Quantum interferometry in the time domain using massive particles

Philipp Geyer, Jonas Rodewald, Nadine Dörre,
Philipp Haslinger and Markus Arndt

Quantum nanophysics, VCQ, University of Vienna

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Motivation

Foundations of quantum physics

- Exploring the mass limits of the wave particle duality
  - Testing collapse models
- Decoherence studies
  - Photofragmentation decoherence
  - Collisional decoherence

Applications: Precise measurements of nanoparticle properties

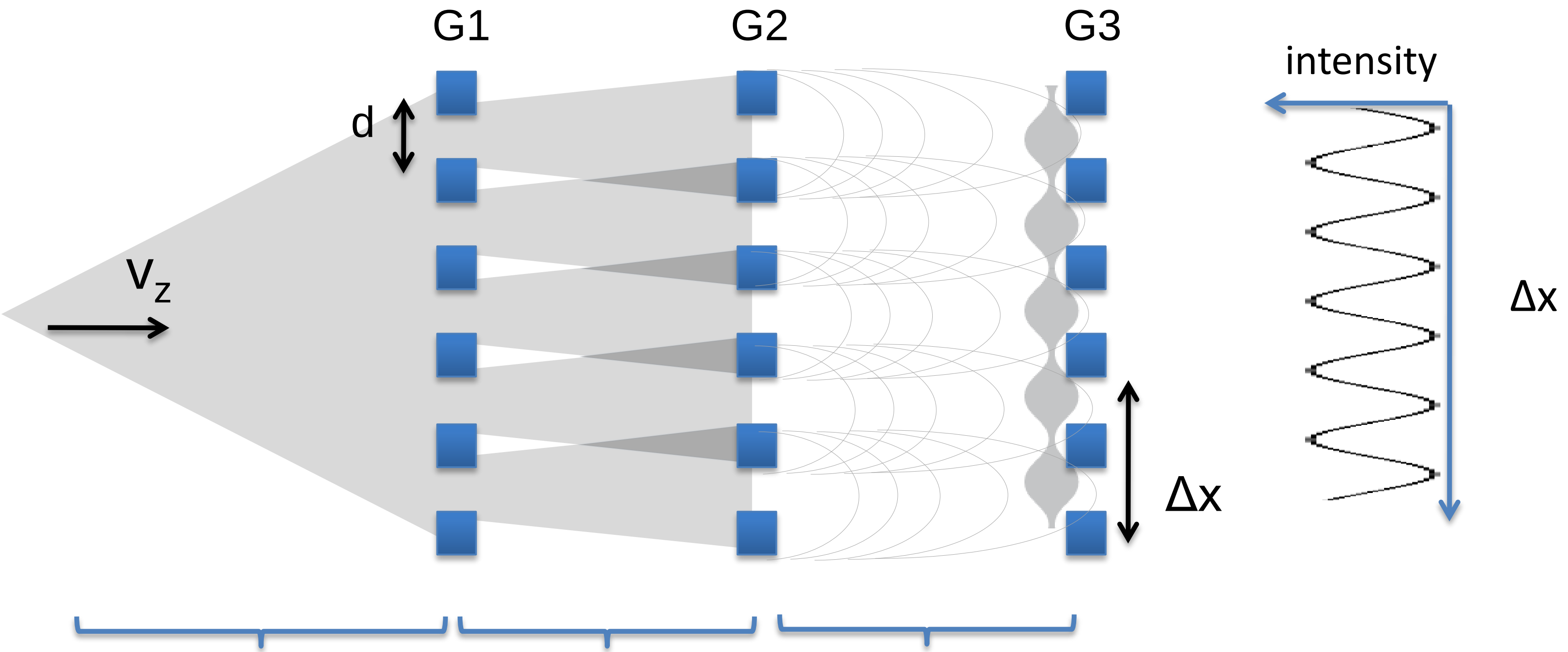
- Absorption spectroscopy
- Polarisability spectroscopy
- Magnetic and/or electric deflectometry

Opt. Comm. 264, 326-332 (2006).

Phys. Rev. A 83, 043621 (2011).

New J. Phys. (2011).

Talbot-Lau interferometry



Incoherent matter waves	Preparation of transversal coherence	Diffraction	Detection by shift of G3

$$\lambda_{dB} = \frac{h}{m \cdot v_z}$$

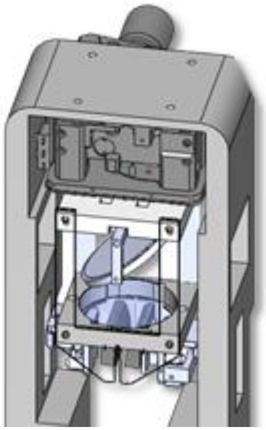
$$L_T = \frac{d^2}{\lambda_{dB}}$$

Talbot, Philos. Mag. 9 (1836)
Lau, Ann. Phys. 2 (1948)
Brezger et.al., PRL 88 (2002)
Hornberger et.al., Rev. Mod. Phys. (2011)

Talbot-Lau interferometry with ionizing optical gratings in the time domain

transition to time-domain

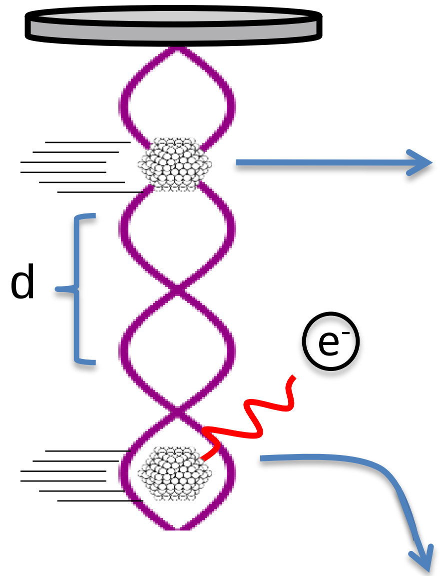
$$L_t = \frac{d^2}{\lambda_{dB}} \quad \longrightarrow \quad T_t = \frac{md^2}{h}$$



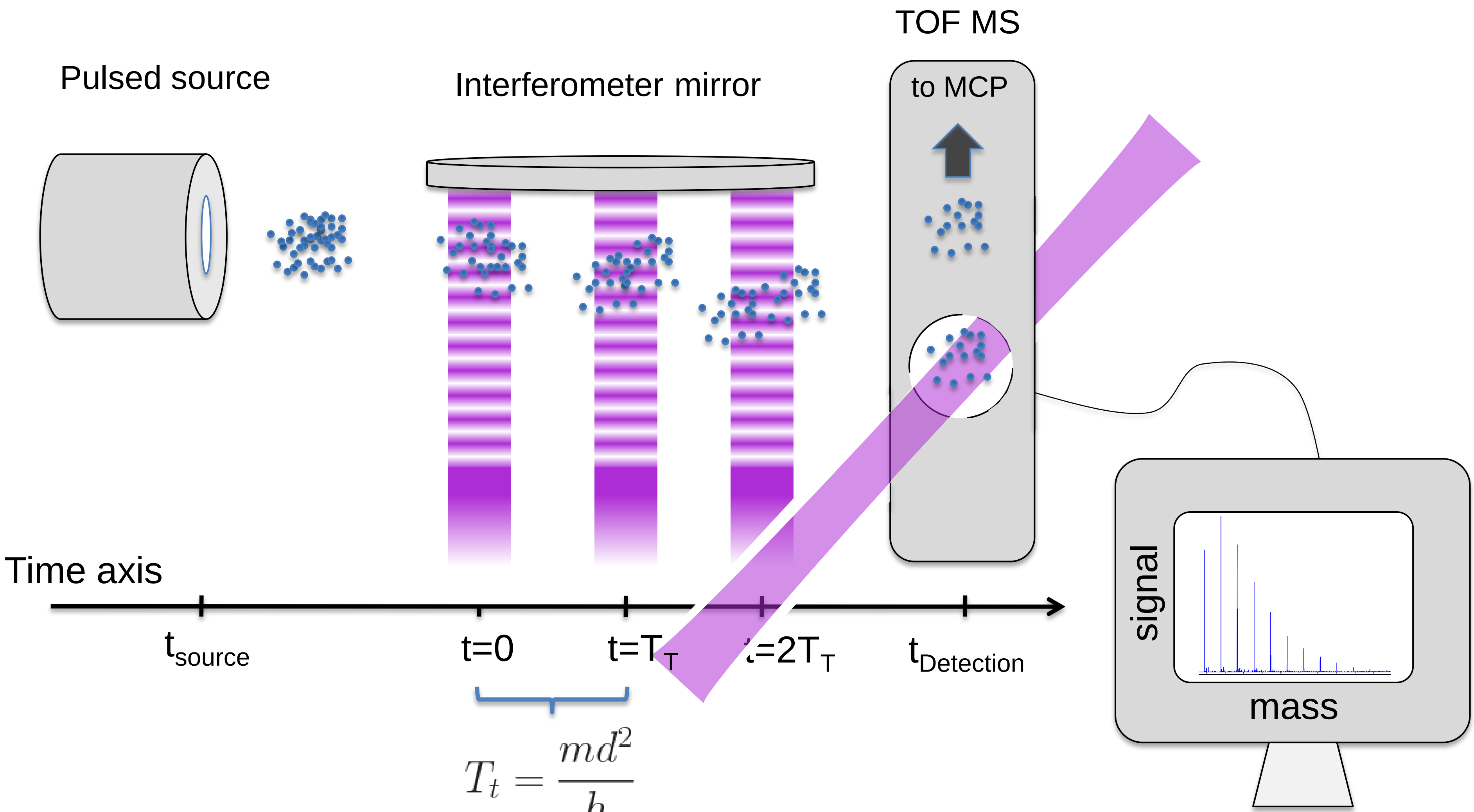
After the same time, all particles with the same mass produce the same interference pattern, regardless of their velocity!

Gratings made of laser light pulses

- Small grating period: d=78,5 nm
- No van der Waals interactions
- No velocity selection needed
- Expected visibility: V $\simeq$ 100%
- Precise timing: Δt < 2 ns
- Variable pulse energy $\rightarrow$ fine control over grating opening fraction



OTIMA's Experimental Setup

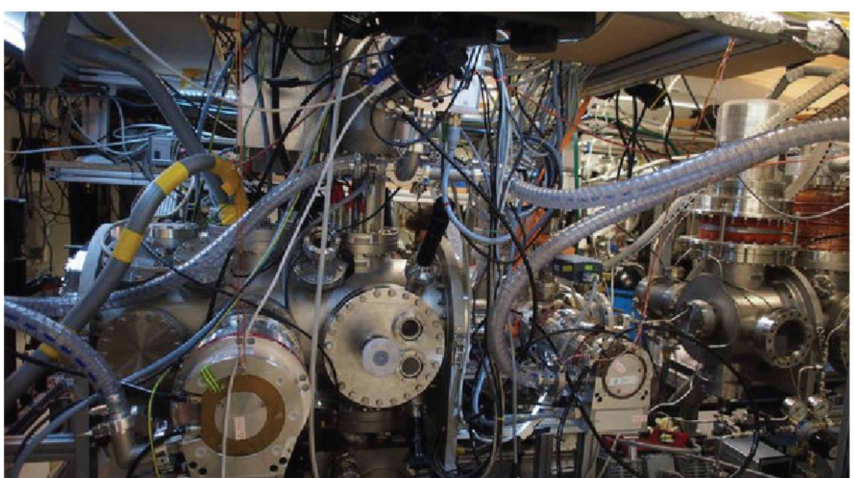


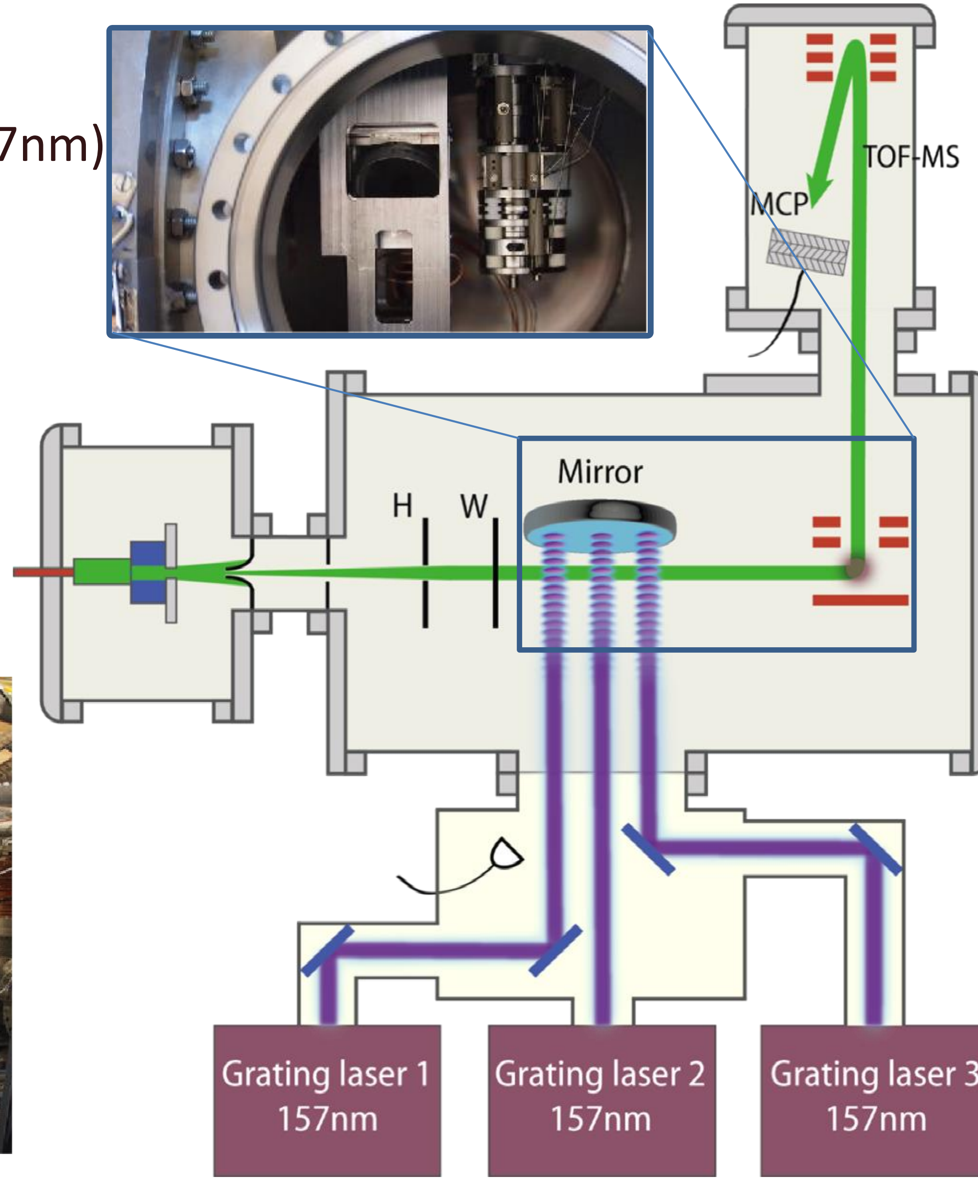
$$T_t = \frac{md^2}{h}$$

Haslinger et. al. Nature Physics (2013)
Nimmrichter et.al., NJP 13 (2011)

The OTIMA Apparatus

- Even Lavie valve (20 us)
- VUV Excimer Lasers (~7ns, 157nm)
- TOF-MS (m/Δm ~ 5000)
- 10bit 8GHz Digitizer
- Custom Acquisition Software

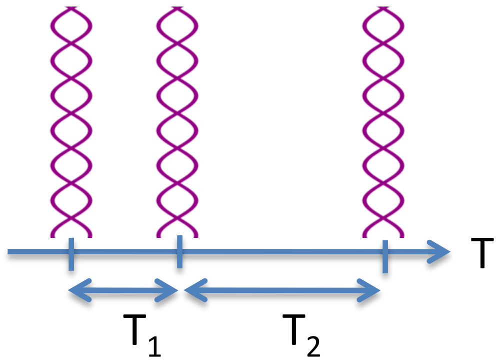




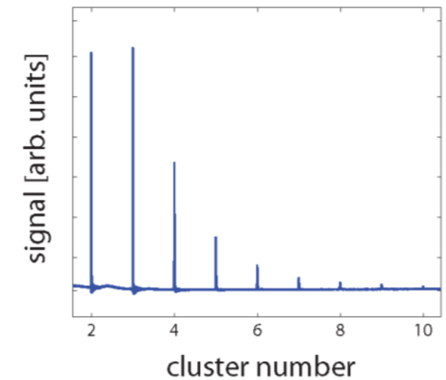
OTIMA's Experimental Protocol

TL-off-resonant

$$T_1 + 200ns = T_2$$

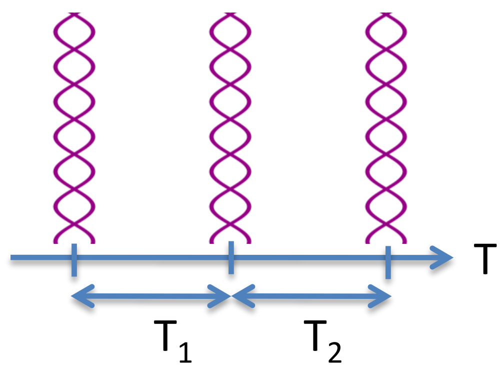


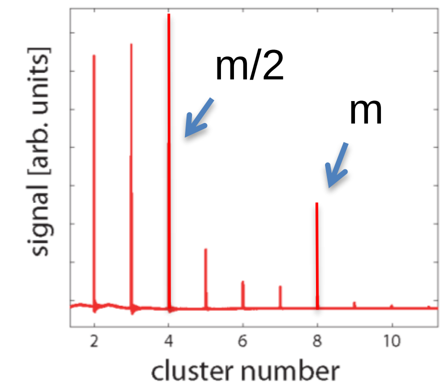
record the mass spectrum



TL-resonant
for mass m

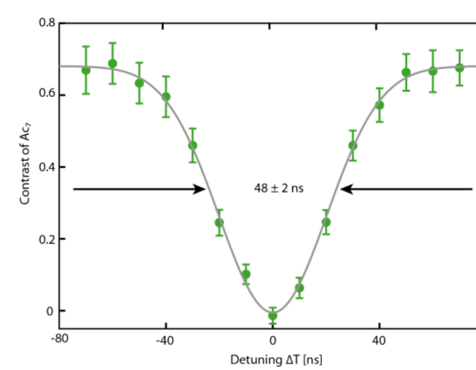
$$T_1 = T_2 = T_T(m)$$



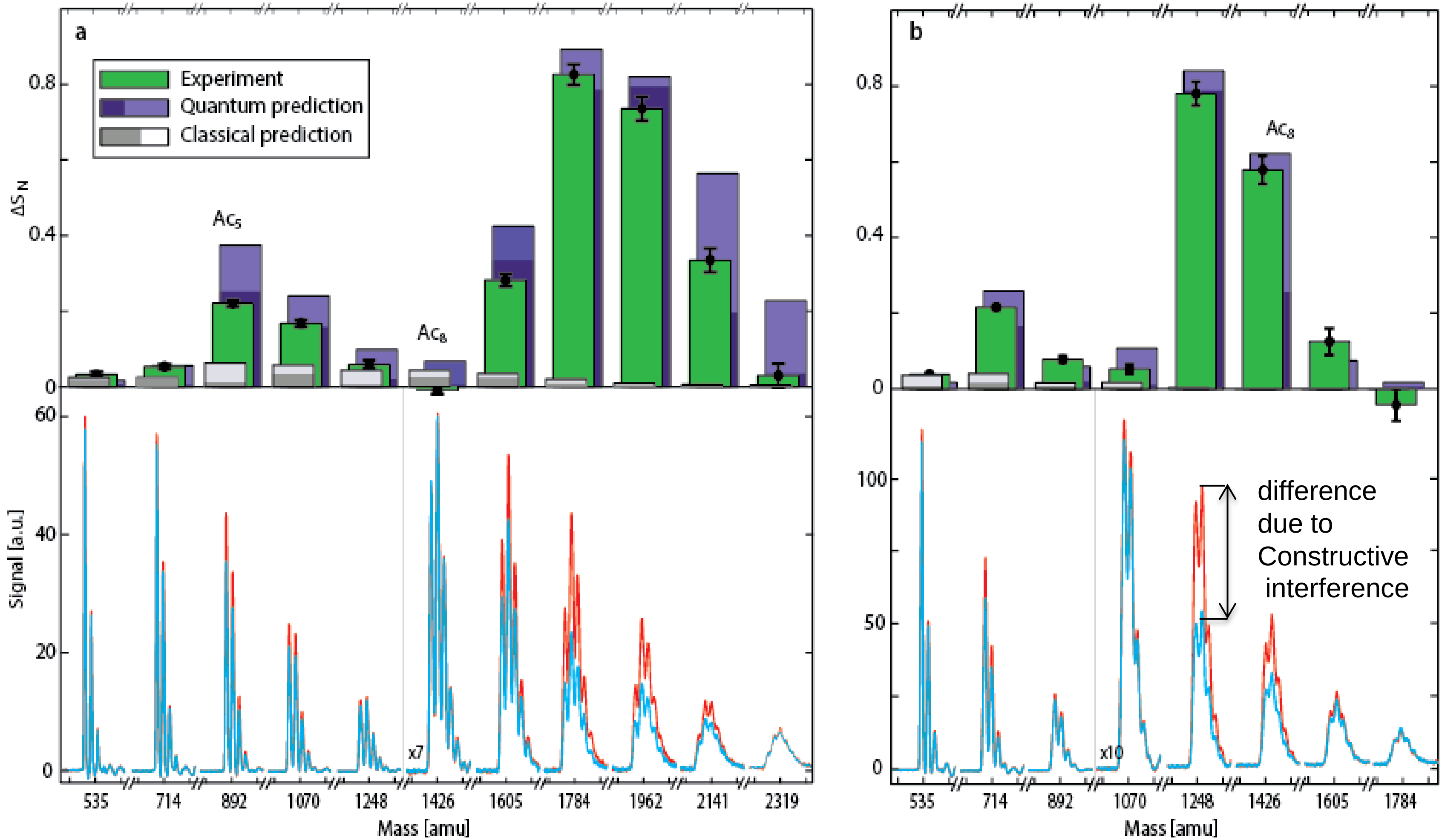


$$T_t = \frac{md^2}{h}$$

$$C_N = \frac{\text{resonant} - \text{off resonant}}{\text{off resonant}}$$



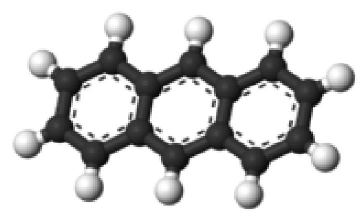
Anthracene interference



Argon seedgas, $v_{avg} \approx 700 m/s$

Neon seedgas, $v_{avg} \approx 920 m/s$

$C_{14}H_{10}$ (178 amu)



Haslinger et. al. Nature Physics (2013)

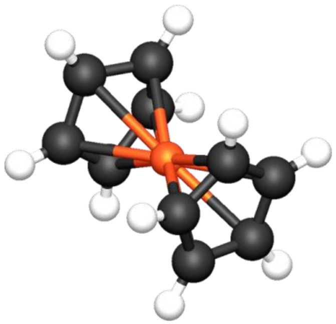
Other Clusters of molecules that also have been interfered in the OTIMA

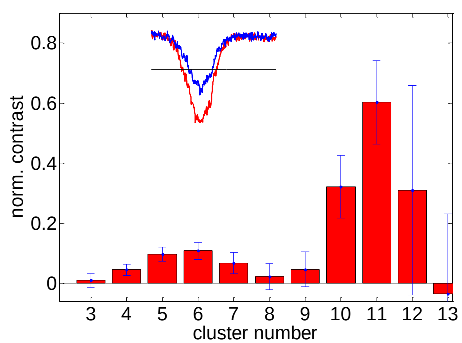
Ferrocene

$Fe(C_5H_5)_2$

m = 186 amu

1973

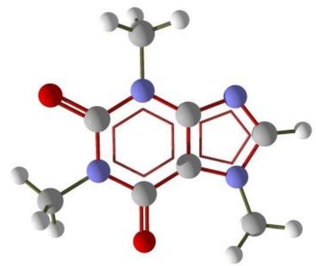


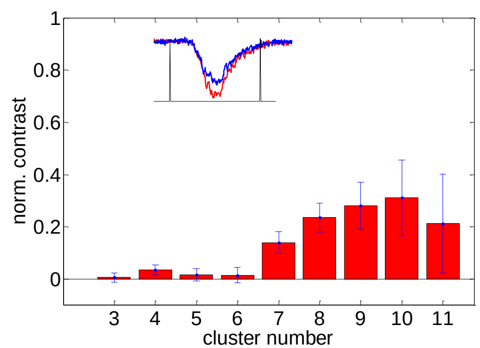


Coffein

$C_8H_{10}N_4O_2$

m = 194 amu

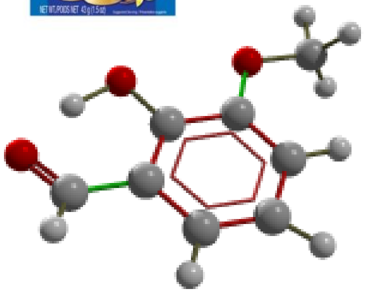


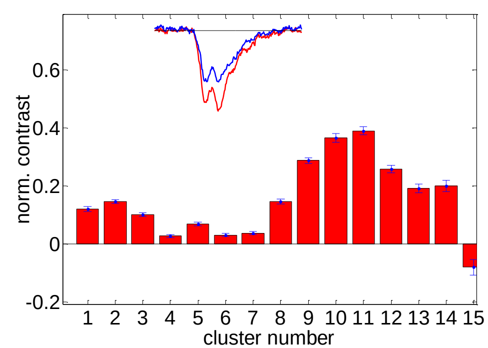


Vanillin

$C_8H_8O_3$

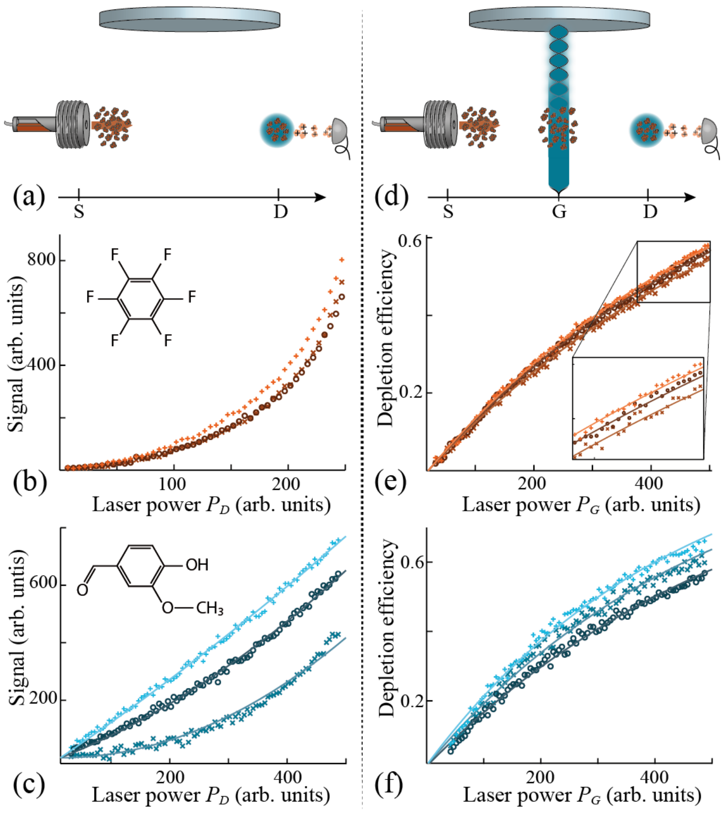
m = 152 amu

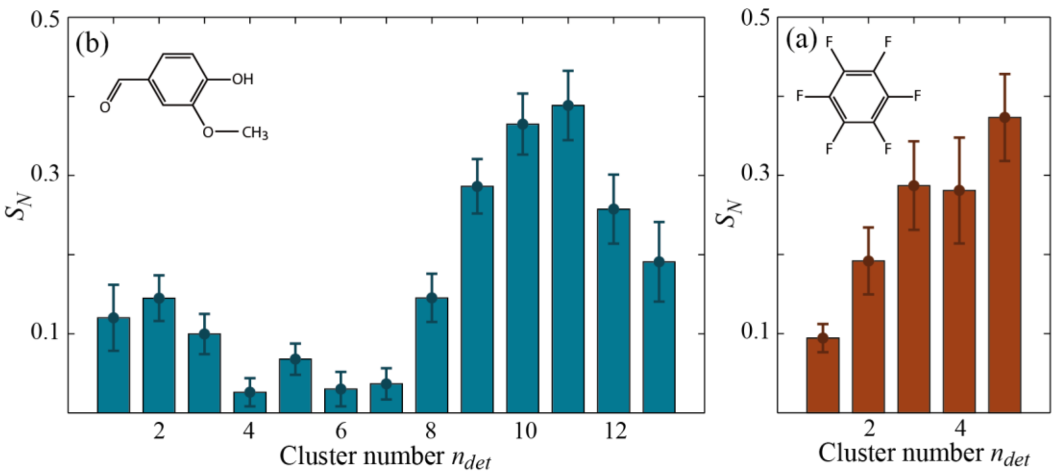




Single Photon Fragmentation Grating

- Van der Waals clusters ca be easly fragmented
  - Hexafluorbenzol Clusters
  - Vanillin Clusters
- No more need for single photon ionisation
- Interference with new molecules in reach





N. Dörre et. al. 2014

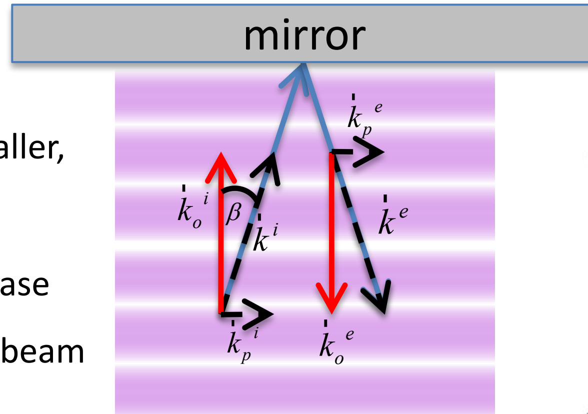
Alternative Experimental Protocols

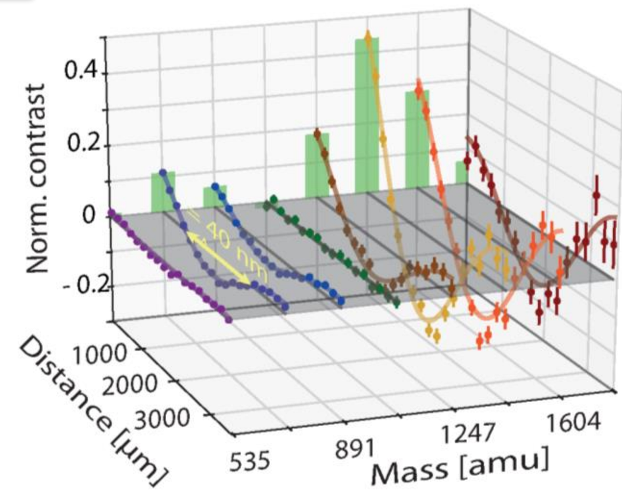
Tilt 2nd grating (few mrad)

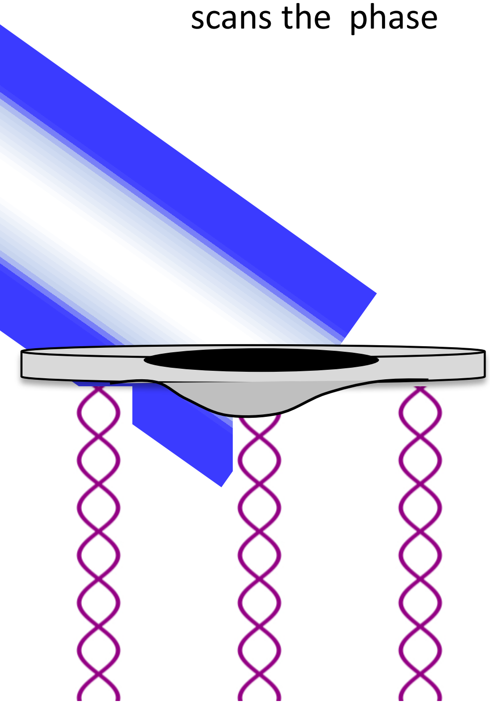
→ k-vector orth. to mirror surface smaller, grating period longer

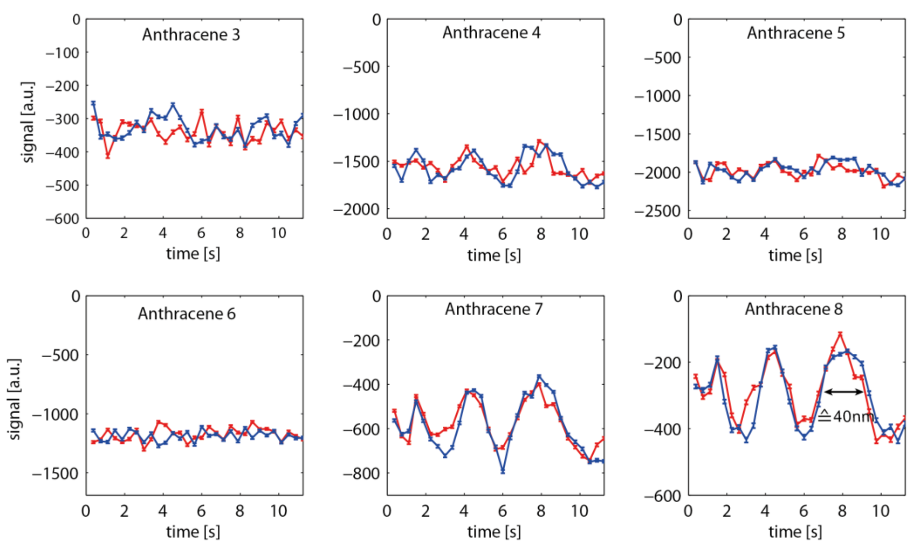
→ Accumulation of an effective G2-phase over the distance mirror-cluster beam

→ Scanning mirror-cluster distance scans the phase









Heat the mirror over G2

→ Thermal expansion shifts G2

→ Scanning heating time scans the temperature

→ Scanning the temperature scans the phase

Outlook: Towards Large Masses

No dispersive Van-der-Waals interaction.

→high interference contrast expected for masses even beyond 10^6 amu

mass	Talbot time	required velocity	required vacuua	gravitational deflection
10^6 amu	15 ms	1.3 m/s	10^{-9} mbar	4.5 mm
10^7 amu	150 ms	13 cm/s	10^{-11} mbar	45 cm
10^8 amu	1.5 s	1.3 cm/s	10^{-12} mbar	45 m

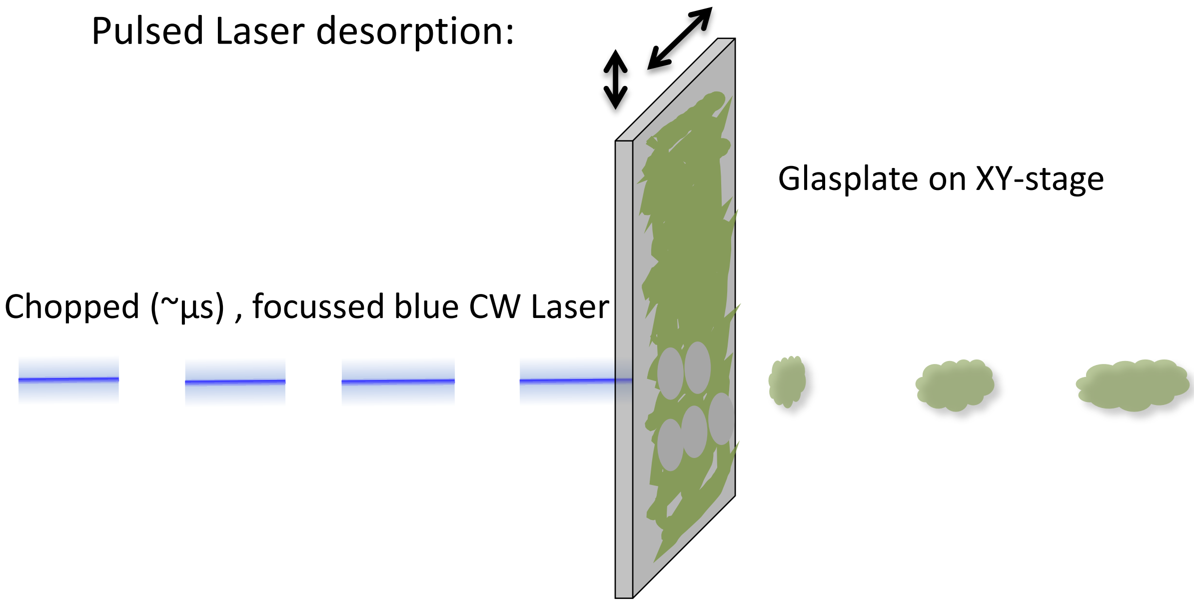
Cooling and/or trapping necessary

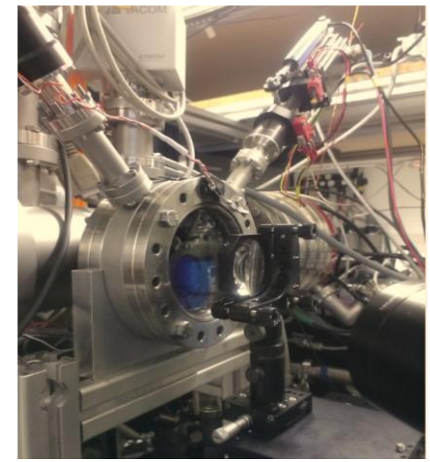
Managable

Requires a vertical interferometer and/or no gravity

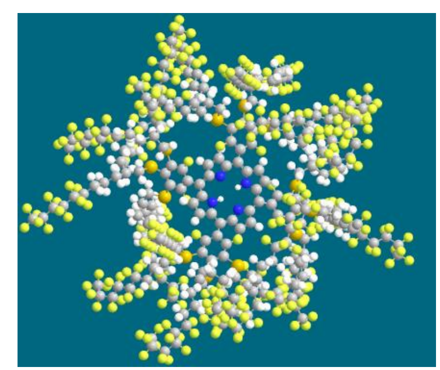
Outlook: New Molecuar Sources

Pulsed Laser desorption:





- Pulsed thermal beams of slow particles (few 100m/s)
- Ideal for volatilization of fragile bio molecules
- Ideal for large tailor-made molecules



$C_{284}H_{190}F_{320}N_4S_{12}$ m=10,123 amu

The OTIMA crew 2014