Represents work performed as part of the MRO Project
at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the
National Aeronautics and Space Administration

Mars Reconnaissance Orbiter (MRO)

The Next Step in Mars Exploration

ATLAS V-401

LOCKHEED MARTIN

MRO

LOCKHEED MARTIN

THE UNIVERSITY OF ARIZONA.

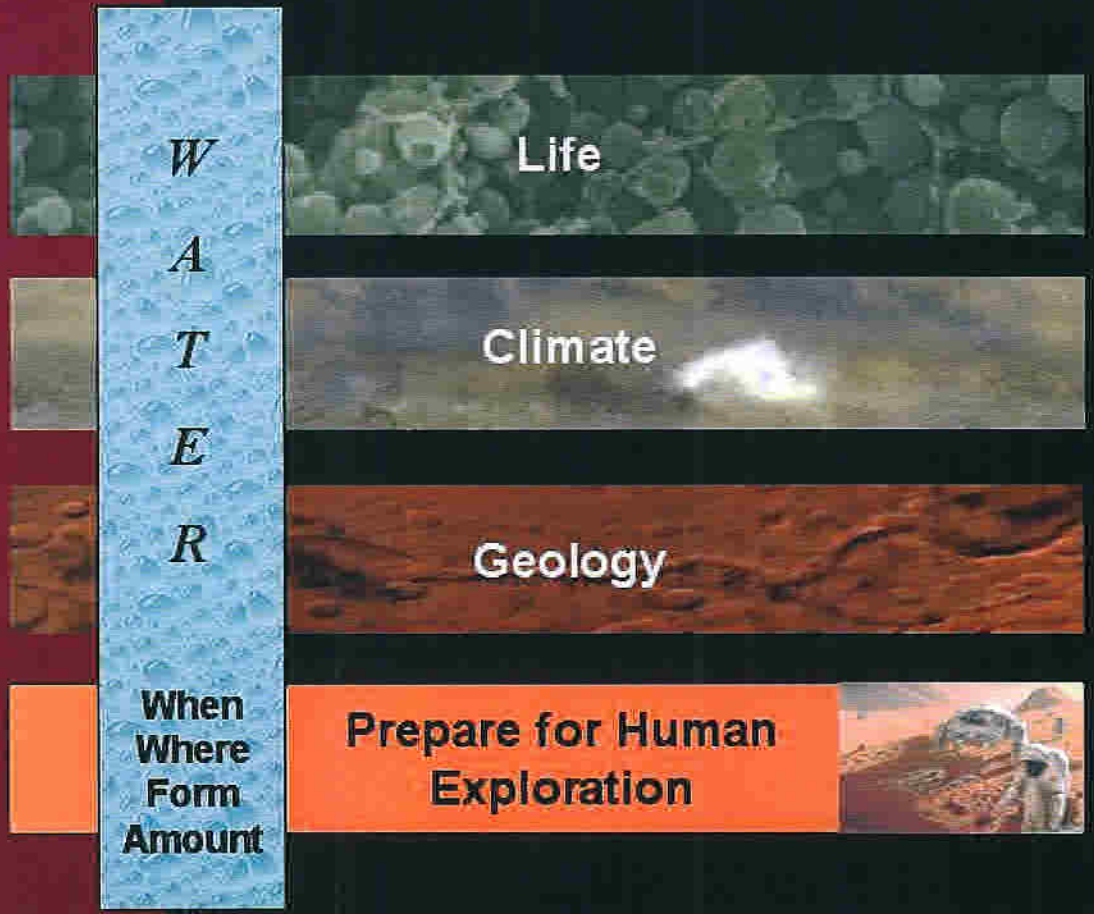
Malin Space Science Systems

JPL

agenzia spaziale italiana

The Mars Science Strategy: "Follow the Water"

- When was it present on the surface?
- How much and where?
- Where did it go, leaving behind the features evident on the surface Mars?
- Did it persist long enough for life to have developed?



Understand the potential for life elsewhere in the Universe

Characterize the present and past climate and climate processes

Understand the geological processes affecting Mars' interior, crust, and surface

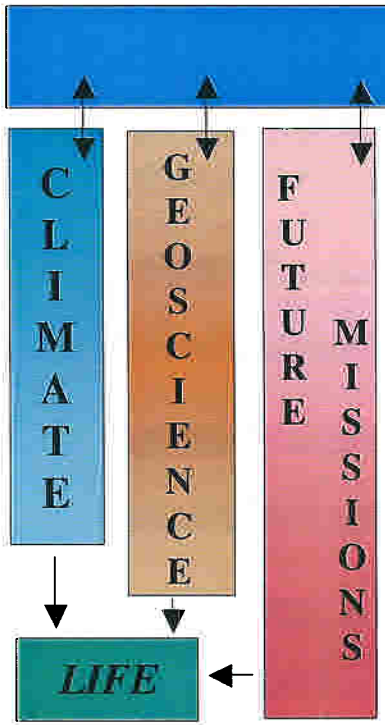
Develop Knowledge & Technology Necessary for Eventual Human Exploration

Mars Exploration Program

MRO Science | Mars Reconnaissance Orbiter

MRO Science Objectives

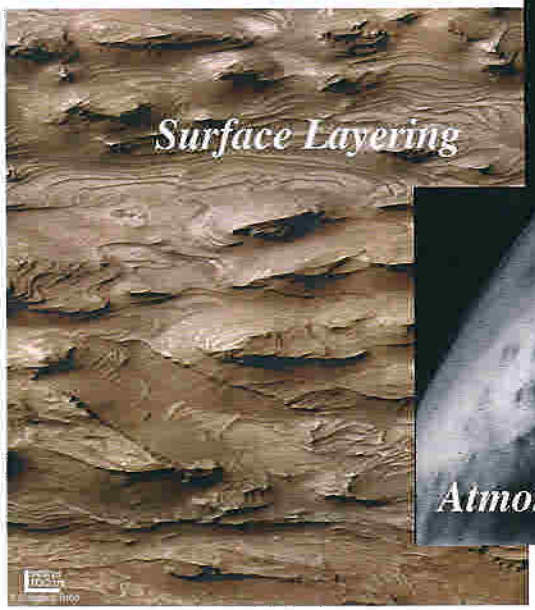
The Mars Reconnaissance Orbiter (MRO) Mission will make a major advance in our understanding of Mars in the context of the NASA Mars Exploration Program

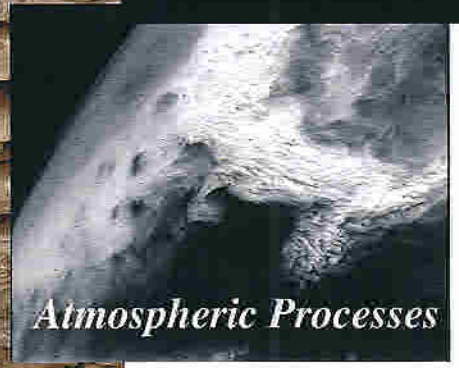


- ✓**Characterize present & past climates of Mars**
- ✓**Advance our understanding of surface and subsurface structure and composition**
- ✓**Identify and characterize prime sites for exploration by future Mars missions**
- ✓**Return scientific data from Mars missions launched in 2007 and 2009**

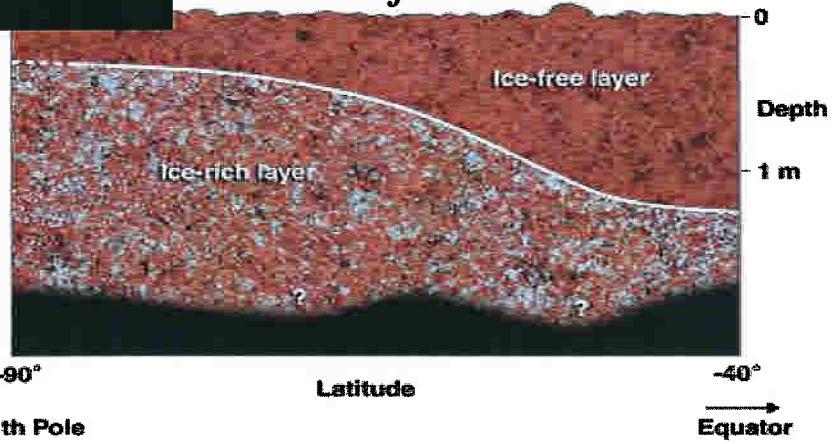
Mars: A Complex Planet

Comparative Planetology



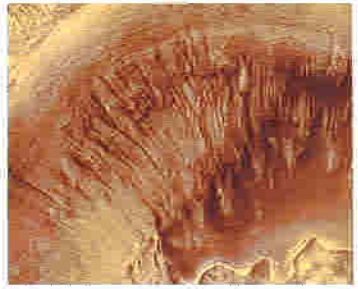


Subsurface Reservoirs



Mars Reconnaissance Orbiter

- **Competed S/C: LMA**
  - **Competed Launch Vehicle**
    - **Competed Payload**
      - **MCO: MARCI, MCS**
      - **MRO AO: HiRISE, CRISM**
        - **FACILITY: CTX, SHARAD**
        - **PI/TLs: M. Malin, D. McCleese**
          A. McEwen, S. Murchie, R. Seu
          G. Keating, M. Zuber, R.Phillips



- **Launch: August 2005**
  - **Arrive: March 2006**
  - **Aerobraking: 6 months**
- **Science Mission: Dec '06 - Dec '08**
  - **Capability to extend 1 Mars Year**
- **Relay Support: Aug '08 to Dec '10**

Science Objectives

- **Map Water & Dust in the Present Climate**
- **Identify Sites with Aqueous Minerals/Sediments**
- **Resolve Detailed Surface Stratigraphy**
- **Explore the Solid Planet (radar & gravity)**
- **Identify Sites for Future Landed Missions**

MRO Following the Water: Major Questions Remain

- ***Were there ancient seas, lakes, or springs?***
  - => Survey planet for sites showing mineralized sediments (e.g., hydrates & carbonates), which may also preserve biosignatures <= *CRISM*
  - => Observe surface layering & geologic structure <= *HiRISE, CTX, SHARAD*
- ***What is the nature of layered terrain?***
  - => Characterize deposits at poles & elsewhere <= *HiRISE, CRISM, CTX, SHARAD*
- ***Are there subsurface water/ice reservoirs?***
  - => Search for signs of near-surface water release or active hydrological systems ("springs", gullies, mineral deposits) <= *CRISM, HiRISE*
  - => Probe shallow subsurface for layering and water/water ice <= *SHARAD*
  - ⇒ Detect release of water vapor from ground sources <= *MCS*
- ***Are hydrothermal systems active today?*** <= *HiRISE, CRISM, CTX*
- ***Where are ice and dust accumulating today?***
  - => Characterize water & dust transports & surface changes <= *MCS, MARCI,CRISM*
  - => Monitor polar processes <=*MCS, MARCI, CTX*

Science Pathways: Two Key Examples

Are water-lain materials present on the surface of Mars?

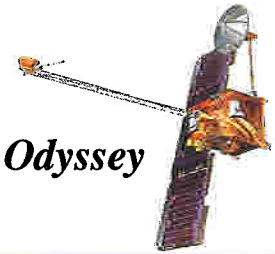
MGS

1-km scale IR data revealed just 3 regions that may have aqueous minerals

Why are the expected deposits so difficult to find?

Deposits may be covered, exposed only in small areas; Deposited material may be too fine-grained to be detected in Thermal IR

Are there major reservoirs of water/ice in the subsurface of Mars?



Odyssey

Hydrogen (water ice) detected in uppermost 1 meter of crust

Is this ice layer just a thin layer in equilibrium with today's atmosphere? Is it connected to a deeper and larger reservoir of water?

Understand the current Mars climate; Probe the shallow subsurface for water/water ice

Science Mission Drivers

MRO Science — Mars Reconnaissance Orbiter

Observe at Different Wavelengths

Observe at much Higher Spatial Resolution

Payload Selection

CRISM: Visible to Near Infrared Spectral Imaging in 512 spectral channels
- **SHARAD: Shallow Sounding Radar (15 cm wavelength)**

HiRISE: 1-meter resolution visible imaging
CTX: 6 m/pixel visible context imaging
CRISM: 20 m footprint spectral imaging
MCS: 5 km vertical profiling of atmosphere
MARCI: Daily global weather monitoring
SHARAD: ~ 15-m profile to 0.5 - 1 km depth

Mission Design

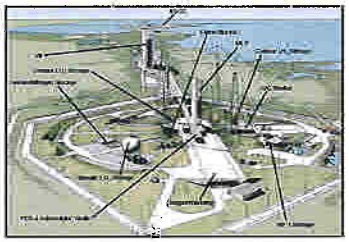
- Must Return Large Data Volume (>26Tbits)
- Design Orbit for Coverage & Resolution
  - Near-Polar, 3 p.m./3 a.m.
  - 255 km x 320 km
- Integrate Observation Modes:
  - Global Monitoring for 1 Mars Year
  - Regional Survey
  - Site Targeting with Precision

Spacecraft Design

Mission Overview

Launch

Aug 2005

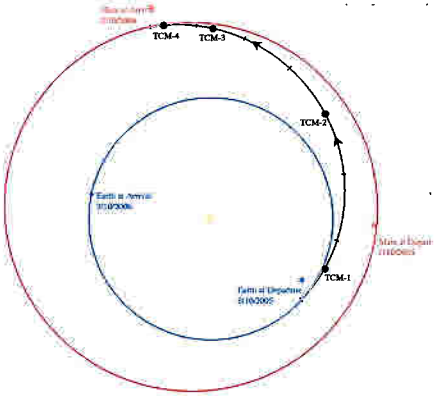


LC-41

Atlas V-401

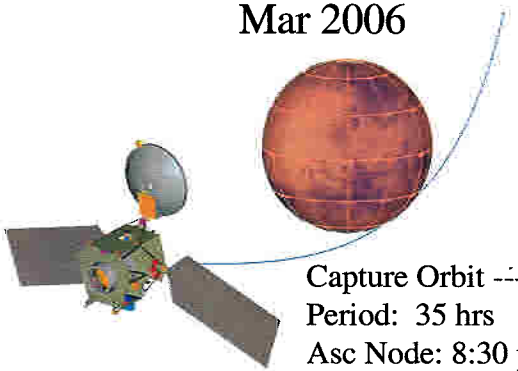
Interplanetary Cruise

Aug 2005 - Mar 2006



Approach and Orbit Insertion

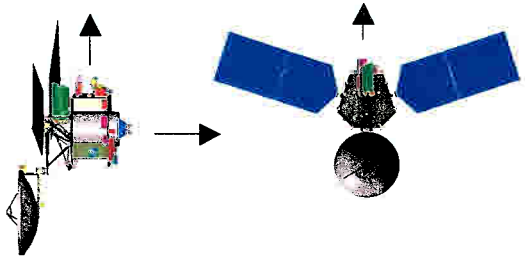
Mar 2006

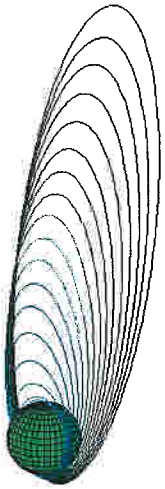


Capture Orbit ---
Period: 35 hrs
Asc Node: 8:30 pm LMST

Aerobraking

Mar-Nov 2006

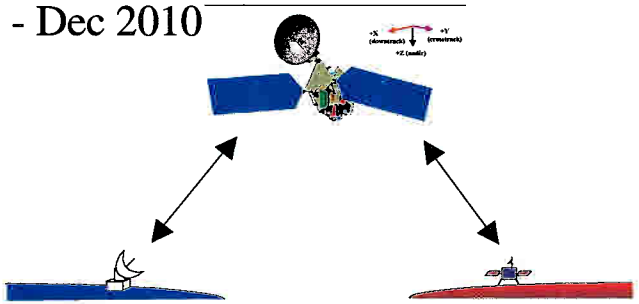




Primary Science/Relay

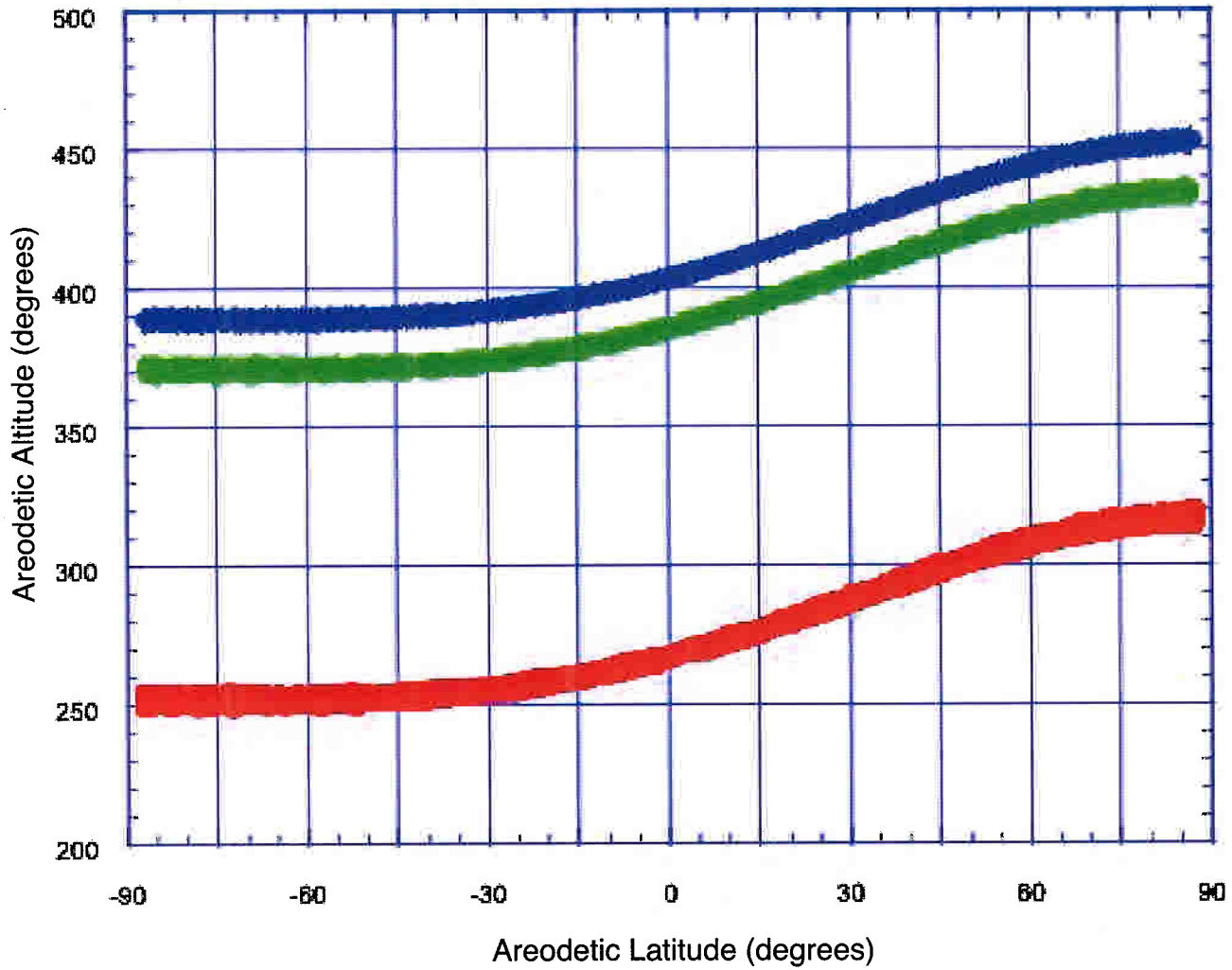
Dec 2006 - Dec 2010

Science Data Acquisition/Return



Primary Science/Relay Orbit ---
Period: 112 min
Hp: 255 km Ha: 320 km, Frozen
Ascending Node: 3:00 pm LMST (Sun-Sync)

MRO, MGS, and Odyssey Science Orbits



Orbit Nodal Orientations:
ODY: 5:00 PM DN LMST
MGS: 2:00 PM AN LMST
MRO: 3:00 PM AN LMST

MRO Orbiter Overview

2180 kg Launch Mass (Atlas V)

1545 m/s Delta-V

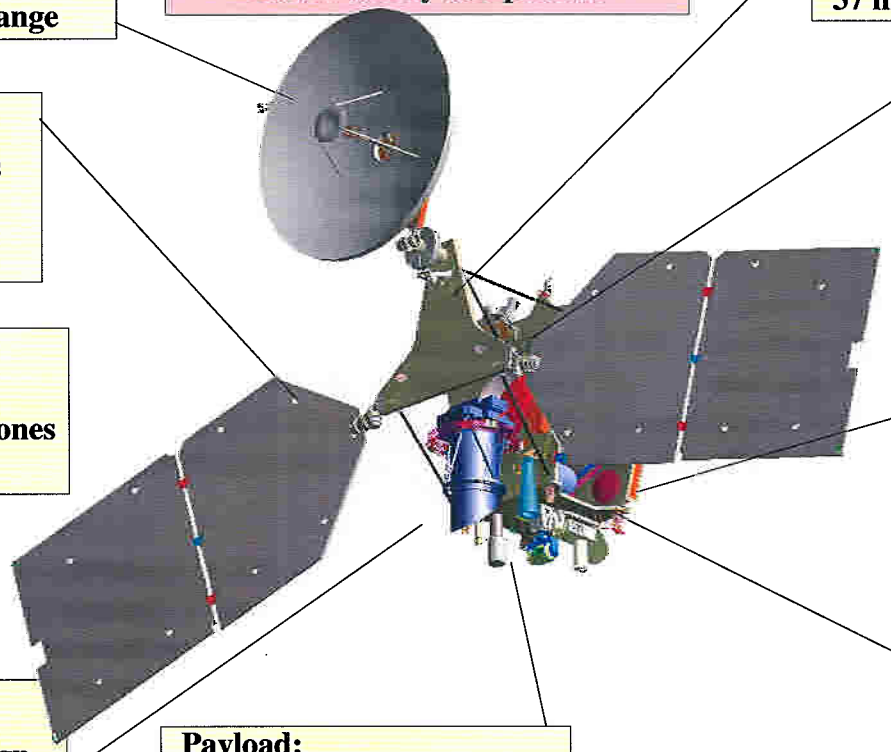
2000W Array at Aphelion

Telecom:
- Dual X and Ka-Band Capability
- 3m HGA
- Dual Fwd-Aft Tx/Rcv LGA
- 500 kbps @max earth Range

Structure:
- M55J Composite Construction
- Stiff Strut / Panel / Clip Design
- Symmetric / Aero-Stable Design
- 37 m^2 AB Drag Area

EPS:
- Dual 50 A-Hr NH_2 Batteries
- 20 m2 GaAs 3J Solar Cells
- 23% Margin at Aphelion

Mechanisms:
- Redundant DC-Brushless Motors
- 16-Bit Resolvers
- Redundant Release Mechanisms
- > 2X Holding torque During MOI



Thermal:
- Cold-Biased Passive Design
- Largely FSW Controlled Htr Zones
- 200W Allocation

C&DH:
- RAD750 FPC
- 160 Gbit SSR
- Turbo or RS Encoding
- 100Mbps Science I/F

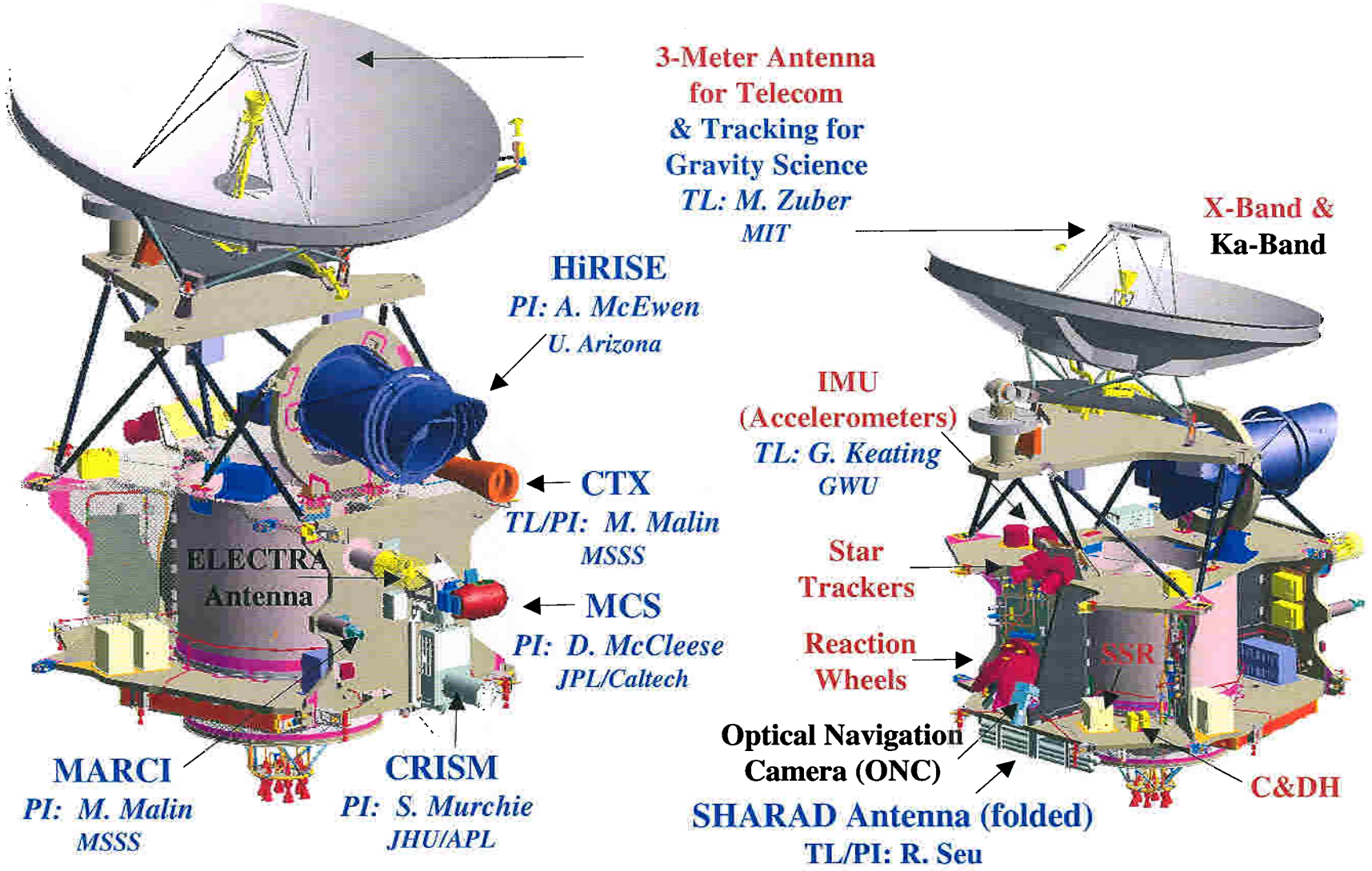
GN&C:
- Redundant 100n-m-s RWA's
- Ephemeris-Based Targeting
- Cont/Auto Yaw Compensation
- < 1 mrad Pointing Accuracy

Propulsion
- Single-Tank Mono Prop Design
- Engine-Out Capability
- Coupled Thrust
- Regulated During MOI

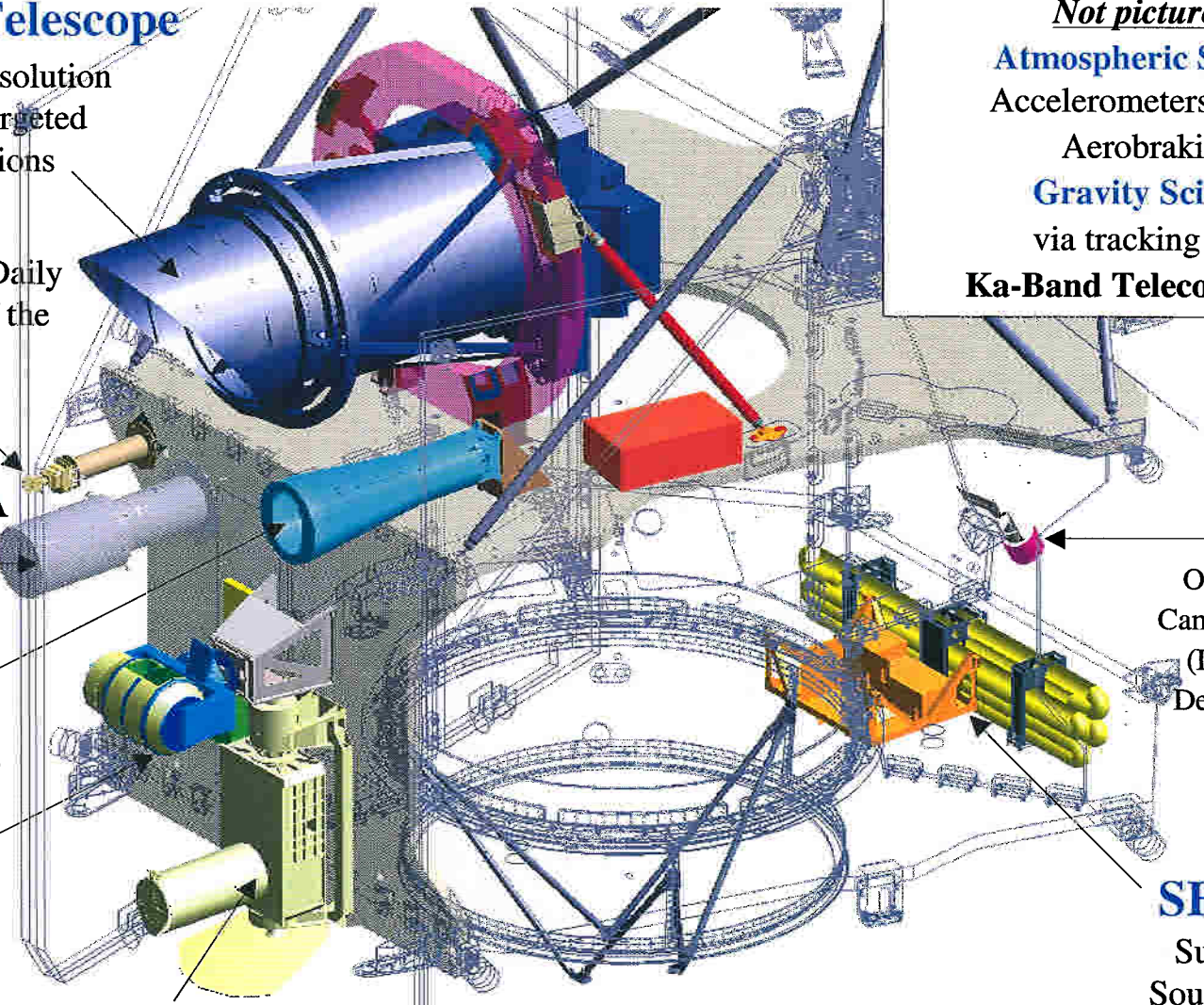
Payload:
- 6 Science Payloads
- 2 Eng Payload
- Electra Eng SS
- Simultaneous Operations
- Nested Targeting

FSW:
- Flexible / Parameterized Design
- Fully Enabled Fault Protection
- Ephemeris-Based Targeting
- Time-Tagged Seq Fully Supported

Orbiter Payload Accommodation



Science and Engineering Payloads



HiRISE Telescope
Very high resolution Imager - targeted observations

MARCI
Color Imager - Daily global views of the atmosphere

ELECTRA Antenna
UHF Relay

CTX
Context Imager

MCS
Atmospheric Sounder

CRISM
High-resolution Imaging Spectrometer

Not pictured:
Atmospheric Science
Accelerometers during Aerobraking
Gravity Science
via tracking data
Ka-Band Telecom Demo

ONC
Optical Navigation Camera Demonstration (Images Phobos & Deimos during Mars approach)

SHARAD
Sub-surface Sounding Radar

MRO Science Investigations (1 of 2)

Instrument	Type	PI/TL, Institution	Science Goals	Attributes
CRISM	Compact Reconnaissance Imaging Spectrometer for Mars	*Scott Murchie, PI* **Johns Hopkins University Applied Physics Lab** ***Selected thru MRO -2005 AO***	Regional & Local Surface Composition; Atmospheric Properties	**High Spectral & Spatial Resolution** Targeted & Regional Survey **Very High Data Rate**
CTX	Context Imager	*Michael Malin, TL* **Malin Space Science Systems (MSSS)** ***Facility Instrument*** ***Replaces MCO MARCI-MAC***	Regional Stratigraphy and Morphology	**High Resolution with Coverage** Targeted & Regional Survey **High Data Rate**
HiRISE	High-Resolution Imaging Science Experiment	*Alfred McEwen, PI* **University of Arizona** ***Selected thru MRO-2005 AO***	Stratigraphy, Processes, Site Morphology	**Very High Resolution** Targeted Imaging **Very High Data Rate**
SHARAD	Shallow Subsurface RADAR	*Roberto Seu, TL/PI* **University of Rome** *Roger Phillips, DTL* ***NASA-ASI Selection***	Regional Near-Surface Ground Structure	**Shallow Radar Sounding** Regional Profiling **High Data Rate**

MRO Science Investigations (2 of 2)

Instrument	Type	PI/TL Institution	Science Goals	Attributes
MARCI	Mars Color Imager	Michael Malin, PI Malin Space Science Systems Recover MCO MARCI-WAC	Global Weather and Surface Change	**Daily Global Coverage** Daily,Global Mapping **Moderate Data Rate**
MCS	Mars Climate Sounder	Daniel J. McCleese, PI Jet Propulsion Laboratory California Institute of Technology Recover MCO PMIRR Science	Atmospheric Fields, Transport & Polar Processes	**Global Atmospheric Limb Sounding** Daily,Global Limb & On-Planet Mapping; **Low-Data Rate**
Gravity Science	Facility Science Team Investigation	Maria Zuber, TL MIT / GSFC Selected thru MRO-2005 AO	Improved Gravity Field Model; transient Mass Change	**Data from DSN tracking using Spacecraft X & Ka Band Telecom**
Atmospheric Structure (ACCEL)	Facility Science Team Investigation	Gerald Keating, TL GWU / LaRC Selected thru MRO-2005 AO	Upper Atmospheric Structure & Variability; A/B Support	**Data from Spacecraft Accelerometers during Aerobraking**
Future	Participating Scientists & Guest Observers may be selected and funded as part of a future Announcement of Opportunity or Research Announcement			

MRO Science Instrument Requirements (1 of 2)

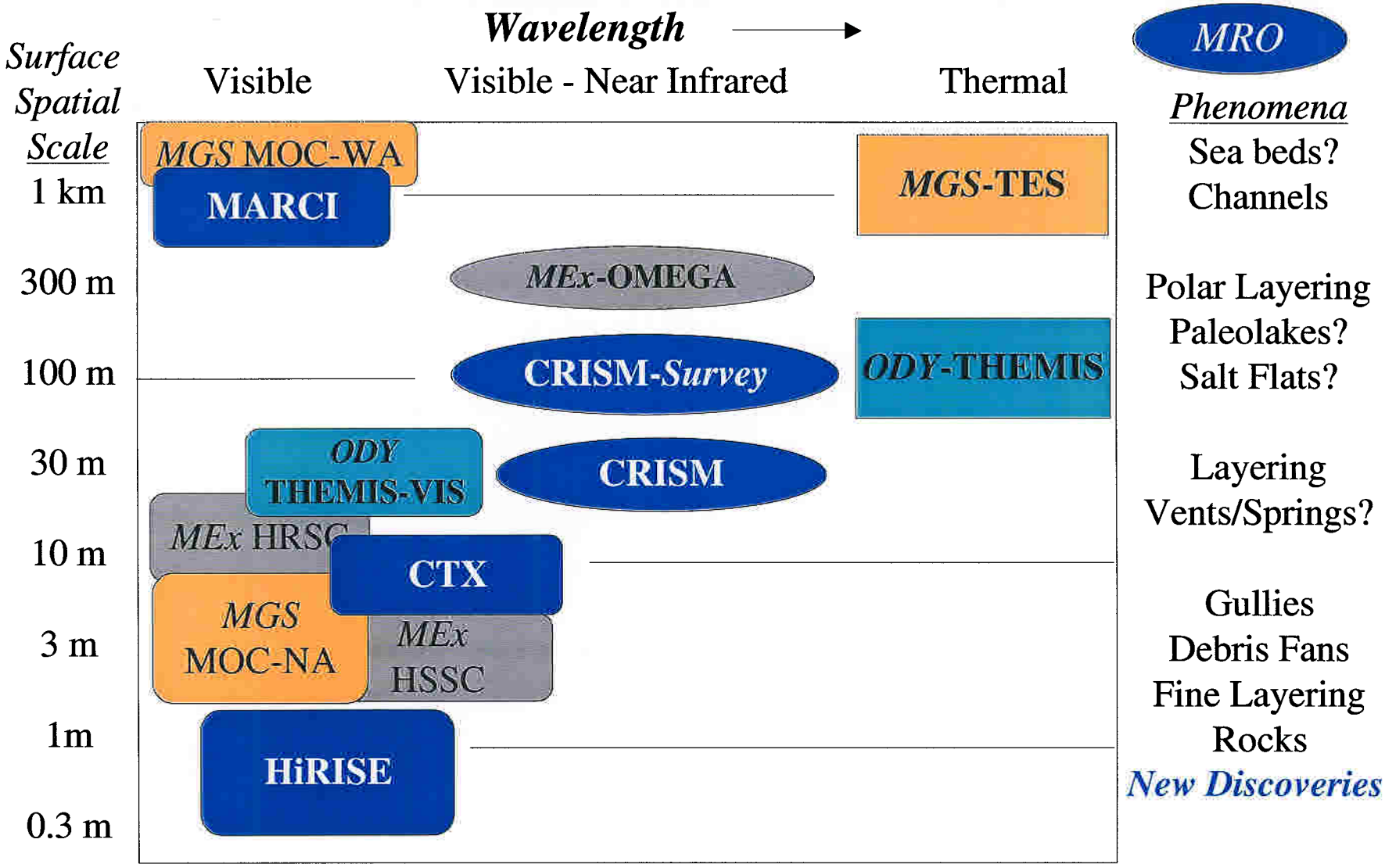
Instrument	Attributes	L1 Requirements	Baseline Capabilities
CRISM	Highest Ground Resoln.*	< 40 m/pixel	GSD = 18 m/pixel
	Swath Width*	> 7 km	10.8 km
	Spectral Resolution Spectral Range	≤ 10 nm 0.4 - 3.6 μm	6.55 nm 0.4 - 4.05 μm
CTX	Highest Ground Resoln.*	≤ 10 m/pixel	GSD = 6 m/pixel
	Swath Width*	≥ 20 km	30 km
	Spectral Bands	Single Bandpass	500 - 700 nm
	SNR	≥ 20	> 20
HiRISE	Highest Ground Resolution*	Resolve 1-meter scale objects & structure	GSD =0.3 m/pixel
	Swath Width*	≥ 3.5 km	6 km
	Spectral Bands	Single Bandpass	Red (6 km swath*) Blue-Green & NIR (1.2 km swath*)
	SNR	≥ 50	≥ 100
	Stereo Capability	By Revisit	Revisit (typically within 17 days)

***Referenced to 300 km orbital altitude**

MRO Science Instrument Requirements (2 of 2)

Instrument	Attributes	L1 Requirements	Baseline Capabilities
MARCI	Re-flight of MCO MARCI Wide-Angle Camera	Re-build MARCI WAC (140° FOV)	New Electrical Interface & 180° FOV
	Spectral Bands	2 UV, 5 VIS/NIR	7 bands from 0.28-0.8 μm
	Observation Mode	Daily Global Mapping	Daily Global Mapping
MCS	Recover MCO PMIRR Science	Solar Channel & 8 Thermal IR Channels	Broadband Solar Channel & 8 Thermal IR Channels
	Vertical Range, Resoln.	0 - 80 km; $\leq$ 6 km	0 - 80 km; 5 km
	Observation Mode	Globally Distributed, Daily Atmospheric Limb & On-Planet Observations	Globally Distributed, Daily Atmospheric Limb & On-Planet Observations
SHARAD	Vertical Penetration & Resolution	Several hundred meters at many locations 15 m (free-space)	Several hundred meters at many locations 15 m (free-space)
	Horizontal Footprint (from 300 km)	< 7 km x 1 km (cross-track x down-track)	6 km x 1 km (SAR processing down-track)
	Operating Frequency	f_o > 10 MHz	20 MHz(f_o, central frequency)

Relation to Other Mars Missions for Imaging



Science/Engineering Payload Description

Name	Type	Provider	Ground Sampling Distance @ 300 km	Swath @ 300 km	Other	Mass (kg) CBE	Orbital Average Power (W) CBE
HiRISE	Optical Targeted	UA/BA	30 cm/pixel	6 km	3 colors	60	59
CRISM	Optical Targeted	APL	20 m/pixel	11 km	0.4 - 4.0 μm	31	38
Context Imager	Optical Regional	Facility MSSS	6 m/pixel	30 km	Panchromatic Minus Blue	4	6
Sounding Radar (SHARAD)	Radar Regional	Facility ASI	< 1x6 km (w) < 7 m (v)	6 km (w) 1 km (v)	20 MHz Center 10 MHz Bandwidth	13	23
MARCI	Optical Global	MSSS	1 to10 km/pixel	limb-to-limb	0.25 - 0.75 μm, 180° optics	1	6
MCS	Atmo-spheric Global	JPL	~ 5 km vertical	0-80 km (v) @limb	12 - 50 μm 0.3 - 3.0 μm	10	8
OpNav	Optical Nav	JPL MT	24 μrad/pixel Phobos/Deimos	--	0.45 - 0.6 μm	3	0
Electra	Radio	JPL MT/MRO	--	--	UHF	15	80 (p)
Ka Band Demo	Radio	JPL TMOD/MRO			Ka Hardware	9	79 (p)
Total						146	140
Science Payload					peak power = (p)		
Engineering Payload							

Accommodating Science Drivers

✓ Mixed Observation Modes during Science Phase:

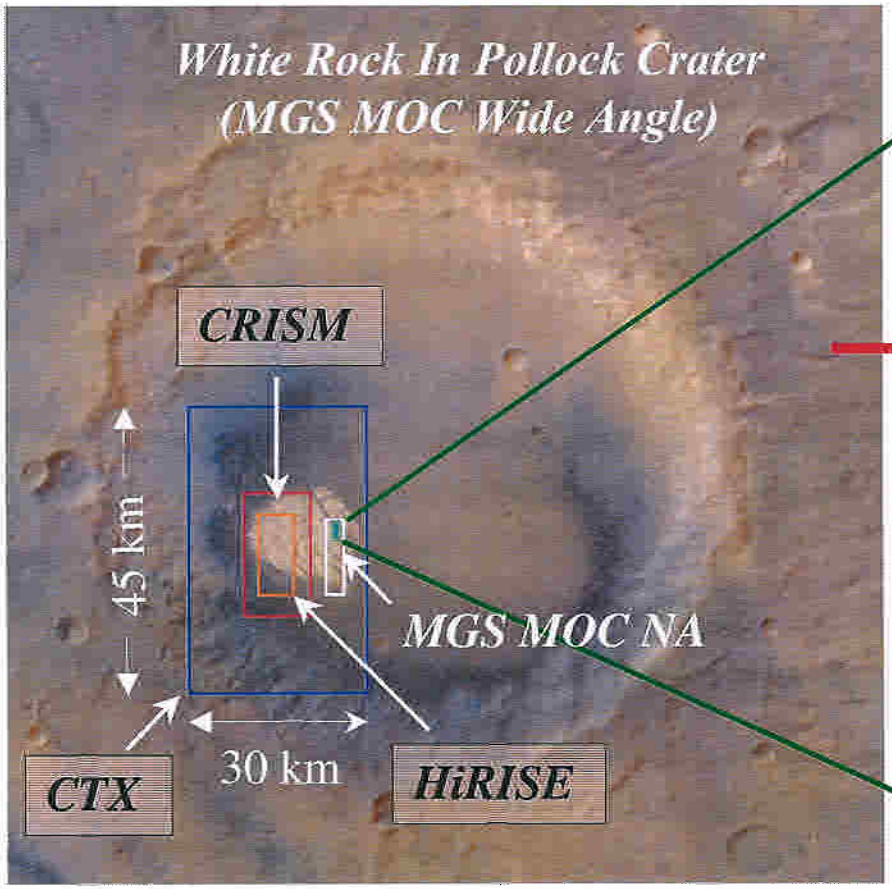
- **Global Monitoring throughout one Mars year (all seasons)**
  - **Daily and Seasonally: MARCI, MCS**
  - **Seasonally: CRISM (Atmospheric Mode), Tracking (Gravity)**
- **Regional Surveys of Martian Surface and Subsurface**
  - **SHARAD, CTX, Tracking (Gravity)**
  - **Low Resolution Modes: CRISM, HiRISE**
- **Targeted high spatial resolution observations**
  - **HiRISE, CRISM**
  - **Supported by CTX**
- **Simultaneous Operations by Multiple Instruments**

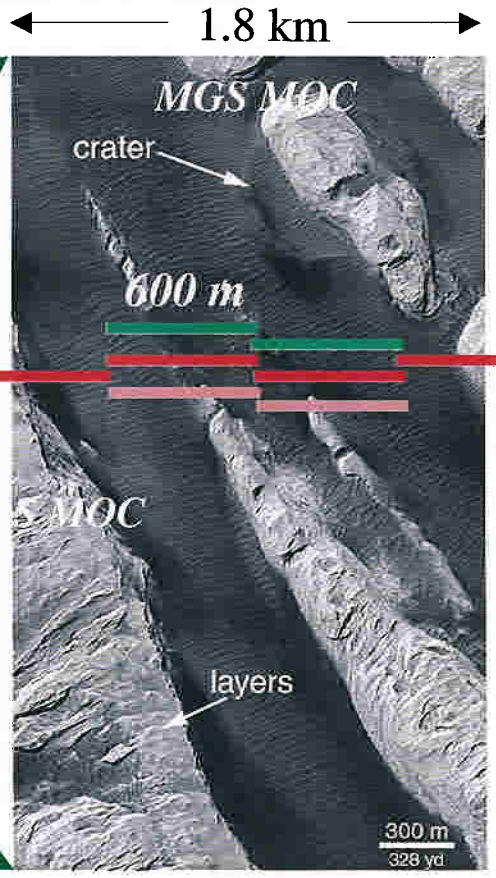
✓ Spatial resolutions unprecedented for Mars missions

- **Enabled by instrument capabilities and mission design (orbit)**
- **Spacecraft capabilities adequate to return required data volumes**
  - **Project Requirement ~ 34 Tbits**
- **Data return capability determines areal coverage and number of sites observed at the highest spatial resolutions**

✓ Coordinated observing for science & site characterization

MRO Coordinated Observations





(1 of 10 HiRISE red CCDs arrayed crosstrack; 4 not shown)

Nested Coverage Provides Context

High Resolution Provides Detail

IMAGES from NASA/JPL/MSSS

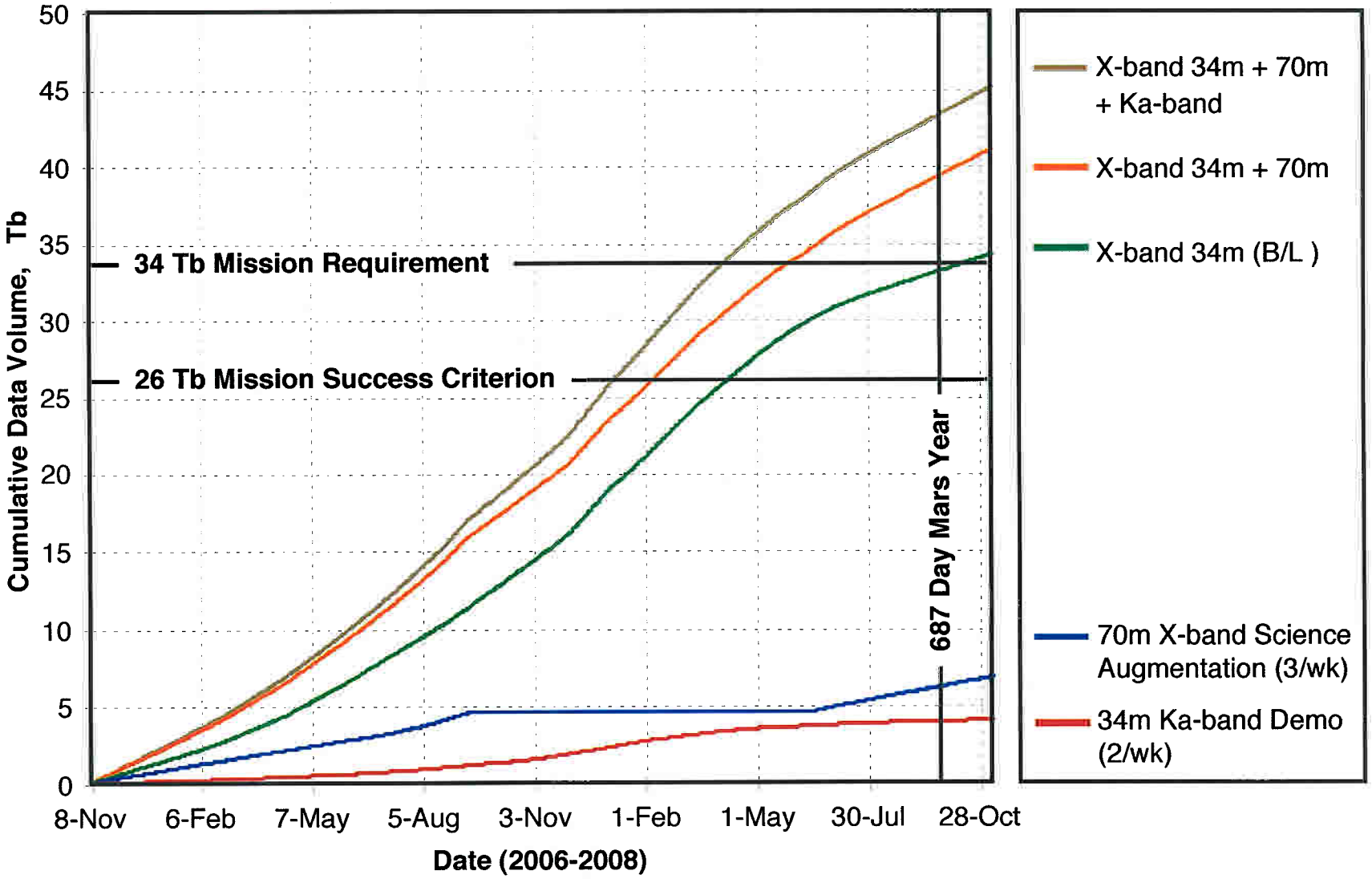
MRO Data Return Goals

- *Committed Data Volume Return of 26 Tbits allocated as follows:*
  - **Daily Global Mapping (MCS, MARCI) 7%**
  - **SHARAD Regional Survey 15%**
  - **CTX Imaging Support and Survey 13%**
  - **CRISM 30%**
  - **HiRISE 35%***

  **HiRISE data compressed using hardware compressor on SSR*

- *Enables significant areal coverage at lower spatial/spectral resolution. Current goals for 1 Mars year:*
  - **CTX 20%**
  - **CRISM (survey) 100%**
  - **HiRISE 1%**

Cumulative Mission Data Volume



Mars Climate Objectives

Dust Storms;

Atmospheric Transport:

MCS, MARCI, CRISM

Seasonal Cycles;

Water Sources & Sinks:

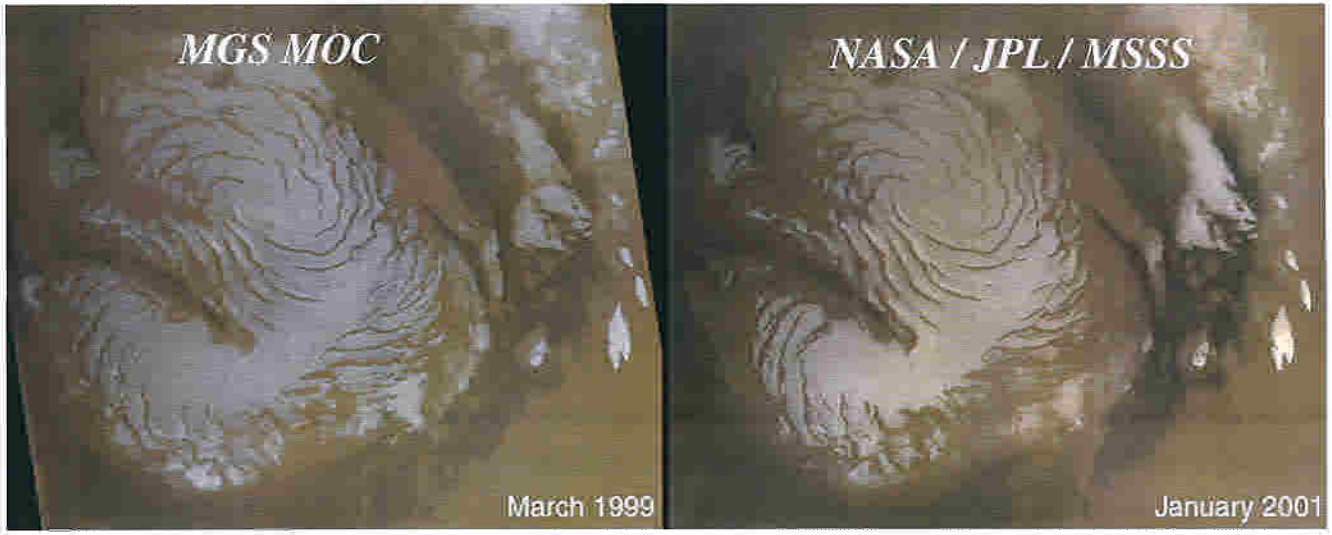
MCS, MARCI, CRISM

Polar Layering;

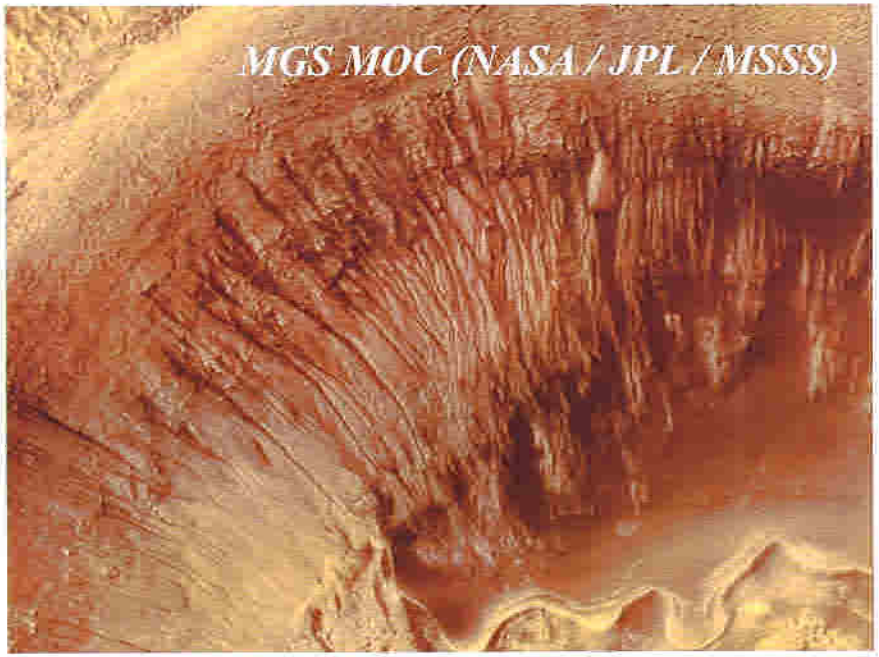
Structure & Seasonal Changes:

CTX, HiRISE, MARCI

Polar Monitoring:
Radiation Balance
& Morphology
MCS,
CTX, MARCI



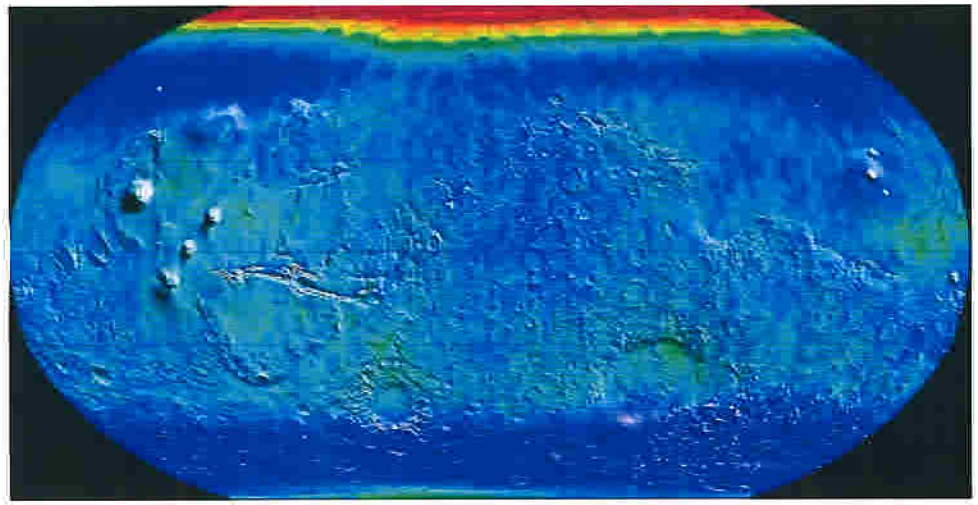
"Follow the Water" thru Different Data Types



Visual Imaging Reveals
Geomorphology:
Structure & Age
HiRISE, CTX
MARCI

Spectral Imaging Reveals
Composition & History
CRISM
MARCI, HiRISE

Probing the Subsurface

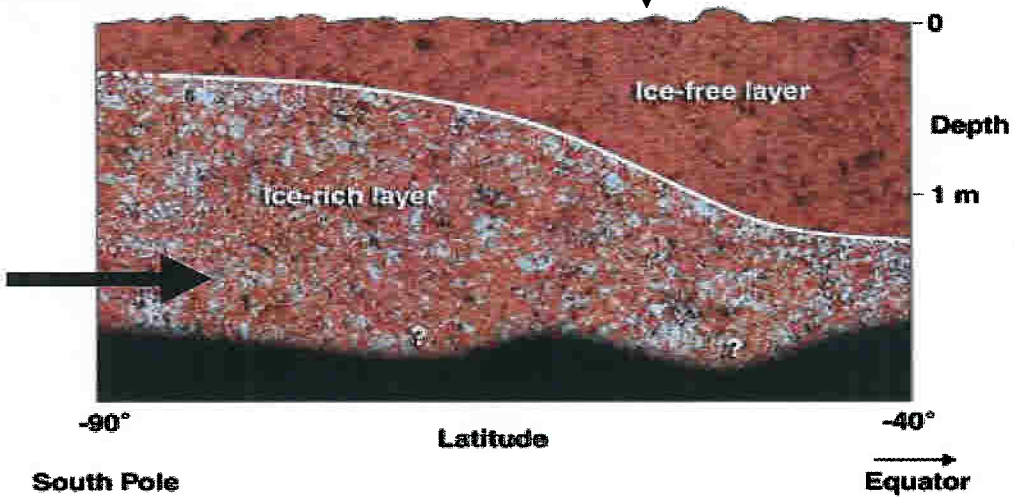


Hydrogen (Ice) Map
2001 Mars Odyssey
GRS-Neutron
Spectrometer
& HEND

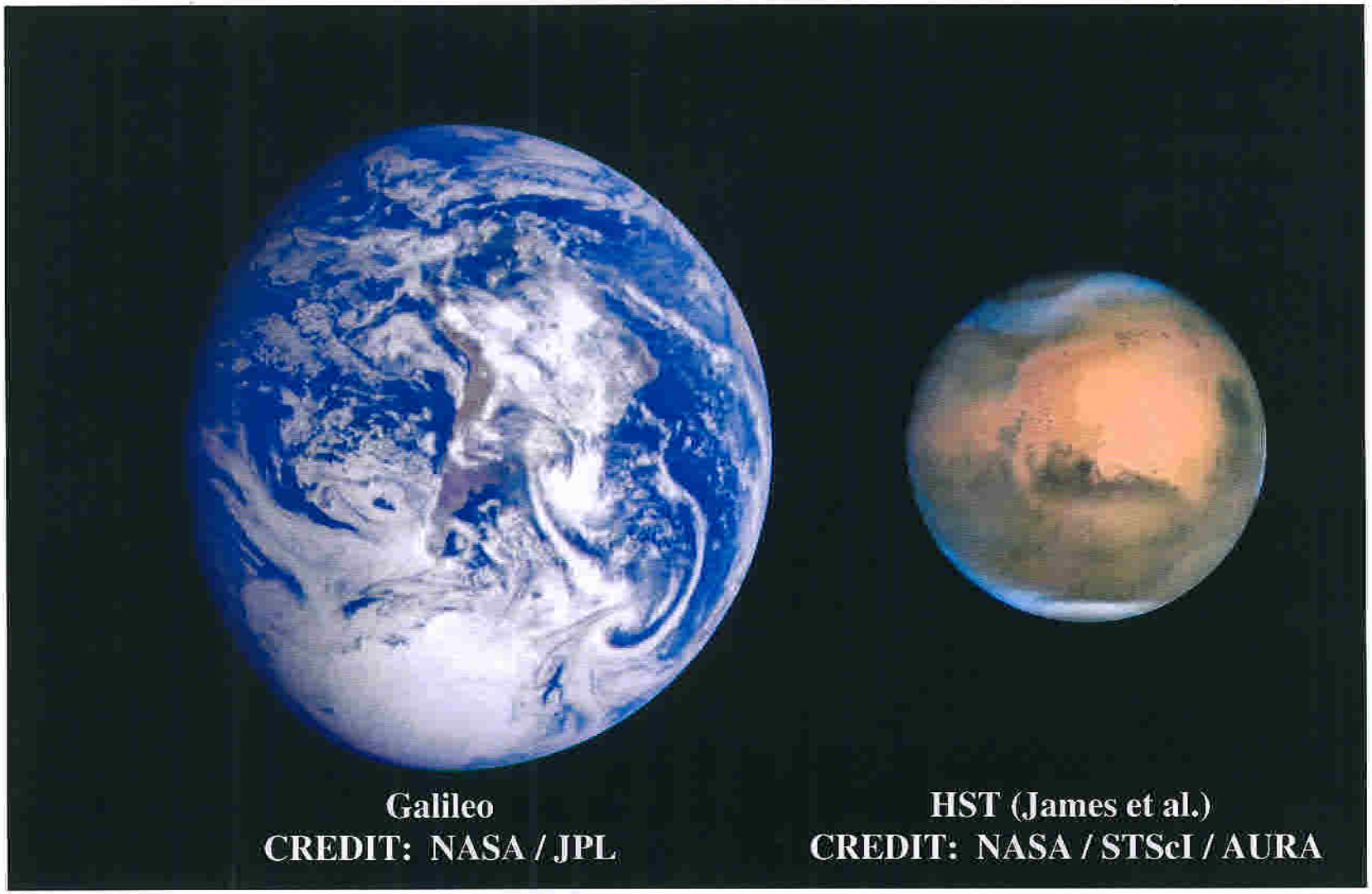
NASA / JPL / University of Arizona
Los Alamos National Laboratory

How Deep is this Layer?
Is it in Equilibrium with
Today's Climate?
Is it the Top of the Ancient
Water Reservoir?

SHARAD



Earth & Mars


Galileo
CREDIT: NASA / JPL
HST (James et al.)
CREDIT: NASA / STScI / AURA

Mars Reconnaissance Orbiter (MRO)

Salient Features

- 4 Earth years in Mars orbit (near polar, 3 p.m., 255 x 320 km)
  - 2 years science observations plus relay support
  - 2 years relay mode with capability to extend science operations
- International Science Payload:
  - Meter- scale and context (6 m/pixel) imaging
  - Hyperspectral (20 m, 10 nm) compositional mapping
  - Atmospheric profiling and weather monitoring
  - Radar probing of the near-subsurface; gravity science
- Relay Telecom Payload + Optical Navigation & Ka-Band Experiments
- Launch: August 2005; Arrive: March '06; Aerobrake: Mar.- Oct '06; Mission End: Dec., 2010

Science

- Characterize Mars' seasonal cycles and daily variations of water, dust & carbon dioxide.
- Characterize Mars' global atmospheric structure, transport and surface changes.
- Search sites for evidence of aqueous and/or hydrothermal activity.
- Characterize in detail the stratigraphy, geology & composition of Mars surface features.
- Characterize the Martian ice caps and the polar layered terrains.
- Profile the upper crust while probing for subsurface water and ground ice.
- Characterize the Martian gravity field and upper atmosphere in greater detail.
- Identify and characterize many sites for future landed missions.