The Physical Properties and Effective Temperature Scale of O-type Stars as a Function of Metallicity. II. Analysis of 20 More Magellanic Cloud Stars, and Results from the Complete Sample

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In order to determine the physical properties of the hottest and most luminous stars, and understand how these properties change as a function of metallicity, we have analyzed {\it HST}/UV and high S/N optical spectra of an additional 20 Magellanic Cloud stars, doubling the sample presented in the first paper in this series. Our analysis uses NLTE line-blanketed models that include spherical extension and the hydrodynamics of the stellar wind. In addition, our dataset includes {\it FUSE} observations of OVI and {\it HST} near-UV He~I and He~II lines to test for consistency of our derived stellar properties for a few stars. The results from the complete sample are as follows: (1) We present an effective temperature scale for O stars as a function of metallicity. We find that the SMC O3-7 dwarfs are 4000 K hotter than Galactic stars of the same spectral type. The difference is in the sense expected due to the decreased significance of line-blanketing and wind-blanketing at the lower metallicities that characterize the SMC. The temperature difference between the SMC and Milky Way O dwarfs decreases with decreasing temperature, becoming negligible by spectral type B0, in accord with the decreased effects of stellar winds at lower temperatures and luminosities. The temperatures of the LMC stars appear to be intermediate between that of the Milky Way and SMC, as expected based on their metallicities. Supergiants show a similar effect, but are roughly 3000-4000 K cooler than dwarfs for early O stars, also with a negligible difference by B0. The giants appear to have the same effective temperature scale as dwarfs, consistent with there being little difference in the surface gravities. When we compare our scale to other recent modeling efforts, we find good agreement with some CMFGEN results, while other CMFGEN studies are discordant, although there are few individual stars in common. WM-Basic modeling by others have resulted in significantly cooler effective temperatures than what we find, as does the recent TLUSTY/CMFGEN study of stars in the NGC~346 cluster, but our results lead to a far more coeval placement of stars in the H-R diagram for this cluster. (2) We find that the wind momentum of these stars scale with luminosity {\it and} metallicity in the ways predicted by radiatively-driven wind theory, supporting the use of photospheric analyses of hot luminous stars as a distance indicator for galaxies with resolved massive star populations. (3) A comparison of the spectroscopic masses with those derived from stellar evolutionary theory shows relatively good agreement for stars with effective temperatures below 45000 K; however, stars with higher temperatures all show a significant mass discrepancy, with the spectroscopic masses a factor of 2 or more smaller than the evolutionary masses. This problem may in part be due to unrecognized binaries in our sample, but the result suggests a possible systematic problem with the surface gravities or stellar radii derived from our models. (4) Our sample contains a large number of stars of the earliest O-types, including those of the newly proposed O2 subtype. We provide the first quantitative descriptions of their defining spectral characteristics and investigate whether the new types are a legitimate extension of the effective temperature sequence. We find that the NIII/NIV emission line ratio used to define the new classes does not, by itself, serve as an effective temperature indicator within a given luminosity class: there are O3.5~V stars which are as hot or hotter than O2~V stars. However, the He~I/He~II ratio does not fare much better for stars this hot, as we find that He~I $\lambda 4471$/ He~II $\lambda 4542$, usually taken primarily as a temperature indicator, becomes sensitive to both the mass-loss rate and surface gravities for the hottest stars. This emphasizes the need to rely upon {\it all} of the spectroscopic diagnostic lines, and not simply N~III/N~IV or even He~I/He~II, for these extreme objects. (5) The two stars with the most discordant radial velocities in our sample happen to be O3 ``field stars'', i.e., found from the nearest OB associations. This provides the first compelling observational evidence as to the origin of the field O stars in the Magellanic Clouds; i.e., that these are classic runaway OB stars, ejected from their birth places.

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