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Near-Infrared Spectroscopy of H_2 in Proto-Planetary Nebulae

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Abstract. We measured 2.1 – 2.3 μm spectra for a fairly complete sample of known proto-planetary nebulae (PPN) at declinations greater than -30°. This spectral range includes the H_2 emission lines 1-0 S(1), 1-0 S(0), 2-1 S(1), 2-1 S(2), and 3-2 S(3). We detected H_2 emission from 16 of the 51 nebulae in our survey, including radiatively-excited H_2 from several non-bipolar PPN.

1. H_2 Emission and Nebular Morphology

In planetary nebulae (PNe), there is a very strong correlation between H_2 emission and bipolar morphology. Kastner et al. (1996) surveyed 109 PNe. They detected H_2 emission from 2/3 of the bipolar nebulae, but they detected H_2 emission from less than 20% of the nebulae that lack clear bipolar morphologies. Since all of the H_2-emitting non-bipolars are candidate bipolars, they find it likely that every H_2-emitting PNe possesses bipolar structure. They also find that the strongest H_2 emission comes from the waist region, not from the bipolar lobes.

The tight correlation between H_2 emission and bipolar morphology and the tendency for the brightest H_2 emission to come from the waist region of these bipolars can be explained if dust shielding has preserved the H_2 in a dusty ($A_v \gtrsim 4$) torus (Tielens 1993). Since the H_2 excitation and destruction process are identical, H_2 emission should have been prominent in the non-bipolars and in the lobes of young bipolars while the H_2 was being dissociated. In this study, we observed PPNe spanning B-G spectral types. We find that H_2 emission commences at a spectral class of mid-G in nebulae with optically thick shells and bipolar morphologies. The H_2 emission in these nebulae is excited collisionally. Radiative excitation becomes important in PPNe when the central star reaches early-B spectral type, just before photoionization of the nebula and the commencement of the PNe phase. Almost all of the PPNe with B central stars show H_2 emission; the nebulae with optically thin shells show a pure radiative H_2 spectrum, while the bipolars show a mixed collisional plus radiative spectrum.

2. Photodissociation of H_2

Since H_2 emission is not seen from non-bipolar PNe, the destruction of H_2 in these nebulae must be roughly coincident with the photoionization of the nebula. Using IRAS 20462+3416 as a template and assuming a core mass of 0.7 $M_\odot$, we calculated photodissociation rates as a function of spectral type. To dissociate 0.2 $M_\odot$ of H_2, we find timescales of 400 years at B1 and 250 years at O9 spectral types. The evolutionary time for this transition is roughly 60 years. The H_2 should thus be fully dissociated by the time the central star reaches about O8 spectral type. For lower mass PNe, the photodissociation rate is a little lower but the spectral evolution is much slower and the H_2 will be dissociated by O9-B0 spectral type.

3. Thermal Excitation of H_2 in Bipolar PPNe

Bipolar nebulae begin to show H_2 emission at mid-G spectral types. In these young nebulae, the H_2 appears to be excited by wind interactions at the ends of the bipolar lobes. H_2 emission is weak or absent in the torus region. Optically thin PPNe do not show H_2 emission at these early spectral types. From these data and from the observation that bipolar nebulae often have high-speed molecular winds, we surmise that an optically thick torus is acting to collimate the outflow in these objects. Such winds would have a very strong effect on the morphological evolution of the nebulae.

4. H_2 Emission, Optical Thickness, and Galactic Latitude

An interesting property of H_2-emitting PNe is that they lie at low Galactic latitudes, with a scale height of 150 pc (Kastner et al. 1996). We used the criteria of Ueta et al. (2000) to determine if our nebulae are optically thin or optically thick. We did not find as clear of separation between these two classes as was found by Ueta et al., but by using all of their criteria, we were still able to make distinctions in most cases. We see a clear dichotomy between the Galactic latitudes of our H_2-emitting optically thick and optically thin nebulae. The optically thick nebulae have Galactic latitudes of 3.5 ± 2.2 degrees, whereas the optically thin nebulae are found at 11.1 ± 6.4 degrees. This result is consistent with the findings of Ueta et al. (2000) and with their suggestion that optically thick PPNe are the progenitors of bipolar PN.

References

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