The Black Hole Explorer: Mission Overview and Instrument Cryocooling

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The Black Hole Explorer (BHEX) is a space Very Long Baseline Interferometry (VLBI) mission concept currently in formulation. The mission addresses fundamental black hole physics while aiming to detect and study the theoretically predicted 'photon ring' of light orbiting a black hole and produce the sharpest images from space in the history of astronomy. To achieve the required angular resolution, the BHEX instrument will extend the interferometer baseline beyond the diameter of the Earth, allowing for a hybrid VLBI observatory. The scientific objectives demand the ability to reach milliJansky sensitivity at frequencies sufficiently high to mitigate the effects of synchrotron self-absorption and strong interstellar scattering. This necessitates a sophisticated instrument comprising a 80-350GHz receiver system integrated with a spaceflight cryocooling unit, coupled to a large light-weight antenna, fast digital processing, high-stability frequency reference, and a ultra-high-speed laser downlink.

The BHEX receiver front-end will observe simultaneously in two bands. Firstly, a 90 GHz channel will employ cryogenic low noise amplifiers, enabling high-frequency observations, and will require an operating temperature of 20K. Secondly, channels at either 230 or 345GHz consisting of SIS receivers will offer quantum-limited sensitivity in order to succeed in imaging the black hole photon ring, and require an operating temperature of 4.5K. The estimated heat load is 200mW and 30mW at the 20K and 4.5K stages, respectively. Whilst previous larger space missions have utilised liquid helium for cooling to similarly low temperatures, this is infeasible for the 2-year BHEX mission with greater mass and cost constraints. Leveraging the cryogenic system produced by Sumitomo for the JAXA X-Ray Imaging and Spectroscopy Mission (XRISM), the BHEX cryocooling concept consists of a two-stage Stirling cryocooler system that provides both a 100K and a 20K cooling stage, with a Joule-Thomson cooler employed to reach 4.5K. The BHEX cryocooler design has challenges which are discussed.