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Temperature Variations from HST Imagery and Spectroscopy of NGC 7009

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1. Introduction

We obtained new HST/STIS long-slit spectra and WFPC2 imagery of the planetary nebula NGC 7009 in order to obtain high spatial resolution of the intrinsic flux ratio [O III] 4364/5008, which is a well-known diagnostic for electron temperature (T_e). Our primary purpose was to quantify T_e variations across the nebula. We address whether the observational data support the possibility that the [fractional] mean-square T_e variation (t^2) (Peimbert 1967) in NGC 7009 may be as large as $\sim$0.1. Such large values are required to reconcile the "abundance dichotomy" by T_e variations alone. The abundance dichotomy (discussed by Liu at greater length elsewhere in this volume) refers to the significantly higher heavy element abundances derived from optical recombination lines (e.g., a factor of $\sim$5 for NGC 7009, Liu et al. 1995) compared with the corresponding values deduced from collisionally-excited lines.

2. Observations

The observations were made as part of our HST GO-8114 program. The WFPC2 observations (with corresponding line of interest as vacuum rest wavelength in Å) were made in line filters F437N ([O III] 4364), F487N (Hβ 4863), F502N ([O III] 5008), and F656N (Hα 6565). The pixel size is 0.0996″. The STIS long-slit spectra were taken at position angle (PA) = 86.72° which was the closest PA, that allowed for a pair of guide stars, to our original desire to align the slit

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with the major axis (PA = 78.5°). We used a slit width of 0.5″ and a slit length of 52″ for these CCD observations. Data included [O III] 4364 Å, Hγ 4342 Å, [O III] 5008, 4960 Å, Hβ 4863 Å, Hα 6565 Å, and the [N II] 6550, 6585 Å lines.

3. Analysis and Results

With the STIS data, we are interested here in the distribution of line flux along the slit spatial direction. This was accomplished using IRAF and with specialized software tools that we developed ourselves. The analysis of both data sets for the average T_e and mean-square T_e variation in the *plane-of-the-sky*, which we call $T_{0,A}$ and t_A^2, gave consistent results. We restrict the analysis to the interior main body of the nebula, with the highest signal-to-noise (S/N). This provides plenty of real estate to address T_e fluctuations. For the WFPC2 data, this area is an ellipse with semi-major and semi-minor axes of 14.5″ and 11.7″ centered on the central star (CS).

One of the most important operations involved partitioning the contributions to the WFPC2/F437N emission. We consider these as due to [O III] 4364, Hγ, and continuum emission. (An examination of our STIS spectra shows no other emission lines will contribute significant flux.) In order to assess the contribution of 4364 and Hγ leakage to our F437N data, we did a careful spatial registration/comparison of the highest S/N portions of our STIS data with corresponding WFPC2 filters. Because the dominant contribution to the nebular continuum for NGC 7009 is recombination processes, we estimate the continuum contribution to each of the WFPC2 filters from recombination theory. The WFPC2 T_e map is rather uniform; almost all values are between 9000 – 11,000 K, with the higher T_es closely coinciding with the inner He^{++}-zone. The results indicate very small values – $\lesssim$ 0.01 – for t_A^2 throughout. The overall $T_{0,A}$ = 9912 K and t_A^2 = 0.00360 for the 52,995 good pixels within the most distant elliptical contour used (excluding the CS region).

Our STIS data allow an even more direct determination of T_e, and thus $T_{0,A}$ and t_A^2, albeit for a much smaller area than with WFPC2. We present results from binning the data along the slit into tiles that are 0.5″ square (matching the slit width). The average [O III] temperature using 45 tiles (excluding the CS and STIS fiducial bars) is 10,139 K; t_A^2 is 0.0035.

The measurements of T_e reported here are an average along each line of sight. Therefore, despite finding remarkably low t_A^2, we cannot completely rule out T_e fluctuations along the line of sight as the cause of the large abundance discrepancy between heavy element abundances inferred from collisionally excited emission lines compared to those derived from recombination lines.

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References

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