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A wide-field study of Holmberg II and evidence for ram pressure stripping

E. J. Bernard[1], A. M. N. Ferguson[1], M. K. Barker[1], M. J. Irwin[2], P. Jablonka[3,4], and N. Arimoto[5,6]

[1] SUPA, Institute for Astronomy, University of Edinburgh, Royal Observatory, Blackford Hill, Edinburgh, UK; e-mail: ejb@roe.ac.uk
[2] Institute of Astronomy, Cambridge University, Cambridge, UK
[3] Laboratoire d'Astrophysique, EPFL, Observatoire, Sauverny, Switzerland
[4] Observatoire de Paris, CNRS UMR 8111, Université Paris Diderot, Meudon, France
[5] Subaru Telescope, Hilo, Hawaii, U.S.A.
[6] Graduate University for Advanced Studies, Mitaka, Tokyo, Japan

Abstract. We present a deep, wide-field optical study of the M81 group dwarf galaxy Holmberg II (HoII) based on Subaru/Suprime-Cam imaging. Individual stars are resolved down to $I \sim 25.2$, i.e., about 1.5 mag below the tip of the red giant branch (RGB). We use resolved star counts in the outskirts of the galaxy to measure the radial surface brightness profile down to $\mu_V \sim 32$ mag arcsec^{-2}, from which we determine a projected exponential scalelength of $0.70' \pm 0.01'$ (i.e., 0.69 ± 0.01 kpc). The low surface-brightness stellar component of HoII is regular and symmetric and has an extent much smaller than the vast H I cloud in which it is embedded. We compare the spatial distribution of the young and old stellar populations, and find that the old RGB stars are significantly more centrally concentrated than the young stellar populations, contrary to what is observed in most dwarf galaxies of the Local Universe. We discuss these properties in the context of the comet-like distribution of H I gas around HoII, and argue for the presence of a hot intragroup medium in the vicinity of HoII to explain the contrasting morphologies of the gas and stars.

Key words. galaxies: individual: Holmberg II – galaxies: dwarf – galaxies: irregular – galaxies: stellar content – galaxies: groups: individual: M81 group – intergalactic medium.

1. Introduction

We present the stellar distribution in Holmberg II (HoII), a dwarf irregular galaxy of the M81 group located about 3.4 Mpc away. To date the only deep resolved stellar populations study comes from HST/ACS observations which cover a relatively small fraction of the galaxy. The need for deep wider data is especially motivated by the striking morphology of its H I cloud (see Figure 1), compressed on one side with a faint extended component on the opposite side, with the tail pointing away from the centre of the M81 group (Bureau & Carignan 2002, hereafter BC02). BC02 argued that HoII is moving toward the M81 group and that ram pressure from a hot intragroup medium (IGM) is responsible for the H I morphology,

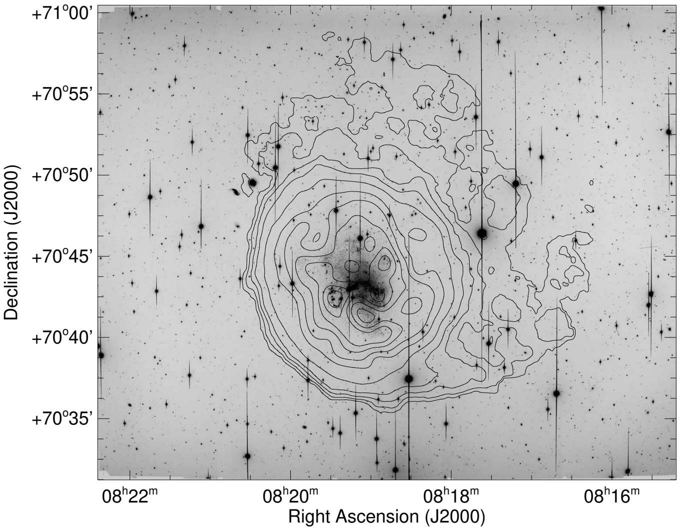

Fig. 1. Mosaic V image of HoII, showing the whole field-of-view of our Subaru data (~35.8′×29.3′). The H I contours from BC02, ranging from N_{HI} = 0.1 to 19×10^{20} atoms cm^{-2}, are overplotted. Note the comet-like morphology of the outermost contour.

although they could not rule out the alternative interpretation of a gravitational interaction between HoII and one of its fainter companion galaxies. Since stars do not respond to ram pressure, while tidal forces affect gas and stars equally, comparing the large-scale distribution of the stars with that of the gas in HoII has the potential to reveal whether the H I morphology was caused by ram pressure, tidal forces, or a combination of both.

2. Observations

The observations of HoII were obtained in service mode with the Suprime-Cam instrument on the 8-m Subaru telescope (P.I.: M. Barker). Thanks to its large field-of-view (FOV; 34′×27′), a single pointing was sufficient to cover the whole galaxy, including the large H I cloud in which it is embedded (R ~ 16′; BC02). The total exposure times are 6,000 sec in Johnson V and 2,400 sec in Cousin I. The PSF photometry was carried out with DAOPHOT/ALLFRAME (Stetson 1994) on the individual exposures. The resulting colour-magnitude diagram (CMD) reaches down to I ~ 25.2, i.e., about 1.5 mag below the tip of the red giant branch (RGB).

3. Spatial distribution and radial profile

We analysed the spatial distributions of individual stellar populations selected on the CMD, in particular stars belonging to the main-sequence and blue supergiant branch (MS+BSG; ≲160 Myr), and the RGB (≳1.5 Gyr). Because of the high stellar density close to the center of the galaxy, the distribution of the faint RGB stars is not clear from our Subaru data, so we checked their distribution in the HST/ACS data from the ACS Nearby Galaxy Survey Treasury program (ANGST; Dalcanton et al. 2009). These are shown in Figure 2.

The difference between the distributions of the MS+BSG and RGB samples is striking: despite the small area covered by the HST data, it is obvious that the old, RGB stars are significantly more concentrated than the younger stars. The former are also distributed in a roughly circular distribution, whereas the latter

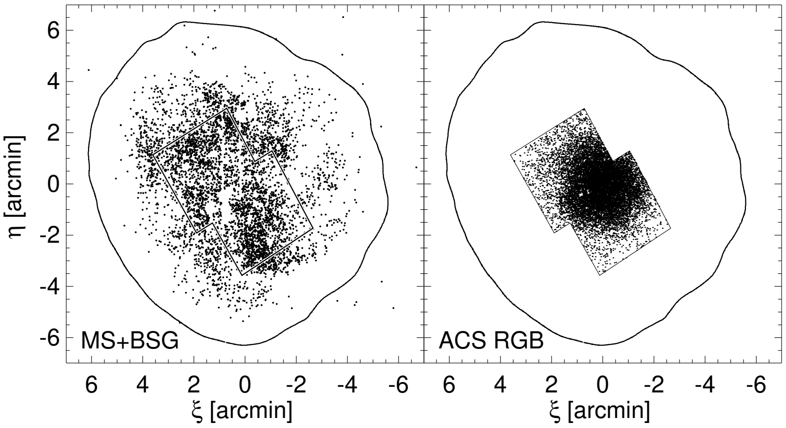

Fig. 2. Zoomed-in spatial distribution of MS+BSG stars in the Subaru FOV, and RGB stars from HST/ACS data. Several small holes in the stellar distributions are due to highly saturated stars and their associated bleed spikes. The $2{\times}10^{20}$ atoms cm^{-2} H I contour from BC02, as well as the outline of the combined footprint of the two ACS pointings, are shown.

present a very irregular distribution. Within the ACS footprint, the density of RGB stars almost vanishes close to the edges while the density of blue stars is roughly uniform. Using only the ACS data to avoid the uncertainties due to incompleteness and different spatial coverage, we find exponential scalelengths for the MS+BSG and RGB samples of $3.1' \pm 0.5'$ and $0.76' \pm 0.04'$, respectively. Figure 2 also shows that the blue stars, besides having a larger spatial extent, also seem to delineate short spiral arms. These arms follow the same counterclockwise orientation as the H I arms observed by Bureau et al. (2004) in the northwest of HoII, which further suggests they are real.

To obtain the radial density profile of HoII over the whole extent of the galaxy, we combined the diffuse light in the central, crowded region with the resolved star counts at larger radii. The resulting profiles are presented in Figure 3. The completeness-corrected star counts and the diffuse light give very similar information in the inner regions, while the star count data allow the profile to be extended to R $\sim 7'$ where $\mu_V \sim 32$ mag arcsec^{-2}. We thus find that the stellar component of HoII is significantly more compact than the H I cloud in which it is embedded, which extends out to $\sim 16'$ (BC02). Even if some stars belonging to HoII are present beyond R $\sim 7'$, their contribution to the galaxy luminosity is likely to be negligible. Assuming an exponential profile, such a population would represent less than 0.1 per cent of the total galaxy light.

4. Discussion

HoII is embedded in a massive H I cloud that is significantly more extended than the optical counterpart. The remarkable morphology of the cloud in the low density outskirts, compressed on one side with a cometary appearance on the opposite side (see Figure 1), is very suggestive of ram pressure stripping due to the presence of a hot IGM. However, the disturbed appearance of the gas cloud may also be the result of gravitational interactions. While HoII is relatively isolated from the massive galaxies of the M81 group, it has at least two companion dwarf galaxies within a projected distance of $\sim$100 kpc which may have tidally affected the neutral hydrogen cloud.

In addition, both the H I gas and the young stellar component trace short spiral arms on the western side of the galaxy, and the detailed

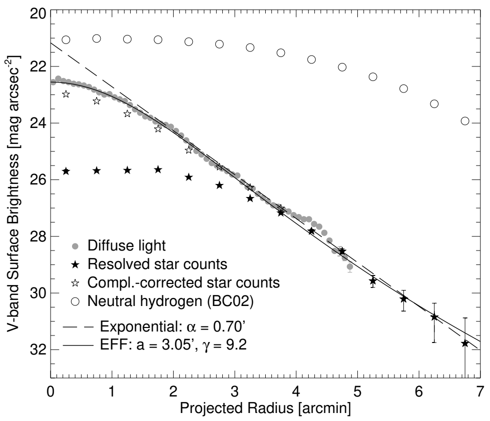

Fig. 3. Background-subtracted surface brightness profiles from the diffuse light (gray filled circles), resolved star counts (filled stars), and completeness corrected star counts (open stars). The open circles represent the H I density profile, from BC02. The dashed and solid lines are exponential and EFF profiles fit to the composite surface brightness profile.

star formation histories of HoII by Weisz et al. (2008) and Dalcanton et al. (2012) reveal a significant enhancement in the last few hundred million years. These features are often associated with tidal interaction events. However, theoretical models which include gas cooling have shown that ram pressure can produce spiral arms, as well as enhance the star formation rate (e.g., Schulz & Struck 2001). The fact that the spatial distribution of young stars closely follows that of the H I contours strongly supports this interpretation.

Therefore, while the morphology of the H I cloud and the observed enhancement of the recent star formation rate cannot help discriminate between the phenomena at play, the regular circular distribution of the intermediate-age and old stars, the regular rotation of the H I arms, the undisturbed H I distribution of the two nearest dwarf companions and the lack of H I bridges/filaments between them and HoII (Bureau et al. 2004; Chynoweth et al. 2009; Ott et al. 2012), all support the ram pressure stripping scenario. In addition, we do not find a stellar counterpart to the H I cloud beyond R$\sim$7′ where it becomes distorted and forms arms/tails, whereas tidal forces would affect gas and stars equally. Therefore, our data strongly suggest that ram pressure stripping is the main process responsible for the swept-back appearance of the H I cloud.

5. Conclusions

Previous studies based on diffuse optical light or 21 cm data could not definitively determine whether the cloud shape was due to ram pressure from a hot IGM or to a tidal interaction with a nearby companion galaxy. Our deep photometry shows that the intermediate-age and old stars have a regular circular distribution and show no sign of tidal tails/streams. In addition, we find that there are very few, if any, HoII stars beyond R$\sim$ 7′ where the H I becomes distorted. Since tidal forces would affect gas and stars equally, our data strongly suggest that the spectacular morphology of the H I cloud is due to ram pressure. This, in turns, indicates the presence of a hot intragroup medium in the M81 group, at least in the vicinity of HoII.

A description of the data reduction and a detailed interpretation of the results are presented in full in Bernard et al. (2012).

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