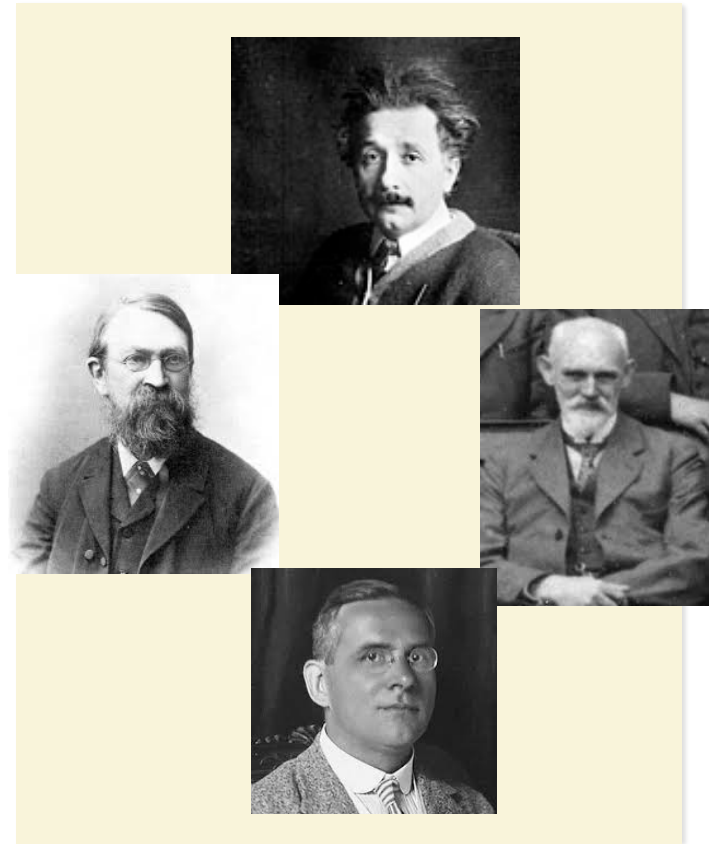
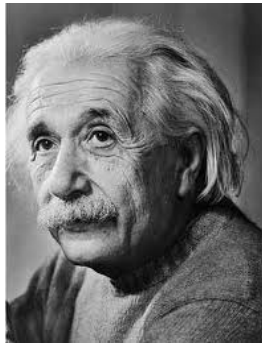


How Einstein came to employ the action-reaction principle in justifying general relativity

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H.R.B. and Dennis Lehmkuhl, '**Einstein, the reality of space, and the action-reaction principle**', in *Einstein, Tagore and the Nature of Reality*, Partha Ghose (ed.), Routledge, London and New York, 2016; pp. 9-36. arXiv:1306.4902v1.



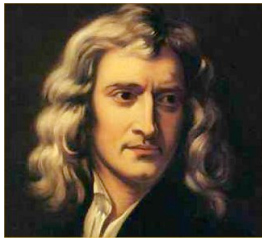
“You consider the transition to special relativity as the most essential thought of relativity, not the transition to general relativity. I consider the reverse to be correct. I see the most essential thing in the overcoming of the inertial system, **a thing which acts upon all processes, but undergoes no reaction.** The concept is in principle no better than that of the centre of the universe in Aristotelian physics.”

Letter to Georg Jaffe 1954

Action-Reaction: the nature of substance.

Plato (*Sophist* 247e3-4)

being as power



Isaac Newton “For although philosophers don’t explicitly define ‘substance’ as ‘entity that can act on things’, they all tacitly understand ‘substance’ in that way ... And they would hardly allow that something is substance if it couldn’t move or act—e.g. couldn’t arouse in the mind any sensation or perception whatever.”

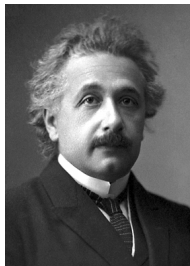
De Gravitatione c. 1666



Wilhelm Gottfried Leibniz. “I maintain also that substances, whether material or immaterial, cannot be conceived in their bare essence without any activity, activity being of the essence of substance in general.” *Philosophical Writings*, 1670

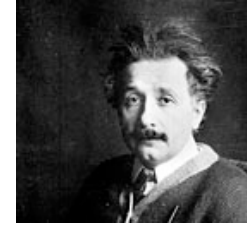
“...the notion of extension ... presupposes the substance of body, which involves the power of acting and resisting.”

Specimen Dynamicum 1695



It is “contrary to the mode of scientific thinking to conceive of a thing . . . which acts itself, but which cannot be acted upon.” 1922

Key principles in Einstein's search for a (post-SR) theory of gravity



- equivalence principle
- principle of relativity of motion (general covariance)
- Mach's principle
- conservation of energy-momentum (Brian Pitts 2015)
- existence of Newtonian limit

absent: the action-reaction principle



Einstein's struggle with Mach's principle I



1912- 19?? inertial mass a result of the action of distant bodies. *MISINTERPRETATION*
Barbour (1990)

1912-1916 **general covariance**, understood as a generalisation of the relativity principle, provides a new implementation of Mach's philosophy!

“The drift of Einstein's thought is now clear. Whereas the logic of Mach's comments called for explicit derivation of the distinguished local frames of reference from a relational law of the cosmos as a whole, Einstein is working towards elimination of the problem of the distinguished frames by asserting that they are not really distinguished at all.” Barbour (1990)

“The generalized relativity principle would go, so at least was Einstein's expectation, a long way, and might actually go all the way, towards an implementation of Mach's critique of classical mechanics in the new theory of gravitation.” Renn and Sauer (2007)

1918 **disaster!** Kretschmann's analysis of **general covariance** ...

“The fact that the general theory of relativity has no preferred space-time coordinates which stand in a determinate relation to the metric is more characteristic of the mathematical form of the theory than of its physical content.” Einstein (1924)



Einstein's struggle with Mach's principle II



1918 precise formulation of “Mach’s Principle” became the claim that the $g_{\mu\nu}$ field must be “conditioned and determined” by the mass-energy-momentum $T_{\mu\nu}$ of matter, resuscitating a view going back to 1913.

“ I myself am of the Machian opinion, which in the language of relativity theory can be put in the following way: All masses of the world together determine the $g_{\mu\nu}$ - field ... Inertia is, in my opinion, a (mediated) interaction between the masses of the world in the same sense as those effects which in Newtonian theory are considered as gravitational effects. (1921) ”

What about vacuum solutions? Einstein introduces cosmological constant in 1917.

problem: Willem de Sitter

In the years between 1918 and 1922, Einstein was forced to admit the metric field $g_{\mu\nu}$ as a dynamical player in its own right according to GR, akin to the electromagnetic field $F_{\mu\nu}$.

“ ... the properties of the space-time continuum which determine inertia must be regarded as field properties of space, analogous to the electromagnetic field. (1921) ”

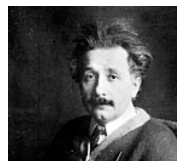
enter Moritz Schlick



Raum und Zeit in der gegenwärtigen Physik (1917)

26 letters exchanged with Einstein 1915-1920

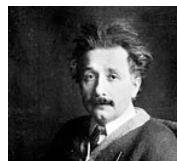
June 1920 Einstein-Schlick correspondence



“... I think it would be correct to say: Newtonian physics has to attribute objective reality to acceleration, independently of the coordinate system. This is only possible if one regards absolute space (i.e., the ether) as something real. Newton does this in a coherent way. ... What remains unsatisfactory is the circumstance that this something enters *only one way* [*nur einseitig*] into the causal chain. [...] The absolute space of Newton is independent, cannot be influenced, the $g_{\mu\nu}$ -field of general relativity is subject to laws of nature, determined by matter (not only determining). ...”



“... absolute space ... does not have to be considered [in Newtonian Mechanics] as a cause in the sense of the principle of causality. In other words: Newtonian Mechanics does not have to consider inertial resistance in the context of certain kinds of motion as an effect of an absolute acceleration. It can instead take the former as the defining criterion of the latter. ...” [Reiteration of point made in 1917]



“... physical space possesses reality according to the general theory of relativity, too, but not an independent one; for its properties are completely determined by matter. Space is incorporated into the causal nexus without playing a one-sided role in the causal chain. ...”



Einstein again

1922 It is “contrary to the mode of scientific thinking to conceive of a thing . . . which acts itself, but which cannot be acted upon.”

1924 “Each physical object influences and in general is influenced in turn by others. The latter, however, is not true of the ether of Newtonian dynamics. The inertia-producing property of this ether, in accordance with classical mechanics, is precisely *not* to be influenced, either by the configuration of matter, or by anything else. For this reason, one may call it 'absolute'.

... [in] the special theory of relativity, the ether was absolute, because its influence on inertia and light propagation was thought to be independent of physical influences of any kind ... [and] the geometry of bodies is influenced by the ether as well as the dynamics. ...

The ether of the general theory of relativity differs from that of classical mechanics or the special theory of relativity respectively, in so far as it is not 'absolute', but is determined in its locally variable properties by ponderable matter.”

final twists

1921 “[I]t is contrary to the mode of thinking in science to conceive of a thing (the space-time continuum) which acts itself but which cannot be acted upon. This is the reason why E. Mach was led to make the attempt to eliminate space as an active cause in the system of mechanics.”

1954, the year before his death, in a letter to Felix Pirani, Einstein admitted that Mach’s Principle was hopeless; he recognised that $T_{\mu\nu}$ cannot even be defined independently of $g_{\mu\nu}$.

Lehmkuhl (2011)