

COSMOLOGY & GRAVITY

Attempts to tell a comprehensive story of the structure and evolution of the universe — from its first moment of existence to its ultimate fate.

Bringing together a unique mix of interdisciplinary researchers, the Cosmology & Gravity program continued to explore the very early universe, neutron stars, black holes and fast radio bursts (FRBs), pulsars, dark matter and galaxies, cosmology and fundamental theory. The recent discovery of gravitational waves by the Advanced Laser Interferometer Gravitational-Wave Observatory (LIGO) is an exciting development in the field that will transform our fundamental understanding of the universe.

This year the program underwent an external review and was successfully renewed for a five-year term under the leadership of R. Howard Webster Foundation Fellow **Victoria Kaspi** (McGill University). The new name, Gravity & the Extreme Universe, reflects a new vision: to lead the way in a new era of gravitational wave astronomy in the 21st century.

At the program meeting, members recognized the leadership and contributions of outgoing Program Director **Dick Bond** (University of Toronto). Discussions included the importance of gravity wave observations for testing general relativity in strong field regimes, progress on new instruments including the Canadian Hydrogen Intensity Mapping Experiment (CHIME), FRBs and pulsars, neutrino and dark matter experiments at SNOLAB in Sudbury, ON, and the cosmic microwave background.

RESEARCH HIGHLIGHTS

The LIGO Scientific Collaboration reported on the detection of gravitational waves from a second set of colliding black holes and a third set from a binary hole of about 49 solar masses located three billion light years away. As a member of the LIGO team, Fellow **Harald Pfeiffer** (University of Toronto) contributed to the studies. The results of the second study confirmed the presence and regularity of many merging black holes in the universe, with one collision occurring roughly every 15 minutes.

- LIGO Scientific Collaboration and Virgo Collaboration, including Abbott BP et al. 2016. GW151226: Observation of gravitational waves from a 22-solar-mass binary black hole coalescence. *Phys Rev Lett.* 116: 241103.
- LIGO Scientific Collaboration and Virgo Collaboration, including Abbott BP et al. 2016. GW170104: Observation of a 50-solar-mass binary black hole coalescence at redshift 0.2. *Phys Rev Lett.* 118: 221101.

CHIME, a novel radio telescope located in British Columbia, aims to image the largest volume of the universe to date, unlocking the nature of dark energy and/or FRBs. This work involves Senior Fellows **Matt Dobbs** (McGill University), **Gary Hinshaw** (University of British Columbia), Ue-li Pen (University of Toronto), **Mark Halpern** (University of British Columbia), **Ingrid Stairs** (University of British Columbia) and **Victoria Kaspi** (McGill University), and Associate Fellow **Scott Ransom** (National Radio Astronomy Observatory), among others. CHIME promises to detect 10–20 FRBs per day, compared with the 27 FRBs in total discovered over the past decade.

- CHIME Scientific Collaboration, including Amiri M et al. 2017. Limits on the ultra-bright Fast Radio Burst population from the CHIME Pathfinder. In: *ArXiv e-prints* (Feb 2017). arXiv: 1702.08040.
- Berger P et al. 2016. Holographic beam mapping of the CHIME Pathfinder array. In: *ArXiv e-prints* (Jul 2016). arXiv: 1607.01473.

A collaboration involving Fellow **Victoria Kaspi** (McGill University) and Associate Fellow **Scott Ransom** (National Radio Astronomy Observatory) localized an FRB and

AT A GLANCE

FOUNDED: 1986

MOST RECENT RENEWAL: 2017

PROGRAM DIRECTORS: J. Richard Bond, University of Toronto

FELLOWS, ADVISORS AND CIFAR AZRIELI GLOBAL SCHOLARS: 46

INSTITUTIONS REPRESENTED: 24, in 5 countries

FIELDS AND SUBFIELDS REPRESENTED: astrophysics; astronomy; astroparticle, computational, high energy and particle physics; observational cosmology

MEETINGS: 1; in Lake Louise, Canada

RELEVANT KNOWLEDGE USERS: educators (e.g., high schools, science centres, museums, outreach organizations)

SUPPORTERS: R. Howard Webster Foundation

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showed that it is inside a dwarf galaxy far outside the Milky Way galaxy. This is the first unambiguous demonstration that the new phenomenon of FRBs has an extragalactic origin.

- Chatterjee S, et al. 2017. A direct localization of a fast radio burst and its host. *Nature*. 541: 58-61.

Other Notable Publications and Outputs

- Scholz P, **Kaspi VM, Ransom SM, Stairs IH** et al. 2016. The repeating fast radio burst FRB 121102: multi-wavelength observations and additional bursts. *Astrophys J*. 833: 177.
- Yang H, Lehner L, Pretorius F et al. 2017. Black hole spectroscopy with coherent mode stacking. *Phys Rev Lett*. 118: 161101.
- Hezaveh YD, Blandford RD, Holder GP et al. 2016. Detection of lensing substructure using ALMA observations of the dusty galaxy SDP.81. *Astrophys J*. 823: 37.

- Masui KW, Pen U-L, Turok N. 2017. Two- and three-dimensional probes of parity in primordial gravity waves. *Phys Rev Lett*. 118: 221301.
- Fonseca E, **Stairs IH, Ransom SM** et al. 2016. The NANOGrav nine-year data set: mass and geometric measurements of binary millisecond pulsars. *Astrophys J*. 832: 167.

IDEAS EXCHANGE

In May 2017, CIFAR partnered with the Ontario Science Centre to present *Untangling the Cosmos: How Research is Changing Our Understanding of the Universe*, a day-long symposium that featured talks by fellows of CIFAR's Cosmology & Gravity program. Hosted by Jay Ingram, the event showcased some of the major insights and advances in understanding that the program has accomplished over the past five years, and where the most promising areas for discovery lie in the years ahead. Almost 320 people attended in person and via webcast, including educators, industry leaders and the interested public. The symposium was held as a Canada 150 event, and CIFAR partnered with Innovation150 and Science Odyssey to increase its profile and reach.

GLOBAL ACADEMY

Program fellows collectively supervise nearly 150 highly qualified personnel each year. Where possible, trainees are invited to program meetings to present their work and engage with fellows.



Senior Fellow Dick Bond, above, and Daryl Haggard, right, presented at the *Untangling the Cosmos* symposium in May.

