IPPW Short Course

Jet Propulsion Laboratory
California Institute of Technology

Bistatic Radar Probing of Planetary Surfaces

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1 MaRS = Mars Express Radio Science Team

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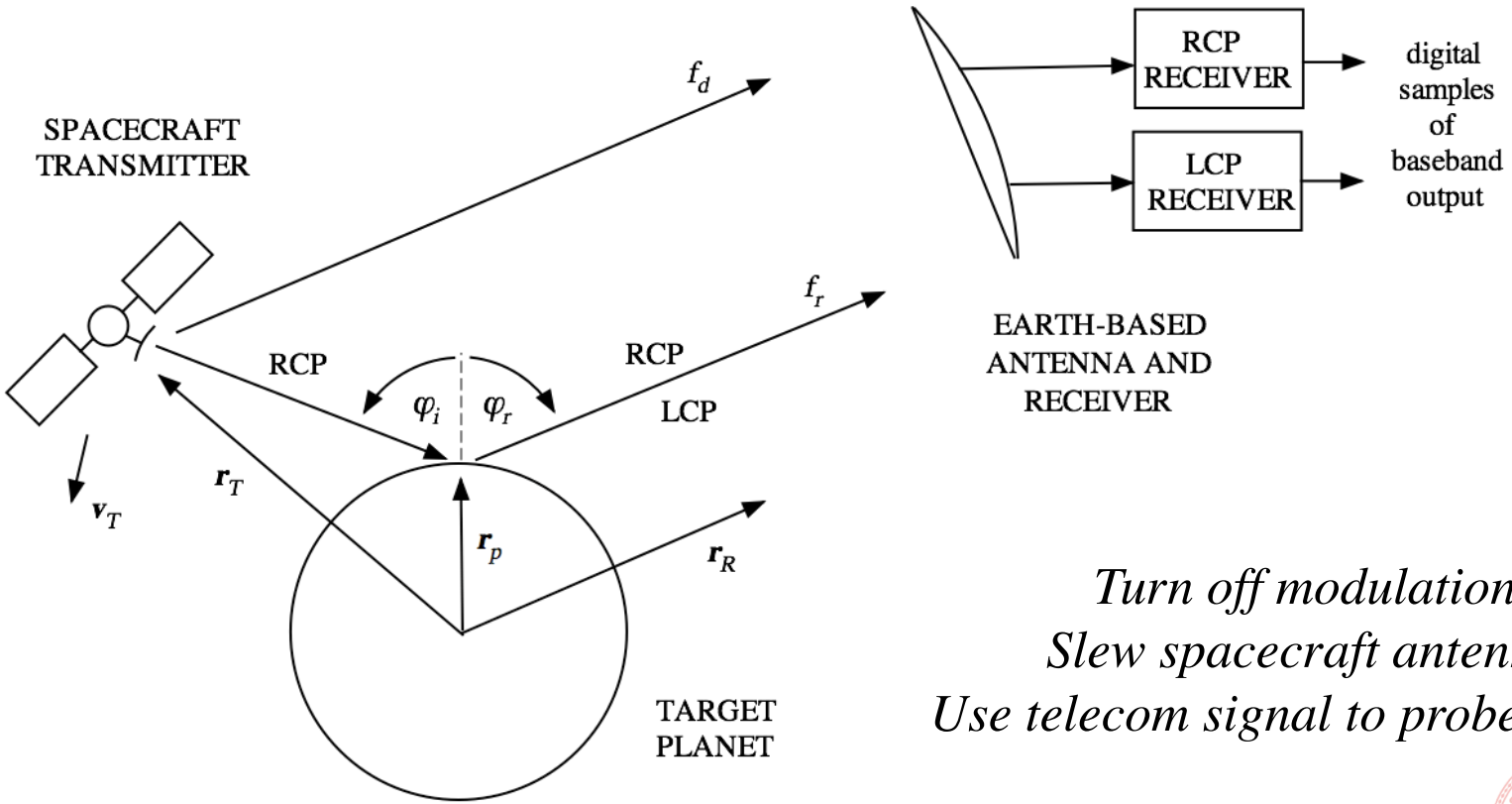
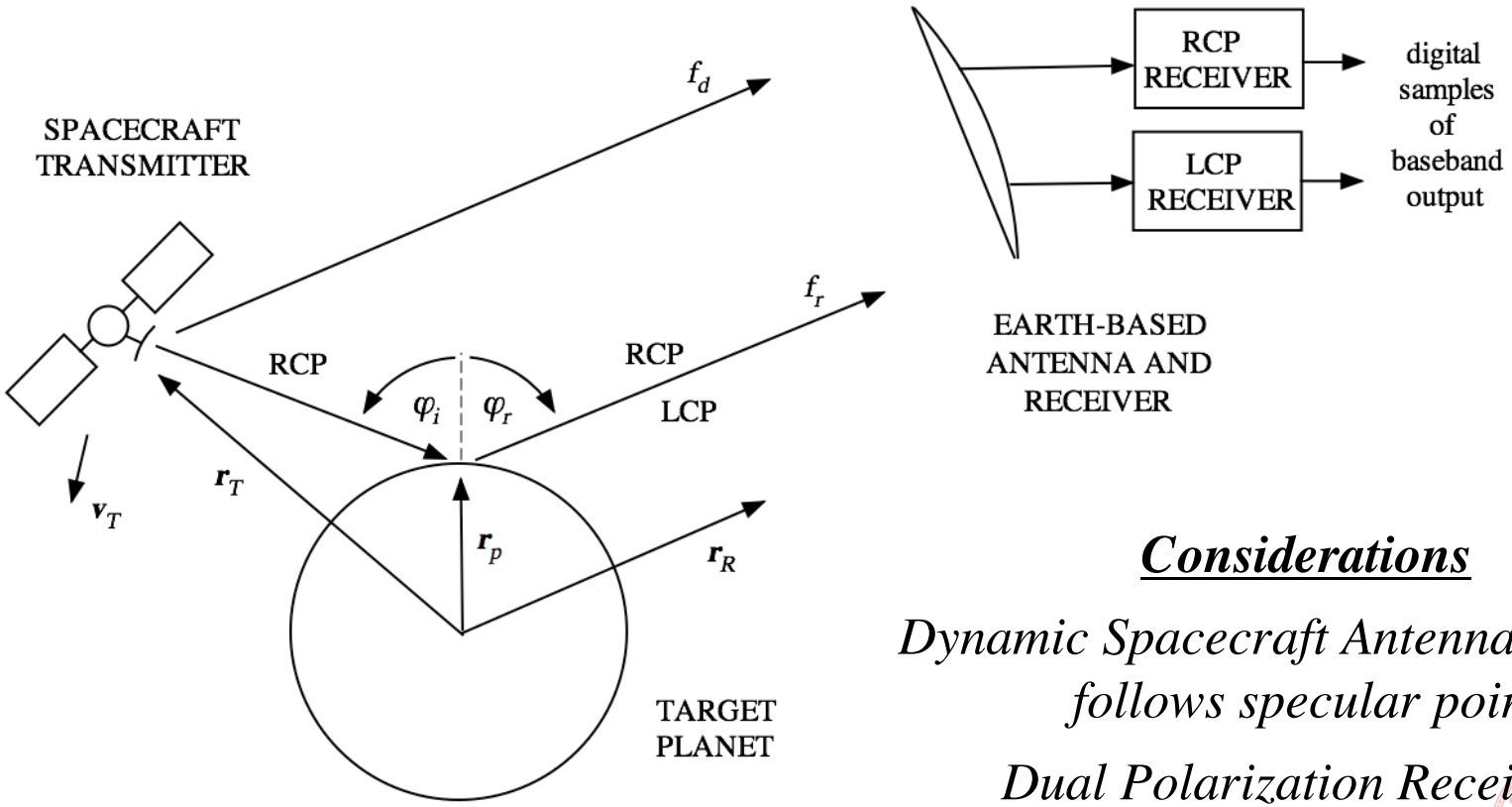
Bistatic Radar — Overview



Turn off modulation
Slew spacecraft antenna
Use telecom signal to probe surface

Bistatic Radar — Operations



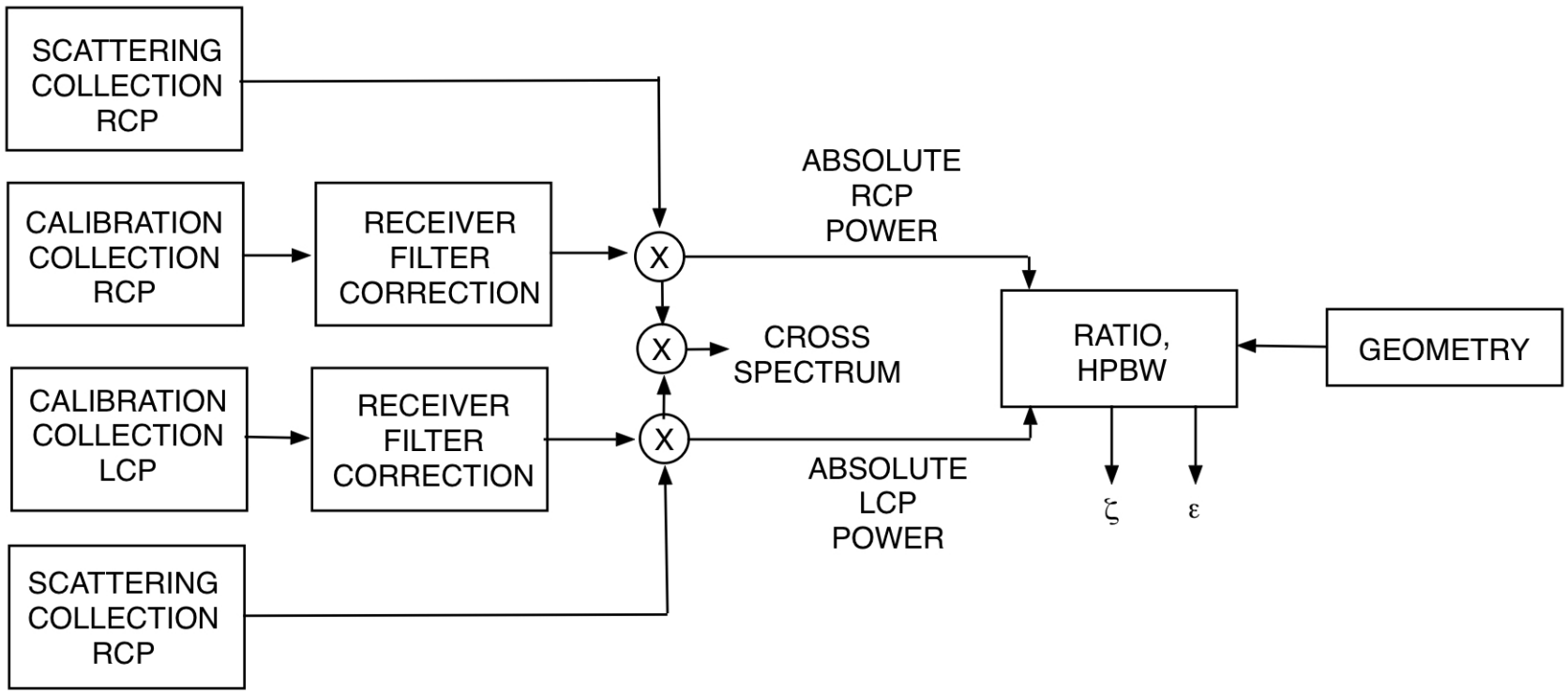
Considerations

Dynamic Spacecraft Antenna Pointing follows specular point

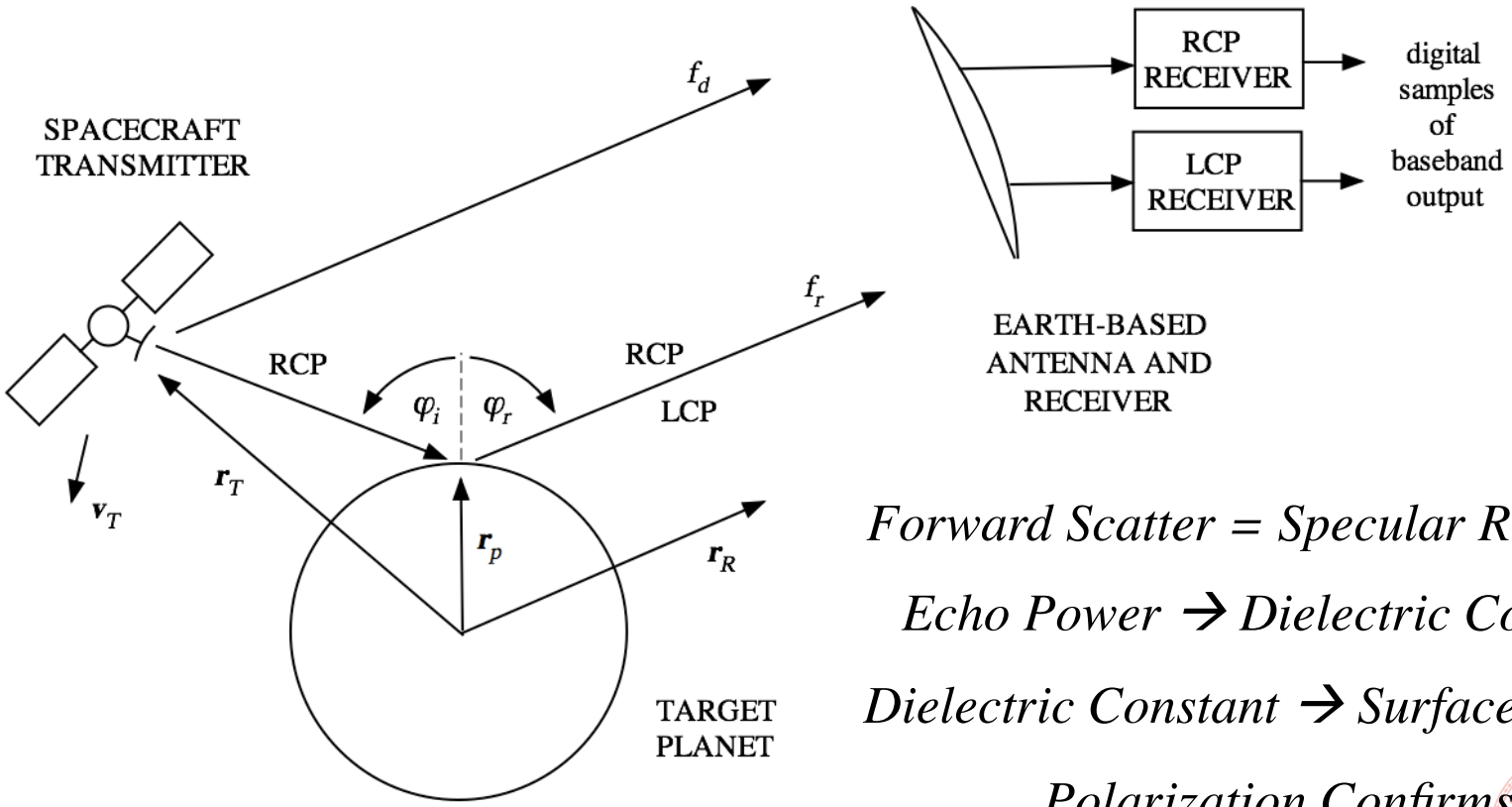
Dual Polarization Receiving

Multiple Frequencies (option)

Data Flow


SCATTERING COLLECTION RCP
CALIBRATION COLLECTION RCP
RECEIVER FILTER CORRECTION
CALIBRATION COLLECTION LCP
RECEIVER FILTER CORRECTION
SCATTERING COLLECTION RCP
X
X
X
ABSOLUTE RCP POWER
CROSS SPECTRUM
ABSOLUTE LCP POWER
RATIO, HPBW
GEOMETRY
ζ
ε

Bistatic Radar — Surface Density Estimation



Forward Scatter = Specular Reflection

Echo Power → Dielectric Constant

Dielectric Constant → Surface Density

Polarization Confirms

Fresnel Reflection

$$R_H = \frac{\cos\phi - \sqrt{\varepsilon - \sin^2\phi}}{\cos\phi + \sqrt{\varepsilon - \sin^2\phi}} \qquad R_V = \frac{\varepsilon\cos\phi - \sqrt{\varepsilon - \sin^2\phi}}{\varepsilon\cos\phi + \sqrt{\varepsilon - \sin^2\phi}}$$

$$R_R = (R_V + R_H)/2$$
$$R_L = (R_V - R_H)/2$$

$$P_i = (P_T G_T / 4\pi r_T^2)\ \sigma_i\ (A_R / 4\pi r_R^2)$$
$$\sigma_i = R_i^2\ \sigma_0$$

Same Radar Equation for both Polarizations — except that R_i is different.

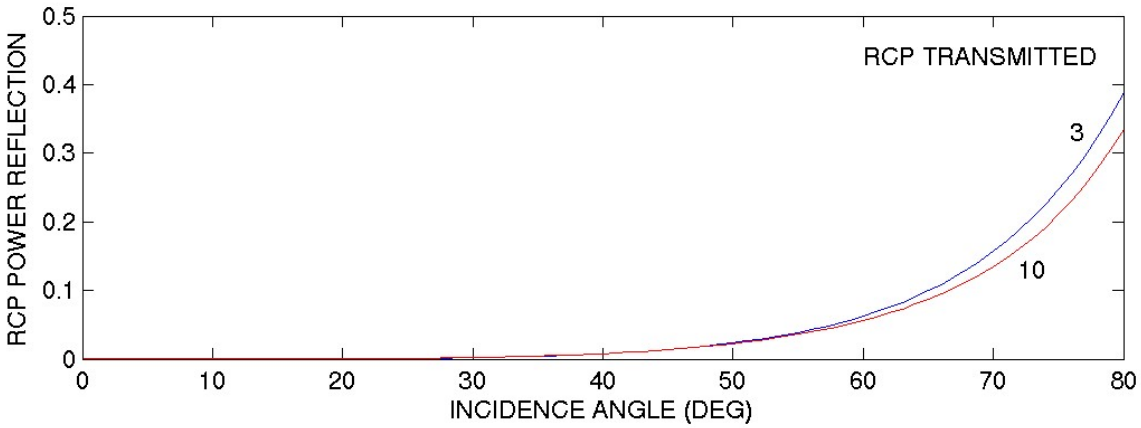
For simplification, we work with ratio P_R/P_L rather than absolute P_R and P_L

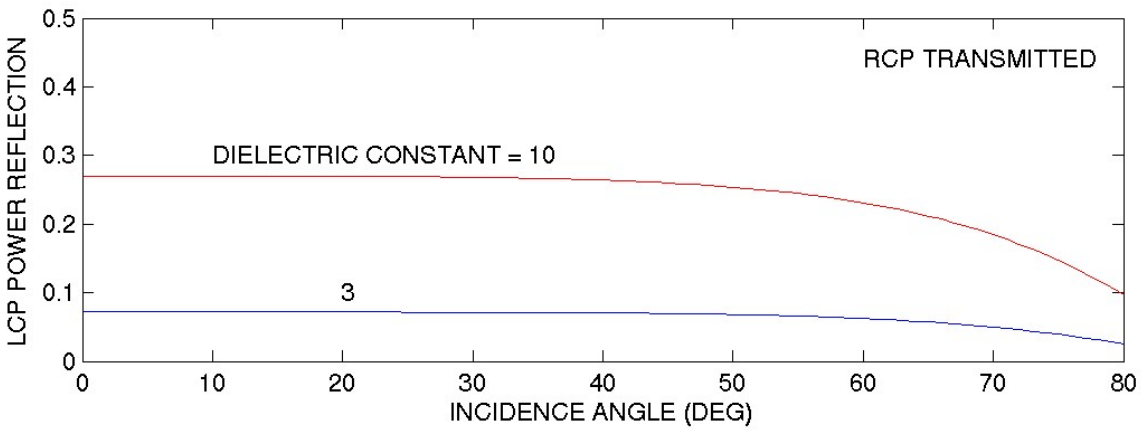
(1) Many common terms drop out

(2) Avoid *most* specular vs diffuse questions

Circular Power Reflection Coefficients

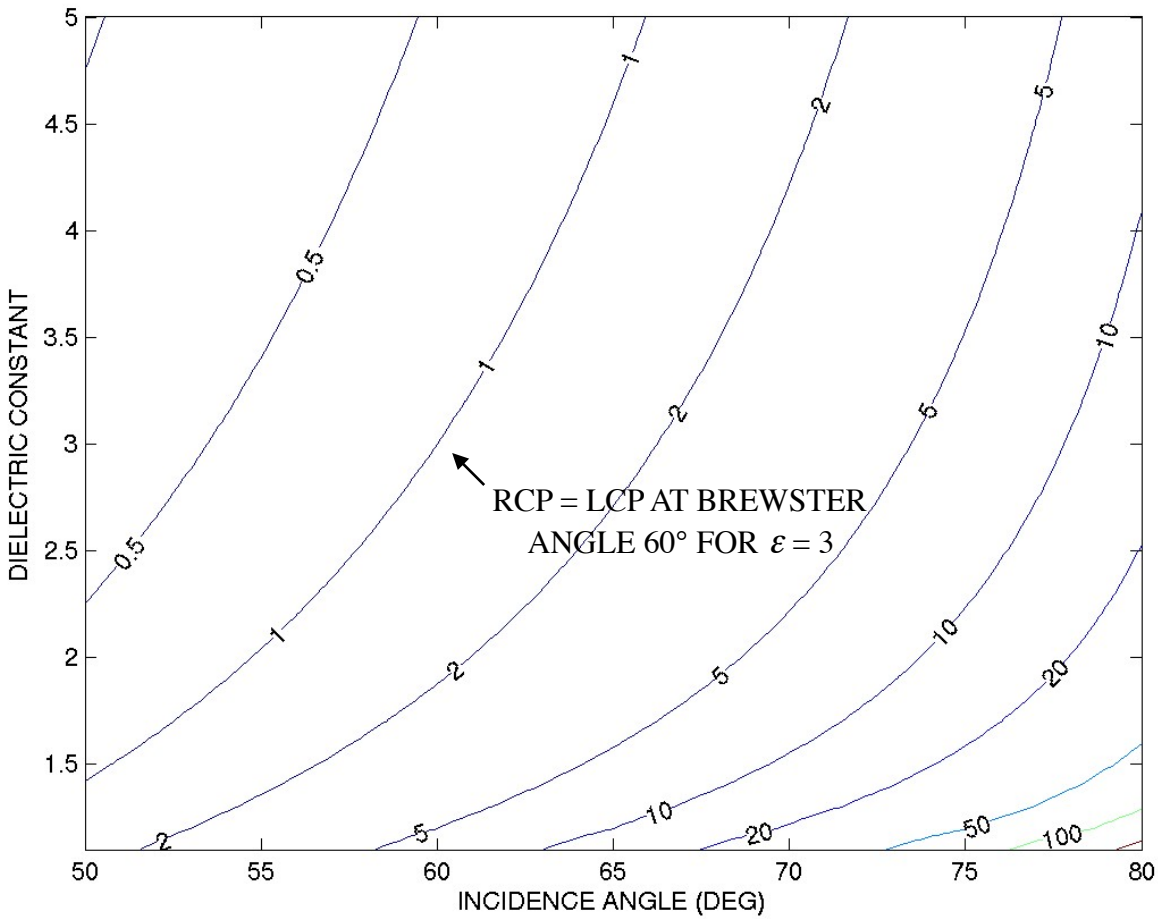
RCP, LCP Fresnel Powers for RCP Transmitted



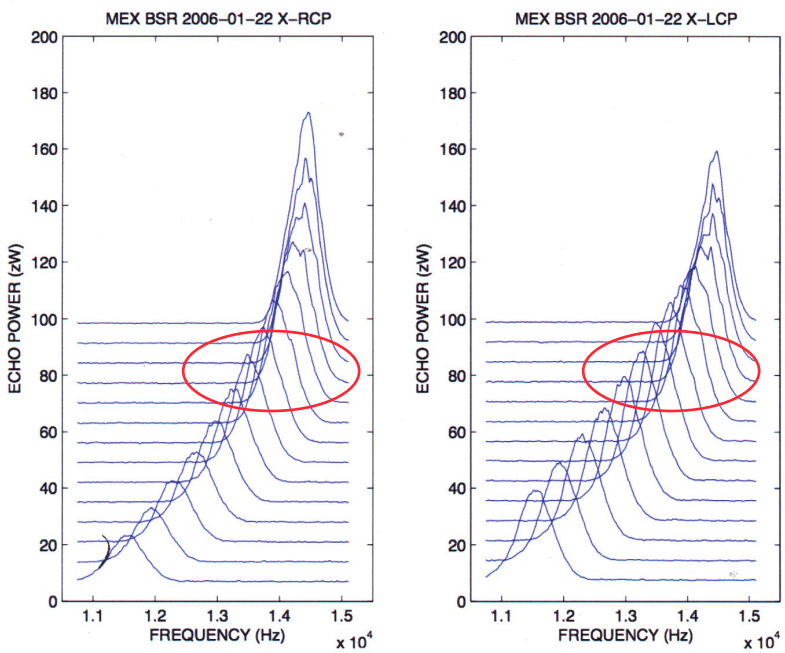


Dielectric Constant from Reflectivity

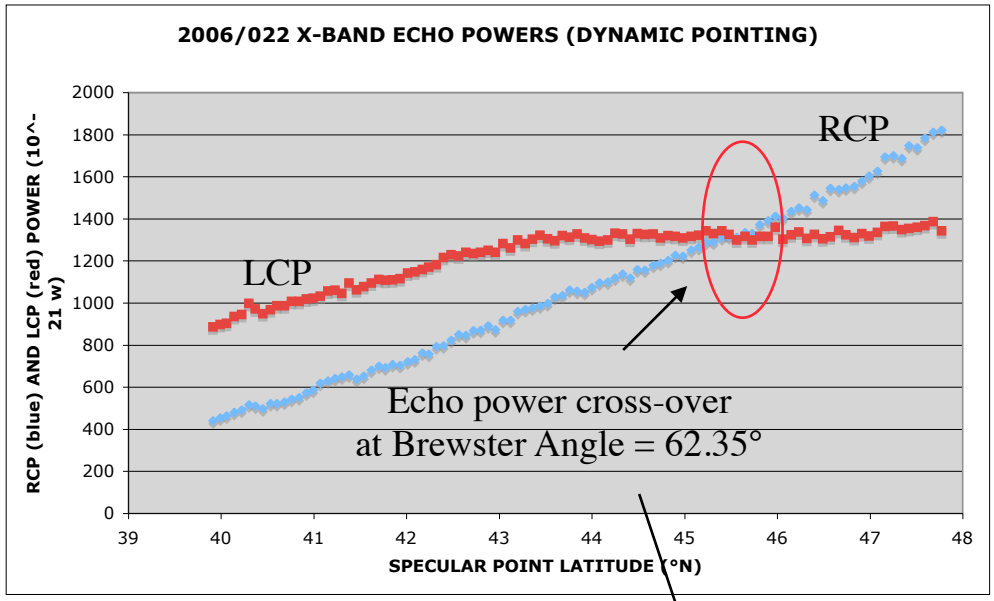
Contours of RCP/LCP Ratio versus ε and ϕ

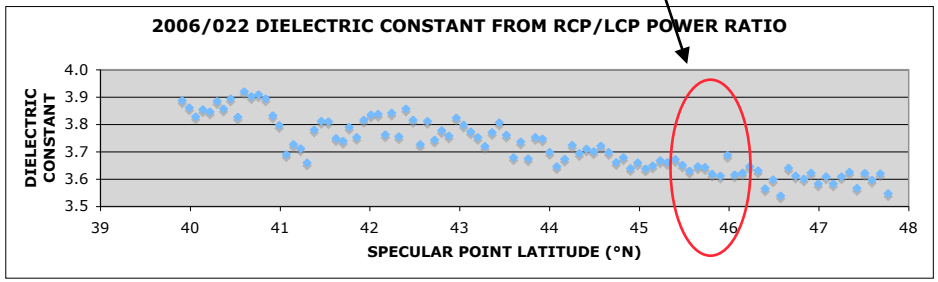


Mars Express Example
(Dielectric Constant ε from RCP/LCP Ratio)

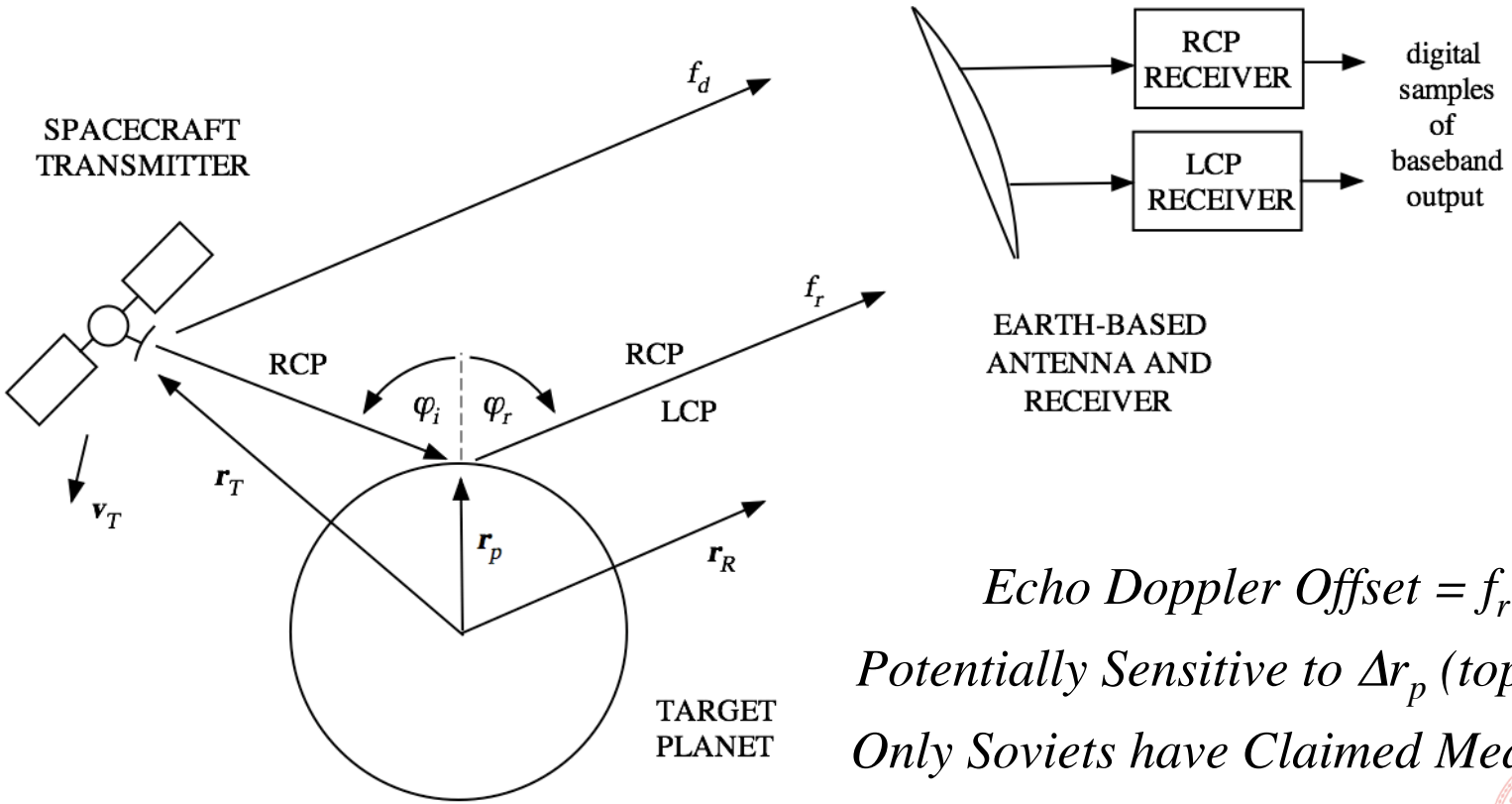


SPECULAR POINT TRACKING
(14 4-minute average spectra)





Bistatic Radar — Vertical Relief (km-scale)

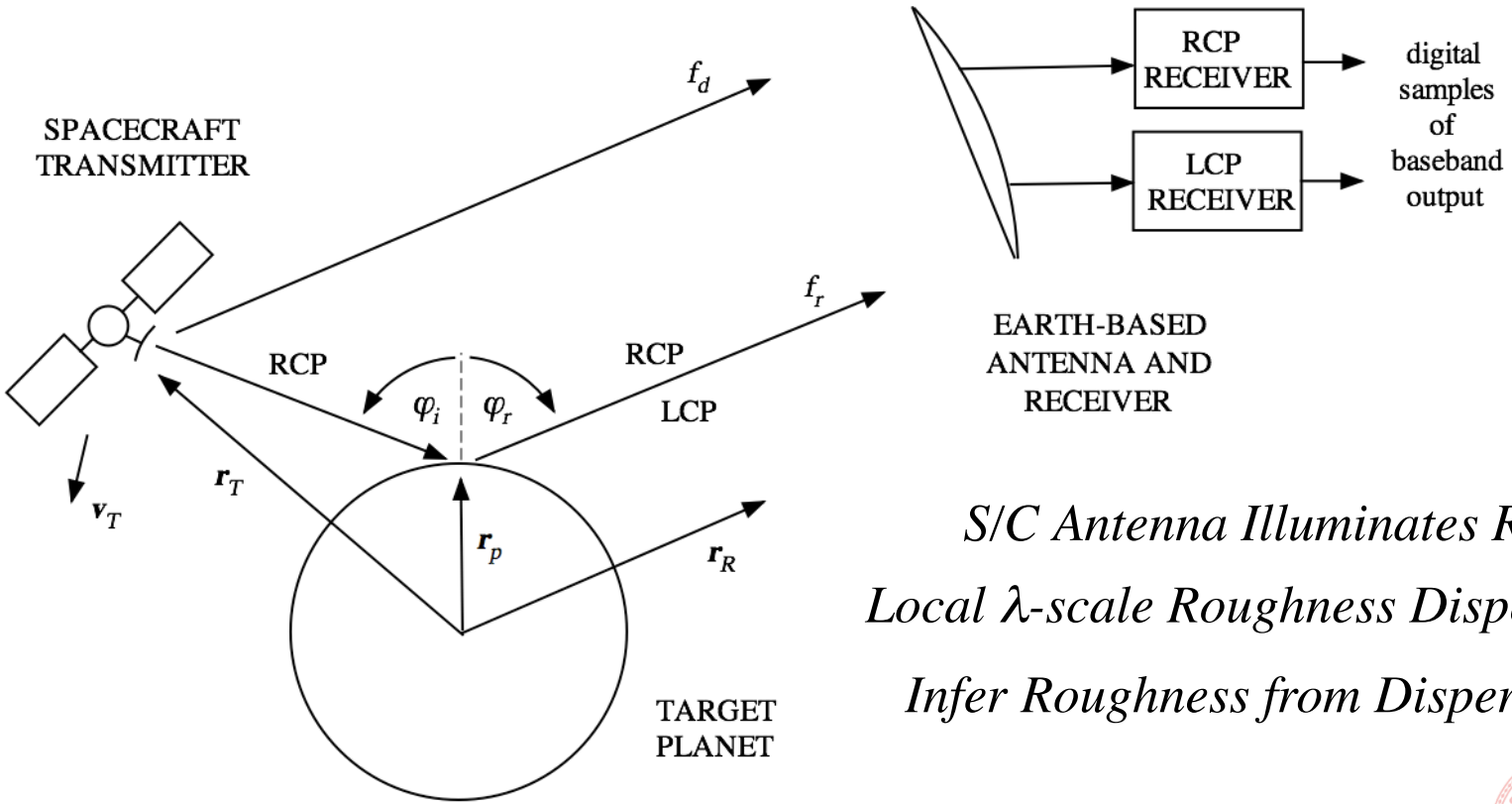


Echo Doppler Offset $= f_r - f_d$

Potentially Sensitive to Δr_p *(topography)*

Only Soviets have Claimed Measurement

Bistatic Radar — Surface Roughness (cm scale)

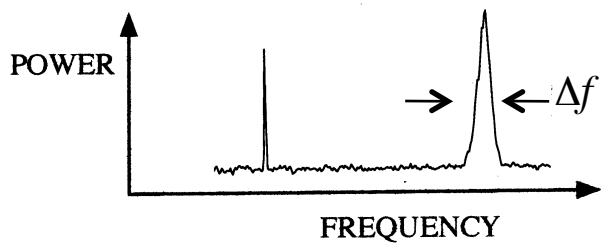


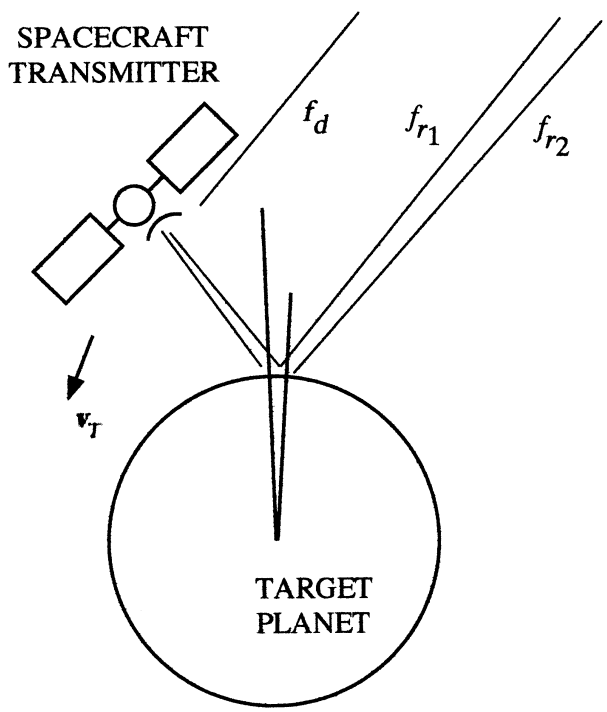
S/C Antenna Illuminates Region

Local λ-scale Roughness Disperses Echo

Infer Roughness from Dispersion (Δf)

Doppler Observations





- Echo separated from direct signal by spacecraft orbital motion (and topography)

- Echo spread in frequency by roughness

$$\Delta f = 4(\ln 2)^{1/2}(V\zeta/\lambda)\cos\phi$$

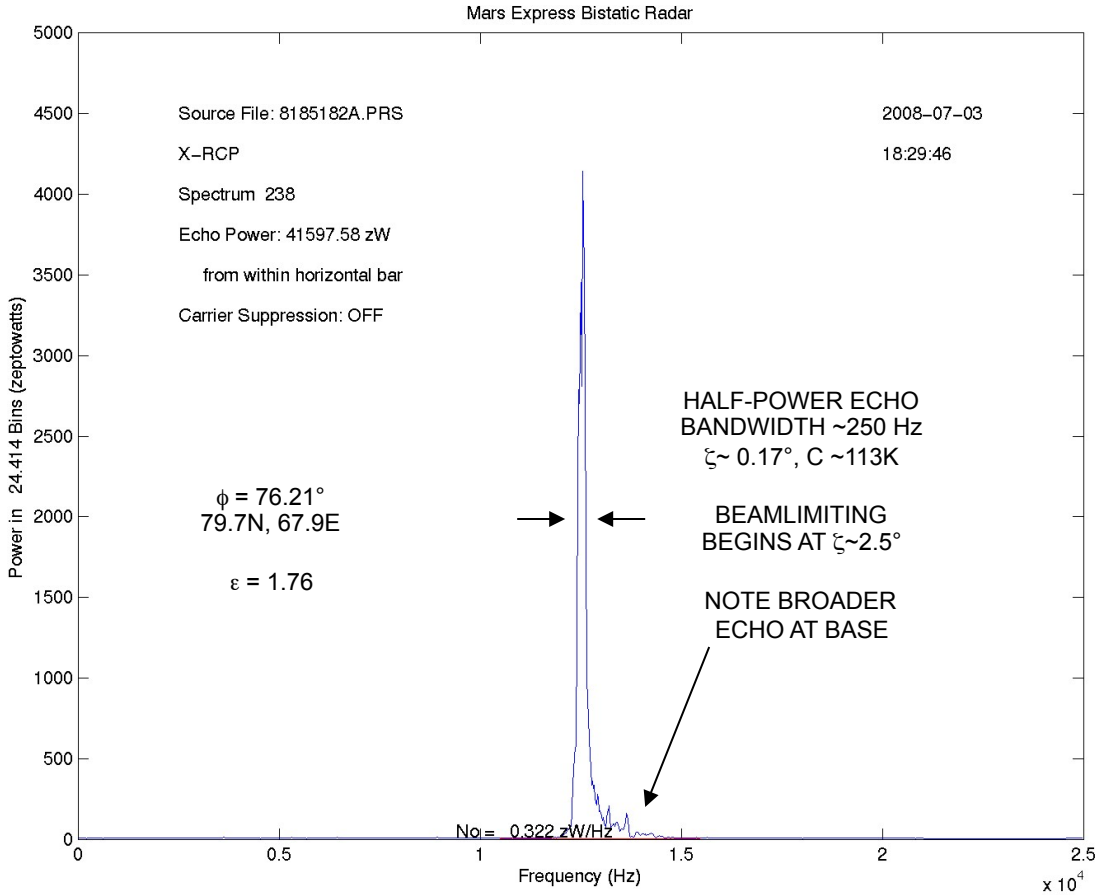
where

V = specular point velocity on surface
ζ = rms surface slope
ϕ = angle of incidence

- Spacecraft HGA can under-illuminate reflecting region (**common** in today's experiments at shorter λ). Then Δf is only a measure of HGA pattern.

MEX BSR 2008/185

Spectrum from Area with Very Low RMS Surface Slope ζ

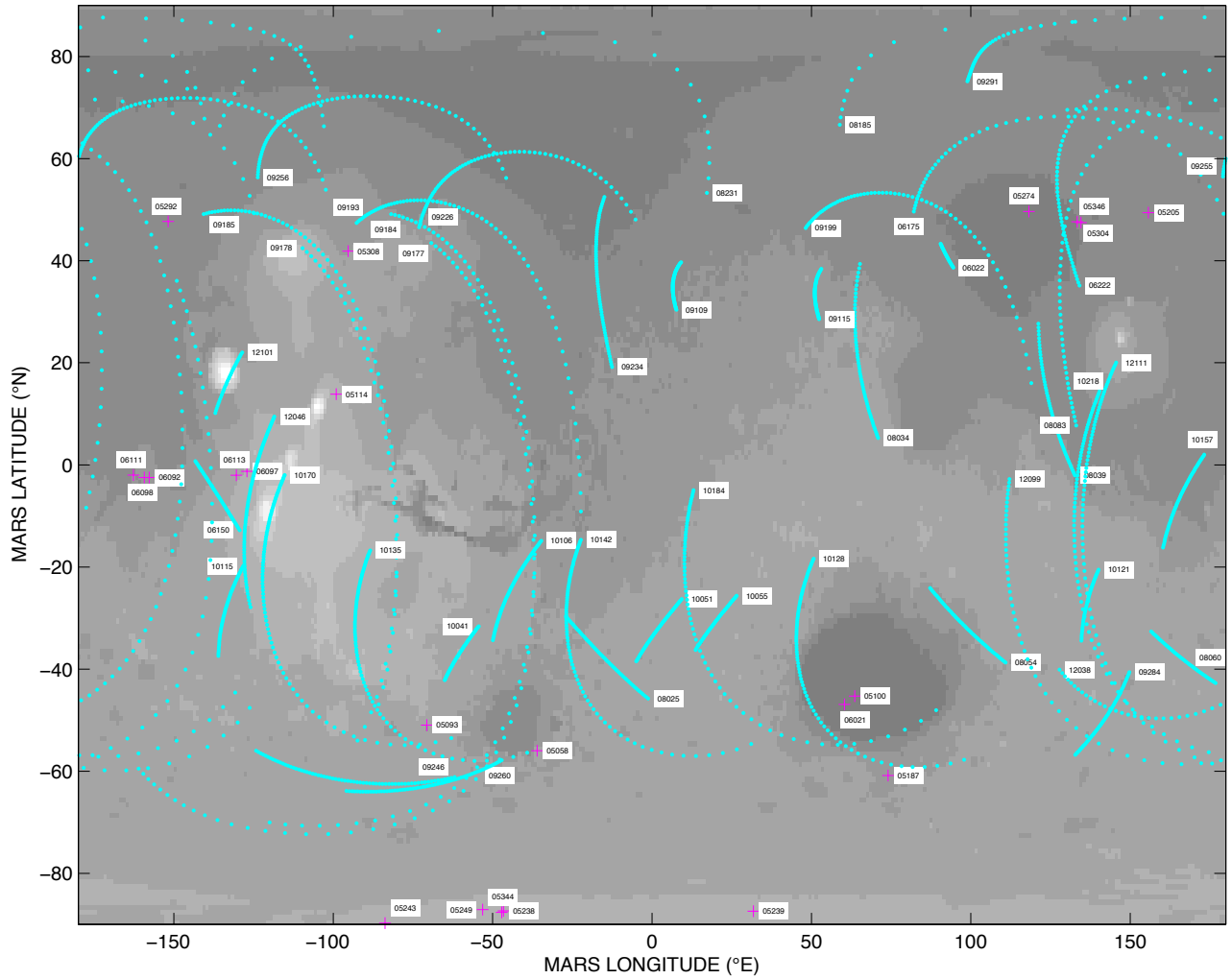


Generally, it is easier to derive dielectric constant than rms slope ζ because the MEX surface echo shape is controlled by the HGA illumination pattern.

In especially smooth areas, echo shape is controlled by surface texture.

In this example, near Mars' north pole, the surface has only 0.17° rms slope, measured at λ = 3.6 cm. Previously, the smoothest surface found by radar was ζ ~0.25° at λ = 13 cm in Syrtis Major.

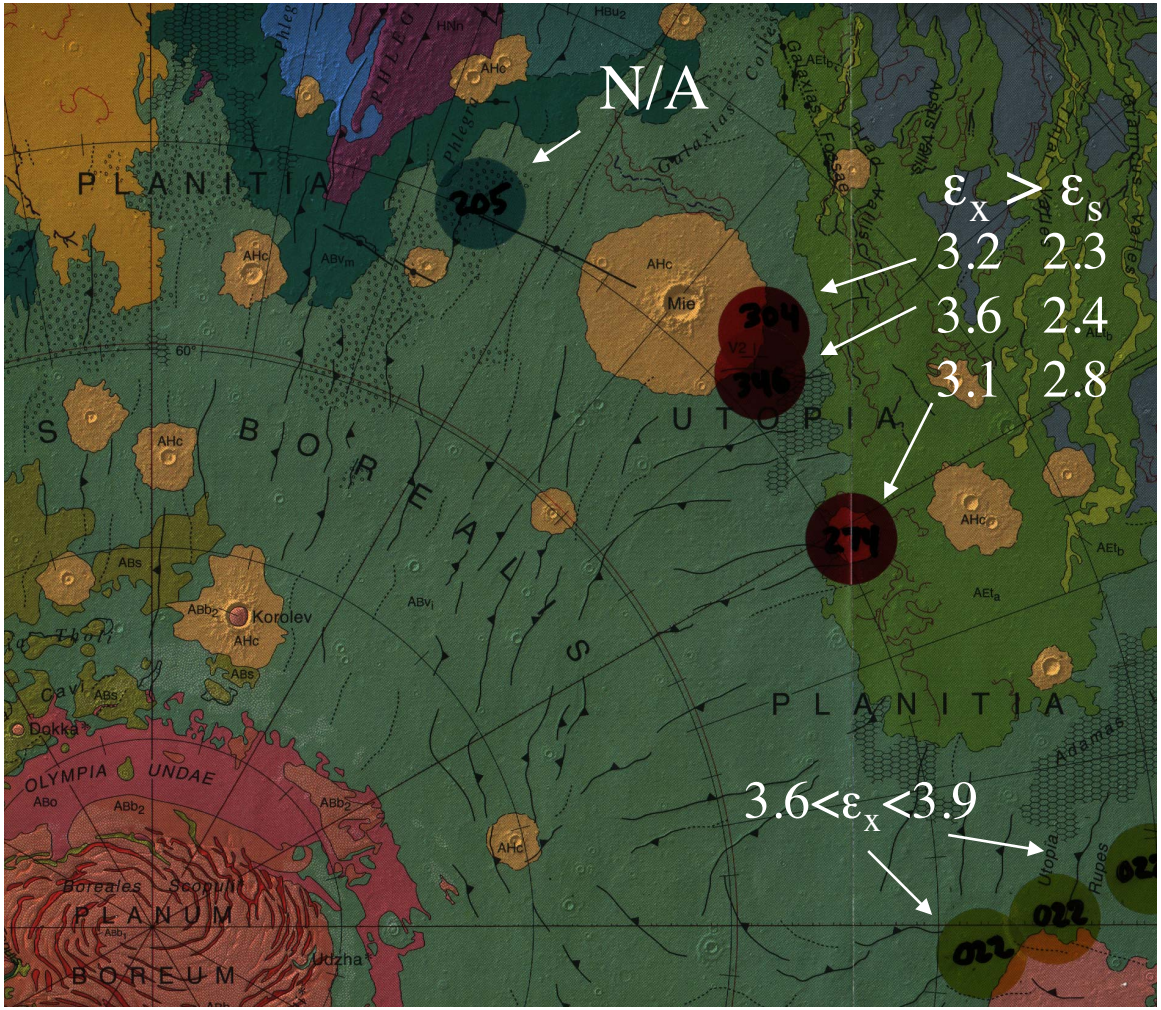
Mars Express Experiments Completed
(2004-2012; 8 more experiments in 2014 not shown)

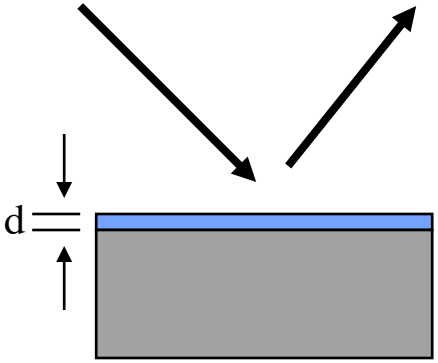


More Results

Utopia Planitia: Surface Crust Layer?

(inferred from $\varepsilon_x > \varepsilon_s$)





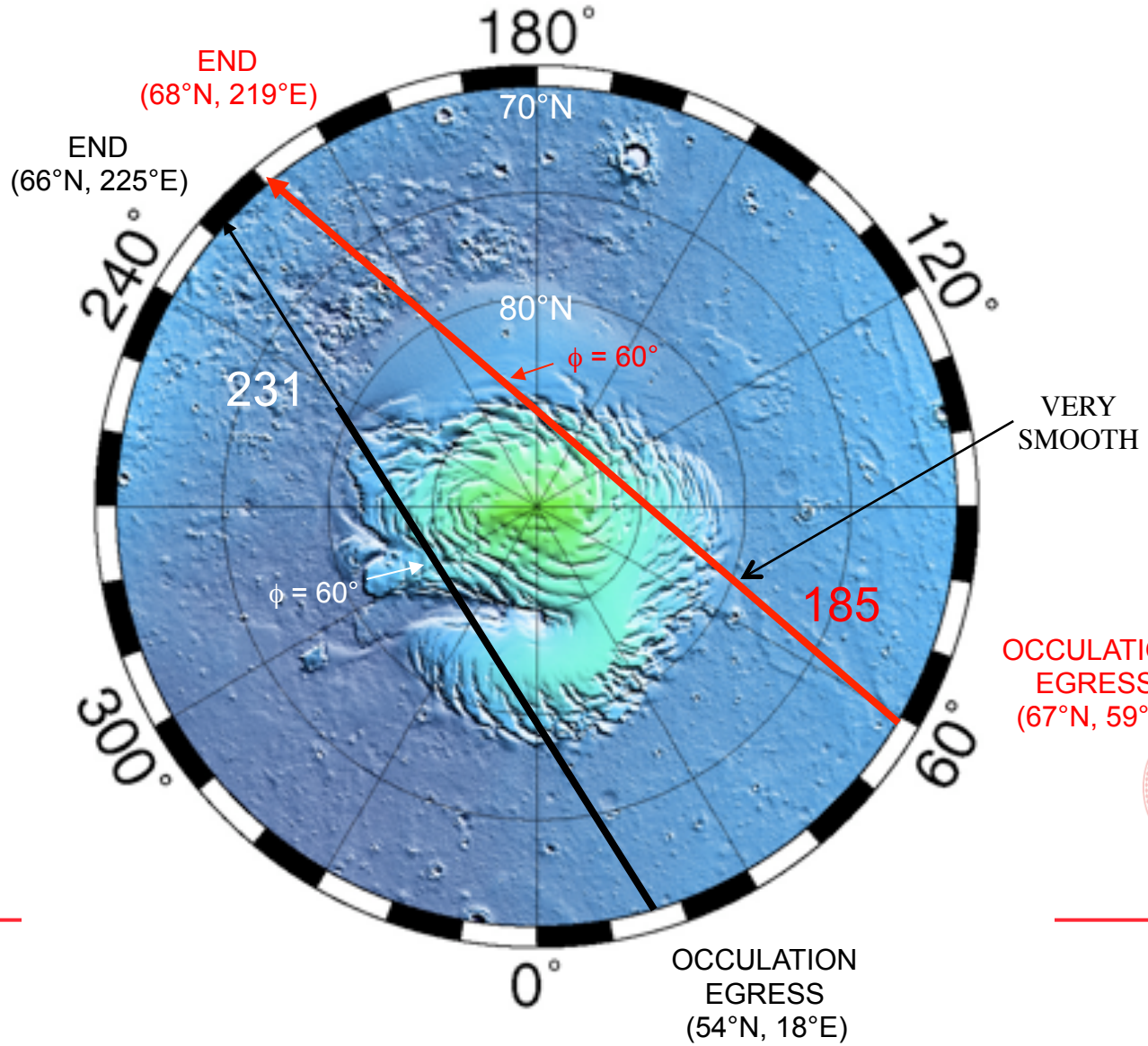
$3.6 \sim d << 13$ cm

gravel layer?
duricrust?

$\lambda_x = 3.6$ cm
$\lambda_s = 13$ cm

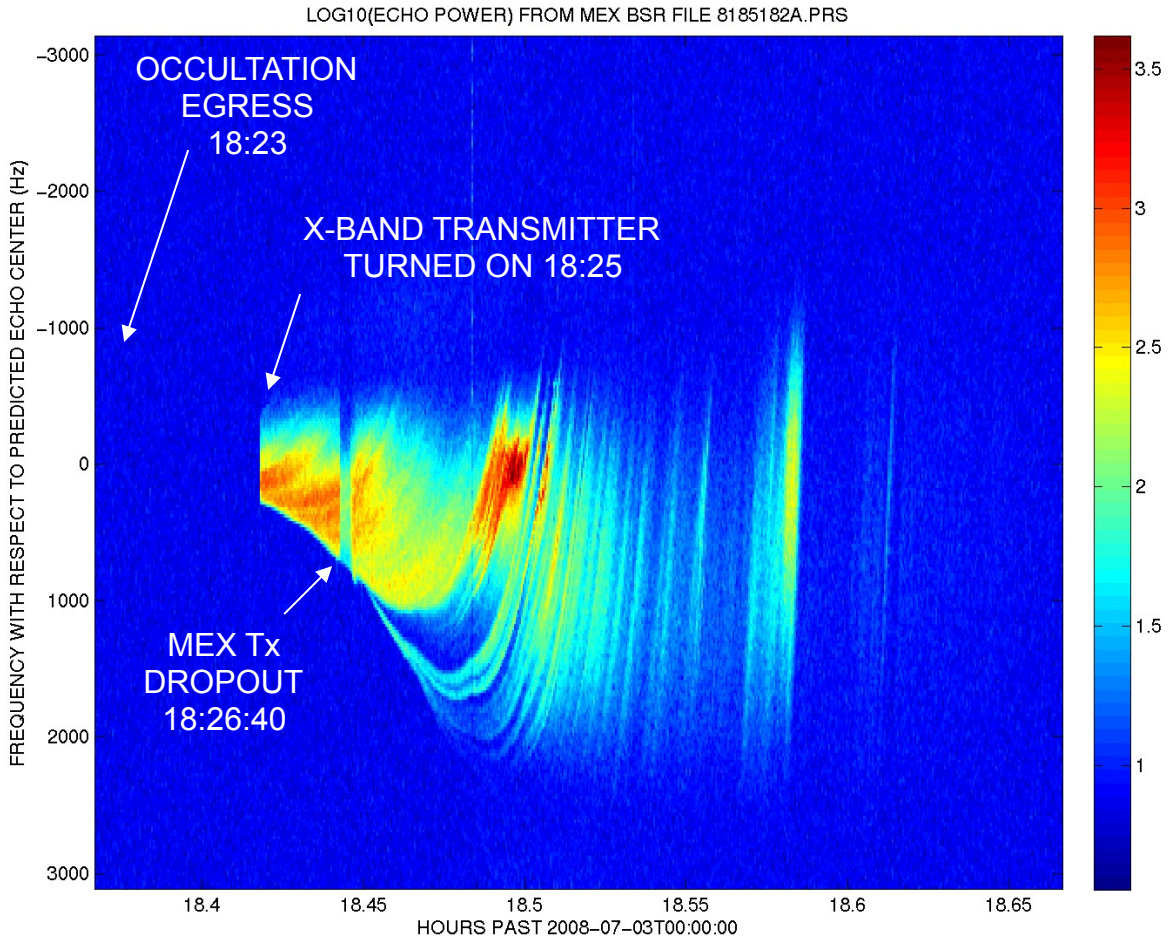
Mars Express Bistatic Radar

North Pole Specular Tracks — 2008, Days 185 and 231



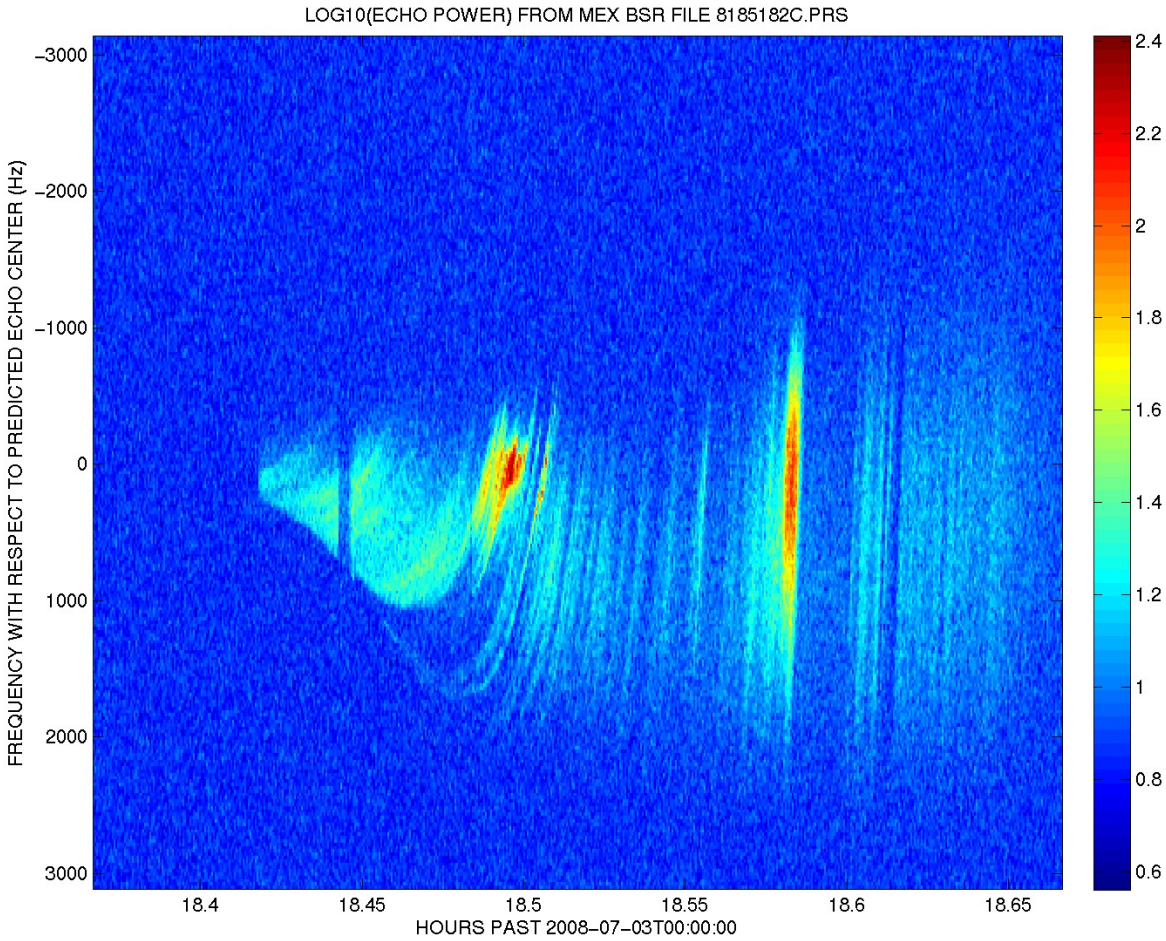
MEX BSR 2008/185

X-RCP Spectrogram (echo drift removed)



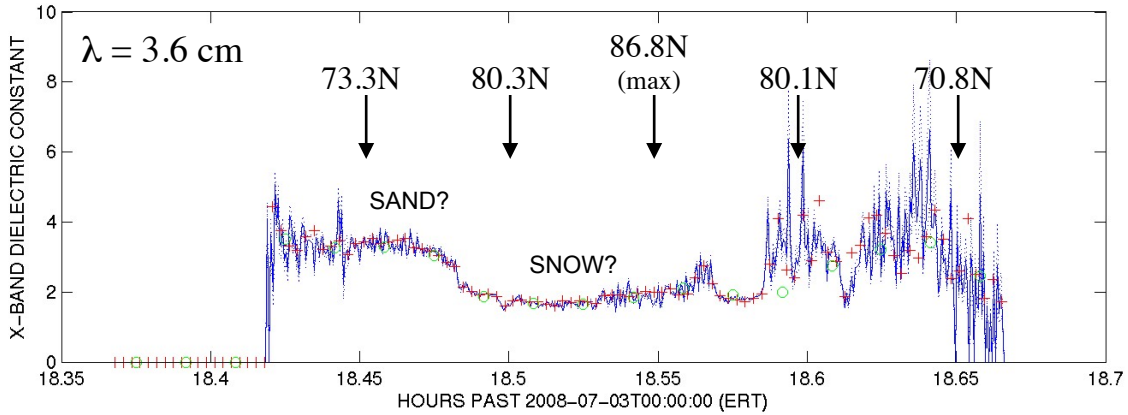
MEX BSR 2008/185

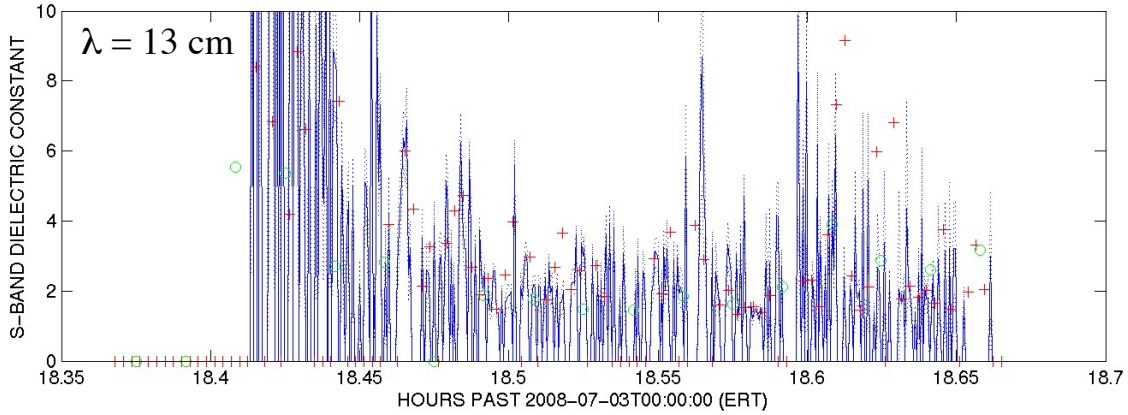
X-LCP Spectrogram



MEX BSR 2008/185

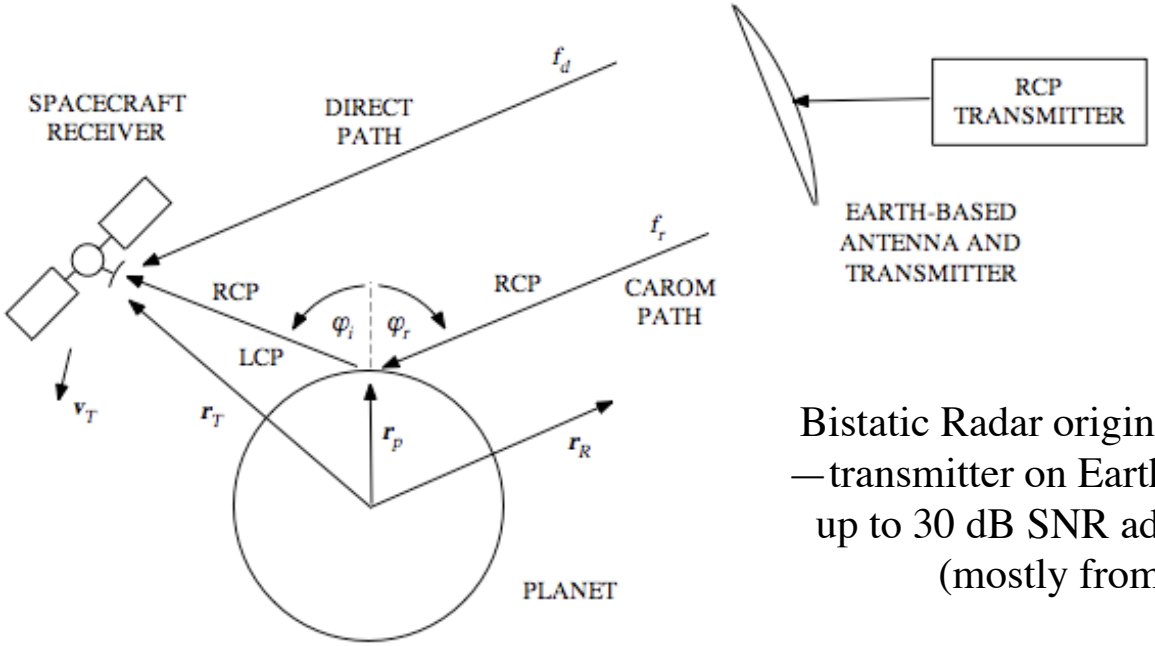
Dielectric Constant ε from RCP/LCP Power Ratio





New Directions

Uplink Bistatic Radar to Spacecraft



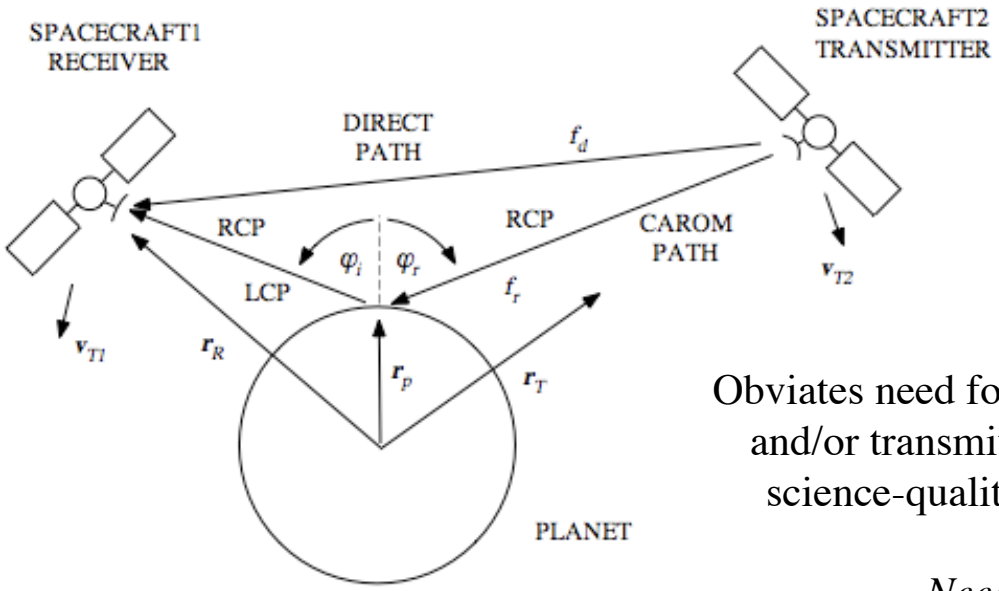
Bistatic Radar originally envisaged as 'uplink' —transmitter on Earth, receiver on spacecraft — up to 30 dB SNR advantage over 'downlink' (mostly from higher Tx power)

First uplink surface observations conducted using Mars Odyssey in 2004

Requires RCP and LCP receivers on spacecraft

New Horizons will attempt an uplink experiment at Pluto in 2015

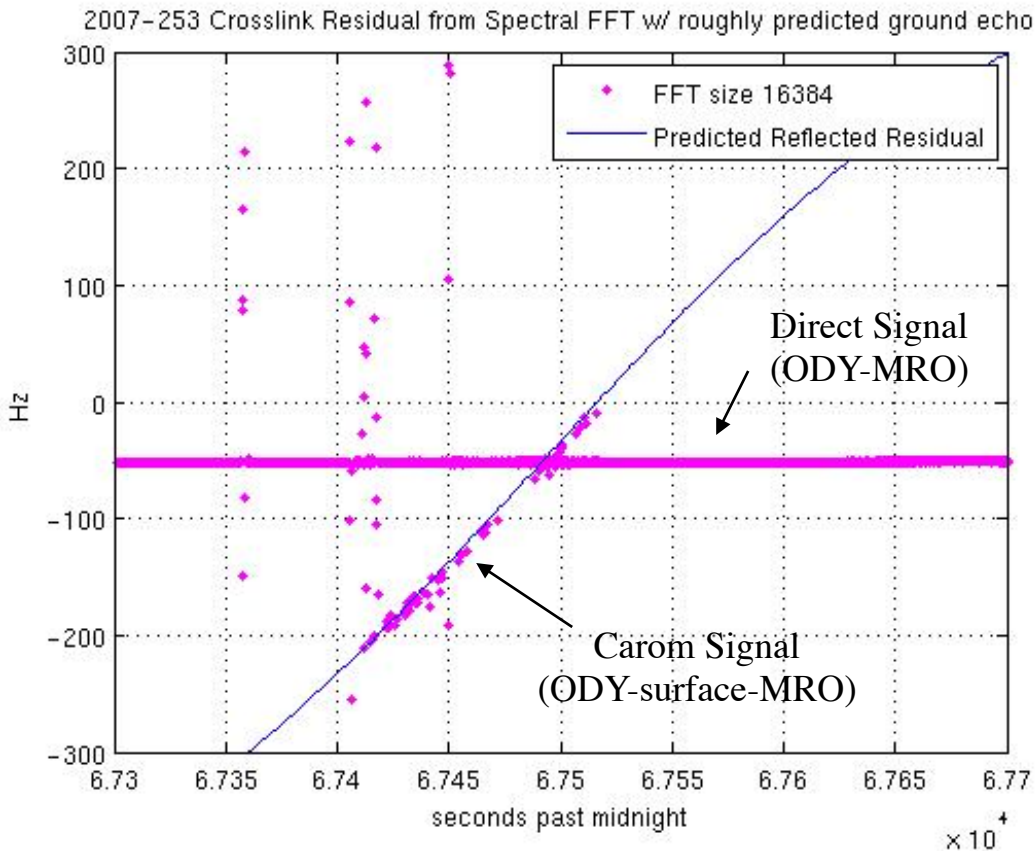
Crosslink Bistatic Radar



Obviates need for large Earth-based antenna, receiver, and/or transmitter; but requires new investment in science-quality spacecraft radio instrumentation

Need: two or more spacecraft
low-noise receiving environment
dual-polarization tunable receivers
precision time/frequency references
high-speed A/D conversion
on-board processor(?)
careful planning and synchronization

Crosslink Feasibility Test



Post-detection frequency residuals of Mars Odyssey (ODY) transmissions received by Mars Reconnaissance Orbiter (MRO) at 437.1 MHz