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A Fabry-Perot interferometer for the wavelength calibration of radial velocity spectrographs

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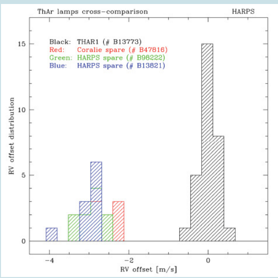
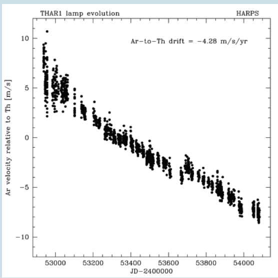
ABSTRACT

Abstract : The radial velocity (RV) technique has pushed the planet detection limits down to super-earths. The current precision achieved by RV is around 69 cm.s^{-1}. To reach the precision required to detect earth-like planets it is necessary to reach a precision around 1cm.s^{-1}. This implies lifting some instrumental limitations, among them the wavelength calibration. The Observatory of Geneva has designed, built and tested in collaboration with ESO a calibrator system based on a Fabry-Perot interferometer to explore its potential to improve the wavelength calibration of RV spectrographs. Unlike the Th-Ar lamp this device allows the production of optimally and regularly spaced calibration lines covering all orders of the spectrograph.

TODAY's LAMPS LIMITATIONS

The standard wavelength calibration sources used in most spectrographs are the hollow-cathode Thorium-Argon (Th-Ar) lamps. These lamps have been used for decades, because there are affordable, easy to operate and stable. However when pushing the performance, a number of limitations arise, the most noticeable being: line blending; long-term variability, the high non-uniformity of the lines distribution and intensity and limited lifetime.

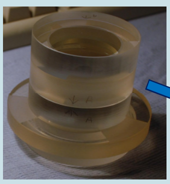




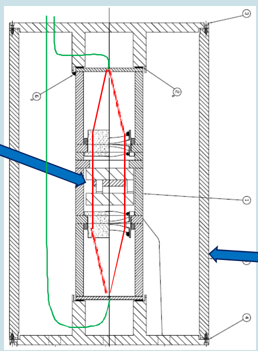
FABRY-PEROT CALIBRATOR DESIGN

The calibrator is a complete *system*. It is made of:

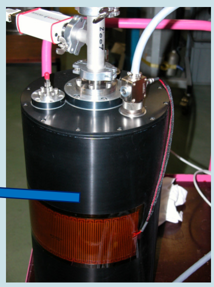
- A Fabry-Perot etalon-type interferometer (fixed spacing). Two constructions are being tested: 100% Zerodur spacers and thermally compensated spacers made with 3 glasses type.
- A mechanical structure holding the optical components together is built in Zerodur and it is optically contacted except the cell holding the lenses.
- A vacuum vessel housing all optics. An operating pressure stable to 10^{-3}mBar is required to insure 10^{-10} stability. (i.e. 3cm/s).
- A high stability thermal control.
- A primary light source (presently a halogen filament lamp with flattening filter)



The Fabry-Perot etalon: the heart of the system



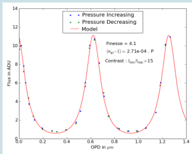
The vacuum vessel with the heating pad



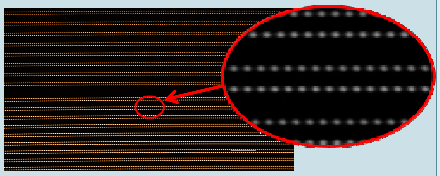
The drawing shows the Fabry-Perot etalon surrounded by the Zerodur structure holding it. A triplet on both sides provides for the coupling with the input and output fibers. The outer part is the vacuum vessel. Optical rays in red, fibers in green

PERFORMANCE

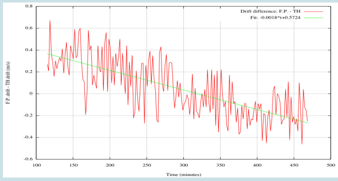
The FP calibrator has been tested for the 1st time during a commissioning run on HARPS in Sept '09. Before that, 0th order parameters where measured like temperature stability (1-2mK rms after 24 hours) and vessel leakage rate (1.5•10^{-4} mBar/hour). Emphasis was put on the measurement of the stability of the wavelength calibration. Series of Fabry-Perot / Fabry-Perot exposures where taken on reference and the sky fiber, as well as series of Th-Ar / Fabry-Perot.



System transmission @633nm. The OPD is scanned by varying the N2 pressure in the vessel.



A few of the central orders of HARPS, when exposed with the FP calibrator on both channels

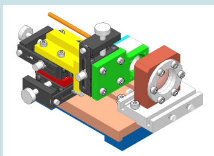


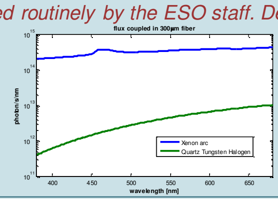
The difference between the Fabry-Perot and the Thorium lamp calibrations (V_{FP}-V_{TH}) shows a drift of 0.108 m/s/hour, only part of which is due to the vacuum vessel pressure leak. After removing the linear trend, the residual has an rms of 0.18m/s, with a photon noise of 0.12m/s. More experiments are needed to understand better the source of this noise.

IMPROVEMENTS

We are in the process of implementing modifications to improve the performance. The main point are:

- An thermo-mechanical instability where the fiber from the calibrator couples into the HARPS calibration fibers. The sensitivity of the FP v.s. Th-Ar seems to be 3.3cm/s per µm of injection fiber transverse motion due in part to the coupling optics producing a focused, undersize image of the FP fiber onto the HARPS calibration fibers. *A new sturdier, lockable mount will be installed in Nov 2009 (see drawing below). It will allow proper, well controlled defocus.*
- The light flux, particularly in the blue, is too weak to allow simultaneous FP on bright stellar targets. A very promising solution based on a Xenon arc lamp is under study. See Xe vs. QTH flux below.
- The vacuum leakage rate is such that the calibrator needs pumping every few days. This is problematic because it is located in the limited access HARPS enclosure. *The FP vacuum pipe is being connected to the HARPS vacuum system so that the FP can be pumped routinely by the ESO staff. Dec 2009.*





CONCLUSION

While not yet on par with the Th-Ar lamps or the future Laser Frequency Comb (LFC) calibrators, the Fabry-Perot calibrator is only starting to be characterized . With a calibration noise of 0.18m/s, the first results are very encouraging. A few technical improvements should enable the system to obtain a substancial improvement over the Th-Ar lamps. Longer term studies and on-sky use will tell us more about its limits.

This system should be able to complement the Laser Frequency Comb currently in development by offering a lower cost, low maintenance alternative.

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