# An astrometric mass estimate for asteroid (223) Rosa

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## Abstract

Outer main belt asteroid (223) Rosa is a possible flyby target of opportunity for ESA's JUpiter ICy moons Explorer (JUICE) mission when passing the asteroid belt on the way to Jupiter. The very low albedo and the featureless red spectra indicate a P-type asteroid in the Tholen taxonomy, though the yet known bulk density did not match very well this classification. Aim of this work was to derive a new estimate for the mass and for the bulk density for (223) Rosa. The mass of Rosa was derived by analyzing the gravitational deflection of small 'test' asteroids which had a close encounter with Rosa in the past. Two independent mass estimates for Rosa were derived from such mutual encounters: $M = (5.32 \pm 2.17) \times 10^{17}$ kg and $M = (3.15 \pm 1.14) \times 10^{17}$ kg, respectively. The weighted mean is $M = (3.62 \pm 1.25) \times 10^{17}$ kg. This yields to a bulk density of $\rho = 1.2 \pm 0.5\,\mathrm{g\,cm^{-3}}$, when adopting an effective diameter of $D = 83 \pm 8$ km. This bulk density is consistent with typical densities for Tholen taxonomy P-type asteroids.

## Introduction

Asteroid (223) Rosa has been recently proposed as potential ESA JUICE mission flyby target of opportunity on its way to Jupiter (Avdellidou et al. 2021; Agostini et al. 2022). Rosa is a very dark ($p_V < 0.05$) outer main belt asteroid (proper semi-major axis $a_p = 3.09011$ au), with an effective diameter $D$ of about 83 km (see box about diameter estimates), and a yet not fully understood composition (e.g. the taxonomic class) and evolution (e.g. the dynamical and collisional history). Important physical parameters characterizing an asteroid are the size, the mass, and therefore the bulk density. While diameter estimates do usually exist for an asteroid provided by at least one of various well known methods like radiometry, stellar occultations and scaled light curve inversion, mass estimates are much harder to derive and are available just for a small number (some $10^2$) of the known asteroids. Gaia DR3 will have an impact on the number of mass estimates, on their accuracy and on the derived bulk densities. However, the accuracy of volume estimates will play a limiting factor for the accuracy of the derived bulk denities.

## Method

The mass of Rosa was derived by analyzing the gravitational deflection of small test asteroids which had a close encounter with Rosa in the past. To find such events suitable for the mass determination, an encounter search with about 900,000 asteroids was performed by integrating them one by one together with Rosa over the time span 1980 – 2030. Those encounters matching defined conditions were finally chosen for the mass determination. The mass M of Rosa is derived by a differential orbit correction of the test asteroid while taking into account the perturbations by Rosa in the gravitational model (i.e. planets, major asteroids and Rosa) and M as an additional solve-for parameter of the orbit fit.

## Results and Discussion

From two individual close encounters with small asteroids, the mass of Rosa was estimated to $M = (5.32 \pm 2.17) \times 10^{17}$ kg and $M = (3.15 \pm 1.14) \times 10^{17}$ kg, respectively. The weighted mean value is $M = (3.62 \pm 1.25) \times 10^{17}$ kg. By adopting $D = 83.3 \pm 8.1$ km as (currently) best value for the diameter, the corresponding bulk densities are $\rho = 1.8 \pm 0.9\,\mathrm{g\,cm^{-3}}$ and $\rho = 1.0 \pm 0.5\,\mathrm{g\,cm^{-3}}$. The weighted mean is $\rho = 1.2 \pm 0.5\,\mathrm{g\,cm^{-3}}$. The EVM mean of the visual albedo is $p_V = 0.033 \pm 0.006$. The mass values derived in this work are smaller than the values $M = (5.979 \pm 2.971) \times 10^{17}$ kg and $M = 9.350 \times 10^{17}$ kg (Fienga et al. 2019; Park et al. 2021), which yield to bulk densities of $\rho = 2.0 \pm 1.1\,\mathrm{g\,cm^{-3}}$ and $\rho = 3.1\,\mathrm{g\,cm^{-3}}$, respectively. Rosa's bulk density obtained in this work agrees well with typical densities of P-type asteroids.

## Test asteroids

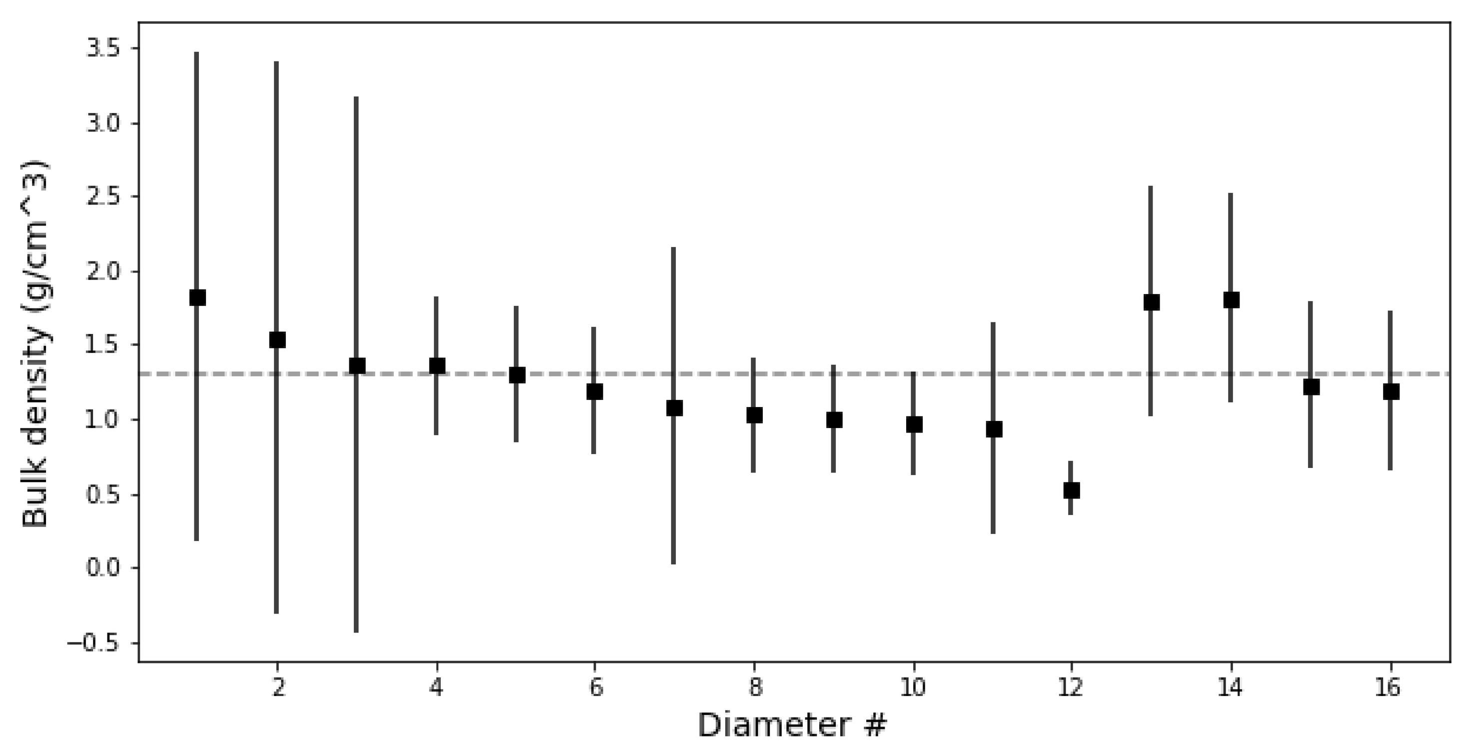
Out of three different close encounters with three different test asteroids, finally two events were used for the mass determination of Rosa: (35525) 1998 FV64 (encounter: 2010-12-31.87, $d = 0.0004$ au, $v = 2.043$ km/sec) and (315162) 2007 FL24 (encounter: 2016-07-04.05, $d = 0.0027$ au, $v = 0.131$ km/sec). $d$ is the euclidian distance and $v$ the relative velocity between the two asteroids during the closest approch.

## Diameter estimates

| # | Diameter $D$ (km) | Albedo $p_V$ | Method | Ref. |
|---|---|---|---|---|
| 1 | 72.33 ± 20.18 | 0.040 ± 0.050 | NEATM | a |
| 2 | 76.46 ± 29.36 | 0.035 ± 0.023 | NEATM | b |
| 3 | 79.68 ± 33.85 | 0.036 ± 0.037 | NEATM | c |
| 4 | 79.81 ± 0.31 | 0.040 ± 0.010 | NEATM | d |
| 5 | 80.93 ± 1.46 | 0.037 ± 0.002 | NEATM | e |
| 6 | 83.39 ± 2.97 | 0.034 ± 0.005 | NEATM | f |
| 7 | 86.05 ± 26.43 | 0.033 ± 0.046 | NEATM | c |
| 8 | 87.61 ± 4.40 | 0.031 ± 0.003 | STM | g |
| 9 | 88.50 ± 3.79 | 0.031 ± 0.003 | NEATM | h |
| 10 | 89.37 ± 3.53 | 0.030 ± 0.002 | STM | h |
| 11 | 90.43 ± 20.33 | 0.030 ± 0.020 | NEATM | a |
| 12 | 109.16 ± 0.95 | 0.020 ± 0.003 | NEATM | i |
| 13 | 72.8 ± 6.3 | 0.034 ± 0.005 | LCI + TPM | j |
| 14 | 72.5 ± 4.2 | 0.035 ± 0.005 | LCI + TPM | j |
| 15 | 82.6 ± 8.2 | 0.032 ± 0.002 | c.w. mean | - |
| 16 | 83.3 ± 8.1 | 0.033 ± 0.006 | evm mean | - |

Compilation of literature values for the effective diameter, reproduced from Avdellidou et al. (2021) and completed with recent publications. Two different averages are also provided, the classical weighted (c.w.) mean and the EVM (Expected Value Method, Birch & Singh (2014)) value. Entries with asymmetric uncertainties (entries #13 and #14, reference (j)) are therefore symmetrized (Audi et al. 2017, Appendix A, method 2). References: (a) Nugent et al. (2016), (b) Masiero et al. (2017), (c) Masiero et al. (2020), (d) Masiero et al. (2014), (e) Usui et al. (2011), (f) Masiero et al. (2011), (g) Tedesco et al. (2002), (h) Ryan & Woodward (2010), (i) Masiero et al. (2012), (j) Marciniak et al. (2021).

## Density estimates




Bulk density as function of the diameters given in table above for the final mass estimate $M = (3.62 \pm 1.25) \times 10^{17}$ kg. The horizontal dashed line marks the typical density $\rho \approx 1.3\,\mathrm{g\,cm^{-3}}$ for Tholen taxanomy P-type asteroids.

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