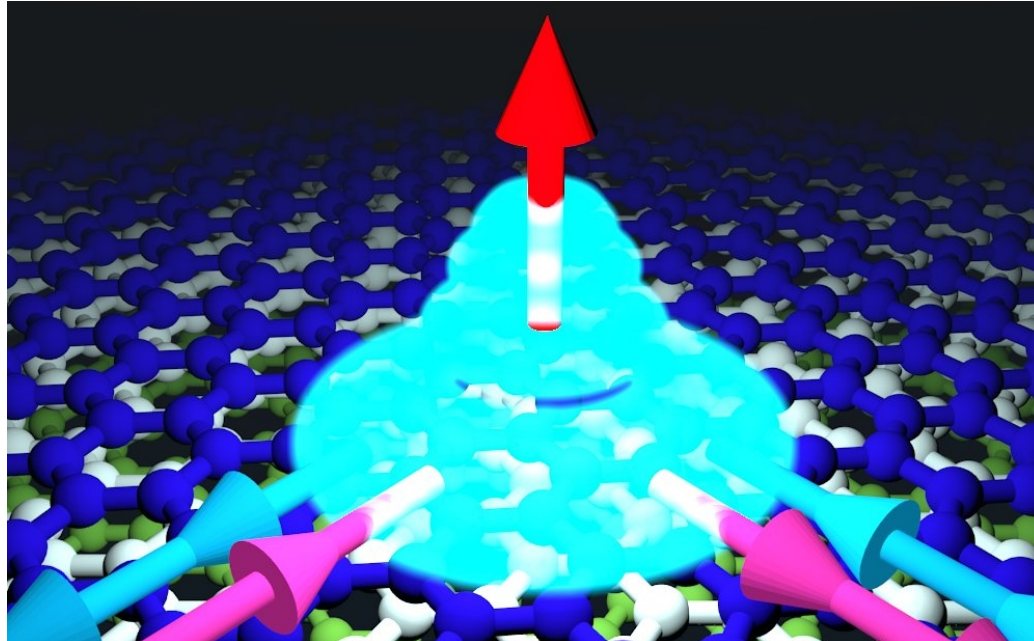


Engineering heavy fermions in twisted graphene multilayers

Jose Lado¹, Aline Ramires²

¹*Department of Applied Physics, Aalto University, Finland*

²*Paul Scherrer Institute, CH-5232 Villigen PSI, Switzerland*



Phys. Rev. Lett. 127, 026401 (2021)

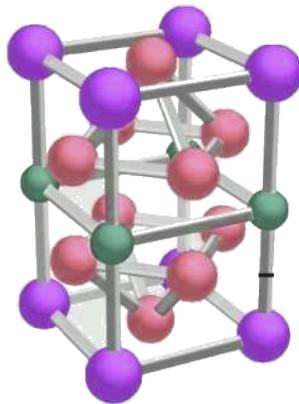
APS March Meeting 2022, March 15th 2022

Searching for new heavy fermion compounds

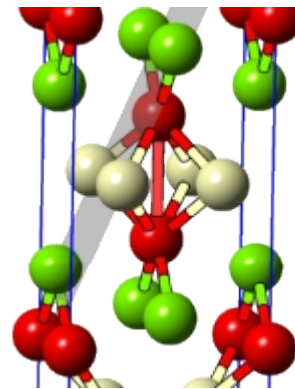
We have a rich family of bulk heavy-fermion compounds



Science 375, 6576, 76-81 (2021)



Nature 579, 523–527 (2020)



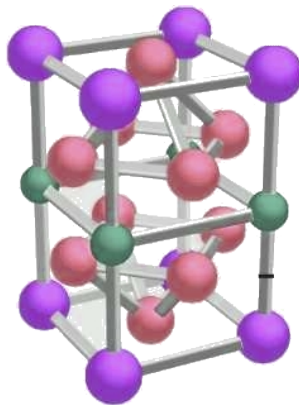
- Strongly correlated matter, dominated by Kondo lattice physics
- Unique system to realize quantum criticality and unconventional superconductivity
- Found in rare-earth compounds, such as UTe_2 or UPt_3

Searching for new heavy fermion compounds

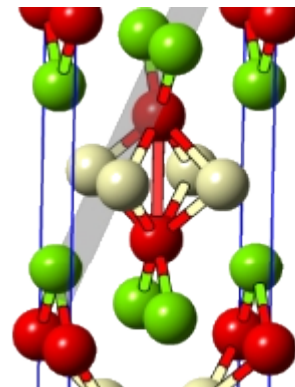
We have a rich family of bulk heavy-fermion compounds



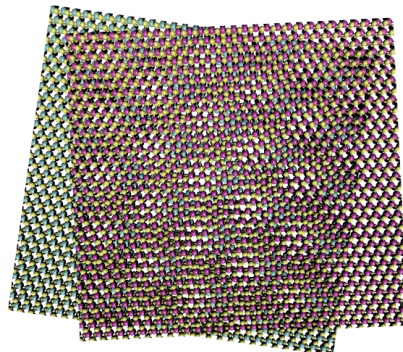
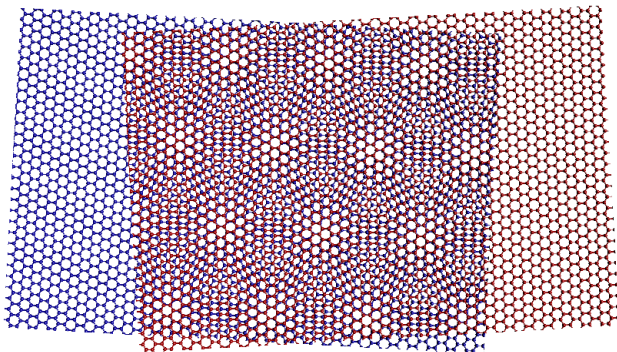
Science 375, 6576, 76-81 (2021)



Nature 579, 523–527 (2020)



Can we realize heavy-fermion physics with two-dimensional materials?



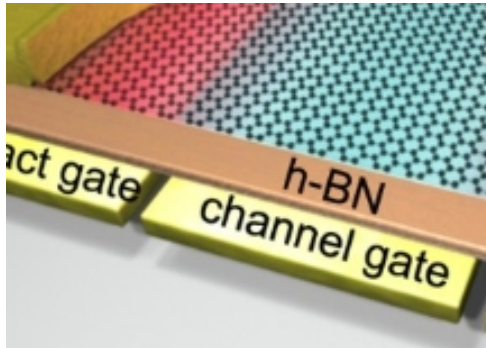
Phys. Rev. Lett. 127, 026401 (2021)
Nature 599, 582–586 (2021)
Phys. Rev. Research 3, 043173 (2021)
arXiv:2110.11962

Controlling a heavy-fermion state in van der Waals materials

*Of course, we can use the typical knobs of bulk heavy fermion compounds
(pressure, chemical doping, etc)*

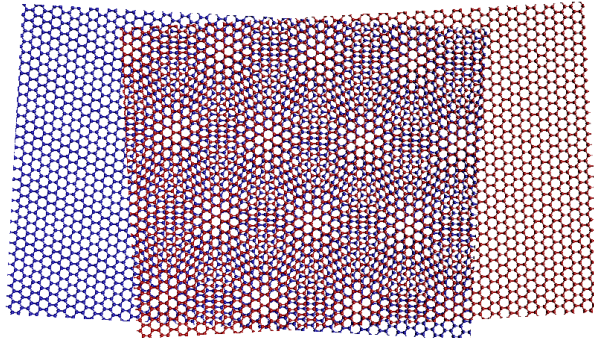
Most importantly, we can exploit the full tunability of van der Waals materials

Gating



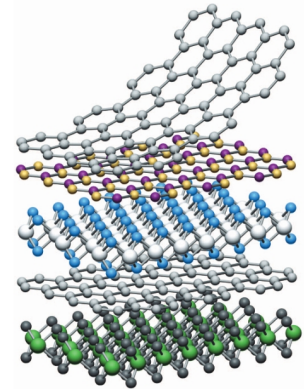
Science 306, 5696, 666-669 (2004)

Twist engineering



Nature Reviews Materials 6, 201–206 (2021)

Materials engineering



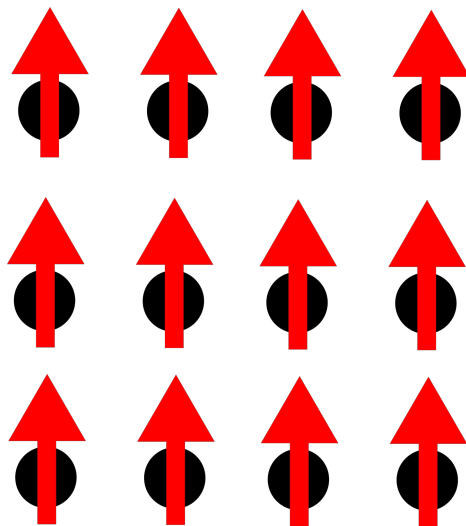
Nature 499, 419–425 (2013)

Allowing to independently control Kondo coupling, exchange coupling, doping and electronic dispersion

Building an artificial heavy fermion state



Lattice of Kondo impurities



f-electrons in
rare-earth compounds

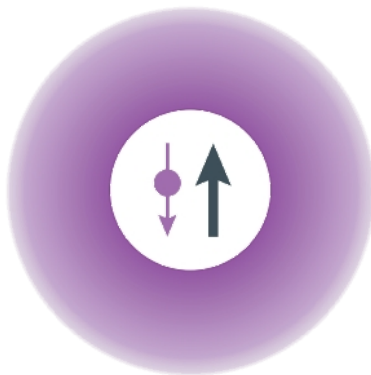
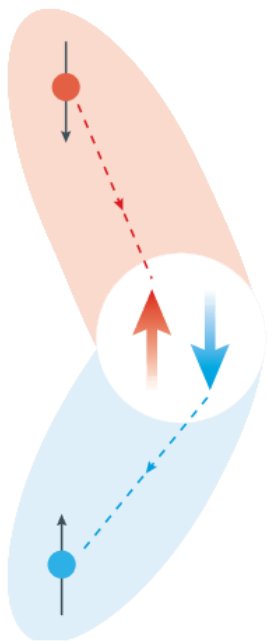
Dispersive electron gas



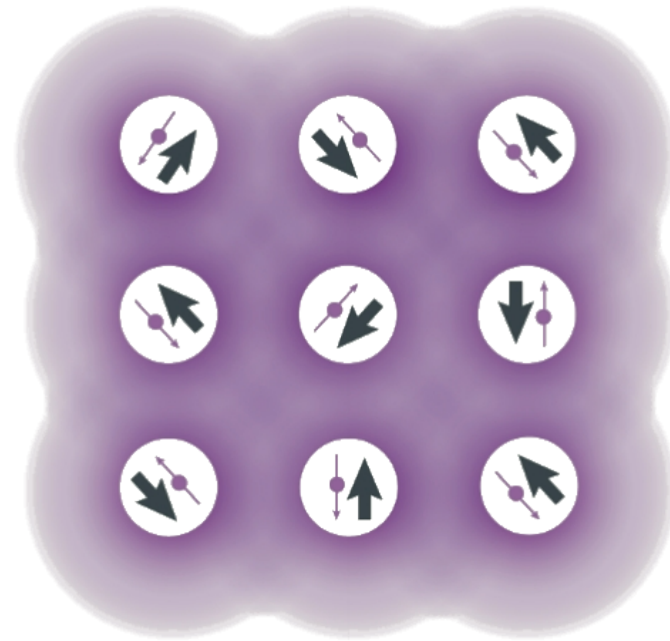
s/p/d-electrons in
rare-earth compounds

Building an artificial heavy fermion state

Conduction electrons form
Kondo singlets with the impurities



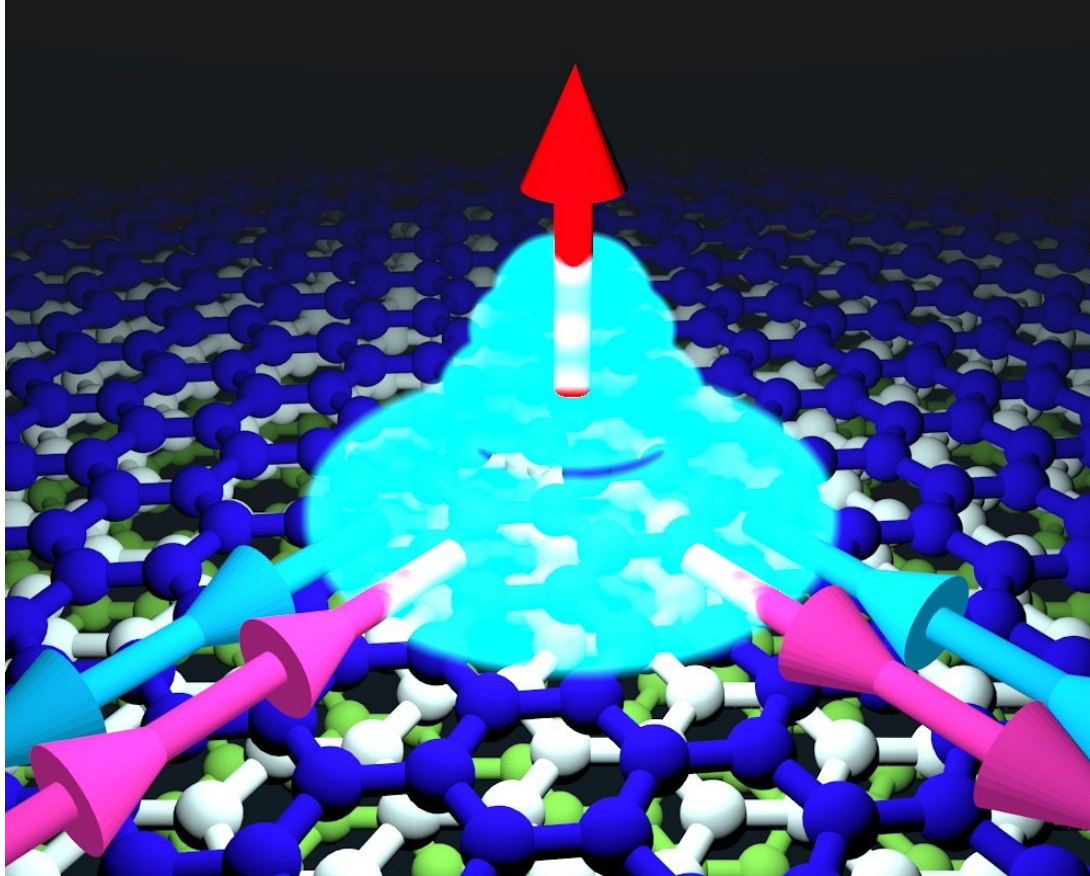
Kondo-lattice model



Associated with Kondo lattice physics:

- Colossal mass enhancement of electrons
- Quantum criticality
- Unconventional (topological) superconductivity

Heavy-fermions in twisted graphene trilayers



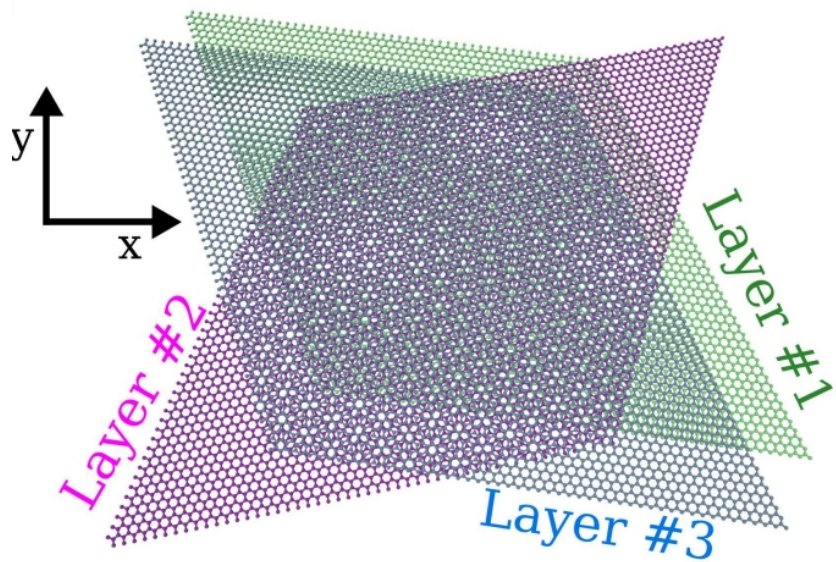
Aline Ramires



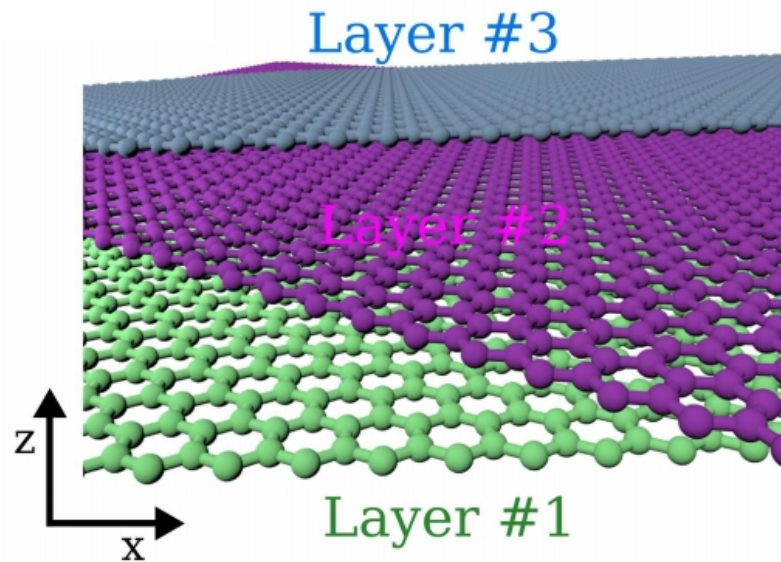
Phys. Rev. Lett. 127, 026401 (2021)

Heavy-fermions in twisted graphene trilayers

Top view

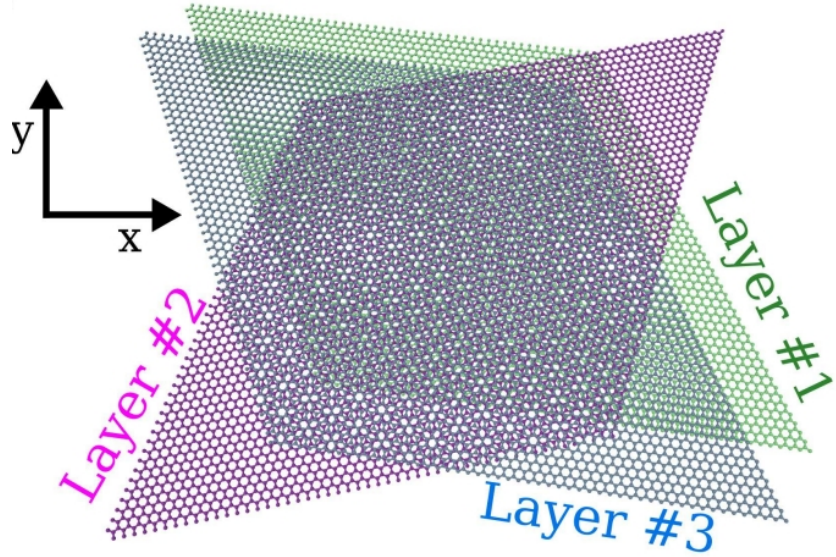


Lateral view

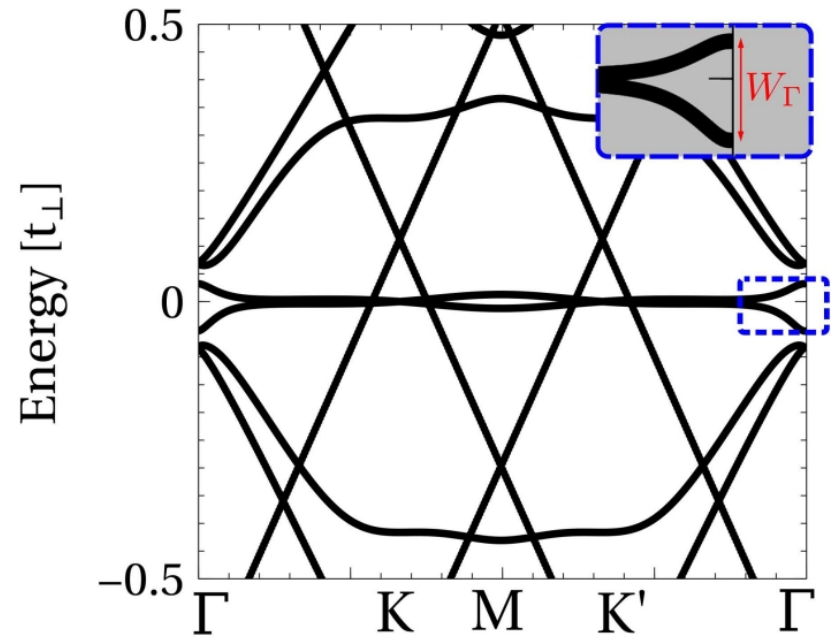


Heavy-fermions in twisted graphene trilayers

Top view

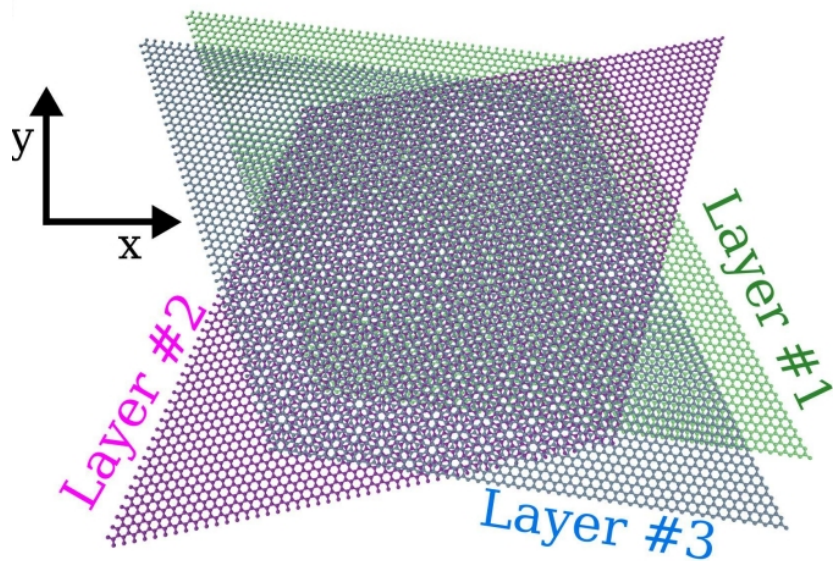


Band structure

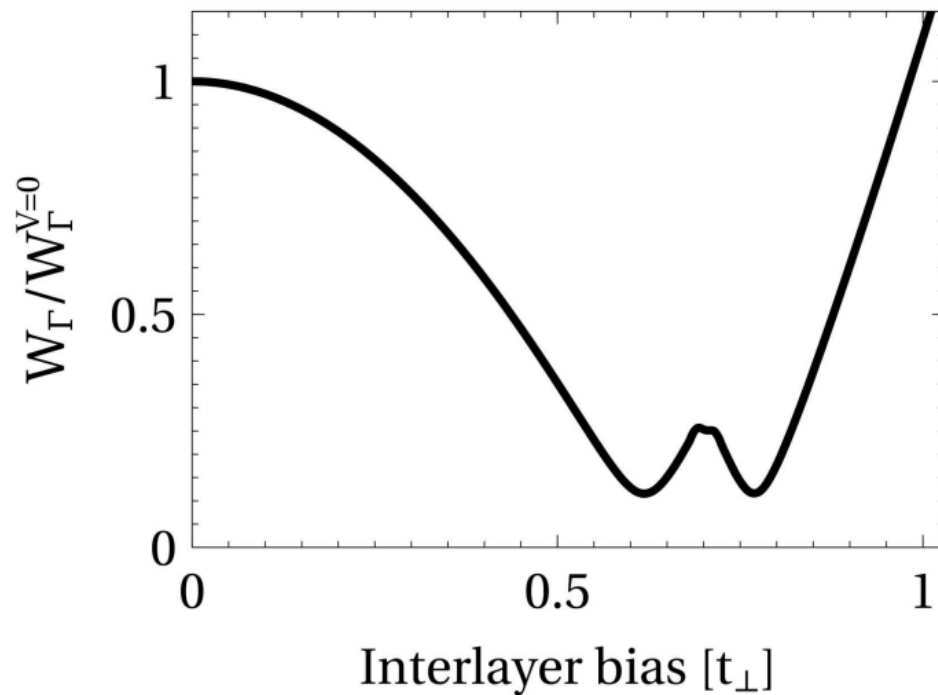


Heavy-fermions in twisted graphene trilayers

Top view



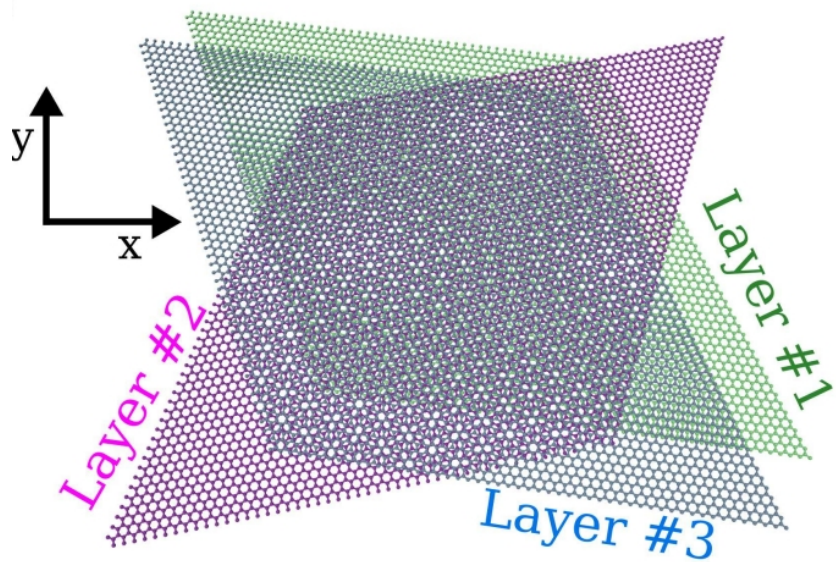
Bandwidth of nearly flat bands



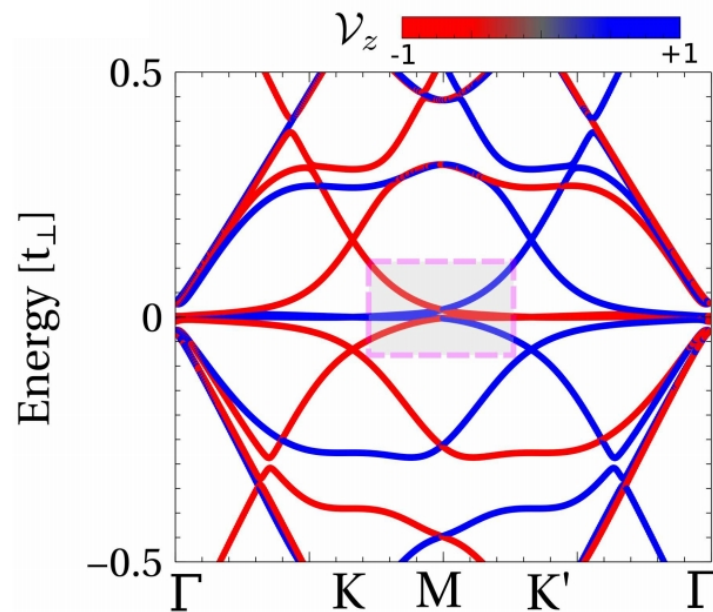
Band flattening as an interlayer bias is applied

Heavy-fermions in twisted graphene trilayers

Top view

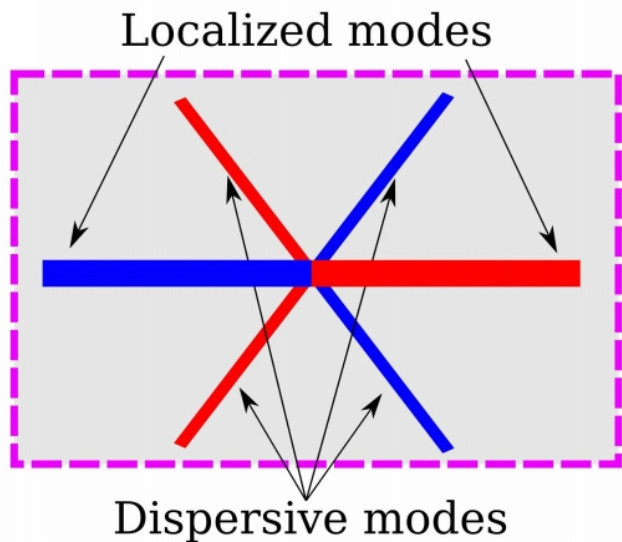


Electronic structure in the presence of an electric bias

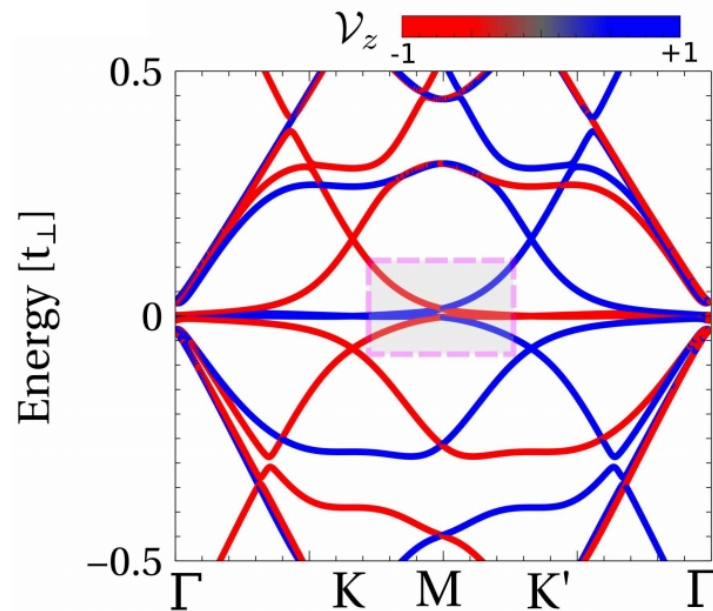


Heavy-fermions in twisted graphene trilayers

Low energy model

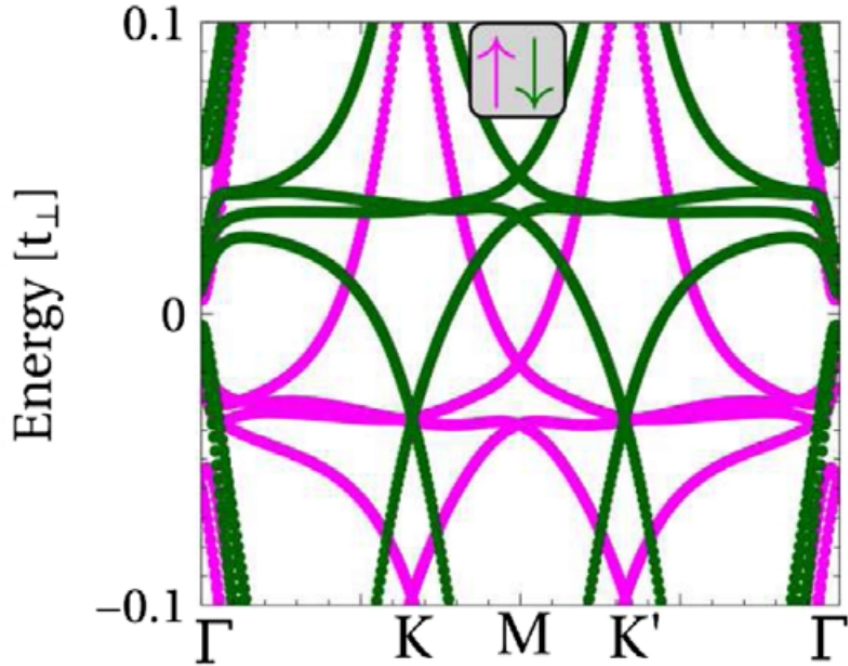


Electronic structure in the presence of an electric bias

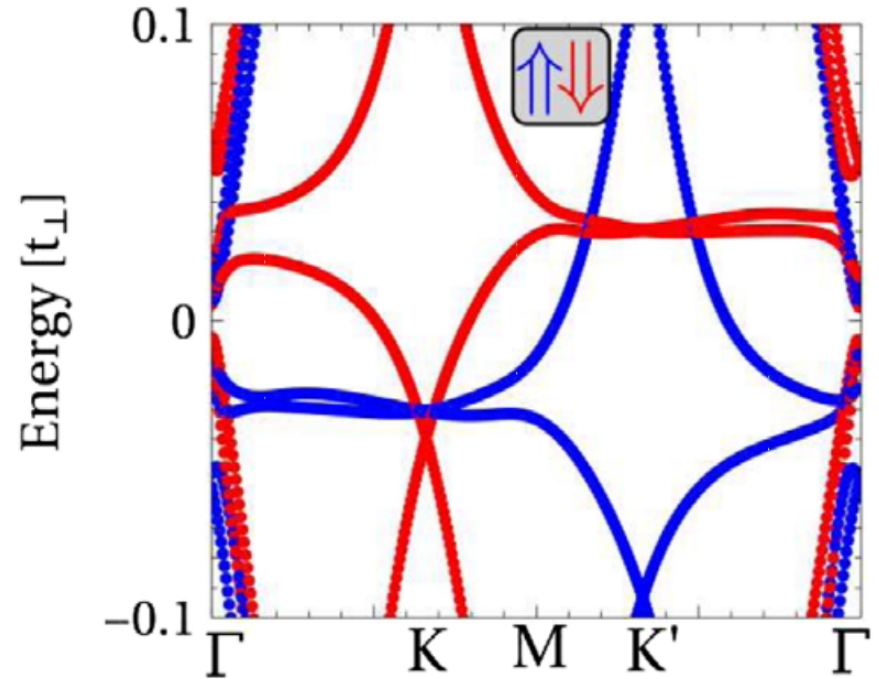


Mean-field electronic structure at half filling

Promoting spin moment formation



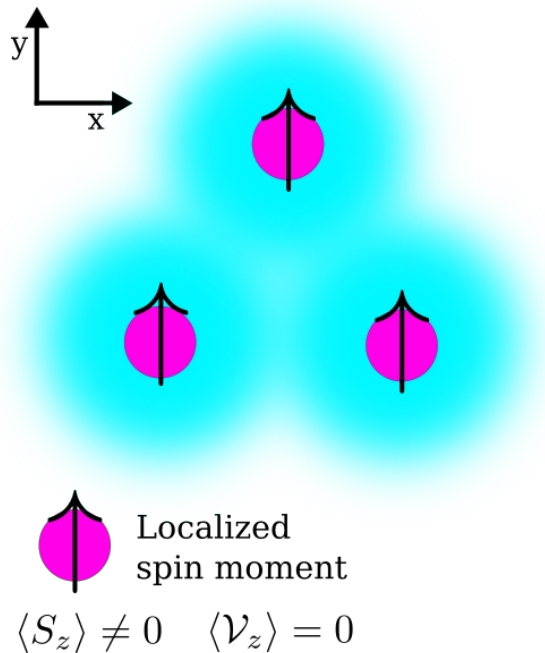
Promoting valley moment formation



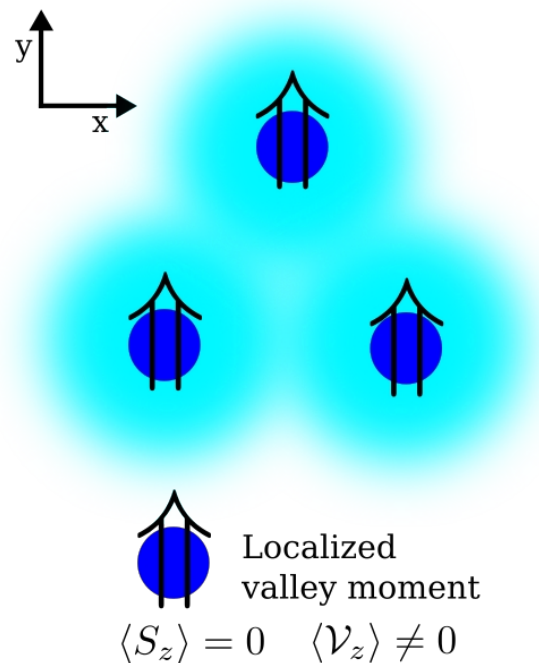
Local spin and valley moments appear when including electronic interactions at the mean-field level

Mean-field electronic structure at half filling

Promoting spin moment formation



Promoting valley moment formation

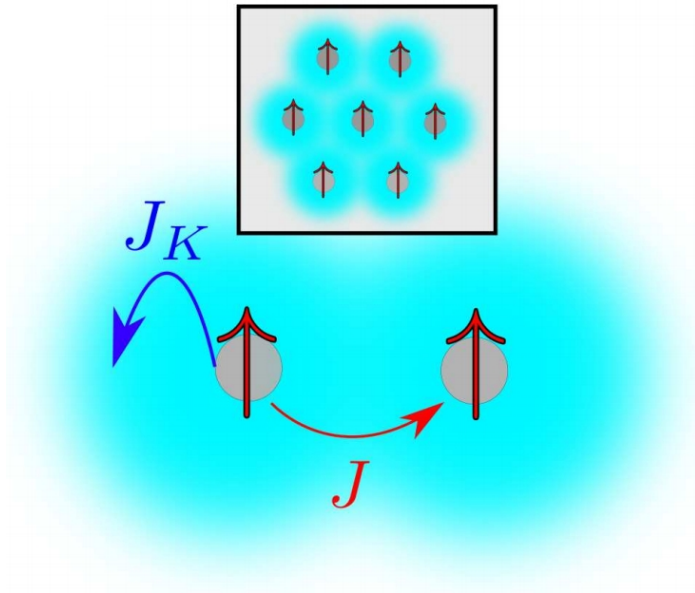


Dispersive
modes

Local spin and valley moments appear when including electronic interactions at the mean-field level

Kondo lattice model in the presence of interactions

Interactions of the Kondo lattice model



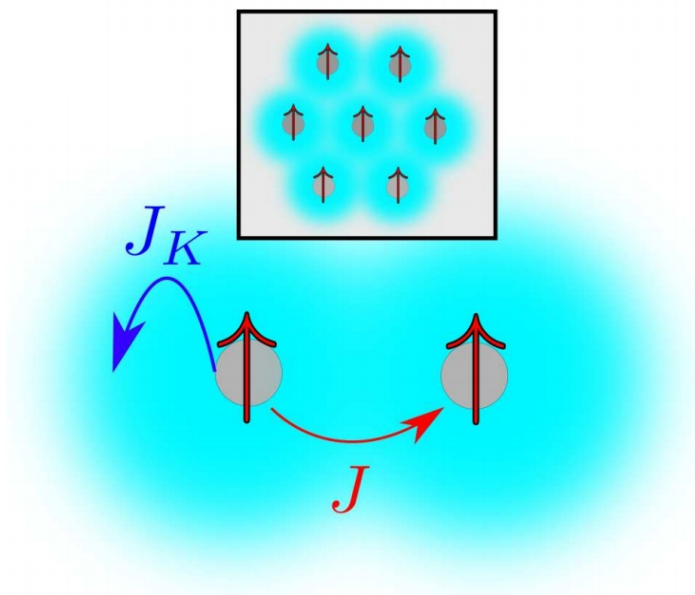
Kondo coupling Exchange coupling

$$H = H_{\text{dispersive}} + J_K \sum_{\langle i\alpha \rangle} \mathbf{S}_i \cdot \mathbf{s}_\alpha + J \sum_{\langle ij \rangle} \mathbf{S}_i \cdot \mathbf{S}_j$$

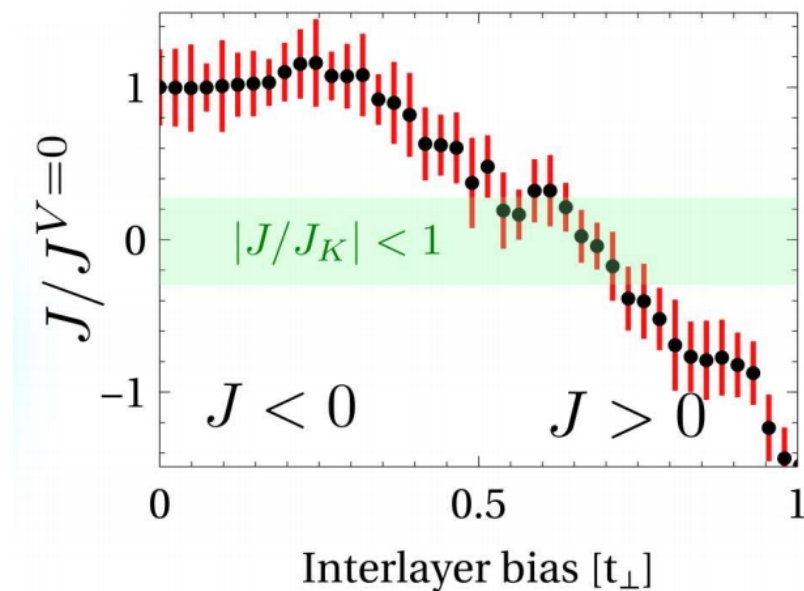
Promotes Kondo screening Promotes magnetic order

Kondo lattice model in the presence of interactions

Interactions of the Kondo lattice model



Electric control of the Kondo regime

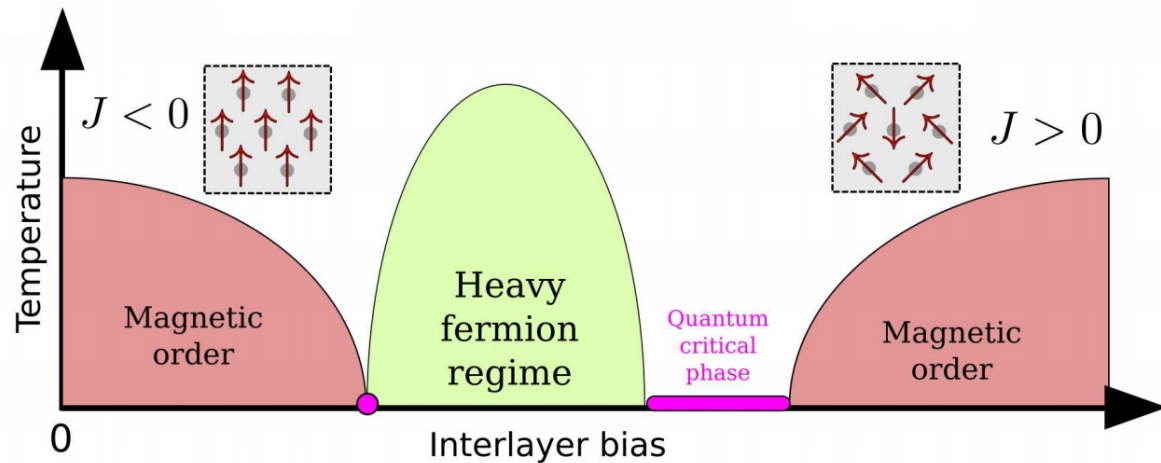


A heavy fermion regime appears when the Kondo coupling dominates over the exchange coupling

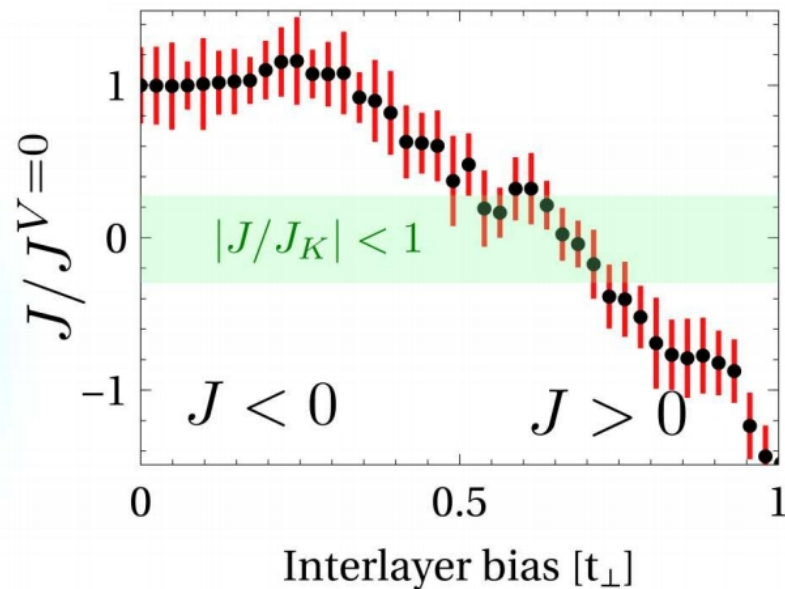
$$|J/J_K| < 1$$

Heavy-fermions in twisted graphene trilayers

Heavy-fermion (Doniach) phase diagram



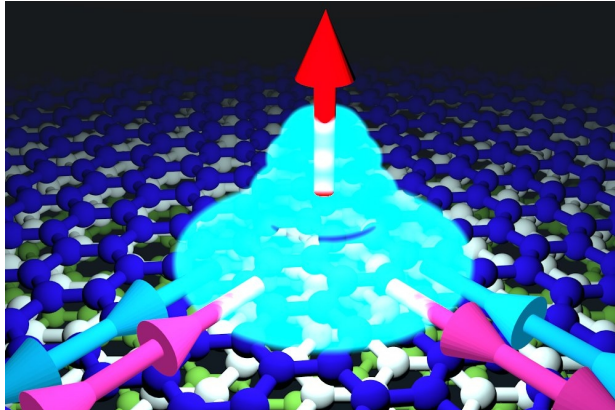
Electric control of the Kondo regime



The full phase diagram of the heavy fermion system can be explored in a single twisted graphene, by tuning the system with an electric bias

Take home

Twisted graphene trilayers provide a platform to engineer heavy-fermion physics, potentially allowing to explore a full heavy-fermion Doniach phase diagram by means of an electric bias



Phys. Rev. Lett. 127, 026401 (2021)

Thank you!

Funding from

