HAS WIGNER RESEARCH
CENTRE FOR PHYSICS

Laser plasma diagnostics in rubidium vapor cell

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Motivation and issues found in measurements

- Plasma generation in Rb vapor by ultrashort laser pulses
- Plasma diagnostics by CW diode lasers: plasma density

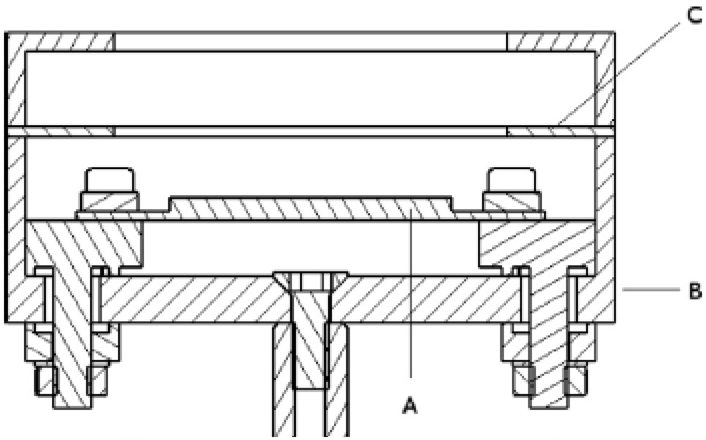
Why rubidium cell?

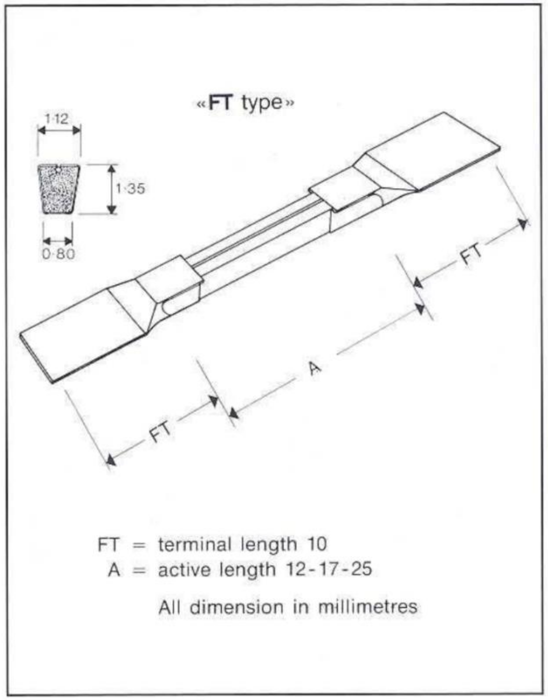
Easily vaporized Rb
Convenient spectral lines 780nm
Vapor density simply controllable by temperature

Why diode laser?

Commercially available
Cheap (CD writer 780nm)
Simple to operate
Easy frequency tuning

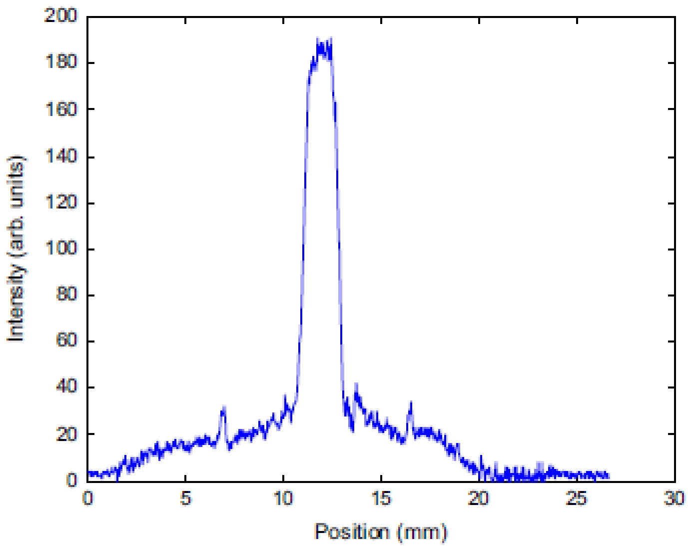
Another simple plasma source





Rb vapor source .

getter @ double slit



Rb vapor distribution above the slit

Direct way of plasma diagnostics: collecting charged particles

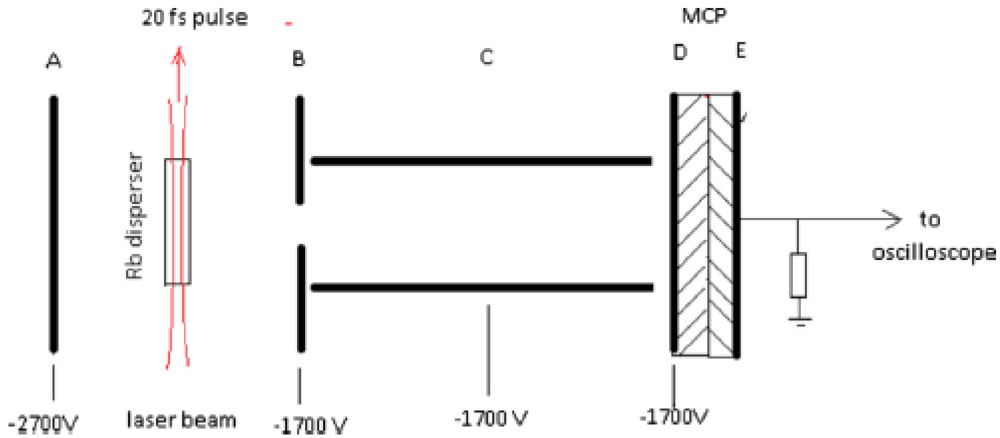
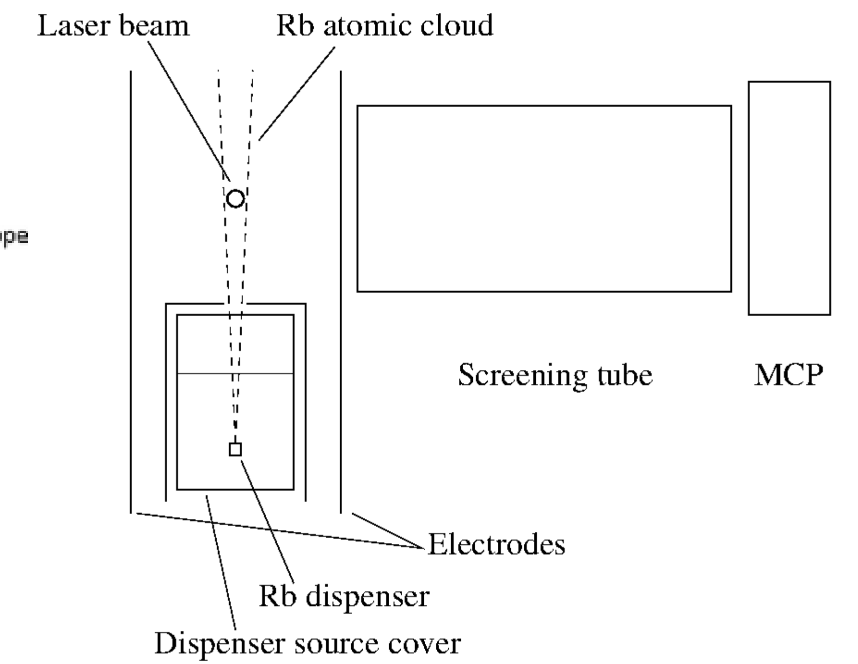


Fig. 1. The scheme of the experimental setup.

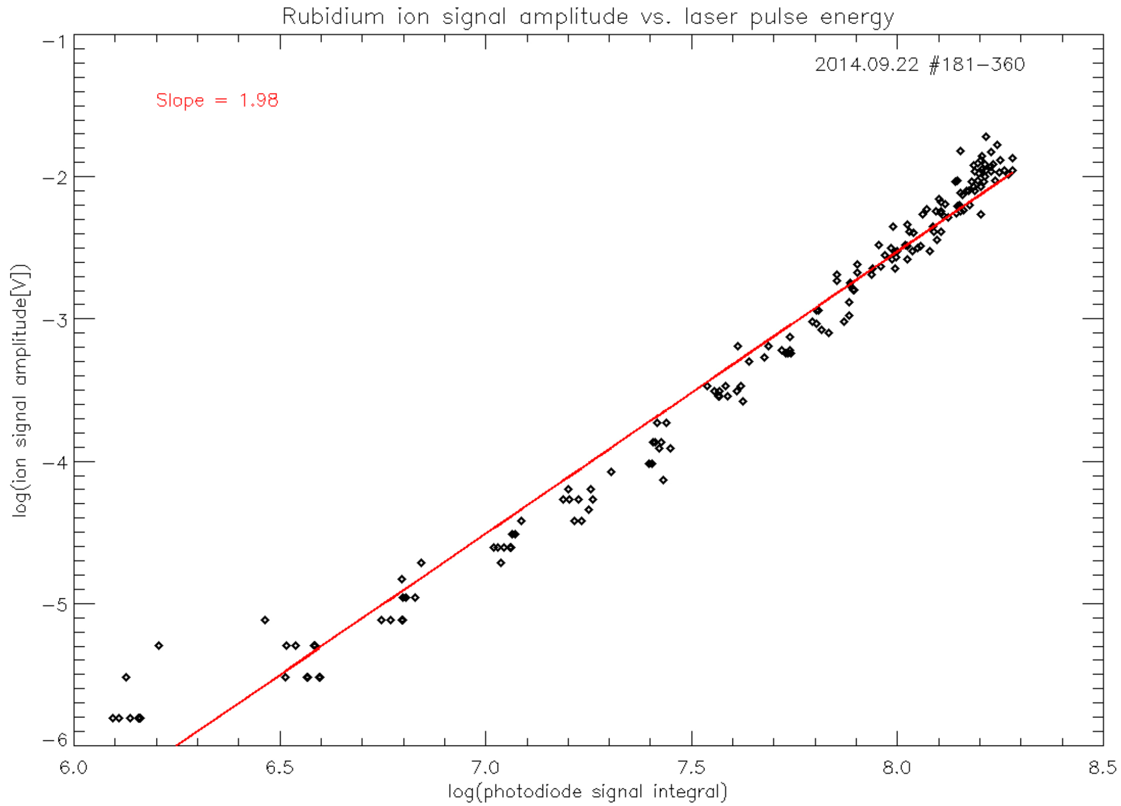


Langmuir flat probe:
1. Simple design
2. Ions/electrons come from 'somewhere' , calibration difficulties

Results of direct ion detection

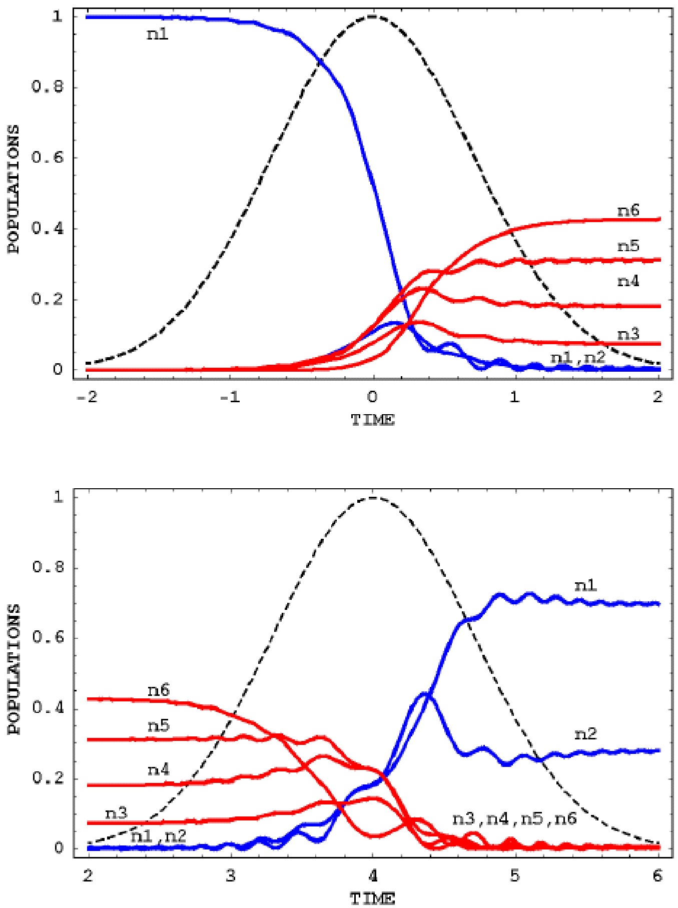
ionization dependence on laser intensity

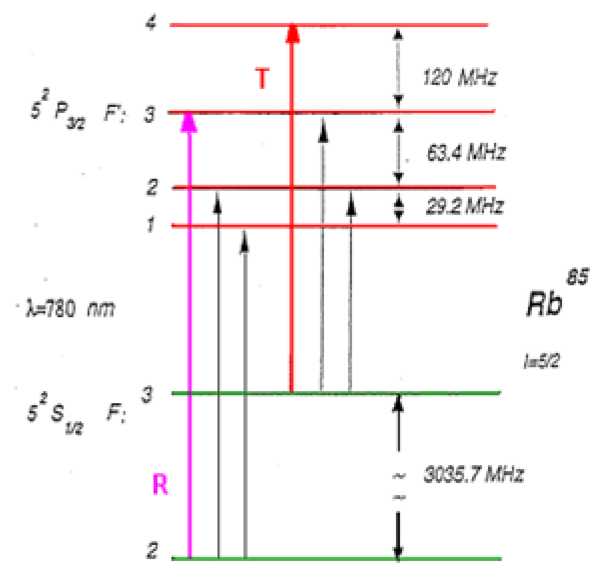
Slope: ~ 2



Maximum laser intensity: 10^{11} W/cm^2

Indirect plasma diagnostics: plasma = ‘lack’ of neutral atoms



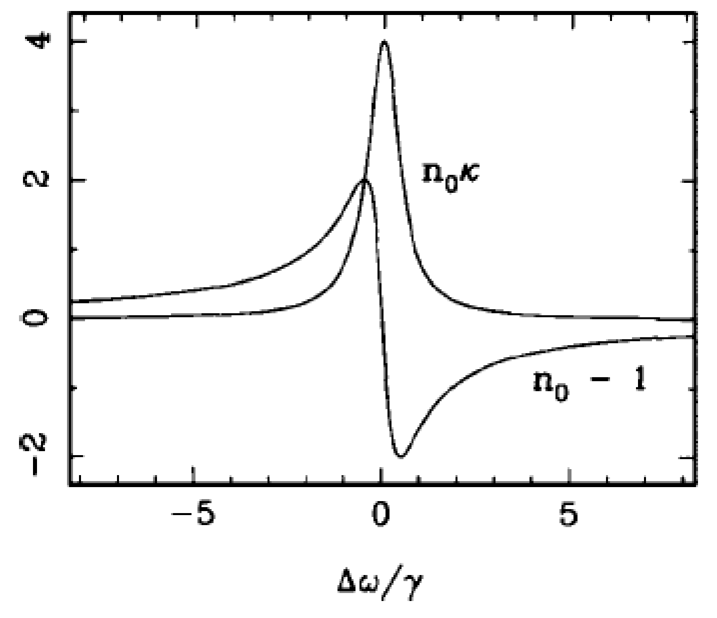


Atomic processes:
Decay time some 10 ns

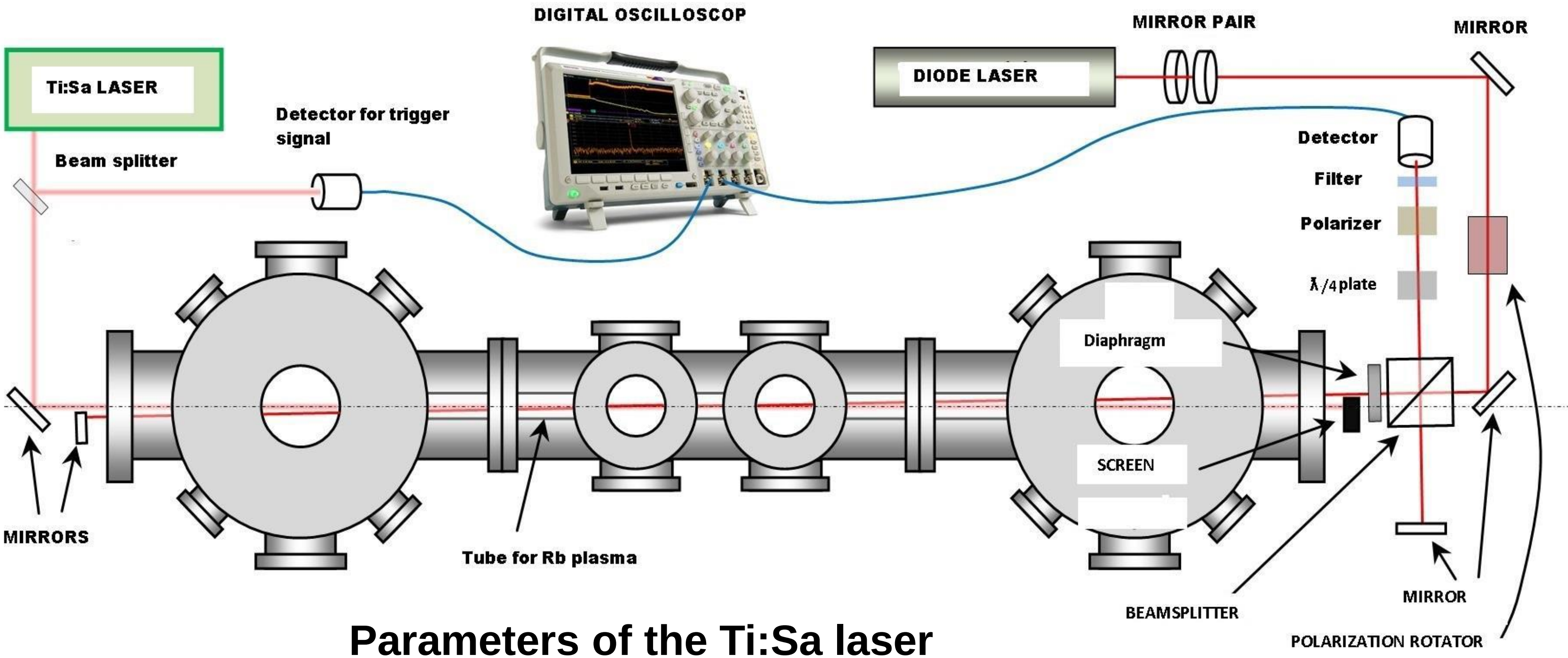
Population dynamics for a pair of resonant pulses

Plasma diagnostics by CW diode lasers

Atomic Lorentz model:
resonant absorption @
interferometry



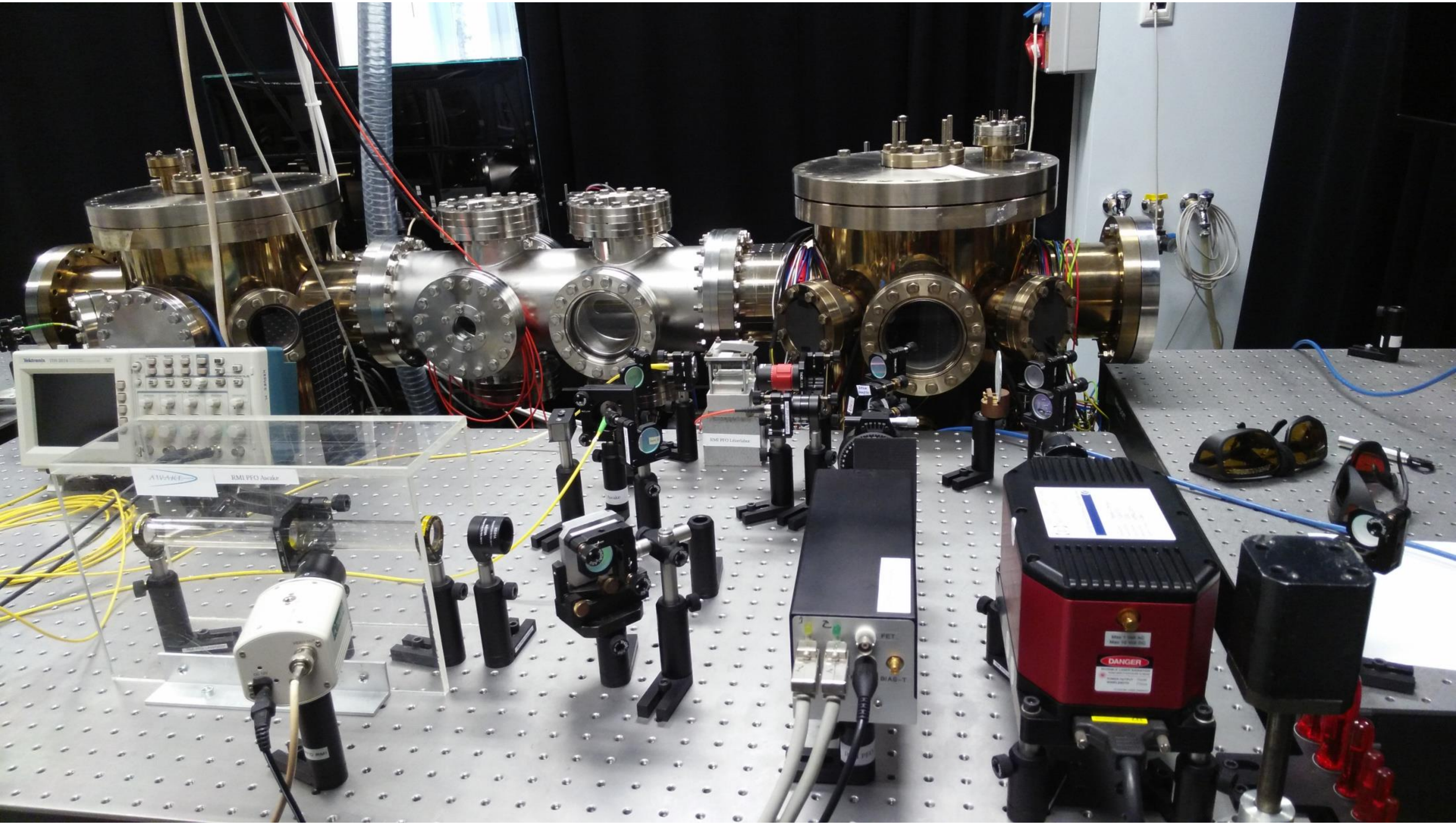
Experimental layout



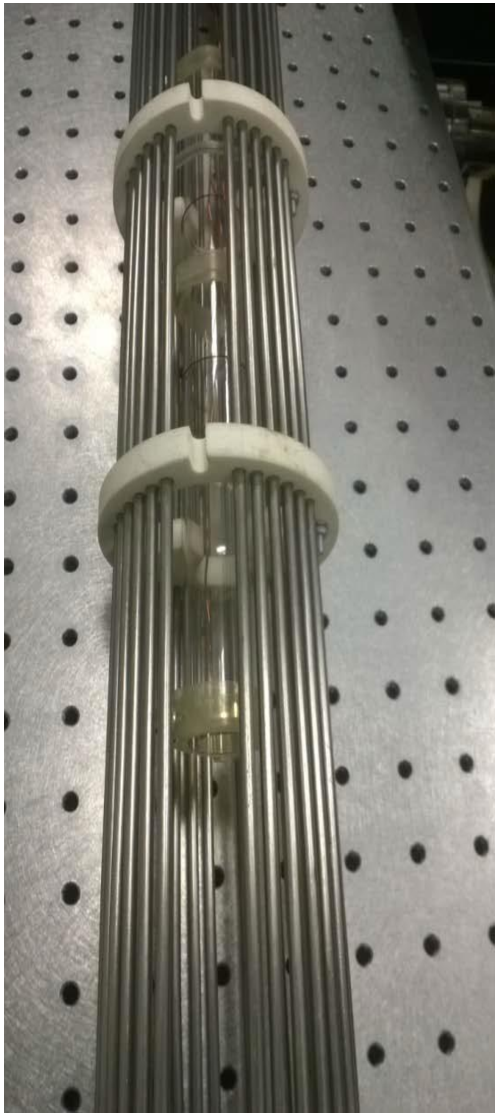
Parameters of the Ti:Sa laser
Mean wavelength 806 nm
Beam Diameter:9 mm (1/e2Gauss)
Polarisation:Linear, vertical
Repetition Rate 1 kHz
Pulse duration (FWHM):35 fs
Pulse 3.5 mJ

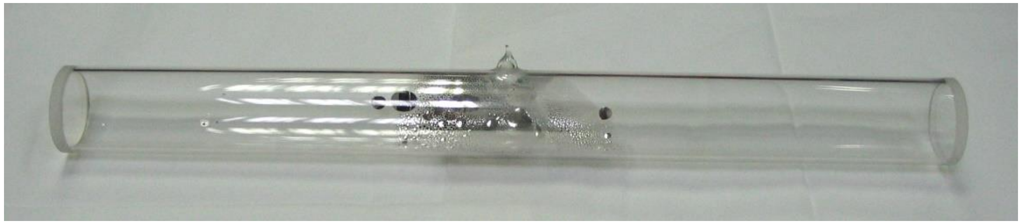
Courtesy of
A. Czitrovszky, P. Dombi,
P. Rácz, A. Nagy, I. Márton

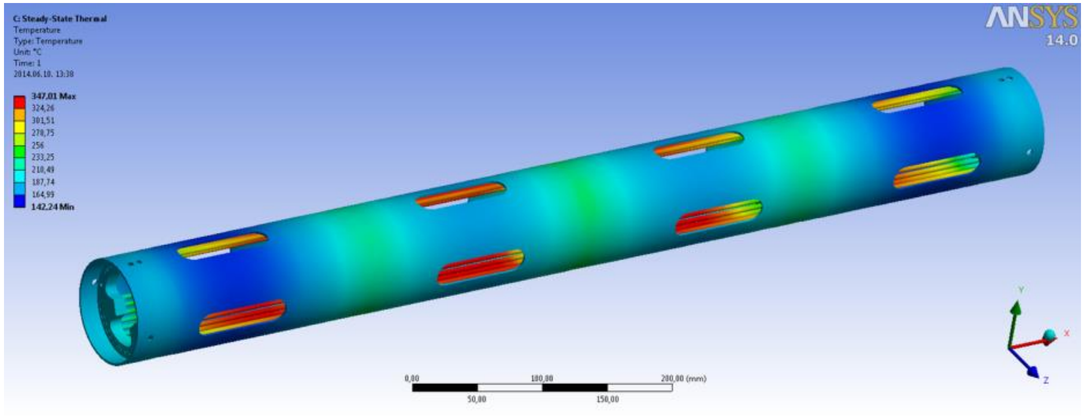
Experimental layout



Vapor cell, heating wires, reflector







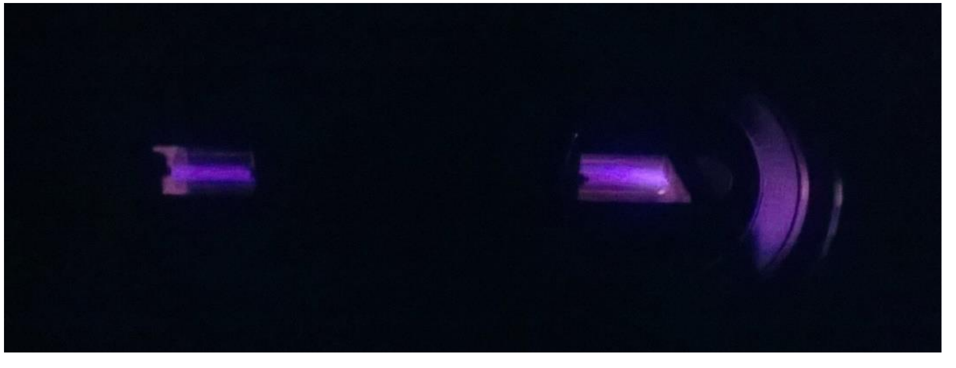
Temperature distribution

Courtesy
A. Bendefy (BME)

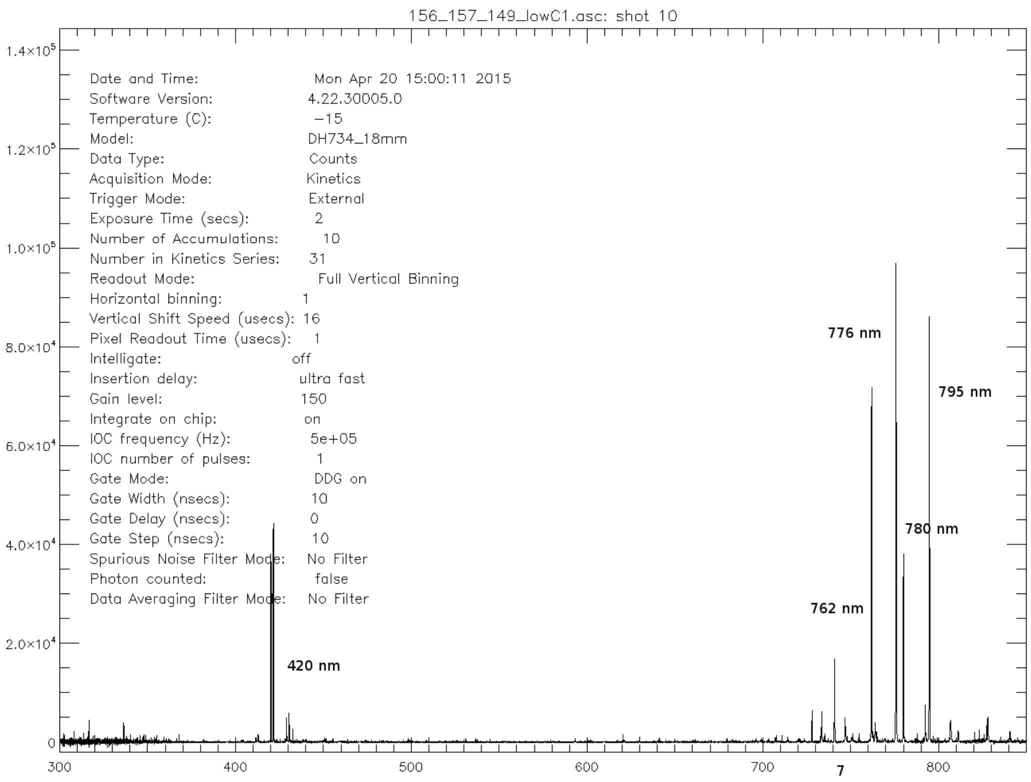
Spectroscopic observations

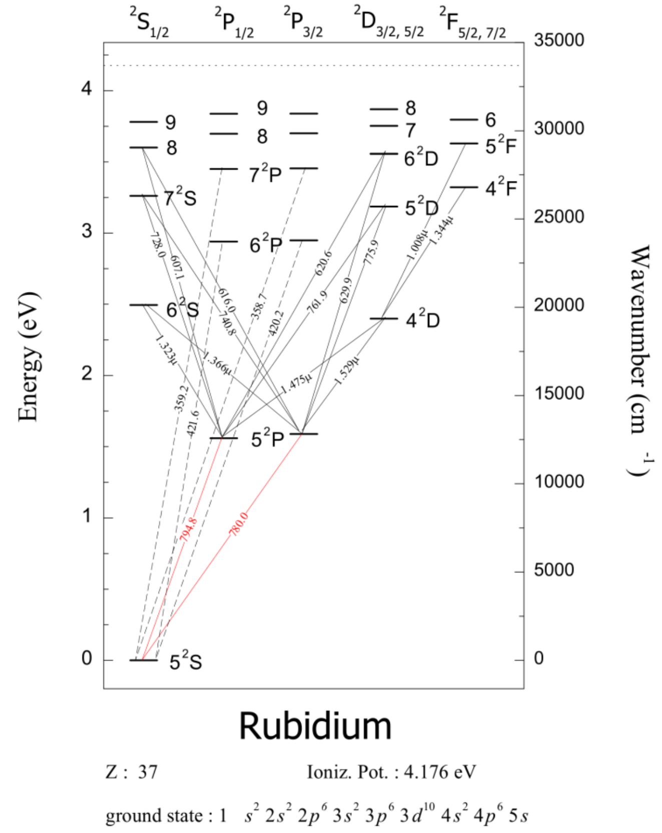
Detection of the radiation of the plasma by a fast spectrograph (Andor Mechelle 5000)
High spectral resolution (0.05 nm accuracy)
High temporal resolution with intensified camera (~ ns)

Spectrograph courtesy of L. Kocsányi (BME), and help with the measurements R. Bolla (WRCP)

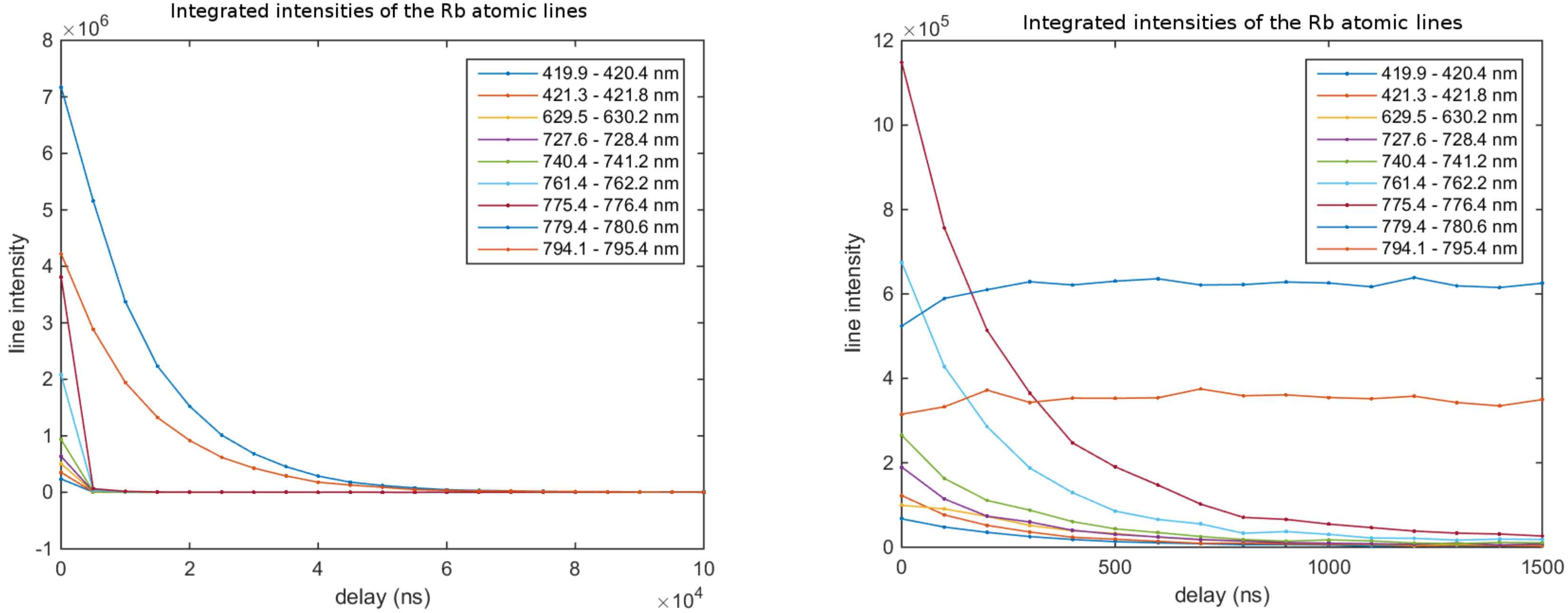


Observed spectral lines of Rb





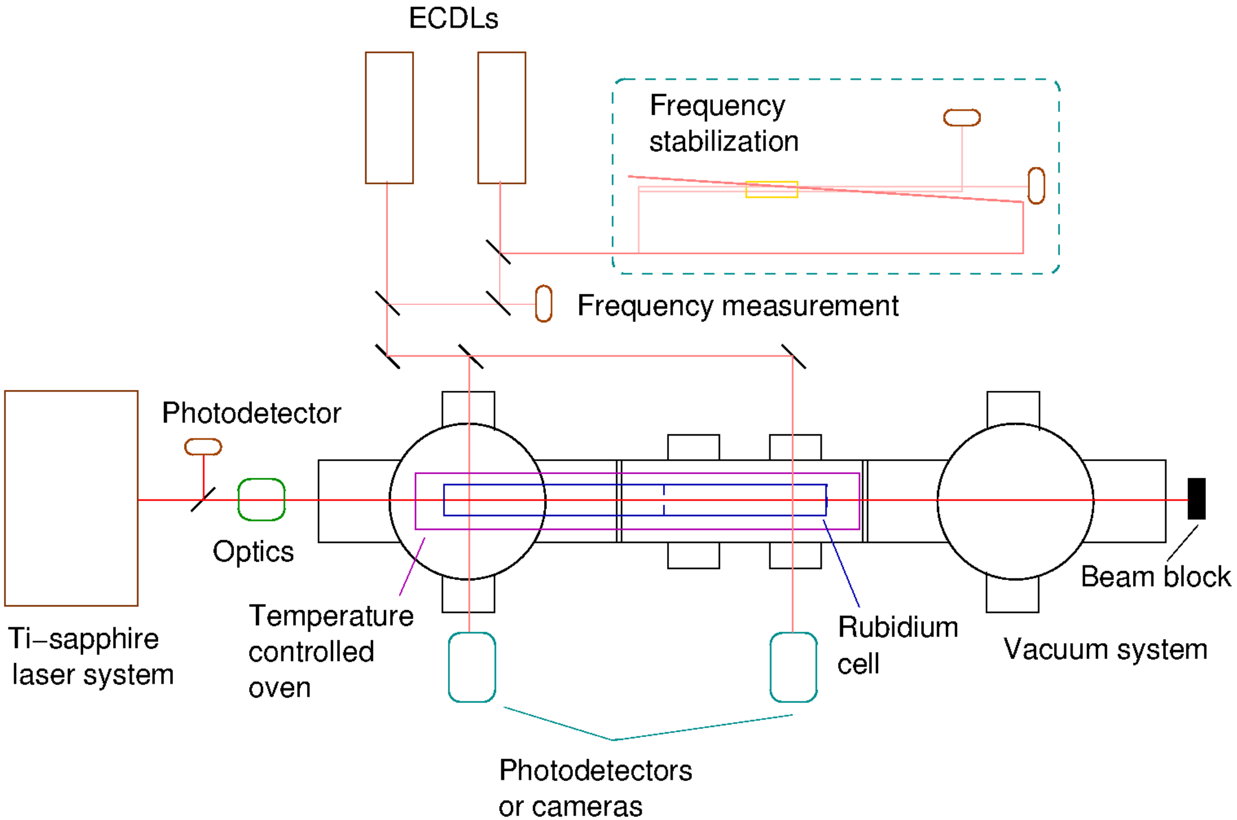
Time dependence of the spectral emission



Temperature: ~ 200 C^o

Ion relaxation mainly through D2 lines (and D1)

Transversal absorption measurements

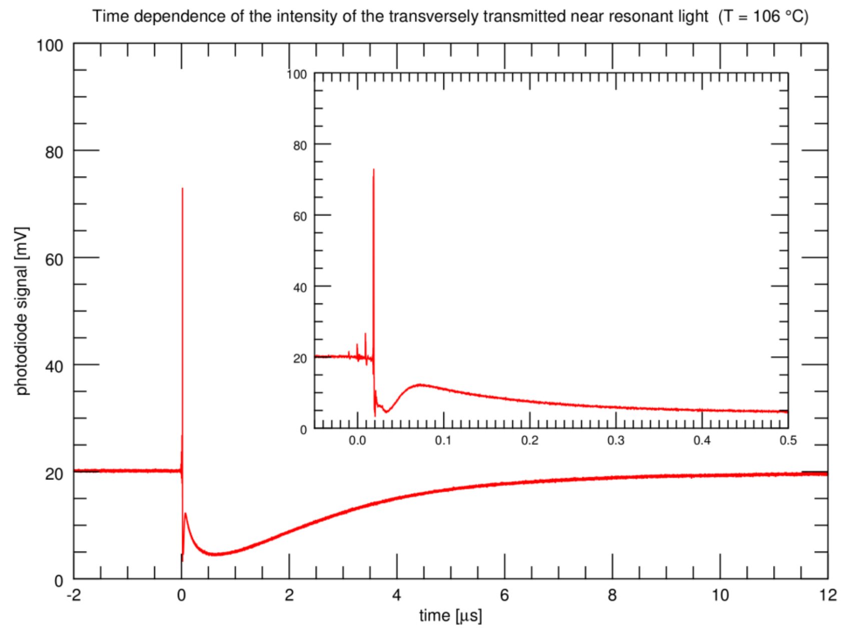


Parameters:
1. Ionizing laser intensity
2. Probe laser detuning
3. Vapor density

Tipical transmission signals on microsec scale

(different) CW level: Positive peak @ Negative peak and relax.
(New Focus 1591NF): 4.5 GHz

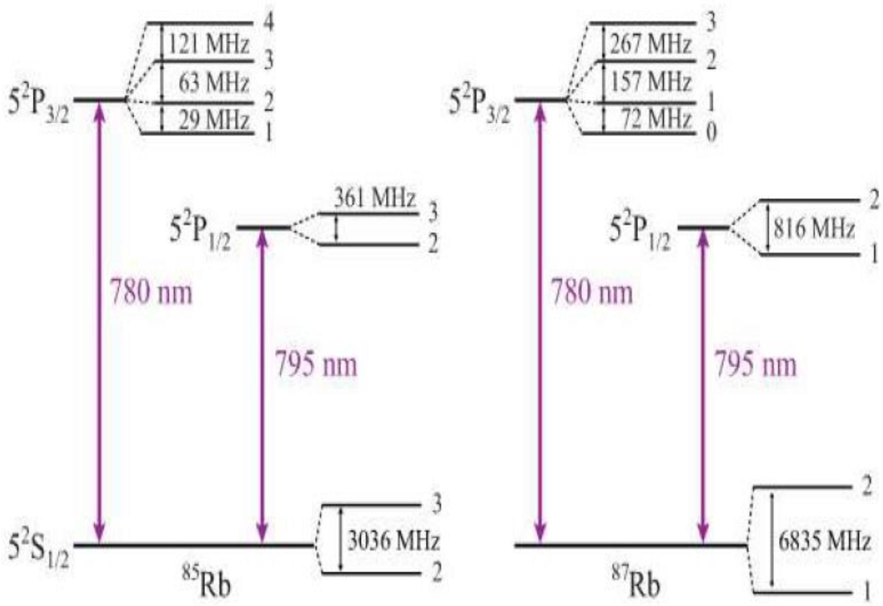
Very fast peak: AC Stark shift
10 ns decay: atomic relaxation
Slow (1-10 microsec) decay:
plasma relaxation

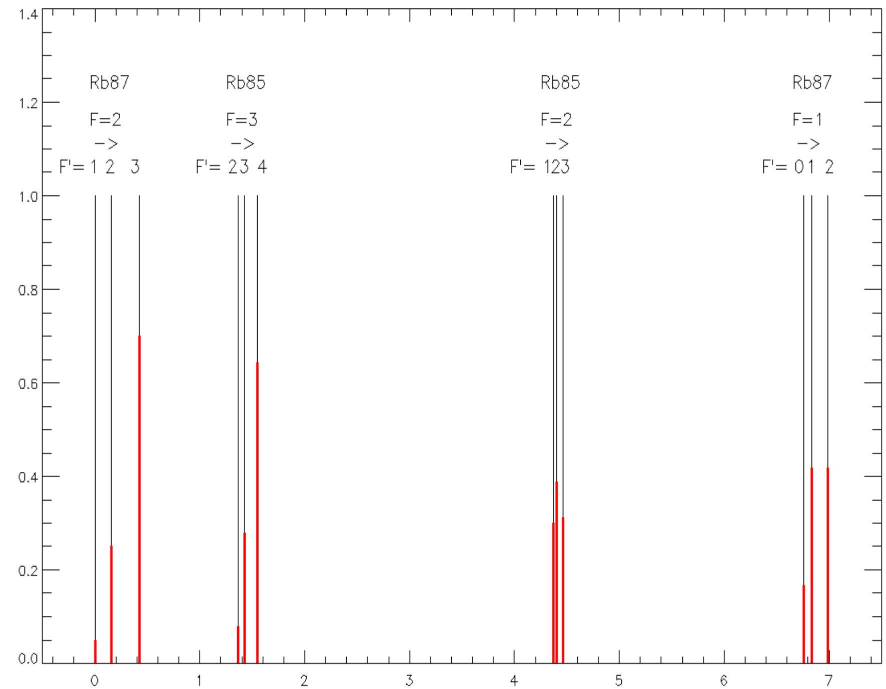


Decrease of transmission is attributed to reflection on the boundaries of the plasma channel.

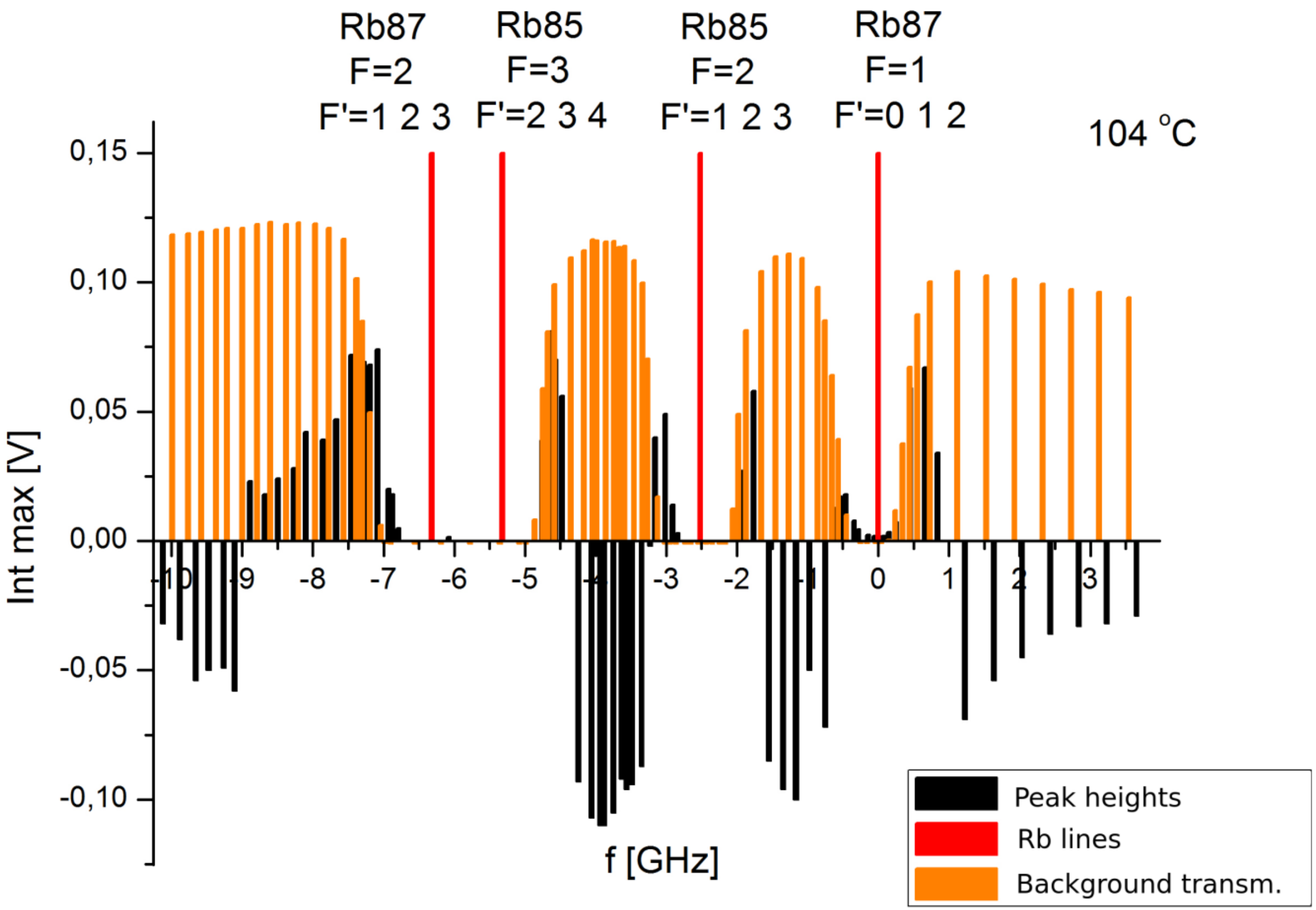
Initial condition: atoms in the ground state

Detuning:Rubidium frequency reference

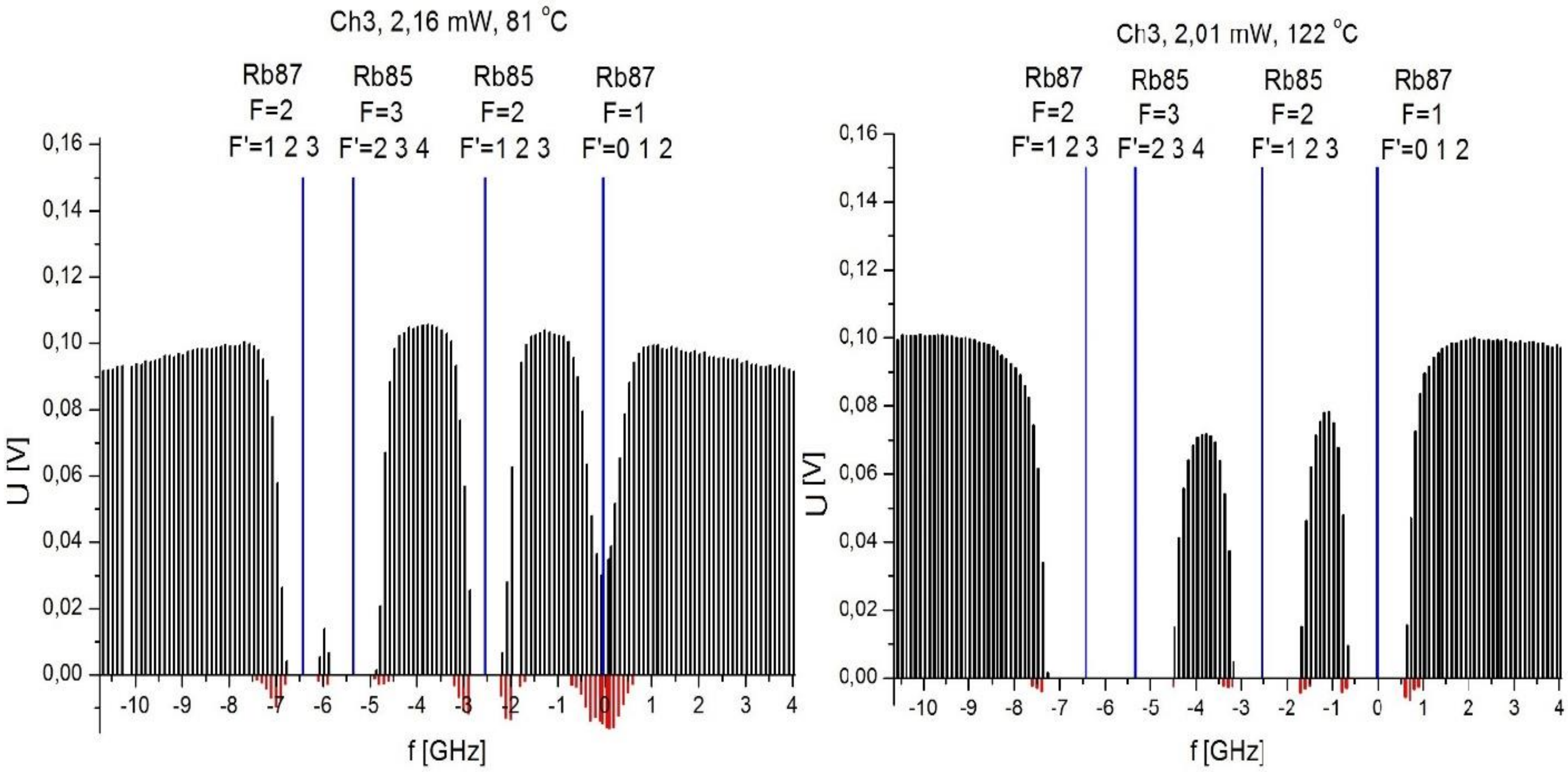




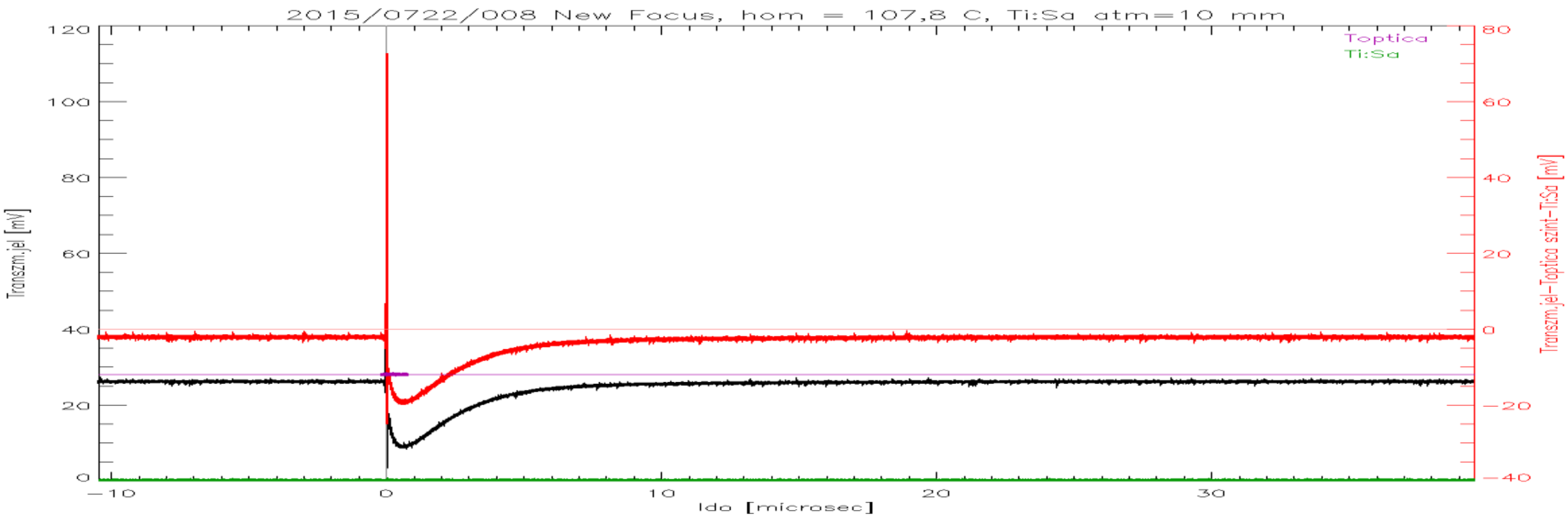
Dependence of the fast peak maxima on the laser frequency



Slow relaxation component (negative peak) at different vapor densities

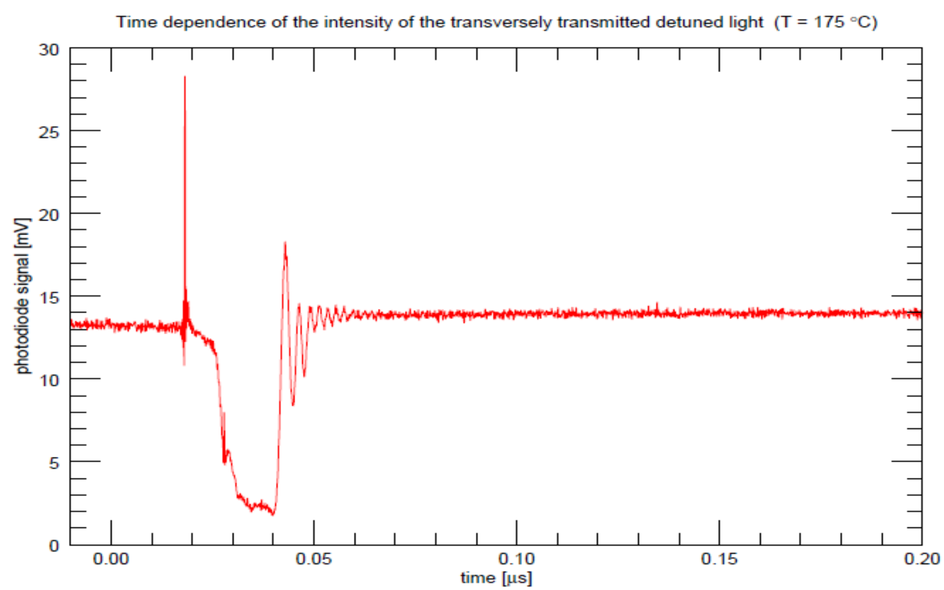


Transmission signal vs. vapor density



Signal oscillations ?
Plasma freq.100 GHz

$$\omega_p = \sqrt{\frac{n_e e^2}{\varepsilon_0 m_e}}$$



Repeated reflections on the boundaries of the plasma channel

Summary of transmission signal detection

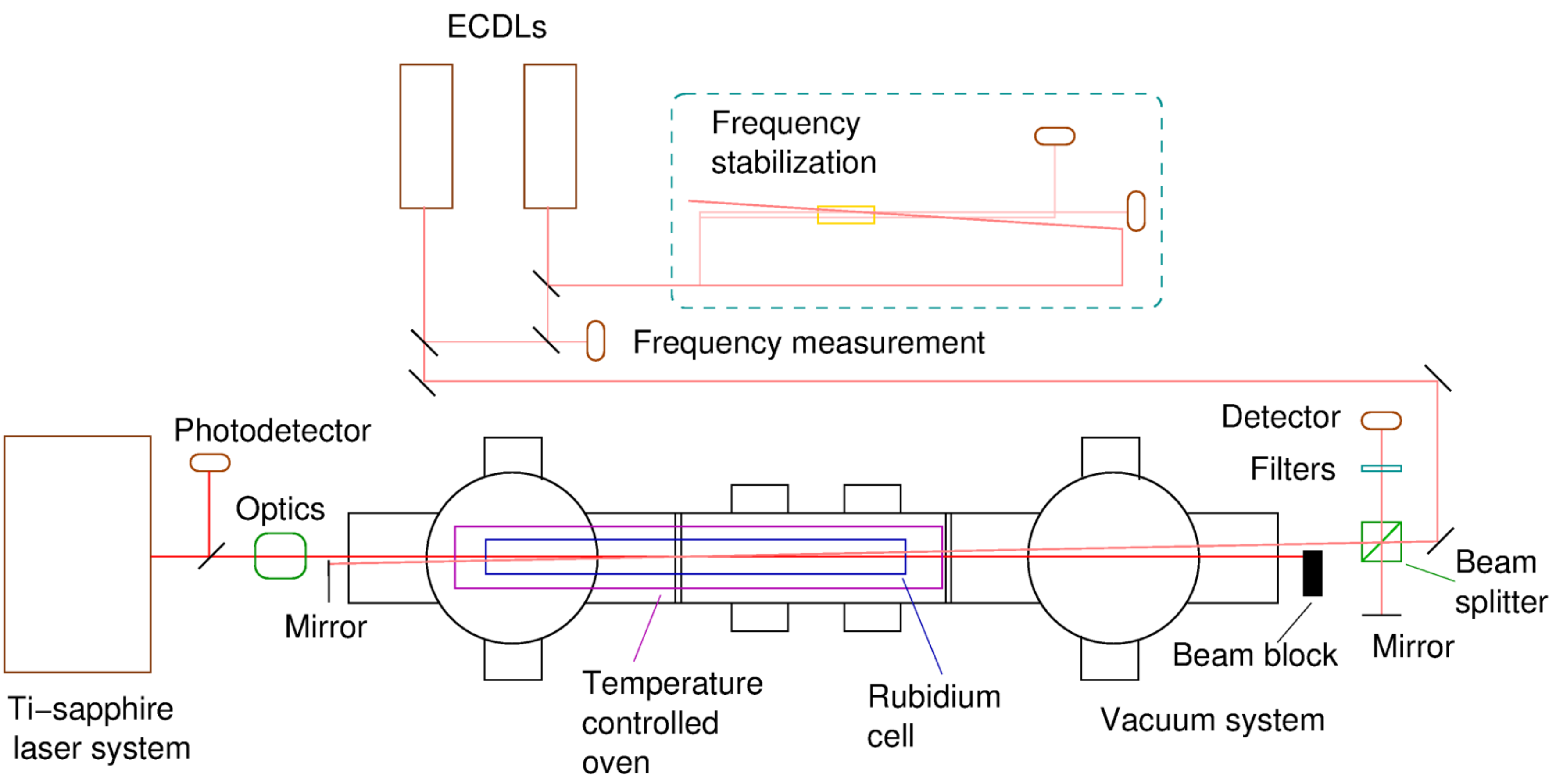
Cw level is different for detector 1 and detector 2:
- beam divergency, different coupling into the detector fiber
- condensed Rb on the windows surface
- different vapor temperature and density

- CW signal is absorbed close to the resonance lines

- Negative peak sygnal is missing far from the atomic lines

- ‘Plasma oscillations’

Plasma density measurements by longitudinal interferometry



Phase variation

$$I_{\text{int}\,erf}(t) = I_{tr}(t) + I_{ref} + 2\varepsilon\sqrt{I_{tr}(t) I_{ref}}\cos(\varphi_0 + \varphi_1(t))$$

$$\varphi_1(t) = (2\pi/\lambda) L \Delta n(t)$$

Phase variation

$$n(\Delta\omega) = 1 - \frac{N\pi f e^2}{2m}\sum_{i=1}^{2} p_i \sum_{j=1}^{2} \frac{\Delta\omega_j^{(i)}}{\omega_{0j}^{(i)}(\Delta\omega_j^{(i)2} + \Gamma^2)}$$

Refractive index

$$\Delta N_p(t) L = \varphi_1(t)\frac{2\lambda_L m}{\pi^2 f e^2} / [\sum_{i=1}^{2} p_i \sum_{j=1}^{2} \frac{\Delta\omega_j^{(i)}}{\omega_{0j}^{(i)}(\Delta\omega_j^{(i)2} + \Gamma^2)}]$$

Plasma density * length

Phase variation @ Doppler broadening

$$n(\Delta\omega) = 1 - \frac{\pi\Delta\omega N f e^2 / m\omega_0}{\Delta\omega^2 + \Gamma^2}$$

$$n(\Delta\omega) - 1 = -\Gamma\alpha_0 \int_{-\infty}^{\infty} D(\sigma)\frac{(\Delta\omega+\sigma)}{(\Delta\omega+\sigma)^2 + \Gamma^2} d\sigma$$

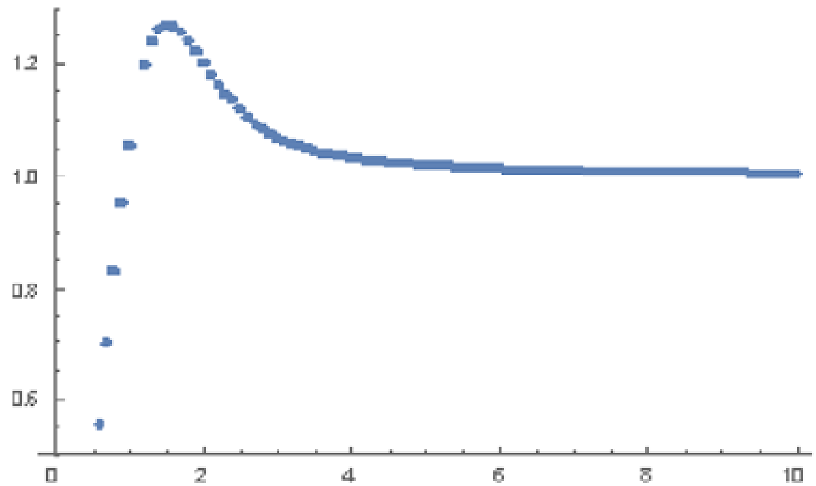
$$\alpha_0 = \pi N f e^2 / (\Gamma m \omega_0)$$

Absorption coefficient

$$D(\sigma) = \frac{1}{\sqrt{\pi}\sigma_0} e^{-\sigma^2/\sigma_0^2}$$

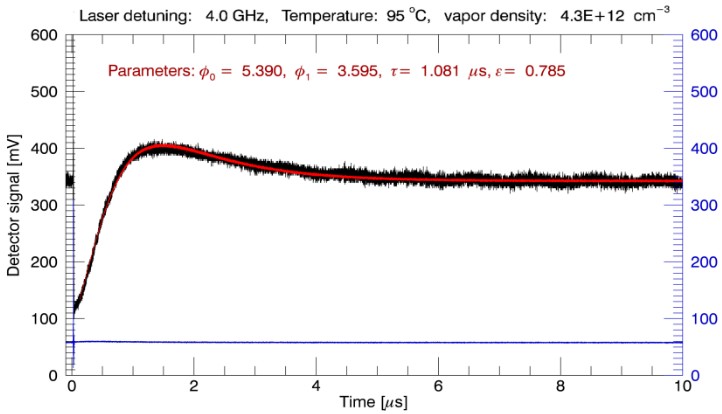
Doppler broadening

Comparative function: $\Theta(\Delta\omega) = \Delta N_p(t) / \Delta N_p^{(D)}(t)$

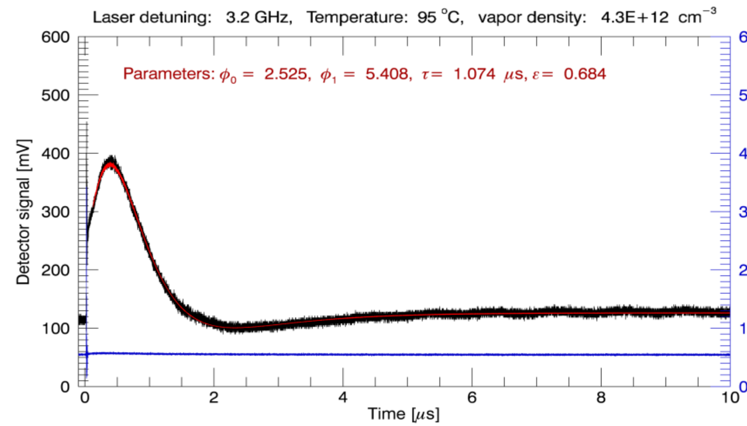


Normalized detuning

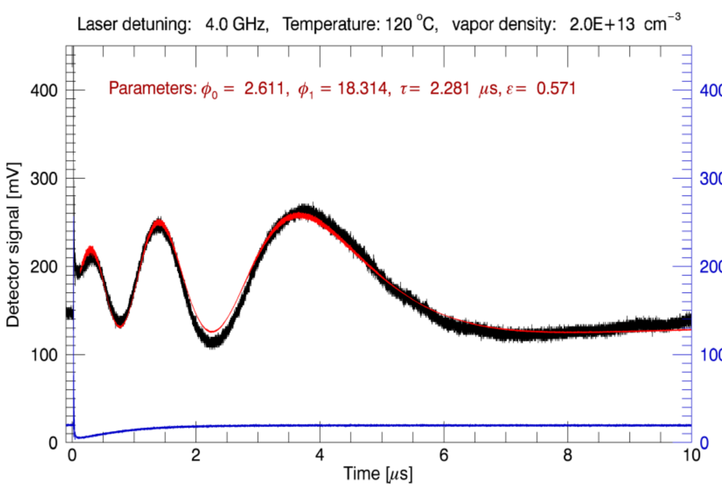
Results: time dependent fringes



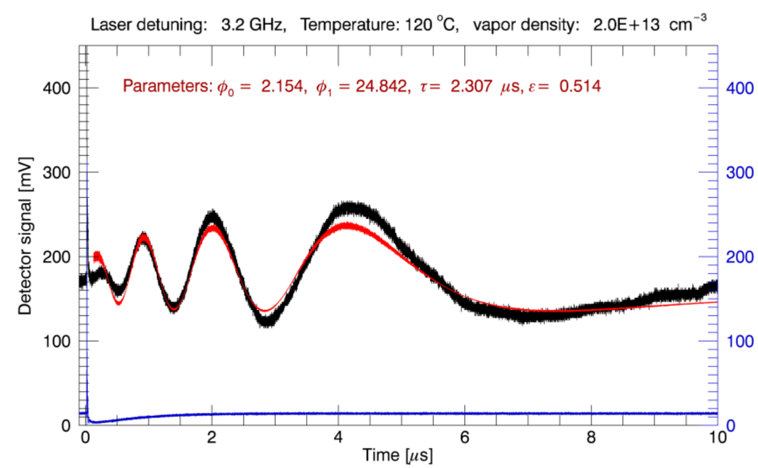
ΔN =2.0x10^{11} cm^{-3} 7.8% 3.6 rad



ΔN=2.4x10^{11} cm^{-3} 10.8% 5.4 rad



ΔN =1.0x10^{12} cm^{-3} 8.5% 18.3 rad



ΔN =1.1x 10^{12} cm^{-3} 10.6% 24.8rad

Plasma relaxation

$$I_{\text{int}\,erf}(t) = I_{tr}(t) + I_{ref} + 2\varepsilon\sqrt{I_{tr}(t) I_{ref}}\cos(\varphi_0 + \varphi_1(t))$$

$$\frac{dN}{dt} = -\frac{1}{\tau}N \qquad N_D = N_0 e^{-t/\tau_{N0}}$$

Diffusion model

$$\frac{dN}{dt} = -\alpha N^2 \qquad N_{3B} = \frac{N_0}{1 + N_0 \alpha t}$$

3 body recombination model

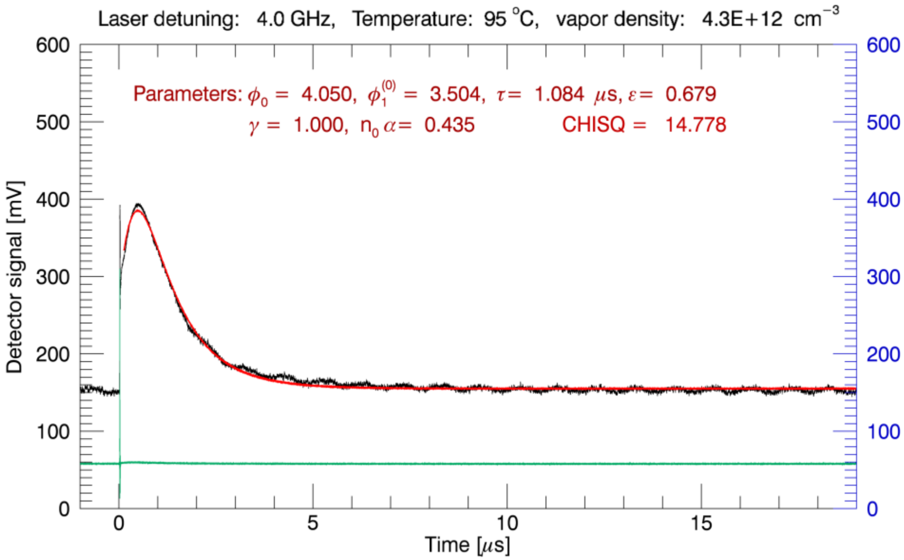
$$\frac{dN}{dt} = -\beta N^3 \qquad N_{3BP} = \frac{N_0}{\sqrt{1 + 2N_0^2 \beta t}}$$

Pitaevski: $\alpha = \beta N$

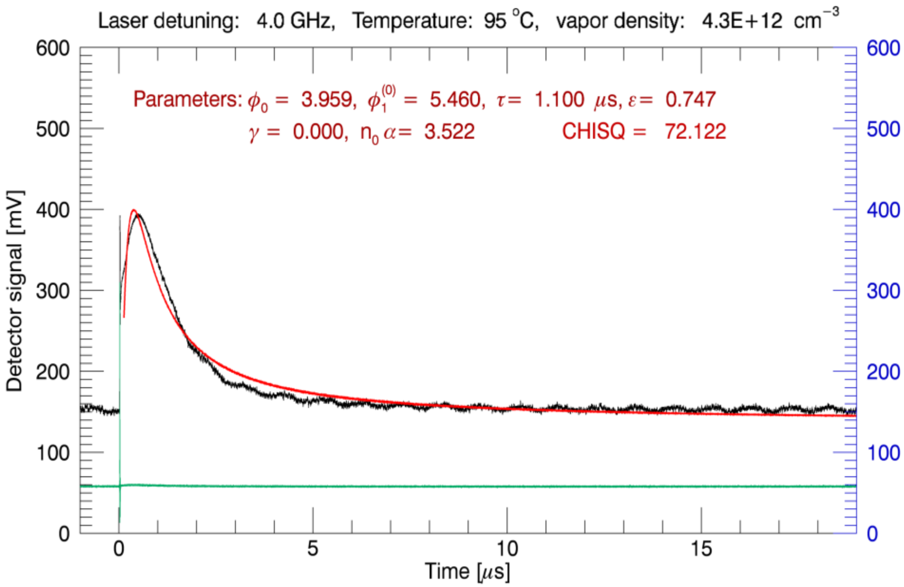
$$N_{PM} = \gamma N_0 e^{-t/\tau_{N0}} + (1-\gamma)\frac{N_0}{1 + N_0 \alpha t}$$

P. Muggli MPP

Curve fitting for diffusion @ 3body model

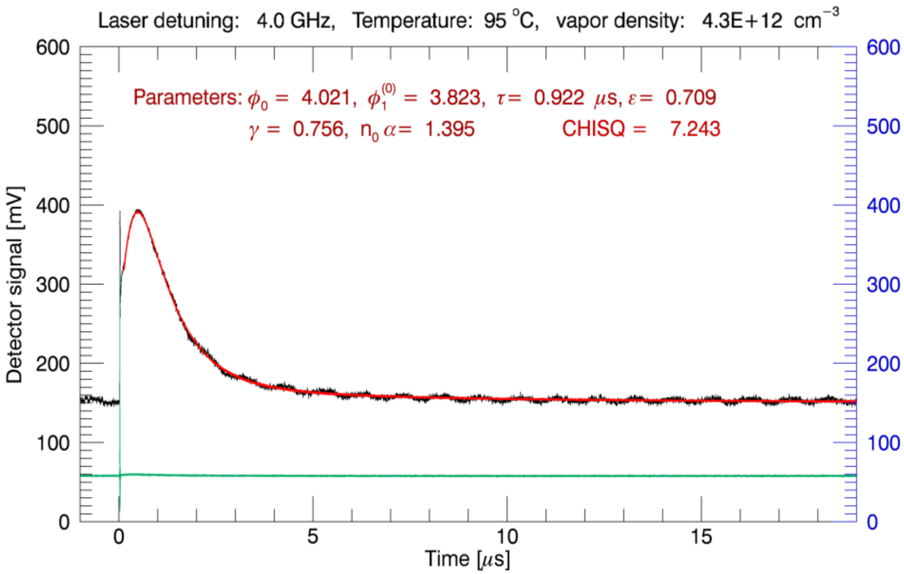


$$N_D = N_0 e^{-t/\tau_{N0}}$$

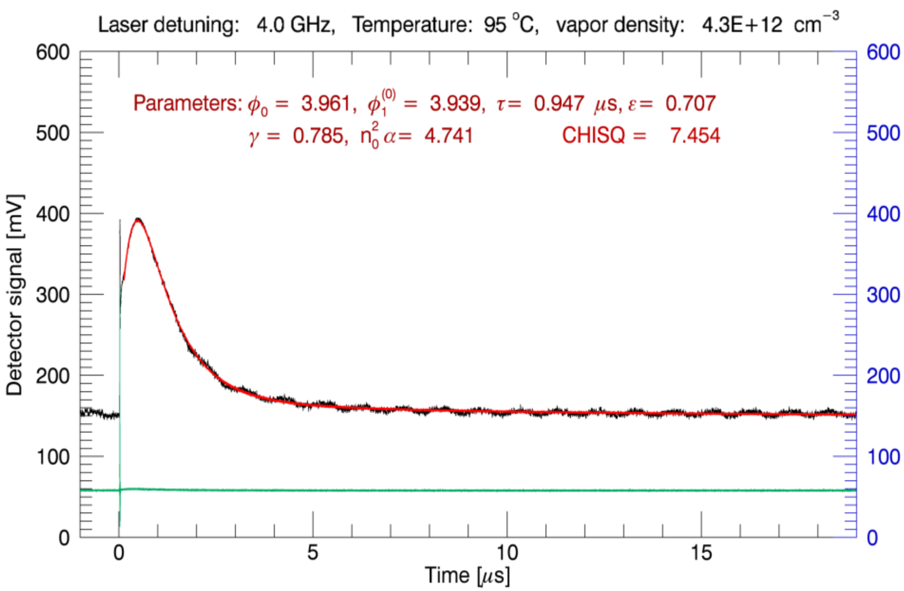


$$N_{3B} = \frac{N_0}{1 + N_0 \alpha t}$$

Curve fitting for mixed models



$$N_{PM} = \gamma N_0 e^{-t/\tau_{N0}} + (1-\gamma)\frac{N_0}{1+N_0\alpha t}$$



$$N_{D+3BP} = N_0\left[\gamma e^{-t/\tau_{N0}} + (1-\gamma)\frac{1}{\sqrt{1+2N_0^2\beta t}}\right]$$

Fit courtesy of M. Kedves

Interpretation of decay time

Knudsen regime: mean free path ~ characteristic length

Intermediate state between molecular flow and viscous flow

Mean free path in Rb vapor:

$$L = \frac{1}{\sqrt{2}d^2 \pi N}$$

$L =$ 4.5cm at 120 C^o and 2x10^{13} cm^{-3}

$L =$ 20.9cm at 95 C^o and 4,3x10^{12} cm^{-3}

$d = 5x10^{-10} m$ atomic diameter for Rb

Rb vapor cell below 120 C^o : quasi collisionless flight of atoms:

Probe beam channel is filled with neutral atoms out of the channel

$$v_{rms} = \sqrt{\frac{3k_B T}{m}}$$ ~ 330 m/s at 95 C^o and 340 m/s at 120 C^o

$$\frac{dN}{dt} = -\frac{1}{\tau_{N0}} N$$ Linear kinetic equation

$$N = N_0 e^{-t/\tau_{N0}}$$ Exponential decay

Ratio of collisions on a characteristic length $l = 1cm$ $N_C / N_0 = (1 - e^{-l/L})$

$N_C / N_0 = 0.05$ at 95 C^o

$N_C / N_0 = 0.2$ at 120 C^o

The greater the density

The greater the decay time

Thank you

for your

attention