Astrophysics with GW detections, 6-7 September 2019

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Book of Abstracts

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Detectability of continuous gravitational waves from isolated neutron stars in the Milky Way: the population synthesis approach

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We investigate the visibility of single Galactic pulsars in the gravitational waves. We integrate the signal for a period of one year, a comparable length to the current O3 LIGO/Virgo observing run, by computing the interferometr response and compering it to the design sensitives of LIGO and Virgo detectors. With an assumption of single radio pulsar population model, classical rotating quadrupole GW emission model (with parameterized and decaying ellipsoidity of the NS), and by defining a detection SNR equal to 8, we find observability of any single pulsar within our Galaxy unlikely.

2

Time-domain model for kiloHertz gravitational-waveforms from neutron star merger remnants

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The remnant star of a neutron star merger is an anticipated loud source of kiloHertz gravitational waves that conveys unique information on the equation of state of hot matter at extreme densities. Observations of such signals are hampered by the photon shot noise of ground-based interferometers and a challenge for gravitational-wave astronomy. We develop an analytical time-domain waveform model for postmerger signals informed by numerical-relativity simulations. The model completes effective-one-body waveforms for quasi-circular nonspinning binaries in the kiloHertz regime. We show that a template-based analysis can detect postmerger signals with signal-to-noise (SNR) ratios of 9. Thus, events like GW170817 will be targeted by third-generation interferometers. Using Bayesian model selection and the complete waveform model it is possible to infer whether the merger outcome is a prompt collapse or a remnant star. We further discuss how to investigate the equation of state's stiffness at extreme densities using postmerger observations.

3

The origin of low effective spins, high black hole masses, and O1/O2 rates in LIGO/Virgo binary black hole mergers

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All of the ten LIGO/Virgo BH-BH merger O1/O2 detections have near zero effective spins. One explanation makes BH spin magnitudes small.

We test this hypothesis with the classical isolated binary evolution scenario. We test three models of angular momentum transport in massive stars: mildly efficient transport by meridional currents (as employed in the Geneva code), efficient transport by Tayler-Spruit magnetic dynamo (as implemented in the MESA code), and very-efficient transport (as propsed by Fuller et al.) to calculate natal BH spins. We allow for binary evolution to increase the BH spins through accretion and account for the potential spin-up of stars through tidal
interactions. Additionally, we update calculations of stellar-origin BH masses,
include revisions to the history of star formation and chemical evolution across cosmic time.

We find that we can match simultaneously the observed BH-BH merger rate density, BH masses, and effective spins. Models with efficient angular momentum transport are favored. The updatd stellar-mass weighted gas-phase metallicity evoltuion now used in our models appears to be a key in better reproducing the LIGO/Virgo merger rate estimate. Mass losses during the pair-instabilty pulsation supernova phase are likely overestimated if the merger GW170729 hosts a BH more massive than 50 Msun.

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The host galaxies of merging compact objects

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In the new era of gravitational-wave astronomy, understanding the properties of the host galaxies of merging compact objects is crucial.
I will present a method to explore the galaxies where merging compact objects form and merge, by combining galaxy catalogs from cosmological simulations together with state of the art population synthesis models.
I will show that the merger rate per galaxy strongly correlates with the stellar mass of the host galaxy for merging double neutron stars (DNS), double black holes (DBH), and black hole neutron star binaries (BHNS). I will also discuss the merger rate per galaxy in terms of early and late-type galaxies. Our results show that most of DNSs, BHNSs, and DBHs merging in the local Universe are in early-type galaxies.
Finally, I will present how these results can assist the electromagnetic follow-up search of future gravitational wave detections.

5

Chemical evolution of the Universe and the properties of merging double compact objects

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Gravitational wave observations begin to probe the properties of the populations of merging double compact objects, providing constraints that can be confronted with theoretical models and help to validate the assumptions about the evolution of their progenitor systems.

The formation and characteristics of various transients of stellar origin, in particular double BH mergers, are highly sensitive to metallicity. Furthermore, compact binaries that merge within the local Universe originate from progenitor systems formed at different redshifts and in different environments (i.e. metallicities). Hence, to correctly compare the observations with theoretical results one needs to know the amount of star formation occurring at different metallicities and redshifts and understand the associated uncertainties.

Different approaches have been taken in the literature to learn about the distribution of the cosmic star formation rate over metallicities and redshifts (SFRD(Z,z)), leading to different results. We investigate the effect of the assumed distribution on the properties of merging double compact objects, in particular on their merger rate densities. We use the observational properties of star forming galaxies to find the observation-based SFRD(Z,z) and constrain its uncertainty due to currently unresolved questions in the determination of various characteristics of galaxies.

6

Synthetic catalog of black holes in the Milky Way

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We present a synthetic catalog of Galactic black holes (BHs) divided into disk, bulge and halo. To calculate evolution of single and binary stars we used updated population synthesis code StarTrack and new model of star formation history and chemical evolution of Galactic components. At the current moment Milky Way contains about 1.6×10^8 single BHs with average mass of about 13 M_sun and 9.3×10^6 BHs in binary systems with average mass of 19 M_sun.
We present properties of BH population such as distributions of masses, velocities or numbers of systems in different evolutionary configurations.
The most massive BH, 130 M_sun, originates from a star merger in a low metallicity stellar environment in halo. We constrain that only ~0.005 % of total halo mass (including dark matter) could be hidden in the form of stellar origin BHs which are not detectable by current observation surveys.
Galactic binary BHs are minority (~10% of all BHs) and most of them are in BH-BH systems. We calculated current Galactic double compact objects (DCOs) merger rates for two models, which are: 3-81 Myr^−1 (BH-BH), 1-9 Myr^−1 (BH-NS), 14-59 Myr^−1 (NS-NS). We show how DCOs merger rates evolved since Galaxy formation till current time.

7

The connection between ultra-luminous X-ray sources and double compact objects

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We explore the different formation channels of merging double compact objects (DCOs: BH-BH/BH-NS/NS-NS) that went through an ULX phase (X-ray sources with luminosity exceeding the Eddington luminosity of a 10 $M_\odot$ black hole). There are two major formation channels which can naturally explain the formation of DCO systems: isolated binary evolution and dynamical evolution inside dense clusters. It is not clear which channel is responsible for (majority/all) LIGO/Virgo sources. Finding connections between ULXs and DCOs can potentially point to the origin of merging DCOs as more and more ULX are being discovered.
We use the StarTrack population synthesis code to show how many of the observed ULXs may form merging DCOs in the framework of isolated binary evolution. We find that in the local universe as many as 50% of merging DCO progenitor binaries have evolved through an ULX phase. This shows that ULXs can be used to study the origin of LIGO/Virgo sources. We also find that $5\% - 40\%$ of the observed ULXs will form DCOs in the future.

8

Could gravitational lensing impact the observed BBH population?

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Just like visible light, gravitational waves can be lensed by heavy masses between source and observer. Hence, a fraction of the observed distant binary black hole mergers could be magnified by lensing, some sources may have produced multiple observable images, and individual waveforms may be affected by wave optics and microlensing effects.
The predicted rate of such lensing is small for the current detector generation, and the first dedicated studies on aLIGO O1+O2 data have not found any evidence for lensed events.
However, with increasing detection rates, we are now approaching a regime where it will be worthwhile to make the step from stand-alone lensing studies towards properly including lensing into hierarchical models of the observed vs intrinsic BBH populations. This could help explain outliers in the observed distribution and reduce potential biases in the mass distribution and redshift evolution. But to avoid under-/overfitting, it will require careful treatment of astrophysical priors and of degeneracies with other population parameters.

9

Chirp mass - distance distributions of the sources of the gravitational waves

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The detection of gravitational waves emitted by binary black holes raises a question of the binaries' origin. There are several models present in the literature involving binary evolution in both field

and clusters. Here I aim to compare predictions of these models with the observations.
Using the Bayesian inference I compare the models with the up-to-date detections using the distributions of the observed chirp mass and luminosity distance of the source.

I present the ranking of ability to explain all current gravitational waves detections by the models. It is shown that the best models correspond to the binary evolution with low metallicity and disfavours evolutions in globular clusters. I also calculate the number of observations required to distinguish each pair of models, the answer varies from 10 to several thousand for some pairs.

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The common envelope channel as test-bed for massive star evolution

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The evolution of massive stars remains highly uncertain due to a number of poorly constrained factors such as internal mixing, angular momentum transport, mass loss rates, or effects of binarity. Detections of gravitational waves from BH binary mergers offer a unique opportunity to probe the evolution of a particular subset of massive stars: those that have (most likely) initiated and survived a common envelope phase in a binary with a BH companion. I will demonstrate how this condition narrows down the evolutionary stage and position in the HR diagram of the donor star at the point when it initiates the common envelope. By comparison with modern evolutionary tracks at different metallicities, I will showcase how those constraints can be a valuable test-bed for the evolution of massive stars in general, probing the efficiency of internal mixing, wind mass loss from extended supergiants evolving near their Eddington limit, and location of core-helium burning in the HR diagram. I will also discuss an overlooked aspect of the evolution of low-metallicity massive stars that could significantly limit any tidal spin-up during BH-WR stage.

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Computing the spin tilt angles at formation from gravitational wave observations of binary black holes

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The angles between the spins of binary black holes and the binary's orbital angular momentum (often known as tilt angles) give important information about the evolution of the binary. For instance, for the isolated binary formation channel, the tilt angles when the binary is formed give information about supernova kicks. One can obtain the tilt angles at the binary's formation computationally efficiently using precession-averaged evolution to (mathematically idealized) infinite separation. However, precession-averaged evolution is not accurate when the binary is close to merger, which is where one measures the spin directions using gravitational wave observations with ground-based detectors. Thus, one first has to evolve the spins backwards in time using orbit-averaged evolution and switch over to precession-averaged evolution once it is sufficiently accurate. We investigate the maximum orbital speed at which one can switch from orbit-averaged to precession-averaged evolution to obtain a given accuracy in the tilts at infinity. We also discuss our formulation of the

precession-averaged equations that allows one to use them for mass ratios very close to unity, as one finds in some posterior samples for binary black hole events detected by LIGO and Virgo.

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Population of neutron stars and its observability in GW

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Dynamically driven mergers of black holes in dense stellar environments

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