Searches for stochastic gravitational-wave backgrounds

Joseph D. Romano

Les Houches Summer School
July 2018

Abstract

These lecture notes provide a brief introduction to detection methods used to search for a stochastic background of gravitational radiation—a superposition of gravitational-wave signals either too weak or too numerous to individually detect. The lectures are divided into two main pieces: (i) an overview, with a description of different types of stochastic backgrounds and an introduction to the correlation method using multiple detectors; (ii) details, extending the previous discussion to non-trivial detector response, what to do in the absence of correlations, and a recently proposed Bayesian method to search for the gravitational-wave background produced by stellar-mass binary black hole mergers throughout the universe.

Contents

1 Motivation

A stochastic background of gravitational radiation is a superposition of gravitational-wave signals either too weak or too numerous to individually detect. The individual signals making up the background are thus *unresolvable*, unlike the large signal-to-noise binary black-hole (BBH) and binary neutron-star (BNS) merger signals recently detected by the advanced LIGO and Virgo detectors.

Stochastic backgrounds can be of either astrophysical or cosmological origin:

(i) A potential astrophysical background for the current generation of ground-based interferometers is the combined signal from the population of stellar-mass BBH and BNS mergers throughout the universe. We will discuss the prospects of detecting this potential background throughout these lectures; the last section is devoted to a recently proposed detection method that targets this particular source.

(ii) A potential cosmological background is formed from *relic gravitational waves*—that is, quantum fluctuations in the geometry of space-time, driven to macroscopic scales by a period of rapid expansion (e.g., inflation) a mere $\sim 10^{-32}$ s after the Big Bang. This relic background is too weak to be detected by advanced LIGO, Virgo, etc., but is potentially detectable by its effect on the polarization of the cosmic microwave background (CMB) radiation. The Planck satellite and BICEP experiment (located at the South Pole) are searching for this signal.

The ultimate goal of gravitational-wave background searches is to produce the GW analogue of Figure **??**. Figure **??** is a sky map of the temperature fluctuations in the CMB blackbody radiation, relative to the $T_0 = 2.73$ K isotropic component. (The dipole contribution due to our motion with respect to the cosmic rest frame has also been subtracted out.) Recall that the CMB is a background of electromagnetic radiation, produced at the time of last scattering, roughly 380,000 yr after the Big Bang. At that time, the universe had a temperature of ~ 3000 K, roughly one thousand times larger than the temperature today, but cool enough for neutral hydrogen atoms to first form and photons to propagate freely. The temperature fluctuations in the CMB radiation tell us about the density of matter on the surface of last scattering and also about the integrated ...

For perspective, this map of the temperature fluctuations in the CMB was produced by the Planck mission in 2013, almost 50 years after its initial detection by Penzias and Wilson in 1965.

2 Different types of stochastic backgrounds

3 Mathematical characterization of a stochastic background

4 Correlation methods - basic idea

5 Some simple examples

We now apply the above correlation method

6 Non-trivial detector response

7 Non-trivial correlations

8 What to do in the absence of correlations?

9 Searching for the background of binary black-hole mergers

References

A few references, which you might find helpful. *Disclaimer: This list is not in anyway complete, and there may be better references that you already know of.*

1. B. Allen - "The stochastic gravitational-wave background: sources and detection," from Les Houches School in Oct 1995
2. M. Maggiore - "Gravitational-wave experiments and early universe cosmology" (2000)
3. C. Caprini, D. Figueroa - "Cosmological backgrounds of gravitational waves" (2018)
4. T. Regimbau - "The astrophysical stochastic gravitational-wave backgrounds" (2011)
5. J. Romano, N. Cornish - "Detection methods for stochastic gravitational-wave backgrounds: a unified treatment" (2017)
6. R. Smith, E. Thrane - "Optimal search for an astrophysical gravitational-wave background" (2018)
7. Plus recent observational papers from LIGO, Virgo, pulsar timing arrays, etc., quoting upper limits on the strength of stochastic gravitational-wave backgrounds