MTW 50

Kip Thorne

3 May 2023
Zoom Event Sponsored by
International Society of General Relativity and Gravitation
The Historical Context

- 1940 -1950s: GR - largely mathematical explorations
  - Astrophysicists’ attitude - Jesse Greenstein

- 1954: John Wheeler (Princeton) turned from nuclear physics to GR ... injected new viewpoints and very physical approach
  - Charles Misner: 1954-57 PhD student ; 56-63 faculty. 63 ➔ U Maryland professor
  - Kip Thorne: 1962-65 PhD student ; 65-66 postdoc 66 ➔ Caltech professor
GR Texts that I Studied or Browsed

- Landau & Lifshitz - Classical Theory of Fields (1962)
- 1963 Les Houches Lectures: Relativity Groups & Topology
- Tolman - Relativity, Thermodynamics & Cosmology (1934)
- Bergman - Introduction to the Theory of Relativity (1942)
- Synge - Relativity the General Theory (1960)
- Weber - General Relativity & Gravitational Waves (1961)
Motivations for New GR Textbook

• New astrophysical/cosmological applications
  ▶ 1963 Quasars; 64-65 CMB; 67 Pulsars
• Tie to modern differential geometry (a la Cartan)
• Focus on physical interpretation; physical intuition
• Geometric interpretation of GR; physics as geometry
John, Charlie and Kip
Agreement & Planning to Write MTW

- November 1967: NYC - Chinese Restaurant Treaty
  - When two authors declare we are finished, we finish.
  - Book will be concise.
    - Ernst Schmutzer Relativistische Physik (1968) 968 pp
    - ?Sadly?: MTW 1279 pp
We Worked on MTW for 5 Years: 1967-72

- A period of intense change in GR & Relativistic Astrophysics
- compact X-ray sources - Cygnus X-1 black hole
- BH accretion disks; quasars powered by massive BHs
- Uniqueness of BHs ("no hair")
- Laws of BH mechanics
- Global methods & singularity theorems. Mixmaster & BKL
- Cosmic censorship
- BHs as dynamical objects; pulsations
- Gravitational wave geometric optics; energy/momentum
- PPN
- …
Some Remarks About the Authors
John Wheeler

- Conservative politics & demeanor
- Colorful physics style
John Wheeler

- Conservative politics & demeanor
- Colorful physics style
- Deep physical intuition & willingness to speculate
- Mathematically strong

Richard Feynman
Charles Misner

- Mathematically the deepest
- ADM [Arnowitt Deser Misner]
  3+1 Hamiltonian formulation of GR
Kip

- Closest to astrophysics & experiment
1967-68 Preparing to Write MTW

- Misner and Wheeler teaching GR courses at Maryland and Princeton; Kip at U Chicago with Chandrasekhar

Misner Lecture Notes

In this lecture we begin by discussing red shifts in accelerated frames. This topic is important enough that we will discuss it several times, that is:

1) From the "Newtonian" viewpoint with more knowledge of the behavior of light than Newtonian mechanics assumes.

2) From the viewpoint of general relativity.
1967-68 Preparing to Write MTW

- Misner and Wheeler teaching GR courses at Maryland and Princeton; Kip at U Chicago with Chandrasekhar

**Wheeler Lecture Notes**

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PRINCETON UNIVERSITY
DEPARTMENT OF PHYSICS
NOTES FOR THURSDAY 7 MAR. 1968

THE PHYSICAL COMPONENTS OF THE CURVATURE TENSOR ("TIDE PRODUCING FORCE")

Physics looks simple only when described locally, according to Einstein. Hence what is relevant about gravitation is not the acceleration of one particle relative to some mythical all pervasive Newtonian frame of reference, but the relative acceleration of two test particles — as for example in a swarm of test particles orbiting the earth like a swarm of bees. (For more on this way of looking
```
Part I  A 10 week course on fundamentals of GR
• Chapter 1: Special Relativistic Preliminaries
  - inertial frames, fundamentals of SR, Stress-energy tensor,
  - accelerated reference frames
• Chapter 2: Intro to Differential Geometry
• Chapter 3: Einstein Field Equations
• Chapter 4: Relativistic Stellar Structure
• Chapter 5: Intro to Cosmology
• Chapter 6: Schwarzschild-Kruskal
• Chapter 7: Elementary Theory of Gravitational Waves
• Chapter 8: Experimental tests of GR

Part II  A deeper, more detailed treatment of the most important special topics.
• Chapter 1: Modern Differential Geometry
• Chapter 2: Problems with Spherical Symmetry
• Chapter 3: Electromagnetic Theory
• Chapter 4: Exact Solutions (RN, Kerr Taub-NUT, charged
  - Kerr-NUT, Weyl, Methods of generating new solutions)
• Chapter 6. Gravitational Radiation Theory
• Chapter 7: Equations of Motion
• Chapter 8 Post Newtonian Approximation
• Chapter 9 Cosmology
• Chapter 10 Singularities
• Chapter 11 Initial Value Formulation
• Chapter 12 Kinetic Theory
• Chapter 13: Rotation
• Chapter 14: Geometrodynamics
• Chapter 15: Alternative Relativistic Rheories of Gravitation

Summer 68 - Spring 69
• Many long discussions / planning
• Low level of work on book
• Drafts of chapters & pieces of chapters
• Reorganization: Track 1 & 2 mingled
• Boxes introduced
Summer 1969 - Summer 1970

- Intense, near 100% effort on book - leading to First Preliminary Edition in September 1970

- Whenever two of us expected to be together, the third was obligated to try to join, at least for a few days

- We met, and wrote and revised in — among others —
  - Princeton U., Princeton Institute for Advanced Study, U. of Maryland, Caltech, U. Texas Austin, National Airport Washington DC, Dublin Ireland, Kyoto (Japan), USSR (Moscow, Kiev, Leningrad), … and Maine

- Particularly memorable: Summer 1970 in Maine
For each chapter:

- One of us wrote first draft.
- Circulated to other authors … at least three times around (nine revisions) … until converged.
- Sent out for typing whenever the manuscript got too messy.
CHAPTER 25

THE "PIT IN THE POTENTIAL" AS THE CENTRAL FEATURE OF MOTION IN SCHWARZSCHILD GEOMETRY

"Eccentric, entwined, yet regular,\nThen meet, when most irregular they seem;\nAnd in their motions harmony divine."

§ 25.1 From Kepler’s laws to the effective potential for motion in Schwarzschild geometry

No greater glory crowns

Newton’s theory of gravitation than the account it gives of the principal features of the solar system: a planet in its motion sweeps out equal areas in equal times; its orbit is an ellipse with foci at the sun; a
John - Typical First Draft of a Box

13.1 METRIC
Data on Distances

The shape of the earth be described by giving distances between identifiable points: buoys, ships, floating objects, icebergs, lighthouses, peaks and distances to be given is

\[ n(n-1)/2 \]

With 200 distances per page of printout, this means 10^{12} pages weighing 6 kg each, or 6 \times 10^6 metric tons of data. With 6 tons per truck this means 10^6 truck loads of data; or with one truck passing by every 5 seconds of night and day traffic 5 \times 10^6 seconds or 2 months to get in the data.

Distances to First Distillation: Nearby Points Only
Part 7  Gravitational Waves

Chapter W  Propagation of Gravitational Waves

Linearized Theory.

The most fundamental objection to Newtonian gravitation is that it predicts that gravitational effects propagate with infinite velocity. The major motivation for devising a relativistic theory of gravity was to fix this.
34.1 Global Techniques

Until the 1960's, computations in gravitation theory used local techniques almost exclusively. The Einstein field equation describes how the stress-energy tensor $T_{\mu\nu}$ at a given event generates curvature $G_{\mu\nu}$ at that same event. When reduced to differential equations for the metric, $G_{\mu\nu} = 8\pi T_{\mu\nu}$ relates $g_{\mu\nu}, \frac{\partial g_{\mu\nu}}{\partial x^\rho},$ and $\frac{\partial^2 g_{\mu\nu}}{\partial x^\rho \partial x^\sigma}$ at each given event to $T_{\gamma\delta}$ at that same event. The solution of these differential equations is effected, on a computer, or in any initial-value type analysis, by integrating forward in time from event to event. The nongravitational laws of physics are obtained by invoking the equivalence principle in a local Lorentz frame at each individual event in spacetime. To build upon an understanding of the global structure of spacetime, one performs local computations near each event, and then patches the local results together to form a global picture.

Why this great reliance on local analyses? Because the laws of gravitation physics take on particularly simple forms when stated locally.

That gravitation physics is also subject to powerful and simple
and everywhere locally isometry in character ("local
isometry character of this Riemannian geometry")}. 

John.

Kip.

Charlie.
Exercise 27.13  TURN-AROUND UNIVERSE
MODEL NEGLECTING MATTER DENSITY.
If turn-around occurs far to the right
(larger $a$) of the maximum of the potential $V(a)$
in equation (27.74), the matter terms will
be negligible. Set $g_{m0} = g_{r0} = 0$. Then add
what signs of $k, \Lambda$ are needed for turn-
amound? and solve to show that
$\Lambda = \frac{3}{2} (a_{\text{min}})^{-2}$, $H = (a_{\text{min}})^{-1} \tanh \left( \frac{t}{a_{\text{min}}} \right)$
and that the deceleration parameter $q = -\frac{1}{a^2} (\frac{da}{dt})^2$ has the value
$q = -a^2 \left( a^2 - a_{\text{min}}^2 \right)^{-1} < -1$.

Exercise 27.14  "HESITATION" UNIVERSE
Neglect radiation in equation (27.74)
but assume $K_0$ and $\Lambda$ chosen so that
the universe spent a very long time
with $a(t)$ near $a_h$ ($a_h$ measures location
of highest point of the barrier, or the size
For the first half century of its life general relativity was a theorist's Paradise, but an experimentalist's Hell. No theory was thought more beautiful, and none was more difficult to test. The situation has changed, but all that is changing now. In the last few years general relativity has become one of the most exciting and fruitful branches of experimental physics. The march of technology has finally caught up with Einstein's genius, half a century late -- not only on the astronomical front, but also in laboratory experiments.

On the astronomical front observers avidly study and search for phenomena in which relativity is important: cosmology, pulsars, quasars, gravitational waves, black holes. Unfortunately, in pulsars and quasars, and in the sources of cosmological radiation and gravity waves, gravitational effects are tightly interwoven with the local behavior of matter and magnetic fields. There is little hope of separating them sufficiently to get clean tests of the nature of gravity. Instead, astrophysicists must put the laws of gravity into their calculations along with all the other laws of physics and the observational data; and they must then seek, as output, informations...
Manuscript Mailed Princeton to Caltech
First Preliminary Edition
September 1970

GRAVITATION

Charles W. Misner
Department of Physics and Astronomy, University of Maryland

Kip S. Thorne
Kellogg Radiation Laboratory, California Institute of Technology

John Archibald Wheeler
Joseph Henry Laboratories, Princeton University

UNIVERSITY OF MARYLAND
DEPARTMENT OF PHYSICS AND ASTRONOMY
COLLEGE PARK, MARYLAND
• 9 Parts vs 10 in final book
• 33 chapters vs 44 in final book
Summer 1970 - Summer 1971

• Extensive Revisions. Eleven Chapters and One Part Added. Converging

• Got together in Maine, Princeton U, Institute for Advanced Study, U Maryland, Caltech, San Felipe (by the sea) Mexico
Second Preliminary Edition
September 1970

- Same 9 Parts as final book
- Same 44 Chapters as final book, but some titles a little different

Despite what I said in my talk, this edition in fact was printed at and distributed by the Physics Department of the University of Utah - under the auspices of Richard Price.
- Kip
§33.1. Why "Black Hole"?

SAGREDUS: What is all this talk about "black holes"? When an external observer watches a star collapse, he sees it implode with ever-increasing speed, until the relativistic stage is reached. Then it appears to slow down and become "frozen," just outside its horizon (gravitational radius). However long the observer waits, he never sees the star proceed further. How can one reasonably give the name "black hole" to such a frozen object, which never disappears from sight?

SALVATIUS: Let us take the name "black hole" apart. Consider first the blackness. Surely nothing can be blacker than a black hole. The very redshift which makes the collapsing star appear to freeze also makes it darken and become black. In the continuum approximation, where one ignores the discreteness of photons, the intensity of the radiation received by distant observers decreases exponentially as time passes, $L \propto \exp(-t/3\sqrt{M})$, with an exceedingly short e-folding time.
In Meantime: May 1971

Chose Publisher

Negotiated Contract

WH Freeman & Company
San Francisco
owned by Scientific American

I took responsibility for
interactions with publisher

Agreement for Publication

THIS AGREEMENT, made this Third day of May, 1971, by and between

CHARLES W. MISNER, KIP S. THORNE, and JOHN ARCHIBALD WHEELER
hereinafter called the AUTHOR, and W. H. FREEMAN AND COMPANY, a California corporation, San Francisco, California, hereinafter called the PUBLISHER:

Witnesseth:

I. The author agrees to deliver to the publisher a manuscript in duplicate for a book on general relativity.

The manuscript shall be legible and suitable in form as copy for editing and typesetting. It shall be of such content as the author and publisher are willing to have published.

II. The publisher agrees to publish, manufacture, and distribute this work and to pay all of the expenses of publication, manufacture, and distribution, except as provided in Paragraph V of this agreement. The publisher shall have the right of final decision on all matters relating to publication, manufacture, and distribution.

III. The author hereby grants to the publisher, for the period of the copyright and renewal of the copyright, the sole and exclusive right to publish, manufacture, and distribute this work, including the exclusive right to publish revisions, abridgements, and translations, and the right to take out copyright in the name of the publisher, or in the name of the author, if the author so desires. The author agrees to apply for the renewal of the copyright at least six months prior to its expiration.

IV. The publisher agrees to pay royalties to the author at the following terms:
   A. On domestic sale of bound books:
      15% of list price.
   B. On foreign sale of bound books:
      Sales in Canada: 15% of list price.
      Other foreign sales: 7-1/2% of list price.
   C. On sale of translation or other rights:
      50% of net receipts.
   D. On sale of printed sheets:
      10% of net receipts.
   E. No royalty shall be paid on sales made at or below manufacturing cost nor shall royalties be paid on gratuitous copies.
   F. In the event a trade edition—that is, a long discount edition—is published in addition to the text edition, the royalty on the sales of the trade edition shall be computed on the list price of the text edition.
   G. An accounting of sales and royalties due the author shall be made as of June 30 of each year and shall be reported to the author as soon thereafter as is possible. Royalties shall be paid to the author within three months after June 30.
   H. The authors shall notify the publisher before publication date of the distribution of the remaining copies.
Fall 1971 - Summer 1972

- Massaged manuscript.
  - added a dedication
Motivation for Dedication

Letter from John - 25 January 1972

I would like to “… take up and expand on … a theme that you sounded, Charlie, at the end of your chapter on … Mixmaster cosmology, about the interest of the public in science. I must say I am upset every time intellectuals set themselves up on pedestals as objects of worship rather than as servants of the larger public…”

In that vein he proposed this dedication
This book is dedicated
To the humble old lady
Sweeping the walk with her broom
The eager child,
And all who with their love of truth
Take from their own wants
By taxes and gifts,
And now and then send forth
A dedicated servant out of their number,
To forward the search
Into the mysteries and marvelous simplicities
of this strange and beautiful Universe
Our home.
This book is dedicated

To the humble old lady

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The eager child,

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And all who with their love of truth

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And now and then send for

A dedicated servant out of their number,

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Into the mysteries and marvelous simplicities

of this strange and beautiful Universe

Our home.
Fall 1971 - Summer 1972

• Massaged manuscript.
  - added a dedication

• Added and checked references.
  - John took responsibility; maintained bibliography

• Checked equations in manuscript & searched for errata
  - Goal: NO errors in equations - if readers find errors they quickly lose faith.
    ▶ (I’m aware of about 10 errors in the first printing of the entire book.)

  - We each took responsibility for 1/3 of chapters, and hired a student to help. - Mine was Carlton Caves
Chapter Assignments for Equation Checking

There remains the crucial problem of getting the errors out of our equations. Let me remind you that we have each agreed to recheck every equation in the following sets of chapters:

<table>
<thead>
<tr>
<th>Charles</th>
<th>Kip</th>
<th>John</th>
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I have already hired a student to help me with my rechecking. I hope that you are both proceeding in one manner or another. Of course, the recheck must be completed by galley-proof time. And that is not far off. I gather we can expect to start receiving galleys on the early...
Errata from Readers

Dear Dr. Greiner,

Last semester I took Dr. Brill's relativity course at Maryland using your "Second Preliminary Edition" of your book Gravitation. I circled the errors I found, but never wrote them down to send to you. Enclosed, you will find my corrections for volume I. I don’t have time to do the same for volumes II and III because I must study for my qualifying exams on Aug 23-24. After that I will gladly write up my corrections if you can still make use of them. Please notify me of the latest date at which you would still want them. If possible could you

August 4, 1972

Kip S. S. Love

Kellogg Radiation Laboratory
California Institute of Technology
Pasadena, California 91109

I have incorporated, with thanks for C's 14-15, since I am not familiar with N. Blaney's, Aug 72.

Kip S. Love

520C Newton St. Apt. 72
Boulder, Colo. 80303

Dear Dr. Greiner,

I have incorporated the errors listed except those for C's 14-15, since I am not familiar with N. Blaney's.

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X Box 1.3, page 5/5, line 6, "Length of SAB", should be "Length of SAB".
X chap. 2, p. 46, line 3 from below, "events components (2.3)" should be "events components (2.3)".
X chap. 9, some references are incomplete.
X chap. 15, p. 124, 2.4, "(Figure 5.3-a)" should be "(Figure 5.3-b)".
X chap. 15, p. 125, 1.5 from below, "in Figure 5.3" should be "in Figure 5.4".
X Box 5.3, p. 73, 1.17, [u, v] = (u⊗uxi - u⊗uxbo)(d/da)
X chap. 10, p. 31, 2.1, "gradient of a (½) tensor" should be "gradient of a (½) tensor".
X chap. 10, p. 233, 2.4 from below, "at the event De = 0" should be "at the event De = 0".
X Box 10.2, page 416, 2.12, "derivative of f along U" should be "derivative of f along U".
X chap. 11, p. 254, 1.5, "to (11.12)" should be "to (11.14)".
X chap. 11, p. 255, eq. (11.14), S + Riemann (11.14) Similar change: Riemann (11.16) should be Riemann (11.14).
X Box 12.1, p. 2/2, last eqn., d2n^2 =
X chap. 13, p. 245, 2.1, eqn., x = m + n^2 x = m + n^2 x.
X chap. 13, p. 209, 2.2 from below, "(Fig. 13.4a)".
X Figure 13.4, Notation in the figure is consistent with where p = \(p = \theta \), and in the case where p = \(p = \theta \), the curve.
X chap. 17, p. 17, 2.2, "and (iv) vanishes".
X chap. 17, p. 17, 2.6, "and (iv) vanishes".
X chap. 17, Box 17.2, p. 17, 2.7, "Box 17.2 is part".
with it. [...] Freeman had not been expecting to pick up the textbook market with this book” at all, but rather to prepare an expensive hardcover edition for sale to libraries.

Kip Thorne to John Wheeler and Charles Misner, February 17, 1972

We negotiated a reduction in royalties, in return for which a paperback edition would be priced below or same as Weinberg’s book.

Publisher did a market survey. Estimated lifetime sales of 8000 copies (I was told in extreme confidence)
~ September 1972? - Another Shock

• We were beginning to submit chapters for copy editing. Publisher told me: Production much more complex than they had anticipated. *No way book could be out in time for classes in autumn 1973!*

• I went to San Francisco and discussed with editorial and production staff. A recently hired young woman named *Beth Eddy* asserted that, if they put her in charge of production, she could make that deadline.

• She was given the job, succeeded, made a great reputation for herself, and after our book came out, left Freeman for greener pastures.

*from my memory - I can’t find paper documentation*
# Beth’s Production Schedule

<table>
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<th>Task Description</th>
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- galleys to authors
- rechecked equations once again
- page proofs to authors
- I indexed in San Francisco
- Book Published
Colleagues’ and Reviewers’ Reactions to MTW

What Kind of Book is MTW?

“A pedagogic masterpiece.”
Dennis Sciama, Science (March 22, 1974)

“One of the great books of science, a lamp to illuminate this Aladdin’s cave of theoretical physics whose genie was Albert Einstein.”
Michael Berry, Science Progress (1975)

“This is a difficult book to read in a linear, progressive fashion. [...] There is a commendable attempt at informality, but this reviewer found the breeziness irritating at times.”
L. Resnick, Physics in Canada (June 1975)

“The variety of gimmicks is bewildering—framed headings with quotations, marginal titles, ‘boxes’ sometimes extending over several pages, heavy type, light type, large type, small type. Clearly the book is an experiment in presentation on a grand scale.”
W. H. McCrea, Contemporary Physics (July 1974)

A reader would be most comfortable with MTW “if he is a regular subscriber to Time magazine—the writing of these authors has much in common with its breathless style.”
Ian Roxburgh, New Scientist (September 26, 1974)
Colleagues’ and Reviewers’ Reactions

- S. Chandrasekhar (Chandra), a close personal friend of mine, wrote a review for Physics Today

There is one over-riding impression this book leaves: “It is written with the zeal of a missionary preaching to cannibals” … But this reviewer (probably for historical reasons) has always been allergic to missionaries.”

The last paragraph of the review left me chuckling for about ten minutes.

- Differences in style between Chandra and John Wheeler.
MTW as a “Cult” Book

- Street People in Berkeley ~ 1973 - 1975
- U Texas Austin Physics Department

Are thoughts of the ‘Why’ keeping you up at night?

Us too, and we have coffee.

UT Physics
Demise of MTW

• WH Freeman was purchased by Scientific American in 1964 (before our 1971 signing with them)
• In 1986 Scientific American sold WH Freeman to Holtzbrink publishing group
• In 1999 McMillan Publishers was sold to the Holtzbrinck, and in 2007 Holtzbrinck in the U.S. changed its name to Macmillan. After that Freeman became an imprint of Macmillan.
• In 2008 John died. - Huge loss!
• Around 2014 Macmillan classified MTW as Chemistry and moved it into its Chemistry Catalog and appears to have stopped marketing it on Amazon. Sales dropped precipitously, and in 2015 Macmillan took MTW out of print without notifying the authors.
• I got a few emails from people having trouble buying the book, and the next royalty statement from Macmillan showed zero sales in the U.S.
Resurrection

• After consulting with Charlie and with John Wheeler’s children Jamie, Letitia, and Alison, I arranged for Joan Winstein (who was experienced in dealing with Macmillan on similar matters) to negotiate with Macmillan.

• A few days after LIGO announced discovery of gravitational waves, Joan began trying, via emails and phone calls, to get Macmillan to either put MTW back into print, or return rights to the authors. Macmillan showed no interest in doing either, despite pleadings that the discovery of gravitational waves would trigger increased sales.

• After two months of total inaction by Macmillan, Joan had an attorney write a letter demanding the return of rights to the authors, on grounds that Macmillan had failed to put the book back in print or even say they would do so. Macmillan quickly responded, returning us all rights to the book.
With rights in hand, we explored republishing with Dover and Princeton University Press - and chose Princeton.

Sales with Princeton, in five years (2017-2022) have been 25,000: 5,000 a year on average.

- for ebook at list price $44.
- in hardback at list price $60. — which deflates to about $10.
  in 1973
  - compared to list price about $20. for paperback in 1973, when first published.

Lifetime Sales have been about 110,000 - compared to WH Freeman & Company’s 1972 Market estimate of 8,000.
It looks strange and it looks strange, and it looks very strange, and then suddenly it does not look strange at all, and you cannot understand what made it look strange in the first place.” - Gertrude Stein