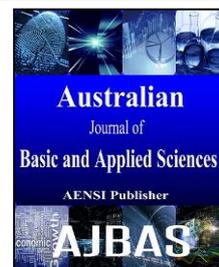




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Photometric Viewpoint to the Structure of Spiral Galaxy NGC 3351 with *griz*-Filters

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ABSTRACT

The term 'photometry' refers to the accurate determination of the apparent brightness of an astronomical object. Until roughly 1980, nearly all astronomical photometry was done by means of analog measurements of photographic plates, or by analog or digital (photon-counting) techniques with photomultipliers. These photometers produced brightness readings which were typically displayed on dials, plotted on strip charts or printed on strips of paper, and it was often quite practical to analyse these raw data with pencil, paper and a slide rule or table of logarithms. However, during the late 1970s electronic area detectors for astronomy became more advanced: first, for a brief period, television-type cameras were employed, but these were soon supplanted by CHARGE-COUPLED DEVICES (CCDs), which remain overwhelmingly the detector of choice to the present day (Murdin 2001). The spiral galaxy NGC 3351 is chosen to study its photometric properties by using surface photometric techniques with *griz*-filters which is the main goal of this study. Observations are obtained from the seventh Sloan Digital Sky Survey (SDSS) Data Release (DR7) (Abazajian *et al.*, 2009). All the images are corrected for bias and flat field by SDSS pipeline. We have analyzed the overall structure of the galaxy (a bulge, a disk, a bar), together with isophotal contour maps, luminosity profiles and performed a bulge/disk decomposition of the galaxy images, although we have estimated the disk position angle, ellipticity and inclination of the galaxy, it is favorable for investigating the brightness and color distributions over the disk of the galaxy. It is clear that the galaxy has a bright ring dominates the appearance of the circumnuclear, and a faint disk does not take on a spiral form, and from the position angle, ellipticity and B4 profiles of galaxy isophotes the values of the P.A. and ellipticity are fluctuated because of the bar and ring. The luminosity profile shows that the outer disk of this galaxy is of type II Freeman. Finally, the color indices of the NGC 3351 galaxy are characteristic of a normal spiral galaxy with some irregularity.

INTRODUCTION

NGC 3351 is a barred inactive spiral galaxy, hosts a large-scale stellar bar and an inner molecular bar-like feature in the centre (Gaele *et al.* 2007). The bulge hosts a clear spiral structure and a nuclear ring (Fisher and Drory 2010). The bright starburst ring dominates the appearance of the circumnuclear region. Within the ring there is a great deal of dust structure, although it does not take on a spiral form (Martinet *et al.*, 2003), see Fig. 1 which represents the color image combine of *griz*-filters. NGC 3351 appears to be symmetric in both its outer and inner portions, and, with the exception of the nuclear starburst, it appears quite regular, with none of the tidal features that are observed in many of the other galaxies. The classical morphological description of this galaxy is a ringed-barred Sb. SBb(r)II NGC 3351 is seen almost face on. The details of the nearly complete inner ring are well seen at this viewing angle (Sandage and Bedke 1994). Bar and disc measurements for this

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galaxy was made using R-band images from the NOT (the 2.5-m Nordic Optical Telescope), supplemented in some cases by J and Ks images from the WHT (unpublished William Herschel Telescope), bar measurements are from the r-band image of Frei *et al.* (1996); the outer-disc profile is Type II (Freedman *et al.* 2001) (Erwin 2005 and references therein). In this study, we will give a modern photometric and morphological description of this galaxy with CCD photometric technique.

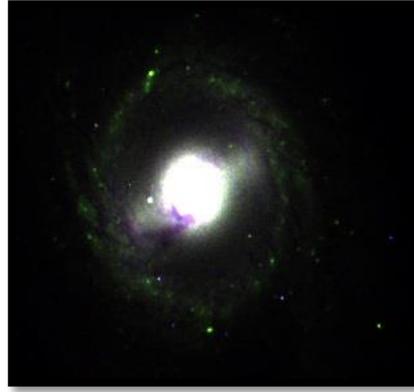


Fig. 1: Color image combine of NGC 3351 galaxy with *griz*-Filters.

Table 1: Basic parameters of NGC 3351 spiral galaxy.

Characteristics	NGC 3351
type	SB(r)b
B_T^0 , mag	10.26
M_{BT}^0 , mag	-26.36 ^a
V_{hel} , km/sec	778±4
$D, M_{pc}(H_0=74.4 \text{ km s}^{-1} \text{ Mpc}^{-1})$	10.5
d_{25} , arcsec minor	9.02
d_{25} , arcsec major	9.09
i , deg	54.6 ^a
Axis Ratio (b/a)	0.99
P.A., deg[J2000]	119
RA(2000)	10h 43m 57.7s
DEC(2000)	+11d 42m 14s

^a HyperLEDA(Makarov *et al.* 2014).

Observations And Data Reduction:

The galaxy images are obtained from the seventh Sloan Digital Sky Survey (SDSS) Data Release (DR7). All the images are corrected for bias and flat field by SDSS pipeline. Table 2 shows the studied galaxy name, date of observations, and the names of the fits file.

Table 2:Galaxies names and dates of observations

Galaxy name	SDSS Name	Observation Date	Fits File Name
NGC 3351	J104357.70+114213.7	23/10/2003	fpC-004204-x5-0122.fit

* x is the filter name which may be *g*, *r*, *i*, or *z*.

The subsequent reduction of the data was carried out using the standard procedures in the IRAF image-reduction Package. The main reduction steps are (Okamura 1988 and references there in):

1. The contribution of the sky background signals is subtracted by choosing empty regions in the image frame far from objects and measures its average intensity value. This is done easily by IRAF.

2. Masking is done for the superimposed and nearby objects, stars or galaxies as shown in Fig. 2. The IRAF ISOPHOTE ELLIPSE task is applied to obtain the intensity and structural profiles.

3. For each intensity profile, the followings are done before fitting:

a- Conversion from pixel units to arcsec²: by dividing on the scale (1 pixel = 0.396" for Apache Point 2.5m Observatory (APO)).

b- Normalization for exposure: by dividing on the exposure time value given in the header (the value is the same for all filters, it equals 53.907456 seconds).

c- Correction for atmospheric extinction, galactic extinction and transformation to the standard system (using the zeropoint of the SDSS photometric system at the time of observation) by multiplying the counts by the factor *f* where:

$$f = 10^{(z_p + k * \text{airmass})} \quad (1)$$

Where z_p and k are the zeropoint magnitude and the atmospheric extinction, respectively. Table 3 lists these values for the galaxy in each filter.

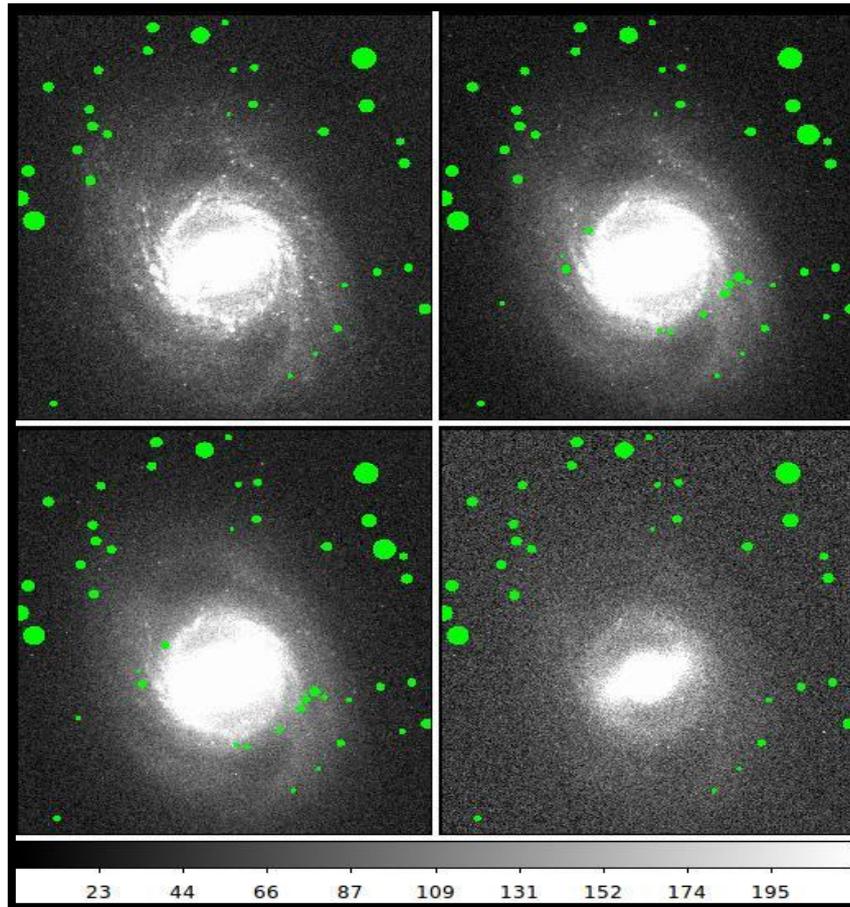


Fig. 2: NGC 3351 Images with masking in $griz$ -filters from upper left to right, North is up and East is at left.

Table 3: Values of airmasses, zeropoints, and atmospheric extinctions

Galaxy	Band	Airmass	Zeropoint	Atmospheric Extinction
NGC 3351	g	1.12	-24.481	0.1942
	r	1.127	-23.999	0.0956
	i	1.125	-23.747	0.0568
	z	1.121	-21.841	0.04413

d- Conversion to magnitude units by the well known formula (Fix 2006):

$$m = -2.5 \log(I) \quad (2)$$

The resulted magnitude profiles are the ones to be fitted.

e- We corrected all the data (brightness and color indices) for Galactic extinction (based on NED).

We assume throughout this work a Hubble constant of $H_0 = 74 \pm 4 \text{ kms}^{-1} \text{ Mpc}^{-1}$. Given the adopted distances to the galaxies from Tully *et al.* (2013) which is about 10.5 Mpc, the image scales are 50.905 pc/arcsec.

RESULTS AND DISCUSSION

1 Morphologies and Contour maps of NGC 3351:

$griz$ -band images of NGC 3351 are displayed in Fig. 3, where it is clear that the galaxy has bright ring dominates the appearance of the circumnuclear region to about 31", with a bar at 8.9" to 19.5", with a faint disk does not take on a spiral form elongated to about 99", see (Martini *et al.*, 2003). The g, r, i and z isophotal contour maps of NGC 3351 are shown in Fig. 4, the surface brightness levels are listed in Table 4.

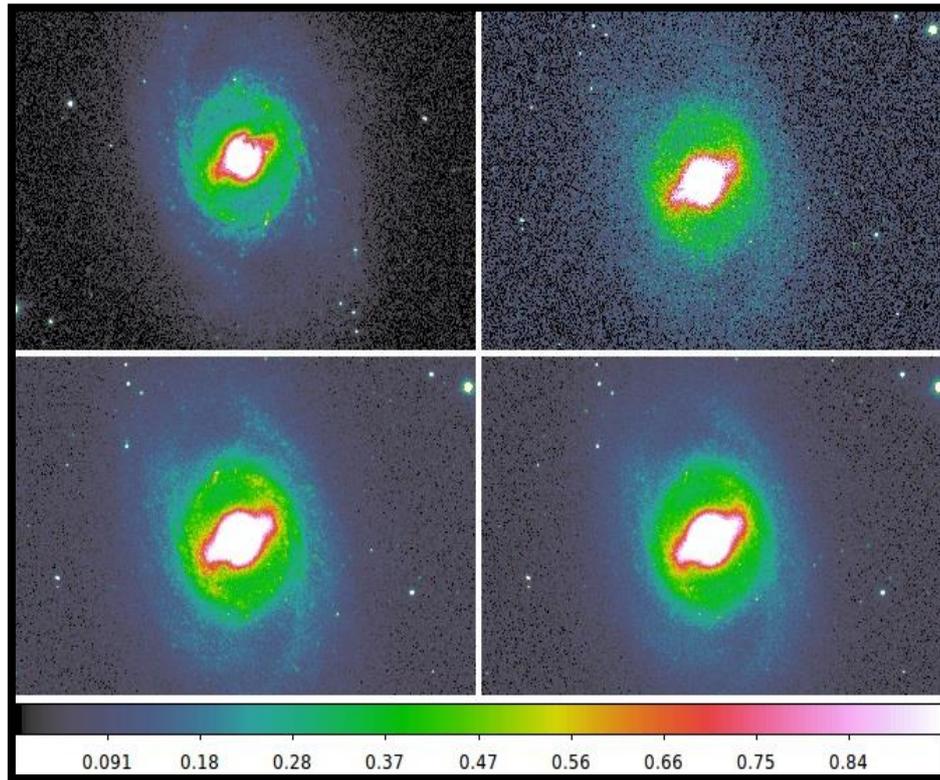


Fig. 3: NGC 3351 Images in griz-filters from upper left to right, North is up and East is at left.

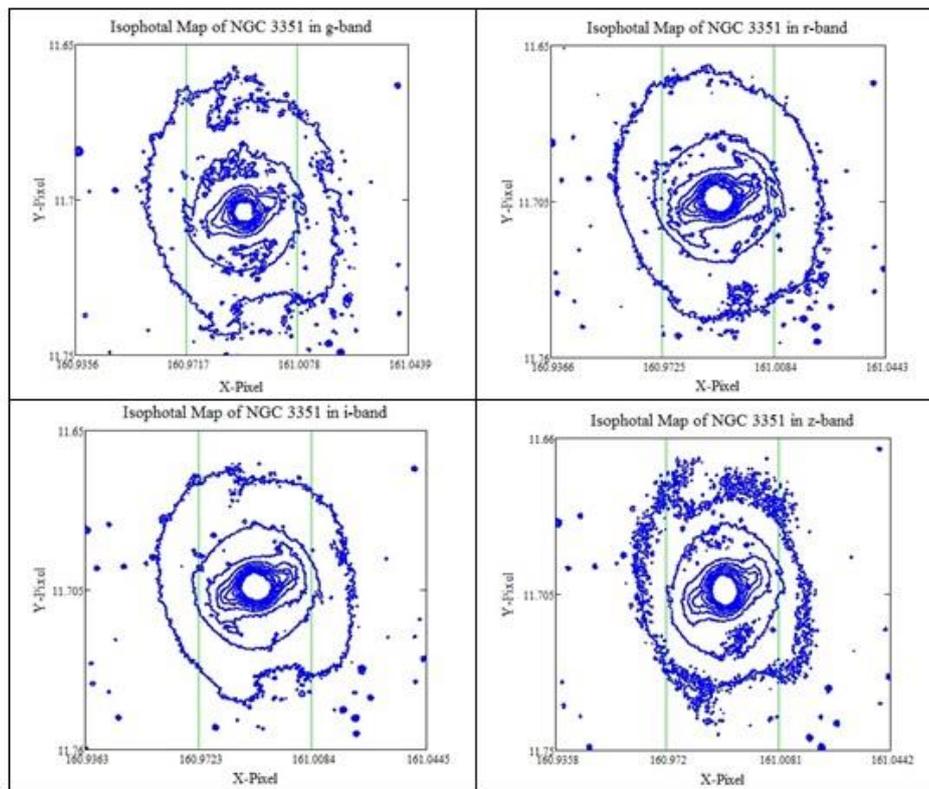


Fig. 4: Isophotal Contour Maps of NGC 3351 Galaxy in gri and z-bands, North is up and East is at left.

Table 4: Outer isophotal level and steps of the contours of NGC 3351 galaxy.

Band	Outer isophot level (mag)	Outer isophot level (mag/arcsec ²)	Steps
g	26.965	25.057	1.286
r	26.206	24.298	1.232
i	25.422	23.514	1.137

z	22.914	21.006	1.019
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2 Position Angle, Ellipticity and B4 Profiles:

The position angle (P.A.), ellipticity ($\varepsilon \equiv 1-b/a$) and B4 (4th harmonic deviations from ellipse) of the galaxy isophotes were determined using the ellipse task of the STSDAS library in IRAF image-reduction system. The dependences of the position angle and ellipticity on the equivalent radius r'' from the center of the galaxy are presented in Fig. 5 and 6 respectively. The average values of the P.A. and ellipticity are found to be approximately 101° , 108° , 101° , 102° , see (Moshir *et al.*, 1990) and 0.23, 0.2, 0.18, 0.19, see (Adelman-McCarthy *et al.*, 2006) in *griz*- filters respectively.

According to data, the position angle of the major axis of the galaxy grows smoothly from 29.1° at $r=18.4''$ to about 152.6° at about $43.5''$, and then decrease to 38.5° at about $97.5''$ and then become more or less flat with average value of 73.6° (see Table 6 and Fig. 5).

The ellipticity profiles of the galaxy fluctuate from the center of the galaxy to about 0.256 at $109''$, and then became nearly flat in the outer parts with average value of 0.25 (see Fig. 6).

The inclination is calculated from (Lu 1998):

$$\cos^2 i = \begin{cases} \frac{(1 - \varepsilon)^2 - 0.2^2}{1 - 0.2^2} & \text{if } \varepsilon \leq 0.8, \\ 0 & \text{otherwise.} \end{cases} \quad (1)$$

The average values of the inclination are 52° , 50.5° , 45.3° , and 48° at *griz*-filters respectively for comparison see (Braine *et al.*, 1993).

The B4 profile is presented in Table 6 and illustrated in Fig. 7. The general trend of the galaxy is to be disk.

Table 6: Isophotal position angle, ellipticity and inclination of NGC 3351.

Band	PA($^\circ$)	ε	Inclination($^\circ$)	B4
g	150	0.35	52	0.0154
r	151.2	0.37	50.5	0.0058
i	145	0.28	45	-0.0044
z	141.4	0.31	47.9	0.0087
global value	146.9	0.33	48.9	0.006

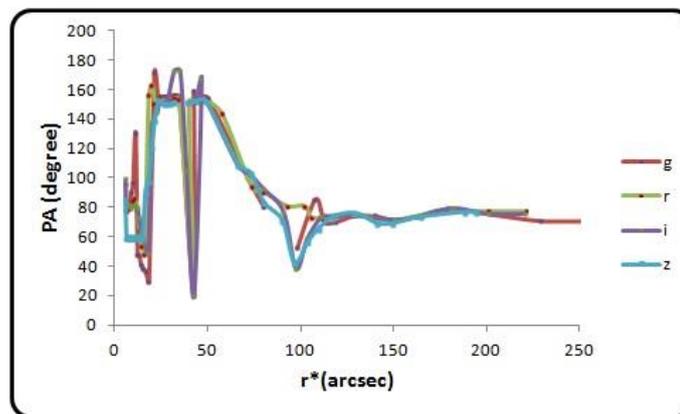


Fig. 5:Position angle profiles of the spiral galaxy NGC 3351 in *gri* and *z*-filters.

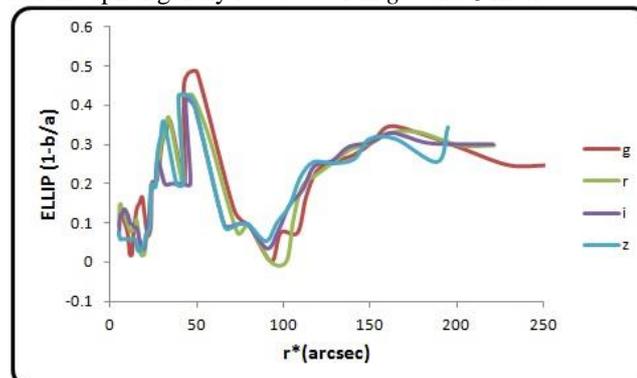


Fig. 6:Ellipticity profiles of the spiral galaxy NGC 3351 in *gri* and *z*-filters.

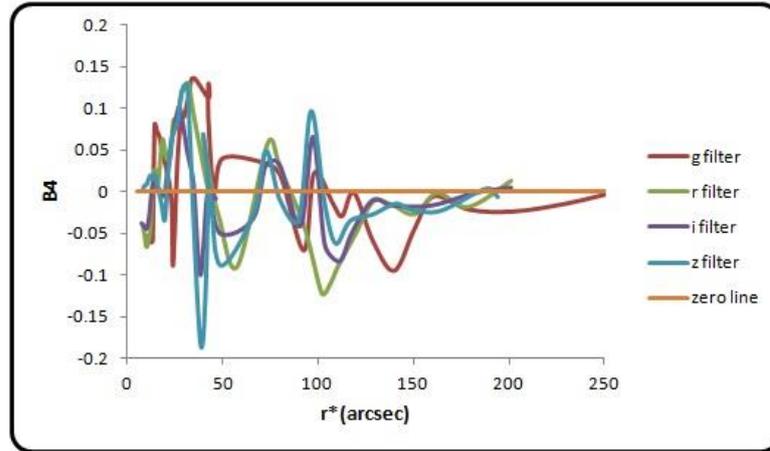


Fig. 7:B4 profiles of the spiral galaxy NGC 3351 in in *gri* and *z*-filters.

3 Luminosity Profile: Decomposition:

The *gri* and *z* equivalent luminosity profiles of the NGC 3351 galaxy have been decomposed into the spheroidal ($r^{1/4}$) and disk (exponential) components using the technique of least square fitting. The results of the decomposition are given in Fig. 8 of *g*, *r*, *i* and *z* bands from upper left to right. The results are also summarized in Table 7, see Fig. 8 and Table 7). It is clear from the Fig.8 that the luminosity profiles represent an object with a several components: bulge, bar, ring, and spiral arms.

The *griz*-band and luminosity profile shows that the outer disk of this galaxy is of type II Freeman (Freeman 1970).

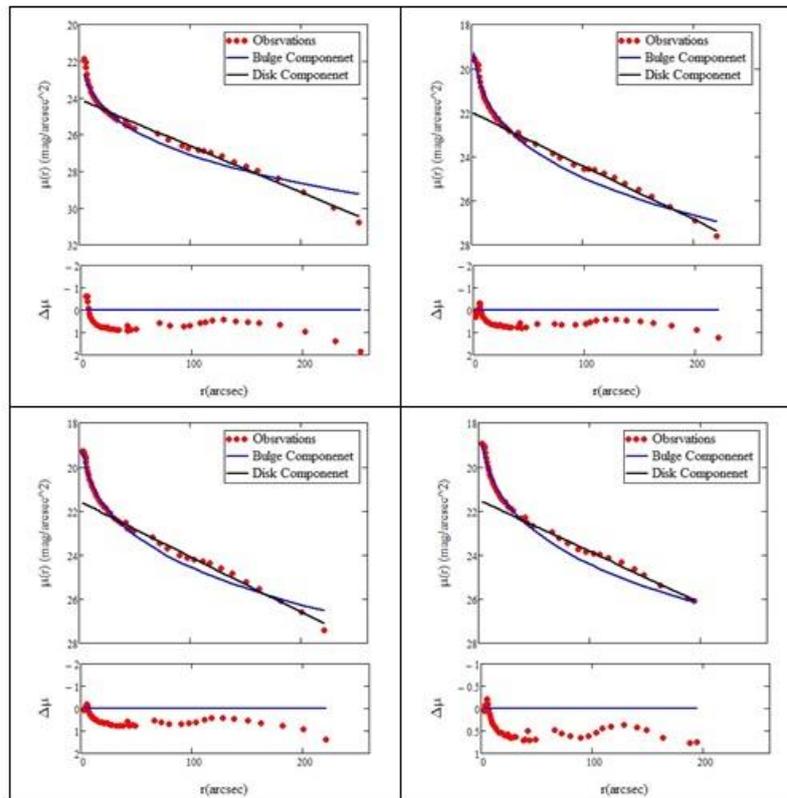


Fig. 8:Decomposition of surface brightness profiles of *g*, *r*, *i* and *z*-bands as well as the residual between the (Bulge + Disk) model and the observed data for NGC 3351 galaxy.

Table 7:Bulge and disk fitting parameters of NGC 3351.

Band	Bulge				Disk			LB _T (mag)	B/D
	range (arcsec)	μ_c (mag/arcsec ²)	r_c (arcsec)	Standard error	μ_0 (mag/arcsec ²)	r_0 (arcsec)	Standard error		
<i>g</i>	7.3-50.04	27.2	104.25	0.06	24.08	42.9	0.07	13.71	0.64

r	5.9-57.5	24.2	70.61	0.08	21.99	44.7	0.05	11.55	0.63
i	6.07-49.2	23.8	70.39	0.06	21.56	43.2	0.06	11.15	0.65
z	5.6-48.8	23.2	57.88	0.06	21.50	46.6	0.04	11.00	0.62

4 Color Index Profiles of NGC 3351 Spiral Galaxy:

Profiles of the $g-r$, $r-i$, and $i-z$ color indices, along the equivalent radius are shown in Fig. 9. The color distribution from the nuclear part ($r \leq 9''$) is with $\langle g-r \rangle = 1.14 \pm 0.04$, $\langle r-i \rangle = 0.6 \pm 0.03$, and $\langle i-z \rangle = 2.2 \pm 0.007$. For the disk of this galaxy ($r > 9''$) $\langle g-r \rangle = 1.11 \pm 0.09$, $\langle r-i \rangle = 0.61 \pm 0.06$ and $\langle i-z \rangle = 2.15 \pm 0.05$.

The color indices in the inner and in the outer regions of this galaxy are characteristic of a normal spiral galaxy with some irregularity in some regions.

Table 8: Color Index Profiles of NGC 3351.

	Radius(")	Average Value(mag)
$g-r$	179.4	1.11 ± 0.09
$r-i$	178.5	0.61 ± 0.06
$i-z$	164.3	2.15 ± 0.05

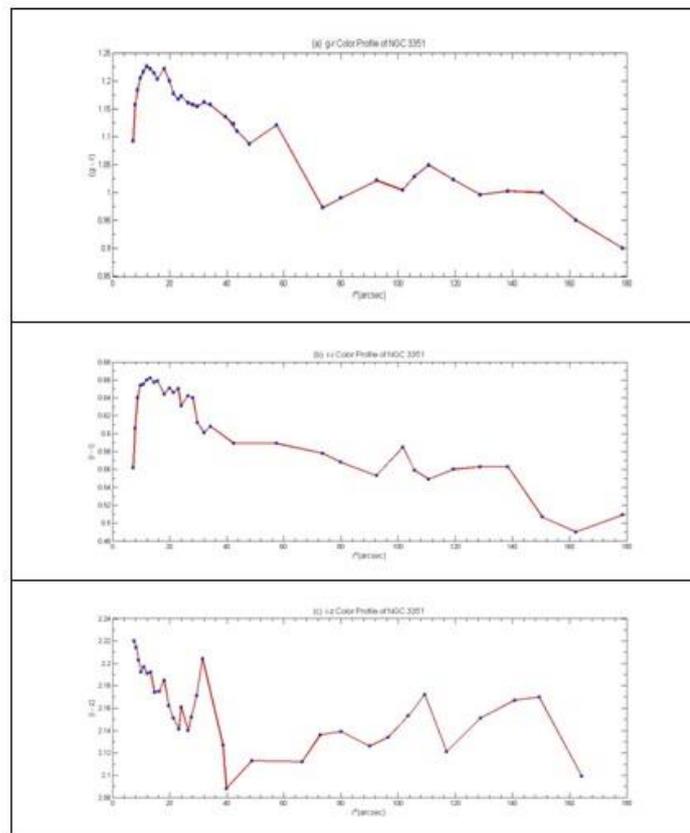


Fig. 9: $g-r$, $r-i$ and $i-z$ Color Index Profiles of NGC 3351.

Conclusion

Surface photometry is one of the powerful tools to study the structure and properties of galaxies. From the present study, It is clear that the galaxy has a bright ring dominates the appearance of the circumnuclear region to about $31''$, with a bar at $8.9''$ to $19.5''$, and a faint disk does not take on a spiral form elongated to about $99''$.

From the position angle, ellipticity and B4 profiles of galaxy isophotes the values of the P.A. and ellipticity are fluctuated because of the bar and ring and found to be approximately 101° , 108° , 101° , 102° and 0.234 , 0.2 , 0.18 , 0.19 in $griz$ - filters respectively. The luminosity profile shows that the outer disk of this galaxy is of type II Freeman. Finally, the color indices of the NGC 3351 galaxy are characteristic of a normal spiral galaxy with some irregularity in some regions especially in ($i-z$) profile.

In the future work we hope to take an observations with our own telescopes and make a data reduction and analysis to the celestial objects from observational point in our country.

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