LUNAR LASER RANGING

EARTH ROTATION (UT0) FROM LUNAR LASER RANGING CERGA 89 M 01

A determination of UT0 has been made at CERGA from the Lunar Laser Ranging data obtained from October 1987 till March 1989.

C. Veillet. J. Pham-Van OCA/CERGA - Avenue Copernic - F-06130 Grasse

Normal points have been used from three stations : the McDonald Laser Ranging Station (MLRS). the Haleakala station on Maui (Hawai), and the CERGA station in Grasse.

The same method as JPL has been used (Dickey et al..1985) for deriving UT0-UTC values from residuals on the measured ranges. Precession (Lieske et al., 1977: Lieske, 1979), nutation (Seidelmann. 1982) and Greenwich mean sidereal time (Aoki et al., 1982). No plate motion has been considered for this series covering 18 months.

The lunar position from the JPL ephemeris DE121/LE65 has been modified by fitting the lunar ephemeris to the observations (using the JPL partials). The lunar libration (LLB13) hasn't been changed.

A set of station coordinates has been determined with this UT series. The following table gives the values determined from the data set (the formal errors are given in the unit of the last digit). TLRS position is poorly determined as the data set from this station is small.

SSC(CERGA)89 M 01

IGNF NUMBER	SITE	DOMES NUMBER	X m	Y m	Z m	PLATE
10S001	GRASSE	10002S002	4581692.174	556195.580	4389354.610	EURA
2S002	FORT DAVIS	40442S007	-1330121.190	-5328531.937	3236146.778	NOAM
8S002	MAUI	40445S005	-5466006.939	-2404427.766	2242188.408	PCFC
2S003	FORT DAVIS	40442S014	-1330021.660	-5328402.784	3236481.167	NOAM

SX SY, SZ = 0.030m. EPOCH-MJD = 47328.

Separation between Haleakala transmitter and receiver has been taken as given in BIH Annual Report for 1986 page D-29, and conforms to a survey.

ACKNOWLEDGEMENTS.
We wish to acknowledge station staff at Mc Donald, Haleakala and CERGA for getting data, as well as R. Ricklefs and P. Shelus at UTex for MLRS and Maui normal points, and JPL for the ephemeris provided.

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EOP(CERGA)89 M 01 Available from 1987 to 1988

Number of measurements and RMS uncertainty per year
Units : 0.001" for X,Y,dPsi,dEps; 0.0001s for UT; ms for D

YEAR	Nb	UTO Sigma
1987	22	2.78
1988	79	3.19

EARTH ROTATION (UT0) FROM LUNAR LASER RANGING JPL 89 M 01

XX Newhall, J.G.Williams. and J.O.Dickey - Jet Propulsion Laboratory
California Institute of Technology - Pasadena. California 91109-8099

Lunar Laser Ranging (LLR) data have been acquired and analyzed between August, 1969 and January. 1989. These data are used to estimate station locations, reflector locations, and lunar gravity and orbit parameters. Beginning in 1970, data acquisition was sufficiently dense to permit determinations of Earth rotation UT0. Values of UT0-UTC through 1987 have been submitted previous-ly : 81 such values were derived from data acquired in 1988.

The full range data set comprises 6000 normal points taken from six sites: the McDonald Observatory 2.7-meter telescope; the McDonald Laser Ranging Station (MLRS, situated in separate locations before and after a move in early 1988): the Haleakala observatory on Maui, Hawaii: the Orroral Valley observatory in Australia: and the CERGA system in Grasse, France. These normal points are used to estimate the set of lunar and Earth-related parameters. The post-fit residuals are analyzed by the daily-decomposition method (Dickey et al., 1985) to obtain estimates of UT0-UTC for each station-reflector pair on every day for which sufficient data are available. Uncertainties in the submitted values have a median value of 0.20ms, with a minimum value of 0.04ms.

The IAU expression has been used for Greenwich mean sidereal time (Aoki et al.1982). The planetary and lunar ephemeris used in the fit was DE121/LE65; this ephemeris uses the equator and equinox of B1950.0. It is on the dynamical equinox and has a zero point consistent with that of the FK5 star catalog. The numerically integrated lunar physical librations used are designated LLB13. Small corrections to the nominal ephemerides and librations result during the fitting process.

This year, plate motion has been applied to the station coordinates using the AM0-2 model of Minster and Jordan (1978). The LLR UT0 system has been adjusted so that it approximates that of the IERS.

A correction to the luni-solar precession constant (Lieske et al.,1977; Lieske, 1979) has been estimated, giving a correction of -0.0031"/y. The correction has been made so as not to cause a rate change in UT (Williams and Melbourne, 1982; Zhu and Mueller, 1983).

The IAU nutation (Seidelmann, 1982) has had an annual correction of 0.0021" (taken from Herring's solution given in Carter, 1988) applied ($\Delta\varepsilon$ = 0.0021" cos 1', and sin $\varepsilon\,\Delta\psi$ = 0.0021 sin 1').

Corrections to the 18.6y nutation coefficients were estimated, yielding

$$\Delta\varepsilon = +0.0045''\cos\Omega + 0.0034''\sin\Omega$$
$$\sin\varepsilon\,\Delta\psi = -0.0055''\sin\Omega + 0.0025''\cos\Omega$$

The two out-of-phase terms (the second terms on the right side) were constrained to the expected ratio: the constraint of the two in-phase terms also includes a correction for the precession change and the preliminary solid-body correction of Kinoshita (1988). Subject to the two constraints, the uncertainty in the four nutation coefficients is about 0.002", and the precession uncertainty is 0.0006"/y. Without the two constraints these uncertainties would be larger.

With the production of the 1988 values of UT0-UTC a set of station locations has been established. The base epoch for plate motion is January 1, 1988 (MJD 2447161.5). The IERS designation is EOP SSC (JPL) 89 M 01, and the components are given in the following table:

SSC(JPL) 89 M 01

IGNF NUMBER	SITE	DOMES NUMBER	X m	Y m	Z m	PLATE
2S001	FORT DAVIS	40442S002	-1330781.573	-5328755.568	3235697.347	NOAM
2S002	FORT DAVIS	40442S007	-1330121.335	-5328532.089	3236146.516	NOAM
2S003	FORT DAVIS	40442S014	-1330021.586	-5328403.177	3236481.500	NOAM
8S002	MAUI	40445S005	-5466007.069	-2404427.759	2242188.444	PCFC
10S001	GRASSE	10002S002	4581692.249	556195.508	4389354.856	EURA

SX SY SZ = 0.030m. EPOCH-MJD = 47161.

Cylindrical station coordinates

Station	Spin Radius (meters)	East Longitude (arc seconds)	Z-Height (meters)
McDonald 2.7 m	5492414.360	921520.7967	3235697.347
MLRS (old site)	5492037.599	921542.8208	3236146.516
MLRS (new site)	5491888.367	921545.2830	3236481.500
Haleakala Tmtr	5971474.368	733478.7249	2242188.444
CERGA	4615328.516	24917.6355	4389354.856

Haleakala Rcvr-Tmtr	Spin Radius	-7.446m
	East Longitude	0.000"
	Z-height	18.151m

The separation between the Haleakala transmitter and receiver conforms to a survey.

It should be noted that the McDonald 2.7m telescope ceased LLR activity in June, 1985.

The above station locations were derived using the formulation of the relativistic solar-system barycentric frame of reference. The transformation to the relativistic geocentric formulation requires the application of a scale factor.

The Jet Propulsion Laboratory provides current values of UT0-UTC on the General Electric Mark3 system for the benefit of interested users.

Acknowledgments.

We wish to acknowledge and thank the staffs of CERGA, Haleakala, the University of Texas McDonald Observatory, and the Lunar Laser Ranging associates. Normal points were constructed from individual photon returns by R.Ricklefs, P.Shelus, J.Storm, and J.Ries at the University of Texas for the MLRS and for Haleakala data. M.White and D.O'Gara produced Haleakala normal points independently. C.Veillet provided normal points for the CERGA data. The planetary ephemeris was produced by E.M.Standish. This paper presents the results of one phase of research carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

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EOP(JPL) 89 M 01 Available from 1970 to 1988

Number of measurements and RMS uncertainty per year
Units : 0.001" for X,Y,dPsi,dEps; 0.0001s for UT; ms for D

YEAR	UTO	
	Nb	Sigma
1970	14	17.24
1971	33	14.73
1972	73	9.61
1973	104	14.10
1974	72	12.38
1975	81	13.73
1976	75	12.20
1977	71	9.44
1978	61	12.00
1979	72	9.80
1980	77	9.62
1981	46	7.60
1982	6	10.26
1983	10	10.71
1984	78	11.35
1985	163	10.60
1986	42	6.79
1987	45	2.86
1988	80	4.16

UT0 DETERMINATION FROM LUNAR LASER RANGING OBSERVATIONS UTXM0 89 M 01

A. L. Whipple, J. Gyorgyey Ries, R. L. Ricklefs, P. J. Shelus, J. R. Wiant
McDonald Observatory / Department of Astronomy The University of Texas at Austin - Austin, Texas 78712 (USA)
R. W. King Department of Earth and Planetary Sciences Massachusetts Institute of Technology Cambridge, MA 02139 (USA)

We have analyzed all short pulse Neodymium-YAG lunar laser ranging data to determine UT0-UTC. The data were acquired between November 1984 and December 1988. A total of 1206 normal points, from the Haleakala Observatory on Maui, Hawaii, the McDonald Laser Ranging Station (saddle site and Mt. Fowlkes site) near Fort Davis, Texas, and the CERGA station in Grasse, were used in this solution. The data were edited and reweighted using an automated and objective scheme which identifies suspected outliers and adjusts station assigned weights to yield consistent distributions of the weighted residuals for all stations. There were sufficient data for 135 station/reflector pair estimations of UT0-UTC on 114 nights, including 56 UT0 estimates in 1988. A significant development of 1988 was the acquisition, by the CERGA station, of data on several nights which permitted the determination of UT0 from more than one, and sometimes all four, retroreflectors.

Our method of analysis was similar to that described by Langley et al. (1981). We first used the MIT Planetary Ephemeris Program (PEP) to estimate corrections to the global parameters. The MERIT standards were used with constrained corrections made to the constant of precession, obliquity of the ecliptic, and the 18.6 year, annual, semi-annual, and fortnightly nutation terms. Adjustments to the MIT ITR-78 solution were made for the Earth-Moon barycenter orbit, lunar orbit, and lunar libration. The node of the Earth-Moon barycenter orbit was fixed to tie the longitude of the celestial frame. The AM0-2 plate motion model was used without adjustment. Our a priori Earth orientation series was the University of Texas Center for Space Research (CSR) LGN7689. We estimated slopes for the polar motion components of this series and a piecewise linear spline to model long period deficiencies in the UT1 series. The longitude of the terrestrial frame was tied by fixing the zero point of the CSR Earth orientation adjustments at the last CSR IRIS tie of 13 January 1989. The station coordinates which resulted from the fit are given below. We also estimated a third degree and order lunar potential, lunar love number, and lunar dissipation parameter along with the selenocentric retroreflector coordinates. Lastly, we estimated time delay biases, relative to MLRS, for Maui and CERGA.

Following the global solution, we analyzed the post-fit residuals in the usual fashion (e.g., Stolz et al., 1976) to determine nightly corrections to UT0 and a bias. The nightly corrections were then added to the corrections contained in the UT1 spline, and the a priori UT1-UTC series to obtain the final values of UT0-UTC. A minimum of three normal points for each station/reflector

pair and at least a 1.5 hour span of coverage were the criteria we adopted for the nightly UT0 estimations. The weighted rms of the final postfit range residuals was 2.9 cm.

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SSC(UTXMO)89 M 01

IGNF NUMBER	SITE	DOMES NUMBER	X m	Y m	Z m	PLATE
2M001	FORT DAVIS	40442M001	-1330185.538	-5328511.363	3236150.176	NOAM
2M002	FORT DAVIS	40442M006	-1330081.173	-5328386.640	3236480.617	NOAM
8M001	MAUI	40445M001	-5466033.416	-2404366.189	2242187.274	PCFC
10S001	GRASSE	10002S002	4581698.654	556143.910	4389354.433	EURA

SX SY. SZ = 0.100m. EPOCH-MJD = 45700.

EOP(UTXMO) 89 M 01 **Available from 1984 to 1988**

Number of measurements and RMS uncertainty per year
Units : 0.001" for X,Y,dPsi,dEps; 0.0001s for UT; ms for D

YEAR	UTO Nb	UTO Sigma
1984	1	1.41
1985	25	0.63
1986	20	0.41
1987	32	0.38
1988	57	0.23

DETERMINATION OF UNIVERSAL TIME BY LUNAR LASER RANGING SHA 86 M 01

Jin Wenjing Qian Changxi
Shanghai Observatory Academia Sinica. Shanghai. China

Universal time has been determined from global data of Lunar Laser Ranging during Jan.1-Sept.7 1988. The data set obtained from McDonald. Grasse and Haleakala contains 358 normal points reflected from four retroreflectors and were usable for determination of universal time. Due to the needs of solving the normal equation, the data with observing interval of less than one hour, one normal point and bad points in a day rejected. Only 192 normal points have been used for the present results. The theoretical distances from the stations to the retro-reflectors of the Moon are calculated using the IAU 1976 system of astronomical constants (Melbourne et al.,1983). The new IAU expressions have been used for precession, nutation and Greenwith mean sidereal time. The influence of ocean load, lunar tide and Earth tide are taken into account. The planetary and lunar ephemeris DE200/LE200 are used for calculating the positions of the Moon, the Earth and major planets. LLB200 is adopted for calculating the lunar physical libration.

The station coordinates are adopted as follows.

SSC(SHA) 86 M 01

IGNF NUMBER	SITE	DOMES NUMBER	X m	Y m	Z m	PLATE
2S002	FORT DAVIS	40442S007	-1330120.991	-5328532.157	3236146.357	NOAM
10S001	GRASSE	10002S002	4581692.359	556195.489	4389354.773	EURA
8S001	MAUI	40445S002	-5466003.619	-2404426.691	2242197.421	PCFC
2S003	FORT DAVIS	40442S014	-1330021.443	-5328403.185	3236481.380	NOAM

SX SY, SZ = 0.100m. EPOCH-MJD = 45700.

The reflector coordinates are adopted from MERIT standards.

The mathematical model is described in Reference (Jin et al.,1985).UTOR-UTC is calculated in one-day interval. The precision of the normal point is taken for the weight of observational equation.

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ERP(SHA) 86 M 01 **Available from 1983 to 1988**

Number of measurements and RMS uncertainty per year
Units : 0.001" for X,Y,dPsi,dEps; 0.0001s for UT; ms for D

YEAR	UT1	
	Nb	Sigma
1983	14	18.78
1984	66	11.49
1985	103	17.71
1986	46	14.00
1987	49	1.91
1988	61	2.16