Exploring Black Holes, Second Edition

Edwin F. Taylor, John Archibald Wheeler, and Edmund Bertschinger

For Instructors and Individual Readers

Exploring Black Holes: Introduction to General Relativity uses the properties of non-spinning and spinning black holes to introduce Albert Einstein's theory of curved spacetime and applies the resulting *general relativity* to the Universe around us. In this second edition -- labeled EBH2e -- coauthor Edmund Bertschinger joins Edwin F. Taylor to revise and expand the first edition by Edwin F. Taylor and John Archibald Wheeler published in 2000. What happened to the first edition? See the PS2 at the end of this document.

There is no published hard copy textbook of EBH2e. Instead, you may freely download the online version for personal and class use. Download one chapter or the entire book at the dropsite exploringblackholes.com

THE STRATEGY: In EBH2e we choose to make every measurement and observation in a *local* inertial frame, so we can analyse them using special relativity. This assumes that almost everywhere -- except possibly at the center of a black hole -- spacetime curves gently enough so that it is sufficiently flat over a small region to use special relativity.

Our strategy has two parts: The metric and the Principle of Maximal Aging. First the metric:

- Choose to index each event in curved spacetime with an arbitrarily chosen set of global coordinates, which we call *map coordinates*. Submit these map coordinates to Einstein's field equations, which return the *global metric*. The input to the global metric is the differential separation in global map coordinates between two adjacent events. The output of the global metric is the differential of a measureable quantity.

- One of several measurable quantities is the *wristwatch time*, the time between two events measured on a wristwatch that moves directly from one event to its neighbor.

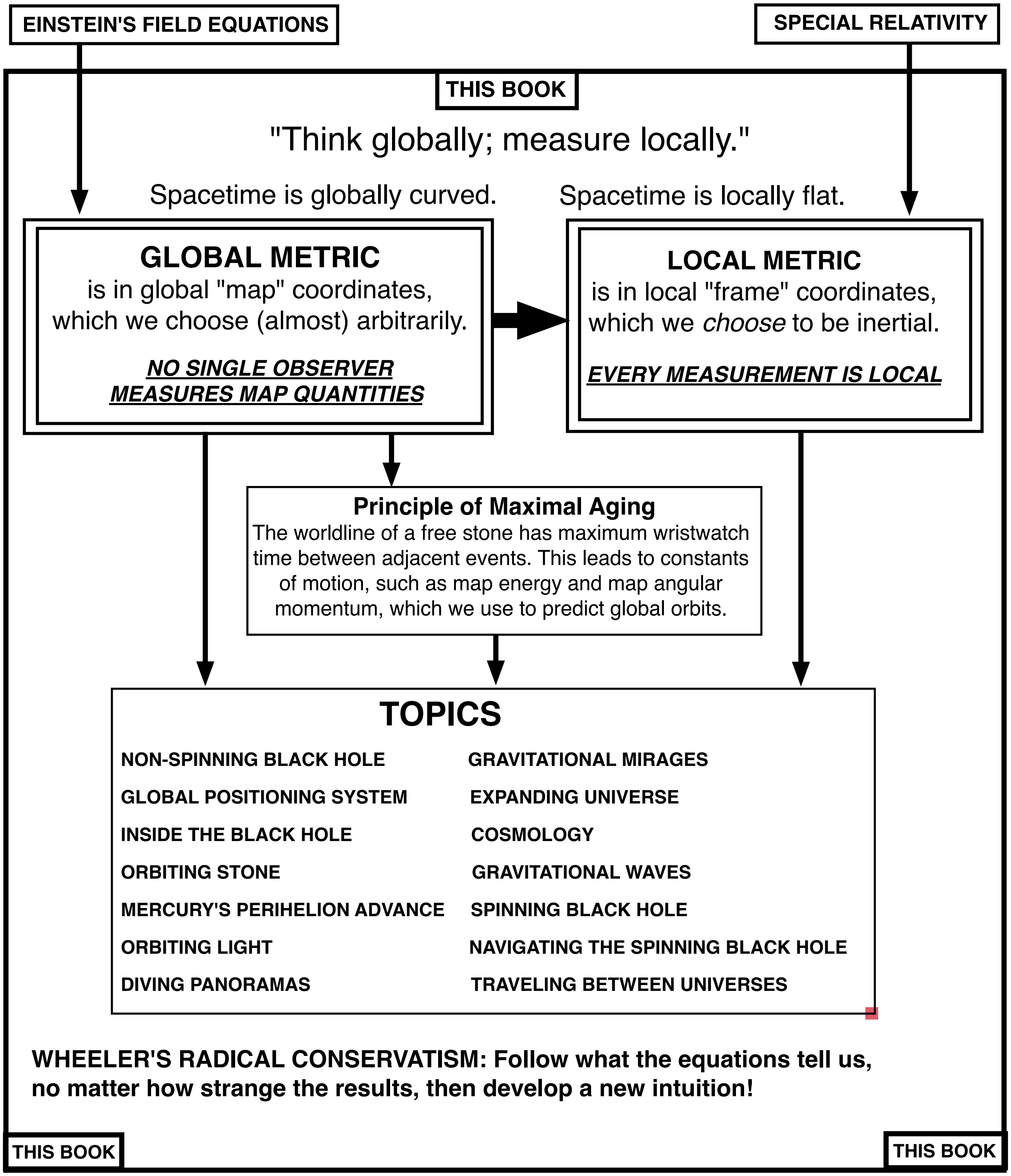
- Next, we "elbow" the differentially small region of spacetime of the metric into a slightly larger region in which to construct a local inertial frame big enough to carry out our desired measurement. In this region the exact differential global metric becomes an approximate local metric that separates space and time for analysis by special relativity.

- Finally, the global metric allows us to connect measurements of, say, a fast-moving particle that passes along a *worldline* across one local inertial frame, then across a second local inertial frame far from the first.

The second part of our strategy: The Principle of Maximal Aging, tells the stone how to move:

> The worldline of a free stone has maximum wristwatch time between adjacent events. This leads to global constants of motion, such as map energy and map angular momentum, which we use to predict global orbits.

This double strategy is diagrammed on the back cover of the book, reproduced on the following page.



KEY IDEAS: Just three words summarize this book: <u>spacetime</u>, <u>motion</u>, <u>measurement</u>!
The global metric--with arbitrary global coordinates--describes <u>spacetime</u>.
The Principle of Maximal Aging describes free <u>motion</u>.
C*hoose* to report every <u>measurement</u> with respect to a local inertial frame.

To Assemble the Book

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Print each CHAPTER on two sides of every sheet, with odd-numbered pages on the right. This means that the unnumbered initial page -- containing chapter contents and teaser questions -- will be a left-hand page facing the chapter's first page.

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Constants and conversion factors. Fifty-seven questions.

AContents
With a brief description of every chapter.

Chapter 1 Speeding
Special relativity presented so as to lead naturally to general relativity

Chapter 2 The Bridge: SR to GR
What is the difference between flat spacetime and curved spacetime?

Chapter 3 Curving
Describe curved spacetime outside Earth and down to the center of a non-spinning black hole.

Chapter 4 The Global Positioning System (GPS)
Locate yourself anywhere on Earth with a hand-held device which is useless without general relativity.

Chapter 5 Global and Local Metrics
Over a sufficiently small region of spacetime, special relativity correctly describes every measurement.

Chapter 6 Diving
Dive into a black hole. How do you feel? How long do you live? Why do you die?

Chapter 7 Inside the Black Hole
A relaxed life with spectacular effects around you and an ending certain.

Chapter 8 Circular Orbits
What circular "parking" orbits are available to you near a black hole?

Chapter 9 Orbiting
Transfer between circular "parking" orbits. Close to the black hole, killer tides threaten humans and robots.

Chapter 10 Advance of Mercury's Perihelion
An early victory of Einstein's brand new general relativity theory.

Chapter 11 Orbits of Light
Trajectories of light around a black hole.

Chapter 12 Diving Panoramas
What changing panoramas surround you as you drop into a black hole? What is the last thing you see?

Chapter 13 Gravitational Mirages
Stars, galaxies, and black holes act like distorting lenses as we look outward into the Universe.

Chapter 14 Expanding Universe
The shape in space and time of an expanding universe.

Chapter 15 Cosmology
Ordinary matter? Dark matter? Dark energy? The Big Bang and its consequences.

Chapter 16 Gravitational Waves
Gravitational waves tell us about cosmic catastrophes and regions close to the monster black hole.

Chapter 17 Spinning Black Hole
Irresistible motion, multiple horizons, falling with a raindrop.

Chapter 18 Circular Orbits around the Spinning Black Hole
Circular orbits far from and close to a spinning black hole. The accretion disk powers a quasar.

Chapter 19 Orbiting the Spinning Black Hole
Moving between circular orbits near a spinning black hole

Chapter 20 Orbits of Light around the Spinning Black Hole
What do you see as you orbit around and plunge into a spinning black hole

Chapter 21 Travel Through the SpinningBH
Pass inward through the horizon of the spinning black hole; emerge into another Universe.

Chapter 22 Deriving the Metric
(To be written) Einstein's field equations for static spherical spacetimes; derive the Schwarzschild metric. Metrics for spherical stars, charged black holes, white holes, wormholes, and inflationary cosmology.

V Appendix A Wheeler's Rules of Writing
Motivate! Simplify! Self-descriptive terminology, and the dullness of simply being.

W Appendix B Glossary
Words forbidden in our book. Definitions of permitted words.

X Appendix C Acknowledgments

Y Inside the Back Cover
General relativity briefing

Z Back Cover
Diagrammed strategy of this book

The spinless black hole is like a spinning black hole, but its gate to other universes is closed. For the spinning black hole, this gate is ajar.

--- Luc Longtin

SOFTWARE GRorbits
The interactive software program GRorbits, by Slavomir Tuleja, plots many figures in the book and is available for the reader to plot orbits of a stone or a light flash around a black hole, predicted by three alternative theories:

1. Newtonian mechanics
2. general relativity on a flat plane through the center of a non-spinning black hole
3. general relativity on the flat symmetry plane -- the equator -- of a spinning black hole, with arbitrary mass and any value of spin permitted by the theory.

Here is the link to the GRorbits website: http://stuleja.org/grorbits/
Here is the direct link to the GRorbits download site: http://stuleja.org/grorbits/run.html

For Mac users, this puts GRorbits into the Applications folder.

Please note, there are some pre-programmed scenarios which can be downloaded for use by the GRorbits program, obtained from http://stuleja.org/grorbits/scenarios.html

PS1. EXERCISES. Early chapters have lots of exercises. Later chapters have fewer. For exercise assignments, the instructor may ask you to solve one or more QUERIES in the body of the chapter.

PS2. WHAT HAPPENED TO THE FIRST EDITION of *Exploring Black Holes* by Edwin F. Taylor and John Archibald Wheeler? The first edition is now out of print. The original publisher no longer exists. Copies of the first edition are available online at exorbitant prices. In contrast, the contents of this draft second edition, from this dropsite, contain more material, is more up to date, and is free.

"Man fears time, but time fears the pyramids" by "The learned Arab of the twelfth century" (quot. 1923) who has not been identified.

CORRECTIONS? OBJECTIONS? SUGGESTIONS?

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JOHN ROGOSICH, President of Techsetters, Inc., contributed his services to design, redesign, and continually upgrade the LaTeX format of chapters under the demanding requirements of authors and reviewers. The LaTeX style file has the name EBH.sty

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