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THE TERRESTRIAL GRAVITATIONAL WAVE ENVIRONMENT FROM KNOWN SOURCES

FINAL TECHNICAL REPORT

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Objective

The objective of this project was to produce a gravitational wave spectral line list of all known binary stars producing expected strain amplitudes at Earth in excess of $h = 10^{-21}$, or gravitational wave fluxes in excess of $F = 10^{-12}$ erg cm^{-2} s^{-1}. These strain and flux limits lie above the anticipated detection thresholds for space-borne laser interferometers capable of detecting gravitational radiation in the 10 μHz to 1 Hz frequency range. The source list was intended to provide frequency (including each harmonic), amplitude and phase (for each polarization and harmonic), and celestial coordinates for each system, lacking only the orientation of the principal polarization axis with respect to the pole of the coordinate system, and the sign of the source phase and frequency (or, equivalently, of the sense of rotation of the strain tensor with time) from providing a complete source description. Such a spectral line list would lay essential groundwork for high-sensitivity, low-frequency searches for gravitational radiation.

Project Execution

A full description of the gravitational wave signal from a given binary star requires knowledge of 11 quantities: (1) l — galactic longitude of the star, (2) b — galactic latitude of the star, (3) d — distance of the star from earth, (4) M_1 — mass of its primary component, (5) M_2 — mass of its secondary component, (6) P — orbital period (or A — orbital separation), (7) i — inclination of the orbital axis to the line of sight, (8) e — orbital eccentricity, (9) T — epoch of periastron (or of ascending node, in the case of a circular orbit), (10) ω — longitude of periastron, and (11) Ω — position angle of ascending node on the plane of the sky. In principle, thorough observational study can, in favorable circumstances (namely, eclipsing, double-lined spectroscopic binaries), provide nearly all of the required data; only the last item, Ω (which determines the orientation of the principle polarization axis of the gravitational wave on the plane of the sky), is indeterminate (except for a very small number of peculiar binaries). In practice, it is necessary in most cases to apply less direct observational constraints to fill out the required parameter set. This is particularly the case for binaries seen nearly pole-on (which corresponds to the peak of the gravitational wave beam pattern), since these systems to not eclipse.

This project was designed as a three-year project, organized in four phases: (1) candidate source selection, (2) data collection, (3) source analysis, and (4) gravitational wave spectrum synthesis. The first three phases overlapped to the extent that new observational material continuously became available, or that the observational material at hand for an individual source became complete enough to justify a thorough analysis of that system to produce its requisite gravitational wave parameter set. Selection criteria for the inclusion of individual binary stars in this study were derived from standard spectral type-mass-luminosity relations for main sequence stars, and are described and illustrated in part in the project proposal. The data collected in the course of this study is contained in the draft *Catalogue of Potentially Bright Close Binary Gravitational Wave Sources*, which also identifies the various source analysis techniques employed (albeit without elaboration). Actual calculation of the gravitational wave spectrum was to be undertaken upon completion of the first three phases. However, only the first year of this project was funded, and only a partial source analysis had then been completed.

Scientific Findings

A total of 1773 putative close binary systems were identified as satisfying the threshold conditions for inclusion in this study as candidate sources. Of this number, data collection and analysis had proceeded far enough to produce a complete parameter set (l, b, d, M_1, M_2, P, i, e, T, and ω, with Ω being in nearly all cases indeterminate) for 773 systems, although for 162 of these systems the observational material at hand could only constrain the possible range of one or more of these parameters (typically because the secondary component was not detectable photometrically or spectroscopically). The parameter sets are partially complete for most of the remaining systems, although it is likely that in a majority of these cases it would only be possible to constrain the range of remaining parameters. A handful of the remaining systems, although suspected of being binary, were determined fairly unambiguously to be single stars; 15 such cases were confirmed, with a somewhat larger number likely among those systems with partial parameter sets. Inasmuch as funding was not continued beyond the first year of this project, and analysis could not then be completed for those systems with partial parameter sets, a full gravitational wave spectrum synthesis was not attempted. However, it is expected that the majority of bright sources are already accounted for among the systems for which analysis was completed. The data contained in the results of this research are sufficient to calculate the gravitational wave signatures of the 773 systems with compete parameter sets.

Disposition of Results

The data selected on candidate sources, and the results of the analysis of individual systems are assembled in the draft *Catalogue of Potentially Bright Close Binary Gravitational Wave Sources*, copies of which have been distributed with this final technical report to the NASA Technical Officer for this Grant, the Grants Officer, and the NASA Center for Aerospace Information, as instructed in the award document. Because of it is incomplete and still needs verification of many of its entries, it is unsuitable for publication in its present form. However, the Principal Investigator has realized from the inception of this project that this compilation and analysis of available data on close binary stars, especially if made truly comprehensive, would be of enormous utility to stellar astronomy, since these objects are the source of nearly all knowledge of the properties of stars beyond the Sun, and interacting binaries both account for most stellar sources detected at non-optical (X-ray and radio) wavelengths and display, through their interaction, a wide variety of phenomena not found among single stars. The *Catalog of Potentially Bright Close Binary Gravitational Wave Sources* has therefore been subsumed into a continuing survey of the properties of close binary stars generally, which follows the same structural format, but encompasses all systems without regard to their importance as gravitational wave sources. A working copy of this expanded *General Catalog of Close Binary Systems* (5 vv., 2183 pp.) has been deposited in the Library of the U.S. Naval Observatory (call number QB821.W3 1993), and support for its completion is being solicited through separate channels.

It will provide all of the information needed for a full gravitational wave spectrum synthesis from close binary sources should the need for such a spectrum synthesis be revisited in future.

PUBLICATIONS

Webbink, R.F. 1993, *A Catalogue of Potentially Bright Close Binary Gravitational Wave Sources* (Urbana: University of Illinois), iv + 508 pp. [Manuscript]

Webbink, R.F. 1994, "A General Catalogue of Close Binary Systems," in *Interacting Binary Stars*, ed. A.W. Shafter (San Francisco: Astronomical Society of the Pacific), pp. 440-442.