The Stellar Halo of M31

The first generations of stars to form in galaxies are believed to be located in extended halos; the spatial distribution and metallicity distribution of halo stars therefore provide important information on the earliest phases of galaxy collapse. It follows that the study of stellar halos of galaxies provides important constraints on theories of galaxy formation.

The nearest halo is that surrounding our own Milky Way. However, Galactic halo stars are vastly outnumbered by nearby disk stars; it is therefore very difficult to obtain large, pure samples of Galactic halo stars. This problem is to a large extent alleviated in studies of the halos of other galaxies; the nearby Local Group galaxy M31 (=NGC 224) offers an unparalleled opportunity for such work. M31 possesses a prominent bulge, and so by inference might be expected to possess a strong halo population; such a population is in fact observed. M31 is close enough that its red giant branch is easily visible in 1 hour CFHT exposures; longer exposures clearly reveal horizontal branch stars (see, for example, Pritchet and van den Bergh 1987, Ap. J., 316, 517).

Using the prime focus camera of the CFHT, we have obtained 2-colour CCD observations of a number of fields in the halo of M31. These fields lie for the most part along the minor axis of M31, and stretch from 40' (r=8.6 kpc) from the nucleus out to 5° (r=66 kpc) from the nucleus. We also have observations in two halo fields at position angles closer to the major axis, and in three fields at very large projected distance (r>100 kpc) from the nucleus of M31. The off-axis fields are dominated by halo stars, and are being used to study the flattening of the stellar halo; the large-r fields are used to monitor the number and gradients in foreground and background objects.

Figure 17 shows 80° x 80° subrasters for our three innermost minor axis fields (θ=40°, 1°, and 1.5°, corresponding to projected separations r = 8.6, 12.9, and 19.4 kpc if d_M31 = 740 kpc). These exposures are through a V filter, and each represents 1 hour of exposure time (limiting magnitude V~ +25 for S/N ~ 5 detection). It is clear that there is a dramatic gradient in the surface density of stellar objects in these frames. Whereas the inner field is "swamped" with red giants from the stellar halo of M31, the outer field is quite empty.

The preliminary colour-magnitude diagrams (CMDs) for these fields are shown in Figure 18. (This figure also shows fiducial sequences for 3 Galactic globular clusters with metallicities [Fe/H]=-2.2 (M92), -1.40 (M8), and -0.7 (47 Tuc).) Not surprisingly, the M31 halo possesses a very prominent giant branch whose tip is at V~ 22.5, and which is intermediate in colour between the giant branches of 47 Tuc and M5 -- in good agreement with our earlier results (Ap. J., 331, 185). None of the CMDs reach deep enough to show the horizontal branch. The principal conclusion from overlaying these CMDs, and also from comparing histograms of the colour distributions of stars between V=23 and 24, is that the median B-V colour of the M31 halo giant branch does not appear to change by more than about ±0.2 mag. This indicates that there is not a large gradient in metallicity in the (inner) halo of M31, an observation which appears to be confirmed by the fact that the V magnitude of the giant branch tip is about the same for each of these three inner fields. The range in radius which is sampled by these observations is fairly limited (about a factor of 2), and so this observation does not rule out the presence of a significant metallicity difference between the outer (say, r=50 kpc) and inner halo.

Figure 17: V images of M31 halo fields at 40°, 1°, and 1.5° (field A, B, and C respectively) from the nucleus of M31. All fields are along the minor axis, and each exposure is 1 hour. The displayed subrasters are all 80° x 80° and the limiting magnitude is around 25. Most of the stars visible in the innermost field are on the upper red giant branch of the M31 halo; the strong gradient in stellar density is clearly visible.
A large and significant fraction (as much as 50%) of the V luminosity of an old stellar population originates from stars brighter than the horizontal branch. It is therefore possible to convert the V band star counts into M31 halo surface brightness measurements, after allowing for the fraction of light that is missed, and the numbers of foreground and background objects. A very preliminary calculation shows that we are reaching a surface brightness of about 31.0 mag/arcsec\(^2\) in our third minor axis field (\(\Theta 1.5\)\(^\circ\)), and that the minor axis surface brightness profile appears to match fairly smoothly onto earlier work at small \(\Theta\) by de Vaucouleurs (1955, Ap. J., 128, 465). There is also some evidence that our off-axis fields possess higher star counts than would be found for minor axis fields at the same \(r\); this result may be indicative of some halo flattening.

Figure 18: Colour-magnitude diagrams for the fields in Figure 17. Fiducial sequences are also shown for the Galactic globulars (left to right) M92, M6, and 47 Tuc; these sequences have been shifted by \(E_{B-V} = 0.08\) mag and \(A_V = 0.24\) mag to match the observed reddening towards M31.

The bulk of the objects found in fields beyond \(r=1.5\)\(^\circ\) are background galaxies. To properly analyze these fields requires that faint contaminating galaxies be identified and eliminated using star/galaxy discrimination techniques, before constructing CMD's and luminosity functions. Such work is now underway.

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