MESSENGER Mission to Mercury:

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SmallSat?

• Why talk about such a large S/C at the SmallSat Conference?
  – A Mercury mission was a multi-billion dollar flagship for 30 years
  – That’s why it was always passed over for more urgent science

• Only when innovative technologies brought the cost to Discovery class, was MESSENGER approved

• That is the spirit of the SmallSat Conference

• *Find new ways to do things at a much lower cost*
Mercury Is Difficult to Study

From the ground...

Mercury/Venus/Saturn conjunction, July 2005

Earth orbit...

Mercury transit of the Sun, 7 May 2003
...or spacecraft

Mariner 10 launch, 3 Nov 1973

Flybys of Mercury in 1974 and 1975

9 August 2011
Legacy of Mariner 10
Mercury is a Planet of Extremes

- Highest uncompressed density
- Highest diurnal variation in temperature
  - 470 to -185 °C (-300 to 875 °F)
- Only solar system object in 3:2 spin-orbit resonance
  - Mercury solar day lasts 2 Mercury years
- Geological history ended earliest among the terrestrial planets
- Smallest planet with global magnetic field
- Most Earth-like magnetosphere
A Few Mercury Facts

- All inner planets formed and evolved by common processes.
- Mercury is ~ 5% of an Earth mass.
- Mercury’s core is ~ 60% or more by mass.
- Mercury and Earth are the only inner planets with magnetic fields.
- Mercury’s silicate shell is ≤ 600 km thick.

Possible interior models for Mercury [Riner et al., 2008]. The radii of neither the outer core (yellow) nor any solid inner core (metallic grey) are known.
Why is Mercury so dense?
What is the geologic history of Mercury?
What is the nature of Mercury’s magnetic field?
What is the structure of Mercury’s core?
What are the unusual materials at Mercury’s poles?
What volatiles are important at Mercury?

Map the elemental and mineralogical composition of Mercury’s surface
Globally image the surface at a resolution of hundreds of meters or better
Determine the structure of the planet’s magnetic field
Measure the libration amplitude and gravitational field structure
Determine the composition of the radar-reflective materials at Mercury’s poles
Characterize exosphere neutrals and accelerated magnetosphere ions

Unchanged from First Proposal in 1996
Polar Deposits

- Radar-bright polar deposits are confined to the floors of high-latitude craters.
- Cold trapping of ice in permanently shadowed crater floors is the leading explanation.
- Cold trapping of elemental S is a competing hypothesis.
- Chemical remote sensing and altimetry can distinguish among alternatives.

Arecibo radar image of north polar deposits [Harmon et al., 2001].
...is the 7th Discovery Mission

- Discovery began as a NASA Program in FY 1994.
- Program goal is frequent, small, scientifically focused missions.
- Missions are led by a Principal Investigator
- Mission proposals are competed and undergo rigorous scientific and technical reviews.
Team Members

Principal Investigator
Sean C. Solomon,
Carnegie Institution of Washington

Science Team: 47 scientists from 21 institutions

Project Management: APL

Spacecraft Development/Operations: APL

Propulsion: Aerojet

Structure: Composite Optics

Instruments: APL, Goddard Space Flight Center, University of Colorado Laboratory for Atmospheric and Space Physics, University of Michigan Space Physics Research Laboratory

Sponsor

NASA Headquarters
Science Mission Directorate
Discovery Program Office
Launch Vehicle:
Delta II 7925H

Getting There: Over 15 Times Around the Sun

MESSENGER
Mercury Surface, Space Environment, Geochemistry, and Ranging

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Getting There: Over 15 Times Around the Sun
Technology Challenges

• **Severe thermal environment**
  – >14 kW/m² thermal input at Mercury (>130 W/ft²)
  – Front of S/C > 360° C (680° F)
  – S/C can be sandwiched between Sun and planet
  – Desire to use standard space electronics

• **Extreme propulsion required**
  – > 2300 ms⁻¹ (5150 mph) in-space propulsion to get into Mercury orbit
  – Implies very tight mass constraints

• **Power generation at high temperatures**
  – Solar panels can reach 270° C (520° F)

• **Communications reliability**
  – Keep antenna from thermal extremes
  – Return > 75 Gbits from Mercury

• **Need to operate cryocooled detector at Mercury**
Ceramic cloth sunshade

667-N bi-prop thruster

Low mass, carbon fiber structure

3 large custom propellant tanks

Custom aluminum launch vehicle adapter

Solar panels are 2/3 mirrors

Phased array high-gain antenna

Key Characteristics:
- 1100 kg total mass
- 2300 m/s ΔV capable
- >720 W orbit power
Flight Solar Array is 2/3 Mirrors
John H. Glenn Research Center
Tank 6 facility

- 18.5 x 7.7 meter horizontal pressure vessel
- LN₂ and high vacuum capability
- Divergent beam solar simulator
  - Designed to simulate 1 AU solar dynamic power system testing
- One Sun accomplished with nine 30 KW xenon lamps
- 11-Sun beam ~ 1 meter diameter
11-Sun Test Panel

- Sunshade,
- solar panel,
- Sun sensors,
- Antennas
- X-Ray monitor

9 lamps @ 30 KW / 11.2 Suns average
The MESSENGER payload:

- Mass of 47.2 kg
- Average power consumption of 84.4 W

1.79 W/kg
Spacecraft Assembly

- Final assembly and test ~ 1 yr
- 5 frames per day
  - 2 April 2003 through 1 Jan 2004
  - APL Highbay through 7 Dec 2003
  - To GSFC 20 Dec 2003
Launch 3 August 2004
Earth Flyby 2 August 2005
Three Mercury flybys by MESSENGER (2008-2009)

- Flyby 1: ~ 500 MB of data, 1317 images
- Flyby 2: ~ 650 MB of data, 1287 images
- Flyby 3: ~ 710 MB of data, 1214 images
Approaching Mercury:
CA - 30hr; 630,000 km
To
CA - 100 min; 34,000 km
1 frame every 20 min
Mercury Flyby 14 Jan 2008

Resolution
~2500 m/pixel

“Color” on Departure

Images at 1000, 700, and 430 nm in red, green, and blue channels

~45 minutes after closest approach at ~15,000 km
“Stretched Color” Units

- Color controlled by rock types and space weathering
- Color variations are very subtle
- Statistical methods isolate color differences
- Color differences are shown in color composites (not actual color!)
- Three large scale units
  - Orange smooth plains
  - Low reflectance blue material
  - Brown intercrater plains
- A fewer lesser units
  - Volcanics (?)
    - Fresh ejecta
    - Other very small occurrences
The Other Side of Mercury

- Wide-angle camera image
- Minutes after closest approach 6 October 2008
- Looks different from flyby 1
- Who painted the meridians white?
Plasma in the Magnetosphere

but **NO** energetic ions/electrons
Solar Wind Hits Mercury

- Movie from STEREO A spacecraft
- Heliosphere imager captures faint differences in scattered sunlight from solar wind
- Sun is at the right
- Venus and Mercury are bright spots
- Vertical lines are artifacts caused by bright objects
Mercury Flyby Coverage

97.7% coverage at 500 m/pixel

Mercury flyby 3 approach

Mercury flyby 1 approach

Mercury flyby 2 approach

Mercury flyby 2 departure

Mercury flyby 1 departure

Mariner 10

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Observations from Mariner 10 and MESSENGER

Illumination angle is key

MARINER 10

MESSENGER
Color Stretch of Flyby Images
Composite of MESSENGER flyby data

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• Flood lavas behave like water, fill low areas and embay high areas when confined
• Lava may have different composition with different spectral properties (color)
Ellipsoidal Shape from M1 & M2

- Laser altimeter and radio measurements
- $a = 2440.0 \text{ km}$
- $b = 2438.9 \text{ km}$
- $a-b = 1.135 \text{ km}$
- Longitude Offset of Ellipsoid:
  - $\Delta \Phi = 0.00877^\circ$
- RMS $\sim 929 \text{ m}$
- Better analysis puts $a-b = 1.6 \text{ km}$
- Some local masscons needed to account for all of the data
Magnetosphere Structure from Flybys

Slavin et al., Science 2008
Exosphere Tail Observations

- Solar radiation pressure sweeps gas back into tail
- Sodium, calcium, and magnesium observed

First simultaneous observations of sodium and calcium

First detection of magnesium in Mercury's exosphere
• Orbit Insertion 18 March 2011
• Near polar, highly elliptical ~12 hr orbit about Mercury
What Have We Learned in Orbit?

• In Mercury orbit ~half of a Mercury day
• All instruments working well
• What progress is being made on those 6 science questions?
  – Examine:
    configuration, 
surface composition, 
exosphere, 
magnetic field 
magnetosphere
Dark Rims, Bright Floors, Vents
Central crater "Apollodorus" ~40 km in diameter
Lobate Scarp – Crust Shrinkage

370 km long. Crosscuts 100 km crater

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Constraining the Polar Deposits

Crater >2 km deep
Global History of Volatiles from Natural Radioactivity

An important clue to the formation and early history of Mercury
Composition with X-rays ...and an Active Sun!

X-RAY SPECTROMETER
Magnetic Field Measurements …

Dipolar Field – but with a Northward Shift

South pole is more exposed to charged particles
~30 keV Electron Bursts Observed

Particle Events in Context

- Magnetic field
- Magnetic Equator
- Sun

Consistent with Mariner 10 observations
Electron Burst Distribution

- Electron bursts seen by:
  - Energetic Particle Sensor
  - X-ray spectrometer
  - Neutron spectrometer
  - Gamma ray spectrometer
- Observed almost every orbit
- Mostly in northern hemisphere
Assembling High Resolution Map
What is the Future?

- The 12-month primary orbital mission spans 2 Mercury solar days, and 4 Mercury years.
- MESSENGER has already collected more than 40,000 images and more than 290 orbits of observations with the rest of the payload.

MDIS WAC Color
Acquired 29 March 2011
Centered at 3.1°N, 352.3° E
Resolution: 1.5 km/pixel
Scale: Mercury radius = 2440 km