Radar Observations of an Asteroid 1991JX

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Abstract

By taking an opportunity of a close approach of an asteroid 6489 (=1991 JX) to the Earth at 0.034 AU in June 1995, test observations of the radar echo from the asteroid were carried out under an international collaboration among the US, Russia and Japan. We report the detection of the radar echoes from the data obtained with 34m antenna at Kashima. The asteroid 6489 became the first solar system object observed by means of radar technique in Japan and it was a quite important step towards the future radar observations of asteroids. Although the observations were short duration for test and demonstration purposes, we could retrieve information about the size and reflectivity of the asteroid.

1. Introduction

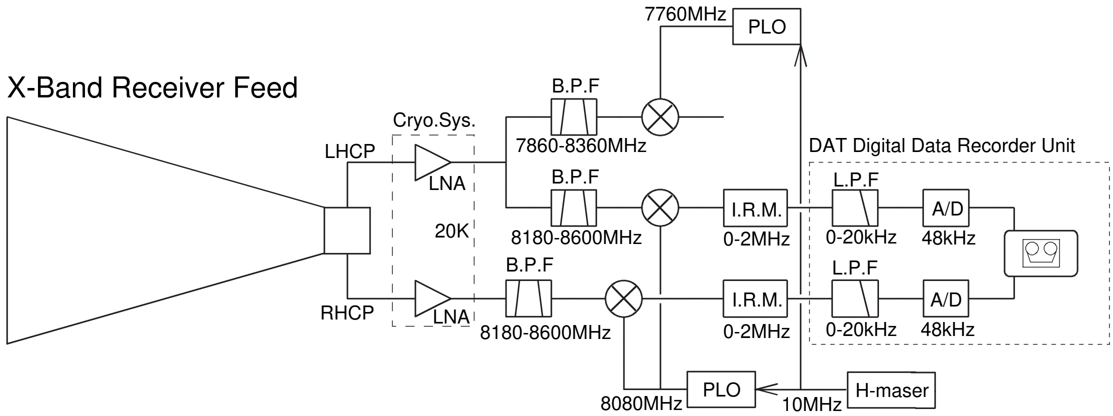
An asteroid 6489 (=1991 JX) approached the Earth in June 1995, and the closest distance from Earth reached 0.034 AU which was the closest approach since its discovery and for at least next two centuries. Taking this opportunity, the first attempt to detect radar echo signals reflected by an asteroid in Japan was made. This was part of the first attempts to carry out an inter-continental radar experiment. 34m antenna at Kashima Space Research Center (KSRC) of Communications Research Laboratory (CRL) and 64m antenna at Usuda Deep Space Center (UDSC) of Institute of Space and Astronautical Science (ISAS) were used as receiving stations along with other stations in Ukraine and in Germany. Among these four stations, radar echo signals were detected from data observed at Kashima on June 15 and at Evpatoria (Ukraine) on June 13, 14, and 15. In this paper, we report the observations and results obtained at Kashima.

2. Experiments

High power radio signals transmitted towards the asteroid 1991 JX from a 70m antenna at Goldstone, which is one of worldwide telecommunication facilities operated by Jet Propulsion Laboratory (JPL) for tracking of deep space spacecraft, were reflected by the asteroid and then received by a 34m antenna at Kashima. Since our objective was to detect the radar echo from an asteroid for the first time in Japan and to ensure the feasibility of conducting international asteroid radar experiments, a sinusoidal wave form was transmitted in Left-Hand-Circular-Polarization without any of the modulation normally used for time delay measurements and two dimensional imaging (Ostro, 1993). Transmitted signal was controlled its frequency so that the received signal at Usuda stay at a target frequency 8510.0001MHz. It was done by using *a-priori* information of the asteroid's orbit and the Earth's rotation. Since Kashima is located about 200km east of Usuda, received signal at Kashima had a small extra doppler shift changing by about 1 Hz/min.

At Kashima, the received signals were down-converted to about 10 kHz and sampled at 48 kHz sampling rate after a low-pass-filter. The low-pass-filter is built-in in a DAT digital data recorder unit, which has a cut frequency at 20 kHz. The digitized data were recorded on a DAT tape. Both Right-Hand-Circular-Polarization and Left-Hand-Circular-Polarization data were recorded. A DAT tape can record two data channels for two hours. The configuration of the observation system is shown in Figure 1.

Figure 1. Block diagram of the observation system set-up used at Kashima.



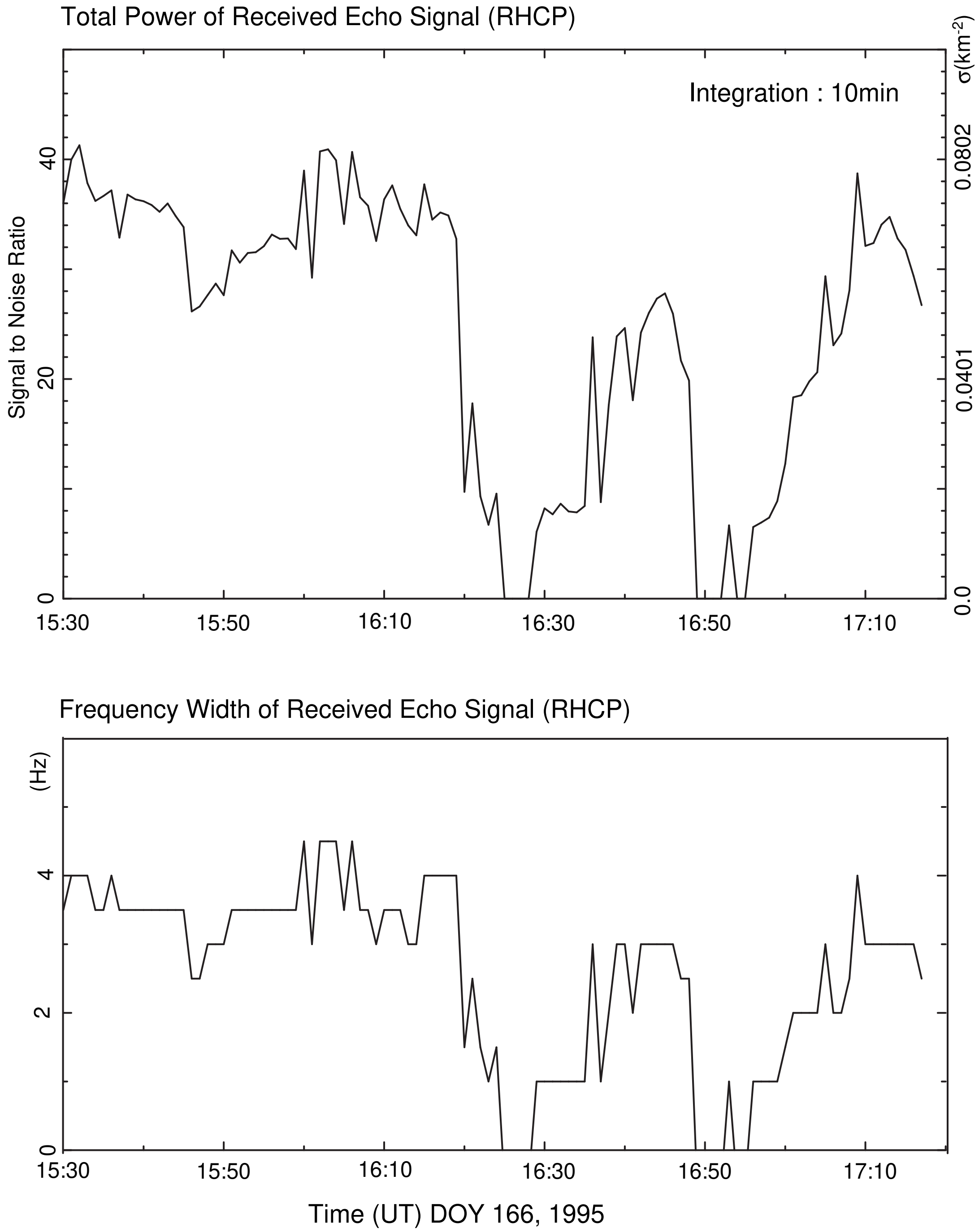
3. Data Analysis and Results

Observations were made on June 14 and on June 15, 1995 for two to three hours each, about a week after the closest approach of the asteroid to the Earth. After the observations, the data recorded on a DAT tape were transferred to a PC through a parallel interface and then to an UNIX workstation through an Ethernet network. Power spectra of the signal were calculated from 2 seconds of data duration at frequency resolution of 0.5 Hz, and then integrated for 10 minutes by compensating the doppler-shift. From the RHCP data, the radar echo was detected with a peak Signal-to-Noise-Ratio of 8.70 varying with time. The echo signal had a broad frequency width in spite the transmitted signal was a pure tone signal because of the rotation of the target body. Total power of the received echo signal can be evaluated by integrating the power spectra over the frequency and compare it with the power of receiving system noise from a bandwidth of 0.5 Hz. Figure 2 shows the time variation of the total power of received radar echo and its frequency width for about two hours from 15:30 UT, 15 June, 1995. The frequency width of the echo was derived from the width of the power spectrum of the signal level at 2.83 times the standard deviation of the noise which gives the probability of false signal detection of 0.01.

Time label in the figure indicates the beginning of the 10 minutes of integration period. As shown in the figure, the echo signal disappeared twice around 16:26 and 16:49. The cause of the latter interruption of the signal is due to a mechanical problem reported from the transmitting station, whereas the cause of the former interruption is not known yet. Apart from these two signal interruptions, there is still some time variation in the total power and the frequency width of the received echo signal, which indicates the target body has irregularity of shape and roughness on its surface.

Total power of a radar echo signal has a relation with an effective cross section, σ, of a target asteroid expressed by the following equation.

Figure 2. Total power of the received radar echo and its frequency width.



$$\mathrm{P_r} = \frac{P_\mathrm{t} G_\mathrm{t} G_\mathrm{r} \sigma \lambda^2}{4\pi R_\mathrm{t}^2 \cdot 4\pi R_\mathrm{r}^2 \cdot 4\pi} \tag{1}$$

Here, P_t is the transmitting signal power, G_t is the gain of the transmitting antenna, and R_t is the distance of the asteroid from the transmitting station. P_r, G_r and R_r are similar parameters for the receiving path, and λ is the wave length of the radar signal. On the other hand, the power of the noise, N, can be evaluated by an equation,

$$N = k_\mathrm{B} T B \tag{2}$$

where k_B is the Boltzmann constant, T is the system noise temperature of the receiving station, and B is the frequency width of the noise to be evaluated which is 0.5 Hz in this case. Before the observations each day, calibration measurements of the receiving system were performed by using two calibrated dummy sources and CAS-A. As results of these measurements, G_r and T were measured as 65.5 dB and 56.8 K, respectively. During the observations on June 15, R_t and R_r were roughly equal to 0.0474 AU, and λ was 0.0353 m. P_t and G_t are 470 kW and 74.3 dB, respectively, according to the specifications of the 70m antenna at Goldstone. Using these parameter values, the Signal-to-Noise-Ratio of 41.3, which is the peak value in the Figure 2, corresponds to σ of 0.0828km^2. If the reflectivity of the asteroid is assumed as 0.5, and the shape of the asteroid is assumed as a sphere, the diameter of the sphere becomes $\sim 460m$.

The size of the asteroid can also be evaluated from the frequency width of the received echo signal if the rotation period of the asteroid is known. If the maximum dimension of the asteroid perpendicular to its apparent rotation axis is D, and its apparent rotation angular velocity is ω, then the doppler frequency width Δf becomes,

$$\Delta f = \frac{2D\omega \sin\theta}{c} f_0 \tag{3}$$

where f_0 is the frequency of the central frequency of the received echo signal, c is the velocity of light, and θ is the angle between the apparent rotation axis and the direction towards the receiving station seen from the asteroid. From the optical observation, the rotation period of the asteroid is known as about 6 hours (Hudson and Ostro, 1995). From the Figure 2, Δf is 4 Hz ± 0.5 Hz most of the time, which leads $D\sin\theta = 240\mathrm{m} \pm 30\mathrm{m}$. This result is consistent with the results obtained from the equation (1), if the angle between the apparent rotation axis of the asteroid and the radial vector of the asteroid from the receiving station was small. The independent investigations on the data observed at Goldstone suggested the angle was about 20 degrees (Hudson and Ostro, 1995), which is quite consistent with our results.

4. Concluding Remarks

The radar echo signals from an asteroid was detected and analyzed from the data obtained by the 34m antenna at Kashima. It was the first but a successful and hence a important step towards the future radar observations in Japan. Although the observations were short duration, the capability of the observation facilities for asteroid radar experiments was satisfactory demonstrated. Based upon this encouraging success, opportunities of further radar experiments will be considered for many near earth asteroids in coming years.

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References

Ostro, S. J., "Planetary radar astronomy," *Rev. Modern Phys.*, **65**, pp. 1235-1279, 1993

Hudson, R. S. and S. J. Ostro, "Radar-Based Physical Models of Earth-Crossing Asteroids," abstracts to the 27th annual meeting of the *Div. Planetary Sci., American Astron. Soc.*, 1995