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DYNAMICS OF THE INTERACTING GALAXY PAIR KPG 302 (NGC 3893/96)

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RESUMEN

Se presentan observaciones cinemáticas del par de galaxias en interacción tipo M51 KPG 302 (NGC 3893/96), las implicaciones que pueden hacerse sobre el contenido de materia obscura y visible de las componentes del par y un análisis muy preliminar de la interacción basado en simulaciones con un código de N-cuerpos. Las conclusiones principales son que nuestra cinemática es compatible con halos de materia obscura tanto NFW o pseudoisotérmicos y que el cociente de masas entre las galaxias del par tendría que ser mayor que 1/50 para que pudiera desarrollarse la estructura espiral observada en la componente más masiva del par.

ABSTRACT

In this work we present scanning Fabry-Perot observations of the M51-type interacting galaxy pair KPG 302 (NGC 3893/96), the derivations one can make about the content of visible and dark matter of the components of the pair and a very preliminary analysis of the encounter based on simulations made with an N-body code. The main conclusions we reach are that our kinematics is equally compatible either with NFW dark matter profiles or pseudo-isothermal halo profiles and that the mass-ratio of the galaxies in the pair should be larger than 1/50 in order to develop the observed spiral structure seen in the larger component of the pair.

Key Words: galaxies: individual (NGC 3893, NGC 3896) — galaxies: interactions — galaxies: kinematics and dynamics — galaxies: spiral

1. INTRODUCTION

Interacting galaxy pairs of the M51-type are pairs formed of a large spiral galaxy and a less massive companion, with some sign of interaction. These pairs are relevant in many ways but here we focus on the fact that for these pairs there are at least two independent ways of estimating the dark matter content of the large galaxy: (1) by means of the rotation curve (RC) of the large galaxy, and (2) by means of the orbital motion of the satellite galaxy around the large galaxy. NGC 3893/96 is an interacting galaxy pair with number 302 in the Catalog of Isolated Pairs of Galaxies in the Northern Hemisphere (KPG, Karachentsev 1972). NGC 3893 is a grand-design Sc type galaxy similar to M51. Its companion, NGC 3896, appears to be a lenticular galaxy (S0a). Though optical images of this pair do not show an apparent connection between the two galaxies, radio images show extended HI emission encompassing both galaxies (Verheijen & Sancisi 2001). This common HI envelope is elongated from SE to NW, parallel to the line that joins the nuclei of both galaxies. HI isophotes also show what could be considered as a broad arm going from NGC 3893 to NGC 3896. The kinematical analysis derived from the PUMA Fabry-Perot observations has been already published in Fuentes-Carrera et al. (2007). Here we will summarize the main results of that work and describe preliminary results of N-body simulations obtained by taking the observational results as boundary conditions.

2. OBSERVATIONS AND DATA REDUCTION

Observations of NGC 3893/96 (KPG 302) were done at the 2.1 m telescope at the OAN-SPM (México) using the scanning Fabry-Perot (FP) interferometer PUMA (Rosado et al. 1995). In that way we obtained FP object cubes at Hα covering a field of view of $10'$, with spatial resolution of $1.16''$ pixel^{-1}, and sampling spectral resolution of 19 km s^{-1} with a free spectral range of 912 km s^{-1}. Calibration cubes have also been obtained by using an Hydrogen lamp and isolating the Hα line at rest.

Data reduction and analysis were done using mainly the ADHOCw[4] software and the CIGALE

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[4]`http://www.oamp.fr/adhoc/adhocw.htm` developed by J. Boulesteix.

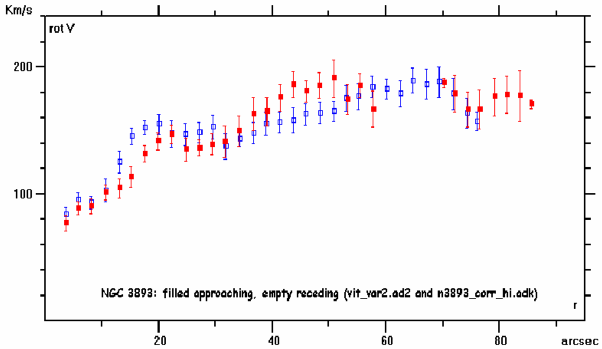

Fig. 1. RC of NGC 3893. Both sides of the curve have been superposed. Open squares (blue) correspond to the receding side of the galaxy. Filled squares (red) correspond to the approaching side.

software (Le Coarer et al. 1993). The velocity fields as well as the RCs along the major axis of the galaxies were obtained. Further details on the observations and data reduction can be found in Fuentes-Carrera et al. (2007).

3. MAIN KINEMATIC RESULTS

Figures 1 and 2 show the RCs of NGC 3893 and its companion NGC 3896 as obtained from the Hα FP data. From these RCs it is possible to have a mass estimate for the galaxies using the Lequeux method (Lequeux 1983) which gives the mass of a galaxy inside a certain radius R as 0.6 (for a disk-like system) to 1.0 (for an spheroidal system) $\times$ RV^2(R)/G. According with this, a total mass of 5 to 8.4 $\times\ 10^{10}\ M_{\odot}$ is obtained for NGC 3893, inside a radius of 10.8 kpc, while inside the first 1.5 kpc of NGC 3896, the total mass contained is 4.8 to 8 $\times 10^8\ M_{\odot}$. Thus, the mass ratio M_2/M_1 is constrained to vary between 1/63 to 1/168.

Figure 3 (taken from Fuentes-Carrera et al. 2007) shows a multi-wavelength RC for NGC 3893 using both the optical PUMA data and the HI kinematical data from Verheijen & Sancisi (2001). As seen in this figure, the interior part of this galaxy has very similar kinematics in both the ionized and the neutral gas. This fact confirms our previous mass estimate because the maximum amplitude of the rotation velocity (190 km s^{-1}) is obtained both for the ionized and the neutral gas. Towards the exterior part, the HI shows a decrease in rotational velocities (see the two outermost points of the RC).

In order to study the mass distribution in NGC 3893 we used the mass model from Blais-Ouellette et al. (2001). This model uses both the light distribution of the galaxy and a theoretical dark halo profile to compute a rotation curve that best fits the observed one. The mass-to-light ratio of the disk $(M/L)_{DISK}$ as well as the dark matter halo properties –central density ρ_0 and core radius R_0– are free parameters. The DM halo can be either a pseudo-isothermal sphere (Begeman 1987) or a NFW profile (Navarro et al. 1996). Taking the optical photometry of Hernández-Toledo & Puerari (2001) and a value for the mass-to-light ratio of the disk, $(M/L)_{DISK}$ =0.56 (Kranz et al. 2003), we were able to fit non-maximal disks and either NFW or pseudo-isothermal halos at similar confidence levels. However, the outermost points of the RC could not be fitted. This can be explained if the halo of NGC 3893 is truncated, among other possibilities.

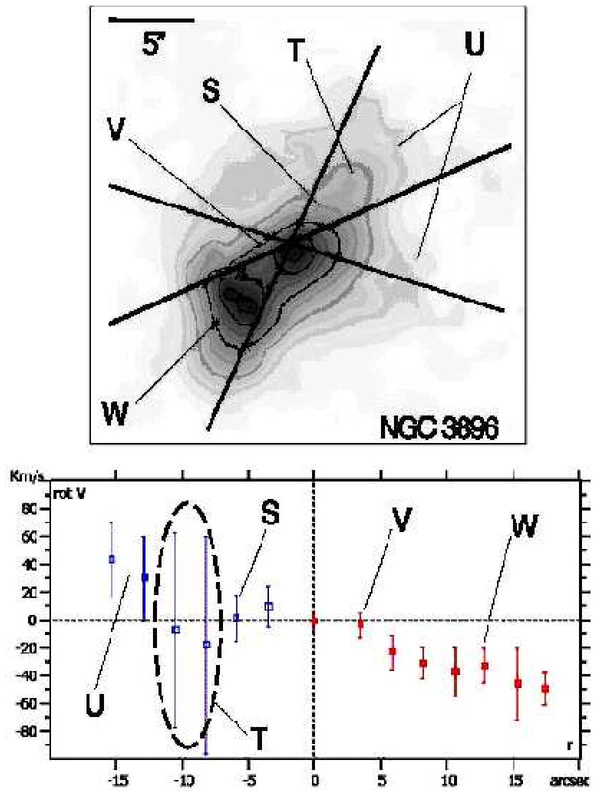

Fig. 2. Top: Hα image of NGC 3896 showing different features labeled with letters. The solid lines indicate the galaxy's position angle (PA) and the angular sectors from both sides of the major axis considered for the computation of the galaxy's RC. Bottom: RC of NGC 3893. Open squares correspond to the receding side of the galaxy. Filled squares correspond to the approaching side. The location of the different features is also marked.

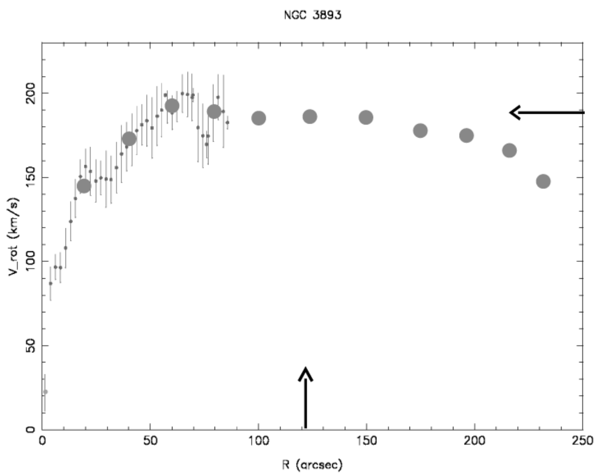

Fig. 3. Multi-wavelength curve of NGC 3893. Small dots in the inner parts of the curve correspond to PUMA Hα observations. Larger dots in the outer parts correspond to the HI curve derived by Verheijen & Sancisi (2001). The horizontal arrow indicates the point with maximum rotation velocity. The vertical arrow shows the radius considered for mass estimation using the method by Lequeux (1983).

4. PRELIMINARY SIMULATIONS

We have used the kinematical results mentioned earlier as boundary conditions for simulating the encounter. The simulations were done using GADGET and the geometry displayed in Figure 4, where it is seen that we took the satellite galaxy as a point-mass in a retrograde elliptic orbit (e = 0.79). The N-body simulations consider NGC 3893 as a galaxy formed of a disk and a NFW halo with 10000 and 60000 particles, respectively. In these simulations we do not consider the presence of gas. We have done two different simulations, the first with a $M_2/M_1 = 1/50$ and the second with $M_2/M_1 = 1/10$. The first simulation (which is the one that approaches more to the mass ratio derived from the RCs) showed that after one revolution (250 Myr) no grand-design spiral pattern is formed. On the other hand, the second simulation (that considers a more massive satellite) indeed develops grand-design spiral arms but the pair of galaxies merges too fast (within 500 Myr).

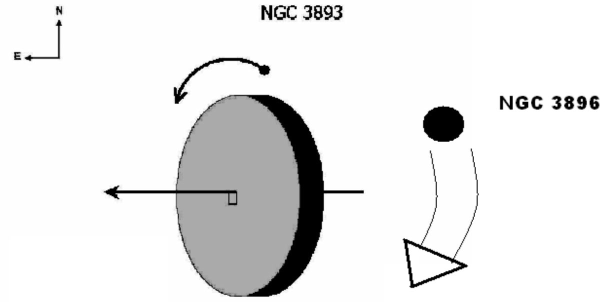

Fig. 4. Geometry considered in the N-body simulations.

While the results of these preliminary simulations differ from observations, we think that the inclusion of a structure to the satellite galaxy, of gas, of a truncated halo for NGC 3893 or even the assumption of a common halo for the galaxy pair, could give a deep insight into the secular evolution of this system and could allow to determine in an independent way the mass of the galaxies.

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