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 \(\mu\)m).
- 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 51MSMA fiber adaptor (Fig. 2).
- The spectral region is located between 5000 cm\(^{-1}\) (~0.8 \(\mu\)m) and 12000 cm\(^{-1}\) (~2 \(\mu\)m).
- FTS is operating with a CaF\(_2\) beam-splitter and an InGaAs detector.
- Radiometrically calibrated by recording low-resolution spectra of a tungsten lamp just before and after the measurements.

Data analysis:

- **Identified lines** (Fig. 2): Emission lines at less than 0.01 cm\(^{-1}\) from the line in the Redman catalog [2] with full width half maximum (FWHM) 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**: Emission 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 \(\mu\)m 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 approx. 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.

- **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 \(\mu\)m 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 (\(\mu\)) and the standard deviation (\(\sigma\)) for each lamp.

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 ).

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