Testing the Dark Matter Caustic Ring Theory Against Observations in the Milky Way

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Abstract

We test a particular theory of dark matter, in which dark matter axions form ring "caustics" in the plane of the Milky Way. According to this theory, cold collisionless dark matter particles with angular momentum flow in and out of the Milky Way as it forms. These flows form caustic rings (at the positions of the rings, the density of the flow is infinite) at the locations of closest approach to the Galactic center. We show that the caustic ring dark matter theory reproduces a roughly logarithmic halo, with large perturbations near the rings. We show that the theory can reasonably match the known Galaxy rotation curve. We explore the effects of the caustic rings on dwarf galaxy tidal disruption using N-body simulations. Simulations of the Sagittarius dwarf galaxy in a caustic halo potential match observations as far as 90 kpc from the Galactic center. The source code for calculating the caustic halo acceleration has been made publicly available in the NEMO Stellar Dynamics Toolbox and the Milkyway@home client repository.

Introduction

The dark matter caustic ring theory has been developed by Pierre Sikivie (Sikivie, Tkachev, & Wang 1995; Sikivie 2003; Natarajan & Sikivie 2007; Duffy & Sikivie 2008; Sikivie 2011; Banik & Sikivie 2013) over the past 20 years. Although Sikivie started from the spherically symmetric self-similar models of Fillmore & Goldreich (1984) and Bertschinger (1985), it is important to note that the Sikivie model has evolved to include physics of dark matter particles beyond a simple gravitational interaction. The physics results in dark matter flows that rotate with the stellar disk.

For the Milky Way (rotation speed of 220 km/s at 8.5 kpc from the Galactic center and the current accelerating model of the Universe age = 13.7 Gyr), the inner ring caustics are predicted to exist at radius: a_n = 40/n kpc, (n = 1, 2, 3,...). The first four caustics should be rings at distances of 40, 20, 13, and 10 kpc from the center of the Galaxy (Duffy & Sikivie 2008). Here we compare results where the gravitational potential of the Milky Way dark matter halo is represented by the caustic ring, Navarro, Frenk, and White (NFW; 1996), logarithmic, and triaxial (Law & Majewski 2010) models. A future goal is to investigate whether the gravitational field of dark matter caustic rings could cause a migration of stars similar to what is observed in the stellar ring structures in the Milky Way (Monoceros Ring; Newberg et al. 2002).

Results

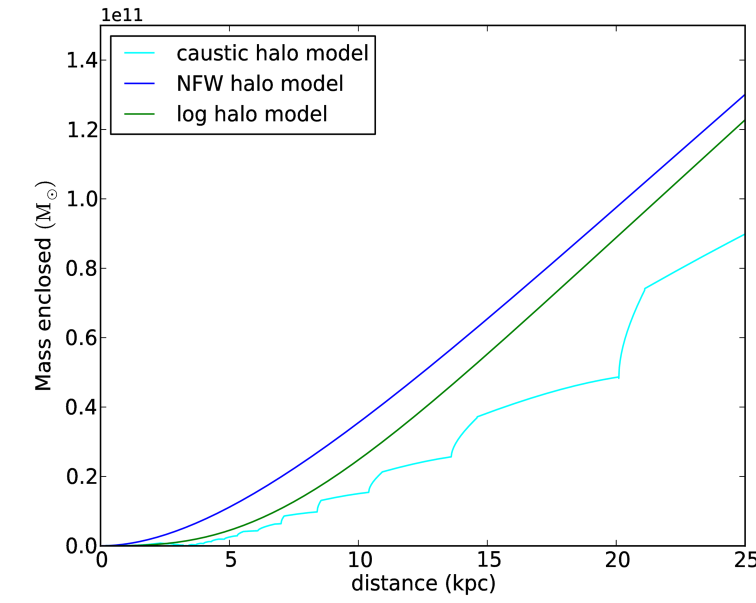

Figure 1. Dark matter mass vs distance from the Galactic center. Note the bumps in the caustic model curve (cyan) where the caustic rings are predicted. The mass of the NFW (blue) and logarithmic halo (green) are shown for comparison.

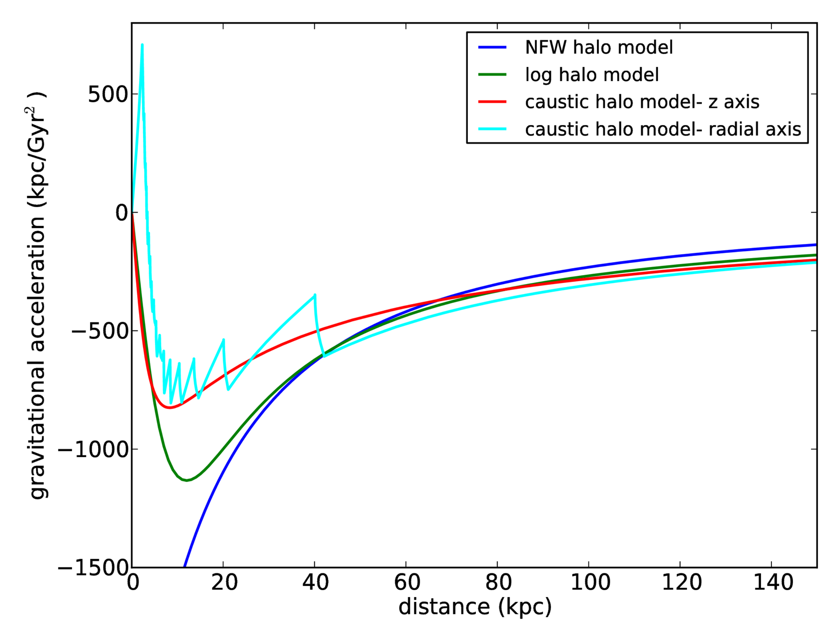

Figure 2. Gravitational acceleration vs distance from the Galactic center. Caustic halo model- radial axis (cyan) is the acceleration along the radial direction in the Galactic plane (z=0). Caustic halo model- z axis (red) is the acceleration along the z axis of symmetry (r=0). Note the bumps in the caustic model curve where the caustic rings are predicted. The acceleration of the NFW (blue) and logarithmic halo (green) are shown for comparison.

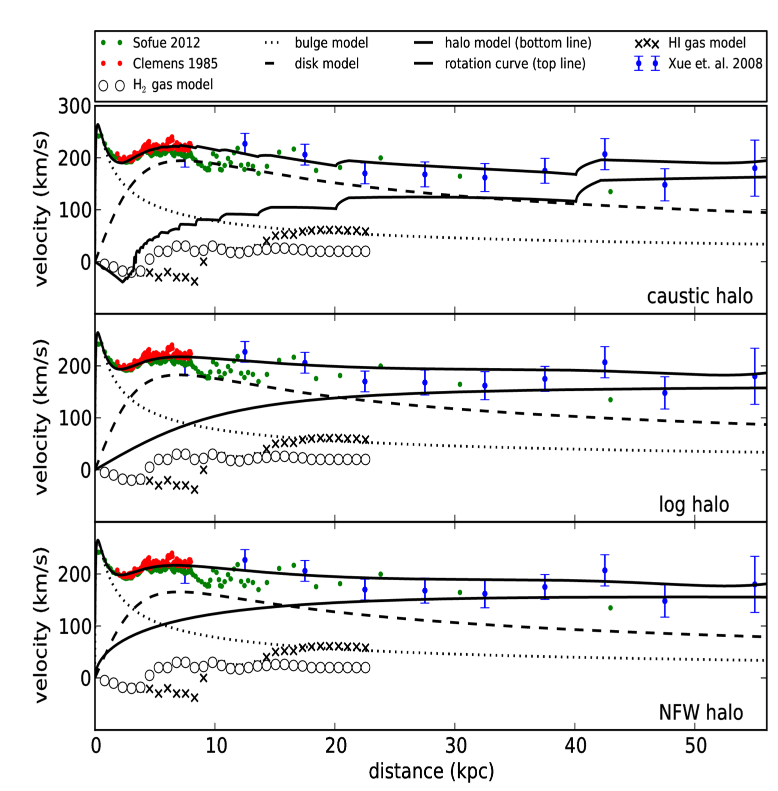

Figure 3. Rotation curve of the Milky Way. The sum of the Hernquist (1990) bulge (dotted line), Miyamoto-Nagai (1975) disk (dashed line), halo (lower solid line), and hydrogen gas (open circles and crosses) models (Olling & Merrifield 2000) produce a rotation curve (upper solid line) that matches observations from Clemens 1985, Sofue 2012, and Xue et al. 2008 (red, green, and blue points respectively).

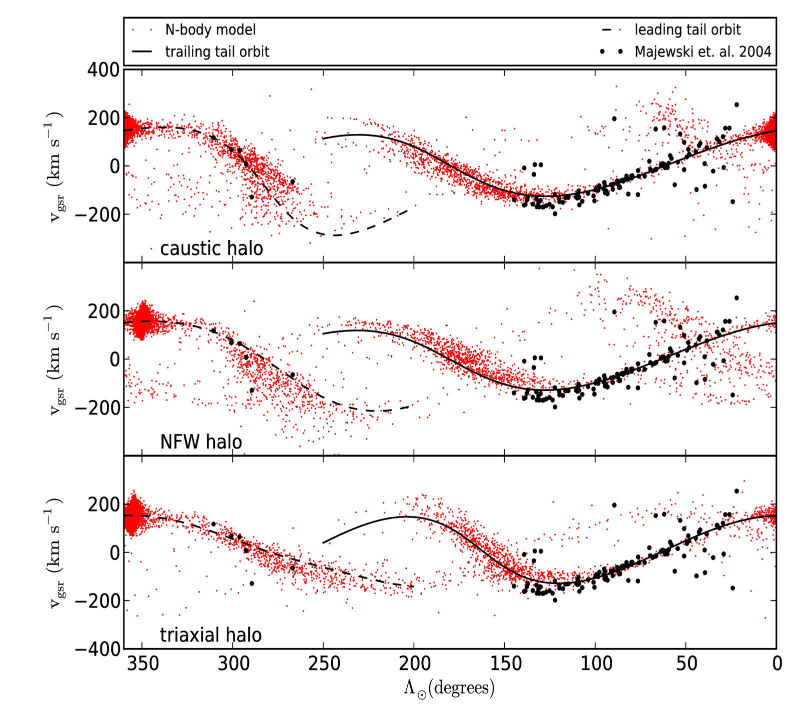

Figure 4. Galactic standard of rest velocities vs. orbital longitude (Sgr Heliocentric spherical coordinate system defined by Majewski et al. 2003) for the Sagittarius (Sgr) dwarf galaxy tidal stream. The leading (dotted line) and trailing (solid line) best-fit orbits to the 2MASS M giant data from Majewski et al. 2004 (black dots) is shown with corresponding N-body simulations (red dots). The fits for the caustic (top), NFW (middle), and triaxial (bottom) halo models are shown for comparison.

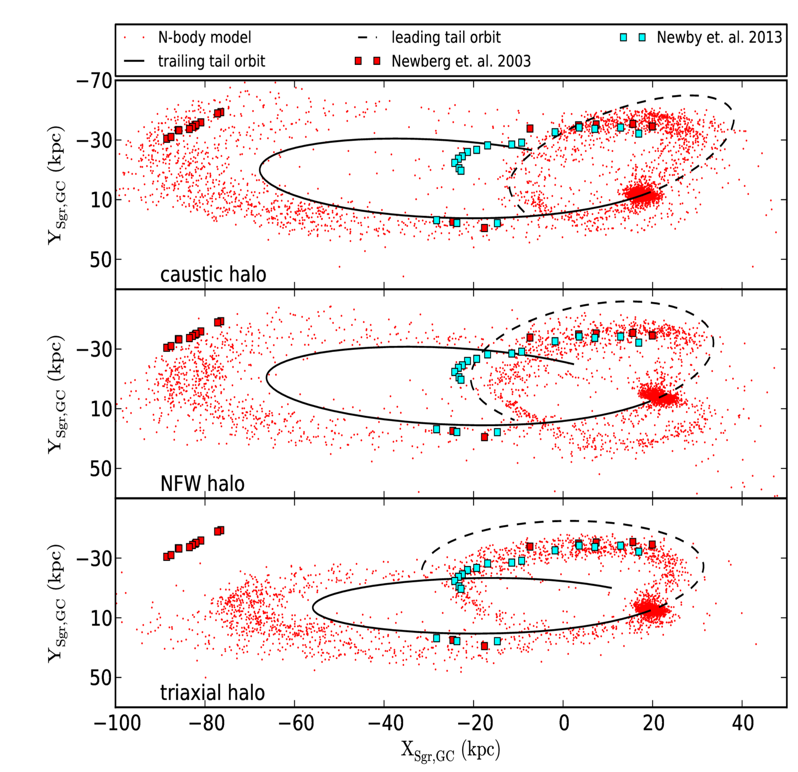

Figure 5. Ysgr,gc vs. Xsgr,gc (Sgr Galactocentric spherical coordinate system defined by Majewski et al. 2003) for N-body simulations (red dots) of the Sagittarius (Sgr) dwarf galaxy tidal stream. The galaxy was evolved in a caustic (top), NFW (middle), and triaxial (bottom) halo model. The leading (dotted line) and trailing tail (solid line) orbits are also plotted. Recent observations from Newby et al. 2013 (cyan squares) and Newberg et al. 2003 (red squares) are also shown for comparison. Note the caustic halo tidal debris matches observations out to 90 kpc.

Acknowledgements

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