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 explore the hypothesis of a heavy self-gravitating warped disk. Characteristics of such a model are compared with observations. The dynamic is then studied through periodic orbits populating an self-gravitating warped N-body model.

1 Observed properties of warps

Global properties of warps can be summarized in for rules (Briggs [2]) :

1. Warps are a common phenomenon and thus must be long-lived or continuously generated.
2. Warps are generally flat inside radius R_{25} (radius at the 25 mag arcsec^{-2}) .
3. The line of nodes (LON) is straight inside radius $R_{26.5}$.
4. Out of $R_{26.5}$ the LON forms a leading spiral.

In the context of the warps, the heavy disk assumption, which is strongly rotational, is attractive for several reasons :

- 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. Such a change appears to be natural for a heavy disk.
- The straight LON can be the 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 examble, by an accretion event.

Moreover, other arguments play in the favor of the heavy disk assumption, as the mass distribution of the galactic center (Gerhard [5]), the correlation beetween the dark matter and HI surface density (Bosma [1]), or the existence of B stars in the outer disk of M31, which reveals the presence of molecular gas in the outer part (Cuillandre, Lequeux, Allen et al. [4]).

2 N-body model

Following the work of Revaz & Pfenniger [7], where quasi circular periodic orbits where found in an analytical warped potential, this work explore similar 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. The total rotation curve is modeled to be straight well after 30 kpc.

In order to get a warp, the galactic disk is embedded in a non-rotating warped potential. The potential, calculated with a grid code, corresponds to the potential of the initially flat disk. The warp is then added by including a perturbing term in the vertical coordinate : $z \to z - wR^2 \cos\phi$, where 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. The disk follows the perturbation and warps slowly. A leading LON forms. At $t = 1200$ 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. Between $t = 1200$ and $t = 1300$ the outer potential is slightly removed and the disk becomes self-gravitating. The consequence is a disk instability and the formation of a bar which is already well developed at $t = 1350$. At $t = 1500$ the center of the galaxy has formed a new tilted disk. During the following 600 Myr the inner disk grows while the LON straightens. This evolution can be seen a the result of angular momentum diffusion from the center to the outer. At $t = 2100$ the galaxy is flat again, up to $30 =$ kpc.

3 Periodic orbits

In order 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 generated by the equations of motion. A complete description of the procedure is exposed in Pfenniger & Friedli [6].

Five families have been found in our model :

- 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 $y = 0$. They are always unstable.
- families $t2+$ and $t2-$ are similar to the $s2+$ and $s2-$ but are rotated for 45° in the azimuth. (These families are called $sz+$ and $sz-$ in Revaz & Pfenniger [7]). They are always unstable.

In an axisymmetric potential, families $s2+$,$s2-$ and $t2+$,$t2-$ are degenerated.

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. A detailed study of the orbits reveals the existence of quasi-circular stable orbits. Finally, such model underlines the importance of the heavy disk hypothesis in the context of dark matter.

References

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