Spitzer Observations of M83 and the Hot Star, H II Region Connection

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Abstract. Emission-line observations made with the Spitzer Space Telescope are used to test the predicted ionizing spectral energy distributions of various stellar atmosphere models.
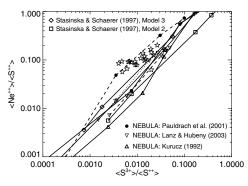
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1. Introduction

H II regions play a crucial role in the measurement of current interstellar abundances. Like planetary nebulae, they also serve as laboratories for atomic physics and provide fundamental data about heavy element abundances that constrain models of galactic chemical evolution. In 2005, February and July, we observed emission lines of [S IV] 10.5, [Ne II] 12.8, [Ne III] 15.6, & [S III] 18.7 μm cospatially with the Spitzer Space Telescope using the Infrared Spectrograph (IRS) in short-high mode (SH). From the measured fluxes, we determine the ionic abundance ratios Ne^{++}/Ne^+, S^{+3}/S^{++}, and S^{++}/Ne^+ in 24 H II regions in the nearly face-on spiral galaxy M83. We covered a range of deprojected galactocentric radii (R_G) from 0.46 to 5.16 kpc. Important advantages compared with prior optical studies are: 1) the IR lines have a weak and similar electron temperature (T_e) dependence, while optical lines vary exponentially with T_e and 2) the IR lines suffer far less from interstellar extinction. We examine the variation of S^{++}/Ne^+ and Ne^{++}/Ne^+ with R_G. The data constrain the ionizing spectral energy distribution (SED) for the stars exciting these nebulae. We compare the ionic ratios with predictions made using stellar atmosphere models from several different LTE and non-LTE model sets.

2. Variation of ionic ratios with R_G

We find a clear correlation with R_G of the ionic abundance ratio S^{++}/Ne^+, which is derived from the measured line flux ratios for each H II region. For H II regions in M83, an electron density (N_e) of 100 cm^{-3} is used as a typical value; an upper limit is roughly 1000 cm^{-3}. For the lower N_e, a linear least-squares fit yields $<S^{++}>/<Ne^+> = 0.426 + 0.0347\,R_G$ (with R_G in kpc), where angular brackets denote fractional ionization. The least-squares fit for an assumed $N_e = 1000$ cm^{-3} is $<S^{++}>/<Ne^+> = 0.365 + 0.0297\,R_G$. In the linear fits, we have assumed an Orion Nebula Ne/S abundance ratio of 14.3 (Simpson *et al.* 2004). Because Ne and S are "primary" elements, their production is expected to vary in lockstep and Ne/S would not be expected to show a radial gradient within a galaxy (Pagel & Edmunds 1981). The fit to the ionic abundance ratio Ne^{++}/Ne^+ also shows a positive correlation with R_G. For $N_e = 100$ cm^{-3}, $Ne^{++}/Ne^+ = 0.0326 + 0.0112\,R_G$ with extremely little change to this equation at 1000 cm^{-3}. There is more scatter about the fit than for the $<S^{++}>/<Ne^+>$ ratio because the [Ne III] line
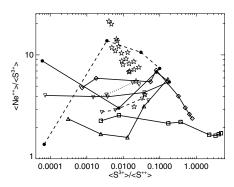
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Figure 1. Left panel: Theoretical predictions of the $<Ne^{++}>/<S^{++}>$ ratio vs. the $<S^{3+}>/<S^{++}>$ ratio. The line segments connect the points which are the results of nebular models calculated using the ionizing SEDs that are predicted from various stellar atmosphere models as labeled. Two curves show the results from Stasińska & Schaerer (1997). The rest result from using our photoionization code NEBULA (e.g., Simpson *et al.* 2004; Rodríguez & Rubin 2005) changing no other parameter except the SED. For the H II region models calculated with Pauldrach *et al.* atmospheres, the solid line connects models with dwarf atmospheres and the dashed line connects models with supergiant atmospheres. For the H II region models calculated with Lanz & Hubeny atmospheres, the solid line connects models with atmospheres with $\log g = 4.0$ and the dotted and dashed lines connect models with atmospheres with $\log g = 3.0$ to 3.5 and with Lyman continuum luminosities of 10^{49} and 10^{50} photons s^{-1}, respectively. To compare our data with the models, we need to divide the observed Ne^{++}/S^{++} and Ne^{++}/S^{3+} ratios by an assumed Ne/S abundance ratio. We use the Orion Nebula Ne/S = 14.3. The star points (adjusted by the assumed Ne/S) are derived from our line fluxes using N_e of 100 cm^{-3}. An N_e of 1000 cm^{-3} will shift these points slightly to the upper right. **Right panel:** The same as left panel except the ordinate is $<Ne^{++}>/<S^{3+}>$. An N_e of 1000 cm^{-3} will shift these points slightly to the bottom right. Both panels dramatically illustrate the sensitivity of the H II region model predictions of these ionic abundance ratios to the ionizing SED that is input to nebular plasma simulations. The M83 data lie closest to the Pauldrach *et al.* supergiant locus.

is weaker than either the [Ne II] or [S III] line in these objects. There is a correlation of increasingly higher ionization with R_G. This is most likely due to the lower metallicity at larger R_G causing the exciting stars to have a harder ionizing spectrum.

3. Comparison with models

The best fit to the data (see Fig. 1) results from the nebular models that utilize the Pauldrach *et al.* (2001) supergiant stellar atmosphere models (the dashed line connecting filled circles). This result is not sensitive to the range of N_e ($\sim$ 100–1000 cm^{-3}) expected for these M83 nebulae.

Acknowledgements

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