High resolution metrology of the 1S–3S transition frequency of the hydrogen atom

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Physique quantique et applications

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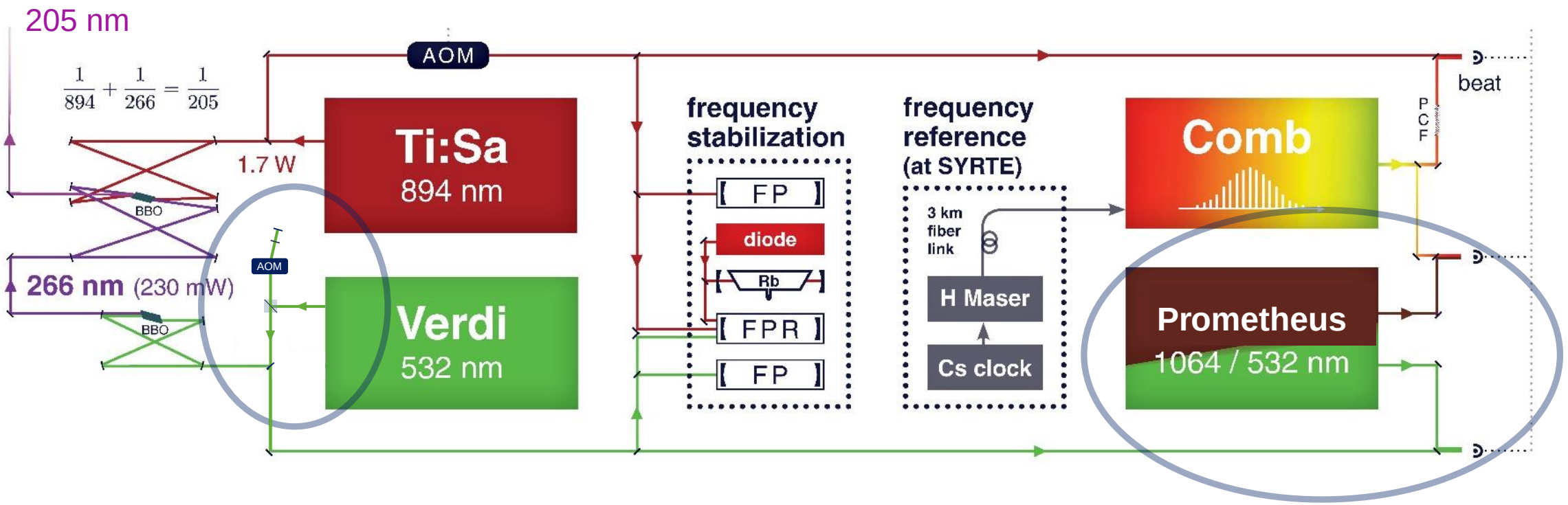
Changes in the experimental setup

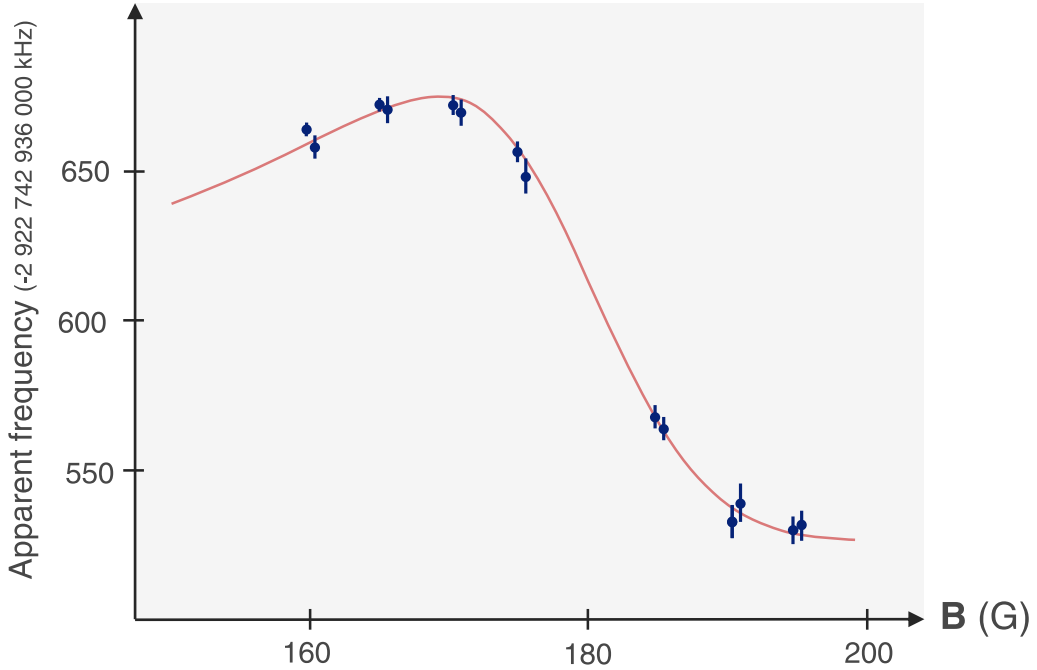
Phase stabilization of the Verdi + t**ransfer laser** between the Verdi and the frequency comb



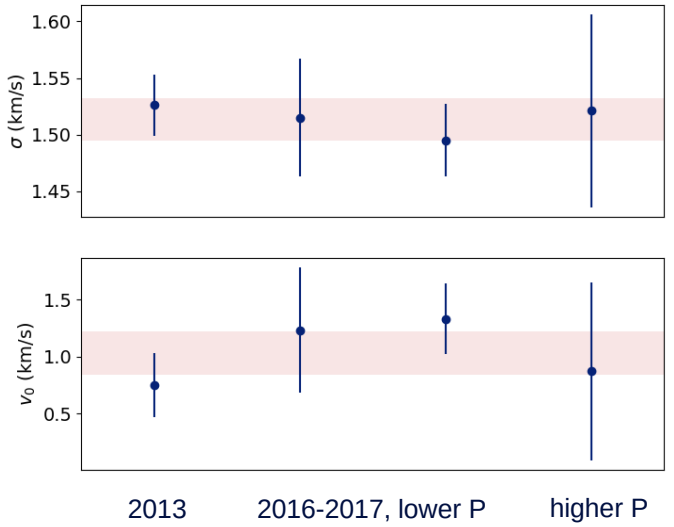
+ replacement of the BBO cristals, the pressure gauge, the discharge tube, etc.

Pressure dependency of the $\vec{v}$ distribution

Determination of σ and v_0:



→ no noticeable pressure dependency



→ 3 kHz of variability, added in quadrature to the uncertainty on Sandrine's correction at ≠ P.

Residual EM fields:

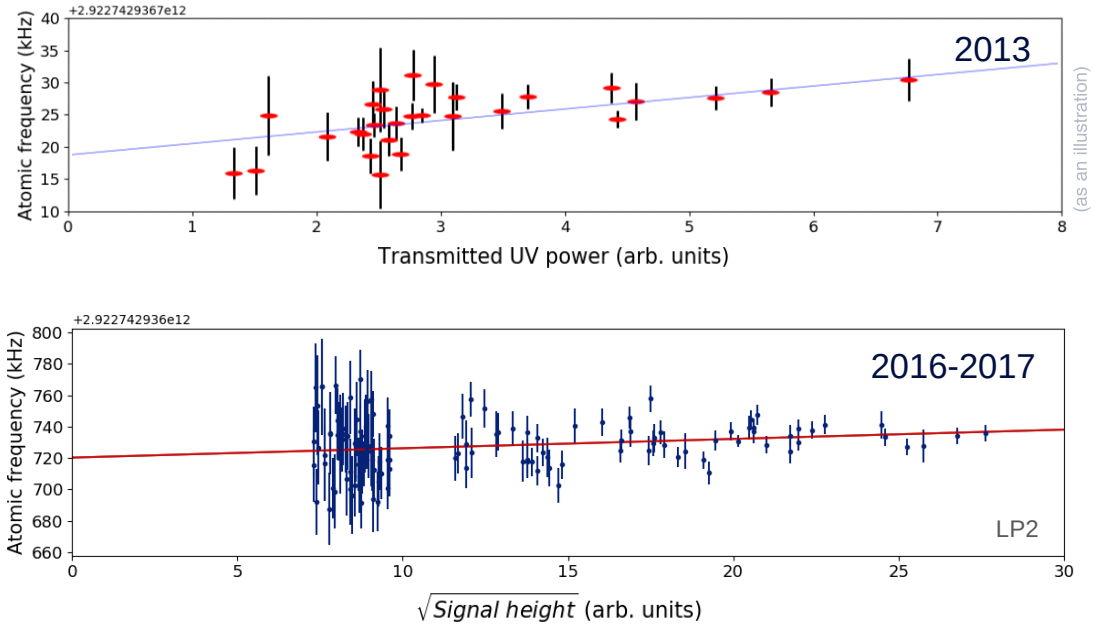
- applied-$\vec{B}$ direction reversed every two runs;
- earth-$\vec{B}$ compensation + aquadag paint redone ;
- fit including $\vec{E}_{residual} \Rightarrow \vec{E}_{residual} = 0$.

Model dependency:

- negligible m_F ground state population difference;
- Voigt broadening under study at ≠ $\vec{B}$;
- QI being added to the theoretical lineshape.

Remeasurement of light & collisional shifts

Extrapolation to zero UV power:

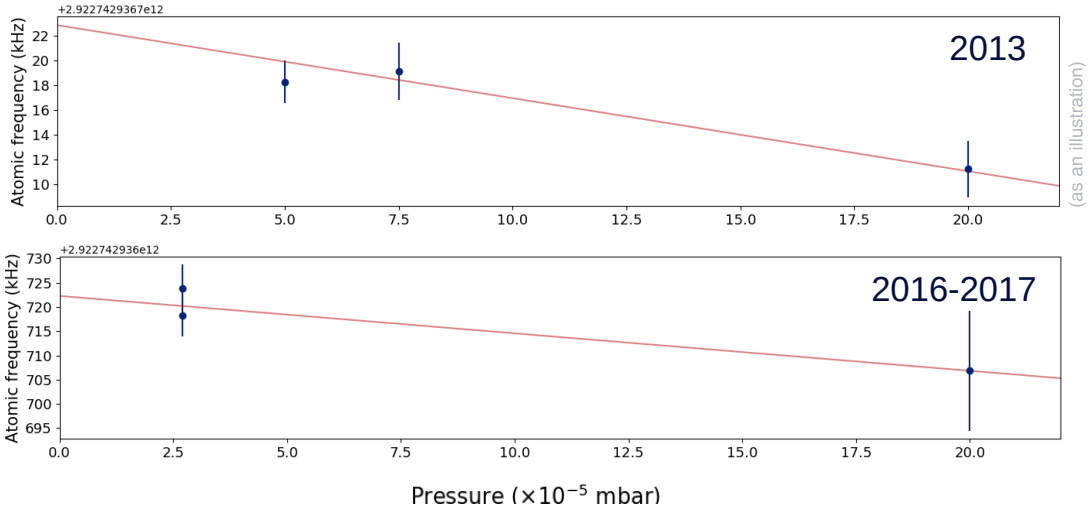


Agreement between different I_{UV} estimations:

- incident power;
- transmitted power (with fluorescein);
- √ signal height (corrected).

Negligible gaussian beam light shift dependency.

Extrapolation to zero pressure:

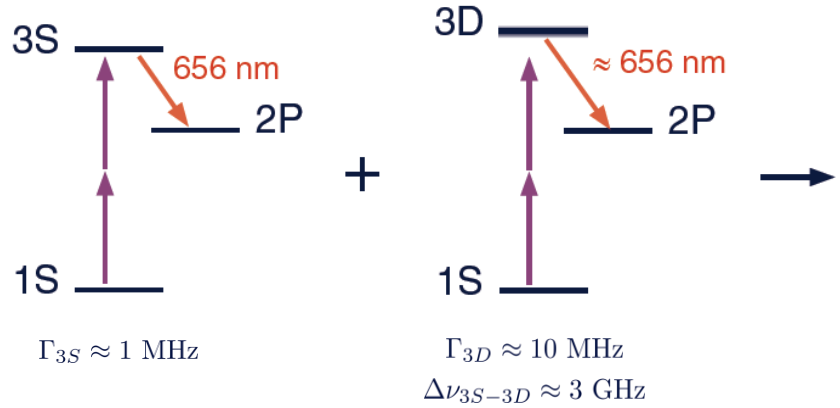


Relative pressure measurement (side of the vacuum chamber).

Agreement within the experimental uncertainties after Doppler, light & pressure shifts correction, of the results of the different data sets.

Cross damping effect

Interference between quantum paths

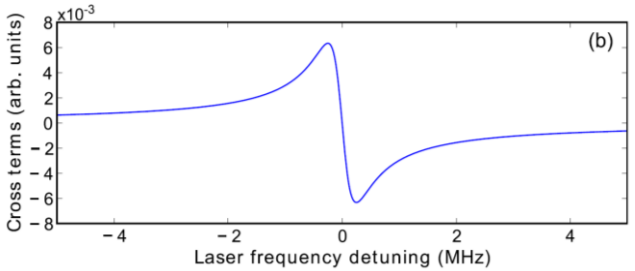


$\Gamma_{3S} \approx 1$ MHz

$\Gamma_{3D} \approx 10$ MHz

$\Delta\nu_{3S-3D} \approx 3$ GHz

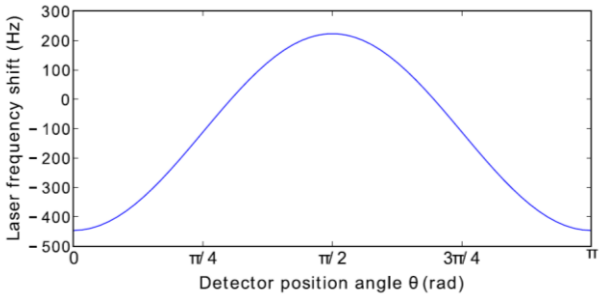
$$\frac{d\sigma}{d\Omega}(\omega) \propto \sum_{f=2P,\vec{\epsilon}} \left| \sum_{k=3S,3D} \frac{\hat{Q}_{ik}\hat{D}_{kf}}{\omega_{ik} - 2\omega - i\frac{\Gamma_k}{2}} \right|^2$$



Variation of the excitation probability.

Leading to a resonance frequency shift
dependant on the detection geometry.

→ correction of 0.6(2) kHz.



(Fleurbaey et al., Phys. Rev. A **95**, 2017)

Our results

After H-maser and hyperfine centroid corrections:

$$f^{2013}_{1S-3S} = 2\,922\,743\,278\,671.6\ (2.8)\ \text{kHz}$$
$$f^{2017}_{1S-3S} = 2\,922\,743\,278\,671.0\ (4.9)\ \text{kHz}$$

} estimated covariance: (1.6 kHz)²

(from the added uncertainty due to the $\vec{v}$-distribution determination)

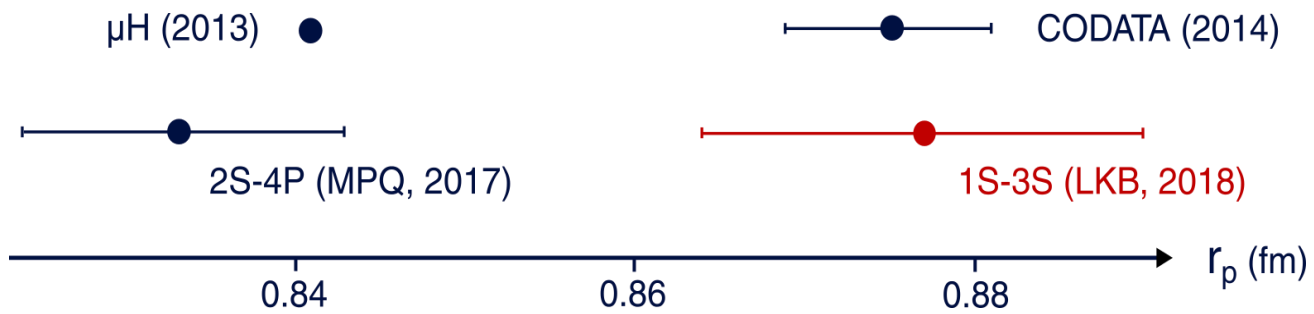
$$f_{1S-3S} = 2\,922\,743\,278\,671.5\ (2.6)\ \text{kHz}$$

$u_{rel} = 9 \times 10^{-13}$

$$R_\infty = 10\,973\,731.568\,53(14)\ \text{m}^{-1} \qquad r_p = 0.877(13)\ \text{fm}$$

(when combined with f_{1S-2S}, MPQ, 2011)

Data set	2013	LP1	LP2	HP
σ (km/s)	1.526(27)	1.515(52)	1.495(32)	1.521(85)
v_0 (km/s)	0.75(28)	1.23(55)	1.33(31)	0.87(78)
ν_A (kHz)	592.2(0.7)	596.8(0.9)	594.4(1.1)	581.6(2.2)
Δ (kHz)	132.6(1.3)	137.4(3.8)	135.9(2.1)	131.6(6.8)
ν_{fit} (kHz)	724.8(1.5)	734.2(3.9)	730.3(2.4)	713.2(7.1)
Δ_{LS} (kHz)	−5.9(1.2)	−10.4(3.0)	−12.1(3.6)	−6.3(10.2)
ν_{LS} (kHz)	718.9(1.9)	723.8(4.9)	718.2(4.3)	706.9(12.4)
Δ_p (kHz)	3.6(2.0)	Pressure extrapolation		
$\nu_{\text{LS},p}$ (kHz)	722.5(2.8)	722.3(4.9)		
Δ_{cd} (kHz)	0.6(0.2)	0.6(0.2)		
Δ_{maser} (kHz)	−0.599(6)	−1.043(6)		
$\nu^{(F=1)}_{1S-3S}$	722.5(2.8)	721.9(4.9)		

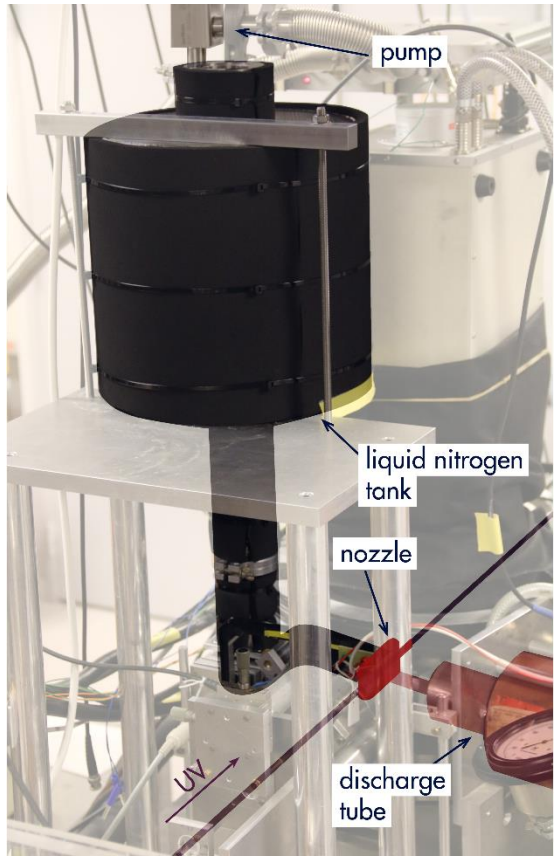


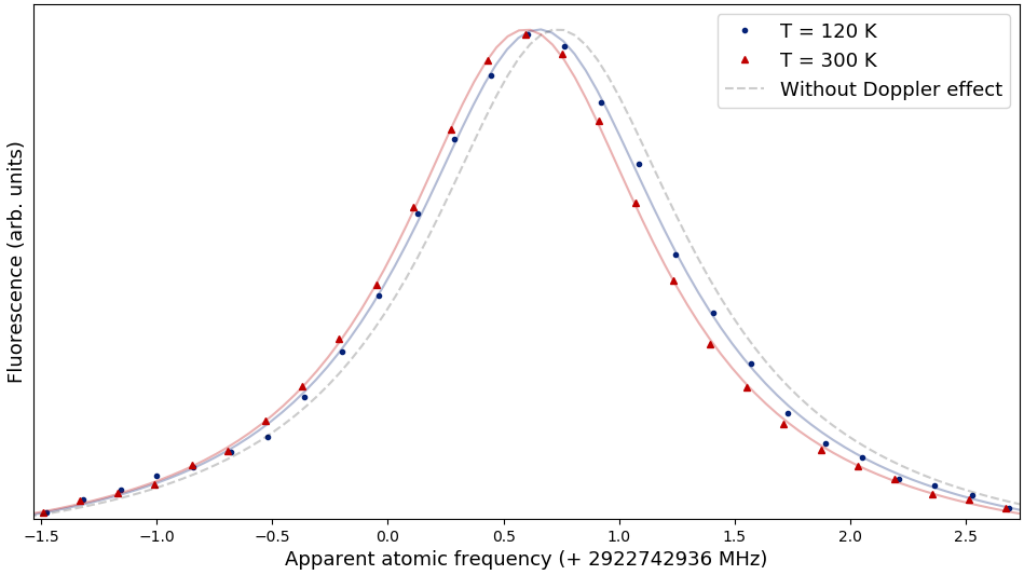
2.8σ away from muH, 0.1σ from CODATA14

(Fleurbaey et al., Phys. Rev. Lett. **120**, 2018)

Since last year: fresh atoms

A new nozzle cooled down by liquid nitrogen





- reduction of the 2nd order Doppler effect (~60%);
- test of the $\vec{B}$ method with a different $\vec{v}$-distribution;
- but longer measurement time…

What next?

- 1S–3S in **deuterium**
  - only already observed
  - reduced Doppler effect
- **1S–4S** in hydrogen
  - yet to be observed
  - Γ_{1S-4S} = 0.7 MHz
  - possible determination of the $\vec{v}$-distribution via the Doppler shift of a 2S–nP transition.

Thank you for your attention!