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→ 4th ESA ADVANCED TRAINING ON OCEAN REMOTE SENSING

SAR Instrument Principles, Imaging Mechanisms and Processing

7–11 September 2015 | IFREMER | Brest, France

- Atmospheric boundary layer – upper ocean mixed layer. Dynamics and thermodynamics
- Air-sea interaction
- Wind field ----- surface waves, Stokes drift, Ekman current and mixing
- What is in common: Surface roughness at all scales from cm to 100 of km.
- SAR imaging: Bragg scattering in response to cm waves, coupled with modulation by: longer waves, wind field variations and surface current variations. This is the highly important capability of imaging radars like SAR.

Spaceborne SAR intruments typically operate with wavelengths in the range of:

$\lambda = c\,T = 2\text{ cm} - 30\text{ cm}$

corresponding to fequencies in the range of:

$f = c/\lambda = 1/T = 15\text{ GHz} - 1\text{ GHz}$

ERS, Env. ASAR-C band

Radarsat II – C band

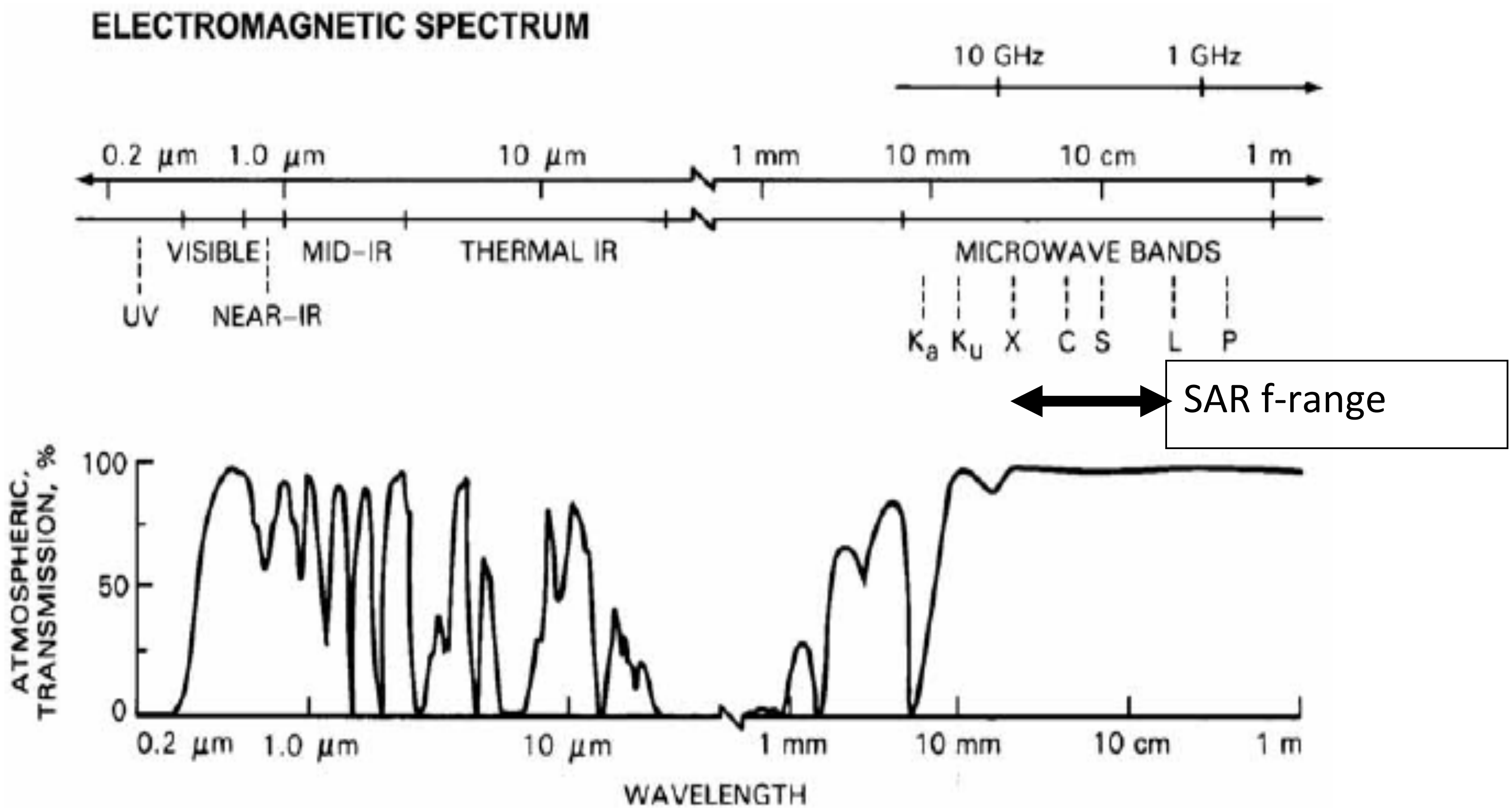
Sentinel-1 C-band

TerraSAR – X band

Cosmo-Skymed – X band

ALOS Palsar – L band

$$\lambda = c * T = c * 1/f$$



The ocean surface roughness is influenced by wind and waves, currents, surface slicks and sea ice and is different in open ocean versus coastal or ice covered regions

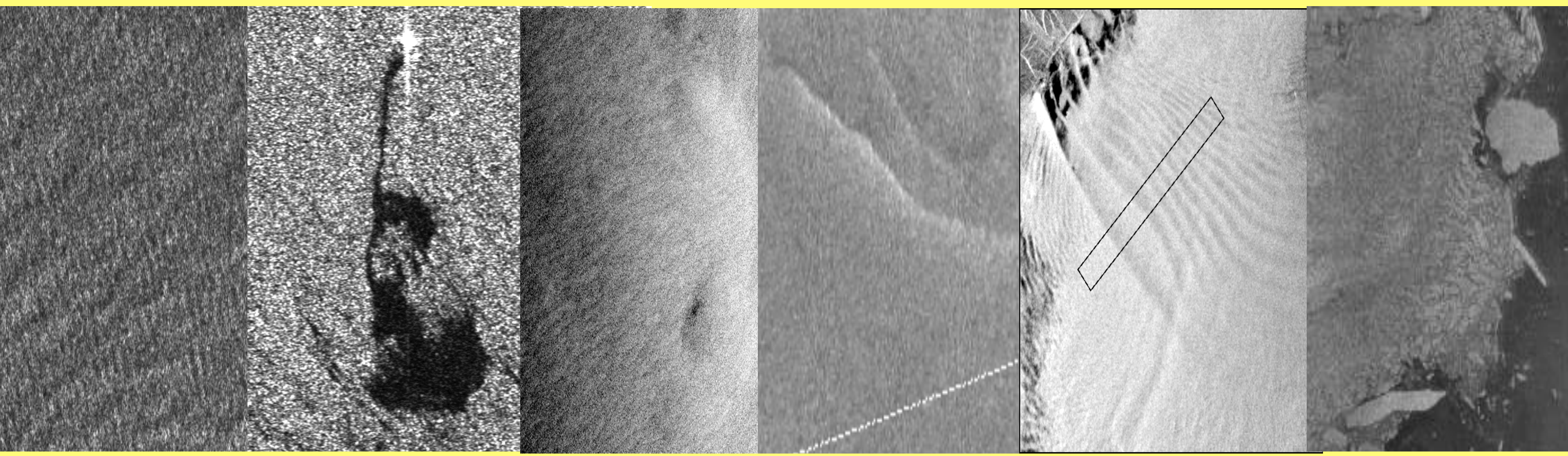
The surface roughness is the source for the backscatter of the SAR signal.

The signal that arrives at the antenna is registered both in amplitude and phase.

Spatial resolution around 10 m

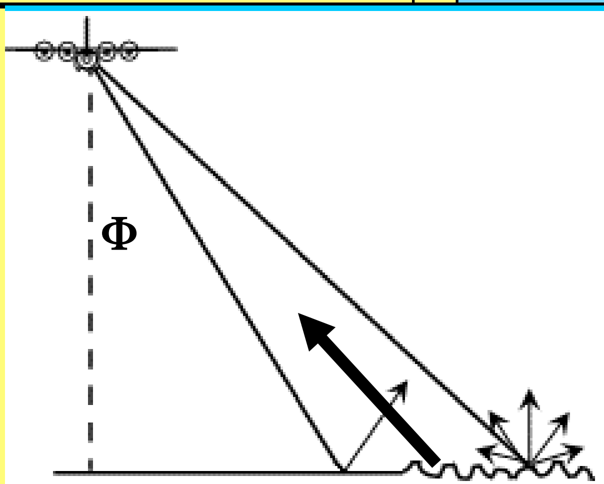
The SAR images manifest expression of

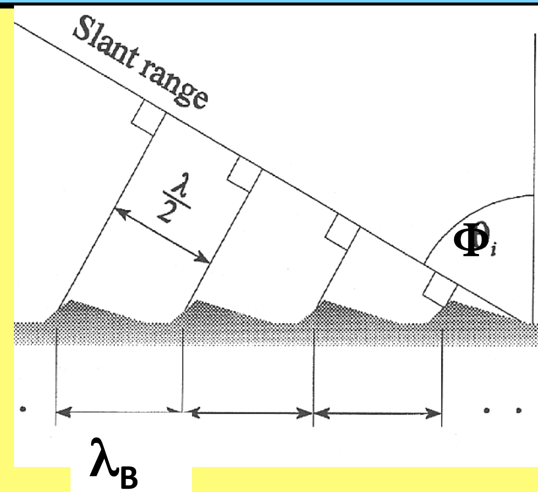
Wave field | Oil spill and ships | Wind field | Current fronts | Internal waves | Sea ice

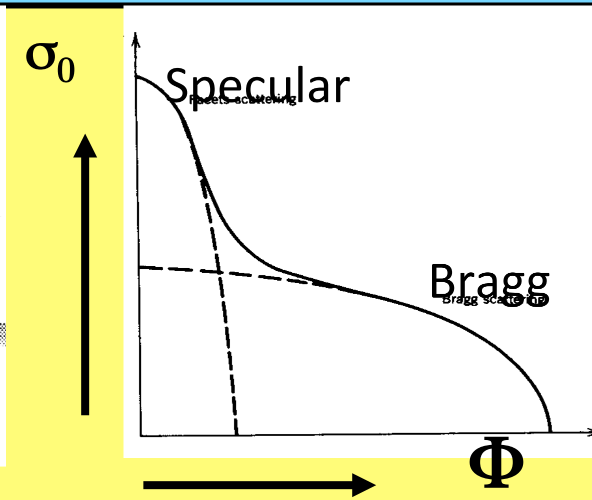


SYNTHETIC APERTURE RADAR

The radar backscatter is primarily determined by the Bragg scattering: $\lambda = 2\,\lambda_B \sin\Phi$
for incidence angles in the range of 20 to 50 degrees







SAR is a transmitting-receiving instrument where

$$P_r = (P_t / 4\pi R^2)\, G\, (\sigma / 4\pi R^2)\, A$$

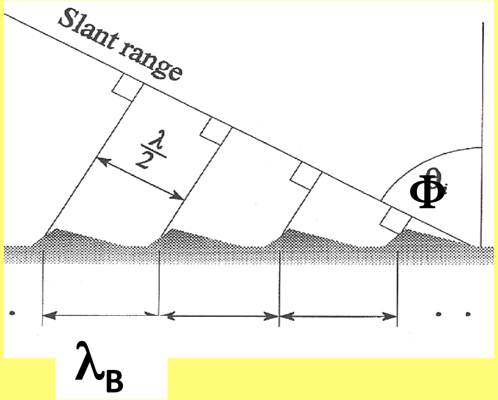
P (r=receive, t=transmit), R = range distance, G = antenna gain, σ = radar cross section, A = antenna area,

$\sigma_0 = \sigma$ /unit area is defined as radar backscatter (=function of surface roughness)

The SAR backscatter arising from the sea surface is caused by surface waves of the order of the radar wavelength.

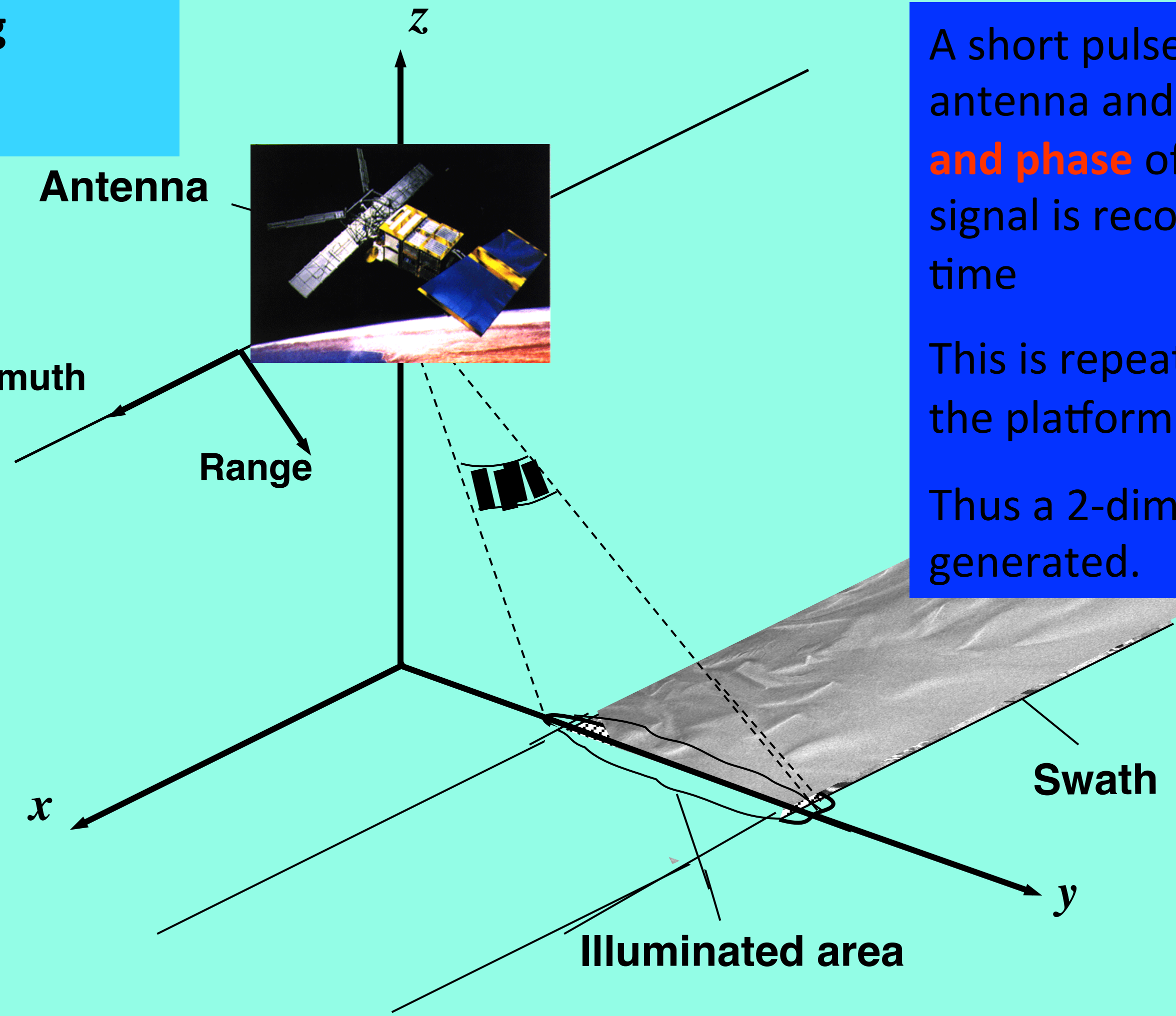
These waves are called " Bragg waves". They obey the " Bragg resonance condition":

$$\lambda_B = \lambda_r /2 \sin\Phi$$



where λ_B = Bragg wavelength, λ_r = radar wavelength, and Φ= incidence angle

SAR imaging geometry

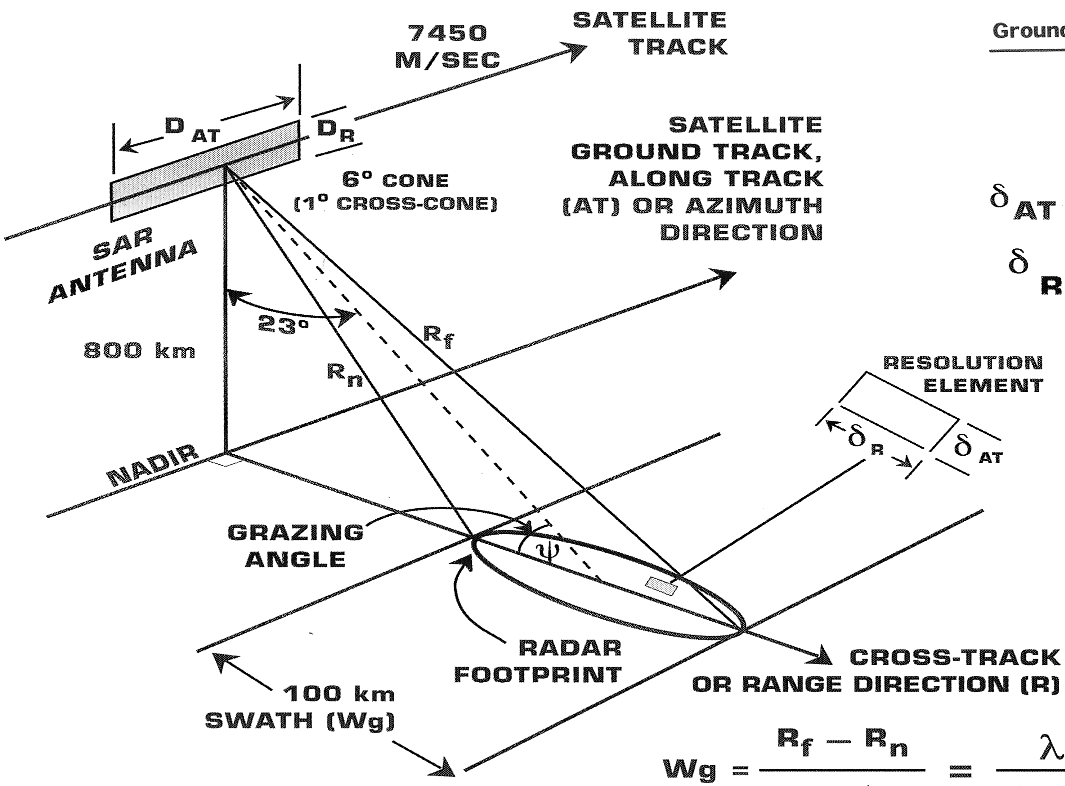


A short pulse is emitted by the antenna and then the **amplitude and phase** of the backscattered signal is recorded as a function of time

This is repeated over again while the platform is moving

Thus a 2-dimensional image is generated.

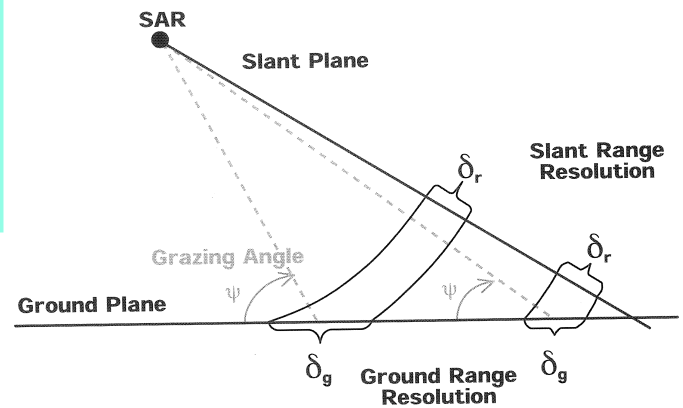
SAR imaging geometry



$$\delta_{AT} \geq \frac{D_{AT}}{2}$$

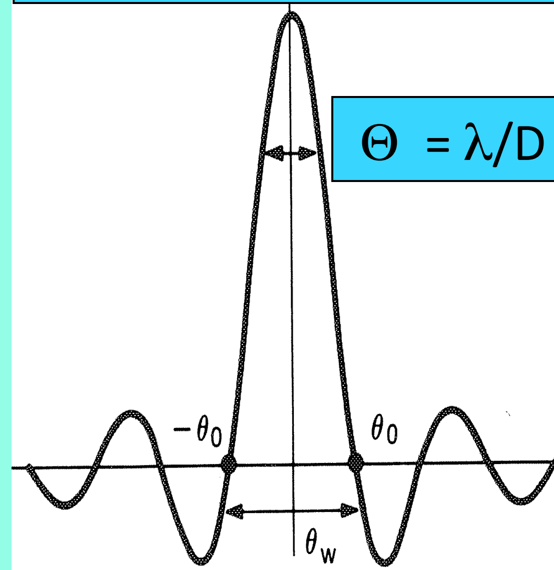
$$\delta_{R} \geq \frac{c}{2\beta}$$

$$W_g = \frac{R_f - R_n}{\cos\psi} = \frac{\lambda R}{D_R \sin\psi}$$



HALF POWER BEAM WIDTH

$$\Theta = \lambda/D$$



SAR resolution is independent of the height

in range X_r **= c τ/2sinΦ** (c: speed of light, τ: pulse duration, Φ:inc.angle)

in azimuth X_a **= D/2** (D = antenna length)

This is achieved by use of *frequency chirp* in range and *synthetic aperture* principle in azimuth. The synthetic aperture principle utilize the motion effects of the antenna which is equivalent to flying a very long antenna.

The independence from the platform height is achieved at the expence of very demanding SAR signal processing.

The smaller the antenna, the better the azimuth resolution:

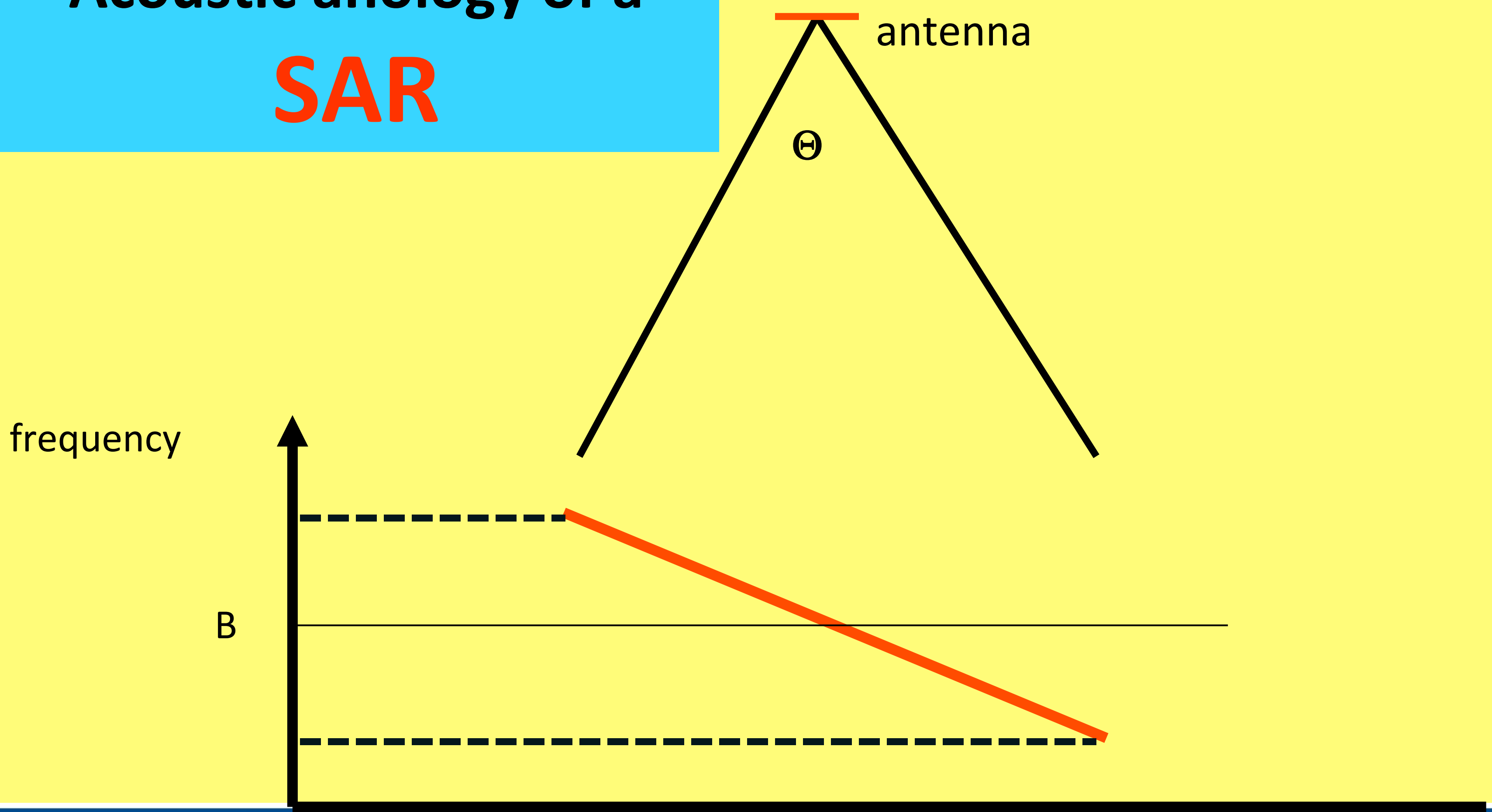
$$X_a = D/2$$

The resolution is independent of the platform altitude. This is completely contrary to what applies for other remote sensing instruments.

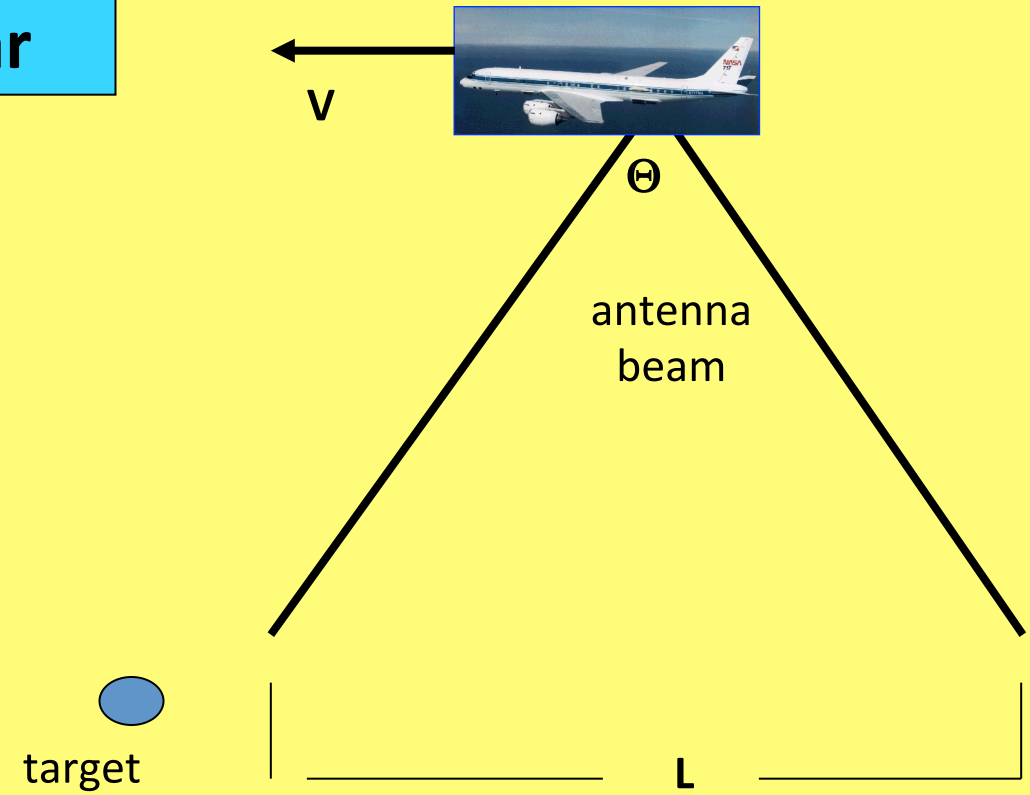
It arises from the well known engineering principles where an electrical system with a bandwidth B can resolve a signal that has a time length of $\Delta t = 1/B$

Deriving fine azimuth resolution (courtesy of Prof. W. Alpers)

Acoustic anology of a SAR



Synthetic aperture radar



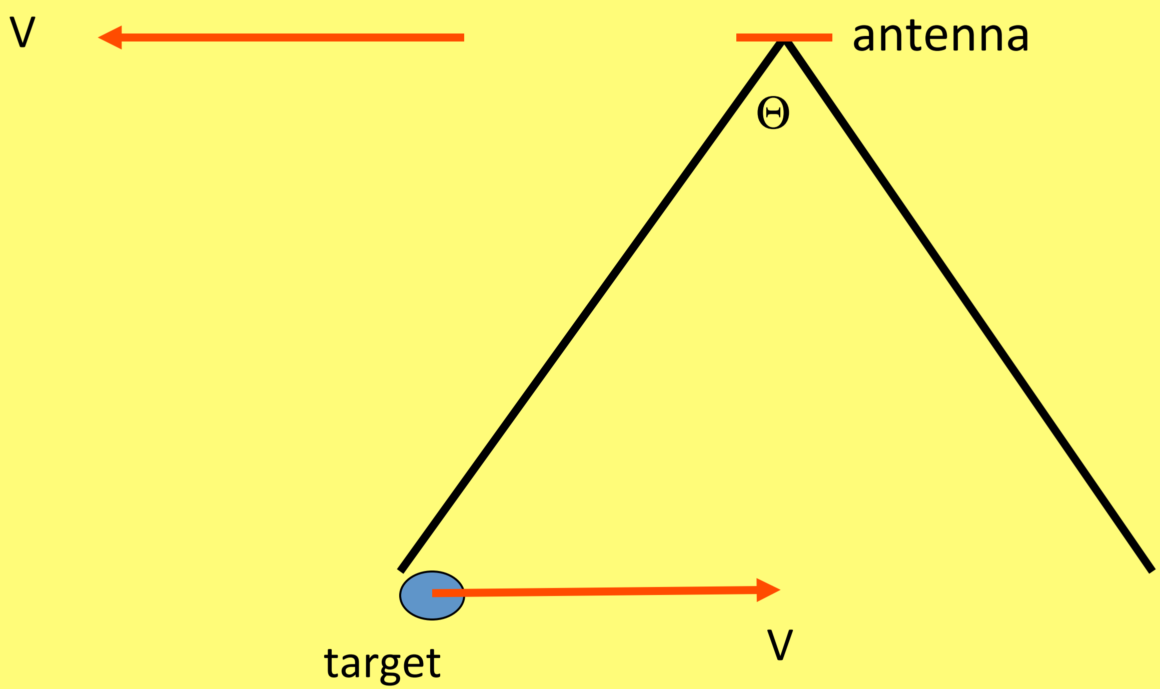
V = platform velocity

T = integration time

L = length of the synthetic antenna

The target is for T seconds (T = L/V) in the antenna beam

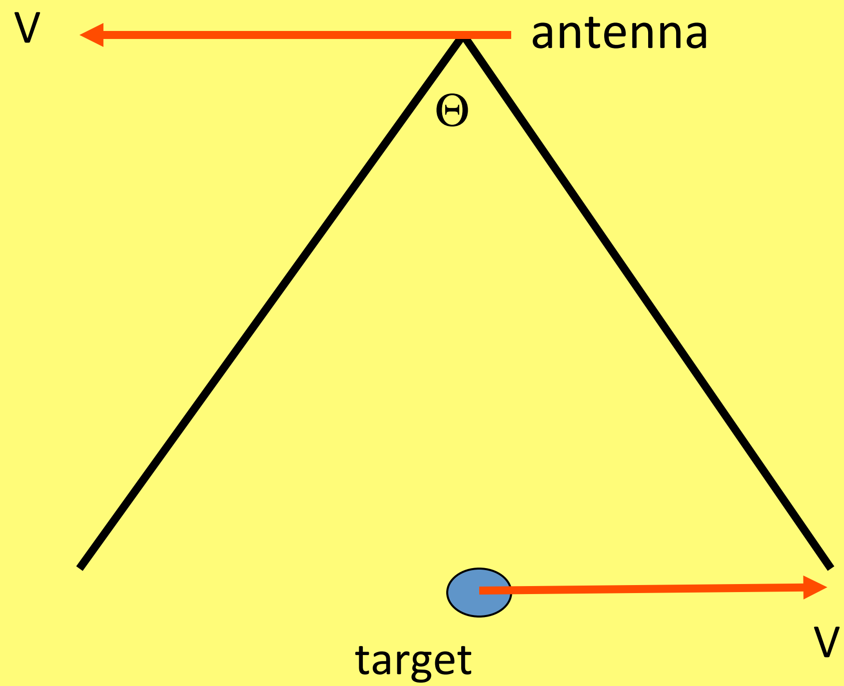
Synthetic aperture radar principle (after Alpers)



$$f_d = + V\theta / \lambda$$

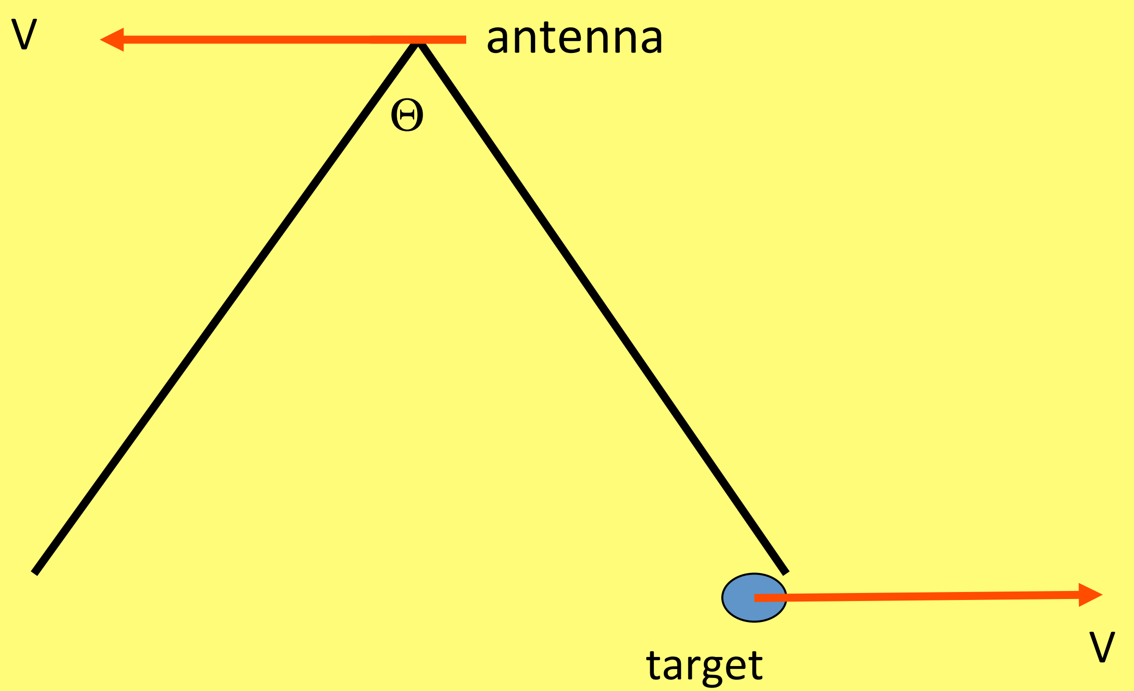
f_d = Doppler shift

Synthetic aperture radar principle - 2



$f_d = 0$

Synthetic aperture radar principle - 3



$$f_d = -V\theta/\lambda$$

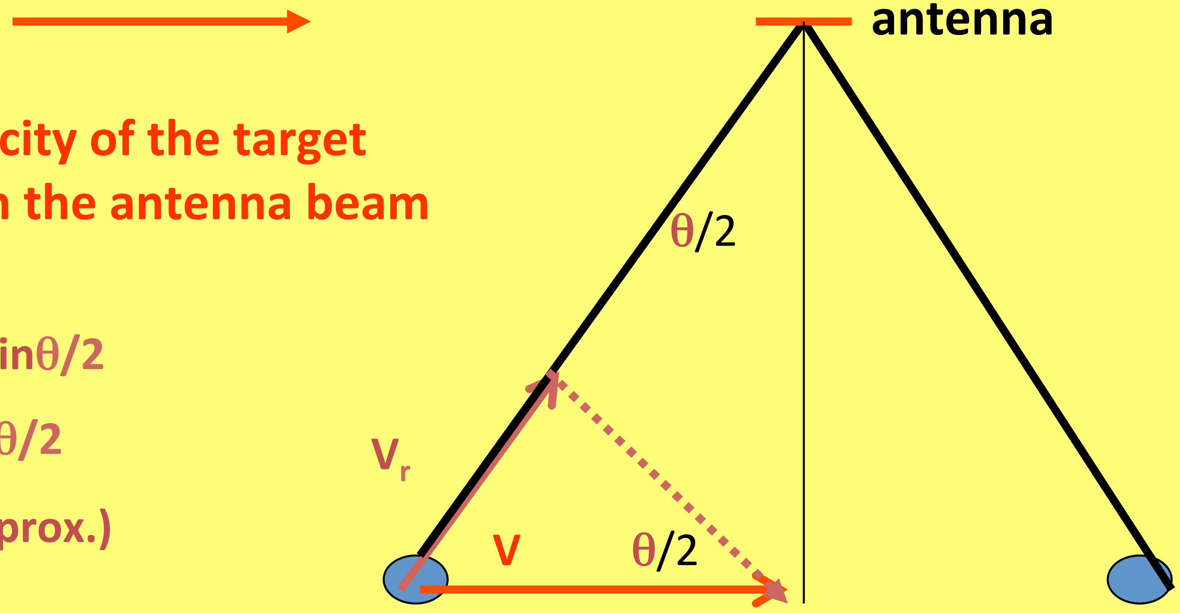
Change of the Doppler shift f_d **across** the aperture

V= velocity of the target through the antenna beam

$V_r = V\sin\theta/2$

$= V\,\theta/2$

(approx.)



$$f_d = +2V_r/\lambda \;\; (= (2V_r/c)\, f\,) = +V\theta/\lambda$$

Change of Doppler shift across the aperture = $f_d - (-f_d) = 2f_d = 4V_r/\lambda = 2V\theta/\lambda$

$2f_d = B$ is called the Azimuthal Bandwidth of the SAR

THE UNIQUE SAR AZIMUTH RESOLUTION

The time interval that can be resolved is

$\Delta t = 1/B = 1/2f_d = \lambda / 2V\theta = D/2V$ **(because of** $\theta = \lambda/D$**).**

The spatial interval in flight direction that can be resolved =azimuthal resolution = $X_a = V\Delta t = D/2$.

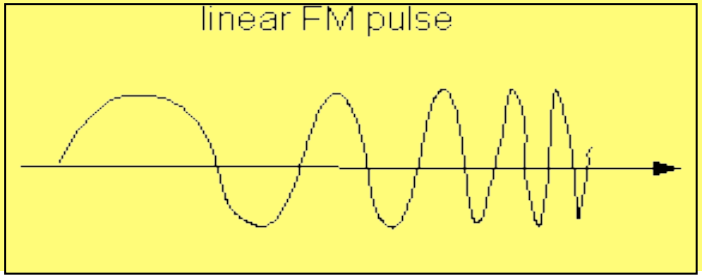
Thus, the azimuthal resolution of a SAR is independent of range R and is proportional to D

Increase of the range resolution

The range resolution $X_r = c\,\tau/2\,\sin\theta$ is also independent of the platform height.

But, it is technically not possible to generate a radar pulse that has a length of only a few meters.

Radar engineers use a long pulse with a (linearly) modulated frequency - called a Chirp. With this technique it is possible to increase the range resolution



Pulse is not frequency modulated

| L = cτ |

Target 1 Target 2

L/2

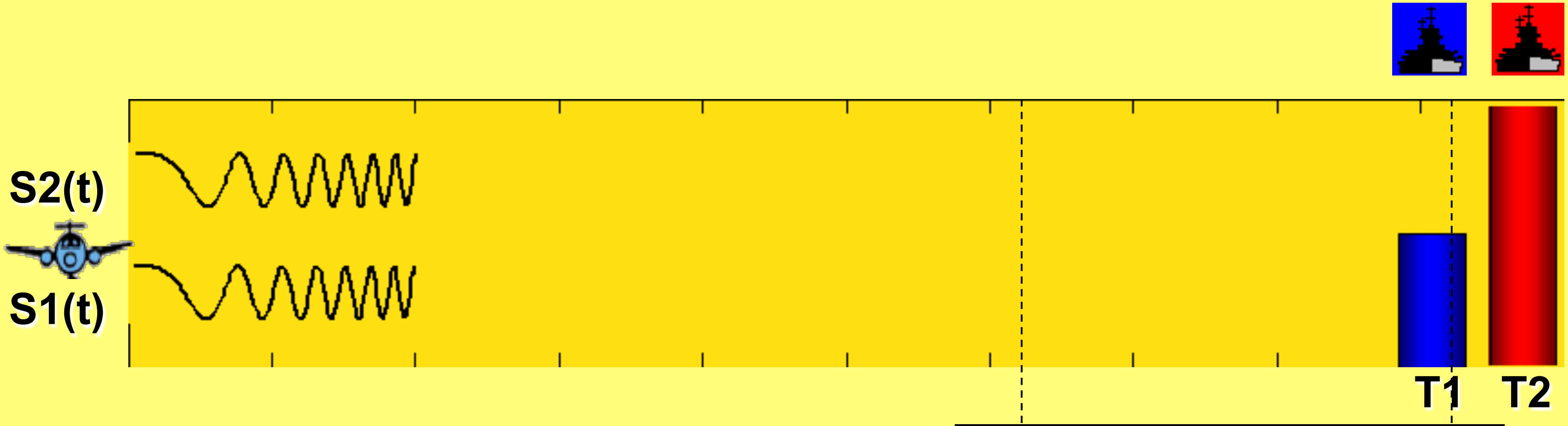
L=pulse length

L/2 = separation of the targets

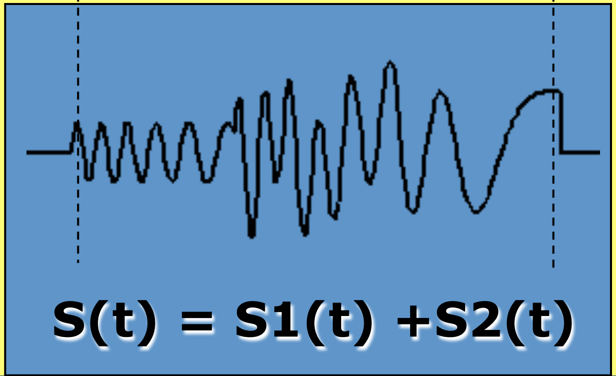
The two targets separated by L/2 can only be resolved when the pulse length cτ is equal to or smaller smaller than L/2.

Range resolution: $X_r = c\tau/2\sin\theta$

Improvement of the range resolution by using a frequency modulated pulse



Backscattered signal S(t), is the sum of the backcattered signals from target 1 and target 2.

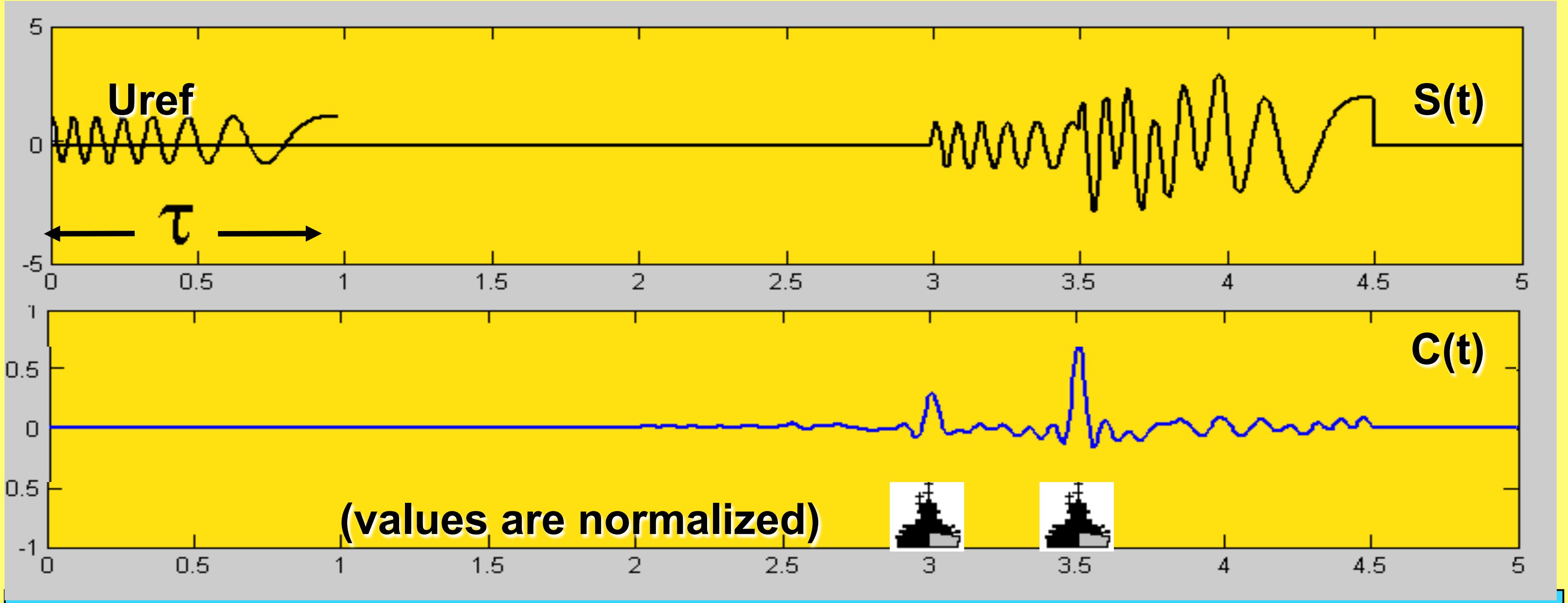


A frequency modulated pulse can resolve targets which are separated by less than L/2.

This is achieved by cross-correlating the backscatterd pulse $s(t) = s_1(t) + s_2(t)$ with a reference signal $u_{ref}(t)$, which is the complex conjugate of the emitted signal:

$$c(t) = \int_{-\infty}^{+\infty} s(t + t') \cdot u_{ref}(t') \, dt'$$

Improvement of the range resolution by using a frequency modulated pulse



The positions of the two targets show up in the correlation function c(t) as two separate peaks.

The unique SAR range resolution

In azimuth direction, the frequency modulation of the backscattered signal results from the motion of the platform and is thus naturally induced.

In range direction, on the other hand, the frequency modulation of the backscattered signal originates from the emitted chirped signal and is thus artificially induced.

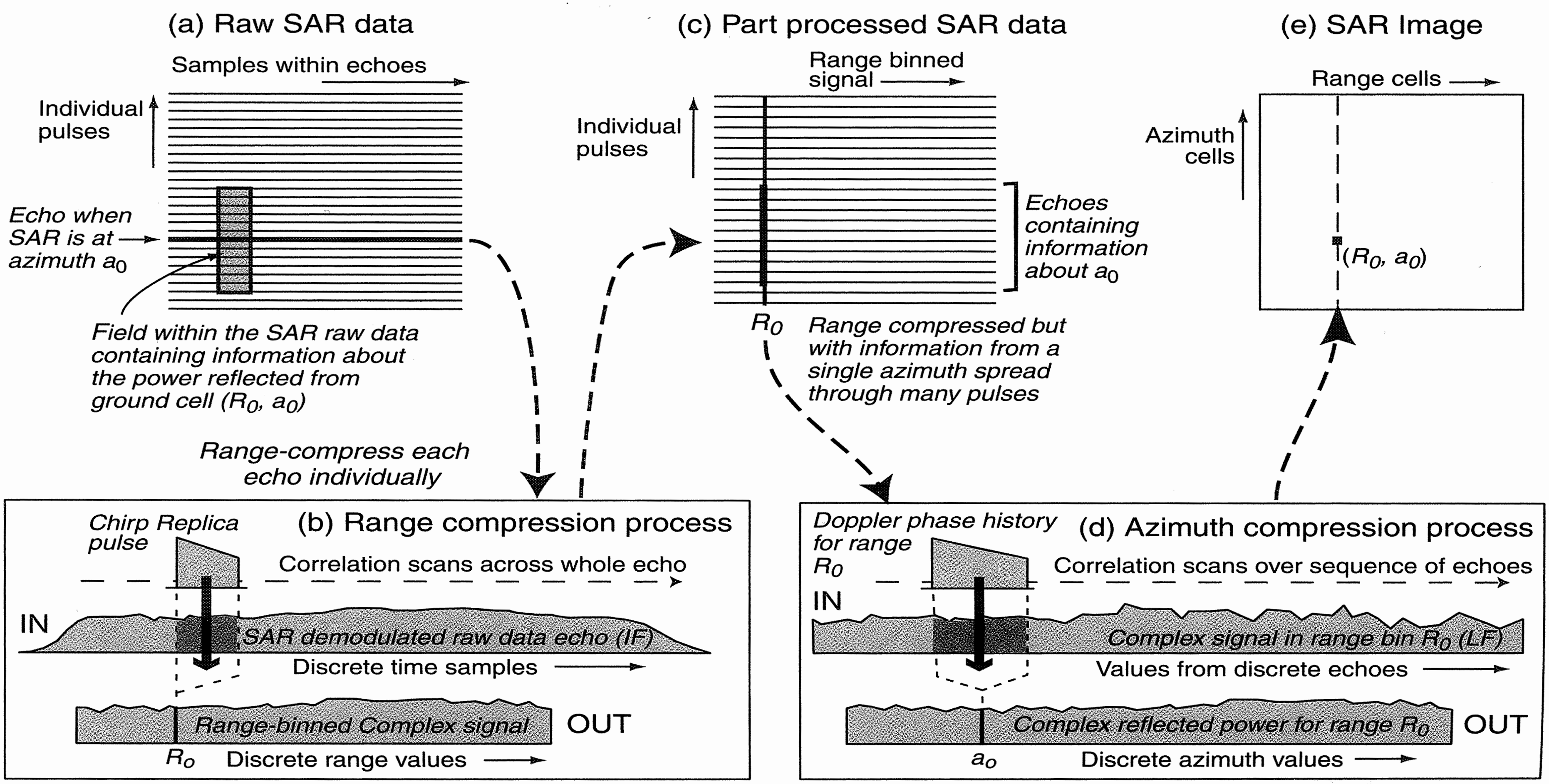
Consequently, in both directions, we have signals which are linearly frequency modulated.

In the SAR processor these frequency modulations are used to improve the resolutions in range X_r and azimuth X_a. This is called azimuth compression and range compression respectively.

$X_a = D/2$ $\quad$ $X_r = c\,\tau/2\sin\Phi = c/2B\sin\Phi$

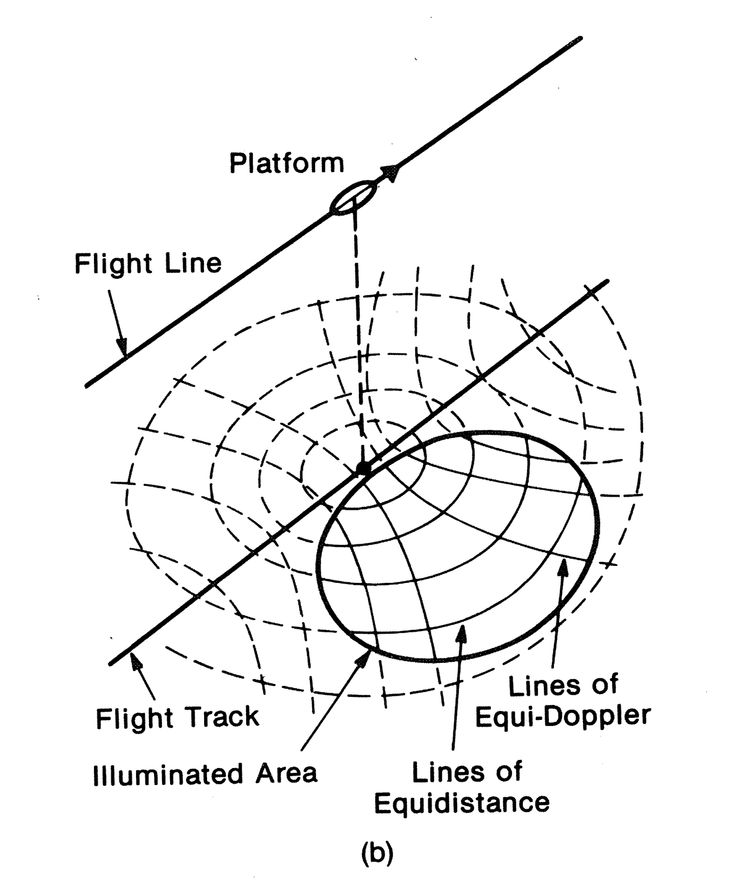
Therefore the SAR processor consists essentially of 2 correlators, one for range and one for azimuth.

STAGES IN SAR IMAGE COMPRESSION



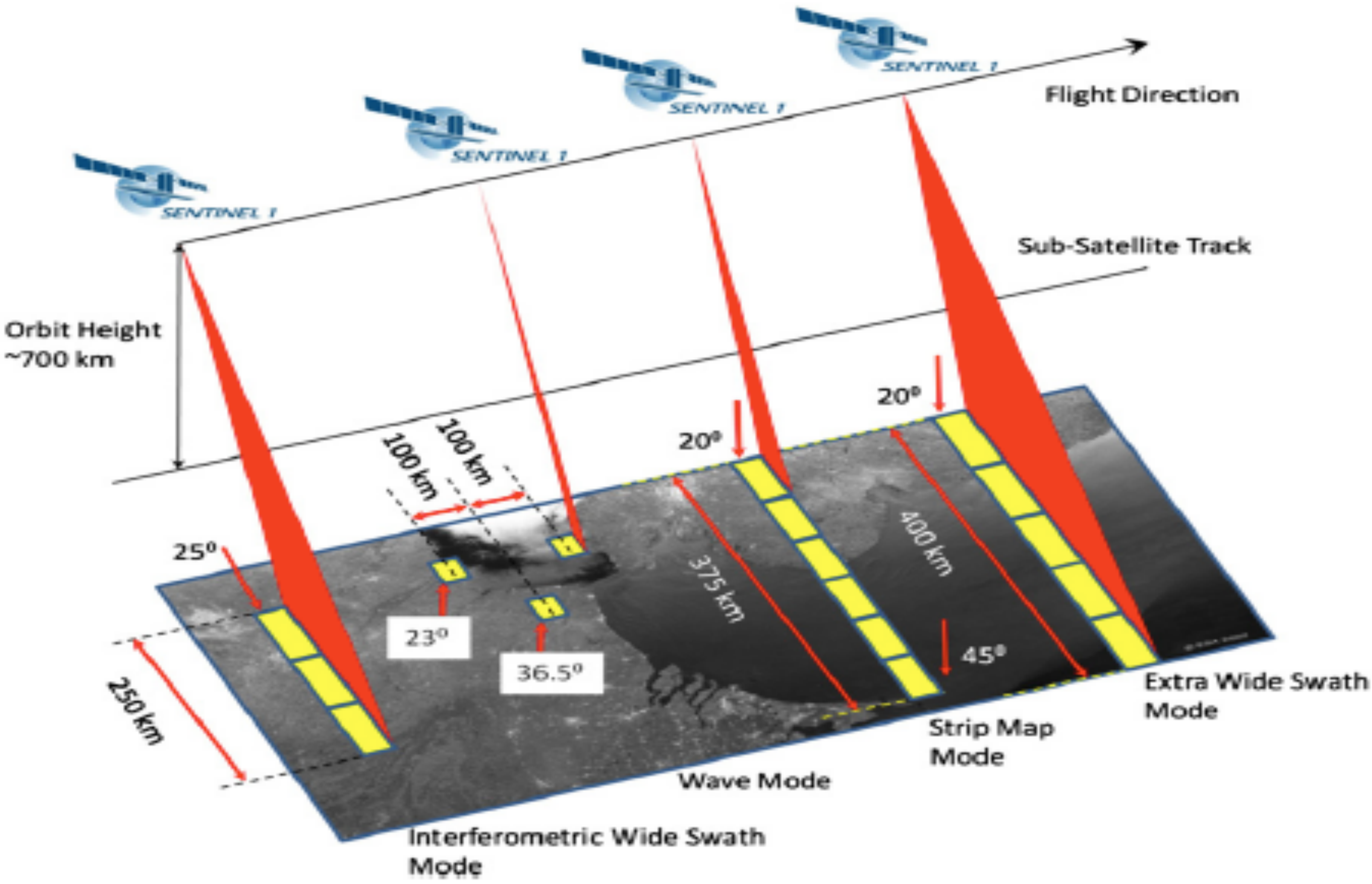
(after Robinson, 2004)

SAR imaging coordinate system



The illuminated area can be referenced to a coordinate system of concentric circles (equi-distances) and coaxial hyperbolas (equi-Doppler). Each point in the image plane can be uniquely identified by its time delay and Doppler shift.

Sentinel-1 Operating Modes



Sentinel-1

Waves

Near Surface Wind

Internal Waves

Surface Current

Ship detection Oil spill

Sea ice