COMPAS: A rapid binary population synthesis suite

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Most massive stars—those with initial masses greater than 8 $M_{\odot}$—are born with another massive star as a companion (Moe & Di Stefano, 2017; Sana et al., 2012). Massive binary stars are responsible for producing many exotic astrophysical phenomena, such as the observed diversity of supernovae, binary pulsars, X-ray binaries and merging compact objects. The latter are now regularly observed by the ground-based gravitational wave observatories Advanced LIGO and Virgo (B. P. Abbott et al., 2016; R. Abbott et al., 2021). Population models of massive binary evolution make it possible to interpret existing observations and to make predictions for future observing campaigns.

Statement of need

Binary population synthesis generates population models of isolated stellar binaries under a set of parametrized assumptions. These models permit comparisons against observational data sets, such as X-ray binaries of gravitational-wave mergers.

In particular, rapid binary population synthesis is needed in order to efficiently explore a broad parameter space of uncertain assumptions about the physics of stellar and binary evolution.
including supernova remnant masses and natal kicks, mass transfer efficiency and stability, and the outcome of common-envelope events.

A range of binary population synthesis codes have been developed over the last three decades. These include the Scenario Machine (Lipunov et al., 1996), IBIS (Tutukov & Yungelson, 1996), SeBa (Portegies Zwart & Verbunt, 1996), BSE (Hurley et al., 2002), StarTrack (Belczynski et al., 2008), binary_c (Izzard et al., 2004), MOBSE (Giacobbo et al., 2018) and COSMIC (Breivik et al., 2020). These codes range from private to semi-public to fully public, and differ in the range of available tools, computational complexity, and speed of execution.

COMPAS is a rapid binary population synthesis suite. It parametrizes complex astrophysical processes with prescriptions calibrated to detailed models. COMPAS is designed to allow for flexible modifications as evolutionary models improve. All code is fully public and, including pre-processing and post-processing tools. COMPAS is computationally efficient, with a focus on the statistical analysis of large populations, particularly but not exclusively in the context of gravitational-wave astronomy.

Details

The core engine of COMPAS—responsible for calculating the evolution of single (Hurley et al., 2000) and binary (Hurley et al., 2002) stars—is written in object oriented C++ for speed and flexibility. COMPAS is able to simulate the evolution of a typical binary over 10 Gyr in approximately 10 milliseconds.

A detailed description of the implementation of the COMPAS suite can be found in Team COMPAS: Riley et al. (2021).

In addition to the core stellar and binary evolution engine, we provide Python scripts for both pre- and post-processing COMPAS outputs. Post-processing can account for integrating populations formed throughout cosmic history (Neijssel et al., 2019) and methods to account for gravitational-wave selection effects (Barrett et al., 2018). A set of examples is also provided.

COMPAS is embarrassingly parallel and can be trivially run on high performance computers and distributed on cloud computing.

COMPAS was initially designed to focus on studies of merging binaries containing neutron stars and black holes that are being observed through gravitational waves (Stevenson et al., 2017; Vigna-Gómez et al., 2018). In recent years, the scope of systems investigated with COMPAS has expanded to incorporate, e.g., Be X-ray binaries (Vinciguerra et al., 2020) and luminous red novae (Howitt et al., 2020) (see Team COMPAS: Riley et al. (2021) or the COMPAS collaboration website for a summary of COMPAS publications to date.)

COMPAS development happens on Github. We maintain a Zenodo community where data from many publications using COMPAS is publicly available.

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