Electron dynamics in highly excited quantum dots

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Model + questions

- Single quantum dot
- Magnetic field
- Several electrons
- Nonparabolic confinement

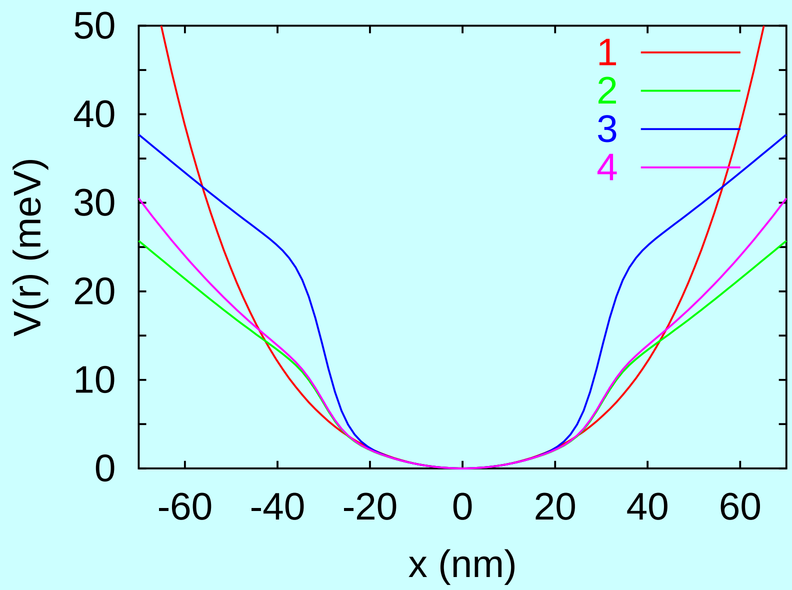
- Density oscillations in time-dependent HF-models
- FIR-absorption, linear regime
- Strong excitation, nonlinear regime

Nonparabolic confinement → no Kohn theorem

$$v_{ext}(r) = v_1(r)\, f_1(r) + [v_2(r) - v_2(R_0) + v_1(R_0) + \Delta]\; f_2(r)$$

$$\begin{aligned} v_{1,2}(r) &= \frac{1}{2}\omega_{1,2} r^2 \\ f_{1,2}(r) &= \frac{1}{2}\left(1 \mp \tanh \frac{r - R_0}{\sigma}\right) \end{aligned}$$

$$\begin{aligned} R_0 &= 30 \quad \text{nm} \\ \Delta &= 6 \quad \text{meV} \\ \sigma &= 5 \quad \text{nm} \\ \omega_{1,2} &= 3.37 \quad \text{meV} \end{aligned}$$



Time-dependent Hartree-Fock approximation

Linear response, (tdHF*)

$$\phi^{\mathrm{e}xt}(\mathbf{r},t) = \mathcal{E}^{\mathrm{e}xt} r \exp\left[\pm i\theta - i(\omega + i\eta)\right]$$

$$\phi^{\mathrm{sc}}(\mathbf{r},t) = \phi^{\mathrm{e}xt}(\mathbf{r},t) + \phi^{\mathrm{i}nd}(\mathbf{r},t)$$

$$P(\omega) = \omega \mathcal{E}^{\mathrm{e}xt} \sum_{\alpha\beta} \langle\beta|r|\alpha\rangle 2\pi \delta_{M_\beta, M_\alpha \pm 1} \times \Im\left\{ f^{\alpha\beta}(\omega) \langle\alpha|(\phi^{\mathrm{sc}})|\beta\rangle \right\}$$

$$f^{\alpha\beta}(\omega) = \frac{f^0_\beta - f^0_\alpha}{\omega + (\omega_\beta - \omega_\alpha) + i\eta}$$

Real-time response, (tdHF)

$$
\begin{aligned}
i\frac{\partial}{\partial t}\varphi_{i\eta}(\mathbf{r}_1,t) &= \left[\frac{(-i\nabla+\gamma\mathbf{A}(\mathbf{r}_1))^2}{2} + v_H(\mathbf{r}_1,t) + v_{ext}(\mathbf{r}_1,t)\right.\\
&+ \left.\frac{1}{2}g^* m^* \gamma B s_z\right]\varphi_{i\eta}(\mathbf{r}_1,t) - \int d\mathbf{r}_2\,\frac{\rho_\eta(\mathbf{r}_2,\mathbf{r}_1,t)}{r_{12}}\,\varphi_{i\eta}(\mathbf{r}_2,t)
\end{aligned}
$$

$$
\gamma = e/c, \qquad \rho_\eta(\mathbf{r}_2,\mathbf{r}_1,t) = \sum_{i,occ.}\varphi_{i\eta}(\mathbf{r}_2,t)^*\varphi_{i\eta}(\mathbf{r}_1,t)
$$

Cranck-Nicholson algorithm

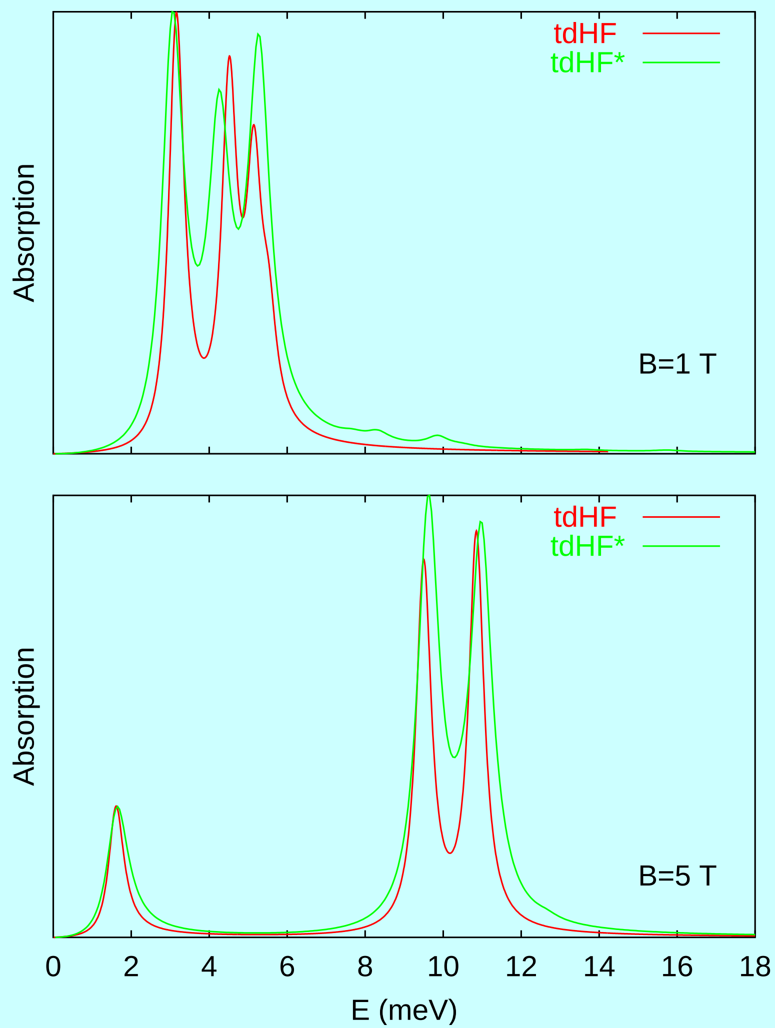
$$
\left(1+\frac{i\Delta t}{2}h_0^{(k+1)}\right)\varphi_{i\eta}^{(k+1)} = \left(1-\frac{i\Delta t}{2}h_0^{(k)}\right)\varphi_{i\eta}^{(k)} + \frac{i\Delta t}{2}\left(\mathcal{V}_{i\eta}^{(k)}+\mathcal{V}_{i\eta}^{(k+1)}\right)
$$

Initial rigid displacement $\mathbf{e}$, $\rightarrow$ analyse dipole moment $\langle \mathbf{e}\cdot\mathbf{r}\rangle_t$

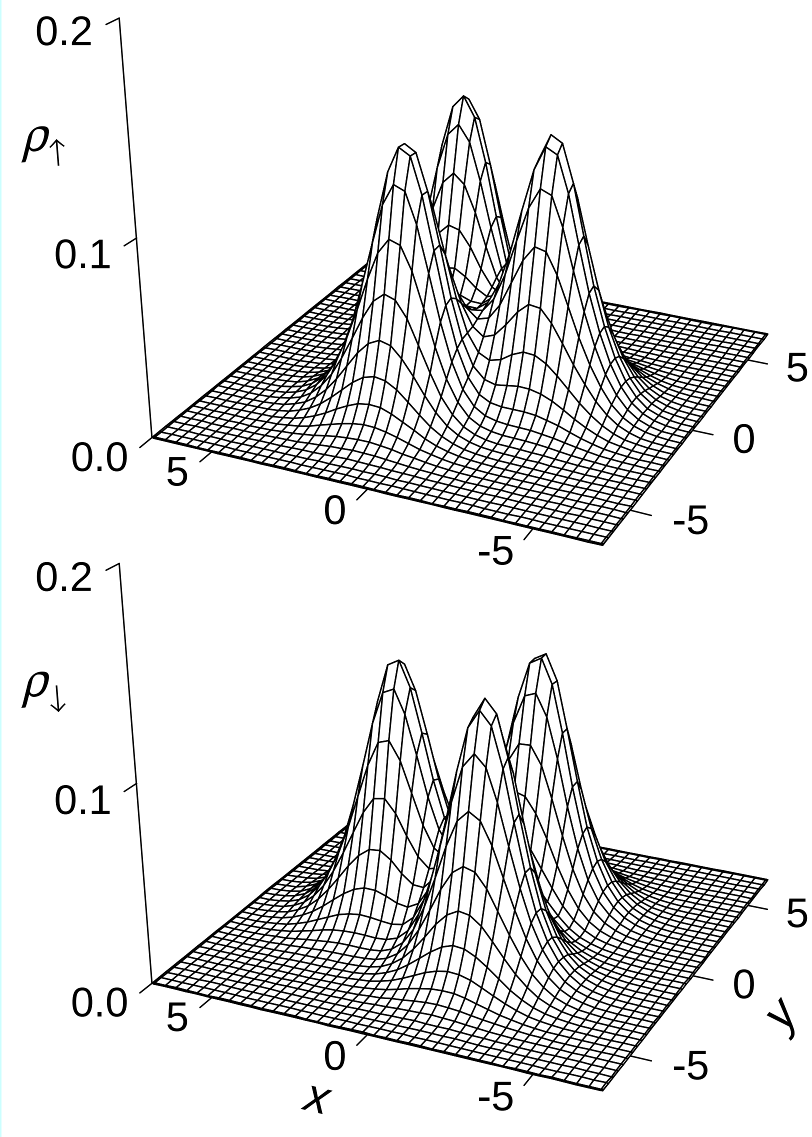
Comparison in the linear regime

- Circular symmetric tdHF*
- Symmetry-free tdHF
  - noncircular at $B = 1$ T
  - circular at $B = 5$ T

6 electrons



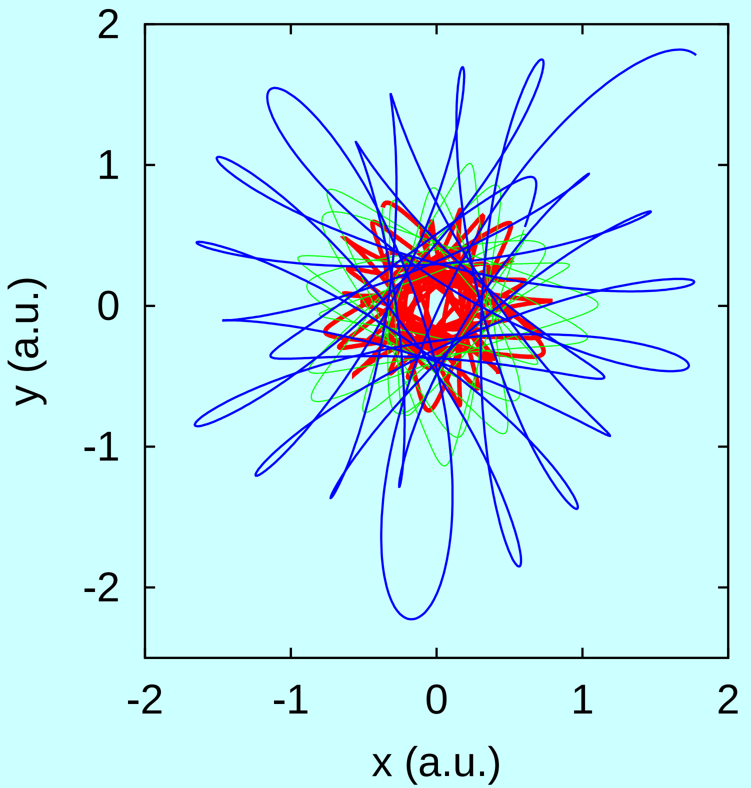
Ground state with broken symmetry



$B = 1$ T

Motion of the center-of-mass in the tdHA

- 9000 time-steps
- 3 intervals of 12 ps
- $B = 1$ T
- Amplitude shrinks
- Total energy is constant



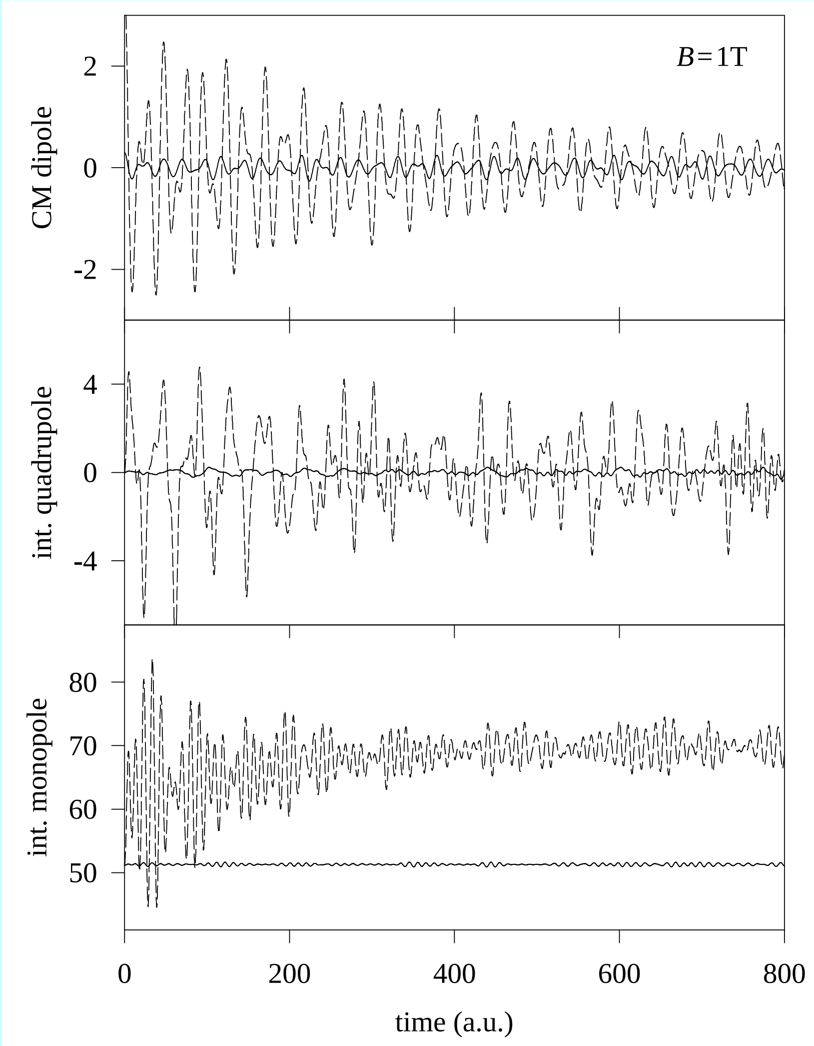
→ Energy must flow into internal modes

Internal Quadrupole and Monopole, (cm-frame)

$$\tilde{\mathbf{r}} = \mathbf{r} - \mathbf{R}_{cm}$$

$$\tilde{Q} = \sum_i \tilde{x}\tilde{y} = \sum_i x_i y_i - \frac{1}{N} \sum_{ik} x_i y_k$$

$$\tilde{M} = \sum_i \tilde{x}^2 + \tilde{y}^2 = \sum_i x_i^2 + y_i^2 - \frac{1}{N} \sum_{ik} x_i x_k + y_i y_k$$



Time evolution

- Weak amplitude
- Strong amplitude

Quantum dot expands →
Monopole oscillation
around new configuration
(Breathing mode)

New configuration, shape

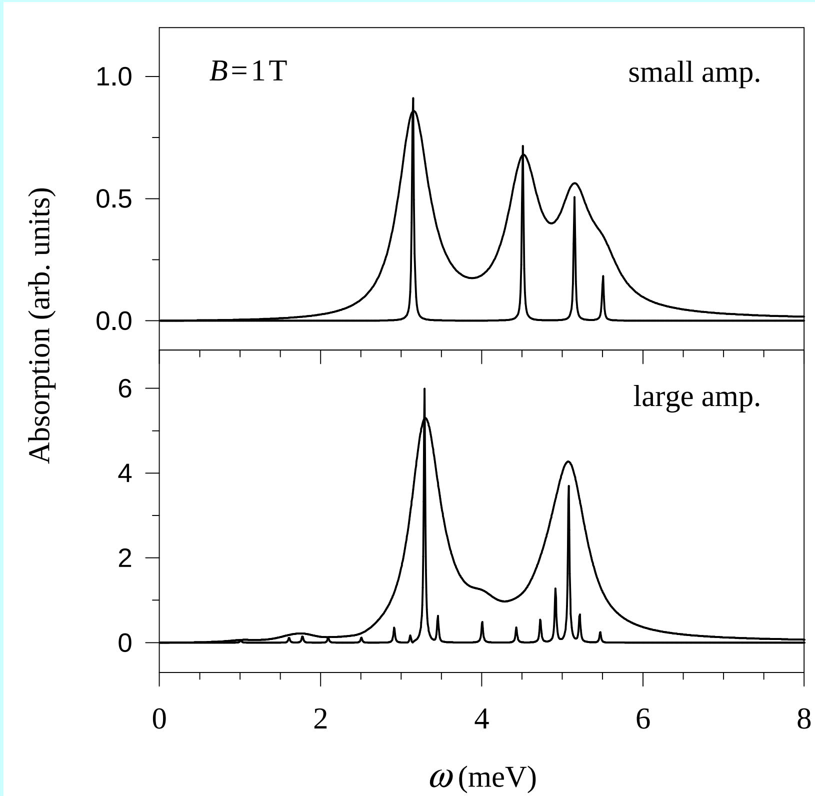
⇓

Modified dipole absorption

Large fluctuations of
mean field

⇓

Large variations in effective
single-particle energies



Two peak widths

Time window after expansion "Below-Kohn mode" vanishes

Conclusions

- Linear regime:
  - Equivalence of tdHF and tdHF*
  - FIR absorption is insensitive to internal structure of dot
- Nonlinear regime:
  - Dot expansion
  - Time-resolved energy flow between modes
  - Modified dipole absorption
- Experiments?