761 BRENDELIA: A NEWLY IDENTIFIED BINARY ASTEROID FROM PRO-AM COLLABORATION

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Photometric observations taken by GORA observatories during 2024 July 24 - August 5 revealed that minor planet 761 Brendelia is a binary system with an orbital period of 57.079 ± 0.016 h. Mutual eclipse/occultation events that are 0.6-0.8-magnitude deep suggest that both components are of similar sizes. This configuration also suggests that the pair has reached tidal coupling, which would explain why their rotation periods are both 58 hours. Eclipses are occurring every 29 hours. We applied relative photometry assigning V magnitudes to the calibration stars. The image acquisition was performed without filters and with exposure times of a few minutes. All images used were corrected using dark frames and, in some cases, bias and flat-field corrections were also used. Photometry measurements were performed using *FotoDif* software and for the analysis, we employed *Períodos* software (Mazzone, 2012).

761 Brendelia is a main-belt asteroid discovered in 1913 by F. Kaiser. Classified as a SC-type asteroid according to the Tholen taxonomy, it is a member of the Koronis family (Nesvorny et al., 2015). The diameter is 20.763 km. The reported rotational period for this asteroid is 57.96 h (Durech et al., 2018).

Between 2024 July 24 and October 20, we recorded ten significant brightness drops (0.6- to 0.8-magnitude deep) in the asteroid’s lightcurve that cannot be explained by its rotational modulation alone (Fig. 1). The first two events were detected serendipitously. After observing the second brightness dip, we hypothesized that these were mutual eclipses caused by the alignment of two components of a previously undetected binary system.

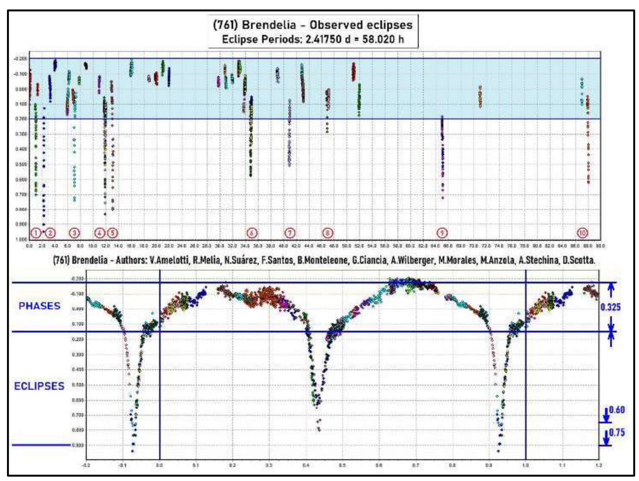

Fig. 1: Observed eclipses of (761) Brendelia.

Our analysis indicates that 761 Brendelia is likely a binary asteroid system. The components appear to orbit their common center of mass with a period of approximately 58 hours, producing mutual eclipses approximately every 29 hours. During the observation window, the Sun was aligned with the orbital plane of the system, enabling the detection of these eclipses; this was an unexpected outcome since our initial objective was simply to determine the rotational period and lightcurve (Table I).

Eclipse period: 2.41750 d = 58.020 h			
Eclipse N°	Date	UT	Phase:
1	25/7/2024	02:19	0.424
2	26/7/2024	07:19	0.924
3	31/7/2024	03:22	0.924
4	4/8/2024	23:24	0.924
5	6/8/2024	04:25	0.424
6	27/8/2024	22:35	0.424
7	2/9/2024	23:38	0.924
8	9/9/2024	00:41	0.424
9	27/9/2024	03:50	0.924
10	20/10/2024	03:02	0.424

Table I: Observed eclipses of (761) Brendelia.

This geometric alignment, apparently never recorded before, provided the unique conditions necessary to reveal the binary nature of 761 Brendelia. GORA happened to be observing the asteroid at precisely the right time. With this evidence, we submitted two reports to the Central Bureau for Astronomical Telegrams (CBAT) of the International Astronomical Union (IAU) in early August, requesting the issuance of an electronic telegram officially crediting GORA with the discovery. *IAU Electronic Telegram No. 5435* was subsequently published on 2024 August 21.

One of the immediate questions that arose was whether or not the eclipses might have been missed in previous observations. Assuming that the observed brightness dips were caused by mutual shadow projection — i.e., eclipses — between the two components of the system as illuminated by the Sun, we set out to estimate past "eclipse seasons" (Table II) based on GORA's observations and the known orbital parameters of 761 Brendelia.

(761) Brendelia - ECLIPSING BINARY ECLIPSE SEASONS IN THE PAST				
Orbital period		4,843827343 years	Date	Elong.
Half of the orbital period		2,421913671 years		
		884,6039685 days		
Time 2° eclipse GORA		2460517,80763 GJD	26/7/2024	176,6
-1	Ephemerides -1	2459633,20366 GJD	22/2/2022	148,7
-2	Ephemerides -2	2458748,59969 GJD	22/9/2019	109,8
-3	Ephemerides -3	2457863,99572 GJD	20/4/2017	82,8
-4	Ephemerides -4	2456979,39176 GJD	17/11/2014	56,4
-5	Ephemerides -5	2456094,78779 GJD	16/6/2012	35,6
-6	Ephemerides -6	2455210,18382 GJD	13/1/2010	11,7
-7	Ephemerides -7	2454325,57985 GJD	13/8/2007	5,8
-8	Ephemerides -8	2453440,97588 GJD	11/3/2005	31,0
-9	Ephemerides -9	2452556,37191 GJD	8/10/2002	48,1
-10	Ephemerides -10	2451671,76795 GJD	7/5/2000	76,0

Table II: Estimate past "eclipse seasons."

We took as a reference the date of minimum brightness observed during the second eclipse among the ten recorded by GORA between 2024 July and October. The parameters used for the calculation were:

- Orbital period: 4.8438273428 d
- Date of the second observed eclipse: JD 2460517.80763 (2024 July 26, 07:19 UT)

Since two opportunities for eclipses occur per orbital period, we subtracted half the orbital period successively from the reference date to project previous eclipse events. We also assumed that each "eclipse season" spans approximately six months, or twice the duration over which we observed eclipses during 2024.

However, we did not know the exact duration of each eclipse season, since the inclination of the mutual orbit relative to the heliocentric orbit is unknown. If the inclination were $i = 0°$, eclipses would be continuous; if $i = 90°$, eclipse seasons would be very brief. Similarly, the maximum and minimum distances between the two components are not precisely known; only rough estimates exist. Based on our observations, which span over 88 days, it is evident that the inclination $i << 90°$ and/or the mutual distance $d << 93$ km. These conditions would favor the extension of eclipse seasons (Fig. 2).

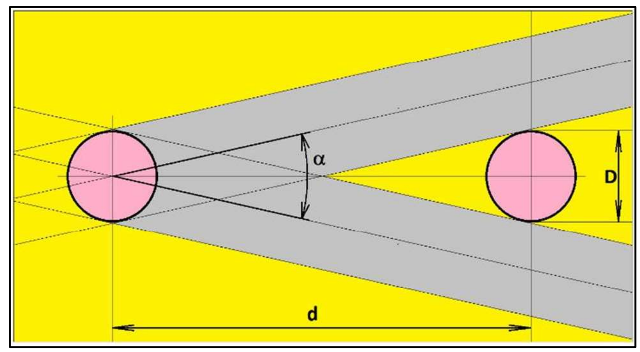

Fig. 2: Eclipse seasons assuming i = 90°.

Eclipse seasons = α*P/360°; Tg (α/2) = D/d; (assuming $i = 90°$)

with: Eclipse seasons > 88 days;
$P = 1769$ days;
$D \approx 14.7$ km;
$a \approx 72$ km.

this gives $\alpha > 17.9°$ and $d < 93$ km (with conditions for short eclipse seasons).

We also examined the solar elongation of Brendelia during those periods, an important observational factor:

- When elongation is near 180° (opposition), the asteroid is observable throughout much of the night, being closest to Earth and at peak brightness.
- When elongation is near 0° (conjunction), the asteroid is unobservable at night, farthest from Earth, and at minimum brightness.

We then compared the epochs of all published observations of 761 Brendelia with the eclipse seasons we calculated. We computed ten such seasons retroactively, the asteroid having been observed seven times since the start of this century.

From this comparison, we find that all seven published lightcurve phase diagrams were constructed using data obtained outside the predicted eclipse seasons (Table III). This may explain why the binary nature of 761 Brendelia was not detected in previous studies prior to the GORA observations.

Ephemerides (Ref: 2° eclipse GORA)		Observations in the past		
Date	Elongation	From	To	Authors
26/7/2024	176,6	23/7/2024	19/10/2024	M. Colazo et al.
22/2/2022	148,7	No observational data		
22/9/2019	109,8	No observational data		
20/4/2017	82,8	No observational data		
17/11/2014	56,4	10/3/2013	21/4/2013	Stefphen M. Slivan et al.
16/6/2012	35,6	No observational data		
13/1/2010	11,7	20/5/2009	17/6/2009	Stefphen M. Slivan et al.
13/8/2007	5,8	2/3/2008	14/3/2008	Stefphen M. Slivan et al.
		9/12/2006	10/2/2007	Stefphen M. Slivan et al.
11/3/2005	31,0	6/9/2005	7/10/2005	Stefphen M. Slivan et al.
8/10/2002	48,1	21/2/2003	20/5/2003	Stefphen M. Slivan et al.
7/5/2000	76,0	No observational data		

Table III: Observations made in the past.

Another question that arose following the discovery was whether or not eclipses will be observable again in the future (Table IV).

(761) Brendelia - ECLIPSING BINARY ECLIPSE SEASONS IN THE FUTURE				
Orbital period		4,843827343 years	Date	Elong.
Half of the orbital period		2,421913671 years		
		884,6039685 days		
Time 2° eclipse GORA		2460517,80763 GJD	26/7/2024	176,6
1	Ephemerides 1	2461402,41160 GJD	27/12/2026	128,7
2	Ephemerides 2	2462287,01557 GJD	30/5/2029	99,0
3	Ephemerides 3	2463171,61954 GJD	1/11/2031	68,7
4	Ephemerides 4	2464056,22350 GJD	3/4/2034	49,2
5	Ephemerides 5	2464940,82747 GJD	4/9/2036	23,0
6	Ephemerides 6	2465825,43144 GJD	5/2/2039	6,1
7	Ephemerides 7	2466710,03541 GJD	9/7/2041	18,5
8	Ephemerides 8	2467594,63938 GJD	11/12/2043	36,8
9	Ephemerides 9	2468479,24335 GJD	13/5/2046	62,0
10	Ephemerides 10	2469363,84731 GJD	14/10/2048	85,2

Table IV: Estimate in the future "eclipse seasons."

We again used as a reference the date of minimum brightness observed during the second eclipse among the ten recorded by GORA between 2024 July and October. This time, we successively added half of the orbital period to that reference date and calculated ten eclipse seasons projected into the future.

In addition to the current favorable season for eclipse observations, we will have another opportunity to observe such events toward the end of 2026. In mid-2029, another potential eclipse season is predicted; however, detection may be more difficult due to the system's quadrature position relative to the Sun, which reduces observational windows and visibility. To encounter similarly optimal conditions for observing eclipses again, we will likely need to wait until the second half of the current century.

Based on the observational evidence and lightcurve analysis, several working hypotheses have been proposed to explain the physical and dynamical characteristics of the 761 Brendelia binary system.

Size of the Components: Based on the depth of the brightness drops observed in two consecutive events (eclipse and occultation), we infer that both components have similar dimensions. This symmetry supports the classification of the system as a binary asteroid, rather than a primary asteroid with a smaller satellite.

Synchronization of Rotation and Revolution. Our proposed model envisions the system as composed of two rugby ball-shaped ellipsoids, co-orbiting in a tidally locked configuration. That is, both bodies have achieved tidal synchronization, meaning that their rotation period equals their orbital period, or approximately 58 hours. This would account for the presence of two minima and two maxima in the published lightcurves, consistent with the classical bimodal shape model expected for a single elongated ellipsoidal body.

Phase Diagram. If both components are ellipsoidal, it is plausible that their alignment with Earth occurs when their major axes are pointed toward the observer, coinciding with the minima in the phase diagram. Conversely, the maxima occur when we observe the long sides of both ellipsoids from the side.

Orbital Size and System Resolution. We estimate the duration of each eclipse to be approximately 3 hours. If both components have similar diameters (*D*), their orbits should also be comparable in size. During an eclipse, each body would traverse an arc approximately equal to its own diameter.

According to physicist Robert Johnston, the equivalent diameter of each component is about 14.7 km. Based on GORA's observations, Johnston estimates the semi-major axis of each orbit to be 72 km.

The maximum separation between the two components would slightly exceed 200 km. From Earth, this corresponds to an angular separation of approximately 0.14 arcseconds — below the resolving power of most conventional telescopes. This explains why the system cannot be visually resolved using standard observational equipment.

Finally, we present the results from two key diagrams. Fig. 3, which includes eclipses, allowed us to determine the periodicity of these events. Meanwhile, Fig. 4, without eclipses, provided the data needed to identify the rotation periods of both components. Together, these findings confirm the binary nature of 761 Brendelia and underscore the importance of continued Pro-Am collaboration in advancing asteroid research.

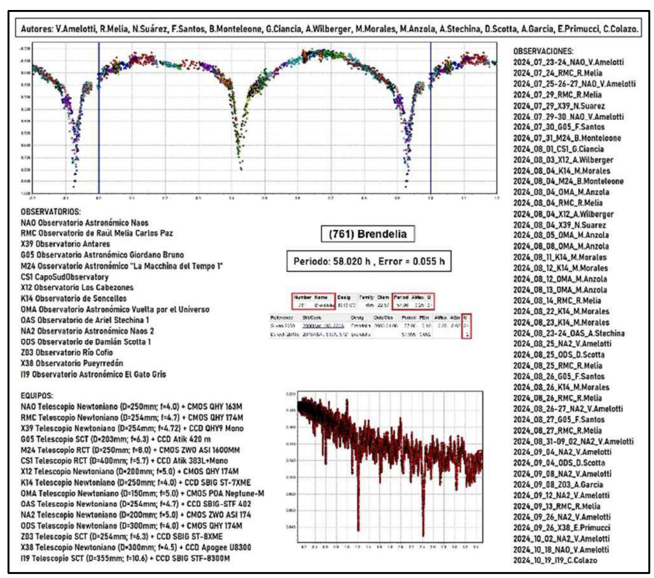

Fig. 3: Observations made with eclipses.

Number	Name	yy/ mm/dd- yy/ mm/dd	Phase	L_{PAB}	B_{PAB}	Period(h)	P.E.	Amp	A.E.	Grp
761	Brendelia	24/07/27-24/10/20	*04.3,21.4	311	-2	57.98	0.06	0.28	0.03	KOR

Table 5. Observing circumstances and results. The phase angle is given for the first and last date. If preceded by an asterisk, the phase angle reached an extremum during the period. L_{PAB} and B_{PAB} are the approximate phase angle bisector longitude/latitude at mid-date range (see Harris et al., 1984). Grp is the asteroid family/group (Warner et al., 2009). KOR: 158 Koronis.

Observatory	Telescope	Camera
G05 Obs.Astr.Giordano Bruno	SCT (D=203mm; f=6.3)	CCD Atik 420 m
I19 Obs.Astr.El Gato Gris	SCT (D=355mm; f=10.6)	CCD SBIG STF-8300M
K14 Obs.Astr.de Sencelles	Newtonian (D=250mm; f=4.0)	CCD SBIG ST-7XME
M24 Oss.Astr.La Macchina del Tempo	RCT (D250mm; f=8.0)	CMOS ZWO ASI 1600MM
X12 Obs.Astr.Los Cabezones	Newtonian (D=200mm; f=5.0)	CMOS QHY 174M
X38 Observatorio Pueyrredón	Newtonian (D=300mm; f=4.5)	CCD Apogee U8300
X39 Obs.Astr.Antares	Newtonian (D=250mm; f=4.72)	CCD QHY9 Mono
Z03 Obs.Astr.Río Cofio	SCT (D=254mm; f=6.3)	CCD SBIG ST-8XME
CS1 CapoSudObservatory	RCT (D=400mm; f=5.7)	CCD Atik 383L+Mono
NAO Obs.Astr.Naos	Newtonian (D=250mm; f=4.0)	CMOS QHY 163M
NA2 Obs.Astr.Naos 2	Newtonian (D=200mm; f=5.0)	CMOS ZWO ASI 174
OAS Obs.Astr.de Ariel Stechina 1	Newtonian (D=254mm; f=4.7)	CCD SBIG STF-402
ODS Obs.Astr.de Damián Scotta 1	Newtonian (D=300mm; f=4.0)	CMOS QHY 174M
OMA Obs.Astr.Vuelta por el Universo	Newtonian (D=150mm; f=5.0)	CMOS POA Neptune-M
RMC Obs.Astr.de Raúl Melia Carlos Paz	Newtonian (D=254mm; f=4.7)	CMOS QHY 174M

Table 6. List of observatories and equipment.

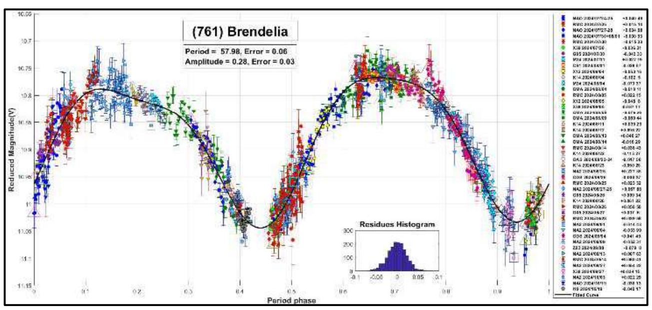

Figure 4: Phase diagram without eclipses.

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