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AIP Leibniz-Institut für Astrophysik Potsdam

Astronomical frequency comb for calibration of low and medium resolution spectrographs

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- **innoFSPEC at AIP has several years expertise in astronomical instrumentation.**
- **innoFSPEC succesfully developed a new technique to generate an optical source (called astro-comb) suitable for calibration of low and medium resolution spectrographs.**
- **The instrument is compact and easy to operate and has been tested on-sky using the Potsdam Multi-aperture Spectrometer (PMAS) at the 3.5 m telescope at the Calar Alto Observatory (Spain).**
- **The instrument offers a continuous tune of the position of the calibration lines – this brings the possibility of a complete characterization of the line spread function of the spectrograph at any resolution.**
- **We seek for partners at GEMINI that can use this instrument and could request for additional features of our tunable calibration source.**

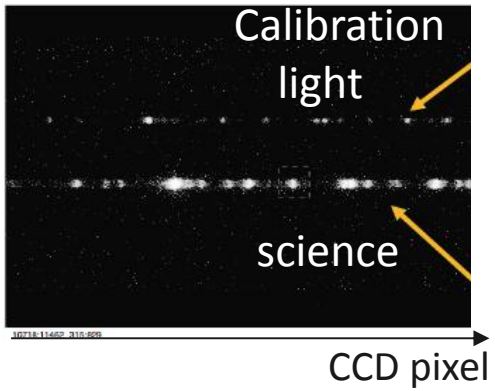
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The next slides describe the standing problems in wavelength calibration and results of the on-sky test with the frequency comb source developed at innoFSPEC Potsdam

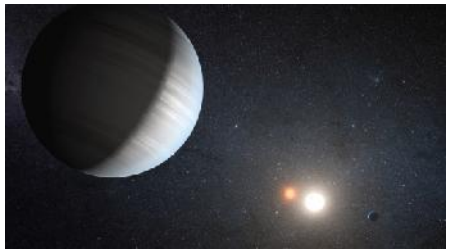
Wavelength calibration

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Use of astronomical instrumentation relies heavily on accurate **calibration** procedures.

- Spectrographs are calibrated in: wavelength and flat field.
- Throughput: Response of whole telescope optics and spectrograph.
- Accurate **wavelength calibration** is required for:
  - Search for extra-solar planets via the radial velocity method.
  - Search for time variation of the fine structure constant (α).
  - Measurement of the acceleration of the universe expansion.
  - Stellar population.

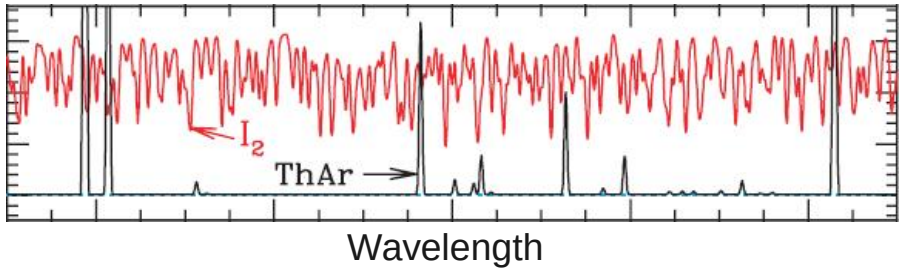


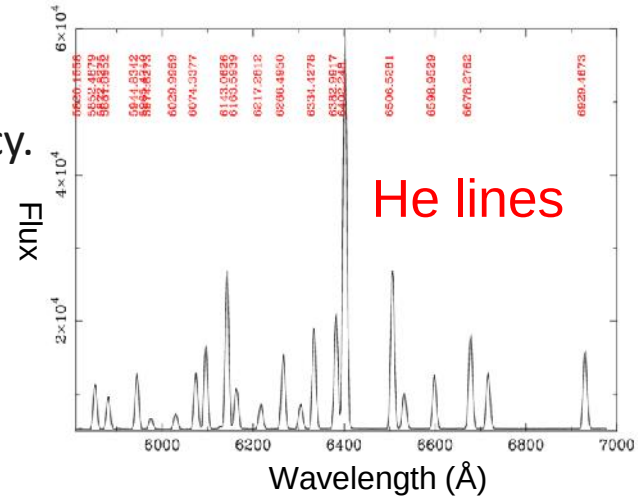
- Wavelength calibration sources:
  - **Lamps of He, U-Ne, Th/Ar, Hg.**
  - **Iodine cells.**

Calibration sources

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- Lamps characteristics limit the accuracy of wavelength calibration:
  - Lines are not equally spaced nor equally intense.
  - Lines are blended.
  - Narrow spectral coverage.
  - Lines' frequencies are known with $\Delta \nu/\nu = 10^{-7}$ accuracy.

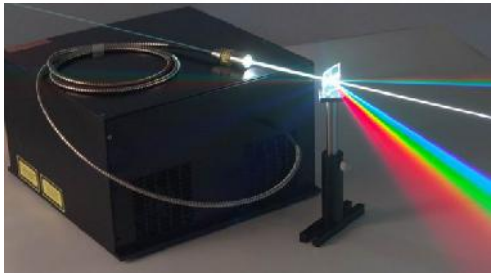




- 'Ideal' wavelength calibration source:
  - Equally spaced and equally intense lines.
  - Lines spaced 3-4 times the resolution of the spectrograph.
  - Spectral coverage over the whole spectrograph operation range.
  - Lines' frequencies known with $\Delta \nu/\nu = 10^{-8}$ accuracy or better.

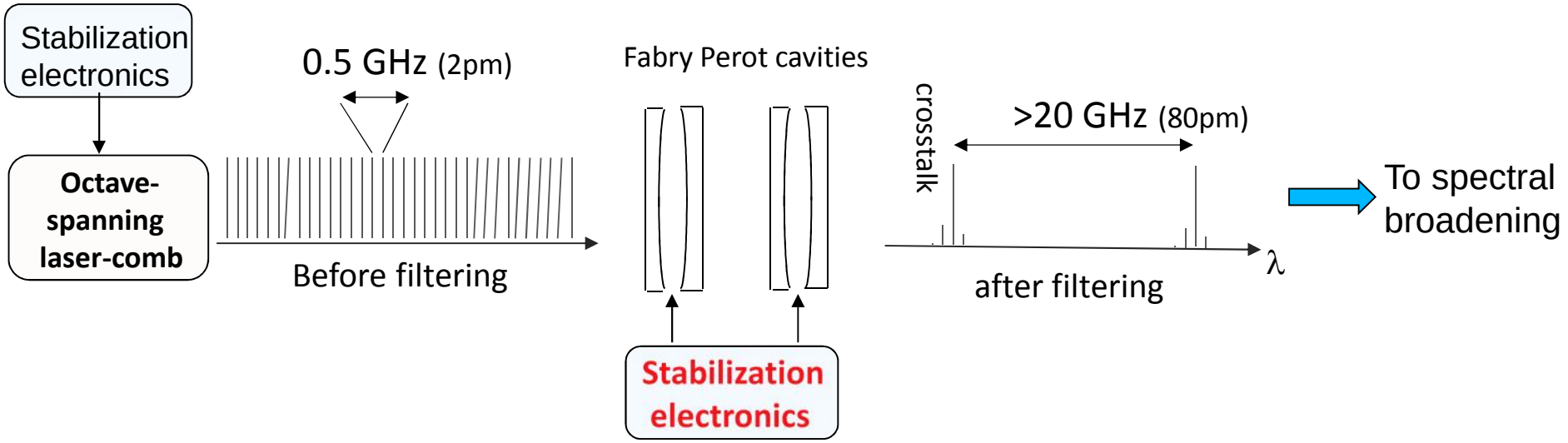
Astro-comb

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- Astronomical combs (astro-combs) have the characteristics of an ideal calibrator: but too tightly spaced lines.

- Comb mode spacing is increased by filtering with Fabry-Perot cavities.

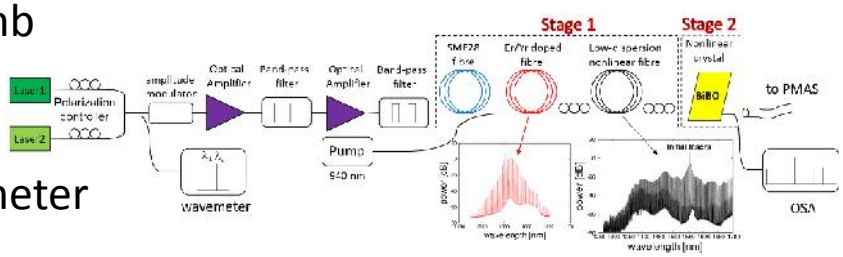


Astro-combs are commercially available at 500-700 K Euro

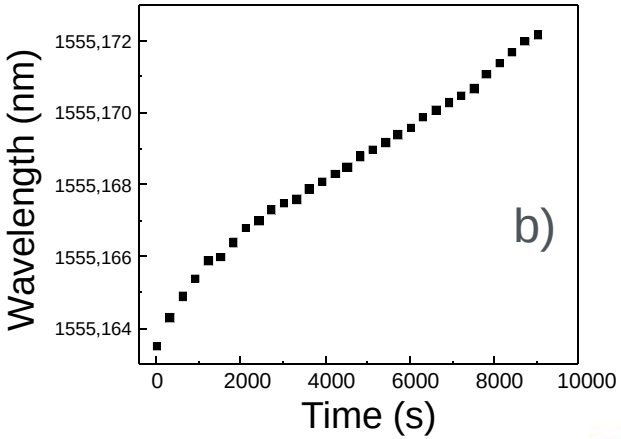
Any alternative to actual astro-combs?

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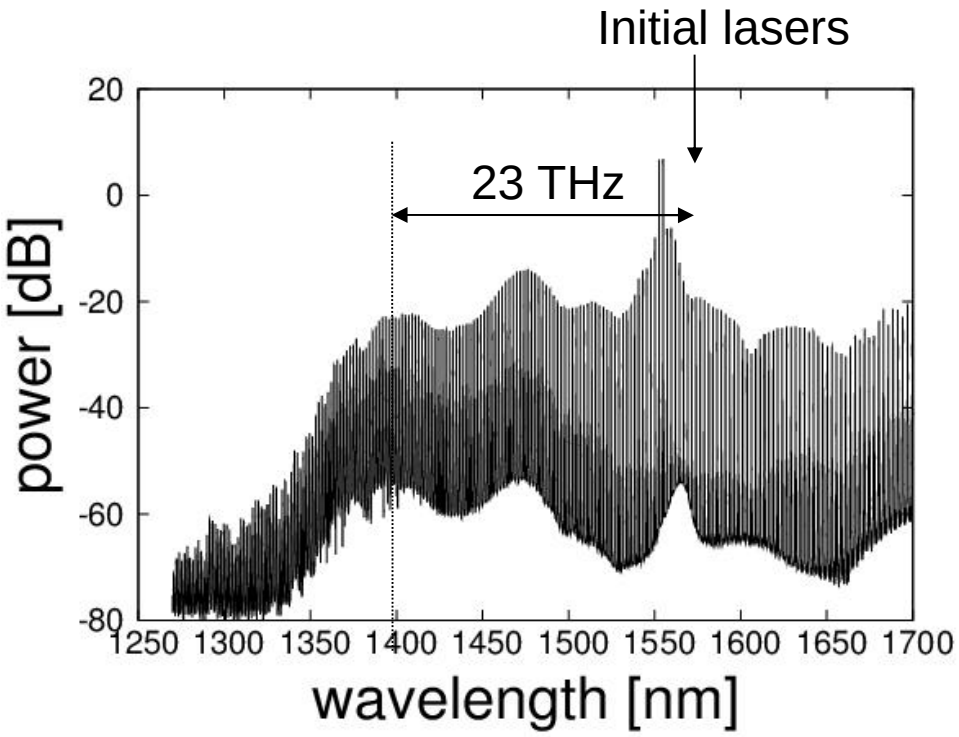
- Actual astro-combs are complex and expensive.
- We developed a tunable and compact astro-comb for medium and low resolution spectrographs.
- The astro-comb stability is tracked with a wavemeter having 0.3 pm resolution.
- The comb lines are stable within 0.025 pm during the astro-comb exposure time.







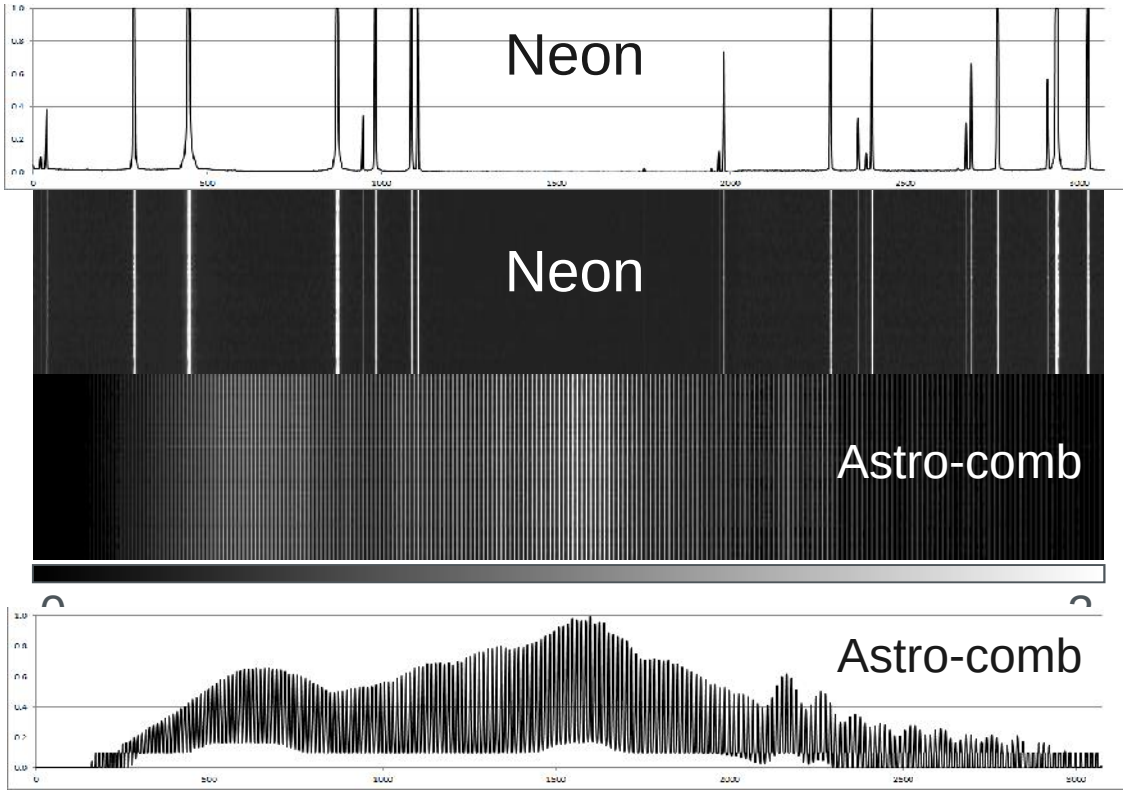
Comb generation bandwidth



- Broadband spectrum (400 nm bandwidth) centered at 1580 nm.
- Optical-signal-to-noise ratio > 30 dB.
- 170 equally spaced lines are generated out of 2 lasers.
- After frequency doubling, spectrum is centered at 800 nm.

On-sky test with PMAS at Calar Alto

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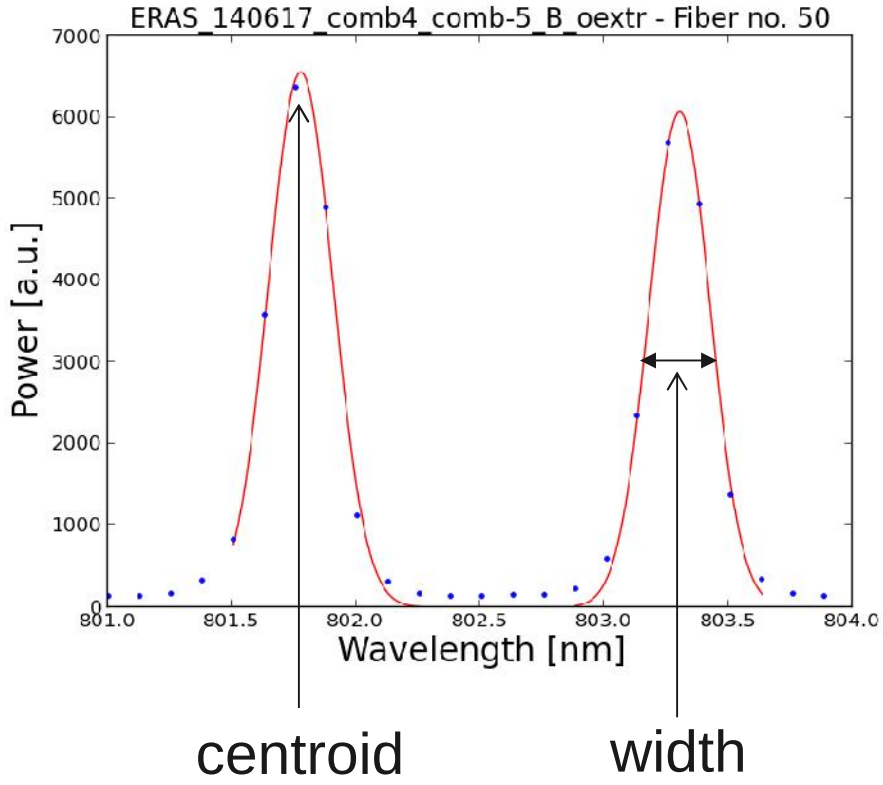


- PMAS: Integral Field Instrument at the Calar Alto Observatory 3.5 m telescope:
  - Wavelength coverage from 390 to 930 nm
  - 4096×4096 CCD detector with 15 mm pixel size.
  - Resolution of ~7000 (@800 nm).

- Neon: 20 randomly distributed lines with very unequal intensities.

- Astro-comb: 300 lines evenly spaced in frequency.

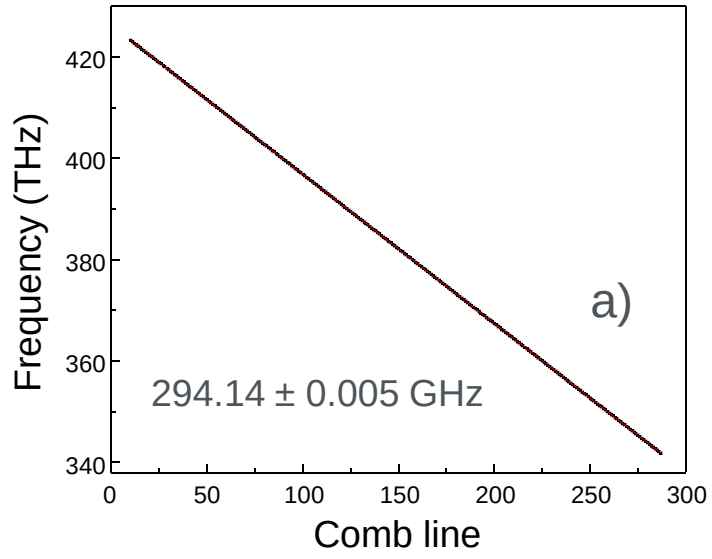
Gaussian fitting

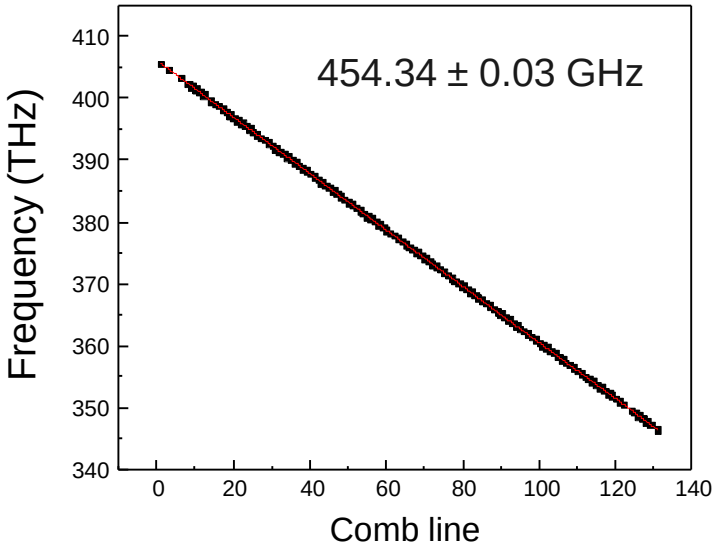


- A P3d data reduction software allows analyzing the measured spectra.
- Each comb line is sampled by ~5 pixels: fitting uses a Gaussian function.
- Determination of the centroid and the width of each comb line.
- Calculation is performed for each of the 400 fibers.

Line profile (width) measures the resolution of the spectrograph.

Tunability of astro-comb

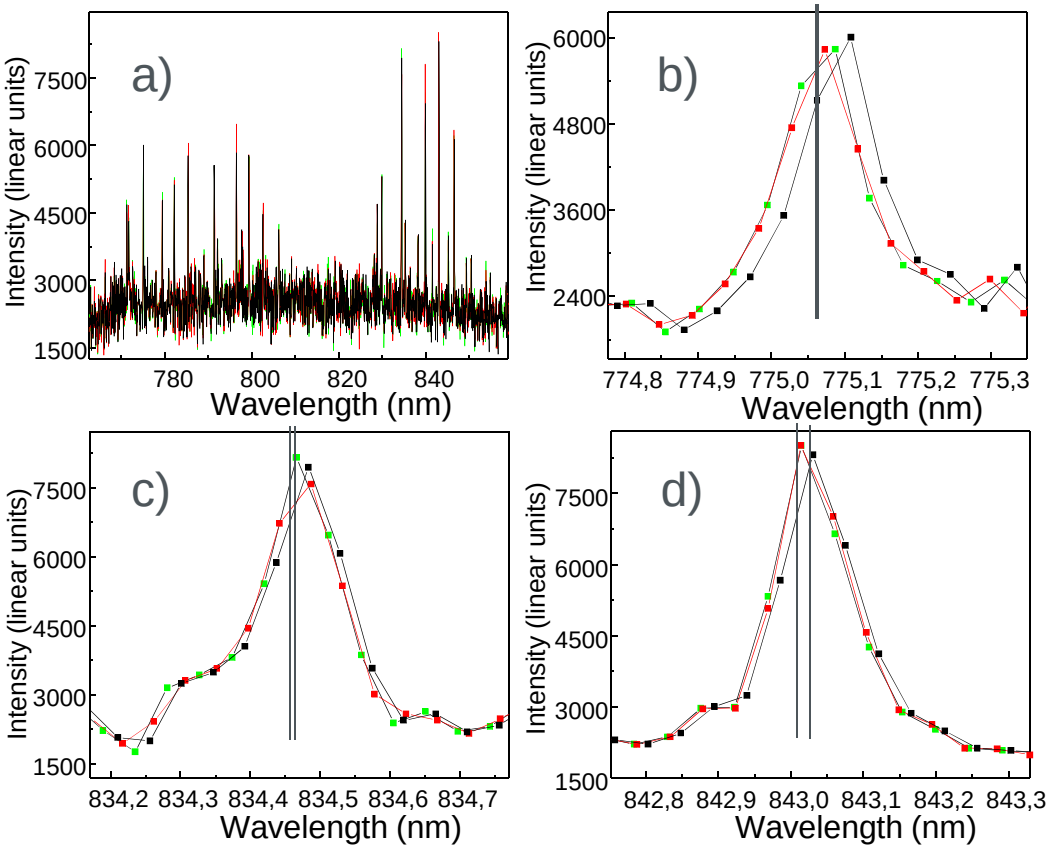




- The astro-comb can be set for several comb spacing.
- Approriate for low-, medium- and high-resolution spectrographs.
- Frequency equidistancy is verified with 1 pm accuracy.
- Useful for assessing line spread function characteristics.

Sky lines exposures with PMAS

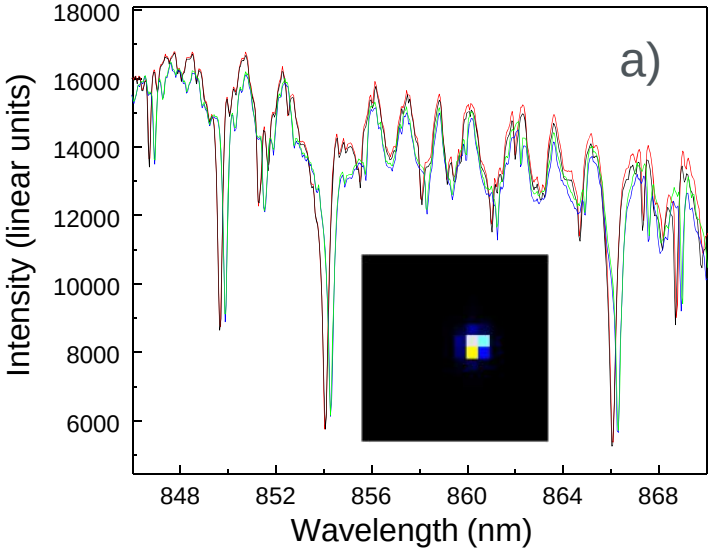
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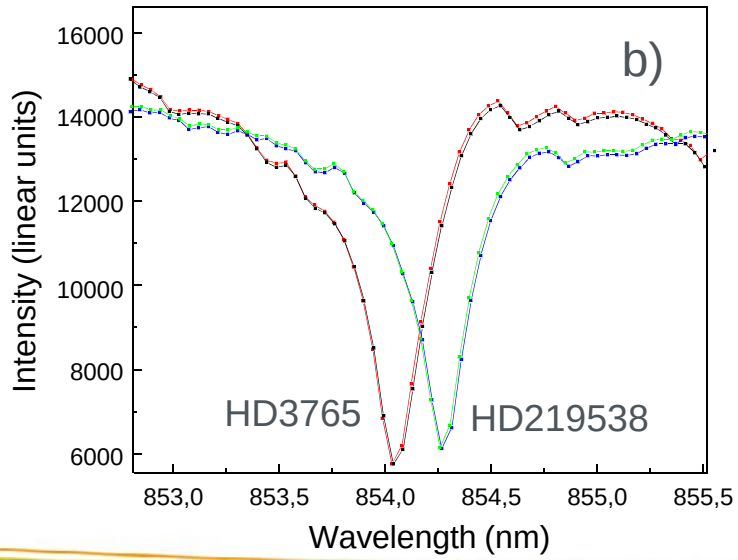


- Exposures of OH emission lines were calibrated either with Neon (black) or astro-comb (green and red) light.
- The wavelengths of the OH doublets are indicated with vertical lines.
- Due to the lack of Neon lines at some spectral intervals the calibration is Inaccurate up to 20 pm.
- Astro-comb offers more accurate wavelength calibration.

Ca-triplet exposures in stars

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- Exposures on several stars to analyze Ca triplet absorption lines.
- Wavelength calibration is performed with Neon and astro-comb.
- Examples with HD3765 and HD219538 show the ability of astro-combs to perform wavelength calibration perhaps with superior accuracy than Neon lamps.

Conclusions

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- Simple scheme for tunable astro-comb generation was demonstrated.
- Astro-comb provides much more calibration (stable) lines than lamps.
- **On-sky test shows astro-comb suitability through examples with OH emission lines detection and stellar exposures.**

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