Andreev molecule in parallel InAs nanowires

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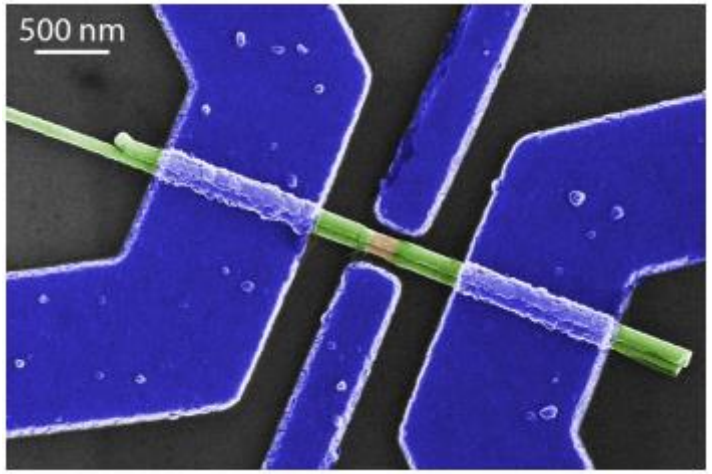
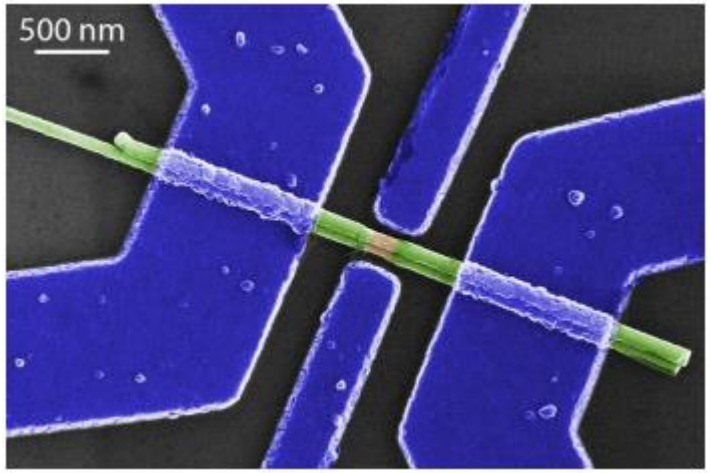


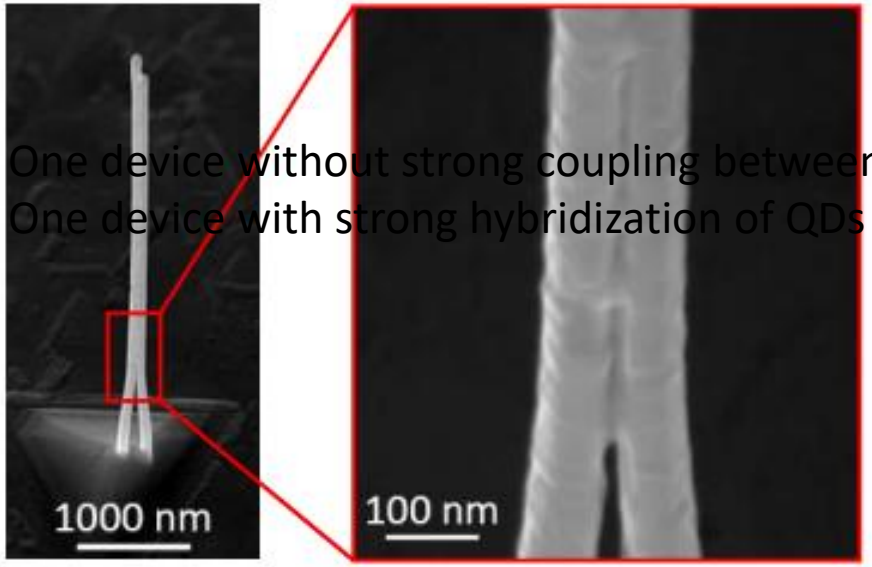
Outline

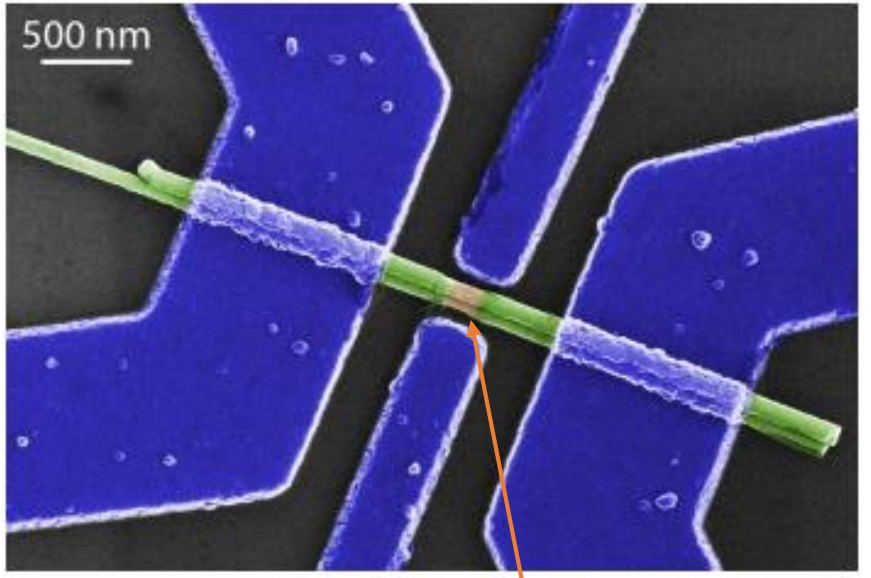
- Device architecture
- Non-interacting picture
- Interdot Coulomb repulsion
- SC coupling
- Conclusions



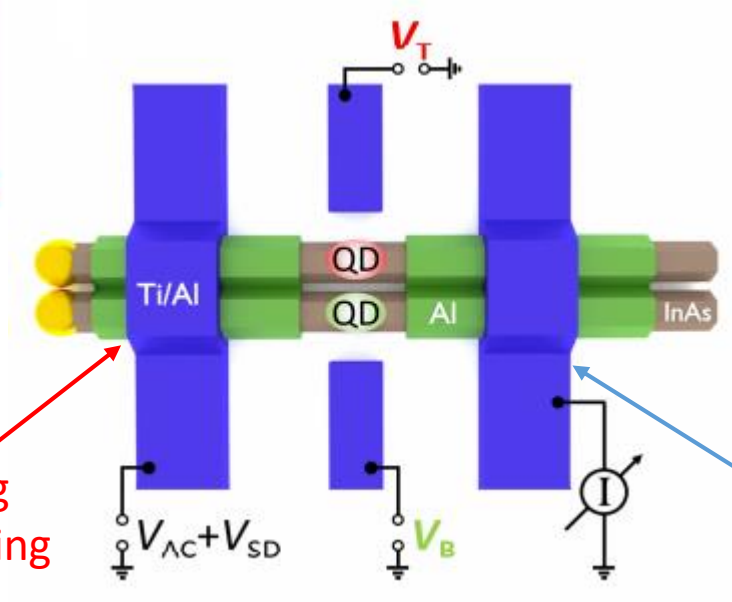
Device Architecture

One device without strong coupling between NW
One device with strong hybridization of QDs with molecular states observed





~250 nm



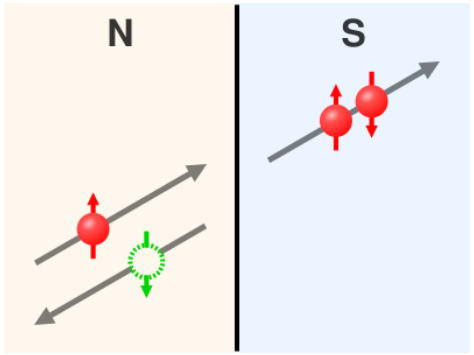
strong coupling

SC tunnel probe

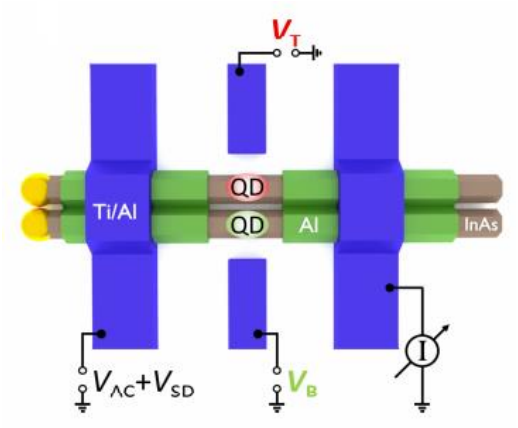
SC-QD-I-SC

Wurtzite phase
20 nm Al shell
80 nm NW

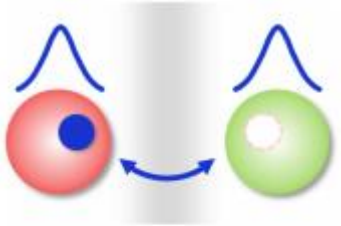
Andreev Stuff



Andreev Reflection

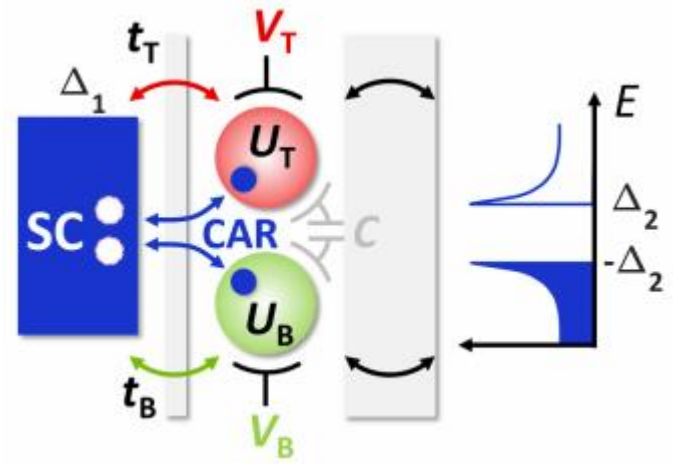


Standard DQD
(artificial atom)



Andreev Molecule

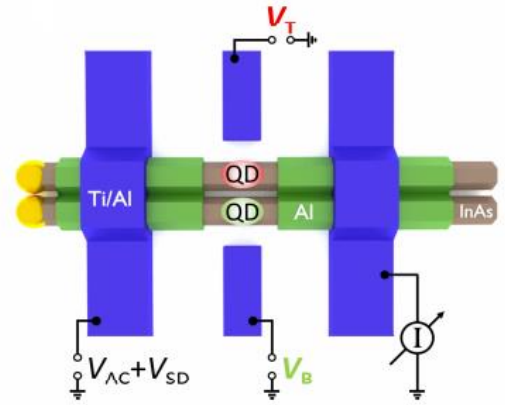
Yu–Shiba–Rusinov states
(Also known as Shiba states.) Subgap excitation bound to a magnetic impurity in a superconductor. The bound excitation is formed because the coupling to the impurity reduces the minimal energy for exciting quasiparticles. The magnetic exchange mechanism that creates these excitations is akin to the Kondo effect in metals.

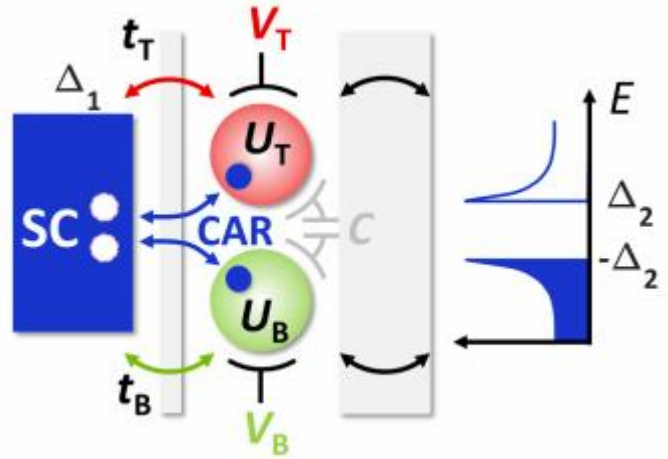


YRS state: $U > \Delta$
ABS: $\Delta > U$

Requirements

- QDs must be strongly coupled to the SC
- Distance must be minimized between the QDs
- Tunneling between QDs must be prevented (avoid direct coupling)
- Bonus: individual level tunings of the QDs very helpful

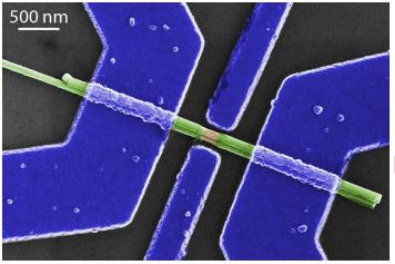


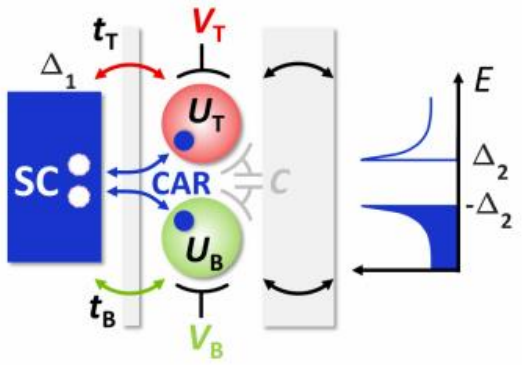


➔ Utilize double wires connected through epitaxial aluminum!!

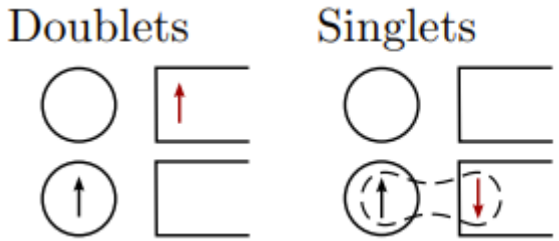
(maybe then one day someone makes a Majorana chain)

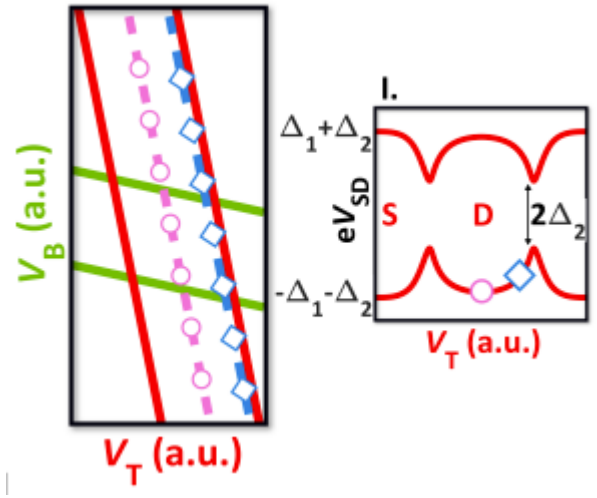
QD-SC States

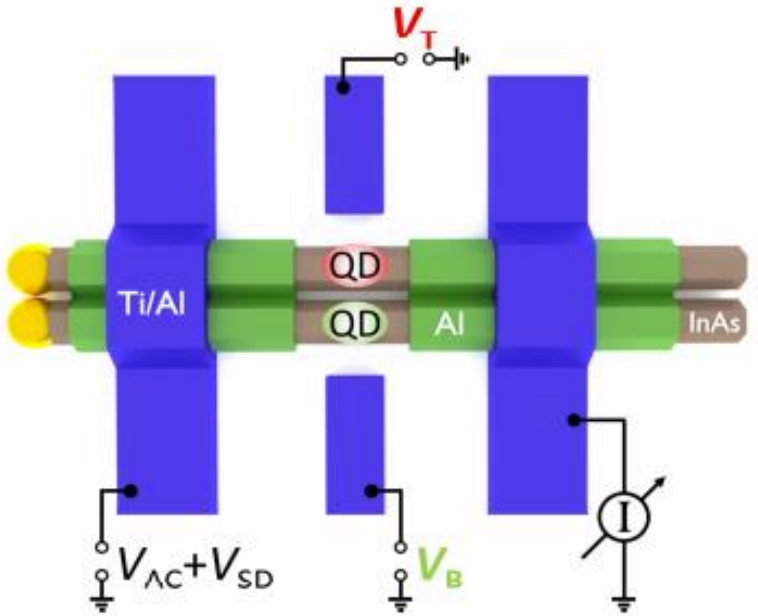


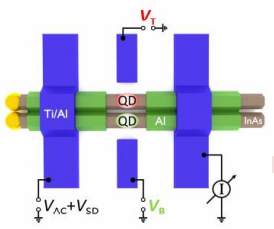


- With Coulomb repulsion > SC gap, relevant particle numbers in QD and SC restricted to 0 or 1
  - Odd: doublet
  - Even: singlet
- Finite tunnel coupling between QD and SC hybridize states, allowing transitions between them
  - Leads to “eye-shaped” excitations visible in bias spectroscopy as function of $V_{T,B}$



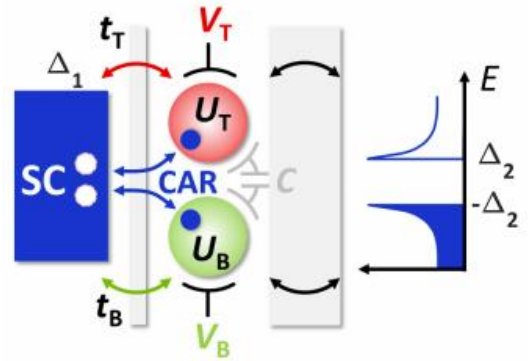


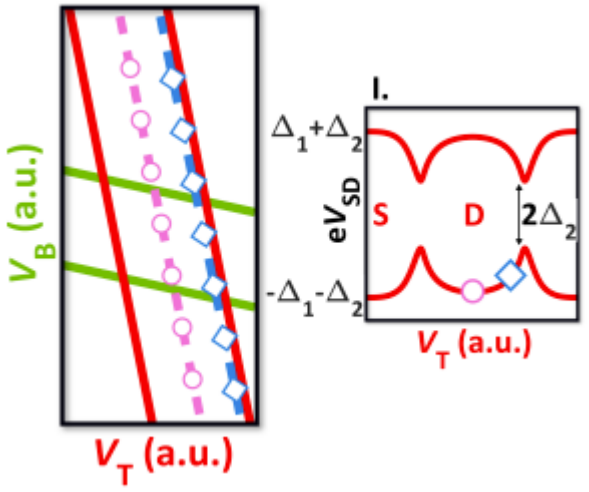


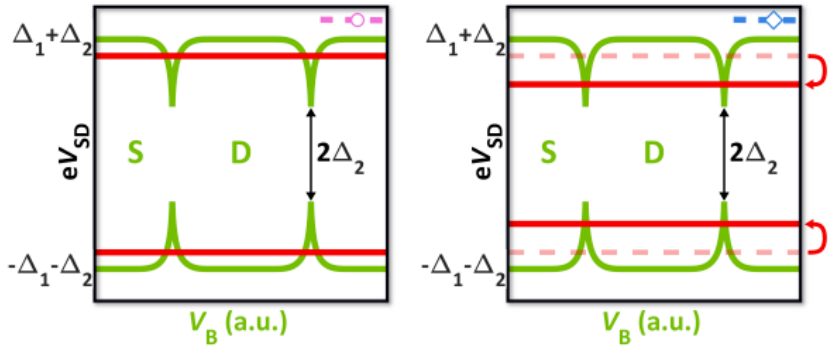


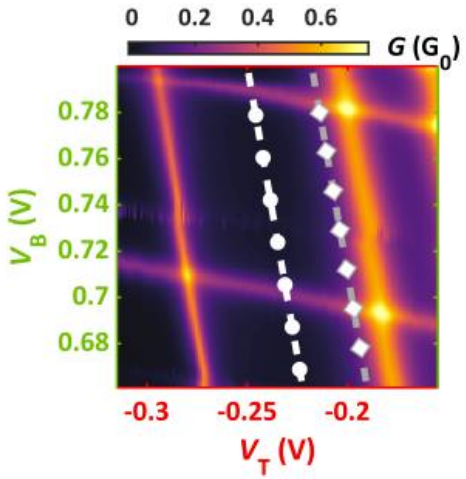
Non-Interacting YSR States

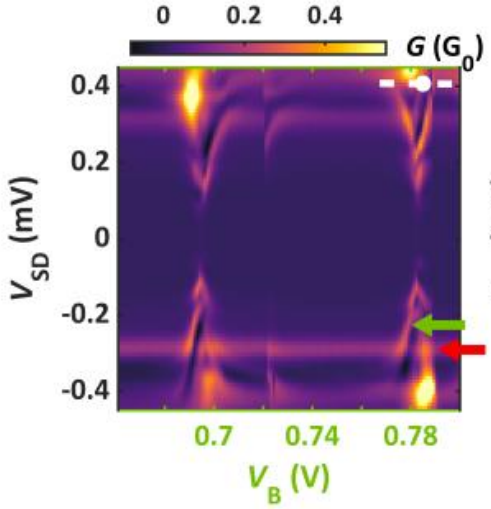
- Negligible interdot capacitance, finite cross-capacitance between top (bottom) gate and bottom (top) QD
- "eye-shaped" excitation (green) + constant-energy excitation (red)
- Local signal, non-local signal (slicing parallel to V_T resonances)
- Conductance of YSR_T > YSR_B → $t_T > t_B$

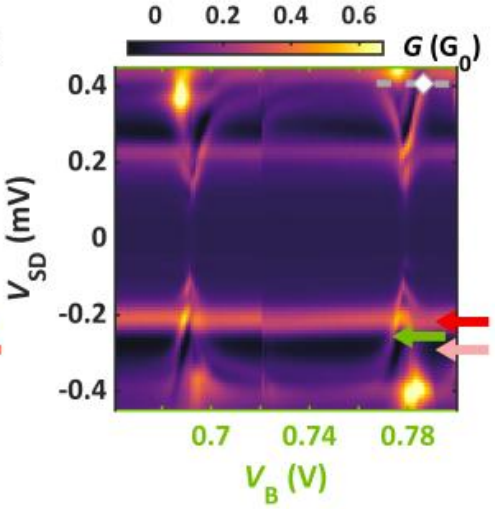




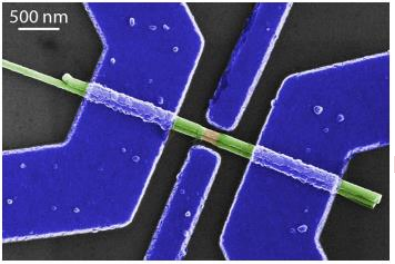








(normal state, 250 mT)

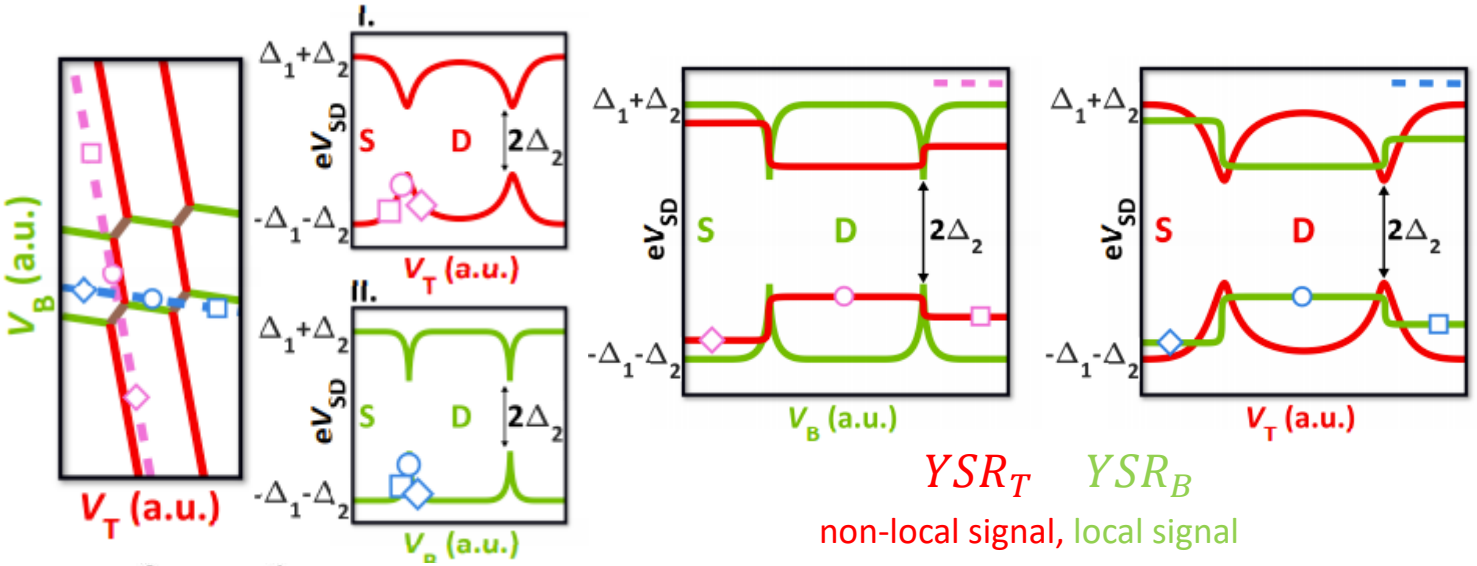


Interdot Coulomb Repulsion

- Parallel slices yield charge-state-dependent YSR state

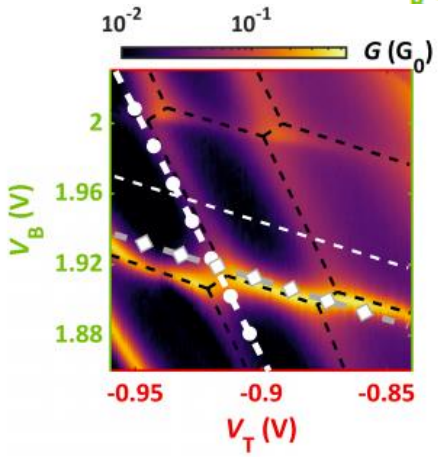
- (I)
  - Small V_B → off resonance (◊ doublet state)
  - o on resonance, gating top QD, lowering energy of YSR_T
  - ■ going through another resonance of bottom QD bringing YSR_T to singlet state

- Second device doesn't fit the simple interdot model
  - Anticrossings (white arrows) suggest hybridization
  - Blue cut doesn't take "eye-shaped" curve
  - Non-local signal follows shape of local one

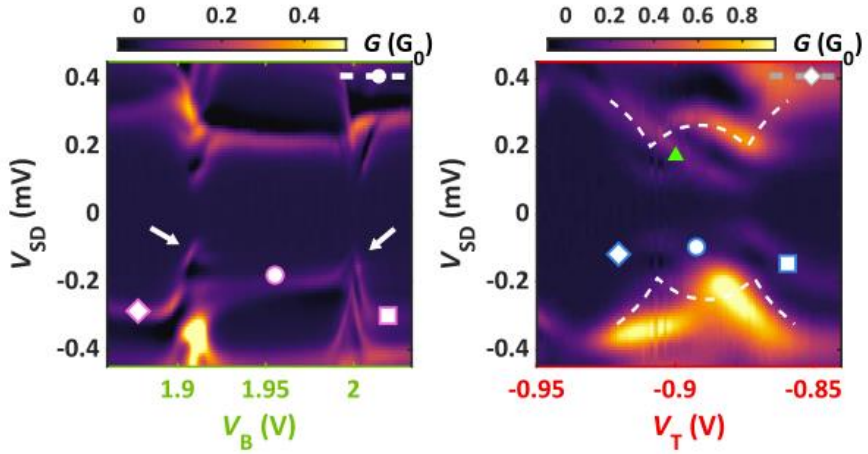


YSR_T YSR_B

non-local signal, local signal



(normal state, 250 mT)



Molecular State

Argument:

i. "eye-shaped" YSR_T completely distorted

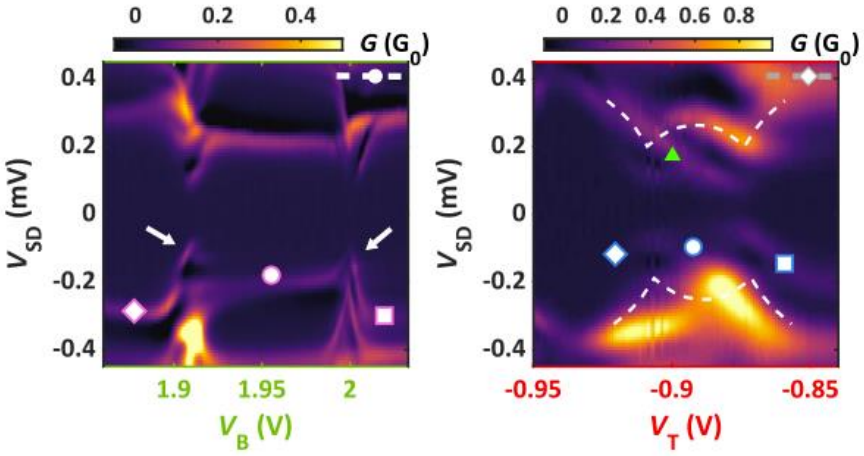
ii. Expected horizontal non-local signal not flat in doublet region (blue circle)

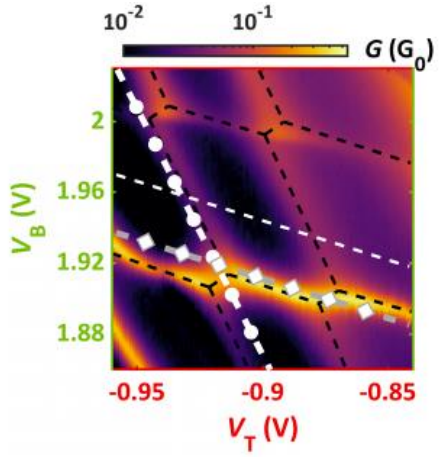
iii. Despite lack of well-pronounced anti-crossings, extra dispersive lines (green triangle) appear between local and non-local signals

iv. Measured spectrum is asymmetric w.r.t. bias

v. Unusual evolution robust along any cuts near charge degeneracies

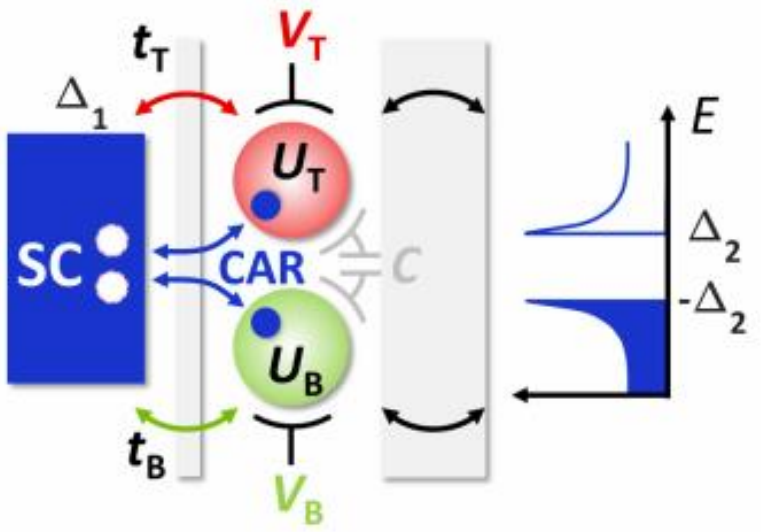
Author's conclusion: YSR states in the QDs interact with each other via the SC electrode, forming an Andreev Molecule



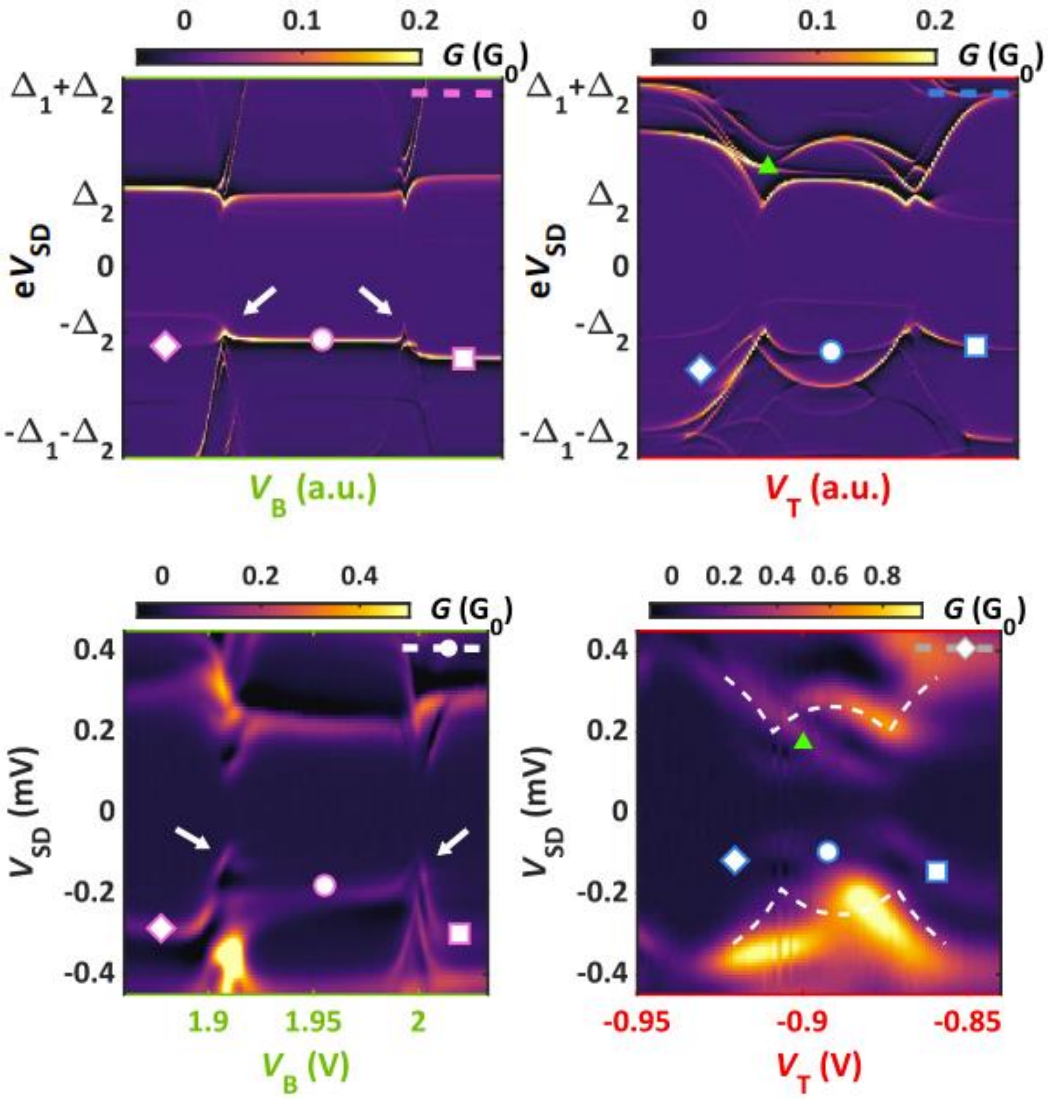


(normal state, 250 mT)

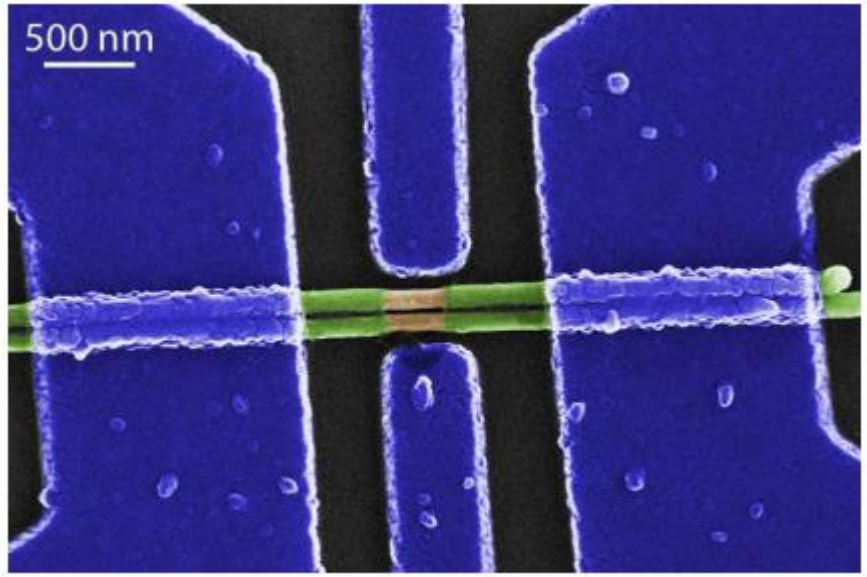
SC Coupling Simulations

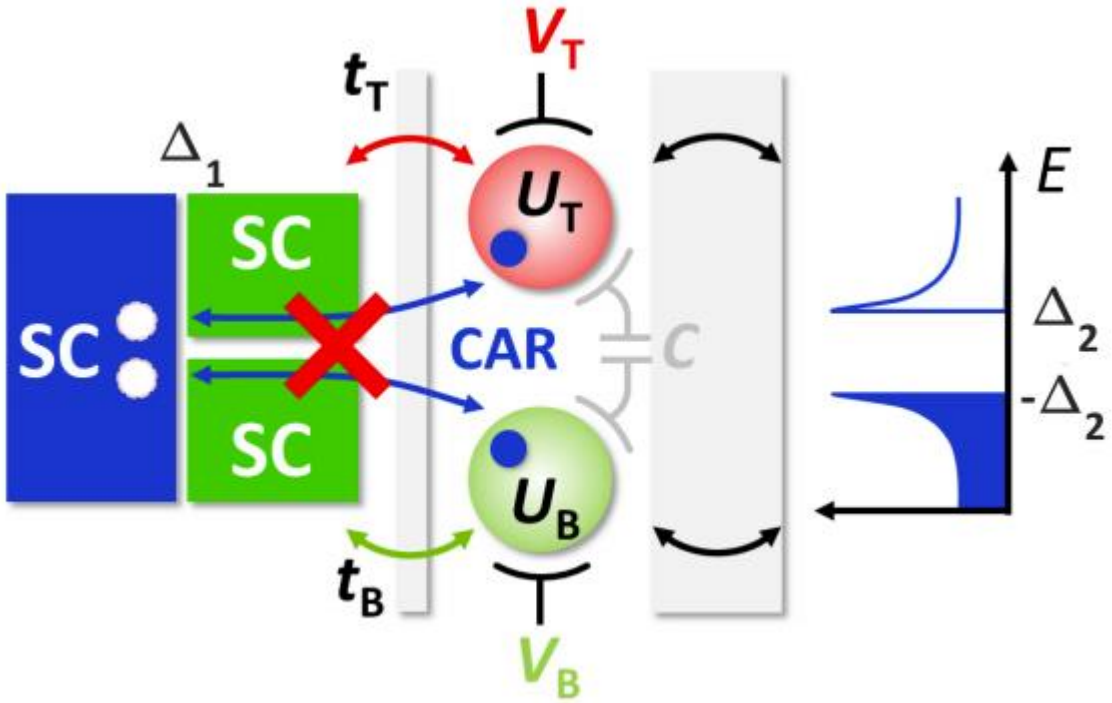


Simulations in “good agreement” with measurements



Device A (no hybridization)





Conclusion

- Exciting new platform for complex interactions
- Evidence for Andreev molecular state show in one of the devices
- Not 100% (for me) convincing that it is what they claim, but it's definitely interesting

Thanks for listening!!!