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ROTATING CURVE OF THE GALAXY NGC 1068

Abstract. The matter in the body of spiral galaxies (stars, nebulae, clusters), judging by their images, is distributed very non-uniformly. Moreover, all objects have their own velocities in space. However, in general, they are affected by the gravitational field of the total mass, referred to the center of the galaxy. One of the main aim is to evaluate this mass. In order to weaken the effect of random velocities, the average spectrum from fairly large sections of the galaxy along the entrance slit of the spectrograph is recorded.

In the Fesenkov Astrophysical Institute (FAPHI) the spectral observations of the bright Seyfert galaxy NGC 1068 were carried out in the red region of the spectrum. The telescope AZT-8 with a diameter of 0.7 m and a slit spectrograph designed and manufactured in FAPHI was used. The spectra were recorded on a SBIG CCD ST-8 (1530x1020, 9μ). The spectrograms obtained with the long slit were used to measure the profiles of the Hα and [NII], 6583Å, emission lines, namely, the radial velocities were determined at different distances from the center in the 9 "x10" areas. Further processing assumes that the galaxy is a thin circular disk whose matter rotates around the center so that at each distance from the center the rotation velocity is constant and it depends only on the distance to the center, and the disk itself is observed as an ellipse due to the inclination to the line of sight.

In order to obtain a real dependence of the rotational velocities on the distance from the center under these assumptions, it is necessary to translate the distances along the slit and the radial velocities measured at these points into the galaxy plane by taking into account its inclination to the line of sight. As a result, the dependence of the rotation velocities of matter on the distance to the center was obtained. The mass of the disk with a radius of 6 parsec was estimated.

Keywords: seyfert galaxies, emission lines rotating curve; individual: Sy NGC 1068.

Introduction

NGC 1068 is one of the closest and brightest Seyfert galaxies (Sy). It has a complex structure. The velocity field of the matter motion in this galaxy was studied in detail with the large telescopes [1, 2]. A map of isolines of the equal radial velocities was obtained, which shows a very complex picture [1]. Mass estimation is usually performed using the laws of mechanics and experimental data on the velocities of the mass movement along the rotation curve. Obtaining of a rotation curve for galaxies, visible from the edge is the simplest procedure. In such case, the distances from the center are measured directly from the spectrogram, however, the measured positions of the line can differ markedly from the true rotation velocities. At each distance from the center in this case, the total radiation of objects falling on the line of sight in this direction is recorded. Contribution is made by all regions, including distant objects, which also appeared on the line of sight. This leads to large errors in the estimates of the true velocities.

More accurate rotation curves can be obtained for galaxies with such an inclination to the line of sight, at which the integration during spectroscopy occurs in a fairly narrow volume of the galaxy. At the same time, galaxies, having the form of an ellipse, should not have an eccentricity close to zero, so that the projections of the measured velocities are not commensurate with measurement errors. It should be noted that the transition to the true velocities and distances implies that the galaxy is flat, thin enough and has circular symmetry. The galaxy NGC 1068 - one of the most studied in a wide range of wavelengths seyfert galaxies, satisfies to such criterion. Its global characteristics, in particular the mass, are known not very well. To obtain general characteristics, observational data should be averaged. Averaging can be carried out directly during observations.

This paper uses the results of spectral studies of NGC 1068 obtained with a small telescope. The procedure for processing and accounting for the orientation of the galaxy is describes in details below.

Observations and processing

Observations were carried out in the 11.2 m Cassegrain focus of the telescope AZT-8 (diameter of 0.7 m) with the diffraction spectrograph made in FAPHI [3]. CCD camera SBIG ST-8 (1530x1020, 9μ) was used as a receiver. For the wavelength calibration, the spectrum of the lamp with HeI, NeI and ArI emission lines was used. The observations were carried out on 2007, October 28. Three 30 minutes exposures were made. To use the different parts of the matrix, the center of the galaxy was shifted along the slit by 15" at different exposures. The broad 10" slit of spectrograph was oriented parallel to the celestial equator. Along the dispersion, the scale was 0.183Å/pixel, and across the dispersion - 0."65/pixel.

Processing was carried out separately for each of the three spectrograms. The wavelengths of the two emission lines Hα and [NII] 6583 Å were determined. The measurements were carried out in the 6" bands close to each other from the center in both directions until at least one of these lines remained measurable. The results are presented in Table 1. It was especially difficult to carry out measurements in the central band. Figure 1 shows a fragment of the spectrum in this central band, where narrower emissions are superimposed on the broad asymmetric lines Hα and [NII] 6583 Å. There is also an example of a fragment of the spectrum at a distance of +18 ", where there are no difficulties with measurements. For this reason, a number of authors, for example [1], do not give any data on the velocities in the central region of the galaxy NGC 1068.

If to assume that the galaxy has axial symmetry, then, having the radial velocity along the section passing through the center, the angle of inclination of the galaxy plane «i» or the eccentricity of the observed galaxy «e» and the angle between the observed major axis and the «φ» section, it is possible to get a true rotation curve in the plane of the galaxy itself. To do this, one can use any section that passes through the center, except for that one along the minor axis.

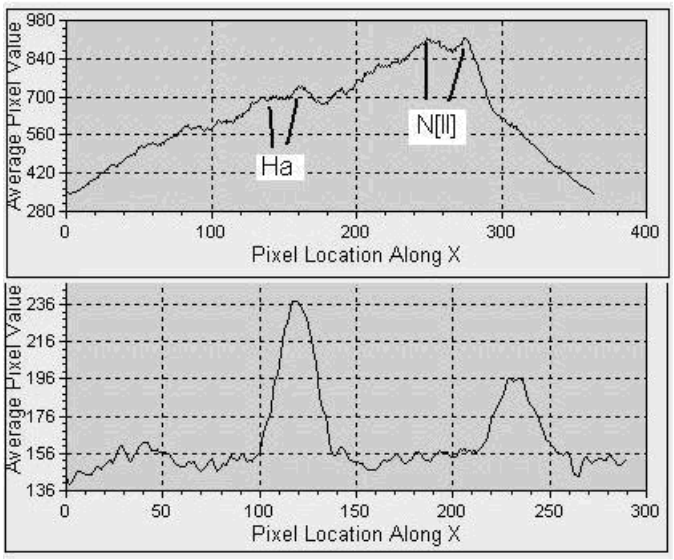

Figure 1 - Fragments of the spectrograms near emission lines of Hα and [NII], 6583Å in the 9 image lines. Axis X shows the numbers of pixels. The upper panel – the spectrum of the central band, where besides the broad lines, the narrower emission, shifted to the «red» side, are visible. The bottom panel – fragment of the spectrogram on the 18" distance from the centre, where the wavelengths of these lines are unambiguously measurable

Further, the result must be corrected for the effect of the projection of the section distances from the center and radial velocities for the inclination of the galaxy to the line of sight. The transition to the true distances «r» under the assumption that the galaxy is a circular disk tilted to the line of sight at an angle «i» can be made using the following formula, where «e» is the eccentricity of the visible image and «φ» is the angle between the major axis of the galaxy image and the slit direction

$$r = r_{obs} \cdot \frac{\sqrt{(1-e^2 \cdot \cos^2 \varphi)}}{(1-e)} \quad (1)$$

In this case, the true rotation velocities in the galactic plane V at the corresponding distances «r» are related to the observed Vr values by the formula:

$$V=Vr/\cos \varphi/\sin i \quad (2)$$

We used the following parameters: i = 32.50 [4], e = 0.5373, φ = 450. Thus, r"= r" obs · 1.8483 and V = Vr / 0.2687 for all distances from the center.

The results of the observations given in Table 1 allow us to obtain the dependence of the rotational velocitis of the annular zones in the galaxy plane on their distances from the center, expressed in parsecs. For this the redshift of the galaxy and the Hubble constant are required. The values Vr = +1137 km / s [4] and H = 72 km/s/Mpc were assumed.

Table 1 – The wavelengths of the emission lines Hα and [NII], measured on the different distances from the centre

R"	Hα (A)	N[II] (A)	Hα (B)	N[II] (B)	Hα (C)	N[II] (C)
-42			6585.6	6605.3		
-36	6585.6	6605.7	6585.2	6605.3	6585	6606.6
-30	6583.8	6605.3	6583.2	6606.6	6585.2	6605.9
-24	6584.3	6605.2	6584.3	6605	6584.7	6605.5
-18	6584.5	6605.7	6584.7	6605.9	6584.5	6605.3
-12	6585.2	6606.4	6584.9	6605.7	6584.9	6606.3
-6	6585.4	6606.1	6585.8	6607.2	6584.5	6605.9
0	6589.4	6609.4	6585.4	6605	6584.9	6586.7
6	6590.7	6610.1	6591.1	6607.2	6590.7	6610.7
12	6590.3	6610.8	6590.2	6610.7	6590.3	6611.1
18	6590.2	6610.8	6589.6	6610.7	6589.8	6610.5
24	6590	6610.5	6589.8	6611	6589.8	6610.7
30	6588.7	6610.5			6590	6610.1
36	6588.7	6609.7			6590.5	
42	6587.6	6608.8				

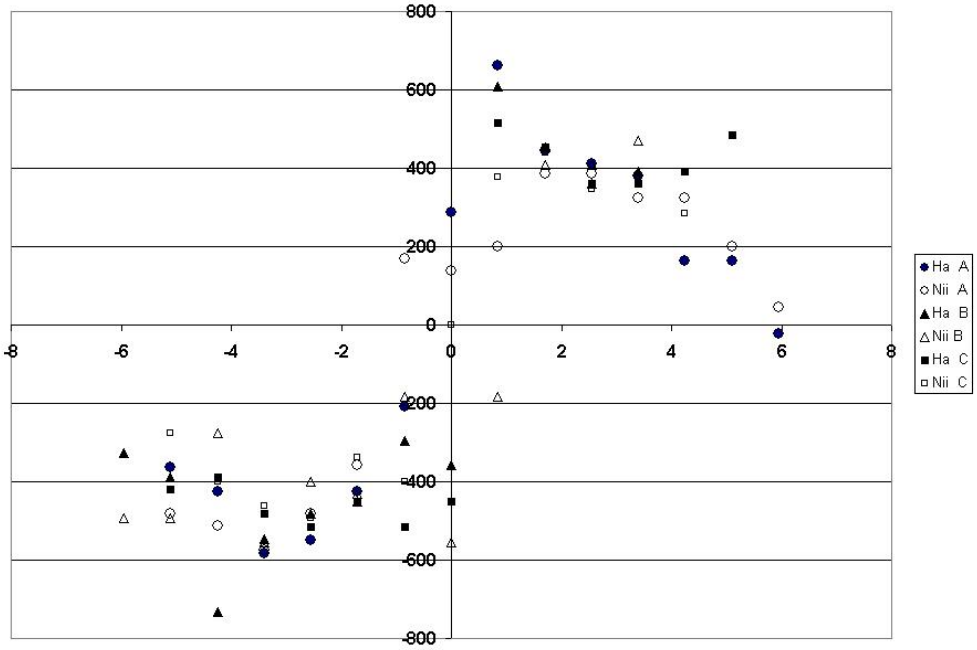

Fig. 2 - The Y axis shows the true rotational velocities of the regions of the galaxy NGC 1068 at distances through the 6″ to both sides of the center. The distances in kpc are on the X axis. For each distance, the values are obtained for each of the spectrograms (A, B and C) along Hα and [NII]]6583Å lines (see the icons on the right)

Obtained results

Figure 2 shows the rotation curve of the galaxy NGC 1068. It is based on the results of measuring the position of the line (in radial velocities) at different distances from the center. The emission lines Hα и [NII], 6583 were used. Measurements were taken every 6" in three spectrograms. It can be seen that there are differences in the rotation of the eastern and western (relative to the center) parts of the galaxy. In the region of ± 1.5 kpc, the rotation is close to solidstate. If to assume that at a distance of 6 kpc, the average rotational speed is about 300 km/s (see Fig. 2), then the mass inside this radius can be estimated by the formula $M = V^2 \cdot r / G$, and will be equal to ~ $1.25 \cdot 10^{11}$ M☼. Earlier for r = 5.7 kpc, the mass estimate of $6.4 \cdot 10^{10}$ M☼ was obtained [4].

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NGC 1068 ҒАЛАМЫНЫҢ АЙНАЛУ ҚИСЫҒЫ

Аннотация. Ірімді ғаламдарда материя (жұлдыздар, тұмандықтар, шоғырланулар), олардың суреттеріне қарағанда біртексіз таралатындығын көреміз. Сонымен бірге, кеңістікте барлық объектілердің өзіндік жылдамдықтары бар. Ғаламның центріне бағытталған, жиынтық массаның гаравитациялық өрісі әсер етеді. Солардың ең негізгі бір есебі массаларын анықтау болып табылады. Спектрографтың саңылауына кіретін бойымен, кездейсоқ жылдамдықтардың әсерін әлсіретуге ғаламның анағұрлым үлкен бөлігінің орташа спектрі тіркеледі.

ФАФИ спектрдің қызыл аймағында аса жарық сейферт ғаламының спектрлік бақылаулары жүргізілді. ФАФИ құрастырылған және жасалған саңылаулы спектрограф және диаметрі 0.7 м АЗТ-8 телескобы қолданылды. Спектрді ЗБА SBIG ST-8 (1530x1020, 9μ) камерасы арқылы тіркелді. Алынған ұзын спектрограммаларда Hα және [NII], 6583Å эмиссиялық сызықтарының кескіндері, соның ішінде центрден әртүрлі қашықтықтан ауданының өлшемі 6"x10" болатын сәулелік жылдамдықтар анықталды. Өңдеулерден кейін ғалам жуан, дөңгелек диск, материя центрдің айналасында айналады, центрден әрбір қашықтықтағы жылдамдық тұрақты және тек қана центрден қашықтыққа ғана тәуелді деп болжанады және де, көру сәулеленуіне көлбеулігіне байланысты диск эллипс болып бақыланады.

Осы болжамдардан, айналу жылдамдығының центрден қашықтыққа нақты тәуелділігін алуға көру сәулеленуінің көлбеулігін есепке алып ғалам жазықтығында сәулелену жылдамдығы өлшенген осы нүктелерді және саңылау бойындағы қашықтыққа аудару қажет. Нәтижесінде, материя айналу жылдамдығының центрден қашықтыққа тәуелділігі алынды және радиусы 6 парсек дисктің массасы анықталды.

Түйін сөздер: сейферт ғаламдары, эмиссиялық сызықтар; айналу қисығы; жеке объектілер: Sy NGC 1068.

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КРИВАЯ ВРАЩЕНИЯ ГАЛАКТИКИ NGC 1068

Аннотация. Материя в теле спиральных галактик (звезды, туманности, скопления), судя по их изображениям, распределяется весьма неоднородно. При этом все объекты имеют свои скорости в пространстве. Однако в целом на них действует гравитационное поле суммарной массы, отнесенной к центру галактики. Одна из основных задач состоит в том, чтобы оценить эту массу. Для того, чтобы ослабить влияние случайных скоростей, регистрируется средний спектр от достаточно больших участков галактики вдоль входной щели спектрографа.

В АФИФ проведены спектральные наблюдения яркой сейфертовской галактики NGC 1068 в красной области спектра. Использовался телескоп АЗТ-8 диаметром 0.7 м и щелевой спектрограф, спроектированный и изготовленный в АФИФ. Регистрация спектров велась на ПЗС камеру SBIG ST-8(1530x1020, 9μ). На спектрограммах, полученных с длиной щелью, измерялись профили эмиссионных линий Hα и [NII], 6583Å,

а именно определялись лучевые скорости на разных расстояниях от центра в площадках размером 6"x10". При дальнейшей обработке предполагается, что галактика является толстым круглым диском, материя которого вращается вокруг центра так, что на каждом расстоянии от центра скорость вращения постоянна и зависит только от расстояния до центра, а сам диск наблюдается как эллипс из-за наклона к лучу зрения.

Для того, чтобы в этих предположениях получить реальную зависимость скоростей вращения от расстояния от центра, необходимо перевести расстояния вдоль щели и измеренные в этих точках лучевые скорости в плоскость галактики путем учета ее наклона к лучу зрения. В результате получена зависимость скорости вращения материи от расстояния до центра и оценена масса в диске с радиусом 6 парсек.

Ключевые слова: сейфертовские галактики, эмиссионные линии; кривая вращения; индивидуальные объекты: Sy NGC 1068.

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