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SURFACE PHOTOMETRY OF NGC 5610 – A BOX/PEANUT STRUCTURE IN AN INTERMEDIATELY INCLINED GALAXY

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Abstract. We report NGC 5610 as a new case of an intermediately inclined barred spiral galaxy with a box/peanut-shaped bulge. The ellipticity and the position angle of the galaxy measured at 25 B mag arcsec^{-2} isophote are 0.67 ± 0.02 and 99.7 ± 1.1 degree, respectively. The galaxian inclination estimated from the ellipticity is 70.7 ± 1.2 degree. The weight-averaged bar length, ellipticity and position angle are 17.3 ± 0.5 arcsec (or 5661.7 ± 162.3 pc), 0.83 ± 0.01 and 92.1 ± 0.6 degree, respectively.

1. INTRODUCTION

Recent statistics based on 734 disk galaxies selected from RC3 catalogue shows that $45.0 \pm 4.5\%$ of S0-Sd galaxies have box/peanut-shaped bulges (Lütticke et al., 2000a). Therefore, the research on these bulges is important to clarify the evolution of disk galaxies. However, the physical processes leading to box/peanut (hereafter b/p) bulges are not clear yet. According to the most popular scenario b/p bulges are explained by dynamical processes in bar potential (Combes and Sanders, 1981; Combes et al., 1990; Raha et al., 1991; Pfenniger and Friedli, 1991; Lütticke et al., 2000a; Lütticke et al., 2000b). This scenario is supported mainly by N-body simulations (e.g. Combes and Sanders, 1981). Additional support comes from spectroscopic observations (characteristic bar signatures in velocity fields are found, Kuijken and Merrifield, 1995) and from statistical studies (overall frequency of barred galaxies, about 55%, is able to explain the high fraction of b/p bulges, Lütticke et al., 2000a; Knapen et al., 2000). On the other hand, the connection between b/p bulges and the presence of a bar is difficult to be proved by surface photometry – b/p bulges are observable only in almost edge-on galaxies (inclination less then about 75 degree for an edge-on bar, Shaw et al., 1990; Combes et al., 1990; Lütticke et al., 2000b). However, there is photometric evidence in a few edge-on galaxies from cuts parallel to the major axis (de Carvalho and da Costa, 1987; Dettmar and Ferrara, 1996) and in two intermediately inclined galaxies (NGC 4442, Bettoni and Galletta, 1994 and NGC 7582, Quillen et al., 1997) pointing to bars. In particular, the observations of intermediately inclined galaxies is important in clarifying the nature of b/p bulges because in such cases both the bar and the b/p bulge can be observed simultaneously.

Table 1: Journal of observations for NGC 5610

Date [d.m.y]	Band	Exposure [second]	Seeing [arcsecond]	Number of frames
01.06.1997	V	300	1.82	1
01.06.1997	R_{C}	80	1.89	1
03.03.1998	U	180	1.83	2
03.03.1998	B	120	1.66	2
03.03.1998	V	60	1.56	2
03.03.1998	R_{C}	60	1.27	2
03.03.1998	I_{C}	60	1.37	2

In this paper we report the observation of a new case of intermediately inclined galaxy with a b/p bulge, namely, the barred spiral galaxy NGC 5610.

2. OBSERVATIONS AND DATA REDUCTION

The galaxy NGC 5610 was observed with the Photometrics CCD camera attached to the 2-m telescope of Rozhen NAO in $UBVR_{\mathrm{C}}I_{\mathrm{C}}$ bands. The journal of observations is presented in Table 1.

The Photometrics CCD camera has 1024×1024 pixels, $0.24\,\mu$m each, a field of view 5.3×5.3 arcsec with the 2-m telescope and a non-binned scale of 0.309 arcsec px^{-1}. The possibility for 2×2 binning can be used for matching the seeing to the CCD pixel size. The CCD camera can be operated in two regimes of sensivity: (1) conversion factor $4.93\,\mathrm{e}^-\,\mathrm{ADU}^{-1}$ and readout noise $5.1\,\mathrm{e}^-\,\mathrm{px}^{-1} = 1.03\,\mathrm{ADU\,px}^{-1}$ and (2) conversion factor $1.21\,\mathrm{e}^-\,\mathrm{ADU}^{-1}$ and readout noise $3.3\,\mathrm{e}^-\,\mathrm{px}^{-1} = 2.73\,\mathrm{ADU\,px}^{-1}$. We used the first regime and 2×2 binned camera during the observations.

The basic reduction steps for both dates are as follows: bias subtraction, flat fielding, defringing (applied to I_{C} frames only) and cosmic rays cleaning. All frames in each band were aligned and then averaged (applied to June, 1998 data only).

Adaptive filtering (Lorenz et al., 1993), multiple masking and sky background subtraction were made. Next, ellipse fitting was performed following Bender and Möllenhoff (1987) method. Finally, the images and the one-dimensional surface brightness profiles were transformed to the standard system. We used (1) NGC 7790 cluster for calibrating June, 1997 data (Odewahn et al., 1992; Petrov et al., 2001), and (2) NGC 4147 cluster (Davis, private comminication) for calibrating March, 1998 data.

3. RESULTS AND DISCUSSION

We present the isophotes of the V band image of NGC 5610 taken in June, 1997 in Fig. 1. The flattening of the bulge light distribution is clearly seen; one can recognize a peanut structure inside the boxy isophotes. This is an indication for a b/p shaped bulge (see Shaw, 1987)

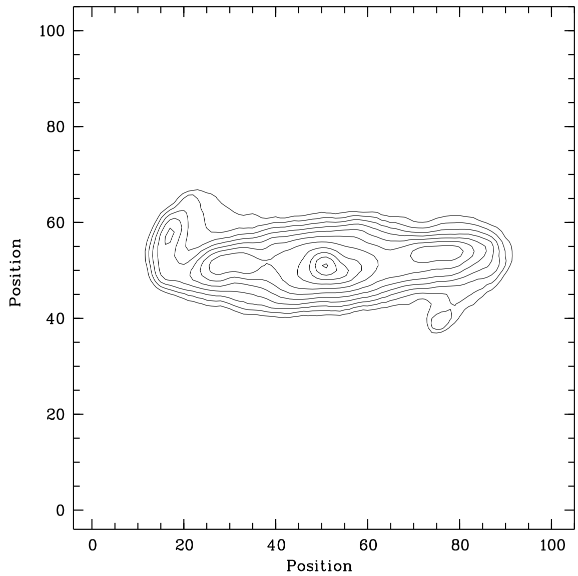

Figure 1: Isophotes of the V band image of NGC 5610 taken in June, 1997. Isophotes are drawn from 19.0 mag to 21.5 mag with a step of 0.25 mag. Axes labels are in units of pixels (1 pixel corresponds to 0.309 arcsec). A b/p structure could be identified in the central part of the galaxy. North is at the top, East is to the left.

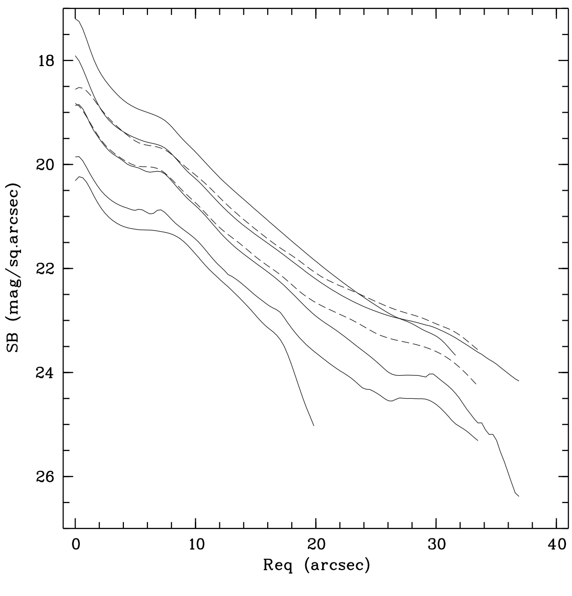

Figure 2: $UBVR_{\mathrm{C}}I_{\mathrm{C}}$ surface brightness profiles for NGC 5610: dashed lines – June, 1997, and solid lines – March, 1998. U band profile is the lower one, and I_{C} band profile is the upper one.

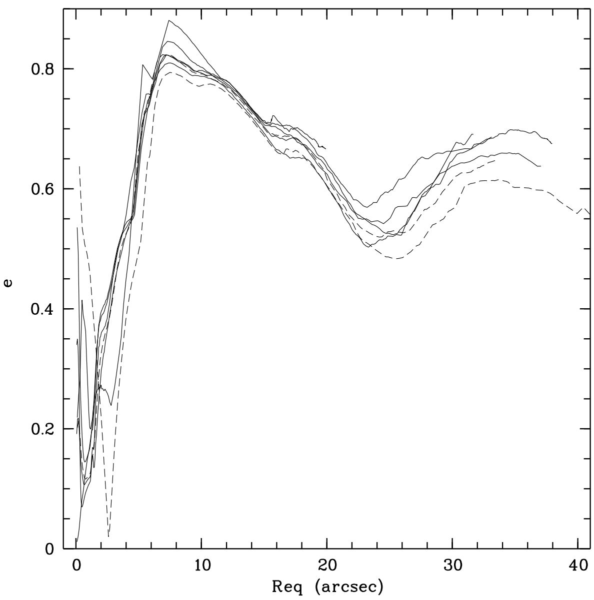

Figure 3: $UBVR_{\mathrm{C}}I_{\mathrm{C}}$ ellipticity profiles for NGC 5610: dashed lines – June, 1997, and solid lines – March, 1998.

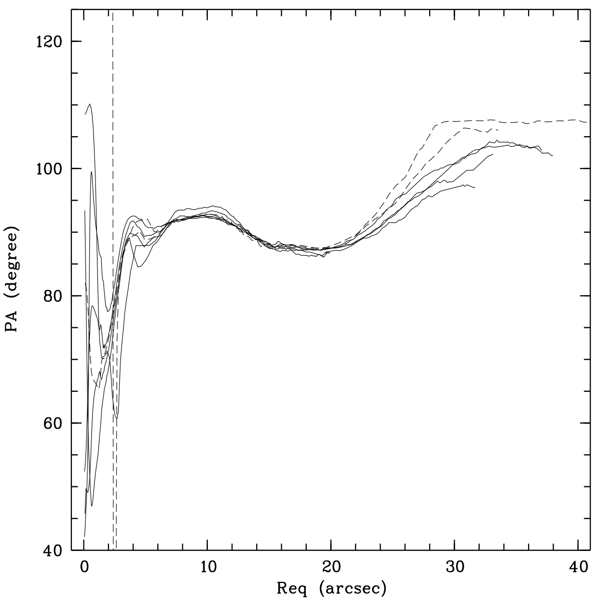

Figure 4: $UBVR_{\mathrm{C}}I_{\mathrm{C}}$ position angle profiles for NGC 5610: dashed lines – June, 1997, and solid lines – March, 1998.

Table 2: Estimated bar parameters for different epoches and bands

Date [d.m.y]	Band	Length [arcsec]	Length [parsec]	Ellipticity	Position angle [degree]
01.06.1997	V	16.5 ± 1.7	5388.5 ± 556.0	0.82 ± 0.04	91.5 ± 2.1
01.06.1997	$R_{\rm C}$	16.5 ± 1.2	5400.0 ± 384.6	0.79 ± 0.03	91.9 ± 1.8
03.03.1998	U	21.4 ± 2.1	7019.8 ± 697.3	0.88 ± 0.02	93.2 ± 1.3
03.03.1998	B	18.6 ± 6.4	6077.2 ± 2091	0.85 ± 0.11	92.0 ± 6.2
03.03.1998	V	17.4 ± 1.0	5688.7 ± 318.1	0.82 ± 0.02	91.5 ± 1.2
03.03.1998	$R_{\rm C}$	17.0 ± 1.6	5579.6 ± 517.7	0.82 ± 0.03	91.7 ± 1.9
03.03.1998	$I_{\rm C}$	17.2 ± 0.9	5645.6 ± 287.9	0.81 ± 0.02	92.0 ± 1.1

The ellipticity ($e = 1 - b/a$, where b and a are the minor and major semi-axes) and the position angle (PA, North through East) measured at $25\,B\,\mathrm{mag\,arcsec^{-2}}$ isophote are $e = 0.67 \pm 0.02$ and $PA = 99.7 \pm 1.1$ degree, respectively. According to HyperLeda database the ellipticity and the position angle of NGC 5610 are 0.65 and 108 degree, respectively, so, there is a good agreement between the catalogue values and ours. We plot the surface brightness, ellipticity and position angle profiles as a function of the equivalent radius ($R_{\rm eq} = \sqrt{ab}$) in Figs. 2-4, respectively. The correspondence between the surface brightness profiles observed in different epoches and between the ellipticity and the position angle profiles observed in different bands and in different epoches is satisfactory. This points to a good internal accuracy of our data.

The inclination ($i = \cos^{-1}(1-e)$) of NGC 5610 determined by us is 70.7 ± 1.2 degree compared to $i = 66.5$ degree for NGC 4442 and to $i = 64.1$ degree for NGC 7582 (the data about the intermediately inclined galaxies with b/p bulges NGC 4442 and NGC 7582 are taken from HyperLeda database).

The bar could be defined as a region of gradually rising ellipticity while position angle remains almost constant (e.g. Mulchaey et al., 1997). The bar length is then given by the major axis length of the ellipse at which the rising ellipticity reaches its maximal value. Our estimates of the bar length are presented in Table 2. We used heliocentric radial velocity of $5063 \pm 22\,\mathrm{km\,s^{-1}}$ taken from NED and Hubble parameter of $75\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$ to calculate the bar length in parsecs. One can see that within the errors there is a good correspondence between the bar parameters derived from observations obtained in different epoches and in different bands. The weight-averaged (over all epoches and all bands) bar length, ellipticity and position angle are 17.3 ± 0.5 arcsec (or 5661.7 ± 162.3 pc), 0.83 ± 0.01 and 92.1 ± 0.6 degree, respectively.

In conclusion, NGC 5610 could be considered as a new case of intermediately inclined galaxy that shows b/p bulge. Further study of this galaxy is useful.

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References

Bender, R., Möllenhoff, K.: 1987, *Astron. Astrophys.*, **177**, 71.
Bettoni, D., Galletta, G.: 1994, *Astron. Astrophys.*, **281**, 1.
Combes, F., Sanders, R.H.: 1981, *Astron. Astrophys.*, **96**, 164.
Combes, F., Debbasch, F., Friedli, D., Pfenniger, D.: 1990, *Astron. Astrophys.*, **233**, 82.
de Carvalho, R.R., da Costa, L.N.: 1987, *Astron. Astrophys.*, **171**, 66.
Dettmar, R.-J., Ferrara, A.: 1996, IAU Symp. 171, New Light on Galaxy Evolution, eds. R. Bender and R. Davis, Kluwer, p. 362.
Knapen, J.H., Shlosman, I., Peletier, R.F.: 2000, *Astrophys. J.*, **529**, 93.
Kuijken, K., Merrifield, M.R.: 1995, *Astrophys. J.*, **433**, L13.
Lorenz, H., Richter, G.M., Capaccioli, M., Longo, G.: 1993, *Astron. Astrophys.*, **277**, 321.
Lütticke, R., Dettmar, R.-J., Pohlen, M.: 2000a, *Astron. Astrophys. Suppl. Series*, **145**, 405.
Lütticke, R., Dettmar, R.-J., Pohlen, M.: 2000b, *Astron. Astrophys.*, **362**, 435.
Mulchaey, J. S., Regan, M.W., Kundu, A.: 1997, *Astrophys. J. Suppl. Series*, **110**, 299.
Odewahn, S.C., Bryja, C., Humphreys, R.M.: 1992, *Publ. Astron. Soc. Pacific*, **104**, 553.
Petrov, G., Seggewiss, W., Dieball, A., Kovachev, B.: 2001, *Astron. Astrophys.*, **376**, 745.
Pfenniger, D., Friedli, D.: 1991, *Astron. Astrophys.*, **252**, 75.
Quillen, A.C., Kuchinski, L.E., Frogel, J.A., Depoy, D.L., 1997, *Astrophys. J.*, **481**, 179.
Raha, N., Sellwood, J.A., James, R.A., Kahn, F.D. : 1991, *Nature*, **352**, 411.
Shaw, M., Dettmar, R.-J., Barteldrees, A.: 1990, *Astron. Astrophys.*, **240**, 36.
Shaw, M.A.: 1987, *Mon. Not. R. Astron. Soc.*, **229**, 691.