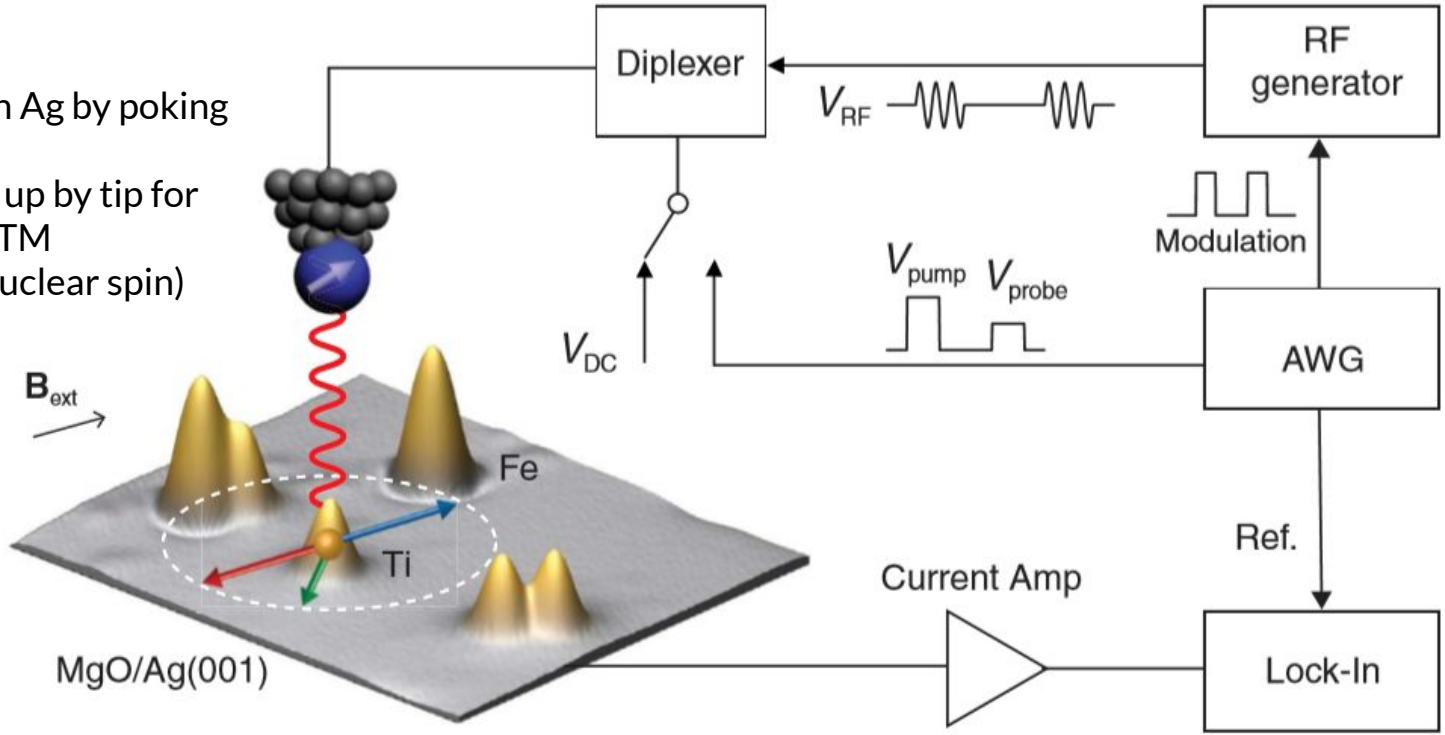
Coherent spin manipulation of individual atoms on a surface

Combining STM atomic manipulation with pulsed spin resonance to drive coherent transitions in magnetic adsorbed atoms.

- Rabi oscillations in single-atom qubits
- Spin echoes for improved quantum coherence
- Controlled spin dimer state mixing with spin exchange interactions

Experiment

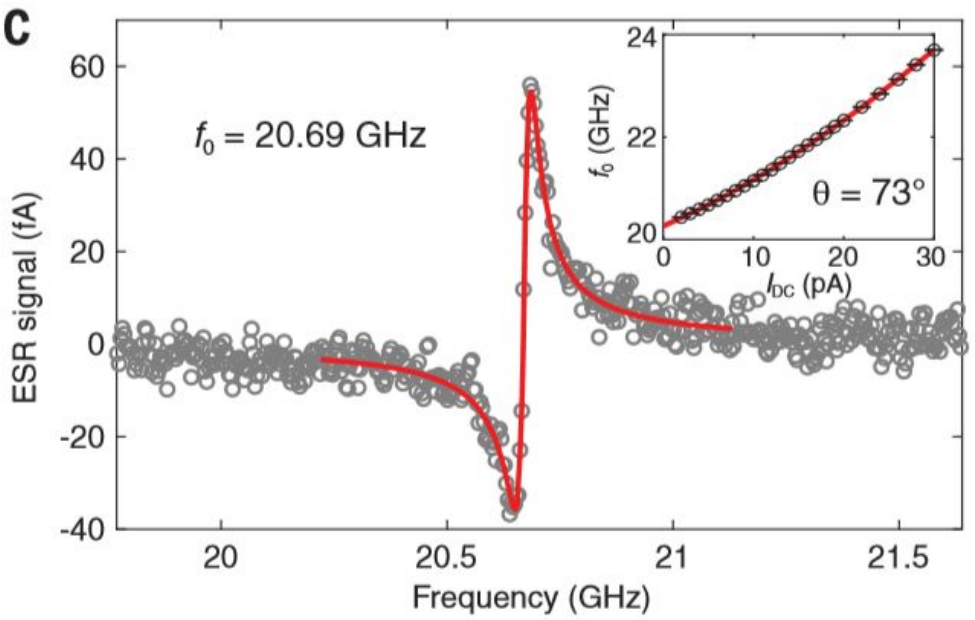
- UHV 1.2 K STM
- Ir tip coated with Ag by poking surface
- Fe atoms picked up by tip for spin-polarized STM
- Spin ½ Ti (zero nuclear spin) magnetic atoms



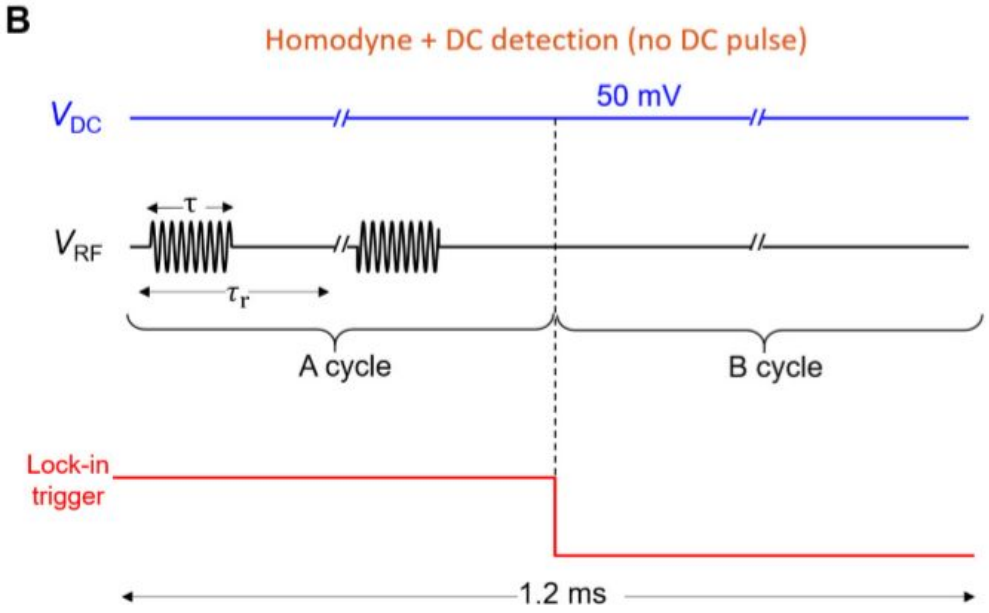
Electron spin resonance

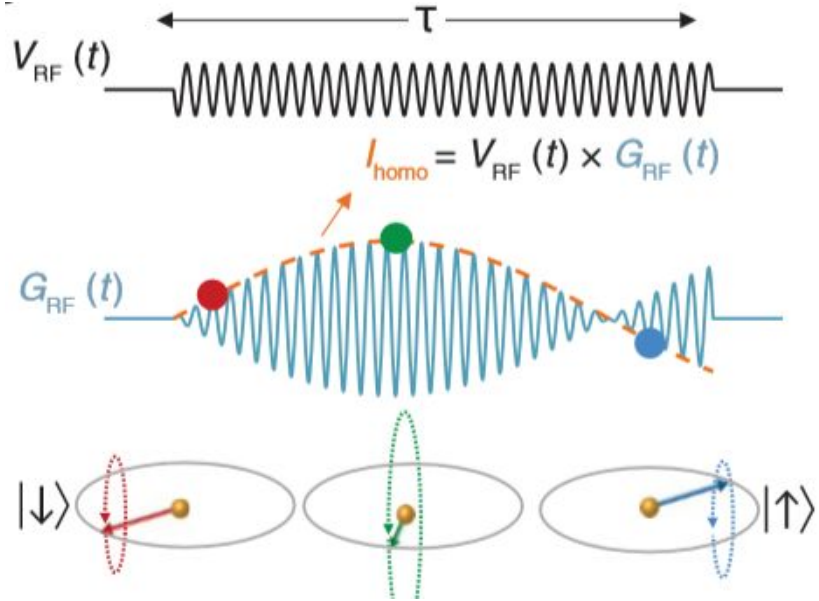
$$H = \gamma\hbar[\mathbf{B} + \Delta\mathbf{B}_{\text{tip}}\cos(2\pi ft)] \cdot \mathbf{S}$$

- Ti spin qubit experiences static and oscillatory fields
  - Static field: external (0.9 T) and tip field from DC tunneling current
  - Oscillatory field: from RF voltage generator at angle due to tip magnetic moment
- Perpendicular field component allows for resonant spin state oscillations when driving at the Zeeman splitting frequency of the Ti spin.
- By sweeping the RF frequency at constant static B field, the resonant frequencies can be identified.

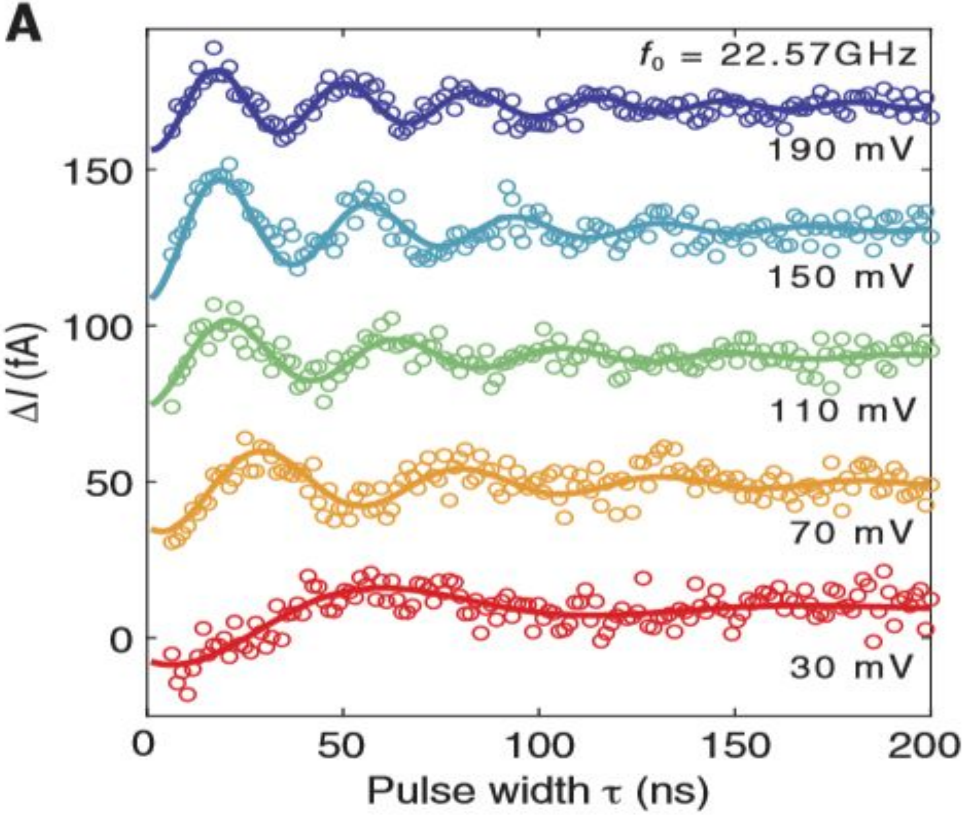


Coherent Rabi Oscillations: Protocol

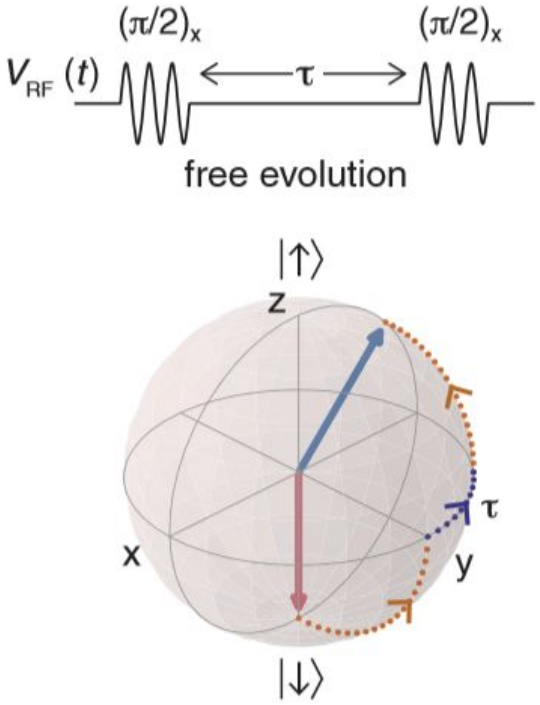


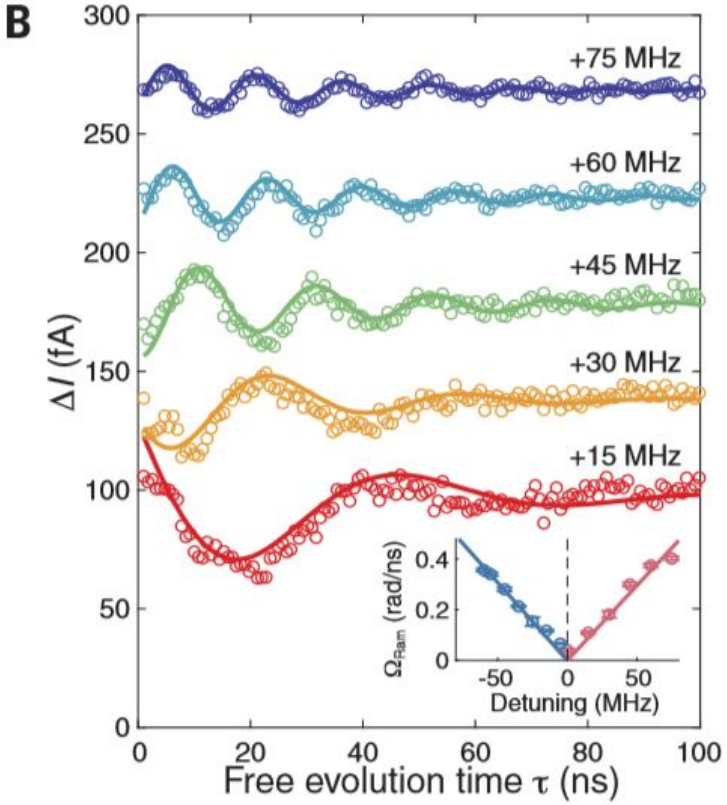


Coherent spin manipulation: Rabi Oscillations

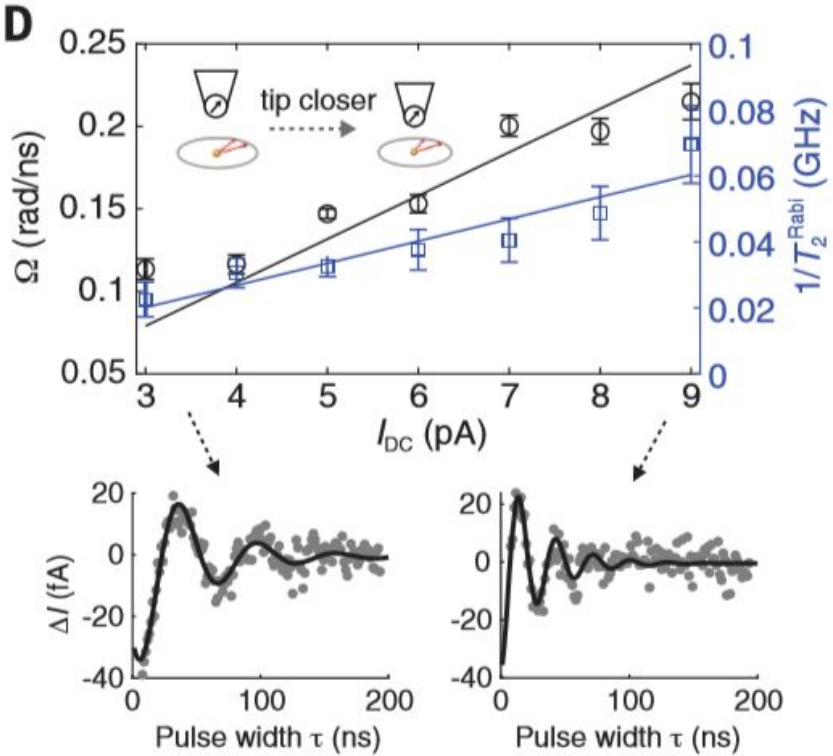


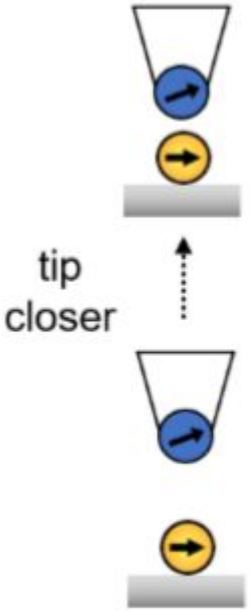
Coherent spin manipulation: Ramsey Signals

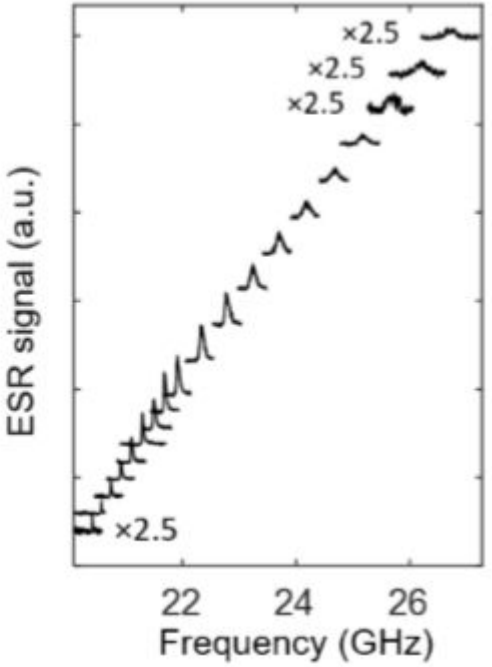




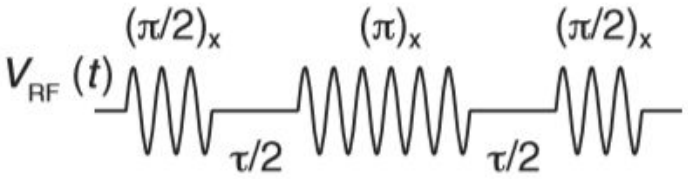
Decoherence effects

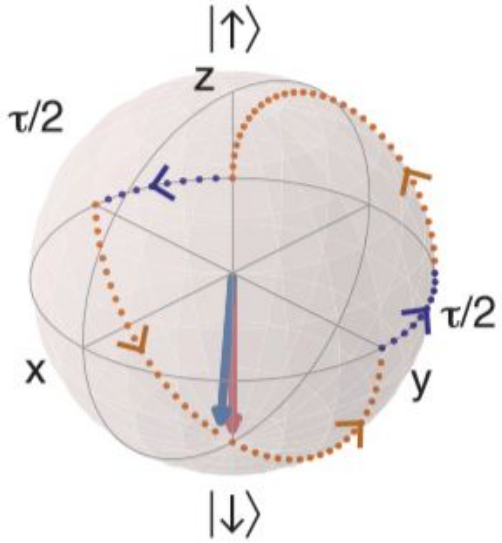


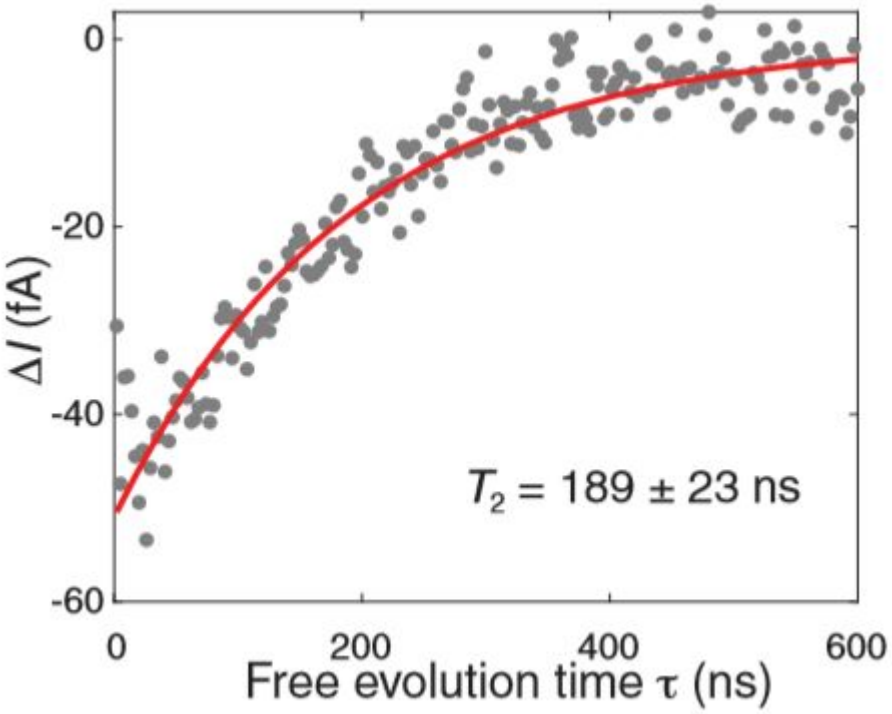




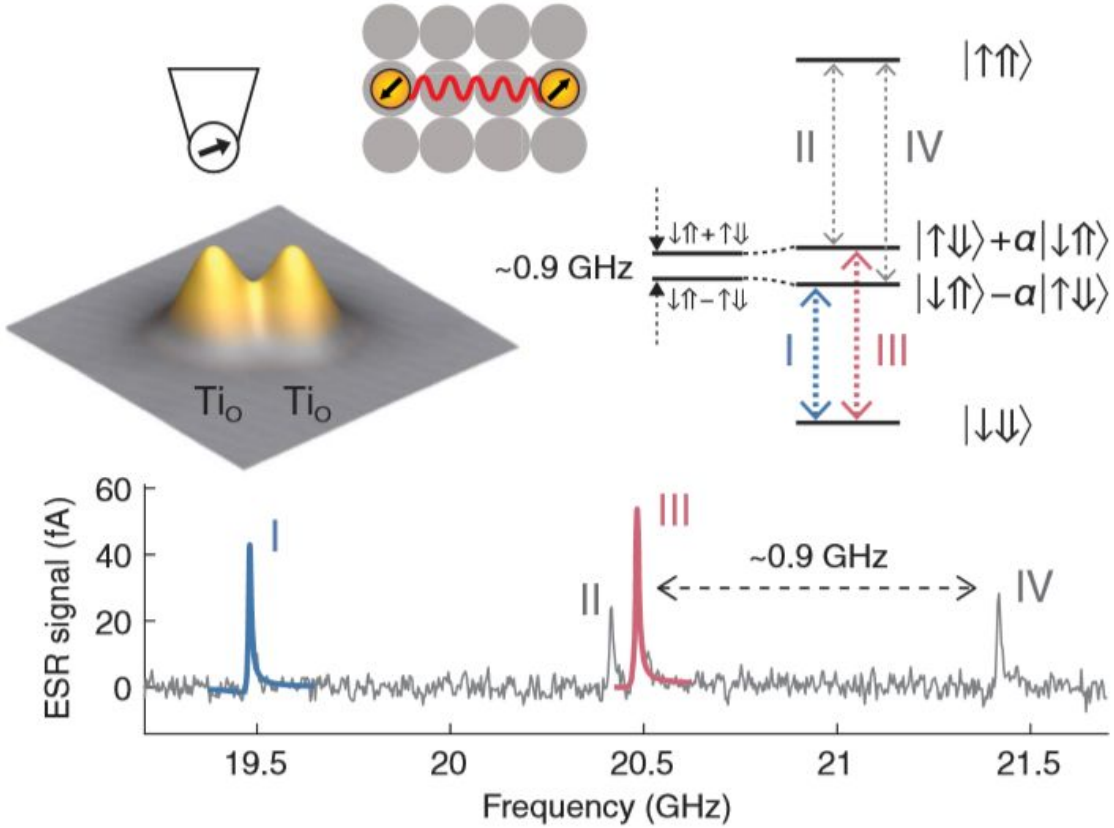
Spin Echo


$(\pi/2)_x$
$(\pi)_x$
$(\pi/2)_x$
V_{RF} (t)
τ/2
τ/2

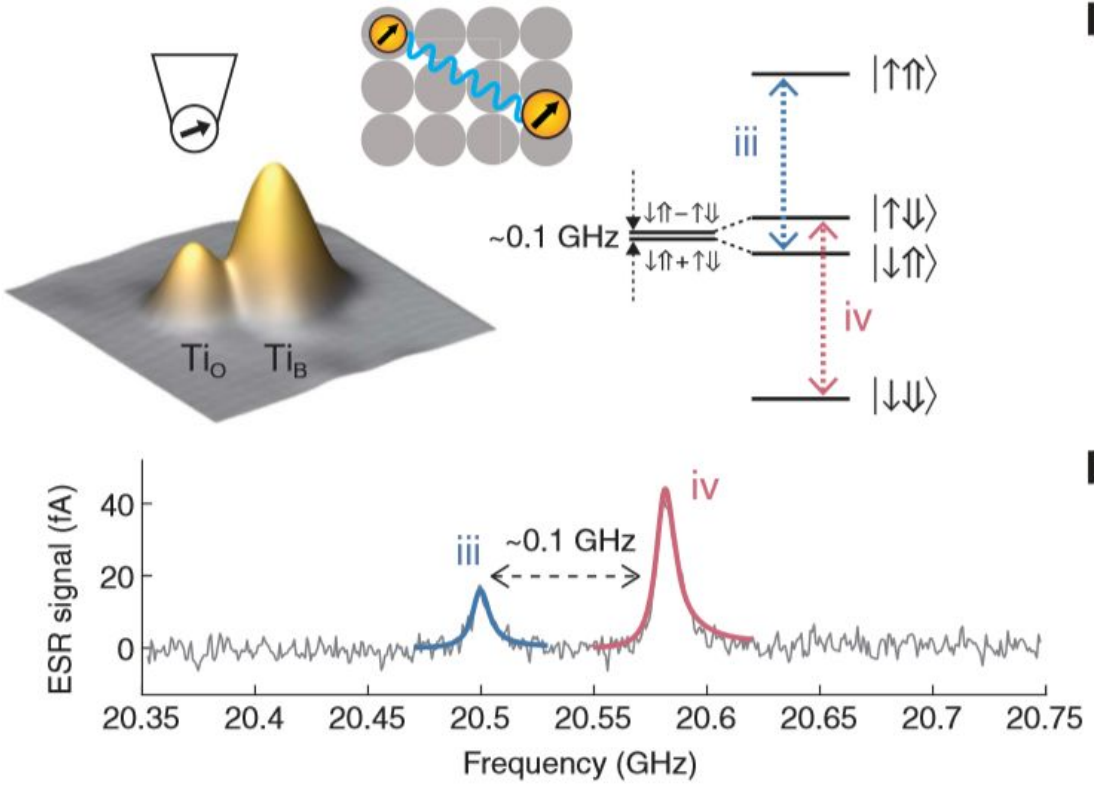

|↑⟩
z
τ/2
τ/2
x
y
|↓⟩


0
-20
-40
-60
ΔI (fA)
T_2 = 189 ± 23 ns
0
200
400
600
Free evolution time τ (ns)

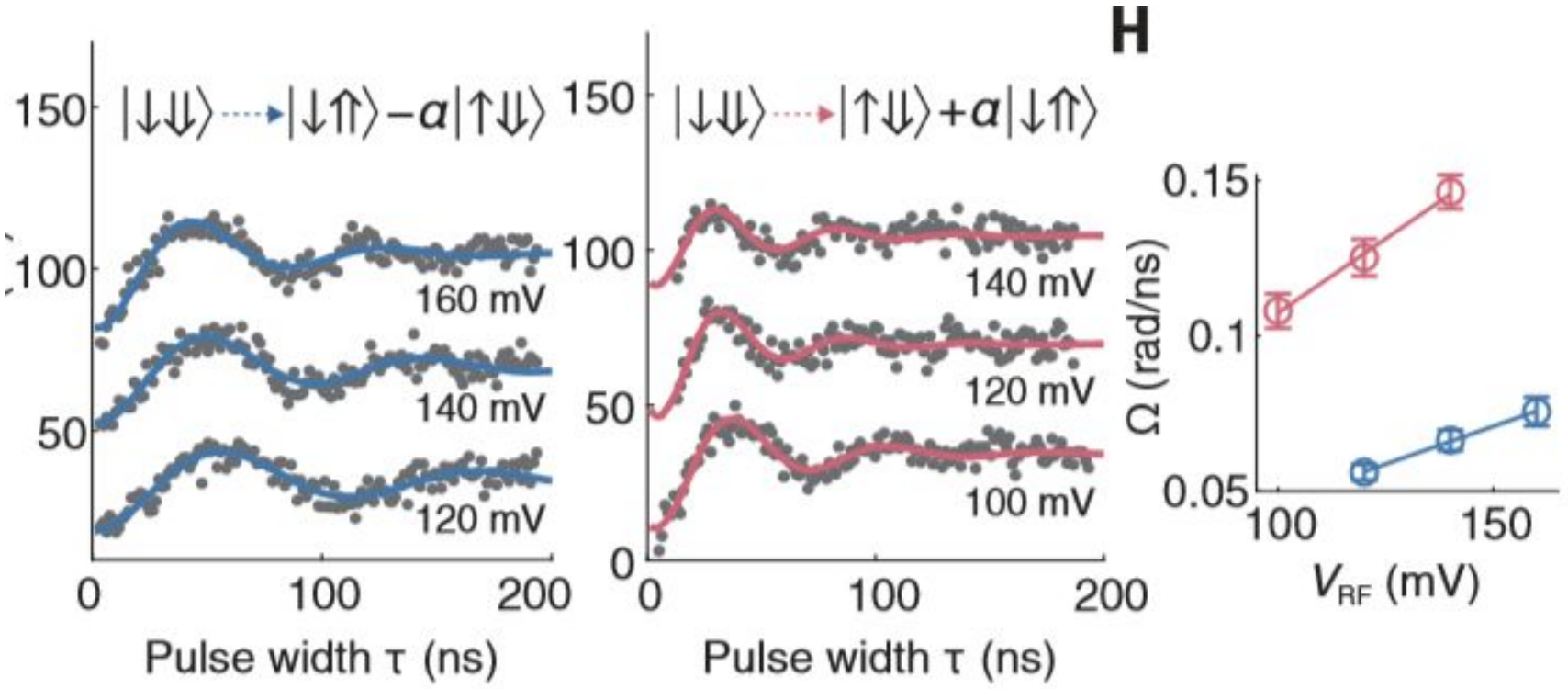
Engineered Atomic Dimers: Strong Interaction



Engineered Atomic Dimers: Weak Interaction



Titanium Dimer state rotations: Strong Interaction



Titanium Dimer state rotations: Weak Interaction