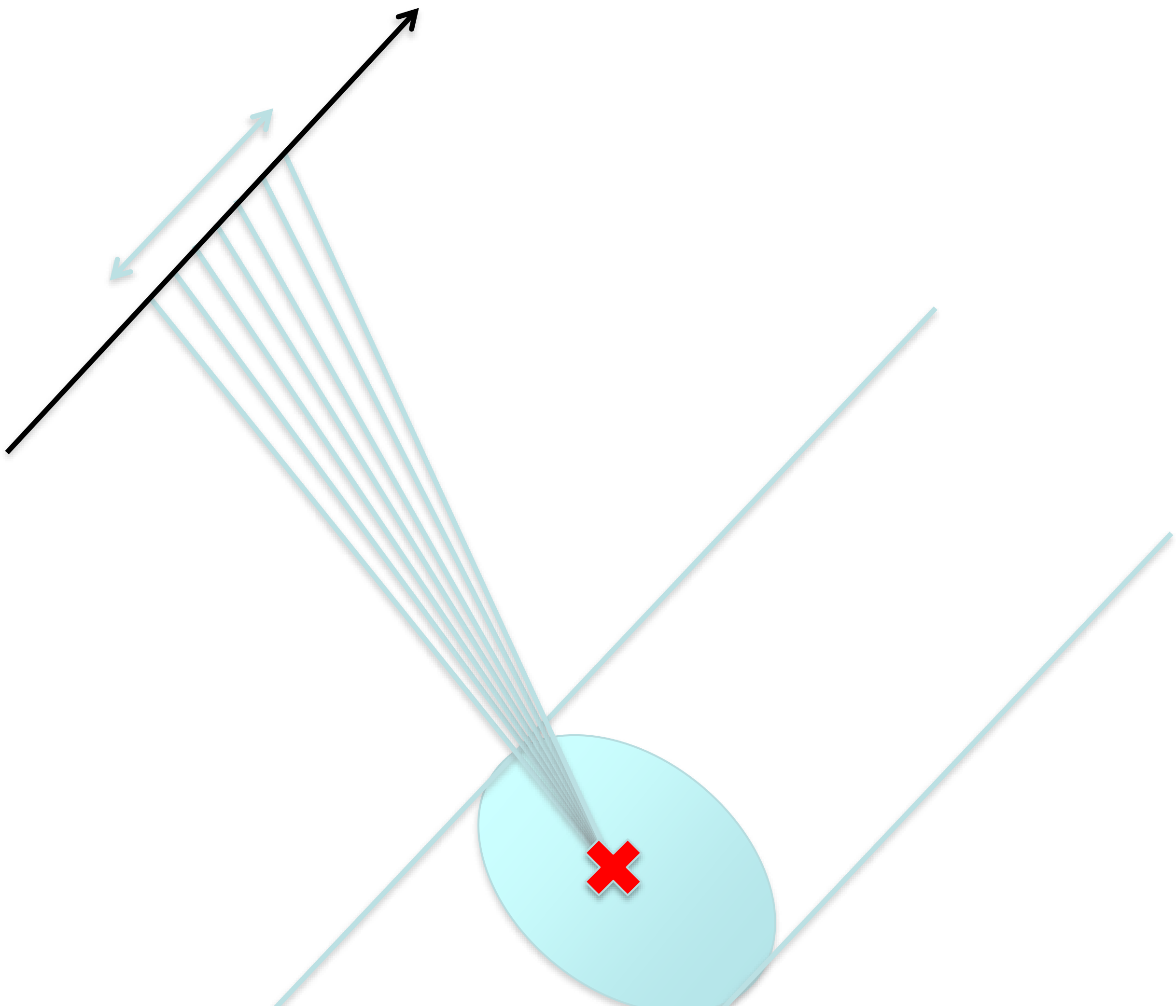
InSAR training 2024

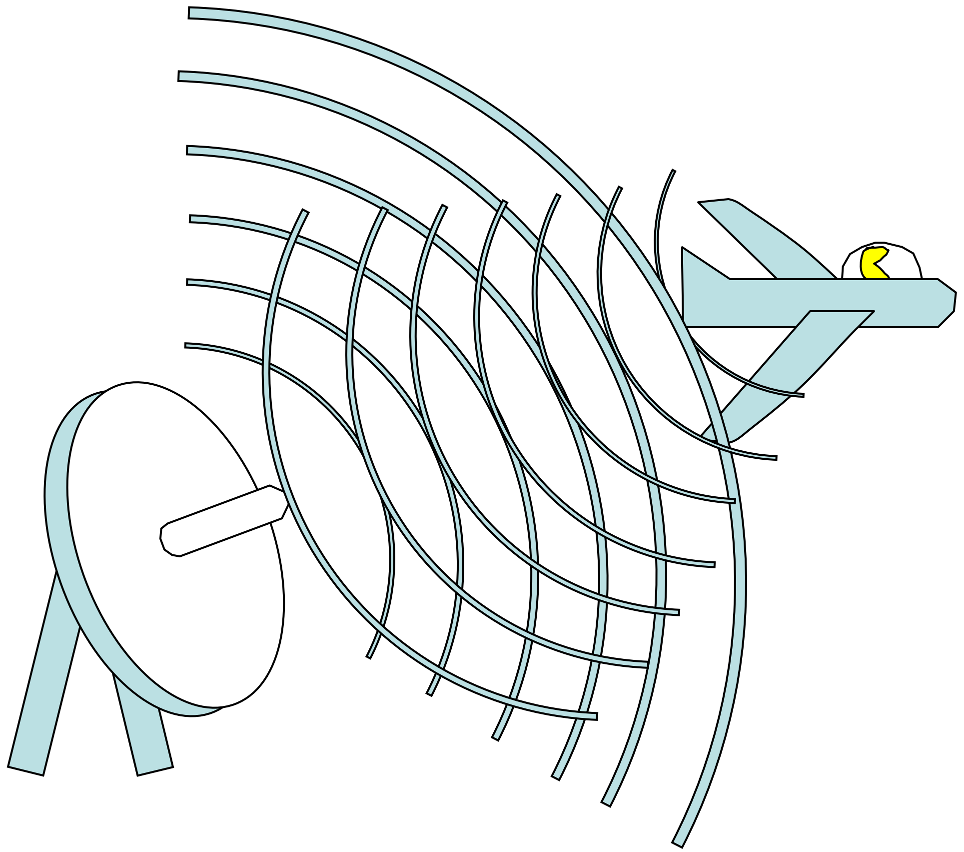


Synthetic Aperture Radar

Overview

- Detection radar, what it is, how it works
- Why use radar for remote sensing?
- Side-looking radar, backscatter, swath width and resolution
- Forming a synthetic aperture, radar focusing, SLCs
- Geometric issues with SAR, foreshortening, layover and shadow
- SAR satellites in common use, the role of wavelength

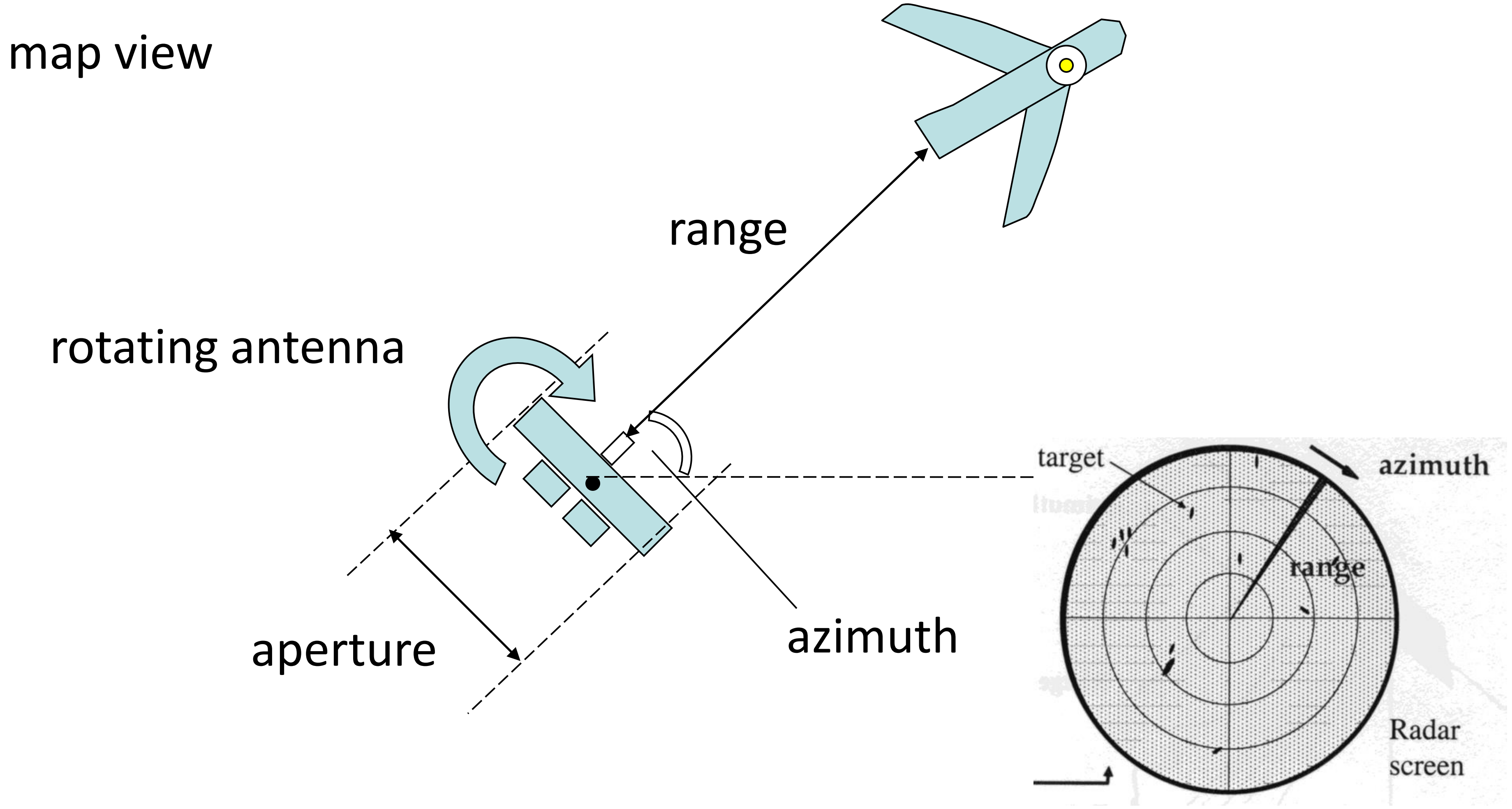
Detection radar: how it works



A pulse of e-m radiation is emitted from a radar antenna, and the echoes scattered by the object recorded back at the antenna

The time delay is directly related to the distance

Detection radar nomenclature



'Aperture', 'azimuth' and 'range' are terms still used in satellite radar

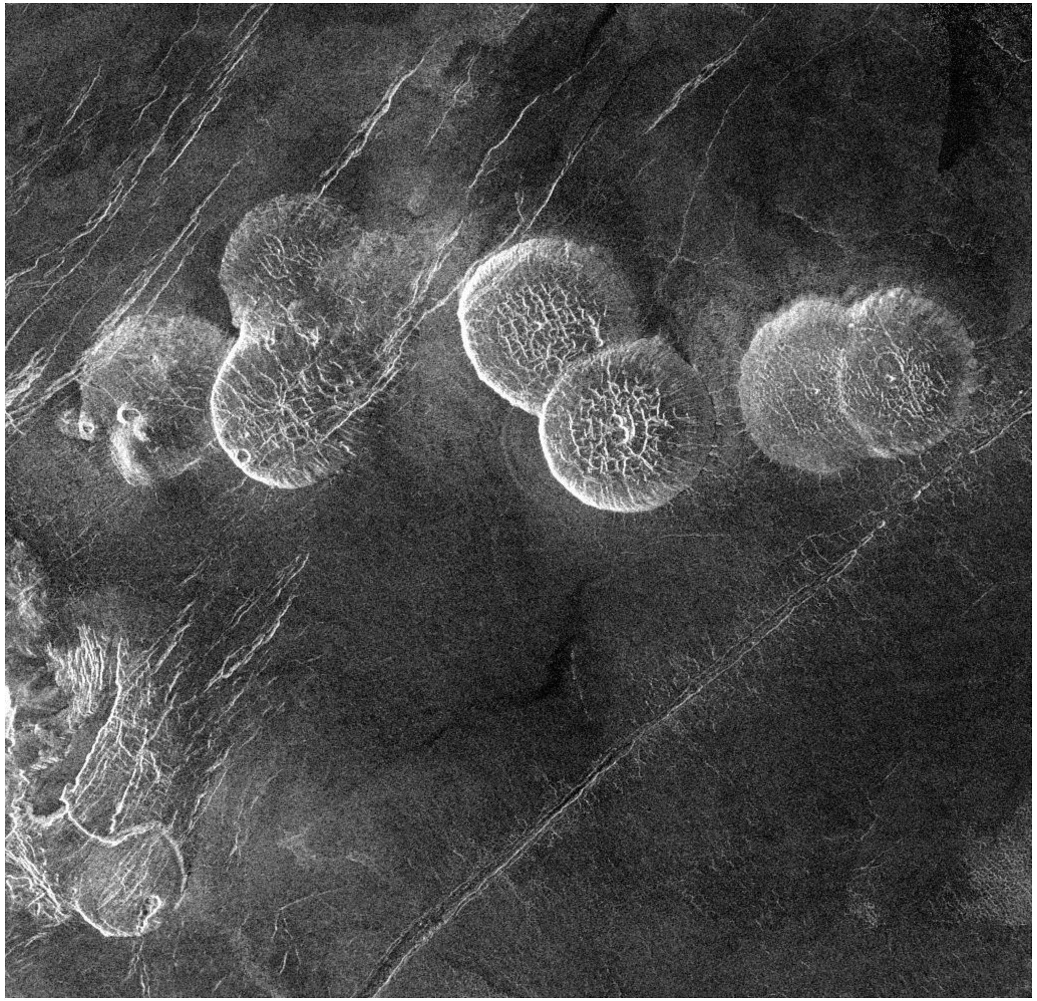
Why radar for remote sensing?

Radar does not rely on passive illumination by the Sun (it is an 'active' method)

Radar is not impaired by clouds (e.g. right)

On average, a radar satellite will generate 5x more useable images at high latitudes than an optical satellite

Radar interacts differently with the ground to optical methods, and so can give us additional information

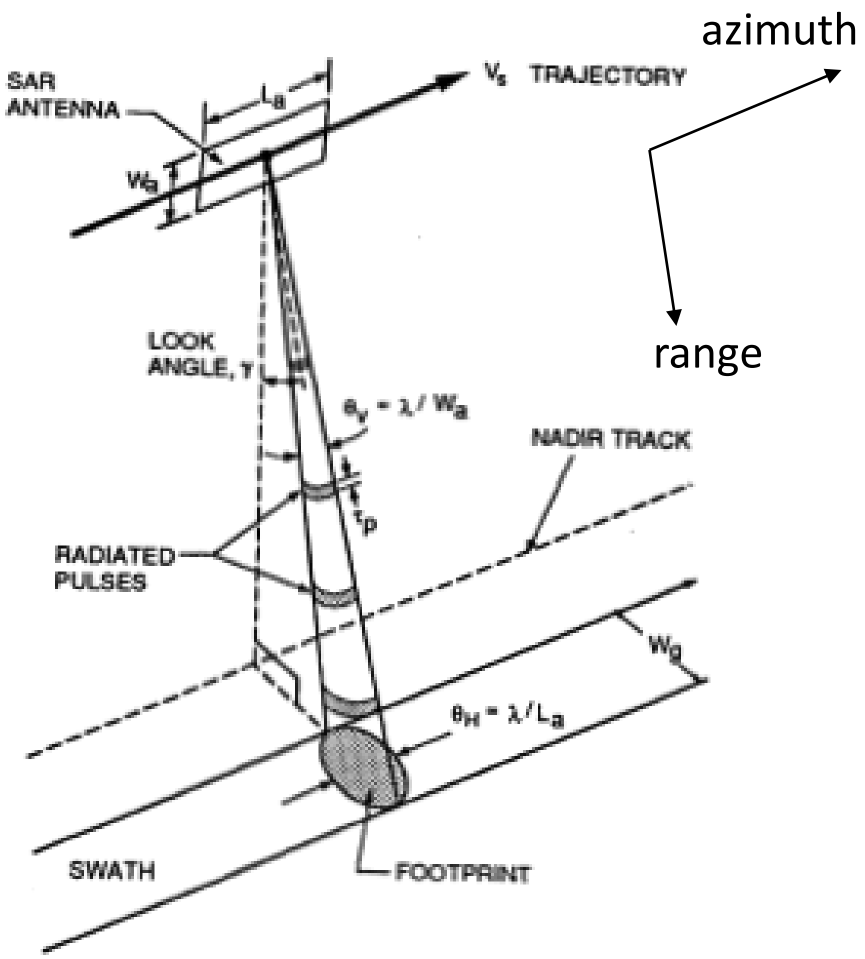


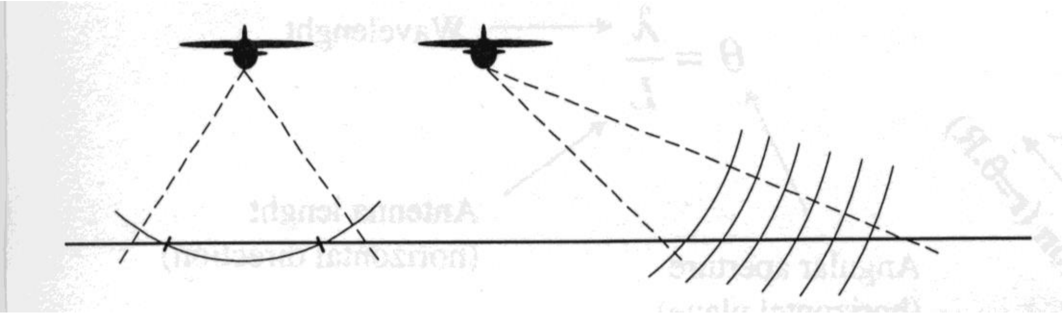
Lava domes on Venus, from the Magellan mission

Side-looking real aperture radar

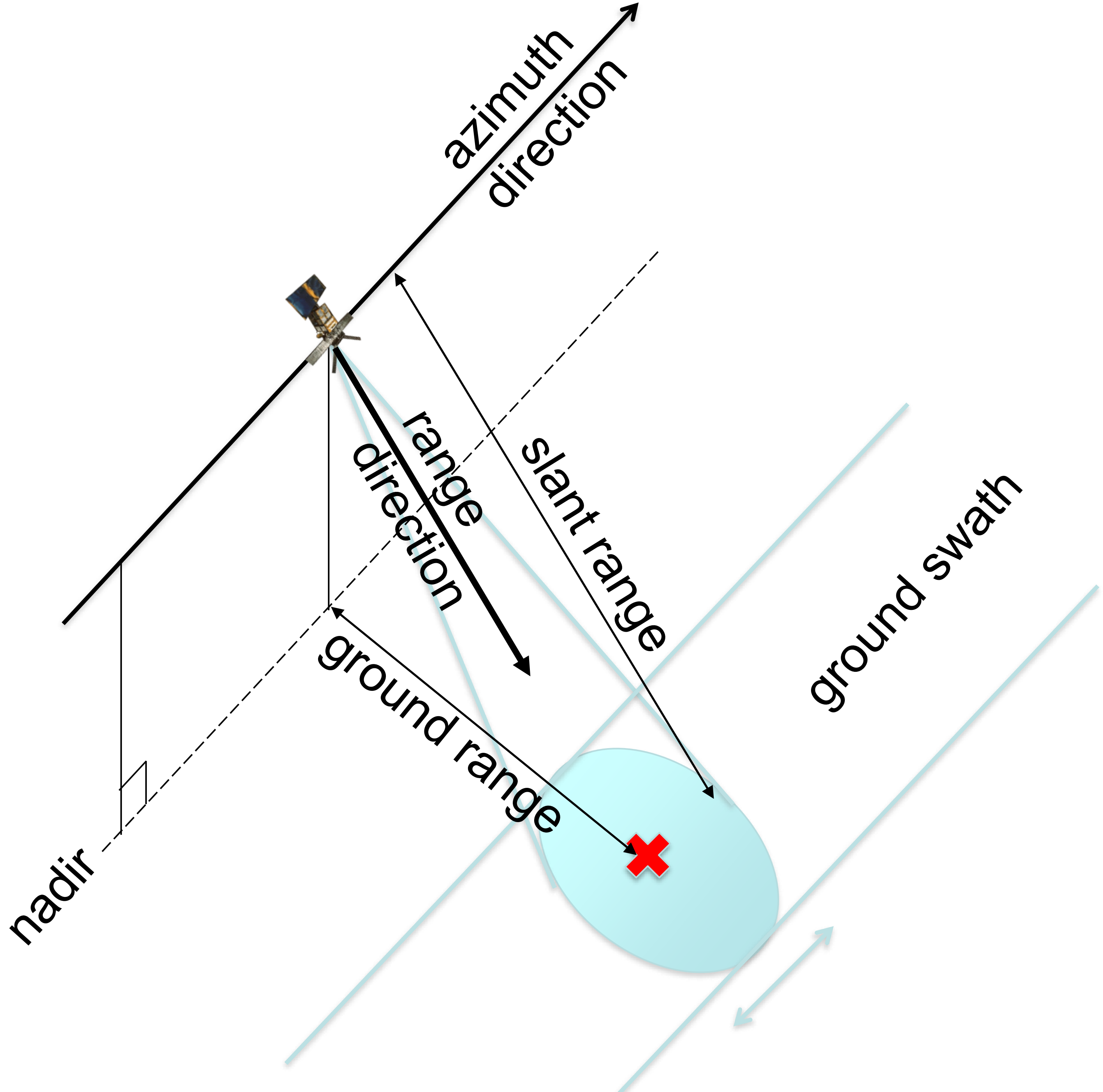
Standard remote sensing configuration (whether airborne or satellite)

Side-looking means that only backscattered radiation from that side of the ground swath is received (cf. radiation from the nadir)

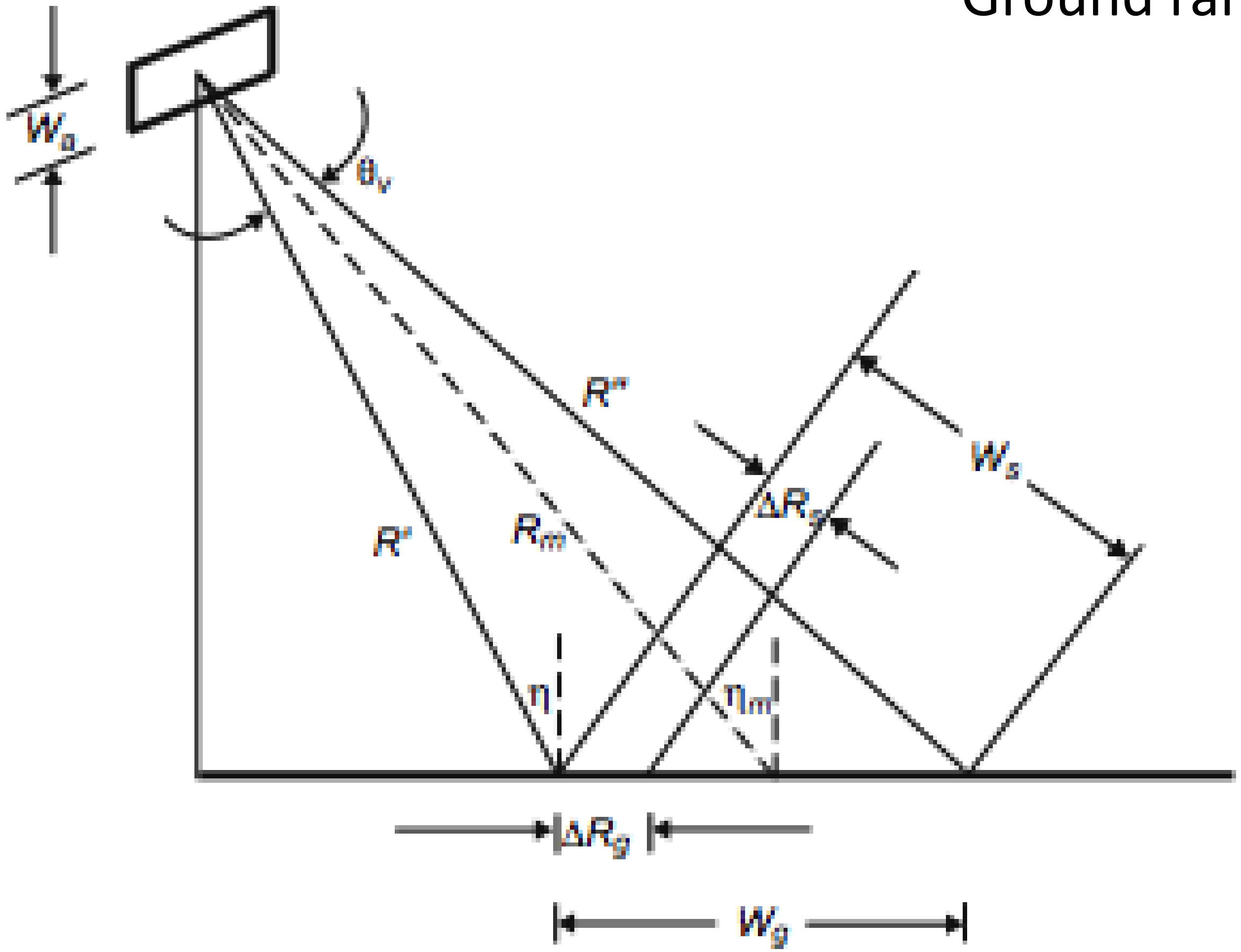




Imaging radar nomenclature



What resolution can we get? (1)



Ground range resolution: $$\Delta R_g = \frac{\Delta R_s}{\sin \eta} = \frac{c\tau_p}{2 \sin \eta}$$

τ_p = radar pulse duration

c = speed of light

For ERS, τ_p = 37 μs, giving $\Delta R_g \approx$ 14 km (!)

What resolution can we get? (2)

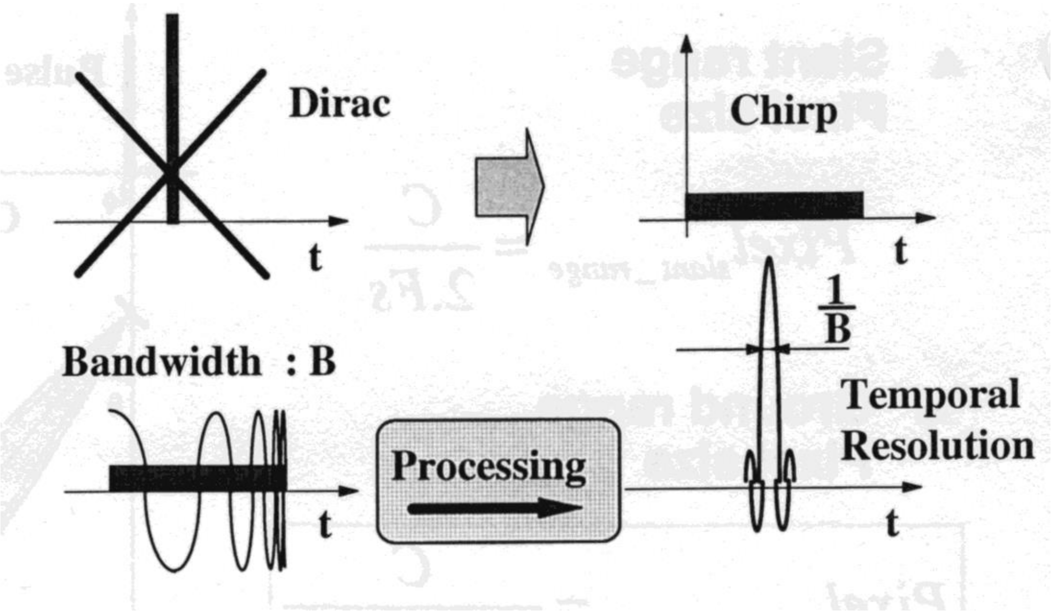
A ground range resolution of ~20 m, would require a pulse duration of ~50 ns

It is essentially impossible to put out such a short radar pulse with sufficient power!

Instead, we use a processing trick; a 'chirped' (frequency modulated) pulse can be compressed to a pulse of effective length, τ_e = 1/B (B = chirp bandwidth)

In this case, $$\Delta R_g = \frac{c\tau_e}{2\sin\eta} = \frac{c}{2B\sin\eta}$$

For ERS, B = 15.5 MHz, $\Delta R_g \approx$ 25 m



Ground azimuth resolution

The along-track (azimuth) length of the radar beam, is

$$\theta_H = \frac{\lambda}{L_a}$$

L_a = effective antenna length

Therefore, the length of the ground swath is:

$$L_g \approx R_m \theta_H \approx \frac{R_m \lambda}{L_a}$$

This is equivalent to resolution in the azimuth direction

For airborne or ground systems, R_m is small, and the minimum resolvable distance is small. For ERS, L_a = 10 m, giving L_g = 4.8 km, not so small

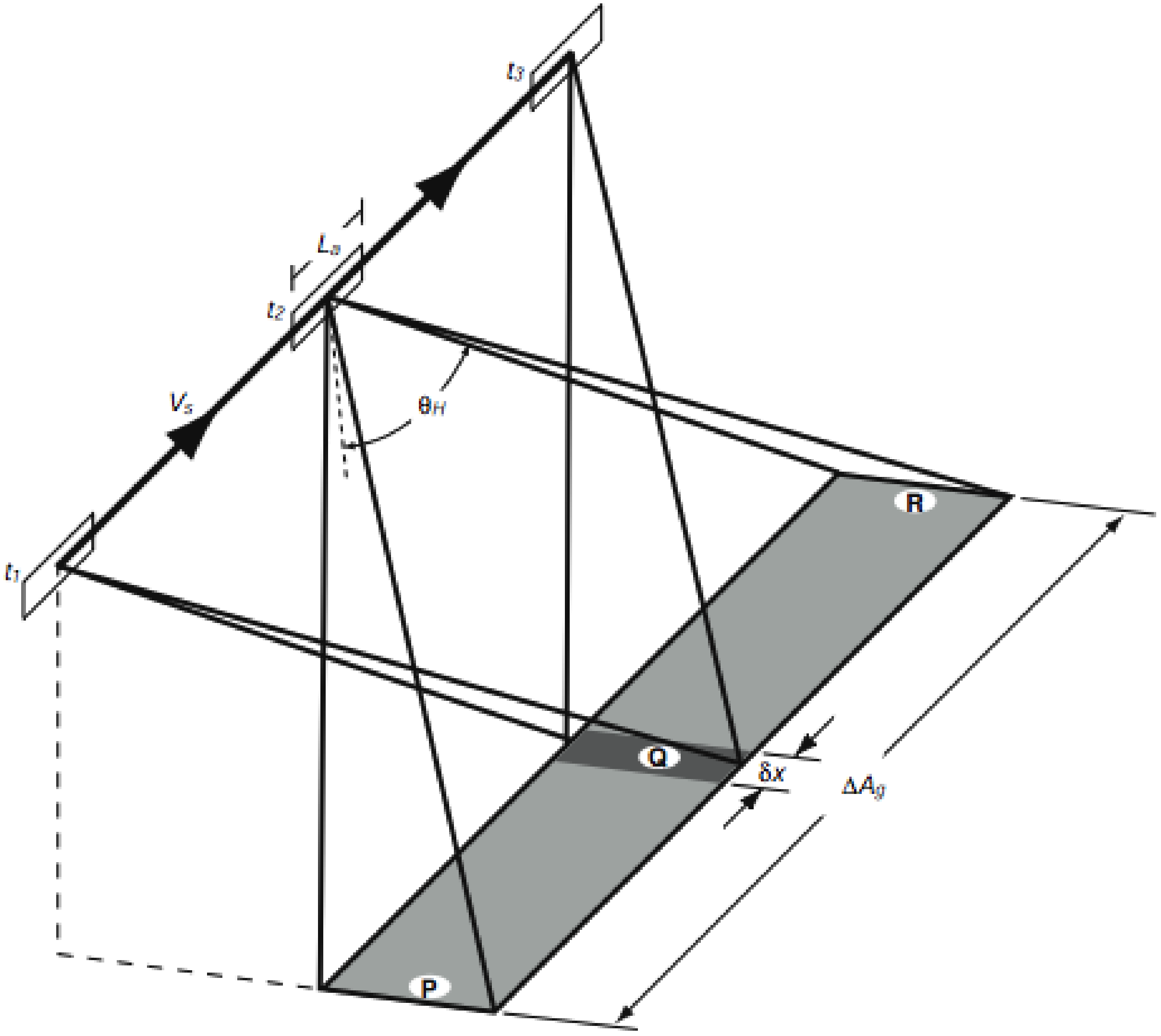
How to get better resolution?

Given the reciprocal relationship between antenna length and minimum resolvable distance, to get a shorter resolvable distance, you need a much longer antenna

e.g. to get 20 m resolution, you need L_a = 2.4 km!

Even if you could assemble such a thing, power considerations and solar radiation (and thermal re-radiation) pressure would make such an instrument unmanageable

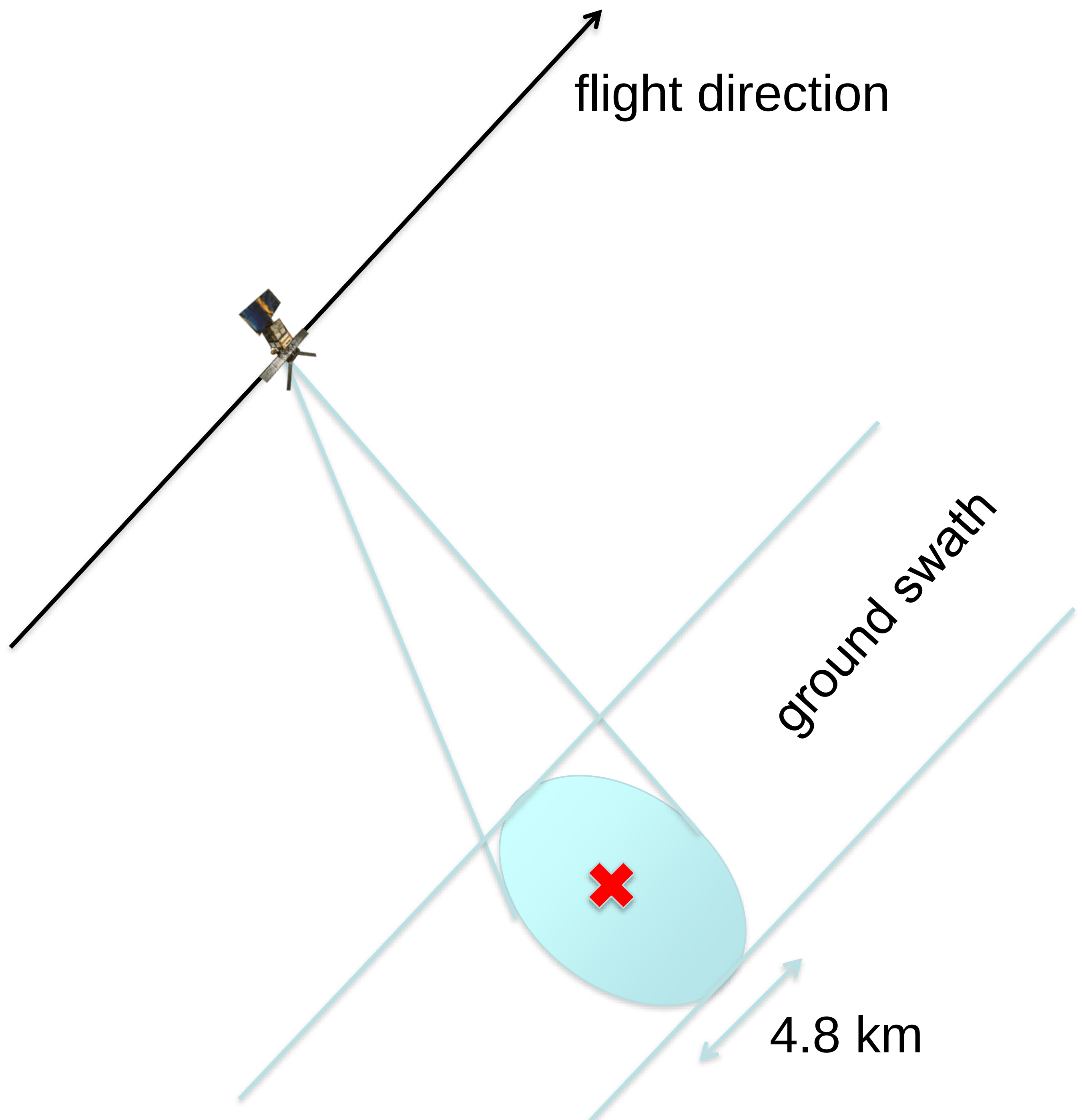
Forming a synthetic aperture

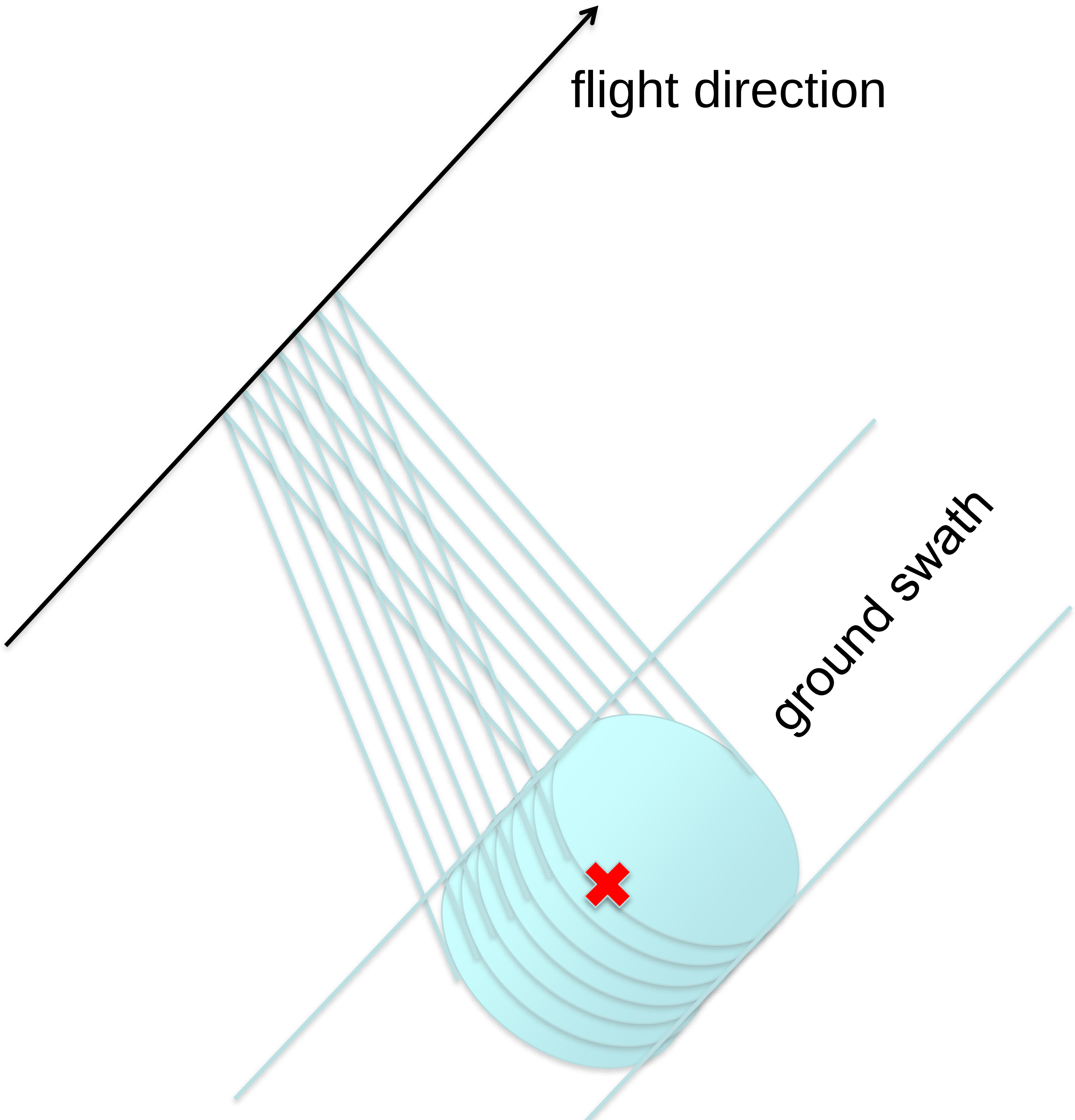


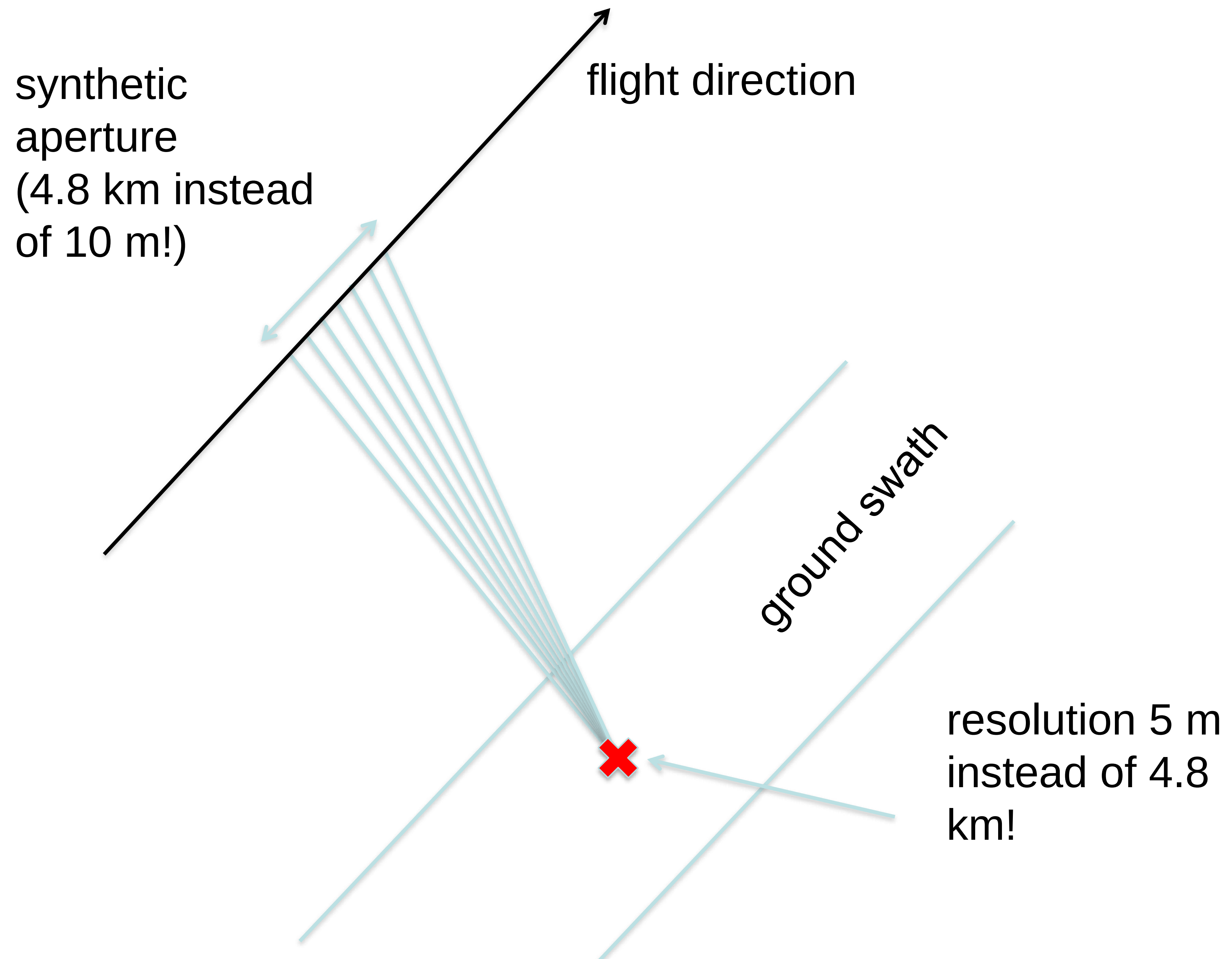
Instead of launching a satellite with a longer antenna, we use the property that the satellite is moving to construct a longer, virtual antenna

This is known as a 'synthetic aperture'

A point on the ground is visible over a distance the length of the azimuth ground swath


flight direction
ground swath
4.8 km

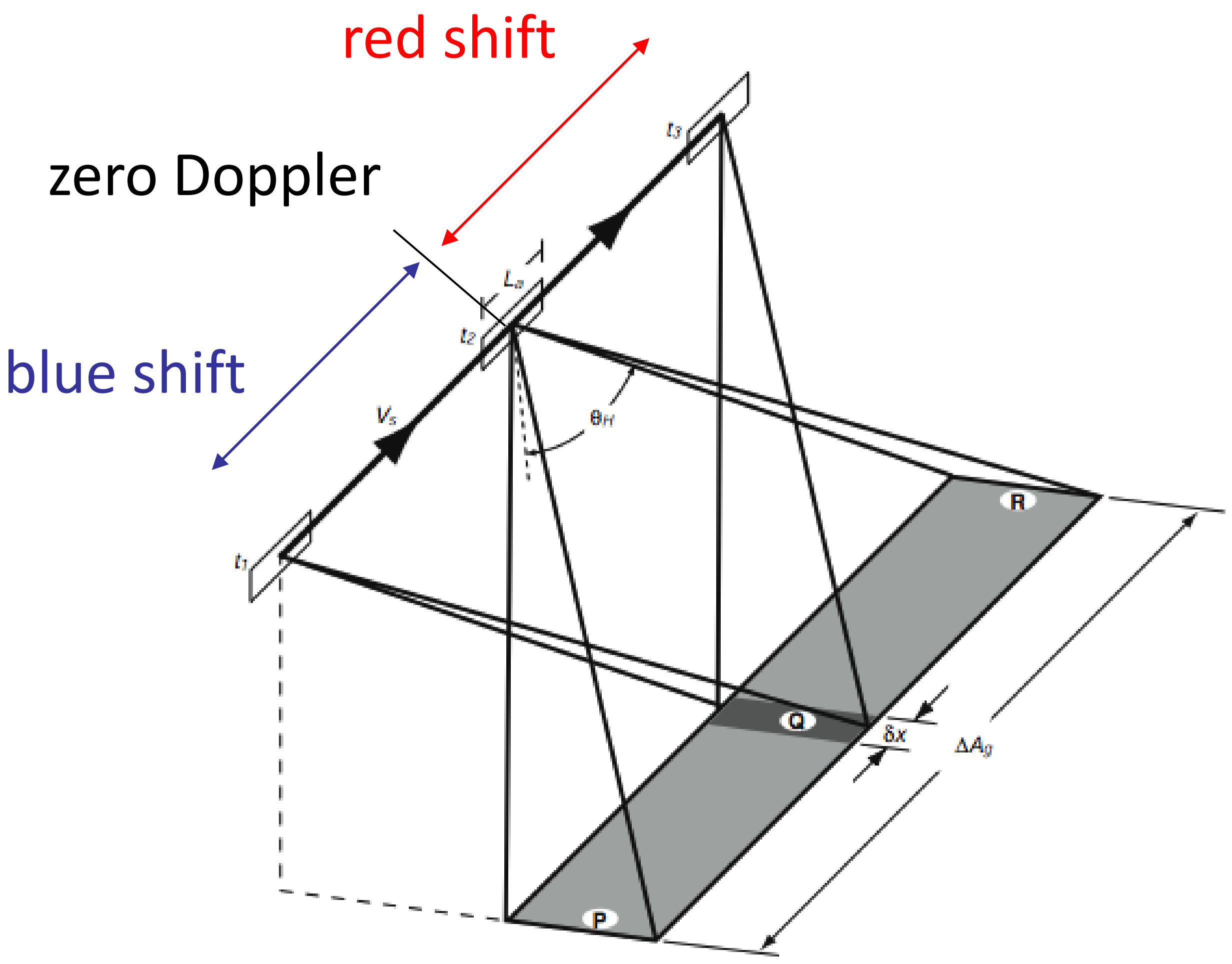

flight direction
ground swath


synthetic
aperture
(4.8 km instead
of 10 m!)
flight direction
ground swath
resolution 5 m
instead of 4.8
km!

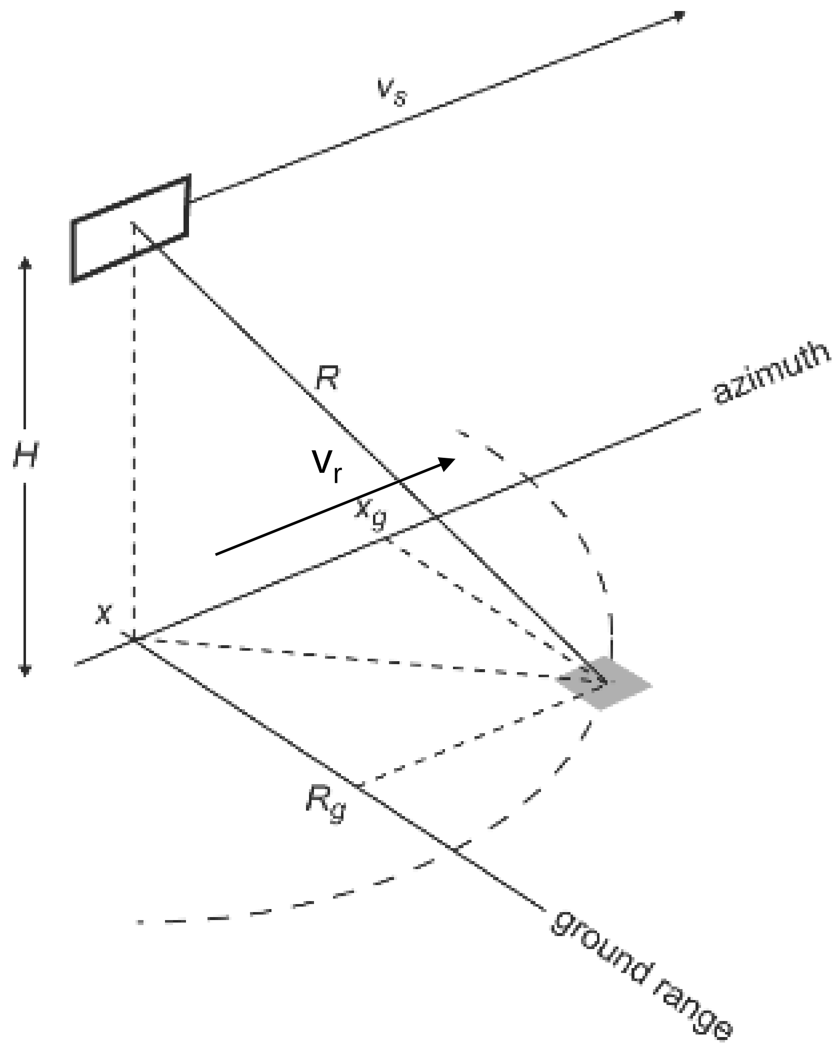
Identifying a ground pixel (1)

In order to correctly assemble a synthetic aperture, all of the echoes from a given pixel on the ground need to be identified

This can be achieved by considering the Doppler shift of the echoes



Identifying a ground pixel (2)



Can derive 2 equations:

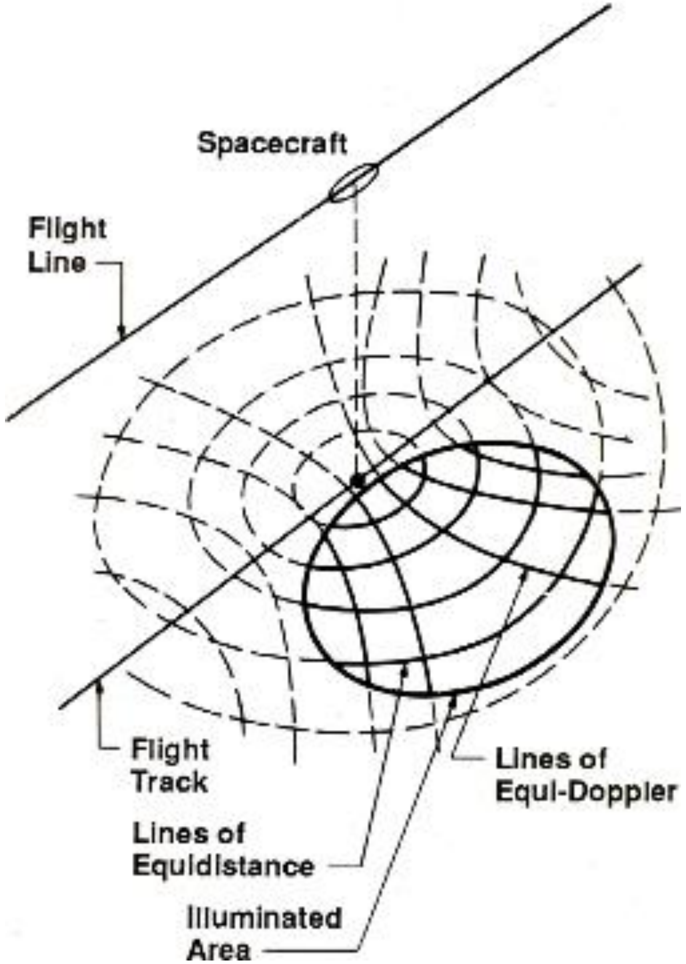
1) Distance of satellite to ground (form: a circle)

$$(x_g - x)^2 + R_g^2 = \left(\frac{c\tau_0}{2}\right)^2 - H^2$$

x_g, R_g = position of ground target

(in practice, modern SAR processors also take ground target height into account)

Identifying a ground pixel (3)



Can derive 2 equations:

1) Distance of satellite to ground (form: a circle)

$$(x_g - x)^2 + R_g^2 = \left(\frac{c\tau_0}{2}\right)^2 - H^2$$

2) Relationship between Doppler shift and position (form: a hyperbola)

$$(x_g - x)^2 \left[\left(\frac{2V_r}{\lambda f_{D_{tot}}}\right)^2 - 1\right] - R_g^2 = H^2$$

Pixel is located where the hyperbola and circle intersect!

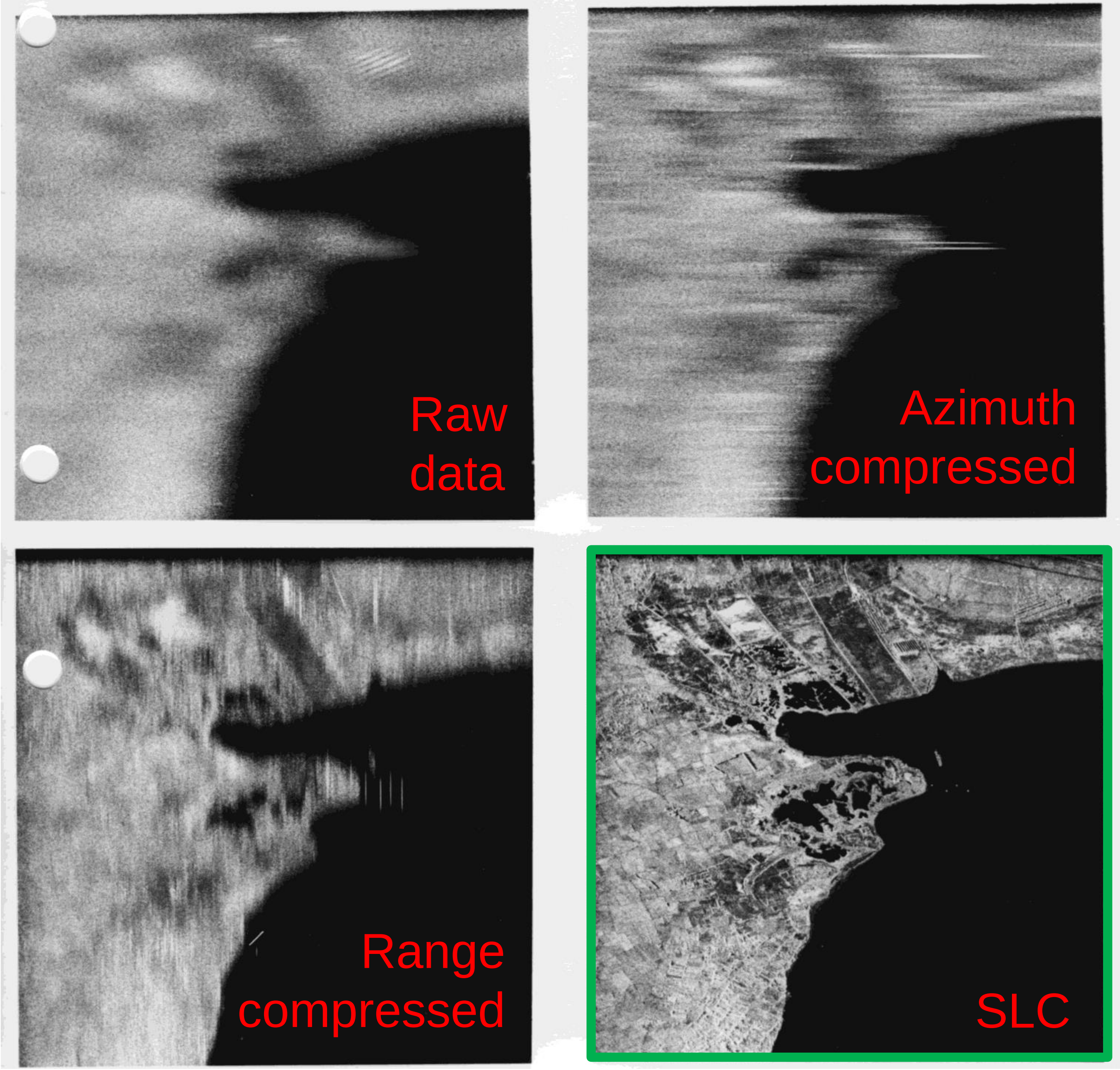
The SLC image

SLC = 'Single Look Complex'

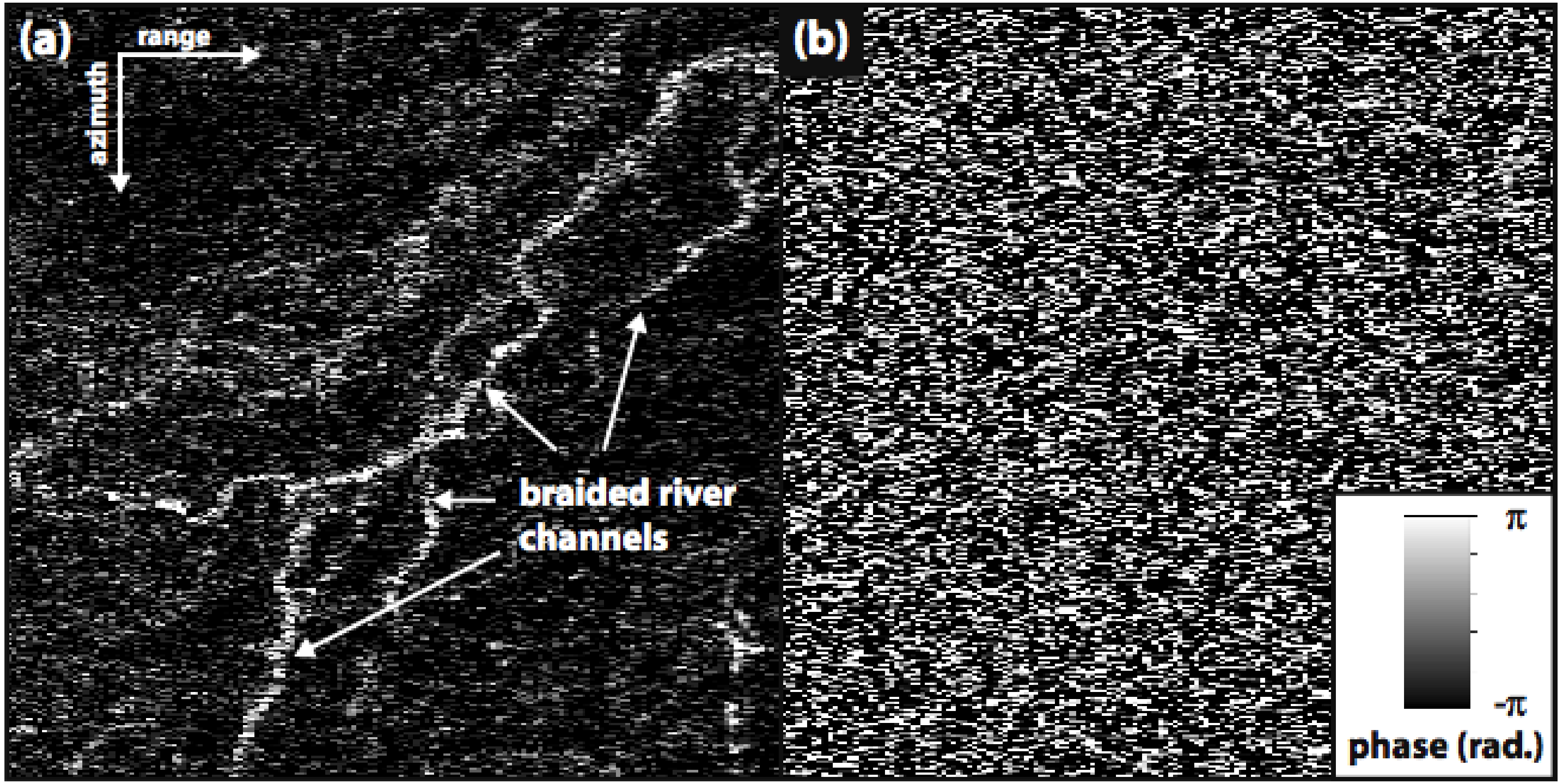
'Single look' = full resolution

'Complex' = stored as a complex number, with amplitude and phase

The SLC is the end-product of SAR processing



The SLC image



amplitude

phase

- SAR imaging uses amplitude (intensity) of backscattered echoes
- Surface roughness and slopes control the strength of the backscatter
- Applications: ship tracks, ice tracking, oil slicks, land-use changes, planetary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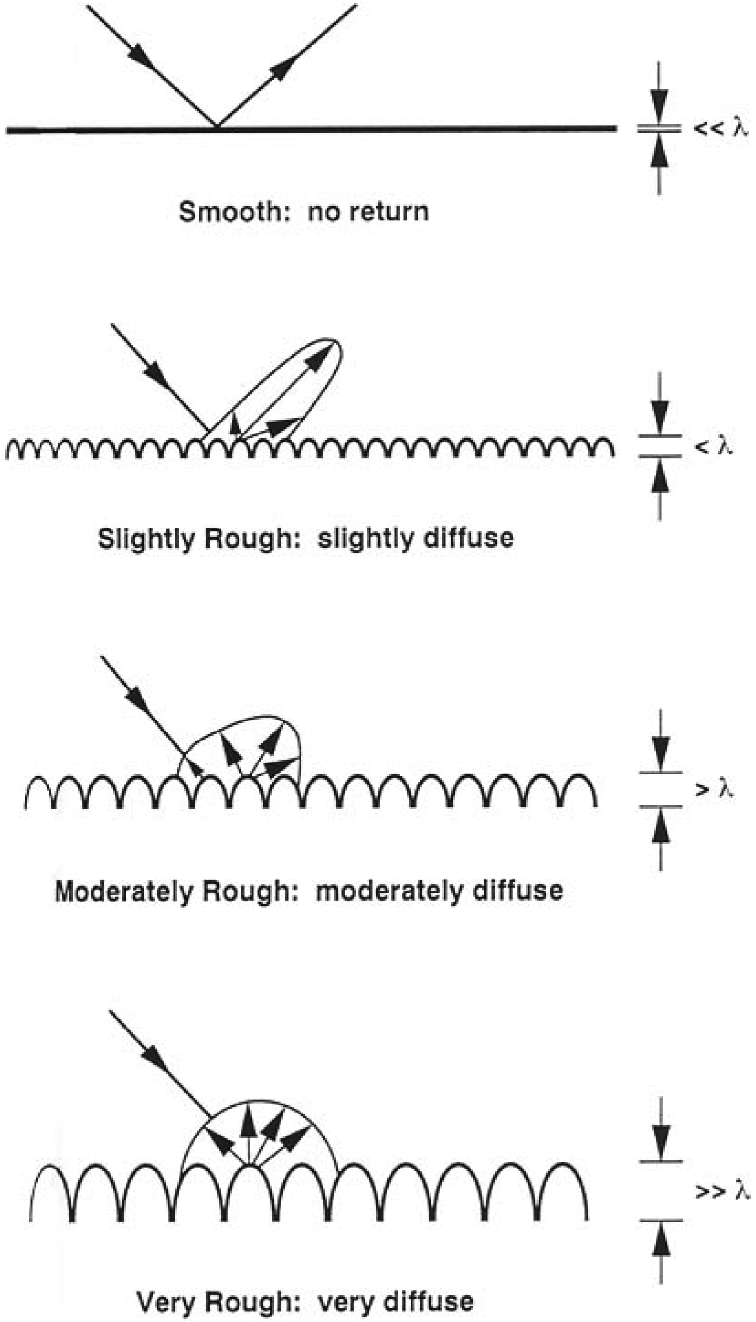
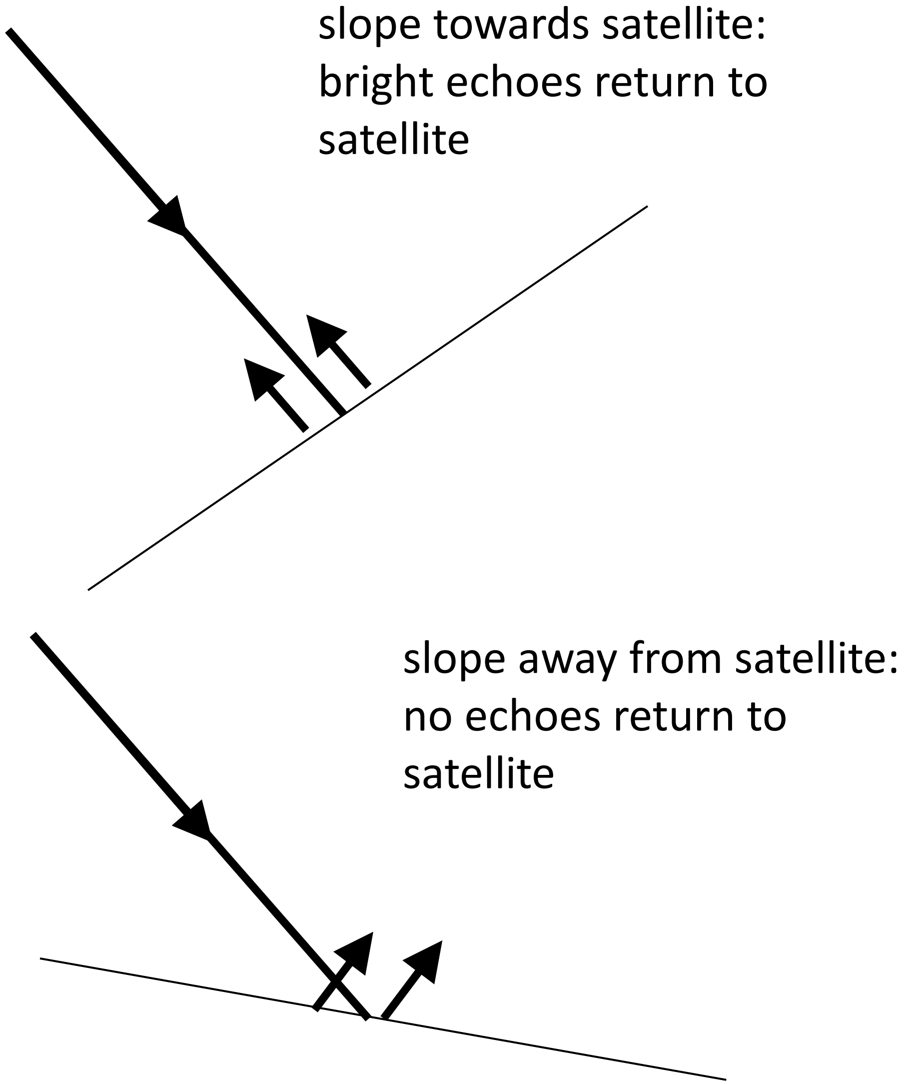
Backscatter

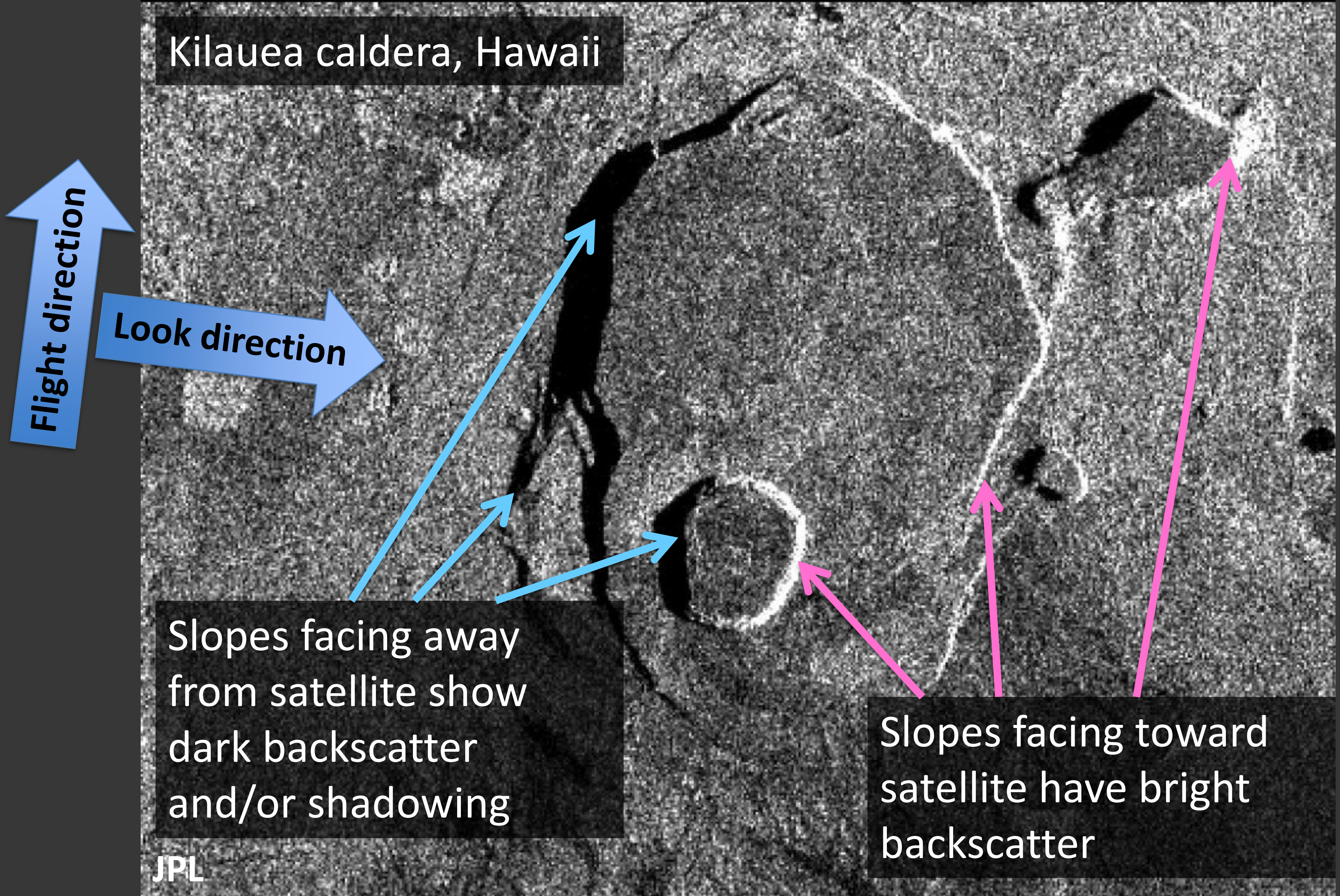
The intensity of the radiation scattered back towards the satellite depends on the roughness of the ground

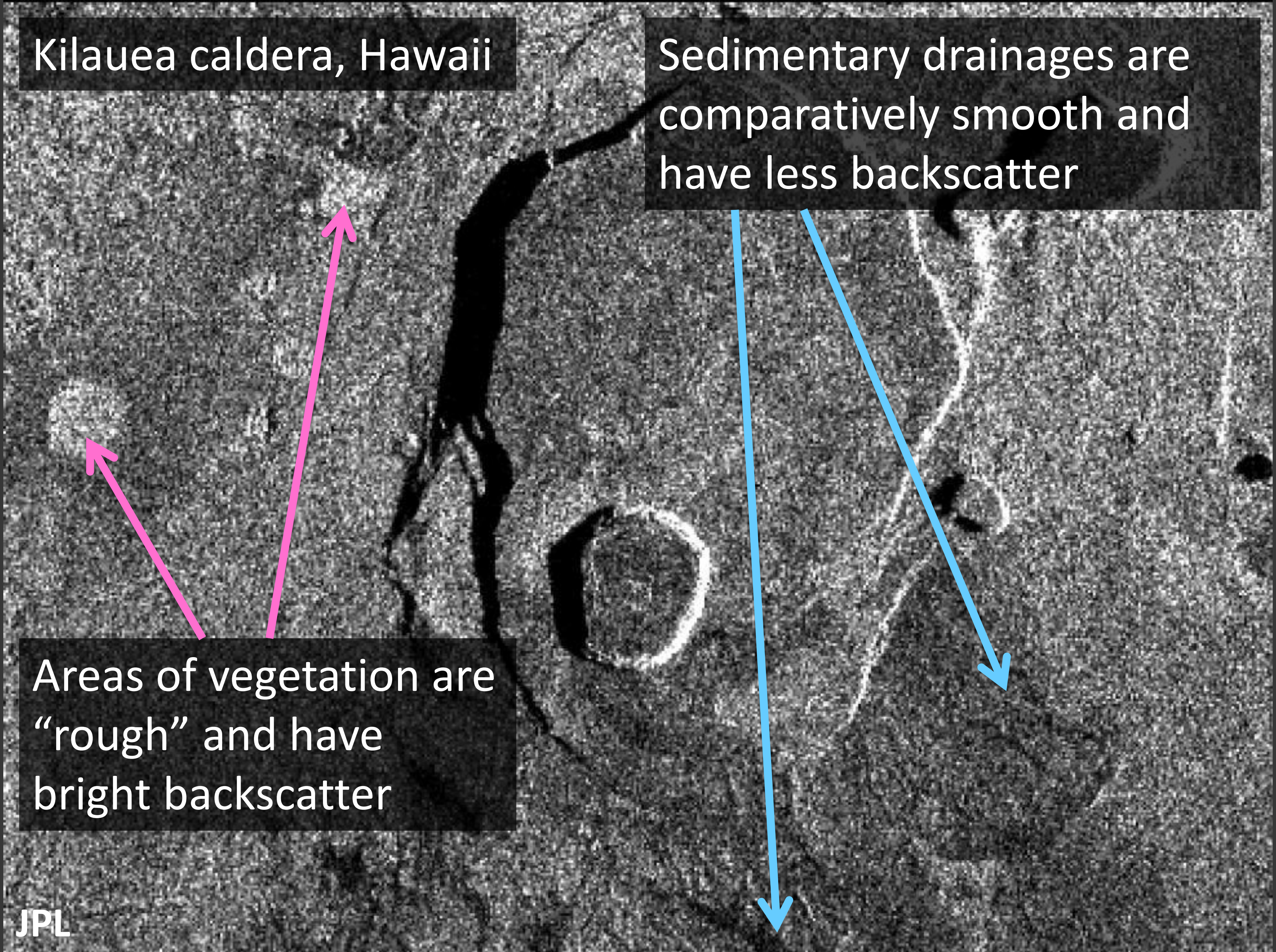


Slopes

The intensity of the radiation scattered back towards the satellite depends on the angle and direction of any slope on the ground




Kilauea caldera, Hawaii
Flight direction
Look direction
Slopes facing away from satellite show dark backscatter and/or shadowing
Slopes facing toward satellite have bright backscatter
JPL


Kilauea caldera, Hawaii
Sedimentary drainages are comparatively smooth and have less backscatter
Areas of vegetation are “rough” and have bright backscatter
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Elementary SAR interpretation

I will show you a Russian SAR image of Paris. The incidence angle of the radar was 48°. It was attached to the left side of the satellite. Pixel size is 5.2 m.

Look at the image and try to answer these questions:

Is there a preferred illumination for buildings and bridges?

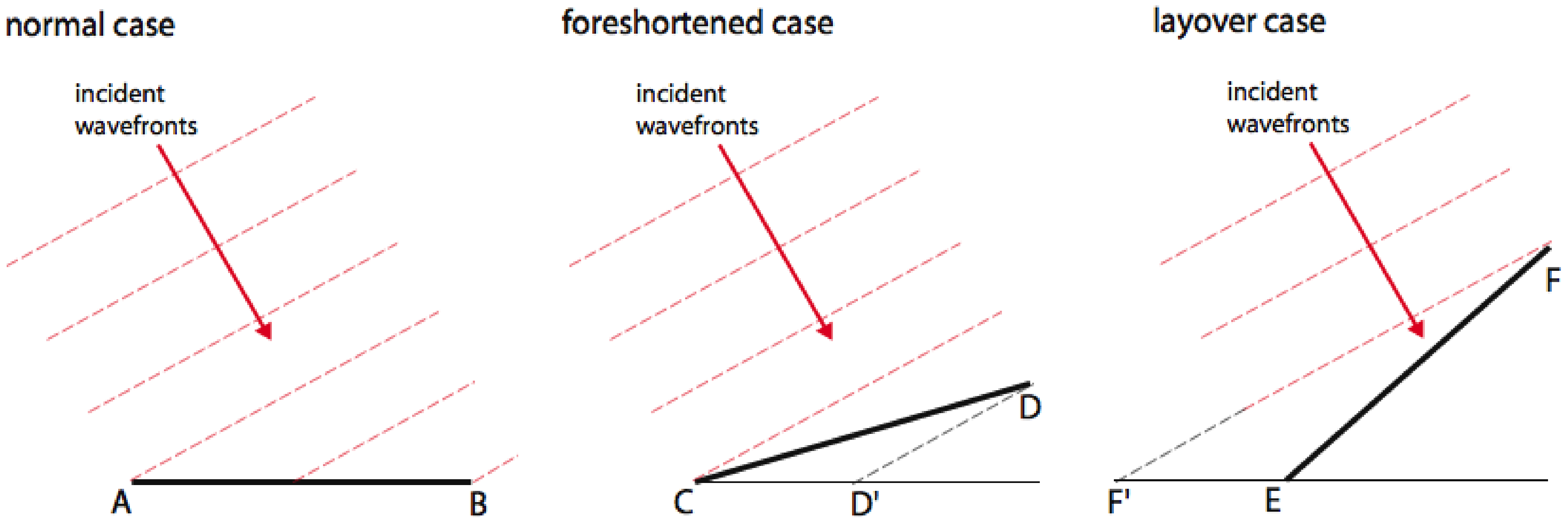
What effect does the SAR viewing geometry have on tall buildings?

In which direction was the satellite flying?


~50 pixels

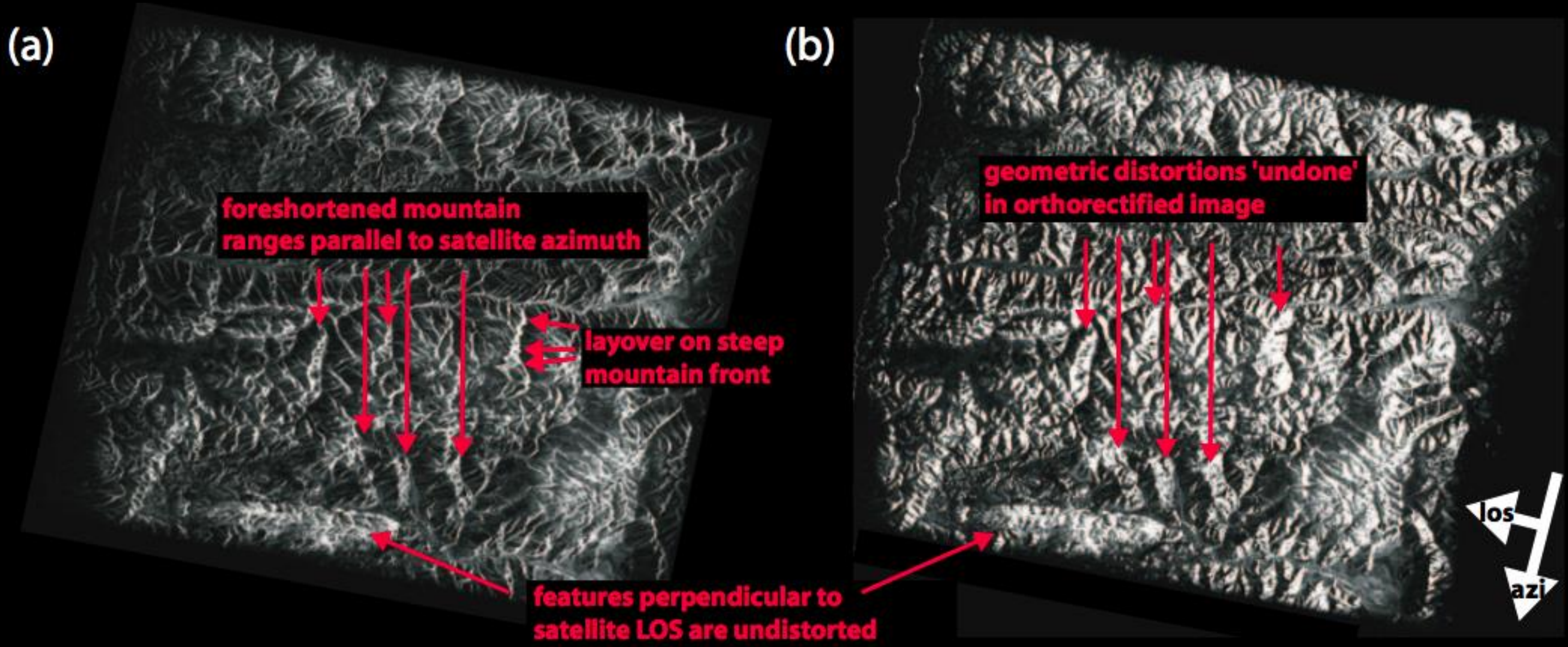
Geometrical effects in SAR

Radar differs from optical imagery where slopes are concerned



Layover causes a loss of signal in the covered up area and often a shadow behind it

Geometrical effects in practice



uncorrected

geometrical distortions 'undone'