A UHF SAR Mission to Mars

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Abstract -- A Mars orbiting mission carrying a UHF SAR to map the hidden surface of Mars is described. UHF SAR is shown to be an ideal selection for probing the thick dust mantle, which covers more than a third of the Martian surface. Mapping is carried out in both HH and VV polarizations, with the comparison of the two expected to yield a distinction between surface and subsurface features up to 5m depth. Some Repeat-pass Interferometry data is collected in an investigation of whether the Martian surface is subject to temporal deformation.

This paper describes the technical design of the UHF SAR for global mapping of Mars and the characteristics of the proposed mission to achieve this goal.

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Keywords: Synthetic Aperture Radar (SAR), UHF

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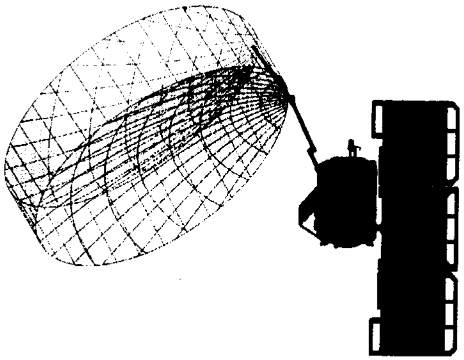

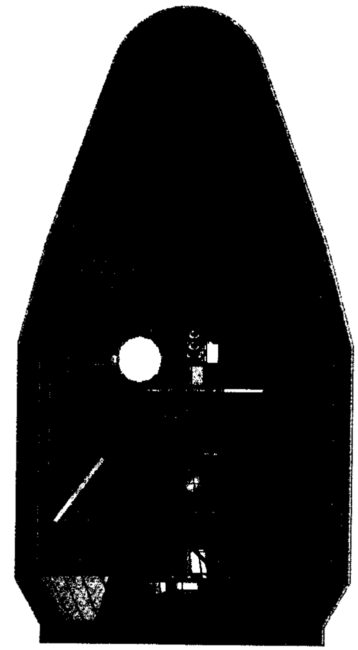

A UHF SAR Mission to Mars
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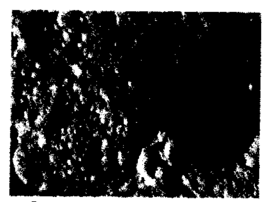
Bruce Campbell
Anthony Freeman

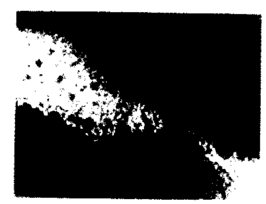

Origin of Ice


Duricrust vs. Bedrock


Hydrologic Cycle


Penetrating Dust


Probing the Poles


Recent Transport?

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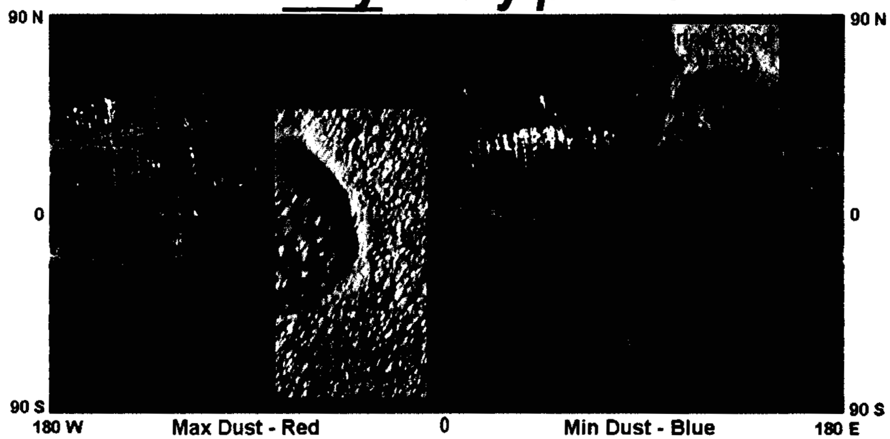
Overview

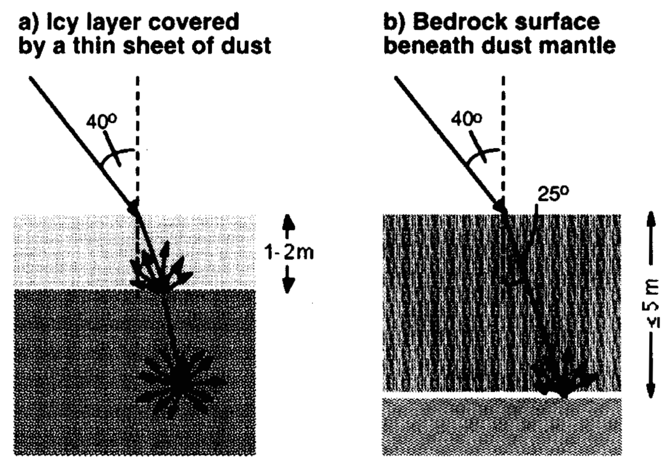
Mars is a very dusty planet



Thermal infrared data show extent of Martian dust cover

Neutron spectrometer data reveal large quantities of water 'just beneath the surface'

Longer-wavelength imaging radar can peer beneath the dust to reveal the 'hidden face of Mars'



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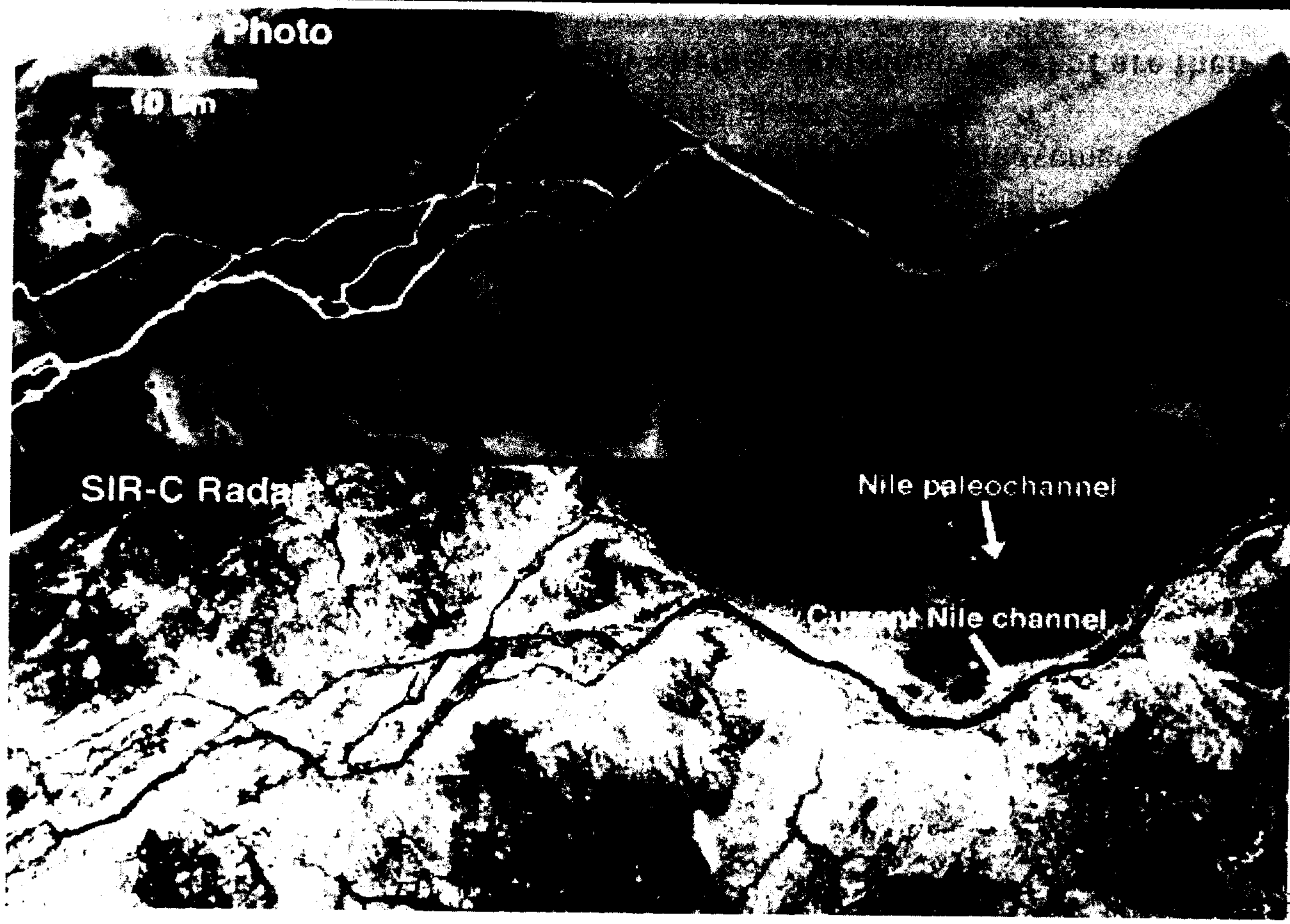
Terrestrial Radar Penetration Example
Shuttle Radar, Nile River



Science Questions and Objectives

(1) What is the physical structure of the near-surface environment?

(a) Map the global near-surface geologic regime (rock, duricrust, dust).

(b) Map the occurrence, extent, and possible sources of surficial deposits.

(c) Sound the polar deposits to assess diversity of ice structure and dust loading.

(2) How are the near-subsurface features related to hydrologic activity?

(a) Identify subsurface features associated with past hydrologic activity.

(b) Identify ice-related changes in ground properties at high latitudes.

(3) What are the most recent geologic events that have occurred on Mars?

(a) Identify the signatures of volcanism, sedimentation, mass movement, and hydrologic changes in the near subsurface over the entire planet.

(4) Are there current changes in the near-surface environment, what are their rates, and are they related to water?

(a) Identify areas of possible surface deformation, physical change, or sediment movement.

Measurement Requirements

(1) Map the entire surface of Mars at 100-m spatial resolution, with the capability of detecting a rough interface buried beneath up to 5 m of overlying mantle.

(2) Map selected regions at 30-m spatial resolution, with the same penetration requirements.

(3) Collect near-nadir sounding data for selected areas to characterize surface dielectric constant.

(4) Map the entire surface of Mars at 100-m spatial resolution in a second polarization, suitable for inference of surface dielectric constant.

(5) Map selected regions at 100-m spatial resolution with repeat-pass geometry suitable for change detection (==> < 1km repeat tracks for P-Band measurements).

Instrument Requirements

- Synthetic aperture radar (SAR) capable of:
  - 30-100 m spatial resolution.
  - Detection of rough interfaces beneath 5 m of dust/ash/regolith.
  - Near-nadir sounding capability for reflectivity mapping.
  - Repeat-pass interferometric correlation.
  - Orthogonal polarizations suitable for dielectric constant mapping.
- Baseline Design:
  - 67-cm wavelength radar, 6-m antenna, 30 m minimum horizontal range resolution.
  - VV polarization, noise floor -35 dB, incidence angle 40 degrees
  - Near-nadir observations permitted by S/C roll
  - Interferometric processing possible from complex data (no burst mode)
  - Dual-string HH polarization receiver and feed.

Mars Program Context

- Long Wavelength SAR fills a unique niche in the remote sensing of Mars
- Selected Mars remote-sensing data in hand or expected by 2008:

Viking MDIM	Visible	231 m	100%
MGS Context Imager	Visible	200 m	100 %
MRO Context Imager/Mars Express HRSC	Visible	10-30 m	100%
MOC	Visible	5-10 m	<5%
HIRISE	Visible	30-50 cm	<5%
Viking IRTM	Thermal IR	3 km	30%
TES	Thermal IR	3 km	100%
THEMIS	Thermal IR	100 m	Possibly 100%
Goldstone/VLA	3 cm	30 km	100 %
Arecibo Radar	12.6 cm	10 km	100%

(Sounding radars such as SHARAD and MARSIS do not have surface imaging capability)

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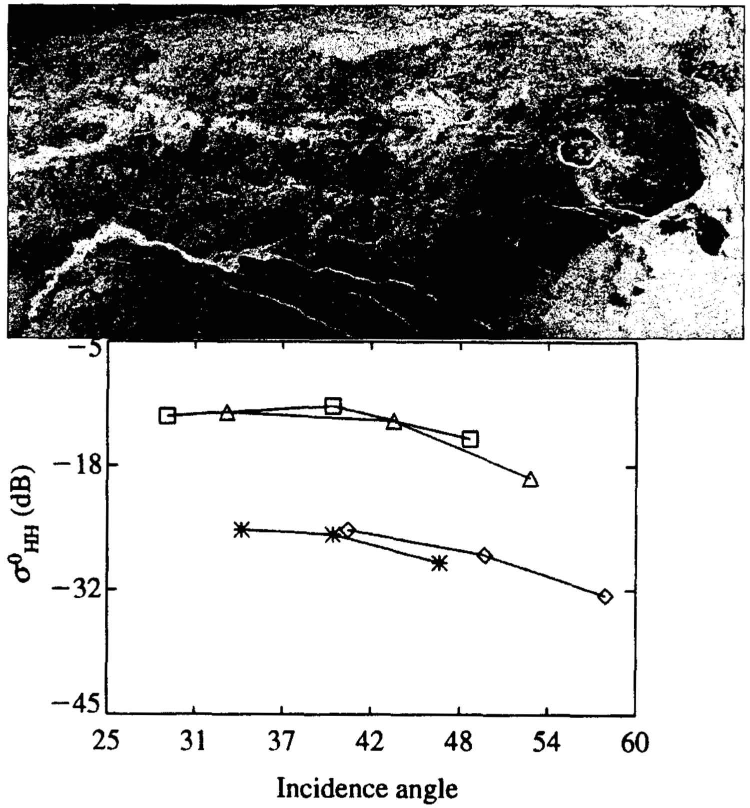
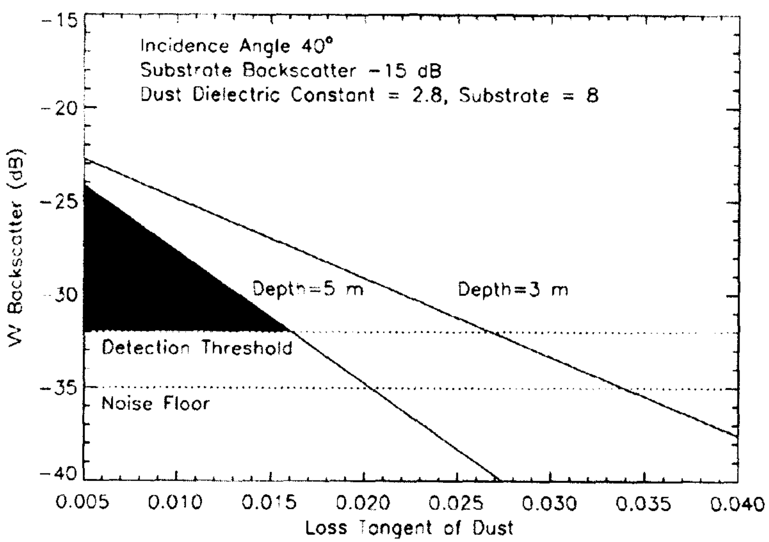
Wavelength/Polarization/Angle Choice



P-band AIRSAR HH image of Kilauea, and backscatter coefficients for lava flows and smooth playa.

- P-band (67cm) wavelength chosen to maximize subsurface penetration and volume scattering, within the spatial resolution and receiver detection limits.
- Good heritage in P-band observations of Earth and Moon.
- Good evidence for S-band penetration of Mars dust (Harmon et al., 1999)
- Imaging requirement of 30/100 m.
- Noise equivalent σ^o of -35 dB adequate to characterize terrestrial targets at 40 deg incidence.
- VV polarization will permit greater subsurface penetration and scattering.
- 40 deg incidence angle chosen as compromise between backscatter signal strength (decreasing with angle) and Fresnel coefficient difference (increasing with angle).

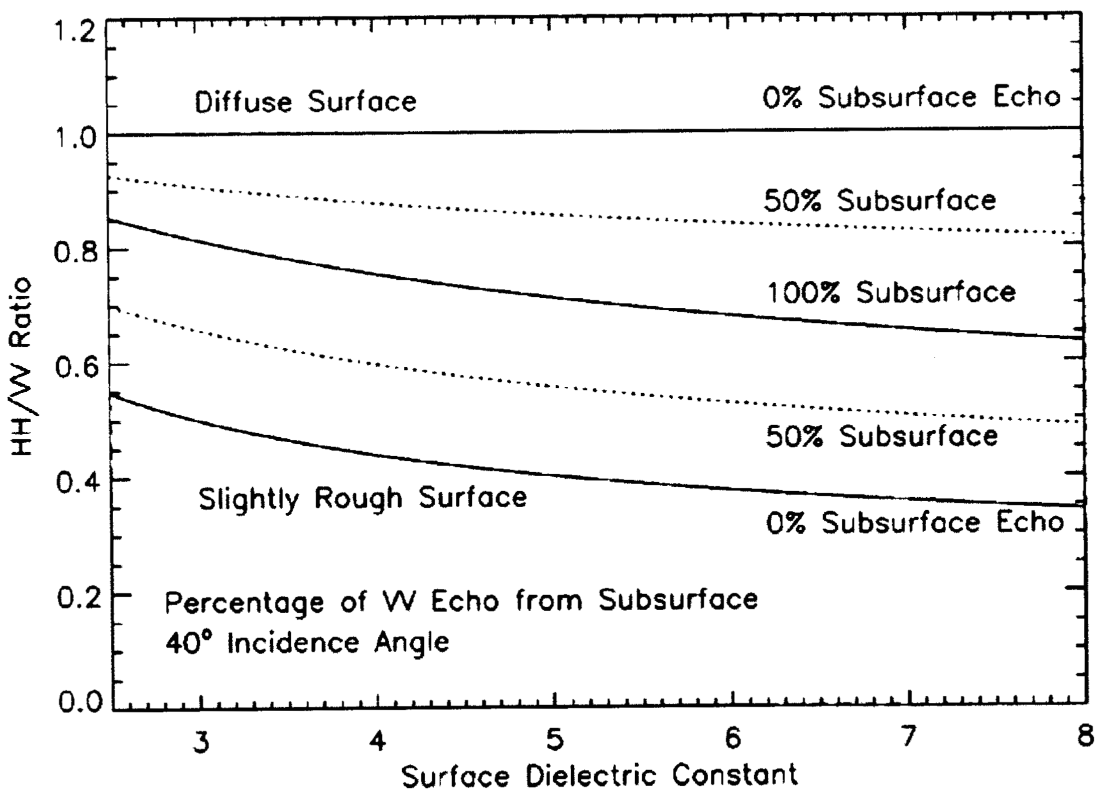
Detection of Subsurface Features



Plot of observed VV backscatter coefficient for a rough surface beneath 3, 5, and 8 m of mantling dust. Dust and rock dielectric constants are 2.7 and 8, respectively.

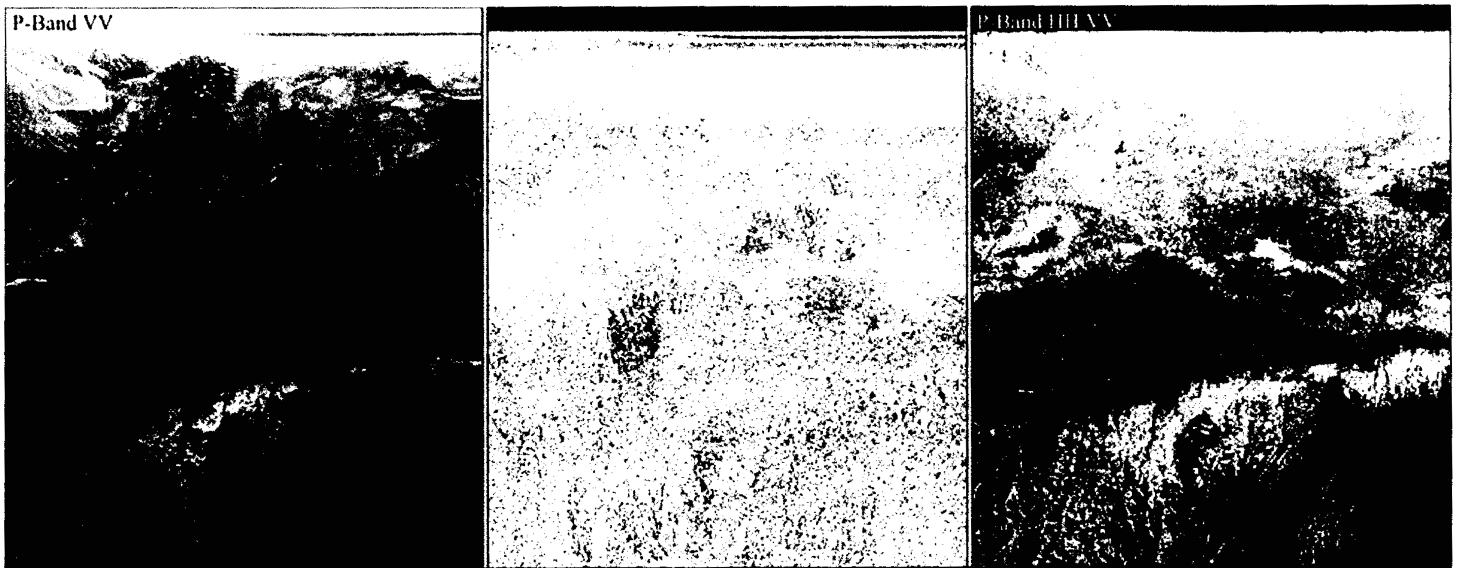
- Very rough surfaces have P-band backscatter coefficient, at 40 deg, of about -10 db.
- Loss tangent largely controls signal penetration
- For loss tangents <0.025, 67-cm wavelength can satisfy the science requirement, using a 3 dB threshold.
- Penetration depth in ice will be considerably greater.
- Addition of magnetically lossy materials will decrease signal penetration.
- Experience with lunar 70-cm data shows that buried lossy material (mare basalt) can also be detected where covered by low-loss (highland) debris.

Polarization Properties At ϕ=40°



Advantage of HH and VV Observations

- V-polarized echoes from a subsurface reflector are greater than H-polarized returns due to Fresnel transmission at the surface.
- HH/VV ratio is related to the fraction of subsurface scattering.
- Images below illustrate increase in subsurface return with increasing wavelength.



P-band VV radar image, and C- and P-band HH/VV ratio maps of the Stovepipe Wells area of Death Valley.
White corresponds to HH/VV=1.0 (primarily surface scattering), black to HH/VV=0.
Lower HH/VV ratios correspond to greater proportion of subsurface return.

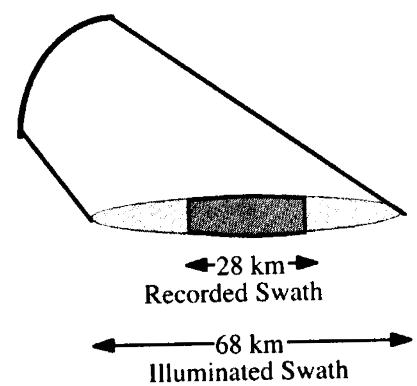
Payload Summary

Instrument Performance Summary:

Imaging Geometry	a) Look angle 37° (off-nadir) b) Nadir-pointing
Wavelength	67 cm
Polarizations	VV or HH
Number of science modes	3
Spatial resolution	30/100 m
Swath width	8 – 28 km
Noise equivalent σ^o	-35 dB
Ambiguity levels	< -20 dB
Mass CBE (Contingency)	76.9 (20.8) kg
Antenna size/type	6m diameter deployable reflector
Stowed antenna dimensions	176 x 33 x 33 cm
Electronics box dimensions	20 x 30 x 40 cm
Average Power needs CBE (contingency)	100 (30) W
Data rates	0.9 – 2.9 Mbps
Onboard data reduction	(8, 4) BFPQ + X4 Azimuth presum
Pointing accuracy requirement	0.75 °

- Ground swath of 28 km is over-illuminated by ~X3
- Reduces effects of Martian terrain ht. variations on calibration, timing constraints

Radar Ground Illumination:



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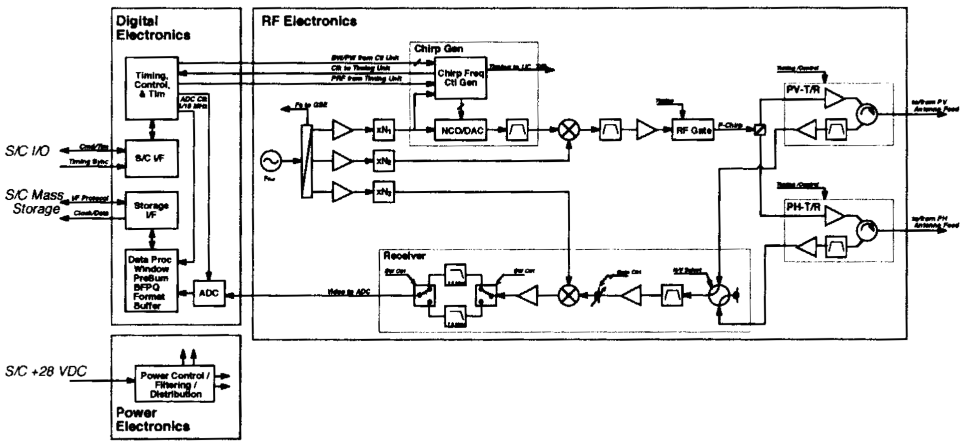
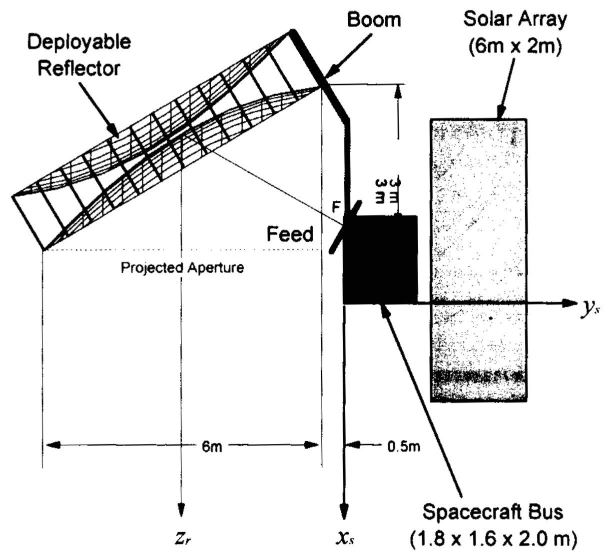
Payload Summary

- **UHF Synthetic Aperture Radar** (JPL)

Radar Block Diagram



Antenna Configuration



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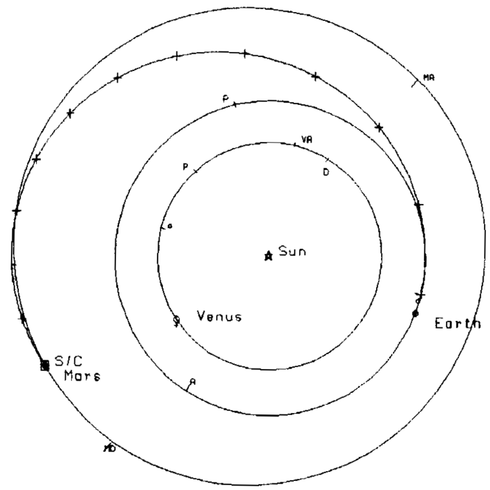
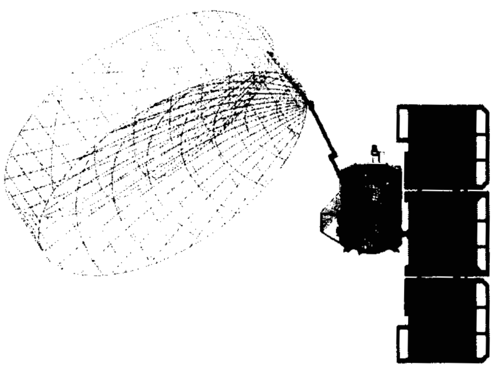
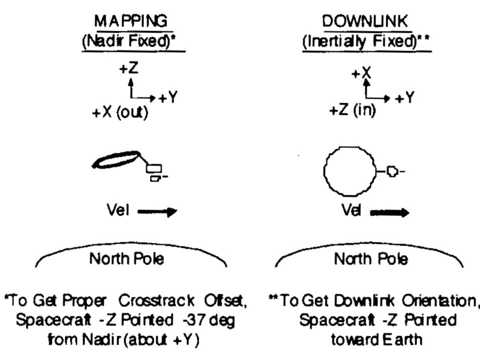
Mission Summary

- Launch on Delta II 7925
- Type II trajectory (11 months), C3 from 13 to 17 km^2/s^2
- MOI into 12-hour capture orbit (1050 m/s), Odyssey was 24-hour at 1433 m/s
- Aerobraking less than 60 days, Odyssey was 75
- No orbit phasing required, go immediately into Science phase
- Frozen, sun synchronous orbit at 92.6 deg with 240 X 320 km altitude
- Dual Use Antenna - UHF SAR and X-band data return to Earth
- Two 20 week mapping campaigns at VV and HH polarization, followed by 12 week selected site high resolution mapping



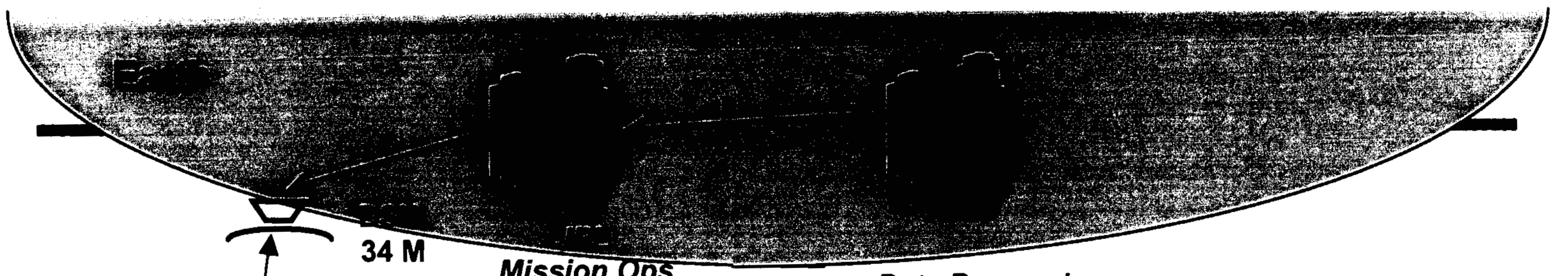


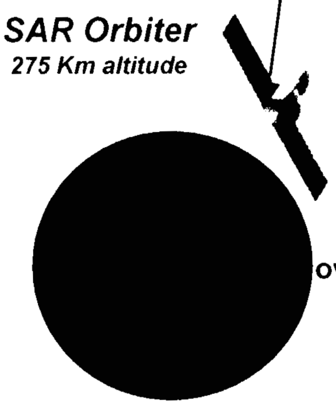


Flight System Margins:

Parameter	CBE	Capability	Margin
Launch Mass	645.4 kg	850.0 kg	24.1%
Propellant Mass	249.1 kg	328.1 kg	24.1%
Power	432.5 W	638.9 W	22.9%
Battery Power	5.0 A-hr	11.2 A-hr	48.4%
Data Storage	15 Gbits	32 Gbits	52.3%
Telecom Links	-	-	3 dB

EEIS and Ground System Overview





- Mission Timeline – 3 year mission
  - 11 month cruise
  - 11 months aerobraking and orbit phasing
  - Two 30 week mapping cycles +
- Data Collection Strategy
  - SAR Mapping for 8 half-orbits per day
  - 1.6 Gbits per orbit
- Data Return Strategy
  - Playback for 3 orbits each day over one 5.7 hour DSN pass
  - Up to 19 Gbits per playback