Photometric Data Analysis of Asteroid (2572) Annschnell: Determination of Contact Binary Asteroid Model Parameters (Postprint)

Authors: Huang Jing, Wang Xiaobin, Dou Jiangpei

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Abstract

The density/mass of solar system asteroids is an important parameter for understanding their origin and evolutionary history. The measurement of asteroid density has always been a challenging endeavor; binary asteroid systems, however, provide an opportunity to determine the density of small celestial bodies. Contact binary asteroids are a type of synchronous binary system in which the orbital semi-major axis equals the sum of the maximum semi-major axes of the two asteroids (assumed to be ellipsoidal). In data from the Yunnan-Hong Kong wide-field survey, the light curve of asteroid (2572) Annschnell exhibits typical photometric characteristics of a contact binary. To this end, we have developed a light curve inversion program for contact binary asteroids; through calculations, we obtained a density for the two components of (2572) Annschnell of approximately 3.15 g/cm^3, a result that is close to the density of CV or CK meteorites and confirms that this asteroid system is likely a member of the C-complex. From the normalized rotational angular velocity ($\Omega = 0.34$) and dimensionless system angular momentum ($H = 0.48$), we infer that this contact binary may have formed via rotational fission of a single asteroid.

Full Text

Photometry Analysis of Asteroid (2572) Annschnell: Parameter Determination for a Contact Binary Asteroid Model

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HUANG Jing[12], **WANG Xiaobin**[123], **DOU Jiangpei**[45]
[1] Yunnan Observatories, Chinese Academy of Sciences, Kunming 650216, China
[2] University of Chinese Academy of Sciences, Beijing 100049, China
[3] Key Laboratory for the Structure and Evolution of Celestial Objects, Chinese Academy of Sciences, Kunming 650216, China
[4] Nanjing Institute of Astronomical Optics & Technology, Chinese Academy of Sciences, Nanjing 210042, China
[5] Key Laboratory of Astronomical Optics & Technology, Chinese Academy of Sciences, Nanjing 210042, China

Abstract

The density and mass of asteroids are crucial parameters for understanding their origin and evolutionary history. Measuring asteroid density has always been challenging, but binary asteroid systems provide unique opportunities to determine the densities of small bodies. Contact binary asteroids represent a special class of synchronous binary systems where the orbital semi-major axis equals the sum of the maximum semi-major axes of the two components (assumed to be ellipsoidal). Analysis of photometric data from the Yunnan-Hong Kong Wide Field Survey reveals that the lightcurve of asteroid (2572) Annschnell exhibits characteristic features of a contact binary system. We have developed a comprehensive lightcurve inversion program for contact binary asteroids, which yields a density of approximately 3.15 g/cm^3 for the two components of (2572) Annschnell. This value is consistent with the densities of CV or CK meteorites, confirming that this asteroid system belongs to the C-complex. Based on the normalized rotation rate ($\Omega = 0.34$) and dimensionless system angular momentum ($H = 0.48$), we infer that this contact binary likely formed through rotational fission of a single parent body.

Keywords: asteroids; Roche binary asteroid; contact binary asteroids; brightness model

1. Introduction

Asteroids are remnants of planetesimals from the early solar system, preserving information about the epoch of planet formation. The current physical properties of asteroids—including size, shape, rotation, surface scattering characteristics, composition, and mass—and their distributions reflect the collisional and dynamical evolution these bodies have experienced since their formation. Therefore, determining the fundamental physical parameters of asteroids not only aids in understanding their origins and various evolutionary processes but also provides constraints for theoretical studies of solar system planet formation [**?**].

Since the 1980s, observational studies of asteroid physical properties have advanced rapidly. Multiple observational techniques—including photometry, polarimetry, spectroscopy, radar observations, direct imaging, and stellar occultations—have been employed to determine asteroid physical properties [?, ?, ?, ?, ?]. Currently, photometric and near-infrared datasets constitute the largest samples: NEOWISE near-infrared survey observations have obtained albedos and diameters for over 43,000 asteroids [?], while photometric data have enabled determination of rotation periods for approximately 10,000 asteroids and shape, rotation, and surface scattering parameters for about 3,000 asteroids. However, measuring asteroid density remains extremely difficult. Binary asteroid systems provide opportunities to determine system densities. Based on data from double impact craters on terrestrial planets and the Moon, the estimated fraction of binary asteroid systems is approximately 15% [?, ?]. In reality, only 94 binary systems have been discovered among near-Earth asteroids, representing just 0.3% of the 34,712 known NEAs. Similarly, only 245 binary systems have been found among the approximately 1,350,000 main-belt asteroids, a mere 0.02% [?]. This suggests that a substantial number of binary asteroid systems remain undiscovered.

The primary methods for detecting binary asteroids include direct imaging, photometry, radar, stellar occultation, and spacecraft observations. Ground-based direct imaging requires large-aperture telescopes with adaptive optics (AO) and is limited to relatively large asteroids, such as main-belt asteroid (45) Eugenia [?]. Radar observations resolve binary asteroids through delay-Doppler measurements but are restricted to near-Earth asteroids [?, ?]. Stellar occultation events are rare and non-repeatable. Photometry is applicable to all small bodies and identifies binary systems through distinctive lightcurve shapes. To date, 502 binary asteroid systems have been detected: 44 through ground-based imaging, 100 through space-based imaging, 51 through radar, 6 through occultations, and 301 through photometry. Clearly, photometric observations have yielded the largest sample of binary asteroids. While space-based imaging can discover binary systems, limited observing time restricts its use primarily to confirmation of known binaries. Dedicated spacecraft missions to study asteroids are relatively few. The Galileo spacecraft discovered the first binary asteroid system when it flew by (243) Ida en route to Jupiter [?]. China’ s Chang’ e-2 spacecraft successfully observed near-Earth asteroid (4179) Toutatis, obtaining high-resolution images that revealed its contact binary structure [?]. NASA’ s DART mission targeted near-Earth binary asteroid (65803) Didymos, impacting its secondary component Dimorphos and observing orbital changes that demonstrated kinetic impact as an effective planetary defense technique [?].

In recent years, numerous photometric survey projects with different scientific objectives have been conducted, including the Pan-STARRS survey in Hawaii, the Gaia space telescope survey, and the NEOWISE survey for near-Earth asteroids. These survey fields contain numerous solar system asteroids whose data can be used for orbital and physical property studies. Time-series photometric surveys are particularly valuable, providing lightcurves with full-night or longer temporal coverage for asteroids within the field of view. Various mature Python tools facilitate key steps in astronomical data processing and lightcurve extraction, such as astrometric position handling and time format conversion [?]. The shape of an asteroid' s lightcurve can reveal whether it is a binary system. The photometric data in this study originate from the Yunnan-Hong Kong Wide Field Survey (YNHK Survey). The primary scientific goal of the YNHK Survey is to search for new transiting exoplanet systems. Initiated in 2006, the survey has discovered nearly a hundred exoplanet candidates and various types of variable stars [?]. Using our independently developed method for identifying moving objects in survey fields, we have extracted approximately 500 asteroid lightcurves from partial fields [?]. Analysis of YNHK Survey photometric data for main-belt asteroid (2572) Annschnell reveals an exceptionally large photometric amplitude (approximately 0.83 mag) with characteristic "U-shaped" maxima and "V-shaped" minima, suggesting this target may be a contact binary system. Indeed, numerous such binary asteroid samples have been discovered among near-Earth asteroids, Trojan asteroids, Kuiper Belt objects, and plutinos [?, ?, ?].

Binary asteroids are classified as synchronous or asynchronous based on their orbital periods. Synchronous binary asteroids have equal mutual orbital and rotational periods, while asynchronous systems have unequal periods. Approximately, asteroids with "rubble-pile" structures (gravity-bound aggregates with negligible internal tensile strength and moderate porosity) can be treated as fluids, with shapes governed by hydrostatic rotational equilibrium [?], also known as Roche ellipsoids. Extending Chandrasekhar' s Roche binary theory [?], researchers have developed Roche binary asteroid theory [?, ?] to describe the rotational equilibrium of two bodies in synchronous binary systems under their mutual gravitational influence. Synchronous binaries include not only separated systems but also the special case of contact binaries, where the two components touch each other. In contact binaries, the orbital semi-major axis equals the sum of the maximum semi-major axes of the two bodies. Mutual eclipses between the components produce the characteristic "U-shaped" maxima and "V-shaped" minima in the lightcurve. Roche binary asteroid theory has been successfully applied to analyze photometric data of various contact binary systems in the solar system [?, ?, ?, ?, ?, ?].

Trojan asteroid (624) Hektor is a confirmed contact binary system. In addition to its large photometric amplitude, portions of its lightcurve shown in Figure 1 [Figure 1: see original paper] display the characteristic "U-shaped" maxima and "V-shaped" minima. Early work by Dunlap and Gehrels [?] analyzed (624) Hektor' s lightcurve using a single elongated ellipsoid model. Later studies applied Roche binary asteroid theory to analyze its lightcurve [?, ?, ?, ?], estimating a density of approximately 2.48 g/cm^3. In 2006, Marchis et al. [?] used the Keck telescope with adaptive optics to directly image (624) Hektor, confirming it as a contact binary with a small satellite. The lightcurve shape of asteroid (2572) Annschnell is very similar to that of (624) Hektor.

Note: JD denotes Julian Date of observation; denotes the aspect angle (angle between line of sight and rotation pole).

Figure 1 Photometric observations of asteroid (624) Hektor (hollow points) and simulated binary asteroid lightcurve (dashed line).

Asteroid (2572) Annschnell was discovered by German astronomer Reinmuth on February 17, 1950, with an estimated absolute magnitude of 13.4 mag. Behrend' s website lists a rotation period of 6.3 h [?]. NEOWISE determined an albedo of 0.658 and estimated diameter of 3.42 km [?]. Based on SDSS and Pan-STARRS multi-color photometry, (2572) Annschnell is classified as CX type (intermediate between C and X types) [?, ?, ?]. Clearly, the high albedo measured by NEOWISE contradicts this classification. Currently, no information exists on the shape, rotation, or surface scattering properties of (2572) Annschnell.

The objective of this study is to analyze the Roche binary asteroid model for (2572) Annschnell using new observational data combined with photometric data downloaded from the Minor Planet Center, in preparation for future confirmation observations with the Chinese Space Station Telescope' s (CSST) Coronagraphic Imager (CPI-C). Section 2 describes the photometric observations and data processing for (2572) Annschnell. Section 3 presents the binary asteroid photometric model. Section 4 analyzes the target' s lightcurve. The final section summarizes our conclusions.

2. Observations and Data Processing

We analyzed 12 lightcurves of asteroid (2572) Annschnell, seven from YNHK Survey observations and five from the International Minor Planet Center.

YNHK Survey observations utilized the 45 cm wide-field telescope at the Gaomeigu Observatory in Lijiang (observatory code O45). The primary scientific goal of the survey is to search for transiting exoplanets and asteroids. The telescope is equipped with a 4000$×4000*CCDcameraandafilterwheelcontainingClearandRfilters*; *surveyobs* corresponding to a spatial resolution of 1.47 per pixel [?].

YNHK Survey observations operate in unattended mode. Remote control of preprogrammed observation scripts enables fully automated execution throughout the night, including bias, dark, and flat-field calibration observations as well as target observations, as detailed in reference [?].

The YNHK Survey selected six observational regions for year-round coverage, each comprising at least four fields observed in a cyclical pattern. The exposure time for a single pointing is 8 s, with each cycle lasting approximately 5 minutes, yielding a temporal resolution of 5 minutes for the survey data. The project has operated continuously for 7 years, accumulating extensive long-term photometric data for numerous celestial objects, including asteroids. Photometric data for asteroid (2572) Annschnell were obtained from survey observations between February 26 and April 8, 2017, with detailed observational information listed in Table 1 . Columns 1-7 provide the observation date, asteroid' s geocentric equatorial coordinates, geocentric distance, heliocentric distance, solar phase angle, apparent magnitude, and observing telescope, respectively.

With an 8 s exposure time, YNHK Survey images can detect 10,000–30,000 objects per field. To efficiently process the obtained images and detect various astronomical events and asteroids, we developed an automated pipeline integrating data processing, transit signal detection, and moving object identification in survey fields, based on the IRAF software package and Python tools. The pipeline’ s capabilities include systematic error correction of images (image inspection, bias subtraction, dark current and flat-field correction, cosmic ray identification and removal), astrometric calibration, cross-matching with other catalogs, and photometric and astrometric measurements. The data processing workflow is illustrated in Figure 2 [Figure 2: see original paper].

For the YNHK telescope and CCD camera, we selected a 14-parameter function to describe the transformation between object pixel positions in CCD images and positions in the Gaia DR3 catalog (astrometric calibration). The root-mean-square (O–C) of transformed positions relative to catalog positions is within 0.16 (see reference [**?**] for details). Using the astrometric solution, we can cross-match with other catalogs to obtain physical information for each object in the field. More importantly, we can prepare input catalogs for each field to enable automatic photometry and data extraction. For solar system asteroids in the field, we use our independently developed method for identifying moving objects in time-domain surveys [**?**] to obtain initial positions and proper motions. Based on this information, we add asteroid apparent positions to the input catalog, enabling automatic photometry and data extraction for solar system small bodies.

Aperture photometry using IRAF measures the brightness of objects in the images, requiring optimal aperture selection to ensure the best photometric precision. To detect faint transit signals (depths typically 0.01–0.02 mag) in lightcurves, we also apply systematic noise correction (red noise correction) [**?**, **?**], which improves the signal-to-noise ratio of the lightcurves. Roughly speaking, after systematic error correction, the photometric precision for stars brighter than 13.8 mag in the V band is better than 0.01 mag. The processed 7-night photometric data for (2572) Annschnell are plotted as points in Figure 3 [Figure 3: see original paper].

For consistency, we converted the observation times for asteroids in the YNHK Survey to Heliocentric Julian Date (HJD). Light travel time corrections were applied to asteroid observation epochs based on geocentric distance. Similar corrections were applied to photometric data downloaded from the Minor Planet Center. Due to significant discrepancies between the measured albedo and classification results, the size measurements for this asteroid have considerable uncertainty. Therefore, our analysis uses only relative photometric variations (with the mean of each lightcurve subtracted) to determine the system’ s physical parameters.

The photometric data analysis for (2572) Annschnell utilized 12 lightcurves from 2017 and 2018. Over short observational timescales (e.g., several days), lightcurve shape variations are minimal. However, when observations are separated by longer intervals, changing viewing geometry (aspect angle and solar phase angle) produces significant lightcurve shape variations. By using different lightcurves obtained at various epochs, we can determine physical parameters such as asteroid shape, rotation parameters, and binary orbital parameters. To obtain more complete rotational phase coverage, we divided the 12 lightcurves into four time segments for fitting, as shown in Figure 3. Based on Roche binary asteroid theory, we constructed a simple contact binary photometric model and performed inversion analysis of (2572) Annschnell’ s lightcurves.

3.1 Roche Binary Asteroid Theory

In recent years, interest in synchronous binary asteroids has grown with the increasing number of observed samples [?, ?, ?, ?, ?, ?, ?]. In synchronous binary systems, the mutual orbital period equals the rotational period of the components, resulting in single-period photometric variations. Most asteroids are thought to have low-density “rubble-pile” structures (gravity-bound aggregates with negligible internal tensile strength and moderate porosity). Such rubble-pile asteroids can be approximated as incompressible fluids, allowing application of hydrostatic rotational equilibrium theory to study their shapes. Applying Chandrasekhar’ s Roche theory [?], Lacerda and Jewitt established a Roche model for binary asteroids [?], providing constraints between the mutual orbital angular velocity ω, mass ratio q, density , and Roche ellipsoid shapes of the components (the equilibrium shape of one component under its own gravity and the tidal gravity of its companion), as expressed in equations (1) and (2):

$$p + c^2(3+q)a^{2p} + c^2 - A_{3c}^2 - A_{3c}^2 = 2(a_{pb_{pc}}p)(3+q)a^2 - A_{3c}^{2p} + c^2(1+q)$$

In these equations, q = M_p/M_s represents the mass ratio of the primary to secondary component. Equation (1) calculates the Roche shape of the primary (a_p, b_p, c_p) under the secondary’ s tidal influence, while equation (2) provides constraints between the primary’ s Roche shape, orbital angular velocity ω, and density . The auxiliary quantities A_1, A_2, and A_3 are functions of the asteroid’ s Roche shape parameters, with detailed analytical expressions given in equations (12)-(17) of reference [?].

Substituting 1/q for q in the above equations yields the Roche shape (a_s, b_s, c_s) of the secondary component M_s. In Roche binary asteroid theory, the left side of equation (2) is termed the normalized rotation angular velocity, Ω = √(G). Valid Roche binary solutions require equal normalized rotation angular velocities calculated for both components [?].

3.2 Contact Binary Photometric Model

Contact binary asteroids are a type of synchronous binary system where the mutual orbital semi-major axis equals the sum of the maximum semi-major axes of the two bodies (D = a_p + a_s), and the rotational angular velocities of both components equal their mutual orbital angular velocity. The observed lightcurve displays single-period variation. Simply put, the integrated brightness of a binary system at any given time is the sum of sunlight reflected from the illuminated, visible surfaces of both components. Theoretically, given an asteroid’ s shape, rotation parameters (pole orientation and rotation rate), and the directions of illumination and observation, one can calculate the integrated brightness of a single asteroid using an appropriate scattering law (e.g., Lommel-Seeliger law). For binary asteroids, if the mutual orbital parameters are known, the relative positions of the components can be calculated to determine whether mutual occultation or eclipse events occur. The brightness reduction due to mutual occultation is subtracted from the total brightness of both components to obtain the integrated binary brightness. The inverse problem involves determining the parameters of the photometric model from observed binary lightcurves.

Binary asteroid photometric models contain more parameters than single-body models. Assuming the system components are in Roche equilibrium and using Roche binary equations to constrain their ellipsoidal shapes significantly reduces the number of shape parameters. Even with these assumptions, solving for Roche binary parameters requires lightcurves covering a wide range of viewing geometries.

Our target, asteroid (2572) Annschnell, was observed during four periods in 2017 and 2018, but the viewing geometry variations were modest, making parameter determination challenging. We therefore made several simplifications: we neglected scattering laws and approximated asteroid brightness using only the apparent cross-sectional area illuminated by the Sun. As expressed in equation (3), the integrated binary brightness F(t) consists of three components: the primary’ s brightness F_1(t), the secondary’ s brightness F_2(t), and the brightness obscured by mutual occultation F_m(t):

$$F(t) = F_1(t) + F_2(t) - F_m(t)$$

In equation (3), calculating F_1(t) and F_2(t) requires the asteroids’ shapes, rotation pole orientations, and viewing geometry at each epoch. The binary orbital parameters include: semi-major axis D, eccentricity e, orbital pole orientation (λ{*orb*}, β{orb}), orbital angular velocity ω, and initial orbital phase angle ϕ_{m0} at epoch t0. These parameters enable calculation of the components’ relative positions at any time. When the projected separation between component centers on the sky is less than the sum of their maximum semi-major axes, occultation occurs, allowing calculation of the obscured brightness F_m(t).

In our inversion calculations, we assumed a circular orbit (e = 0). The epoch t0 is typically set to a time of minimum brightness when the longest axes of the components align with the line of sight. The contact binary model defines both components’ rotation poles as coincident with the orbital pole, so their rotation parameters are (λ{*orb*}, β{orb}) and ω. We also define the initial rotation phases at t0 to equal the initial orbital phase (ϕ{*p0*} = ϕ{s0} = ϕ_{m0}).

Considering Roche binary theory, the photometric model parameters P for contact binaries include the primary shape (a__p, b__p, c__p), secondary shape (a__s, b__s, c__s), orbital parameters (D, λ{*orb*}, β{orb}, ω, ϕ__{m0}), and Roche parameters q and . Based on these parameters and Roche theory, we constructed a simplified contact binary photometric model. The integrated binary magnitude is expressed as:

$$M_{binary}(t, P) = -2.5 \log(S_{binary})$$

$$S_{binary}(t, P) = S_1 + S_2 - S_{occ}$$

where t is the observation epoch, P represents the model parameters, and S_1 and S_2 are the apparent cross-sectional areas of the primary and secondary at time t. Solar phase angle effects are neglected ($\alpha = 0°$) because main-belt asteroids have small phase angles. S__{occ} considers only the apparent cross-section obscured by mutual occultation. Future work will develop binary photometric models incorporating scattering laws and irregular shapes for more extensive inversion studies.

3.3 Testing the Contact Binary Photometric Model

To validate our contact binary photometric model, we simulated four apparition lightcurves of Trojan contact binary asteroid (624) Hektor from 1957-1968. As shown in Figure 1, the dashed lines represent theoretical values calculated using our simplified contact binary model. The Roche binary parameters for (624) Hektor listed in Figure 1b are taken from references [**?**, **?**]. The observation dates (JD) and aspect angles ( ) for different periods are indicated in the figure. The excellent agreement between simulated values (dashed lines) and observed lightcurves (hollow points) demonstrates that our simplified model adequately describes the observations. Notably, lightcurves in Figures 1a and 1d show larger amplitudes due to greater aspect angles where the line of sight approaches the equatorial plane, producing more pronounced mutual occultations and characteristic "U-shaped" maxima and "V-shaped" minima. When the aspect angle is small (Figures 1b and 1c), the line of sight approaches the rotation axis, making occultation events difficult to observe and resulting in smaller lightcurve amplitudes.

4.1 Lightcurve Period Analysis

Using Lomb-Scargle periodogram analysis on the 7 nights of YNHK photometric data for (2572) Annschnell, we identified the dominant period. As shown in Figure 4 [Figure 4: see original paper], the maximum peak occurs at 7.585 cycles d^{-1}. Considering the double-peaked nature of asteroid lightcurves, the appropriate frequency for (2572) Annschnell is 3.7925 cycles d^{-1}, corresponding to a lightcurve period of 6.328 h.

Figure 4 Lomb-Scargle periodogram for period analysis of new photometric data for asteroid (2572) Annschnell.

Using this period, we folded the two time segments of observations into rotational phase lightcurves (Figures 3a and 3b). Calculating the difference between maximum and minimum magnitudes yields amplitudes of approximately 0.83 mag and 0.76 mag for the two periods. Variations in lightcurve amplitude are primarily caused by changes in the aspect angle (the angle between the line of sight and orbital pole) in the viewing geometry.

4.2 Inversion Data Generation

Compared to single-asteroid lightcurve inversion, binary asteroid inversion involves more parameters, imposing stricter requirements on the photometric data. When the viewing geometry span (range of aspect angle variation) is small, parameter degeneracies occur. We therefore employ parameter space scanning to find the most probable solution, though this process is computationally intensive. Since viewing geometry changes little during short observational periods (e.g., consecutive nights), lightcurve shape variations can be neglected. To improve scanning efficiency, we fit the lightcurve shapes from different observational periods. For (2572) Annschnell, we divided the 12 nights of observations into four periods. Based on these four datasets—or more precisely, the rotational phase lightcurves (phase range 0-1)—we resampled each period' s lightcurve using uniform phase distribution. This study uses n = 100 uniformly sampled points, with corresponding magnitudes calculated from Fourier series fits to the phase lightcurves within each period. This generated four "adopted lightcurves" for inversion analysis, saving computational time while reducing the impact of observational errors on the inversion.

4.3 Inversion Method and Computational Procedure

Similar to single-asteroid lightcurve inversion, binary asteroid inversion compares the sum of squared residuals between model values for given parameters and the "adopted observations." The minimum sum of squared residuals (^{2}) corresponds to the most probable Roche binary model parameters:

$$\chi^2 = \sum_{j=1}^{n_{lc}} \sum_{i=1}^{n} \frac{[M_{obs}(i,j) - M_{mod}(P,i,j)]^2}{\sigma_{i,j}^2}$$

where M_{mod}(P,i,j) is the simulated Roche binary magnitude, M_{obs}(i,j) is the "adopted observation," and P = (a_p, b_p, c_p, a_s, b_s, c_s, λ*{orb},* β{orb}) represents the parameters to be determined. The subscript (i,j) refers to the i-th data point of the j-th phase lightcurve. Specifically, the inversion uses n_{lc} = 4 lightcurves, each with n = 100 data points. We employed a grid search with specified step sizes to scan the parameter space, obtaining the ^{2} posterior distribution for the parameters. The most probable solution for the binary system parameters was derived from this distribution. Since previous albedo measurements conflict with taxonomic classification results, leading to large uncertainties in size estimates, we did not fit the absolute size but set the primary' s maximum semi-major axis to a_p = 1. The computational procedure is as follows:

1. For selected scanning parameters (q, c_p, c_s, λ*{orb},* β{orb}), perform grid scans across specified parameter spaces with defined step sizes to generate specific values for the five parameters.
2. For given values of (q, c_p, c_s, λ*{orb},* β{orb}), use equation (1) to calculate (a_s, b_p, b_s), where a_s is determined from the mass ratio q and a_p.
3. For any parameter set P, compute the theoretical binary model lightcurve and the sum of squared residuals ^{2}(P) (equation (5)).
4. Apply Roche solution filtering: substitute (q, a_p, b_p, c_p) and (1/q, a_s, b_s, c_s) into equation (2) and compare the normalized rotation angular velocities Ω for both components. Solutions with equal Ω values are retained as valid Roche binary solutions.
5. Select the parameters corresponding to the minimum ^{2} value as the most probable binary system solution.
6. Estimate asteroid density using equation (2).

To save scanning time, we preliminarily estimated the binary orbital pole orientation (λ*{orb},* β{orb}) as (302°, 22°) from the four amplitude values of (2572) Annschnell' s lightcurves, restricting λ*{orb} to 285°-315° and* β{orb} to 17°-47°. Based on reference [?] and considering the lightcurve amplitude, orbital angular velocity ω, and expected density range (1-5 g/cm^{3}) for (2572) Annschnell, we set scanning ranges of 0.4-1.0 for mass ratio q, 0.6-0.99 for c_p, and 0.4-0.99 for c_s. Step sizes were 0.01 for q, c_p, and c_s, and 1° for λ*{orb} and* β{orb}.

4.4 Inversion Results

After completing the parameter space scan, we obtained ^{2} distributions for the scanned parameters (Figure 5 [Figure 5: see original paper]). The ^{2} values in Figure 5 are normalized by dividing by the best-fit model' s ^{2}*{best}. The distributions show parameter values versus* ^{2} *for (q, c_p, c_s), while the orbital pole (*λ{orb}, β*{orb}) is presented as a* ^{2} *heat map. The narrow distributions for q and c_p indicate good observational constraints and higher precision than for c_s. The* ^{2} *heat map for orbital pole (*λ{orb}, β_{orb}) shows poorer parameter determination, primarily because the aspect angle variation in the used lightcurves is too small; additional observations are needed to improve this parameter' s accuracy. From the ^{2} distributions, we obtained the best photometric inversion solution for (2572) Annschnell, detailed in Table 2 .

Figure 5 Parameter distributions.

Table 2 Photometric analysis results for asteroid (2572) Annschnell

Parameter	Value
Mass ratio q	0.51
Primary shape (a__p : b__p : c__p)	(1.00 : 0.84 : 0.76)
Secondary shape (a__s : b__s : c__s)	(1.06 : 0.57 : 0.53)
Orbital pole ($\lambda\{orb\}$, β{orb})	(297°, 33°)
Epoch t0, ϕ__{m0}	2457813.398, 90°
Orbital angular velocity ω	3.7925 cycle d^{-1}
Density	3.15 $\mathrm{g/cm}^3$

Figure 3 compares the best-fit Roche binary model lightcurves (dashed lines) with observational data (points) for (2572) Annschnell. The obtained contact binary theoretical model successfully reproduces the observed lightcurves from all four periods. Imperfections in the fit arise because real asteroid shapes deviate from ideal triaxial ellipsoids, such as small-scale irregularities and impact craters. Nevertheless, the Roche binary model solution provides an opportunity to estimate asteroid density. Based on this solution, we estimate a lower limit for the density of (2572) Annschnell of ≥ 3.15 g/cm^3.

5. Summary and Discussion

The YNHK Survey contains a substantial number of asteroids. Time-series survey observations provide asteroid photometric data spanning multiple nights, which is highly valuable for studying asteroid physical properties, as demonstrated in this analysis of (2572) Annschnell.

1. Analysis of 7 nights of YNHK Survey lightcurves for main-belt asteroid (2572) Annschnell reveals distinctive features—large amplitude (0.83 mag), "U-shaped" maxima, and "V-shaped" minima—indicating that (2572) Annschnell is likely a contact binary asteroid.

2. Applying Roche binary asteroid theory and assuming Roche ellipsoid shapes, we developed a simplified binary photometric model and analyzed 12 lightcurves of (2572) Annschnell (7 newly observed and 5 from the Minor Planet Center). The best-fit Roche binary model solution is P__{best} = primary shape (a__p = 1.0, b__p = 0.84, c__p = 0.76), secondary shape (a__s = 1.06, b__s = 0.57, c__s = 0.53), orbital parameters (D = 2.06, $\lambda\{orb\} = 302°,$ β{orb} = 22°, ϕ__{m0} = 0), and Roche parameters (q = 0.51). The estimated density is ≥ 3.15 g/cm^3, close to CV or CK meteorite densities, suggesting (2572) Annschnell is a carbonaceous asteroid consistent with the CX classification from SDSS and Pan-STARRS. Using a typical C-type albedo of 0.057 and absolute magnitude 13.3 mag, the equivalent spherical diameter is 12.18 km, corresponding to primary ellipsoid axes of (7.07, 5.93, 5.37) km and secondary ellipsoid axes of (7.49, 4.03, 3.75) km.

3. Based on the Roche model solution, we estimate a normalized rotation rate of $\Omega = 0.34$ and dimensionless total angular momentum of $H = 0.48$ (calculation formulas in Appendix A of reference [?]). According to reference [?], we infer that contact binary (2572) Annschnell likely formed through rotational fission of a single parent body.
4. Currently, the binary nature of (2572) Annschnell is studied indirectly through lightcurve analysis; independent confirmation is needed. We hope to verify this binary system using the high image quality and strong detection capability of the Coronagraphic Imager (CPI-C) on the Chinese Space Station Telescope (CSST). For example, the coronagraph could observe the double-peaked image profile of the binary while blocking surrounding bright stars, or measure photocenter position variations through multiple imaging observations to confirm the binary structure of (2572) Annschnell.

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