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A Martian origin for the Mars Trojan asteroids

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Table I: Circumstances of observations

Asteroid	Date	Total exp. time [min]	Image num.	R [AU]	Delta [AU]	Alpha [degrees]	V. mag	Standard star
311999	2016 Feb 13	84	42	1.47	0.57	25.5	18.9	L98-978, L102-1081
385250	2016 Feb 14	124	54	1.47	0.49	5.2	18.6	L98-978, L102-1081

- Columns: asteroid designation, date of observation, combined exposure time, number of images, heliocentric and geocentric distances, phase angle, V-mag from MPC, and Solar analog used for calibration.

YORP timescale

It was suggested[3] that the thermal Yarkovsky-O'Keefe-Radzievskii-Paddack (YORP) effect[37] spun-up Eureka resulting with fragments being ejected by the rotational-fission mechanism[38]. Indeed, the rotation period of Eureka is 2.6902 hours[39] near the "spin barrier", the threshold of asteroid rotation at ~2.2 hours (for bodies[40] with a diameter D>0.2 km such as Eureka[25] with D=1.9±0.2 km). The YORP effect timescale for a 2 km object in a Mars Trojan orbit is about 10^8 yrs. This timescale is short compared to the dynamical lifetime of Eureka in the Mars Trojan region[18] (greater than the age of the solar system), so there is enough time for multiple rotational fission events including a few catastrophic events resulting in the seven members observed today.

The YORP effect is a thermal torque imposed on asteroids due to the reflection and re-emission of sunlight from the body's asymmetric surface. Since the YORP effect is applied by the momentum carried by sunlight photons, it is mainly a function of the asteroid radius R and its heliocentric distance, characterized by its semi major-axis a. The resulted change in the spin rate of the asteroid *dω/dt* can be defined by[41]:

$$\frac{d\omega}{dt} = \frac{Y}{2\pi\rho R^2}\frac{F}{a^2\sqrt{1-e^2}}$$

where ρ is the density of the body and e is the eccentricity of its orbit. F is the solar irradiance (1.361 kW/m^2, at 1 AU) modified by the speed of light to derive solar radiation pressure and normalized to a unit distance[41] ($\sim10^{14}$ kg km s^{-2}). Y is a non-dimensional YORP coefficient determined by the asymmetric shape of the asteroid and the obliquity of its rotation. The YORP timescale τ_{YORP} is defined by:

$$\tau_{YORP} = \frac{\omega}{\left|\frac{d\omega}{dt}\right|}$$

where ω is the spin rate.

Observational studies have shown that the YORP effect can double the spin rate of an asteroid in a relatively short timescale of about a million to 10 million years for a km-sized (D=1 km) near-Earth (a=1 AU) asteroids[42,43,44,45,46]. For a Mars Trojan, located at a semi-major axis of a=1.5 AU, with a diameter D=2 km, *dω/dt* should decrease by $(1.5/1)^2(2/1)^2 \sim 10$, which sets the τ_{YORP} at 10 to 100 million years, at least an order of magnitude smaller than the dynamical age of the Eureka cluster, giving sufficient time for Eureka to spin-up beyond the spin limit due to the YORP effect and to shed mass.

Estimating asteroid diameters

The diameters of the Trojans were evaluated by their absolute magnitude H (from the Minor Planet Center website: http://www.minorplanetcenter.net/iau/mpc.html), with an uncertainty[47] of +0.542 and -0.242, assuming a typical albedo[48] of Pv=0.19±0.03, a spherical shape, and the relation[49]: $D = \frac{1329}{\sqrt{P_V}} 10^{-0.2H}$.

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