University of Glasgow

ICCUB

EXCELENCIA MARÍA DE MAEZTU

Institut de Ciències del Cosmos
UNIVERSITAT DE BARCELONA

Renormalisation-group study of Bose polarons

Phys. Rev. A **104**, 023317 (2021)

Felipe Isaule[1,2]

felipe.isaulerodriguez@glasgow.ac.uk

felipeisaule.github.io   felipeisaule

Collaborators:

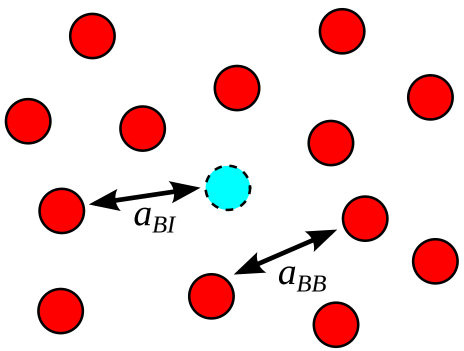
I. Morera[2], P. Massignan[3], B. Juliá-Díaz[2]

[1]University of Glasgow
[2]Universitat de Barcelona
[3]Universitat Politècnica de Catalunya

BEC2021 Conference

13th September 2021

<u>Bose polaron:</u> impurity immersed in a Bose gas



- The problem of an impurity immersed in a **Bose gas** has attracted significant attention in the past few years.

- Experimentally, Bose polarons have been observed with cold atoms by different groups.
  <u>Aarhus</u>: PRL **117**, 055302 (2016). <u>JILA</u>: PRL **117**, 055301 (2016). <u>MIT</u>: Science **368**, 190 (2020).

- Theoretically, different techniques have provided successful descriptions of the strong-coupling regime of three-dimensional Bose polarons.
  <u>Variational</u>: PRX **8**, 011024 (2018). <u>Ladder</u>: PRX **8**, 031042 (2018). <u>MC</u>: PRA **99**, 063607 (2019). <u>GPe</u>: PRA **103**, 013317 (2021).

- Nevertheless, there are a plethora of open questions, including the importance of multi-body correlations, the role of the dimensionality, etc.

- We propose a new method to study Bose polarons based on the **functional renormalization group** (FRG).

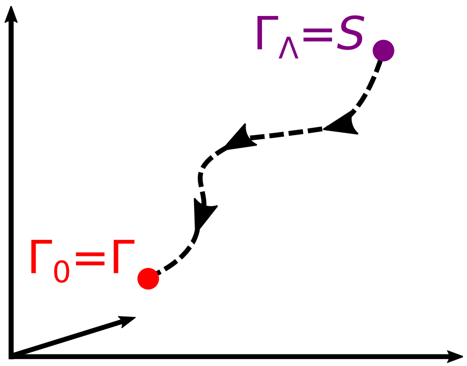
- We study a single impurity immersed in Bose gases in d=2,3 at T=0.

$$\mathcal{S} = \int_x \left[\psi_B^\dagger \left(\partial_\tau - \frac{\nabla^2}{2m_B} - \mu_B \right) \psi_B + \psi_I^\dagger \left(\partial_\tau - \frac{\nabla^2}{2m_I} - \mu_I \right) \psi_I + \frac{g_{BB}}{2} |\psi_B|^4 + g_{BI} |\psi_B|^2 |\psi_I|^2 \right]$$

B : bath bosons
I : impurity

The functional renormalization group (FRG)

- The FRG is a non-perturbative technique where the **effective action** Γ is obtained by solving a RG equation.
- **Fluctuations** are gradually incorporated in the RG flow.
- It is particularly useful to study **strongly-interacting systems**. This makes the FRG suitable to study the strong-coupling regime of Bose polarons.
  Recent comprehensive review: N. Dupuis *et al.*, Physics Reports **910**, 1 (2021).



- The flow of Γ is obtained by solving the Wetterich equation:

$$\partial_k \Gamma_k = \frac{1}{2} \mathrm{tr} \left[\partial_k R_k (\Gamma^{(2)} + R_k)^{-1} \right]$$

C. Wetterich, Phys. Lett. B **301**, 90 (1993)

- In contrast to Fermi polarons, **three- and higher-body correlations** play an important role in Bose polarons due to the bosonic nature of the bath.
- The FRG enables us to include and quantify multi-body correlations easily.
- We focus on the attractive branch of the Bose polaron.

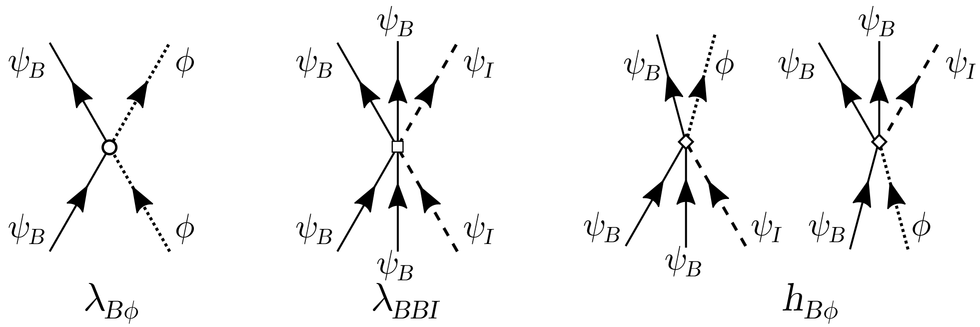
Ansatz for the attractive Bose polaron

- We propose an ansatz using dimer fields ϕ to mediate the B-I interactions:

$$\Gamma_k = \int_x \Big[\psi_B^\dagger \left(S_B \partial_\tau - \frac{Z_B}{2m_B}\nabla^2 - V_B \partial_\tau^2 \right)\psi_B + \psi_I^\dagger \left(S_I \partial_\tau - \frac{Z_I}{2m_I}\nabla^2 + U_I(\rho_B) \right)\psi_I$$
$$+ \phi^\dagger \left(S_\phi \partial_\tau - \frac{Z_\phi}{2m_\phi}\nabla^2 + U_\phi(\rho_B) \right)\phi + U_B(\rho_B) + H_\phi(\rho_B)\left(\phi^\dagger \psi_B \psi_I + \phi \psi_B^\dagger \psi_I^\dagger \right) \Big]$$

where $\phi \sim \psi_B \psi_I, \quad \rho_B = \psi_B^\dagger \psi_B$

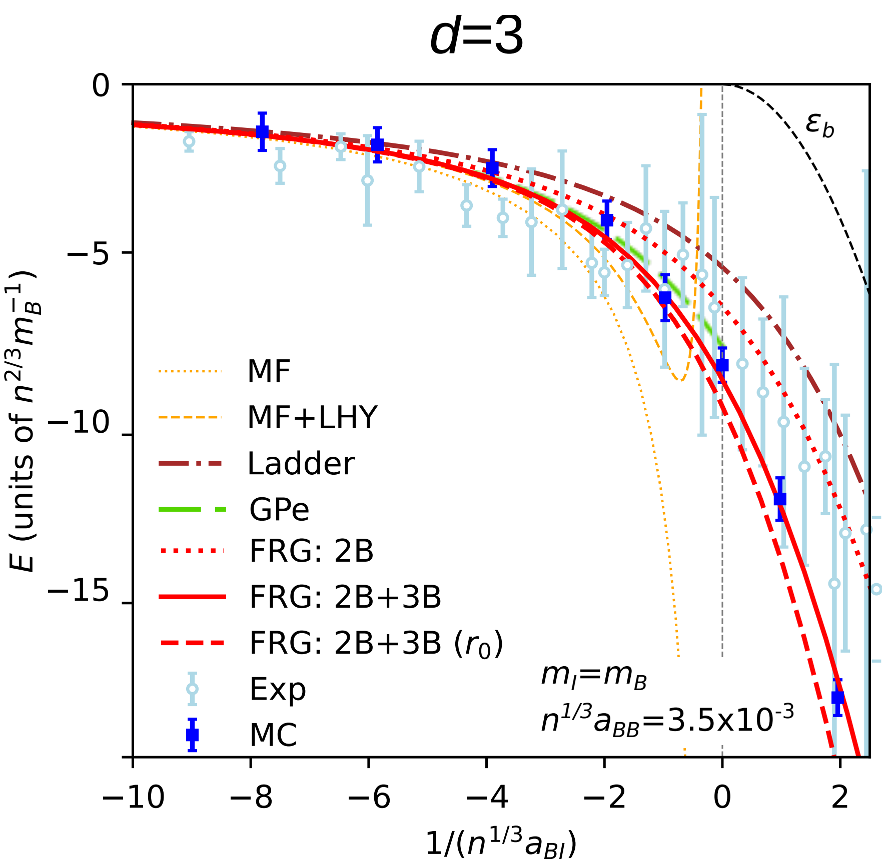
- We consider up to three-body boson-impurity couplings:

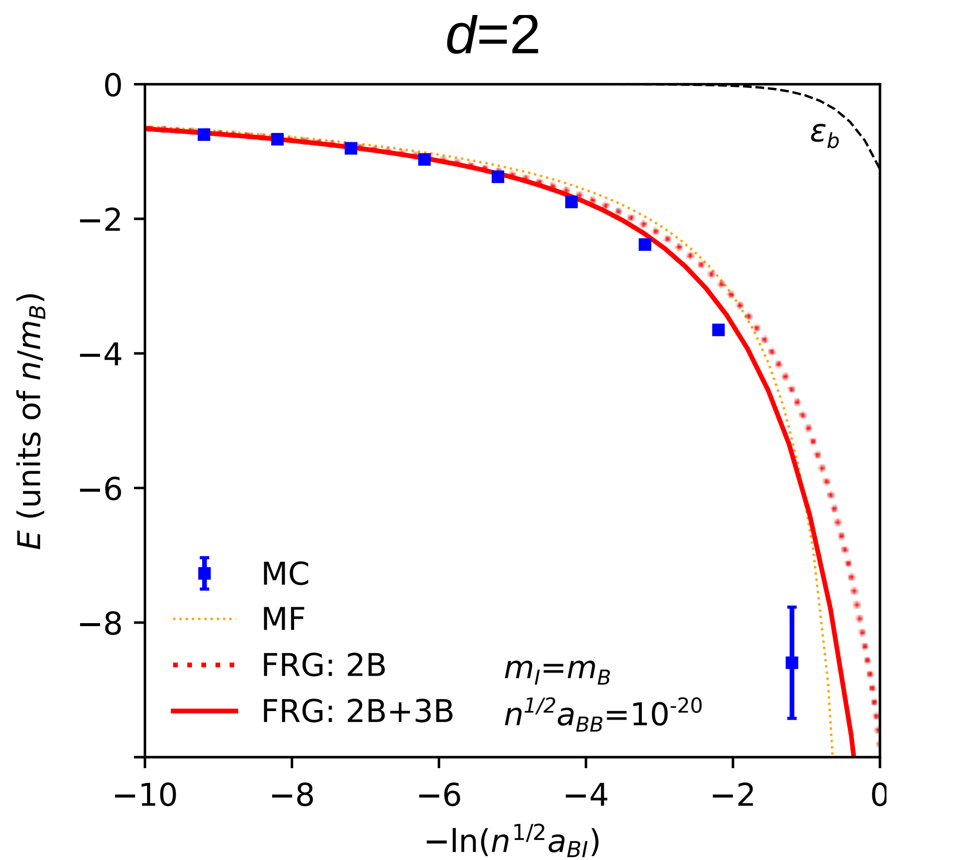


- Inputs: a_{BB}, a_{BI}, μ_B, μ_I, r_0 (B-I effective range).

- We find the physical **polaron energy** μ_I^* from the choice of μ_I that gives a vanishing inverse impurity propagator $\det(G_I^{-1})=0$.

Results





GPe: N.-E. Guenther *et al.*, PRA **103**, 013317 (2021).
Ladder: A. Camacho-Guardian and G. Bruun, PRX **8**, 031042 (2018).
MC: L. Peña Ardila *et al.*, PRA **99**, 063607 (2019).
Exp: N. B. Jørgensen *et al.*, PRL **117**, 055302 (2016).

MC: L. Peña Ardila et al., PRR **2**, 023405 (2020).

More results and comparisons in our paper: F. Isaule *et al.*, PRA **104**, 023317 (2021)

Conclusions

- The FRG can provide a successful description of two- and three-dimensional Bose polarons, including the **strong-coupling regime**.

- **Three and higher-body correlations** are conceptually easy to include within the FRG. Moreover, the FRG enables us to quantify their importance.

- Future work:

  - Include four- and higher-body correlations.

  - Study polarons at finite temperatures, particularly around the critical temperature of the bath (impact of BKT transition in 2D?).

  - Study Efimov physics in three dimensions.

  - Consider impurities in other quantum mediums, such as in cold atom mixtures.