OBSERVING THE ICY JOVIAN SATELLITES WITH THE GALILEO PHOTOPOLARIMETER RADIOMETER INSTRUMENT

L. K. Tamppari (1), J. R. Spencer (2), T. Z. Martin (1)

(1) Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91109

(2) Lowell Observatory, 1400 Mars Hill Road, Flagstaff, AZ 86001

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Address Correspondence to:

Leslie K. Tamppari

Jet Propulsion Laboratory

4800 Oak Grove Dr.

Mail-Stop 264-765

Pasadena, CA 91109

Telephone: (818) 393-1226

FAX: (818) 393-4530

internet: ltamppari@gllsvc.jpl.nasa.gov

ABSTRACT:

The Photopolarirneter/Radiometer (PPR) instrument aboard the Galileo spacecraft will go into orbit around Jupiter in December, 1995. The 23 month tour offers PPR four Gan ymede encounters, three Callisto encounters, and three Europa encounters with maximum PPR resolution varying from 0.5 ktn to 8 km and typical resolution of 200 km. In addition, there will be one Ganymede, one Callisto, and two Europa 'non-targeted' encounters giving maximum PPR resolution from 58 km to 200 km with a typical resolution of 300 km. There is a single Io encounter before Jupiter orbit insertion that will provide resolutions ranging from 400 km to 2.5 km, and numerous subsequent opportunities to observe Io with resolution as good as 600 km. The PPR will be used to study the polarization of reflected sunlight from each satellite over a wide range of phase angles. It will also map daytime and nighttime surface temperatures to look for spatial variations in thermophysical properties, study volcanic activity on Io, and look for possible endogenic thermal activity on Europa. These observation plans are presented.

1. INTRODUCTION

The Galileo spacecraft will arrive at Jupiter on December 7, 1995 to commence its nearly two year tour of the Jovian system [*Byrnes and Johannesen,* 1994]. In addition to studying the magnetosphere and Jupiter's atmosphere, the spacecraft will study the Galilean satellites in much greater detail than that provided by the Voyager flyby encounters. For more details on the Galileo mission see Johnson, *et* al., 1992. The Photopolarimeter Radiometer (PPR) instrument is one of the four scan platform remote sensing instruments aboard the Galileo spacecraft [Russell, et *al.*, 1992]. The PPR has been designed to perform precision photometry, polarimetry, and long wavelength (17 -110 μm) radiometry. It was designed primarily to study the Jovian atmosphere and those objectives are described by Russell, *et al.*, 1992.

The expected data return from Galileo is now smaller than that originally envisioned due to the incomplete deployment of the high gain antenna. However, the PPR instrument will return satellite data sets with better spatial resolution and coverage than Voyager. This is being accomplished partly by the addition of new processing algorithms which are discussed below. The experiment data return strategy now favors global coverage at good resolution, but with fewer wavelengths used for each type of observation. The PPR will also return less data from collaborative observations with other instruments, called "ride-along" observations. The choice to play back some of these data can be made once telemetry capability is known.

The data products we intend to produce will, in general, be two dimensional images or contour maps for the thermal data. The polarimetry and photometry data will be produced in the form of phase and brightness curves.

This paper gives a comprehensive presentation of the Jovian satellite objectives and observation designs from the PPR perspective. W e will first give an overview of the PPR instrument characteristics followed by the operational aspects to be used during the Jupiter tour, including enhancements designed for the low-rate telemetry environment. The satellite observational plan and background science will be given next, followed by the observation detail.

2. OVERVIEW OF THE PHOTOPOLARIMETER RADIOMETER (PPR) INSTRUMENT

Since a complete description of the PPR instrument was presented by Russell *et al.*, 1992, only a brief overview is given here. The PPR resides in a position on the scan platform of the Galileo spacecraft that allows the PPR to view the largest phase angles of any scan platform instrument. The upper phase angle limit for the PPR is 1 S5° when the spacecraft is sun pointed. This limit, imposed by the spacecraft sunshade, depends on the sun-earth separation; the spacecraft is normally earth-pointed which is a maximum of 12° off sun. All other scan platform instruments are obscured by the sunshade at lower phase angles. This placement enhances the PPR's ability to observe the night side of the target body which is one of our major objectives. The field of view (FOV) of the PPR is circular with a 2.5 mrad diameter.

The PPR is a hybrid instrument designed to accomplish both precision photometry and radiometry. Table 1 shows the wavelength coverage afforded by the 23 filter positions on the rotating filter wheel [*Russell et al.*, 1992]. As shown, the instrument has three distinct functions: polarimetry, radiometry, and photometry.

The radiometry mode utilizes the PPR's two telescopes: the scene view and the space view. A chopper, operating at 30 Hz, alternately directs the flux from the scene and space view telescopes onto the lithium tantalate pyroelectric detector. The radiometry data which will be sent to the ground will have the space view signal subtracted from the scene view signal. To aid in determining the correct brightness temperature of a relatively cool target which was measured by a relatively warm instrument, the PPR contains ten internal thermistors on different optical elements.

For both photometry and polarimetry, the scene view flux passes through the filter and then through a Wollaston prism that gives two spatially separated and orthogonally polarized beams. These beams are then detected by two silicon photodiode detectors. In addition, the polarimetry filters include a halfwave retarder. Since one light beam is split by the Wollaston prism and directed to two detectors, a simultaneous signature in both detectors may be used as a powerful means of determining a real signal from noise.

3. PPR OPERATIONS DURING THE JUPITER TOUR

The PPR instrument has five modes of operation: Cycle mode (CYCLE), Radiometry (RAD), Photometry/Polarimetry (PP/PH), Photometry (PHOTOM), and Position Select (POS SEL). Referring to the filter order shown in Table 1, CYCLE mode wil 1 cycle through all the filters, RAD mode will cycle from the 17 μm filter through the solar+ thermal filter and back, PP/PH mode will skip over the Radiometry filters, Photometry mode will cycle from the 618.7 nm filter through the 891.8 nm filter and back, and finally, POS SEL mode allows selection of any filter position. In the POS SEL mode, it is possible to command one, three, or five additional positions. In every mode, it is possible to vary the number of samples taken while in a particular filter position before stepping to the next one.

As a result of the Galileo mission being performed with the low gain antenna [*O'Neil et* al., 1993], there are two additional and highly constrained data collection resources. The first is the number of telemetry bits received on the ground and the second is space on the tape recorder. During each orbit, the tape recorder will be filled only once during the Jupiter/satellite encounter period and subsequently played back during the cruise portion of the orbit.

To compensate for these constrained resources, changes are being made to the Galileo Command and Data Subsystem (CDS) to enhance the PPR data return. The most significant change is the PPR Burst Mode capability, which enables PPR to return a much larger amount of data than would otherwise have been possible. It allows pre-editing of the PPR data to delete redundant data that the CDS would normally collect from the PPR instrument. This redundancy arises from repetitive CDS sampling of the PPR data during a PPR cycle. The deletion of redundant data results in more observation time for the same number of telemetry bits to ground. The edited data are then saved in a buffer in the CDS; once filled, it "bursts" the data to the tape recorder at 7680 bits per second (the lowest tape record speed). Since the nominal bit rate of the PPR is only 216 bits per second of the 7680, it is clear that this is a large savings in tape. Another important capability that is being added to the CDS is the ability to perform lossless compression on the PPR data. When the data are read from the tape recorder into the CDS in preparation for downlink, an algorithm known as Rice Compression [Rice, 1993] will be performed on the data. It is estimated that this algorithm will give an average of 1.3:1 compression of the PPR data.

4. PPR SATELLITE OBSERVATIONAL PLAN

4.1 Icy Satellites

The PPR instrument will observe each of the four Galilean satellites but first we will concentrate on the observations of the icy satellites: Europa, Ganymede, and Callisto. The Galileo two year Jupiter tour allows several 'targeted' encounters (defined as closest approach distance of 200-3,100 km): four Ganymede, three Callisto, and three Europa. These close encounters are used for gravity assists. In addition, it offers a few 'non-targeted' encounters (defined as a closest approach distance of 23,000 - 80,000 km): one Ganymede, one Callisto, and two Europa. Table 2 shows the orbit number and designation along with the targeted satellite, non-targeted satellite and Galileo's altitude at closest approach in each case. Although detailed planning of the observations has started, there will be time allowed (starting six weeks prior to each orbit encounter) to accommodate small changes based on knowledge gained from returned data,

Below, we will review our current knowledge of the thermal and polarimetric properties and discuss how Galileo will contribute to extending that knowledge.

4.1.1 Thermal Properties

Our knowledge of the thermal properties of the icy Galilean satellites is derived from a combination of groundbased and Voyager radiometric observations. The thermal emission of the satellites in the 10 and 20 μm windows has been studied extensively from the ground, both in sunlight [*Gillett et al.* 1970, *Hansen* 1972, *Morrison et al.* 197 *2]* and during eclipse by Jupiter *[Morrison and Cruikshank, 1973, Hansen* 1973]. Sunlit observations have shown brightness temperatures consistent with known albedos and diameters, under the assumption of instantaneous equilibrium with sunlight.

Observations of entry into and exit from Jupiter's shadow have shown unexpectedly rapid initial cooling of the surface, interpreted as being due to a thin, remarkably low thermal inertia surface layer overlying a more thermally conducting substrate, though models in which the high and low thermal inertia materials are spatially segregated can also fit the data [Spencer, 1987]. It is also possible that the eclipse cooling is influenced by the fact that some of the absorbed solar energy may be deposited below the immediate surface, forming a "solid-state greenhouse" [*Matson and Brown, 1'389]*.

Hundreds of spatially resolved 8-50 μm thermal infrared spectra of the icy satellites were obtained by the Infrared Interferometer Spectrometer (IRIS) instrument on the Voyager spacecraft in 1979, with a best spatial resolution of 270 km, on Ganymede [*Hanel et al.* 1979]. These data show good correlation of temperature and albedo on Ganymede, and the diurnal temperature variations are consistent with the ground based eclipse observations [*Spencer*, 1987]. Equatorial nighttime temperatures drop to 75-90 K on Ganymede and Callisto. Despite the very high S/N of the data and the presence of water ice spectral features in this wavelength range, no structure is seen in the spectra. However, the spectra are not simple blackbodies and show a brightness temperature that increases at shorter wavelengths (the "spectrum slope"), as expected if unresolved temperature contrasts are present in the field of view. On Callisto the spectrum slope increases dramatically from the subsolar point towards the terminator, probably because the apparent unresolved temperature contrasts are clue to topography which produce large temperature variations at low sun angles, but on Ganymede there is little dependence of spectrum slope on solar-incidence angle. This probably indicates a smoother surface at relevant spatial scales (centimeters to kilometers) on Ganymede than Callisto. However, near the subsolar point, spectrum slopes on Ganymede are higher than on Callisto, suggesting another source of unresolved temperature contrasts on Ganymede. A likely explanation is the presence of cold, bright, ice-rich and warm, dark, ice-poor surface units on Ganyrnede, intermixed at scales below Voyager imaging resolution, possibly caused by thermal segregation of dirty water ice [Spencer, 1987b].

There has been one intriguing observation of possible endogenic thermal emission from Europa: an apparent sixfold increase in 4.8 μm flux on one night in April 1981 [*Tittemore and Sinton,* 1989]. This has not been confirmed by other observations, however, and recent attempts by *Goguen et al.*, to detect short-wavelength thermal emission from Europa in Jupiter eclipse have placed severe upper limits on the amount of warm material exposed on Europa's surface at the time of the observations [*J. Goguen,* personal communication].

The PPR thermal observations of the Galilean satellites are designed to complement the Voyager observations. PPR has poorer spectral resolution and coverage than the Voyager IRIS instrument, but better spatial resolution and coverage. Voyager performed only a cursory examination of nightside temperatures on the Galilean satellites and obtained very poor coverage on Europa. We will therefore concentrate our efforts on the following areas: daytime and nighttime thermal mapping, evaluation of the anisotropy of thermal emission, and high resolution samples.

Regional mapping of daytime thermal emission on Ganymede and Callisto will be performed with better spatial resolution than Voyager, but in one filter only in order to maximize coverage. Complete coverage of the daytime hemispheres will often not be possible: we will concentrate on high-resolution maps of selected regions to look for correlations between surface temperature, and thus surface thermophysical properties, and surface geology. Thermophysical properties such as thermal inertia are controlled by surface grain size and compaction, and may provide useful geological information. Determination of surface temperatures is also important for evaluating volatile stability. Figures 1 and 2 show maps of Ganymede and Callisto along with the dayside longitudes available for the higher resolution encounters.

Global mapping of daytime thermal emission from Europa will be done as well. Europa was poorly mapped by Voyager and has more potential for interesting variations in surface thermophysical properties than Ganymede or Callisto. This is due to its complex, geology and the possible absence of an impact regolith on its young surface. We will map the entire daytime hemisphere, using multiple wavelengths to look for unresolved temperature contrasts. Figure 3 shows a map of Europa along with the available dayside longitudes.

Global mapping of the nighttime thermal emission will be done for all three icy satellites. We will use multiple wavelengths to look for unresolved temperature contrasts. The night hemisphere gives our best chance to look for endogenic thermal emission on Europa, because contrast with the surrounding passively-heated surface will be maximum at night. Nighttime temperatures also show the most sensitivity to thermal inertia variations. We will aim to map as many nighttime longitudes as the tour provides (Figures 1, 2, and 3) on each of the icy satellites.

Evaluation of the anisotropy of thermal emission is important since the Voyager INS data showed a brightness temperature decrease of about 5 K between 30° and 60° phase [*Spencer,* 1987]. To determine the kinetic surface temperatures from the derived brightness temperatures, it will be necessary to put constraints on the anisotropy of the thermal emission. The PPR will map thermal emission from a selected region on each satellite at the same time of day but different phase angles to accomplish this objective.

The Galileo Jupiter/satellite tour also offers the opportunity to measure the thermal emission from a few regions with very high spatial resolution (0.7 - 20 km) near closest approach. These samples will measure local variations in surface temperatures, providing an additional tool for studying variations in surface thermophysical properties and volatile movement, In addition, this will provide a high resolution search for small sources of endogenic heat on Europa.

4.1.2 Photopolarimetric properties

Both Voyager-based and earthbased photometric and polarimetric studies have provided a lot of information about the properties of the Galilean satellites that affect their surface light scattering. For example, hemispheric differences in the surface texture of Europa are assigned to the effects of magnetospheric bombardment [*Burratti et al.,* 1988]. Polarization work by various investigators suggests a dusty surface on the leading side of Callisto [e.g., *Mandeville et al.,* 1980]. Thus, another scientific objective is to investigate the surface optical properties, including the al bedo, refractive index and surface texture, for a variety of terrain types. *Hapke* has shown [1993] that, for phase angles in. the range from about 30° to 80°, the difference between the absolute reflectance for orthogonal polarizations is largely dependent on the refractive index. Such an observation is of particular interest for Io, where distinguishing between sulfur and silicate materials may be possible. This goal is addressed by a PPR observation at the closest approach to Io prior to orbit insertion.

Mapping of specific areas at phase angles about twice the Brewster angle should provide information on icy surfaces. This angle, where polarization is expected to be maximal, enables determination of whether that ice has a glazed or rough texture at the scale of the wavelength employed. Such observations will be planned for regions of contrasting albedo or terrain type.

Satellite photopolarimetry observations at a variety of phase angles are planned for each Galilean satellite in order to fill out the phase curves obtained by cart.hbased observers, up to 12°, and beyond that range by Voyager [e.g., *Buratti,* 1991]. These observations use a single wavelength (678 nm) but additional filter\ retarder positions to determine the complete set of Stokes parameters [*Russell et al.,* 1992]. Such data can. be interpreted to yield particle scattering characteristics and state of compaction and roughness for the optically active surface layers. Particular attention will be given to the signature of water crystals near 42° phase angle [*Goguen,* 1994], and the low-phase negative polarization minima defined by terrestrial observers [*Veverka, 1977*]. As many as a dozen SATPOL observations are done during each encounter period, for what ever phase opportunities are available, under the condition that the PPR field of view be readily contained within the lit side of the body. Added polarimetry observations up to about 150° phase may be done when the satellite is smaller than the PPR field of view. The set of attainable phase angles is detailed in Figure 4. It won't be possible to obtain phase curves for discrete types of features on the satellites, because the observing time near closest approach periods, when PPR has adequate resolution, is in very high demand.

4.2 Io Observational Plan

The PPR observational plans for Io are included here for completeness. The Galileo tour provides one close approach to Io (1000 km) which occurs several hours before the Jupiter Orbit Insertion (JOI) maneuver on December 7, 1995. Due to the intense radiation at that distance from Jupiter, this is the only close flyby to Io planned for the mission. There are, however, distant Io encounters on other orbits, with Io subtending between 2-6 PPR fields of view. The infrared science goals of the PPR at Io fall into two categories: study of volcanic thermal emission and study of the temperatures and thermophysical properites of the passively-heated surface. These are discussed separately below.

4.2.1 Volcanic Thermal Emission

The Galileo Near Infrared Mapping Spectrometer (NIMS, see related article, this issue) and PPR instruments provide complementary information on Io's volcanic hot spots: the NIMS 1-5 μm wavelength range is sensitive to surface materials at temperatures above about 250 K, while the PI?R 17-50 μm range is sensitive to cooler surface materials that may account for most of the volcanic heat flow [*McEwen, et al.*, 1992, *Johnson, et al., 1984*]. Unfortunately, a large fraction of the volcanic thermal radiation is emitted in the 5-17 μm gap between the two instruments. This gap can be bridged to a limited extent by differencing fluxes received in a "wide open" PPR channel that includes all reflected sunlight and thermal emission and a second channel which covers the 0.3-4 μm region.

Measurement of Io's total volcanic heat flow is a major goal of the PPR observations. Current estimates of this geophysically important parameter are hampered by two things: limited spatial coverage in the case of the Voyager IRIS observations [*McEwen, et* al., 1992] and the problem of subtraction of passive thermal re-radiation of absorbed sunlight in the case of groundbased disk-integrated measurements [*Johnson, et al.*, 1984]. Passive thermal emission is greatly reduced during Jupiter eclipse observations [*Sinton and Kaminski*, 1988], but only the Jupiter-facing hemisphere of Io can be studied from Earth in this way.

During the 1000 km Galileo flyby of Io, PPR observes the anti-Jupiter hemisphere. This flyby provides a unique opportunity to study the heat flow from this hemisphere, using the high spatial resolution to improve discrimination of volcanic radiation and passive thermal radiation. Global scans are planned for this purpose, and these will also provide information on the distribution of heat flow with latitude and longitude. Statistical information on smaller and lower temperature volcanic sites, which may contribute significantly to global heat flow, will be otainable from partial coverage at higher resolution.

Nightside observations are especially useful for heat flow studies since the passive surface temperature drops from c. 125 K to c. 90 K which increases the contrast and detectability of hot spots. High-resolution observations of 10’s night side will be limited to 15 minutes after closest approach. However, this should allow time for a study of small and hopefully representative areas at very high resolution. In addition, disk-integrated and lower resolution observations of the night side will be possible throughout the Jupiter/satellite tour. Some of these lower resolution observations will be performed during eclipse by Jupiter. These will be especially useful for heat flow information since the thermal contribution from the sunlit crescent will be greatly reduced.

PPR can also provide volcanological information for specific volcanic sites seen at high resolution. PPR observations will shed light on topics such as the cooling rates of plume particles, the temperature distributions at plume sources or active fows, and the correlation of volcanic activity with morphological features. The known volcanic centers that will be observed at high resolution include the Voyager-era plume sites Prometheus, Amirani/Maui, and Volund. The hot spot "Kanehekili," seen in recent ground-based infrared images of Io [*Spencer, et al.*, 1990, *Spencer, et al., 1992*], will be observed on the night hemisphere at high resolution immediately after closest approach.

Of particular interest are the infrequent high-temperature outbursts seen in ground-based radiometry [e.g., *Johnson, et al.*, 1988]. The locations, characteristics, and mechanisms for these outbursts are very poorly known, and frequent monitoring of 10 during the two-year orbital tour, in conjunction with NIMS, will be important for detecting and understanding these dramatic events.

4.2.2 Passive Thermal Emission

Io's passive thermal emission is interesting in its own right. Observations of surface temperatures away from obvious volcanic centers will constrain the thermophysical properties of the surface. Most of the surface appears to be covered by very low thermal inertia material [*Morrison and Cruikshank, 1973*, and *Sin ton and Kaminski, 1988*], but the surface is very heterogeneous and regions such as young lava flows without pyroclastic cover may have higher thermal inertias, and may show up as "cold spots" in daytime observations because they will warm up more slowly during the day than surrounding regions. Direct measurements of the temperatures of the extensive equatorial SO_2 deposits of Colchis Regio, on the anti-Jupiter hemisphere, will also be important for understanding the distribution and stability of Io's atmosphere.

Nighttime surface temperatures are a strong constraint on surface thermal inertia, and nighttime observations of the surface between the hot spots will also have high priority.

An understanding of passive thermal emission will also help with the problem of separating passive and active thermal emission from Io, and will thus assist in the evaluation of 10's heat flow.

5. SATELLITE OBSERVATION DESIGN DETAIL

5.1 Icy Satellite Observational Strategy

In general, the PPR will scan approximately along a latitudinal band, and will "flyback," or slew very fast, to begin the next scan. In many cases, the design will have 50/50 coverage, i. e., 50% overlap from field of view (FOV) to field of view and 50% overlap from scan to scan. The map will also cover the area of interest plus another half of a field of view or so to allow for scan platform pointing uncertainty. The following sections will give details on each of the observation types.

5.1.1 Darkside Thermal Maps (DRKMAP)

This observation will obtain as near to global nighttime coverage as the tour provides for each of the satellites. In general, we will select one radiometry filter with one additional position commanded. Typically, the filter choice will be 27 μm and >45 μm, and each filter will sample four times before stepping to the next. The time to take four samples with the 27 μm filter and four with the >45 μm filter including the filter stepping time is 4.1.3 seconds. This 4.13 sec cycle time between plotted fields of view (Figure 5) is the way in which we design the percentage of overlap from FOV to FOV. The resolution for these observations will be typically 220 km.

5.1.2 Dayside Global and Regional Thermal Maps (DGTM, DRTM)

On Europa, we will obtain as much coverage at all longitudes as the tour permits. For Ganymede and Callisto, we will obtain nearly global coverage, but due to spacecraft resource limitations, we may not obtain all longitudes provided by the tour. Consequently, we would obtain 'regional' maps. These thermal maps will be done in at least one thermal filter, typically 27 μm, with the possible addition of one other thermal filter if observing time and resources permit. Thus, the cycle time is either 0.5 sec for one sample in one filter or 4.13 sec for four samples in each of two filters plus stepping time. This observation will nominally be done at less than 30° phase and a resolution of 220 km.

5.1.3 Thermal Phase observations (TPO)

These observations are planned to be done once during the tour for Ganymede and Callisto and twice for Europa. Nominally, each TPO set will consist of three observations of the same longitude region at different phase angles. The phase angles are approximately 30, 60, and 90°. A typical resolution will be 110 km for Europa and Callisto and 240 km for Ganymede. We will nominally select one radiometry filter, 27 μm, with a cycle time of 0.5 seconds.

5.1.4 Polarimetry Phase Observations (PPO) and Satellite Polarimetry (SATPOL) Observations

The polarimetry phase observations will be very similar to the TPO observations (i. e., typically 110 km for Europa anti Callisto and 240 km for Ganymede). The data will result in maps of the same longitude region at two widely spaced phase angles. This observation will be done once for each icy satellite during the tour. The SATPOL observations will consist of a single scan across the disk or a small mosaic. Typically, the target body will be slightly larger or slightly smaller than the PPR field of view (Figure 6). In other words, these observations may vary from disk integrated up to several PPR fields of view across. The observations will span 0-180° phase with 5° resolution. A set of these measurements will be obtained for each of the icy satellites providing complete phase curves of both photometric and polarimetric parameters. The PPR will be commanded to a polarimetry position with five additional positions selected, (to get the complete polarization information). This choice has a cycle time of 3.0 seconds.

5.1.5 High Resolution Samples (HIRESS)

The radiometric High Resolution Sample (0.7 to 20 km) data set will consist of one or more observations taken near each targeted satellite closest approach. This observation set can consist of targets of opportunity, i. e., it may follow the ground track as the spacecraft flies by the satellite. The set can also be a small PPR dedicated map of a particular region of interest, or a ride-along map with another scan platform instrument, the Near Infrared Mapping Spectrometer (NIMS), [*Carlson et* al., 1992], in particular. A ride-along observation with the NIMS instrument will typically have a much slower scan rate than the PPR requires and will also give incomplete coverage, as the NIMS slit is 5 times the PPR diameter. The PPR will be commanded to one radiometry filter, typically 17 μm, with a cycle time of 0.5 seconds.

5.2 Io Observation Strategy

Since there is only one close approach to Io for the entire Jupiter/satellite tour, we will separate the Io observations into two parts: close encounter and orbital tour.

5.2.1 Io Observation Strategy: Close Encounter

During the single close Io encounter in December 1995, we will carry out global and regional thermal mapping with the best possible spatial resolution. A combination of dedicated PPR scans and "ride-along" sequences designed for other instruments will be used.

5.2.1.1 Global Observations

There are two PPR dedicated global observations planned (Figure 7). These are both of the anti-Jupiter facing hemisphere. The first starts at about -3.5 hours from closest approach. It is performed in RAD mode (24.8 second cycle time) and has 42S km resolution, The second starts at -1.25 hours, is performed in a single 17 μm filter (0.5 second cycle time), and has 130 km resolution. Each has edge to edge field of view coverage for that cycle time. For comparison, the Voyager IRIS instrument obtained only about 60 spectra with a spatial resolution better than 270 km, providing very incomplete surface coverage.

5.2.1.2 Partial Coverage Observations

The PPR will obtain partial coverage while riding along with the NIMS instrument since the length of the NIMS field of view is 4 times the PPR diameter. One of these maps will be in RAD mode while the other is in the 17 μm filter.

In addition, there are several observations of specific known hot spots on Io (Figure 7). The PPR will have several scans across the Prometheus region in RAD mode (62 km resolution), as well as scans across the Colchis Regio (14 km resolution) and Volund (15 km resolution) regions in the 17 and 21 μm filters. The Amirani/Maui region will be scanned at 32 km resolution in the 17 μm filter as well.

Within several minutes near closest approach, 10 passes through a large range of phase angles; a 6 km resolution PPR observation near -1/141 lat/lon will be done with full polarimetry at one wavelength for refractive index determination (Figure 7).

The PPR will observe the darkside of Io just after the closest approach (Figure 7). The first observation is a 9 km resolution equatorial strip in the 27 μm filter which extends from 89 W longitude to 33 W longitude. Following that is a 22 km resolution, 7° x 7° map of the hot spot Kanhekili at (-10, 40) in the same filter. Additionally, there are two other strips, one which extends from (-10, 10) through O to (15, 320) at 32 km resolution and one which extends from (-1S, 25) straight up to the north pole at 50 km resolution. Both of these are in two filters: the 27 μm and >45 μm. Finally, there is a Loki Plume observation in the 27 μm filter, which will look at the plume (if any) from the Loki volcano on Io's limb.

5.2.2 Io Observation Strategy: Orbital Tour

During the orbital tour, disk-resolved PPR observations are possible near every perijove, with a best resolution of 6 PPR fields of view across Io's disk. During these opportunities, full disk maps will be performed in RAD mode. These observations will allow monitoring of hot spot activity over a two year period at most 10 longitudes. Disk-integrated observations, for instance to look for volcanic outbursts, will be possible during the orbital tour as well. Both disk-resolved and disk-integrated observations will be especially useful during Jupiter eclipse when the passive thermal background is reduced. There are several eclipse opportunities throughout. the tour in which PPR will participate with either dedicated or "ride-along" observations. When possible these observations will be done in RAD mode.

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Table 1. PPR Measurement Functions and Wavelengths

Measurement function	Center 1	Full width at half max
Polarimetry	944.6 nm	10.8 nm
	678.5 nm	8.7 nm
	410.1 nm	60.0 nm
Radiometry	16.8 µm	4.2 µm
	21.0 µm	3.0 µm
	35.5 µm	6.9 µm
	27.5 µm	7.2 µm
	$\lambda > 45$ µm	45 - 110 µm
	solar	0.3-4 µm
	Solar + therms	0.3- 110+ µm
Photometry	618.7 nm	7.0 nm
	633.3 nm	8.6 nm
	648.0 nm	7.4 nm
	788.7 nm	11.9 nm
	829.3 nm	11.9 nm
	840.3 nm	7.1 nm
	891.8 nm	11.1 nm

Table 2. Galileo Icy Satellite Encounters

Orbit #	Designation	Encounter (Targetted = T) (Non-targetted = NT)	Altitude (km)
0	JO	Io (T)	1000
		Europa (NT)	32489
1	G1	Ganymede (T)	500
2	G2	Ganymede (T)	25.5
3	C3	Callisto (T)	1100
		Europa (NT)	31947
4	E4	Europa (T)	695
6	E6	Europa (T)	588
7	G7	Ganymede (T)	3065
		Europa (NT)	23244
8	G8	Ganymede (T)	1584
		Callisto (NT)	33499
9	C9	Callisto (T)	416
		Ganymede (NT)	79961
10	Clo	Callisto (T)	S24
11	El 1	Europa (T)	1119

Table\ Figure Captions

TABLE 1: PPR measurement functions and wavelengths. The PPR instrument has three distinct modes: polarimetry, radiometry, and photometry. Derived from *Russell, et al, [1992].*

TABLE 2: Galileo icy satellite encounters. The altitude refers to the spacecraft altitude at closest approach. There is no orbit five listed since it is during a solar conjunction period when the Sun - Earth - spacecraft angle is less than 5°. This orbit is considered a 'phasing' orbit in the tour and no observations wil 1 be done.

FIGURE 1: (a) A Voyager air brushed map of Ganymede. (b) Dayside longitudes available by orbit. M = Morning terminator, E = Evening terminator. (c) Darkside longitudes available by orbit.

FIGURE 2: (a) A Voyager air brushed map of Callisto. (b) Dayside longitudes available by orbit. M =- Morning terminator, E = Evening terminator. (c) Darkside longitudes available by orbit.

FIGURE 3: (a) A Voyager air brushed map of Europa. (b) Dayside longitudes available by orbit. M = Morning terminator, E = Evening terminator. (c) Darkside longitudes available by orbit.

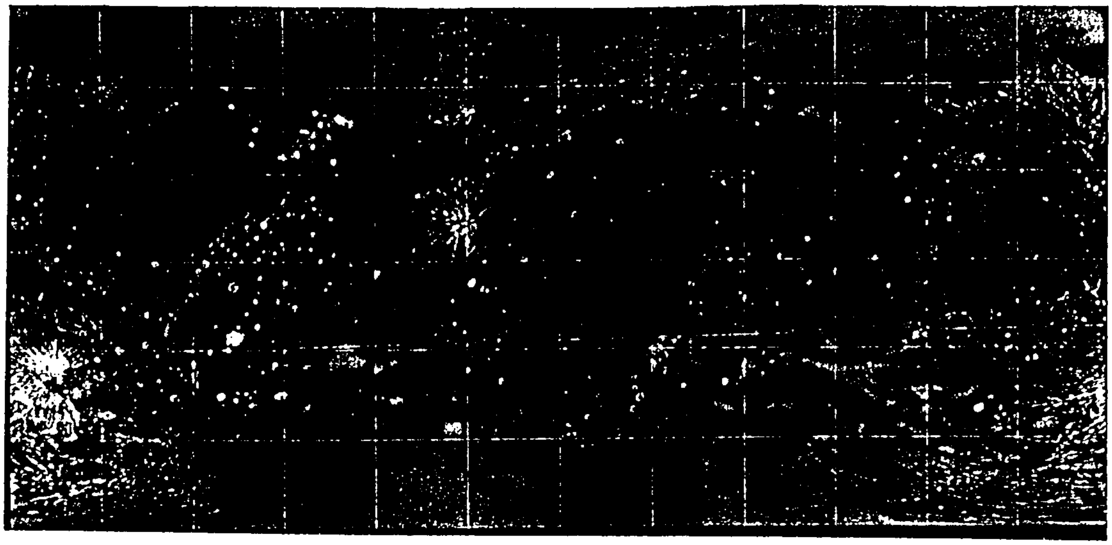
FIGURE 4: The set of attainable phase angles during the tour for (a) 1o, (b) Europa, (c) Ganymede, and (d) Callisto.

FIGURE 5: Example Darkside Thermal Map (DRKMAP) design. This is one of the DRKMAPs planned for the first Ganymede (G I) encounter. The resolution ranges from 200 km to 250 km from the start to end of this map due to the receding spacecraft. This design uses two thermal filters (27 μm and >45 μm; each sampled four times) with a corresponding cycle time of 4.13 seconds. A field of view is plotted every 4.13 seconds. The overlap is about 25$K0 FOV to FOV and 25% scan to scan. This observation starts at approximately Ganymede closest approach plus 3.0 hours and has a duration of 50 minutes.

FIGURE 6: Typical satellite photopolarimetry (SATPOL) design. This is an observation of Europa at a phase angle of 120°, completed in less than 1 min to conserve tape usage.

FIGURE 7: (a) A Voyager air brushed map of 10 showing the very high resolution scans that are performed during the Io flyby. The resolutions of each region are: Prometheus (62 km), Amirani/Maui (32 km), Volund (15 km), Colchis Regio (14 km), polarimetry phase observation (6 km), equatorial strip (9 km), Strip 1 (32 km), and Strip 2 (50 km). (b) Bars showing the longitude coverage for the two global dayside thermal maps on the inbound leg. Global 1 is in RAD mode with a resolution of 425 km. Global 2 uses the 17 μm filter with a resolution of 130 km.

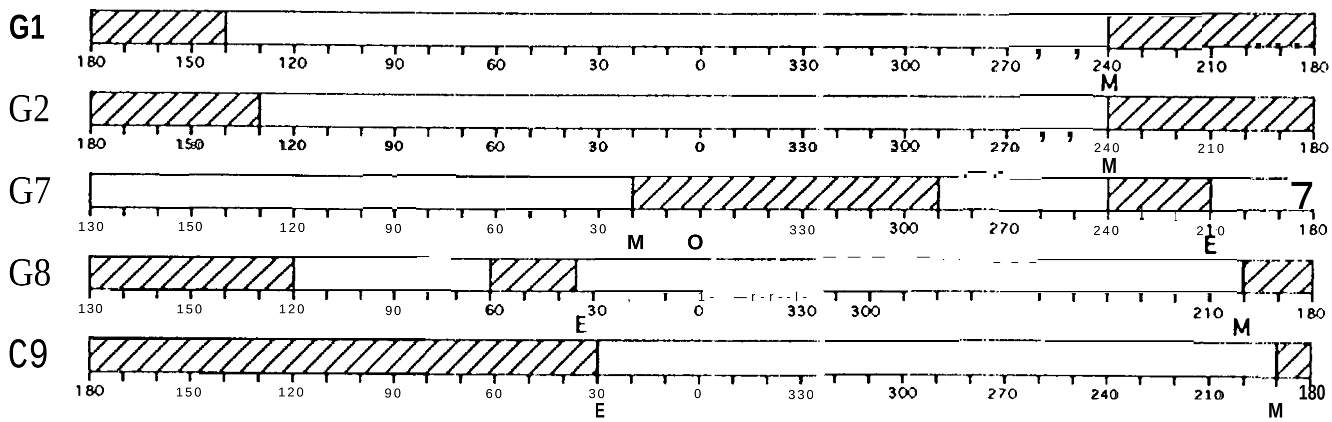
(a) GANYMEDE Figure



180 90 0 270 180

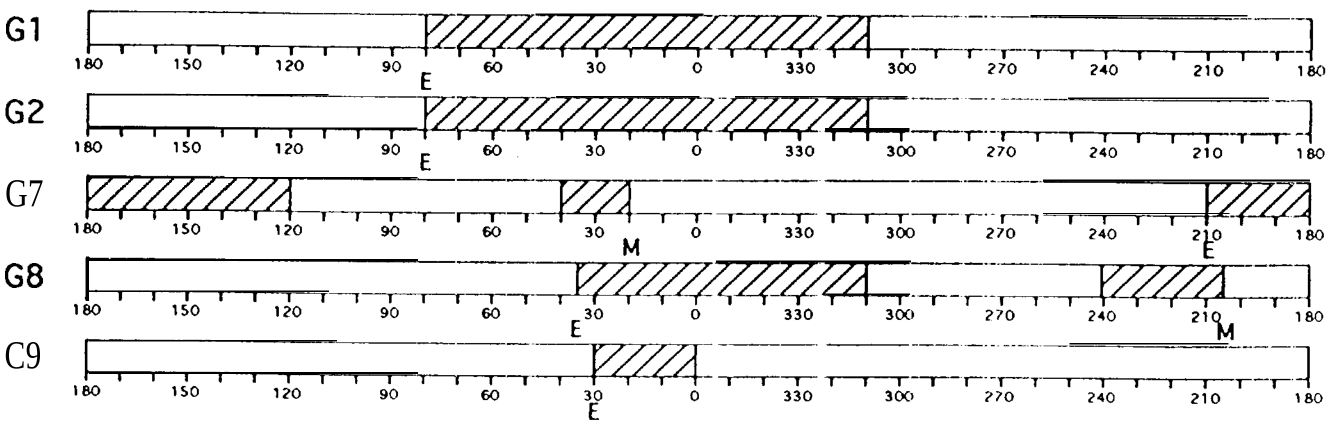
(b)

Ganymede Dayside opportunities



(c)

Ganymede Darkside Opportunities



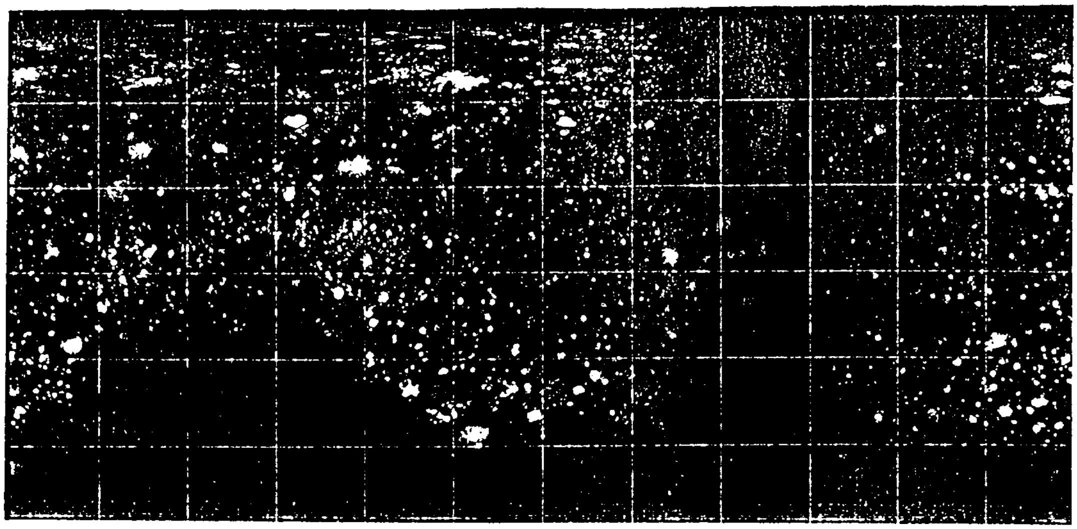
Longitude

10/20/94
LKT/ejw

CALLISTO

Figure 2

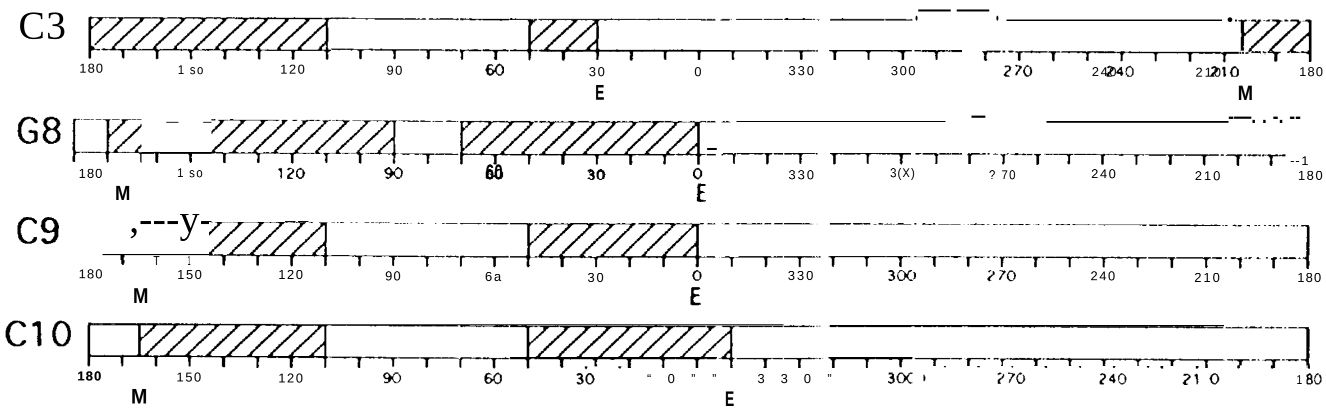
(a)



180 90 0 270)00

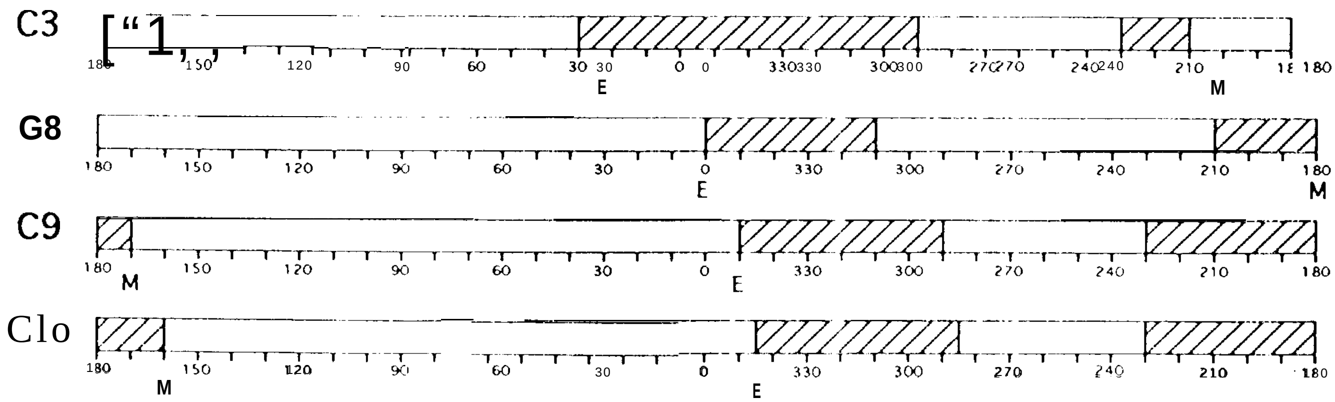
(b)

Callisto Dayside Opportunities



(c)

Callisto Darkside Opportunities

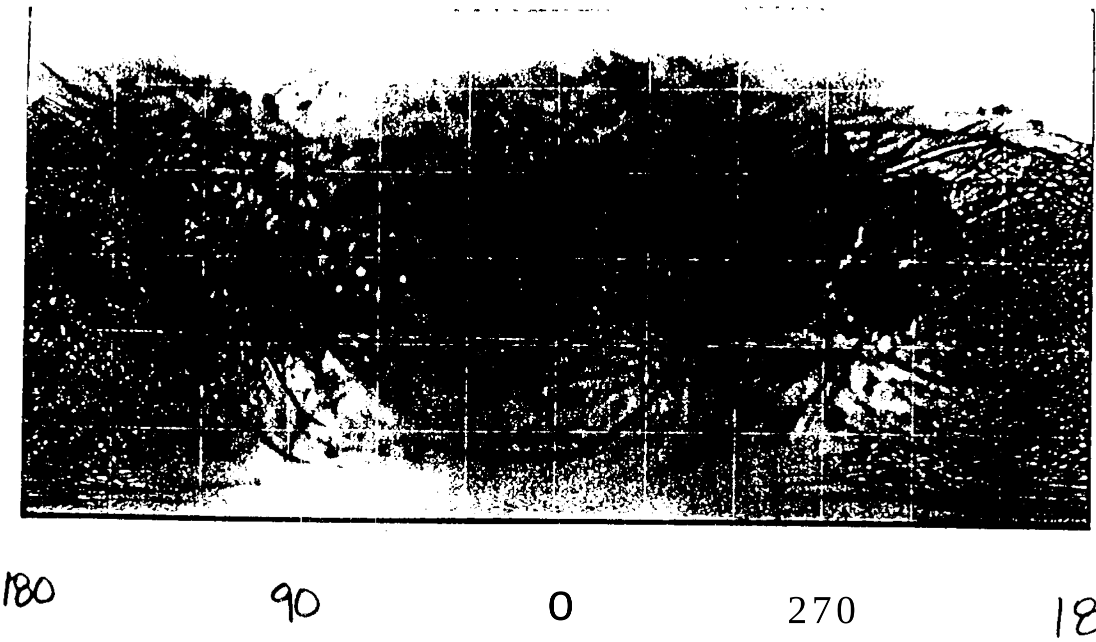


12/13/94
LKT/ejw

EUROPA

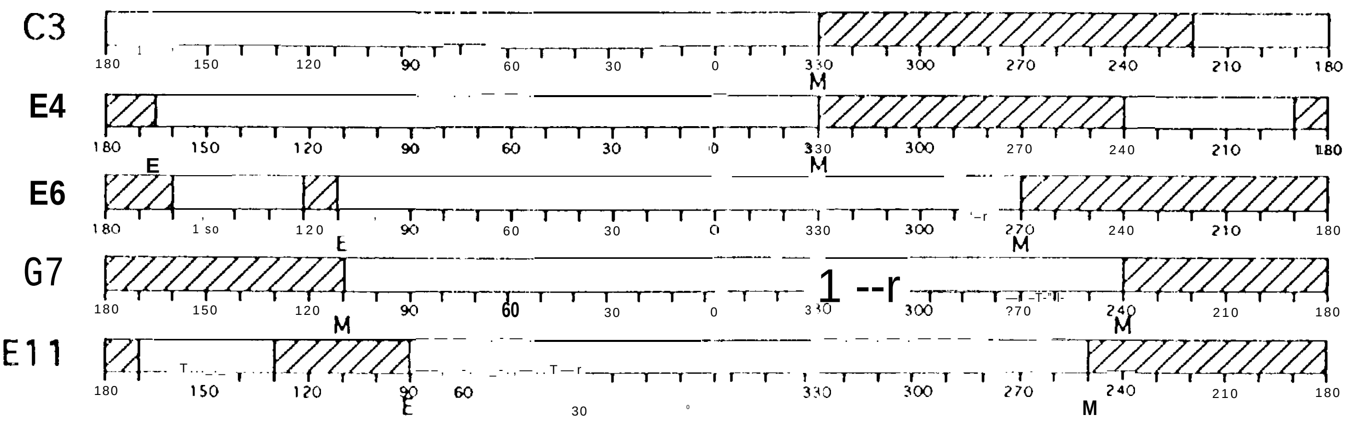
Figure 3

(a)



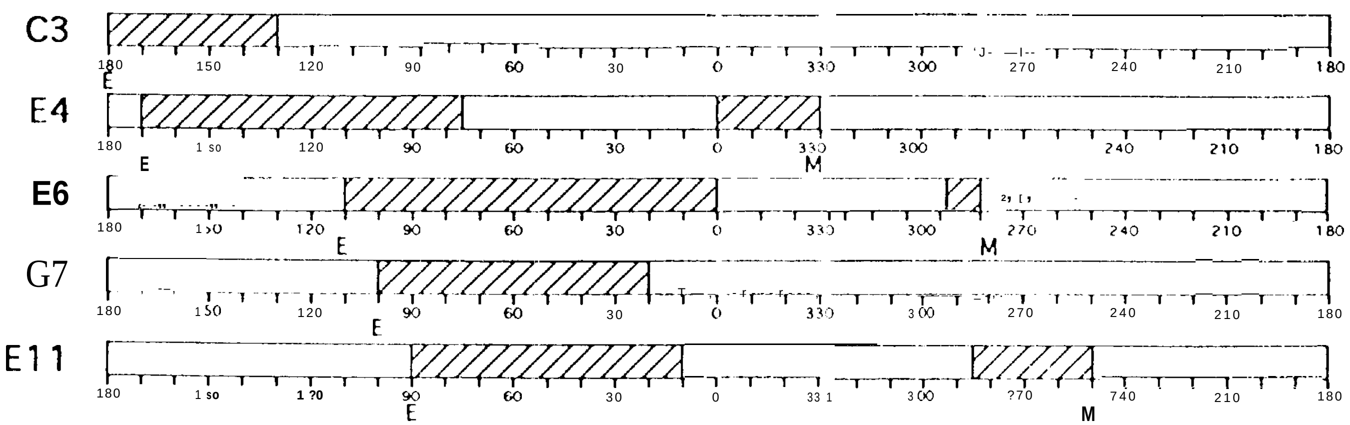
(b)

Europa Dayside Opportunities



(c)

Europa Darkside Opportunities



12/13/94
LKT/cjw

Figure 4

(a)

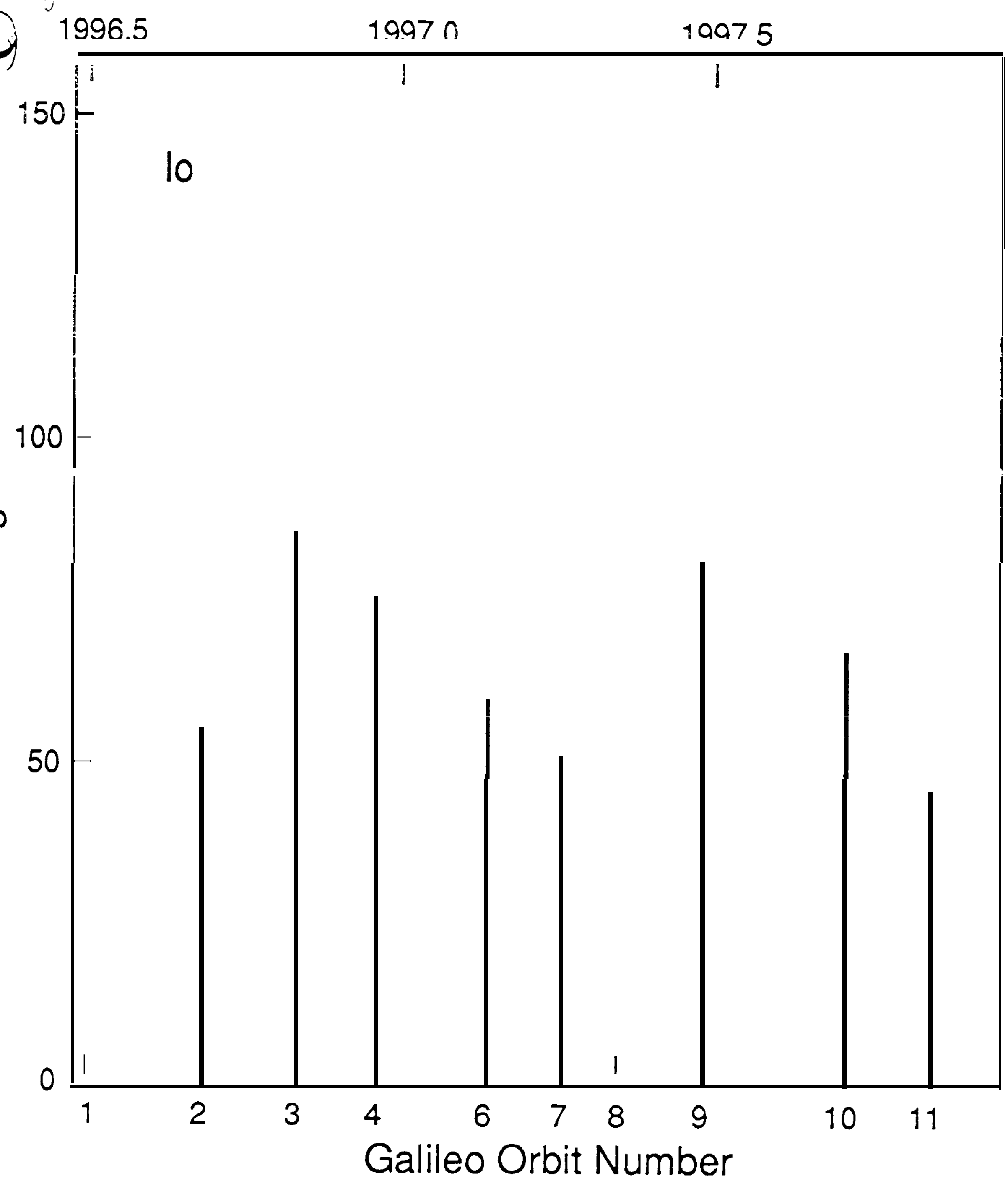
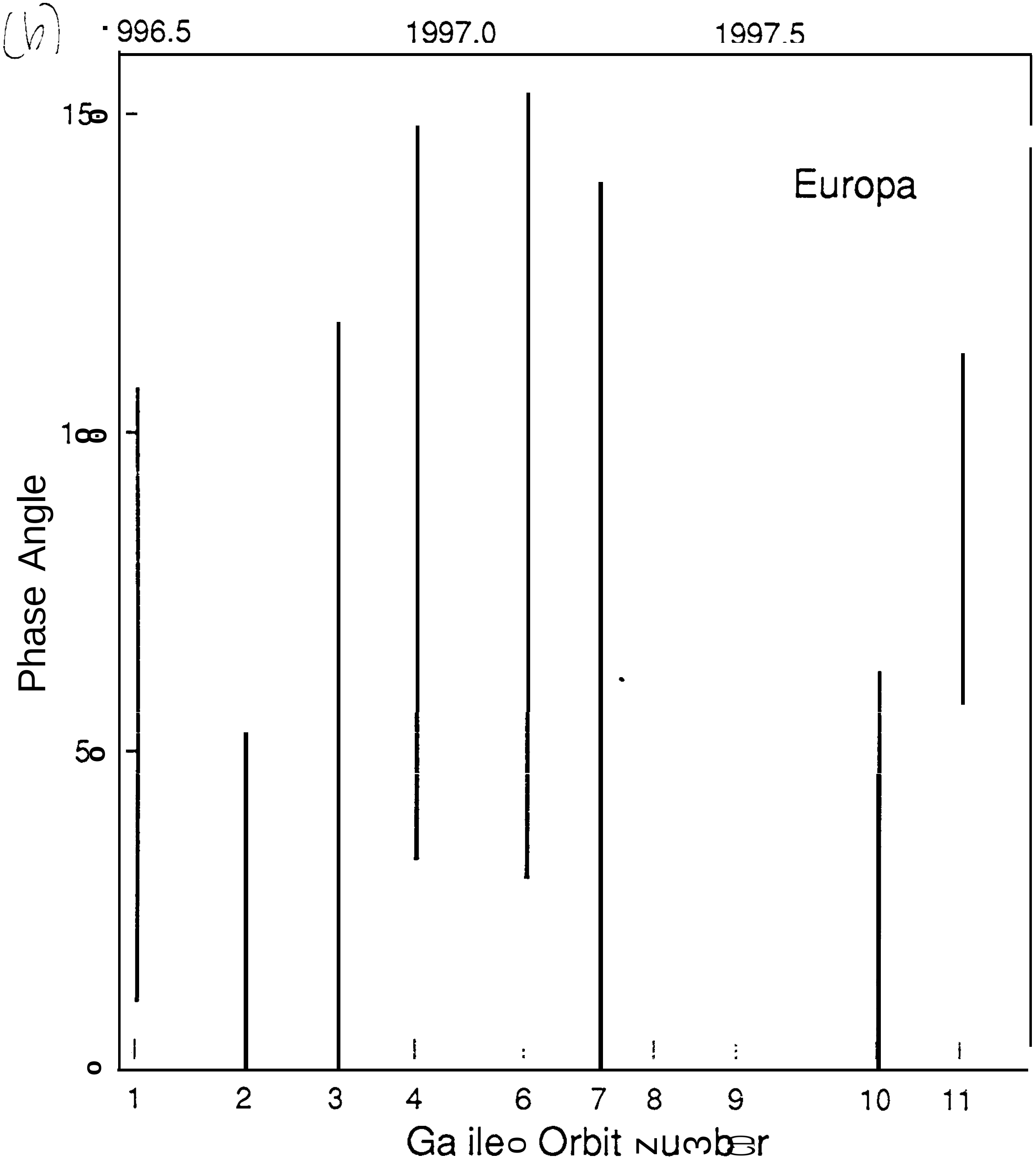
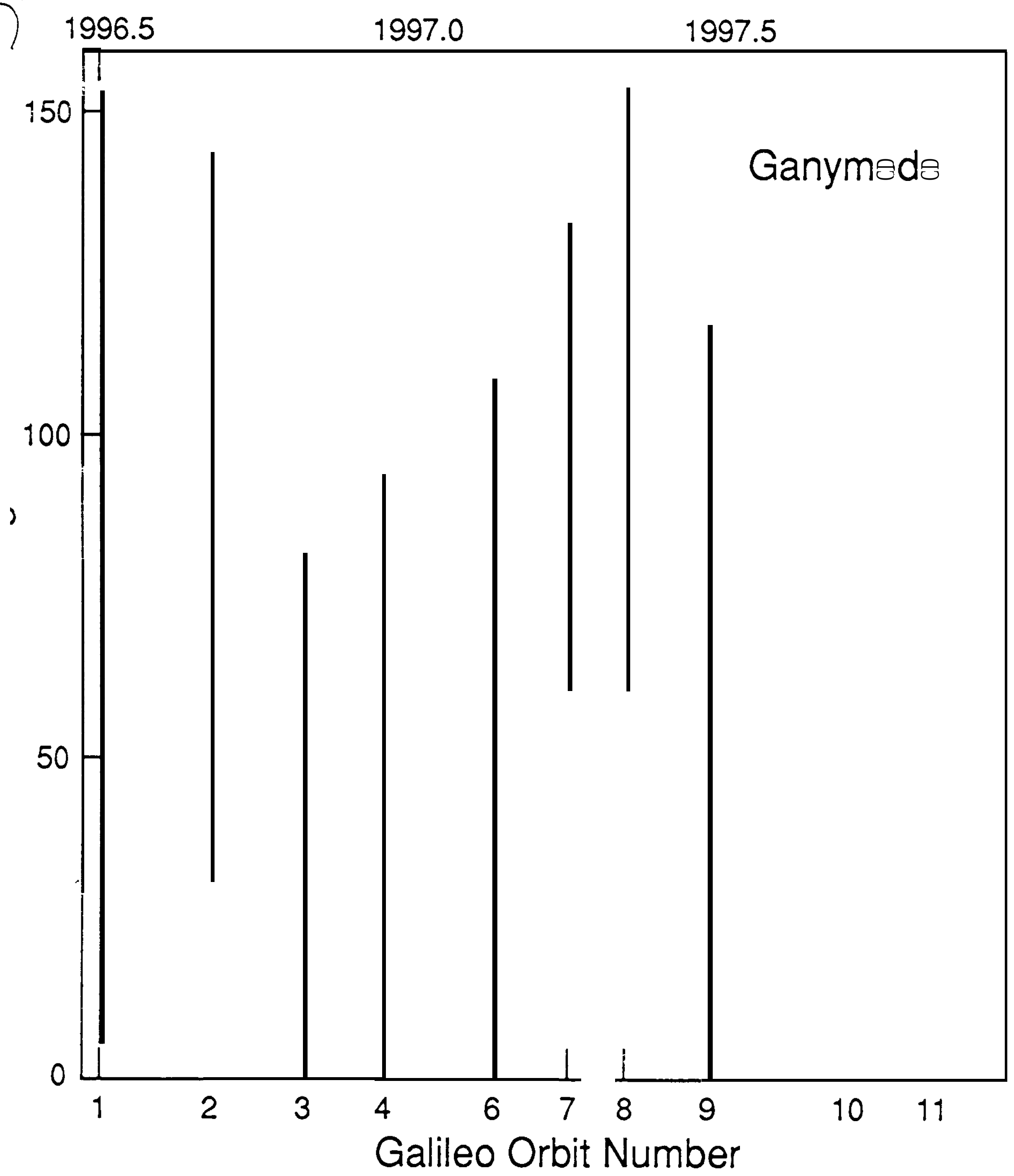

1996.5
1997.0
1997.5
150
100
50
0
Io
1
2
3
4
6
7
8
9
10
11
Galileo Orbit Number

Figure 4
(b)



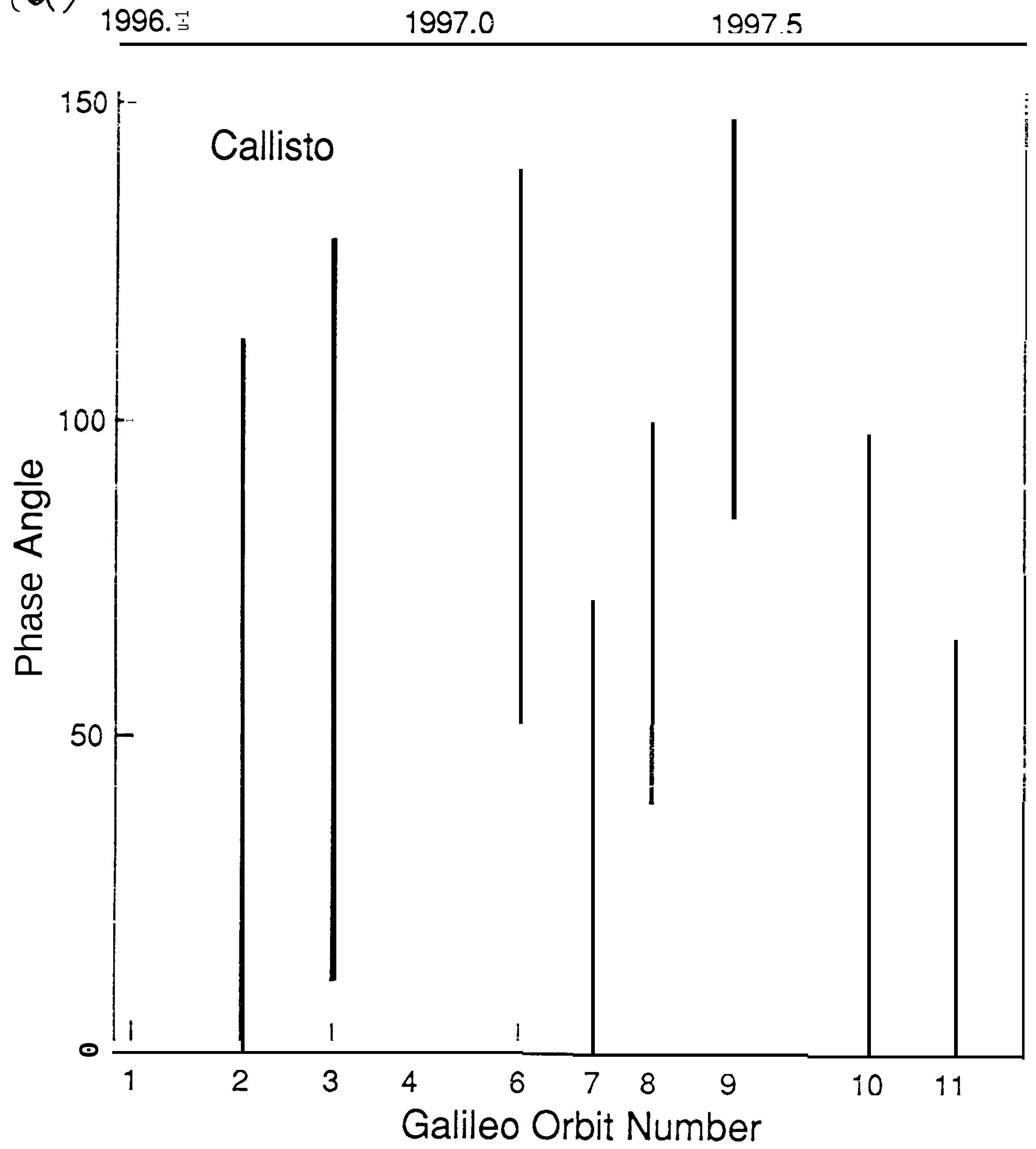
996.5
1997.0
1997.5
Europa
Phase Angle
0
50
100
150
1
2
3
4
6
7
8
9
10
11
Galileo Orbit Number

Figure 4
(c)



1996.5
1997.0
1997.5
150
100
50
0
Ganymede
1
2
3
4
6
7
8
9
10
11
Galileo Orbit Number

Figure (d)



1996.5
1997.0
1997.5
Callisto
Phase Angle
150
100
50
0
1
2
3
4
6
7
8
9
10
11
Galileo Orbit Number

Figure 5* Darkside Thermal Map Design for Ganymede 1 Encounter

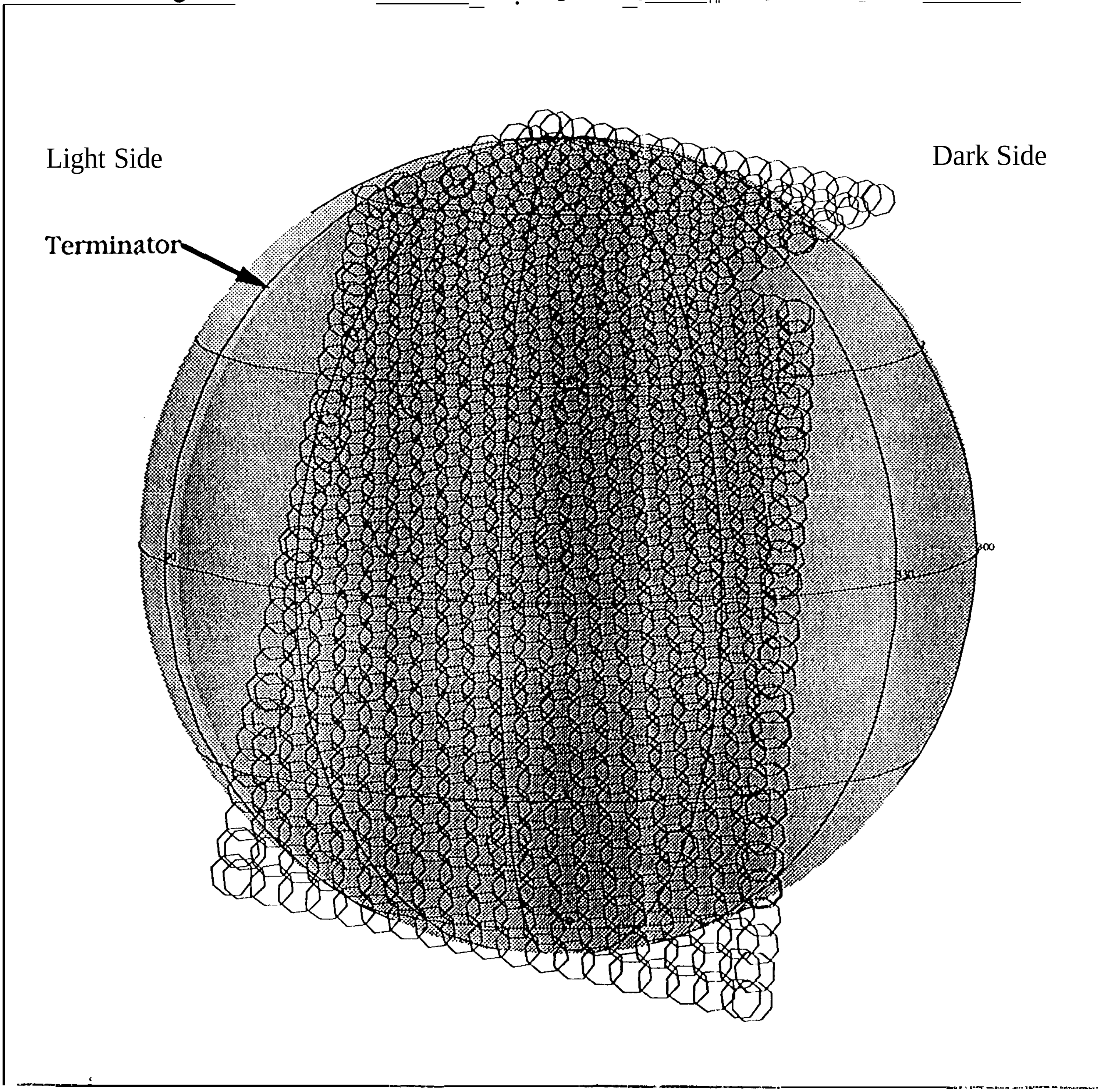
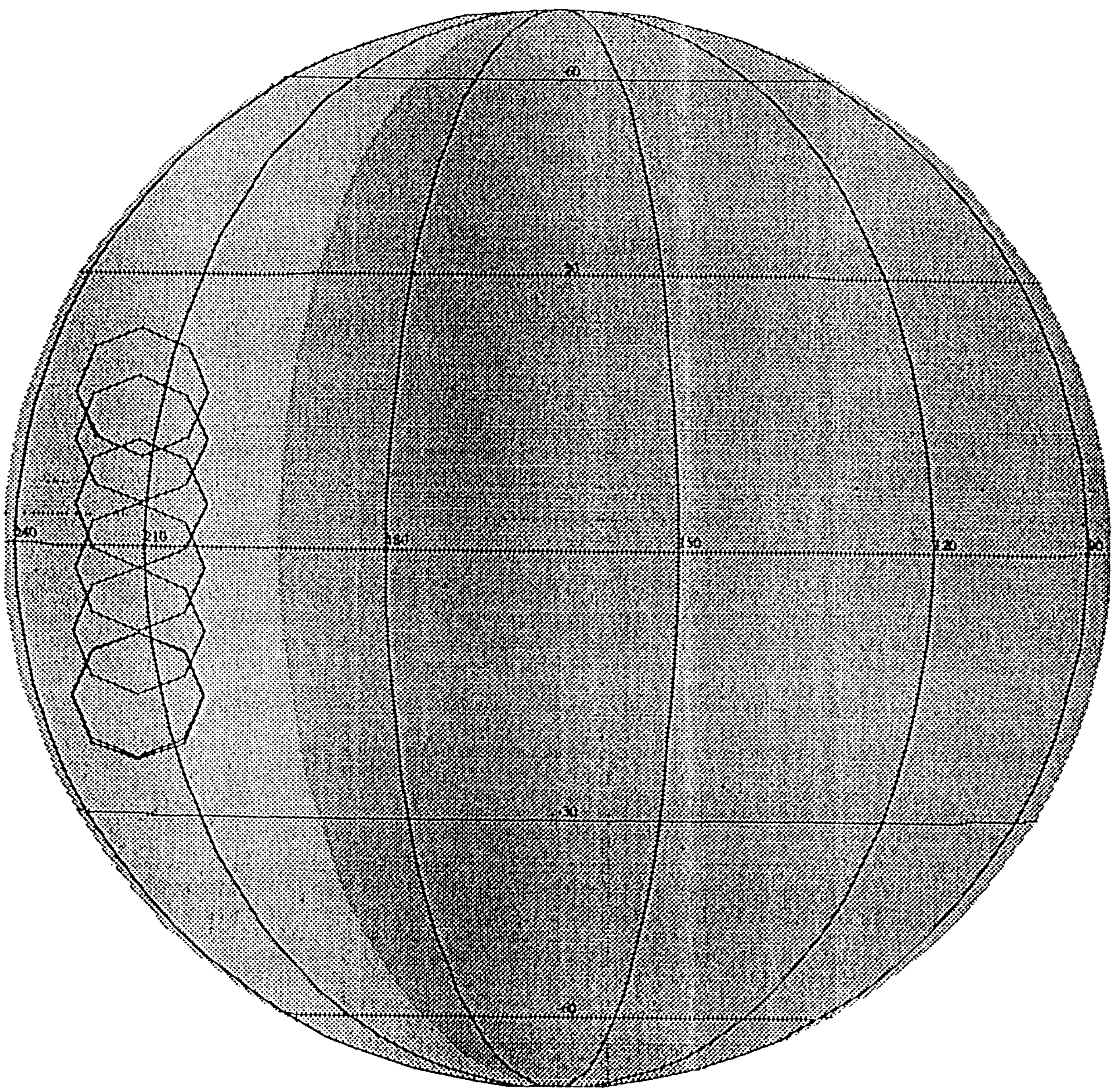
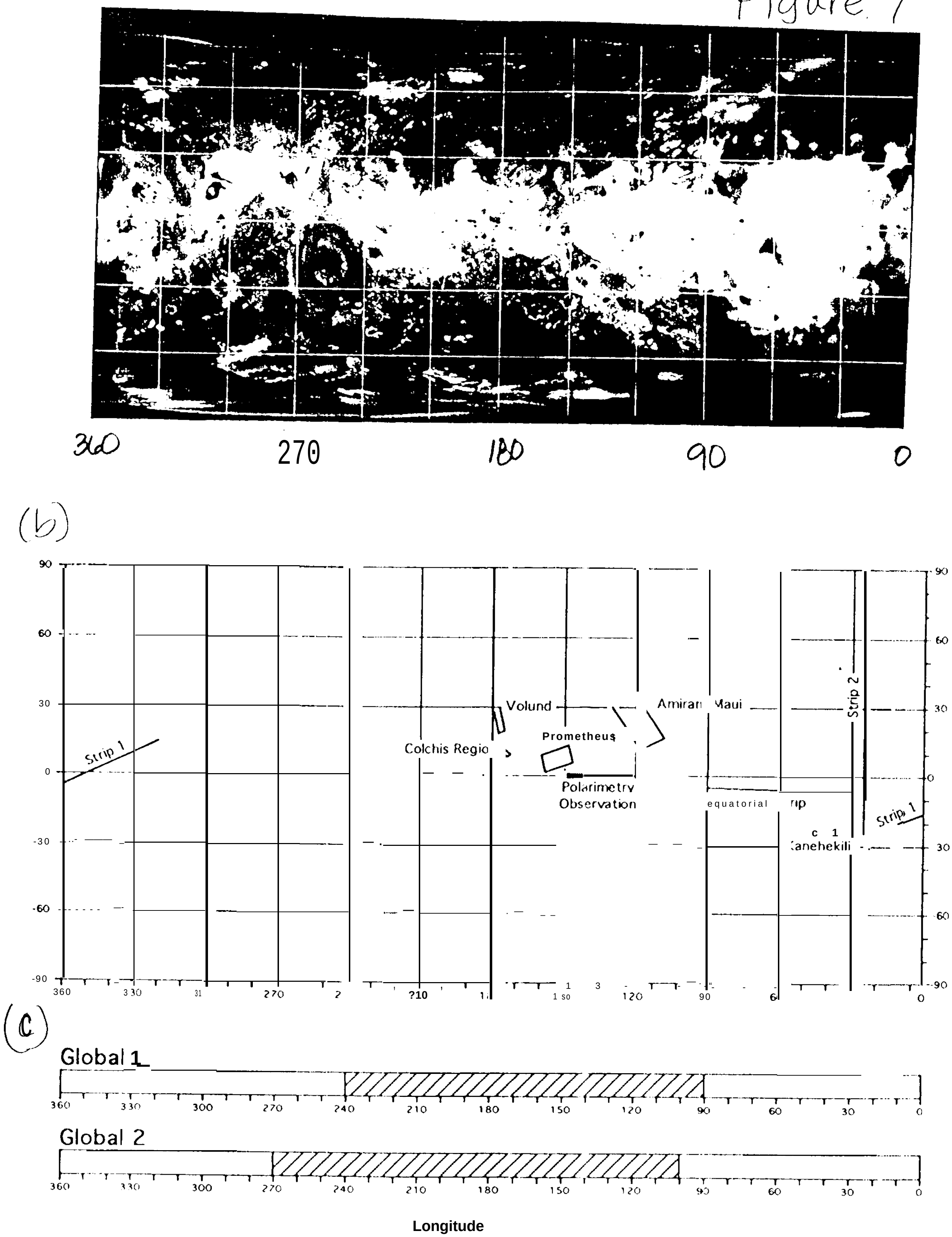


Figure 6. Satellite Photopolarimetry Design for Europa 4 Encounter



IO

Figure 7



10/20/94
LKT/ejw