Characterizing U-Ne hollow cathode lamps at near-IR

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In an effort to optimize precision radial velocity measurements at near-IR wavelengths (between 950 and 1700 nm) for the CARMENES survey, we are characterizing 12 commercial U-Ne hollow cathode lamps using a high resolution Fourier Transform Spectrograph. We have recorded spectral atlases of U-Ne operated at 8, 10 and 12 mA. In addition to that, we analyze properties like warm-up times, average intensities from lines of different elements, positions and the width of emission lines, and blends. None of our lamps show strong peculiarities in the spectra or significant contamination. Our line list can add a significant number of lines particularly in the range around 9000 cm^{-1} (1100 nm) where the Redman et al. catalog (2011) is incomplete because of limited detector sensitivity. The increased number of U lines at wavelengths relevant to radial velocity surveys can yield a significant improvement in the accuracy of radial velocity measurements.

1 Introduction

• Hollow Cathode Lamps (HCLs) are the most common calibrator for astronomical échelle spectrographs.

•CARMENES project will use a F-P etalon for nightly drift check and a HCL as a standard reference (Th-Ne, visible; U-Ne, nIR).

• The manufacturing process is very delicate [1].

• Uranium catalog [2] lacks lines because of reduced sensitivity in the region between 8700 and 9700 cm^{-1} (1.03-1.15 µm).

• Characterization of every HCL is necessary.

•We aim to obtain an emission line list of the commercial HCLs and to verify the status of every single lamp for the CARMENES survey.

2 Methodology

We have characterized 12 commercial *Photron* U-Ne HCLs for the nIR calibration unit of the CARMENES project.

Main considerations of the experimental setup are:

•The lamps belong to the same batch and have consecutives serial numbers.

•The lamps are placed in a housing designed and built by the Thuringian State Observatory (Fig. 1).

• We use our high resolution Fourier Transform *Bruker IFS 125 HR* spectrograph, a high resolution Fourier Transform Spectrograph with a maximum optical path difference of 208 cm.

•The fore-optics consists of the same elements that the CARMENES calibration unit. It reimages the cathode into a SM1SMA fiber adaptor (Fig. 2).

•The spectral region is located between 5000 cm^{-1} (~0.8 µm) and 12000 cm^{-1} (2 µm).

• FTS is operating with a CaF_2 beam-splitter and an InGaAs detector.

• Radiometrically callibrated by recording low-resolution spectra of a tungsten lamp just before and after the measurements.

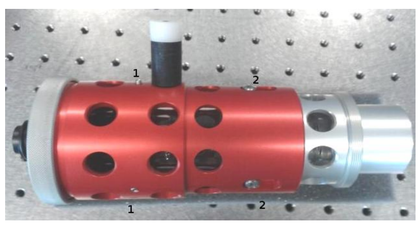


Fig. 1. HCL housing. Numbers indicate the three screw for alignment (1) and three screws for focusing (2).

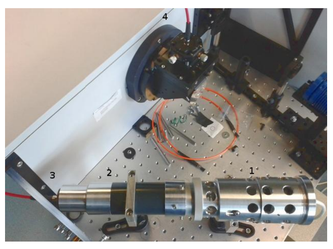


Fig. 2. (1) U-Ne+housing. (2) Optical alignment tool. (3) Fiber input. (4) FTS parallel port.

Data analysis:

• ***Identified lines*** □ **:** Emission lines at less than 0.01 cm^{-1} from the line in the Redman catalog [2] with full width half maximum (FHWM) comparable to U lines.

•***Detected lines*** ●**:** FWHM comparable to emission U emission lines at a distance larger than 0.01 cm^{-1} to the nearest line in the referred catalog.

3 Results

❑ **Experiment 1: Emision line list for the CARMENES survey.**

One U-Ne HCL operated at 8, 10 and 12 mA: 150 scans at a resolution of 0.01 cm^{-1} at a maximum aperture of 1mm and a 400 µm fiber.

In **Figure 3** we analyzed the intensity of 1695 U I lines and 129 Ne I *identified lines* in all three spectra U I lines have higher relative increment of intensity than Ne I [2].

In **Figure 4, we *detected* aprox. 50 lines** above the dash-dotted line, which indicates an intensity upper limit in the U catalog [1]. We *detected* 807 U lines where the catalog lacks sensitivity, 170 are detected in the spectra at 8 and 10 mA.

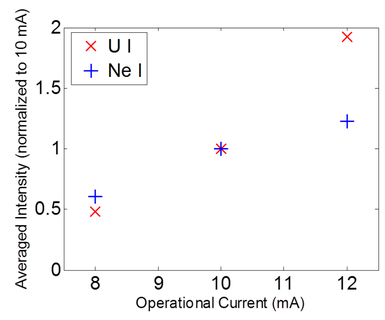


Figure 3. Y-axis normalized to the averaged intensity (at 10 mA).

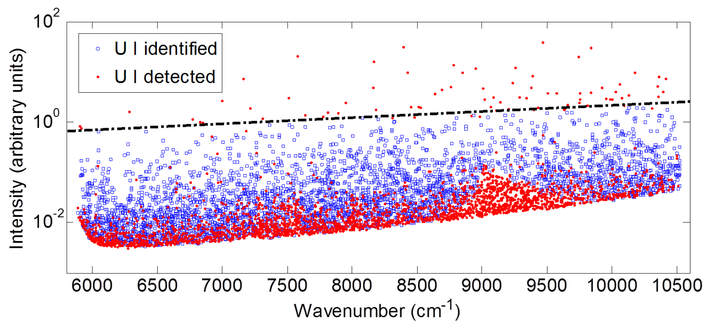
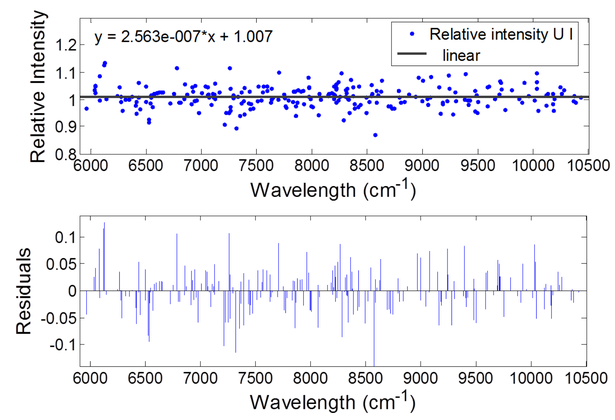


Figure 4. *Identified* U I lines, □;**detected** U I lines ● (12 mA spectrum).

❑ **Experiment 2: Status of every single HCL.** We recorded 120 spectrum of every lamp operated at 6 mA at a resolution of 0.035 cm^{-1} with a 2 mm aperture, and 910 µm fiber. We analyze the line intensity of the *identified uranium lines* (250) in the 12 spectra by fitting the distribution. The table below shows the average (µ) and the standard deviation (σ) for each lamp.



HCL #	µ	σ (10^{-2})
HKH0120	0.753	4.2
HKH0121	1.052	3.9
HKH0122	0.842	3.8
HKH0123	0.986	3.5
HKH0124	0.985	3.7
HKH0125	0.869	3.4
HKH0126	0.841	4.4
HKH0127	1.357	3.4
HKH0128	1.007	4.4
HKH0129	1.106	4.1
HKH0130	0.907	3.4
HKH0131	1.278	4.3

Figure 5. Intensity comparison between HKH0128 and the averaged of all the lamps.

5 Conclusions

- No failures or significant contamination in any lamps.
- Different behavior of U lines and Ne lines can help to identify ambiguous lines.
- New U detected lines at wavelengths relevant to radial velocity (RV) surveys can yield a significant improvement in the accuracy of RV measurements.
- Lamps show largely comparable relative intensities; and a remarkable reproducibility (about 4 % dispersion).

Acknowledgements: European Research Council under FP7 GA 279347 and Spanish MINECO/FEDER AyA-2011-30147-C03-03, AyA-2012-39612-C03-01

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