WHAT'S GOING ON OUT THERE?: THE STELLAR EDGES OF IRREGULAR GALAXIES

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1. INTRODUCTION

Over the past decade I have obtained very deep Hα images of normal, non-interacting irregular (Im) galaxies in order to examine the distribution of star formation in these systems. I have been puzzled by the fact that the Holmberg radius R_H is usually larger than the extent of HII regions even though the gas extends well beyond there.

In Sextans A, for example, R_H is 50% larger than the extent of the Hα emission although the HI extends to 6R_H (Hunter & Plummer 1996). Yet, R_H, defined as the radius at a μ_{photo} of 26.5 mag of $1''^{\ 2}$ or 26.4 in V, implies that there are significant numbers of stars out there. For example, a μ_V of 28 would correspond roughly to the star formation in 30 Orion nebulae, or about one Orion every 300 Myrs over 10 Gyrs if star formation is a continuing process out there.

The outer distribution of starlight is potentially a convolution of in situ star formation and spatial diffusion of stars from further in. However, for plausible kinematics the stars beyond R_H would be unlikely to be *soley* stars that wandered out there from the central regions of the galaxy. Hence, it seems likely that star formation activity must have occurred at least some time in the past in the outer reaches of the stellar distribution.

Several models of galactic star formation predict that star formation in galaxies end when the surface density of the gas falls below a critical density (Quirk 1972, Kennicutt 1989), or where the disk pressure is too low to allow the cold, dense phase in the interstellar gas (Elmegreen & Parravano 1994). These models predict a rather precipitous radial end to star formation rather than a gradual petering out as it becomes more difficult for the galaxy to form a gas cloud.

So what is going on out there? To explore the stellar populations in the outer disk, I have obtained very deep BV images of two irregulars. There are three questions that I want to answer: 1) Where do Im galaxies end in terms of stars? 2) How are stars distributed in the outer regions? and 2) What is the star formation history at the edges of Im galaxies?

2. THE DATA

Phil Massey kindly obtained deep images of DDO 133 and IZw115 with the Mosaic CCD camera on the KPNO 4m in May 2002. For DDO 133 there are 10×900 s exposures in V and 5×1000 s exposures in B; for IZw115 there are 8×600 s exposures in V. The telescope was stepped between exposures. Dome flats and twilight sky flats were used to determine the pixel-to-pixel variations and remove the pupil ghost. The images were corrected for geometrical distortions and stacked to produce a single final image in each filter. The Mosaic images were calibrated using field images and standard stars observed at the Lowell Observatory 1.1 m telescope.

Background galaxies and foreground stars were edited from the image. Then the 2D background was fit and removed. The greatest uncertainty in the galaxy surface photometry of the outer regions is in distinguishing galactic from other objects.

Because Im galaxies are lumpy, I determined the center of the galaxy, position angle, and ellipticity "by hand" from a contour plot of a smoothed version of the V images. Then I integrated in fixed ellipses that increase in semi-major axis length in $10''$ steps. I geometrically matched the continuum-subtracted Hα images to the V-band images and applied the same ellipse integrations.

The photometry was corrected for reddening using the foreground reddening plus 0.05 mag for BV and 0.1 mag for Hα and a Cardelli et al. (1989) extinction curve. The foreground E(B$-$V) for DDO 133 is 0.003 and for IZw115 is 0.008.

3. THE FIGURES

The images show the outer-most ellipse that was used. The surface photometry was terminated because of the presense of a bright foreground star (DDO 133) or peculiar diffuse emission (IZw115).

In the surface photometry plots, along with μ_V, I have plotted the azimuthally-averaged Hα surface brightness. The scales for $\Sigma_{H\alpha}$ and μ_V have been set so that they cover the same logarithmic interval.

4. DDO 133

DDO 133, at a distance of 6.1 Mpc, has a luminosity ($M_B = -16.7$) and star formation rate ($\log SFR = -3.82$ $M_\odot$ /yr/kpc^2) that are typical of Im galaxies. Like some Im galaxies, it also has a bar that is off-center with respect to the outer isophotes.

The surface photometry shows a break in the slope at about 1.2R_{25}. This is about 1.2 kpc beyond the bar, which ends about $r = 2.5$ kpc, and so is not due to the bar. Beyond there, μ_V drops more steeply. The star formation activity is roughly constant out to about R_{25}. Beyond there it also drops steeply, more steeply than μ_V, and it ends at R_H, whereas the stars continue for at least another 1.5 kpc.

Interestingly, the azimuthally-averaged colors are approximately constant at $(B-V)_0 =$ 0.3 throughout the entire galaxy and up to the end of the photometry. That is, the blueness of the inner galaxy extends even to the very low surface brightness "edges." Thus, it appears that the star formation history has been the same throughout the entire galaxy, including the outer edges. For constant but low level star formation, models produce a B$-$V of 0.3 for an age of $\sim$5 Gyr (Larson & Tinsley 1978; $-$0.1 mag added for low metallicity). By 10 Gyr, B$-$V would be 0.4. According to the models, star formation must have occurred in the past 200 Myr for such a color; no star formation for the past 1 Gyr would produce a B$-$V of 0.5.

5. IZw115

IZw115 is at a distance of 12.3 Mpc. It has a luminosity ($M_B = -15.5$) and star formation rate ($\log SFR = -3.76$ $M_\odot$ /yr/kpc^2) that are typical of Im galaxies. However, IZw115 is classed as a Blue Compact Dwarf (BCD), and like many BCDs, the current star formation activity is concentrated near the center of the galaxy.

There is a peculiar low surface brightness ($\mu_V = 26.2$) region that is detached from the main body, located to the SW of the galaxy's center, but along the major axis of the galaxy.

This region is present in all of the individual frames and so seems likely to be real. I cannot say whether it is part of IZw115 or not. I stopped the surface photometry of IZw115 before the ellipse would include this region.

In IZw115 the surface brightness profile has the same slope to the end of our measurements. Since the stars continue about 3 kpc beyond the central HII region, the galaxy clearly cannot have always formed stars the way it is now.

6. SUMMARY

- For both galaxies, starlight is detected as far as the measurements extend. We have not found an "edge."
- The surface brightness profile of the outer region is a continuation of that further in. However, in DDO 133, there is a break in the surface brightness profile between R_{25} and R_H.
- The color of the bulk stellar population in the outer part of DDO 133 is the same as that everywhere else in the galaxy. This implies that the star formation history has been the same everywhere in the galaxy, including the outer regions.

7. ACKNOWLEDGMENTS

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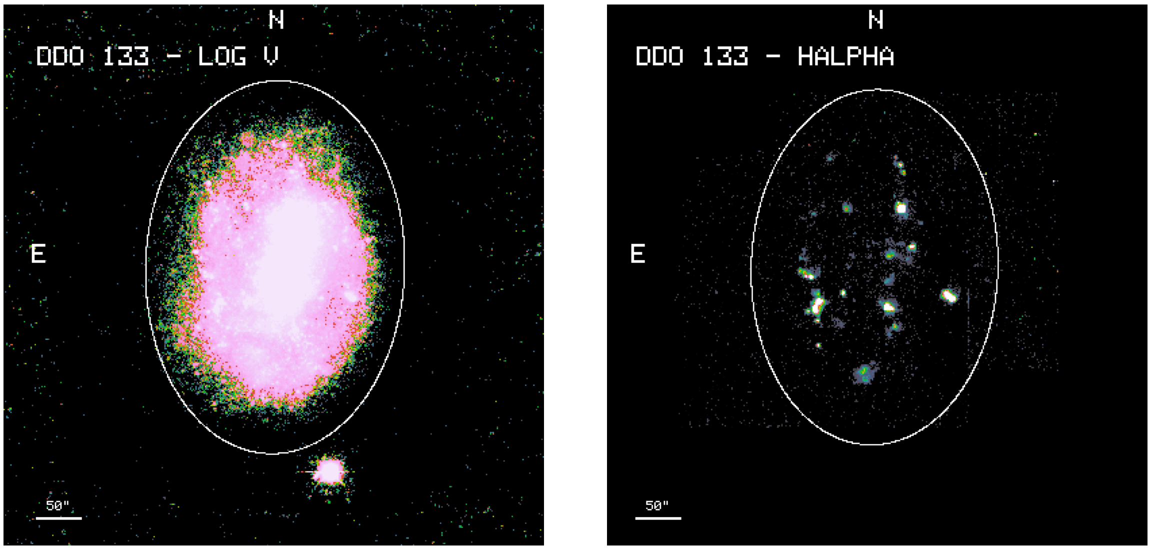

Fig. 1.— Outer-most ellipse measured in DDO 133 shown on log V and Hα images.

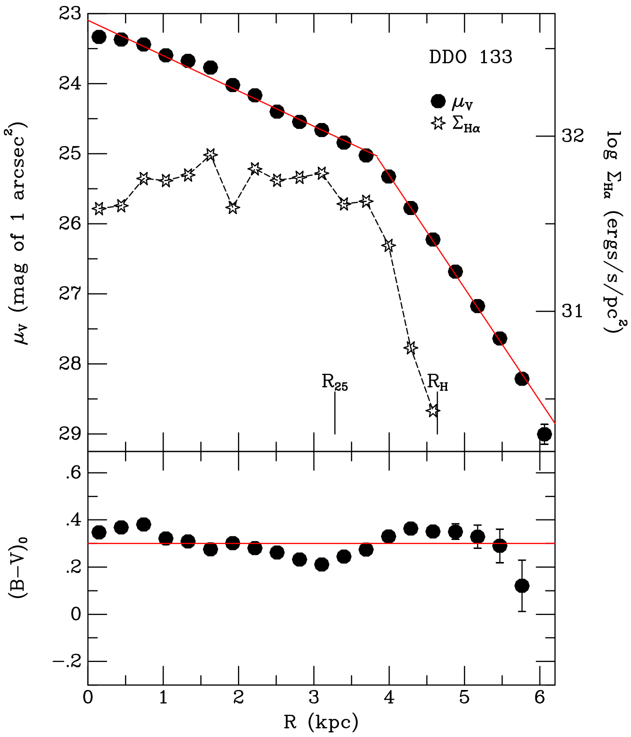

Fig. 2.— Surface brightness photometry and colors in azimuthally-averaged ellipses from B, V, and Hα images of DDO 133.

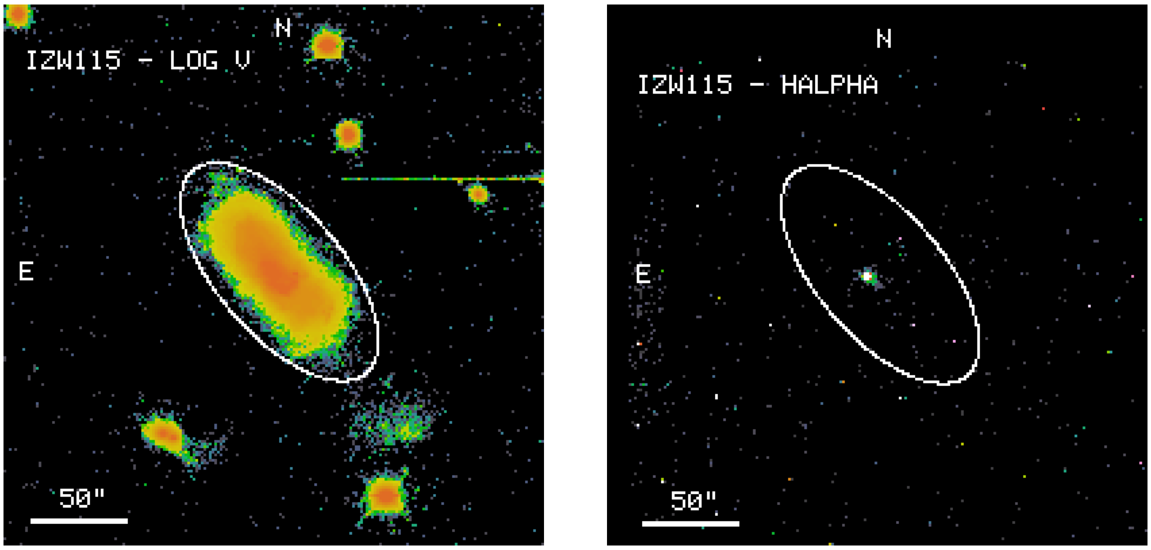

Fig. 3.— Outer-most ellipse measured in IZw115 shown on log V and Hα images.

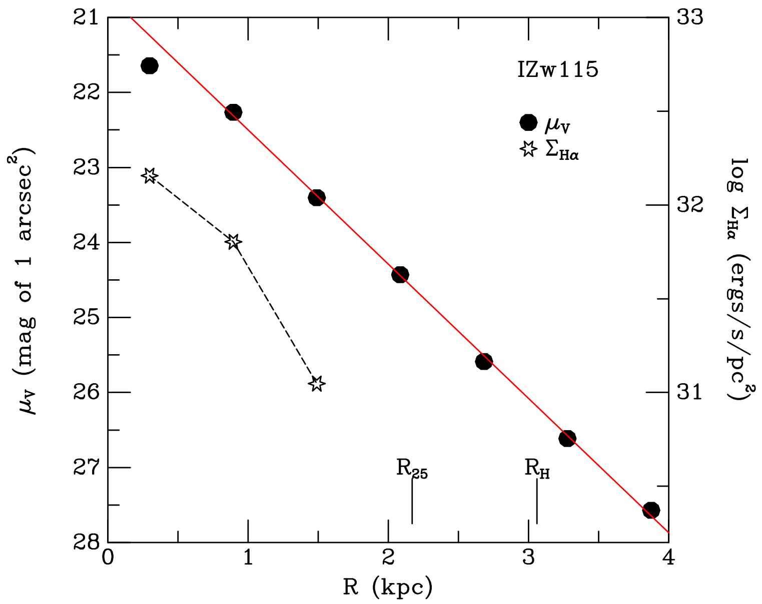

Fig. 4.— Surface brightness photometry in azimuthally-averaged ellipses from V and Hα images of IZw115.