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Quantum interference and surface states transport in Bi and $Bi_{0.83}Sb_{0.17}$ nanowires

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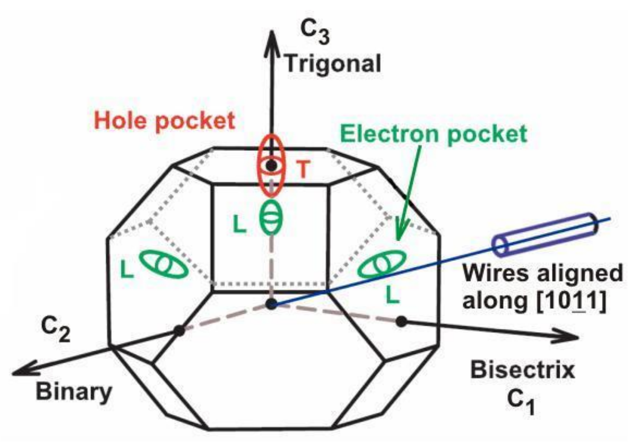
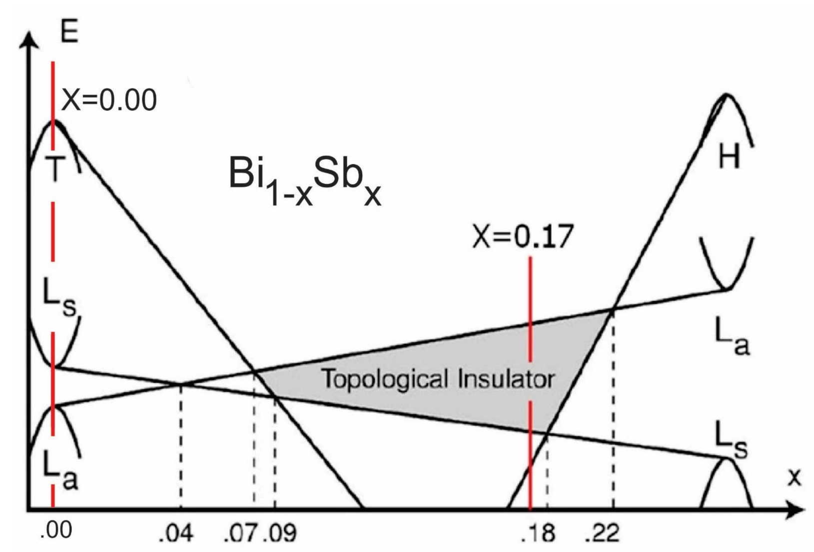
Here, we report on a study of the magnetoresistance (MR) of small-diameter individual Bi and $Bi_{0.83}Sb_{0.17}$ nanowires down to 1.5 K and for magnetic fields up to 14 T. Glass-coated single-crystal microwires were fabricated by the Ulitovsky method. The thin nanowires samples, *d* < 100 nm, that were investigated displayed pronounced *h/e* and *h/2e* resistance oscillations (Aharonov-Bohm (AB) oscillations [1]) as a function of magnetic flux. The observation of these periods is consistent with considering Bi and Bi-Sb nanowires as a tube of surface states. The most intriguing is the presence of MR oscillations equidistant in the magnetic field when the magnetic field is perpendicular to the nanowires axis, when the magnetic flux through the nanowire cross section is zero. In 45-nm Bi nanowires, the self-organization of helical edge states of Bi bilayers led to the formation of series-connected stacks of bilayers, each of which had a closed conducting loop in a transverse magnetic field which results in the appearance of AB oscillations. Apparently, a similar interpretation can be applied to $Bi_{0.83}Sb_{0.17}$ nanowires.

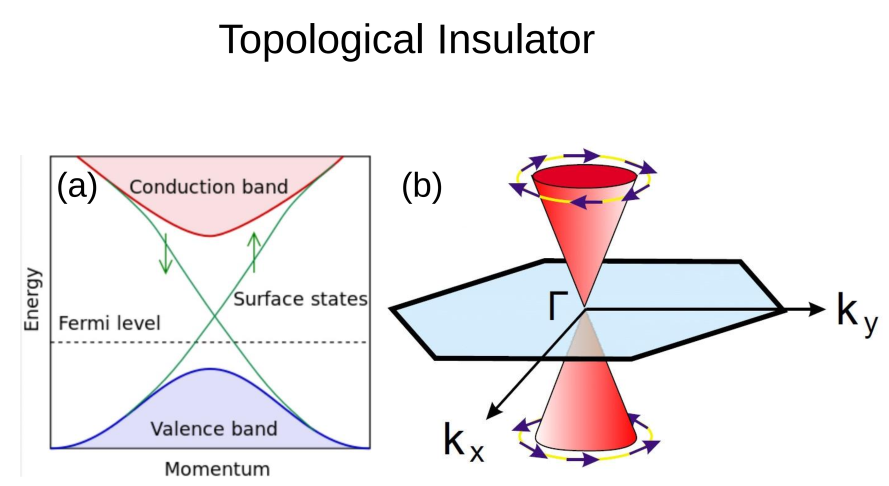
Keywords: Bi, Bi-Sb, glass-coated nanowire, magnetoresistance, topological insulator, Aharonov-Bohm oscillations.



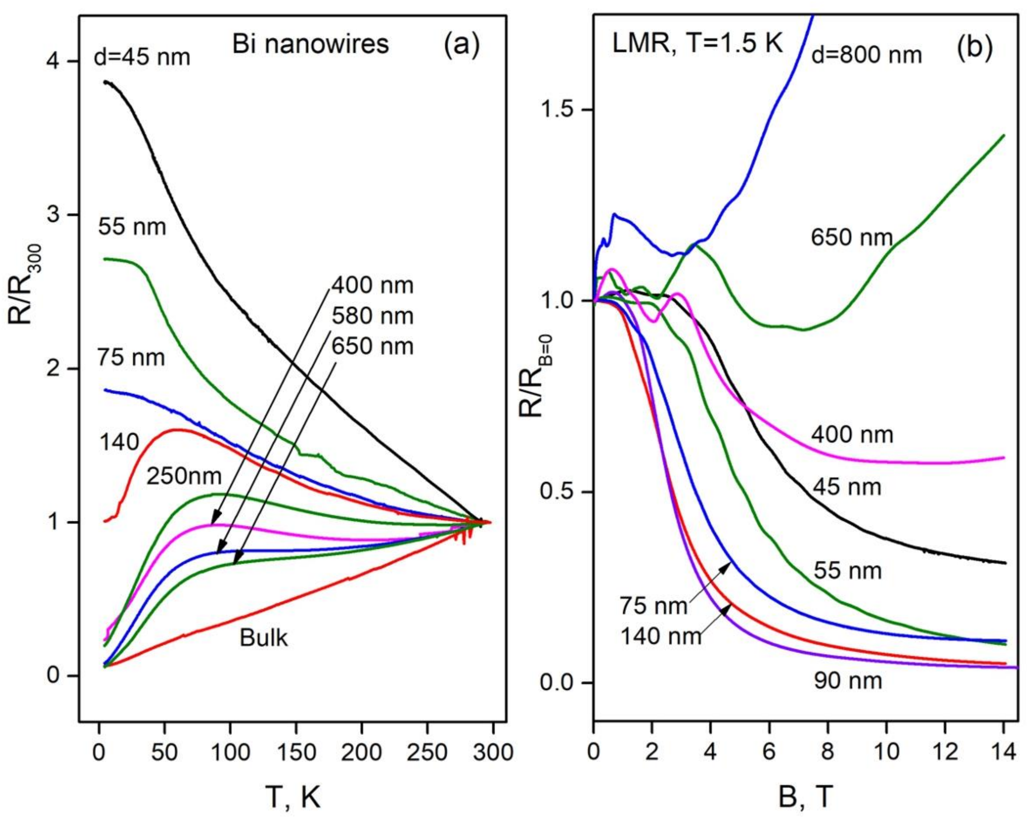
The 3-fold degenerate *L*-point electron pockets and the *T*-point hole pocket in the first Brillouin zone of bulk $Bi_{1-x}Sb_x$.



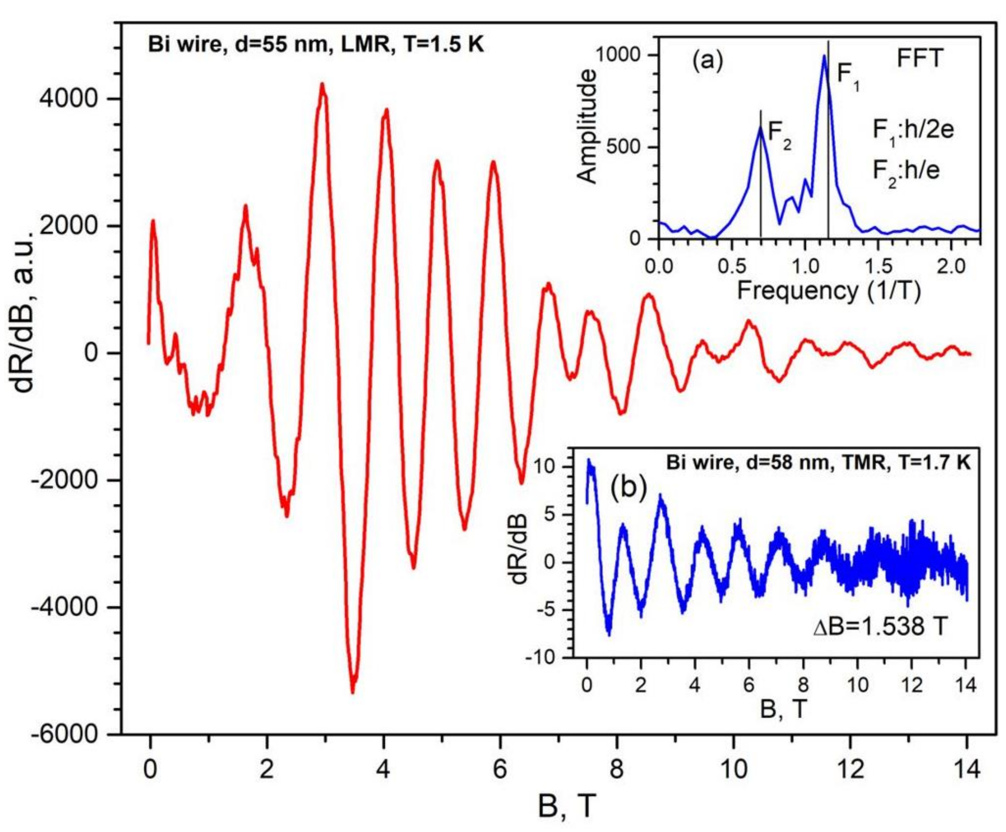
Schematic representation of band energy evolution of $Bi_{1-x}Sb_x$ as function of x.



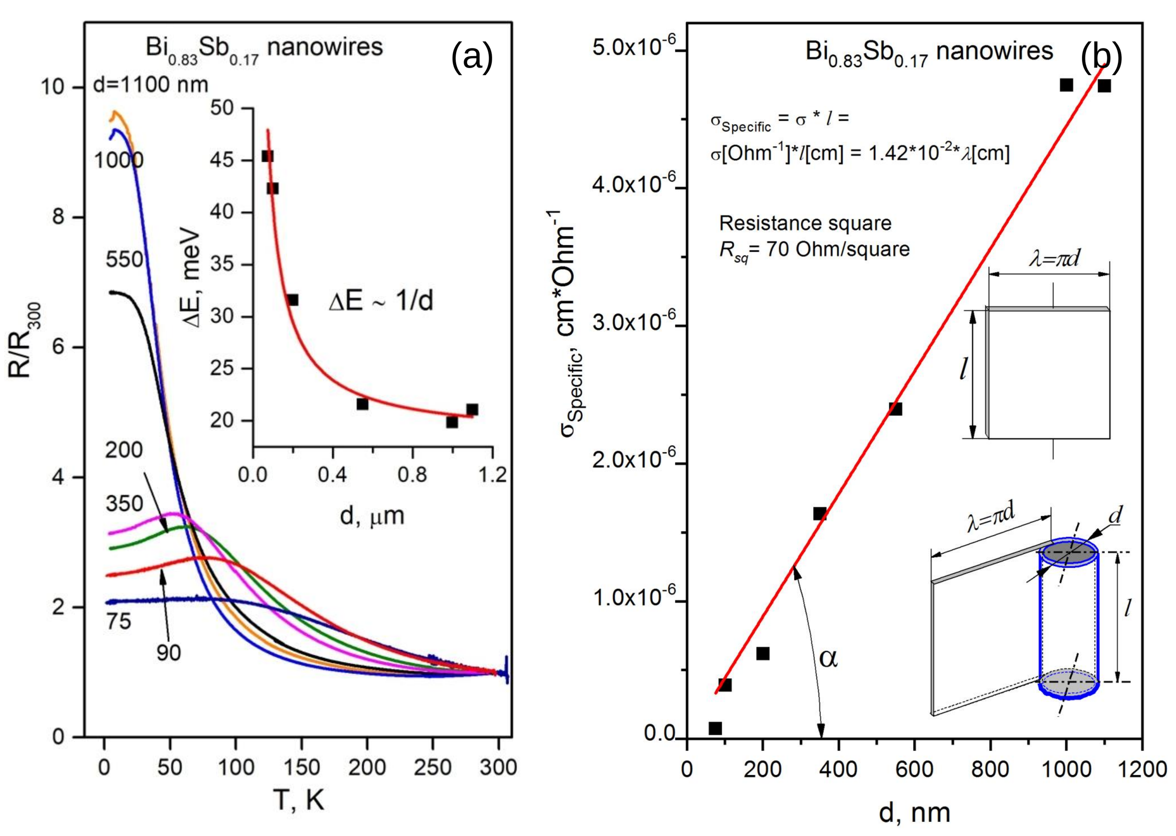
(a) Band structure for a topological insulator.
(b) Dirac dispersion and spin orientation in helical liquid on the surface of a strong topological insulator.



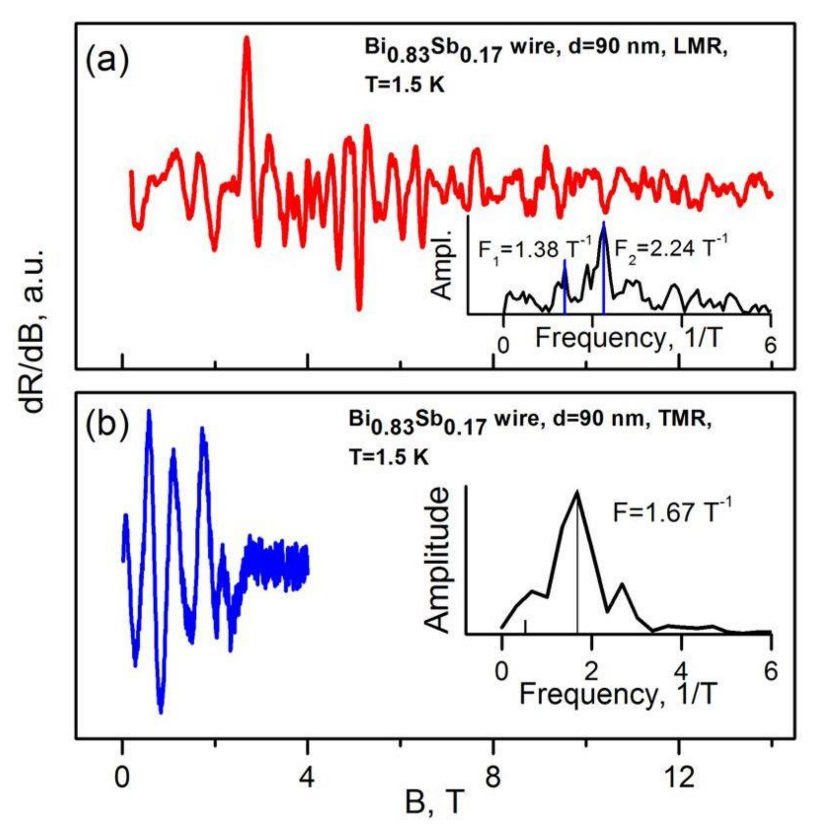
(a) Temperature dependence of the relative resistance for Bi nanowires. (b) Magnetic field dependence of the longitudinal MR for Bi nanowires, *T*=1.5 K. Longitudinal MR decreases for increasing magnetic field. This is a manifestation of the Chambers effect, which occurs when a magnetic field focuses electrons toward the core of the wire away from the surface, thereby avoiding surface collisions.



Magnetic field dependence of the derivative of longitudinal MR for 55-nm Bi nanowire, *T* = 1.5 K (the monotonic part is subtracted). Inset (a): FFT spectra of the longitudinal MR oscillations for 55-nm Bi nanowire. Inset (b): Magnetic field dependence of the derivative of transverse MR for 58-nm Bi nanowire, *T* = 1.5 K (the monotonic part is subtracted).

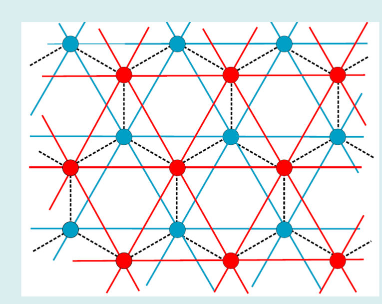


(a) Temperature dependence of the relative resistance for $Bi_{0.83}Sb_{0.17}$ nanowires. Inset: Dependence of the energy gap ΔE on $Bi_{0.83}Sb_{0.17}$ nanowires diameter. The data are well approximated by the equation $\Delta E \sim 1/d$.
(b) Dependence of specific conductivity of $Bi_{0.83}Sb_{0.17}$ nanowires on nanowire diameter at *T* =4.2 K. The square resistance R_{sq} of surface states, R_{sq}=70 Ohm is calculated from the line slope.

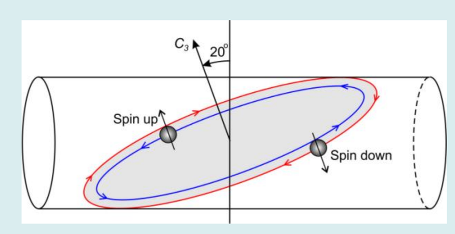


(a) Magnetic field dependence of the derivative of longitudinal MR for 90-nm $Bi_{0.83}Sb_{0.17}$ nanowire, *T* = 1.5 K (the monotonic part is subtracted). Inset: FFT spectra.
(b) Magnetic field dependence of the derivative of transverse MR for 90-nm $Bi_{0.83}Sb_{0.17}$ nanowire, *T* = 1.5 K (the monotonic part is subtracted). Inset: FFT spectra.

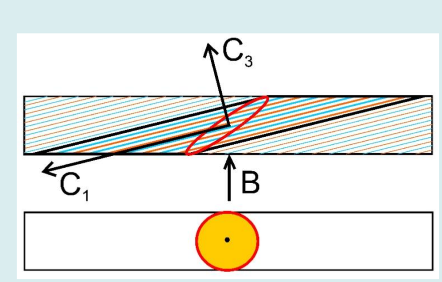
AB oscillations in a transverse magnetic field



Crystal structure of the (111)-bilayer Bi. The upper and lower layers are denoted by red and blue, respectively. 2D single-bilayer bismuth has a pair of helical edge states carrying spin currents with opposite spins. 2D bismuth is in the quantum spin-Hall phase. (S. Murakami, PRL 97, 236805 (2006)).



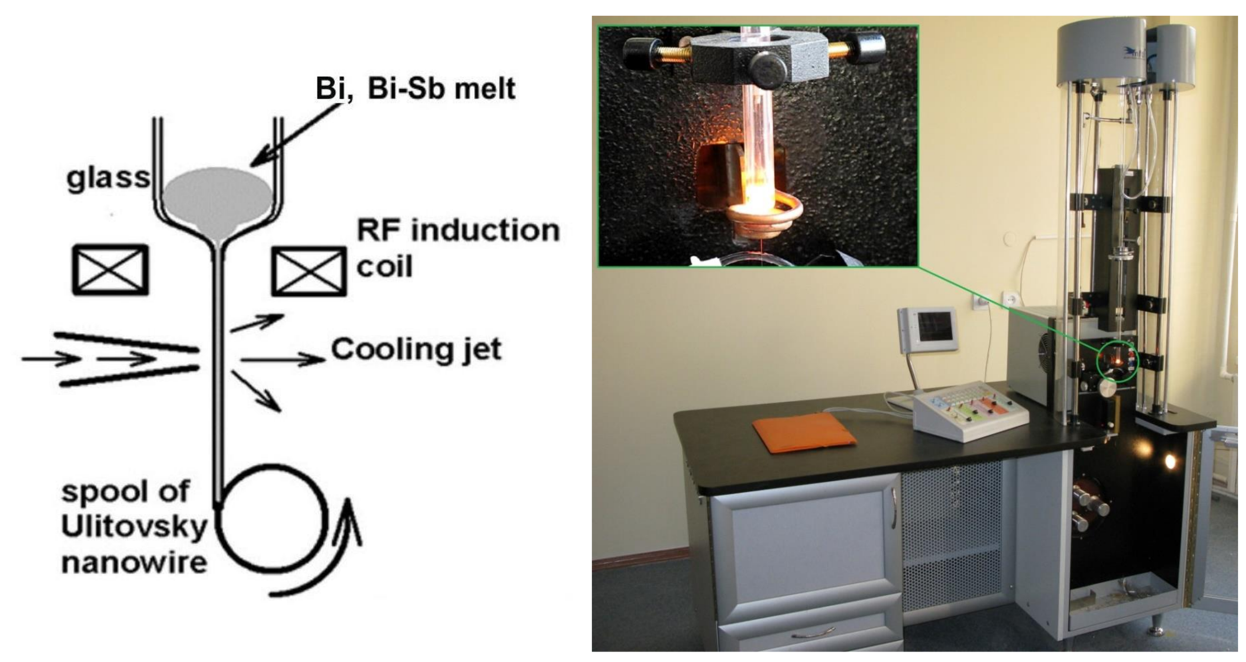
Location of the Bi bilayer in the Bi nanowire.



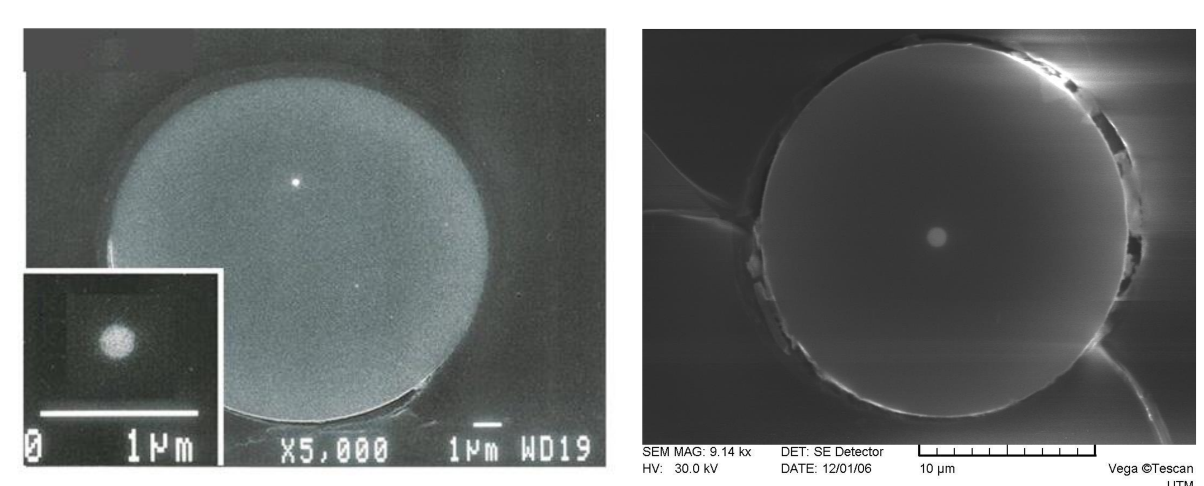
Sketch of the stack of Bi bilayers. In 58-nm Bi nanowire, the self-organization of helical edge states leads to series-connected stacks of bilayers, each of which in a transverse magnetic field contains a closed conducting loop, which results in the appearance of AB oscillations.

In 90-nm $Bi_{0.83}Sb_{0.17}$ nanowire, AB oscillations are also observed in transverse MR. Apparently, a similar interpretation of the conditions for the occurrence of AB oscillations in a transverse magnetic field is also applicable to $Bi_{0.83}Sb_{0.17}$ nanowires.

Fabrication of Bi and Bi-Sb nanowires



Installation ITMF-3, which uses Ulitovsky method for making long Bi, Bi-Sb nanowires in glass coating.



Scanning electron microscope cross sections of 220 nm and 1000 nm Bi wires in their glass coating.

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