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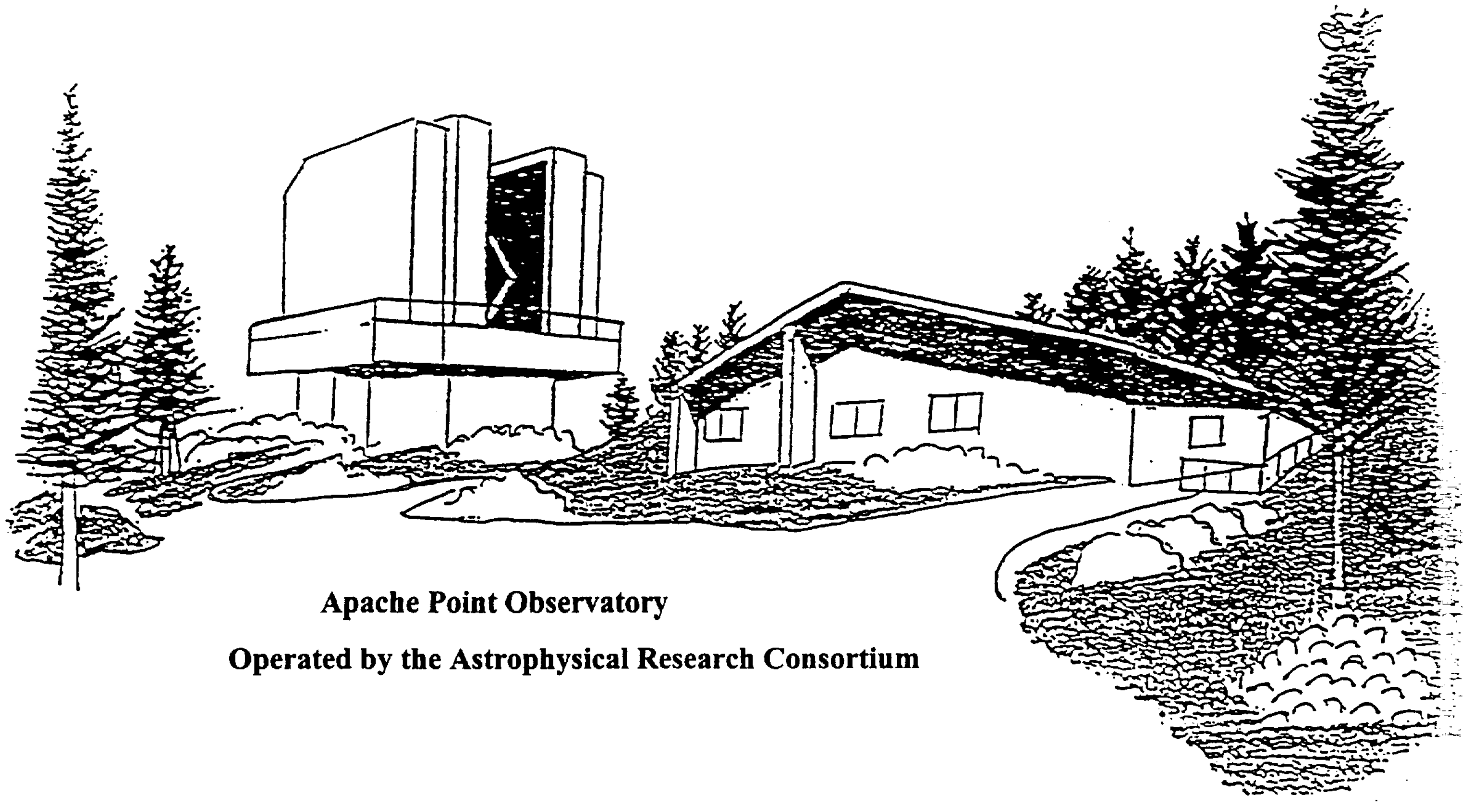

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The Massive Stellar Population in the Diffuse Ionized Gas of M33

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Abstract. We compare Far-UV, Hα, and optical broadband images of the nearby spiral galaxy M33, to investigate the massive stars associated with the diffuse ionized gas. The Hα/FUV ratio is higher in HII regions than in the DIG, possibly indicating that an older population ionizes the DIG. The broad-band colors support this conclusion. The HII region population is consistent with a young burst, while the DIG colors resemble an older population with constant star formation. Our results indicate that there may be enough massive field stars to ionize the DIG, without the need for photon leakage from HII regions.

INTRODUCTION

The majority of the ionized gas mass in galaxies exists as diffuse ionized gas (DIG). The importance of this phase of the ISM is emphasized by the huge amount of energy required to keep it ionized: for example, the Hα luminosity of the DIG in M31 is 40% of the total luminosity [1]. If the DIG is photoionized, 40% of the ionizing photons from OB stars are required to keep the DIG ionized, more energy than that produced by supernovae. This energy requirement is typical of most of the galaxies that have been studied [2]. Only OB stars seem to be able to provide this much energy, but how the ionizing photons from these stars get to the DIG is still a mystery, since DIG is seen as far as a kiloparsec away from any HII regions in galactic disks. The question is whether the photons from OB stars in HII regions are leaking into the diffuse medium, or whether there are enough OB stars outside of HII regions to locally ionize the DIG. We are addressing this problem by investigating the UV and optical emission from the stars in HII regions and DIG in the nearby spiral M33, and comparing to the Hα emission from the gas in both environments.

DATA

B, V, Hα, and red continuum images of M33 were obtained with the 0.6 meter Burrell-Schmidt telescope at Kitt Peak National Observatory. The 75Å wide Hα filter centered on λ6570 also includes the [NII] λ6548 & λ6584 lines. No correction was made for the [NII] contribution. The Hα image contains a total of 5 hours of integration time, and the broadband images are 20 minutes each. The data were reduced using standard methods. The continuum image was scaled to the Hα image using foreground stars and subtracted. The broadband images were calibrated using the published magnitudes for M33. The Hα image was calibrated using the published R magnitude and the known shape and transmission of the continuum and line filters. The data will be described and analyzed in Hoopes, Greenawalt, & Walterbos [3]. The Far-Ultraviolet image is a 424 second exposure taken with the *Ultraviolet Imaging Telescope* [4–6], through the B1 (λ=1520Å, $\Delta\lambda$=354Å) filter, and was obtained from the public archive. All images were convolved to the same resolution ($\sim 4''$) and registered to the same grid.

RESULTS

We measured the FUV and Hα fluxes in fixed $20'' \times 20''$ regions centered on DIG and HII regions. No background was subtracted from the HII regions, so there is a disk contribution to the flux in both bands. The ratio of FUV to Hα fluxes in DIG is systematically higher than that in HII regions (figure 1a). This indicates a difference in the average stellar populations. If the ionizing photons are produced locally, this could mean that the ionizing stars in the DIG are of later spectral type than those in HII regions. Alternatively, it may mean that the ionizing photons in the DIG are not produced locally but are leaking from HII regions, and the FUV flux is produced by non-ionizing B and A stars. If the difference were due to higher extinction in the HII regions, 0.7 magnitudes A_V in excess of that in the DIG would be necessary to explain the result using a foreground screen model, and at least 1.5 magnitudes in a uniform mixture of dust and stars. Greenawalt, Walterbos & Braun [7] found, on average, a 0.3 magnitude difference between HII regions and DIG in M31.

The number of Hα photons in a region is directly proportional to the number of ionizing photons emitted by the stellar population, assuming ionization equilibrium [8] and ignoring the effects of dust absorption. Figure 1b shows the ratio of Lyman continuum photons (from the Hα flux) to the FUV flux versus Hα intensity. The DIG regions with the highest ratio are those with the highest Hα surface brightness. Higher ratios correspond to earlier type stars, so this may indicate that the brightest DIG, which is usually closest to HII regions [1], is affected by photon leakage, or that there is a younger field population near HII regions.

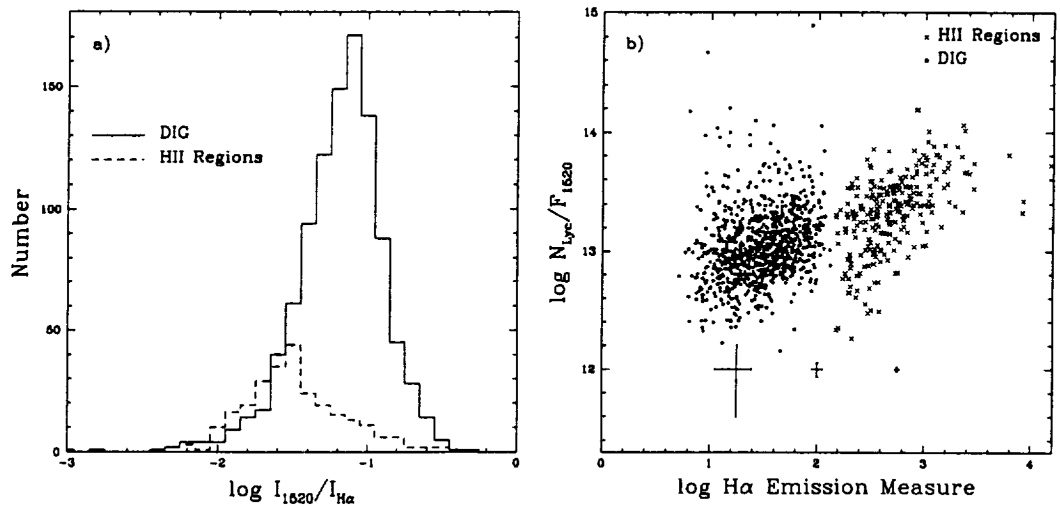

FIGURE 1. (a) Histogram of the FUV to Hα intensities in 20″ × 20″ (80 pc × 80 pc) boxes centered on HII regions and DIG. The values have been corrected for extinction using the mean HI column density in the disk of M33 and an extinction model consisting of a uniform mixture of stars and dust, neglecting scattering. The DIG has a systematically higher ratio, which is consistent with later type stars dominating the radiation field. (b) The Lyman continuum photon to FUV luminosity ratio, as a function of Hα surface brightness. The representative error bars, which reflect a combination of photon noise and flat-fielding uncertainty, are shown shifted down by a factor of 10 for clarity. The brightest DIG has the highest ratio, which corresponds to earlier-type ionizing stars if the ionizing photons are produced locally.

The observed ratios can be explained with evolution models presented in Hill *et al.* [9], as shown in figure 2a. HII regions are described by a 0–5 Myr burst population, and DIG can be described by an older burst model. However, a steady state model reproduces the peak of the DIG distribution remarkably well. The observed ratios in the DIG are also consistent with later-type ionizing stars, as shown in figure 2b. If the FUV and Lyman continuum are both produced locally, the ratio in the DIG would indicate that B0V-O9V stars dominate the radiation field, while HII regions are powered by O8V and earlier type stars. This is an important prediction which can be tested by spectroscopy, using the λ5876 HeI recombination line. Helium will be ionized by stars of type O7 or hotter, so if this line is present in the DIG, then at least some of the ionizing photons must come from stars in HII regions. The line was tentatively detected in the DIG of M31 [7].

The optical colors in the same 20" × 20" regions are systematically bluer for HII regions, again indicating a younger stellar population (figure 3a). Note that both regions contain a contribution from the disk, since a local background was not determined. This makes the colors redder than they would be for a single population. The B−V colors in both environments are compared

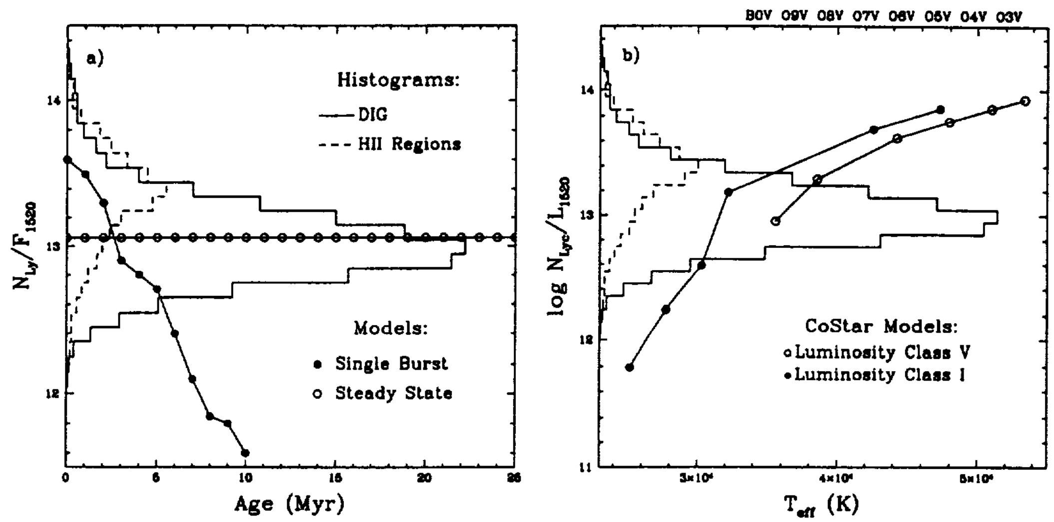

FIGURE 2. (a) Ratio of Lyman continuum photons to FUV luminosity, compared to the evolution models presented in Hill *et al.* [9]. The histograms are the same as in figure 1a. DIG matches an old population with constant star formation, while HII regions are better reproduced by a young burst population, assuming that the Lyc photons are produced locally. (b) Ratio of Lyman continuum photons to FUV luminosity, compared to the *CoStar* stellar atmosphere models of Schaerer & de Koter [10]. The observed ratios are consistent with later-type ionizing stars in the DIG.

to the evolution models of Bruzual & Charlot [11] in figure 3b. DIG matches an old population with a steady influx of new stars, while the HII region colors are clearly affected by a younger component.

CONCLUSIONS AND FUTURE WORK

Although the Hα-FUV comparison and FUV-optical colors of DIG and HII regions in M33 can rule out neither Lyman photon leakage from HII regions nor ionization by local stars, we do show that the stellar populations in HII regions and DIG are clearly different, the colors are consistent with a population of later-type ionizing stars in the DIG, and the observed Lyman continuum emission relative to the FUV flux can also be produced by these stars. The crucial test will be to see whether the stars that Hα-FUV analysis predicts are actually present in the DIG. In the next step in our investigation we will use HST FUV and optical observations to investigate the stars in regions of DIG and HII regions in M33, and see whether the numbers and spectral types agree with the UIT predictions. Spectroscopy of the DIG in M33 is also planned, and will be used to search for the HeI λ5876 recombination line. This line can test whether the ionizing radiation field in the DIG matches the stars observed there by UIT and HST (see figure 2b).

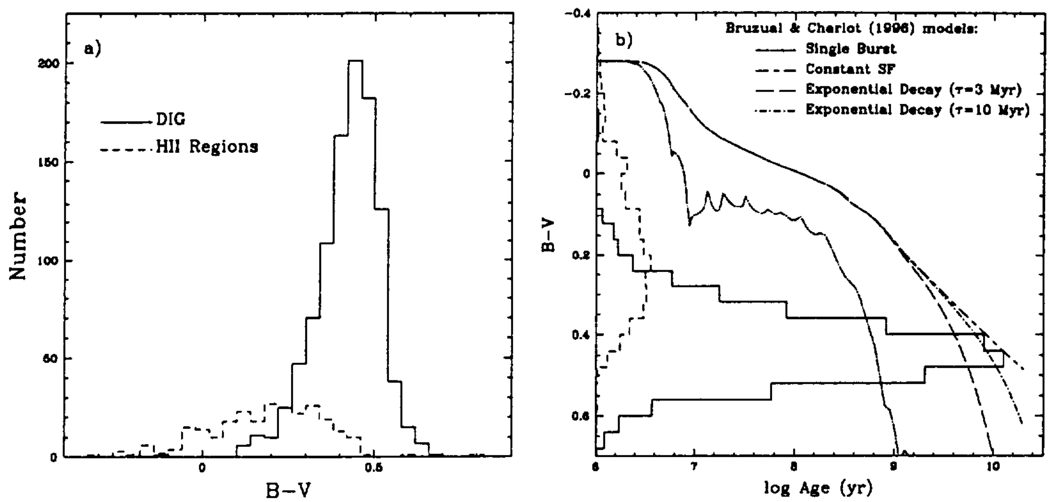

FIGURE 3. (a) Comparison of the B−V colors for the same DIG and HII regions as in figure 1. The stars in HII regions are systematically bluer than DIG, as expected from the younger population in the HII regions. (b) Models of evolving stellar populations from Bruzual & Charlot [11]. The redder colors of the DIG are consistent with a steady state population, with a steady inflow of new stars. The colors of HII regions indicate a younger population. While the DIG colors are also consistent with a ~1 Gyr burst, the lack of ionizing photons in such a population (fig 2a) rules this out. The colors in HII regions include the contribution from the old disk population since no background was subtracted.

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REFERENCES

1. Walterbos, R. A. M., & Braun, R., 1994, ApJ, 431, 156
2. Hoopes, C. G., Walterbos, R. A. M, & Greenawalt, B. E 1996, AJ, 112, 1429
3. Hoopes, C. G., Greenawalt, B. E, & Walterbos, R. A. M 1997, in preparation
4. Stecher, T., *et al.* 1992, ApJL, 359, 1
5. Stecher, T., *et al.* 1997, PASP, 109, 584
6. Stecher, T., *et al.* 1997, this volume
7. Greenawalt, B. E., Walterbos, R. A. M., & Braun, R., 1997, ApJ, in press
8. Osterbrock, D. E. 1989, Astrophysics of Gaseous Nebulae and Active Galactic Nuclei (University Science Books, Mill Valley)
9. Hill, J. K., *et al.* 1995, ApJ, 438, 181
10. Schaerer, D. & de Koter, A., Schmutz, W., & Maeder, A. 1996, A&A, 312, 475
11. Bruzual, A. G., & Charlot, S. 1996, in preparation (see [12])
12. Leitherer, C. *et al.* 1996, PASP, 108, 996