Probing black hole growth with Intermediate mass black holes

SUMMARY

There is a dearth of black hole observations in the mass range $10^2 - 10^5 M_\odot$ falling between stellar remnants and supermassive black holes. Gravitational wave detections by LIGO and Virgo hinted at the existence of such intermediate mass black holes. The detection of an intermediate mass black hole population could have far-reaching astrophysical implications for the understanding of the formation and growth of supermassive black holes. This emerging population could also provide information on stellar evolution, especially in the context of the pair-instability supernova mass gap. Mergers involving intermediate mass black holes are the the farthest detectable sources for many XG detector configurations, making them a key probe to cosmic evolution. Since high mass binary mergers emit low frequency gravitational-waves, the XG detector which is expected to have improved low frequency ($< 10\,\mathrm{Hz}$) sensitivity would be crucial in detecting a large population of intermediate mass black hole binaries.

Key question(s) and scientific context in brief

Intermediate mass black holes (IMBHs) are a missing link between stellar mass black holes formed by stellar core collapse, and supermassive black holes found in the centers of galaxies. As the origin of supermassive black holes is not well understood, observing intermediate stages of black hole growth could provide critical information. In addition, a mass gap ($50\,M_\odot \lesssim M \lesssim 130\,M_\odot$) is expected at the lower end of this mass range when the stellar core mass is high enough for pair production leading to a Pair-Instability Supernova, where no remnant is left behind. Gravitational waves from binaries with component masses in the pair-instability supernova mass gap trigger far-reaching astrophysical investigations pertaining to our understanding of stellar evolution and formation mechanisms of such systems. Furthermore, intermediate mass binary black hole mergers are one of the farthest detectable sources of gravitational waves that can be probed with the upcoming XG detector configurations, advancing our understanding of the distant universe.

Potential scientific impact of XG detectors on the key questions

IMBH binaries correspond to lower frequency gravitational-wave emissions and are limited by the low-frequency noise barrier of the current ground-based gravitational-wave detectors. XG detectors will significantly improve the low frequency sensitivity to gravitational waves thereby enabling us to observe heavier IMBH systems at higher redshifts. This will be critical in probing the emerging IMBH population, especially at the higher masses. The enhanced sensitivity will also grant access to the inspiral features of IMBH binaries allowing exploration of possible multipole signatures that were previously undetectable. This will help in identifying various formation channels accurately. The sensitivity to low frequency ($< 10\,\mathrm{Hz}$) of XG detectors makes it the best suited for shedding light on the pair-instability supernova mass gap as compared to space-based gravitational-wave detectors which are sensitive to milli-hertz frequencies.

Benchmarks for XG detectors to enable the scientific impact

The key features used to benchmark intermediate mass binaries are the following:

- **The low frequency sensitivity cutoff which determines the highest mass of the IMBH binary** that can be observed by the XG detectors.
- **Detection rate and mass distributions of the emerging IMBH population.** Numerous detections of binaries with at least the primary mass component lying in the pair-instability supernova mass gap will characterize the IMBH population helping us better understand stellar evolution.

SCIENTIFIC IMPACT OF XG DETECTORS

Challenging the stellar evolution models; establishing the emerging IMBH population; determining formation channels of IMBH binaries; probing the missing link between stellar mass black holes and supermassive black holes.

Dependencies on other multi-messenger capabilities

- Multi-messenger observations are generally not critical in answering key questions relating to IMBH mergers, which can be inferred from gravitational waves alone.
- Detecting gravitational waves from IMBH binary mergers with electromagnetic observations, e.g., in AGN disks, can shed light on the formation scenario and the environment of the astrophysical event. Emission is possible throughout the electromagnetic spectrum. Similar capabilities are ideal as to neutron star merger follow-ups, except that low latency is less relevant.

XG DETECTOR AND NETWORK REQUIREMENTS

The sensitivity of XG detectors at lower frequencies should increase the sensitivity of detected IMBH mergers allowing us to probe higher redshifts and higher masses. Apart from this, the network requirements are not vital for IMBH science in general.

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