THE U. S. PLANETARY PROGRAM

BY

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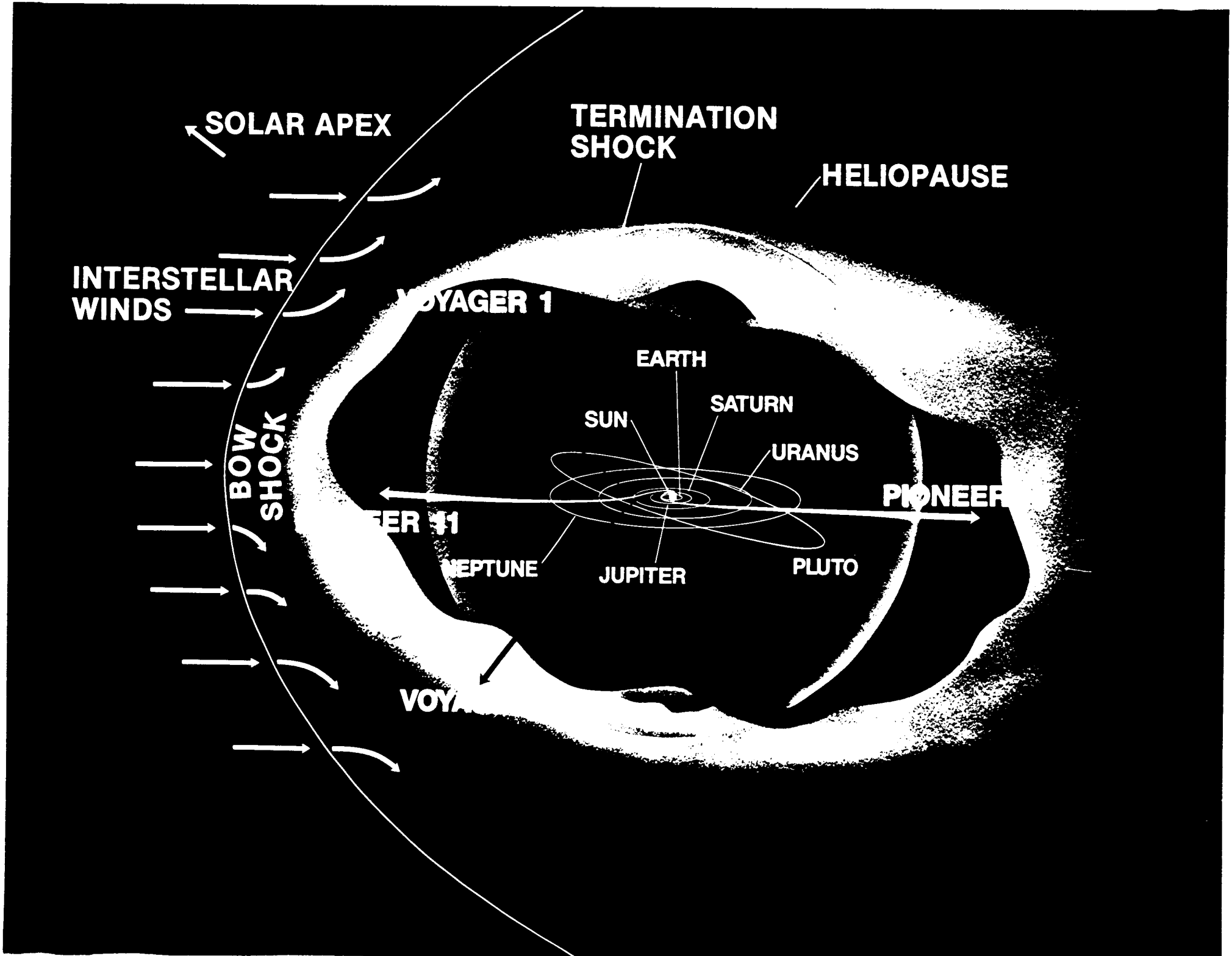
DEPUTY DIRECTOR
TECHNOLOGY & APPLICATIONS PROGRAM
JET PROPULSION LABORATORY

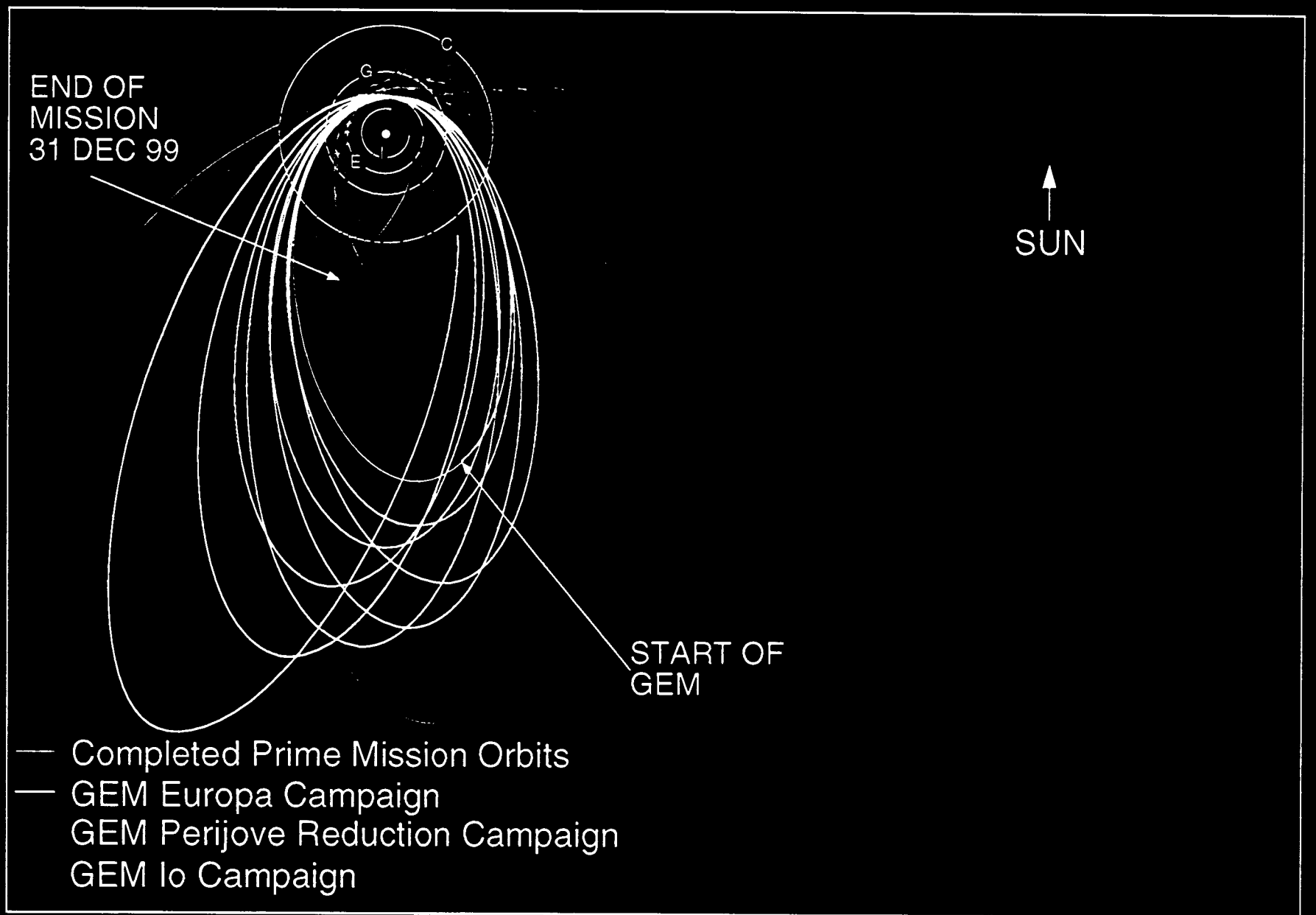
JPL

MISSIONS IN FLIGHT

- VOYAGER
- GALILEO
- NEAR EARTH ASTEROID RENDEZVOUS (NEAR)
- MARS GLOBAL SURVEYOR
- MARS PATHFINDER
- CASSINI
- LUNAR PROSPECTOR


SOLAR APEX
TERMINATION SHOCK
HELIOPAUSE
INTERSTELLAR WINDS
BOW SHOCK
EARTH
SUN
SATURN
URANUS
PLUTO
JUPITER
NEPTUNE
PIONEER

GALILEO EUROPA MISSION (GEM) AND PRIME MISSION TOURS



Galileo Europa Mission (GEM) Timeline

97 | 1998 | 1999

D J F M A M J J A S O N D | J F M A M J J A S O N D

Ice: Europa Campaign

E12 16 | E13 10 | E14 29 | E15 31 | E16 21 | E17 26 | E18 22 | E19 1

Jupiter Water Study

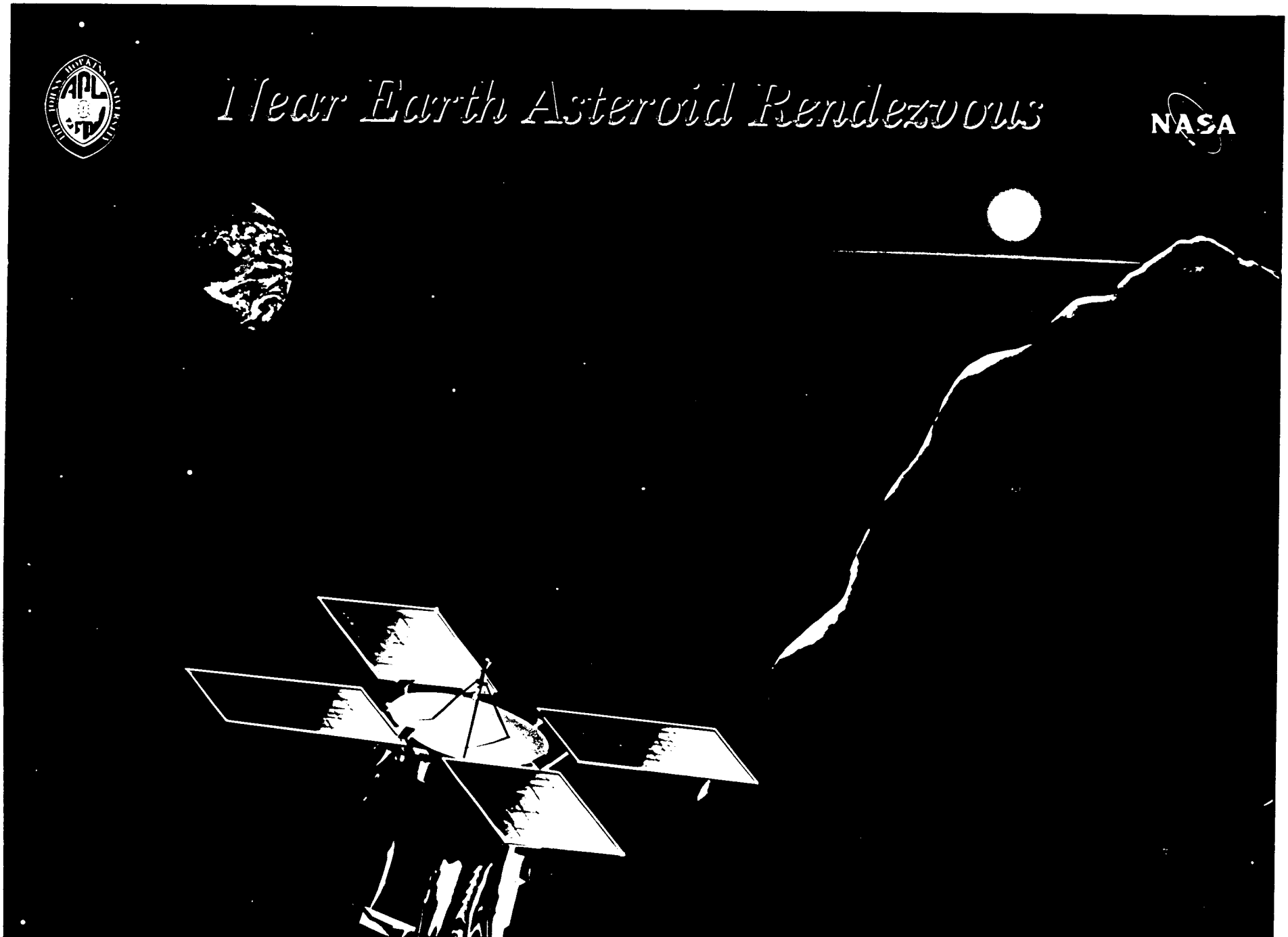
C20 5 | C21 30 | C22 14 | C23 16

Torus Passages

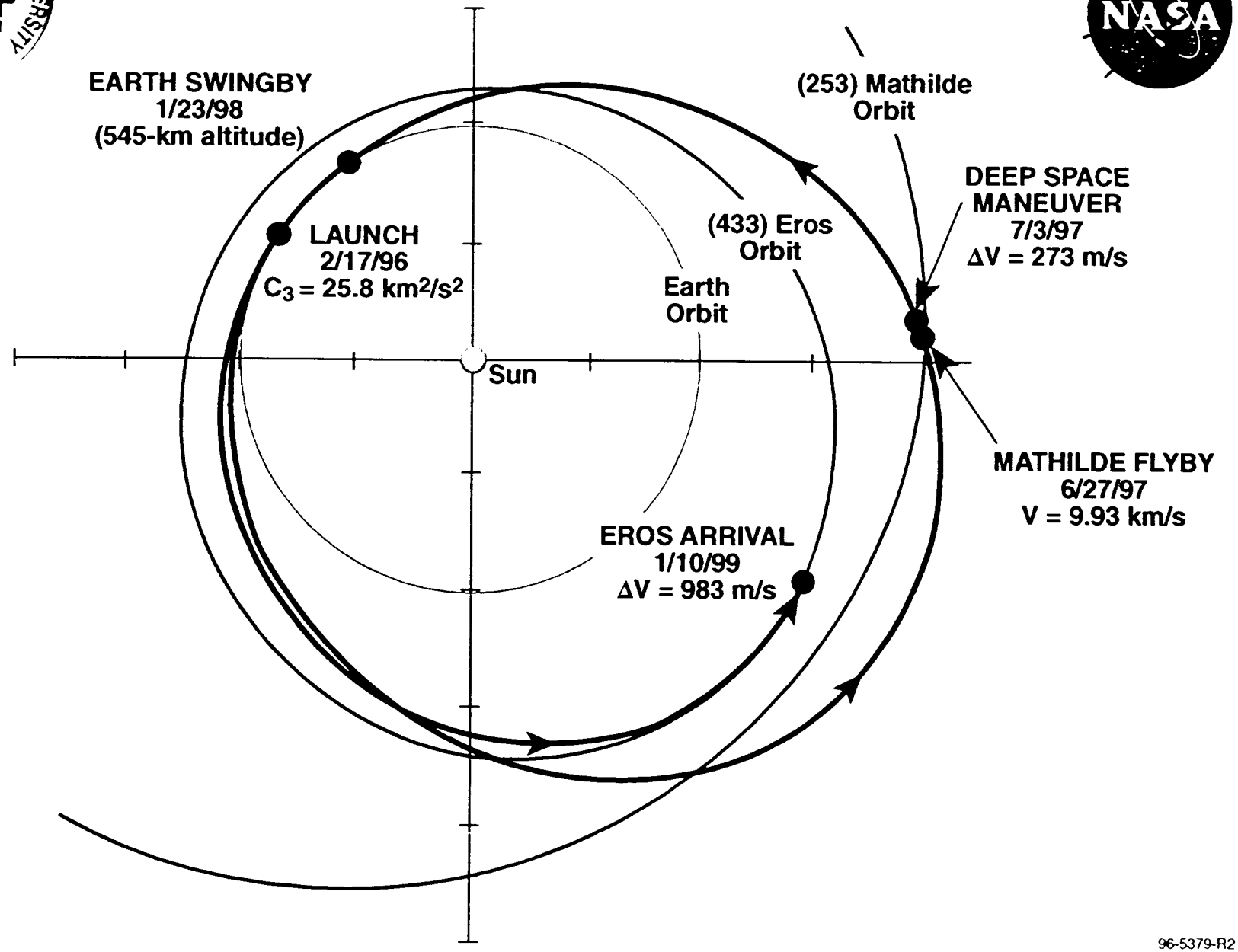
3 | 2 | 12 | 14 | 11 | 26

24 | 25

11 | 26


Near Earth Asteroid Rendezvous
NASA
95-3807-JE

NEAR Trajectory Profile



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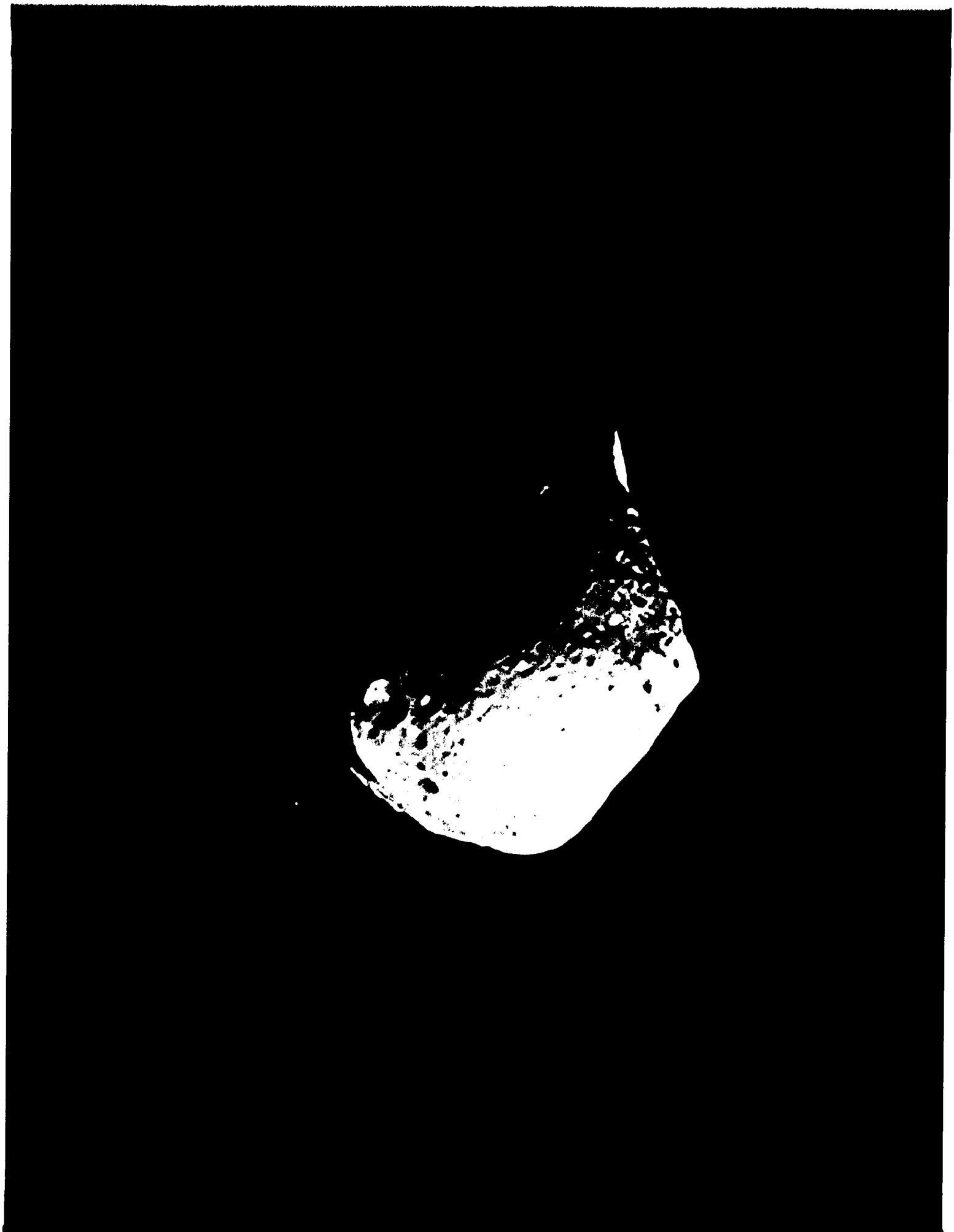
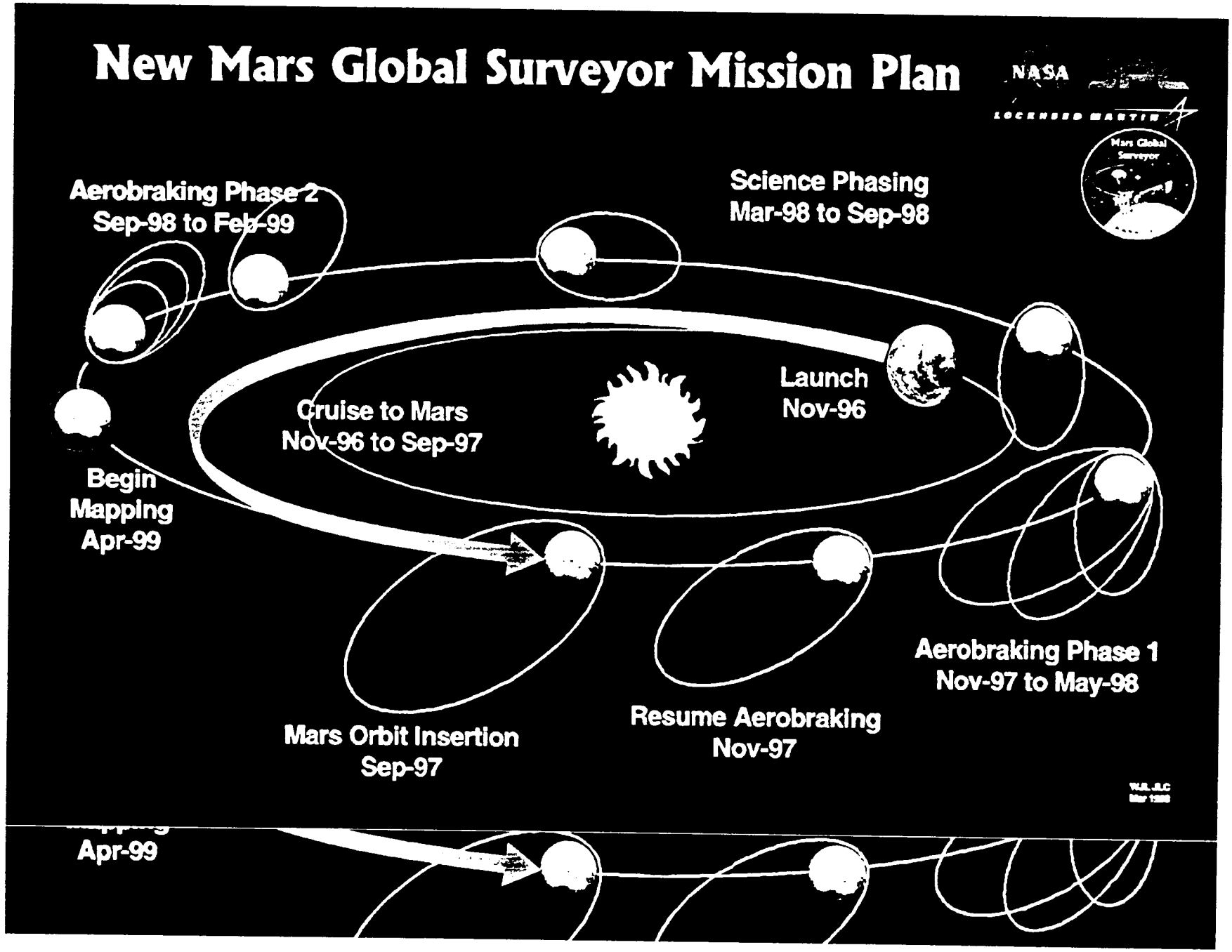
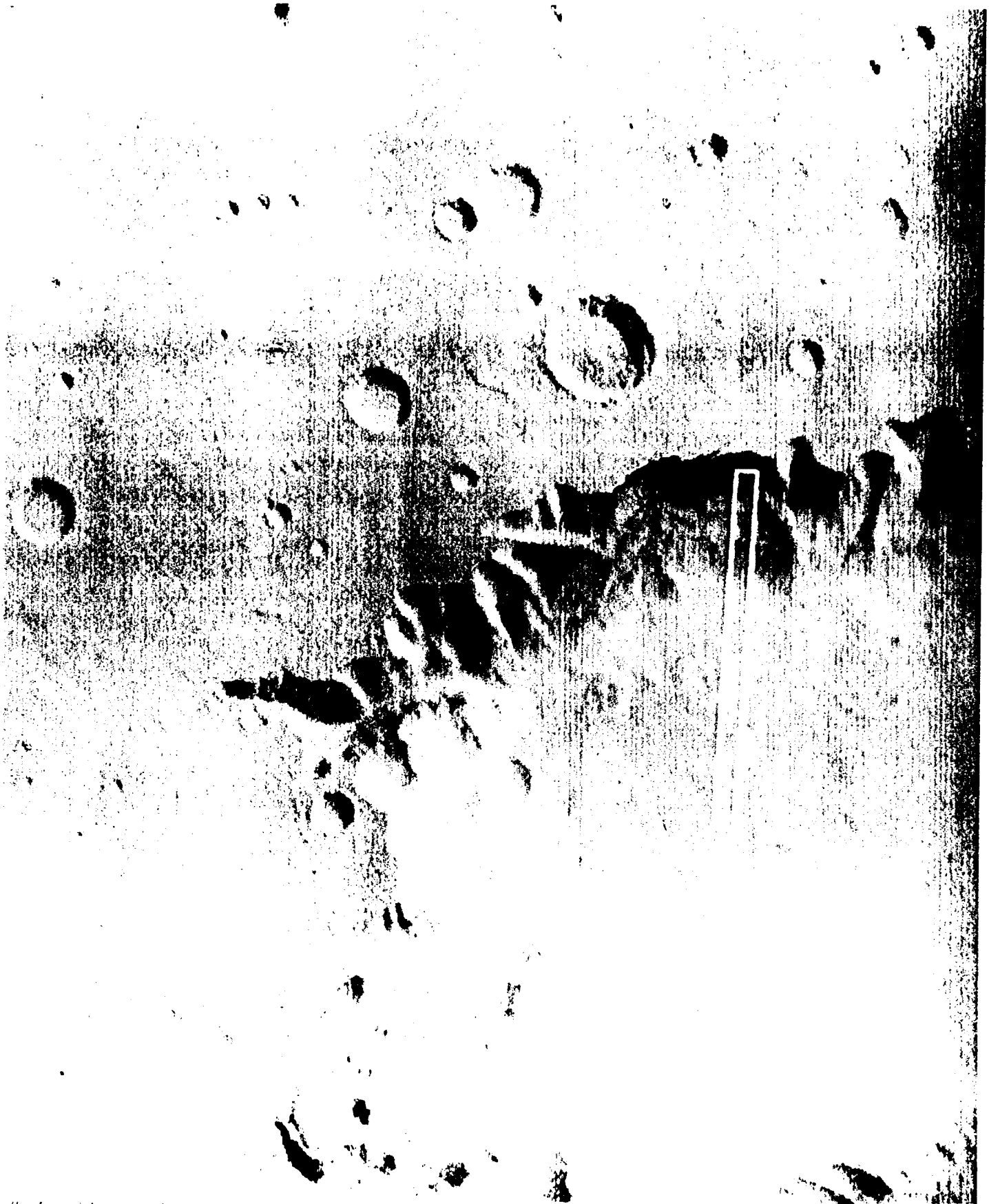
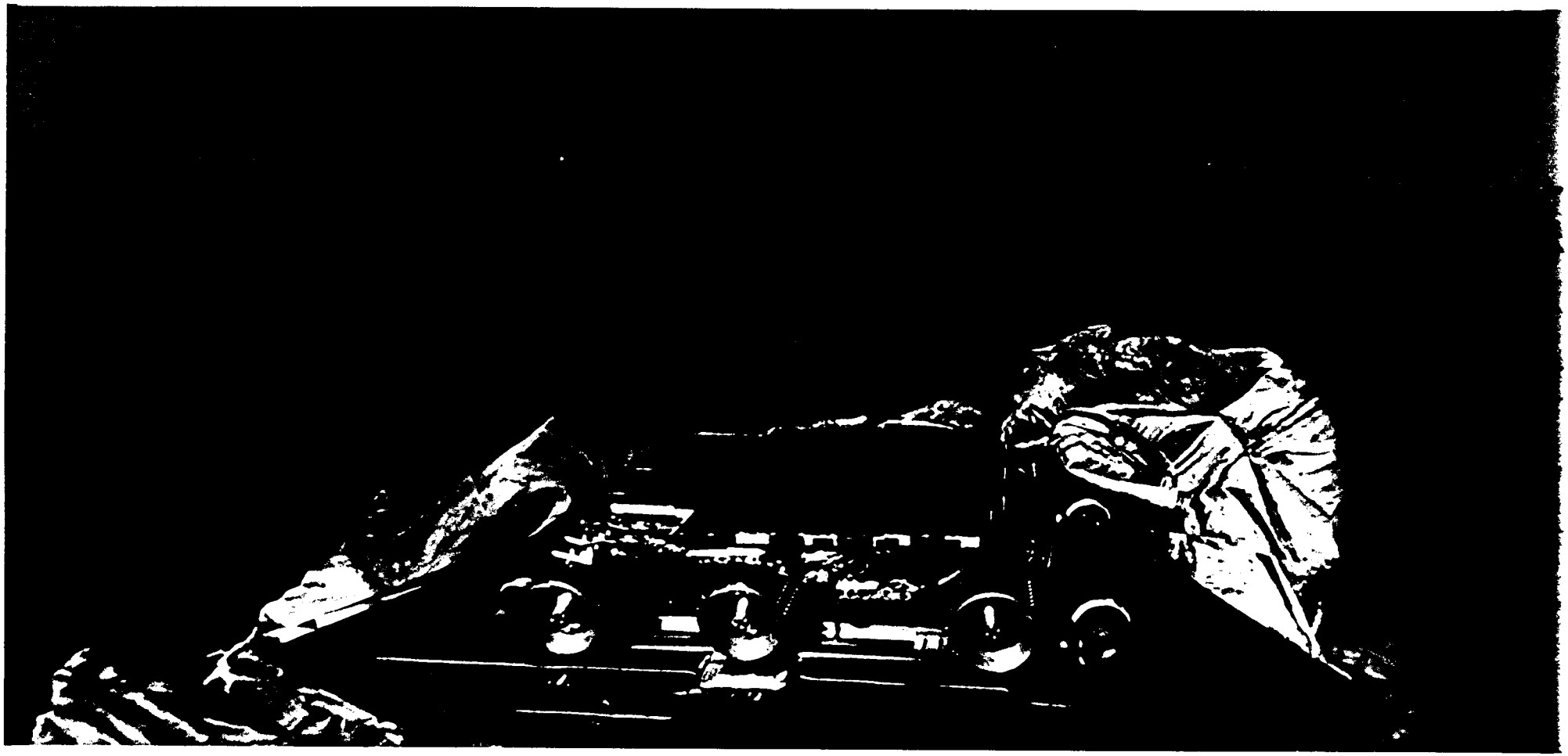
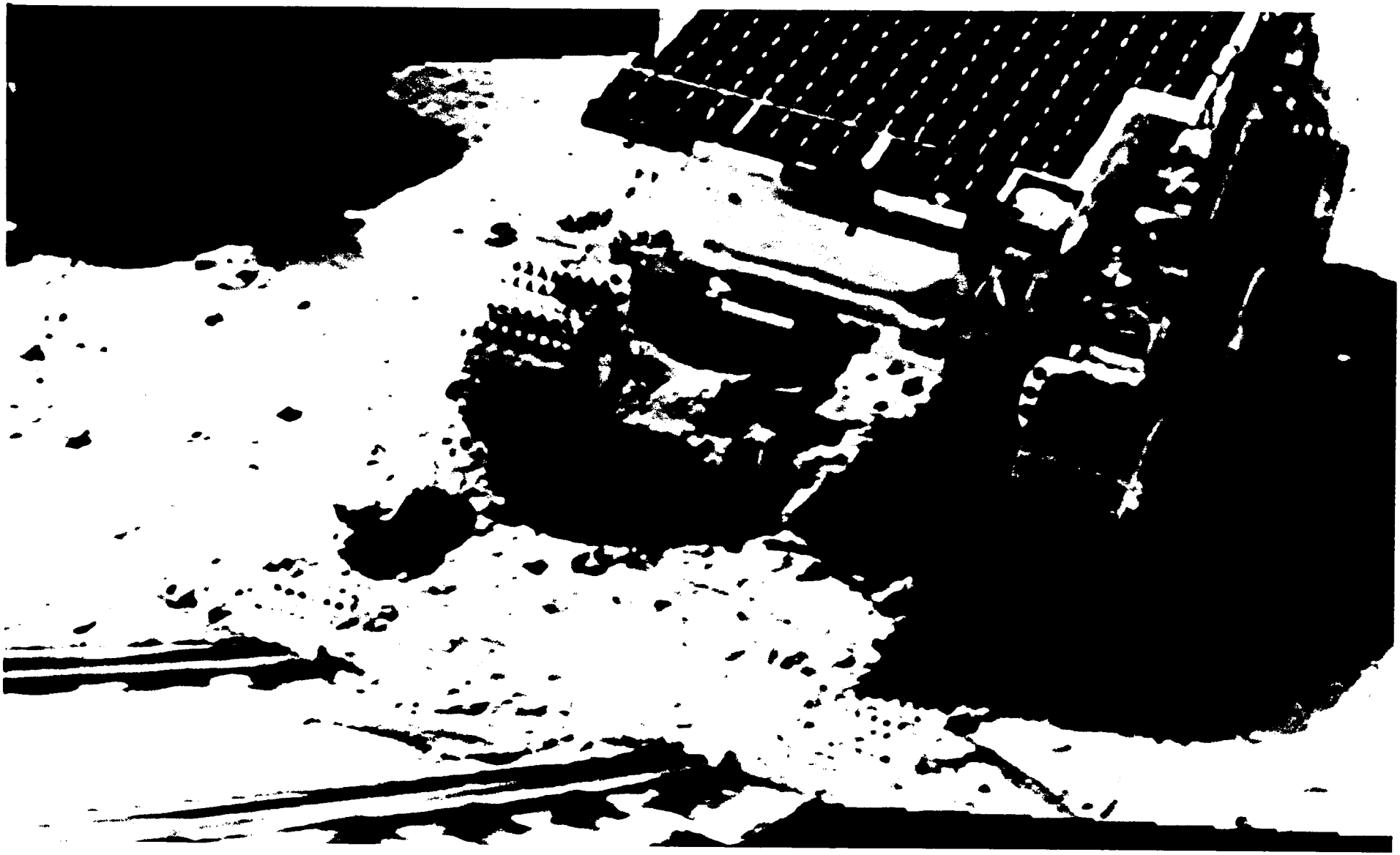


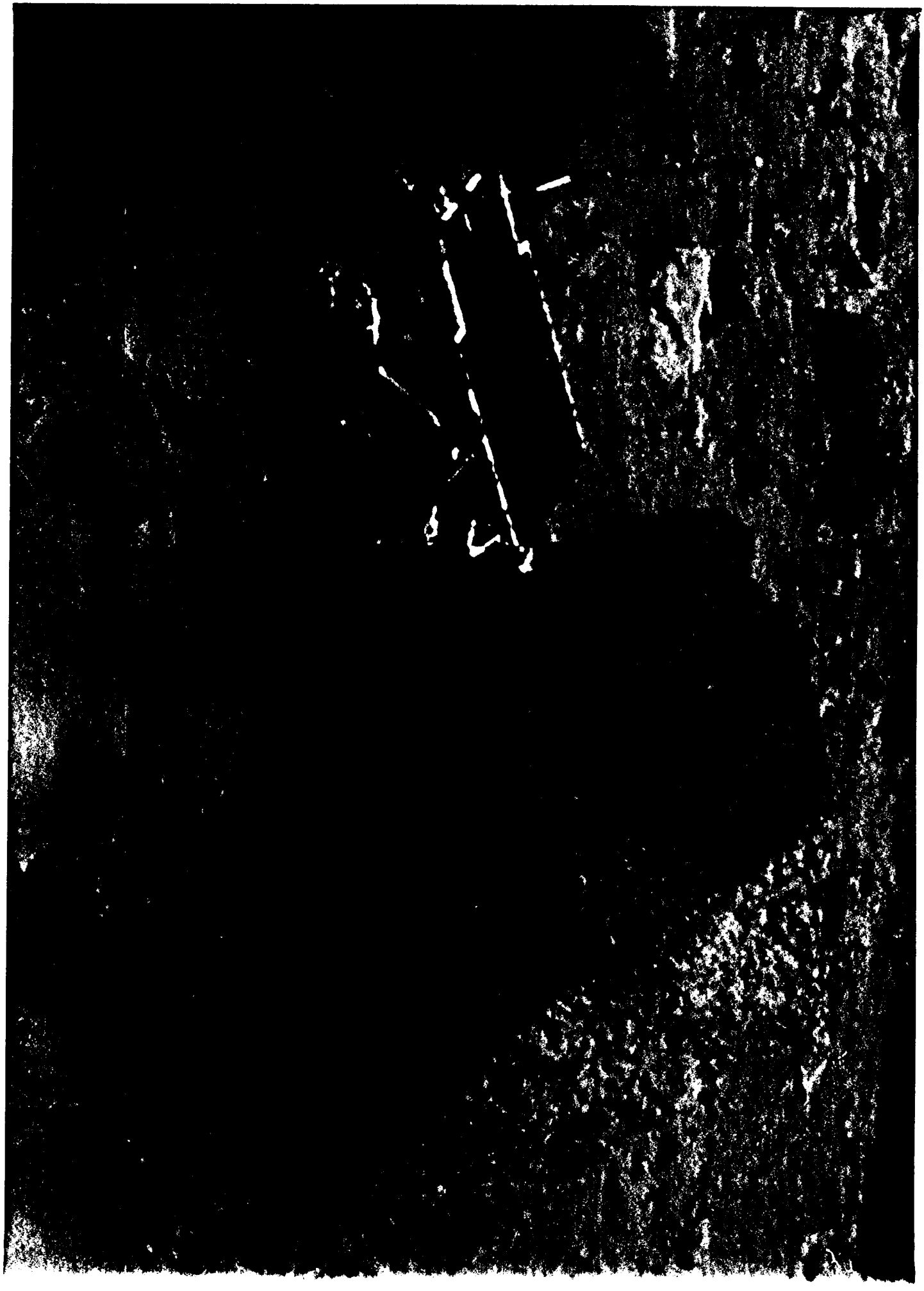
New Mars Global Surveyor Mission Plan

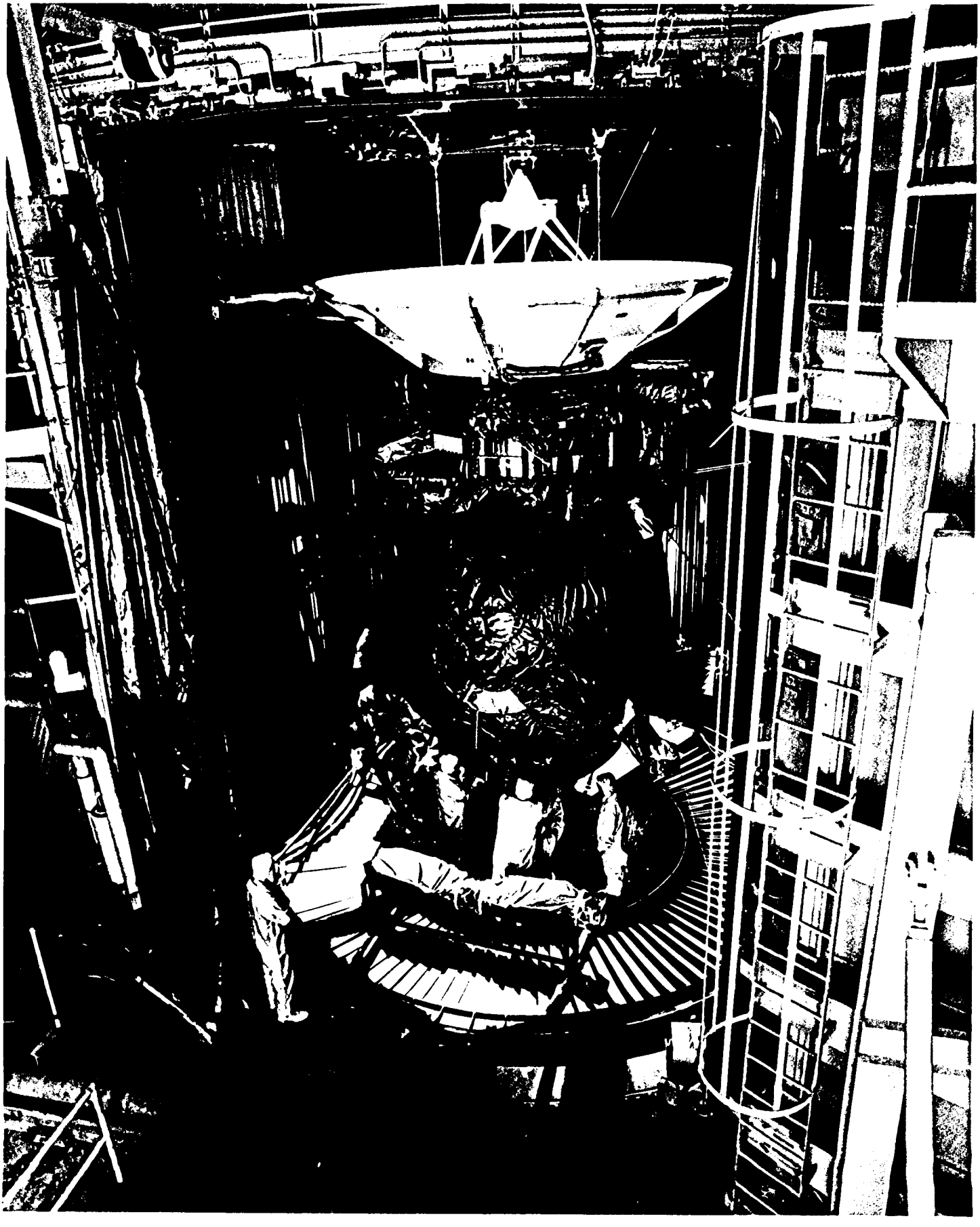




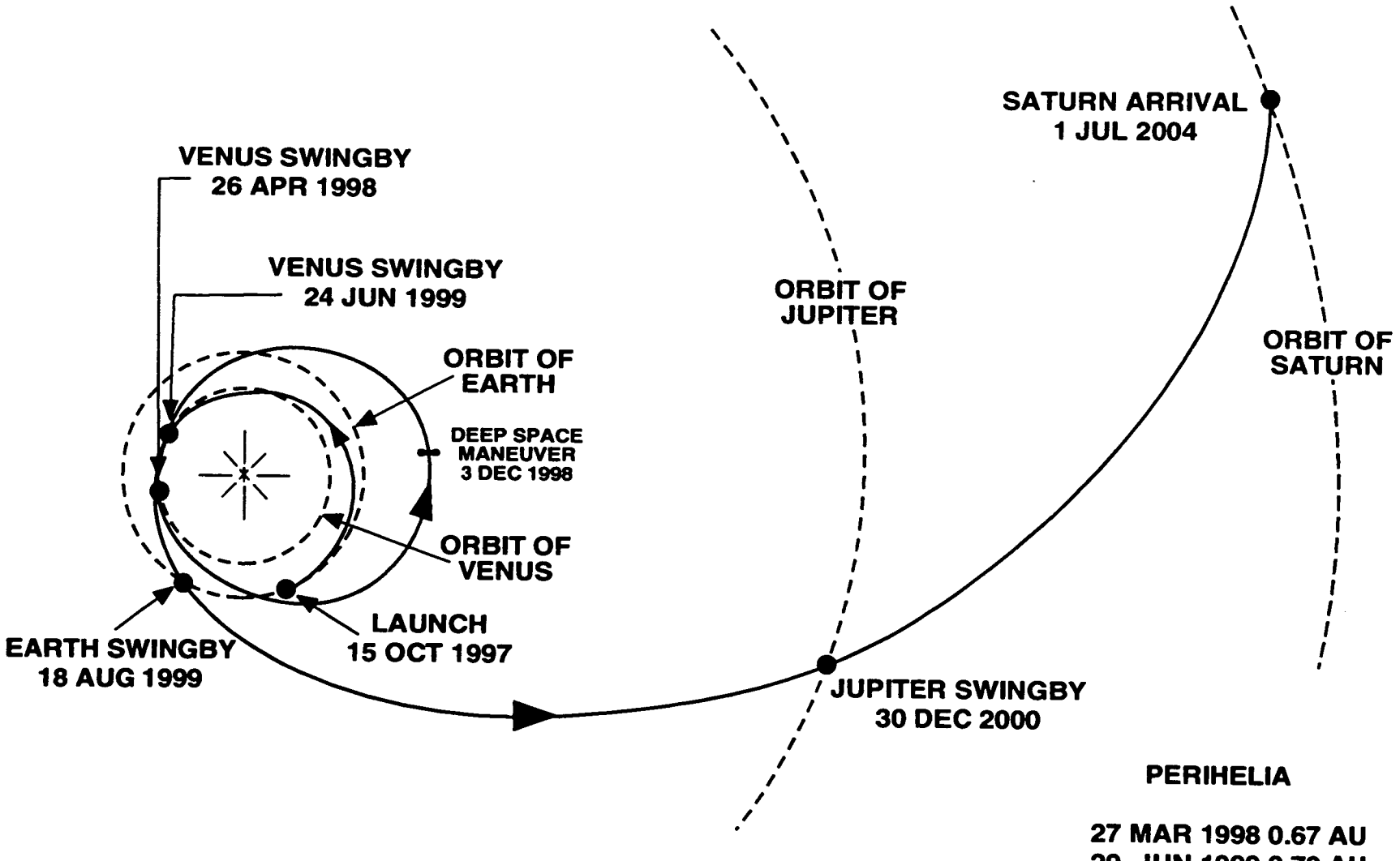








CASSINI
INTERPLANETARY TRAJECTORY



esa
european space agency
agence spatiale européenne

NASA
National Aeronautics and Space Administration

CASSINI SCIENCE OBJECTIVES

MAGNETOSPHERE

1. CONFIGURATION AND CURRENT SYSTEMS
2. PARTICLE COMPOSITION, SOURCES AND SINKS
3. DYNAMICS OF THE MAGNETOSPHERE
4. INTERACTION WITH SOLAR WIND, SATELLITES AND RINGS
5. TITAN'S INTERACTION WITH SOLAR WIND AND MAGNETOSPHERE

SATURN

1. CLOUD PROPERTIES/ATMOSPHERIC COMPOSITION
2. WINDS AND TEMPERATURES
3. INTERNAL STRUCTURE AND ROTATION
4. SATURN'S IONOSPHERE
5. ORIGIN AND EVOLUTION OF SATURN

RINGS

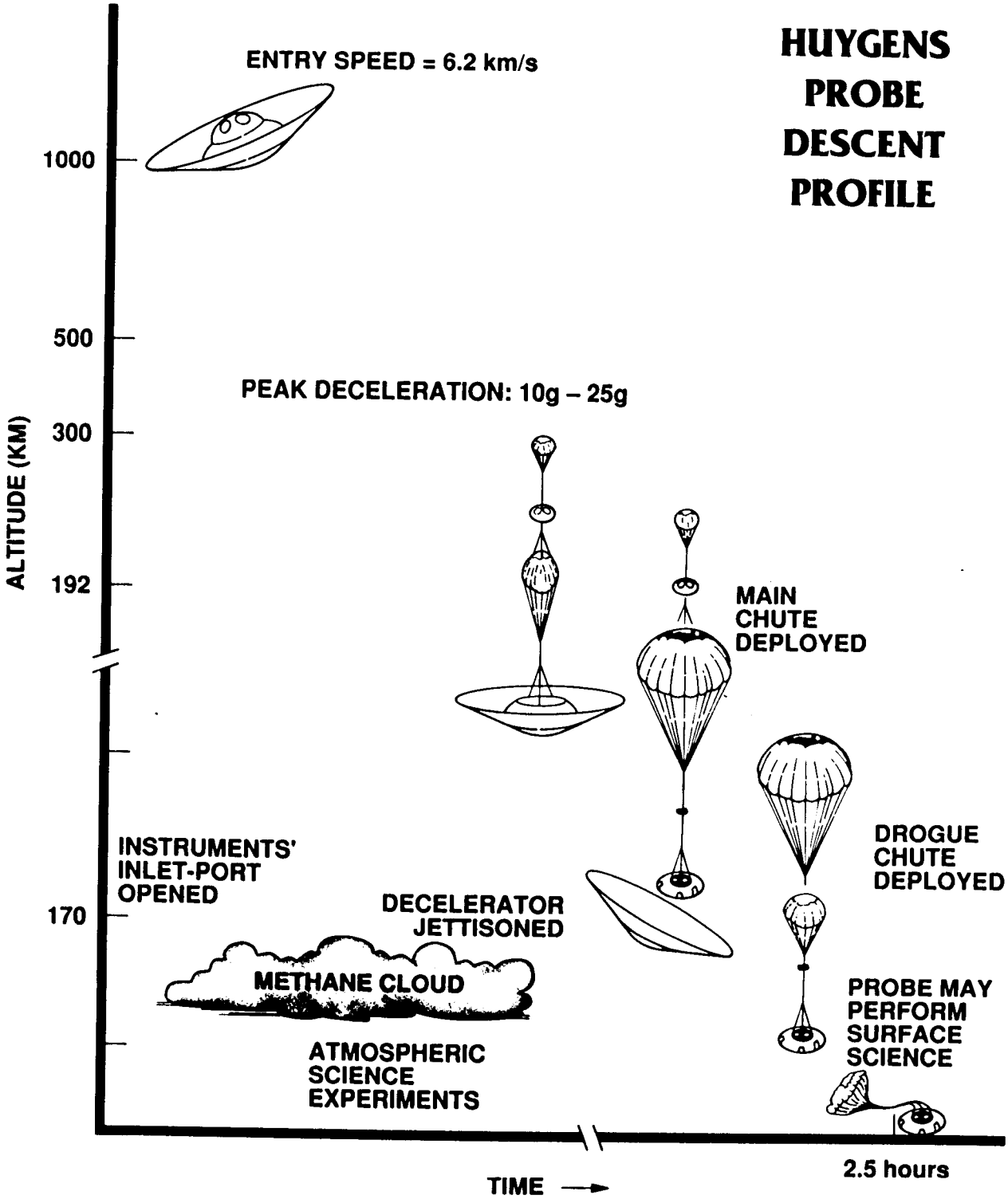
1. STRUCTURE AND COMPOSITION
2. DYNAMICAL PROCESSES
3. INTERRELATION OF RINGS AND SATELLITES
4. DUST MICROMETEOROID ENVIRONMENT

TITAN

1. ATMOSPHERIC CONSTITUENT ABUNDANCES
2. DISTRIBUTIONS OF TRACE GASES AND AEROSOLS
3. WINDS AND TEMPERATURES
4. SURFACE STATE AND COMPOSITION
5. UPPER ATMOSPHERE

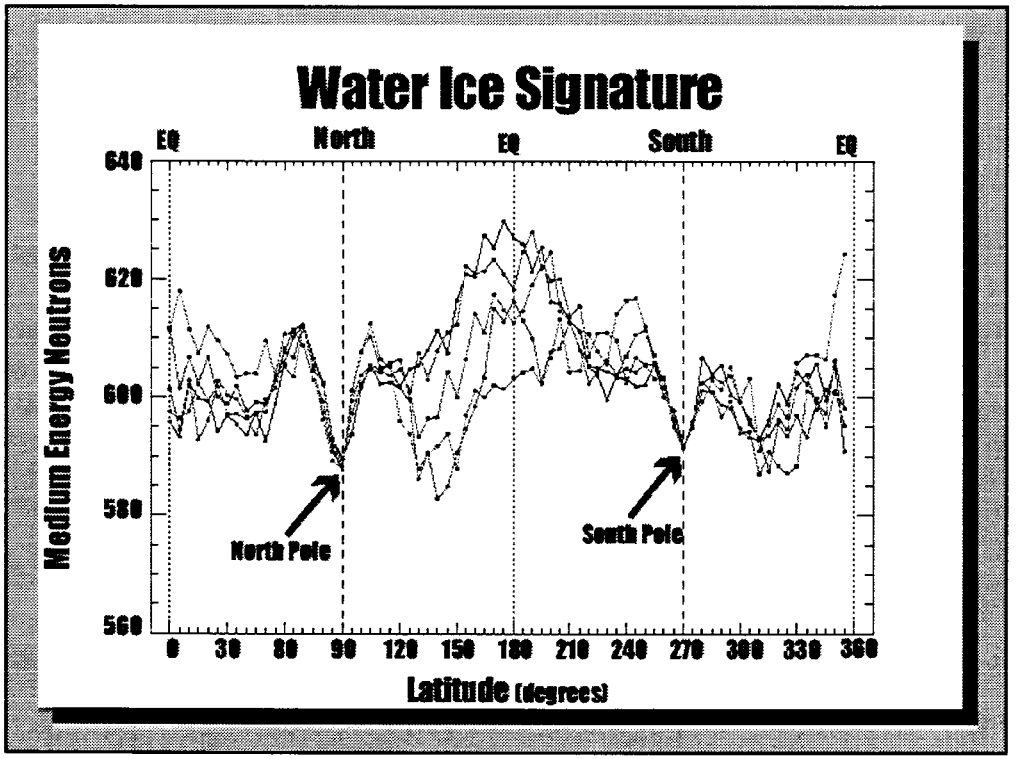
ICY SATELLITES

1. CHARACTERISTICS AND GEOLOGICAL HISTORIES
2. MECHANISMS OF SURFACE MODIFICATION
3. SURFACE COMPOSITION AND DISTRIBUTION
4. BULK COMPOSITION AND INTERNAL STRUCTURE
5. INTERACTION WITH MAGNETOSPHERE


HUYGENS
PROBE
DESCENT
PROFILE
ENTRY SPEED = 6.2 km/s
1000
500
PEAK DECELERATION: 10g – 25g
300
192
ALTITUDE (KM)
MAIN
CHUTE
DEPLOYED
DROGUE
CHUTE
DEPLOYED
INSTRUMENTS'
INLET-PORT
OPENED
DECELERATOR
JETTISONED
170
METHANE CLOUD
PROBE MAY
PERFORM
SURFACE
SCIENCE
ATMOSPHERIC
SCIENCE
EXPERIMENTS
2.5 hours
TIME

Finding Water Ice

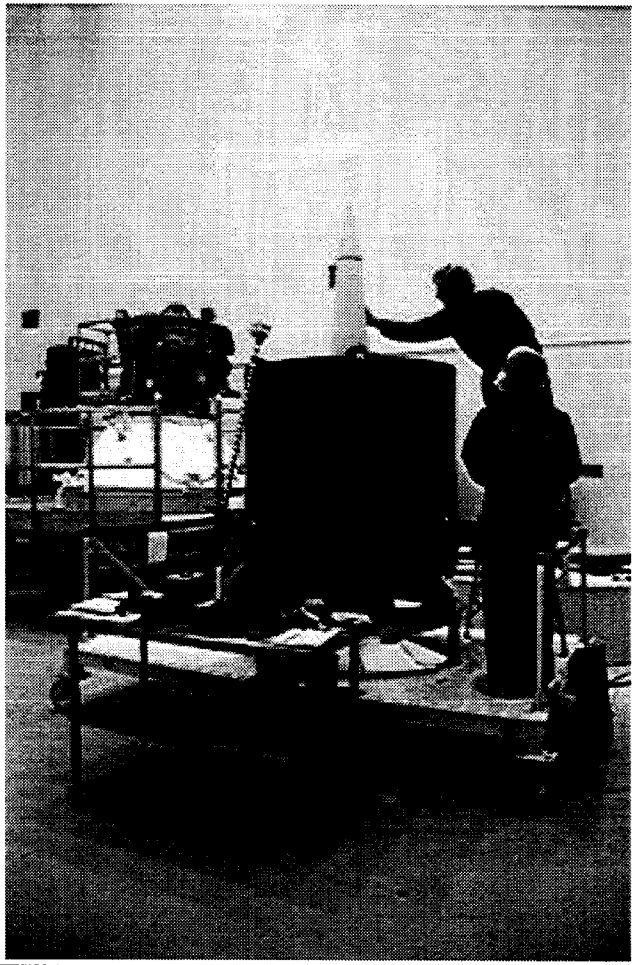
- Results from LP's NS shows lunar Hydrogen distribution.
- Most lunar Hydrogen comes from the solar wind, but...
- Hydrogen at the lunar poles, in permanetely shaded craters, had to have another source.
- Based on cosmic abundance and chemistry statistics...
- The only logical conclusion is Hydrogen in the from H_2O.
- 10 million to 300 million metric tons of ice crystals.

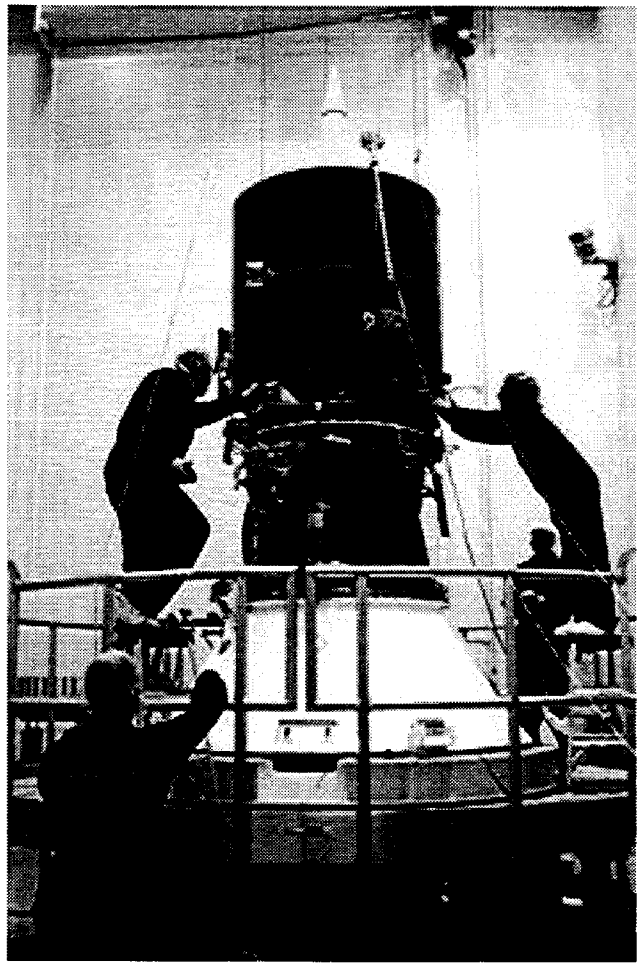


Plot of Hydrogen abundance over lunar surface. Note the consistent concentrations at North and South poles.

Discovery is another first for Lunar Prospector.

Getting Ready to Launch





Spacecraft and TLI during launch processing operations.

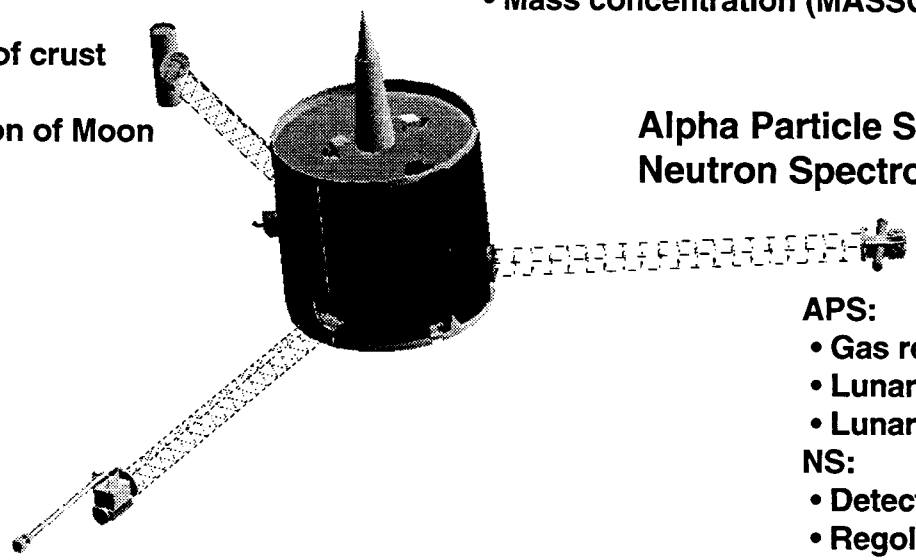
What Prospector does...

Gamma Ray Spectrometer (GRS)

- Elemental abundance
- Distribution Maps
- Bulk composition of crust
- Approx. 18 in deep
- Origin and evolution of Moon

Doppler Gravity Experiment:

- Lunar gravity field
- Mass concentration (MASSCON) mapping



Alpha Particle Spectrometer / Neutron Spectrometer (APS/NS)

APS:

- Gas release events
- Lunar volcanic activity
- Lunar evolution

NS:

- Detects and quantifies Hydrogen
- Regolith maturity
- Search for lunar ice deposits

Magnetometer / Electron Reflectometer (MAG/ER)

- Lunar magnetic field
- Existence / sizing of lunar core
- Lunar structure and origin

Lunar Prospector launched on 6 January 1998 at 9:28 p.m. EST.

JPL

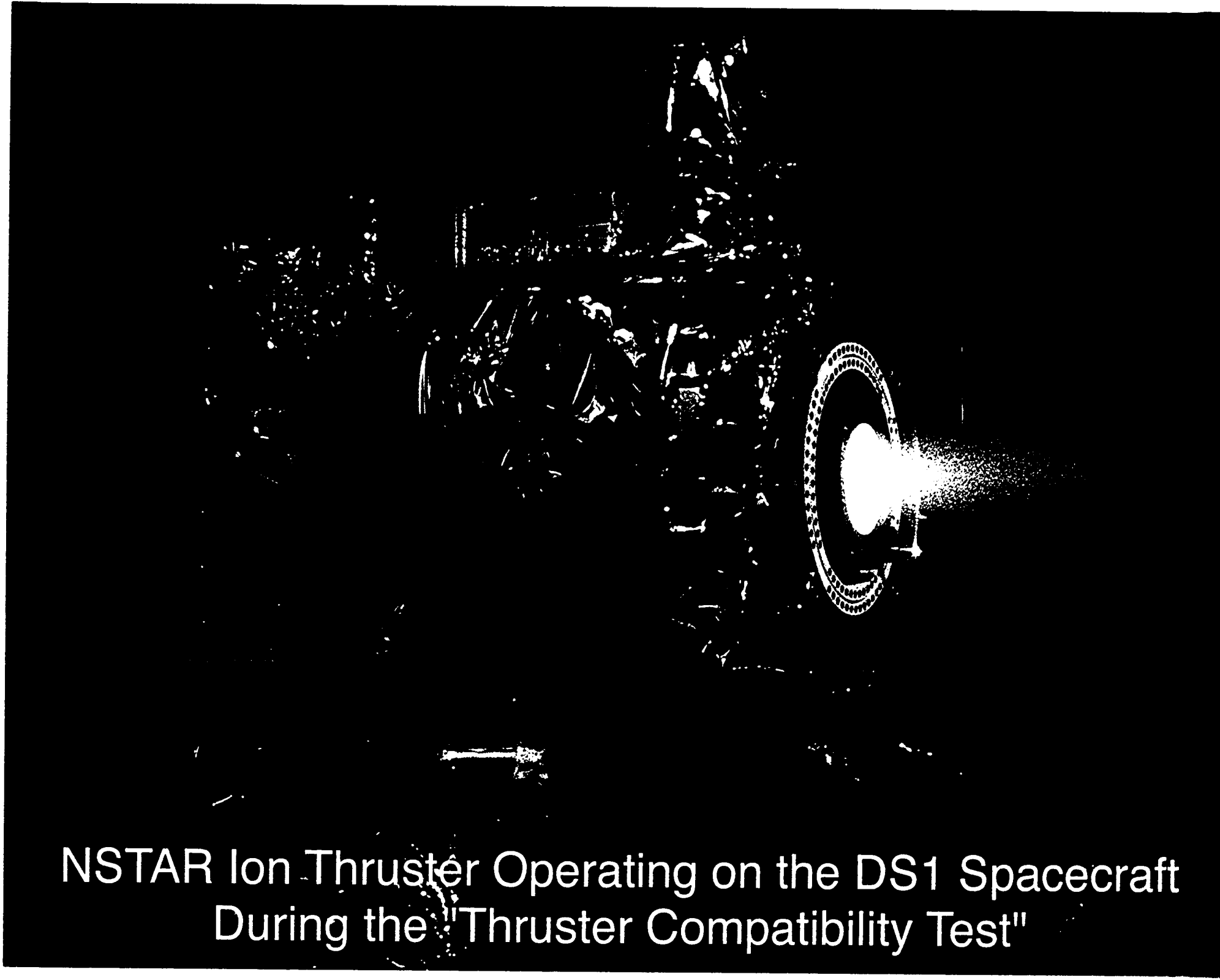
MISSIONS IN DEVELOPMENT

- NEW MILLENNIUM DS-1 (COMET & ASTEROID FLYBY)
- MARS SURVEYOR (1998)
- NEW MILLENNIUM DS-2 (MARS MICROPROBE PENETRATOR)
- STARDUST
- GENESIS
- MARS SURVEYOR 2001 & 2003
- MUSES-CN NANOROVER
- CONTOUR (COMET NUCLEUS TOUR)
- CHAMPOLLION/DS-4 (COMET LANDER & SAMPLE RETURN)
- MARS 2005 SAMPLE RETURN
- OUTER PLANETS/SOLAR PROBE
  - EUROPA ORBITER
  - PLUTO KUIPER EXPRESS
  - SOLAR PROBE

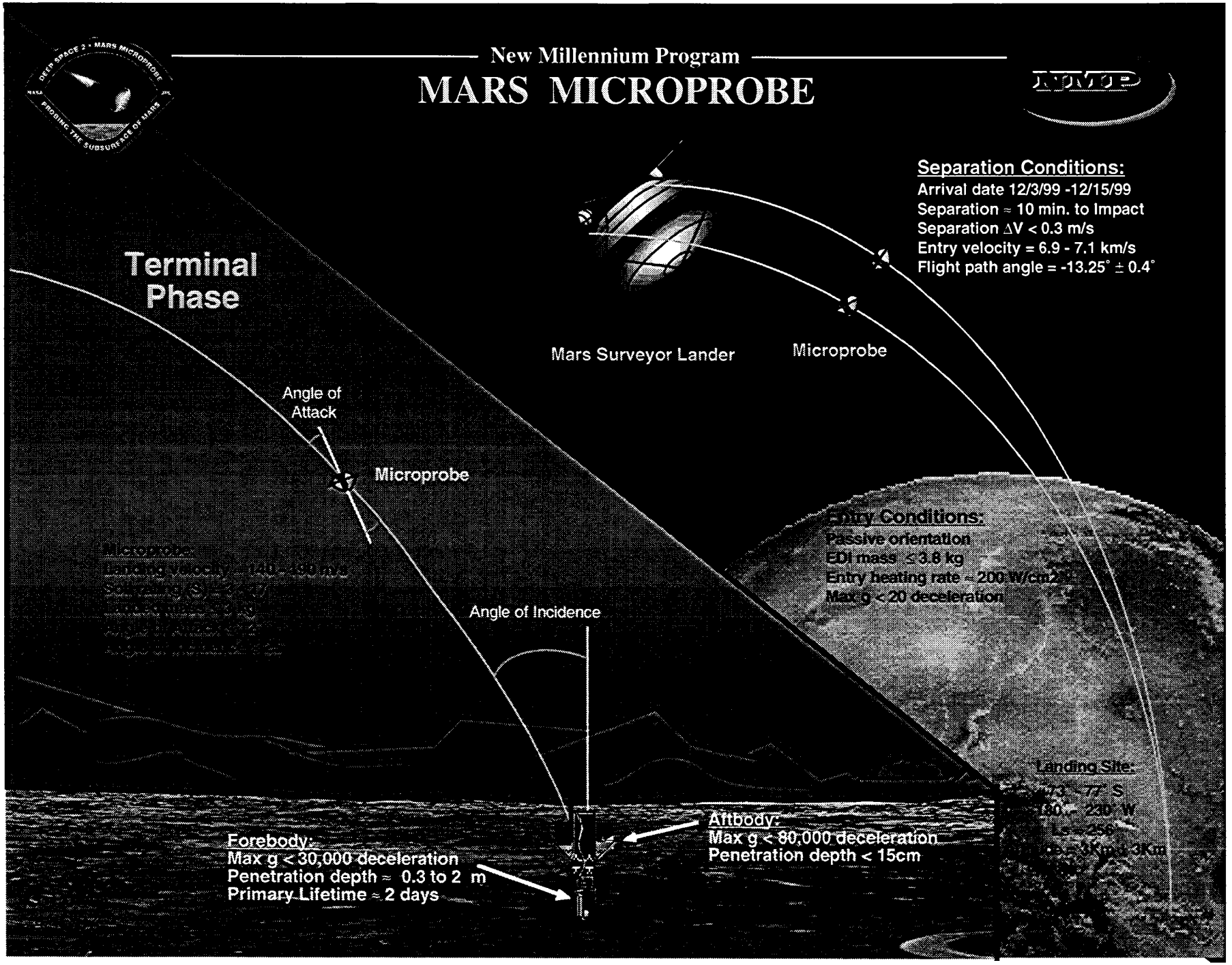
DS1 Mission

- Validate the following prime technologies through space flight
  - Solar electric propulsion as primary propulsion
  - Advanced solar array
  - Autonomous navigation as primary navigation
  - Miniature imaging camera spectrometer

- Validate the following additional technologies through space flight:
  - Small deep-space transponder
  - Autonomy - remote agent architecture
  - Miniature ion and electron spectrometer
  - Autonomy - beacon monitor operations
  - Ka-band solid state power amplifier
  - Low power electronics experiment
  - Multi-functional structure
  - Power actuation and switching module



NSTAR Ion Thruster Operating on the DS1 Spacecraft
During the "Thruster Compatibility Test"


New Millennium Program
MARS MICROPROBE
NMP
Separation Conditions:
Arrival date 12/3/99 -12/15/99
Separation ≈ 10 min. to Impact
Separation ΔV < 0.3 m/s
Entry velocity = 6.9 - 7.1 km/s
Flight path angle = -13.25° ± 0.4°
Terminal Phase
Mars Surveyor Lander
Microprobe
Angle of Attack
Microprobe
Angle of Incidence
Entry Conditions:
Passive orientation
EDI mass ≤ 3.6 kg
Entry heating rate ≈ 200 W/cm2
Max g < 20 deceleration
Landing Site:
73° - 77° S
80° - 230° W
Forebody:
Max g < 30,000 deceleration
Penetration depth ≈ 0.3 to 2 m
Primary Lifetime ≈ 2 days
Aftbody:
Max g < 80,000 deceleration
Penetration depth < 15cm

Technology Demonstrations

Non-erosive, lightweight, single-stage atmospheric entry system

Microtelecommunications system with mixed digital/analog/RF ASICs

Power microelectronics with with mixed digital/analog ASICs

Ultra low temperature lithium battery

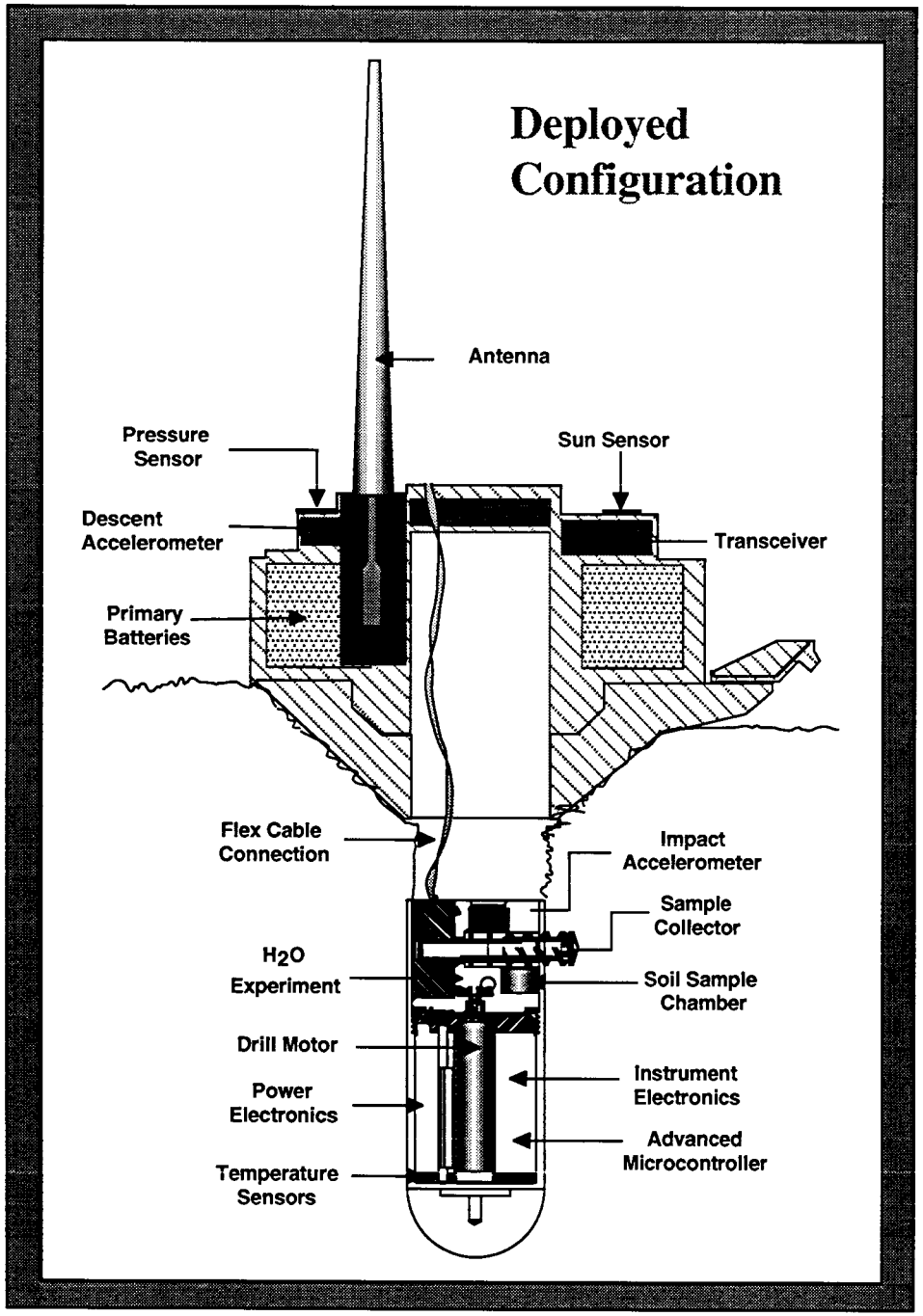
Advanced 3D HDI microcontroller

Flexible interconnects for system cabling

Meteorological high-g pressure sensor

Soil conductivity high-g temperature sensor

Sample/water experiment



STARDUST MISSION OVERVIEW

Comet Wild-2

Earth Gravity Assist
01/14/01

Wild-2 Encounter
01/02/04
Velocity=6.1 km/s
Solar Range=1.9 AU
Earth Range=2.6 AU

Return
01/15/06

Launch
02/06/99

Earth
Orbit

1

2

3

A

B

Interstellar Particle Stream

≡ Heliocentric Loops 1, 2 and 3
02/99-01/01, -07/03, -01/06

✧ Deep Space Maneuvers
1-3: 4/00, 2/02, 6/03

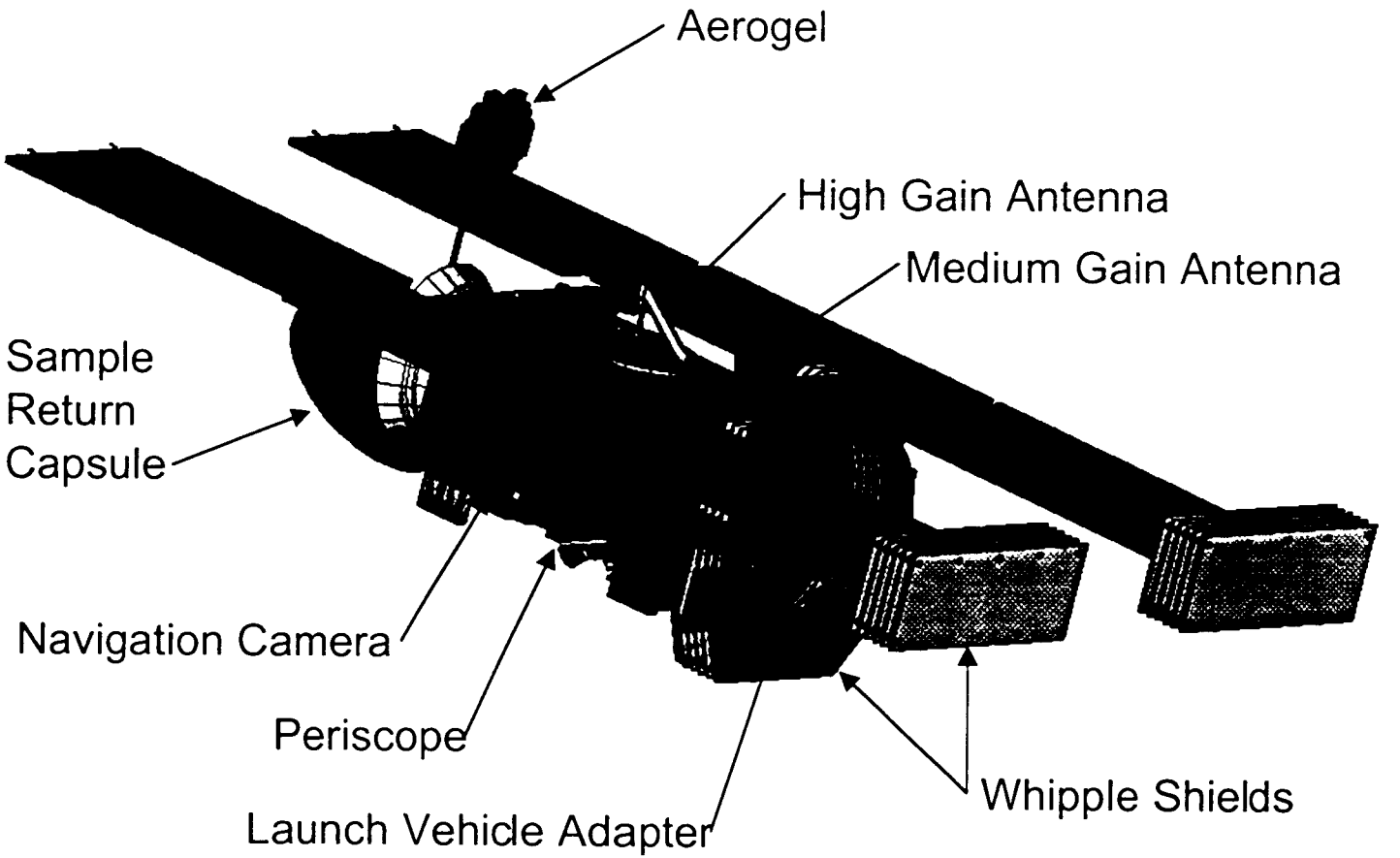
= Interstellar Particle Collection
A-B: 10/99-3/00, 6/02-10/02

LOCKHEED MARTIN

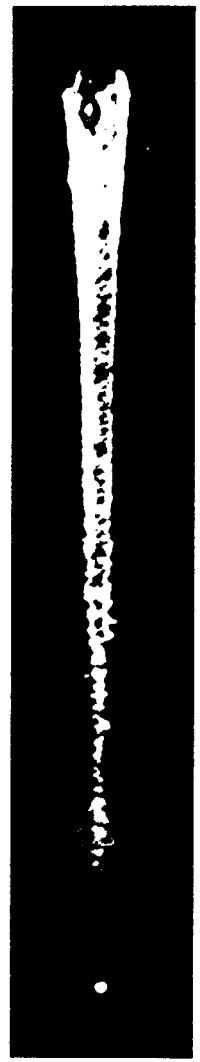
JPL

NASA

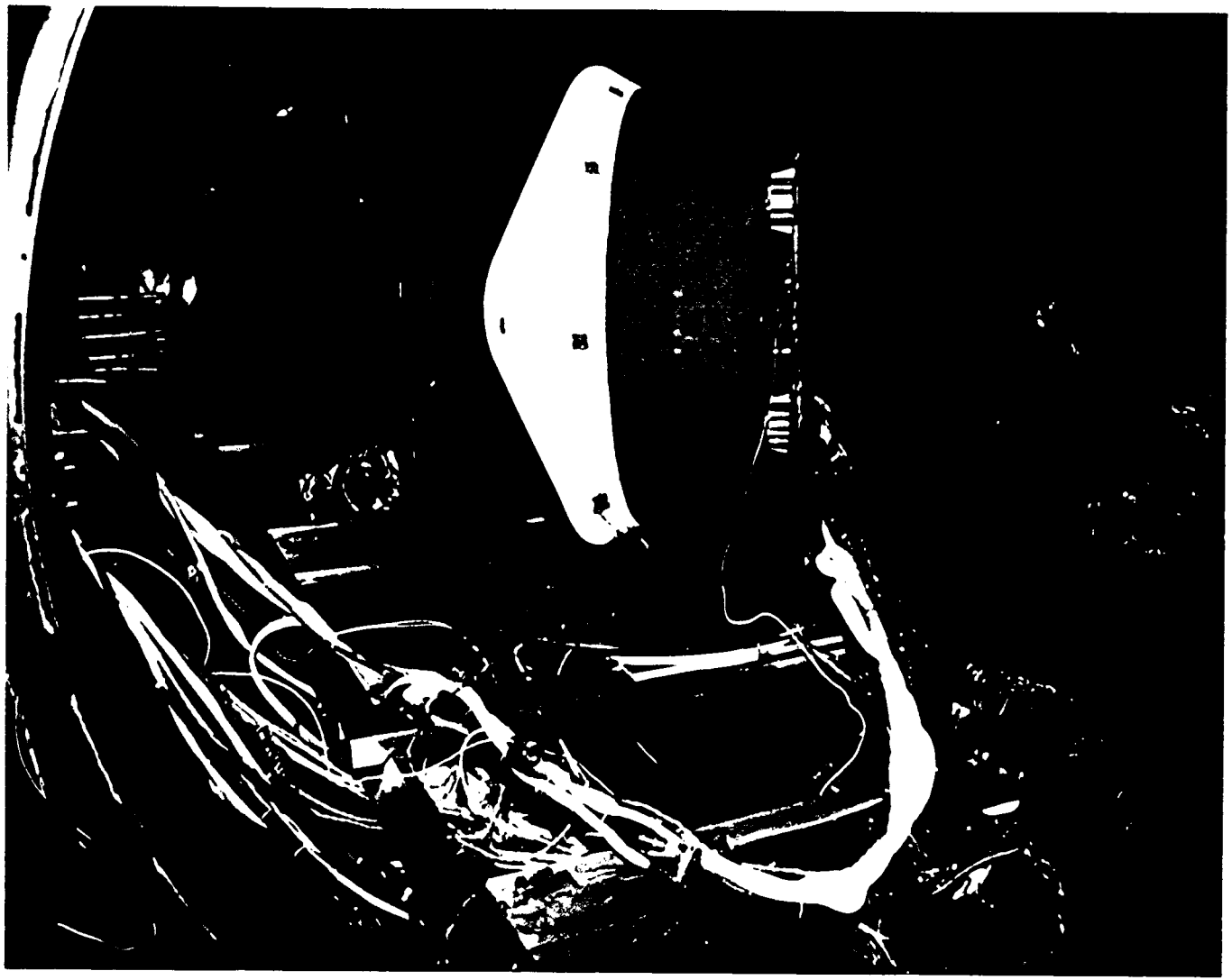
STARDUST, +X, -Y, +Z



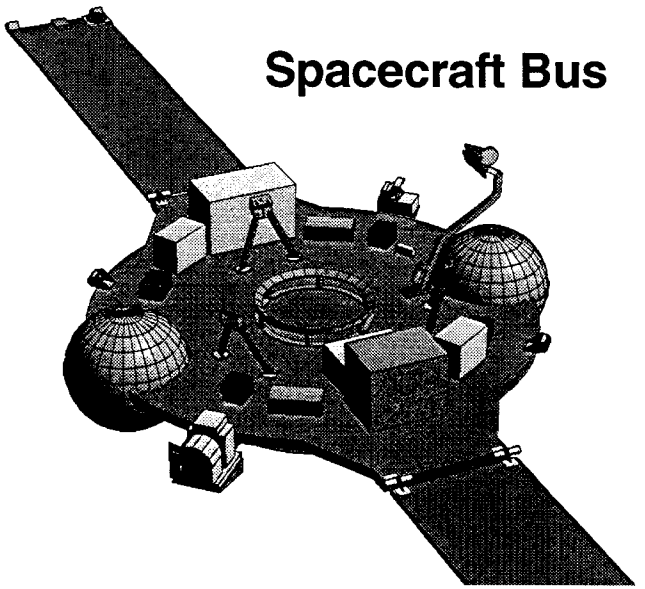
Capturing "Bullets"



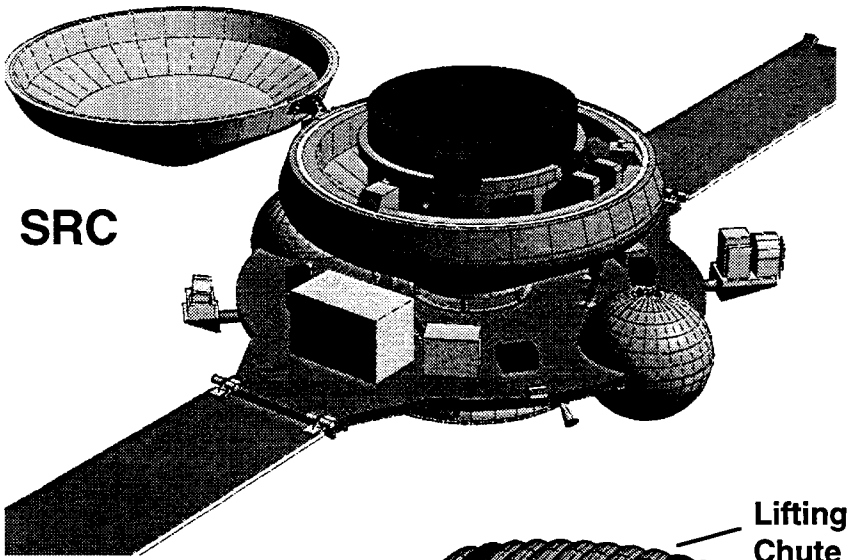
SRC STM in TV Chamber



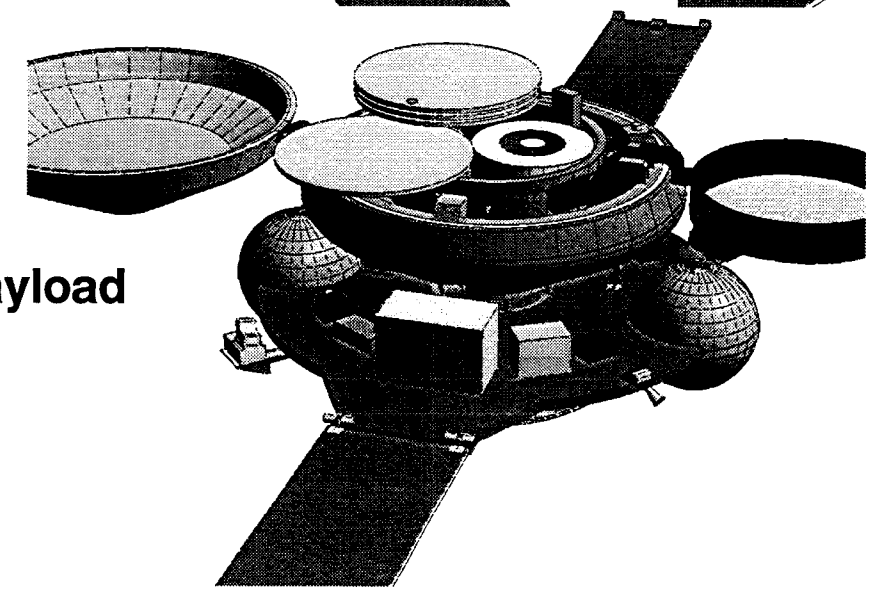
Spacecraft/SRC/Payload/Recovery



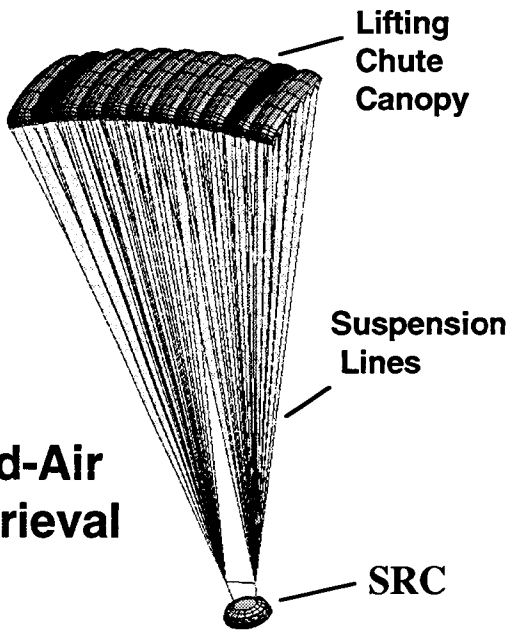
Spacecraft Bus



SRC

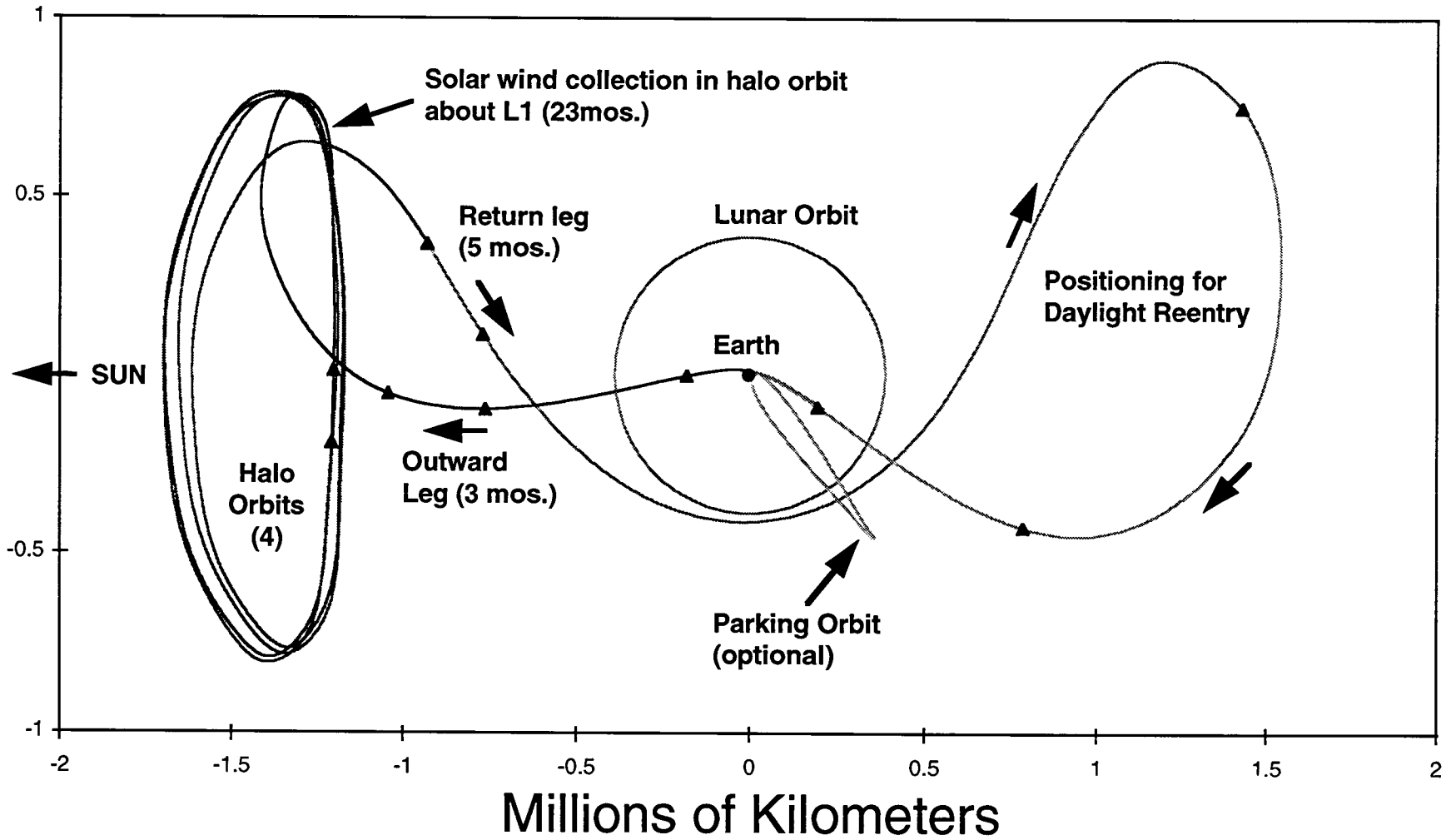


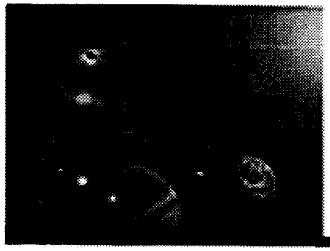
Payload



Mid-Air
Retrieval

Mission Description





GENESIS

Mission In a Nutshell

- Place a Spacecraft Outside the Earth's Magnetosphere. Launch Aboard a Delta II in January 2001

- Expose Ultra-Pure Materials (Collectors/Concentrator)
  - Capture solar wind for two years
  - Solar wind ions and elements collected be above the "noise floor" of the collectors $\Rightarrow$ clean collectors

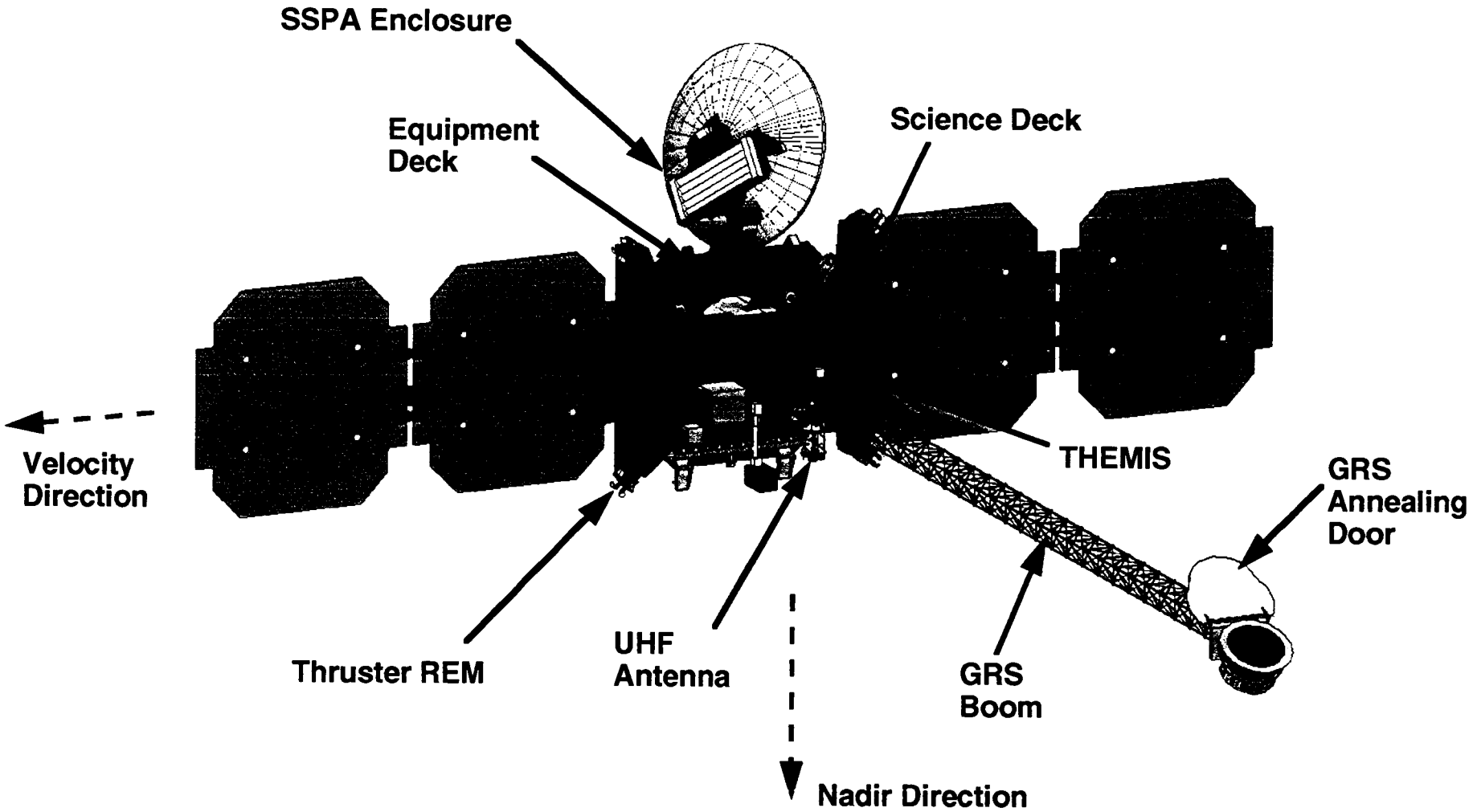
- Return the Imbedded Solar Wind Samples to Earth. Sample Return August 2003 at Utah Test & Training Range

- Analyze the Samples With State-of-the-Art Laboratory Instruments

Mission Overview

- Integrated Space Science, Space Flight, and Life & Microgravity Sciences & Applications 2001 Mission
  - Orbiter
  - Long-Lived Lander with Rover
- Two Launches, Delta 7425
- Cost Constrained/Capabilities Driven Mission
  - Maintain Mars Surveyor Program Heritage
  - MSP '98 $\rightarrow$ MSP '01 $\rightarrow$ MSP '03
- Conduct Mars Science, Mars Environment, and Technology Experiments

Science Orbit Configuration (GRS Deployed)



J

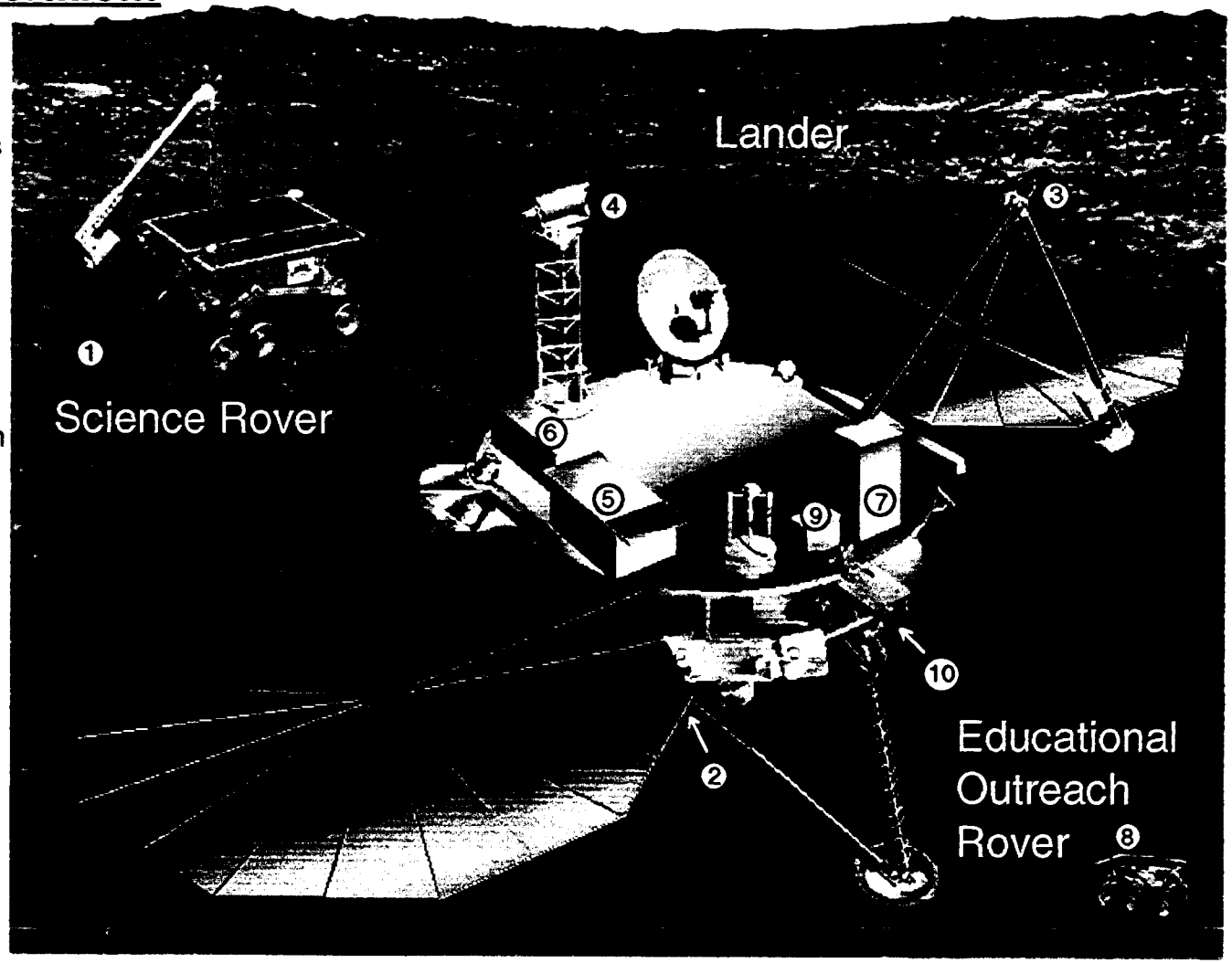
Deployed Lander/Rover

Science Under Consideration:

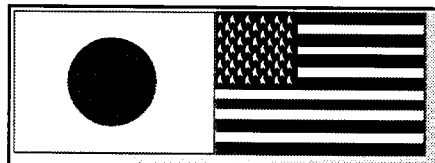
Planetary Science
1 Rover with Camera & Instruments
2 Descent Imager Camera
3 Robotic Arm
4 Stereoscopic Imager

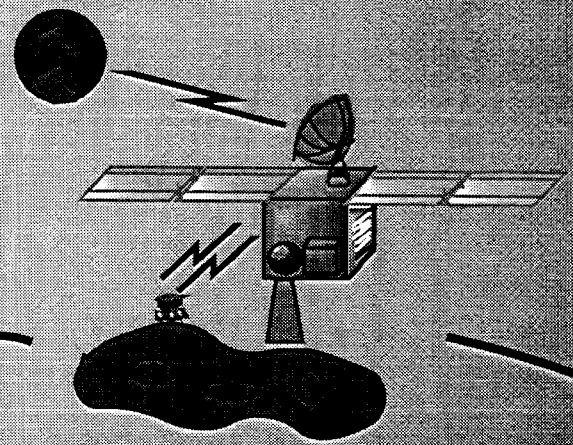
Human Exploration and Development of Space
5 Mars InSitu Propellant Production
6 Soil and Dust Experiment
7 Radiation Monitor

Educational Outreach
8 Student Nano-Rover
9 Greenhouse Experiment
10 Mars Long Duration Exposure Facility



MUSES-C/ CN Mission Overview





Earth Return: 32 months
Solar electric propulsion
Three Nereus samples
No science activities
Mini-rover stays on Nereus

Cruise: 15 months
Solar electric propulsion
No Science Activities

MUSES-C S/C

4660 Nereus (radius = 0.5 km)

Asteroid Operations: 4/6/03 - 5/30/03
MUSES-C: Nereus gravity mapping and remote science, sample collection
MUSES-CN: imaging, Near-IR point spectrometry, AXS (5/16/03 - 5/30/03)

MUSES-CN
Micro-rover

Launch: Jan 7, 2002
M-5 Launch Vehicle
Kagoshima Space Center, Japan

Re-entry
V=12.6 km/sec
Spin-stabilized
h=200 km

h=10 km

Earth Return:
Jan 20, 2006

Ranges for Key Mission Events (AU)

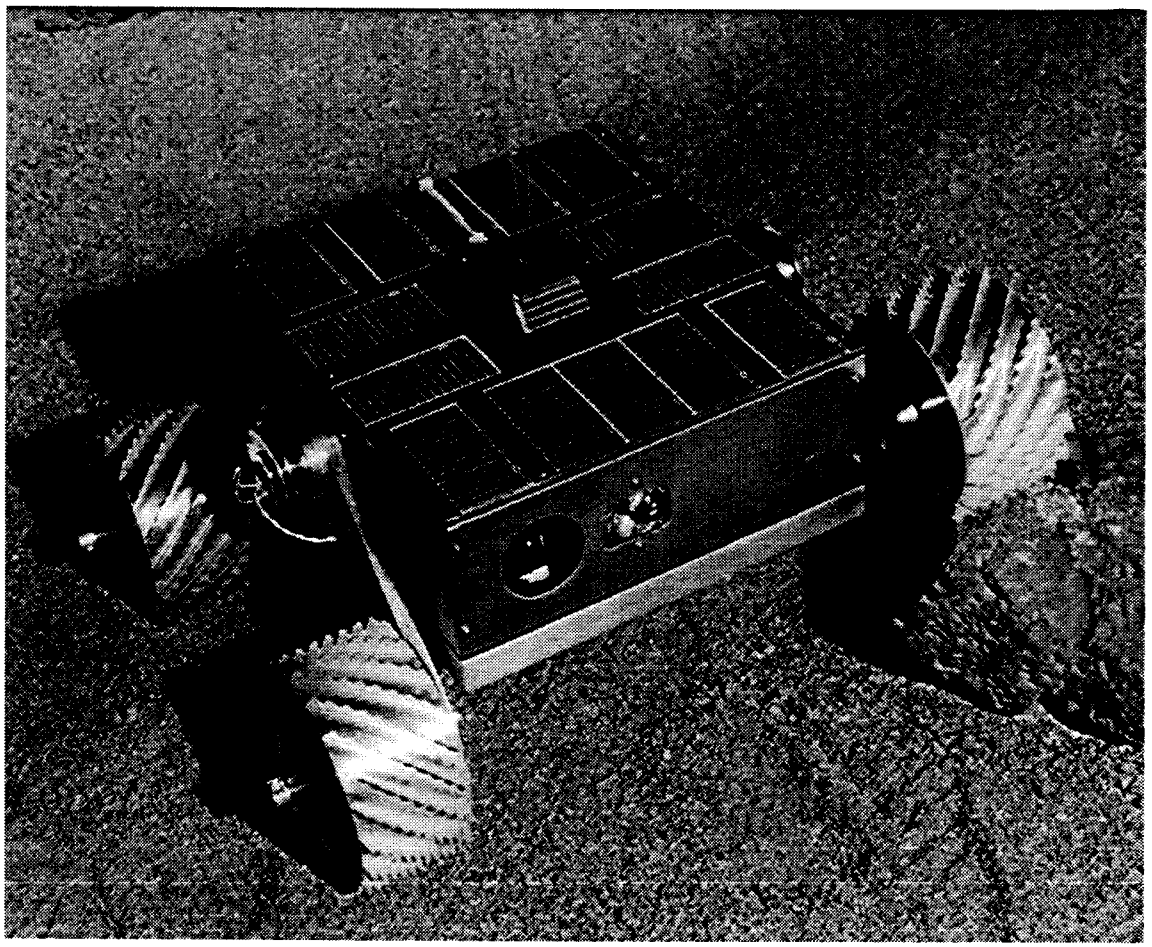
Event	Sun-S/C	Earth-S/C
Launch	0.98	0.00
Cruise (max)	2.02	2.97
Arrival	1.85	2.61
Departure	1.66	2.05
Return (max)	2.38	3.34

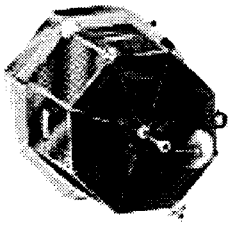
SSW 2/17/98

MUSES-CN Rev 0 Rover

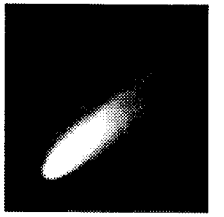
- panoramic imaging at 1 mrad/pixel in 8 vis/VNIR spectral bands,
- microscopic imaging at < 10 microns/ pixel in those same bands
- NIR spectrometry from 1.2 to 2.2 microns at ~20 nanometer resolution
- Sojourner Like AXS
- body articulation allows "hopping" in 10μG environment and "posing" of instruments
- comm relay to MUSES C
- Development process modelled after Sojourner (and many of same team):
  - Software Development Model evolves into Engineering Model as SW workalikes are replaced with flight-likes
  - Build a protoflight unit/flight spare (SIM) and a Flight Unit Rover (FUR)
  - "Sojourner Like" Product Assurance
- 30 month PDR to Ship

four 6.5cm dia wheels on 7 cm articulated struts,
Power ~3 watts; 14 x 14 x 6 cm; 1250 g



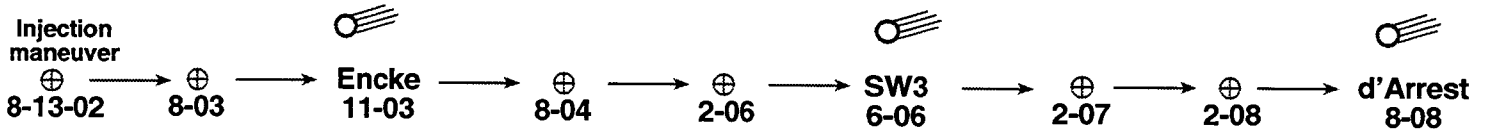


CONTOUR



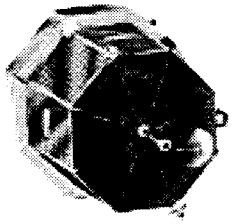
Comet Nucleus Tour—CONTOUR

A Mission to Study the Diversity of Comet Nuclei



Encounter Date	Sun Distance (AU)	Earth Distance (AU)	Phase Angle (deg)	Flyby Speed (km/s)
Encke, Nov 12, 2003	1.07	0.27	12	28.2
SW3, Jun 18, 2006	0.95	0.33	100	14.0
d'Arrest, Aug 16, 2008	1.35	0.36	68	11.8

- All encounters occur near maximum comet activity and at time of excellent viewing from Earth.
- First encounter (Encke) occurs only 15 months after launch. All three comets visited within 5 years.
- Possibility of extended mission to provide second look at Encke.
- High probability of encountering a "new comet."



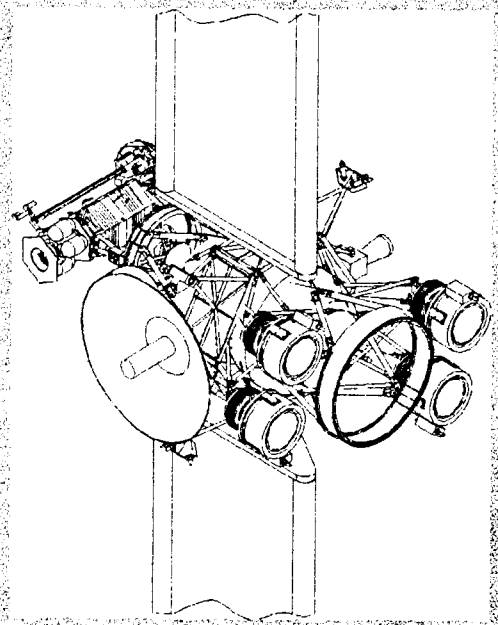
CONTOUR

Comet Nucleus Tour—CONTOUR

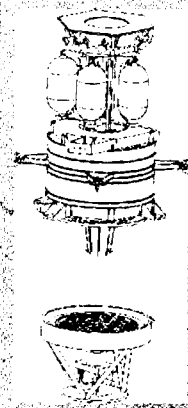
- **Mission Concept:** Uses Earth gravity-assist maneuvers to accomplish multiple cometary encounters
- **Target Selection:** Emphasis on diversity and unique objects.
- **Small, focused science payload**
  - High-Resolution Imager/Mapping Spectrometer (CRISP)
  - Wide-Angle Imager (CFI)
  - Dust Analyzer/Counter (CIDA)
  - Neutral/Ion Mass Spectrometer (NGIMS)
- **Simple, robust spacecraft**
- **Launch Vehicle: Delta-7425 (Med-Lite)**

Deep Space 4 / Champollion
Key Technology Developments

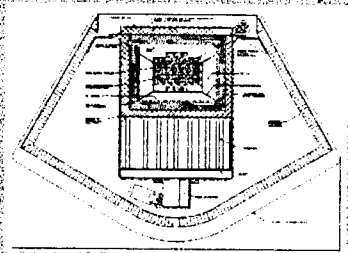
Precision Guidance
for Landing and Docking



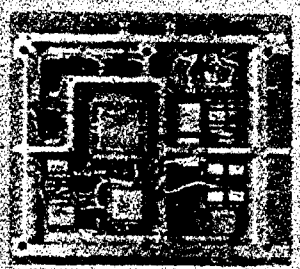
Inflatable
Rigidizable
Solar Array



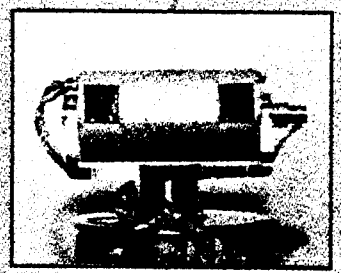
Autonomous Docking



Sample
Return

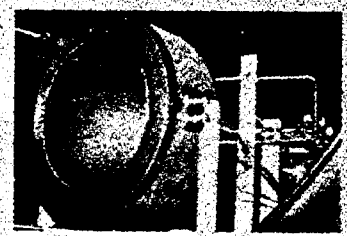


Micro Electronics
and Software



In-Situ Analysis
Instruments

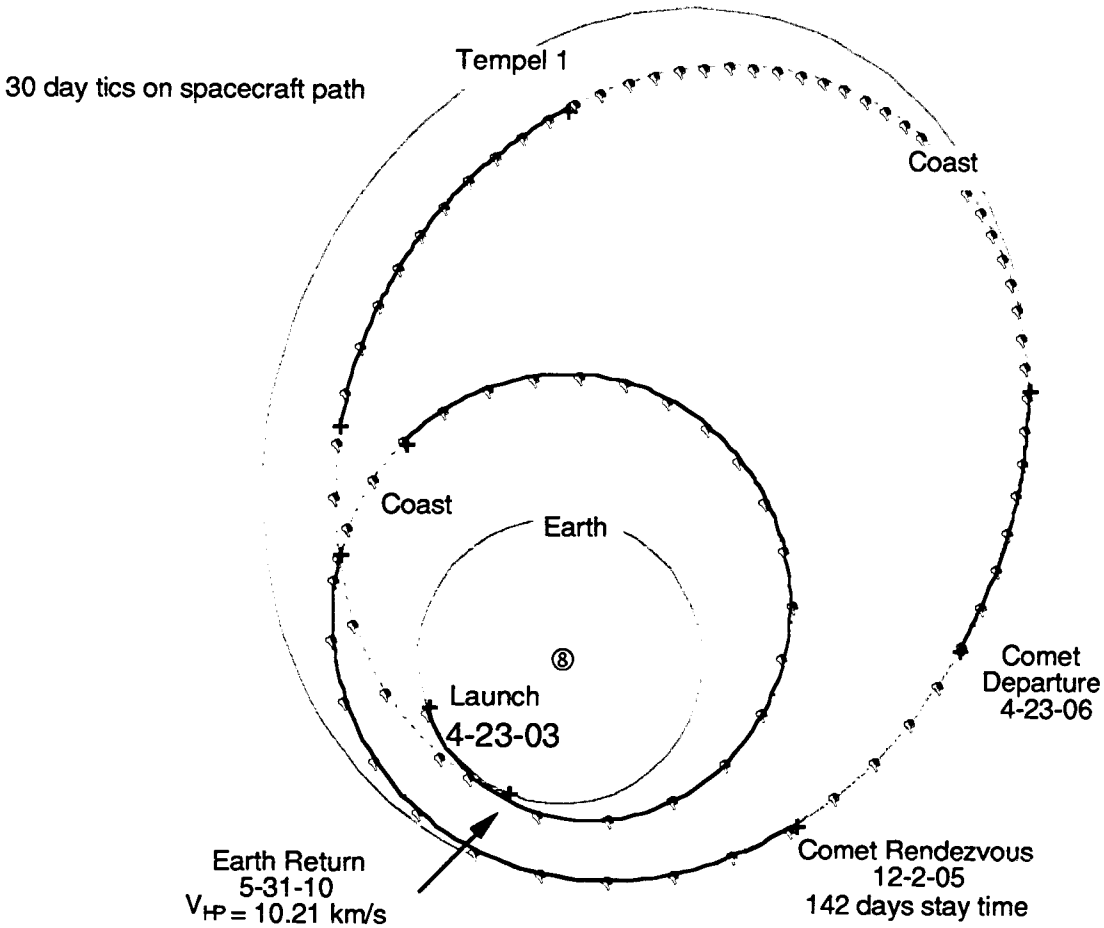
Sample
Acquisition
and Transfer



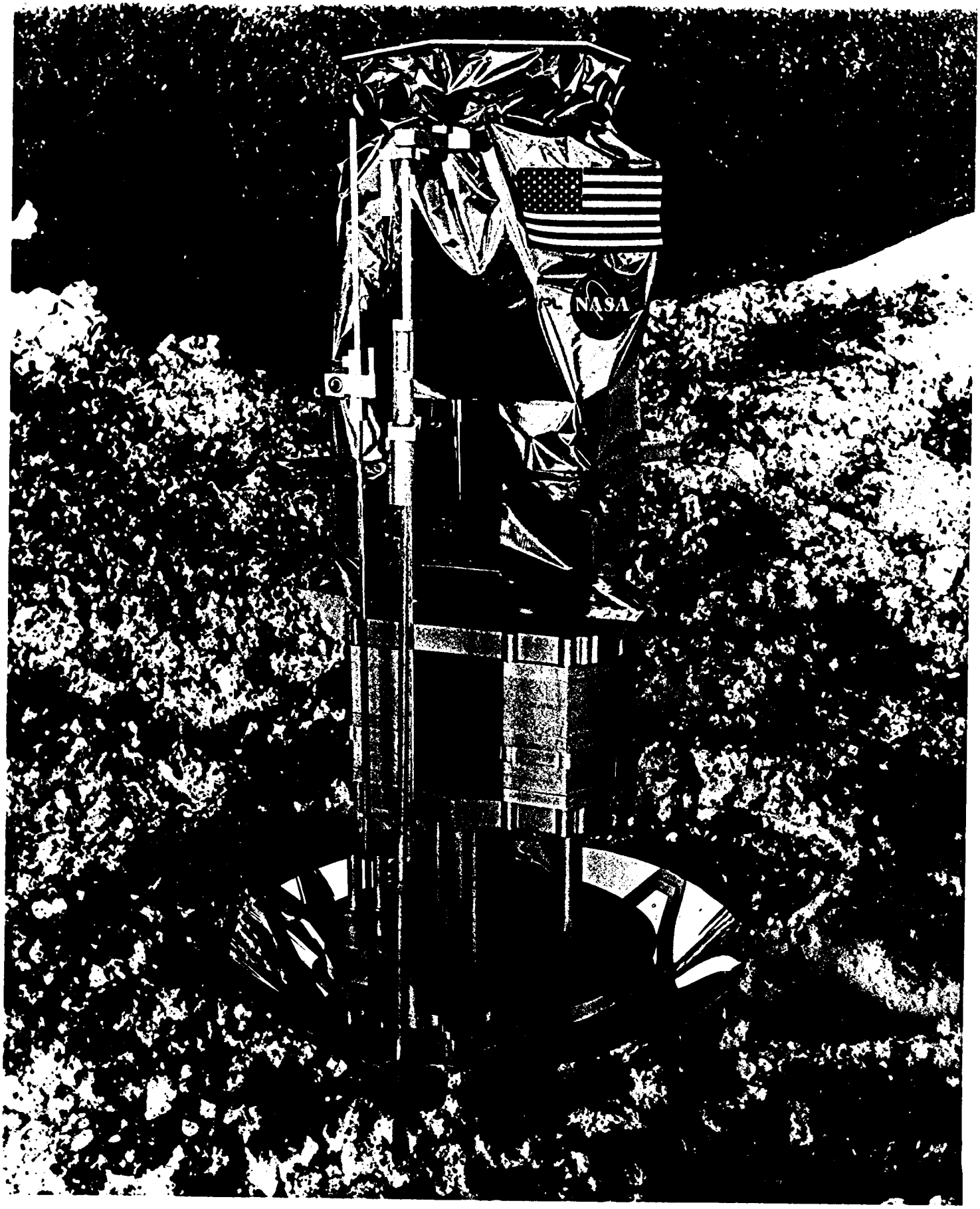
Advanced Solar
Electric
Propulsion

Comet Tempel 1 Sample Return

(Delta 2 7925)

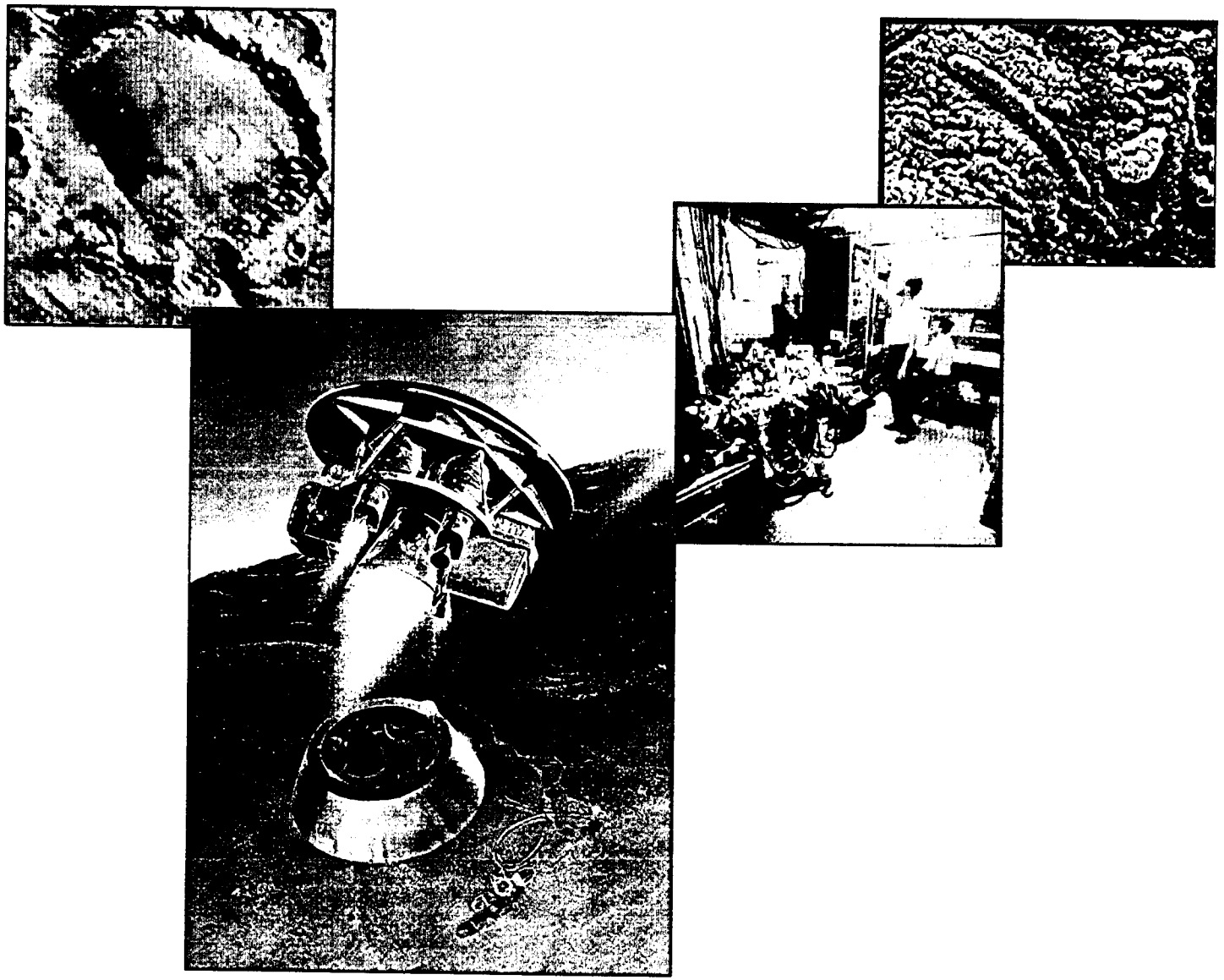


C_3 = 5.8 km^2/s^2
Flight time = 7.1 years
Minj = 1066 kg
M_{xenon} = 400 kg
$M_{S/C,net}$ = 666 kg
M_{LVA}= 15 kg
Available Power @ 1 AU= 11 KW
Monoprop ΔV=50 m/s
Cold gas ΔV=10 m/s
Ventry at Earth = 15.13 km/s


NASA

Mars Sample Return

M S R

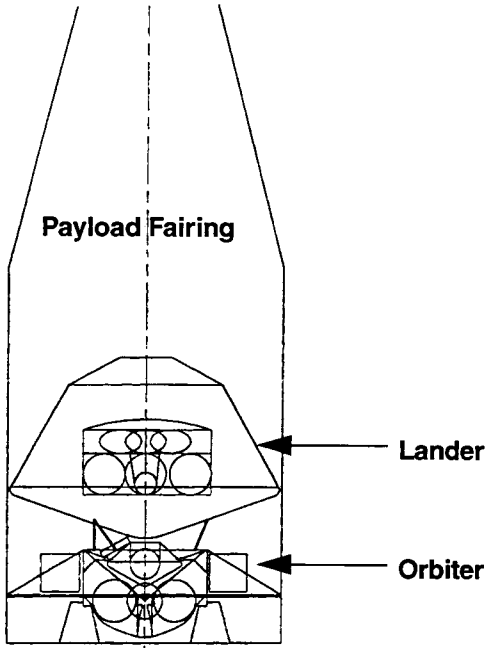


MARS
SURVEYOR
PROGRAM

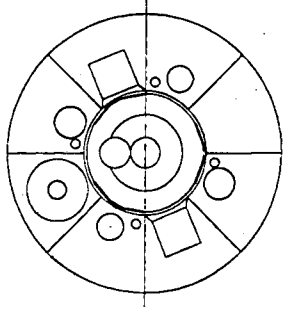
Baseline Spacecraft Configuration

Mars Sample Return Mission

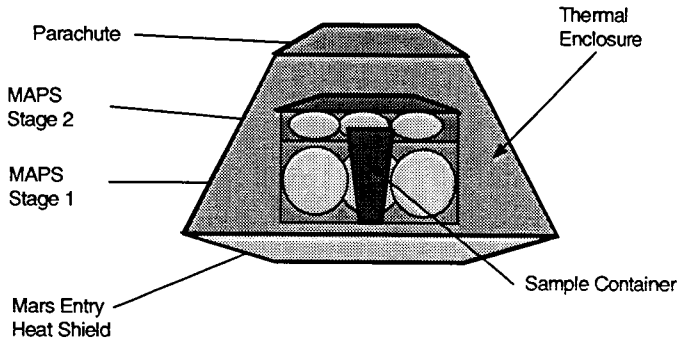
Launch Configuration Side View



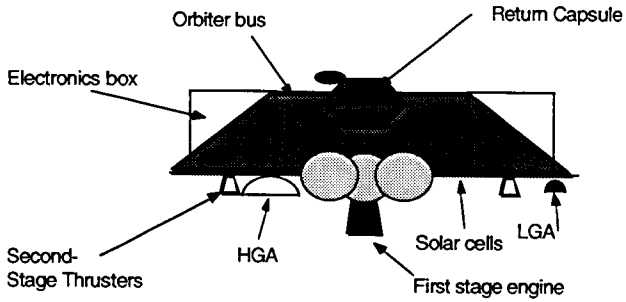
Launch Configuration Bottom View

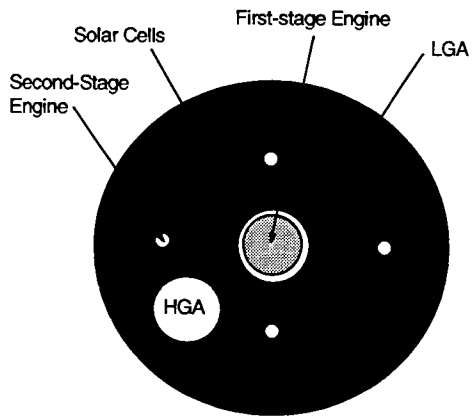


Lander



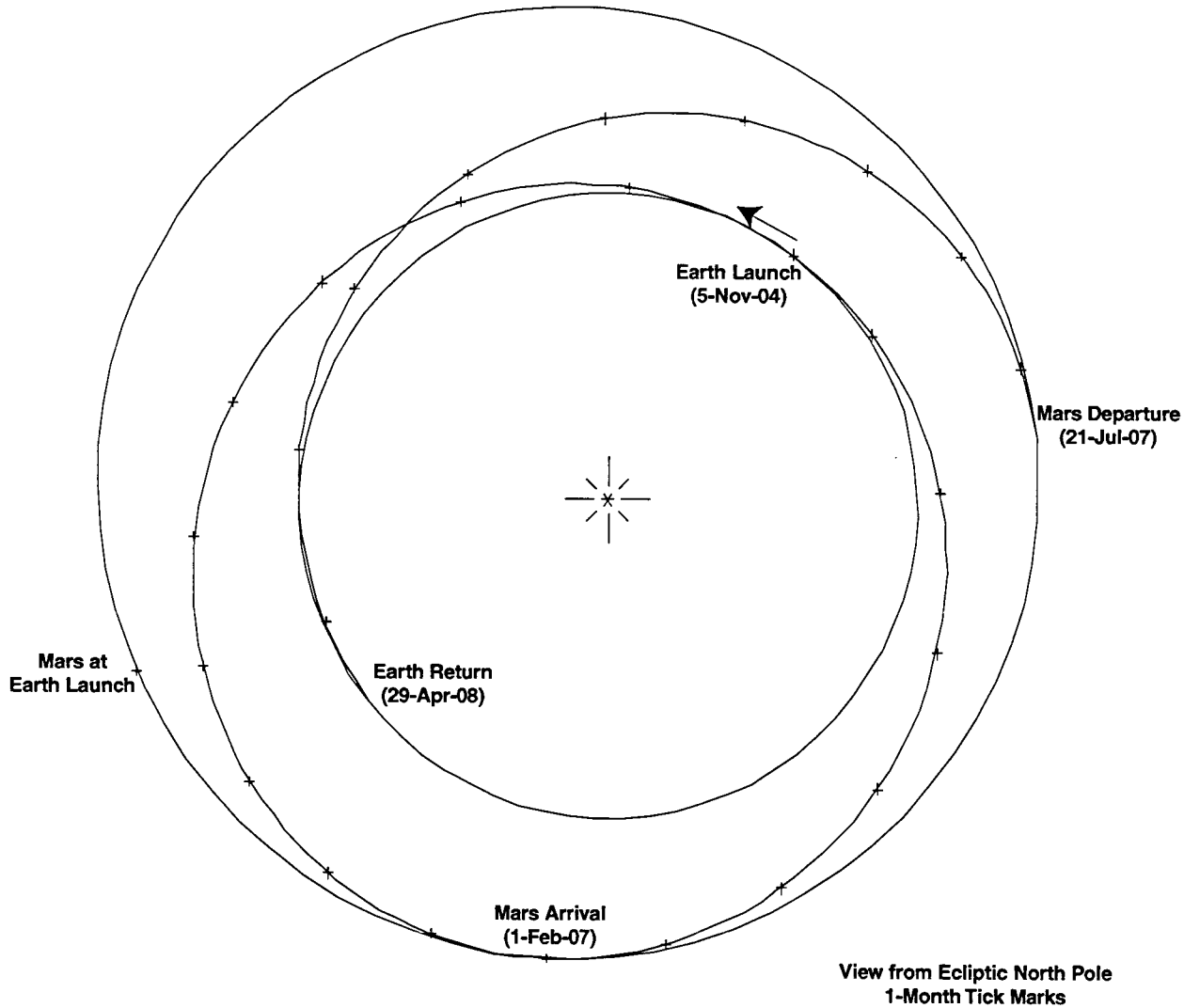
Orbiter

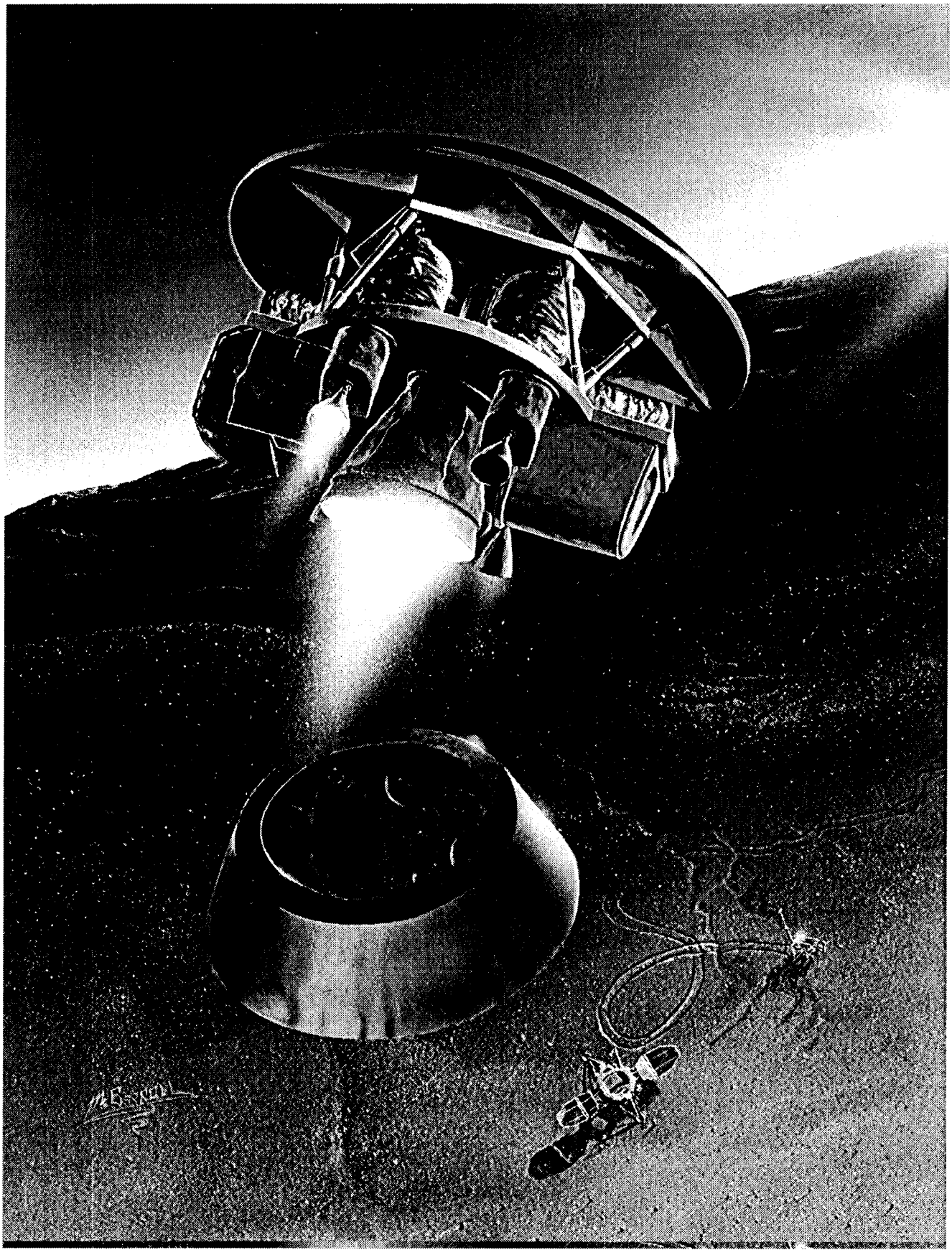


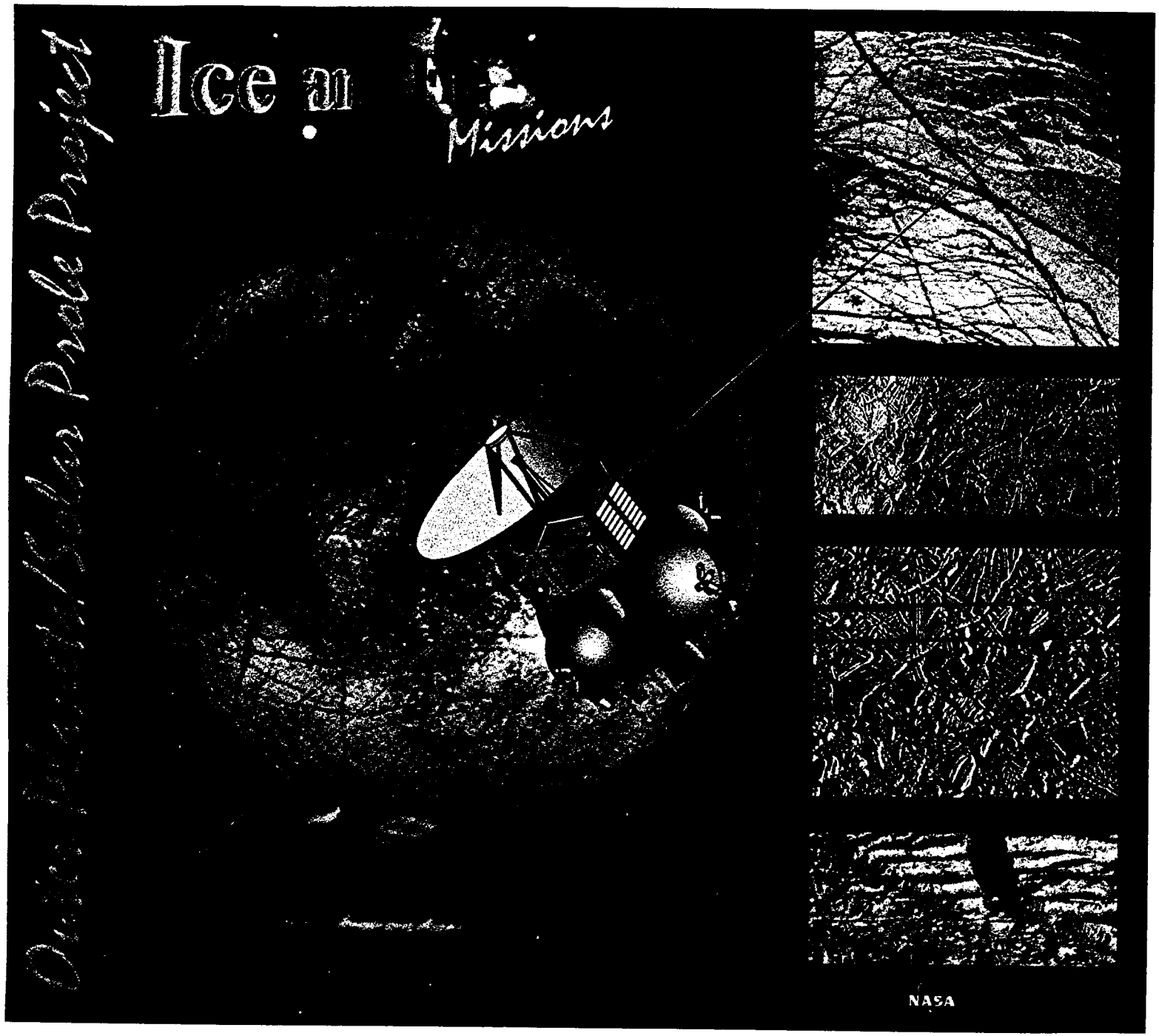


Reference Trajectory Characteristics

Mars Sample Return Mission






Ice an
Missions
NASA

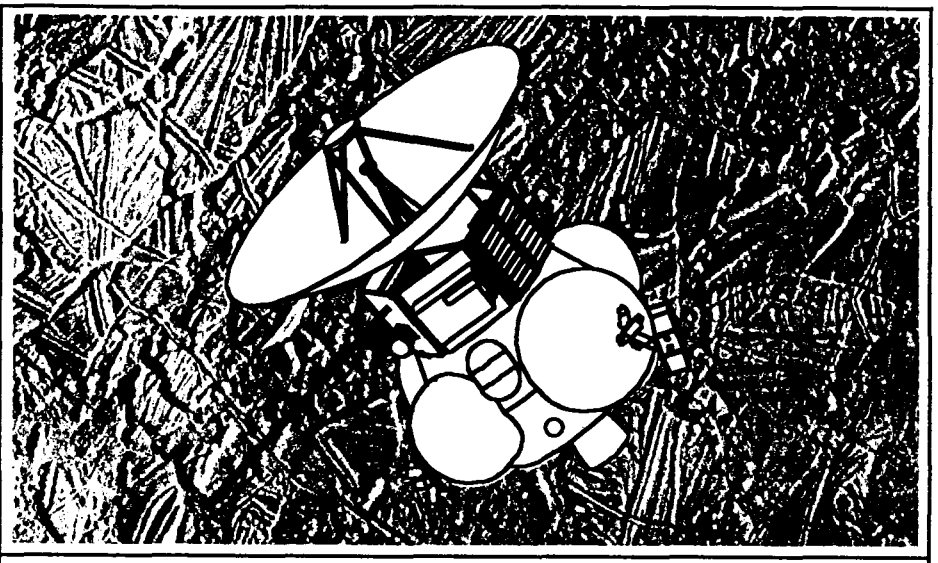
EUROPA ORBITER

SCIENCE OBJECTIVES

- Determine the presence or absence of a subsurface ocean
- Characterize the three-dimensional distribution of subsurface liquid water and its overlying ice layers
- Characterize the morphology of the surface and identify sites of recent or current activity

INVESTIGATIONS

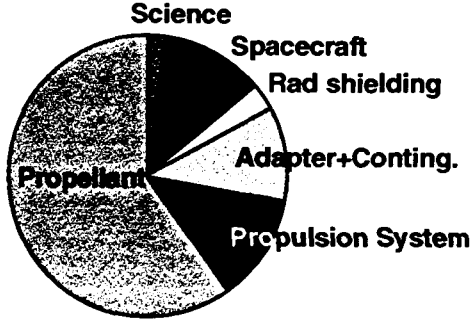
- Precision gravity field determination
- Laser Altimetry
- Ice-penetrating radar
- Imaging



LAUNCH - TRAJECTORY OPTIONS

	Direct	VVVGA
Launch Date	Nov. '03 Every 13 mos.	Aug. '04 every ~2 yrs
Flight Time to Jupiter (yrs.)	3.0	~7.0
Launch System	STS/IUS/ Star 48	Delta 7925H/ Star 30C

DESIGN STATUS



MASS BREAKDOWN:

Science	20 kg
Spacecraft	109 kg
Rad shielding	27 kg
Adapter+Conting.	102 kg
Propulsion System	111 kg
Propellant	553 kg

TECHNOLOGY: X2000 avionics under development. Propulsion system mass reduction is critical. Radar development proposed via PIDDP.

SDT: Chris Chyba, chair. Cat 1A objectives established.

MISSION: IUS utilization discussions with Boeing, USAF

PLUTO-KUIPER EXPRESS

SCIENCE OBJECTIVES

Pluto and Charon:

- **Characterize surface geology and morphology.**
- **Surface composition mapping.**
- **Characterize neutral atmosphere structure and composition.**

Possible Extended Mission:

- **≥ 1 Kuiper Disk object flyby.**

INVESTIGATIONS

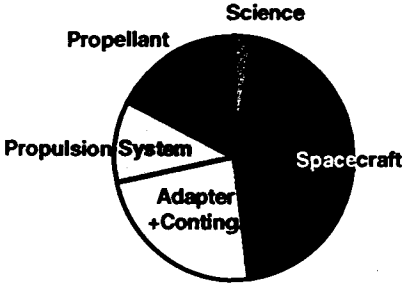
- **Imaging**
- **IR Mapping Spectrometry**
- **UV Spectrometry**
- **Radio Science Uplink Occultation**

LAUNCH - TRAJECTORY OPTIONS

	JGA	JGA	Direct
Launch Date	Nov 03, Dec 04	Nov 03 Dec 04	Feb 03 Yearly
Flight Time (yrs)	10-12	8	10
Launch System	Delta 7925H/ Star 30C	STS/IUS/ Star 48*	STS/IUS/ Star 48/ Star30

*** Margin might allow Jupiter Deep Probe opportunity**

DESIGN STATUS



MASS:

Science	7 kg
Spacecraft	95 kg
Adapter+ Conting	50 kg
Propulsion System	24 kg
Propellant	37 kg

TECHNOLOGY: X2000 Avionics development. Breadboard payload pkg developed.

SDT: J. Lunine, chair. Cat 1A objectives established.

KBC/SCB 980205

SOLAR PROBE

SCIENCE OBJECTIVES

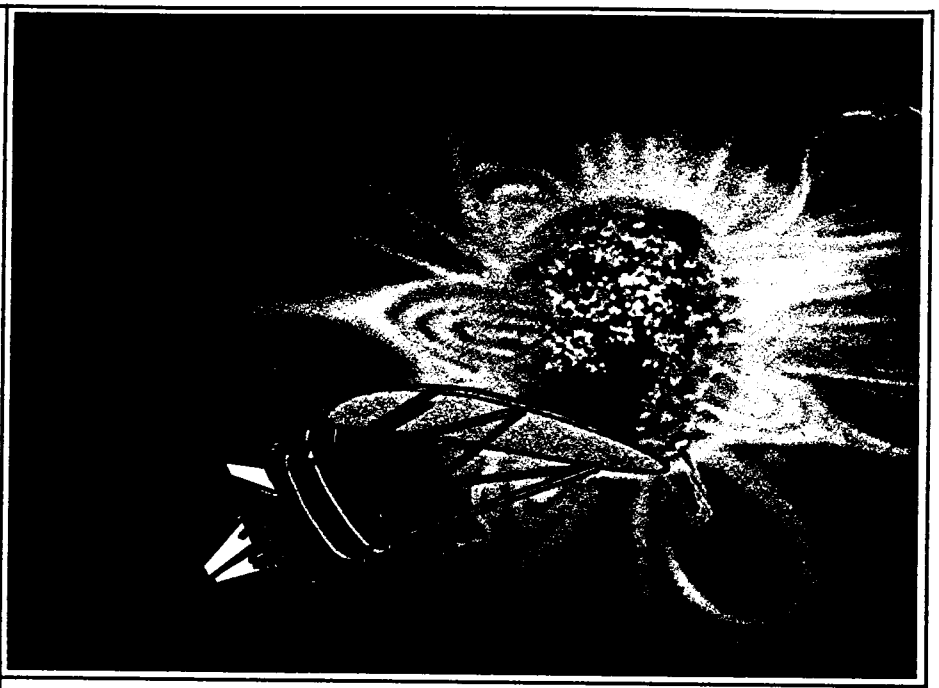
- Determine the mechanisms that accelerate the solar wind.
- Find the source and trace the flow of energy that heats the million degree corona.
- Determine the three-dimensional structure of the inner corona above the polar regions and the equatorial belt.
- Map the configuration and state of the magnetic field, and the pattern of the surface and subsurface flows from pole to pole.
- Find the origin of the fast and slow solar wind near the surface of the sun.

INVESTIGATIONS

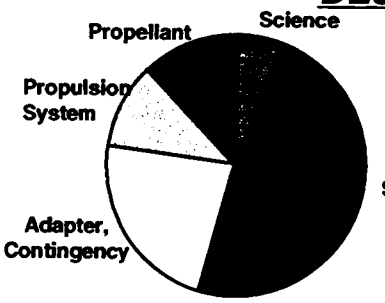
- Integrated Fields + Particles (magnetometer, plasma wave, plasma/ particles sensors)
- Remote Sensing (EUV imager, Vis/X-ray magnetograph, all-sky coronal imager)

LAUNCH - TRAJECTORY OPTIONS

	JGA (Retrograde)	ΔV-EJGA (Retrograde)
Launch Date	Nov '03 Every 13 mos.	Dec '03 Every 13 mos.
Flight Time (yrs)	3.8	5.8
Launch System	Delta III / Star 48V	Delta 7925H / kickstage



DESIGN STATUS



MASS:

Science	15 kg
Spacecraft	126 kg
Adapter, Conting	59 kg
Propulsion System	27 kg
Propellant	32 kg

TECHNOLOGY: X2000 avionics development underway. Thermal shield and solar arrays are critical unique items that are not presently supported. Integrated instrument package development required.

SDT: George Gloeckler, chair. Cat 1A objectives established

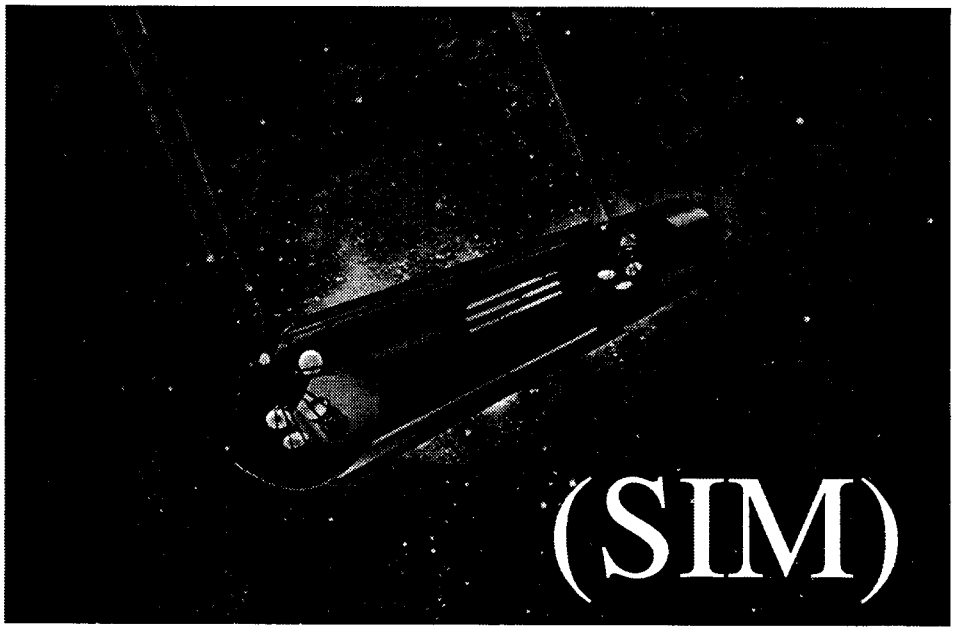
JPL

BEYOND THE SOLAR SYSTEM

(PLANETARY EXPLORATION IN OTHER SOLAR SYSTEMS)

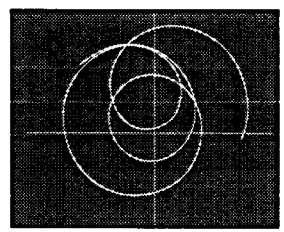
- NEW MILLENNIUM DS-3: FORMATION FLYING INTERFEROMETER
- SPACE INTERFEROMETRY MISSION (SIM)
- INTERSTELLAR TRAVEL

Space Interferometry Mission

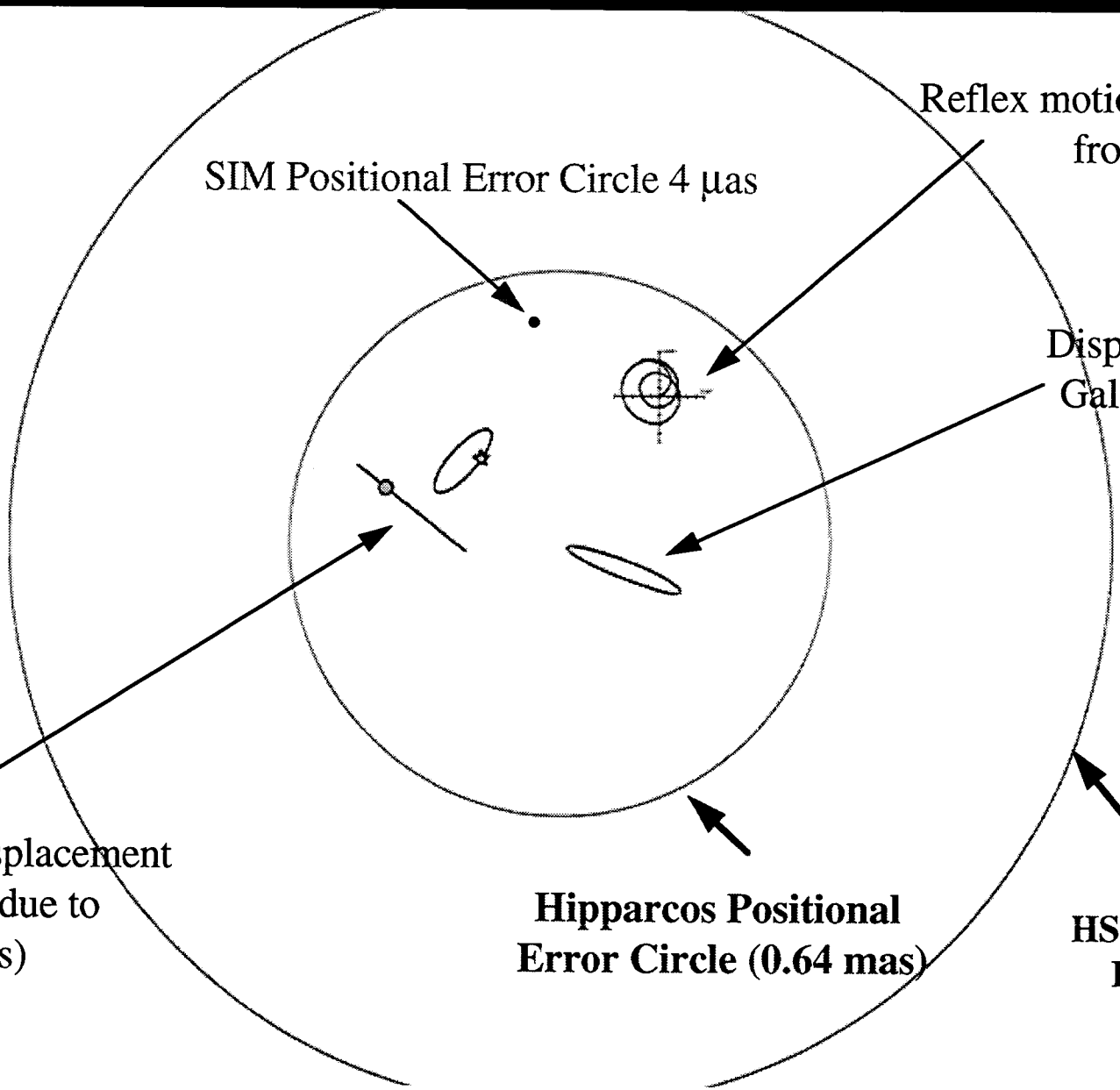


- 10-m Optical Interferometer
- Astrometry
  - 4 μas global
  - 1 μas narrow angle
- Imaging
  - 10 mas
  - 10^{-4} starlight nulling

- Looking at the Universe with μ arcsecond precision shows subtleties in the Universe never before detectable

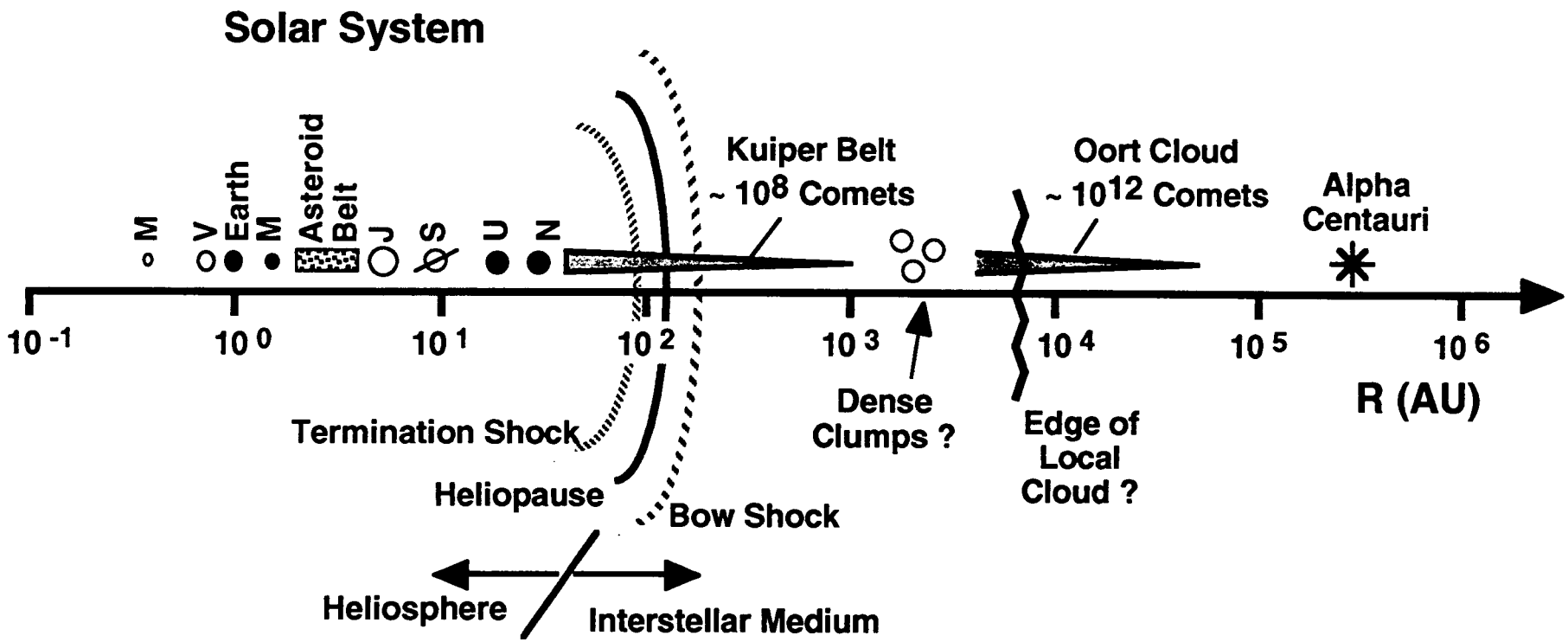


Microarcsecond Precison Opens a New Window to a Multitude of Phenomena Observable with SIM



Scale Of The Heliosphere and Local Interstellar Medium

JPL

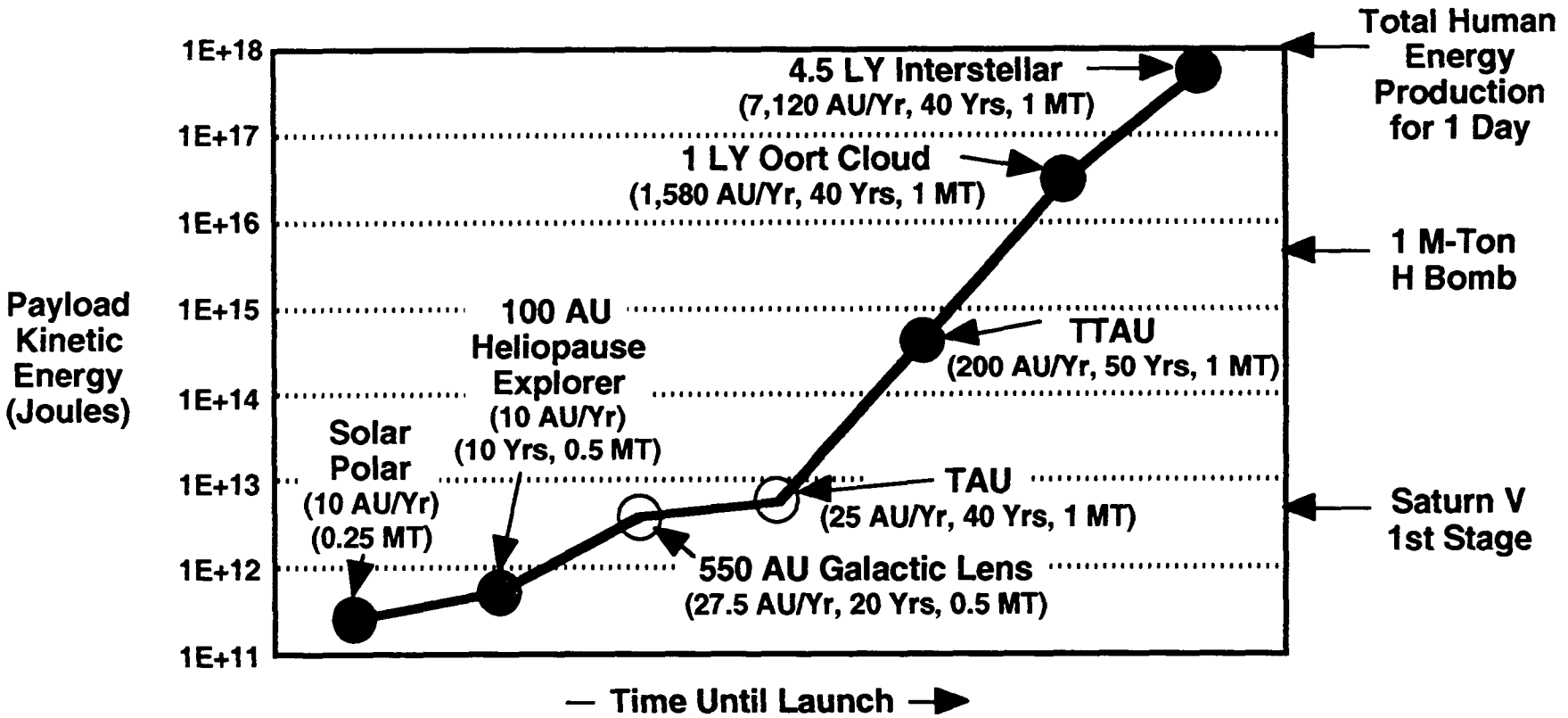


After Richard Mewaldt, Caltech, 1998

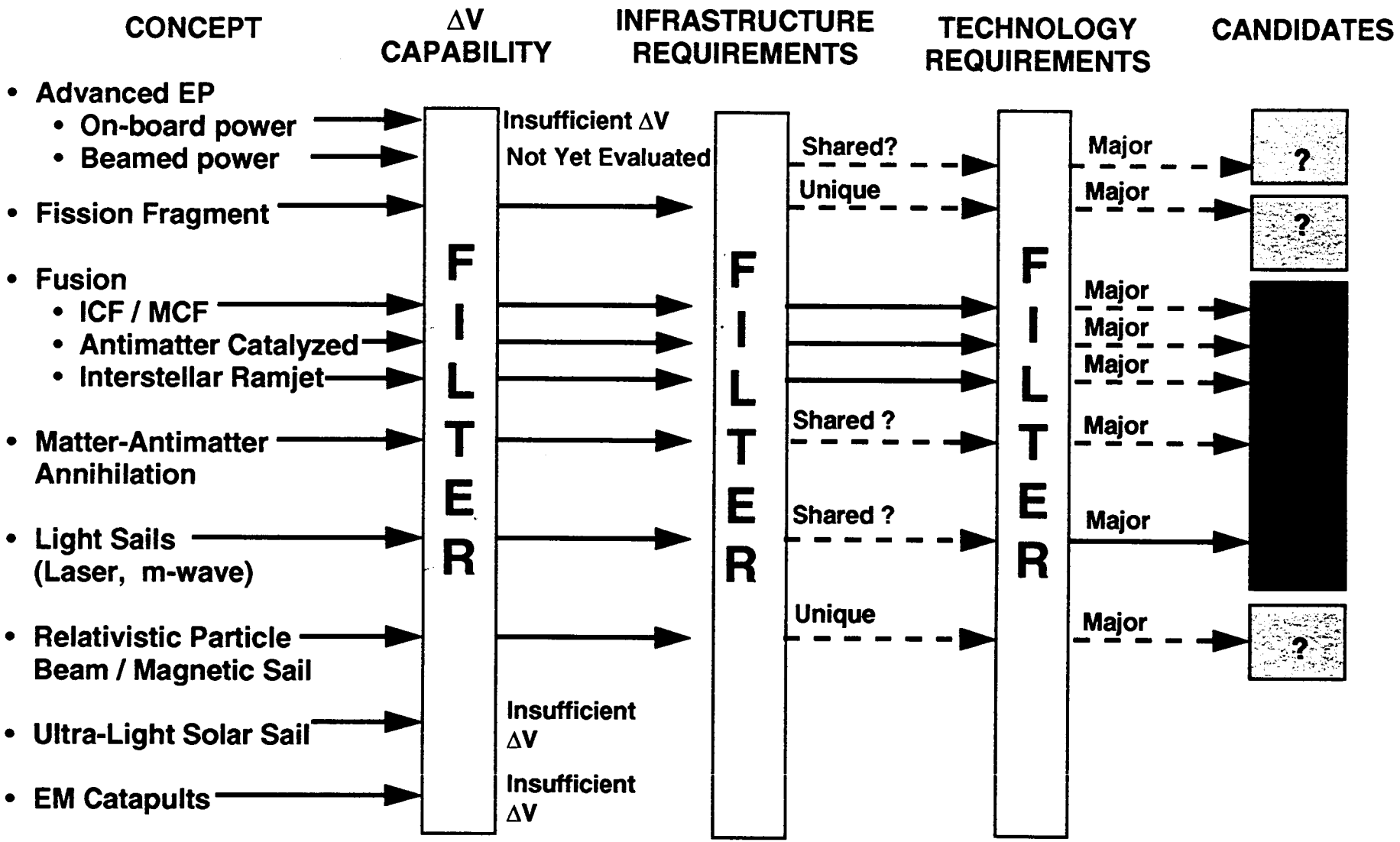
Ambitious Future Missions are More Propulsively Demanding

JPL

Candidate Missions Under Consideration in On-Going JPL Studies of Interstellar and Interstellar Precursor Flights

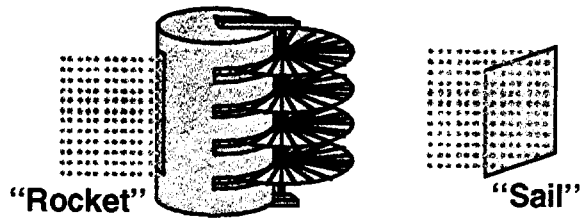


Preliminary Evaluation Results

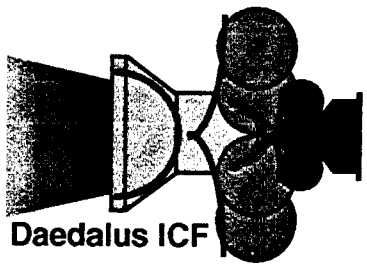


CANDIDATE PROPULSION SYSTEMS FOR INTERSTELLAR MISSIONS

FISSION
Fission Fragment



FUSION
Inertial / Magnetic Confinement Fusion (ICF / MCF)

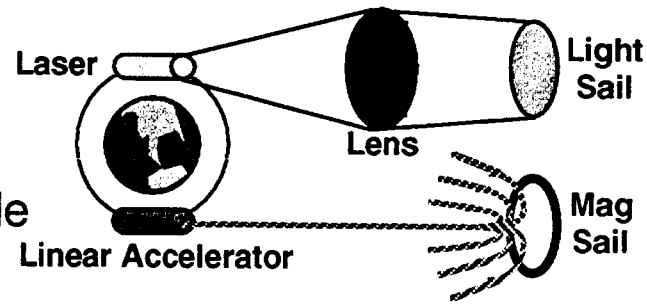


MATTER-ANTIMATTER
Beam-Core Antimatter Rocket

BEAMED MOMENTUM SAILS

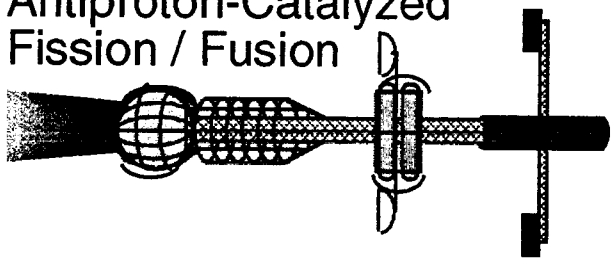
Laser Lightsail

Relativistic Particle Beam / MagSail

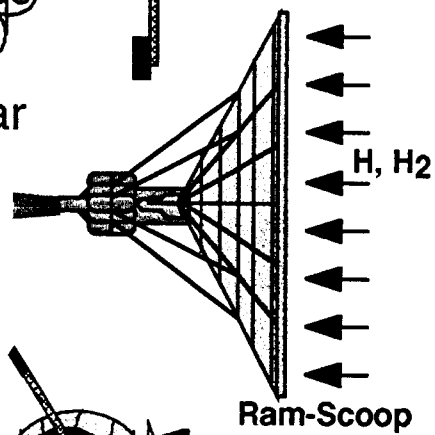


COMBINATIONS

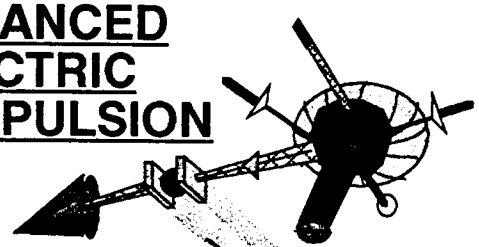
Antiproton-Catalyzed Fission / Fusion



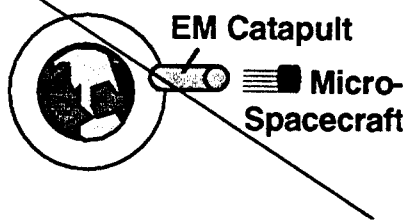
Bussard Interstellar Ramjet (Fusion)



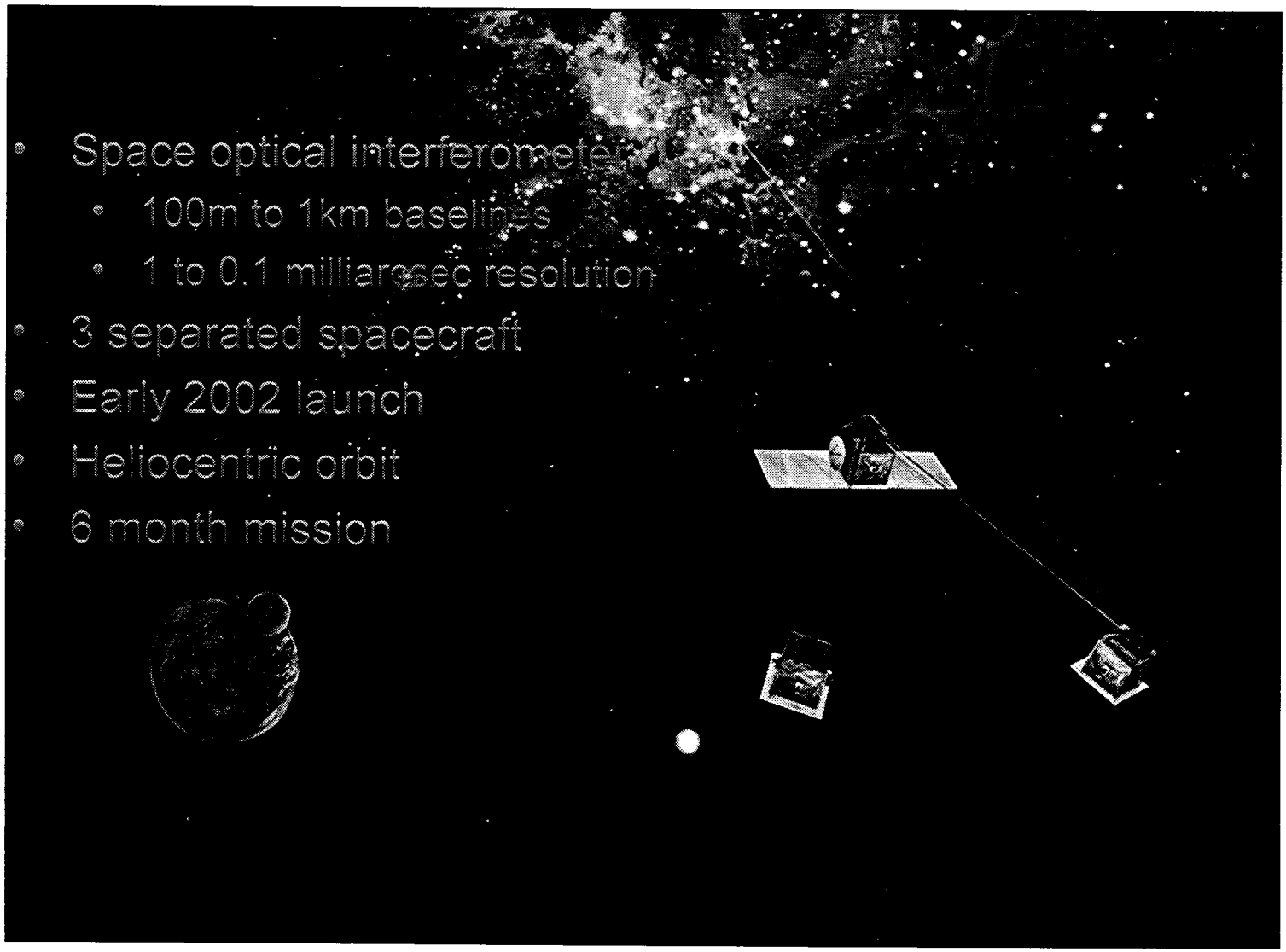
ADVANCED ELECTRIC PROPULSION

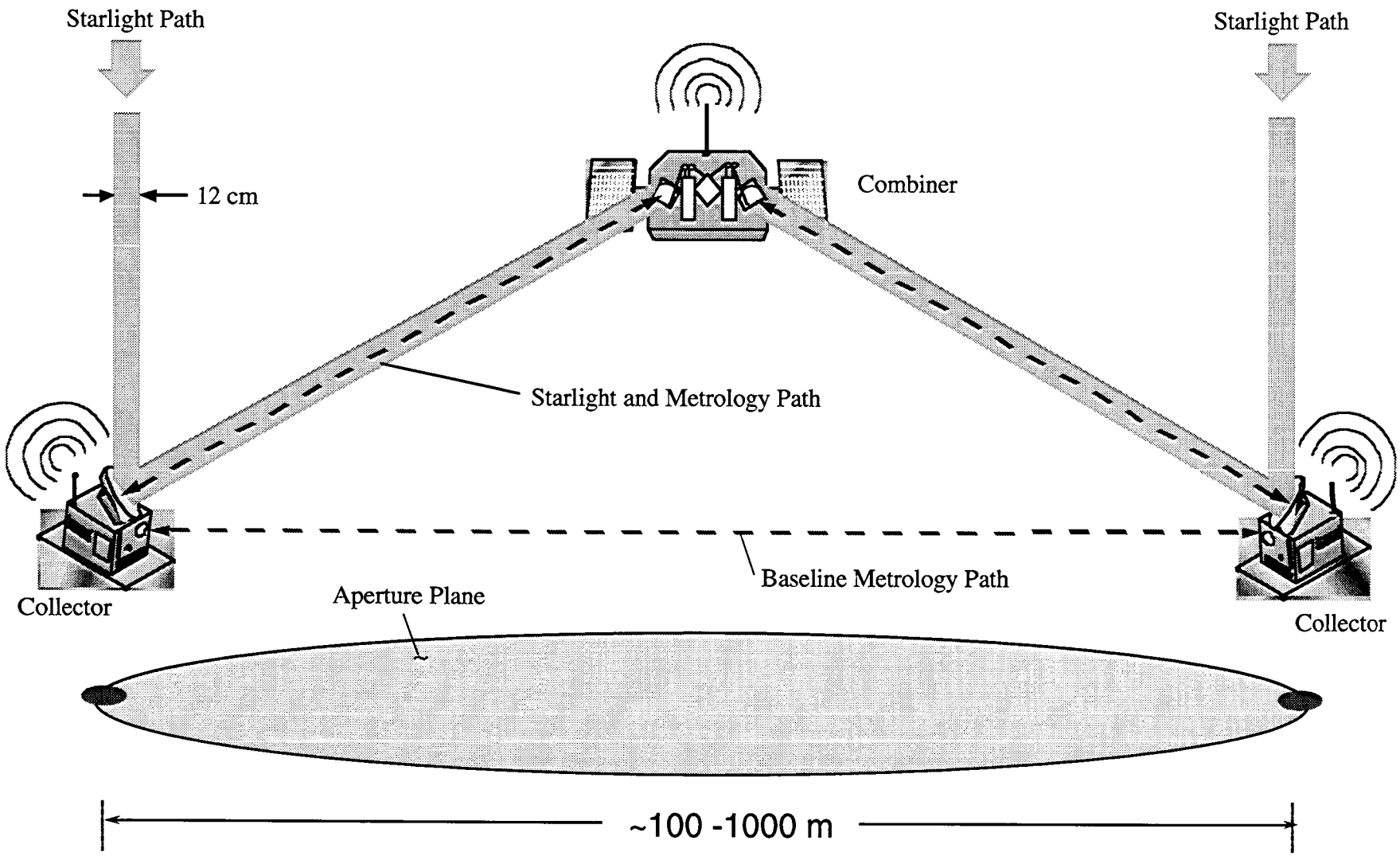


ELECTRO-MAGNETIC CATAPULTS



DS3: NEW MILLENNIUM INTERFEROMETER



Baseline Configuration

- 3 Spacecraft Formation Flying with 2-D aperture synthesis
- 100-1000 m baseline