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COMET 252P/LINEAR: BORN (ALMOST) DEAD?

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ABSTRACT

Previous studies have revealed Jupiter-family comet 252P/LINEAR as a comet that was recently transported into the near-Earth object (NEO) region in ∼1800 AD yet only being weakly active. In this Letter, we examine the "formed (almost) dead" hypothesis for 252P/LINEAR using both dynamical and observational approaches. By statistically examining the dynamical evolution of 252P/LINEAR over a period of 10^7 years, we find the median elapsed residency in the NEO region to be 4×10^2 years, which highlights the likelihood of 252P/LINEAR as an (almost) first-time NEO. With available cometary and meteor observations, we find the dust production rate of 252P/LINEAR to be on the order of 10^6 kg per orbit since its entry to the NEO region. These two lines of evidence support the hypothesis that the comet was likely to have formed in a volatile-poor environment. Cometary and meteor observations during the comet's unprecedented close approach to the Earth around 2016 March 21 would be useful for understanding of the surface and evolutionary properties of this unique comet.

Key words: comets: individual (252P/LINEAR) – meteorites, meteors, meteoroids

1. INTRODUCTION

Comets are small, icy objects originating from the outer solar system. They are the leftover planetesimals from the formation of the outer planets. These objects remain in the outer solar system for most of their lifetime, until perturbations sent them into the inner solar system where they become visible. It has been noted that the observable comet population displays a large diversity in ice composition that, apart from evolutionary effects, is linked to predictions that comet nuclei were formed at different places and times in the solar nebula (e.g., Whipple 1987; Bockelée-Morvan et al. 2004). Thus, the observation of comets provides a unique opportunity for understanding the range of chemistry in the primitive solar nebula.

However, the quest is not without its obstacles. Observational interpretations are biased by the fact that more active comets tend to be easier to detect and study, meaning that less active comets are somewhat underrepresented in the sample. Dynamical investigations are limited by the chaotic nature of the orbital evolution of small bodies, which make it challenging to reconstruct the orbit of history over even modest timescales (e.g., $\sim10^3$ years). The fact that the evolutionary processes of cometary nuclei are little understood makes it difficult to isolate evolutionary effects from formation diversity when addressing the volatile inventory of individual objects.

Numerical integrations carried out by Tancredi (2014) indicate that Jupiter-family comet (JFC) 252P/LINEAR might have entered the near-Earth object (NEO) region[3] only ∼50 orbits ago. This short dynamical timescale suggests that 252P/LINEAR should be a "physically young" comet, considering the typical physical lifetime of near-Earth JFCs of 150–200 revolutions (Di Sisto et al. 2009). However, with an absolute total magnitude of $M_1 = 18.6$[4], 252P/LINEAR exhibits the characteristics of a weakly active comet (Ye et al. 2016). Considering its recent entry to the NEO region, we expect evolutionary processes to have played a relatively minor role in altering the subsurface volatile composition. One possible explanation of the weak activity in this young comet could be a volatile-poor environment at the time of formation of the nucleus.

The 2016 perihelion passage of 252P/LINEAR offers an exceptional opportunity for Earth-based observers to study the comet. The comet will pass perihelion on 2016 March 15 and make a close approach to the Earth on 2016 March 21 at 0.036 au, which is one of the closest cometary approaches to the Earth on record.[5] The Earth may also have passed through the dust trails produced by 252P/LINEAR during its past revolutions[6], potentially producing meteor activity. Despite the proximity of 252P/LINEAR's nodal point to the Earth's orbit, meteor activity from 252P/LINEAR has not been reported. However, it is well known that meteor observations are useful in understanding of the physical history of a comet (e.g., Yeomans 1981; Jenniskens 2004). Meteoroids from 252P/LINEAR could provide clues to the recent history of the comet.

In this Letter, we examine the "born (almost) dead" scenario for the case of 252P/LINEAR in preparation for the observation campaigns in 2016 March. We adopt two approaches: an examination of the dynamical evolution of the comet (Section 2), as well as an analysis of the available comet and meteor observations guided by an existing cometary dust model (Section 3). Results from both tracks are discussed and summarized in Section 4.

2. DYNAMICAL EVOLUTION

We generated 1000 "clones" of 252P/LINEAR using its orbital covariance matrix provided in JPL 28[7] (Table 1) and integrated them 10^5 years backward in time from 2000 AD. Integration was performed with the MERCURY6 package using the symplectic integrator (Chambers 1999). Clones are

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[3] NEO region refers to the region within 1.3 au from the Sun.

[4] From the JPL Small-Body Database, http://ssd.jpl.nasa.gov/sbdb.cgi?sstr=252P, accessed 2015 December 21.

[5] http://www.minorplanetcenter.net/iau/lists/ClosestComets.html, accessed 2015 December 21.

[6] M. Maslov (unpublished), http://feraj.narod.ru/Radiants/Predictions/252p-ids2016eng.html, accessed 2015 December 21.

[7] From the JPL Small-Body Database, http://ssd.jpl.nasa.gov/sbdb.cgi?sstr=252P, accessed 2015 December 21.

Table 1
Orbital Elements and Relevant Parameters of 252P/LINEAR

Parameter	Value
Epoch	Julian Date 2455731.5
Perihelion distance q	1.00006 au
Semimajor axis a	3.05560 au
Eccentricity e	0.67271
Inclination i	10°.38990
Longitude of the ascending node Ω	190°.99780
Argument of perihelion ω	343°.28753
Epoch of perihelion passage t_p	2010 Nov 13.66041 UT
Non-gravitational radial acceleration $\mathcal{A}_1$	3.25×10^{-9} au d^{-2}
Non-gravitational transverse acceleration $\mathcal{A}_2$	2.04×10^{-10} au d^{-2}
Non-gravitational normal acceleration parameter $\mathcal{A}_3$	3.36×10^{-10} au d^{-2}
Nucleus radius R_N	0.5 km[a]

Notes. Orbital elements are extracted from JPL 28
[a] M. Drahus (2015, private communication).

considered to have been ejected from the solar system when they reach a heliocentric distance of 100 au.

As shown in Figure 1, we confirm the recent (circa 1800 AD) entry of 252P/LINEAR into the NEO region. The distribution of the clones is extremely compact until a close approach to Jupiter in 1690 AD (miss distance ~0.1 au). There have been a few recent approaches to the Earth: 0.10 au in 2000 March (when the comet was discovered), 0.08 au in 1921 March, and 0.05 au in 1847 February. If the activity level of 252P/LINEAR in the 19th century is comparable to what it is today, the comet would have been at +10 mag during its approach in 1847. We searched through the catalog of 19th century comets compiled by Kronk (2008) but did not find any association. Comets at this magnitude may be at the observational limit for 19th century observers (Everhart 1967), but the lack of detection also implies that the comet was probably not substantially much more active at that time compared to today.

With evidence that 252P/LINEAR has possibly been very weakly active since its current entry to the NEO region, it is possible that the comet depleted most of its volatiles during a previous residency in the NEO region. The question then becomes: how long did 252P/LINEAR reside in the NEO region in the past? To answer this question, we extend our integration backward and forward in time for 10^7 years. We find the median elapsed residency in the solar system (i.e., the time that the clone *already* spent as a bounded object) to be 1.3×10^5 years and the median elapsed NEO region residency to be 4×10^2 years. The median dynamical lifetime (i.e., the *total* time that the clone has and will spend as a bounded object) and median integrated time as an NEO are found to be 2.5×10^5 years and 4×10^3 years, respectively. While this dynamical and NEO lifetime is comparable to the values for the general JFC population (Fernández et al. 2002), we note that the elapsed residency as an NEO is virtually null as it is certain the comet has already spent ~200 years in the NEO region (since its current entry in ~1800 AD). This suggests that 252P/LINEAR is likely a first-time (or, almost first-time) visitor to the NEO region.

We also examine the time that 252P/LINEAR has spent in a "visible" state (i.e., $q < 2.5$ au; Quinn et al. 1990). The value of 2.5 au is considered to be the distance from the Sun that water-ice sublimation is expected to start (e.g., McNamara et al. 2004). We find the elapsed and total median time of 252P/LINEAR as a visible comet to be 4×10^3 years and 1.2×10^4 years, the latter of which is more in line with literature values (~8.5×10^3 years as given by Levison & Duncan 1994) compared to that in the NEO region. This indicates that 252P/LINEAR may have been active for some time before it entered the NEO region, but the process of thermal devolatilization occurs on longer timescales for comets with larger q (e.g., Jewitt 2004).

3. CURRENT AND PAST DUST PRODUCTION

The current and past dust production of comets can be constrained by cometary and meteor observations. A parameter commonly used as a proxy for cometary dust production is the $Af\rho$ parameter (A'Hearn et al. 1984):

$$Af\rho = 4r_H^2\Delta^2\rho^{-1}\cdot 10^{0.4(m_\odot - m)} \tag{1}$$

where r_H is the heliocentric distance of the comet, Δ is the geocentric distance of the comet, ρ is the linear radius of the photometric aperture at the distance of the comet, and $m_\odot$ and m are the apparent magnitudes of the Sun and the comet.

Prior to its 2016 perihelion passage, 252P/LINEAR had only been observed during its 2000 and 2010 passages (the 2005 passage was not observed possibly due to poor viewing geometry). However, the 2010 passage was only observed at $r_H = 2.5$ au on its outbound leg, and the comet had likely already ceased activity. Hence, we only use the observations from the 2000 passage that cover a section of $r_H = 1.1$ au to 1.5 au on the outbound leg of the comet. We obtain a total of 80 observations from the Minor Planet Center Observation Database (http://www.minorplanetcenter.net/db_search/show_object?object_id=252P) and calculate the $Af\rho$ quantity using Equation (1). The ρ parameter accounts for the photometric aperture that differs among observers; to simplify the problem, we adopt an aperture of $13''$ from the conservative (small) end of coma diameter estimations (Shelly et al. 2000). The computed $Af\rho$ are therefore at the upper end of possible values.

The temporal variation of the $Af\rho$ parameter of 252P/LINEAR during its 2000 perihelion passage is shown as Figure 2. The upward trend before $t_P + 55$ d (t_P is the perihelion epoch) is likely an artifact due to small Δ at the time of the observation and the conservative ρ used in the calculation, resulting in an underestimation of the cometary flux (coma diameter estimation given in Shelly et al. 2000 varies from $13''$ to $1'$). The median $Af\rho$ value is 0.6 cm, one of the lowest numbers ever measured for a comet and comparable to the reported $Af\rho$ of another low-activity comet, 209P/LINEAR (Schleicher & Ye 2014). We further note that the $Af\rho$ may be contaminated by the light reflected from the nucleus given the extremely low dust production of 252P/LINEAR, which may result in some overestimation of the measured $Af\rho$; hence, the actual $Af\rho$ could be even lower.

To search for any meteor activity originated from 252P/LINEAR, we make use of the Monte Carlo meteoroid stream model developed in our earlier works (cf. Ye et al. 2015 and references therein). Integrations are performed using the 15th-order RADAU integrator bundled with the MERCURY6 package (Everhart 1985). Gravitational perturbations from the eight major planets (with the Earth–Moon system represented by a single mass at the barycenter of the two bodies), radiation

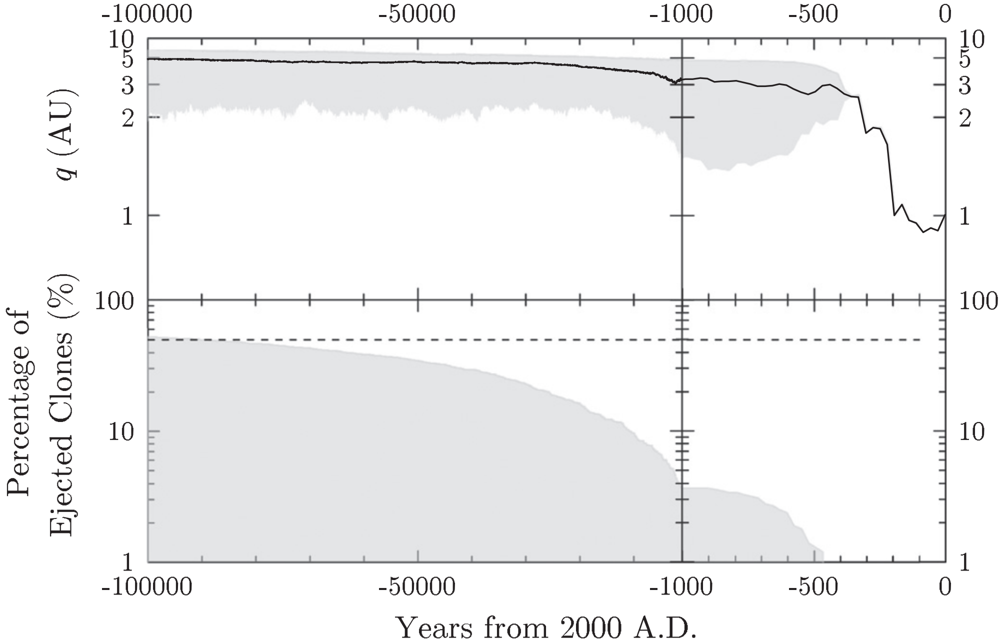

Figure 1. Dynamical evolution of 1000 clones of 252P/LINEAR over a time interval of 10^5 years with a zoomed section for 1000 years. Upper panel: median (black line) and $\pm 1\sigma$ region (shaded) of the evolution of perihelion distance q. Lower panel: percentage of ejected clones (clones that reach heliocentric distance of 100 au).

pressure, and Poynting-Robertson effect are included. We first integrate 252P/LINEAR back to 1800 AD (i.e., back to its entry into the NEO region) and then integrate it forward in time, releasing meteoroids in the diameter range of 0.5 mm $< a <$ 50 mm (i.e., the diameter range that associates with visible meteors) when the comet is at each perihelion, assuming a bulk density of 1000 kg m^{-3} and a size distribution of $dN/da \propto a^{-2.6}$. Modeling of meteoroid streams is usually insensitive to the ejection model (e.g., Williams 2001; Williams & Ryabova 2011); however, since 252P/LINEAR is apparently a low-activity comet, we use two different ejection models and repeat the simulation for each one of them: the "low-activity scenario" described in Ye et al. (2016) and the "normal scenario" described in Brown & Jones (1998). At the completion of the integration, we examine two scenarios of possible meteor activity: (1) meteor outbursts from young meteoroid trails. This is examined by selecting meteoroids that are approaching the Earth within 0.01 au in the period of interest and (2) annual "background" activity, i.e., activity from older, more dispersed trails. This is examined by selecting meteoroids with the minimum orbit intersection distance (MOID) with respect to the Earth's orbit <0.01 au.

The simulation result for 2001–2020 is listed in Table 2. We note that the result is sensitive to the choice of ejection model in contrast to other meteor showers, probably due to the relatively young age of the trails and small encounter speed. By applying the flux estimation technique outlined in Ye et al. (2015), we find that most of these computed activities are below the detection limit of modern meteor surveys, except for the outburst cases of 2011 and 2016. In 2011, the Earth passed close to the 1984 and 1989 trails, which are very young and compact trails that formed recently. However, the characteristic MOID of both encounters are close to the selection limit (close to ∼0.01 au); therefore, the possibility of meteor activity is likely minimal. In 2016, the Earth will pass close to the 1915, 1921, and 1926 trails. Assuming a dust production rate of 252P/LINEAR in the 1920s is comparable to its current value; the meteor flux is likely to be on the order of 10^{-4} to $10^{-3}\,\mathrm{km}^{-2}\,\mathrm{hr}^{-1}$, or less than a few meteors in terms of zenith hourly rate (ZHR).

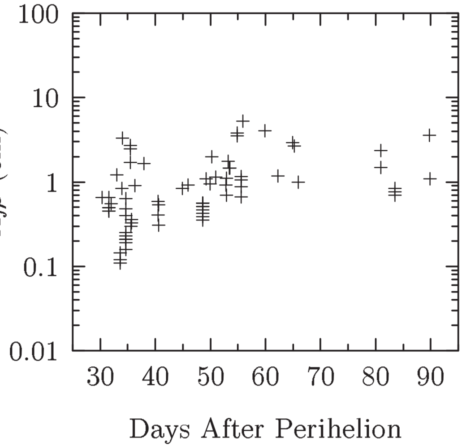

Figure 2. Temporal variation of the $Af\rho$ parameter of 252P/LINEAR during its 2000 perihelion passage. The median value is 0.6 cm.

Next, we conducted a search in the survey data collected by the Canadian Meteor Orbit Radar (CMOR; cf. Jones et al. 2005 and references therein). We apply the wavelet technique described in Brown et al. (2008) at the computed radiants to search for meteor activity, without finding any enhancement (Figure 3). Using the number of background meteors detected by CMOR within a radius of 10° of the expected radiant and 10% from the expected meteoroid speed, as well as the CMOR collection area as a function of the declination (Brown & Jones 1995), we estimate the upper limit of the meteoroid flux to be on the order of $10^{-4}\,\mathrm{km}^{-2}\,\mathrm{hr}^{-1}$ to a limiting mass of $\sim 10^{-7}$ kg, with an uncertainty within a factor of several due to the unconstrained mass distribution of the stream (which affects the collection area).

From the simulation, we find the meteoroid delivery efficiency (i.e., the fraction of the ejected meteoroids with MOID $<$ 0.01 au) to be $\eta = 17\%$. Assuming that the

Table 2
Computed Meteor Activity from 252P/LINEAR in 2001–2020, with the Low-activity Ejection Model from Ye et al. (2016) and Normal Ejection Model from Brown & Jones (1998)

Year	Ejection Model	Trail	Peak Time (UT)	Radiant α_g, δ_g	v_g (km s^{-1})
2002	Low-activity	1910	2002 Mar 28 03:40	$89\overset{\circ}{.}9$, $-12\overset{\circ}{.}4$	10.3
	Normal	1910	2002 Mar 28 06:23	$90\overset{\circ}{.}0$, $-12\overset{\circ}{.}1$	10.3
2008	Low-activity	1905	2008 Apr 15 16:47	$77\overset{\circ}{.}4$, $+4\overset{\circ}{.}6$	10.9
	Normal	1905	2008 Apr 15 18:50	$77\overset{\circ}{.}5$, $+4\overset{\circ}{.}7$	10.9
2011	Normal	1984	2011 Apr 4 16:45	$75\overset{\circ}{.}7$, $-9\overset{\circ}{.}1$	11.1
		1989	2011 Mar 31 2:11	$77\overset{\circ}{.}4$, $-16\overset{\circ}{.}0$	11.0
2016	Low-activity	1915	2016 Mar 28 00:10	$78\overset{\circ}{.}2$, $-17\overset{\circ}{.}7$	11.0
		1921	2016 Mar 27 20:47	$78\overset{\circ}{.}1$, $-17\overset{\circ}{.}4$	11.0
	Normal	1915	2016 Mar 28 00:36	$78\overset{\circ}{.}2$, $-17\overset{\circ}{.}9$	11.0
		1921	2016 Mar 27 22:42	$78\overset{\circ}{.}1$, $-17\overset{\circ}{.}7$	11.0
		1926	2016 Mar 27 15:09	$78\overset{\circ}{.}0$, $-17\overset{\circ}{.}1$	11.0
Annual	Low-activity	···	$\lambda_\odot = 10°$	77°, −16°	10.9
	Normal	···	$\lambda_\odot = 10°$	77°, −16°	10.9

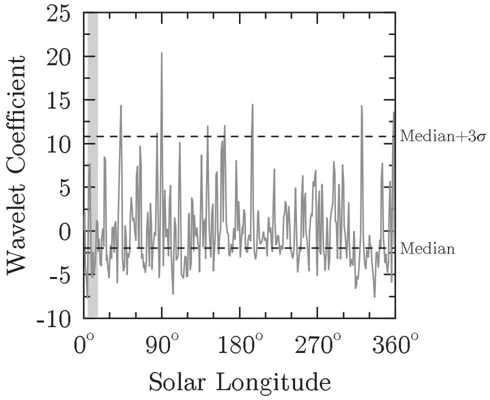

Figure 3. Temporal variation of wavelet coefficient of CMOR data, centered at the computed radiant ($\alpha_g = 77°$, $\delta_g = -16°$, $v_g = 10.9$ km · s^{-1}) of meteor activity from 252P/LINEAR. Shaded region indicates the predicted meteor activity from 252P/LINEAR.

meteoroids are uniformly distributed along the orbit of 252P/LINEAR, we can estimate the past dust production since the comet's entry into the NEO region using

$$N = \frac{\mathcal{F}P \cdot \Delta X^2}{\eta N_{\rm orb}}$$

where N is the meteoroid production per orbit, $\mathcal{F} = 10^{-4}$ km^{-2} · hr^{-1} is the upper limit of meteoroid flux constrained by meteor data, $P = 5$ years is the orbital period of the meteoroids, $\Delta X = 0.01$ au is the collection area, and $N_{\rm orb} = 50$ is the number of orbits that the comet is active. By inserting numbers from a previous analysis, we get $N = 10^{12}$ meteoroids, or $\sim 10^6$ kg per orbit appropriate to millimeter-sized dust (assuming a bulk density of 1000 kg m^{-3}). For comparison, the dust production rate of 55P/Tempel-Tuttle (parent of the Leonid meteor shower) is of the order of 10^{11} kg per orbit (Vaubaillon et al. 2005). While the actual number may be off by an order of magnitude, such an extremely low number illustrates 252P/LINEAR as a comet with very low dust production, as well as its lack of significant activity since its entry into the NEO region.

4. SUMMARY

The two lines of evidence—dynamical and observational—have outlined 252P/LINEAR as a comet that is likely an (almost) first-time visitor to the NEO region, yet only a little active in terms of dust production. This evidence supports the hypothesis that 252P/LINEAR was likely to have formed in a volatile-poor environment, as compared to other members in the visible JFC population. Cometary and meteor observations during its close approach in 2016 March will likely provide more information regarding the surface and evolutionary properties of this unique comet.

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