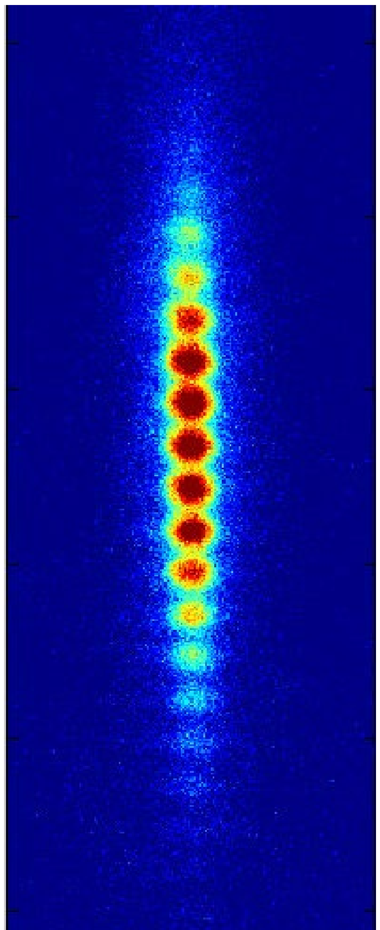
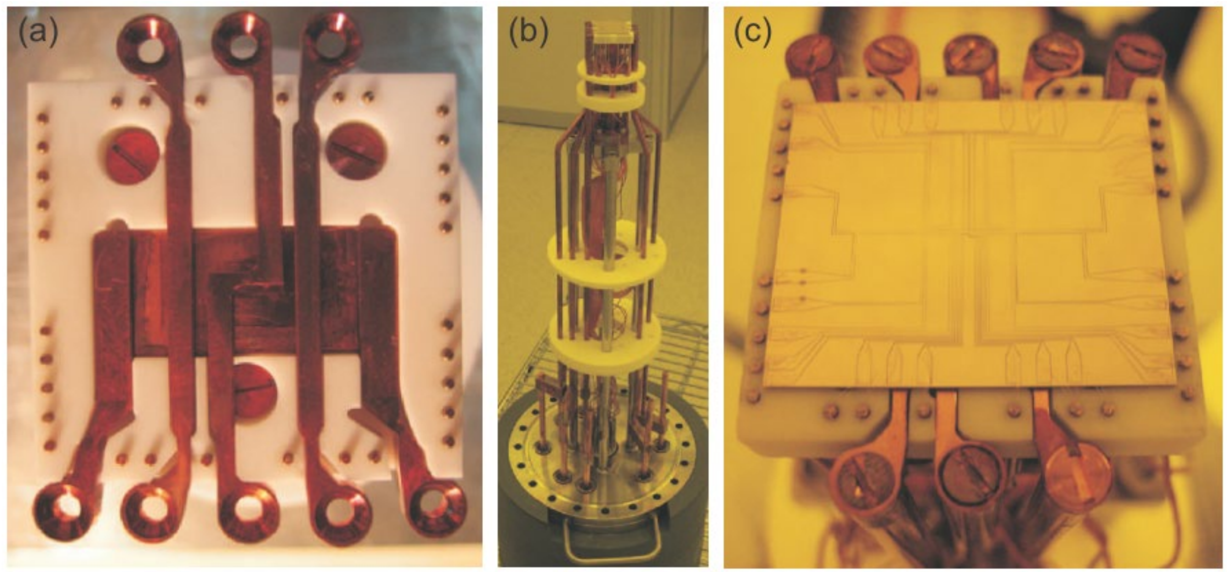
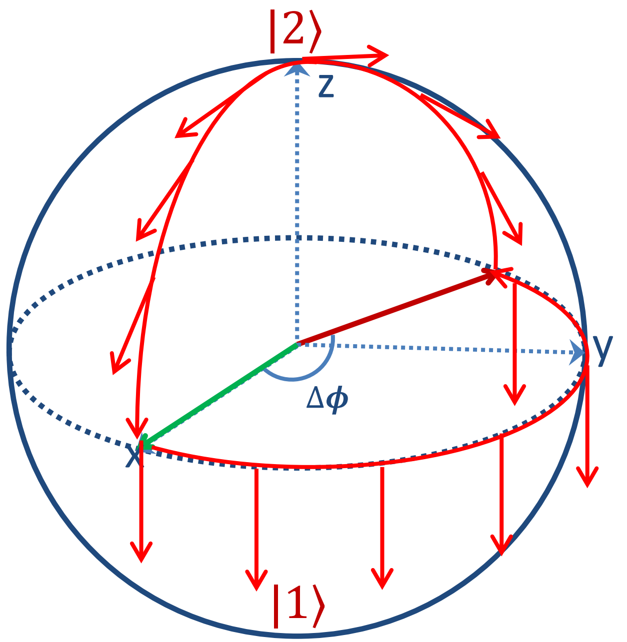
An experimental test of the geodesic rule proposition for the non-cyclic geometric phase

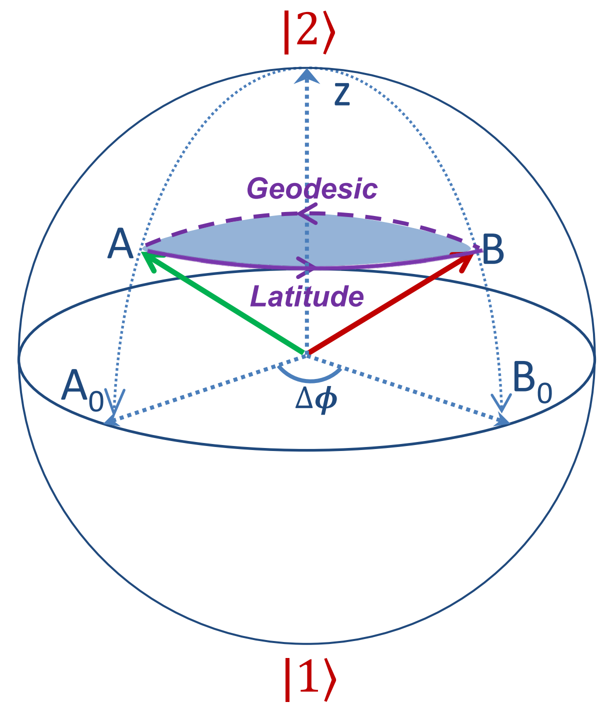




Zhifan Zhou, Atom chip group, Physics Department, Ben-Gurion University, @ PQE, Jan.8th, 2020

Cyclic and non-cyclic geometric phase





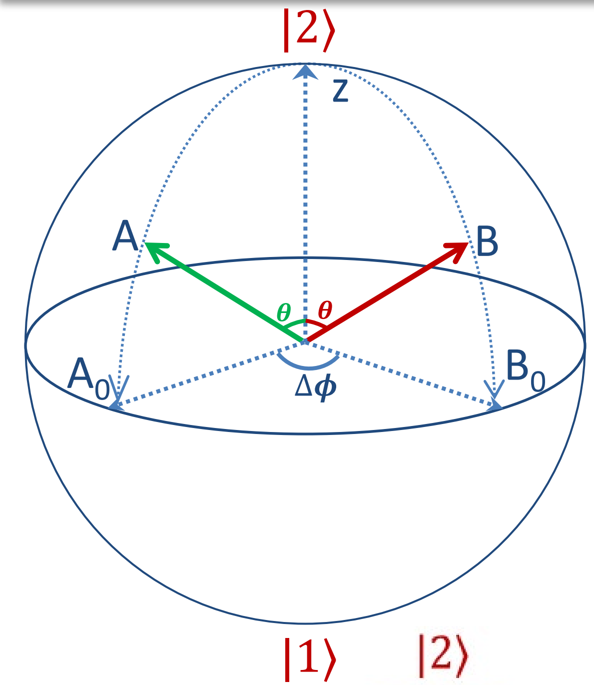
Berry's phase ---- when the Hamiltonian returns to its initial state, the system acquires an extra phase over and above the dynamical phase. ---
M. V. Berry, Proc. Royal Soc. London A 392, 45 (1984).

In a more general context, the evolution of the quantum system need be neither unitary nor cyclic and may be interrupted by quantum measurements, *e.g. A to B*.

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

J. Samuel, R. Bhandari, General setting for Berry's phase, Phys. Rev. Lett. 60, 2339 (1988).

The phase of interference between two vectors



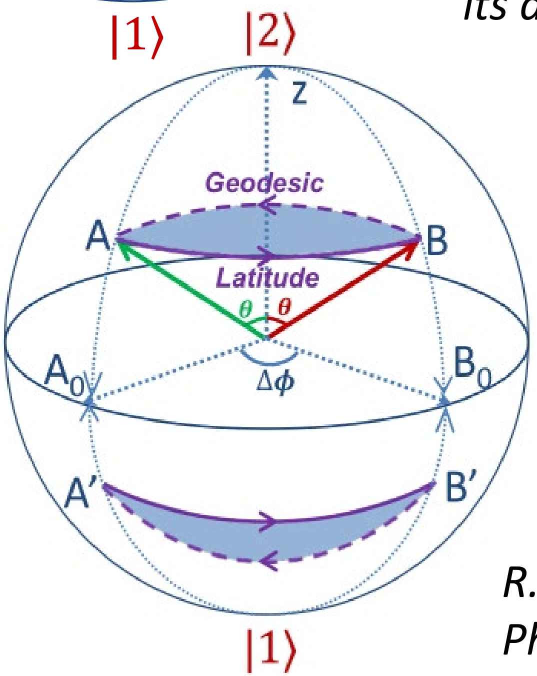
$$\Psi_A = \psi_A(r)(\cos\frac{\theta}{2}|2\rangle + \sin\frac{\theta}{2}|1\rangle),$$

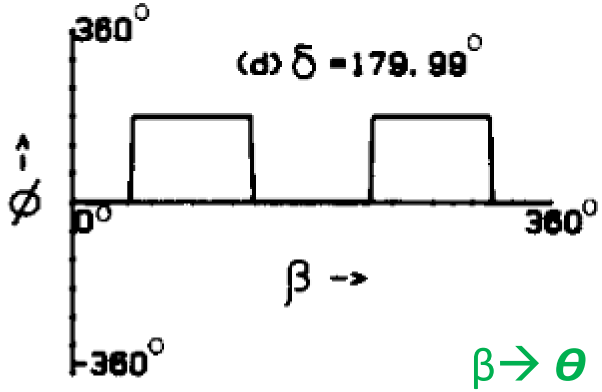
$$\Psi_B = \psi_B(r)(\cos\frac{\theta}{2}|2\rangle + \exp(i\Delta\phi)\sin\frac{\theta}{2}|1\rangle),$$

$$\Phi = \arg\langle\Psi_A|\Psi_B\rangle = \left\{\frac{\sin^2(\theta/2)\sin\Delta\phi}{\cos^2(\theta/2)+\sin^2(\theta/2)\cos\Delta\phi}\right\}$$

Interference pattern

S. Pancharatnam, Generalized theory of interference and its applications, Proc. Indian Acad. of Sciences 44, 247 (1956).



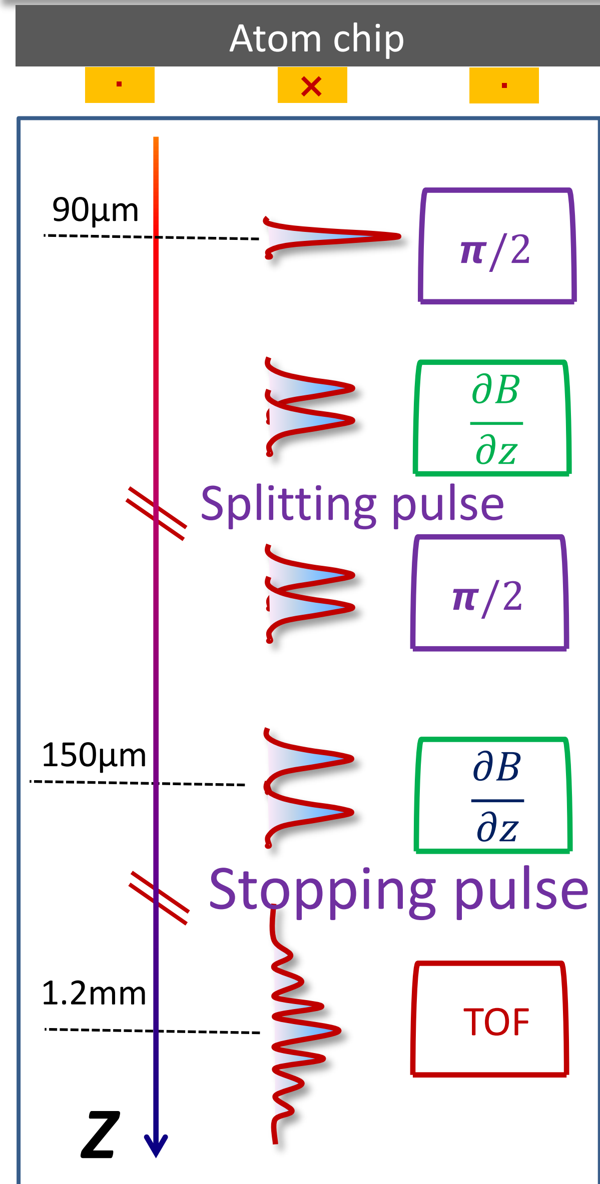


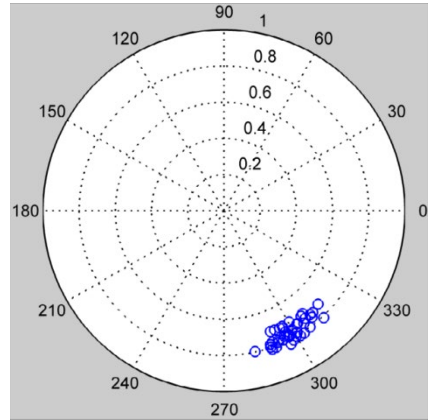
$\delta \rightarrow \Delta\,\boldsymbol{\phi}$

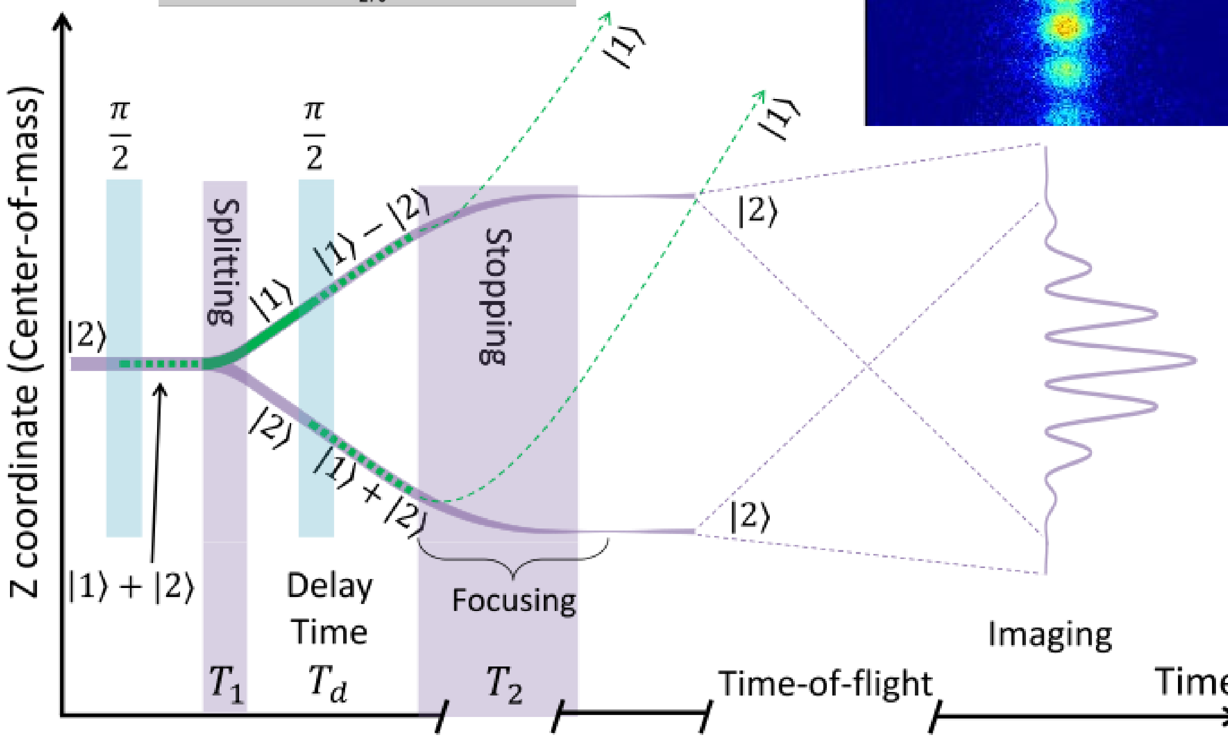
$\beta \rightarrow \boldsymbol{\theta}$

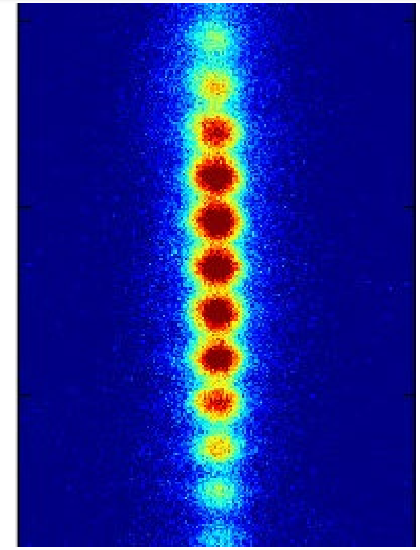
R. Bhandari, SU(2) phase jumps and geometric phases, Phys. Lett. A 157, 221 (1991).

Matter-wave interferometer with an atom chip



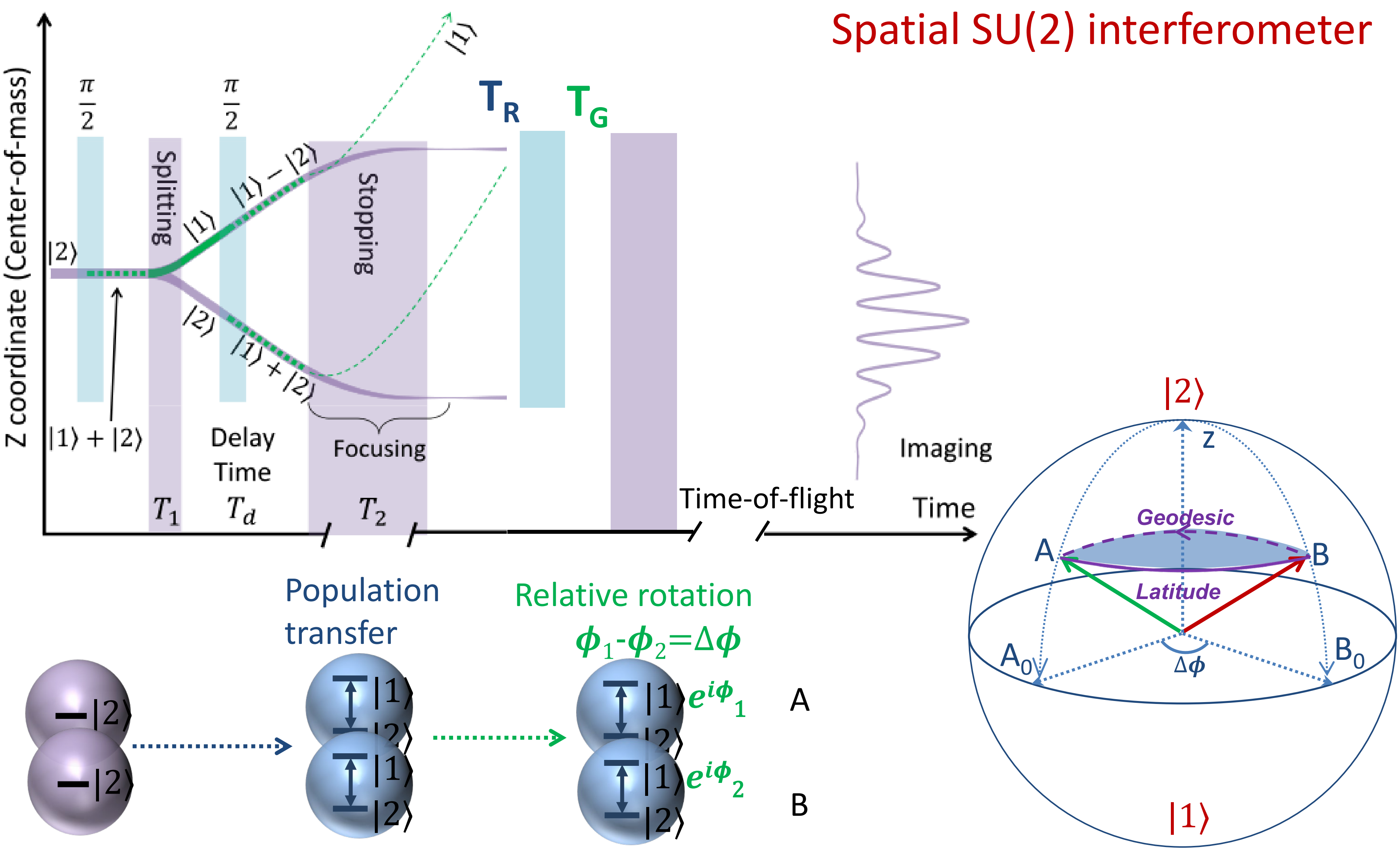




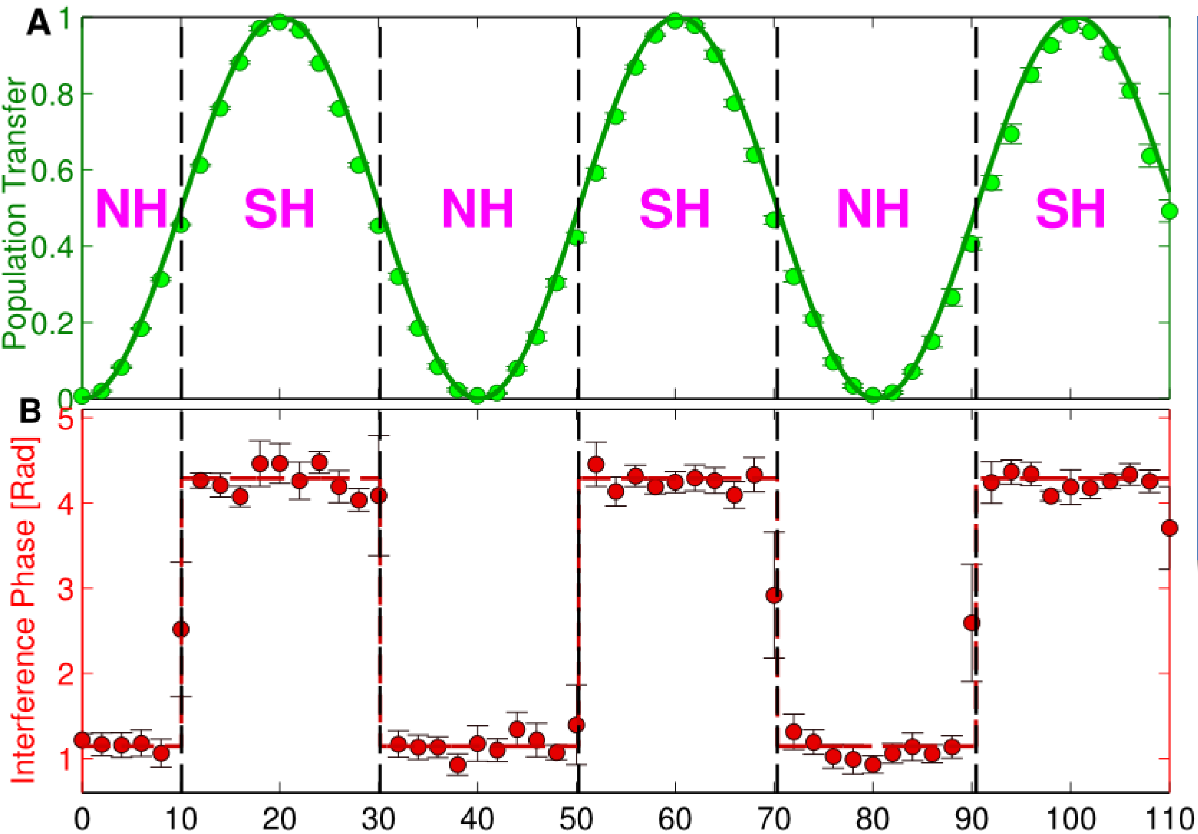


Yair Margalit et al. Analysis of a high-stability Stern–Gerlach spatial fringe interferometer, New J. Phys. 21, 073040 (2019).

Experimental scheme



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).

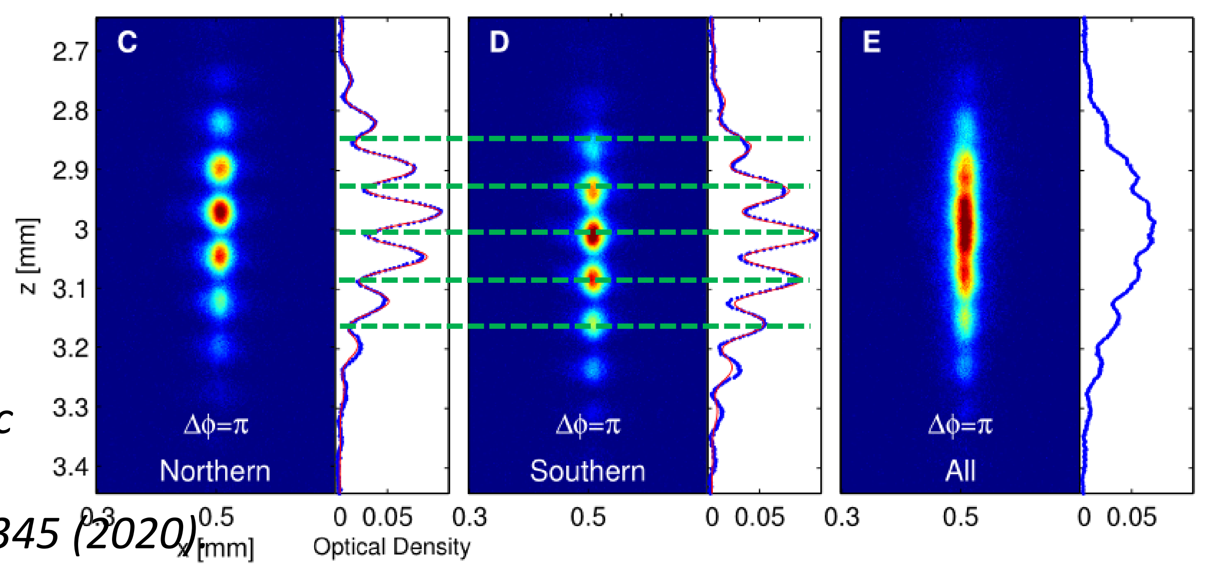


Experimental π phase jump at the equator and phase rigidity within each hemisphere

NH: Northern hemisphere.
SH: Southern hemisphere.

Scanning *θ*
(20→*π*)

π phase jump
phase rigidity



An experimental test of the geodesic rule proposition for the non-cyclic geometric phase, Sci. Adv. 6, eaay8345 (2020).

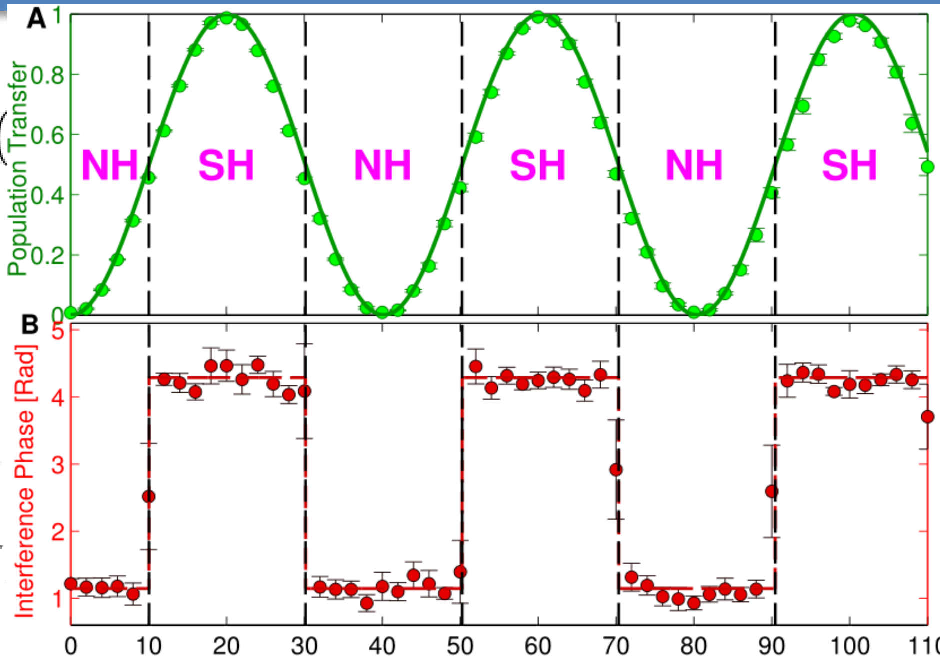
Interpretation through Pancharatnam connection

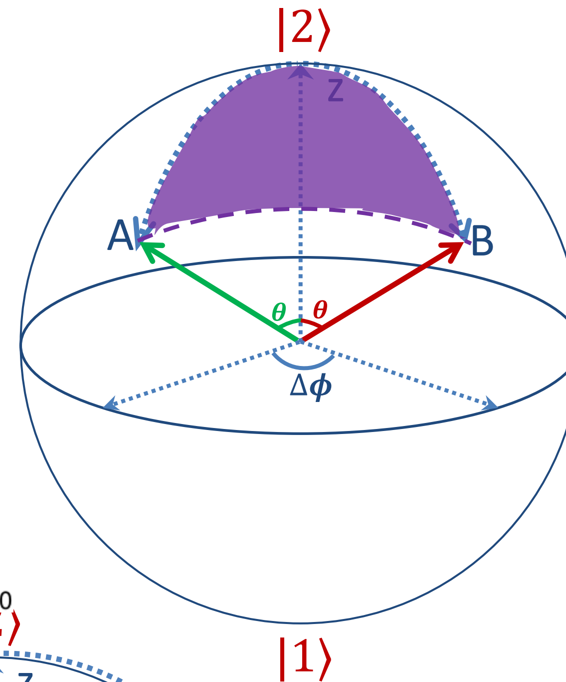
$\Psi_B = \psi_B($

$\Psi_A =$

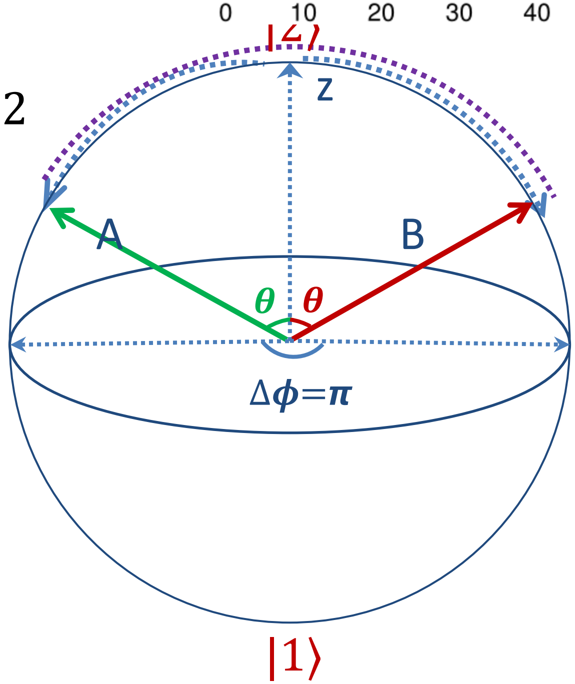
$\arg\langle\Psi_A$

$\Phi = \arg\langle\Psi$

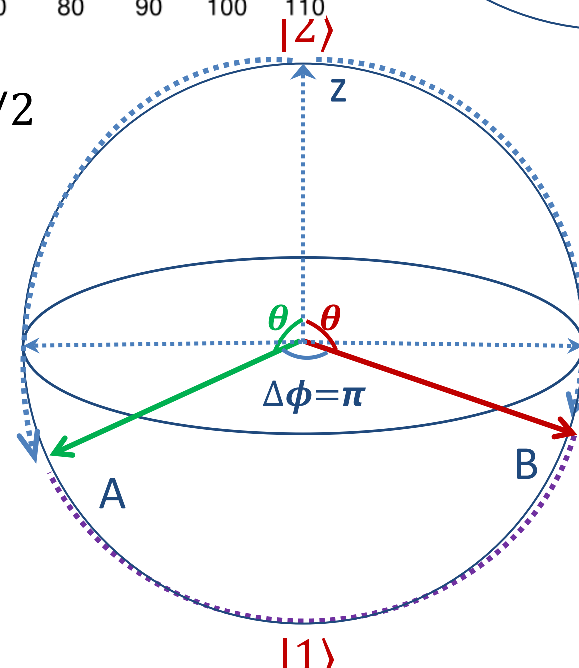




θ<π/2

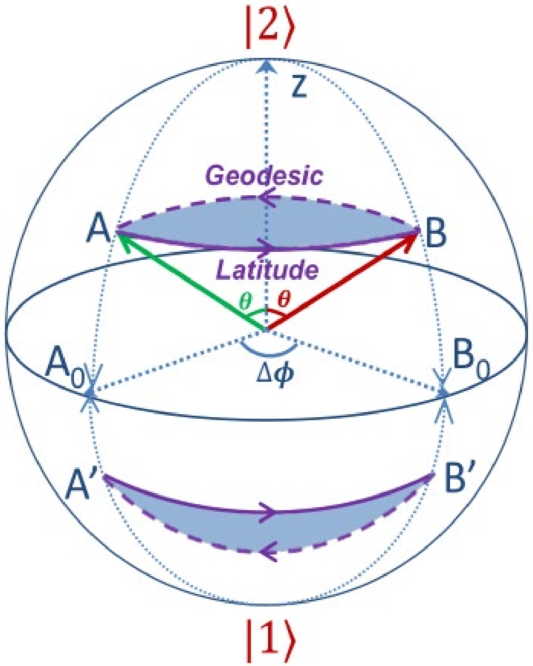


θ>π/2



Sci. Adv. 6, eaay8345 (2020).

Total phase = geometric phase + dynamical phase



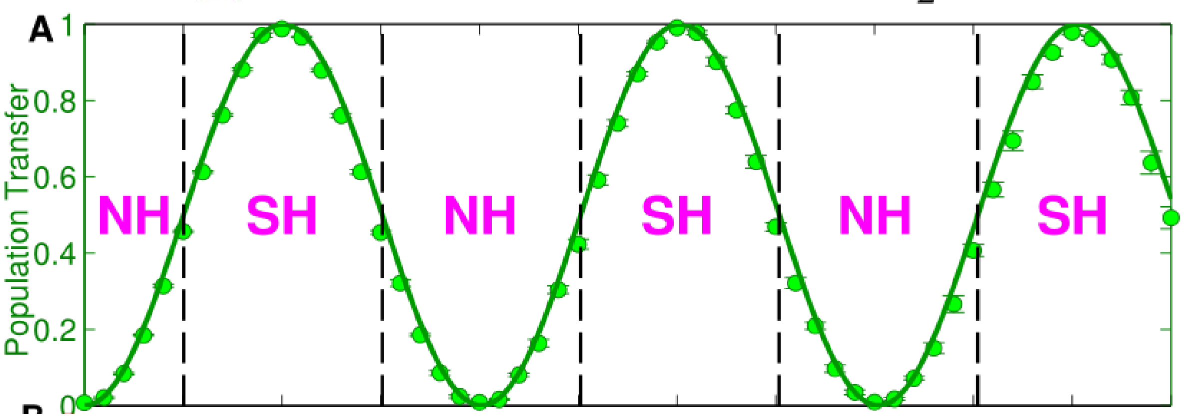
$$\Phi_G = \Phi - \Phi_D$$

$$\frac{1}{\hbar}\langle\psi(t)\,|\,H\,|\,\psi(t)\rangle$$

Y. Aharonov and J. Anandan, Phase Change during a Cyclic Quantum Evolution , Phys. Rev. Lett. 58, 1593 (1987).

$$\Phi_D = \mathrm{Im}\int^{s_2}\langle\psi(s)|\dot{\psi}(s)\rangle ds.$$

$$\psi(s) = (\cos\tfrac{\theta}{2}|2\rangle + \exp(is\Delta\phi)\sin\tfrac{\theta}{2}|1\rangle)$$



$$\Phi_D = \frac{\Delta\phi}{2}(1-\cos\theta),$$

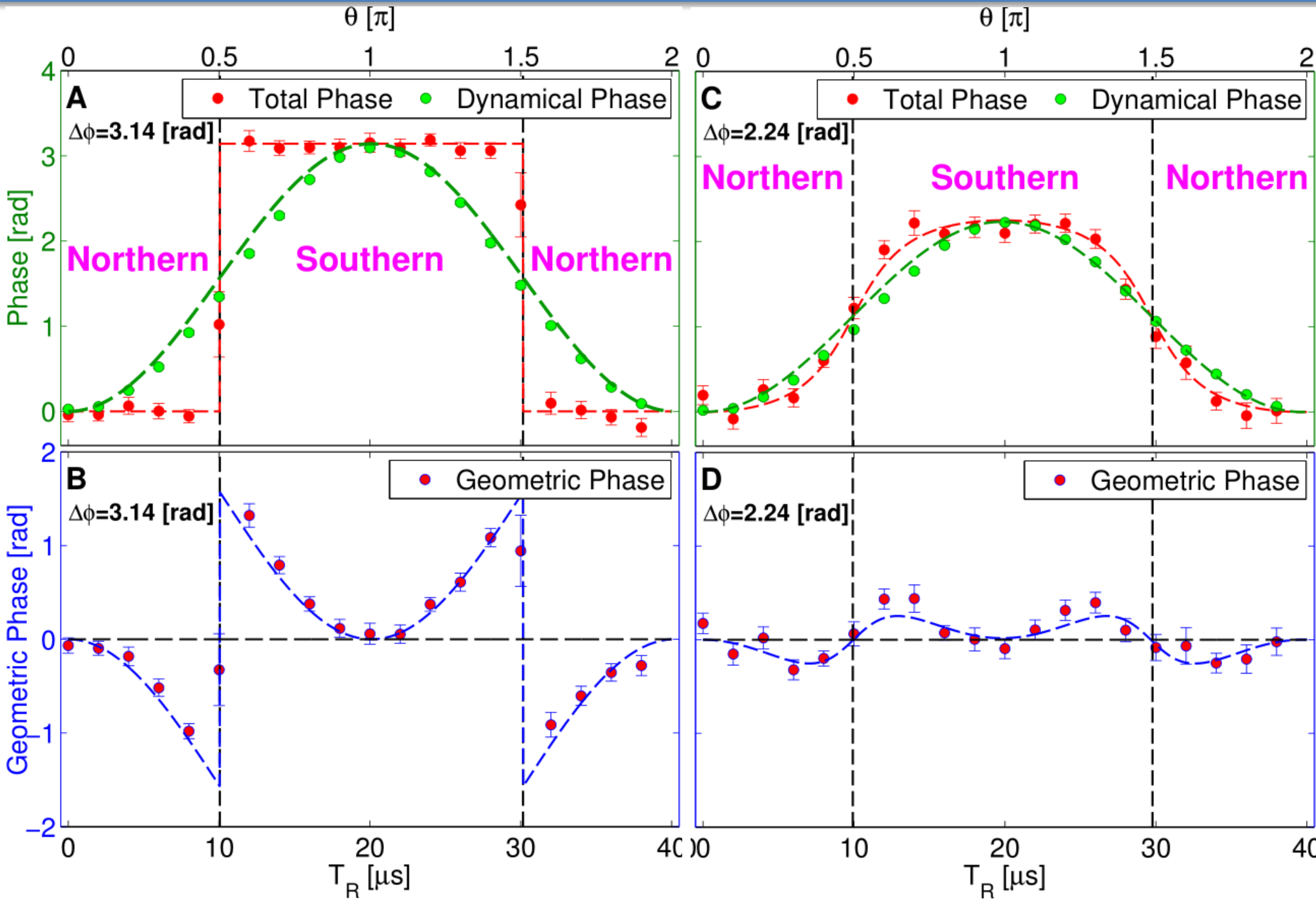
$$\frac{1-cos\theta}{2} = \sin^2\left(\frac{\theta}{2}\right)$$

Population transfer.

The population transfer is in fact a measurement of dynamical phase.

Sci. Adv. 6, eaay8345 (2020).

Geometric π phase jump and sign flip



$$\Phi_G = \arctan\left\{\frac{\sin^2(\theta/2)\sin\Delta\phi}{\cos^2(\theta/2)+\sin^2(\theta/2)\cos\Delta\phi}\right\} - \frac{\Delta\phi}{2}(1-\cos\theta)$$

arXiv:1908.03008, Science Advances, in print.

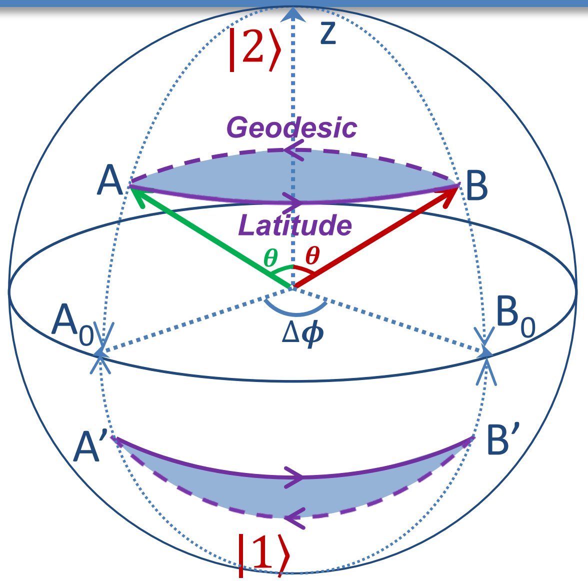
Conclusion

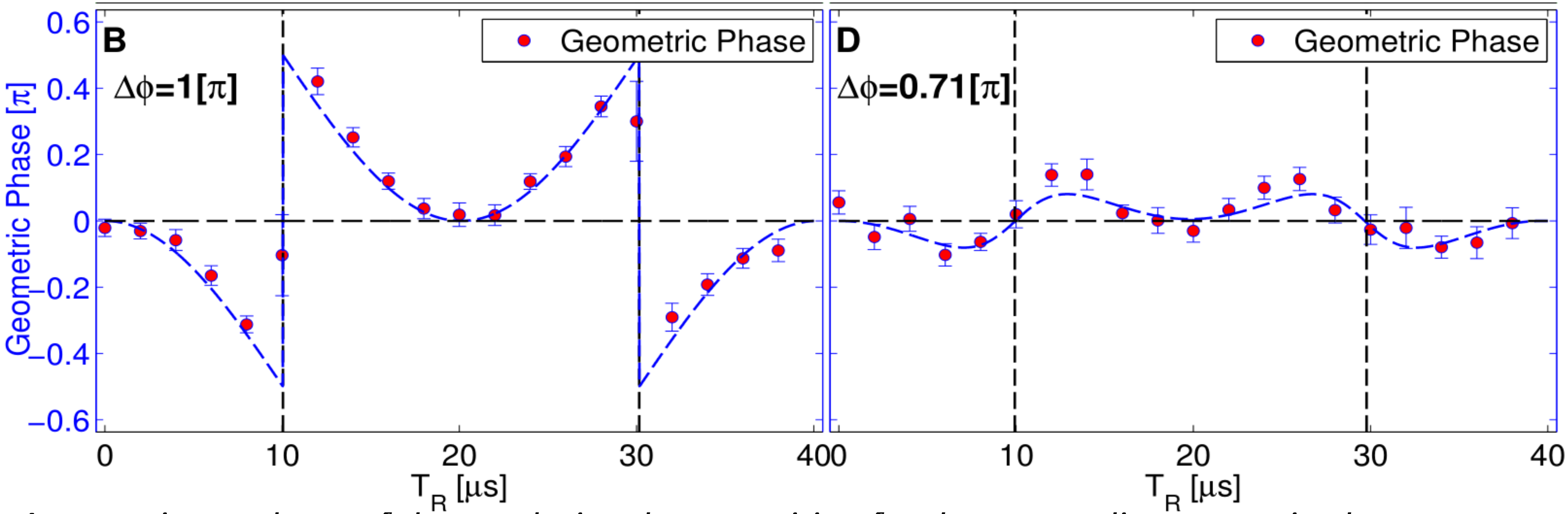
- We report a novel experimental confirmation of the geodesic rule for a non-cyclic geometric phase by means of a spatial SU(2) matter-wave interferometer.
- We demonstrate the predicted phase sign change and π jumps.
- We show the connection between our results and the Pancharatnam phase.

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, arXiv:1908.03008, Science Advances, in print.

Outlook – possible applications

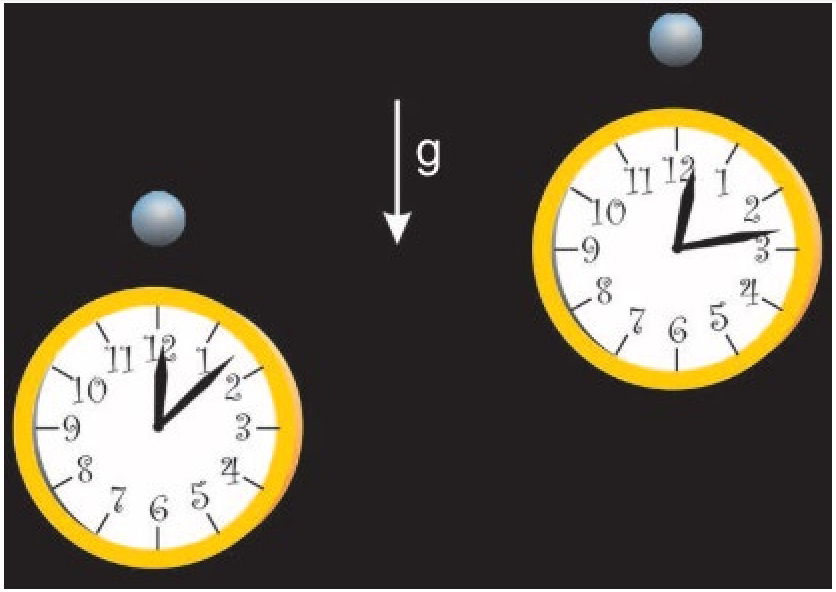
- Quantum optimal control
- Quantum geometric computing
- New sensor for gravitational detection?





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, arXiv:1908.03008

Possible new concept for gravitational sensor?



Our experiment

$$\Delta\phi = \Delta(E_1 - E_2) \times t/\hbar$$

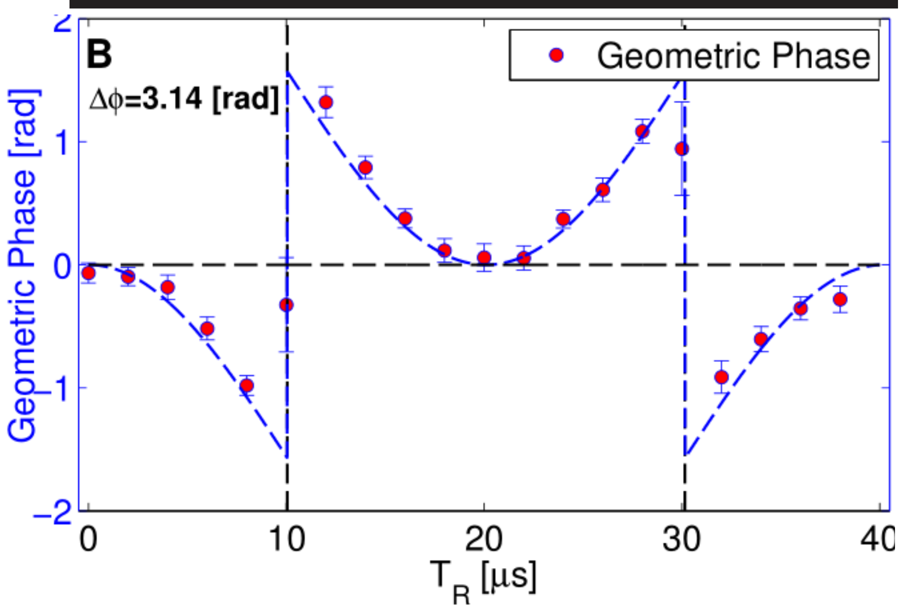
Magnetic gradient

Gravitational sensor

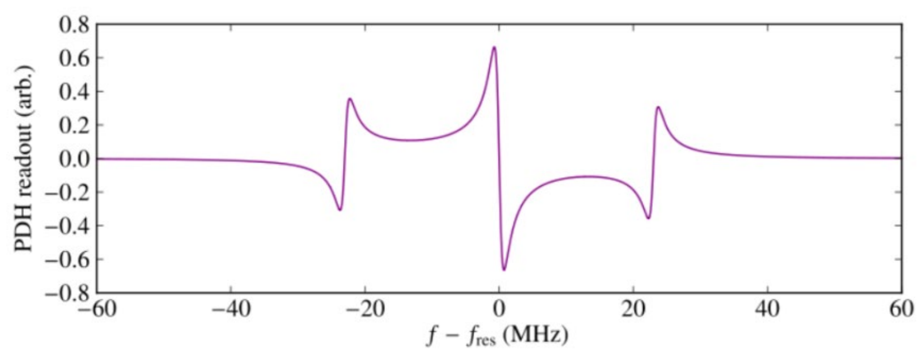
$$\Delta\phi = (E_1 - E_2) \times \Delta t/\hbar$$

Proper time

Same theory: both have a sharp phase jump.



Reminds of Pound–Drever–Hall technique



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, arXiv:1908.03008

An experimental test of the geodesic rule proposition for the non-cyclic geometric phase

Zhifan Zhou, Yair Margalit, Samuel Moukouri , Yigal Meir,

Ron Folman

arXiv:1908.03008, Science Advances(in print), *Ben-Gurion University of the Negev, Be'er Sheva, Israel*

Acknowledgements

Technical: Zina Binstock, BGU nanofabrication facility

Financing: Israel Science Foundation
EC "MatterWave" consortium
German-Israeli Project Cooperation (DIP)
Council for Higher Education (PBC)
Ministry of Immigrant Absorption
John Templeton Foundation

and thank you ... for your attention!

Atom Chip Group *http://www.bgu.ac.il/atomchip/*
Ilse Katz Institute for Nanoscale Science and Technology *http://www.bgu.ac.il/en/iki*