

**FM 14:**  
**The Gravitational Wave Symphony  
of Structure Formation**

# The Gravitational Wave Symphony of Structure Formation: Overview

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**Keywords.** gravitation, gravitational waves, galaxy mergers, fundamental physics, black hole physics, surveys, pulsars, instrumentation

This Focus Meeting was designed to lie at the scientific intersection of structure formation and gravitational wave studies. In broad-strokes terms, binary supermassive black holes (BSMBHs) and cosmic strings may both play a central role in shaping the Universe as we know it.

Mergers are now accepted as an integral component of galaxy assembly and evolution. BSMBHs will should form during the merger of two massive galaxies, gradually sinking to form a binary at the core of the merger remnant and shaping the galaxy as the binary evolves to coalescence. Additionally, early in the Universe, cosmic strings may have formed from phase transitions. Both SMBH binaries and cosmic strings should generate low frequency (nanohertz to millihertz) gravitational waves.

Significant observational and theoretical developments have been made recently in structure formation and understanding BSMBH evolution. Simulations and modeling are required to make predictions about both galaxy mergers and gravitational wave emissions, while a wealth of new searches and discoveries of BSMBH systems are now poised to test those predictions.

Meanwhile much closer to home, exciting advances are being made with experiments that are sensitive to these distant sources of nanohertz to millihertz gravitational waves. In particular, pulsar timing arrays and future space-based gravitational wave observatories will be uniquely sensitive to the waves emitted by BSMBHs and cosmic strings. Excitingly, the sensitivity of pulsar timing arrays—constructed from a set of precisely timed millisecond radio pulsars—are beginning to encroach upon the gravitational wave strain amplitudes predicted from some structure formation scenarios. Further, the recent decision by ESA for a focus on the Gravitational Universe provides a path toward the detection of millihertz gravitational waves.

Focus Meeting 14 inspired a number of exciting discussions. Officially, the Focus Meeting—and hence the following proceedings—featured a mix of discussions on the topics of

- How the parameters of hierarchical structure formation models affect the expected GW signal and how GW observations might inform our understanding of the galaxy merger process;
- The current status of pulsar timing arrays and realistic near-term sensitivity predictions;
- The path toward a future space-based interferometer; and
- The discovery potential of current electromagnetic surveys for discrete SMBH binary systems.

These proceedings form a report of the meeting which encompass the meeting's central goals, however a large number of additional talks and posters contributed to excellent discussions. Discussion highlights included whether the “last parsec problem” is still a problem (it doesn't seem to be) and the vast knowledge we've gathered on hierarchical structure formation through galaxy mergers, on the strong statements that pulsar timing arrays are already making and will continue to make in the future, on exciting efforts in BSMBH discovery and how these effect GW signals, and on the promise of future space-based gravitational wave experiments.



### Acknowledgement

We thank our fellow members of the Scientific Organizing Committee for their input and advice in constructing an exciting and productive Focus Meeting—K. Holley-Bockelmann, R. Batty, S. Buchner, G. Hobbs, F. M. Khan, M. Kramer, C. Miller J. L. Han, and L. Wen. Part of this research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration. The National Radio Astronomy Observatory is a facility of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc. The NANOGrav Project receives support from NSF Physics Frontier Center award number 1430284.