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THE VELOCITY FIELD AND KINEMATICS OF THE GALAXY NGC 784 IN THE H_α LINE

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In this paper we present the H_α map, the 2D velocity field and the rotation curve of the galaxy NGC 784 obtained with the ByuFOSC2 scanning Fabry-Perot interferometer, attached at the prime focus of the 2.6-m telescope of Byurakan Observatory. The H_α image shows several HII condensations along the major axis of the galaxy. The galaxy has an asymmetric distribution of the H_α emission. The rotation curve is quite symmetric with a low gradient in the central part of the galaxy.

Key words: *Galaxies:kinematics - galaxies:individual:NGC 784*

1. *Introduction*. A bar is a widespread structural feature of disk galaxies. According to available data, one third of disk galaxies have a well-defined bar, while another third have a weak inner bar. The star formation evidently occurs more efficiently in barred galaxies than in unbarred ones [1-5]. On the average, the barred galaxies in groups are redder than those outside of groups [2]. Such a difference may be due to the star forming activity of barred galaxies in groups.

The knowledge of the inner kinematics of the galaxies with an active star formation is fundamental for a good understanding of the nature of these systems. Ionized gas is a good tracer in galaxies, which gives possibility for detailed study of internal motions and rotation. Furthermore, the H_α emission line is a tracer of the current star formation activity and information obtained by using the H_α line observation will help to determine the star formation properties of galaxies.

The velocity fields of spiral galaxies have been investigated in different ways (see, e.g. [6] for summary). However, the Fabry-Perot technique allows to obtain velocity measurements all over the observed galaxy. This enables to derive a complete 2D velocity field, hence providing the true rotation curve. The Fabry-Perot scanning interferometer coupled with 2D detectors (IPCS or CCD) allows one to increase both spatial and spectral resolution.

In recent years, a new generation of large telescopes and improvement in detectors have made it possible to obtain more and more information about those with low surface brightness called dwarf galaxies. They are defined as galaxies with an absolute brightness in the visual spectral range $M_V > -11$ mag;

their masses are typically about 10^8 solar masses. Dwarf galaxies are in fact the dominating population of galaxies, since they are much more abundant than normal galaxies.

The barred irregular dwarf galaxy NGC 784 is the subject of this article. The aim is to obtain high-resolution 2D velocity fields in the H_α line of ionized hydrogen for NGC 784. For distance calculation we have adopted a Hubble constant of $H_0 = 75\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$.

2. *Observations and data reduction*. NGC 784 has been observed in October 13, 1999 at the F/3.8 prime focus of the 2.6-m telescope of the Byurakan Astrophysical Observatory with the ByuFOSC2 scanning Fabry-Perot (798) interferometer and CCD detector [7]. A focal reducer gave a final aperture ratio F/1.9 and total field of view 6'.8 x 6'.6 on 530 x 514 pixel of the CCD detector. The spatial scale is 0".77 $\mathrm{pixel^{-1}}$ on the detector. An H_α interference filter (77B) was selected to match the redshift of NGC 784. The observation parameters were:

Spectral range	H_α interference filter centred at 6567 Å
Radial velocity	198 km $\mathrm{s^{-1}}$
Total exposure time	168 min
Free spectral range	8.28 Å (378 km $\mathrm{s^{-1}}$)
Sampling step	0.34 Å (16 km $\mathrm{s^{-1}}$)
Number of channels	24

Calibration before and after observations were obtained by scanning the narrow and stable Ne 6599 Å line under the same condition as the observation of the target galaxy. Comparing the observed profiles with those given by a Neon lamp used as a wavelength reference enables one to compute the wavelength shift through the Doppler effect, hence giving the radial velocity for each part of ionized gas in the observed galaxy. Star-free sky regions were measured around the galaxy in order to subtract background radiation from the H_α and continuum images.

The data reduction has been made with the software ADHOCw, written by J.Boulesteix (http://www-obs.cnrs-mrs.fr/adhoc/adhoc.html). The main procedures of the data reduction are the following:

a) Adding and cleaning the original images. First step is to correct image of the data from dark current and flat field. After the flat field and dark current corrections, it is necessary to remove cosmic rays and correct the data cube from transparency fluctuations and seeing variation.

b) Computing the phase map from the calibration rings, which gives the reference wavelength for the line profile, observed inside each pixel.

c) Converting the observed interference patterns of the galaxy into wavelength maps, by using the phase map. The subtraction of the night skylines, such as OH emission lines, is made at this step of the data analysis.

d) Computing the velocity field, monochromatic and continuum maps. The row data are smoothed in order to increase the S/N ratio. A Gaussian smoothing is applied to the H_α profiles (with 3 channels FWHM). A spatial smoothing is applied as well (in X and Y, with 3 pixel FWHM).

e) The rotation curve is computed from the velocity field along the points found within ±50° angular sector from the major axis.

f) The centre of symmetry of the velocity field, hence of the rotation curve, was adopted as the coordinates of the rotation curve. The systemic velocity is a velocity of the centre of mass of the galaxy.

g) The position angle of the major axis is measured counter clockwise from the North.

The main kinematical parameters of NGC 784, together with some fundamental parameters found in the literature are:

Morphological type, from the LEDA data base	SBdm
Total apparent corrected B magnitude, from LEDA	$11^m.11$
Size of the galaxy, from LEDA	$6'.6 \times 1'.5$
Systemic velocity, deduced from our velocity field	191 km s^{-1}
Distance, deduced from the systemic velocity	2.5 Mpc
Inclination angle, deduced from the analysis of our velocity field	69°
Position angle of the major axis, deduced from our velocity field	182°

The accuracy we obtained for the systemic velocity is about 5 km s^{-1}. For P.A. of the major axis and the inclination angle the accuracy is 10°.

3. ***Results***. NGC 784 (UGC 1501, IRAS 01582+2836) is a barred irregular dwarf galaxy, seen nearly edge-on. It is a member of a group of

Fig.1. DSS image (10' x 10') of NGC 784 (the North is up, the East to the left).

galaxies LLG 11 (LEDA). Broelis and van Woerden [8] studied the structure and kinematics of NGC 784 in the HI line, showing that its neutral hydrogen

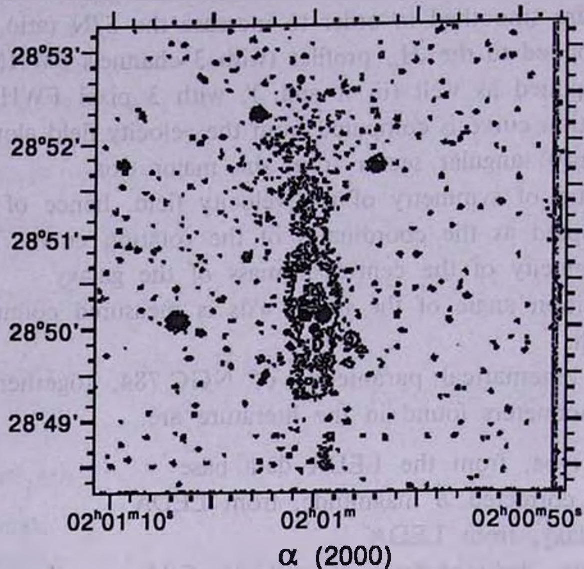

Fig.2. H_α image of the central part of NGC 784 restored from the ByuFOSC2 scanning sequence (the orientation as in Fig.1).

content is typical for an irregular galaxy. Drozdovsky and Karachentsev [9] using photometry of the brightest stars in NGC 784 have estimated distance to the NGC 784 of 5 Mpc. The results of *UBV* and H_α imaging of a sample of gas-rich dwarf irregular galaxies show that most of these systems can be well

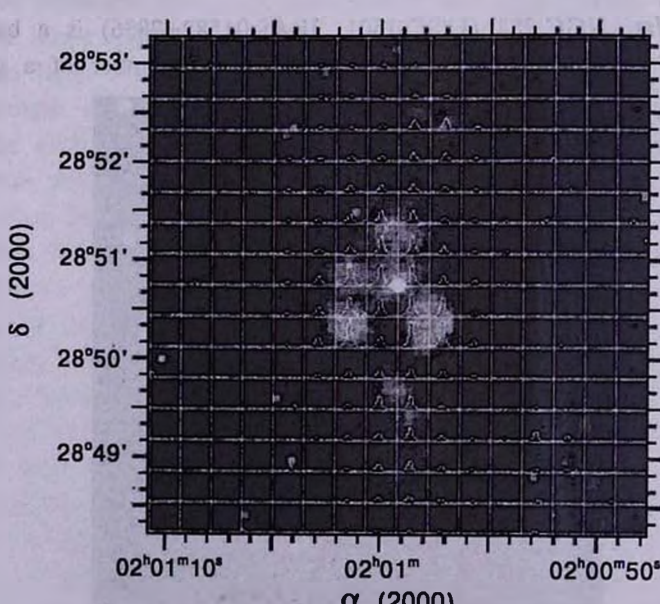

Fig.3. H_α profiles superposed on the H_α image of the central part of NGC 784.

fitted by single exponential disks and have only minor colour gradient [10]. The observed HII regions are sparsely distributed across the optical disk [10].

DSS (Digital Sky Survey) image of the galaxy is presented in Fig.1. Fig.2 shows the H_α image of NGC 784 restored from the ByuFOSC2 scanning sequence. The H_α image is derived from the analysis of the H_α line profiles by measuring the flux density inside the line for each pixel. It gives a pure monochromatic image of the galaxy. The relative intensity levels are coded here through gray levels. The H_α image clearly shows noteworthy HII condensations along the major axis. Fig.3 shows an example of the H_α profiles superimposed on the H_α image of the central part of NGC 784. The isovelocity lines superimposed on the H_α image of the galaxy are presented in Fig.4. These lines were drawn from the original velocity field (subtracting the heliocentric velocity) after a Gaussian smoothing. The systemic velocity

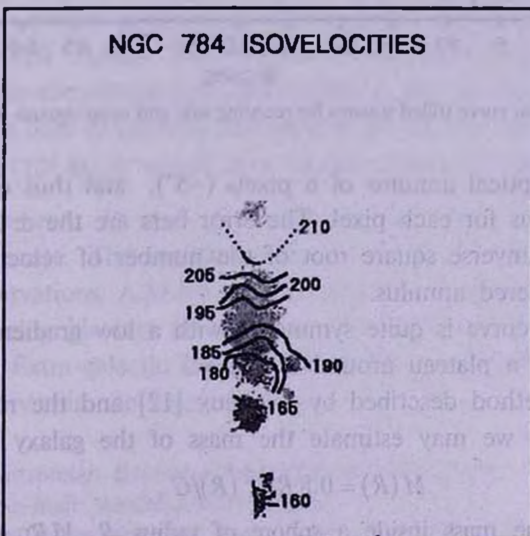

Fig.4. The isovelocity lines superposed on the H_α image of NGC 784.

we found for NGC 784 is 191 ± 10 km s^{-1} (heliocentric velocity). This value is in perfect agreement with the HI line observation of NGC 784 [8], which gave 195 ± 10 km s^{-1}. Moreover, the average value indicated in the RC3 from radio observations is 198 ± 5 km s^{-1} for the heliocentric radial velocity of NGC 784, which is consistent with our observation. The optical observation of NGC 784 yields 198 ± 1 km s^{-1} [11] for the heliocentric radial velocity.

The galaxy has an asymmetric distribution of the H_α emission, the northern part being rather poor whereas the southern part exhibits bright HII regions.

The rotation curve of NGC 784 is shown in Fig.5. We have plotted the curve with both sides of the galaxy, with respect to the centre itself, in the same quadrant, using different symbols for the receding (filled squares) and approaching (open squares) side. The rotation curve is drawn as explained in the previous section. The velocity points are weighted means for the entire data set. The plotted points are weighted means inside concentric annuli of elliptical shape (because of the inclination of the galaxy). We consider a

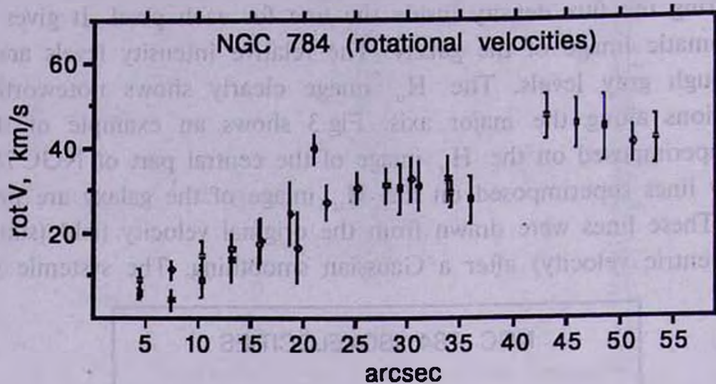

Fig.5. H_α rotation curve (filled squares for receding side and open squares for approaching side).

width of the elliptical annulus of 6 pixels (~5"), and thus obtain a middle velocity and radius for each pixel. The error bars are the ± 1 rms dispersion weighted by the inverse square root of the number of velocity points found inside the considered annulus.

The rotation curve is quite symmetric with a low gradient in the central part and reaches a plateau around 30 km s^{-1}.

Using the method described by Lequeux [12] and the rotation curve of NGC 784 (Fig.5) we may estimate the mass of the galaxy as

$$M(R) = 0.8\, RV^2(R)/G\,,$$

where $M(R)$ is the mass inside a sphere of radius R, $V(R)$ is the maximum rotation velocity at the radius R and G is the gravitation constant. Numerically this equation writes, with $M(R)$ in $M_\odot$, R in kpc and $V(R)$ in km s^{-1},

$$M(R) = 1.86 \cdot 10^5\, R(\mathrm{kpc})V^2\left(\mathrm{km\ s^{-1}}\right).$$

For NGC 784 we find $M = 4.25 \cdot 10^8 M_\odot$ within 47" (R=1.13 kpc, V=45 km s^{-1}). The total HI mass of NGC 784 is $1.1 \cdot 10^8 M_\odot$ (Westerbork Survey of HI in spiral galaxies (WHISP), http://www.astro.rug.nl/whisp), which is almost a quarter of the total central mass of the galaxy.

Following Kim [13], we can estimate the total mass of the ionized gas:

$$M_{\mathrm{HII}} = 2.8 \cdot 10^{-3} D^2 F(\mathrm{H}_\alpha)\, n_e,$$

where M_{HII} is expressed in $M_\odot$, the distance D in Mpc, the H_α flux $F(\mathrm{H}_\alpha)$ in 10^{-14} erg cm^{-2} s^{-1} and the electron density n_e in cm^{-3}. According to [10] for NGC 784 $F(\mathrm{H}_\alpha) = 171 \cdot 10^{-14}$ erg cm^{-2} s^{-1}. D=5 Mpc is used as the distance for NGC 784. We have assumed for $n_e \sim 100\,cm^{-3}$ [14]. We find the total mass of ionized gas for NGC 784 $M_{HII} \sim 10^3 M_{\odot}$, which is a very low mass ($\sim 2 \cdot 10^{-4}$ % of the mass of the central region of NGC 784), and is negligible component of the total galaxy mass.

Unfortunately, the H_2 gas content of NGC 784 has not been reported in the literature, however this component of the total mass is very small and can be neglected, since it is difficult to detect CO emission (which is a tracer of the molecular hydrogen content) in low-mass galaxies due to its low abundant.

Despite the fact that dwarf irregular galaxies are considered gas-rich systems, the gas density is well below the threshold for star formation [15]. Therefore, the star formation activity in these galaxies is still unclear.

4. *Conclusions.* NGC 784 has an asymmetric distribution of the H_{α} emission, the northern part being rather poor whereas the southern part exhibits bright HII regions. The rotation curve has a symmetric shape with a low gradient in the central part and reaches a plateau around 30 km s^{-1}. The rotation curve is used to estimate the mass of the central part (~1 kpc) of NGC 784 ($M = 4.25 \cdot 10^8 M_{\odot}$), which is a typical value for dwarf galaxies.

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ПОЛЕ СКОРОСТЕЙ И КИНЕМАТИКА ГАЛАКТИКИ NGC 784 В ЛИНИИ H_{α}

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В статье представлена карта в H_{α}, 2D поле скоростей и кривая вращения галактики NGC 784, полученные с помощью сканирующего Фабри-Перо интерферометра ByuFOSC2, установленного в первичном

фокусе 2.6 метрового телескопа Бюраканской обсерватории. Изображение в H_α показывает несколько HII конденсации вдоль большой оси галактики. Наблюдается асимметричное распределение H_α эмиссии. Кривая вращения довольно симметричная с низким градиентом в центральной области галактики.

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