Instruments Two sets of magnetometers, one consisting of a triaxial fluxgate system and the other consisting of two perpendicular search coil magnetometers.
Experimenter Dr. L. J. Cahill, Jr., University of Minnesota, Minneapolis, Minn.

6. DC Electric Field Measurement.

Objectives To obtain a two-component DC measurement and low-frequency variations between 0.3 and 30 Hz.
Instruments An electric field antenna with two 5.5 in. diameter metal spheres separated by 16 ft and four rms spectrometer channels.
Experimenter Dr. D. A. Gurnett, University of Iowa, Iowa City, Iowa

7. AC Electric Field Measurement.

Objective To determine the potential difference between the spheres for a measurement of the electric field.
Instruments The same electric field antenna as in item 6 above and 16 narrow-band filters.
Experimenter Dr. D. A. Gurnett, University of Iowa, Iowa City, Iowa

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5. COSPAR WORKING GROUPS

PROPOSED STANDARDS FOR DISTRIBUTION AND DOCUMENTATION OF LUNAR LASER RANGING DATA

A Report prepared for COSPAR Working Group 1

by J. Derral Mulholland, University of Texas at Austin, McDonald Observatory

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1. Prefatory Note

Laser ranging to the moon promises to provide the means for investigating a number of lunar and terrestrial phenomena to a much higher precision than has been heretofore possible. The interesting lunar problems can be pursued with data from any one or more observatories, although restriction to a single facility does introduce the hazard of local bias in the solutions due to unrecognized systematic errors in the observations. In contrast, very little can be accomplished in earth physics studies using range data from a single observatory. It is imperative to the effective use of these data that there exist a viable means for their distribution or exchange in a sufficiently complete and readily usable form.

This problem was first addressed during COSPAR XIII, when the Chairman of Working Group 1 directed that the present report be prepared. At the same time, a Working Party on Lunar Laser Ranging was formed within the Working Group. Subsequently, the Working Party was endorsed by both IAU and IUGG, and the membership was enlarged to include their representatives.

In an unrelated sequence of events beginning in 1964, IAU Commission 4 established a Working Group on Ephemerides for Space Research. This body served as the inspiration for an informal working group, founded in 1967, which provided working-level communication and coordination in ephemeris research within the USA. This latter group met on numerous occasions during 1967–1969. In addition to providing for standard test cases for areas of desirable duplication of effort, and direct exchange of data and software to reduce unnecessary duplication, this informal group produced two results of some interest to the present discussion. First, the transmission of data was facilitated by adoption by the participants of standard 80-column punched card formats[1]. Second, the three US members of the IAU Working Group were asked to carry back to that body certain recommendations concerning international exchange of astrometric and ephemeral data. This was at least a contributing factor in the establishment last year of the IAU Information Bureau on Astronomical Ephemerides, to provide information on the existence and availability of such data. COSPAR Working Group 1 will be represented in the membership of the Bureau.

[1] O'Handley, D. A. "Card Format for Optical and Radar Planetary Data" Jet Propulsion Laboratory Tech. Rpt. 32-1296, Pasadena, 1968.

This report is based on the premise that these two lines of development towards international cooperation and exchange represent two convergent aspects of the same problem, and must be treated as complementary.

The author is pleased to acknowledge the helpful suggestions of many of his colleagues in the preparation of this report. This effort was funded by the National Aeronautics and Space Administration, under Grant No. NGR 44-012-219.

2. Philosophy of the Proposed Standards

We desire to establish some minimum criteria for the permanent recording, cataloguing, and transmission of the laser ranging data. This requires a somewhat different, more comprehensive approach to data recording and preservation than has frequently been the case in the past. The signal generation and detection devices, combined with the level of precision attainable in the observations, dictate that more parameters be preserved. It is also important to avoid crucial ambiguities. For example, the observations are time delays. Does the time delay clock run at the same rate as the clock that measures the epoch of observation? Both rates are necessary for application of the data. By presenting standards for data documentation, we do not propose to specify exactly what information is to be recorded, nor in what way to do the recording, but rather to state *minimum* guidelines for what data seem to be required to insure that the laser measures can be made to satisfy their enormous potential.

In addition to the general documentation criteria, we propose some very specific standards for the transmission of data between institutions or their deposition in public data centers. The need for machine-readable formats seems self-evident. Efficient use of machine-readable data from various sources requires the establishment of uniform standards insofar as this is possible. Since a similar exercise has been undertaken for optical and radar observations, it seems unreasonable to pursue the present goal *ab initio*. We propose, therefore, to maximize the compatibility of our data transmission formats with those of O'Handley*. It is to be hoped that these formats will provide the basis for a more comprehensive codification by the Information Bureau on Astronomical Ephemerides.

We have already implied that there should exist multiple classifications of data standards, since complete archival documentation is not customarily necessary to or desired by the user of astrometric data. It seems to be convenient to discriminate three categories, to be described in detail in subsequent sections of this report. The categories can be considered as approximating the functions of journal publication, public deposition, and archive data, respectively. These represent three levels of detail, corresponding to different purposes to which the data may be applied.

In their present form, these proposals are intended as first-order approximations, evolved from experience within the laser program and from the discussions held within Working Group 1 during the 14th Plenary Meeting. As further experience is gained, some modifications will surely follow.

* op. cit.

3. Reduced Data Set

The "reduced data set" will consist of sufficient information to satisfy the requirements of non-critical application, such data as one might publish in a scientific journal. The items recommended for inclusion are:

- Epoch of observation, and its meaning;
- Observed time delay, modified by corrections for geometric and electronic calibration delays and for the atmospheric refraction delay;
- System time delay resolution;
- Telescope and reflector identification;
- Time base identification for both epoch and time delay.

These data, which are certainly adequate for many purposes, are easily accommodated on a standard 80-column punched card. A proposed card format is specified in Appendix C.

4. Astrometric Data Set

This category is of most critical interest from the standpoint of serious application of the data, and it represents those data which we propose should constitute the standard grouping for deposition in a public data center or publication comparable to observatory annals. Here we must distinguish between data provided for each observation and other data recorded at most once for each run, but which are needed for high-confidence use of the data:

Each observation

- Epoch of observation, and its meaning;
- Observed time delay, unaffected by any corrections;
- Observational uncertainty, with a description of its basis;
- Gravimetric data (*)
- Telescope and reflector identification;
- Time base identification for both epoch and time delay.

Each run

- Clock calibration data;
- Electronic and geometric calibration delays to be subtracted from the observation;
- Atmospheric data (temperature, pressure, humidity, seeing, wind speed);
- Laser parameters (energy, pulse length, frequency);
- Detector parameters (count rates, inherent resolution, range gate structure);
- Number of shots per run.

Once

- Station description;
- Nominal telescope coordinates;
- Precise separations between transmitter and receiver, if appropriate;
- Relation of primary mirror position to fixed reference point.

* The measurement of relative gravimetric data is considered desirable for those locations for which a simple analytic model is not adequate to account for solid earth tides.

A separation can be based on considerations of application. Customarily, use of the data to nanosecond accuracy requires only certain of these data. A conventional card format is proposed for these data in Appendix C. The other items permit either finer-scale reduction of the observations or re-evaluation of confidence levels and uncertainty estimates. A second machine-readable format is proposed for these data. The principal virtue claimed for these formats is that we propose immediately to begin using them in transmissions of lunar ranging data from the McDonald Observatory.

5. System Data Set

Each of the data-taking organizations will wish to maintain its own archive files, basically observatory logs, which will contain all of the information contained in the "astrometric data set" for that observatory, but also such additional items as might be useful in evaluating system performance. This might include such parameters as laser beam divergence, spatial and spectral filter width, filter/laser wavelength matching, etc. This seems to be a purely local matter of little impact on the astrometric use of the time delays, and thus this category does not lie within the scope of the present report. One will note that the McDonald formats (Appendix C) will include some of these items.

6. Distribution Mechanisms

Central to the entire purpose of this report is the precept that full utilization of these astrometric data of unprecedented precision can only occur if the data are made conveniently available outside the originating organization, indeed outside the country of origin. It may be admitted that each observing group may wish to restrict access to their own data for some specified time. It is further understood that, particularly in the early stages of an observational program, the observational identification problem (noise filtering) may not permit adherence to intended distribution schedules. Nonetheless, it seems unambiguous and unarguable that some mechanism for general and open distribution of the data need be endorsed in principle and, insofar as possible, adhered to in practice.

COSPAR has provided for open repositories of space science data in the network of World Data Centers, whose charter includes the handling of "precise positional observations... of great scientific value." There can be no question that the laser observations satisfy this description. We propose that Working Group 1 urge the WDC's to accept the responsibility of serving as a focal point for the dissemination of these data. We further propose that all lunar laser ranging facilities in countries whose National Scientific Institutions adhere to COSPAR be urged to agree to submit their observations, in the form of astrometric data sets, either to the WDC's directly or to national data centers that exercise free exchange with the WDC's (e.g. the US National Space Science Data Center). Each group should also be free to make other distribution arrangements as well, including acces to reduced data sets or system data sets as they see fit.

In addition to making explicit distribution arrangements, the observing organizations should be urged to register these arrangements with the IAU Information Bureau on Astronomical Ephemerides, for the convenience of those scientists unfamiliar with the COSPAR organization. It is presumed that the COSPAR representatives in the Information Bureau organization will provide coordination between the function of the Bureau and the wishes of COSPAR Working Group 1. Dr. Veis has also suggested that the COSPAR/IUGG Central Bureau for Satellite Geodesy be kept informed of available data.

Appendix A

Notes on Selected Data Items

Epoch of observation

Systems may be designed with either the transmission time or the reception time as the epoch reference. In every case, the appropriate option must be explicitly available. In addition, if reception time is used, this must be *observed* reception time, rather than predicted.

Observational uncertainty

This parameter is somewhat subjective and, for a given observation, may be revised *ex post facto*. Its minimum value is the shot-by-shot resolution, but may be much higher if electronic or other operating problems exist in the observing system.

Electronic delay

This represents the time delay in the detection circuitry, which does not relate to a distance.

Geometric delay

The observations will need to be reduced to a point in the light path fixed relative to the telescope pier. The geometric calibration delay represents the total light path from that point to the front face of the laser, plus the total light path from the fixed point to the detector. For bistatic operation, a fixed point reference is required separately for receiver and transmitter.

Nominal telescope coordinates

These should refer to the fixed point(s) described above. The nominal coordinates should be (as nearly as practical) the best available estimate of the coordinates relative to the Earth's center of mass, along with a description of the method of determination. Spherical coordinates are to be preferred to rectangular. Astronomical coordinates (including radial distance) may be given if more appropriate data are not available.

Primary mirror

Some telescope designs require the primary mirror to describe some space path relative to a fixed point such as the intersection of the rotation axes. High-accuracy discussion of observations from such telescopes will require that such motion be taken into account.

Appendix B

Proposed Standard Codes and Units

Epoch of observation

The standard unit is the Julian Date, with decimal fraction.

Observed time delay

The standard unit is the second.

Observational uncertainty

The standard unit is the nanosecond.

Electronic and geometric delays

The standard unit is the nanosecond.

Telescope identification

This will consist of three distinct codes: one for the observatory, one to indicate whether the system uses a single telescope or separate transmitter and receiver, and a third to identify distinct telescope locations in case different arrangements have been used at a single site. The total code requires five digits.

For the basic observatory code, we propose adherence to the established three-digit code used by the IAU Minor Planet Center. The center is willing to assign codes to presently unlisted observatories in a fashion consistent with past practice.

The number of telescopes used could serve as a one-digit code by itself, but we find it convenient from external considerations to propose that a one-digit code distinguish two characteristics. The fourth digit of the observatory code specifies either a single telescope (monostatic) operation or separate transmitter and receiver (bistatic) operation, and it also specifies if the epoch refers to transmission or reception time, according to the following table:

	Monostatic	Bistatic
Transmit	1	2
Receive	3	4

Finally, each observatory will be responsible for assigning a one-digit code (0–9), the fifth digit of the observatory code, specifying distinct sites on the premises. One may note that a changeover from monostatic to bistatic operations need not affect this digit, as that change may be accommodated unambiguously by the preceding digit code.

Reflector identification

A one-digit code should suffice for this parameter, with the digits assigned in the order of emplacement, as follows

0 – Apollo 11 (Tranquility Base)
1 – Luna 17 (Imbrium)
2 – Apollo 14 (Fra Mauro)
3 – Apollo 15 (Hadley)

Other numbers will be assigned as new reflectors are activated.

Time base identification

We assume that observation epoch will always be referred to a time base available in real time, regardless of the nature of the observation. The system UTO is included for the sake of generality, even though one does not expect it to be used for laser observations. The time delay will always be based on an oscillator frequency, but we must allow for the possibility of a non-standard frequency. The proposed codes are

0 – UTO
1 – UTC
2 – A.1 (USNO)
3 – A^{3} (BIH)
4 – USSR atomic time
9 – non-standard frequency

Clock calibration

The standard units are microseconds (epoch) and hertz (frequency)

Atmospheric data

The standard units are: for temperature, Celsius degrees
for pressure, millibars
for humidity, % saturation
for seeing, arc seconds
for wind speed, km/hour

For the present purpose, no distinction need be made between 99% and 100% humidity.

Laser parameters

The standard units are joules (energy) and nanoseconds (pulse length) full width between the half-power points.

Telescope coordinates

The standard units are: for radial distance, km
for longitude, degrees *east*
for latitude, degrees north
for rectangular coordinates, km

Appendix C

Proposed Standard Punched Card Formats

Standard formats are presented below for the transmission of reduced and astrometric laser data via 80-column punched cards. Some of the details of the formatting were chosen for compatibility with present usage of other data familiar to the author. This is particularly true of the placement and field size of certain data, such as body identifier, epoch, and observatory code.

Reduced data card

Col. 1: = P (11-7 punch)
2–4: = 011 (Body identifier)
5–21: Epoch of observation (Julian date with 10 decimal digit fraction, decimal implied following col. 11)
22–26: Observatory code
27: Blank (not used)
28: Reflector code
29: = L (11-3 punch, observation type)
30: Epoch time base
31–42: Two-way time delay (seconds, decimal implied following col. 32, 10 decimal digit fraction)
43–47: Observational precision estimate (nanoseconds, decimal implied following col. 46)
48–53: Refraction delay removed from observation
54–56: Blank (not used)
57–58: = 4 (identifies reduced data)
59–62: Blank (not used)
62–66: Frequency offset of time delay clock from nominal rate. If Col. 67 = 9, offset is from A^1 (parts in 10^{11})
67: Time delay time base
68–72: Blank (not used)
73–80: Year, month, day

Astrometric data card

Col. 1–47: Identical with reduced format
48–53: Electronic delay (nanoseconds, decimal implied following col. 52)
54–58: Geometric delay (nanoseconds, decimal implied following col. 57)
59–67: Identical with reduced format
68–72: Atmospheric pressure (mbars, decimal implied after col. 71)
73–80: Identical with reduced format

Operational environment data card

Col. 1: = Z (0–9 punch)
2–4: Observatory code (first 3 digits)
5–14: Julian date beginning run (truncated to 3 decimal digits, decimal implied following col. 11)
15: Blank (not used)
16–22: Clock epoch offset (μsec) to be added to clock reading
23–25: Temperature (°C)
26–27: Humidity (% saturation)
28–29: Wind speed (km/hr)
30–31: Seeing (0.1 arc sec)
32–34: Blank (not used)
35–37: laser energy (0.1 joule)

Col. 38–42: laser frequency (10^{14} Hz)
43–45: pulse length (0.1 nanosec)
46–48: resolution (0.1 nanosec)
49–51: photomultiplier dark count (kHz)
52–54: Moon count rate (kHz)
55–57: Star count rate (kHz)
58–62: Calibration star identification
63–65: Filter spectral width (0.1 Å)
66–68: Filter spatial width (0.1 arc sec)
69–72: Number of shots this run
73–80: Year, month, day