Schedule of Lectures for “Singularities, Black Holes, Thermodynamics in Relativistic Spacetimes”

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Summer, 2014
Mo. 12:10–14:00 (real time)
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References

N.b.: many of the required and suggested readings are available online at the course’s website, though they may not be listed as such in the bibliography:

http://strangebeautiful.com/1mu/2014-summer-sings-bhs-thermo.html

1 Week 1: Introduction to General Relativity; Differential Geometry I (Apr. 07)

a brief overview of general relativity, including the motivation behind it (the principles of equivalence and general covariance, among other things); differential manifolds

Required Reading

2. Wald (1984, ch. 1; ch. 2, §1), *General Relativity*

Suggested Reading—Physics

2. Lorentz, Einstein, Minkowski, and Weyl (1952), *The Principle of Relativity*
4. Anderson (1967, ch. 1, §§1–8, 10–11; ch. 4, §§1–3; ch. 10, §§1–3), *Principles of Relativity Physics*
7. Hawking and Ellis (1973, ch. 1; ch. 2, §§1–2), *The Large Scale Structure of Space-Time*
8. Misner, Thorne, and Wheeler (1973, ch. 1; ch. 8, §§1–4; chs. 9, 16), *Gravitation*
9. Penrose and Rindler (1984, ch. 2, §§1–4; ch. 4, §1), *Spinors and Spacetime: Two-Spinor Calculus and Relativistic Fields*
10. Schrödinger (1950, chs. 1-11), *Space-Time Structure*
11. Spivak (1965, chs. 1–2, 5), *Calculus on Manifolds*
12. Spivak (1979a, chs. 1–4, 7), *A Comprehensive Introduction to Differential Geometry*, vol. 1
14. Weyl (1921, ch. i, §§1–8; ch. ii, §13), *Space-Time-Matter*
15. Will (1993, chs. 1–3, 7–8), *Theory and Experiment in Gravitational Physics*

Suggested Reading—Philosophy

5. Gauss (1979), “General Investigations of Curved Surfaces”
14. Synge (1960, preface; ch. 3), Relativity: The General Theory
15. Torretti (1996, ch. 5), Relativity and Geometry
16. Weyl (1921, ch. 1, §§1–4; ch. ii, §10), Space-Time-Matter
17. Weyl (1949, ch. iii), Philosophy of Mathematics and Natural Science

2 Week 2: Differential Geometry II (Apr. 14)

tangent vectors; vector fields; integral curves; cotangent vectors

Required Reading

2. Wald (1984, ch. 2, §2), General Relativity

Suggested Reading—Physics

1. Anderson (1967, chs. 2–3), Principles of Relativity Physics
5. Hawking and Ellis (1973, ch. 2, §§4–8; ch. 4, §§1–2), The Large Scale Structure of Space-Time
7. Penrose and Rindler (1984, ch. 4, §§2–3, 8), Spinors and Spacetime: Two-Spinor Calculus and Relativistic Fields
9. Schrödinger (1950, chs. iii–vii, ix), Space-Time Structure
10. Spivak (1979a, chs. 5–6, 8–9), A Comprehensive Introduction to Differential Geometry, vol. 1
13. Weyl (1921, ch. ii, §§11–12, 14–18), Space-Time-Matter

Suggested Reading—Philosophy

3 Week 3: HOLIDAY: NO LECTURE (Apr. 21)

4 Week 4: Differential Geometry III (Apr. 28)

abstract-index notation; tensor analysis; diffeomorphisms; action of diffeomorphisms on tensors

Required Reading


Suggested Reading—Physics

1. Anderson (1967, chs. 2–3), Principles of Relativity Physics
5. Hawking and Ellis (1973, ch. 2, §§4–8; ch. 4, §§1–2), The Large Scale Structure of Space-Time
7. Penrose and Rindler (1984, ch. 4, §§2–3, 8), Spinors and Spacetime: Two-Spinor Calculus and Relativistic Fields
10. Spivak (1979a, chs. 5–6, 8–9), A Comprehensive Introduction to Differential Geometry, vol. 1
13. Weyl (1921, ch. II, §§11–12, 14–18), Space-Time-Matter

Suggested Reading—Philosophy


5 Week 5: Differential Geometry IV (May 05)

the Lie derivative; derivative operators; geodesics; curvature; (pseudo-)Riemannian metrics

Required Reading

2. Wald (1984, ch. 3, §4; ch. 4, §§1–3), General Relativity

Suggested Reading—Physics

1. Anderson (1967, ch. 10, §§4–8), Principles of Relativity Physics
Lectures: “Singularities, Black Holes, Thermodynamics”

3. Eddington (1923, chs. 3–4; ch. 5, §§65–69), Mathematical Theory of Relativity
5. Hawking and Ellis (1973, ch. 3; ch. 4, §§1–3), The Large Scale Structure of Space-Time
11. Schrödinger (1950, chs. x–xi), Space-Time Structure
12. Synge (1957, chs. i–iv), The Relativistic Gas
17. Weyl (1921, ch. iii, §§19, 21–22, 24–25), Space-Time-Matter

Suggested Reading—Philosophy

10. Earman (1989, ch. 9), World Enough and Space-Time
14. Geroch (1981, chs. 7–8), General Relativity from A to B
19. Reichenbach (1958, ch. III B), Philosophy of Space and Time
23. Sklar (1976, ch. 3), Space, Time and Spacetime
24. Torretti (1996, ch. 6), Relativity and Geometry
6 Week 6: General Relativity, The Core (May 12)

relativistic spacetimes; stress-energy and the Einstein field-equation; Killing fields (isometries); conserved quantities

Required Reading

2. Wald (1984, ch. 3, §4; ch. 4, §§1–3), General Relativity

Suggested Reading—Physics

1. Anderson (1967, ch. 10, §§4–8), Principles of Relativity Physics
3. Eddington (1923, chs. 3–4; ch. 5, §§65–69), Mathematical Theory of Relativity
5. Hawking and Ellis (1973, ch. 3; ch. 4, §§1–3), The Large Scale Structure of Space-Time
11. Schrödinger (1950, chs. x–xi), Space-Time Structure
12. Synge (1957, chs. i–iv), The Relativistic Gas
17. Weyl (1921, ch. iii, §§19, 21–22, 24–25), Space-Time-Matter

Suggested Reading—Philosophy

10. Earman (1989, ch. 9), World Enough and Space-Time
Lectures: “Singularities, Black Holes, Thermodynamics”

14. Geroch (1981, chs. 7–8), General Relativity from A to B
19. Reichenbach (1958, ch. III.B), Philosophy of Space and Time
23. Sklar (1976, ch. 3), Space, Time and Spacetime
24. Torretti (1996, ch. 6), Relativity and Geometry

7 Week 7: Causal Structure (May 19)

orientability; causality conditions and closed timelike curves; domains of dependence and causal horizons; global hyperbolicity

Required Reading

1. Hawking and Ellis (1973, ch. 6), The Large Scale Scale Structure of Space-time
3. Geroch and Horowitz (1979), “Global Structure of Spacetimes”, pp. 212–255 (through §5.2) and the appendix
4. Manchak (2009a), “Can We Know the Global Structure of Spacetime?”
5. Wald (1984, ch. 8), General Relativity

Suggested Reading—Physics

15. Penrose (1968), “Structure of Spacetime”
16. Penrose (1972), Techniques of Differential Topology in Relativity

Suggested Reading—Philosophy

Lectures: “Singularities, Black Holes, Thermodynamics”

2. Earman (1995, chs. 5–7), Bangs, Crunches, Whimpers and Shrieks: Singularities and Acausalitites in Relativistic Spacetimes
8. Manchak (2009a), “Can We Know the Global Structure of Spacetime?”
11. Manchak (2011a), “No No-Go: A Remark on Time Machines”

8 Week 8: Singularities, I (May 26)
geodesic congruences and the Raychaudhuri equation; conjugate points; incomplete curves; extensions of spacetimes

Required Reading
1. Hawking and Ellis (1973, ch. 4, §§4–5), The Large Scale Structure of Space-Time
2. Wald (1984, ch. 9, §§1–4), General Relativity

Suggested Reading—Physics
3. Clarke (1993), The Analysis of Space-Time Singularities
4. Joshi (1993, ch. 5), Global Aspects in Gravitation and Cosmology
5. Joshi (2007), Gravitational Collapse and Spacetime Singularities

Suggested Reading—Philosophy

9 Week 9: Singularities, II (Jun. 02)
possible definitions of a singularity; the Geroch-Hawking-Penrose theorems; naked singularities and cosmic censorship

Required Reading
Lectures: “Singularities, Black Holes, Thermodynamics”

4. Wald (1984, ch. 9, §5), General Relativity

Original Literature


Suggested Reading—Physics

8. Clarke (1993), The Analysis of Space-Time Singularities
17. Hawking and Ellis (1973, ch. 8), The Large Scale Structure of Space-Time
20. Joshi (1993, chs. 6–7), Global Aspects in Gravitation and Cosmology
27. Senovilla (2007), “A Singularity Theorem Based on Spatial Averages”
33. Tipler (1977b), “Singularities in Conformally Flat Spacetimes”

Suggested Reading—Philosophy

3. Earman (1995, chs. 1–4), Bangs, Crunches, Whimpers and Shrieks: Singularities and Acausal-
   ities in Relativistic Spacetimes
5. Ellis and Schmidt (1979), “Classification of Singular Spacetimes”
   sions”

10 Week 10: HOLIDAY: NO LECTURE (Jun. 09)
my birthday!

11 Week 11: Schwarzschild and Kerr Spacetimes; Black Holes (Jun. 16)

isolated systems; sphericity, staticity, stationarity, axisymmetry; derivation of the metrics; Birkhoff’s Theorem; Lense-Thirring effect; Penrose process; conformal infinity; trapped surfaces and event horizons; asymptotically flat black holes; uniqueness theorems

Required Reading

1. Hawking and Ellis (1973, ch. 5, §§5–6; ch. 9), The Large Scale Structure of Space-Time
Lectures: “Singularities, Black Holes, Thermodynamics”

2. Wald (1984, ch. 6; ch. 11, §1; ch. 12), *General Relativity*

Original Literature

1. Bekenstein (1972b), “Nonexistence of Baryon Number for Static Black Holes”
3. Carter (1968), “Global Structure of the Kerr Family of Gravitational Fields”
17. Penrose (1968), “Structure of Spacetime”
22. Teitelboim (1972a), “Nonmeasurability of the Lepton Number of a Black Hole”
23. Teitelboim (1972b), “Nonmeasurability of the Quantum Numbers of a Black Hole”

Suggested Reading—Physics

1. Anderson (1967, ch. 10, §5; ch. 11, §§3–4), *Principles of Relativity Physics*
12. Heusler (1996), *Black Hole Uniqueness Theorems*
Lectures: “Singularities, Black Holes, Thermodynamics”


Suggested Reading—Philosophy


12 Week 12: The Laws of Black Hole Mechanics; Black Holes and Thermodynamics (Jun. 23)

the Four Laws of black-hole mechanics; the analogy with the thermodynamical Laws; the thermodynamical character of black holes

Required Reading

6. Wald (1994, ch. 6), *Quantum Field Theory in Curved Spacetime and Black Hole Thermodynamics*

Original Literature

10. Israel (1973), “Entropy and Black Hole Dynamics”

Suggested Reading—Physics


Suggested Reading—Philosophy


13 Week 13: Hawking Radiation (Jun. 30)

Hawking radiation; black-hole evaporation; information loss; non-unitary evolution

Required Reading

1. Wald (1994, chs. 5, 7), Quantum Field Theory in Curved Spacetime and Black Hole Thermodynamics

Suggested Reading—Physics


13

Suggested Reading—Philosophy

3. Hawking and Penrose (1996), The Nature of Space and Time

14 Week 14: Basic Cosmology; Cosmological Singularities and Thermodynamics (Jul. 07)

homogeneity and isotropy; derivation of the FLRW spacetimes and their properties; dark energy and the cosmological constant; the initial-state problem; Penrose’s Weyl Curvature Hypothesis; sudden singularities; possible measures of gravitational entropy

Required Reading

Lectures: “Singularities, Black Holes, Thermodynamics”

6. Wald (1984, ch. 5), General Relativity

Suggested Reading—Physics

1. Anderson (1967, ch. 14), Principles of Relativity Physics
7. Cattoën and Visser (2005), “Necessary and Sufficient Conditions for Big Bangs, Bounces, Crunches, Rips, Sudden Singularities and Extremality Events”
13. Dabrowski and Denkiewicz (2009), “Barotropic Index \( w \)-Singularities in Cosmology”
14. Ellis, Maartens, and MacCallum (2012, chs. 5–9, 13–14, 17–19), Relativistic Cosmology
17. Griffiths and Podolský (2009, chs. 4–6; ch. 22, §§1–2, 7–8), Exact Space-Times in Einstein’s General Relativity
18. Hawking and Ellis (1973, ch. 5, §§2—4, 7), The Large Scale Structure of Space-Time
19. Joshi (1993, ch. 8), Global Aspects in Gravitation and Cosmology
23. Ellis and Sciama (1972), “Global and Non-Global Problems in Cosmology”
24. Shepley and Ryan (1978), Homogeneous Cosmological Models
31. Weinberg (2008, ch. 1, §§1–7; ch. 3, §1; ch. 4), Cosmology

Suggested Reading—Philosophy
Lectures: “Singularities, Black Holes, Thermodynamics”


15 PAPER DUE (Sep. 19)

References


Curiel, E. (2013). On tensorial concomitants and the non-existence of a gravitational stress-energy tensor. This paper has been submitted for review at *Journal of Mathematical Physics*.


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Senovilla, J. (1997). Singularity theorems and their consequences. *General Relativity and Gravitation* 29(5), 701–848. doi:10.1023/A:1018801101244. On Springer’s website, this article is cited as being in volume 30 in the year 1998; on the article itself, however, is written volume 29, 1997; the issue number and page numbers are the same.


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