APOLLO FILE

A Proposal to the

National Aeronautics and Space Administration

for

Far Ultraviolet Spectrometric Determination of the Density and Composition of the Lunar Atmosphere with an Orbiting Apollo Spacecraft

Submitted by The Johns Hopkins University

in cooperation with

The University of Colorado
and
The University of Pittsburgh

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Introduction

This proposal has been prepared by Mr. Wm. G. Fastie, Adjunct Professor, Department of Physics, The Johns Hopkins University Homewood Campus. It is a formal, detailed version of an informal proposal of the same title submitted in April, 1969, in response to AFO MAL Mar 7 1969 for Apollo missions. It has been tentatively approved for Apollos 19 and 20 and assigned experiment No. 21-001-079.

The following coexperimenters have informally agreed to cooperate in the conduct of the proposed experiment:

Dr. Thomas M. Donahue, Professor, Department of Physics, University of Pittsburgh

Dr. Charles A. Barth, Professor, Department of Astrophysics, University of Colorado

Dr. Gary Thomas, Associate Professor, Department of Astrophysics, University of Colorado

Dr. Richard Henry, Assistant Professor, Department of Physics, Johns Hopkins University

Additional scientists will be proposed for the coexperimenters team as the experiment evolves.

The Space Development Department, Applied Physics Laboratory, Silver Spring, Maryland, will provide scientific, technical and management support for the proposed experiment.

The Laboratory for Atmospheric and Space Physics, University of Colorado has informally agreed to conduct the optical-mechanical design and to construct the required optical-mechanical systems. The Applied Physics Laboratory proposes to provide the electronic design and to construct the required electronic systems.

Because of large uncertainties in the details of the support requirements, a finalized budget and a management section are not included in this proposal. However, for general guidance, a budget estimate is included in the technical section.

I. Summary

We propose to determine the lunar atmospheric composition and density with a far ultraviolet Ebert spectrophotometer aboard a lunar-orbiting manned Apollo spacecraft.

The measurement technique involves observing spectral emissions from atmospheric species by resonance reradiation of absorbed solar flux in the spectral range 1000 A to 1800 A.

It is predicted herein that the lunar atmosphere is composed predominantly of xenon, in concentrations perhaps as great as 10^7 atoms/cc at the lunar surface. The measurement technique is potentially capable of measuring a density of 250 xenon atoms/cc.

The proposed experiment is capable of detecting many other atmospheric constituents which are not expected to be present in concentrations above 10^5 atoms/cc and which probably are below the detectable limit of the experiment.

The proposed electro-optical equipment has been developed over the past decade for studies of planetary atmospheres from rockets, satellites and interplanetary spacecraft.

Two instruments of the type proposed have been flown to Mars to study UV and far UV emissions from the Martian atmosphere.

The proposed mode of operation involves a fixed installation in the scientific instrument module of the lunar orbiting spacecraft. The equipment need only be turned on and off in the command module. Operation will be automatic and no manipulation of the equipment will be required during the observations.

The presently proposed experimental equipment and measuring techniques are similar to those proposed in 1963 for the Ranger spacecraft in conjunction with Professor T. M. Donahue of the University of Pittsburgh.

II. Analysis of Lunar Atmosphere

There is only one experimental fact about the lunar atmosphere, namely that the total density of the light atmospheric constituents (atomic hydrogen, oxygen, nitrogen) is less than 10^7 atoms/cc. This conclusion is based on radio occultation experiments with a lunar orbiting spacecraft.

This one experimental fact leads to one simple conclusion. The base of the lunar exosphere is the lunar surface itself. The scale height on the illuminated side (T = 400˚K, a = 140 cm/sec^2) is given by the relationship

$$H(KM) = \frac{2800}{M} \qquad (1)$$

where M is the atomic weight

Table I compares several earth and lunar parameters.

Table I

Atom	Atomic Wt.	Lunar Scale Ht. (KM)	Av. Lunar Velocity (cm/sec)	Earth Scale Ht. (1000˚K) (KM)	Av. Earth Velocity (cm/sec)
Hydrogen	1	2800 K	2.9×10^5	1000	4.7×10^5
Carbon	12	233	8.3×10^4	83	1.3×10^5
Nitrogen	14	200	7.7×10^4	71	1.2×10^5
Oxygen	16	175	7×10^4	62	1.1×10^5
Argon	40	70	4.6×10^4	25	7.4×10^4
Krypton	83	34	3.7×10^4	12	5.1×10^4
Xenon	131	21	2.6×10^4	7.5	4.2×10^4
Escape Velocity			2.35×10^5		1.2×10^6
Velocity of Solar Wind Protons			1×10^8 cm/sec		

Any quantitative analysis leading to values for equilibrium concentration of atmospheric constituents at the lunar surface requires a knowledge of the lunar degassing rate, which is unknown. Quantitative calculation of the thermal escape or of escape by collisions with solar wind particles or of escape by EVU ionization and ion escape in a solar wind induced electromagnetic field is therefore inconclusive. Consequently, only a qualitative analysis is presented, based on the facts in Table I.

A. Solar wind protons cannot provide a high hydrogen atom concentration by picking up an electron at the surface because the escape velocity is less than the average thermal velocity of such atoms and the solar wind density is very low. The concentration would probably be reduced by the formation of H_2 in the surface. The experiment cannot detect H_2 in the quantities that might exist. However, an atomic concentration of hydrogen of the order of 1 per cc can be detected by the proposed experiment.

B. Nitrogen and oxygen molecules will be lost by escape. Because of their large scale height, these constituents will also escape as a result of collisions with solar wind protons and through ionization. Those atoms which survive a ballistic excursion are probably tightly held by the lunar surface when they return, which would further reduce the equilibrium concentration.

C. The noble gases listed in Table I would be expected to enjoy a longer lifetime. Their loss rate from direct escape is very small; their shorter time of flight per orbit reduces the probability of a collision with a solar proton and increase the chance that such collisions will drive them to the lunar surface, and their greater mass decreases the velocity imparted by a collision with a solar proton. Furthermore, these atmospheric components will not bind at the lunar surface and can quickly recycle to the atmosphere after a ballistic impact. At each impact, the atoms should thermally equilibrate with the surface and neutralize if ionization occurred during flight.

D. The conclusions of (C) above are particularly true for the heaviest of the noble gases – xenon, mass 131, scale height 21 KM, mean velocity 2.6 x 10^4 cm/sec. In fact, xenon could very possibly be the predominant species of the lunar atmosphere.

If we assume that the total xenon content of the earth's atmosphere (10^{12} atoms/cc at the surface, 10^{36} atoms total) can be scaled for the lunar atmosphere in proportion to the moon/earth mass ratio, the total number of xenon atoms in the moon's atmosphere is about 10^{34} and the surface density is 10^{11} atoms/cc. The above calculation assumes that all of the earth's xenon is in its atmosphere and therefore provides a lower limit for the original lunar supply. Clearly, either the moon has lost most of its xenon by EUV ionization and ion escape in the solar wind induced electromagnetic field or some remains trapped beneath the lunar surface. Although the above numerical exercises are inconclusive, they emphasize the two key points of this proposal.

1. Xenon may exist in the lunar atmosphere in densities as great as 10^7 atoms/cc.

2. If the moon has an atmosphere, xenon is a prime candidate for the title of major constituent.

It is demonstrated below that the proposed experimental equipment can measure a lunar xenon concentration as small at 250 atoms/cc.

III. Proposed Instrumentation

A. General Description

As described above, most atomic species that may be present in the lunar atmosphere are very sparse, probably below the limit of 10^2 to 10^3 atoms/cc of the proposed experiment. It is therefore necessary to maximize the sensitivity of the spectrophotometer. Accordingly, the largest and most sensitive system we have developed for studying planetary atmospheres is proposed for lunar studies, namely a ½-meter focal length Ebert spectrometer with 6 cm long slits, ½ cm wide, a 100 cm^2 grating with 3600 grooves/mm, and collecting optics to direct the dispersed radiation to a solar-blind low dark current (less than 1 false event/sec) photomultiplier tube which employs pulse counting circuitry with a dynamic range of 10^6 to measure the light intensity.

The proposed instrument is similar in design to the Mariner VI and VII UV spectrometers which have flown by Mars, but the increased dimensions provide almost an order of magnitude increase in sensitivity. The proposed detector and pulse counting circuitry have been successfully employed in our rocket program and provide another factor of four in detectivity.

B. Sensitivity

The proposed instrument will give an output of about 100 photoelectrons per second per Rayleigh. With an observation time of the order of a hundred seconds the limit of detection would be about .01 Rayleighs.

C. Weight, Size and Power

The proposed instrument will weight about 30 lbs., require 5 watts of raw spacecraft power and a telemetry transmission rate of 80 bits per second, 1 channel, including engineering data. The instrument would be rectangular, 30″ long, 10″ wide and 7″ deep. There would be a long baffle extending from the entrance slit to the removable door of the scientific instrument module.

IV. Proposed Observations

In the spectral range 1000 to 1700 A several neutral atomic constituents have ground state resonance lines. Table II lists these elements, the wavelength of their resonance lines, the solar brightness at these wavelengths, and the expected minimum detectable concentrations.

Table II

Constituent	λ (A)	Solar Flux ph/A/cm^2/sec	Expected Min. Detectable Surface Conc. Atoms/cc	Brightness Rayleighs
Hydrogen	1216	4×10^{11}	1	100
Carbon	1657	5×10^{10}	10^2	.1
Nitrogen	1200	8×10^8	10^3	.1
Oxygen	1304	2×10^9	2×10^2	.1
Argon	1048	$10^6 - 10^7$	10^5	.1
Krypton	1236	$10^7 - 10^8$	10^4	.1
Xenon	1470	1×10^9	2.5×10^2	.1

Table II demonstrates that the proposed experiment can detect several possible lunar atmospheric species in the concentration range which might exist. In particular, the detectivity for xenon gives a high probability that it will be detected. It is believed unlikely that any other constituent, except hydrogen, will be detected.

However, it is important to know whether the lighter species exist in the virgin lunar atmosphere before man adds much more contamination. For example, the minimum amount of oxygen, nitrogen, and carbon which can be detected represents only a few hundred pounds of each of these constituents in the lunar atmosphere.

V. Experimental Procedure

It is proposed that the experimental package be installed in the scientific instrument module so that it views the lunar surface at an angle of about 30° to the spacecraft-moon center line and with the viewing angle in the plane of the orbit. During crossings of the twilight limb, the spacecraft would be oriented in the forward direction so that the illuminated lunar atmosphere at the terminator could be observed against the unilluminated lunar surface with minimization of scattering from the illuminated surface. During crossing of the dawn limb, the experiment is optimized by reversing the axis of the spacecraft. However, as long as the spacecraft is in its normal flight pattern with the instrument module roughly moon center oriented, significant measurements can be made and it is proposed that the UV spectrometer be operated continuously.

Another mode of operation involves reorienting the spacecraft so that the instrument looks away from the lunar surface at the galaxy, but not directly at the sun. This mode might optimize sensitivity to the lighter atmospheric constituents, but might also be degraded by the galactic background. It is proposed to survey the galaxy during the earth-moon cruise to determine the galactic correction to be applied to this mode of observation.

Our qualitative analysis of the lunar atmosphere assumes that metallic atoms and ions which may be introduced into the lunar atmosphere by a number of processes are not present in detectable amounts, largely because they do not circulate, i. e. they execute a single trajectory and are bound to the surface on impact. We also assume that charge separation in the solar wind would occur to neutralize any surface charge which might develop. However, during solar storms, high energy solar particles might provide increased sputtering of metallic atoms and ions from the lunar surface and might produce a transient electric field which could suspend the ions above the surface. The following ions wuld be detected by the proposed experiment in the concentration range of 10^2 to 10^4 per cc. [Si^+ (1265 A) C^+ (1335 A) C^{++} (1175 A) N^+ (1085 A)]

The high sensitivity of the UV method makes it possible to detect the combustion products from the engines of the lunar landing module. This observation can be of significance in determining the atmospheric loss mechanisms which deplete the lunar atmosphere.

Budget

It is impossible to present a firm budget at the present time because there are so many uncertainties, particularly with respect to the support requirements and hardware specifications. However, for fiscal guidance a preliminary budget estimate and time schedule is presented below.

Preliminary Budget Estimate

Apollo UV Spectrometer

(includes overhead costs)

	Yearly Costs in $1000 Amts.				
	69-70	70-71	71-72	72-73	Total
Personnel (Principal Investigator, project scientist, project engineer, research engineer, programmer, research assistants, technician, secretary)	125	170	170	130	595
Design	50	50			100
Instrumentation (includes optical components, detectors, optical-mechanical systems electronics, ground station equipment and spares)	150	500	100		750
Calibration Facility		100			100
Data and Computing Costs	10	25	25	35	95
Travel	25	25	40	20	110
Totals	360	870	335	185	1,750

Additional funds will be required for personnel and hardware if extreme quality control specifications are required. For example, to meet Mariner spacecraft specifications an additional $750,000 would be required.

THE END OF BILL'S 13-PAGE PROPOSAL THAT GOT US TO THE MOON
(Paul Feldman was shortly added as a Co-Investigator)