Cavity ring-down Spectroscopy

Before and after frequency combs

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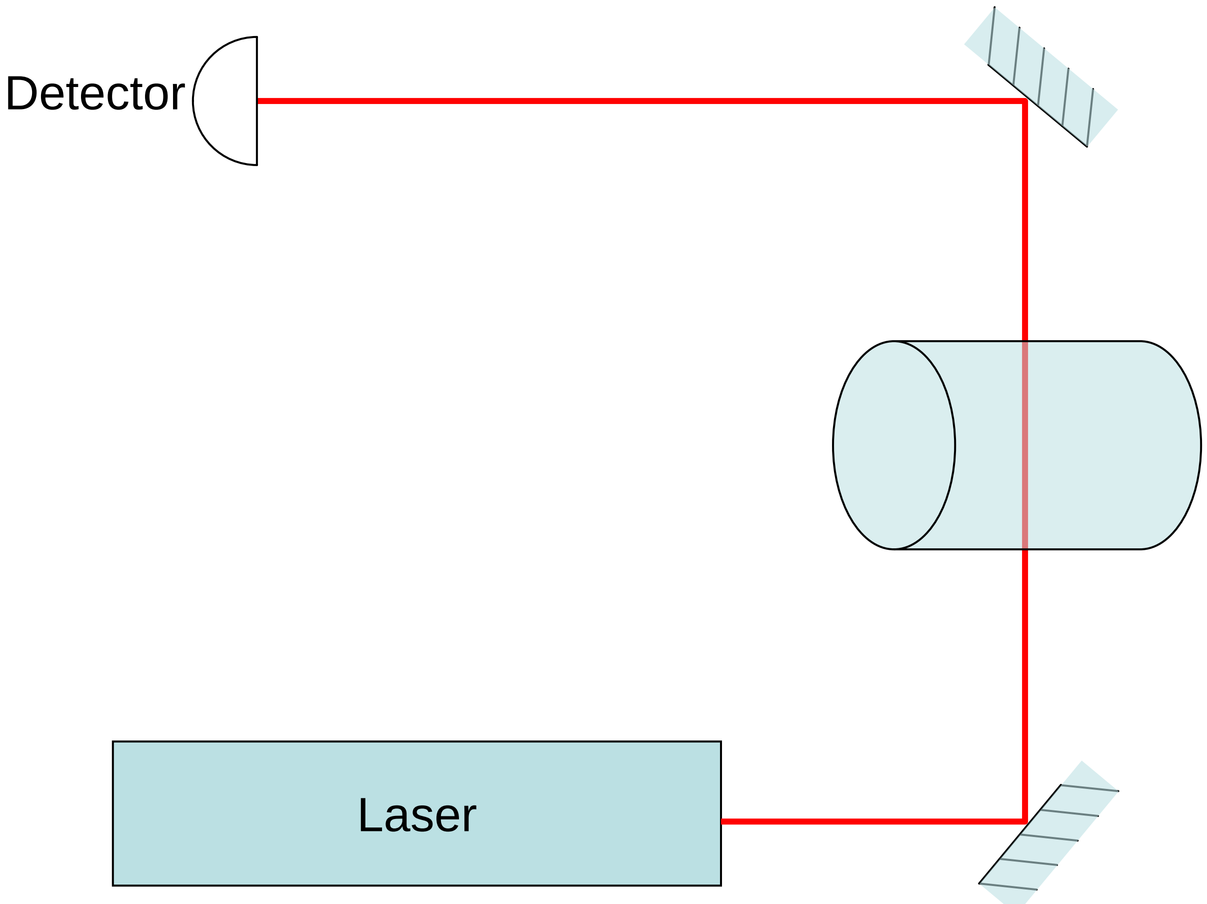
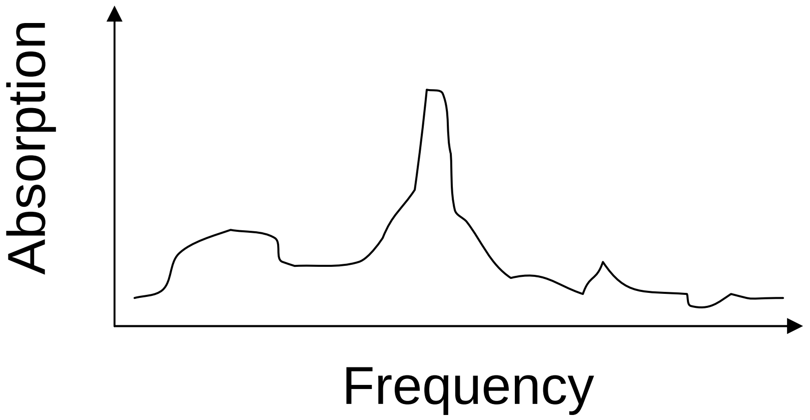
April 6, 2006

Example: Basic Absorption Spectroscopy



Absorption Spectroscopy

Want to know:



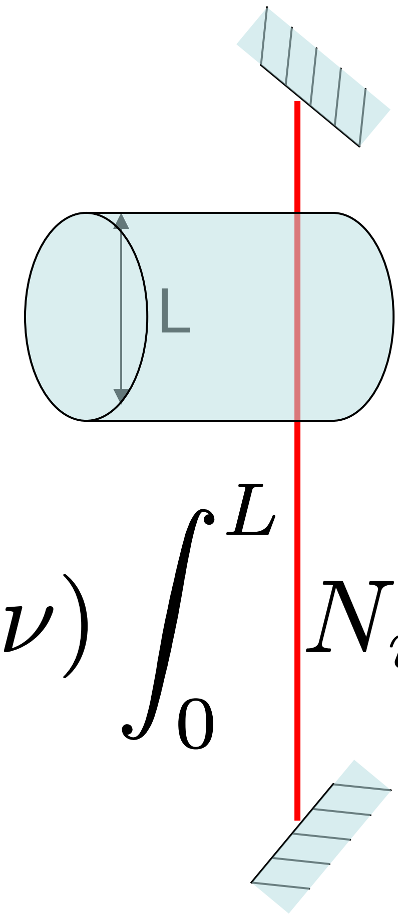
Gives information about what and how much

Other possible methods

- Photothermal Spectroscopy
- Florescence spectroscopy
- Polarization Spectroscopy
- Ionization Spectroscopy

How much light is absorbed?

Beer's Law:
Absorption $e^{-\alpha L}$



$$\alpha(\nu)L = \sum_i \sigma_i(\nu) \int_0^L N_i(x)\ dx$$

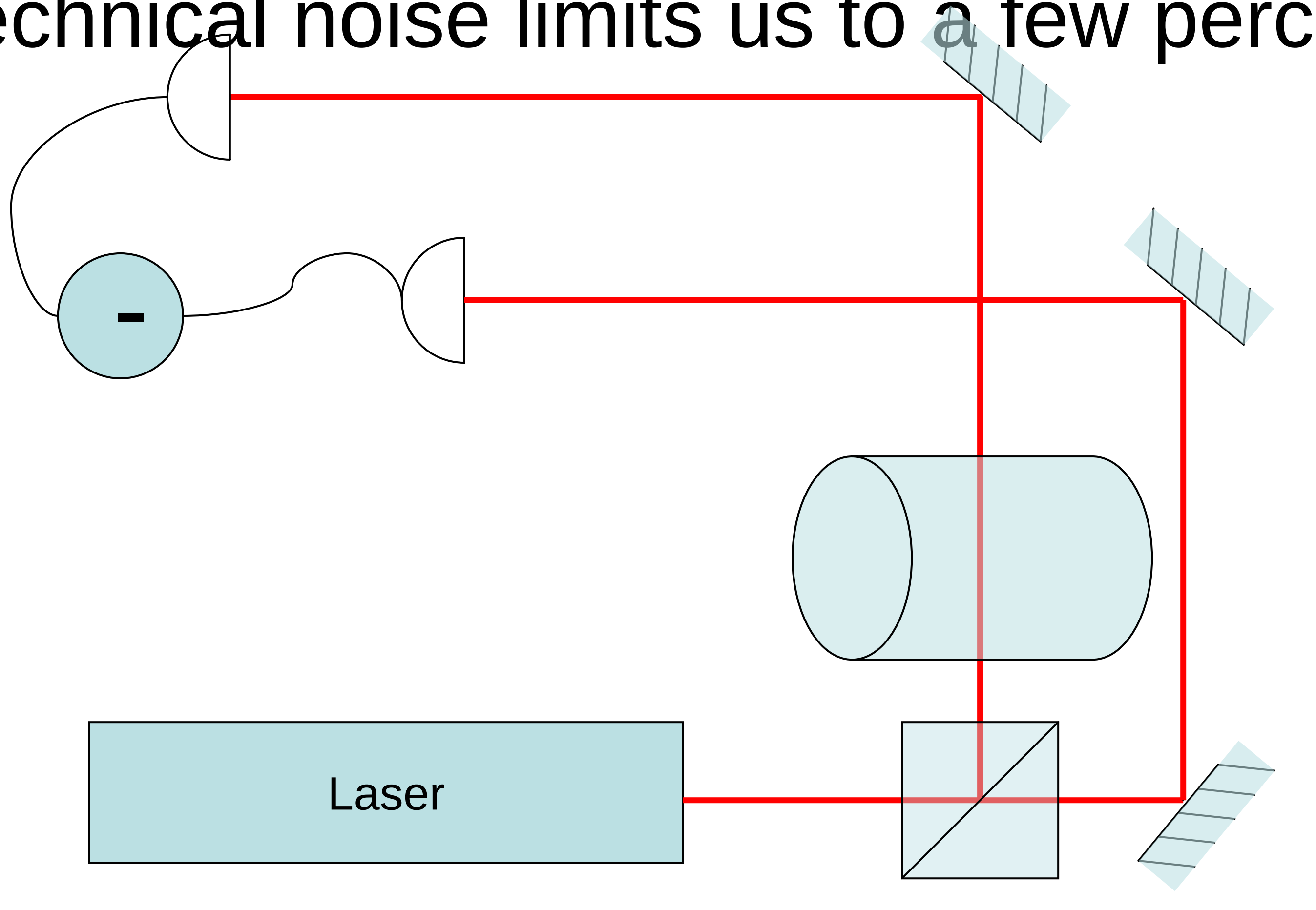
How small of an absorption can we resolve?

- Technical limitations: Laser noise, detector noise..
- Fundamental limitations: Shot-noise

$$\alpha L_{\min} = \sqrt{\frac{2eB}{\acute{}\; P_0}} \sim 10^{-8}$$

How small of an absorption can we resolve?

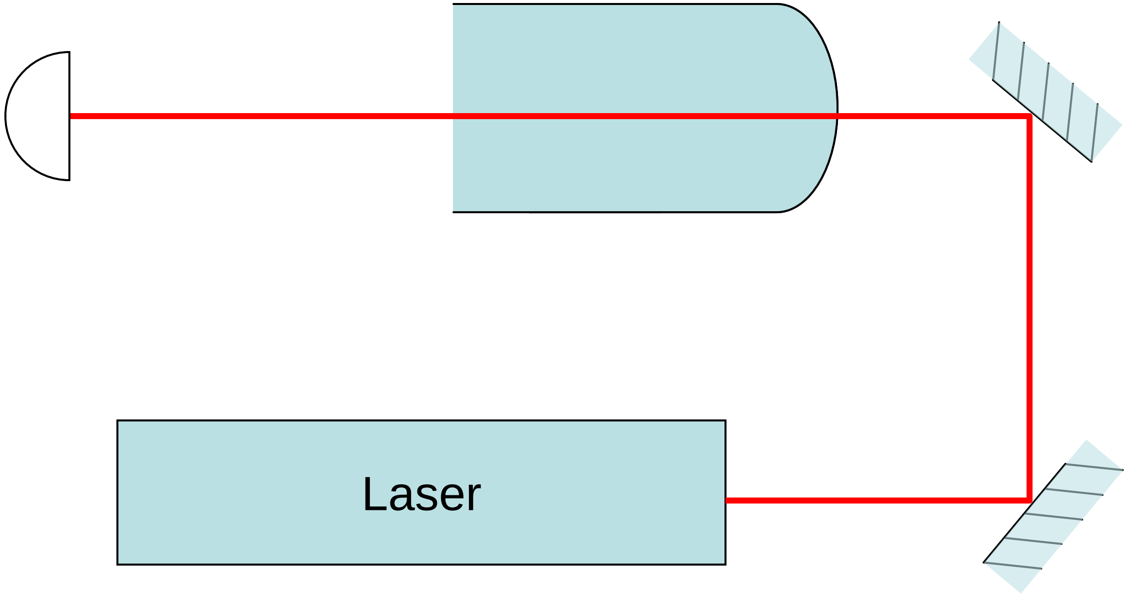
- Technical noise limits us to a few percent



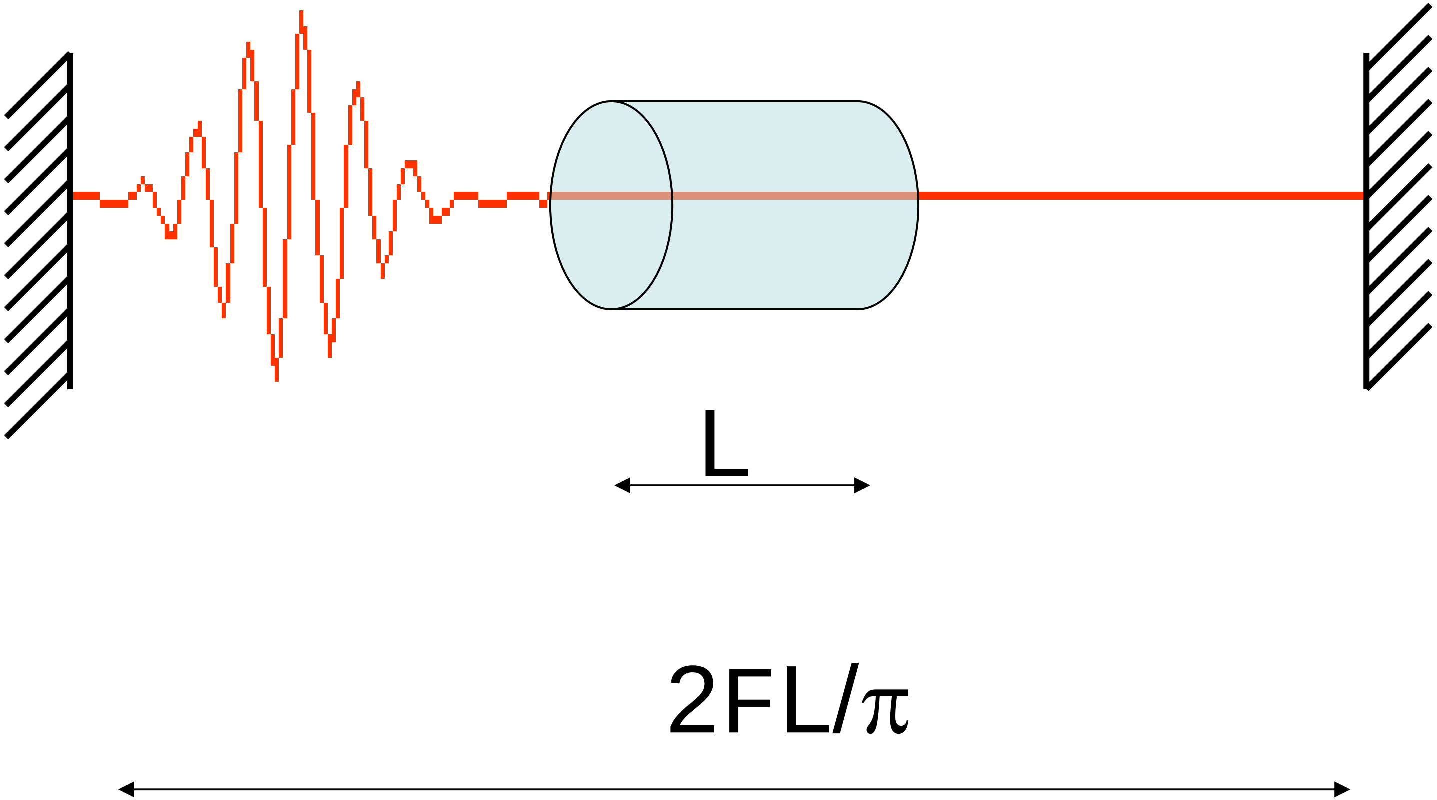
Another option:

- Increase the path length:

Absorption $e^{-\alpha L}$

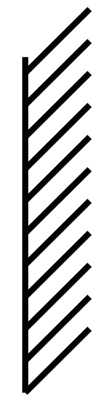


Cavity enhanced path length



Cavities in general

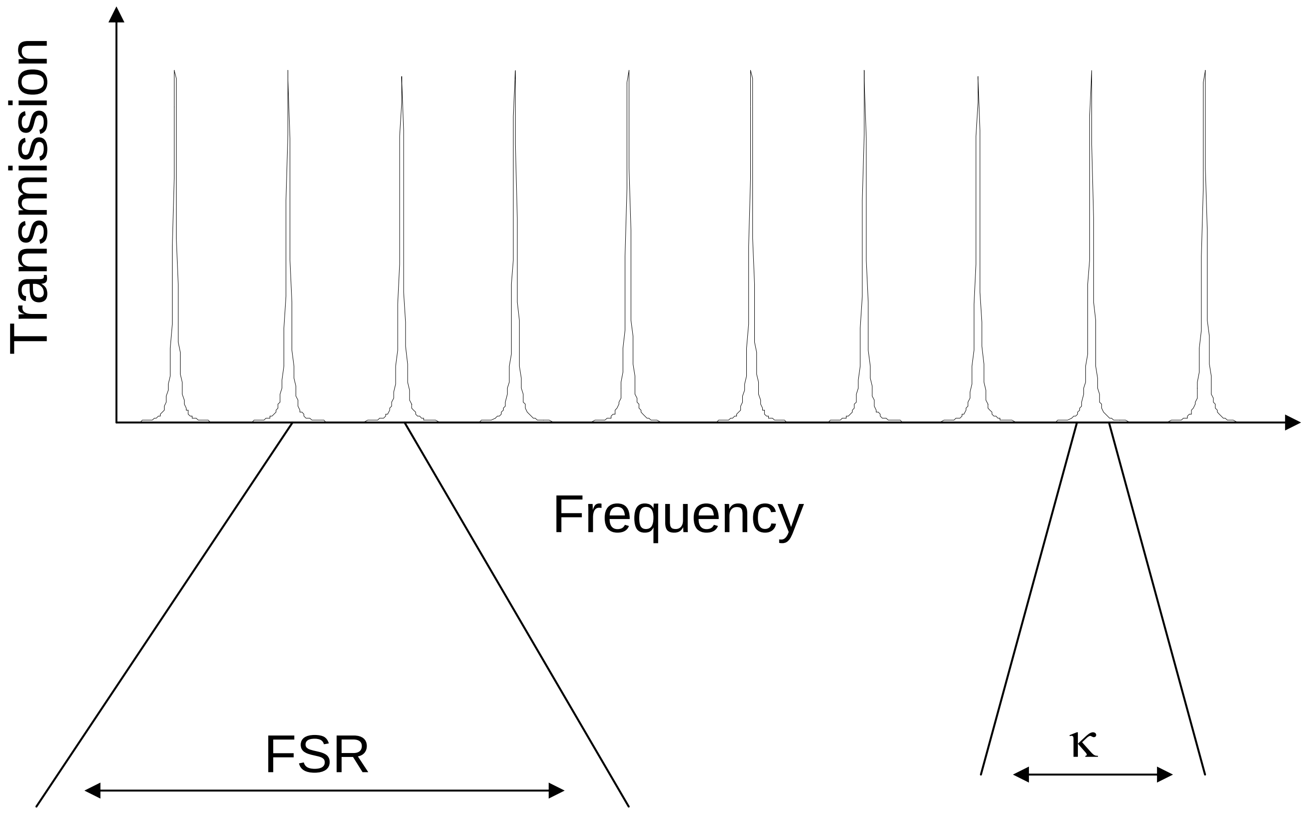
- Cavity length L
  - FSR = c/2L



- Mirrors have Losses: not perfect reflectors, scattering losses

$$F = 2\pi/\text{Losses}$$

Cavity Spectrum



$$F = FSR/\kappa$$

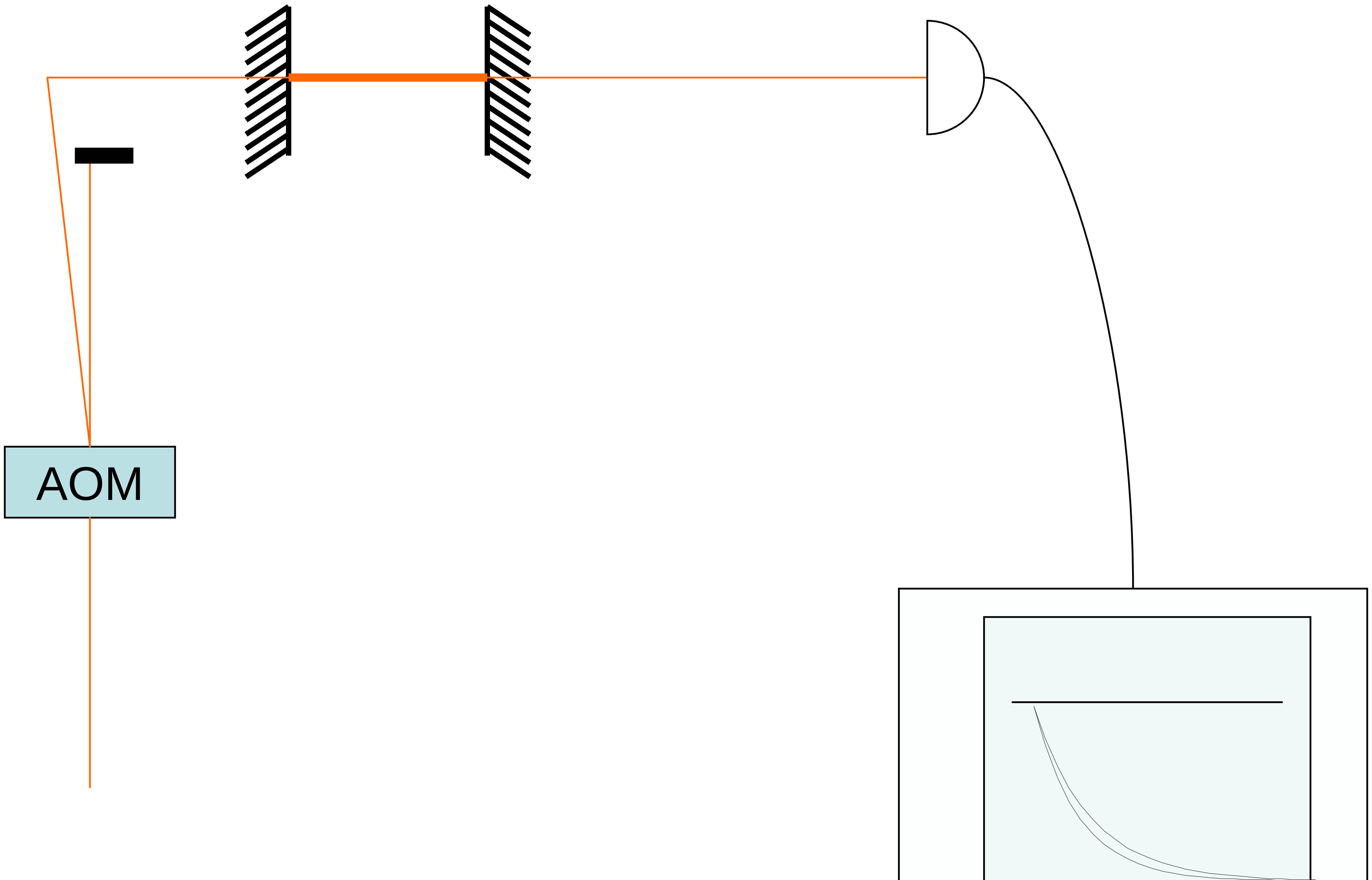
Cavity Ringdown

$\tau=1/\kappa$ κ depends on losses from mirrors

Include other losses such as absorption

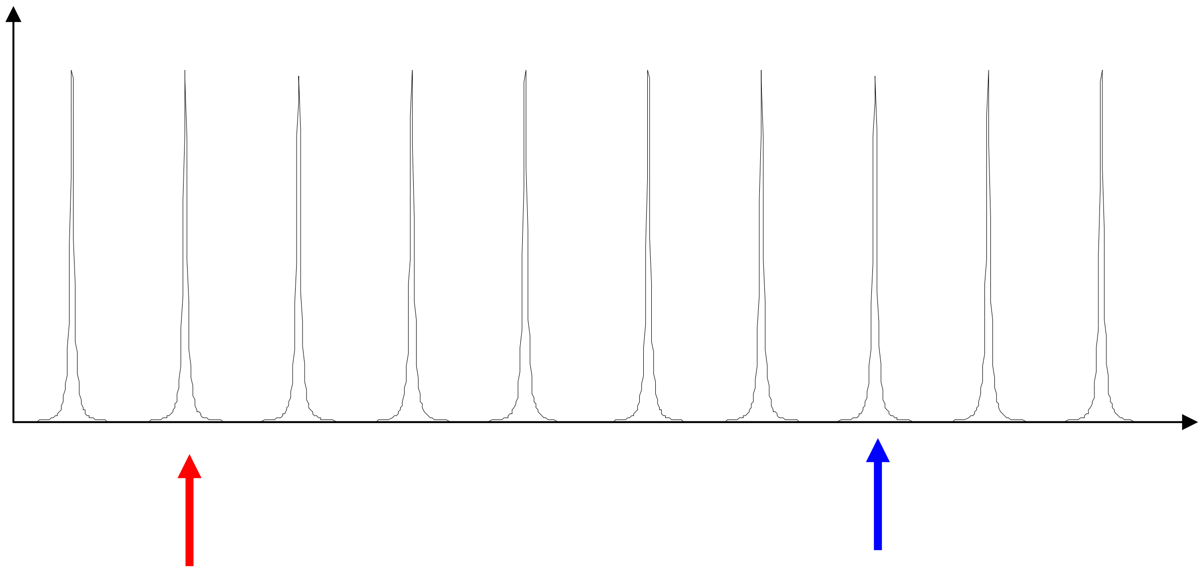
$$\tau = \frac{2\pi}{FSR(L_{\mathrm{mirror}} + \alpha)}$$

Cavity Ringdown



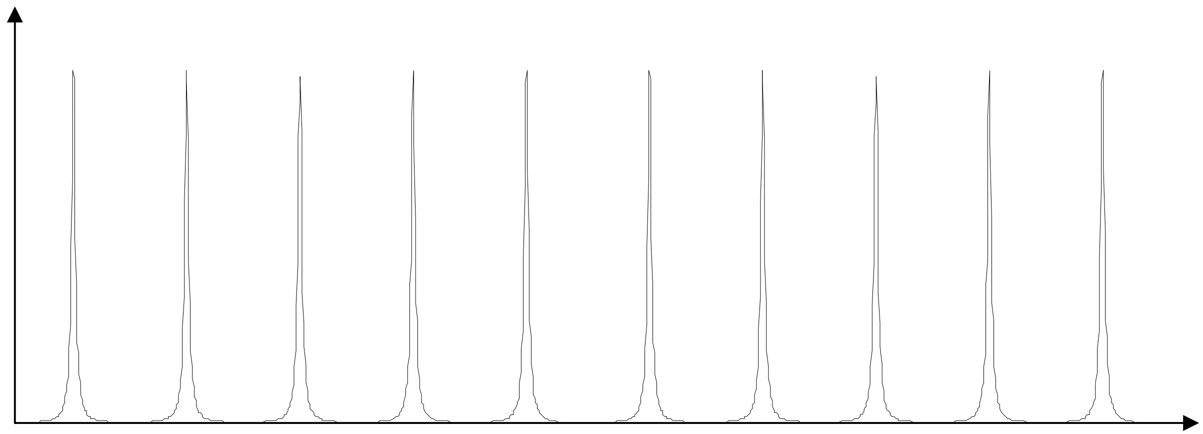
Cavity Ringdown Spectroscopy

- Fast measurement
- high sensitivity to small absorptions
- Limited to probing one frequency at a time

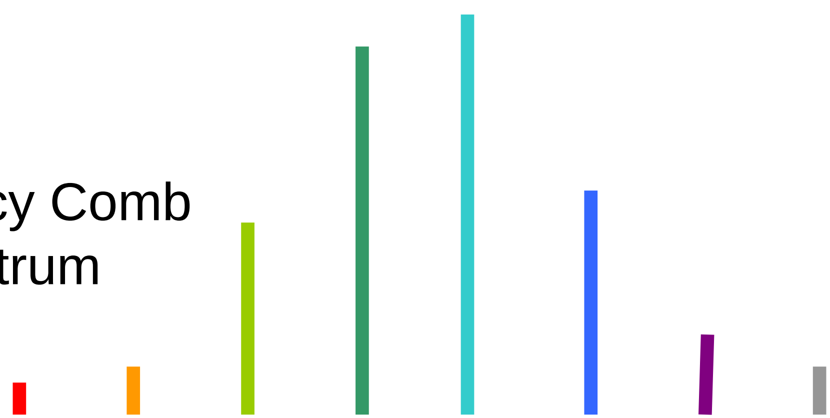


A natural idea

Cavity Spectrum

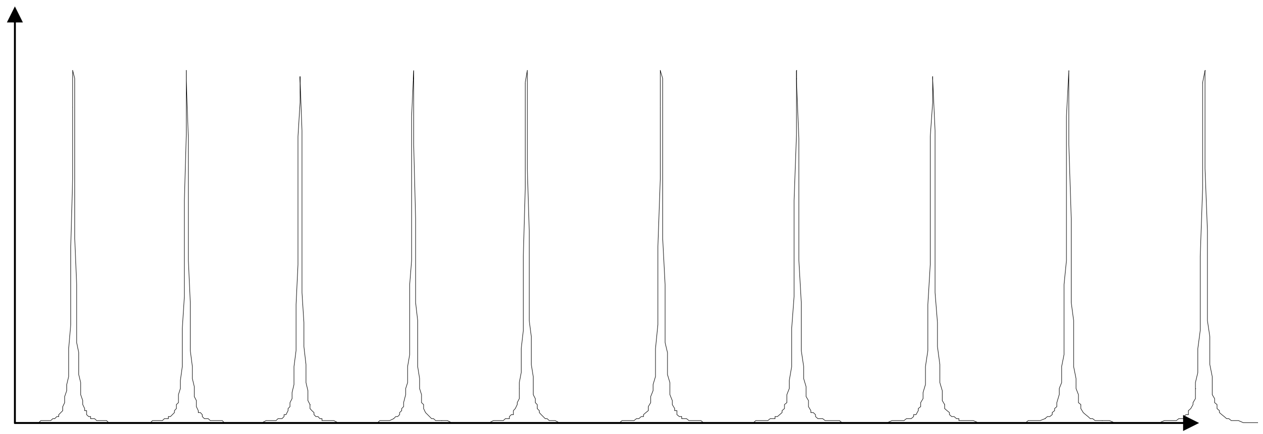


Frequency Comb Spectrum

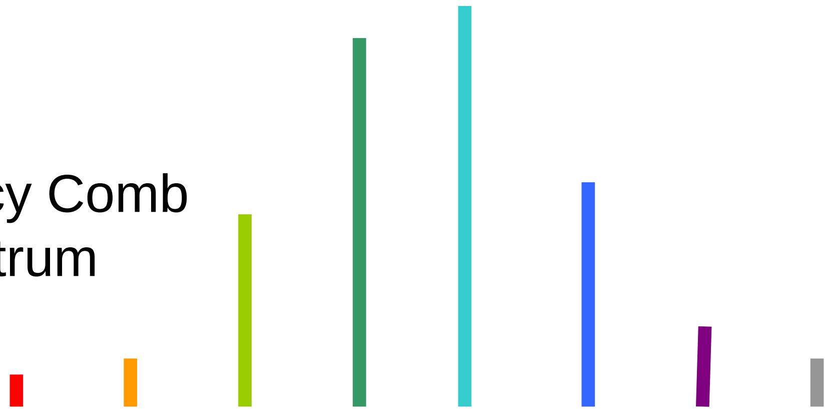


The real world

Cavity Spectrum



Frequency Comb Spectrum



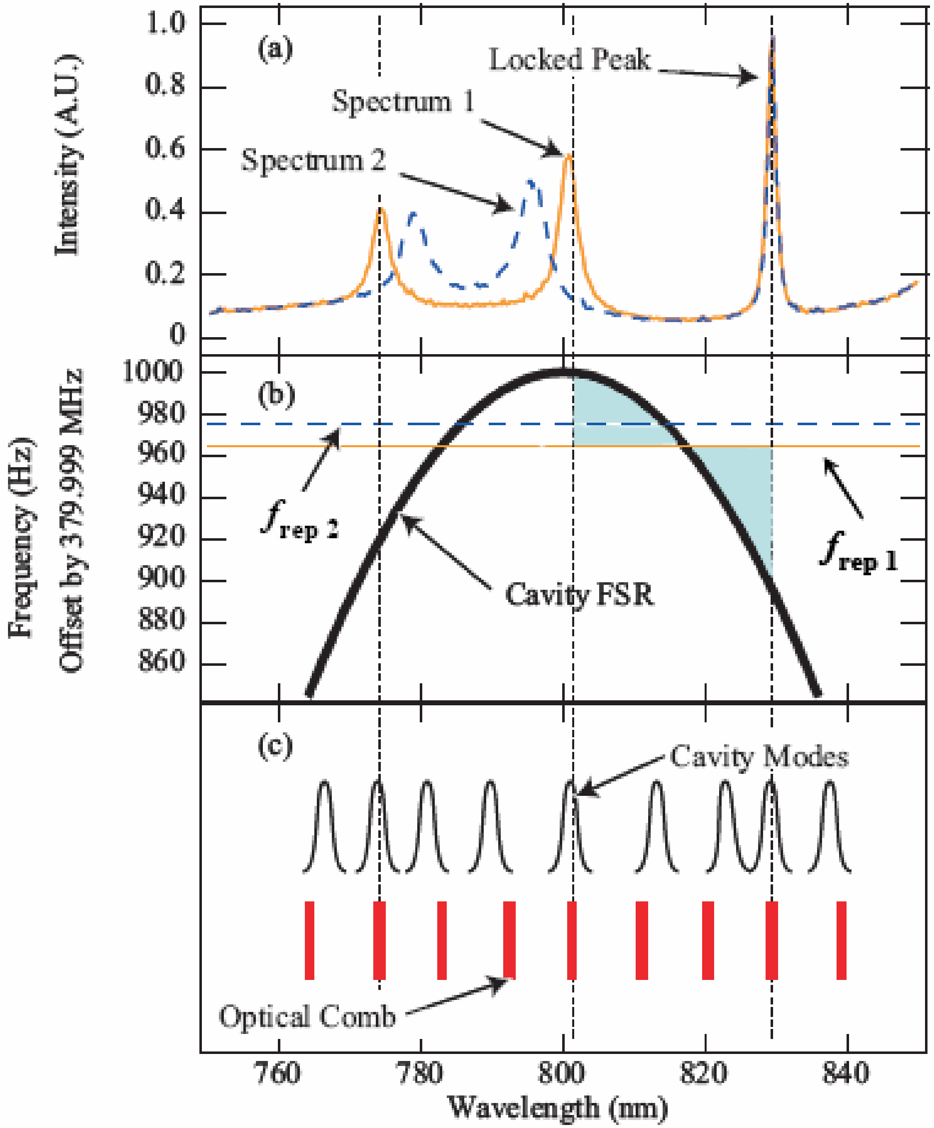
Group Delay Dispersion

$$k(\omega) = k_0 + \frac{\partial k}{\partial \omega}(\omega - \omega_0) + 1/2\frac{\partial^2 k}{\partial \omega^2}(\omega - \omega_0)^2 + ...$$

Inverse Group Velocity

Second Order Dispersion
Group delay dispersion

Measuring Cavity Dispersion



Need to compensate for dispersion of gas under interrogation with variable negative dispersion mirrors

"Highly sensitive, massively parallel, broad-bandwidth, real-time spectroscopy"

- Detection over 100 nm
- single shot absorption sensitivity of 2.5×10^{-5} over 1.4ms
- 1×10^{-8} in 1second
- 3 μs time resolution
- 25 Ghz resolution

Broadband Cavity Ringdown Spectroscopy for Sensitive and Rapid Molecular Detection

Michael J. Thorpe, Kevin D. Moll, R. Jason Jones, Benjamin Safdi, Jun Ye*

We demonstrate highly efficient cavity ringdown spectroscopy in which a broad-bandwidth optical frequency comb is coherently coupled to a high-finesse optical cavity that acts as the sample chamber. 125,000 optical comb components, each coupled into a specific longitudinal cavity mode, undergo ringdown decays when the cavity input is shut off. Sensitive intracavity absorption information is simultaneously available across 100 nanometers in the visible and near-infrared spectral regions. Real-time, quantitative measurements were made of the trace presence, the transition strengths and linewidths, and the population redistributions due to collisions and the temperature changes for molecules such as C_2H_2, O_2, H_2O, and NH_3.

The real-time detection of trace amounts of molecular species is needed for applications that range from detection of explosives or biologically hazardous materials to analysis of a patient's breath to monitor diseases such as renal failure (*1*) and cystic fibrosis (*2*). Spectroscopic systems capable of making the next generation of atomic and molecular measurements will require the following: (i) a large spectral bandwidth, allowing for the observation of the global energy level structure of many different atomic and molecular species; (ii) high spectral resolution for the identification and quantitative analysis of individual spectral features; (iii) high sensitivity for the detection of trace amounts of atoms or molecules and for the recovery of weak spectral features; and (iv) a fast spectral acquisition time, which takes advantage of high sensitivity, for the study of dynamics.

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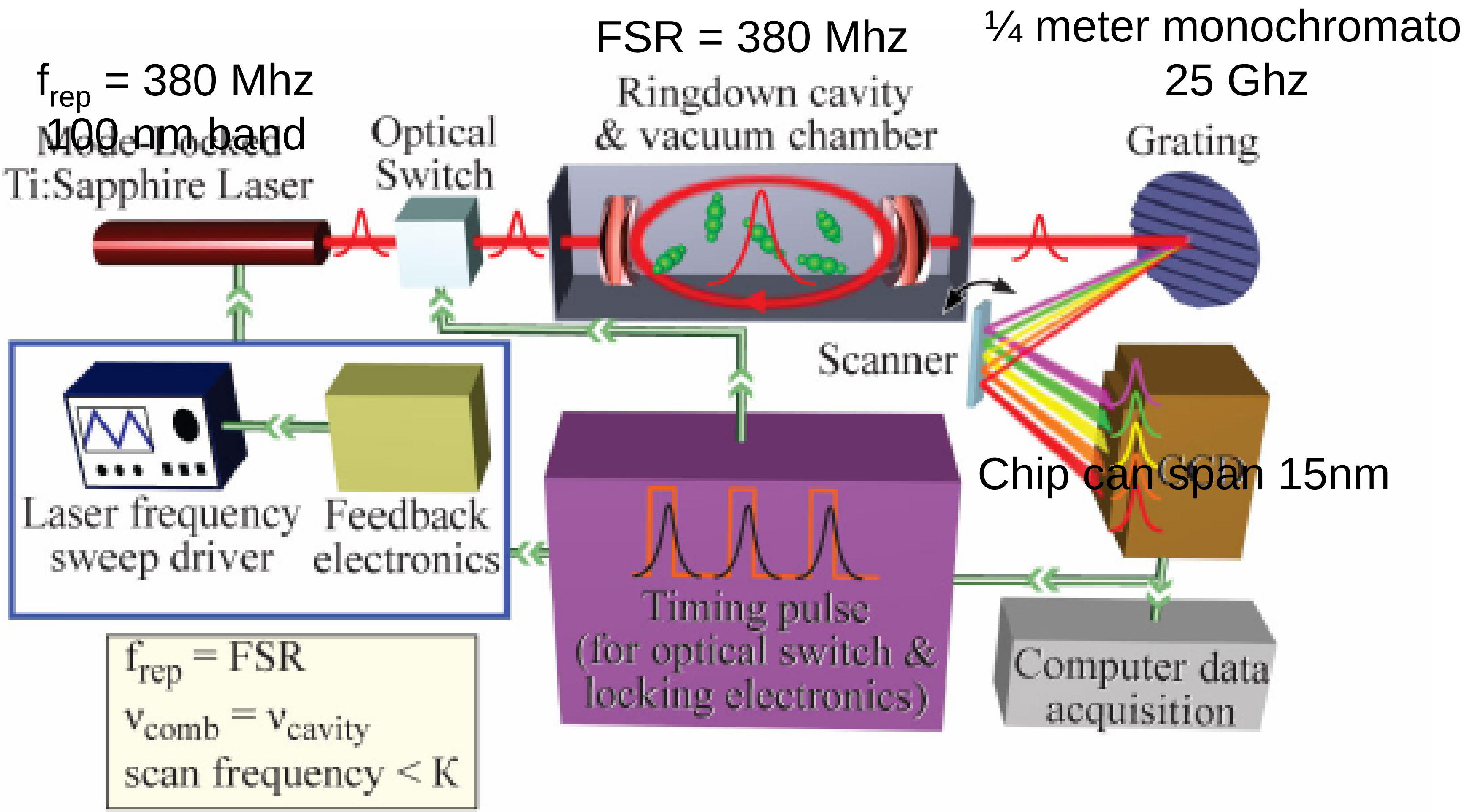
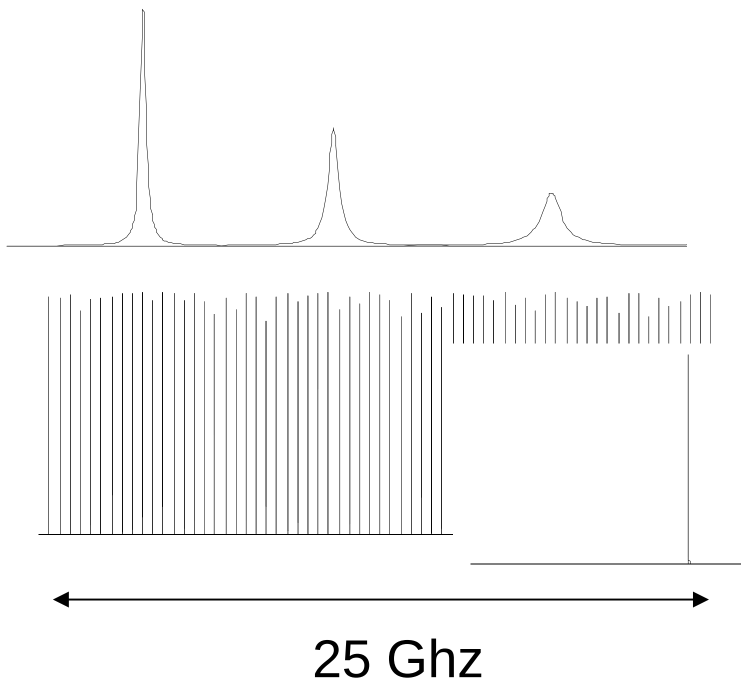
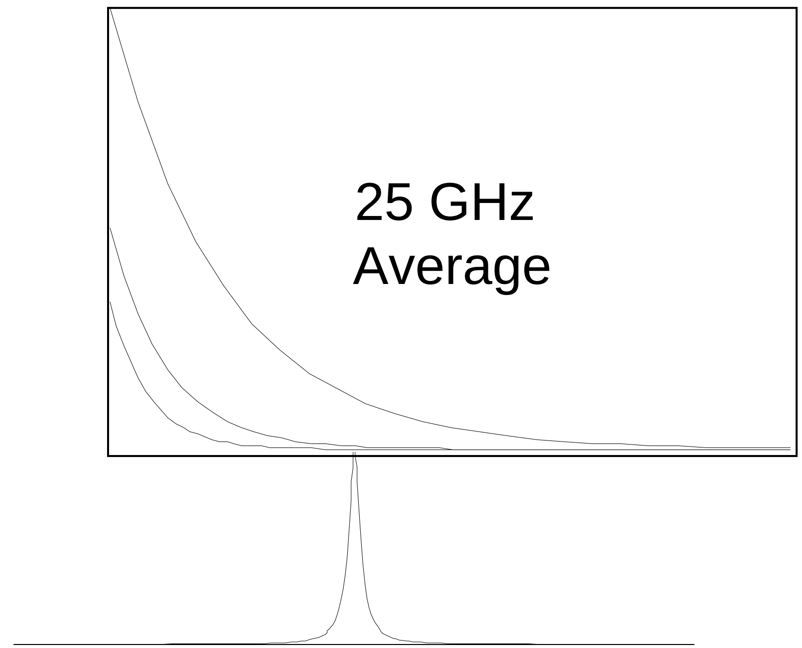


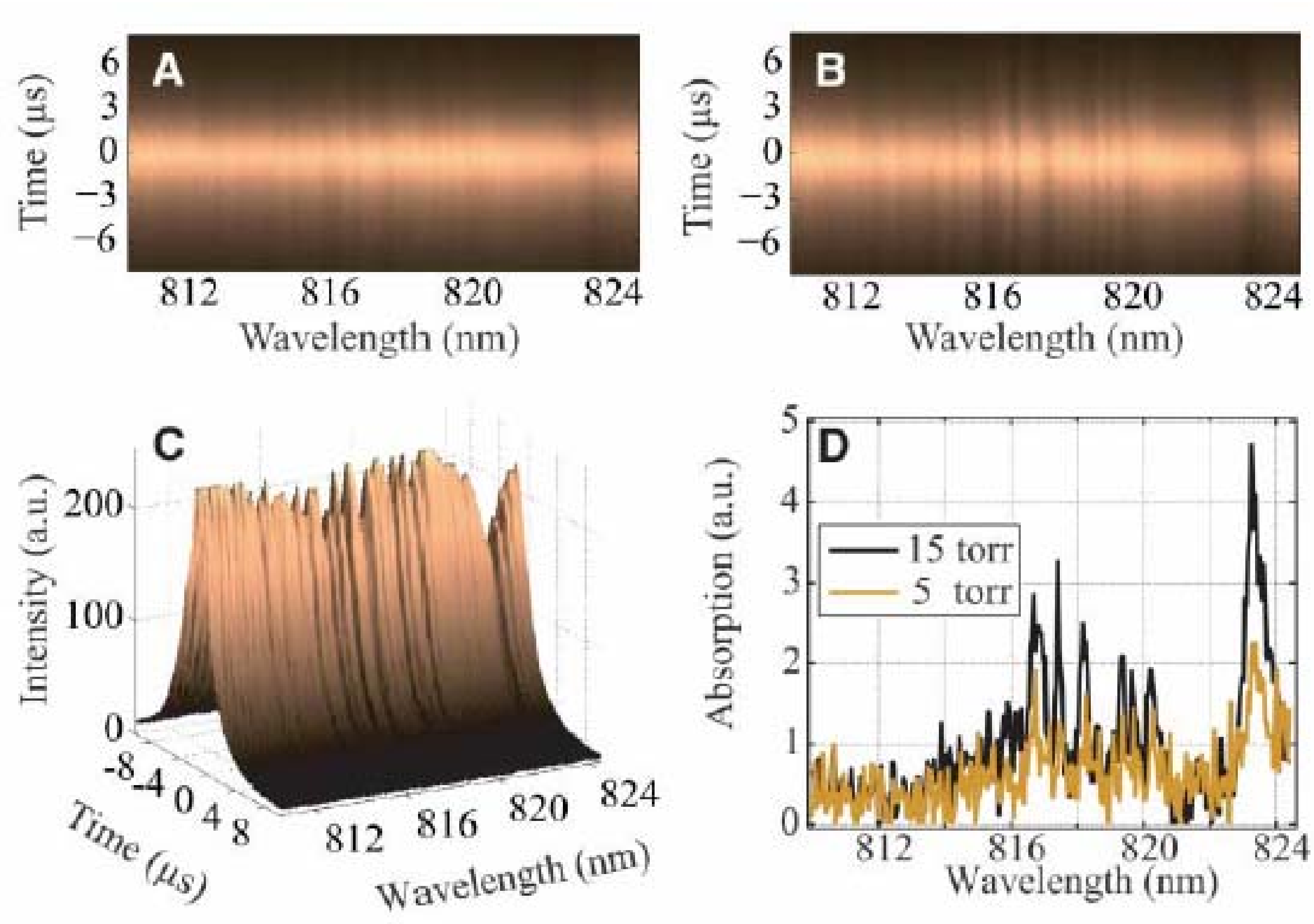
f_rep = 380 Mhz
100 nm band
Ti:Sapphire Laser
Optical Switch
FSR = 380 Mhz
Ringdown cavity & vacuum chamber
¼ meter monochromator
25 Ghz
Grating
Scanner
Chip can span 15nm
Laser frequency sweep driver
Feedback electronics
Timing pulse (for optical switch & locking electronics)
Computer data acquisition
f_rep = FSR
ν_comb = ν_cavity
scan frequency < K

Resolving lineshapes





Single Shot H_20 spectrum



What's next?

- Larger monochromator, or virtually imaged phase array (VIPA) can improve resolution to a few GHz
- Acquisition time is limited by scanning piezo, in principle should be limited by τ
- Anticipate sensitivity of 10^{-10} in 1sec

The requisite slides about why people should care...

A rival for NQMOR in the airport security line

Fast detection of trace toxins

Refrences

- Broadband Cavity Ringdown Spectroscopy for Sensitive and Rapid Molecular Detection. M. Thorpe , K. Moll, R. J. Jones, B. Safdi, J. Ye. Science 311, 1595 (2006)
- Ultrasensitive detections in atomic and molecular physics: demonstration in molecular overtone spectroscopy. J. Ye, L-S Ma, J. Hall. J. Opt. Soc. Am. B. Vol. 15, No. 1 (1998)
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- Precise measurements of optical cavity dispersion and mirror coating properties via femtosecond combs. M. Thorpe, R. J. Jones, K. Moll, J. Ye. Optics express, Vol. 13, No. 3 882 (2005)