Lecture Course

Advanced Experimental Methods

W. Ubachs; part B

Wavelength – Frequency Measurements

Frequency:
- unit to be measured most accurately in physics
- frequency counters + frequency combs (gear wheels)
- clocks for time-frequency

Wavelength:
- no longer fashionable (for precision measurements)
- unit [m] no longer directly defined
- always problem of the medium- index of refraction

Units: exercise convert
- Ångstrom -> nm
- eV, J, cm^{-1}, Hz, kcal/mole

(Wave)Length standard

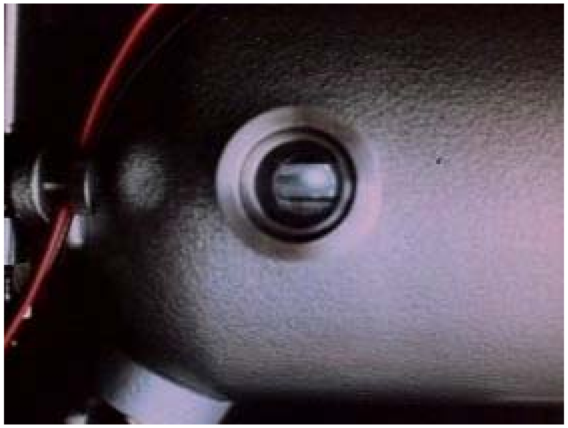
Until 1960

Now, since 1983

$$L = c \cdot t$$

$$c = 299792458 \frac{m}{s}$$

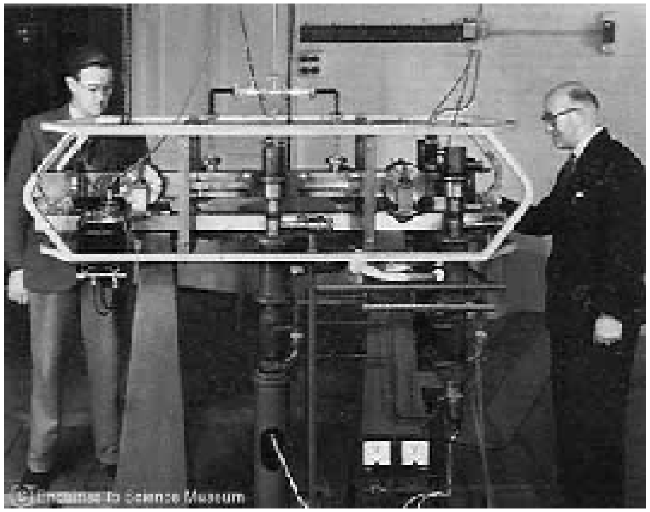
Krypton (Kr):
International Standard of Length



The picture shows a device holding a tube of krypton gas. The isotope Kr-86 contained in the tube can be excited so that it emits light. The international standard of length is one meter, which is 1,650,763.73 wavelengths of radiation emitted by Kr-86.

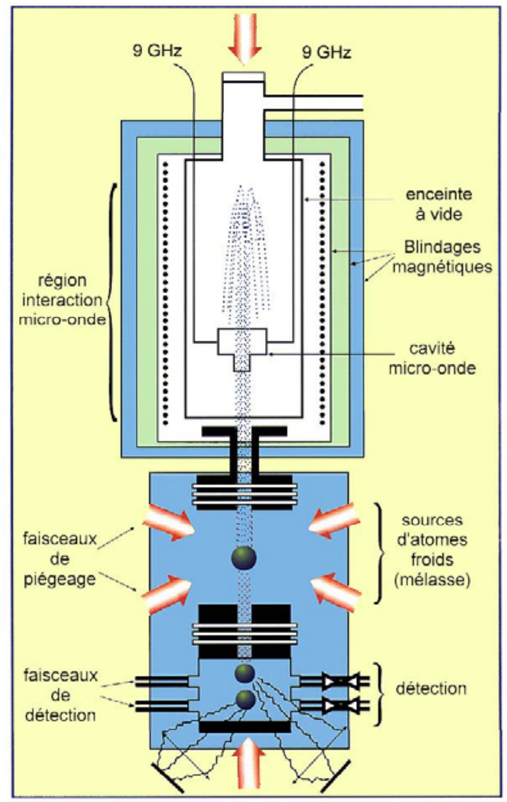
A practical realisation of the metre is usually delineated (not defined) today in labs as 1,579,800.298728(39) wavelengths of helium-neon laser light in a vacuum.

Time standard (and realization)



10^{-13} accuracy

the duration of 9,192,631,770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium 133 atom



Cs fountain clock

Classical Spectrometers

Spectral resolution

limited by the diffraction determined by total aperture
(size of prism or grating)
→ study this

Prisms:

how does the dispersion (resolution) depend on
geometry/material of prism

Grating:

study the avantages of the “Echelle grating”

Spectroscopy and Calibration

Absolute measurements (wavelength or frequency)

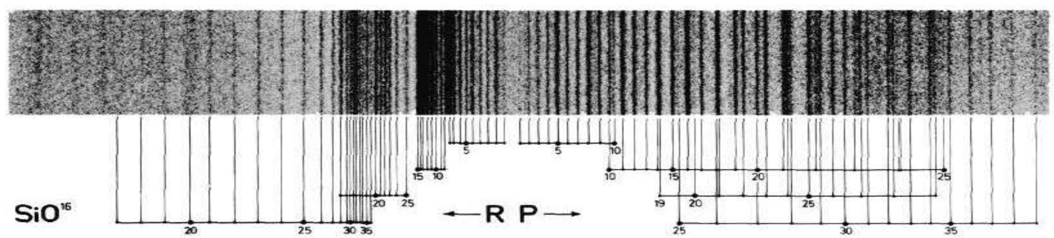
Relative measurements (line separations)

Spectral referencing (use of atlases)

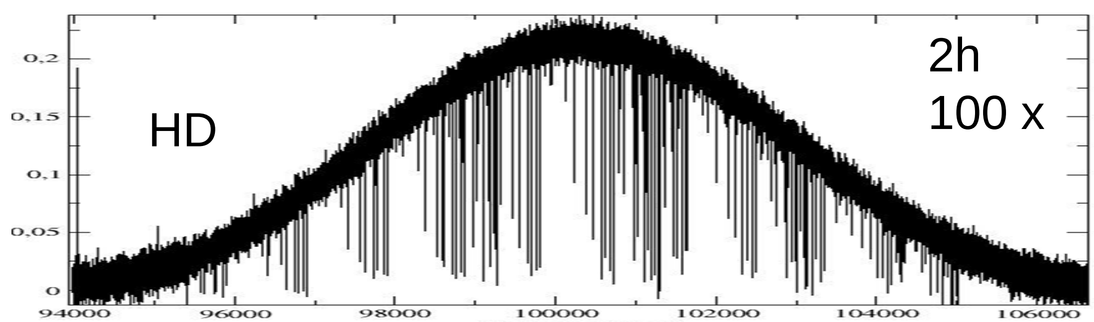
I_2, Te_2, Hollow-cathode lamps, Th-Ar

Scanning vs Multiplex spectroscopy

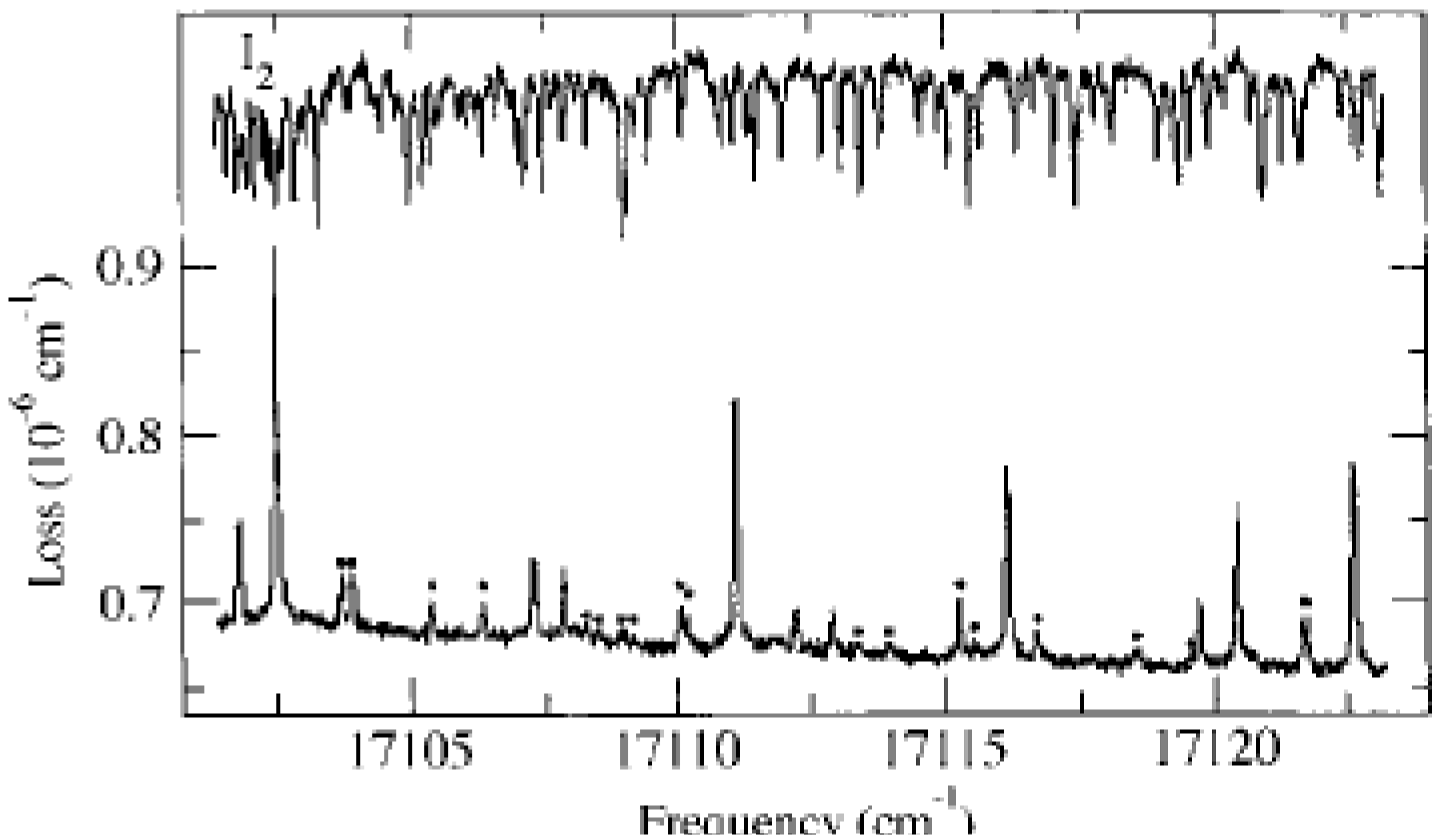
Classical emission with grating



Fourier-transform spectroscopy

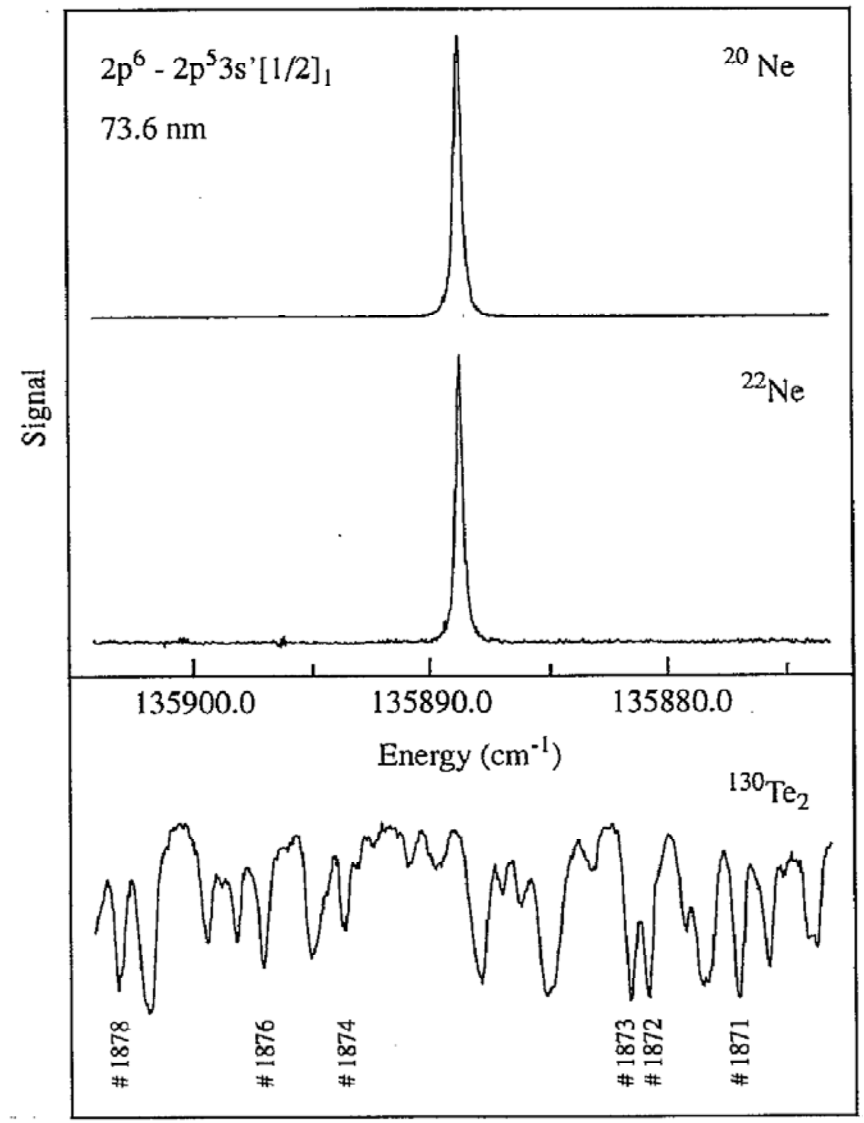


Spectral referencing in laser spectroscopy



H_2O absorption

Referencing against tellurium 130Te2

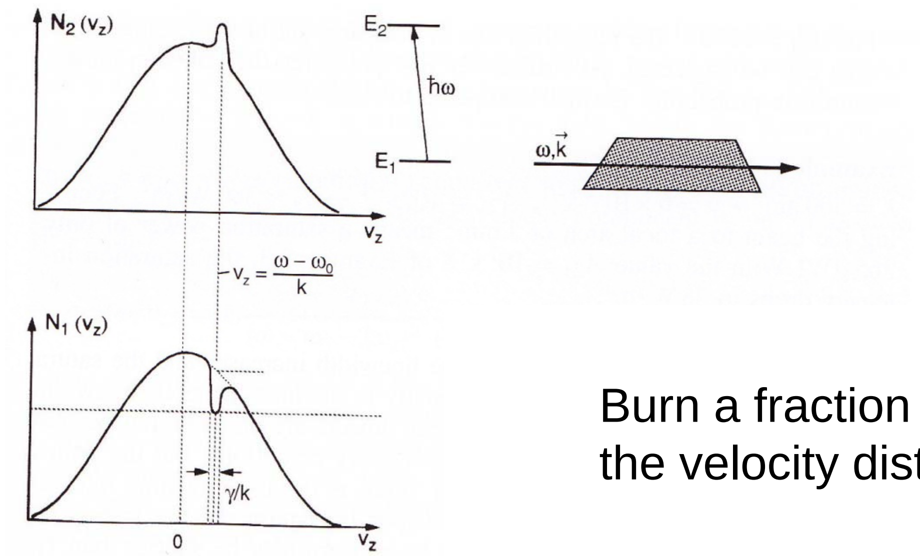


Precision Doppler Free Spectroscopy

1. Saturation spectroscopy – Lamb dips
2. Polarization spectroscopy
3. Two-photon spectroscopy
4. Molecular beam spectroscopy

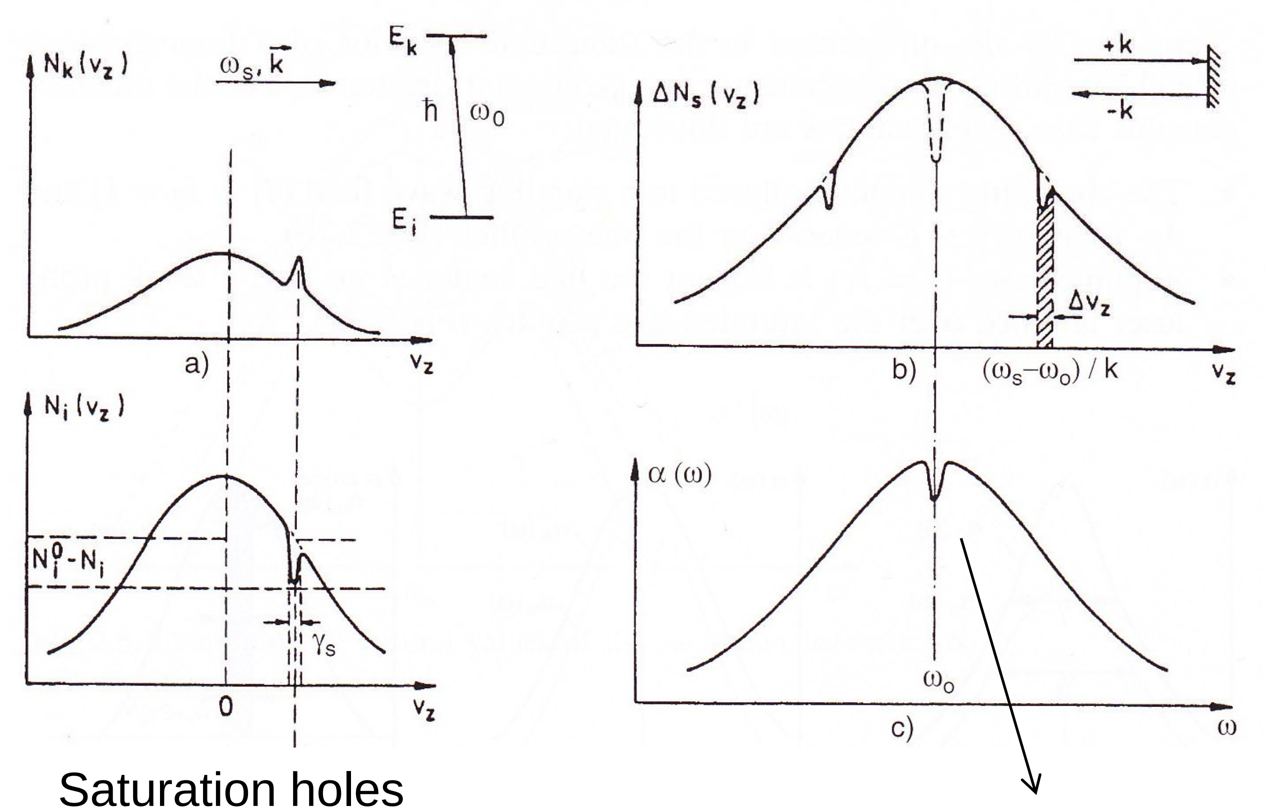
Bennet peak

Bennet hole



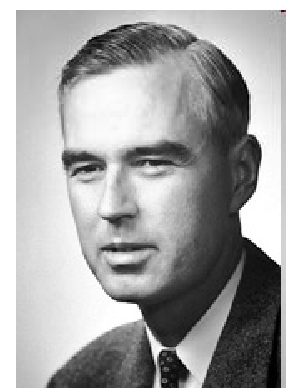
Burn a fraction out of the velocity distribution

Lamb Dips



Saturation holes

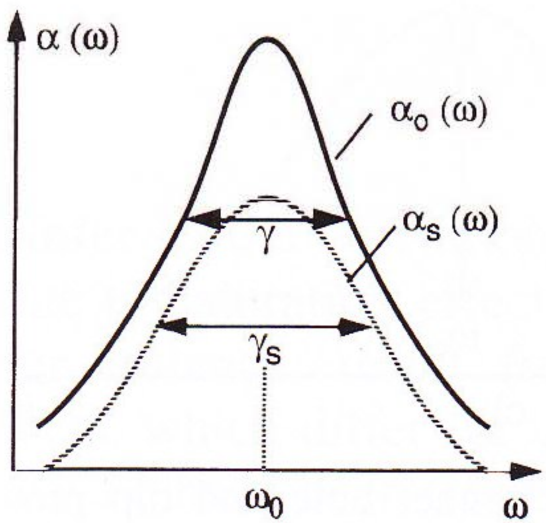
Lamb dip in scanning



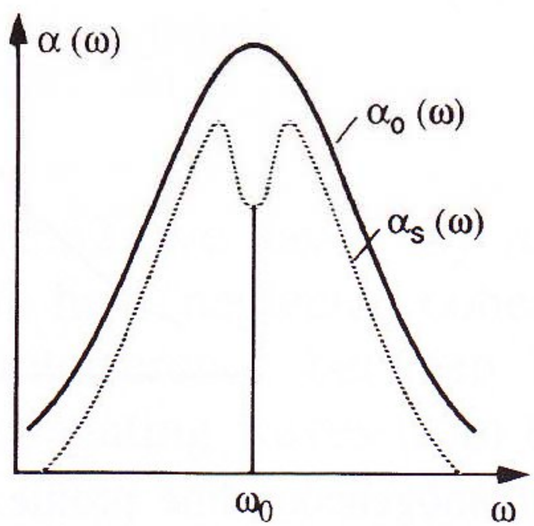
Willis E Lamb

Nobel Prize in Physics 1955

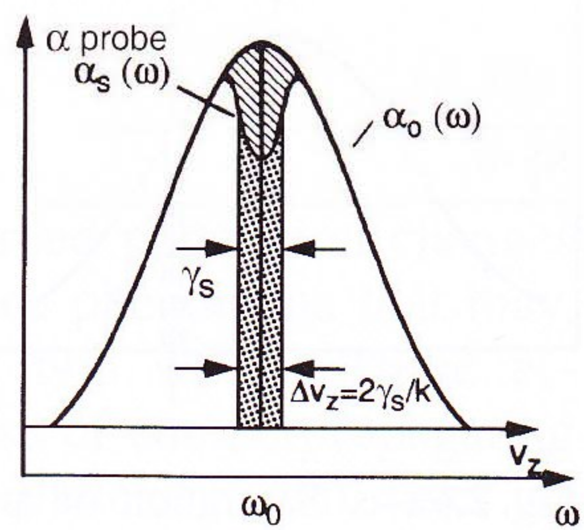
Lamb Dips



Saturation in
Homogeneous broadening



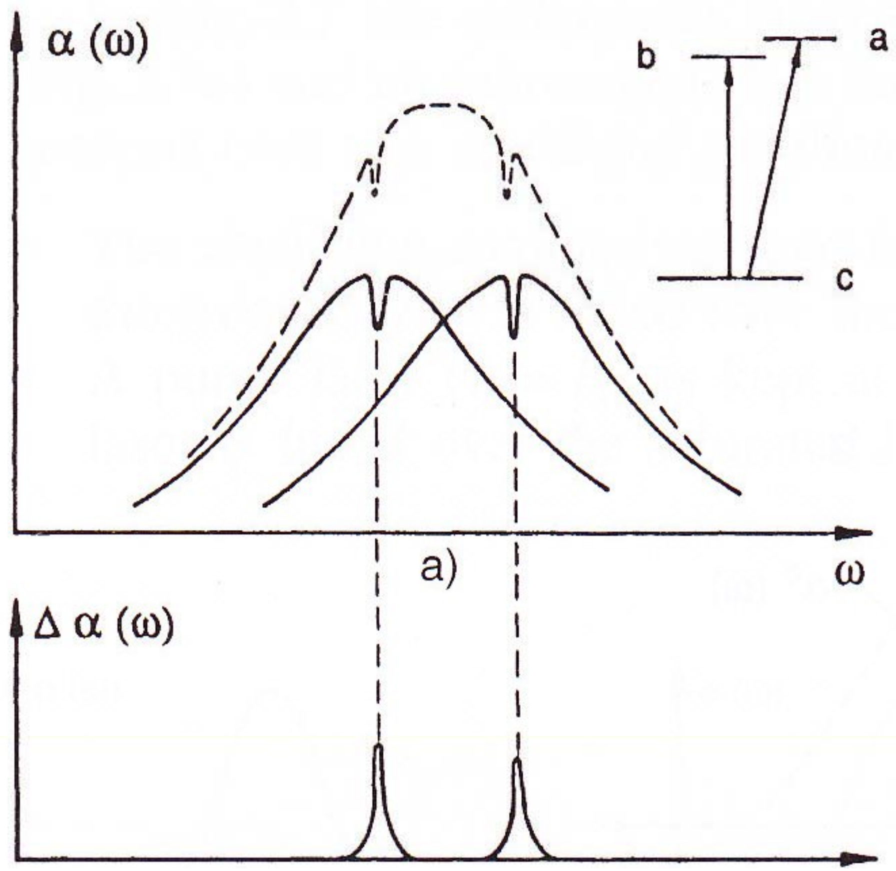
Saturation in
Heterogeneous broadening
Standing wave field



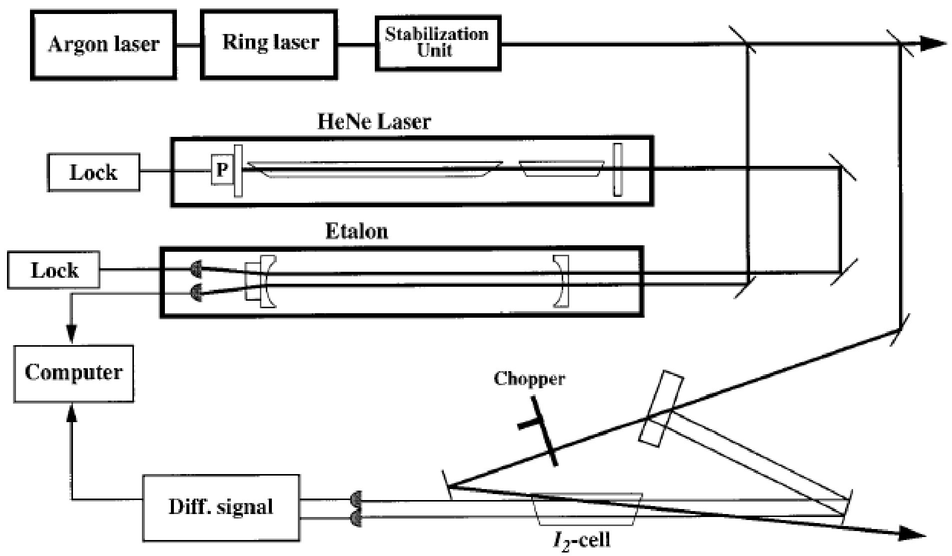
Saturation in
Heterogeneous case
Weak field
probing

Intermezzo

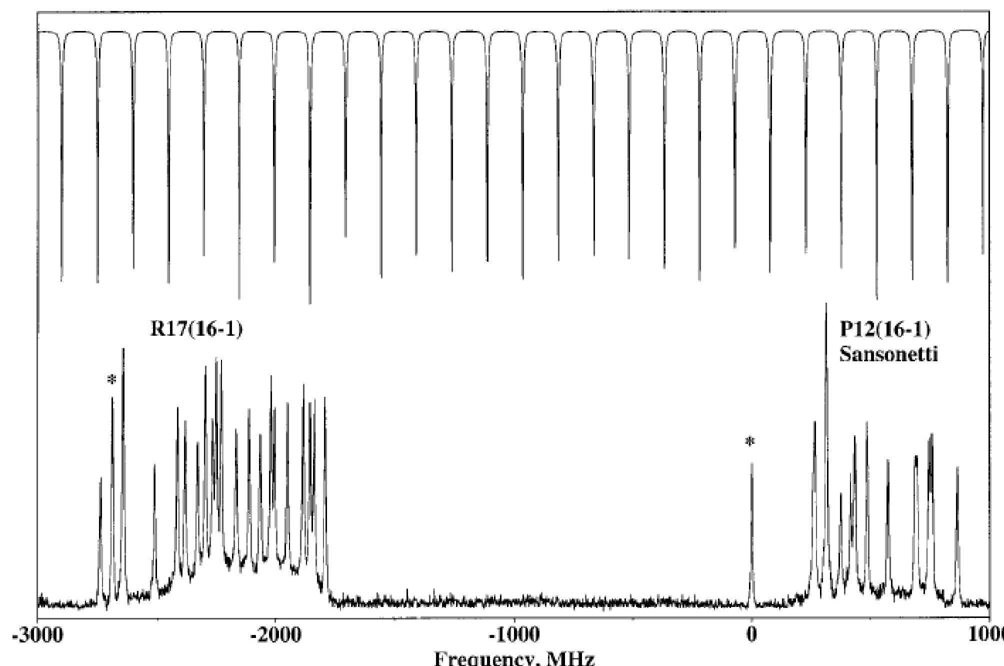
Lamb dip spectroscopy unraveling overlapping lines



Saturated absorption for referencing



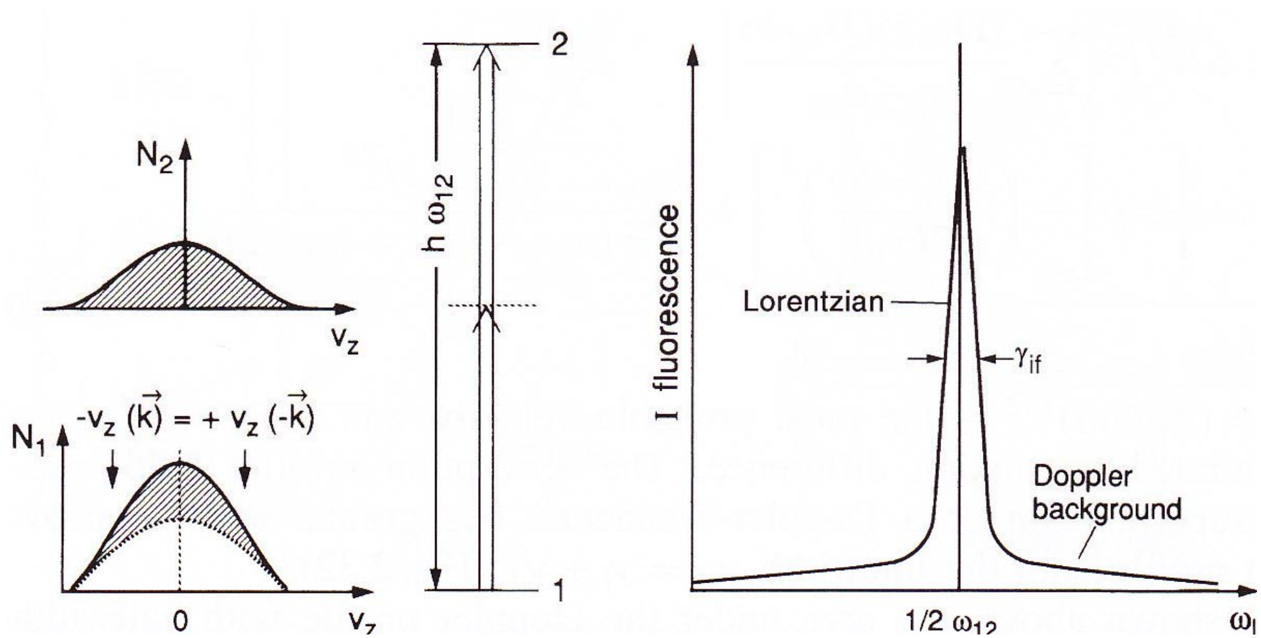
+ Phase sensitive detection
lock-in principle



Doppler-free two-photon absorption (excitation)

Doppler shift: $\omega' = \omega - \vec{k} \cdot \vec{v}$

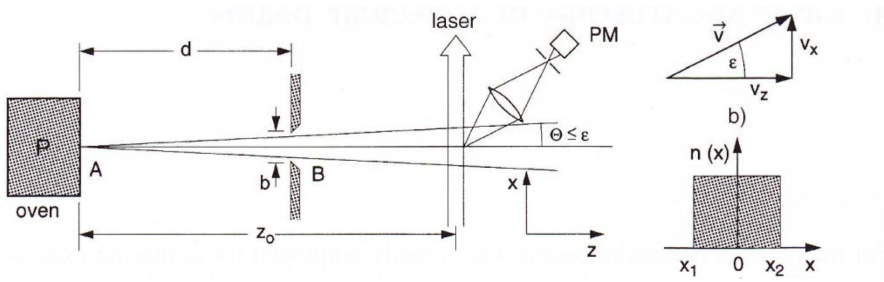
Resonance condition: $\left(E_f - E_i\right)/\hbar = \left(\omega_1' + \omega_2'\right) = \omega_1 + \omega_2 - \vec{v} \cdot \left(\vec{k}_1 + \vec{k}_2\right)$



All molecules, independent of their velocities, absorb at the sum frequency

$$\omega_1 + \omega_2 = 2\omega$$

Sub-Doppler spectroscopy in a beam

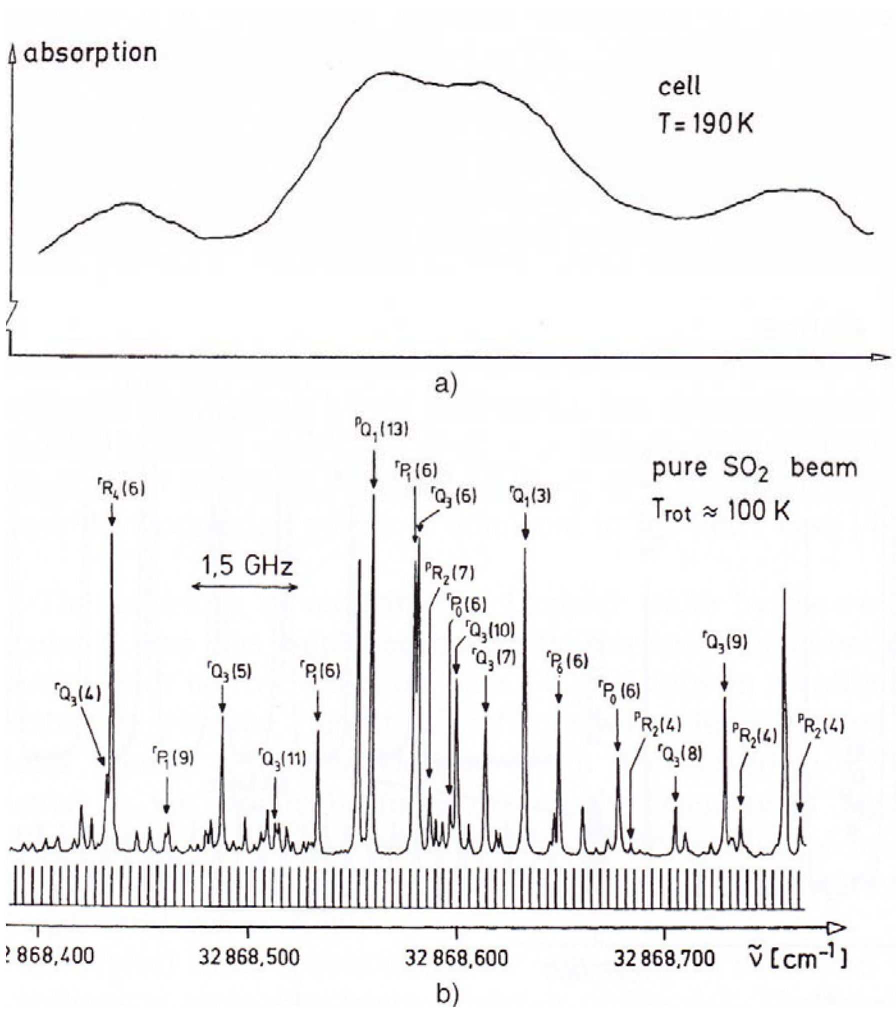


$$\omega' = \omega_0 - \vec{k} \cdot \vec{v} = \omega_0 - k v_x$$

Reduction of the Doppler width:

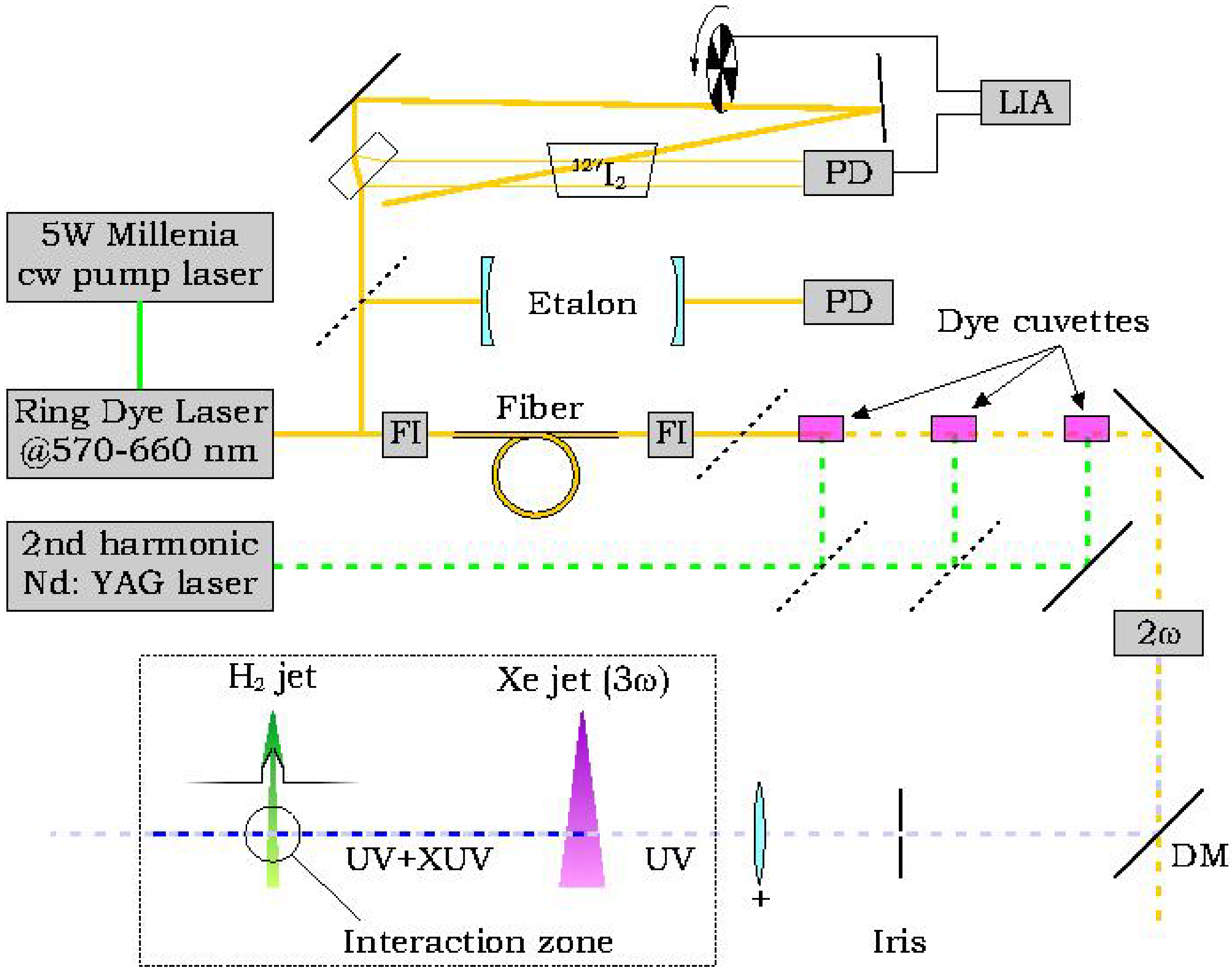
$$\Delta\omega_D' = \Delta\omega_D \sin\varepsilon \qquad \Delta\omega_D = 2\omega_0 \frac{v_p}{c}\sqrt{\ln 2}$$

Molecular beam spectroscopy;
Two-fold advantage: resolution + cooling

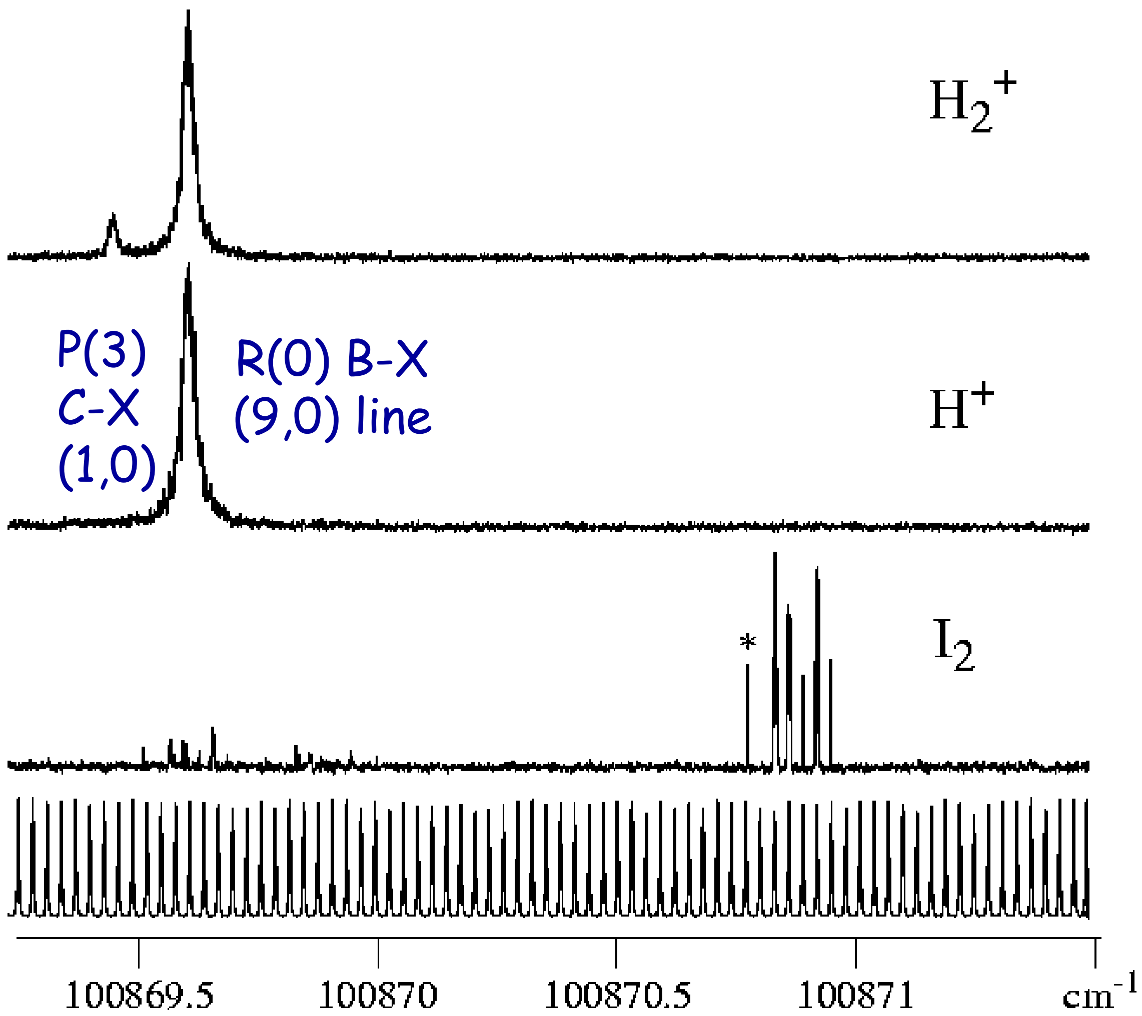


Laser-based calibration techniques

“Harmonics” + “saturation”

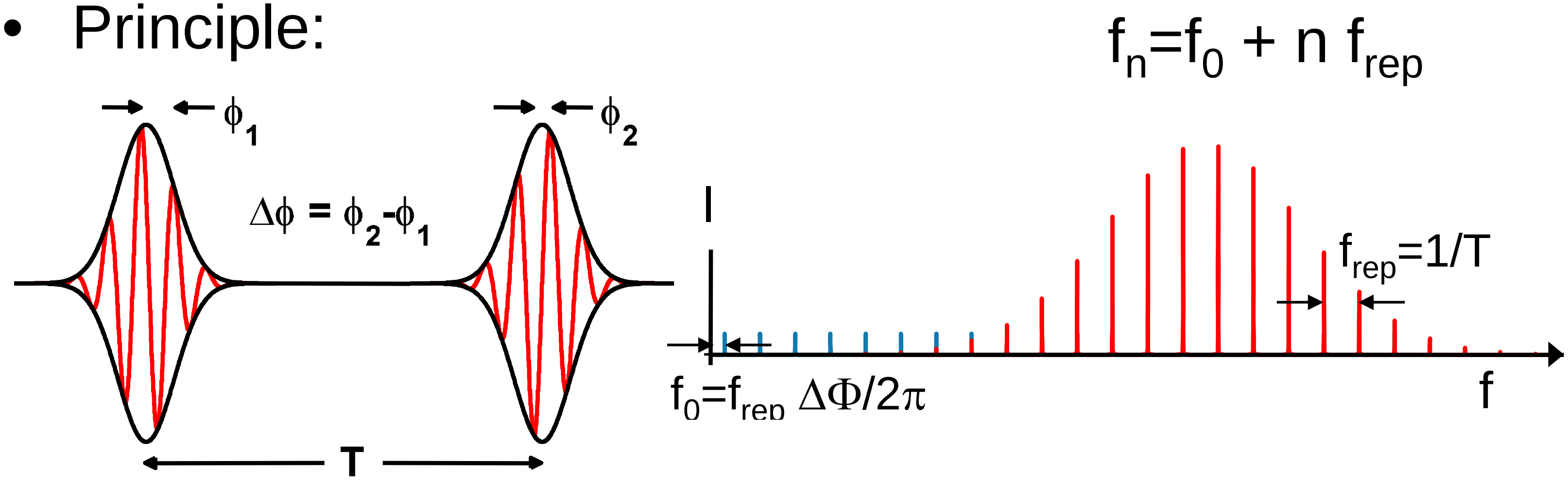


Calibration of H_2 spectral lines (in XUV)



Frequency measurements in the optical domain with a frequency comb laser

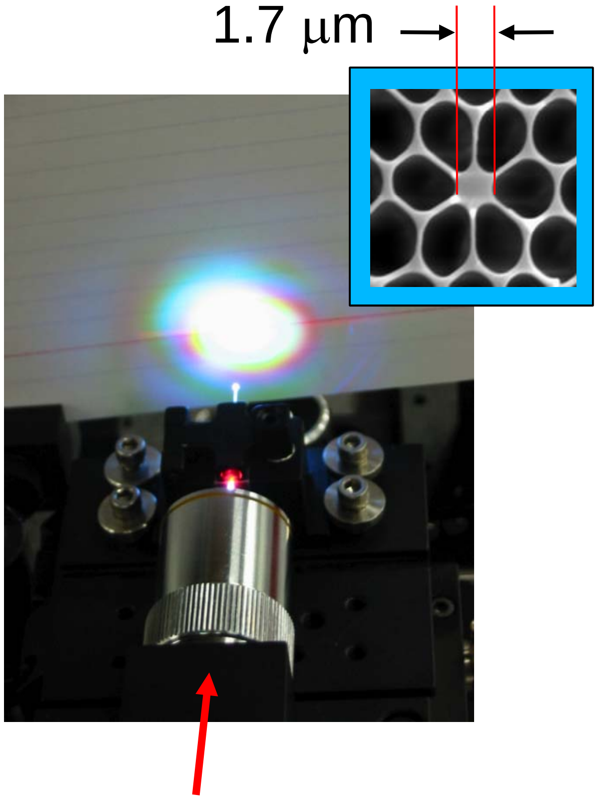
- Principle:



- Pulses in time generated by mode-locked laser
- Frequency spectrum of discrete, regularly spaced sharp lines

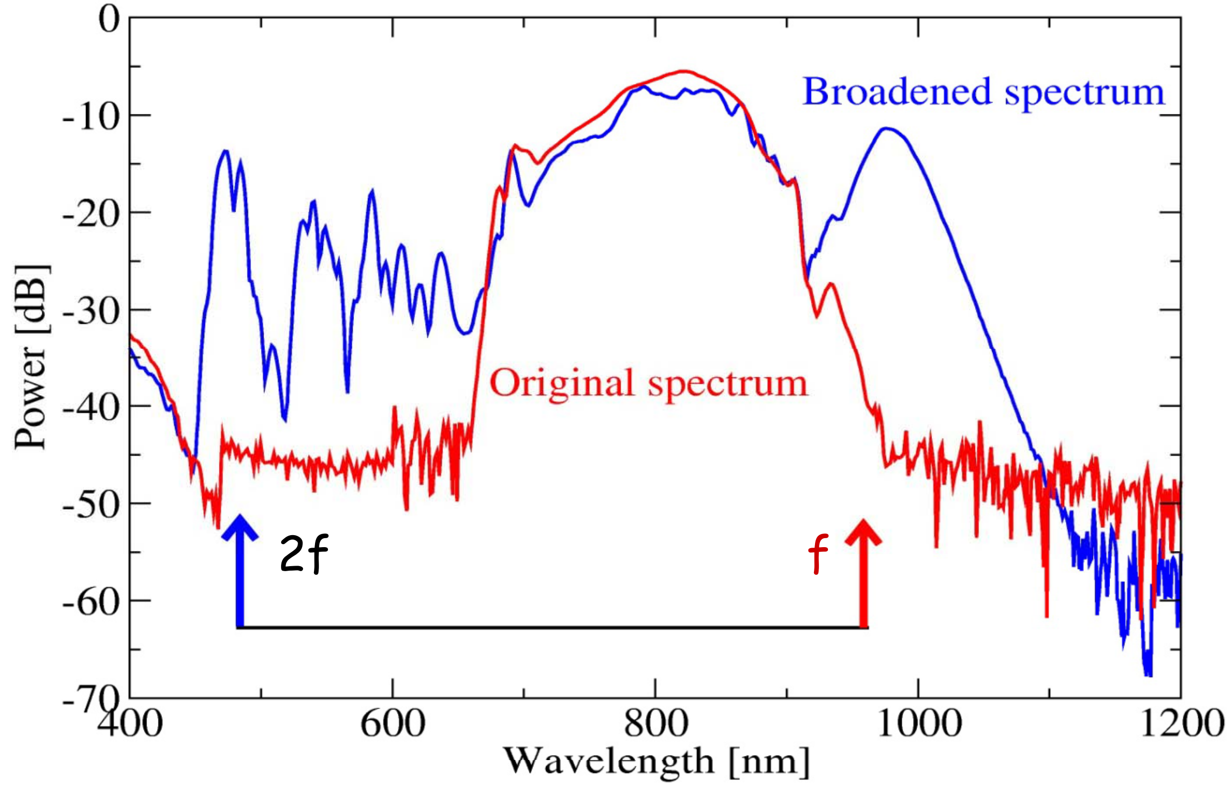
Is it a pulsed or a CW laser ?

Broadening the spectrum to “octave spanning”

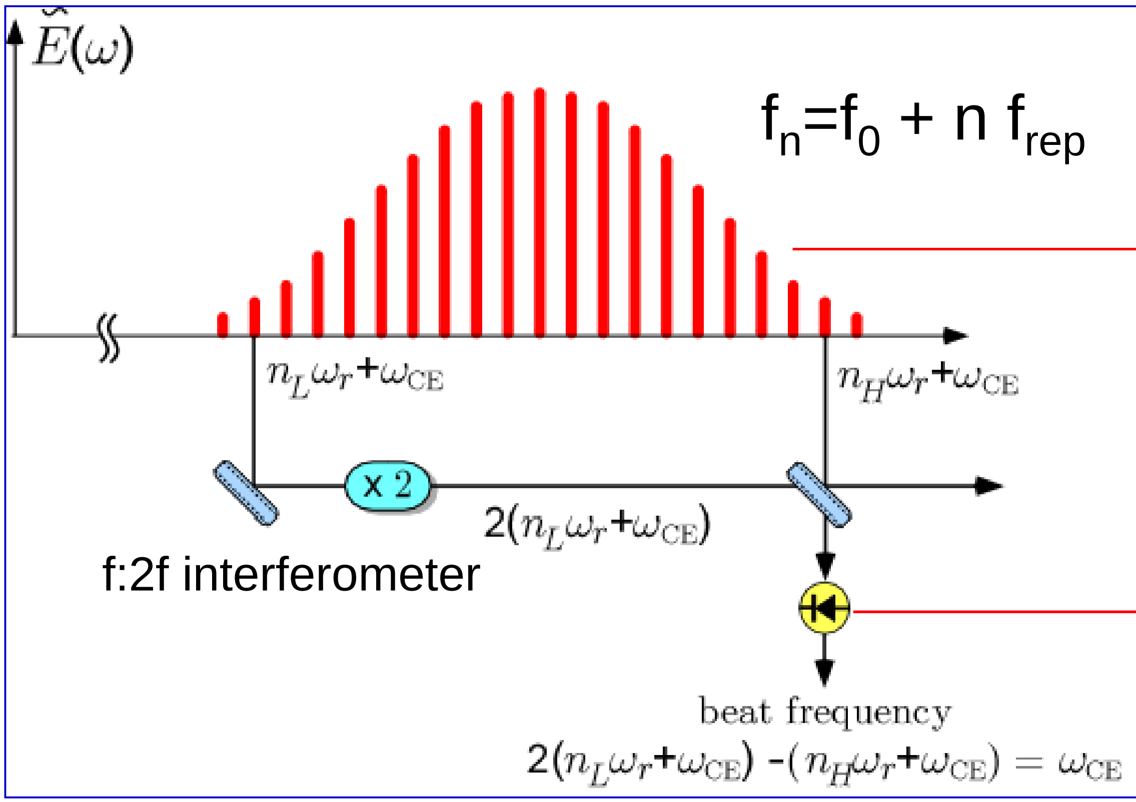


10 fs, 2 nJ in a 1.7 μm
fused silica core holey fiber

- self phase modulation
- shockwave formation
- Raman scattering, FWM ...



Frequency measurements in the optical domain



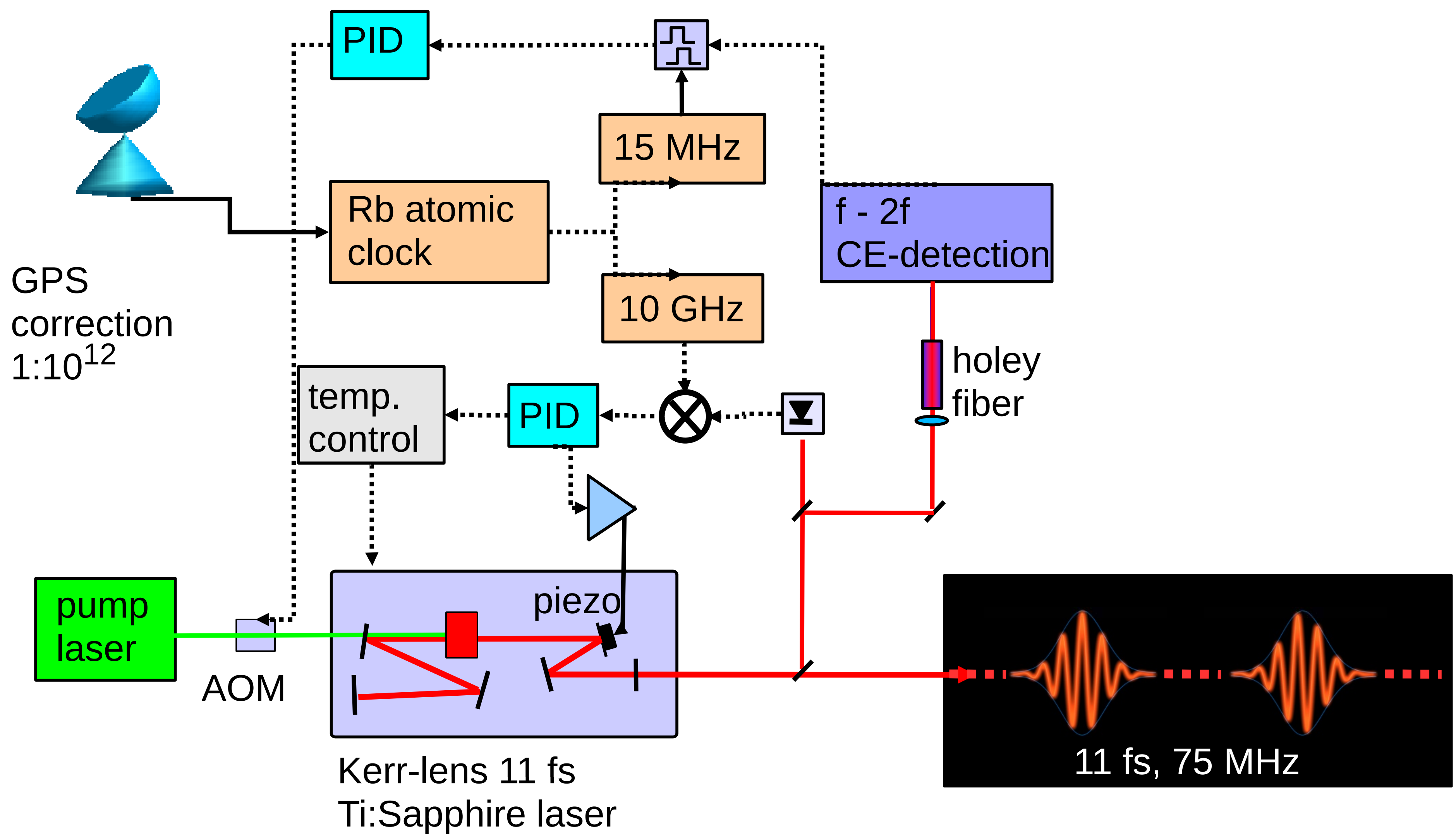
Measure ω_{rep}

Feedback

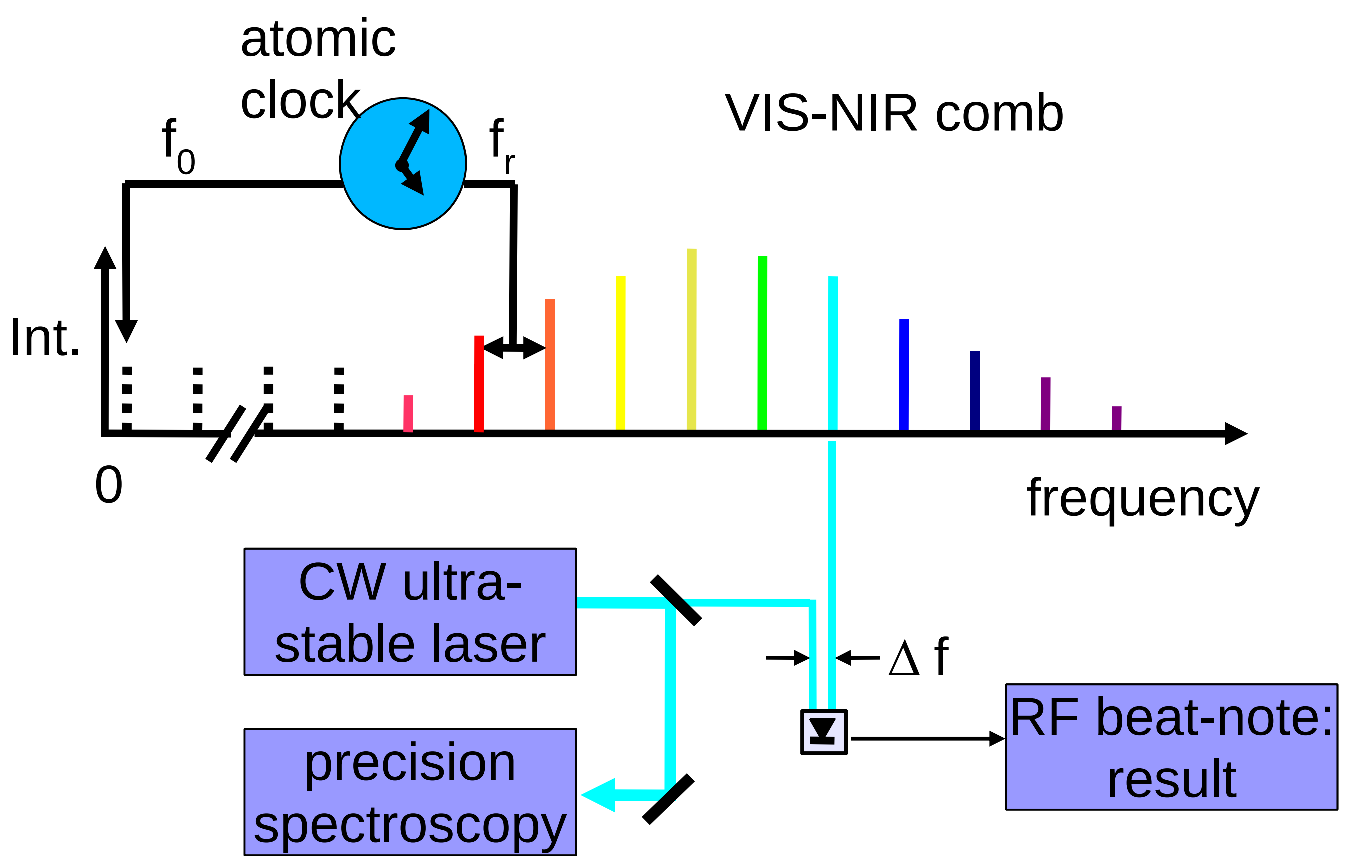
Measure ω_{ce}

Extend the spectrum to octave spanning

Feedback to stabilize the laser on RF signals



Using the FC-laser as an optical reference standard



$$f_{result} = \pm\Delta f + nf_{rep} + f_0$$