Syllabus

Course Name	Numerical Relativity
Course Number	PHY 7566
Pre-requisites	General Relativity (PHY 6938)
Instructor	Dr. Pedro Marronetti - Charles E. Schmidt College of Science
	Room SE 440. (297-3386) - pmarrone@fau.edu
Classroom	SE 435
Office Hours	MW / 11:00AM – 12:00PM
Classes	MW / 9:30AM – 11:00 AM
Course Website	Blackboard Assigned
Required Text	None

Bibliography

Introduction to 3+1 Numerical Relativity – 1st Ed. M. Alcubierre. Oxford University Press, 2008.

Numerical Relativity - 1st Ed. T. W. Baumgarte and S. L. Shapiro. Cambridge University Press, 2010.

Course Description

In the past couple of decades, the field of numerically relativity has suffered a critical transformation, going from a discipline plagued with numerical and theoretical roadblocks to becoming the leading thrust in relativistic research across the globe. One of many indicators of this growth is the 400% increase in the number of contributed papers related to Numerical Relativity (computation and theory) submitted to the APS Annual Meeting in the past decade (Bull. Am. Phys. Soc. **45**, 2000, Bull. Am. Phys. Soc. **55**, 2010). This amazing development could be attributed to several causes, being the most important the final solution to the problem of evolving two orbiting black holes.

Our course will cover the principal topics in the theory of Numerical Relativity, including hydrodynamics and gravitational wave extraction. Note that for this course background knowledge in General Relativity is required but **not in computational or numerical science**, since the subject will be the theoretical basis behind the art and science of Numerical Relativity and not the numerical algorithms (though some of these will be mentioned and/or explained). The course has not only value to those students pursuing numerical work, but also for those interested theoretical studies of the analytical framework upon which Numerical Relativity is founded. Currently, a good fraction of purely analytical researchers are dedicated to advances in this field.

Instructional Objectives

The course prepares the students for research in the area of Numerical Relativity. By the end of the course, the students will have the theoretical background needed to understand the theoretical framework upon which relativistic numerical codes are built.

Topics Covered

1. ***Brief Review of General Relativity (Weeks 1- 2)***

   1.1. *Manifolds & Tensors*

   1.2. *The Metric Tensor*

   1.3. *Lie Derivatives and Killing Fields*

   1.4. *Coordinate Transformations*

   1.5. *Covariant Derivatives*

   1.6. *Curvature*

   1.7. *General Relativity*

   1.7.1. *Matter and the Stress-Energy Tensor*

   1.7.2. *Einstein Field Equations*

   1.8. *Weak Field and Gravitational Waves*

   1.8.1. *Newtonian Limit*

   1.8.2. *The Transverse Traceless Gauge*

   1.9. *Important Solutions*

   1.9.1. *Black Holes*

   1.9.2. *Oppenheimer-Volkoff Equilibrium Stars*

1.9.3. *Oppenheimer-Snyder Dust Collapse*

2. *The 3+1 Formalism (Week 3-5)*

2.1. *Spacetime Slicing*

2.2. *Spatial Tensors and Projection Operators*

2.3. *Spatial Covariant Derivatives*

2.4. *Extrinsic Curvature*

2.5. *Splitting the Riemann Tensor*

2.6. *Einstein Field Equations in 3+1 (ADM) Form*

2.6.1. *Constraint Equations*

2.6.2. *Evolution Equations*

2.6.3. *The Lapse Function and the Shift Vector*

2.7. *Notions of Hyperbolicity*

2.8. *The BSSNOK Formulation*

3. *Gauge Conditions(Week 6)*

3.1. *The Lapse Function*

3.1.1. *Geodesic Slicing*

3.1.2. *Maximal Slicing*

3.1.3. *K-Driver Slicing*

3.1.4. *Hyperbolic Slicing Conditions*

3.2. *The Shift Vector*

3.2.1. *Quasi-Isotropic and Radial Shifts*

3.2.2. *Minimal Distortion Shift*

3.2.3. *Γ-Driver Shift*

4. *Initial Data (Weeks 7-8)*

4.1. *Conformal Transformations*

4.2. *Simple Black Hole Solutions*

4.3. *Decomposition of the Extrinsic Curvature*

4.4. *The Conformal Transverse Traceless (CTT) Method*

4.4.1. *Spinning Black Holes*

4.4.2. *Boosted Black Holes*

4.5. *The Conformal Thin-Sandwich (CTS) Approach*

5. ***Mass, Linear and Angular Momentum (Week 9)***

5.1. *Rest-mass or Baryonic Mass*

5.2. *ADM Mass*

5.3. *Komar Mass*

5.4. *Linear and Angular Momenta*

6. ***Binary Black Holes (Week 10)***

6.1. *Quadrupole Formula*

6.2. *Two Point-masses in Circular Orbit*

6.2.1. *Quasi-equilibrium Solutions and the Effective Potential Method*

6.3. *Initial Data*

6.3.1. *CTT Solutions*

6.3.1.1. *The Punctures Method for Initial Data*

6.3.1.2. *Identifying Circular Orbits*

6.3.2. *CTS Solutions*

6.4. Binary Black Hole Evolutions

6.4.1. Black Hole Excision

6.4.2. The Moving Puncture Method

6.4.3. Latest Results from Numerical Simulations

7. Matter Sources (Week 11-12)

7.1. Hydrodynamics

7.1.1. Perfect Fluids

7.1.2. Wilson Method

7.1.3. High-Resolution Shock-Capturing (HRSC) Schemes

7.1.4. Imperfect Fluids: Heat and Viscosity

7.2. Radiation Hydrodynamics

7.3. Magneto-Hydrodynamics (MHD)

8. ***Generators and Extraction of Gravitational Waves (Week 13)***

8.1. Sources of Gravitational Radiation

8.2. Extraction of Gravitational Waves

8.2.1. The Moncrief Method

8.2.2. The Newman-Penrose Method

9. ***Brief Description of Numerical Methods (Week 14)***

9.1. Finite-Difference and Convergence Tests

9.2. Adaptive Mesh Refinement

Assessment Procedures

The final grade will be determined by the successful completion of all the homework assignments (60% of the final grade), a Midterm Test (20% - Week 8), and a Final Test (20% - Final's Week). The deadline for all the homework assignments is the day before final's week.

Grading Criteria

A = 95% - 100, **A-** = 90% - 94%, **B+** = 85% - 89%, **B** = 80% - 84%, **C+** = 75% - 79%, **C** = 70% - 74%, **D+** = 65% - 69%, **D** = 60% - 64%, **D-** = 50% - 59%, **F** < 50%.

University "Students with Disabilities" Policy

In compliance with the Americans with Disabilities Act (ADA), students who require special accommodation due to a disability to properly execute course work must register with the Office for Students with Disabilities (OSD) -- in Boca Raton, SU 133 (561-297-3880); in Davie, MOD 1 (954-236-1222); in Jupiter, SR 117 (561-799-8585); or at the Treasure Coast, CO 128 (772-873-3305) – and follow all OSD procedures.

University Honor Code

Students at Florida Atlantic University are expected to maintain the highest ethical standards. Academic dishonesty is considered a serious breach of these ethical standards, because it interferes with the University mission to provide a high quality education in which no student enjoys an unfair advantage over any other. Academic dishonesty is also destructive of the University community, which is grounded in a system of mutual trust and places high value on personal integrity and individual responsibility. Harsh penalties are associated with academic dishonesty. For more information, see University Regulations, Chapter 4, Regulation 4.001, Code of Academic Integrity at www.fau.edu/regulations.