# What to do when Gravity waves

## The Detection, Characterization, and Exploitation of Gravitational Waves

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General Relativity, the modern theory of gravity, stands as a cornerstone of our understanding of the universe. However, Gravitational Waves, one of its key consequences, were not directly observed until nearly 100 years after they were first predicted. The culmination of decades of research to build sufficiently sensitive detectors and understand the expected sources, the first direct detection of Gravitational Waves from two coalescing Black Holes in September 2015 opened a new era in astrophysics. In the four short years since, the field has exploded at an increasing rate with the first detection of coalescing Neutron Stars, the first observation of electromagnetic counterparts to Gravitational-Wave signals, and the not-so-gradual accumulation of a catalog containing several dozen binay Black Hole systems. With the detectors currently taking data with unprecedented sensitivity, we will explore exactly what scientists do when gravity waves in real-time, as several new detections are almost guaranteed to occur before the year's end.

Gravitational Waves (GWs) are a completely new way of observing our universe and have already revolutionized our understanding of multiple types of astrophysical phenomena in the 4 short years since they were first directly detected. In this lecture series, we'll review the basics of General Relativity (GR), the modern theory of gravity, and investigate how we can detect one of GR's main predictions, GWs. We'll study the types of systems that create detectable GWs, how they're formed and where they're found in the universe in addition to examining the astonishing technological achievements that are ground-based GW detectors, what makes them so sensitive, and why we need such sensitive machines in the first place. After describing how we search for GWs in our detector data, we'll review the types of signals detected to date, including merging Black Holes and Neutron stars, and what we can say about the population of such objects in the universe. We'll also study how multi-messenger astronomy, the use of GW, electromagnetic, and astro-particle detectors to simultaneously observe the same objects, has enabled new insights into our universe, including the behavior of matter at supra-nuclear densities within Neutron star cores and tests of GR itself. Finally, we'll review how GW astrophysics has evolved as a field and where we're headed over the coming decades.

**Sep 28: Introduction to the Lectures and General Relativity (aka Gravity)**

- Current gravitational-wave detectors
- Astrophysical phenomena of interest
    - Stellar remnants
    - Explosions
    - (supra-)nuclear matter
- General Relativity in 10 minutes
- What are Gravitational Waves?
- Basics of data analysis

**Oct 5: Astrophysical Sources of Gravitational Waves**

- Why are astrophysical objects needed?
- Types of astrophysical sources
    - Compact Binary Coalescences (CBCs)
        - Why do they need to be compact?
        - How do they get into binaries?
        - What happens when they coalesce?
    - Bursts
    - Stochastic sources
    - Continuous sources

**Oct 12: Detecting Gravitational Waves on Earth**

- Interferometers
    - measuring distances by timing light
    - Gaussian noise sources and isolation techniques
    - Non-Gaussian noise sources and mitigation techniques
- Other detection techniques

**Oct 19: Searching for Gravitational Waves in Noisy Detector Data**

- Search techniques
    - What to do if you know what the signal looks like?
    - What to do if you do not know what the signal looks like?
- Establishing detection confidence
    - What is a background?
    - Distinguishing signal from background
- Estimating source parameters

**Oct 26: Gravitational-Wave Populations and Cosmology**

- Populations of sources
    - Selection effects within GW astronomy
- Overview of the O1/2 catalog of compact binary coalescences
- Cosmological effects
    - Basics of an expanding universe

    - How to measure the universe’s expansion rate with GWs (Standard Sirens)

**Nov 2: Multi-Messenger Counterparts**

- Core Collapse SuperNova
    - What would we see?
    - What would we learn?
- Compact Binary Coalescence
    - What did we see?
        - (short) Gamma Ray Bursts
        - Kilonova
        - Radio and X-ray afterglows
    - What did we learn?

**Nov 9: The Physics of Neutron Stars (as seen with GWs)**

- What are neutron stars?
    - Properties of extremely dense matter
    - Equations of stellar structure
- What do neutron stars do in CBCs?
    - Tidal deformation
    - Tidal disruption
- How can we use GWs to infer the properties of neutron stars?

**Nov 16: Testing General Relativity with Gravitational Waves**

- Review of General Relativity
- Review of Compact Binary Coalescence signal types
- Tests of General Relativity with different types of signals
    - The speed of gravity
    - Changes in orbital dynamics
- Calibrating our detectors with astrophysical signals

**Nov 23: Gravitational Waves over the Next 40 Years**

- The history of gravitational-wave theory and experiment
- Expectations for the (current) Advanced Detector Era
- “3G” ground-based interferometers
- Space-based interferometers
- Pulsar timing arrays