Using Non-Gravitational Force Modeling to Estimate Masses of Cometary Nuclei

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Knowledge about the masses and bulk densities of cometary nuclei is cosmogonically important, since it places constraints on formation scenarios for planetesimals during the earliest stages of planetary formation. However, comet bulk densities are very difficult to measure, even during in situ observations - only one out of nine spacecraft missions to a comet has resulted in a reliable bulk density estimate. Several indirect methods for estimating bulk densities are also available, e.g., non-gravitational force modeling. Here, thermophysical models are used in order to calculate the thrust force acting on the nucleus due to outgassing, which yields predictions regarding orbital modifications caused by this "non-gravitational force". Matching calculated and observed orbital changes then makes it possible to estimate the mass of the comet, which translates into a bulk density if the nucleus volume is known or estimated. Here, the non-gravitational force analysis of the following comets is discussed: 19P/Borrelly, 67P/Churyumov-Gerasimenko, 81P/Wild 2, and 9P/Tempel 1. In all cases, the bulk density is found to be substantially lower than expected for solid material, implying a substantial nucleus porosity.