CHAPTER 6

Conclusions and Future Outlook

"There is a theory which states that if ever anyone discovers exactly what the Universe is for and why it is here, it will instantly disappear and be replaced by something even more bizarre and inexplicable. There is another theory which states that this has already happened"
– Hitchhiker's Guide To the Galaxy

In the work presented in this Ph.D. thesis, we have studied star-forming dwarf galaxies called Blue Compact Dwarf galaxies (BCDs). These represent an important class of dwarf galaxies that are often believed to be connecting links in the evolutionary track of the diverse dwarf galaxy population. At the same time, their physical and chemical characteristics are similar to galaxies in the early Universe. Thus understanding their assembly and evolution is crucial to complete the picture of galaxy assembly and evolution. The wide field, deep and high-resolution UV observations with *AstroSat-UVIT*[7], combined with optical to near-infrared (NIR) archival observations, have allowed us to uncover the spatially extended star formation in distant BCDs for the first time. Through this work, we gain insight into the assembly process of BCDs via the migration of massive outer star complexes or clumps that likely build up the central concentration of stars seen in today's BCDs. At the same, we get an idea of how the old, underlying stellar host of BCDs assemble over their lifetime. In the following, we present the important findings of the thesis in each chapter.

6.1 Key results: Multi-wavelength morphologies

In **Chapter 2**, we present multi-wavelength 1D surface photometry (FUV to NIR) and modelling for a sample of 14 BCDs in the *GOODS-South* field ($0.1 \leq z \leq 0.24$). We find that:

- BCDs at intermediate redshifts extend spatially out to twice or more (based on S/N = 3 criteria) in the FUV as compared to their optical counterparts.
- Modelling of the 1D surface brightness profiles reveals that the PSF-corrected intrinsic FUV scale-lengths for 10 BCDs are larger than their optical and NIR counterparts.
- The fraction of FUV light in the XUV region of the BCDs with larger FUV scale-lengths; defined by the area enclosed within FUV and optical extents, is greater than zero.

Above findings establish the existence of XUV disks in distant BCDs which has been confirmed using existing criteria. This implies a significant fraction of young stars at the far outskirts and an ongoing assembly of these BCDs via cosmic accretion.

6.2 Key results: Outer FUV clump analysis

In **Chapter 3**, we present the robust detection of massive outer clumps ($\sim 10^6$ $M_\odot$) beyond the optical boundaries of distant XUV host BCDs. We find that:

- We identify a total of 12 FUV clumps (S/N>3) beyond the optical boundaries of 7 BCDs. Based on FUV fluxes, the clump masses ranged from ~ 0.6 - 8×10^6 $M_\odot$.
- Due to dynamical friction acting on the clumps, they will migrate radially inwards into the central region of the galaxies. In a dark matter halo only setup, we find that the average clump accretion time is $\sim$5.5 Gyr and the average rate is $\sim 1.1 \times 10^6$ $M_\odot$ Gyr^{-1}.

- The differential shear in outer disks would bring the clumps together to form larger ones over timescales approximately their orbit time. Such massive clumps will migrate inwards even faster.

- The torques from the clumps will drive the young outer disks inwards over timescale ≥Hubble time for most of the BCDs.

Massive outer clumps in XUV disks of BCDs produce sufficient torques to drive themselves or an equivalent mass towards the inner regions of the disk that builds up their central stellar concentration. This is similar to the formation of bulges and spheroids in high redshift galaxies which also facilitates gas inflow from the environment. Young outer disks in BCDs will likely fade away into extended old stellar disks, as seen in nearby BCDs, because clump torques are not sufficient to drive the whole outer disk inwards within a Hubble time.

6.3 Key results: UV colours and outer SFRD

In **Chapter 4**, we present a case for the UV-optical-NIR colours and low-density star formation in distant BCDs. We find that:

- The SFRDs within their optical boundaries are similar to those of local dwarf galaxies. In the XUV regions, the values reach as low as a few factors of 10^{-6} $M_{\odot}yr^{-1}kpc^{-2}$. Such low SFRDs would translate to gas densities less than 1 $M_{\odot}pc^{-2}$.

- The rest-frame optical-NIR and UV-NIR colours are bluer as compared to those of local BCDs.

- The stellar ages in the XUV region mostly come out to be a few tens - few hundred Myr.

The outer SFRDs mark sites of paramount importance to the understanding of star formation in extreme conditions that prevailed when the first stars formed. Blue colours of BCDs at intermediate redshifts indicates enhanced star formation compared to the local ones.

The star formation within the optical boundaries is similar to those of local dwarf galaxies.

6.4 XUV disks in local BCDs and their mass assembly

In **Chapter 5** we present our results from the multi-wavelength study of nearby BCDs. We find that:

- The BCDs are mostly disky in the optical and while most of the BCDs are similar in sizes in terms of their half-light radii (R_{eff}), a few of them deviate from this behaviour in the FUV. The BCDs are also smaller in the FUV in terms of their S/N = 3 extents.
- We find that for 6 BCDs, the overall gradient, ∇(FUV-r) is negative - meaning younger stars at larger radii.
- The average radial sSFR profiles show a flat gradient. However, there are individual cases on either side. We however do not see any dependence of this behaviour on the stellar masses of the BCDs.
- The FUV light fraction in the outer LSB region, defined by the region within 80% r-band contour and expected μ_{FUV}=27.25 mag arcsec^{-2}, reveals that 6 BCDs have a higher percentage as compared to that in the r-band. Incidentally, 4 of these BCDs also have larger outer disk FUV scale-lengths.
- The FUV light fraction compared with the UV-optical scale-length ratios show that 7 BCDs have FUV light fraction >0 and scale-length ratio >1.
- We have at least 4-6 BCDs with larger FUV scale-lengths and blue FUV-r colours in the outer regions.

Local BCDs also host XUV disks similar to distant ones albeit with a lower incidence ($\gtrsim$16%) as observed with the current sample. This fraction is similar to what is seen from previous studies in the nearby Universe. The nearby BCD population typically show a self-similar

mass assembly mode as seen in previous studies for high redshift low-mass galaxies. We of course find outliers in our study. The physical basis for the observed flattening of sSFR profiles as well as the assembly mode in low-mass galaxies still remain elusive. The study of accurate spatially resolved star formation histories and kinematics in the future will likely provide clues to solving this puzzle in low-mass galaxy assembly.

6.5 Future Outlook

We see from our study in this thesis that local and intermediate redshift BCDs host XUV disks. This phenomenon is most likely associated with cosmic gas accretion which in turn is associated with an inside-out mass-assembly of the galactic disk. Observations of the general population of dwarf galaxies show an outside-in assembly. Whether this observation is intrinsic in nature for low-mass galaxies and what different factors play a significant role in it is not yet clear. We plan to address this puzzle in the near future as follows:

- We plan to construct a systematic and larger sample of dwarf galaxy population in general, containing early as well as late types, to address the diversity of observed properties. We will utilise our deep *UVIT* observations of the *GOODS* fields in conjunction with existing high quality *HST* data to understand the mass assembly of these galaxies. The *UVIT* will provide better resolution in the rest frame FUV in the intermediate redshift regime for a wider field. In addition we hope to utilise observations from IR observatories including *JWST* to further constrain the star formation histories of the galaxies.

- The work presented in this thesis is lacking in the domain of spectroscopy. We plan to utilise publicly available spectroscopic information from existing state-of-the-art observatories like *HST* and *JWST* and instruments like *MUSE* and *VIMOS* to name a few to understand the distribution of metals in low mass galaxies and how it influences their global properties. In addition to already available spectroscopic surveys like 3DHST, VANDELS and MUSE-HUDF, new survey data like JADES, CLEAR, HDHα are being released for the public now. These will in turn allow us to probe the stellar as well as gas kinematics and energetics arising due to star formation activity.

- In our work, we haven't explored the influence of black holes in the observed properties of the star-forming dwarf galaxies. Recent studies have shown the existence of active nuclei in nearby dwarf galaxies as well[444, 445]. As dwarf galaxies are characterised by their shallow potential wells, black hole activity should have played a pivotal role. We plan to explore the contribution of galactic nuclei in shaping their overall mass assembly.

In addition to the above, the exploration of dwarf galaxies in the future is very promising with upcoming mega projects such as LSST at Rubin Observatory, MICADO on Extremely Large Telescope (ELT), Thirty Metre Telescope (TMT), Roman Space Telescope (WFIRST), Drangonfly Wide Field Survey, Square Kilometre Array (SKA), Giant Magellan Telescope (GMT) to name a few. These projects will supply a plethora of high-quality observations that will favour the detection and study of fainter and smaller galaxies in great detail for a few decades to come. A better understanding of the galaxy formation and evolution in the low mass regime will further help complete the picture of galaxy evolution over cosmic time.