# TCAN Workshop on BH/NS and BNS Discussion Topics - June 6-10, 2020

## Scientific Program @ compact-binaries.org:

https://compact-binaries.org/content/events/2020-06-15/tcan-binary-neutron-stars-workshop-2020

## Monday July 6 - Overview: observations and theory

### Brainstorming Q&A:

Discussion Leads: Ariadna & Federico LA

**Q1: What are the major science questions for theory and simulation to address?**

- Ariadna: We know lanthanides are created in dynamical ejecta, but how much in outflows from accretion disk? How is Ye there? Which are the simulations that provide best Ye?
- Julian: Total amount of production is also interesting, since not the only source.
- Yoseff asks about LGRB as a source of lanthanides. New paper coming soon with D. Siegel about it.
- Adriana: how does your method compare with Los Alamos' (MIller, et al)
- Yoseff: They found they need very low Ye, Daniel recurres to wind but Miller takes 0.5 as assumption.
- Phil C: The best we can get out of this simulation is the mass of dynamical ejecta.
- David R: We found agreement on the mass of dynamical ejecta for comparable q in GRMHD. Newtonian simulations show larger ejecta because, for instance, Newtonian gravity predicts larger NS.
- David R proposes another topic for discussion, can we help with parameters estimations from these simulations? For instance, constraining q.

**Q2: Can we come up with recipes for accurate, preferably self-consistent post-merger evolutions (resolution requirements, neutrino treatment, EOS, magnetic fields, etc.)?**

- We concluded we made a lot of progress towards consistency, but far from complete consistency.

**Q3: How important is EOS for post merger?**

- Erika Holmbeck: About GW? Kilonova signature? Of course it changes Ye and consequently r-process.
- Bruno: How important is the phase transition? It is difficult to simulate properly.
- David R: we should be concerned about phase transition. Most model phase transitions artificially.
- Zach E: Best analogy for this question is supernova simulations. What physics are most important there? All of them, gravity, MHD, neutrinos, phase transitions, and the EoS of course.
- Rahul K: Interested in knowing how MRI is activated in postmerger disks.
- David R: hope to resolve MRI on disk, but inside the HMNS the length scale is very small (1m). We need to inject artificially large B.
- Julian: Degree to which fluid mechanics is appropriate for HMNS. Crystal structure like WD?
- David R: At this temperature the crust will be melted (~MeV).
- Julian: What about quantum correlations deeper inside?
- Phil C: There are some results on young NS that have not gone superfluid transition. Then, in HMNS, we can be pretty confident that this doesn't happen.
- Julian: Neutrons and nucleons sufficiently coupled? What is the collision rate between nucleons and neutrons?
- David R: Probably high enough because strongly coupled.
- Bruno: resistivity in BNS mergers http://arxiv.org/abs/1803.09215.
- Ian H: Disagrees with these papers. Length scale argument based on length waves throughout inspiral but through the merger you have shocks and that changes length scales.

**Q4: In what scenarios is turbulence important and how important is it qualitatively and quantitatively?**

- Phil: Resolve turbulence is possible to any degree?
- Julian: In most contexts dissipation scales are so short that nobody resolves turbulence. Usually we test whether wavenumber scales are in our range of resolution. You may get some new physics if better resolve.
- Phil: What is the scale for NS mergers?
- David R: Most unstable MRI mode. Very few claim to resolve it.
- Phil: MRI on star or disk?
- David R: Some even in the star, but need to inject high B (1E16). There are some studies with self consistent fields.
- Julian: ID on realistic B?
- David R: some runs start with a dipolar field, other poloidal confined in stars. The latter is more realistic just before merger.

- Bruno: In our case we resolve partially MRI, Jay?
- Jay: HMNS differential rotation gradient is positive, we do not find MRI. Outside we can resolve. It amplifies B, and creates some structures

**Q5 What are the problems with initializing a B-field in simulations?**

- Bruno: Force free outside the star?
- Milton: We set an artificial atmosphere, explore different values, and results don't depend on it.
- Bruno: Have you compared with FF?
- Milton: We have for single NS and find agreement in luminosity. In some limits ideal-MHD is force free. We are modeling magnetic pressure dominance basically.
- Zach: When do you inject B in the simulation?
- Milton: Both before merger and at the beginning (5 orbits). Results are the same. See paper around 2009.
- Manuela: for how long do you evolve the post-merger?
- Milton: We followed for 60ms in total, until jet formation.

**Q6 Regarding resolution requirements, how effective / mature are subgrid modeling for merger and post-merger simulations? (Linked to turbulence question)**

- Carlos P: Doubling resolution in post merger is very expensive. Need strong motivation.
- David R: We actually need models for turbulence. This is the only way to explore binaries. The goal of subgrid models should be to provide the errors of this model.

**Q7 Moving forward, do you think AI/ML can help us better in terms of speeding up the simulations or any other such relevant uses/applications?**

- Julian: It is very hard to define a wide range of circumstances and train the network.
- Carlos P: Agree, and you need data for training, so more simulations.
- Julian: We are far from enough tests.
- David R: In finite volumes we solve conserved eqs. This scheme is exact, but not close because you solve the total mass on the cell. ML convolves fluid variables and reconstructs much better than standard methods.
- Julian: What calculations/data do you actually need for training and looking inside the cell?
- David R: It's been done for isotropic turbulence, with simple BC (periodic). You do a HRes run, then you coarsen the grid by taking averages and train the reconstruction scheme with HRes data. But for BNS we would need to train for different scales: KH during merger, MHD turbulence, etc.
- Julian: Isotropic doesn't apply to our case: mean magnetic fields, gravity, etc.
- Mark: Directions that the community can take for moving-mesh codes? This would be an intermediate step between static-mesh and subgrid models?

- Phil: Moving-mesh codes are second order accurate. This is a big difference in convergence with respect to fourth-order. For some instabilities may be better, but much debate.
- Mark: Convergence means something specific in simple cases like shocks or isotropic turbulence, but in more complex systems? How to quantity?
- Ian H chat: The fundamental limitation is going to be the timestep. The only way around that is to change the model. Adaptive *Model* Refinement is the only method I know that will do that.

**Q8 How sensitive are the results to initial conditions? Is this important? What about the angular momentum (e.g., spins) of the stars?**

- Ariadna: Our results so far are very sensitive to the atmosphere.
- Vassilios: How large are the errors or EoS in ID? For instance, how severe are the errors by setting the ID with a specific EoS but move to another EoS for evolution?
- Zach E:  Depends on how close the EoS are. There are some piecewise polytropics that mimic realistic EoS.
- Federico Cipoletta: We compared TOV evolution. Lots of oscillations on rho_max because interpolation errors on tabulated values versus analytical expression of polytrope.

**Q9 What about making simulation data sets of post-merger snapshots publicly available?**

- Bruno: We usually make everything public, but not 3d snapshots because it's expensive. What's the interest for this?
- Manuela: Interesting for TCAN because we are taking over from previous runs.
- Bruno: OK, it needs coordination as well.
- Zach: Reference to paper that phi-averages the end of simulation and keep it running in 2D. Might be a good idea to agree on 2D datasets.

## Key References


http://arxiv.org/abs/1803.09215
A. Bauswein+ (2013) -- NSM dynamical ejecta
https://journals.aps.org/prd/abstract/10.1103/PhysRevD.101.084024
https://arxiv.org/abs/1903.03040
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