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EXCELENCIA MARÍA DE MAEZTU

Scientific context of Einstein's visit to Catalonia and Spain

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ICE Pizza-Lunch Seminar, June 16, 2023

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Prelude

Albert Einstein visited Spain only once, and this happened exactly one hundred years ago. This fact has been celebrated, and reported in the local media in considerable detail, during the last couple of months. Probably you'll have already heard about it. But some aspects of Einstein's visit went unnoticed. I am going to emphasize them here, namely the important social and scientific circumstances surrounding his visit.

They were the first to come to my mind –after thinking for a while– when a journalist came to my office begging for information about Einstein's stay in Barcelona. What on earth could I tell him that had not yet been said in the piles of local chronicles? I started to think… 1923…

A Catalan version of this talk can be found in: https://www.youtube.com/watch?v=WDRbphvGdBs&t=2767s

One hundred years ago …

- … Year 1923! Friedmann!!
  - ✓ Equations for the Universe!!!
- For theoretical physicists: an unbelievable milestone
- General context 1923: historical, social, economical, …
- Hiperinflation, Munic *putsch*, Hitler in jail
- Einstein leaves 6m: Japan, China, Palestine, Spain
- 1922-23 Einstein-Friedmann controversy ⟹ FLRW

What had Einstein done by 1923?

- 1905, 25 years, Bern patent office, *annus mirabilis*
- Four extraordinarily momentous and innovative articles:
  - ✓ Theory of the photoelectric effect
  - ✓ Brownian motion
  - ✓ Theory of special relativity
  - ✓ On the mass-energy equivalence $E=mc^2$
- 1915-17 GTR & KB. Verifiable evidence his theory was correct, he proposed:
  - ✓ anomalous perihelion precession of Mercury
  - ✓ deflection of light in gravitational fields
  - ✓ gravitational redshift
- 1915 Einstein calculates, approx, anomalous precession of Mercury's perihelion !!
- Four years before the famous observation of the solar eclipse in 1919:
  - ✓ Einstein had gone further than Newton!!!

A Einstein: Principles of Gen Theo Relat

1. The relativity principle
   - Goes back to Galileo, it has sense to formulate Laws of Physics
   - Laws are same for inertial and for accelerated sys. Form changes (Lorentz trans.)
   - *Not* total relativity (Mach's principle)
2. Speed of light, c, is constant in any ref. frame
   - Together with Galileo's relat princ (inert frame) → Special Relativity Theory
3. The equivalence principle
   - Grav force is like any force. Equiv of inertial and gravitational mass: $m_i = m_g$
   - Space-time manifold locally Minkowskian
4. Zero-torsion hypothesis ($\nabla_X Y - \nabla_Y X = [X,Y]$)
   - Christoffel symb symm. Can be suppressed (Einstein-Cartan, string th.)
5. Reduction to Newton's laws
   - To define the universal constants

Silence, please, it is *Galileo himself* who speaks to us

Galileo states his principle of invariance: *the laws of physics are the same in all inertial reference systems*. 1632 *"Dialogo sopra i due massimi sistemi del mondo"*, in words of Salviati (2nd day), with a *gedanken* experiment [silence, please, it is Galileo himself who speaks to us ...]:

> *"Lock yourself up with a friend in the main cabin, under the deck of a rather large ship; and bring with you flies, butterflies, and other small flying animals. Hang a bottle so that it drains, drop by drop, into a large container below. Make the ship go at the speed you prefer, but always the same: a smooth motion, without fluctuations in one direction or the other. The drops will fall into this container, without being deflected aft, even if the ship has moved forward while the drops are still in the air. The butterflies and flies will continue their usual flight from side to side, as if they never tire of following the course of the ship, however fast it may go; and it will never happen that they concentrate at the stern of it."*

"der glücklichste Gedanke meines Lebens" AE

- AE 1905, derived the Lorentz transformation under the only two assumptions of the principle of relativity or covariance (that of Galileo) and of the constancy of the speed of light (in ideal vacuum conditions) in any inertial frame of reference (M&M) – no ether!
- In this way, he added full meaning to the Lorentz and Poincaré transformations, previously considered by several physicists since 1887
- The consequences of these two, so simple postulates are extraordinary and very difficult to grasp for those of us who always move at insignificant speeds compared to that of light
  - ✓ the simultaneity of two events is relative (to the reference system)
  - ✓ time dilation — length contraction — relativistic contribution to the Doppler effect
  - ✓ and the famous formula: $E=mc^2$ [Lise Meitner, Otto Frisch; Otto Hahn, Fritz Straßmann (1938-39)]
- Principle of equivalence: at Patent Office in Bern, sitting in his usual chair, he thought about what would happen to him if he were to fall upright from the roof of his house
  - ✓ There would be no gravity, in turn!
  - ✓ If I would let go of an apple, or a coin, they wouldn't fall!

"We assume the complete physical equivalence of a gravitational field and a corresponding acceleration of the reference system" (Einstein, 1907)

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Curvatura i Matèria: Equacions de Camp d'Einstein

$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = 8\pi G T_{\mu\nu}$$

convencions Wald 1984

mètrica: -+++

tensor de curvatura $R_{\mu\nu\rho}{}^{\sigma} = \Gamma^{\sigma}_{\mu\rho,\nu} - \Gamma^{\sigma}_{\nu\rho,\mu} + \Gamma^{\alpha}_{\mu\rho}\Gamma^{\sigma}_{\alpha\nu} - \Gamma^{\alpha}_{\nu\rho}\Gamma^{\sigma}_{\alpha\mu}$

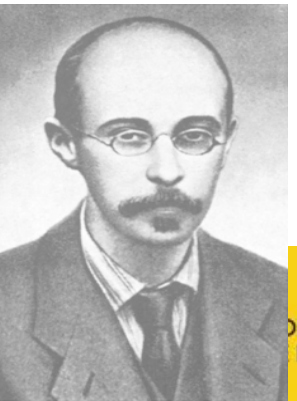
tensor de Ricci $R_{\mu\rho} = R_{\mu\sigma\rho}{}^{\sigma}$, $R = R^{\mu}_{\mu}$ escalar de curvatura

Exemples

$$ds^2 = (1 + 2GM/rc^2)\, c^2 dt^2 - (1 + 2GM/rc^2)^{-1}\, dr^2 - r^2(d\theta^2 + \sin^2\theta\, d\varphi^2)$$

"Es ist immer angenehm, über strenge Lösungen einfacher Form zu verfügen." – Karl Schwarzschild, 1916

mètrica de Schwarzschild



$$\mathrm{d}s^2 = -\mathrm{d}t^2 + a(t)^2 \left(\frac{\mathrm{d}r^2}{1 - kr^2} + r^2 \mathrm{d}\theta^2 + r^2 \sin^2\theta\, \mathrm{d}\phi^2 \right) \rightarrow R = 3k$$

Aleksandr Friedmann, 1924

mètrica de Friedmann–Lemaître–Robertson-Walker (FLRW)

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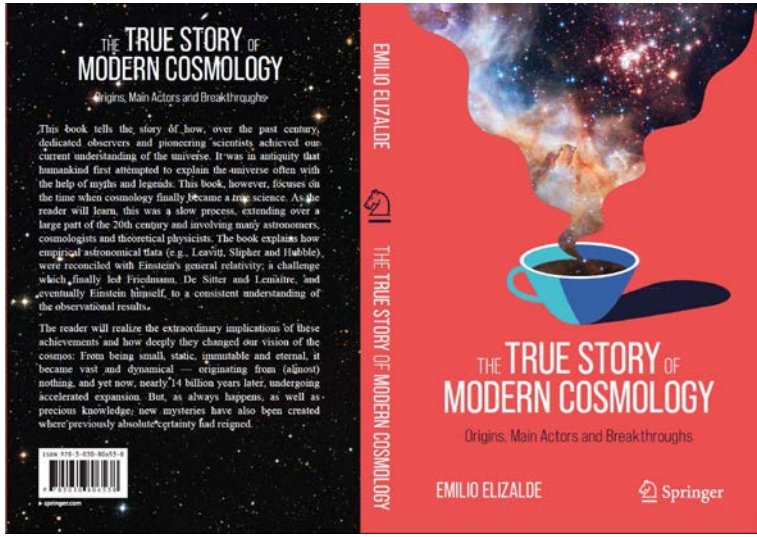
Important obs! Einst Eqs. & Symmetry

- Are postulates 1st & 3rd independent?
  - ✓ Answer is tricky: yes and no !
  - ✓ By definition they are independent
  - ✓ But the aproxs. carried out in the formulation of GR (cut to 2nd ord) make the equiv principle also aprox.
  - ✓ Higher order differentials & gradients do differ
  - ✓ This is seen at very high energies

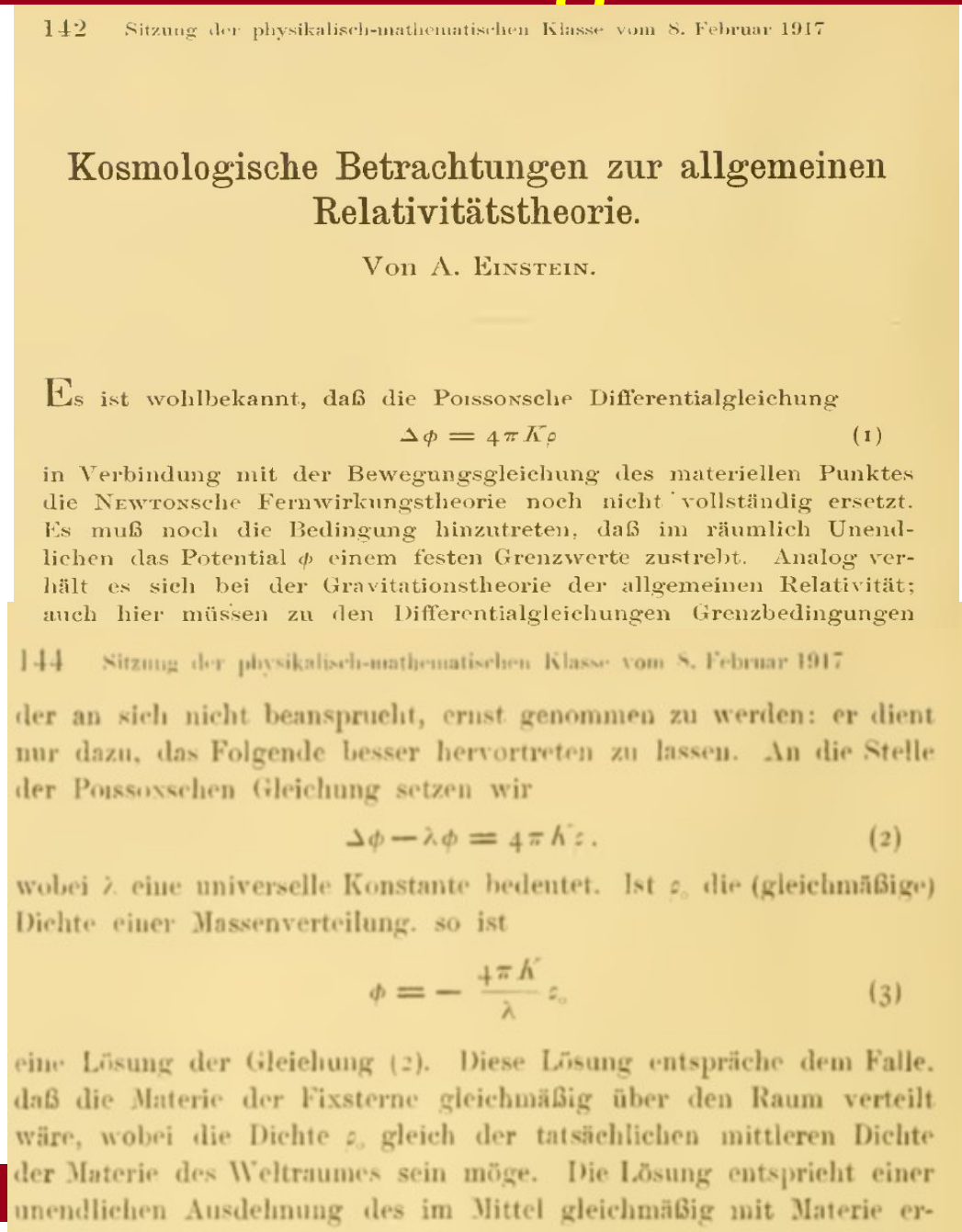


- Einstein's theory *not* final (AE *dixit*) — Symm Break
  - ✓ Mach's principle of total relativity *not* incorporated
  - ✓ Einstein was the first to recognize this fact his theory was incomplete, was convinced someone would improve it soon. Now: S-T, f(R), ... QG? ...
  - ✓ F Wilczek (04): total relat → GR, modif Symmetry Breaking paradigm

Kosmologische Betrachtungen …

1917: Einstein applies his GTR to the Universe

- As in the Newtonian case, he concludes that the masses in the Universe should have strongly curved space
- He finds a solution by introducing, next to the Laplacian of Poisson's equation, a constant term (p. 144) that acts as "antigravity" (Robert Hooke)
- Analogously, on page 151 he introduces the same type of universal constant, *"eine vorläufig unbekannte universelle Konstante"* in his eqs
- And he also reasons that as long as λ is small enough, when applied to the domains of the solar system they will give results indistinguishable from those of Newtonian physics



142 Sitzung der physikalisch-mathematischen Klasse vom 8. Februar 1917

Kosmologische Betrachtungen zur allgemeinen Relativitätstheorie.

Von A. Einstein.

Es ist wohlbekannt, daß die Poissonsche Differentialgleichung

$$\Delta\phi = 4\pi K\rho \qquad (1)$$

in Verbindung mit der Bewegungsgleichung des materiellen Punktes die Newtonsche Fernwirkungstheorie noch nicht vollständig ersetzt. Es muß noch die Bedingung hinzutreten, daß im räumlich Unendlichen das Potential ϕ einem festen Grenzwerte zustrebt. Analog verhält es sich bei der Gravitationstheorie der allgemeinen Relativität; auch hier müssen zu den Differentialgleichungen Grenzbedingungen

144 Sitzung der physikalisch-mathematischen Klasse vom 8. Februar 1917

der an sich nicht beansprucht, ernst genommen zu werden: er dient nur dazu, das Folgende besser hervortreten zu lassen. An die Stelle der Poissonschen Gleichung setzen wir

$$\Delta\phi - \lambda\phi = 4\pi K\varrho. \qquad (2)$$

wobei λ eine universelle Konstante bedeutet. Ist ϱ_0 die (gleichmäßige) Dichte einer Massenverteilung, so ist

$$\phi = -\frac{4\pi K}{\lambda}\varrho_0 \qquad (3)$$

eine Lösung der Gleichung (2). Diese Lösung entspräche dem Falle, daß die Materie der Fixsterne gleichmäßig über den Raum verteilt wäre, wobei die Dichte ϱ_0 gleich der tatsächlichen mittleren Dichte der Materie des Weltraumes sein möge. Die Lösung entspricht einer unendlichen Ausdehnung des im Mittel gleichmäßig mit Materie er-

Einstein and the Nobel Prize in Physics

- Einstein was convinced that he would be granted the NP:
  - ✓ In his diary he does *not* mention the day he found out he had been awarded it!
  - ✓ 1918 he "gives" the full amount of the prize (50 sal) to Mileva and son in divorce agreement
  - ✓ Gets it 1922 (corresp to 1921); makes acceptance speech in July 1923
  - ✓ On getting it writes Nobel comm: *"...thanks...I'll get rid of annoying guys..."*
- Awarded *"for his services to theoretical physics, and especially for the discovery of the law of the photoelectric effect"*
  - ✓ Exp proven already in 1916, by Robert Millikan (NP 1923)
- Due to hyperinflation in Germany, in 1923, capitals suddenly lost all value

Some notable events of the time

- 9 Jan 1923: Juan de la Cierva makes the first flight in his autogyro
- 11 Jan: French and Belgian troupes occupy the Ruhr region, in order to force Germany to pay the war reparations agreed to in the Treaty of Versailles
- Feb 1923: inflation grows, one dollar is exchanged for 57.500 mark
- 23 Feb 1923: the German Parliament approves a decree law against speculators
  - July: 1 dollar = 353.000 Papiermark (more than 200 times its value at the beginning of January)
  - 15 Nov 1923: 1 dollar = 4.200.000.000.000 Papiermark
- End of 1923: in Munich, brewery *putsch*, Adolf Hitler and Rudolf Hess prosecuted and sentenced to prison
- Tutankamon, Salvador Seguí, Pancho Villa, P. Rivera

An almost 6-month-long escape

- Oct 1922 — Mar 1923: conferences in the Far East, Palestine and Spain
- Not for the pleasure of traveling or giving talks, but to escape from Germany (Walther Rathenau murder, “list”)

The Travel Diaries of Albert Einstein: The Far East, Palestine, and Spain [6 Oct 1922–12 Mar 1923]

6th Oct. *Night trip in overfilled train after reunion with Besso and Chavan. Lost wife at border.*

7th Oct. *Sunrise shortly before arrival in Marseille. Silhouettes of austere flat houses surrounded by pines. Marseille, narrow alleyways. Voluptuous women. Vegetative living. We were taken in tow by seemingly honest youth, dropped off at ghastly inn by the railway station. Bugs in morning coffee. Made our way to the shipping company and to the old harbor near the old city quarter. At the ship ...”*

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An almost 6-month-long escape

"I'm drawn to the Japanese people... more so than any people I've met so far: quiet, modest, intelligent, art appreciative and considerate, nothing about appearances, but all about substance ..."

In Hiroshima, Einstein wrote that on the beautiful summit of Mount Misen, he had been surrounded by *"pure souls like nowhere else in the world. One cannot but love and admire this country"*

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Einstein in Catalonia

Brief details about Einstein's visit to Catalonia and Spain

- Invited by Esteve Terradas, phys and engin, and Julio Rey Pastor, mathemat
- Terradas offered 7,000 pts, double the annual salary of a professor, to give lectures in Barcelona and Madrid
- Ship docks in Marseille, probls checking luggage in Berlin or Zurich: no warning
- Hotels: Cuatro Naciones (modest), Colon (7d, inv 692 ptas), 883 bcc, 500 racab

Doc. 379. Travel diary [March 1923], p. 325-326

Febrary 17, 18, 19*. Indigestion from bad food. High seas and rain. 19 in the morning, Stromboli well in sight. Afternoon, 6 o'clock, Naples. Vesuvius with gray clouds, cloudy sky. So cold and unpleasant that one is glad to stay on the boat. An Englishman from Australia turns out to be from Mecklenburg. News of a rail strike in France and more and more retaliation in the Ruhr, how will things go? In Toulon friendly people, in Marseille, dangerous to speak German. The manager of the freight depot refuses to send our baggage to Berlin, or even to Zurich.*

Febrary 22-28*. Stop in Barcelona. Very tired, but very friendly people (Terradas, Campalans, Lana, Tirpitz's daughter). Popular songs, dances. refectorium How beautiful it was!*

March 1*. Arrival in Madrid. Departure from Barcelona, farewell. Terradas, German consul with Tirpitz's daughter, etc.*

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Einstein in Catalonia

Albert Einstein in front of the Fonda Ibérica de l'Espluga de Francolí, on February 25, 1923. What attracted the children was not Einstein but the magnificent automobile in which he was traveling, from Casa Elizalde, Type 29 torpedo (33,000 ptas.) Photos: Casimiro Lana Sarrate.

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Scientific context of his visit

- From travel Diary: often occupied with physics questions
- Diary 9 Oct 1922: reads Ernst Kretschmer's book *"Physics and character"* and Henri Bergson's book on *Relativity*
- Compares approxs. from Riemann and Weyl to the problem of the "unification of gravity with electricity"
- Talked about this in Spain, but mainly on relativity th.
- Spent a lot of time on that in the future: unified theory

However, this will *not* be our subject here !

The really important scientific context

- Alexander Friedmann (or Alexandr Fridman, 1888-1925 Sant Petersburg), prof. at SP Mining Inst., mathemat. interests
- End 1920: letter to Ehrenfest (Lorentz Inst., Leiden), AF had already obtained some simple solutions to Einstein's field equations
- Early 1922: another letter "…*possible universe with curvature radius that varies with time*" in Russian, never publ, Ehrenfest -> Schouten
- 29 Jun 1922: *Zeitschrift für Physik, "Über die Krümmung des Raumes"*

"…The case of a variable Universe admits, on the other hand, a large number of possible situations. In some cases, the radius of curvature of the universe increases steadily with time. And there are other situations that correspond to a radius of curvature that changes periodically…"

The really important scientific context

- Einstein analyzed Friedmann's paper quite quickly
- Note received by *Zeitschrift für Physik,* 18 Sep 1922
  (few weeks before embarking for his 6 month trip)

  "...As for the non-stationary Universe, the results contained in the work seem suspicious to me. In fact, the solution given for this case turns out not to satisfy the field equations..."
- Friedmann learned of Einstein's criticism through his friend Yurii Krutkov, who was visiting in Berlin at the time
- And, on December 6, 1922, Friedmann wrote a letter to Einstein answering all his objections
- When Friedmann's letter arrived in Berlin, Einstein had already left!

The really important scientific context

- In the letter, Friedmann tells Einstein:

"...Given that the possible existence of a non-stationary Universe is of interest, I would like to present here the calculations I have made, so that you can verify and critically evaluate them. [Details of mathematical operations follow]. If you find the calculations I present in this letter to be correct, please be so kind as to inform the editors of Zeitschrift für Physik about this conclusion. Perhaps in that case you yourself would like to post a correction to the statement you made, or at least give me a chance to post the operations part of this letter..."

- May 1923, Krutkov and Einstein meet in Leiden [Hendrik Lorentz retires] face to face at Ehrenfest home [appted Lorentz's successor]

The really important scientific context

- Two short paragraphs in Krutkov's letters to his sister in SP. First

  "...On Monday, May 7, I was with Einstein, reading Friedmann's article of ZfP in detail..."

- In a second letter, written on May 18, 1923, he states:

  "...I have defeated Einstein in the argument of Friedmann's work. Petrograd's honor is saved!..."

- And Einstein writes a note in Zeitschrift für Physik where he retracts:

  "In my previous note I criticized Friedmann's work on the curvature of space. However, a letter from Mr. Friedmann, which I got through Mr. Krutkov, convinced me that my criticism was based on an error in my calculations. Now I consider that the results of Mr. Friedmann are correct and they bring new light...."

The really important scientific context

AE's retractation note ends:

"...It is shown that the field equations, together with the static solution, also admit dynamic solutions (i.e. with a variable time-coordinate), with central symmetry for the spatial structure".

Notiz zu der Arbeit von A. Friedmann „Über die Krümmung des Raumes".

Von **A. Einstein** in Berlin.

(Eingegangen am 31. Mai 1923.)

Ich habe in einer früheren Notiz [1]) an der genannten Arbeit [2]) Kritik geübt. Mein Einwand beruhte aber — wie ich mich auf Anregung des Herrn Krutkoff an Hand eines Briefes von Herrn Friedmann überzeugt habe — auf einem Rechenfehler. Ich halte Herrn Friedmanns Resultate für richtig und aufklärend. Es zeigt sich, daß die Feldgleichungen neben den statischen dynamische (d. h. mit der Zeitkoordinate veränderliche) zentrisch-symmetrische Lösungen für die Raumstruktur zulassen.

[1]) ZS. f. Phys. **11**, 326, 1922.
[2]) Ebenda **10**, 377, 1922.

The really important scientific context

- But: for at least a decade, no one considered the two works of Friedmann (2^{on} 1924) as possible models for o Universe
- It took Einstein 10y to admit the Universe expansion!!
- Lemaître 1927, linked eqs (Fried.)–obs (Slipher, Hubble)
- 1932 Robertson & Walker: Friedmann sol. is UNIQUE!!
- Univ. Model: Friedmann-Lemaître-Robertson-Walker (FLRW)

The 2 revolutions of Modern Cosmol

- At the heart of the 1st revolution in Modern Cosmology (1912-32): Henrietta Leavitt, Vesto Slipher up to Edwin Hubble, and includes theorists A Einstein, A Friedmann, W de Sitter & G Lemaître
- Had to wait for elaborate formulation of the Big Bang model, final verification of the cosmic background radiation (CMB), and still for an important and crucial remodeling (inflation), prelude of 2nd revol.
- 2nd revolution (1985-2005): Univers expansion accelerates !?!?
- 1923: *A pivotal episode in the history of physics, of cosmology and, even further, of all Human History*

Conclusion

- Einstein's personal contribution in this specific episode cannot be said to have been as brilliant as on other occasions
- But no one can deny that the origin of everything lies in the field equations of his general theory of relativity, worked out by other researchers of a very high level and great intuition
- Einstein himself was not able to understand all the consequences of the exceptional theory he had created, out of extremely basic and natural principles
- It has taken +100y and the dedication of thousands of researchers:

Despite the weight, which at times may seem infinite, of the great geniuses, progress in knowledge is always, without exception, a collective task.

THE TRUE STORY OF MODERN COSMOLOGY

Origins, Main Actors and Breakthroughs

This book tells the story of how, over the past century, dedicated observers and pioneering scientists achieved our current understanding of the universe. It was in antiquity that humankind first attempted to explain the universe often with the help of myths and legends. This book, however, focuses on the time when cosmology finally became a true science. As the reader will learn, this was a slow process, extending over a large part of the 20th century and involving many astronomers, cosmologists and theoretical physicists. The book explains how empirical astronomical data (e.g., Leavitt, Slipher and Hubble) were reconciled with Einstein's general relativity; a challenge which finally led Friedmann, De Sitter and Lemaître, and eventually Einstein himself, to a consistent understanding of the observational results.

The reader will realize the extraordinary implications of these achievements and how deeply they changed our vision of the cosmos: From being small, static, immutable and eternal, it became vast and dynamical — originating from (almost) nothing, and yet now, nearly 14 billion years later, undergoing accelerated expansion. But, as always happens, as well as precious knowledge, new mysteries have also been created where previously absolute certainty had reigned.

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Thank
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