SQUID interferometry, higher order topology and mesoscopic transport

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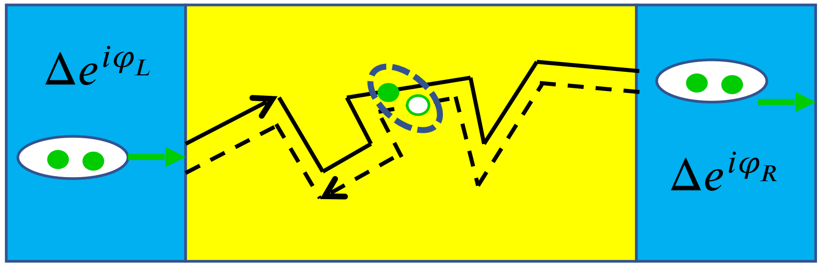
First, a few things about the SNS junction

SNS junction : supercurrent in a normal metal

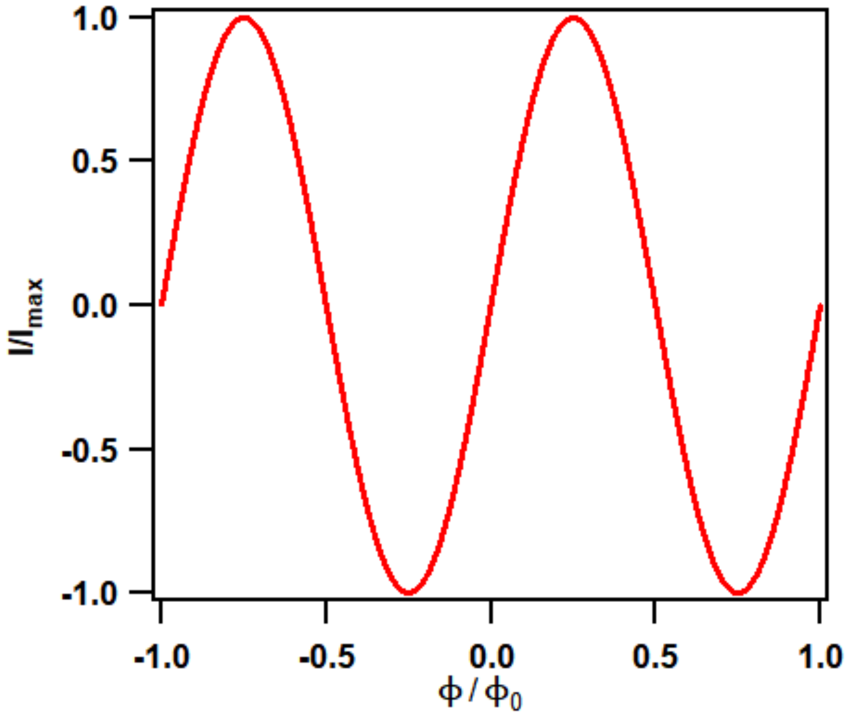


Supercurrent flows in the normal metal
- depends on the phase difference φ
- can be controlled using a magnetic field

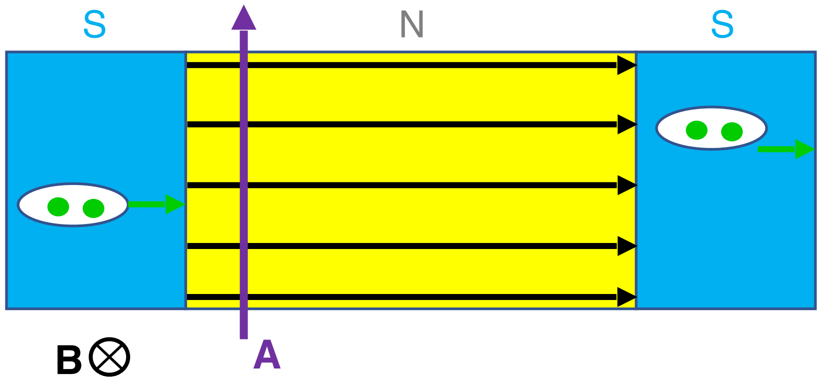
$$\varphi = -2\pi \frac{\phi}{\phi_0}$$

B field
> magnetic flux
> phase difference

Simplest current-phase relation

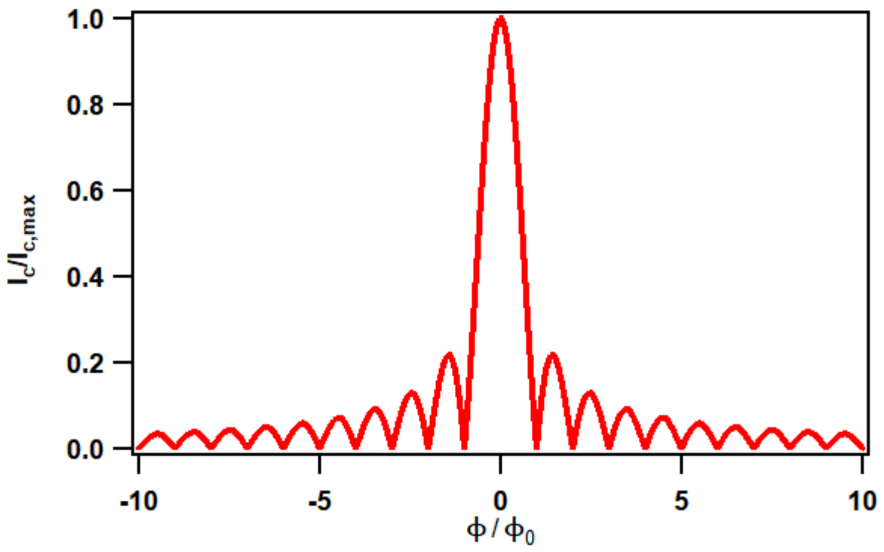


SNS junction : interferences



Of course I'm keeping secret lots of hypotheses made here…

$$I_c(\varphi) = \max(\mathrm{FT}(\mathrm{J}(\mathrm{x})))$$



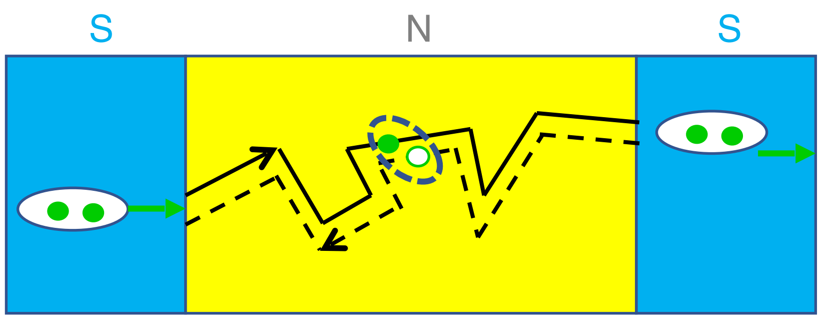
- Uniform supercurrent distribution
- B field : leads to vector potential
- Add a phase term depending on the position

Leads to interferences !

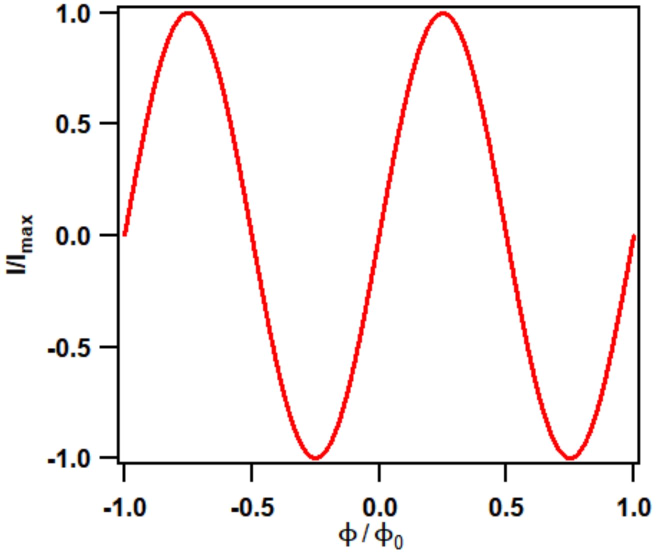
Keep in mind : this is similar to Young's single slit experiment, where **A** takes the role of the optical path difference.

Different types of transport

« Long » diffusive



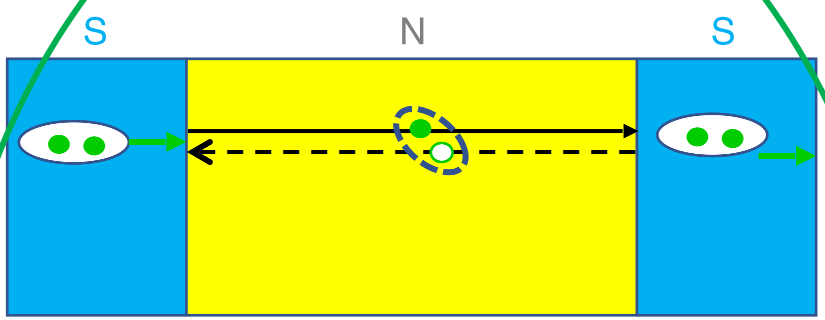
- Easy to understand : disorder implies electrons scattering
- Sine-like CPR



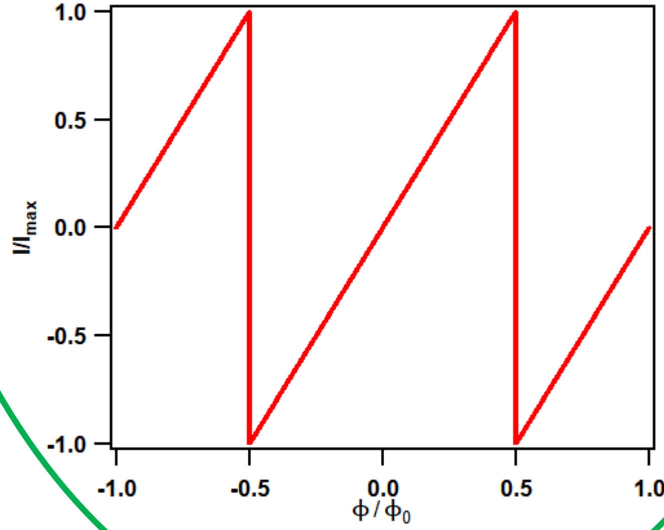
Two questions :

- How do we measure the CPR ?
- Where to find long ballistic transport ?

« Long » ballistic

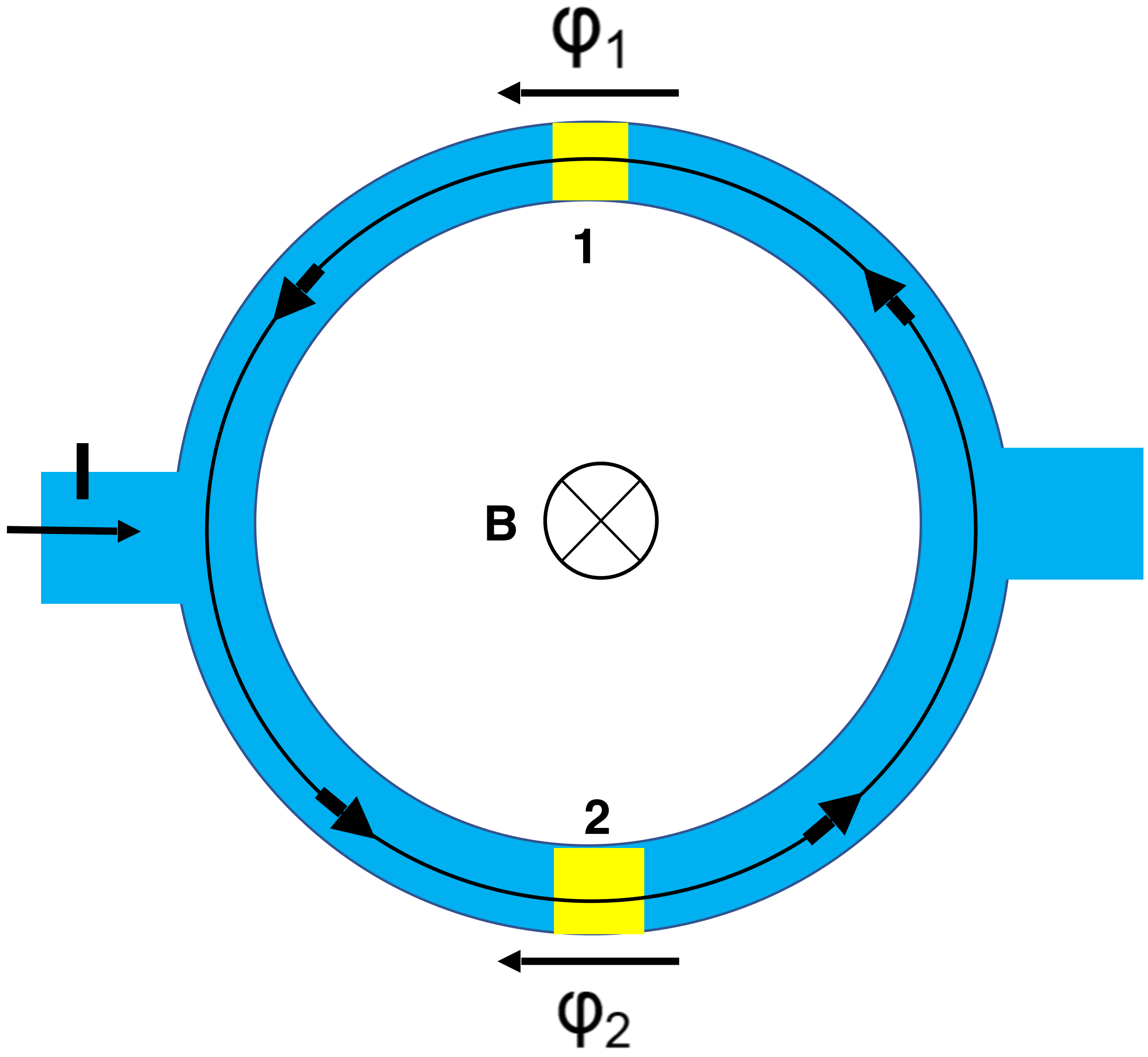


- Ballistic electronic transport : how ?
- Sawtooth CPR



Asymmetric SQUID : a tool to measure the CPR

Superconducting QUantum Interference Device



- Two SNS in parallel : SNS_1 & SNS_2 (double-slit experiment)
- Maximum (« critical ») current of SNS_1 is much higher than the one of SNS_2 i.e. $I_{c,1} >> I_{c,2}$
- We measure the current passing through the whole device

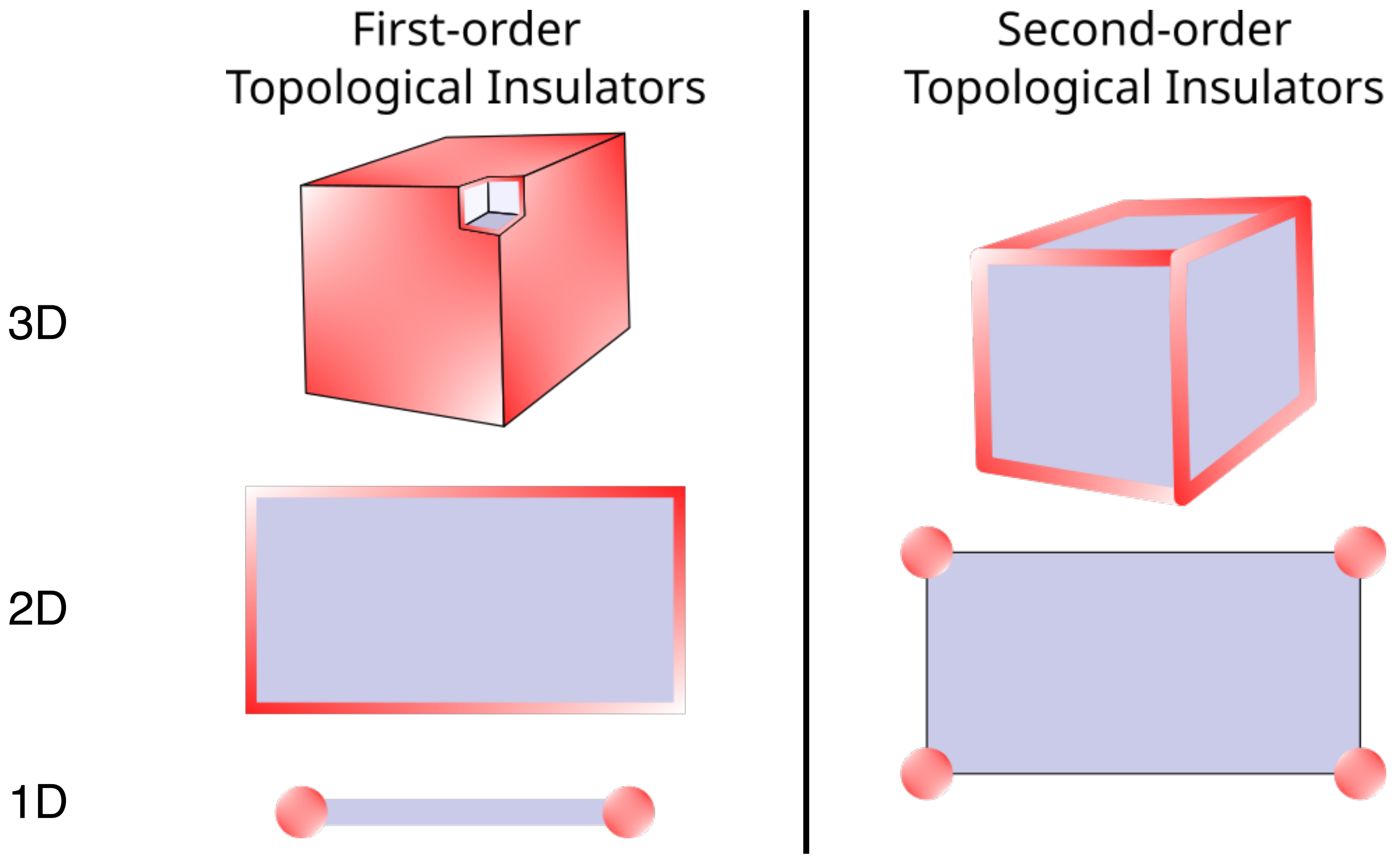
$$I_c(\varphi) = I_{c,1} + I_{c,2}(\varphi)$$

Huge background coming from JJ_1 and small modulation coming from JJ_2

Idea : the « big » junction will be diffusive while the « small » will be ballistic !

And now enters the higher order topological insulator

Topological insulators



Insulating behavior in dimension d
Conducting behavior in (d-1)

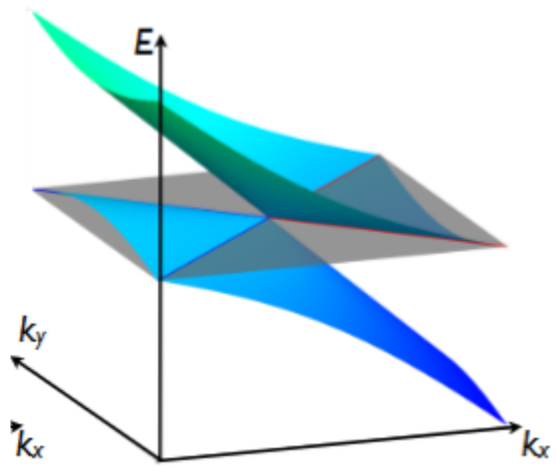
Insulating behavior in dimension d, d-1
Conducting behavior in (d-2)

Topological protection : these edge/hinge/corner states are robust against disorder (temperature, B field)

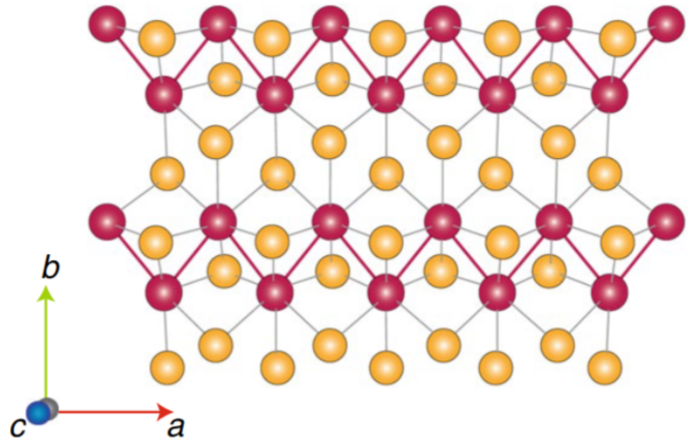
And our candidate : WTe_2

- WTe_2 : a type II Weyl semimetal
- Also expected to be a 2DTI when in the monolayer limit
- Experiments already show the existence of hinge states in 3D !

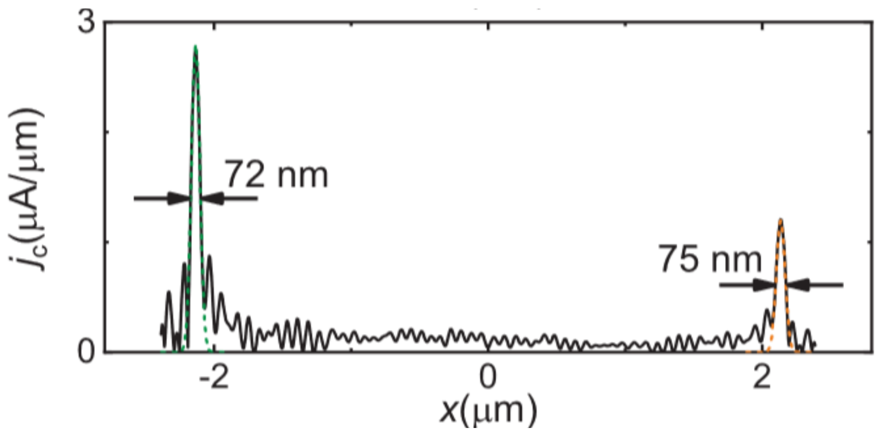
A long ballistic CPR would be the sign of these topologically protected hinge states !



Soluyanov et al., Nature (2015)
WTe_2 is a type II WSM



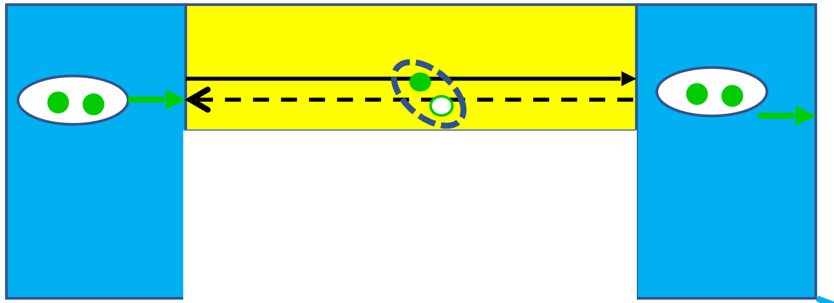
Fei, Z., Palomaki, T., Wu, S. et al. Nature Phys (2017)
WTe_2 is a 2D topological insulator

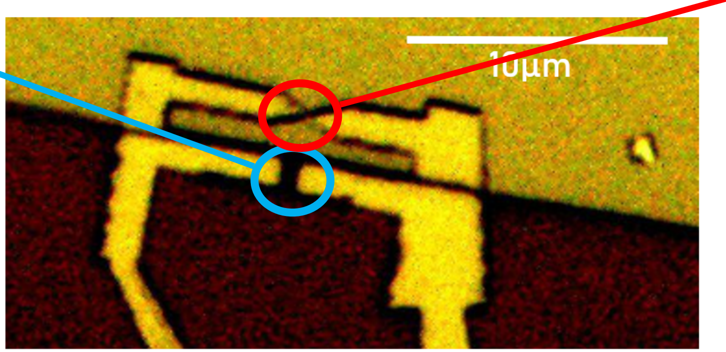


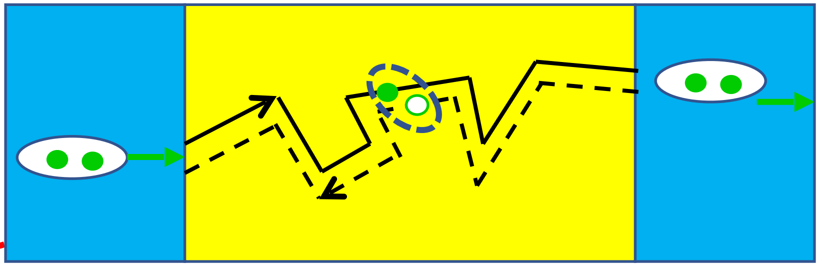
Kononov et al., Nano Letters (2020)
Multilayer WTe_2 exhibits hinge states.

Finally, experiments and results

Building an asymmetric SQUID using WTe_2





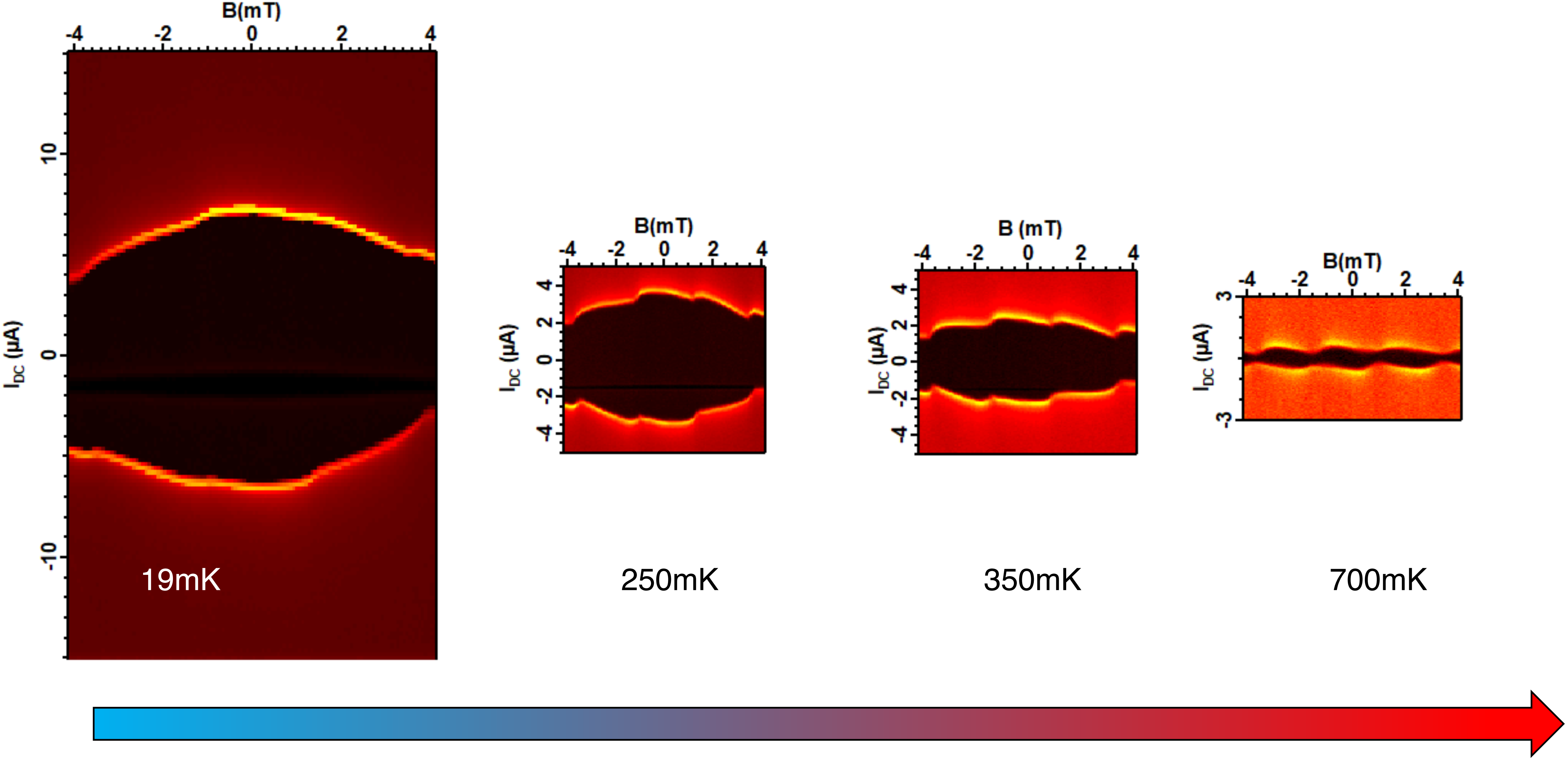


- SNS on the hinge of the flake
- Minimize the number of states, then carries a small value of supercurrent.

- SNS on the bulk : 3D junction
- Shorter, hence carrying a huge value of supercurrent

Controlling the geometry (lengths, areas, …) is important !

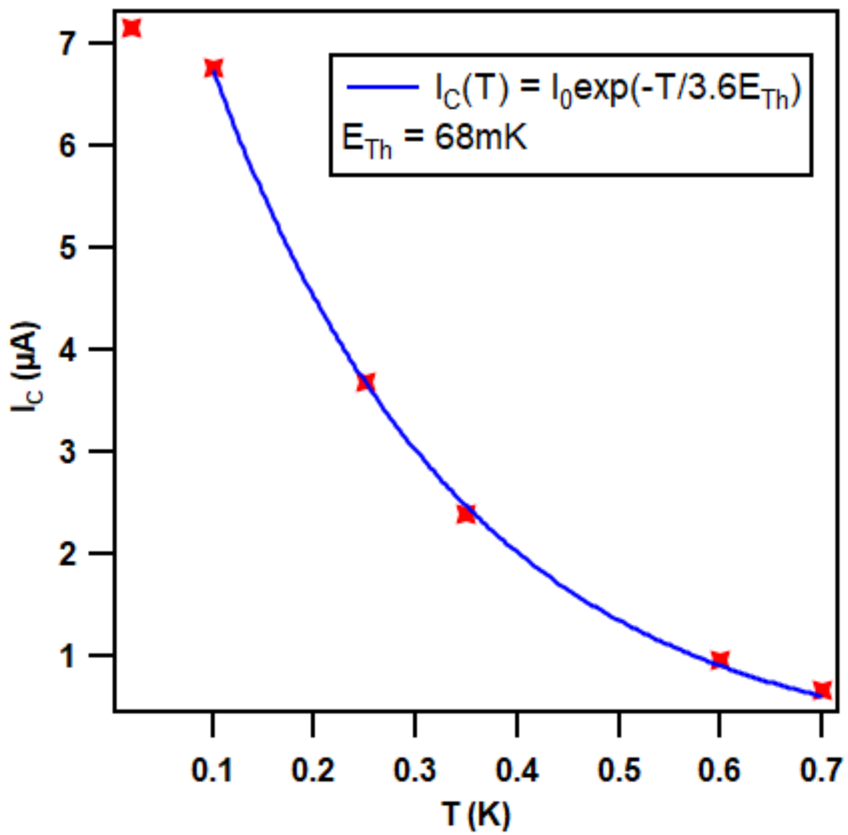
Temperature evolution



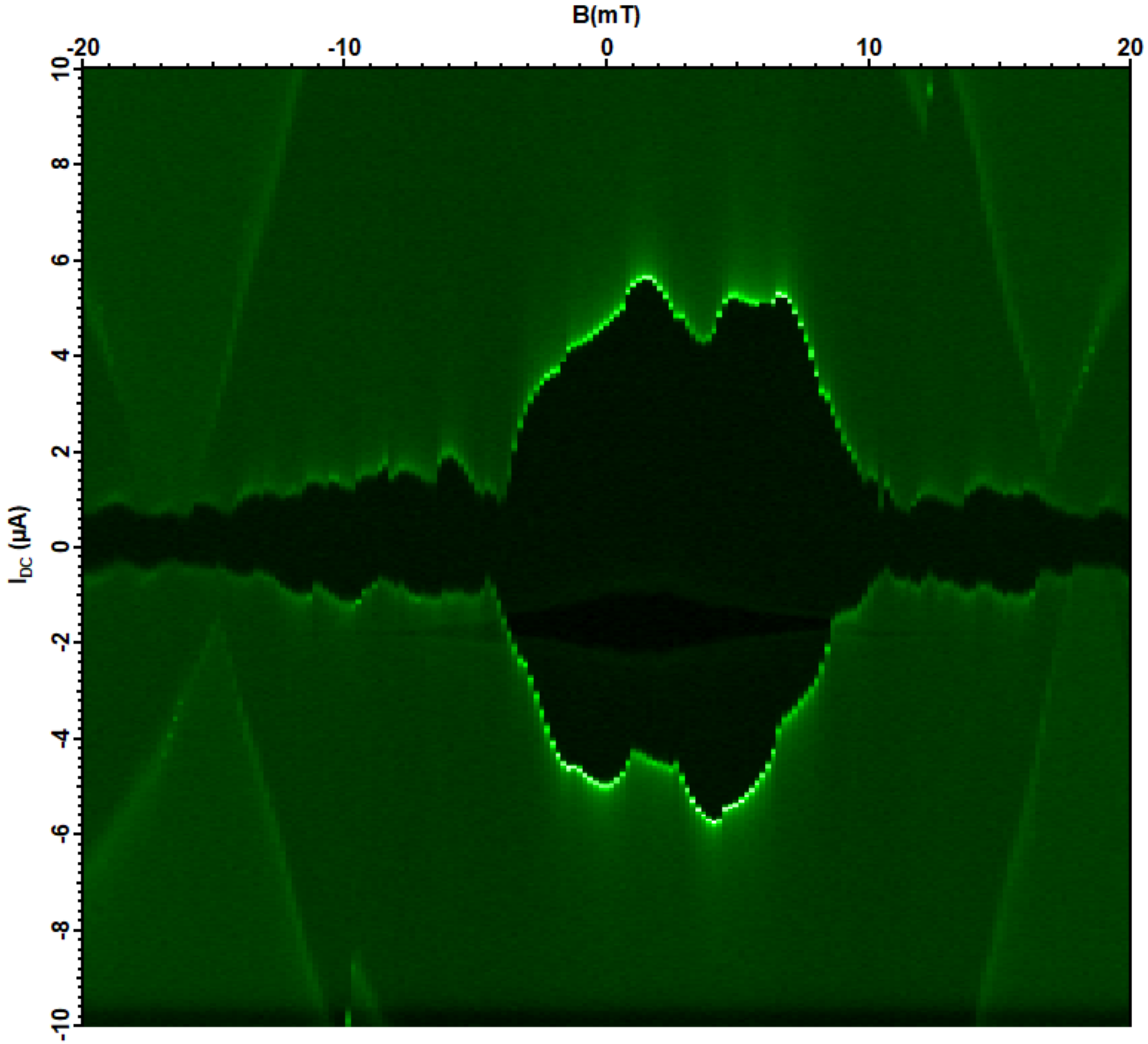
Characterizing the big junction

- At first glance, we are not able to say anything, but let's try some raw analysis…
- Take the value of the critical current at B = 0, and plot it with T.
- $I_{C,B=0}(T) = I_0 \exp(-T/3.6E_{Th})$ reveals a long diffusive junction !

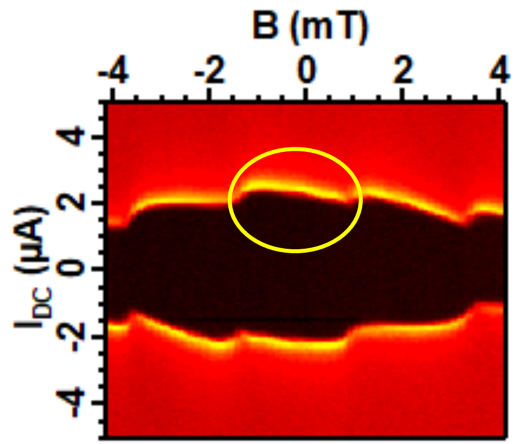
Ok nice, but we wanted a long ballistic…



Try to go to higher fields maybe ?



Dirty but it looks like a Fraunhofer pattern !



The reference junction shows some Fraunhofer interferences, modulated by a sawtooth-like CPR ?!

Numerical simulations

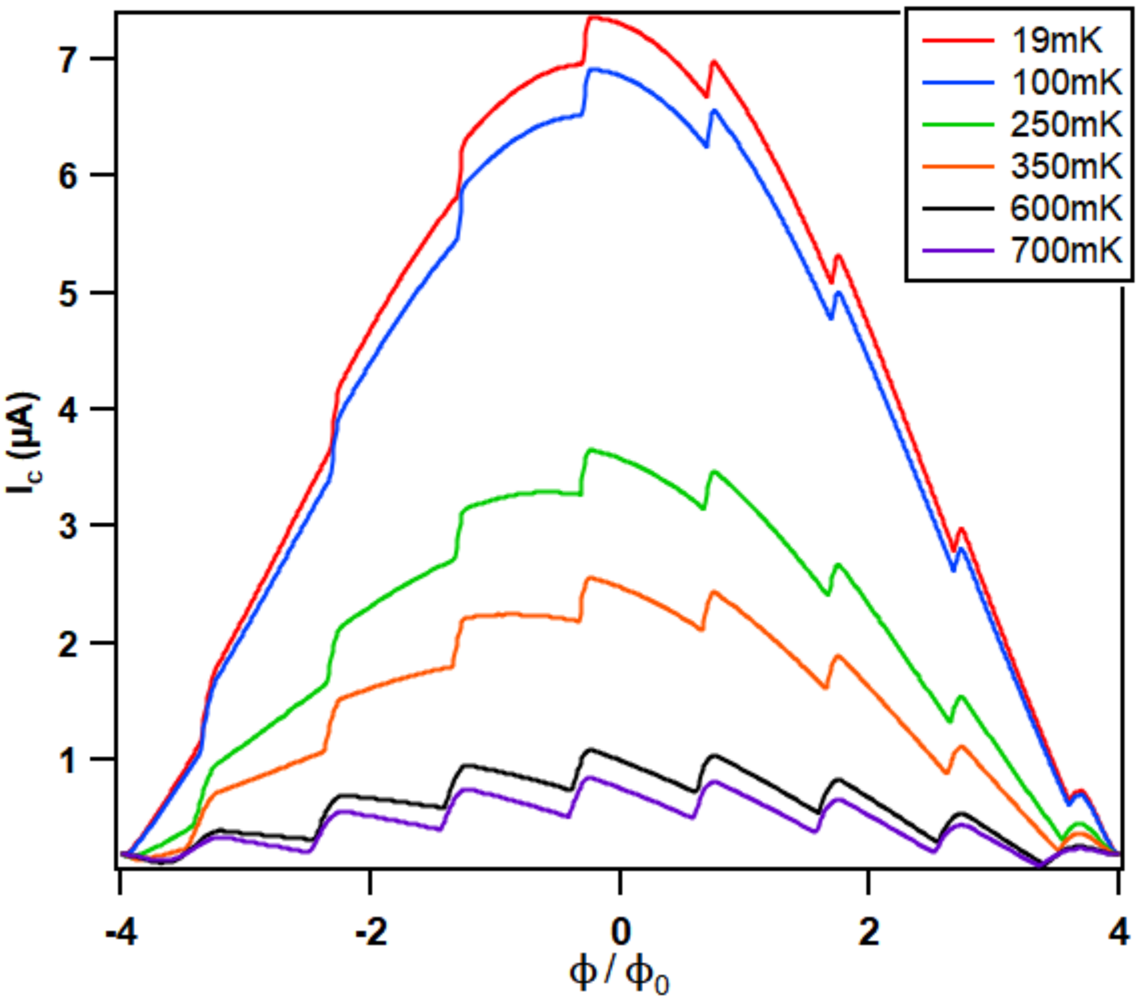
- Simulation of 2 SNS junctions in parallel.

- SNS_1 : long diffusive, B and T dependence known.

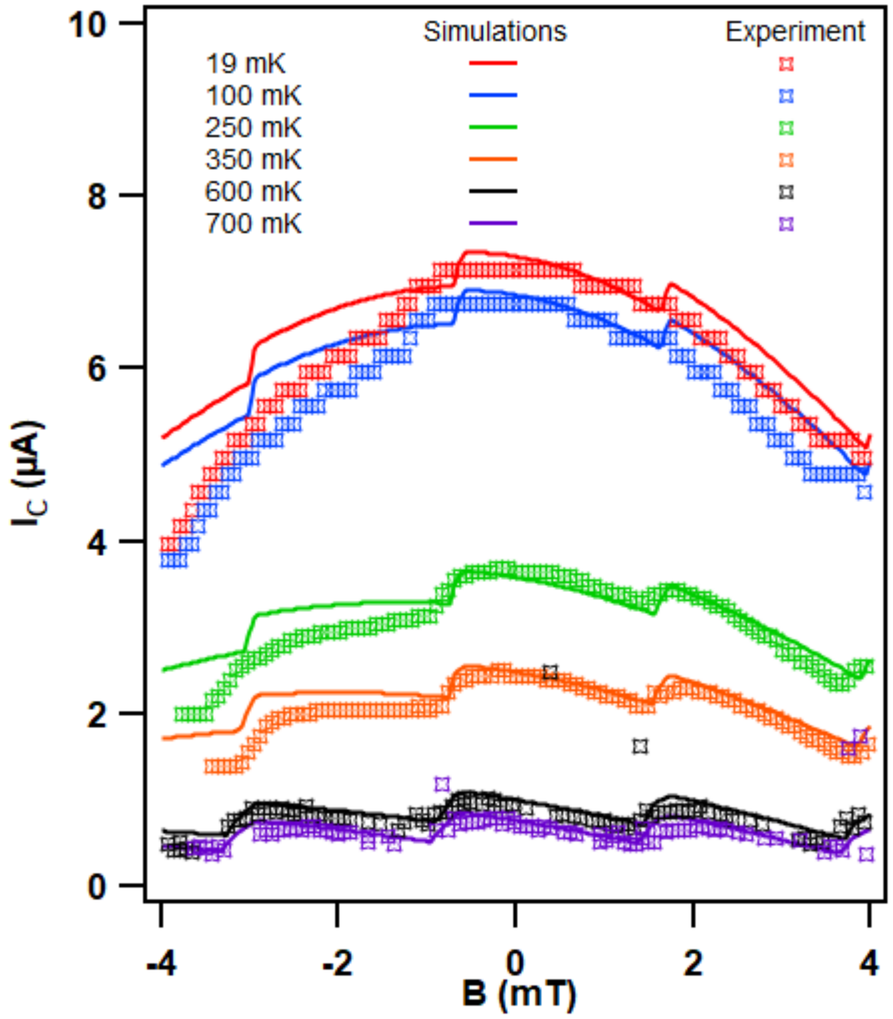
$$I(\varphi, B, T) = I_c(T)\sin(\varphi)\mathrm{sinc}(\alpha B)$$

- SNS_2 : long ballistic, no T nor B dependence.

$$I(\varphi) = I_c\mathrm{sawtooth}(\varphi + \pi)$$

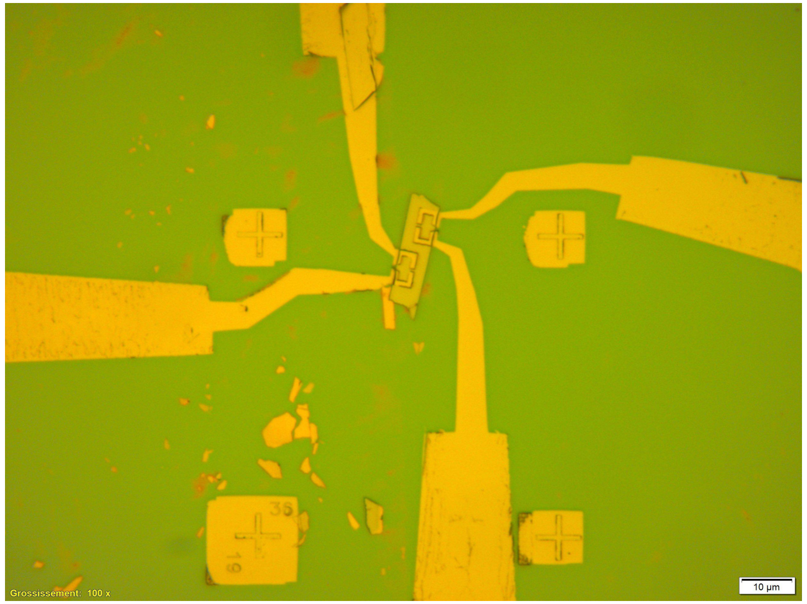


Evidence for topological hinge states



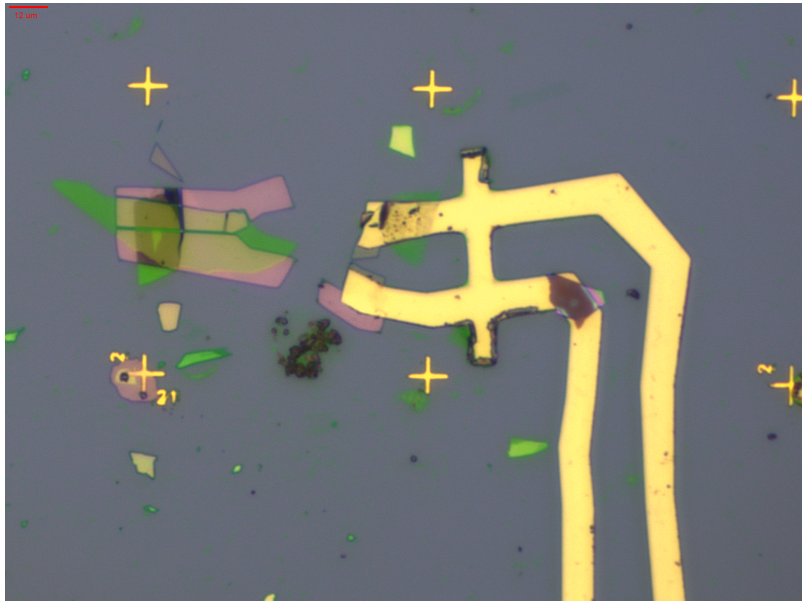
- Not a real Fraunhofer pattern.
- Low T : hinge states drown, hence he bad quality of the fit.
- Analytical calculations confirms our experimental results.

Perspectives



On the topological aspect :

- Going back to supercurrent noise measurement.
- Helicity/Parity measurement using two SQUIDs.
- AC SQUID combined with GMR and low-frequency noise.



On the Weyl or interplay between insulating and conducting phases :

- Find transport signatures of Fermi arcs.
- Moiré physics using WTe_2 stacks.
- Monolayer limit and 2D topological insulators.

That’s all for today.
Thank you.