Unconventional Superconductivity in Graphene Based Systems

Szombathy Dominik
Budapest University of Technology and economics

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Source articles:

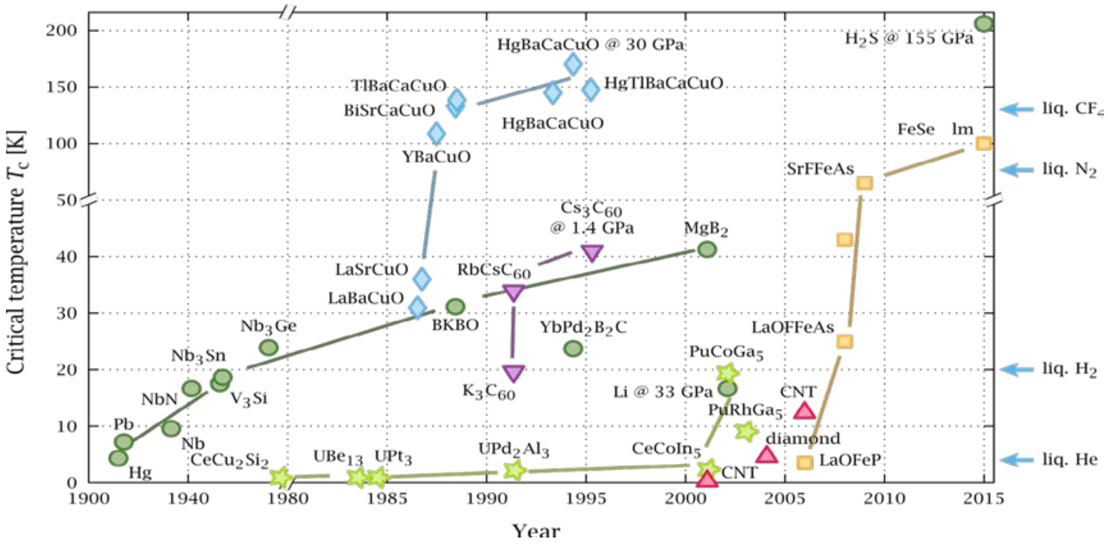
- Cao, Y., Fatemi, V., Fang, S., Magic-angle graphene superlattices: a new platform for unconventional superconductivity, (2018), 10.1038/nature26160
- Cao, Y., Fatemi, V., Demir, A., Fang, S., Tomarken, S. L., Luo, J. Y., Sanchez-Yamagishi, J. D., Watan- abe, K., Taniguchi, T., Kaxiras, E. , Ashoori, R. & Jarillo-Herrero, P. Correlated Insulator Behaviour at Half-Filling in Magic Angle Graphene Superlattice. arXiv:1802.00553 (2018).

What and where is superconductivity(SC)?

- State of the solid which usually present under a critical temperature (Tc)
- No electrical resistance
- Meissner effect etc...

Superconductivity is used widely
- Particle accelerators
- NMR
- Quantum computers

SC's critical temperature ranges from mK's up to 200 K.



https://en.wikipedia.org/wiki/Superconductivity#/media/File:Timeline_of_Superconductivity_from_1900_to_2015.svg

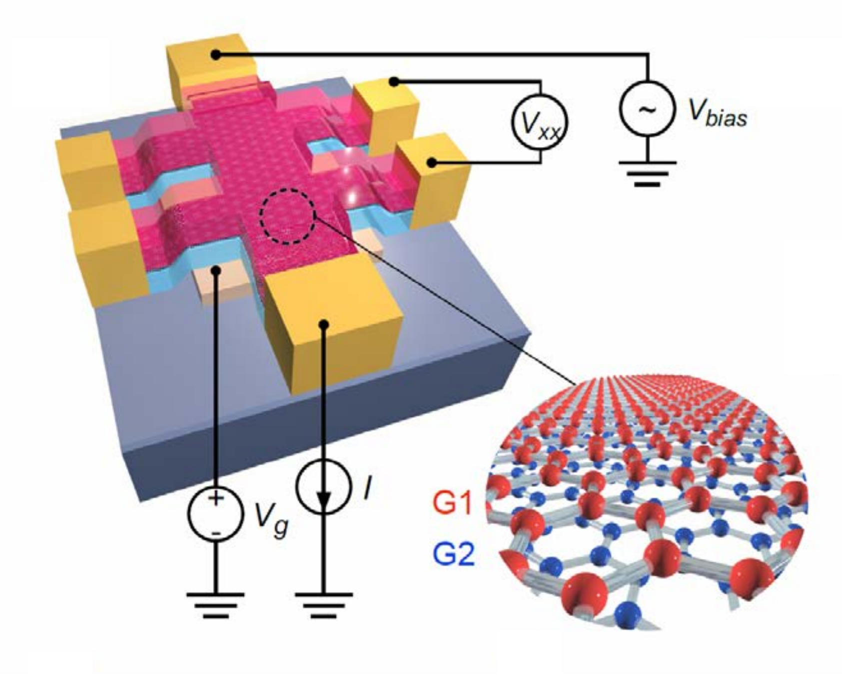
Unconventional Superconductivity (USC) or what it isn’t

- High temperature SC’s
- SC’s which BSC and/or G-L theory cannot describe

Many different definition exists for these materials

These are usually heavy fermionic materials, Cuprates like $CeCu_2Si_2$ ect… and also graphene based systems.

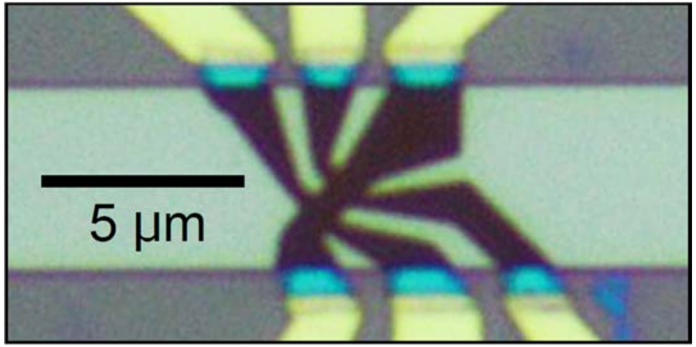
The fabrication of magic angle twisted bilayer graphene (MA-TBG)



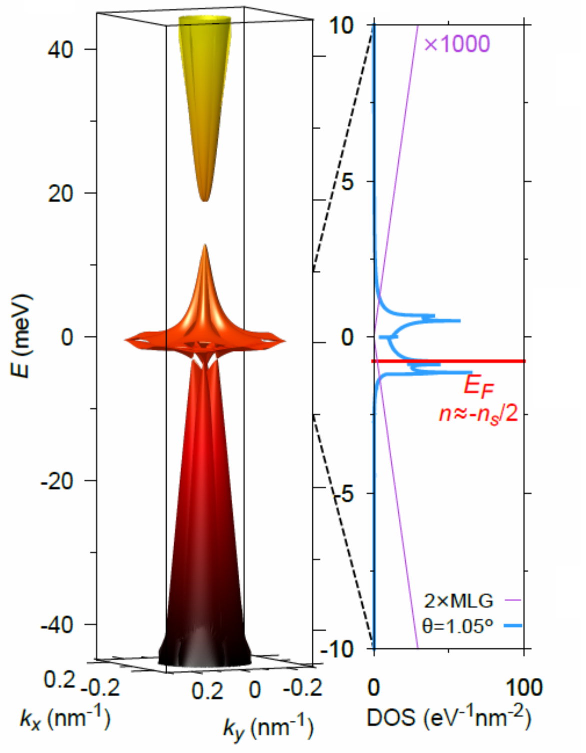
Magic angle = 1.1°

- Dry-transfer method
- Precision: 0.1-0.2°

Two devices: 1.05° and 1.16°



Moire pattern by the magic angle



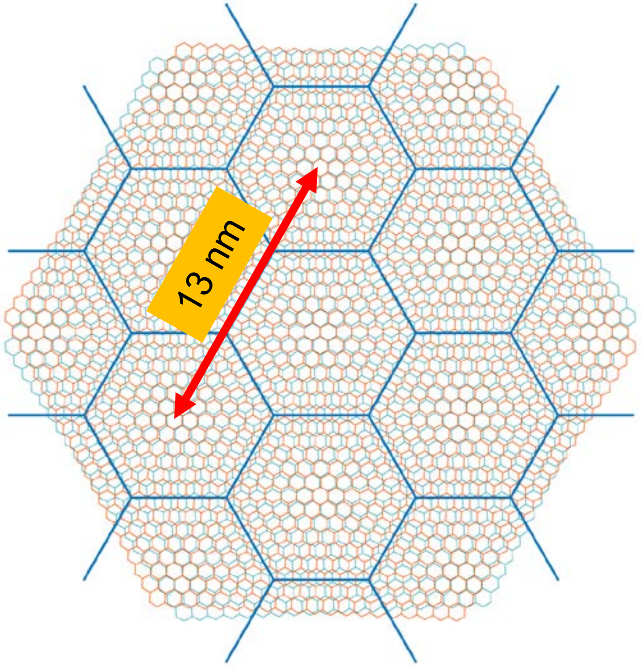
Carrier density

⬇

Superlattice density

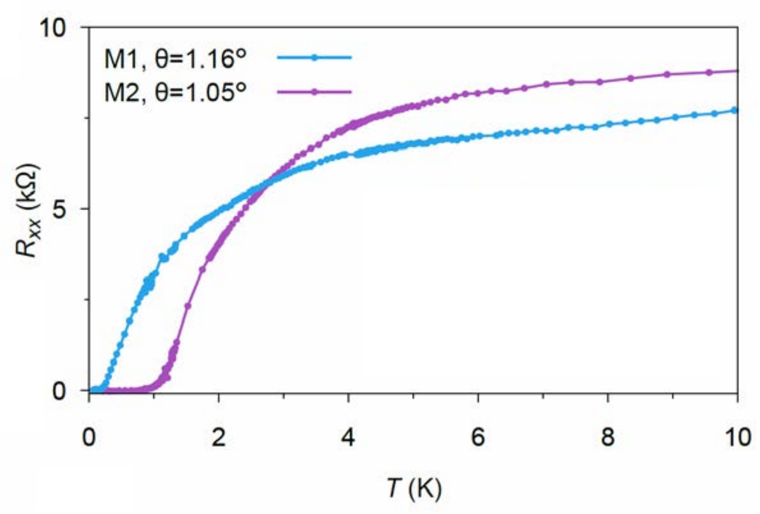
$$n = \frac{4}{A}$$

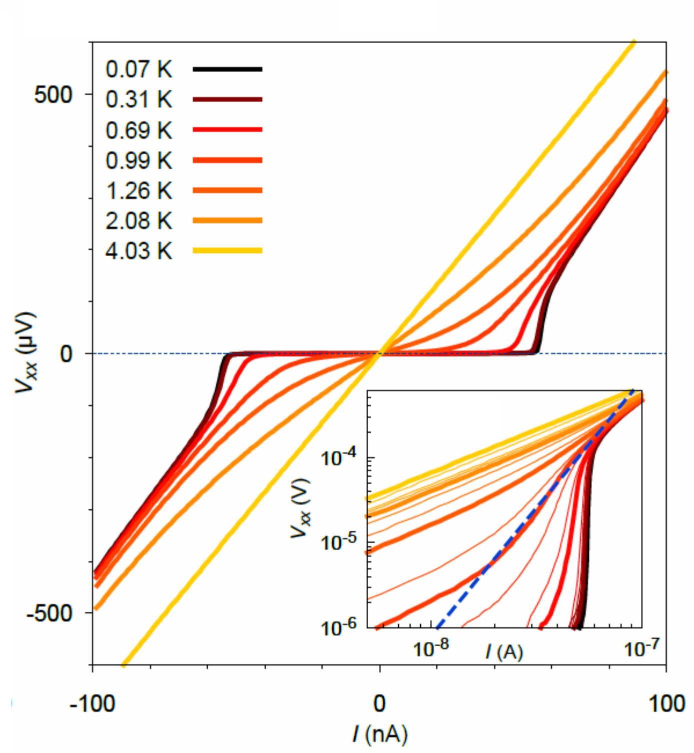
$$A = \frac{\sqrt{3}a^2}{2\theta^2}$$



https://www.quantamagazine.org/when-magic-is-seen-in-twisted-graphene-thats-a-moire-20190620/

Supercurrent measurements





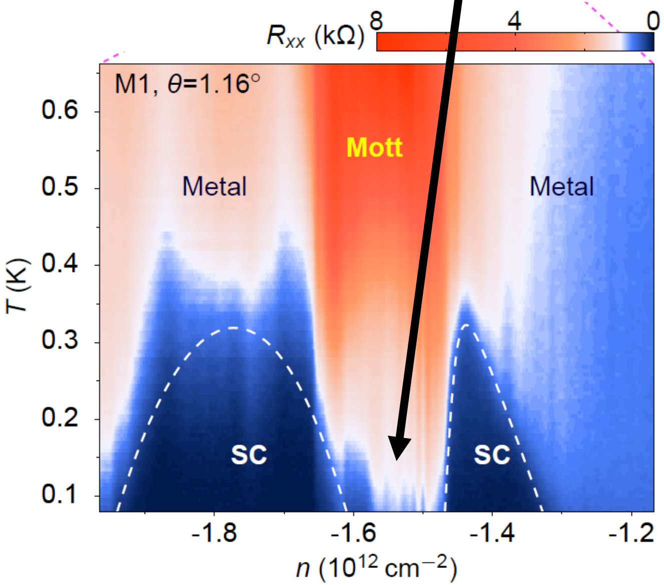
Lower bound for MA-TBG's Tc = 1.7 K

$V \sim I^3$ *power law*

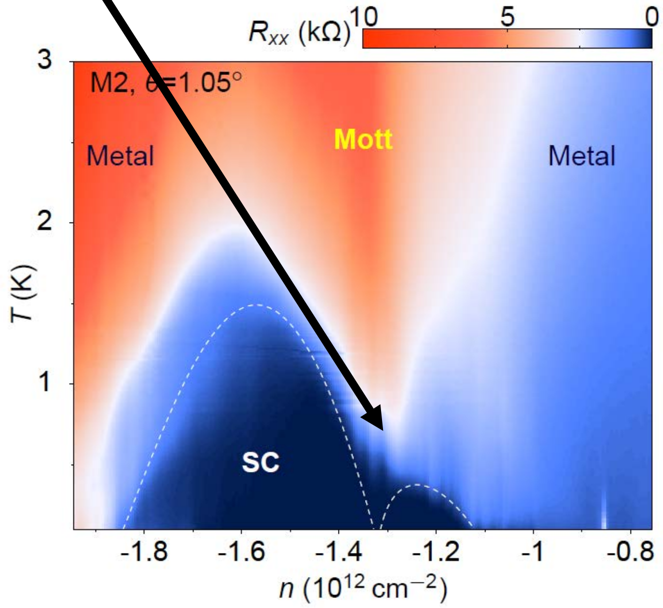
Superconducting can be achived with small doping and low enough temperatures

Weakly superconducting state

Previously observed SC state



Possible cause of weak superconducting phase is a not negligible inhomogenity in the superlattice density

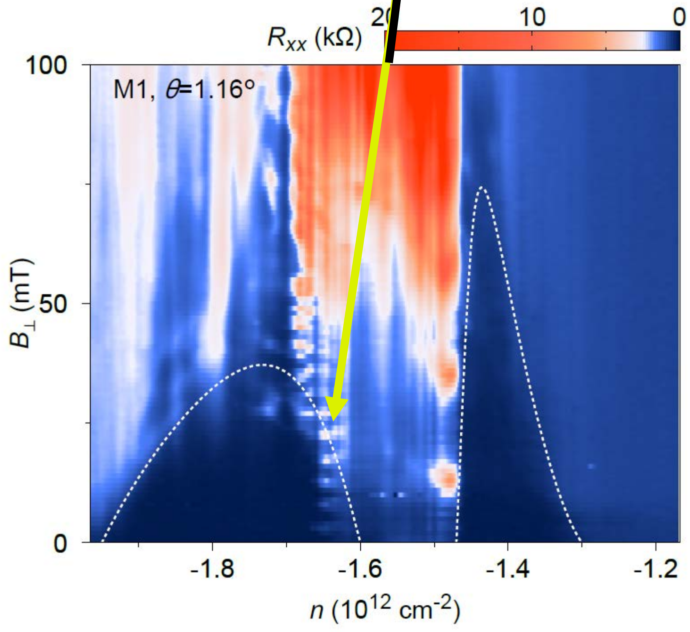


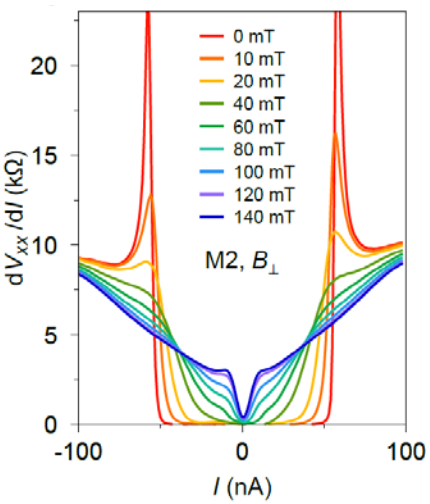
Introducing another parameter – SC in magnetic fields.

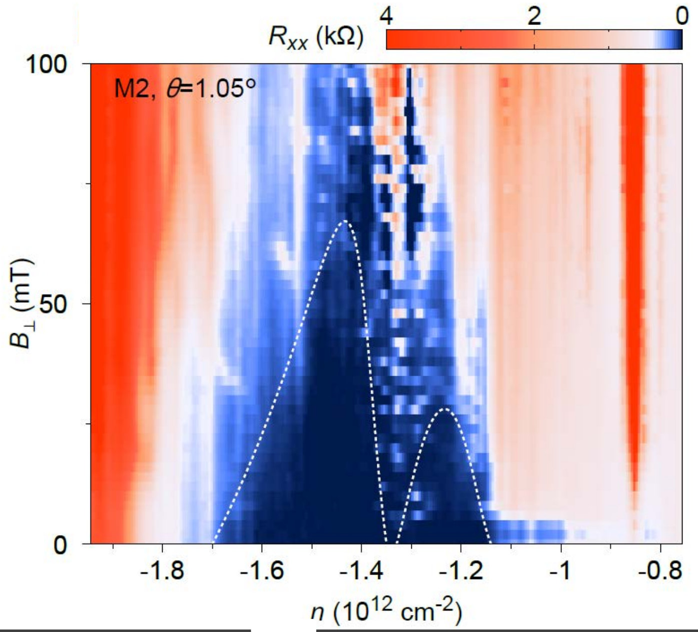
Critical field in both devices
$B_c = 70mT$

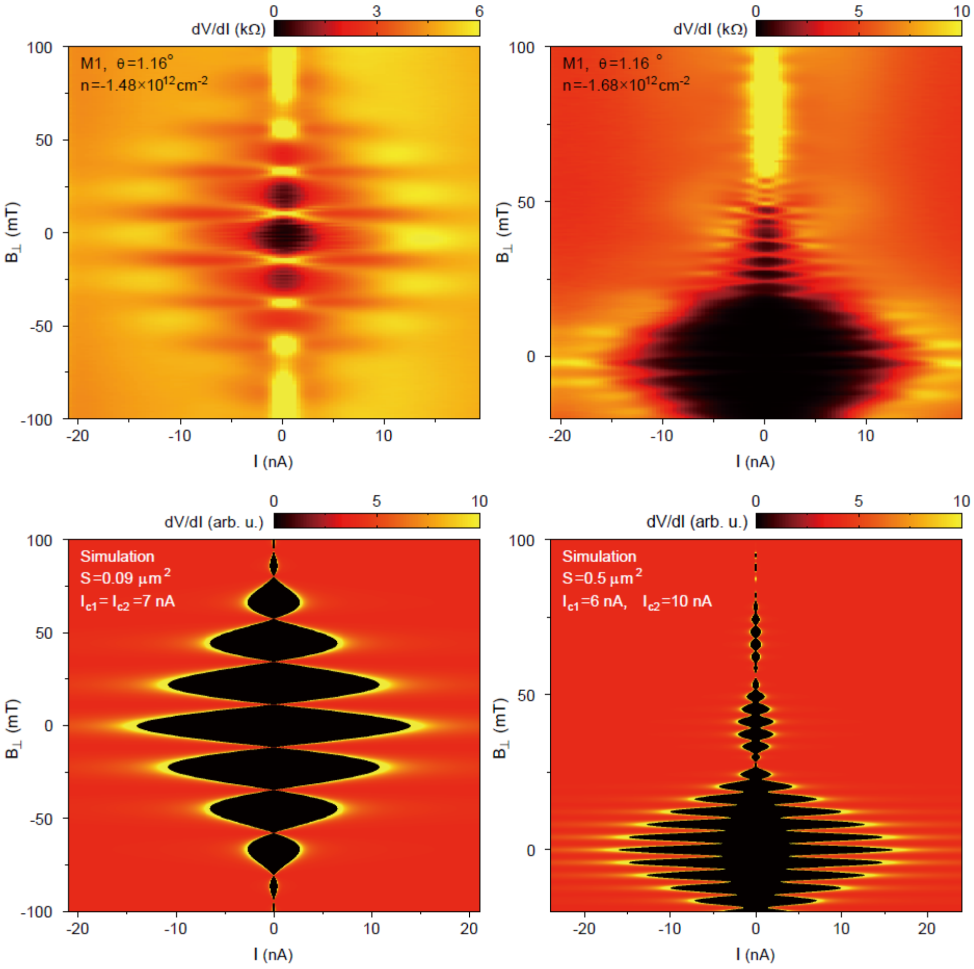
Specific doping densities introduce oscillating effects

Perpendicular magnetic field → Dissipation
Perpendicular magnetic field → Critical field; SC state









Phase coherent transport in Josephson junctions

Josephson junction in this case: electron pair tunneling through an insulator part of the device

Modelled using **S**uperconducting **Qu**antum **I**nterference **D**evice and the G-L theory.

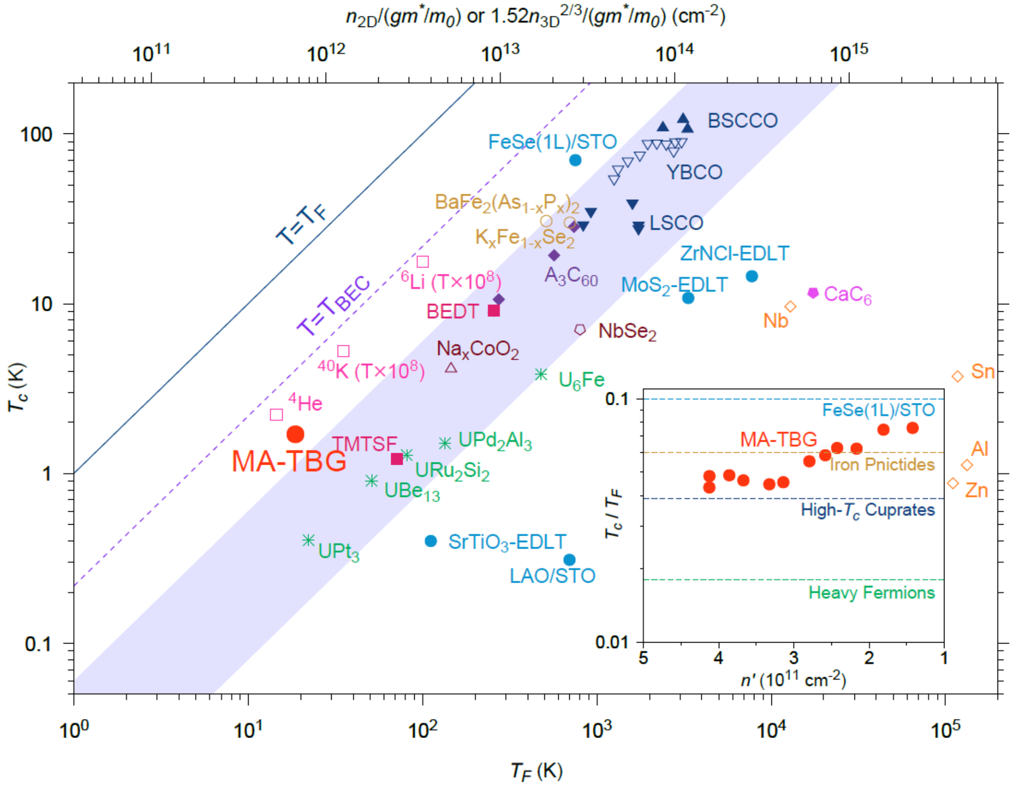
$$B_c = \frac{\phi_0}{2\,\pi\,\epsilon_{GL}^2}\left(1 - \frac{T}{T_c}\right)$$

Comparing twisted bilayer graphene to other superconductors

Usual USC $\frac{T_C}{T_{F(2D)}}$ values are between 0.01-0.05, TBG is above this trend line.

MA-TBG's

- $\frac{T_C}{T_{F(2D)}}$ is higher than the usual cuprates, heavy fermionic SCs, etc…
- $\frac{T_C}{T_{BEC}} = 0.37$



Short summary

- **Gate, Temperature and Magnetic field tunable superconductor in a high mobility system**
- **Greater electron correlation and interlayer interaction than in other USCs.**
- **Future experiments**

  introducing strains

  experimenting with pressure sensitivity

Thank you for your attention.