

Polar ring galaxies and dark matter



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Polar ring galaxies are rare and peculiar objects. It is necessary to understand their formation mechanisms, to grasp more insight in galaxy evolution. A team of Paris Observatory has studied the formation of polar rings during galaxy collisions and interactions. The kinematics of polar rings also gives informations on the shape of dark matter halos around galaxies.

Polar ring galaxies

Figure 1 - Polar ring galaxy NGC4650A (photo VLT/ESO). The polar ring is the large structure, the small one is the host galaxy. In this case, the ring is larger than the host galaxy, but in some other cases the ring is small and thin. Polar ring galaxies are made-up of two distinct systems : the host galaxy and the polar ring. The host galaxy is a normal galaxy that gathers stars in a rotating disk. It is surrounded by a rotating ring, that contains stars and interstellar gas clouds. This ring is perpendicular to the plane of the host galaxy disk, thus is a polar ring. As the ring contains more interstellar gas than the host galaxy, we know that the ring has formed after the host galaxy, at not at the same time.

Figure 2 - Four polar ring galaxies (from Whitmore et al. 1990). Notice how the radius and thickness of rings vary. NGC4650A (Figure 1) is shown top left. Rotational velocities observed in galactic disks are too large to be accounted for by the visible mass only : this means that galaxies contain a large amount of invisible matter. Galaxies are said to be surrounded by a dark matter halo, but the shape of this halo remains unknown. Knowing whether halos are spherical or flattened is crucial to understand the nature of dark matter. In polar ring galaxies, the presence of two systems, rotating in two perpendicular planes, the host galaxy and the polar ring, enables the shape of the dark halo to be studied.

Formation of polar rings

The formation of polar rings around pre-existing host galaxies has first been studied. Two scenarios are possible for this formation : either the polar ring is formed during a head-on galaxy collision, or it is the result of the interaction of two galaxies at small distance but without collision, leading to gas exchange between the two galaxies. Numerical simulations, including the dynamics of stars and interstellar gas, as well as star formation, have been used to study both scenarios. The results of numerical models have been compared to observations of several polar rings, and this has shown that most polar rings, and maybe all of them, are formed during the interaction of two galaxies without collision. Tidal effects that occur during such an interaction strongly disturb one of the two galaxies, and drags its gas out until a tidal bridge appears between the two galaxies, which finally winds up into a polar ring around the other galaxy. A polar ring galaxy, similar to those observed, finally remains (see Figure 3).

Figure 3 - Numerical simulation of the formation of a polar ring during the interaction of two galaxies. At the beginning, the future host galaxy (at the center) is a normal spiral galaxy. Another galaxy interacts with it, even if no merger occurs. Tidal forces are so strong that a part of the second galaxy is captured by the host galaxy and winds up around the host disk, to form the polar ring. The companion galaxy, after having lost most of its gas, escapes and runs away from the host.

Polar rings and dark matter

In polar ring galaxies, the presence of two different systems allows the spatial distribution of dark matter to be studied. The more a system contains dark matter, the faster it rotates. By comparing the rotation velocity of the ring with that of the host galaxy disk, one can know whether the dark matter halo is spherical (both velocities should then be equal), flattened along the host galaxy (the host disk rotates faster than the ring), or flattened along the polar ring (the ring rotates faster than the host disk). Figure 4 shows this comparison : the relation between luminosity and rotational velocity is tested for polar rings. In general all disk galaxies obey the Tully-Fisher relation between their luminosity L and their rotational velocity V : $L = k V^4$. The green line represents this relation on Figure 4 (each green point represents a normal galaxy). In contrast, polar rings do not obey this relation (see blue symbols on Figure 4). For a given luminosity, polar rings rotate faster than host galaxies. The rotational velocity is larger in the polar ring plane than in the equatorial host disk. This indicates that more mass is present in or along polar rings than in host galaxies, while the visible mass in polar rings is smaller than in host galaxies. The comparison of these data with numerical models shows that the only explanation is that the dark matter halo is flattened towards the polar ring.

Figure 4 - Relation between luminosity and rotational velocity for polar ring galaxies (blue symbols). Horizontally, the velocity of the ring is shown (log of velocity), and Vertically the magnitude ($2.5 \times \log$ of luminosity). The so-called Tully-Fisher relation for normal galaxies is shown by the green line ; each green point is a normal galaxy. Host galaxies do verify this relation ; polar rings do not and have larger rotational velocities than host galaxies, for a given luminosity. The flattening of dark halos along polar rings can be confronted with the formation mechanism of polar rings. It has been shown above that polar rings are formed during the tidal interaction of two galaxies, and the subsequent mass exchange between the two galaxies. The only solution to form a dark matter halo flattened along the polar ring, is that a large part of the dark matter is cold gas. This gas would be transferred from a galaxy to the polar ring, as is the case for the visible interstellar gas that is observed in polar rings. The dark halo would then be flattened along the plane of the polar ring. Around normal spiral galaxies, as our own, large quantities of cold gas would then be present, even if not observed, and would represent part of the dark matter of the Universe.

Reference

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