Physical Conditions in NGC 6543

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We observed NGC 6543 (the Cat's Eye Nebula) with the HST WFPC2 camera in ten narrow-band filters covering a range of emission lines. These images are used to further look at the physical conditions in NGC 6543. We discuss the [O III] electron temperature, ionization state throughout the nebula, and the results of photoionization models of individual structures.

The [O III]λ5007,4363 emission-line images were used to make a full map of the [O III] electron temperature across NGC 6543. To reduce noise the [O III] images were binned and the temperature map smoothed, resulting in a final spatial resolution of about 0.2″. The λ4363 image was corrected for nebular continuum (0.015F(Hβ)) and Hγ contamination by subtracting a scaled Hβ image.

The mean [O III] temperature is 8000 K with a standard deviation of 625 K, measured from the peak and width of the histogram of temperatures. Although the map is noisy in a number of regions, in general large variations in temperature are not seen, with 90% of the pixels showing a temperature in the range 7000 K – 9000 K. No distinct temperature differences are seen in either the [O III]-bright "bubble" or the [O I]-bright equatorial ring. However, small temperature differences may exist between nebular components. The temperature appears to rise in the core and towards the central star, to over 10,000 K, but temperature values in this region are uncertain because the central star is very saturated in the λ4363 image. Any wings on the WFPC2 stellar PSF would have a significant effect on the temperature determination. The temperature appears to increase slightly in the caps, to ~8300 K from ~7700 K just interior to the caps. Although λ4363 flux is very weak past the caps near the ansae, temperature seems to drop to ~7200 K in this region. The λ4363 flux is not high enough to measure temperature in the jets.

The variation seen in the [O III] electron temperature map is small — about 12%. A typical value for the temperature fluctuation parameter t^2 is 0.04, or a 20% variation in temperature (Kingdon & Ferland 1995). Kingsburgh et al. (1996) measured t^2=0.057 in NGC 6543 using the forbidden and recombination lines of the O^{++} ion. However, the temperature variations implied by either t^2 are not seen in our temperature map.

The ionization state in the nebula is illustrated with a false-color map made by combining the [O III] λ5007, [O II] λ3727, and [O I] λ6300 images. As expected, the knots in the equatorial ring have neutral cores ([O I]) surrounded by ionized gas ([O II]). Similarly, the ansae have a filament of [O I] running through them which is surrounded by strong [O II] emission. The high-ionization gas ([O III]) is not confined to the elliptical bubble but extends out, disk-like, to the ring of knots.

The high spatial resolution of the WFPC2 images enables isolation of emission from specific, small-scale components of NGC 6543 such as the jets, ansae and caps. Isolated fluxes can be difficult to measure accurately with most ground-based telescopes and instruments with component dimensions as small as 1″. Synthesized spectra from the ten emission lines observed are presented for each of the isolated structures in Table 1. The

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Table 1: Emission-line Fluxes[a] of Isolated Components

line	λ	global[b]	core	ring	caps[c]	ansae[c]	N jet	S jet
Hβ	4861	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Hα	6563	2.992	2.913	3.066	3.024	2.960	3.322	3.666
HeI	5876	0.205	0.215	0.202	0.203	0.199	0.211	0.115
[OIII]	5007	6.211	6.481	6.283	6.224	5.145	5.811	4.895
[OIII]	4363	0.047	0.068	0.034	0.037	0.066	0.118	0.230
[OII]	3727	0.420	0.268	0.308	0.881	2.042	4.715	3.095
[OI]	6300	0.045	0.041	0.040	0.083	0.143	0.345	0.242
[NII]	6584	0.345	0.050	0.260	1.302	2.411	4.258	3.608
[SIII]	9531	1.047	0.730	1.172	1.380	1.129	1.091	1.009
[SII]	6724	0.097	0.059	0.079	0.226	0.498	0.928	0.942

[a] fluxes are not corrected for nebular continuum or reddening
[b] sum in ellipse with major axis=40.5″, minor axis=22.5″
[c] total in point-symmetric structures

SYNPHOT package was used for flux calibration of the images. The fluxes are normalized to Hβ=1.0, and are not corrected for nebular continuum (~2% Hβ) or reddening. Although the Hα, [N II], and [O III]λ4363 fluxes are corrected for bandpass contamination by neighboring lines, the [O I]λ6300 fluxes still contain a contribution from [S III]λ6312 which is sizable in some apertures.

We present two photoionization models which show strong emission in the low-ionization lines of [O II], [N II], [S II] and [O I] similar to what we observe in the caps and ansae of NGC 6543. We do not claim the models are unique. The models were made using the photoionization code CLOUDY (Ferland 1993), with the central star spectrum model of de Koter et al. (1996, T_{eff}=48,000). The central star ionizing fluxes (de Koter, private communication) were scaled for a distance of 1.5 kpc. The abundances used for the models were close to average: He/H=0.12, C/H=7.94E-4, N/H=1.26E-4, O/H=5.01E-4, Ne/H=9.77E-5, S/H=8.91E-6. These models show that it is not necessary to resort to shock-heating or abundance anomalies to explain the spectrum of the caps and ansae in NGC 6543.

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