Central star formation in I Zw 81 : A massive S0 galaxy in the Bootes Void

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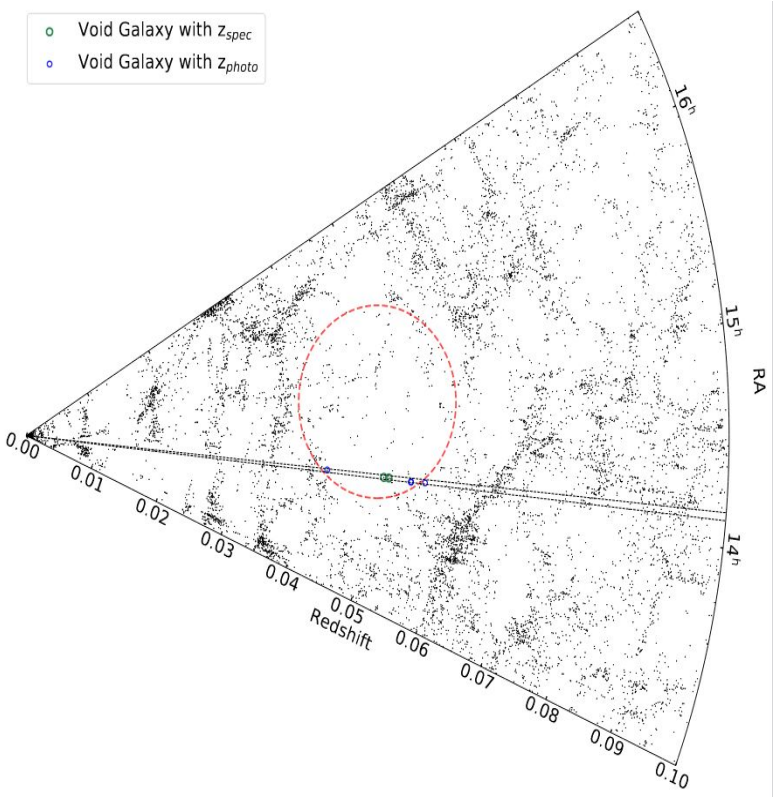
UVIT Survey of Bootes Void

- A survey of a small section of the Bootes void (615 sq arcmin) was conducted using F154W and N242W filters of UVIT.
- We performed source classification of extracted sources using CLASS STAR parameter and UV-optical color-color diagrams (Bianchi 2007).
- We procured spectroscopic redshift from SDSS archive (8 galaxies), and calculated the photometric redshifts of sources using EAZY (Brammer 2008) for the remaining extended sources (159 galaxies) to identify void galaxies in the sample.
- We detect six void galaxies in the FoV.



Results of UVIT Observation of Bootes Void

- We detected a total of six void galaxies having FUV observation. Of these, three are new detections within the area of UVIT FoV.

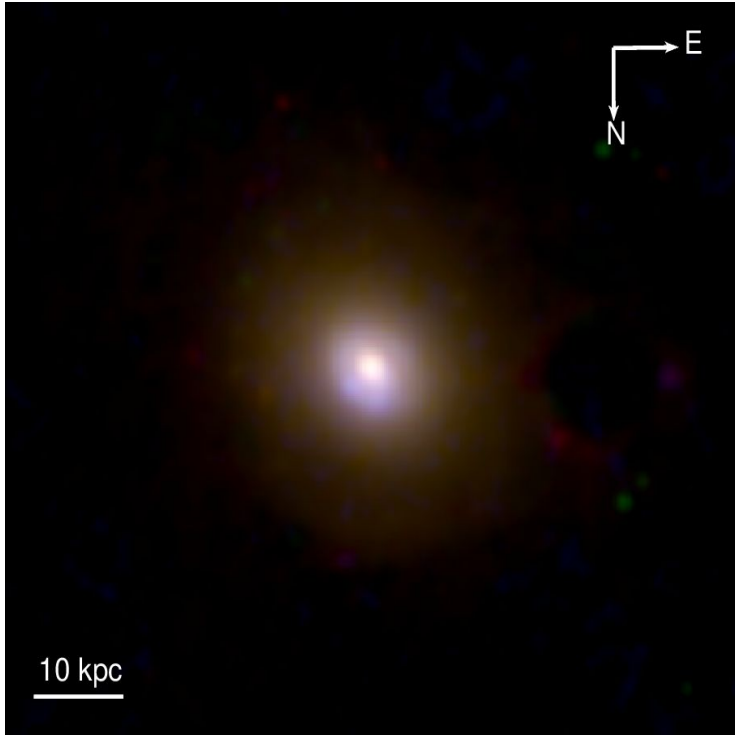
- The UV and optical color-color and color-magnitude diagram showed that our void galaxies are bluer in color. They possess disc-like morphology with spiral features in some cases. The most of our void galaxies have optical and UV luminosities less than L_* galaxies.

- The median SFR_{FUV} for the reported void galaxy sample is 3.96 $M_\odot$ yr^{-1}. We find that most of the FUV SFRs are comparable to normal spiral galaxies present in the different environments. We find weak effect of the environment on SFRs in these galaxies. The work is published in **Pandey, Saha and Pradhan ApJ 2021**.

- **I Zw 81** was identified as the most massive galaxy with strong UV emission, detected in isolated environment.

I Zw 81 (z=0.0518)

- RA: $14^h08^m13.59^s$ Dec: $48^d51^m44.74^s$
- Stellar mass (M_*) : 7.8 X 10^{10} $M_\odot$
- M_r = -22.1 mag, NUV-r = 3.46 mag (Pandey et al. 2021)
- Blue and massive early-type galaxies (similar to I Zw 81) are thought to be major-merger remnants (Kannapan et al. 2009). **We investigate whether this galaxy has undergone a similar evolution scenario.**
- **We have performed the detailed structural analysis and star formation. We use GALFIT to model the light profile and CIGALE for SED fitting.**



False color image of I Zw 81. NUV (blue), CFHT g (green) and CFHT r (red).

Structural Analysis

We use GALFIT on deep CFHT g- and r-band data for 2D structural analysis of the galaxy. The analytical functions used for modelling the individual components are: **(PSF, Sersic, tow expdisk, and truncated expo function)**

1. **PSF function** for the nuclear component
2. **Sersic function** for the bar:

$$\Sigma(r) = \Sigma_e \exp\left(-\kappa\left[\left(\frac{r}{r_e}\right)^{\frac{1}{n}} - 1\right]\right)$$

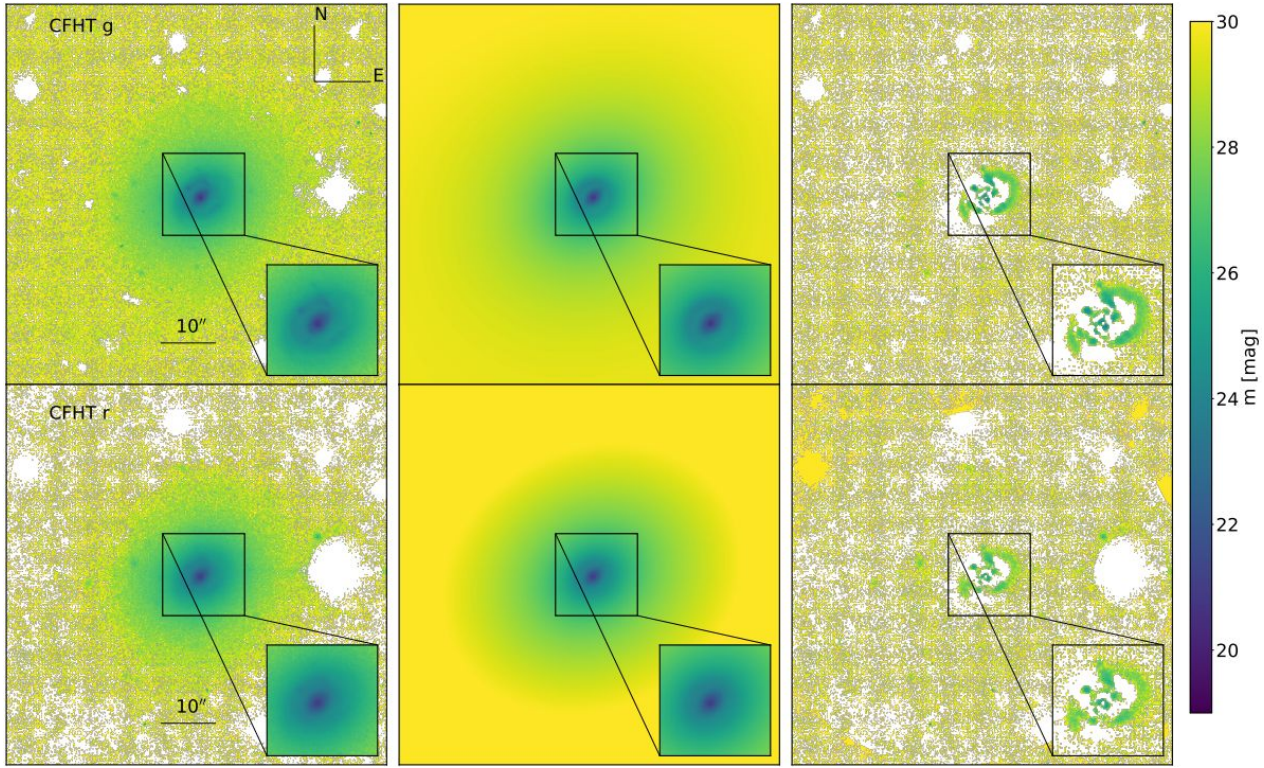
3. **Exponential disk function** for stellar disks:

$$\Sigma(r) = \Sigma_0 \exp\left(-\frac{r}{r_s}\right)$$

4. **Truncated exponential function** for stellar ring:

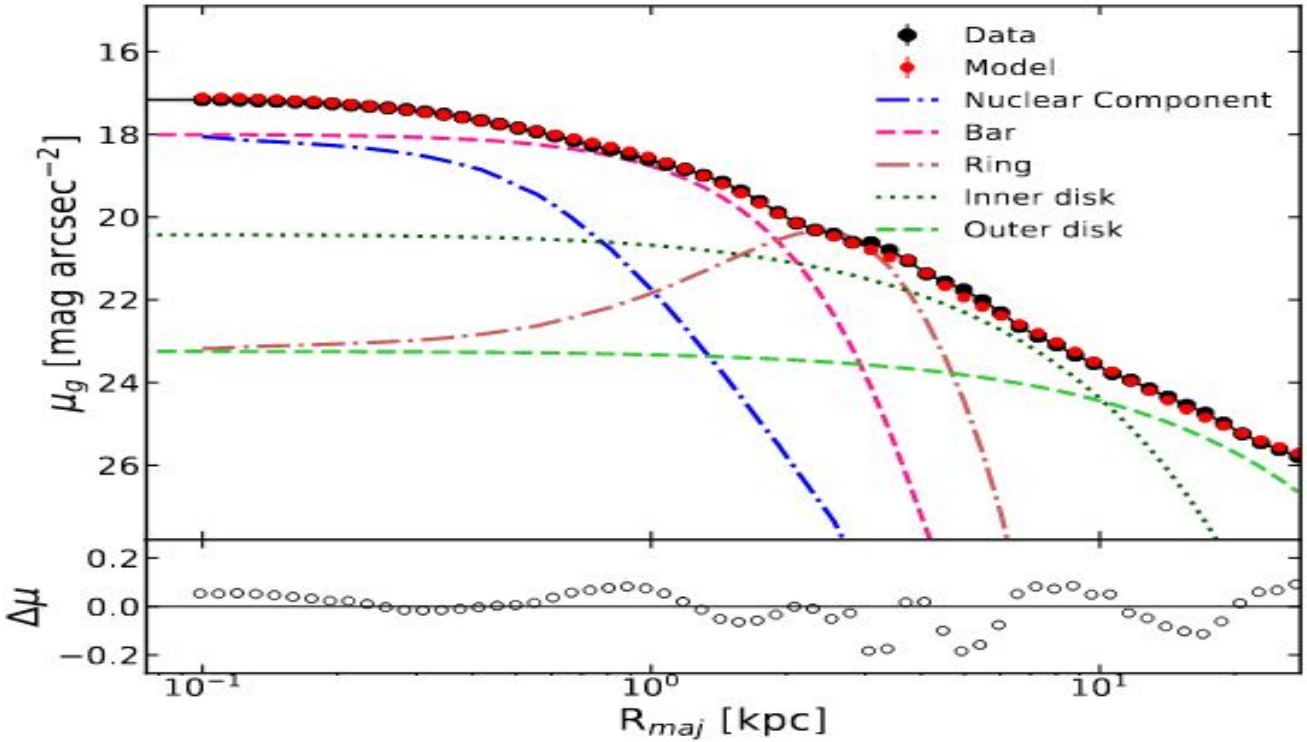
$$P(x, y) = \tanh\left(x, y; x_0, y_0, r_{break}, \Delta r_{soft}, q, \theta_{PA}\right)$$

GALFIT Output



Left to right: CFHT image of the galaxy, GALFIT model and corresponding residue.

Isophotal surface brightness profile of I Zw 81



I Zw 81 is classified as a lenticular galaxy.

Interpretation of Model Parameters

- The galaxy hosts a **compact nucleus**
- The galaxy hosts a **flat and strong bar** (n = 0.57, Bar/Total light ratio = 0.23)
- **High surface brightness inner disk** ($\mu_B > 22.5$ mag/arcsec^2)
- **Low surface brightness outer disk** ($\mu_B < 22.5$ mag/arcsec^2)
- Radially asymmetric **ring** at the co-rotation radius of the bar

Table 1. GALFIT 2D best fit results for the g- and r-band.

Components	Bulge	Bar			Inner disk		Outer disk	
Galfit funcion	PSF	Sersic			expdisk		expdisk	
Band	$(m_0)_{bulge}$ (mag)	$(m_0)_{bar}$ (mag)	$(r_e)_{bar}$ (arcsec)	n_{bar}	$(m_0)_{ID}$ (mag)	$(r_s)_{ID}$ (arcsec)	$(m_0)_{OD}$ (mag)	$(r_s)_{OD}$ (arcsec)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
g	18.52	16.90	0.92	0.57	16.36	2.04	16.53	7.35
r	17.84	16.42	0.92	0.65	15.74	1.93	15.80	7.57
Light fraction in g-band	0.06	0.23			0.38		0.32	

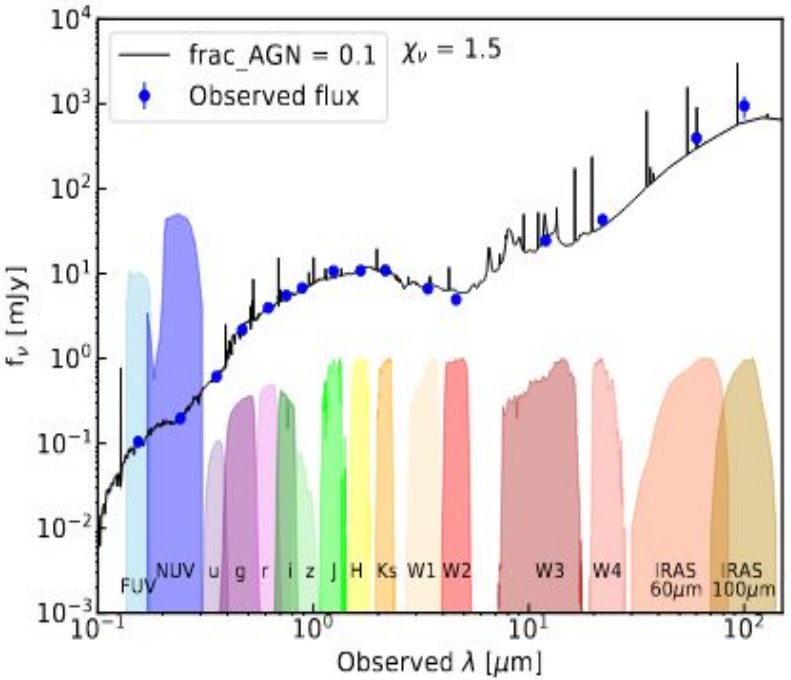
Spectral energy distribution (SED)

We use CIGALE for SED fitting (UV to far-IR) of I Zw 81.

- The galaxy is star-forming with log(sSRF) ~ -10 yr^{-1} . Stellar mass (M_*) : 7.8 X 10^{10} $M_\odot$

- Based on the value of frac_AGN parameter =0.1, I Zw 81 hosts a low-luminosity AGN.

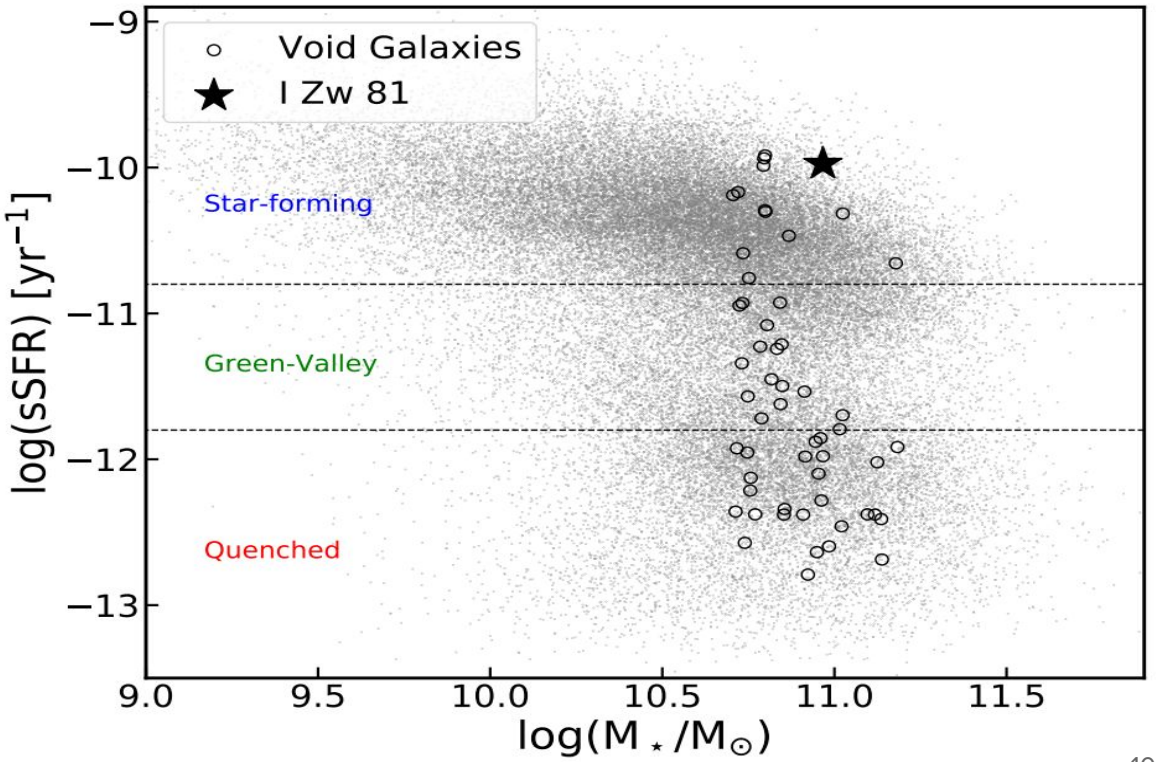
- The stellar population age ~ 8 Gyr. We find that the galaxy hosts younger stellar population than bright S0 galaxies present groups and clusters (Barway et al. 2013).



Best-fit SED output of I Zw 81 produced by CIGALE (Boquien et al. 2019).

sSFR vs M_* distribution for massive void galaxies

- The background galaxies are from Salim et al. (2016)
- The void galaxies are from Pan et al. (2012)
- sSFR and $M_\star$ values are from Liske et al. (2015)
- sSFR of I Zw 81 lie half a dex above the star-forming main sequence.



Star Formation Analysis

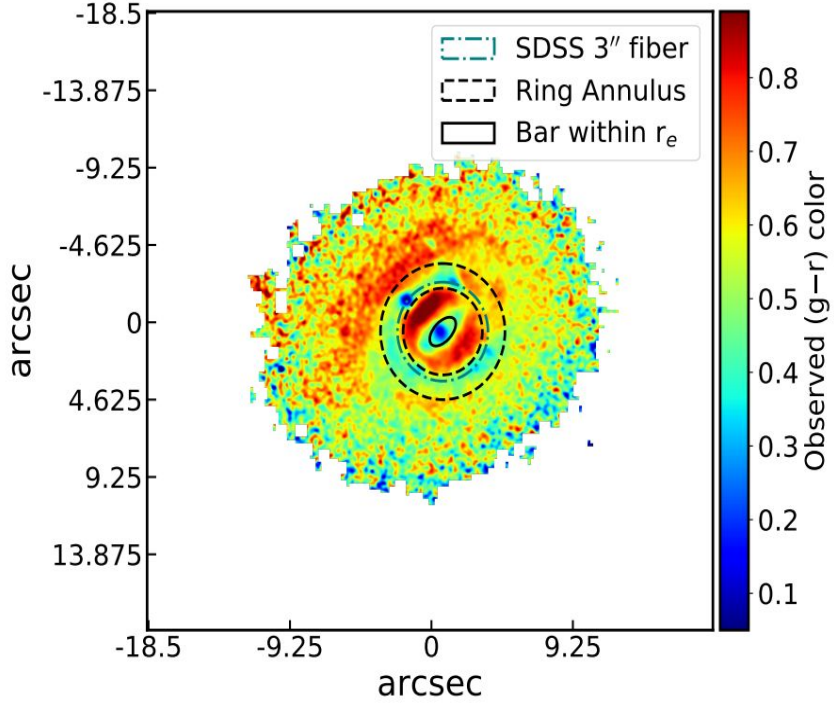
We found the optical colors of the individual components of the galaxy using GALFIT:

$(g\text{-}r)_{bar}$= 0.40 mag, $(g\text{-}r)_{ID}$= 0.58 mag, $(g\text{-}r)_{OD}$= 0.70 mag

Following intriguing features observed in the galaxy:

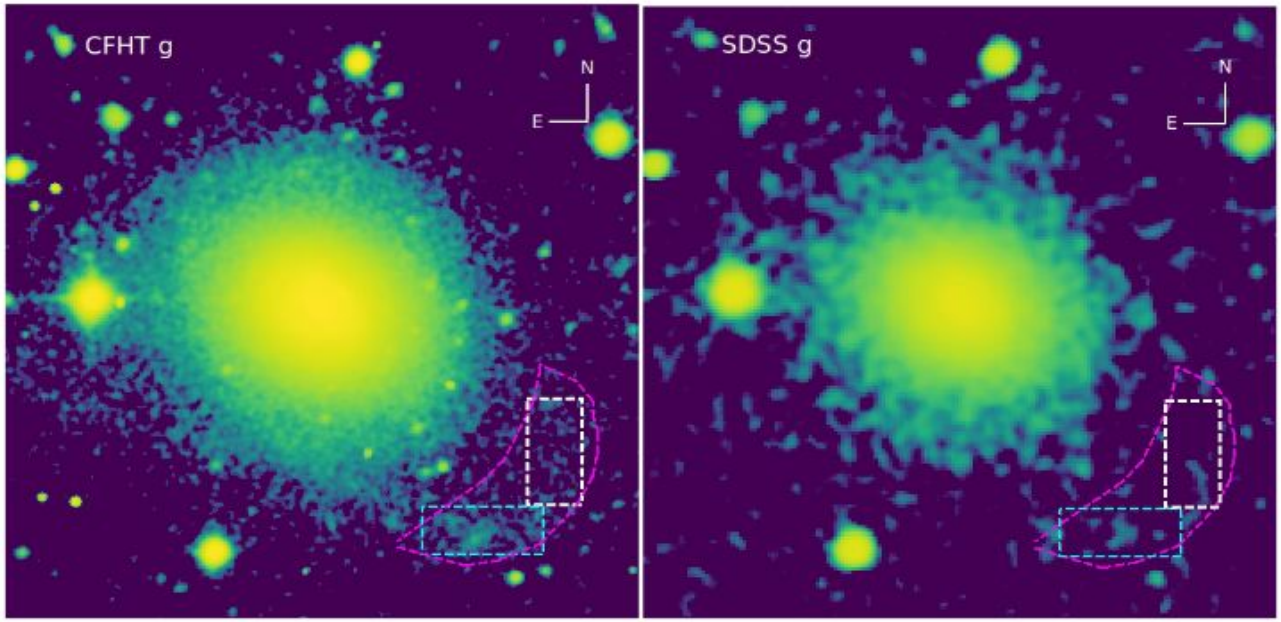
- Disk is inclining towards redder side of color-scale.
- Clumpy star-forming ring ($(g\text{-}r)_{ring}$= 0.45 mag)
- Central star formation in an old-stellar population-dominated massive galaxy

We discuss the impact of various external and internal mechanisms on the ongoing star-formation.



Optical color map of the galaxy combining CFHT-g and -r bands.

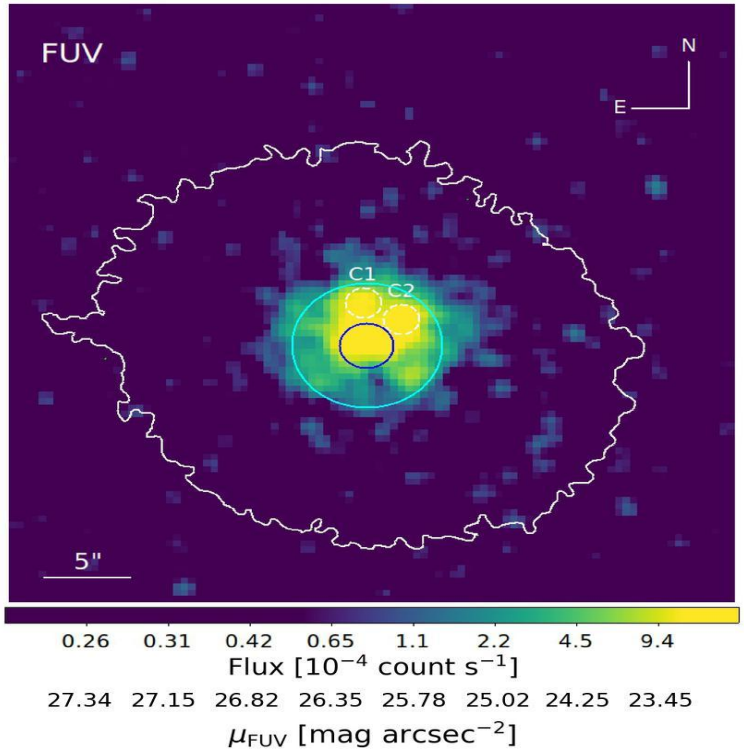
Sign of minor-merger interaction



CFHT g-band vs. SDSS g-band observation

We find a tidal tail-like feature signifying the possibility of minor merger interactions in CFHT observation marked by a crescent shape segment, and horizontal and vertical boxes. SDSS observation do not reveal any such features.

Star Formation:UVIT observation of I Zw 81



UVIT FUV filter image of the galaxy. The cyan colored circle denotes the outer radius of the ring.

- The resultant internal extinction corrected FUV SFRs for clumps C1 and C2 are 0.13 $M_{\odot}yr^{-1}$ and 0.23 $M_{\odot}yr^{-1}$, respectively.
- From the UV emission and optical colors we claim that the entire central region (4 − 5 kpc) enclosing the bar is star-forming.
- It is reported that only gas-rich late-type galaxies exhibit similar star formation along the bar (Diaz-Garcıa et al. 2020) as shown by the galaxy.
- The detection of FUV emission in the center along the bar and a quenched outer disk is likely a result of bar-quenching of disks generally observed in S0 galaxies.

Summary

- Sparse environment of the void impacts the ongoing star formation in the galaxy. I Zw 81 is able to conserve its gas supply for a longer period of time due to lack of external perturbations.
- Star formation enhancement from minor-merger interaction is suspected.
- Low luminosity AGN is unable to quench the star formation in the galaxy.
- Central star formation is produced due to the action of bar. The bar tunnels gas from outskirts of the galaxy leaving a red outer disk.
- The work is presently under review in **ApJ (Pandey et al. 2022).**

Thank You