# Physics and Astrophysics of Black Holes and Neutron Stars

Emanuele Berti
Department of Physics and Astronomy, The University of Mississippi, University, MS 38677, USA
Website: http://www.phy.olemiss.edu/GR/

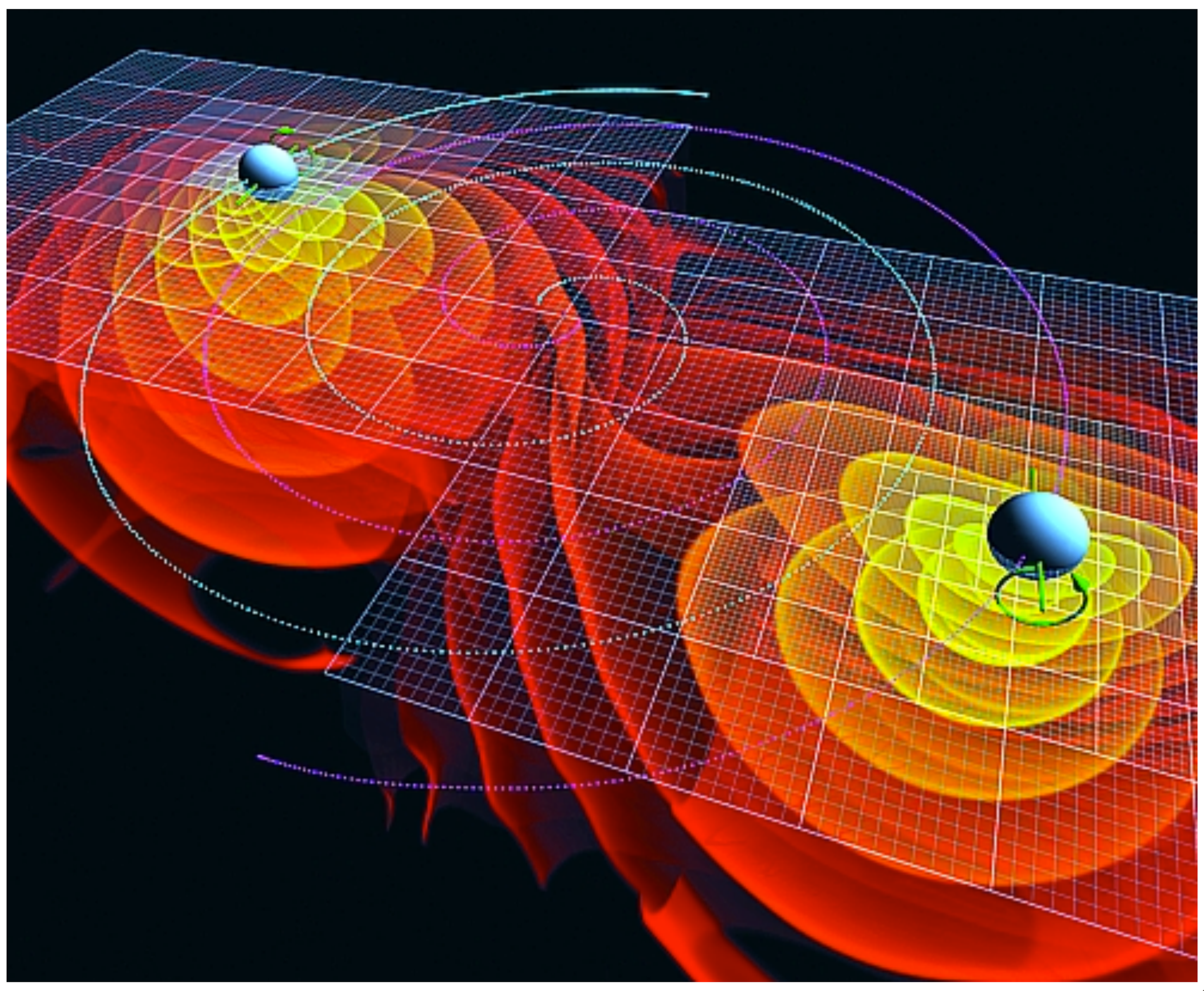
## Compact Binaries

My group studies binary systems composed of black holes and/or neutron stars.

Einstein's theory of gravity, **General Relativity** (GR), was formulated in 1916 and passed many stringent experimental tests [1]. According to the theory, binary systems lose orbital energy to gravitational waves and get closer to each other ("inspiral") until they finally coalesce in a violent merger. For example the double pulsar PSR J0737-3039, discovered in 2003, will merge in about 85 million years.

Coalescing binaries are the most promising source of **gravitational waves** (GWs) to be observed by experiments such as LIGO (the largest physics experiment in the nation right now) or the planned space-based mission eLISA/NGO. Searching for these binaries requires an accurate knowledge of the GWs they emit. Analytical and numerical techniques must be used to understand the binary dynamics [2] (the figure shows a modern simulation of two coalescing black holes).

GW observations of these binaries will shed light on several **open problems in theoretical physics and astrophysics**: is Einstein's theory correct? How can we reconcile it with quantum mechanics? Are the compact objects we see at galactic centers black holes, and how did they get there? What is dark energy?



*Credits: NASA Goddard Numerical Relativistic Astrophysics Group; Visualization: Chris Henze, NASA/Ames*

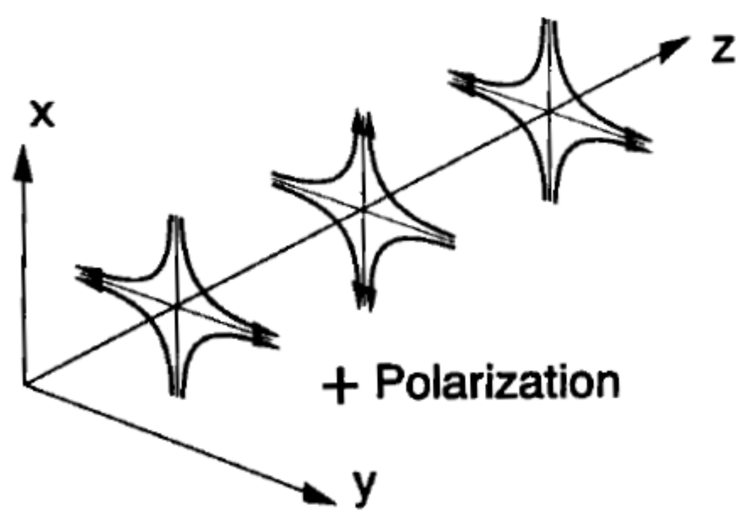
## Gravitational-Wave Astronomy and Astrophysics

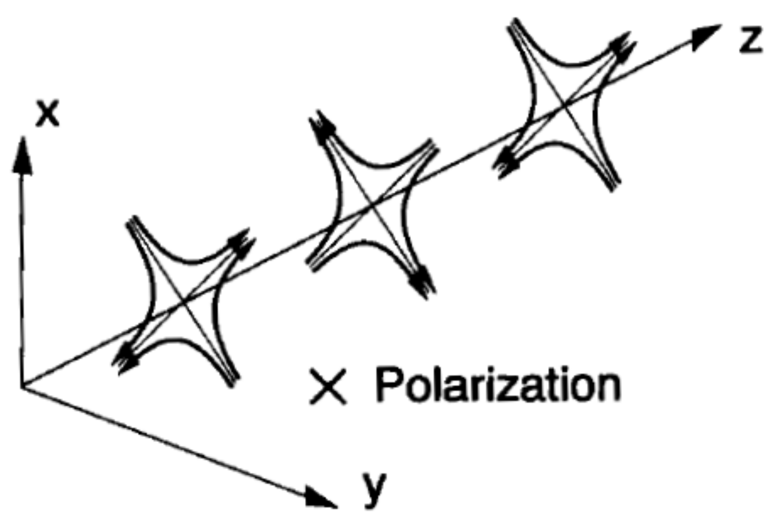
Laser interferometric GW observatories such as Advanced LIGO (USA), Virgo (Europe), LCGT (Japan) and the proposed Einstein Telescope promise to open a new astronomical window at frequencies ranging from a few Hz to about one kHz. Planned space-based mission like eLISA/NGO will "listen" to GWs in the range between $10^{-5}$ Hz and 1 Hz.

### Potential Payoff of Gravitational-Wave Astronomy

- reveal nature of black holes [3]
- constrain theories alternative to GR [4]
- census of massive black holes [5]
- hints of new physics (scalar fields?) [6]
- behavior of matter at high densities [7]
- gravitational echoes from the Big Bang

GW physics will provide outstanding results in the immediate future, and may drive theoretical and experimental research in fundamental physics in the next decades.



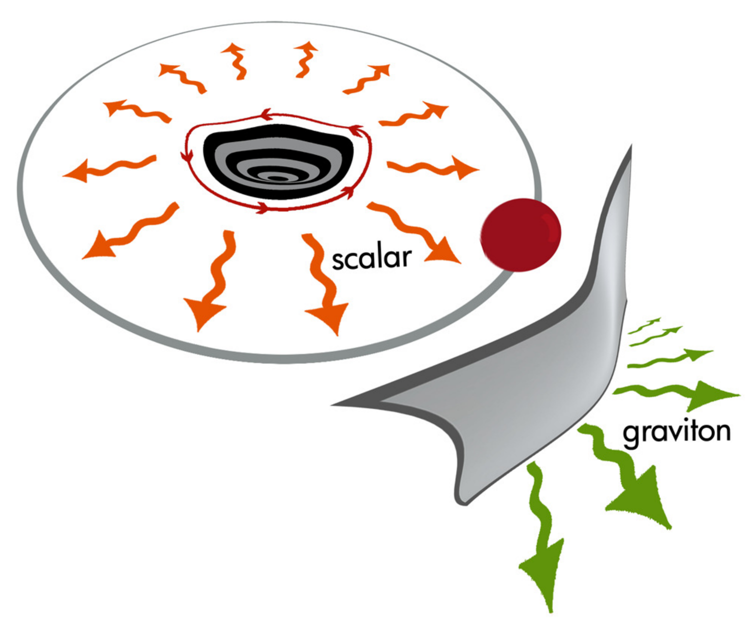

## Fundamental Physics

Einstein's GR is an extremely successful theory of gravity and a pillar of modern physics, but there are strong theoretical and experimental motivations to go **beyond GR**:

| **Theoretically:** | **Experimentally:** |
|---|---|
| Singularities | Dark energy |
| Quantum gravity | Dark matter |
| Cosmological constant | Strong curvature |

### Lines of Research

1) **Study black hole collisions near the speed of light** in four and higher dimensions: TeV-gravity scenarios, cosmic censorship, gauge/gravity duality.
2) **Probe strong-field gravity using astrophysical observations** of merging compact binaries or compact stars.
3) **Investigate alternative theories**, look for "corrections" to GR in astrophysics: hints to unify GR and quantum mechanics?




## Main Grants and Awards

▸ **NSF CAREER Grant PHY-1055103**
*CAREER: Physics and Astrophysics of Compact Binaries* (9/2011-8/2016). Total: $460,000

▸ **NSF Grant PHY-0900735**
*Gravitational waves from black hole binaries: modeling, astrophysics and strong-field tests* (9/2009-8/2012). Total: $150,000

▸ **NSF TeraGrid grant PHY-090003**
*High energy grazing collisions of black holes* (1/1/2009-12/31/2011). PI: Ulrich Sperhake, Co-Is: E. Berti, V. Cardoso and F. Pretorius. Total: 4,500,000 CPU hours

▸ **International Research Staff Exchange Scheme (IRSES)**
*Numerical Relativity and High Energy Physics*, proposal 295189/NRHEP (2012-2016). PIs: E. Berti, V. Cardoso, L. Crispino, L. Gualtieri, C. Herdeiro (coordinator) and U. Sperhake

▸ **APS Outstanding Referee Award**
of the American Physical Society (2011)

## People

| **Ole Miss** | **Collaborators** |
|---|---|
| **Emanuele Berti (PI)** | Yanbei Chen |
| Vitor Cardoso | Luís Crispino |
| Ulrich Sperhake | Leonardo Gualtieri |
| Jocelyn Read | Carlos Herdeiro |
| Sagnik De | Paolo Pani |
| Zhongyang Zhang | Frans Pretorius |
| Barnabas Kipapa | Carlos Sopuerta |

**3 Faculty (2 Adjunct), 1 Postdoc, 3 Students**

**Collaborating Institutions:** Caltech, Princeton, IST (Portugal), IEEC (Spain), Rome (Italy), Cambridge (UK), Albert Einstein Institute (Germany), Pará U. (Brazil)...

**High productivity:** about 35 papers in major international journals (PRL, PRD, CQG...) funded by NSF Grants in the last 3 years

**High impact:** The PI has $\sim$ 2200 citations, with an average of $\sim$ 35 citations per paper and Hirsch index $h = 28$ (as of 11/2011)

## References

[1] C. M. Will, Living Reviews in Relativity **9**, 3 (2005)
[2] **E. Berti**, **V. Cardoso**, J. A. Gonzalez, **U. Sperhake**, M. Hannam, S. Husa, B. Bruegmann, Phys. Rev. **D76**, 064034 (2007)
[3] **E. Berti**, **V. Cardoso**, A. Starinets, Class. Quant. Grav. **26**, 163001 (2009) (*CQG Highlight 2009/2010*)
[4] **E. Berti**, A. Buonanno, C. M. Will, Phys. Rev.**D71**, 084025 (2005)
[5] A. Sesana, J. Gair, **E. Berti**, M. Volonteri, Phys. Rev. **D83**, 044036 (2011)
[6] **V. Cardoso**, **S. Chakrabarti**, **P. Pani**, **E. Berti**, **L. Gualtieri**, gr-qc/1109.6021 (2011)
[7] D. Tsang, **J. S. Read**, T. Hinderer, A. L. Piro, R. Bondarescu, arXiv:1110.0467