A STUDY OF THE PRE-DISCOVERY MOTION OF THE TWO ASTEROIDS 1983 SA AND 1983 XF

Daniel Benest
Observatoire de Nice, F-06003 Nice Cedex, France

Reinhold Bien
Astronomisches Rechen-Institut, Mönchhofstrasse 12-14
D-6900 Heidelberg 1, Federal Republic of Germany

Hans Rickman
Astronomiska Observatoriet, Box 515
S-75120 Uppsala, Sweden

ABSTRACT. Our investigation demonstrates that the asteroidal objects 1983 SA and 1983 XF can be considered as temporary visitors of the 4/3 and 2/1 resonance with Jupiter, respectively. Evidence is given that both objects are first rank candidates for a cometary origin. The case of 1983 SA is remarkable in so far as (279) Thule is up to now the only known asteroidal 4/3 librator.

1. INTRODUCTION

Object 1983 SA has a perihelion distance $q = 1.21$ AU and an aphelion distance $Q = 7.25$ AU. Equivalently, the semi-major axis is $a = 4.23$ AU, and the eccentricity is $e = 0.71$. The orbital inclination i amounts to 31°. In case of object 1983 XF, one gets $q = 1.45$ AU, $Q = 4.78$ AU (or $a = 3.12$ AU, $e = 0.54$), and $i = 4°$.

The aim of the present paper is to investigate the question of a dynamical relationship to comets. In fact, the orbital characteristics of the two objects, as given above, are not usual for asteroids. The values for a and e, and for the Tisserand invariant T (1983 SA: $T = 2.49$; 1983 XF: $T = 2.98$), are rather typical for a considerable number of short-period comets, cf. Kresák (1979, Fig.1). Additionally, the orbital features are dynamically interesting, since 1983 SA is obviously close to the 4/3 resonance with Jupiter, whereas 1983 XF is not far from the 2/1 resonance.

2. BASIC MATERIAL

According to the Minor Planet Circular 8678, the orbital elements of 1983 SA have been determined from 54 observations during the period

A. Carusi and G. B. Valsecchi (eds.), Dynamics of Comets: Their Origin and Evolution, 365–370.

https://doi.org/10.1017/S0252921100084049 Published online by Cambridge University Press

1983 Sep. 10 to 1984 Mar. 3; the mean residual is 1".2. In case of 1983 XF the published orbit is based on 35 observations during 1983 Nov. 28 - 1984 Mar. 8; mean residual: 1".5 (see M.P.C. 8679). In the following, we call these elements "new initial values" for an integration.

"Old initial values" are taken from M.P.C. 8394 (1983 SA, 41 observations 1983 Sept.10 - Nov. 9, mean residual 1".1) and M.P.C. 8467 (1983 XF, 24 observations 1983 Nov.28 - 1984 Jan.4, mean residual 1".5).

3. MODELS

We used three different dynamical models. The first one is the three-dimensional elliptic three-body problem Sun-Jupiter-massless object. The eccentricity of Jupiter's orbit is 0.048061 (cf.Astron.Ephem.1984) and Jupiter's mass is equal to 1/1046.390 Solar masses. Details of the integration technique (fourth-order Runge-Kutta method with variable step length) are given by Benest (1974). In the second model, Saturn's perturbations are taken into account. Finally, the third model includes all major planets from Venus to Neptune; Mercury is added to the Sun and Pluto's mass is neglected. The integration technique in the last two cases (four-body model and nine-body model) is Bulirsch and Stoer's method (1966), where the step length is also variable; masses and initial values for the last two models are taken from Schubart and Stumpff (1966).

We consider the old initial elements as a reasonable variation of the new ones. In any case, one might expect that an integration of both sets in three different models, using two different integration techniques, reveals a reliable picture of the dynamics of 1983 SA and 1983 XF.

4. RESULTS FOR 1983 SA

The new initial values of 1983 SA have been integrated backward over 1 000 yr in the four-body model. During this period the object is in 4/3 resonance with Jupiter. This result is shown in Fig.1, where the "critical argument" $\sigma_{4/3}$ (according to Kresák, 1974) is plotted versus time. For convenience the definition of $\sigma_{p/q}$ is as follows:

$$\sigma_{p/q} = (p-q)\,\tilde{\omega} - p\ell_J + q\ell \quad .$$

Here, p and q are relative prime integers with $p/q \approx n/n_J$, and n, ℓ, $\tilde{\omega}$ denote mean motion, mean longitude, longitude of perihelion of the massless body, and the subscript J refers to the corresponding Jovian quantities.

The evolution of a is given in Fig.2. The jump of the semi-major axis at - 64 yr (counted from the present) is probably caused by a close encounter with Jupiter at a minimum distance of 0.64 AU. During the integration interval from - 1 000 yr to the present the argument of perihelion, ω, increases from 275° to 317°, see Fig.3, whereas e decreases from 0.79 to 0.71, and i increases from 18° to 31°.

A backward integration of the new values over 400 yr in the nine-body model shows no significant discrepancies; in particular, the

https://doi.org/10.1017/S0252921100084049 Published online by Cambridge University Press

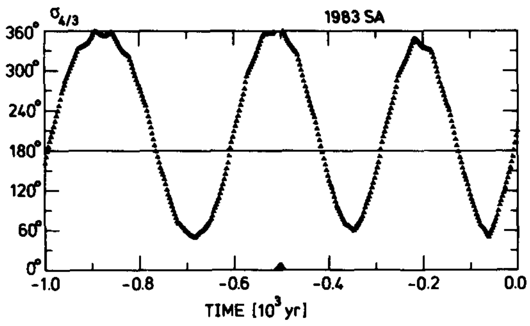

Fig.1. 1983 SA: evolution of the critical argument $\sigma_{4/3}$. Time is given in years counted from the present. Every 2.7 yr a small triangle is plotted.

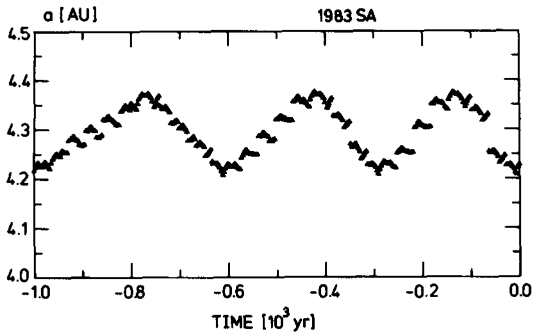

Fig.2. 1983 SA: semi-major axis a versus time.

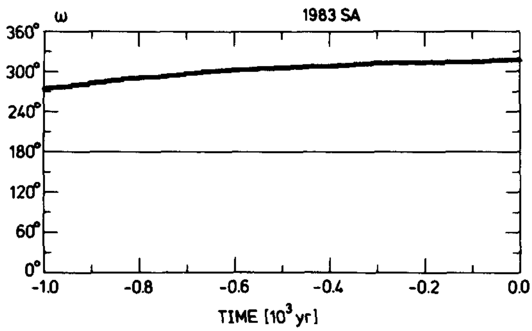

Fig.3. 1983 SA: argument of perihelion ω versus time.

https://doi.org/10.1017/S0252921100084049 Published online by Cambridge University Press

libration around the 4/3 resonance is confirmed.

Moreover, an investigation of the new initial values in the three-body model, and of the old initial values in the four-body model lead to practically the same librational feature.

5. RESULTS FOR 1983 XF

Analogously, we have integrated backward the new initial values of 1983 XF over 1 000 yr in the four-body model. The main result is that since about 900 yr the object has been trapped into a libration around the 2/1 resonance. The critical argument $\sigma_{2/1}$ is plotted in Fig.4, and Fig.5 shows the semi-major axis. Before and after the beginning of libration we found close encounters with Jupiter (minimum distance at -986 yr: 0.37 AU, at -819 yr: 0.36 AU). The smallest minimum distance was reached at -558 yr, namely 0.29 AU.

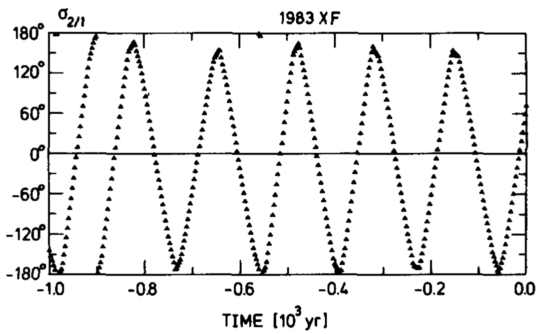

Fig.4. 1983 XF: critical argument $\sigma_{2/1}$ versus time.

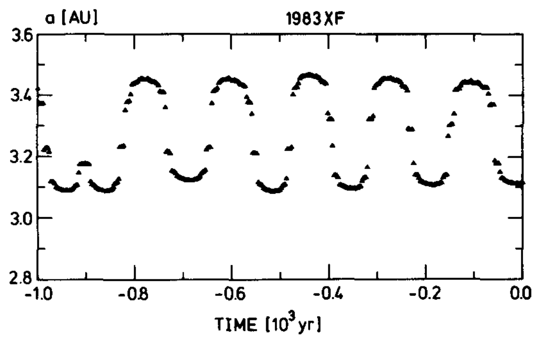

Fig.5. 1983 XF: semi-major axis a versus time.

https://doi.org/10.1017/S0252921100084049 Published online by Cambridge University Press

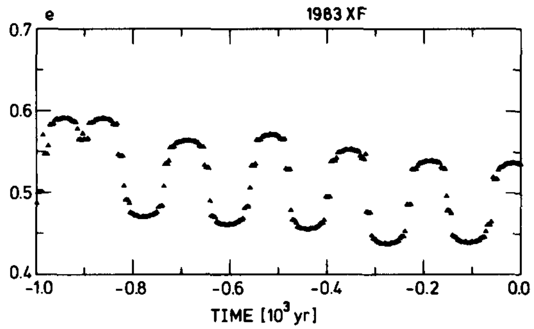

Fig.6. 1983 XF: eccentricity e versus time.

The eccentricity shows an oscillation of large amplitude following the period of libration, while the mean value of e decreases (roughly spoken) from 0.54 to 0.48; see Fig.6. During the whole time interval between -1 000 yr and the present, the inclination takes values between 10° and 3°.

As in the case of 1983 SA, the nine-body model (new values, backward integration over 400 yr) confirms the results of the four-body model. The three-body model confirms the librations.

Larger deviations have been found in the evolution of the old initial values (four-body model). After a more or less chaotic behaviour, where a takes values up to 5.5 AU, the libration around the 2/1 resonance started only about 300 yr ago. It is interesting that at the same time the object approached Jupiter up to 0.14 AU.

6. REMARKS ON THE FUTURE MOTION OF 1983 SA AND 1983 XF

A forward integration over 2 000 yr of both new sets of initial values (four-body model) indicates a rupture of the libration. In case of 1983 SA the libration ends after 600 yr; a takes values around 4.6 AU. 1983 XF leaves the resonance near +400 yr and ends in a rather chaotic orbit ($a > 6$ AU, minimum distance to Jupiter < 0.1 AU).

We mention that in case of 1983 SA ω reaches a maximum value of 318° and is finally reduced to 286°.

7. DISCUSSION AND CONCLUSION

Our results are surely affected by uncertainties of the starting conditions of both the massless bodies and the planets, as well as by errors of the masses of the major bodies. Nevertheless, the following conclusions should be sufficiently realistic. Moreover, Hahn and Rickman (1984) found in a three-body model the same dynamical behaviour.

Both 1983 SA and 1983 XF are in orbital resonance with Jupiter, at least temporarily. In each case the amplitudes of the critical argument are very large and the object passes repeatedly close to Jupiter. We note that (944) Hidalgo is the only numbered asteroid which can pass similarly close to Jupiter (0.38 AU; see Marsden, 1970).

The libration of 1983 SA is remarkable, since (279) Thule is so far the only known asteroidal librator of this type. There are indeed some conspicious dynamical differences: The maximum eccentricity of the orbit of (279) Thule is 0.14 corresponding to $Q = 4.9$ AU, the miminum distance from Jupiter is not smaller than 1.1 AU (Marsden, 1970). The critical argument oscillates around 0° (see Takenouchi (1962), where the reader should replace θ by $-\sigma_{4/3}$). On the other hand, the orbit of 1983 SA is highly eccentric and $Q > a_J$; $\sigma_{4/3}$ oscillates around a value of roughly 210° and the oscillatory behaviour is obviously disturbed. The object approaches Jupiter up to 0.6 AU according to our backward integration. The forward integration yields 0.3 AU and an entirely different type of motion is indicated for the future, where $a \approx 4.6$ AU, a value which is unknown for asteroids.

In comparing 1983 XF with asteroids, one notices that the 2/1 librators (1362) Griqua, (1921) Pala and (1922) Zulu have stable motions and cannot approach Jupiter closer than 2.0 AU (cf. Schubart, 1979). Actually, the motion of 1983 XF, characterized by a temporary libration involving close encounters with Jupiter,is rather typical for a certain mechanism of cometary 2/1 librations. A well-known example of this case is comet P/Pons-Winnecke (see Marsden (1970), Kresâk (1974), and Vaghi and Rickman (1982)).

In conclusion, our investigation demonstrates that from a dynamical point of view, 1983 SA and 1983 XF must be considered as serious candidates for a cometary origin.

REFERENCES

Benest,D.: 1974, *Astron.Astrophys.* **32**, 39

Bulirsch,R., Stoer,J.: 1966, *Numer.Math.* **8**, 1

Hahn,G., Rickman,H.: 1984, paper submitted to *Icarus*

Kresâk,L.: 1974, *Asteroids, Comets, Meteoric Matter,* Eds.: C.Cristescu and W.J.Klepczynski, IAU Coll. No.22, p.193

Kresâk,L.: 1979, *Asteroids,* Ed. T.Gehrels, p.289

Marsden,B.G.: 1970, *Astron.J.* **75**, 206

Schubart,J., Stumpff,P.: 1966, *Veröff.Astron.Rechen-Inst. Heidelberg* No.18

Schubart,J.: 1979, *Dynamics of the Solar System* (IAU Symp.No.81), Ed. R.L.Duncombe, p.207

Takenouchi,T.: 1962, *Ann. Tokyo Obs.* **7**, 191

Vaghi,S., Rickman,H.: 1982, *Sun and Planetary System,* Eds. W.Fricke and G.Teleki, p.391