Ultracold Quantum Gases

Thomas Busch

Ultracold Quantum Gases Group

founded

2006

sfi

science foundation ireland

fondúireacht eolaíochta éireann


5 EURO

sfi

science foundation

fondúireacht eolaíochta

embarkinitiative

Investing in People and Ideas

Currently

4 group members

Thomas Busch

John Goold

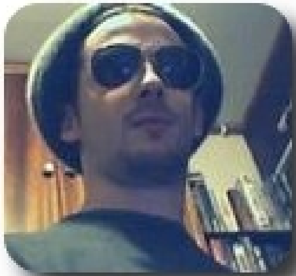
Suzanne McEndoo

Brian O'Sullivan

Tony Blake
Donal O'Donoghue
Tomas Ramos
Brendan Cahill
Colm Kelleher

Jimmy Brophy



we

are

a theoretical group

however

sometimes

we

like to

do

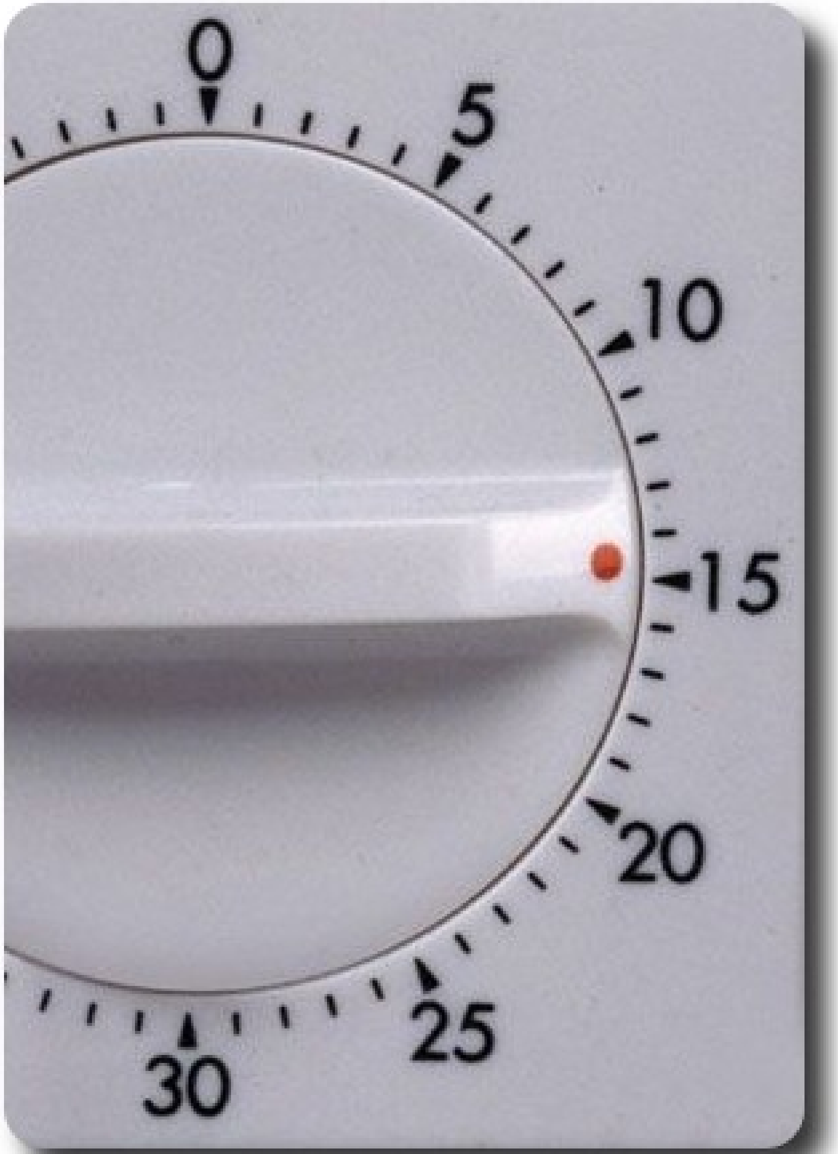
experimental talks.

what do we work on?

(as the title suggests)

ultracold quantum gases

however...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5
10
15
20
25
30

will not talk about

specific work we do

but

rather about

why we do the things we do

or

in different words

why we bother with

ultracold quantum gases

Two reasons, really

1

we want to know

what are their

fundamental properties?

2

How can we make them *useful*?

1

(fundamental properties)

why choose ultracold atoms?

answer:

(very general answer)

matter in extreme conditions
is **always** interesting

don't believe me?

ask

Paddy

Denise

Paul

Sile

Niall

Mike

John

Frank

Andy

Stephen

Michel

Dave, Paul, Andrew or Bob

who will

(hopefully)

enthusiastically
talk about

extremely

fast
hot
small
large
far away
slow
dense
theoretical

etc…

SO

what kind of extreme

gives us our

transcendental kick ?

cold

ultracold

atoms

@

nano-Kelvin

$T \sim 10^{-9} K$

pico-Kelvin

$T \sim 10^{-12} K$

which are

(modestly speaking)

simply

the coldest systems in the universe

and they are available

right here

in lots of labs on earth!

Now

because T is low

energies are low

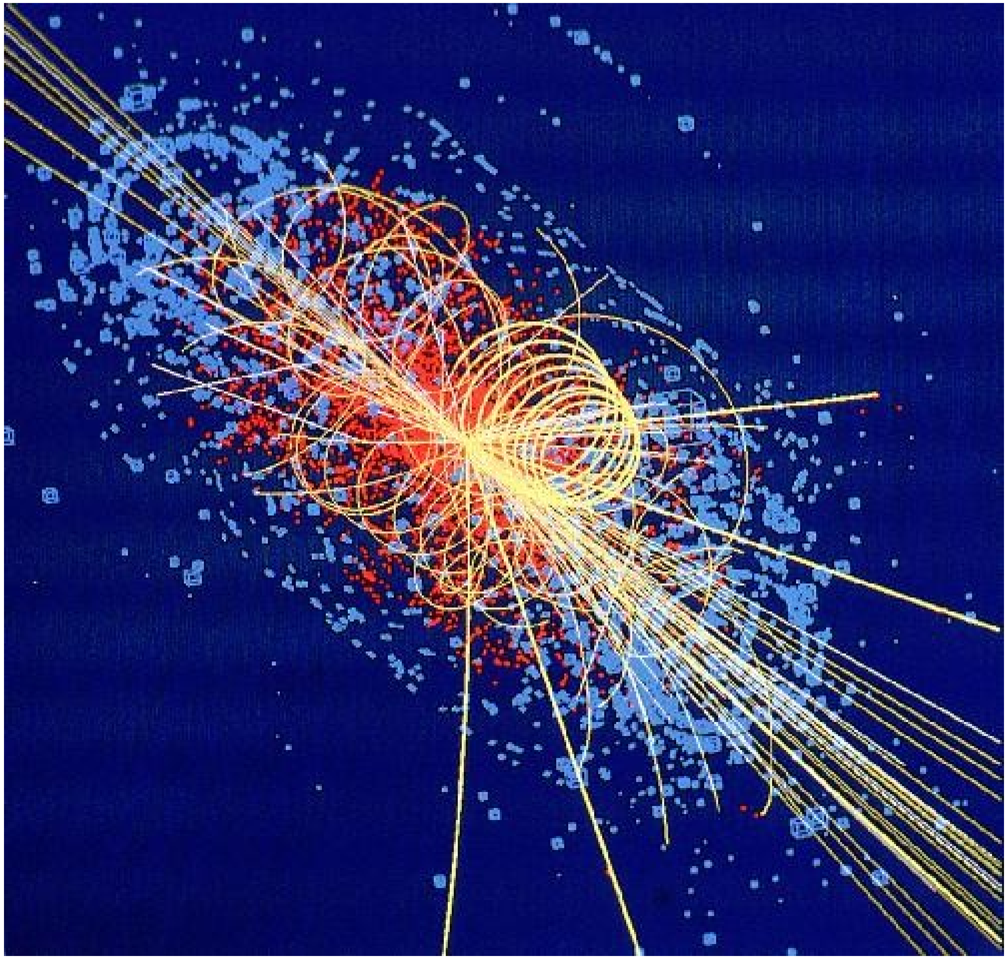
dynamics is restricted

which means that

fundamental effects appear very clearly!

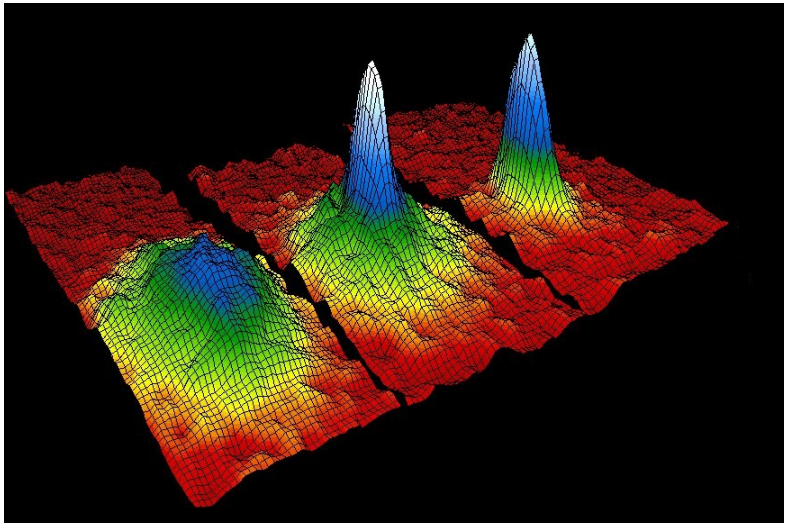
Example: Higgs Boson

(high energy)



Example: Bose-Einstein Condensate

(low energy)



dramatic difference

clean signals

which

help to

isolate *fundamental* effects

to better understand

fundamental theories:

1. quantum mechanics

2. statistical physics

the other side we care about

2

applications

you might wonder:

applications ???

YES!

there are quite a few…

1. precision metrology

which includes

interferometry

and

atomic clocks

2. model systems

to isolate effects in other
(not so clean)
systems

a. solid state

highly complex systems

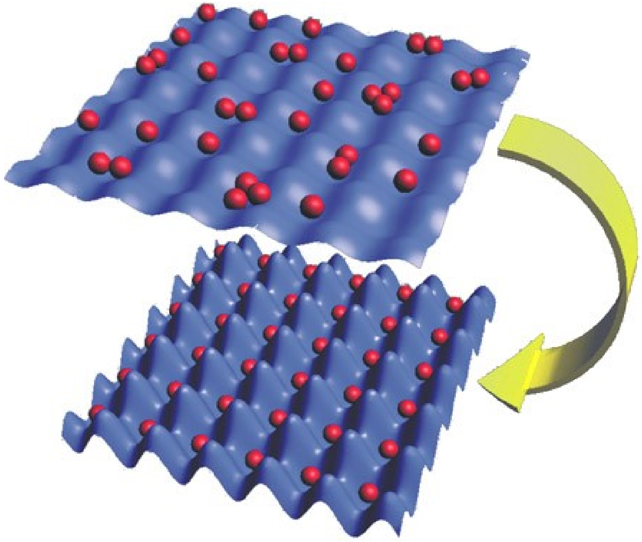
fundamental effects shadow each other

meet

optical lattices

1. take standing waves in three spatial direction

2. trap atoms in the intensity extrema



advantage

clean, cold, highly controllable

a) simulate all kinds of
known
solid state systems

e.g.

high T_C superconductivity

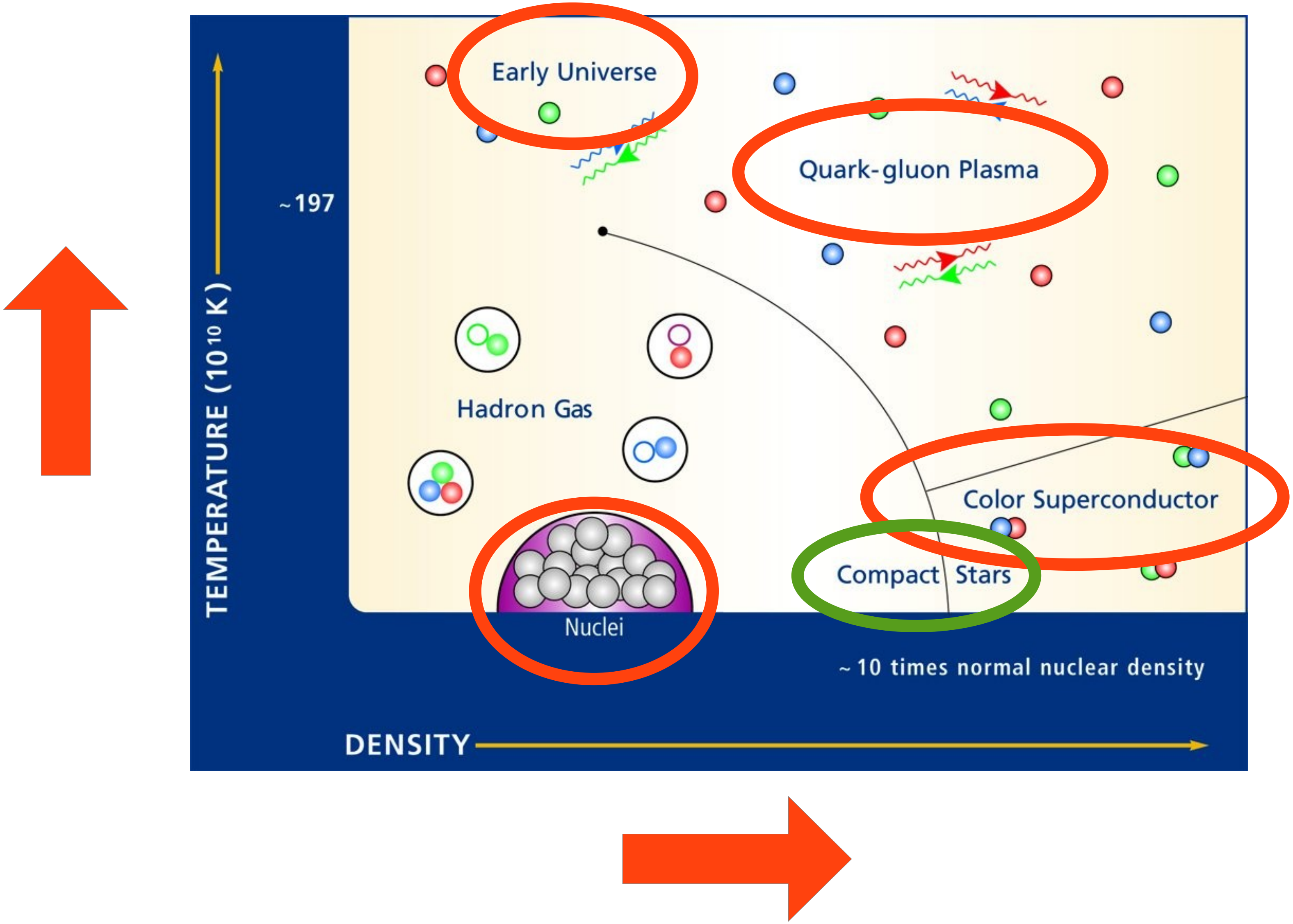
b) find new states of matter

example

b. high energy physics & astro physics

believed theoretical phase diagram of strong interaction

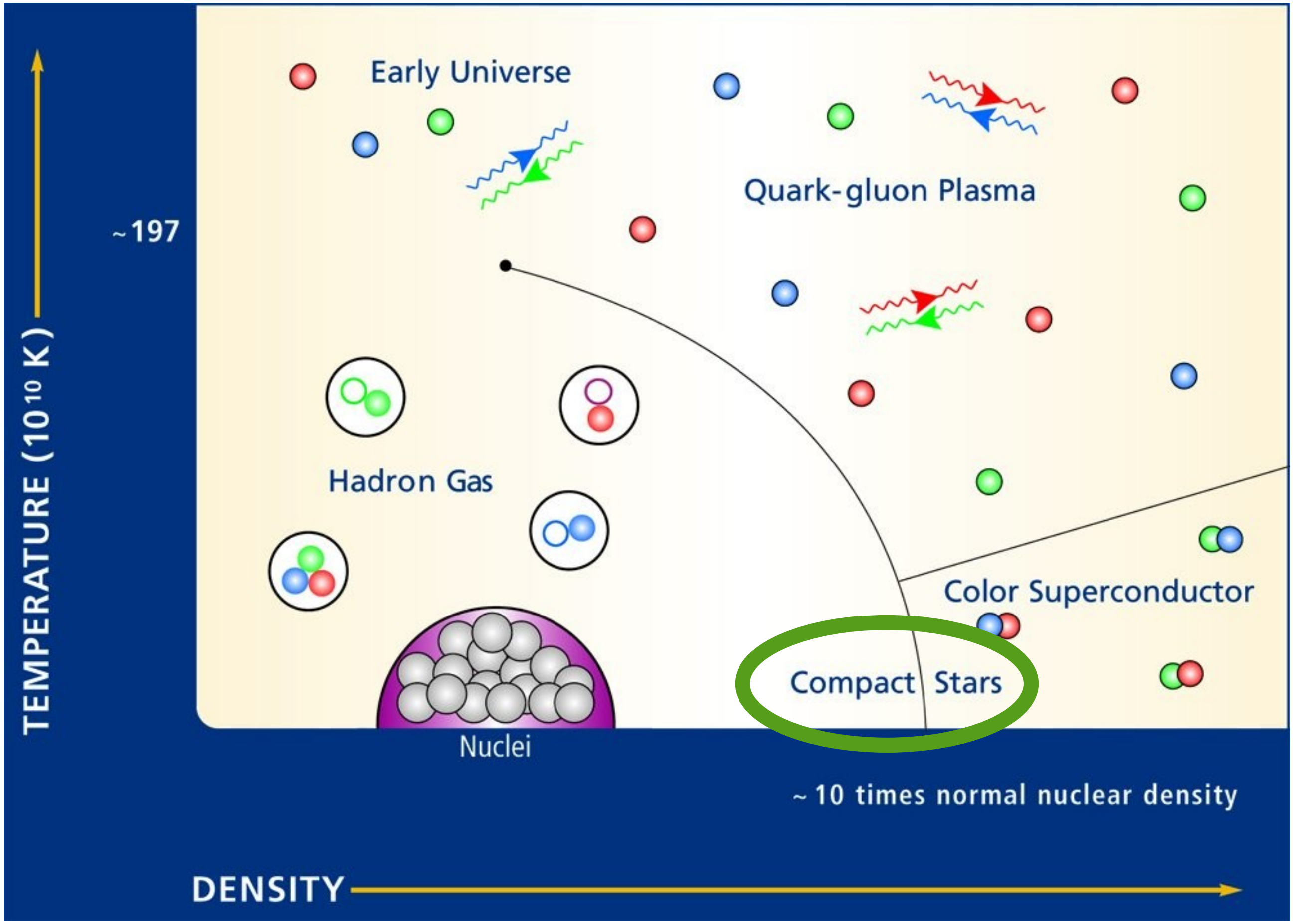
i.e. what do quarks when?



Early Universe
Quark-gluon Plasma
~197
TEMPERATURE (10¹⁰ K)
Hadron Gas
Color Superconductor
Compact Stars
Nuclei
~10 times normal nuclear density
DENSITY

centre of neutron stars

(Paul???)


Early Universe
Quark-gluon Plasma
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Nuclei
~10 times normal nuclear density
TEMPERATURE (10^10 K)
DENSITY

are these really all the
phases physically possible?

Theory: NO

FFLO phase

(predicted by Fulde, Ferrell, Larkin & Ovchinnikov)

anisotropic, crystalline
'BCS' state

Experimentalists:

well

kind of hard to do experiments in the centre of a neutron star

(two spin electrons: Meissner effect)

meet

ultracold quantum gases

turns out that the

existence

FFLO phase

depend *only* on

differences in Fermi energies

between the *different* quarks

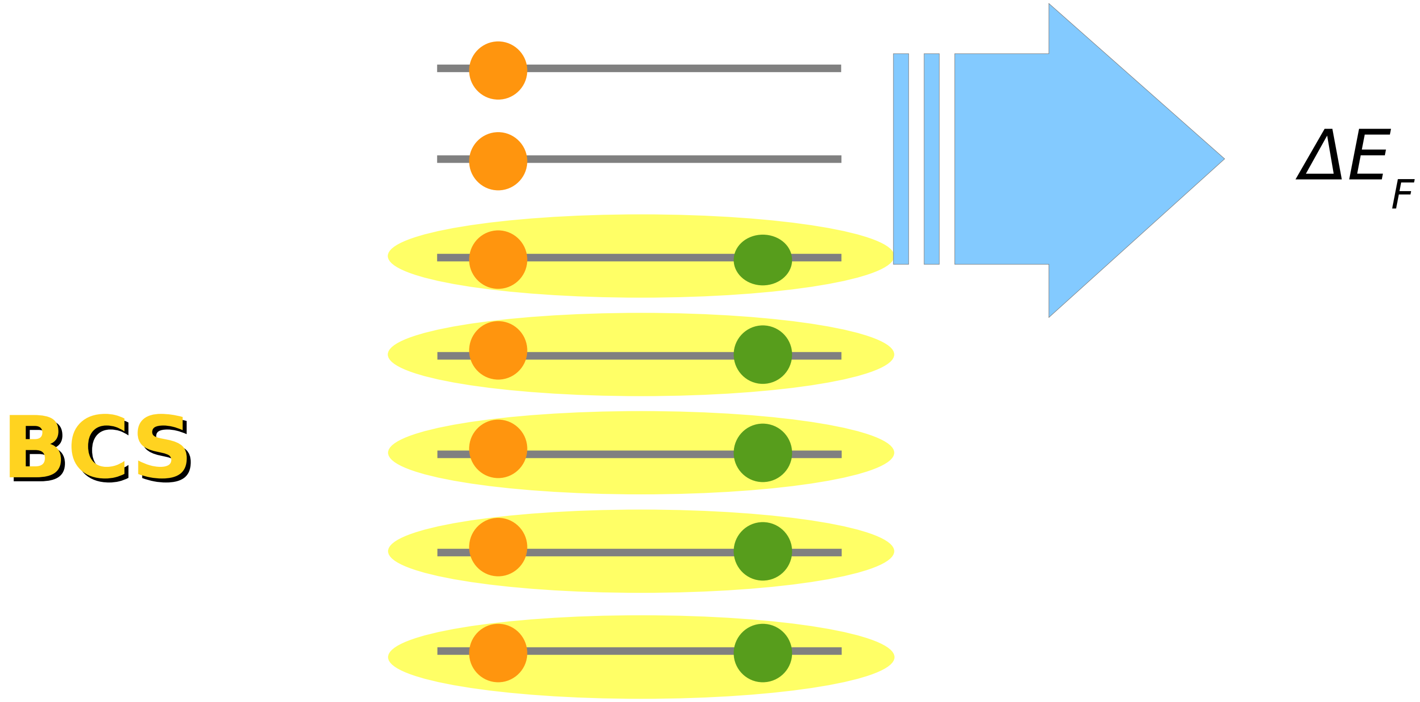
(given by their different masses)

and

Fermi energies

at low temperatures

depend on particle numbers only



BCS
ΔE_F

the question

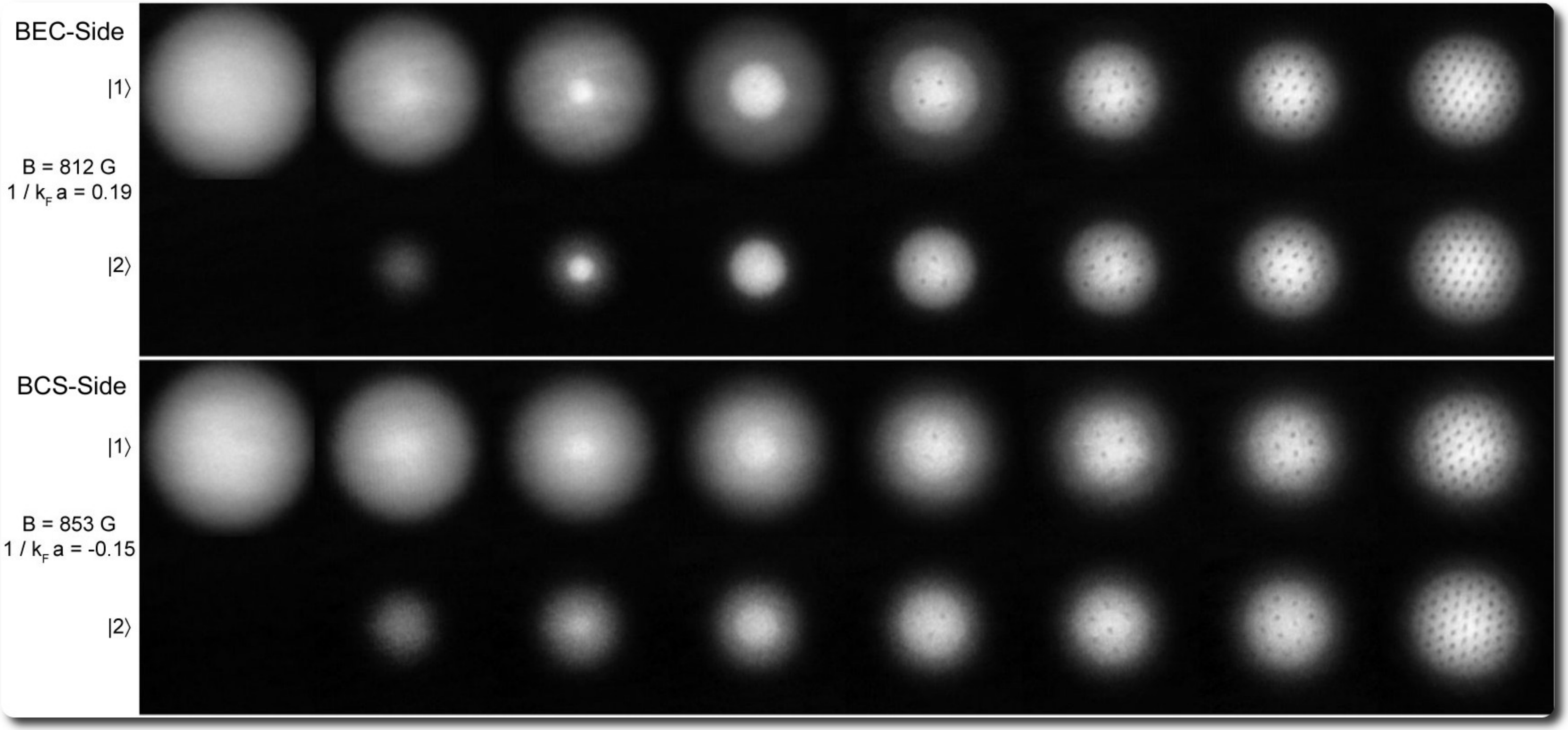
ultracold quantum gases

therefore can answer is:

will the system still be

superfluid?

molecules



Cooper pairs

MIT

3. quantum computing

what do I need?

highly controllable systems

controllable on quantum scale

and

at the same time

low decoherence

Does that sound like

impossible, like?

well

no

ultracold quantum gases

combined with

quantum optical tools

are perfect!

ultracold quantum gases

almost no phonon modes

essential for *quantum* computing

almost no interactions

quantum optical tools

essential for *quantum* computing

highly developed techniques

therefore

Last
but not
Least

4th Year Project

How

can one create

the most general

spatial
quantum
superposition
state
of
a
single
atom?

START:

$$|\psi\rangle$$

carry out a physical process

FINAL STATE:

$$|\psi\rangle = \frac{1}{2}\left(|\psi_1\rangle + e^{i\phi}|\psi_2\rangle\right)$$

where we want to have
full control over ϕ !

But

when I said

'carry out a physical process'

I meant

one is only allowed
to move the atom.

Nothing else.

Interested?

CONCLUSION

if you

are interested

want to work with us

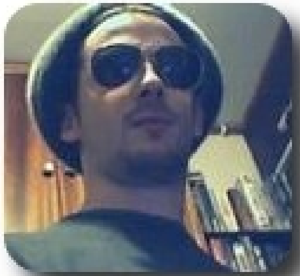
have questions

are completely confused

please come and talk to us

John Goold

Suzanne McEndoo



Brian O'Sullivan

KB 202

Thomas Busch

KB 215B

thank you for your patience and attention

(in case you have questions about neutron stars,
you are probably better off phoning extension 3211)