

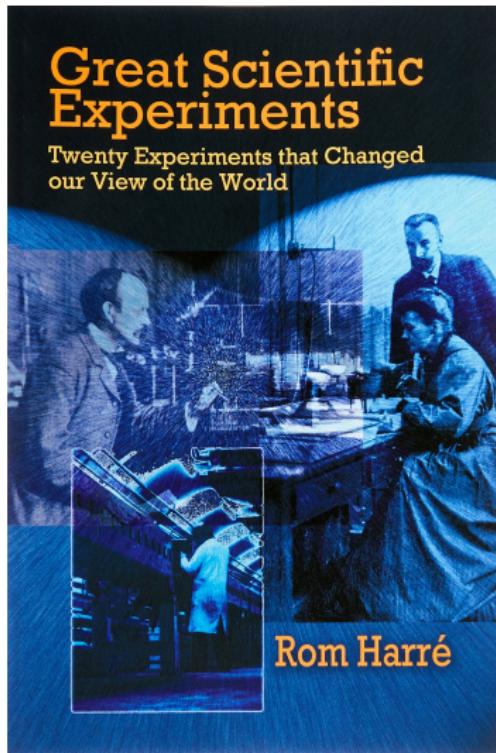
# Great Scientific Experiments

Arnaud Legrand and Jean-Marc Vincent

Scientific Methodology and Performance Evaluationxs

# Plagiarism Alert

All these slides should be considered as an advertising for:



Rom Harré in Tartu, at the philosophy of science workshop of the Institute of Philosophy and Semiotics. 2011

# Finding out about Nature

*What is fire/heat/light ? Why do we die ? ...*

## Building Theories

- Observation = unfolding of nature without intervention
  - Used to devise theories (**inductivism**)
- Experiments = action on nature
  - Used to refute/test theories (**fallabilism**)

## Apparatus

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## Apparatus

- ① Measure
- ② Extend our senses
- ③ Keep some parameters constant

# Outline

## ① Formal Aspects of Method

Exploring the Characteristics of a Naturally Occurring Process

Deciding between Rival Hypothesis

Finding the Form of a Law Inductively

The use of Models to Simulate otherwise Unsearchable Processes

Exploiting an Accident

Null Results

## ② Developing the Content of a Theory (**one day maybe**)

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Existence Proofs

The Decomposition of an Apparently Simple Phenomenon

The Demonstration of Underlying Unity within Apparent Variety

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# Aristotle



## Theories of organic generation before Aristotle

- Filling out a pre-existing plan ? (pre-formation)
- Stage by stage (epi-genesis)

384 BC → 322 BC

# Aristotle

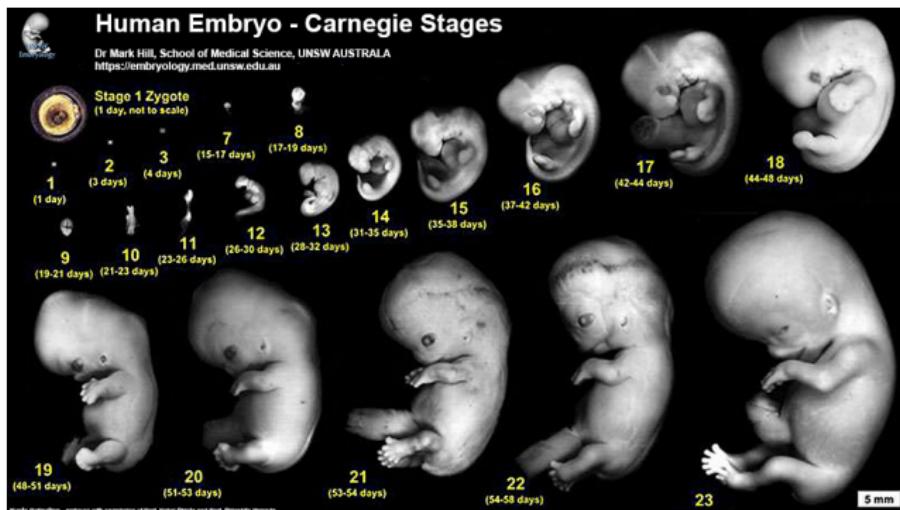


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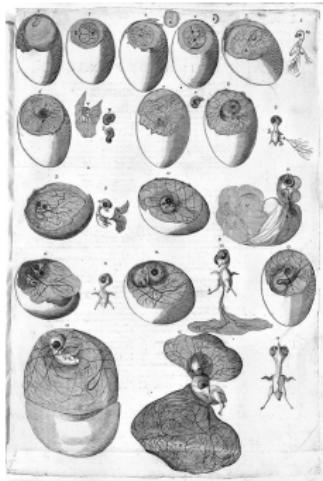
384 BC → 322 BC

## Modern view



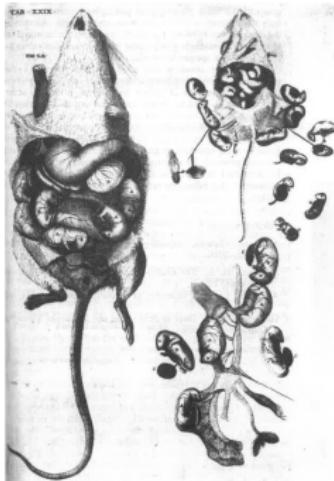
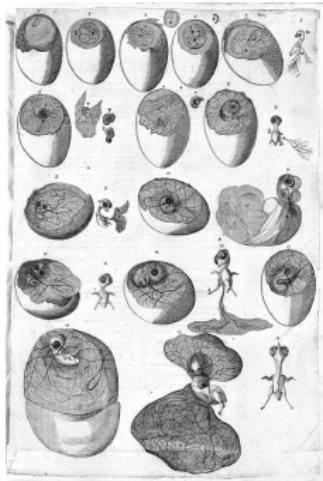
# Aristotle: *The Embryology of the Chick*

*Take 20 eggs or more, and set them for brooding under two or more hens. Then on each day of incubation from the second to the last, that of hatching, remove one egg and open it for examination. You will find that everything agrees with what I have said, to the extent that nature of bird ought to be compared with that of a man.*



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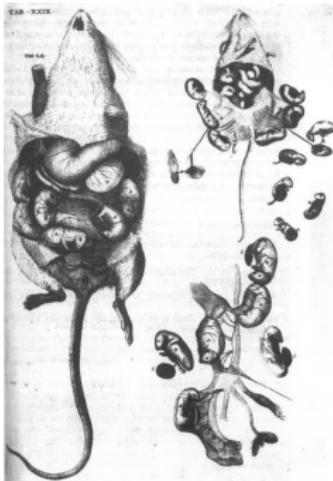
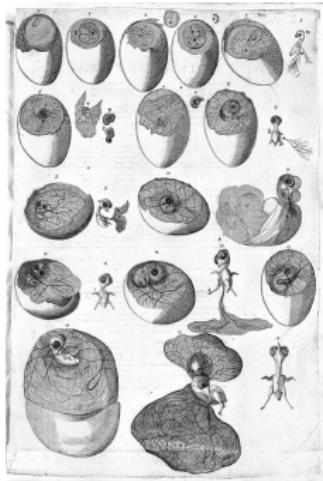
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Engravings from H. Fabricius  
*De formatione Ovi et Pulli* (1621)  
*De formato Foetu* (1604)

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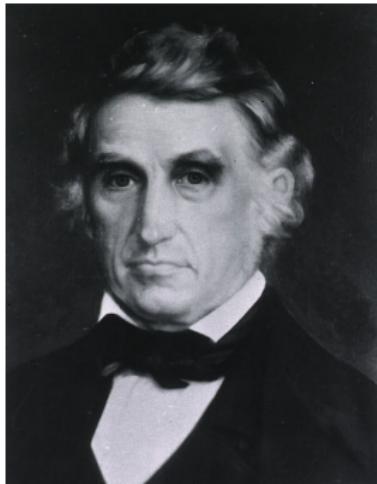
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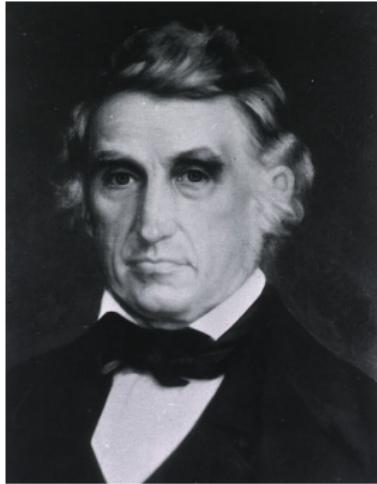
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A natural process was isolated and systematically observed. Its unfolding was not able to be controlled.

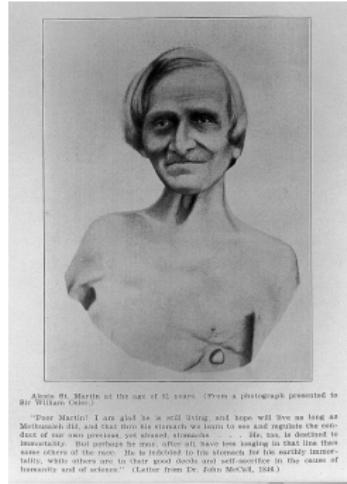
William Beaumont: *The process of Digestion as Chemistry*



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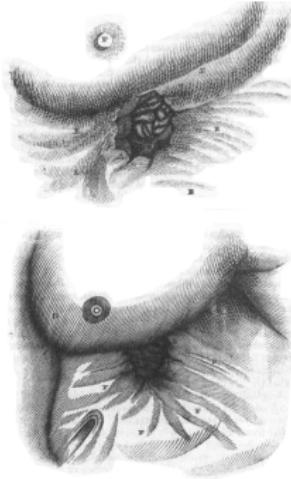
1785 - 1853



Alexis St Martin (1794 - 1880), wounded in 1822

## Early theories and work on digestion

- Digestion = cooking brought by the heat of stomach (coction), special vital force
- 1662: van Helmont, acid + ferment



Alexis St Martin at the age of 85 years. (From a photograph presented to Sir William Osler.)

"Dear Martin! I am glad to still living, and hope will live as long as God sees fit. I have been able to contribute to the happiness and success of our own species, yet should strenuously . . . He, too, is destined to immortality. But perhaps he may, after all, have less longing in that line than some others. He has, however, done much good, and has nobly interceded, with others and to their good deeds and self-sacrifice in the cause of humanity and of science." (Letter from Dr. John McClell, 1844.)

# WILLIAM Beaumont: *The process of Digestion as Chemistry*

*Showcng the mean time of digestion of the different Articles of Diet, naturally in the Stomach, and artificially in Vials, at a bath.*

The proportion of gastric juice to aliment, in artificial digestion, was generally calculated at one ounce of the former to one drachm of the latter, being kept near practical temperature 60° reinekein,

	Measures of classification		
	boiled	do.	do.
Tupio	15	5	
Barley,	2 00	30	
Milk,	3 00		
	2 00	15	
	2 00	45	
Pig's fo. sons	1 00		
Tripe, do.	1 00		
Brains, instl.		do.	30
	boiled	15	
Spinal marrow, animal	2 40	do.	
Turkey, domesticated	3 30		
	roasted		
Duck, wild,	2 10		
Goose, do.	2 30		
Pig, sucking	2 30		
Lamb, fresh,	boiled	30	
Lamb, fresh,	do.	30	
Chicken, full grown	grecia's 2 45		
Eggs, fresh	hhd. 30	bld.	60
Do. do.	soft	do.	
Do. do.	3 30		
Do. do.	poasted	2 15	
Do. do.		15	
Do. whipped		15	
Castard,		whipped	
	2 45	baked	30
Codfish, codc. dry,	2 00		

*Show ing the temperature of the interior of the Stomach, in different conditions, taken in different seasons of the year, and at various times of the day, from 5 o'clock in the morning, till 12 o'clock at night.*

A logical and lengthy set of experiments

- Gastric juice = solvent

*capable even out of the stomach* of effecting perfect digestion with the aid of due and uniform degree of heat ( $100^{\circ}\text{F}$ ) and gentle agitation. [...]

*I'm impelled by the weight of evidence to conclude that the change affected by it on the aliment, is purely chemical*

- A unique walking apparatus. Only one stomach was ever involved but the scientific community never doubted that Beaumont's results applied to the stomachs of all mankind. No one questioned the principle that one stomach is very like another (intensive design vs. extensive design).

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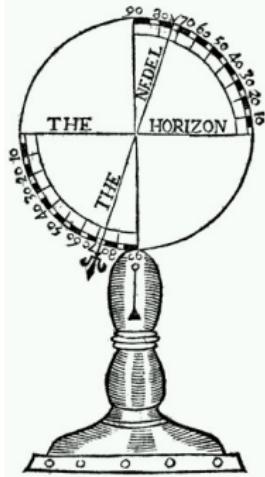
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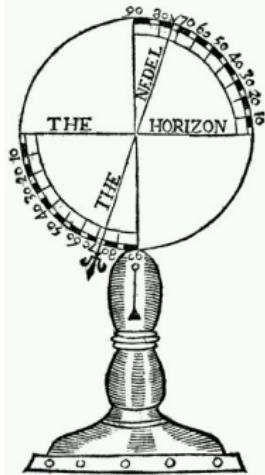
# Robert Norman: *The discovery of Dim and the Field Concept*

- The **dip**: an irritating anomaly

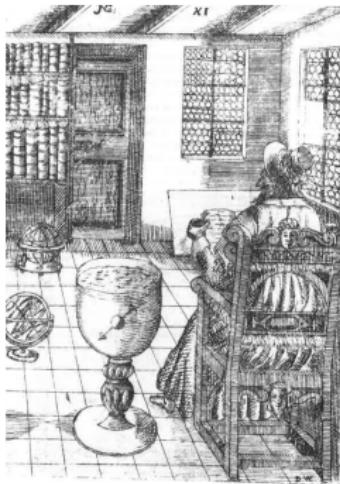


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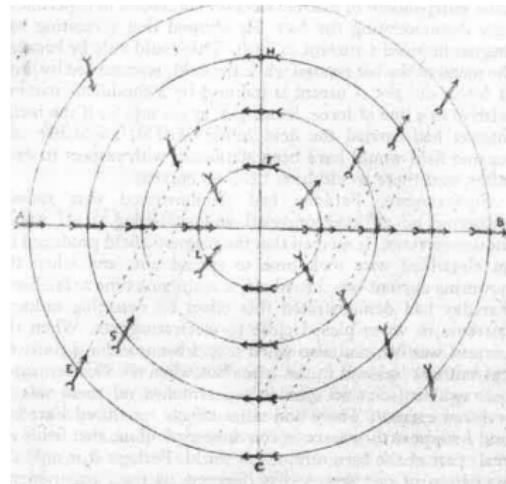
- The **dip**: an irritating anomaly



*The Newe Attractive* (1581)



*Gilbert De Magnete* (1628)



- **Attraction** : the Field and the 'wine glass' experiments with a needle floating in water

Both a **refutation** and an **illustration** of the field concept.

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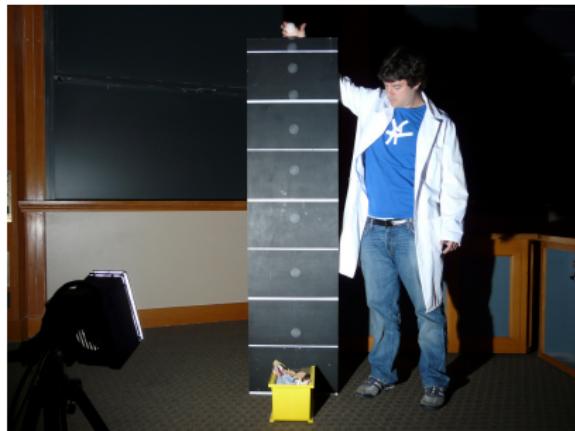
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# Galileo: *The Law of Descent*

A uniformly accelerating body will cover a distance equal to what he would have covered in the time, if it had been moving uniformly at its mean velocity ( $D = \frac{v_0 + v_f}{2} t$ )

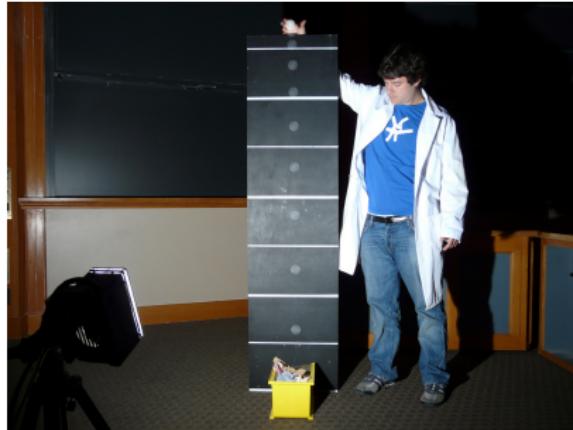
How we teach nowadays



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How we teach nowadays



A replica made in 1775



Merton's theorem  $\approx$  14th century

Galileo made a careful distinction between **mathematical study** of motion and **empirical study** of movement

A **demonstration** of the power of a theory

How Galileo (1564 - 1642) demonstrated in 1603



# Robert Boyle: *The Measurement of the Spring of the Air*



The study of gases prior to Boyle

- Nature and even the possibility of the *vacuum*.

## Robert Boyle: *The Measurement of the Spring of the Air*



*A table of the rarefaction of the air.*

	<i>A</i>	<i>B</i>	<i>C</i>	<i>D</i>	<i>E</i>
<i>A.</i> The number of equal spaces at the top of the tube, that contained the same parcel of air.	1	100	29½	29½	
	1½	10½	19½	19½	
	2	15½	14½	14½	
<i>B.</i> The height of the mercurial cylinder, that together with the spring of the included, air counterbalanced the pressure of the atmosphere.	3	10½	9½	9½	
	4	22½	7½	7½	
	5	24½	5½	5½	
	6	24½	4½	4½	
	7	25½	4½	4½	
	8	6½	3½	3½	
<i>C.</i> The pressure of the atmosphere.	9	26½	3½	3½	
<i>D.</i> The complement of <i>B</i> to <i>C</i> , exhibiting the pressure sustained by the included air.	10	26½	3½	3½	
	12	27½	2½	2½	
	14	27½	2½	2½	
	16	27½	2½	2½	
	18	27½	1½	1½	
<i>E.</i> What that pressure should be, according to the hypothesis.	20	28½	1½	1½	
	24	28½	1½	1½	
	28	28½	1½	1½	
	32	28½	1½	1½	
			Subtracted from 29½ leaves		

## The study of gases prior to Boyle

- Nature and even the possibility of the *vacuum*.
  - Boyle thought it was due to the very expensive nature of the air:  $P \times V = \text{constant}$

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- Nature and even the possibility of the *vacuum*.
- Boyle thought it was due to the very expensive nature of the air:  $P \times (V - a) = \text{constant}$  (by Amagat in 1899)

*I shall not venture to determine whether or no the intimated theory will hold universally and precisely [...] No one perhaps yet knows how near to an infinite compression the air may be capable of, if the compressing force can be competently increased.*

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## Theodoric of Freibourg: *The causes of the Rainbow*

- How are colours formed and why are they always in the same order?
- Why does it have such a unvarying geometrical form?

### The state of rainbow studies before Theodoric

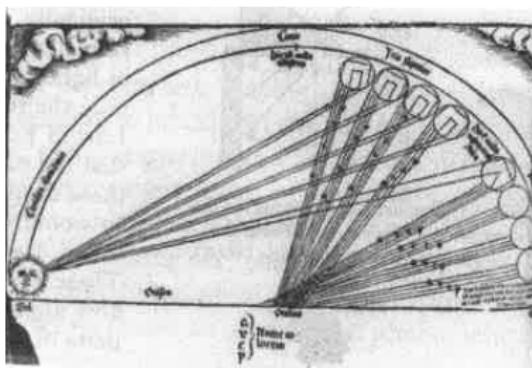
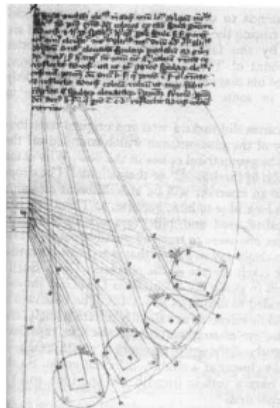
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- Reflection of the circular disc of the sun

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← *De Iride*, 1304-1311

A wildly wrong theory of colors though carefully and honestly verified by experience

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# Louis Pasteur: *The preparation of Artificial Vaccines*

## Disease theory before Pasteur

- van Helmont (1626) proposed that diseases should be looked as the effect of an invasion of the body by an army of alien beings (*archae*) that produced poisonous waste
- Popular belief: malfunctions of the diseased organism, bad smells cause diseases, observed microbes were considered as side-effect



1822 - 1895

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1822 - 1895

*Chances favors only the prepared mind.*

*"by simply changing the process [...];  
by merely placing a longer interval [...] we have obtained a method"*

Define virulence and study it **systematically**

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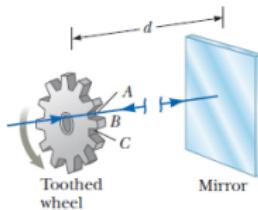
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# Michelson and Morley: *The Impossibility of Detecting the Motion of the Earth*

## The situation prior the Michelson-Morley experiment

- Light must have a finite velocity (thought as stream of particles, evidence from astrological observation, 1675)



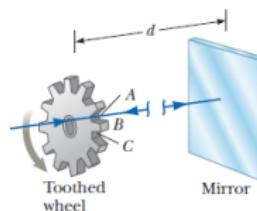
Fizeau, 1849

With  $d \approx 8\text{km}$ ,  
 $v \approx 315,000\text{km/s}$

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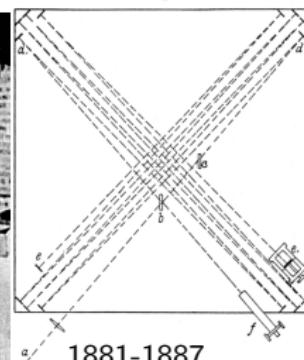
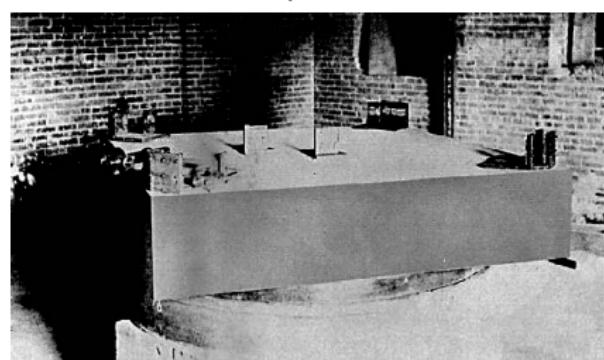
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With  $d \approx 8\text{km}$ ,  
 $v \approx 315,000\text{km/s}$



- $\text{Shift} = Dv^2/c^2$ , hence 0.04 fringe distance in theory
- Increased distance with mirrors and got rid of vibrations with a bath of mercury

## Further thoughts:

- Maybe the apparatus contracts itself (intra-molecular forces could be transmitted through the ether)
- Einstein's reformulation of Physics laws

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The Demonstration of Underlying Unity within Apparent Variety

## ③ Technique (**one day maybe**)

Accuracy and Care in Manipulation

The Power and Versatility of Apparatus