N87-15074

NEAR-INFRARED SPECTROSCOPY OF PLANETARY NEBULAE: HOW STRONG IS THE H_2 EMISSION?

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Excited molecular hydrogen emission in a planetary nebula was first detected ten years ago in NGC 7027 (1). In NGC 7027, which is known to have an extensive molecular envelope, the presence of H_2 at the interface between the ionized and neutral zones seems natural. However, in view of the lack of previous evidence for neutral matter around most other planetary nebulae, the high detection rate of H_2 emission near 2 µm found by later searches (2,3,4) is something of a surprise. Any pattern in the incidence of H_2 in planetaries is not yet clear, however, since detections have been reported both for extended, presumably evolved objects (e.g.the Ring), and for compact, presumably young nebulae. If H_2 is indeed present in a large fraction of all planetaries, this implies that most planetaries have not yet evolved into fully-ionized, matter-bounded regions and that they may have substantial amounts of associated mass in neutral form.

In an effort to understand the systematics of the H_2 emission from planetary nebulae, we have undertaken a program of near-infrared spectroscopy using the University of Texas infrared reticon spectrometer. This instrument has a 1x32 element InSb photodiode array as a detector. All of the observations reported here were made on the McDonald Observatory 2.7 m telescope, with spectral resolving power $\lambda/\Delta\lambda = 600$. Our spectral coverage allows us to measure simultaneously the strengths of Brackett γ, He I 2.113 µm, He II 2.189 µm, and the v = 1-0 S(1) line of H_2 at 2.122 µm. One of the most important advantages of this instrument is that we are able to resolve H_2 from the adjacent He I line. Most previous observations of planetaries have been made at spectral resolving powers of about 100, which blend these lines. The contribution of the He I line has generally been dismissed as being unimportant (3), but we show that this may not be valid. Our higher resolving power also improves the line-to-continuum contrast; in some cases, the continuum is the limiting factor in detecting faint lines.

We have observed a central position on about 12 planetary nebulae in a 3" diameter beam. In most cases, we see He I 2.113 µm emission as well as Br γ. The He I line is typically of the order of 4 % the strength of Br γ, which we assume is due to nebular recombination emission; this is comparable to the reported strength of H_2 S(1) in several planetaries observed at low resolution. Failure to account for He I emission could therefore lead to overestimating the strength of H_2, or even mistaking He I for H_2 emission. In two nebulae, BD+30 3639 and SwSt 1, we see a stronger (relative to Br γ), apparently broad line at 2.113 µm. We note that the central stars of these two nebulae are both Wolf-Rayet (WC 9) stars, and suggest that the additional strength of the observed line is due to a stellar contribution. These results emphasize the importance of using sufficiently high spectral resolution when measuring the S(1) line to verify its identification and resolve it from He I. The S(1) line is intrinsically one of the strongest H_2 lines, and its strength relative those of other transitions is the chief means for probing the excitation mechanism responsible for the emission (5).

We find evidence for H_2 emission in roughly half the sample observed to date,which includes both nebulae previously claimed to contain H_2 and new candidates. In particular, the S(1) line appears to be present in several of the most compact objects, including IC 5117 and Vy 2-2, but we do not detect it (to levels of < 1-2 % of Br γ) in the similarly compact nebulae IC4997 and Hb 12. However, Hb 12 had previously been shown to exhibit H_2, and was one of the few objects observed at high enough spectral resolution (2) that confusion with He I was not a problem. We suggest that this is a beam-size effect, and that the reason for this discrepancy lies in the spatial distribution of the H_2 emission. Several extended planetary nebulae including NGC 7027 and the Ring have been mapped in H_2 and it has been found that the H_2 intensity peaks outside the optical nebula, as if the molecular gas is distributed in a shell around the ionized region (2,4,6). We find the same effect in BD+30 3639, in which the ratio of H_2/Br γ increases dramatically toward the edge of the nebula.

In summary, emission from hydrogen molecules does appear to be quite common in planetary nebulae. However, care must be taken to allow for two potentially serious observational effects which can influence the conclusions of such studies. Future work must proceed with the following caveats in mind: (1) Sufficiently high spectral resolution is needed to resolve the S(1) line, often relied upon because it is relatively strong, from He I 2.113 μm, especially in view of possible stellar as well as nebular contributions to the helium line. (2) It appears to be generally the case that the H_2 is distributed in a shell outside the ionized region, so that mapping will be necessary in order to provide a realistic and complete picture of the molecular emission from planetary nebulae.

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