H_2 excitation temperature through mid-infrared Spitzer spectroscopy of PNe

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We present mid-infrared (MIR) spectroscopy acquired with the Spitzer Space Telescope (Spitzer) of a sample of PNe. These spectra that most of the MIR H_2 ν = 0–0 emission is clearly concentrated in the main nebulae. The present H_2 detections correspond to the ν = 0–0 transitions alone. The relative line intensities have been used to diagnose the trend of the population levels allowing us to determine the rotational excitation temperatures.

IRS-Spitzer Spectra

Spectra were obtained in Basic Calibrated Data (BCD) from the Spitzer Heritage Archive for the planetary nebulae NGC 2346, NGC 2818, NGC 6072 and NGC 6537, among others. The spectral regions studied were in the IRS Short-Low (SL: 5.5-14.5 μm) range. These spectra were calibrated and extracted using the CUBISM software package.

H_2 Excitation

The H_2 molecule can be excited through a variety of different mechanisms, including infrared fluorescence and collisional excitation. In the first case, absorption of an ultraviolet photon in the Lyman and Werner bands leads to a rotational-vibrational cascade in the ground electron state. The UV photons may originate directly in the central star, or as a result of emissions from strong shocks. In the second case, the H_2 transitions may arise through thermal excitation. Both mechanisms are important to investigate the physical conditions in the nebulae.

For the present case, where there is no change in the vibrational state v, the column density of a transition with rotational state *J*, relative to the ν=0-0 transition with *J*=4, is given by

$$\frac{g_4 N(\nu,J)}{g_J N(0,4)} = \exp\{-\frac{E(\nu,J)-E(0,4)}{kT_{ex}}\}$$

Where the left-hand side is equivalent to

$$\frac{F(\nu',J')\nu_{0,2S(2)}A_{0,4\rightarrow 0,2}g_4}{F(0,4)\nu_{\Delta\nu,\Delta J}A_{\nu',J'\rightarrow\nu''J''}g_J}$$

We have used this expression, in conjunction with Einstein *A* coefficients, to determine the population trends illustrated in the figures. The reciprocal gradient of the trend indicates the excitation temperature for the H_2.

Results

It is evident that the data points on these plots present a straightforward linear log–log trend. These trends have been used to derive temperatures for the selected nebulae in the range from 830 to 910 K, in agreement with previous findings (e.g., Phillips, et al 2011). The deviations of some data points from the log-log relation are caused by the averaging over differing regions of the nebular shell. A forthcoming paper will refine this analysis and expand the sample of objects.

References:
Phillips, J.P., Ramos-Larios, G. & Guerrero, M.A, MNRAS, 2011, 415.
Smith, J. D. T., et al., PASP, 2007, 119.1133S

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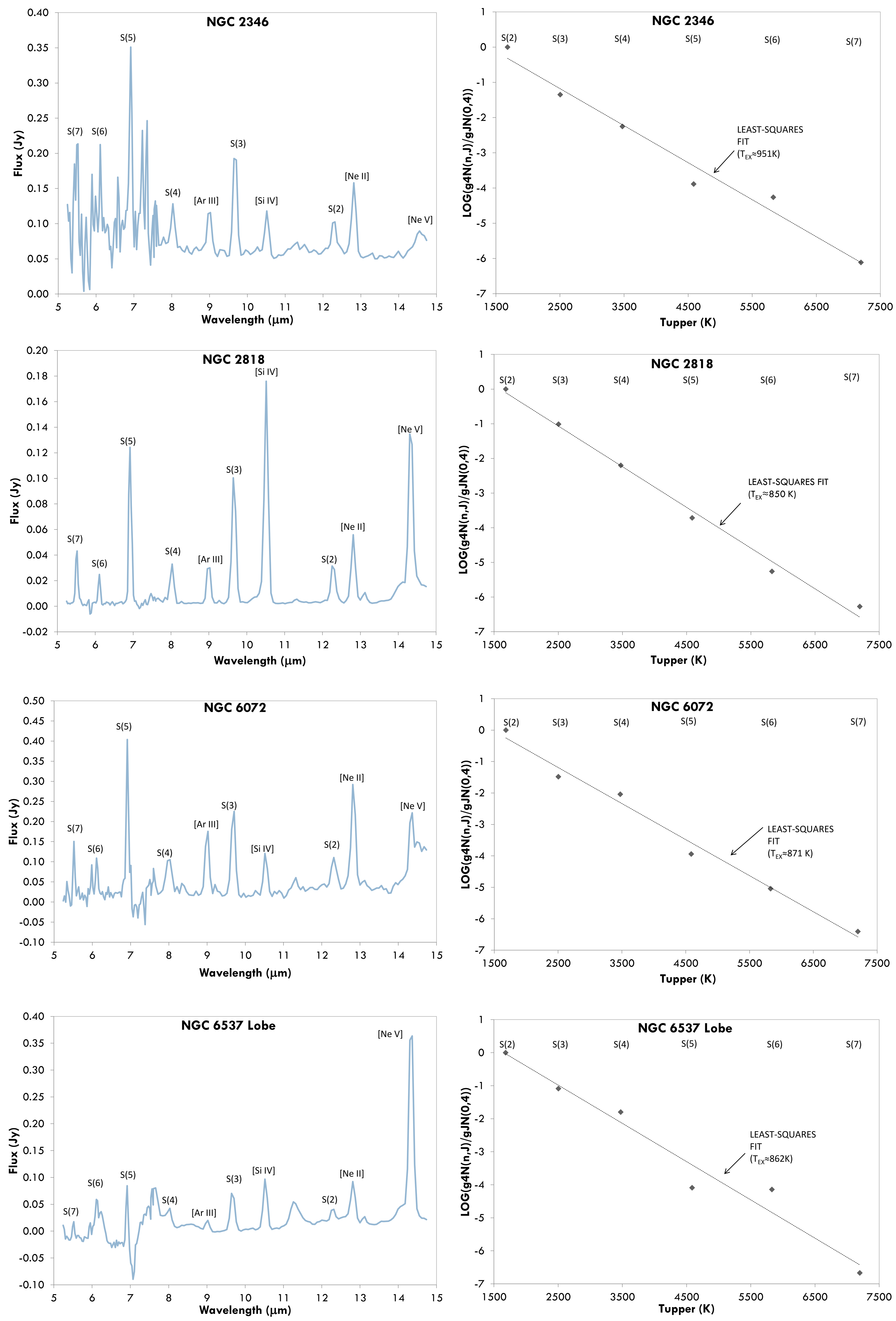
Spectroscopy and Analysis



(*left*) Mid-IR SPITZER spectra of NGC 2346, NGC 2818, NGC 6072, and the bipolar lobes of NGC6537. Each spectrum covers the SL1 and SL2 regions. Lines from v=0-0 transitions S(2) through S(7) are marked on each spectrum, along with other prominent ionic lines. (*right*) Mean variation plots of the H_2 vibrational–rotational populations for the v = 0–0 S(2)–S(7) transitions. The data points are the average of the line strengths for all available spectral positions. The least-square fit to the population of these levels provides the rotational excitation temperature of the H_2 molecule.