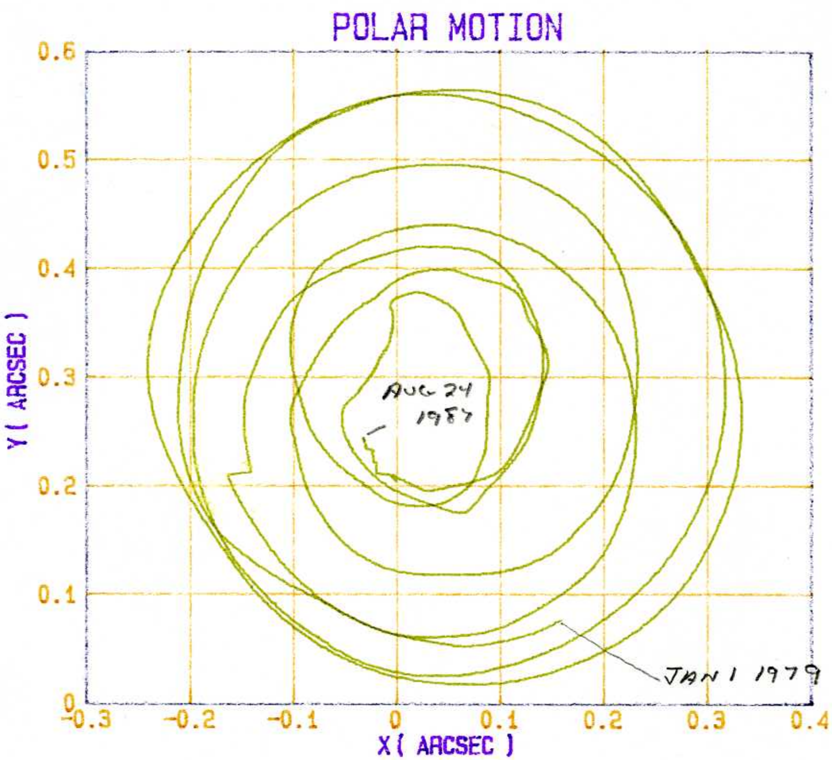
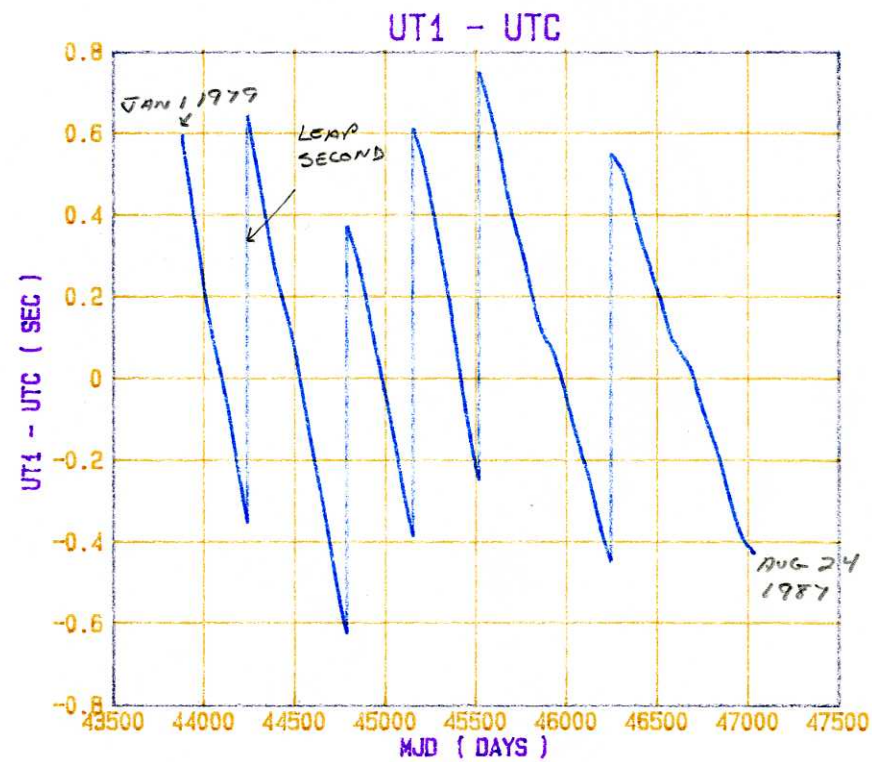


TIME DRIFT



EARTHS WOBBLE ON ITS AXIS

JAN 1 1979 STARTED USING INTERFEROMETER TO PREDICT EARTHS WOBBLE

U. S. NAVAL OBSERVATORY
WASHINGTON, D. C. 20390

THE U. S. NAVAL OBSERVATORY RADIO ASTROMETRY PROJECT: OPERATION OF THE GREEN BANK INTERFEROMETER

PROGRESS REPORT
30 May 1980

1. Purpose. It has been shown that a radio interferometer is inherently capable of determining Earth Rotation parameters (UT and PM) with considerably greater precision and accuracy than the optical technique of observing stars passing through the zenith. In order to provide the accuracy presently required for spacecraft navigation, star positions, and satellite navigation systems, the Bureau International de l'Heure (BIH) in Paris collects, and statistically weights and averages data provided to it by about 75 observatories world-wide (including over 40 communist observatories). The United States is entirely dependent on this international effort for the data. The radio interferometer can also determine a fundamental reference frame based on the positions of compact radio sources. This reference frame is an order of magnitude more accurate than the optical reference frame now used. Such a radio reference frame will allow independent calibration of the navigational satellite systems now in operation or under development.

2. Background. The U. S. Naval Observatory (NAVOBSY) inaugurated a Radio Astrometry project in FY79, using the Radio Interferometer at Green Bank, West Virginia. The purpose of this project is to evaluate the capabilities of the radio astrometry technique for providing fundamental celestial navigational data, such as Universal Time (UT), Polar Motion (PM), and accurate positions of a selected group of radio sources, with the aim of eventually using this technology in an operational mode. In the exploratory phase, the project is a joint project with the Naval Research Laboratory (NRL).

3. Mode of operations

a. The National Radio Astronomy Observatory (NRAO), operated by Associated Universities, Inc. under contract with the National Science Foundation (NSF), maintains and operates their radio interferometer in Green Bank, West Virginia for the exclusive use of the NAVOBSY on a 24-hour, seven-days-a-week basis. The NSF is reimbursed by the NAVOBSY for the costs involved in this operation. The ground rules are laid down in a memorandum of understanding between the NSF and the NAVOBSY.

b. The 4-element radio interferometer consists of three telescopes of 85 ft. diameter on a 2.4 km. baseline and a 45 ft. diameter telescope located on a hill 35 km away and connected to the main site by a microwave link. The telescopes operate at frequencies of 2695 and 8085 MHz. The NAVOBSY provides an observing program which is executed by the NRAO operating staff. NAVOBSY staff make frequent visits to the NRAO to discuss the program operation, implement program changes, and improve equipment performance on the basis of analysis of the results.

4. Data acquisition and analysis

a. The standard observing program consists of observations of approximately 20 radio sources, each observation of about 10 minutes duration, 24 hours per day. The data, recorded on magnetic tape, and consisting of phase and amplitude measurements of the interferometer fringes of the four interferometer pairs, are shipped to the NAVOBSY daily and reduced and analyzed using the NAVOBSY computer in Washington. The NAVOBSY distributes the data to users as appropriate.

b. Because no instrumental parameters are changed in this continuing program and the same sources are observed over and over, it is possible to detect ever more subtle atmospheric and instrumental effects, study their origin and take steps to correct them or apply corrections to the current and previously taken data. Consequently, as these effects are better understood, both source positions and current and prior determinations of UT and PM will improve.

5. Detailed discussion

a. The entire program is currently aimed at exploring the feasibility of the radio interferometry method as a permanent tool for accurate determination of Earth Rotation parameters. Improvement of existing equipment, development of new equipment, and new computer programs are an integral part of the effort. Analysis of the accumulating data bank is expected to provide deeper insights into the subtle effects which antenna deformation with temperature and solar illumination, cable delay changes, and delay changes in the receivers can have on the data. Studies of atmospheric delays as a function of weather, temperature, humidity, etc. will allow a correction for these effects. Combining the data from the two frequencies has recently led to a considerable improvement in correction for the effects of the ionosphere. Work toward understanding and modeling the effects of the Earth's atmosphere (both wet and dry components) is progressing.

b. Continued observations of source positions will lead to an answer to the question whether these objects (usually quasars) are really stationary or whether small changes in position occur due to peculiarities in the radiation mechanism. Some nearby radio stars (real optical stars which show occasional radio flares) will be added to the program in order to give insight into the flaring mechanism. Both these studies will determine whether the optical and radio positions can really be assumed to coincide. This is important for the connection of the radio to the optical fundamental reference frames.

c. The rotation of the Earth is not well understood. Polar Motion studies on a daily basis have never been made with this accuracy. In addition, the short period nutation terms in the theory of Earth rotation, which will be obtained in the course of this project, will allow improvement in the theory.

d. The extensive data base that will be collected will be checked against other UT and PM data to determine the consistency and in particular to determine the degree of improvement over the old methods that can be reached. It will also be used as a base against which other systems, currently under development (laser ranging, doppler, VLBI) can be tested.

e. Development of plans for a second 30-35 km station at right angles to the first (to better determine Polar Motion) is in progress. FY80 and FY81 funds will be used for establishment of this station as well as a new radio link connecting the two remote stations with the main observatory, and a water vapor radiometer to allow for the means to measure the amount of differential water vaper along the line of sight between two antennas.

6. Results to date

a. The fundamental observed quantities, from which our estimate of UT is derived, are the x, y, and z components of the interferometer baseline (B_x, B_y, B_z). Data have been obtained on a regular basis since October 1978. This data set is supplemented by some experimental data obtained at roughly monthly intervals between December 1977 and July 1978.

b. Initially, using two-day averages of observations made at a single S-band frequency (2695 MHz) between October 1978 and March 1979, our values for UT indicated an internal error (precision) 1 ms and an external error (accuracy) of 4 ms after removal of a systematic difference between the BIH values for UT and those determined by the interferometer. Since March 1979, we have been observing at two frequencies and correcting our observations for ionospheric effects. The resulting values for UT from October 1979 indicate an internal error (precision) of 1 ms and an external error (accuracy) of 1.9 ms after removal of a 4.5 ms periodic difference between the BIH values and those obtained by the interferometer, a significant improvement. Figure 1 exhibits the difference between the interferometer determinations for UT and those determined by the BIH. The points after October 1979 have been corrected for ionospheric effects. Currently, the data prior to October 1979 are being corrected for ionospheric effects.

c. For the component of Polar Motion observed by the interferometer, we obtain an internal precision of 0".014 (40 cm.) and an external precision of 0.029 (80 cm.). The results for both UT and Polar Motion are summarized in Table I, and refer to 3-day averages.

TABLE I.

	UT		Polar Motion	
	uncorr. for ionosphere	corrected for ionosphere	uncorr. for ionosphere	corrected for ionosphere
Internal Error (precision)	2.0 ms	1.0 ms	0".028	0".014
External Error (accuracy)	4.0 ms	1.9 ms	0".061	0".029

It should be noted that the precision in UT and PM is already at the level expected for fully satisfactory operation, which is comparable to that of the BIH 5-day values. The studies of the atmospheric effects mentioned below are expected to remove the systematic errors which cause the difference between accuracy and precision, and the addition of the second baseline is essential for the accurate resolution of all three components of the Earth's motion; other equipment is expected to improve the data to the target 0".010. It should also be noted that the 35 km baseline length over two years of operation has remained constant to within 2 mm, but variations in the three components of the baseline vector are still of the order of 5 mm.

7. Current Research

The effects of the neutral atmosphere (both dry and wet components) on the observations are currently being investigated. First, an improved model atmosphere, which contains seasonally adjusted atmospheric profiles and incorporates ground-based meteorological measurements, is being developed. It is expected that an improved tropospheric model will eliminate the systematic differences between the interferometric data and the BIH and improve the external precision of our day-to-day data. Secondly, water vapor radiometers are being developed to allow measurement of the observed differential water vapor seen along the line of sight between two antennas in order to better calibrate our model atmosphere. These atmospheric studies represent a new attack on understanding and modeling the Earth atmosphere and its effects on radio propagation; the availability of precise date on atmospheric delay on a 10-minute basis, 24 hours per day throughout the year, forms a very powerful new data base for these studies.

Research on the theory of Earth Rotation, especially nutation, is continuing. Some nearby radio stars have already been included in the program and studies on the position, and the strong intensity fluctuations of one of them (SS433) have yielded results unsurpassed by other observatories.

8. Publications The following publications have resulted from the project so far:

a. K. Johnston, J. Spencer, C. Mayer, W. Klepczynski, G. Kaplan, D. McCarthy and G. Westerhout (1978) "Requirements for a Radio Coordinate Reference Frame for the Determination of Earth Rotation Parameters", in *Modern Astronomy* (IAV Coll.48) edited by F. V. Prochazka and R. H. Tucker, published by University Observatory Vienna.

b. G. Westerhout (1978) "Future Developments in U. S. Naval Observatory Time Service", in *Proceedings 9th Annual PTTI Applications and Planning Meeting 1977.*

c. K. J. Johnston, J. H. Spencer, C. H. Mayer, W. J. Klepczynski, G. H. Kaplan, D. D. McCarthy, G. Westerhout (1979) "The NAVOBSY/NRL Program for the Determination of Earth Rotation and Polar Motion", in *Time and Earth's Rotation,* edited by D. D. McCarthy and J. D. Pilkington, published by D. Reidel.

d. D. D. McCarthy, W. J. Klepczynski, G. H. Kaplan, F. J. Josties, G. Westerhout, K. J. Johnston, J. M. Spencer (1979) "Variations of Earth Orientation Parameters from Change in the Orientation of the 35-hour Baseline of the Green Bank Interferometer", in *Annual Report of the BIH 1978.*

e. W. J. Klepczynski, K. J. Johnston, G. H. Kaplan, D. D. McCarthy, J. H. Spencer, F. J. Josties, R. L. Branham (1980) "Progress Report on the USNO/NRL Green Bank Interferometer Program", in *Radio Interferometry Techniques for Geodesy,* edited by R. Coates, published by NASA-GSFC.

6. G. H. Kaplan, V. V. Kallarakal, R. S. Harrington, K. J. Johnston, J. M. Spencer (1980) "The Coincidence of the Radio and Optical Emission from SS433", Astronomical Journal 85, 64, 1980.

In addition, progress reports on various aspects of the program were presented at meetings of professional societies (with abstracts in the proceedings) by W. J. Klepczynski, D. D. McCarthy, K. J. Johnston, and G. Westerhout.

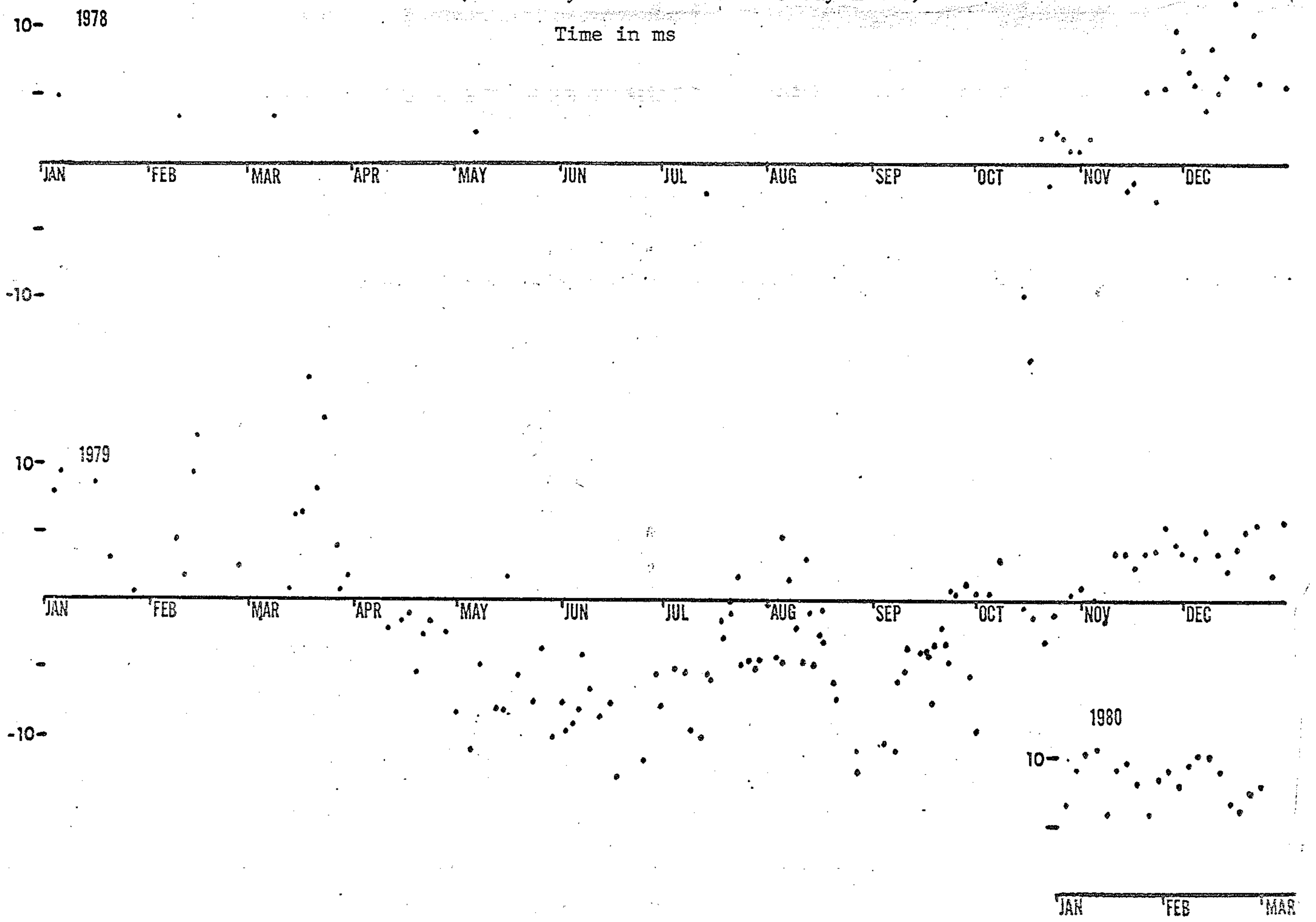
9. Prognosis. An independent United States determination of improved, accurate UT and PM and a better fundamental reference frame is being provided to DoD users. It is anticipated, based on current excellent results, that regular distribution of independent NAVOBSY UT1 and PM information will start in September 1980.

G Westerhout

Gart Westerhout
Scientific Director

UTO - UTC (BIH 5-day means — USNO 3-day means)

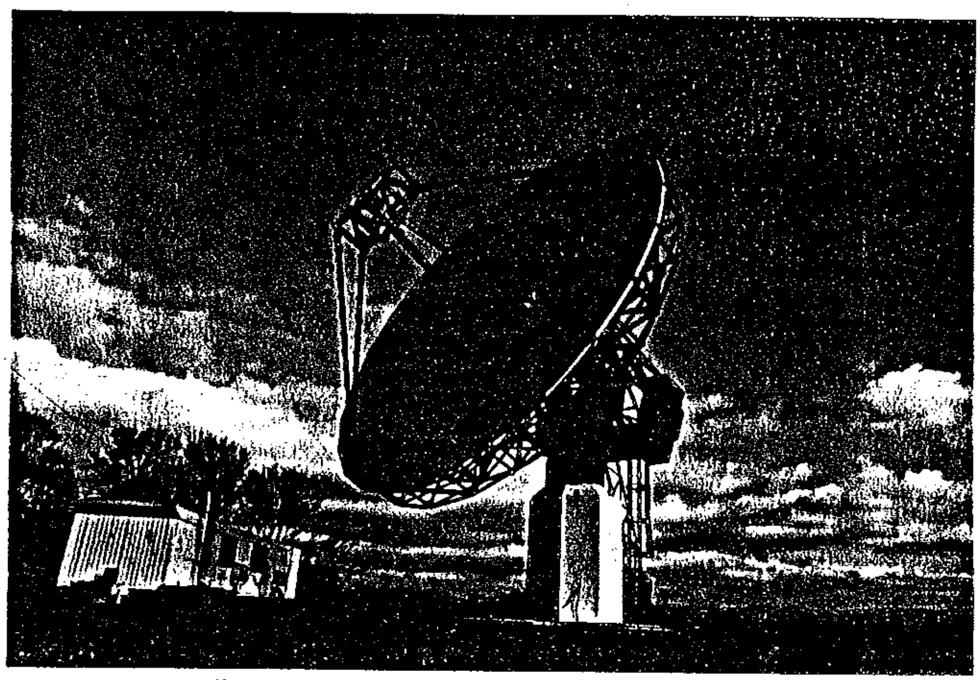
Time in ms



DEPARTMENT OF THE NAVY
U.S. NAVAL OBSERVATORY
34TH AND MASSACHUSETTS AVE., NW
WASHINGTON, D.C. 20390

IN REPLY REFER TO
Public Affairs Office:
202/653-1541 (AM4)
No.4/83
22 Feb 1983

FOR IMMEDIATE RELEASE



NEW RADIO TELESCOPE IN WEST VIRGINIA

High atop a distant mountain in the hills of West Virginia, a new telescope points skyward. At a ribbon-tying ceremony celebrating the completion of the construction of a 14.2 meter radio telescope, 12 employees of the National Radio Astronomy Observatory (NRAO) at Green Bank, West Virginia and 2 from the U. S. Naval Observatory in Washington, D.C., braved 17 degree temperatures and mountain winds to observe a demonstration of the new instrument. The telescope was built by NRAO for the exclusive use of the Naval Observatory.

In the fall of 1983, two radio telescopes located presently at the Green Bank Observatory site, will join a radio telescope located atop Brushy Mountain near Huntersville, W. Virginia (35 kilometers distant), and the new 14.2 meter telescope outside Monterville (32 kilometers away) to form what is called an INTERFEROMETER. The new interferometer will replace the present version now operating, to determine more accurately the rotation of the Earth.

NRAO in Green Bank is operated by Associated Universities, Inc., under a contract with the National Science Foundation. The West Virginia site is located in what is known as 'The National Radio Quiet Zone' where no strong radio or television transmitters are allowed anywhere nearby. Therefore, there is little interference from other radiation sources; even the motor vehicles at the site are diesel powered to eliminate the radio interference caused by electrical ignitions.

-MORE-

The four telescopes are synchronized to look at the same objects at the same time. The observing will be done continuously, 24 hours a day, 7 days a week. The control commands to the remote telescopes will be sent by a microwave radio link from the Control Building at Green Bank. These signals will be relayed by reflectors placed atop the mountain ridges separating the telescopes. The data on each object observed will then be transmitted back to Green Bank where it will be recorded on magnetic tape and sent daily to the Naval Observatory in Washington D.C. The microwave link should be completed this spring, and observations with the new telescope should begin in the fall of 1983.

Information gained by the interferometer will be used to determine more accurately the Earth's rotation on its axis, by observations of distant radio sources called quasars. Quasars are a group of extragalactic objects in the Universe hundreds of millions, or billions of light years away, that radiate strongly in the radio wavelength portion of the spectrum. Some 20 quasars will be observed as well as such peculiar objects within our Galaxy as Cygnus X-3 (located within the constellation of Cygnus the Swan). Each of these objects will be observed several times a day for a period of up to 10 minutes at each observation.

Radio telescopes operate by collecting the radiation of that part of the spectrum that has a longer wavelength than that which the human eye can detect. (Visible light is just a very small part of the electromagnetic spectrum). The field of radio astronomy was pioneered by Karl Jansky in 1931 when he worked for Bell Laboratories. While experimenting with a radio antenna to track down sources of static, he noticed that certain static was appearing every day, but four minutes earlier each day. He realized that because of this 4 minute gain, he was picking up something that was not on the Earth. Jansky, it turns out, was receiving radiation from the center of the Galaxy!

Radio astronomy is similar to optical astronomy: radio waves behave just like light waves - only the lengths of the waves differ. Because radio wavelengths are longer than light wavelengths, they cannot be photographed. Instead, they are collected in 'dishes', which bounce the wave up to the antenna. This, in turn, converts the wave into a tiny electric signal, just like any radio antenna. After amplification, a graph can be made to show the strength of the signal. Radio maps are made by moving the telescope and scanning the objects from point to point. The larger the telescope, the more detail can be mapped. It turns out that the brightest objects in the optical sky are not identical with the brightest objects in the radio sky. Most optically bright objects in the sky are weak radio emitters.

-MORE-

The requirements of spacecraft launches and geodesy have increased the importance of extremely precise measurements of the Earth's motions in space. Unfortunately, the Earth rotates at an irregular rate, and this irregularity is by no means predictable. Therefore, it becomes essential that we measure the irregular motion of the Earth with the greatest accuracy possible. This work is coordinated by the Bureau International de l'Heure (BIH) in Paris, France and the International Polar Motion Service (IPMS) in Mizusawa, Japan. The U. S. Naval Observatory is a major contributor of information to these international bureaus.

The complex forces that the Earth is subjected to, such as the gravitational attraction of the Sun and Moon, the gravitational friction of the Earth's oceans responding to these forces, and the fluid core in the center of the Earth, all conspire to complicate the Earth's rotation. First, we must measure the changing orientation, or "pointing" of the Earth's celestial pole in space. The slow, long-term circular motion of the pole through space is called 'precession' and takes roughly 26,000 years to repeat. (The star Vega will become our pole star in about 12,000 years because of this changing orientation of the pole). The pole's short period, small-amplitude motion is called 'nutation'.These two motions may be affected by the internal structures of the Earth.

The periodic "wobble" of the Earth's pole is the second phenomenon that is measured. This is called 'polar motion' which, on the Earth's surface, causes the pole's position to move. This motion can be contained in an area smaller than that of a tennis court. The 'wobble' is attributed to the fact that the Earth's rotation axis is not aligned with its symmetry axis. (The Earth is slightly bulged about the equator).

The third motion that is measured is Universal Time, or the rotation of the Earth. One complete rotation of the Earth takes roughly 86,164.09 seconds, but is by no means constant. The length of the day is increasing by a very small amount each century, because the Earth's rotation rate is slowing down. (At the time of the dinosaurs, a day lasted 23 hours!). Furthermore, there are seasonal variations. These seem to be due to tidal friction and changes in the atmosphere, among other things.

Because the four radio telescopes used by the U. S. Naval Observatory in Green Bank will essentially be operated as one, the effective dish size is about 35 kilometers in diameter. The position of the objects observed can be determined more precisely than by any individual telescope. The Naval Observatory is the only observatory which uses radio telescopes on a daily basis to determine Universal Time, nutation, and polar motion.

Optical astronomers study and measure the positions and motions of objects that are visible. The Earth's rotation can be measured by them only with an accuracy as great as the knowledge they have of the positions and motions of those objects. The stars themselves have motions which must be accounted for. Because the extragalactic objects studied by radio astronomers are so incredibly distant, the motions these objects have are essentially negligible, and create what is called a 'fixed reference frame'. With the extragalactic objects as the reference, the object of interest, then, becomes the Earth itself, whose motions can be studied with heretofore unattainable detail and accuracy.

The U. S. Naval Observatory plans to expand its observing list to include even more radio sources, with the eventual goal of producing a sizeable catalog of radio sources with precisely determined positions. This catalog will ultimately be of tremendous use in future deep-space exploration, as well as Earth-based navigational systems. The new radio telescope high atop Point Mountain in West Virginia is helping to further the Naval Observatory's 150-year involvement in measuring the complex motions of the Earth.

-END-

Memo

To: Scientific Director, NRAO Greenbank, West Virginia

TS USNO

TS3 USNO

From: Robert A. Hull TS3H USNO

Date: September 15, 1986

The U.S. Naval Observatory installed a Precise Time Station (PTS) in Greenbank, West Virginia in July of 1984. The equipment installed was an HP 9915 computer, VHF switch and modem. This equipment is owned by USNO. Other equipment in this system purchased by the National Radio Astronomical Observatory are an Austron Loran C receiver, an HP 5335 counter, and most recently a Datum GPS receiver.

The present systems monitored by the PTS are the Hydrogen MASER, located at the 140 foot antenna; the GPS and Loran receviers, located in the Interferometer control room; and two Cesium clocks located in the basement of the control building.

The purpose of this PTS is to provide the Interferometer as well as the entire Greenbank Observatory with precise timing down to the nanosecond level. Other benefits include monitoring of Loran chains for the Naval Observatory, providing precise positioning and location in the GPS reference frame, as well as outputing standard frequencies for electronic equipment.

Possible uses for this system in the future may be in timing pulsars, determining seasonal and daily land path delays for Loran signals, calculating atmospheric path delays with GPS ,VLBI ,and water vapor radiometers, as well as providing for a distribution of clocks in the Naval Observatory mean.

The Precise Time Station at Greenbank, West Virgina records on the hour, time and frequency measurements. The station each day is called up by an HP 1000 computer from the Naval Observatory. Presently this computer accumulates the hourly data which are analyzed for anomalies each week by USNO and interferometer personnel. The data format is easy-to-read and can be accessed through most modems and computers. The data are archived on floppies, for an historical record, before the HP 1000 computer files are purged each week. Access to weekly data can be acquired by contacting Mr. Miranian at 202-653-1522. For data older then a week, floppies can be provided by Mr. Hull at 202-653-0585. For daily or instantaneous readings the PTS station can be called up. The data format is similar to that found on the HP1000.

The data format for the PTS is shown below. A VHF switch has four starts and four stops. The switch permits frequencies or pulses to flow through it. It is controlled by the HP 9915B computer and acts as a multiplexer for the input to the counter. Readings are made on the hour by the computer but can also be performed at any time by directly controlling the switch through a remote computer.

46661.3333333	MJD
800	UT
.000000001	CES1-CES1
.000003626	CES1-GPS
.000008378	CES1-HMASER
.044004526	CES1-LORAN
.999997312	CES2-CES1
.000000938	CES2-GPS
.000005692	CES2-HMASER
.044001854	CES2-LORAN
.999991623	HMASER-CES1
.000012443	HMASER-GPS
0	HMASER-HMASER
.04399616	HMASER-LORAN
.957842464	SIDCLOCK-CES1
.963306873	SIDCLOCK-GPS
.968772503	SIDCLOCK-HMASER
.018222935	SIDCLOCK-LORAN
99600.4	LORAN CHAIN
.04400389	LORAN OFFSET

GPS time, while accurately read as a pulse input to the switch, is also acquired by the 9915B computer through an RS232 link. The GPS receiver performs its own statistical analysis, smoothing data, and outputs its calculated offset of a Cesium 1 PPS against a satellite. This data is of better quality. The user is assured that the offset is calculated from a specific satellite and not just a slewed 1 PPS passed through the receiver as would be the case if no satellite is present. The GPS file obtained by the 9915B can be accessed by any remote computer. It's format is shown below.

DOY	DATE	TIME	SV	EL	AZM	SN	IOD	INTERVAL	TI	TI FIT	TI RATE	MJD
212	31JUL86	003115	13	54	337	19	016	192546	+000003375	+000003375	+2.4162E-14	46
212	31JUL86	004417	13	57	346	26	015	192533	+000003375	+000003375	+2.3060E-15	46
212	31JUL86	005718	13	60	357	24	015	192526	+000003375	+000003375	-4.1564E-15	46
212	31JUL86	011019	13	63	009	24	014	192522	+000003374	+000003375	-1.7496E-14	46
212	31JUL86	012320	13	65	023	28	014	192520	+000003375	+000003375	-1.2379E-14	46
212	31JUL86	013620	13	66	039	27	014	192519	+000003375	+000003375	-1.0553E-14	46
212	31JUL86	014921	13	66	056	28	014	192513	+000003375	+000003375	-2.6218E-15	46
212	31JUL86	020223	13	64	072	29	014	192509	+000003375	+000003375	+1.4775E-15	46
212	31JUL86	021523	13	62	086	27	014	192500	+000003374	+000003375	-3.3390E-15	46
212	31JUL86	022824	13	59	099	26	015	192497	+000003375	+000003375	-1.3024E-15	46
212	31JUL86	024128	13	55	109	25	016	192502	+000003375	+000003375	-4.6883E-15	46
212	31JUL86	025429	13	50	118	24	016	192500	+000003374	+000003375	-2.1104E-15	46
212	31JUL86	030731	13	45	125	18	018	192492	+000003375	+000003375	+1.3636E-16	46
212	31JUL86	032033	13	40	132	18	019	192497	+000003374	+000003375	+1.2124E-15	46
212	31JUL86	033335	13	34	137	19	022	192497	+000003376	+000003375	+3.5683E-15	46
212	31JUL86	034638	13	29	141	14	026	192485	+000003372	+000003375	+3.8535E-15	46
212	31JUL86	035939	13	23	145	14	029	192484	+000003375	+000003375	+4.0040E-15	46

To get measurements accurate to the nanosecond level, GPS data acquired from Greenbank must be matched MJD-to-MJD and satellite-to-satellite to USNO acquired data. This practice is called common view. A file on the HP 1000 computer in Washington lists USNO observed offsets of each satellite during their passes over the Eastern United States. This file is called @GPSD3. It's format is shown below.

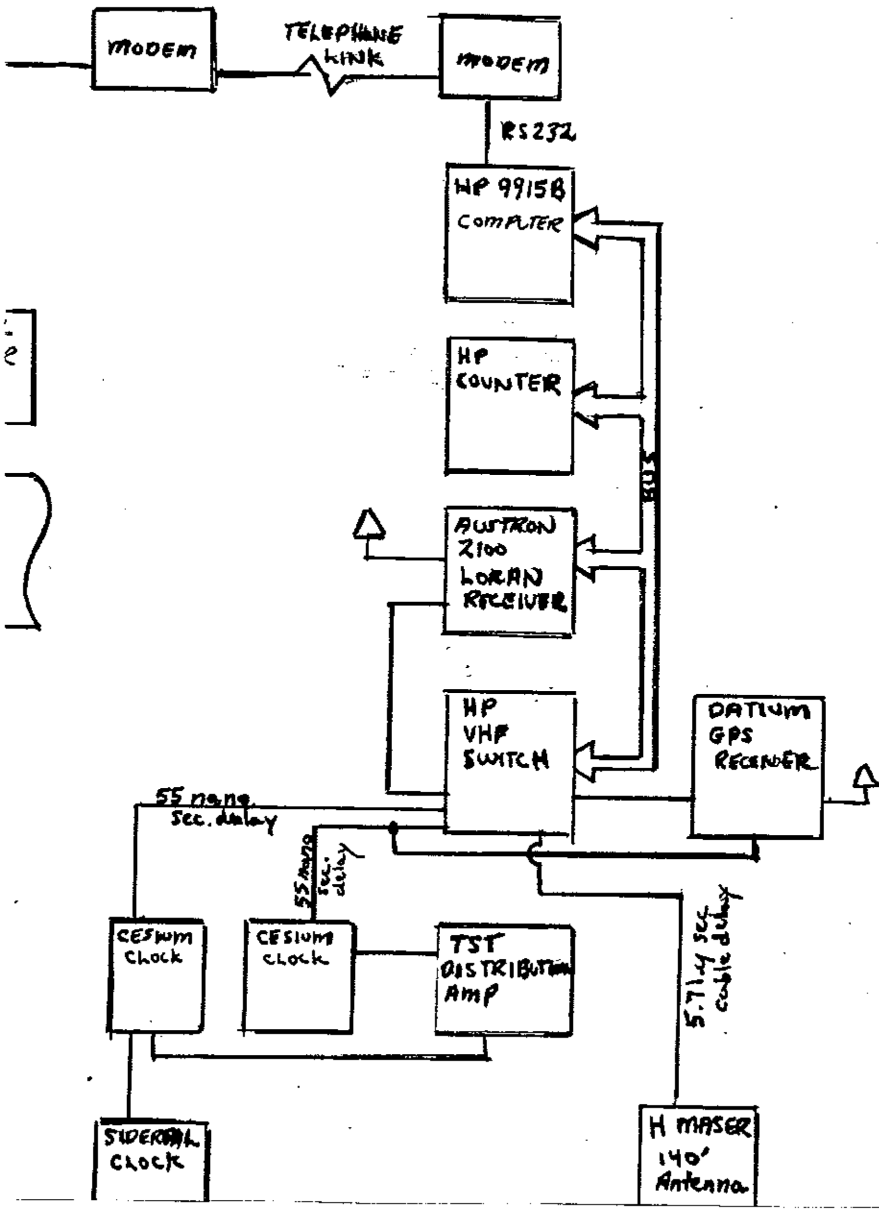
USNO GPS DATA COLLECTED DURING WEEK START DAY 224

PRN	BEG.TRK DDDD.ddd	BEGTRK D	HHMMSS	TRKTIME SSSS	MC-GPS US	SLOPE PS/S	RMS NS	SAMP N	ELV	AZMT	D.AGE DHHMM	MC-SAT NS
3	6654.624	2	145800	780	-.583	-16	18	129	12	170	00005	2490
3	6654.633	2	151100	780	-.600	11	19	129	18	169	00007	2470
3	6654.642	2	152400	780	-.602	5	15	130	24	169	00007	2466
3	6654.651	2	153700	780	-.595	-13	13	129	30	168	00007	2470
3	6654.660	2	155000	780	-.596	-7	15	129	37	167	00007	2466
3	6654.669	2	160300	780	-.605	9	14	130	44	166	00009	2454
3	6654.678	2	161600	780	-.603	-1	14	130	50	164	00009	2454
8	6654.692	2	163600	780	-.543	-30	20	130	14	193	00005	-802427
8	6654.701	2	164900	492	-.550	-39	16	82	20	194	00005	-802461
3	6654.714	2	170800	780	-.610	7	13	129	77	135	00011	2441
3	6654.723	2	172100	780	-.607	-5	12	130	80	103	00011	2443
3	6654.732	2	173400	780	-.608	3	13	130	78	65	00011	2441
3	6654.741	2	174700	780	-.605	-9	12	129	73	45	00011	2444
3	6654.758	2	181200	780	-.603	1	13	130	61	33	00012	2446
6	6654.771	2	183000	780	-.569	-6	12	130	26	325	00008	68378
8	6654.782	2	184600	780	-.568	0	14	130	77	252	00008	-802729
8	6654.791	2	185900	780	-.570	8	12	130	79	284	00004	-802760

It is a simple matter to match the USNO-GPS, Greenbank-GPS data sets. Once a match is made between space vehicles and date MJD of observation, the calculated offset can be determined between the USNO Master clock and the Greenbank Clocks. A BASIC or C language program can be provided by Robert Hull that does this. The output of these programs might look like the following.

SV	USNO START TIME	USNO-GPS	DAS START TIME	DAS-GPS	USNO-DAS
13	6641.169	-623	6641.1651	+3376	-3999
6	6641.226	-630	6641.2251	+3375	-4005
12	6641.378	-634	6641.3801	+3375	-4009
12	6641.387	-641	6641.3892	+3375	-4016
12	6641.396	-643	6641.3983	+3375	-4018
12	6641.408	-636	6641.4074	+3375	-4011
12	6641.417	-635	6641.4166	+3375	-4010
12	6641.426	-638	6641.4257	+3375	-4013
12	6641.435	-630	6641.4348	+3375	-4005

It should be noted that the GPS file on the 9915B computer only stores 300 passes or about three days of data. Presently, due to personnel shortages, a file has not been implemented on the HP 1000 that records this data for a historical record. In any case, as soon as one is set up, it most likely will not keep data older then a week or two. If it proves useful, this data may be archived by Mr. Hull. Your suggestions are encouraged on this point.


MODEM
TELEPHONE LINK
MODEM
RS232
HP 9915B COMPUTER
HP COUNTER
BUS
AUSTRON 2100 LORAN RECEIVER
HP VHF SWITCH
DATUM GPS RECEIVER
55 nano sec. delay
55 nano sec. delay
CESIUM CLOCK
CESIUM CLOCK
TST DISTRIBUTION AMP
5.71 μ sec cable delay
SIDEREAL CLOCK
H MASER 140' Antenna