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Warped galaxies and the dark matter connection

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Abstract. While most works on warped galaxies are based on the assumption of a spherical or triaxial dark matter halo, none of them are able to clearly satisfying all the constraints provided by the observations. Following another way, this paper explores the hypothesis of a heavy self-gravitating and warped disk. Characteristics of such a model are compared with observations. The dynamic is then studied through periodic orbits populating a self-gravitating warped N-body model.

1. Observed properties of warps

Global properties of warps can be summarized by four rules (Briggs 1990) : (i) Warps are a common phenomenon and thus must be either long-lived or continuously generated. (ii) Warps are generally pronounced outside R_{25}. (iii) The line of nodes (LON) is straight inside radius $R_{26.5}$. (iv) Outside $R_{26.5}$ the LON forms a leading spiral.

In the context of warps, the heavy disk assumption, which implies a strong rotational support, is attractive for several reasons : (i) The radical change of the dynamic between the inner flat disk and the outer warp is hardly explained by a hot halo which imposes a uniform dynamic over a large scale. In contrast, such a change appears natural for a heavy disk. (ii) The straight LON can result of a slow diffusion of angular momentum which is a quasi conserved quantity. Thus, a strong rotational support in the dark matter will be more prone to keep the LON straight than a spherical component. The angular momentum can be deposited, for example, by an accretion event.

Moreover, other arguments play in the favor of the heavy disk assumption, such as the mass distribution of the optical disk (Gerhard 2000), the correlation beetween the dark matter and HI surface density (Bosma 1981), or evidences of ongoing star formation in the extreme outer HI disk of M31, meaning that molecular gas exists there (Cuillandre, Lequeux, & Allen 2001).

2. N-body model

In this work, we explores orbits in a warped self-gravitating N-body disk model. The disk, made of 10^6 particles, is composed of a bulge, a visible exponential disk and a heavy disk of dark matter. This latter, which contains about 3/4 of the total mass, is a flaring disk. In order to get a warp, the galactic disk is embedded in a non-rotating warped potential. The potential, calculated with a

grid code, is a deformation of the potential of the initially flat disk and is induced by modifying the z coordinate : $z \rightarrow z - wR^2 \cos\phi$. ϕ is the azimuthal angle and w, the warp parameter. To warp adiabatically the disk, the outer potential is flat at $t = 0$ and warps in function of the time. Then, the disk follows the perturbation and warps. At $t = 1200\,\mathrm{Myr}$ the maximum of the perturbation is reached ($w = 0.015\,\mathrm{kpc}^{-1}$). The warp of the disk is then comparable to the one of the Milky Way. A leading LON has formed. Between $t = 1200$ and $t = 1500$ the outer potential is progressively removed and the disk becomes self-gravitating. After the perturbation, during the following 1500 Myr, the amplitude of the warp decreases, a flat disk grows at the centrer and the LON straightens. This evolution can be the result of outwards angular momentum diffusion.

3. Periodic orbits

To find periodic orbits in our N-body model, we have used a grid code to compute the corresponding potential at a given time. The periodic orbits are determined by numerically finding the fixed points of the 4D Poincaré map associated to the equations of motion.

Five families have been found : Family p is the correspondent of the circular family in an axisymmetry disk. It is always stable. Families $s2+$ and $s2-$ are vertical 2:1 resonances. They cross the p-family at the LON. These famillies are unstable. Families $t2+$ and $t2-$ are similar to the $s2+$ and $s2-$ but are rotated by 45° in azimuth and are stable (These families are called $sz+$ and $sz-$ in Revaz & Pfenniger (2001)). Note that in an axisymmetric potential, families $s2+$, $s2-$ and $t2+$, $t2-$ are degenerate.

4. Conclusion

Numerical simulations of warped heavy disks reveal the consistency of such models with the available observations. During the galaxy evolution, the LON straightens and a flat disk develops at the center. The galaxy needs no less than 800 Myr to loose its warp up to 30 = kpc. A detailed study of the orbits reveals the existence of quasi-circular stable orbits. This study confirms the intuitive idea that orbits follow the warp and justify the use of the ring models. Finally, such model underlines the viablility of the heavy disk hypothesis in the context of dark matter.

References

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