

The making of a legacy

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Einstein's Legacy

- ◆ Putting Symmetry First
- ◆ Dynamical Space-Time
- ◆ Physical Cosmology
- ◆ Unification

Einstein's Legacy

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- ◆ **Dynamical Space-Time**
- ◆ **Physical Cosmology**
- ◆ **Unification**

Putting Symmetry First

“Now the relativity theory is based on nothing but the idea of invariance, and develops from it the conception of tensors as a matter of necessity...”

The Wave Equations of the Electron (1928)

Charles G. Darwin

(1887-1962)

Putting Symmetry First

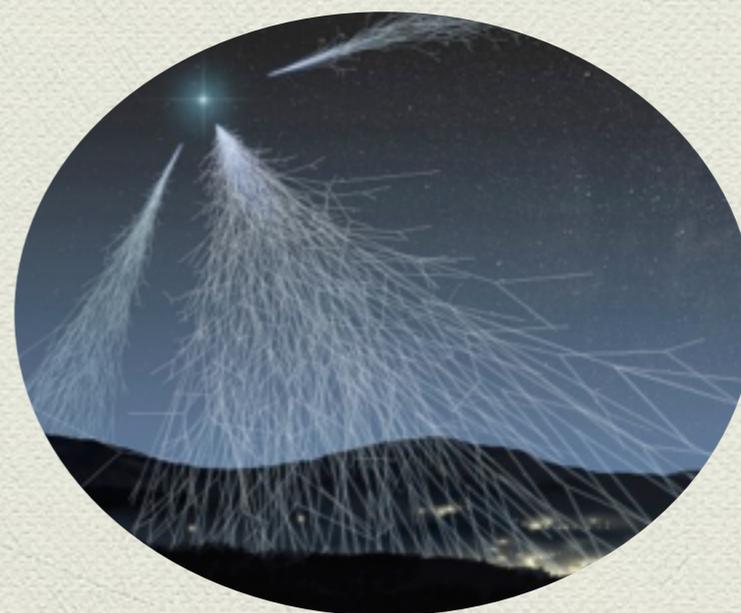
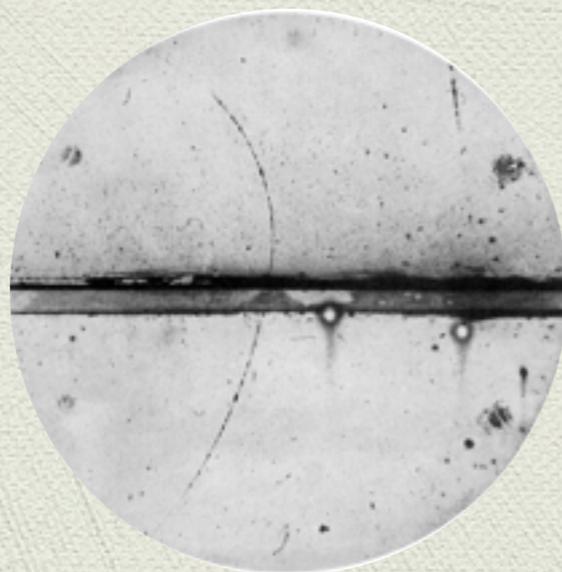
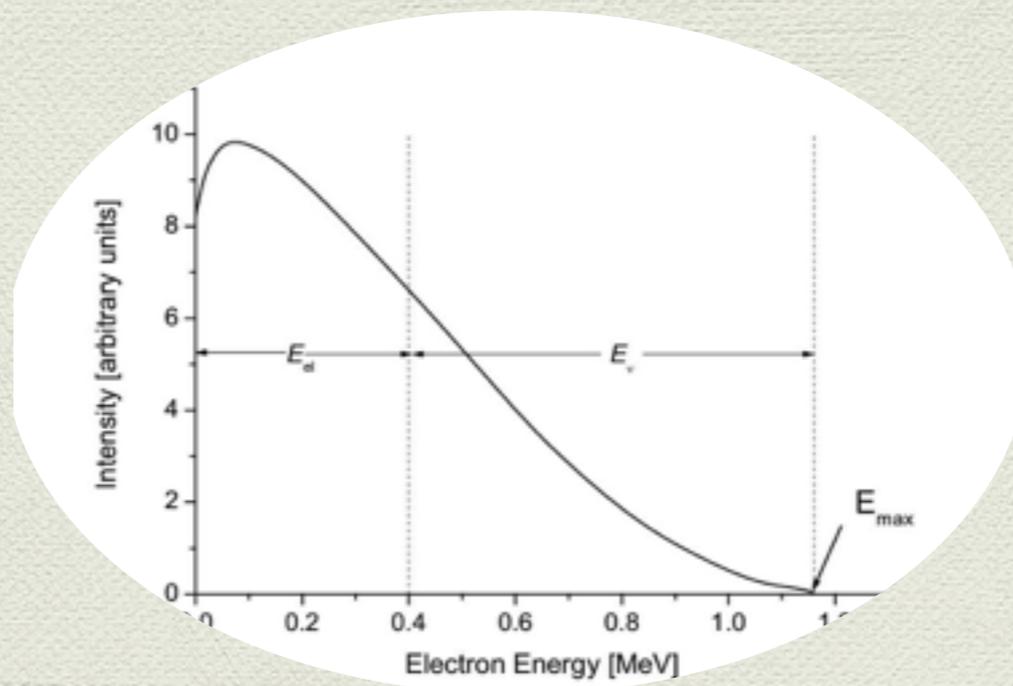
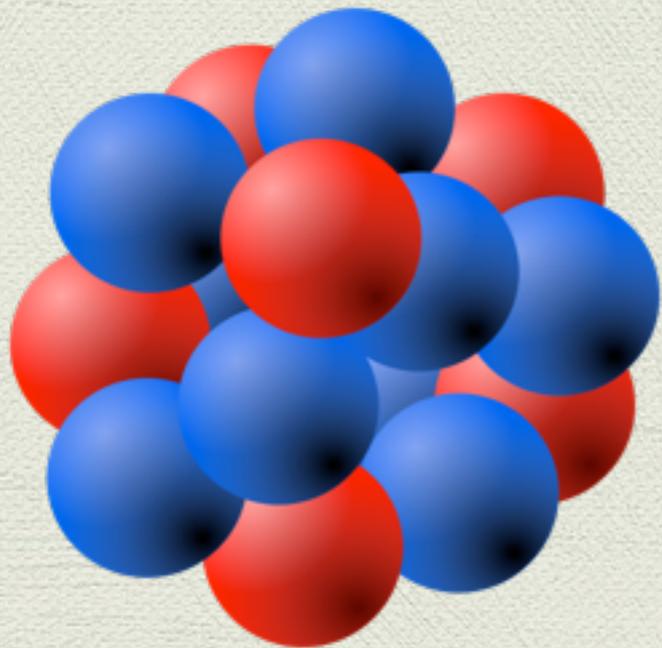
“...and it is rather disconcerting to find that apparently something has slipped through the net, so that physical quantities exist which it would be, to say the least, very artificial and inconvenient to express as tensors.”

The Wave Equations of the Electron (1928)

Charles G. Darwin

(1887-1962)

Putting Symmetry First



Putting Symmetry First

“It also seems logically satisfying to me, that in a theory in which the rest masses of the particles are arbitrary, the spin should be arbitrary as well.”

Letter to Heisenberg, May 1938

Wolfgang Pauli

(1900-1958)

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Dynamical Space-Time

„ In the particular case of spin 2, rest-mass zero, the equations agree [...] with Einstein's equations for gravitational waves in general relativity...“

On relativistic wave equations for particles of arbitrary spin in an electromagnetic field (1939)

Markus Fierz
(1912-2006) and
Wolfgang Pauli

Dynamical Space-Time

„One can either say that physical space-time is really curved and that the flat space [...] is only for convenience in calculation, or one can say that physical spacetime is flat and the [metric tensor of GR] is not a metric tensor but only a gravitational tensor.“

Nathan Rosen
(1905-1995)

General Relativity and Flat Space (1939)
Draft Manuscript sent to Einstein

Dynamical Space-Time

„[W]e can regard the Minkowskian space as the zero-th order approximation to the Riemannian space. Moreover, by expanding all the field quantities in powers of [Newton's constant], it is possible to express as expansions in the Minkowskian space. This procedure does not involve any departure from Einstein's ideas.“

Suraj N. Gupta

Quantization of Einstein's Gravitational Field: General Treatment
(1952)

Dynamical Space-Time

„[W]e imagine that in some small region of the universe, say a planet such as Venus, we have scientists who know all about the other thirty fields of the universe, who know just what we do about nucleons, mesons, etc., but who do not know about gravitation. And suddenly, an amazing new experiment is performed which shows that two large neutral masses attract each other with a very, very tiny force...

Richard Feynman
(1918-1988)

Lectures on Gravitation (1962/63)

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Physical Cosmology

“In my opinion, it would be unsatisfactory if a world without matter were possible. Rather the [metric] field should be *fully determined by matter and not able to exist without the matter*. That is the core of what I mean by the requirement of the relativity of inertia. One could just as well speak of the ‘matter conditioning geometry.’ To me, as long as this requirement had not been fulfilled, the goal of general relativity was not yet completely achieved. This only came out with the [cosmological constant] term.”

Einstein to de Sitter, 24 March 1917

Physical Cosmology

Boundary conditions obeying Mach's principle
(inertial mass goes to zero, as test body recedes to infinity):

$$g_{\mu\nu} \rightarrow \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \infty \end{pmatrix}$$

Doesn't work, because observed universe everywhere
approximately Minkowskian

Can't find Machian boundary conditions

Physical Cosmology

Get rid of boundary conditions by having a close universe

Along with several (empirically motivated) conditions (static universe, homogeneous matter distribution) this needs a cosmological constant:

$$\Lambda = \kappa \frac{\rho}{2}$$

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Unification

“I am not very satisfied with Heisenberg and my whole theory (although I do believe that it shares ‘certain features’ with a future correct theory).”

Letter to Bohr, July 1929

Unification

“We have 3 kinds of fields, which appear to logically independent:
a) the matter waves for the protons
b) the matter waves for the electrons
c) the electromagnetic field.
[...] A unified understanding of all wave fields is in my opinion absolutely desirable.”

Letter to Oskar Klein, February 1929

Unification

“That electrodynamics is [...] not quite closed is indicated, not alone by the fact that for finite [electron charge] the present theory is not after all self-consistent, but equally by the existence of those small interactions with other forms of matter to which we must in the end look for a clue, both for consistency, and for the actual value of the electron's charge.”

J. Robert
Oppenheimer
(1904-1967)

1948 Solvay Talk