Gravitational Wave Astrophysics with MAGIS

progenitors and pre-merger localizations of Advanced LIGO/Virgo binary-merger events

C.C. Teddy Cheung[1], Jason Hogan[2], Peter Graham[2], Mark Kasevich[2] , Surjeet Rajendran[3], Roger Romani[2]
Babak Saif[4], Matthew Kerr[1], Michael Lovellette[5], Kent Wood[5], Peter Michelson[2], for the MAGIS Team*
[1]Naval Research Laboratory, [2]Stanford University; [3]UC Berkeley,[4]NASA/GSFC; [5]Praxis, resident at Naval Research Laboratory

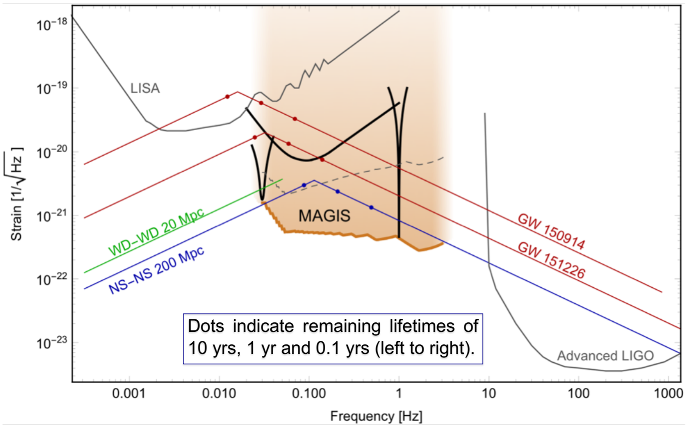
Gravitational wave observations in the ~30 mHz to 3 Hz range (*mid-band*) provide degree-scale localizations and binary system parameters prior to their merger detections with LIGO/Virgo. MAGIS, the Mid-band Atomic Gravitational Wave Interferometric Sensor [1], a proposed NASA probe-class space mission concept, will be capable of such measurements.

*The MAGIS team is a collaboration between institutes in the U.S. including Stanford, AOSense, Harvard, NASA/GSFC, NASA/JPL, NIST, NRL, and UC Berkeley, and international partners at Birmingham, Bordeaux, CNRS, Dusseldorf, Ecole Normale Superieure, Florence, Hannover, and Ulm University.

Summary

- The Mid-band Atomic Gravitational-wave Interferometric Sensor (MAGIS) is a probe-class space-mission concept [1], using an atom-based gravitational wave (GW) detector. MAGIS will provide all-sky strain sensitivities of ~10^{-21} √Hz and better (1-year) in the GW-frequency *mid-band* (~30 mHz to 3 Hz) between LISA/L3 (~2034 launch) and ground-based Advanced LIGO/Virgo interferometers.
- Joint GW-observations with MAGIS and Advanced LIGO/Virgo offer a path to determining binary system parameters and progenitors by covering all stages of binary coalescence, from inspiral to merger. The GW- degree-scale localizations and distance measurements will be powerful paired with galaxy catalogs, to enable unique galaxy counterpart identifications. Because most neutron star (NS) binary systems (BH-NS, NS-NS) will not have favorable system geometries, and black hole (BH) binary mergers are likely absent of detectable electromagnetic counterparts, GW mid-band observations will uniquely provide information on galaxy demographics of these systems.

MAGIS Mid-band Gravitational Wave Sensitivity and Sources



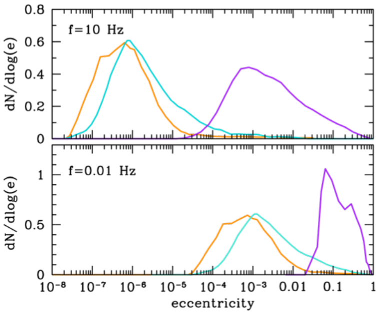
Dots indicate remaining lifetimes of 10 yrs, 1 yr and 0.1 yrs (left to right).

MAGIS gravitational wave sensitivity. Example resonant sensitivity curves (at two arbitrarily chosen frequencies) and the broadband mode sensitivity are shown in solid, thick black. The envelope of the possible resonant curves is shown by the lower brown boundary/line. The dashed gray curve is the appropriate, approximate sensitivity curve for the discoverability of shorter-lived sources such as the LIGO-detected BH binaries. The LISA [8] and Advanced LIGO strain curve (design) are also shown. From [1]

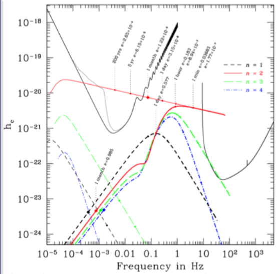
Expected sources shown are two LIGO-observed binary black hole merger events (red), a WD-WD binary at 20 Mpc (with masses $0.5M_\odot$ − $0.5M_\odot$; green), a NS-NS binary at 200 Mpc (masses $1.4M_\odot$ − $1.4M_\odot$; blue).

Binary black hole progenitors

- The progenitors of the binary black hole systems discovered at higher-frequencies by LIGO/Virgo remains an open problem. They can be formed in isolated or dense environments, leading to different ensemble eccentric distributions [2, 3]. Eccentricities are best-measured in the mid-band – these binaries circularize before they reach the LIGO/Virgo band and the most eccentric binaries are missed by LISA.



Expected eccentricity distributions for binary BHs formed in the field (orange), in globular clusters (turquoise), and near a central massive black hole (purple). The systems' higher eccentricities are most-easily measured at lower frequencies before their orbits circularize at latter stages. From [2]

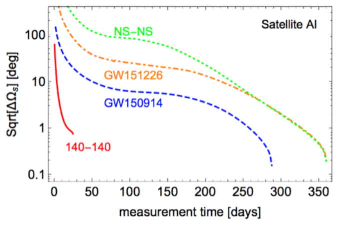


GW frequency evolution of example binary BHs, each 30 $M_\odot$, at D = 500 Mpc. The systems have initial eccentricities, e=0.05 (top red curve) and e=0.999 (bottom curves) at 0.1 a.u., before their orbits circularly and become indistinguishable at 1 Hz and above. From [3]

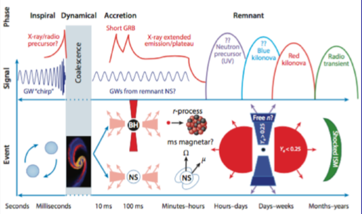
- Moreover, triple systems that tend to form in dense environments, are distinguishable in the mid-band by MAGIS, and can result in successive GW merger events observable by LIGO/Virgo within years timescales [4,5].

Pre-Merger Localizations

- Binary systems last for 100's days in the mid-band, providing *advanced (pre-merger) degree-scale localizations, distances (redshifts), and predicted merger epochs, ~weeks prior to their merger-detections with LIGO/Virgo*. The observations will distinguish between neutron star (< 2.8 $M_\odot$) and black hole systems, constrain binary system parameters including orientations, that will facilitate different follow-up strategies. Importantly, the full sequence of events unfold within PhD-timescales.
- These gravitational wave source forecasts make possible, *previously unimagined electromagnetic observations of GW sources, including: (i) searches for precursor emission (possible orbital- or disk-modulated X-ray/UV emission), (ii) progenitor identification (optical/IR galaxy survey within GW-localized volume), & (iii) unique characterization of prompt post-merger transient emission (optical-to-γ-ray polarimetry of SGRBs, γ-ray line spectroscopy of kilonovae emission, VLBI jet structures).*



Accumulation of the positional measurement accuracies for example binary systems (NS-NS at 140 Mpc; LIGO-detected BH-binaries; IMBH-binary at 410 Mpc, 140 $M_\odot$ each) with a satellite atom interferometer resonant detector. From [6]



Phases of a binary NS merger with associated observations signatures and underlying physical mechanisms (From [7]). MAGIS will give advanced notice of localizations and merger times to enable unique pre- and post-merger observations.

References & Acknowledgments

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