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1991 DA : AN ASTEROID IN A BIZARRE ORBIT

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Summary

Asteroidal object 1991 DA has an orbit of high inclination, crossing the planets from Mars to Uranus. This is unique for an asteroid, but not unusual for a comet of the Halley-type: it therefore seems likely that 1991 DA is an extinct or dormant comet. Previous CCD imaging has shown no indication of a coma; here we report spectroscopic observations of 1991 DA which lack any evidence of strong comet-like emissions. We also perform numerical integrations of the orbit of this object which show that it has been remarkably stable for the past ~20,000 yr, but chaotic before that. This may allow a new estimate to be made of the physical lifetimes of comets.

Introduction

The object denoted 1991 DA was discovered by the second-named author on a U.K. Schmidt Telescope plate exposed on 1991 February 18. It is estimated to be about 5 km in size. Astrometric observations soon showed it to have one of the most bizarre orbits known for any asteroid (Chapman, 1991): at 61.9^0 its inclination is the third highest of all known minor planets, and its eccentricity of 0.866 is also the third highest amongst asteroids. With a perihelion distance of 1.58 AU and aphelion at 22 AU, 1991 DA crosses the paths of Mars, Jupiter, Saturn and Uranus, and therefore would be expected to have a dynamical lifetime of at most $\sim 10^{5-6}$ years. CCD imaging of 1991 DA by English and Freeman (*IAU Circ. 5199*) and by West and by Ryder (*IAU Circ. 5208*) has shown no evidence of a coma despite the fact that the object was close to perihelion at the time. Here we report spectral observations with the Anglo-Australian Telescope which lack any comet-like emissions, backing up the conjecture that 1991 DA is asteroidal in nature. 1991 DA may therefore be a totally de-volatilized comet, or a comet which has formed an insulating crust.

Numerical integrations may indicate the path by which the present orbit of 1991 DA has come about, especially if non-gravitational forces have been negligible in the past. We have carried out such integrations extending over the last 50,000 yr and find that the orbit has been remarkably stable for at least the last ~20,000 yr, prior to which nodal crossings near Saturn lead to large changes in the orbit in close approaches to that planet. Before then the orbit is chaotic with longer integrations being of statistical interest only. A more detailed discussion of such integrations, over a longer time-base, is given by Hahn and Bailey (1991).

Spectroscopic Observations

We observed 1991 DA using the 3.9 m Anglo-Australian Telescope on the night of 1991 March 17. We had planned to obtain a high-dispersion spectrum covering the strong emissions from CN, CH, C_2 and C_3 in the range 380–520 nm manifested by many comets but an instrumental fault limited us to a spectrum from 530–1095 nm obtained with the Faint Object Red Spectrograph on the AAT. This is shown in Figure 1 after subtraction of the sky background and ratioing against the solar-analogue star 70 Virginis. There is no evidence for strong comet-like emissions in the spectrum, except possibly at 530–580 nm where C_2 emission may occur. Atmospheric absorption, particularly near 760 nm, is evident (the star and asteroid were at rather different zenith angles) and longwards of 900 nm the atmospheric transmission was both low and variable, leading to the great scatter in this ratio spectrum (and the strong spike, absent in another spectrum). On this basis, therefore, we do not find any compelling evidence for cometary emissions from 1991 DA.

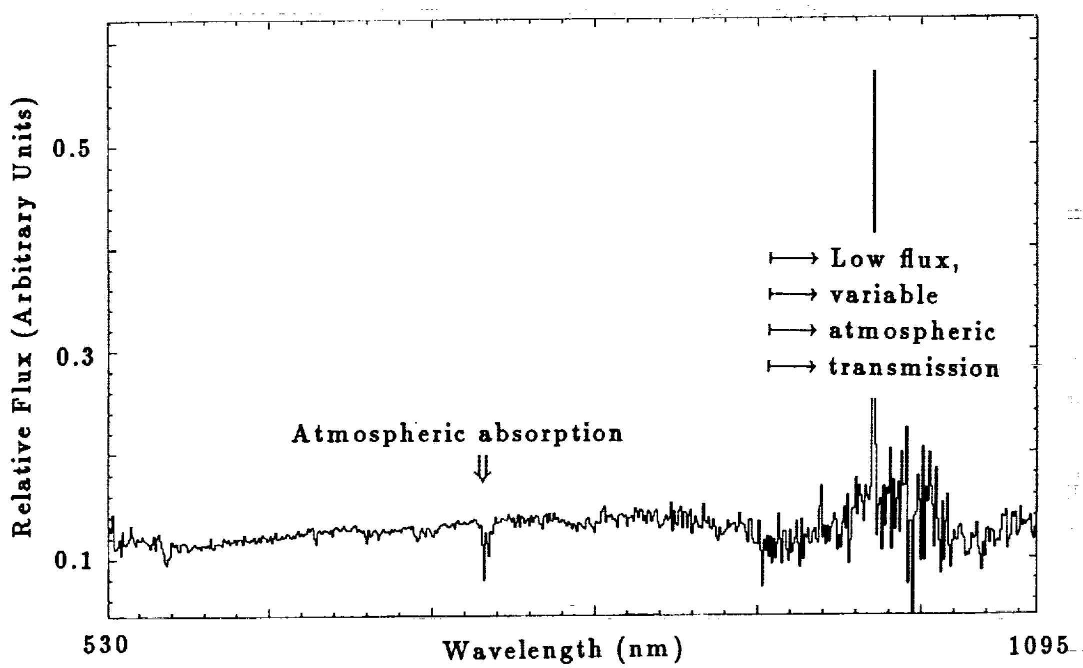

Figure 1: Ratio spectrum from 530–1095 nm for 1991 DA / 70 Virginis after subtraction of atmospheric background. No strong cometary emission lines are found. Above 900 nm the spectrum is noisy due to low signals and variable atmospheric transmission.

Numerical Integrations

We used a 7th order Runge-Kutta-Nyström integrator developed by Dormand and Prince (1978). It is a variable step-length method shown by Fox (1984) to be very efficient for high-eccentricity orbits. Fox (1984, personal communication) provided a Fortran subroutine implementing the method. Our steplengths ranging from a little below 0.1 yr at $r = 1.6$ AU to about 3 yr at $r = 22$ AU mean that we are not solving the equations of motion to anywhere near the limit of machine accuracy, but this is probably sufficient given the uncertainties in starting elements and the eventual chaotic nature of the orbit.

We included the six planets from Earth out to Neptune, updating their orbital elements every 500 yr using smoothed elements from Quinn (1991, personal communication) derived from the planetary integration of Quinn *et al.* (1991). Jupiter and Saturn dominate the effect on the secular change in elements of 1991 DA, and the long-term effect of precessing planetary elements is noticeable. The initial elements of 1991 DA were taken from MPC 18437: *viz.* $a = 11.8721271$ AU, $e = 0.8670227$, $i = 61.88558^0$, $\Omega = 313.40412^0$, $\omega = 191.25159^0$, $M = 8.95122^0$ at 1991.94.

In Figure 2 we show the history of the semi-major axis of 1991 DA for six different sets of starting elements; the topmost plot is with the elements just listed, and then descending we modify a by $+0.0001$ AU, e by $+0.000001$, and i, Ω and ω by $+0.001^0$ (one only of these changes in turn from the nominal orbit). These represent smaller uncertainties in the orbit than exist due to the short arc over which 1991 DA has been observed.

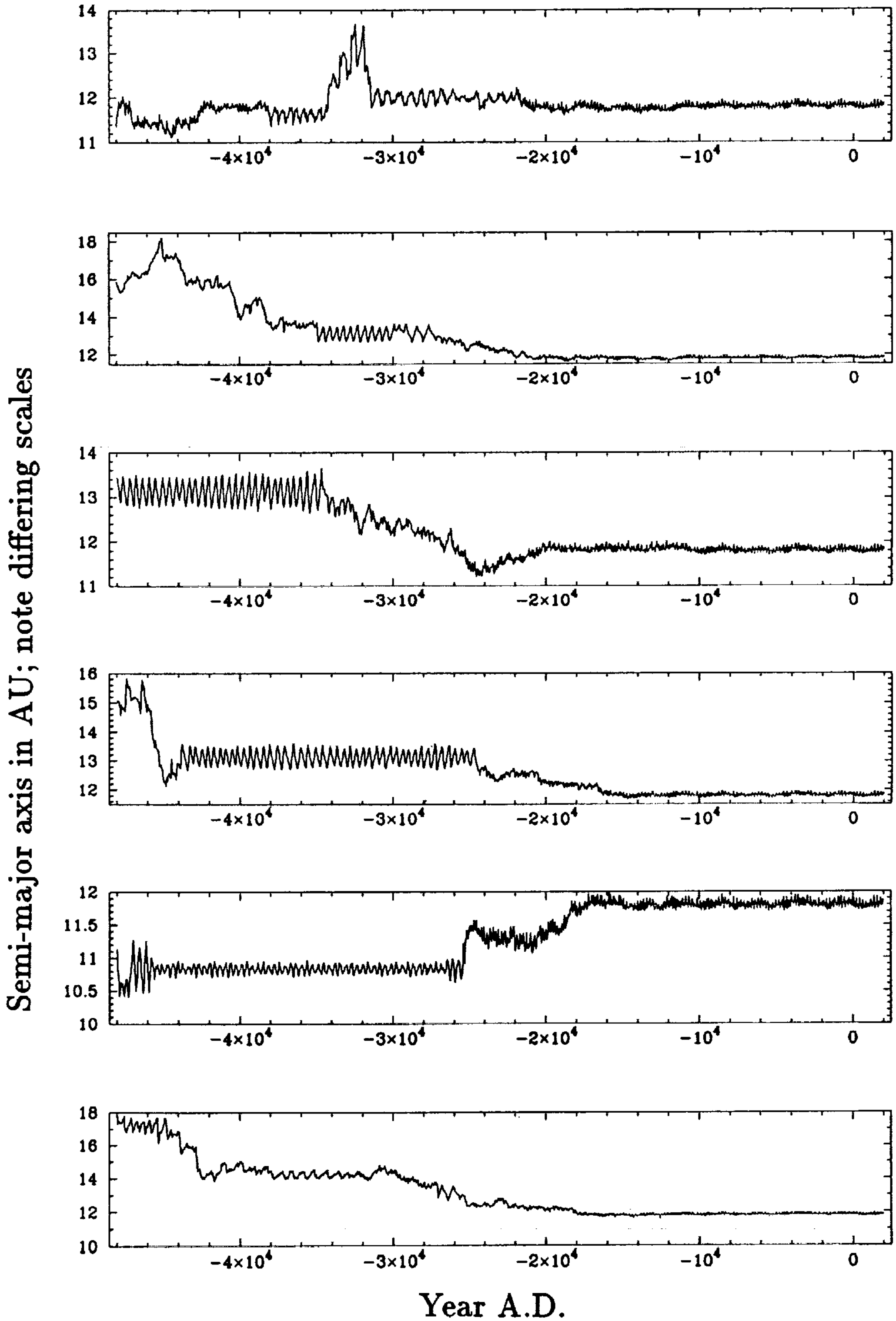

Figure 2: Results of numerical integrations of 1991 DA backwards over 50,000 yr from the present for slightly different starting parameters: for details see text. Only the semi-major axis for each of the six hypothetical orbits is shown. The plots do not start to diverge appreciably until ~20,000 yr ago when close approaches to Saturn become possible. The oscillatory parts of each plot are due to commensurabilities with Jupiter, which are described in the text.

The asteroid is currently close to the 7:2 resonance with Jupiter and this and other commensurabilities are clearly seen in Figure 2. In particular the long-term oscillatory phases seen in the second, third and fourth plots are due to the 4:1 resonance (a = 13.11 AU); in the fifth plot the 3:1 resonance (a = 10.82 AU); and in the sixth plot the 9:2 resonance for −38,000–32,000 A.D. (a = 14.18 AU) and 6:1 for −47,000–45,000 A.D. (a = 17.17 AU). In the first plot, using the nominal elements, the 7:2 resonance (a = 11.99 AU) occurs at −32,000–26,000 A.D., and the 10:3 resonance (a = 11.61 AU) at −38,000–34,000 A.D. It appears to be due to the action of these resonances that 1991 DA owes its remarkable stability; for a more detailed discussion see Hahn and Bailey (1991) and Steel and Asher (1991).

There is little divergence between these six orbits until about 20,000 yr ago. At that time, ω attains values of around 220^0 and nodal intersections with Saturn occur. Since the exact distances of the close approaches which occur in that epoch depend critically upon the starting elements, the six integrations begin to differ markedly at that point and there is no likelihood of determining the exact orbital history prior to that time. The integrations are thus of statistical interest only.

In view of the increasing awareness of the effects upon the terrestrial environment of large comets and asteroids such as this, and also the integrations of Hahn and Bailey (1990) for 2060 Chiron which showed that this massive asteroid/comet may well have had an Earth-crossing orbit in the past, it is of interest to note here that of the six separate integrations represented in Figure 2 two of them attain a perihelion distance $q < 1.0$ AU within the last 50,000 yr, and another reaches $q < 1.1$ AU. These results are presented in more detail by Steel and Asher (1991). The original comet (if this is the source of the remnant left as 1991 DA), which may have been over 20–25 km in size if the asteroid represents only the silicate fraction, could therefore have left a very substantial amount of material in an Earth-crossing orbit in the astronomically-recent past.

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