Evidence for 2009 WN25 being the parent body of the November i-Draconids (NID)

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Abstract

In this work we propose the Amor-type asteroid 2009 WN25 as the likely progenitor of the November i-Draconids (NID, IAU#392), a recently detected weak annual meteoroid stream. We first describe our recovery and follow-up effort to obtain timely ground based astrometry with large aperture telescopes, and ensure that 2009 WN25 would not become lost. We then discuss the possible parent-stream association, using its updated orbit to model the ejection of dust particles from the surface of the parent body and match the observed properties of the stream.

Keywords: Meteors, Near-Earth objects, Interplanetary dust

1. Introduction

The high rate of near-Earth object discoveries in the past decade resulted in a large database of objects in Earth-approaching orbits, and some of them have already been proposed as possible parents of known meteor showers. The first attempt to create a systematic list of proposed parents, published by Jenniskens (2006)\textsuperscript{1}, included about 60 objects, most of which were newly proposed associations with objects in Jupiter-family comet orbits, all having orbital elements similar to the meteoroid streams. Other works, such as Babadzhanov et al. (2008), addressed the identification of parents of specific meteor showers using less strict similarity criteria, and also proposing many asteroidal candidates.

If the compilation of a list of stream progenitors is not simple, the definition of a trustworthy list of meteoroid streams has been even more difficult, because historically no single organization has been responsible for the maintenance of a homogeneous census of meteor showers. The first attempt to collect all published activity reports (and the associated stream orbits) was again by Jenniskens (2006), who made an effort to identify as many literature references as possible to known or proposed streams.

Starting in 2007, his work has formed the basis for a list of known showers, published and now routinely updated by Tadeusz J. Jopek at the IAU Meteor Data Center (MDC), under the authority of the International Astronomical Union (IAU).

Even more recently, the establishment of systematic surveys such as the optical CAMS (Jenniskens et al., 2011) and the radar CMOR (Brown et al., 2008) surveys. Nowadays, new showers are routinely established by some of these surveys, and systematically evaluated and approved by the IAU before inclusion in the official list.

1.1. The November i-Draconids

The MDC list contains two established showers active in early December from the area of Draco, each describing two apparently separated clusters of activity visible in Fig. 1\textsuperscript{1}. The two showers are known as the December $\alpha$-Draconids (DAD, IAU#334), peaking at $\lambda = 256.6^\circ$ from $\alpha = 207.9^\circ$ and $\delta = +60.6^\circ$, and the December $\kappa$-Draconids (KDR, IAU#336), peaking at $\lambda = 250.2^\circ$ from $\alpha = 186.0^\circ$ and $\delta = +70.1^\circ$.

In addition to these radiants, the same area contains an additional proposed stream with similar properties, the November i-Draconids (NID, IAU#392)\textsuperscript{1} active in late November of each year from a solar longitude $\lambda \sim 241^\circ$, they originate from a radiant located at $\alpha \sim 200^\circ$, $\delta \sim +65^\circ$.

Already clearly visible in the SonotaCo Network database (http://sonotaco.jp/doc/SNM/), this complex activity was formally proposed by Brown et al. (2010)\textsuperscript{2} on the basis of radar data, and it was subsequently confirmed by CAMS (see Fig. 1). All these streams share a relatively high geocentric velocity of $v_g \sim 43$ km s$^{-1}$, which directly suggests a progenitor in an orbit significantly different from Earth’s.

The designation November i-Draconids is now often used to identify the diffuse component that encompasses both showers, while the two established designations December $\alpha$-Draconids and December $\kappa$-Draconids identify the separate clusters visible in Fig. 1. In the following we will use the name November i-Draconids to identify all the components together, since our

\textsuperscript{1}The shower is sometimes incorrectly given as “November $i$-Draconids”, with a Greek letter “iota” instead of an “i”.

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results suggest that the entire complex structure of radiants can be generated by the same parent body.

2. Establishing a possible progenitor of the stream

A preliminary analysis of possible progenitors for the November i-Draconids, conducted according to the methods outlined in [Micheli (2013)] and on the sole basis of the radiant information in the MDC database, shows an extremely good match of the shower’s observing circumstances with those of possible stream associated with 2009 WN25, an Amor-type asteroid discovered on 2009 November 22 by the Catalina Sky Survey in Arizona, USA. The asteroid has a very peculiar orbit, with \( a \approx 3.25 \text{ au}, e \approx 0.66 \) and \( i \approx 72^\circ \); its absolute magnitude is approximately 18.3, suggesting a diameter of approximately 1 km if its albedo is at least moderately dark. Although inactive at the time of discovery, its Tisserand invariant with respect to Jupiter is \( T_J \approx 1.96 \), which immediately suggests a non-asteroidal origin and likely cometary nature.

However, at the time of this preliminary analysis 2009 WN25 only had observations spanning an arc of 25 days, from its discovery to a last detection from Siding Spring, Australia, on 2009 December 17. After that, the object became too faint, or too far south, for most follow-up stations, and would have become lost at its subsequent apparition. In addition, the short observational coverage, although sufficient to suggest a possible linkage with the stream, was far too short to meaningfully characterize the past dynamical evolution of the object, or to simulate possible particle ejection scenarios that may account for the generation of the observed stream. Additional follow-up was therefore necessary to confirm or discard this possible association.

2.1. Recovery of 2009 WN25

Around the time 2009 WN25 was first noticed as a possible stream progenitor, the object was quickly receding from Earth, with a magnitude fainter than \( V = 23 \) and located in the Southern sky, at a declination of about \(-50^\circ\). Furthermore, the sky-plane uncertainty at the time was about 15', making it a difficult target for most small-field imagers that are available on large telescopes.

A search for possible instruments in the Southern hemisphere, with large enough aperture and field of view to detect such an object, showed that the only possible match at that time was the Mosaic II imager on the 4.0 m CTIO Blanco telescope in Chile. Fortunately one of the observers scheduled at the telescope around that time agreed to obtain a few exposures of the object just after twilight of her two nights at the telescope, on 2010 June 6 and 7. These observations allowed us to recover the object about 2' away from our own predicted ephemeris, and about 4' from the nominal MPC solution. An image from the second recovery night is presented in the left panel of Fig. 2.

A few days later, we were able to obtain an additional single detection of the object with the 2.0 m Faulkes Telescope South at Siding Spring, Australia. Although the detection was much fainter than the one from CTIO, it provided us with an independent confirmation that the original recovery was indeed correct.

These observations in 2010 already extend the observed arc on 2009 WN25 from 25 to 203 days, a coverage sufficient to properly model the past dynamics of the stream. Most of the results of this work can already be established on the basis of this observational arc.

However, to better understand the association it is essential that the object does not become lost even after further follow-up has been obtained. For this reason, we also attempted additional recovery observations of 2009 WN25 in May 2012, using the 8.2 m Gemini North telescope. Observations for the program were collected under very poor seeing conditions on 2012 May 26, and the image quality was not sufficient to achieve a detection of the object, which at the time was predicted at \( V = 25.5 \).
To take advantage of the next favorable observational opportunity for this object we had to wait until mid-2015, when 2009 WN25 emerged from solar conjunction at high Northern declinations, becoming observable again from the Northern hemisphere. We successfully recovered the object on 2015 August 11 with the MegaPrime one-degree imager on the 3.6 m Canada-France-Hawaii Telescope atop Mauna Kea, Hawaii, USA (Fig. 2, central panel), and confirmed it one night later with the 2.2 m University of Hawai‘i reflector on the same mountain (Fig. 2, right panel). The object was located only 7′ away from the prediction based on our 2010 CTIO observations. Without them, the asteroid would have been more than 20° away from the nominal position, effectively lost inside a skyplane uncertainty region more than 60° long.

2.2. Dust ejection models

Before the association of an object with a stream can be considered significant, it is important to verify it with a dynamical simulation of the stream creation process, modeling the ejection of meteoric particles in the distant past and checking if any ejection scenario can match the current activity profile of the stream.

The first step of this modeling is to numerically integrate the orbit of the parent for a few centuries in the past. This integration is meaningful only if the orbit of the object is known with sufficient accuracy, explaining the need for the recovery observations presented in Sect. 2.1. When a sufficient observed arc is available, ideally many months to a few years long, we can use standard integration software tools to determine the past evolution of the orbit. For this project we used the SolSyIn package[^1] to integrate the orbit of the parent object to the desired epoch in the past, taking into account all planetary perturbers (including the Earth and the Moon as separate masses) and relativistic effects.

To investigate the possible creation of a meteoroid stream at a certain epoch, synthetic particles with various masses are then ejected from the object (at perihelion) with different velocities. The choice of the maximum ejection velocity is done using the empirical formula from Whipple (1951):

\[ v_{ej} = \sqrt{\frac{43.0 D_e}{\rho d^2 r^9/4}} - 0.559 \rho_c D_e^2 \]  

where \( d \) is the size of the particle (in cm) and \( \rho \) is its density (in g cm\(^{-3}\)), while \( D_e \) and \( \rho_c \) are those of the parent body (this time in km and again g cm\(^{-3}\)), and \( r \) is the heliocentric distance at the time of ejection (in au, which we assume to be equal to the perihelion distance \( q \)). We also assume \( \rho = \rho_c = 1 \) g cm\(^{-3}\), meaning that the ejected particles have the same density as the parent body, assumed to be the same as water.

In our model a few hundreds of particles of a given size are isotropically ejected from the surface of the asteroid, with velocities up to \( v_{ej} \). From there on they are treated as separate bodies, and the dynamics of each one is then independently integrated forward to the present time, taking into account non-gravitational effects (such as radiation pressure and relativity) that are significant for small-size particles.

Each particle of the cloud can now be treated as an independent meteoroid: the time of its close approach with Earth, its radiant and its entry velocity can be determined with the procedures from Neslusan et al. (1998), and compared with the observed properties of the candidate meteor shower, to confirm or reject the attribution of the stream to the specific parent that was used in the simulation. In most of these simulations there is a quite significant degeneracy between the size of the particles, the ejection velocity and sometimes the epoch of ejection. In each simulation we chose to eject particles with a range of velocities from zero to the threshold defined by Eq. (1) while keeping the particle size fixed. The best match between observed and simulated properties of the shower is then searched by repeating the simulation with different discrete choices of particle size and ejection time; as a result, the values

[^1]: http://math.ubbcluj.ro/~jsberinde/solsyin/index.html
presented below should be viewed only as an approximation of the actual properties of the stream.

Using our updated orbit of 2009 WN25 we computed a set of ejection models to attempt a match with the observed properties of the November i-Draconids stream. Different particle sizes (from 10 μm to 1000 μm) and different ejection times (from 100 to 500 years ago) were tested, and their Earth-intersecting orbits were computed by the adjustment of perihelion method of Neslusan et al. (1998) (chosen because it provided the smallest orbital discrepancy as estimated by the D-criterion of Southworth and Hawkins, 1963).

The best possible match was obtained with particles of about 30 μm ejected from the parent body a century ago (see Fig. 3), although other combinations produced similar results, the main difference being a more or less compact distribution of the radiant points around the same general structure.

The model not only replicates the appropriate radiant position, but also the complex morphology with multiple subradiants (DAD, NID and KDR) visible in the CAMS and SonotaCo data. However, the node of the encounter is not in agreement: the observed showers are detected during solar longitude 231°–248°, 239°–268° and 250°–255° respectively, while the calculated clusters are encountered at solar longitude 231°–235°, 222°–230° and 220°–222° instead.

This complex structure reproduced by our simulations is likely to be the peculiar recent dynamical evolution of 2009 WN25, which had an unusually small MOID with Jupiter for the entire last century, reaching a minimum of less than 10^{-4} au around 1971; Although the object itself did not have any exceptionally close approach around that time, coorbital particles located along the orbit could have been dramatically affected, creating the features we see in the current radiant of the November i-Draconids. Slight changes in the geometry of these close approaches may also be responsible for the mismatch of the solar longitudes noted above.

3. Conclusions

In this work we presented the successful recovery of 2009 WN25, and suggested its association with the November i-Draconids (NID), a proposed complex of weak meteoroid streams. Although 2009 WN25 is currently inactive, it is shown that this NEO could have ejected meteoric particles approximately a century ago, and they would have evolved into orbits that are a good match to the observed radiant distribution of the stream. Furthermore, the peculiar structure of the November i-Draconids complex of radiants is also matched by the simulations, thus giving further credit to the association. A discrepancy in the solar longitudes of arrival may be on account of past close encounters with Jupiter.

Thanks to our observations 2009 WN25 now has a well-established orbit that will allow further monitoring in the future, instead of becoming another member of the growing collection of lost NEOs. It is possible that 2009 WN25 may show cometary activity in one of its future apparitions, thus making evident its cometary nature and strongly supporting its association with a meteoroid stream. Furthermore, if taxonomic observations can be obtained in the future, they may show a primitive nature for this object, giving further support to its association to this meteor shower, even in the absence of current activity.

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