# Zero-area THz optical pulses in gases.

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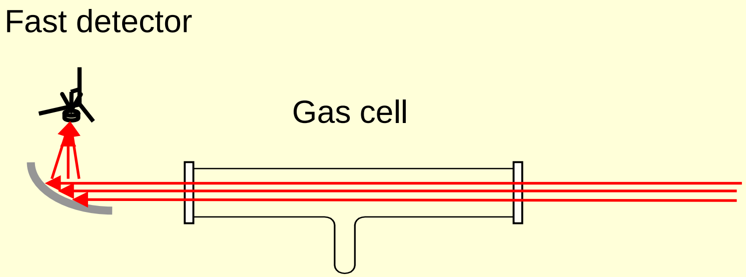
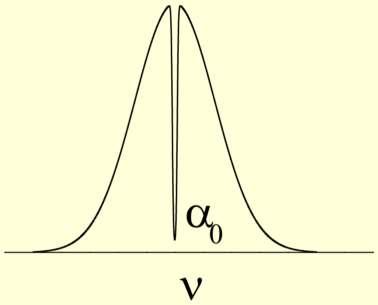
# Unusial transformation of the laser pulse.

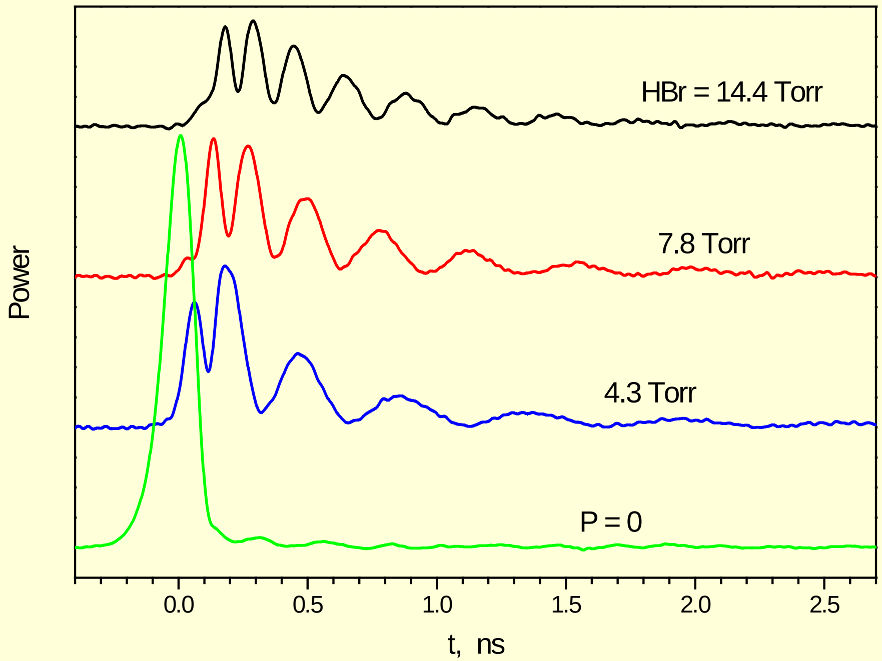



5.6 MHz
5 – 20 μJ
120 ps

Terahertz FEL pulses.




Narrow absorption line.
High optical density.

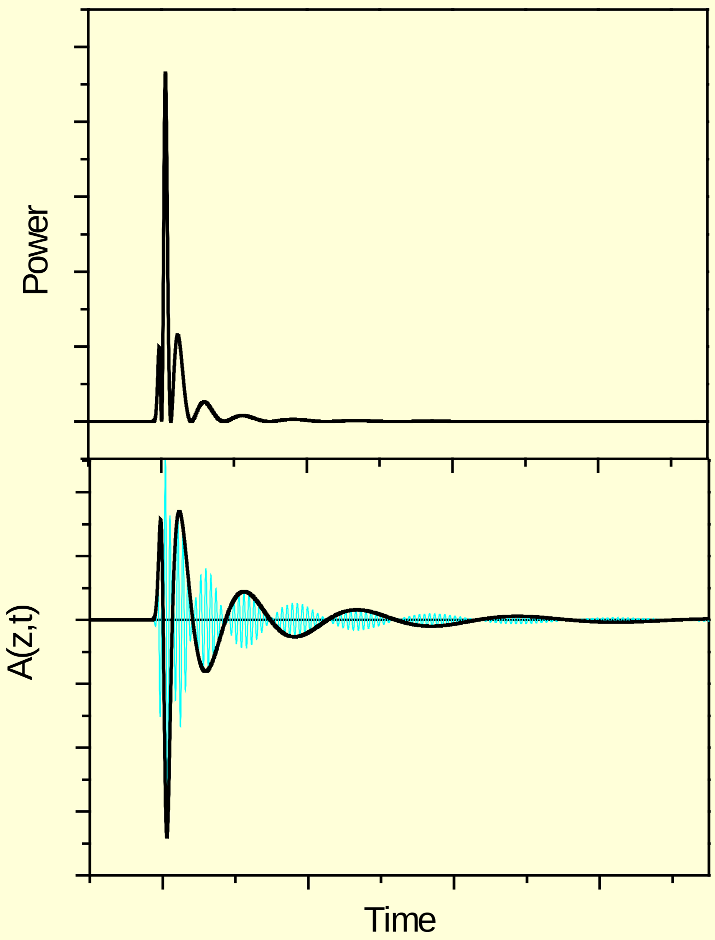


# Area of the optical pulse.

$$E(z,t) = A(z,t) \cdot e^{-i(\omega_0 t - kz)}$$

Amplitude (slow)

Carrier frequency (fast)




Area $\theta(z) = \frac{d_{12}}{h} \int A(z,t)\,dt$

In absorption media:

$\theta \to 0;$

$\theta \to 2\pi;$

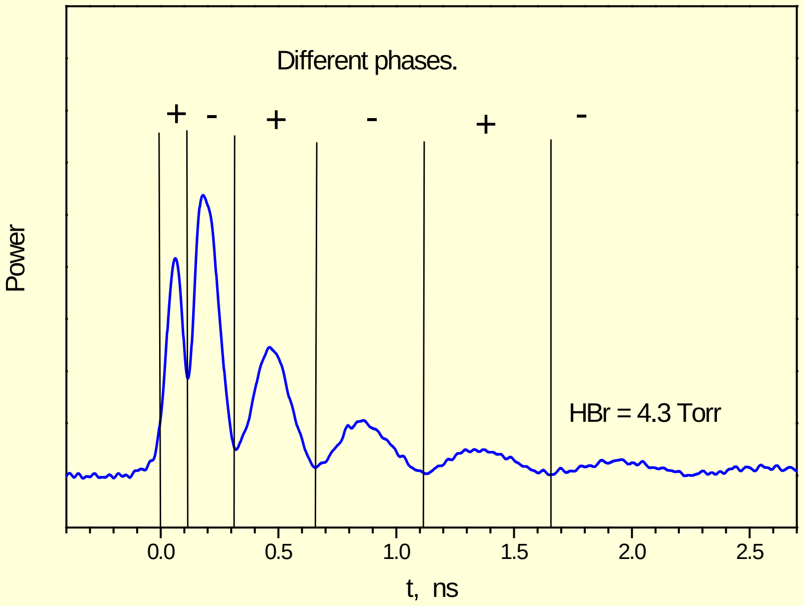
$\theta \to 4\pi;$

.....

Beer -Lambert law. $\theta(z) = \theta_0 \exp(-\alpha_0 z)$

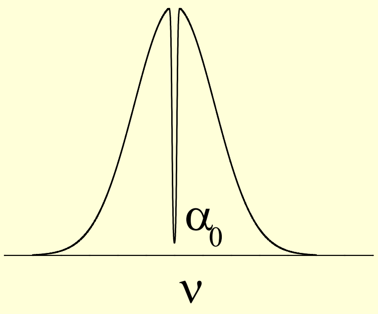
Our experimental signal.

$\theta = 0.$




1. How the as the zero-area optical pulse is forming?
2. How it transformed by passing through an absorbing medium?

# Exact analytical solution.  Grisp 1972.




Assumptions.

1. Small area $\theta$ <<1
2. Single Lorentz absorption line.
3. Input: short optical pulse:  E(z,t) = δ(t-kz)

$$\frac{E(t)}{E_{empty}(t)} = -\sqrt{\frac{\chi}{t}} \cdot J_1\left(2\sqrt{\chi t}\right) \cdot \exp\left(-t\frac{\gamma}{2}\right)$$

$$n(\omega) = 1 + \frac{\alpha_0 c}{\pi\gamma\ \omega_0} \cdot \frac{i}{1 + 2i(\omega - \omega_0)/\gamma}$$

$$\frac{I(t)}{I_{empty}(t)} = \frac{\chi}{t} \cdot J_1^2\left(2\sqrt{\chi t}\right) \cdot \exp(-\gamma\ t)$$

Tail of the pulse   -   Free Induction Decay.   (FID)

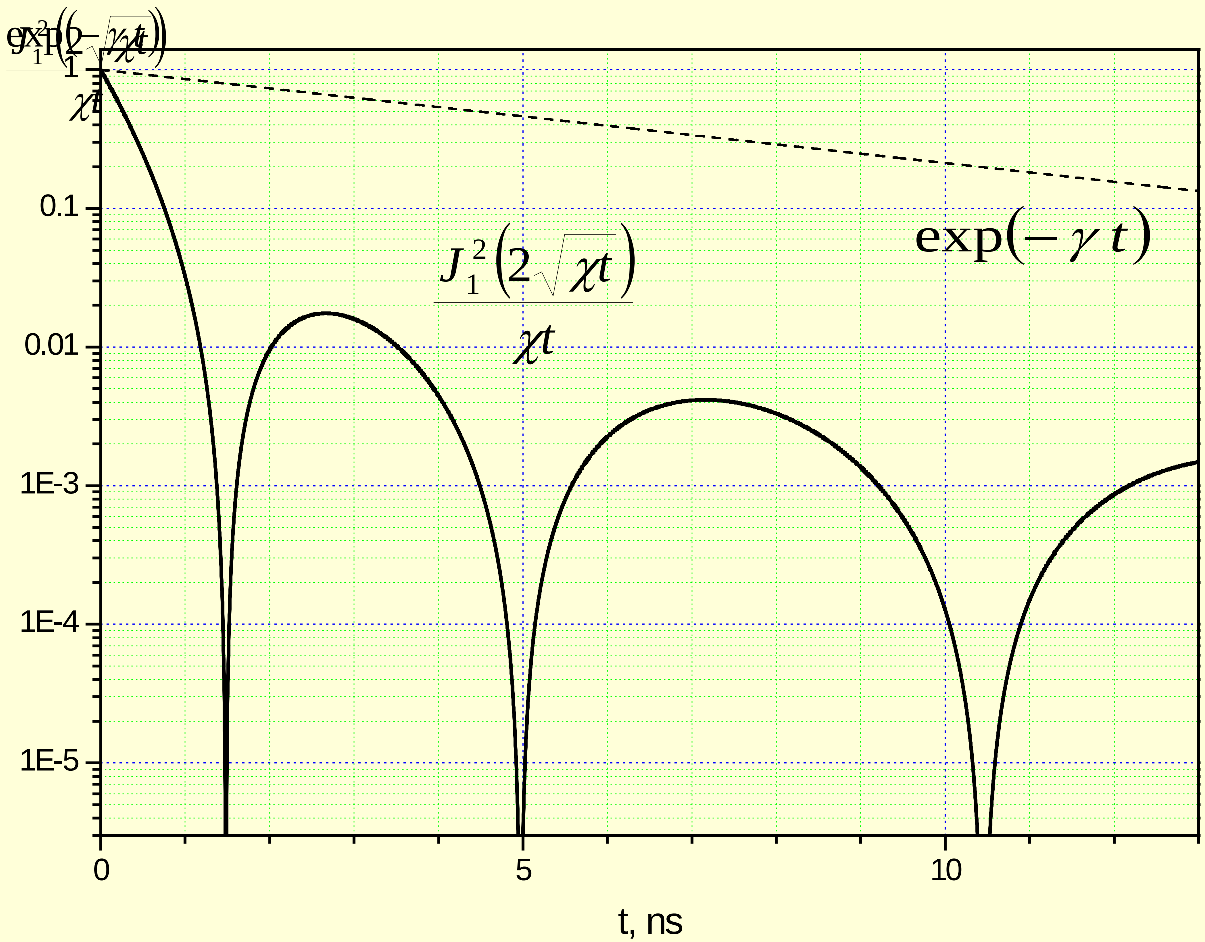
Two parameters:   $\gamma$  -  linewidth,

$$\chi = \frac{L}{\pi} \int \alpha(\omega) d\omega$$   -line integrated intensity

# Formation of the zero-area pulses.

## FID at high optical dencity. Two factors.

$$I(t) = \frac{\chi}{t} \cdot J_1^2\left(2\sqrt{\chi t}\right) \cdot \exp\left(-\gamma\, t\right) \qquad \chi = l\alpha_0 / \pi$$

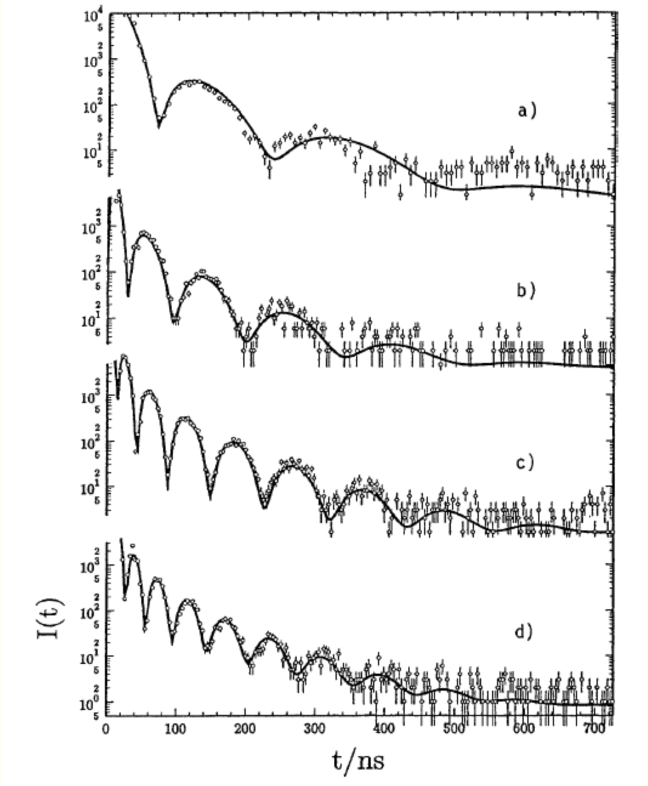



*Values of the rates:*
$\gamma$ = *0.155·10^9 sec^-1*
$\chi$ = *9.9·10^9 sec^-1*

$$\chi / \gamma = $$
$$= \alpha(\omega_0) l / 2$$

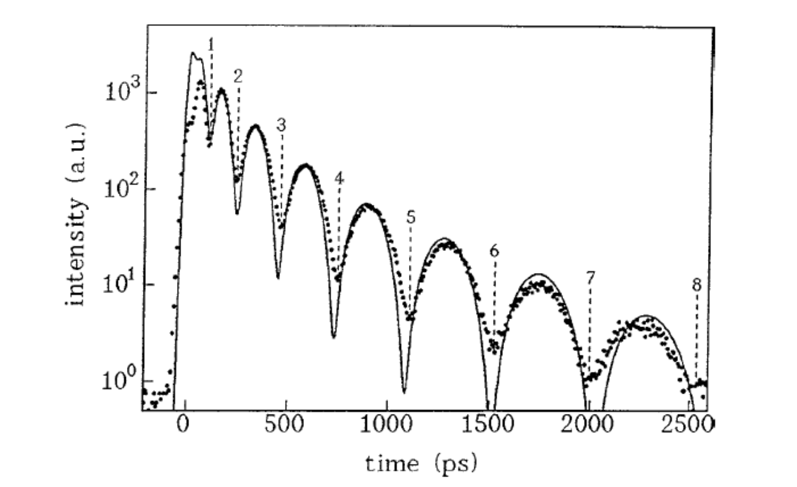
# The universality of the phenomenon.

Mossbauer spectroscopy, $^{57}$Fe the 122 keV




Y.V. Shvyd'ko, U. van B.urck, W. Potzel, P. Schindelmann, E. Gerdau, O. Leupold, J. Metge, H.D. R.uter and G.V. Smirnov, Phys. Rev. B 57 (1998) 3552.

Exciton resonance in $Cu_2O$ at 2eV




D. Fr.ohlich, A. Kulik, B. Uebbing, A. Mysyrowicz, V. Langer, H. Stolz and W. von der Osten,Phys. Rev. Lett. 67 (1991) 2343.

**How this formula works for molecular rotation spectra in terahetz?**

# Experiments in terahertz region.

## Choice of the object.

Single absorption line within FEL spectra.

Rotation spectra.

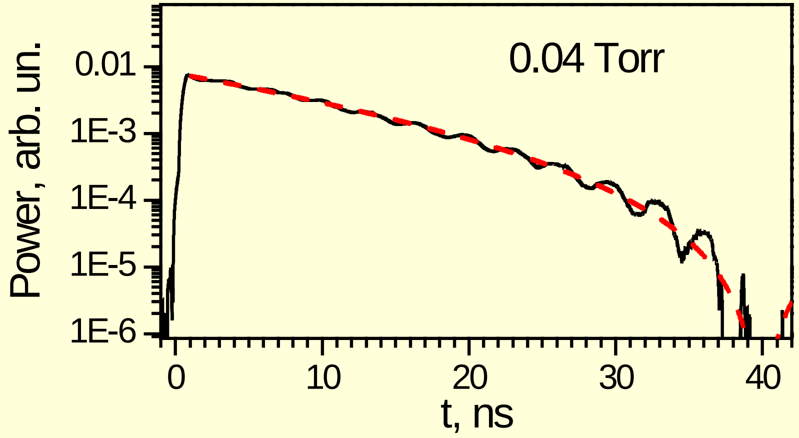
HCl - - chlorine isotops, quadrupole quadrupole splitting.
HBr - - bromine isotops, quadrupole quadrupole splitting.
HF +++ ?? May be good.
CO - low dipole moment.
HCN +++ strong widely spaced lines.

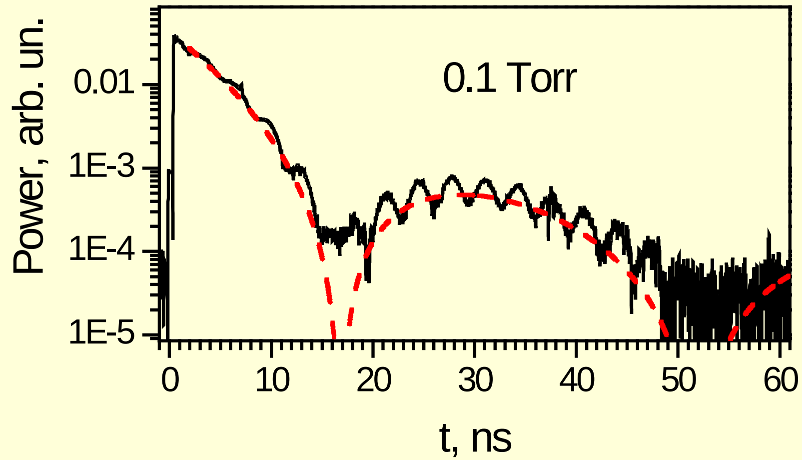
# Experiments with  HCN.

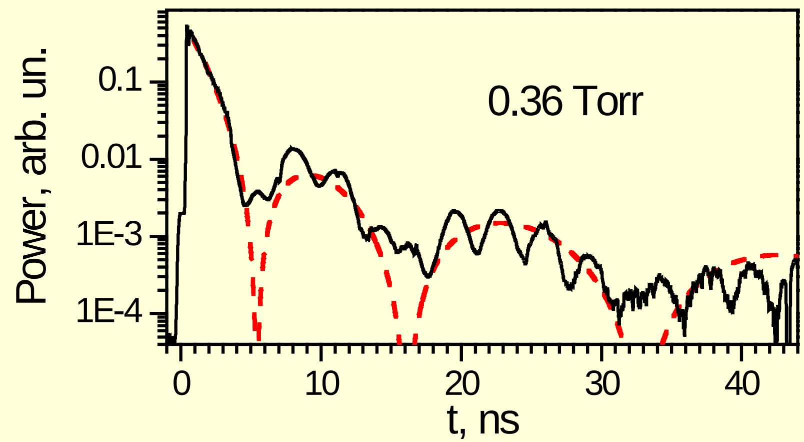
*Table 1.    Calculated and experimental positions of the first minimum of FID signals at different pressures.*

| Pressure | 0.04 Torr | 0.1 Torr | 0.36 Torr |
|---|---|---|---|
| $t_1$ experimental | 39 ns | 17 ns | 5.5 ns |
| $t_1$ calculated | 37 ns | 15 ns | 4.1 ns |

$$I(t) = \frac{\chi}{t}\cdot J_1^2\left(2\sqrt{\chi t}\right)$$



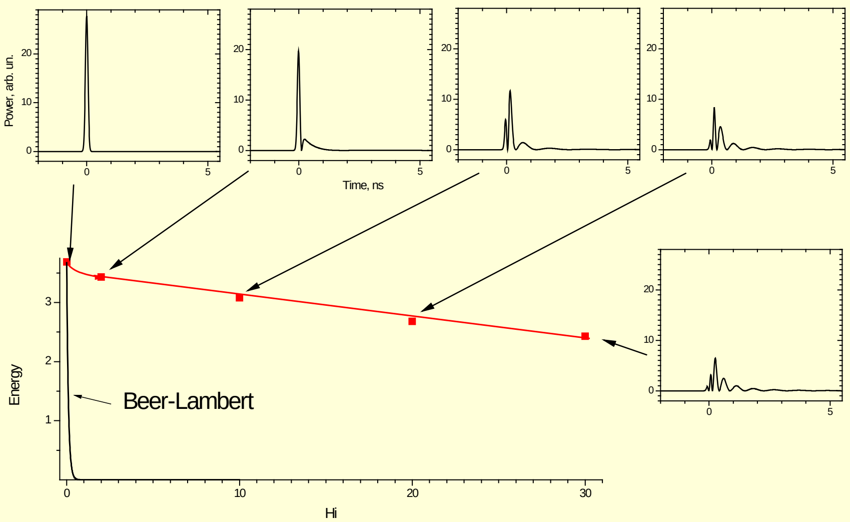



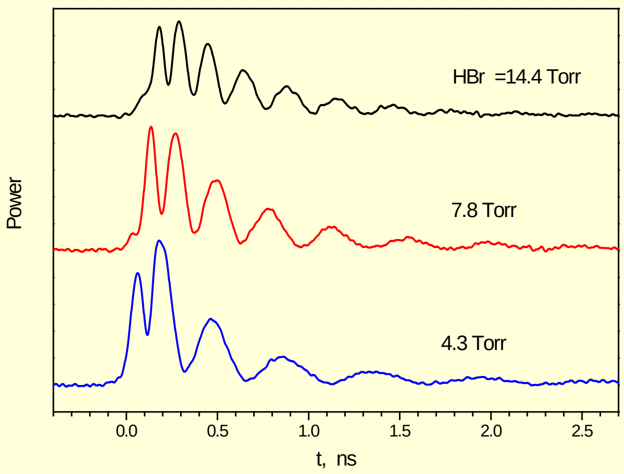

**The formula is valid in Teraherts also.**

# Energy dissipation

$$\left|\frac{d_{12}}{h}\int A(z,t)\,dt\right|^2 = 0$$ - transition probability

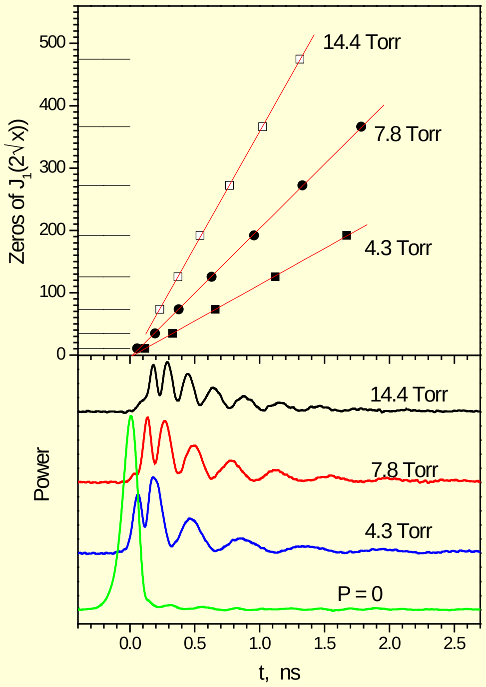
According to perturbation theory - no energy absorption.



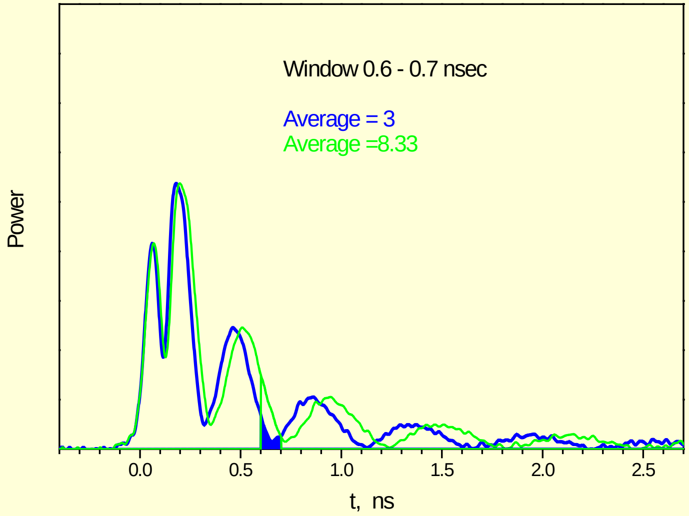



# Possible applications.

Precise measurement
of the transition oscillator strengh

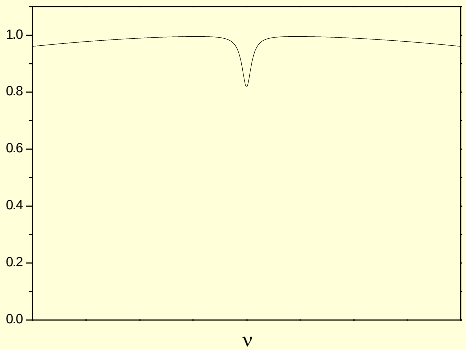



Detectionof the small variation
of concentration in time-resolved experiments.



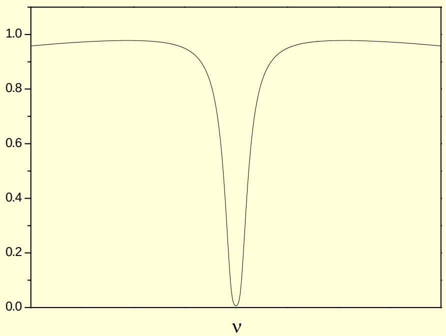
# Lifetime of the Free Induction Decay signals

Low optical density.




$$E_{FID}(t) \approx -\exp\left(-t\frac{\gamma}{2}\right)$$

High optical density.




$$E_{FID}(t) \approx -\frac{J_1\left(2\sqrt{\chi t}\right)}{\sqrt{\chi t}}$$

Lifetime might be shorter.

The narrow absorption lines and a large optical density are typical for pulse propagation in the atmosphere.



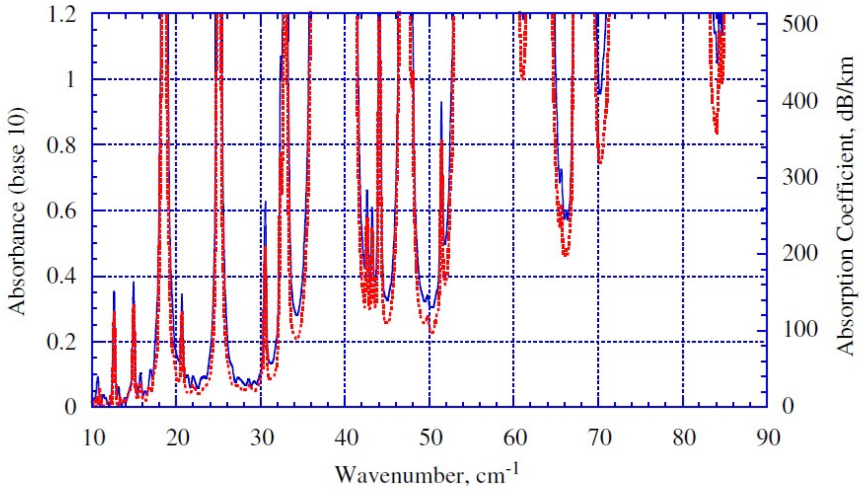



Fig. 3. Absorption spectra of a mixture composed of water vapor at 0.67 kPa and nitrogen at 70 kPa. Top and bottom spectra were obtained at 293 and 333 K, respectively.

Path length = 23 m

Thank you for attention.