Far-Infrared Spectroscopy of Planetary Nebulae with the KAO

R.H. Rubin[1,2], **S.W.J. Colgan**[1,3], **M.R. Haas**[1], **S.D. Lord**[4] **and J.P. Simpson**[1,3]

[1]NASA Ames Research Center; [2]Orion Enterprises; [3]SETI Institute;
[4]IPAC/California Institute of Technology

We present new far-infrared line observations of the planetary nebulae (PNs) NGC 7027, NGC 7009, NGC 6210, NGC 6543, and IC 4997 obtained with the Kuiper Airborne Observatory (*KAO*). The bulk of our data are for NGC 7027 and NGC 7009, including [Ne V] 24 μm, [O IV] 26 μm, [O III] (52, 88μm), and [N III] 57 μm. Our data for [O III] (52, 88) and [N III] 57 in NGC 7027 represent the first measurements of these lines in this source. The large [O III] 52/88 flux ratio implies an electron density (cm^{-3}) of log N_e[O III] = 4.19, the largest N_e ever inferred from these lines. We derive $N^{++}/O^{++} = 0.394\pm0.062$ for NGC 7027 and 0.179 ± 0.043 for NGC 6210. We are able to infer the O^{+3}/O^{++} ionic ratio from our data. As gauged by this ionic ratio, NGC 7027 is substantially higher ionization than is NGC 7009 – consistent with our observation that the former produces copious [Ne V] emission while the latter does not. These data help characterize the stellar ionizing radiation field.

We find the ratio of fractional ionizations $<O^{+3}>/<O^{++}>$ is less than $\sim$0.10 for NGC 7009. We infer $O^{++}/H^{+} = 4.5\pm0.5\times10^{-4}$ from our data and the radio flux of 0.649 Jy at 2 cm (Milne & Aller 1982). From Hyung & Aller (1995a,b), $O^{+}/O^{++} < 0.1$. Corrections for O^{+} and O^{+3} would imply that our O^{++}/H^{+} requires an upward revision of $<$ 20% to be converted to a total gas-phase O/H abundance. At face value, this would tend to corroborate the O/H value found from UV/optical, collisionally excited lines (e.g., Kingsburgh & Barlow 1994) and not the much larger O/H from recombination lines (Liu et al. 1995). The direct inference from this agreement in O/H values obtained from the collisionally excited UV/optical lines (with strong T_e dependence) and from the collisionally excited FIR lines (with weak T_e dependence) is that T_e fluctuations cannot be large.

We determined accurate rest wavelengths for the [Ne V] $2s^2 2p^2\ ^3P_1 \rightarrow 2s^2 2p^2\ ^3P_0$ ($\lambda_{\rm rest}$ = 24.316$\pm$0.008 μm) and [O IV] $2s^2 2p\ ^2P^0_{3/2} \rightarrow 2s^2 2p\ ^2P^0_{1/2}$ ($\lambda_{\rm rest}$ = 25.887$\pm$0.007 μm) transitions from observations of one or both of the bright PNs NGC 7027 and NGC 7009. Our [O IV] value, to the best of our knowledge, is the most accurate direct determination of this $\lambda_{\rm rest}$ prior to *ISO*.

These new *KAO* data will be beneficial for comparison with *ISO* observations.

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