Modern Special Relativity

Presented by Johann Rafelski

THE UNIVERSITY OF ARIZONA

Polskie Towarzystwo Fizyczne

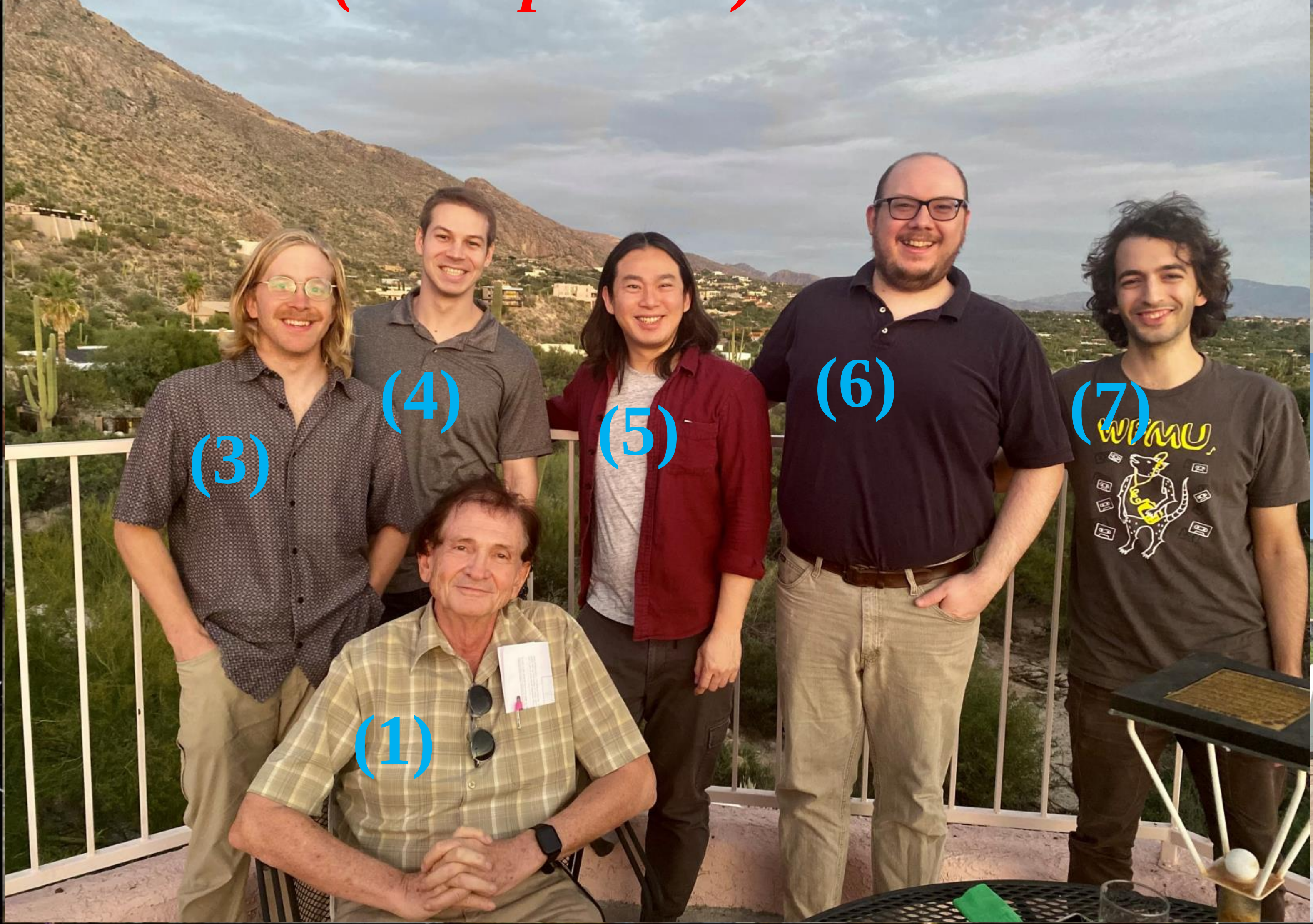
Oddział w Katowicach

April 7th, 2022

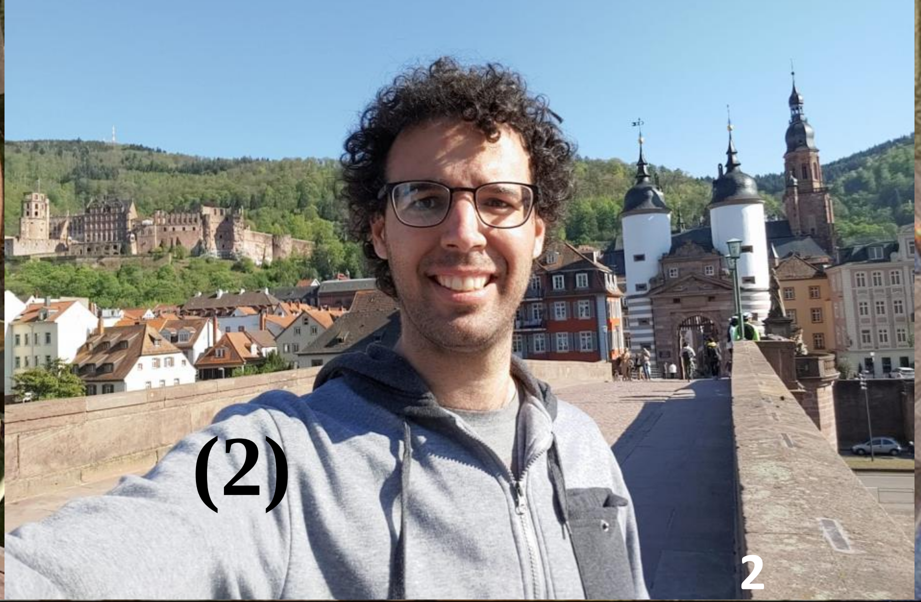
Research Group at Tucson, Arizona

1. **Dr. Johann Rafelski**
2. **Dr. Martin Formanek**
3. **Chris Grayson**
4. **Will Price**
5. **Cheng Tao Yang**
6. **Andrew Steinmetz**
7. **Stefan Evans**

UArizona (2014-present)

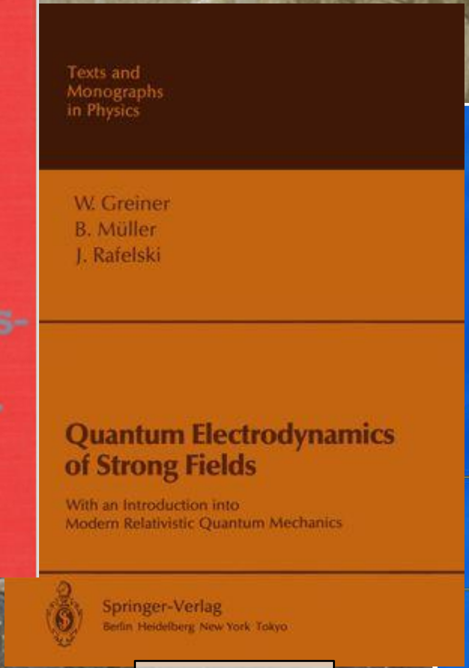


MPI Heidelberg (2021-present)

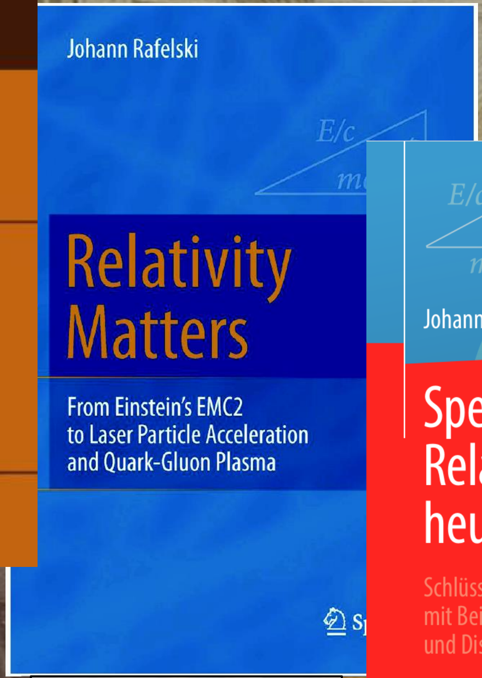


My lifelong interest in Special Relativity and Strong Fields

(1983-1992)

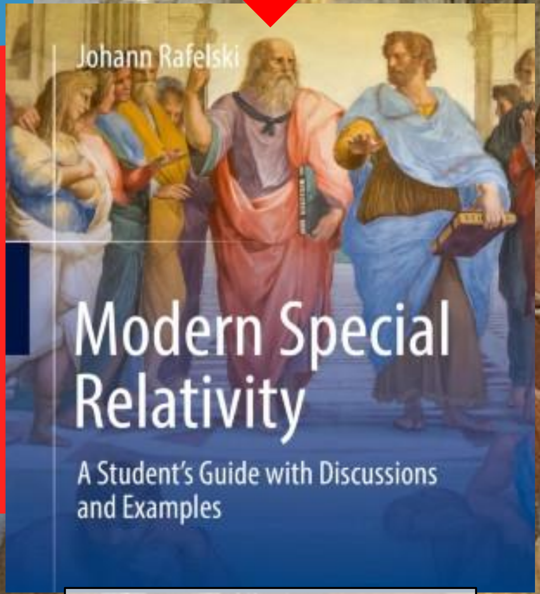


(1986)



(2006-2016)

(2018)



(March 2022)

What is “Modern” about Special Relativity?

- Modern ways of teaching.
- Modern developments in understanding origin of matter.
- First student accessible book which describes how small acceleration accumulates to generate body contraction and time dilation.
- Aether is back as structured quantum vacuum.
- Modern applications of using light to accelerate particles.
- Outlook to relativistic interstellar space travel.

Scope of change in a 150 years since need (Maxwell’s Equations) for SR was born

"On the Electrodynamics of Moving Bodies" A. Einstein, 1905

"Does the Inertia of a Body Depend upon its Energy Content?" A. Einstein, 1905

3. ***Zur Elektrodynamik bewegter Körper;***
von A. Einstein.

Daß die Elektrodynamik Maxwells — wie dieselbe gegenwärtig aufgefaßt zu werden pflegt — in ihrer Anwendung auf bewegte Körper zu Asymmetrien führt, welche den Phänomenen nicht anzuhaften scheinen, ist bekannt. Man denke z. B. an die elektrodynamische Wechselwirkung zwischen einem Mag-

13. ***Ist die Trägheit eines Körpers von seinem Energieinhalt abhängig?***
von A. Einstein.

Die Resultate einer jüngst in diesen Annalen von mir publizierten elektrodynamischen Untersuchung[1]) führen zu einer sehr interessanten Folgerung, die hier abgeleitet werden soll.

As Einstein titles/content imply SR is about:

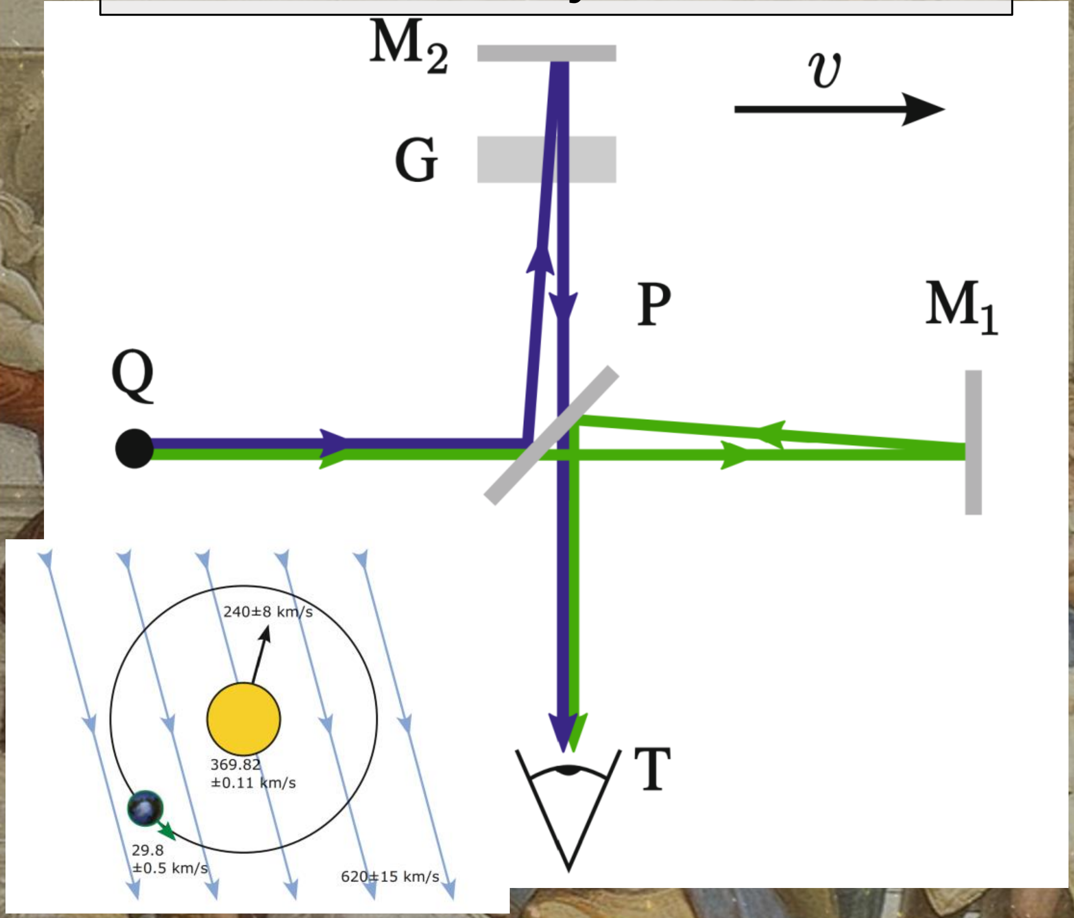
- Electromagnetism.
- Body contraction.
- Time dilation.
- $E = mc^2$
- Constancy of the speed of light.

Einstein in 1905 SR introduced the principle of relativity into EM and explored consistency consequences.

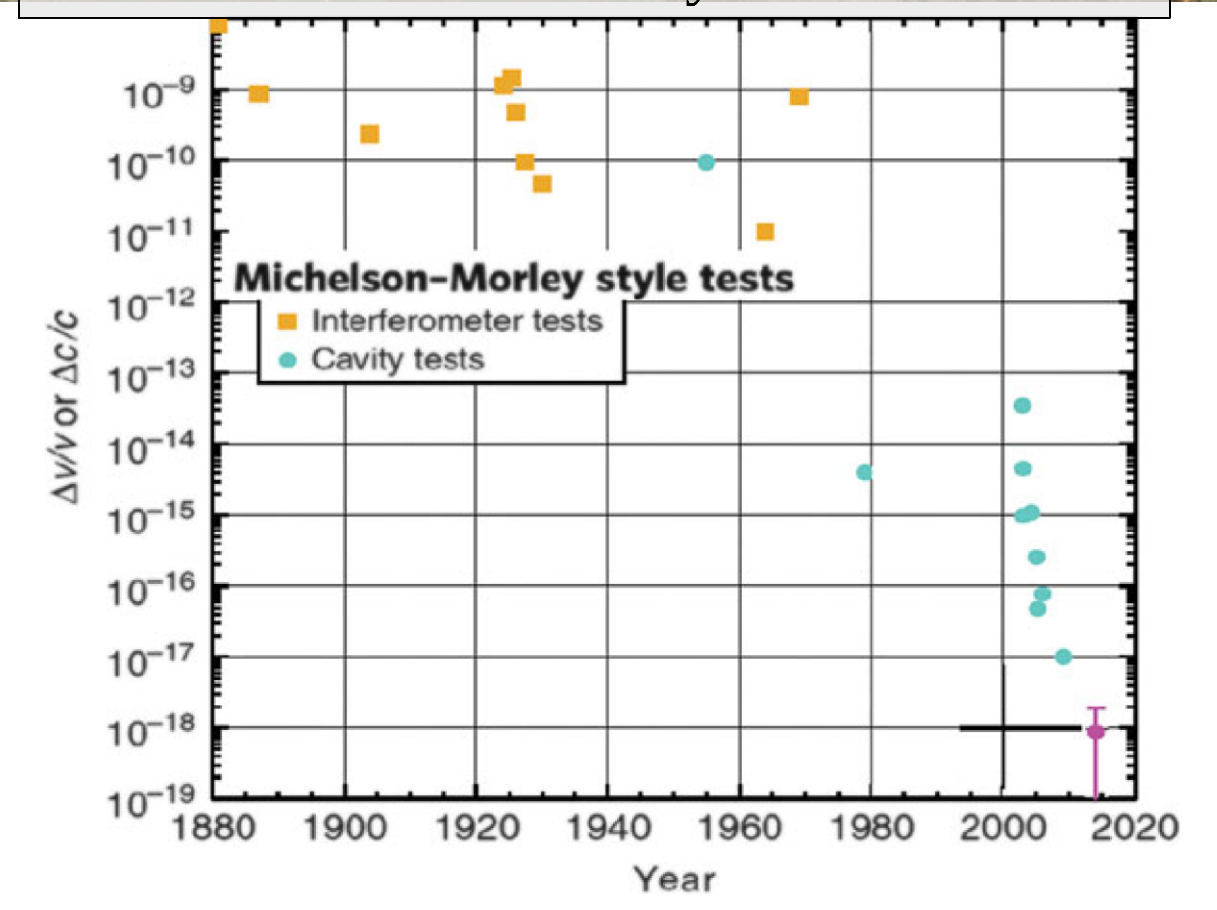
SR is not about gravity and/or space-time.

Water carries water waves, shouldn't something carry light waves?

Michelson-Morley Interferometer



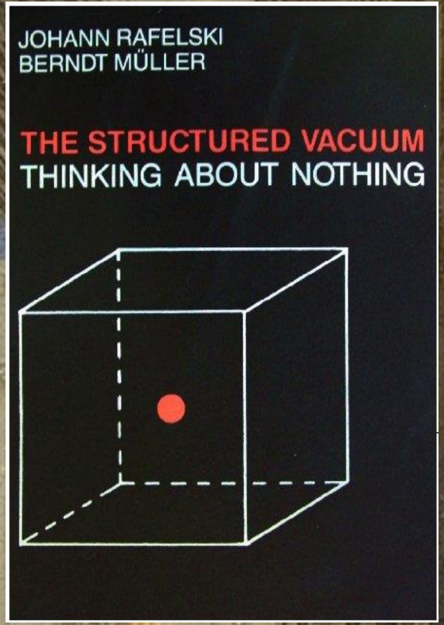
No evidence for a velocity-sensitive aether.

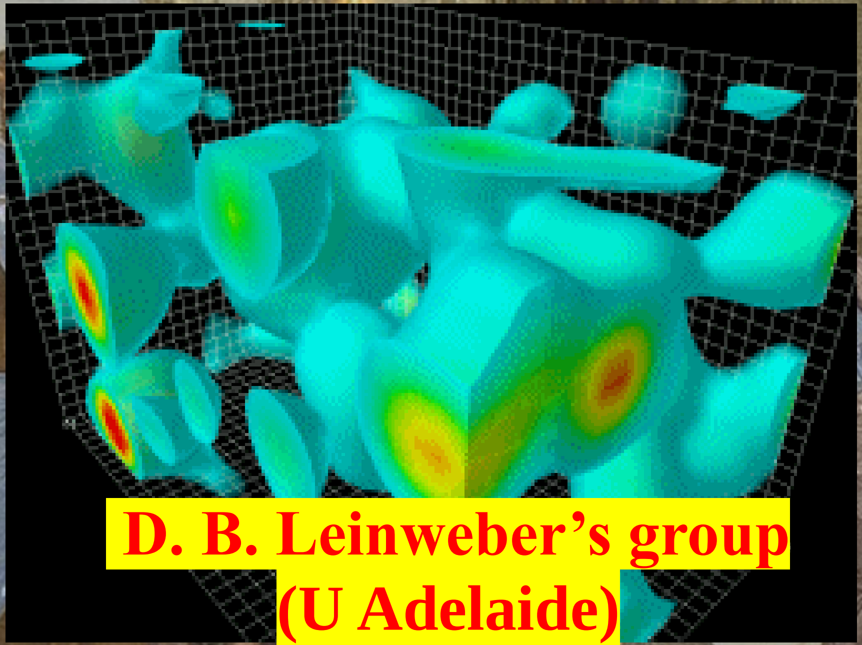


After fourteen years (1919/1920) Einstein brings back the Aether

"It would have been more correct if I had limited myself, in my earlier publications, to emphasizing only the non-existence of an æther velocity, instead of arguing the total non-existence of the æther, for I can see that with the word æther we say nothing else than that space has to be viewed as a carrier of physical qualities."
– A. Einstein, 1919 in a letter to H. A. Lorentz

Outlook:
Today, the modern understanding of the aether is the **"structured quantum vacuum."**





D. B. Leinweber's group (U Adelaide)

Classical Electromagnetism is incomplete!

We have two separate theories:

- Given sources of charges and currents, calculate EM fields.
- Given EM fields, calculate charged particle motion.

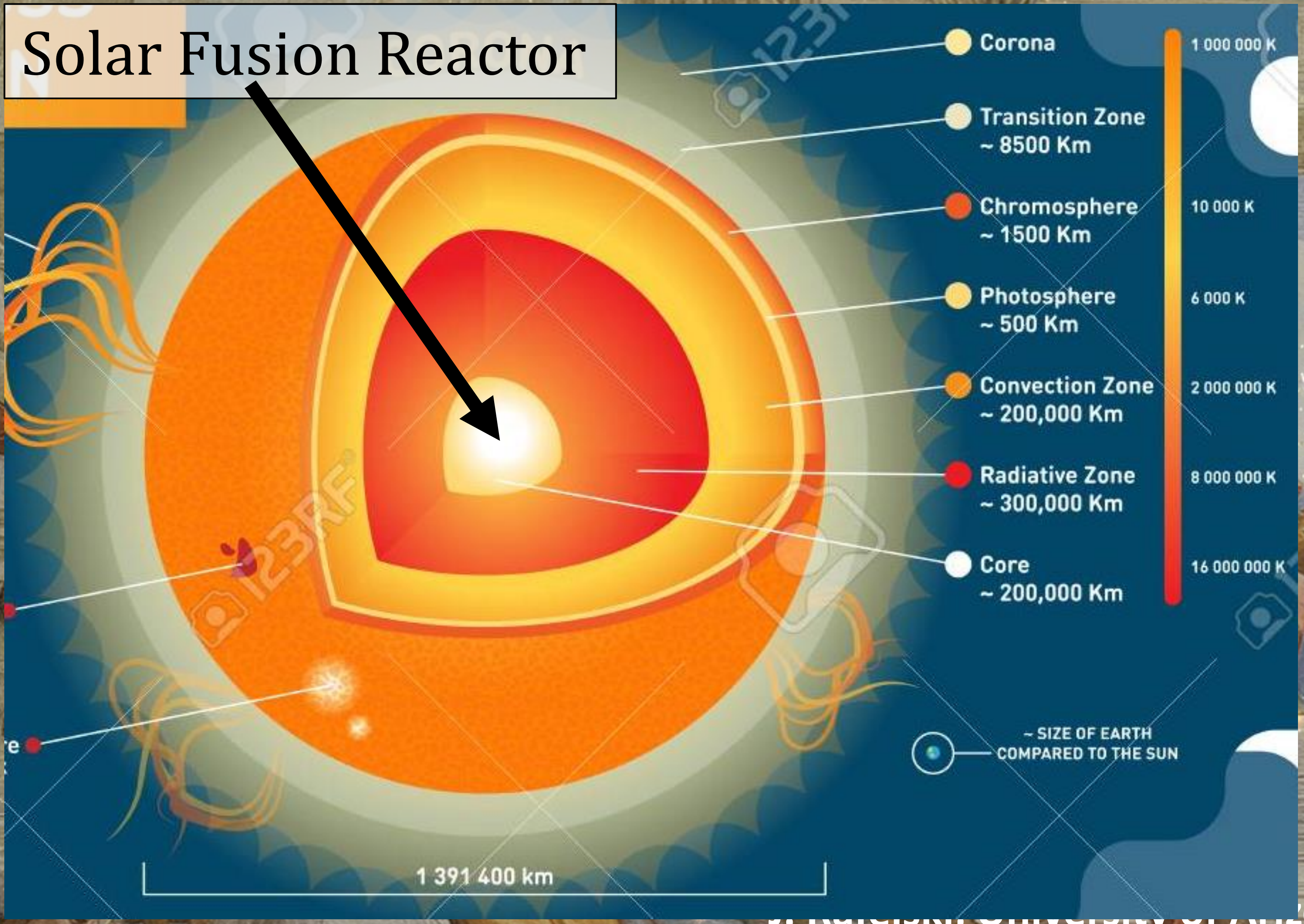
"… a complete satisfactory treatment of the reactive effects of radiation does not exist."
– J. D. Jackson, *Classical Electrodynamics*, p. 781, (1999).

There is a disconnect as accelerated charges radiate and lose energy and momentum which should be reflected in their motion! A self-consistent reaction/friction force is needed.

There are many models of radiation friction, but no action principle.
To solve the problem, we need to connect acceleration and SR.

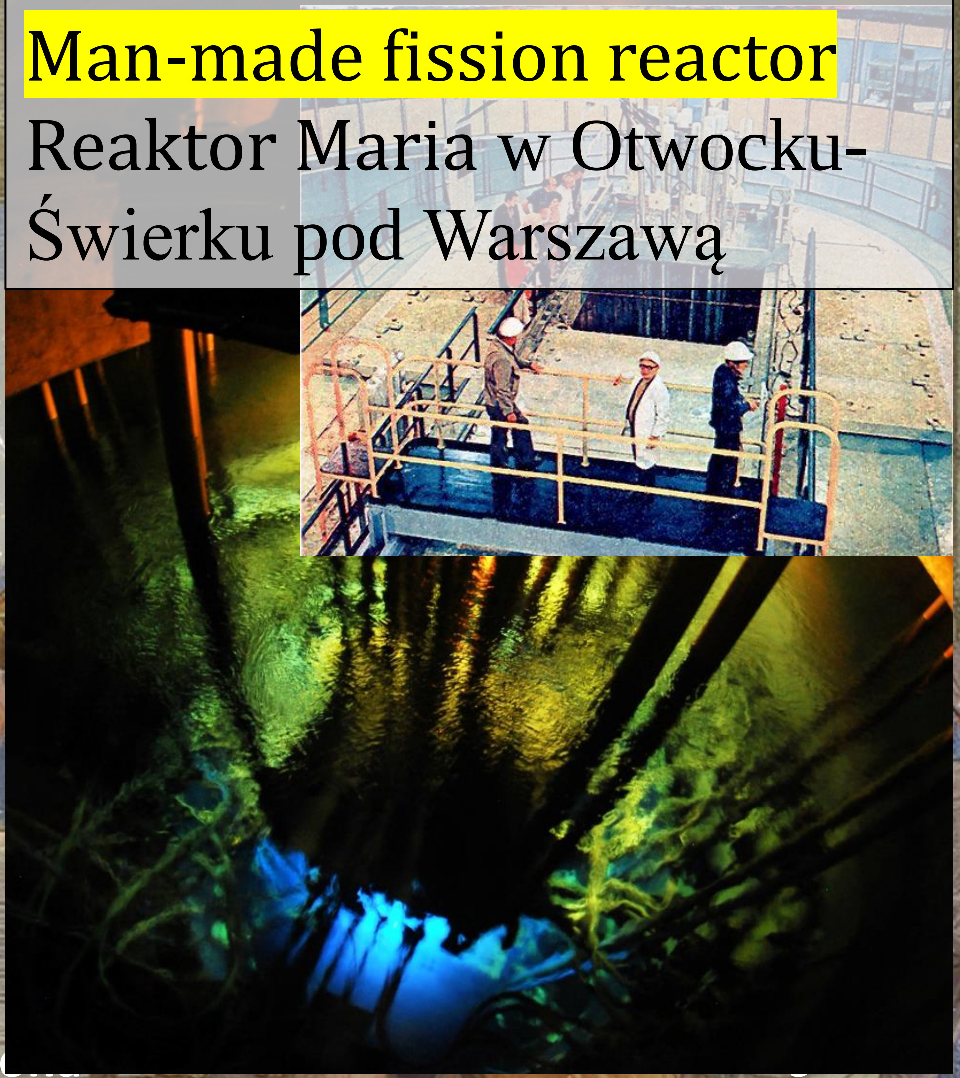
Matter to Energy: $E = mc^2$

Solar Fusion Reactor



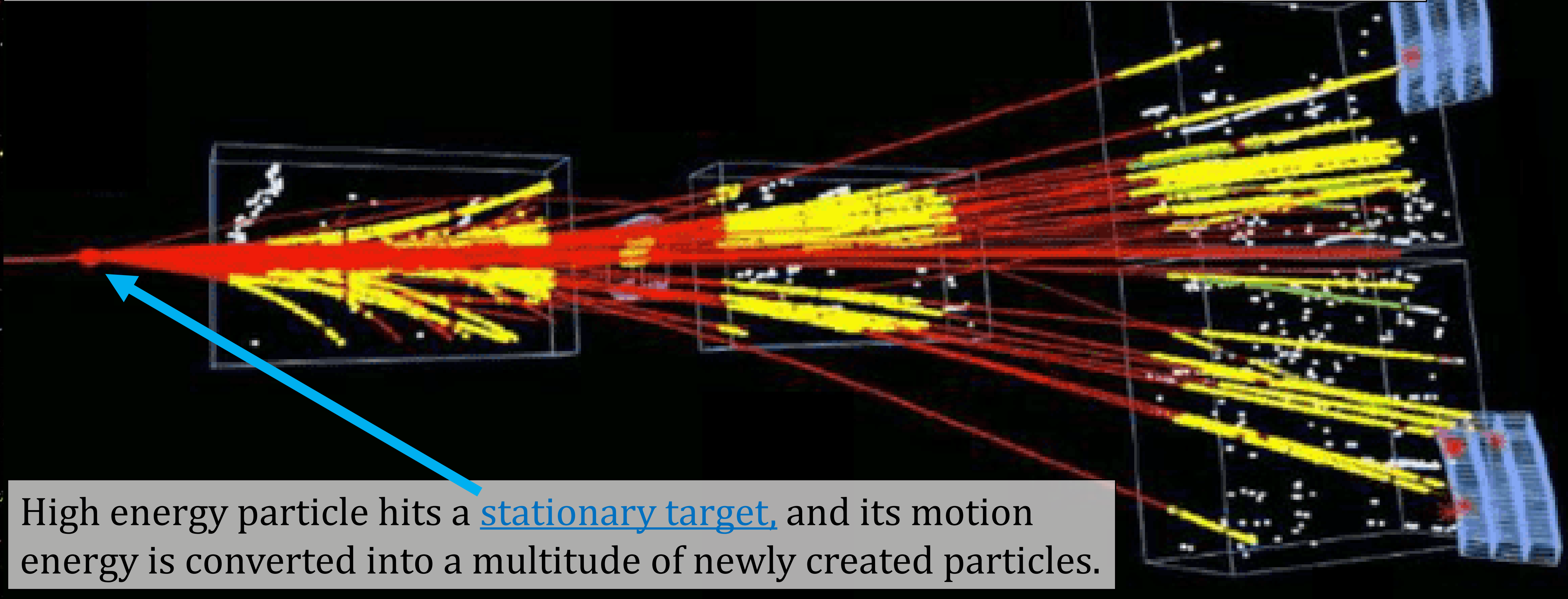
Man-made fission reactor

Reaktor Maria w Otwocku-Świerku pod Warszawą



Energy to Matter: $E = mc^2$

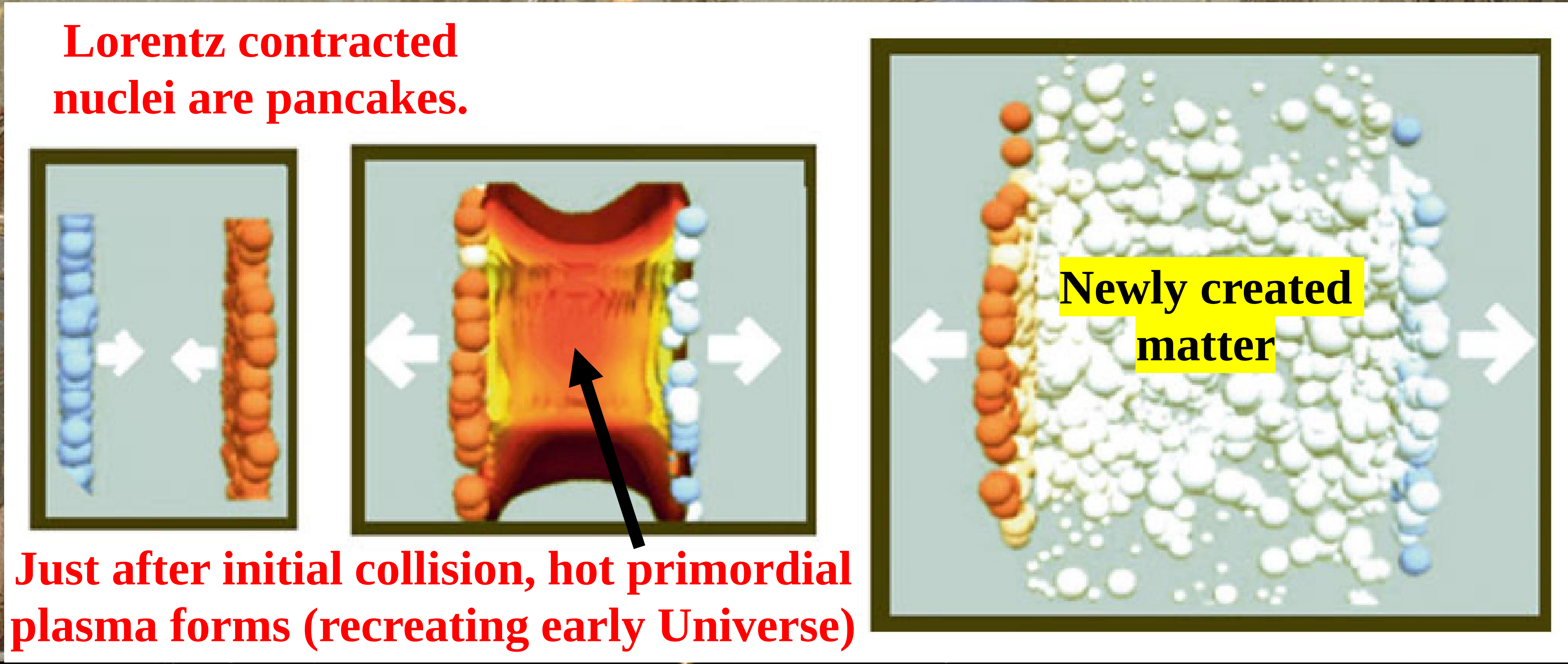
NA61/SHINE Collab. (adapted from CERN/Seweryn Kowalski lecture)



High energy particle hits a stationary target, and its motion energy is converted into a multitude of newly created particles.

Lorentz-FitzGerald body contraction: Mechanism of matter creation

When atoms nuclei (or any object) travels at a relativistic speed relative to you, it becomes body contracted and flattened like a pancake.



LETTERS TO THE EDITOR.

****Correspondents are requested to be as brief as possible. The writer's name is in all cases required as proof of good faith.*
The editor will be glad to publish any queries consonant with the character of the journal.
Twenty copies of the number containing his communication will be furnished free to any correspondent on request.

The Ether and the Earth's Atmosphere.

I HAVE read with much interest Messrs. Michelson and Morley's wonderfully delicate experiment attempting to decide the important question as to how far the ether is carried along by the earth. Their result seems opposed to other experiments showing that the ether in the air can be carried along only to an inappreciable extent. I would suggest that almost the only hypothesis that can reconcile this opposition is that the length of material bodies changes, according as they are moving through the ether or across it, by an amount depending on the square of the ratio of their velocity to that of light. We know that electric forces are affected by the motion of the electrified bodies relative to the ether, and it seems a not improbable supposition that the molecular forces are affected by the motion, and that the size of a body alters consequently. It would be very important if secular experiments on electrical attractions between permanently electrified bodies, such as in a very delicate quadrant electrometer, were instituted in some of the equatorial parts of the earth to observe whether there is any diurnal and annual variation of attraction, — diurnal due to the rotation of the earth being added and subtracted from its orbital velocity; and annual similarly for its orbital velocity and the motion of the solar system.

GEO. FRAS. FITZ GERALD.

Dublin, May 2.

Lorentz-FitzGerald Body Contraction, 1889

Body contraction in the direction of motion was first described by FitzGerald in 1889.
Lorentz once made aware, called it "FitzGerald body contraction." FitzGerald who passed away before SR was fully developed could not defend his priority.

Restatement of FitzGerald text:
"We know that electric forces are affected by the motion of the electrified bodies relative to the ether, and it seems not an improbable supposition that the molecular forces are affected by the motion, and that the size of a body alters consequently."

Some people deny physical reality of special relativistic effects. What is “real”?

The kinetic energy of a car depends on your frame of reference like a pedestrian versus the driver point of view.

In special relativity body properties and the passage of time depends on your frame of reference.

The point of view matters.

Coordinate transforms change neither the observed body nor spacetime

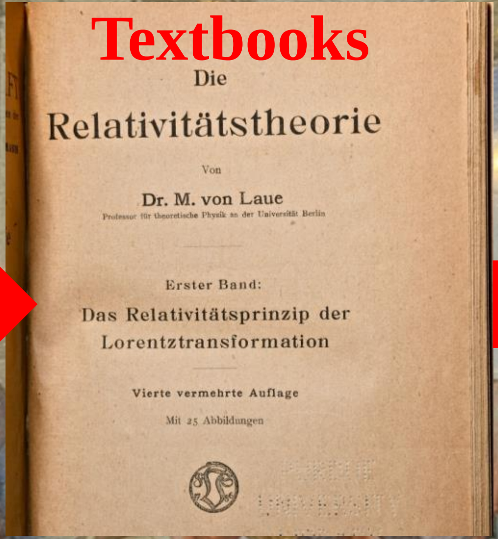
Lorentz coordinate transformations let you describe the coordinate systems of different observers.

The “set” of all possible transformations (rotations, translations, and more) in an empty spacetime is called the Poincare group.

But no matter what perspective you take, the object itself is unchanged. Coordinate transformations do **NOTHING** to the object or spacetime.

To understand principles of special relativity, it is best to look at original work. Why?

Telephone game with Lorentz-FitzGerald body contraction:



Die
Relativitätstheorie
Von
Dr. M. von Laue
Professor für theoretische Physik an der Universität Berlin
Erster Band:
Das Relativitätsprinzip der
Lorentztransformation
Vierte vermehrte Auflage
Mit 25 Abbildungen

"Body is contracted."
Correct.

"Length is contracted."
Correct,
but requires context.

"Distance is contracted."
Misleading.
"Space is contracted."
Junk!

Coordinate transformations must be consistent with body properties

Galilean transformations:

$$t' = t \qquad y' = y$$

$$x' = x - v_x t' \qquad z' = z$$

Galilean transformations assure simultaneity for all observers.

Time transforms so simultaneity is not assured. For Lorentz transforms, one only observer is simultaneous.

Lorentz transformations (in Larmor form):

$$t' = t\sqrt{1 - \frac{v_x^2}{c^2}} - \frac{v_x}{c^2}x' \qquad y' = y$$

- When $x' = 0$, then t' corresponds to the clock time of the body and we have time dilation.

$$x' = x\sqrt{1 - \frac{v_x^2}{c^2}} - v_x t' \qquad z' = z$$

- When $t' = 0$, then x' corresponds to the contracted observed body length of a moving object.

Simultaneity is not protected in SR

Imagine if two events occur at the same time in two different places for one observer O' so that

$$\Delta t' = t_1' - t_2' = 0$$

Then another observer O with relative velocity v will see

$$\Delta t = t_1 - t_2 \neq 0$$

And will believe the explosions happen at different times.

Lorentz transformations (in Lorentz form):

$$\Delta t = \frac{\Delta t' + \frac{v_x}{c^2}\Delta x'}{\sqrt{1 - \frac{v_x^2}{c^2}}} \qquad \Delta x = \frac{\Delta x' + v_x \Delta t'}{\sqrt{1 - \frac{v_x^2}{c^2}}}$$

- If $\Delta t^2 - \frac{\Delta x^2}{c^2} > 0$ then this is a “time-like” distance.
- If $\Delta x^2 - \Delta t^2 c^2 > 0$ then this is a “space-like” distance.
- This notion never changes under Lorentz coordinate transformations.

Lorentz-FitzGerald body contraction:
Can we directly measure it?

Eur. Phys. J. A (2018) 54: 29
DOI 10.1140/epja/i2018-12370-4

Letter

THE EUROPEAN PHYSICAL JOURNAL A

Measurement of the Lorentz-FitzGerald body contraction

Dedicated to Walter Greiner; October 1935 – October 2016.

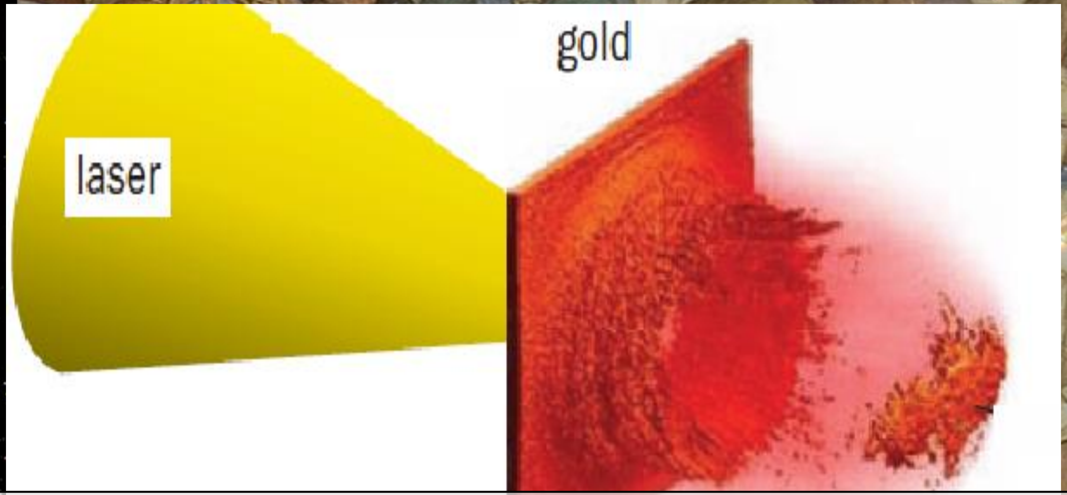
Johann Rafelski[a]

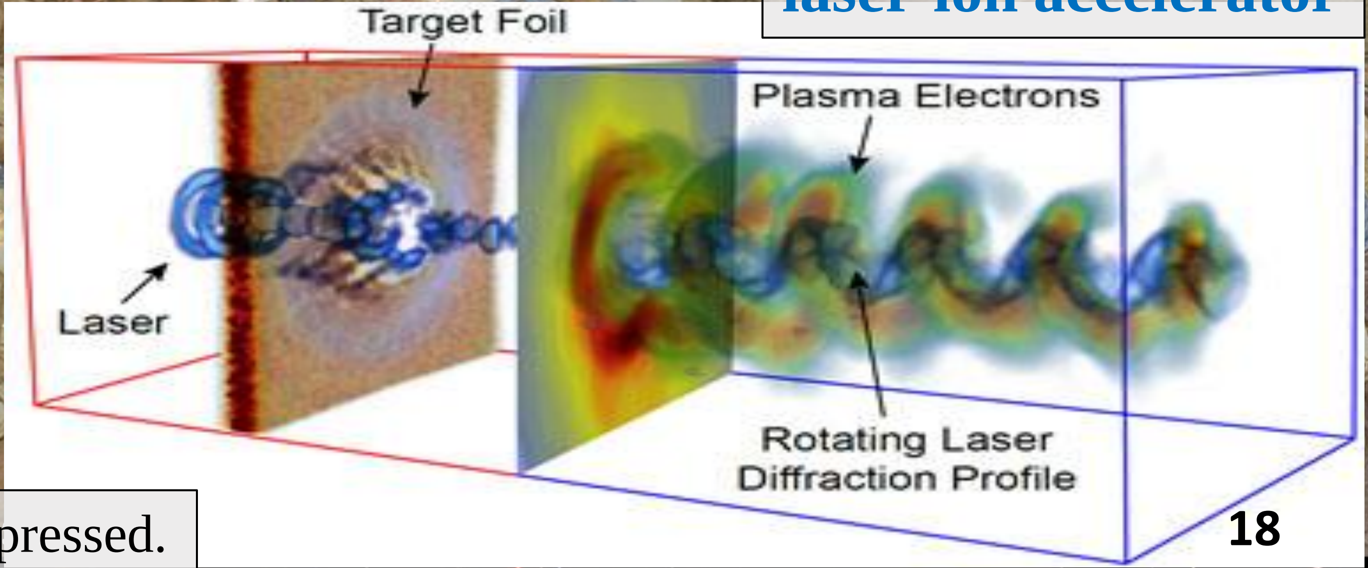
Published online: 20 February 2018

Department of Physics, The University of Arizona, Tucson, AZ, 85721, USA

Abstract. A complete foundational discussion of acceleration in the context of Special Relativity (SR) is presented. Acceleration allows the measurement of a Lorentz-FitzGerald body contraction created. It is argued that in the back scattering of a probing laser beam from a relativistic flying electron cloud mirror generated by an ultra-intense laser pulse, a first measurement of a Lorentz-FitzGerald body contraction is feasible.

Concept drawing of laser-ion accelerator





The "moving electron cloud mirror" is body compressed.

Lorentz-FitzGerald body contraction:

Is a passenger on a relativistic train aware they are “body contracted?”

A. **Einstein, 1911:** No – there is no absolute reference frame in the Universe, they cannot know against what he or she contracts.

We know that the Big Bang reference frame defines speeds of all things in the Universe; is this relevant to understanding of SR?

J. S. Bell, 1976 (of “Bell inequality fame”) invokes Lorentz-Janossy reality point of view: Using **acceleration** the passenger transports from one inertial frame to another. This allows them to know and measure relative contraction.

CERN 1985 March 12

Dear Johann, the only thing I can thoroughly recommend on relativity is my own paper. I enclose a copy. I refer there to the book of Janossy. But it is very long, and insufficiently explicit

that the Einstein approach is perfectly sound, and very elegant and powerful, (but pedagogically dangerous, in my opinion).

best wishes

John

Bell rockets: Spatial distance versus body length

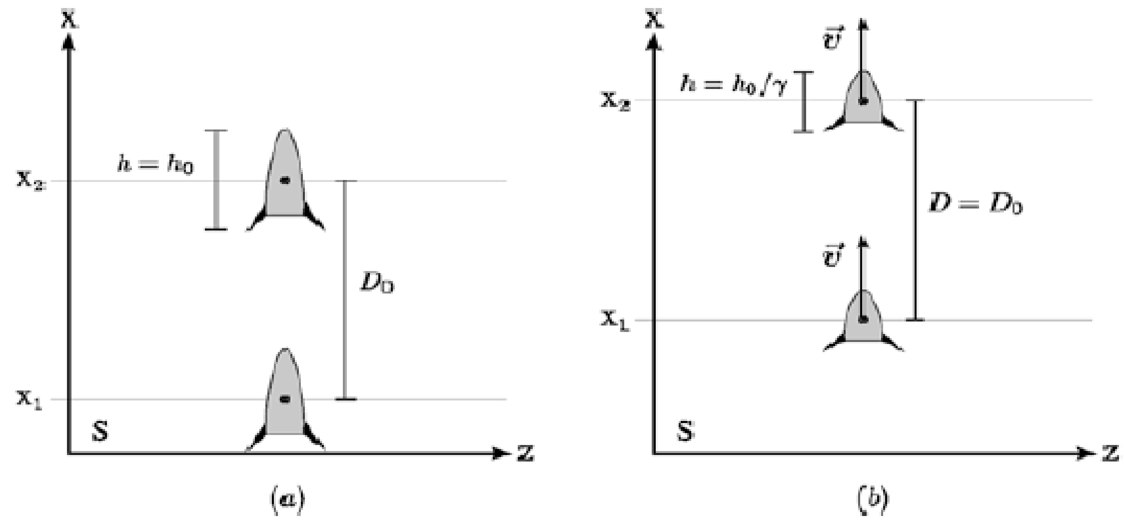


Fig. 10.2 Two rockets of length h separated by distance $D = x_2 - x_1 = D_0$. (a) at rest, and in case (b) moving at velocity $\vec{v}$ acquired at a later time

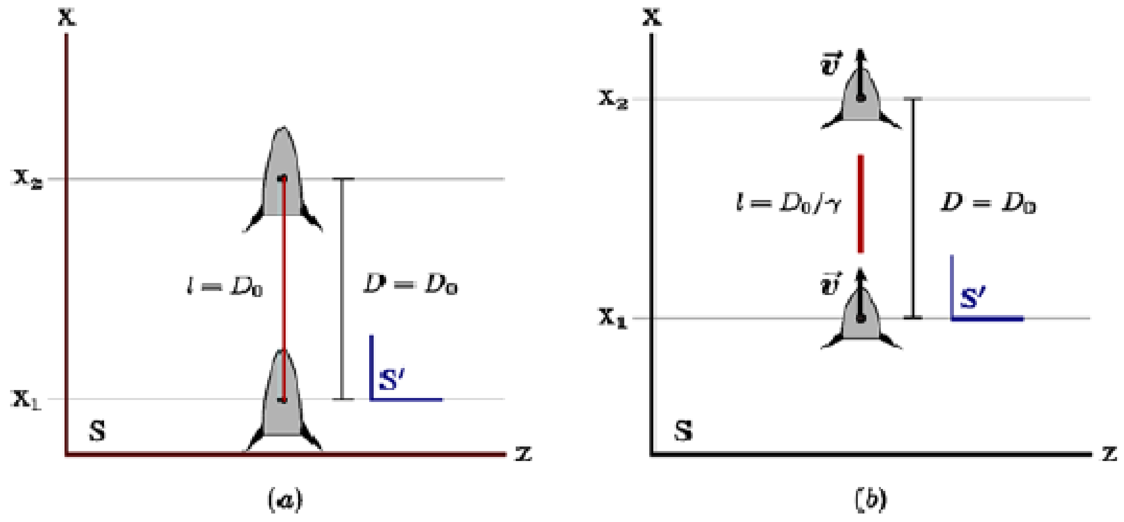


Fig. 10.3 Two rockets separated by distance $D = x_2 - x_1 = D_0$ and connected by a thin thread of (a) at rest, and in case (b) moving at velocity $\vec{v}$ acquired at a later time

If you connect two rockets with a thin string and let them identically accelerate, each rocket and the string will body contract.

A thin string can't handle the stress and will break.

The spatial distance between the rockets however is unchanged.

Time dilation

The only observer independent time quantity is the Lorentz invariant **proper time $\boldsymbol{\tau}$** of a body:

$$c^2\tau^2 - 0 = c^2t^2 - x^2 = c^2t'^2 - x'^2$$

Proper time of a body ($\boldsymbol{x = 0}$) is meaningful. A returning traveller must have aged $\boldsymbol{\tau < t}$. For two airplanes going around the rotating Earth: When they meet after a full circle, Earth has rotated underneath and one has travelled further than the other, hence clock on airplanes would have travelled different distances and recorded different passages of time. Note that one airplane moves with the speed added to rotation, while the other moves with speed subtracted from rotation.

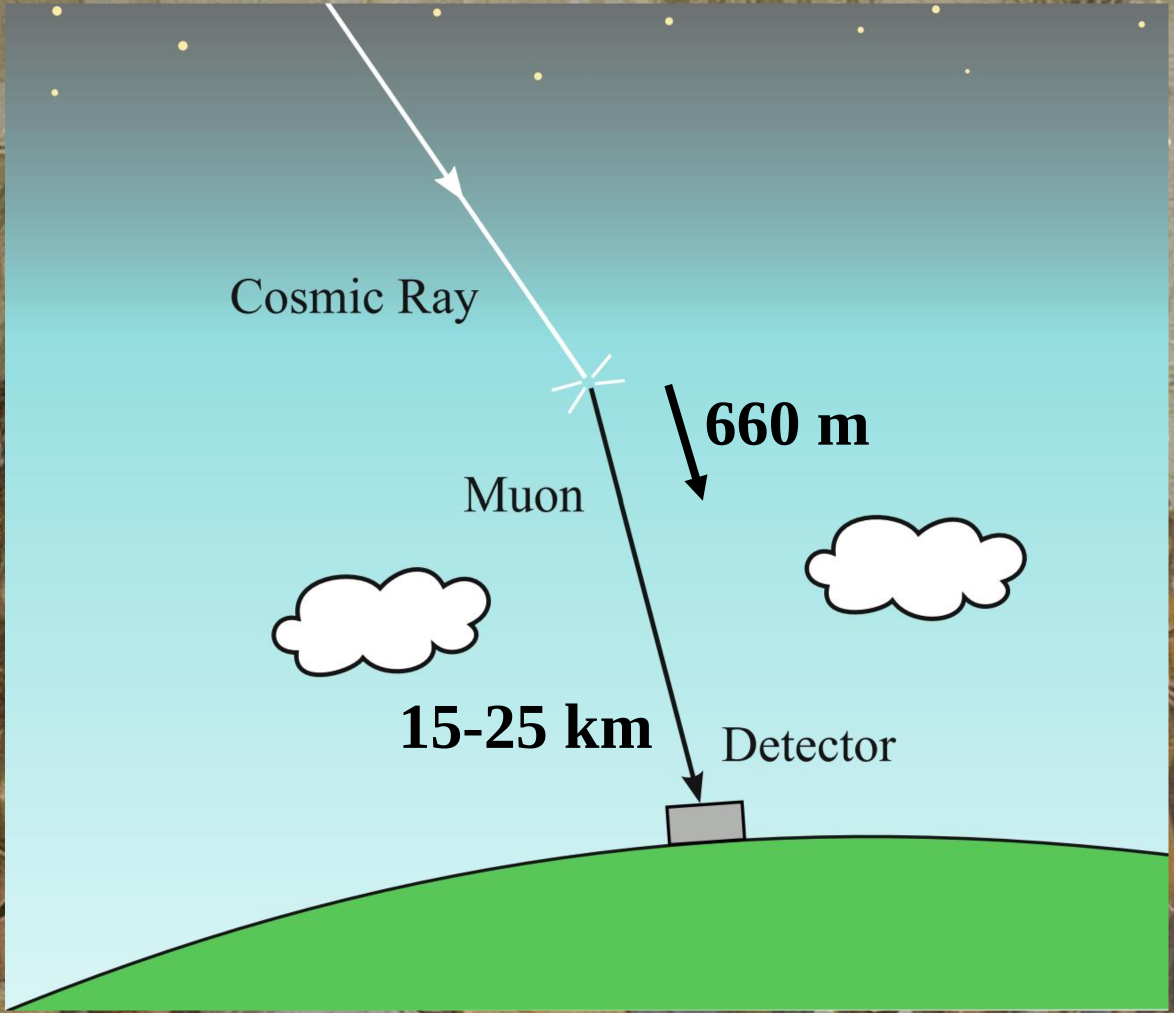
Around-the-World Atomic Clocks: Predicted Relativistic Time Gains

Abstract. *During October 1971, four cesium beam atomic clocks were flown on regularly scheduled commercial jet flights around the world twice, once eastward and once westward, to test Einstein's theory of relativity with macroscopic clocks. From the actual flight paths of each trip, the theory predicts that the flying clocks, compared with reference clocks at the U.S. Naval Observatory, should have lost 40 ± 23 nanoseconds during the eastward trip, and should have gained 275 ± 21 nanoseconds during the westward trip. The observed time differences are presented in the report that follows this one.*

J. C. HAFELE*
Department of Physics, Washington University, St. Louis, Missouri 63130

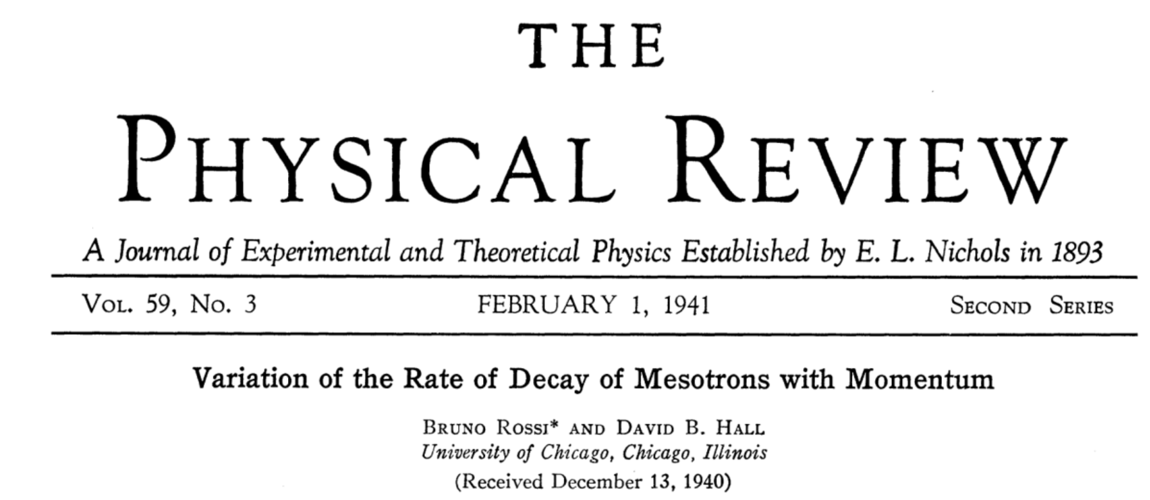
RICHARD E. KEATING
Time Service Division, U.S. Naval Observatory, Washington, D.C. 20390

Time dilation



When muon are produced in the upper atmosphere, they should only live 2.197 μs and travel about 660 m.

Instead, they make it all the way to the ground. How can this be?


THE

PHYSICAL REVIEW

A Journal of Experimental and Theoretical Physics Established by E. L. Nichols in 1893

VOL. 59, NO. 3 FEBRUARY 1, 1941 SECOND SERIES

Variation of the Rate of Decay of Mesotrons with Momentum

BRUNO ROSSI* AND DAVID B. HALL
University of Chicago, Chicago, Illinois
(Received December 13, 1940)

Time dilation:
Unstable particle range.

Imagine observing a muon in intergalactic empty space (no nearby mountains) so there is no LFG body contraction of anything. Using the invariant proper lifespan of the particle and its relative velocity to the observer, we obtain the distance traveled in empty space as reported by the observer.

$$c^2\tau^2 = \left(1 - \frac{v^2}{c^2}\right) c^2 t^2$$

Time dilation

$$x^2 = c^2t^2 - c^2\tau^2$$

$$c^2\tau^2 = c^2t^2 - x^2$$

Space-time interval

$$\frac{E}{mc^2} \approx 39$$

$$v = \frac{x}{t}$$

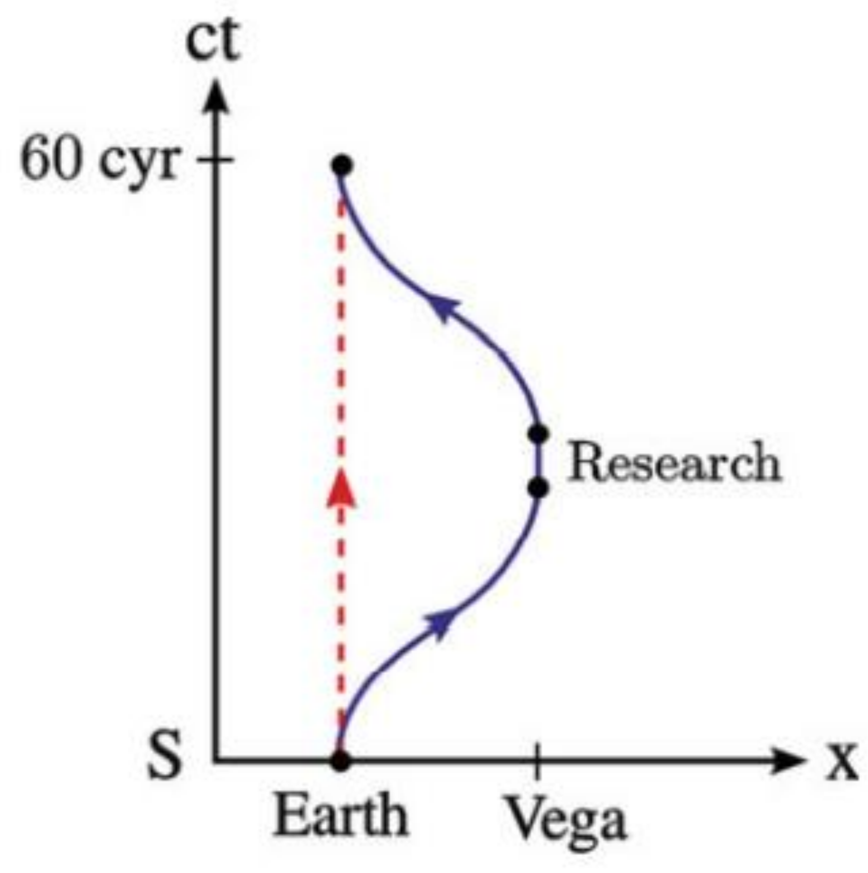
$$x = \frac{\tau v}{\sqrt{1 - \frac{v^2}{c^2}}} = \frac{(2.197\ \mu\mathrm{s})(0.99968c)}{\sqrt{1 - 0.99968^2}} = \mathbf{26\ km}$$

The muon travels the Lorentz extended distance $\boldsymbol{x}$ during its lifespan $\boldsymbol{\tau}$.

A trip to the stars: Traveling to Vega and back

Two teams plan a trip to the star Vega. One team stays at base, while the other flies a rocket to Vega.

The rocket team has to accelerated at least four time to visit Vega and come back. The rocket team will be younger than the base team because of this.



See pg. 435-436 in “Modern Special Relativity”

$$\Delta t_E = 54.1 \text{ years}$$

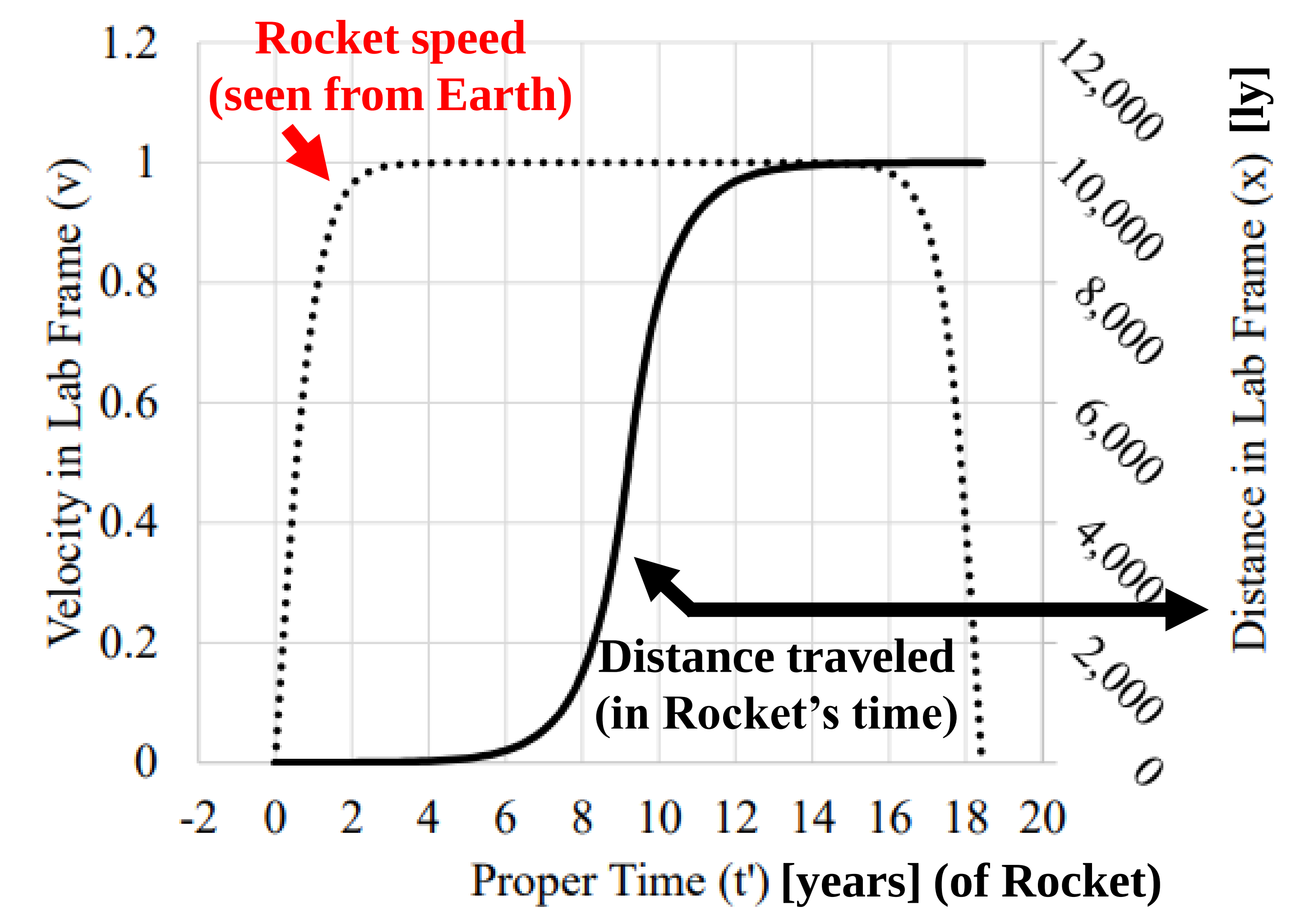
$$\Delta t_T = 13.4 \text{ years}$$

$$a_T = 1\text{ g} = 9.8\,\frac{\text{m}}{\text{s}^2}$$

A trip to the edge of the galaxy: One way trip going 10,000 light-years

Large acceleration isn't needed to visit the stars. Instead, we only need a small acceleration over a long period of time.

A rocket going with acceleration $\mathbf{1}\boldsymbol{g} = \mathbf{9.8}\,\frac{\mathbf{m}}{\mathbf{s^2}}$ can travel thousands of light-years within a human lifespan.



New research in SR happens every day!

PHYSICAL REVIEW D **105,** 016024 (2022)

Radiation reaction and limiting acceleration

Will Price,* Martin Formanek,† and Johann Rafelski‡
Department of Physics, The University of Arizona, Tucson, Arizona 85721, USA

(Received 9 December 2021; accepted 7 January 2022; published 26 January 2022)

We investigate the strong acceleration properties of the radiation reaction force and identify a new and promising limiting acceleration feature in the Eliezer-Ford-O'Connell model; in the strong field regime, for many field configurations, we find an upper limit to acceleration resulting in a bound to the rate of radiation emission. If this model applies, strongly accelerated particles are losing energy at a much slower pace than predicted by the usual radiation reaction benchmark, the Landau-Lifshitz equation, which certainly cannot be used in this regime. We explore examples involving various "constant" electromagnetic field configurations and study particle motion in a light plane wave as well as in a material medium.

DOI: 10.1103/PhysRevD.105.016024

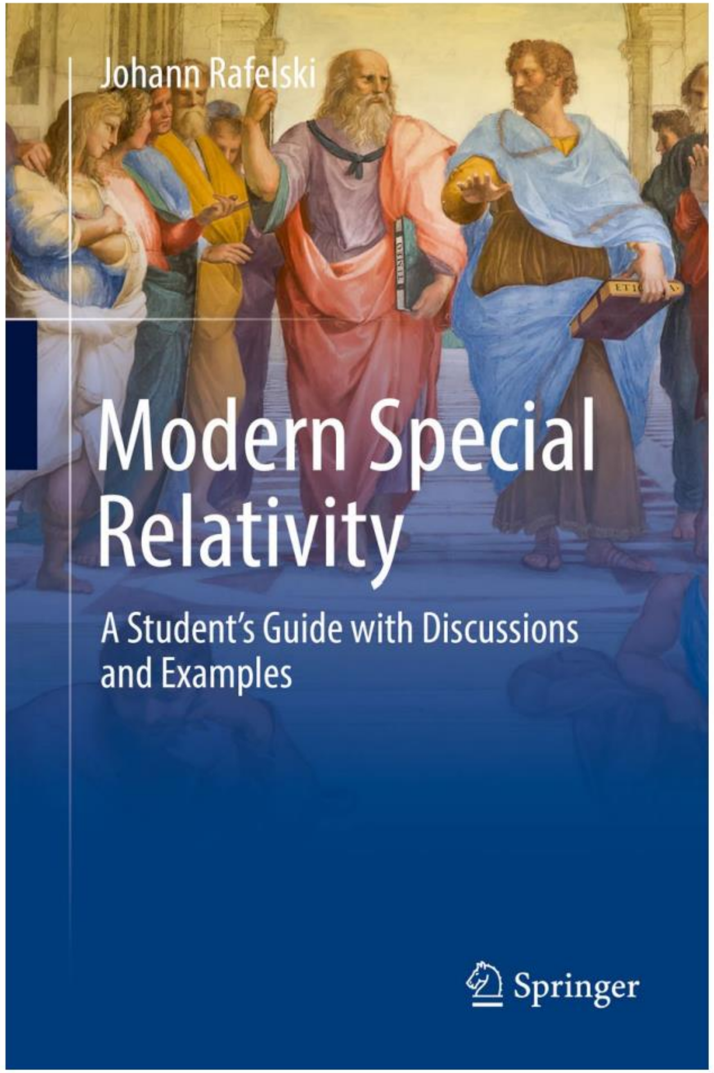
Let's celebrate fifty years of published work in strong fields and SR

VOLUME 27, NUMBER 14 PHYSICAL REVIEW LETTERS 4 OCTOBER 1971

Superheavy Elements and an Upper Limit to the Electric Field Strength*

Johann Rafelski, Lewis P. Fulcher,† and Walter Greiner
Institut für Theoretische Physik der Universität Frankfurt, Frankfurt am Main, Germany
(Received 9 August 1971)

An upper limit to the electric field strength, such as that of the nonlinear electrodynamics of Born and Infeld, leads to dramatic differences in the energy eigenvalues and wave functions of atomic electrons bound to superheavy nuclei. For example, the $1s_{1/2}$ energy level joins the lower continuum at $Z = 215$ instead of $Z = 174$, the value obtained when Maxwell's equations are used to determine the electric field.



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J. Rafelski

Modern Special Relativity

A Student's Guide with Discussions and Examples

- Designed for students, it provides many solved problems that help master the subject
- The concepts of special relativity are introduced in a clear and simple way, without making use of four-vector formalism
- Presents the existing connections between special relativity and particle, nuclear, and high intensity pulsed laser physics

Supplementary Slides

SR teacher facing students

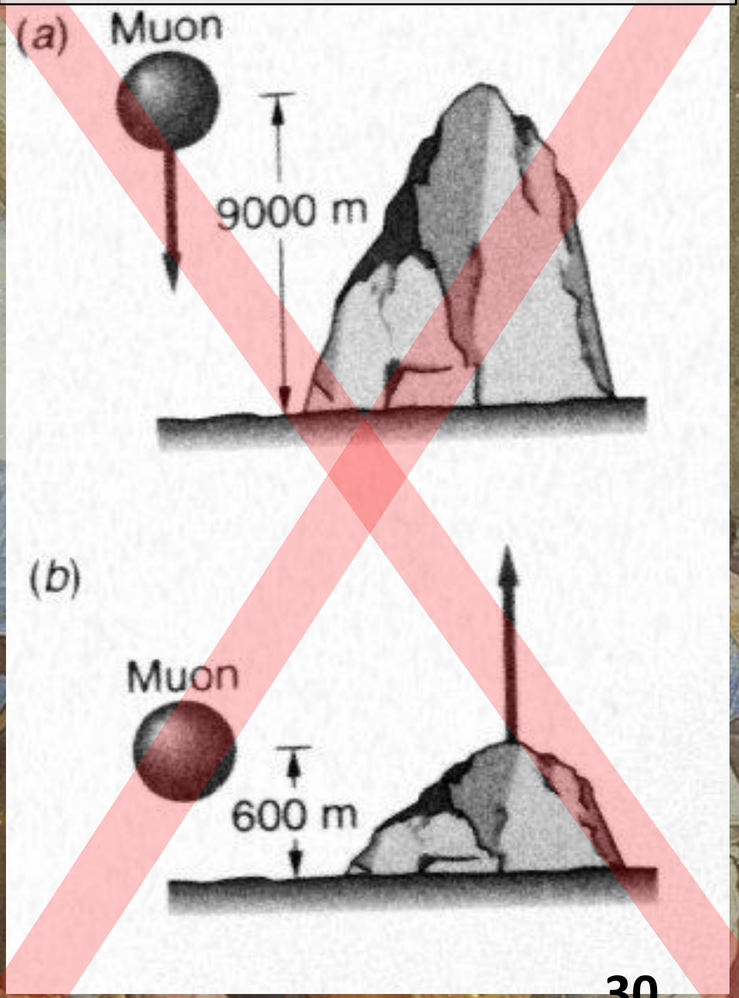
- Books claims Lorentz contraction and time dilation are the same and that one confirms the other. This is wrong.

- Books claim that SR has “paradoxes” or “not real” effects whereas frame-dependant phenomena are well established in other areas of physics.

- Students fact-check you live against **internet prophets** and their **wrong but entertaining videos.**

- I think SR is a living and evolving theory while SR is taught as a footnote of GR.

From a serious book that millions of students have used.



Be careful when reading about SR online!

pl.wikipedia.org/wiki/Szczególna_teoria_względności#Najważniejsze_konsekwencje

Najważniejsze konsekwencje [edytuj | edytuj kod]

Dwa postulaty Einsteina jednoznacznie prowadzą do transformacji Lorentza[1], a one – do dalszych przewidywań. Jeśli prędkości względne są porównywalne do prędkości światła w próżni (c), to fizyczne wnioski z STW są różne od tych z mechaniki Newtona. Prędkość c jest nieporównywalnie większa niż te, z którymi ludzie się spotkają na co dzień. Dlatego też niektóre konsekwencje szczególnej teorii względności są początkowo sprzeczne z intuicją:

- Względność jednoczesności – dwa zdarzenia określone przez jednego obserwatora jako jednoczesne, mogą nie być jednoczesne dla innego obserwatora[8][9].
- Dylatacja czasu – czas, jaki mija pomiędzy dwoma zdarzeniami, nie jest jednoznacznie określony, lecz zależy od ruchu obserwatora. Odstępy czasowe między zdarzeniami są większe („czas płynie wolniej"), jeśli obserwator się porusza, a nie spoczywa względem ich położenia. Innymi słowy: jeśli zjawisko – zachodzące w jakimś punkcie przestrzeni – jest obserwowane z układów poruszających się względem tego punktu, to trwa dłużej niż w układzie odniesienia, w którym punkt tego zjawiska spoczywa[10][9].

  Konsekwencją tego zjawiska – w kontekście zawracającego układu inercjalnego – jest paradoks bliźniąt. Został sformułowany przez Langevina[potrzebny przypis] i potem był podnoszony przez Bergsona jako argument przeciwko STW[potrzebny przypis].
- Kontrakcja przestrzeni lub relatywistyczne skrócenie długości, skrócenie Lorentza – odległości między punktami zależą od układu odniesienia. Wszystkie poruszające się przedmioty obserwuje się jako krótsze niż wtedy, gdy spoczywają[1]. Relatywistyczne skrócenie obiektu zawsze wyniesie tyle samo procent dla danej prędkości[11].

  Zjawisko prowadzi do paradoksu drabiny – drabina może mieć długość większą niż długość stodoły, ale zmieścić się w tej stodole w całości, jeżeli drabina będzie poruszała się odpowiednio szybko w układzie spoczynku stodoły.
- Relatywistyczne składanie prędkości[1] – prędkości nie transformują się przez dodawanie do i odejmowanie od względnej prędkości układów odniesienia. Przykładowo: jeżeli rakieta oddala się od obserwatora z prędkością $2/3\ c$ i wysyła pocisk z prędkością $2/3\ c$ w układzie swojego spoczynku, to obserwator nie zanotuje prędkości $4/3\ c$ $(2/3\ c + 2/3\ c)$, przewyższającej prędkość światła w próżni. W tym przykładzie obserwator widziałby pocisk poruszający się z szybkością $12/13\ c$. Podobnie przy dwóch strumieniach cząstek poruszających się z prędkością bliską c – jedne emitowane na lewo od źródła, drugie na prawo – z perspektywy jednych cząstek drugie nie będą uciekały szybciej niż c[12].

Internet Misconceptions: Reinventing Lorentz-FitzGerald body contraction.

- **Many prophets claim <u>space</u> is contracted. NO!**

  Before GR (gravity!) nobody would confound the properties of a material body with space-time. SR is flat space-time for everyone.

- **Others say this is <u>distance</u> contraction. What does that mean?**

  No free ride! Either causes confusion or leads back to body contraction. A coordinate transformation (measured by physical clocks and rulers) must be consistent with the behavior of material bodies. Coordinate transformation of the body ends, measured at equal time in observers frame, is consistent with the Lorentz-FitzGerald body contraction.

- **Some claim this is an <u>apparent</u> and <u>unphysical</u> contraction. !?!?!?**

  Einstein wrote in 1911 explaining that his and Lorentz's views agree: Body contraction is physical and real.

Strong forces imply strong acceleration creating new challenges

Einstein developed SR invoking only inertial observers. The word acceleration does not appear in his 1905 work. Is the Lorentz force complete?

In daily life, all accelerations are far below the natural "unit-1" value of acceleration.

$$a_{cr} = m_e c^2 \frac{c}{\hbar} = 2.33 \times 10^{29} \frac{\mathrm{m}}{\mathrm{s}^2}$$

This is also the acceleration generated by Schwinger "critical" EM fields:

$$E_{cr} = \frac{(m_e c^2)^2}{e\hbar c} = 1.323 \times 10^{18} \frac{\mathrm{V}}{\mathrm{m}}$$

$$B_{cr} = \frac{(m_e c^2)^2}{e\hbar c^2} = 4.414 \times 10^{9}\ \mathrm{T}$$

SR absorbs nano-acceleration setting $\Delta v = a\Delta t$ but Langevin was clear: Accelerated twins age slower compared to inertial twins.

Ultra-relativistic electron in a magnetic field of 4.41 T at CERN:

$$a_{CERN} = \left(\frac{e}{m_e}\right) \boldsymbol{v} \times \boldsymbol{B} = 2.33 \times 10^{20} \frac{\mathrm{m}}{\mathrm{s}^2} \sim \textbf{nano } \boldsymbol{a_{cr}}$$

Maybe acceleration is not what we think: Connecting temperature and acceleration

Strong Fields → ***Temperature*** ← ***Acceleration***

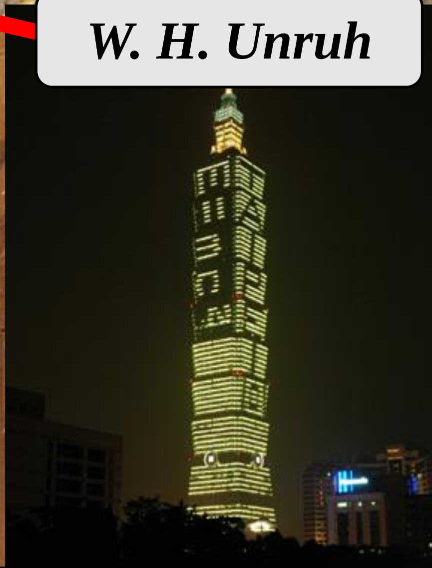
Interpretation of external fields as temperature

Temperature representation of Euler-Heisenberg action in electric-dominated fields.

Notes on black-hole evaporation

Thermal background (Unruh temperature) experienced by an observer undergoing constant acceleration in a field-free vacuum.

W. H. Unruh



Gravity Swing, Taipei 101, (2012)

B. Müller, W. Greiner, and J. Rafelski. “Interpretation of external fields as temperature.’ Physics Letters A 63.3 (1977)

W. G. Unruh, “Notes on black-hole evaporation.” Physical Review D 14.4 (1976)

L. Labun and J. Rafelski, “Acceleration and vacuum temperature.” Phys. Rev. D 86, 041701(R) (2012)

Time dilation requires acceleration which unlike velocity cannot be “removed” by choice of a suitable observer: velocity is “relative,” acceleration is “absolute”

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tions de la physique doivent conserver leur forme quand on passe de l’un à l’autre. Pour de tels systèmes tout se passe comme s’ils étaient immobiles par rapport à l’éther: une translation uniforme dans l’éther n’a pas de sens expérimental.

Mais il ne faut pas conclure pour cela, comme on l’a fait parfois prématurément, que la notion d’éther doit être abandonnée, que l’éther est inexistant, inaccessible à l’expérience. Seule une vitesse uniforme par rapport à lui ne peut être décelée, mais tout changement de vitesse, toute accélération a un sens absolu. En particulier c’est un point fondamental

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aura moins vieilli entre son départ et son retour que si elle n’avait pas subi d’accélérations, que si elle était restée immobile par rapport à un système de référence en translation uniforme.

On peut dire encore qu’il suffit de s’agiter, de subir des accélérations pour vieillir moins vite; nous allons voir dans un instant combien l’on peut espérer gagner de cette manière.

“...a uniform translation motion in the æther is not experimentally detectable... From this it should not be concluded, as has sometimes happened prematurely, that the æther must be abandoned having no physical reality since it cannot be experimentally probed. Only the uniform velocity relative to the æther cannot be detected, any change of velocity, that is, any acceleration, has an absolute meaning.”

“Concluding, we can say it is sufficient to be set in motion, to experience acceleration in order to age less quickly.”

- Langevin, Scientia X (1911)

Simultaneity is not protected in SR

Imagine if two explosions occur at the same time in two different places for one observer O' so that

$$\Delta t' = t_1' - t_2' = 0$$

Then another observer O with relative velocity v will see

$$\Delta t = t_1 - t_2 \neq 0$$

And will believe the explosions happen at different times.

Lorentz transformations (in Lorentz form):

$$\Delta t = \frac{\Delta t' + \frac{v_x}{c^2}\Delta x'}{\sqrt{1 - \frac{v_x^2}{c^2}}} \qquad \Delta x = \frac{\Delta x' + v_x \Delta t'}{\sqrt{1 - \frac{v_x^2}{c^2}}}$$

Relativistic Doppler effect (RDE):
No relation to time dilation

Time dilation of the source cannot be part of RDE since the relative speed with respect to the yet undetermined observer cannot be known at the time of light emission.

Einstein's 1905 paper works in the following way: The light wave carries to the observer information about the source allowing the determination of the RDE shift in frequency and wavelength and position aberration at the time of actual observation of the light signal.

$$\Phi = \Phi'$$
$$\omega t - \boldsymbol{k} \cdot \boldsymbol{x} = \omega' t' - \boldsymbol{k}' \cdot \boldsymbol{x}'$$

Use the Lorentz transformation for $\boldsymbol{x}'$ and t' to obtain Doppler effect including aberration.

As Einstein's argument is very terse and he presents without detailed calculation, it can be easily misunderstood. von Laue's SR book discussing RDE can also be misread.

~~Beobachter untersucht werden~~ — Durch Anwendung der in § 6 gefundenen Transformationsgleichungen für die elektrischen und magnetischen Kräfte und der in § 3 gefundenen Transformationsgleichungen für die Koordinaten und die Zeit erhalten wir unmittelbar:

$$X' = X_0 \sin \Phi', \qquad L' = L_0 \sin \Phi',$$

$$Y' = \beta\left(Y_0 - \frac{v}{V} N_0\right) \sin \Phi', \qquad M' = \beta\left(M_0 + \frac{v}{V} Z_0\right) \sin \Phi',$$

$$Z' = \beta\left(Z_0 + \frac{v}{V} M_0\right) \sin \Phi', \qquad N' = \beta\left(N_0 - \frac{v}{V} Y_0\right) \sin \Phi',$$

$$\Phi' = \omega'\left(\tau - \frac{a'\xi + b'\eta + c'\zeta}{V}\right),$$

wobei

$$\omega' = \omega\beta\left(1 - a\frac{v}{V}\right), \qquad a' = \frac{a - \frac{v}{V}}{1 - a\frac{v}{V}},$$

$$b' = \frac{b}{\beta\left(1 - a\frac{v}{V}\right)}, \qquad c' = \frac{c}{\beta\left(1 - a\frac{v}{V}\right)}$$

gesetzt ist.

Aus der Gleichung für ω' folgt: Ist ein Beobachter relativ zu einer unendlich fernen Lichtquelle von der Frequenz ν mit der Geschwindigkeit v derart bewegt, daß die Verbindungslinie „Lichtquelle–Beobachter" mit der auf ein relativ zur Lichtquelle ruhendes Koordinatensystem bezogenen Geschwindigkeit des Beobachters den Winkel φ bildet, so ist die von dem Beobachter wahrgenommene Frequenz ν' des Lichtes durch die Gleichung gegeben:

$$\nu' = \nu \frac{1 - \cos\varphi \frac{v}{V}}{\sqrt{1 - \left(\frac{v}{V}\right)^2}}.$$

Dies ist das Doppelersche Prinzip für beliebige Geschwindig-

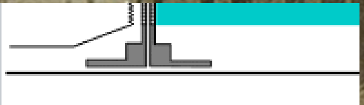
How did the mix up between time dilation and Doppler effect happen?

Ives and Stilwell in 1938 measure (transverse) Doppler shift claiming they measure time dilation.

Ives–Stilwell experiment

From Wikipedia, the free encyclopedia

https://en.wikipedia.org/wiki/Ives–Stilwell_experiment



Ives–Stilwell experiment (1938). "Ca... mostly H_2^+ and H_3^+ ions) were acce...

The **Ives–Stilwell experiment** tested the contribution of relativistic time dilation to the Doppler shift of light.[1][2] The result was in agreement with the formula for the transverse Doppler effect and was the first direct, quantitative confirmation of the time dilation factor.

Resnick around 1960 learns using what appears to be garbled translation of von Laue's SR book and relies on the language of Ives-Stilwell. **This is copied in most English language books and is today found all over the internet.**

Further reading on Relativistic Doppler Effect

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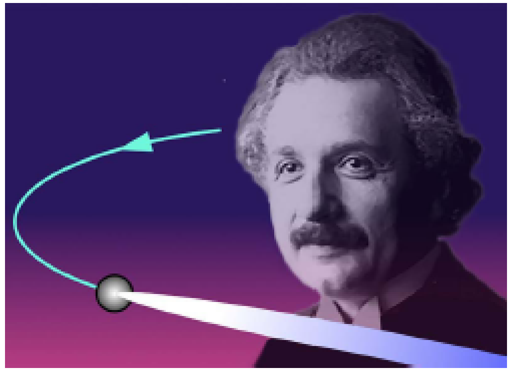

OPEN ACCESS

The relativistic foundations of synchrotron radiation

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Special relativity (SR) determines the properties of synchrotron radiation, but the corresponding mechanisms are frequently misunderstood. Time dilation is often invoked among the causes, whereas its role would violate the principles of SR. Here it is shown that the correct explanation of the synchrotron radiation properties is provided by a combination of the Doppler shift, not dependent on time dilation effects, contrary to a common belief, and of the Lorentz transformation into the particle reference frame of the electromagnetic field of the emission-inducing device, also with no contribution from time dilation. Concluding, the reader is reminded that much, if not all, of our argument has been available since the inception of SR, a research discipline of its own standing.


Distinct features of radiation reaction models

LAD

- Requires self-interaction
- Unphysical runaway solutions
- Computationally impossible

Kinematic variables only
$\boldsymbol{a^\mu, \dot{a}^\mu}$

LL

- Equivalent to LAD in perturbative limit
- Useless for strong accelerations

Field variables only
$\boldsymbol{F^{\mu\nu}, \dot{F}^{\mu\nu}}$

EFO

- Maximum limiting acceleration.
- Equivalent to LL for weak acceleration.

Kinematic and Fields
$\boldsymbol{a^\mu, \dot{F}^{\mu\nu}}$

Name	Covariant equation	Year
Lorentz-Abraham-Dirac (LAD)	$ma^\mu = \mathcal{F}^\mu + \tau_0 P^\mu_\nu \frac{d}{d\tau}(ma^\nu)$	1938
Eliezer-Ford-O'Connell (EFO)	$ma^\mu = \mathcal{F}^\mu + \tau_0 P^\mu_\nu \frac{d}{d\tau}(eF^{\nu\alpha}u_\alpha)$	1948, 1991
Landau-Lifshitz (LL)	$ma^\mu = \mathcal{F}^\mu + \tau_0(e\frac{d}{d\tau}(F^{\mu\nu})u_\nu + \frac{e^2}{m}P^\mu_\nu F^{\nu\alpha}F_{\alpha\beta}u^\beta)$	1962
Mo-Papas (MP)	$ma^\mu = \mathcal{F}^\mu + e\tau_0 P^\mu_\nu F^{\nu\alpha}a_\alpha$	1971

W. Price, M. Formanek, and J. Rafelski. "Radiation reaction and limiting acceleration". In preparation. (2021)
P. A. M. Dirac, "Classical theory of radiating electrons," Proc. R. Soc. A 167, 148 (1938)
L. D. Landau and E. M. Lifshitz, The Classical Theory of Fields, 2ed, London, England: Pergamon (1962)
S. E. Gralla, A. I. Harte, R. M. Wald. "A Rigorous Derivation of Electromagnetic Self-force." Rev. D80, 024031(2009)