Galactic Nuclei, Gravitational Wave Sources, and Their Electromagnetic Counterparts

1 Abstract

The historic detection of gravitational waves by the LIGO–Virgo Collaboration inaugurates a new era of doing astronomy and astrophysics. While new gravitational-wave sources will continue to be detected in the years to come, it is believed that more ground-breaking discoveries await the detection of electromagnetic counterparts, which in principle will help us pinpoint the location of gravitational-wave sources, elucidate their astrophysical origin (e.g., whether in the field or in star clusters), and possibly reveal new physics in the regime of strong gravity.

The aforementioned coincidence between gravitational-wave sources and electromagnetic radiation could be more easily produced in the innermost parsec of a galaxy, i.e., in an environment similar to the center of our Galaxy. This is partly because galactic nuclei are known to be a breeding ground of compact objects, such as white dwarfs, neutron stars, stellar-mass black holes, and supermassive black holes (more massive than 10^6 solar masses). Dynamical interaction and mergers of these compact objects will produce a wide spectrum of gravitational wave radiation, with frequencies extending across the sensitivity bands of different ground- and space-based detectors. Another reason is that the density of stars and gas is usually very high in a galactic nucleus, so that compact-object binaries are more likely to interact with baryonic matter and produce electromagnetic radiation.

The scientific goal of this project is to model and observe the electromagnetic counterparts to those gravitational-wave sources inside galactic nuclei. Potential topics include but are not limited to: (i) Event rate of different types of compact-object mergers in galactic nuclei, such as mergers of stellar-mass black holes or the inspiral of stellar-mass black holes into supermassive ones. (ii) Detection rate of these gravitational wave sources by LIGO/Virgo/LISA or the Chinese Taiji/Tianqin programs[1]. (iii) Interaction between gas and stars with gravitational-wave sources and the associated electromagnetic radiation. (iv) Propose observations or use archive data to search for electromagnetic counterparts. (v) Implications that can be derived from the Galactic Center, where both stellar-mass and supermassive black holes exist and data in multiple wavebands are available.

Both theorists and observers are encouraged to apply for this fellowship. Of particular interest are candidates with experience in (i) stellar dynamics of globular and nuclear star clusters, (ii) hydrodynamics of accretion disk and modeling its radiation, (iii) modeling

[1] http://www.nature.com/news/chinese-gravitational-wave-hunt-hits-crunch-time-1.19520

astronomical transients, such as supernovae, gamma-ray bursts, and tidal disruption events, and (iv) modeling and observation of dense star clusters. Applicants are also encouraged to relate their proposals with the current and upcoming facilities available in Chile and China, such as VLT, ALMA, LSST, CTA[2], FAST[3], Einstein Probe[4], and the Taiji or Tianqing programs.

2 Sponsors and Host Institutes

Prof. Xian Chen: Astronomy Department, Peking University, China.
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Prof. Jorge Cuadra: Instituto de Astrofísica, Pontificia Universidad Católica de Chile.
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In collaboration with: Prof. Fukun Liu (Peking University), Dr. Pau Amaro-Seoane (Max-Planck Institute for Gravitational Physics), Dr. Alberto Sesana (University of Birmingham), Prof. Rainer Spurzem (National Astronomical Observatories of China and Heidelberg University), Prof. Runqiu Liu (Institute of Applied Mathematics, Chinese Academy of Sciences), Dr. Zhenya Zheng (Shanghai Astronomical Observatory), Dr. James Guillochon (Harvard University), Einstein Probe Science Working Group, Cherenkov Telescope Array, Gravitational Wave Astrophysics Group of the National Astronomical Observatories of China, Max-Planck Partner Group on Galactic Centre Astrophysics.

3 Scientific Justification and Chile-China Connection

There are ambitious plans to build next-generation telescopes both in Chile and China. Most of these telescopes, in fact, are well suited for gravitational-wave astronomy. Exploring this common ground and identifying potential synergy between different telescopes could greatly increase the scientific payoff of each facility. The following are several possible approaches.

(i) The next breakthrough in gravitational-wave astronomy is finding in time domain an electromagnetic counterpart. For this purpose, the Large Synoptic Survey Telescope (LSST) to be built in Chile and the China-led Einstein Probe (EP), a satellite dedicated to X-ray transients, will both play crucial roles. These observations can be used to recover the spectral energy distribution, which is important for our understanding of the radiation mechanism (e.g. thermal or non-thermal).

(ii) Relativistic motion of matter around gravitational-wave sources usually produces shocks, which in the long run would manifest themselves by radiating infrared and radio emission (e.g. a supernova remnant). Detecting such radiation requires telescopes to have large aperture and high sensitivity, since the source is expected to be faint. The

[2]https://portal.cta-observatory.org
[3]http://fast.bao.ac.cn/en/
[4]http://ep.bao.ac.cn

ideal instruments would be, for example, the Very Large Telescope (VLT) and the Atacama Large Millimeter/submillimeter Array (ALMA) currently operating in Chile, or the world's largest single-dish radio telescope, the Five-hundred-meter Aperture Spherical radio Telescope (FAST), which was built in China and just begins operation.

(iii) Between 2020 and 2030, Chile will also have the world's largest gamma-ray telescope, the Cherenkov Telescope Array (CTA), which is ideal for the search of neutron-star mergers. China, on the other hand, has proposed two space-borne programs to be launched during 2030s, namely Taiji and Tianqin, both of which are very sensitive to detect mergers of stellar-mass compact objects. Signals in both types of telescopes, if detected, can be used to test fundamental physics, such as the Lorentz violation.

(iv) The nucleus of a galaxy is a likely breeding ground of many types of gravitational-wave sources (see Abstract). In fact, the first gravitational-wave sources detected by LIGO and Virgo could have been black-hole mergers in galactic nuclei. The proto-typical galaxy nucleus is the Galactic Center, which resides in the souther hemisphere of the sky and is accessible by most radio, infrared, and γ-ray telescopes in Chile. It provides a useful testbed of those theoretical models and observational techniques relevant to the electromagnetic counterparts.

This project is based on the currently existing collaboration between Prof. Xian Chen and Prof. Jorge Cuadra as well as their previous works related to VLT, ALMA, CTA, EP, and LIGO/Virgo/LISA (see Publications). Prospective postdoctoral fellows will cultivate the rich observational resources available in Chile and China to conduct high-impact research in the frontier of gravitational-wave astronomy. A joint Chile–China team, formed by the postdoc fellow, the sponsors, and interested colleagues in both countries and beyond, is expected to take shape during the project and play an active role in China's future gravitational-wave projects.

4 Implementation Details

This China–Conicyt fellow is appointed for two years, with the possibility of a third-year extension. The postdoctoral fellow is expected to divide his/her time in China and Chile according to the needs of the project, with the general expectation of a minimum stay of six months in each country.

5 CVs of the Sponsors

Xian Chen:

- **Nov 2016-present**: Assistant Professor, Astronomy Department of Peking University, joint appointment with the Kavli Institute for Astronomy and Astrophysics at Peking University, China

- **Feb 2015-Oct 2016**: EMBIGGEN Fellow and China-Conicyt Fellow, Instituto de Astrofísica, Pontificia Universidad Católica de Chile.

- **Nov 2012-Dec 2014**: Postdoctoral Researcher, Max-Planck Institute for Gravitational Physics in Germany (Albert-Einstein-Institute).

- **Sep 2010-Nov 2012**: Kavli Fellow, Kavli Institute for Astronomy and Astrophysics at Peking University, China.

- **Jul 2010**: Ph.D in Astrophysics, Astronomy Department, Peking University. Advisor: Prof. Fukun Liu (Peking University). Co-Advisor: Prof. Piero Madau (UC Santa Cruz).

- **Dec 2007-Dec 2009**: Visiting Student, Department of Astronomy and Astrophysics, UC Santa Cruz, USA.

Jorge Cuadra:

- **July 2010–present**: Assistant, then Associate Professor at the Instituto de Astrofísica, Pontificia Universidad Católica de Chile (PUC), Santiago, Chile.

- **Jan 2016–present**: Head of the Max-Planck Partner Group on Galactic Centre Astrophysics at PUC.

- **Sept 2008–July 2010**: Joint postdoctoral research position between the Max-Planck Institute for Astrophysics, Garching, Germany, and the Shanghai Astronomical Observatory, China.

- **Nov 2006–Sept 2008**: Postdoctoral researcher at JILA, University of Colorado, Boulder, USA.

- **Aug 2002–Nov 2006**: PhD in Astronomy at the Max-Planck Institute for Astrophysics, Garching, Germany. Advisers: Dr. S. Nayakshin and Prof. R. Sunyaev.

6 Selected Recent Publications

1. Fontecilla, C., **Chen, X.**, & **Cuadra, J.**, "A Second Decoupling Between Merging Binary Black Holes and the Inner Disc – Impact on the Electromagnetic Counterpart", 2016, MNRAS submitted

2. **Chen, X.**, Amaro-Seoane, P., & **Cuadra, J.**, "Stability of Gas Clouds in Galactic Nuclei: An Extended Virial Theorem", 2016, ApJ, 819, 138

3. **Chen, X.**, Gómez-Vargas, G. A., & Guillochon, J., "The γ-ray afterglows of tidal disruption events", 2016, MNRAS, 458, 3314

4. Goicovic F. G., **Cuadra J.**, Sesana A., Stasyszyn F., Amaro-Seoane P., Tanaka T. L., "Infalling clouds on to supermassive black hole binaries - I. Formation of discs, accretion and gas dynamics", 2016, MNRAS 455, 1989

5. Amaro-Seoane, P. & **Chen, X.**, "Relativistic mergers of black hole binaries have large, similar masses, low spins and are circular", 2016, MNRAS, 458, 3075

6. **Cuadra J.**, Nayakshin S., Wang Q. D., "The role of feedback in accretion on low-luminosity AGN: Sgr A* case study.", 2015, MNRAS, 450, 277

7. **Chen, X.** & Amaro-Seoane, P., "Sculpting the Galactic Center", 2015, CQG, 32, 4001

8. Dunhill A. C., **Cuadra J.**, Dougados C., "Precession and accretion in circumbinary discs: the case of HD 104237", 2015, MNRAS, 448, 3545

9. Brem P., **Cuadra J.**, Amaro-Seoane P., Komossa S., "Tidal Disruptions in Circumbinary Disks. II. Observational Signatures in the Reverberation Spectra", 2014, ApJ, 792, 100

10. **Chen, X.**, Sesana, A., Madau, P., & Liu, F. K., "Tidal Stellar Disruptions by Massive Black Hole Pairs. II. Decaying Binaries", 2011, ApJ, 729, 13