Geometric phase and topology in a field gradient matter-wave interferometer

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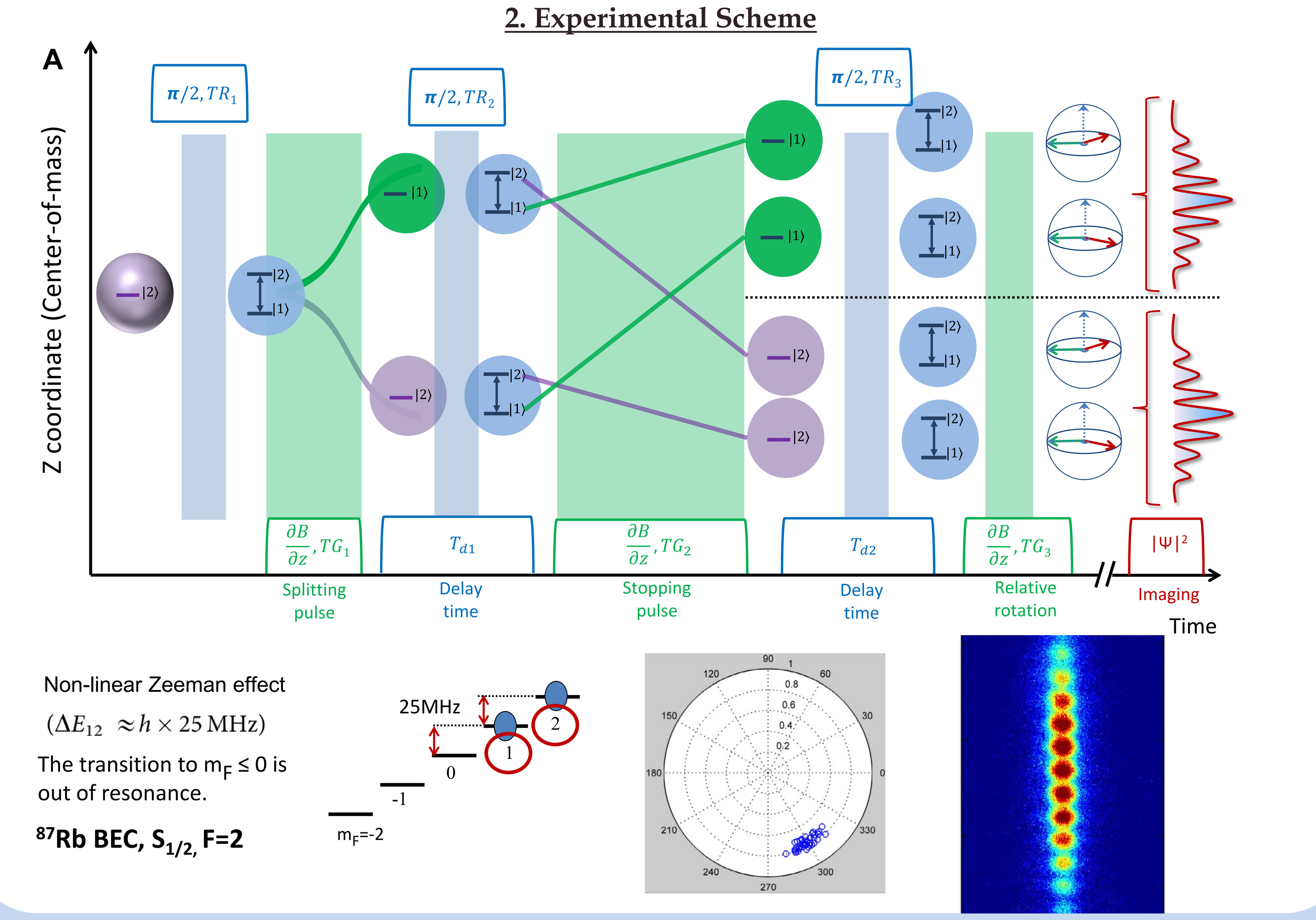
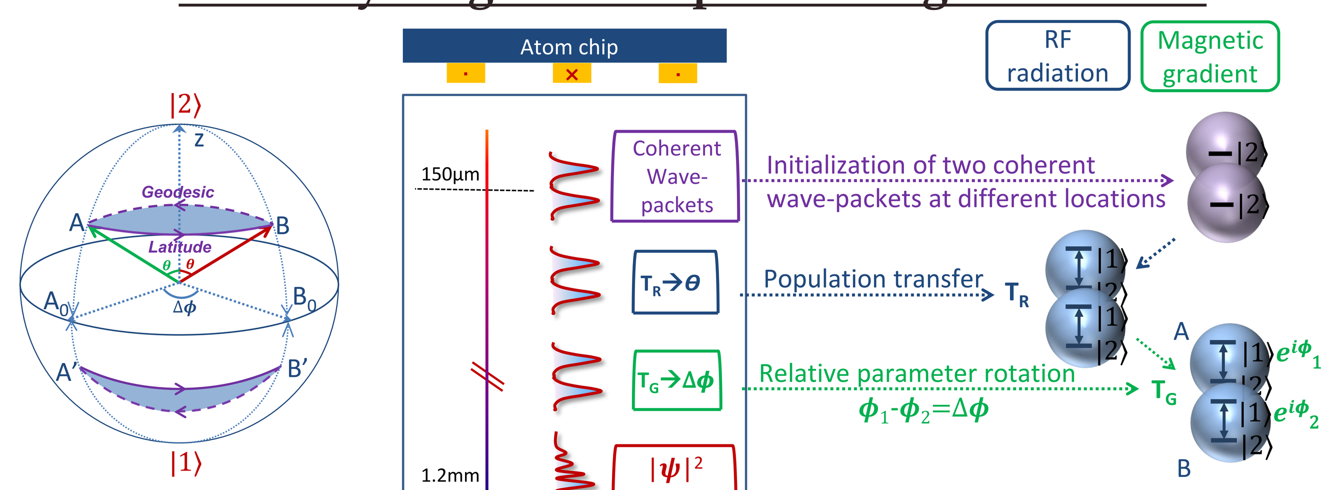
1. Introduction

- The geometric phase due to the evolution of the Hamiltonian is a central concept in quantum physics and may become advantageous for quantum technology. In noncyclic evolutions, a proposition relates the geometric phase to the area bounded by the phase-space trajectory and the shortest geodesic connecting its endpoints. We report:
- a previously unshown experimental confirmation of the geodesic rule for a non-cyclic geometric phase using a spatial SU(2) matter-wave interferometer, demonstrating, with high precision, the predicted phase sign change and π jumps [1].
- Momentum states exhibit steps like Shapiro steps in Josephson junctions, driven by geometric phase and topology.

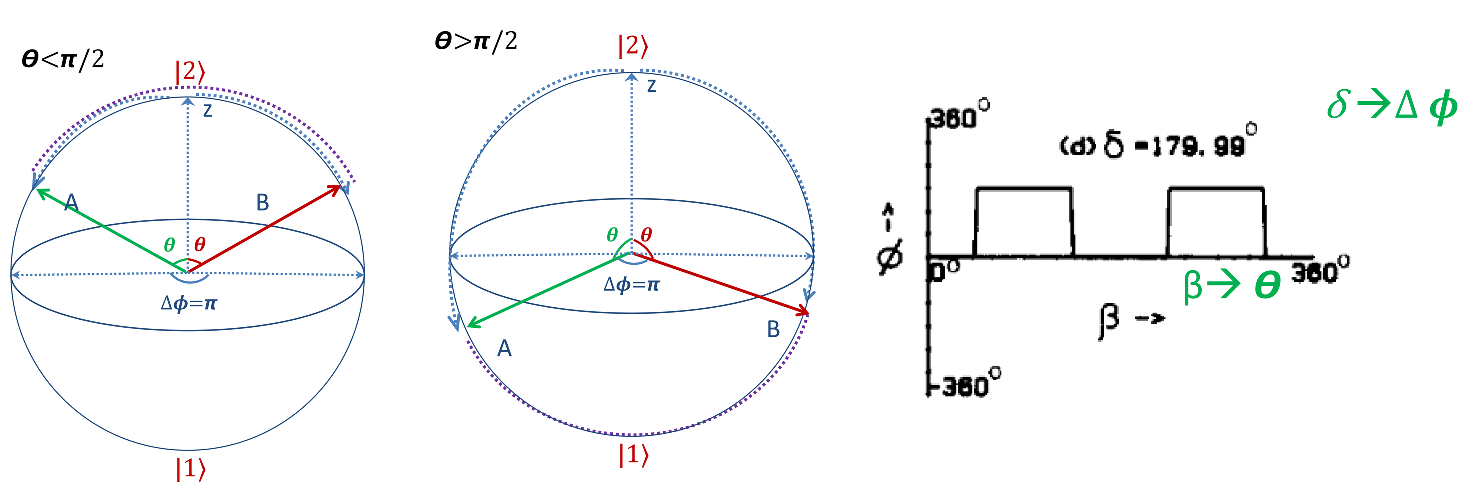
2. Experimental Scheme



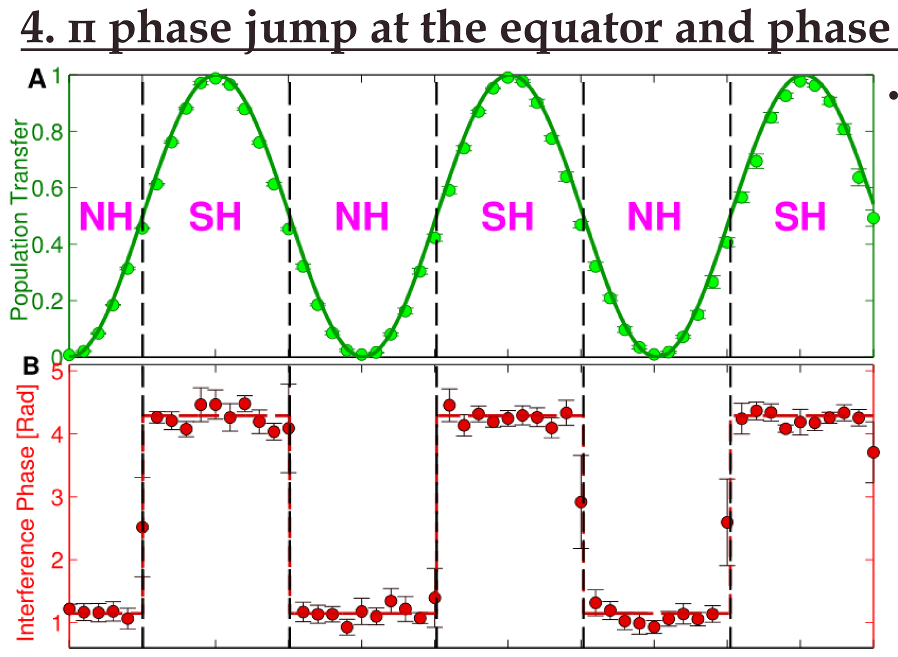
3. Non-cyclic geometric phase and geodesic rule



The geodesic rule - the evolution back along *any geodesic curve joining B to A*. The enclosed area corresponds to the geometric phase. [2,3]



4. π phase jump at the equator and phase rigidity within hemisphere

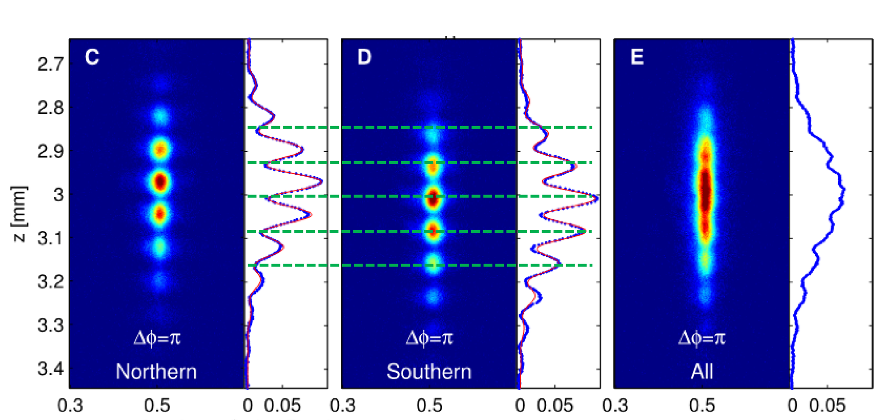


- (A) Population transfer to state |1⟩ versus the duration of the RF radiation pulse.

NH: Northern hemisphere. SH: Southern hemisphere. Scanning θ (20μS→π)

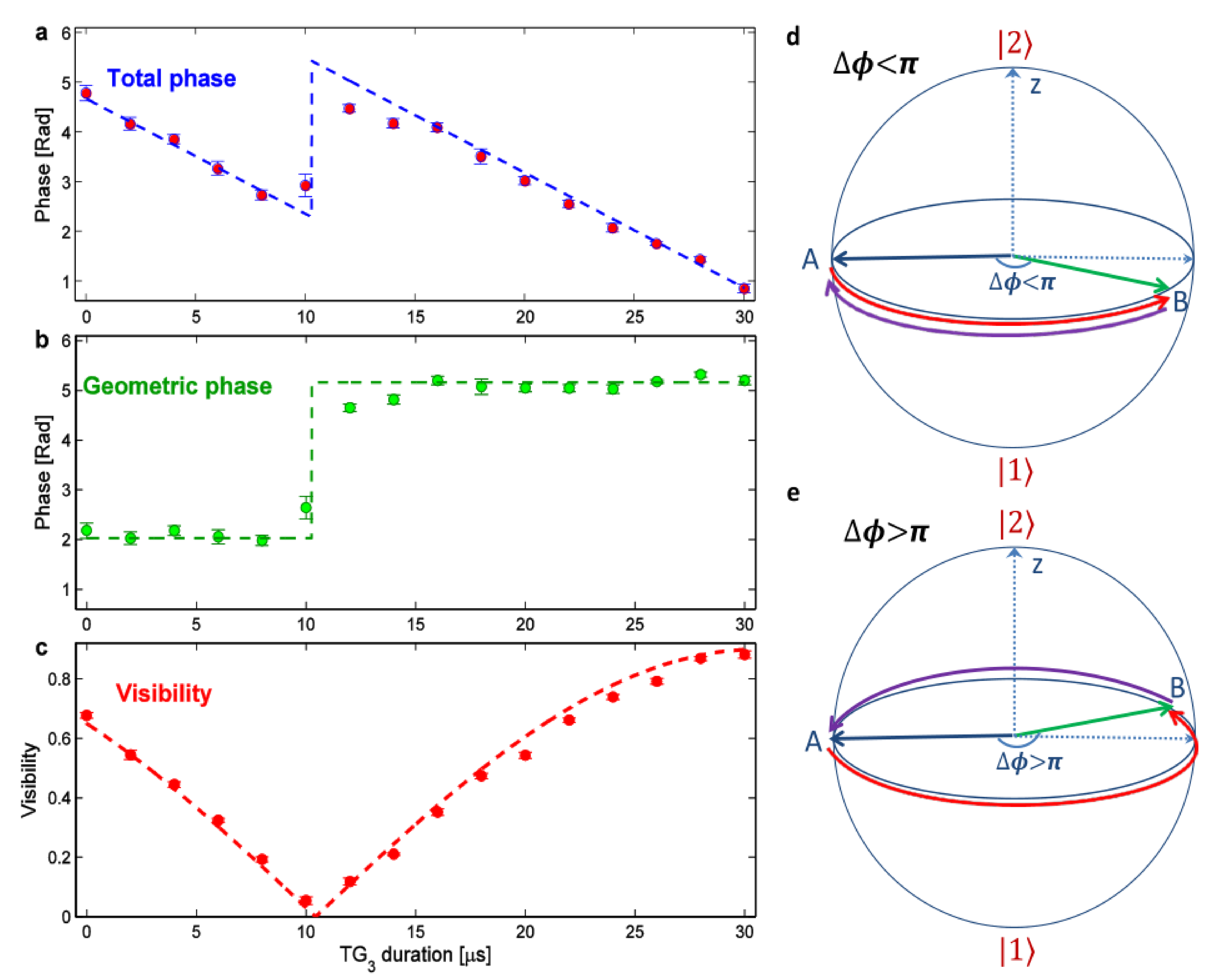
π phase jump & phase rigidity (when $\Delta\phi=\pi$)

- (B) The interference phase as a function of Rabi oscillation.



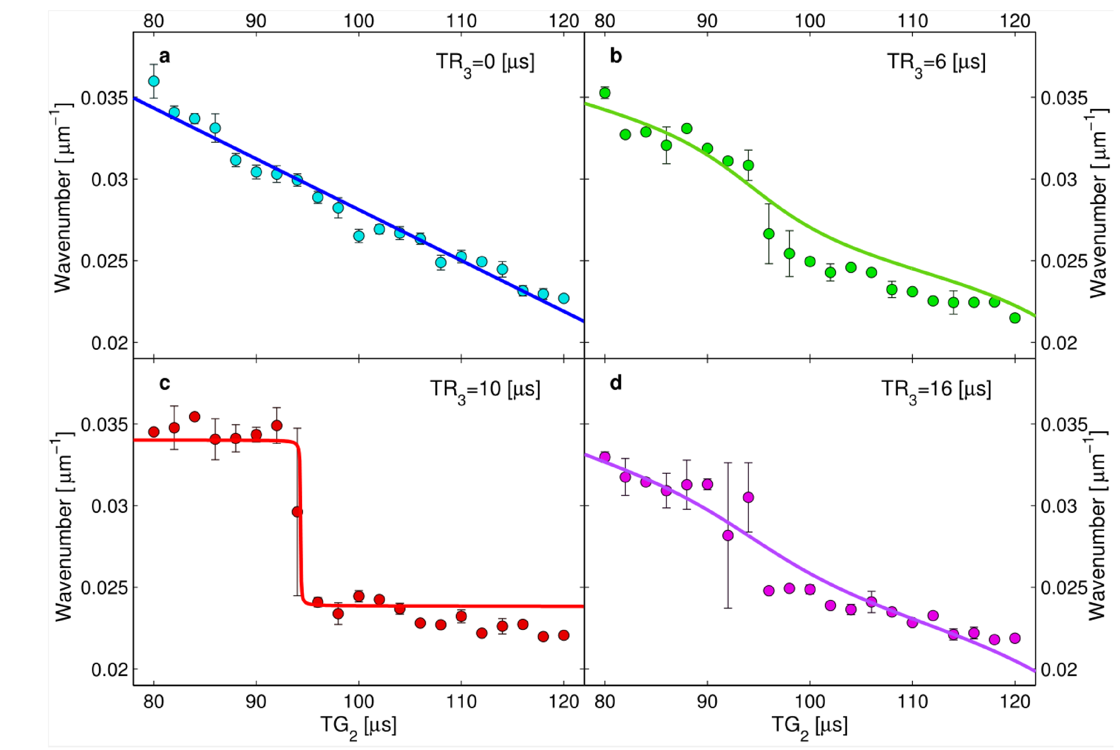
- (c) Averaged CCD image of interference when the Bloch vectors are all in the northern hemisphere (D) Averaged picture of the second half of the data, in which the Bloch vectors are all pointing in the southern hemisphere. (E) Averaged picture of all the data.

5. Geometric phase jump - "phase slip"



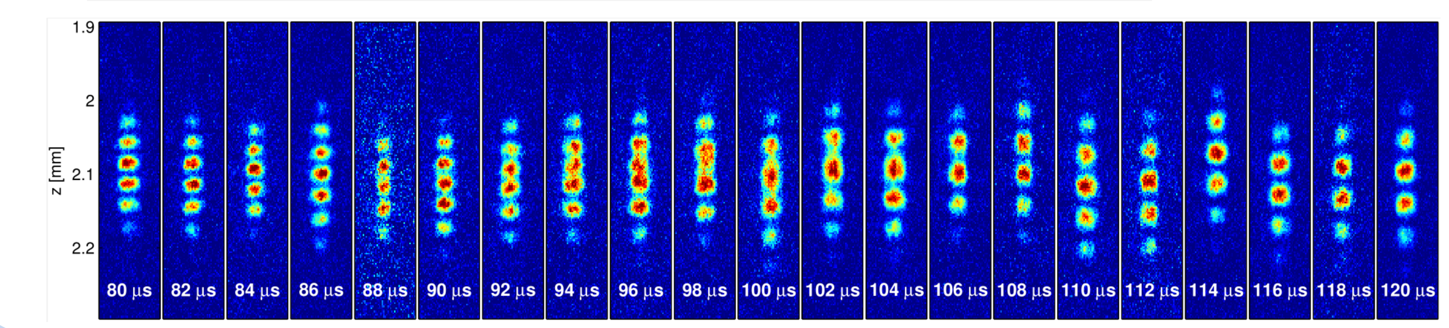
(a), the measured total phase when $TR_3=\pi/2$. Here the relative rotation between the two vectors is decided by $\Delta\varphi = \Delta E \times TG_3/h$. As the two-level system consists of the mF=1 and mF=2 states, there is an additional phase resulting from TG_3. The phase jump around TG_3 = 10μs is obvious. (b), the geometric phase with the strip of the dynamical phase. The phase rigidity and the π phase jump are clearly shown; (c), the corresponding change of the visibility, as $|\cos(\Delta\varphi)/2|$, which also implies the boundary conditions. (d) and (e), the geometric phase is decided by the enclosed area between the Hamiltonian line (red) and the geodesic connection (purple).

6. Dependence on internal superposition and raw figures

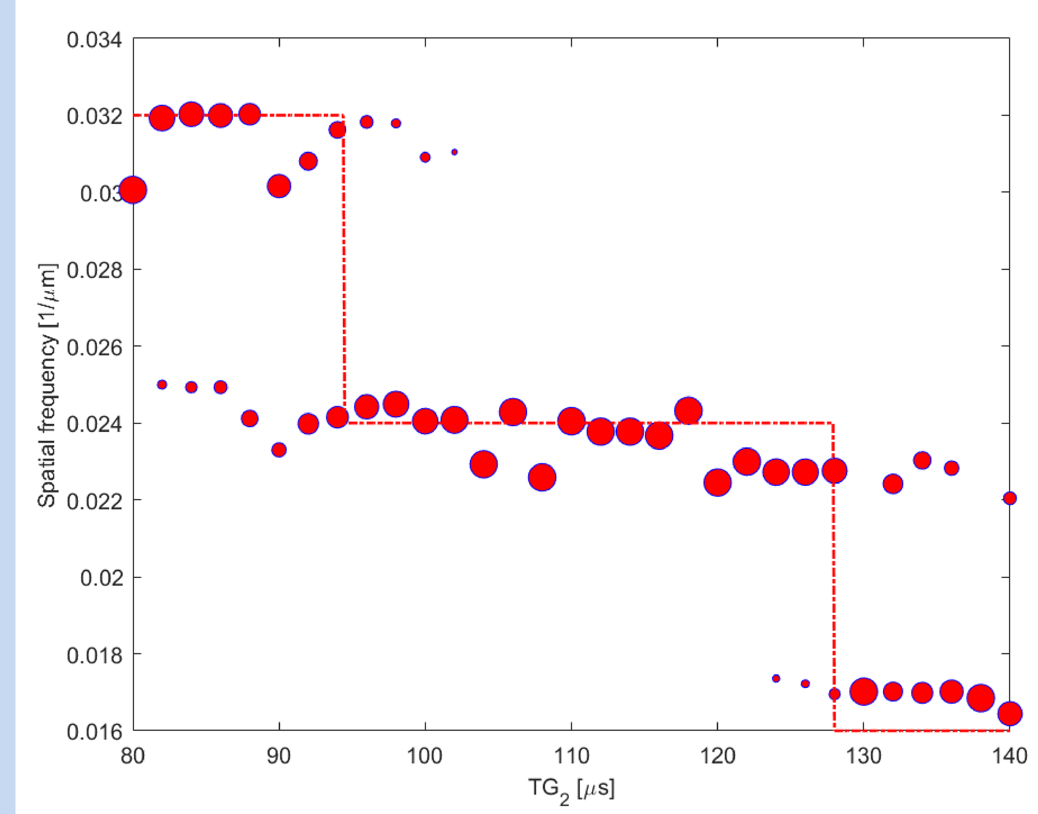


(TR_3 20μS→π)

Raw figures of Momentum step in c



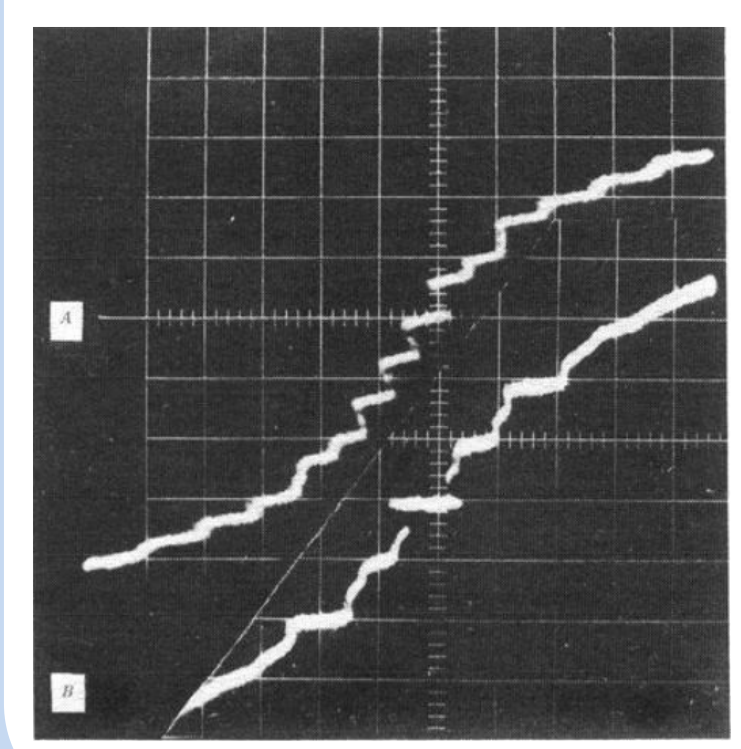
7. Momentum steps and Shapiro steps

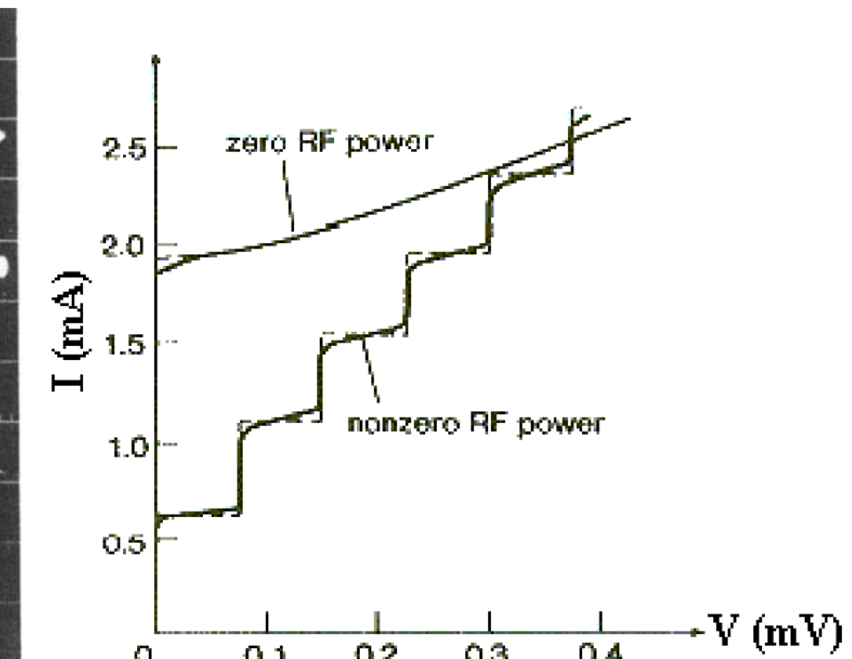


4:3:2

The range is limited by the camera range. Scanning TG_1 also shows similar phenomena.

When a superconductor-insulator-superconductor junction is radiated by the microwave/radiofrequency photons of frequency ω, a constant voltage U (also known as the Josephson voltage) is developed by the Cooper pair tunneling across the junction. The voltage step size is U=hω/(2e). [4,5]





8. References

[1] *An experimental test of the geodesic rule proposition for the non-cyclic geometric phase, Zhifan Zhou, Yair Margalit, Samuel Moukouri, Yigal Meir, and Ron Folman. Sci. Adv. 6, eaay8345 (2020).*

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[3] *R. Bhandari, SU(2) phase jumps and geometric phases, Phys. Lett. A 157, 221 (1991).*

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[5] *Shapiro steps in Josephson Junctions, Peder Heiselberg, Niels Bohr Institute, University of Copenhagen*

[6] *The a.c. and d.c. Josephson effects in a Bose–Einstein condensate, S. Levy, E. Lahoud, I. Shomroni and J. Steinhauer, Nature 449, 579 (2007).*