12th Interplanetary Probe Workshop (IPPW-12) Cologne, Germany
Short Course "Radio Flyers" June 2015

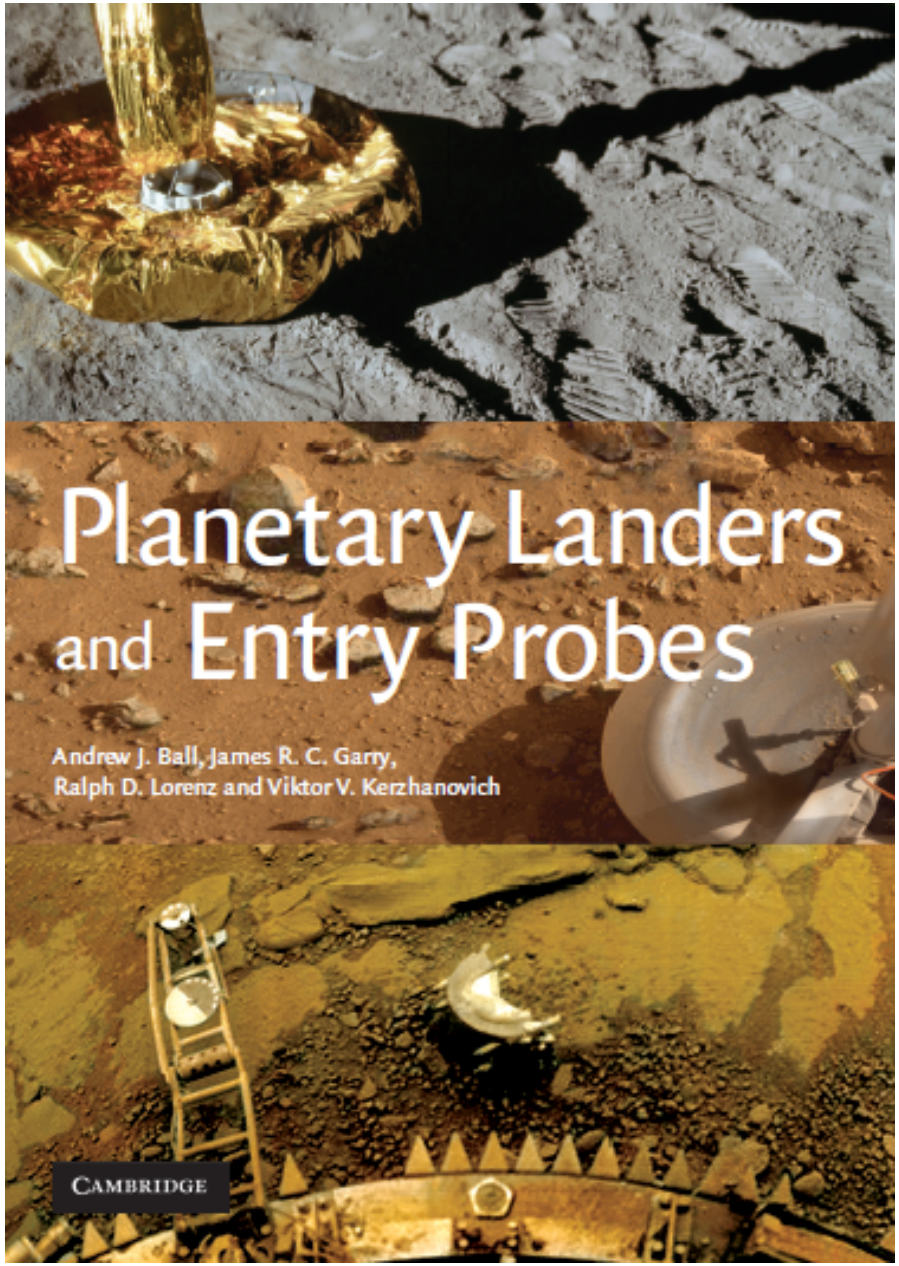
Radar Altimeters on Probes and Landers*
*(*and Doppler radars)*

Ralph D. Lorenz
Johns Hopkins University Applied Physics Laboratory, Laurel, MD. USA

Ralph.lorenz@jhuapl.edu
http://www.lpl.arizona.edu/~rlorenz

Note: this presentation is being worked into a journal paper with references etc. Please enquire of the author the status as it would be better to make any external reference to the paper than this talk.

JOHNS HOPKINS
APPLIED PHYSICS LABORATORY


Planetary Landers
and Entry Probes
Andrew J. Ball, James R. C. Garry,
Ralph D. Lorenz and Viktor V. Kerzhanovich
CAMBRIDGE

CUP 2007

Harland and Lorenz
SPACE SYSTEMS FAILURES
SPACE SYSTEMS FAILURES
Disasters and Rescues of Satellites, Rockets and Space Probes
David M. Harland and Ralph D. Lorenz
Springer
PRAXIS

Springer, 2006

Radars on Landers

Altimeter – trigger descent operations, input for propulsive descent [pulse, or FMCW]

Doppler Velocity Sensor – input for propulsive descent (horizontal speed) [typically CW]

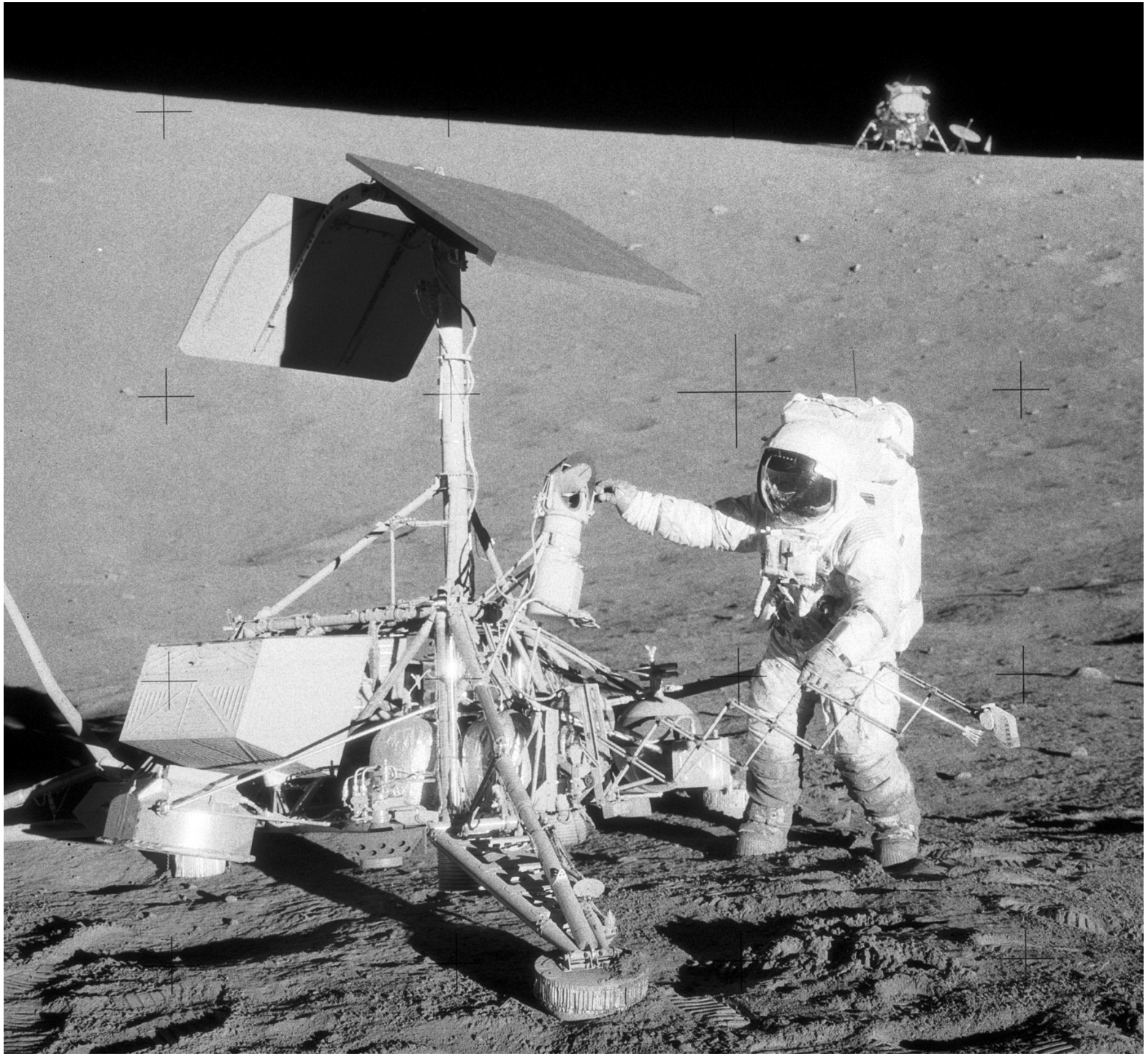
Target	Mission	Radar Altimeter	Doppler Velocimeter
Moon	Ranger (Block II)	X	
	Luna	X	
	Surveyor	X	X
	Apollo	X	X
	Luna 23, 24	X	
	Chang' e 3	X	
Venus	Venera 4, 8	X	
Titan	Huygens	X	
Mars	Viking	X	
	Pathfinder	X	
	MER	X	
	Phoenix	X	X
	MSL Curiosity /M2020	X	X
	ExoMars/EDM	X	X

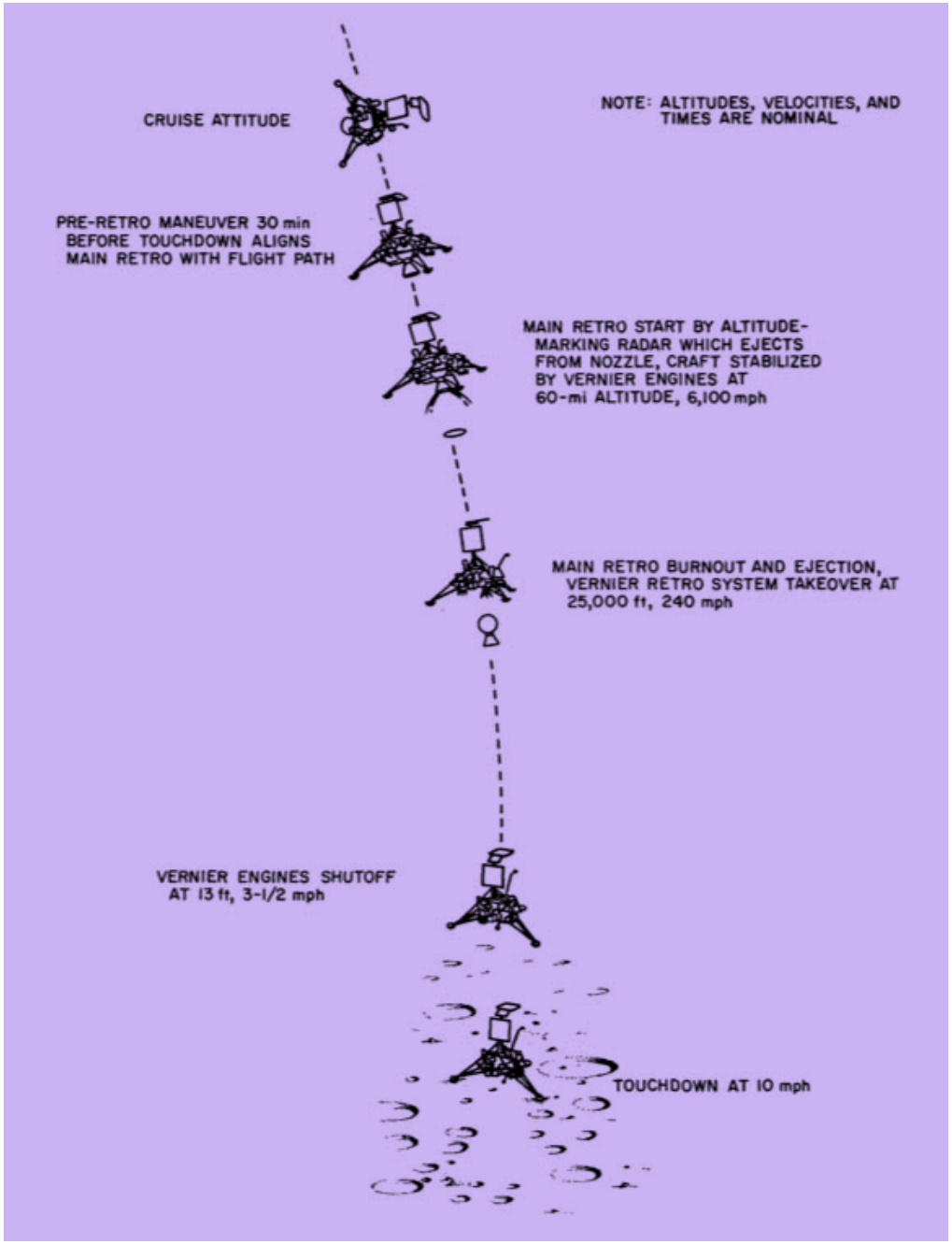
Early Venus probes have flown altimeters; not needed once P/T profile understood

Soft-landing with propulsion tends to need velocity sensing

Semi-hard landing can get away with altimeter only (MER a special case)

Optical sensing beginning to supplant Doppler function (MER / Chang' e)





Altitude-marking pulse radar altimeter triggers solid rocket motor firing (removes 95% of velocity)

Throttled liquid engines control descent and null horizontal velocity sensed by 4-beam FMCW altimeter and doppler velocity sensor

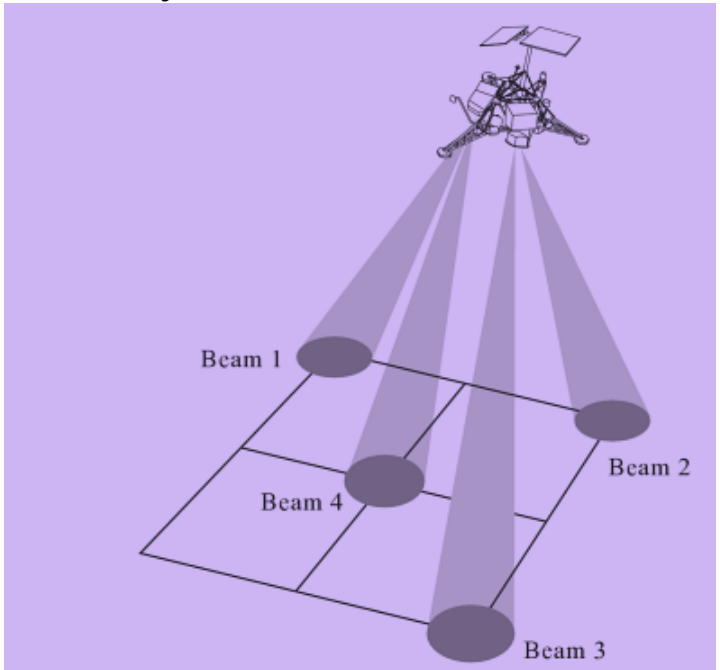


Figure 5.4. Surveyor RADVS (Parks, 1966).

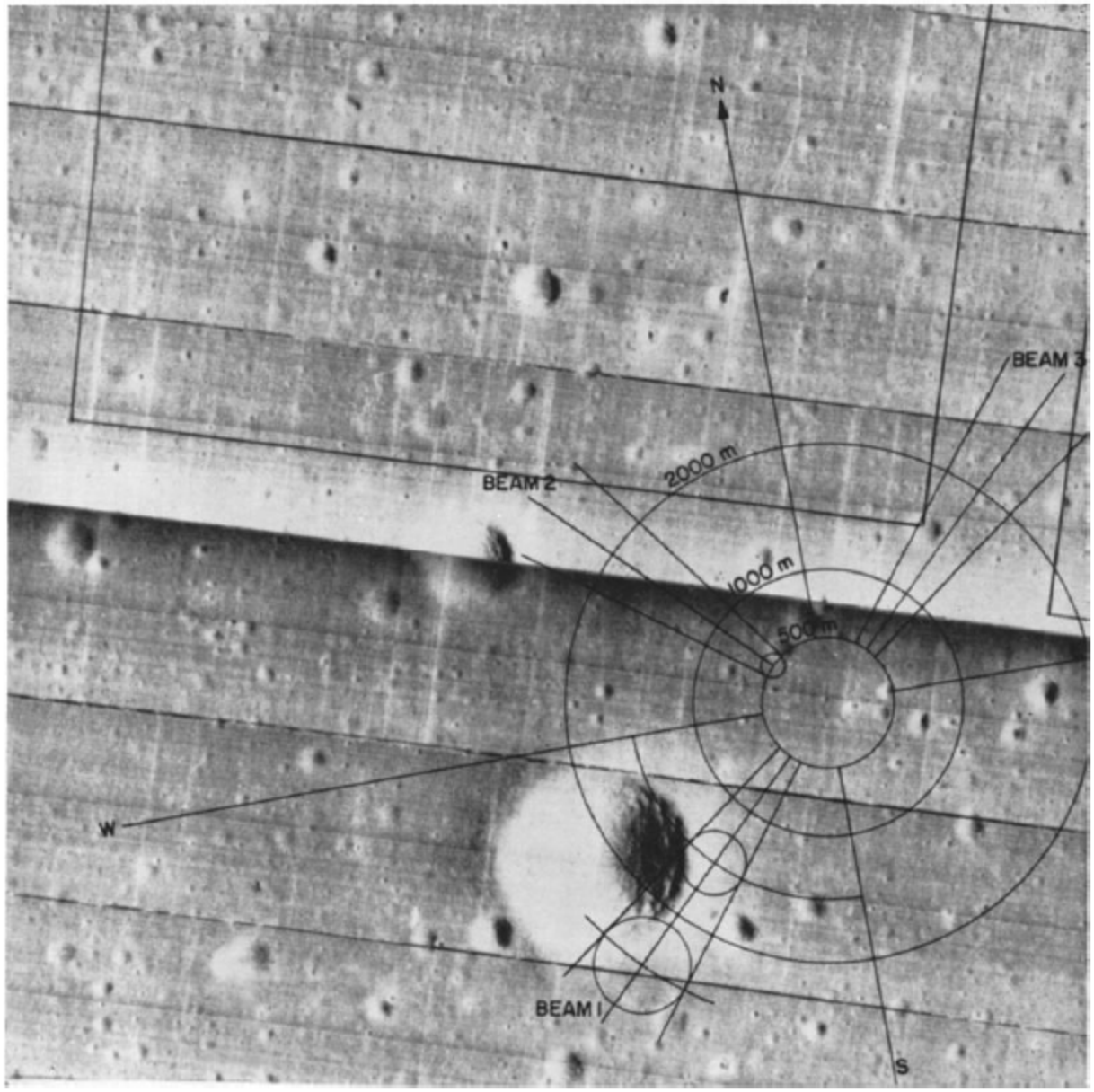


Fig. 10. *Brown.* Probable location of Surveyor 1 landing site. Photograph from Lunar Orbiter.

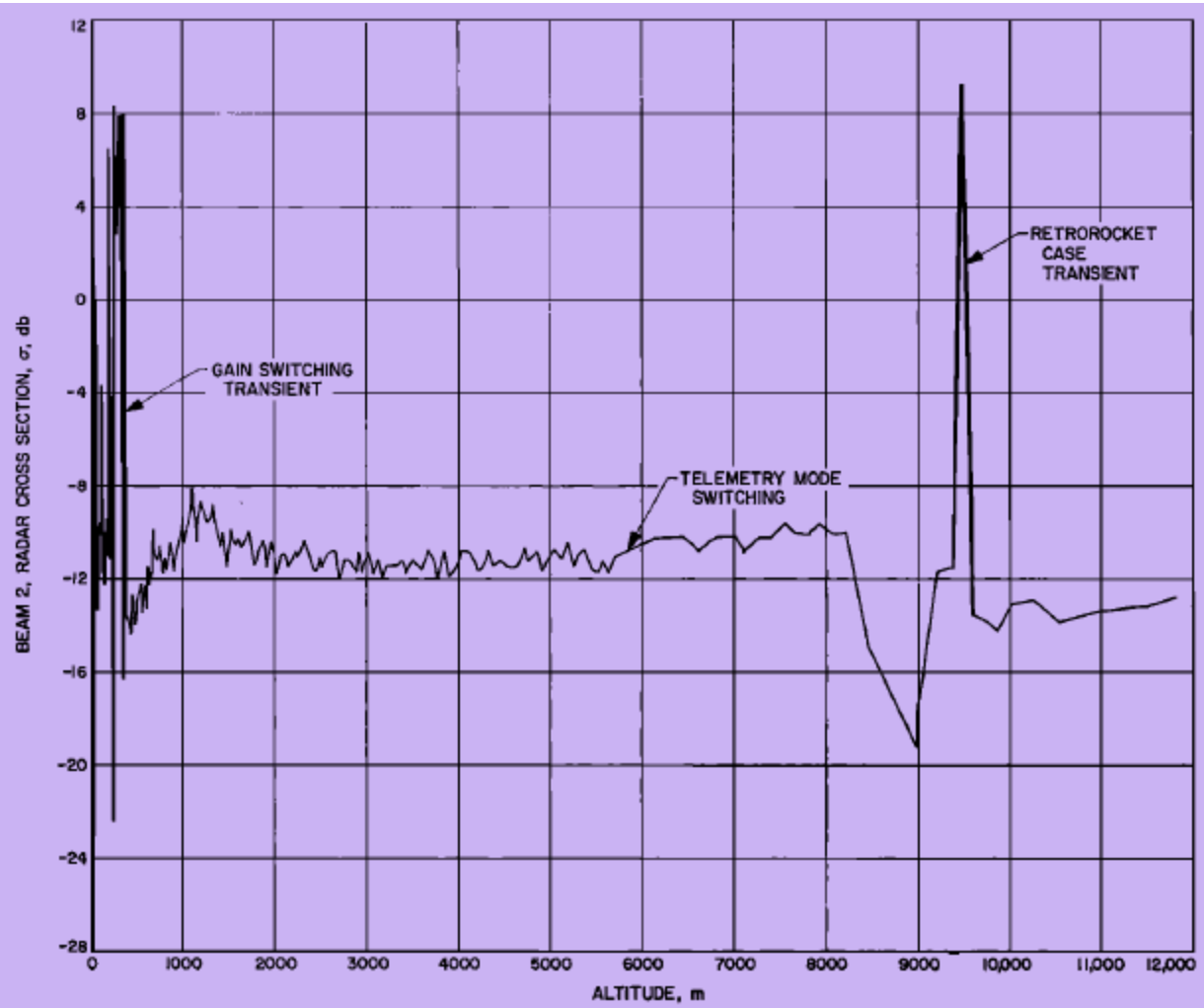


Fig. 4. Beam 2 radar cross section versus altitude.

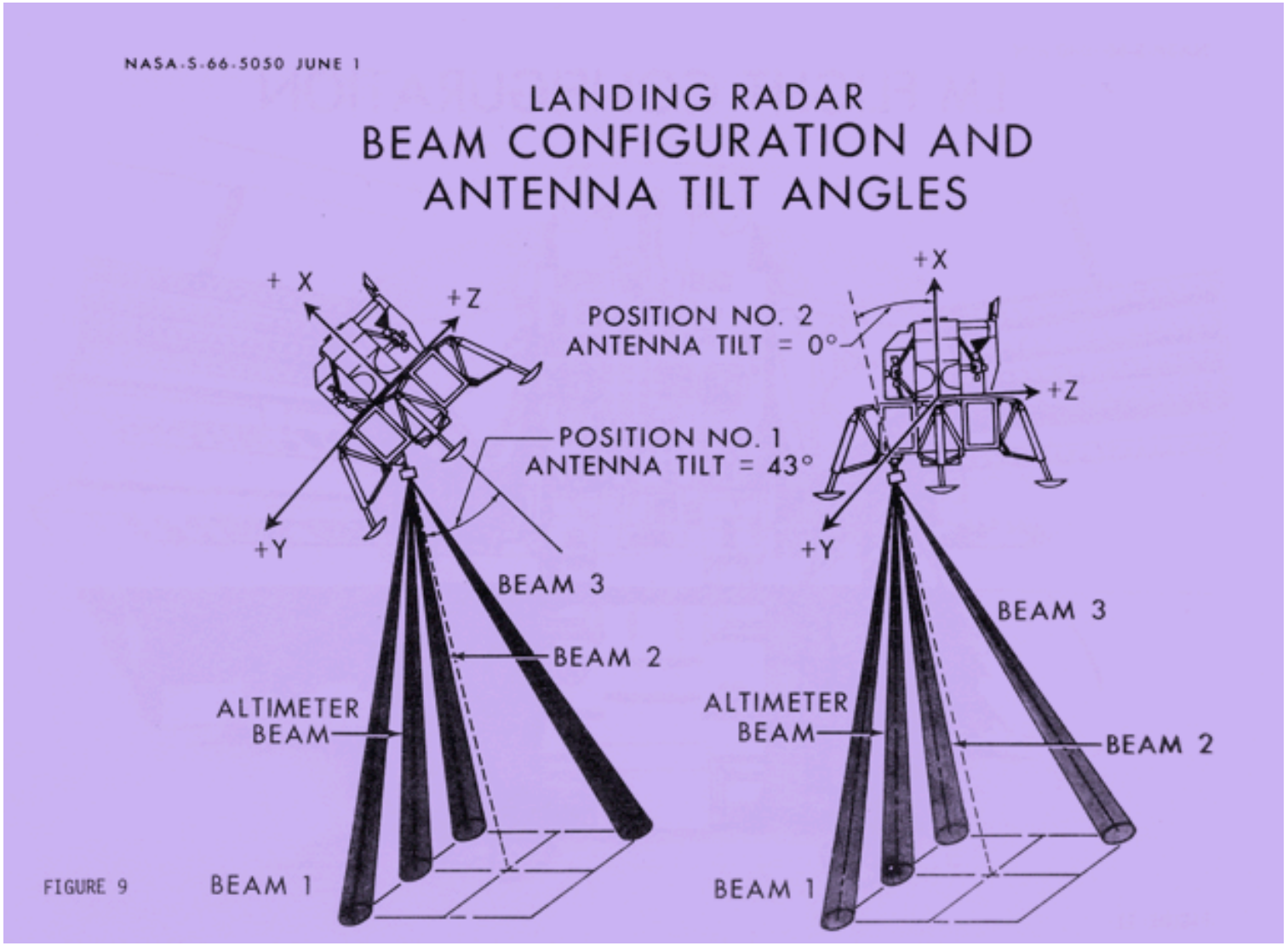
JOURNAL OF GEOPHYSICAL RESEARCH VOL. 72, NO. 2 JANUARY 15, 1967

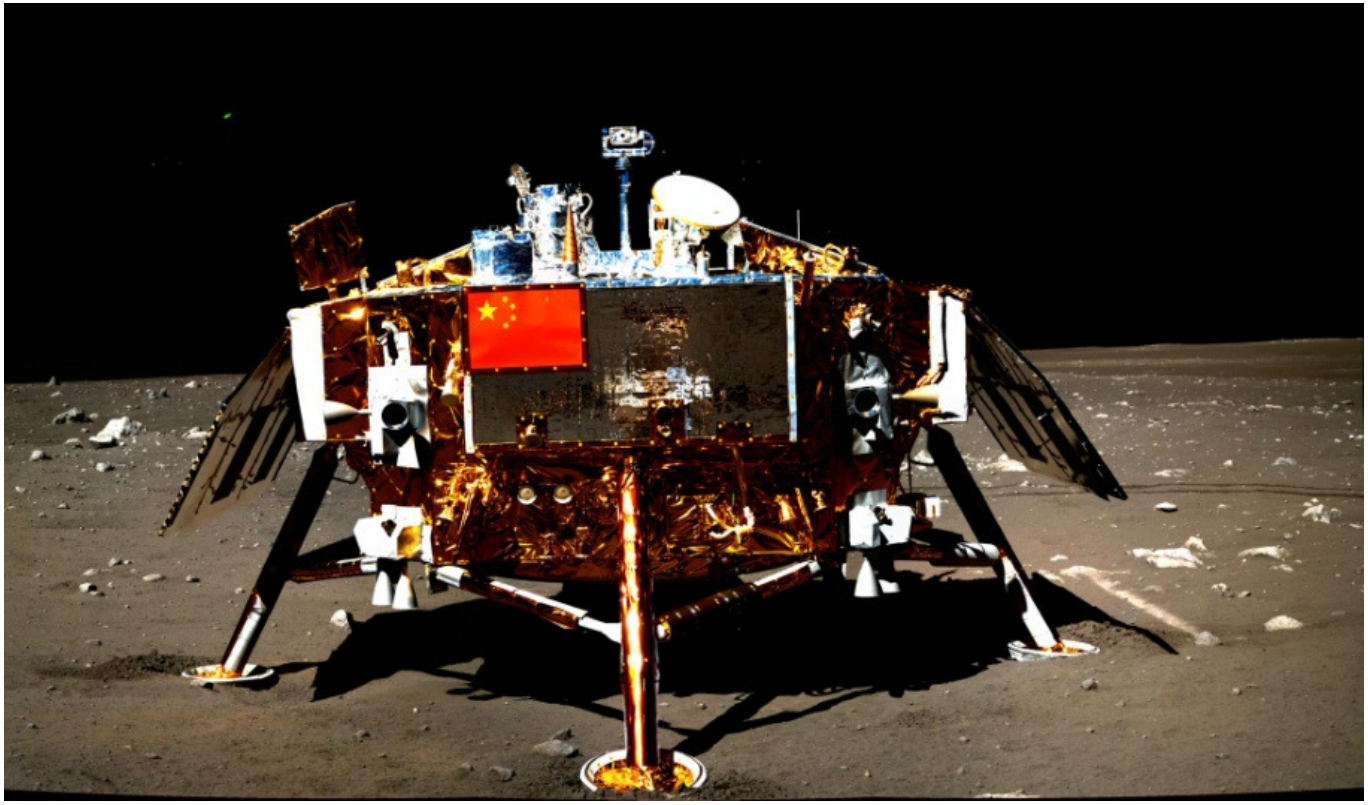
Brown ,

Lunar Surface Surveyor Radar Response

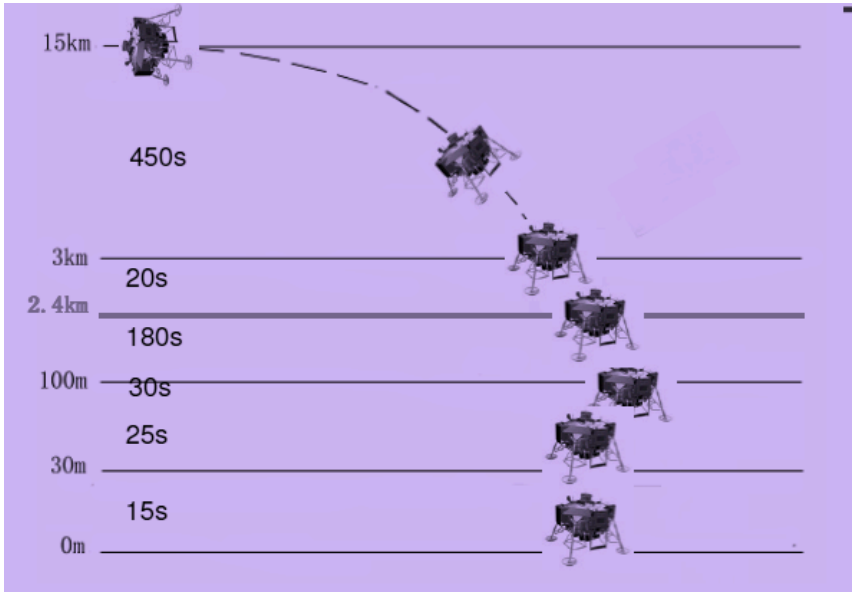
W. E. BROWN, JR.

Apollo system a little more sophisticated as wider attitude range (LM landed from orbit, so initially in horizontal orientation during retro firing)





Chang’e-3
Used lidar and a microwave range sensor
Optical imaging for hazard avoidance
(and Gamma Ray sensor for 4m engine cutoff !)
[Radar altimeters usually have minimum range]



Venera – 8 (Lavotchkin Museum, Moscow Photo
© Ralph Lorenz

Venera 8 Terrain Profile

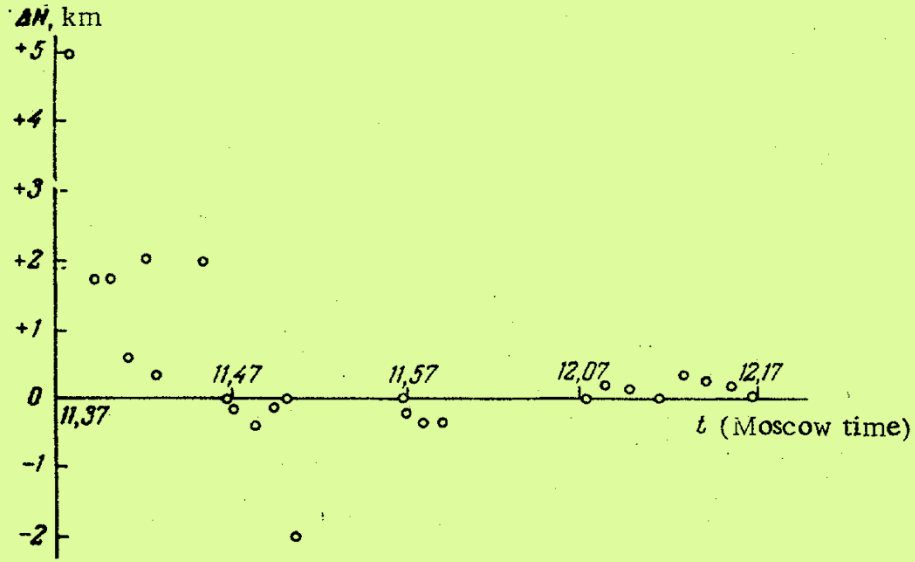


Fig. 1. Difference of altitudes, measured by radioaltimeter, and calculated from atmospheric temperature and pressure data, as a function of time.

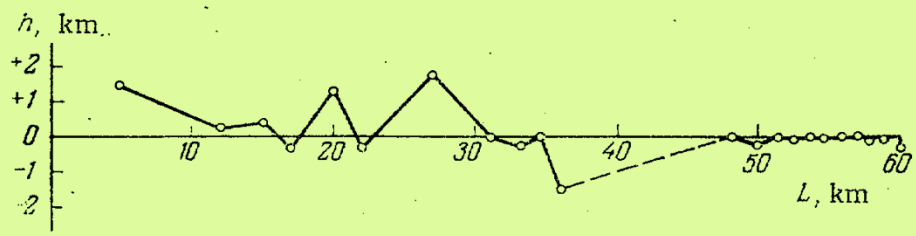
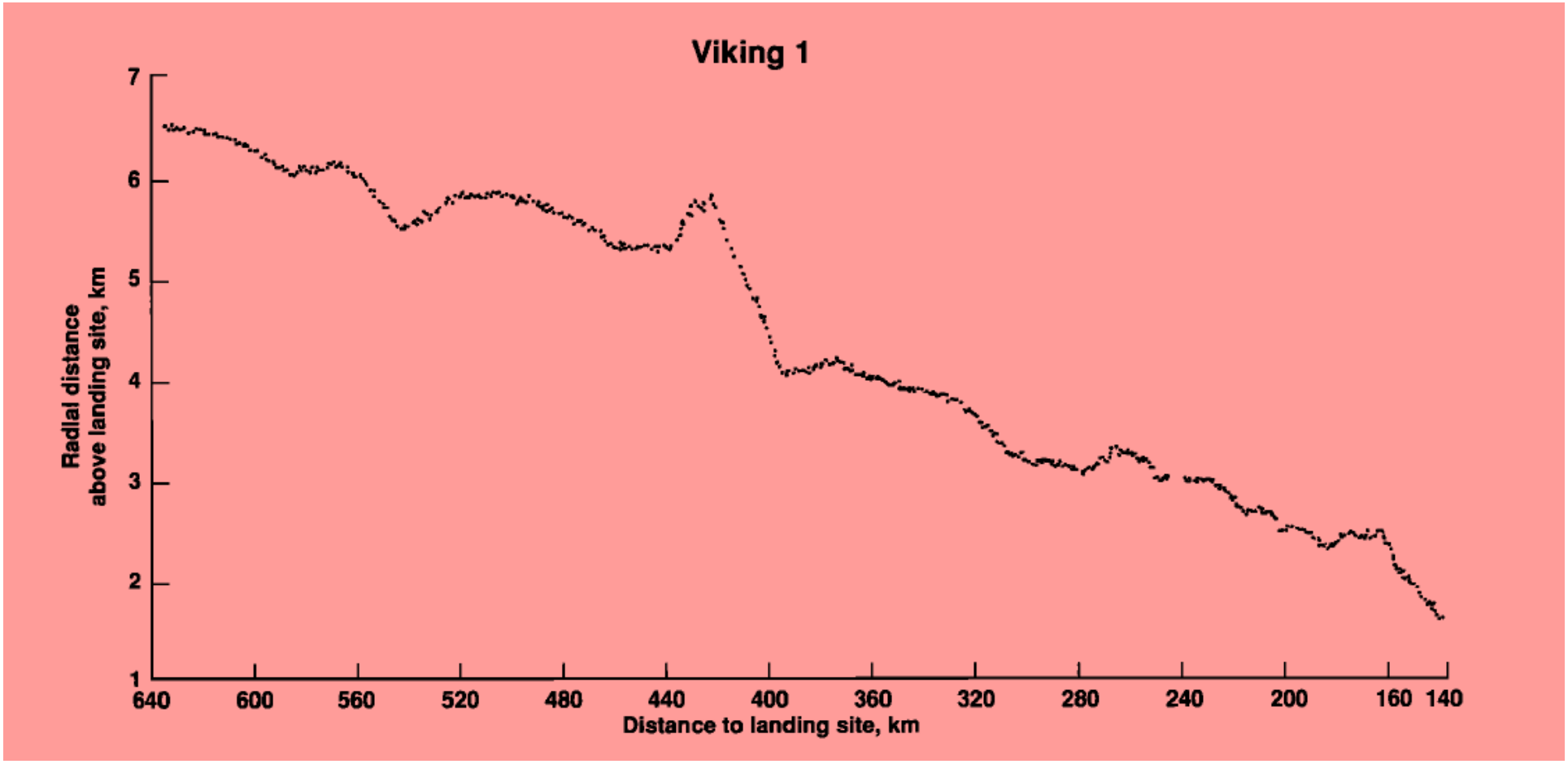


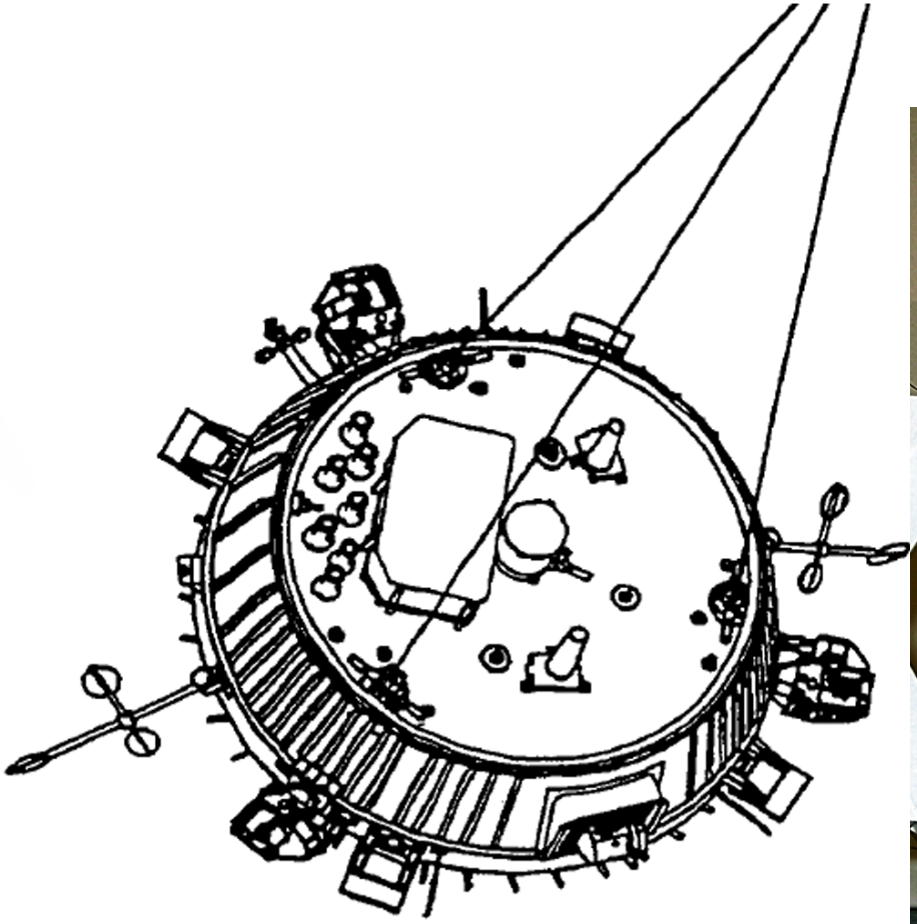
Fig. 2. The rugged profile of Venus' surface in the landing area along the descent vehicle's path.

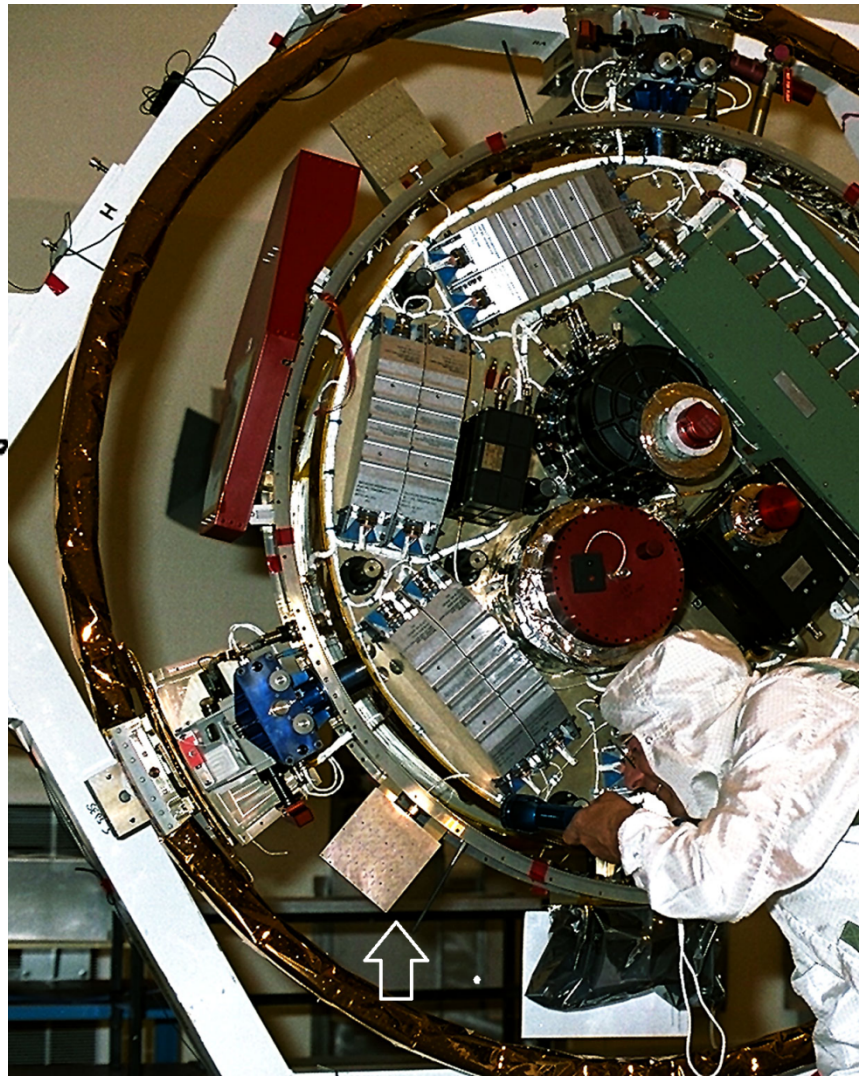
NB Venera 4 had a radar altimeter. Reported 26km altitude at start of descent (but was actually double that..)

Data initially misinterpreted. Vehicle only designed to survive to ~20 bar (ceased operation at 25km, 22bar, 277 C)

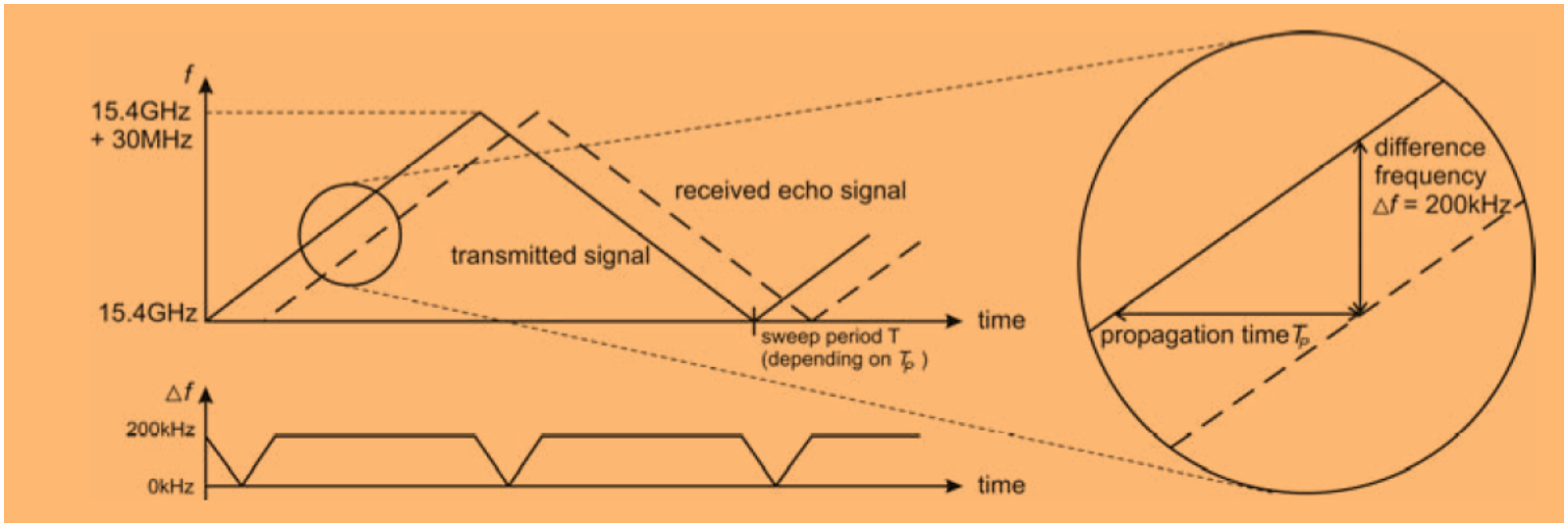


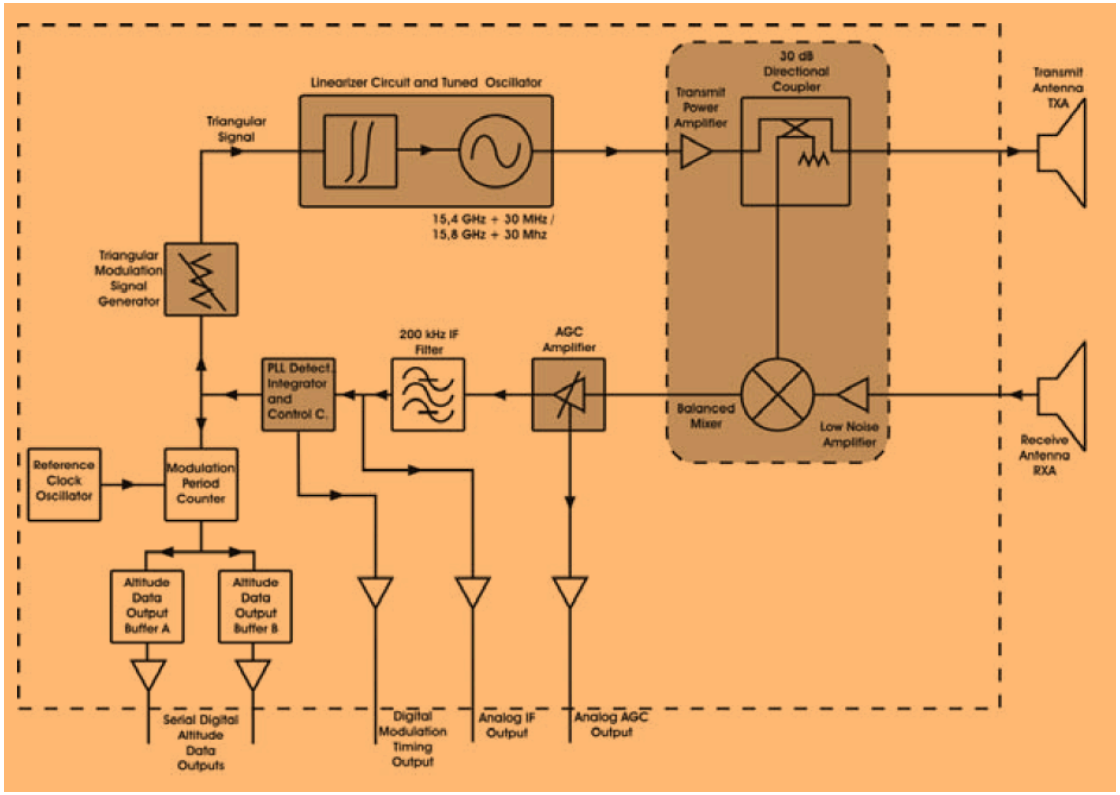
Viking lander made entry from orbit, so long shallow trajectory. Radar altimeter therefore provided usefully-long terrain profile

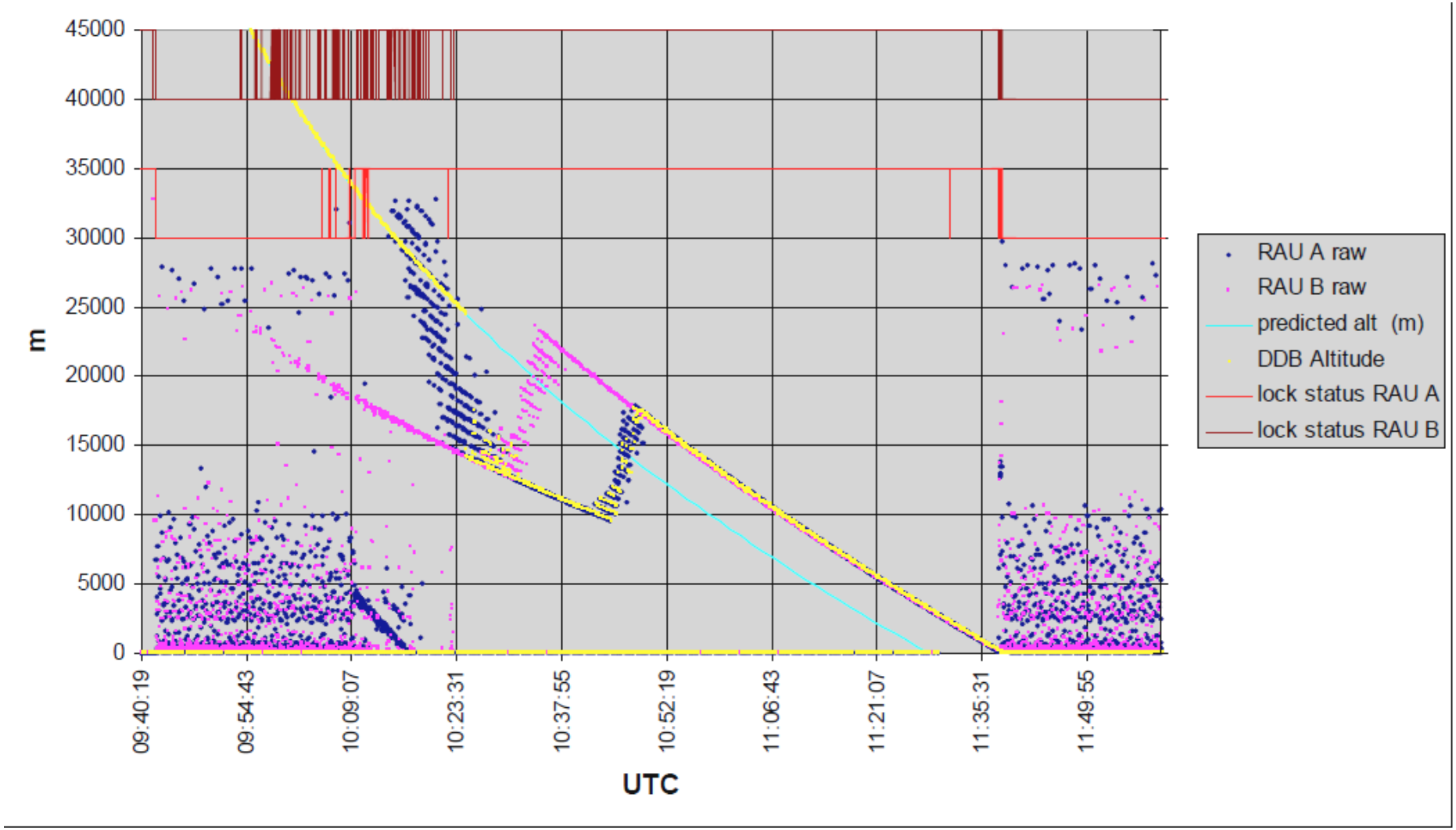




Huygens Probe
Redundant FMCW radar altimeters

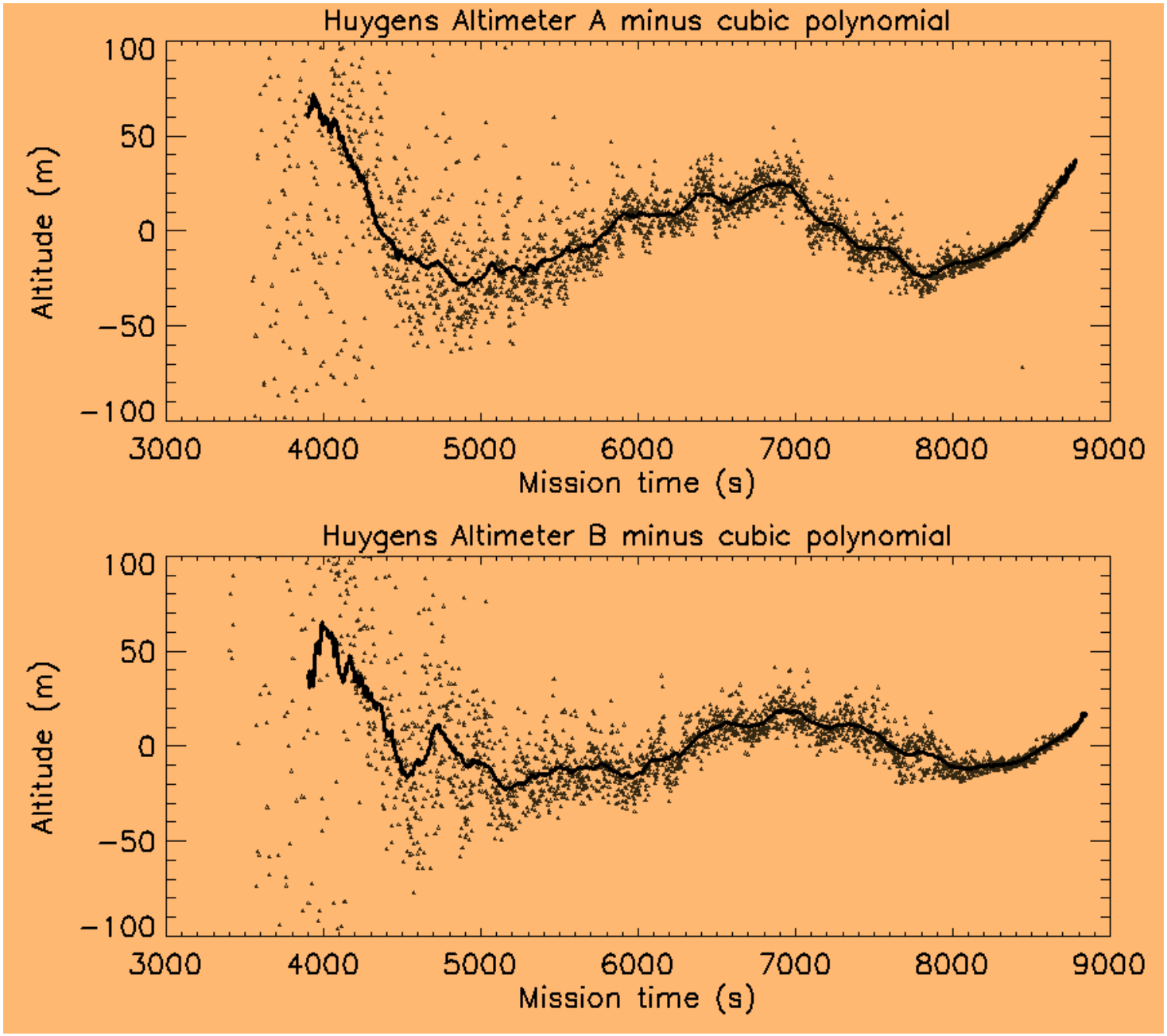

f
15.4GHz
+ 30MHz
15.4GHz
received echo signal
transmitted signal
time
sweep period T
(depending on T_p)
difference
frequency
Δf = 200kHz
propagation time T_p
Δf
200kHz
0kHz
time

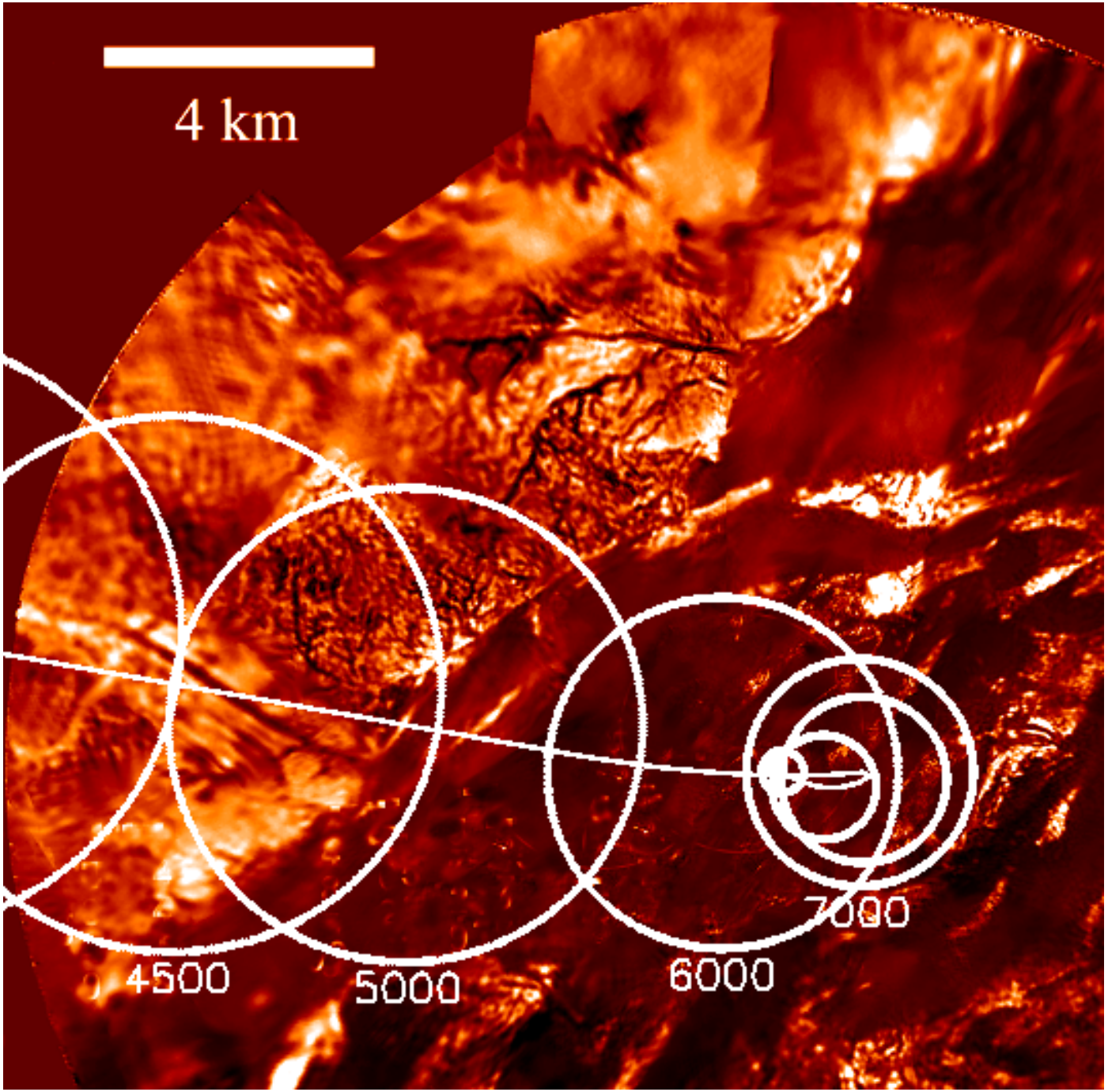

Linearizer Circuit and Tuned Oscillator
Triangular Signal
15,4 GHz + 30 MHz /
15,8 GHz + 30 Mhz
30 dB Directional Coupler
Transmit Power Amplifier
Transmit Antenna TXA
Triangular Modulation Signal Generator
200 kHz IF Filter
AGC Amplifier
PLL Detect. Integrator and Control C.
Balanced Mixer
Low Noise Amplifier
Receive Antenna RXA
Reference Clock Oscillator
Modulation Period Counter
Altitude Data Output Buffer A
Altitude Data Output Buffer B
Serial Digital Altitude Data Outputs
Digital Modulation Timing Output
Analog IF Output
Analog AGC Output

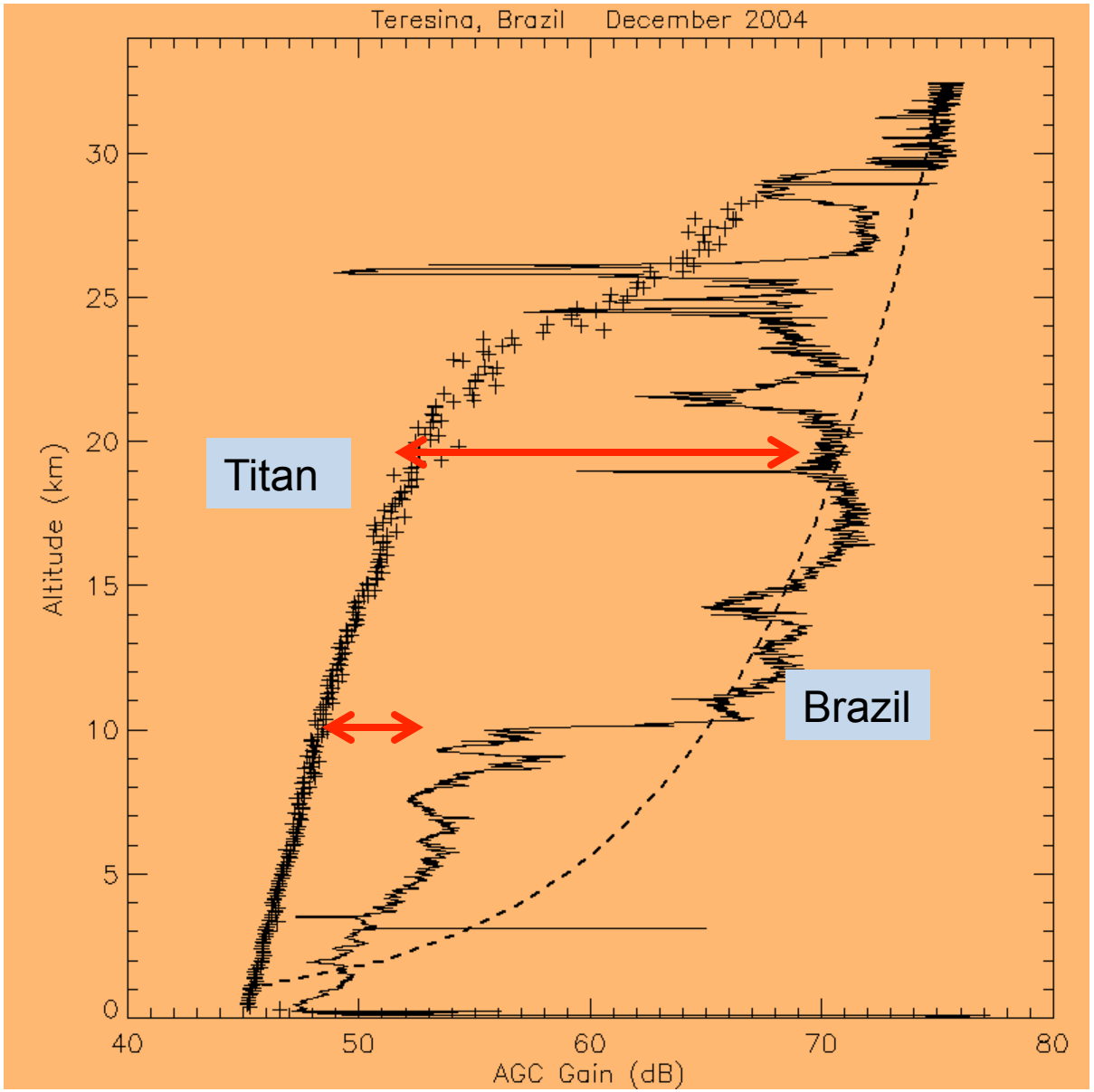


Formal requirement – mark 10km altitude to trigger camera operations. Science desired early switch-on for radar investigations

Digital circuit error (discovered very late) allowed false lock on Altitude/2. On-board logic switched from predicted profile to altimeter signals when both altimeters locked incorrectly! RAU-A recovered at ~23km, but was outvoted until RAU-B recovered just in time….


Huygens Altimeter A minus cubic polynomial
Altitude (m)
100
50
0
−50
−100
3000
4000
5000
6000
7000
8000
9000
Mission time (s)
Huygens Altimeter B minus cubic polynomial
Altitude (m)
100
50
0
−50
−100
3000
4000
5000
6000
7000
8000
9000
Mission time (s)

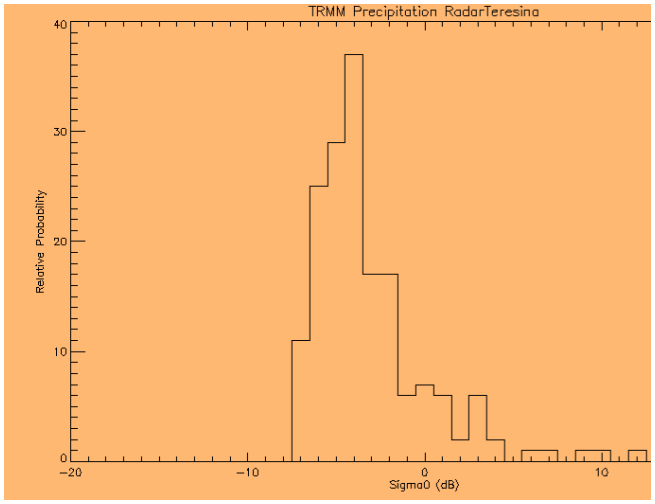

4 km
4500
5000
6000
7000

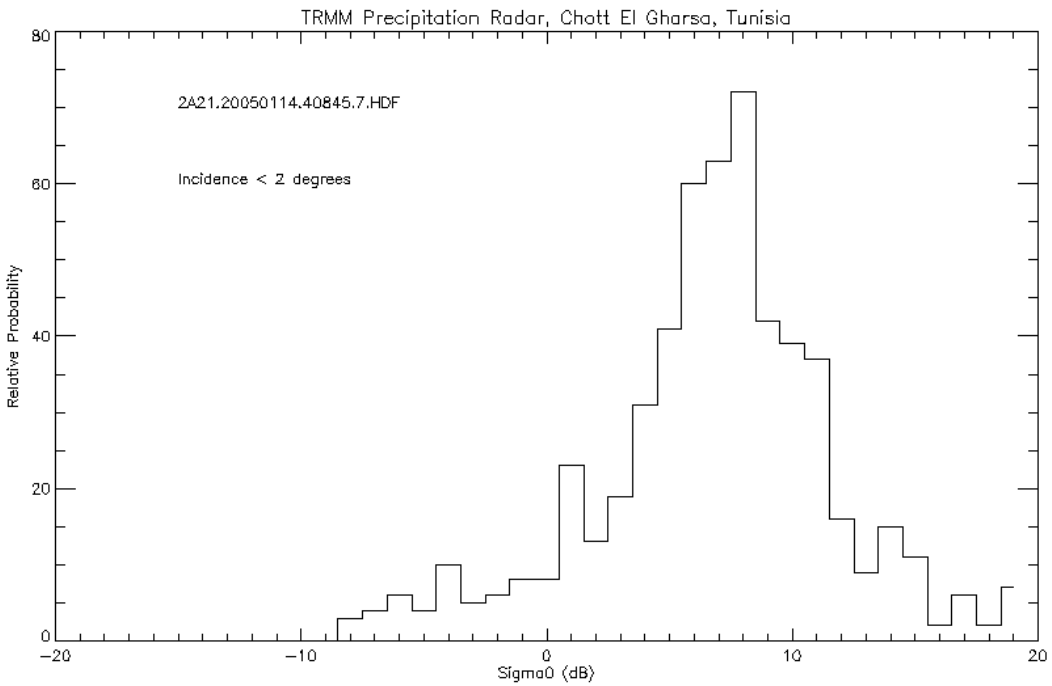


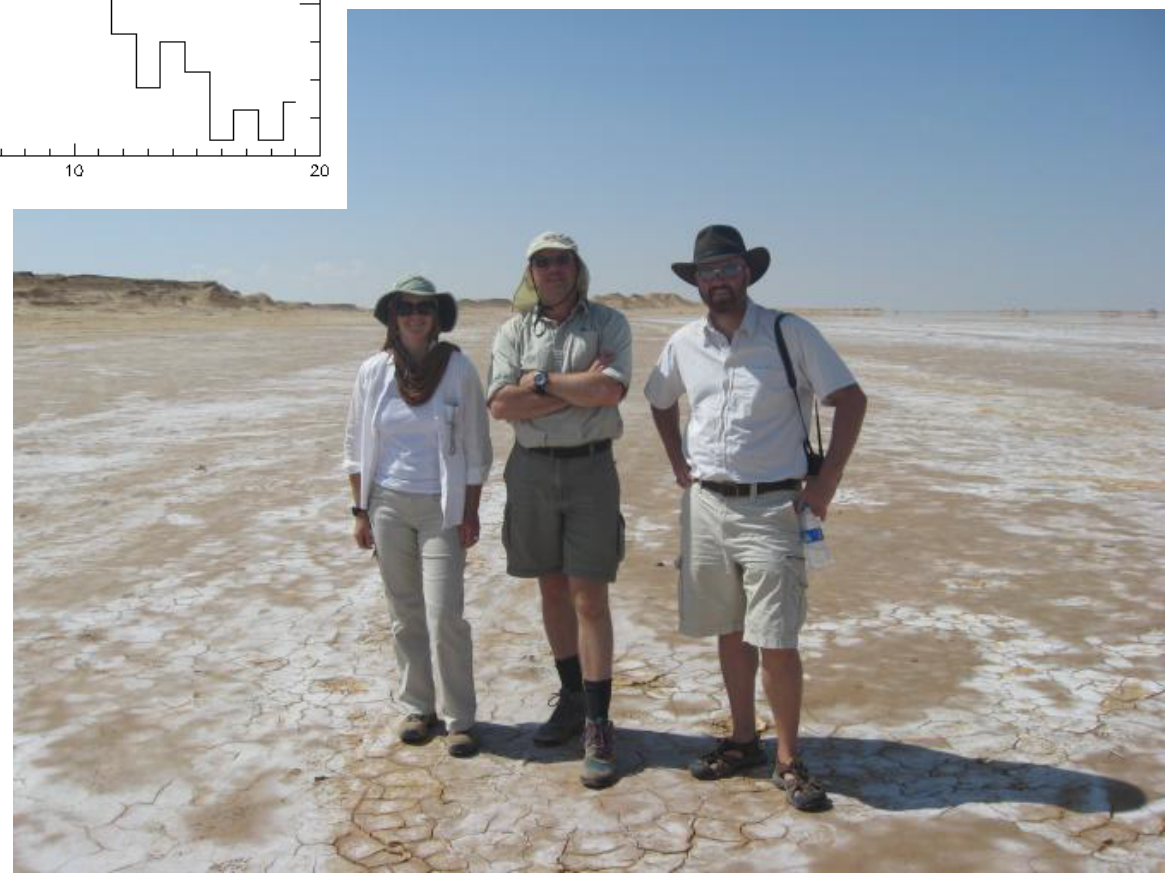
No formal scatterometer calibration, but AGC voltage in telemetry gives an indication of reflectivity

Titan surface ~17dB brighter than typical Brazil (-7dB -→ +10dB)

~5dB brighter than airstrip





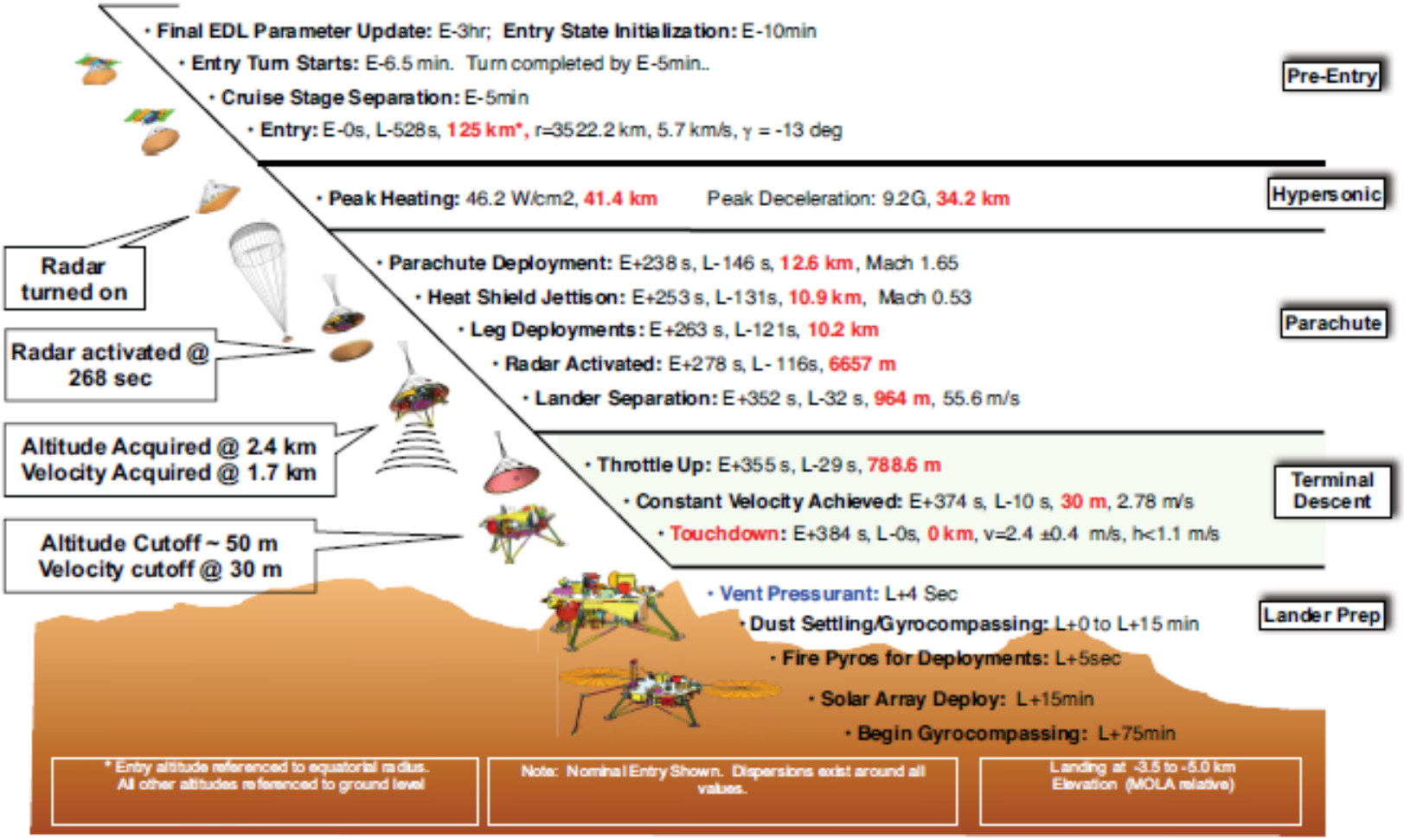


Is this part of Titan like clay pan/salt flats (Chott, playa etc. ?)

Or is another scattering mechanism responsible for the brightness?

Phoenix

EDL Timeline Overview



Copyright 2008, California Institute of Technology. Government sponsorship acknowledged.

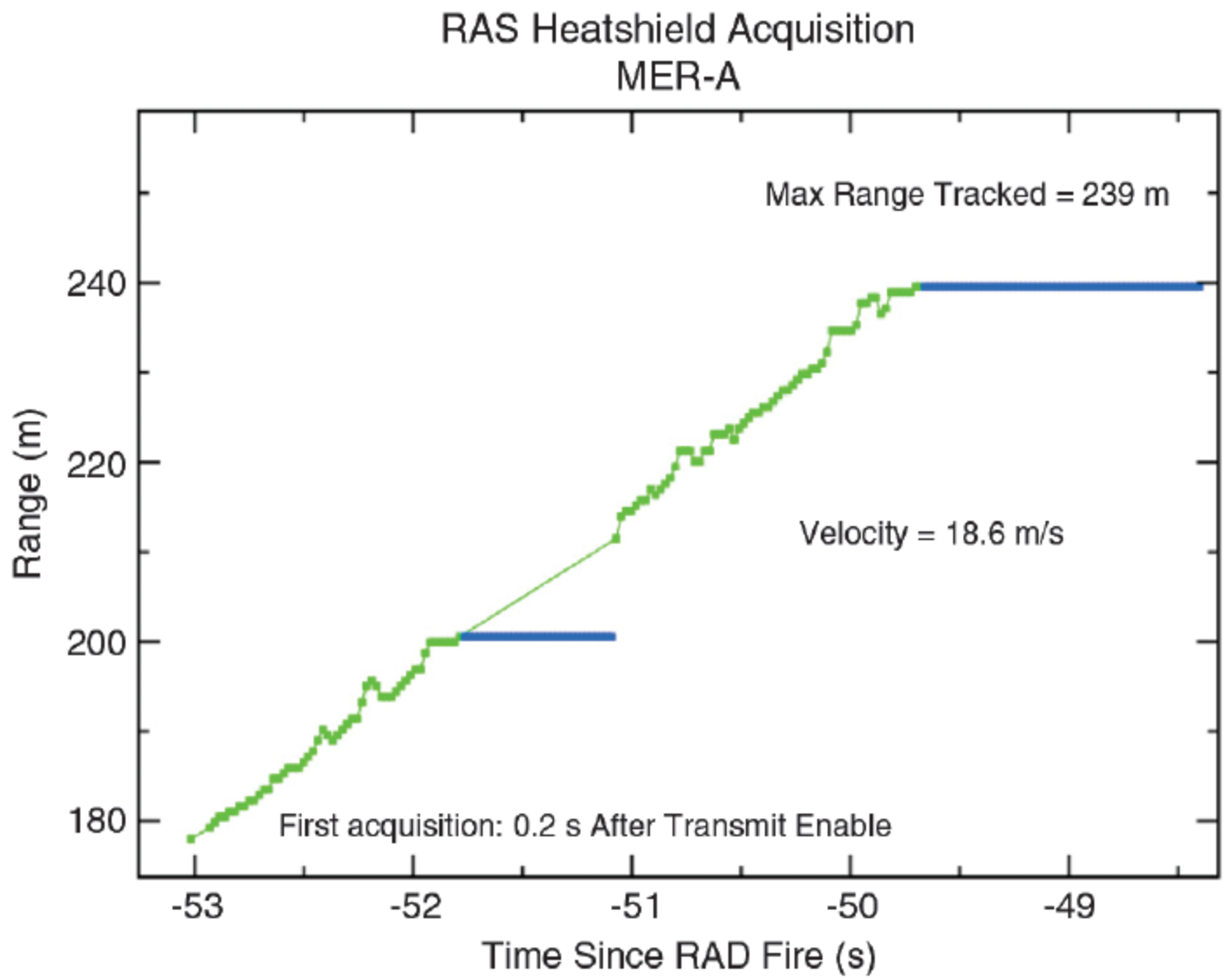
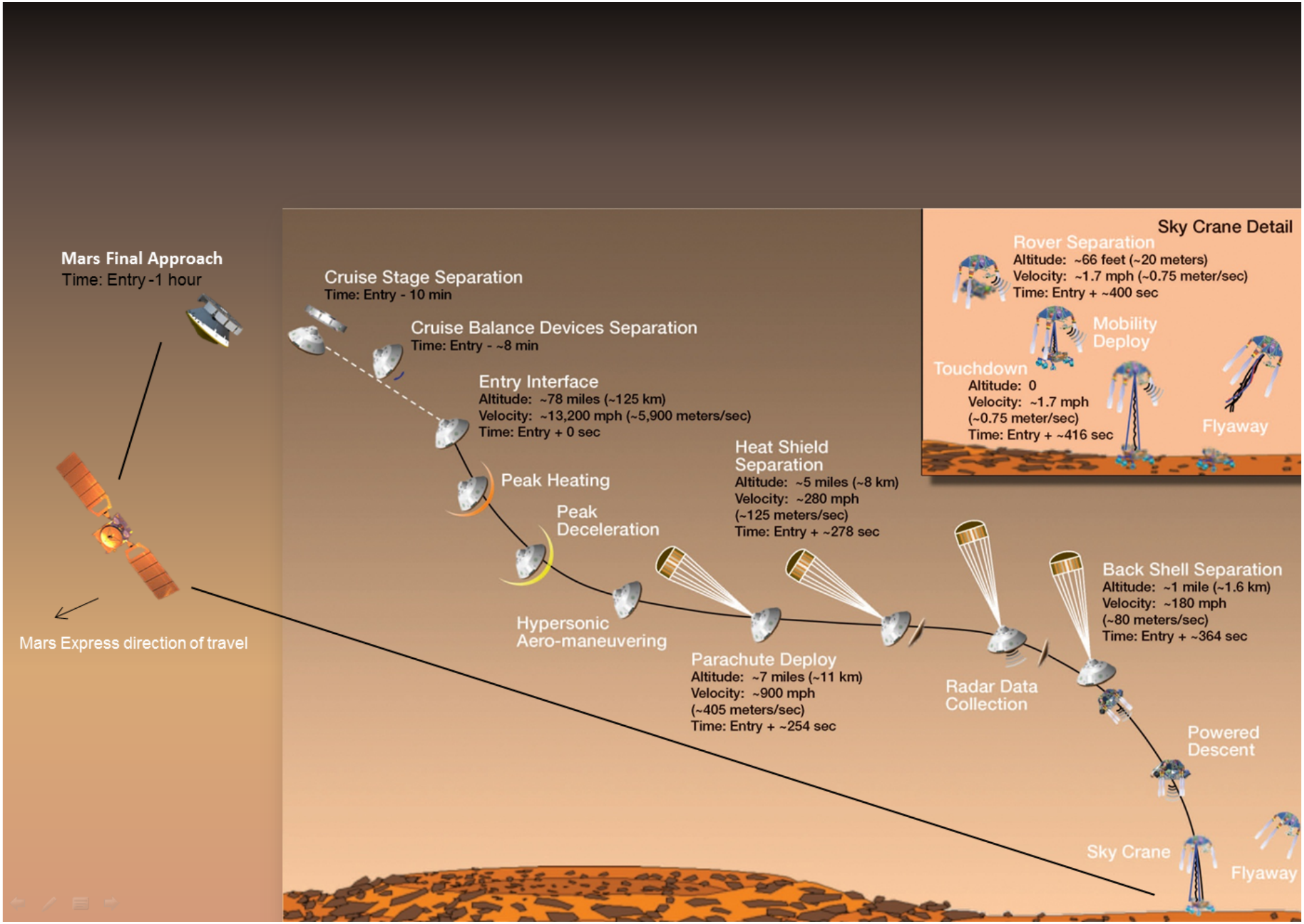


Fig. 2 MER EDL: Green and blue points show RAS measurements from Spirit's EDL.


Mars Final Approach
Time: Entry -1 hour
Mars Express direction of travel
Cruise Stage Separation
Time: Entry - 10 min
Cruise Balance Devices Separation
Time: Entry - ~8 min
Entry Interface
Altitude: ~78 miles (~125 km)
Velocity: ~13,200 mph (~5,900 meters/sec)
Time: Entry + 0 sec
Peak Heating
Peak Deceleration
Hypersonic Aero-maneuvering
Heat Shield Separation
Altitude: ~5 miles (~8 km)
Velocity: ~280 mph
(~125 meters/sec)
Time: Entry + ~278 sec
Parachute Deploy
Altitude: ~7 miles (~11 km)
Velocity: ~900 mph
(~405 meters/sec)
Time: Entry + ~254 sec
Radar Data Collection
Back Shell Separation
Altitude: ~1 mile (~1.6 km)
Velocity: ~180 mph
(~80 meters/sec)
Time: Entry + ~364 sec
Powered Descent
Sky Crane
Flyaway
Sky Crane Detail
Rover Separation
Altitude: ~66 feet (~20 meters)
Velocity: ~1.7 mph (~0.75 meter/sec)
Time: Entry + ~400 sec
Mobility Deploy
Touchdown
Altitude: 0
Velocity: ~1.7 mph
(~0.75 meter/sec)
Time: Entry + ~416 sec
Flyaway

Requirement	Value
Altitude Range of Operation	10 m – 3500 m
Beam LOS Velocity (V) Range of Operation	-20 m/s – 160 m/s
Radar Beam Off-nadir Angle Range of Operation	0 – 60 deg.
Fraction of Valid Data in Operational Envelope	95%
Range Measurement Precision	2% of beam LOS range
Maximum Range Bias	0.5 m
Velocity Measurement Precision	0.75% V + 0.2 m/s
Maximum Velocity Bias	0.03 m/s
Maximum Velocity Scale Factor	0.25% V

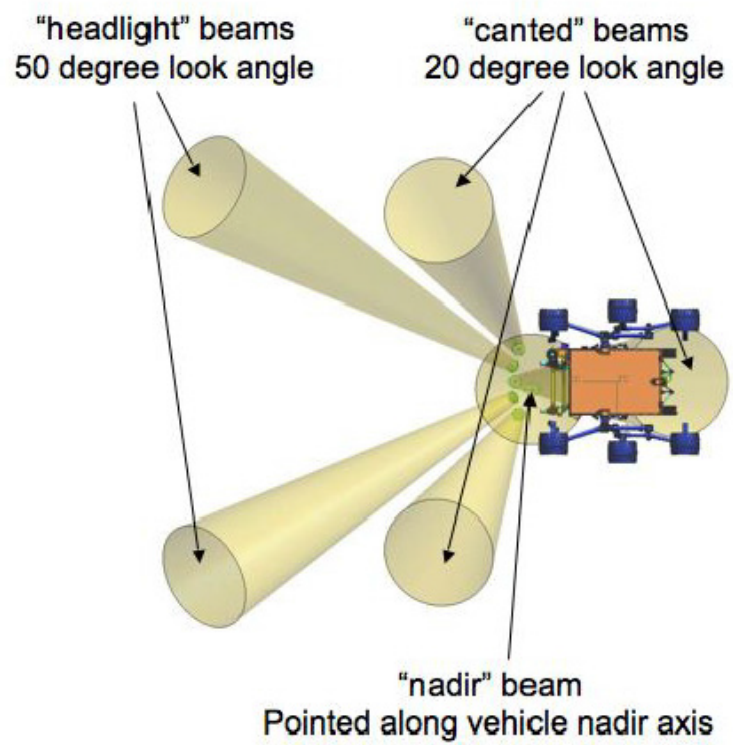
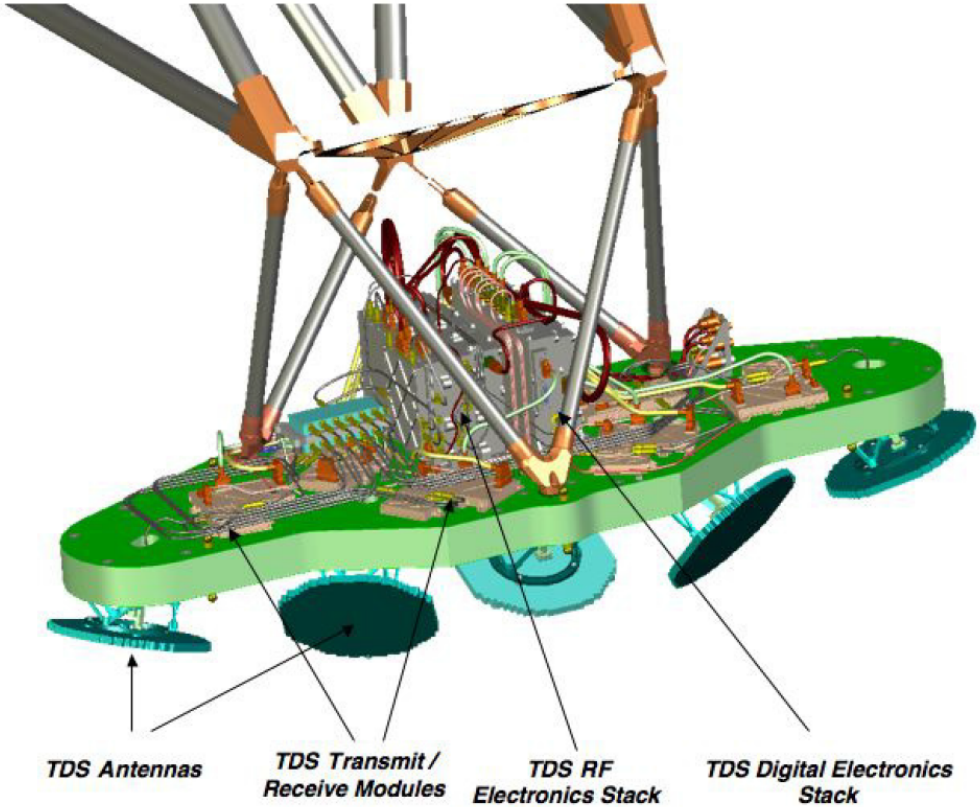
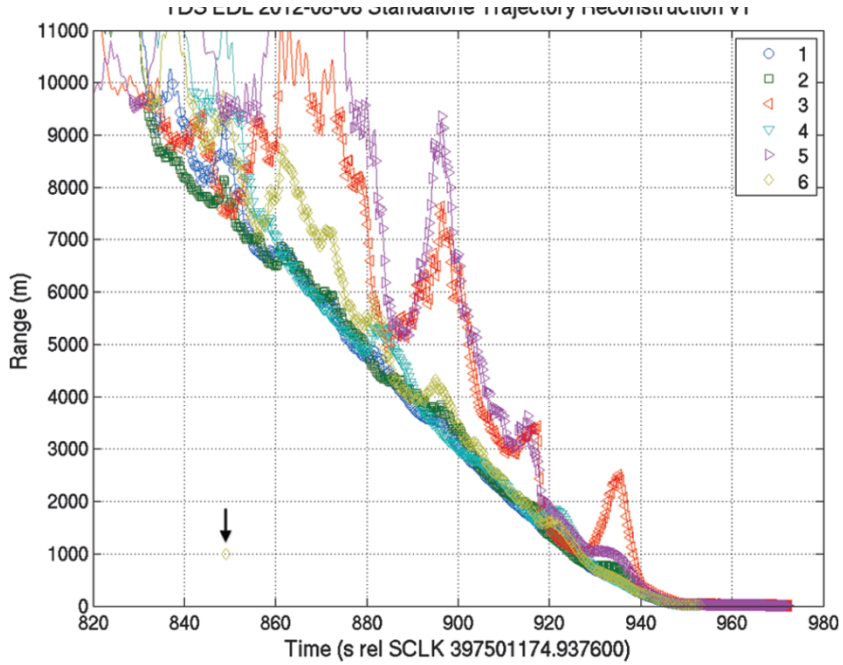


Table 2 Key radar parameters

Parameter	Value
Number of beams/antennas	6
Center frequency	35.75 GHz
Wavelength	8.3858 mm
Antenna diameter (per beam)	0.22 m
Peak radiated power (per beam)	2 W
Measurement update rate	20 Hz
Pulse width	4 ns to 16 μs
Pulse repetition interval	75 to 250 μs

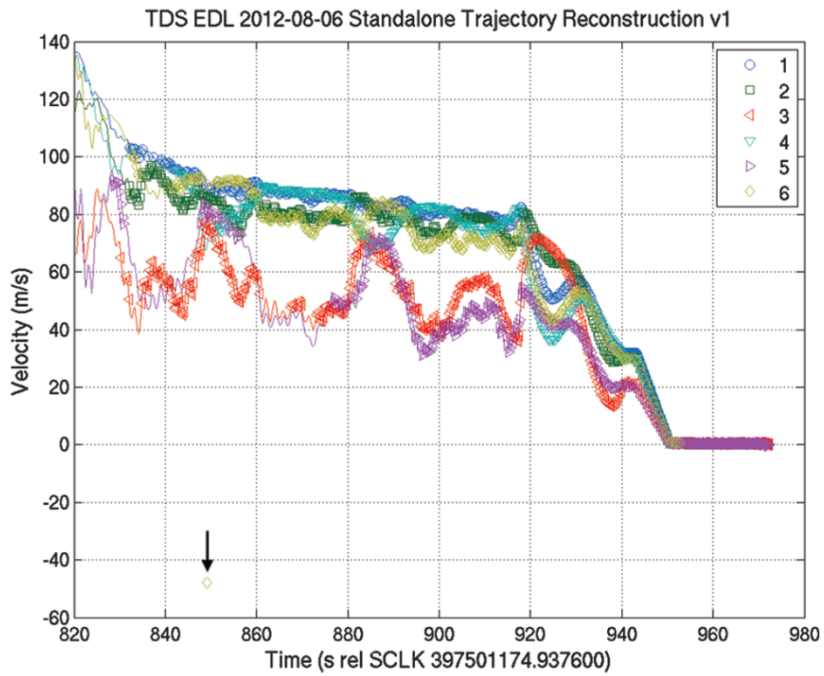




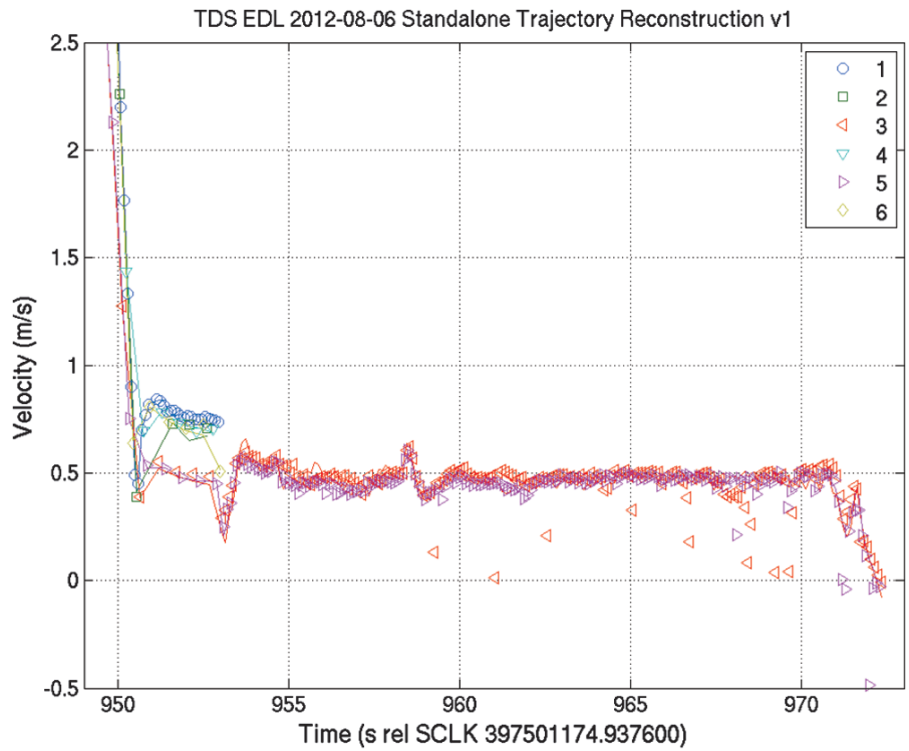
a)

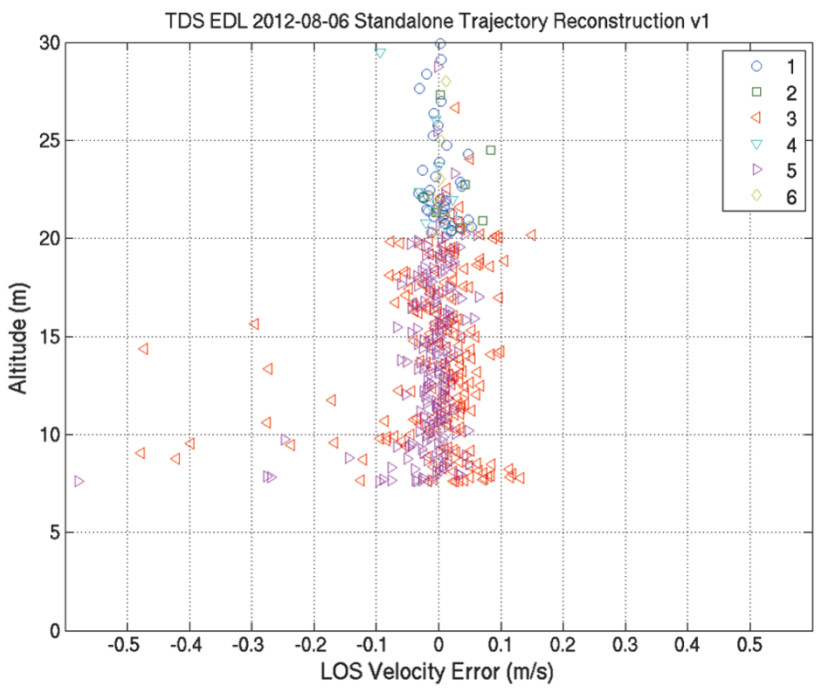
Rich MSL data shows good EDL performance

One spurious datapoint (arrowed), presumably heatshield

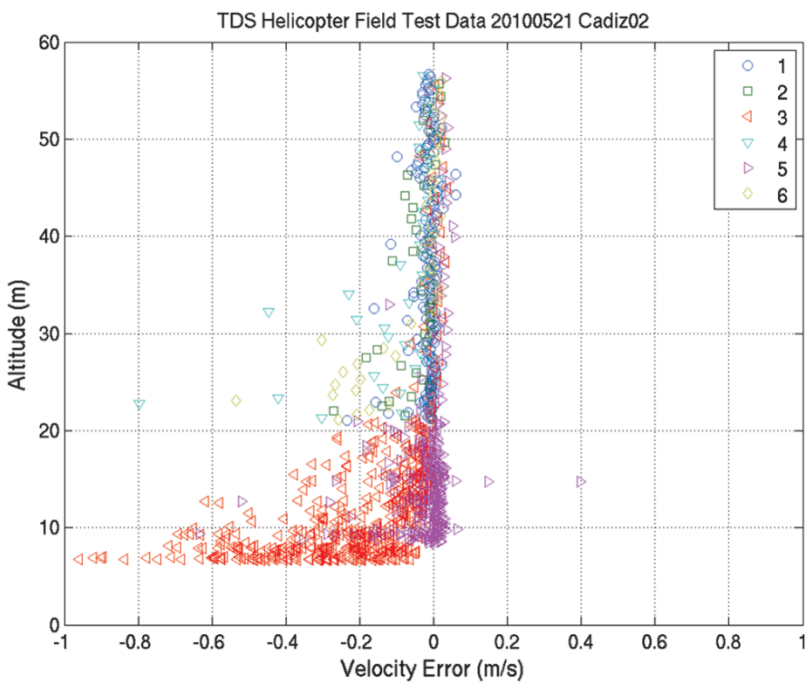


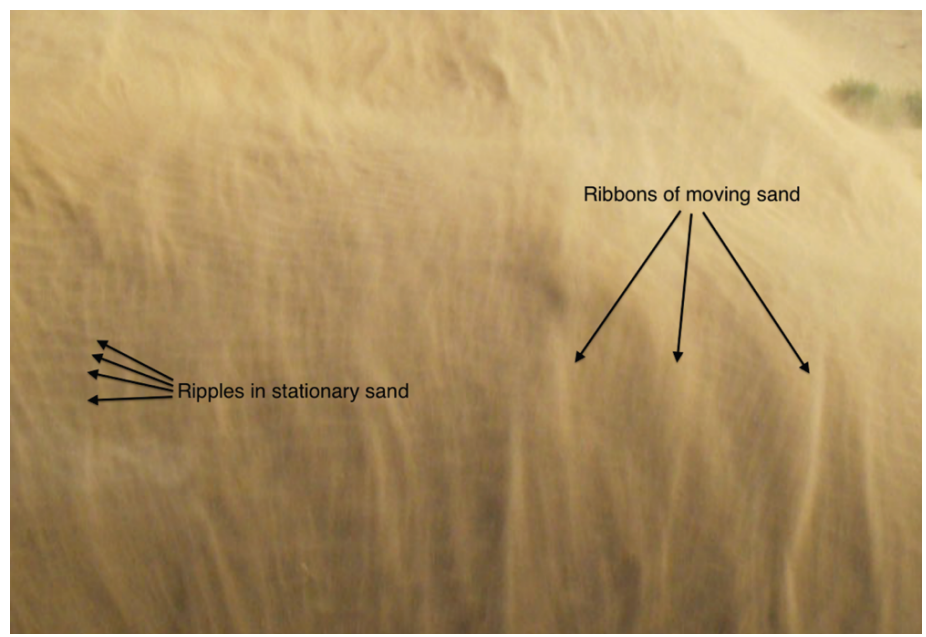
b)

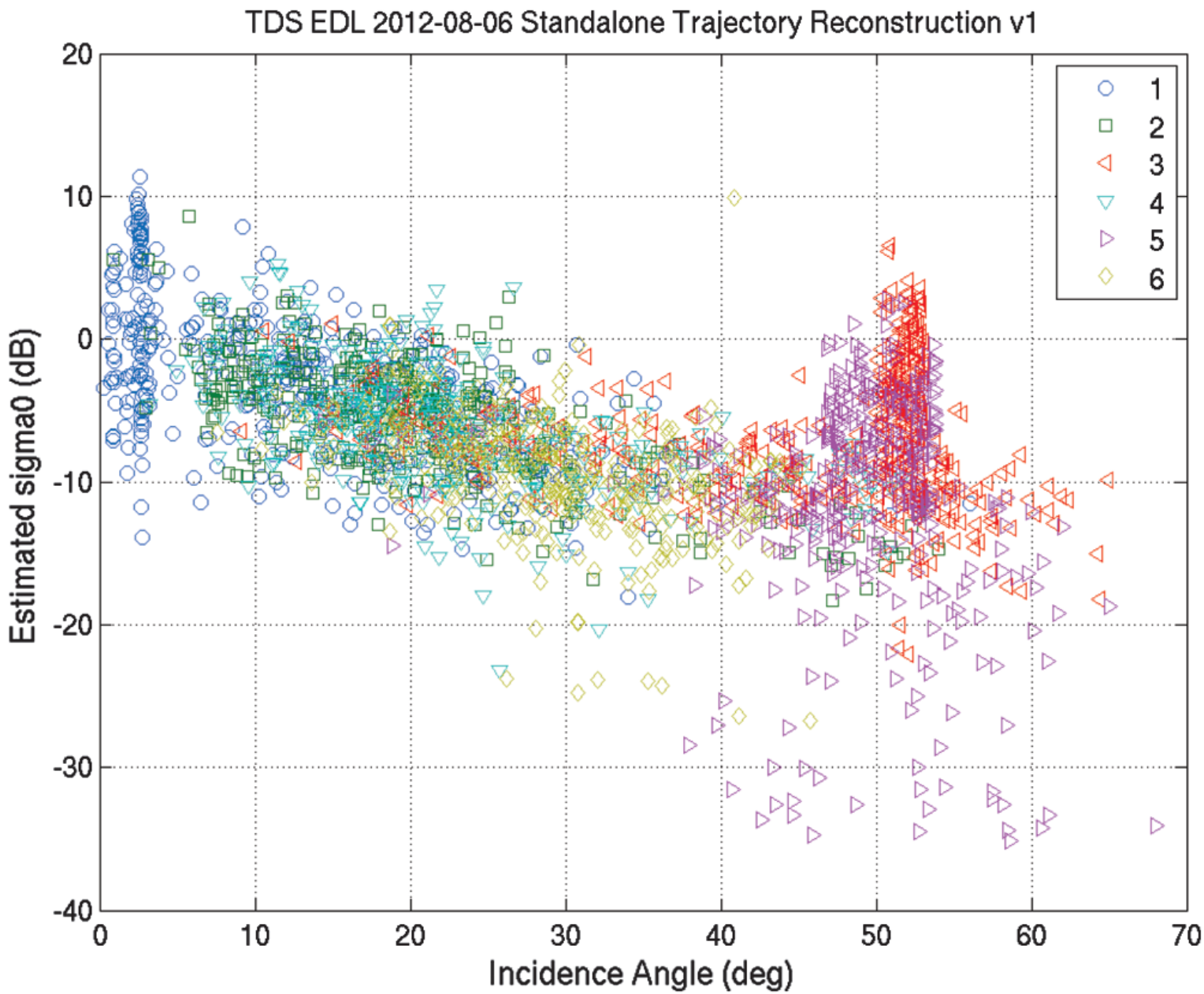




MSL/Curiosity Ka-band Radar is sensitive to sand particles. Moving sand in helicopter downwash gave spurious velocity indications at lowest altitude in field tests






TDS EDL 2012-08-06 Standalone Trajectory Reconstruction v1
Estimated sigma0 (dB)
Incidence Angle (deg)
20
10
0
-10
-20
-30
-40
0
10
20
30
40
50
60
70
1
2
3
4
5
6

Lander Radars

Still the best way to control descent and trigger operations on Mars, large airless bodies.

Can avoid on Venus/Titan, IF terrain is known well enough and accuracy requirement is modest (use pressure altimeter instead).

Radars have not infrequently encountered anomalies (spurious lock), considerable testing/simulation effort required to work around. So avoid a radar if you don't need one.

If you do carry one, telemeter/archive/release the data – it has scientific value! (Luna-18 sample return mission crashed in rugged terrain – but scientific results from its radar altimeter were published !)