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A highly flattened stellar disk in the elliptical galaxy NGC 4564

D.K. Sahu, S.K. Pandey

School of Studies in Physics, Pt. Ravishankar Shukla University, Raipur 492 010, India

A.K. Kembhavi

IUCAA, Post Bag 4, Ganeshkhind, Pune 411 007, India

Abstract. We present the R band isophotal shape analysis of the E6 elliptical galaxy NGC 4564 by fittng ellipses to the observed isophotes using Fourier expansion procedure. The galaxy is found to have pointy isophotes, showing excess light along its major axis throughout the range of radii. An examination of the residual image obtained by subtracting a smooth elliptical model from the original galaxy image leads to the detection of a fairly prominent stellar disk along its apparent major axis. We use an iterative method to decompose the surface brightness profile into a pure elliptical bulge, obeying de Vaucouleurs law and an exponential disk to derive the best fit parameters of the two components. The stellar disk is highly flattened in consistent with the kinematics of the galaxy.

Key words : Galaxies – elliptical – NGC 4564 – structure

1. Introduction

Elliptical galaxies range in shape from almost spherical (E0) to highly flattened (E7). Originally these galaxies were defined as smooth objects having perfectly elliptical isophotes having no traces of substructures in them. They were believed to consist of old red stars, with no evidence of young stellar populations, and hence were recognized as old stellar systems, which has exhausted all its interstellar matter and are now incapable of forming stars.

The traditional view of elliptical galaxies is no longer valid. With the advent of charge coupled devices (CCD) as a nearly perfect detectors together with the advancement in computing capabilities and efficient image processing softwares our understanding on elliptical galaxies has changed drastically. In mid seventies investigations of Bertola & Capaciolli (1975), and Illingworth (1977), demonstrated beyond doubt that the flattening of these galaxies is not because of their rotation but it is due to the anisotropy in the stellar velocity

distribution. A large fraction of these galaxies are now known to have interstellar matter in all possible forms and other faint features like core (Franx & Illingworth 1988), shells or ripples (Malin & Carter 1983), which provide information about their formation processes by merger/interaction. Their isophotes deviate significantly from perfect ellipses (Bender *et al.* 1988 and references therein). This deviation is usually quantified in terms of the fourth order harmonics 'b4' in the Fourier expansion of isophotal intensity along major axis. Galaxies with positive 'b4' are known as disky while with negative 'b4' are known as boxy. The pointy isophotes are thought to reflect the presence of an embedded faint stellar disk (Scorza & Bender 1990, 1995), while boxy isophotes are explained in terms of the tube orbits, and anisotropic velocity distribution. The disky ellipticals are SO like systems at the end of the disk-to-bulge luminosity sequence in the Hubble classification (Bender *et al.* 1989, Nieto & Bender 1989).

In the present work a detailed structural analysis of the flattened elliptical galaxy NGC 4564 is reported. Previous investigations (Goudfrooij *et al.* 1994, Michard & Marchal 1994) on this galaxy had shown a fairly prominent disk aligned with its apparent major axis. In this paper we have carried out the bulge-to-disk decomposition of the brightness profile of the galaxy to derive the best fit characteristics scale lengths for the two components and the disk-to-bulge ratio. Our detailed structural analysis reveals the disk to be highly flattened as compared to the underlying bulge, a feature which is consistent with the kinematical properties of the galaxy.

2. Observation and data Reduction

This galaxy was observed at the prime focus (f/3,25) of 2.34 m telescope of the Vainu Bappu Observatory, Kavalur, India on the night of Feb. 5, 1994. The detector used was a GEC P8603 CCD with pixel size of 22μm x 22μm. This yields a scale of 0.6" per pixel and a field of 3.8' x 5.78' at the prime focus of VBT. This galaxy was observed in the Cousins R filter, with an exposure of 1200 sec. Seeing was ~ 2.5". Several sky flats and bias frames were also taken for pre processing of the CCD data.

Preliminary CCD data reduction steps (bias subtraction, flat fielding, cosmic ray removal, sky subtraction) were carried out using standard tasks within IRAF[1] to obtain clean image of the galaxy. The isophotes of elliptical galaxies are ellipses to a high degree, and therefore ellipses are fitted to these isophotes. The isophotal shape analysis was carried out using the ellipse task within STSDAS[2] which is based on the method described in detail by Jedrzejewski (1987). Obvious foreground stars in the galaxy region were masked off and excluded from the ellipse fit. For a given semi-major axis length, an initial guess for the fitting parameters, namely, the centre, ellipticity and position-angle of the ellipse were made and the galaxy image was sampled along the trial ellipse at equal intervals in the eccentric anomaly. The fitting program calculates the first two harmonics of the Fourier series representing the deviation from

[1] IRAF is distributed by the National Optical Astronomy Observatories (NOAO), which is operated by the Association of Universities, Inc. (AURA) under co-operative agreement with the National Science Foundation.

[2] The Space Telescope Science Data Analysis System STSDAS is distributed by the Space Telescope Science Institute.

constant intensity along the trial ellipse, and performs several iterations, each time applying corrections to the initial parameters so as to minimize the Fourier coefficients to obtain the best fit ellipse. The higher order (>2) harmonics of the residual intensity from the best fit ellipse are then eveluated using the method of least squares. For the purpose of interpretation the amplitudes of these higher order terms expressed in intensity units are transformed to coefficients that describe deviation from a unit circle, by dividing them by the local intensity gradient and the semi-major axis length. The ellipse fitting procedure generates profiles of surface brightness distribution, ellipticity, position angle and higher order harmonics. The isophotal profiles for the galaxy are dispolayed in Figure 1. We notice a significant deviation (light excess) in luminosity distribution from the de Vaucouleurs $r^{1/4}$ profile. The b4 coefficient is positive for the whole range of major axis length and is as high as 4%. Other higher order harmonics (b6, b8) are also found to be significantly positive.

3. Image decomposition into bulge and disk

With a view to separate the spheroidal component, a certain fraction (up to 40%) of the brightest pixels are clipped at each stage of ellipse fitting, and a smooth model is generated. The smooth model is subtracted from the original galaxy image to obtain residual image which reveals extra brightness along the major axis of the galaxy (Figure 2). This in turn reflects the presence of a prominent stellar disk lying along the apparent major axis of the galaxy. The residual image is subtracted from the original galaxy and ellipses are again fitted to this and the procedure is repeated until the disk subtracted galaxy is left with perfectly elliptical isophotes. The profiles of disk free galaxy is used to get the parameters of bulge by fitting de Vaucouleurs law to it. The best fit parameters for bulge are : *effective radius* of the bulge r_{eff} = 40.8" *ellipticity* = 0.35.

The best fit bulge image constructed with the above parameters using *artdata* task within IRAF is subtracted from the original galaxy, to obtain the disk component embedded in the galaxy. This can be used to make an initial guess to the disk parameters. In order to examine the properties of the disk, perfectly exponential disks are modelled with central surface brightness I_0 and scale length r_s. The other parameters i.e. inclination and position angle are kept free. The disk models are then convolved with the seeing psf and added to the spheroidal component to obtain the model galaxy. Isophotal profiles obtained for the model galaxy are compared with those of the original galaxy. The dependence of model galaxy profiles on disk parameters is studied by varying disk parameters. The comparison between the model galaxy profiles with those of original galaxy gives an estimate of the inclination of the disk, position angle and central surface brightness. The profiles of isophotal parameters are plotted in Figure 3 for model and the original galaxy. The best fitting parameters for the disk embedded in the galaxy are : *scale length* of the disk r_s = 28.14" *axial ratio b / a* = 0.3 and *position angle* = 40°.

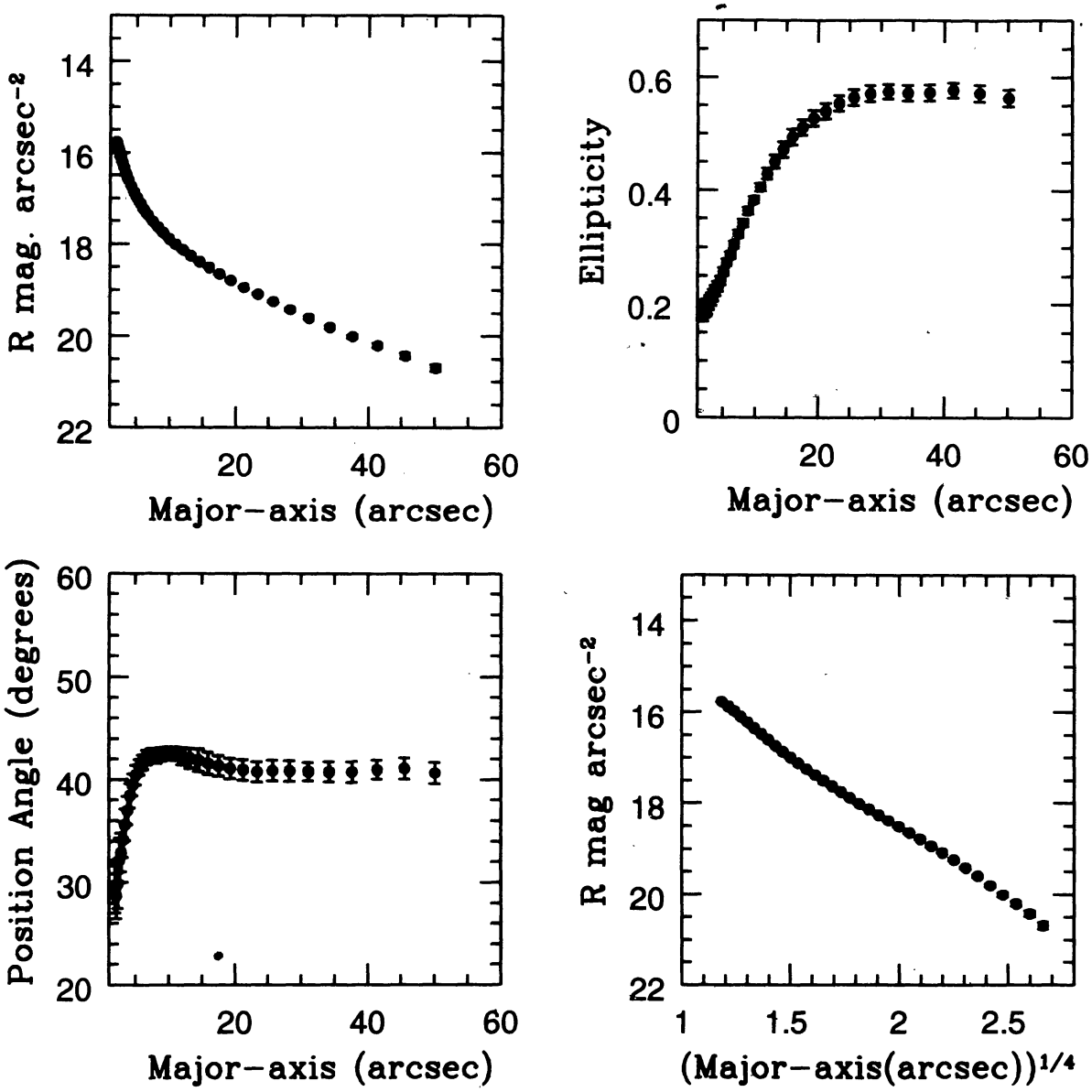

Figure 1 a. Profiles of NGC 4564.

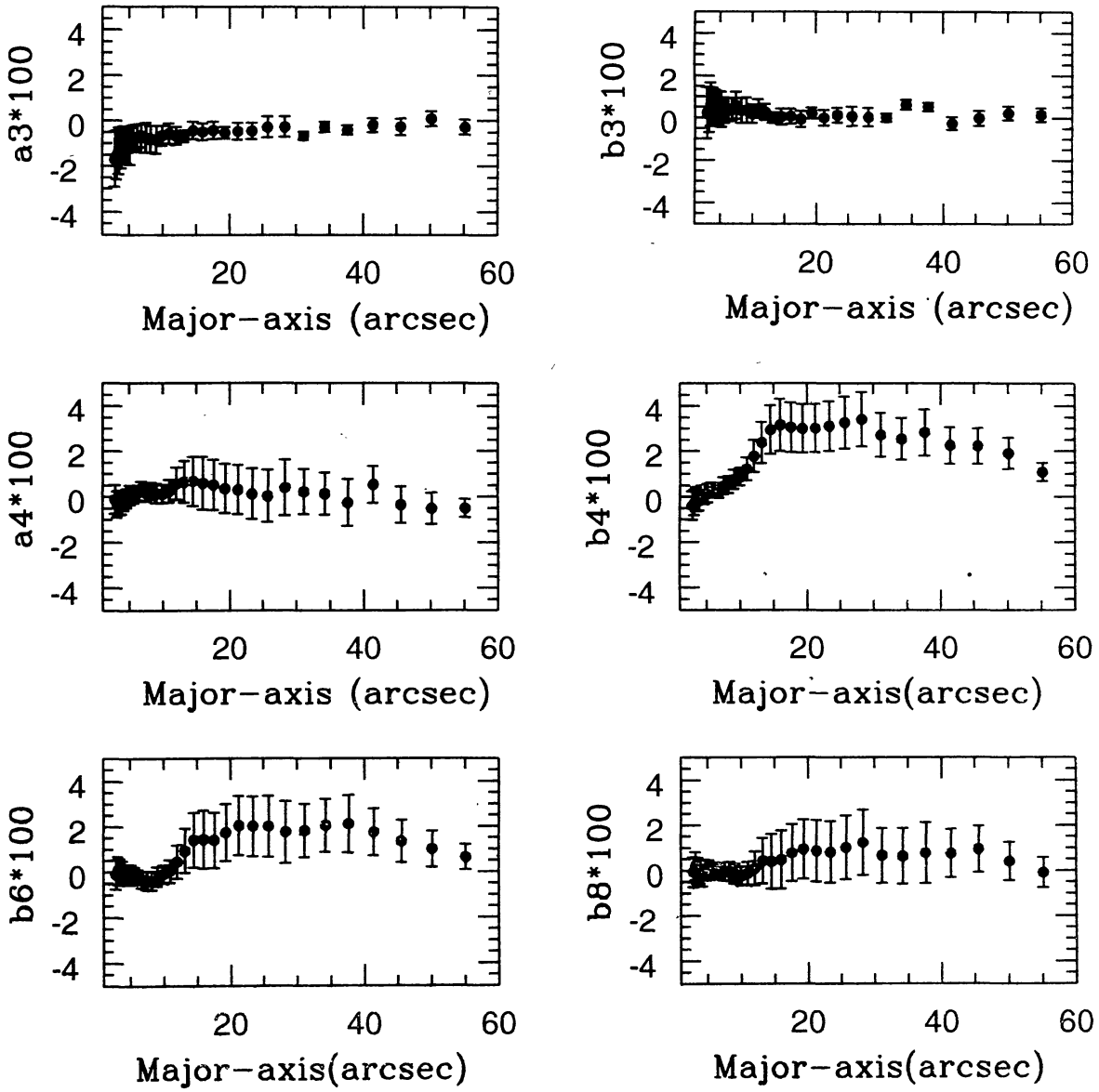

Figure 1 b. Profiles of NGC 4564.

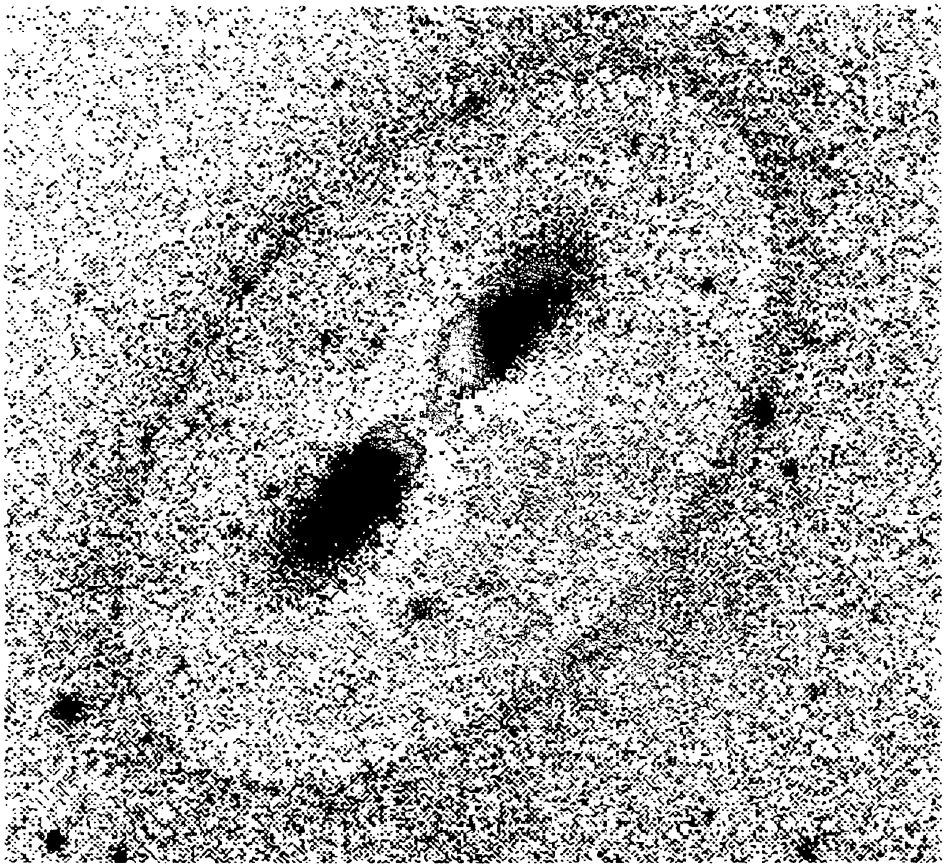

Figure 2. Residual image showing the disk along apparent major axis.

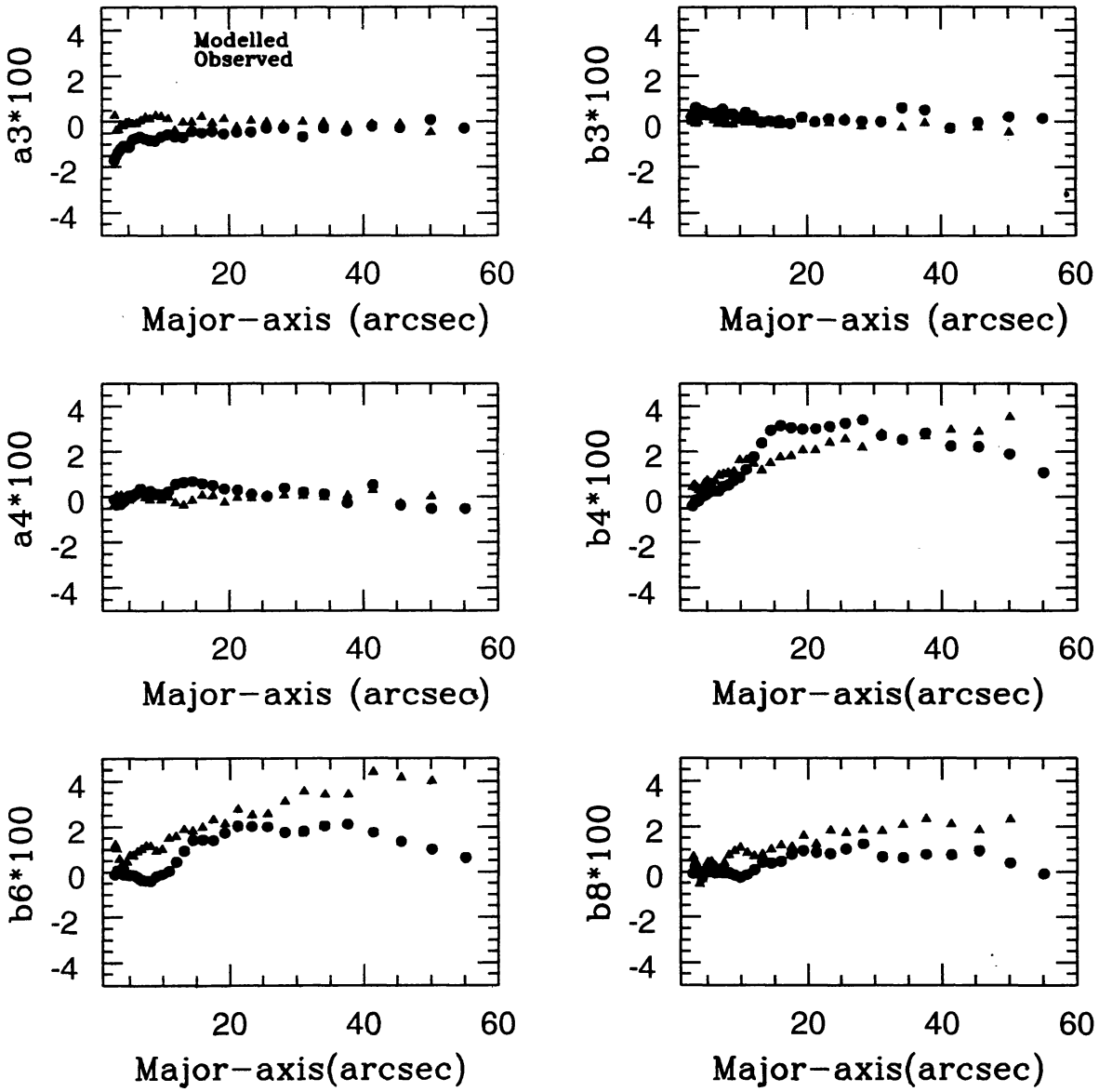

Figure 3. Profiles of the shape deciding parameters for the original and modelled galaxy.

3. Image decomposition into bulge and disk

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4. Discussion

A comparison of the ellipticity for the two components shows that the stellar disk embedded in NGC 4564 is highly flattened as compared to the bulge. Further, the small inclination ~ 18° of disk from the line of sight makes it a suitable galaxy for the detection of embedded disk. The ratio (υ / σ) of velocities corresponding to the rotational kinetic energy and that corresponding to the kinetic energy of line of sight component of random motions is ~ 1.14 (Busarello *et al.* 1992) for this galaxy, which indicates that this galaxy is rotating fast enough to support a stellar disk. The galaxy is a weak radio source (Heckman 1983) and also is X-ray quiet (Nieto *et al.* 1994). These properties are consistent with the isophotal properties of the galaxy.

5. Conclusions

In the present paper the R band photometric anaysis of galaxy NGC 4564 is discussed. The main conclusions are :

1. The galaxy possesses a highly flattened stellar disk along its major axis, in consistent with the kinematical properties of the galaxy.

2. The best fit structural parameters for the bulge and the disk are :
   a. Bulge $r_e = 40.8''$ ellipticity = 0.35
   b. Disk $r_s = 28.14''$ ellipticity = 0.70
   c. Disk-to-Bulge ratio = 0.18

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