Observation of a Smooth Polaron–Molecule Transition in a Degenerate Fermi Gas

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2. Fermi impurity problem

- **Helium 3**
  - M. I. Dykman, K. Kono, D. Konstantinov, M. J. Lea, PRL 119, 256802 (2017)

- **High-$T_c$ superconductors**
  - N. F. Mott, JPCM 5, 3487 (1993)

- **Neutron stars**
  - M. Kutschera & W. Wójcik, PRC 47, 1077 (1993)

- **Fermi impurity problem**
  - W. H. Sio, C. Verdi, S. Poncé, F. Giustino, PRL 122, 246403 (2019)
2. Fermi impurity problem

Increasing interaction

N. Prokof'ev & B. Svistunov, PRB 77, 020408 (2008)
M. Punk, P.T. Dumitrescu, W. Zwerger, PRA 80, 053605 (2009)
R. Schmidt & T. Enss, PRA 83, 063620 (2011)
3. Hallmark of the first-order transition

- A. Schirotzek, ..., M. W. Zwierlein, PRL 102, 230402 (2009)
- S. Nascimbène, ..., C. Salomon, PRL 103, 170402 (2009)
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F. Chevy, PRA 74, 063628 (2006)
M. Punk, P.T. Dumitrescu, W. Zwerger, PRA 80, 053605 (2009)
4. Observation of a smooth transition

We developed:
• Raman spectroscopy with high-sensitivity fluorescence detection
• Theoretical model of many impurities at $T > 0$

We found:
• Finite impurity density leads to a smooth transition
• Finite temperature enhances this effect
• Polarons and molecules coexist around the transition
5. Raman spectroscopy
with high-sensitivity fluorescence detection

C. Shkedrov, GN, Y. Florshaim, Y. Sagi, PRA 101, 013609 (2020)
5. Raman spectroscopy of weakly-interacting atoms

For weakly-interacting atoms:

\[ \hbar \omega = \frac{2\hbar^2}{m} \left( \bar{q}^2 + \bar{q}k_z \right) \]

Raman spectrum reveals the momentum distribution

C. Shkedrov, GN, Y. Florshaim, Y. Sagi, PRA 101, 013609 (2020)
6. High-sensitivity Raman spectroscopy

C. Shkedrov, Y. Florshaim, GN, A. Gandman, Y. Sagi, PRL 121, 093402 (2018)
7. Raman spectroscopy of strongly-interacting imbalanced Fermi gas

GN, C. Shkedrov, Y. Florshaim, O. K. Diessel, J. von Milczewski, R. Schmidt, Y. Sagi, PRX 10, 041019 (2020)
8. Zero-momentum polaron energy
9. Molecule binding energy
10. Quasiparticle weight

\[ P(\omega) = \bar{Z}P_{\text{coh}}(\omega; T_p, \epsilon_{\text{pol}}^0, m^*) + (1 - \bar{Z})P_{\text{bg}}(\omega; T_{\text{bg}}, E_b) \]

\[ (k_Fa)^{-1} = -0.06 \]
11. Fermi polaron model

- polaron and molecule variational wave-functions
- populated at finite temperature
12. Summary

1. Smooth polaron–molecule transition is a direct consequence of coexistence for $n_l > 0$, amplified in $T > 0$.

2. High-sensitivity Raman spectroscopy enabled momentum-dependent probing and extraction of the quasiparticle residue.

3. Outlook: repulsive polaron, Raman injection spectroscopy.

Thank you!

GN, C. Shkedrov, Y. Florshaim, O. K. Diessel, J. von Milczewski, R. Schmidt, Y. Sagi, PRX 10, 041019 (2020)