Contribution ID: **68** Type: **Contributed talk**

Young Star Clusters Dominate the Production of Detached Black Hole-Star Binaries

Tuesday, 5 September 2023 10:20 (15 minutes)

The recent discovery of two detached black hole-star (BH-star) binaries from Gaia's third data release has sparkled interest in understanding the formation mechanisms of these systems. We investigate the formation of these systems by dynamical processes in young open star clusters (SCs) and via isolated binary (IB) evolution, using a combination of direct N-body models and population synthesis simulations. By comparing dynamical and isolated systems created using the same model of binary stellar evolution, we find that dynamical formation in SCs is nearly 40 times as efficient, per unit of star formation at producing BH-star binaries as isolated binary evolution. We expand this analysis to the full MW using the star-formation history of a MW-mass hydrodynamical simulation (from the FIRE-2 suite of simulations) as a guide. Even assuming that only 10% of star formation produces SCs with masses $> 1000\ \mathrm{M}_\odot$, we find that the MW contains $\sim 2 \times 10^5$ black hole-star systems, with approximately 4 out of every 5 systems systems being formed dynamically. Many of these dynamically-formed systems have larger orbital periods, eccentricities, and black hole masses than their isolated counterparts, and we show that any system with $e > 0.5$ or $M_{\mathrm{BH}} > 10\,\mathrm{M}_\odot$ can only be formed through dynamical processes. Taking into account the detectability of systems in the current and future Gaia data releases, our MW model predicts between 61 and 210 detections from the complete DR4 Gaia catalog, with the majority of systems being dynamically formed in a massive and metal-rich SC. Finally, we compare our populations to the recently discovered Gaia BH1 and Gaia BH2, and we conclude that the dynamical scenario is the most favorable formation pathway for both of them, and especially for gaia BH2.

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Session Classification: Welcome and WG4: Gaia Fundamentals: Space and Time (I). Chair: Nick Walton