# Analysis of the Atmospheric Drag of the Echo 1 Satellite Using the PERLO Orbital Period Determination Program

By

**I. Almár, A. Horváth** and **E. Illés**

Konkoly Observatory of the Hungarian Academy of Sciences, Budapest, Hungary

**Abstract.** The PERLO program determines the quasi-nodal period of a satellite. Using visual observations of the decaying Echo 1 the density at 800 km was deduced. During April 1968 the solar flux $S_{10.7}$ did not follow the 27-day cycle but the density $\varrho_0$ continued to show this variation.

## 1. Introduction

A new computer program PERLO has been completed at the Konkoly Observatory, Budapest, and the Satellite Tracking Station, Miskolc, in order to deduce the orbital period of satellites with a high time resolution. The procedure is based on A. M. Lozinsky's suggestion [1] to determine the quasi-nodal period of a satellite from its consecutive transits through the topocentric celestial equator of a tracking station. Using the PERLO program, the orbital acceleration of Echo 1 has been studied and correlated with changes in the solar activity in 1968. The results are presented in the following sections.

## 2. Method of Analysis

The PERLO program permits the determination of the crossing time of the topocentric celestial equator with considerable accuracy, if observations with topocentric declinations $|\delta| < 10°$ are used. Frequent positions on both sides of the equator are preferred, but not indispensable. Every observed position (in horizontal or in equatorial system) is the starting point of an arithmetic calculation proposed by M. Ill [2] and of another by I. Almár [3] in order to derive approximate values of the $t(\delta)$ function at $\delta = 0$. The arithmetic mean and the standard deviation are given in both cases. As these methods are based on different assumptions, they supplement and check each other for the case of incomplete series of observations. A further check of the mean values is provided by a least squares solution. The adopted values of all topocentric crossing times are transformed to a common reference latitude using a simple formula requiring only approximate values of the orbital elements [4]. The program is written in ALGOL 60 language and contains 1120 statements.

Changes in the quasi-nodal period have been derived graphically from the $T(t)$ curves, and also numerically using the $O$–$C$ method [5]. We could not find in the present material any sudden change in $\dot{T}$, therefore we confined ourselves to a time resolution of 1 day. (The PERLO program allows a better time resolution up to one orbital period, if necessary.) The acceleration caused by solar radiation pressure was removed by the usual formulae [6]. Atmospheric densities were computed by means of the formula [7]

$$\varrho_\lambda = -\left(\frac{\Phi\,\dot{T}}{3\pi\,a\,\delta}\right)\frac{\exp(c\cos 2\omega)}{1+\dfrac{2\,e\,I_1(z^*)}{I_0(z^*)}+\dfrac{c\,I_2(z^*)}{I_0(z^*)}\cos 2\omega}$$

converted to values at a common height of 800 km

$$\varrho_{800} = \varrho_\lambda \exp\left(\frac{y-800}{H}\right)$$

where $H$ is the density scale height obtained from the CIRA 1965 model atmosphere [8] and $\delta = 288.2\ \mathrm{cm}^2/\mathrm{g}$ based on the results of earlier investigations [9].

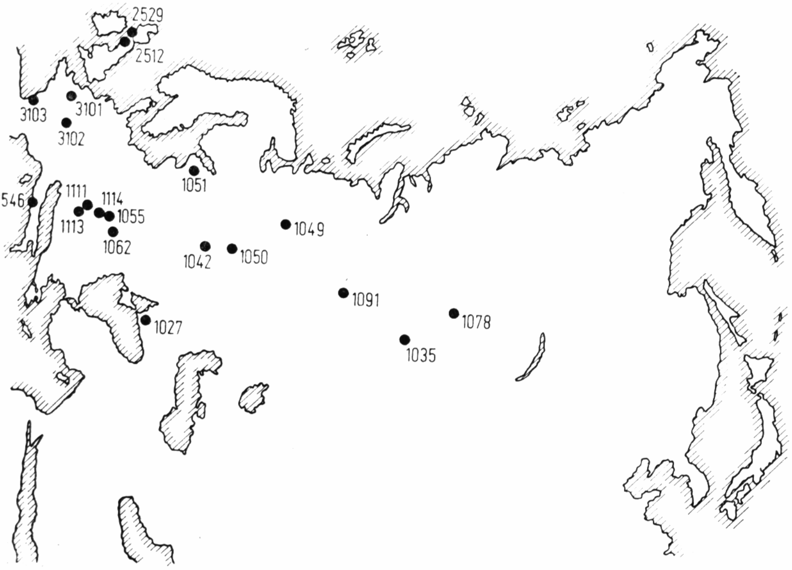

Fig. 1. Distribution of observing stations.

## 3. Observational Material

About 636 visual observations of 104 transits of Echo 1 were reduced by the PERLO program using an ICT-1905 computer. The observations were made at 19 Hungarian, Soviet, French and English tracking stations (see Fig. 1). The estimated average angular accuracy was 0.1°. The mean timing error deduced from independent observations of the same crossing over the same reference latitude but made at different stations proved to be about 1–2 sec. Echo 1 was an unfavourable satellite from this point of view, crossing the topocentric equator of the European stations at a small angle.

## 4. Results and Conclusions

The deduced values of air density at a height of 800 km are shown as circles in Fig. 2. They are joined by continuous lines where the accuracy of the determination permitted continuous monitoring of the variations. The local time of the sub-perigeepoint changed but little, $12^h$ being a good average value over the whole time interval.

In order to display the variation connected with solar radiation more clearly, we need to correct $\varrho_{800}$ for the geomagnetic effect. At the very bottom of Fig. 2 the variation of the planetary geomagnetic index $a_p$ is

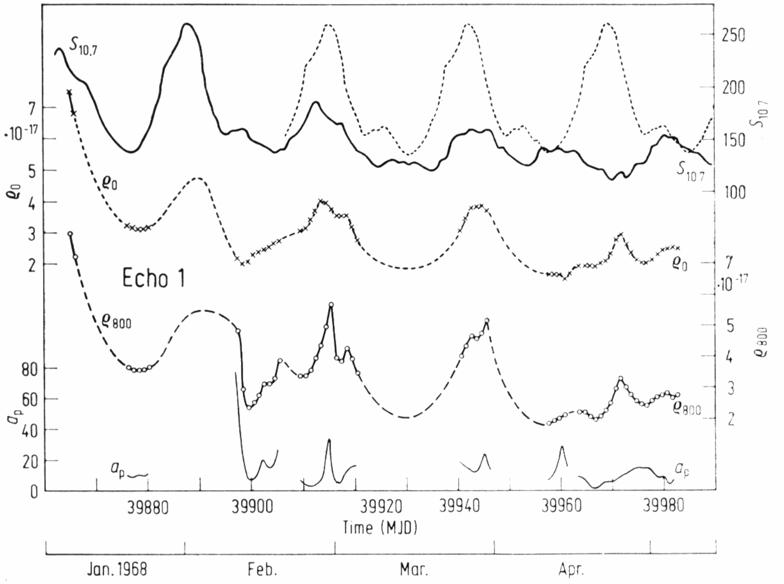

Fig. 2. $\varrho_{800}$: atmospheric densities at 800 km; $\varrho_0$: $\varrho_{800}$ values corrected to $a_p = 0$; $S_{10.7}$: decimetric flux of solar radiation in $10^{-22}$ Wm$^{-2}$ Hz$^{-1}$ (continuous line), and repetition of the January–February cycle (dashed line).

shown during the time covered by the observations. Density values were reduced to $a_p = 0$ by [10]

$$\varrho_0 = \frac{\varrho_{8\,00}}{1 + 0.015\, a_p}$$

making the assumption of a time delay of $0\overset{\mathrm{d}}{.}5$, and are represented by crosses in Fig. 2. The transformation yields a curve revealing an obvious correlation from January till March with the variation of the measured $S_{10.7}$ intensity – represented by the continuous line at the top of Fig. 2 – with a time lag of about two days. The dates of occurrence of the extreme values of $\varrho_0$, however, continue to repeat the 27 day cycle in April as well, whilst the actual $S_{10.7}$ variation was significantly disturbed. This fact is demonstrated by projecting the form of the undisturbed January–February cycle of solar activity repeatedly as a dashed line on later cycles. The correspondence in time is extremely good.

This interesting result is consistent with previous conclusions by KING-HELE and WALKER [11]: "During June 1967 $S_{10.7}$ failed to show the strong 27-day variation apparent in May and July, but the density *did* show this 27-day variation. We must conclude that the 10.7 cm radiation is an imperfect index of the extreme ultraviolet radiation from the Sun ... values of density are in this instance a better index of solar activity than $S_{10.7}$."

The discrepancy between the variation of $S_{10.7}$ and $\varrho_0$ in April 1968 probably occurs because the phase of the 27-day cycle of the 10.7 cm radiation suddenly changed in April by about 180°, but the density variation continued to follow the same run.

It is to be mentioned that the $\varrho_0$ curve – not reduced to a common $S_{10.7}$ value – shows a subsidiary minimum between 10 and 15 April corresponding to that revealed earlier by M. ILL and F. BARLIER by means of different methods. Their paper was presented at this symposium.

## References

1. LOZINSKY, A. M.: In: Trajectories of Artificial Celestial Bodies, Proc. of COSPAR-Symp. Paris 1965, Berlin/Heidelberg/New York: Springer 1966.
2. ILL, M., KASSIMENKO, T. V.: In: Observations of Artificial Satellites of the Earth No. 7 (Sofia 1968) p. 87.
3. ALMÁR, I.: In: Observations of Artificial Satellites of the Earth No. 7 (Sofia 1968) p. 111.
4. HORVÁTH, A., SZABÓ, G.: In: Observations of Artificial Satellites of the Earth No. 5 (Bucuresti 1967) p. 176.
5. ILLÉS-ALMÁR, E., ALMÁR, I.: Mitt. Budapest-Svabhegy No. 59 (1965).
6. HORVÁTH, A.: In: Observations of Artificial Satellites of the Earth No. 8 (Budapest 1969) p. 187.

7. King-Hele, D. G.: Theory of Satellite Orbits in an Atmosphere, London: Butterworth 1964.
8. CIRA 1965 COSPAR International Reference Atmosphere, Amsterdam: North-Holland 1965.
9. Zadunaisky, P., Shapiro, I., Jones, H.: SAO Special Report No. 61, March 1961.
10. Stergin, C. G.: In: Handbook of Geophysics and Space Environments, p. 3–40, New York: McGraw-Hill 1965.
11. King-Hele, D. G., Walker, D.: Planet. Sci. 17 (1968) 197.

Correspondence to: Dr. I. Almár, Konkoly Observatory Budapest 114 Pf. 67.