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Tiivistelmä – Referat – Abstract

In this thesis I investigate the apparent anisotropic distribution of the satellite galaxies of Andromeda (hereafter M31). In the standard cosmological model (ΛCDM) satellite galaxies populate the substructures of their host's dark matter halos, which are expected to be fairly isotropic. Simulations in the ΛCDM context have shown a degree of anisotropy in the satellite distribution, attributed to, for example, preferential accretion directions due to cosmic filaments, or groups of galaxies falling in together and still displaying spatial coherence.

However, the spatial distribution of M31's satellites has long been known to be lopsided, with many more satellites found on its near side than on its far side. In particular, Kanehisa et al. (2025) studied the number of satellites in cones of different opening angles. They found that all but one of M31's 37 known satellites were within an opening angle of 107 degrees, a feature found in less than 0.3% of equivalent systems in cosmological simulations. This would make M31's satellite distribution highly unusual.

It should be noted that this type of analysis has several possible limitations that they didn't address, including the look-elsewhere effect, finite distance errors, and differential completeness due to the fact that many satellite galaxies are faint and that M31's nearest satellites are much closer to the Milky Way than its furthest satellites. In this research I address all of these effects.

I develop an algorithm that generates cones with opening angles ranging from 0.5 to 180 degrees and measures the largest number of M31 satellites to fit into each cone. I then generate an isotropic sample of points to act as mock satellites, which allows me to compare the observed M31 satellite data to the theoretically predicted isotropic data. In order to account for completeness issues, rather than removing parts of the observed data, I also created mock observations taking into account differential completeness and distance errors.

Defining the "anisotropy" at a given opening angle as the fraction of all samples drawn from an isotropic distribution that has fewer points within that opening angle than the observed data, I find that the distribution of M31 satellites reaches its maximum anisotropy at 100 degrees, and find that 1.7% of isotropic samples are more isotropic as M31's satellites at this angle.

However, when considering anisotropy at any angle, rather than the angle at which the M31 satellites are most anisotropic, I found a considerable look-elsewhere effect: 12.5% of isotropic samples contain some opening angle at which the average number of satellites in isotropic samples is below 1.7%. In other words, 1 out of 8 isotropic samples are more anisotropic at their most anisotropic opening angle than the M31 satellite system is at its most anisotropic.

Hence, whilst the M31 satellite distribution appears highly unusual, a further investigation into the isotropic samples reveals that it is not as anisotropic as initially thought. With a relatively small number of satellites, apparent anisotropies can be identified even in samples taken from an isotropic distribution.

Further research is required into combining accurate simulations, that take into account preferential accretion directions and groups of galaxies falling in together, along with observational effects, which I have shown in this project to also have a significant impact on the apparent anisotropy of Andromeda.