IL NUOVO CIMENTO VOL. 15 C, N. 2 Marzo-Aprile 1992

Abnormalities of the Time Comparisons of Atomic Clocks during the Solar Eclipses (*).

S.W. ZHOU and B.J. HUANG

Department of Physics, Huazhong University of Science and Technology
Wuhan, Hubei - 430074 P. R. China

(ricevuto il 15 Ottobre 1990; approvato il 15 Novembre 1991)

Summary. – We have investigated into the time comparison data of the atomic clocks of some stations and have found that the solar eclipse has influence on the time comparison of atomic clocks.

PACS 96.90 – Other topics on the solar system.

1. – Introduction.

On the gravitational abnormal phenomenon, earlier on, there were «the abnormalities in the motion of a paraconical pendulum on an anisotropic support» found by Allais [1] and «1970 solar eclipse as by torsion pendulum» by Saxl [2]. It is found by Zhou *et al.* that during the solar eclipse of September 23, 1987, the spectrum wavelengths of H, D, Ca, ... on the earth showed a relative variation of an order or magnitude of about 10^{-4}.

We have investigated into the time comparison data of the atomic clocks of some stations (see fig. 1) and have found that the solar eclipse has influence on the time comparison of atomic clocks.

2. – Abnormalities of time comparisons during the solar eclipses.

The time comparisons of two clocks during the solar eclipses of 23/9/1987, 18/3/1988 and 22/7/1990 are shown in fig. 2-4, respectively.

The time comparisons of two clocks at the same station are shown in table I, fig. 2 *a*) and fig. 3 *a*). The time comparisons of clocks of two stations by means of ground wave are shown in table II, fig. 2 *b*)-*d*) and fig. 4; those of sky wave are shown in table III and fig. 2 *e*)-*g*).

(*) The authors of this paper have agreed to not receive the proofs for correction.

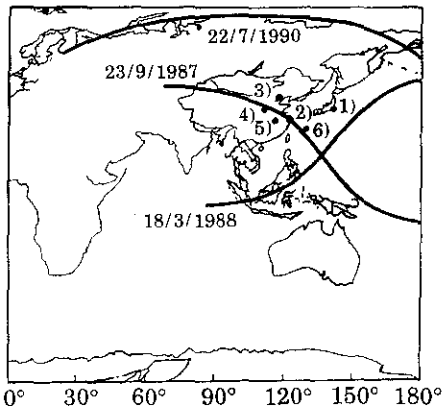

Fig. 1. – The central paths of 3 solar eclipses and the approximate locations of investigated stations. 1) Tokyo, 2) Shanghai, 3) Beijing, 4) Lintong, 5) Wuchang, 6) Okinawa.

In fig. 2-4: the quantity $x(t) = T_a(t) - T_b(t)$ is defined as the difference between the readings of clock a and clock b at instant t; the quantity $\Delta_1 x(\tau) = x(t+\tau) - x(t)$ is the first difference of the time readings with $\tau = 24$ or 6 hours [3]. For instance, $\Delta_1 x_{t=12h}(6h) = x_{t=12h} - -x_{t=6h}$. The horizontal dashed line zone represents an uncertainty zone, the width of which is equal to the difference of $\Delta_1 x_{max}(\tau)$ and $\Delta_1 x_{min}(\tau)$ in ordinary days. The horizontal dashed zone with arrows represents an uncertainty zone for the interval until 1/9 or 30/9. The

TABLE I. – *The time comparisons of two clocks at the same station.*

Station	Clocks	Solar eclipse Date	Magnitude (%)	$3S$	$\lvert\Delta_1 x(6h)\rvert_m$	r	R
Beijing	NewIII – MC	23/9/87	85	0.1 μs	1.0 μs	30	$5\cdot10^{-11}$
Observatory	Cs (2) – Cs (1)	18/3/88	30	0.02 μs	0.6 μs	90	$3\cdot10^{-11}$

TABLE II. – *The time comparisons of two stations by means of ground wave.*

Station — Station	Standard frequencies used	Solar eclipse Date	Magnitude (%)	$3S$	$\lvert\Delta_1 x(6h)\rvert_m$	r	R
Beijing (UTC) — Okinawa (LC)	100 kHz	23/9/1987	85 (Beijing)	0.09 μs	0.34 μs	11	$2\cdot10^{-11}$
Shanghai (UTC) — Okinawa (LC)	100 kHz	23/9/1987	98 (Shanghai)	0.19 μs	0.29 μs	5	$1\cdot10^{-11}$
Lintong (UTC) — Okinawa (LC)	100 kHz	23/9/1987		0.30 μs	0.91 μs	9	$4\cdot10^{-11}$
Wuchang (UTC) — Okinawa (LC)	100 kHz	22/7/1990		0.65 μs	50.1 μs	231	$2\cdot10^{-9}$
Wuchang (Rb) — Okinawa (LC)	100 kHz	22/7/1990		1.85 μs	35.4 μs	57	$2\cdot10^{-9}$
Beijing (UTC) — Lintong (BPL)	100 kHz	18/3/1988	30 (Beijing)	0.04 μs	0.57 μs	43	$7\cdot10^{-12}$

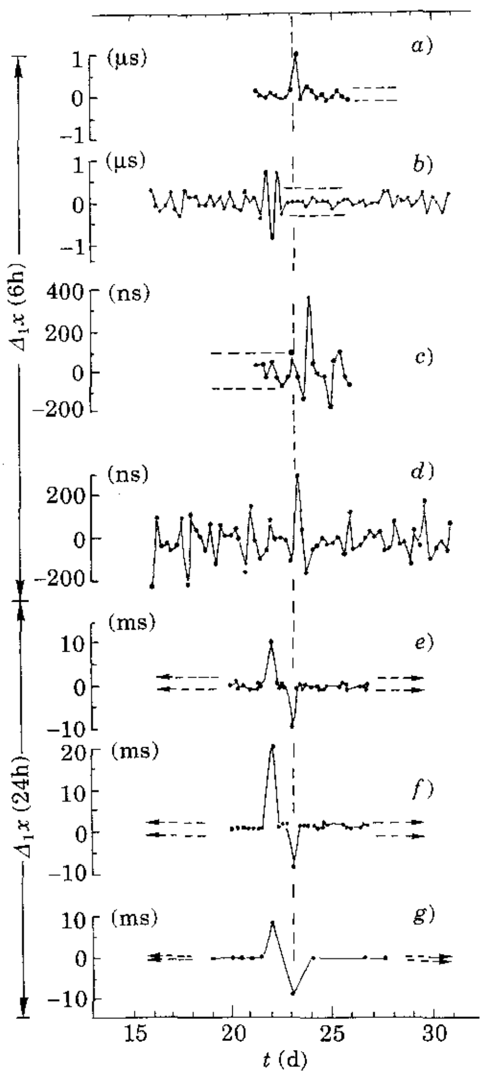

Fig. 2. – The time comparisons on the solar eclipse of September 23, 1987. *a*) The time comparison of NewIII and MC clocks at the Beijing Observatory. *b*) The time comparison between Lintong and Okinawa by means of ground wave (UTC–LC). *c*) The time comparison between Beijing and Okinawa by means of ground wave (UTC–LC). *d*) The time comparison between Shanghai and Okinawa by means of ground wave (UTC–LC). *e*) The time comparison between Wuchang and Lintong by means of sky wave (UTC–BPM). *f*) The time comparison between Wuchang and Lintong be means of sky wave (UTI–BPM). *g*) The time comparison between Wuchang and Tokyo be means of sky wave (UTC–JJY).

perpendicular dashed line to t-axis indicates the midpoint of the solar eclipse.

In tables I-III: the quantity S is the random deviation of $\Delta_1 x(\tau)$ in ordinary days, $S = \frac{1}{6}\left[\Delta_1 x_{max}(\tau) - \Delta_1 x_{min}(\tau)\right]$. The quantity $|\Delta_1 x(\tau)|_m$ is the maximum of $|\Delta_1 x(\tau)|$ during the solar eclipse. The quantity $r = |\Delta_1 x(\tau)|_m / S$ serves as a measure of confidence. The quantity $R = = |\Delta_1 x(\tau)|_m / \tau$ is the relative variation of $\Delta_1 x(\tau)$ during the solar eclipse.

TABLE III. – *The time comparisons of two stations by means of sky wave.*

Station — Station	Standard frequencies used	Solar eclipse Date	Solar eclipse Magnitude (%)	$3S$	$\lvert\Delta_1 x(6\,\text{day})\rvert_m$	r	R
Wuchang — Lintong (UTC) (BPM)	5; 10 MHz	23/9/1987	86 (Wuchang)	1.5 μs	10.2 μs	20	$1\cdot10^{-7}$
Wuchang — Lintong (UTI) (BPM)	5; 10 MHz	23/9/1987	86 (Wuchang)	1.5 μs	20.3 μs	41	$2\cdot10^{-7}$
Wuchang — Tokyo (UTC) (JJY)	5; 10 MHz	23/9/1987	86 (Wuchang)	0.2 μs	9.0 μs	135	$1\cdot10^{-7}$

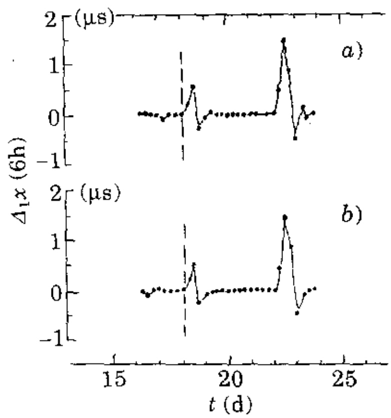

Fig. 3. – The time comparisons on the solar eclipse of March 18, 1988. *a*) The time comparison of Cs(2) and Cs(1) clocks at Beijing Observatory. *b*) The time comparison between Beijing and Lintong by means of ground wave (UTC–BPL).

Looking at fig. 2-4 and tables I-III, one is tempted to believe that the time comparisons of the atomic clocks have made the jumps during the period of the solar eclipse.

3. – Discussion.

1) The abnormal variations of the time comparisons during the solar eclipses are confirmative. The reasons are as follows.

From fig. 2-4 and tables I-III, the fluctuations of $\Delta_1 x(\tau)$ in ordinary days are limited within the uncertainty zone ($-3S <$ width $< 3S$), but the great jumps ($5S < \lvert\Delta_1 x(\tau)\rvert_m < 231S$) occurred in the solar eclipse period.

The abnormalities occur not only on a comparison clock pair but on many comparison clock pairs by means of three methods in 3 solar eclipses.

2) On the causes of the abnormalities, we discuss only the following problems here:

a) The abnormalities cannot be interpreted in the frame of present gravitational theories.

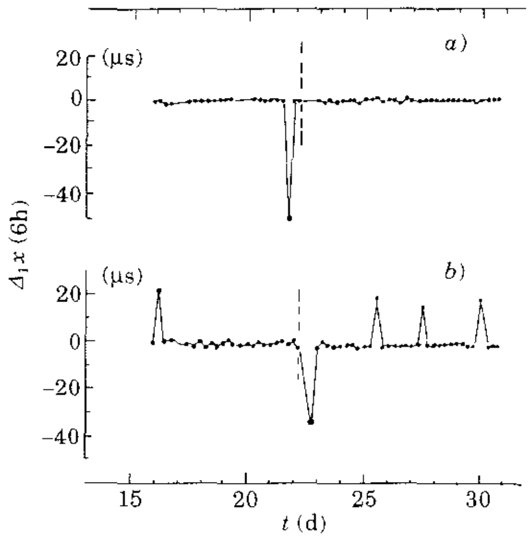

Fig. 4. – The time comparisons on the solar eclipse of July 22, 1990. *a*) The time comparison between Wuchang and Okinawa by means of ground wave (MC–LC). *b*) The time comparison between Wuchang and Okinawa by means of ground wave (Rb–LC).

b) The time comparisons of two clocks in the same station or two stations by means of the ground wave are independent of ionosphere.

c) The time occurred $|\Delta_1 x(\tau)|_m$ may lead to lag time of the midpoint of the solar eclipse by (6 ÷ 24) hours; this means that the abnormalities are not only the effect of the Moon's optical shadow.

3) The relative variation of the order of magnitude during the solar eclipse, for the spectrum wavelengths is 10^{-4}, but for the time comparisons of the atomic clocks is $10^{-11} \div 10^{-7}$. The main cause is that the distance between the investigated clocks is too short. The order of magnitude will be to rise if two clocks are distributed in within and without of the solar eclipse zone, respectively.

* * *

It should be emphasized that the Shanxi Observatory, Beijing Observatory, Wuchang Time Observatory and Shanghai Observatory provided for the related data. To all of them we would like to express our sincere gratitude. We thank senior engineers S.H. Zhen, C.H. Wang and X.R. Chen for their advice and help.

REFERENCES

[1] F.C. ALLAIS: *Aero/Space Eng.*, Sept. Oct. (1959), p. 46.
[2] E.J. SAXL and M. ALLEN: *Phys. Rev. D*, **3**, 823 (1971).
[3] P. KARTASCHOFF: *Frequency and Time* (Academic Press Inc., London, 1978).