FROM THE GALILEAN SOLAR SYSTEM TO THE DETECTION OF NEW MINOR BODIES DETERMINING THE DISTANCE OF 1994 TG2

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Abstract

When in 1610 Galileo Galilei looked at Jupiter with the use of his telescope, he saw four "bodies" circling it. This discovery was in contradiction to the then generally held belief that all heavenly bodies turned round the Earth. This fact represented a scientific revolution at that time and helped in the acceptance of the Heliocentric Copernican System. As Jupiter and their Galilean satellites is a good model of a planetary system our intention is to study this using a set of photographs which we had taken previously.

INTRODUCTION

In the year 1609 the great Italian scientist Galileo Galilei created the first telescope and started a new era in the development of astronomy. The main accomplishment of Galilei, however, is not the creation of the telescope but its genius application. With the help of the visual tube in several months he turns from a physicist-innovator to a great astronomer. He makes unique for the time observations of the Moon, the Milky way and the planets of the Solar System. On the 7th January 1610 he turns his telescope to Jupiter and discovers four small sparkling stars – its satellites. The observation that around a planet there are smaller orbiting planets questions the correctness of the geocentric system, according to which all astronomical objects orbit the Earth. In the end of the year 1610 this great scientist adds more arguments in support of the Copernican system: the observations are of Saturn; discovering the phases of Venus. This is how the real picture of the bodies in the Solar System started appearing. With the development of telescope building, this picture was completed by the discoveries of new bodies in the Solar System: the satellites of the planets, asteorids, comets. The latest observations of Solar System bodies introduced a new classification: the group of planets, group of dwarf planets and group of small bodies (comets and asteroids).

In 2006, the IAU decided to create a new classification category for solar system objects called "dwarf planets" that is distinct from "planets". Pluto was reclassified as a dwarf planet. At present there are only four other members of this category, Ceres, Eris, Makemake and Haumea but it is likely that there will be many more in the future as the Kuiper Belt is more fully explored.

The actual definition of "dwarf planet" is kind of technical: a celestial body that is in orbit around the Sun, has sufficient mass for its self-gravity to overcome rigid body forces so that it assumes a hydrostatic equilibrium (nearly round) shape, has not cleared the neighbourhood around its orbit, and is not a satellite.

In short, something that looks like a planet but isn't a planet.

SMALL BODIES IN THE SOLAR SYSTEM

Planets are the 'big' bodies of the Solar System. There are eight of this kind and six of them are orbited by at least one moon. Some planets in the outer part of the Solar System have also a ring around them, the most famous example is Saturn. The rings consist of small rocky bodies orbiting around the planet which belong to the satellites, too. Asteroids and comets belong to the group of small bodies in the Solar System. Most asteroids are located between the orbits of Mars and Jupiter (this region is called 'Asteroids Belt'), but there are also asteroids beyond Nepute's orbit. The latter objects are called 'Transneptunian Objects'. These two are the main regions, where asteroids were discovered. In addition there are few farther out and some other closer to the Sun than the Earth.

Planets, their satellites and asteroids have one thing in common. Their orbits are circular or not very eccentric elliptical. Contrary to the comets, which have high eccentric orbits. They belong to the Oort Cloud (see Figure 1).

However, the classification of big and small bodies is inconsistent as there are asteroids larger than planets.

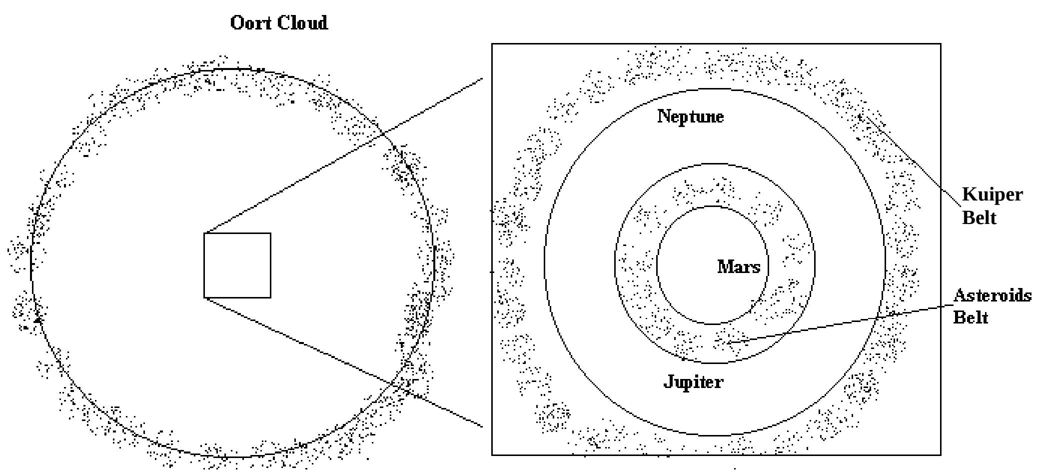

Figure 1. The different locations of small bodies in the Solar System

ASTEROID BELT

More than 10 000 asteroids were until now discovered in the Asteroids Belt. This belt is located between the orbits of Mars and Jupiter. So their distance to the Sun is between 1.52 au and 5.2 au.

Asteroids are rocky and metallic objects. Their sizes range from a diameter of about 1000 km down to the size of pebbles. Only a small number of asteroids have a diameter for more than 240 km.

TRANSNEPTUNIAN OBJECTS - KUIPER BELT OBJECTS

In 1951 Gerard Kuiper wrote a paper mentioning objects beyond Pluto that he supposed were scattered out to the Oorts Cloud by massive Pluto. Nowadays it is well known that Pluto is too tiny to eject objects to the Oorts Cloud. If his theory was true, there should be no objects where Transneptunian Objects are observed. However, the Transneptunian Objects are also called Kuiper Belt Objects.

The Transneptunian Objects are – as their name says – far away from Neptune, in a distance of more than 30 au to the Sun.

1994 TG2

On October 8, 1994 O. Hainaut discovered by observing with the ESO 3.5-metre New Technology Telescope (NTT) in La Silla a new small object in the Solar System. It was detected due to its slow motion relative to the stars. Six accurate positions were measured and allowed to determine its period and its null eccentricity. The observed magnitude is about 24. That is to say that it is about 16 million times fainter than the faintest object that can be perceived by the unaided eye.

Currently, it has been given the designation “1994 TG2” by the Minor Planet Centre of the International Astronomical Union. (Figure 2). The Minor Planet Electronic Circular (MPEC) is published by the Commission 20 of the International Astronomical Union (IAU) and contains information on unusual minor planets and routine data on comets. On October 13, 1994 the discovery of 1994 TG2 was published in MPEC 1994-T14.

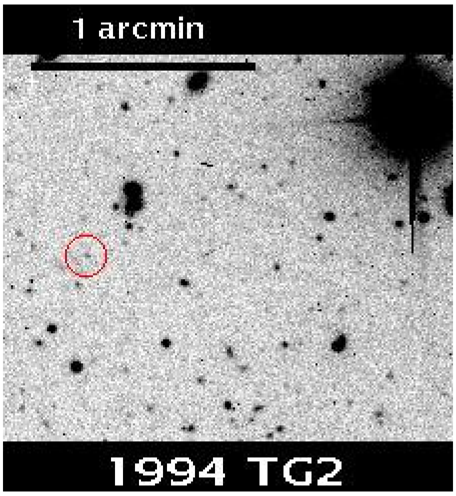

Figure 2. The circleindicates 1994 TG2, a small body of the Solar System that was discovered on October 8, 1994 with the ESO-NTT in La Silla. (ESO-PR-Photo)

This photo shows the faint image of a new transneptunian object, discovered with the ESO 3.5-metre New Technology Telescope in October 1994. It is here seen in a negative reproduction (dark stars on white sky) of the CCD frame on which it was first noticed. It was detected because of its extremely slow motion, only 3 arcsec/hour. Six accurate positions were measured and allowed to determine an approximate distance of about 42 AU, that is 6300 million kilometres from the Sun. This is far outside the orbit of the outermost, large planet, Neptune (4500 million kilometres); hence the classification as a “transneptunian” object. It was given the designation “1994 TG2” by the Minor Planet Center of the International Astronomical Union. The observed magnitude is about 24, i.e., it is about 16 million times fainter than the faintest objects that can be perceived with the unaided eye. Its diameter is probably 100 - 200 kilometres.

MEASUREMENTS AND CALCULATIONS

In the following tasks you will calculate properties of 1994 TG2 by analysing the images obtained with the NTT (Figure 3). Finally, you decide, if 1994 TG2 is an asteroid, a transneptunian object or a member of the Oort cloud.

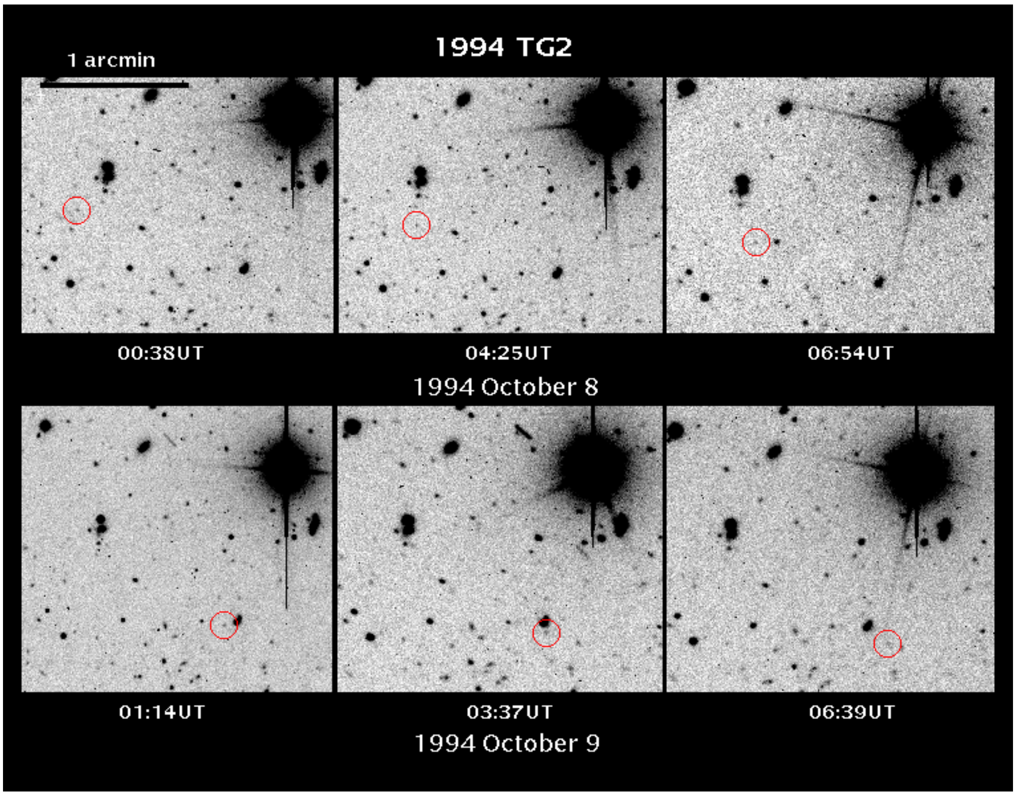

Figure 3. Six images of 1994 TG2 (object indicated by the circle). The upper three images were taken on October 8, 1994, the lower three on October 9, 1994. (O. Hainaut)

- Activity 1

Calculate the scale of the images in Figure 3 in arcseconds per mm. Use the bar indicating 1 arcminute as a scale.

Looking at the six images of 1994 TG2, you can easily see that the object moves relative to the other (background) stars (Figure 3). **Measure the movement of the object**. There are different possibilities of measuring. Here we give one example: Use a transparency. Draw the object and some reference stars (not too bright ones) from the first observation of one night on it. Then take the second observation of the same night, put the transparency on it in a way that the reference stars on the image and on the transparency fit. Mark the position of the object on the transparency. Do so with the third image of the same night, too. Now you have the angular distance.

The object moves around the Sun with a circular orbit. As the time between the observations is quite short, the arc of the movement can be approximated by a line. **Measure the angular distances in mm** that the object has moved between the first and the last observation of each night. Let's call the angular distance of October 8, 1994, d_1 and the one of October 9, 1994, d_2. **Convert the angular distance to arcseconds**.

- Activity 2

We have the angular distances of two nights and we have also the time elapsed between the measurements.

Calculate the angular speeds ω_1 and ω_2 in rad/s of the object for both nights. **Calculate the average angular speed ω in rad/s.**

- Activity 3

Looking at Figure 4, we find using trigonometrical equations:

$$\tan(d) = ((v_E - v_O) \times \Delta t) / (D_O - D_E)$$

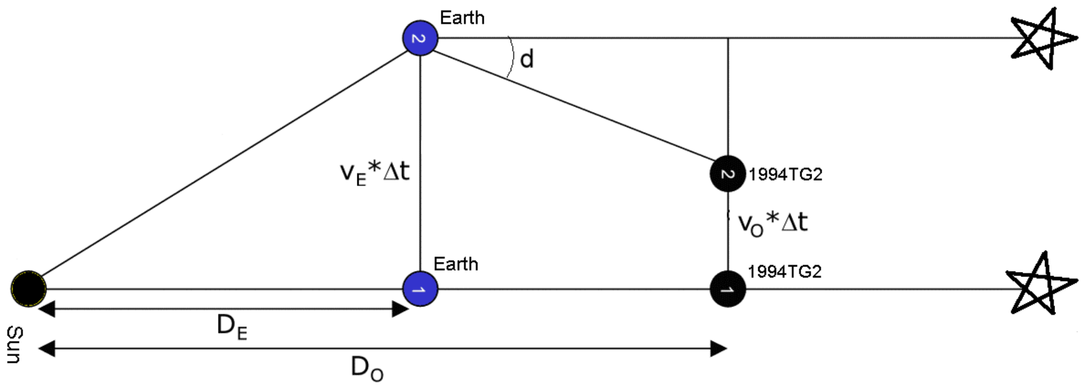

Figure 4. Schematic view. Object an Earth are rotating counter-clockwise around the Sun

As d is a small number and given in radians, we can use the small-angle approximation and say that $\tan(d) \sim d$.

$$d = ((v_E - v_O) \times \Delta t) / (D_O - D_E)$$

As the angular velocity is defined by angular movement divided by time difference:

$$\omega = d/\Delta t = (v_E - v_O) / (D_O - D_E)$$

We need now the 3[rd] Kepler law. P^2/D^3 = const, where P is the period and D is the distance of the object from the Sun. We use it in the following way: On the right hand side of the equation, there are the values for the Earth and on the left hand side, there are the values of 1994 TG2.

$$(P_E)^2 / (D_E)^3 = (P_O)^2 / (D_O)^3$$

The period P is defined as circumference of the orbit divided by the tangential velocity:

$$P = 2D\pi / v$$

(Verifying this equation with Earth values: $P_E = 2 \times 1.496 \times 10^{11}$ m $\times \pi/29786$ m/s = 3.156×10^7 s = 1 year)

We can use for the Earth and for the object. Substitution of P in the 3rd Kepler's law:

$$(2D_E\pi)^2 / (v_E^2 D_E^3) = (2D_O\pi)^2 / (v_O^2 D_O^3)$$

Simplifying:

$$v_E^2 D_E = v_O^2 D_O$$

We obtain D_O from $\omega = (v_E - v_O) / (D_O - D_E)$ and we substitute in the last equation:

$$v_E^2 D_E = v_O^2 (D_E + (v_E - v_O)/\omega)$$

And simplifying we get $(v_E^2 - v_O^2)\, D_E = v_O^2\, (v_E - v_O)/\omega$ which we write:

$$(v_E + v_O)\,(v_E - v_O)\, D_E\, \omega = v_O^2\, (v_E - v_O)$$

and simplifying again $(v_E + v_O)\, D_E\, \omega = v_O^2$ and finally:

$$v_O^2 - D_E\, \omega\, v_O - D_E\, \omega\, v_E = 0$$

The solutions of this equation are:

$$v_O = (D_E\, \omega \pm [\, (D_E\, \omega)^2 + 4\, D_E\, \omega\, v_E\,]^{1/2}) / 2$$

Calculate the values for D_O and v_O inserting values of D_E, ω and v_E in the last equation. After you have calculated D_O, the distance of 1994 TG2 to the Sun, what kind of small bodies dos 1994TG2 belongs to?.

Use the expression for the period, P, and **calculate the period of 1994 TG2, P_O**.

SOLUTIONS

In this exercise we measure the angular distance from the images of 1994 TG2 and calculate the angular velocity. Furthermore, the distance of this object from the Sun is obtained as well as its period. Finally, it is possible to decide, whether 1994 TG2 belongs to the asteroids belt, the Kuipers belt or the Oorts cloud.

- ### Activity 1

Example measurements, made by hand, using a ruler on a 51 mm × 62 mm version of the printed image (the printed size depends on the printer):

1 arcminute ---- 29 mm ---- 2.07 arcseconds/mm

Images obtained on 08.10.94 d_1 = 10.0 mm d_1 = 20.69 arcseconds
Images obtained on 09.10.94 d_2 = 7.5 mm d_2 = 15.52 arcseconds

- Activity 2

on 08.10.94: $\Delta t_1 = 6.26$ hours, $\omega_1 = d_1 / \Delta t_1 = 3.30$ arcseconds/hour $= 4.451 \times 10^{-9}$ rad/s

on 09.10.94 $\Delta t_2 = 5.42$ hours, $\omega_2 = d_2 / \Delta t_2 =$ 2.86 arcseconds/hour $= 3.856 \times 10^{-9}$ rad/s

The average is $\omega = 3.08$ arcseconds/hour $= 4.153 \times 10^{-9}$ rad/s

The angular speed detected by O. Hainaut from the original data (using a more sophisticated method of calculation) was $\omega = 3$ arcseconds/hour.

- Activity 3

Inserting values of D_E ω and v_E:

$v_O = 1.496 \times 10^{11}$ m $\times 4.153 \times 10^{-9}$ rad/s $\times 1/2 \pm [1.496 \times 10^{11}$ m $\times 4.153 \times 10^{-9}$ rad/s $\times 1.496 \times 10^{11}$ m $\times 4.153 \times 10^{-9}$ rad/s $\times 1/4 + 1.496 \times 10^{11}$ m $\times 4.153 \times 10^{-9}$ rad/s $\times$ 29 786 m/s$]^{1/2} = 4.624 \times 10^3$ m/s

Use equation 2 to get $D_O = v_E^2 D_E / v_O^2$ = 29 786 m/s × 29 786 m/s × 1.496×10^{11} m / 4.6238×10^3 m/s / 4.6238×10^3 m/s $= 6.208 \times 10^{12}$ m = 41.498 au

The distance of 1994 TG2 found is 41.5 au, so it belongs to the Transneptunian Objects. From his observations O. Hainaut obtained r = 41.534 au.

The period is obtained using the equation found:

$P_O = 2D_O\pi/v_O = 2 \times 6.208 \times 10^{12}$ m $\times \pi / 4.624 \times 10^3$ m/s $= 8.436 \times 10^9$ s = 267.5 years

The period obtained by O. Hainaut was P = 267.68 years

References

- http://www.sc.eso.org/õhainaut/nice/TG2.html
- http://www.sc.eso.org/õhainaut/nice/TG2.gif