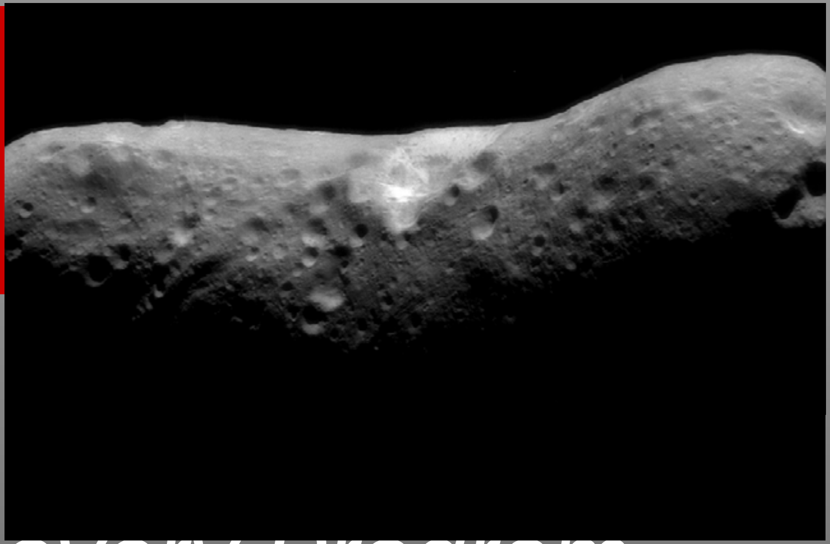
Near Earth Asteroid Rendezvous



First Launch of Discovery Program

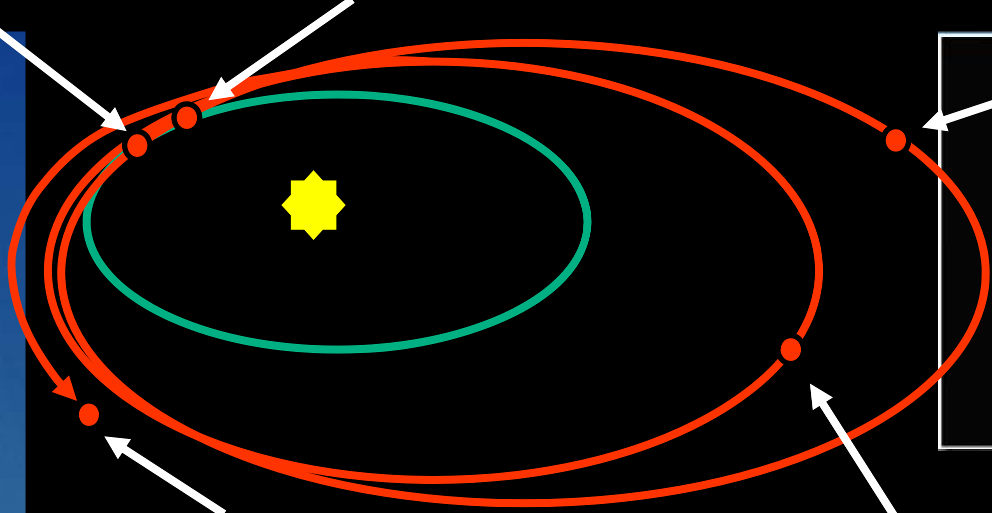
Andrew Cheng (NEAR Project Scientist)

Johns Hopkins University
Applied Physics Laboratory

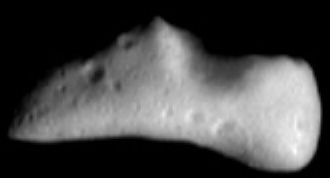
Near Earth Asteroid Rendezvous

Launch
Feb 1996

Earth swingby



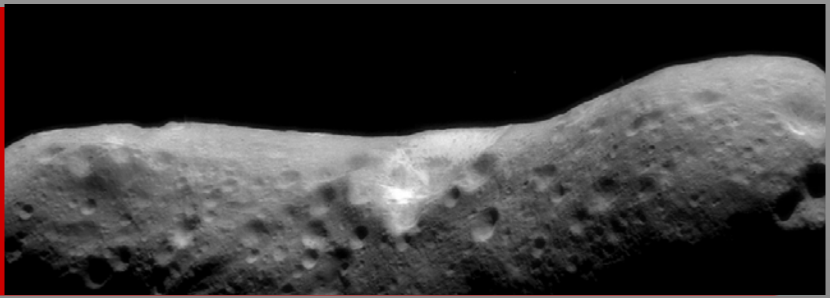
Mathilde
June 27,1997



Eros
December 23, 1998

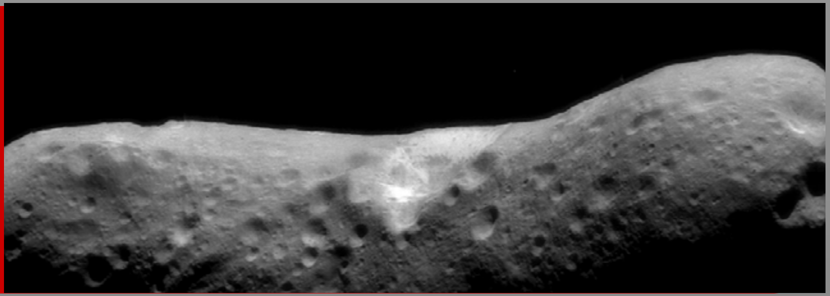
Eros 1998 and 2000

NEAR



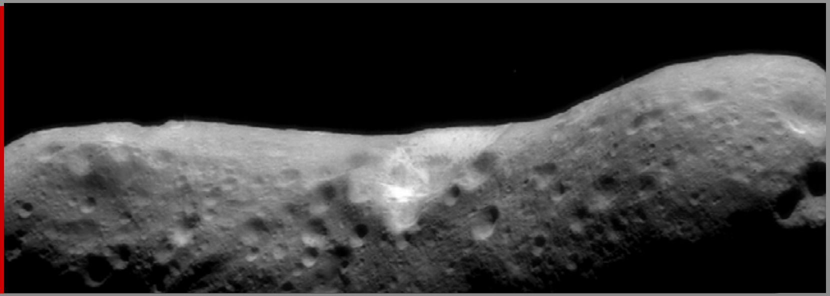
- The first asteroid mission
- The first spacecraft visit to a C-type asteroid (flyby of 253 Mathilde)
- The first asteroid rendezvous (433 Eros)
  - First orbital operations around a small, irregular body
- The first asteroid landing (433 Eros)

More "firsts"



- Programmatic and institutional firsts
  - First planetary mission at APL (also a first for NASA)
- First use of internet for internal and external project communications as well as outreach
  - A.F. Cheng blog, NEAR image of the day
- First missions with open data policy requirements and archive requirements to the Planetary Data System

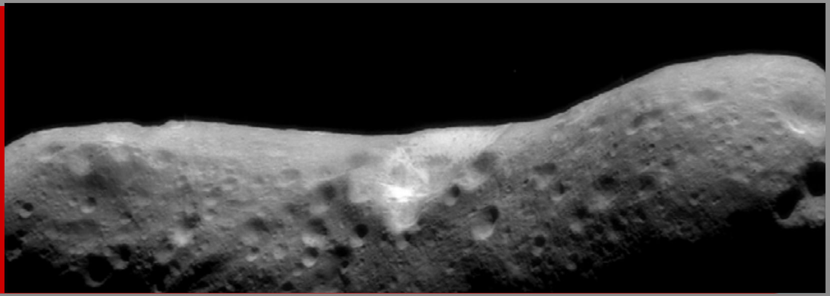
"faster, cheaper, better"



- NEAR: a new way of doing business, at lower cost, with acceptable risk

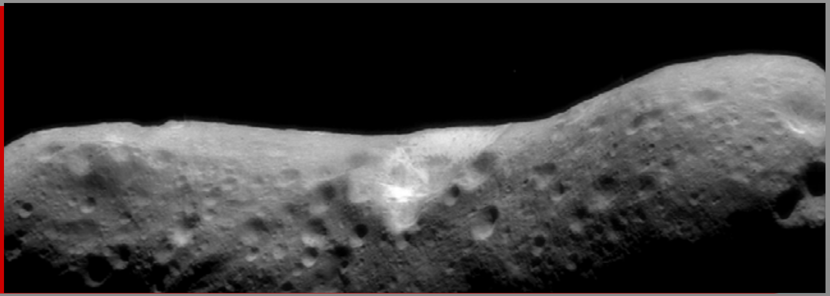
	Discovery Requirement	NEAR Performance	
Development Time	<36 mo	<27 mo	*Faster*
Cost to Launch +30 days (FY-92 $)	<$150M	<$112M	*Cheaper*
Spacecraft and Payload	Acceptable risk Limited scope science	Highly redundant spacecraft Comprehensive payload	*Better*
Launch Vehicle	Delta equivalent or smaller	Delta 7925	

NEAR Implementation



- **APL responsible for project management**
- **APL spacecraft**
- **APL provided facility instruments**
  - NASA selected facility instrument science team
  - NASA selected a participating scientist team
- **APL responsible for mission operations**
- **JPL responsible for navigation and DSN support**

Management Principles

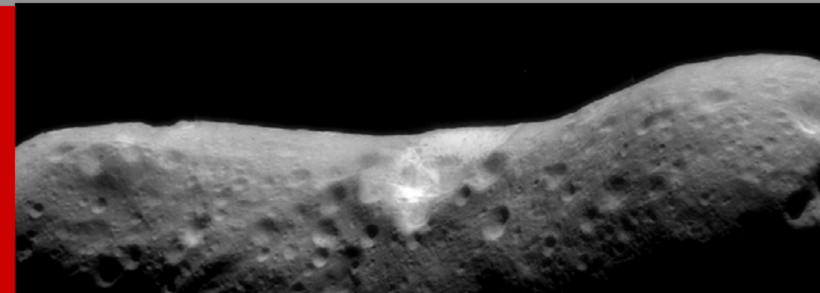


Practices for Inexpensive, Short Development Cycle Spacecraft

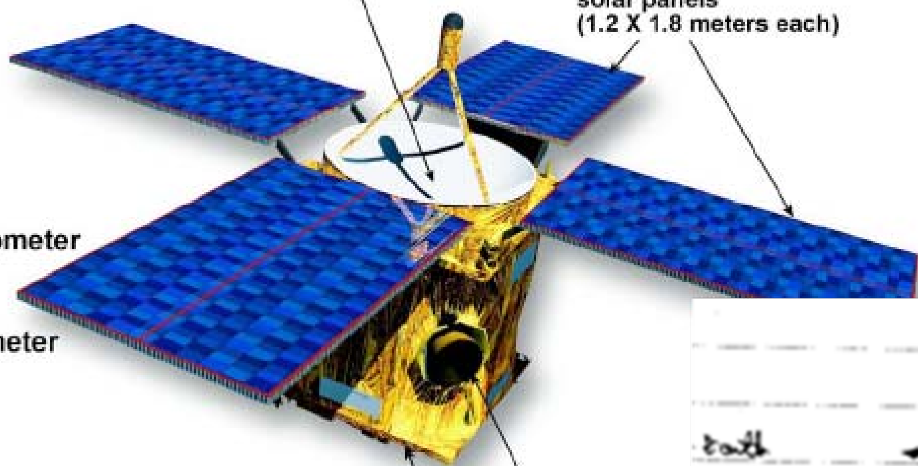
(a'la JHU/APL)

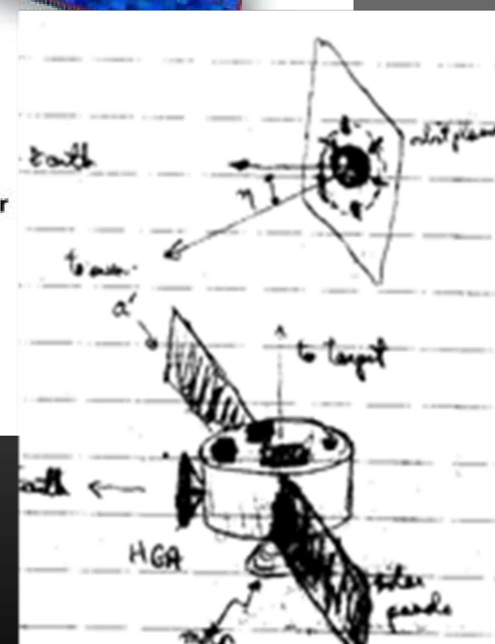
- Schedule from start to launch must be $\lesssim$ 36 months
- Establish small, experienced technical team with authority to do mission
- Design spacecraft and instruments to cost
- Use lead engineer method for all subsystems
- Reliability and redundancy must be designed-in (not expensive)
- Have R&QA engineer report directly to project manager
- Single agency manager to interface with contractor

Simple Spacecraft



- Three-axis stabilized
- Total weight: 805 kg
  - Propellants: 320 kg
  - Experiments: 60 kg
- Science payload
  - Multispectral imager
  - Near-infrared spectrometer
  - X-ray spectrometer
  - Gamma-ray spectrometer
  - Laser altimeter
  - Magnetometer
- Dual-mode propulsion system
  [ΔV capability: 1450 m/s]
- Solar array power @ 1.00 AU: 1800 watts
- Two solid-state recorders: 1.7 x 10^9 bits





AFC lab notebook, January 1991

Focused Mission

Near Earth Asteroid Rendezvous

Measurement Objectives

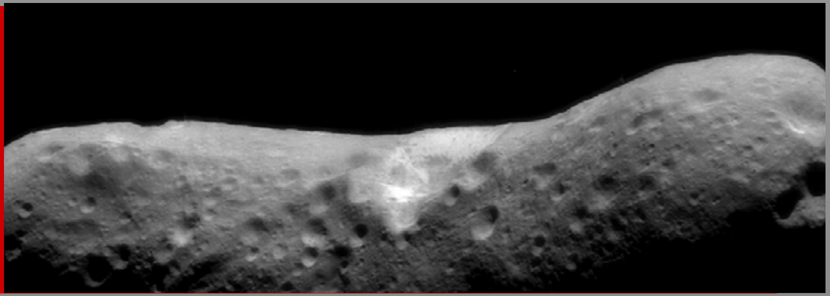
- **Bulk Properties**

shape	gravity field
mass	spin state
density	magnetic field

- **Surface Properties**
  - Elemental and mineralogical composition
  - Heterogeneity of structural and compositional units
  - Physical, geological and morphological characteristics

[original slide scanned from hard copy which predates Powerpoint]

Facility Instruments



Near Earth Asteroid Rendezvous

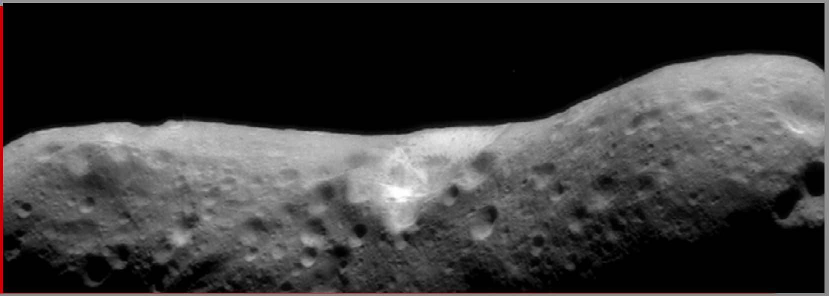
Facility Instrument Characteristics

Visible Imager	95 x 161 μr resolution 2.25° x 3° FOV 8-position filter wheel
X-ray/γ-ray Spectrometer	Al, Mg, Si, Fe, Ti, Ca U, Th, K
NEAR IR Spectrograph	~0.8-2.7 μm spectral range spectral resolution 22/44nm
Magnetometer	sensitivity <1 nT
Laser Altimeter*	range 50 km Resolution 6 m
Radio Science*	two-way Doppler to 0.1 mm/s

*engineering subsystems

[scanned original slide with ancient typos]

PI Mission Management



- How to balance the tensions of PI mission management (who does what)
  - The PI
  - The PM (and PS if you have one)
  - The institution (project management and line management)
- The challenges of leading a strong team
  - You don’t know everything
  - You must make decisions
  - You need your team
  - Your team needs you

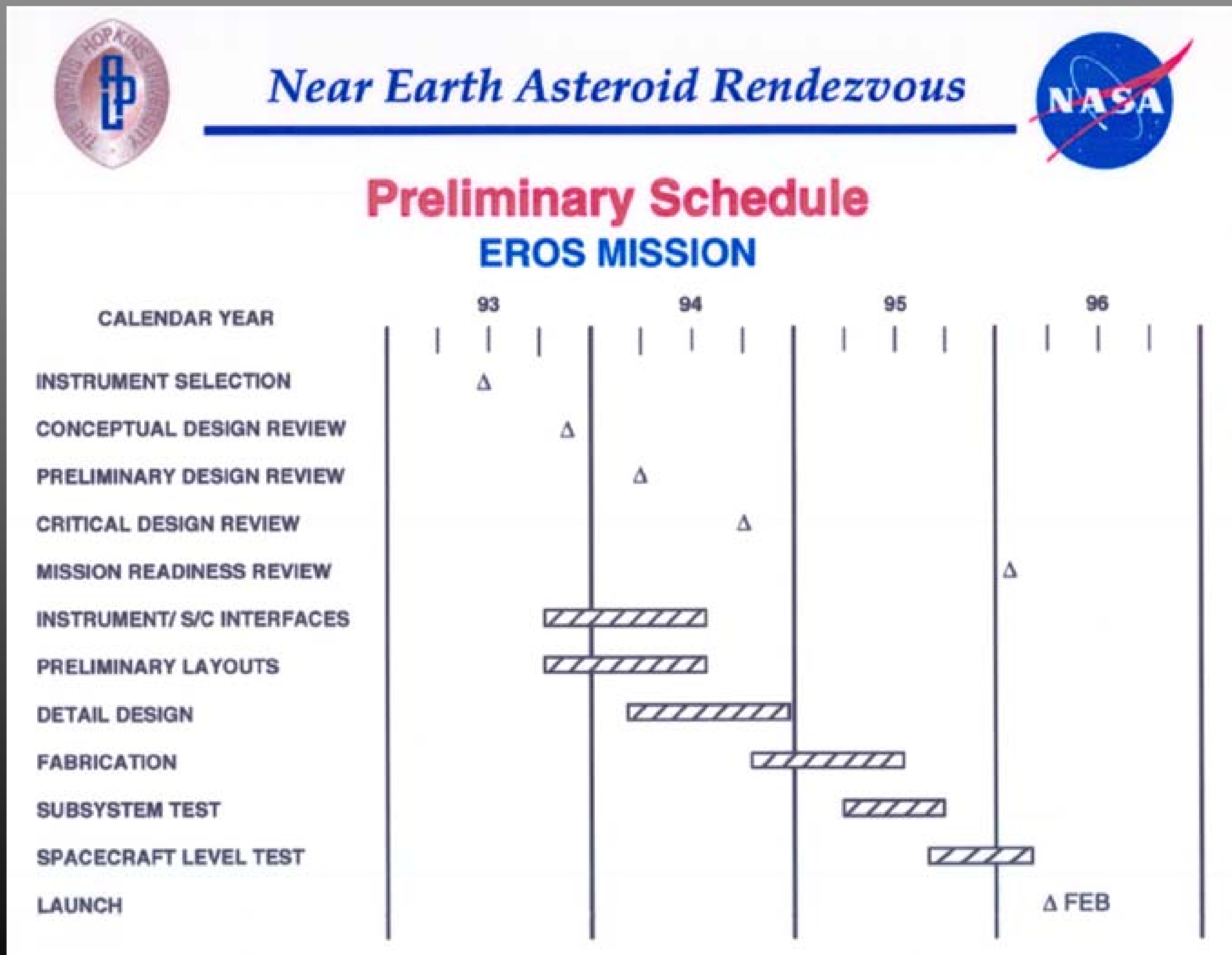
How it was done

Near Earth Asteroid Rendezvous

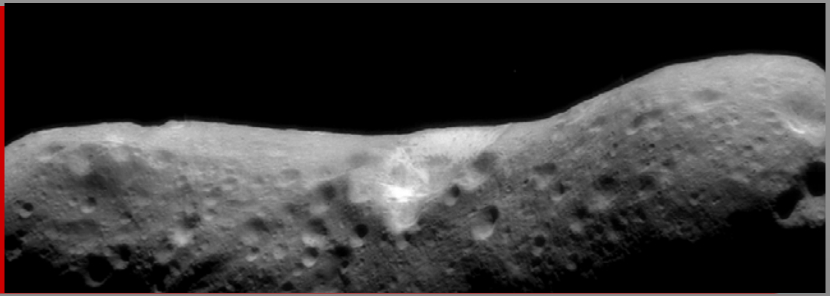
Technical Approach

- **Approach suited to Discovery Mission**
  - Optimized to schedule
  - Consistent with program cost, propellant mass fraction
- **Design to schedule approach**
  - Modularity in propulsion system
  - Distributed architecture
  - Large (50%) use of off-the-shelf components
  - 1533 data bus
  - Qualification of subsystems prior to spacecraft delivery

Schedule set in 1992
and followed through launch

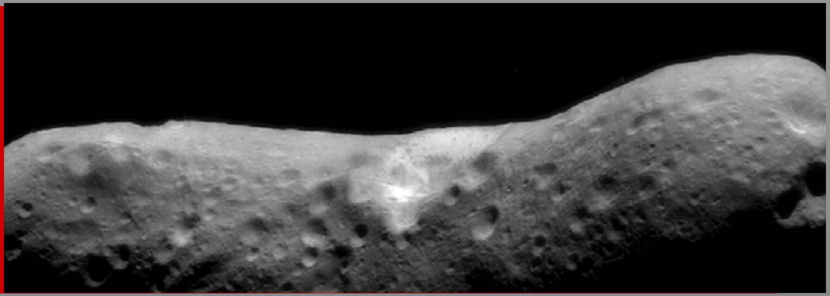


Mission Operations learned in flight



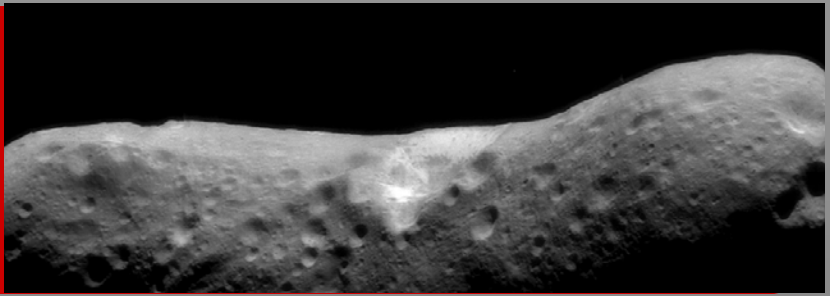
- **Concept of operations developed after launch for a small team**
  - There was no good model for NEAR (the last orbital mission was Galileo)
- **Little or no simulation of orbital operations**
  - No previous orbital mission around an irregularly shaped, small object
  - Navigational accuracy could not be predicted
  - Spacecraft predicted to safe often (which did NOT happen)
- **Eros flyby was in some sense a blessing**

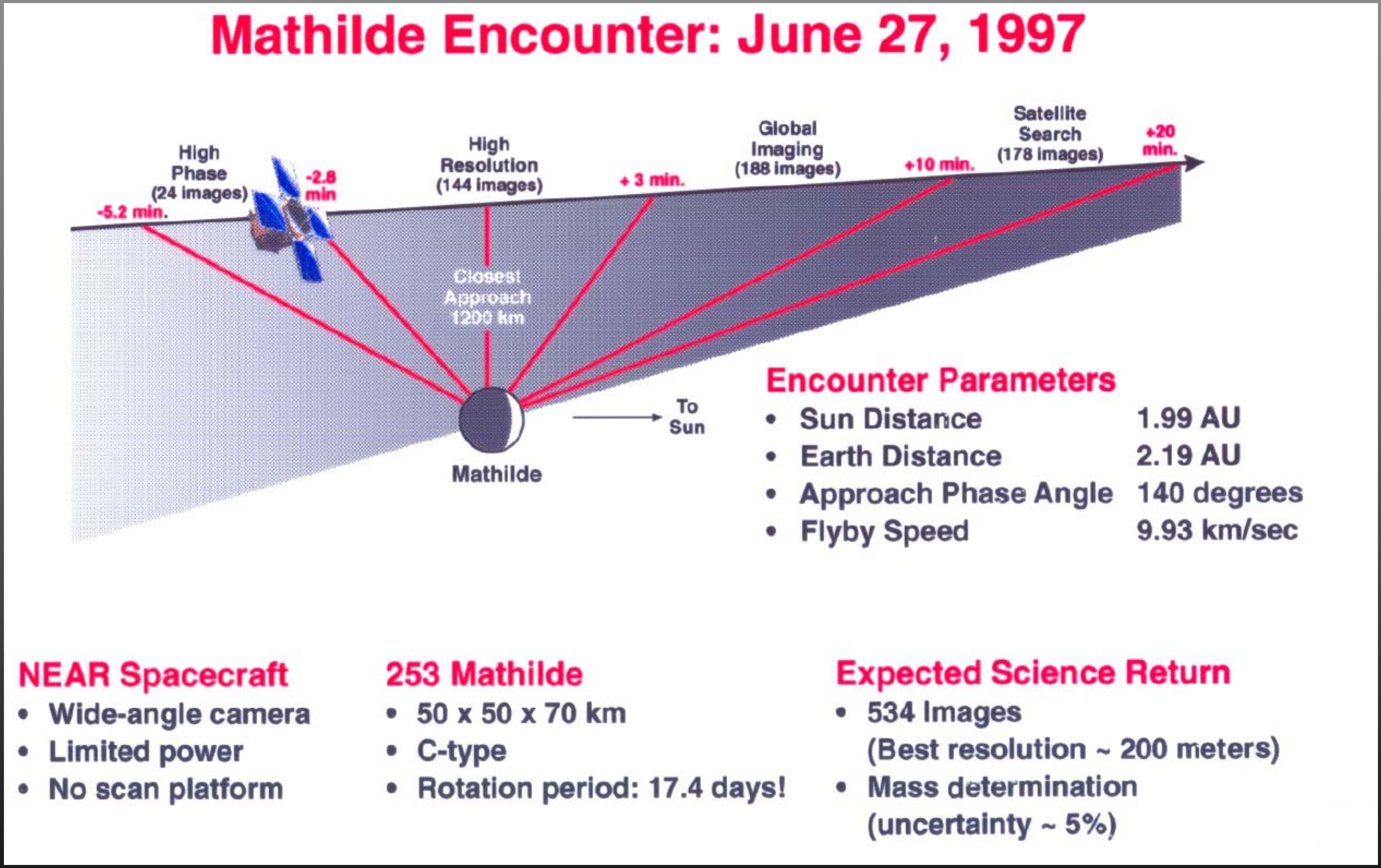
PDS Archive Delivery



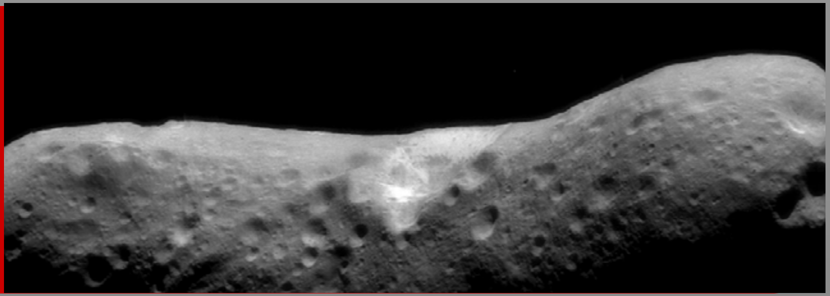
- PDS was in its infancy when NEAR was organizing and implementing its delivery
  - PDS was defining its processes, procedures, and archive definitions
- NEAR data successfully archived
- Lessons Learned:
  - NEAR had different data format for Science Team than PDS (re-create data for archival purposes)
    - learned to define project data formats in a PDS approved format
  - Review of PDS data formats with PDS began past mission midpoint
    - learned to start review process at mission start (with data format definitions) and team with PDS (Data Archive Working Group) to facilitate intermediate reviews

Mathilde Encounter





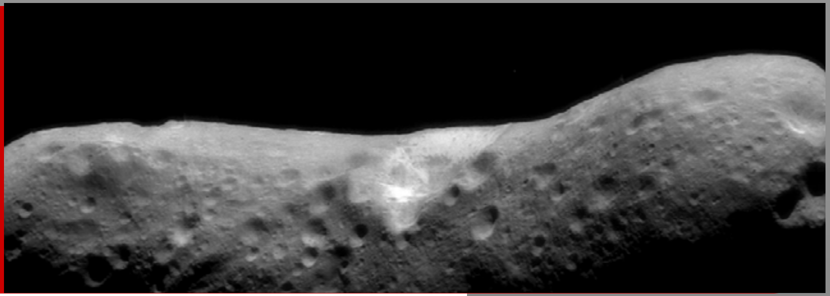
One very bad day

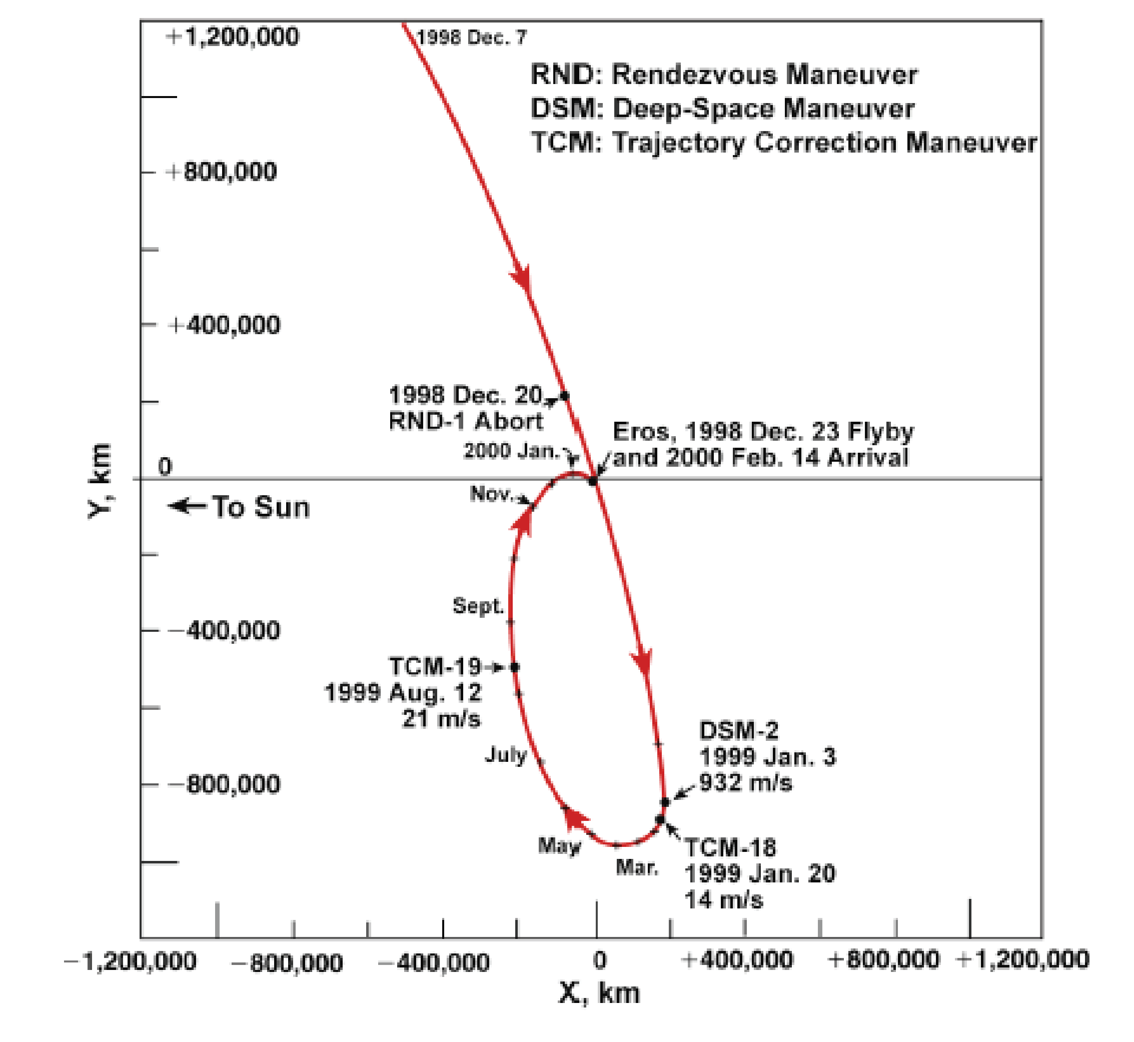


Aborted Rendezvous Burn
December 20, 1998

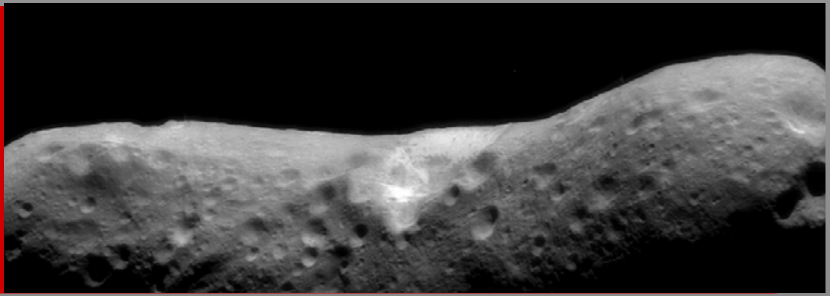
- On board autonomy system shut down main engine at onset
  - Accelerometer normal to thrust vector
- Spacecraft went into "Safe Mode" as planned
- Spacecraft tumbled
  - Expended 28 Kg. of fuel; not as planned and still unexplained
- Spacecraft went deeper to "Sun Safe Mode" as solar arrays exceeded angle to sun
- Recovered spacecraft 27 hours later, as planned
- Eros flyby on December 23,1998
- Successful main engine burn on January 3, 1999
- Rendezvous with Eros delayed until February 2000

U-turn After Burn Abort

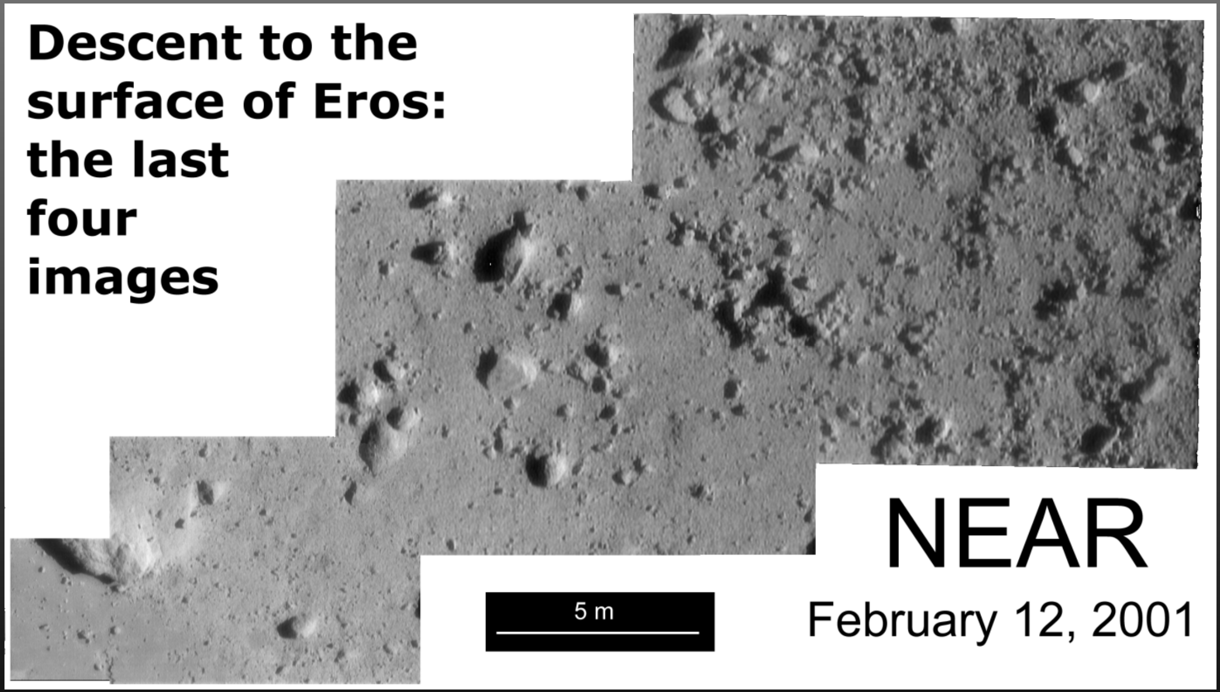




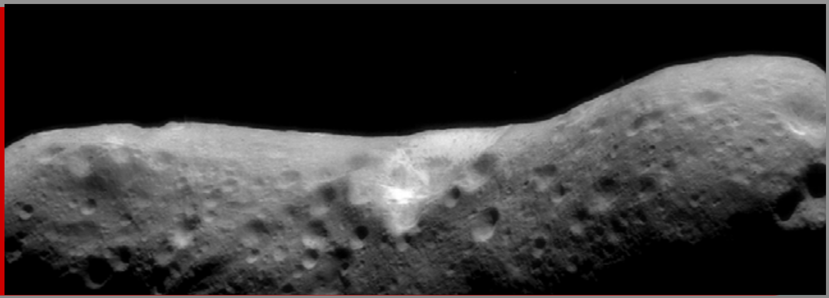
The First Asteroid Landing



- Spacecraft not designed for landing
- Touchdown at ~1.6 m/s, 316 million km from Earth
- Spacecraft acquired scientific data for two weeks after landing



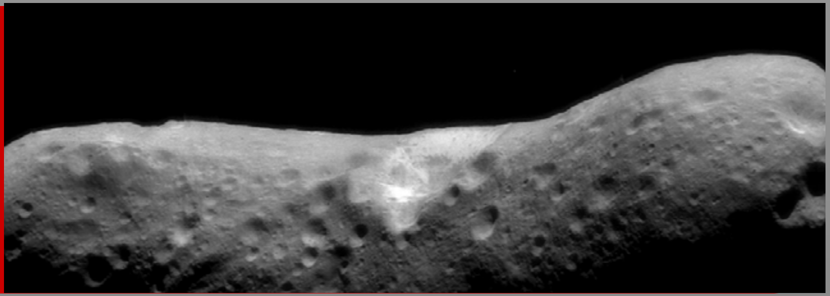
Mission Success



Near Earth Asteroid Rendezvous

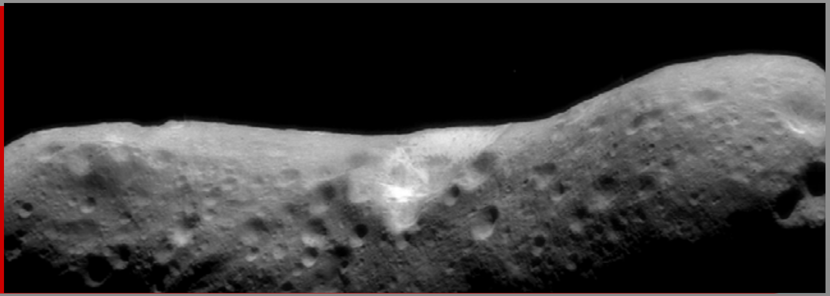
- **Feb 2001 - mission completed with landing on 433 Eros**
  - All data in PDS, September 2001
- **Science Objectives fulfilled**
- **Mission Extras**
  - Mathilde fly-by
  - Two low altitude passes of Eros surface (< 5km)
  - Landing
- **Final Cost within 3% of total mission cost given to NASA in 1994**
  - Includes thirteen month delay due to burn anomaly, December 1998

Science Success



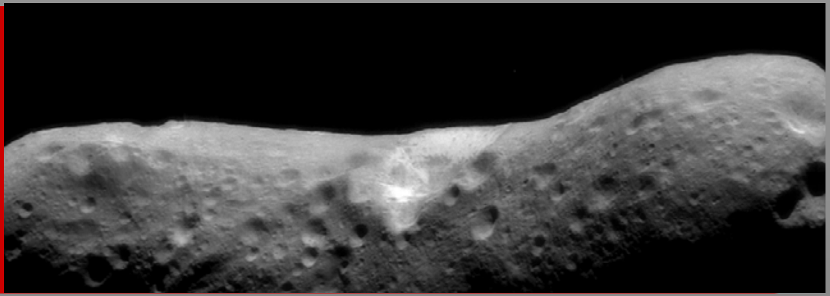
- All science objectives met or exceeded
- More science and data returned than originally planned
  - More than 10x number of images
  - Two low altitude flybys (under 5 km)
  - Landing and science operations on the surface
- No major spacecraft anomalies at Eros

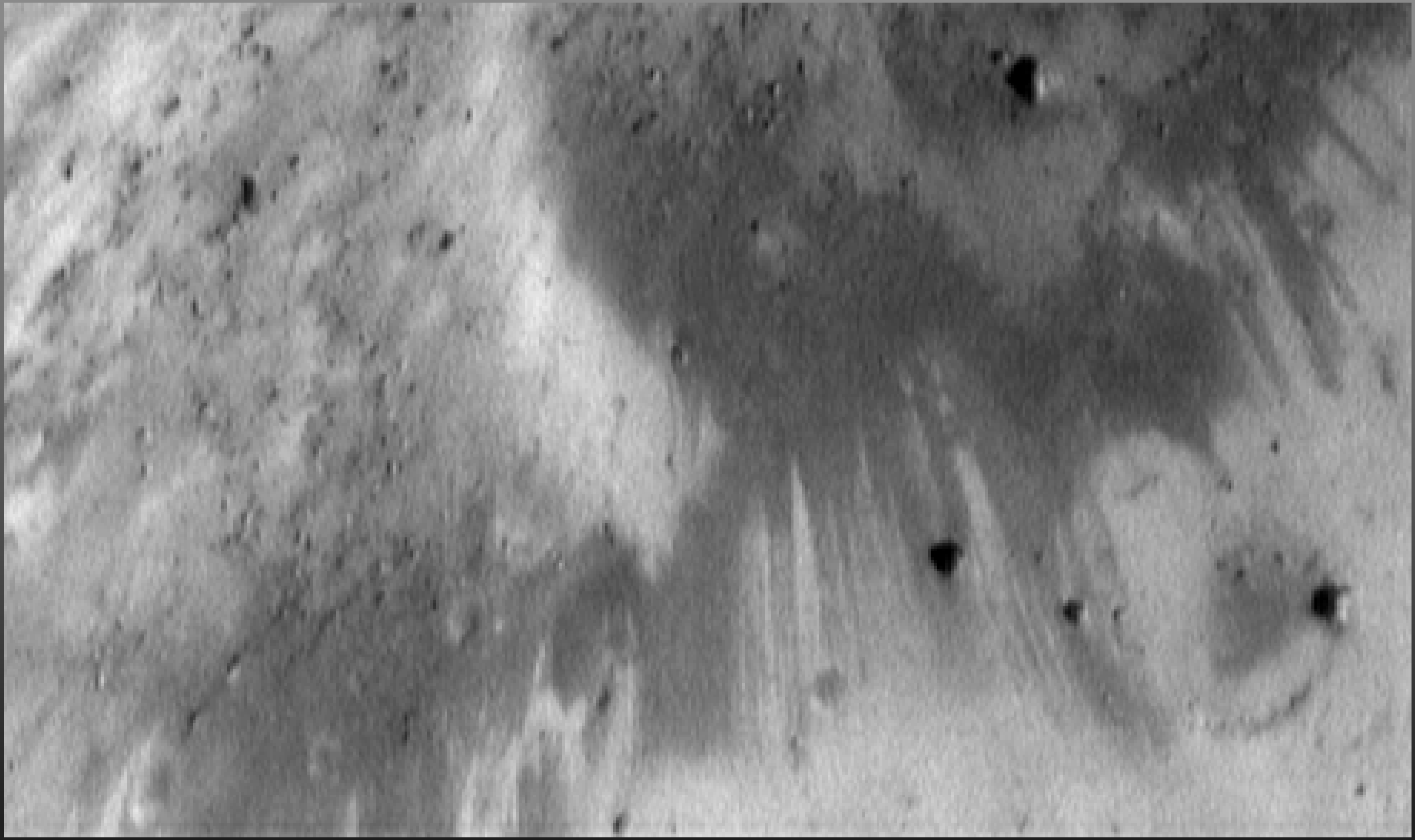
Mission Milestones



- Launch (February 17, 1996)
- Mathilde Encounter (June 27, 1997)
- Earth Flyby (January 23, 1998)
- Eros Flyby (December 23, 1998)
- Eros orbit insertion (February 14, 2000)
- Eros landing (February 12, 2001)
- Landed science operations through end of mission (February 28, 2001)

Geologically Active Surfaces

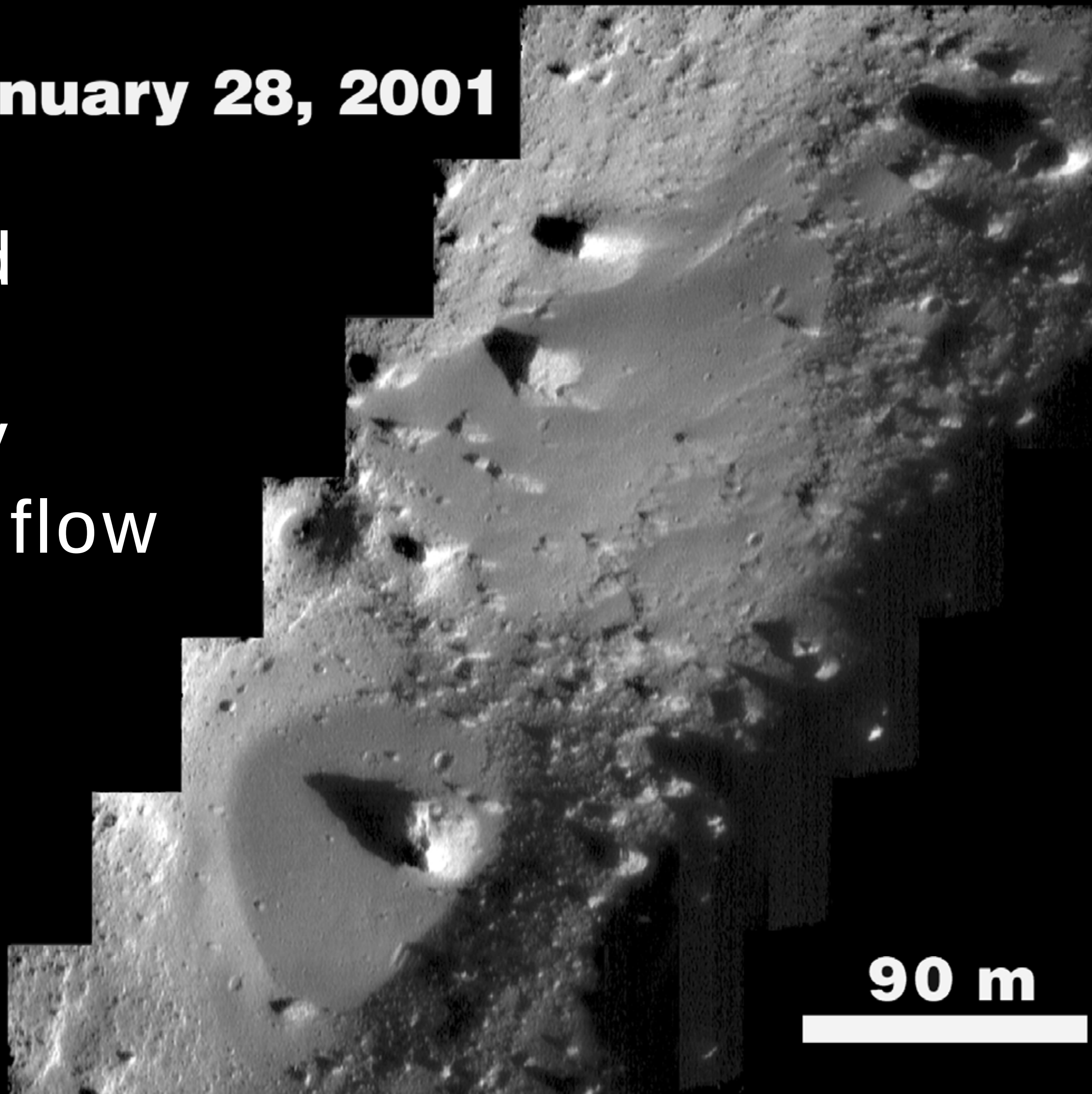




Lobate, downslope-oriented bright streaks at 2.5 m/px in crater Selene [23]

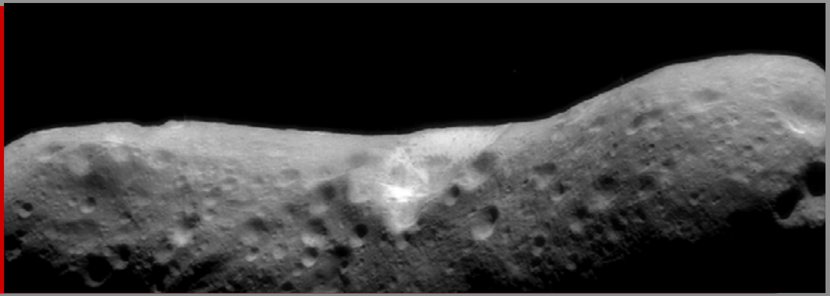
January 28, 2001

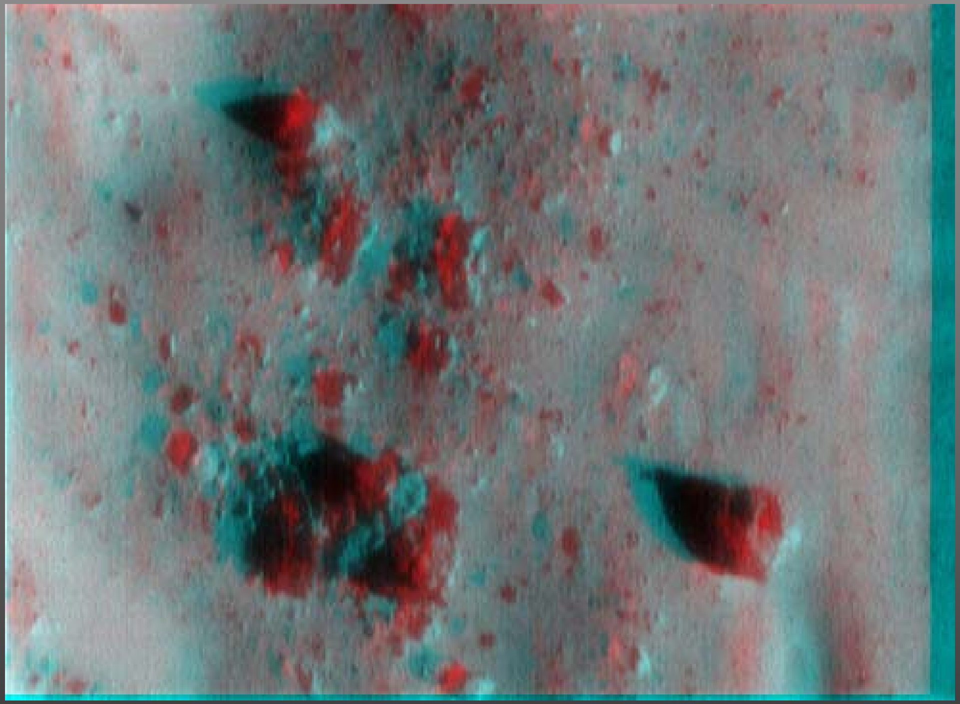
A pond
and a
nearby
debris flow



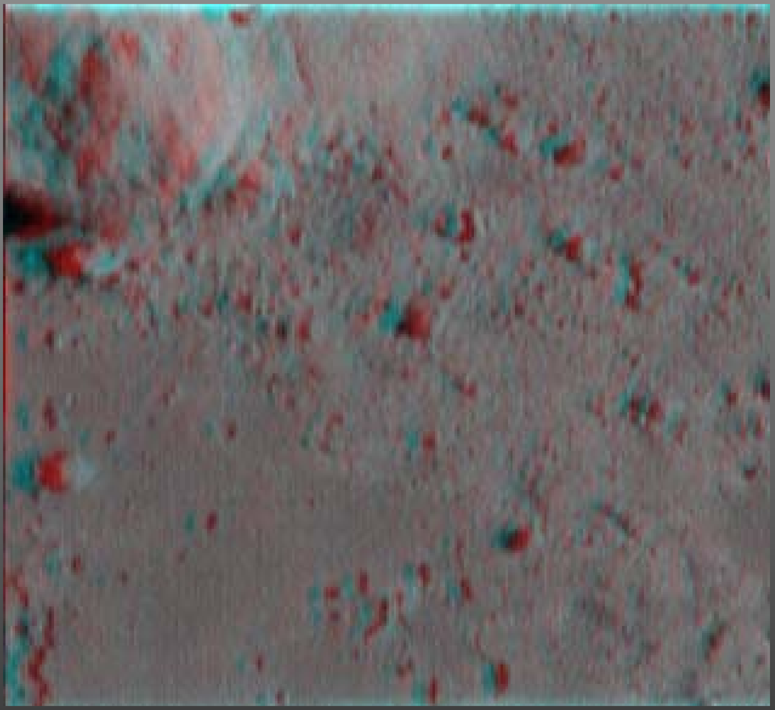
Veverka
01-0185-7

Stereo Close-ups





Ponds and split boulders?



The NEAR landing site