

## Shape model and dynamical state of the asteroid (300) Geraldina: Implications for its possible ancient origin

G. Apostolovska<sup>1</sup>, N. Todorović<sup>2</sup>, E. Vchkova Bebekovska<sup>1</sup>,  
G. Borisov<sup>3</sup>, A. Kostov<sup>3</sup> and Z. Donchev<sup>3</sup>

<sup>1</sup> *Institute of Physics, Faculty of Science, Ss. Cyril and Methodius University in Skopje, Arhimedova 3, 1000 Skopje, Republic of Macedonia (E-mail: gordanaapostolovska@gmail.com)*

<sup>2</sup> *Astronomical Observatory, Volgina 7, P.O. Box 74, 11060 Belgrade, Serbia*

<sup>3</sup> *Institute of Astronomy and National Astronomical Observatory, Bulgarian Academy of Sciences, Tsarigradsko Chaussee Blvd. 72, BG-1784, Sofia, Bulgaria*

Received: February 19, 2026; Accepted: March 27, 2026

**Abstract.** In this study, we present a comprehensive photometric and physical characterization of the main-belt asteroid (300) Geraldina. Our analysis includes determining its sidereal rotational period, shape modeling, spin-axis orientation, as well as dynamical and spectral properties. The investigation is based on two decades of archival photometry from the Bulgarian National Astronomical Observatory (BNAO) Rozhen, complemented by dense CCD lightcurve observations obtained since 2017 at the Astronomical Station Vidojevica (ASV), dense data from ALCDEF, and augmented with sparse-in-time measurements from Gaia Data Release 3 (DR3). By combining these heterogeneous datasets within and using the lightcurve inversion method, we confirmed the asteroid's prograde sense of rotation and obtained two symmetrically mirrored pole solutions for the asteroid model. Our dynamical studies show that (300) Geraldina remains stable in 100 Myr. Although close to the 2:1 mean-motion resonance with Jupiter, it is not captured into it during the observed time. Instead, it exhibits interactions with an unidentified high-order mean-motion resonance, which appears to contribute to its long-term stability. Its spectral type (C) with a primitive carbonaceous composition, in combination with low albedo and long-term stability, is consistent with the assumption that (300) Geraldina is an ancient asteroid.

**Key words:** (300) Geraldina – photometry – dynamical properties – spectroscopy

## 1. Introduction

Determining the asteroid model is an important step for further investigation of the evolution, dynamics, and future of our Solar System. Although the number of asteroids with known models is steadily increasing, it still represents only a small fraction of the total known asteroid population (about 0.8%). Specifically, out of 1,298,026 objects listed in the AstDyS<sup>1</sup> database, only 10,758 have shape models available in the DAMIT<sup>2</sup> database (in December 2025). Having an asteroid with a known model means that both synodic and siderial periods, as well as the coordinates of its axis of rotation, the sense of rotation, and its shape, are known.

Most asteroids observed today are believed to be fragments of larger parent bodies that were disrupted in past collisional events. These fragments typically remain near the original parent body until dynamical processes gradually drift them away. Such groups of related objects are known as asteroid families, in which the largest member is usually considered the remnant of the original body. Studying asteroid models helps in the reconstruction of these collisional events, and also improves our understanding of the dynamical evolution of the Solar System as a whole. By 2015, a total of 122 asteroid families had been confirmed (Nesvorný et al., 2015), and this number remained relatively unchanged until 2024, when Nesvorný et al. (2024) discovered more than 150 new collisional main belt families. Combined with Trojans and other families outside the main belt, the current number of known asteroid families exceeds 300. However, only three families are estimated to have an age of more than 3 Gyr, originating from ancient asteroids.

The asteroid (300) Geraldina, discovered in 1890 by Auguste Charlois, is an outer main-belt asteroid and is considered a possible member of the so-called ancient asteroid population. These bodies are regarded as primordial remnants of the early Solar System and are therefore of particular interest for studies of the collisional and dynamical history of the main belt. The reported diameter in the MP3C database<sup>3</sup>, varies from 66.78 km (Masiero et al., 2012) to 91.56 km (Nugent et al., 2016), whereas the reported albedo ranges from 0.03 (Nugent et al., 2016) to 0.06 (Masiero et al., 2014). A relatively large size, lack of association with any known asteroid family, and a low albedo, make (300) Geraldina a strong candidate for a pristine main-belt object - an ancient asteroid (Delbo' et al., 2017; Ferrone et al., 2023; Athanasopoulos et al., 2022, 2024).

According to the first studies on the rotation of this asteroid, it is derived that its synodic period is 6.818 h (Ivanova et al., 2002). Later, a few more studies have been conducted on the lighthcurve of asteroid (300) Geraldina, and all of them show similar values for its rotational period. The latest value given in the

<sup>1</sup><https://newton.spacedys.com/astdys2/index.php?pc=1.0.0>

<sup>2</sup><https://damit.cuni.cz/>

<sup>3</sup>Available at <https://mp3c.oca.eu/>

JPL Database is 6.8423 h. [Klinglesmith & Hendrickx \(2018\)](#) suggested a possible bimodal period of 13.726 h.

Currently, the model of this asteroid is unknown. The only suggestion so far is given by [Romanishin \(2024\)](#), indicating the possibility of a binary asteroid, specifically a contact binary or an elongated single object. Still, this suggestion was based on three observational nights during one opposition, which can not provide sufficient data points for a clear statement. To construct the asteroid's model, we need photometric observations from several different oppositions, to collect data from various parts of the asteroid's surface and piece them together like a puzzle to form a picture; typically, this requires more than five observing nights, over a longer time period, and much more if the asteroid has an irregular shape. To decrease the observational time on the ground-based telescopes, photometric dense data can be combined with sparse data from space missions like NEOWISE or GAIA. While dense data from a single observational night allows us to collect hundreds of photometric points ([Bebekovska et al., 2019, 2023](#); [Apostolovska et al., 2023](#)), sparse data are rare in time and typically provide only a few points (usually 5) per observational night, but can cover parts of the asteroid that have not been observed during the ground-based observations.

## 2. Instrumentation

Observations of (300) Geraldina were performed during a time span of 23 years. In this period, five different telescopes located in two observatories were used. The campaign began at the Bulgarian National Astronomical Observatory (BNAO) Rozhen, Bulgaria, with the 2m Ritchey-Chrétien-Coude (RCC) telescope, the main instrument of the observatory. The telescope is equatorial mounted, and has two optical systems: Ritchey-Chrétien (for optical observations) and Coude (for spectroscopic observations). The main mirror is two meters in diameter, the focal length is 16 m. The second telescope of BNAO is the 50/70cm Schmidt Telescope - equatorial mounted Schmidt system with 70 cm mirror and 50 cm diameter of the correction plate, and a focal length of 172 cm. The third is the 60cm Cassegrain telescope - equatorial mounted Cassegrain optical system with a main mirror of 60 cm in diameter and a focal length of 7.5 m.

The Astronomical Station Vidojevica (ASV), Serbia, participated with two more telescopes. The first one is the 1.4m Milanković telescope - alt-azimuthal mounted Ritchey-Chrétien system with main mirror of 1.4 m in diameter, and focal length of 11.2 m. The second instrument of the observatory is the 60cm Cassegrain Nedeljković telescope - equatorial mounted Cassegrain optical system with main mirror of 60 cm in diameter, and focal length of 6 m.

The detectors of the telescopes, the component of the observational system that is most frequently updated, were also changed during the observational campaign, leading to 8 different CCD's used in total. In [Tab. 1](#) all these CCD's

are listed. In the first column is the observational run (or period) in which the detector was used, followed by the telescope, where that CCD was attached, chip size in pixels, and the physical dimension of the pixel in  $\mu\text{m}$ .

**Table 1.** Instrumentation used in the observational campaign

Run	Telescope	CCD Detector Model	Chip size [px]	Pixel size [ $\mu\text{m}$ ]
2002 Jan	2mRCC	Photometrics CE200A-SITe	1024 x 1024	24
2003 Apr	5070	SBIG ST-8E	1520 x 1020	9
2008 Jan	5070	SBIG STL-11000M	4008 x 2672	9
2009 ÷ 2010	5070	FLI PL16803	4096 x 4096	9
2011 ÷ 2023	60CAS	FLI PL09000	3056 x 3056	12
2017 Oct	EQ60	Apogee U42	2048 x 2048	13.5
2018 ÷ 2025	AZ1400	Andor iKon-L 936	2048 x 2048	13.5
2023 Oct	EQ60	FLI PL23042 MB	2048 x 2048	15

Notes: The telescope abbreviations are as follows: 2mRCC = 2m Ritchey-Chrétien-Coude (RCC) telescope of BNAO Rozhen; 5070 = 50/70cm Schmidt telescope of BNAO Rozhen; 60CAS = 60cm Cassegrain telescope of BNAO Rozhen; EQ60 = 60cm Cassegrain Nedeljković telescope of AS Vidojevica; AZ1400 = 1.4m Milanković telescope of AS Vidojevica

### 3. Observations and data reduction

Our first observations of (300) Geraldina were conducted over two consecutive nights, 10/11 and 11/12 January 2002, using the 2m telescope at BNAO Rozhen. In Tab. 2 the physical parameters such as diameter, absolute magnitude, albedo, and orbital parameters of (300) Geraldina are shown (as can be found in the JPL Small-Body Database Browser and Asteroid Light Curve Database<sup>4</sup>).

**Table 2.** Asteroid parameters

Asteroid	$D$ (km)	$H$ (mag)	Albedo	$a$ (AU)	$e$	$i$ ( $^\circ$ )
(300) Geraldina	67.37	9.76	0.052	3.20	0.06	0.73

From the acquired photometric data, we derived—for the first time in the case of this asteroid—a synodic rotation period of 6.818 hours and amplitude of 0.317 mag (Ivanova et al., 2002). Licchelli (2006) from his observations in 2005 calculated a more precise rotational period of 6.842 h.

<sup>4</sup>[https://ssd.jpl.nasa.gov/tools/sbdb\\_lookup.html](https://ssd.jpl.nasa.gov/tools/sbdb_lookup.html)

The next observations at BNAO Rozhen were performed with the 50/70cm Schmidt telescope and with the 60cm Cassegrain telescope. Since 2017, Geraldina was observed at Astronomical Station Vidojevica with the 1.4m Milanković telescope and 60cm Cassegrain Nedeljković telescope. The larger Milanković telescope was installed in 2016, and asteroids Geraldina and O'Steen were among the first targets observed with it, to determine their shapes (Todorović et al., 2020). During 2002 and 2003, photometric observations were done in the standard Johnson–Cousins V band and all others in the R band.

**Table 3.** Aspect data for the asteroid (300) Geraldina

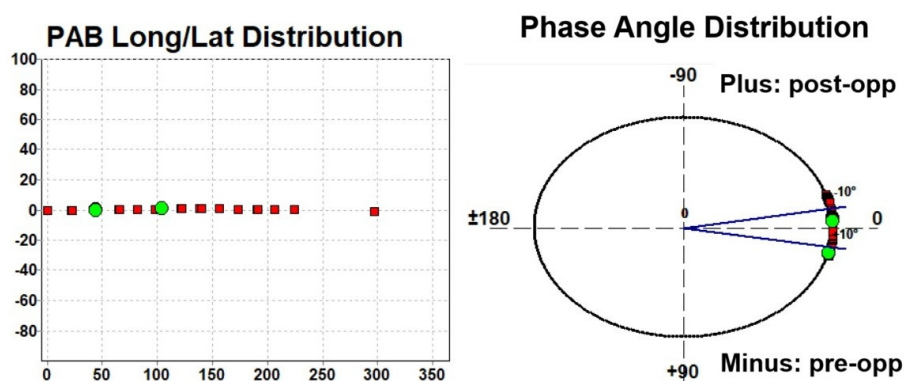
Date (UT)	$r$ (AU)	$\Delta$ (AU)	$\alpha$ ( $^\circ$ )	$PLON$ ( $^\circ$ )	$PLAT$ ( $^\circ$ )	Filter	Note
2002 Jan 11.01	3.368	2.406	9.39	138.74	0.88	V	2mRCC
2002 Jan 12.01	3.276	2.399	9.09	138.76	0.88	V	2mRCC
2003 Apr 28.92	3.368	2.381	4.02	206.59	0.22	V	5070
2003 Apr 29.96	3.367	2.384	4.37	206.57	0.22	V	5070
2003 Apr 30.90	3.367	2.387	4.68	206.56	0.21	V	5070
2008 Jan 09.08	3.319	2.656	14.06	155.98	0.81	R	5070
2008 Jan 09.92	3.319	2.644	13.87	156.04	0.81	R	5070
2008 Jan 11.02	3.320	2.633	13.68	156.11	0.81	R	5070
2009 Apr 24.05	3.353	2.363	3.66	224.28	0.00	R	5070
2009 Apr 25.06	3.353	2.360	3.31	224.27	0.00	R	5070
2010 Jul 13.94	3.161	2.150	2.30	297.25	-0.88	R	5070
2010 Jul 14.98	3.161	2.148	1.94	297.24	-0.88	R	5070
2010 Aug 17.83	3.144	2.241	9.90	297.34	-0.88	R	5070
2011 Oct 30.96	3.037	2.078	5.90	21.62	-0.29	R	60CAS
2011 Nov 29.81	3.040	2.327	14.70	22.93	-0.19	R	60CAS
2011 Nov 30.81	3.040	2.338	14.91	23.01	-0.18	R	60CAS
2012 Nov 12.08	3.178	2.566	15.66	102.12	0.6	R	60CAS
2012 Nov 13.95	3.179	2.545	15.33	102.28	0.65	R	60CAS
2012 Dec 13.04	3.195	2.283	7.85	103.58	0.74	R	60CAS
2013 Jan 08.85	3.210	2.230	1.90	103.33	0.79	R	60CAS
2014 Mar 30.94	3.380	2.423	5.70	173.15	0.64	R	60CAS
2017 Oct 20.08	3.050	2.101	6.79	44.44	-0.03	R	EQ60
2018 Dec 04.01	3.248	2.612	14.87	121.75	0.79	R	60CAS
2018 Dec 07.11	3.250	2.576	14.29	121.98	0.79	R	60CAS
2018 Dec 12.97	3.252	2.513	13.06	122.34	0.81	R	AZ1400
2020 Feb 28.02	3.387	2.546	10.21	190.79	0.51	R	60CAS
2020 Apr 18.96	3.386	2.434	6.36	190.33	0.43	R	2mRCC
2023 Oct 07.04	3.088	2.462	16.25	64.82	0.20	R	EQ60
2023 Oct 15.00	3.092	2.374	14.70	65.52	0.22	R	60CAS
2025 Mar 05.90	3.350	2.449	8.33	140.08	0.84	R	AZ1400

Notes: In the last column, the telescope abbreviations are the same, as in Tab. 1

Geraldina was observed 30 nights during 13 oppositions over more than two decades from 2002 to 2025. In Tab. 3, the aspect data of (300) Geraldina during our observations are reported. The first column is the date of the observation referring to the mid-time of the observed lightcurve. In the other columns are as follows: asteroid distance from the Sun ( $r$ ), distance from the Earth ( $\Delta$ ), Phase Angle ( $\alpha$ ) (the Sun-Asteroid-Observer angle), Phase Angle Bisector Longitude ( $PLON$ ) and Phase Angle Bisector Latitude ( $PLAT$ ) of the asteroid referred to the time in the first column, the broadband filter in which the observations were carried. The last column is a note on the telescope used to acquire images, and an explanation of the abbreviations can be found at the bottom of Tab. 1.

From the Asteroid Light Curve Data Exchange Format (ALCDEF)<sup>5</sup> database (Stephens & Warner, 2018), for (300) Geraldina, we collected dense photometric data from two LCs from Waszczak et al. (2015) and six LCs from Polakis (2018). Sparse data correspond to 37 photometric points from 11 August 2014 to 02 January 2017 from GAIA Data Release 3 (DR3) (Gaia Collaboration et al., 2023; Tanga et al., 2023). Our dense photometric data provide broad coverage of the phase-angle bisector (PAB) longitude distribution, while the Gaia sparse data largely overlap with already sampled regions of the PAB longitude range (Fig. 1).

The data were reduced using standard bias and flat-field corrections, followed by aperture photometry using CCDPHOT by Buie (1996).



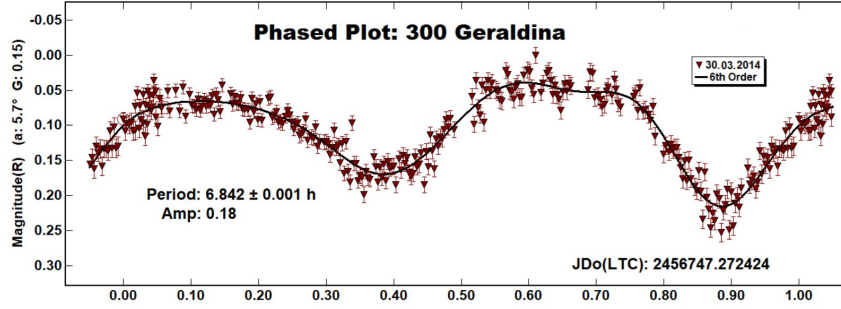
**Figure 1.** Left: Distribution of PAB longitude vs PAB latitude; Right: Distribution of the phase angle. On each of the two plots, the red and green points represent the dense and GAIA DR3 sparse observations, respectively.

<sup>5</sup><https://alcddef.org/>

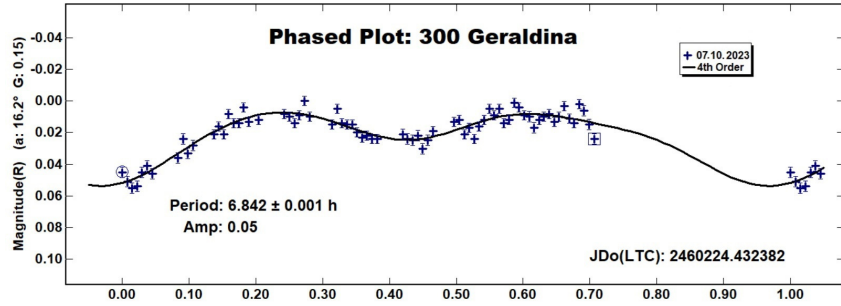
## 4. Results

### 4.1. Lightcurve analysis

Lightcurves obtained during three different oppositions are presented in Fig. 2, Fig. 3, and Fig. 4, illustrating how both the shape of the lightcurve and the amplitude change between apparitions.

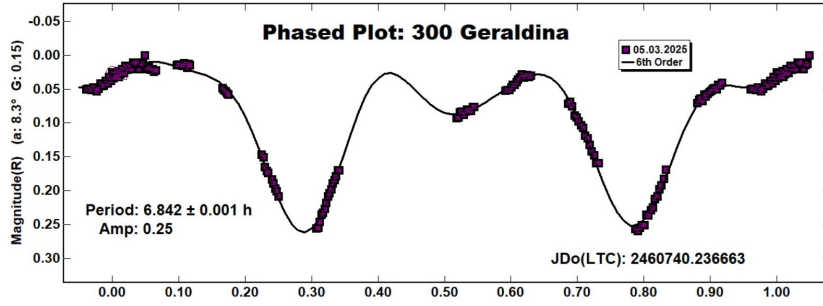


**Figure 2.** The single-night lightcurve of (300) Geraldina was obtained from observations carried out on 30 March 2014. Fourier analysis of the lightcurve, constructed using the accepted rotational period of 6.842 h and a 6<sup>th</sup> order Fourier fit, yielded an amplitude of 0.18 mag.

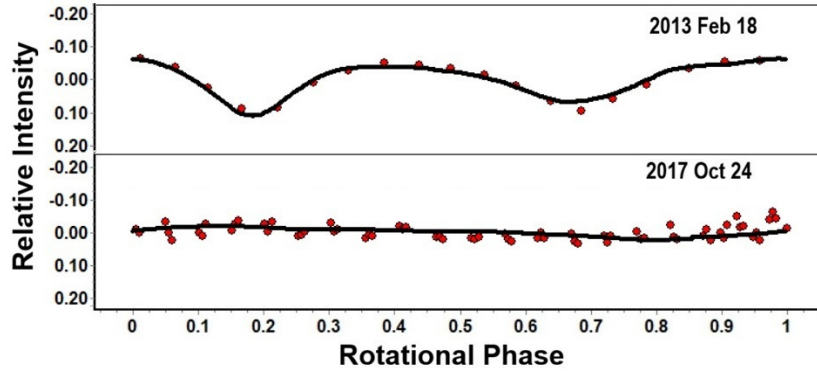


**Figure 3.** The single-night lightcurve of (300) Geraldina was obtained from observations carried out on 7 October 2023. Fourier analysis of the lightcurve, constructed using the accepted rotational period of 6.842 h and a 4<sup>th</sup> order Fourier fit, yielded an amplitude of 0.05 mag.

For the determination of a shape model, we used the lightcurve inversion method (Kaasalainen & Torppa, 2001; Kaasalainen et al., 2001) and the LCInvert programme, part of the MPO Software. Considering the high accuracy of

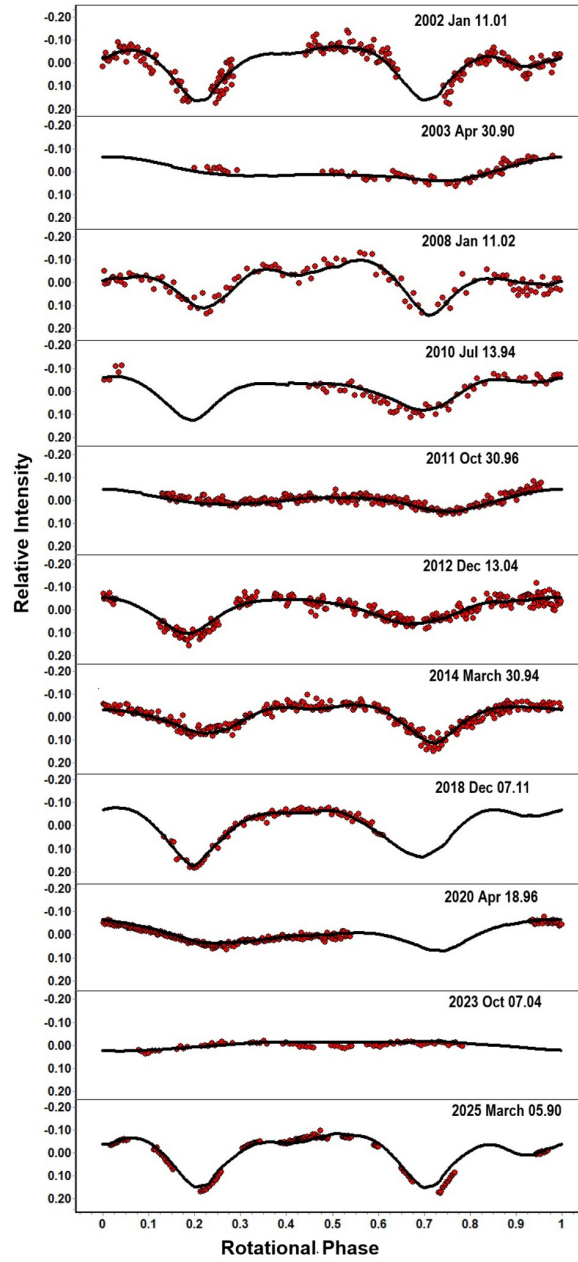


**Figure 4.** The single-night lightcurve of (300) Geraldina was obtained from observations carried out on 5 March 2025. Fourier analysis of the lightcurve, constructed using the accepted rotational period of 6.842 h and a 6<sup>th</sup> order Fourier fit, yielded an amplitude of 0.25 mag.

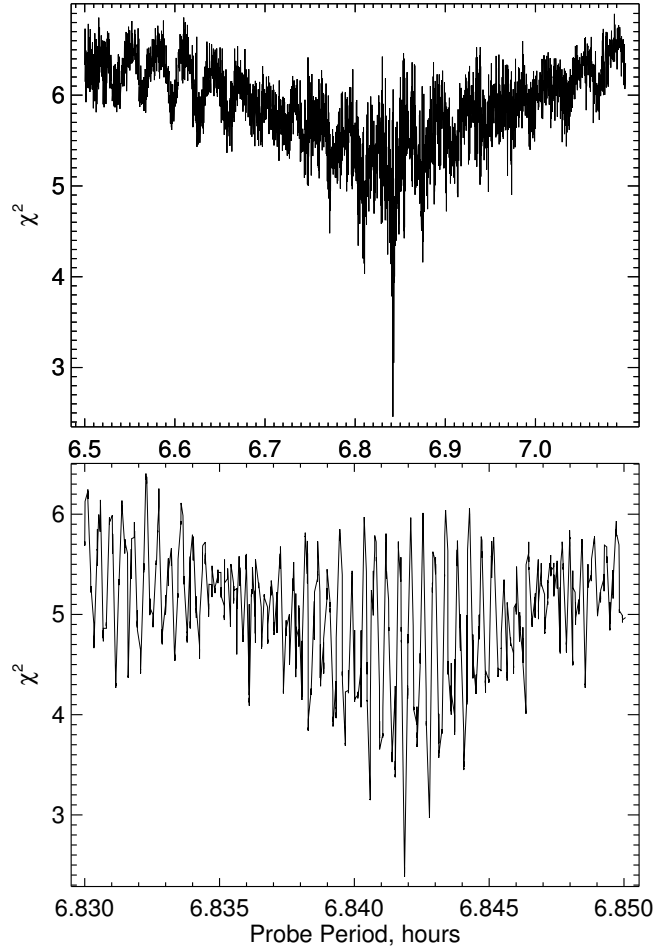


**Figure 5.** The observed lightcurves derived from available published data from AL-CDEF from 2013 and from 2017 (red points) for selected nights are shown superimposed on the synthetic lightcurves generated by the shape–spin model obtained through a combined inversion of all dense datasets and the GAIA DR3 sparse photometry.

the DR3 photometric data, we took the weighting factor to be set to 1.0 for both sparse and for dense photometric data. The rotational period was determined using a light-curve inversion method that fits a simple 3D shape model to the data, instead of standard Fourier techniques. The best period was selected by minimizing the  $\chi^2$  value computed for the modeled and observed light curves. The analysis was carried out with the DAMIT software package (Kaasalainen et al., 2001; Durech et al., 2010). Trial periods were scanned over a wide range using the *period\_scan* routine, testing six initial pole solutions for each trial



**Figure 6.** The observed lightcurves derived from our dense photometric measurements (red points) for selected nights are shown superimposed on the synthetic lightcurves generated by the shape–spin model obtained through a combined inversion of all dense datasets and the GAIA DR3 sparse photometry.



**Figure 7.**  $\chi^2$  vs probe period plot used for a period search (top panel) and the same plot but zoomed around the best solution with the lowest  $\chi^2$  value (bottom panel)

period, to ensure that the global  $\chi^2$  minimum was found.

We made the initial sidereal period search around 6.8 h within the interval of  $\pm 0.3$  h (see Fig. 7 top panel). Several solutions with 10% of the lowest  $\pm 2$  value were found, but a narrower period search found that the most likely period is 6.84186100 h (see Fig. 7 bottom panel.)

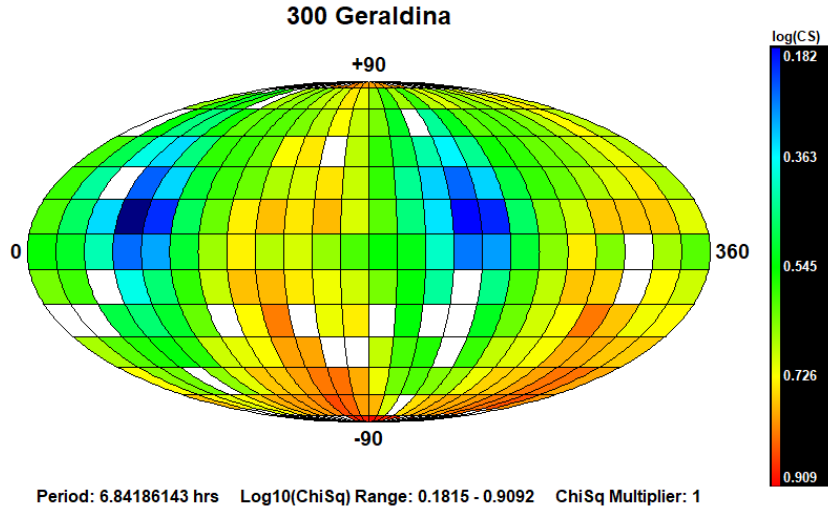
The pole search produced 312 discrete and fixed pole positions distributed over the unit sphere with  $15^\circ$  steps in ecliptic latitude and longitude, varying also the most likely input period. The resulting solutions were used to construct  $\chi^2$  maps (Fig. 8), which allowed the identification of low- $\chi^2$  regions and the

selection of the best-fitting pole. As it is expected for asteroids with orbits close to the ecliptic plane, we encounter two symmetric pole solutions with identical  $\beta$  and  $\lambda \pm 180^\circ$ . The preliminary ecliptic coordinates for the pole are  $\lambda = 45 \pm 7.5^\circ$ ,  $\beta = 15 \pm 7.5^\circ$  and for the mirrored pole solution are  $\lambda = 225 \pm 7.5^\circ$ ,  $\beta = 15 \pm 7.5^\circ$  which suggest prograde sense of asteroid rotation. The finest search centered on these roughly obtained pole positions gave us more precisely determined solutions, presented in Tab. 4. The derived three-dimensional shape model of the asteroid (300) Geraldina is presented in Fig. 9, and the observed and synthetic (derived from the model) lightcurves are presented in Fig. 5 and Fig. 6.

**Table 4.** Parameters of the model of the asteroid (300) Geraldina

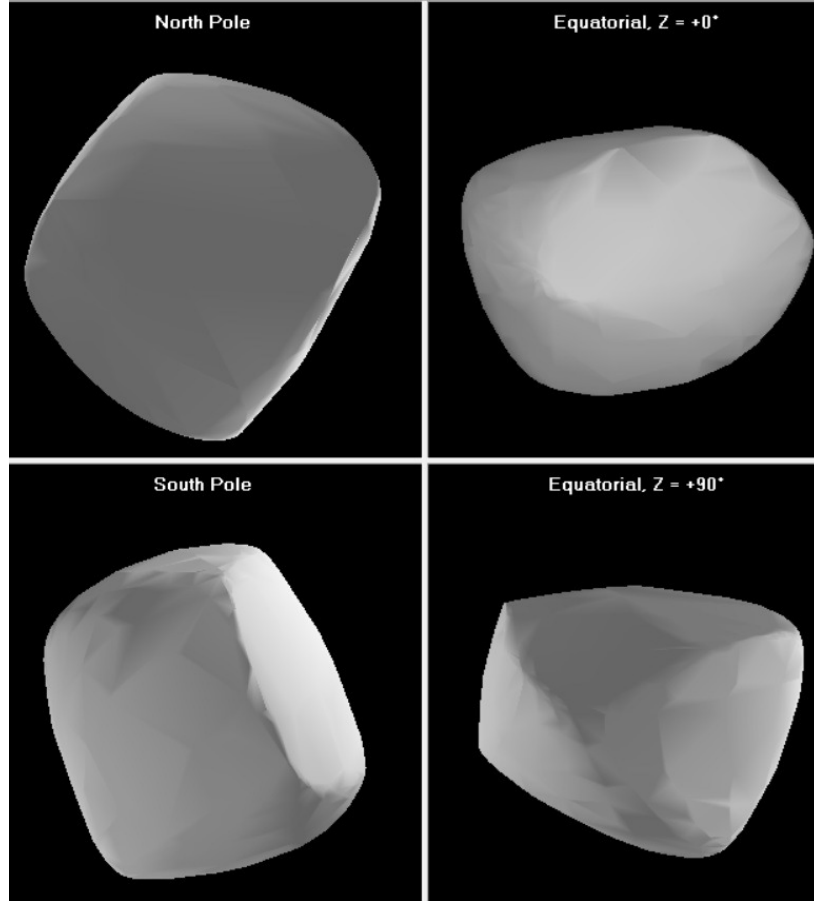
Sidereal period (h)	Sense of rotation	Pole		$a/b$	$a/c$	$b/c$
		$\lambda$ ( $^\circ$ )	$\beta$ ( $^\circ$ )			
6.8418615	P	$52.6 \pm 5.0$	$9.5 \pm 5.0$	1.11	1.29	1.16
6.8418615	P	$232.6 \pm 5.0$	$9.1 \pm 5.0$	1.11	1.29	1.16

Assuming the asteroid as a triaxial ellipsoid, rotating around the shortest axis  $c = 1$  ( $a > b > c$ ), we derived relative shape dimensions  $a/c = 1.29$ . The Tab. 4 gives the sidereal rotational period, sense of rotation (P for prograde),



**Figure 8.** Pole search distribution. The dark blue regions have the smallest value of  $\chi^2$ .

ecliptic coordinates  $\lambda$  and  $\beta$  of the two mirror solutions, and rough relative shape dimensions.



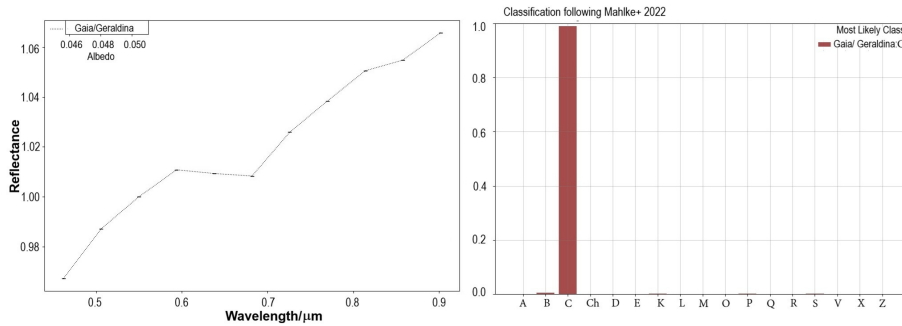
**Figure 9.** The three-dimensional low-resolution convex shape model of the asteroid (300) Geraldina is shown. The left panels present views of the model from the north and south rotational poles, illustrating the overall polar morphology. The right panels display equatorial perspectives separated by  $90^\circ$  in rotational phase, highlighting variations in the projected shape and allowing assessment of the object’s elongation and symmetry during rotation.

Using the maximum observed lightcurve amplitude reported by [Ivanova et al. \(2002\)](#), and applying the empirical relation for C-type asteroids proposed by [Zappala et al. \(1990\)](#), we calculated the ratio of the maximum to minimum projected reflecting surface areas during the asteroid’s rotation, as done in [Vchkova](#)

Bebekovska et al. (2021) and Borisov et al. (2024), obtaining  $a/c = 1.39$ . None of the composite lightcurves raises a suspicion that this might be a binary asteroid as suggested by Romanishin (2024). The minima have approximately the same depths and are separated by half a phase. If (300) Geraldina were a binary asteroid, its lightcurve should have a more irregular shape, as in the case of the suspected binary (12499) 1998 FR47 (Borisov et al., 2024).

## 4.2. Taxonomy from Gaia spectroscopy

The Gaia mission has been observing Solar System objects since the beginning of its operation, and the mean reflectance spectra of selected asteroids are included in its 3rd data release (DR3). As the asteroid (300) Geraldina is among the asteroids with reflectance spectra in DR3, we will use it in order to obtain its taxonomy and composition, relying on the new probabilistic approach by Mahlke et al. (2022).



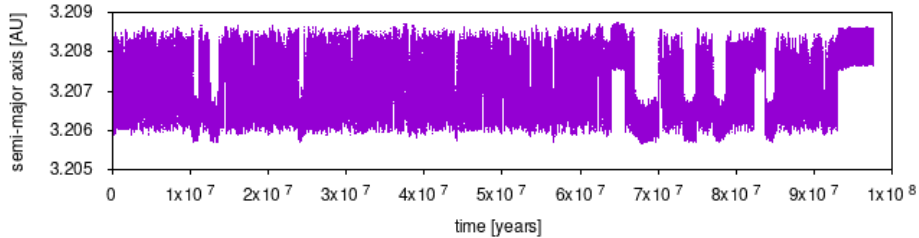
**Figure 10.** Gaia DR3 reflectance spectrum of (300) Geraldina and its taxonomical classification according to Mahlke et al. (2022) (see text for details).

The results are shown in Fig. 10. The left panel shows the Gaia DR3 reflectance spectra of the object, and the right panel presents the possible taxonomy classes with their probabilities. In particular, the asteroid (300) Geraldina has a 99% probability of being a C-class object and 1% for a B-class. Both of these solutions fall into classes that are primitive carbonaceous. The previous taxonomy determination shows the same classification (Carvano et al., 2010). This data set contains Sloan Digital Sky Survey (SDSS) asteroid photometric observations classified according to the SDSS-based Asteroid Taxonomy, as developed by Carvano et al.. Taking into account its reported very low albedo - 0.0331 (Carvano et al., 2010) may also lead to the idea that this object could be an "ancient asteroid"!

### 4.3. Dynamical properties of the asteroid (300) Geraldina

Dynamical properties of the asteroid (300) Geraldina are studied in two ways. First, we integrated the asteroid over the time span of 100 Myrs with the Orbit9 software<sup>6</sup>, incorporating all the planets in the Solar system model. One common way to observe whether an asteroid has undergone dynamical evolution is to track changes in its semi-major axis.

Our results (see Fig. 11) show that (300) Geraldina is a stable asteroid. Its semi-major axis ( $a$ ) exhibits only local oscillations ranging between  $a=[3.206, 3.209]$  AU, along with several sporadic resonant captures that stabilize the asteroid even more. In Fig. 11, these resonant episodes are visible as time intervals where the oscillation amplitudes are smaller. Before approximately 67 Myrs, the longest stays in the resonance are on the order of 100 Kyr. After  $\sim 67$  Myrs, they become longer, with the final and longest resonant episode lasting from 90.3 Myr to the end of the integration.



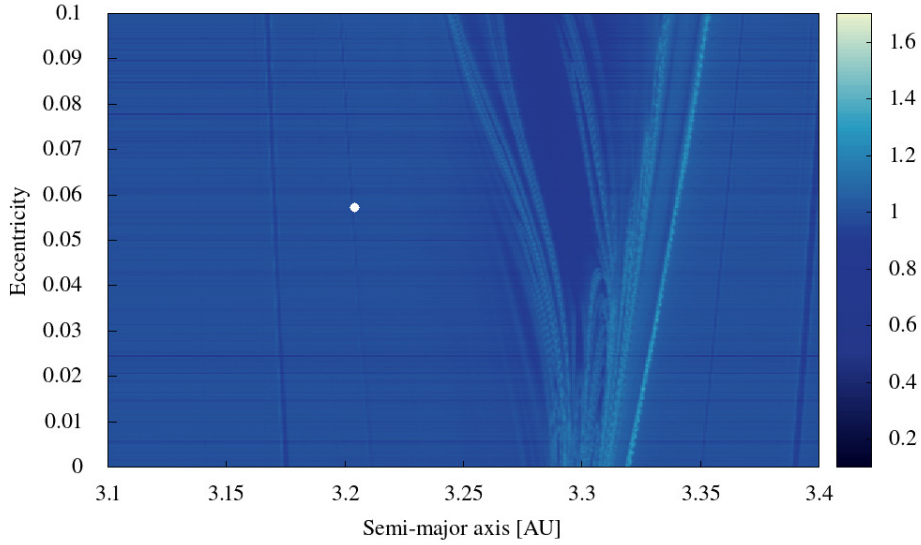
**Figure 11.** The stability of the asteroid (300) Geraldina over 100 Myrs shown through the evolution of its semi-major axis  $a$ . The asteroid remains stable, exhibiting only local oscillation in  $a$ , with several resonant captures (visible as intervals with oscillations of smaller amplitudes) that stabilize the asteroid even more. These captures became more frequent and lasted longer after 67 Myrs.

We also investigated the dynamical environment of the asteroid. Fig. 12 shows an Fast Lyapunov Indicator - FLI map (Froeschlé et al., 1997a,b; Borisov et al., 2024; Todorović, 2017), illustrating the stability properties within a portion of the orbital plane surrounding the asteroid, defined by  $[a \times e] = [3.1\text{AU}, 3.4\text{AU}] \times [0, 0.1]$ . The position of (300) Geraldina at  $(a, e) = (3.204\text{AU}, 0.057)$  is indicated by a white dot, while the remaining orbital elements—the inclination  $i$ , longitude of the ascending node  $\Omega$ , argument of perihelion  $\omega$ , and mean anomaly  $M$ —are set equal to those of Geraldina at epoch JD 2458800.5, obtained from NASA’s JPL Horizons system<sup>7</sup>. This choice of orbital parameters provides a realistic representation of the dynamical environ-

<sup>6</sup><http://adams.dm.unipi.it/orbfit/>

<sup>7</sup><https://ssd.jpl.nasa.gov/horizons.cgi>

ment around the asteroid. The map was computed using the Orbit9 integrator over a timespan of 5,000 years, adopting a full Solar System model.



**Figure 12.** The FLI map showing the dynamical neighborhood of the asteroid (300) Geraldina (marked with a white dot). Lighter colors reveal instabilities, while darker shades of blue represent stable regions. The most dominant structure revealing instability appears around 3.3 AU, and represents one of the strongest resonances in the Solar system - the 2:1 MMR with Jupiter. Although relatively close, (300) Geraldina has not been captured by this resonance during 100 Myrs. The only resonant behavior of the asteroid is observed within a weak high-order MMR, visible on the map as a thin vertical line at about  $a \sim 3.21$  AU.

Each point on Fig. 12 represents one orbit. Pixels colored in light blue represent orbits that have shown instabilities during 5000 years, while the darker shades show stable regions. The most dominant structure on the map is noticeable at 3.3 AU. It represents the trace of one of the strongest resonances in the Solar system, the 2:1 mean motion resonance (MMR) with Jupiter (Chrenko et al., 2015; Brož et al., 2005a). Although (300) Geraldina lies relatively close to this resonance, it has not been driven toward it during the 100 Myr integration (see changes in  $a$  in Fig. 11). Let us mention that the integration does not include the Yarkovsky effect, which could, in principle, cause an asteroid to drift into the resonance (Brož et al., 2005b). However, large asteroids, such as Geraldina, are, in general, not significantly affected by the Yarkovsky force.

Several thin and pale vertical lines in Fig. 12 represent unidentified high-order MMRs. They are not strong enough to make any significant change in the

orbital evolution of an asteroid. Geraldina appears to be on one such resonance. The changes of its semi-major axis shown in Fig. 11 do reveal a resonant behavior, but as mentioned above, it was not strong enough to provide any significant shift of the asteroid. This weak MMR only contributed to the stabilization of the asteroid. Geraldina’s dynamical stability, although not evaluated over a full 4 billion–year timescale, may provide additional evidence of its pristine nature.

## 5. Conclusions

We have presented a combined photometric, spectroscopic, and dynamical analysis of the main-belt asteroid (300) Geraldina, using dense ground-based light-curves spanning more than two decades, complemented by available published data from ALCDEF and by sparse Gaia DR3 photometry. Application of the lightcurve inversion method yielded a well-constrained sidereal rotation period of 6.8418615 h, a prograde sense of rotation, and two mirror pole solutions consistent with the asteroid’s low orbital inclination. The derived convex shape model indicates a moderately elongated body. Gaia DR3 reflectance spectroscopy classifies (300) Geraldina as a C-type asteroid, consistent with a primitive, carbonaceous composition. Together with its reported low albedo, this supports its classification as an ancient asteroid candidate.

Numerical integrations over 100 Myr show that (300) Geraldina remains dynamically stable. Despite its proximity to the 2:1 mean-motion resonance with Jupiter, no resonance capture is observed, and the asteroid instead exhibits weak interactions with a high-order mean-motion resonance without much influence on its long-term orbital evolution.

Taken together, the physical, rotational, taxonomic, and dynamical properties of (300) Geraldina support the hypothesis that it is a primordial asteroid. These results make (300) Geraldina a valuable target for further studies of the primordial collisional and dynamical evolution of the asteroid belt.

**Acknowledgements.** This article is based on data collected with the telescopes of the Rozhen National Astronomical Observatory. The authors gratefully acknowledge observing grant support from the Institute of Astronomy and Rozhen National Astronomical Observatory, Bulgarian Academy of Science. The research that led to these results was partially carried out with the help of infrastructure purchased under the National Roadmap for Research Infrastructure, financially coordinated by the Ministry of Education and Science of Republic of Bulgaria. G.B. and A.K. acknowledge partial support by grant: KII-06-H88/5 "Physical properties and chemical composition of asteroids and comets - a key to increasing our knowledge of the Solar System origin and evolution." by the Bulgarian Scientific Research Fund of the Ministry of Education and Science. The observations at AS Vidojevica and funding for N.T. were financed from the Ministry of Science, Technological Development and Innovation of the Republic of Serbia, under the contract number 451-03-33/2026-03/200002. The authors are grateful to D. Athanasopoulos for valuable discussions and insights on ancient asteroids. The authors gratefully acknowledge Violeta Ivanova, Bonka Bilkina,

and Vasko Umlenski for their contribution to the observational data collected at the National Astronomical Observatory Rozhen and used in this study.

## References

- Apostolovska, G., Todorović, N., & Vchkova Bebekovska, E., Lightcurve Analysis of Asteroids at the Astronomical Station Vidojevica for the first half of 2022. 2023, in *11th International Conference of the Balkan Physical Union*, 41
- Athanasopoulos, D., Hanuš, J., Avdellidou, C., et al., Asteroid spin-states of a 4 Gyr collisional family. 2022, *Astronomy and Astrophysics*, **666**, A116, DOI:10.1051/0004-6361/202243905
- Athanasopoulos, D., Hanuš, J., Avdellidou, C., et al., Spin states of X-complex asteroids in the inner main belt: I. Investigating Athor and Zita collisional families. 2024, *Astronomy and Astrophysics*, **690**, A215, DOI:10.1051/0004-6361/202451363
- Bebekovska, E. V., Apostolovska, G., Kostov, A., & Donchev, Z., Lightcurve analysis on asteroids from NAO Rozhen observations in 2021. 2023, in *11th International Conference of the Balkan Physical Union*, 39
- Bebekovska, E. V., Kostov, A., Donchev, Z., & Apostolovska, G., Asteroid photometry in 2017 from national astronomical observatory Rozhen. 2019, in American Institute of Physics Conference Series, Vol. **2075**, *10th Jubilee International Conference of the Balkan Physical Union* (AIP), 090016
- Borisov, G., Todorović, N., Vchkova-Bebekovska, E., Kostov, A., & Apostolovska, G., The possible dual nature of the asteroid (12499) 1998 FR47. 2024, *Contributions of the Astronomical Observatory Skalnaté Pleso*, **54**, 57, DOI:10.31577/caosp.2024.54.4.57
- Brož, M., Vokrouhlický, D., Roig, F., et al., The population of asteroids in the 2:1 mean motion resonance with Jupiter revised. 2005a, in *IAU Colloquium 197: Dynamics of Populations of Planetary Systems*, ed. Z. Knežević & A. Milani, 179–186
- Brož, M., Vokrouhlický, D., Roig, F., et al., Yarkovsky origin of the unstable asteroids in the 2/1 mean motion resonance with Jupiter. 2005b, *Monthly Notices of the RAS*, **359**, 1437, DOI:10.1111/j.1365-2966.2005.08995.x
- Buie, M. W., CCDPHOT—An IDL Widget Based CCD Photometry Reduction System. 1996, in *Astronomical Society of the Pacific Conference Series*, Vol. **101**, *Astronomical Data Analysis Software and Systems V*, ed. G. H. Jacoby & J. Barnes, 135
- Carvano, J. M., Hasselmann, P. H., Lazzaro, D., & Mothé-Diniz, T., SDSS-based taxonomic classification and orbital distribution of main belt asteroids. 2010, *Astronomy and Astrophysics*, **510**, A43, DOI:10.1051/0004-6361/200913322
- Chrenko, O., Brož, M., Nesvorný, D., Tsiganis, K., & Skoulidou, D. K., The origin of long-lived asteroids in the 2:1 mean-motion resonance with Jupiter. 2015, *Monthly Notices of the RAS*, **451**, 2399, DOI:10.1093/mnras/stv1109

- Delbo', M., Walsh, K., Bolin, B., Avdellidou, C., & Morbidelli, A., Identification of a primordial asteroid family constrains the original planetesimal population. 2017, *Science*, **357**, 1026, DOI:10.1126/science.aam6036
- Durech, J., Sidorin, V., & Kaasalainen, M., DAMIT: a database of asteroid models. 2010, *Astronomy and Astrophysics*, **513**, A46, DOI:10.1051/0004-6361/200912693
- Ferrone, S., Delbo, M., Avdellidou, C., et al., Identification of a 4.3 billion year old asteroid family and planetesimal population in the Inner Main Belt. 2023, *Astronomy and Astrophysics*, **676**, A5, DOI:10.1051/0004-6361/202245594
- Froeschlé, C., Gonczi, R., & Lega, E., The fast Lyapunov indicator: a simple tool to detect weak chaos. Application to the structure of the main asteroidal belt. 1997a, *Planetary Space Science*, **45**, 881, DOI:10.1016/S0032-0633(97)00058-5
- Froeschlé, C., Lega, E., & Gonczi, R., Fast Lyapunov Indicators. Application to Asteroidal Motion. 1997b, *Celestial Mechanics and Dynamical Astronomy*, **67**, 41, DOI:10.1023/A:1008276418601
- Gaia Collaboration, Vallenari, A., Brown, A. G. A., et al., Gaia Data Release 3. Summary of the content and survey properties. 2023, *Astronomy and Astrophysics*, **674**, A1, DOI:10.1051/0004-6361/202243940
- Ivanova, V. G., Apostolovska, G., Borisov, G. B., & Bilkina, B. I., Results from photometric studies of asteroids at Rozhen National Observatory, Bulgaria. 2002, in ESA Special Publication, Vol. **500**, *Asteroids, Comets, and Meteors: ACM 2002*, ed. B. Warmbein, 505–508
- Kaasalainen, M. & Torppa, J., Optimization Methods for Asteroid Lightcurve Inversion. I. Shape Determination. 2001, *Icarus*, **153**, 24, DOI:10.1006/icar.2001.6673
- Kaasalainen, M., Torppa, J., & Muinonen, K., Optimization Methods for Asteroid Lightcurve Inversion. II. The Complete Inverse Problem. 2001, *Icarus*, **153**, 37, DOI:10.1006/icar.2001.6674
- Klinglesmith, III, D. A. & Hendrickx, S., Asteroid Lightcurve Observations at Etscorn Observatory. 2018, *Minor Planet Bulletin*, **45**, 162
- Licchelli, D., Lightcurve analysis of asteroids 300 Geraldina, 573 Recha, 629 Bernardina 721 Tabora, 1547 Nele, and 1600 Vyssotsky. 2006, *Minor Planet Bulletin*, **33**, 50
- Mahlke, M., Carry, B., & Mattei, P.-A., Asteroid taxonomy from cluster analysis of spectrometry and albedo. 2022, *Astronomy and Astrophysics*, **665**, A26, DOI:10.1051/0004-6361/202243587
- Masiero, J. R., Grav, T., Mainzer, A. K., et al., Main-belt Asteroids with WISE/NEOWISE: Near-infrared Albedos. 2014, *Astrophysical Journal*, **791**, 121, DOI:10.1088/0004-637X/791/2/121
- Masiero, J. R., Mainzer, A. K., Grav, T., et al., Preliminary Analysis of WISE/NEOWISE 3-Band Cryogenic and Post-cryogenic Observations of Main Belt Asteroids. 2012, *Astrophysical Journal, Letters*, **759**, L8, DOI:10.1088/2041-8205/759/1/L8

- Nesvorný, D., Brož, M., & Carruba, V., Identification and Dynamical Properties of Asteroid Families. 2015, in *Asteroids IV*, ed. P. Michel, F. E. DeMeo, & W. F. Bottke, 297–321
- Nesvorný, D., Roig, F., Vokrouhlický, D., & Brož, M., Catalog of Proper Orbits for 1.25 Million Main-belt Asteroids and Discovery of 136 New Collisional Families. 2024, *Astrophysical Journal, Supplement*, **274**, 25, DOI:10.3847/1538-4365/ad675c
- Nugent, C. R., Mainzer, A., Bauer, J., et al., NEOWISE Reactivation Mission Year Two: Asteroid Diameters and Albedos. 2016, *Astronomical Journal*, **152**, 63, DOI:10.3847/0004-6256/152/3/63
- Polakis, T., Lightcurve Analysis for Eleven Main-belt Asteroids. 2018, *Minor Planet Bulletin*, **45**, 199
- Romanishin, W., 300 Geraldina: Possibly a Binary With a Tilted Rotational Axis. 2024, *Minor Planet Bulletin*, **51**, 213
- Stephens, R. & Warner, B. D., The ALCDEF Database and the NASA SBN/PDS: The Perfect Merger. 2018, in AAS/Division for Planetary Sciences Meeting Abstracts, Vol. **50**, *AAS/Division for Planetary Sciences Meeting Abstracts #50*, 417.03
- Tanga, P., Pauwels, T., Mignard, F., et al., Gaia Data Release 3. The Solar System survey. 2023, *Astronomy and Astrophysics*, **674**, A12, DOI:10.1051/0004-6361/202243796
- Todorović, N., The precise and powerful chaos of the 5:2 mean motion resonance with Jupiter. 2017, *Monthly Notices of the RAS*, **465**, 4441, DOI:10.1093/mnras/stw3070
- Todorović, N., Apostolovska, G., & Bebekovska, E. V., Lightcurve Photometry of (2525) O’Steen with the new “Milanković” 1.4 m telescope. 2020, in *IAU General Assembly*, 39–39
- Vchkova Bebekovska, E., Todorović, N., Kostov, A., Donchev, Z., & Borisov, G., The Physical and Dynamical Characteristics of the Asteroid 4940 Polenov. 2021, *Serbian Astronomical Journal*, **202**, 39, DOI:10.2298/SAJ2102039V
- Waszczak, A., Chang, C.-K., Ofek, E. O., et al., Asteroid Light Curves from the Palomar Transient Factory Survey: Rotation Periods and Phase Functions from Sparse Photometry. 2015, *Astronomical Journal*, **150**, 75, DOI:10.1088/0004-6256/150/3/75
- Zappala, V., Cellino, A., Barucci, A. M., Fulchignoni, M., & Lupishko, D. F., An analysis of the amplitude-phase relationship among asteroids. 1990, *Astronomy and Astrophysics*, **231**, 548