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KINEMATIC AND CHEMICAL CONSTRAINTS ON THE FORMATION OF M31’S INNER HALO STRUCTURES

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M31’s halo shows a wealth of substructures (Ibata et al. 2001; Ferguson et al. 2002), some of which are indicative of assembly from satellite accretion. Here we report the kinematics and abundances of red giants along the minor axis of M31, based on spectroscopy from Keck/Deimos. Of special interest are deep fields where Brown et al. 2003, 2006, 2007 have obtained extremely deep HST/ACS imaging. We focus on the calcium triplet region, and our sample is cleaned of foreground dwarf contamination based on the gravity sensitive Na doublet, (V-I) colours, and radial velocity information. We derive radial velocities to search for kinematic substructures such as cold, i.e., low velocity dispersion, streams and furthermore we measure metallicities based on the infrared Ca triplet, using a new improved method. We find evidence of cold structures, some of which are consistent with a merger event, and we find an abundance transition at 20 kpc = 1.5°, beyond which there is a relative absence of metal rich stars.

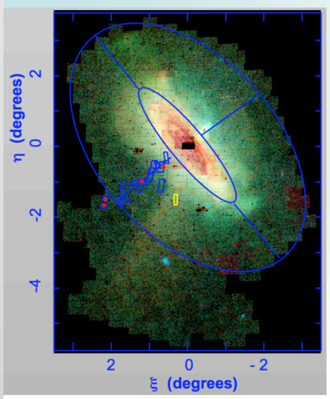
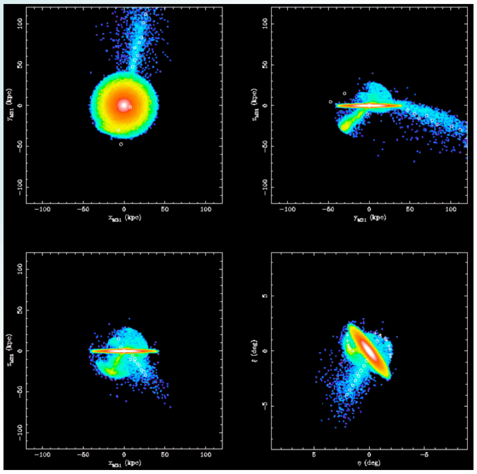


Fig. 1: Location of our observed DEIMOS slitmasks (blue rectangles) on M31’s minor axis, plotted on a surface density map of M31’s surrounding (courtesy of M. Irwin; see Ibata et al. 2007). The yellow box indicates the mask on the giant stream feature, whereas the red squares show deep HST imaging fields (Brown et al. 2006,2007). The abundance (Fig 5) appears to decline sharply at the boundary of the disturbed region. Most of the spectra were obtained at Keck during Rich’s observing time in 2005 August 27-8.

Fig. 2: N-body simulation (Mori & Rich 2007) in which a satellite galaxy with a mass of $10^9 M_\odot$ is accreted. Four spatial projections of the present-day condition of the merger are illustrated (the apparent projection on the sky, with a giant stream and merger debris, is on the lower right). The novelty of this simulation is the use of a ***live*** disk and bulge that respond to the actual infall. The giant stream and the bubble feature above the stream (the so-called shelf) are well reproduced. The satellite follows the orbit of Fardal et al. (2006) in the three component M31 potential of Widrow et al. (2003).



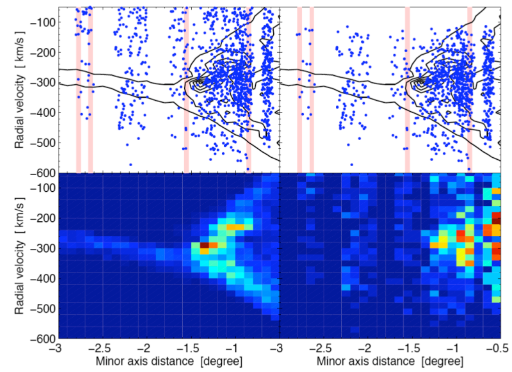


Fig. 3: Top panels: Radial velocities of our targets in the minor axis fields (Fig. 1); red lines indicate the location of Brown’s et al. (2003, 2006, 200, deep HST fields. The top left panel shows our full data including the foreground Galactic dwarfs; in the top right, the dwarfs are statistically removed based on radial velocity, V-I, and Na 8190 equivalent width. The underlying black contours show the number density distribution of the ***stream particles*** from our simulations. This distribution is fully illustrated in the bottom left panel. Finally, the bottom right panel is the number density of the observed, dwarf cleaned sample. Clearly seen is a cold feature at ca. -1.3°, both in observations and in our simulation, which extends like a V-shape towards the inner spheroid. Other substructures are less conspicuous and the *inner* regions appear more smooth than in the simulation (cf. Gilbert et al. 2007).

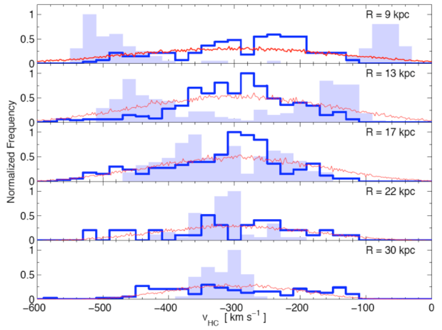


Fig. 4: Observed velocity histograms (solid line) along the minor axis. The region around 17 kpc comprises the cold structure discernible in Fig. 3. Overlaid as blue shaded histogram are velocities from the stream particles with the same spatial distribution from our simulation, scaled to the same number of stars in each field. The dashed red line shows the contribution of M31 halo stars in the simulation data. It is noteworthy that neither disk, nor bulge stars, ejected during the merger event, contribute any considerable fraction to the observed stream-like structures in the velocity histograms. In fact, most of the observations appear to be dominated by the halo component. It is also evident that there is a clear difference between model and observed distributions in the inner spheroid, which suggests that these regions cannot entirely consist of debris from one collision.

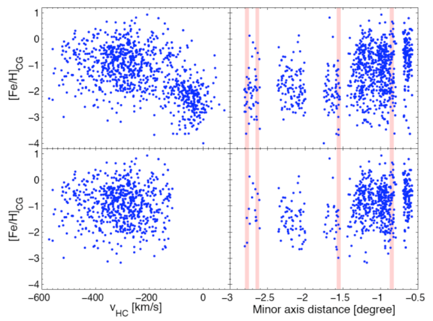


Fig. 5: We measure metallicities from the calcium triplet (CaT). Since the majority of our spectra have low S/N, a simple integration over the traditional bandpasses is susceptible to noise and will enhance errors and smear out potential subcomponents in metallicity space. Thus we devised a ***new method*** to enhance the measurability of the CaT by a weighted coaddition of all three calcium lines. Due to the better signal of the resulting master line, this feature can be fit with a profile giving a more accurate [Fe/H] and allowing us to measure metallicities down to a lower S/N. V band photometry used for the Ca triplet abundance estimates has been derived from CFHT imaging of Ibata et al. 2007 and for the outer halo from Ostheimer et al. 2003.

The top (bottom) panels show the samples before (after) the statistical removal of the dwarf stars. This shows that also our spectroscopic [Fe/H] is a powerful dwarf/giant discriminator. While there is no apparent population substructure discernible within the inner fields, the outer fields are strikingly more metal poor, where we find a pronounced offset from the inner population rather than a gradual transition (cf. Kalirai et al. 2006). Note that Brown et al. (2007) find that an HST field at 25 kpc (middle at -1.5°) is both more metal poor and older than the innermost HST field projected at 11 kpc; the HST pointings appear not dominated by debris.

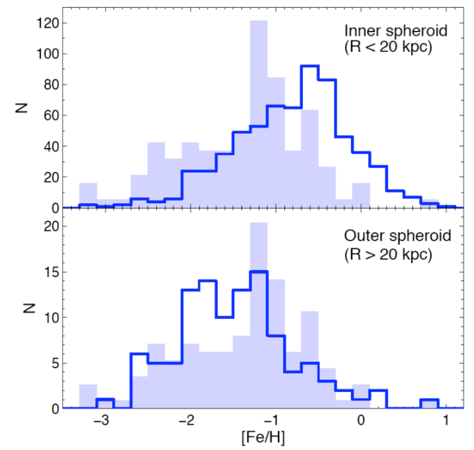


Fig. 6: Metallicity distributions (MDF) for two separate regions along the minor axis (solid lines). There is a clear indication that the outer halo fields are more metal poor by about 1 dex, with an obvious peak around -2 dex. Shown as a shaded histogram is the MDF for our observations of a field on M31’s stellar stream (Ibata et al. 2001; yellow box in Fig. 1). While the merger of a satellite that formed the giant stream may account for parts of the metallicity peak seen in the outer regions, there is only little evidence to connect the inner spheroid’s MDF to such an event; it peaks at a metallicity that is lower by about 1 dex. While the deep ACS CMDs of the stream and inner spheroid fields are very similar (Brown et al. 2006) our spectroscopy suggests different metallicities for these populations.

References:

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