Laser Comb: A novel Calibration System for high resolution Spectrographs

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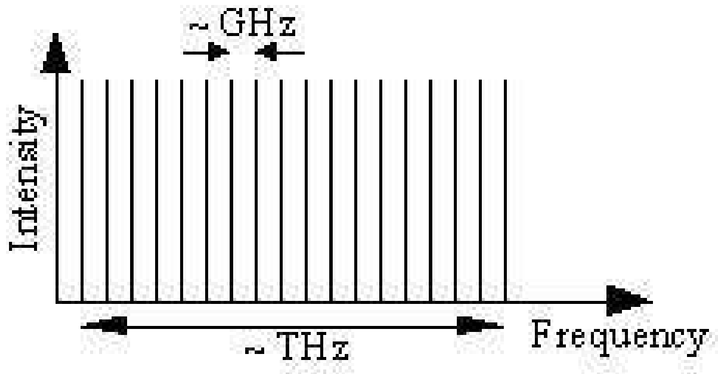
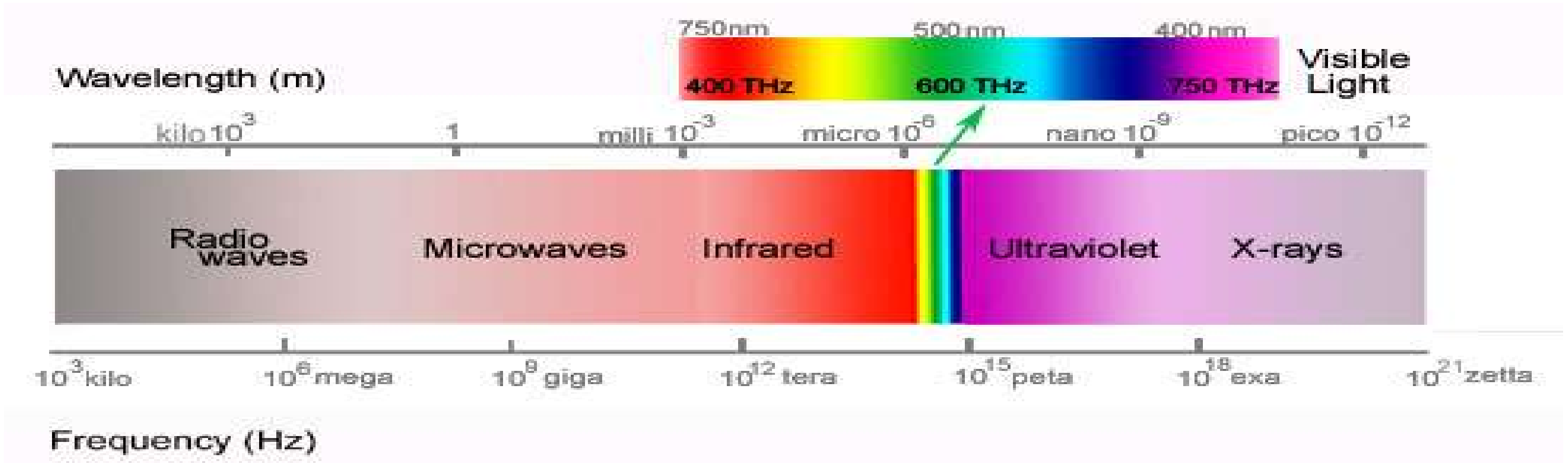
Frequency Comb

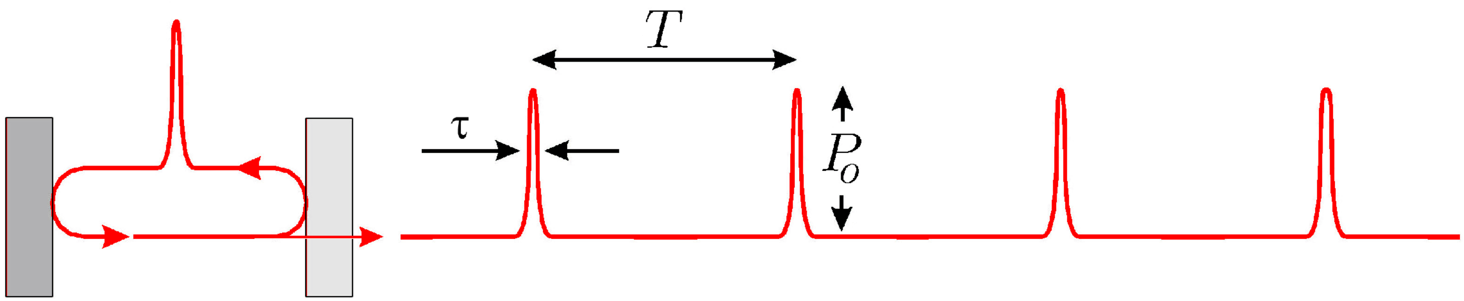


A frequency comb consists of thousands of equally spaced frequencies over a bandwidth of several THz



Basic Features of a Mode Locked Laser

Time domain:



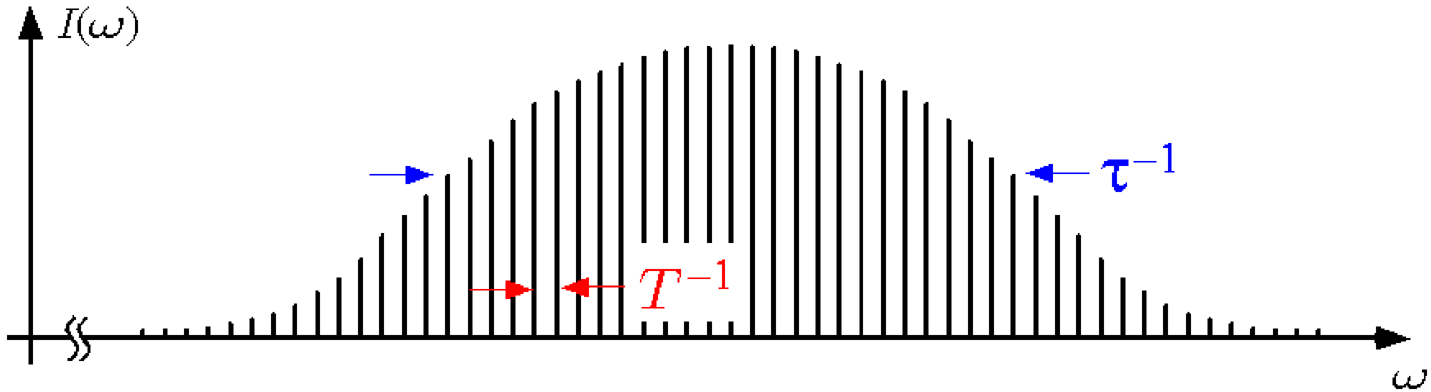
Typical mode locked laser:

- pulse repetition rate T = 1-10 ns

- pulse duration τ = 10 fs

Basic Features of a Mode Locked Laser

Frequency domain:

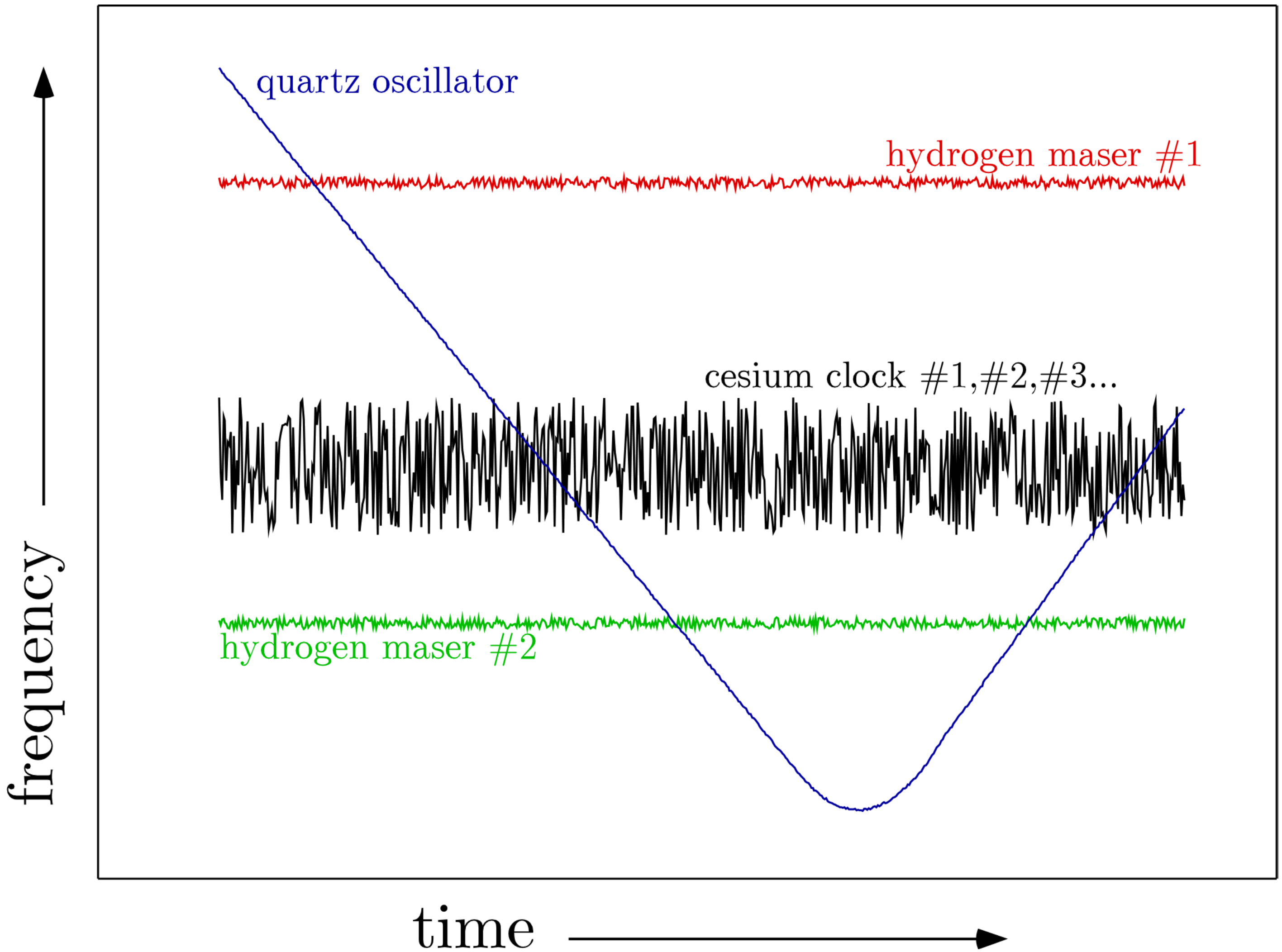


Typical mode locked laser:

- repetition frequency T^{-1} = 0.1-1GHz
- spectral width = τ^{-1} = 100 THz

$N = 10^5 \ldots 10^6$ modes; phase synchronized

Characterization of Frequency Stability



The perfect calibration source

- Wide wavelength range
- Very large number of lines in the wavelength range
- Long-term wavelength stability ($\Delta\lambda / \lambda < 10^{-11}$)
- The wavelengths of individual lines should be known to very high accuracy
- The line intensities should all be about the same.

ThAr hollow cathode emission lamp

☹ Lines differ in intensity and spacing

☹ Ar ions are sensible to pressure lamp changes.

☹ Shift with changing lamp pressure or current

☹ Lamp ages

☹ Lines blends

Laser Frequency Comb

☺ The wavelength of each line is well known

☺ Long term stability and reproducibility

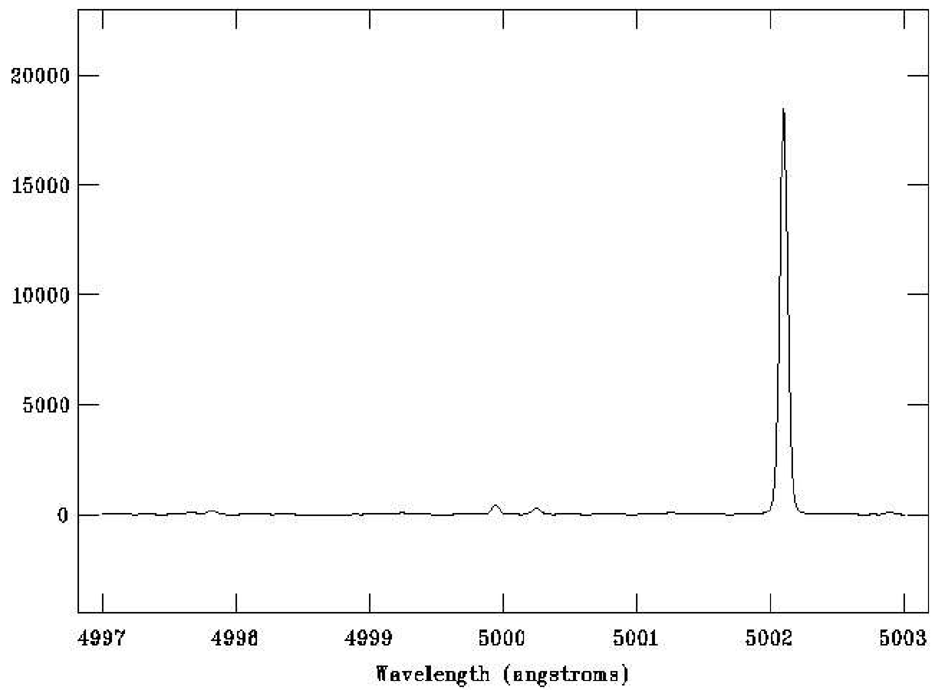
☺ Regular wavelength density

☺ Controlled intensity distribution.

☺ Uniform frequency spacing

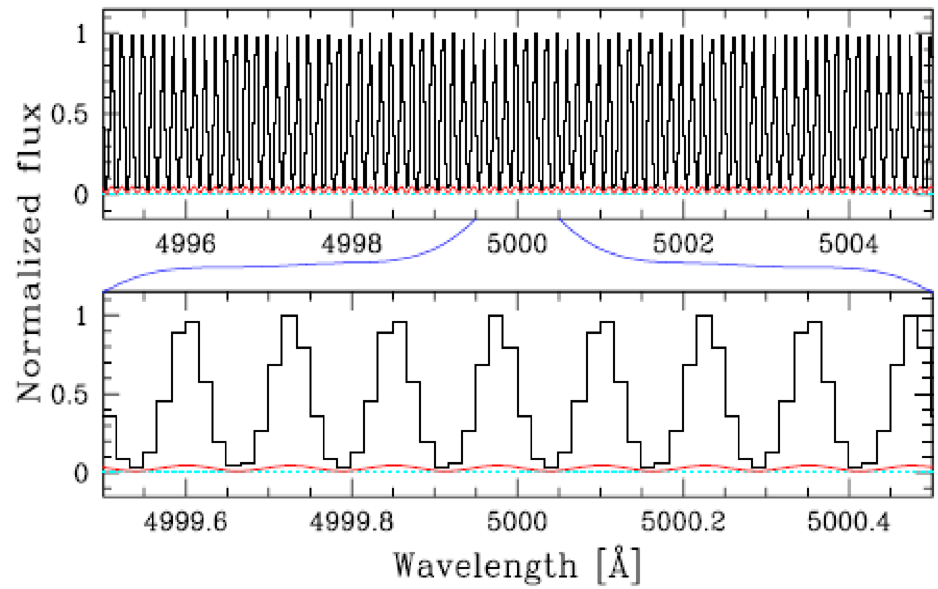
☹ Mode Spacing

Th Ar lamp Spectra



Simulate Comb echelle Spectra

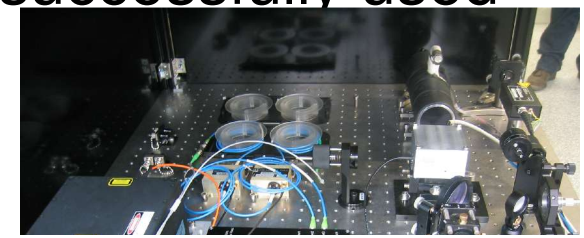
R=150k, Δν=15GHz,λ=5000Å S/N=500



Courtesy M. Murphy

ESO is already using this technology in the VLTI:

A IR laser comb system from Menlo is successfully used in the PRIMA laser metrology system.



1/ Independent characterization of the Laser frequency stabilization system

The performance of this device does not meet the requirements of the wavelength calibration system. !!!

2/ Development of an Absolute metrology system:

Prototype development of an <u>absolute</u> multi-λ metrology: Nd-Yag & ECLD locked on IR Frequency Comb (ESO/ TT-Novatech/ MPE-Menlo)

Publication accepted in Optics Letter:
"Frequency comb referenced two-wavelength source for absolute distance Measurement"
N Schuhler, Y Salvadé, S Lévêque, R Dändliker, R Holzwarth

Infrared regime

Separation between freq modes only MHz ⇨ continuum

Requirements / Specs

- ***~~Wavelength range and spectral distribution~~***
  - Min 400-680nm , goal 350-1000 nm

  Ideally will be obtained from a single-comb system

  For a larger range two combs may be combined to cover it

    – power requirement for nonlinear conversions

- ***Wavelength accuracy*** ⇨ 10^{-11} or better ✓

Known a priori with a very high precision

Achieved with a self-referenced OFC locked to a precision RF oscillator

Reference oscillator : GPS (10^{-11}) Cs clock (10^{-13})

- ***Wavelength stability***
  - Accuracy should remain at same level for decades (or beyond the experiment/instrument lifetime)

- ***Required photon flux*** ⇨ 10^{-11} W per line
  - Integration time a few sec

- ***Relative intensity between lines***
  - Not more than factor of ~5 or 7dB (limited dynamic range of the CCD)

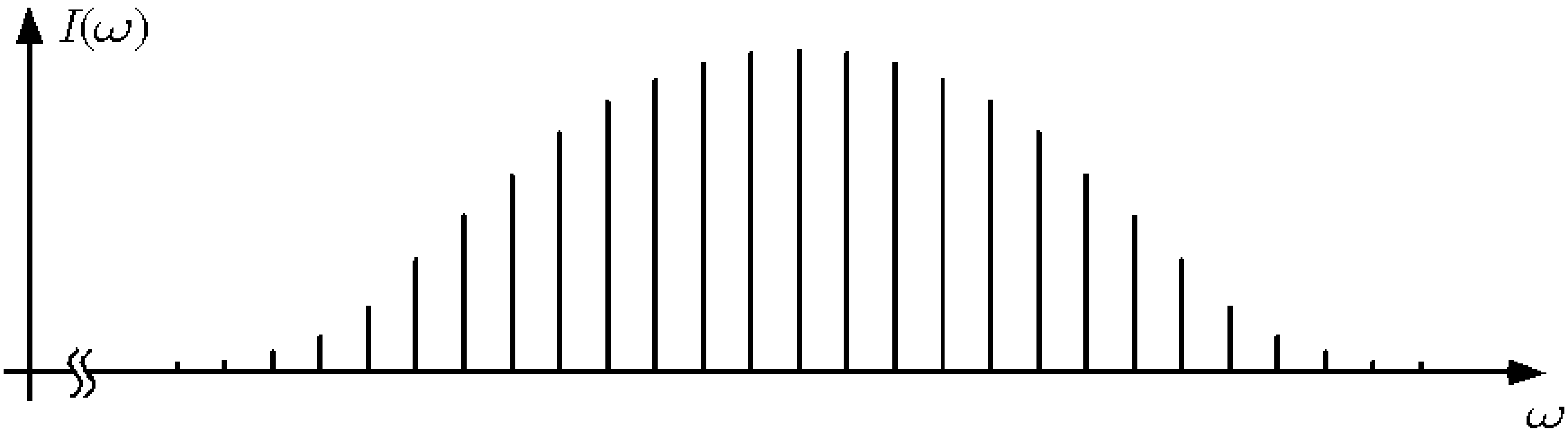
- ***Line distribution***
  - Almost continuous with no gaps to well sample the detector

- ***Comb line separation*** ⇨ Optimum 15 GHz ± 1GHz

Ideally 15GHz fs source ⇨ No demostration of such a source

– New Technology development

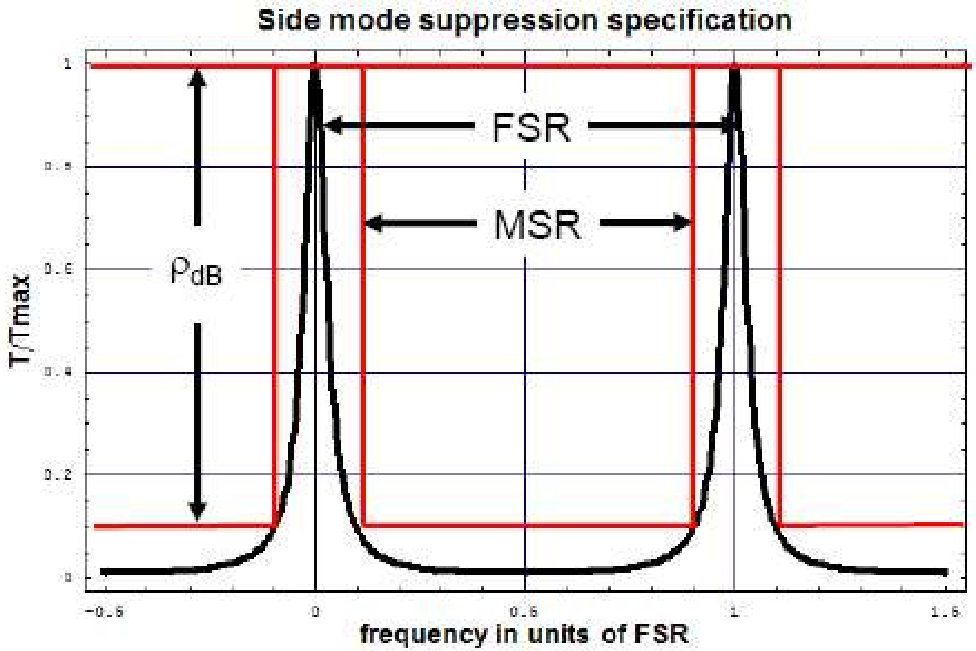
Mode Filter cavity ⇨ final step to achieve the desired 15GHz line spacing



15 GHz mode filter cavity eliminates 9 out of 10 modes

• *Attenuation of supermodes (side modes)*

- Suppressed to a level of 10^{-6} with respect to the main modes (below dynamic rage of the detector)

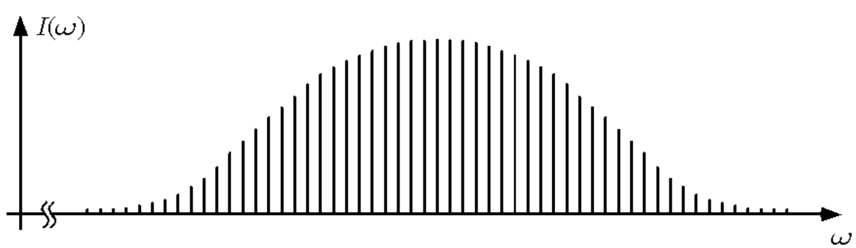


Fabry-Perot transmitted power

Required finesse F:

$$F \approx \frac{10^{\frac{\rho_{dB}}{20}}}{1 - \frac{MSR}{FSR}}$$

FSR = free spectral range
MSR = mode suppr. range
ρ_{dB} = mode suppr. ratio



side mode offset in GHz	sup-pression ratio in dB	required finesse (approx.)
0,25	50	9500
1	50	2400
3	50	850
3,75	50	700
3,75	60	2200

Ongoing activities

- Feasibility study
  - Indentified two technical solutions

- Time schedule: 3 years ⇨ laboratory prototype

- Possible prototype (HARPS) ? ⇨ 4 years...

Conclusions

- With respect to the Th-Ar lamps, the laser comb will have a large number of advantages regarding the calibration of high resolution spectrographs.

- Developments based on laser comb systems offer the possibility of substantially improved spectroscopic wavelength calibration systems capable of meeting the increasing demands from various areas of astrophysical research.

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