Matter-wave experiments and Collapse Models

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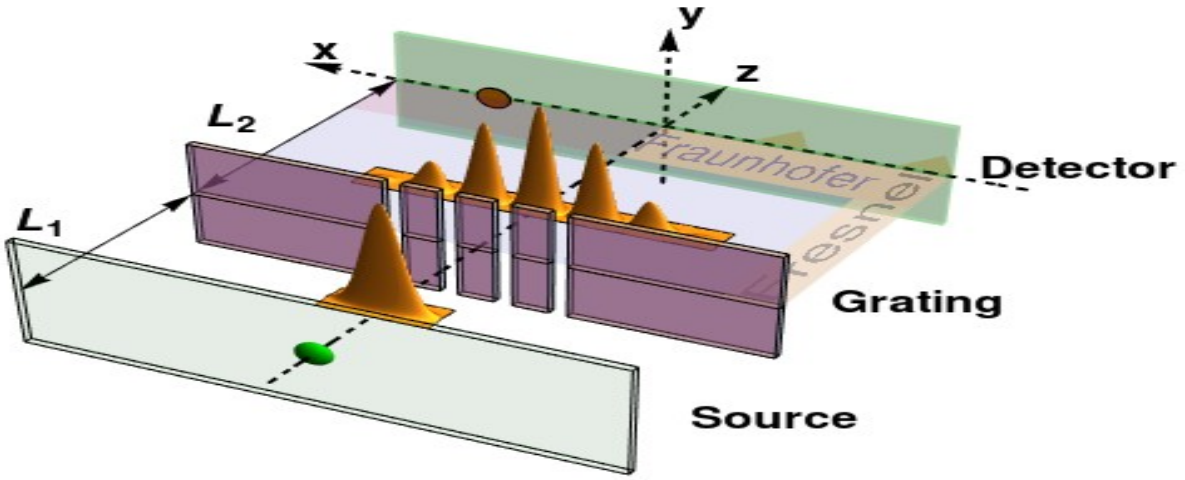


Presentation Overview

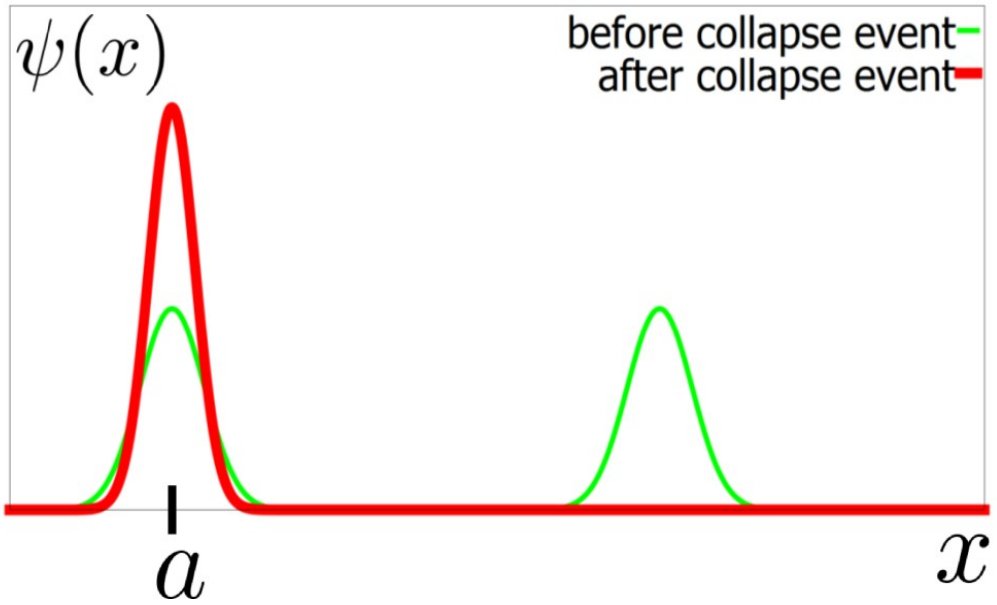
- Brief introduction
  - Collapse models and parameters
  - Interferometry (Far field and Near field KDTL)
- Interference patterns
  - QM and Collapse models
- Parameter bounds
  - Interferometry and macroscopic object constraint
- Summary

Collapse models

Modification of QM dynamics - GRW
(stochastic, nonlinear)

$$|\psi> \longrightarrow \frac{L_a|\psi>}{||L_a|\psi>||}$$

$$L_a = \left(\frac{1}{\pi r_C^2}\right)^{\frac{1}{4}} e^{-\frac{1}{2r_C^2}(\hat{x}-a)^2}$$

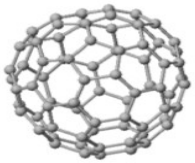


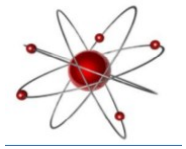
New parameters

$$\lambda_0 = 10^{-16} s^{-1} \qquad r_C = 10^{-7} m$$

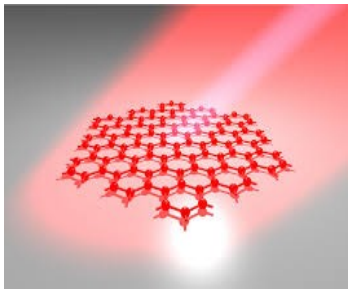
Collapse models

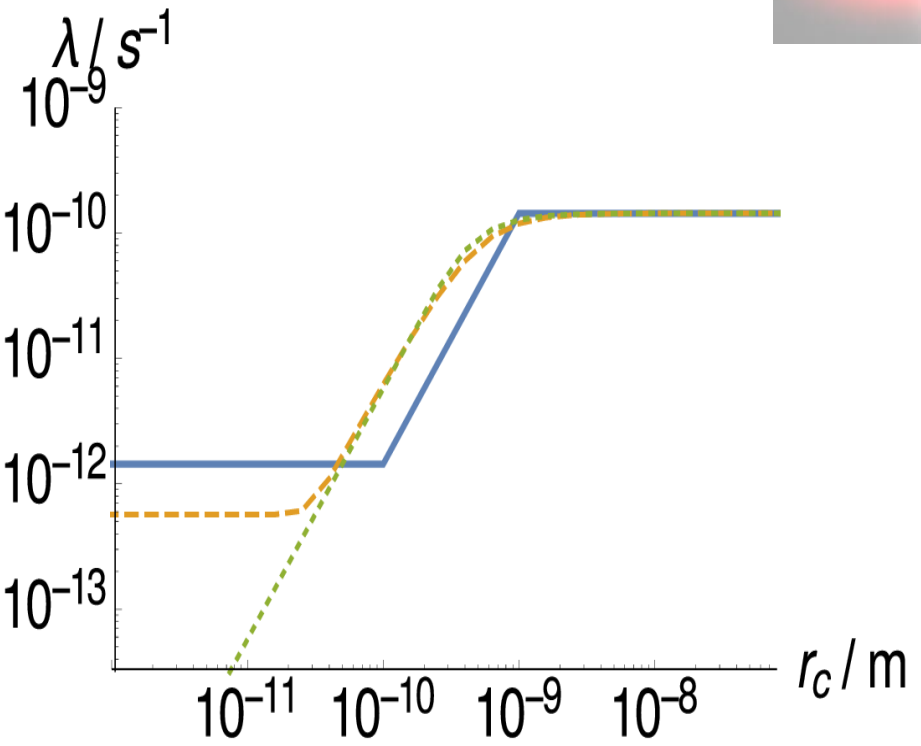
mass





Amplification mechanism - CSL
(2-D lattice of atoms -thin disk)

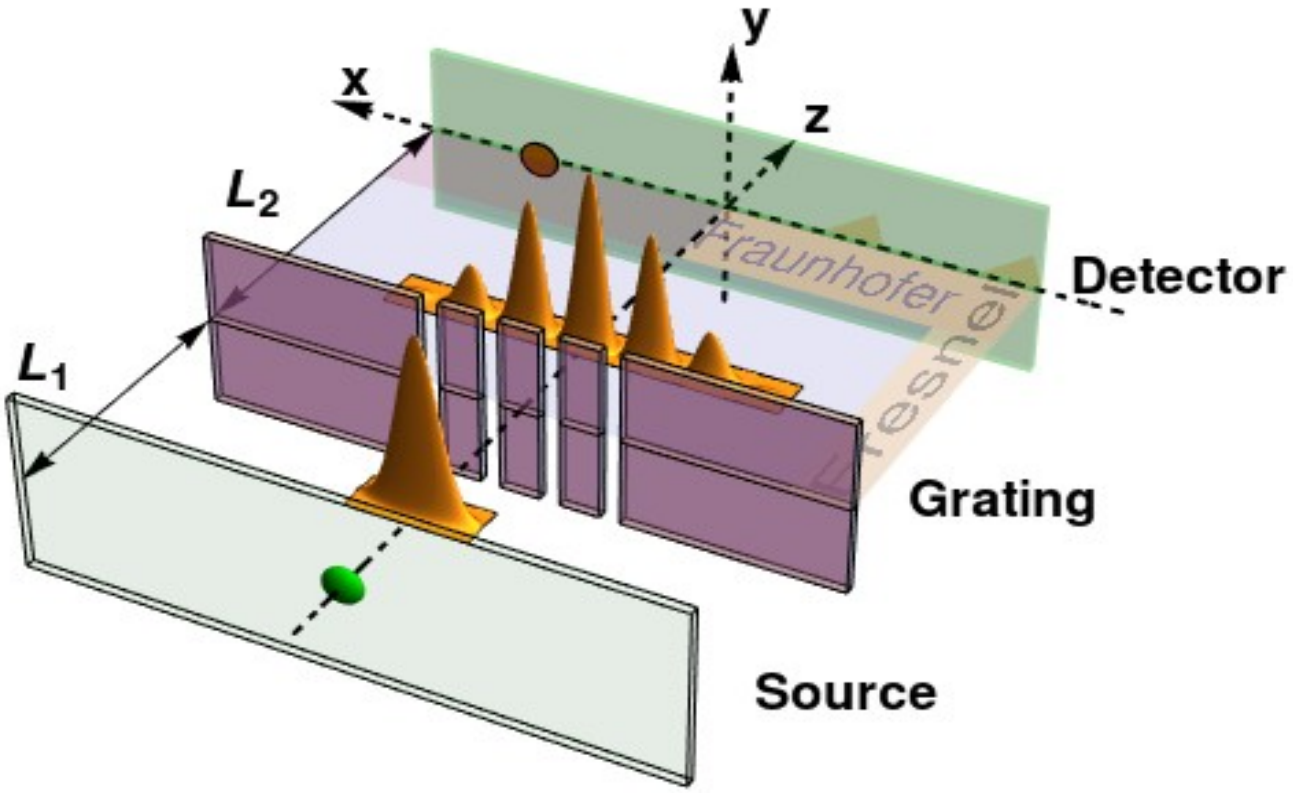


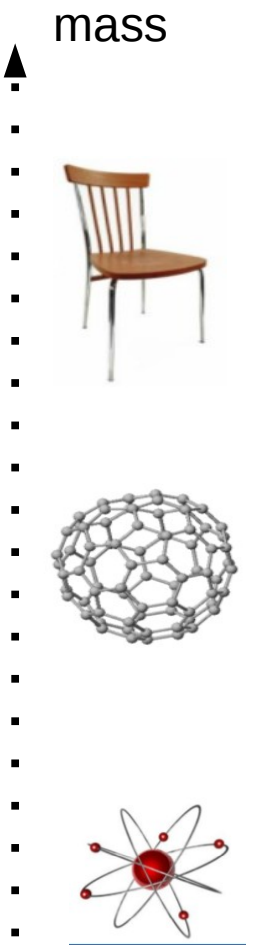


Collapse models

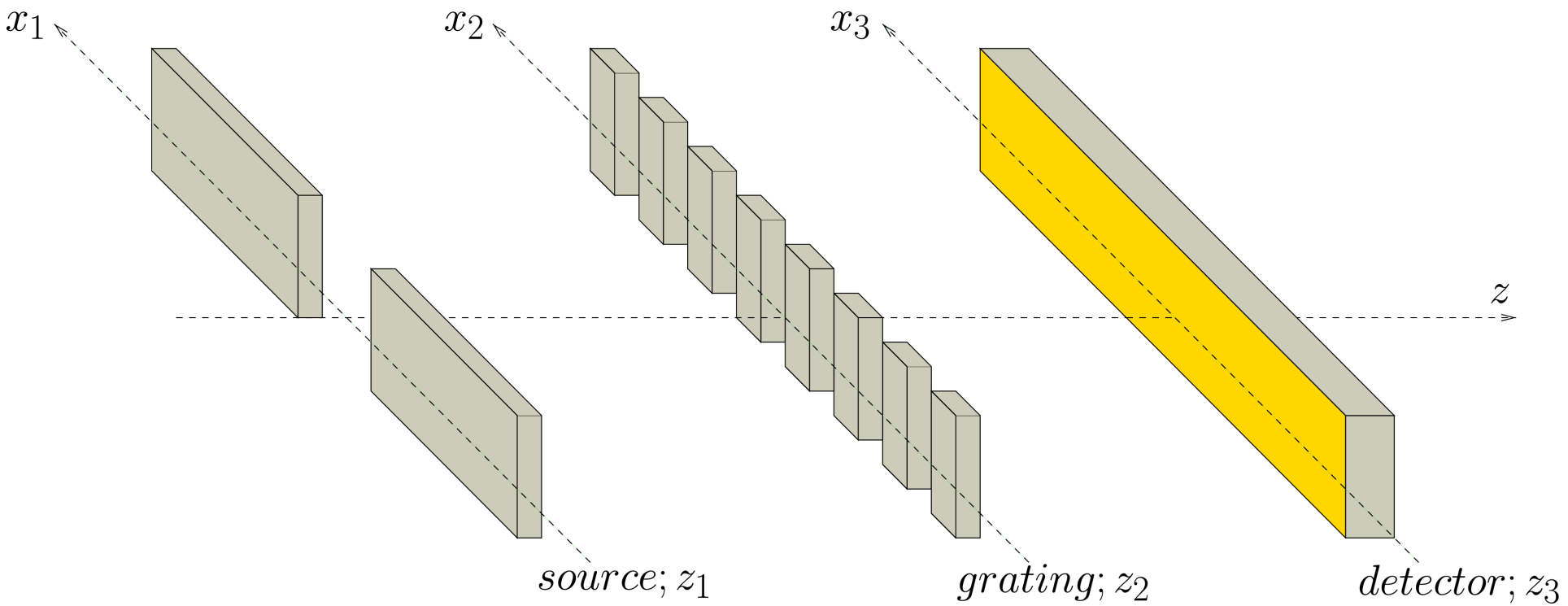
GRW (Ghirardi – Rimini – Weber)	λ_0	r_C	
CSL (Continuous Spontaneous Localization)	λ_0	r_C	
DP (Diósi - Penrose)	$\frac{Gm_0^2}{\hbar\sqrt{\pi}R_0}$	R_0	
dGRW, dCSL (dissipative models)	λ_0	r_C	T
cCSL (colored models)	λ_0	r_C	$\bar{\tau} = \int_0^t f(s)sds$

Interferometry



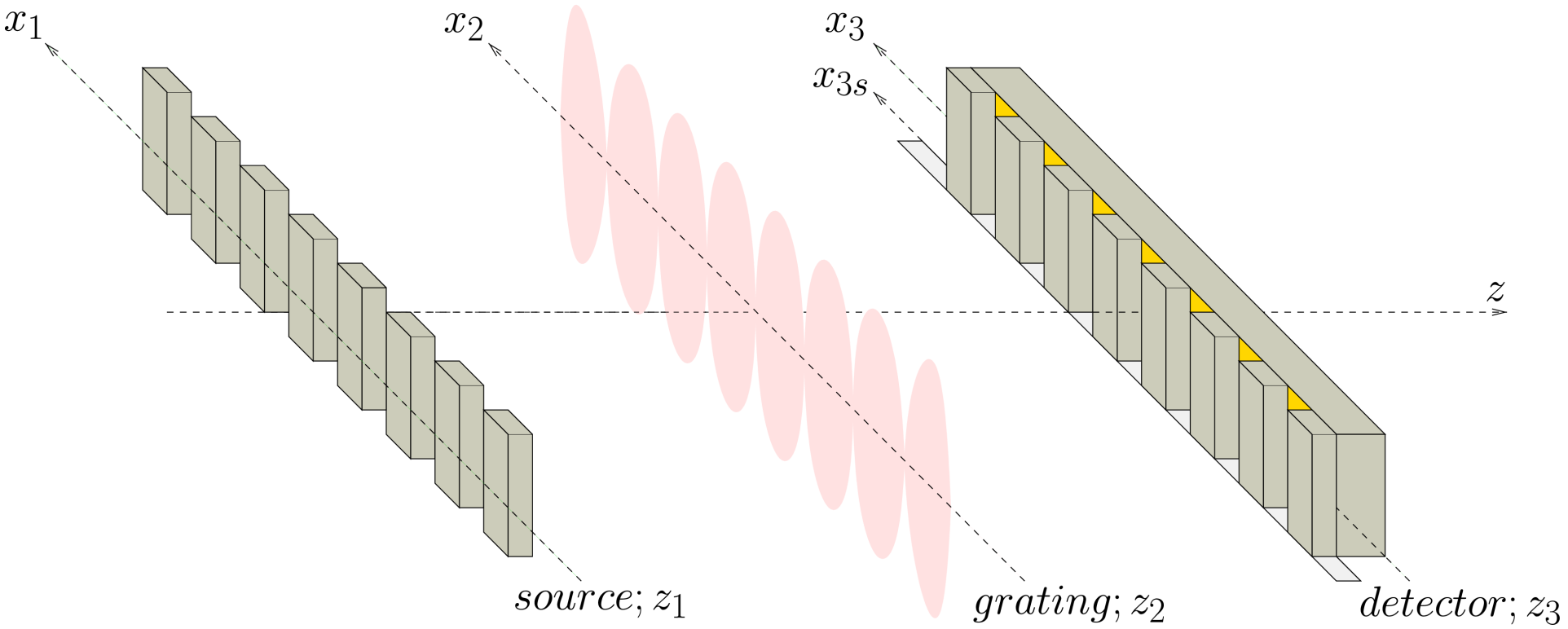


Far field



1) M. Sclafani, Molecular beam methods for quantum optics experiments: sources, detection schemes and coherent manipulation, Ph.D. thesis, Universität Wien (2013).
2) Juffmann, T., et al., Real-time single-molecule imaging of quantum interference. Nat. Nano., 7, 297–300 (2012).

Near field (KDTL)



1) Eibenberger, S., et al., Matter-wave interference with particles selected from a molecular library with masses exceeding 10 000 amu. Phys. Chem. Chem. Phys., 15, 14696 (2013).

Interference patterns

- Near field TL - CSL interference pattern (Wigner function formalism)
  - S. Nimmrichter, K. Hornberger, P. Haslinger, and M. Arndt, Phys. Rev. A 83, 043621 (2011)
  - K. Hornberger, J. E. Sipe, and M. Arndt, Phys. Rev. A 70, 053608 (2004).
- Far field - CSL interference pattern (Wigner function formalism)
  - K. Hornberger, Phys. Rev. A 73, 052102 (2006).
- CSL parameter bounds
  - S. L. Adler, Journal of Physics A: Mathematical and Theoretical 40, 13501 (2007)

    B. Collett, P. Pearle, F. Avignone, and S. Nussinov, Foundations of Physics 25, 1399 (1995).
  - B. Collett and P. Pearle, Foundations of Physics 33, 1495 (2003).

Interference patterns

Interference pattern (para-axial approximation; derived in the density matrix formalism)

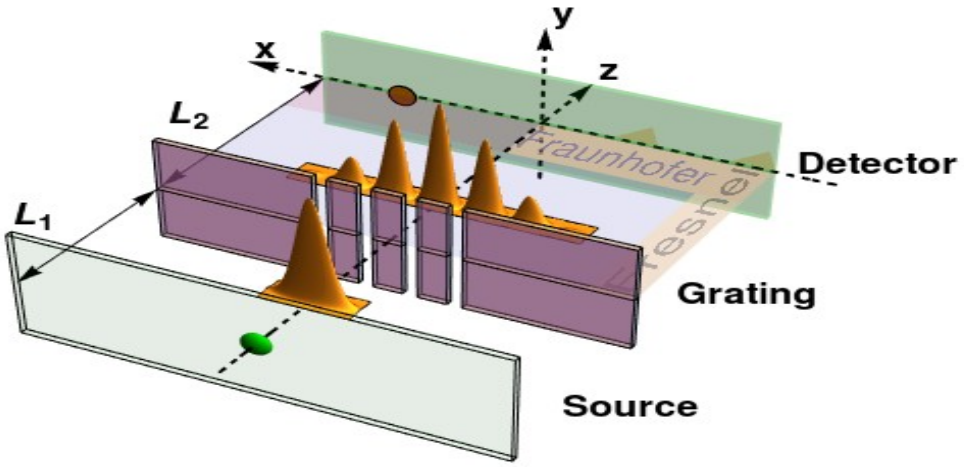
$$p(x) = \int_{-\infty}^{+\infty} dx_2 \int_{-\infty}^{+\infty} dx_2' \; D(x_2 - x_2')$$
$$t(x_2)t^*(x_2')e^{-i\frac{mv}{\hbar}(x_2 - x_2')(\frac{x_1}{L_1} + \frac{x}{L_2})} e^{i\frac{mv}{\hbar}\frac{L_1+L_2}{2L_1L_2}(x_2^2 - x_2'^2)}$$

Quantum Mechanics

$$D(x_2 - x_2') = 1$$

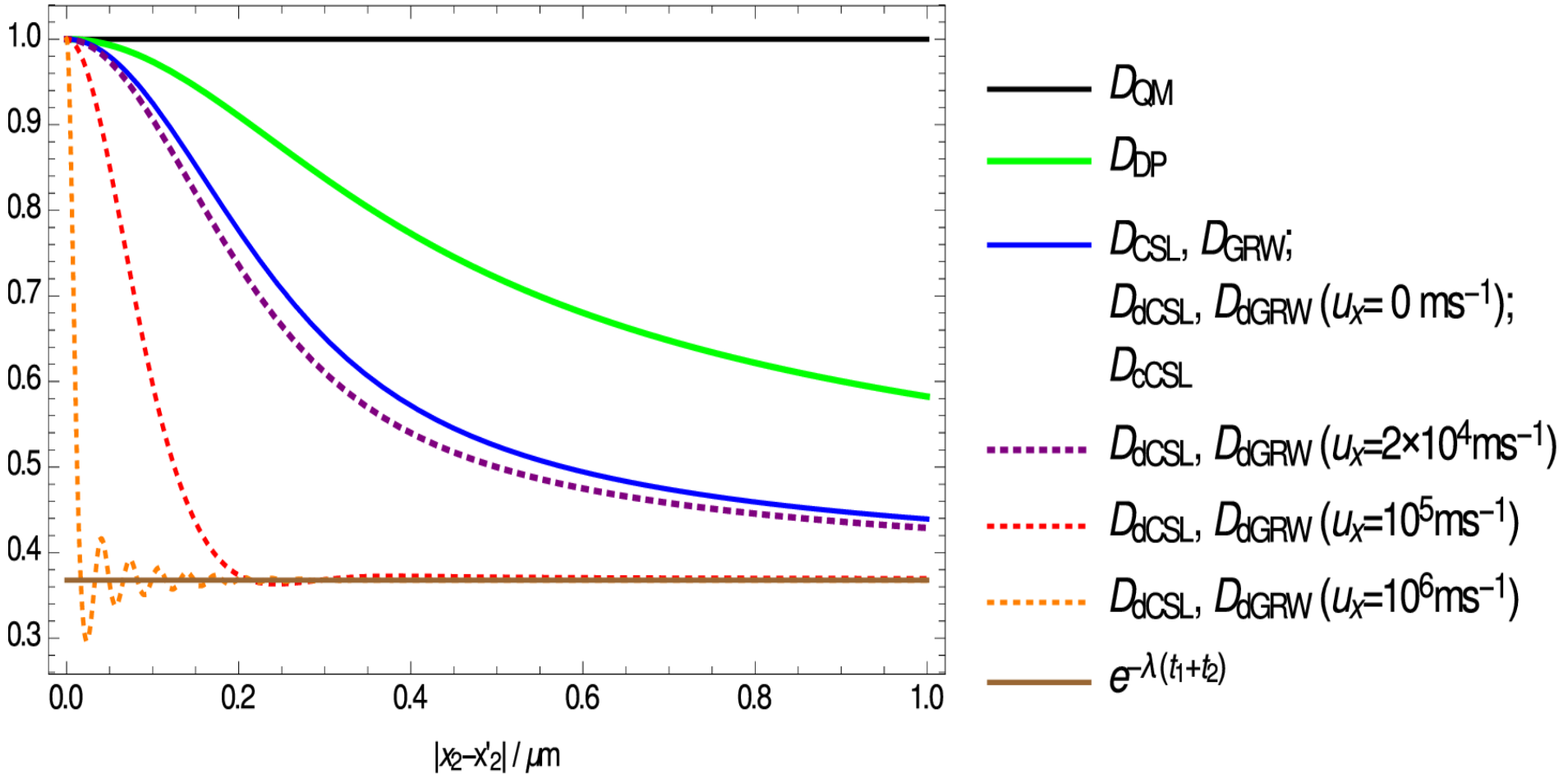
Modified dynamics
(only D changes)

$$D(x_2 - x_2') = ?$$



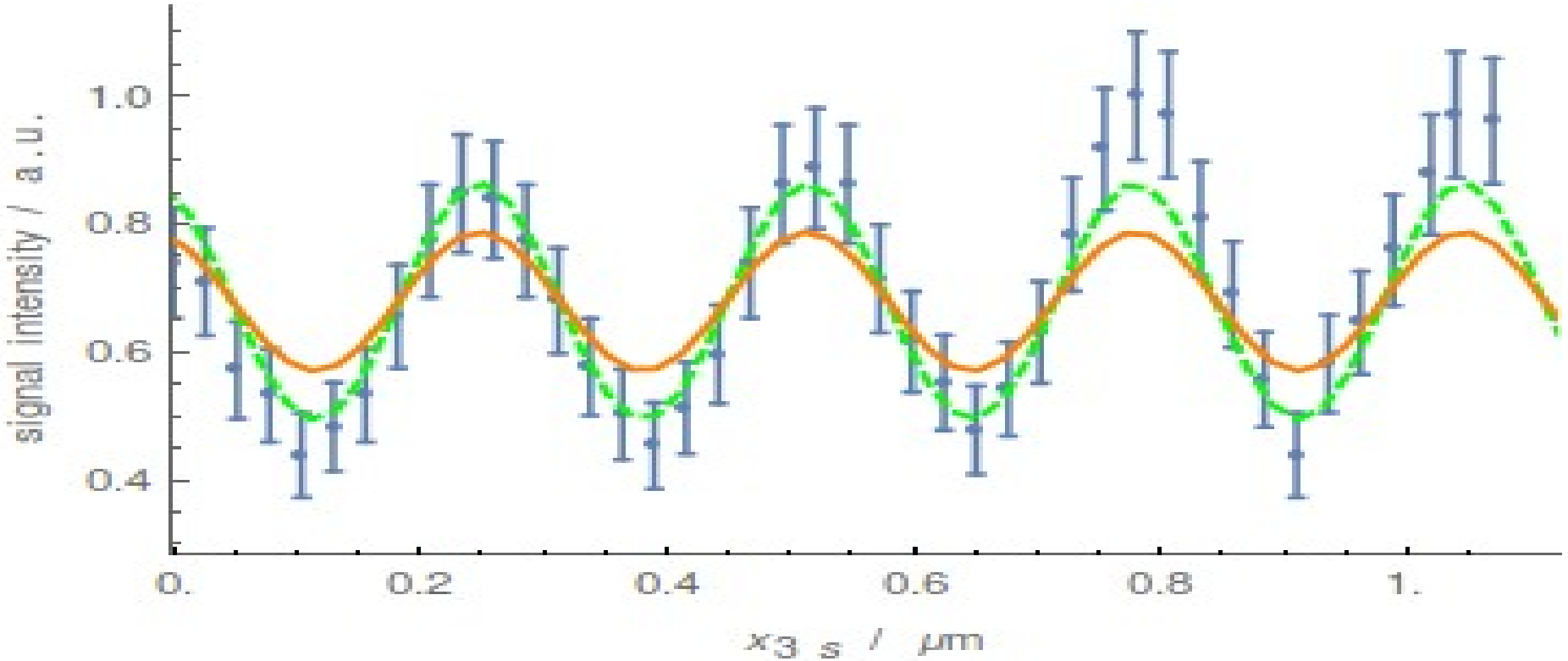
Interference patterns

Interference pattern modification function D



Experimental analysis - KDTL

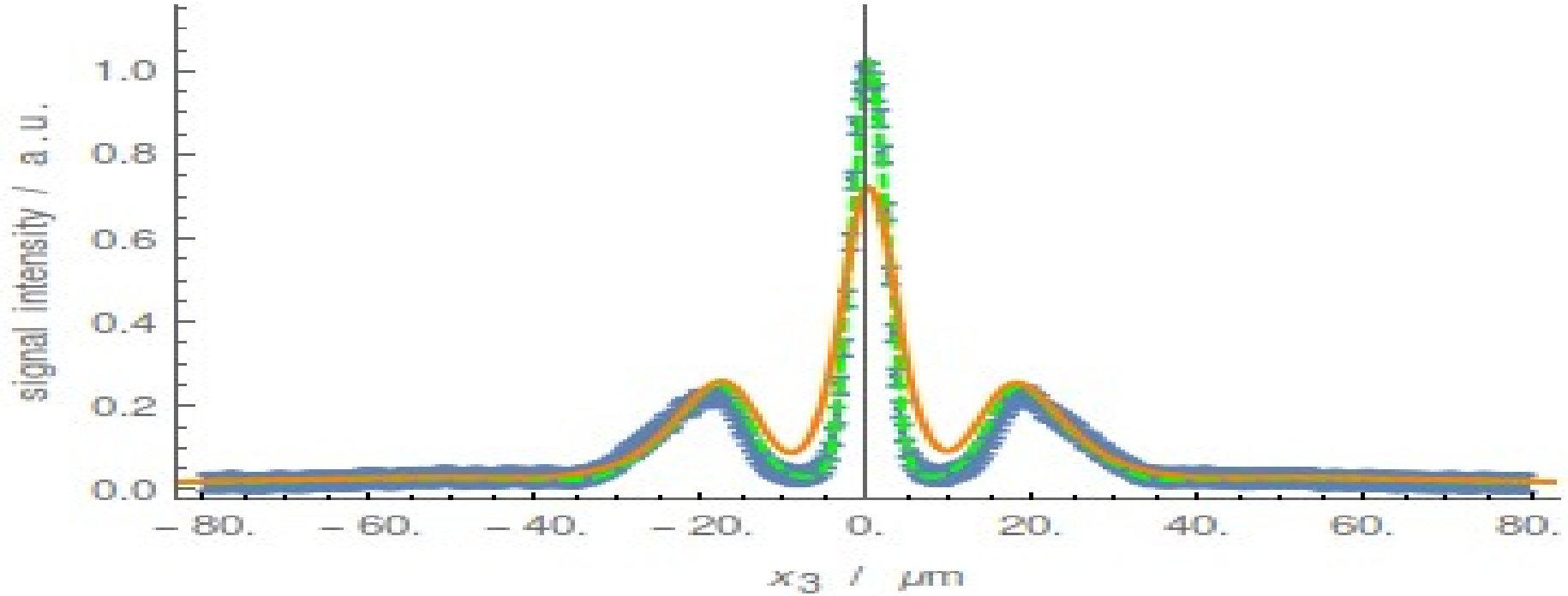
$C_{284}H_{190}F_{320}N_4S_{12}$ $m \approx 10000 a.m.u.$



1) Eibenberger, S., et al., Matter-wave interference with particles selected from a molecular library with masses exceeding 10 000 amu. Phys. Chem. Chem. Phys., 15, 14696 (2013).

Experimental analysis – Far field

$C_{32}H_{18}N_8 \qquad m \approx 500 a.m.u.$



1) M. Sclafani, Molecular beam methods for quantum optics experiments: sources, detection schemes and coherent manipulation, Ph.D. thesis, Universität Wien (2013).
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Macroscopic object constraint

Eye resolution

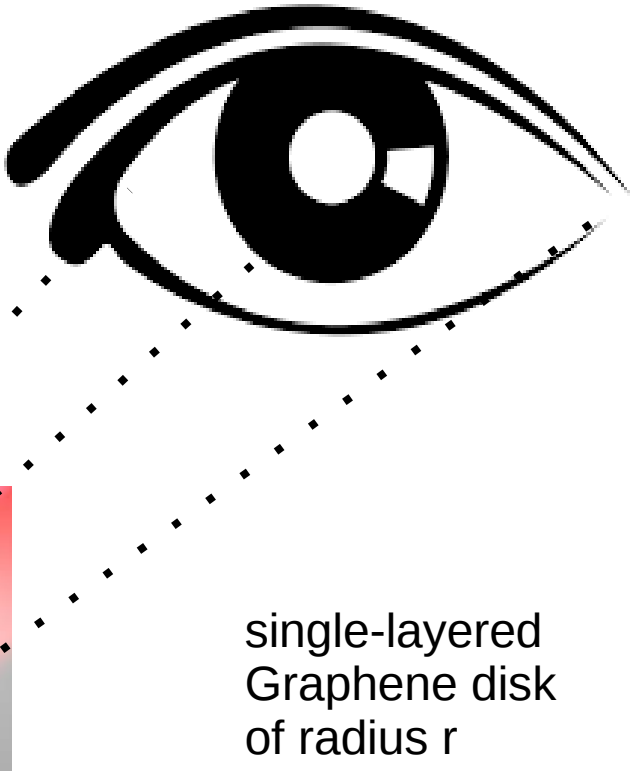
$$t = 10ms \quad r = 0.1mm$$

$$\lambda\, t \approx 1$$

Bounds on parameters

$$\lambda_0, r_C$$

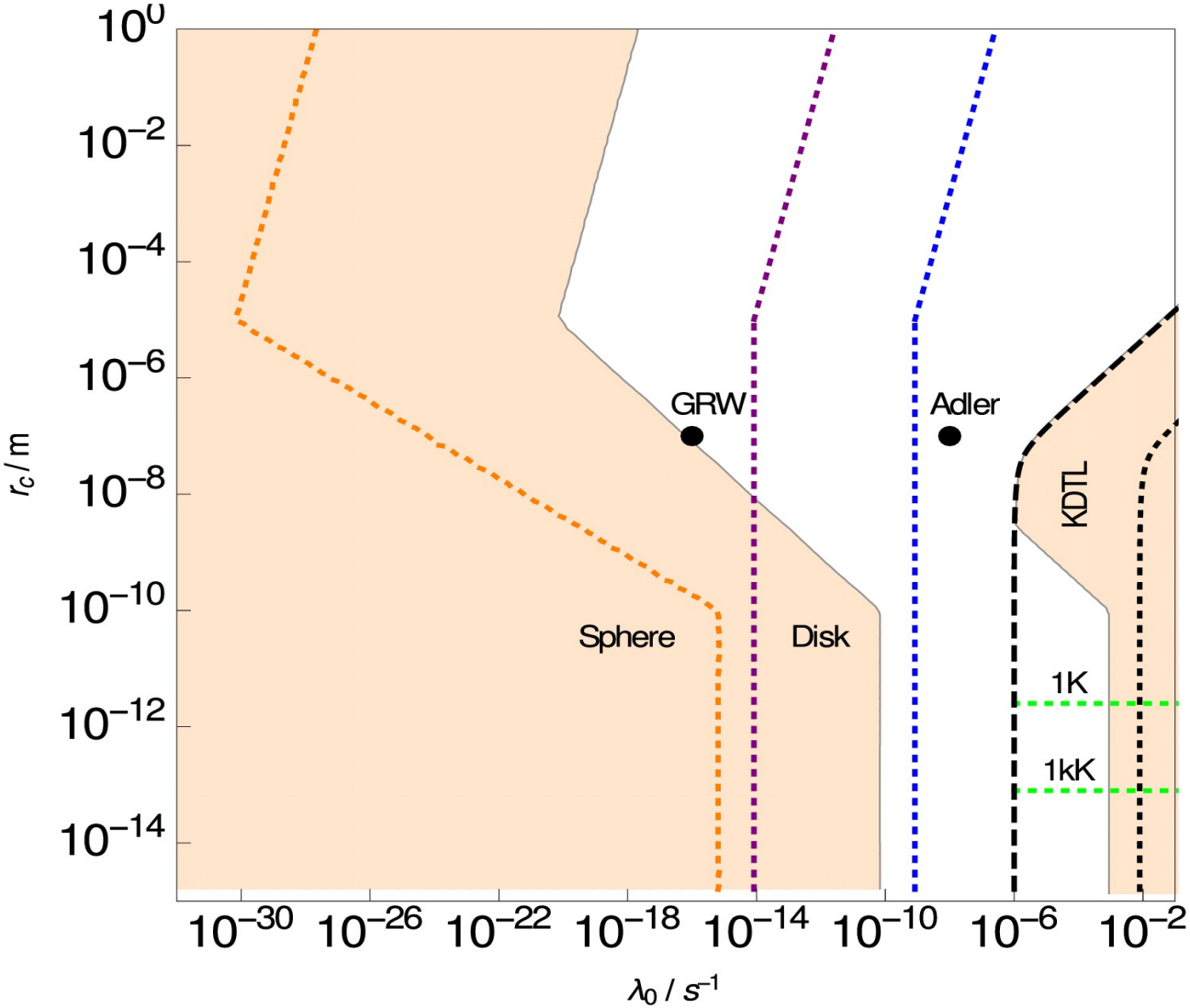
$$R_0$$



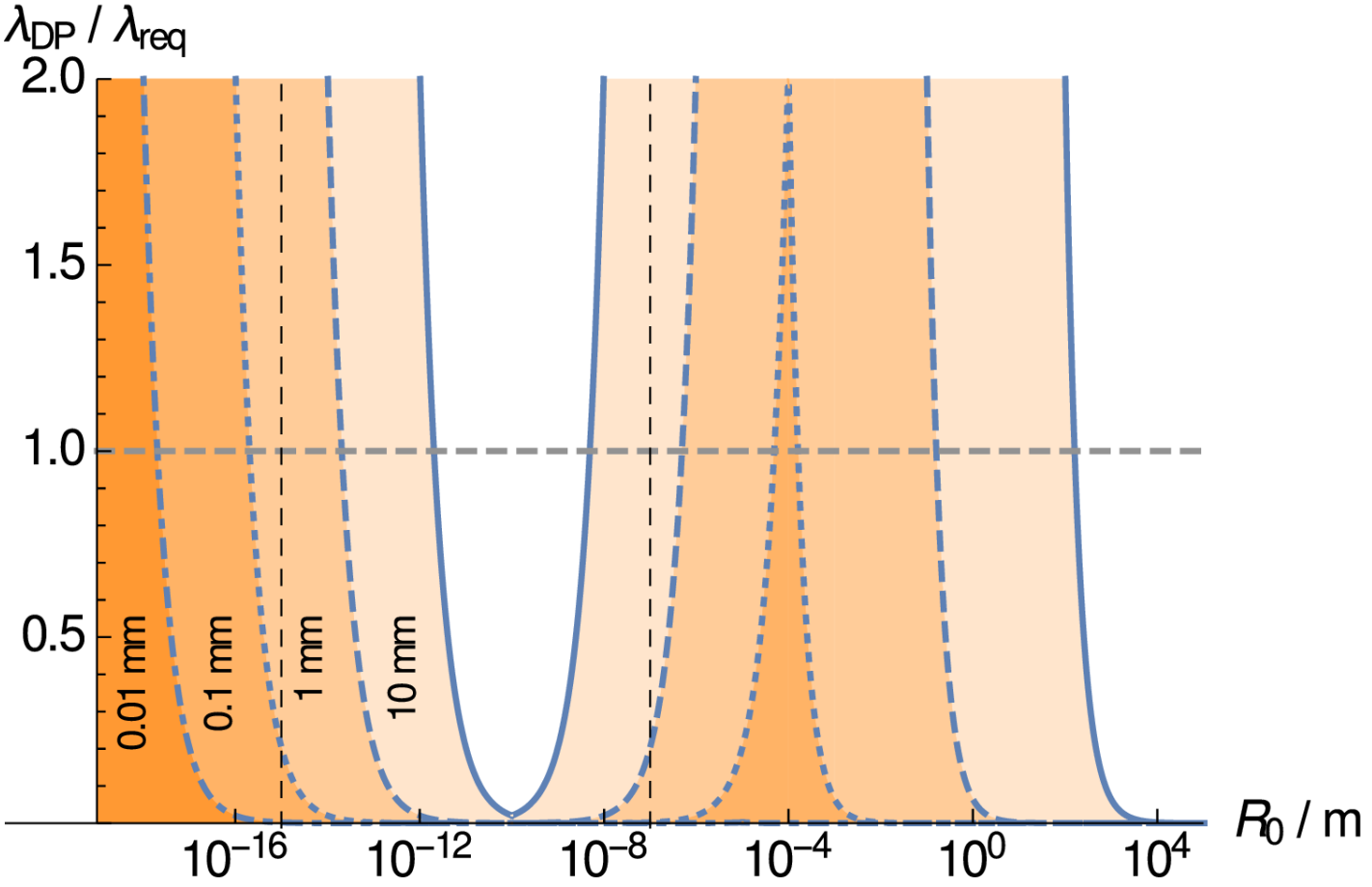
single-layered Graphene disk of radius r

W. Feldmann and R. Tumulka, Journal of Physics A: Mathematical and Theoretical 45 065304 (2012).

CSL / dCSL / cCSL parameter diagram



DP parameter bounds



Summary

- Interferometry
  - far and near field interference patterns
- Parameter bounds
  - interferometry (robust, e.g. CSL, dCSL, cCSL)
  - macroscopic object constraint (strong bounds)
- Future
  - experiments with more massive molecules

Thank you for your attention