Modulation of 0.7 and Zero Bias Anomalies in a Quantum Point Contact controlled by Scanning Gate Microscopy

B. Brun [1], F. Martins [2], S. Faniel [2], B. Hackens [2], V. Bayot [2], D. Mailly [4], U. Gennser [4], S. Huant[1], M. Sanquer [3], H. Sellier [1]

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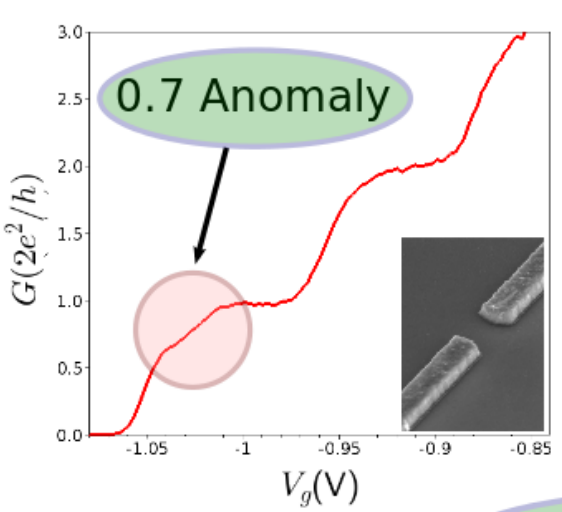
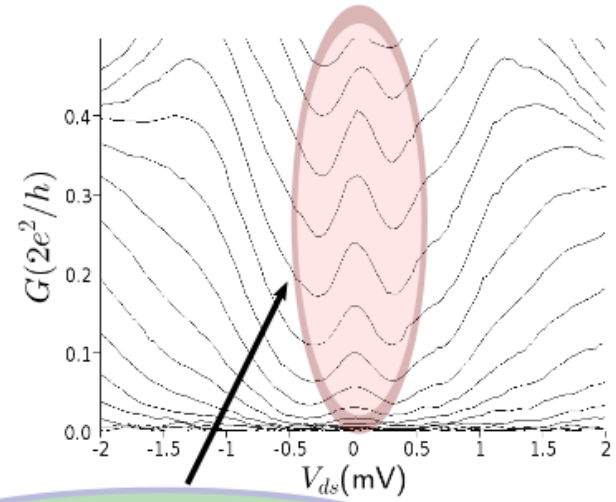
2013, July 2nd

Interactions effects in QPCs:





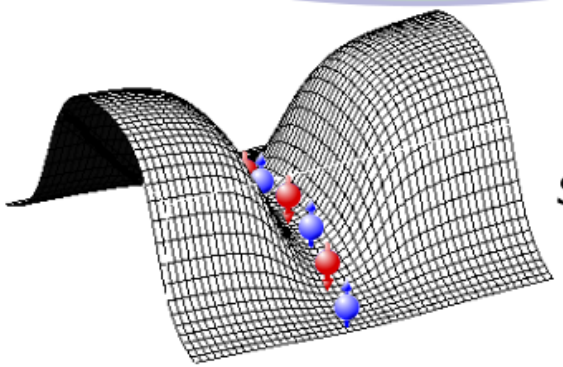
Zero Bias Anomaly

Localization?

Kondo effect?

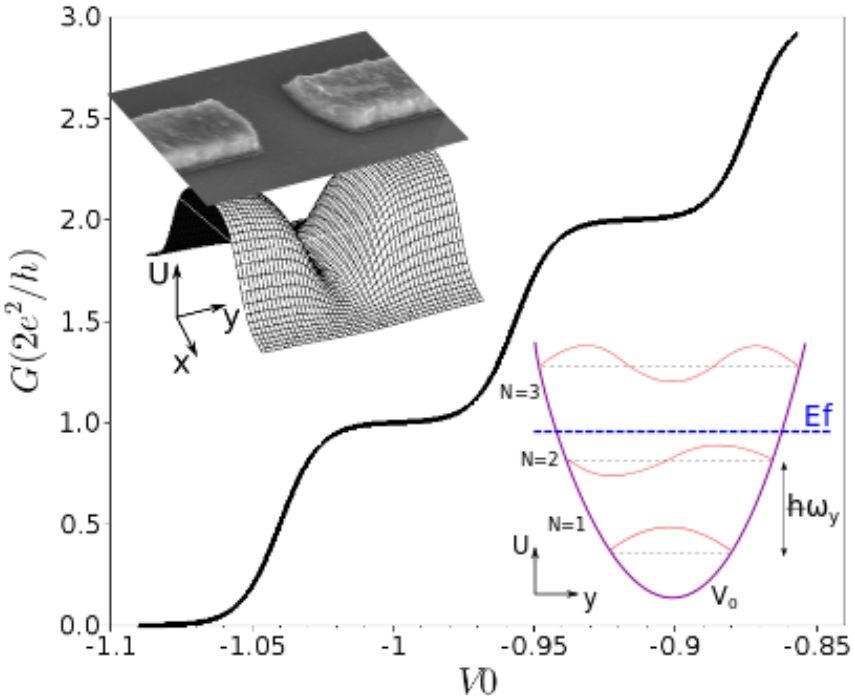
Wigner?

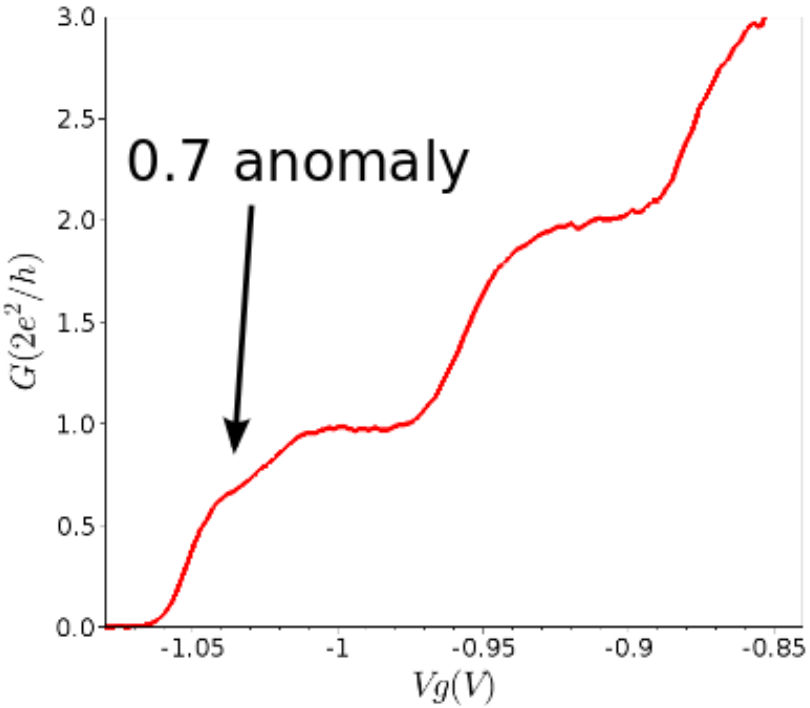
Spin polarization?



Hunting for a microscopic origin...

Linear transport

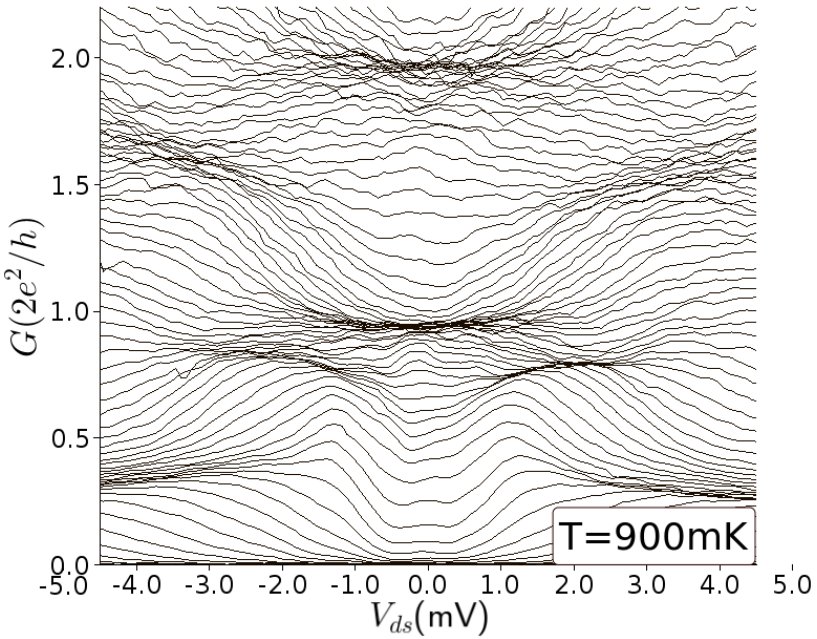


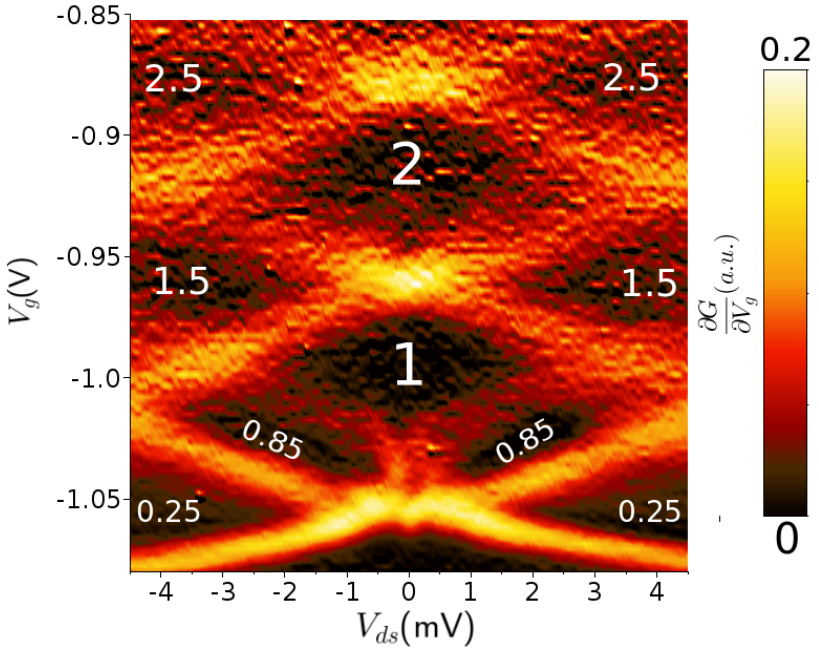


See also: K. J. Thomas, Phys. Rev. Lett. **77** (1996)
A. P. Micolich, J. Phys.: Condens. Matter **23** (2011)

Non linear tranport at 900 mK

The 0.7 anomaly becomes more prominent under small DC polarization:



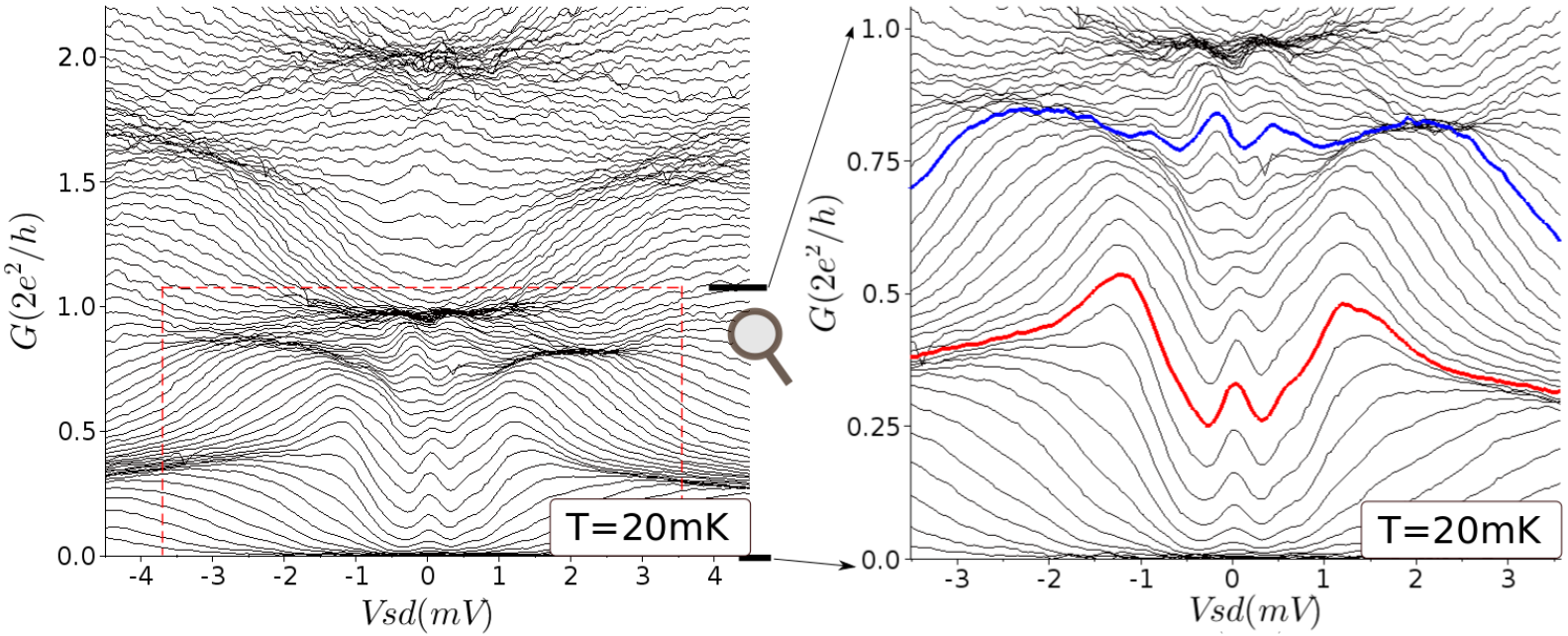


- Measurements are performed in a dilution fridge, down to the base temperature of 20 mK
- Differential conductance G is measured by applying a $10\mu V$ AC voltage

Non linear tranport at 20 mK

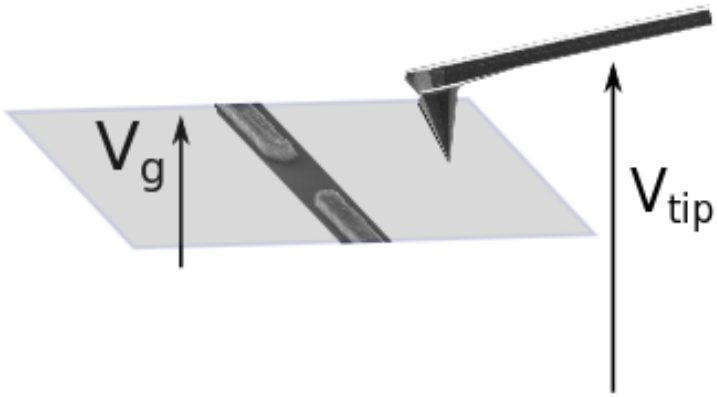
The Zero Bias Anomaly is clearly visible below 500 mK:

...and splits as the QPC opens:



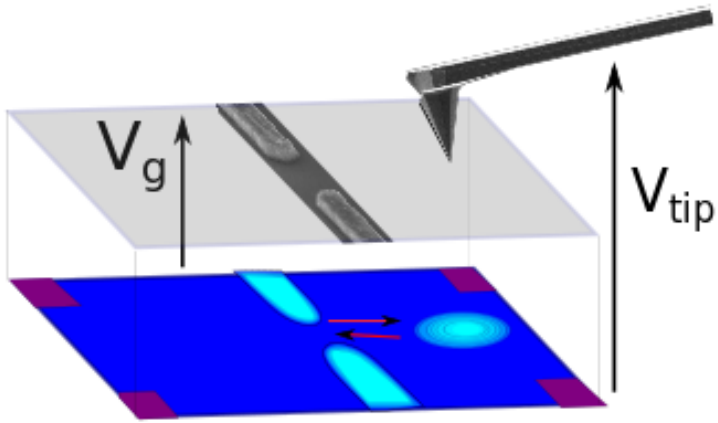
See also: S. M. Cronenwett et al., Phys. Rev. Lett. **88** (2002) for Kondo scaling.
Y. Komijani et al., Phys. Rev. B **87** (2013) for ZBA splitting.

Principle of Scanning Gate Microscopy



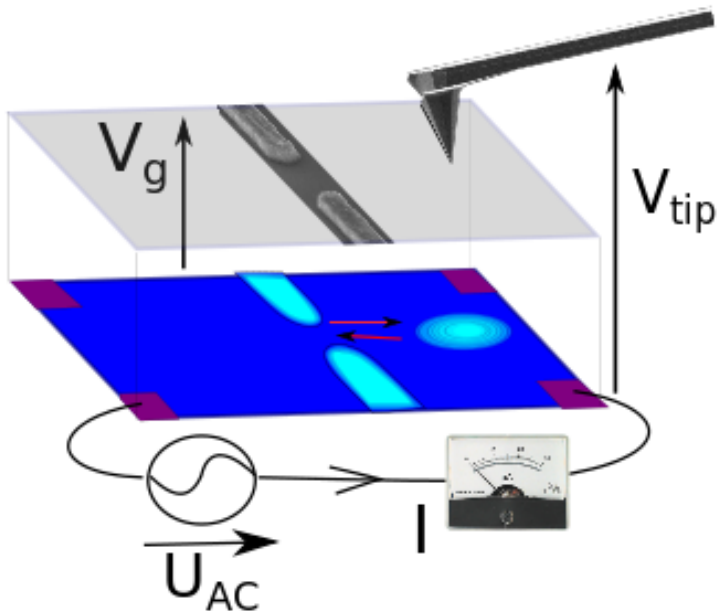
- A negatively charged AFM tip is scanned above the sample surface.

Principle of Scanning Gate Microscopy



- A negatively charged AFM tip is scanned above the sample surface.
- This creates a depletion region below the tip, and modifies the potential landscape in the 2DEG.

Principle of Scanning Gate Microscopy

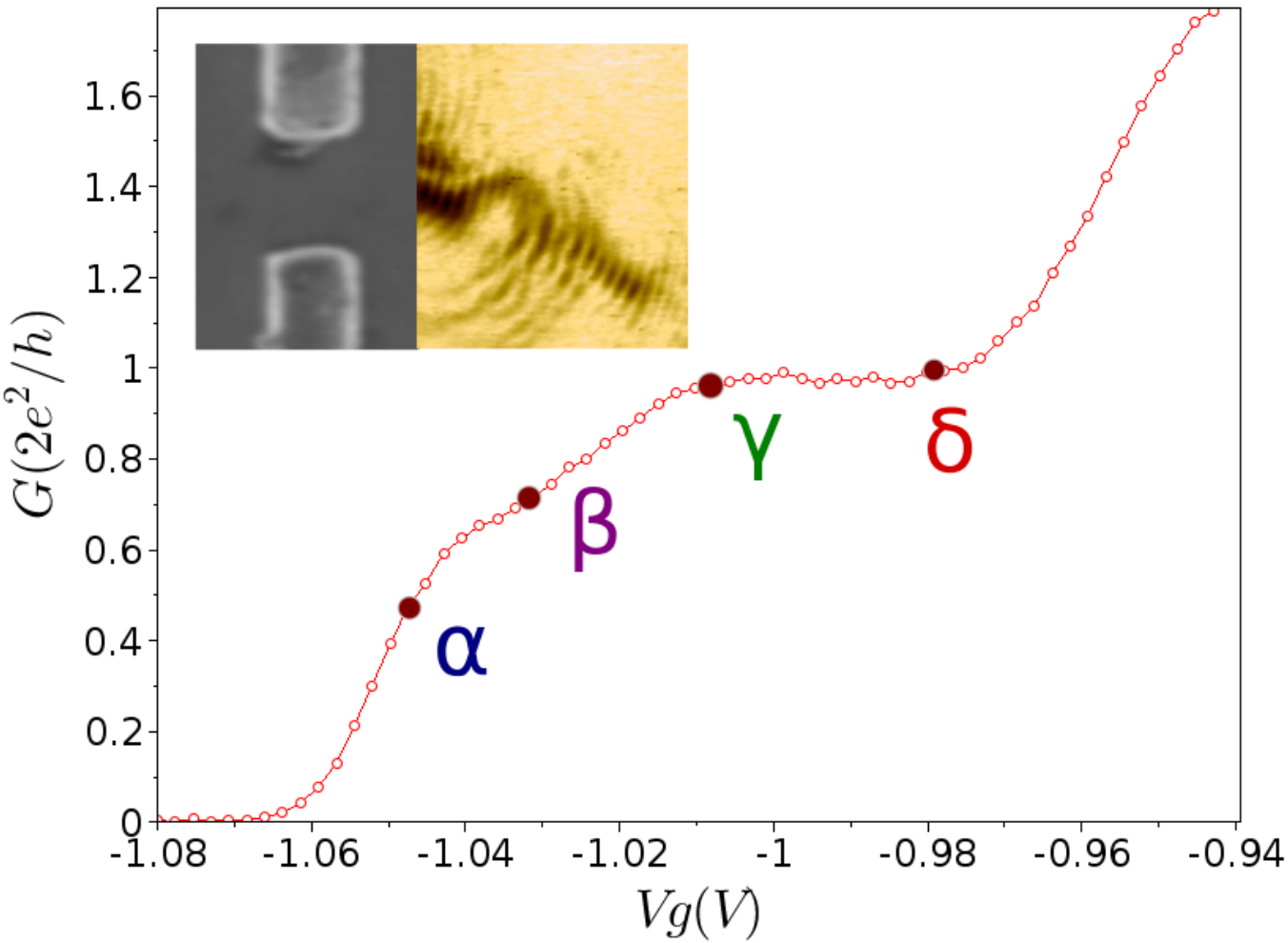


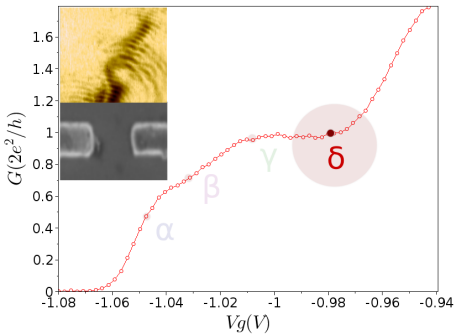
- A negatively charged AFM tip is scanned above the sample surface.
- This creates a depletion region below the tip, and modifies the potential landscape in the 2DEG.

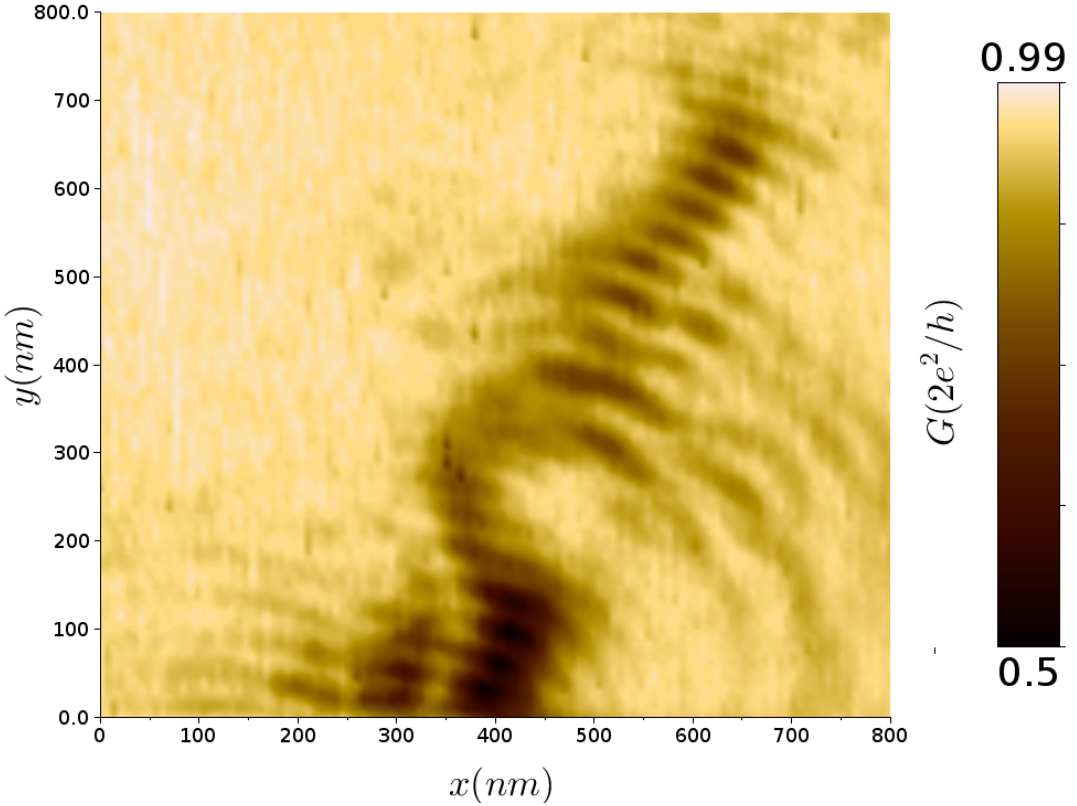
We record the device conductance w.r.t. the tip position $G(x, y)$.

See also: M. A. Topinka et al., Nature **410** (2001).
R. Crook et al., Science, **312** (2006).
A. A. Kozikov et al., New. J. Phys. **15** (2013)

Overview


1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
$G(2e^2/h)$
-1.08
-1.06
-1.04
-1.02
-1
-0.98
-0.96
-0.94
$Vg(V)$
α
β
γ
δ

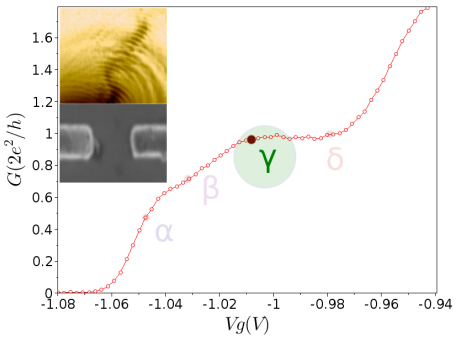


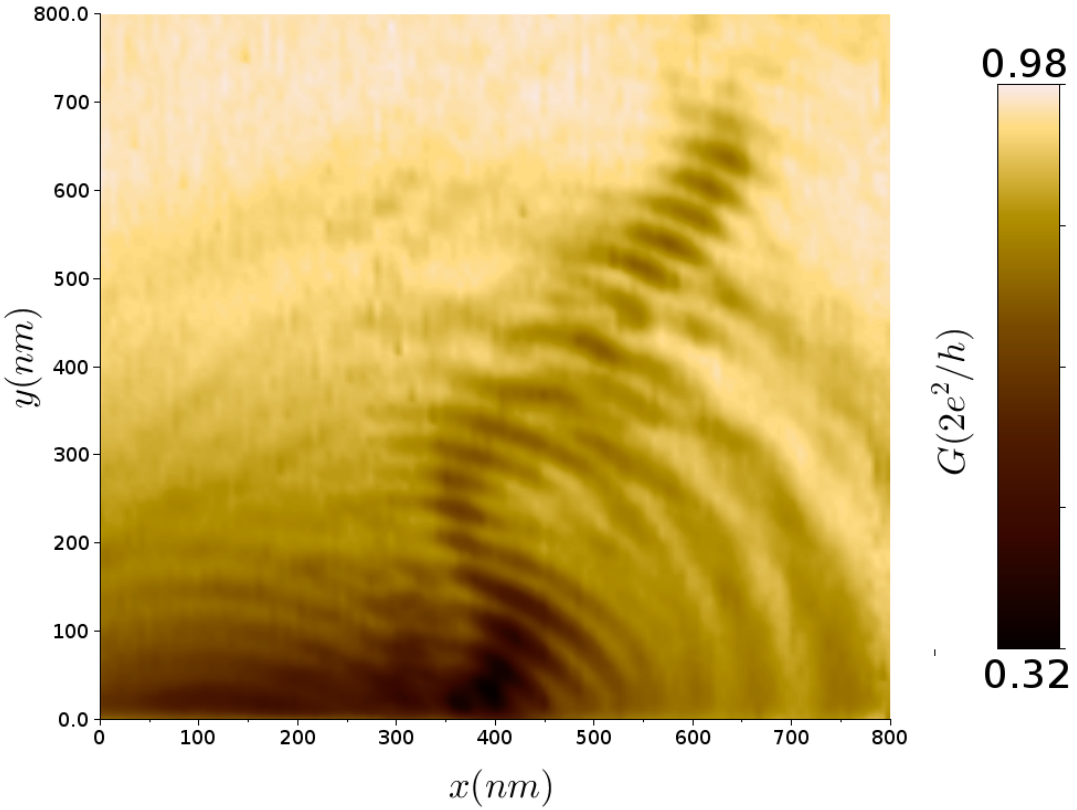


On the plateau, SGM images exhibit a branched electron flow decorated with interferences fringes spaced by $\frac{\lambda_F}{2}$

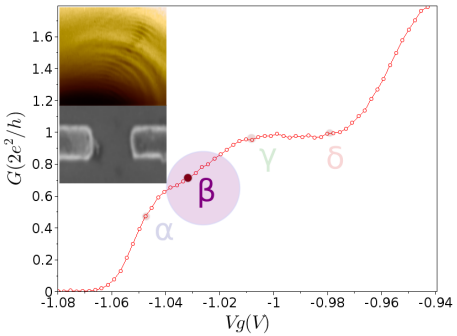
See also: M. P. Jura et al., Nature Physics **3** (2007)

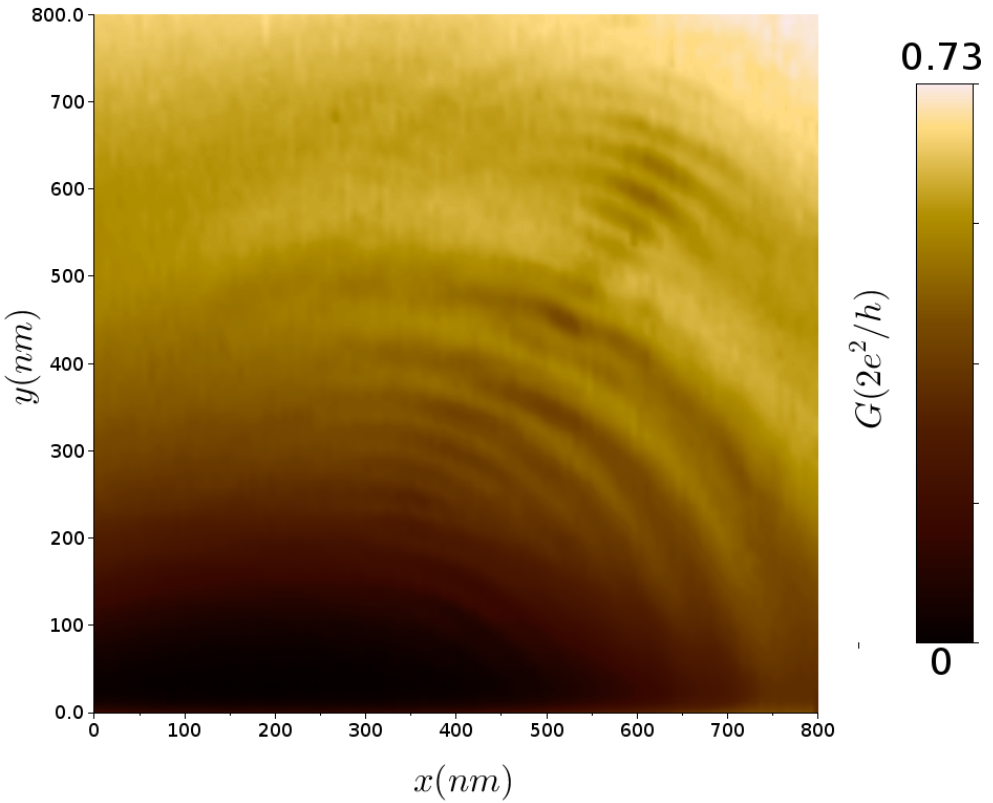
Cross-talk


$G(2e^2/h)$
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-1.08
-1.06
-1.04
-1.02
-1
-0.98
-0.96
-0.94
$Vg(V)$
α
β
γ
δ


800.0
700
600
500
400
300
200
100
0.0
$y(nm)$
0
100
200
300
400
500
600
700
800
$x(nm)$
0.98
0.32
$G(2e^2/h)$

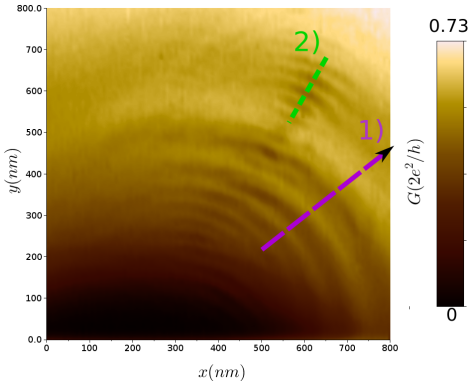
New concentric rings

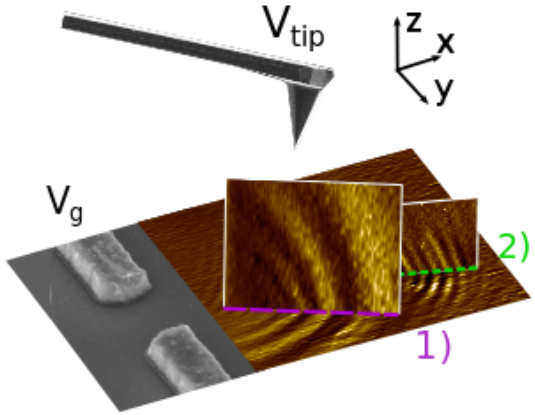


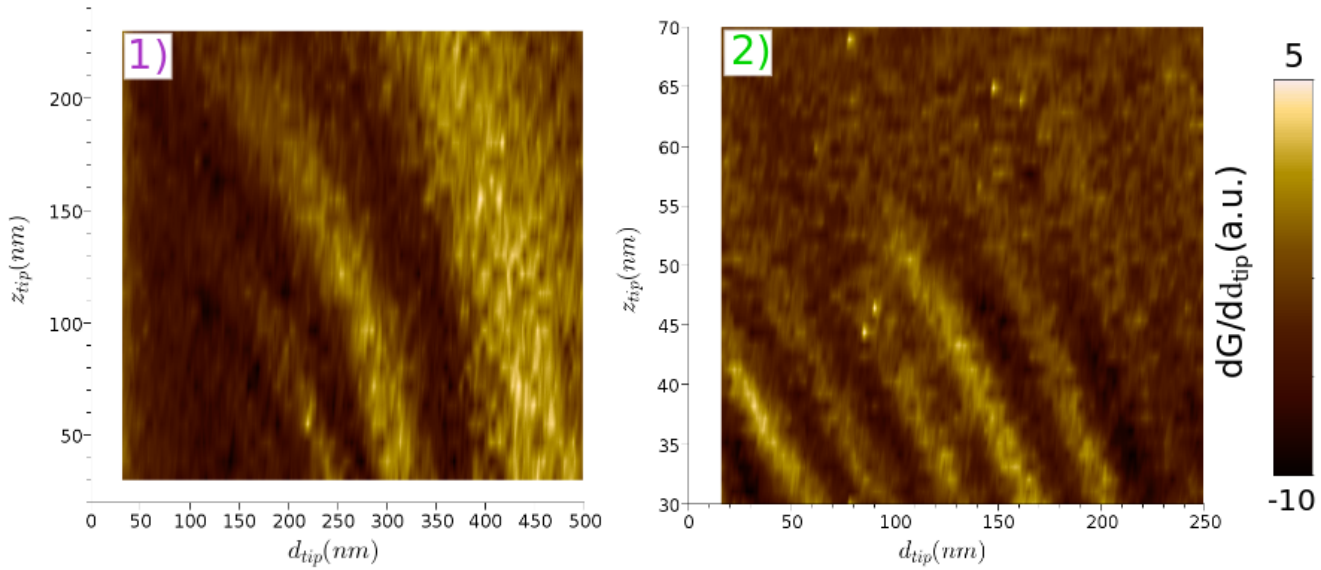


Below the first plateau, a new type of fringes can be observed, with increasing spacing.

Tip height dependance

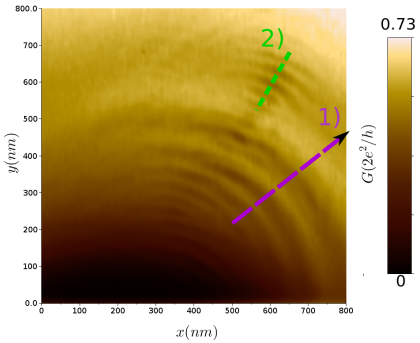




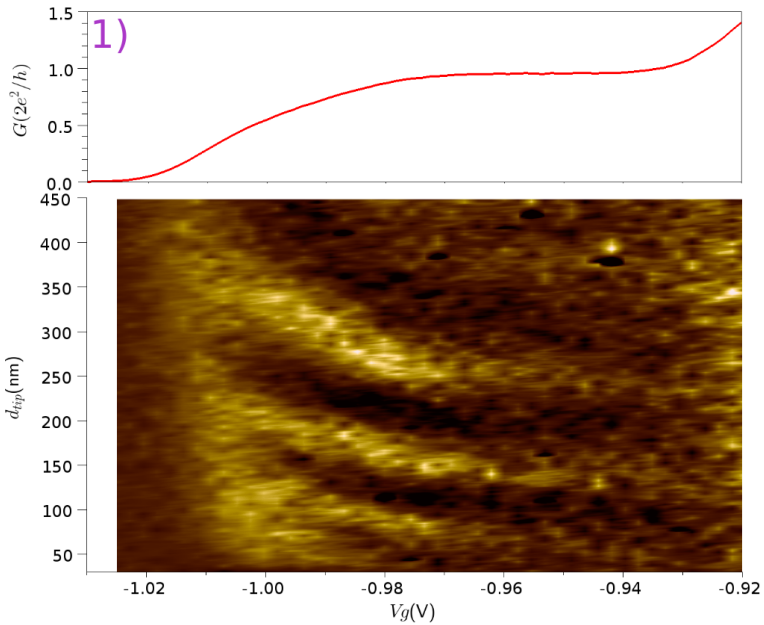


→ Concentric rings are not interferences,
but direct electrostatic tuning of the channel potential

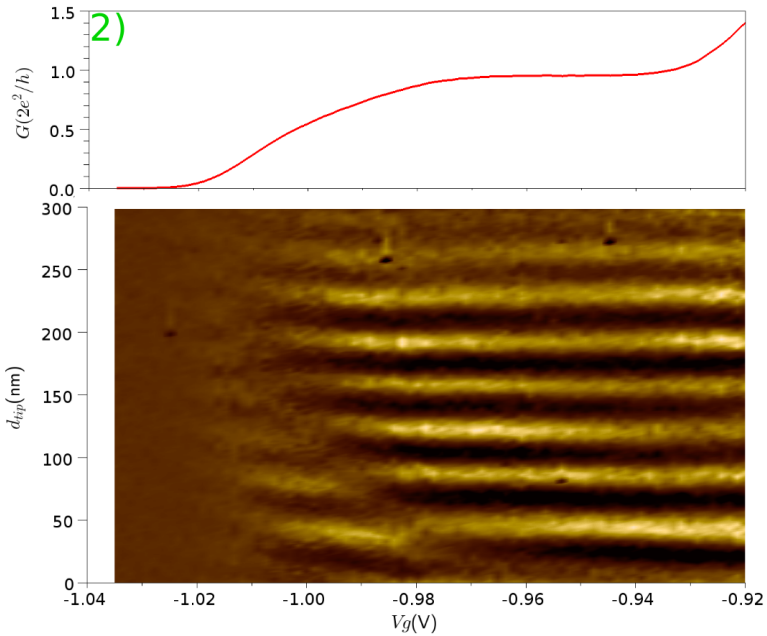
Evolution with QPC opening



The interferences are more contrasted on plateaus whereas rings are visible only below the first plateau.



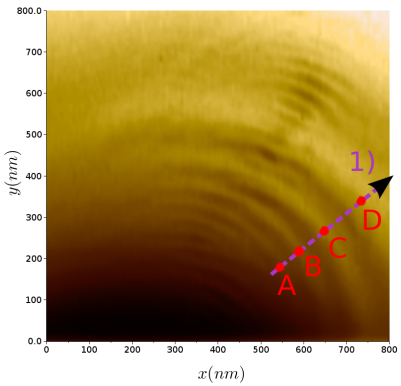
Along purple line 1)

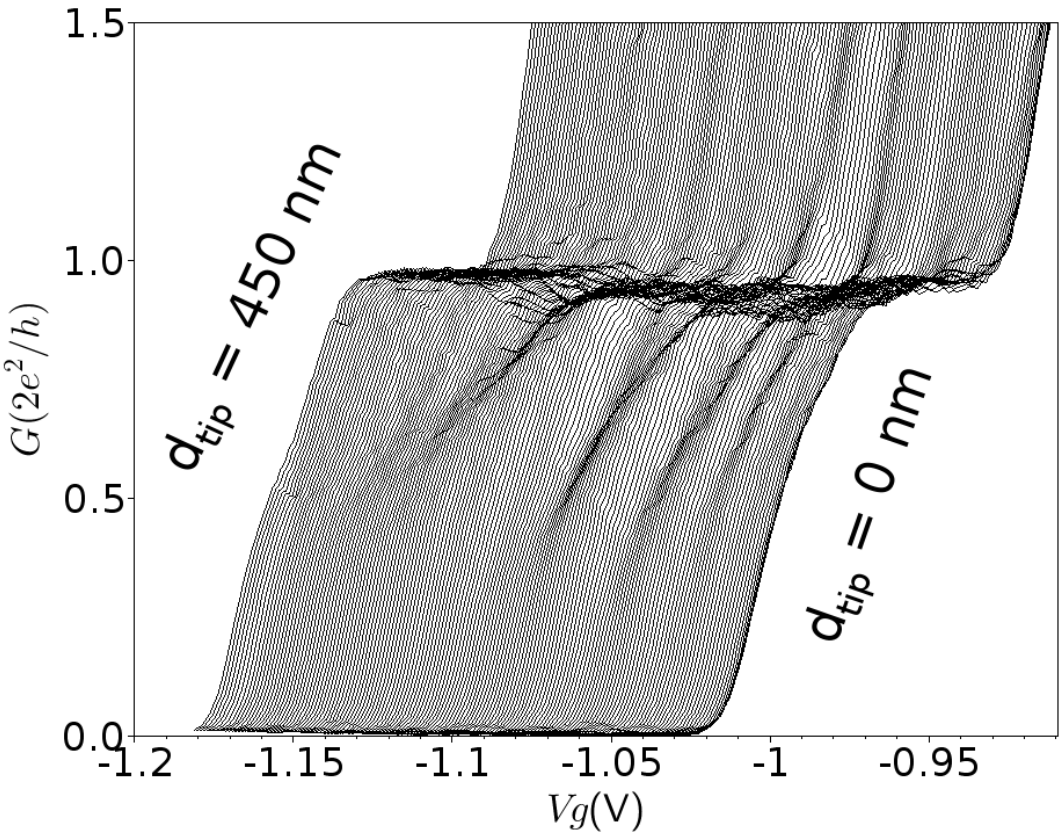


Along green line 2)

Modulation the 0.7 anomaly

The concentric rings correspond to an alternating modulation of the 0.7 anomaly:

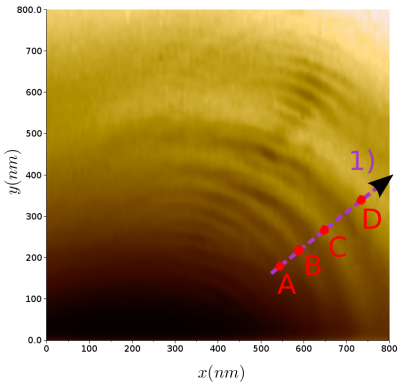


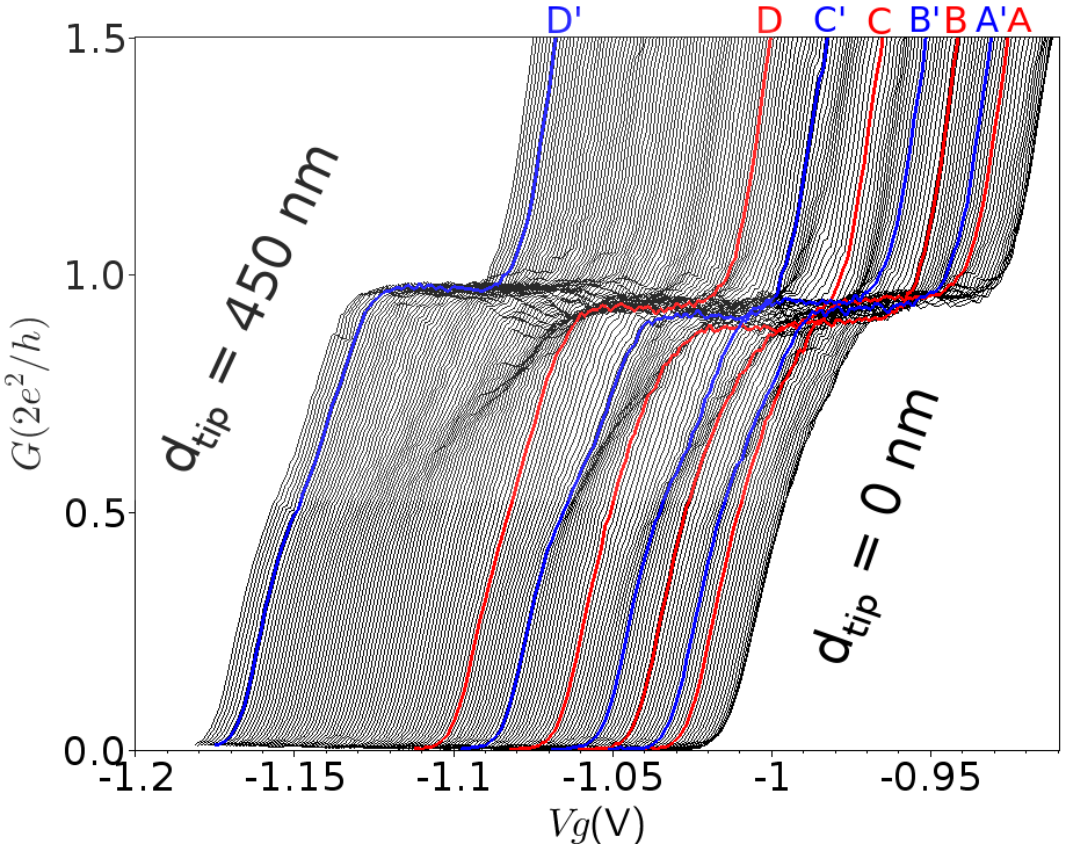


See also: M. J. Iqbal et al., J. Appl. Phys. **113**, 024507 (2013)

Modulation the 0.7 anomaly

The concentric rings correspond to a periodic modulation of the 0.7 anomaly:

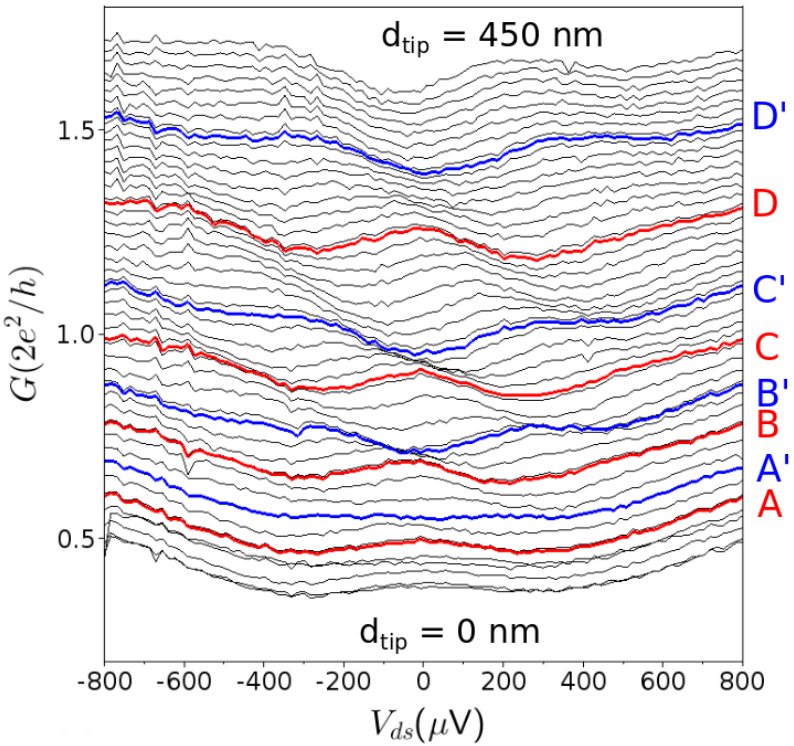


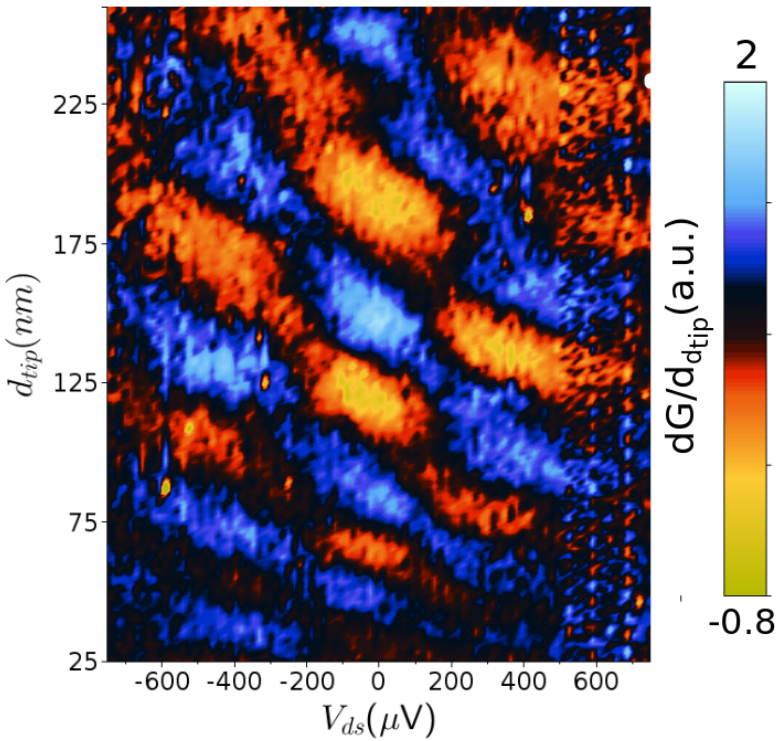


See also: M. J. Iqbal et al., J. Appl. Phys. **113**, 024507 (2013)

Modulation the ZBA

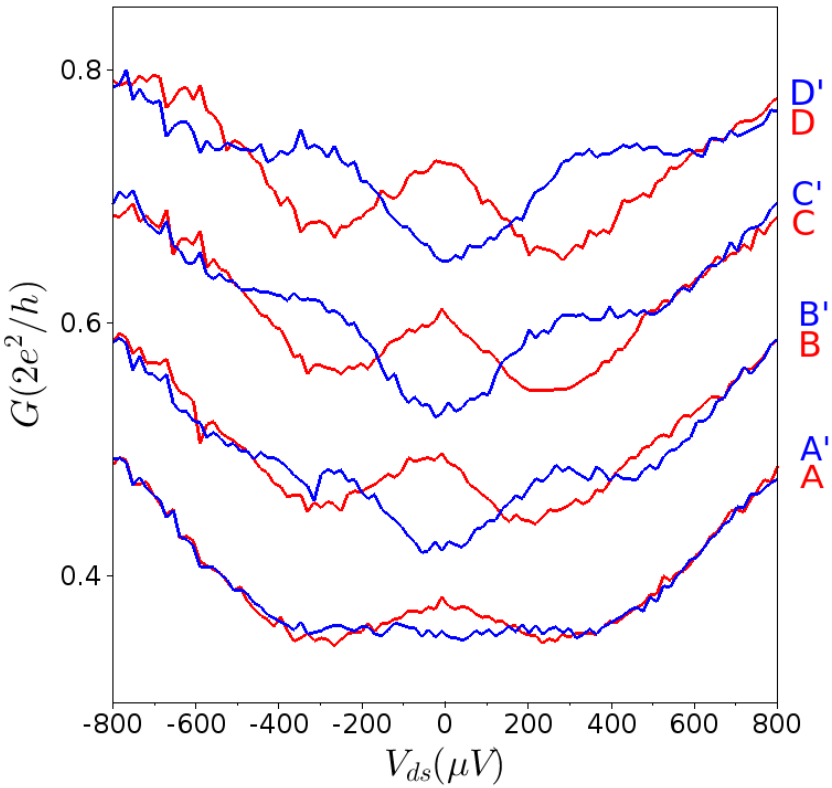
The rings also correspond to a periodic splitting of the ZBA:

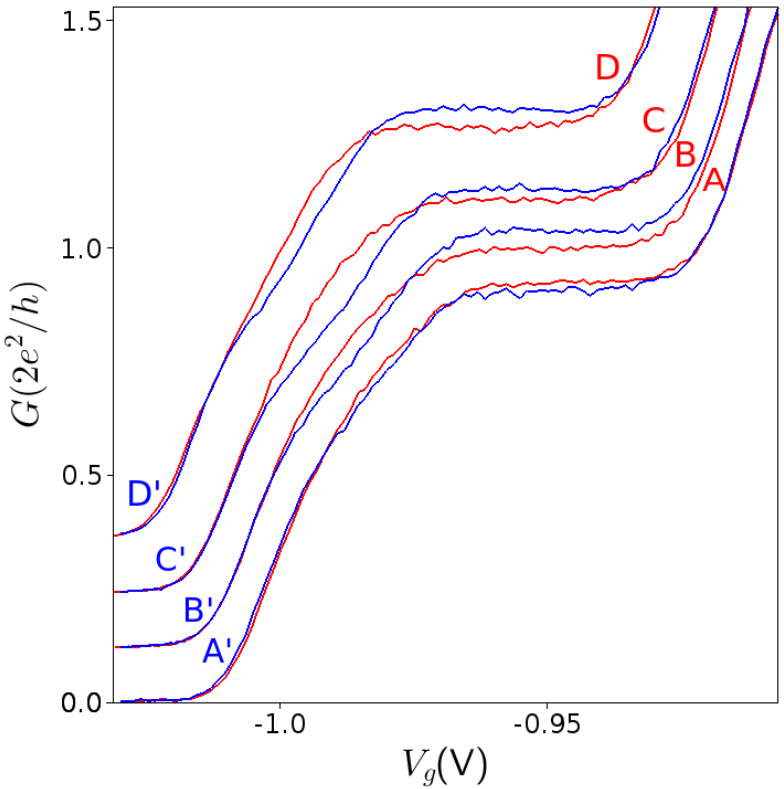




Correlation

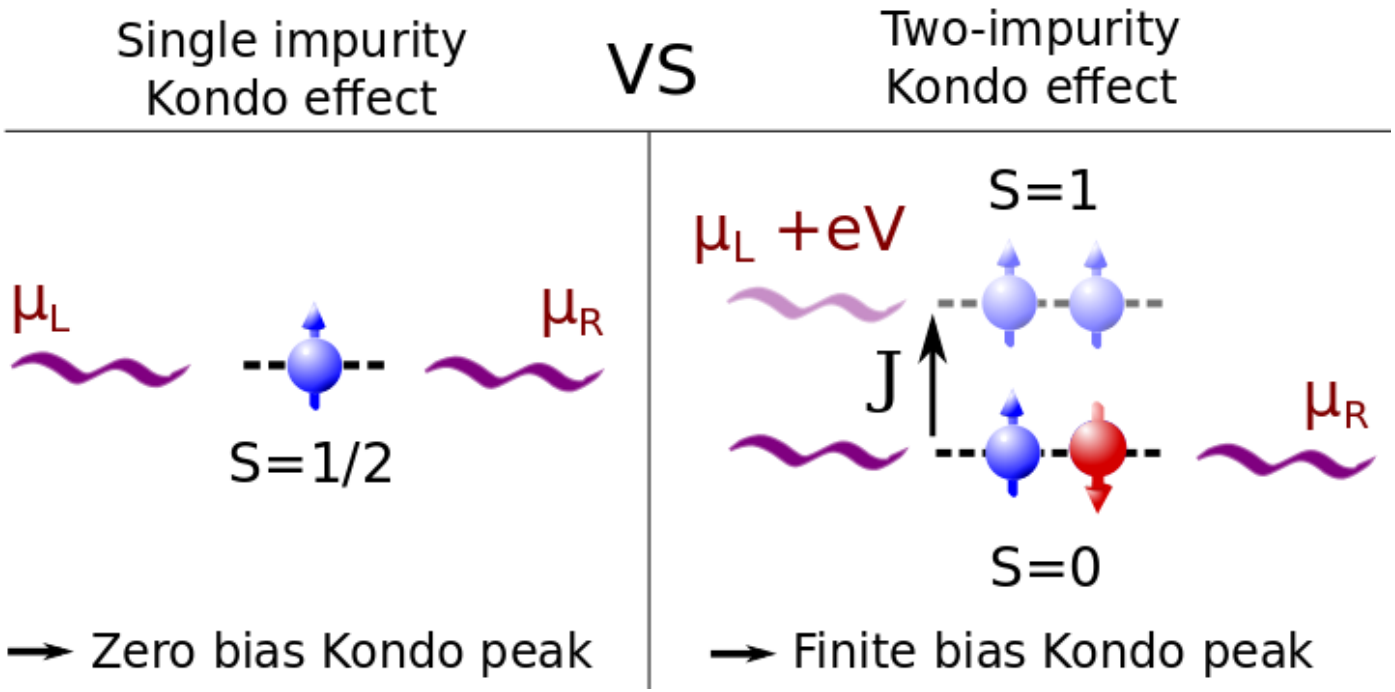
The modulation of 0.7 and ZBA are simultaneous:





Two impurity Kondo effect

The splitting of the zero bias Kondo peak can be explained in terms of two-impurity Kondo effect

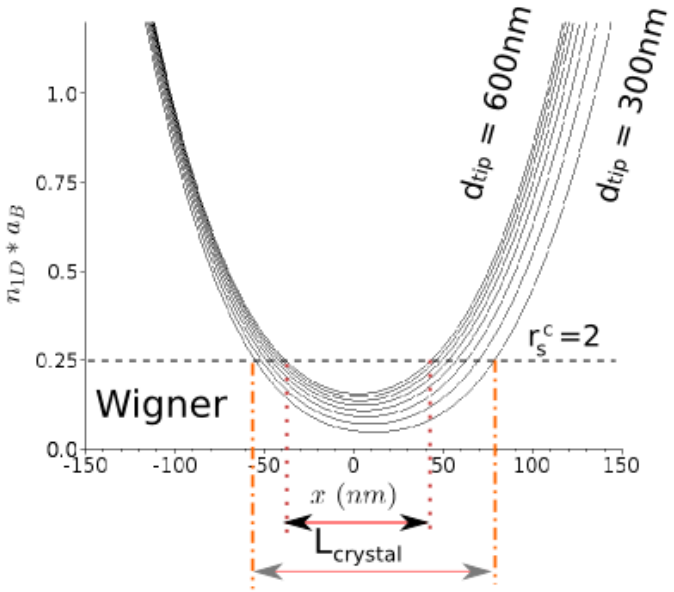


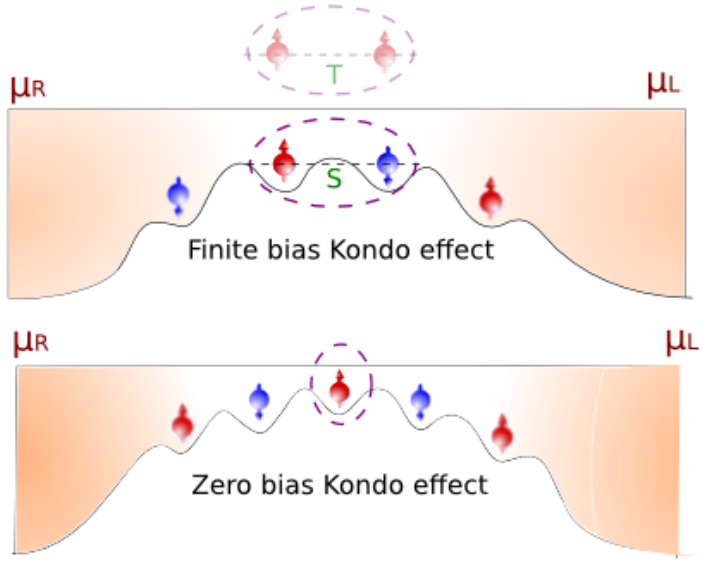
This is often observed in oddly/evenly charged quantum dots

S. Sasaki et al., Nature **405**, 764 (2000)

Possible 1d Wigner crystallization

At low density, Coulomb interactions overcome kinetic energy, and can induce localization in the 1d channel:



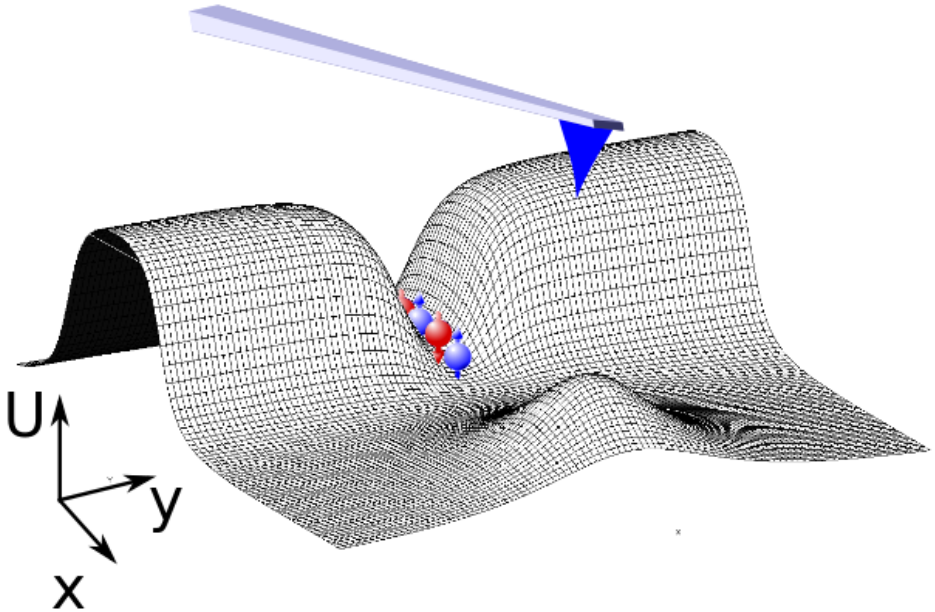


The tip can modify the number of charges

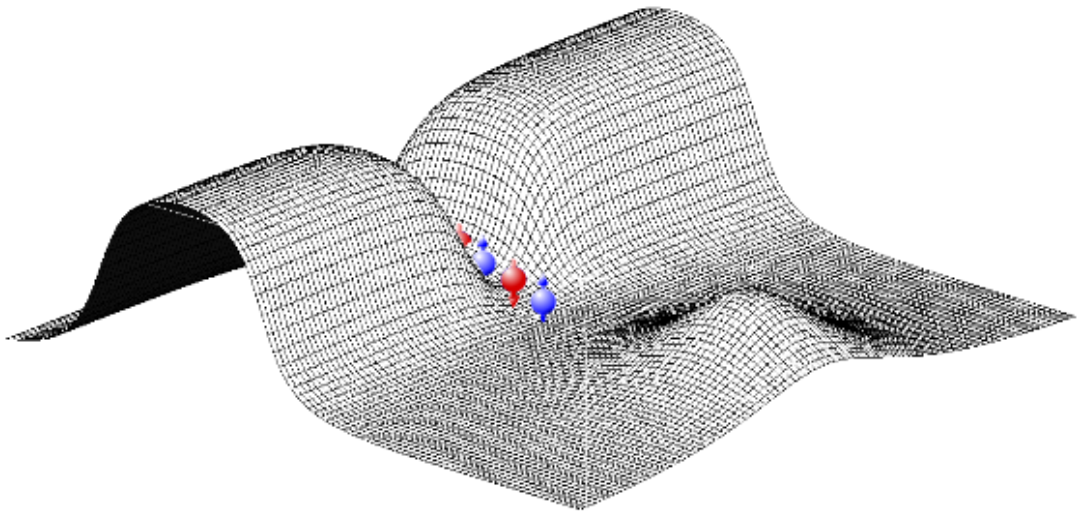
See also: T. Rejec and Y. Meir, Nature **442**, 900 (2006)
A. D. Guçlu et al., Phys. Rev. B **80**, 201302(R) (2009)

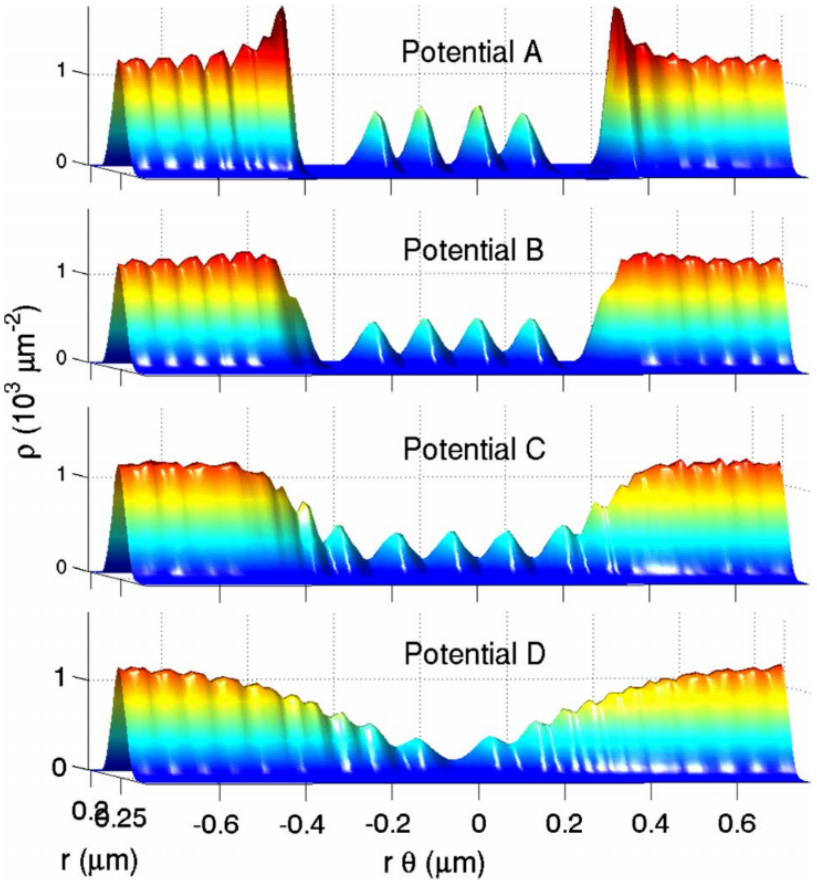
Conclusion

- 0.7 and Zero Bias Anomalies in QPCs are investigated by SGM.
- This unveils an alternation between single and two-particle Kondo effects.
- We interpret it as a tiny Wigner crystal containing odd or even number of charges, depending on tip position.

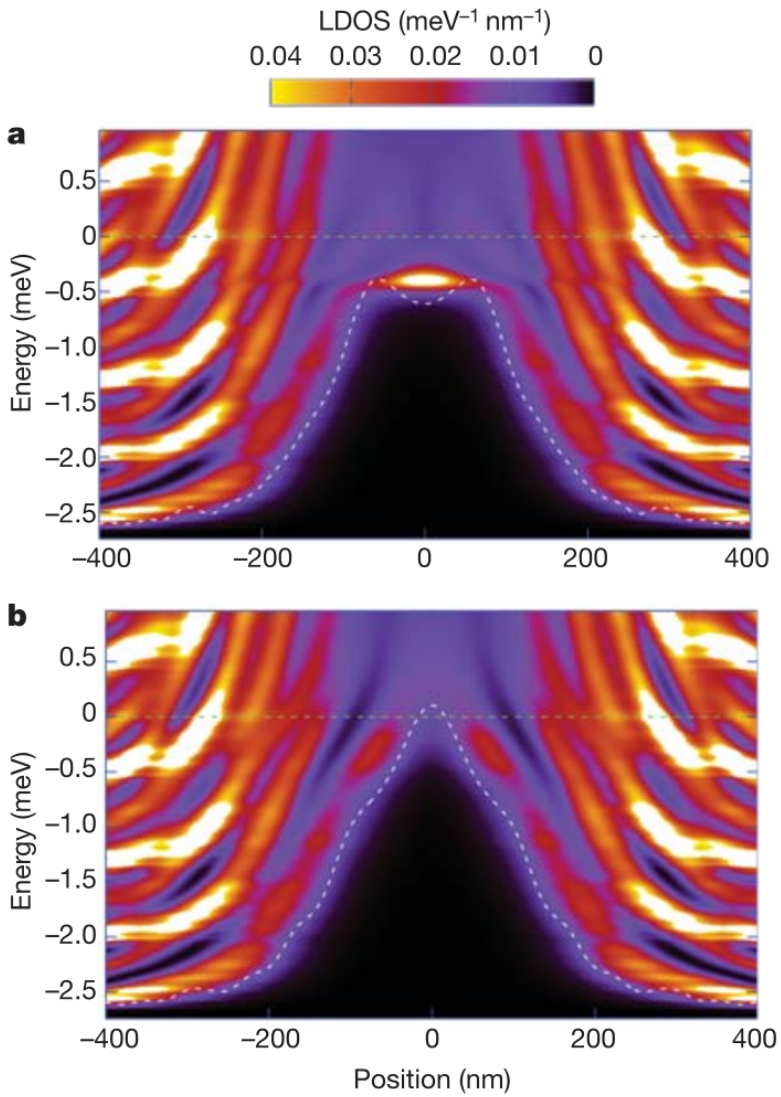


Thank you for your attention!





Adapted from *A. D. Güçlü et al.*,Phys. Rev. B **80**, 201302R (2009)



Adapted from *Y. Meir and T. Rejec*,Nature **442**, 900 (2006)