Polar Ring Galaxies

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Abstract

We present here a brief review on polar ring galaxies. First we shall discuss the morphology of these objects, with particular emphasis on the criteria that need to be met in order for a galaxy to be considered as a confirmed polar ring galaxy. We shall also describe the possible formation mechanisms which have been postulated for polar ring galaxies and examine numerical simulations for both scenarios. Finally, we will discuss what polar ring galaxies can possibly teach us about dark matter halos and their three dimensional geometry.

Subject headings: galaxies: peculiar – galaxies: kinematics and dynamics – galaxies: formation – galaxies: interactions – galaxies: structure – dark matter

1. Introduction

A polar ring galaxy (hereafter PRG) is a peculiar system made of two rather distinct components. First, there is a central spheroidal component which very much resembles an S0 or lenticular type of galaxy mostly devoid of any gas. Second is a ring of gas, dust and stars which orbits nearly perpendicular to the plane of the central galaxy. This seems to be a particular case of galaxy interaction. Speaking of PRGs, Schechter once said “These are particular cases of mergers where the merging galaxies have been hung up in an odd shape where we can see what happened. Its an auto wreck that hasnt been cleared from the road.” Indeed, it seems that PRGs are the vestiges of the interaction between two galaxies in the recent past and can offer some insight into the dynamics of such interactions. Unfortunately, very few PRGs are actually known. The first large study of these objects was undertaken by Whitmore et al. (1990) who looked at ~100 galaxies and only uncovered six kinematically confirmed PRGs. Although still very few are known, the count had risen to 17 by 2003 and new ones are still being discovered. The case of the nearby galaxy NGC 6822 is one example of a recently discovered PRG where Demers et al. (2006) have shown the existence of an H I disk orbiting perpendicular to a spheroidal stellar population which they traced using the carbon stars they initially where attempting to study.

We shall begin by looking at the morphology and classification scheme used to categorize PRGs. Secondly, we will discuss the two competing formation scenarios that have been put forth to explain the existence of PRGs. In particular, we will look at the results of numerical simulations which offer insight into the exact conditions that are required in order to form a PRG. Finally, we will examine how PRGs can offer a unique opportunity to study the three dimensional gravitational potential, with a particular focus on determining the full spatial distribution of the dark matter halo.

2. Morphology

Whitmore et al. (1990) were the first to perform a large survey in order to identify PRGs and the final result was the Polar Ring Catalog (PRC). In the process they looked at over 100 galaxies and classified them into 4 distinct categories: A, B, C, and D. We shall define these 4 categories in turn.

Category A – These are the kinematically confirmed PRGs of which the Whitmore et al. (1990) catalog contained only six. In order to classify an object as a confirmed PRG, one needs spectroscopic evidence of the existence of two distinct angular momentum vectors aligned approximately perpendicular to each other and with similar amplitudes. Furthermore, the system needs to be in equilibrium or quasi-equilibrium with similar systemic velocities and with the centers of the two components closely aligned. Finally, the polar ring needs to be luminous, almost planar and comparable in size to the central component. For example, Centaurus A, a well known merger remnant, cannot be a PRG since its ring consists almost exclusively of dust. We show in Figure 1 an image of NGC 4650A, the prototype of the PRG class, which is a perfect example of a category A PRG.

Category B – These objects are considered as good candidates for PRGs but the viewing angle is such that their nature is difficult to confirm and the spectroscopic evidence for two kinematic components is lacking. Otherwise, these galaxies are characterized by nearly orthogonal projections of the major axes of the two components. Additionally, the centers of the two components must be closely aligned and the polar ring must be luminous, nearly planar and of comparable size to the central component.

Category C – These galaxies are considered as possible candidates for PRGs. In some instances there is clearly some form of interaction occurring but whether the final outcome will be a PRG is unknown. Otherwise, these can be “normal” galaxies which display very subtle PRG-like characteristics, indicating that we possibly have a poor viewing angle.

Category D – These are objects which are possibly related to PRGs but it is unlikely that they will ever become PRGs. Whitmore et al. (1990) include 8 different types of galaxies in this category, galaxies of all shapes and sizes, some interacting galaxies, and in some cases possibly just a chance superposition of two galaxies which might be mistakenly identified as a PRG.
However, there are important parameters which govern whether a PRG is actually formed during such an event. First, PRG formation seems to be sensitive to the angle at which the progenitors collide. At angles of $\sim 30^\circ$ or less no polar ring is formed. This explains why the polar rings of PRGs are so polar, if the angle is shallow, the matter from the intruder will simply merge into the disk of the victim. Other factors include the initial orbital angular momentum and the inclusion of gas (i.e. dissipation) in the interaction. Models that include only stellar components do not form polar rings. Another parameter studied by Bekki (1998) was the mass ratio between the intruder and the victim. If the mass of the intruder is to small, no polar rings are seen to form. Simulations where the mass ratio is larger than $\sim 0.7$ result in PRGs. When the mass ratio is $\sim 0.5$, double rings and helical rings, like the ones seen in ESO 474-G26 and NGC 2685 respectively, are produced. Finally, when the mass ratio is lowered to $\sim 0.3$, the victim is not greatly disrupted whereas the intruder is completely destroyed.

Bekki (1998) conclude that their simulations do succeed in producing many of the observed characteristics of PRGs such as S0 type central galaxies and the different types of polar ring structure and believe that the idea of galaxy mergers is a promising candidate to explain the formation of PRGs.

3.2. Accretion Scenario

The second scenario, first proposed by Schweizer et al. (1983), is that of accretion. In this scenario, a close encounter between two galaxies allows the primary to strip the secondary of a substantial amount of material which will then form the polar ring around the primary. This scenario was more recently studied by Bournaud & Combes (2003) who performed numerical simulations of such encounters. As was the case with the merger mechanism, it seems the internal parameters of the two galaxies do not play a primary role in determining the outcome. The most relevant parameters seem to be the gas content of both galaxies as well as their orbital or collisional, parameters. Those include the angle between the planes of the two galactic disks, the relative velocity of the galaxies involved and the distance of nearest approach of the galactic centers.

An example of one of the simulations from Bournaud & Combes (2003) is displayed in Figure 3. In blue is the stellar component of the host galaxy whereas red and green depict the stellar and gaseous elements of the "donor" galaxy. The simulation shown in Figure 3, which covers a timescale of 3 Gyr, shows how the donor is tidally disrupted by the host galaxy as it passes by and is stripped of a portion of its mass, sometimes up to 40%, mostly in the form of gas. As for the host galaxy, it is marginally disrupted experiencing mostly dynamical heating which causes its disk to become thicker. As in the case of the merging scenario, Bournaud & Combes (2003) show that their simulations can also reproduce the varying forms of PRGs observed. One way to confirm this scenario would be to identify the donor galaxies from which the material in the polar ring originated. However, since the interaction leaves no obvious link between the donor and the host, no donor galaxies have been identified as of yet.

The final conclusion of Bournaud & Combes (2003) is
that both scenarios seem relatively robust and able to explain the amount of PRGs that are known, but they believe the accretion model is the most likely of the two based on comparisons with observations. However, no consensus exists as of yet.

4. DARK MATTER & THE TULLY-FISHER RELATION

One interesting aspect about PRGs is that they offer a unique opportunity to study the full 3-dimensional distribution of the dark matter halo. Although, it must be pointed out that it is the halo of a galaxy which has undergone some form of interaction in the recent past, be it a merger or an accretion episode. So PRGs cannot necessarily tell us anything about the dark matter halos of isolated galaxies.

Some of the evidence regarding the nature of the dark matter halos in PRGs has come from studying the location of PRGs in the log $\Delta V$-$L$ plane with respect to the Tully-Fisher (TF) relation of say spiral galaxies. It is hard to predict where one would expect the PRGs to lie since the 2 quantities in question are related to the two disparate components of the system. The rotational velocity obtained through observed $H\ I$ line widths probes the polar ring whereas the total luminosity originates largely from the central galaxy. Figure 4 shows the location of 16 PRGs with respect to the TF relation of a sample of 787 disk galaxies. We see that the majority of PRGs have larger velocities than disk galaxies of similar luminosity. On the face of it, one might actually expect to see the opposite relationship, that is PRGs with smaller velocities. This would be explained by the fact that the observed velocities (approaching and receding) are only really measured at the poles. If the polar ring has an appreciable eccentricity, then the poles would actually be the place where velocity is at a minimum. Therefore, one would expect that the observed velocities underestimate the average velocity in the ring thus placing the PRGs to the left of the TF relation. This is obviously not the case. How then can we reconcile the observed velocities with what the TF relation tells us to expect? This is where the dark matter halo and its 3-dimensional distribution seem to come in.

Iodice et al. (2003) explain that the velocities depend mostly on the shape of the dark halo as well as the eccen-
tricity of the polar ring, they only scale as the square root of the total mass and depend even less on the dark mass. In fact, the dark-to-visible mass ratio must be raised to \( \sim 3-4 \) in order to reproduce the observed velocities. These dark masses are rather unrealistic however. Somehow the halo density must decrease more slowly than \( 1/r \) without an appreciable increase of mass. One way to achieve this is by altering the geometry of the dark matter halo instead of its mass. Prolate or oblate halos whose major axes lie in the plane of the central galaxy must still be afforded a larger mass in order to provided the desired results. On the other hand, numerical models indicate that prolate dark matter halos can effectively reproduce the observed velocities if the major axis is aligned with that of the polar ring.

5. CONCLUSION

PRGs are peculiar galaxies which seem to have undergone an important transformation in the recent past. Whether this be by a merger with another galaxy or through an episode of accretion from a passer-by is still undecided. Both formation scenarios seem able to reproduce PRGs and perhaps each scenario accounts for a certain percentage of the PRG population. Besides being visually stunning objects, PRGs can also offer an intriguing insight into the dark matter halos in which they are imbedded. Indeed the polar ring allows one to probe the 3-dimensional structure of the halo and it seems that a prolate geometry is required to account for observed velocities in the polar ring. However, one must remember that these are halos of galaxies which have undergone a significant interaction. Therefore, what we learn about the halos of PRGs cannot be applied to the case of isolated galaxies.

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REFERENCES