The field of Streams: Sagittarius and its siblings – Hans Buist - 1470566

Introduction
From our current cosmological models we know that the Milky Way should have merged with dwarf galaxies many times during its history. Modeling and observations have lead to the conclusion that such a merger involves a disruption process of the dwarf galaxy. This disruption often occurs with distortion of the dwarf and with large stellar streams, tracing the path of the dwarf around the galaxy. One of the dwarf galaxies that is currently merging with our Milky Way is the Sagittarius Dwarf Spheriodal Galaxy (SgrdSph). It was discovered in 1995 by Ibata et al., and was found quite close to the plane of the Milky Way, which also explains why we didn’t see it before (fig 1). SgrdSph is dominated by an intermediate age population of around 6-9 Gyr, while there is also evidence for an even older population (>10 Gyr). The metallicity is very low, ranging from -2 to 1 (solar units), typical for halo objects. The orbital period of the dwarf is around 0.7 Gyr.

![Figure 1: Sagittarius Dwarf, Ibata et al, 1998 (APOD)](image1)

![Figure 2: The Sagittarius stream, traced with M dwarfs (Majewski et al. 2003)](image2)

Previous Research
The first indication of the Sagittarius dwarf disruption was found in 1997, when tidal debris was found in the direction of the elongation of the Sagittarius dwarf galaxy. More evidence was found using the first data release of the Sloan Digital Sky Survey (SDSS). It turned out that blue A-type stars (Yanny et al. 2000, Ibata et al. 2001) and RR Lyrae stars (Ivezic et al. 2000) traced the orbit of the dwarf, giving a stream around our galaxy. The most conclusive evidence was found with data from the Two Micron All Sky Survey (2MASS) by Majewski et al in 2003. They found that M-giants very clearly indicated the stream on the southern hemisphere, and also in the northern hemisphere (fig 2).

Finding the stream
The article I write about used the 5th data release of SDSS. If we just look at a portion of sky in the SDSS map then we will not see anything. The reason is that we look really through a lot of stars from the Milky Way. What we really need to do is find a method to filter out only the halo. The left image in figure 3 shows theoretical isochrones in a color-magnitude diagram (CMD), fitted for different metallicities. The most interesting stars are always those around the main-sequence turn off (MSTO), because it is then possible to distinguish different populations. Given our metallicity, we can conclude that the color $g-r < 0.4$ to find the MSTO. The right image in figure 3 shows the true CMD in the 5th SDSS release. The most right overdensity corresponds to the disk, the upper overdensity to the thick disk, while the bottom-left overdensity corresponds to the halo, which is what we are after. Also, $g-r < 0.4$ seems to select the halo. If we also apply a magnitude limit, then we avoid the problem of very distant structures and nearby faint dwarfs so the authors took $r < 22; g < 23$.

After this selection one can obtain the left image of figure 4, which shows a surprising amount of substructure. The main feature is the Sagittarius stream, which also splits in half (stream A and stream B). Perpendicular to this is an unknown orphan stream, while more to the plane of the Milky Way, the Monoceros ring is seen. This is ring thought to have come from a dwarf that merged while at low inclination to the Milky Way plane. The found part of the stream neatly corresponds to the M-giant image, as seen in the right image of figure 4.
Examining the stream

The stream is apparently split in two, and another feature is that the magnitude changes along the stream. If the stream consists of one population only, then this means that the stream is inclined towards our view, so the right part of it is closer by. One can also try to investigate the population along the streams. To only select the stream population one can take color-magnitude diagrams and then compensate for the background population by subtracting the off-stream population, as seen in figure 5. In field A7, one can observe two sub-giant branches in stream A, which could indicate either two populations, or one population but at different distance. Because the magnitude difference between the two branches changes along the stream, we should conclude that it actually means there is another stream behind stream A.

We can also compare the total population along the stream with the CMD from Sagittarius. Figure 6 shows the result, and the match is very good, except for the red giant branch, but this not a significant issue, because star counts are really low there. To make the images overlap, a 0.6 mag shift had to be done, indicative of the distance difference between the Sagittarius dwarf and the stream. Because the distance to Sagittarius is known, we can then convert magnitude to distance. In figure 7, magnitude/distance vs. right ascension is
plotted. The figure shows that stream A and B are indeed inclined along the line of sight, while behind A another structure seems to appear

Comparing with models
The results obtained can be compared with models by Helmi (2004) and Fellhauer et al. (2006), as seen in figure 8. The main conclusions that can be drawn is that the different streams A, B and the stream behind A, are streams of stars, lost at different times in history. One of the parameters in their models is the shape of the halo. It turns out that a more oblate halo causes sharp edges in the stream, while it also smears out other parts of the stream. This is incompatible with the data, which show smooth and narrow streams, indicating that the halo is likely not oblate, but rather prolate or spherical.

Conclusions
The use of a proper color cut can actually reveal a lot of substructure in the halo. Also, the streams obtained from the SDSS sample match with the Sagittarius dwarf stellar population. The CMDs showed that there is also a more distant stream behind stream A. Modelling shows that these streams could be explained with stars lost at different moments in history. The modelling also indicates that the shape of the halo is likely not to be oblate. This investigation also shows that there is a lot more to see in the halo than one previously had could have hoped for.

References
V. Belokurov 2006: The field of streams: Sagittarius and its siblings
A. Helmi 2004: Is the dark halo of our Galaxy spherical?
V. Belokurov 2006: An orphan in the “field of streams”
M. Fellhauer 2006: The origin of the bifurcation in the Sagittarius stream
L.V. Sales 2008: On the genealogy of the Orphan Stream
Astronomical Picture of the Day