy by eye (see ‘Clump significance’ for clump detection significance).

Most disk galaxies including dwarfs follow intrinsic exponential profiles. The observed surface-brightness profiles in different bands are modelled with exponential profiles convolved with the appropriate point spread function (PSF; Fig. 2). The fitted intrinsic profiles of GS3, GS6 and eight others (except GS12 and GS14) are shallower in the FUV than in the optical, implying that the FUV disks are intrinsically more extended than the optical, not just apparently extended because of the broad PSF. FUV measurements were not possible owing to non-detection in GS8; GS9 was too compact to model. For GS3 and GS6, the intrinsic FUV scale lengths are about 1.4 and 2.4 times their respective optical scale lengths (Extended Data Table 1). Figure 2 shows that the observed FUV surface brightness, corrected for foreground extinction and cosmological dimming, goes at least as low as about 28–29 ABmag arcsec\(^{-2}\). This is well below the threshold of 27.25 ABmag arcsec\(^{-2}\) used as one of the criteria to define type-1 XUV disks for local spirals. The equivalent threshold star-formation-rate surface density (SFRD) with a Salpeter initial mass function (IMF) and solar metallicity \(Z = 0.02\) is SFRD\(_{th} = 3 \times 10^{-4} \text{M}_\odot \text{yr}^{-1} \text{kpc}^{-2}\) (Methods). For the average intrinsic surface brightness in the XUV region of GS3 and GS6, the SFRDs are 1.82 \(\pm 0.43 \times 10^{-4} \text{M}_\odot \text{yr}^{-1} \text{kpc}^{-2}\) and 2.25 \(\pm 0.48 \times 10^{-4} \text{M}_\odot \text{yr}^{-1} \text{kpc}^{-2}\), respectively. These values would be about 10\% lower at 0.4 \(Z = 0.02\) because the FUV emission of a 100-Myr-old population is 1.1-times brighter. Our SFRD estimates are comparable to previous measurements that reach about 10\(^{-5}\)–10\(^{-6}\) \(\text{M}_\odot \text{yr}^{-1} \text{kpc}^{-2}\) (Fig. 3a) in low-density, extreme environments, for example, galaxy outskirts or stripped gas tails within galaxy clusters. If the FUV SFRD follows the Kennicutt relation, it would suggest star formation at an average gas surface density of less than 1 \(\text{M}_\odot \text{pc}^{-2}\) (refs. 19,20). For a steeper slope of the Kennicutt relation as seen in the XUV region of M63, our SFRDs probe

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Blue compact dwarf (BCD) galaxies are low-luminosity (absolute K-band magnitude, \(M_K > -21\) mag), metal-poor (\(1/50 \leq Z/Z_\odot \leq 1/2\), where \(Z\) is the metallicity in terms of the solar metallicity \(Z_\odot\)) centrally concentrated galaxies with bright clumps of star formation. Cosmological surface-brightness dimming and the small size of BCDs limit their detection at high redshifts, making their formation process difficult to observe. Observations of BCDs are needed at intermediate redshifts, where they are still young enough to show their formative stages, particularly in the outer regions where cosmic gas accretion should drive evolution. Here we report the observation of excess far-ultraviolet (FUV) emission in the outer regions of 11 BCDs in the GOODS South field at redshifts between 0.1 and 0.24, corresponding to look-back times of 1.3–2.8 billion years in standard cosmology. These observations were made by the Ultra-Violet Imaging Telescope on AstroSat. For ten BCDs, the radial profiles of the intrinsic FUV emission, corrected for the instrument point spread function, have larger scale lengths than their optical counterparts observed with the Hubble Space Telescope. Such shallow FUV profiles suggest extended star formation in cosmically accreting disks. Clumpy structure in the FUV also suggests that the outer FUV disks are gravitationally unstable. Dynamical friction on the clumps drives them inwards at an average rate exceeding \(10^8\) solar masses per billion years.
gas (H$_1 + \text{H}_2$) surface densities (independent of metallicity because the molecules are fully observed in M63) of about 2.9 $M_\odot$ pc$^{-2}$ and about 4.9 $M_\odot$ pc$^{-2}$ for GS3 and GS6, respectively. The nature of star formation at such low density is largely unexplored.

Figure 3b shows the SFRD versus FUV – NUV colours, directly measured from the extinction-corrected UVIT images, for 11 of our BCDs (excluding GS5). As massive OB stars typically dominate FUV emission, FUV and NUV can detect star formation in the past 100 Myr to 200 Myr. Negative values of the colour indicate very young portions of the disk. Seven of our galaxies have FUV – NUV < 0, while four have 0 < FUV – NUV < 0.5 in their XUV region. GS3 and GS6 have FUV – NUV values of about 0.3 and about 0.2, respectively, within the observed optical extent, similar to local LITTLE THINGS dwarfs. We calculate the stellar population ages of these XUV disks by comparing their observed FUV – NUV colours with model colours obtained using the Starburst99 code (Methods). In the case of an instantaneous burst at $Z_{\odot}$, the ages are 7.1 Myr and 12.3 Myr for GS3 and GS6, respectively, whereas for a continuous star-formation history, they are 106 Myr old and 306 Myr old (the stellar populations are older by a factor of about 2 at 0.4 $Z_{\odot}$).

The relative excess FUV emission beyond the convolved optical extent, denoted by $\Delta L_x$ for 12 BCDs is shown in Fig. 4. Ten of them have $R_{\text{FUV}}/R_{\text{opt}} > 1$ and $\Delta L_x > 0$, including GS5, the marginal case. GS12 and GS14 have $R_{\text{FUV}}/R_{\text{opt}} < 1$ but $\Delta L_x < 0$ (Table 2). The $\Delta L_x$ refers to the scalelength of the FUV and optical disk respectively. These parameters can be useful to infer the presence of XUV emission when the spatial resolution is poor, especially in distant galaxies. In our downsized sample of 12 BCDs, 7 with clumps qualify for Thilker’s type-1 XUV criteria, 10 follow the type-2 criteria, and 5 follow both types (Methods and Extended Data Table 5).

XUV emission implies a significant fraction of young stars at large radii, possibly accompanied by an ongoing assembly of the outer disk over billion-year timescales. We assess the outer-disk evolution from its clumpy structure, focusing on seven BCDs resembling star-forming disks of high-redshift massive galaxies. As resolved by the HST, the optical disks are often clumpy too (insets in Fig. 1c,f). The clumpy structure suggests that the disks are gravitationally unstable, and the clump sizes are comparable to the turbulent Jeans length. For GS3, the large FUV clumps in the inner disk are comparable to the turbulent Jeans length. For GS3, the large FUV clumps in the inner disk are comparable to the turbulent Jeans length. The relative excess FUV emission beyond the convolved optical extent, denoted by $\Delta L_x$ for 12 BCDs is shown in Fig. 4. Ten of them have $R_{\text{FUV}}/R_{\text{opt}} > 1$ and $\Delta L_x > 0$, including GS5, the marginal case. GS12 and GS14 have $R_{\text{FUV}}/R_{\text{opt}} < 1$ but $\Delta L_x < 0$ (Table 2). The $\Delta L_x$ refers to the scalelength of the FUV and optical disk respectively. These parameters can be useful to infer the presence of XUV emission when the spatial resolution is poor, especially in distant galaxies. In our downsized sample of 12 BCDs, 7 with clumps qualify for Thilker’s type-1 XUV criteria, 10 follow the type-2 criteria, and 5 follow both types (Methods and Extended Data Table 5).
\[ F_{\text{clump}} = \frac{4\pi \ln AG^2M^2d}{V^2} \left( \text{erf}[X] - \frac{2X e^{-X^2}}{\sqrt{\pi}} \right) \]

where \(V\) is the clump orbital speed, \(\dot{V}\) is the unit vector along the velocity direction, \(X = V/(2\sqrt{\theta}a)\) for halo three-dimensional velocity dispersion \(a\) with a Maxwellian distribution function, \(p\) is the halo density and \(G\) is the gravitational constant. The \(\frac{\pi}{2}\) term increases from 0 to 1 as \(X\) increases. We assume a pseudo-isothermal halo with a core radius \(R_c\) and associated asymptotic rotation speed \(V_0 = \sqrt{2a}\). Assuming a factor of \(a = 2.7\) to convert stellar mass to dynamical mass as in the local BCD, NGC 4861, we obtain the dark-matter halo mass, \(M_{\text{dm}} = 6.42 \times 10^8 M_\odot\), for GS3. Then the circular velocity at the radius of the clump C3A (Fig. 1) is \(V_c = 25\) km s\(^{-1}\), and the Coulomb factor is \(\ln \Lambda = 5\). \(\Lambda\) denotes the Coulomb logarithm. The inspiral timescale, \(T_{\text{insp}}\), is then derived by integrating the equation for angular momentum change, \(dL_z/dt = r \times F_{\text{clump}}\), where \(L_z\) is the z component of the angular momentum, \(t\) denotes the time and \(r\) is the radius of the clump, from the current clump position to the optical radius, \(R_{\text{opt}}\), for all 12 clumps detected in our sample of BCDs (Extended Data Table 4). For the largest clump C3A in GS3, \(T_{\text{insp}} = 5.6\) Gyr is 4.3 times the look-back time at \(z = 0.1\). For the clump in GS14 (\(z = 0.1\)), C14A, \(T_{\text{insp}} = 2.4\) Gyr.

The clump mass divided by \(T_{\text{insp}}\) gives the instantaneous clump accretion rate, and their sum for each galaxy gives the summed clump accretion rate, \(M_{\text{clump}}\). The average value of \(M_{\text{clump}}\) for all the galaxies is about \(1.1 \times 10^6 M_\odot\) yr\(^{-1}\). For GS3, \(M_{\text{clump}} = 2.3 \times 10^6 M_\odot\) yr\(^{-1}\) and the average clump accretion time is \(T_{\text{clump}} = 5.5\) Gyr. This time is less than the Hubble time, implying that clump torques can lead to substantial evolution of the outer structures.

The time, \(T_{\text{XUV}}\), over which a mass equal to all the young stellar mass in the XUV disk would be accreted by clump torques, is larger than \(T_{\text{insp}}\) because the XUV mass is larger than the summed clump mass.

Fig. 3 Comparison of the star-formation properties of our BCDs with those of local galaxies. a. SFRD values of our sample BCDs (shown in filled blue and red), other local dwarfs (dashed green—measured with GALEX within their Holmberg radii), outer regions of galaxies (solid cyan), LSB galaxies (dashed magenta), apertures on M51 (dashed grey) and normal/Irr (Irr) galaxies (dashed purple). b. SFRD versus observed FUV–NUV colour of the current BCD sample (blue and red squares), local BCDs (green stars) and other local dwarfs (green points). The measurements for local BCDs and other dwarfs are within their Holmberg radii. All our measurements are shown with 1σ error bars.
The accretion time should be considered upper limits because the young stellar clumps are more massive if they contain gas. As typical star-formation efficiencies in the youngest regions are on average, the mass multiplier from gas could be a factor of $50$ for such regions, decreasing the timescale in inverse proportion. The timescale would also be longer than just from the halo torques because disk stars and gas may also exert torques on a clump. In addition, differential shear in the outer disks could bring the clumps closer together so they coalesce and form bigger clumps with faster accretion. The clump collision time from shear ($\tau_{\text{coll}}$ in Extended Data Table 4) is approximately the orbit time. If these effects are considered, the clump accretion time could be shorter by a factor of five or more. Then for BCDs with $\Delta L_{\text{opt}} \geq 10\%$, the effective accretion time for the young stellar mass in the XUV disk, $\tau_{\text{XUV}}$, is approximately a few billion years. In GS3 and GS14, with this revision, $\tau_{\text{XUV}} = 1\text{ Gyr}$. Such large, young stellar accretion rates are likely to be accompanied by simultaneous gas accretion.

We conclude that the BCDs studied here, at redshifts of $0.1$ to $0.24$, typically have more extended FUV disks than their optical counterparts, suggesting significant outer, low-density star formation. These extended FUV disks contain $10^9 M_\odot$ clumps that produce enough torques to drive them, or an equivalent mass, inwards to the optical disk, contributing to a more centrally concentrated structure. The torques are not large enough to bring in the whole outer disks, which should fade into the extended old disks and halos of today's BCDs.

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Methods

A flat Λ cold dark-matter cosmology with Hubble constant, \( H_0 = \text{70 km s}^{-1}\text{Mpc}^{-1} \), \( \Omega_m = 0.3 \) and \( \Omega_\Lambda = 0.7 \) was adopted throughout the article (\( \Omega_m \) and \( \Omega_\Lambda \) are the matter and dark energy density parameter). All magnitudes quoted hereafter in the paper are in the AB system\(^{31} \).

AstroSat observation and other archival data

Our sample of BCDs is selected based on the following criteria: (1) central surface brightness <22 mag arcsec\(^{-2}\) in HST F435 filter; (2) rest-frame \( B - R < 1.0 \); (3) stellar mass >10\(^{8}\) \( M_\odot \) and redshift \( z < 0.25 \) (obtained from ref. \(^32\)) considering surface-brightness dimming affecting the observation of low-surface-brightness outskirts of these galaxies. These criteria select only 14 BCDs\(^8\) in the GOODS South field for which high-quality multi-wavelength data are available.

In the current study, we use archival observations from the HST\(^{33}\) and high acuity wide-field K-imager (HAWK-I)\(^{34}\) along with new ultraviolet (UV) observations from UVIT\(^\text{a}\). The orbit-wise UVIT dataset\(^b\) of GOODS South field (principal investigator Kanak Saha, ID GT05-240) was processed using the official L2 pipeline. We removed frames affected by the cosmic-ray shower. These frames were excluded (resulting in about 15% data loss) in the final science-ready images and the subsequent photometry calculation. In addition, there was data loss owing to the mismatch in time stamp on the VIS (visual) filter and NUV or FUV filters. The final science-ready images had a total exposure time of about 17.2 h and about 17.3 h in F154W and N242W, respectively.\(^{35}\) The PSF full-widths at half-maximum (FWHMs) are about 1.4 arcsec (F154W) and 1.3 arcsec (N242W)—more than a factor of 3 better resolution than the galaxy evolution mapper (GALEX) UV deep field\(^{36}\).

We estimated the sky background following a standard procedure. We ran Source Extractor 2.25.0\(^c\) (SExtractor) on the parent UVIT image with a low detection threshold and dilated the obtained segmentation map to mask all detected sources. We then placed a large set of boxes of size 9 pixels randomly over the masked image and created a flux (within the box) histogram. The procedure also required visual inspection to avoiding the masked regions. The resulting histogram was fitted with a Gaussian function, the mean of which is the estimated background. For FUV and NUV, they are 28.43 ± 0.01 mag arcsec\(^{-2}\) and about 28.17 ± 0.003 mag arcsec\(^{-2}\), respectively. The 3\(|\sigma\rangle\) limiting background subtracted from the FUV and the NUV passbands, respectively, are 28.43 ± 0.01 \(|\sigma\rangle\) counts per second per pixel and 3.54 ± 10\(^{-3}\) \(|\sigma\rangle\) counts per second per pixel in the F154W and N242W, respectively. These median values correspond to limiting surface-brightness levels of 29.6 mag arcsec\(^{-2}\) (FUV) and 29.7 mag arcsec\(^{-2}\) (NUV) at 3\(σ\) above the background in a circular area of radius equal to PSF FWHM.

Multiband surface photometry

While fitting isophotes in the F435W imaging, the centre was kept fixed. We then fit elliptical isophotes to the BCDs in background-subtracted F435W-band images using the image reduction and analysis facility (IRAF)\(^40\) elliptical isophote analysis (ELLIPSE)\(^41\) task. We mask all the sources around each BCD before performing surface photometry. At the centre of each galaxy, the photometric zero points\(^6,33\) are given by magZP = 17.78 (F154W), magZP = 19.81 (N242W), magZP = 25.68 (F435W) and magZP = 25.94 (F160W). The error in the surface-brightness values (\(\Delta\mu\)), measured for the total flux within each annulus area, is estimated by taking into account the background-sky root mean square within each annulus as follows:

\[
\text{Flux error} = \sqrt{n_{\text{pix}} \sigma_{\text{sky}}^2 + \frac{\text{Flux}}{\text{exptime}}} \quad \text{and} \quad \Delta\mu = \frac{\text{Flux error}}{\text{Flux}} \cdot 2.5 \quad \text{mag} \quad \text{per} \quad \text{pixel} \quad \text{scale}^{-2}
\]

where \(n_{\text{pix}}\) is the number of pixels within each annulus, Flux and exptime refer to the total counts per second within the annulus and total exposure time, respectively. For the HST images, the associated weight images are used to compute the sky root mean square, \(\sigma_{\text{sky}}\). The median values of locally obtained \(\sigma_{\text{sky}}\) are 6.41 ± 10\(^{-3}\) \(\text{counts per second per pixel}\) and 3.54 ± 10\(^{-3}\) \(\text{counts per second per pixel}\) in the F154W and N242W, respectively. These median values correspond to limiting surface-brightness levels of 29.6 mag arcsec\(^{-2}\) (FUV) and 29.7 mag arcsec\(^{-2}\) (NUV) at 3\(σ\) above the background in a circular area of radius equal to PSF FWHM.

Outer extent of a galaxy

Throughout our analysis, along with the one-dimensional (1D) SBP, we also obtain a 1D signal-to-noise (S/N) profile for each galaxy and mark their extents in any band as the extent beyond which the S/N goes below 3 (this position is determined by a combination of the galaxy profile and the sky noise and would be a larger extent for lower sky noise). The FUV and optical extents (Fig. 1) are corrected for the effect of the PSF as follows:

\[
\text{r}_{\text{corr}} = \sqrt{\text{r}_{\text{obs}}^2 - \text{FWHM}^2}
\]

where \(r_{\text{corr}}\) is the corrected extent, \(r_{\text{obs}}\) is the observed extent at which we find S/N = 3, and HWHM is the half-width at half-maximum in a filter. Unless otherwise noted, all the extents quoted in the text have been corrected for the PSF as above.

Modelling of surface-brightness profiles

We use PROFILER v2.0\(^{42}\) to model the HST SBPs with a combination of Sersic plus exponential or an exponential alone.\(^d\) The disk SBPs can be broadly classified into type I, type II and type III\(^d\). Therefore, in addition to Sersic plus exponential, we also consider truncated exponential profile for a more realistic modelling of the HST images of the BCDs (Fig. 2).

The UV disk was modelled with a different approach because error bars are not taken into consideration in PROFILER\(^{42}\). For simplicity, we consider a pure exponential disk in both FUV and NUV having the same ellipticity as that of the outermost fitted ellipse (having S/N ≥ 3) in the observed HST/F435W. We do not rule out the existence of truncated exponential disks, but given the resolution and angular size of the galaxies, we cannot justify assuming this. Thus, the intrinsic UV disks are assumed to be single exponential. By convolving the exponential disk with the UVIT PSFs, we create model disk galaxies in the UV. We obtain 1D SBPs of the models at the same SMA lengths as considered for UV surface photometry. The 1D model profiles are then fitted to the observed UV profiles via least-squares optimization using

\[
\mu = -2.5 \log \frac{I}{\text{pixel scale}^2} + \text{magZP}
\]
the MPFTT routine\textsuperscript{44}, which is an implementation of the MINPACK-1\textsuperscript{45} Levenberg–Marquardt nonlinear least-square optimization algorithm. This provides us with the deconvolved scale lengths and central surface brightnesses of the BCDs in the UV. The method can effectively recover an intrinsic exponential disk of a galaxy. However, multiple intrinsic components cannot be effectively recovered and the outcome could be biased. Photometry in faint outskirts of galaxies is also sensitive to the sky background. To test the effect, we model the profiles again by subtracting sky values ±1σ about the mean sky. We also include this sky uncertainty into the error budget of the radial profiles. It is found that for 9 BCDs, a change in ±1σ sky results in a change of FUV scale length up to 20%. In the cases of GS7, GS13 and GS14, the difference was 70%.

Parameters of the XUV disks
We check for the XUV emission in the BCDs using the classification scheme defined for the local galaxies\textsuperscript{43}. We convert the surface-brightness values into the equivalent SFRDs following the SFR calibration\textsuperscript{43} at solar metallicity as:

\[
\text{SFRD} = \frac{1}{A} \times 10^{\frac{\mu + 48.59}{25}} \times 4\pi D_L^2 \times 1.4 \times 10^{-28},
\]

where SFRD is in $M_{\odot}$ yr\textsuperscript{-1} kpc\textsuperscript{-2}, $\mu$ is the surface brightness in mag arcsec\textsuperscript{-2}, $A$ is the angular scale in kpc arcsec\textsuperscript{-1} and $D_L$ is the luminosity distance in cm. The presence of structured UV emission beyond a threshold value of $\text{SFRD}_{\text{th}} = 3 \times 10^{-4} M_{\odot}$ yr\textsuperscript{-1} kpc\textsuperscript{-2} $= 27.25$ mag arcsec\textsuperscript{-2} defines a type-1 XUV disk\textsuperscript{14}. Sizes of such structures are considered to be about 1 kpc in Thilker’s definition\textsuperscript{14}. However, at $z = 0.1–0.24$, the size of a minimum 4-connected pixels in the FUV image will be in the range of about 1.5–3 kpc. Although it is strictly not possible to follow the type-1 definition at these redshifts, the presence of star-forming clumps beyond the detectable optical radii (Fig. 1a, d and Extended Data Fig. 1) in seven BCDs implies they are type-1 XUV disks. It is noted that all our observed FUV profiles reach 27.25 mag arcsec\textsuperscript{-2} and below, beyond the optical radii. Type-2 XUVs do not necessarily have structured UV clumps, but show recent and high star-formation activity at large galactocentric radii. Type-2 XUV disks satisfy the following two criteria\textsuperscript{14}:

\begin{align*}
\text{FUV} - \mathcal{K}_s &\leq 4 \\
A_{\text{LSB}} &\geq 7 \times A_{K80}
\end{align*}

where FUV−$K_s$ colour is computed in the low surface brightness (LSB) zone (defined as the area between the ‘threshold’ SFRD contour and the contour enclosing 80% of the total flux in $K_s$ band). $A_{\text{LSB}}$ is the area of the LSB zone in the FUV and $A_{K80}$ refers to the area enclosing 80% of the total flux in the $K_s$ band. We refer to the aforementioned XUV disk criteria as ‘Thilker’s criteria’ throughout the text. It is noted that to check whether our BCDs are type 2, we consider the LSB zone’s outer radius to be $R_{\text{out,FUV}}$. As FUV and $K_s$-band PSFs differ by more than a factor of 3, we compute the colour using the intrinsic FUV models matched to the PSF of $K_s$-band imaging (about 0.4 arcsec)\textsuperscript{14}. We find that GS3 (FUV−$K_s = 1.25$, $A_{\text{LSB}} = 16.9A_{K80}$), GS6 (FUV−$K_s = 0.56$, $A_{\text{LSB}} = 7.2A_{K80}$) and eight others, that is, a total of 10 BCDs, satisfy the type-2 XUV criteria. In short, 11 BCDs in our sample are either type 1 or type 2, or both, based on Thilker’s criteria.

Clump detection and stellar-mass estimates
We use a threefold approach to identify young star-forming structures in the BCDs. For this, we run SExtractor\textsuperscript{37} and Noise Chisel 0.16.1-0eff\textsuperscript{48} on the FUV cut-outs of the BCDs, to detect and identify sources, with the configurations presented in Extended Data Table 2. Our third approach is visually motivated where both tools succeed to detect but fail to deblend these structural irregularities in the XUV region. We estimate the S/N of the detections using the segmentation maps in both the cases of SExtractor (solid yellow contours in Fig. 1 and Extended Data Fig. 1) and Noise Chisel (marked by magenta dashed contours in Fig. 1 and Extended Data Fig. 1). In addition, for the SExtractor clumps we estimate their S/N based on the Kron-like apertures (Extended Data Table 4). For the visually identified sources, we estimate the S/N within a fixed elliptical aperture (marked by red ellipses in Fig. 1 and Extended Data Fig. 1). For all the sources detected and identified, we consider only those detections with S/N $\geq 3$ (or >5 $\sigma$ above the background) for subsequent analysis. Of these, the ones in the XUV region without any HST counterpart are referred to as ‘clumps’ and considered to be part of the host BCD. We follow this definition of clumps throughout the paper.

It is noted that the photometry of faint objects will be influenced by the background. For example, in GS3, we obtain a local background of 28.77 mag arcsec\textsuperscript{-2} using SExtractor\textsuperscript{37}, compared with a higher value to 28.53 mag arcsec\textsuperscript{-2} (obtained as described in AstroSat observation and other archival data). This, however, did not have any drastic effect on the stellar masses of the clumps; the mass of the fainter clump (C3B) only differed by about 0.2 dex. Similarly, varying the SExtractor parameters also brings changes in the clump masses. For example, changing the detection threshold from 1.5σ to 2σ while keeping the smoothing kernel intact, the stellar mass of the clump C3A changes by about 0.2 dex. In contrast, changing the smoothing kernel from gauss 1.5 to gauss 2.0 (at a fixed detection threshold of 1.5σ) has a lesser effect; for
example, the clump mass of C3A changes by about 0.1 dex. Beyond a
detection threshold ~2 in SExtractor, most of the FUV clumps go unde-
tected. Therefore, we finally use parameters (Extended Data Table 2)
motivated by those used in existing deep and large-scale surveys\(^{30,49}\),
especially to pick faint sources.

**Clump significance.** We detect a total of 12 clumps: 4 with SExtrac-
tor, 2 with Noise Chisel and 6 clumps by visual identification in the
XUV regions of the BCDs. To measure the statistical significance and
frequency of our FUV clumps, we perform the following experiment.
We choose a large patch (341 × 341 pixels = 20,220 arcsec\(^2\)) of the
GOODS South image in the FUV and run SExtractor (and Noise Chisel)
with the same settings as used to find the clumps in our BCDs. This
has resulted in a detection of 625 (157) sources. Of these, 13 (11) FUV
sources have S/N ≥ 3 and without any HST counterpart. This translates
to a clump density of 0.0006429 (0.0005440) arcsec\(^{-2}\) in the patch.
If these clumps are due to background fluctuations alone, we would
expect about 0.3 (0.2) similar clumps using SExtractor (and Noise
Chisel) in the XUV regions, with a total area of about 458.5 arcsec\(^2\)
around all BCDs. When we randomly place elliptical apertures (same
as red ellipses, shown in Fig. 1d and Extended Data Fig. 1) on the same
patch, we find 0 out of 1,604 apertures to have S/N ≥ 3 and without any
HST counterpart. We then visually identify 435 FUV sources without
a HST counterpart in the same patch (once all SExtractor-detected
sources are removed) and estimate their S/N. We find that none meet
the S/N ≥ 3 threshold.

The S/N of the SExtractor-detected sources outside the XUV
regions of GS3 and GS6 are presented in Extended Data Table 3, and
outlined in the Extended Data Fig. 3c,e. We find that all 6 sources
surrounding GS3 and 6 of the sources (positive peaks) in GS6 have
S/N < 3; these are all cyan circles in the figure. The cyan boxes (with
HST counterparts) and the orange box (without an HST counterpart)
have S/N ≥ 3 and without any HST counterpart. We then visually identify 435 FUV sources without
a HST counterpart in the same patch (once all SExtractor-detected
sources are removed) and estimate their S/N. We find that none meet
the S/N ≥ 3 threshold.

The stellar-mass estimates. We convert the measured FUV fluxes of the
clumps into SFRs\(^{48}\) and estimate their stellar masses (Extended Data
Table 4) assuming a constant SFR for 100 Myr as:

\[
\text{SFR} (M_\odot \text{ yr}^{-1}) = 1.4 \times 10^{-28} L_\nu \quad (\text{erg s}^{-1} \text{ Hz}^{-1})
\]

where \(L_\nu\) stands for luminosity and \(\nu\) for frequency. It is noted that all
the FUV-flux-derived stellar masses, quoted throughout the paper,
have been corrected for internal dust extinction with the help of the
UV slope (\(\beta\)), obtained by fitting a straight line within 1,268–2,580 Å to the
intrinsically spectral-energy-distribution models. The colour excess is
then obtained as\(^{50}\)

\[
E(B-V) = \frac{1}{4.684} (\beta + 2.616) \quad (11)
\]

Owing to the sensitivity of \(\beta\) to metallicity (Z), stellar ages and
the star-formation history\(^{32,35}\), the derived extinction can be biased.
We use intrinsic spectral-energy-distribution models with \(Z = Z_\odot\)
and 0.4 \(Z_\odot\), and find \(\Delta\beta\) up to 0.26 or equivalently, \(\Delta E(B-V)\) up to
0.06 mag only. We proceed with \(E(B-V)\) at \(Z_\odot\) and use Starburst99
models (see ‘UV colour and stellar population ages’) to model clump masses. For a 100-Myr-old instantaneous burst, our mean
clump mass is in good agreement with the mean model clump mass.
Model masses gradually deviate by about 0.5 dex to 3.5 dex
for 200-Myr-old to 1-Gyr-old bursts. A difference of about 0.9 dex
is seen for a 100-Myr-old CSFH.

**Inspiral timescale.** To estimate the inspiral timescale owing to the dynamical friction
from the dark-matter halo, we assume Binney’s logarithmic spherical
potential:\(^{25}\) given by:

\[
\Phi_\alpha (r) = \frac{\alpha M}{r} \ln[r_1^2 + r^2],
\]

where \(r_1\) is the core radius of the dark-matter halo and \(V_\alpha\) is the asymptotic velocity. We then integrate the equation \(dl_\alpha / dr = -r \times \vec{F}_\alpha\), where \(F_\alpha\) is the dynamical friction force (equation (1))
onto the halo, to obtain the inspiral timescale. The Coulomb factor appearing in equation (1)
can be written as

\[
\ln A = \ln \left( \frac{R_{\text{gal}}}{R_{\text{min}}} \right) = \ln \left( \frac{M_{\odot}}{M_{\text{min}}} \right) = \ln \left( \frac{a}{M_{\odot}} \right),
\]

where \(R_{\text{gal}}\) is the size of the galaxy and \(R_{\text{min}} = GM_{\odot} / V_\alpha^2\) is the strong
encounter radius. Then the inspiral timescale is given by

\[
T_{\text{inspiral}} = \frac{a M_{\odot}}{\ln(a M_{\odot}/M_{\text{min}})} \left( \frac{\dot{X}_{\text{gal}}}{2\pi (R_{\text{out}}/p R_\alpha)^2} \right).
\]

The indefinite integral \(I_{\text{dm}}\) (above equation (15)) can be written as
\(I_{\text{dm}} = I_{\text{dm,1}} + I_{\text{dm,2}}\) such that

\[
I_{\text{dm},1} = \frac{1}{2} \left[ x \sqrt{1 + x^2} - 3 \ln(x + \sqrt{1 + x^2}) \right].
\]

and

\[
I_{\text{dm},2} = \frac{1}{2 \sqrt{6}} \left[ \ln \left( \frac{2x + \sqrt{1 + x^2}}{\sqrt{1 + x^2}} \right) - \ln \left( \frac{2x - \sqrt{1 + x^2}}{-\sqrt{1 + x^2}} \right) \right].
\]

In the above equations, \(R_\alpha\) is the disk scale length; \(\dot{X}_{\text{gal}}\) and \(R_{\text{out}} / p R_\alpha\) (orbital
timescale) are given by

\[
\dot{X}_{\text{gal}} = \frac{V_\alpha^2}{\nu_0} = \frac{a}{a-1} h(R_{\text{out}}/p R_\alpha) \quad \text{and} \quad \tau_{\text{out}} = \frac{2\pi R_{\text{out}}^{3/2}}{\sqrt{6} G a M_{\odot}}
\]

where \(V_\alpha\) is the circular velocity calculated at the location of the clump
\((R_\alpha)\) owing to the total dynamical mass \((M_{\odot} = a M_\alpha)\) of the galaxy,
with \(a = 2.7\) for all BCDs. This, in turn, fixes the dark-matter halo mass as
\(M_{\text{dm}} = (a - 1) M_\alpha\); and \(R_\alpha = p R_\alpha\). In all our calculations, we consider the
\(p = 2\) case. Increasing the parameter \(p\) reduces the inspiral timescale.
Varying the parameter \(p\) either to 1 or 3 changes the inspiral timescale
by about 10%. The function \(h(y) = y^{1/2} / (1 + y)^2\) represents the radial dependence
of the circular velocity curve for the assumed dark-matter halo
potential. For GS3 with \(M = 3.78 \times 10^9 M_\odot\), the orbital time is \(1.7\) Gyr at \(R_{\text{out}} = 7\) kpc.
Clump accretion rate and timescale. On the basis of the clump mass conservation, we calculate the net clump accretion rate in the galaxy as the sum of individual clump accretion rates due to the dynamical friction alone as

\[ M_{\text{clump}} = \sum_{j=1}^{n} \frac{M_{\text{clump},j}}{T_{\text{infall},j}}, \quad (19) \]

where \( n \) denotes the total number of detected clumps in the galaxy; \( T_{\text{infall},j} \) denotes inspiral time for \( j \)th clump. In GS3, \( M_{\text{clump}} = 2.3 \times 10^7 M_{\odot} \text{ Gyr}^{-1} \). We utilize the net clump accretion rate to estimate the timescale for the clumps to reach the optical disk of the galaxy as:

\[ \tau_{\text{clump}} = \frac{M_{\text{clump}}}{M_{\text{clump}}} \quad (20) \]

In addition, we estimate the timescale required for the clumps to transfer an amount of mass equal to the young stellar mass associated with the XUV disk into the optical region of the BCDs. We first note that galaxies with low \( \Delta_{L_x} \), in the range of a few percent, have XUV disk masses that are less than the summed clump masses. The average radial profile could be flatter in the outer regions where the clumps are, making it a type-III profile. To account for this in the timescale for outer-disk evolution, we add the summed clump masses to the extrapolated XUV masses that come from the intrinsic fits in those six cases where \( \Delta_{L_x} \) is low. We do not add the clump masses to the other cases. This difference in the two cases is evident in the UV images also because the low-\( \Delta_{L_x} \) cases have outer clumps with much less contrast to the rest of the outer disk than the high-\( \Delta_{L_x} \) cases. Thus we evaluate the XUV evolution timescales from the following equations and show them in Extended Data Table 5:

\[ \tau_{\text{XUV}} = \frac{\Delta_{L_x} M_{\text{young}}}{M_{\text{clump}}}; (\Delta_{L_x} > 10\%) \quad (21) \]

\[ \tau_{\text{XUV}} = \frac{\Delta_{L_x} M_{\text{young}} + M_{\text{clump}}}{M_{\text{clump}}}; (\Delta_{L_x} < 10\%) \quad (22) \]

Clump–clump collision timescale. Clumps formed in the XUV disk will interact gravitationally and might merge to grow bigger, in which case they will fall faster to the central region of the host BCD. The clump infall time would essentially be determined by the clump–clump collision timescale. The collision cross-section of a clump (assuming spherical shape) is simply \( \sigma_{\text{clump}} = \pi R_{\text{clump}}^2 \), where \( R_{\text{clump}} \) is the radius of the clump. Then the mean free path of the clump is given by

\[ l_{\text{clump}} = \frac{1}{n_{\text{clump}} \sigma_{\text{clump}}}, \quad (23) \]

where \( n_{\text{clump}} \) denotes the number density of the clumps within the XUV region. The clump–clump collision timescale, denoted as \( \tau_{\text{cc}} \), relative to the orbit time can then be written as

\[ \frac{\tau_{\text{cc}}}{\tau_{\text{orb}}} = \frac{1}{2} \left( \frac{M_{\text{clump}}}{H \left( \frac{R_{\text{XUV}}}{R_{\text{clump}}} \right)^2} \right) \quad (24) \]

In the above equation, \( R_{\text{XUV}} \) denotes the size of the XUV region, \( H \) is the thickness of the disk and the rest of the parameters have their usual meaning. In all our calculations, we assume \( H/R_{\text{XUV}} = 0.2 \), for simplicity. In both GS3 and GS6, the mean clump collision timescale is about 1.5 Gyr (about \( \tau_{\text{orb}} \)). In other words, clumps in most BCDs will collide with another within an orbital timescale.

Data availability

The HST imaging data are available at https://archive.stsci.edu/hlsps/hif/v1.5/ and the 3D-HST catalogue is available at https://3dhst.readysciencearchivefacility-com/. The original level 1 far-UV data observed by UVIT/AstroSat are available for download from the ISSDC site at https://astrobrowse.isssdc.gov.in/astro_archive/archive/Home.jsp.

Code availability

We have used standard data reduction tools in Python, IRAF, and the publicly available code SExtractor (https://www.astromatic.net/software/sexttractor) and PROFILER (https://github.com/BogdanCiambur/PROFILER/) for this study. We also have used the MPFIT routine translated to Python language here (https://people.ast.cam.ac.uk/~rcooke/python/packages/mpfit.py). The pipeline used to process the Level 1 AstroSat/UlV data can be downloaded from http://astrosat-ssc.iucaa.in/.

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Author contributions A.B. contributed to the data acquisition, analysis, figures and writing. K.S. conceptualized the overall project, reduced the UVIT raw data with the L2 pipeline, and contributed to analysis and writing. B.E. contributed to the analysis and writing. R.G., F.C. and S.N.T. participated actively in the scientific discussion and interpretation throughout the project, and provided critical inputs to the manuscript.

Competing interests The authors declare no competing interests.

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Extended Data Fig. 1 | Imaging of BCD sample. Same as Fig. 1 (a,b,d,e) but for the rest of the BCDs in our sample (see ED Fig. 1 for the rest of the BCDs). Individual panel sizes are 15”x15”, except GS12–18”x18”. We include the XUV disk type, if qualified, for each BCD in the lower left corner of each panel. We find a total of 6 sources (orange boxes) having S/N ≥ 3 and without any HST counterpart outside the XUV region of the BCDs. Colour bar label is flux in counts per second.
Extended Data Fig. 2 | 1D Surface brightness profile fitting of BCD sample. Same as in Fig. 2 but for the rest of the BCDs in our sample (see ED Fig. 2 for the rest of the BCDs). In each panel, we include the XUV types and ΔL values for each BCD. All data points have 1σ error bars.
Extended Data Fig. 3 | Test for clump significance. 

**a.** Patch of sky of size 341 × 341 pixels devoid of bright and large sources in the GOODS South field. Red circles denote sources having S/N ≥ 3 and their number is 49. Of these, 13 are marked with black circles that do not have any HST counterpart. 

**b.** S/N histogram of sources detected in the patch shown in **a.** Panel **c, e** GS3 and GS6 with the same size as presented in Fig. 1. Cyan circles and boxes mark the SExtractor-detected sources. Sources having S/N < 3 are marked with cyan circles. Sources having S/N ≥ 3 and HST counterparts are marked with cyan dashed squares. The orange square has S/N ≥ 3 and no HST counterpart. Magenta circles mark noise dips below a flux value of zero. Panel **d, f** represent flux (measured within a fixed aperture of size 0.7" radius) histograms corresponding to panel **c, e.**
| BCD | z   | $M_{FUV}$ | $M_{Ks}$ | $\mu_0$, $FUV$ | $\mu_0$, $NUV$ | $r_{e, FUV}$ | $r_{e, NUV}$ | SFR     | FUV–NUV          |
|-----|-----|----------|----------|----------------|----------------|-------------|-------------|---------|------------------|
|     |     | mag      | arcsec$^{-2}$ | mag           | arcsec$^{-2}$ | kpc         | kpc         |         | mag              |
| GS1 | 0.13| -15.13   | 23.9±0.3  | 22.7±0.2      | 2.1±0.3       | 1.1±0.0     | 0.08±0.00   | -0.32±0.11 |
|     | -16.97| -       | 20.5±0.1  | -             | 1.0±0.0       |             |             |         |                  |
| GS2 | 0.24| -16.40   | 24.0±0.2  | 21.2±0.1      | 3.4±0.3       | 1.4±0.1     | 0.30±0.02   | 0.17±0.09 |
|     | -18.44| -       | 21.4±0.6  | 2.4±0.1       | 2.0±0.2       |             |             |         |                  |
| GS3 | 0.1 | -15.47   | 23.0±0.1  | 20.7±0.3      | 1.1±0.1       | 0.8±0.1     | 0.11±0.00   | 0.18±0.05 |
|     | -18.05| -       | 20.0±0.1  | 0.7±0.0       | 0.7±0.0       |             |             |         |                  |
| GS4 | 0.15| -15.57   | 23.7±0.2  | 22.2±0.8      | 1.8±0.2       | 1.4±0.3     | 0.13±0.01   | 0.25±0.08 |
|     | -18.81| -       | 20.9±0.9  | 1.0±0.1       | 1.1±0.0       |             |             |         |                  |
| GS5 | 0.13| -15.00   | 23.5±0.3  | 21.3±0.1      | 1.3±0.2       | 1.1±0.0     | 0.07±0.00   | 0.34±0.09 |
|     | -19.04| -       | 19.0±0.1  | 0.9±0.1       | 1.1±0.0       |             |             |         |                  |
| GS6 | 0.21| -15.87   | 24.6±0.2  | 21.7±0.3      | 3.4±0.3       | 1.4±0.1     | 0.18±0.01   | 0.04±0.11 |
|     | -18.48| -       | 21.3±0.3  | 1.5±0.1       | 2.1±0.1       |             |             |         |                  |
| GS7 | 0.23| -16.91   | 22.5±0.2  | 21.1±0.1      | 2.0±0.2       | 1.4±0.0     | 0.47±0.02   | 0.07±0.09 |
|     | -18.18| -       | 19.7±0.1  | 1.2±0.1       | 1.1±0.0       |             |             |         |                  |
| GS8 | 0.16| -18.30   | 23.96±0.31| 2.23±0.23     | 2.35±0.14     |             |             |         |                  |
|     | -19.70| -       | 19.97±0.07| 2.35±0.14     |             |             |             |         |                  |
| GS9 | 0.15| -17.07   | 24.43±0.55| 1.70±0.46     | 1.46±0.04     |             |             |         |                  |
|     | -18.03| -       | 22.18±0.08| 1.46±0.04     |             |             |             |         |                  |
| GS10| 0.19| -15.92   | 24.2±0.2  | 21.7±0.1      | 3.6±0.3       | 1.5±0.1     | 0.18±0.01   | 0.18±0.09 |
|     | -18.03| -       | 21.9±0.8  | 1.5±0.1       | 2.1±0.3       |             |             |         |                  |
| GS11| 0.22| -17.96   | 21.7±0.1  | 21.1±0.8      | 2.4±0.1       | 1.5±0.2     | 1.24±0.03   | 0.31±0.04 |
|     | -19.66| -       | 21.7±0.8  | 1.5±0.0       | 2.0±0.0       |             |             |         |                  |
| GS12| 0.08| -15.53   | 22.5±0.1  | 21.6±0.1      | 1.1±0.1       | 1.3±0.0     | 0.11±0.00   | 0.19±0.04 |
|     | -18.43| -       | 20.2±0.0  | 0.7±0.0       | 0.8±0.0       |             |             |         |                  |
| GS13| 0.22| -16.19   | 24.0±0.2  | 20.8±0.2      | 2.8±0.3       | 1.0±0.1     | 0.24±0.01   | 0.00±0.09 |
|     | -18.13| -       | 19.9±0.2  | 1.2±0.1       | 1.1±0.0       |             |             |         |                  |
| GS14| 0.1 | -14.99   | 23.8±0.2  | 23.1±0.3      | 1.5±0.1       | 2.0±0.2     | 0.07±0.00   | 0.68±0.07 |
|     | -18.62| -       | 18.9±0.1  | 0.7±0.0       | 1.7±0.1       |             |             |         |                  |

Column 1: The galaxy IDs. Column 2: The redshifts. Column 3: The $K_s$ and $FUV$ band absolute magnitudes. Column 4 and 5: The central surface-brightness values in all four bands - $FUV$ (F154W), $NUV$ (N242W), optical (F435W) and NIR (F160W), corrected for redshift dimming and foreground extinction. Column 6 and 7: The scale lengths from $FUV$ to $NIR$; for comparison purposes, if a truncated exponential is used, the outer scale length is given here. Column 8: The measured total SFRs from the $FUV$ light assuming solar metallicity (these rates are lower by 10% at $0.4Z_\odot$). Column 9: The measured $FUV$ – $NUV$ colours. All quoted uncertainties are $1\sigma$. 

Column 1: The galaxy IDs. Column 2: The redshifts. Column 3: The $K_s$ and $FUV$ band absolute magnitudes. Column 4 and 5: The central surface-brightness values in all four bands - $FUV$ (F154W), $NUV$ (N242W), optical (F435W) and NIR (F160W), corrected for redshift dimming and foreground extinction. Column 6 and 7: The scale lengths from $FUV$ to $NIR$; for comparison purposes, if a truncated exponential is used, the outer scale length is given here. Column 8: The measured total SFRs from the $FUV$ light assuming solar metallicity (these rates are lower by 10% at $0.4Z_\odot$). Column 9: The measured $FUV$ – $NUV$ colours. All quoted uncertainties are $1\sigma$. 

Extended Data Table 1 | Photometric and structural parameters of the BCDs
Extended Data Table 2 | Clump detection parameters

| SExtractor parameters |  |
|-----------------------|------------------|
| DETECT MINAREA        | 5                |
| DETECT THRESH         | 1.5, 2, 2.5      |
| FILTER NAME           | gauss 1.5 3x3.conv, gauss 2.0 3x3.conv |
| DEBLEND NTHRESH       | 64               |
| DEBLEND MINCONT       | 1×10⁻⁶           |
| CLEAN PARAM           | 10               |
| BACK TYPE             | MANUAL (locally obtained background as described above) |

| Noise Chisel parameters | Detection | Segmentation |
|-------------------------|-----------|--------------|
| erode                   | 1         | tilesize     |
| erodengb                | 8         | minskyfrac   |
| tilesize                | 40,40     | kernel       |
| interpnumg              | 4         | interpnumg   |
| minskyfrac              | 0.1       | snquant      |
| meannedqdiff            | 0.05      | gthresh      |
| detgrowquant            | 0.9       | snminarea    |
| noerodequant            | 0.9       | objbordersn  |
| dthresh                 | 0.1       |              |
| snminarea               | 3         |              |
| sigmaclip               | 3.50      |              |
| qthresh                 | 0.8       |              |
| snthresh                | 3.0       |              |

The configuration for SExtractor and Noise Chisel used to detect the ‘clumps’. A detection threshold of 1.5σ and gauss 1.5 pixel FWHM filter (boldface) has been used in our final calculations.
Extended Data Table 3 | S/N of SExtractor-detected sources around GS3 and GS6

|       | GS3   |       | GS6   |       |
|-------|-------|-------|-------|-------|
|       | x     | y     | S/N   | x     | y     | S/N   |
| -3.87 | 15.86 | 3.24  | *     | 7.81  | 11.11 | 3.3   |
| -13.55| -12.35| 2.27  | -17.33| 8.64  | 3.2   | *     |
| -4.19 | -16.88| 2.60  | -11.14| 6.64  | 3.0   | *     |
| -10.45| 9.46  | 2.30  | 12.57 | 1.91  | 2.4   |       |
| 11.17 | -12.80| 2.34  | 9.75  | -3.00 | 2.3   |       |
| -8.36 | 12.54 | 1.86  | 9.36  | -6.63 | 2.3   |       |
| -14.10| -7.29 | 2.25  | 11.48 | -10.30| 2.4   |       |
|       | -9.17 | 0.11  | 2.8   |       |       |       |
|       | 8.80  | 8.26  | 2.1   |       |       |       |

The coordinate columns represent relative positions with respect to the galaxy’s centre. All the above tabulated sources are shown in Extended Data Figure 3 c,e with outlines. Those with * have S/N ≥ 3 with an HST counterpart and are marked with cyan boxes, and the one with # also has S/N ≥ 3 but has no HST counterpart and is marked with an orange box.
## Extended Data Table 4 | Full FUV-clump analysis in our sample of BCDs

| Clump ID | S/N  | MAG mag | $A_{FUV}$ mag | SFRD$_{clump}$ $\log M_\odot \, yr^{-1}$kpc$^{-2}$ | $M_*_{clump}$ $M_\odot$ | $T_{\text{inspirial}}$ Gyr | $\dot{M}_{\text{clump}}$ $M_\odot \, Gyr^{-1}$ | $\tau_{\text{clump}}$ Gyr | $\tau_{\text{cc}}$ Gyr |
|---------|------|---------|---------------|---------------------------------------------|-------------------------|----------------------------|---------------------------------|----------------|----------------|
| C1A     | 3.3  | 26.18   | 1.21          | $7.63 \times 10^{-1}$                       | 6.42                    | 12.6                      | 0.21 $\times 10^3$             | 12.5           | 0.9           |
| # C3A   | 4.3  | 25.30   | 2.00          | $4.98 \times 10^{-4}$                       | 6.84                    | 5.6                       | 2.3 $\times 10^4$             | 1.0            |               |
| # C3B   | 3.7  | 25.46   | 2.00          | $4.82 \times 10^{-4}$                       | 6.77                    | 6.0                       | $2.3 \times 10^6$             | 5.5            | 1.9           |
| * C6A   | 3.2  | 26.84   | 0.86          | $1.16 \times 10^{-3}$                       | 6.49                    | 7.5                       | 0.43 $\times 10^9$             | 7.2            | 1.5           |
| * C10A  | 3.2  | 26.91   | 1.21          | $1.31 \times 10^{-3}$                       | 6.50                    | 8.3                       | 0.40 $\times 10^9$             | 7.9            | 1.8           |
| # C12A  | 3.2  | 26.40   | 1.30          | $5.44 \times 10^{-4}$                       | 5.90                    | 11.8                      | 1.1                            | 1.1            |               |
| # C12B  | 3.4  | 26.53   | 1.30          | $6.90 \times 10^{-4}$                       | 5.85                    | 54.8                      | 0.6                            |               |               |
| # C12C  | 4.0  | 26.28   | 1.30          | $9.42 \times 10^{-4}$                       | 5.95                    | 26.5                      | 0.5                            |               |               |
| # C12D  | 3.2  | 26.67   | 1.30          | $1.30 \times 10^{-4}$                       | 5.80                    | 72.0                      | 0.13 $\times 10^6$             | 23.2           | 0.4           |
| * C13A  | 3.0  | 27.04   | 1.63          | $2.93 \times 10^{-3}$                       | 6.76                    | 18.6                      | 0.9                            |               |               |
| * C13B  | 3.4  | 26.64   | 1.63          | $7.89 \times 10^{-3}$                       | 6.92                    | 13.1                      | 0.96 $\times 10^3$             | 14.6           | 0.7           |
| # C14A  | 3.8  | 26.26   | 2.95          | $9.49 \times 10^{-4}$                       | 6.83                    | 2.4                       | $3.0 \times 10^3$              | 2.2            | 1.8           |

**Column 1:** Clump IDs identified by SExtractor (#), Noise Chisel (*) and visual inspection (*).  
**Column 2:** Measured S/N of the clumps (in SExtractor Kron-like apertures).  
**Column 3:** Clump magnitudes using SExtractor within Kron-like apertures (using detected pixel flux in the case of Noise Chisel and aperture fluxes in the case of visually identified clumps).  
**Column 4:** Internal dust extinction estimated using the UV slope ($\beta$).  
**Column 5:** Clump star-formation rate surface density.  
**Column 6:** Clump stellar mass.  
**Column 7:** Inspirial time of the clumps.  
**Column 8:** Net clump accretion rate.  
**Column 9:** Total clump accretion timescale.  
**Column 10:** Clump–clump collision timescale.
Extended Data Table 5 | Various metrics derived for the XUV disks of the BCDs

| BCD | \( M_{\text{*, total}} \) | \( M_{\text{*, young}} \) | FUV-K | \( \Delta L_x \) | XUV | \( \Delta L_x \) | FUV-NUV | \( SF RD_{XUV} \) | \( \tau_{XUV} \) | \( \tau_{SF} \) |
|-----|-----------------|-----------------|-------|-----------------|-----|-----------------|-------|-----------------|-----|-----|
| GS1 | 8.13            | 7.4             | 0.08  | 17.6            | T1,T2 | 12.3±5.7       | -1.78±0.29 | 1.3±0.49 \times 10^{-4} | 14.6 | 1.7 |
| GS2 | 8.73            | 8.12            | -0.03 | 13.4            | T2   | 34.5±5.6       | 0.00±0.18  | 2.4±0.49 \times 10^{-4} | -   | 1.8 |
| GS3 | 8.57            | 7.83            | 1.25  | 16.9            | T1,T2 | 3.2±0.1        | -0.37±0.21 | 1.8±0.43 \times 10^{-5} | 6.6  | 3.4 |
| GS4 | 9.02            | 7.9             | 1.53  | 15.0            | T2   | 11.6±3.5       | -0.42±0.33 | 8.7±2.30 \times 10^{-5} | -   | 8.1 |
| GS5 | 8.92            | 7.87            | 3.24  | 6.5             | –    | 0.1±0.1        | -0.92±1.45 | 1.1±8.58 \times 10^{-5} | -   | 11.9 |
| GS6 | 8.65            | 7.6             | 0.56  | 7.2             | T1,T2 | 33.6±6.7       | -0.44±0.24 | 2.3±0.48 \times 10^{-5} | 31.3 | 2.5 |
| GS7 | 8.70            | 8.43            | -0.87 | 34.1            | T2   | 1.8±1.1        | -0.29±0.22 | 1.8±0.83 \times 10^{-5} | -   | 1.1 |
| GS10| 8.48            | 7.74            | -0.41 | 10.3            | T1,T2 | 39.2±5.4       | 0.11±0.20  | 3.9±0.64 \times 10^{-4} | 54.9 | 1.7 |
| GS11| 8.99            | 8.69            | -0.01 | 22.2            | T2   | 3.0±0.1        | 0.14±0.13  | 6.4±1.10 \times 10^{-5} | -   | 0.8 |
| GS12| 8.66            | 7.57            | 3.68  | 6.1             | T1   | 0.1±0.0        | -0.56±0.20 | 5.8±0.13 \times 10^{-6} | 26.3 | 4.2 |
| GS13| 8.59            | 8.07            | -0.61 | 20.1            | T1,T2 | 21.9±6.4       | -1.15±0.28 | 2.7±0.74 \times 10^{-4} | 26.6 | 1.6 |
| GS14| 8.73            | 8.02            | 2.17  | 14.0            | T1,T2 | 4.2±1.4        | 0.20±0.29  | 2.4±0.63 \times 10^{-5} | 3.7  | 7.7 |

**Column 2**: Total stellar mass of the galaxy. **Column 3**: Young stellar mass of the galaxy. **Column 4**: FUV-K, colour and fraction of LSB area measured to check for Type 2 XUV disk. **Column 6**: Type of XUV disk as per Thilker’s criteria, Type-1 (T1) and Type-2 (T2). **Column 7**: FUV fraction in XUV region. **Column 8**: Observed FUV – NUV colour in the XUV region of the BCDs. **Column 9**: Intrinsic, profile-integrated SFRD values in the XUV region. **Column 10**: XUV disk evolution timescale. **Column 11**: Galaxy star-formation time. The quoted uncertainties are 1σ.
### Extended Data Table 6 | XUV ages based on observed FUV – NUV colour and stellar population synthesis

| Column 2, 3: | Column 4, 5: |
|-------------|-------------|

| BCD | SF burst $Z_\odot$ | continuous SF $Z_\odot$ | SF burst $0.4\ Z_\odot$ | continuous SF $0.4\ Z_\odot$ |
|------|------------------|----------------------|------------------|---------------------|
| GS1  | -                | -                    | -                | -                   |
| GS2  | 52.2             | 748.2                | 72.0             | 769.8               |
| GS3  | 7.2              | 106.2                | 19.1             | 196.8               |
| GS4  | 6.7              | 73.6                 | 17.4             | 155.3               |
| GS5  | -                | -                    | -                | -                   |
| GS6  | 12.3             | 306.3                | 34.3             | 472.4               |
| GS7  | 8.1              | 175.2                | 24.3             | 321                 |
| GS10 | 81.9             | >1000                | 98.2             | >1000               |
| GS11 | 72.6             | >1000                | 93.6             | ~1000               |
| GS12 | 7.0              | 99.5                 | 18.8             | 190.0               |
| GS13 | 1.8              | 2.6                  | 3.0              | 4.7                 |
| GS14 | 12.3             | 327.5                | 37.5             | 482.1               |

**Column 2, 3:** Age estimates using an instantaneous burst and CSFH with $Z_\odot$.  
**Column 4, 5:** Age estimates using a SF burst and continuous SF with $0.4\ Z_\odot$. We ignore GS1 due to extreme blue colour and GS5 due to being a marginal case.