Laser-locked Fabry-Perot etalons for spectrograph calibration

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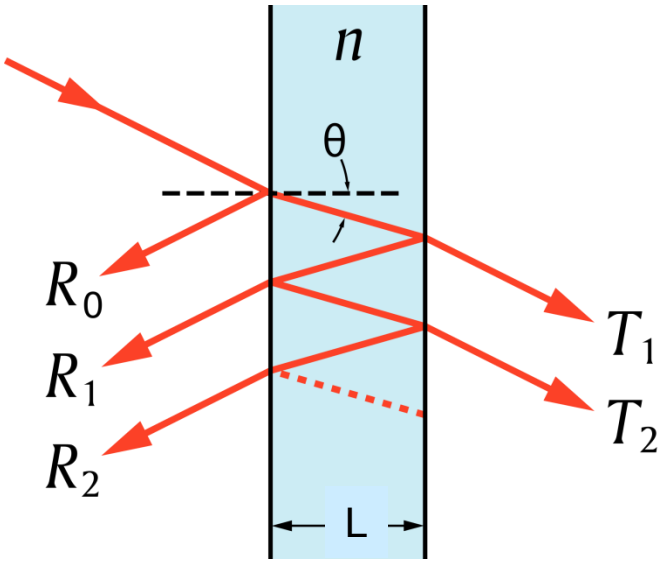
Etalon basics



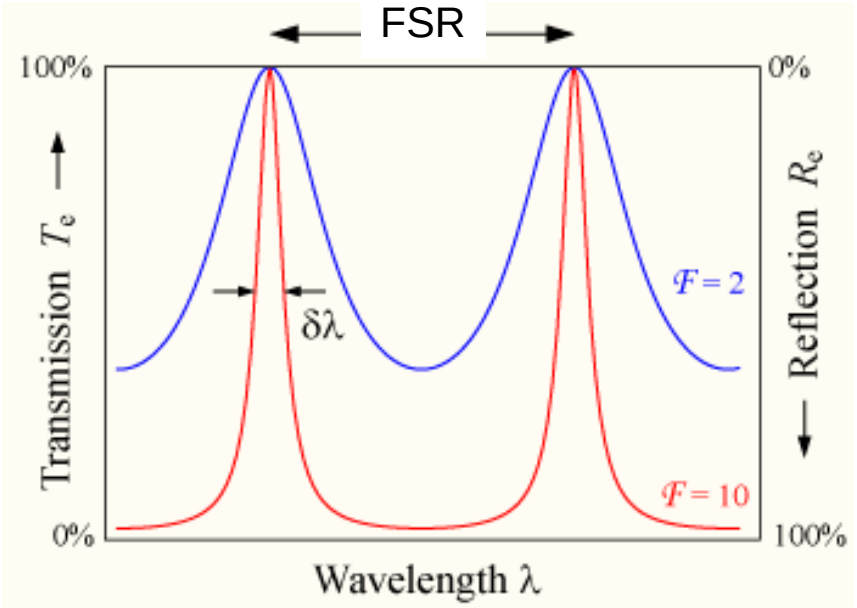
Free spectral range (FSR):

$$\mathrm{FSR}: \frac{c}{2nL\cos\theta}; \frac{\lambda^2}{2nL\cos\theta}$$

Finesse: $\mathcal{F} = \dfrac{\mathrm{FSR}}{\delta\lambda} \approx \dfrac{\pi\sqrt{R}}{1-R}$

Transmission peaks occur at

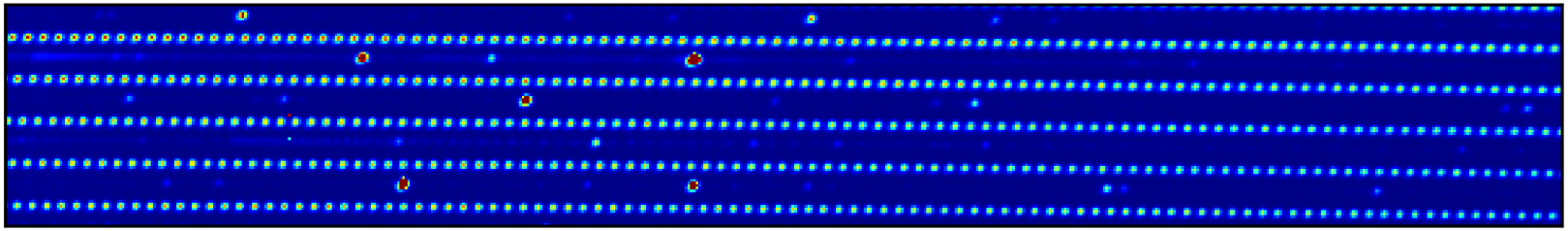
$$2nL\cos\theta = m\lambda$$

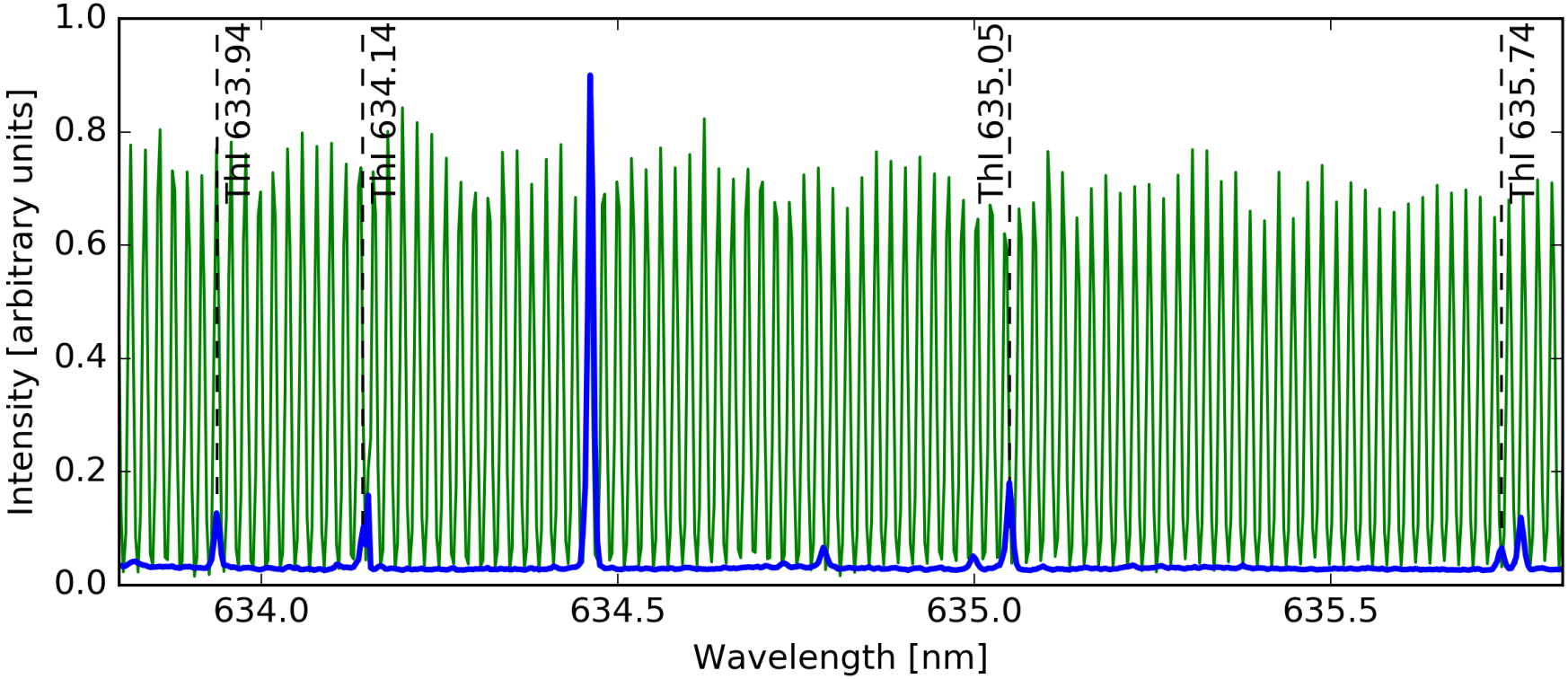


Features of ideal calibrator

- ✓ Lines are uniformly spaced & cover entire spectrum
- ✓ All lines are equally bright
- ✓ Line spacing > spectrograph resolution
- ✓ Linewidth << spectrograph resolution
- ✗ Lines at known wavelengths determined by fundamental physics
- ~ Wavelengths are stable over long timescales
- ✓ Easy to use/low maintenance
- ✓ Reasonably low cost

ThAr – etalon comparison





Stabilizing the etalon spectrum

$$2nL\cos\theta = m\lambda$$

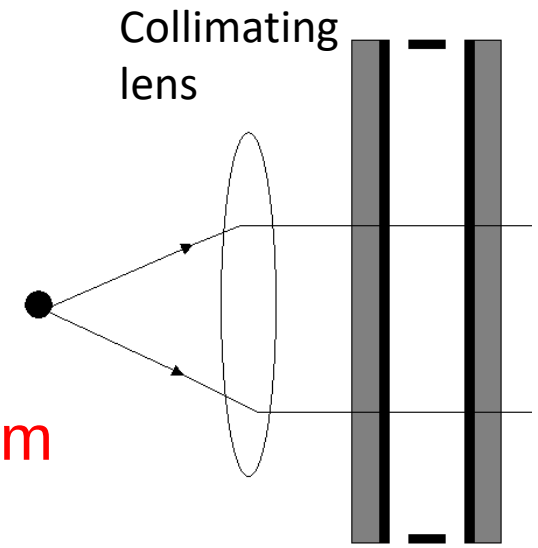
n - pressure, temperature
L - temperature
θ - alignment

$$\frac{\delta v}{c} = \frac{\delta \nu}{\nu} = \frac{\delta \lambda}{\lambda} = \frac{\delta x}{x}$$

$x = n$, L, or $\cos\theta$

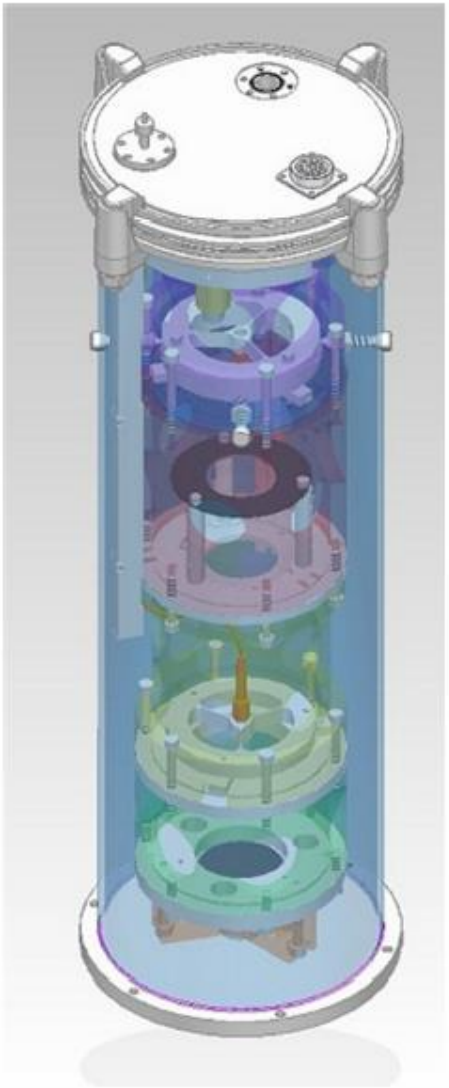
3 cm/s RV precision

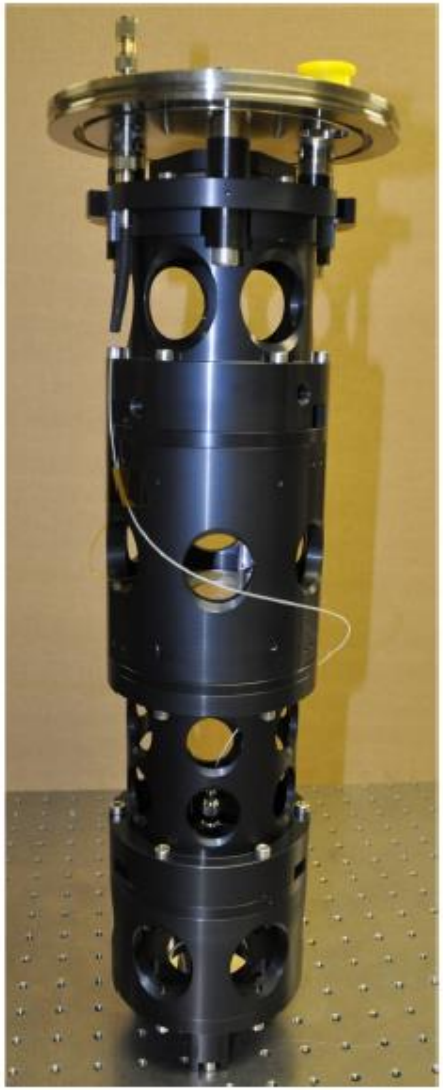
- Air-gap etalon with Zerodur spacer: 5 mK
- Fused silica fiber etalon: 14 μK
- Plane etalon: 8×10^{-4} deg alignment
- Fiber with f=100 mm collimating lens: 1.4 μm



Schäfer and Reiners, Proc. SPIE 8446, 844694 (2012).

HARPS calibration etalon





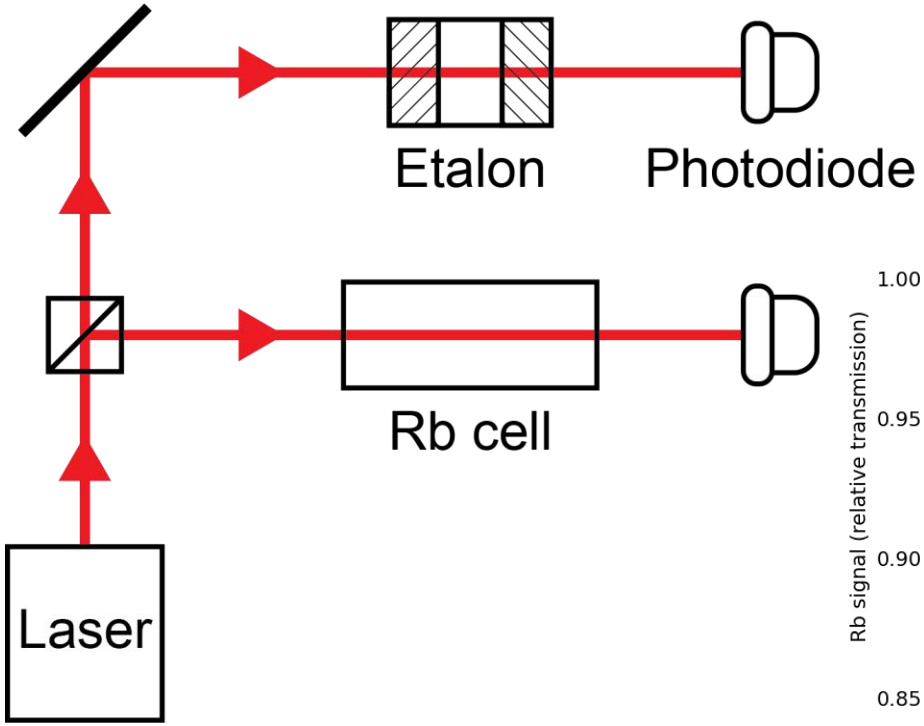
- Temp: 1-2 mK rms
- Press: 0.002 mbar

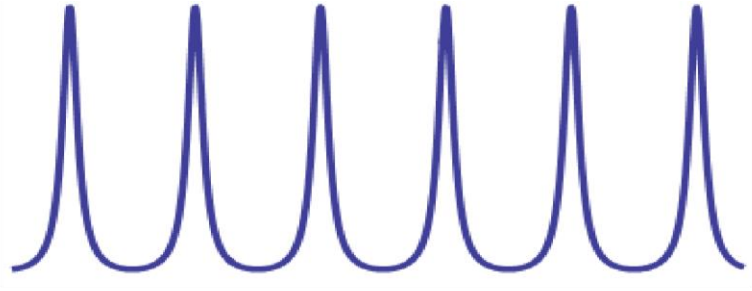
- 2 cm/s precision in 40 s exposure (7 cm/s with ThAr)

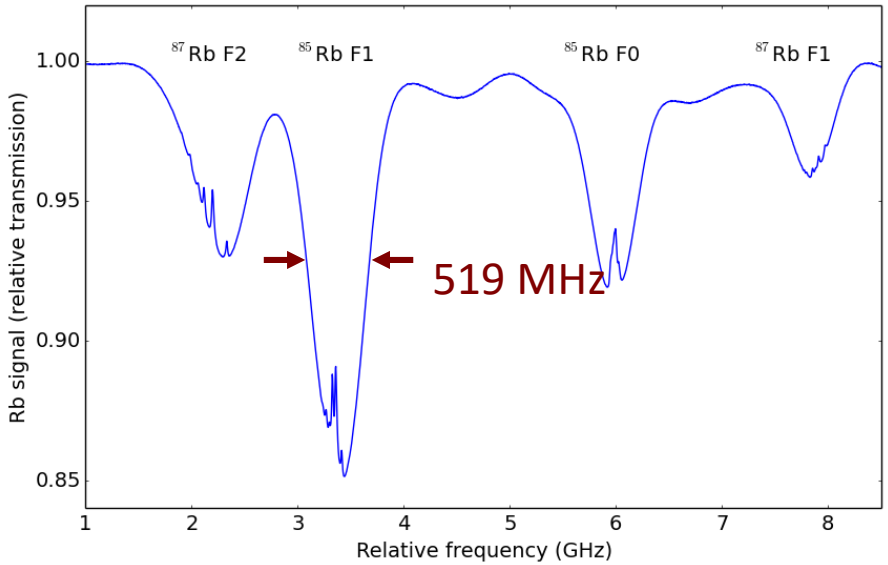
- drift..?

Wildi, Chazelas, and Pepe, Proc. SPIE 8446, 84468E (2012).

Laser-locked etalon

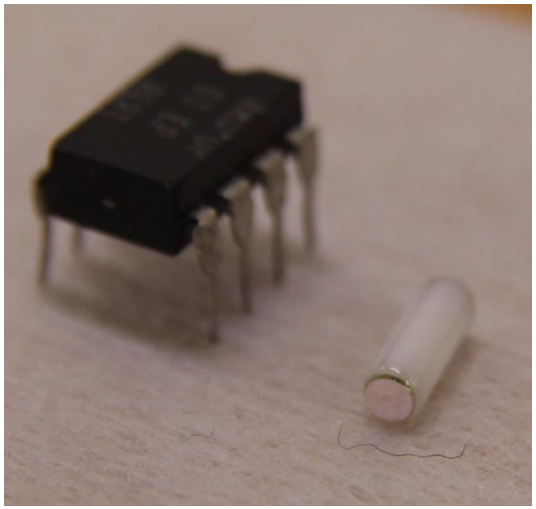


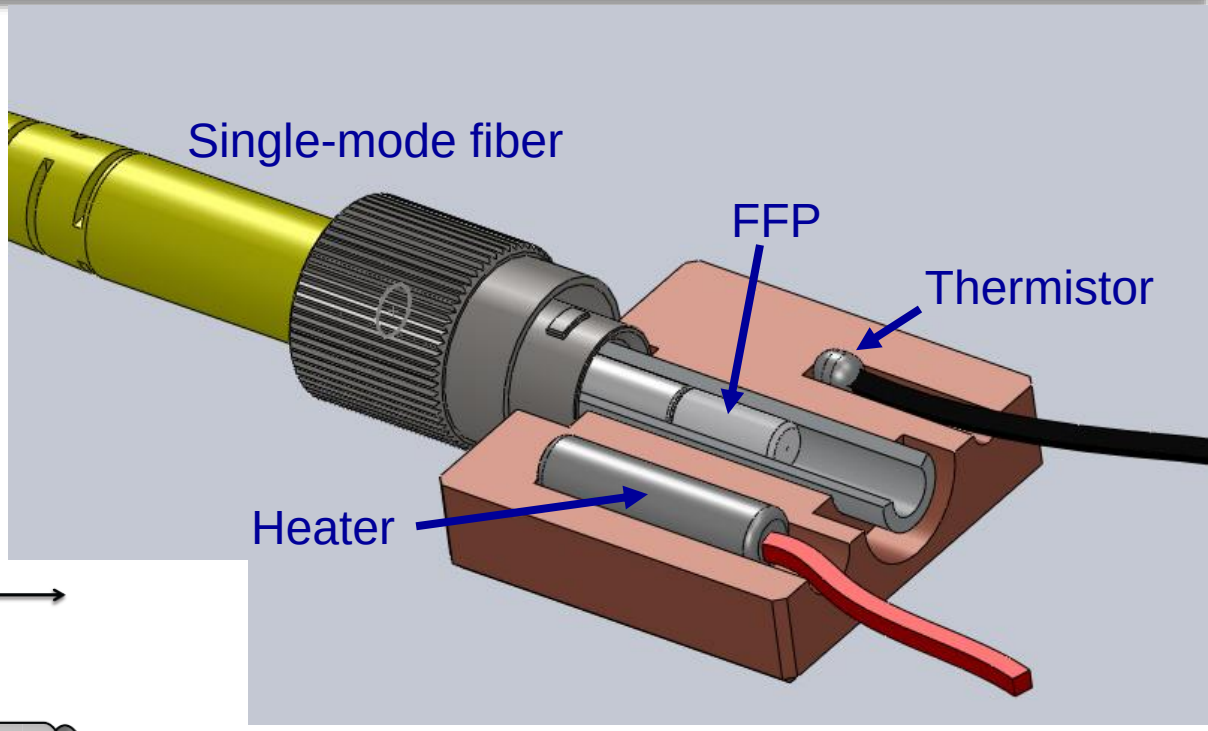


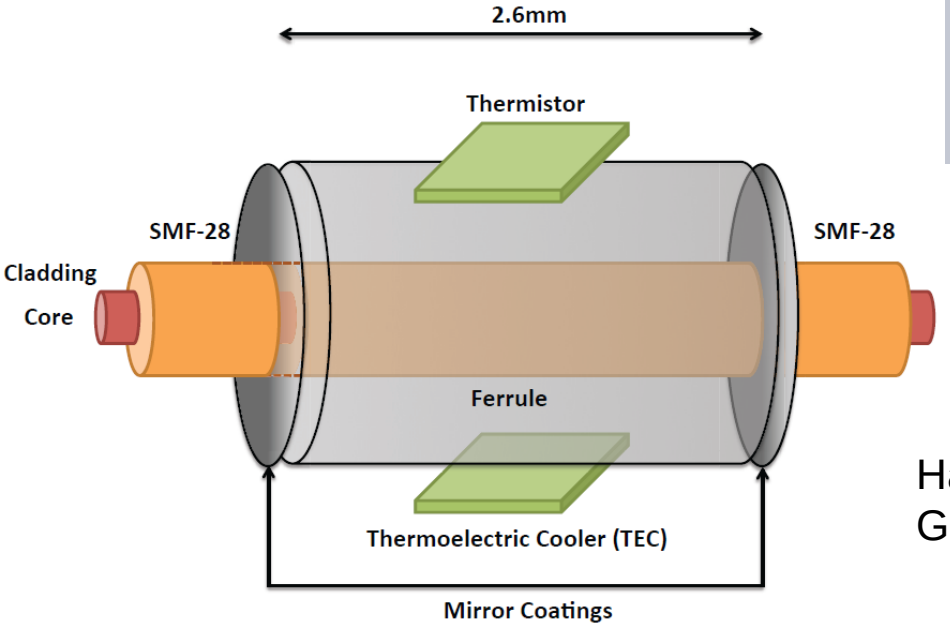


Rb D_2 transition

Fiber Fabry-Perot etalon

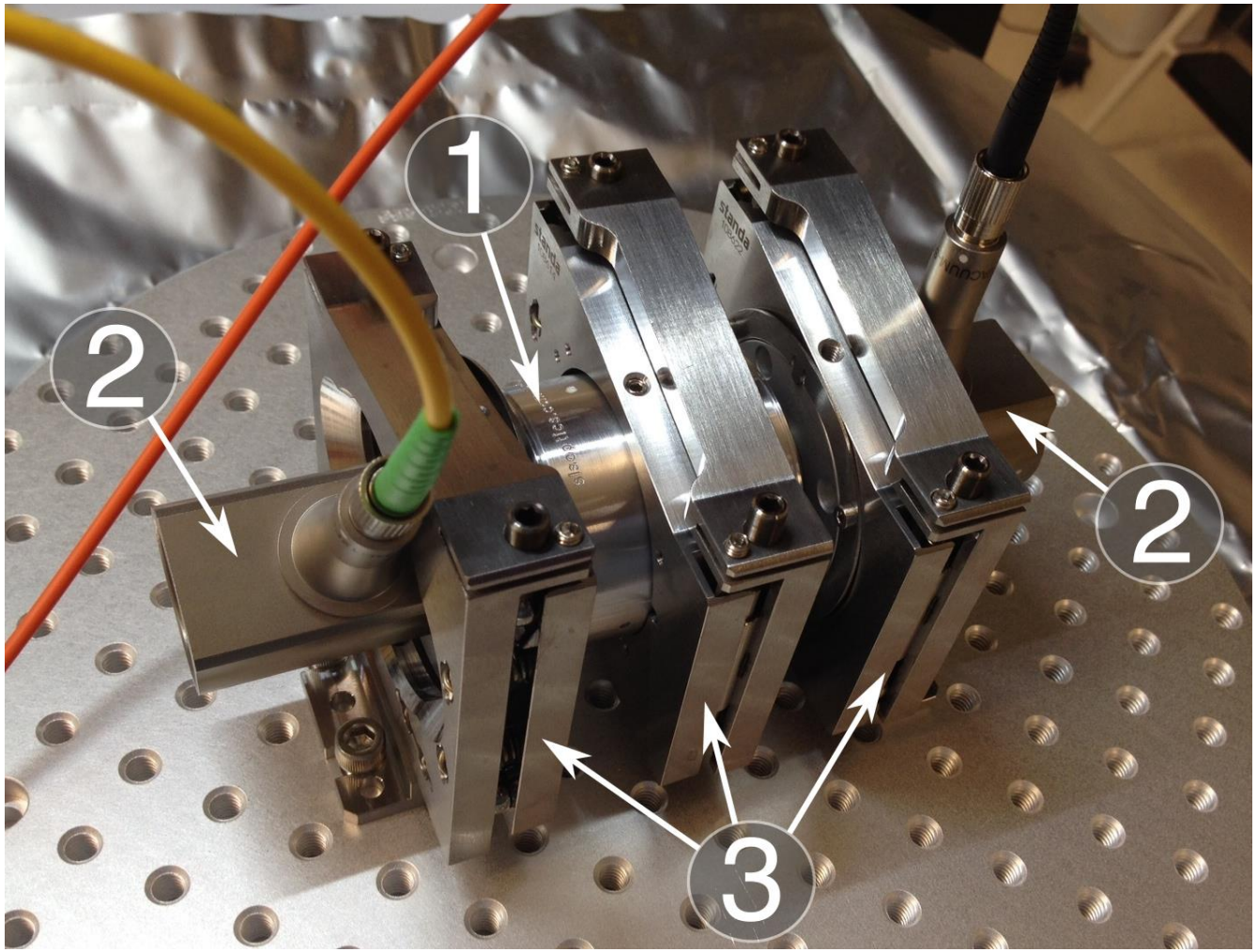






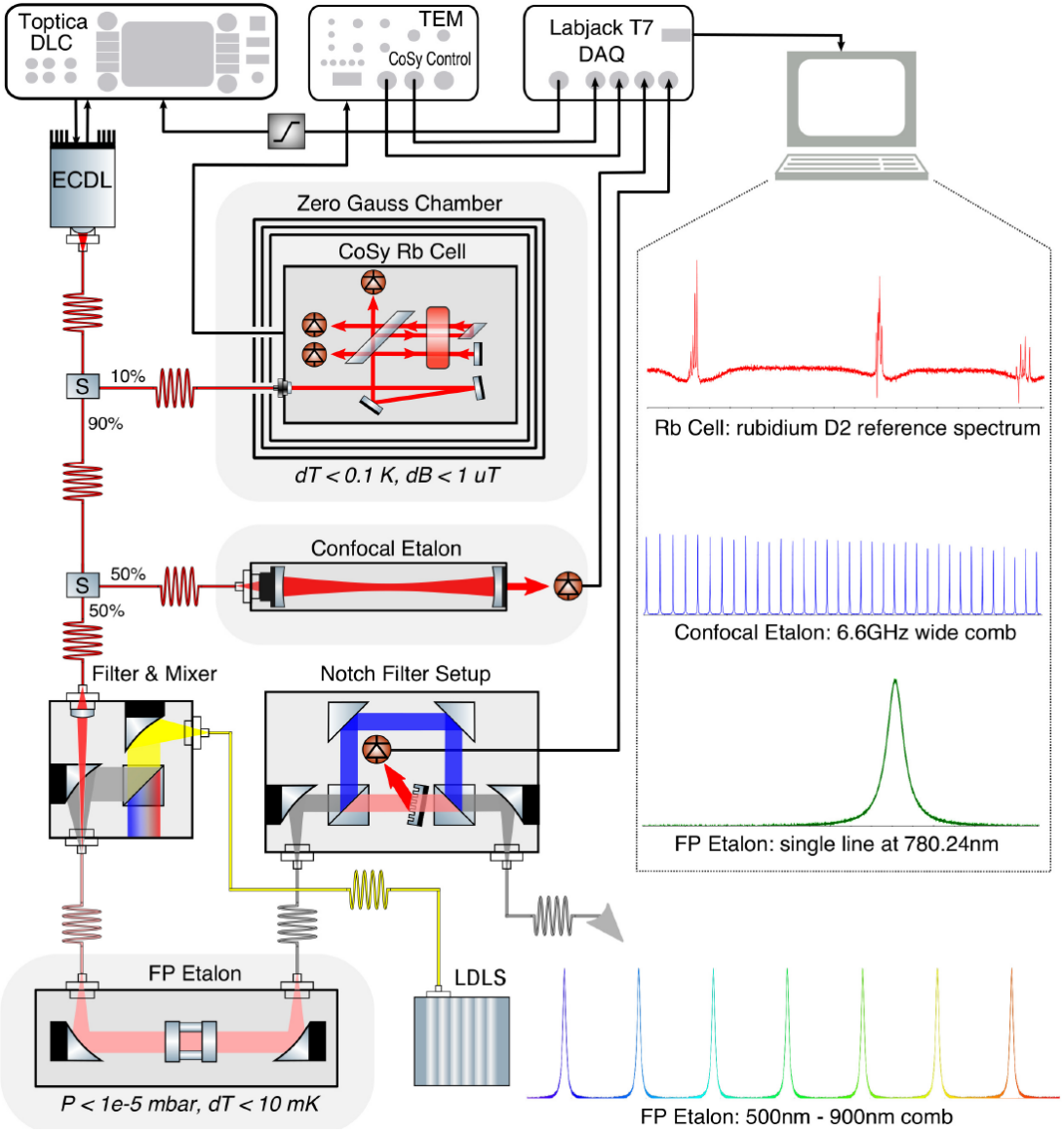
Halverson et al, Proc. SPIE 8446, 84468Q (2012).
Gurevich et al 2014, SPIE

Maroon-X etalon



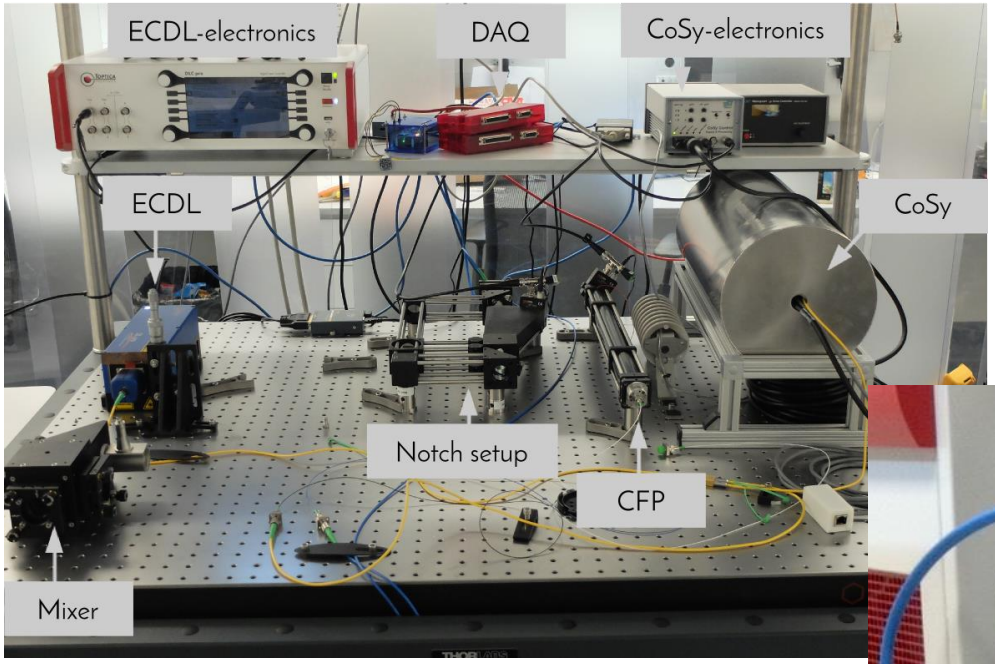
- Reflective collimators
- Kinematics mounts, bench mounted
- SMF

Apparatus



- Laser source
- Rb SatAbs setup
- Science Etalon
- Confocal Etalon
- Light source
- DAQ
- T control

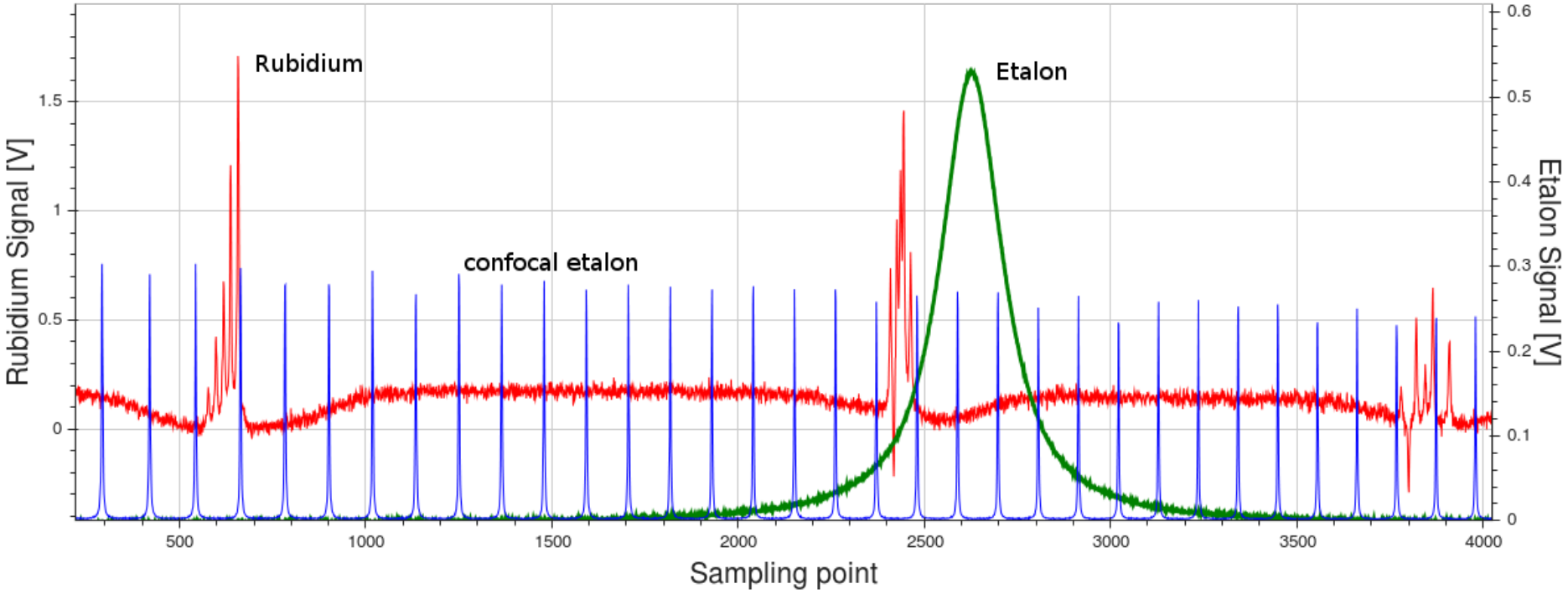
Maroon X bench setup



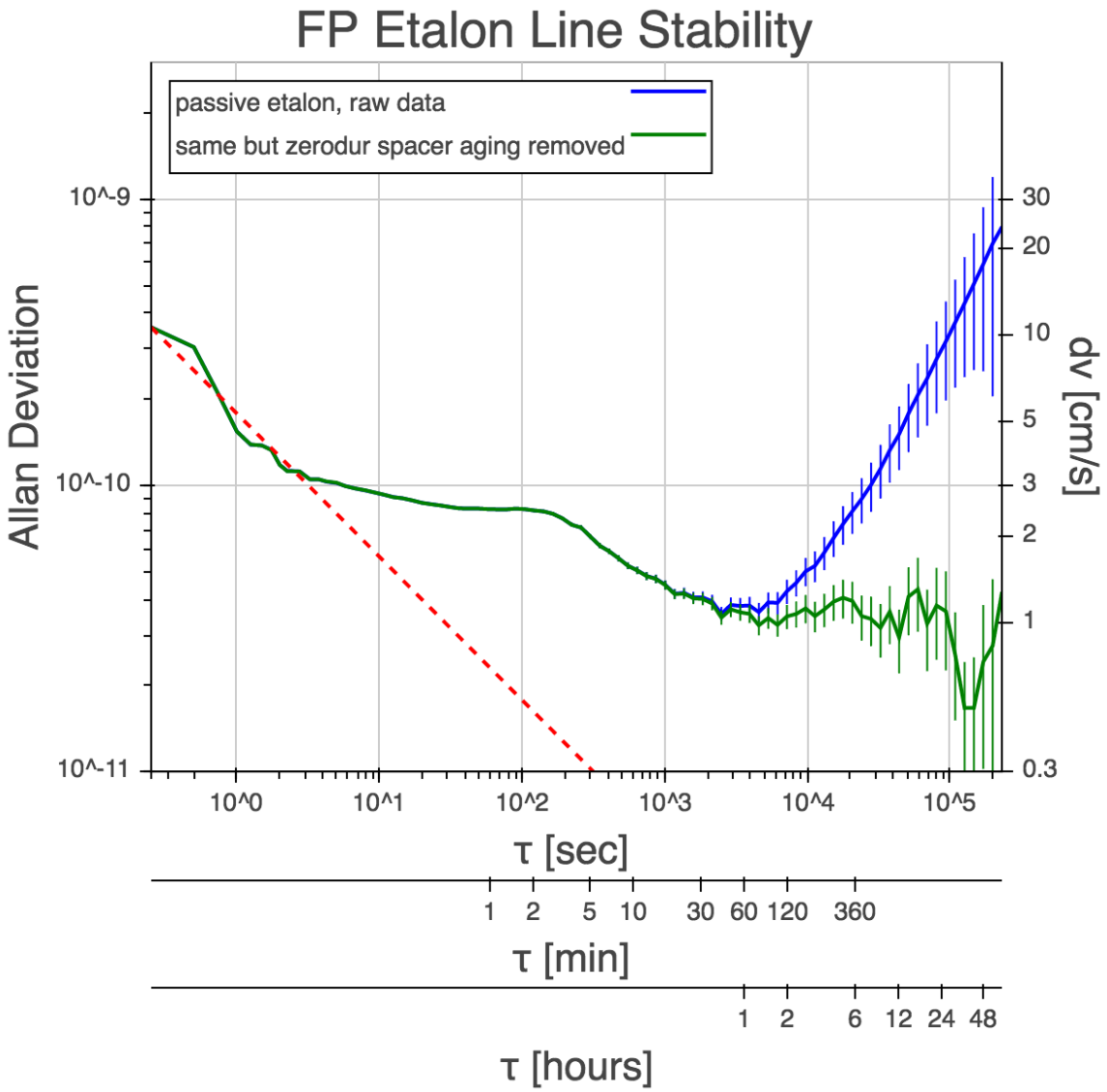
- Water temp. control
- Vacuum controller with IGP

Locking program

- DAQ interface records few-Hz scans with 100kHz sampling
- Scan shows Rb, science Etalon and aux. confocal etalon

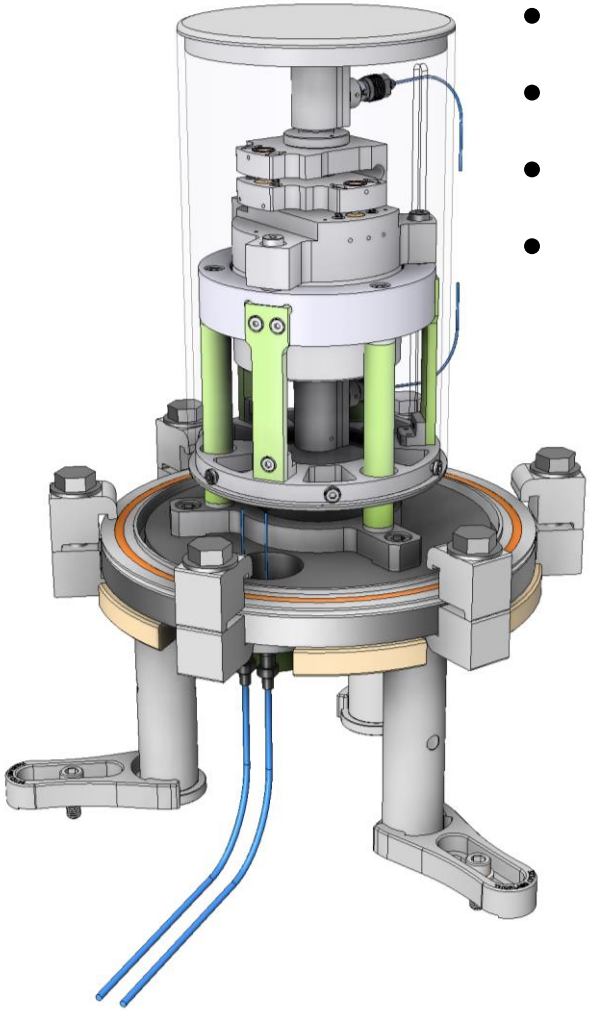


Line stability

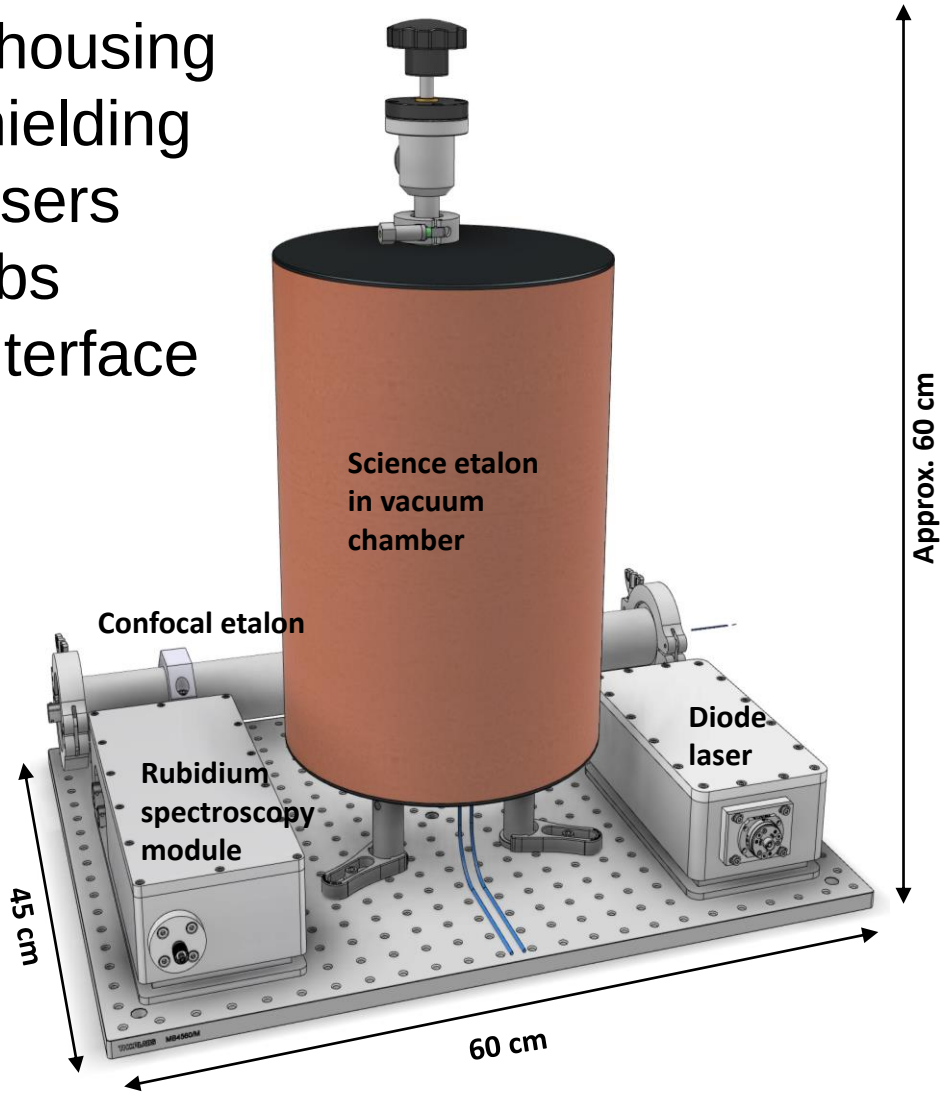


- Passively controlled etalon is very stable
- See Zerodur phase change after 30min

Full model



- New etalon housing
- Improved shielding
- Hermetic Lasers
- Stable SatAbs
- Hardened interface



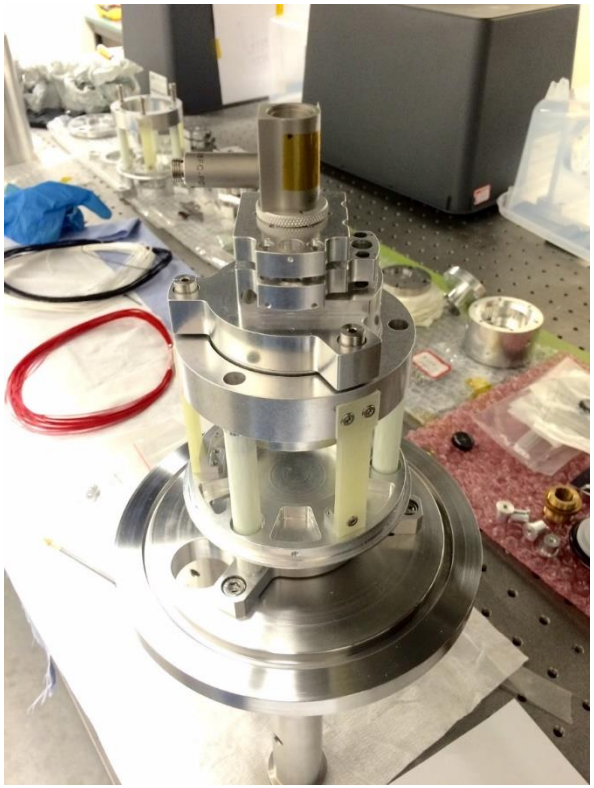
First time in the field!

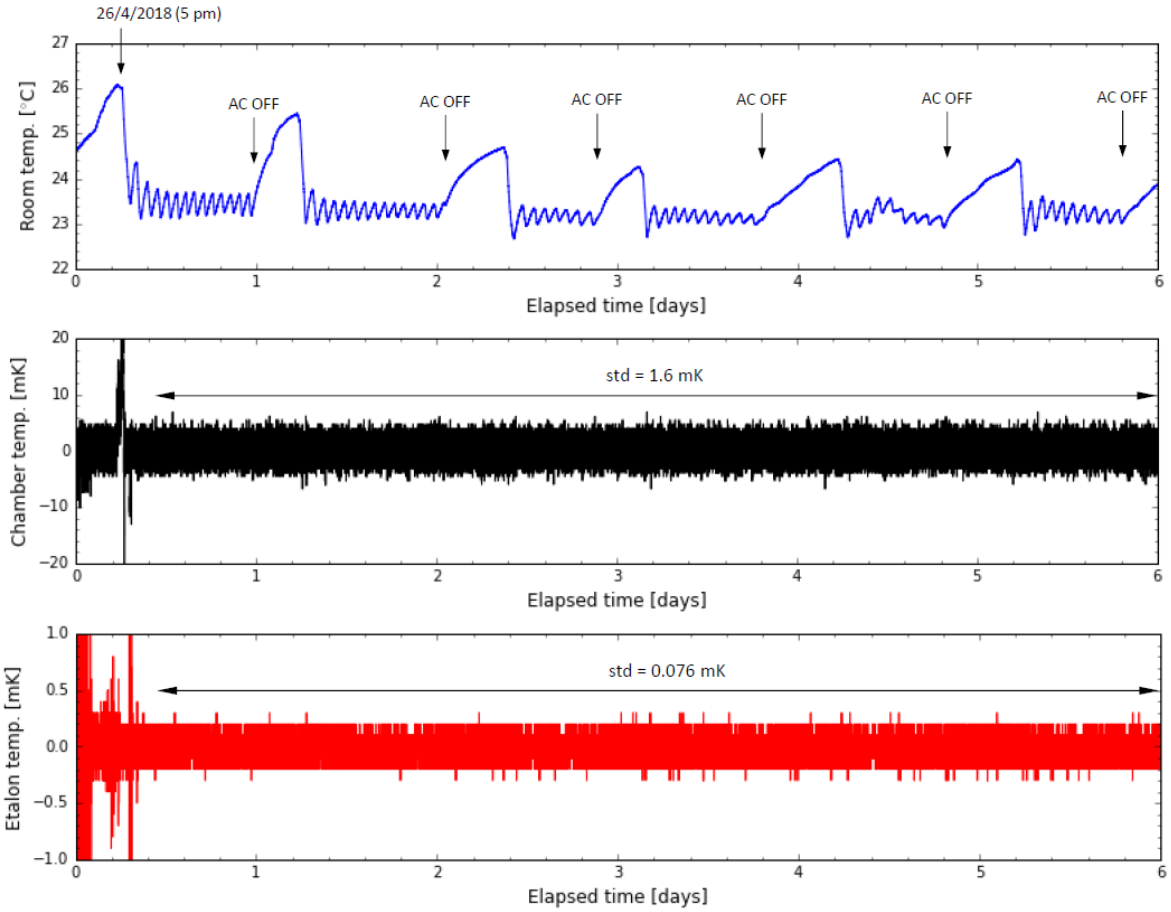
Used solid etalon for alignment of Veloce Rosso spectrograph

Not stabilized – simply required many unresolved lines

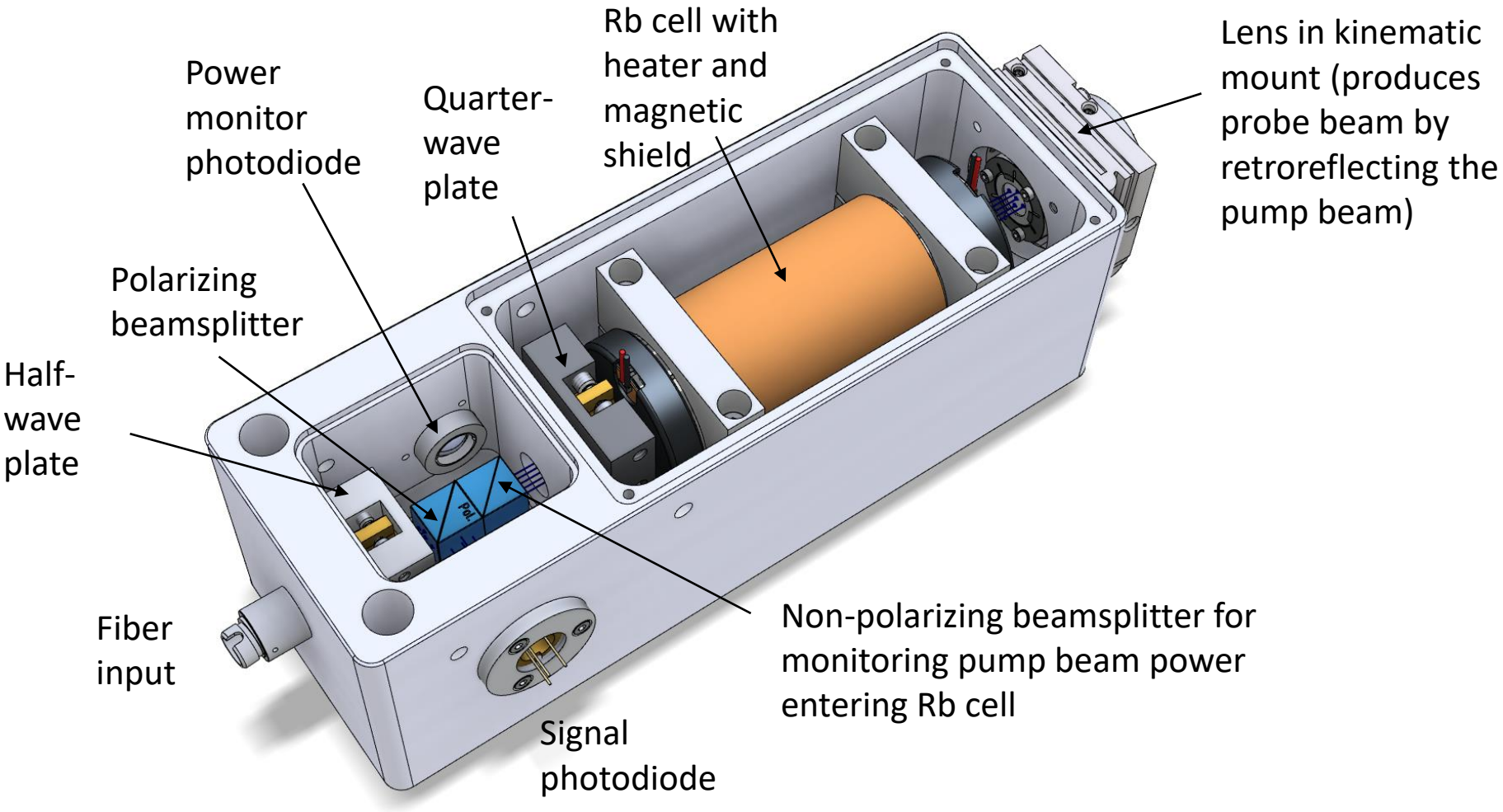
Key to remove astigmatism from optical setup

Temperature control

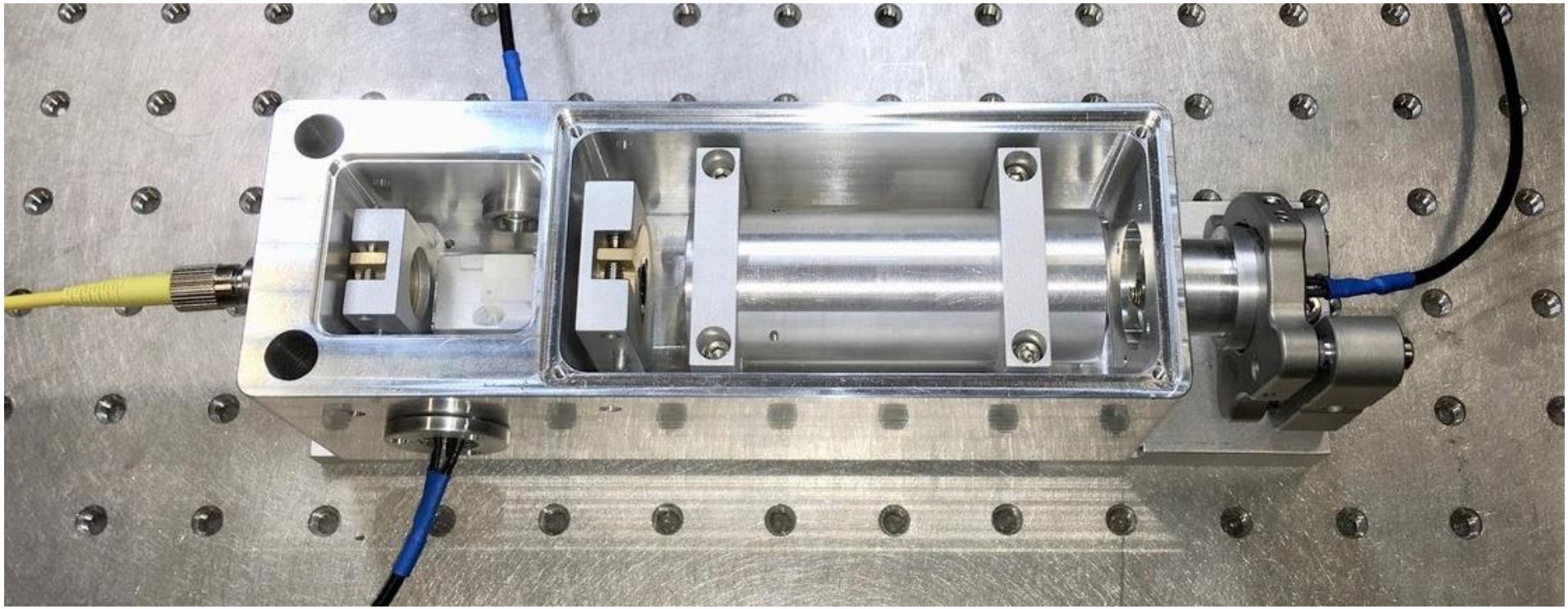




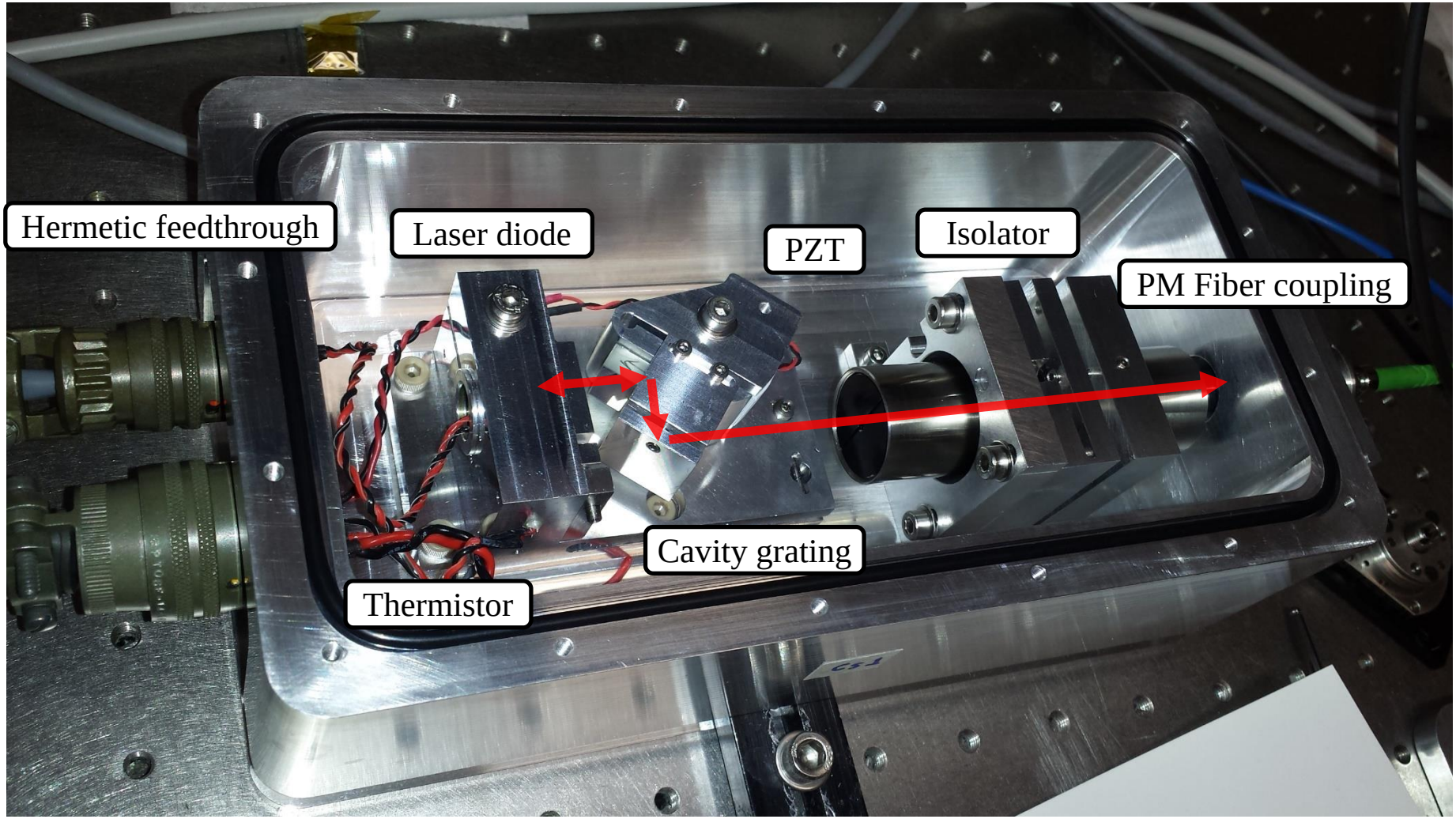
Stabilized Rb module



Stabilized Rb module

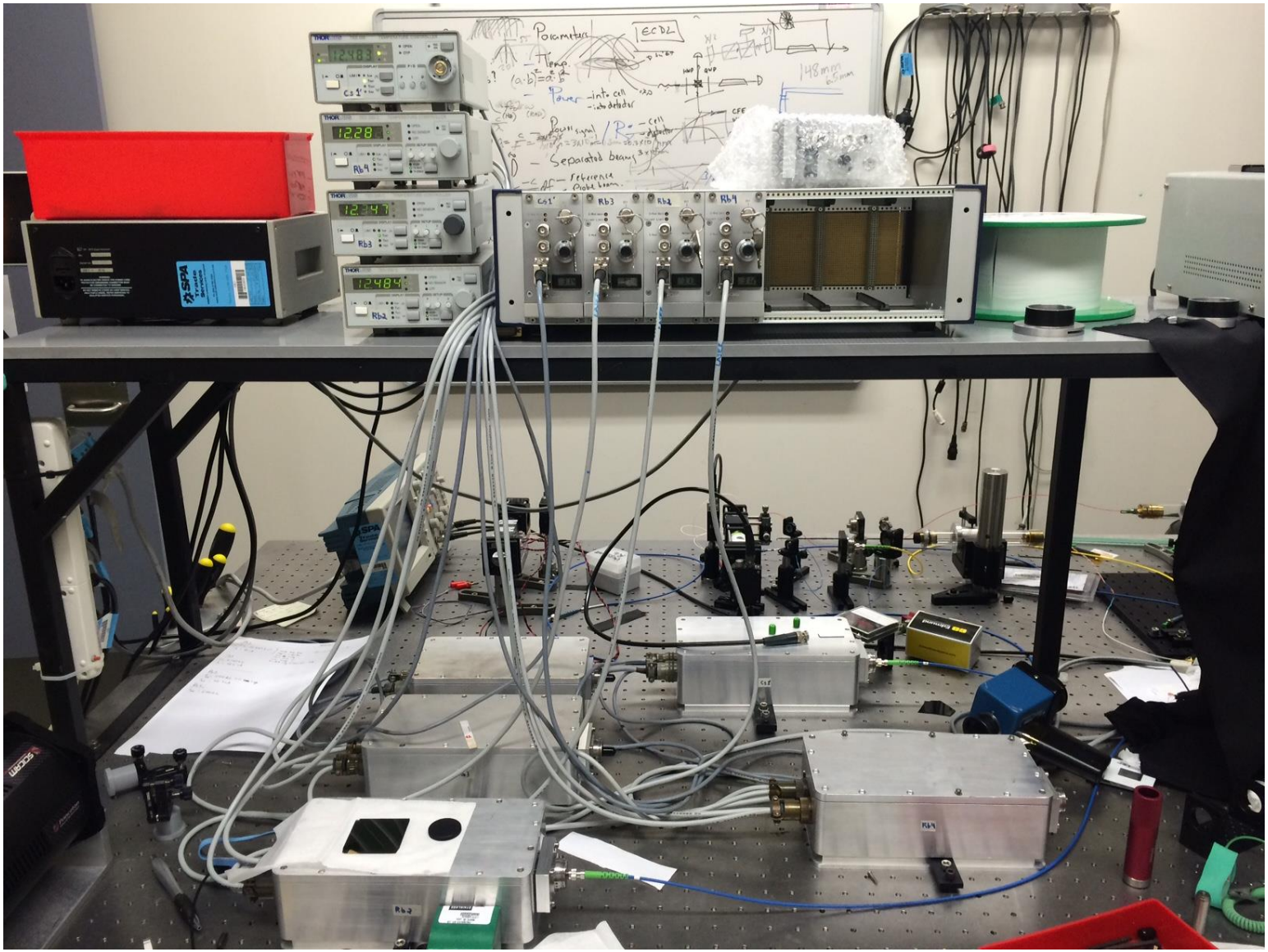


Hermetic ECDL



Standardized ECDL packaging developed for Rb (780 nm) and Cs (852 nm) diode packages

The lab


Parameters
ECDL
Power
Separated beams
Reference
Probe beam
Cs1'
Rb3
Rb2
Rb4

Summary

- FPs provide close to ideal spectral properties for spectrograph calibration
- Laser spectroscopy anchors FP to atomic frequency standard
- Stabilization applicable to essentially any etalon
- Simple, robust setup; affordable and easy to operate
- Passive etalons: HARPS et al, Carmenes, Spirou, PEPSI, HPF, NEID
- Working on calibration for Maroon-X, iLocater, FIES, KPF, Hermes