Lyα Pumped Molecular Hydrogen Emission in the Planetary Nebulae NGC 6853 and NGC 3132

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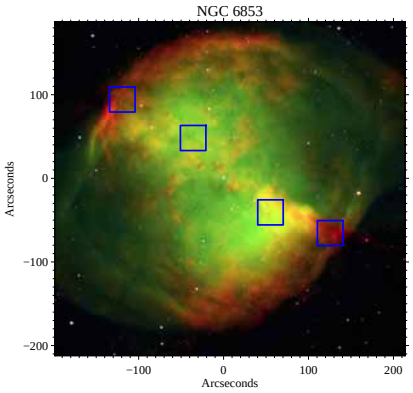
Abstract We report the first detection of Lyα pumped molecular hydrogen emission in planetary nebulae, based on *FUSE* observations of NGC 6853 (905 – 1187 Å) and *HUT* observations of NGC 3132 (820 – 1840 Å). In both cases, the H_2 line ratios and strengths require vibrationally hot H_2 at a temperature in the 2000 K range and a ~0.4 Å wide Lyα with a deep self-reversal. These parameters satisfy both short and long wavelength observations, pointing to similar conditions of the molecular gas in the two nebulae. A particular choice of the Lyα specific intensity allows us to place constraints on the H_2 temperature, column density and turbulent motion. The ro-vibrational cascade following Lyα pumping is predicted to have low surface brightness signatures in the visible and near infrared.

Observations Four nebular observations of NGC 6853 were made by *FUSE* on 2004 May 26 using the low-resolution (LWRS) aperture (30″×30″). Spectra were obtained in the 905-1187Å bandpass at a filled aperture resolution of ~0.33 Å . The average exposure time was 3374 s.



FUSE LWRS aperture overlays on the NGC 6853 VLT 8.2-m image, obtained from ESO.

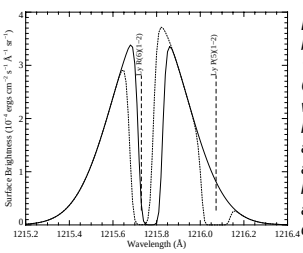
NGC 3132 was observed by *HUT* aboard *Astro-2* for 946 s during orbital night on 1995 March 14. This spectrum, downloaded from *MAST*, was acquired through the 10″×56″ slit, at an offset from the central stars. The exact slit coordinates are uncertain. The resolution of the *HUT* spectrum is roughly 3 Å .

Data Analysis The observed H_2 UV emission can be explained by excitation of vibrationally hot H_2 by Lyα photons. This is the first detection of resonant excitation by Lyα of the B-X (1-2) P(5) 1216.07 Å and B-X (1-2) R(6) 1215.73 Å molecular hydrogen lines in planetary nebulae. Similar fluorescence has been previously found in T-Tauri stars, Herbig-Haro objects, planetary atmospheres and sunspots (Shull 1978).

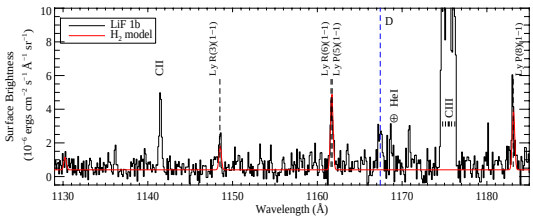
NGC 6853 and NGC 3132 were modeled using a fluorescent H_2 emission code similar to the one described in France et al. 2005.

The exciting Lyα radiation field was a ~0.4 Å Gaussian with a deep self reversal, required by the observed weak fluorescence following the B-X (1-2) R(6) transition. In order to mimic self-reversal, absorption by neutral hydrogen with a column density of 1×10^{14} cm^{-2} was used to modify the exciting Lyα profile.

A total Lyα brightness for NGC 6853 was chosen as 2/3 of the Hα brightness of 19416.0 R measured using the DIS at APO 3.5-m telescope.



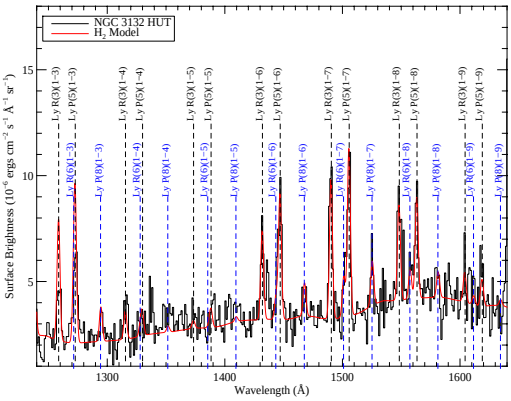
Exciting Lyα profile absorbed by an H I column density of 1×10^{14} cm^{-2} used for the NGC 6853 model. Velocity offsets with respect to the molecular hydrogen reference system are 25 km s^{-1} for both emission and H I absorption. The dotted line corresponds to an H_2 absorption profile for a column density of 6×10^{18} cm^{-2}.



FUSE spectra of NGC 6853 at the third pointing. The H_2 emission is prominent together with C II, C III and geocoronal He I. The Lyα pumped H_2 fluorescence model is shown in red. The line labeled D is unidentified.

In the NGC 3132 case, the continuum has a very unusual shape, most likely due to the superposition of the central stars and the inhomogeneous dust distribution within the nebula.

Although the total Hα luminosity is assumed similar to NGC 6853, the resulting Lyα brightness is much higher, due to the smaller dimensions of the nebula.



HUT spectrum of NGC 3132 at long wavelengths. The H_2 model added to an empirical fit to the continuum is shown in red.

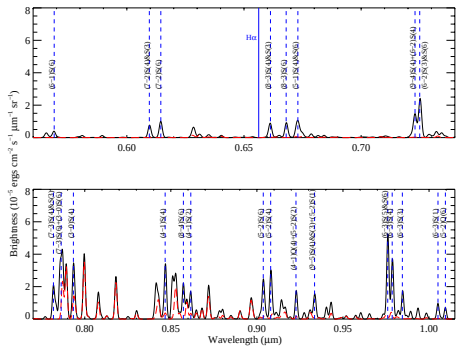
Parameter	NGC 6853	NGC 3132
Excitation Source	H I Lyα	H I Lyα
Lyα Doppler shift (km s^{-1})	25	30
Lyα FWHM (Å)	0.40	0.45
Lyα Total Intensity (R)	12944	217523
N(H_2) (cm^{-2})	6×10^{18}	3×10^{18}
T(H_2) (K)	2040	2040
N(H I) (cm^{-2})	1×10^{14}	2×10^{16}
b (km s^{-1})	8	9

The molecular hydrogen temperature of 2040 K and velocity offsets of ~30 km s^{-1} are in agreement with recent measurements from absorption spectra of NGC 6835 (McCandliss et al. 2006).

Derived values for the H_2 column density, *b* value, and Doppler shifts are very sensitive to the Lyα shape and total brightness. The fit could be improved by using a more rigorous profile, based on radiative transfer considerations.

Ro-vibrational Cascade The ground state population determined by a thermal distribution and following Lyα pumping were considered separately as starting point for the ro-vibrational cascade.

The line strengths in the absence of collisions were determined using the transition probabilities from Wolniewicz et al. 1998.



Predicted ro-vibrational cascade following Lyα pumping in NGC 6853, added to the ro-vibrational cascade model for a thermal population at 2040 K, shown in red.

The detection of these lines represents an observational challenge from the ground. The ro-vibrational cascade at a level of few×10^{-5} ergs cm^{-2} s^{-1} sr^{-1} μm^{-1} is about 1000 times smaller than the typical airglow lines in the 0.56-1.015 μm interval. A higher spectral resolution (few Å) may allow the detection of the (8-3) S(6) line at 6681.40 Å.

The expected depletion of levels (v″,J″) (2,6) and (2,5) is not found to be significant. Correcting for the ro-vibrational transitions that repopulate these levels, we obtain that the population decrease relative to the thermal distribution ($\Delta N_{v,J}/N_{v,J}^{thermal}$) is about 0.0107 and 0.0012, respectively.

Conclusions

- Continuum pumped H_2 fluorescence is not detected, pointing to non-trivial radiative transfer effects.
- The observed UV fluorescence spectrum is likely due to H_2 molecules shielded from the UV continuum inside shock heated globules, surrounded by strong nebular Lyα emission.
- The measured line ratios and strengths are a valuable diagnostic tool for molecular temperature and velocity, as well as Lyα line shape.
- The predicted ro-vibrational cascade following Lyα pumping has little contribution longward of ~1 μm. As a consequence, line pumped UV fluorescence can be expected in regions where measured IR line ratios around 2 μm are consistent with a thermal distribution.
- While molecular hydrogen pumping by Lyα shows strong features in UV spectra, it could remain unobservable in the IR and visible. UV observations are thus a requirement for investigating this process in various environments where hot H_2 is exposed to the presence of Lyα.

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