Mars Advanced Radar for Subsurface and Ionospheric Sounding (MARSIS)

MARSIS subsurface sounding mode characteristics				
Centre frequency (MHz)	1.8	3.0	4.0	5.0
Bandwidth (MHz)	1.0	1.0	1.0	1.0
Radiated power (W)	1.5	5.0	5.0	5.0
Transmit pulse width (μS)	250 or 30			
Pulse repetition rate (s^{-1})	130			
Minimum science data rate (kbps)	18			
Maximum science data rate (kbps)	75			

MARSIS ionosphere sounding mode characteristics	
Start frequency (kHz)	100
End frequency (MHz)	5.4
Number of frequencies	160
Transmit pulse length (μS)	91.43
Frequency step (kHz)	10.937
Pulse repetition rate (s^{-1})	130
Sweep duration (s)	7.38

Mars Advanced Radar for Subsurface and Ionospheric Sounding (MARSIS)

"The primary objective is to map the distribution of liquid and solid water in the upper portions of the crust of Mars." [*Picardi et al.*, 2004]

Table 1. Dielectric properties of the subsurface material.

	Crust Material		*Pore-Filling Material*	
	Andesite	*Basalt*	*Water Ice*	*Liquid Water*
ε_r	3.5	7.1	3.15	88
$\tan\delta$	0.005	0.014	0.00022	0.0001

Recall: Interaction of light with materials

relative electric permittivity $\varepsilon_r = \varepsilon/\varepsilon_0$

a.k.a. ***dielectric constant***

Absorptive materials have a *complex* dielectric constant

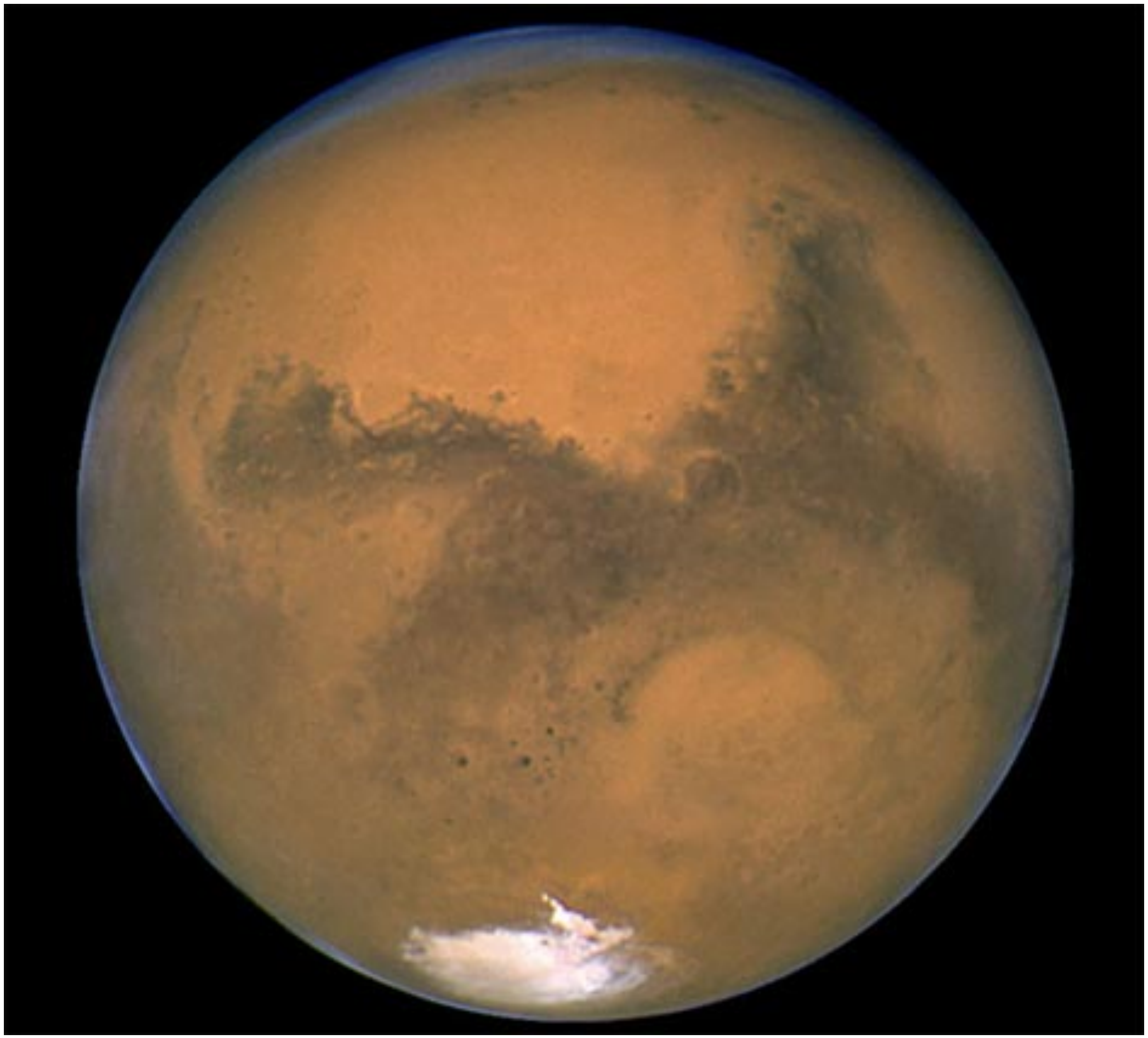
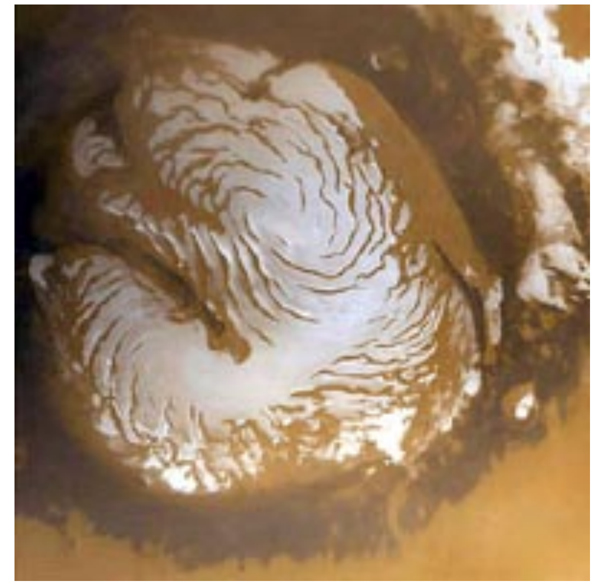
$$\varepsilon_r = \varepsilon' - i\varepsilon''$$

$$= \varepsilon'(1 - i\tan\theta)$$ for ***loss tangent*** $\tan\theta$

This, in turn, makes $n = \sqrt{(\varepsilon_r)}$ complex …

Martian polar caps

Mostly* H_2O, seasonal CO_2 cover


MARSIS view: north polar layered deposits

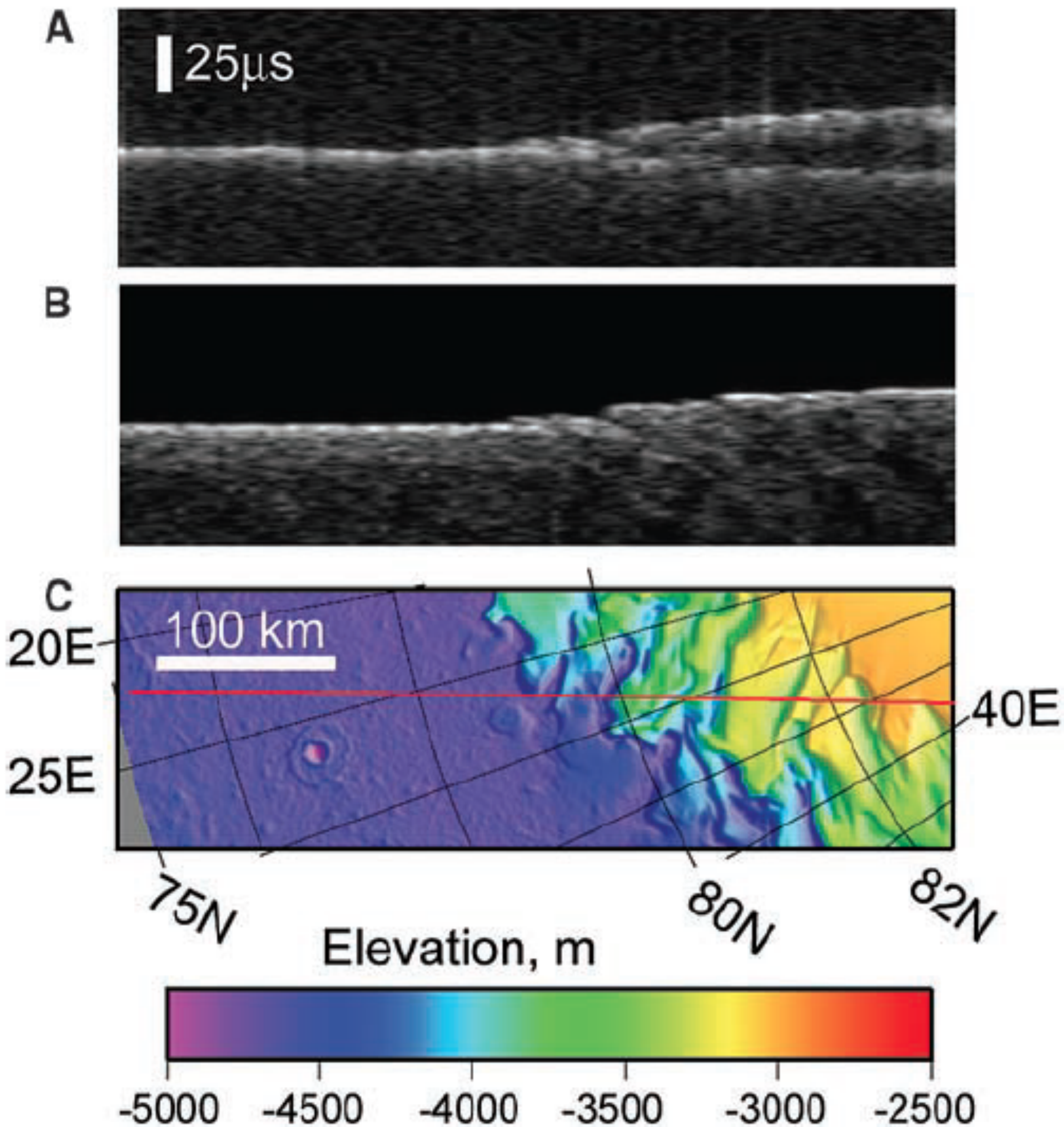


Fig. 1. (A) MARSIS data in radargram format for orbit 1855 as it crossed the margin of the NPLD. (B) Simulated MARSIS data if echoes are only from the surface (nadir and off-nadir clutter). (C) MOLA topography along the ground track (red line); elevation is relative to mean planetary radius. MARSIS data at 5 MHz show a split of the strong return into two as the ground track reaches the NPLD (higher terrain to the right). Maximum time delay to the second reflector is 21 µs, equivalent to 1.8-km depth in water ice.

Picardi et al. (2005)

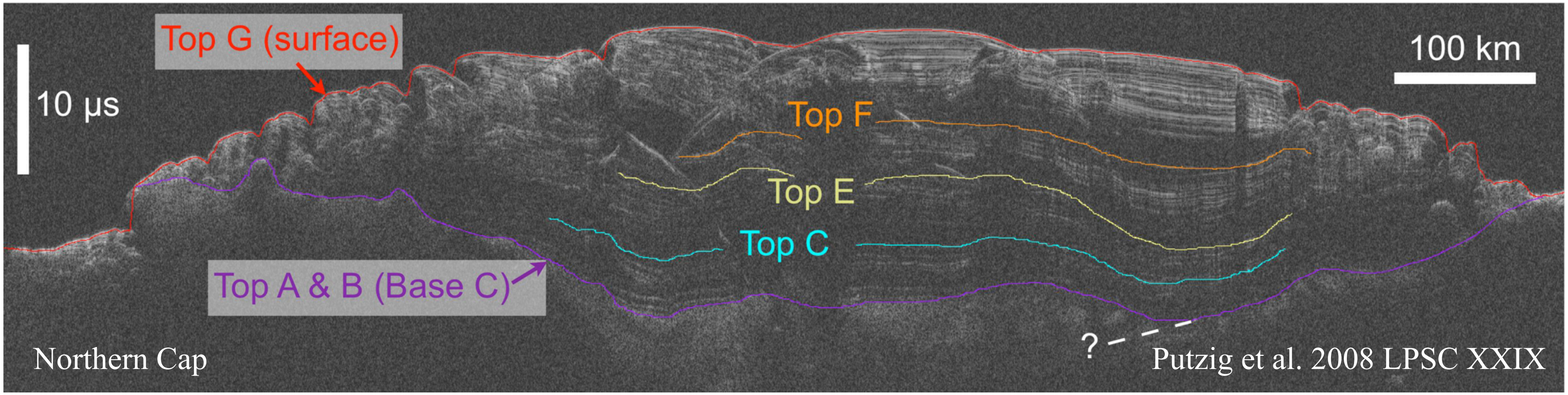
MRO's Shallow Radar (SHARAD)

Table 2. SHARAD and MARSIS Instrument Parameters

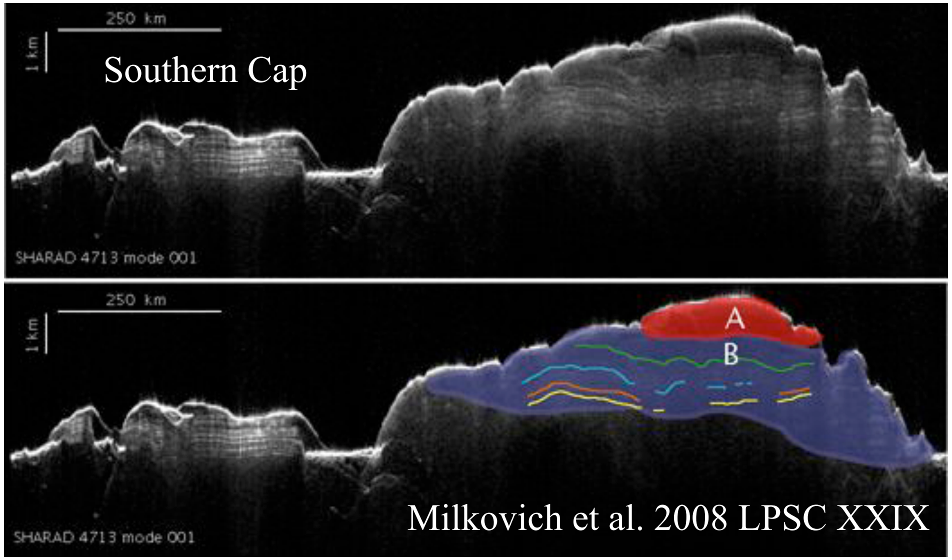
	SHARAD	MARSIS
Frequency band	15–25 MHz chirp	1.3–2.3 MHz, 2.5–3.5 MHz, 3.5–4.5 MHz, 4.5–5.5 MHz chirps
Vertical resolution, theoretical, reciprocal bandwidth, $\varepsilon_r = 4$	7.5 m	75 m
Transmitter power	10 W	10 W
Pulse length	85 μs	250 or 30 μs
PRF	700/350 Hz	127 Hz
Antenna	10-m tip-to-tip dipole	40-m tip-to-tip dipole
Postprocessor SNR (worst-best)	50–58[a] dB	30–50[b] dB
Horizontal resolution (along track × cross track)	0.3–1 km × 3–6 km	5–10 km × 10–30 km

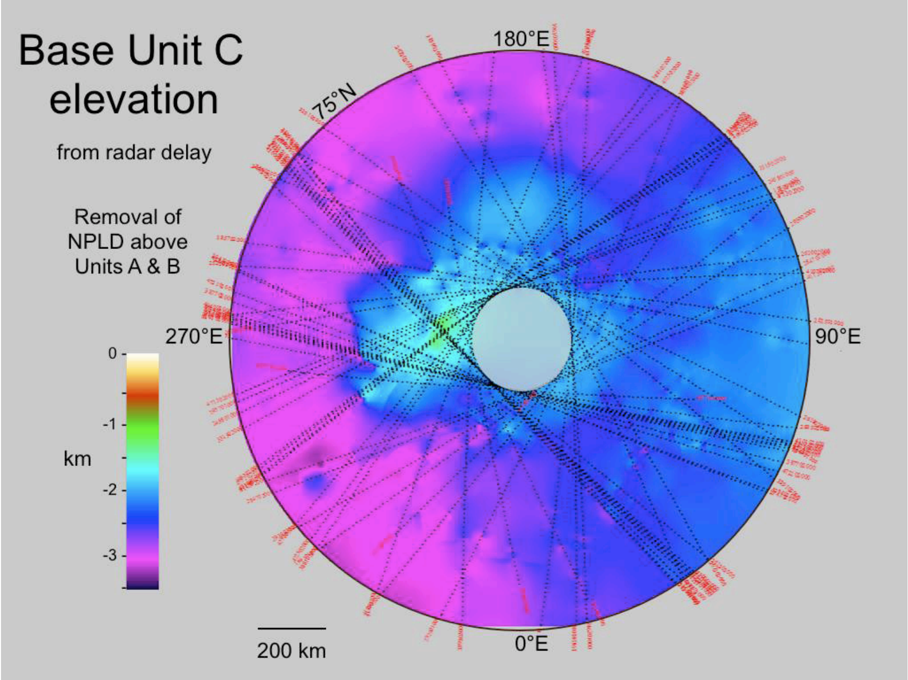
[a]Estimate.
[b]Actual.

Polar Caps: Radar & Interior Structure



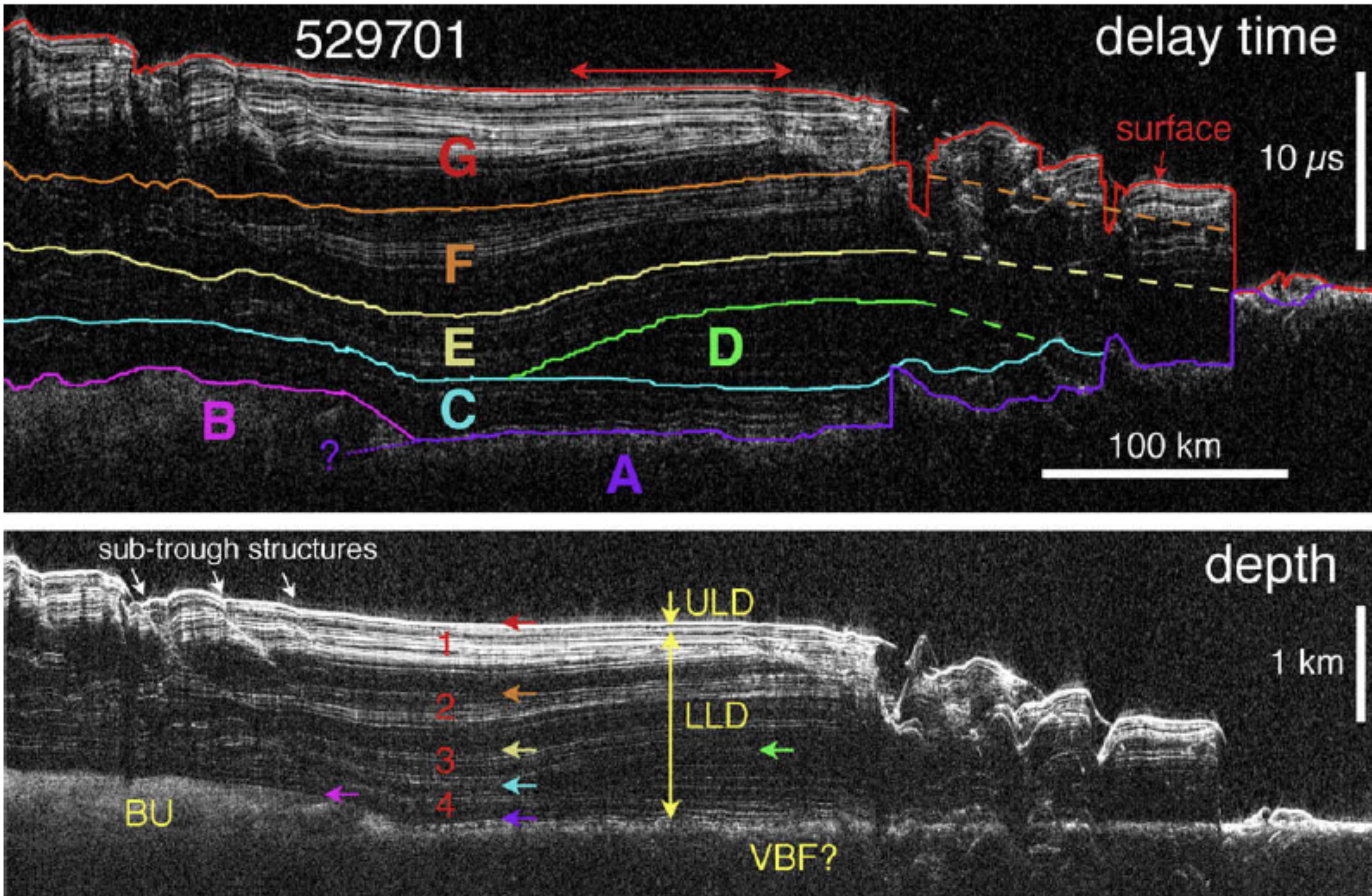
Data from MRO SHARAD.

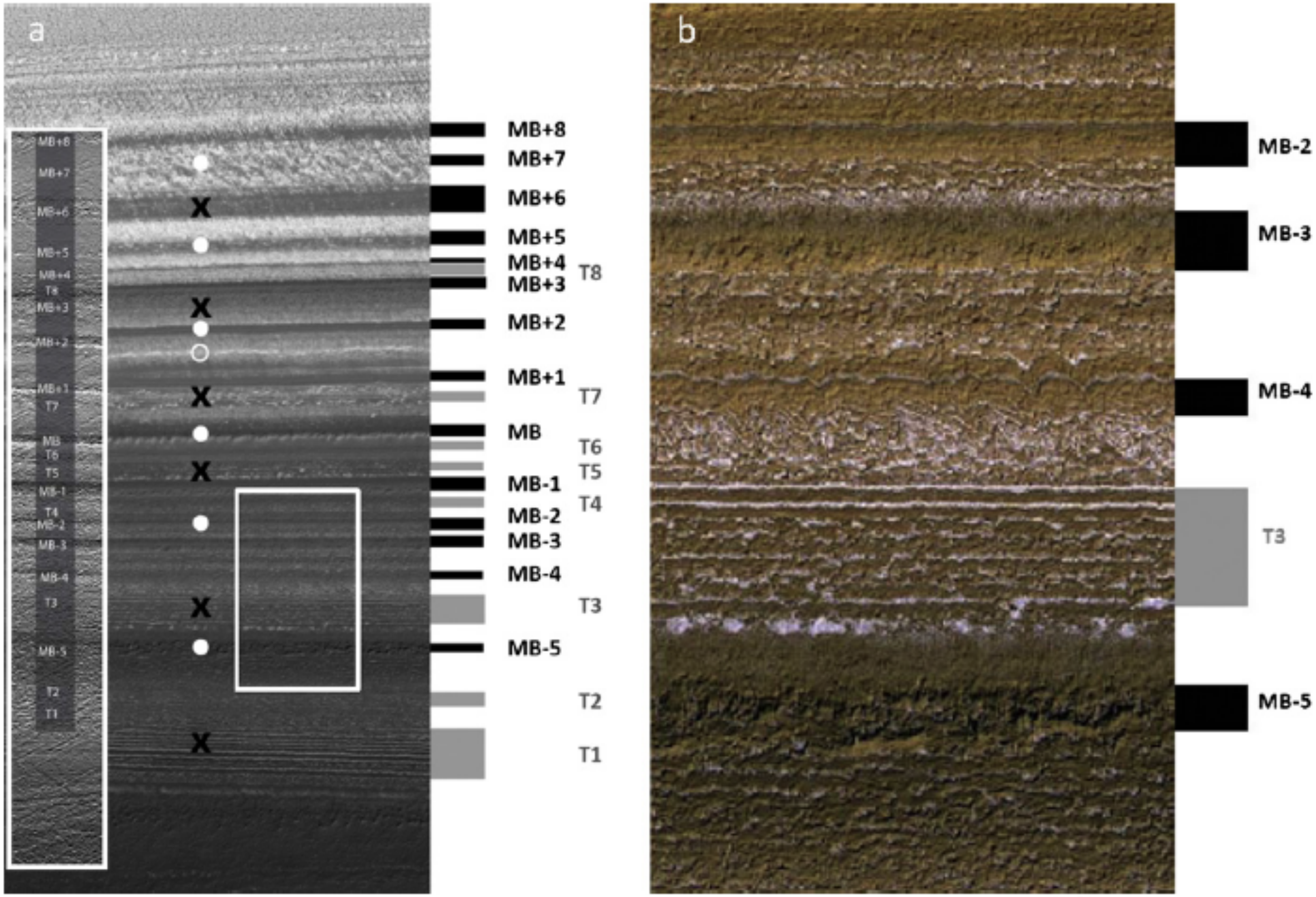




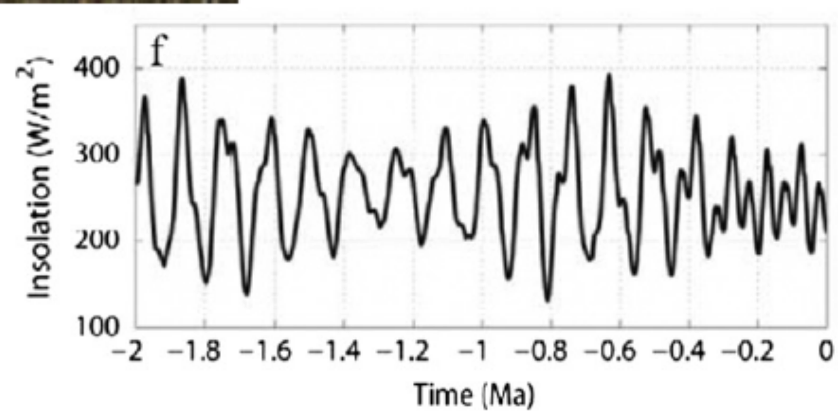
Mars: ground (ice)-penetrating radar

N.E. Putzig et al. / Icarus 204 (2009) 443–457





Hvidberg et al. (2012)



Can compare RADAR view to visible images, climate history models

Mapping mid-latitude ice

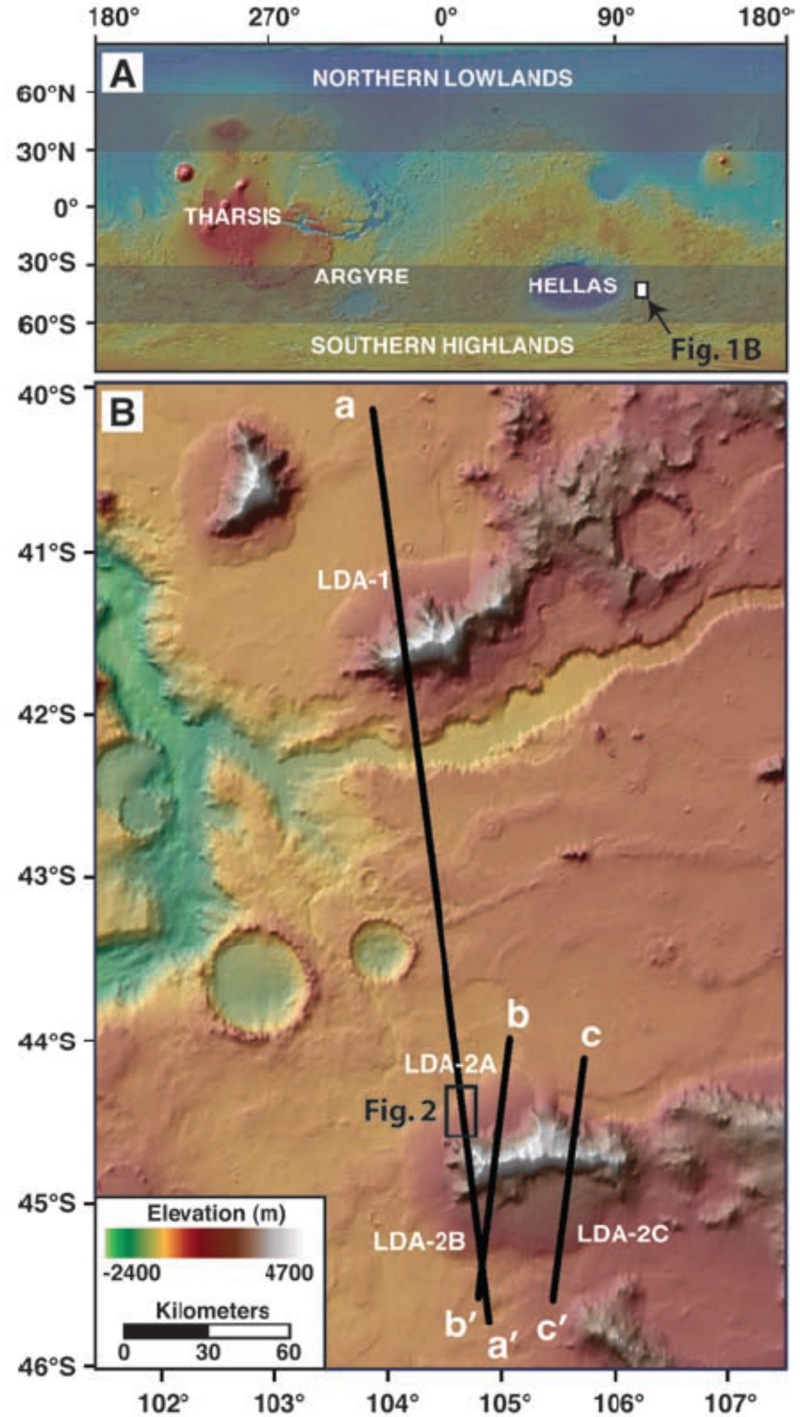
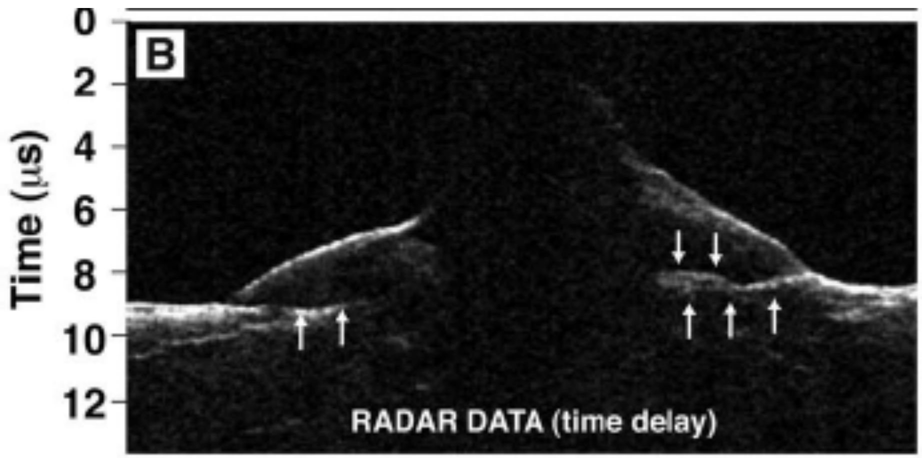
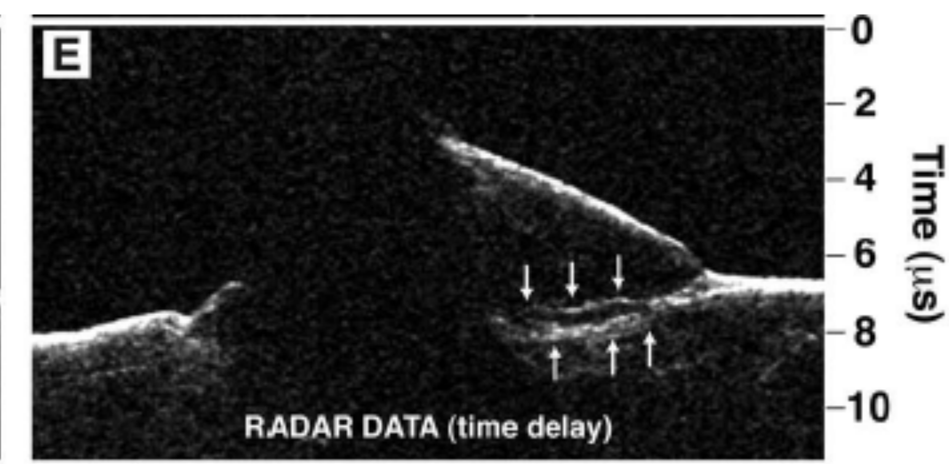


Fig. 1. (**A**) Topography of Mars (*24*). Major features are identified, and latitude bands exhibiting lobate debris aprons (LDAs) and lineated valley fill are highlighted (*1*, *2*). The location of our study area along the eastern rim of the Hellas impact basin is also denoted. (**B**) Topography of study area, with MRO/SHARAD ground tracks shown for orbits 6830 (a-a′), 7219 (b-b′), and 3672 (c-c′). LDAs crossed by these tracks are labeled.





Ground-based planetary radar facilities

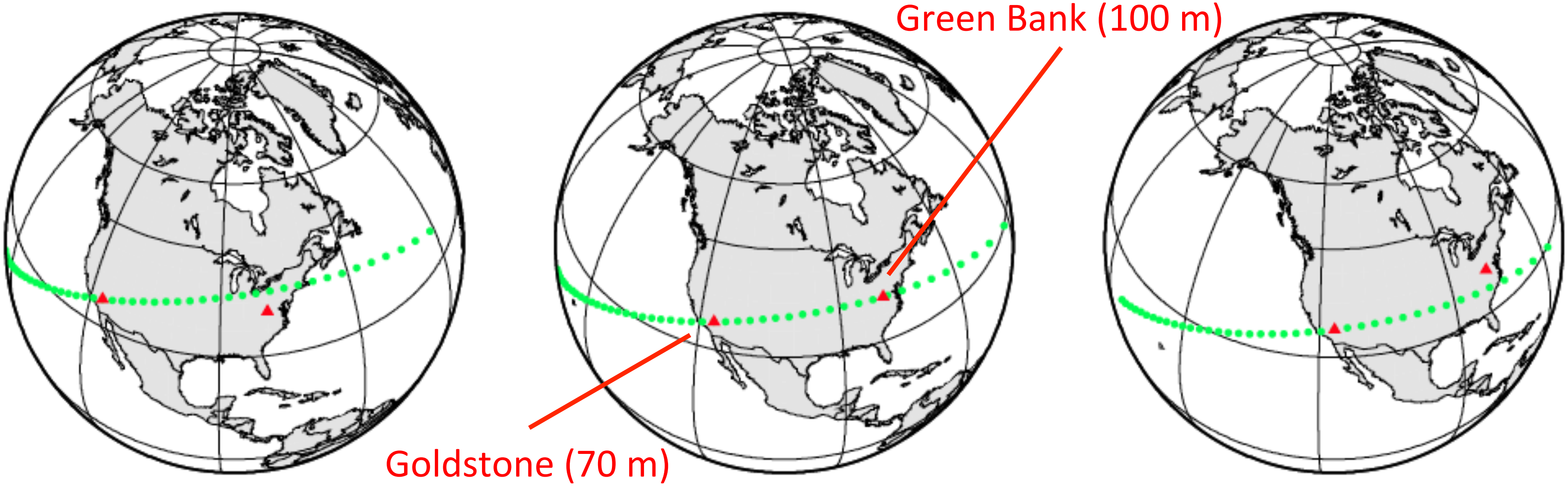
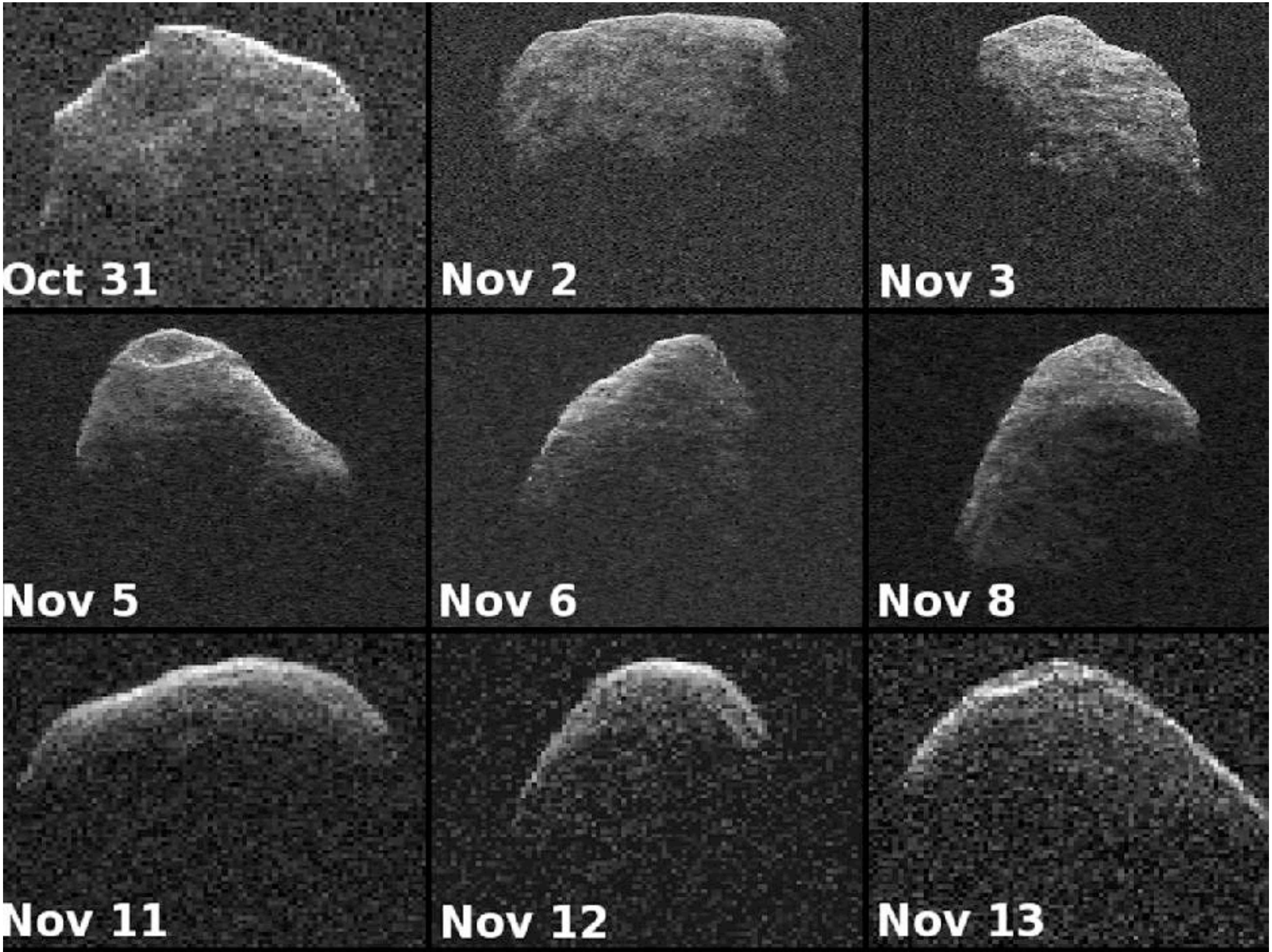


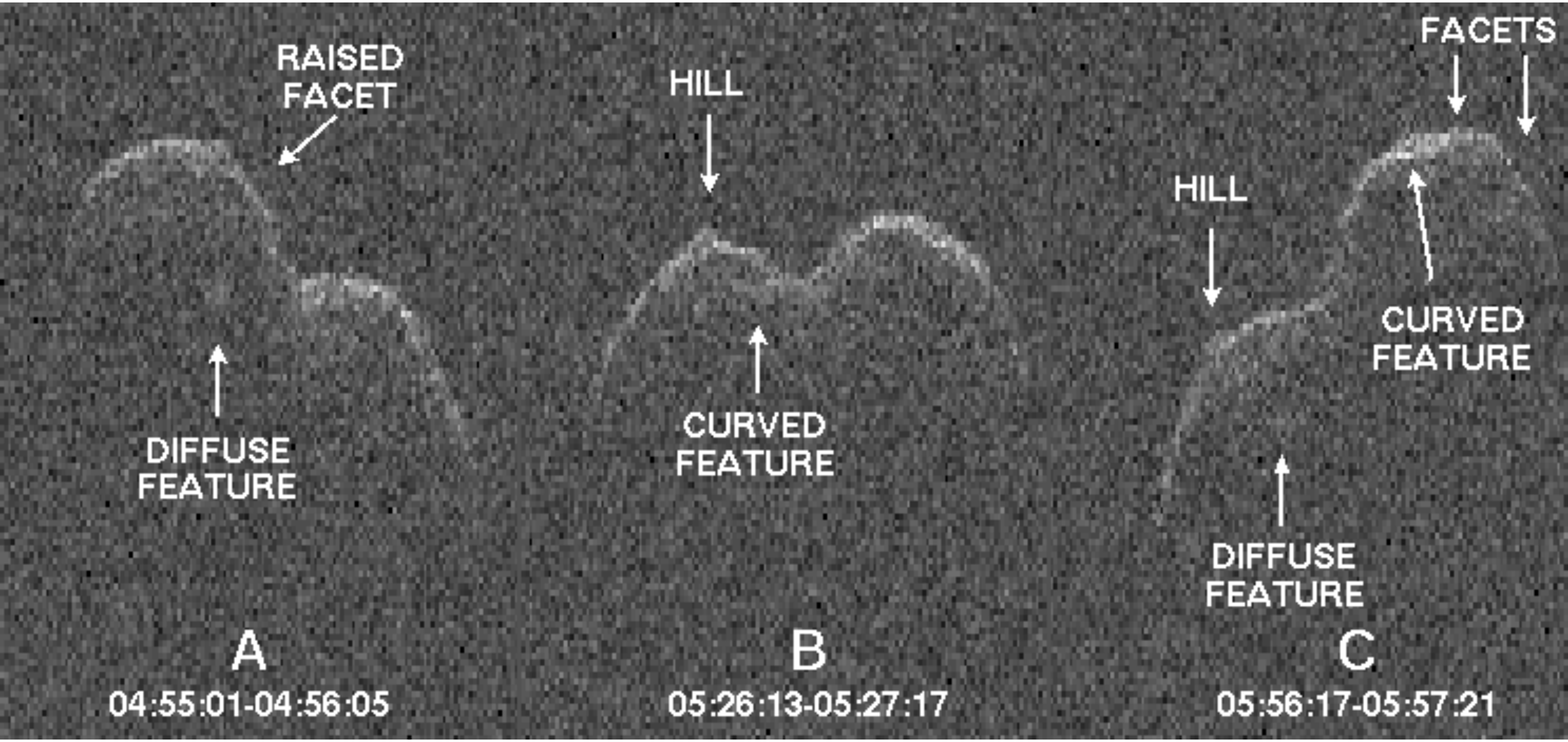
Figure 1. Radar echoes from Mercury sweep over the surface of the Earth during the 2002 May 23 observations. Diagrams show the trajectory of the speckles one hour (left) before, (middle) during, and (right) one hour after the epoch of maximum correlation. Echoes from two receive stations (red triangles) exhibit a strong correlation when the antennas are suitably aligned with the trajectory of the speckles (green dots shown with a 1 s time interval).

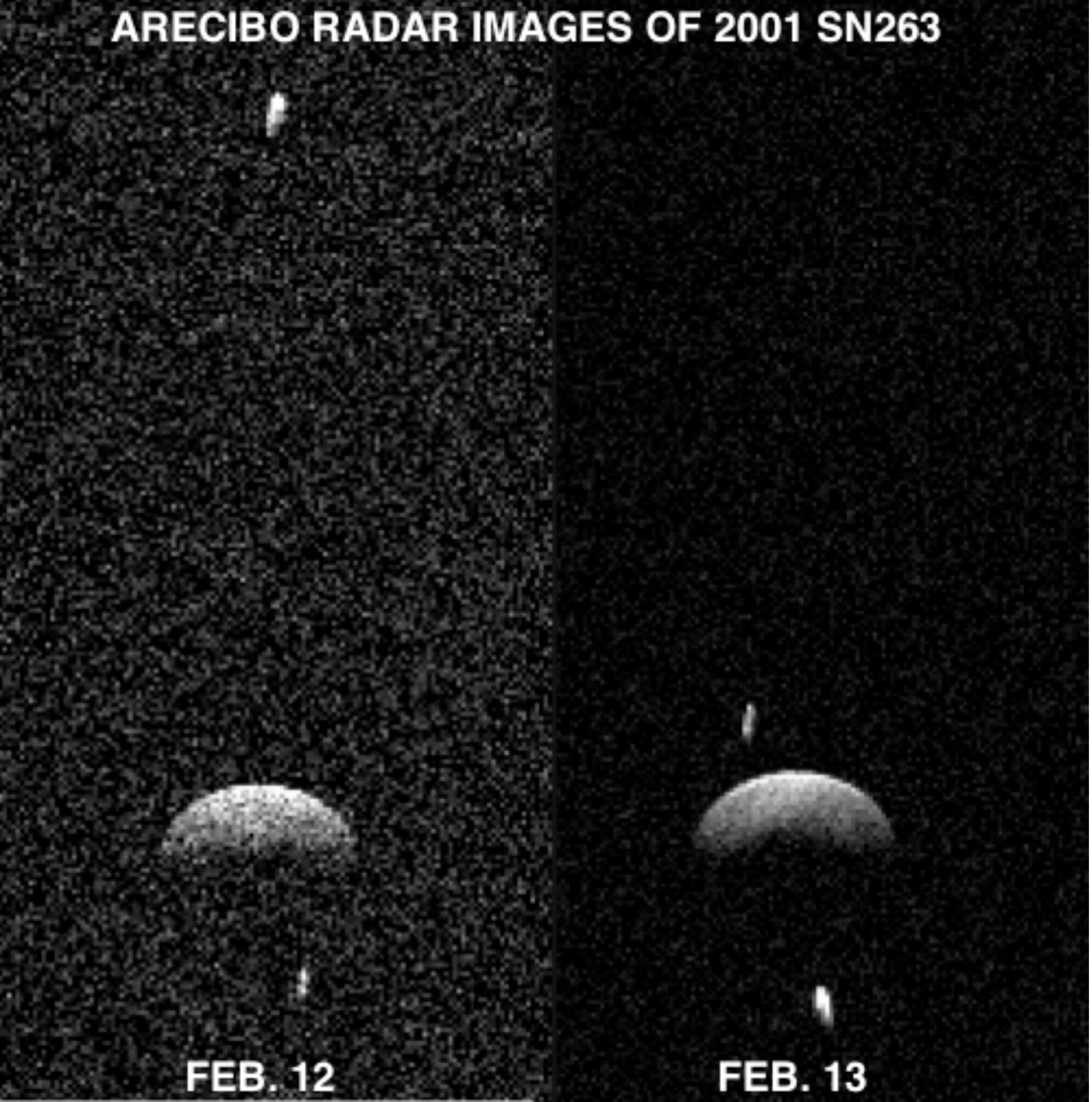
- Arecibo (305 m), Goldstone are the only two that transmit
- *Margot et al.* (2007) inferred Mercury has molten core

Radar Delay-Doppler Mapping of Asteroids



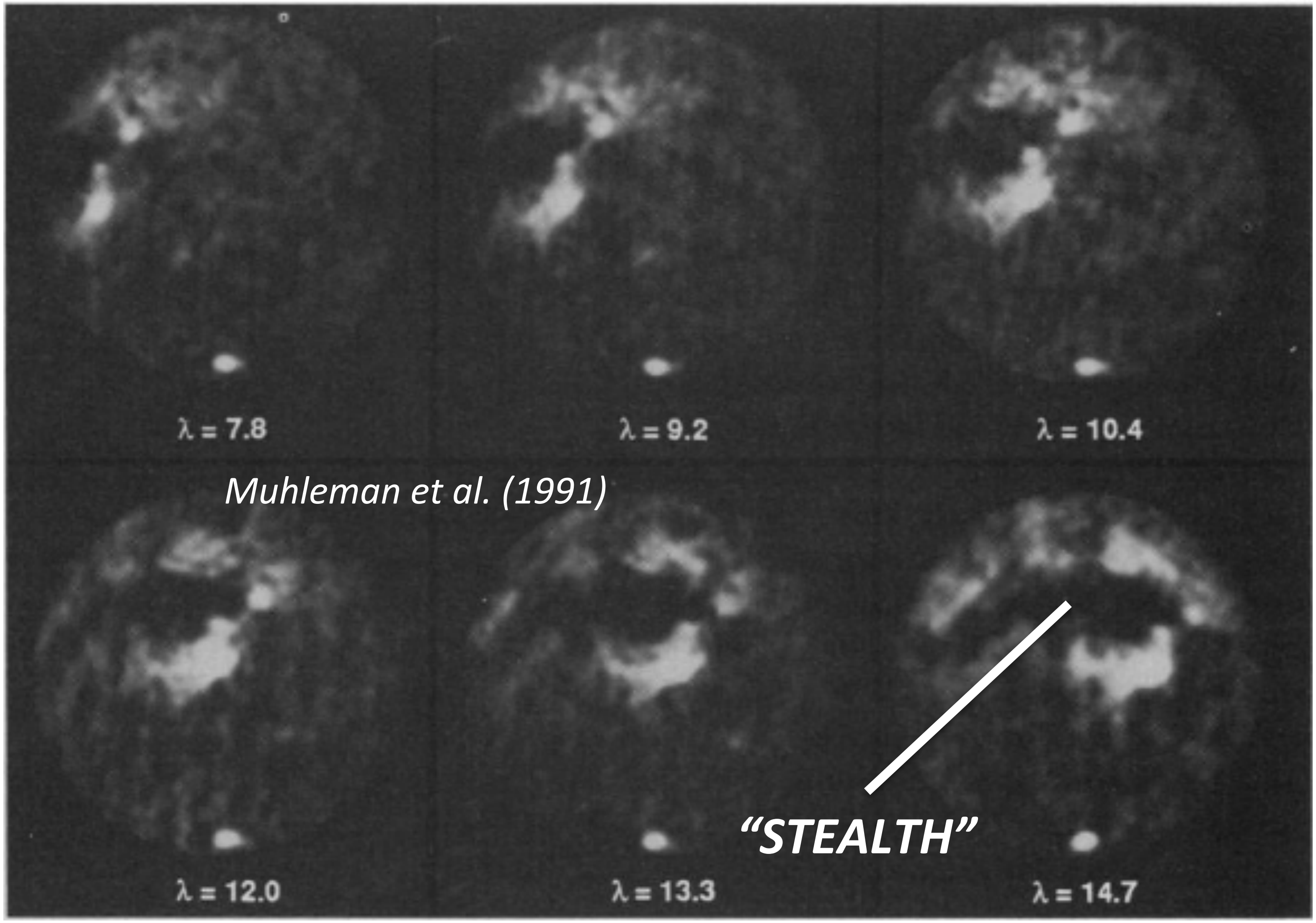
“Contact Binary” Asteroid 2005 CR37





Triple Asteroid!

Mars radar images (Goldstone→VLA), 3.5 cm



λ values are (erroneous) ***longitudes*** (should each be multiplied by 10)

Radar "stealth": very low density, meters thick

Table 1. Major depolarized features.

Name*	Brightness† (Jy per beam)	Longitude (degrees)	Latitude (degrees)	Extent (km)‡ (north-south by east-west)
RSPIC	1.83 ± 0.04	53.2	−87.4	80 by 90
South Tharsis	1.31 ± 0.05	121.9	−21.0	85 by 240
Pavonis Mons	0.88 ± 0.02	107.4	0.6	85 by 100
Arsia Mons	0.77 ± 0.02	119.5	−9.1	80 by 100
Olympus Mons 1	0.70 ± 0.02	124.3	16.5	300 by 600
Olympus Mons 2	0.47 ± 0.02	156.5	14.9	185 by 260
Ascraeus Mons	0.64 ± 0.02	102.8	11.0	100 by 120
South Feature	0.36 ± 0.05	93.4	−40.9	70 by 140
Stealth	0.0 ± 0.02	125 to 168	0	500 by 2300
Average surface§	$\sim(0.15 \pm 0.02)\cos\theta_I$			

*The name is either taken from a nearby feature or invented here. †The brightness is the average of the brightest pixel from each snapshot and the rms value about this mean. The longitude and latitude value is the mean position of the brightest pixel averaged over the snapshots. ‡The extent is the rms wander of the surface position of the brightest pixel from the snapshots. It tends to be smaller than the region of half-brightness relative to the peak. For example, RSPIC is roughly 300 km in diameter but the brightest point is smaller. §θ_I is the angle of incidence of the radar beam.

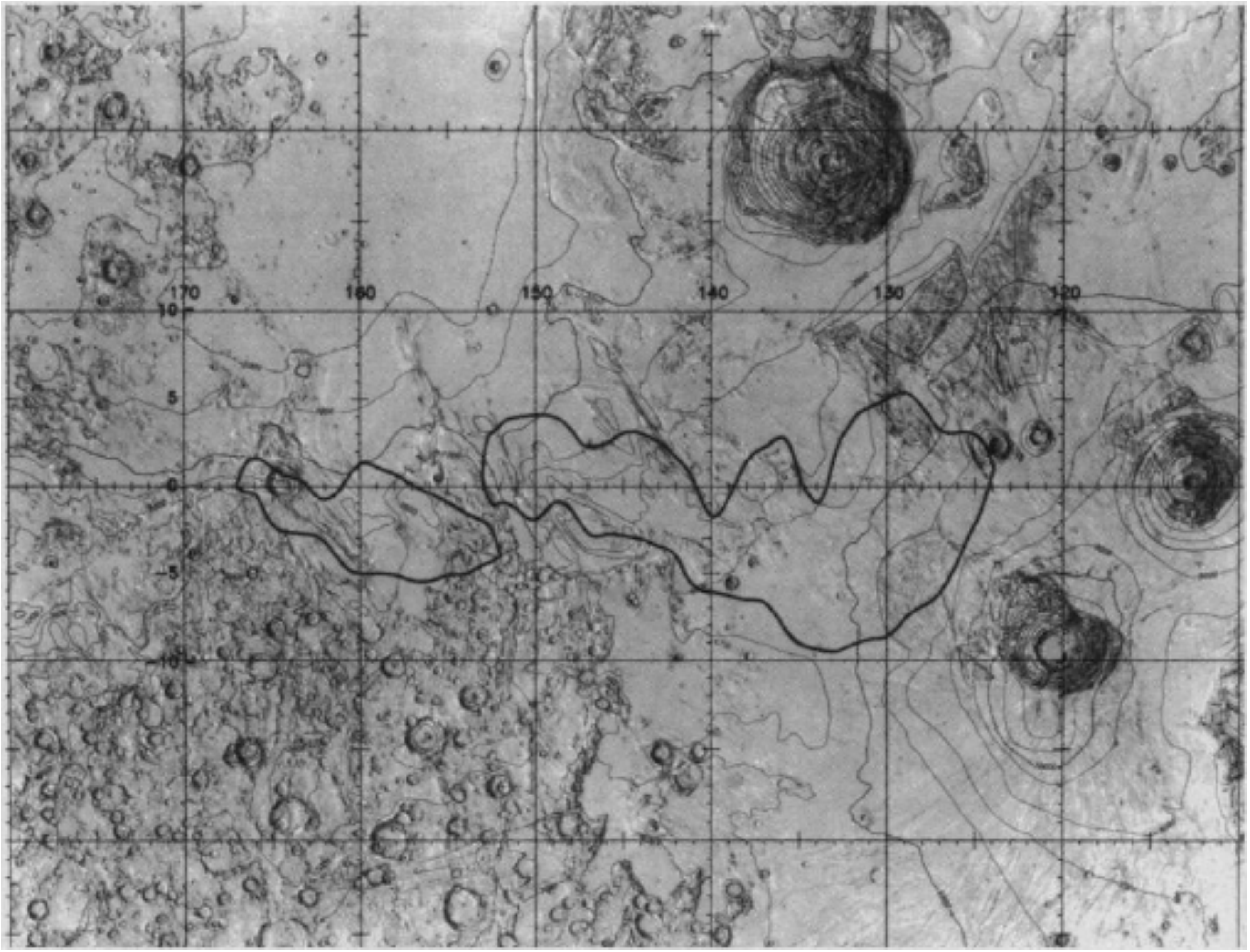
Table 3. Depth of a Lossy dielectric sheet over a dielectric half-space that makes the conductor effectively invisible.

Density* (g cm^{-3})	Dielectric constant†	Reflectivity infinite layer (%)	Minimum depth (m)
0.1	1.077 − *i*0.00086	0.03	3.2
(0.1)	(1.077 − *i*0.00043)	(0.03)	(5.8)
0.2	1.16 − *i*0.0019	0.14	1.3
0.4	1.33 − *i*0.0043	0.51	0.65
(0.4)	(1.33 − *i*0.00215)	(0.51)	(1.25)
0.6	1.53 − *i*0.0073	1.12	0.45
0.8	1.75 − *i*0.0112	1.93	0.25
1.0	2.00 − *i*0.0160	2.95	<0.2

*The listings in parentheses have one-half the imaginary part of the dielectric constant above it, corresponding to less mafic materials, that is, less elemental iron. †Values for basaltic powders, packed with bulk densities given in column 1.

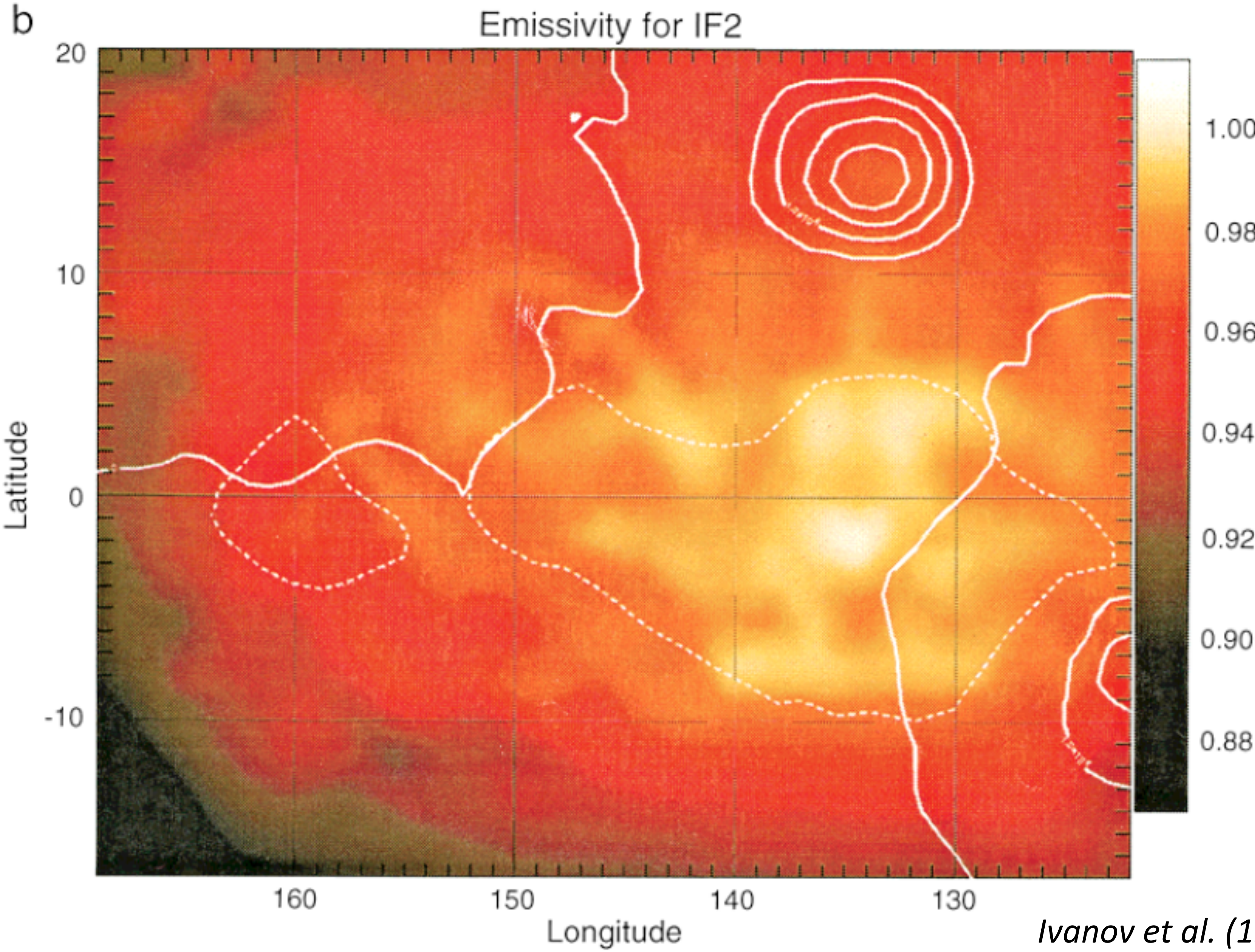
Muhleman et al. (1991)

Radar "stealth" zone, west of Tharsis volcanoes

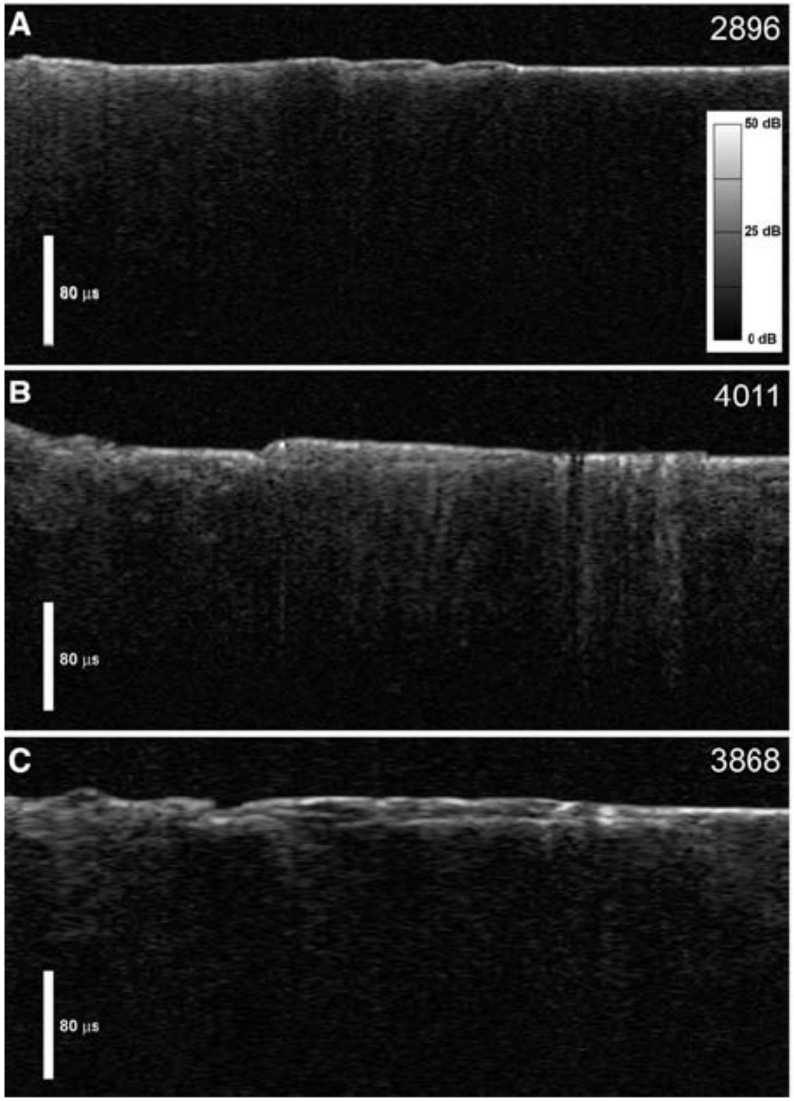


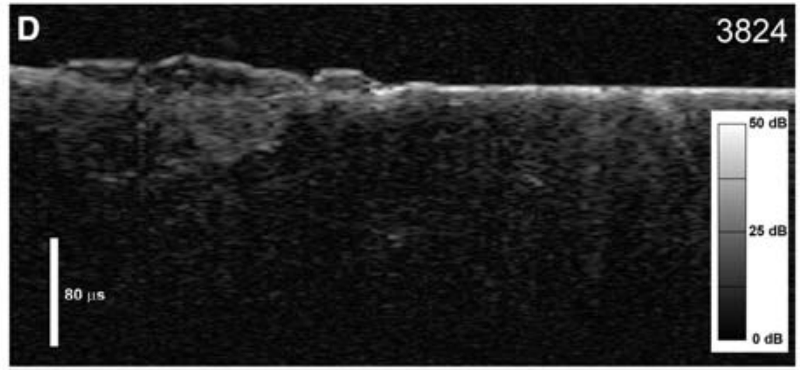
Muhleman et al. (1991)

“Stealth” also visible in passive microwave data



Ivanov et al. (1998)





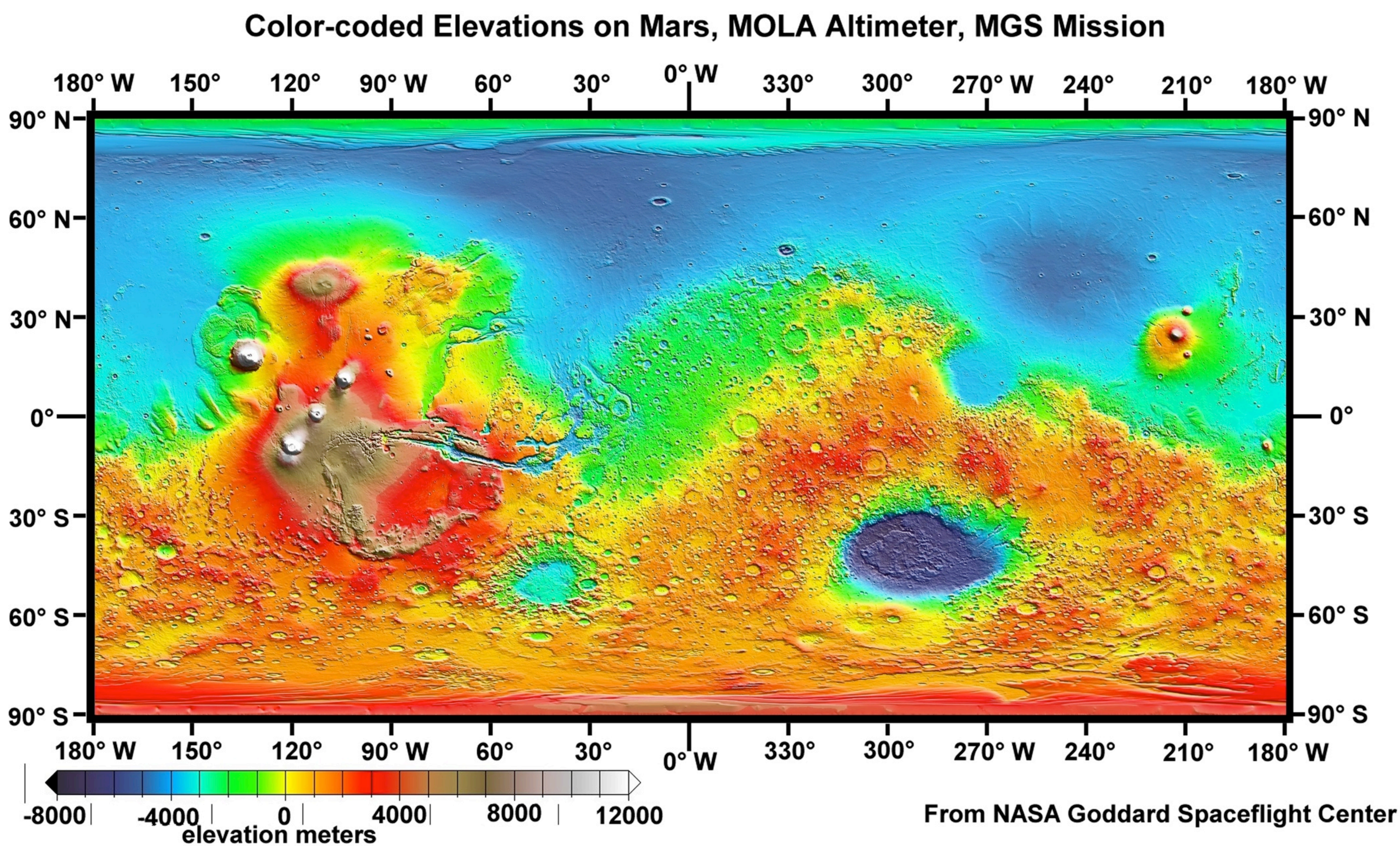
Radar Sounding of the Medusae Fossae Formation Mars: Equatorial Ice or Dry, Low-Density Deposits?

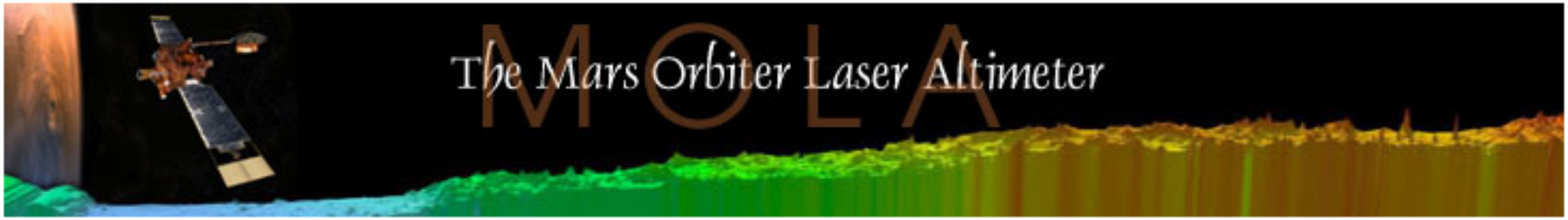
Thomas R. Watters,[1*] Bruce Campbell,[1] Lynn Carter,[1] Carl J. Leuschen,[2] Jeffrey J. Plaut,[3] Giovanni Picardi,[4] Roberto Orosei,[4] Ali Safaeinili,[3] Stephen M. Clifford,[5] William M. Farrell,[6] Anton B. Ivanov,[3] Roger J. Phillips,[7] Ellen R. Stofan[8]

The equatorial Medusae Fossae Formation (MFF) is enigmatic and perhaps among the youngest geologic deposits on Mars. They are thought to be composed of volcanic ash, eolian sediments, or an ice-rich material analogous to polar layered deposits. The Mars Advanced Radar for Subsurface and Ionospheric Sounding (MARSIS) instrument aboard the Mars Express Spacecraft has detected nadir echoes offset in time-delay from the surface return in orbits over MFF material. These echoes are interpreted to be from the subsurface interface between the MFF material and the underlying terrain. The delay time between the MFF surface and subsurface echoes is consistent with massive deposits emplaced on generally planar lowlands materials with a real dielectric constant of ~2.9 ± 0.4. The real dielectric constant and the estimated dielectric losses are consistent with a substantial component of water ice. However, an anomalously low-density, ice-poor material cannot be ruled out. If ice-rich, the MFF must have a higher percentage of dust and sand than polar layered deposits. The volume of water in an ice-rich MFF deposit would be comparable to that of the south polar layered deposits.

Units of the Medusae Fossae Formation (MFF) occur discontinuously at equatorial latitudes along the boundary of the hemispheric dichotomy from Amazonis to Elysium Planitiae (~130°E to 240°E) (*1*, *2*). The MFF may be among the youngest surficial deposits on Mars, unconformably overlying ancient Noachian heavily cratered highlands and young Amazonian lowlands (*1*–*8*). However, pedestal craters on the outer edge of the MFF

LIDAR: Mars Orbiter Laser Altimeter





How MOLA makes its Range Measurement

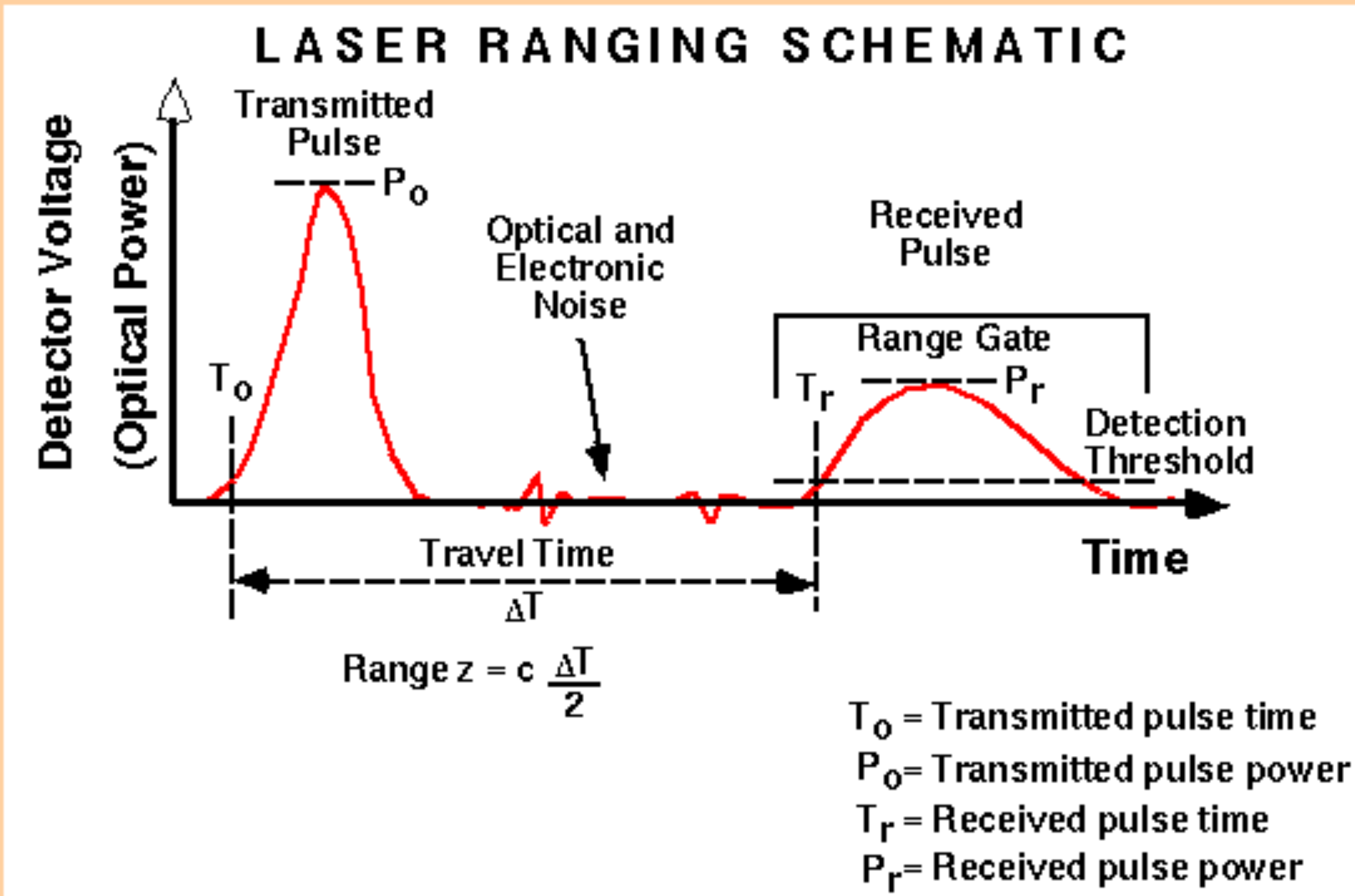
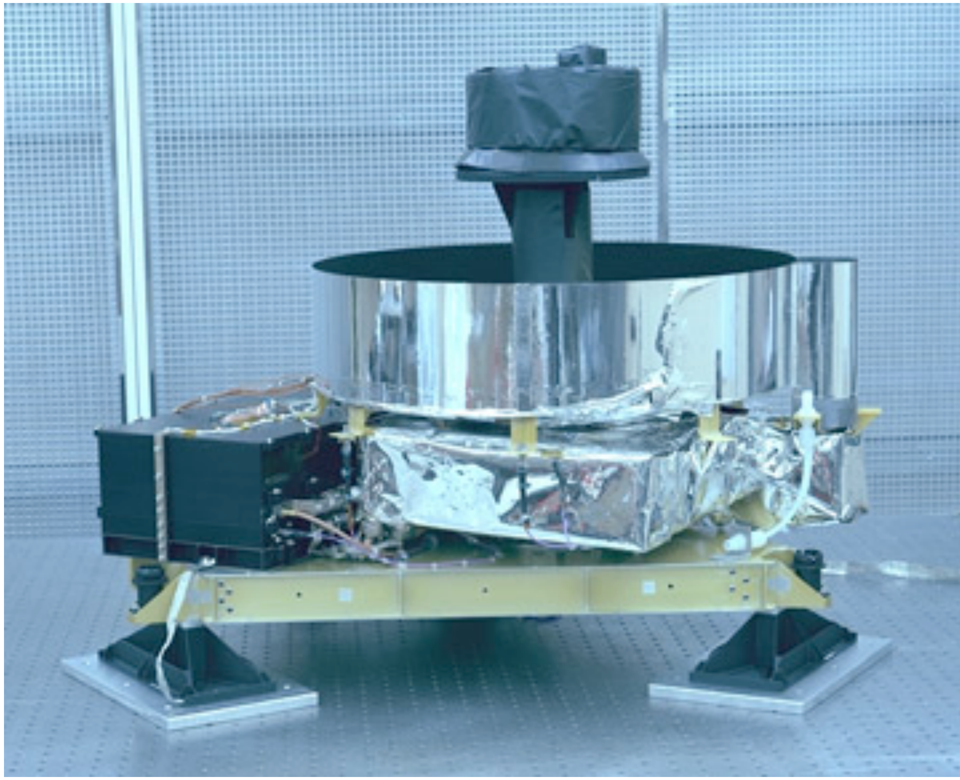
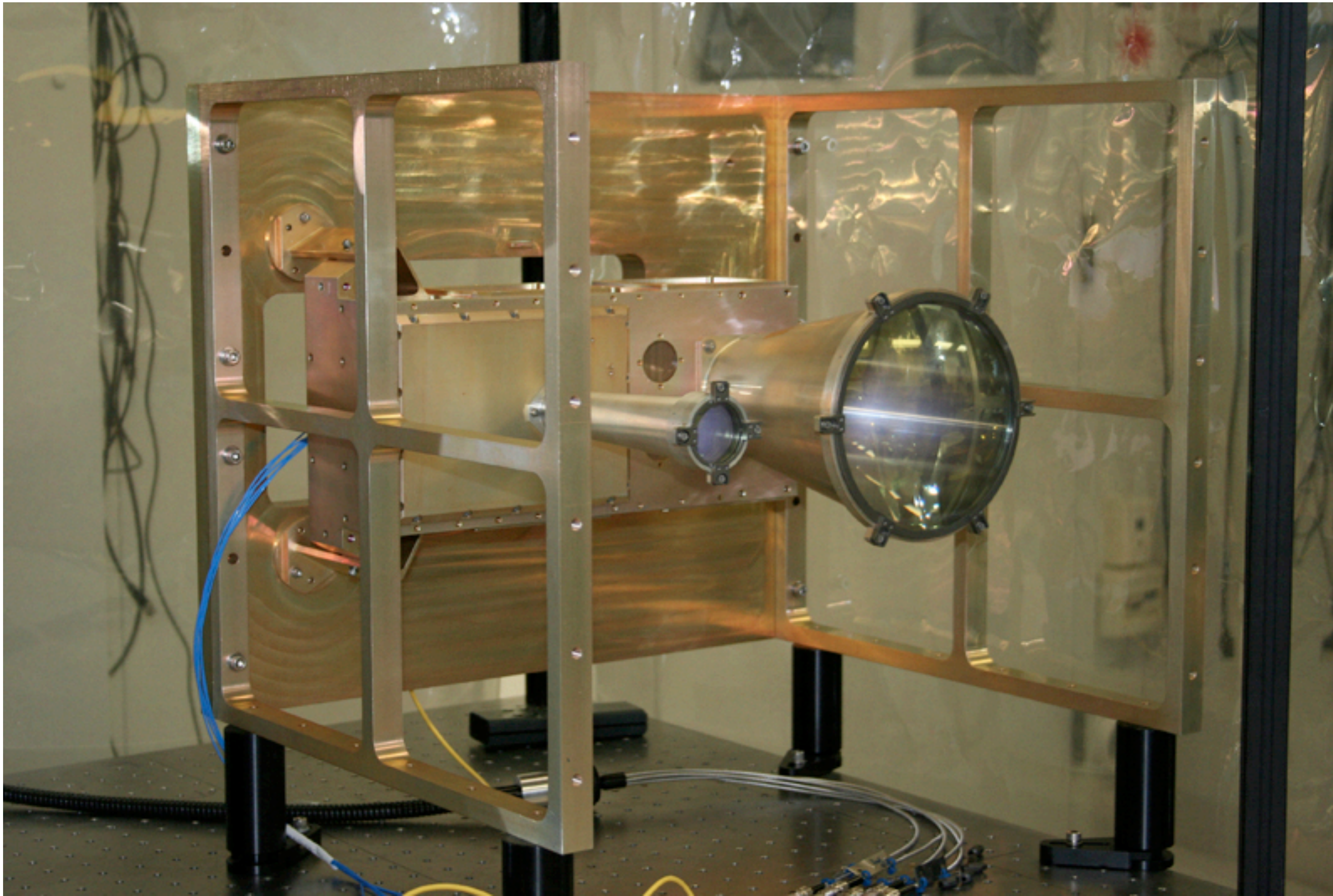


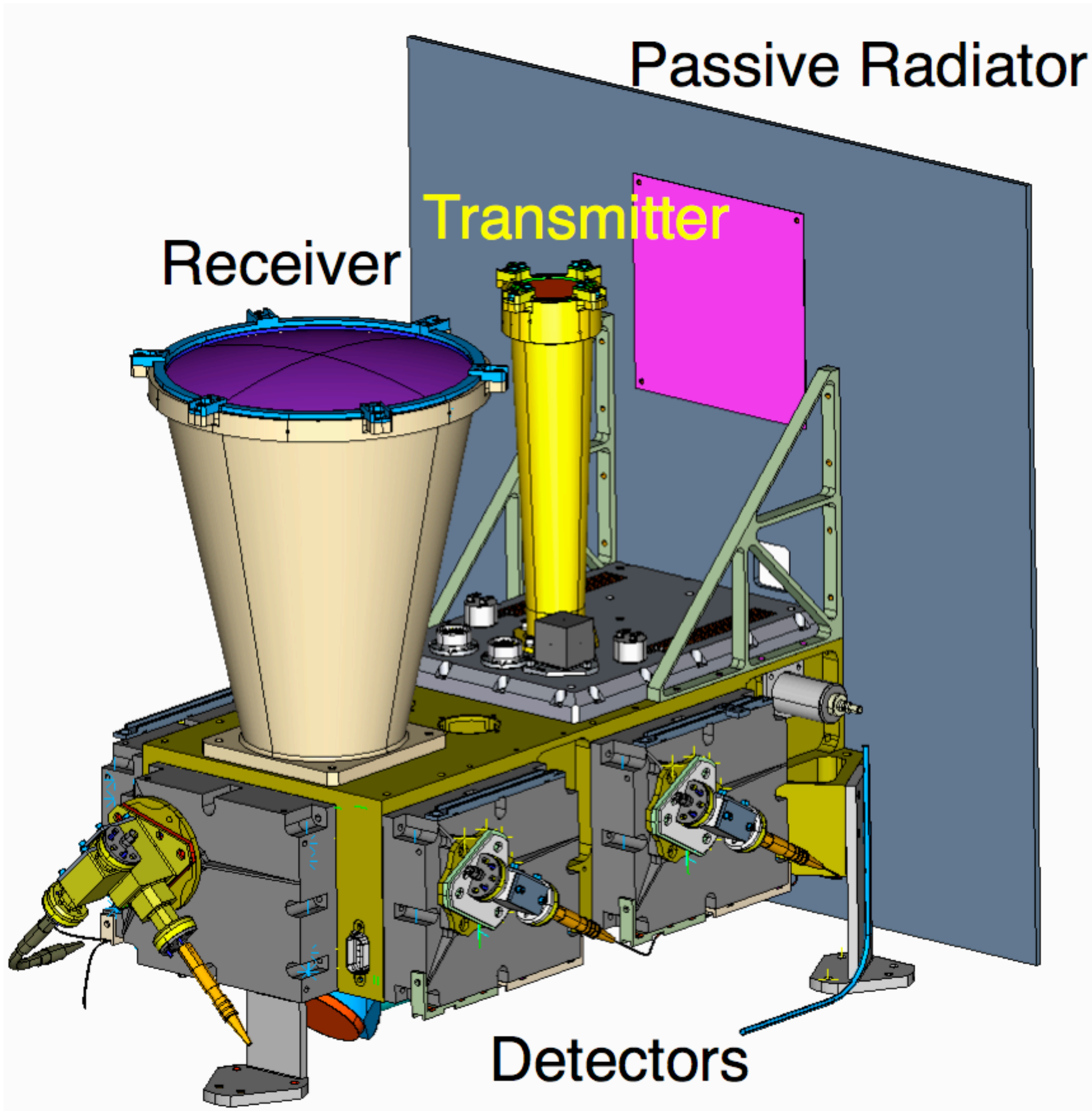
Table 1. MOLA Instrument Specifications

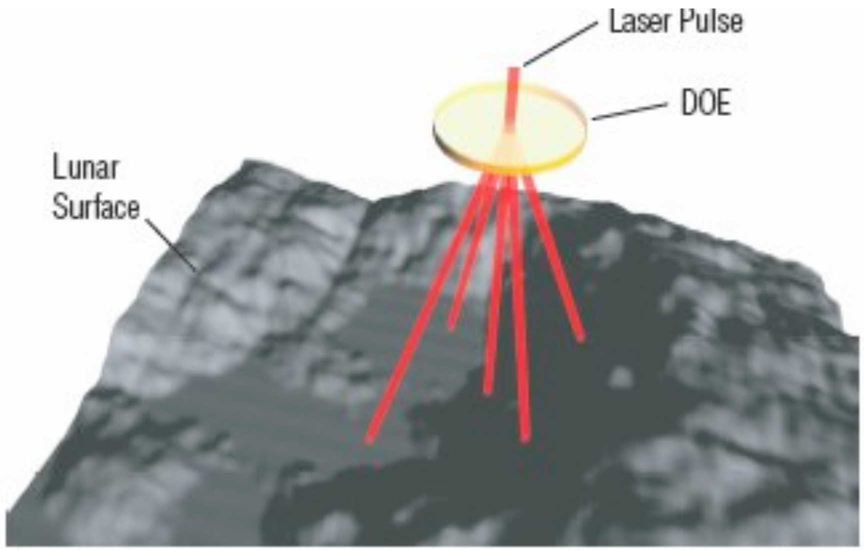
Parameter	Specification
Mass	23.8 kg
Power consumption[a]	34.2 W
Transmitter	
Laser type	diode pumped, Q-switched, Cr:Nd:YAG
Wavelength	1.064 μm
Pulse rate	10 Hz
Energy[b]	48 mJ pulse^{-1}
Laser divergence	420 μrad
Pulse length	8 ns
Receiver	
Mirror	50-cm parabolic
Detector	silicon avalanche photodiode
Field of view	850 μrad
Electronics	
Microprocessor	80C86
TIU frequency	99.996 MHz
Filter channel widths	20, 60, 180, 540 ns
Data rate	618 bits s^{-1} continuous
Resolution	
Maximum ranging distance[c]	787 km
Range resolution	37.5 cm
Vertical accuracy[d]	1 m
Surface spot size[e]	168 m
Along-track shot spacing	300 m
Across-track shot spacing[f]	4 km

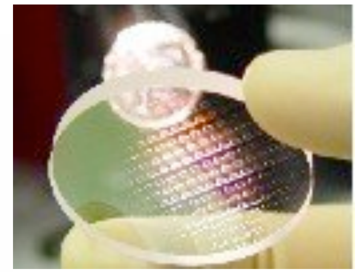


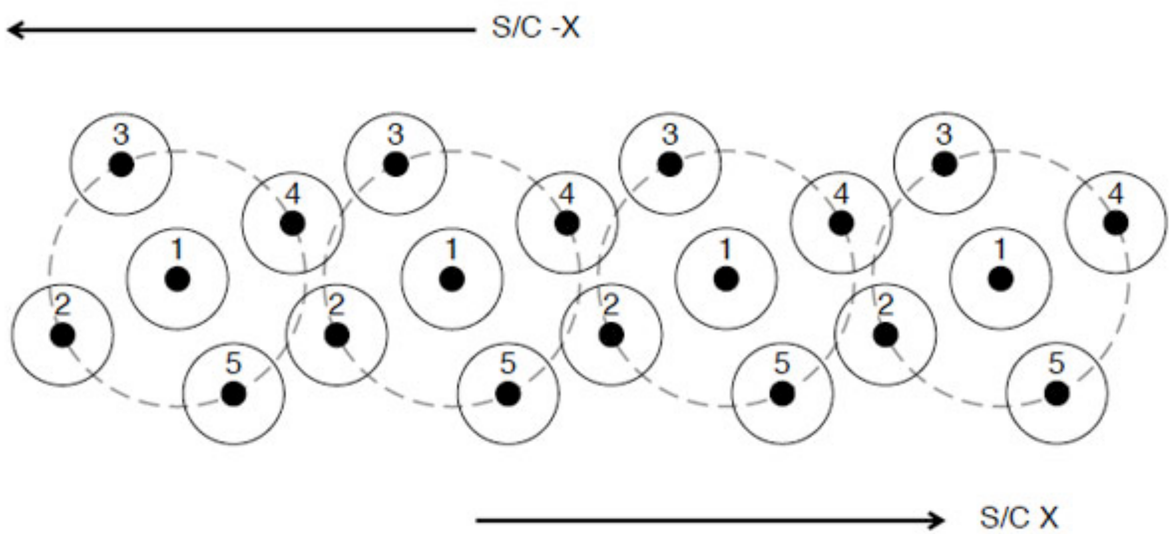
[a] Includes replacement heat for temperature control.
[b] At arrival at Mars; degrades with time.
[c] Hardware limited.
[d] Includes radial orbit error.
[e] In 400-km-elevation mapping orbit.
[f] Average at equator; varies with cos(latitude).



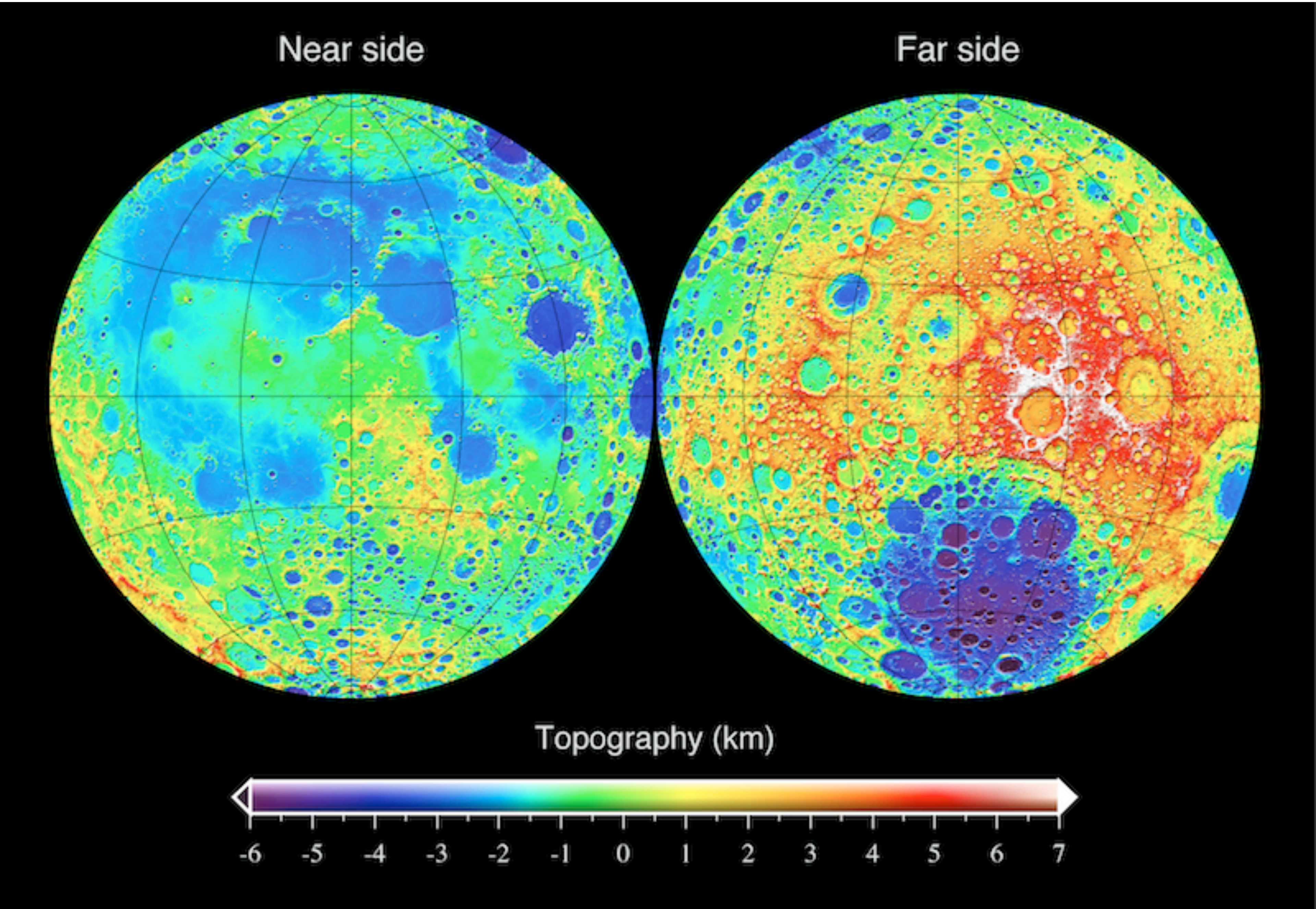

Passive Radiator
Transmitter
Receiver
Detectors


Laser Pulse
DOE
Lunar
Surface

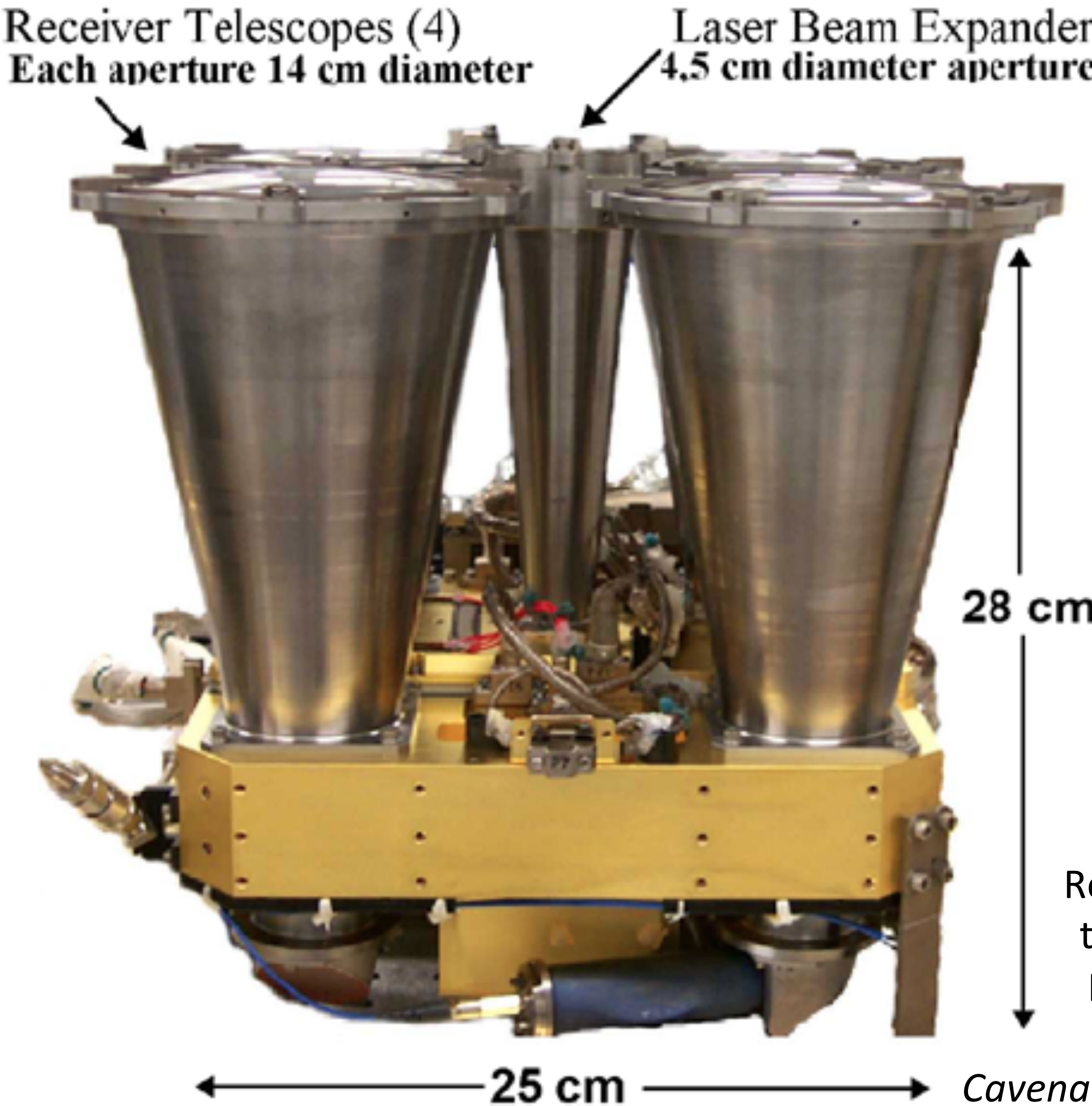


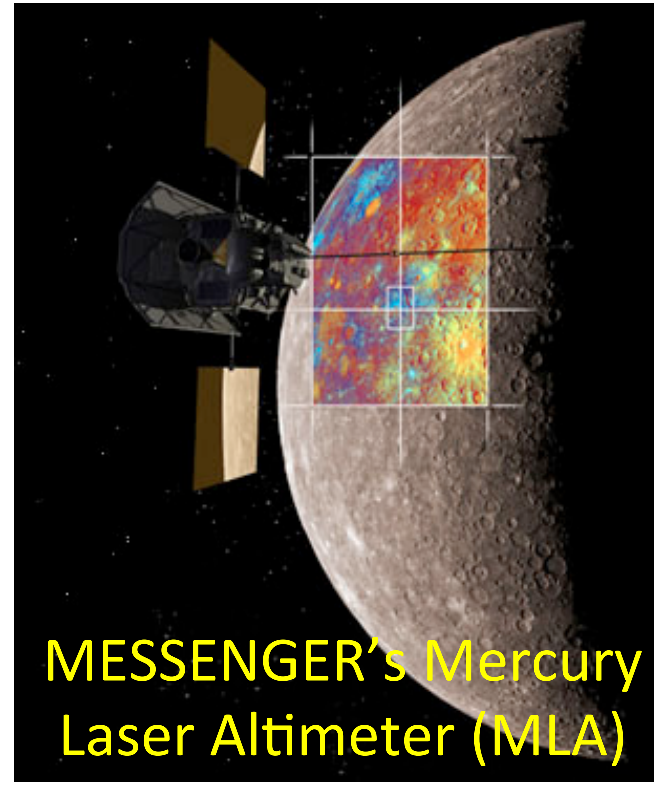

S/C -X
3
4
1
2
5
S/C X

LOLA results



Planetary lidar: siblings of MOLA, LOLA



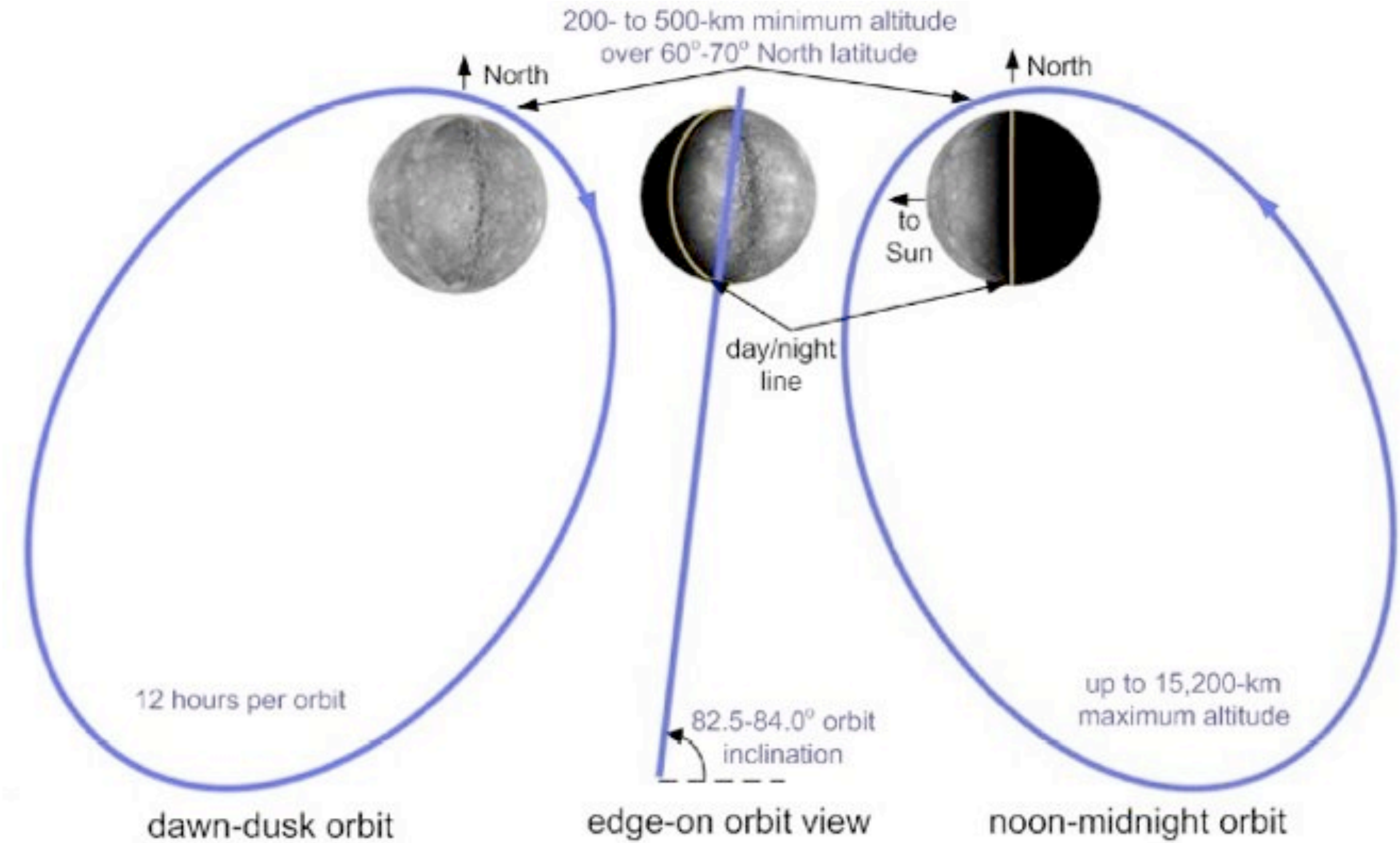


Refractive optics chosen instead of the usual reflective, to withstand Mercury's thermal environment

Cavenaugh et al. (2007)

MESSENGER's Mercury Laser Altimeter (MLA)

Measures topography, 1064 nm reflectivity ***within <800 km of surface***



MESSENGER’s Mercury Laser Altimeter (MLA)

Topography
from ~55 to 90° N