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Synthesis of compact binaries in the Cosmos

Guilherme Renato Cunha Sampaio

First Name:	Guilherme Renato
Last Name:	Cunha Sampaio
Institution/Affiliation:	IAG-USP
Country of Residence:	Brazil
Preferred type of presentation	Poster
Will you attend in person or online?	—
Email	guilhermerenato@usp.br

Abstract

Binary Population Synthesis (BPS) is fundamental for understanding the origin of compact object mergers detected through gravitational waves. Our study systematically evaluates how stochastic mass prescriptions and models that statistically map progenitor binary systems influence the formation of neutron stars (NSs) and black holes (BHs) in binary systems, using the BPS COMPAS code. Our approach analyzes initial-final masses relationships, typical binary evolution events such as mass transfer, supernova probability criteria based on pre-supernova core structure, and probabilistic models for remnant masses and natal kicks. Preliminary results reveal that the abrupt, step-like transitions between NS and BH populations, characteristic of deterministic prescriptions that assign a single remnant outcome for given progenitor properties, are substantially softened when stochastic approaches, which assign a probability distribution of remnant masses for a given progenitor, are applied. Rather than a sharp gap, this continuous stochastic transition fills in artificial gaps in the mass distribution, aligning with observational evidence for a coherent, overlapping mass spectrum in compact remnants. Furthermore, incorporating multiple physical channels—such as the magnitude and dispersion of natal kicks—proves critical for post-collapse orbital stability, affecting the preservation of the binary configuration. We conclude that adopting stochastic paradigms is indispensable for reconciling simulations with observational data, thereby refining predictions of merger rates and population properties of compact objects.