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The Formation of Low-Ionization Emission in the Halo of NGC 891

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INTRODUCTION:

Imaging and Spectroscopic study first revealed the presence of a *diffuse ionized medium* (DIM), having unusual excitation, pervading the lower halo of the edge-on spiral galaxy NGC 891.[1,2] Emission from this DIM is strongest northeast of the nucleus,[3] at radii between 2 and 8 kpc (hereafter region 1), where $H\alpha$ emission can be traced out to $|z| \simeq 2$ kpc and the electron density is $n_e \simeq \frac{1}{2} \phi^{-1/2} e^{-|z|/z_0}$ cm^{-3} for a DIM filling factor ϕ. The [NII] $\lambda 6583$/Hα and [SII] $\lambda\lambda 6716,6731$/Hα ratios increase dramatically with $|z|$ in region 1, from 0.6 and 0.5 respectively at $|z| \simeq 500$ pc to 1.1 and 1.0 at $|z| \simeq 1$ kpc,[4] while nondetections of [OI] $\lambda 6300$ and [OIII] $\lambda 5007$ emission yield upper limits of [OI] $\lambda 6300$/Hα $\lesssim 0.05$ and [OIII] $\lambda 5007$/Hα $\lesssim 0.15$ for $|z| \lesssim 1$ kpc.[3] Previous photoionization models,[5] using the radiation field from disk O and B stars, have been successful in reproducing the elevated [NII] $\lambda 6583$/Hα and [SII] $\lambda\lambda 6716,6731$/Hα ratios observed. However, these radiation bounded models also produce significant [OIII] $\lambda 5007$ emission, in conflict with the observed upper limit. Here, we report the results of new, matter bounded models for the photoionization of the DIM in region 1 of NGC 891.

PHOTOIONIZATION MODELING:

We use the photoionization code CLOUDY[6] to examine the parameter space available to individual photoionized DIM elements (clouds, filaments, sheets) using plane-parallel, constant (low) density, matter bounded models. All models include the optical and thermal (heating and cooling) properties of standard interstellar dust grains,[6] and use the hardened radiation field of a Salpeter IMF stellar population detailed elsewhere.[5] Depleted elemental abundances, calculated using standard interstellar depletion parameters[7] for an average density of $\frac{1}{2}$ cm^{-3} are used throughout. Acceptable reproduction of the observational constraints can be obtained for ionization parameters of order 10^{-4} and hydrogen columns in the range $5 \times 10^{18} \lesssim N_H$ (cm^{-2}) $\lesssim 2 \times 10^{19}$. We compare model results with observations in Table 1 and present the $N_H = 10^{19}$ cm^{-2} line ratios Figure 1.
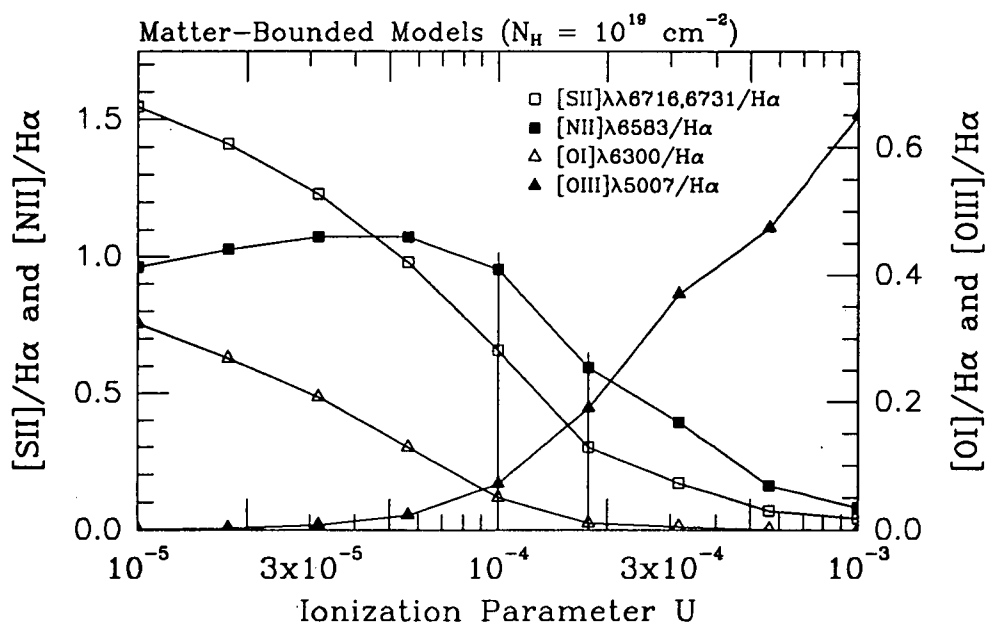
We can estimate the ionization parameter throughout the DIM of NGC 891 by using the electron density distribution given above and appealing to its ionization equilibrium. Specifically we find; $U(|z|) \simeq \alpha_{rec} (\int_{|z|}^{\infty} \phi\, n_e^2(z')\, dz')/(n_e(|z|)\,c)$, where α_{rec} is the hydrogen recombination coefficient (2.6×10^{-13} cm^3 sec^{-1} at 10^4 K) and c is the speed of light. This yields $U(|z|) \simeq 5 \times 10^{-3} \phi^{1/2} e^{-|z|/1\text{kpc}}$ throughout region 1. Therefore, the ionization parameter falls by a factor of 5 out to $|z| \simeq 2$ kpc, and by a factor of ~ 1.5 over 500 pc $\leq |z| \leq 1$ kpc. Successful reproduction of the full range of [NII] $\lambda 6583$/Hα ratios observed and the strong emission gradients with $|z|$ requires $U \simeq 10^{-4}$ at $|z| = 1$kpc. This suggests that the DIM filling factor is ~ 0.003, significantly lower than previous estimates.[5]

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Table 1: Model Results

Emission Property	Observed	Model		
		5×10^{18}	1×10^{19}	2×10^{19}
[SII] $\lambda\lambda\,6716,6731/\mathrm{H}\alpha$	0.5 - 1.0	0.3 - 1.0	0.3 - 1.0	0.2 - 0.9
[NII] $\lambda\,6583/\mathrm{H}\alpha$	0.5 - 1.1	0.6 - 1.0	0.5 - 1.1	0.5 - 1.1
[OI] $\lambda\,6300/\mathrm{H}\alpha$	$\lesssim 0.05$	$\lesssim 0.02$	$\lesssim 0.05$	$\lesssim 0.08$
[OII] $\lambda\,3727/\mathrm{H}\alpha$	Unknown	1.2 - 1.6	1.2 - 1.8	1.0 - 1.9
[OIII] $\lambda\,5007/\mathrm{H}\alpha$	$\lesssim 0.15$	$\lesssim 0.1$	$\lesssim 0.2$	$\lesssim 0.3$

Figure 1: Results of matter bounded photoionization models having $N_H = 10^{19}$ cm^{-2}. The solid vertical lines delimit the ionization parameter range estimated to exist over 500 pc $\lesssim |z| \lesssim$ 1kpc, for $\phi \simeq 0.003$.

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