Development of Orbit Analysis System for Spaceguard

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Abstract

The activity for the collisions of celestial bodies to the earth is called "spaceguard." We have developed a system that determines the orbits of asteroids, checks the possibilities of earth approach, and calculates the probability of collision. We also have made analyses for deflection of asteroids by colliding space probe to asteroids. In this paper, we show the results of these analyses.

スペースガードに向けた軌道解析システム開発

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摘要

天体の地球問題を扱う活動がスペースガードであるが、小惑星の軌道を決定し、地球への接近の可能性を調べ、可能性がある場合には衝突確率を計算するシステムを構築した。また、衝突回避のために宇宙機を対象小惑星に体当たりさせることで、小惑星の軌道を変更することについての解析も行った。ここでは、これらの結果について報告する。

1. What is Spaceguard?

Up to now (2009), the orbits of more than 400,000 asteroids have been determined, and this number is increasing quite rapidly. This is because discovery and follow-up observations of asteroids have been done vigorously by many observers in the world with the purpose of finding Near Earth Objects (NEOs). If an NEO collides to the earth, we will have incredibly large damage. So it is very important to find such objects that will collide to the earth well in advance.

This is what we call "Spaceguard" activity. Spaceguard is the activity that treats the issues of collisions of celestial bodies to the earth. The spaceguard activity has been activated since 1990's. The first purpose is to find NEOs and to determine their orbit precisely. The definition of NEO is those celestial objects like asteroids and comets whose perihelion distance is less than 1.3 AU. Such objects have potential of colliding to the earth in the future. If we know the orbits of NEO precisely, we can know whether they will collide to the earth or not in next 100 years or so just by calculating its orbital evolution. Therefore, discovery and precise orbit determination are first step of the spaceguard and this is quite important. At present, we know more than 6,000 asteroids, which are classified into NEOs. Figure 1 shows the distribution of asteroids in the inner part of the solar system. All the asteroids inside the orbit of Mars are NEOs. Many NEOs also exist in the main asteroid belt, between the orbits of Mars and Jupiter.

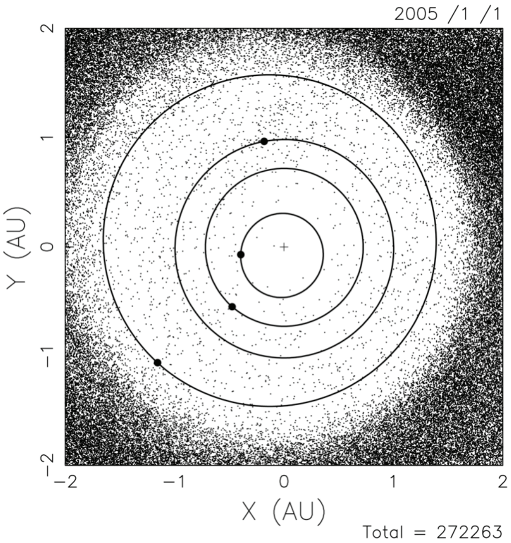

Figure 1. The distribution of asteroids in the inner part of the solar system. The center is the sun and the orbits are those of Mercury, Venus, the earth and Mars.

The second purpose of the spaceguard is to find the means of avoiding collisions of NEOs. The most feasible way under the current technology is to change the orbit of the colliding body slightly by some methods such as hitting the body by spacecraft or exploding bombs near the surface. Even if the change of the orbit is only a little, this change will increase as the time passes. Therefore, if there is long time before the collision to the earth, the orbit will be changed large enough until the collision time so that the body passes near the earth without colliding to it. The simplistic thinking such as blasting the body by bombs is not a good idea, because all the fragments will fall down to the earth and it will be impossible to deal with such many fragments. If the size (or mass) of the colliding body is large, it is not easy to change its orbit, but in such cases, we will try many attempts to change its orbit. Anyway, if we use this method, we need enough time before collision, so the discovery as early as possible is very important. The knowledge of interior structure of colliding bodies is also very important when we try to change its orbit by some methods mentioned above.

On the surface of earth, more then 150 impact craters were found, so it is true that collisions of asteroids or comets occurred in the past. We also know Tunguska explosion in 1908, which is thought that the explosion was caused by a small celestial object (the size is about 60m) that collide to the earth. More over, we witnessed many meteors falling down on the earth. Therefore, the collisions of celestial bodies are not fiction but what happen in reality.

In this study, we made an orbit analysis system for spaceguard. In section 2, we quickly summarize about this system, and some examples are shown in sections 3.

2. Spaceguard Orbit Analysis System

The purpose of this study is to make an orbit analysis system for spaceguard. The general idea of the total system is shown in Figure 2.

The input data is the observed position (Right Ascension and Declination) of asteroids or comet (In the followings, we mention only asteroids for simplicity, but the comet data is analyzed by the same way). In Japan, the observations of asteroids are carried out in Bisei Spaceguard Center and some astronomical observatories. Bisei Spaceguard Center is a facility where asteroids and space debris are mainly observed. It is in Okayama prefecture in Japan, and it was established in 2000. Of course, the data of Minor Planet Center, where all the observed data are collected, are also used in our system.

After getting the observed data, the orbits of asteroids are determined first. If the orbits of asteroids are well determined, then orbital evolutions will be calculated to check that these asteroids will collide or approach very closely to some planets or not. Then, if some asteroids come very close to some planets, the probability of collision will be calculated. This is the main part of this system.

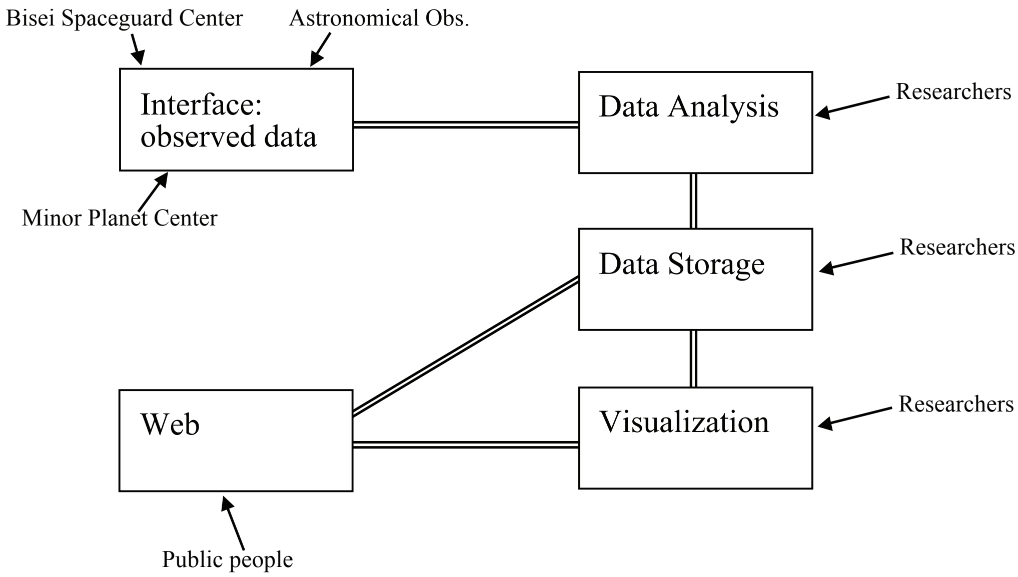

Figure 2. The general idea of the orbit analysis system for spaceguard

This system also has the data storage, where the observed data and analyzed data are stored. Also this system has visualization programs, which help us to understand the calculated results. The calculated results will be open to public by web. Up to now, the orbital analysis software has been made mostly. But the data storage, visualization, and the web for presenting the calculated results are not completed, and they will be done in future works.

We made the cluster computing system for the hardware of this system (Figure 3). It has 32 node of Intel Core 2 Quad (Q9550, 2.83GHz), so it is the system with 128 cores. We do not need such powerful system for usual calculations of orbit determination and orbital evolution. But if we carry out Monte Carlo simulation, such system is quite helpful. Figure 3 is the photograph of the cluster computing system that we made. As for the visualization system, we use Mac Pro Computer (2.8HGHz, 8 core).

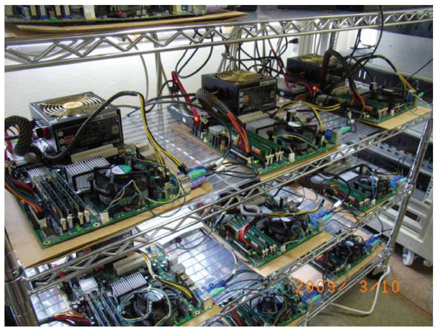

Figure 3. The cluster computing system (a part)

In Table 1, the software that is necessary for this system is summarized.

Table 1. Software prepared for this system

Category of software	**Functions**	**Status**
Data preparation	Check input data	under preparation
Numerical Analysis	Orbit propagation Orbit determination Collision probability calculation Error analysis	almost ready
Visualization	Show orbits, motion, error	under preparation
Web	Show the calculated results by web	future work
Automatic data processing	Make the analysis automatic	future work

3. Examples of analysis

The cluster computing system is ready and the software for the numerical analysis has been almost prepared, so we tried to apply this system for some specific cases. Here we show two examples, one is for the asteroid 2008 TC3, and the other is for asteroid 1999 JU3.

The asteroid 2008 TC3 is a quite small asteroid, whose size is about 3 m. It fell in the north part of Sudan at 02:46 UTC on Oct. 7, 2008. This is the first case that the collision of an asteroid to the earth was predicted before the actual collision. Since the size of this object was small, there was no damage. Many people thought that it will be burned out in the atmosphere, but actually the small meteorite was found on the ground later.

This asteroid was discovered at 06:39 UTC on Oct. 6, 2008. So there was less than one day before the collision. After the discovery and quick orbit determination, it was found that this object collides to the earth. This information was announced to astronomical observatories in the world, and many observations were carried out. Finally more the 500 data were obtained before it collided. Figure 4 shows the results of the orbit determination by our system. This shows O-C (Observation - Calculation) of Right Ascension and Declination. Since the values of O-C are distributed around 0, we think the orbit of this body is determined well.

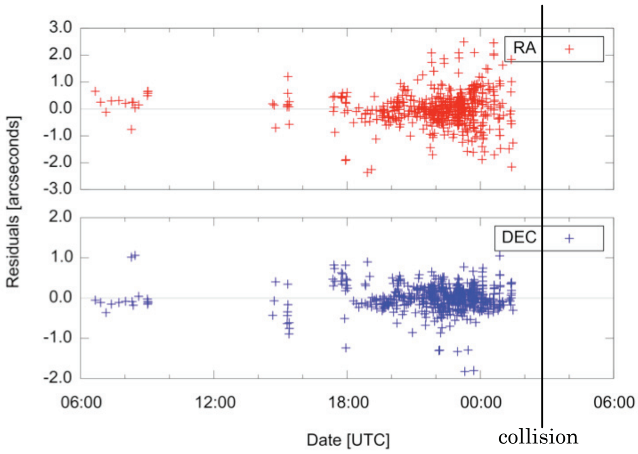

Figure 4. O-C of Right Ascension (RA) and Declination (DEC) of 2008 TC3.

Next we calculated the position where this asteroid collides. The error was calculated by covariance analysis and the results are shown in Figure 5. Two cases are shown; one is orbit determination using first 26 data, and the other is orbit determination using all the data (531 data). The size of the error ellipse (3σ error) of collision position at the altitude of 100km is 43.7 km and 1.14 km, respectively. So if there are many observation data, we can predict the position of collision very precisely.

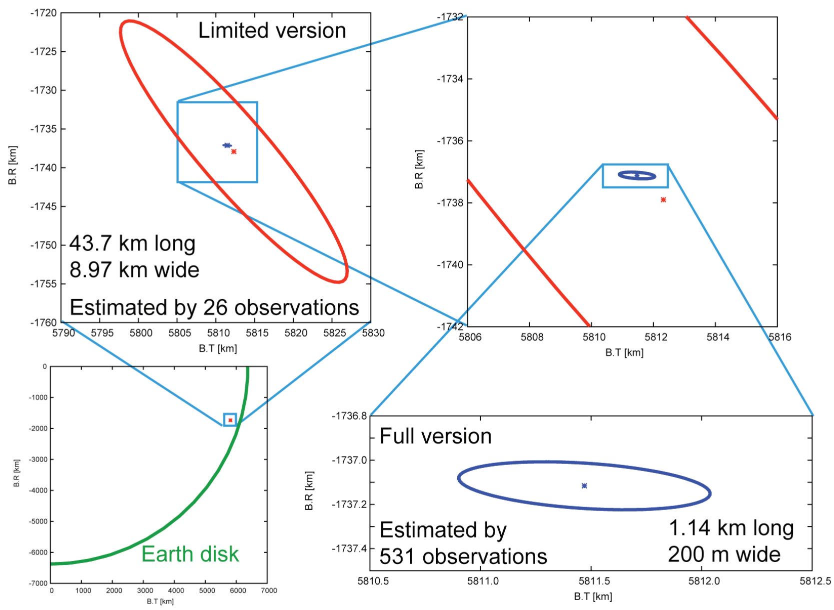

Figure 5. The estimation of the position where 2008 TC3 collides. Upper left figure shows the result of estimation with first 26 data, and the lower right figure shows the result with 531 data. The collision position is at the altitude of 100 km from the surface of the earth.

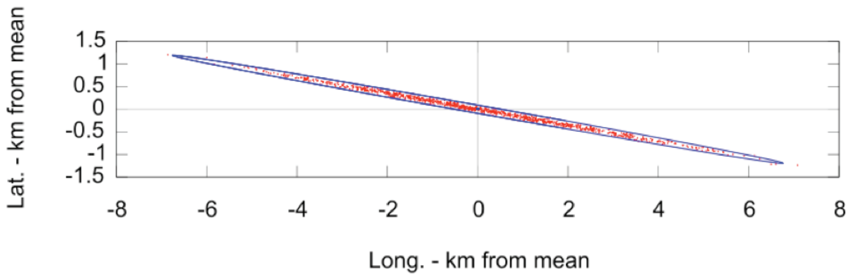

Figure 6. The error estimation of collision position at 50km above the surface of the earth. The ellipse is result of the covariance analysis and the dots are Monte Carlo simulation.

Table 2. Comparison with the results by JPL.

	JPL	This work
Longitude [deg]	31.804 E	31.723 E
Latitude [deg]	20.858 N	20.863 N
Time uncertainty (1 sigma) [sec]	0.16	0.176

The error estimation shown in Figure 5 was done by the covariance analysis but we also checked the error by using Monte Carlo simulation. The results are shown in Figure 6. In this figure, the errors of collision position at the altitude of 50 km are shown. The elongated ellipse shows the result by the covariance analysis and the dots are result by Mote Carlo simulation. These results agree quite well.

Finally, we checked our results by comparing with the results announced by JPL (Jet Propulsion Laboratory). The result is shown in Table 2. We can say that the agreement is good, so we think our software works well.

The second example is for asteroid 1999 JU3. This asteroid is the target of Hayabusa-2 mission. Hayabusa-2 mission is the follow-on mission of Hayabusa, which is the asteroid sample return mission. Hayabusa-2 is still under consideration, and various possibilities have been studied up to now. One of them is an impactor. The purpose of the impactor is to create a new crater to study the material under the surface of the asteroid. Although the purpose of the impactor is not for spaceguard, we can consider that this is the simulation for the deflection of the orbit of asteroids. So we calculated the orbital change of the asteroid by the impactor.

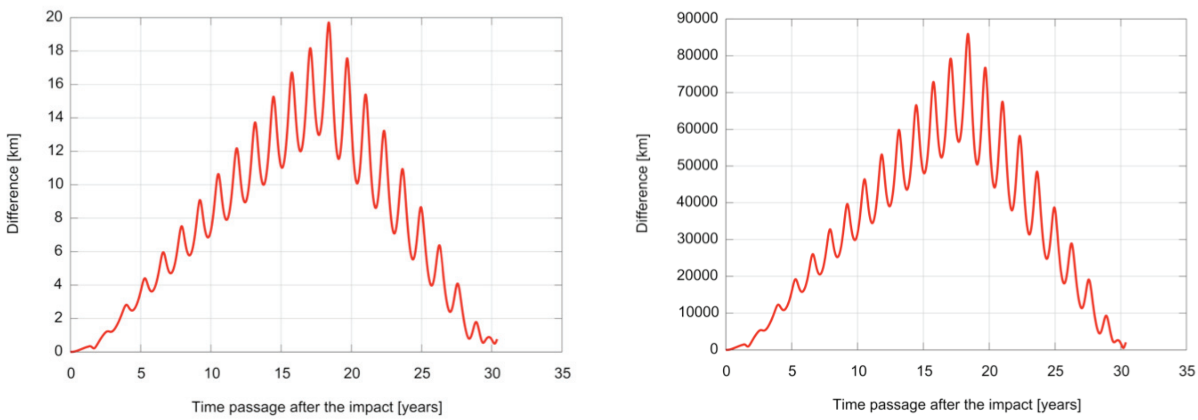

Figure 7. Orbital change of asteroid 1999 JU3 by the impactor.
The actual size (980m in diameter) is assumed for 1999 JU3 in left figure, and much smaller size (60m in diameter) is assumed in the right figure.

There are several kinds of impactors, from one spacecraft to a small module carried by mother spacecraft. Here we assume that the impactor is one spacecraft and it collides to the asteroid in the velocity of about 3km/s. The mass of impactor assumed here is 300kg. We calculated the orbital change by this impactor. The results are shown in Figure 7. If we assume that the size of 1999 JU3 is about 980m in diameter, which is the estimated value by observation, and that the shape is sphere with the density is $1g/cm^3$, then the orbital change is about 20km in position in 20 years. This is quite small so we cannot avoid the collision. (Of course, asteroid 1999 JU3 does not collide to the earth near future, so this is just a simulation.) However, if we assume the size of 1999 JU3 is only 60m in diameter, then the orbit change is about 90,000 km. In this case, the change is large enough, so we can say that it is possible to avoid collision to the earth. Since the 60m object can cause large damage like the Tunguska explosion in 1908, this is quite meaningful.

As these examples show, the software for numerical calculations is working well. As we mentioned in the section 2, our system has the function of visualization, which is still under preparation. Figure 8 shows one example of the visualization function. This figure shows the positions of planets and many asteroids. One can change the view angles or displayed area. This helps people understand the orbit of solar system bodies.

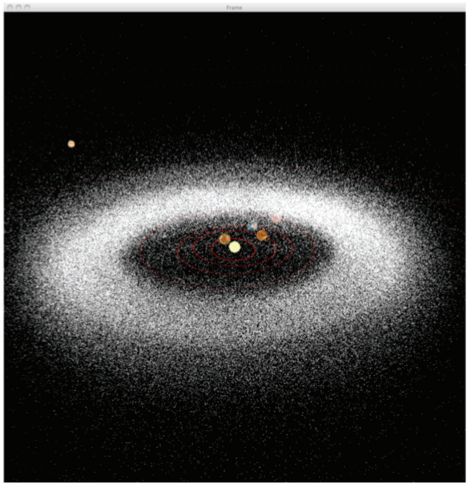

Figure 8. An example of the visualization function.

4. Summaries and Future Works

We are making the orbit analysis system for spaceguard in JAXA. Up to now, the main part is almost finished for both hardware and software. As for the hardware, the cluster computing system with 128 cores were constructed. As for the software, programs for orbital analysis have been made. The next step is to make this system work automatically, and to show the results of analysis to public people. If this system complete, it will work as follows: (1) new observation data are input to this system, (2) orbit determination is done, (3) possibility of close approach or collision to planets is checked, (4) the probability of collision is calculated, (5) the results are shown on the web. We hope such system will be completed near future.