Here's why we should put a gravitational wave observatory on the moon

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Gravitational Wave science holds great potential that scientists are eager to develop. Is a gravitational wave observatory on the moon the way forward? Credit: NASA/Goddard/LRO.

Scientists detected the first long-predicted gravitational wave in 2015, and since then, researchers have been hungering for better detectors. But the Earth is warm and seismically noisy, and that will always limit the effectiveness of Earth-based detectors.

Is the moon the right place for a new gravitational wave observatory? It might be. Sending telescopes into space worked well, and mounting a GW observatory on the moon might, too, though the proposal is obviously very complex.

Most of astronomy is about light. The better we can sense it, the more we learn about nature. That's why telescopes like the Hubble and the JWST are in space. Earth's atmosphere distorts telescope images and even blocks some light, like infrared. Space telescopes get around both of those problems and have revolutionized astronomy.

Gravitational waves aren't light, but sensing them still requires extreme sensitivity. Just as Earth's atmosphere can introduce "noise" into telescope observations, so can Earth's seismic activity cause problems for gravitational wave detectors. The moon has a big advantage over our dynamic, ever-changing planet: it has far less seismic activity.

We've known since the Apollo days that the moon has seismic activity. But unlike Earth, most of its activity is related to tidal forces and tiny meteorite strikes. Most of its seismic activity is also weaker and much deeper than Earth's. That's attracted the attention of researchers developing the Lunar Gravitational-wave Antenna (LGWA).

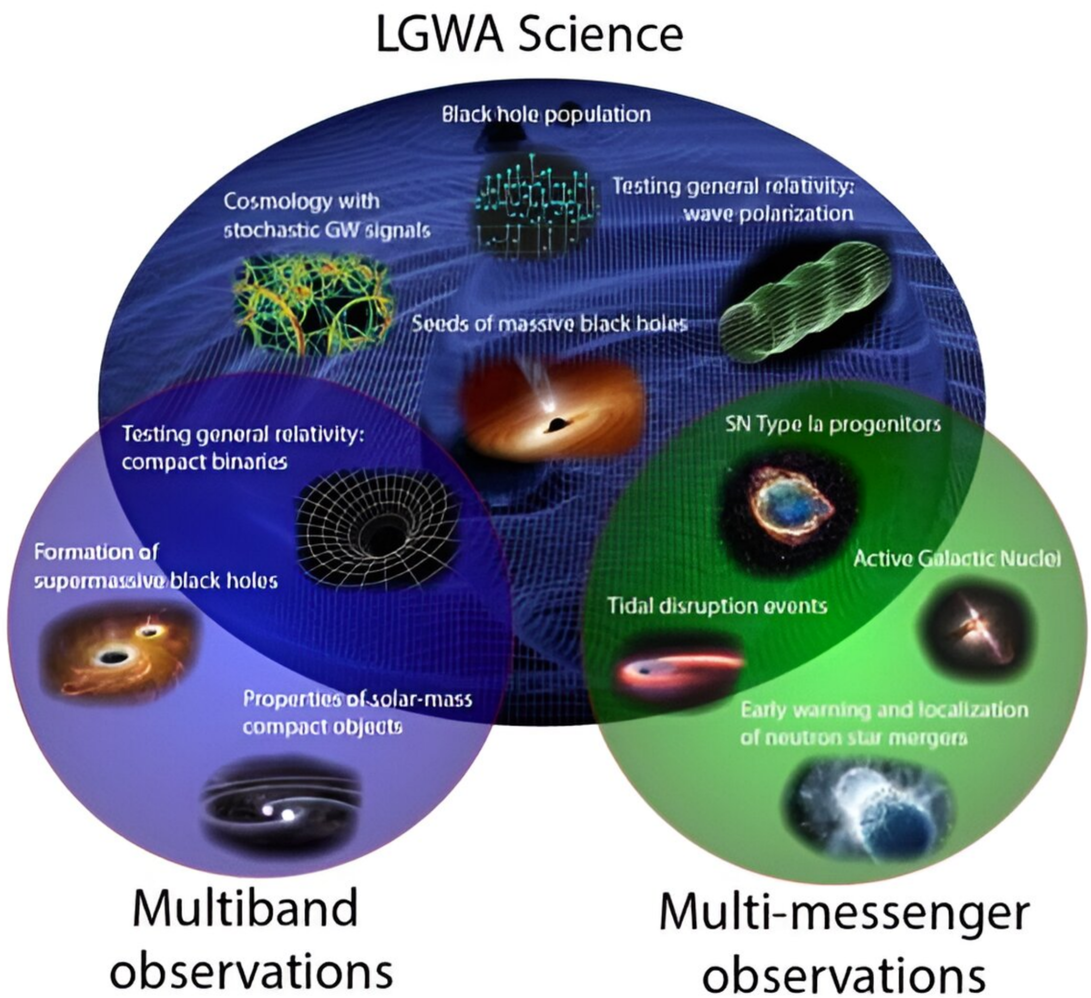
The developers of the LGWA have written a new paper, "The Lunar Gravitational-wave Antenna: Mission Studies and Science Case," and posted it to the *arXiv* preprint server. The lead author is Parameswaran Ajith, a physicist/astrophysicist from the International Center for Theoretical Science, Tata Institute of Fundamental Research, Bangalore, India. Ajith is also a member of the LIGO Scientific Collaboration.

A gravitational wave observatory (GWO) on the moon would cover a gap in frequency coverage.

"Given the size of the moon and the expected noise produced by the lunar seismic background, the LGWA would be able to observe GWs from about 1 mHz to 1 Hz," the authors write. "This would make the LGWA the missing link between space-borne detectors like LISA with peak sensitivities around a few millihertz and proposed future terrestrial detectors like Einstein Telescope or Cosmic Explorer."

If built, the LGWA would consist of a planetary-scale array of detectors. The moon's unique conditions will enable the LGWA to open a larger window into gravitational wave science. The moon has extremely low background seismic activity that the authors describe as 'seismic silence." The lack of background noise will enable more sensitive detections.

The moon also has extremely low temperatures inside its permanently shadowed regions (PSRs.) Detectors must be super-cooled, and the cold temperatures in the PSRs make that task easier. The LGWA would consist of four detectors in a PSR crater at one of the lunar poles.



A graphical summary of the LGWA science case, including multi-messenger studies with electromagnetic observatories and multiband observations with space-borne and terrestrial GW detectors. Credit: Ajith et al 2024/LGWA

The LGWA is an ambitious idea with a potentially game-changing scientific payoff. When combined with telescopes observing across the electromagnetic spectrum and with neutrino and cosmic ray detectors—called multi-messenger astronomy—it could advance our understanding of a whole host of cosmic events.

The LGWA will have some unique capabilities for detecting cosmic explosions. "Only LGWA can observe astrophysical events that involve WDs (white dwarfs) like tidal disruption events (TDEs) and SNe Ia," the authors explain. They also point out that only the LGWA will be able to warn astronomers weeks or even months in advance of solar mass compact binaries, including neutron stars, merging.

The LGWA will also be able to detect lighter intermediate-mass black hole (IMBH) binaries in the early universe. IMBHs played a role in forming today's supermassive black holes (SMBHs) at the heart of galaxies like our own. Astrophysicists have a lot of unanswered questions around black holes and how they've evolved and the LGWA should help answer some of them.

Double White Dwarf (DWD) mergers outside our galaxy are another thing that the LGWA alone will be able to sense. They can be used to measure the Hubble Constant. Over the decades, scientists have gotten more refined measurements of the Hubble constant, but there are still discrepancies.

The LGWA will also tell us more about the moon. Its seismic observations will reveal the moon's internal structure in more detail than ever. There's a lot scientists still don't know about its formation, history, and evolution. The LGWA's seismic observations will also illuminate the moon's geological processes.

The LGWA mission is still being developed. Before it can be implemented, scientists need to know more about where they plan to place it. That's where the preliminary Soundcheck mission comes in.

In 2023, the ESA selected Soundcheck into its Reserve Pool of Science Activities for the moon. Soundcheck will not only measure seismic surface displacement, magnetic fluctuations and temperature, it will also be a technology demonstration mission. "The Soundcheck technology validation focuses on deployment, inertial sensor mechanics and readout, thermal management and platform leveling," the authors explain.

In astronomy, astrophysics, cosmology, and related scientific endeavors, it always seems like we're on the precipice of new discoveries and a new understanding of the universe and how we fit into it. The reason it always seems like that is because it's true. Humans are getting better and better at it, and the advent and flourishing of GW science exemplifies that, even though we're just getting started. Not even a decade has passed since scientists detected their first GW.

Where will things go from here?

"Despite this well-developed roadmap for GW science, it is important to realize that the exploration of our universe through GWs is still in its infancy," the authors write in their paper. "In addition to the immense impact expected on astrophysics and cosmology, this field holds a high probability for unexpected and fundamental discoveries."

More information: Parameswaran Ajith et al, The Lunar Gravitational-wave Antenna: Mission Studies and Science Case, *arXiv* (2024). DOI: 10.48550/arxiv.2404.09181

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