The interface between numerical relativity and data analysis

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Introduction

How can numerical relativity be used to improve GW searches?

- Since NR predicts the merger waveform, it can be used to construct complete templates
- Such templates necessarily involve combining the NR results with PN inspiral calculations
- This is not trivial because NR and PN are built on completely different formalisms and approximation schemes
- See posters by F. Ohme and R. Sturani

Introduction

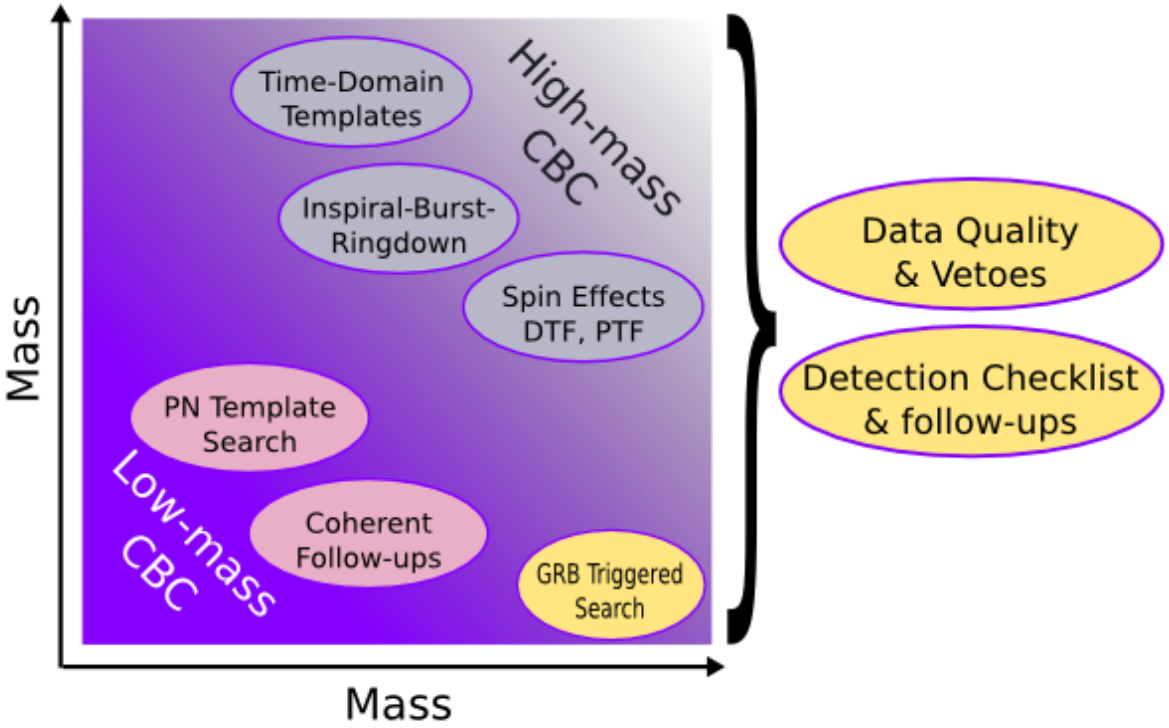
- Still, it turns out that sensible matching procedures can be carried out
- EOB is a successful approach and can be calibrated by using NR results
- A more “phenomenological” approach for combining NR and PN also works well
- The large parameter space with precessing spins and arbitrary mass-ratios (and eccentricities) still remains to be conquered
- Current models work for aligned spins and for at least moderate mass ratios
- Further progress to be expected in the near future (eg in the NR-AR collaboration)

Introduction

- NR is also very useful in directly testing DA pipelines through signal injections
- There are a variety of DA pipelines, and we would like to understand their comparative advantages and limitations for detecting mergers
- Get the NR and DA groups to interact more closely and to understand needs and limitations
- This is where the NINJA project comes in

LSC-Virgo (LVC) analyses of interest

- The low mass search with non-spinning 3.5pN SPA templates (total mass 1-35 $M_\odot$)
- The high mass search currently using non-spinning EOBNR templates (total mass 25-100 $M_\odot$)
- Unmodeled burst searches
- The ringdown search (total mass range is approximately 50-400 $M_\odot$)
- Other searches not ruled out



NRDA Meetings and NINJA

Meetings focused on the NR-DA interface have been very useful

- NRDA 2006 at MIT
- KITP Mini-program at Santa Barbara (Jan 2008)
- NRDA 2008 at Syracuse (3.5 Days, 60 Participants)
- NRDA 2009 at Potsdam (3.5 Days, 85 Participants, scope broadened to also include matter simulations)
- GWBURST 2009 at Chichen Itza (35 participants, more focus on GW bursts and astrophysics)
- NRDA 2010 will take place in June at the Perimeter Institute in Canada

These meetings have been instrumental in starting several collaborations

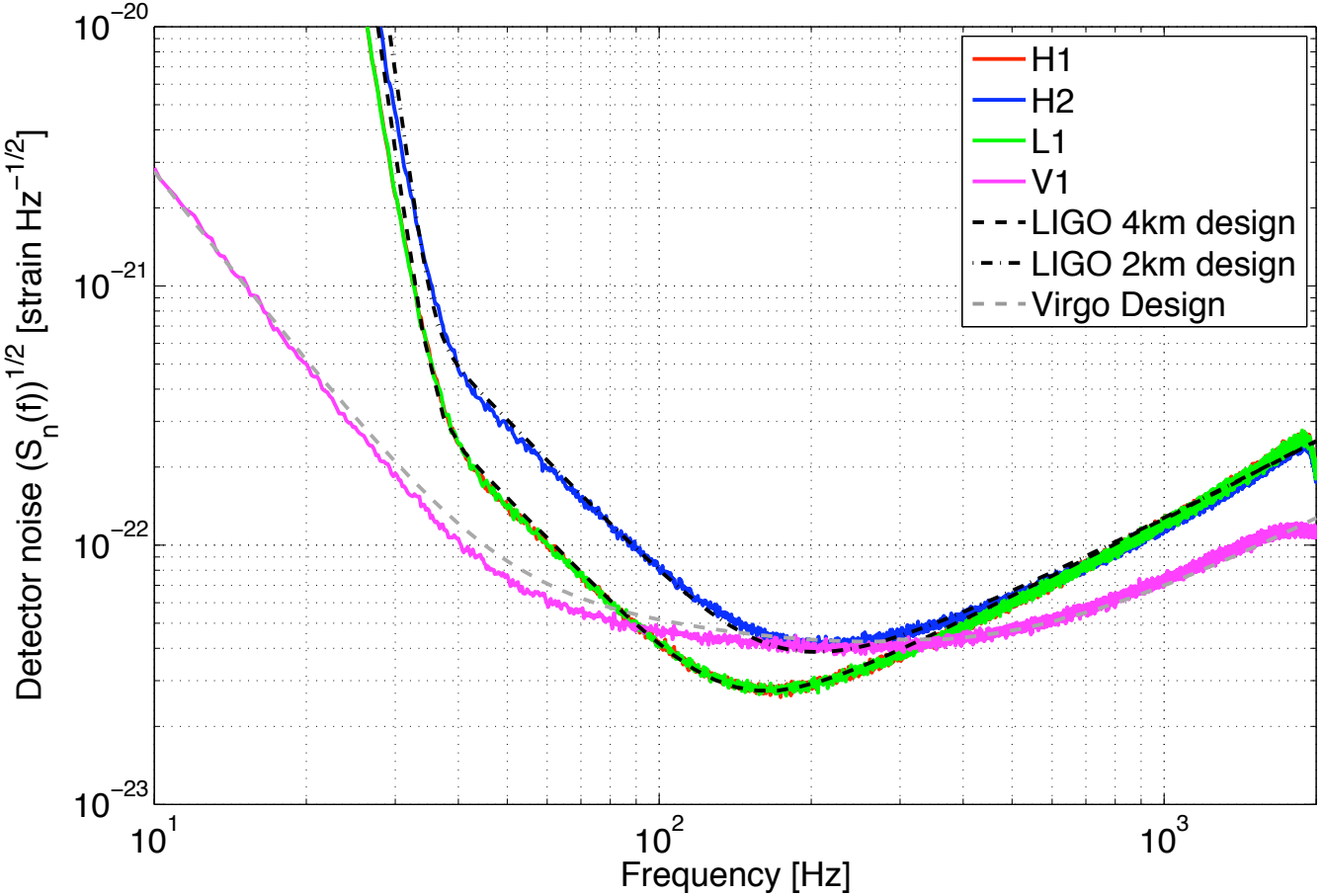
- NINJA was the broadest of these collaborations
- NINJA-1 started in spring 2008 and completed in early 2009

NINJA 1 Protocol

- Developed a format for exchanging waveforms between groups - arXiv:0709.0093
- 10 numerical relativity groups contributed binary black hole merger waveforms of their choice
- Waveforms were added tosimulated colored Gaussian noise
- 9 data analysis groups analyzed the data using a variety of algorithms
- Data analysis groups free to decide what analysis to perform and how to present the results
- Waveform repository only to be used for this project, unless separate agreements are made

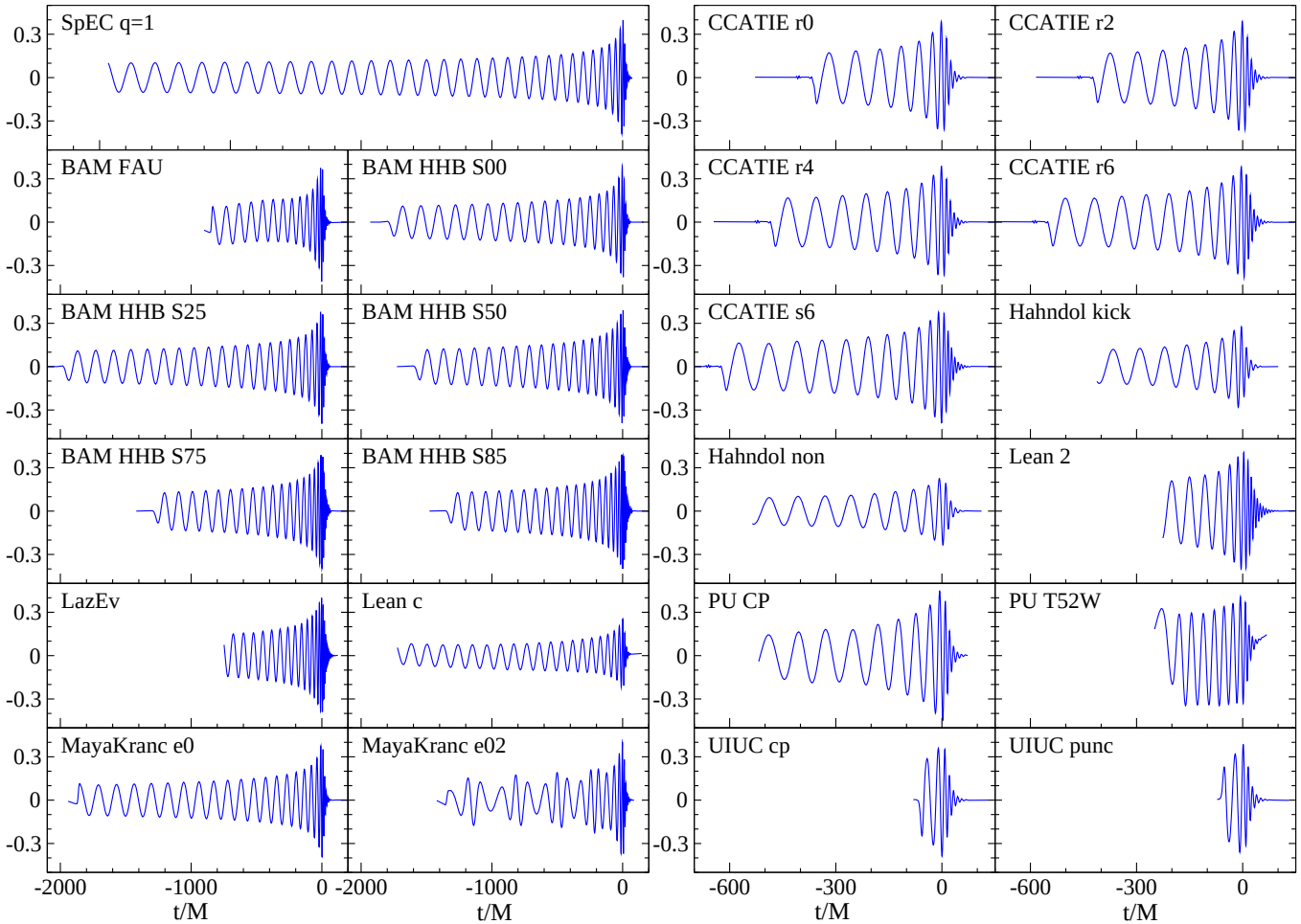
NINJA-1 Noise

The simulated noise included 3 LIGO and Virgo detectors



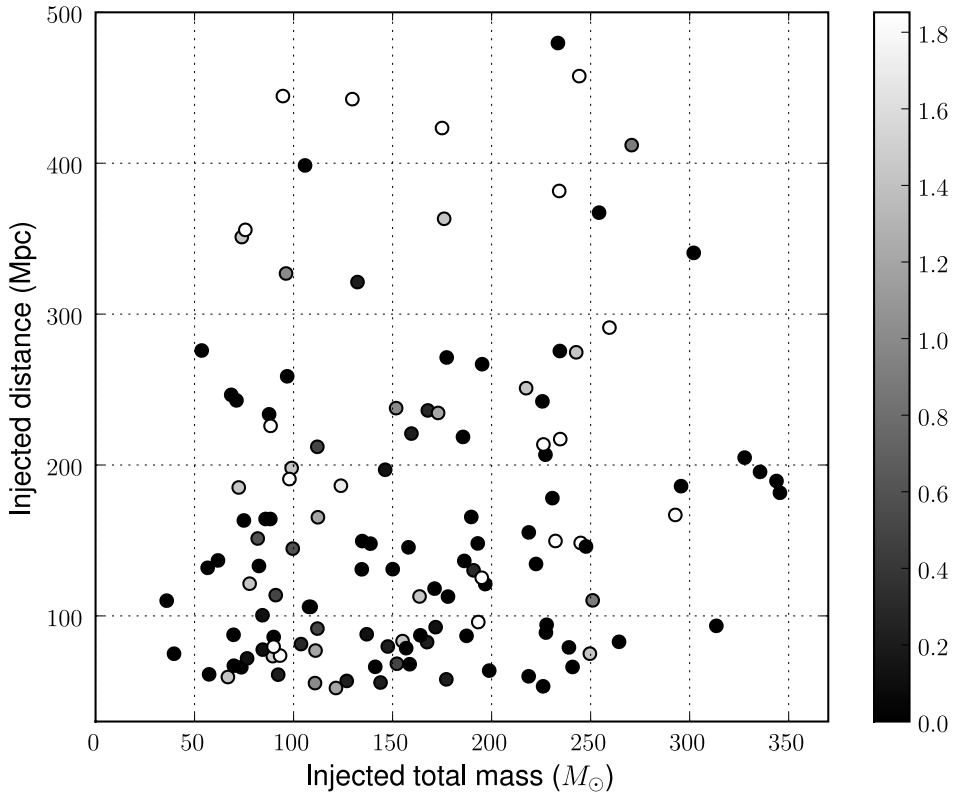
NINJA-1 Waveforms

- All NR groups with BBH waveforms participated
- Variety of mass-ratios, spin configurations, and also eccentricities



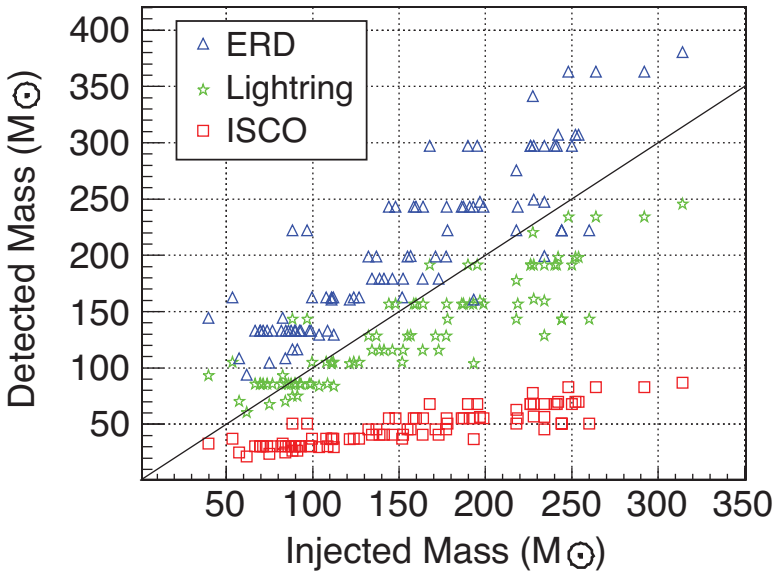
NINJA-1 Data

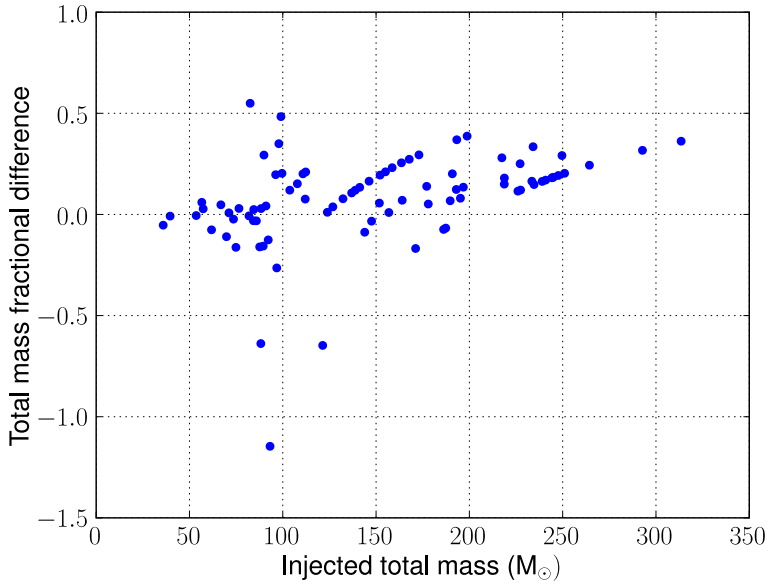
- 126 injections into 30 hours of data
- The starting frequency of the dominant (2,2) mode must be below 30 Hz to avoid abrupt turn-on of the signal in band
- The optimal matched filter SNR must be greater than 5 in at least one detector
- longer waveforms biased to low masses to cover mass range



Some NINJA-1 results

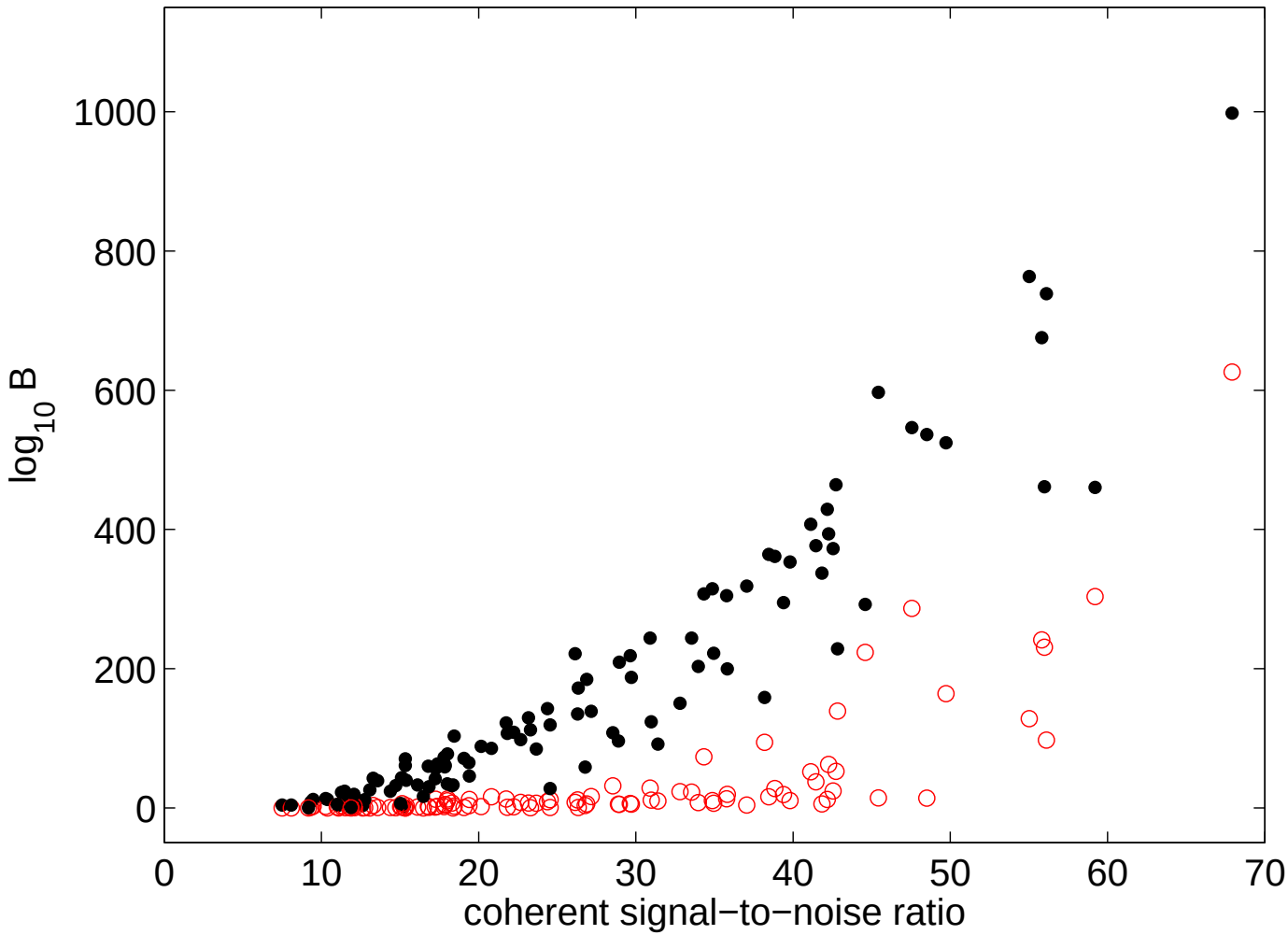
Mass Estimation for burst and EOB searches





Some NINJA-1 results

Bayesian evidence: Taylor F2 vs. Phenomenological templates



Some NINJA-1 results

Bottomline:

- All algorithms found the loud injections
- Parameter estimation is an open issue and all pipelines need to work on this

NINJA-1 Related Publications

Main NINJA papers:

- Status report: arXiv:0905.4227, CQG 26, 114008 (2009)
- The NINJA paper: arXiv:0901.4399, CQG 26, 165008 (2009)

Five papers detailing DA searches:

- Santamaria et. al., CQG 26, 114010 (2009) CBC search with phenomenological templates
- Farr et. al., CQG 26, 114009 (2009) CBC search with PN inspiral and EOBNR templates
- Aylott et. al., CQG 26, 114011 (2009) Bayesian nested-algorithm search
- Stroeer et. al., CQG 26, 114012 (2009) Burst search with HHT method
- Cadonati et. al., CQG 26, 204005 (2009) Burst search with Q-pipeline

Successes and limitations

NINJA-1 was a great success!

- Good contributions from everyone involved
- 10 NR groups (all groups with BBH waveforms) and 9 DA groups

Some factors which contributed

- Clearly defined and realistic goals
- Time scale was aggressive, but feasible
- Easy for people to get involved and no hierarchy

Some things that need to be improved

- Gaussian noise prevented realistic false alarm calculation
- No requirements on waveform accuracy
- Short waveforms for NINJA-1 only useful for very high mass
- Tighter coordination between search groups

NINJA-2 Goal

In a nutshell:

- Systematic tests and comparisons of current LIGO-Virgo (LVC) searches using non-precessing hybrid (NR+PN) waveforms injected in real LVC data

Real data is important:

- Everyone knows how to deal with Gaussian noise
- Most DA pipelines have ways to handle non-gaussianity, signal consistency tests, different detection statistics etc
- We cannot meaningfully compare these choices in simulated noise
- False alarm rates and thresholds can be very different in simulated and real data

The need for hybrid waveforms

We want to inject at low masses, so need hybrid NR waveforms stitched with PN

- NR waveforms must be sufficiently long and accurate to do this
- NR groups can choose their own reasonable matching procedures and comparisons between different groups are encouraged
- Details need to be firmed up in follow-up discussions – this will hopefully be one of the scientific results from NINJA-2

We propose to consider only systems with various mass ratios and only aligned (or anti-aligned) spins

- This keeps the scope of NINJA-2 reasonable and is feasible to complete in the desired timeframe

Science goals

The key questions:

- What are the relative detection efficiencies of the different searches over the mass space?
- How well do non-spinning templates work with non-precessing spinning waveforms?
- How do the searches perform in a LISA-style blind Mock Data Challenge?
- How well do parameter estimation techniques work with candidates from these searches

Data Analysis

- We propose to do a LISA-style blind mock-data challenge
- Additional training data sets will be provided as well (Gaussian noise and real data)
- The goal is understanding the efficiency of the detection pipelines and the accuracy of parameter estimation
- The blind challenge data sets can be used to test parameter estimation codes, seeded by information from the search pipelines
- Will strongly encourage close coordination and cross-checks between different analyses
- As a collaboration with the LSC and Virgo, NINJA-2 data analysis will be tightly coupled to the work of the LSC and Virgo search groups

Time scale

- NINJA-2 kickoff telecon was held on Oct 15, 2009
- Well attended and work is underway
- Will need agreement with LVC to be able to use real data
- Publication will thus have NINJA + full LVC author list
- Mike Boyle and Ajith Parameswaran elected as points of contact for LVC (will rotate every 6 months)
- Currently preparing science case and getting agreement within NINJA
- Hope to get started by spring 2010

Matter NINJA

Start dialog between DA & modelers:

- Education of modelers in DA problems & techniques.
- Education of DA in source/emission physics.
- Can we tell supernova mechanisms apart?
- How close does the supernova have to be for this to be possible?
- What other physics/parameters can be constrained (rotation/EOS)?
- Does it make sense to even try to produce systematic templates? How close does the template have to be to the real signal

Plan is to start NINJA-1 style analysis with simulated data

Conclusions

- We want to build on success of NINJA-1
- Benefits for both NR and DA communities
- Aim is to have closer interaction with LVC and to be ready for advanced detectors and GW detection
- Matter NINJA project at earlier stage of development, but expect them to get started soon as well
- See `https://www.ninja-project.org` for further information