ASU Arizona State University

NSF

May 17, 2026

Miransky's Legacy: From Symmetry Breaking to New Frontiers

Igor Shovkovy

Arizona State University

MIRANSKY MEMORIAL CONFERENCE

International Conference on Symmetry Breaking Phenomena in Quantum Field Theory

May 16 – 18, 2026

Hefei, China

Education

- **1962 – 1967 (B.Sc.):** Kyiv State University*

  Denied admission to a Ph.D. program

- **1967 – 1969:** Institute for Problems of Materials Science, Kyiv, Ukraine

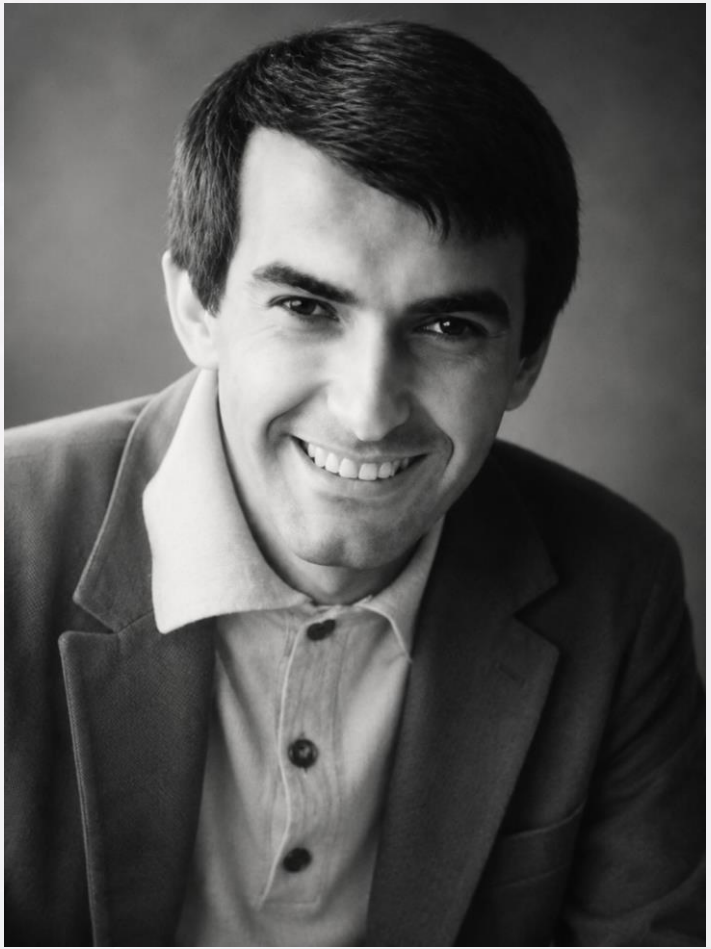
  Love as way into theoretical physics

- **1969 – 1972 (Ph.D.):** Bogolyubov Institute for Theoretical Physics, Kyiv, Ukraine

https://en.wikipedia.org/wiki/Draft:Vladimir_A._Miransky

Academic career

- **1972 – 2001:** Research Scientist, Bogolyubov Institute for Theoretical Physics, Kyiv, Ukraine*
- **1988 – 1989:** Visiting Researcher (JSPS), Nagoya, Japan
- **1990 – 1992:** Visiting Researcher, UC Santa Barbara, U North Carolina, U Western Ontario
- **1992 – 1993:** Visiting Researcher, Ohio State University and Yukawa Institute, Kyoto, Japan
- 1994: V. A. Miransky briefly returned to Kyiv!
- **1994 – 1997:** Visiting Researcher @ UC Santa Barbara, UCLA, U Western Ontario, Nagoya
- **2001 – 2021:** University of Western Ontario, London, Canada

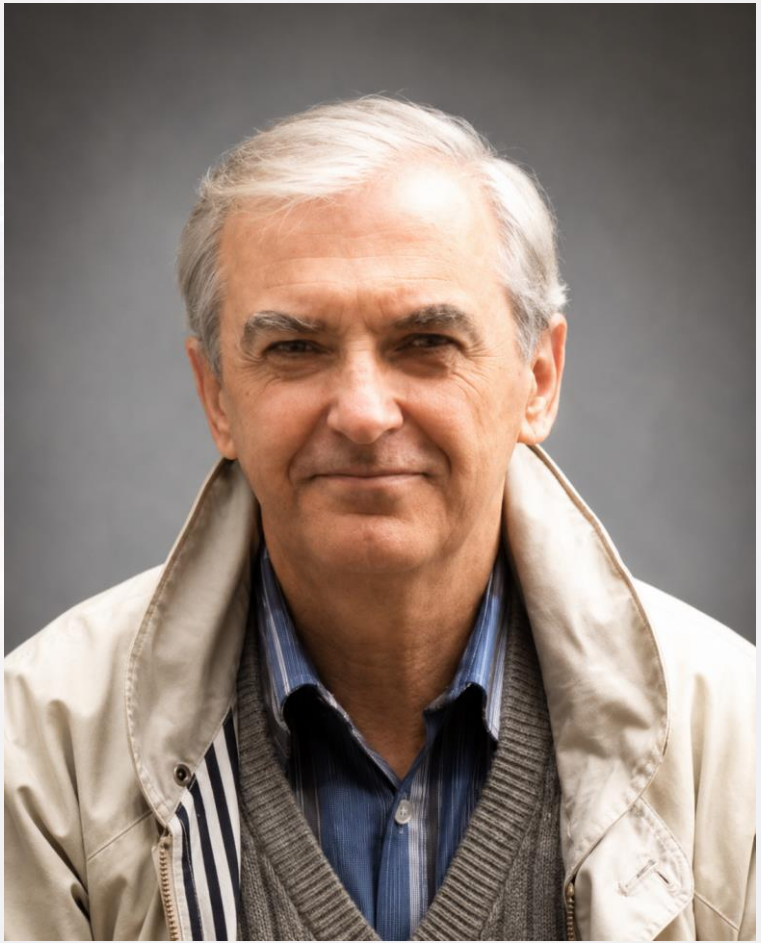


Taiwan,1993

My journey in physics

- **1992-1993:** my first undergraduate research adviser was Valery P. Gusynin
- **Oct. 1993:** I was admitted to a Ph.D. program at Bogolyubov Institute for Theoretical Physics, Kyiv, Ukraine
- **1994:** Volodya Miransky returns to Kyiv and we start the "**magnetic catalysis**" project(s)
- **1995-1996:** Exchange graduate study at University of Western Ontario, Canada*
- **1997:** Volodya helped me get my 1st postdoc*
- **From 1999 onward:** intense collaboration on numerous projects ($\gtrsim$ 65 papers total)

… and the rest is history



Magnetic catalysis (1994-1997)

"If I have seen further it is by standing on the shoulders of Giants." (Sir Isaac Newton in a letter to Robert Hooke, 1675)

- 1989-1991: several studies reveal that magnetic fields enhance dynamical mass generation in NJL-type models

  [Klevansky & Lemmer, (1989); Suganuma & Tatsumi (1991)]

- This seemed counterintuitive by analogy with the Cooper pairing and BCS superconductivity

- Partial explanation: "magnetic field aids in anti-aligning the helicities which are bound by the NJL interaction"

  [Klevansky & Lemmer, (1989)]

- Eureka moment: dimensional reduction, $D \to D - 2$, and the associated density of states enhancement near $E = 0$

  [Gusynin, Miransky, Shovkovy, Phys. Rev. Lett. **73**, 3499 (1994)]

- Final conclusion: underlying mechanism for magnetic catalysis (MC) is as universal as the Cooper pairing

Dirac spectrum at $B \neq 0$

- Landau energy levels at $m = 0$

$$E_n^{\pm} = \pm\sqrt{2n|eB| + p_z^2}$$

where $n = k + \frac{1}{2} + \mathrm{sgn}(eB)s_z$

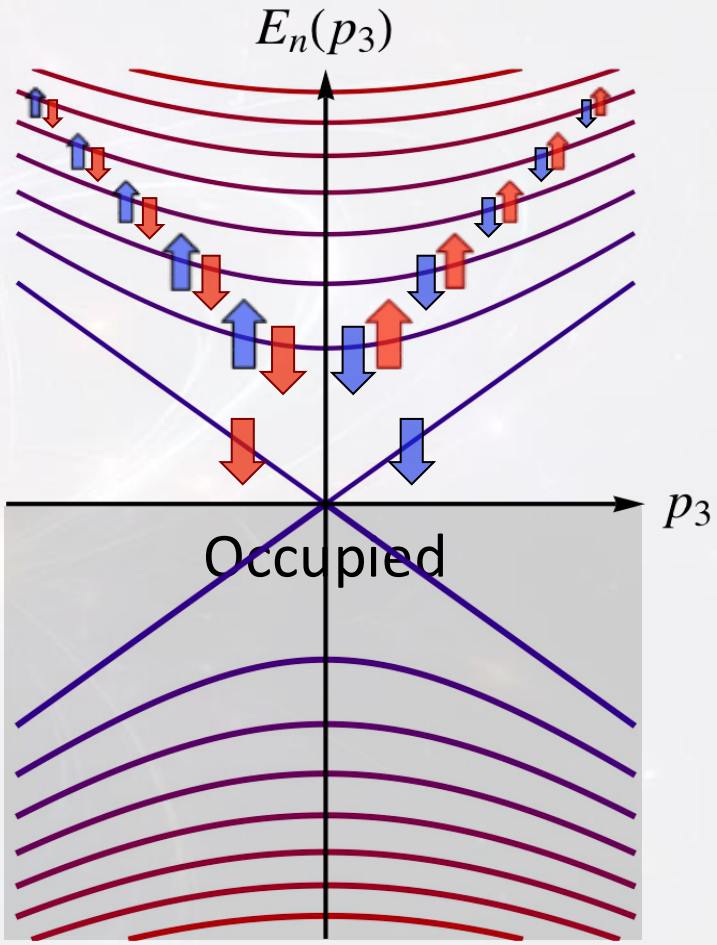
- Lowest Landau level as in 1D:

$$E_0^{\pm} = \pm p_z \qquad (k = 0,\ s_z = -\tfrac{1}{2})$$

- **Density of states** at E=0 is nonzero:

$$\left.\frac{dn}{dE}\right|_{E=0} = \frac{|eB|}{4\pi^2}$$

- **Dimensional reduction** $D \to D - 2$ is very important as it strongly enhances pairing!



Bound states in 3D

- For a 3D potential well in quantum mechanics [Landau & Lifshitz,Vol. 3]

$$U(r) = \begin{cases} -g\dfrac{\pi^2\hbar^2}{8m_* a^2} & \text{for} \quad r \le a \\ 0 & \text{for} \quad r > a \end{cases}$$

- Bound states form only for deep enough wells (namely, $g > 1$):

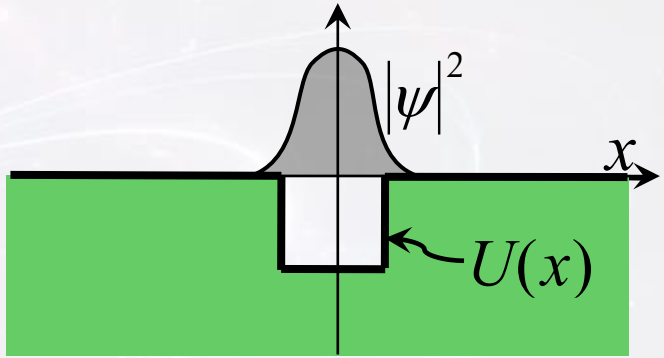
$$\left|E_{3D}\right| \approx \frac{\pi^4\hbar^2}{2^7 a^2 m_*}\left(g-1\right)^2, \quad \text{assuming} \quad 0 < g-1 << 1$$

- In contrast, there are no bound states for $g < 1$ (or $g \to 0$)

Bound states in 1D

- At least one bound state always exists

$$\left|E_{1D}\right| \approx \frac{m_*}{2\hbar^2}\left(-\int_{-\infty}^{+\infty} U(x)dx\right)^2$$



- This is a perturbative result (!)

$$\left|E_{1D}\right| \propto g^2, \quad \text{when} \quad U(x) \to gU(x)$$

- Rigorous statement: at least one bound state exists if

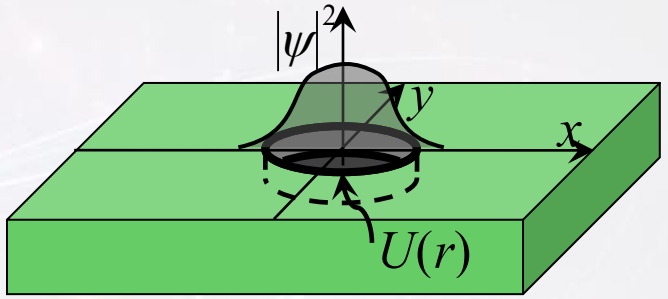
$$\int (1+|x|)|U(x)|\,dx < \infty \quad \& \quad \int U(x)dx \leq 0$$

[B. Simon, Annals Phys. 97 (1976) 279]

Bound states in 2D

- At least one bound state always exists

$$|E_{2D}| \approx \frac{\hbar^2}{a^2 m_*} \exp\left(-\frac{\hbar^2}{m_*} \left| \int_0^\infty r U(r) dr \right|^{-1} \right)$$



- This is a non-perturbative result

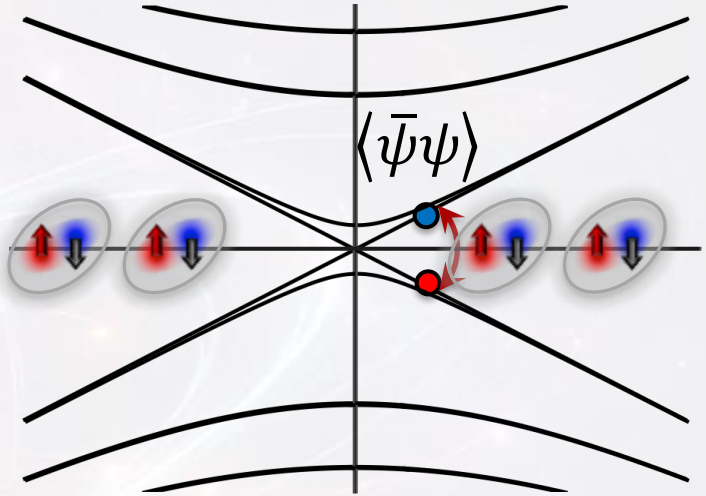
$$|E_{2D}| \propto \exp\left(-\frac{C}{g} \right), \quad \text{when} \quad U(x) \to g U(x)$$

- Rigorous statement: at least one bound state exists if

$$\int |U(x)|^{1+\varepsilon} d^2x < \infty, \qquad \int (1+x^2)^{\varepsilon} |U(x)| \, d^2x < \infty \quad \& \quad \int U(x) d^2x \leq 0$$

[B. Simon, Annals Phys. 97 (1976) 279]

Recap: Universal MC



- Dirac fermions ($m = 0$) at $\vec{\boldsymbol{B}} \neq \mathbf{0}$
  - Approximate dimensional reduction in LLL
  - Nonzero density of states ($\propto |eB|$) at E=0
  - Attraction between particles and antiparticles
- Universal outcome:
  - Copious particle-antiparticle pairing at $E \approx 0$
  - Boson pairs condense and produce $\langle\bar{\psi}\psi\rangle \neq 0$
  - The ground state changes and a nonzero gap ($m \neq 0$) opens
  - Chiral symmetry breaks down

[Gusynin, Miransky, Shovkovy, Phys. Rev. Lett. **73**, 3499 (1994)]
[Gusynin, Miransky, Shovkovy, Phys. Rev. Lett. **83**, 1291 (1999)]

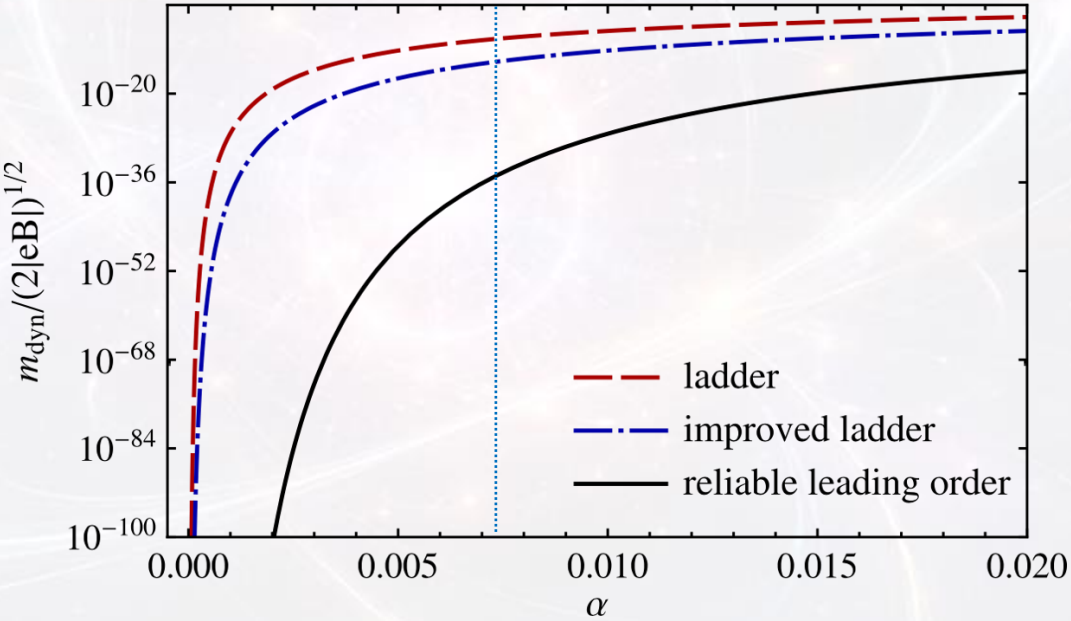
- This is similar to the Cooper pairing of electrons in metals

MC in massless QED

- Synthesis of analytical & numerical study produces

$$m_{dyn} \simeq \sqrt{2|eB|}\,(\alpha N_f)^{1/3} \exp\left[-\frac{\pi}{\alpha \ln \frac{C_1}{\alpha N_f}}\right], \quad C_1 \approx 1.82 \pm 0.06$$

[Gusynin, Miransky, Shovkovy, PRL **83**, 1291 (1999)]



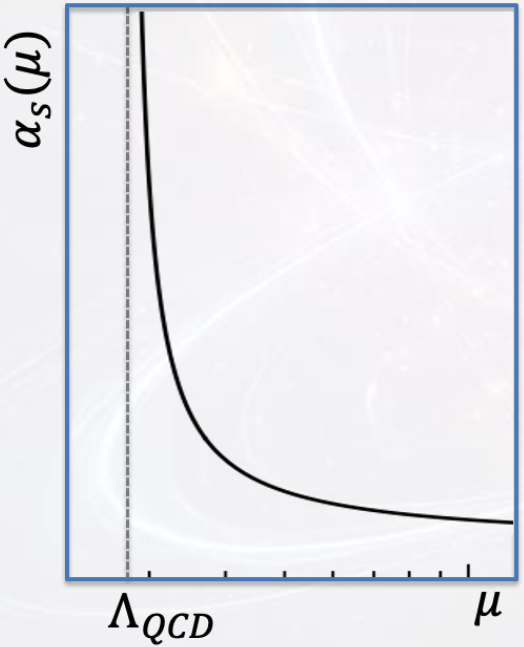
- Recent lattice study confirms magnetic catalysis in QED ($\alpha = 0.2$)

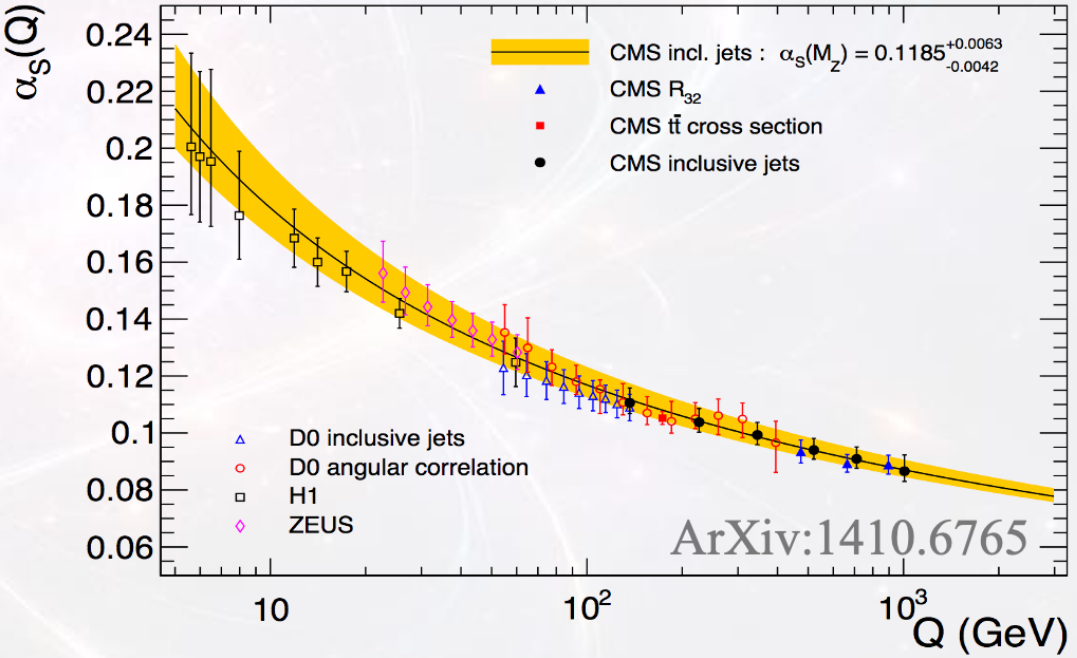
[Kogut & Sinclair, PRD 109, 034511 (2024)]

What about QCD?

- Coupling constant in QCD runs with the energy scale,

$$\frac{1}{\alpha_s(\mu)} \simeq b \ln \frac{\mu^2}{\Lambda_{QCD}^2}, \quad \text{where} \quad b = \frac{11\,N_c - 2N_f}{12\pi}$$

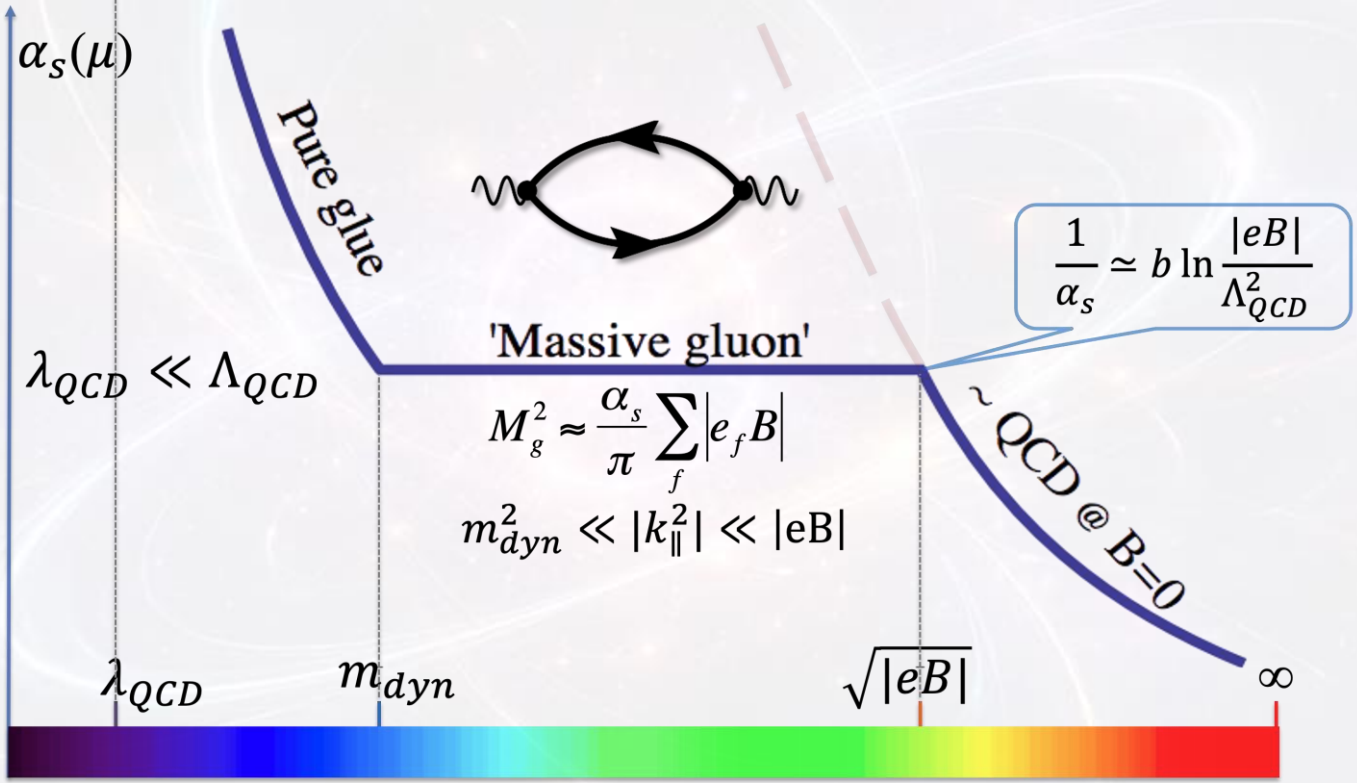




- What happens in a strong magnetic field?

Running α_s in QCD at $B \neq 0$

- At sufficiently strong B, running of α_s freezes at $\mu \sim \sqrt{eB}$



[Miransky & Shovkovy, Phys. Rev. D 66, 045006 (2002)]

MC in QCD

- Assuming $\sqrt{|eB|} \gg \Lambda_{\rm QCD}$, dynamical masses are

$$m_q^2 \simeq 2C_1|e_qB|\left(c_q\alpha_s\right)^{2/3}\exp\left[-\frac{4N_c\pi}{\alpha_s(N_c^2-1)\ln(C_2/c_q\alpha_s)}\right]$$

where $C_1 \simeq C_2 \simeq 1$ and $c_q \simeq (2N_u + N_d)|e|/(6\pi|e_q|)$

- The pion decay constants are

$$f_u^2 = \frac{N_c|eB|}{6\pi^2} \quad \text{and} \quad f_d^2 = \frac{N_c|eB|}{12\pi^2}$$

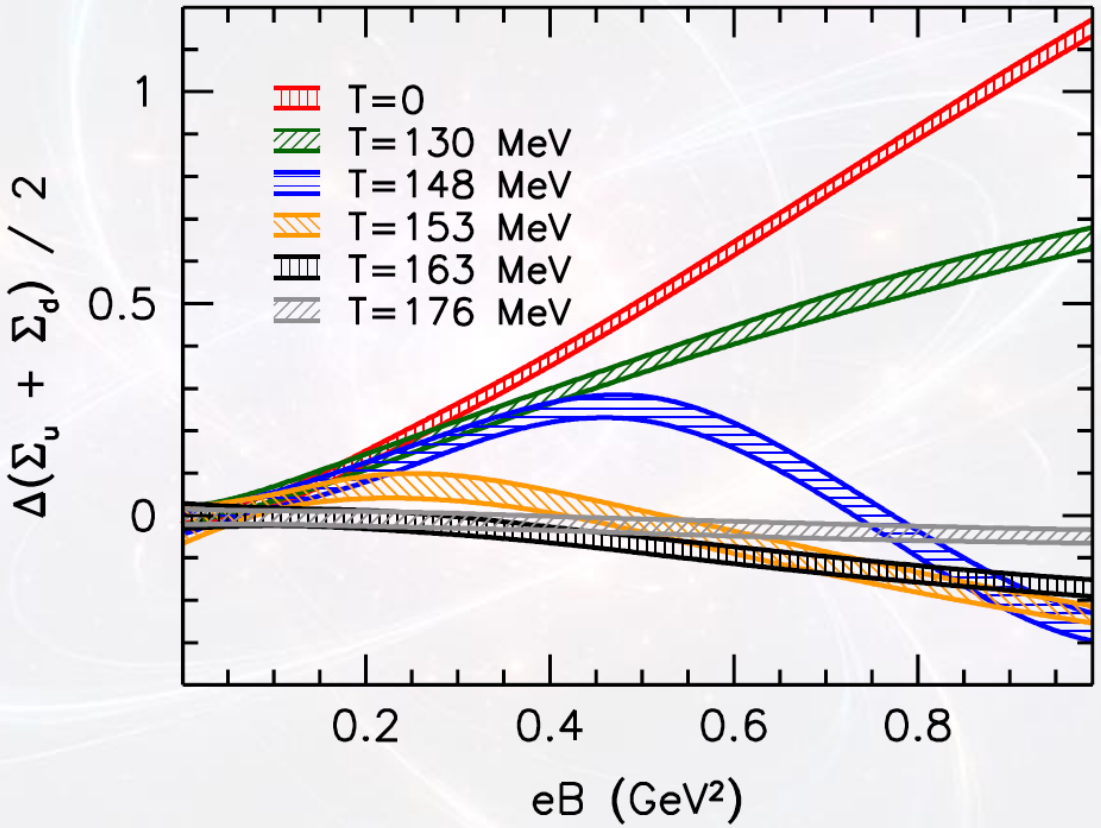
- Pure gluodynamics in the IR region ($\mu^2 \lesssim m_{\rm dyn}^2$) with

$$\lambda_{QCD} = m_{\rm dyn}\left(\frac{\Lambda_{QCD}}{\sqrt{|eB|}}\right)^{\kappa}, \qquad \kappa = \frac{11\,N_c - 2N_f}{11\,N_c}$$

[Miransky & Shovkovy, Phys. Rev. D 66, 045006 (2002)]

Lattice results: MC

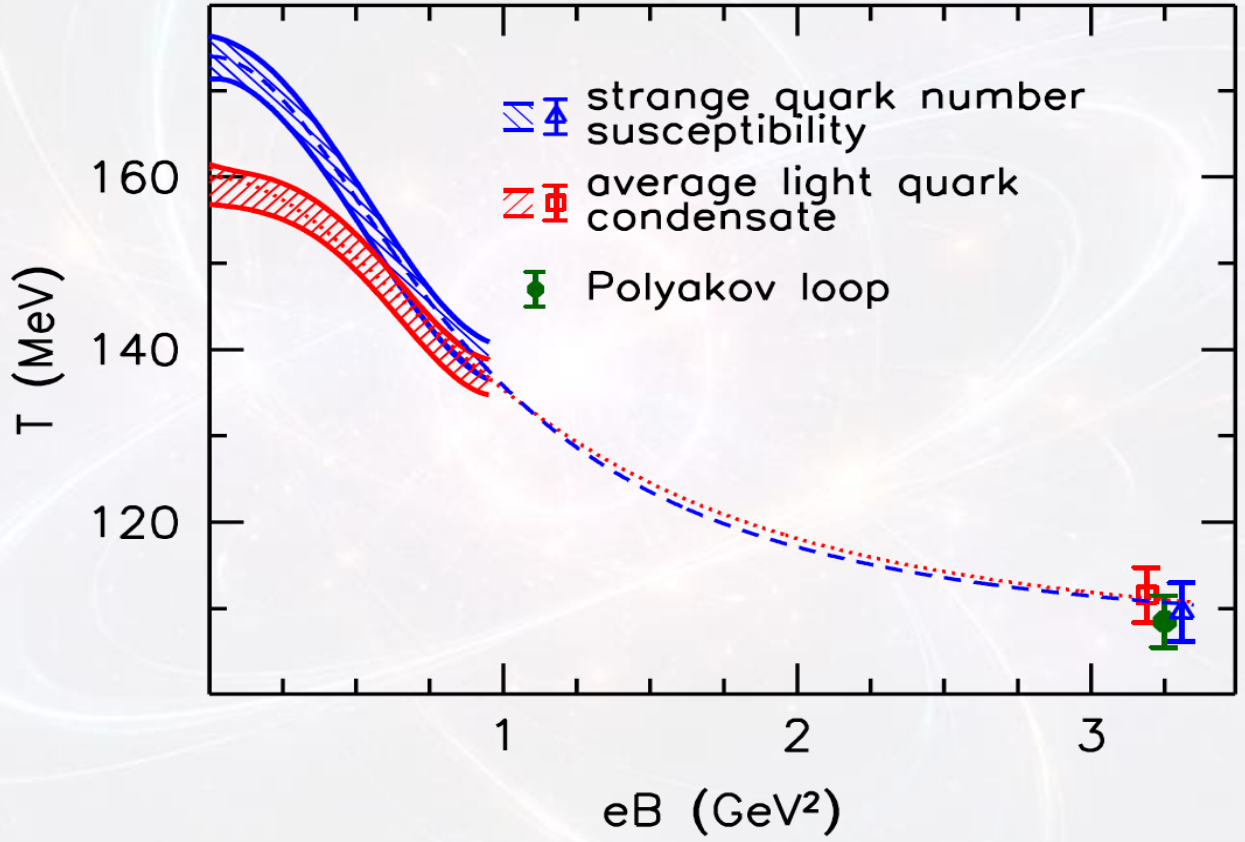
- Magnetic catalysis at $T = 0$ [Bali et al., Phys. Rev. D**86**, 071502 (2012)]



- However, situation is less clear at $T \neq 0$

Lattice results: IMC

- Inverse catalysis at nonzero temperature



[Bali et al., JHEP 02, 044 (29012)], [Bali et al., PRD**86**, 071502 (2012)], [G. Endrodi, JHEP 1507 (2015) 173]

Graphene (2002)

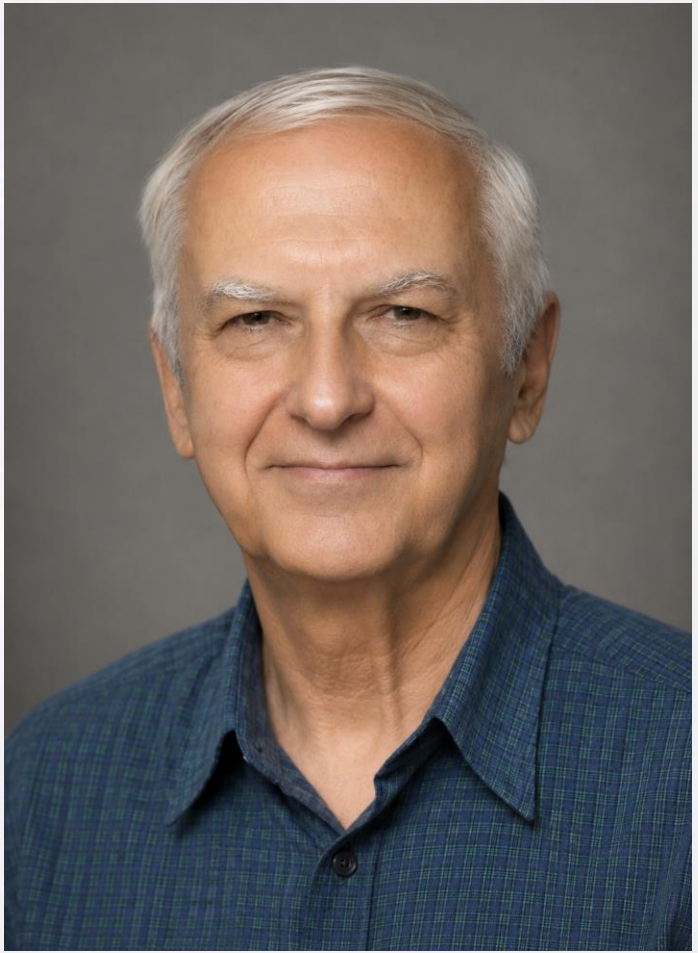
"You may set out to find one thing and end up by discovering something entirely different." (Alexander Fleming, 1928)

- **1999-2002:** Experiments of Yakov V. Kopelevich revealed a magnetic-field-driven metal-insulator-type transition in graphite (HOPG)

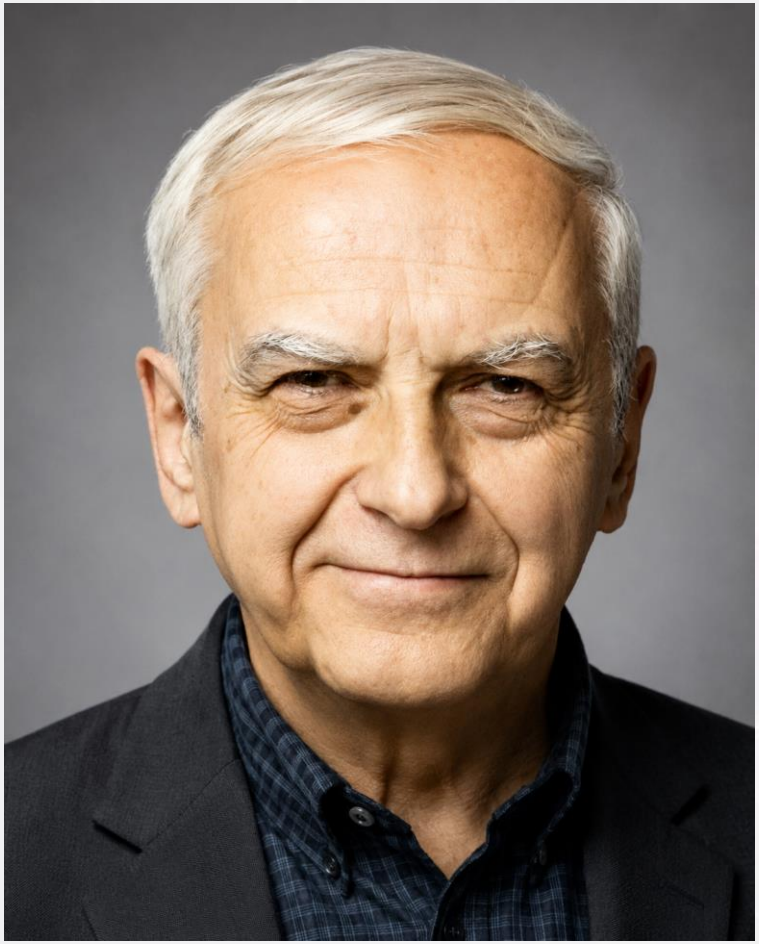
  [Kopelevich et al., Phys. Solid State **41**, 1959 (1999)]
  [Kempa et al., Solid State Commun. **115**, 539 (2000)]
  [Sercheli et al., Solid State Commun. **121**, 579 (2002)]

- Graphite is a semimetal with quasi-relativistic electron quasiparticles (~massless Dirac fermions)
- Idea: magnetic catalysis drives a mass (gap) generation causing a field-driven metal-insulator phase transition
- (2+1)-dimensional model seemed "sufficient" for a first-try theoretical study and seemed to work in general
- Accidental byproduct: anomalous/topological Hall effect for (2+1)-dimensional fermions (~graphene)

[Gorbar, Gusynin, Miransky, Shovkovy, Phys. Rev. B 66, 045108 (2002)]



Chiral effects (2009-2018)



"Chance favors only the prepared mind." (Louis Pasteur, 1854)

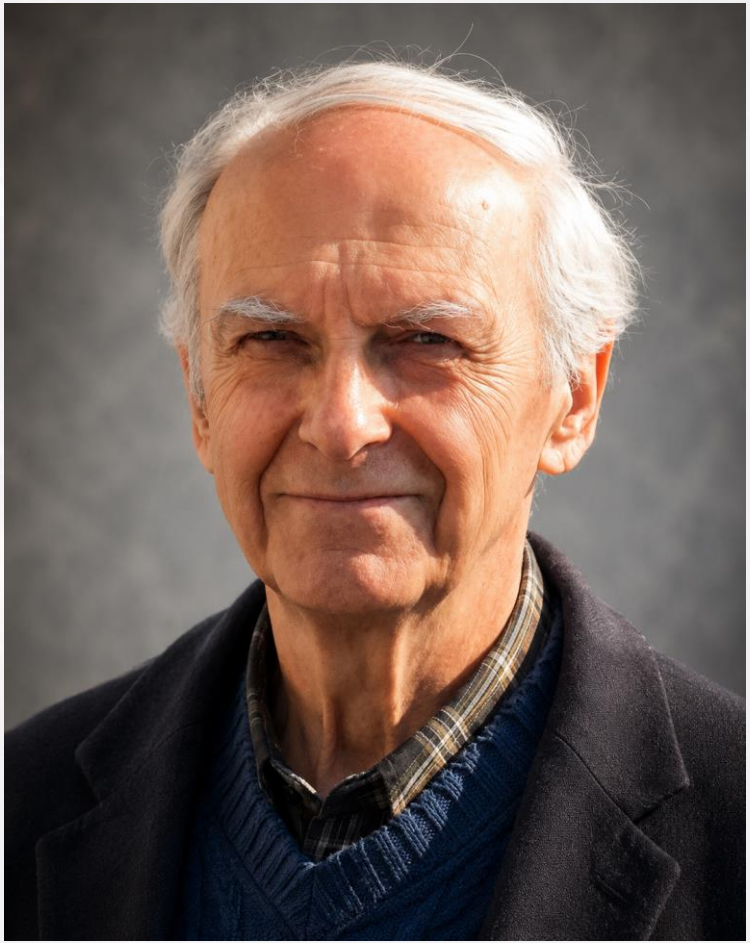
- Chiral asymmetry in magnetized dense relativistic matter
  [Gorbar, Miransky, Shovkovy, Phys. Rev. C **80**, 032801 (2009); Phys. Lett. B **695**, 354 (2011)]
- Quadrupole correlations in HIC (aka. chiral magnetic wave)
  [Gorbar, Miransky, Shovkovy, Phys. Rev. D **83**, 085003 (2011)]
- Radiative corrections to chiral separation effect in QED
  [Gorbar, Miransky, Shovkovy, Wang, Phys. Rev. D **88**, 025025 (2013)]
- Chiral anomaly and magnetoresistivity of Weyl and Dirac semimetals
  [Gorbar, Miransky, Shovkovy, Phys. Rev. B **89**, 085126 (2014)]
- Consistent chiral kinetic theory (anomaly vs. charge conservation) and its observable implications
  [Gorbar, Miransky, Shovkovy, Sukhachov, Phys. Rev. Lett. **118**, 127601 (2017)]
- Consistent hydrodynamic theory of chiral electrons in Weyl semimetals
  [Gorbar, Miransky, Shovkovy, Sukhachov, Phys. Rev. B **97**, 121105 (2018)]

Physics Reports (2014-2015)

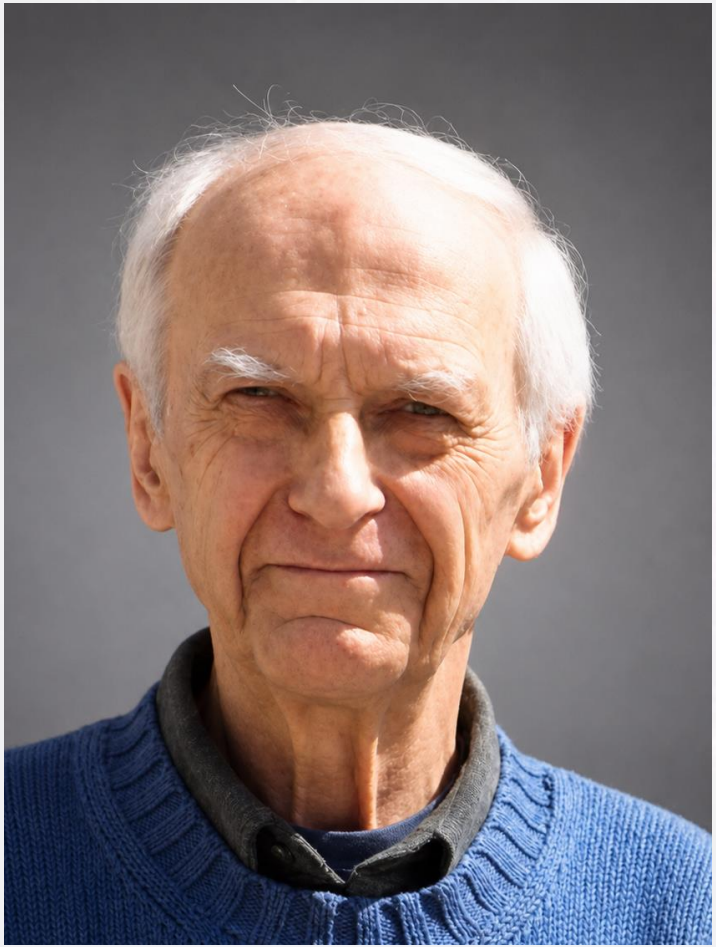
"Every great and deep difficulty bears in itself its own solution." (Niels Bohr)

- **Fall 2014:** While I was on sabbatical in Beijing, we were finalizing our review for Physics Reports
- Volodya was proofreading and correcting the text. Both strong-willed, we often argued and fought over details
- But it was also a lot of fun! Volodya would tell jokes about famous physicists, politicians, and more
- We submitted the final manuscript on December 31, 2014!

  [Miransky & Shovkovy, Physics Reports **576** (2015) pp. 1-209]
- At the time, I "decided" I would never want to write another review again…
- But later, of course, I wrote and co-authored several more… and even a book



Dirac & Weyl materials



"The important thing is not to stop questioning. Curiosity has its own reason for existing." (Albert Einstein in his essay *Old Man's Advice to Youth: "Never Lose a Holy Curiosity"*)

- Pavlo Sukhachov brought new energy to the group, with the main focus on Weyl semimetals
- Fermi arcs and the origin of their dissipative transport

  [Gorbar, Miransky, Shovkovy, Sukhachov, Phys. Rev. B **93**, 235127 (2016)]
- Novel collective excitations: chiral magnetic plasmons and pseudomagnetic helicons

  [Gorbar, Miransky, Shovkovy, Sukhachov, PRL **118**, 127601 (2017); PRB **95**, 115202 (2017)]
- Origin of Chern-Simons (Bardeen-Zumino) anomalous contributions in finite-band Dirac and Weyl materials

  [Gorbar, Miransky, Shovkovy, Sukhachov, PRB **96**, 085130 (2017)]
- Chiral response and anomalous thermoelectric phenomena in Weyl semimetals

  [Gorbar, Miransky, Shovkovy, Sukhachov, PRB **96**, 125123 (2017); PRB **96**, 155138 (2017)]
- Finally, the monograph *Electronic Properties of Dirac and Weyl Semimetals*, World Scientific, 2021

Lessons learned

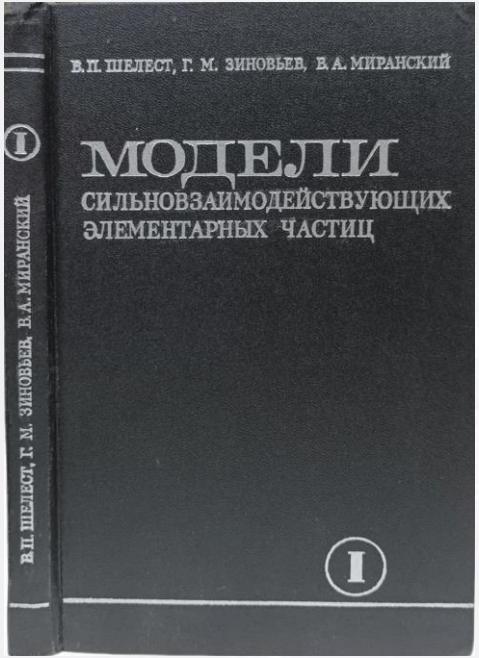
"Nearly everything is really interesting if you go into it deeply enough." (Richard Feynman in *What Do You Care What Other People Think?*)

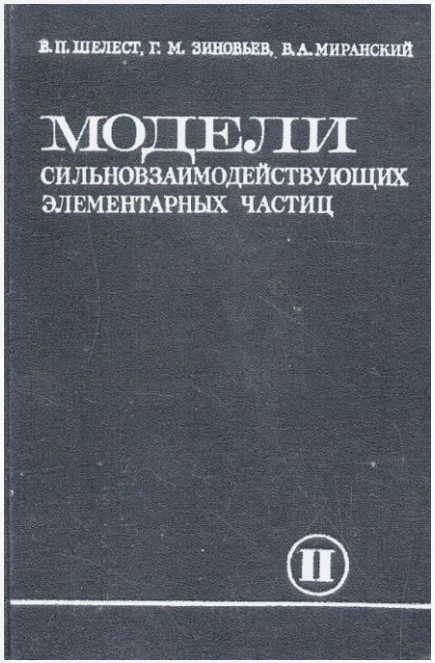
- If someone has "solved" a problem but the underlying explanation is still unclear, it may be worth digging deeper to expose the real mechanism
- Search broadly for possible applications, and push the limits of what can be explored with the tools available now
- Explore theoretical limits as a way to test the theory and gain deeper understanding
- Writing high-quality reviews is painful, but it can be deeply rewarding
- Changing research directions is risky, but it often broadens your horizons and opens unexpected opportunities.
- In the end, a little luck plus sustained hard work is what turns it into real results

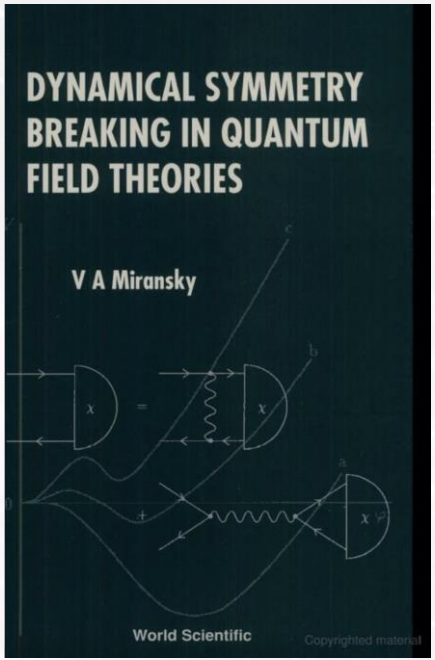
Summary of Miransky's Legacy

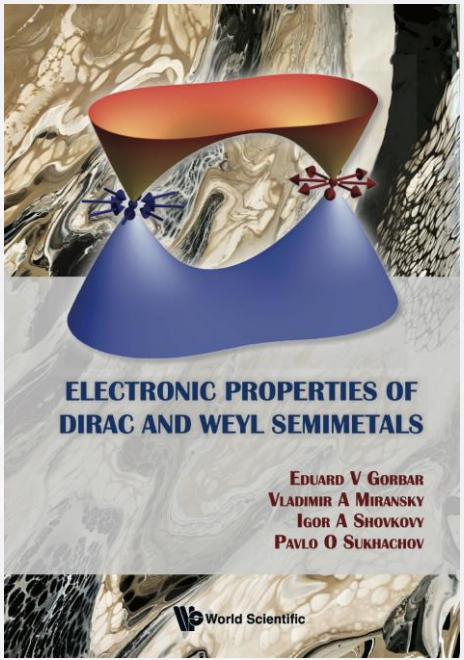
- Dynamical symmetry breaking in gauge theories (Fomin, Gusynin, Miransky, Sitenko, 1983)
- Top-quark condensate and electroweak symmetry breaking (Miransky, Tanabashi, Yamawaki, 1988-1989)
- Miransky scaling (1985) & Conformal phase transitions (Miransky, Yamawaki, 1989-1997)
- Color superconductivity in dense quark matter (Hong, Miransky, Shovkovy, Wijewardhana, Semenoff, Gorbar, Hashimoto, 1999-2001)
- Magnetic catalysis (Gusynin, Gorbar, Miransky, Shovkovy, 1994-2002)
- Abnormal number of Nambu-Goldstone bosons (Miransky, Shovkovy, 2002)
- Quantum Hall physics in graphene and Dirac/Weyl materials (Gorbar, Gusynin, Miransky, Shovkovy, Junji Jia, Sukhachov, 2002-2021)
- Chiral anomalous effects (Gorbar, Miransky, Shovkovy, Wang, Sukhachov, 2011-2021)

Books









1. V. P. Shelest, V. A. Miransky, G. M. Zinovjev, Models of strongly interacting elementary particles, Atomizdat, Vol.1, 1975 & Vol. 2, 1976.
2. Dynamical symmetry breaking in quantum field theories, V.A. Miransky, World Scientific, 1994
3. Electronic properties of Dirac and Weyl semimetals, E.V. Gorbar, V.A. Miransky, I.A. Shovkovy, P.O. Sukhachov, World Scientific, 2021.

Awards

- **1989: M. P. Barabashov Prize** of the National Academy of Sciences of Ukraine for *"Prediction and study of the phenomena of gravitational and chiral instability of the vacuum and their consequences in cosmology and elementary particle physics."*

- **2005: Distinguished Research Professorship** from University of Western Ontario, London, Canada

- **2006: State Prize of Ukraine in Science and Technology** awarded by the President of Ukraine for *"effects of spontaneous symmetry breaking and phase transitions in elementary particle physics and condensed matter physics"*

Mentees & Collaborators

"Try not to become a person of success, but rather try to become a person of value." Albert Einstein (1955)

Students & postdocs

- Valery Gusynin (~1975-2012)
- Igor Shovkovy (~1994-2021)
- Eduard Gorbar (~1989-2021)
- Pavlo Sukhachov (~2014-2021)
- Michio Hashimoto (~2005-2006)
- Junji Jia (~2006-2011)
- Pavlo Pyatkovskiy (~2011-2014)
- Xinyang Wang (~2012-2013)
- Misha Zubkov (~2013-2015)

Collaborators

- Peter I. Fomin (14)
- Yurii A. Sitenko (13)
- V.P. Shelest (8)
- L.C. Rohana Wijewardhana (7)
- Gennady M. Zinovjev (6)
- Mark I. Gorenstein (5)
- Koichi Yamawaki (5)
- Sergei G. Sharapov (4)
- Victor W. Elias (4)
- Volodymyr A. Kushnir (4)
- G.M. Zinovev (3)
- Boris Struminsky (3)
- Masaharu Tanabashi (2)
- Thomas G. Steele (2)
- Farrukh Ahmed Chishtie (2)
- Alexander S. Buchel (2)
- D.G.C. McKeon (2)
- Deog Ki Hong (1)
- G.W. Semenoff (1)
- Michael Scadron (1)
- Stuart Raby (1)
- William Bardeen (1)
- Sherwin T. Love (1)
- G.V. Bugrii (1)
- …