CBC BBH NR Projects

LIGO-T1600380

Numerical relativity (NR) is required to produce the best possible estimates of binary parameters by tuning analytic waveform models and by providing NR waveforms to compare directly with the data. The statements below pertain only to binary black holes (BBH). Systems with matter will be considered separately. NR waveforms contributed to the LVC must be in a format that can be directly used by LIGO/Virgo analysis codes. That format should be one agreed upon by the CBC and Burst co-chairs in consultation with the numerical relativists.

The following CBC projects and their publications rely on accurate BBH waveforms:

- Catalogue of Compact Binaries
- Astrophysical Rate and Distribution
- Testing General Relativity

Contributions of NR to these projects take the following forms:

Waveform model development and assessment

To ensure robust results from BBH detections, we must study the validity and applicability of our current waveform models, including surrogate models.

> *Step 1:* Compile a list of regions in BBH parameter space where existing models are valid. This should rely on existing literature and internal LVC review statements, but it should be a subset of the parameter space for which we have genuine consensus that waveform models are “good enough” including a definition what “good enough” means.
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> *Step 2:* Determine the regions of parameter space where we know there are deficiencies in waveform models and believe that we have the current technology to address the deficiencies either by using existing waveform catalogs or asking for new simulations to be run that are within the reach of current NR abilities. *Groups can propose to do NR simulations to fill in the gaps according to this study that will be considered as a contribution to LSC activities.* This includes running NR injections to test current searches.
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> Step 3: Determine the regions of parameter space which will remain unknown unknowns due to a lack of technical ability to assess them. This is in development for beyond O2.

Validation of parameter estimation and tests of GR:
The expectation is that the collaborating NR groups will provide a library of NR waveforms that have been verified to be of "sufficient" accuracy, this is referred to as the LVC NR Bank below. The accuracy will be determined by LVC NR groups in consultation with CBC. We understand and agree with the following possible outcomes in response to a BBH trigger.

Possible outcomes of a BBH trigger

a. Data shows consistency with existing models; e.g., PE results with multiple methods agree, and the recovered parameters are within the regions both where the models are well-calibrated and where mismatches between models and GR are expected/demonstrated to be < 1/SNR^2 with a suitable event-driven PSD. A statement in the paper will be made to reflect this and appropriate citations will be given.
b. Data shows inconsistency with existing models and we have sufficient simulations in the LVC NR bank available to use for PE.
    i. The simulations are injected and recovered with PE using our analytic waveform models, in order to assess systematics due to our waveform models and the biases are assessed. These results will have necessarily been evaluated in advance as part of the "Assessment of Waveform…" project. (note just evaluating systematics is option (d) - identical except that simulations already exist)
    ii. Simulations are directly used for PE (e.g., comparing to NR infrastructure)
c. Data shows inconsistency with existing models and we do not have sufficient simulations available in the LVC NR bank to use for PE.
    i. If these simulations are within the capabilities of the NR groups, they will provide simulations and/or hybrids of the appropriate parameter range and use these results for PE.
    ii. These new simulations will be organized through the "Assessment of Waveform…" project in order to be synced with the broader goal of improving future models.
    iii. If possible, an updated waveform model will be produced and used to verify that systematics are understood.
d. Data shows inconsistency with existing models, we don't have NR simulations to address it, and we don't have the technology or time to complete the necessary NR simulations. In this case we attempt to bound the systematic error and present it as our final result. Note, we may do *some* NR simulations if they can be shown to improve the bound on the systematic error, even if they

cannot cover the space adequately for use in full PE. We can consider a follow-up publication when/if new models / simulations shed light on the event.

Event Visualization: Events that are released to the public so far have been accompanied by numerical relativity simulations for visualization. We believe that this is an important contribution and should be continued. For any event at least two groups should simulate the most likely event parameters and show agreement. At least one high quality visualization should be derived from those simulations. All visualizations that use results, e.g., parameters obtained from LVC work should be coordinated with the LVC.

Policy on NR waveforms contribution and use:

The new members will be held to the standard LVC policies on publication (LIGO-M050172[1]) and data management (LIGO-M1000066[2]). Below we enumerate a plausible interpretation of those policies in light of questions that NR groups might have.

1. The NR waveforms will be contributed to the LVC in a standardised file format with documentation of their origin (T1500606[3]).
2. A list of contributed waveforms will be maintained, and all contributed waveforms are available for use by all collaboration members in non-published work (e.g. for technical development and review). The list will include information on the public availability of each waveform.
3. The creators of the NR waveforms have the right to write short-author papers on the waveforms they contributed according to LVC publication policies.
4. Groups which contribute waveforms for use in any paper of the LIGO-Virgo collaboration have the right to request co-authorship on the paper according to LVC publication policies.
5. Waveforms produced specifically for an LVC publication will be made public at the time of publication.
6. Short author papers by other LVC members can use NR waveforms as follows: (i) public NR waveforms can be used with correct citation. (ii) non-public NR waveforms can only be used with prior permission of the creators of the NR waveforms and subject to any authorship/citation requests of the creators.
7. LVC computing resources will not be available for NR simulations, however, we request that the groups report the resources used.

[1] https://dcc.ligo.org/LIGO-M050172/public
[2] https://dcc.ligo.org/LIGO-M1000066/public
[3] https://dcc.ligo.org/LIGO-T1500606