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Molecular Hydrogen Emission from the Photodissociation Region in Hubble 12

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Abstract.
Infrared spectra of molecular hydrogen (H_2) line emission, from the photodissociation region in the planetary nebula Hubble 12, are presented. The spectra range between 0.7 and 2.5 μm. Approximately 75 H_2 lines were measured with over 100 lines actually detected. The ortho/para ratio for H_2 was measured and it is shown that there is a decreasing trend in this ratio with energy level. This is qualitatively interpreted as the radiative excitation of 'fresh' molecules from the molecular cloud by a still evolving and young photodissociation region.

1. Introduction

Hubble 12 is a young, bright planetary nebula, whose ionised core is surrounded by a 4-7 arcsec torus of H_2 emission. The first near-infrared spectrum of the H_2 emission from this region was obtained by Dinnerstein et al. (1988), from which it was deduced that the line ratios indicate fluorescent emission from a gas of density 10^4 - 10^5 cm^{-3} excited by UV photons from the central source. Since then, improved spectra of Hubble 12 were obtained by Ramsay et al. (1993) which were consistent with the findings of Dinnerstein et al., concluding that the H_2 emission is essentially purely fluorescent with no influence from collisional processes. Since then there have been other spectral studies of Hubble 12, which have in the main concentrated on the central ionised core of the planetary nebula.

The data presented here for the first time, represent a further improvement to the H_2 data set from Hubble 12. The wavelength range stretches between 0.7 μm and 2.5 μm, with improved spectral resolution across the whole spectrum.

2. Observations

The data were collected over a number of observing runs between September 1992 and May 1994. The near-IR 1.0 - 2.5 μm data were collected with CGS4 on the 3.8m United Kingdom Infrared Telescope, in Hawaii. The far-red 0.7 - 1.0 μm data were collected with ISIS on the 4.2m William Herschell Telescope, in La Palma. All the data were measured on the maximum of the H_2 emission, 5 arcsec East of the core of the planetary nebula.

Over 100 H_2 lines were identified, including transitions from energy levels as high as $\sim$ 50,000 K, from which it was possible to obtain measurements for 75 lines. These spectra and further analysis will be presented in a future publication. In this paper, we will present results for our measurements of the ortho/para ratio of H_2.

3. The H_2 Ortho/Para Ratio in Hubble 12

The ortho/para ratio gives the relative populations of H_2 in its ortho state (spin, s=1) to its para state (s=0). The degeneracies of the spin states are given as ($2s$ + 1), such that in conditions of local thermodynamic equilibrium where collisional processes dominate the energy level population, the ortho/para ratio is equal to 3.

The ortho/para ratio can be calculated from the intensities of pairs of lines from adjacent odd and even rotational states, together with the rotational temperature (for further details see Chrysostomou et al. 1993 and Ramsay et al. 1993). Figure 1 shows our measurements of the ortho/para ratio in Hubble 12 as a function of energy level. The general trend is a decrease of the ortho/para ratio as a function of energy level. The ortho/para ratio is $\sim$ 2 for energy levels $<$ 25,000 K and then begins to decrease to $\sim$ 0.5 for energy levels $\sim$ 40,000 K. Also included in the figure are our analysis of data published by Hora & Latter (1996) and Luhman & Rieke (1996), for comparison. These observations were taken at different telescopes with different instruments (and towards a different position in Hubble 12) and so serve as credible and independent confirmation of our own data, thus implying that the trend is real. This is the first time that such a trend has been observed in Hubble 12 or for any PDR.

3.1. Understanding the Trend in Ortho/Para Ratio

We can begin to qualitatively understand the trend we see in Figure 1 if we consider the physical conditions of the molecule before and during the fluorescent cascade.

The molecule is first excited by a UV photon to the first electronic level from where it then begins the fluorescent cascade down through its energy levels to the ground state. For high PDR densities, the molecule would suffer many spin-exchange collisions with other species present in the PDR. The most dominant spin-exchange reactions are those with H^+ and H (e.g. Flower & Watt 1984). Other reactions proceed much slower. In this case, the ortho/para ratio of H_2 would quickly find its equilibrium value as spin-exchange reactions would occur rapidly.

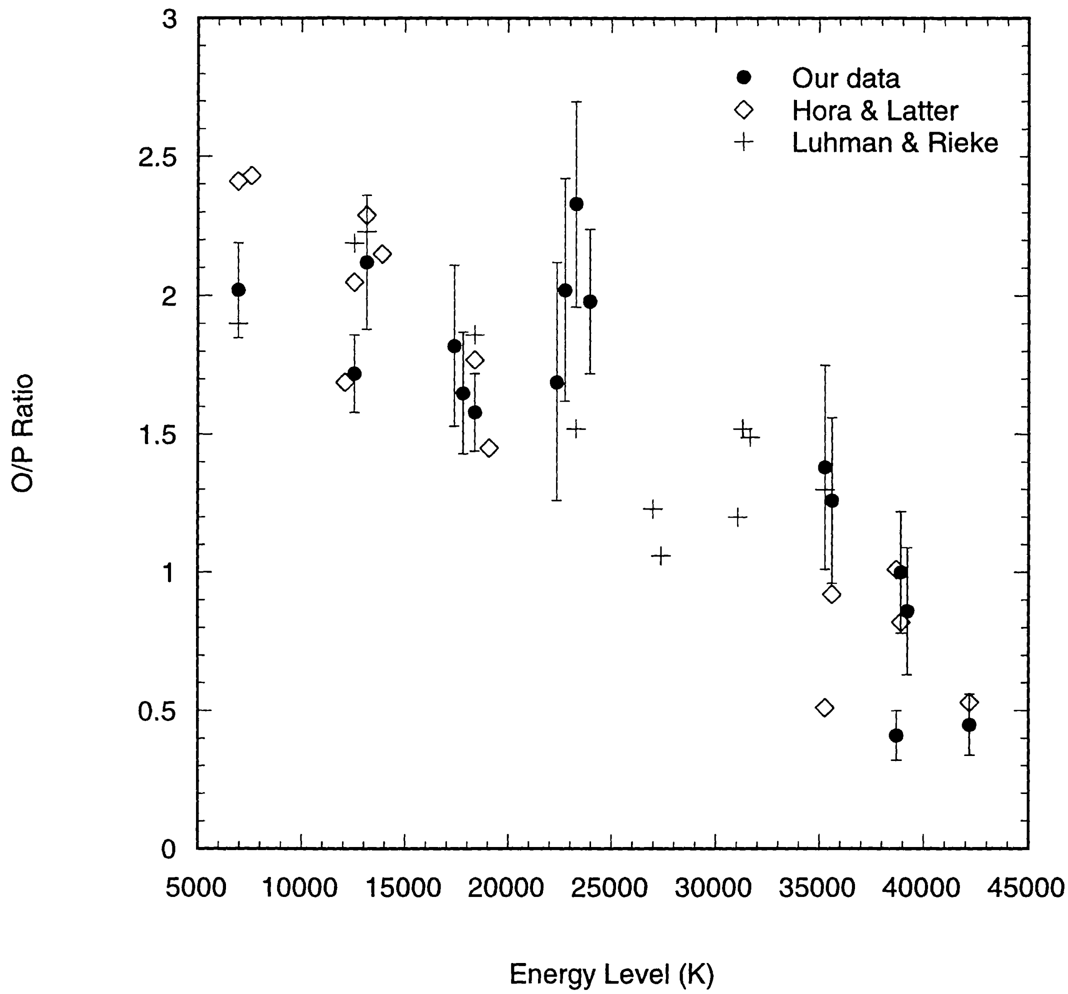

Figure 1. Ortho/Para ratio of H_2 in Hubble 12 as a function of energy level. Our data are shown as filled circles with error bars, while data from Hora & Latter and Luhman & Rieke are shown as empty diamonds and crosses, respectively.

The timescales for these reactions scale with the densities of H_2 and the reactive species. The timescale for a particular H_2 molecule at a particular energy level to emit a photon, however, does not. This is governed by the spontaneous decay rate. It is conceivable, therefore, that at low PDR densities, molecules which have just been radiatively excited by UV photons are able to radiate a finite number of times at the beginning of their cascade, *before* they suffer any spin exchange collisions which may alter the initial H_2 ortho/para ratio. It is already an established fact that Hubble 12 *is* a low density PDR.

3.2. A Young PDR

The model we have put forward in section 3.1, therefore implies that fresh material from the cold ambient molecular cloud is excited repeatedly. This material would have to have an H_2 ortho/para ratio of ~ 0.5 which is consistent with a gas temperature of ~ 60 K (e.g. see Burton, Hollenbach & Tielens 1992).

As the ortho/para ratio is a temperature sensitive quantity, once the gas has been heated up by the advancing PDR we would expect the ortho/para ratio to tend towards a value of 3 across all energy levels. As we clearly do not see this, this implies that the photodissociation front is still advancing into the cold molecular cloud.

Thus, Hubble 12 represents a PDR which is young and therefore requires a time-dependent, rather than the more common static, PDR model prescription. Time-dependent models by Goldschmidt & Sternberg (1995) suggest an age for Hubble 12 of $\sim 10^5$ years.

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