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A Change in the Lightcurve of Contact Binary 2001 QG$_{298}$

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Abstract

New observations show that the lightcurve of Kuiper belt contact binary (139775) 2001 QG$_{298}$ has changed substantially since the first observations in 2003. This change is most simply interpreted if QG$_{298}$ has an obliquity near 90°. Current estimates of the fraction of contact binaries in the Kuiper belt assume that they have randomly oriented spins. If, as QG$_{298}$, KBO contact binaries tend to have large obliquities their abundance may be higher than previously believed.

1. Introduction

Many Kuiper belt objects (KBOs) are binary [1]. Among the dynamically cold, "classical" population the binary frequency is ∼20%, while in other dynamical subsets the fraction is lower, at 5 to 10%. Binaries formed early on, when the belt was >100× more massive, because the current KBO number density is too low for frequent pair encounters. Thus, binaries are old and can be used not only to probe the conditions under which planetesimals formed but also the collisional and dynamical processes that have eroded the original population. Most known binaries are resolved (physical separations >1500 km). The exception is the $500\,\mathrm{km} \times 175\,\mathrm{km}$ contact binary (139775) 2001 QG$_{298}$, identified from analysis of its rotational lightcurve (Fig 1) [2]. Models of the lightcurve suggest that QG$_{298}$ is formed of two mutually eclipsing, tidally elongated components (bulk density $\rho \sim 0.6$ g/cc) seen almost equator-on (Fig 2). The example of QG$_{298}$ suggests that more than 10% of KBOs could be contact binaries. This matches the distribution of resolved binaries which increases dramatically with decreasing orbital separation [1]. The high abundance of contact binaries and the prospect of measuring their densities makes these primitive objects particularly interesting targets of study.

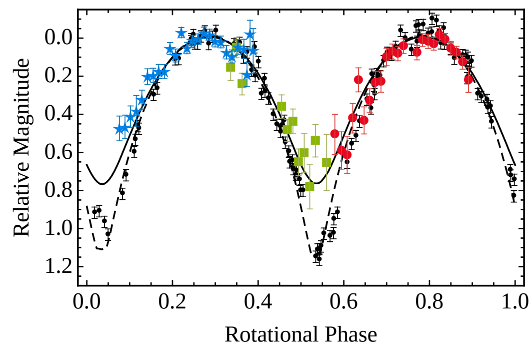

Figure 1: QG$_{298}$ lightcurve in 2003 (black points) and 2010 (colored symbols) and fits (dashed and solid lines) based on a single Roche contact binary model (shown in Fig 2) with obliquity $\varepsilon = 90°$.

2. New data

QG$_{298}$ has travelled 16° in its heliocentric orbit since the first observations in 2003. Expecting the change in observing geometry to impact the lightcurve, we re-observed QG$_{298}$ in 2010 Aug 15-17 using the 2.5-m Isaac Newton Telescope, on the island of La Palma. At its brightest, QG$_{298}$ was 21.63 ± 0.02 mag through the SDSS r filter. The new lightcurve, shown in Fig 1 relative to maximum brightness, appears in phase with the 2003 data but displays a shallower $\Delta m_{10} = 0.7 \pm 0.1$ mag versus $\Delta m_{03} = 1.14 \pm 0.04$ mag in 2003.

3. Model

To interpret the change in the lightcurve in terms of QG$_{298}$'s obliquity (angle between the inner, mutual binary orbit and the outer, heliocentric orbit) we used the Roche contact binary model from [3] (Fig 2). We simulated lightcurves for a range of obliquities $0° \leq \varepsilon \leq 90°$ in the time interval between 2003 and 2014. Fig 3 shows the predicted Δm versus time and Fig 4 overplots the model lightcurves on our new 2010 data. We find that the new data are incompatible with low obliquity. Monte Carlo and χ^2 statistical analyses of the fits in Fig 4 imply that QG$_{298}$ has an obliquity

$\varepsilon = 90 \pm 30°$. A self-consistent, simultaneous fit to the 2003 and 2010 data based on the model in Fig 2 is shown in Fig 1.

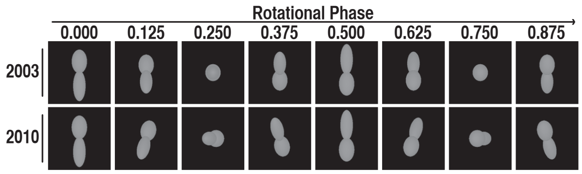

Figure 2: Roche binary model of QG_{298} as seen from Earth in 2003 (top) and in 2010 (bottom) assuming obliquity $\varepsilon = 90°$. Successive rotational phases (left to right) simulate rotation and show maximum and minimum cross-sections.

4. Implications

The large obliquity of QG_{298} is not unique. Table 1 lists bodies with extreme shapes and effective diameters $D_e > 100$ km. They all have obliquities in the range $50° < \varepsilon < 130°$. Assuming isotropic spin poles, the chance that all 4 have obliquities in that range is $(\cos 40°)^4 = 0.17$. Hence, the sample in Table 1 is too small to rule out an isotropic spin distribution. However, if contact binaries do tend to have large obliquities (as predicted by a recent theory for their formation [4]), then their abundance has been underestimated by assuming that they are isotropically oriented. The probability that the spin pole of the model in Fig 2 lies sufficiently distant from the line of sight to permit identification as a contact binary is $p = 0.15$ in the isotropic case. If contact binaries are restricted to obliquities $50° < \varepsilon < 130°$ then the detection probability is only $p\prime = 0.11$. The implication is that the intrinsic contact binary abundance in the KB is higher than previously believed by a factor $p/p\prime = 1.4$.

Table 1: Obliquity of large extreme shape objects.

Object	Group	D_e [km]	Shape	ε [°]
90 Antiope	MBA	120	close binary	53±2
216 Kleopatra	MBA	135	bi-lobed	84±2
624 Hektor	Trojan	230	contact binary	98±5
QG_{298}	KBO	250	contact binary	90±30

5. Conclusions

(a) The 2003 and 2010 lightcurves of QG_{298} appear in phase when shifted by an integer number of full

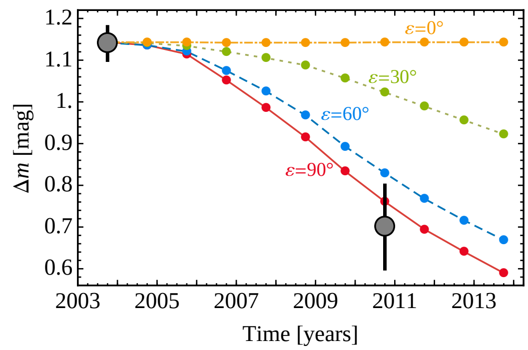

Figure 3: Predicted photometric range for QG_{298} as a function of time and obliquity. Measured Δm in 2003 and 2010 are shown with 1-σ error bars.

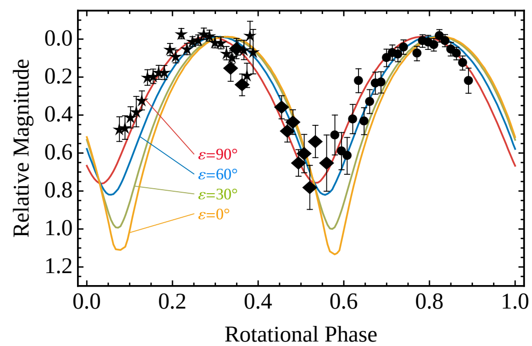

Figure 4: Models versus 2010 lightcurve (points with 1-σ error bars). Fits for $\varepsilon = 0°, 30°, 60°, 90°$ have respective reduced χ^2 values $\chi^2_{\rm red} = 18.8, 12.3, 4.4, 1.7$, favoring the solution $\varepsilon = 90°$.

rotations but the latter has a peak-to-peak range of $\Delta m_{10} = 0.7 \pm 0.1$ mag, significantly lower than the former, $\Delta m_{03} = 1.14 \pm 0.04$ mag; (b) The change between the 2003 and 2010 lightcurves is most simply explained if QG298 possesses a large obliquity, $\varepsilon = 90 \pm 30°$; (c) If, as QG298, contact binaries tend to have large obliquities their abundance may be larger than previously believed.

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References

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[2] Sheppard, SS, & Jewitt, D 2004, AJ 127, 3023
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