Cascading fragmentation of comet 73P/Schwassmann-Wachmann 3 in 2006.

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Abstract:

We present results of implemented numerical integrations of orbits of fragments of comet 73P/Schwassmann-Wachmann 3. The main purpose of the work is to identify the progenitor of second-generation fragments, produced during 2006 apparition of the comet and their corresponding fragmentation moments. We compare our results for the first-generation fragments with the fragmentation scenario of 73P proposed by Sekanina (2005) and with the observed splitting moments for the corresponding fragments.

1. Introduction

Comet 73P/Schwassmann-Wachmann 3 is a periodic comet which is classified as JFC (Jupiter family comet). It was discovered on photographic plates in 1930 by two astronomers **Arnold Schwassmann** and **Arno Arthur Wachmann,** working at the **Hamburg observatory** in **Bergedorf**, **Germany**.

During its 1995 apparition a huge outburst in the optical and radio wavelengths was observed suggesting that the comet has broken into several separate fragments. Five large fragments were observed labeled 73P-A, B, C, D and E. In 2005 a fragmentation scenario was proposed by the Sekanina (2005) in which the disintegration sequence and hierarchy of comet 73P/ Schwassmann-Wachmann 3 was studied by means of his multiparameter model (Sekanina 1978, 1982). The model described the splitting event associated to the 1995 break up as well as the future orbits of the five largest fragments, namely A, B, C, D and E.

During the 2006 return of the comet the disintegration process continued and presently, the number of those fragments counts over 60.

Which of the original older sub-nuclei are the progenitors of the new fragments? The answer of that question is the subject of this paper.

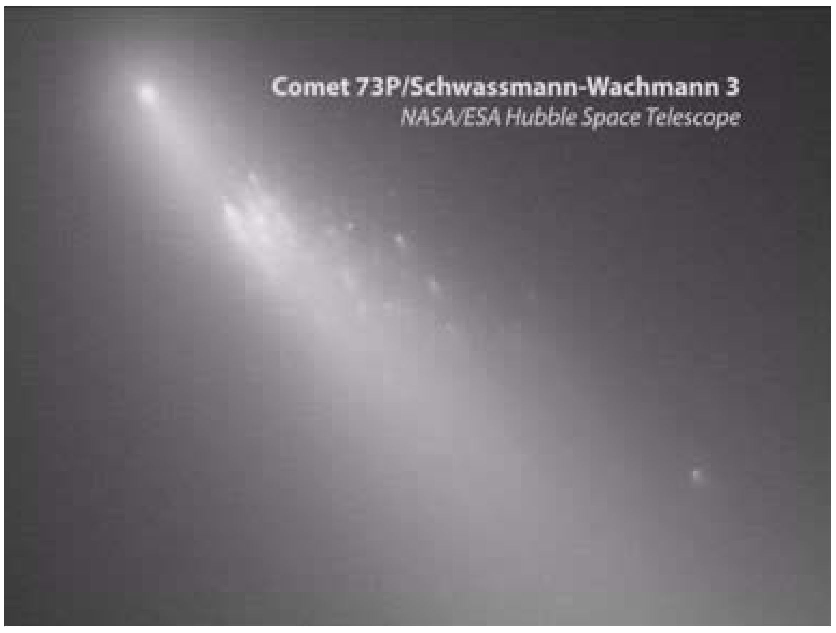

Fig.1 Disintegration of comet 73P/Schwassmann-Wachmann 3. The comet split into more than 60 pieces during its 2006 apparition.

2. The Model

The fragmentation model proposed by (Sekanina 2005) allowed him to determine five parameters of the splitting phenomenon which are as follows:
The time of fragmentation, the influence of the non-gravitational force owing to the outgassing of the nucleus, and the three components of the companion's separation velocity. The proposed fragmentation scenario is presented in fig.2.

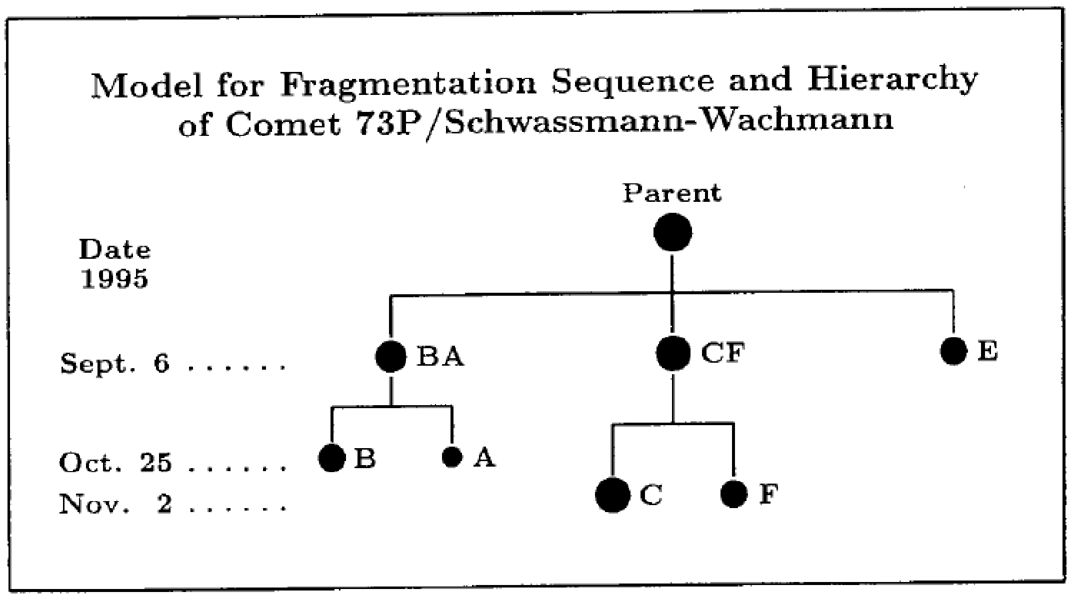

Fig 2. Fragmentation sequence and hierarchy of comet 73P/Schwassmann-Wachamann 3 in 1995, (Sekanina 2005).

Our model represents backward numerical integration of fragments orbits, with 5 perturbing planets included (Mercury, Venus, the Earth, Mars and Jupiter), assuming that the gravitational interaction between the fragments is negligible. For that purpose we have used the N-body integrator package **Mercury6**, developed by John E. Chambers (Chambers 1999), which includes four different algorithms for solving differential equations, Bulirsch-Stoer, MVS (Multi Variable Step Size), Hybrid and RADAU methods.
Numerical backward integrations have been carried out in order to identify the progenitors of three more fragments, excepting those studied by (Sekanina 2005), which have been observed as recently as May, 2006. The studied fragments are labeled as 73P- H, G and K which probably have broken from the fragments which had been produced in 1995 namely, A, B, C, D and E.

The free parameters in our model were orbital elements, taken from **JPL small body database browser**, which are available at http://ssd.jpl.nasa.gov/sbdb.cgi, as well as the components of the non-gravitational deceleration. For relatively fast and high precision divergence we used RADAU algorithm, which was first implemented by Everhart (1985).
The aim here is to trace backwards the orbital evolution of comet's semi-major axes to check where and when the axes of the fragments of interest approach the same value and thus to identify their progenitors and the corresponding fragmentation time, respectively.
One should be very careful when implementing numerical integration of orbits of small bodies in the Solar system, such as comets and asteroids, since the final solution is strongly dependant on the accuracy of the initial parameters, i.e. initial orbital elements and non-gravitational parameters. Since the accurate determination of comet orbits strongly depends on the number of the observations carried out, we have picked orbital elements for those fragments which had been observed more extensively. Unfortunately, the non-gravitational parameters for those fragments were unavailable, since determination of non-gravitational deceleration of the second-generation fragments could be rather pointless due to their negligible mass in contrast to the mass of first generation fragments and therefore more chaotic behavior which on the other hand is result of the extensive outgassing of the nucleus. For that reason the time of splitting could be rather inaccurate due to the lack of information on the non-gravitational parameters of the fragments but the probable progenitor could be identified well accurate.
The orbit of the parent body 73P/Schwassmann-Wachmann 3 is shown in figure 3.

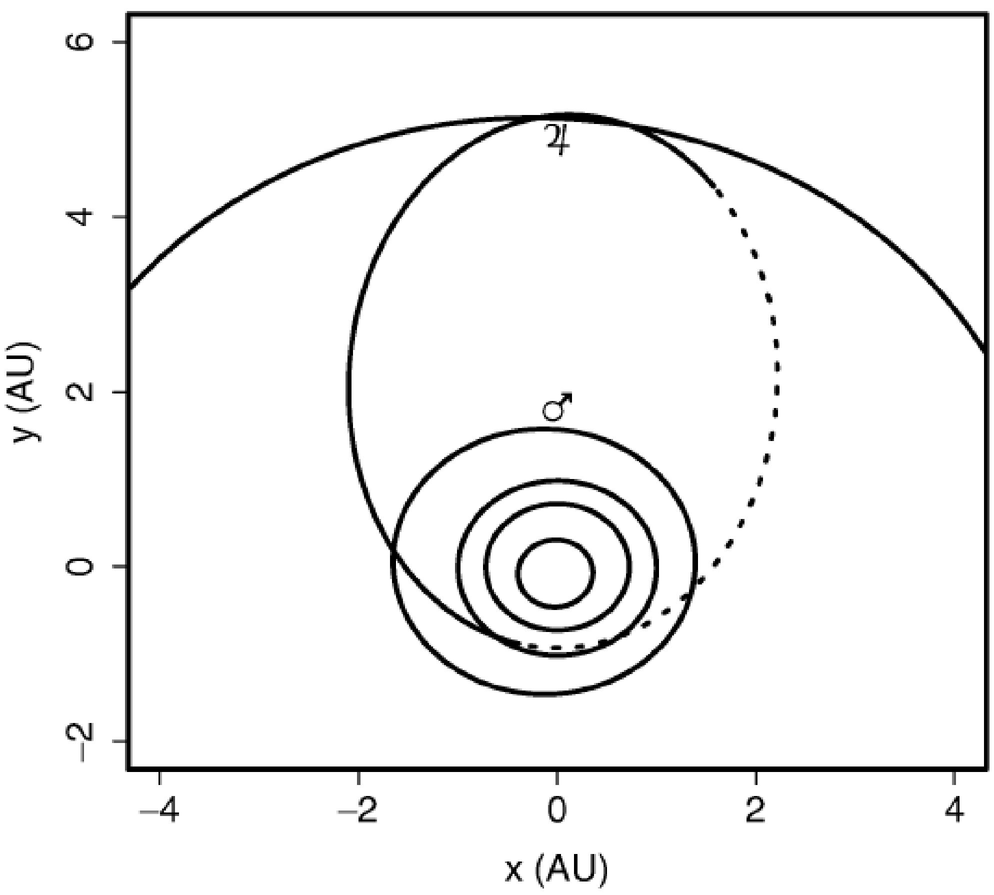

Fig 3. Orbit of comet 73P/ Schwassmann-Wachmann 3. The solid line indicates the part of the orbit above the ecliptic and the dashed one the part under the ecliptic, respectively, (Wiegert 2005).

In general, the separation velocity of the fragments from the parent body is of the order of few tenths cm/s to 1-2 m/s suggesting that inclination of the orbits of the fragments would be practically the same as that of the parent body, as well as the other angular orbital elements, this as a consequence of conservation of the angular momentum. Since, the orbital energy of a comet depends on the square of the orbital velocity, and the semi-major axis depends on the total energy, we would expect more measurable change in the size and the shape of the orbit, namely the semi-major axis and the eccentricity. Therefore we have decided to analyze the evolution of the semi-major axis of the fragments rather than the evolution of the angular orbital elements.

3. Integration and results

Backward numerical integrations were implemented for three second-generation fragments labeled, 73P-G, H and K from the epoch 2454466.5 JD (01 Jan, 2008) to 2449718.5 (01 Jan, 1995).
Before that, in order to check the validity of our approach and to compare it with Sekanina's results, we traced back the evolution of the orbital elements of the larger first-generation fragments B, C and E. The splitting moments and the corresponding progenitors are presented in figures 4 and 5.

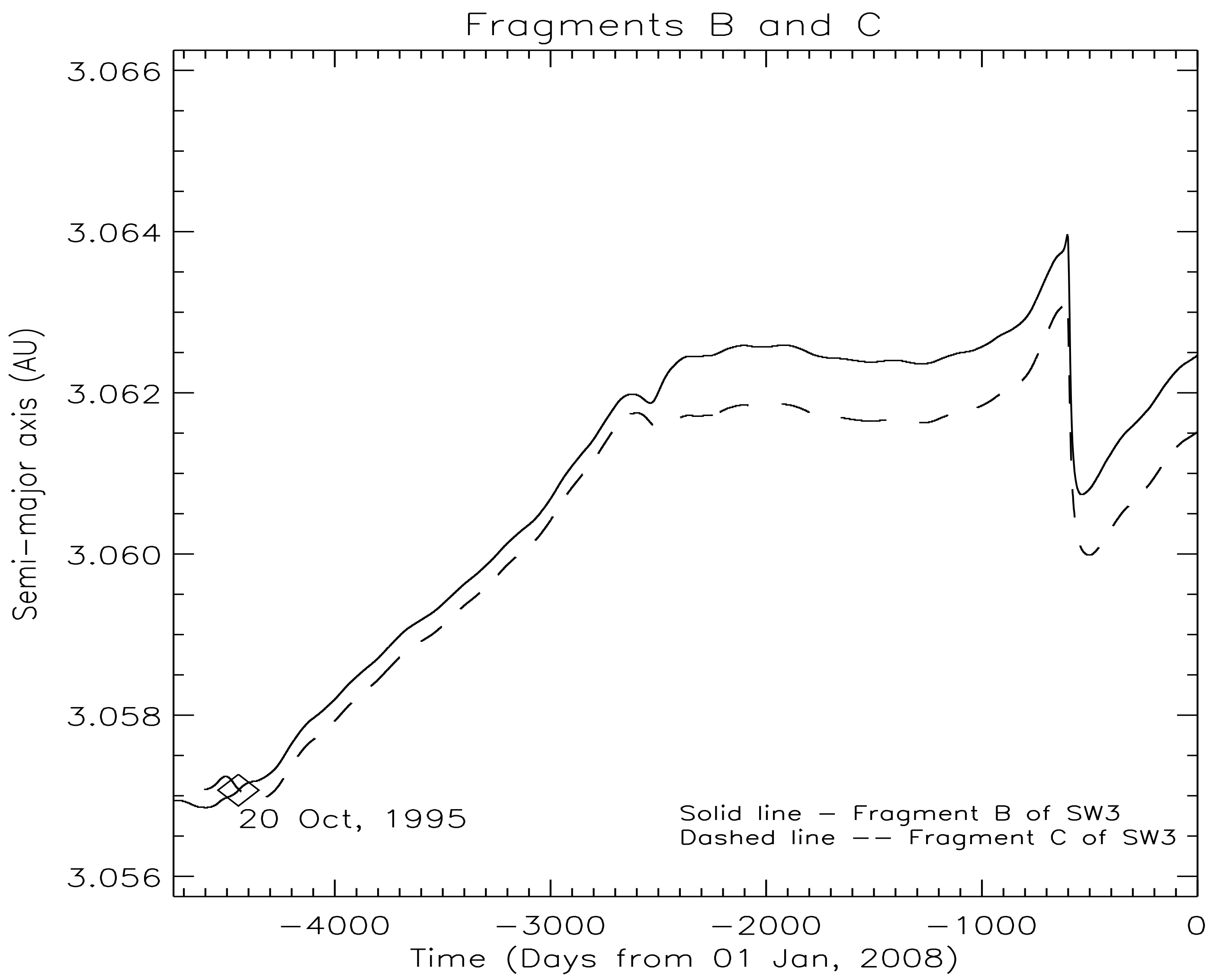

Fig 4. Evolution of the semi-major axes of the first-generation fragments B and C and the corresponding fragmentation time

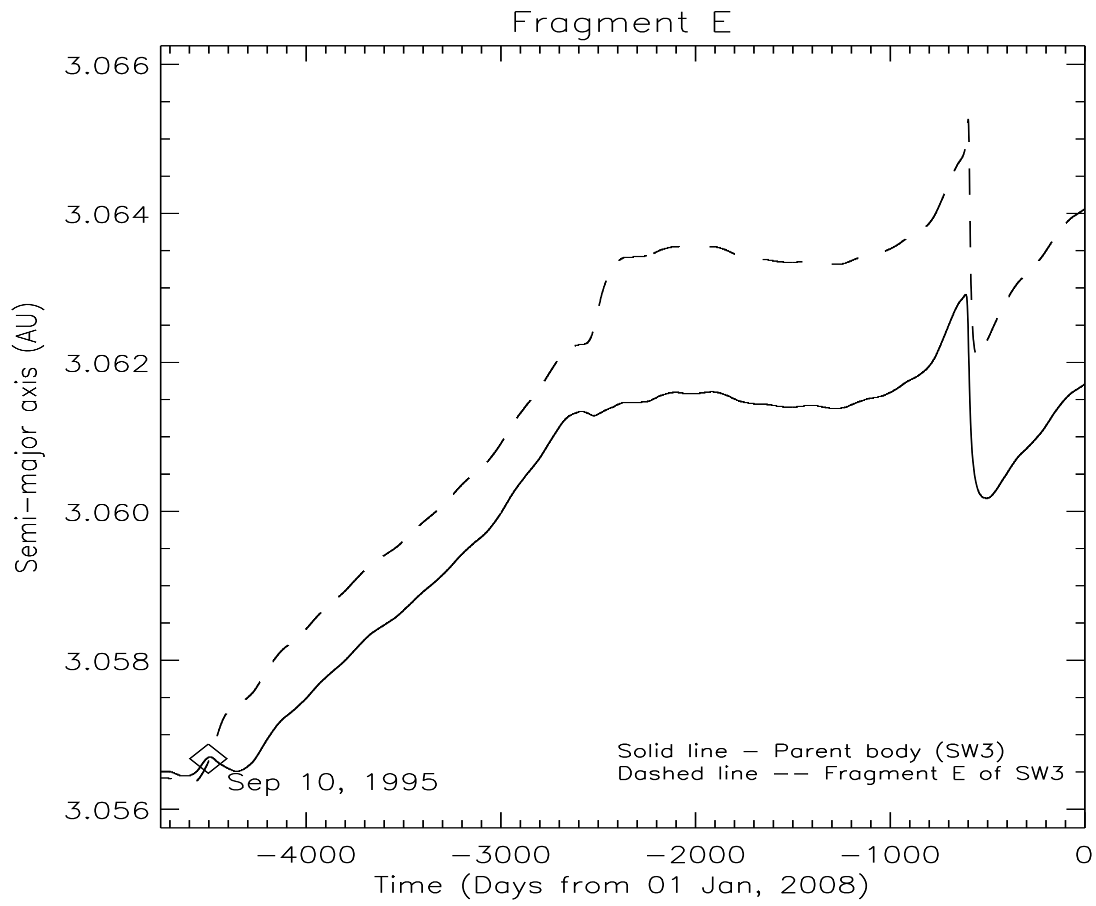

Fig.5 Evolution of the semi-major axes of the first-generation fragment E and the parent body along with the corresponding fragmentation time.

In our model the corresponding fragmentation times are 20 Oct, 1995 for the fragment B and C and Sep 10, 1995 for the fragment E. For comparison with Sekanina's model, see Fig. 2. The difference, in the moments of splitting is just few days, which is in a good agreement with the model proposed by Sekanina.

Our results for the second-generation fragments are shown in figures 6, 7, 8 and 9.

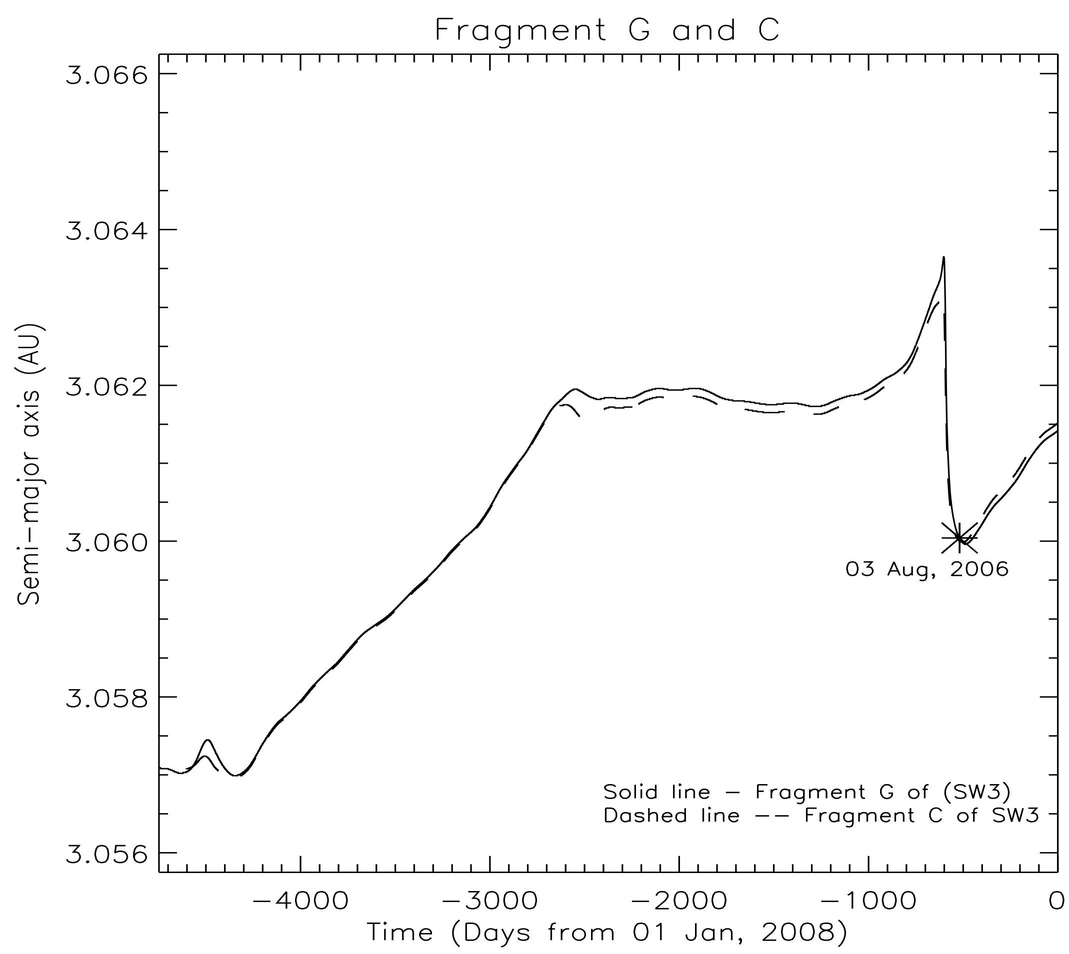

Fig. 6 Evolution of the semi-major axis of fragment G of comet 73P/Schwassmann-Wachmann 3 along with its probable progenitor – fragment C. The fragmentation moment is indicated with the asterisk.

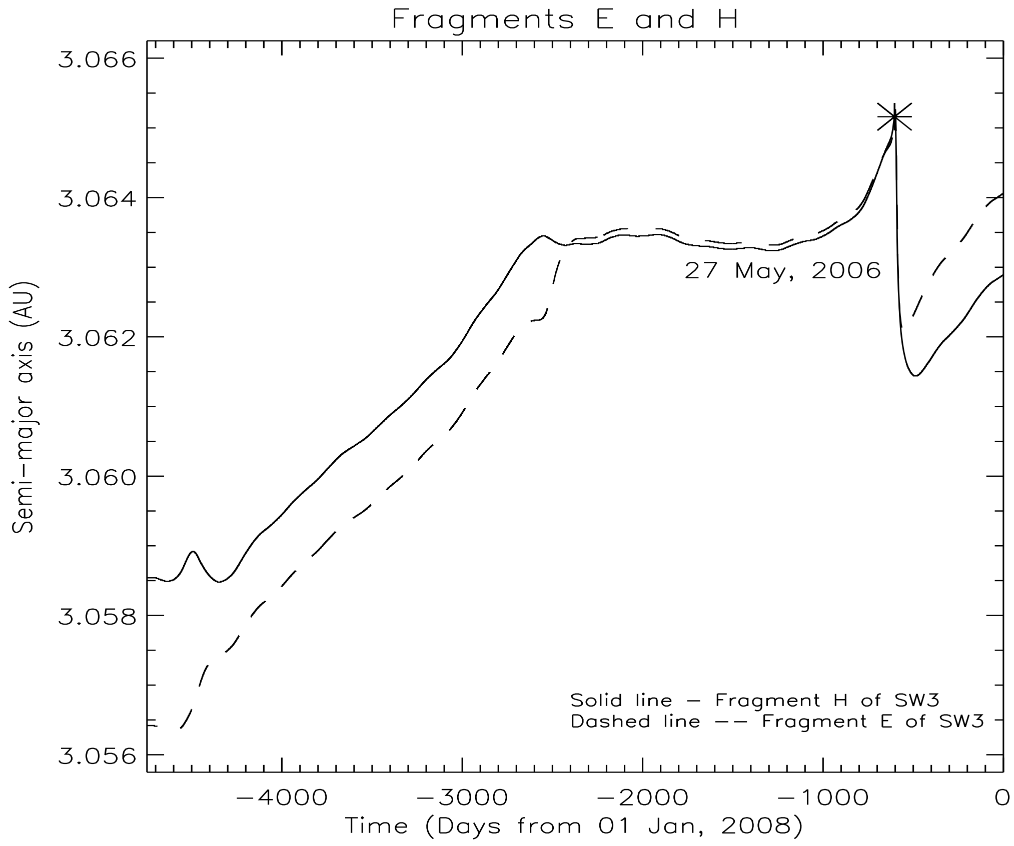

Fig. 7 Evolution of the semi-major axis of fragment H of comet 73P/Schwassmann-Wachmann 3 along with its probable progenitor – fragment E. The fragmentation moment is indicated with the asterisk.

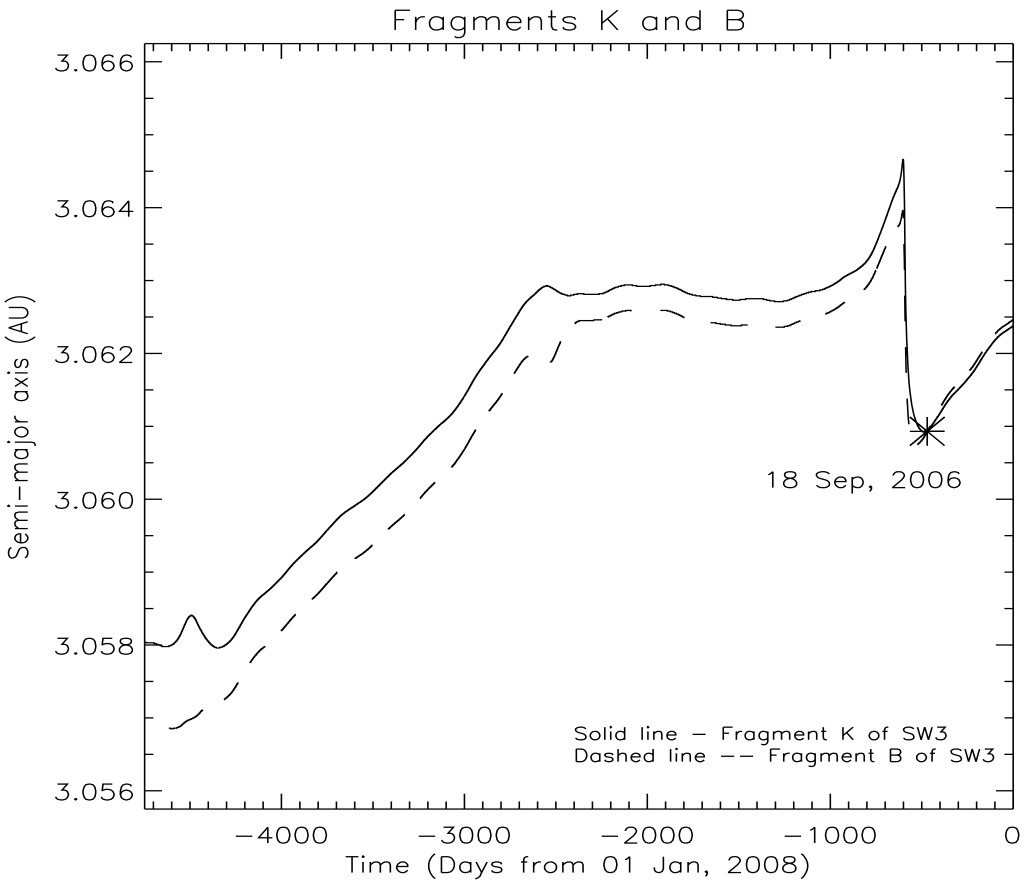

Fig. 8 Evolution of the semi-major axis of fragment K of comet 73P/Schwassmann-Wachmann 3 along with its probable progenitor – fragment B. The fragmentation moment is indicated with the asterisk.

As a final result our proposed scenario of cascading fragmentation is shown in fig. 9. Comparing our results of theoretically obtained moments of fragmentation for the second-generation fragments, produced during the comet's 2006 outburst, with the moments of first observations of those fragments, our model tends to differ with approximately six months. These discrepancies are probably due to the fact that we were not able to take the non-gravitational effect into account due to the lack of information about them.

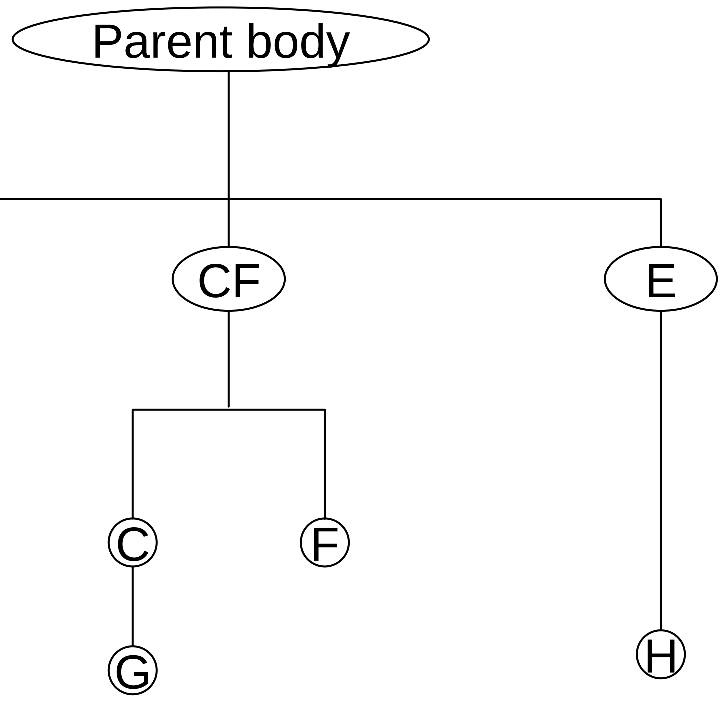

Fig.9 Scenario of cascading fragmentation of comet 73P/Schwassmann-Wachmann 3, proposed by our model.

4. Future work

In future we expect to extend our work by theoretically obtaining the non-gravitational parameters for the second-generation fragments which seem to play a crucial importance in numerically determination of comet orbits. Then we could improve our model by taking into account the propulsion forces which are result of the extensive outgassing of the comet nuclei.

Acknowledgments

I am grateful to John E. Chambers for providing his Mercury6 integrator package to publicity which is available free on his Home page at:
http://www.arm.ac.uk/~jec/home.html

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