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BASELINE SCIENCE PAYLOAD FOR SOP²

Panel 2
G. Orton, Chairman, J. Blamont, L. Colin,
G. Siscoe, D. Morrison, J. Pollack

G. ORTON: We would like to discuss baseline science and baseline payloads for SOP^2.

J. POLLACK: One important element for a probe payload is a capability to determine atmospheric composition. A second thing is information about cloud and aerosol properties, such as size and location. Third, we would like to have information on the winds themselves. That's an important piece of meteorology. Doppler tracking capability could give us information on how the vertical winds vary as a function of altitude.

I would also like to get some information on the surface of Titan. We have to think seriously about what types of instruments might be feasible. The real problem is we've got to expand our horizons a bit beyond things like alpha scattering experiments, which are directed towards silicates, since on Titan the things we'll want to go after are primarily the ices and organics.

I also think that if one goes far enough to speak about a lander that stays around and operates for a while on the surface, there's quite a bit one could get from imaging information. One could get information on properties and particles in the atmosphere and monitor how they change.

G. ORTON: For Titan do you see any need for additional or modified instrumentation from the Galileo Jupiter probe or a Saturn probe in order to more fully exploit the possibility and the extent of organic compounds?

J. POLLACK: Well, I certainly think that one would have to consider a gas chromatograph very seriously. When you have a wide enough range of possibilities as to compositions that you're going after, you would like to cut in several dimensions so that you can best pin down what you're looking at. A mass spectrometer gives a nice cut in one dimension. A gas chromatograph gives you a cut in a complementary direction.

D. MORRISON: What kind of gas chromatograph capability would be required to provide a substantial orthogonal data set to what you would get with a mass spectrometer?

J. POLLACK: I think the gas chromatograph that was proposed for Galileo gives you a first order answer to that question. There was an electron capturing device that was proposed as a primary detector; for certain C and N compounds it had enormous sensitivity. With certain selected compounds of particular organic interest, it has very high sensitivity.

S. CHANG: There's a particular advantage in Titan, too, because you don't have the enormous excess of hydrogen and helium to deal with. If you are interested in looking for trace organics, you already have the three order of magnitude advantage over the case in Jupiter. Furthermore, the non-condensable gases that comprise the major portion of the atmosphere are nitrogen and methane, and if you are interested in three more orders of magnitude of concentration, these can be swept through. The concentration mechanism can be used to further enhance your detection capability. I think it's a very sensitive and high-resolution method.

J. CUZZI: What about imaging on the way down?

J. POLLACK: I think there are radiation experiments that give you more valuable data than imaging would on the way down, but once you get to the surface, then it's a different ballgame. On the way down, I really don't see that imaging does too much.

D. HUNTEN: I would like to mention that we should consider where we'll be in instrument development after Pioneer Venus, because a number of the proposals that have been made – Doppler tracking, gas chromatography, and so on – are being implemented on Pioneer Venus. We'll have a much better handle on how well these things actually work in the real world by about a year from now.

J. BLAMONT: As far as the dynamics are concerned, I don't believe that with one single probe you can learn something. Just imagine that you would have Mariner 4 as the only description of Mars. What do you learn? Nothing.

But I think it's easier to send entry probes to Titan than to Jupiter. Therefore, I think that at least you have to find a way of having more than one vertical probe. This is essentially why I made the presentation of the hot air balloon, because you want to have more than one vertical profile of the wind.

If you obtain only one single measurement of circulation, you'll have nothing. Even if you have one good Doppler measurement, you won't go very far from there.

G. ORTON: As far as your idea about the hot air balloon, it's going to be necessary to wait in order to know whether the atmosphere will or will not support a balloon.

J. BLAMONT: It's possible to have a hot air balloon which would fly at 10 millibars. We are just starting to study this and we hope to be able to provide you with a list of possibilities.

J. CUZZI: At Ames, we talked a little bit about sub-surface measurements, like sticking a penetrator in the ground. I would be interested in hearing what people have to say about that.

J. POLLACK: One of the really fundamental things that you'd like to know is the heat flow. And I'm not quite sure how easy it would be to implement it on the lander, but that certainly would be one of the important things to do.

D. HUNTEN: I would like to suggest that anybody who is advocating a heat flow measurement should take one or two plausible models for the heat flow of Titan and combine them with the heat conductivity of, let's say, solid water ice or solid tar or liquid tar, and see if it's within orders of magnitude of it being feasible. I would be very surprised if any such measurement is possible.

S. CHANG: There may be some interesting things resulting from sub-surface chemical analysis, too; composition may vary significantly with depth below the surface.

D. HUNTEN: I'd like to raise a plea again for pre-entry science, which hasn't really been discussed in this particular panel. Measurements of the ionosphere and upper atmosphere have been quite seriously considered for Galileo, but had to be abandoned because of the high cost and added mission complexity. But Titan is a relatively easy and a very interesting place in which to make some measurements of positive ion chemistry and, preferably, even upper atmospheric composition. The highest priority instrument is an ion mass spectrometer. The optimum complement is what Pioneer Venus carries, which is a neutral mass spectrometer, ion mass spectrometer, ion trap, and Langmuir probe.

Sherwood Chang has made the proposal that a good deal of the organic aeronomy that goes on in Titan may be going on in the upper atmosphere, mediated by auroral particle bombardment. This adds to the excitement of these kinds of measurements.

G. ORTON: The distinguishing characteristics between pre-entry and probe science are, I assume, that pre-entry is pre-Mach 1.

D. HUNTEN: Well, even more than that. It's done at heights where the mean-free path is long enough or the vacuum is good enough so you don't need vacuum pumps; the region of the ionosphere, or a little bit above.

L. COLIN: You want a candidate Saturn probe payload. Let me suggest a list of high-priority instruments and low-priority instruments, with the high-priority instruments in order of priority:

(1) In the area of composition: a neutral mass spectrometer and a gas chromatograph.

(2) For atmospheric structure: temperature, pressure, and accelerometer measurements.

(3) For cloud structure: the multiple scattering nephelometer that we have on Galileo.

(4) For dynamic experiments: Doppler ratio tracking or possibly balloon techniques.

(5) For thermal balance, the net flux radiometer, which hopefully will tell us why the winds are being driven the way they are.

(6) Finally, a plea again for pre-entry science; I listed two instruments: An ion mass spectrometer and a retarding potential analyzer.

That adds up to a total of seven hardware instruments, which I think is in the right ballpark.

That leaves for lower priority experiments, a helium abundance detector, a cloud particle size spectrometer, and a lightning radio emission detector. Among aeronomy instruments, in a lower priority are the electron temperature probe and neutral mass spectrometer. And finally, the magnetospheric-type experiments of low priority, such as an energetic particle detector and a magnetometer.

D. MORRISON: For the Saturn probe, should magnetospheric experiments be given such low priority? In the extensive debates over where to target Pioneer 11 at Saturn, some very cogent sounding arguments were made that one really wanted to measure the energetic particle and magnetic field profiles in the regions of interaction with the ring particles and inside them in the gap where the D Ring may or may not extend all the way to the surface of the planet. Only with a Saturn probe that has an extensive magnetospheric complement of instruments can we study that aspect of magnetospheric physics. Is that a reasonable argument?

J. POLLACK: I think the thing that would worry me on an argument like that is the question of priorities; in other words, you are getting a one-shot sample so that, in the case of magnetic field, you get a hint of the asymmetries, but you really wouldn't be able to actually define that asymmetry. So from that point of view, I wouldn't put it in as high a priority class.

E. STONE: If you just trade, say, the magnetospheric experiments on a probe versus magnetospheric experiments on an orbiter, my own impression is that a comprehensive magnetospheric orbiter package will, in the end, yield much more science about the magnetosphere than would the package on the probe.

D. MORRISON: Suppose you were considering just an energetic particle detector as part of the pre-entry science on the probe. Would you put it as low priority as Larry did?

E. STONE: A simple energetic particle experiment on the probe could give us some information about the magnetic field direction, as well as something about whether or not there are particle sources inside of the visible rings. Whether one would rank that as high as the first seven you listed, I don't know. I think it may well be high up in the second category.

D. HERMAN: Let me ask a question about the need for a GC into Saturn. I heard a debate at a Physical Sciences Committee meeting between John Lewis and Carl Sagan, where John calculated the abundance of organics that would exist in Jupiter, if they do exist, and that dictated the kind of sensitivity you need in a GC. Using whatever model you wish, if there are organics in the atmosphere of Saturn, what would you anticipate is a relevant abundance?

J. POLLACK: I think it depends how you define the word "organics". If you are speaking about amino acids or something like that, I would be surprised if there were measurable quantities. If, on the other hand, you are speaking about a variety of other interesting compounds that are more plausible on other grounds, I think it's an entirely different situation.

Let me just give you a couple of examples of surprises that we have encountered in the case of Jupiter, which is why I think there is a wider range of possibilities in the real case than one might predict on very simple grounds: We know that there are measurable quantities of both carbon monoxide and phosphine in the atmosphere of Jupiter.

D. HUNTEN: Measurable by a GC?

J. POLLACK: Yes. In fact, that was explicitly part of our GC proposal for Galileo. Just to explain that a little bit more, the reason that we think that these compounds are actually there in the case of Jupiter is that they get manufactured by thermodynamics at very high temperatures in deep layers, and then get mixed up quickly, so it would be nice to see some of those vertical gradients to understand how the compounds get up there.

G. ORTON: Do we need a dedicated helium-hydrogen instrument? Should one measure helium for its contribution to cosmogony? The answer, I think is very definitely yes.

D. HUNTEN: I think it's another mildly interesting thing to do in about the same class as, let's say, pre-entry science.

G. ORTON: On the record we have clear differences of opinion.

D. MORRISON: I am confused by the vehemence of your assertion, Don, that the helium abundance is only mildly interesting. If I understood Jim correctly, he is saying that there appears to be a discrepancy between theory and observation in the internal heat source of Saturn. By determining the helium ratio, we might find the clue to that discrepancy. It would seem to me that if that argument is valid, then measuring the helium is in the same class as measuring the internal heat source of Saturn for understanding what went on at the time the planet was formed.

D. HUNTEN: I don't disagree, except I'm not sure that once we've measured the helium we will have the ultimate solution to that particular puzzle. There's a near infinity of solutions even once you know the helium.

J. POLLACK: Perhaps you could enlarge on that, Don? Tell me the near infinity.

G. ORTON: That would take a long time.

D. HUNTEN: In anything as complicated as a planet, a unique explanation of anything that complicated practically never happens, Jim. In the context of today's theories, yes, it may discriminate but that doesn't mean we find the true answer.

J. POLLACK: Let me just explain my remark and then you could just very quickly just take a look, on a quantitative basis that is, to what energy sources you have available. And the only thing that's going to produce something of the right order of magnitude is some type of gravitational energy release, and so the real focus of trying to understand the excess heat source is to understand the mechanism of gravitational energy release. A desirable accuracy would be one percent of the ratio of helium to hydrogen.

D. CRUIKSHANK: With all humility and great trepidation, I would like to ask a question about deuterium. No one has mentioned deuterium and I realize it's been found spectroscopically on Saturn recently. But I wonder if it's something that should be given attention in a probe measurement. It seems like a number we'd like to know on Titan, at least, and it may relate to whether or not the Titan atmosphere is the original atmosphere or a secondary atmosphere.

D. HUNTEN: I think you raise a good point. Isotopic ratio measurements tend to be taken for granted as a primary objective, but should be brought out explicitly.

S. CHANG: Is it possible that because there are differences between the densities of Saturn and Jupiter, that Saturn is not only somewhat chemically fractionated, but also isotopically fractionated from the point of view of the stable elements, light elements as well as the rare gases. Would that be a particularly interesting measurement; that is, by comparison with Jupiter, would there be an anomalous elemental fractionation pattern or isotopic pattern?

J. POLLACK: Recent suspicion has been that it's much more an elemental than it is isotopic. Elemental, in the sense that it's hydrogen-helium versus rocky and icy material.

D. MORRISON: I have talked about the orbiter payload already, but I have a couple of general comments. Saturn missions are difficult because Saturn is a long way away, and several things work against us:

(1) We have less knowledge than on nearer planets from ground-based studies on which to base mission plans.

(2) The missions are of longer duration and that means if we have to build upon the knowledge from one mission to go on to the next, the interval between them is longer. It is difficult to talk meaningfully about a Saturn mission before we've had any spacecraft to Saturn, and I conclude that

we should not now foreclose any options. The uncertainty is particularly severe in things having to do with the magnetosphere, but there are other areas as well.

In reference to the payload on an orbiter, there are three major questions in my mind about science priorities:

(1) The role of magnetospheric physics and measurements. They were omitted by the Space Science Board, but perhaps one just cannot make a judgment on that until after Pioneer 11 has gone there.

(2) Synoptic Saturn studies. The Space Science Board did not recommend synoptic studies of Jupiter, where we know there is a lot of atmospheric motion that's reflected in the visible appearance, but is has recommended, although at a fairly low priority, synoptic studies of Saturn for a Saturn orbiter. I suspect that until we have Voyager pictures, we won't have a feel for whether those kinds of studies are likely to be very useful or not.

(3) Although, given enough time, the SOP^2 orbit can almost be selected at will, I suspect there will be some kind of conflict between ring observations and satellite observations. Most of the ring studies will require cranking up to moderately high inclinations, and that makes it much harder, although not impossible, to encounter other satellites. If we really want to do a detailed comparison of 4 or 5 or 6 Saturn satellites, we might find that in conflict with the kind of extensive ring measurements that we would also want to do.

J. POLLACK: Given the flexibility to change the inclination, wouldn't you choose to have an equatorial inclination most of the time, but then at some point change to an inclination that would let you do the rings and then go back again?

D. MORRISON: The Saturn system has a kind of atmospheric dynamics in it that is absent from Jupiter because of the changing tilt of the rings and of the pole. This argues for a relatively long orbiter mission that's phased to the inclination of the rings and pole. For a good ring study, we would like to get above the rings, below the rings, to see them under different illumination angles; observe their thermal emission, for instance, under different heating regimes.

The season and the ring shadow may also influence our study of the motions of Saturn's atmosphere. Both rings and weather argue for a mission lasting several years. The next question is the arrival time. The maximum ring exposure corresponds to a flat maximum several years long. If we got on the tail end of that maximum, say at about 20°, in the next three years they'd go down through zero tilt. That might be a very attractive range of times to make orbiter observations.

W. WELLS: Or arrive at zero and go up?

D. MORRISON: Yes. But you wouldn't want to arrive just plus or minus one to two years of zero. For one thing, you'd duplicate Voyager too much. That's around 1995. And you wouldn't want to arrive right when they were maximum full open either, because it's such a flat maximum. These times are 1988 or 2002.

E. STONE: I would be very surprised if, in fact, the magnetosphere is not an important part of the Saturn system. It will surely be an important part of understanding what's going on with Titan, some aspects of the rings, and possibly the other satellites with their curious surface characteristics.

Voyager will not have the appropriate geometry of flyby, except for Titan, to do much in the way of assessing the environment around the satellites, and it does not have the capability for the mass analysis of plasma.

In fact, one is almost sure after Voyager to have the same situation we had after Pioneer at Jupiter, that the magnetosphere is an important part of understanding the Saturnian system. The combination of experiments which are on Galileo are the typical complement which is basic in the sense that they make a coupled set in terms of their interactions.

G. SISCOE: I would like to agree with what Ed said. It seemed to me that what the Space Science Board did was to react to the absence of hard data on the magnetic field of Saturn as contrasted to Jupiter, where we knew there was a strong magnetic field before the Pioneers went. I think that the way to proceed is to assume that if the magnetosphere were as big as it could be, then it would be a very important scientific objective, both from the point of view of the magnetospheric science and also from the point of view of what it does to the Saturnian system.

J. POLLACK: I would like to turn to a type of instrument that is not on Galileo but might profitably be part of an SOP^2 orbiter: a multi-channel infrared radiometer for the 20 μm - 1 mm wavelength region. It would be directed towards getting information on the composition of the ring particles at different positions within the rings. Such an experiment would also be nice to have for both Titan and for Saturn to do atmospheric sounding.

M. KLEIN: I would like to suggest that you consider longer wavelengths than 1 mm. There are several reasons:

(1) There is a one-meter probe relay antenna hanging on the spacecraft already. You could make use of that after the probe has gone as a very efficient microwave antenna to probe the atmosphere. You can do synoptic mapping of Saturn's atmosphere itself, looking for large scale circulations, changes in the ammonia relative humidity, if it has belts and zone-type structure like Jupiter.

(2) You can look at the very cold temperatures of the satellites, particularly the night-side temperatures of the satellites. This is easy to measure with a microwave system, whereas I don't know about the infrared.

(3) Probably less significant, you might be able to do some magnetospheric studies by measuring synchrotron emission if you have a long enough wavelength - (around 30 cm).

J. CUZZI: I want to reemphasize that I think this millimeter region is extremely important for studying the rings. In this region the ring particle behavior goes from that of absorbing and emitting to that of scattering. It's a transition region, where the action is and where we're going to learn the most. It's going to tell you about particle size, composition, impurities, and structure. We want to learn the maximum particle size, and how absorbing they are, whether they have silicates, and this is where to look. The range is probably down to a couple of hundred μm.

D. MORRISON: I think that's an interesting point, and I would ask the question more broadly. The things Saturn has that Jupiter doesn't are Titan and a ring system. We've talked a lot about Titan; for the ring system it's fair to ask the question: How do you modify the payload to take advantage and attack the problems associated with that unique element. Infrared and millimeter radiometry is one way, and perhaps there are some other ideas.

J. CUZZI: We haven't really talked about doing any bistatic radar.

G. ORTON: It's been mentioned. Any of it's advocates care to stand up and be counted at this point?

J. CUZZI: I'll stand up. That's the second important handle on the rings, and I should elaborate on that a little bit more.

Presumably, there'll be another two-wavelength radio-science experiment. I think that would be extremely nice, 3 and 12 cm or something like that. It would be extremely valuable. I would support a two frequency (S and X band) telemetry. It could be used for extensive bistatic radar mapping of the rings. And it would be nice to have the orbit cranked to 10° inclination. I would also support the desire to have the rings inclined by about 20° when we get there.

It would also be nice to be able to take the orbit and slew it around once so you can look at different parts of the rings from different angles, elevation angles, and investigate the size distribution.

L. TYLER: By bistatic, I think you mean phase angle coverage at centimeter wavelengths.

J. CUZZI: Yes, the spacecraft bouncing radar off the rings and being received at the Earth, both from above and below, and at all different scattering angles.

J. POLLACK: To contrast this a little bit, what Voyager will be doing, primarily, is something with scattering angles of half a degree or so, and the things that Jeff Cuzzi was mentioning could go up to maybe 30° scattering angles. And if backscatter is possible, it can give shape information.

G. COLOMBO: (1) I would consider very important a study of a mission whereby the spacecraft is periodically and sequentially transferred, with minimum energy expenditure, from a Saturn orbiter to a Titan orbiter, and vice versa. This will allow detailed study of both long and short term variations in the Titan and Saturn atmospheres and a complete exploration of the inner Saturn satellite system and planet. Of particular interest is the region between Rhea and Titan for the reason outlined in the next paragraph. I emphasize here that the mass of Titan is large enough to give quite a large flexibility in the maneuvering capability with relatively small consumption of the propellant of the auxiliary propulsion systems. Typical trajectories of the restricted three body problem may be used as reference. The efficiency of the satellite Rhea in a similar role may also deserve some consideration. The other satellites may be too small and the relative velocity may be too large for gravity assisted maneuvering. (2) I consider very crucial a deep survey of the intersatellite region between Rhea and Titan and just outside Titan. The similarity of the dynamical environment inside the belt between Mars and Jupiter and the dynamical environment between Rhea and Titan lead us to think that a belt of sparse and relatively small objects may be present similar to the asteroidal belt. We should also look for Trojan type objects in the triangular Lagrangian position. Besides it seems probable that Hyperion is one of the members of a family of smaller objects just outside the Titan orbit.

(3) Concerning the inner Saturn system, we expect the existence of a swarm of small limited number of bodies between Mimas and the ring A of Saturn. In particular we think that the inner boundary of ring B could be caused by a resonance effect due to bodies orbiting Saturn just outside the Roche limit. In fact, from photometric observations of the light curve of Iapetus, eclipsed by the rings, it seems now clear that the outer boundary of ring A is 2000 km inside the circular orbit of a hypothetical satellite, or swarm of small bodies in a 3 to 2 orbital resonance with Mimas. This possible satellite(s) could excite a strong resonance (2 to 1) at the inner boundary of ring B causing the conspicuous drop in density at this boundary distance from the planet.

(4) The near Saturn environment may be quite different from the Jupiter environment both in regard to energetic particles and intersatellite solid (meteor or meteorite) components. This characteristic should allow a better exploration of the inner system than that which will be done with Galileo on the Jupiter inner system. The density of the solid component of the intersatellite space and rings may require a re-examination of any mission profile when more information will be available from the Voyager mission and in 1979 from the Pioneer flyby. A very intense observation program both from ground and from the space telescope will be crucial in the mission planning. We wanted to emphasize the difficulty we are encountering at present in optimizing the mission because of lack of information.

CONCLUSIONS AND RECOMMENDATIONS: EXPLORATION OF THE SATURN SYSTEM

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Summarized by

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Areas of Investigation

In its *Report on Space Science 1975*, the Space Science Board adopted as policy the report of its Committee on Planetary and Lunar Exploration (COMPLEX). The section on "Saturn objectives" (pp. 47-49) begins by pointing out that the flybys of Pioneer 11 and Voyagers 1 and 2 will complete the reconnaissance phase of Saturn investigation. COMPLEX then "anticipates that [follow-on] missions will have the following principal goals, in order of importance:

(1) Intensive investigation of the atmosphere of Saturn ...

(2) Determination of regional surface chemistry and properties of the surface features of satellites and properties of ring particles ...

(3) Intensive investigation of Titan ...

(4) Atmospheric dynamics and structure ...

... The comparative planetology of the satellites will also be of great interest

... The rings of Saturn are potential treasure-houses of information ...

"For these reasons, we consider it essential that NASA be in an adequate posture to initiate exploration of the Saturnian system in the middle 1980's following the reconnaissance of this system."

The present Workshop and report constitute an early step towards reaching this posture.

COMPLEX's omission of the magnetosphere was presumably intentional. Indeed, its outer parts can be expected to be similar to the corresponding regions around Jupiter. But the inner magnetosphere may be a different story. Even since

1975 we have increasingly realized the profound effects that charged-particle bombardment can have on Jupiter's inner satellites, particularly Io. Io emits vast quantities of sodium, sulfur, and presumably other materials into the surrounding space, most probably because of sputtering by energetic particles. Its ionosphere also is thought to be generated by particles rather than solar photons. Similarly, the gases emitted may be a major, even dominant, source for the magnetosphere. Though Titan lies farther from its primary than does Io, important effects in both directions are expected, and the influence on ring particles could be even more important. Thus, it seems to us essential to be able to explore the inner magnetosphere, both as a phenomenon in itself and as an aspect of the Saturnian environment. While we agree that all four of the COMPLEX goals are important, we add another:

(5) Exploration of the inner magnetosphere and its relationship to the rings and satellites.

It is desirable that a mission to Saturn contribute significantly to the study of all five goals.

Scientific Questions and Their Investigation

In this section we state what, in our view, are the most important questions concerning the various bodies and media in the Saturn system, and attempt to predict what the state of knowledge will be late in 1981, when Pioneer 11 and Voyagers 1 and 2 will have performed their flybys. Account is also taken of the likely progress in ground-based measurements, and the competition, even beyond 1981, from Earth-orbiting telescopes.

Study of the present state of the Saturn system is of great interest. Certain results have added interest because they bear on questions of history and origin, and they are highlighted. Since we did not discuss priorities between the various areas, they are arranged in decreasing order of mass.

Saturn The basic state of the atmosphere is described by its composition, temperature profile, and cloudiness. With this information, further questions, such as energy balance, mass transport, and condensation can be investigated; knowledge of the radiation fields is very helpful. We expect to find abundances of volatile elements similar to solar (or Jovian) values, but any deviations will be of particular interest.