



UNIVERSITY OF PISA
DEPARTMENT OF PHYSICS «ENRICO FERMI»



Many-Body Entanglement in Fermi Gases for Quantum Metrology



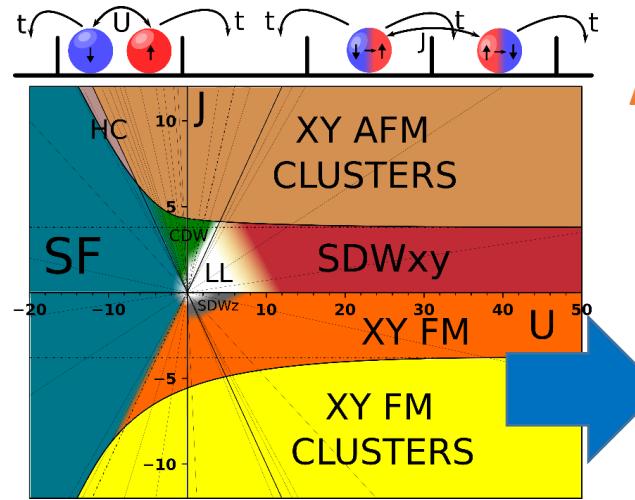
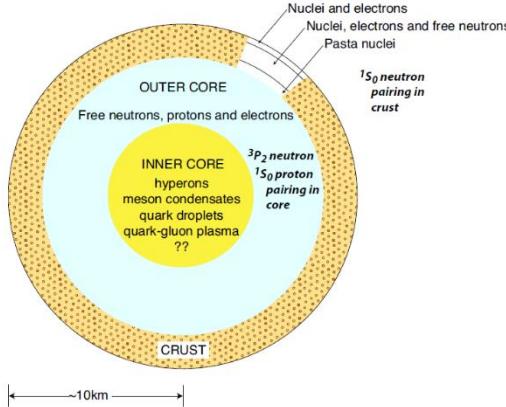
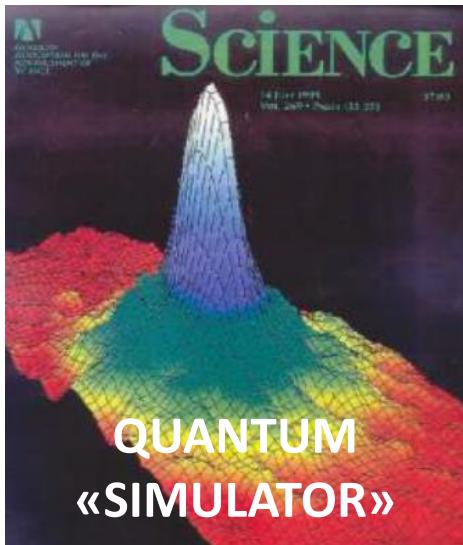
[L. Lucchesi & M.L. Chiofalo, PRL, in press]

Leonardo Lucchesi and Marilù Chiofalo

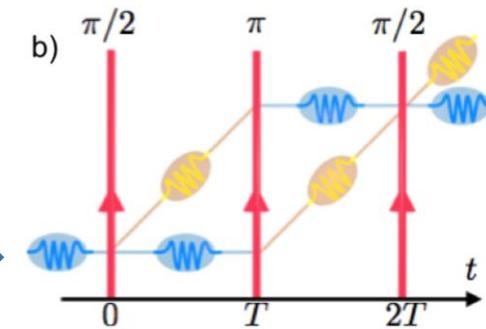
Dipartimento di Fisica «Enrico Fermi»

Università di Pisa e INFN

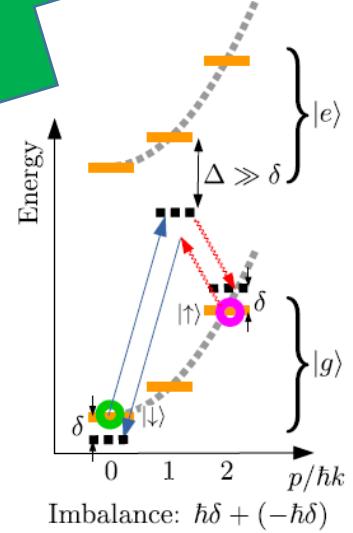
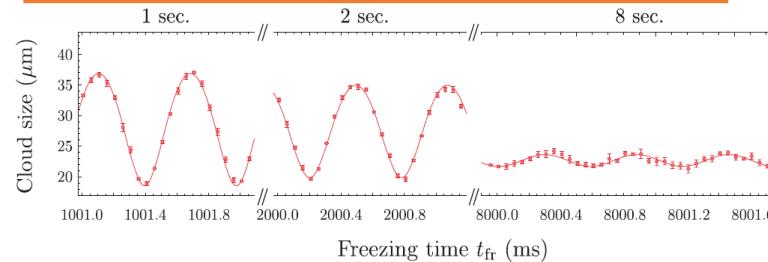
Simulating Gravitation and Cosmology in Condensed Matter and Optical Systems
ECT@Trento, July 22-25th 2019



ATOMIC INTERFEROMETER



**MANY-FERMIONS ENTANGLED STATES
METROLOGY PARADIGMS
SQUEEZED MOMENTUM STATES
GALILEO PENDULUM 4 ATOMS**





Cornell University

the

arXiv.org > astro-ph > arXiv:1907.03867

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Astrophysics > Instrumentation and Methods for Astrophysics

SAGE: A Proposal for a Space Atomic Gravity Explorer

G. M. Tino, A. Bassi, G. Bianco, K. Bongs, P. Bouyer, L. Cacciapuoti, S. Capozziello, X. Chen, M. L. Chiofalo, A. Derevianko, W. Ertmer, N. Gaaloul, P. Gill, P. W. Graham, J. M. Hogan, L. Iess, M. A. Kasevich, H. Katori, C. Klempert, X. Lu, L.-S. Ma, H. Müller, N. R. Newbury, C. Oates, A. Peters, N. Poli, E. Rasel, G. Rosi, A. Roura, C. Salomon, S. Schiller, W. Schleich, D. Schlippert, F. Schreck, C. Schubert, F. Sorrentino, U. Sterr, J. W. Thomsen, G. Vallone, F. Vetrano, P. Villoresi, W. von Klitzing, D. Wilkowski, P. Wolf, J. Ye, N. Yu, M. S. Zhan

(Submitted on 8 Jul 2019)

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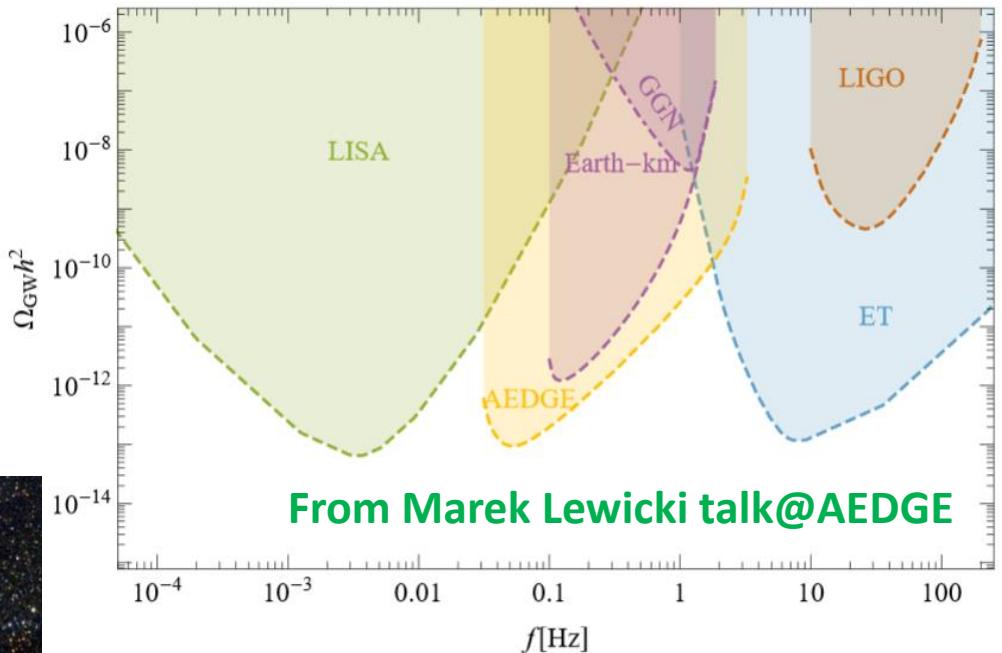
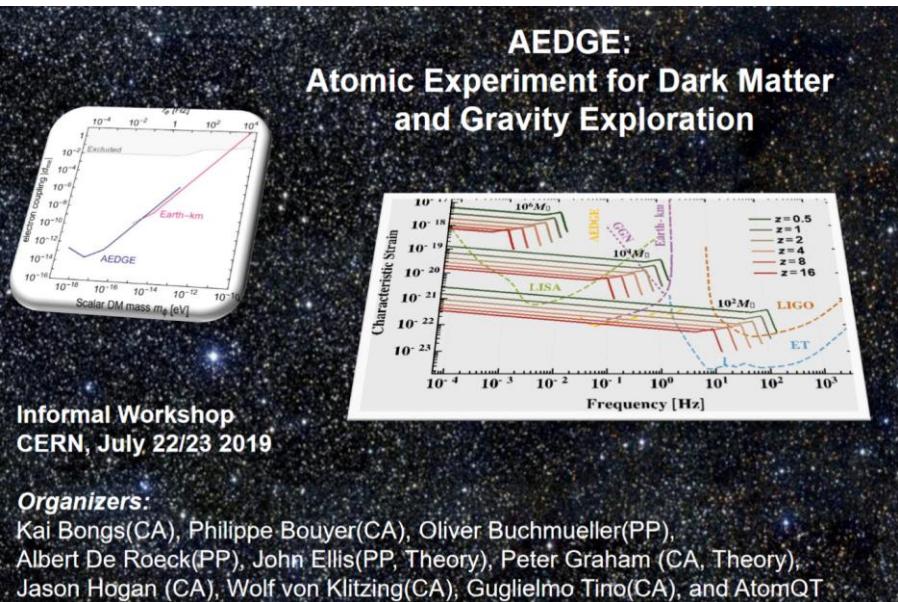
arXiv.org > gr-qc > arXiv:1908.00802

General Relativity and Quantum Cosmology

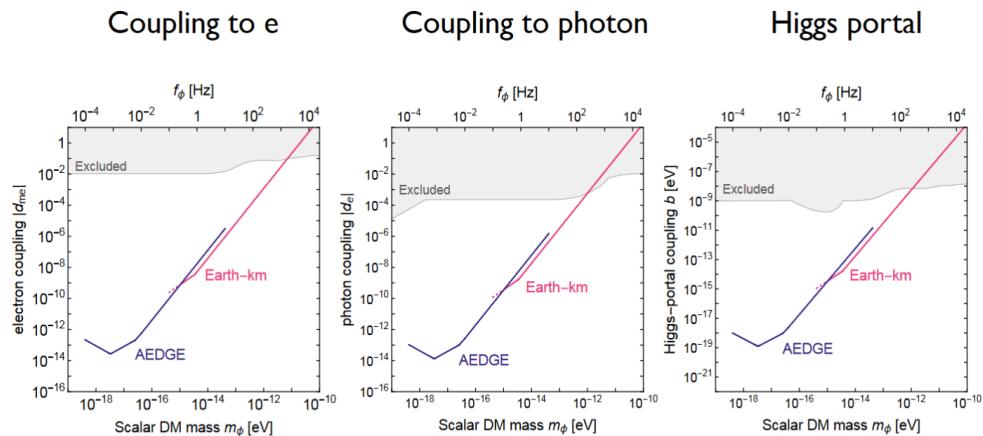
AEDGE: Atomic Experiment for Dark Matter and Gravity Exploration in Space

Andrea Bertoldi, Kai Bongs, Philippe Bouyer, Oliver Buchmueller, Benjamin Canuel, Laurentiu-Ioan Caramete, Maria Luisa Chiofalo, Jonathon Coleman, Albert De Roeck, John Ellis, Peter W. Graham, Martin G. Haehnelt, Aurelien Hees, Jason Hogan, Wolf von Klitzing, Markus Krutzik, Marek Lewicki, Chris McCabe, Achim Peters, Ernst Rasel, Albert Roura, D. O. Sabulsky, Stephan Schiller, Christian Schubert, Carla Signorini, Fiodor Sorrentino, Yajpal Singh, Guglielmo Tino, Ville Vaskonen, Ming-Sheng Zhan

(Submitted on 2 Aug 2019)



Scalar DM: AEDGE sensitivity

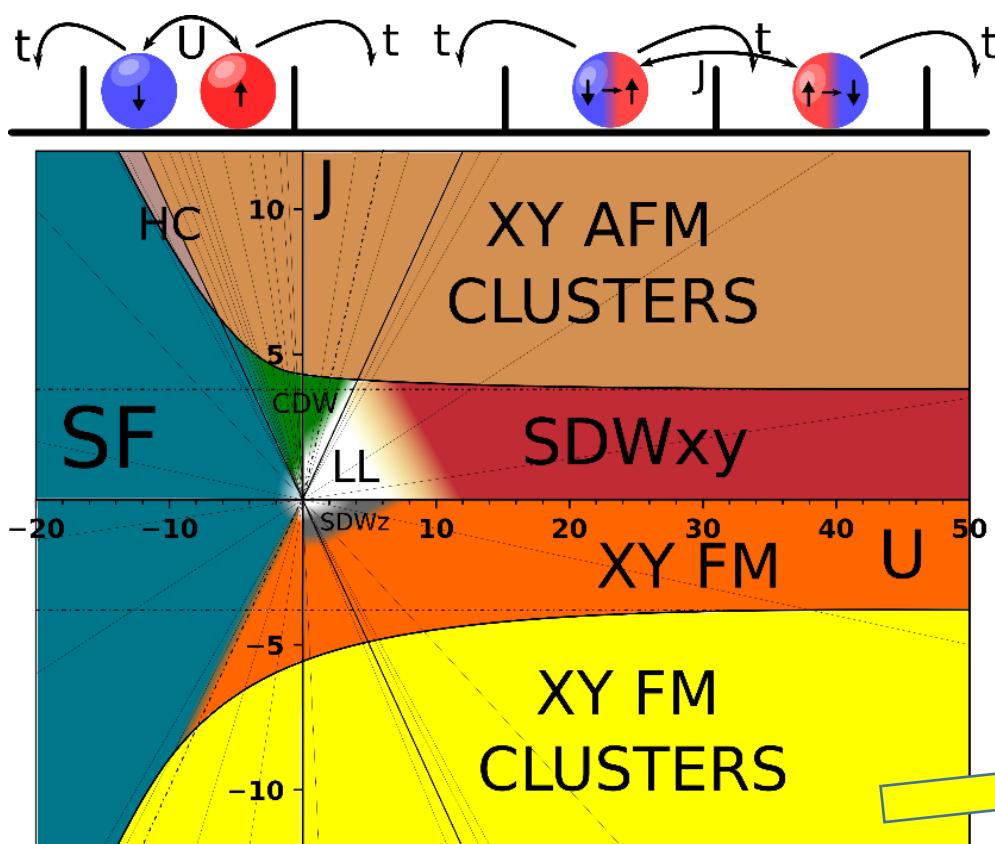


Based on Arvanitaki et al, PRD97 075020 (2018)

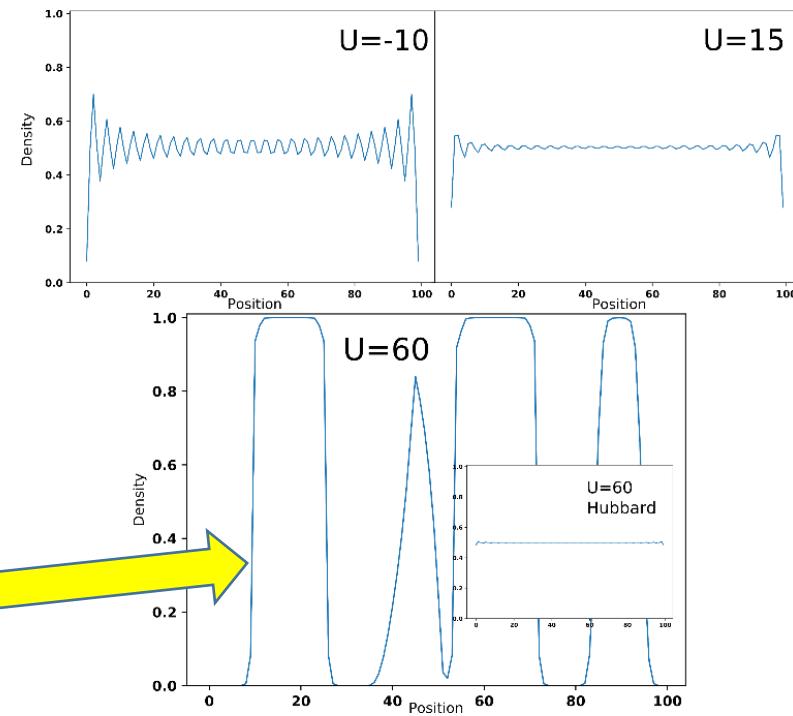
From Christopher McCabe talk @AEDGE

TAILORING MANY-FERMIONS ENTANGLED STATES FOR METROLOGY WITH TUNABLE-RANGE INTERACTIONS

Leonardo Lucchesi+MLC (PRL19) + Luca Lepori (in preparation)



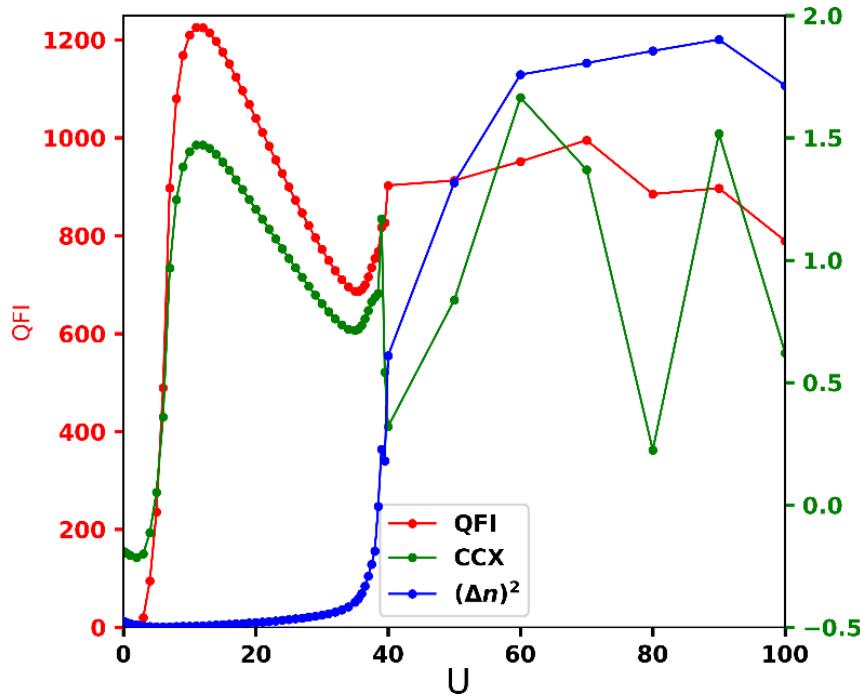
[e.g. tunable-range interactions
in multimode cavities: see
B. Lev PRX 2018]



VIA DMRG METHODS

$$H = \sum_i [-t(c_{i\sigma}^\dagger c_{i+1\sigma} + \text{h.c.}) + U n_{i\uparrow} n_{i\downarrow} + J(s_i^+ s_{i+1}^- + \text{h.c.})]$$

METROLOGICAL USABILITY: THE QUANTUM FISHER INFO

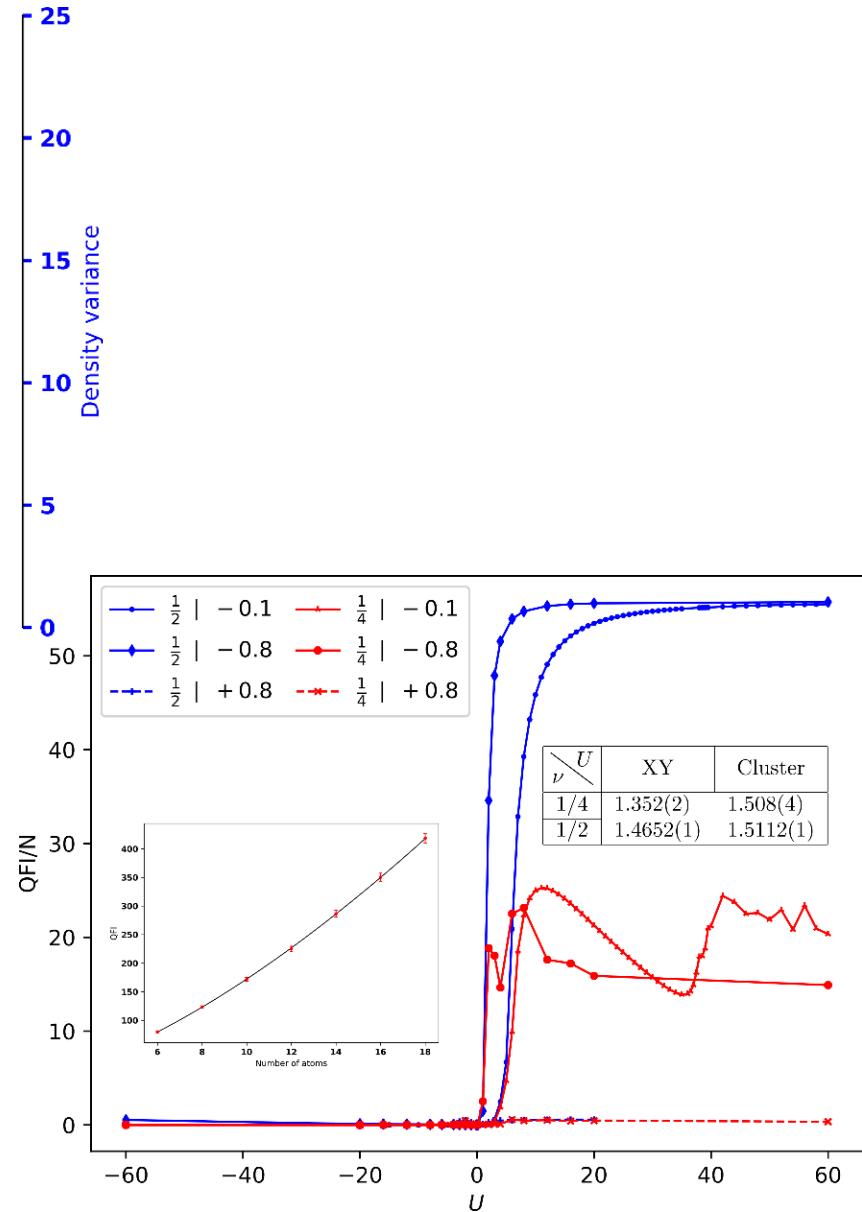


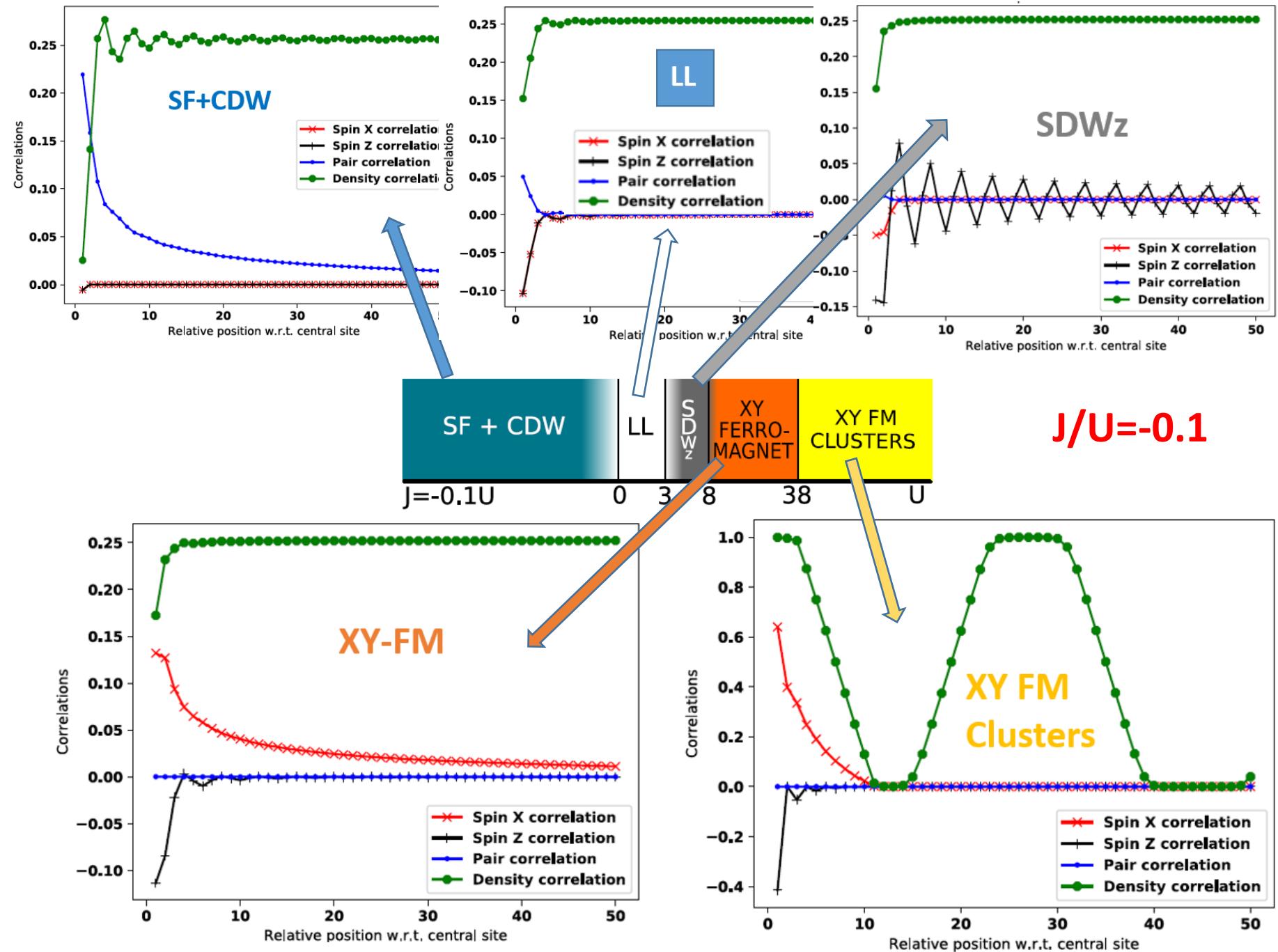
QUANTUM CRAMER-RAO LOWER BOUND

$$(\Delta\theta)^2 \geq 1/F[\rho, \hat{S}]$$

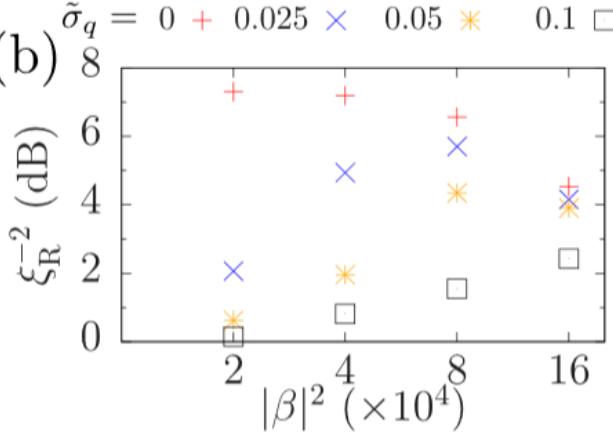
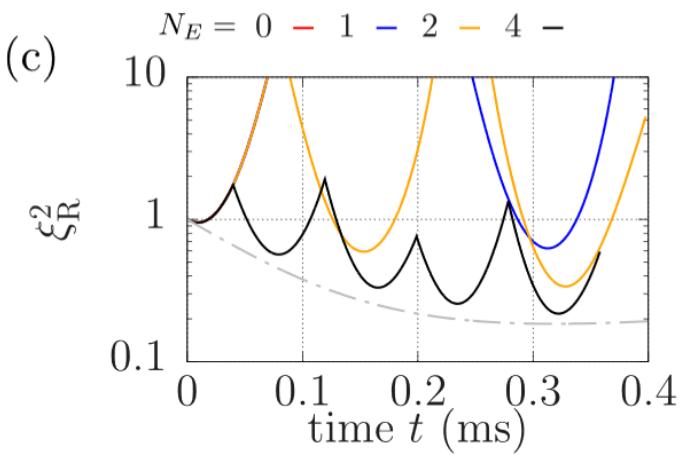
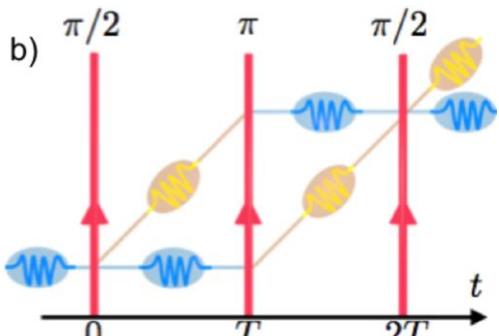
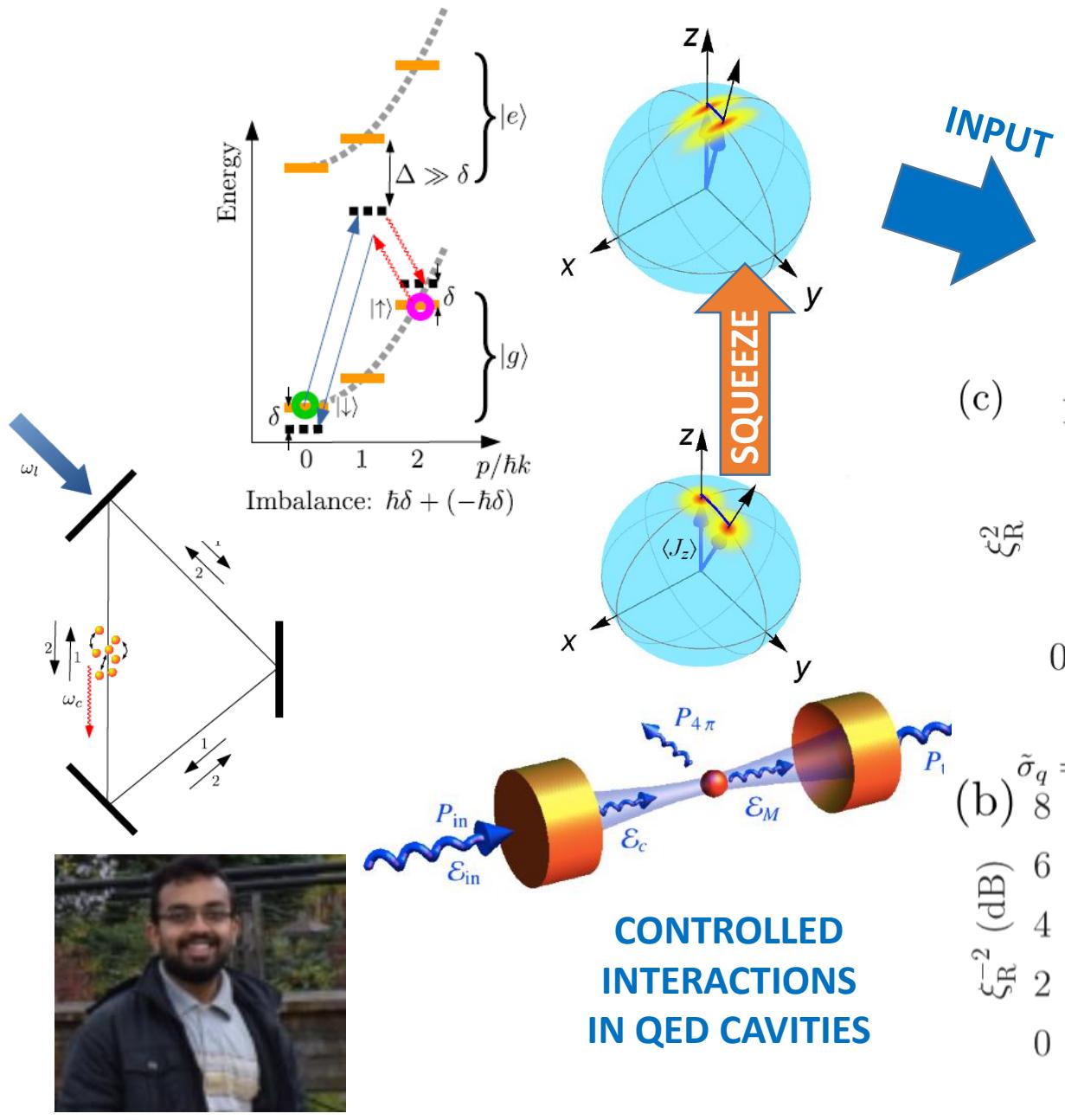
QUANTUM FISHER FOR PURE STATE

$$F[\psi, \hat{S}_{\vec{a}}] = 4(\Delta S_{\vec{a}})_{\psi}^2$$





BRAGG ATOMIC INTERFEROMETER FOR GW DETECTION (MAGIA-Advanced)



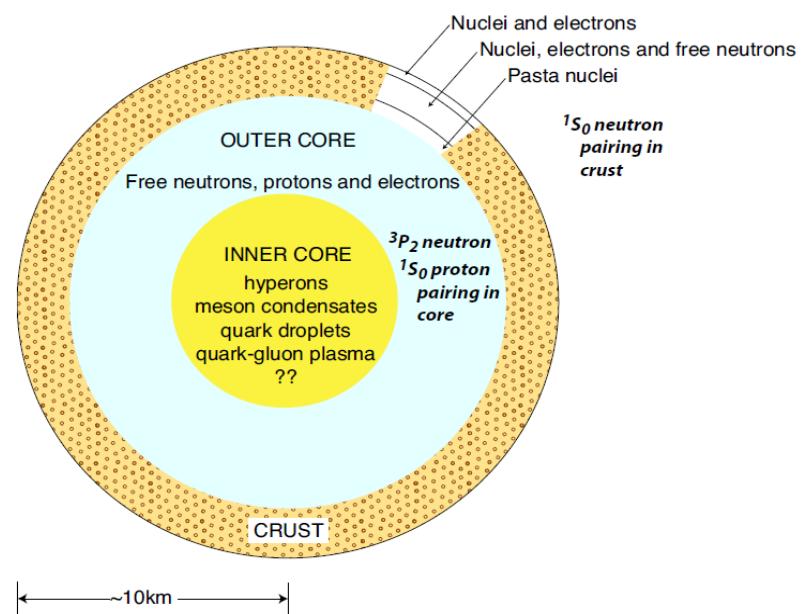
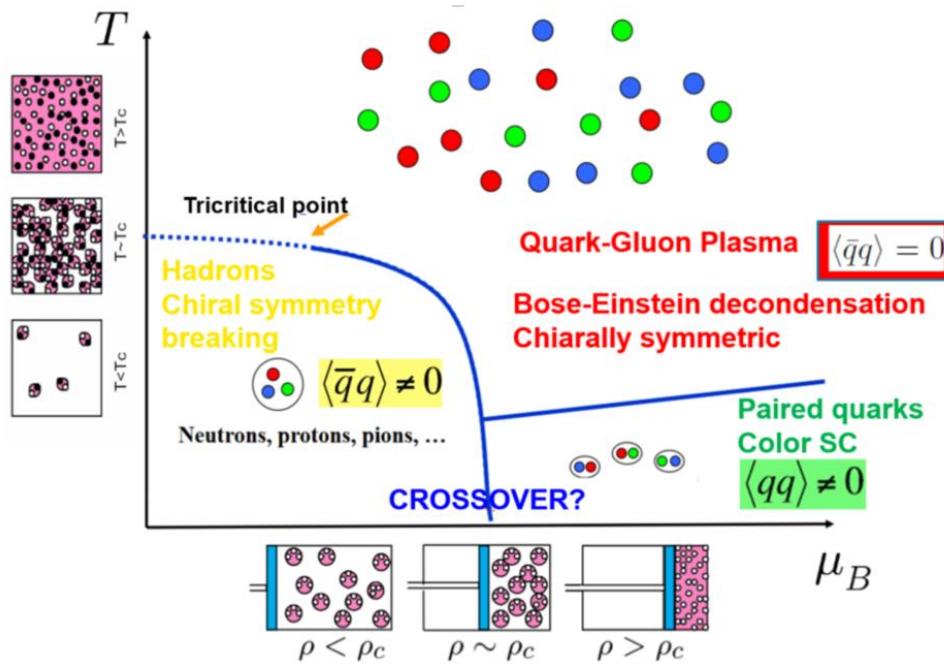
CURRENT WORK AND PERSPECTIVES

- PREDICT QFI FROM UNIVERSAL BEHAVIOR ANALYSIS [LUCA LEPORI]
- CONCEIVE PROTOCOL FOR ATOMIC INTERFEROMETER: NON TRIVIAL!
- IMPLEMENT IN REAL PLATFORMS:
 - FERMI-HUBBARD SIMULATOR @ MARKUS GREINER (HARVARD)
 - DIPOLAR FERMIONS @ FRANCESCA FERLAINO (INNSBRUCK)
 - MULTIMODE CAVITIES @ BEN LEV (STANFORD)
- MULTIMODE CAVITIES: INCLUDE DRIVEN-DISSIPATIVE EFFECTS AND DYNAMICS IN THE INTERFEROMETER. WORK ONGOING WITH:
 - FABRIZIO VARCHETTA, MD@UNIVERSITY OF PISA, CURRENTLY @ STRATHCLYDE
 - JONATHAN KEELING @ ST. ANDREWS, EDINBURGH
 - ANDREW DALEY @ STRATHCLYDE
 - BEN LEV @ STANFORD
- PLAY WITH ANALOGUES WHILE USING FULL QUANTUM SYSTEM VERSATILITY
- AEDGE PHYSICS

TWO MORE PROBLEMS
[NOT YET FULLY MENTIONED AT THIS CONFERENCE]

PHASE DIAGRAM OF QUARK-GLUON PLASMA & NEUTRON STARS

G. Baym, BCS: 50 yrs (2011)



NEUTRON STARS and more recent QUANTUM GASES: need to account for interaction range!

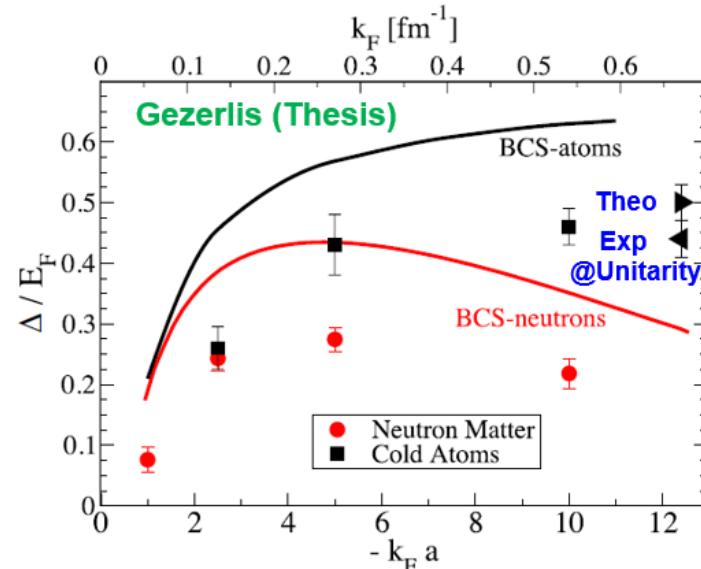
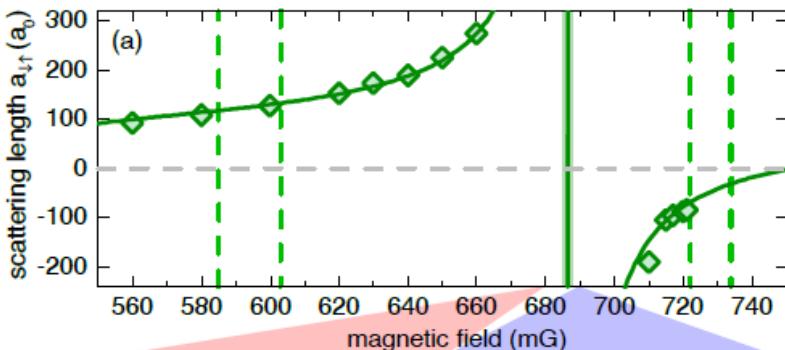
Schwenk&Pethick (2005)

	Quantum Gases	Neutron Stars	Quark-Gluon Plasma
$T \approx$	10^{-6} - 10^{-9} K	10^6 K	10^{12} K \approx 10^2 MeV
Interaction strength \approx	$k_F a$ in $(-\infty, +\infty)$ $1/k_F a \approx 100$ Bohr	$k_F a \approx -13$ $1/k_F a \approx 1.4$ fm	$g \approx 1/2$
Range \approx	$k_F R_e \ll 1$ (broad) $k_F R_e \approx 1$ (\rightarrow narrow)	$k_F R_e \approx 2$	-----

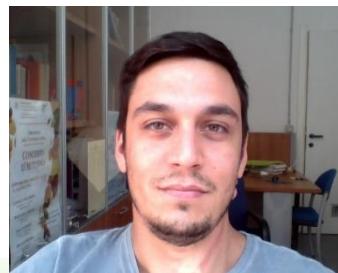
$$\frac{E}{N} = \xi(k_F r_e) \frac{3k_F^2}{10m}$$

$$\xi(k_F r_e) \rightarrow \xi = 0.44 \pm 0.01$$

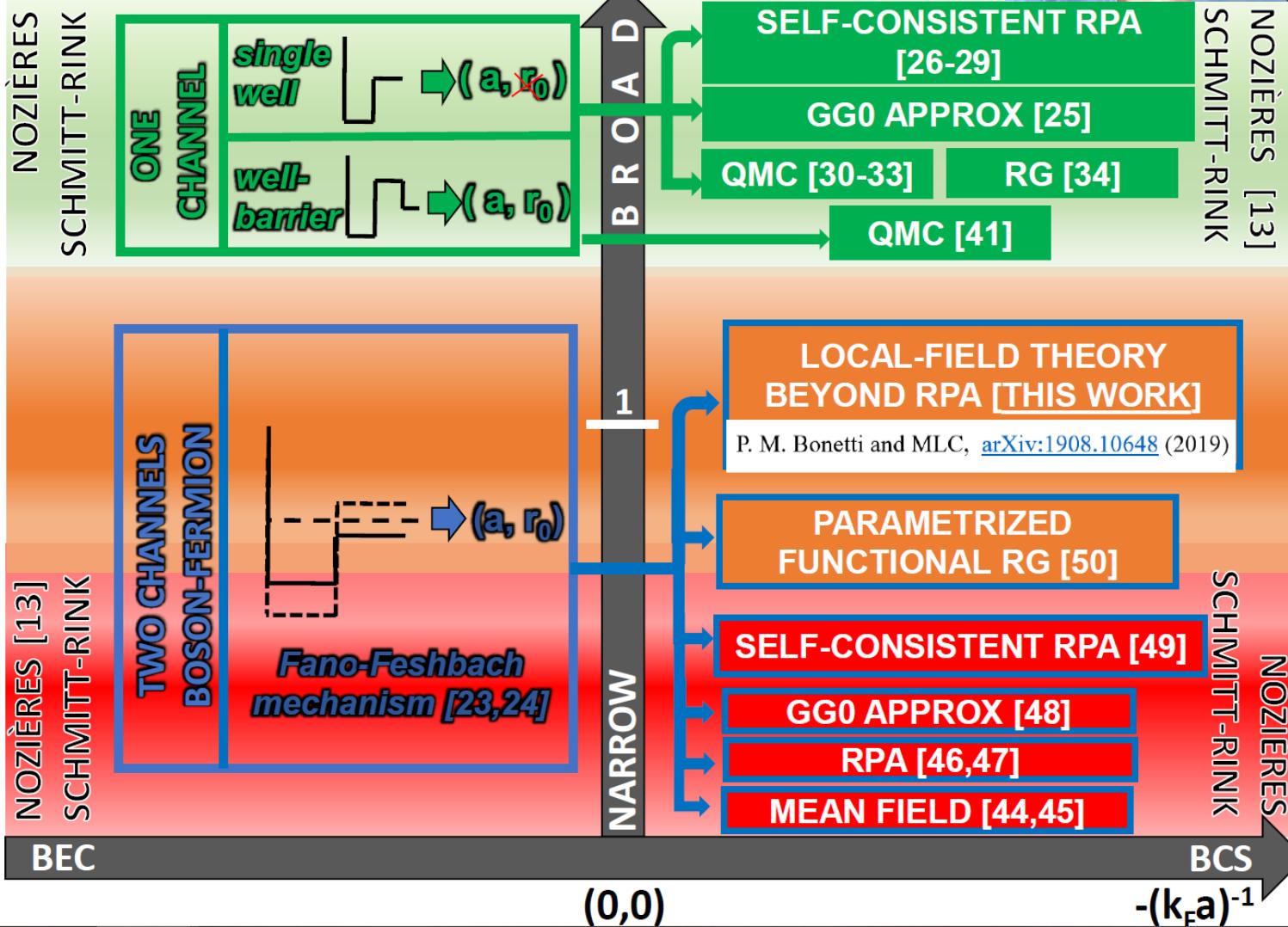
^{167}Er @Francesca Ferlaino LAB (PRL 2018)



THEORIES FOR SUPERFLUIDITY IN THE CROSSOVER



Pietro M. Bonetti
Now PhD@MPI
Stuttgart with W.
Metzner

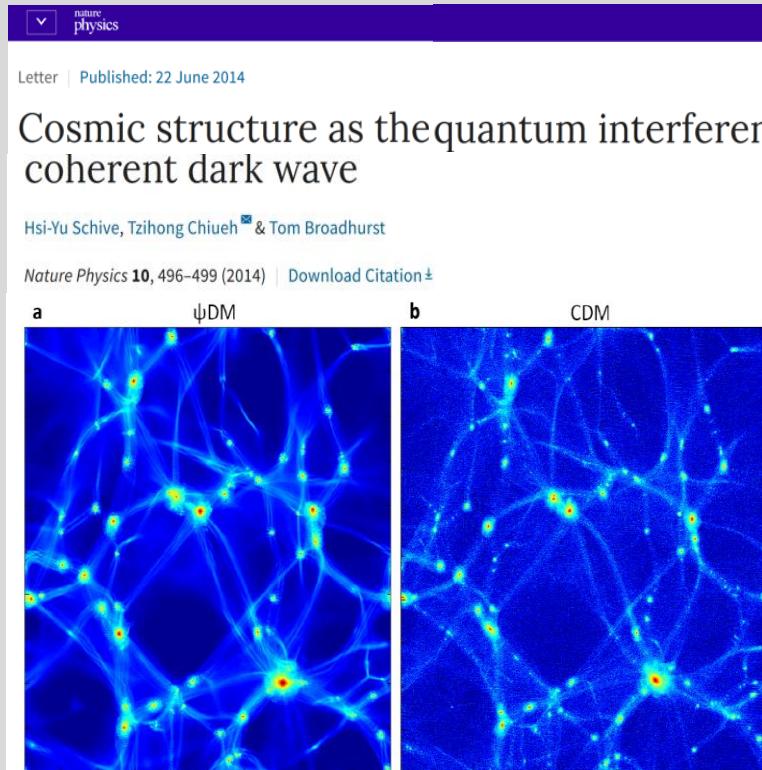




UNIVERSAL RATIO

n/s

FUZZY DARK MATTER



In collaboration with

- Dario Grasso@INFN, Pisa
- Stefano Liberati @SISSA, Trieste
- Giovanni Tricella @SISSA, Trieste
- Andrea Trombetti@CNR+SISSA, Trieste



Carla Signorini
Until Dec 2018, Head of
Electrical Department at
ESA. Now PhD @ UniPi
In collaboration with
Andrea Ferrara@SNS

FERMIIONS IN QED CAVITIES&QUANTUM OPEN SYSTEMS

- Ben Lev (Stanford)
- Jonathan Keeling (St. Andrews, Edinburgh, UK)
- Andrew Daley (Strathclyde, Glasgow, UK)
- &Araceli Venegas Gomez, PhD
- Davide Rossini (UniPi)
- Luca Lepori (SNS, PD)

Former students

Elvia Colella

MD UniPi, now PhD

@Innsbruck with
Helmut Ritsch



QUANTUM GASES 4 METROLOGY

- Guglielmo Tino (LENS, Firenze)
- &Leo Salvi, PD
- Nicola Poli (LENS, Trieste)
- Murray Holland (JILA, Colorado)
- &Athreya Shankar, PhD
- Andrea Trombettoni (SISSA, Trst)
- &Giacomo Gori

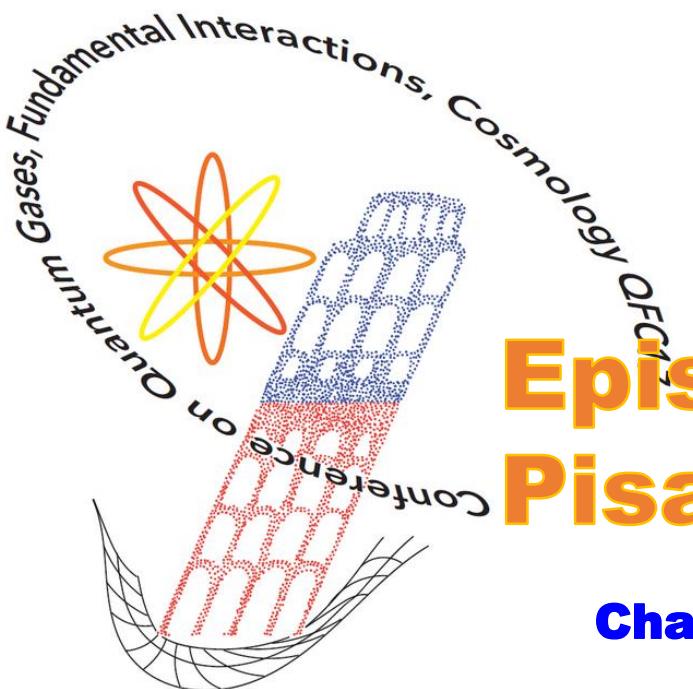
Former students

Cosetta Baroni

MD UniPi, now PhD

@Innsbruck with
Rudy Grimm





STARWARS
EPISODE II
ATTACK OF THE CLONES
ANALOGUES

Episode II: Pisa, 23-25 October 2019

Chair: Marilù Chiofalo (ColdAt)

LOC: Dario Grasso (Astro), Dario Buttazzo (FundInt), Carla Signorini (Cosmo-ColdAt)

Advisory Board:

**Eric Cornell (ColdAt)
Guido Tonelli (PartPhys)
Sandro Stringari (ColdAt)
Lev Pitaevskii (ColdAt)
Andrea Ferrara (Cosmo)
Massimo D'Elia (FundInt)
Steve Shore (Astro)
Guglielmo Tino (ColdAt)**

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Volker Bromm (Cosmo)
Iacopo Carusotto (ColdAt)
Dmitri Karzehev (FundInt)
Sabino Matarrese (Cosmo)
(QFC17 keynote Speakers)**

<https://agenda.infn.it/event/QFC2019>

**THANKS TO YOU
FOR YOUR ATTENTION!**