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Polar rings dynamics in the triaxial dark matter halo

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Abstract. Spectroscopic observations at the Russian 6-m telescope are used to study the two polar ring galaxies (PRGs) from the catalogue by Moiseev et al.: SPRC-7 and SPRC-260. We have analyzed the kinematics of the stellar component of the central galaxies as well as the ionized gas kinematics in the external ring structures. The disc-halo decomposition of rotation curves in two perpendicular directions are considered. The observed 2D velocity fields are compared with the model predictions for different dark halo shapes. Based on these data, we constrain that for potential of DM halo semiaxis ratios is $s = 0.8$, $q = 1$ for SPRC-7 and $s = 0.95$, $q = 1.1$ for SPRC-260. Using 3D hydrodynamic simulations we also study the dynamics and evolution of the polar component in the potential of the galactic disc and dark halo for these two galaxies. We show that the polar component is dynamically quasi-stable on the scale of ~ 10 dynamical times (about a few Gyr). This is demonstrate the possibility for the growth of a spiral structure, which then steadily transforms to a lopsided gaseous system in the polar pane.

Key words. Galaxies: general – Galaxies: evolution – Galaxies: halos – Galaxies: kinematics and dynamics

1. Introduction

The modern ΛCDM cosmological theory predicts the presence of dark matter in the vicinity of galaxies. Which leads to the fact that the rotation of disc galaxies is partly supported by the massive dark matter component (Athanasoula et al. 1987; Bottema 1993). Cosmological simulations also predict a non-spherical density distribution in DM haloes at $z = 0$ (Allgood et al. 2006; Hayashi and Navarro 2006). On the other hand, the observational constraints on the galactic halo shapes are coming from the gaseous and stellar kinematics in the disc galaxies (Merrifield 2002). Polar ring galaxies (PRGs) are unique objects for the investigation of DM halo shapes because the rotation of the matter happens in two perpendicular directions (Sackett and Pogge 1995; Combes 2006). In this letter we have obtained the constrains on the shape of dark matter for two PRGs using the observations of the rotation curves of host S0 galaxies and polar gaseous components.

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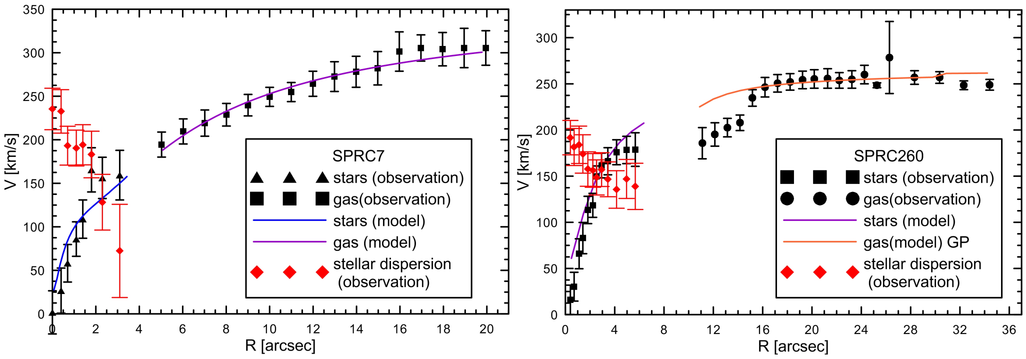

Fig. 1. Observation data of the rotation in the galaxy and in the polar ring planes for both galaxies. Best fit model rotation curves are shown by solid lines. The observed line-of-sight velocity dipsersion distributions of stars (red symbols) were also used in the simulations.

2. Observations

Spectroscopic observations at the 6-m telescope of the SAO RAS were used to study two polar ring galaxies from the catalogue by Moiseev et al. (2011): SPRC-7 and SPRC-260. SPRC-7 is an inclined system with the relative angle $\triangle\ i = 70^\circ$ towards the central galaxy, meanwhile SPRC-260 is a classic polar case with $\triangle\ i = 89^\circ$. The observations were carried out with the multi-mode focal reducers SCORPIO (Afanasiev & Moiseev 2005) and SCORPIO-2 (Afanasiev & Moiseev 2012) in the scanning Fabry-Perot interferometer and long-slit spectroscopic modes. The results of observations are

1. The line-of-sight velocity and velocity dispersion distributions of the stellar component along the central galaxy major axis;
2. The ionized gas velocity fields for the polar component. The data for SPRC-7 were already presented in Brosch et al. (2010).

3. Simulations

We have simulated the dynamics of the polar gaseous ring solving 3D hydrodynamical equations in the cylindrical coordinates (r, φ, z) with the TVD MUSCL scheme, but neglecting the selfgravitation of gas. The ring was orientated in the plane $z = 0$. The external potential consists of a triaxial isotermal DM halo (Khoperskov et al. 2012) and a contribution from the flattened S0 galaxy. It is well known that the disc perturbs the velocity field of the polar ring (Theis et al. 2006). Thus it is very important to carefully estimate the vertical structure of the galaxy potential for the dynamics of the polar component. We calculate the potential of the galaxy by TreeCode method (Barnes and Hut 1986) using an adequate distribution of test particles, reproducing the structure of the central S0 galaxy. This technique allows us to estimate the correct potential far away from the disc plane.

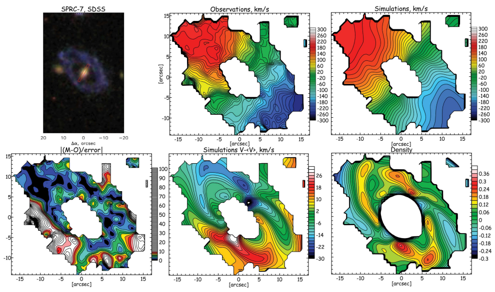

Fig. 2. SPRC-7. The top row: an optical SDSS image (left); the ionized gas line-of-sight velocity field $V_{obs}(x, y)$ taken from observations (middle); the best-fit model $V_{mod}(x, y)$ of the velocity field (right). The bottom row: the difference between V_{obs} and V_{mod} normalized to the observational errors (left); the velocity perturbation $V_{mod} - \langle V_{mod} \rangle$ (middle); the simulated column density of gas in the polar component at 5 rotational periods (right).

Initially, the gas dynamic simulations started from the observed kinematics of polar components (fig. 1). For both galaxies the simulated velocity field generally agrees with the observations (see Figs. 2 and 3) during many rotation periods (period is $T \sim 300 \div 400$ Myr). This systematic deviation could be associated with the polar ring warping (fig. 2). Relative velocity perturbations correlate with the features in the spacial density distribution. However, the polar component is unstable towards the formation of some large-scale clumps. The maxima of density distributions are situated in the regions of intersection of the polar component plane with the host galaxy rotation plane. These points are also prominent on the maps of velocity perturbation $V - \langle V \rangle$ (where $\langle V \rangle$ is the azimuthal averaged velocity). The results of simulations of SPRC-260 do not allow to determine any morphological features on the velocity maps. Despite this fact, the simulated and observed maps are quite similar. We showed that the polar component is dynamically stable on the scales of about 10 dynamical times (about a few Gyr).

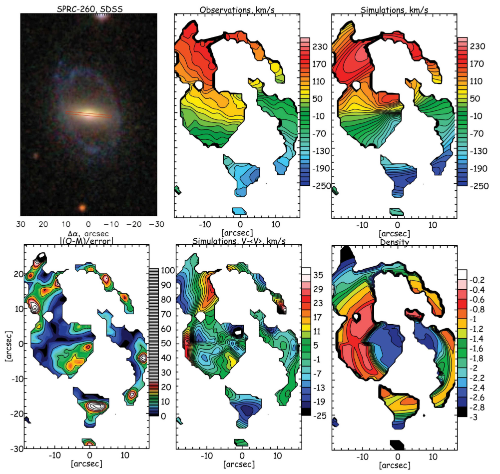

Fig. 3. Figures are the same as in figure 2 for SPRC-260, respectively.

The observed 2D velocity fields for both PRGs were compared with the model predictions for different dark halo shapes at different times. We have build a χ^2_{ring}-distribution for the observed and simulated velocity fields of the polar gaseous component, depending on time and the halo shape parameter $s = c/b$; the other χ^2_{gal}-distribution for the host galaxy stellar kinematics is also dependent on time and $q = a/b$ (where a, b, c are the semiaxises of the DM halo potential). We have found that there are no significant time-dependent variations of χ^2 up to 10 rotation periods and it is increasing slightly.

Detailed simulations are able to investigate the internal evolution of gas in the ring components. An interaction with a non-axisymmetrical perturbation from the host galaxy and the triaxial DM halo leads to the formation of spiral structures in the rings. There is a 2-arm tightly wound spiral structure formation in SPRC-260, which transforms to a lopsided system. For SPRC-7, multiple arms formed with a large pitch angle (fig. 4).

The best fits (minima of χ^2_{ring} distributions) pointed out the oblate character of the DM halo potential distribution in the polar plane for both galaxies: $s = 0.8$ for SPRC-7 and $s = 0.95$ for SPRC-260. For the halo density distribution q and s should be significantly smaller.

4. Results and discussions

We propose an oblate DM halo potential for SPRC-7 with the semiaxis relations: $s = 0.8$, $q = 1$ and a triaxial halo for SPRC-260: $s = 0.95$, $q = 1.1$. Note that this halo shape contradicts with a previous conclusion by Iodice et al. (2003) based on the investigation of the polar ring galaxies properties from the Tully-Fisher relation: "a flattened polar halo, aligned with the polar ring". But an oblate halo is strongly preferred over a prolate one from the estimations of dSgr dynamics $s = 0.90 - 0.95$ (Johnston et al. 2005). Numerous cosmological simulations also predict an oblate DM halo shape (e.g. Kuhlen et al. 2007).

The evolution of morphology for both polar components is quite different, but there is a common feature, namely, the formation of spirals, which could be determined from the velocity and density distributions. A spiral structure forms in the non-self-gravitating gas due to the interactions with the non-

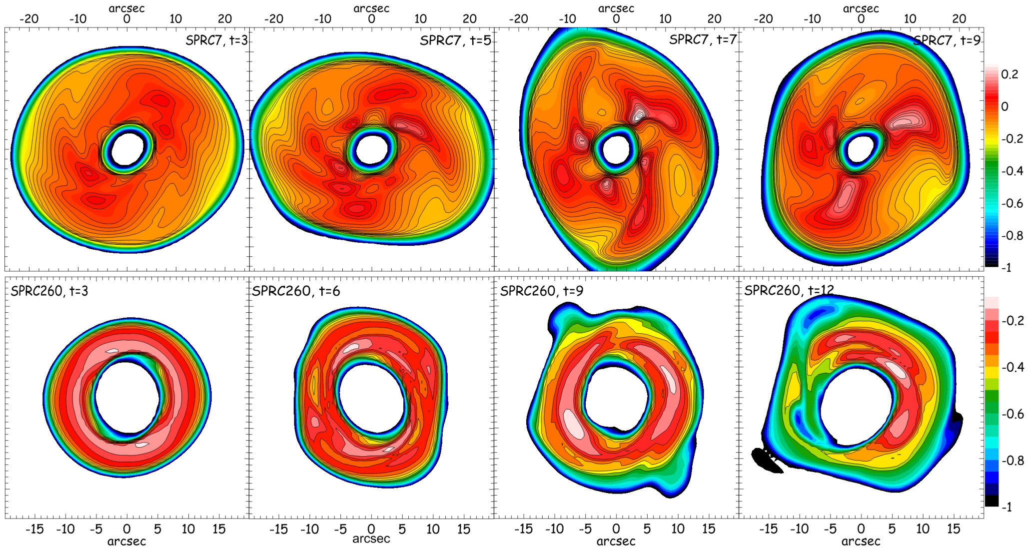

Fig. 4. The time-depend evolution of the column density of polar components for SPRC-7 (upper panel) and SPRC-260 (down panel). Time unit corresponds to the one rotation period of the outer side of thering.

axisisymmetric perturbations of the gravitational potential (DM halo and SO galaxy). However, the formations on nonlinear large-scale spirals in the polar component require to take into account the self-gravity of the gas and stellar fractions of the polar component.

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