Politecnico di Milano
INFM - Department of Electronics and Information Science
and CNR-CSTS

Frequency stability measurements of 1.5 *m*m erbium lasers locked to acetylene absorption lines

Cesare Svelto and Elio Bava

CPEM ‘98
Washington, July 6-10 1998

INTRODUCTION

♦ DIODE-PUMPED SOLID-STATE LASERS find several **scientific and technical applications** due to their highest levels of **amplitude and frequency stability** e.g. in the fields of

- **Metrology**
  Optical frequency standards and measurements
- **Physics**
  Gravitational wave interferometers, QED tests
- **Doppler radar measurements in the atmosphere**
  H_2O vapor and pollutant detection, wind velocity, geodesy
- **Optical communications**
  Dense-WDM systems for long haul communications

WDM AND D-WDM SYSTEMS REQUIREMENTS

- Widely spaced channels (WDM)
  already in use with 4-8 channels, *D* ~ 500 GHz
- Tightly spaced channels (Dense-WDM)
  now 32 and in next future 64 channels, *D* ~ 50-100 GHz

♦ **Grid of optical frequencies at 1.5 *m*m**, ***D*=100 GHz** (0.8 nm)
ITUT-T - *Draft recommendation G.692* (May 1997)
"Optical interfaces for Multichannel Systems with Optical Amplifiers"

♦ **Absolute frequency stability *Dn* / *n* = 10^{-9}** (***Dn*** ≅ 200 kHz)
NPL - *Requirements Survey* (PRO_AFS-FR-2)
"Absolute frequency Standards for Optical Communications"
***Dn* / *n* = 10^{-10}** for laboratory calibrations

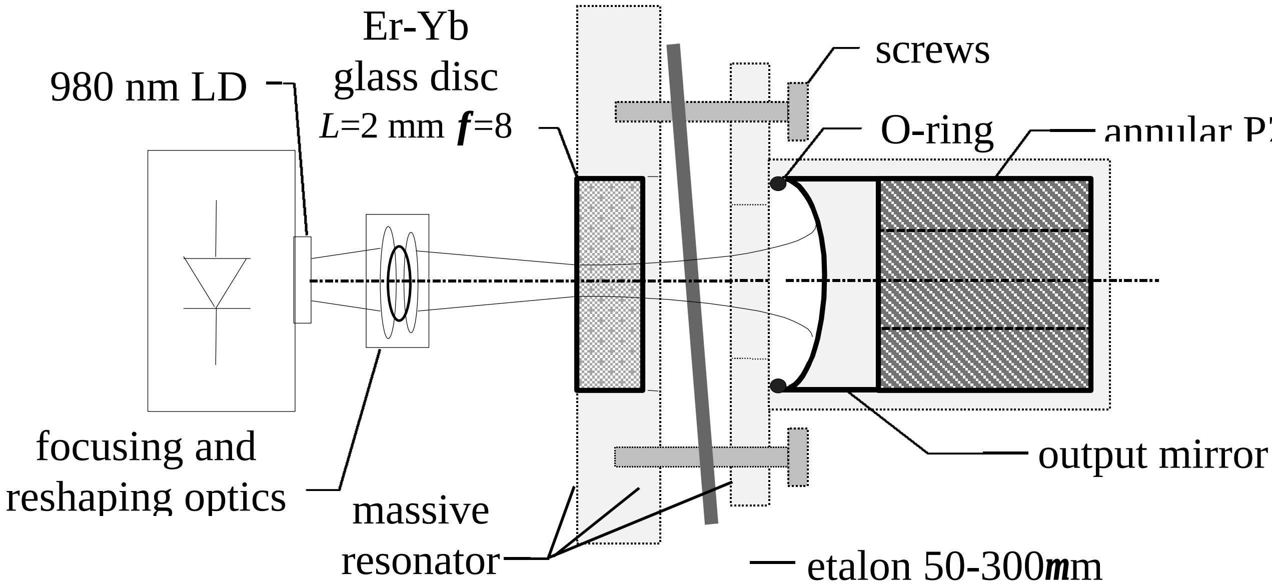
PURPOSE OF THIS WORK

- ♦ **Frequency stabilization of Er-Yb lasers at 1.5 *m*m** against absolute frequency references

- Study and development of **novel Er-Yb lasers** for frequency stabilization in a **wide wavelength interval**

- Frequency stabilization against rovibrational lines of the acetylene molecule **(C_2H_2 and $^{13}C_2H_2$)**

THE ERBIUM-YTTERBIUM TUNABLE MICROLASER

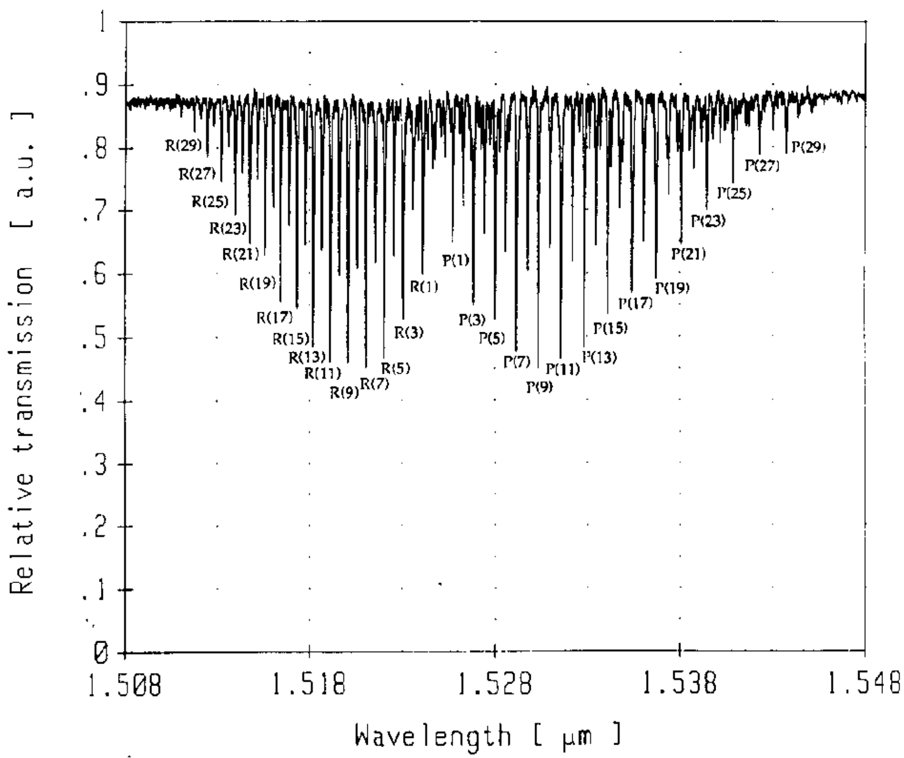


♦ **Novel Er-Yb:glass lasers** with >10 mW single-frequency output power in the **1528-1571 nm** wavelength interval

♦ **Microlaser** cavity (2×3×2 cm), with thin etalon (~50 ***m***m) for **single** axial **mode** selection, linear polarization and **wide wavelength tunability** (>5 THz) + **PZT for active frequency control** [possibility of 4-6 oscillating lines without the etalon]

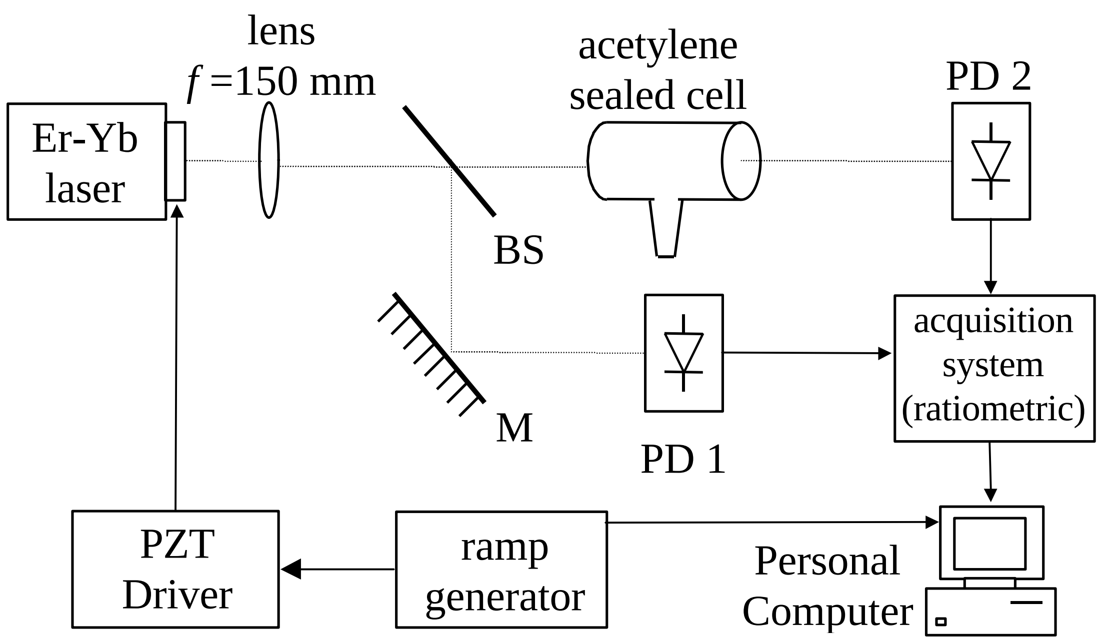
ABSOLUTE FREQUENCY REFERENCE AT 1.5 *m*m: ROVIBRATIONAL LINES OF THE C_2H_2 MOLECULE

♦ **Acetylene (C_2H_2)**: strong rovibrational absorption lines, with ~70 GHz spacing, in the **1510-1540 nm spectral region**



♦ **Isotopic acetylene ($^{13}C_2H_2$)** for locking at **1530-1550 nm**

SPECTROSCOPIC MEASUREMENTS ON C_2H_2

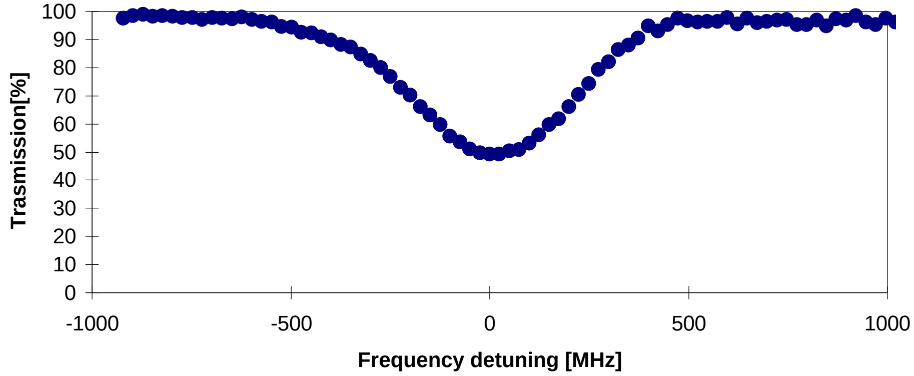


- **Experimental set-up** for the measurement of transmission profiles of C_2H_2 lines at different gas pressures (1 kPa, 2 kPa and 5 kPa)

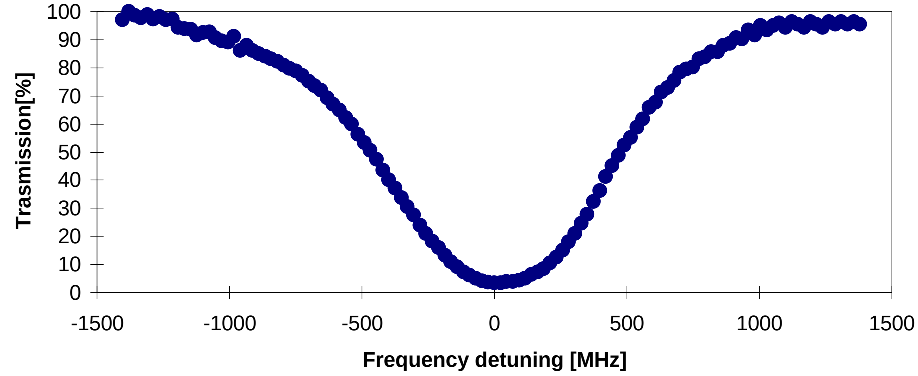
- Amplitude noise compensation via numerical normalization

SPECTRAL PROFILES OF P(15) ABSORPTION LINE

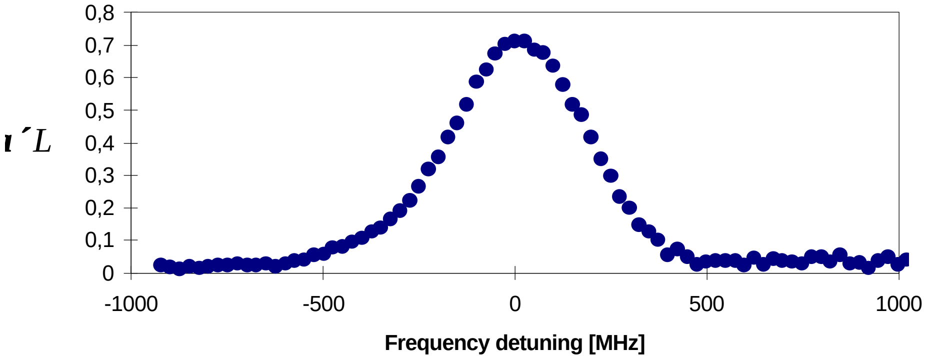
Cell transmission at 1 kPa
FWHM = 480 MHz



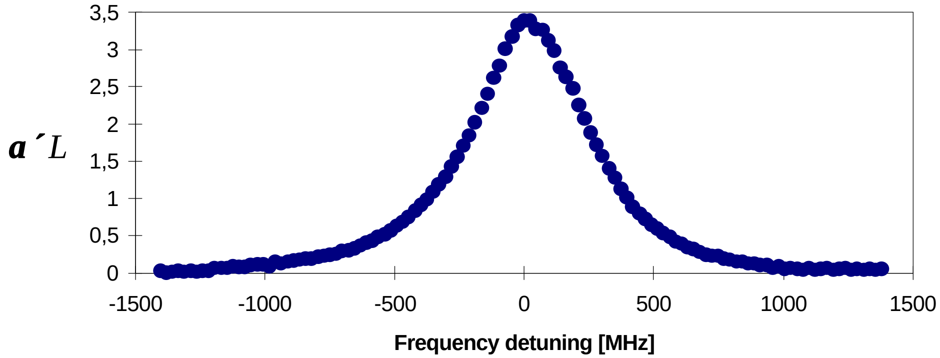
Cell transmission at 5 kPa
FWHM = 900 MHz



Absorption coefficient at 1 kPa
FWHM = 420 MHz



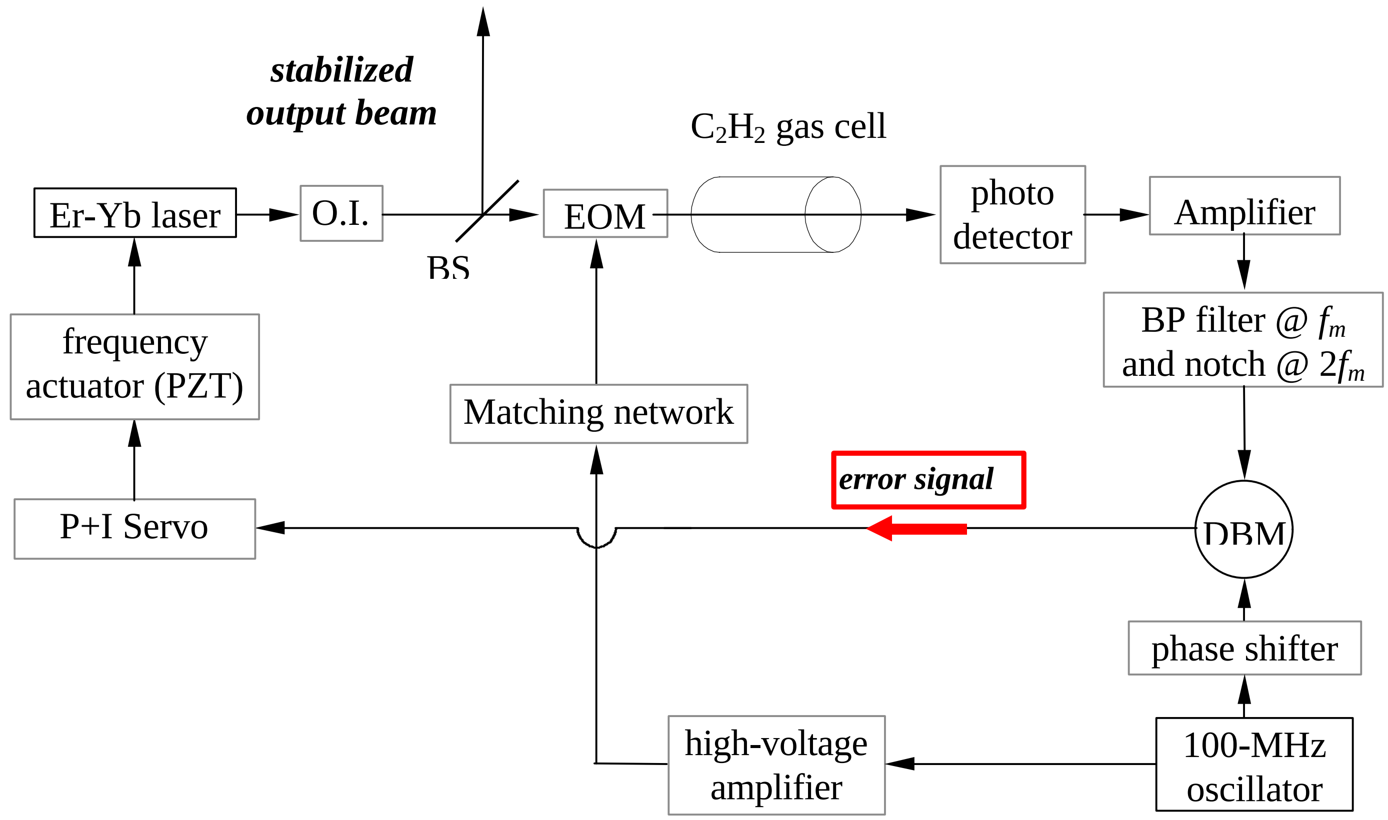
Absorption coefficient at 5 kPa
FWHM = 540 MHz



- ♦ **Transmission profiles** (C_2H_2 in quartz cells L=0.1 m)
- • calculation of the absorption coefficient ***a*** [m^{-1}]

POUND-DREVER FREQUENCY STABILIZATION

- **Electrooptic phase modulation** (f_m=100 MHz, m=0.16 rad) and **synchronous detection** (*mixer*: DBM)



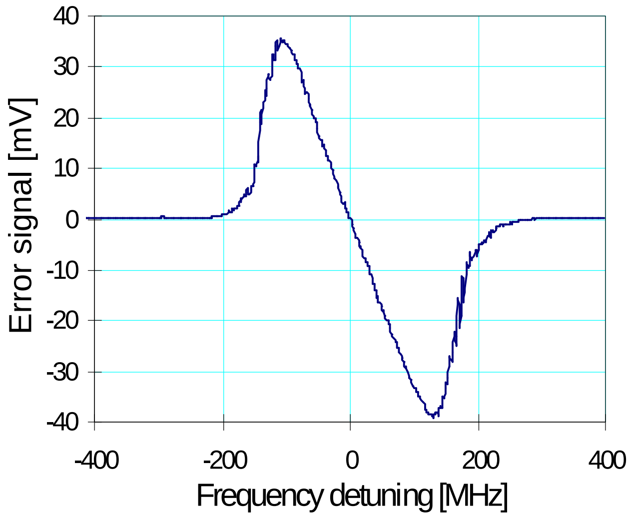
- **Two identical lasers** independently locked to the peak of

C_2H_2 P(15) line with a transition wavelength of **1534.099 nm**

DISPERSION-LIKE PROFILES FOR THE P(15) LINE

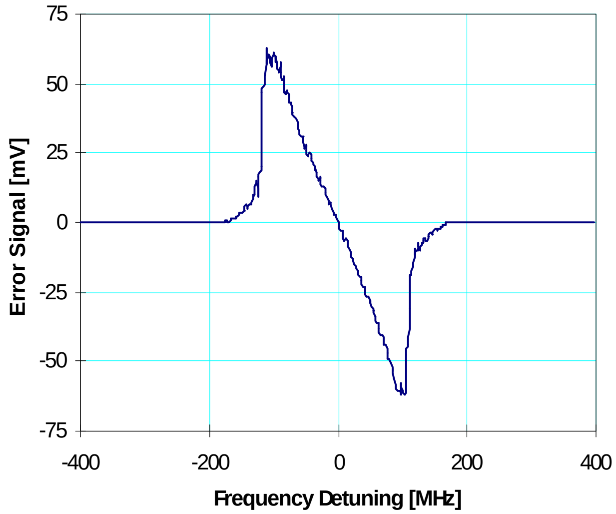
- **Discriminator curves** (voltage vs. frequency detuning) for C_2H_2 cells with L=100 mm at different pressures

slope = 0.40 mV/MHz



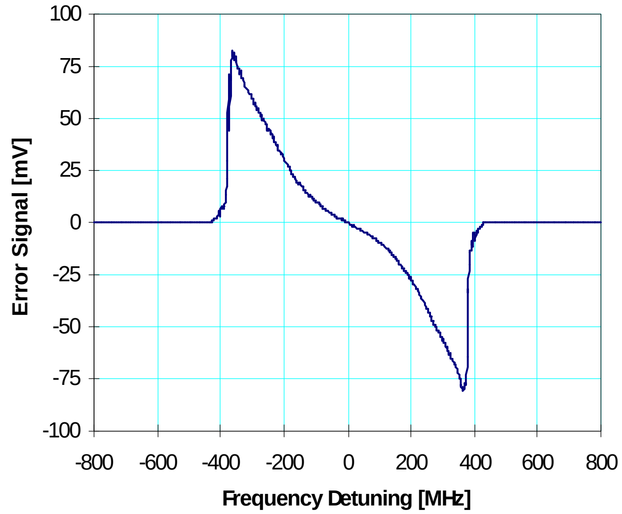
p = 1 kPa

slope = 0.52 mV/MHz



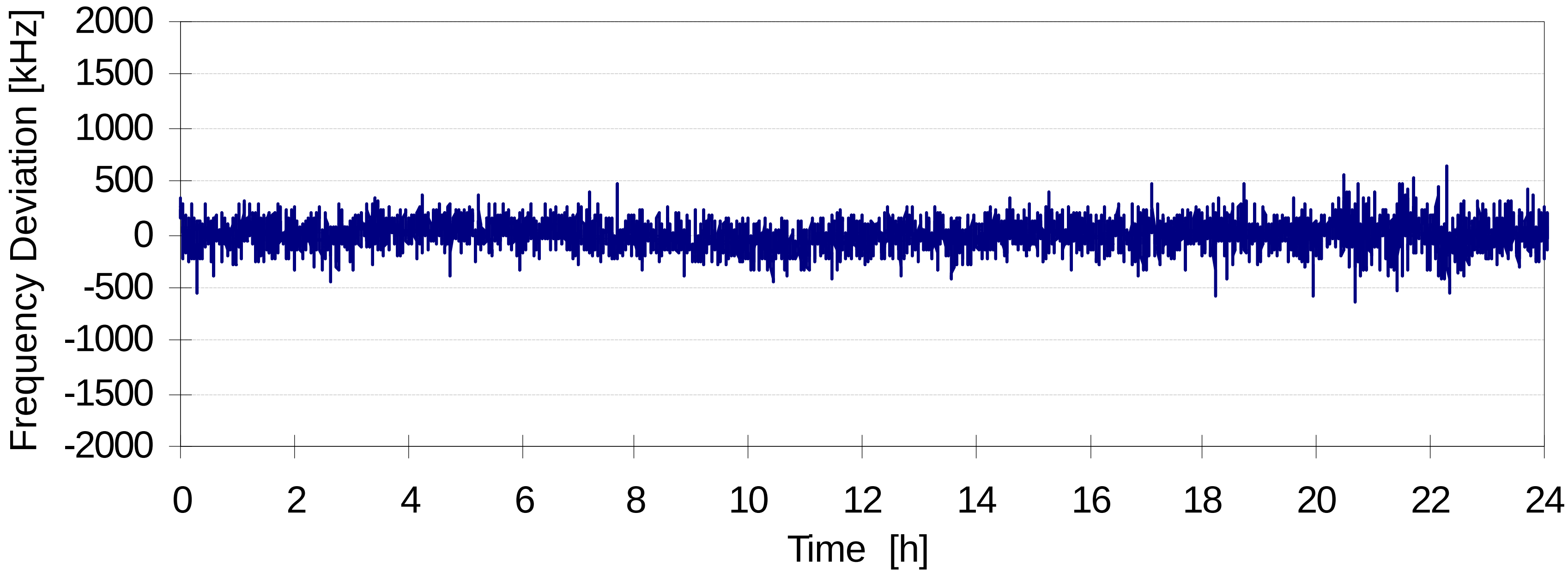
p = 2 kPa

slope = 0.09 mV/MHz



p = 5 kPa

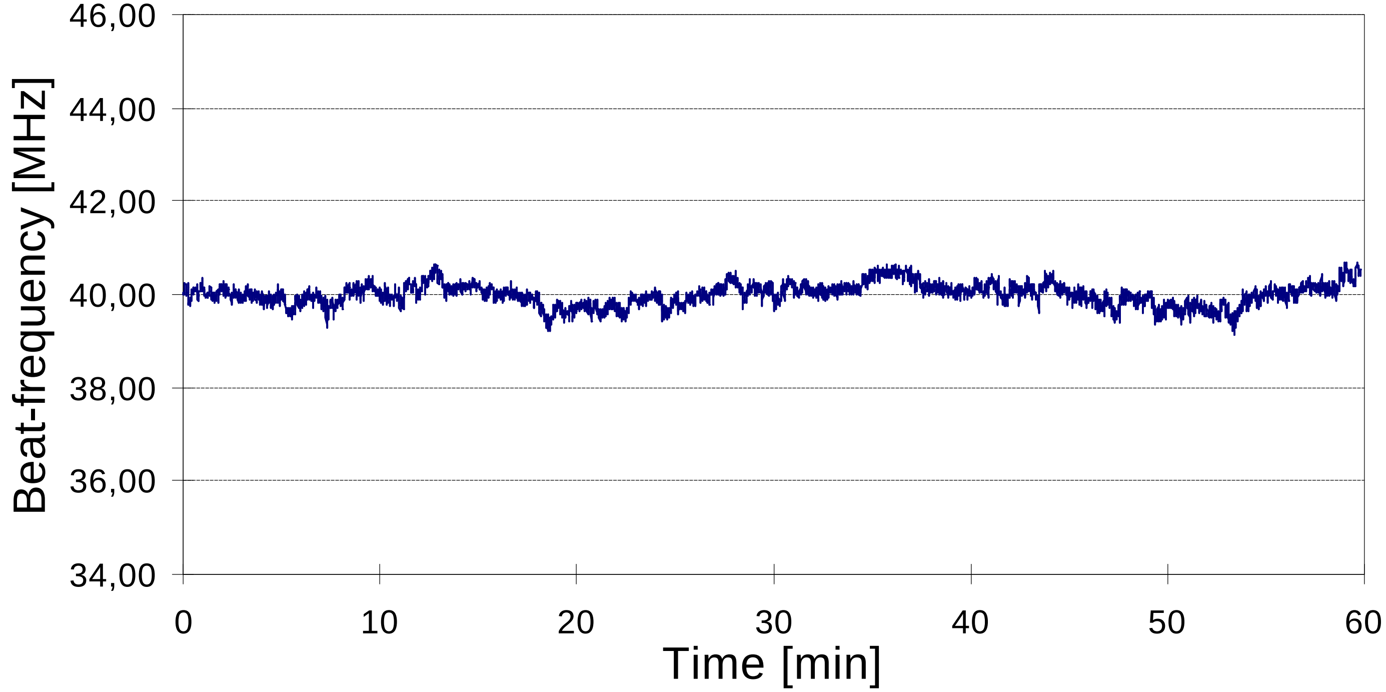
FREQUENCY STABILITY RESULTS WITH POUND-DREVER LOCKING AGAINST C_2H_2 P(15) LINE



Time behavior of the closed-loop error signal

♦ $\boldsymbol{n_{e,rms}}$ **= 160 kHz** over **24 h** (***Dn*** **/*n*** $<1\times10^{-9}$); $f_{\mathrm{sampl.}} = 0.05$ Hz

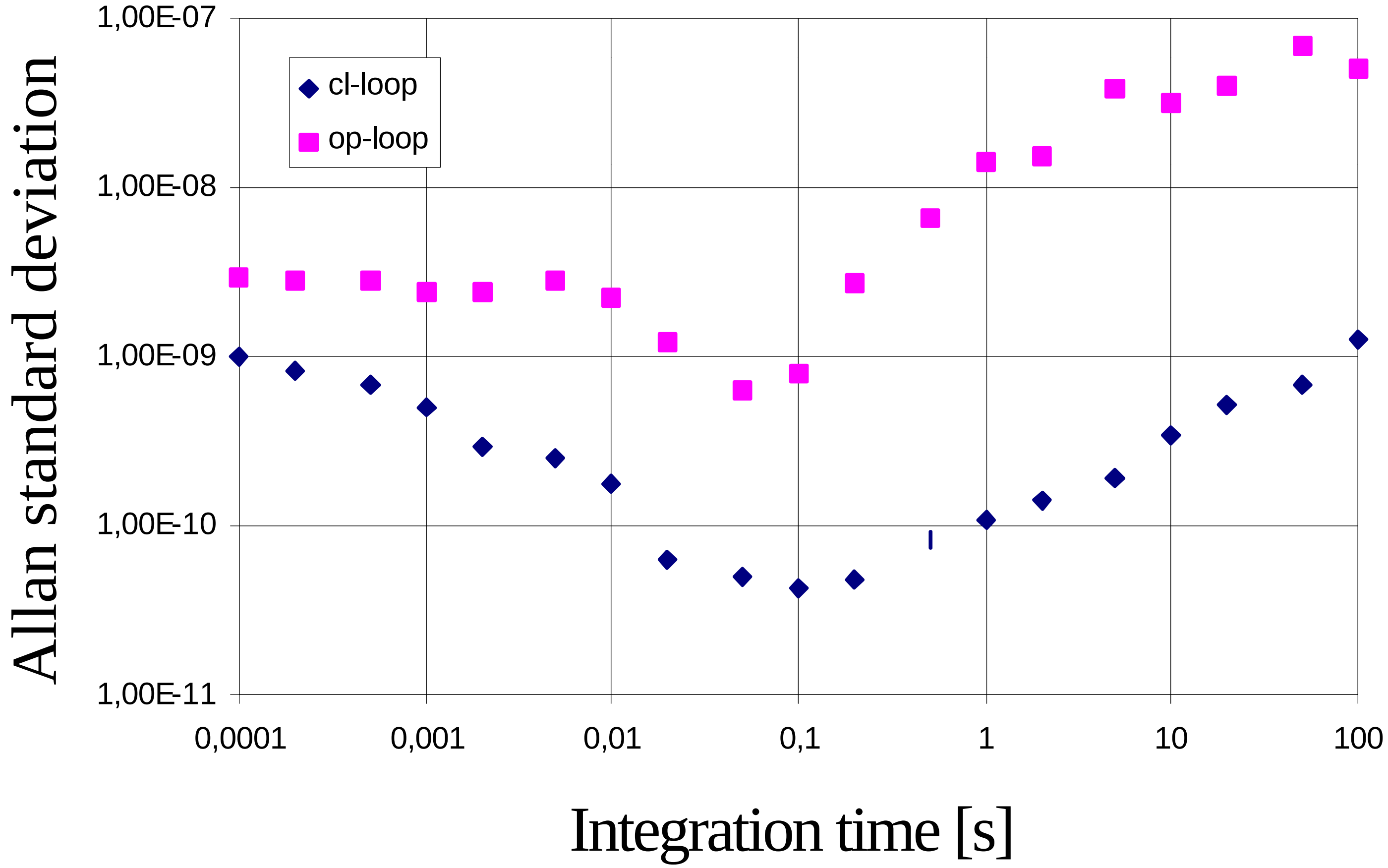
FREQUENCY STABILITY RESULTS WITH POUND-DREVER LOCKING AGAINST C_2H_2 P(15) LINE



Time behavior of the beat note frequency

♦ $\boldsymbol{n_{batt,rms}}$ **= 280 kHz** over **60 min** (***Dn*** **/*n*** $\cong 1.4\times10^{-9}$)
$f_{\text{sampl.}} = 0.5$ Hz

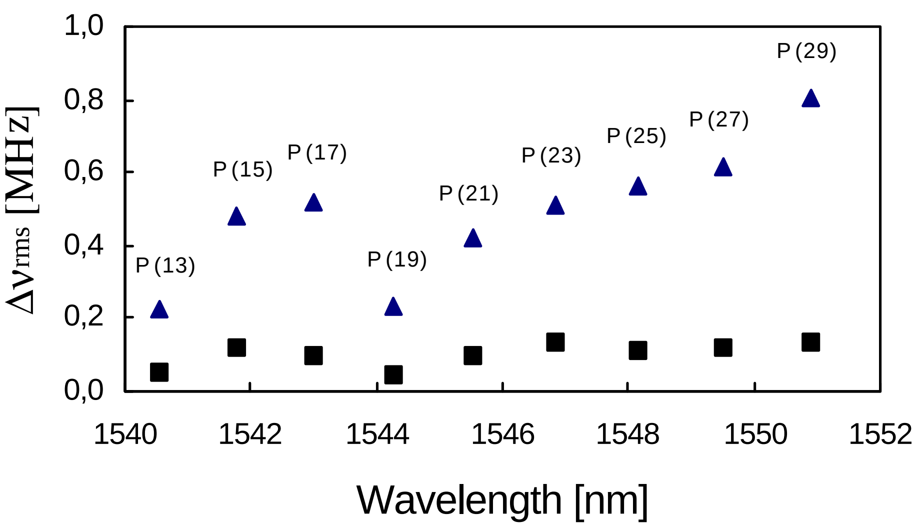
ALLAN STANDARD DEVIATION

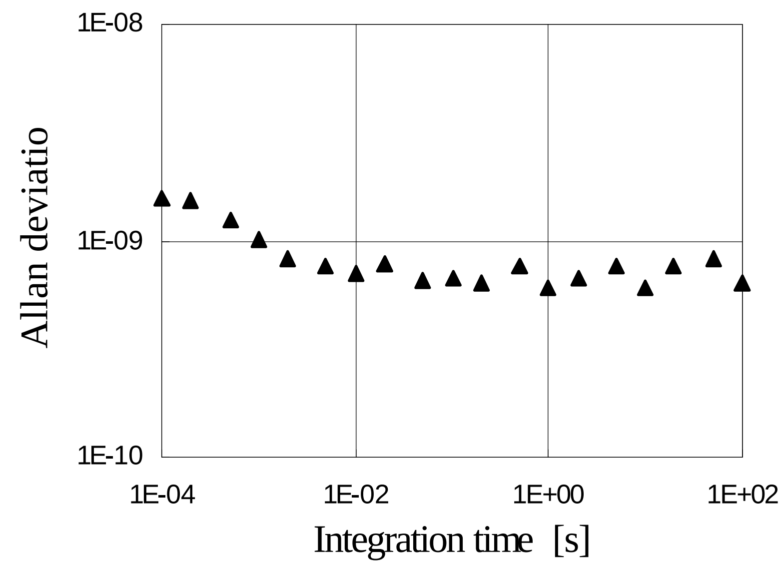


- **St.dev. s (2,t)** of n_{batt}/n_o **< 1×10^{-9}** for 100 ms ≤ t ≤ 100 s
  s **= 4×10^{-11}** for t = 0.1 s
- Noise reduction between 20 and 40 dB

FRINGE-SIDE-LOCKING AGAINST $^{13}C_2H_2$

- **Wavelength tunability** and frequency locking from 1540.567 nm, **P(13)** line, to 1550.866 nm, **P(29)** line, of the $^{13}C_2H_2$ **molecule**





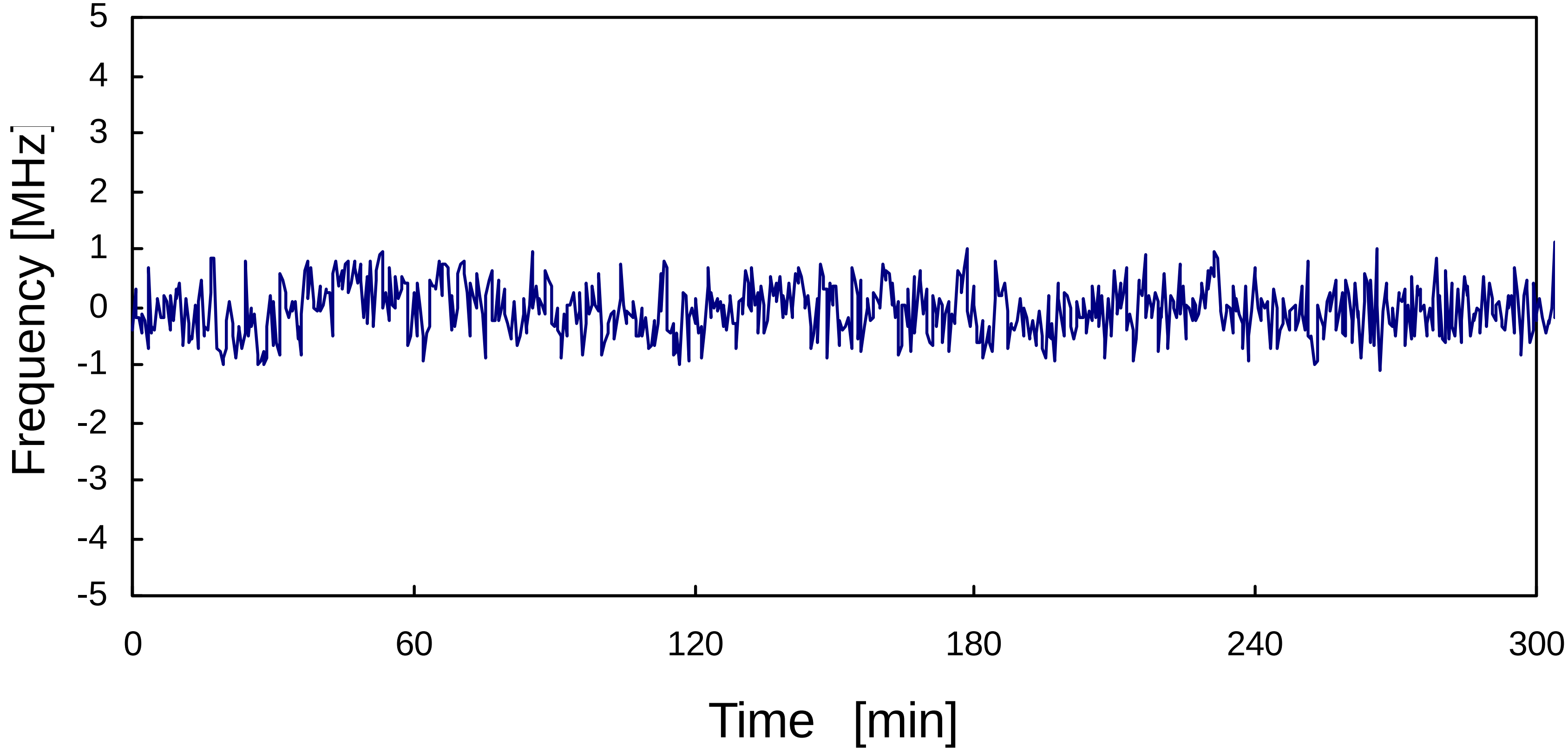
Tunability and frequency locking

Allan standard deviation

Averaging time: “♦” 50 ms ;” “ 1 s

- **10^{-9} Allan st. dev.** between 0.1 ms and 100 s when locked against P(13) line (strongest odd line)

BEAT NOTE RECORDING



Beat note frequency fluctuations [against C_2H_2 P(13) line]

- $\boldsymbol{n_{e,rms}}$ **= 440 kHz** over **5 h** (***Dn*** /***n*** <2.7×10^{-9}); $f_{sampl.}$= 0.04 Hz

CONCLUSIONS

- Novel widely-tunable Er-Yb microlasers with >40 nm wavelength tunability in single-frequency operation at >10 mW TEM_{00} output power linearly polarized 100:1 + PZT and temperature cavity length control

- *Pound-Drever technique*
  Er-Yb lasers frequency stabilized on **C_2H_2 P(15) line** at 1534.099 nm with $<10^{-10}$ Allan standard deviation
  measured rms frequency stability: 160 kHz (error signal)
  280 kHz (beat note)

- *Fringe-side-locking technique*
  Er-Yb against frequency stabilized on **$^{13}C_2H_2$ P(13)-P(29)** lines with $\sim10^{-9}$ frequency stability

FUTURE DEVELOPMENTS

- Frequency stabilization of a comb of optical frequencies in multi-axial mode operation
- Use of simpler frequency references e.g. temperature stabilized gratings
- Linewidth reduction by a fast control loop employing an electro-optical modulator
- Frequency stabilization against C_2H_2 Doppler-free absorption lines by intra- or extra-cavity saturated absorption