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An excitation mechanism for torsional oscillations on the tangent cylinder

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Over the last few decades there has been much interest in torsional oscillations, wavelike motion of fluid cylinders (each co-axial with Earth's rotation axis) in the outer core. This interest has been sparked in part by the fact that they are theoretically predicted, but perhaps moreover by their two principal observational signatures. Firstly, because the waves redistribute angular momentum in the fluid core, they directly affect the rotation rate of the mantle and therefore the length of day, for which accurate time-series exist. Secondly, the secular variation signal they produce by inductive effects at the top of the core can also be identified in geomagnetic observations at the Earth's surface. Furthermore, their propagation speed inherently contains a signature of the core's internal magnetic field which couples the coaxial cylinders together: stronger magnetic fields are associated with tighter coupling and faster wave speeds, an effect used to great advantage in a very recent study (Gillet et al. 2010, Nature) which presented evidence for a much stronger internal field than previously thought.

This recent study of Gillet et al., along with several others, presented evidence that the torsional waves travel outwards from the tangent cylinder, the coaxial cylinder that is tangent to the inner core. However, so far there have been no definitive theoretical reasons why the waves should travel principally in this particular outward direction; that is, why their source should be on the tangent cylinder. For instance, if the oscillations were driven by turbulent fluctuations in the convecting core, then (other effects aside) they should travel isotropically.

In this presentation, we will provide a theoretical explanation of why a strong excitation mechanism lies on the tangent cylinder. Torsional oscillations themselves are believed to be small stable perturbations of the magnetohydrodynamic system in the core relative to a particular equilibrium state that satisfies a condition known as Taylor's constraint. In a spherical shell, as we will discuss, this picture is complicated further by a new set of conditions that guarantee continuity of the core flow on the tangent cylinder. Should these constraints be violated, certain components of the flow become not just discontinuous but singular, manifested by an infinite azimuthal jet on the tangent cylinder. Such a circumstance will not be tolerated by the magnetic field threading through the tangent cylinder, which will resist this shearing effect and will attempt to smooth out the shear layer by radiating away the problematic disturbance by a torsional wave. We suggest that such a mechanism is a principal excitation effect of the torsional oscillations and explains why they travel radially outwards from the tangent cylinder.