Charles F. Lillie

THE MARINER JUPITER/SATURN PHOTOPOLARIMETER EXPERIMENT

I will discuss the observations of Saturn's rings we plan to make with our photopolarimetry experiment. I will consider only Saturn's rings, although, of course, we also have quite interesting scientific objectives that deal with the planets and their satellites.

The MJS photopolarimeter is basically a simple, general-purpose photometer which also has a capability for making polarization measurements. Figure 1 shows the instrument's location on the scan platform, boresighted with the television, ultraviolet spectrometer, and infrared spectrometer experiments.

Figure 2 illustrates the conceptual design of the instrument. It consists of a 6-in. Cassegrainian telescope, photomultiplier tube, aperture plate, analyzer wheel, and filter wheel. It is a simple instrument designed to make measurements of intensity and polarization at 7 wavelengths in the 2200 Å to 7300 Å spectral region.

The aperture plate provides four alternative fields of view, 4°, 1°, 1/4°, and 1/16° in diameter. The analyzer and filter wheels are shown in figure 3. Each wheel has eight positions. The filter wheel contains seven filters and a calibration source. The analyzer wheel contains a dark slide, an open position, and two sets of polarizing filters with different orientations so that we can make measurements of the polarization of light reflected from the rings of Saturn, for example. One set of polarizers is used for faint object measurements; the other set is combined with neutral density filters and is used for planetary observations.

James Pollack How many polarizer orientations will you have?

Lillie There are three orientations for each set of polarizers: 0°, 60°, and 120°. Our standard sequence is to make an open measurement and then three measurements through these polarizing filters.

We have tried to select filter band passes which isolate the various spectral features in the atmospheres of the outer planets. For example, at 2200 Å there is

University of Colorado.

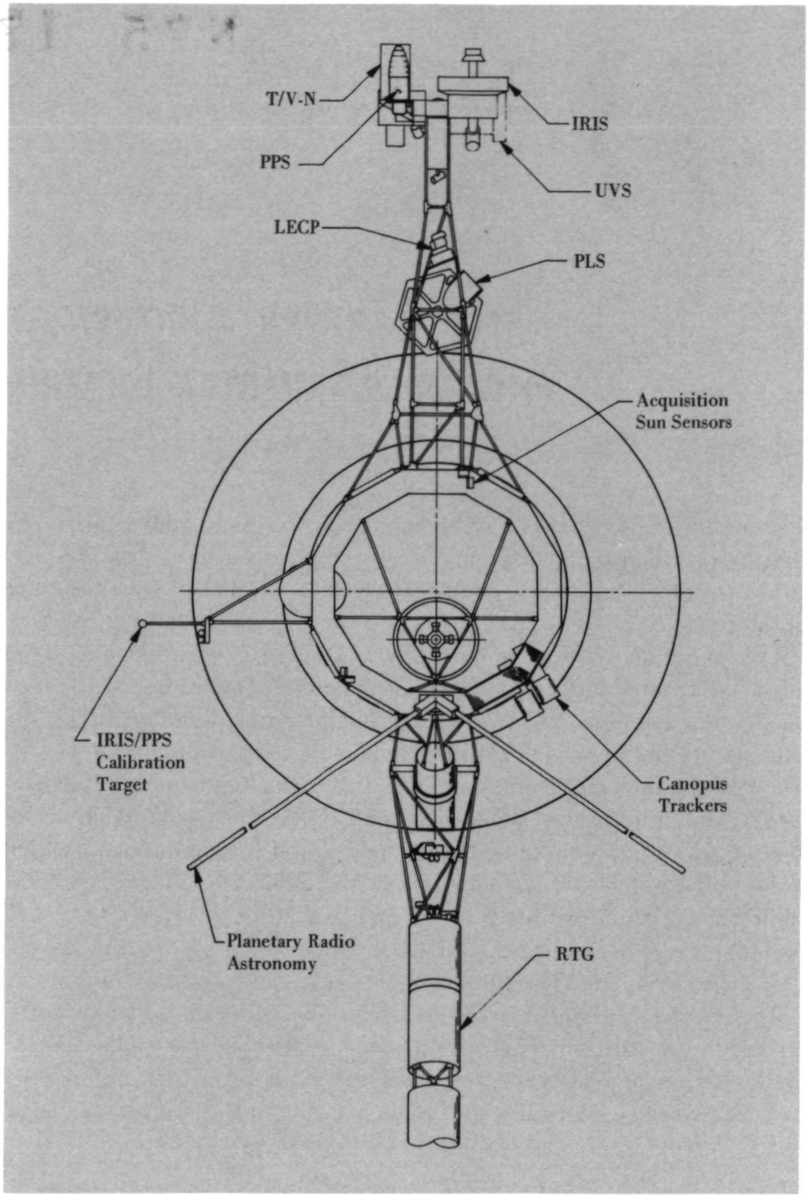

FIGURE 1.—*Spacecraft configuration showing location of photopolarimeter (PPS) on scan platform.*

an ammonia absorption edge, so the principal source of opacity in this band pass will be ammonia. The 7270-Å filter is centered on a methane absorption band, so it is selective for methane.

In light of what Jacques Blamont said (see preceding contribution), our 3150-Å filter is selective for OH emission at 3090, so we will have a sensitivity for OH if it is present near the rings of Saturn.

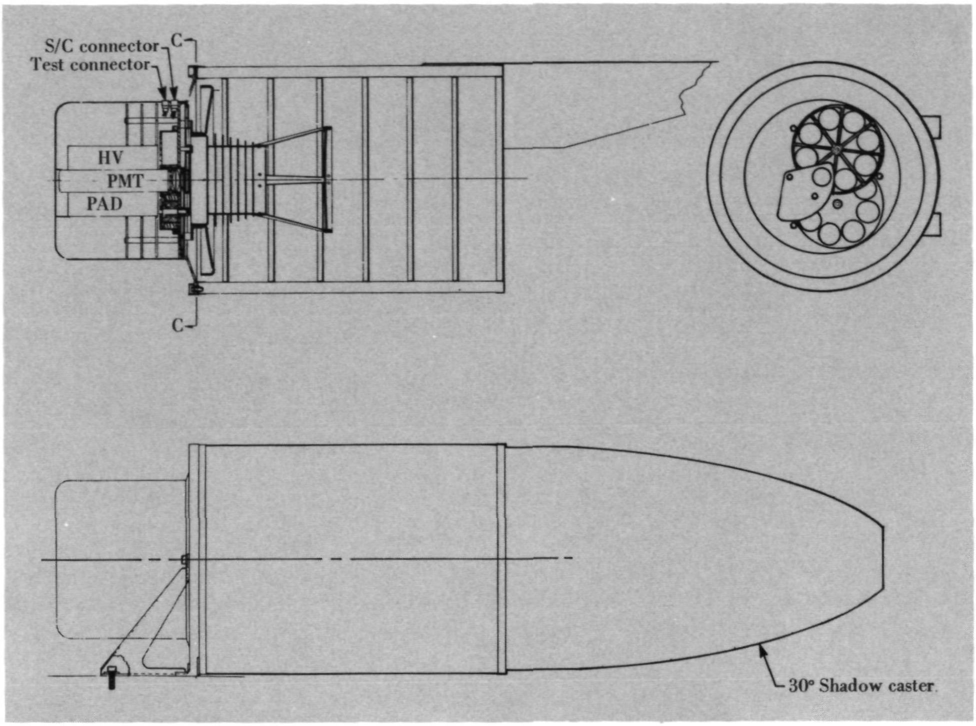

FIGURE 2.—*Conceptional design of photopolarimeter.*

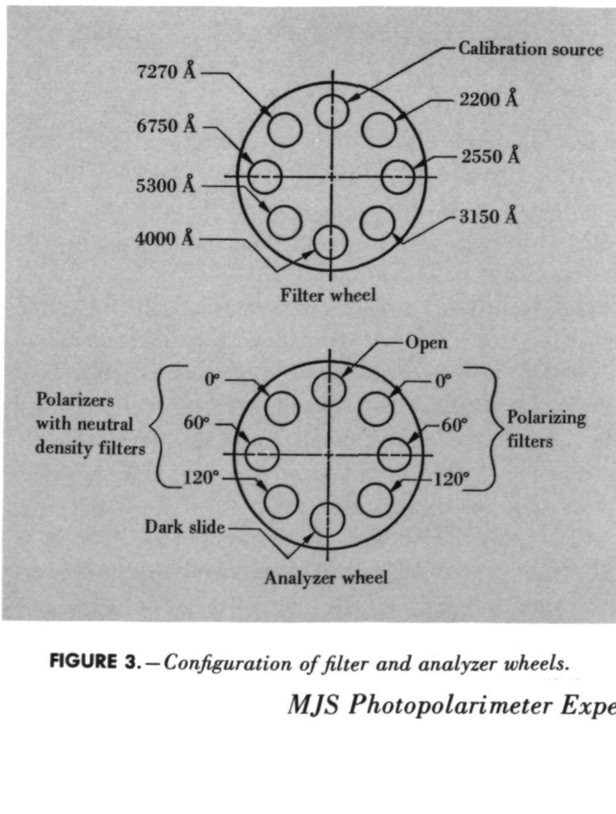

FIGURE 3.—*Configuration of filter and analyzer wheels.*

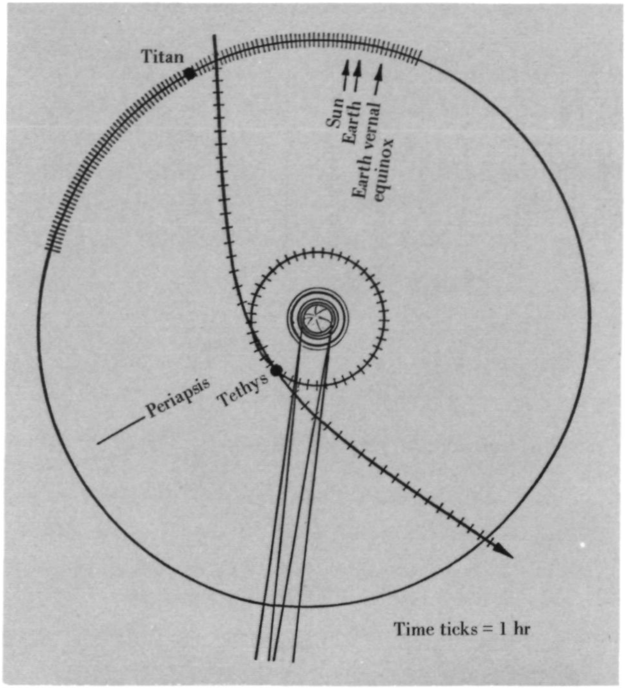

FIGURE 4.—*JSX from north pole of Saturn trajectory.*

Figure 4 shows the path of a sample trajectory (JSX) during encounter with Saturn. The unique thing about this experiment is not the instrument itself but the fact that it is on a spacecraft being sent to the vicinity of Saturn. This offers us the opportunity to make the same sort of measurements that we do from the ground, only in situ, with different geometries than those we can obtain from Earth and of course at much higher spatial resolution. The advantage of going to Saturn is demonstrated by the fact that at closest approach the spacecraft will be about 3600 times closer to Saturn than the Earth ever is. Thus, a feature that subtends an angle of 1 arc sec as seen from Earth will subtend an angle of 1° when seen from the spacecraft near Saturn.

We have the possibility of making observations with much higher spatial resolution, and the big, bright scattering disk that interferes with ground-based observations will be a long way from our field of view as we fly by the planet.

Figure 5(a) shows Saturn as seen from the JSX spacecraft at closest encounter minus 8 hr. Note the orientation of the rings and the view we will have. A 5°-wide-angle TV frame has been superimposed on the planet to give you an idea of the size of the planet as seen from the spacecraft. Our 4° field of view, of course, would fit just inside this wide-angle TV frame, and our 1/4° field of view would fit in about 20 times. At this time we would be able to make photometric maps of the surface brightness of the rings that would have a resolution better than the best ground-based observations. From about 10 hr before encounter to 10 hr after encounter, the resolution with our instrument with a 1/4° field of view is equivalent to a resolu-

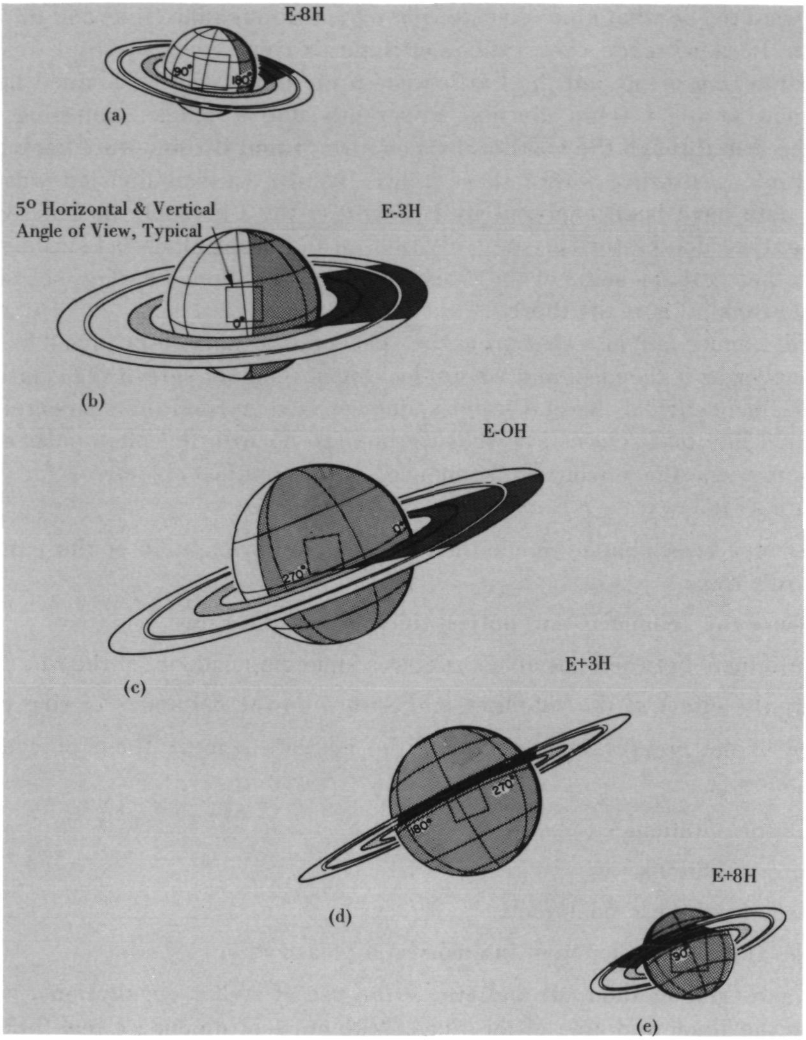

FIGURE 5.—*View of Saturn as seen from JSX trajectory.*

tion of better than half an arc second with a ground-based telescope.

Figure 5(b) shows the planet at encounter minus 3 hr. You can see the changing orientation of the rings and the difference in apparent size of the planet. Figure 5(c) shows the viewing geometry at closest approach and maximum apparent diameter of Saturn. In figure 5(d) you can see that we have crossed the ring plane (at about 5 R_S) and are now viewing the rings from the underside. We plan to observe the rings periodically during the encounter phase and to measure their surface brightness from various angles. We are particularly interested in observations during ring plane crossing when we see the rings on edge and then immediately following when the Sun is on one side of the plane and the spacecraft is on the other.

We want to see what kind of scattering we get through the rings and the Cassini division. Barnard made observations of Saturn's rings when the Sun was on one side of the ring plane and the Earth was on the other, and he noticed light condensations at the Cassini division, apparently due to single scattering of light from the Sun through the Cassini division. The A and B rings were dark because of multiple scattering within these rings, but the Cassini division was bright. These data have been analyzed by I. Ferrin at the University of Colorado, who found optical depths for Cassini's division on the order of $\tau = 0.14 \pm 0.09$, which implies that perhaps some of the "missing mass" mentioned earlier (see contribution by Franklin) is really there.

Finally, figure 5(e) is a view from the spacecraft at encounter plus 8 hr. Saturn gets smaller as it recedes, and we are looking at the dark side of the rings. This is the basic geometry of the encounter sequence as seen from the spacecraft.

I would like to discuss next what we hope to do with the photopolarimeter as we go through the encounter sequence. Our scientific objectives for Saturn's rings are as follows:

Determine size, shape, albedo, distribution, and orientation of the particles in Saturn's rings

Measure the geometric and optical thickness of the rings

Discriminate between possible structures and compositions for the ring particles

Study the effect of the satellites and Saturn on the dynamics of ring particles

Some of the measurements that will be made to achieve these objectives are listed below:

Stellar occultations

Solar occultations

Surface brightness photometry

Phase angle dependence of intensity and polarization

One powerful method, we believe, is the use of stellar occultations, primarily through the shadowed area of the rings. With our instrument we feel that we can make a measurement every 64th of a second on stars as faint as $V = 4^m$. We will be able to determine the optical depth of each of the rings as a function of wavelength, and we will be able to say something about particles with radii smaller than 10 μm.

Hugh Kieffer What is the noise limit or digitization limit for a fourth-magnitude star—just a rough estimate?

Lillie We get a signal-to-noise ratio of 10 when we look at an eighth-magnitude star.

Kieffer The limit is noise rather than digitization?

Lillie That's right, we are using a pulse counting system for the detection of photometric events.

Jacques Blamont Isn't the limit set not by the instrument noise but by the scattered light from the rings?

Lillie Yes. We must worry about the baffling of the instrument so that we reject light from the disk of Saturn, even though it is quite a bit off axis, and from the bright portion of the rings. The stellar occultation measurements will very definitely have to be made through the dark side of the rings.

James Pollack How accurately can you measure polarization?

Lillie Our objective is a precision of 0.5 percent. We believe we have demonstrated that we can achieve this accuracy.

We also hope to make observations of solar occultations by looking at a target on the spacecraft to measure variations in the solar flux reaching the spacecraft when it is in the shadow of the rings.

As we approach the planet, we plan to map the surface brightness of the rings in seven band passes and to determine polarization as a function of wavelength. We do not expect to be able to make complete maps of the rings at all phase angles, but we do hope to select areas in the rings for which we follow the intensity variations and the variations in polarization as a function of phase angle as we sweep by the planet.

In addition to getting the wavelength dependence of the optical depth, we also hope to be able to say something about the size of any large particles by observing their Fresnel diffraction patterns. At a distance of about 50 000 km, we feel that we will be able to see the Fresnel diffraction pattern from any particles larger than about 5 m.

Brad Smith Do you have the time resolution necessary for that measurement?

Lillie A 64th of a second should be sufficient. The instrument has the capability of making more rapid observations. The way the instrument is designed, the integration time is specified by the flight data system, and the format we have specified at present calls for a 64th of a second, but that is a variable and can be adjusted.

Smith That is a tough measurement. The size of the Fresnel zone would be small and the relative velocity large.

Pollack The Fresnel zone you are speaking of is from individual ring particles.

Lillie Individual ring particles occulting a star, for example.

Pollack I don't quite understand, how do you separate that from all the other ring particles?

Lillie If there are particles on the order of tens of meters in diameter, they should individually occult the star. If there is a superimposition of the Fresnel diffraction patterns, you have a modeling problem, but presumably you can get the rate at which these events occur, make a model that assumes a characteristic size for the particles, and fit that to the fluctuations in the signal from the star.

Robert Murphy That is going to be on the order of 60 Hz if you go to the extreme of large particles.

Lillie In situ measurements have the following advantages:

Phase angle coverage

Dark sky background

High spatial resolution

Extended wavelength coverage

I would like to elaborate a little bit about the dark sky background with respect to some of the remarks made yesterday about the surface brightness of the D′ ring, which may or may not be there. We are going to reduce the surface brightness of the night sky quite a bit just by going out there. As seen from Earth, the surface brightness of the night sky is principally due to air glow and the zodiacal light, neither of which will be a factor when we get to Saturn. Putting some numbers on these parameters, the air glow contributes about 150 $S_{10}(V)$, where 1 $S_{10}(V)$ is the surface brightness equivalent to one 10th-magnitude visual star per square degree. The zodiacal light contributes about 200 $S_{10}(V)$, and integrated starlight contributes about 30 $S_{10}(V)$ if the galactic latitude is greater than 40°, which should be the case for some flyby geometries.

Thus, from the ground, we see a sky brightness of about 380 $S_{10}(V)$ or about 22.5 magnitudes per square second of arc. Without the contributions of air glow and zodiacal light, the sky brightness at Saturn is only about 8 percent of that on Earth, a decrease of 2.8 magnitudes.

Thus, the sky background is going to be about 25.3 magnitudes per square second of arc, the darkest sky we are apt to get until we get out of our galaxy. Kuiper (1973) has measured a surface brightness of 15 magnitudes per square second of arc for the D′ ring, which seems to be at or very near the limit of ground-based capability, primarily due to scattered light from Saturn. If this really represents a signal-to-noise ratio of 1:1, then, with our instrument using the large field of view, we have the same signal-to-noise ratio when we are looking at a surface brightness of about 30 magnitudes per square second of arc. It seems the D′ ring as we fly by Saturn is going to seem exceedingly bright as compared to the weakest signal that we can detect with this instrument.

It is of interest to note that, with our 4° field of view and an integration time of about 1 min, the threshold of detectability at a signal-to-noise ratio of 10:1 is about 1.5 10th-magnitude stars per square degree, which is the predicted level of the cosmic sky background due to external galaxies in the field of view of our instrument. Thus, in the vicinity of Saturn, another objective of our experiment is to measure the contribution of the extragalactic light to the sky background, or at least to set upper limits on it.

These basically are the observations we plan to make with the photopolarimeter. With polarization data, we are going to be able to say something about the properties of particles in the rings. We should be able to determine particle shape as being spherical, irregular, or of a regular crystalline form. In the case of spherical particles, we should be able to find accurate values of the mean particle refractive index. For nonspherical particles, it will be possible to distinguish between particles that are larger than, on the order of, or smaller than the wavelength of the scattered light. It will also be possible to confirm or reject particular particle shape and refractive index possibilities such as ice crystals.

In the case of large particles several meters in diameter, it should be possible to say something about surface texture and the composition of any coatings. If their surface resembles that of Phobos and Deimos, we should be able to determine that and to derive an albedo from the polarization data. There is a definite relationship between the phase function of polarization and the geometric albedo of the asteroids so that from the polarization-phase-function diagram you can find the albedo of particles directly.

In summary, by going to the vicinity of Saturn, the photopolarimeter experiment will be able to repeat the classical observations and extend them to shorter wavelengths with larger phase angle coverage at higher spatial resolution than has been possible heretofore from the ground.

DISCUSSION

James Pollack You say that you thought you could get refractive index information even if the particles were irregular? How is that possible? For a spherical particle, you have Mie theory to compare your answers against. What do you have to compare your answers against for nonspherical particles?

Charles Lillie I meant to say it would be possible to confirm or reject certain particular particle shape and refractive index possibilities. In other words, if you assume a particular particle like a solid ammonia crystal or an ice crystal, which has an index of refraction associated with it, you can reject certain combinations.

Walter Jaffe Is there a program for this instrument of general astronomical observations before the encounter?

Lillie We do have a target-of-opportunity program associated with the MJS mission plan. During cruise, certain selected objects will be observed for calibration purposes.

Brad Smith We have a request for a target-of-opportunity program.

Lillie The program is still under negotiation. I assume that it is going to be accepted. If it is, we will be making observations of planets other than Jupiter and Saturn, and there will be some observations of stars for calibration purposes.

Jaffe I was also thinking of extragalactic, very low-surface-brightness objects.

Lillie We are interested in making observations like that. Whether they will be in the timeline for the spacecraft is not clear at this time.

REFERENCE

KUIPER, G. P.: The Origin of the Solar System, Part I. Celestial Mechanics, in press.