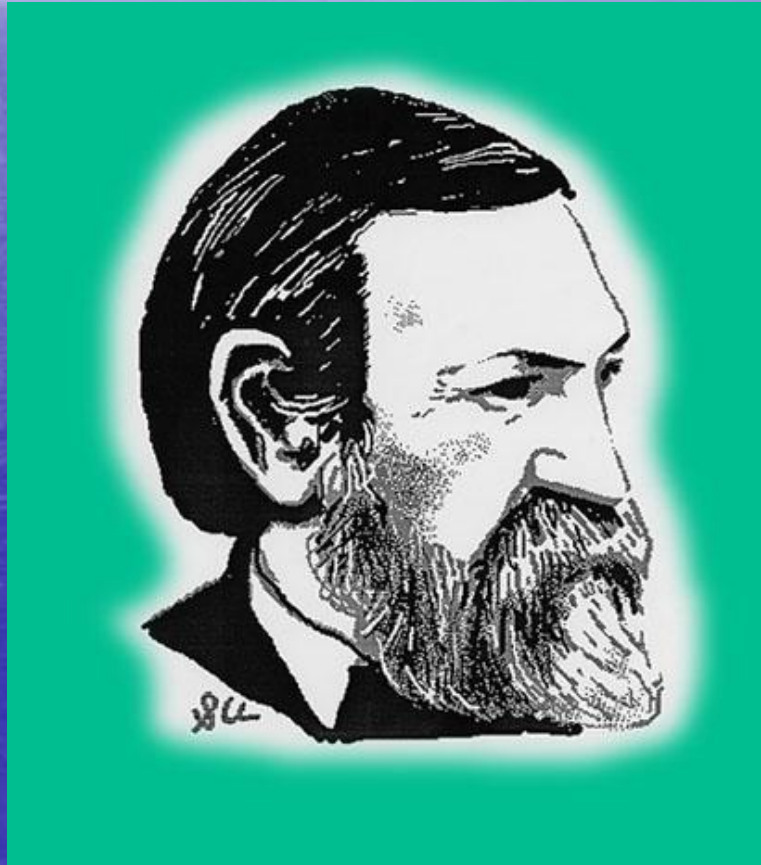# Mach and Interpretation of Inertial Mass

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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 <u>absolute space and time</u> in favor of <u>relative motion</u>

- Any phenomena that would seem attributable to absolute space and time (e.g. <u>inertia</u>, and <u>centrifugal force</u>) 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

- 1620 $2/10^3$ Galilei
- 1692 $1/10^3$ Newton
- 1889 $5/10^9$ Eötvös
- 1964 $1/10^{11}$ Dicke
- 1972 $1/10^{12}$ Braginsky

Mach's principle

- According Mach, velocity and acceleration are not meaningfull 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 important source of ideas for general theory of relativity
- Masses there in space influence local space that it will cause inertia here.
- Einstein used this idea for his theory of gravitation
- He could not solve analytically 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 · 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: $MG/[R_4 \cdot (dR_4/dt)^2] = constant$

- The solution of this differential equation is $R_4(t) = constant \cdot t^{2/3}$, 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"

  Proceedings of the International Workshop on Mach's Principle

 and the Origin of Inertia held at the Indian Institute of

Technology, Kharagpur, India, Feb. 6-8, 2002.

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.