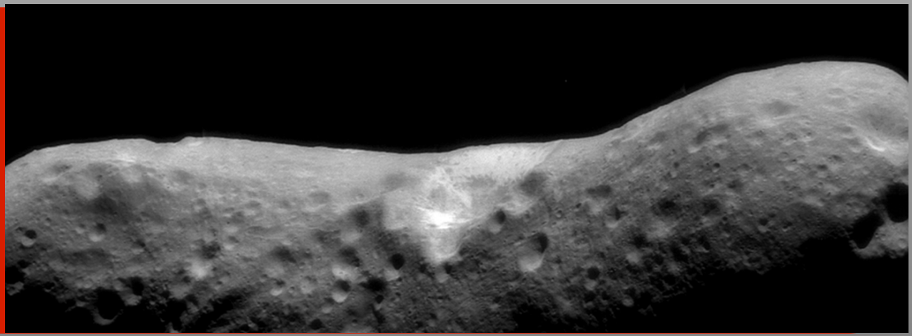
PI Masters Forum



Near Earth Asteroid Rendezvous: First Launch of Discovery Program

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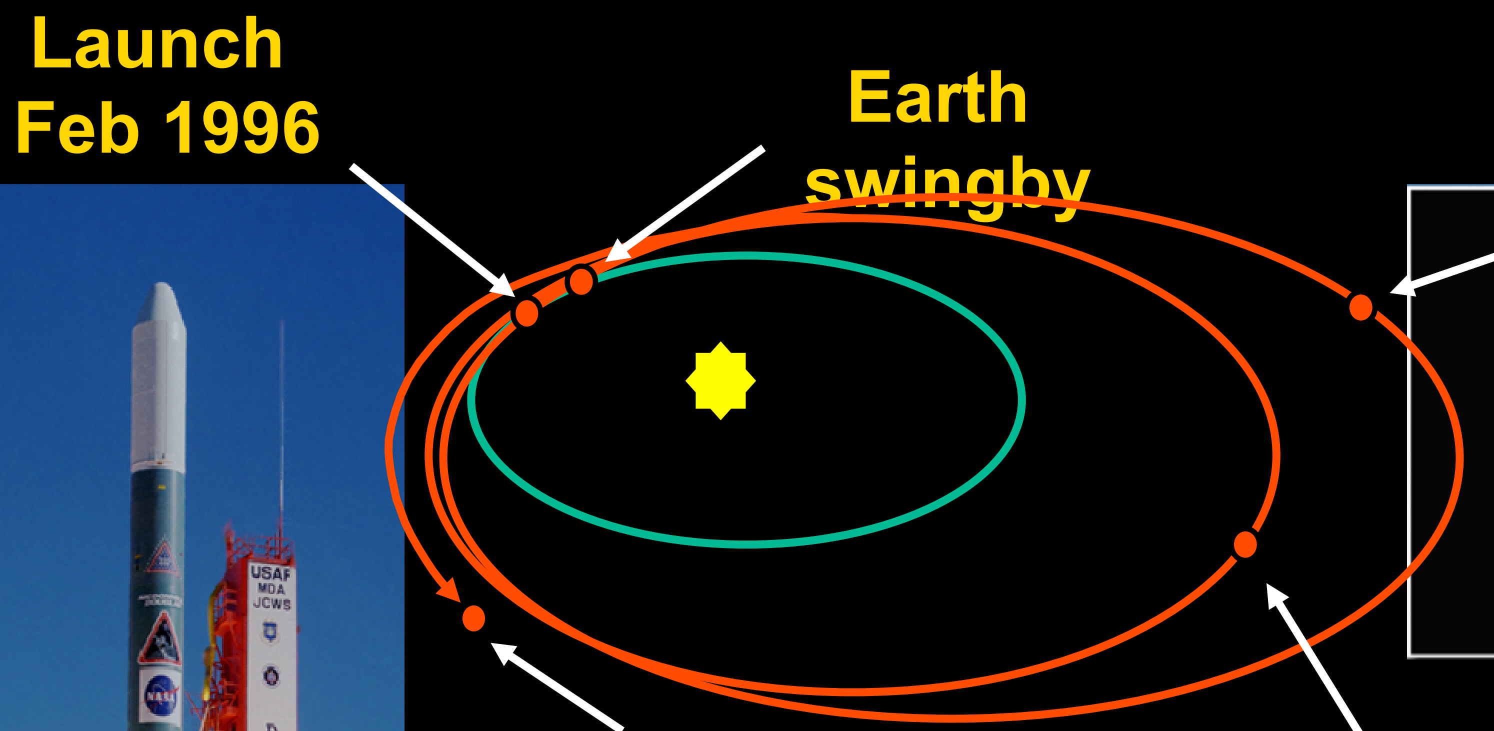
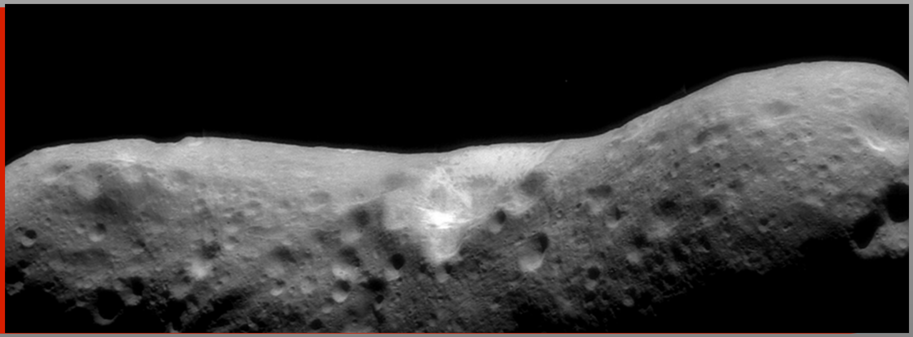
Applied Physics Laboratory

Near Earth Asteroid Rendezvous



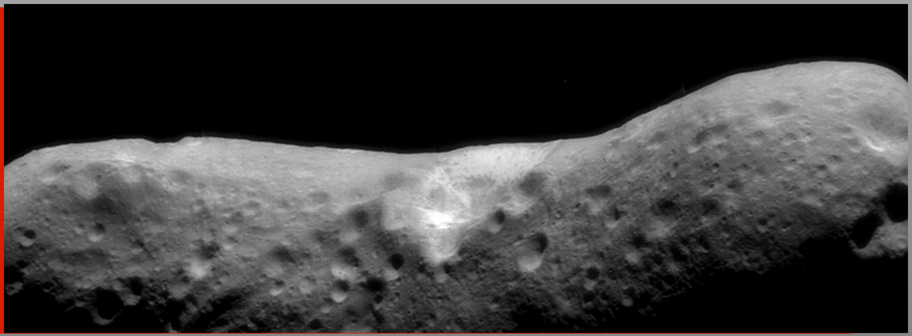
Eros 1998 and 2000

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"



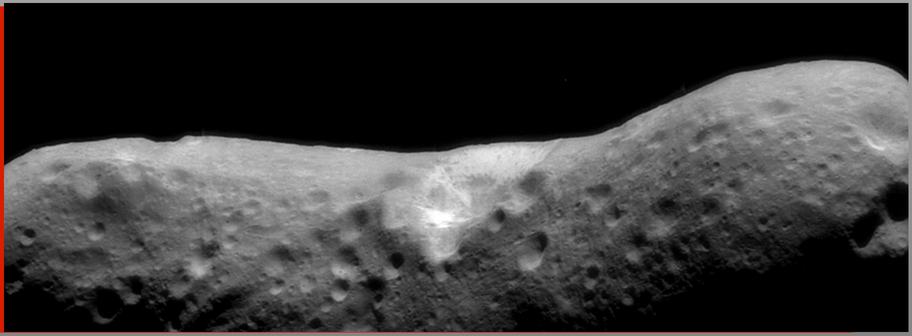
- Programmatic and institutional firsts
  - First planetary mission at APL (also a first for NASA)
- First use of internet for internal and external project communications as well as outreach
  - A.F. Cheng blog, NEAR image of the day
- First missions with open data policy requirements and archive requirements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

Focused Mission



Near Earth Asteroid Rendezvous

NASA

Measurement Objectives

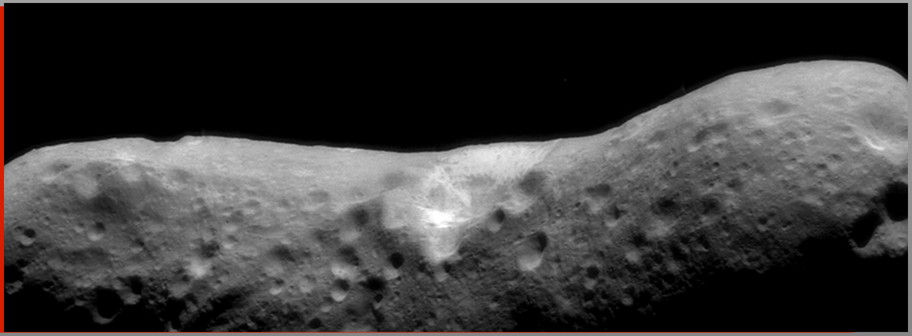
- **Bulk Properties**

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

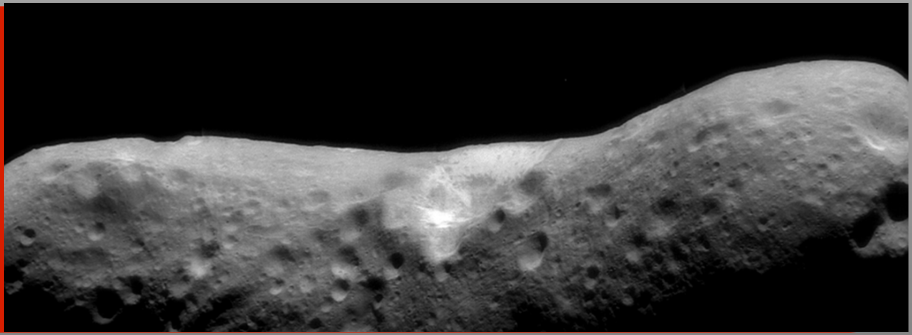
Facility Instrument Characteristics

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**

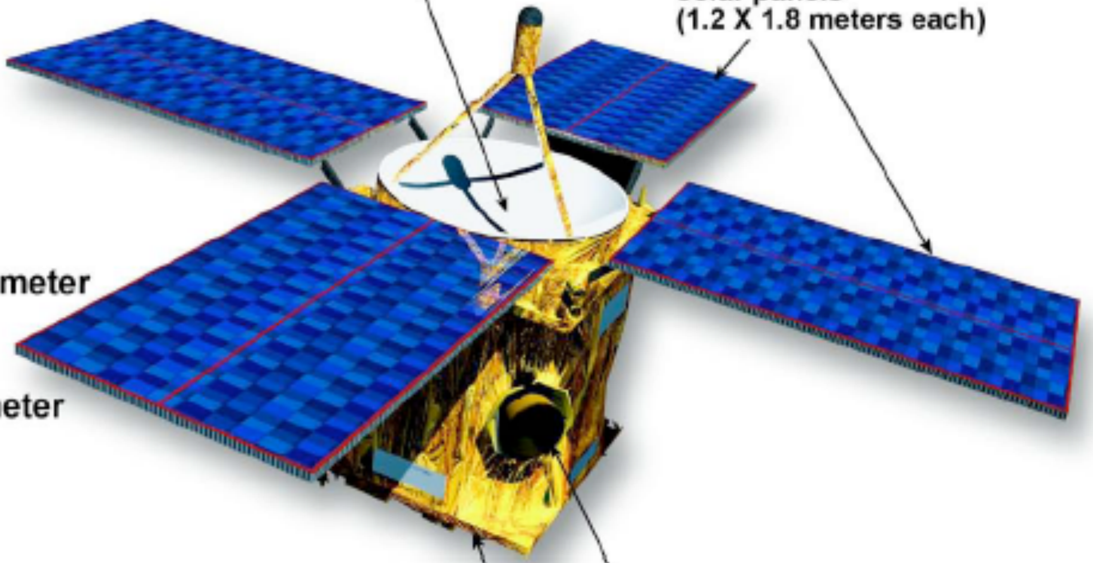
[scanned original slide with ancient typos]

Simple Spacecraft

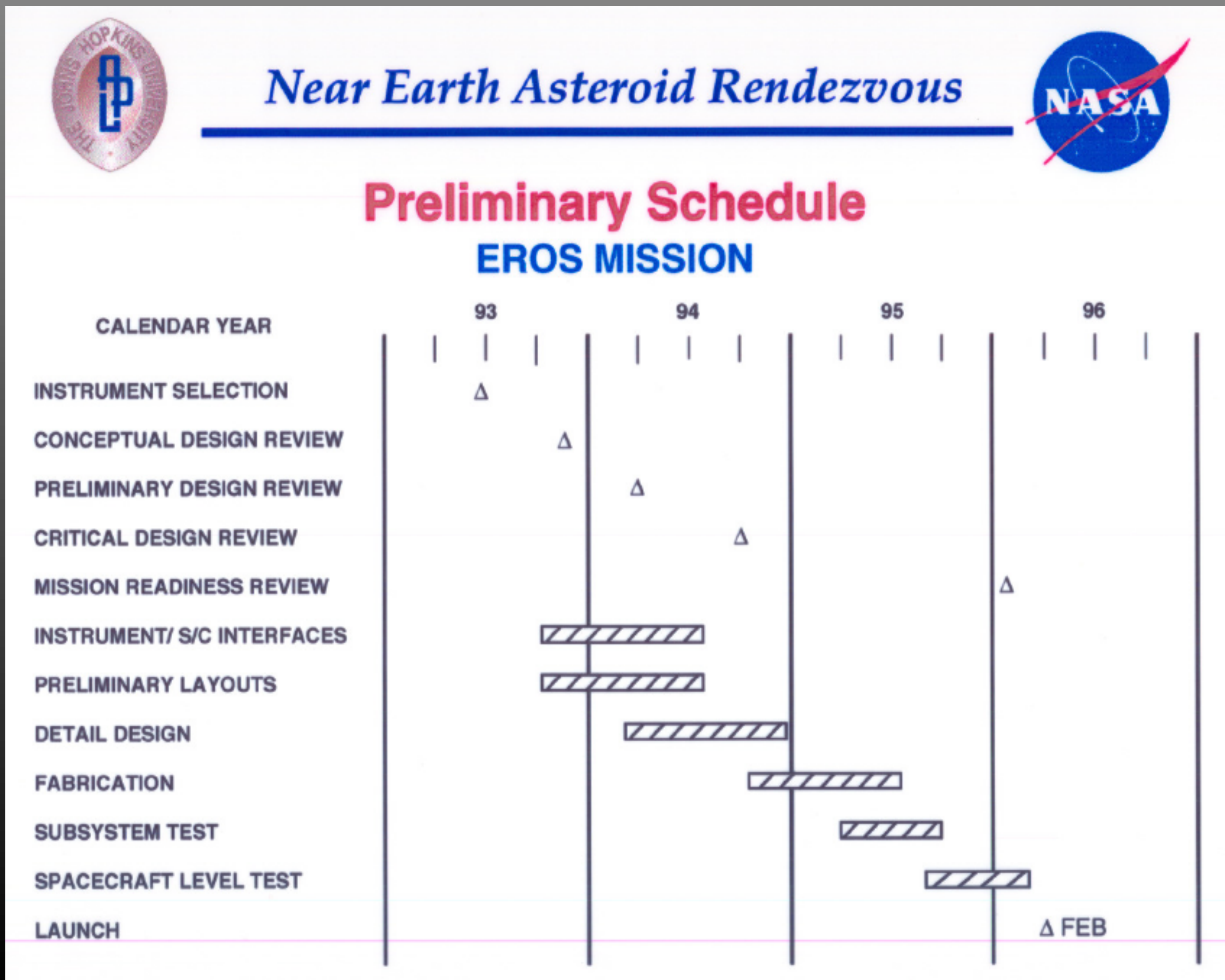


- Three-axis stabilized
- Total weight: 805 kg
  - Propellants: 320 kg
  - Experiments: 60 kg
- Science payload
  - Multispectral imager
  - Near-infrared spectrometer
  - X-ray spectrometer
  - Gamma-ray spectrometer
  - Laser altimeter
  - Magnetometer
- Dual-mode propulsion system

  [ΔV capability: 1450 m/s]
- Solar array power @ 1.00 AU: 1800 watts
- Two solid-state recorders: 1.7 x 10^9 bits



Schedule set in 1992
and followed through launch



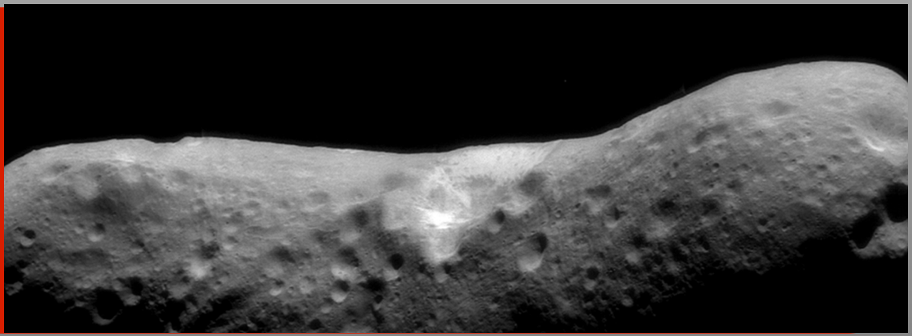
How it was done

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

Mission Milestones



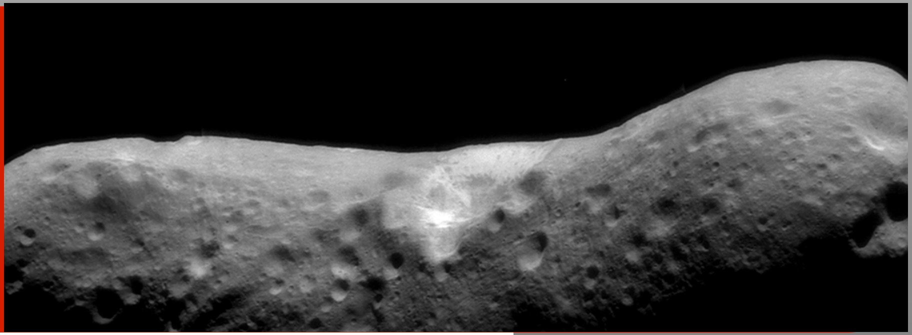
- Launch (February 17, 1996)
- Mathilde Encounter (June 27, 1997)
- Earth Flyby (January 23, 1998)
- Eros Flyby (December 23, 1998)
- Eros orbit insertion (February 14, 2000)
- Eros landing (February 12, 2001)
- Landed science operations through end of mission (February 28, 2001)

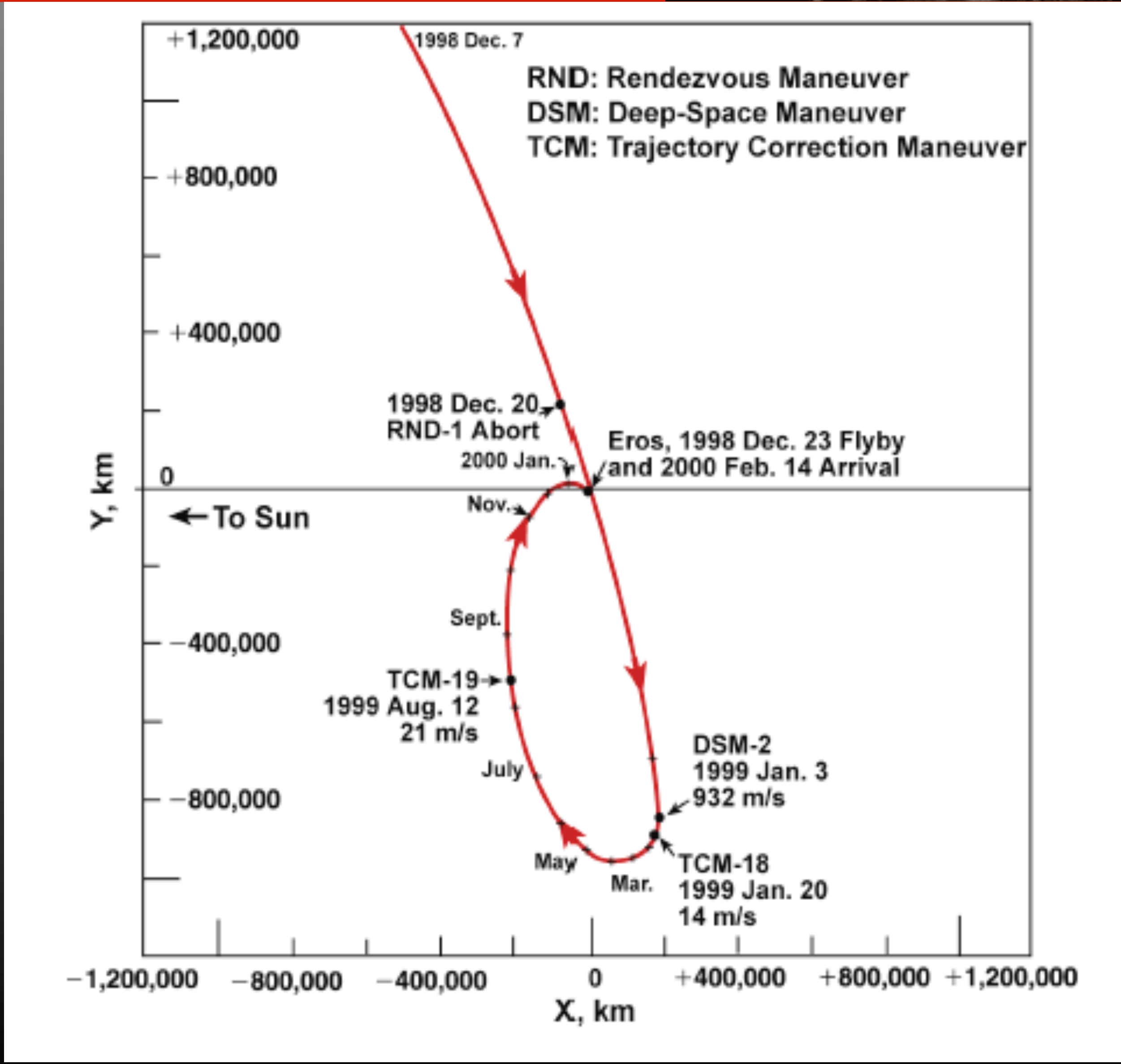
One very bad day

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





Then and now

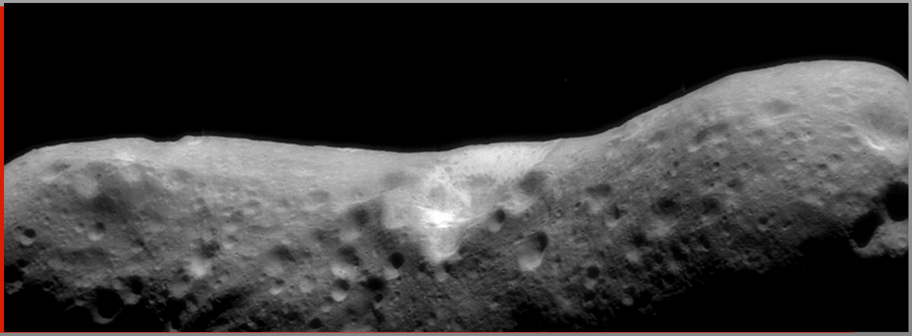
Review History

Technical and Cost Review	December 1–3, 1993
Preliminary Design Review	April 25–26, 1994
Critical Design Review	November 29–30, 1994
Independent Readiness Review	December 1, 1994
Quarterly Reviews	Throughout
Subsystem Reviews	Each subsystem had *at least* one
I&T Initiated	June 4, 1995
Pre-Environmental Review	September 18, 1995
Independent Readiness Review	October 12, 1995
Pre-Ship Review	December 4, 1995
Mission Readiness Review	January 29, 1996

Documentation Creep

- Minimal documentation was required for NEAR by NASA
  - MOC-SOC ICD
  - SOC Requirements
  - Software Requirements and ICDs
- Current missions, partially due to increased complexity, require more detailed documentation
  - Data Management Plan
  - Science Analysis Plan
  - Instrument Calibration Plans and Requirements
  - Cruise Operation Plan
  - Orbital Concept of Operations
  - Instrument Software Interface Specification documents (describe data formats)
  - Navigation ICD

Mission Operations learned in flight



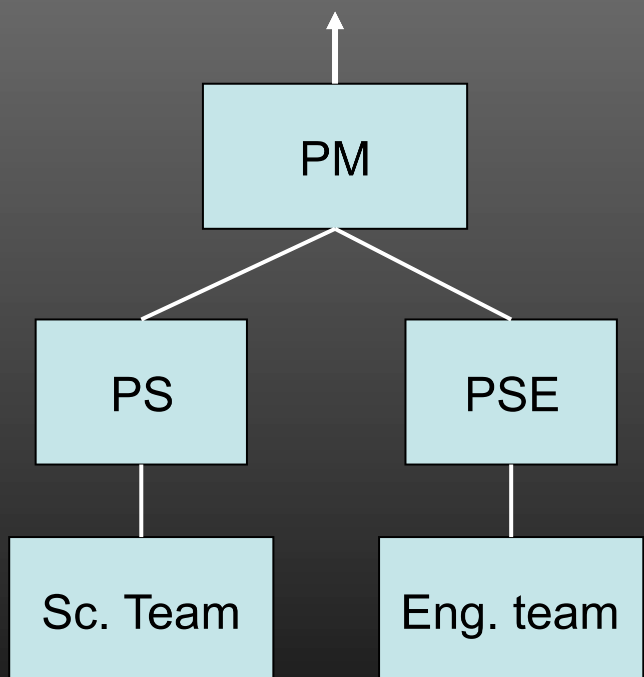
- **Concept of operations developed after launch for a small team**
  - There was no good model for NEAR (the last orbital mission was Galileo)
- **Little or no simulation of orbital operations**
  - No previous orbital mission around an irregularly shaped, small object
  - Navigational accuracy could 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

Project Management

- Simple, clearly defined lines of authority and responsibility



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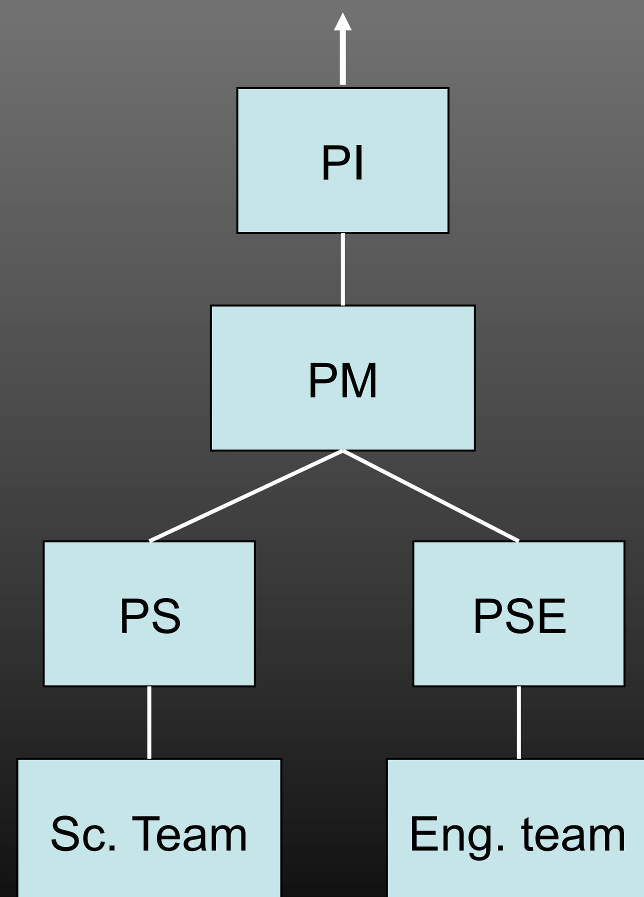
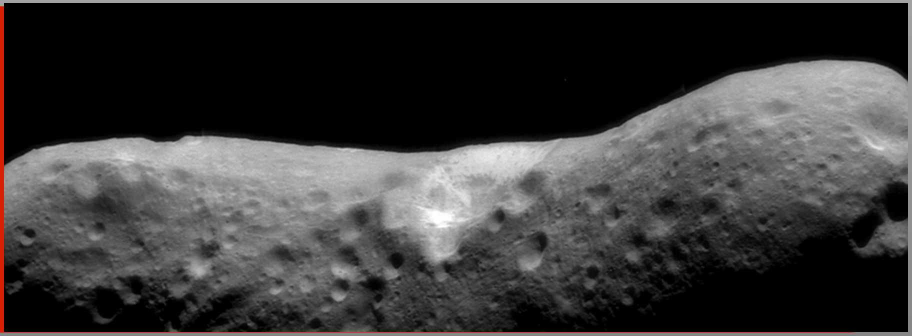


Mission Success

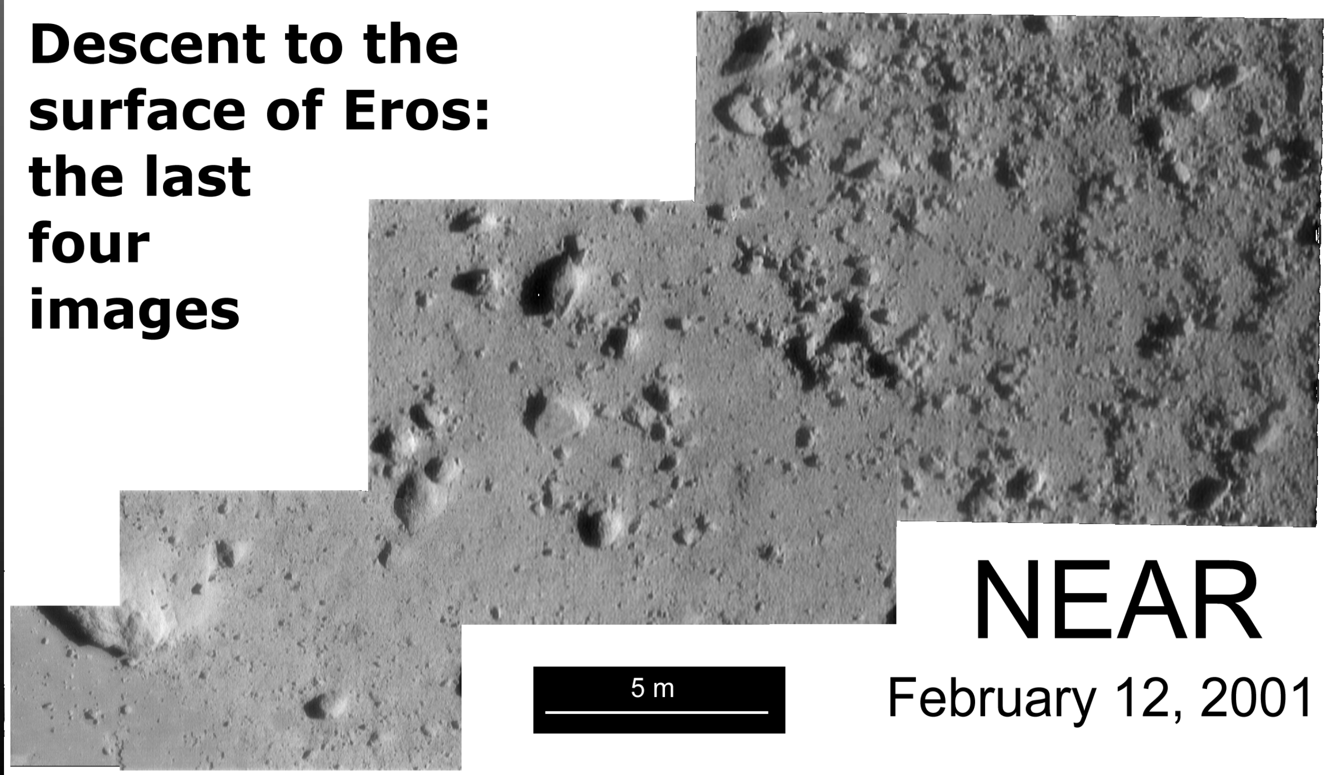
Near Earth Asteroid Rendezvous

- **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

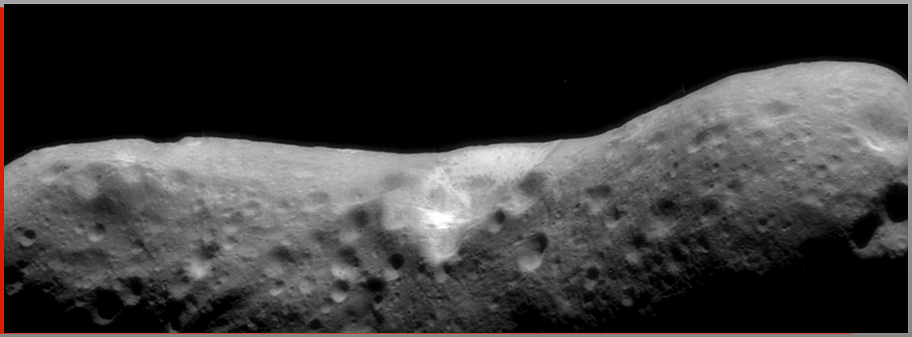
The First Asteroid Landing



- 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



Science Success



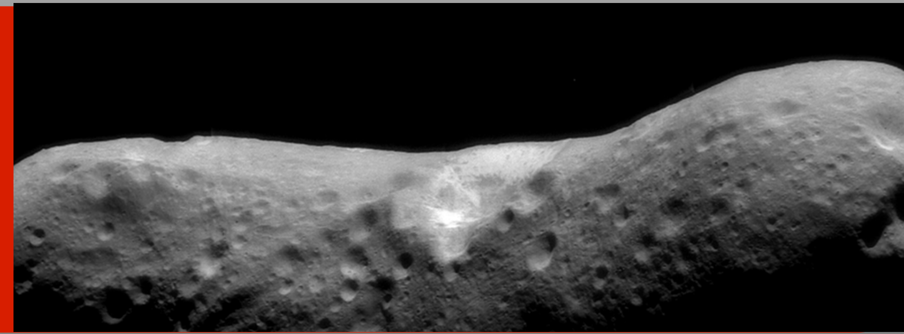
- All science objectives met or exceeded
- More science and data returned than originally planned
  - More than 10x number of images
  - Two low altitude flybys (under 5 km)
  - Landing and science operations on the surface
- No major spacecraft anomalies at Eros

Mission Success

what it's

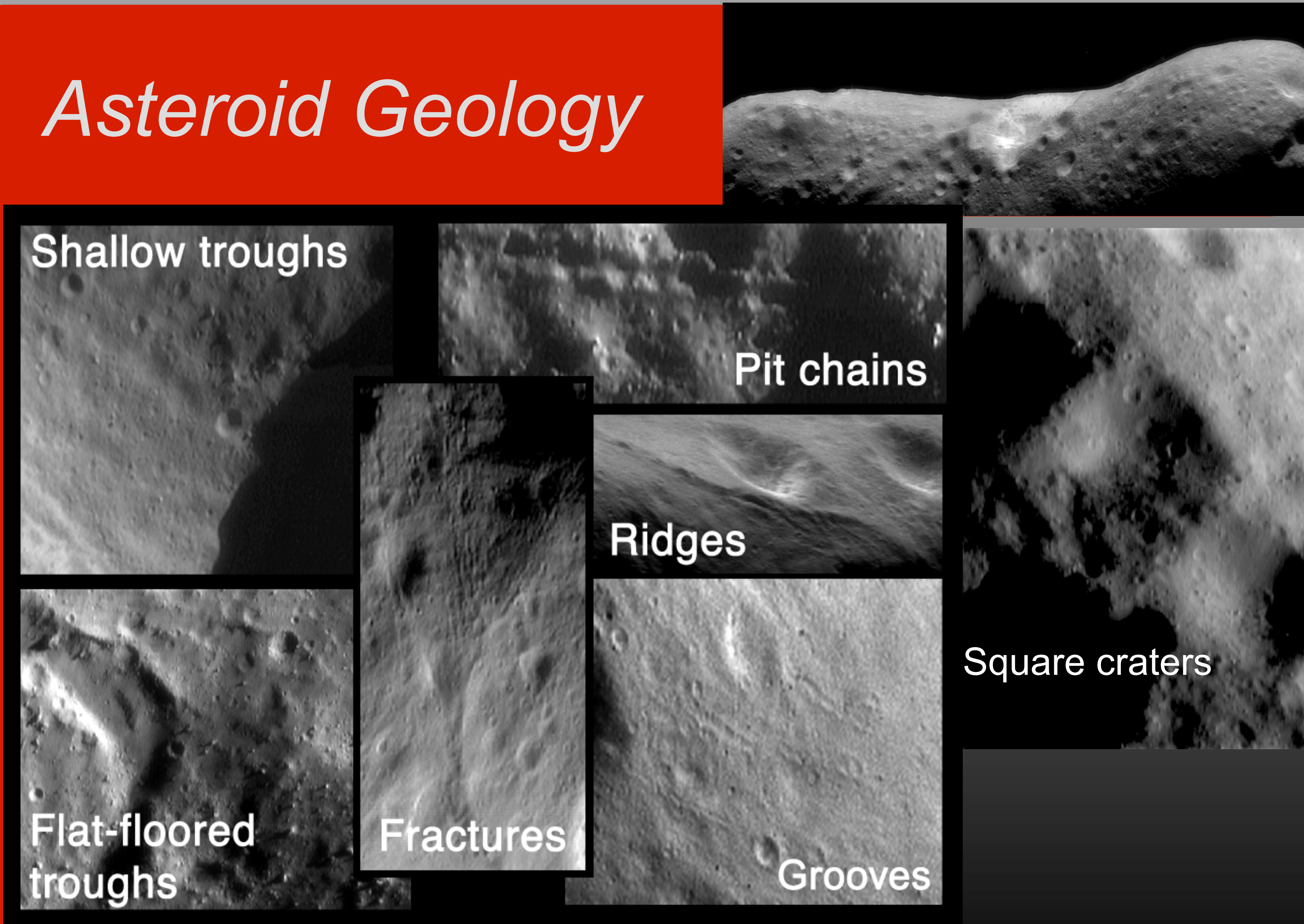
all about

Not a Rubble Pile

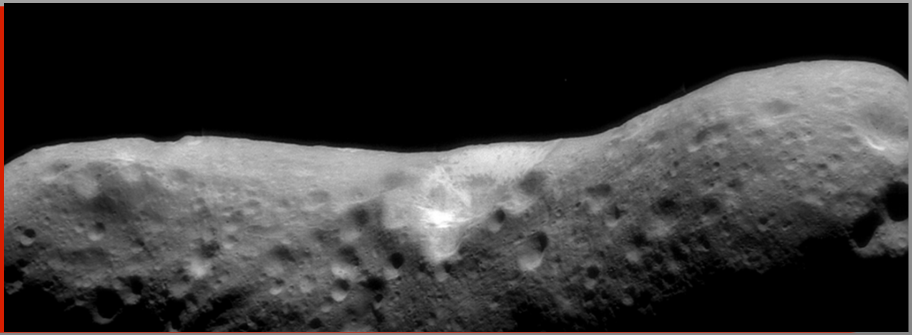


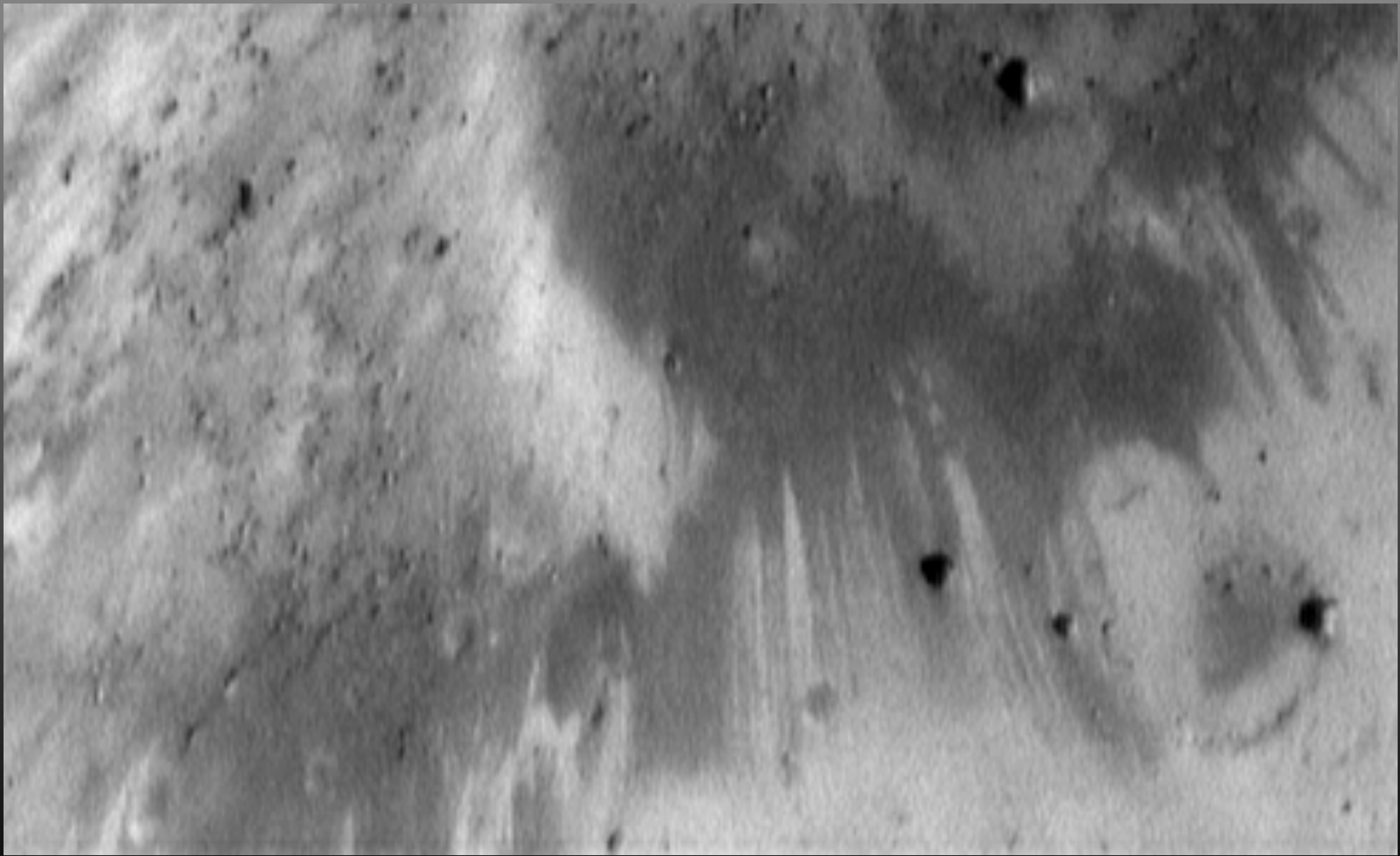
Linear Structural Features

Asteroid Geology



Geologically Active Surfaces

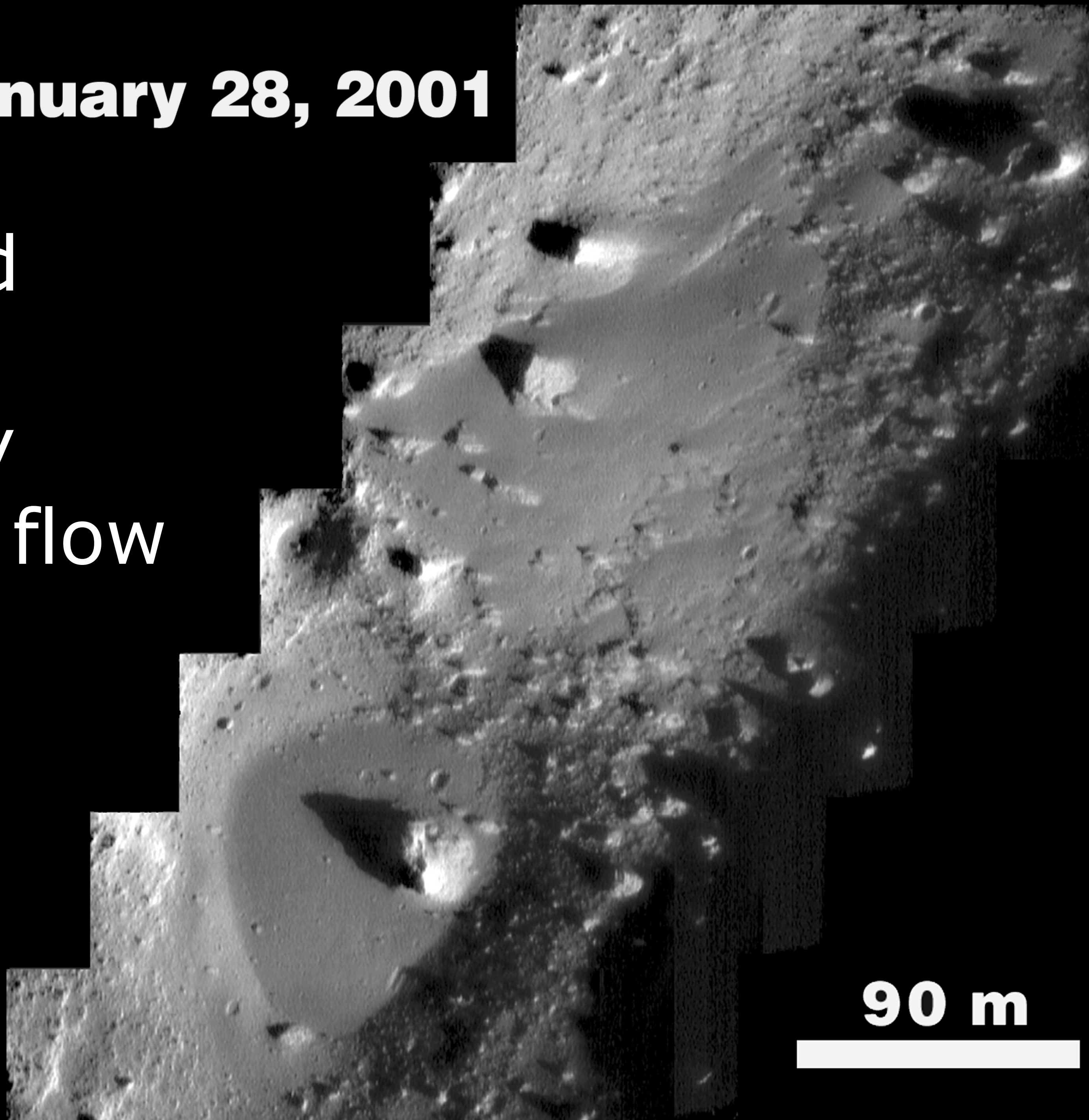




Lobate, downslope-oriented bright streaks at 2.5 m/px in crater Selene

January 28, 2001

A pond and a nearby debris flow



Veverka
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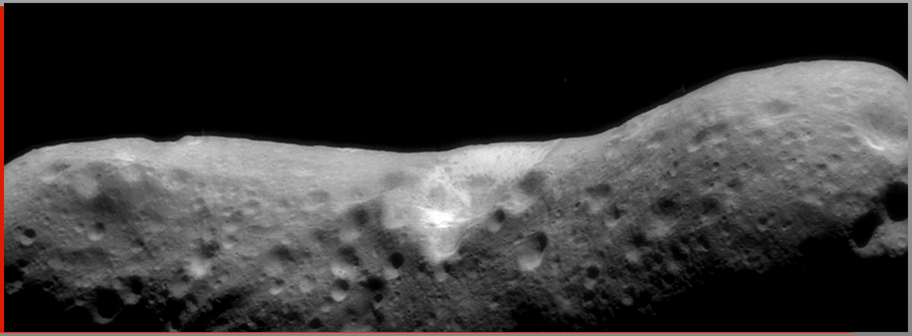
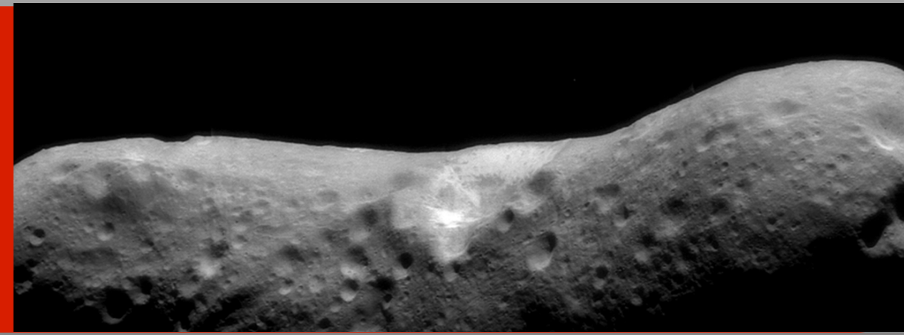
What is Eros made of?



- Meteorites – rocks from space
  - Meteorites are pieces of asteroids
  - A detailed record of physical and chemical conditions in the early solar system
- Is Eros related to ordinary chondrites?
- Eros is made of primitive material that was never melted
  - Eros parent body was not differentiated

Management Principles

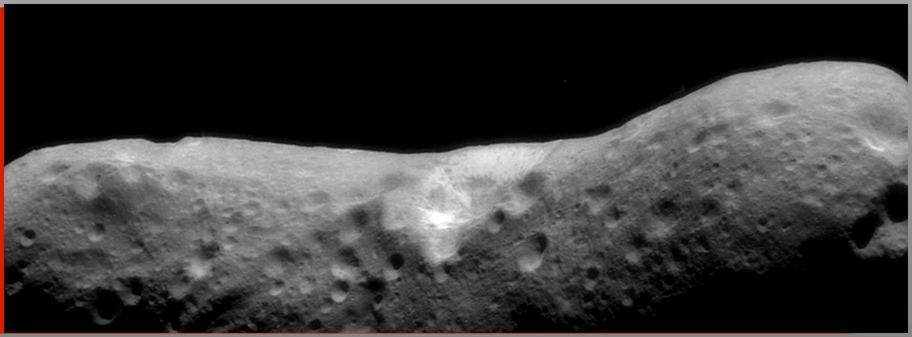


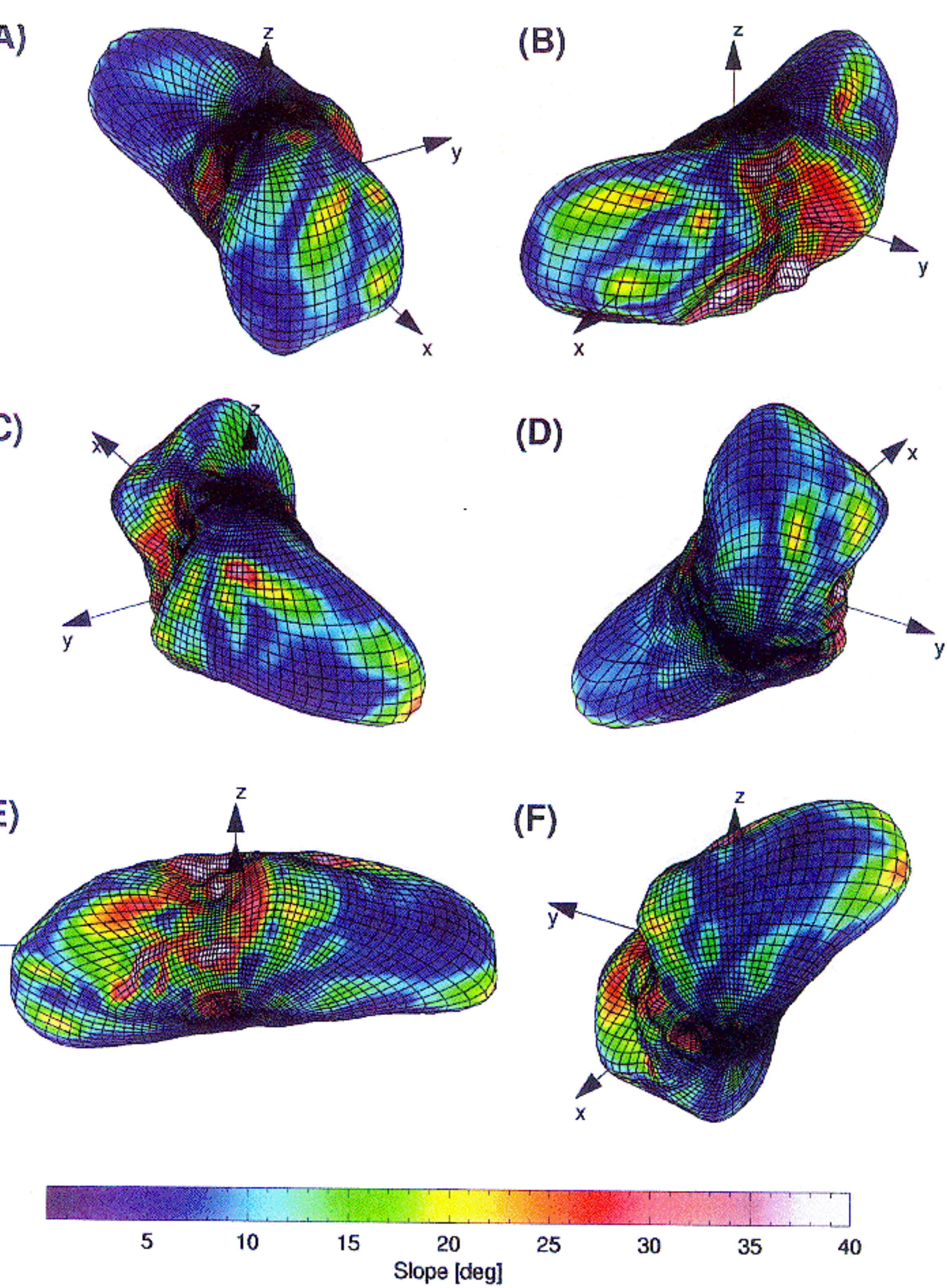
Practices for Inexpensive, Short Development Cycle Spacecraft

(a'la JHU/APL)

- Schedule from start to launch must be ≲ 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

Global Views of Eros





Surface Slopes

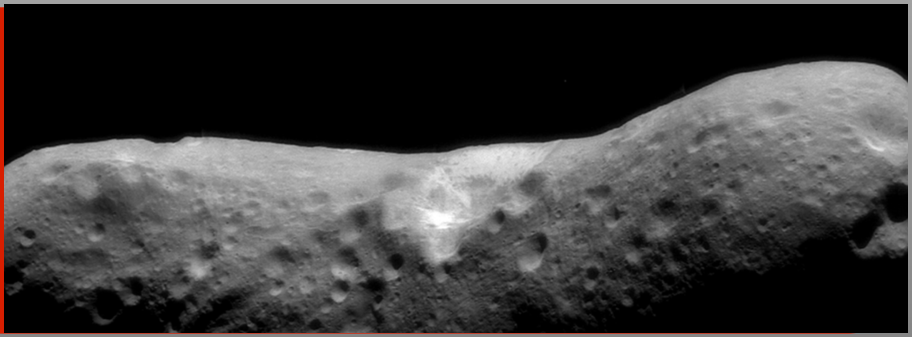
of 433 Eros re Constant Density Gravity Field

Steep slopes around Himeros and Psyche

97% of surface area below 30° slope on 400 m baselines

Zuber et al. (2000)

NEAR was unique



- Unlike later Discovery missions, NEAR was not a PI-led mission
  - Facility instruments and science team
- NEAR had a Project Manager (Tom Coughlin) and a Project Scientist (Andy Cheng)
- Project Scientist led science team and reported to the Project Manager

Eros spectral reflectances

- Silicate mineralogy from visible and near-IR spectra consistent with ordinary chondrites
- Significant albedo variations, subtle spectral variations; uniform composition over surface
- Brighter surfaces correlate with deeper 1μ bands and with steep slopes
- Surface "weathering" to different color and albedo end-state than in lunar maria

Eros is undifferentiated, but…

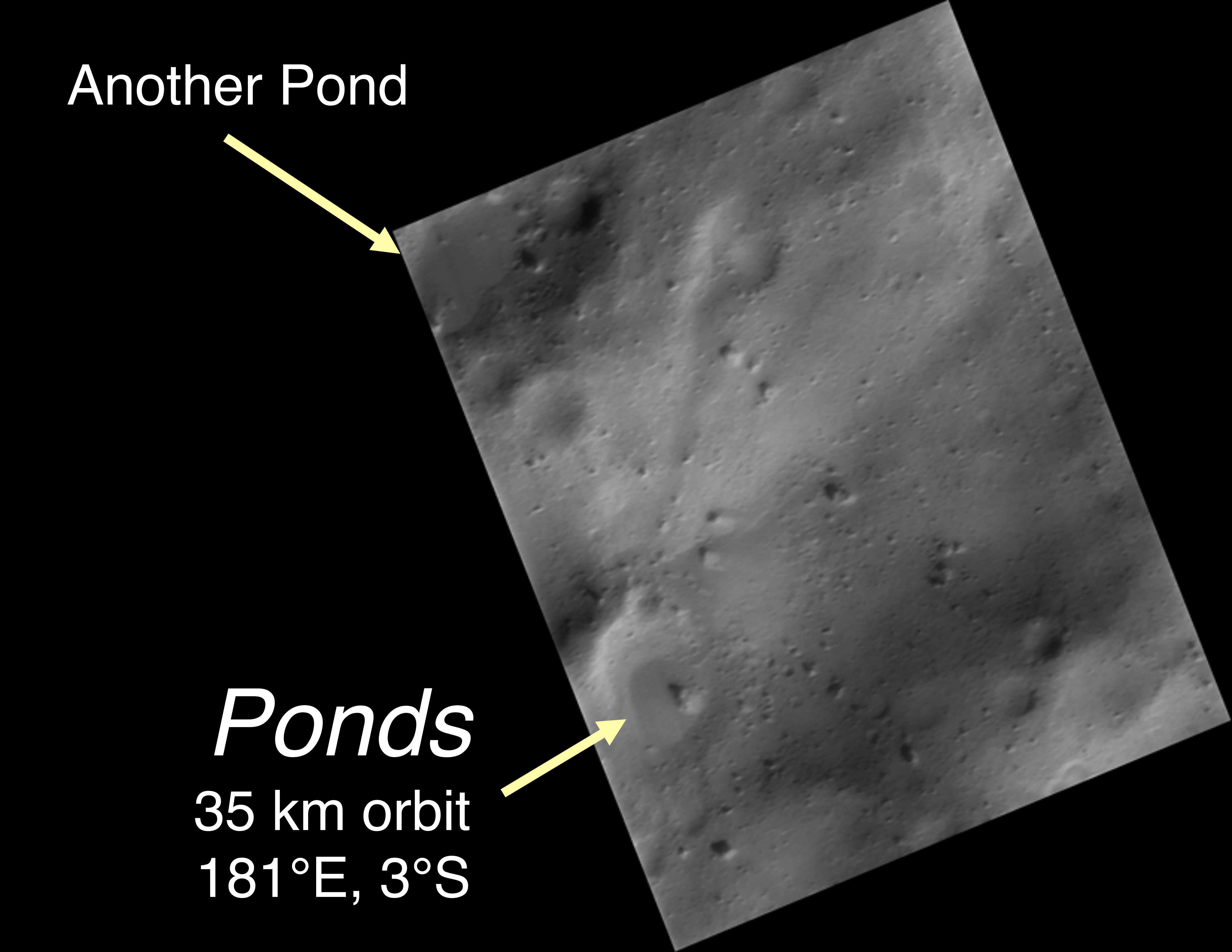
- Abundances of major rock-forming elements consistent with ordinary chondrites for regions measured by X-ray fluorescence
- NEAR x-ray observations suggest depletion of S relative to chondritic
- Some degree of partial melting, or a primitive achondrite composition, not ruled out by elemental abundances
- Near-IR spectra inconsistent with known primitive achondrites

Eros is undifferentiated, but…

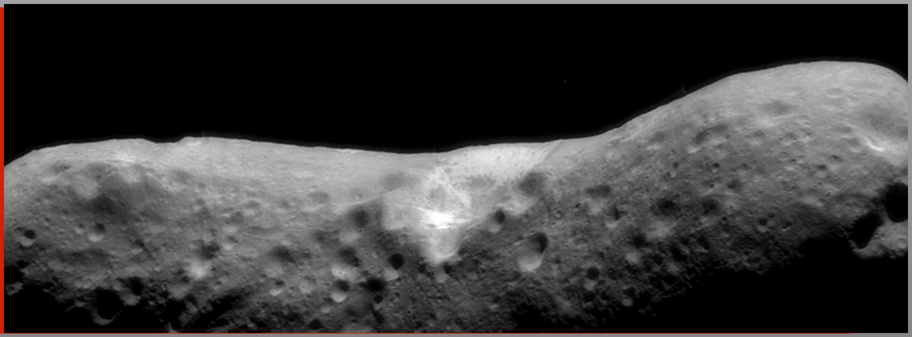
- Gamma ray spectrum from NEAR landing site shows chondritic Mg/Si
- However, GRS finds Fe/O and Fe/Si depleted relative to chondritic values.
- Also K is not depleted relative to chondritic (a bit surprising, given depletion of S).
- NEAR landed in a pond – are ponded fines fractionated?

Eros is mysterious up close…

- No intrinsic or induced magnetism
- Density uniform to within a few percent
- Principal axis rotation within 0.1 degree
- Marked deficiency of craters <100 m diameter compared with Moon; more boulders than small craters!
- Craters shallower than on Moon; filling of craters
- Mobile regolith of typical depth 10’s of m; seismic shaking?


Another Pond
Ponds
35 km orbit
181°E, 3°S

Instrument Operations



- Science Team organized by instrument and science discipline
- Science team was responsible for data calibration and analysis
- Each Instrument had science team leader
- Each Instrument had an Instrument Scientist, Instrument Sequencer, Instrument Engineer, and each had a back-up
- Instrument Sequencer was responsible for command load generation
- Instrument Scientist was responsible for science planning and data validation
- Instrument Engineer was responsible for monitoring health and safety