ASC

ASTRO SCIENCES CENTER

ORBITAL IMAGERY FOR PLANETARY EXPLORATION

VOLUME II

DEFINITIONS OF SCIENTIFIC OBJECTIVES

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CONTENTS

1. INTRODUCTION

This document is the second volume of a five volume series dealing with the use of imaging sensor systems in the unmammed exploration of the planets. Volume I - Technical Summary presents a general description of the entire study and summarizes the results. This volume describes the scientific objectives of planetary exploration and identifies those objectives for which orbital imaging systems are expected to be most useful. Volume III - Orbit selection and Definition defines, for each scientific objective, those orbits which appear to be most suitable for imaging experiments, while Volume IV - Imaging Sensor Systen Scaling Laws describes the different imaging systems and presents methods of estimating sensor system weights, power requirements, data rates, and other support requirements. Finally, Volume V - Support Requirements for Planetary Orbital Imaging tabulates these support requirements for those imaging systems which are identified in Volume II as useful in the context of a specific scientific objective.

An observable (i.e., observable property), as derived and used in the course of the study, is a detailed version of an exploration objective. Many observables, when considered in concert, make up an objective. For example, if a scientific objective is "to understand planetary crustal structure," the observables which help identify the crustal structure are "contacts, layering, attitudes of rock units, and structure of surface features". A search for, and measurement of, these observables constitutes a series of measurements in support of the objective. It is in this context that the observable descriptions are used - to identify the measurement requirements in support of the exploration objectives.

Two major functions are incorporated in the description: (1) determination of the applicability of remote sensing, and (2) identification of the usefulness of imaging in support of the objectives. The same logical sequence is used throughout all 92 descriptions as follows:

(1) Definition - defines the observable in the context of the exploration objective. In some cases fairly restricted definitions are necessary.

(2) Phenomena - indicates the ways in which an observable manifests itself. This may be by emission or absorption spectra, by texture, coloration, or hardness, etc.

(3) Possible Techniques - these are deduced directly from the phenomena. They are conceptual measurement techniques and do not relate directly to any form of instrumentation. For example, typical possible techniques for measuring coloration are multispectral remote sensing, spectrometry, colorimetry, surface sampling, etc.

(4) Remote Sensing - On the basis of the possible techniques and the phenomena to which they apply, a determination of the applicability of remote sensing is made. Remote sensing, in this study, is restricted to mean detection of electromagnetic radiation of any wavelength from orbital altitudes. In situ measurements and Earth-based remote sensing are specifically excluded.

If remote sensing is applicable, then the following subsections are completed:

(5) Measurement philosophy - indicates the nature of the measurements which utilize remote sensing.

(6) Coverage & Distribution - states how much of the planet

should be investigated and how the measurements should be distributed over the planet.

(7) Scale of observable - the characteristic size of the observable in planetocentric terms. If, for instance, craters are being investigated, then the characteristic size of craters of interest is stated.

(8) Spatial resolution - quoted in planetocentric terms and based on the scientific requirements of the measurement.

Items (6), (7), and (8) all relate to the geometrical constraints imposed on the measurement. These are important in assessing the usefulness of imaging, since imaging implies a two-dimensional array of data points.

(9) Acquisition Time - based on the rate of change of the observable with time. The acquisition time is the maximum time which can be spent obtaining one set of data on the observable.

(10) Repetition Rate - the frequency with which sets of data must be collected. It also is based on the time rate of change of the observable.

Items (9) and (10) are used to define the requirement for an essentially simultaneous collection of a set of data, such as is automatically provided in an image.

(11) Spectral Band & Resolution - a specification of the spectral region which is of interest.

(12) Imaging - here a judgment is made as to whether imaging adds useful information over and above that which can be obtained simply from remote sensing.

(13) Imagers - where imaging is indicated as useful, an identification of imagers is made and their usefulness is grossly estimated for each planet.

The complete list of imagers thus identified in the observable description is used as an input to the imaging sensor system subtask and to the determination of experiment subsystem requirements.

The descriptions of those observables for which imagery is useful are utilized in the measurement definition subtask which results in specification of planet-dependent imaging measurements and desired operational conditions.

2. OBSERVABLE DESCRIPTIONS

The following series of descriptions are grouped into the following categories:

(1) Planetary Composition

(2) Planetary Structure

(3) Active Planetary Processes

(4) Atmospheric Composition

(5) Atmospheric Structure

(6) Active Atmospheric Processes

(7) Fields

(8) Active Biota

(9) Extinct Biota

2.1 Planetary Composition

2.1 Planetary Composition

A. Objective: Mean Density of Planet

1. Mass
2. Radius
3. Oblateness

B. Objective: Gross Elemental Composition of Crust

1. Elemental abundances

C. Objective: Surface Isotopic Ratios

1. Isotopic abundances

D. Objective: Composition of Surface Materials

1. Petrology
2. Mineralogy
3. Liquids

OBJECTIVE: Mean Density of the Planet

Observable: Mass

Definition: The gravitational mass of a planet.

Phenomena: The acceleration due to gravity.

Possible Techniques: Tracking (microwave and visual) of natural or artificial satellites. Tracking (visual) of planets, asteroids, or comets (for perturbations). In situ surface and orbital gravimetry.

Remote Sensing: Not applicable, technique independent of direct planetary sensing.

OBJECTIVE: Mean Density of the Planet

Observable: Radius

Definition: The distance in km from the center of the planet to the surface (usually the equator).

Phenomena: Visual diameter of the planet, surface elevations, length of arc on the surface.

Possible Techniques: In situ surface survey, remote (microwave and laser) spacecraft altimetry, earth-based (visual and microwave) occultation observations (occultation of stars or spacecraft), remote (visual) (full disk) diameter measurements.

Remote Sensing: Useful

Measurement Philosophy: Measurement of the planetary radii with an accuracy of 1 part in 10^4 needed for physical studies of planet. Need average equatorial radius, approximately 100 measurements to eliminate topographic effects.

Moon	-	Accomplished by astronomical methods and by Lunar
	-	Orbiter Program.
Mercury	-	Present accuracy 1% (Ash, Shapiro, & Smith 1967)
Mars	-	Present accuracy 0.1% (Mariner IV results).
Venus	-	Present accuracy perhaps 0.2% (Ash, Shapiro & Smith 1967).
Jupiter	-	Search to determine if there is a definable solid body radius.

Planetary Coverage & Distribution: Measurements should be uniformly distributed about the equator.

Scale of Observable:

Moon	-	1500 km	
Mercury	-	2500 km	
Mars	-	3500 km	Approximate planetary radii
Venus	-	6500 km	
Jupiter	-	75,000 km	

Spatial Resolution:

Moon	-	0.1 km	
Mercury	-	0.2 km	
Mars	-	0.3 km	Resolution needed for 1 part in 10^4 accuracy
Venus	-	0.6 km	
Jupiter	-	7 km	

Acquisition Time: Not applicable, observable is not time-dependent

<u>Measurement Repetition Rate</u> : Not applicable, observable is not time-dependent.

<u>Spectral Band & Resolution</u>:

Moon, Mercury, Mars - Visible broadband (4000-7500Å), radar (1-100 cm), visible or IR laser

Venus - Radar (3-100 cm), dense atmosphere makes visible sensing unlikely.

Jupiter - Visible broadband (400-7500Å) to determine visual disk radii, not solid surface radii.

<u>Imaging</u>: Of marginal value. Unlikely to achieve desired accuracy, few data points required, non-imaging remote techniques are far more accurate at present and near-future state-of-the-art.

OBJECTIVE: Mean Density of the Planet

Observable: Oblateness

Definition: The oblateness of the planet as defined by $(r_e - r_p)/r_e$ where r_e = equatorial radius and r_p = polar radius (see comments).

Phenomena: Acceleration due to gravity, visual planetary diameters, surface elevations, length of arc on the surface (Kuiper et al. 1954).

Possible Techniques: Tracking (microwave & visual) of natural or artificial satellites, in situ surface gravimetry and surveying, earth-based (visual and microwave) occultation observations of stars and spacecraft, remote (microwave & laser) spacecraft altimetry, remote (visual) diameter measurements, and in situ orbital gravimetry.

Remote Sensing: Useful

Measurement Philosophy: Measure dynamical and optical figures (see comments) to one part in 10^4. Radii measurements are needed at numerous (~100) latitudes and longitudes.

Planetary Coverage & Distribution: (~100) radii measurements are needed at different latitude and longitudes with emphasis on polar and equatorial regions.

Scale of Observable: Current estimates of oblateness are:

Moon	-	Very small due to slow rotation
Mercury	-	Probably very small due to slow rotation
Mars	-	0.00525 (dynamical), perhaps 0.012 (optical)
Venus	-	Probably very small due to slow rotation
Jupiter	-	0.065 (dynamical), 0.061 (optical)

Spatial Resolution:

Moon	-	0.1 km	To obtain one part in 10^4 accuracy
Mercury	-	0.2 km	
Mars	-	0.3 km	
Venus	-	0.6 km	
Jupiter	-	7 km	

Acquisition Time: Not applicable, observable is not time-dependent

Measurement Repetition Rate: Not applicable, observable is not time-dependent

Spectral Band & Resolution:

Moon
Mercury — Visible (4000-7500Å), radar (1-100 cm); Laser in visible or IR

Venus - Dense atmosphere will make visible sensing of surface unlikely, radar (3-100 cm).

Jupiter - Visible (4000-7500Å), (measurements not of surface, but of visible disk).

Imaging: Of marginal value. Not likely to achieve required accuracy. Few data points required.

Comments: There are two types of figures, the first is the optical figure as defined by $(r_e - r_p)/r_e$ directly, the second is the dynamical figure which is derived from satellite perturbation theory (Loomis 1965). These two types of figures are identical if the planet is in hydrostatic equilibrium. Both values are required in order to evaluate any disequilibrium.

OBJECTIVE: Elemental Composition of the Crust

Observable: Elemental abundances

Definition: The percentage abundances of the major crustal constituents such as O, Si, Al, Fe, Cu, Na, Mg, and H.

Phenomena: Chemical and atomic properties of surface materials, atomic absorption and emission spectra.

Possible Techniques: Remote sensing of x-ray absorption and emission line edges; in situ surface sampling for chemical analysis; mass spectroscopy; UV-visible emission spectroscopy; in situ surface α-scattering, neutron activation and γ-ray spectroscopy.

Remote Sensing: Useful

Measurement Philosophy:

Determine the average elemental abundances of the surface over the whole planet and in local regions. 1% accuracy in composition is desired.

Moon, Mercury, Mars } All major terrestrial crustal elements are of importance.

Venus - All major terrestrial crustal elements are of importance with special interest in C (due to high CO_2 atmosphere content).

Jupiter - Particular emphasis on H, He, O, C, N due to NH_3, CH_4, H_2, He, and possibly H_2O.

Planetary Coverage & Distribution:

Approximately 100 data points distributed over planet at random, but known positions.

Moon, Mercury, Mars } Particular interest in polar regions and in difference between light and dark areas

Venus - Surface conditions poorly known.

Jupiter - Surface conditions unknown.

Gross Elemental Composition of the Crust - Elemental abundances (Page 2)

Scale of Observables:

Moon
Mercury — Need averages over 100 km areas for regional studies.
Mars
Venus

Jupiter - Interested only in planetary average, if a definable surface exists.

Spatial Resolution: Resolution elements $\leq$ 100 km, each resolution element can be a data point.

Acquisition Time:

Moon — Not applicable, phenomena not time-dependent
Mercury
Mars - May be some seasonal and diurnal variations (H_2O or CO_2 frost)
Venus - Surface conditions not well known.
Jupiter - Surface condition not known.

Measurement Repetition Rate: Not applicable

Spectral Range and Resolution:

Moon — γ-ray spectroscopy (0.002-0.3Å) with $\lambda/\Delta\lambda>100$;
Mercury — x-ray spectroscopy (0.3-100Å) with $\lambda/\Delta\lambda\sim500$;
Mars — UV spectroscopy (1000-4000Å) with $\lambda/\Delta\lambda\sim1000$.

Venus
Jupiter — Spectral range of interest will not penetrate dense clouds and thick atmosphere.

Imaging: Of marginal value. Orbital spectroscopy can be expected to give more accurate information than orbital imagery and few data points are required.

Comments: UV probably not applicable to Mars because of blue haze. Radar reflectivity may give some gross information.

OBJECTIVE: Surface Isotopic Ratios

Observable: Isotopic abundances

Definition: The percentage abundances of isotopes of crustal elements such as O^{16}, O^{18}, S^{32}, S^{34}, C^{13}, C^{14}, U^{238}, U^{235}.

Phenomena: Nuclear properties of crustal materials, atomic absorption and emission spectrum (Jacobs et al. 1959).

Possible Techniques: In situ surface sampling for mass spectroscopy, UV-visible emission spectroscopy, neutron activation, and γ-ray spectroscopy.

Remote Sensing: Not applicable. Careful selection of samples is required for proper interpretation; gross sampling is of little value in determining accurate isotopic abundance.

OBJECTIVE: Composition of Surface Materials

Observable: Petrology

Definition: The types of rocks such as granite, basalts, diorites, sandstones, limestones, gneisses, schists.

Phenomena: Chemical, physical, and nuclear properties of the material; x-ray diffraction; emission and absorption spectra; polarization, reflection, and transmission properties; UV, visual, and IR reflectivity (albedo); UV luminescence; and IR emissivity (Huang 1962).

Possible Techniques: In situ sampling for chemical analysis; UV, visible, and mass spectroscopy; x-ray diffractometry; hand specimen and thin section examination; in situ surface α-scattering and neutron activation; Remote UV, visible and IR narrow band photometry; Remote IR spectrometry and photometry.

Remote Sensing: Useful (see Comments)

Measurement Philosophy:

Determine lithology and distribution of rock units over the surface.

Moon - Identification of rocks on regional, local, and detailed scale and map on local and detailed scale (maps on regional scale already exist - USGS Lunar Stratigraphic Mapping Program).

Mercury, Mars, Venus - Identify and map rock units on regional and local scale.

Jupiter - The normal concept of petrology probably is inapplicable even if Jupiter has a definable surface, because of the probable composition of the surface, i.e., solid or liquid H_2, He, or H_2O.

Planetary Coverage & Distribution:

Moon - Total coverage on local scale, some detailed investigation in areas of special interest.

Mercury, Mars, Venus - Total coverage on regional scale, some local and detailed investigation of areas of special interest.

Jupiter - If definable surface exists, some regional information may be required.

Scale of Observable:

Moon, Mercury, Mars, Venus } Terrestrial and lunar experience suggests a lithologic unit scale from meters to 100 km.

Jupiter - Unknown

Spatial Resolution:

Moon, Mercury, Mars, Venus } 1-5 meters (detailed); 50-150 meters (local); 1 to 3 km (regional) based on terrestrial and lunar experience.

Jupiter - Probably 1-10 km if applicable.

Acquisition Time: Not applicable, phenomena not time-dependent.

Measurement Repetition Rate: Not applicable.

Spectral Band & Resolution:

Moon - UV (1000-4000Å); Visual (4000-7500Å); IR (7500Å-2.5μ) for photometry with $\lambda/\Delta\lambda$ = 10-30; IR (2.5-100μ) for emissivity measurements with $\lambda/\Delta\lambda \sim 100$.

Mercury - UV (1000-4000Å); Visible (4000-7500Å); IR (7500Å-2μ) for photometry with $\lambda/\Delta\lambda$ = 10-30; IR (2-100μ) for emissivity measurements with $\lambda/\Delta\lambda \sim 100$.

Mars - Visible (5000-7500Å); IR (7500Å-2.5μ) for photometry with $\lambda/\Delta\lambda$ = 10-30; IR (2-100μ) for emissivity measurements with $\lambda/\Delta\lambda \sim 100$.

Venus, Jupiter } Desired wavelengths are so strongly attenuated by dense clouds and thick atmosphere that remote sensing is probably impossible for this observable (see Comments).

Imaging: Of marginal value (see Comments)

Comments: Proper detailed identification of rock types can be accomplished only by hand specimen and thin section (microscopic) examination since many different rock types have the same chemical composition but a different origin. For example, granite, rhyolite, arkose, and gneiss may have the same chemical composition but are of intrusive igneous, extrusive igneous, sedimentary, and metaniospheric origin, respectively. Effective use of far IR and microwave techniques for this observable depends upon significant state-of-art advancements in interpretation.

OBJECTIVE: Composition of Surface Materials

Observable: Mineralogy

Definition: Generally a mineral is a distinct chemical compound or solid series solution with a definite, characteristic crystallographic structure. A few minerals are amorphous both chemically and crystallographically.

Phenomena: Chemical and physical properties of the material, x-ray diffraction, emission and absorption spectra; polarization, reflection, and transmission properties (Hurlbut 1961).

Possible Techniques: In situ sampling for chemical analysis, UV, visible, and mass spectroscopy, x-ray diffractometry; hard specimen and thin section examination, in situ surface α-scattering; neutron activation.

Remote Sensing: Probably useless because mineralogic studies require microscopic to 1 mm resolution (see Comments).

Comments:

There is an exception where remote sensing **might** be useful - a monomineralic layer or zone of large extent. For example, the surface of the Martian deserts may be covered with a coating of limonite (Binder and Cruikshank 1966). The mineral may be so widespread and uniform that remote sensing would be applicable for identification.* Generally, however, the scale of heterogeneity is such that individual minerals cannot be detected without near-microscopic resolution.

*See "Elemental Composition of Crust" and "Petrology" for possible effects.

OBJECTIVE: Composition of Surface Materials

Observable: Liquids

Definition: Composition of any fluid material on the surface, such as Pb, Sn, S, for Mercury and Venus; H_2O on Mars (doubtful); H_2 and He on Jupiter.

Phenomena: Chemical and nuclear properties of surface fluids, atomic absorption and emission spectra.

Possible Techniques: Remote sensing of x-ray absorption and emission line edges; In situ surface sampling for chemical analysis, mass spectroscopy, and UV-visible emission spectroscopy; in situ surface α-scattering and neutron activation. Remote UV, visible, and IR colorimetry, and remote IR emission spectroscopy.

Remote Sensing: Useful

Measurement Philosophy:

Determine the chemical composition of surface fluids.

Moon - Probably no surface fluids since there is no atmosphere.

Mercury - May be local fluid metal pools due to high temperature.

Mars - Probably no surface fluids due to low surface pressure.

Venus - May be local fluid metal pools due to high temperature.

Jupiter - Probably liquid H_2, perhaps He, due to high pressures.

Planetary Coverage & Distribution:

Since fluid bodies are usually uniform in composition, a few (10) measurements can be made of those fluid bodies defined by regular planetographic mapping.

Moon - Probably not applicable.

Mercury - Probably local pools of unknown distribution.

Mars - Probably not applicable.

Venus - Probably local pools of unknown distribution.

Jupiter - Unknown (liquid H_2 may cover entire Jovian sphere).

Scale of Observable:

Mercury, Venus - Probably small (estimates at 1-1000 m)

Jupiter - H_2 may cover entire surface.

Composition of Surface Materials - Liquids (Page 2)

Spatial Resolution:

Mercury, Venus - 1-100 m due to scale estimated above
Jupiter - 1-10 km

Acquisition Time: Not applicable, phenomena not time-dependent

Measurement Repetition Rate: Not applicable, phenomena not time-dependent.

Spectral Band & Resolution

Mercury - UV (1000Å-4000Å); Visible (4000-7500Å); IR (7500Å-2μ) for colorimetry with $\lambda/\Delta\lambda \sim 10$-30; IR (2$\mu$-100$\mu$) for emissivity spectroscopy; x-ray (0.3Å-100Å) with $\lambda/\Delta\lambda$ = 100-1000.

Venus, Jupiter - Required wavelengths will not penetrate dense cloud cover and thick atmosphere.

Imaging: Not applicable since composition is required. Also few data points necessary.

Comments: This observable deals only with chemical composition of surface liquids. Determining the presence of surface liquids is considered under "Surface Appearance." At Mercury, IR colorimetry cannot be performed above 2μ, nor IR emissivity measurements below 2μ, because of unwanted emissivity and reflectivity, respectively.

2.2 Planetary Structure

2.2 Planetary Structure

A. Objective: Geometric shape of planet

1. Surface elevations
2. Center of Mass

B. Objective: Internal Structure

1. Density Distribution
2. Discontinuities

C. Objective: Crustal Structure

1. Layering
2. Contacts
3. Attitude of rock units
4. Structure of features

D. Objective: Surface Morphology

1. Surface topography
2. Surface appearance

OBJECTIVE: Geometric Shape of Planet

Observable: Surface Elevations

Definition: The height of the surface above some datum.

Phenomena: Reflectivity, shadows, stereo parallax.

Possible Techniques: Remote (microwave and laser) spacecraft altimetry, remote (visual and microwave) sensing, in situ surface mapping.

Remote Sensing: Very useful

Measurement Philosophy:

Moon, Mercury, Mars, Venus } Identify regional topographic features of the planet in order to define regional deviations of the surface with respect to the basic planetary ellipsoidal shape.

Jupiter - Need to define surface if one exists and get gross topographic information.

Planetary Coverage & Distribution:

Distribution of large scale mapping will be formulated on basis of small scale maps.

Moon, Mercury, Mars, Venus } 100% coverage to provide basic planetocentric information

Scale of Observable:

Moon, Mercury, Mars, Venus } Maximum elevation differences ~ 10 km on planetary scale.

Jupiter - Unknown, possibly 100 km

Spatial Resolution:

Moon, Mercury, Mars, Venus } 5 km since regional data are required.

Jupiter - Unknown, possibly 50 km.

Acquisition Time: Not applicable, phenomena not time-dependent.

Measurement Repetition Rate: Not applicable, phenomena not time-dependent.

Spectral Band & Resolution:

Moon Mercury Mars	Radar (1-100 cm) and visible (4000-7500Å) broadband. Any visual or IR laser frequency
Venus Jupiter	Dense cloud cover will make visual sensing impossible, Radar (3-100 cm) is useful.

Imaging: Useful, since many data points are required.

	Moon	Mercury	Mars	Venus	Jupiter
Visible (4000-7500Å)	C	C	C		
Radar (1-100 cm)	C	C	C	C	C
Visible stereo	A	A	A		
Radar stereo	A	A	A	A	C

(A = very useful, B = useful, C = not very useful)

Comments: Regional contour maps (5 km resolution) should have 1-3km vertical resolution. Below 5000Å the Martian blue haze will interfere.

OBJECTIVE: Geometric Shape of Planet

Observable: Center of Mass

Definition: The location of the planetary center of mass with respect to the geometric center of planetary spheroid.

Phenomena: Acceleration due to gravity

Possible Techniques: Tracking (microwave) of natural or artificial satellites. In situ surface gravimetry. In situ orbit gravimetry.

Remote Sensing: Not applicable due to necessity of in situ measurements and tracking techniques which are independent of direct planet sensing.

OBJECTIVE: Internal Structure

Observable: Density distribution

Definition: Density as a function of the distance from the center of the planet.

Phenomena: Acceleration of gravity, seismic waves, free body oscillations, axial precession. Visual planetary diameters, surface elevations, length of arc on the surface (to determine oblateness) (Kuiper 1954).

Possible Techniques: In situ surface seismic wave detection, in situ astrometry, in situ orbital gravimetry. Tracking (microwave and visual) of natural or artificial satellites, in situ surface gravimetry and surveying, earth-based (visual and microwave) occultation observations of stars and spacecraft, remote (microwave and laser) spacecraft altimetry, remote (visual) diameter measurements.

Remote Sensing: Useful

Measurement Philosophy:

Estimate density distribution from moment of inertia deduced from figure measurements (de Vaucouleurs 1954). Measure dynamical and optical figures to one part in 10^4. Radii measurements are needed at numerous ($\sim$100) latitudes and longitudes with emphasis on the polar and equatorial regions.

Planetary Coverage & Distribution:

$\sim$100 radii measurements are needed at different latitudes and longitudes with emphasis on polar and equatorial regions.

Scale of Observable: Current estimates of oblateness are:

Moon - Very small due to slow rotation.
Mercury - Probably very small due to slow rotation.
Mars - 0.00525 (dynamical), perhaps 0.012 (optical).
Venus - Probably very small due to slow rotation.
Jupiter - 0.065 (dynamical), 0.061 (optical).

Spatial Resolution:

Moon - 0.1 km
Mercury - 0.2 km
Mars - 0.3 km
Venus - 0.6 km
Jupiter - 7 km

} To obtain one part in 10^4 accuracy.

Internal Structure - Density Distribution (page 2)

Acquisition Time: Not applicable, observable is not time-dependent.

Measurement Repetition Rate: Not applicable, observable is not time-dependent.

Spectral Band & Resolution:

Moon Mercury Mars	Visible (4000-7500Å), radar (1-100 cm), any laser in visible or IR.
Venus Jupiter	Radar (3-100 cm), dense atmosphere will make visual or IR sensing of surface unlikely.

Imaging: Of marginal value. Not likely to achieve required accuracy. Few data points required.

OBJECTIVE: Internal Structure

Observables: Discontinuities

Definition: A sudden change or a discontinuous jump in the rate of change of density with respect to depth.

Phenomena: Seismic waves.

Possible Techniques: In situ surface seismic wave detection.

Remote Sensing: Not applicable because seismic wave detection requires a mechanical coupling of the detector with the surface.

OBJECTIVE: Crustal Structure

Observable: Layering

Definition: Most sedimentary rocks, many extrusive igneous rocks, and some metamorphic rocks are found in series of parallel or subparallel tabular units, each unit being a layer in the series.

Phenomena: Geometric shape of the rock units, seismic waves.

Possible Techniques: In situ surface mapping, remote visual sensing, remote microwave sensing, in situ surface seismic wave sensing.

Remote Sensing: Useful

Measurement Philosophy:

Identify layered sequences in contrast to homogeneous or chaotic units. The units will have been delineated by prior mapping (see "Contacts").

Planetary Coverage and Distribution:

Distribution will be determined by prior mapping. Planetary coverage would probably be small, 1% or less, since only positive identification of previously identified units is required.

Scale of Observable

Moon, Mercury, Mars, Venus – Based on terrestrial experience, layers have dimensions (vertical thickness) of 1 cm to 100 meters (Dunbar & Rogers 1957).

Jupiter - Surface conditions are unknown.

Spatial Resolution:

Moon, Mercury, Mars, Venus – 1 mm to 5 m required to define layering.

Jupiter - Estimated to be 1-5 m if applicable.

Acquisition Time: Not applicable, phenomena not time-dependent.

Measurement Repetition Rate: Not applicable, phenomena not time-dependent.

Crustal Structure - Layering (Page 2)

Spectral Band & Resolution:

Moon Mercury Mars	Visible (4000-7500Å) and radar (1-100 cm)
Venus Jupiter	Radar (10-100 cm), dense atmosphere makes visual sensing of surface unlikely.

Imaging: Useful

	Moon	Mercury	Mars	Venus	Jupiter
Visible Broadband (4000-7500Å)	A	A	A		
Radar (~ 10 cm)	A	A	A	A	
Radar (multifrequency 2 wavelengths)	A	A	A	A	C

(A = very useful, B = useful, C = not very useful)

Comments: Multifrequency radar may yield useful near-surface layering information. The 10 cm radar will probably not effectively penetrate the Jovian atmosphere.

OBJECTIVE: Crustal Structure

Observable: Contacts

Definition: The interface between two different, adjacent rock units.

Phenomena: Texture, albedo, color, lithology, mineralogy of rock units (Billings 1962).

Possible Techniques: In situ surface mapping. Remote UV, visual, IR, and microwave sensing (broadband sensing and narrow band photometry).

Remote Sensing: Very useful.

Measurement Philosophy:

Determine the distribution of lithologic units over the planetary surface for studying the development of the visible surface. Provide basic maps for further work.

Moon - Map on local and detailed scale, regional scale now being done (USGS Lunar Stratigraphic Mapping Program).

Mercury, Mars, Venus } Map on regional, local and detailed scale.

Jupiter - Determine if different lithologic units exist.

Planetary Coverage & Distribution:

Distribution of large scale mapping will be made on a basis of the finding of small scale maps. Coverage requirements are based on lunar and terrestrial mapping experience.

Moon - 100% coverage local scale, 5-10% at detailed scale.

Mercury, Mars, Venus } 100% coverage at regional scale, 10-20% at local scale, and 1% at detailed scale.

Jupiter - 1-5% at regional scale if lithologic units exist.

Scale of Attribute: (Typical contact dimension based on terrestrial and lunar experience.)

Moon - Local, 1 km to 100 km; detailed, 1 m to 1 km based on present lunar mapping experience

Mercury, Mars, Venus } Regional, 10 km to 1000 km; Local, 1 km to 10 km; Detailed, 1 m to 1 km

Jupiter - Surface conditions unknown, estimated at 1000 km.

Crustal Structure - Contacts (Page 2)

<u>Spatial Resolution</u>: (based on scale of lithologic units)

Moon - Local, 50-150 m; detailed, 1-5 m

Mercury Regional, 1-3 km;
Mars Local, 50-150 m;
Venus Detailed, 1-5 m

Jupiter - Estimated as 1-10 km for search mode

<u>Acquisition Time</u>: Not applicable, phenomena not time-dependent.

<u>Measurement Repetition Rate</u>: Not applicable, phenomena not time-dependent.

<u>Spectral Band & Resolution</u>:

Moon, Mercury: UV(1800-2800Å), Visible (4000-7500Å), near IR (1-2μ), Far IR (50-200μ), radar (1-100 cm).

Mars - Visible (5000-7500Å), near IR (1-2μ), Far IR (50-200μ), Radar (1-100 cm).

Venus, Jupiter: Radar (3-100 cm), other wavelengths heavily attenuated by atmosphere.

Narrow band photometry requires $\lambda/\Delta\lambda \sim 10$-30

<u>Imaging</u>: Useful

	Moon	Mercury	Mars	Venus	Jupiter
UV Wideband (1800-2800Å)	C	C			
Visible Wideband (4000-7500Å)	A	A	A		
Near IR (1-2μ)	B	B	B		
Far IR wideband (50-200μ)	C	C	C		
Radar (1-100 cm)	B	B	B	A	C
Multispectral (4-6 bands, 1500Å-2μ)	A	A	A		

(A = very useful, B = useful, C = not very useful)

OBJECTIVE: Crustal Structure

Observable: Attitude of rock units

Definition: The attitude of a rock unit is defined by its dip (tilt of rock layer) and strike (orientation of rock layer).

Phenomena: Geometric relationships of rock units.

Possible Techniques: In situ surface mapping (see Comments).

Remote Sensing: Not applicable because direct measurements are needed.

Comments: Inferred dips and strikes can be obtained by remote visual and microwave sensing, but such measurements do not generally give true attitudes.

OBJECTIVE: Crustal Structure

Observable: Structure of Features

Definition: The geometric relationships between and within rock units, such as folds, domes, and graben.

Phenomena: Geometric relationships, surface appearance, seismic waves, magnetic field strength, acceleration due to gravity, electric fields (Billings 1962, de Sitter 1956).

Possible Techniques: In situ surface mapping, in situ surface drilling, in situ "geophysical" exploration (seismic, gravimetric, etc. studies). Remote visual and microwave sensing.

Remote Sensing: Useful (see Comments)

Measurement Philosophy:

Determine structural features of the planetary surfaces to understand the history and structure of the surface.

Moon - Study regional, local, and detailed structures; mapping now in progress on all three scales.

Mercury, Mars, Venus - Study all three scales, since little is known of the surface structures of these planets.

Jupiter - Determine if surface structures exist.

Planetary Coverage & Distribution:

Distribution of large scale mapping will be formulated on basis of small scale maps.

Moon - 100% coverage local scale, about 1% at detailed scale

Mercury, Mars, Venus - 100% coverage regional scale, 10-20% at local scale, and 1% at detailed scale.

Jupiter - 1-5% at regional scale.

Scale of Observable: (based on terrestrial and lunar mapping experience

Moon - 1 km to 100 km local, 1m to 1 km detailed

Mercury, Mars, Venus - 10 km to 100 km regional; 1 km to 10 km local; 1 m to 1 km detailed

Jupiter - 100 km to 1000 km regional

Spatial Resolution: (based on terrestrial and lunar mapping experience)

Moon - 50-150 m local, 1-5 m detailed

Mercury, Mars, Venus: 1-3 km regional; 50-150 m local; 1-5 m detailed

Jupiter - 1-10 km regional

Acquisition Time: Not applicable, phenomena not time-dependent

Measurement Repetition Rate: Not applicable, phenomena not time-dependent

Spectral Band & Resolution:

Moon, Mercury, Mars: Visible broadband (4000-7500Å), radar (1-100 cm), optical or IR laser

Venus, Jupiter: Radar (3-100 cm), shorter wavelengths heavily attenuated by atmosphere.

Imaging: Useful

	Moon	Mercury	Mars	Venus	Jupiter
Visible broadband (4000-7500Å)	A	A	A		
Radar (1-100 cm)	A	A	A	A	C
Visible stereo (4000-7500Å)	A	A	A		
Radar stereo (1-100 cm)	A	A	A	A	C

(A = very useful, B = useful, C = not very useful)

Comments: Although remote sensing is useful, surface study (ground truth) is necessary to obtain accurate knowledge of the surface.

OBJECTIVE: Surface Morphology

Observable: Surface topography

Definition: The shape of the surface.

Phenomena: Reflectivity, shadows, stereo parallax.

Possible Techniques: In situ surface mapping. Remote (laser and radar) spacecraft altimetry, remote (visual and radar) sensing.

Remote Sensing: Very useful

Measurement Philosophy: Determine and define detailed shape of the surface.

Moon
Mercury
Mars
Venus } All scales of topography are poorly known.

Jupiter - Determine if there is surface topography.

Planetary Coverage & Distribution: Distribution of large scale mapping will be formulated on basis of small scale maps.

Moon - 100% coverage local scale, about 1% at detailed scale

Mercury
Mars
Venus } 100% coverage at regional scale, 10-20% at local scale, and 1% at detailed scale

Jupiter - 1-5% at regional scale, if applicable.

Scale of Observable: (based on terrestrial and lunar experience)

Moon - 1-100 km local, 1 m to 1 km detailed

Mercury
Mars
Venus } 10 km to 100 km regional, 1-10 km local, and 1 m to 1 km detailed scale

Jupiter - Surface conditions unknown, estimated 10-1000 km.

Spatial Resolution: (based on terrestrial and lunar experience)

Moon - 50-150 m local, 1-5 m detailed scale

Mercury
Mars
Venus } 1-3 km regional, 50-150 m local, and 1-5 m detailed scale

Jupiter - Unknown, estimated as 1-3 km.

Surface Morphology - Surface topography (Page 2)

Acquisition Time: Not applicable, phenomena not time-dependent.

Measurement Repetition Rate: Not applicable, phenomena not time-dependent.

Spectral Band and Resolution:

Moon, Mercury, Mars: Visible broadband (4000-7500Å), radar (1-100 cm), optical or IR laser.

Venus, Jupiter: Radar (3-100 cm), shorter wavelengths heavily attenuated by atmosphere.

Imaging: Very useful, since many data points are required. Stereo desired.

	Moon	Mercury	Mars	Venus	Jupiter
Visible broadband (4000-7500Å)	B	B	B		
Radar (1-100 cm)	B	B	B	B	C
Visible stereo (4000-7500Å)	A	A	A		
Radar stereo (1-100 cm)	A	A	A	A	C

(A = very useful, B = useful, C = not very useful)

OBJECTIVE: Surface Morphology

Observable: Surface Appearance

Definition: The variations in albedo, shape, and texture of the surface.

Phenomena: Albedo, shape, and texture of the surface.

Possible Techniques: In situ surface mapping, remote visual and microwave sensing.

Remote Sensing: Very useful

Measurement Philosophy: Obtain visual representations of the surface.

Moon - Completed on regional scale, largely completed on local scale.

Mercury, Mars, Venus } Surface appearance is virtually unknown.

Jupiter - Determine what the surface looks like, if one exists.

Planetary Coverage & Distribution:

Distribution of local or detailed observations depends on study of regional observations.

Moon - 100% coverage at local scale, about 1% at detailed scale (Regional scale completed - Orbiter Program)

Mercury, Mars, Venus } 100% coverage at regional scale
10-20% at local scale and 1% at detailed scale
See Comments

Jupiter - 1-5% at regional scale; search mode.

Scale of Observable: (based on terrestrial and lunar experience)

Moon - 1-100 km local, 1 m to 1 km detailed

Mercury, Mars, Venus } 10 km to 1000 km regional
1-10 km local
1m to 1 km detailed scale

Jupiter - Surface conditions unknown, estimated at 100-1000 km.

Spatial Resolution: (based on scale of lithologic units)

Moon - 50-150 m local, 1-5 m detailed

Mercury, Mars, Venus } 1-3 km regional
50-150 m local
1-5m detailed

Jupiter - Estimated 1-3 km

Surface Morphology - Surface appearance (Page 2)

Acquisition Time: Not applicable; phenomena not time-dependent. (See comments)

Measurement Repetition Rate: Not applicable; phenomena not time-dependent. (see Comments)

Spectral Band & Resolution:

Moon Mercury Mars	Visible broadband (4000-7500Å), radar (1-100 cm)
Venus Jupiter	Radar (3-100 cm), shorter wavelengths heavily attenuated by atmosphere.

Imaging: Very useful

	Moon	Mercury	Mars	Venus	Jupiter
Visible broadband (4000-7500Å)	A	A	A		
Radar (1-100 cm)	B	B	B	A	C

(A = very useful, B = useful, C = not very useful)

Comments: Surface appearance is expected to be independent of time except for Mars. Here both diurnal and seasonal changes in surface appearance are of interest. The recession of the polar caps and changes in the albedo of the dark areas (de Vaucouleurs 1954) are of special importance. For study of diurnal variations, the acquisition time should be less than about 5 minutes with measurements repeated hourly; for study of seasonal variations, the acquisition time may be as long as an hour with measurements repeated daily.

2.3 Active Planetary Processes

2.3 Active Planetary Processes

A. Objective: Planetocentric Motion

1. Rotation period
2. Tidal effects
3. Polar wandering

B. Objective: Active Crustal Processes

1. Surface winds
2. Surface liquid motions
3. Topographic changes
4. Thermal anomalies
5. Seismic waves

C. Objective: Active Internal Processes

1. Magnetic field
2. Heat flow
3. Seismic waves
4. Mass motion

OBJECTIVE: Planetocentric Motions

Observable: Rotation Period

Definition: The time the planet requires to turn 360° on its axis.

Phenomena: Doppler shift or spread of spectra, transit of reference points.

Possible Techniques: Remote UV and visual spectroscopy, microwave and visual sensing. In situ transit (stellar) observations.

Remote Sensing: Not useful from planetary orbit. Accuracy of currently known rotation periods exceeds the capabilities of orbital remote sensing by orders of magnitude. Accuracy of rotation period determinations is dependent upon duration of observation and not sensitive to distance from which observations are made.

OBJECTIVE: Planetocentric Motion

Observable: Tidal Effects

Definition: Changes in rotation rates due to the gravitational interaction between astronomical bodies.

Phenomena: Transit of reference points.

Possible Techniques: In situ transit (stellar) and astrometric measurements.

Remote Sensing: Not applicable. No currently conceivable technique offers possibility of ultraprecise measurements required. The rotation period of the Earth changes only one millisecond per century (Kuiper 1954).

OBJECTIVE: Planetocentric Motion

Observable: Polar Wandering

Definition: Change in the axis of rotation relative to the planetary sphere.

Phenomena: Rock magnetism, fossil distribution (see Comments).

Possible Techniques: In situ surface sampling for paleomagnetic measurements and fossils.

Remote Sensing: Not applicable due to necessity of direct sampling.

Comments: Measurements of paleomagnetism of rocks indicate the paleolatitude and longitude of the rock at the time the rock was formed. Fossil distribution indicates paleoclimates which indicate (indirectly) paleolatitudes (Jacobs et. al. 1959).

OBJECTIVE: Active Crustal Processes

Observable: Surface Winds

Definition: Lateral mass movement of air from 0 to 100 meters above the surface, capable of altering the surface.

Phenomena: Aeolian transport of sand, dust, or any particulate material; wind velocity and direction.

Possible Techniques: In situ surface velocity measurement, in situ surface visual sensing, remote visual and microwave sensing.

Remote Sensing: Useful

Measurement Philosophy: Determine the velocity, frequency of occurrence, turbulence, and scale of surface winds.

Moon - Not applicable, no atmosphere.

Mercury - Probably not applicable due to tenuous atmosphere or lack of atmosphere.

Mars - Surface winds have been observed.

Venus - Possibly very strong surface winds due to dense atmosphere.

Jupiter - Surface condition unknown.

Planetary Coverage & Distribution:

Total coverage at low resolution over entire planet since surface wind can occur at any place. Higher resolution coverage and distribution would be determined from the findings of the low resolution examination.

Scale of Observable:

Mercury - Unknown
Mars - Velocities up to 100 km/hr have been observed (deVaucouleurs 1954)
Venus - Unknown
Jupiter - Unknown

Spatial Resolution:

1 to 10 km resolution in order to detect and follow sand or dust storms. If such storms could be actively tracked, then higher resolution (100 m) would be useful to detect turbulence.

Acquisition Time: Approximately 30 sec for low (1-10 km) resolution, based on the time the dust or sand would move 1 resolution element at 100 km/hr. Lower velocities would allow longer acquisition times.

Measurement Repetition Rate: Every 2 or 3 minutes for low resolution, based on movement in a 100 km/ hr velocity storm. Lower velocities would allow lower repetition rates.

Spectral Band and Resolution:

Mercury Mars	Visible broadband (4000-7500Å), passive microwave broadband (1-100 cm), radar (1-100 cm)
Venus Jupiter	Passive microwave broadband (3-100 cm), radar (3-100 cm)

Imaging: Useful at Mercury and Mars. Probably useless at Venus and Jupiter because of dense atmosphere.

	Moon	Mercury	Mars	Venus	Jupiter
Visible broadband (4000-7500Å)		C	A		

(A = very useful, B = useful, C = not very useful)

OBJECTIVE: Active Crustal Processes

Observable: Surface Liquid Motions

Definition: Lateral mass movement of a surface liquid.

Phenomena: Velocity of fluid.

Possible Techniques: In situ surface velocity, in situ surface visual tracking of emplaced buoys, remote microwave tracking of emplaced buoys.

Remote Sensing: Useful

Measurement Philosophy: Track buoys to determine if motion of surface fluids occurs, i.e., search mode. Present planetary knowledge strongly suggests that significant fluid motions may only occur on Jupiter. (See Composition of Surface Materials - Liquids).

Planetary Coverage & Distribution:

Moon, Mercury, Mars, Venus } Most probably not applicable due to absence, or expected limited size, of fluid bodies.

Jupiter - Buoys might be distributed randomly over liquid surface, if buoy design is feasible.

Scale of Observable:

Jupiter - Unknown, due to lack of knowledge of surface conditions.

Spatial Resolution: None required.

Acquisition Time:

Jupiter - Unknown due to lack of knowledge of surface conditions.

Measurement Repetition Rate:

Jupiter - Unknown due to lack of knowledge of surface conditions.

<u>Spectral Band & Resolution</u>: S band microwave

Jupiter - Thick atmosphere may make tracking impossible due to signal attenuation.

<u>Imaging:</u> Not useful.

OBJECTIVE: Active Crustal Processes

Observable: Topographic Changes

Definition: Any change, resulting from a currently active process, in the size or shape of a topographic feature.

Phenomena: Explosions, eruptions, or changes in geometry (Thornbury 1961)

Possible Techniques: Remote visual and microwave sensing, in situ visual and microwave sensing.

Remote Sensing: Useful

Measurement Philosophy:

Observe any active surface feature formation process or any active surface modification process. Development below is confined to slow and semi-predictable changes (see Comments).

Moon - Special interest in cratering processes and slope modification processes.

Mercury, Mars, Venus - Determine what processes are active.

Planetary Coverage & Distribution: Coverage and distribution will have to be determined from regular planetographic mapping (see Comments).

Scale of Observable:

Moon, Mercury, Mars, Venus - 1 m to 10 km (from soil creep to volcanic eruptions).

Jupiter - Unknown, estimated as 10 m - 100 km.

Spatial Resolution:

Moon, Mercury, Mars, Venus - 0.1 mm to 1 m, the scales of the individual units (soil particles, rocks, etc.) being moved.

Jupiter - Estimated as 1-10 m.

Acquisition Time: Estimated as less than a few hours.

Active Crustal Processes - Topographic Changes (Page 2)

Measurement Repetition Rate: Estimated as days or weeks.

Spectral Band & Resolution:

Moon Mercury Mars	Visible broadband (4000-7500Å), radar (1-100 cm).
Venus Jupiter	Radar (3-100 cm), shorter wavelengths heavily attenuated by dense atmosphere.

Imaging: Useful, stereo coverage desirable.

	Moon	Mercury	Mars	Venus	Jupiter
Visible broadband (4000-7500Å)	A	A	A		
Radar (1-100 cm)	A	A	A	A	C
Visible stereo (4000-7500Å)	A	A	A		
Radar stereo (1-100 cm)	A	A	A	A	C

(A = very useful, B = useful, C = not useful)

Comments: Three types of topographic changes might be considered

1) Unpredictable rapid changes such as meteorite impacts, many volcanic eruptions, and land slides. Attempts to record such changes would require continuous time and total planet coverage to record such phenomena.

2) Slow and semi-predictable changes such as soil creep, solution, and some volcanic eruptions. Regular planetographic mapping would indicate the location and extent of the required coverage in various areas of interest.

3) Very slow and large scale processes such as organic uplift. Such processes can be observed only over long ($>$ 100 years) periods of time.

Only slow and semi-predictable changes are considered here.

OBJECTIVE: Active Crustal Processes

Observable: Thermal Anomalies

Definition: Surface areas of different temperature from their general surroundings.

Phenomena: Temperature, radiation emittance.

Possible Techniques: In situ thermometry, remote IR and microwave radiometry.

Remote Sensing: Useful.

Measurement Philosophy:

Moon, Mercury, Mars, Venus - Determine presence, temperature, and spatial distribution of thermal anomalies for correlation with observed surface structures.

Jupiter - Determine if there are thermal anomalies.

Planetary Coverage and Distribution:

Moon, Mercury, Venus, Mars - Regular planetographic mapping might provide some information on where to look for anomalies. Search mode (low resolution) would require 100% coverage, detailed investigation (moderate and high resolution) about 1-5%.

Jupiter - Estimated 100% coverage (low resolution).

Scale of Observable:

Moon, Mercury, Mars, Venus - 1 m to 10 km (based on lunar and terrestrial experience).

Jupiter - Unknown, estimated as 1-100 km.

Spatial Resolution:

Moon, Mercury, Mars, Venus - Search mode, 1 km to detect anomalies; moderate resolution, 50-150 m; high resolution, 1-5 m for local and detailed investigation.

Jupiter - 1-10 km search mode (estimated).

Acquisition Time: Estimated up to 10 hours for a large scale anomaly, since most materials do not cool rapidly.

<u>Measurement Repetition Rate</u>: Estimated every 10-30 hours for those phenomena which may be time-dependent (cooling of lava, ash, etc.).

<u>Spectral Band & Resolution</u>:

Moon, Mercury, Mars	IR broadband (3-100μ), microwave broadband (1 mm -100 cm) with $\lambda/\Delta\lambda \sim 10$ for spectral profiles
Venus, Jupiter	Microwave (3-100 cm) with $\lambda/\Delta\lambda \sim 10$

<u>Imaging</u>: Useful, since many data points are required.

	Moon	Mercury	Mars	Venus	Jupiter
IR broadband (3-100μ)	A	A	A		
Microwave broadband (3-100 cm)	A	A	A	A	C
Multispectral (3-40μ, 40-100μ, 1 mm-10 cm, 10-100 cm)	A	A	A	B	C

<u>Comments</u>: Estimated temperature ranges and desired resolutions are

	Range	Resolution
Moon	120-400°K	1°K
Mercury	100-600°K	5°K
Mars	200-300°K	2°K
Venus	550-700°K	5°K
Jupiter	?	2°K

OBJECTIVE: Active Crustal Processes

Observable: Seismic Waves

Definition: Longitudinal and compressional energy waves whose origins are moderate or large disturbances at the surface or in the crust of the planet.

Phenomena: Acoustic vibrations.

Possible Techniques: In situ surface seismology.

Remote Sensing: Not applicable because of the necessity of direct mechanical coupling between detector and the planet's surface.

OBJECTIVE: Active Internal Processes

Observable: Magnetic Field

Definition: The configuration of magnetic lines of force around the planet.

Phenomena: Magnetic field strength and direction, radio emission (from trapped radiation).

Possible Techniques: In situ orbital magnetometry, in situ surface magnetometry, remote microwave sensing.

Remote Sensing: Not useful (see Comments).

Comments:

To date, in situ spacecraft measurements have shown that Mars (Smith et al. 1965), the Moon (Ness et al. 1967), and Venus (Bridge et al. 1968) do not have internally produced magnetic fields and, because of its slow rotation, no magnetic field is expected. Earth-based microwave observations have shown that Jupiter possesses a very strong magnetic field. Magnetic field measurements to detect active internal processes requires detection of the field, then accurate measurements of the field strength and direction in space and time. Detection of a field is possible with microwave methods, but accurate field strength measurements are not possible remotely.

OBJECTIVE: Active Internal Processes

Observable: Heat Flow

Definition: The amount of thermal energy being released from the interior of the planet per unit area per unit time.

Phenomena: Temperature, thermal conductivity, heat flux.

Possible Techniques: In situ surface and subsurface thermometry and sampling.

Remote Sensing: Not useful due to the necessity of direct contact measurement and sampling (see Comments).

Comments:

Heat flow measurements are made by determining the thermal gradient (dT/dh) and then measuring the thermal conductivity, k, of the material. The heat flow (dQ/dt) is given by

$$\frac{dQ}{dt} = \frac{kdT}{dh}$$

While it might be possible to measure dT/dh remotely (microwave), the thermal conductivity measurements must be made by sampling.

OBJECTIVE: Active Internal Processes

Observable: Seismic Waves

Definition: Longitudinal and compressional energy waves whose origins are below the crust of the planet.

Phenomena: Acoustic vibrations

Possible Techniques: In situ surface seismology.

Remote Sensing: Not applicable because of the necessity of direct mechanical coupling between the detector and the planet's surface.

OBJECTIVE: Active Internal Processes

Observable: Mass Motion

Definition: Movement of subcrustal materials.

Phenomena: Acceleration due to gravity, seismic waves, planetary figure, differences in surface elevations and geometry, magnetic field strengths direction, changes in the magnetic field, structure of the surface units.

Possible Techniques: In situ orbital magnetometry and gravimetry, in situ surface mapping, gravimetry, magnetometry, "geophysical investigation," seismic wave detection, sampling and astronomy, remote laser and radar altimetry, laser holography, UV, visual and IR sensing, visual and microwave stereoscopic sensing, tracking (microwave and visual) of natural or artificial satellites, earth-based (visual and microwave) occultation observations of spacecrafts.

Remote Sensing: Not applicable.

Comments:

Mass movement of subcrustal materials (generally thought to be due to thermal convection and/or differentiation processes) cannot be detected directly, but are inferred from secular variation (Jacobs 1959) in the planet's magnetic field and the geometry and distribution of surface (Howell 1959, Runcorn 1962) structures. Thus those phenomena, techniques, etc., found under magnetic fields, gravity fields, geometric shape of planet, surface morphology, and structure of features are all relevant to this attribute, but do not provide direct measurements.

2.4 Atmospheric Composition

2.4 Atmospheric Composition

A. Objective: Gross Atmospheric Abundances

1. Mean molecular weight
2. Elemental and molecular abundances
3. Isotopic abundances and ratios

B. Objective: Atmospheric Particulates

1. Aerosol and crystal composition
2. Particulate size and distribution

OBJECTIVE: Gross Atmospheric Abundances

Observable: Mean Molecular Weight

Definition: The average or mean molecular weight of the planetary atmosphere.

Phenomena: The molecular weights of the atmospheric constituents.

Possible Techniques: Atmospheric in situ sampling and molecular weight determination. Earth-based tracking of occulting satellite EM signal to determine the atmospheric scale heights (from which the average molecular weight can be determined if the temperature distribution is known).

Remote Sensing: Not applicable. The mean molecular weight is not exhibited directly through emission in the electro-magnetic spectrum.

Comments:

Although some information relating to the mean molecular weight can be obtained by remote spectral line analysis of the individual constituents, this is an unsatisfactory approach because many elements (noble gases, etc.) are not readily detectable in this manner.

OBJECTIVE: Gross Atmospheric Abundances

Observable: Elemental and Molecular Abundances

Definition: The percentage abundance of the important atmospheric constituents.

Phenomena: Constituents may be identified by their atomic size and weight, as well as by their absorption and emission spectra.

Possible Techniques: Atmospheric in situ sampling and element detection. Remote sensing of elemental and molecular absorption and emission lines (UV, visible, IR, microwave).

Remote Sensing: Useful

Measurement Philosophy:

Determine the average abundances of the principal constituents as a function of altitude. Vertical profile data required only at widely spaced positions of latitude and longitude. Each profile should include 10-100 data points at different altitudes.

Moon, Mercury } Expected elements are those of large molecular weight (Ar, Kr, etc.) or products of outgassing.

Mars, Venus } All major constituents are of importance, particularly C, N, O, N_2, CO_2, and H_2O.

Jupiter - Lighter elements are of major concern (H, H_2, He), along with molecules of NH_3, CH_4, and H_2O.

Planetary Coverage & Distribution:

Require a sufficient number of vertical profiles to determine any abundance variations over the planetary globe. Complete vertical profiles at 10 to 100 widely spaced positions of latitude and longitude, including several around the equator and one at each pole.

Scale of Observable: Estimated as the height of the exosphere.

Moon, Mercury, Mars, Venus } $\sim$500 km

Jupiter - >1000 km (?), depending on the location of surface.

Gross Atmospheric Abundances - Elemental & Molecular Abundances (Page 2)

Spatial Resolution: Estimated as roughly equivalent to the scale height.

Moon - 20 km
Mercury - 20 km
Mars - 10 km
Venus - 10 km
Jupiter - 15 km

Acquisition Time: Not critical. No rapid temporal variations expected in the average abundances for a given latitude and longitude.

Measurement Repetition Rate: Desire complete planetary coverage repeated about 4 times during the planetary year. This is judged to be critical only for Mars because of its seasonal variations.

Spectral Band & Resolution: Spectral lines corresponding to the absorption wavelengths of the predominant elemental constituents in the planet's atmosphere.

Imaging: Not useful. No adequate orbital imaging technique exists (even conceptually) which provides useful data on altitude dependence of atmospheric abundances. Few vertical profiles are required.

OBJECTIVE: Gross Atmospheric Abundances

Observable: Isotopic Abundances and Ratios

Definition: The percentage abundance ratios of the major isotopes found in the atmosphere such as He^3/He^4, H^1/H^2, C^{12}/C^{13}, O^{16}/O^{18}, Ar^{40}/Ar^{38}.

Phenomena: Isotopes are characterized by the relative molecular weights of the individual constituents, and by their different spectral characteristics.

Possible Techniques: Atmospheric in situ sampling and analysis. Remote sensing of isotopic absorption and emission lines (principal lines of interest lie within the UV through IR regions).

Remote Sensing: Useful

Measurement Philosophy:

Determine the average abundances and ratios of the major isotopes. Desire spatial data at only a few random positions throughout the atmosphere.

Moon
Mercury — Interested in isotopic ratios of Ar^{40}/Ar^{38} and those of other heavy elements, particularly Xe.

Mars
Venus — Principal interest in C^{12}/C^{13}, O^{16}/O^{18}, Cl^{35}/Cl^{37}, Ar^{40}/Ar^{38} (Kuiper 1964).

Jupiter - Isotopes of lighter elements (He^3/He^4, H^1/H^2, C^{12}/C^{13}) will be most abundant (Owen 1963).

Planetary Coverage & Distribution:

Desire average abundances and ratios at about 5 to 10 widely spaced positions of latitude and longitude, so that a global average can be obtained.

Scale of Observable: Vertical profile extending from the surface to the exosphere. ($\sim$500 km)

Spatial Resolution: Approximately 100 km, isotopic ratios should not vary significantly.

Acquisition Time: Not critical, no rapid temporal variations expected.

Measurement Repetition Rate: None, isotopic ratios are essentially constant in time.

Spectral Band & Resolution:

Spectral line resolutions of $\lambda/\Delta\lambda \sim 500$ are desired. Spectral lines corresponding to the absorption wavelengths of the particular isotope under consideration. Line spectra of interest are in a region extending from the far UV ($\sim$500Å) up through the IR. (See Goody (1964) for individual absorption lines).

Imaging: Not applicable. Few data points.

OBJECTIVE: Atmospheric Particulates

Observable: Aerosol and crystal composition

Definition: The chemical composition of the particulates that are suspended in a planet's atmosphere.

Phenomena: The atomic weight, nuclear properties, absorption and emission spectra.

Possible Techniques: In situ atmospheric sampling and chemical analysis.

Remote Sensing: Not applicable. The particulates in an atmosphere do not exhibit unique detectable absorption lines from which their composition could be readily determined by remote sensing.

OBJECTIVE: Atmospheric Particulates

Observable: Particulate Sizes and Distribution

Definition: The dimensions and physical shape of the atmospheric particulates, and their associated spatial distribution.

Phenomena: Particulate size and geometric form. Radiative scattering, absorption, and polarization properties.

Possible Techniques: In situ atmospheric sampling and particulate analysis. Remote polarization data as a function of wavelength (UV, visible, and IR regions) and phase angle. Remote and in situ measurements of EM pulse reflectivity and attenuation as a function of wavelength (microwave). Remote optical and IR laser techniques.

Remote Sensing: Useful

Measurement Philosophy:

Determine the average size and spatial distribution (i.e., number density) of suspended particulates. This information can be deduced from **polarization data and radar backscatter measurements.**

Moon Mercury	Suspended particulates are of extremely low number density if they exist at all
Mars	- Particular emphasis on blue haze.
Venus Jupiter	Entire atmosphere is of interest.

Planetary Coverage & Distribution: Vertical profile data located at 10-100 widely spaced positions of latitude and longitude.

Scale of Observable: The vertical profile over which particulates are found in a planetary atmosphere.

Moon Mercury	Estimated as 100 km, the existence and extent of possible particulates are unknown
Mars Venus	~100 to 200 km, corresponding to the vertical extent from the surface to the uppermost cloud layers (Kellogg and Sagan 1961).
Jupiter -	~500 km, depending on the location of Jupiter's surface (Brandt and Hodge 1964).

Spatial Resolution: Estimated on the basis of thermal lapse rates.

Moon	~2 km
Mercury	~1 km
Mars	~2 km
Venus	~1 km
Jupiter	~2 km

Acquisition Time: Vertical profile data should be obtained within about one planetary day.

Measurement Repetition Rate:

Desire data repeated about 4 times during the planetary year to include seasonal effects (about 10 repetitions per year are reccommended for Mars because of its large seasonal variations).

Spectral Band & Resolution:

Polarimetry data within at least three different bands in the UV, visible, and IR regions (e.g., 2000-3000Å, 5000-6000Å and 1-3μ with $\lambda/\Delta\lambda \sim 500$). Active microwave backscatter data with at least two wavelengths in millimeter range.

Imaging: Not applicable. Few data points, altitude dependence required.

2.5 Atmospheric Structure

2.5 Atmospheric Structure

A. Objective: Atmospheric Thermodynamic State

1. Temperature profile
2. Density profile
3. Pressure profile
4. Vapor content
5. Global thermal balance
6. Thermal anomalies

B. Objective: Cloud Structure

1. Extent of global cloud coverage
2. Cloud layers

C. Objective: Atmospheric Transport Properties

1. Coefficient of viscosity
2. Thermal conductivity
3. Diffusion coefficients
4. Radiation transfer coefficients

OBJECTIVE: Atmospheric Thermodynamic State

Observable: Temperature Profile

Definition: Temperature is a thermodynamic property of the atmospheric gases, whose value and profile is influenced by the global heat balance and the physical properties of the constituents.

Phenomena: The average thermodynamic temperature and its gradients in a planetary atmosphere. Principal temperature gradients occur in the vertical direction.

Possible Techniques: Atmospheric in situ thermal (IR) emission sensing. Remote determination of EM signal transmission characteristics (occultation experiment) to infer temperature scale heights. Remote sensing of thermal emission of atmospheric constituents as a function of wavelength.

Remote Sensing: Useful.

Measurement Philosophy:

Determine the average temperature as a function of altitude. This vertical profile data is desired at widely spaced positions of latitude and longitude. The accuracy of the temperature determination at a particular spatial position should be within 5°K. Global variations in the vertical temperature profile are the greatest between equatorial and polar positions for Mars and Jupiter. For Mercury, Venus, and the Moon, the largest variations are between the subsolar and antisolar points (Koenig et al. 1967, Brandt and Hodge 1964).

Planetary Coverage & Distribution:

Require a sufficient number of vertical temperature profiles to deduce the horizontal temperature variations also. Complete vertical temperature profiles at distance intervals equivalent to approximately 30° of equatorial longitude, and covering the entire planet.

Scale of Observable: Vertical profile of temperature extending from the surface to the exopshere.

Moon
Mercury
Mars
Venus — ~500 km (typical distance from surface at which interplanetary conditions are approached).

Jupiter - ~1000 km (depends on location of surface)

Spatial Resolution:

Vertical element over which the average temperature does not vary more than 10°K for the near surface regions. Beyond the cloud level (or a distance of 100 km for a cloudless planet), a resolution element of 10 km should be sufficient.

Moon	- ~2 km	For near surface regions, dimensions based on $\Delta T \sim 10°K$ and an adiabatic lapse rate.
Mercury	- ~1 km	
Mars	- ~2 km	
Venus	- ~1 km	
Jupiter	- ~2 km	

Acquisition Time: Much less than planetary day.

Measurement Repetition Rate:

Desire vertical profile data at the same global positions repeated about 4 times during the planetary year. This is particularly important for Mars because of its large seasonal variations.

Spectral Band & Resolution:

Continuous emission intensity for select wavelength bands from UV through the microwave region. About 5 bands should be sufficient with one each in the UV, visible (yellow), near IR, far IR, and microwave regions ($\lambda/\Delta\lambda \sim 1000$).

Imaging: Not applicable. Limited number of data points and vertical profiles are required.

OBJECTIVE: Atmospheric Thermodynamic State

Observable: Density Profile

Definition: The average atmospheric density and its spatial variations (principally altitude variations).

Phenomena: Attenuation and refraction of EM signals due to density gradients.

Possible Techniques: In situ atmospheric sampling and density analysis. Earth-based tracking of atmospheric probes to determine the vehicle drag forces (which are directly proportional to the density). Occultation experiments using earth-based receivers to determine index of refraction profile, and hence density (if the composition is known).

Remote Sensing: Not applicable. The vertical density profile cannot be determined directly from remote (orbital) sensing of the EM spectrum.

OBJECTIVE: Atmospheric Thermodynamic State

Observable: Pressure Profile

Definition: The average atmospheric pressure and the associated spatial variations. Principal spatial variations are with altitude.

Phenomena: The force per unit area exerted by the atmospheric constituents, and the variations as a function of altitude. Broadening effects in spectral lines (see Comments).

Possible Techniques: Atmospheric probe for in situ pressure sensing. Inference of pressure from occultation data using earth-based receivers.

Remote Sensing: Not applicable. Atmospheric pressure profile cannot be obtained directly by remote orbital sensing.

Comments:

Theoretically it is possible to determine pressure from spectral line broadening. However, this technique generally gives pressures characteristic of a certain atmospheric level (e.g., cloud top or surface pressure) and, as such, is not suitable for determining vertical profiles by remote spectral analysis.

OBJECTIVE: Atmospheric Thermodynamic State

Observable: Vapor Content

Definition: The average moisture or vapor content of the upper atmosphere, and its spatial variations.

Phenomena: Molecular composition and chemical properties. Absorption and emission spectra.

Possible Techniques: Atmospheric in situ sampling and chemical analysis. Remote sensing of the vapor absorption or emission lines.

Remote Sensing: Useful

Measurement Philosophy:

Determine the average vapor content in a vertical column above the surface as a function of latitude and longitude. Data required only at widely-spaced positions. Only the vapor phases of the most abundant and readily condensable constituents are of importance (such as H_2O and NH_3) because of their influence in atmospheric thermodynamics.

Moon - (?) Minute traces of H_2O vapor may be present.
Mercury - (?) Unknown (metal vapor may be important).

Mars
Venus
Abundance of water vapor is of prime importance, although only small amounts are expected.

Jupiter - Moisture is expected to be due to H_2O and NH_3.

Planetary Coverage & Distribution:

Require data at widely-spaced positions of latitude and longitude (equivalent to approximately 30° of equatorial longitude), and covering the entire planet.

Scale of Observable: Extent of vertical profile equivalent to distance from surface to upper cloud layers (if any).

Moon
Mercury
Mars
Venus
} ~100 km

Jupiter - ~500 km (?)

Atmospheric Thermodynamic State - Vapor Content (Page 2)

Spatial Resolution: Estimated on the basis of thermal lapse rates.

Moon - ~2 km
Mercury - ~1 km
Mars - ~2 km
Venus - ~1 km
Jupiter - ~2 km

Acquisition Time: Much less than one planetary day.

Measurement Repetition Rate:

Global coverage repeated at least 4 times during the planetary year to include seasonal variations. More frequent measurement repetitions (4 -10) are suggested for Mars because of its large seasonal variations.

Spectral Band and Resolution:

Line spectra resolutions of $\lambda/\Delta\lambda \sim 1000$ are desired. Spectral lines corresponding to the absorption bands of the most abundant liquid vapors in the planet's atmosphere (such as the water vapor and ammonia bands located in the visible and IR regions). See for example Goody 1964 for specific lines.

Imaging: Not applicable. Few data points. Vertical profiles required.

Comments:

Vapor abundances determined from line spectra are strongly dependent on the degree of multiple scattering (usually unknown). Hence, remote spectral sensing will not give reliable results without supporting measurements on the atmospheric radiation and scattering properties.

OBJECTIVE: Atmospheric Thermodynamic State

Observable: Global Thermal Balance

Definition: The global balance between the incident solar radiation and the average emission from the planet into interplanetary space. Only the average thermal flux is desired in order to determine whether internal heat sources or conversion to other forms of energy occurs within a planet or its atmosphere.

Phenomena: EM radiation (x-ray through RF).

Possible Techniques: Earth-based detection of radiation coupled with a knowledge of the planetary albedo and the incident solar radiation. Incident and emitted radiation at orbital altitudes.

Remote Sensing: Not applicable. In situ planetary orbit and Earth-based measurements provide the necessary data.

Comments:

Internal details regarding the thermal balance within the atmosphere are considered in other observables (Temperature Profile, Thermal Anomalies, etc.) and hence their contributions to the total planetary balance are not considered here.

OBJECTIVE: Atmospheric Thermodynamic State

Observable: Thermal Anomalies

Definition: Thermal characteristics associated with anomalous regions of large viscous and ohmic dissipation, continuous volcanic outgassing, latent heat release due to phase changes, and related events.

Phenomena: Temperature and heat flux variations.

Possible Techniques: Remote sensing of localized temperature anomalies (IR and microwave regions). In situ atmospheric thermocouple probe.

Remote Sensing: Very useful.

Measurement Philosophy:

Make regional searches for anomalous temperature departures from the global average, and examine these thermal regions at high resolution.

Moon
Mercury - Not applicable, no large-scale anomalous thermal sources expected in the tenuous atmosphere.

Mars - Emphasis on latent heat due to phase changes expected near the polar regions (Sagan 1961).

Venus - Frictional dissipation from large scale dust and sand storms may be important, as well as possible volcanic injection into the atmosphere (Opik 1961, Davidson and Anderson 1967).

Jupiter - Heat release due to phase changes, viscous dissipation within the rapidly rotating cloud belts, and ohmic currents in the lower atmosphere could all be present (Hide 1965).

Planetary Coverage and Distribution:

Moon
Mercury - Not applicable.

Mars
Venus
Jupiter - Planetwide search required, with detailed studies at high resolution performed only over anomalous regions (such as Jupiter's "red spot").

Atmospheric Thermodynamic State - Thermal Anomalies (Cont'd)

Scale of Observable:

Mars Venus Jupiter	- Unknown, scale can range from 10 km up to planet-wide distribution (depends on source of thermal activity).

Spatial Resolution:

Mars Venus Jupiter	- Unknown, rough guess would be 10 km for search, with 1 km resolution for detailed study. Perhaps less stringent requirements for Jupiter.

Acquisition Time:

Mars Venus Jupiter	- Much less than a planetary day.

Measurement Repetition Rate:

Mars Venus Jupiter	- Global coverage completed at least twice during planetary year, with frequent (perhaps daily or hourly) coverage of anomalous thermal regions at higher resolution once they are detected.

Spectral Band and Resolution:

Mars Venus Jupiter	- Three or four select spectral broadbands within the IR through microwave regions free of strong absorption lines (such as those due to H_2O and NH_3). Suggested bands are in the 8-14μ, 18-30μ, 1-2 mm, and 1-3 cm wavelength regions. Broadband resolution of $\lambda/\Delta\lambda \sim 1000$ is desired.

Imaging: Very useful

	Moon	Mercury	Mars	Venus	Jupiter
IR wideband (3-40μ)			C	B	B
Microwave (1 mm-10 cm)			C	B	A
Multispectral (3-40μ, 40-100μ, 1 mm-10 cm, 10-100 cm)			C	A	A

(A = very useful, B = useful, C = not very useful)

Atmospheric Thermodynamic State - Thermal Anomalies (Cont'd)

Comments:

Estimated temperature ranges and desired resolutions are:

	Range	Resolution
Mars	150-300°K	2°K
Venus	200-700°K	5°K
Jupiter	100-300°K	2°K

OBJECTIVE: Cloud Structure

Observable: Extent of Global Cloud Coverage

Definition: The average large-scale cloud coverage over the planetary surface and the variations in this global coverage during the planetary year.

Phenomena: Spectral emittance and reflectance of global cloud features, and the temporal variations of these features. Particulates associated with cloud forms.

Possible Techniques: Remote sensing (UV, visible, and IR) of clouds to determine their existence and spatial extent. In situ atmospheric probe and cloud particulate detector.

Remote Sensing: Very useful

Measurement Philosophy:

Examine the average spatial cloud coverage surrounding the planet and the long-term or seasonal variations of this coverage. The principal objective is to determine only the gross features of the planetary cloud system.

Moon, Mercury - Not applicable, no known clouds.

Mars - Observed clouds are variable in extent and location.

Venus, Jupiter - Clouds are observed to encompass entire planet.

Planetary Coverage & Distribution:

Determine gross cloud features as a function of latitude and longitude over the planetary disk.

Mars - 60-100% global coverage required in order to ensure inclusion of planetary cloud variations.

Venus, Jupiter - 80-100% coverage needed to encompass entire cloud system.

Scale of Observable:

Highly variable, required dimension is the typical scale over which the cloud forms change appreciably.

Mars - 1200 km x 1200 km
Venus - 2000 km x 2000 km
{Estimated scale based on a region encompassing ~20° of latitude.

Jupiter - 18,000 km x 18,000 km (based on ~15° width of cloud belts and zones)

Spatial Resolution:

Resolution should be considerably better than the 100 km linear resolution obtainable with Earth-based telescopes.

Venus Mars Jupiter	10 km x 10 km	Based on attaining a resolution approximately one order-of-magnitude beyond present data.

Acquisition Time: Desire complete global coverage within approximately one planetary day.

Mars - ~24 1/2 hours (period of rotation)

Venus - ~4 earth days, based on the apparent rotation rate of upper level clouds (Boyer and Newell 1967).

Jupiter - ~10 hours (period of rotation).

Measurement Repetition Rate: Data on the average global cloud coverage is desired at repeated intervals during the planetary year.

Mars Venus Jupiter	Global coverage should be repeated at least 10 times during the planetary year. For Mars this value should be at least doubled to adequately encompass the temporal variations during seasonal changes.

Spectral Band & Resolution:

Mars Venus Jupiter	Near UV (2000-4000Å), visible broadband (4000-7500Å) and IR (1-30μ). Multispectral sensing is desirable to delineate between the gross features of different types of cloud cover (resolution: $\lambda/\Delta\lambda \sim 500$).

Imaging: Very useful. The vast number of data elements and their time dependence requires the use of orbital imaging.

	Mars	Venus	Jupiter
UV broadband (2000-4000Å)	C	C	C
Visible broadband (4000-7500Å)	A	A	A
IR broadband (1-2μ)	C	A	A
IR broadband (10-30μ)	C	A	A
Multispectral (4-6 bands between 2000Å and 30μ)	A	A	A

(A = very useful, C = not very useful)

Cloud Structure - Extent of Global Cloud Coverage (Page 3)

Comments:

It should be noted that global cloud coverage could also be accomplished through the establishment of numerous ground-based observation posts. But the nature of the observable (global cloud coverage) clearly indicates that it is most efficiently studied from orbital distances.

OBJECTIVE: Cloud Structure

Observable: Cloud Layers

Definition: The average number and thickness of cloud forms which exist at various altitudes in a planet's atmosphere.

Phenomena: The composition and size of the particulates characterizing a cloud layer. The reflectivity and scattering properties of clouds.

Possible Techniques: In situ atmospheric probe and particulate detector. Occultation experiment data using Earth-based receivers. Remote sensing of radar returns.

Remote Sensing: Useful

Measurement Philosophy:

Determine the average number of cloud layers and their thickness as a function of altitude. Data required only at random positions ($\sim$100) of latitude and longitude.

Moon
Mercury - Not applicable, no known clouds

Mars - Sparse cloud coverage with only a few distinct layers.

Venus - Very dense atmosphere, could be one extensive cloud or many independent layers.

Jupiter - Strong possibility of multiple cloud layers, some of which may be composed of H_2O and NH_3 ice crystals.

Planetary Coverage & Distribution:

Desire vertical profiles giving the average number and thickness of cloud layers at random positions of latitude and longitude ($\sim$100 profiles), and covering the entire global surface.

Mars - Particular emphasis on polar regions.

Venus - All global positions of approximately equal importance.

Jupiter - Latitude variations of cloud layer and thickness variations below the various belt features are of special interest.

Scale of Observable:

Estimated scales are based on the vertical extent over which cloud layering could exist, which is the distance from the surface to the upper most clouds.

Mars } Venus } 100 to 200 km
Jupiter - 500 km, dependent on the location of surface.

Spatial Resolution:

Mars } Venus } Jupiter } 1 km, estimated from Earth experience on the basis of a characteristic dimension for cloud thickness (Tverskoi 1965).

Acquisition Time: Much less than a planetary day.

Measurement Repetition Rate:

Global coverage repeated at least 10 times during the planetary year to assess seasonal variations. Special emphasis is desired for the aphelion position, particularly for Mars, when the observed clouds are most prevalent (Sharonov 1964).

Spectral Band & Resolution:

Active multifrequency microwave bands (such as the K, X, C, S, and L bands of radar at 1, 3, 5, 10 and 20 cm) to discriminate between the attenuation and reflection due to various types of clouds at different altitudes. Shorter wavelengths (1 and 3 cm) only are useful for Mars.

Imaging: No applicable. Few data points

Comments:

Active radar techniques have a major disadvantage in that, for a completely cloud covered planet with a dense cloud layer at a certain elevation, the radar altitude signal may be reflected at all wavelengths from one of the upper cloud levels. This would prevent detection of lower altitude cloud layers which would have to be detected by some other means, such as an atmospheric probe.

OBJECTIVE: Atmospheric Transport Properties

Observable: Coefficient of Viscosity

Definition: The coefficient of viscosity is a measure of the internal friction of a fluid element.

Phenomena: Phenomenological coefficient which is usually determined experimentally from the ratio of the shear stress to the velocity gradient of a fluid in motion (Prandtl 1952).

Possible Techniques: In situ atmospheric measurements of shear stress and accompanying velocity gradients. Determination of atmospheric temperature and composition (on which the coefficient of viscosity is dependent) and deduction of the viscosity from laboratory comparisons.

Remote Sensing: Not applicable. Direct determination of viscosity requires a sample of the gas.

Comments: Although viscosity information can be estimated from temperature profiles, composition, and atmospheric motion observations, these observables are treated in detail elsewhere.

OBJECTIVE: Atmospheric Transport Properties

Observable: Thermal Conductivity

Definition: The thermal conductivity is a property of the atmospheric fluid which measures the energy exchange capabilities of the gas constituents.

Phenomena: Physical properties of the gas which is determined from the ratio of the heat flux to the spatial temperature gradient.

Possible Techniques: In situ atmospheric measurements of the molecular activity to determine the heat flux and temperature gradients. Determination of atmospheric composition and temperature, and deduction of the thermal conductivity from laboratory comparisons.

Remote Sensing: Not applicable. Samples of the fluid are required for in situ determination.

Comments:

Although the ordinary molecular thermal conductivity can be determined from laboratory comparisons, once the thermal state and composition of the atmosphere is known, the "effective" thermal conductivity needed for many engineering calculations has a component due to atmospheric turbulence. This influence of turbulence is difficult to assess and requires in situ atmospheric experiments. Information relative to the thermal conductivity can be inferred from temperature profiles and global thermal balance.

OBJECTIVE: Atmospheric Transport Properties

Observable: Diffusion Coefficients

Definition: Diffusion coefficients for the various molecular and charged particles are a measure of the ability of the atmospheric constituents to migrate from one spatial region to another when a density gradient exists (see, for example, Chapman and Cowling (1960)).

Phenomena: A transport coefficient which is a property of the individual atmospheric species, and is determined from the ratio of the molecular current density to the number density gradient of a particular constituent.

Possible Techniques: In situ atmospheric measurements of the individual particle migration rates and density gradients. Inference of diffusion coefficients from laboratory results when the thermodynamic state and atmospheric composition are known.

Remote Sensing: Not applicable. The coefficients cannot be directly determined by remote means.

Comments: Some information relative to diffusion coefficients can be deduced indirectly from atmospheric compositional variations, density profiles, and velocity measurements.

OBJECTIVE: Atmospheric Transport Properties

Observable: Radiation Transfer Coefficients

Definition: The value and spatial variations of the atmospheric reflectance, absorptance, and transmittance coefficients.

Phenomena: The amount of radiant energy absorbed, emitted, and reflected by an element of fluid (see, for example, Goody (1964)).

Possible Techniques: In situ atmospheric probe to analyze the variations with depth of the radiation transfer coefficients. Inference of the radiation properties from laboratory results or theory when the atmospheric composition and thermodynamic state are known.

Remote Sensing: Not applicable. Remote measurements will not give the individual coefficients within each layer of the atmosphere.

Comments:

The information related to the average radiation properties in the upper atmosphere could be obtained by remote sensing, but these results would relate to the combined influence of conduction, convection, and turbulence.

2.6 Active Atmospheric Processes

2.6 Active Atmospheric Processes

A. Objective: Atmospheric Circulation & Motion

1. Global wind velocities
2. Convective cells and turbulence
3. Cloud formation and associated motion

B. Objective: Weather

1. Precipitation type and nature
2. Precipitation rate and variations
3. Thunderstorms
4. Cyclone formations
5. Atmosphere-surface interactions

C. Objective: Atmospheric Energy Transfer Processes

1. Solar radiation
2. Airglow
3. α-particles, protons, and electrons
4. Cosmic rays
5. Meteoroids
6. Ionization and recombination rates
7. Surface to atmosphere transfer

OBJECTIVE: Atmospheric Circulation and Motion

Observable: Global Wind Velocities

Definition: The atmospheric motions associated with the large scale global circulation pattern.

Phenomena: The magnitude and direction of the large scale wind patterns (i.e., velocity vector) in a planetary atmosphere.

Possible Techniques: Atmospheric in situ velocity measurements with a probe. Tracking data from buoyant tracers which move with the fluid elements. Remote sensing and analysis of the Doppler shift in the line spectrum of the moving atmospheric constituents.

Remote Sensing: Useful

Measurement Philosophy:

Determine the average velocity vector, and hence circulation patterns, of the large scale motions as representative spatial positions throughout the atmosphere.

Moon
Mercury - Not applicable, since no appreciable mass motions are expected due to the lack of any significant atmosphere.

Mars - General circulation pattern is between equatorial and polar positions (Mintz 1961).

Venus - Major circulation regime is expected to extend from the subsolar and antisolar points (Mintz 1962).

Jupiter - Circulation at the upper cloud levels is principally parallel to the equator, with possible equator to pole motions at lower altitudes (Hide 1966).

Planetary Coverage and Distribution:

Require velocity measurements at a sufficient number of positions (throughout the entire planetary atmosphere) to establish the global circulation pattern.

Mars
Venus
Jupiter - Require vertical profiles of the velocity vector that are spaced at intervals of approximately each 5 to 10° of latitude and longitude, in order to detect possible "wave" type regimes and "jet streams" such as exist in the Earth's atmosphere (Tverskoi 1965).

Scale of Observables:

The minimum significant, large scale, atmospheric dimension (which corresponds to vertical profiles). Beyond the uppermost cloud levels the mass flow rate is probably negligible in comparison to the lower level activity.

Mars, Venus - 100 to 200 km, corresponding to velocity vector profiles extending from the surface to beyond the uppermost cloud levels.

Jupiter - 500 km, dependant on the extent of the significant atmosphere.

Spatial Resolution:

Estimated on the basis of the characteristic dimension (vertical) over which the velocities can change by an order of magnitude. $\sim$1 to 10 km, based on Earth experience since nothing is known about vertical velocity gradients within the atmospheres of other planets.

Acquisition Time:

A time of the order of L/V, where L = minimum resolution dimension and V = fluid velocity (thus for L = 1 km and V = 10 m/sec, the acquisition time $\simeq$ 100 sec).

Measurement Repetition Rate:

Large scale wind and circulation patterns will change slowly with time, with temporal variations principally of a cyclic nature.

Mars - Complete global coverage at least once during each of the 4 seasons.

Venus, Jupiter - Global coverage repeated at least twice during planetary year to evaluate long term variations.

Spectral Band and Resolution:

Depends on the tracer element of buoy signal. For the case of CO_2 lines (Venus and Mars) and CH_4 lines (Jupiter) located in the IR region, a resolution of $\Delta\lambda \sim 3 \times 10^{-4}$ Å is required to detect velocity differences of 5 m/sec.

Atmospheric Circulation and Motion - Global Wind Velocities (Page 3)

Imaging:

Not applicable. Few data points, required spectral resolution very difficult for even futuristic imagers to achieve.

OBJECTIVE: Atmospheric Circulation and Motion

Observable: Convective Cells and Turbulence

Definition: Convective cells consist of adjacent vertical columns of warm and cool fluid alternately ascending and descending, along with the associated large scale turbulence that occurs with thermal instability of a stratified fluid (Chandrasekhar 1961).

Phenomena: Temperature variations between adjacent columns. Velocities associated with rising and falling fluid elements. The number and extent of cellular regions.

Possible Techniques: Remote multispectral (visible, IR, microwave) sensing. Spectrometry to determine motions from the Doppler shift of individual spectral lines. In situ atmospheric probe to determine convective cell motions and temperatures.

Remote Sensing: Useful

Measurement Philosophy:

Make regional searches for convective cells and examine in detail the associated motions and temperature variations only within representative regions.

Moon, Mercury - Probably not applicable due to the lack of any significant atmosphere.

Mars - Mass transfer in cells likely to be small due to tenuous atmosphere.

Venus - High surface temperatures increase the probability for convective activity.

Jupiter - High rotation rate may obscure lower level activity.

Planetary Coverage and Distribution:

Planet-wide search required, with emphasis on regions noted. Detailed studies at high resolution over ~20 percent atmosphere is estimated as sufficient to determine the representative structure.

Mars - Emphasis on equatorial and polar regions.

Venus - Subsolar and antisolar positions are of greatest interest.

Jupiter - Emphasis on anomalous areas (e.g., red spot) and latitude variations through the belt markings.

Atmospheric Circulation and Motion - Convective Cells and Turbulence (Page 2)

Scale of Observable:

Unknown, dimensions of convective cells vary with the degree of thermal instability between atmospheric layers (probable scale could vary from a few kilometers up to several hundred kilometers).

Spatial Resolution:

$\sim$10 km x 10 km for search mode, with $\sim$1 km x 1 km desirable for detailed structure within the cells (estimates based on equivalent resolutions used for study of Earth cloud formations).

Acquisition Time:

Within a time less than any appreciable seasonal variations. Not critical, since the general vertical transport modes and cellular activity would tend to be consistent (or continuously repetitive) within a certain region (e.g., the subsolar point on Venus). Temporal variations on Jupiter might exhibit considerable departures from regularity, but the details are unknown (Focus 1963).

Measurement Repetition Rate:

Mars - Complete coverage during each of the four seasons.

Venus - Global coverage twice during the planetary year is estimated as sufficient.

Jupiter - Same as Venus, unless anomalous temporal variations are detected.

Spectral Band and Resolution:

Broadband with resolution of $\lambda/\Delta\lambda \sim 1000$. Visible red (6500 to 7500 Å). Thermal IR windows which are free of CO_2 lines on Mars and Venus (e.g., 6-14μ and 18-30μ), and free of NH_3 lines on Jupiter (such as 18-30μ). Microwave results (1-3 cm) are also desired for Venus and Jupiter to determine the vertical extent of the convective activity (since the μ-wave emission is capable of penetrating upward from the lower altitudes).

Atmospheric Circulation and Motion - Convective Cells and Turbulence (Page 3)

<u>Imaging</u>: Useful

	Mars	Venus	Jupiter
Visible broadband (6500-7500 Å)	B	A	A
IR broadband (6-14μ)	B	A	
IR broadband (18-30μ)	B	A	A
Passive microwave (1-3 cm)		A	A
Passive microwave (3-10 cm)		A	A

(A = very useful, B = useful)

<u>Comments</u>:

Convective activity within the lower atmospheric layers may be difficult to interpret from remote sensing data if the vertical extent of the cells does not penetrate upward to the higher cloud levels. In this case, atmospheric probes are desirable for supporting measurements. An alternate approach to the broadband sensing discussed above is to sense the emission at several wavelengths within a particular absorption band, from which temperature differences ΔT can theoretically be deduced. This technique requires a knowledge of the atmospheric emission and absorption properties as a function of wavelength (Astheimer 1965) and, hence, is not readily applicable to atmospheres other than the Earth's.

OBJECTIVE: Atmospheric Circulation and Motions

Observable: Cloud Formation and Associated Motion

Definition: Active processes involving condensation and evaporation cycles (and large scale dust cloud formations) in the atmosphere of a planet.

Phenomena: Spectral characteristics (UV, visible, IR, and microwave) associated with the formation and motion of particulates in a cloud system.

Possible Techniques: Remote multispectral broadband (UV, visible, and IR) sensing. In situ atmospheric radiation and particulate detection. Remote spectrometric "Doppler shift" velocity measurements.

Remote Sensing: Very useful.

Measurement Philosophy:

Examine in detail the temporal variations associated with cloud formation and observe the inherent motions associated with the formation process. This data is desired only for representative cloud samples at random positions throughout the atmosphere.

Moon - Not applicable, no known clouds.

Mercury - Not applicable, no known clouds.

Mars - Various cloud forms (white, blue, and yellow) require individual examination (Michaux 1967b).

Venus - Complete cloud coverage of which very little is known.

Jupiter - Complete cloud coverage involving rapid dynamic motions.

Planetary Coverage and Distribution:

Require information on cloud formations selected at random positions over the planet, coverage of 10 to 20 percent is estimated as sufficient to cover representative samples of known planetary clouds.

Mars - Random distribution with particular emphasis on equatorial zones and polar caps.

Venus - Random distribution with emphasis on subsolar, antisolar and polar regions.

Jupiter - Emphasis on regions of red spot, tropical disturbances, and latitude variations of cloud formations.

Scale of Observable:

The exact scale desired will vary appreciably depending on the type of cloud formation and the planet under consideration. Estimated scale size is based on an area covering ~10° of latitude and longitude as being more than sufficient for most presently known planetary cloud formations.

Mars - ~600 km x 600 km

Venus - ~1000 km x 1000 km

Jupiter - ~12,000 km x 12,000 km

Spatial Resolution

Require about 1 km linear resolution for study of individual cloud details (Bird et al. 1964). At Jupiter about 10 km is adequate.

Acquisition Time:

Acquisition time for obtaining data must be much less than the characteristic time required for a cloud to significantly alter its features or location. This is difficult to assess precisely due to extreme variations of cloud types and our ignorance of other planets. The dynamical activity on Jupiter indicates that a shorter acquisition time is necessary than for the terrestrial planets (Hide 1962).

Mars - 1-10 min.

Venus - 1-10 min.

Jupiter - 10 sec (?)

Measurement Repetition Rate:

Can vary appreciably, depending on the type of cloud formation under observation. In general it is estimated that a factor of 10 times the acquisition time should be an adequate interval for most cases. Repeated coverage at designated intervals is required for the duration of the formation process. For Mars, cloud observations should be repeated at least once during each season with special emphasis at perihelion.

Spectral Band and Resolution:

Broadband data required, with relatively low spectral resolution ($\lambda/\Delta\lambda \sim 500$). Multispectral data particularly useful, since different cloud forms reflect radiation most strongly in particular spectral regions.

Imaging: Very useful

	Mars	Venus	Jupiter
UV broadband (2000-4000 Å)	B	B	C
Visible broadband (4000-7500 Å)	A	A	A
IR broadband (1-2μ)	C	A	A
IR broadband (10-30μ)	C	A	A
Multispectral (4-6 bands from 2000 Å to 30μ)	A	A	A

(A = very useful, B = useful, C = not very useful)

Comments:

Multispectral imaging is desired in at least the four bands indicated. The UV results are particularly important for Venus where present data indicates anomalous motions for clouds observed in this band. In addition, IR and UV data would be useful for interpretation of cloud formation levels, temperatures, and the physical processes which are active.

OBJECTIVE: Weather

Observable: Precipitation Type and Nature

Definition: The average composition and phase (e.g., liquid, ice, snow-flake, dust, etc.) of precipitation particulates.

Phenomena: Chemical composition of precipitable particulates. Latent heat associated with phase changes. Chemical phase or state of precipitable materials.

Possible Techniques: In situ atmospheric probe and chemical analysis. Planetary surface-based analysis of precipitated materials.

Remote Sensing: Not applicable. The composition of non-gaseous precipitates and their chemical phases cannot be readily determined by remote sensing.

Comments:

The size and motion of precipitation particulates can be determined remotely, but these aspects are covered separately under other observables (see "Precipitation Rate and Distribution").

OBJECTIVE: Weather

Observable: Precipitation Rate and Variations

Definition: The spatial and temporal varitions in the atmospheric precipitation rate.

Phenomena: The mass, size, and motions associated with precipitating particulates. Radiative emission and scattering properties.

Possible Techniques: In situ atmospheric sampling, particulate analysis, and mass flow meters. Radar attenuation and backscatter.

Remote Sensing: Useful

Measurement Philosophy: Determine the average regional precipitation cycles as a function of latitude, longitude, and time.

Moon, Mercury - Not applicable, no known precipitation

Mars, Venus, Jupiter } Observed cloud systems indicate a reasonable probability for precipitation

Planetary Coverage & Distribution:

Mars - Major variations should be with latitude. Polar regions and areas associated with the wave of darkening are of major interest.

Venus - Longitude and latitude variations are both important. Special emphasis on poles, equatorial zones, and mountainous regions.

Jupiter - Precipitation rates are expected to vary principally with latitude.

Scale of Observable:

Estimated on basis of characteristic cloud formation dimensions (see "Cloud Formation and Associated Motion").

Mars - ~600 km x 600 km
Venus - ~1000 km x 1000 km
Jupiter - ~12,000 km x 12,000 km

Spatial Resolution:

$\sim$10 km x 10 km, estimated on basis of Earth experience as being sufficient resolution to determine the average spatial variations in precipitation (Fleagle and Businger 1963).

Acquisition Time:

$\sim$1 minute to 1 hour. Estimated times based on Earth experience, and it should be noted that conditions on Jupiter could yield significant deviations from these values.

Measurement Repetition Rate:

Unknown due to lack of knowledge of the detailed physical processes occurring. For initial survey attempts, data for a particular precipitation region should be repeated at intervals of about 10 times the acquisition time to determine the average temporal extent of processes. In addition, complete global coverage to locate major precipitation regions should be repeated at least 4 times during the planetary year.

Spectral Band & Resolution:

Radar data at about three wavelengths in the region of 1 to 10 cm (Battan 1959).

Imaging: Useful

	Mars	Venus	Jupiter
Multifrequency radar (3 wavelengths, 1-10 cm)	C	B	C

(B = useful, C = not very useful)

Comments:

For wavelengths greater than 3 to 5 cm, the nonthermal, background radiation (decimetric) on Jupiter may interfere with radar results. On the other hand, the intensity of this emission is relatively uniform (in contrast to the decametric bursts for $\lambda > \sim 1$ m) and future technology should be capable of overcoming this obstacle.

OBJECTIVE: Weather

Observable: Thunderstorms

Definition: The number and extent of atmospheric regions with large energy dissipation rates through lightning discharges and the associated sound waves (or thunder).

Phenomena: High intensity electromagnetic discharges in localized areas. Regions of violent cloud activity. Intense sound waves. Localized charged particles and electric field gradients. "Whistlers" resulting from the propagation of sferics along a planet's magnetic line of force.

Possible Techniques: Remote sensing of sferic activity. In situ atmospheric charged particle and E-field gradient detector. In situ sound detector for thunder.

Remote Sensing: Very useful.

Measurement Philosophy:

Determine the average regional sferic activity in a planet's atmosphere and evaluate the extent and violence of thunderstorms.

Moon, Mercury - Not applicable, no appreciable atmosphere.

Mars - Sferic activity is probably small due to tenuous atmosphere.

Venus - Possible violent activity may be due to extensive dust or sand friction in addition to the usual processes (Opik 1961).

Jupiter - Very extensive and violent sferic activity is anticipated.

Planetary Coverage & Distribution:

Mars - ~50% planetary coverage to encompass white and yellow cloud regions.

Venus, Jupiter - Complete global surveys required to select regions of high storm activity, with detailed sferic sensing performed within representative regions (~50-80% coverage.)

Scale of Observable: 10 km to 20 km, based on characteristic length of Earth lightning strokes (Battan 1959).

Weather - Thunderstorms (Page 2)

Spatial Resolution: ~1 km resolution is desirable to resolve the localized sources of sferic activity in a thunderstorm cloud.

Acquisition Time: ~10 to 30μ sec., based on the typical duration of lightning pulses from Earth experience (Horner 1964).

Measurement Repetition Rate:

Essentially continuous coverage of a thunderstorm region for the duration of the activity. Complete global coverage should be repeated about 10 times during the year to evaluate variations in yearly activity.

Spectral Band and Resolution:

Mars
Venus — Passive RF sensing within the wavelength region of 1-100 m (see Comments).

Jupiter - Passive RF at wavelengths of 1-10 m (larger wavelengths desired, but decameter bursts will interfere).

Imaging: Useful

	Mars	Venus	Jupiter
Passive RF (10-100 m)	B	B	
Passive RF (1-10 m)			B

(B = useful)

Comments:

In the ideal case, sferic detection should be carried out at wavelengths of several kilometers where the peak discharge energy occurs (Horner 1964). For the Earth's ionosphere the upper wavelength cut-off is about 20 m, which limits the wavelengths available for use from orbit. For Mars and Venus, with their less extensive ionospheres, wavelengths up to about 100 m can probably be used; while for Jupiter a much lower cut-off at 10 is anticipated. On the other hand, either active or passive microwave could be used, but this would provide data only at the lower end of the sferic energy spectrum (this also applies to the visible and IR regions).

OBJECTIVE: Weather

Observable: Cyclone Formations

Definition: The number, size, distribution, and characteristics of cyclone formations occurring in a planet's atmosphere, thus indicating the intensity of the weather.

Phenomena: Appearance of cyclone clouds. Velocity and pressure gradients within limited regions.

Possible Techniques: Remote visual and IR sensing of cloud patterns. In situ atmospheric velocity and pressure sensors.

Remote Sensing: Very useful.

Measurement Philosophy:

Determine the average number and extent of cyclones as a function of location and time, and study representative samples in detail.

Moon
Mercury - Not applicable, no or little atmosphere.

Mars - Activity may be limited to "sand devils" and related phenomena of minor intensity.

Venus - No available estimates of cyclonic activity.

Jupiter - Observations of transient cloud features indicate extensive cyclone-like processes (Focus 1963).

Planetary Coverage & Distribution:

Desire global coverage for cyclone number and size distribution, with high resolution data (over about 10 or 20% of the total) to determine the characteristic features.

Mars - White and yellow clouds are of primary interest.

Venus - All regions are of importance, with emphasis on subsolar and antisolar positions.

Jupiter - Emphasis on transition regions between cloud belts, "red spot" area, and tropical disturbances.

Scale of Observable:

10 x 10 km for determining spatial distribution, with 1 km x 1 km resolution for detailed studies (for the smaller "tornado" type activity 100 m x 100 m resolution is required; e.g. Battan (1959)).

Acquisition Time:

~10 min. to 1 hr, on the basis of the characteristic time for Earth cyclones to move (or rotate) a distance equal to their diameter. Times of 1 minute or less may apply for Jupiter.

Measurement Repetition Rate:

Complete global coverage at low resolution should be repeated at least 4 times during the planetary year. High resolution data on characteristic cyclone forms should be obtained at intervals of about 10 times the acquisition time.

Spectral Band and Resolution:

Resolution of $\lambda/\Delta\lambda \sim 500$ desired. Visible broadband (4000-7500 Å) and IR (1-30μ) for determining the number and extent of cyclones. Multispectral results are desirable for detailed high resolution studies of representative cyclones.

Imaging: Very useful

	Mars	Venus	Jupiter
Visible broadband (4000-7500 Å)	A	A	A
IR broadband (1-2μ)	C	A	A
IR broadband (10-30μ)	C	A	A
Multispectral (4-6 bands, 2000 Å-30μ)	A	A	A

(A = very useful, C = not very useful)

Comments:

The measurement specifications above pertain principally to the typical large-scale cyclones that are expected to predominate. For the less frequent (but more violent) hurricane and tornado types of activity, shorter spatial resolutions and acquisition times are desirable. Useful supporting measurements should include radar data to aid in interpretation of the cyclonic activity.

OBJECTIVE: Weather

Observable: Atmosphere-Surface Interactions

Definition: The amount, extent, and type of dynamic activity which is presently occurring through chemical and physical interactions within the near-surface boundary layer regions.

Phenomena: Mass exchange of material through winds and precipitation cycles. Enhancement of chemical activity and weathering through mixing in the boundary region. Chemical activity in the lower atmosphere associated with crustal outgassing, volcanic activity, and precipitating particulates.

Possible Techniques: In situ surface and atmospheric probes to determine mass transfer and chemical activity.

Remote Sensing: Not applicable. Remote sensing cannot provide detailed data on the active physical and chemical processes within the lower boundary layer regions.

Comments:

Remote sensing can provide meager information involving the near-surface atmospheric activity, such as visual sensing of surface conditions prior to and following atmospheric storms. This information is adequately accounted for in "Surface Appearance," "Surface Winds," "Surface to Atmosphere Transfer," and related observables.

OBJECTIVE: Atmospheric Energy Transfer Processes

Observable: Solar Radiation

Definition: The average intensity of solar γ-ray, x-ray, UV, visible, IR, and RF radiation incident on the planet from the sun.

Phenomena: The flux of solar energy into a planetary atmosphere. Reflected solar radiation and planetary albedo.

Possible Techniques: Earth-based radiation detector coupled with the knowledge that the intensity varies inversely as the distance squared from the source. In situ sensing of the solar radiation at orbital positions.

Remote Sensing: Not applicable. Earth-based techniques provide adequate data on the solar radiation flux.

Comments:

Orbital in situ sensing of the incident solar energy flux may be required for Jupiter if energy absorption in the asteroid belt is significant (in which case, the spectrum of radiation at Jupiter could differ from inverse square law predictions). The radiation intensity at different wavelengths within a planet's atmosphere will vary appreciably from solar values in the exosphere, but this aspect of the energy balance is treated by other observables.

OBJECTIVE: Atmospheric Energy Transfer Processes

Observable: Airglow

Definition: Large scale luminescence due to photon-emitting chemical reactions and recombination.

Phenomena: Discrete emission spectra of excited species. Particle excitation energies and reaction rates.

Possible Techniques: In situ atmospheric probes to analyze excitation and emission processes. Remote sensing (UV throgh IR) emission lines and bands.

Remote Sensing: Useful.

Measurement Philosophy: Determine extent and other characteristics of airglow by sensing emission spectra at about 100 widely spaced locations.

Moon
Mercury - Not applicable, insufficient atmosphere.

Mars
Venus - Extent of airglow regions is unknown.

Jupiter - Probably extensive airglow. Lyman-α radiation of hydrogen is probably principal contributor.

Planetary Coverage & Distribution:

Based on Earth experience, airglow data should be obtained at positions approximately 10-20° apart in latitude and longitude over entire planet.

Scale of Observable:

Unknown, estimates from Earth experience are 100 km in thickness covering much of the planet (Tverskoi 1965).

Spatial Resolution: About 10 km in thickness, based on Earth experience.

Acquisition Time: About an hour or more, but data should be collected in darkness to eliminate interference from reflected solar radiation.

Measurement Repetition Rate: About four times per planetary year to assess seasonal effects.

Spectral Band & Resolution: Spectral bands corresponding to emission wavelengths (4000Å-2μ) of predominant excited components.

Imaging: Not applicable. Few data points and phenomenon not rapidly-varying with time.

OBJECTIVE: Atmospheric Energy Transfer Processes

Observable: α-Particles, Protons, and Electrons

Definition: The average flux of solar α-particles, protons, and electrons incident upon the planet.

Phenomena: The mass, charge, and energy distribution of solar particles entering the upper atmosphere.

Possible Techniques: In situ particle detectors to determine the mass, charge, and energy flux at orbital positions. Inference of solar particles and fluxes by extrapolation of Earth-based measurements to other planets.

Remote Sensing: Not applicable. Earth-based techniques and in situ planetary orbit detectors provide sufficient data.

<u>OBJECTIVE</u>: Atmospheric Energy Transfer Processes

<u>Observable</u>: Cosmic Rays

<u>Definition</u>: The incident flux and distribution of both primary cosmic rays (of galactic and solar origin) and secondary cosmic rays (produced in the lower atmosphere).

<u>Phenomena</u>: The energies (10^8 to 10^{19}ev; Brandt and Hodge (1964)) and composition of the primary cosmic rays (mainly protons and α-particles). The spatial distribution, energy, and particle components of the secondary cosmic rays (mainly neutrons and μ-mesons).

<u>Possible Techniques</u>: In situ atmospheric high-energy particle detectors to analyze the types of particles and their energy spectrum.

<u>Remote Sensing</u>: Not applicable. In situ probe and detectors are required.

OBJECTIVE: Atmospheric Energy Transfer Processes

Observable: Meteoroids

Definition: The average flux of meteoroids that are incident on a planet.

Phenomena: The size, weight, and velocity of material objects entering an atmosphere from interplanetary space. The visible and IR emission spectra resulting from entry into a dense atmosphere. Reflection patterns from the ionized trail.

Possible Techniques: In situ atmospheric and orbital particle detectors. Remote sensing of the visible and IR emission during entry. Remote sensing of active radio wave pulse returns from meteor trails.

Remote Sensing: Useful.

Measurement Philosophy: Determine the average number and size of meteoroids entering a planetary atmosphere.

Moon Mercury	Probably not detectable from ionized trails due to lack of an appreciable atmosphere.
Mars Venus Jupiter	Detectable from emission resulting from burnup during atmospheric entry.

Planetary Coverage & Distribution:

Require complete coverage of the planet since both diurnal and seasonal variations in the meteorid flux occur.

Scale of Observable: 10-1000 km, based on length of ionized meteor trail in the planet's atmosphere (Brandt and Hodge 1964).

Spatial Resolution:

1μ to 100 m (for particle detectors), depending on the actual size or diameter of a particular meteoroid. 100 m to 1 km (for trail detection) on the basis of typical meteor trail diameters.

Acquisition Time:

$\sim$1 second (or less) up to a few minutes, depending on the velocity and trajectory of meteoroid prior to burnup or impact.

Measurement Repetition Rate: Global coverage repeated continuously to observe the variability of meteor showers.

Spectral Band & Resolution:

Not applicable due to expected lack of emission spectra.

Imaging: Not applicable.

OBJECTIVE: Atmospheric Energy Transfer Processes

Observable: Ionization and Recombination Rates

Definition: The reaction rates for ionization, dissociation, and recombination of the various atmospheric constituents.

Phenomena: Collision cross sections for the various processes. Particle energies and excitation levels. Excitation and relaxation times.

Possible Techniques: In situ atmospheric detectors and reaction rate analyzers. Inference of excitation process rates from laboratory experience when the atmospheric particle distribution, composition, and thermodynamic state are known.

Remote Sensing: Not applicable. Detailed chemistry of the various excitation and recombination processes cannot be accurately determined by remote orbital sensors.

Comments:

A certain amount of gross information on energy transfer rates between excited particles can be deduced by remote sensing of the emission products in certain phenomena (e.g., airglow and aurora). These particular aspects of an atmosphere are treated as separate observables.

OBJECTIVE: Atmospheric Energy Transfer Processes

Observable: Surface to Atmosphere Transfer

Definition: Energy and mass addition into the atmosphere from specific surface phenomena such as volcanoes or extensive regions of outgassing. Only large scale phenomena that could significantly influence the atmosphere are of interest.

Phenomena: Mass injection rate. Particulate forms such as volcanic dust and vapors. Visual and thermal spectra associated with the surface to atmosphere transport.

Possible Techniques: In situ atmospheric and surface probes to analyze the mass injection mode and associated particulates. Remote sensing of the activity in visual, IR, and microwave spectral bands.

Remote Sensing: Useful.

Measurement Philosophy:

Determine the average number and injection rate of anomalous sources that influence the atmosphere from below. Search mode required to detect the localized phenomena.

Moon Mercury Mars	Visual search is sufficient for detection.
Venus Jupiter	Only IR and μ-wave data are applicable for remote sensing, since clouds will probably obscure the near-surface activity

Planetary Coverage & Distribution:

100% coverage required since specific location of anomolous regions is unknown.

Scale of Observable:

Moon Mercury Mars	Estimated as ~10-100 km, since larger-scale eruptive systems would have probably been detected from Earth.
Venus Jupiter	Unknown, thermal influence of injected material could vary from 10 to several hundred kilometers or more (Davidson and Anderson 1967).

Spatial Resolution:

~1 to 100 km, highly variable (depends on the amount of source material and its resulting signature in the atmosphere).

Acquisition Time:

Moon, Mercury, Mars } ~1 minute, since material will fall back to the surface rapidly in a tenuous atmosphere.

Venus - 1 minute to several hours due to dense atmosphere.

Jupiter - Unknown

Measurement Repetition Rate: Continuous coverage required since variability of sources is unknown.

Spectral Band & Resolution: Broadband resolution of $\lambda/\Delta\lambda$ ~500 is sufficient.

Moon, Mercury, Mars } Visible band (4000-7500Å) with IR on Mars.

Venus - Thermal IR (18-30μ) band (corresponds to region uninfluenced by CO_2 absorption lines). Passive μ-wave (10-50 cm).

Jupiter - Thermal IR (14-30μ) band (corresponds to window not affected by NH_3 absorption). Passive μ-wave (1-70 cm).

Imaging: Useful

	Moon	Mercury	Mars	Venus	Jupiter
Visible broadband (4000-7500Å)	A	A	A		
IR broadband (14-30μ)			C	B	B
Passive microwave (1-100 cm)				B	C

(A = very useful, B = useful, C = not very useful)

Comments:

IR sensing on the Moon and Mercury might be a valuable supporting measurement to help understand the details of the phenomena, and to determine whether or not visual data (dust, whirl-winds, etc.) are actually associated with surface eruptions. The measurements on Venus and Jupiter should be supplemented by probes or other supporting data, since thermal anomalies in the atmosphere are not conclusive evidence for volcanic or other injective types of activity.

2.7 Fields

2.7 Fields

A. Objective: Gravitational Field

1. Field vector
2. Temporal and secular variations
3. Gravitational waves

B. Objective: Magnetic Field

1. Field vector
2. Temporal and secular variations
3. Radiation belts
4. Auroras
5. Paleomagnetism
6. Radio bursts

C. Objective: Electric Field

1. Field vector
2. Temporal and secular variations
3. Ionosphere ring currents
4. Telluric currents

OBJECTIVE: Gravitational Field

Observable: Field Vector

Definition: Magnitude and direction of the acceleration due to gravity at a point

Phenomena: Acceleration due to gravity.

Possible Techniques: In situ surface and orbital gravimetry, Earth-based tracking (microwave and visual) of satellites.

Remote Sensing: Not applicable, technique independent of direct planetary sensing.

OBJECTIVE: Gravitational Field

Observable: Temporal and Secular Variations

Definition: Periodic and non-periodic changes in the value of gravity at a point (see Comments).

Phenomena: Acceleration due to gravity.

Possible Techniques: In situ surface and orbital gravimetry, Earth-based tracking (microwave and visual) of satellites.

Remote Sensing: Not applicable.

Comments:

Temporal variations are due mainly to tidal effects, while secular variations are due to tectonic surface modification processes and internal processes which modify the mass distribution within the planet.

OBJECTIVE: Gravitational Field

Observable: Gravitational Waves

Definition: Transmission of gravitational energy by wave propagation.

Phenomena: Acceleration due to gravity, gravitons.

Possible Techniques: Movement of masses, piezoelectric stress detection (Weber 1961).

Remote Sensing: Not applicable. In situ detection required.

Comments:

Conceivable that Jupiter (being a rotating oblate body) might emit very small flux of gravitational energy which might be detected by in situ orbital sensing.

OBJECTIVE: Magnetic Field

Observable: Field Vector

Definition: The magnitude and direction of the magnetic field strength surrounding a planet.

Phenomena: Magnetic field strength and direction.

Possible Techniques: In situ orbital magnetometry, in situ surface magnetometry.

Remote Sensing: Not applicable due to the necessity of in situ sensing of the field.

OBJECTIVE: Magnetic Field

Observable: Temporal and Secular Variation

Definition: Periodic and non-periodic changes in the field strength and direction.

Phenomena: Magnetic field strength and direction.

Possible Techniques: In situ orbital magnetometry, in situ surface magnetometry.

Remote Sensing: Not applicable due to necessity of in situ sensing of field.

OBJECTIVE: Magnetic Field

Observable: Radiation Belts

Definition: The existence and spatial variations of planetary radiation belts as evidenced by magnetically confined regions with high concentrations of charged particles.

Phenomena: Magnitude and spatial variations of electron and proton number densities. Magnitude and configuration of magnetic lines of force. Solar wind interaction and attenuation.

Possible Techniques: In situ particle charge and energy detectors at orbital and upper atmospheric attitudes. In situ magnetic field measurements.

Remote Sensing: Not applicable. In situ planetary orbit and magnetosphere probes are required for the desired measurements.

Comments:

With the exception of Jupiter, none of the planets under consideration are expected to have any significant radiation belts. For Jupiter, the decametric bursts (which may or may not arise within radiation belts) are discussed as a separate observable, while the decimeter emission can be adequately determined with Earth-based receivers.

OBJECTIVE: Magnetic Field

Observable: Auroras

Definition: Electron excitation of atmospheric constituents over large areas of space.

Phenomena: Discrete emission spectra of excited species. Particle excitation energies and reaction rates.

Possible Techniques: In situ atmospheric probe to analyze excitation and emission processes. Remote sensing of emission spectra.

Remote Sensing: Useful

Measurement Philosophy: Determine extent and other characteristics of auroral phenomena by sensing emission spectra at widely-spaced locations.

Moon
Mercury - Not applicable, insufficient atmosphere.

Mars
Venus Probably not much auroral activity due to expected lack of radiation belts.

Jupiter - Probably intensive auroral activity due to vast radiation belts.

Planetary Coverage & Distribution:

Based on terrestrial experience, data should be obtained at positions about 10° apart in latitude and longitude, with particular emphasis on polar regions.

Scale of Observables:

About 100-600 km in vertical extent and 5,000-10,000 km (or more, especially for Jupiter) in lateral extent, based on terrestrial experience (Silverman et al. 1965).

Spatial Resolution: 100-500 km in lateral extent, based on Earth experience. Vertical resolution not critical.

Acquisition Time: One minute or so, based on time scale of Earth auroras (Fleagle and Businger 1963).

Measurement Repetition Rate: About 5 times per night (10 for Jupiter) at repeated intervals throughout planetary year to determine seasonal variations.

Spectral Band & Resolution: Visible broadband (4000-7500Å) and multispectral with three or more bands.

Imaging: Useful.

	Mars	Venus	Jupiter
Visible broadband (4000-7500Å)	C	B	A
Visible multispectral (3 bands)	B	B	A

(A = very useful, B = useful, C = not very useful)

OBJECTIVE: Magnetic Fields

Observable: Paleomagnetism

Definition: The magnetic fields of past eras.

Phenomena: Rock magnetism

Possible Techniques: In situ surface sampling and testing to determine remnant rock magnetism (Runcorn 1962).

Remote Sensing: Not applicable, due to the necessity of direct surface measurements or sampling.

OBJECTIVE: Magnetic Field

Observable: Radio Bursts

Definition: The spatial and temporal variations of sporadic radiation from a planet's atmosphere at radio wavelengths.

Phenomena: Relatively intense radiation flux densities ($\gtrsim 10^{-24}$ watts/m^2sec) at long wavelengths (>1 meter) with large temporal variations (Michaux 1967a).

Possible Techniques: Remote sensing of radiation at wavelengths between 1 and 100 m. In situ atmospheric probe and radiation detector.

Remote Sensing: Very useful.

Measurement Philosophy:

Examine the spatial and temporal variations of radio emission in order to locate the radio sources and to better understand the physical processes involved.

Moon, Mercury, Mars, Venus — Not applicable, no known intense radio sources.

Jupiter - Strong decametric sources present which emit in bursts ranging upward from a few milliseconds in duration, and with peak flux densities of 10^{-18} watts^2/m^2sec (Smith et al. 1963).

Planetary Coverage & Distribution:

Jupiter - Planetwide coverage to detect individual sources, with particular emphasis on system III longitude variations. The probability of bursts is strongly dependent on the angular position of Io and the other major satellites (Warwick 1967).

Scale of Observable:

Jupiter - Actual dimensions of atmospheric sources are unknown, but the characteristic diameter of active emission regions could extend up to 50,000 km (Gordon and Warwick 1967, Dulk et al. 1967).

Spatial Resolution:

Jupiter - $\sim$100 km, estimated as adequate resolution to locate sources (boundaries of the most intense sources are presently known to within about 1° of longitude or 1200 km).

Acquisition Time:

Jupiter - ~1 millisecond minimum acquisition time to detect radio bursts which vary from milliseconds to tens of seconds in duration (Warwick 1967).

Measurement Repetition Rate:

Jupiter - ~1 minute, based on the minimum characteristic duration of Jupiter's radio storms (Michaux et al. 1967). Particular emphasis on temporal correlations with the sub-satellite positions of Io and the other satellites is required.

Spectral Band & Resolution:

Jupiter - Passive sensing of emission at about three wavelengths in the 7 to 100 m interval, with the principle or central wavelength at about 20 m.

Imaging: Very useful

	Jupiter
Multifrequency passive RF (3 wavelengths, 1-100 m)	A

(A = very useful)

Comments:

Present observations are limited to wavelengths of $\leq$70 m, because of the cut-off by the Earth's ionosphere. It is desirable to extend the data to 100 m or greater.

OBJECTIVE: Electric Field

Observable: Field Vector

Definition: The magnitude and direction of electric field surrounding a planet.

Phenomena: Potential gradient.

Possible Techniques: In situ surface and in situ orbital potential measurements.

Remote Sensing: Not applicable due to the necessity of direct measurement.

OBJECTIVE: Electric Field

Observable: Temporal and Secular Variations

Definition: Periodic and non-periodic changes in the electric field strength and direction.

Phenomena: Potential gradient.

Possible Techniques: In situ surface and in situ orbital potential and measurements.

Remote Sensing: Not applicable due to the necessity of direct measurements.

OBJECTIVE: Electric Field

Observable: Ionosphere Ring Currents

Definition: The charged particle distribution and current intensity associated with induced currents in an ionosphere.

Phenomena: Spatial and temporal aspects of the electric current in the ionosphere. Charged particle concentrations and flux. Induced fluctuations in the geomagnetic field. Electric field associated with ring currents.

Possible Techniques: In situ ionospheric probes with charged particle and current detectors. In situ atmospheric electric and magnetic field measurements. Active RF operating at wavelengths greater than ~30 m. Occultation data using S and L band radar.

Remote Sensing: Useful

Measurement Philosophy:

Obtain data at random positions (100-1000) throughout the atmosphere to obtain refraction and attenuation characteristics, from which electron density variations and current intensities can be deduced.

Moon, Mercury } Not applicable (no appreciable ionosphere expected due to tenuous atmosphere).

Mars, Venus } Ionospheric current and charge densities are expected to be small in comparison to Earth standards.

Jupiter - Extent of ionosphere is unknown because of obscuration by the surrounding radiation belts.

Planetary Coverage & Distribution:

Planetwide coverage desired with data at spaced intervals corresponding approximately to each 30° of longitude and latitude.

Scale of Observables: ~300 km, estimates based on the characteristic thickness of the Earth's ionosphere layer.

Spatial Resolution:

~10 km, based on the Earth experience and the typical dimension over which ionospheric particle densities and currents can alter appreciably (Cormier 1965).

Acquisition Time: Much less than planetary day since current densities are cyclic with the diurnal variations of solar flux (Minnis 1964).

Measurement Repetition Rate: Global coverage repeated about 4 times during the planetary year to assess seasonal variations.

Spectral Band & Resolution: Data is required at multiple frequencies (at least 3 different wavelengths).

Mars }
Venus } Variable frequency active RF data in the range of 30 m to 1 km (very long wavelengths will be required for complete reflection in ionospheres of low electron densities).

Jupiter - Entire range from 1 m to 1 km is desirable, but decameter bursts will interfere in the range of about 7 to 70 m.

Imaging: Not applicable. Little structure is expected and number of data points does not require imaging.

OBJECTIVE: Electric Field

Observable: Telluric Currents

Definition: Electric currents in the crust or mantle of a planet induced by atmospheric or ionospheric currents.

Phenomena: Diurnal changes in magnetic field, electric potential gradient (Howell 1959).

Possible Techniques: In situ surface voltage gradient measurements, in situ magnetometry.

Remote Sensing: Not applicable due to necessity of direct field measurements.

2.8 Active Biota

2.8 Active Biota

A. Objective: Lifeforms

1. Animal life
2. Plant life
3. Microscopic life forms
4. Living cells

B. Objective: Biochemistry

1. Macromolecules
2. Complex molecular structures
3. Biochemical systems

C. Objective: Metabolism

1. Environmental exchanges
2. Growth
3. Heat generation

D. Objective: Reproduction

1. Birth
2. Number density
3. Cellular division
4. Genetic codes

OBJECTIVE: Life Forms

Observable: Animal Life

Definition: Living animals or insects which are visible to the naked eye. The size may range upwards from a few millimeters. Animal life forms are exceedingly complex and, although they may not resemble Earth-type creatures, it is anticipated that they would be recognizable as "alive".

Phenomena: Visual appearance and morphology, mobility, temperature, irritability. Spectral response.

Possible Techniques: In situ surface visual and multispectral (visible, IR) sensing. Remote visual and multispectral (visible, IR) sensing. Surface and remote stereoscopic visible sensing. Remote radar sensing.

Remote Sensing: Useful

Measurement Philosophy:

To observe selected areas of planets in a detailed search for individual species or herds of animal life.

Moon
Mercury - Probably not applicable. Oxygen and water probably insufficient to support complex life (Berkner and Marshall 1965).

Mars - Interest in wave of darkening and temperate surface zones.

Venus
Jupiter - Atmosphere possible habitat because of extreme temperatures on surface (Sagan 1967a and b).

Planetary Coverage and Distribution:

Approximately 10 percent of planetary coverage in temperate areas selected from reconnaissance.

Mars - Wave of darkening and polar regions.

Venus - High surface altitudes and polar regions to avoid high surface temperature.

Jupiter - Nature of surface and lower atmosphere unknown.

Scale of Observables:

It is not known what the sizes of extraterrestrial life are likely to be.

Mars
Venus - mm up to tens of meters.
Jupiter

Spatial Resolution:

It is unreasonable to search for very small creatures from orbit. A surface resolution of about 20 cm appears to be an adequate compromise to a first order. If animal life is very strongly suspected, but not detected at 20 cm, a lower resolution could be used.

Acquisition Time:

Mobility will probably be the determinant for acquisition time.

Mars
Venus - Approximately 1 second based on ground speeds of terrestrial animals.
Jupiter

Measurement Repetition Rate:

In order to record movement of animals, a 10 second repetition rate would seem to be adequate.

Spectral Band and Resolution:

Mars - Visible (5000-7500Å), multispectral (approximately 10 bands between 5000Å and 1-5μ).

Venus - Radar (3 cm)

Jupiter - Atmosphere probably too opaque for remote sensing.

Imaging: Useful

	Mars	Venus	Jupiter
Visible broadband (5000-7500 Å)	B		
Radar (stereo, ~3 cm)		B	C
Multispectral (about 10 bands between 5000 Å and 1-5μ)	A	C	C

(A = very useful, B = useful, C = not very useful).

OBJECTIVE: Life Forms

Observables: Plant Life

Definition: Patches of living plant life which are visible on the surface or in the lower atmosphere of planets. Plants are a complex life form.

Phenomena: Appearance and morphology, spectral response, temperature.

Possible Techniques: In situ surface visual and multispectral (visible, IR) sensing. Remote visual and multispectral (visible, IR) sensing. Remote radar.

Remote Sensing: Useful

Measurement Philosophy:

Observe selected areas of planets for vegetation. Individual species need not be detected for first order measurements, since plants characteristically exist in patches on Earth.

Moon, Mercury - Probably not applicable because of lack of atmospheres.

Mars - Wave of darkening has been suggested as vegetation.

Venus, Jupiter - Atmospheric life possible , surfaces have extreme temperatures.

Planetary Coverage and Distribution:

Approximately 10 percent of planetary surfaces selected for biological potential (temperate).

Mars - Wave of darkening and polar regions.

Venus - High altitudes and polar regions because of high surface temperatures. Temperate cloud layers.

Jupiter - Surface and low atmosphere unknown.

Scale of Observables:

Patches of vegetation can probably range from a few inches to hundreds of kilometers in size.

Spatial Resolution:

First order measurements to a scale of 100 meters will probably be adequate to identify patches of plant life.

Acquisition Time:

The characteristics of emission and absorption of terrestrial plants fluctuate diurnally and seasonally.

Mars
Venus - Hours.
Jupiter

Measurement Repetition Rate:

Understanding of diurnal and seasonal cycles is probably not necessary for just detecting plant life. Repetition rates up to months will probably be adequate.

Spectral Band and Resolution:

Mars - Visible (5000-7500 Å). Multispectral (approximately 10 bands between 5000 Å and 1-5μ).

Venus - Radar (3 cm)

Jupiter - Atmosphere probably too opaque for remote sensing.

Imaging: Useful

	Mars	Venus	Jupiter
Visible broadband (5000-7500 Å)	B		
Radar (stereo, ~3 cm)		B	C
Multispectral (about 10 bands between 5000 Å and 1-5μ)	A	C	C

(A = very useful, B = useful, C = not very useful).

OBJECTIVE: Life Forms

Observable: Microscopic Life Forms

Definition: The nonvisible living matter composed of organized collections of a large number of cells. They include spores, viruses, bacteria, microorganisms, etc.

Phenomena: Visual appearance and morphology. Ability to grow and reproduce. Temperature and temperature gradients on a microscopic scale. Mobility.

Possible Techniques: In situ surface visual microscopic analysis. In situ surface sample preparation and culturing. Microcalorimetry.

Remote Sensing: Not applicable because of the microscopic size of these life forms. It is always possible that they can exist in such large dense populations that they could be observed directly. This contingency is covered by the macroscopic life form measurements.

OBJECTIVE: Life Forms

Observable: Living Cells

Definition: The smallest entity considered to be a life form. Cells are common to all higher forms of life.

Phenomena: Visual appearance and morphology.

Possible Techniques: In situ surface sampling (preparation of sample and microscopy).

Remote Sensing: Not applicable because of microscopic scale of living cells.

OBJECTIVE: Biochemistry

Observable: Macromolecules

Definition: Complex molecules such as DNA, RNA, proteins, enzymes, organic polymers, which if found are highly indicative of life (Ponnamperuma 1965).

Phenomena: Very large molecular weights, chemical properties. Complex spectral signatures.

Possible Techniques: In situ surface sample analysis (mass spectrometry, gas chromatography, pyrolysis, ultracentrifugation).

Remote Sensing: Not applicable because of the molecular scale of the information required.

Comments:

In cases where large numbers of macromolecules yield group properties, the measurements under "Biochemical systems" will be applicable. It is not yet clear that the complex spectral signatures can be used to identify specific macromolecules.

OBJECTIVE: Biochemistry

Observable: Complex Molecular Structures

Definition: The internal molecular structures (long chain, helix, double helix, etc.) which are characteristic of complex macromolecules. It would be desirable to detect structures quite apart from the identification of specific macromolecules.

Phenomena: Internal molecular appearance. Molecular transport properties.

Possible Techniques: In situ surface and atmospheric sample analysis (microscopy, ultracentrifugation, osmometry, viscometry, etc.).

Remote Sensing: Not applicable because of molecular scale of information required. Surface or atmospheric sampling is essential.

OBJECTIVE: Biochemistry

Observable: Biochemical Systems

Definition: Large scale groups or colonies of complex biochemicals which can be detected by their group properties, rather than by their individual molecular properties. Biochemical synthesis and dissociation may be occurring continuously on planets.

Phenomena: Optical activity (polarization) of biochemicals in solvents. Spectral signatures in IR, UV, and visible. Areal distribution color patterns.

Possible Techniques: In situ surface sample analysis (visible polarimetry). Remote sensing of IR, visible, UV signatures. Remote sensing of surface patterns.

Remote Sensing: Useful

Measurement Philosophy:

Detect large scale biochemical systems by their spectral signatures.

Moon - No evidence for gross biochemical systems.

Mercury - Polar regions are of most interest in view of temperatures.

Mars - Wave of darkening and poles are of interest.

Venus, Jupiter - Biochemical systems may exist in atmosphere. Surface conditions may be hostile.

Planetary Coverage and Distribution:

About 10 percent of planet in areas of special interest.

Moon - Not applicable.

Mercury - Polar regions, 75-90° latitude.

Mars - Total planet is of interest (particularly wave of darkening).

Venus, Jupiter - Atmosphere or clouds of interest.

Scale of Observable:

Biochemicals could be distributed on microscopic to planet wide scales. Patches of biochemical activity of first order interest. Require regional scale measurements for first order investigation.

Spatial Resolution:

Compatible with regional scale mentioned above. 1-3 km is required to identify regional biochemical systems.

Acquisition Time: Less than planetary day.

Measurement Repetition Rate:

Measurements corresponding to each season are required (approximately monthly).

Spectral Band and Resolution:

No clear signatures have yet been identified for biochemicals. Resolutions on the order of $\lambda/\Delta\lambda$ = 1000 will probably be required in the visible, UV, and IR.

Imaging: Useful

	Mercury	Mars	Venus	Jupiter
Multispectral (about 10 bands between 5000 Å and 1-5μ)	A	A	C	C

(A = very useful, C = not very useful)

OBJECTIVE: Metabolism

Observable: Environmental Exchanges

Definition: The materials which are absorbed by metabolizing systems from their environment and passed back to their environments. Gaseous exchanges are the most common to terrestrial organisms.

Phenomena: Change of gas concentration in a closed environment. Changes of the pH and Eh. Changes in concentration of specific substrates or solutes.

Possible Techniques: In situ surface sample analysis (mass spectrometry, gas chromatography, pH, Eh monitoring).

Remote Sensing: Not applicable since surface samples must be collected and prepared for carefully controlled experiments.

Comments:

The existence of relatively large quantities of gases, oxygen in particular, in planetary atmospheres may indicate past or present metabolic processes (Berkner and Marshall 1965). These will be detected in such observables as "Atmospheric elemental and molecular composition".

OBJECTIVE: Metabolism

Observable: Growth

Definition: The increase in size (but not population) of active organisms. In general, higher orders of life are most likely to exhibit growth.

Phenomena: Changes in size of individual life forms as a function of time. (This is not usually accompanied by a change in shape.)

Remote Sensing: Not applicable since it is necessary to monitor individual objects for growth. Only organisms that are stationary over a long time scale (i.e., plants) would be appropriate, and they are not expected to be adequately isolated for individual recognition from orbit.

Comments:

Large scale changes in surface appearance due to biological growth is covered in "Plant Life".

OBJECTIVE: Metabolism

Observable: Heat generation

Definition: The small quantity of heat which is continuously released by all metabolizing cells (Hitchcock and Lovelock 1967).

Phenomena: Temperature gradient between metabolizing system and its environment. Heat input into a closed thermal environment.

Possible Techniques: In situ temperature measurement of surface samples. In situ microcalorimetry on surface samples.

Remote Sensing: Not applicable since surface samples have to be collected and prepared to detect the small temperature gradients and heat outputs.

Comments:

Thermal gradients generated by very large numbers of cells are treated under the observables of "Plant Life" and "Microscopic life forms".

OBJECTIVE: Reproduction

Observable: Birth

Definition: The visible process of reproduction of complex animal life forms. It is most apparent at the moment of birth, but may be recognizable for some days afterwards.

Phenomena: Visible delivery of a replicate life form.

Possible Techniques: Of marginal value. The probability of observing the birth of life forms is very low and secondary to the observation of the life forms themselves.

OBJECTIVE: Reproduction

Observable: Number density

Definition: The time dependent population of identical species. Selected, localized distributions of species should be observed in controlled conditions to avoid simply observing the steady state equilibrium common to most established populations.

Phenomena: Rate of change of population.

Possible Techniques: In situ surface sample analysis (culture preparation and visual observation by microscopy, turbidimetry, increases in weight and volume).

Remote Sensing: Not applicable since carefully prepared samples are essential to the interpretation of number density profiles.

Comments:

The recognition of populations of macroscopic life is treated under "Animal life" and "Plant life".

OBJECTIVE: Reproduction

Observable: Cellular Division

Definition: The reproduction of living cells by successive splitting.

Phenomena: Visual appearance of cells, cell counting.

Possible Techniques: In situ surface sample analysis (microscopy).

Remote Sensing: Not applicable because of very small scale of cellular division.

OBJECTIVE: Reproduction

Observable: Genetic Codes

Definition: The macromolecular structures which control the rate and form of cellular reproduction. At present the bases in DNA and RNA are thought to contain the genetic codes.

Phenomena: "Codons" or triplets of the bases in DNA and RNA (Clark and Marcker 1968).

Possible Techniques: In situ sample analysis (molecular structures using microscopy, electrophoresis, etc.)

Remote Sensing: Not applicable since the scale of interest is molecular.

Comments:

The detection of genetic codes will be very important to the establishment of reproduction,but it is secondary to the identification of such macromolecules as DNA and RNA themselves.

2.9 Extinct Biota

2.9 <u>Extinct Biota</u>

A. Objective: Fossils

1. Animal and plant fossils

2. Molecular fossils

B. Objective: Biological Decay Products

1. Hydrocarbons

OBJECTIVE: Fossils

Observable: Animal and Plant Fossils

Definition: The replicate remains of macroscopic life forms. They may be either preserved or impressed in crustal materials. In general, fossils will be under the surface layer, but the location and depth will depend on the depositional and erosional history of the crust.

Phenomena: Visual appearance and morphology.

Possible Techniques: In situ surface sampling (visual observations). In situ digging.

Remote Sensing: Not applicable since surface sampling is necessary to select and identify possible fossils.

OBJECTIVE: Fossils

Observable: Molecular fossils

Definition: Complex biomolecules which were created in the past and which have been preserved without degeneration.

Phenomena: Molecular structure and appearance, chemical properties.

Possible Techniques: In situ surface sample analysis (microscopy, ultracentrifugation, etc.).

Remote Sensing: Not applicable because of molecular scale of information required. Sampling is essential.

OBJECTIVE: Biological Decay Products

Observable: Hydrocarbons

Definition: The liquid, solid, and gaseous byproducts of past life which accumulate in or on the planetary crust. The most common terrestrial examples which are thought to have a biological origin are oil, coal, and natural gas.

Phenomena: Spectral reflectance and emission properties. Chemical properties.

Possible Techniques: In situ surface sample analysis (mass spectrometry, gas chromatography, petrochemical analysis, etc.). Remote multispectral sensing of possible surface hydrocarbons (UV, visible, IR).

Remote Sensing: Useful

Measurement Philosophy:

Search for exposed hydrocarbons on the planetary surface (liquid or solid) on a regional scale.

Moon, Mercury, Mars - Possible liquid pools and solids on surface.

Venus - Possible liquid pools and atmospheric accumulations.

Jupiter - Unknown.

Planetary Coverage and Distribution:

Search over 80 percent of planet on a regional scale for first order data. Widely distributed over planet.

Scale of Observable:

Could range from very localized to regional. First order measurements should be on a regional scale (approx. 1000 km x 1000 km areas).

Biological Decay Products - Hydrocarbons (Page 2)

Spatial Resolution:

1-3 km estimated on Earth experience, although there is limited exposure of hydrocarbons on the Earth.

Acquisition Time: Not applicable

Measurement Repetition Rate: Not applicable

Spectral Band and Resolution:

Moon Mercury	- Multispectral ≃ 10 bands in UV visible, and IR between 1000Å and 10μ.
Mars	- Multispectral as above, but cutting off at 5000Å.
Venus Jupiter	- Not applicable

Imaging: Useful

	Moon	Mercury	Mars
Multispectral (~ 10 bands between 5000Å and 10μ)	B	B	B
Multispectral (~ 10 bands between 1000Å and 10μ)	A	A	B

(A = very useful, B = useful).

Comments:

Geological data on the surface may be useful in determining where subsurface accumulations of hydrocarbons may be anticipated.

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