**What:** Dipolar quantum gases
**For What:** Precision Measurements & Quantum Transport
**Where:** Reduced dimensionality
**How:** Using molecules or Rydberg atoms

# 1D DIPOLAR QUANTUM GASES [3]

## Concept

Hamiltonian of N atoms with mass M and permanent dipolar moments, arranged on a line with density n

$$H = -\frac{1}{r_s^2}\sum_{i=1}^{N}\frac{\partial^2}{\partial x^2} + \frac{1}{r_s^3}\sum_{i<j}^{N}\frac{1}{|x_i - x_j|^3}$$

$r_s = 1/(n\, r_0)$

$$Ry^* = \frac{\hbar^2}{2Mr_0^2}$$

$$C_{dd} = \mu_0 \mu_d^2$$

Magnetic dipole

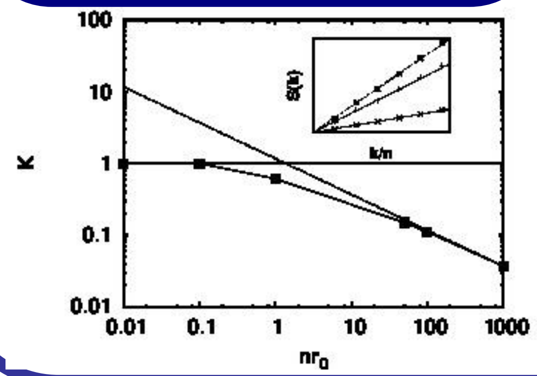
$$C_{dd} = \frac{d^2}{\varepsilon_0}$$

Electric dipole

Combine Bosonozation technique with a Numerical experiment, i.e. Reptation Quantum Monte Carlo

## Results

It is a super-strongly coupled Luttinger Liquid




Momentum distribution & Dynamical Structure

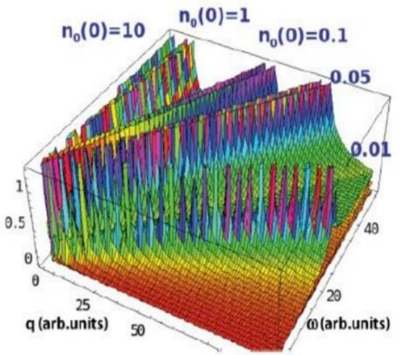



FIG. 1. (Color online) TLL model with $e(nr_0) \propto n^\gamma$ and $\gamma = 2$ in a harmonic trap. $S(q,\omega)$ in arbitrary units in the $(\omega,q)$ plane and different densities at the trap center.

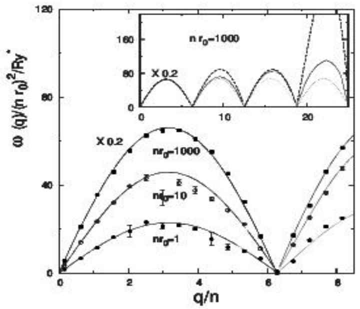



FIG. 2. Lowest excitation energies $\omega(q)$ in $Ry^*$ units and scaled by $(nr_0)^2$ for a dipolar gas with $N$=40 and different values of $nr_0$ =1, 10, and 1000 as in the legend. The symbols with error bars are energies extracted using Eq. (3); the solid line is a guide to the eye. The curve at $nr_0$=1000 is depressed by a factor of 5 for graphical reasons. Inset: zoom on the $\omega(q)$ at $nr_0$=1000 up to $q/n$=$8\pi$ for different $F(q,\tau)$ models: multimode model (3) (solid) and Feynman (dashed) approximation. Dotted line: periodic replica of the first bump.

In conclusion:

Luttinger-liquid is a unifying theory for low-energy behavior of 1D dipolar quantum gases in the whole crossover region evolving into a Tonks-Girardeau gas at low densities and into a quasi-ordered state at high enough densities

# References

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- **[2] Gravity g-measurements:** **Ivanov V, Alberti A, Schioppo M, Ferrari G, Artoni M, Chiofalo M, Tino G**, *PRL* **100**, 43602 (2008); **Alberti A, Ferrari G, Ivanov V, Chiofalo M, Tino G**, *NJP* **12,** 65037 (2010); **Tarallo M, Alberti A, Poli N, Chiofalo M, Yang F, Tino G**, *PRA* **86**, 33615 (2012); **W. Ertmer et al.,** Matter wave explorer of gravity (MWXG), *Exp. Astronomy* **23**, 611 (2009)

[3] **1D Dipolar Gases:** **Citro R, Orignac E, De Palo S, Chiofalo M**, *PRA* **75**, 51602 (2007); **Pedri P, De Palo S, Orignac E, Citro R, Chiofalo M**, *PRA* **77**, 15601 (2008); **De Palo S, Orignac E, Citro R, Chiofalo M**, *PRB* **77**, 212101 (2008); **Citro R, De Palo S, Orignac E, Pedri P, Chiofalo M**, *NJP* **10**, 45011 (2008); **Orignac E, Citro R, De Palo S, Chiofalo M**, *PRA* **85**, 3634 (2012)

[4] **Enhanced SNR g-meas.:** **Peden B, Meiser D, Chiofalo M, Holland M**, *PRA* **80**, 43803 (2009)

[5] **Superfluidity (SF) in Fermi gases:** **Holland M, Kokkelmans S, Chiofalo M, Walser R**, *PRL* **87**, 120406 (2001); **Chiofalo M , Kokkelmans S, Milburn J, Holland M**, *PRL* **88**, 90402 (2002)

[6] **SF with narrow Feshbach resonances:** **De Palo S, Chiofalo M, Holland M, Kokkelmans S**, *PLA* **327**, 490 (2004)

## Ongoing Work [Thesis available]

- **Enhanced SNR in g-meas. via non-destructive cavity-QED methods [4],** where the standing optical-lattice mode amplitude is slaved to atomic motion . **How:** Analytical and light numerical methods (+ experiment). MAGIA challenge

- **Towards novel phase diagram of Fermi gases with attractive cavity-induced interactions**: from superfluidity [5] to spin ferro- and antiferro-magnetic phases. **How:** Analytical+Exact diagonalization methods [**Davide Nigro, Elvia Colella**]

- **Superfluidity in Fermi gases with narrow Fano-Feshbach resonances [6],** leading to tunable interactions and richer crossover phenomena from BCS to BEC, depending on two parameters. **How**: Numerical+Analytical methods [**Silvia Musolino**]

- **Towards novel ground states of 1D quantum dipolar gases with either spin-orbit coupling and/or strong correlations [many-body localization]**