

Space Mission & Campaign Design

# Refining Asteroid Mass Uncertainty via Volume, Porosity, and Density Constraints for Optimal Flyby Mission Design

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The near-Earth object (NEO) discovery rate has increased in recent years, and the discovery rate is expected to further increase dramatically when new telescope systems such as LSST and NEO Surveyor come online during the next several years. Significant increases in NEO discovery rate makes it more and more likely that an asteroid on an Earth-impacting orbit will be discovered during the next decade. Accurately estimating the mass of Earth impacting asteroids is essential for predicting potential Earth impact effects and designing spacecraft missions to prevent Earth impacts. However, asteroid mass estimates are often clouded with significant uncertainties if the asteroid is only observed by ground-based telescopes. The quickest way to reduce these uncertainties is to send a fast flyby spacecraft mission to reconnoiter the asteroid. Directly measuring asteroid mass with a fast flyby mission is very difficult, but capturing camera images of the asteroid is relatively straightforward. Spacecraft camera images of the asteroid can be used to build a shape model of the asteroid using techniques such as stereophotoclinometry, and that shape model yields an estimate of the asteroid's volume and associated uncertainty. However, without additional measurements or a priori constraints, significant uncertainties remain in the asteroid's base material density and bulk porosity (or, taken together, bulk density).

Asteroid mass can be described as the product function ( $f$ ) of volume, base material density, and bulk porosity, and an expression can be derived relating percent uncertainty in  $f$  to the uncertainty in  $f$ 's dependent variables. Asteroid volume uncertainty can be significantly reduced by an appropriately designed flyby mission [1]. Table 1 lists previous missions where spacecraft flyby improved knowledge of the visited asteroids. This begs the question "Given a particular volume uncertainty from processing spacecraft camera images of an asteroid, what are the required a priori uncertainties in bulk porosity and base material density to keep the resulting mass uncertainty below a particular level?". In this study, we explore the interconnected nature of these uncertainties and estimate the lowest asteroid mass uncertainties achievable when only volume measurements are available, based on current abilities to constrain asteroid density and porosity. We also discuss how low the uncertainties on asteroid density and porosity would need to be in order to achieve given levels of asteroid mass uncertainty utilizing only camera imagery collected by fast flyby reconnaissance missions.

The equations and relationships that will be presented can be used to inform asteroid flyby reconnaissance mission design and instrument selection, as they give an indication of the instrument precision and resolution required to achieve a desired goal in asteroid mass uncertainty. Mission implications from a space-systems perspective are explored, helping to inform mission requirements and performance expectations for a given set of estimated asteroid parameters.

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**Table 1: Summary of asteroid and comet missions with estimated mass and volume from fly-by missions.**

<b>Mission</b>	<b>Body</b>	<b>Encounter</b>	<b><math>m</math> (kg)</b>	<b><math>V</math> (m<sup>3</sup>)</b>
NEAR [2]	253 Mathilde	1997	$1.033 \pm 0.044 \times 10^{17}$	$78_{+12}^{-11} \times 10^{12}$
NEAR [3, 4]	433 Eros	1999	$6.687 \pm 0.003 \times 10^{15}$	$2900 \pm 600 \times 10^9$
Rosetta [5]	2867 Steins *	2008	$1.368 \times 10^{14} \pm 1.98 \times 10^{13}$	$76 \times 10^9 \pm 11 \times 10^9$
EPOXI [6, 7]	103P/Hartley 2	2010	$242.7 \times 10^9 \pm 163.5 \times 10^9$	$8.2 \times 10^8 \pm 8 \times 10^7$
New Horizons [8]	486958 Arrokoth	2019	$7.485 \times 10^{14}$	$3.185 \times 10^{12}$

\* These values were obtained used a bulk density assumption of  $1800 \text{ kg/m}^3$

**Comments:** *Oral presentation preferred. NEO Characterization is a possible alternate session.*

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