THE ROTATION CURVE OF NGC 488

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ABSTRACT

The rotation curve of NGC 488 has been measured out to a radius of 20 kpc, at which point the velocity is 363 km s^{-1} and continuing to increase with radius. This rotational velocity is the largest known for an Sb galaxy. For a mass model based on the thin-disk approximation of Kuzmin [Publ. Tartu Astron. Obs. **32**, 211 (1952)], we find the mass and mass-luminosity interior to 20 kpc are $M \gtrsim 4.0 \times 10^{11} M_\odot$ and $\langle M/L \rangle_B \gtrsim 3.6$. Exterior to the nuclear region, the mass-luminosity ratio shows only a gentle increase with radius.

I. INTRODUCTION

Very few kinematical observations have been made to date on early-type spiral galaxies. With this in mind a spectrum of NGC 488 (Hubble type Sb or Sab I) aligned nearly along the major axis was obtained during the course of other 4-m spectroscopy at Cerro Tololo Inter-American Observatory. NGC 488 was of interest also because of its close morphological similarity to NGC 7217, a galaxy on which we had earlier published (Peterson *et al.* 1978) a dynamical study.

In this paper we have derived the rotation curve of the galaxy, and briefly compare it with the limited amount of kinematical data which is available on other high-luminosity Sa and Sb galaxies. A simple mass model has been calculated from the run of velocity. New photoelectric photometry as well as data from the literature are used to compute the run of the blue mass-luminosity ratio.

II. OBSERVATIONAL DATA

A single spectrum (F-1203B, 10/11 July 1978, 90-min exposure at the CTIO 4-m telescope plus Cassegrain image-tube spectrograph, N_2-baked IIIa-J plate, dispersion 49 Å mm^{-1}) is available for study. Although the emission lines of Hα and [N II] 6583 are weak because of the very low surface brightness of the outer part of the galaxy, rotational velocities can be measured to a radius of nearly 90″ from the nucleus, or to 60% of the de Vaucouleurs radius listed in the *Second Reference Catalogue of Bright Galaxies* (de Vaucouleurs, de Vaucouleurs, and Corwin 1976; hereafter SRCBG). The position angle used for the spectrograph slit was 5° and was based on the author's determination of the line of nodes from the appearance of the galaxy on the Palomar Sky Survey Prints. Danver (1942), however, gives 13.3° for the position angle of the major axis and Nilson (1973) gives 15°. To correct our measured velocities for effects of projection, we adopt P. A. 14° for the true line of nodes.

The spectrogram was measured with the two-dimensional Mann measuring engine of the Department of Terrestrial Magnetism, Carnegie Institution of Washington. Reduction to velocities and correction for curvature were handled in a standard manner. The velocity measurements are tabulated in Table I.

The observed rotation curve implies a systemic velocity of V_H = 2260 km s^{-1} relative to the sun, with an estimated error of 20 km s^{-1}. This is in good agreement with the value $V_H = 2180 \pm 150$ km s^{-1} of Humason, Mayall, and Sandage (1956). Adopting our value for the recessional velocity and the conventional correction for the motion of our Galaxy (SRCBG), we have V_0 = 2372 km s^{-1}. According to de Vaucouleurs (1975), NGC 488 is a member of a small group of galaxies (G40) which has a mean recessional velocity of 2431 km s^{-1} on the basis of three velocities from the SRCBG and our new velocity for NGC 488. For an assumed Hubble constant of H = 50 km s^{-1} Mpc^{-1}, this velocity implies a distance of 48.6 Mpc. At this distance, 236 pc = 1″ on the plane of the sky.

The observed rotation curve in P. A. 5° is plotted in Fig. 1, where the velocities of the south side have been reflected through the origin. The observed central velocity gradient (uncorrected for inclination) is steep, $dV/dr \gtrsim 60$ km s^{-1} $arcsec^{-1}$. A sharp turnover occurs at $r \approx 5''$, but at the outermost data point the rotation curve still appears to be rising. A linear least-squares fit to the data beyond $r = 15''$ is $V = 198 + 0.35\, r''$ km s^{-1}.

From Danver (1942) and Nilson (1973), we adopt an angle of inclination of 40°, a value which also is consistent with the axial ratio given in the SRCBG. With this inclination and an angle on the sky of 9° between the spectrograph slit position and the true line of nodes, the correction factor relating the observed velocity to the true

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TABLE I. Heliocentric velocities in NGC 488, P.A. 5°.

Radius (arcsec)	Velocity (km/sec)	Radius (arcsec)	Velocity (km/sec)
	Hα λ6562		
-88 N	2503	-13	2469
-77	2493	-11	2447
-69	2488	-4	2445
-67	2474	+5 S	2058
-64	2466	7	2067
-61	2487	36	2078
-55	2487	38	2056
-53	2473	40	2031
-51	2473	43	2046
-48	2505	45	2039
-43	2505	47	2019
-41	2463	54	2032
-37	2472	73	2065
-35	2463	75	2045
	[NII] λ6583		
-66 N	2470	+5 S	2083
-52	2457	8	2075
-6	2438	54	2040
-4	2440	72	2041

rotational velocity in the plane of the galaxy is 1.60; the factor correcting the radial distance from the nucleus on the plane of the sky to the radial distance in the plane of the galaxy is 1.02. These values, allowing for possible error in both the position of the line of nodes and the inclination, should be accurate to within 5%.

During the course of other photoelectric photometry with the Lowell 0.6-m telescope located on Cerro Tololo, a few measurements were obtained on NGC 488. These data are listed in Table II.

TABLE II. Photoelectric photometry of NGC 488.

Aperture diameter	V	B-V
1.02'	11.48	1.02
1.35	11.22	1.00
1.88	10.91	0.95
2.58	10.65	0.94

III. DISCUSSION

In Fig. 2 a comparison is shown between the rotation curves of NGC 488 and several other early-type spiral galaxies, including NGC 4594 (Faber *et al.* 1977, Schweizer 1978), NGC 4378 (Rubin *et al.* 1978), NGC 7217 (Peterson *et al.* 1978), and M31 (Roberts and Whitehurst 1975). This selection does not represent a comprehensive survey of the literature, as there do exist a few other studies of Sa, Sab, and Sb galaxies. Rather, the sample only illustrates the rotation of NGC 488 with respect to other high-luminosity galaxies of similar Hubble type. In comparison to the morphologically similar NGC 7217, velocities in NGC 488 are higher as we would expect on the basis of both its slightly earlier Hubble type (Sandage 1960) and its luminosity class of I (van den Bergh 1976).

Brosche (1971) and Rubin, Ford, and Thonnard (1978) have shown that there is an upper envelope to the rotational velocities of galaxies and this limit correlates with Hubble type. The data from the study of Rubin *et al.*, a sample of 10 Sa through Sc high-luminosity galaxies, are shown in Fig. 3 as closed circles. NGC 488, shown as a cross (with error bars for both velocity and Hubble type), appears to lie above the Rubin galaxies, but this deviation from the overall trend cannot be considered to be significant. Their sample of massive, high-luminosity, large rotational velocity galaxies is adequate to show the existence of the correlation, but is too small to define accurately the true upper limit to

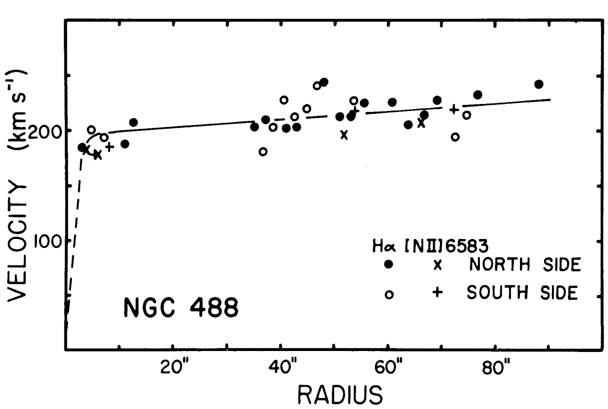

FIG. 1. The observed rotation curve of NGC 488 in position angle 5°. The data on the south side of the galaxy have been reflected through the origin. The solid line is a linear least-squares fit $V = 198 + 0.35\ r''$ km s^{-1}.

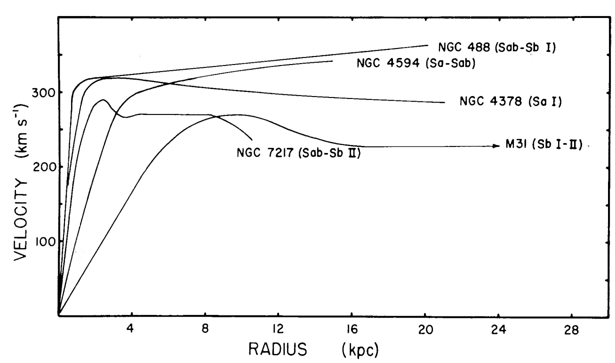

FIG. 2. The rotation curve of NGC 488 (corrected for geometrical projection effects) compared to the rotation curves of several other high-luminosity spiral galaxies of early Hubble type. The data for NGC 4594 come from Faber *et al.* (1977) and Schweizer (1978); NGC 4378, Rubin *et al.* (1978); NGC 7217, Peterson *et al.* (1978); and M31, Roberts and Whitehurst (1975).

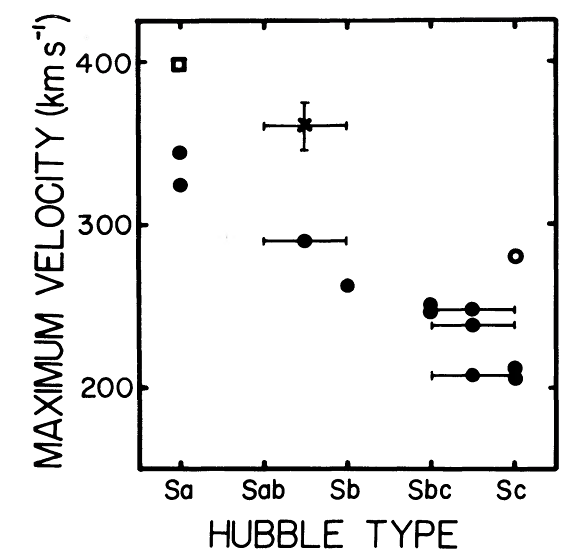

FIG. 3. The maximum rotational velocity observed in high-luminosity galaxies as a function of Hubble type. The closed circles are the data discussed by Rubin, Ford, and Thonnard (1978). NGC 488 is plotted as a cross with error bars showing both the uncertainty in maximum rotational velocity and in its Hubble type. More recent data of Rubin (1979, private communiction) for one Sa galaxy and one Sc galaxy are shown as an open square and an open circle, respectively.

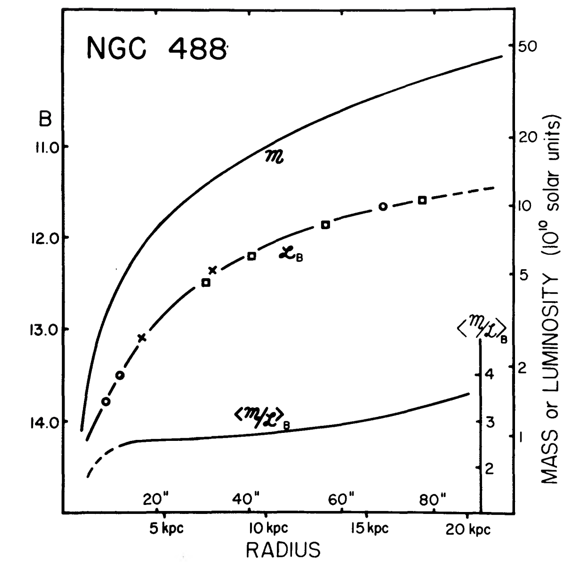

FIG. 4. The growth of mass and blue luminosity with radius in NGC 488. The vertical scale on the right gives both the mass and luminosity in terms of solar units. The scale on the left vertical axis is the observed blue magnitude from concentric aperture photometry of the galaxy. The data of Table II are shown as open squares, data from Pettit (1953) are shown as open circles, and photometry of de Vaucouleurs and de Vaucouleurs (1972) is shown with crosses. The run of the average blue mass-luminosity ratio interior to a given radius is shown at the bottom of the diagram.

rotational velocities. As the number of observations increases, we would expect to find a few galaxies with larger velocities, and this is the case. The Rubin (1979, private communication) survey of the kinematical properties of Sc galaxies now numbers over 20 systems; the largest rotation now known for that Hubble class is 280 km s^{-1} (open circle in Fig. 3). Similarly Rubin and co-workers, in systematically surveying the kinematical properties of Sa galaxies, have discovered one with $V_{max} = 400$ km s^{-1} (open square in Fig. 3); this is UGC 2885 in which the rotation curve can be measured to a radial distance of 122 kpc from the nucleus ($H = 50$ km s^{-1} Mpc^{-1}). In contrast, our data on NGC 488 extend only to 20 kpc from the nucleus. These new data thus continue to confirm the trend discussed by Rubin, Ford, and Thonnard (1978): the brightest and most massive Sa galaxies rotate faster than their Sb counterparts, which in turn rotate faster than the brightest Sc systems.

The rotation curve has been used to compute a mass model using the thin-disk approximation of Kuzmin (1952) increased by a factor of 1.1 (Brandt 1960) to partially compensate for the finite thickness of the galaxy. This model will give a lower limit to the mass. An upper limit would be provided by assuming a spheroidal galaxy, in which case the mass would be 1.4 times larger. In Fig. 4 the integral mass is shown as a function of radius. Also shown is the increase in blue luminosity with radius and the run of $\langle M/L \rangle_B$ with radius. To compute these two quantities, we have used the galactic absorption correction $A_B = 0.22$ magnitudes and approximately have corrected for extinction within NGC 488 via the relationship $A_i = 0.8 \log R_{25} = 0.08$ taken from the SRCBG. The mass-luminosity ratio increases slightly with radius, from $\langle M/L \rangle_B \gtrsim 2.3$ within 2 kpc, to $\langle M/L \rangle_B \gtrsim 3.6$ within 20 kpc radius. If the rotation continues flat beyond our last measured datum, then the mass within the de Vaucouleurs radius, $r = 57'' = 37$ kpc, is $7.5 \times 10^{11}\ M_\odot$ and we estimate $\langle M/L \rangle_B \gtrsim 4.7$. Interior to 2 kpc, our mass model suggests a more rapidly changing mass-luminosity ratio, but as both our mass model is least accurate in this region and photometry is lacking at small angular scales, this result is not of high accuracy. This contrasts with NGC 7217, where we (Peterson *et al.* 1978) found a change from $\langle M/L \rangle_B \sim 1$ interior to 2 kpc to ~ 6 within the de Vaucouleurs radius of 26.6 kpc. Within NGC 4594, Schweizer (1978) also computed a larger change in $\langle M/L \rangle$, but the greater part of the change occurred within the large nuclear bulge; the gradient of $\langle M/L \rangle$ in the disk is much smaller, very similar to the gradient we observe in the disk of NGC 488.

In summary, NGC 488 has the largest rotational velocity, and hence the largest mass, of any Sb galaxy which has been studied. Its rotation is consistent with the upper envelope on velocities as a function of Hubble type which Rubin and colleagues are finding in their survey of the kinematical properties of spiral galaxies. A comparison of the growths of mass and luminosity with radius shows a gentle increase in $\langle M/L \rangle_B$ with radius exterior to the nuclear region of the galaxy. It must be clearly emphasized, however, that the conclusions do rest on two assumptions: first, that the position angle of the line of nodes and the angle of inclination are determined adequately by the geometrical projection onto the plane of the sky of a circularly symmetrical galactic disk, and second, that noncircular motions are not of significance in the galaxy. Although I believe that these assumptions are valid in NGC 488, more comprehensive kinematical data are necessary for their confirmation. The galaxy as a rare example of the most massive high-luminosity systems warrants the additional investigation.

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