^{3}He Universe 2022

Matti Krusius 80

4 November 2022

Topological phases of superfluid 3He contain:

Weyl, Dirac, Majorana, anyons; Higgs bosons, gravitons, axions, magnons; skyrmions, ½ vortices, Kibble walls, …

3He Universe

gravitational Aharonov-Bohm effect (Iordanskii force)
Kibble-Lazarides-Shafi walls bounded by strings
torsion & spinning strings, torsion instanton
fermion zero modes on strings & walls
antigravitating (negative-mass) string
string terminating on domain wall
electroweak monopole, Q-balls
monopoles on string & boojums
Witten superconducting string
nexus, soft core string
Z &W strings
skyrmions
Alice string
Pion string

emergence & effective theories, Weyl, Majorana & Dirac fermions
vacuum polarization, screening - antiscreening, running coupling
momentum-space topology, vacuum as topological insulator *
symmetry breaking (anisotropy of vacuum), gauge bosons
fermionic charge of vacuum, 4-form vacuum variable
vacuum instability in strong fields, pair production
hierarchy problem, supersymmetry, hidden symmetry
Higgs fields, light Higgs, Little Higgs, Nambu sum rule *
parity violation, chiral fermions, Planck physics
Casimir forces, quantum friction, neutrino oscillations
chiral anomaly, Schwinger pair production, axions *
spin, isospin, string theory,
CPT-violation, SM, GUT
2+1 electrodynamics

gap nodes
low -T scaling
broken time reversal
mixed state, stripe phase
*Higgs amplitude modes
chiral anomaly, CME, CVE
Bogoliubov Fermi surface
Khodel-Shaginyan flat band
flat band from Dirac nodes
* flat band room-T superconductivity
*1/2-vortex, fractional flux, vortex sheet
Andreev-Majorana states on vortex
vortex dynamics, spectral flow, Kopnin force

cosmological constant, q-theory
Kibble-Zurek mechanism
primordial magnetic field
anisotropic dark matter
baryogenesis by textures & strings
inflation, matter creation
branes

Newton constant
dark energy, dark matter
effective gravity, tetrads
bi-metric & conformal gravity
vacuum dynamics, 4-form field
conformal anomaly,
graviton, dilaton, spin connection
rotating vacuum, Mach principle
Nieh-Yan anomaly, thermal anomaly
antispacetime, Euclidean signature
ergoregion, event horizon
Hawking & Unruh effects
black hole entropy, vacuum instability
type-II Weyl fermions behind horizon

cosmic strings | **physical vacuum** | **cosmology** | **High Energy Physics** | **high-T & chiral super-conductivity** | **vacuum gravity** | **Gravity** | **^{3}He** | **Condensed Matter** | **1D, 2D systems** | **top. insulators semimetals** | **magnetism** | **black holes** | **QCD** | **Plasma Physics** | **Phenome nology** | **BEC** | **neutron stars** | **quark matter** | **nuclear physics** | **phase transitions** | **hydrodynamics** | **disorder**

intrinsic QHE, spin & FQHE, Chern-Simons, 3D QHE
skyrmion & vortex statistics, Hall viscosity, edge states
Abrikosov Universe: Weyl semimetals
Chern number, nexus, type II Weyl,
higher order topology, Berry monopole,
Dirac line, Fermi arc, Lifshitz transition
synthetic gauge field & gravity
spintronics, magnonics, spinmotive force
spin currents, spin nematic, spin superfluidity
skyrmionics, magnon BEC, coherent precession
mixture of condensates, vector & spinor
BEC of quasipartcles, photon BEC
skyrmion, 1/2 vortex, monopole, nexus

superfluidity of neutron star
vortices, glitches
shear flow instability

quark condensate
Nambu--Jona-Lasinio
Vaks--Larkin
color superfluidity
MIT bag model
Savvidi vacuum
quark confinement, QCD cosmology
intrinsic orbital momentum,
chiral magnetic & chiral vortical effects

Nuclei vs
^{3}He droplet
shell model
pair-correlations
collective modes

quantum Lifshitz
phase transitions
p-space topology

relativistic plasma
photon mass
vortex Coulomb plasma

random
anisotropy
Larkin- Imry-Ma states
classes of random matrices
skyrmion glass, Weyl glass
spin & Hopf glass, torsion glass
Anderson-Fomin theorem

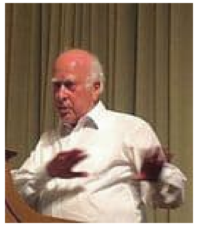
velocity independent Reynolds number
general, relativistic, multi-fluid
turbulence of vortex lines
propagating vortex front
magnetohydrodynamics
shear flow instability
rotating superfluid
spin superfluidity

time crystals & quasicrystals
time crystal Josephson effect
supersolid, topological Floquet phases

some topics in Northeastern ^{3}He Universe

- light & heavy Higgses, hint on 1 TeV Higgs
- asymptotic freedom, zero-charge effect & confinement
- flat band as route to room-T superconductivity

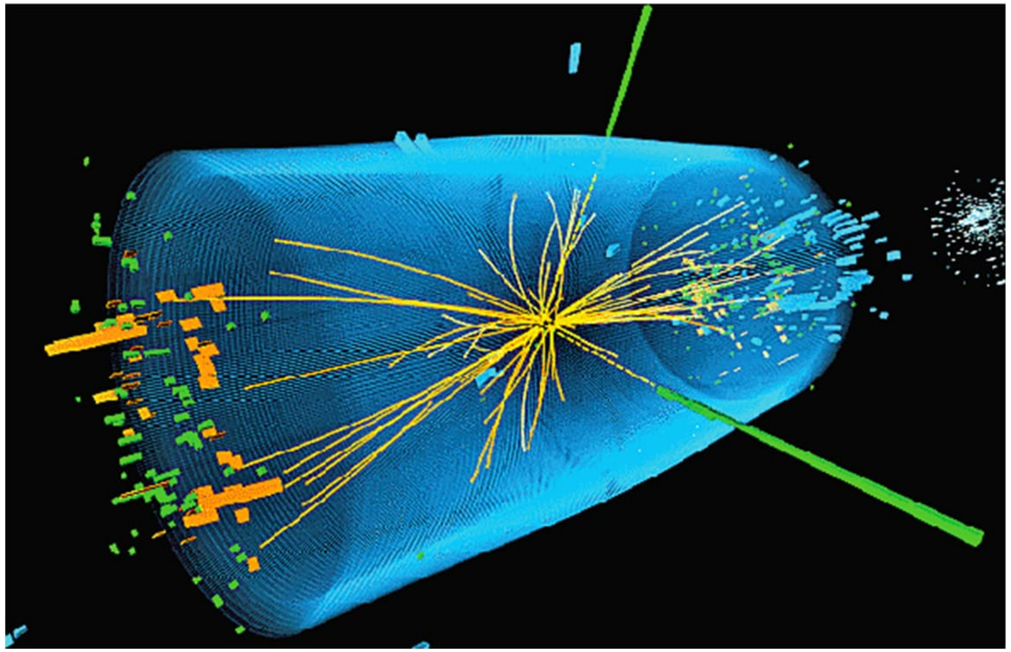
^{3}He prediction:
from light Higgs to heavy Higgs



author of Higgs mechanism & massive Higgs bosons

maybe not so massive?

co-authors of Higgs mechanism



Kibble **Guralnik** **Hagen** **Englert** **Brout**

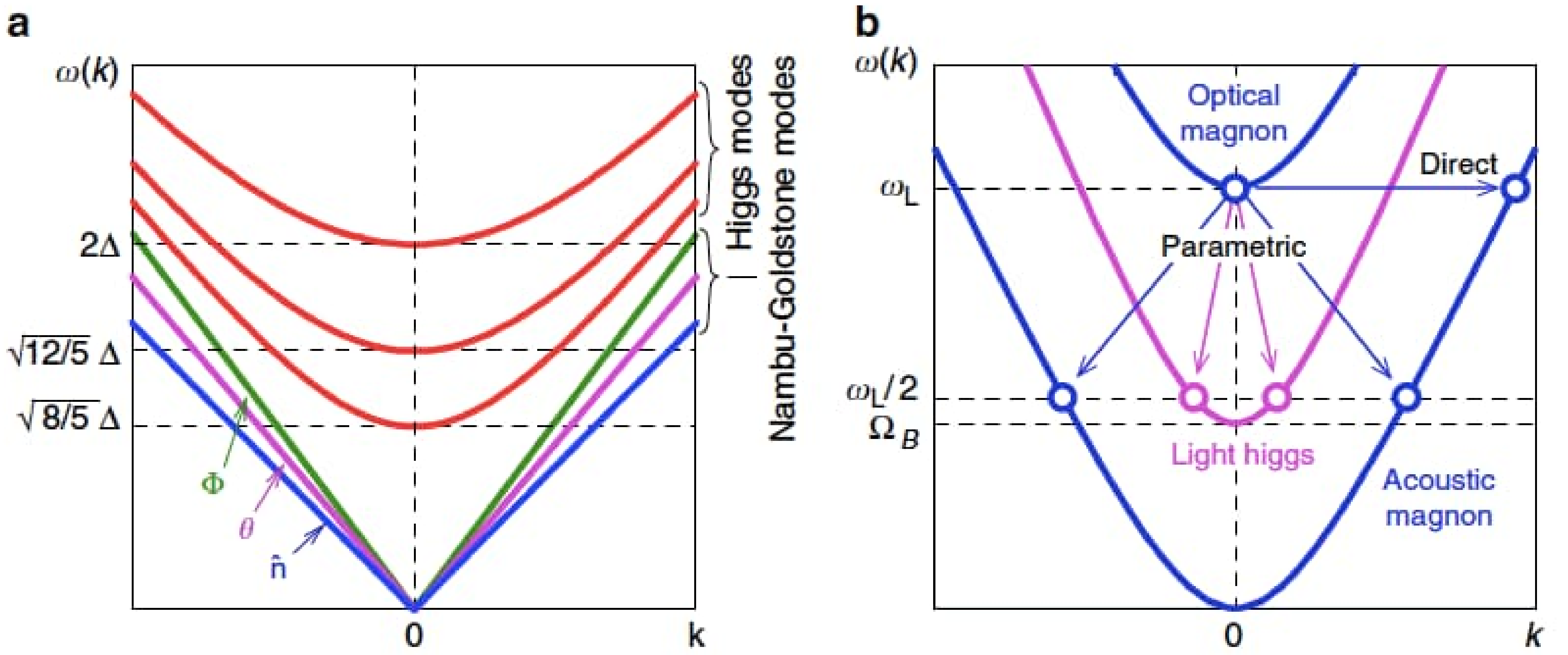
V.M.H. Ruutu, V.B. Eltsov, A.J. Gill, T.W.B. Kibble, M. Krusius, Yu.G. Makhlin, B. Placais, GV, Wen Xu,
Vortex formation in neutron-irradiated superfluid 3He as an analogue of cosmological defect formation, Nature 382, 334 (1996)

Light Higgs channel of the resonant decay of magnon condensate in superfluid ^{3}He-B

V.V. Zavjalov[1], S. Autti[1], V.B. Eltsov[1], P.J. Heikkinen[1] & G.E. Volovik[1,2]

nature COMMUNICATIONS

Received 4 May 2015 | Accepted 26 Nov 2015 | Published 8 Jan 2016



Goldstone modes transform to light Higgs modes
due to spin-orbit interaction and magnetic field

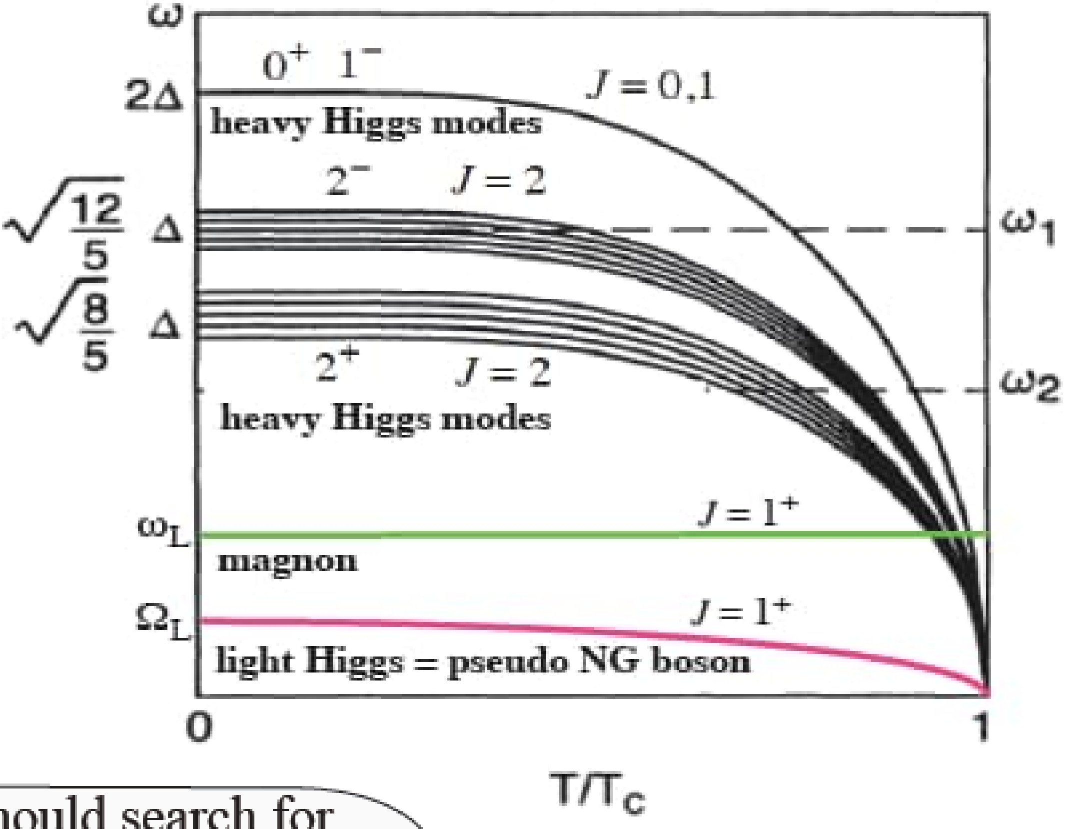
Light Higgs channel of the resonant decay of magnon condensate in superfluid ^{3}He-B

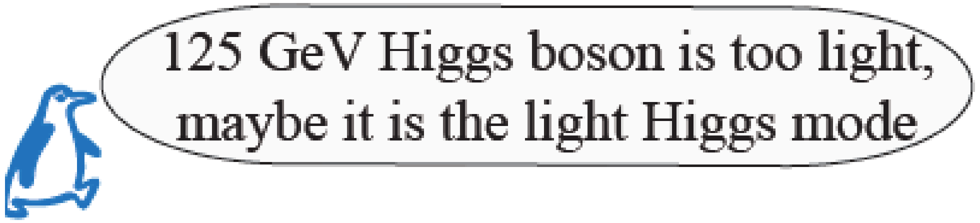
nature COMMUNICATIONS

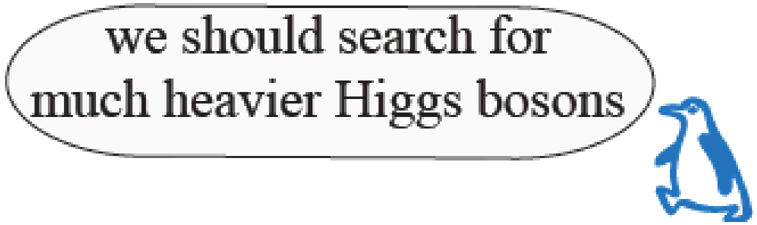
V.V. Zavjalov[1], S. Autti[1], V.B. Eltsov[1], P.J. Heikkinen[1] & G.E. Volovik[1,2]

Received 4 May 2015 | Accepted 26 Nov 2015 | Published 8 Jan 2016

We find that the low-energy physics in superfluid ^{3}He has many common features of the Higgs scenario in Standard Model: both are described by the SU(2) and U(1) symmetry groups; the acoustic and optical magnons correspond to the doublet of W^+ and W^- gauge bosons, which spectrum also splits in magnetic field[34]; the light Higgs mode has parallel with the 125-GeV Higgs boson. However, in addition, the ^{3}He-B has the high-energy sector with 14 heavy Higgs modes. This suggests that in the same manner, the 125-GeV Higgs boson belongs to the low-energy sector of particle physics, and if so, one may expect the existence of the heavy Higgs bosons at TeV scale.

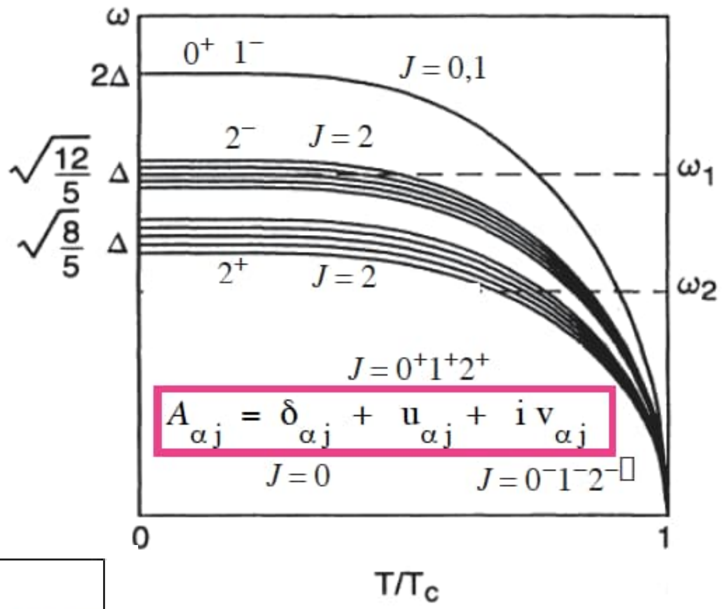






Heavy Higgses

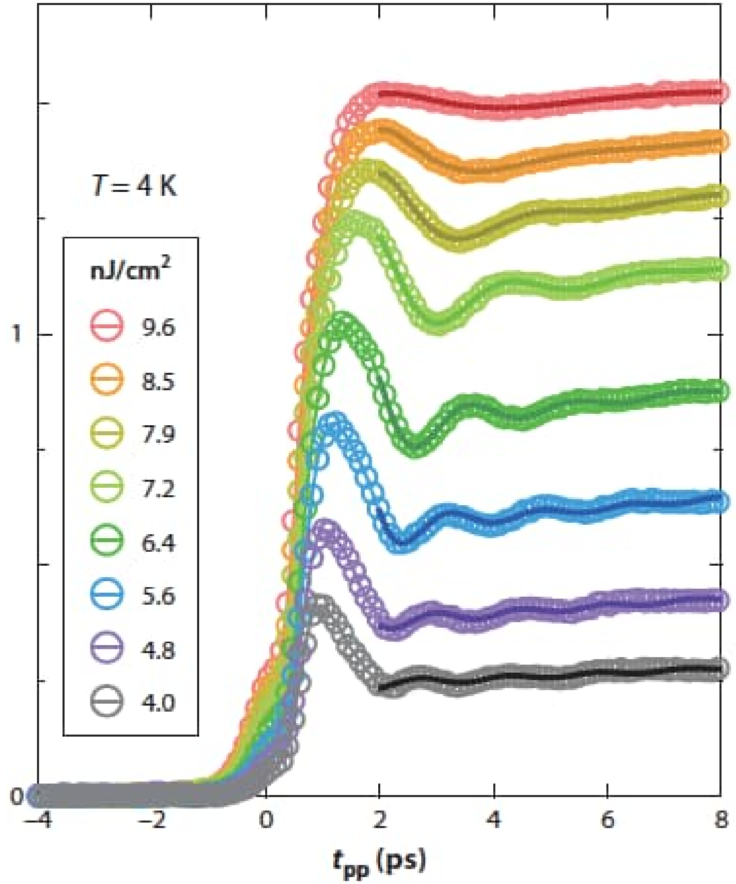
3He-B



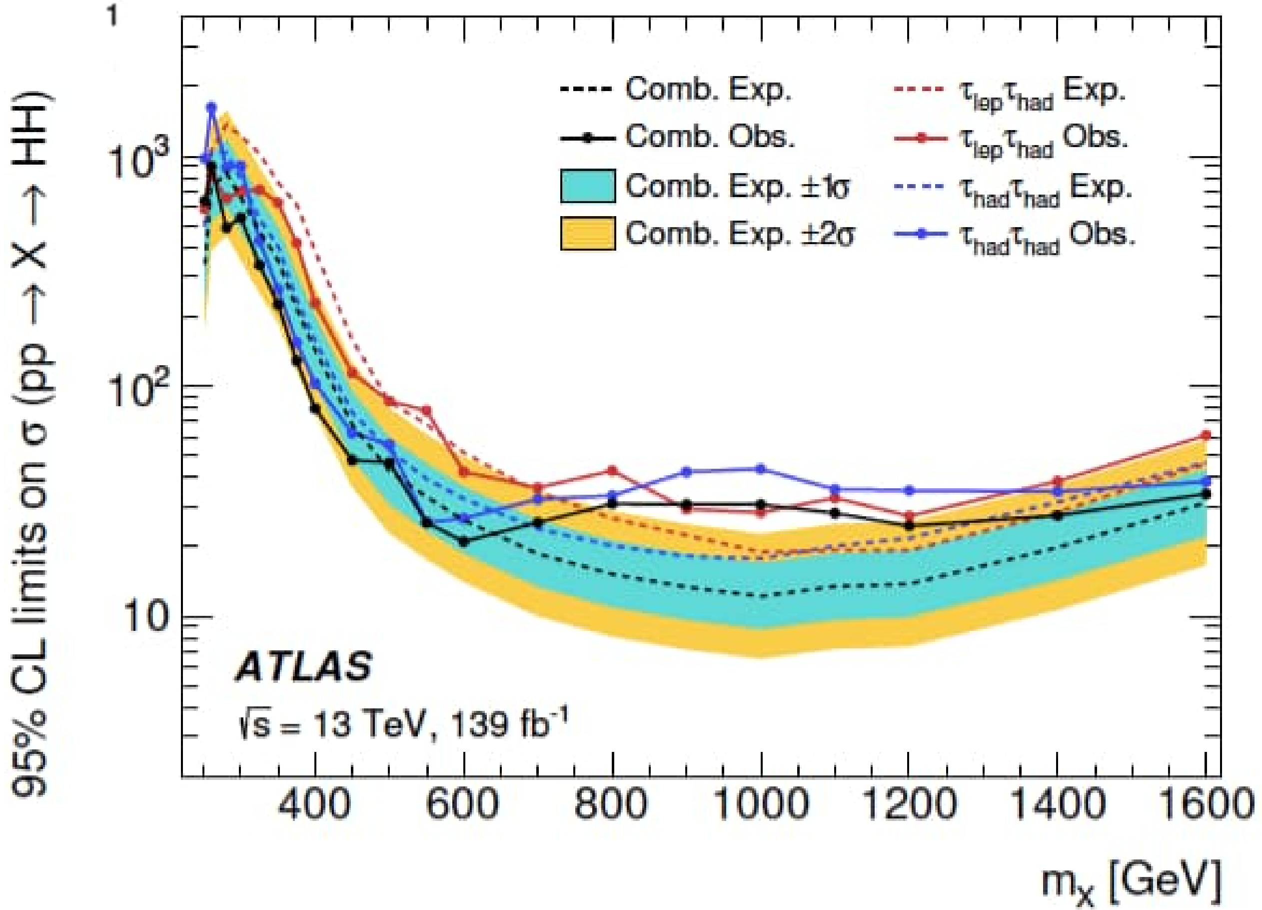
CERN-EP-2022-109

23rd September 2022

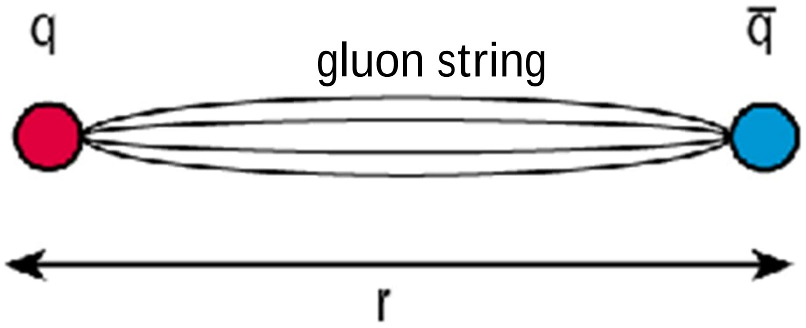
superconductor

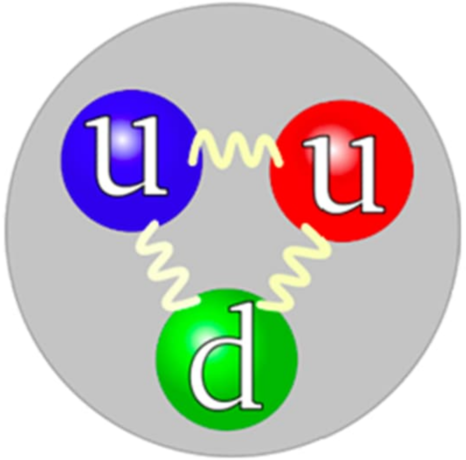


particle physics

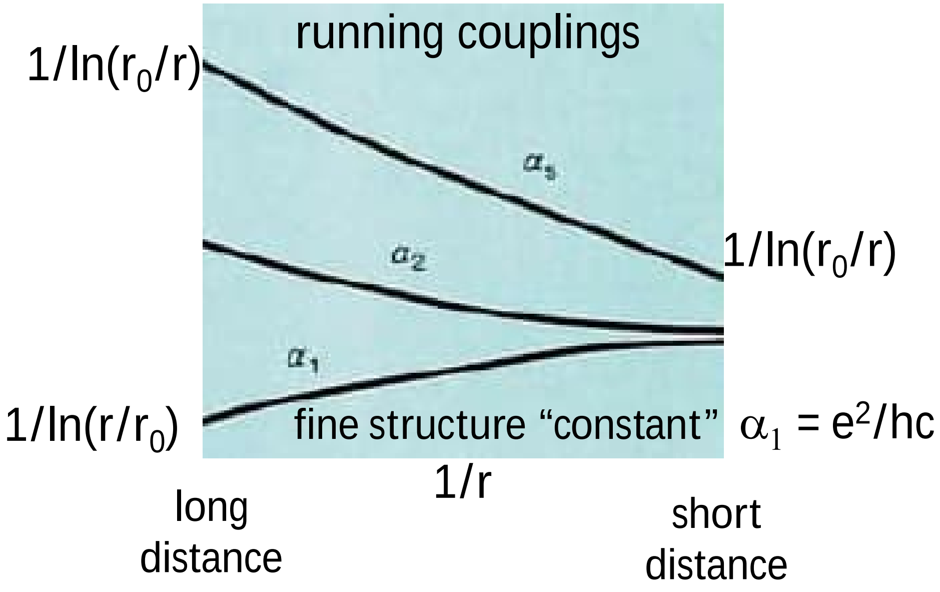


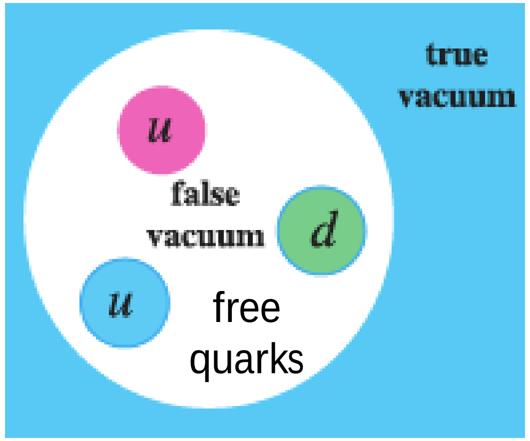
^{3}He & particle physics: zero charge vs asymptotic freedom





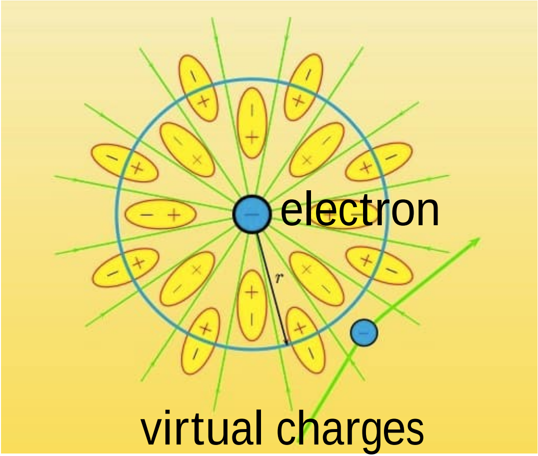
color charge increases with distance:
antiscreening, quark confinment





color charge is small at small distances:
asymptotic freedom, quarks become free

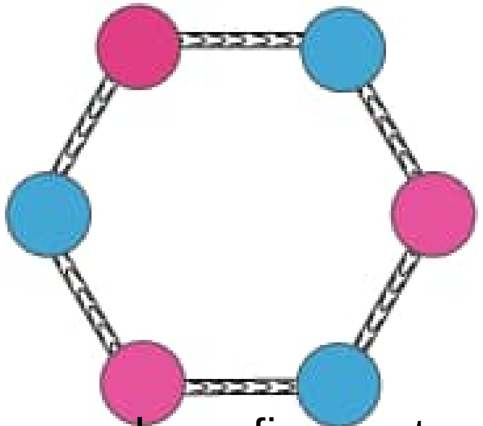
electric charge decays with distance:
screening, zero-charge effect



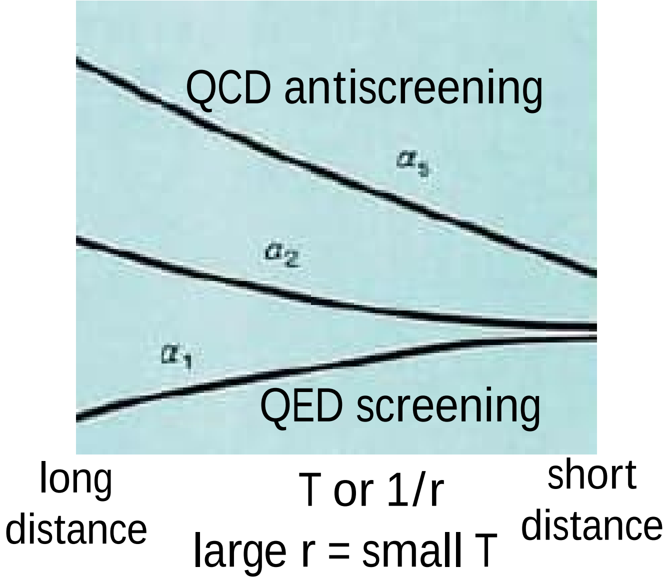
- quark confinement, monopole confinement & 3He-A
- MIT bag model of hadrons & magnon bag in 3He-B
- zero charge effect & skyrmion in 3He-A

$$F_{\rm magn} = \ln\left(\frac{\Delta_0^2}{T^2}\right)\frac{p_F^2 v_F}{24\pi^2\hbar}\left(\hat{\rm l}_0\times(\nabla\times\delta\hat{\rm l})\right)^2 \equiv \frac{\sqrt{-g}}{4\pi e_{eff}^2} g^{ij} g^{kl} F_{ik} F_{jl} \quad .$$

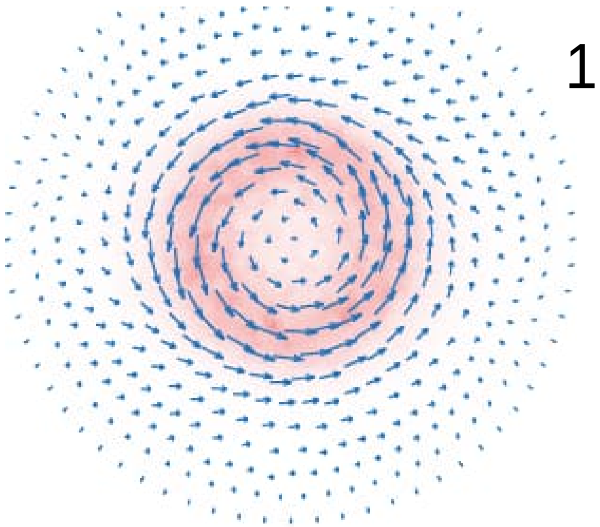
M. Krusius, T. Vachaspati & GV
Flow instability in 3He-A as analog of generation of hypermagnetic field in early Universe, cond-mat/9802005



monopole confinement by cosmic strings

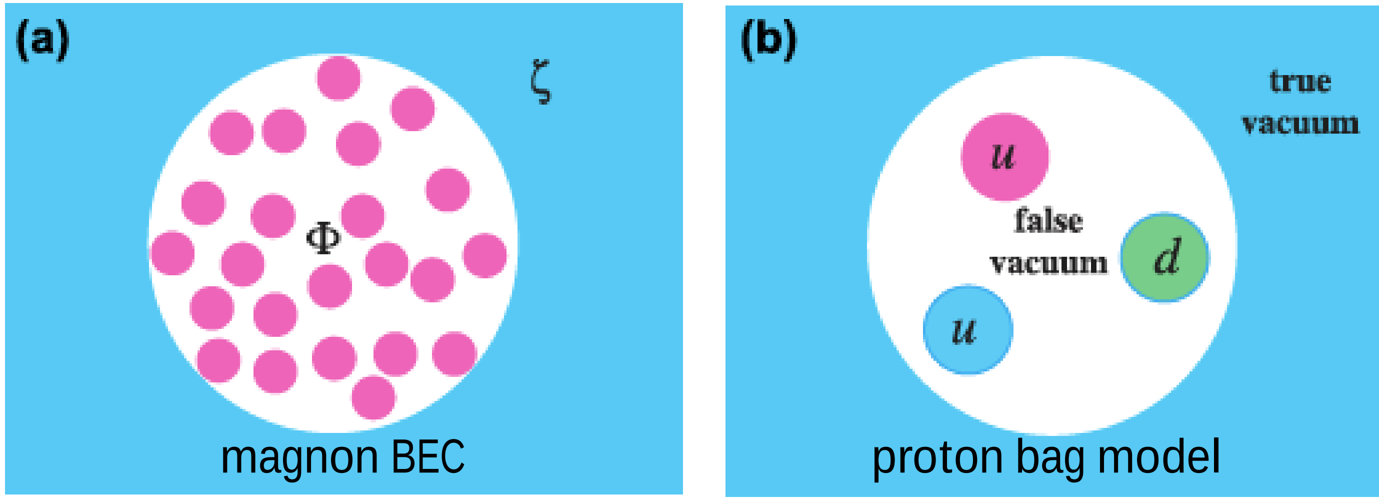


zero-charge effect:
skyrmion -> vortex sheet



$$1/\alpha = \frac{1}{12\pi^2}\ln\left(\frac{\Delta_0^2}{T^2}\right)$$

Rantanen 2022



Autti, Bunkov, Eltsov, Heikkinen, Hosio, Hunger, Krusius & GV,
Self-Trapping ... Box Confinement, PRL 108, 145303 (2012)

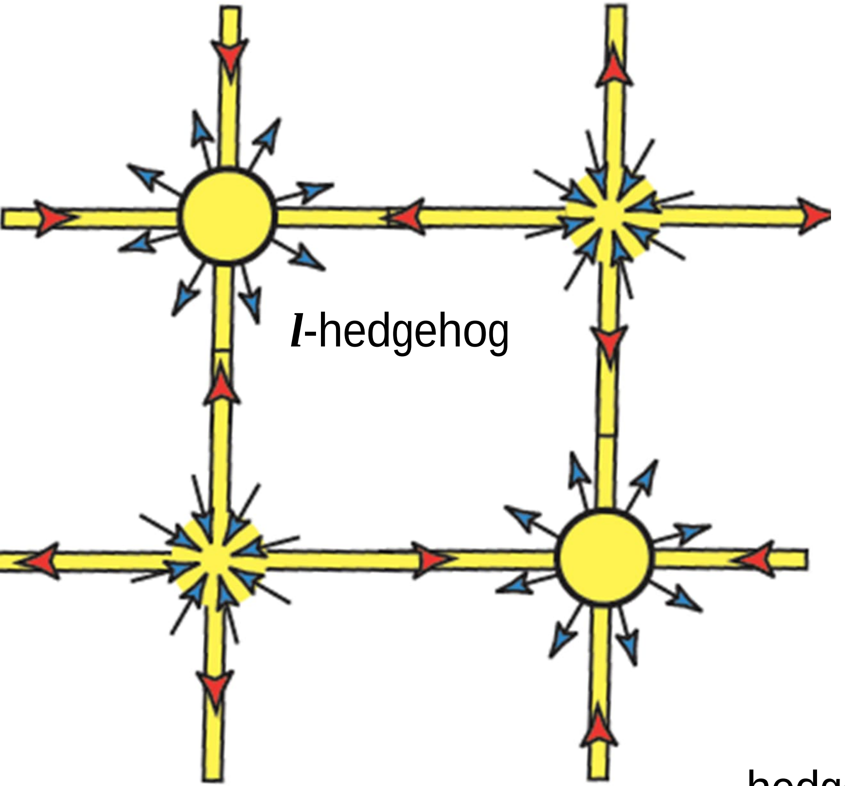
monopole confinement

monopole/quark duality

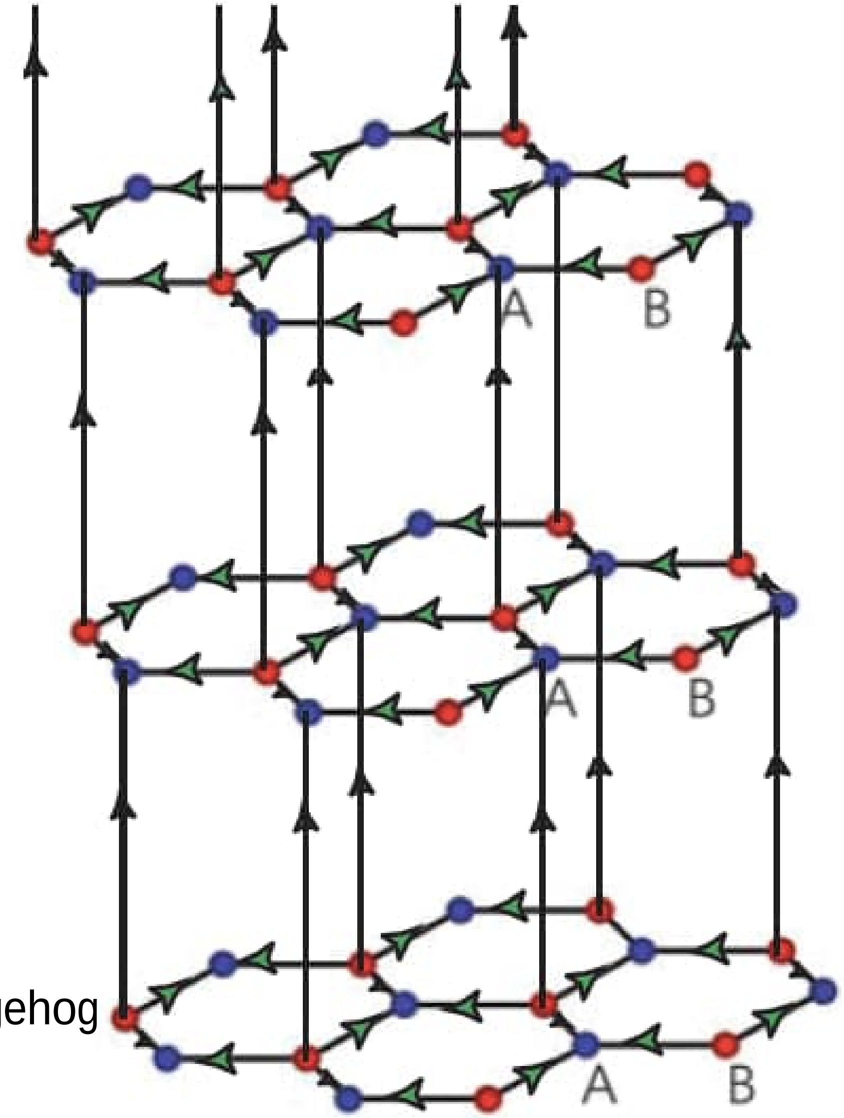
quark confinement

^{3}He-A

Alice string: half-quantum vortex



Alice string

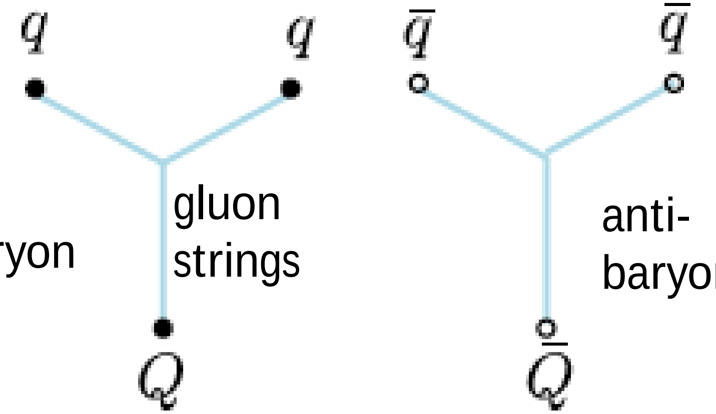


hedgehog

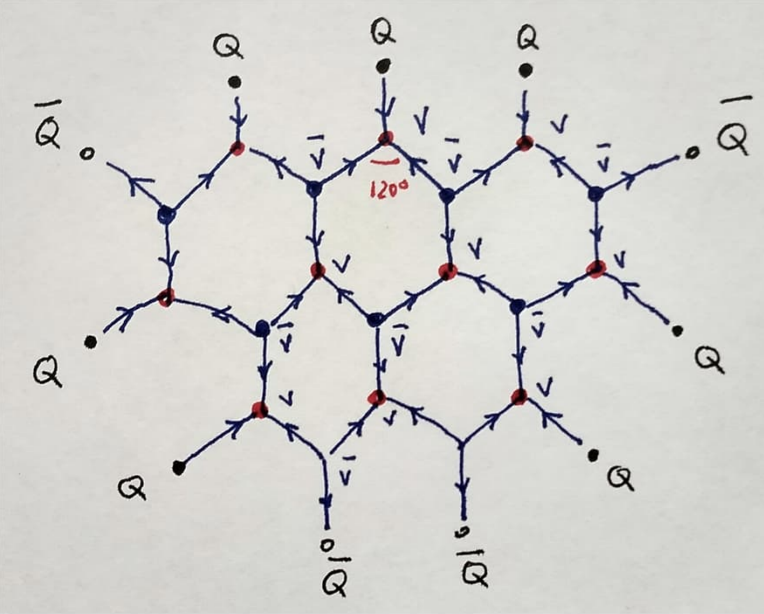
baryon

gluon strings

anti-baryon



hendeca-quark
7 quarks + 4 antiquarks



(Oleg Andreev, 2022)

Dangerous! Huge energy release!

V.B. Eltsov, T.W.B. Kibble, M. Krusius, V.M.H. Ruutu & GV,
Composite defect extends analogy between cosmology and 3He, PRL 85, 4739 (2000)

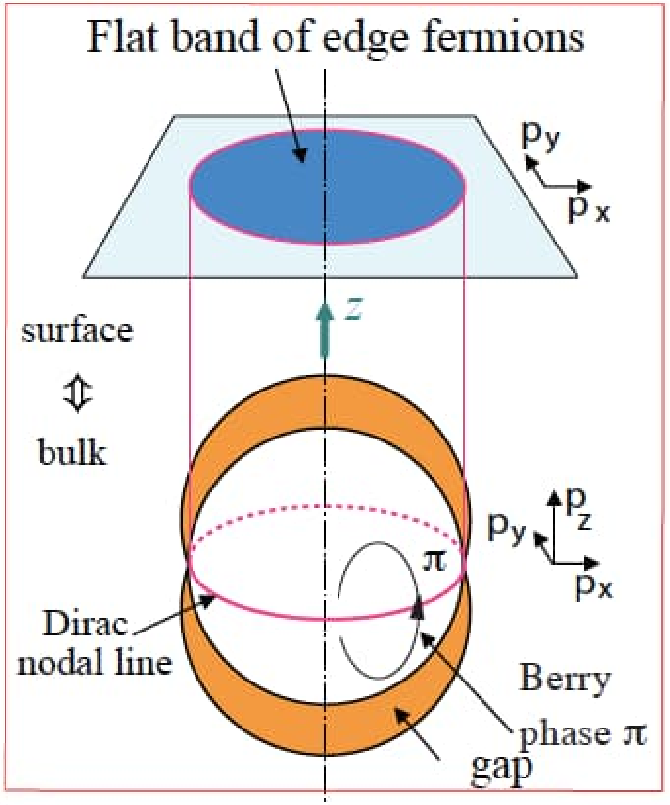
Dirac line, flat band
&
room-T superconductivity

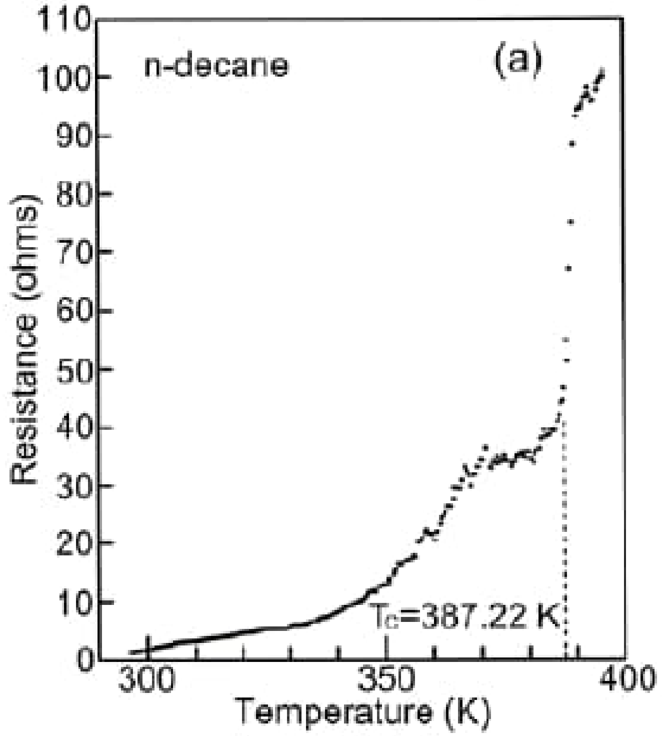
Superconductivity above 500 K in conductors made by bringing n-alkane into contact with graphite

Yasushi Kawashima

Department of Precision Engineering, School of Engineering, Tokai University, Hiratsuka, Kanagawa 259-1292, Japan.

polar phase of 3He





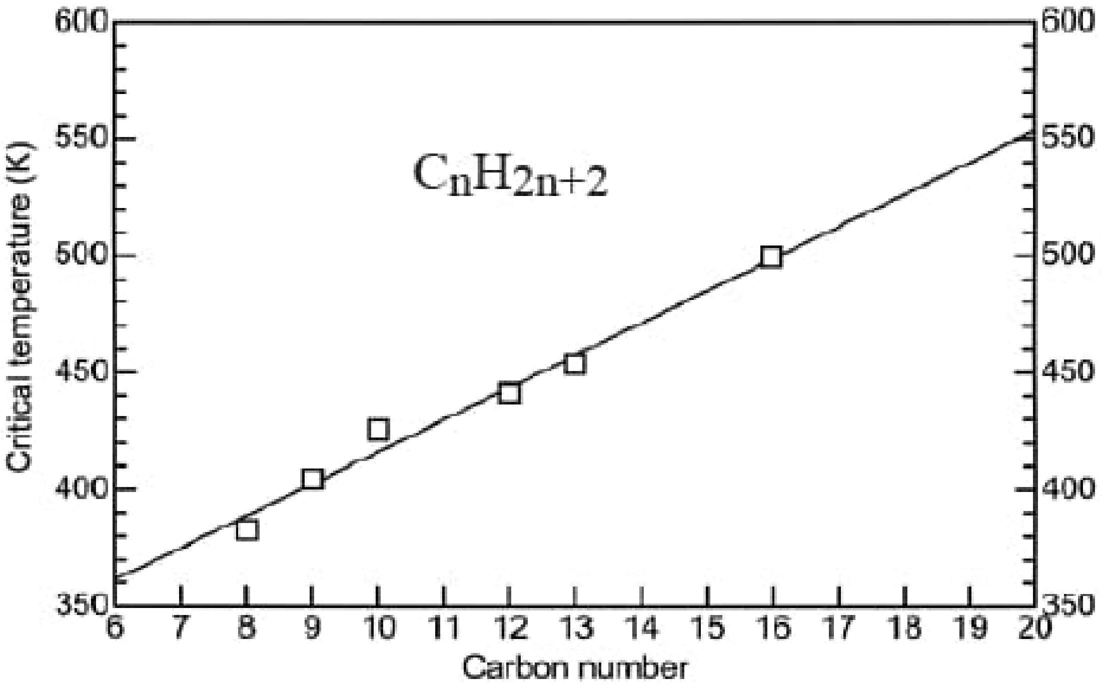


Figure 11 Relationship between the critical temperature and the carbon number of alkanes. A line is drawn to make the relationship easier to see.

Flat band - route to room-T superconductivity

Khodel-Shaginyan, JETP Lett. **51**, 553 (1990)
GV, JETP Lett. **53**, 222 (1991)
Nozieres, J. Phys. (Fr.) **2**, 443 (1992)

$$\Delta = g \int \frac{d^3p}{2h^3} \frac{\Delta}{E(p)}$$

BCS gap equation

g - coupling in Cooper channel

$$E^2(p) = \Delta^2 + \varepsilon^2(p)$$

metal with **Fermi surface**

$$\varepsilon(p) = v_F (p - p_F)$$

$$E^2(p) = \Delta^2 + v_F^2 (p - p_F)^2$$

$$1 = gN(0) \int \frac{d\varepsilon}{E(\varepsilon)} = gN(0) \ln \frac{E_c}{\Delta}$$

$$T_c \sim \Delta = E_c \exp\left[-1/gN(0)\right]$$

metal with **flat band**

$\varepsilon(p) = 0$
in flat band
$E(p) = \Delta$

$$\Delta = g \int \frac{d^3p}{2h^3} = gV_{FB}$$

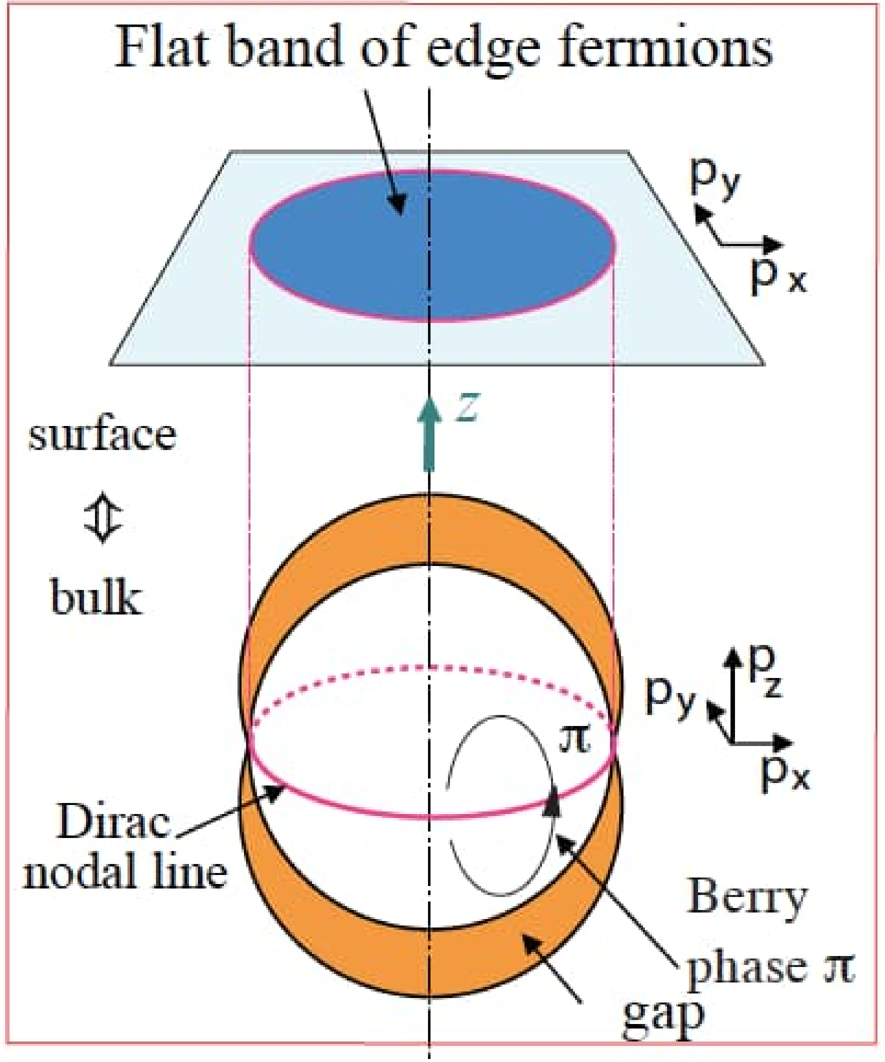
flat band volume

$$T_c \sim \Delta = gV_{FB}$$

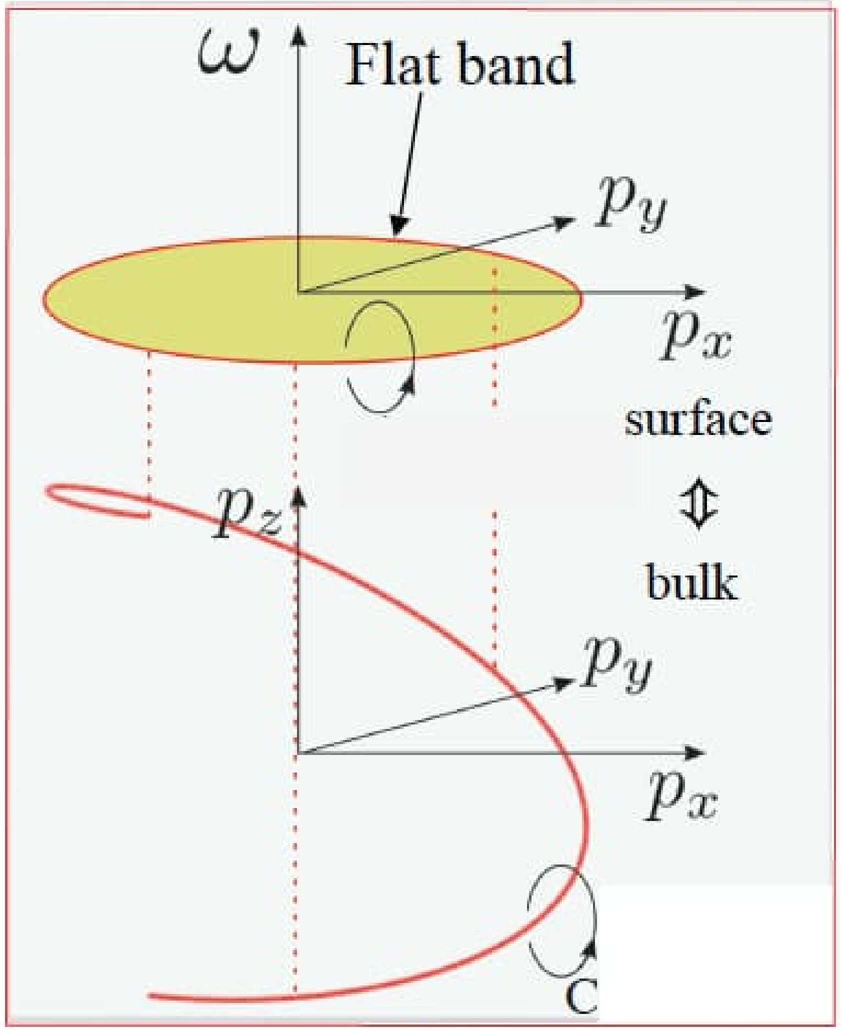
Dirac nodal line generates flat band on the surface

projection of nodal line on the surface determines boundary of 2D flat band

polar phase of 3He



rhombohedral graphite



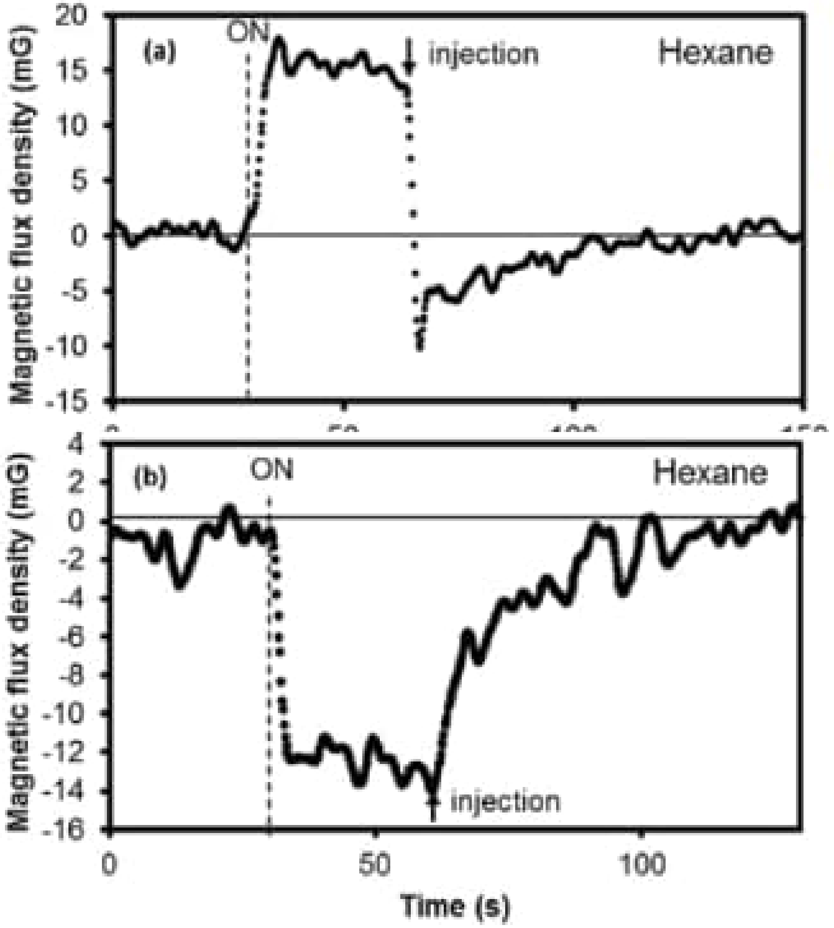
Berry phase = π

Observation of the Meissner effect at room temperature in single-layer graphene brought into contact with alkanes

Can it be so?

Yasushi Kawashima
Department of Precision Engineering, School of Engineering, Tokai University,
Hiratsuka, Kanagawa 259-1292, Japan.

E-mail: kawasima@keyaki.cc.u-tokai.ac.jp



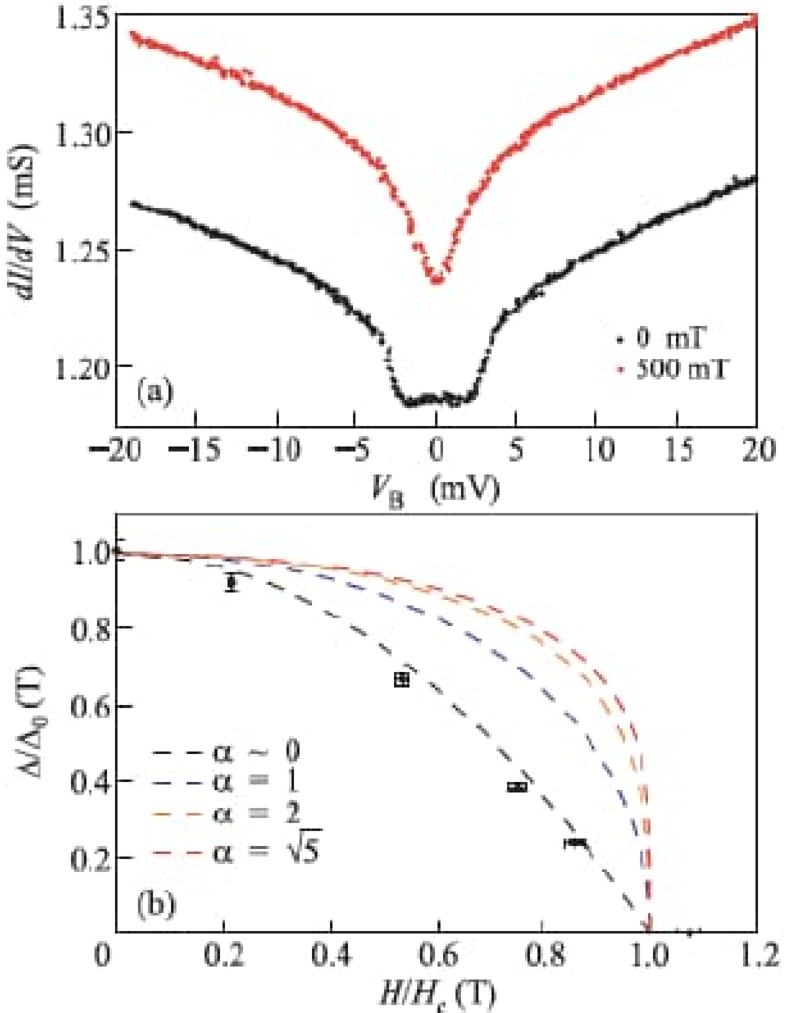
There are claims of synthesis of a room temperature superconductor. However, these claims have not been officially accepted by scientific communities. Currently, the highest transition temperature (Tc) recognized in scientific articles is 135 K at 1 atm of Hg-Ba-Ca-Cu-O system which is a copper oxide superconductor. We packed graphite flakes into a ring-shaped polytetrafluoroethylene (PTFE) tube and further injected heptane or octane. Then we generated circulating current in this ring tube by electromagnetic induction and showed that this circulating current continues to flow continuously at room temperature for 50 days. This experiment suggests that bringing alkane into contact with graphite may result in a material with zero resistance at room temperature. In addition, we showed by means of AC resistance measurements using the two-terminal method that the resistances of graphite fibers brought into contact with various alkanes suddenly change at specific critical temperatures between 363 and 504 K. In this study, we show that after a magnetic field is applied to a single-layer graphene at room temperature, alkane is brought into contact with the single-layer graphene, then the graphene excludes the magnetic field immediately. This phenomenon demonstrates that the alkane-wetted single-layer graphene shows Meissner effect at room temperature. Furthermore, we applied a magnetic field perpendicularly to the annular single-layer graphene brought into contact with n-hexane and immediately removed the magnetic field. After that we observed that a constant magnetic field generates from this annular graphene for some time. In conclusion, the single-layer graphene brought into contact with alkane shows Meissner effect at room temperature, which provides definitive evidence for room temperature superconductivity.

Pis'ma v ZhETF, vol. 107, iss. 9, pp. 604 – 605

Superconducting sweet-spot in microcrystalline graphite revealed by point-contact spectroscopy

F. Arnold, J. Nyéki, J. Saunders[1)]

Royal Holloway, University of London, Egham Hill, TW20 0EX, Egham, United Kingdom



In this article, we show the emergence of a superconducting state with a T_c of 14 K in micro-crystalline graphite observed by point-contact spectroscopy. Point-contact spectroscopy is a powerful technique to probe the local density-of-states and electronic spectrum of a metal [5, 6]. Micro-crystalline graphite, Grafoil [7,8], is

Evidence of superconducting island in graphite marerial with T_c = 14 K

conclusions

era of flat band superconductivity

1. Khodel-Shaginyan fermion condensate due to interaction
(in particular in vicinity of Lifshitz transtions)

2. Flat bands close to Lifshitz transtions
(involve Weyl and Dirac points, Dirac lines, etc.)

3. Topological surface & edge flat bands
(graphene, graphite, nodal line semimetals, ...)

4. Flat bands on topological defects Kopnin-Salomaa Majorana modes
(flat band of Kopnin-Salomaa Majorana modes in vortex core of chiral superfconductor; flat band on dislocations in graphite, ...)

5. Flat band in artificial lattices (Kagome, spin 1, etc.)

6. Flat band from twist

flat band opens parametrically different scenario for onset of superconductivity

$$T_c = T_F \exp(-1/g\nu)$$

$$T_c \sim gV_{FB}$$

normal superconductors: exponentially suppressed transition temperature

interaction ↑ ↑ ***DOS***

coupling ↑ ↑ ***flat band volume***

flat band superconductivity: linear dependence of T_c on coupling g

First crossing

I.M. Khalatnikov, V.P. Mineev & GV,
Theory of the solution of the superfluid Fermi liquid in superfluid Bose liquid,
Proceedings of the 14th International Conference on Low Temperature Physics,
Otaniemi, Finland, August 14-20, 1975
Ed. Krusius, M.; Vuorio, M.,
North-Holland Publishing Company, Vol. 5, pp. 102-121

First common paper

P.J. Hakonen, M. Krusius, M.M. Salomaa, J.T. Simola, Yu.M. Bunkov, V.P. Mineev & GV,
Magnetic vortices in rotating superfluid 3He-B,
PRL 51, 1362 (1983)