THE DEEP SPACE ONE COMET BORRELLY FLYBY

Robert M. Nelson (1), Fran Baganal(2), Daniel C. Boice (3), Daniel T. Britt (4), Robert H. Brown (5), Bonnie J. Buratti(1),Frank Creary(12), Wing-Huan Ip(6), , Juergen Oberst(8), Tobias Owen (7), Bill R. Sandel (5), Lawrence Soderblom(6),S. Alan Stern (10), Nicholas Thomas (6), Joseph Wang(1), Roger Yelle (11), David T. Young (12)

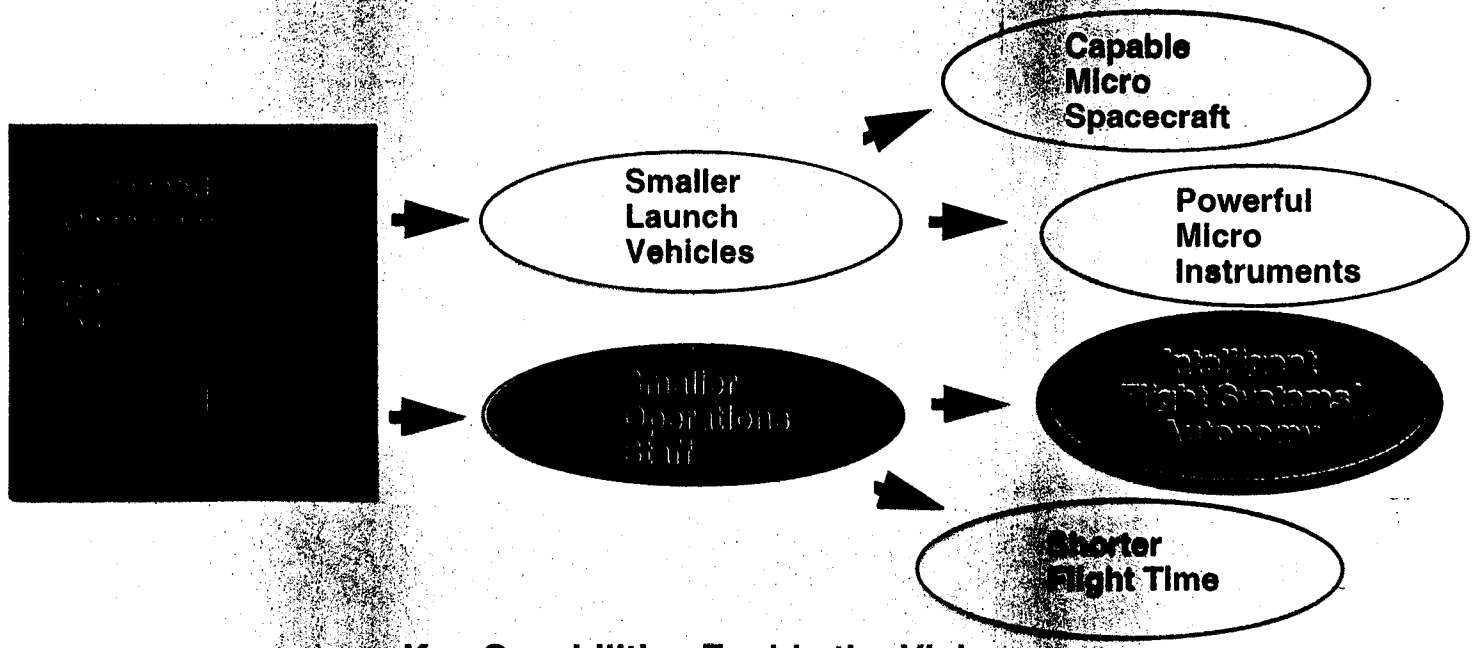
(1)JPL, Pasadena, CA 91109, USA, (2) U. of Colo., Boulder CO, 80309, USA, (3) SWRI, San Antonio TX,78238, USA, (4) U. of Tenn., Knoxville, TN, 37996,USA, (5) U. of Ariz., Tucson, AZ, 85721, USA, (6) MPI fur Aeronomie, Katlenberg-Lindau, Germany, (7) U. of Hawaii, Honolulu, HI, 96822, USA, (8) DLR , Berlin,D-12489, Germany, (9) USGS, Flagstaff, AZ 86001, USA, (10) SWRI, Boulder CO, 80302, USA, (11) N. Ariz. U., Flagstaff, AZ, 86011. USA, (12) U. of Michigan, Ann Arbor, MI, 48109, USA
Robert.M.Nelson@jpl.nasa.gov / Fax: +1-818-3540966

The NASA DS1 spacecraft will encounter comet P/Borrelly in Sept 2001. Two technologies, validated at a 1999 flyby of asteroid Braille, support science observations at Borrelly, the Miniature Integrated Camera Spectrometer (MICAS) and the Plasma Experiment for Planetary Exploration (PEPE). MICAS encompasses a camera, and an infrared imaging spectrometer. PEPE combines an ion and electron analyzer designed to determine the three-dimensional distribution of plasma over its field of view. MICAS includes two visible wavelength imaging channels, and an infrared imaging spectrometer all of which share a single 10-cm diameter telescope. Two types of visible wavelength detectors, both operating between about 500 and 1000 nm are used: a CCD with 13-microrad pixels and an 18-microrad-per-pixel, and a metal-on-silicon active pixel sensor (APS). Unlike the CCD the APS includes the timing and control electronics on the chip along with the detector. The IR spectrometer covers the range from 1200 to 2400 nm with 6.6-nm resolution and 54-microrad pixels. PEPE includes a very low-power, low-mass micro-calorimeter to help understand plasma-surface interactions and a plasma analyzer to identify the individual molecules and atoms in the immediate vicinity of the spacecraft that have been eroded off the surface of the target body. It has common apertures with separate electrostatic energy analyzers. It measures electron and ion energies from 3 eV to 30 keV, with a resolution of five percent. and measures ion mass from one to 135 amu with 5% resolution The startracker on DS1 failed in Nov. 1999. There is no backup unit. The spacecraft team developed an startracking the using the MICAS camera. This technique has performed with great reliability since July 2000.

Correct sentence structure

New Millennium Program DS1

New Millennium Vision



Key Capabilities Enable the Vision

Needed autonomy capability (SWG):

- rapid, low cost development
- extended unattended operation
- operation under uncertain conditions
- cooperating spacecraft (flying clusters, networks, ...)
- operation pointing of instruments & spacecraft

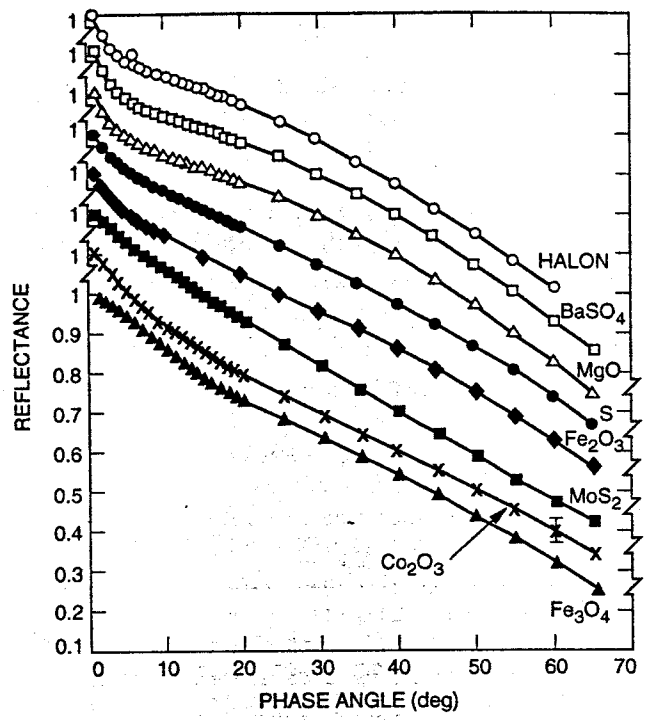
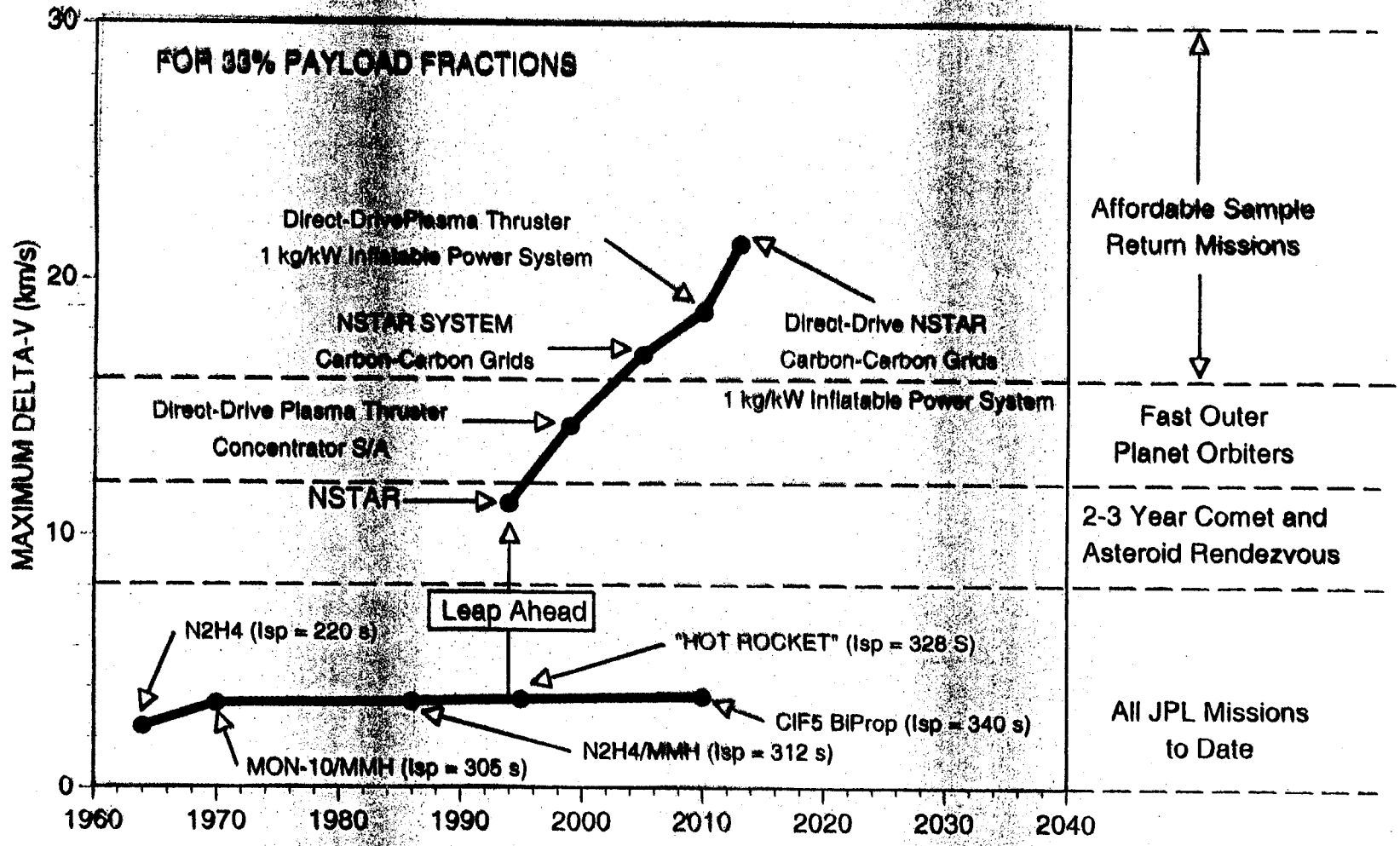


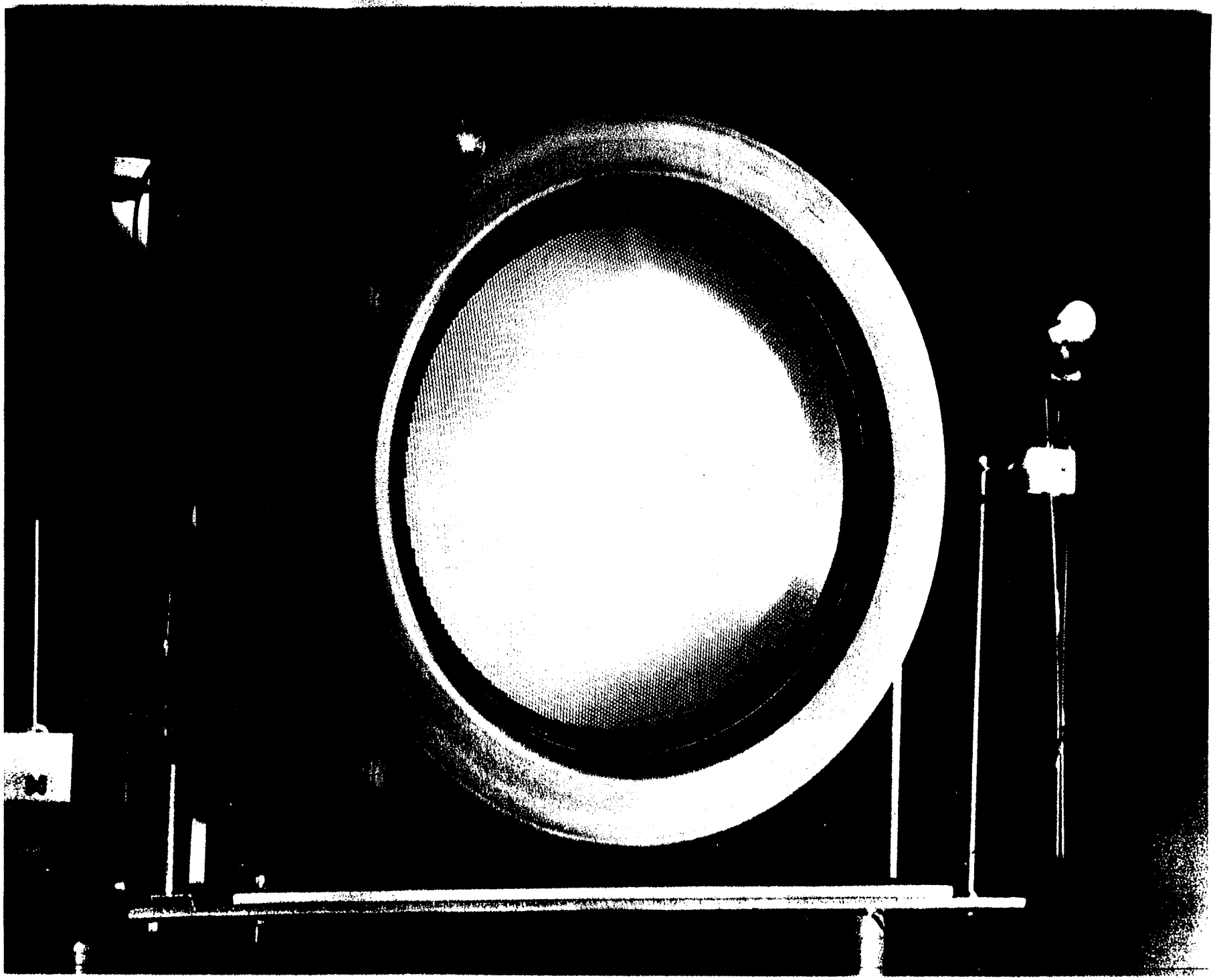
FIG. 2. Phase curves of particulate materials with different reflectance. The highly reflective materials (HALON, $BaSO_4$, MgO, and S) all exhibit a strong narrow opposition surge. This effect is not as pronounced in the more absorbing materials. This is not consistent with the expectations of the shadowing hiding model of the opposition effect. The materials are of different particle size $1 < d < 100\ \mu m$ and crystalline form (Table I).

ION PROPULSION BEGINS A NEW ERA IN SOLAR SYSTEM EXPLORATION

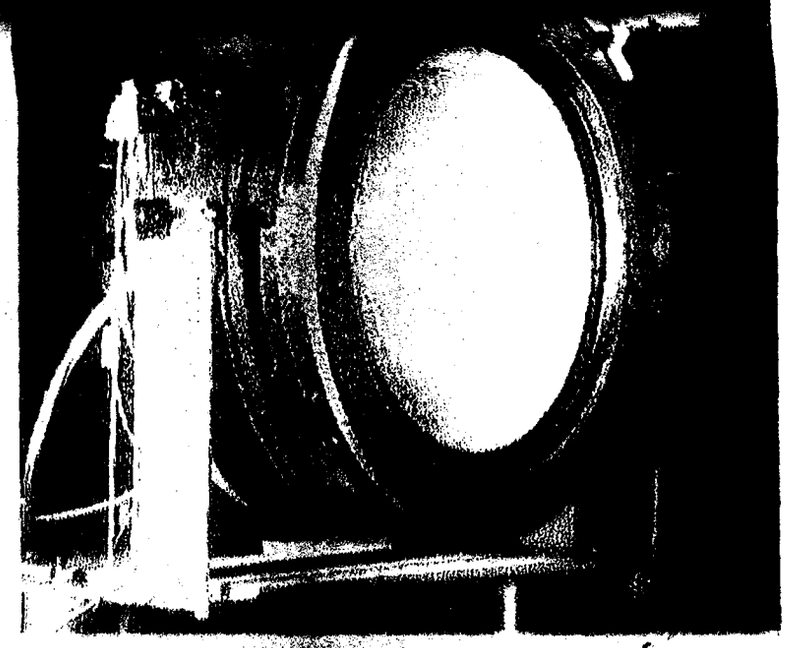


JPL

SPECTRUM ASTRO

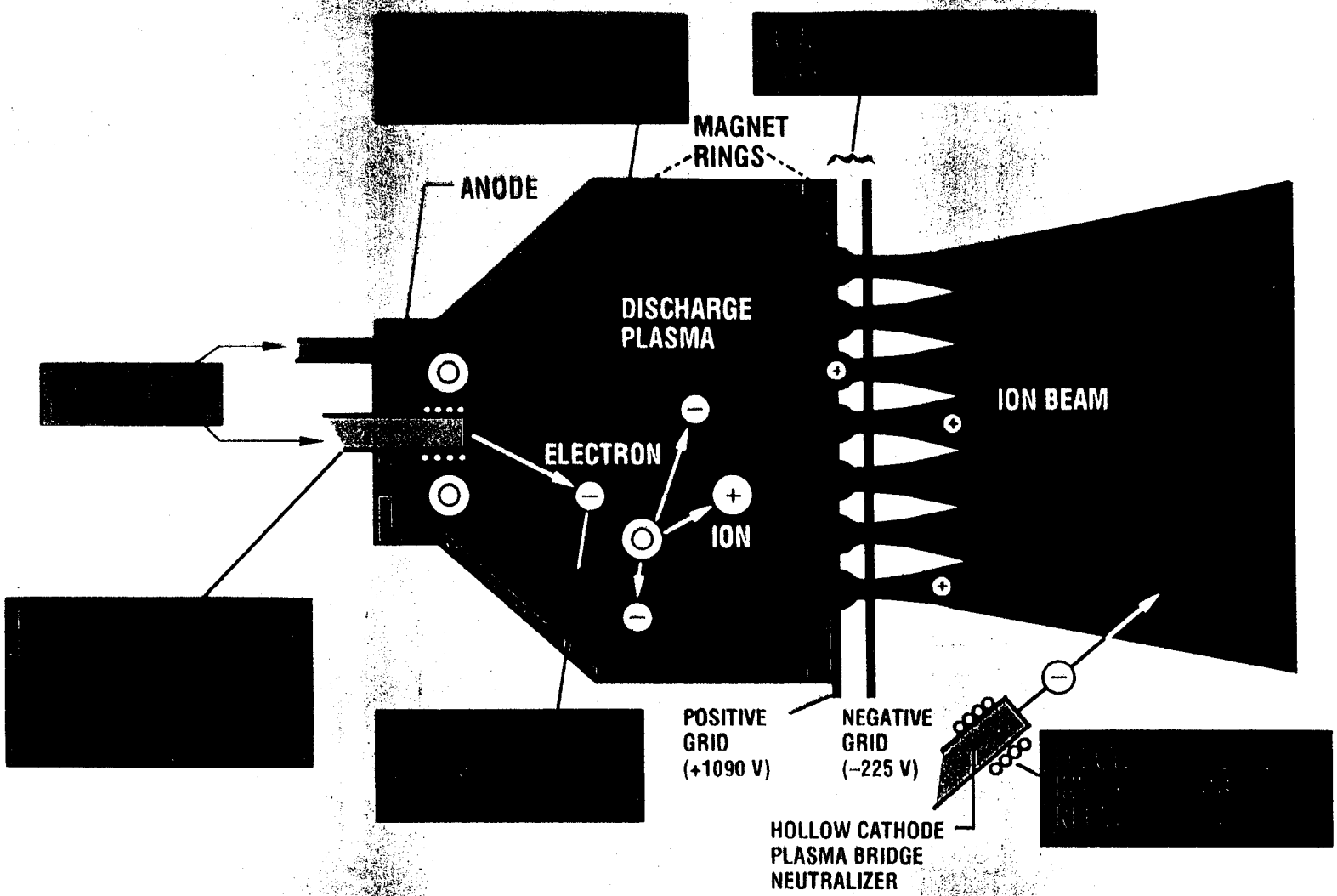


- **Specific Impulse:**
  - 2200 to 3370 s
- **Flow Rates**
  - Main Flow: 0.59 to 2.20 mg/s
  - Cathode Flow: 0.21 to 0.30 mg/s
  - Neutralizer Flow: 0.21 to 0.30 mg/s
- **Physical Size:**
  - 28.5 cm Dia. Ion Beam
  - 40 cm Outer Diameter x 40 cm Long
  - 7 kg Mass
- **Design Life:**
  - 83 kg of Xenon Throughput (8-khrs at full power)



NSTAR Ion Engine Operation at 2.3 kW

ION THRUSTER ELEMENTS AND FUNCTIONS



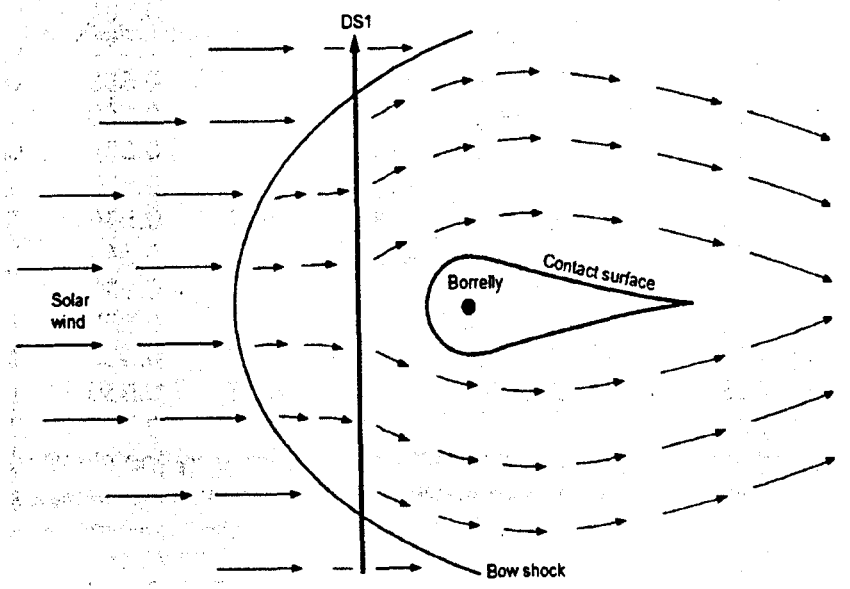
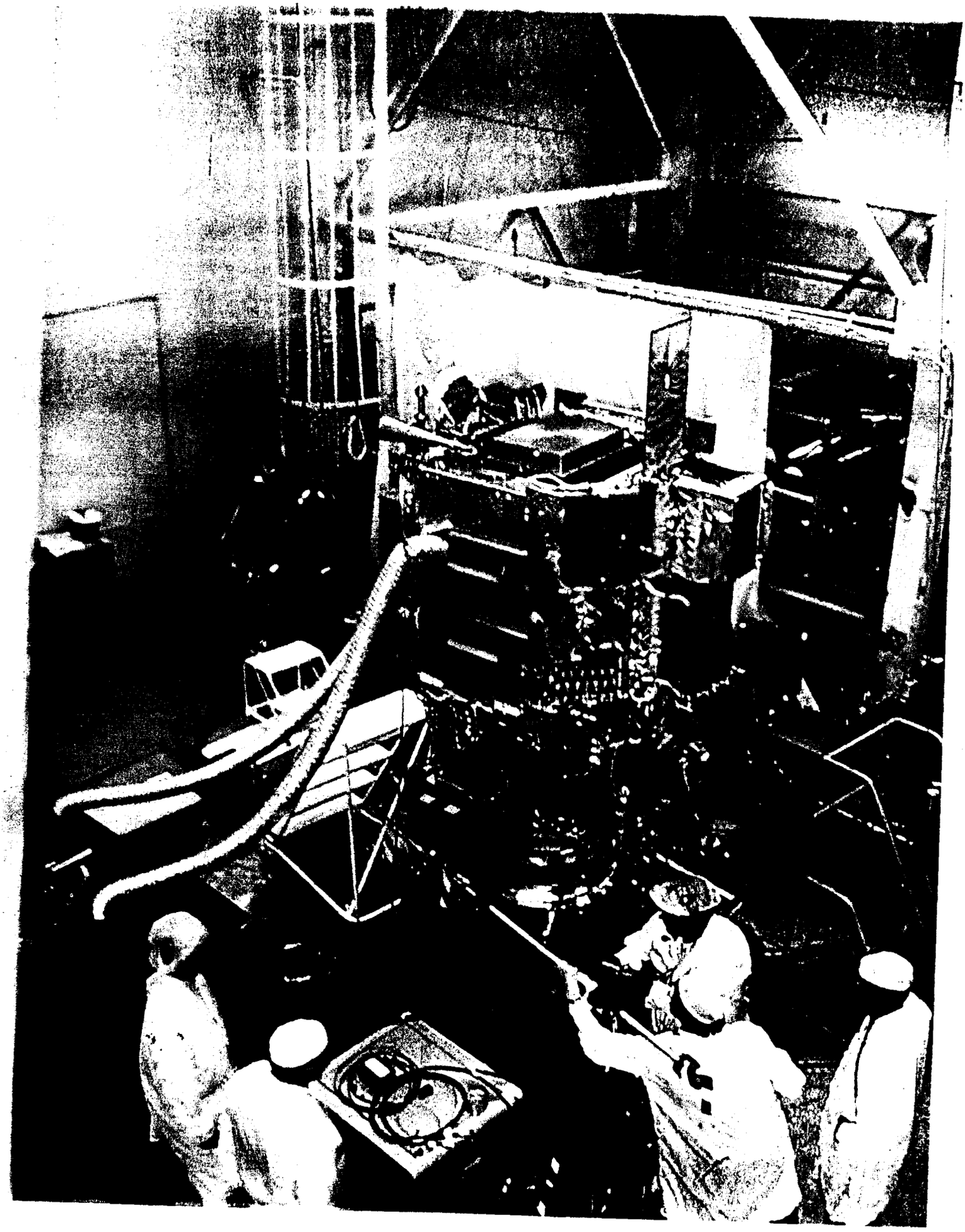


Figure 7. A schematic of the DS1 trajectory (vertical heavy line) with respect to Comet Borrelly and the likely relative location of the bow shock and the contact surface.



0:24:00	0:00:30	2510	VIS	54.6MS	yes	yes	nav	N/A		23.8	95	13			
0:23:30	0:00:30	2510	VIS	109MS	yes	yes	nav	N/A		23.3	95	13			
0:23:00	0:00:30	2510	VIS	54.6MS	yes	yes	nav	N/A		22.8	95	13			
0:22:30	0:00:30	2510	VIS	109MS	yes	yes	nav	N/A		22.3	95	14			
	Start 1x2 mosaic (m1)														
0:22:00	0:00:30	2300	VIS	54.6MS	yes	yes	nav (save)	files	CCD_m1_1_1	21.8	95	14	Mosaic 1		
0:21:30	0:00:30	2300	VIS	109MS	yes		compress	aux	CCD_m1_1_2	21.3	95	14	Mosaic 1		2.2
0:21:00	0:00:30	2300	VIS	54.6MS	yes		compress	aux	CCD_m1_2_1	20.8	96	15	Mosaic 1		2.2
0:20:30	0:00:30	2300	VIS	109MS	yes	yes	nav (save)	files	CCD_m1_2_2	20.4	96	15	Mosaic 1		
	Turn to Boresight														
0:20:00	0:00:30	2515	VIS	54.6MS	yes	yes	N/A	N/A		19.9	96	15			
0:19:30	0:00:30	2515	VIS	109MS	yes	yes	N/A	N/A		19.4	96	16			
	Turn to IR keyhole														
0:18:30	0:01:00	2020	IR	218MS			fixed	aux	IR-kh_1_1	18.4	96	4	Keyhole.		0.1
0:18:29	0:00:01	2020	IR	437MS			fixed	aux	IR-kh_1_2	18.4	96	4	Keyhole.		0.1
0:18:27	0:00:02	2020	IR	1.23S	all		fixed	aux	IR-kh_1_3	18.3	96	4	Keyhole.		0.1
	Turn to Boresight														
0:17:57	0:00:30	2020	VIS	54.6MS	yes	yes	N/A	N/A		17.8	96	17			
0:17:27	0:00:30	2020	VIS	109MS	yes	yes	N/A	N/A		17.3	97	18			
	Turn to IR keyhole, extract previous IR keyholes														
0:16:27	0:01:00	2020	IR	218MS			fixed	aux	IR-kh_2_1	16.4	97	5	Keyhole.		0.1
0:16:26	0:00:01	2020	IR	437MS			fixed	aux	IR-kh_2_2	16.3	97	5	Keyhole.		0.1
0:16:24	0:00:02	2020	IR	1.23S	all		fixed	aux	IR-kh_2_3	16.3	97	5	Keyhole.		0.1
	Turn to Boresight														
0:15:54	0:00:30	2020	VIS	54.6MS	yes	yes	N/A	N/A		15.8	97	19			
0:15:24	0:00:30	2020	VIS	109MS	yes	yes	N/A	N/A		15.3	98	20			
	Turn to IR keyhole, extract previous IR keyholes														
0:14:24	0:01:00	2020	IR	218MS			fixed	micas	IR-kh_3_1	14.3	98	5	Keyhole.	0.28	
0:14:23	0:00:01	2020	IR	437MS			fixed	micas	IR-kh_3_2	14.3	98	5	Keyhole.	0.28	
0:14:21	0:00:02	2020	IR	1.23S	all		fixed	micas	IR-kh_3_3	14.3	98	5	Keyhole.	0.28	
	Turn to Boresight														
0:13:51	0:00:30	2020	VIS	54.6MS	yes	yes	N/A	N/A		13.8	98	22			
0:13:21	0:00:30	2020	VIS	109MS	yes	yes	N/A	N/A		13.3	99	23			
	Begin 1x3 mosaic (m2)														
0:12:51	0:00:30	2310	VIS	54.6MS	yes	yes	compress	aux	CCD_m2_1_1	12.8	99	24	Mosaic 2		2.2
0:12:21	0:00:30	2310	VIS	109MS	yes	yes	compress	aux	CCD_m2_1_2	12.3	99	25	Mosaic 2		2.2
0:11:51	0:00:30	2310	VIS	54.6MS	yes	yes	compress	aux	CCD_m2_2_1	11.8	100	26	Mosaic 2		2.2

Borrelly__matrix.xls

Time before encounter	Time from previous command	Sequence ID	VIS(CCD) or IR	exp	Transfer? Note:	To NAV?	image processing	Directory	File name	Est. distance (1000 (km)	Sun cone angle	Est. nucleus size (pixels)	Comment	micas/images	micas_aux/images
1:12:00	Start far encounter. Turn to Borrelly														
1:10:00		2200	VIS	exp1	yes	yes	nav (save)	files	CCD_far_1_1	69.3	92	4	murky on?		
1:09:20	0:00:40	2200	VIS	exp2	yes		compress	aux	CCD_far_1_2	68.7	92	4	murky on?		
1:08:40	0:00:40	2200	VIS	exp3	yes		nav (save)	aux	CCD_far_1_3	68.0	92	5	murky on?		
1:08:00	0:00:40	2200	VIS	exp4	yes		compress	aux	CCD_far_1_4	67.3	92	5	murky on?		
1:07:20	0:00:40	2200	VIS	exp5	yes		compress	aux	CCD_far_1_5	66.7	92	5	murky on?		
1:06:40	0:00:40	Turn to IR keyhole								66.0	92				
1:06:00	0:00:40	2010	IR	218MS			fixed	aux	IR-far_kh_1_1	65.4	92	1	murky on?		
1:05:59	0:00:01	2010	IR	437MS			fixed	aux	IR-far_kh_1_2	65.3	92	1	murky on?		
1:05:57	0:00:02	2010	IR	1.23S	all		fixed	aux	IR-far_kh_1_3	65.3	92	1	murky on?		
1:05:00	Turn to MurkStar, process and packetize images									64.4	92				
0:35:00	Turn off murky, go on IMU's. Turn from MurkStar to Borrelly									34.7	93				
0:33:00	Turn on RSEN in "silent" mode - data collected and analyzed, but ephemeris updates not u									32.7	94				
0:32:00		2510	VIS	54.6MS	yes	yes	nav	N/A		31.7	94	10			
0:31:30	0:00:30	2510	VIS	109MS	yes	yes	nav	N/A		31.2	94	10			
0:31:00	0:00:30	2510	VIS	54.6MS	yes	yes	nav	N/A		30.7	94	10			
0:30:30	0:00:30	2510	VIS	109MS	yes	yes	nav	N/A		30.2	94	10			
0:30:00	0:00:30	2510	VIS	54.6MS	yes	yes	nav	N/A		29.7	94	10			
0:29:30	0:00:30	2510	VIS	109MS	yes	yes	nav	N/A		29.2	94	11			
0:29:00	0:00:30	2510	VIS	54.6MS	yes	yes	nav	N/A		28.7	94	11			
0:28:30	0:00:30	2510	VIS	109MS	yes	yes	nav	N/A		28.3	94	11			
0:28:00	0:00:30	2510	VIS	54.6MS	yes	yes	nav	N/A		27.8	94	11			
0:27:30	0:00:30	2510	VIS	109MS	yes	yes	nav	N/A		27.3	94	11			
0:27:00	0:00:30	2510	VIS	54.6MS	yes	yes	nav	N/A		26.8	94	11			
0:26:30	0:00:30	2510	VIS	109MS	yes	yes	nav	N/A		26.3	94	12			
0:26:00	0:00:30	2510	VIS	54.6MS	yes	yes	nav	N/A		25.8	94	12			
0:25:30	0:00:30	2510	VIS	109MS	yes	yes	nav	N/A		25.3	95	12			
0:25:00	0:00:30	2510	VIS	54.6MS	yes	yes	nav	N/A		24.8	95	12			
0:24:30	0:00:30	2510	VIS	109MS	yes	yes	nav	N/A		24.3	95	13			

MICAS VISCCD BORRELLY IMAGING (RESOLVED CASE)

LAS
12/13/200

Time to C/A, sec	Angular Velocity, rad/sec	Angular Velocity, pix/sec	Range, km	Phase Angle (g), deg	Resol., m/pix	Exposure milli-seconds	Smear (Uncomp)	Target Diameter pix	Fraction Illum.	Maximum DN Albedo (Rn) and Minneart Coefficient (k) ~[cos(g/2)^k cos(g/2)^k-1]		
									Rn=	0.06	0.02	0.04
	Bold_Italics=	*SWIR-PB*							k=	0.5	1.5	1.0
									C(g)=	0.02	0.02	0.02
10	8.2E-03	630.3	2006.8	5.7	26.09	19.2	12.1	215.7	0.998	1120	372	746
60	6.6E-03	509.7	2231.6	27.3	29.01	38.4	19.6	194.0	0.944	1463	460	948
138	3.6E-03	276.4	3030.6	49.7	39.40	76.8	21.2	142.9	0.823	1810	497	1095
202	2.2E-03	168.0	3887.0	60.0	50.53	76.8	12.9	111.4	0.750	1428	357	824
302	1.1E-03	88.0	5369.4	69.1	69.80	76.8	6.8	80.6	0.678	1148	260	630
242	***1.7E-03***	***127.3***	***4465.9***	64.4	***58.06***	76.8	***9.8***	***96.9***	***0.716***	1288	307	726
250	***1.6E-03***	***120.8***	***4584.3***	65.1	***59.60***	76.8	***9.3***	***94.4***	***0.710***	1265	299	711
346	9.0E-04	69.4	6049.2	71.7	78.64	76.8	5.3	71.6	0.657	1078	236	583
376	7.8E-04	59.7	6518.4	73.1	84.74	76.8	4.6	66.4	0.645	1040	224	557
406	6.8E-04	51.9	6991.2	74.4	90.89	76.8	4.0	61.9	0.635	1009	213	536
436	5.9E-04	45.5	7466.8	75.5	97.07	109.0	5.0	58.0	0.626	1393	290	734
526	4.2E-04	32.0	8906.5	78.0	115.78	109.0	3.5	48.6	0.604	1305	263	676
556	3.7E-04	28.8	9389.5	78.7	122.06	109.0	3.1	46.1	0.598	1283	256	661
586	3.4E-04	26.0	9873.7	79.3	128.36	109.0	2.8	43.9	0.593	1263	250	648
616	3.1E-04	23.7	10358.9	79.9	134.67	109.0	2.6	41.8	0.588	1245	244	637
646	2.8E-04	21.6	10845.0	80.4	140.99	109.0	2.4	39.9	0.584	1229	239	626
681	2.5E-04	19.5	11413.1	80.9	148.37	109.0	2.1	37.9	0.579	1212	234	615
711	2.3E-04	17.9	11900.8	81.3	154.71	109.0	2.0	36.4	0.575	1199	230	606
741	2.2E-04	16.5	12389.0	81.7	161.06	109.0	1.8	34.9	0.572	1187	226	599
				BRAILLE: Actual observation~380 DN/9.6ms/g~90					*Rn=*	*0.4*	*0.4*	*0.4*
				90.0		*9.6*			*0.500*	*559*	*280*	*396*

Parameters:

b= 2000.0 km
v= 16.5 km/s
Approach_phase= 91.0 deg
Solar_range= 1.36 A.U.

MICAS
IFOV= 1.30E-05 rad
omega_naught= 2.00E+06 Dn/s

Borrelly
Major_Axes= 3.6x3.6x8.8 km
Area= 99.5 km^2
Equiv_Radius= 2.81 km