Mach and Interpretation of Inertial Mass

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Ernst Mach (1838-1916)
Machian physics

- Mach is attributed with a number of principles that distill his ideal of physical theorisation — what is now called "Machian physics":
  - It should be based entirely on directly observable phenomena (in line with his positivistic leanings)
  - It should completely avoid absolute space and time in favor of relative motion
  - Any phenomena that would seem attributable to absolute space and time (e.g. inertia, and centrifugal force) should instead be seen as emerging from the large scale distribution of matter in the universe.
Mach’s Principle

Origin of Inertia

130 years history
Layout

• Historical review of the concept of inertial mass
• Ernst Mach and “Mach’s principle”
• Role of Mach’s principle for Albert Einstein’s GTR
• Problems in the development of analytical expression for the Mach’s principle
• Mach’s principle in expanding space
• Contradictions of Mach’s principle with modern physics
Galileo Galilei 1564-1642

“Father” of the equivalence principle
Conclusion by Galilei

- The acceleration produced by gravity on a body is independent of its composition
Equivalence of gravitational and inertial mass from experiments

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<th>Year</th>
<th>Ratio</th>
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<td>1972</td>
<td>$1/10^{12}$</td>
<td>Braginsky</td>
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Mach’s principle

• According Mach, velocity and acceleration are not meaningful in absolute “Newton” space without any reference point
• He proposed that fixed stars could serve as the universal reference for motion
• Also he proposed that all masses in space are cause of inertia
Mach’s principle and Einstein’s general theory of relativity

- Mach’s principle was an important source of ideas for his general theory of relativity.
- Masses there in space influence local space so that it will cause inertia here.
- Einstein used this idea for his theory of gravitation.
- He could not solve analytically the problem of the cause of inertia but postulated that inertial and gravitational mass are equal. This is his (weak) equivalence principle.
Equivalence of inertial and gravitational mass
Theory

- **Newton**, Primordial property of matter (no explanation)
- **Mach**, Mass of whole space is the origin of inertia (no mechanism was presented)
- **Einstein**, Postulated that the ratio of inertial and gravitational mass is constant
Mach and Einstein

- Einstein took later distance from Mach’s principle
- Mach never accepted general theory of relativity
Analytical expression of the Mach’s principle

- Mach never gave an analytical expression
- Einstein either could not
- Main reason for this was that knowledge of the structure of space was very limited and it was not known that space is expanding
Riemann-Einstein proposal

- Space is three dimensional surface of four dimensional sphere. Finite, no boundaries
- Space was thought to be static, Einstein introduced cosmological constant to prevent space to collapse
- Einstein said later that this is biggest blunder in his life
Feynman-Suntola proposal

• Feynman speculated that space could be three dimensional surface of expanding four dimensional sphere

• Suntola developed quantitative theory based on the idea that space is three dimensional surface of expanding four sphere governed by zero energy principle
Surface of four-sphere universe
Observational support

• Space is homogenous and isotropic in large scale
• Space appears to be expanding uniformly relative to any reference point (Cosmological principle)
• Inertial force is same in all directions
• The cosmic microwave background has spherical symmetry (+small fluctuations)
New variable!

- During Mach’s time (and during the invention of GTR by Einstein) it was not known that space is expanding. This information will bring about a new problem to solve. Why does inertia appear to remain constant, despite of the dilution of masses?
Inertia in Tuomo Suntola’s model

- Spherically closed space
- Space is three dimensional surface of four sphere expanding at velocity of light
- Zero energy balance between motion of space and gravitation

Conclusion from his theory

- Inertia is work done against global gravitation = Mach’s principle
Inertia and Mach’s principle

• In Newton’s formula $F=ma$ there is no indication that inertia depends on other masses of space. The reason is that it is basically an experimental observation.

• Let’s assume that the correct formula is $F = f \cdot ma$, where function $f$ contains space dependent variables.
What are space dependent variables

• Total mass in space $M$
• Gravitational constant $G$
• Distance $R_4$ from the origin of expansion
• Expansion velocity $dR_4/dt$
Laws of physics are the same everywhere and all time

• For this reason function $f = F(M,G,R_4,dR_4/dt)$ in $F = f \cdot ma$ must be dimensionless and constant (=1)

• Also the argument of the function $f$ must be dimensionless and constant
Dimensional analysis

- The simplest argument for \( f = F(M, G, R_4, c) \) is
  \[ q = M^i \cdot R_4^j \cdot G^k \cdot c^m, \]
  where exponents \( i, j, k, m \)
  have to be found so that \( q \) is dimensionless.

- The dimension of \( q \) is then
  \[ [q] = [kg^i m^j (m^3/kgs^2)^k (m/s)^m] \]

- The only nontrivial solution turns out to be
  \( (i, j, k, m) = (1, -1, 1, -2) \)
Result

• From the previous dimensional analysis we will get the condition that inertia is constant when space is expanding: $\frac{MG}{R_4 (dR_4/dt)^2} = \text{constant}$

• The solution of this differential equation is $R_4(t) = \text{constant} \cdot t^{2/3}$, when $M$ and $G$ are assumed to be constant.

• Expansion of space is continuously decelerating!
More results

• If expansion velocity is velocity of light we will get zero energy principle
• Dimensional analysis is in full agreement with Suntolas model
• Mach’s principle don’t predict dark energy
Relation of Mach’s principle with modern physics

- Mach’s principle don’t predict accelerated expansion of space and dark energy

  C.S. Unnikrishnan

  “A Universe with its dynamics dominated by a vacuum energy density does not seem appealing”

Relation of Mach’s principle with modern physics

- Dark energy and accelerated expansion of space is in contradiction of Mach’s principle also according Suntola
Higgs particle

• Mach’s principle predicts that inertia is caused by other masses in space by gravitational interaction
• No Higgs particle or field is needed to explain inertial mass
Higgs particle; sceptical views

• Unnikrishnan wrote in June 2012 paper “One Good Reason Why Not The Higgs”
• Ari Lehto has shown that masses of the particles have origin in period doubling (symmetry braking) of Planck’s mass. No Higgs field is assumed
Final conclusion

- Mach’s interpretation of inertial mass has been accepted more or less 130 years.
- Scholars have discussed if the Mach’s principle and general theory of relativity comply. Most of them agree, not all like Einstein himself.
- However, Mach’s principle contradicts now the hottest topics of modern physics; dark energy and Higgs particle. This is so grave that scientific community seems to avoid open discussions on this question.