CATCHING THE WILDEST WAVES: DETECTION TEMPLATE FAMILIES FOR PRECESSING BINARIES OF COMPACT OBJECTS

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Coalescing black-hole–black-hole and neutron-star–black-hole binaries are among the most promising gravitational-wave (GW) sources for first-generation ground-based interferometers,[1] but the possibility of detecting them with standard matched-filtering techniques is seriously imperiled by the uncertainty and complexity of the expected waveforms. Still, the prospects of first-generation interferometers should improve with recently developed search strategies[2,3,4] that emphasize signal detection over parameter estimation, adopting phenomenological template banks that extend beyond the physical ranges of the binary parameters.

BCV1: Anticipating higher-order post–Newtonian effects

The GW signals emitted by inspiral black-hole–black-hole binaries with total masses between 10 and 40 $M_\odot$ enter the frequency range of good interferometer sensitivity at a very late stage in the inspiral, when only few orbits are left before the merger, and when different post–Newtonian approximation schemes predict rather different waveforms.[5] It follows that no template family based on a single scheme can be trusted to represent the physical signals adequately. Buonanno, Chen, and Vallisneri[2] developed a phenomenological *detection template family* (BCV1) that embeds all the credible approximated models, and that extrapolates beyond them. If used to detect the true gravity-wave signals, BCV1 would recover an estimated $\gtrsim 93\%$ of the available signal amplitude, using a total number of templates comparable to what would be needed using a single approximated family. At the time of writing, BCV1 is being used for GW searches in LIGO S2 data.

BCV2: Coping with black-hole spin

A second complication is introduced by black-hole spin, which is expected to play a significant role in the late stages of black-hole–black-hole inspirals.[6] The efficient detection of these systems requires modeling the precession-induced modulations of the signal, which depend on a prohibitively large number of parameters (including the initial directions of the spins, and the position and orientation of the binary with respect to the GW detector). Buonanno, Chen, and Vallisneri[3] developed a family of *modulated detection templates* (BCV2) that are functions of very few physical and phenomenological parameters, and that model remarkably well the dynamical and precessional effects of spin, recovering (on the average) $\gtrsim 95\%$ of the available signal power, for black-hole–black-hole binaries with total mass between 10 and 40 $M_\odot$, using a manageable total number of templates. BCV2 is being implemented as an upgrade on BCV1 for future GW searches on LIGO data. In fact, the BCV2 templates look like BCV1 templates multiplied by simple modulation functions; thus, they can be used to account for spin effects while at the same time interpolating between the predictions of different post–Newtonian models.

PBCV: Modeling neutron-star–black-hole binaries

Buonanno, Chen, and Vallisneri[3] proposed also a separate template family for neutron-star–black-hole binaries (with black-hole mass $\lesssim$ 15 $M_\odot$). This family (PBCV) consists of *essentially exact* waveforms written directly in terms of the physical mass and spin parameters of the binary; by contrast, BCV1 and BCV2 templates cannot be used to estimate source parameters reliably. Pan, Buonanno, Chen, and Vallisneri[4] later devised a fast matched-filtering scheme based on PBCV. In that scheme, the detection statistic is automatically maximized over all the parameters (including the position and orientation of the binary with respect to the detector) except four (the two masses, the magnitude of the single spin, and the opening angle between the spin and the orbital angular momentum). The total number of PBCV templates needed in an actual search appears computationally attainable, if challenging. The scheme can also be adapted to the searches for GW from extreme–mass-ratio inspirals[7,8] to be performed using the space-borne detector LISA.[9]

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