FACULDADE DE CIÊNCIAS
A Ciência de hoje é mais que a Tecnologia de amanhã

Satellite Remote sensing over water surfaces

II-Active sensing of the water surface

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Outline of the Lecture (Part I)):

1) Introduction to pulse radars:

- Remote sensing methods: satellite active sensors
- Real Aperture Radar
- Synthetic Aperture Radar (range and azimuth resolutions)

2) Radar backscatter from the water surface

- Bragg scattering (resonant scattering)
- Non-Bragg scattering: wave breaking

3) Dual polarizarion radar probing

- Example of a dynamic feature detected in dual-pol.

4) Job Announcement!

Introduction

Radar = Radio Detection and Ranging

Analogous terms:

Lidar = Light Detection and Ranging

Sodar =Sound Detection and Ranging

Types of radars:

- **Non-imaging radars,** e.g., radar altimeter
- **Imaging radars**

a) **with a rotating antenna**, e.g., a ship radar or an airfield surveillance radar

b) **with an antenna mounted on a moving platform,** e.g., on an aircraft or a satellite

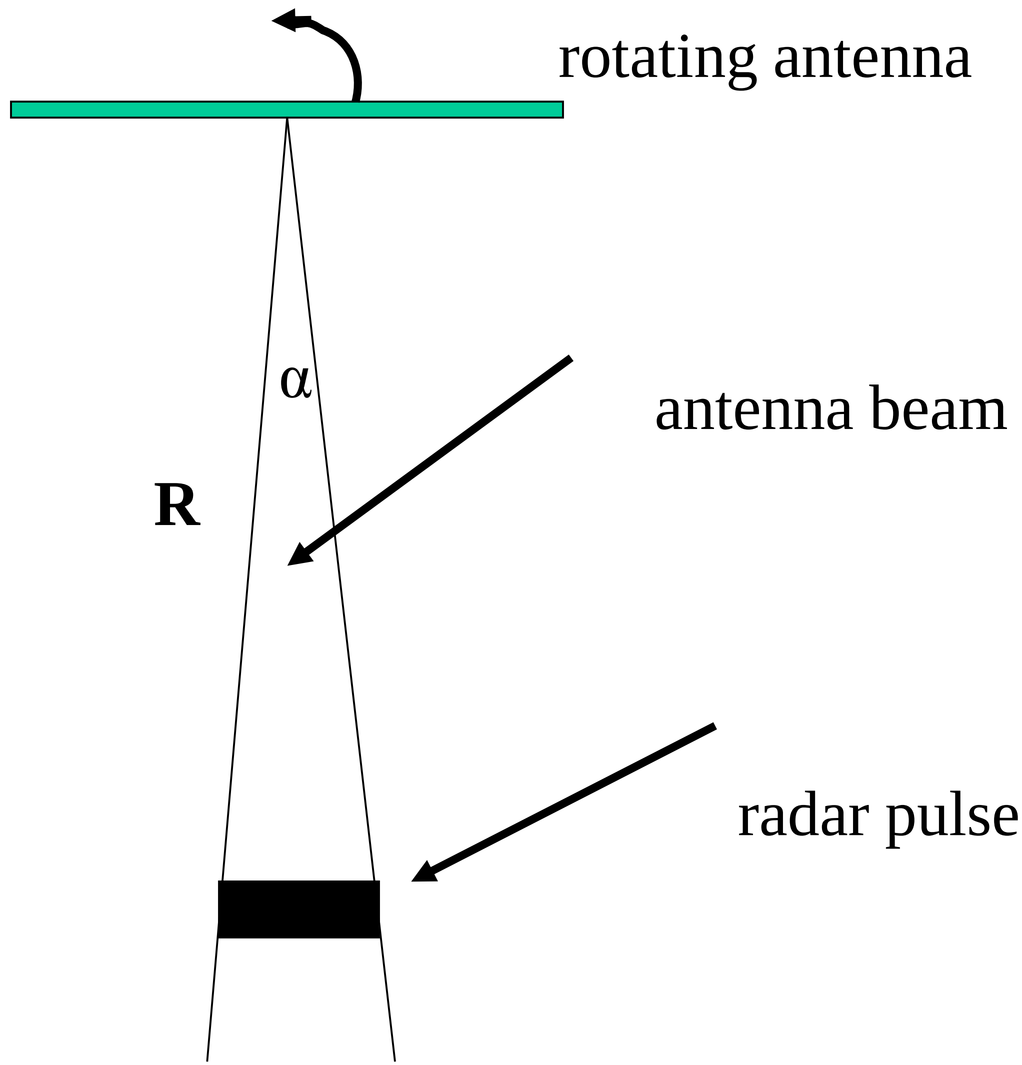
Ship radar:

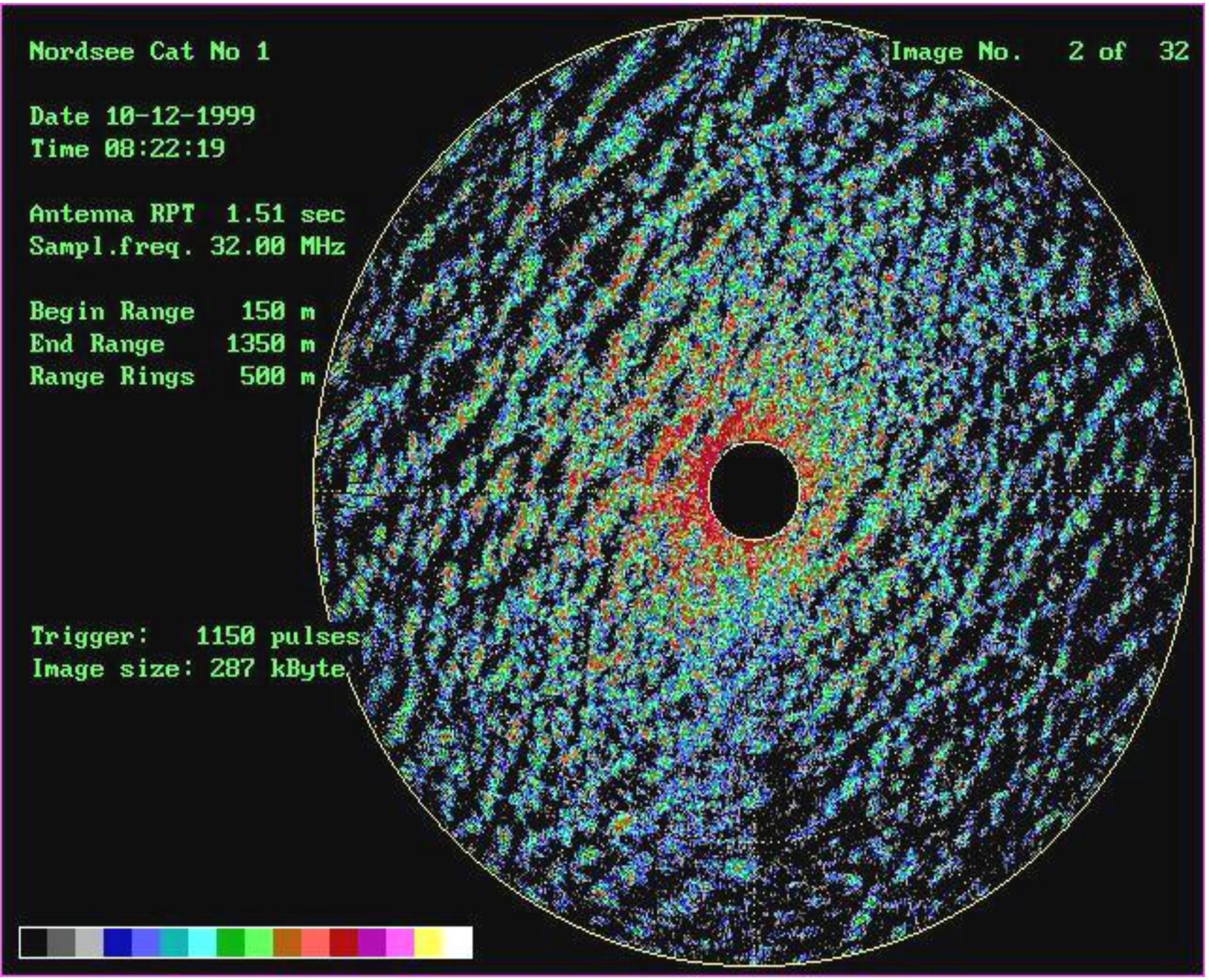
range resolution:

$\rho_r = \mathbf{c}\ \boldsymbol{\tau}/\mathbf{2}$

azimuth resolution:

$\rho_a = \alpha R$





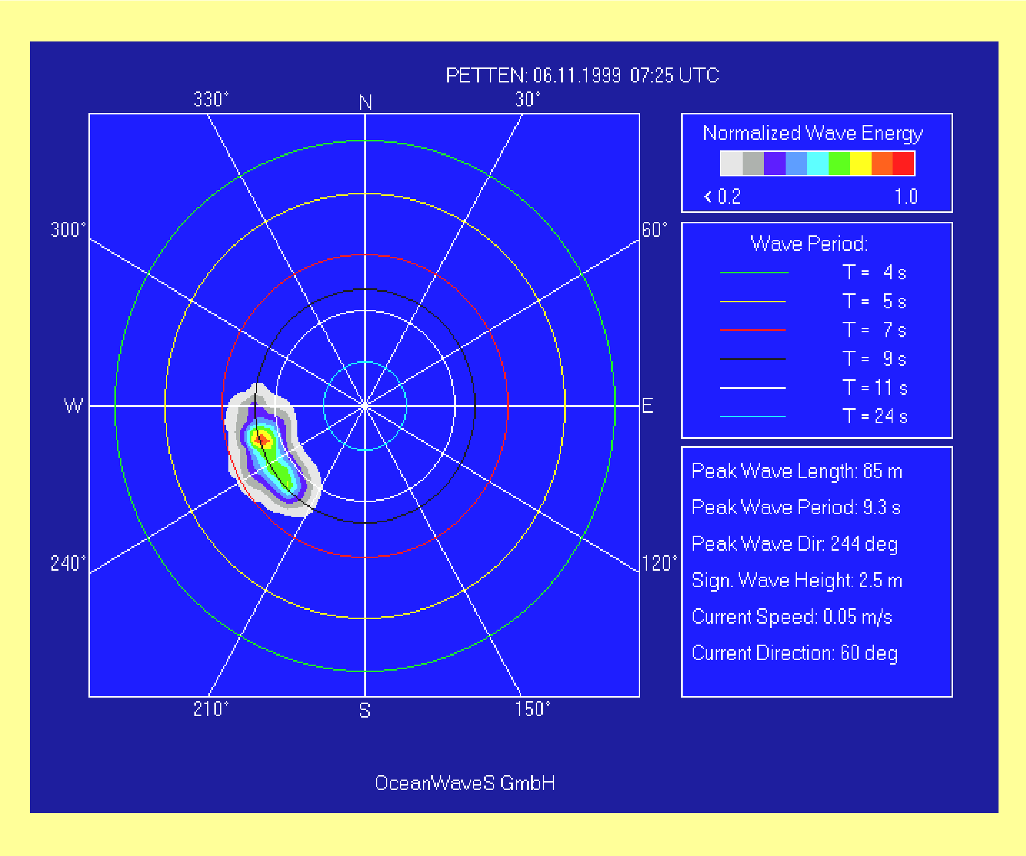
Example of a wave field imaged by a ship radar (WaMoS)

The antenna is located
in the centre of the
image

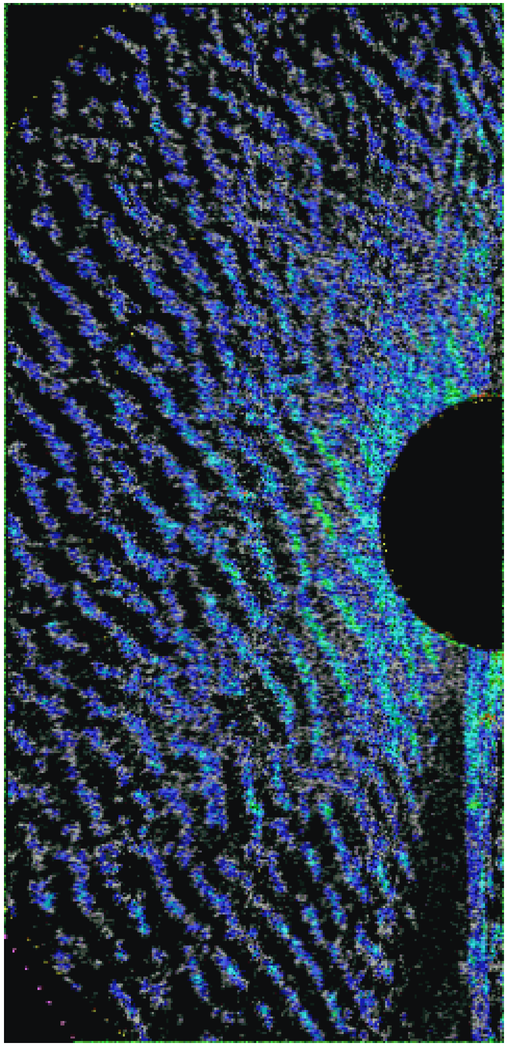
Courtesy of **OceanWaves**

Example of a wave field imaged by a ship radar (WaMoS)

Corresponding 2-dimensional wave spectrum



WaMoS radar image from the Dutch coast



courtesy OceanWaves

Imaging radars

There are two types of side-looking airborne or spaceborne imaging radars: real-aperture radar (RAR) and
synthetic sperture radar (SAR).

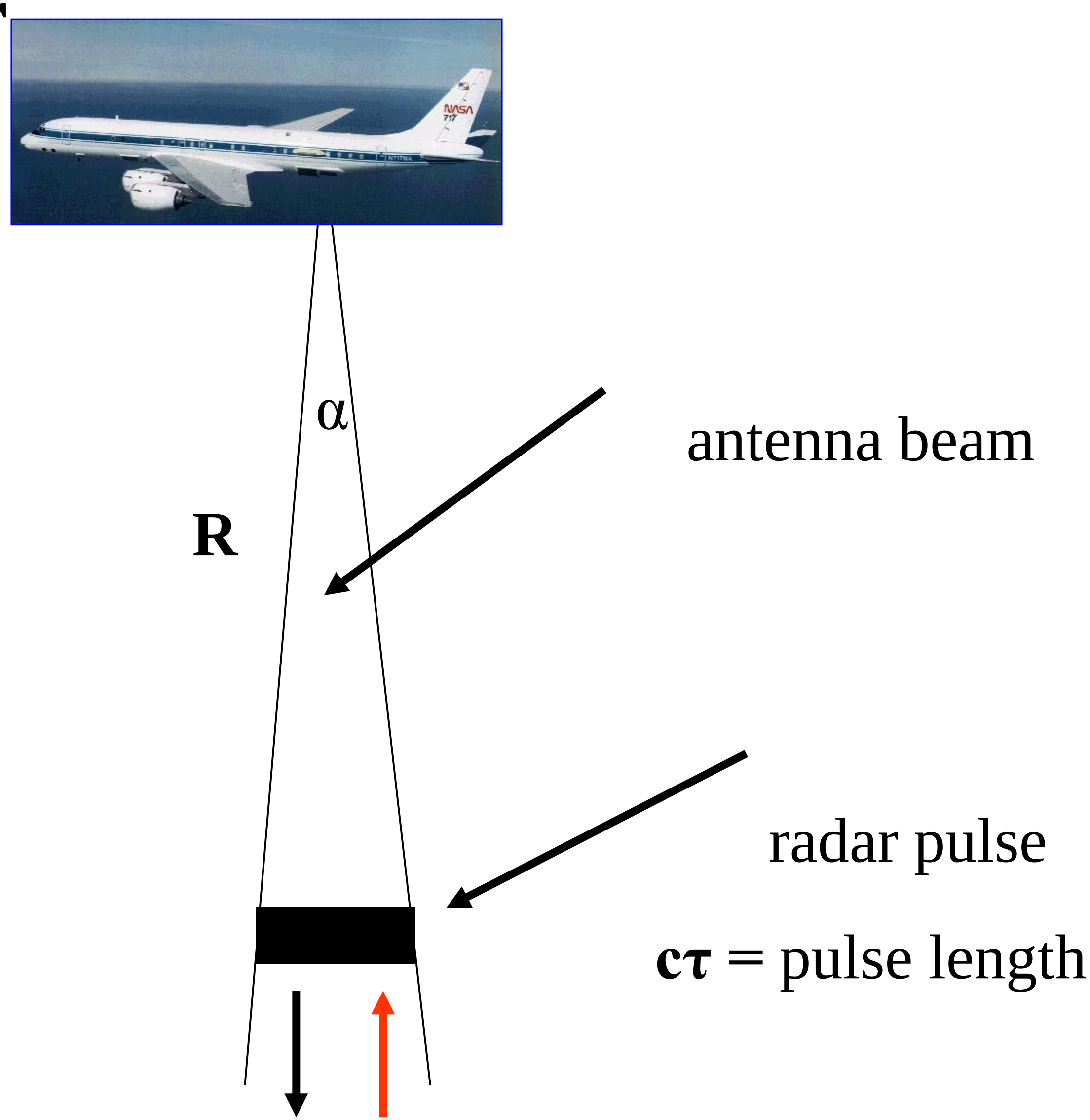
They use microwaves typically at frequencies between 400 MHz and 35.2 GHz corresponding to wavelength between 62 cm and 0.85 cm.

Common frequencies are:
9.4 GHz, 3.2 cm (X-band) TerraSAR-X
5.3 GHz, 5.7 cm (C-band) Sentinel-1, Radarsat, Envisat, ERS
1.25 GHz, 23.5 cm (L-band) Seasat, ALOS Palsar

Principle of a RAR

- **A short pulse is emitted by the antenna and then the amplitude of the reflected signal is recorded as a function of time.**
- **This is repeated again and again while the platform is moving**
- **Thus a 2-dimensional image is generated.**

Side-looking airborne radar = Real Aperture Radar (RAR)



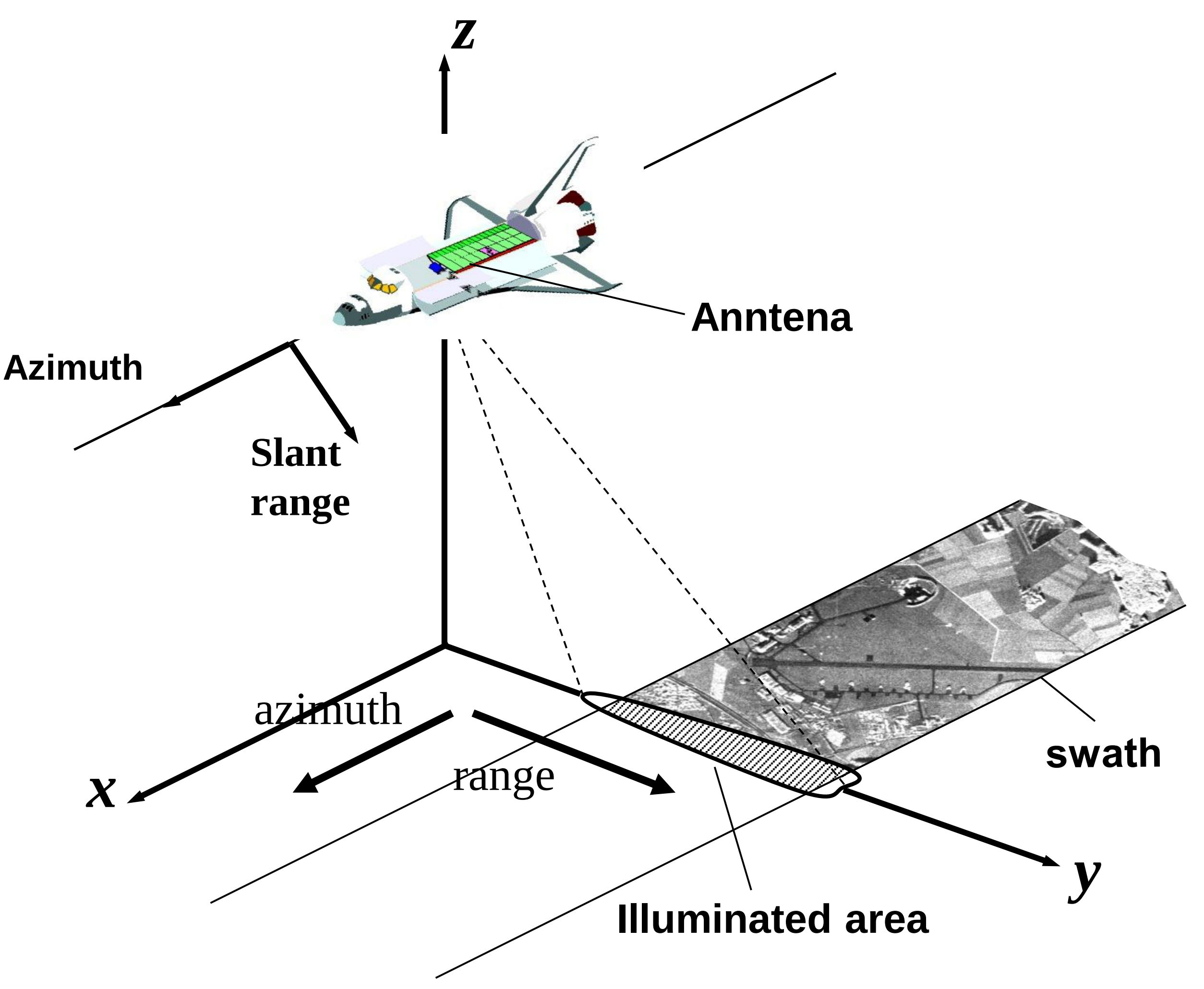
range resolution:

$$\rho_r = c\,\tau/2$$

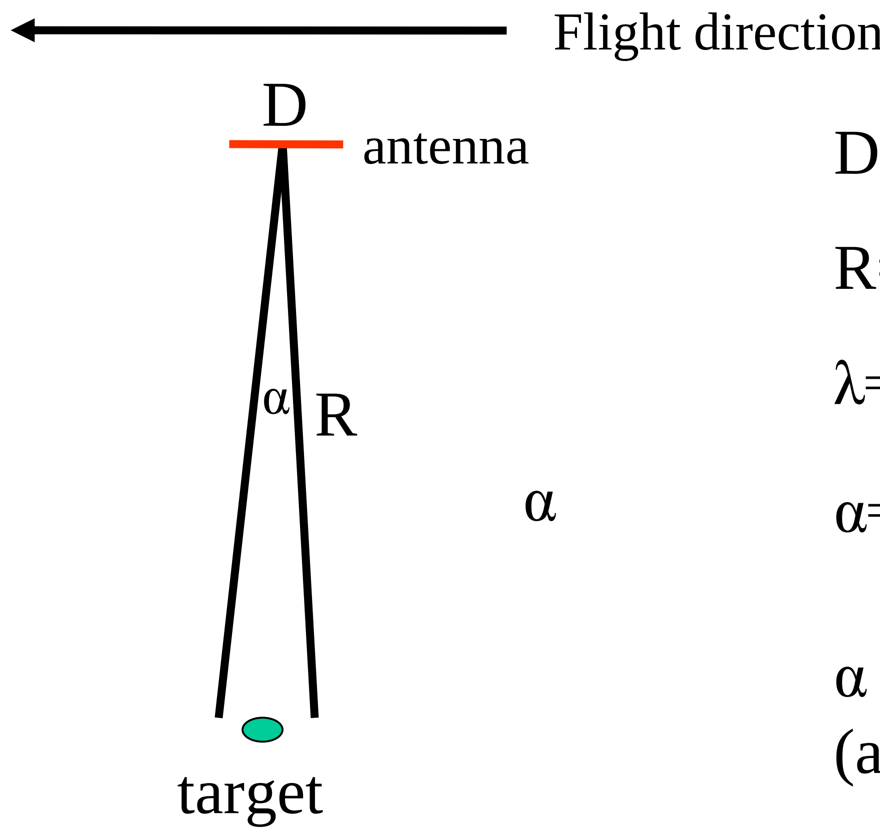
azimuth resolution:

$$\rho_a = \alpha\, R$$

Oblique view geometry



Real Aperture Radar (RAR)



D= antenna dimension

R= range

λ= radar wavelength

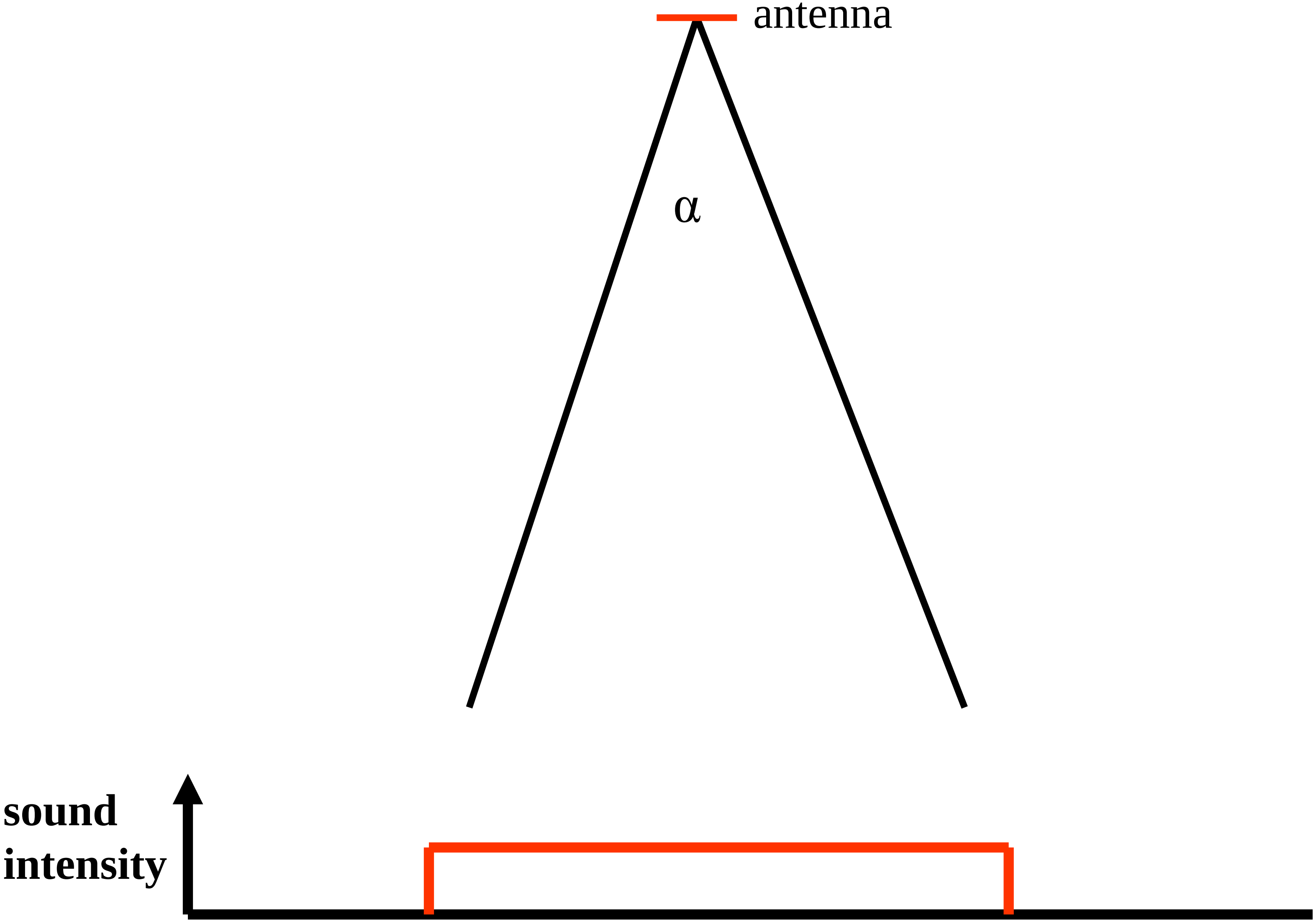
α=antenna beamwidth

α =λ/D (approximately)

Resolution in flight direction (azimuthal resolution): $\boldsymbol{\rho_a = \alpha R = R \lambda / D}$

Resolution in range direction: $\boldsymbol{\rho_r = c \tau / 2}$

Acoustic analogy of a RAR

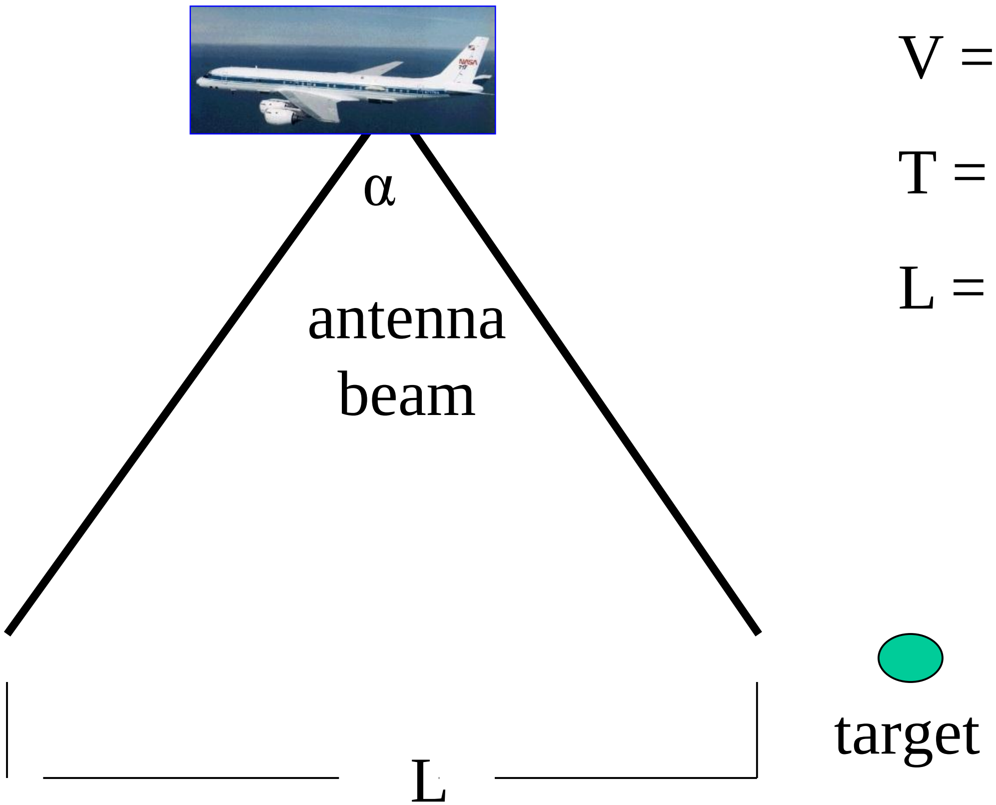


How does a synthetic aperture radar (SAR) work?

Principle of a SAR

- **A short pulse is emitted by the antenna.This is repeated again and again while the platform is moving.**
- **Thus a 2-dimensional image is generatedthe antenna and then the amplitude and phase of the reflected signal is recorded as a function of time.**

Synthetic aperture radar

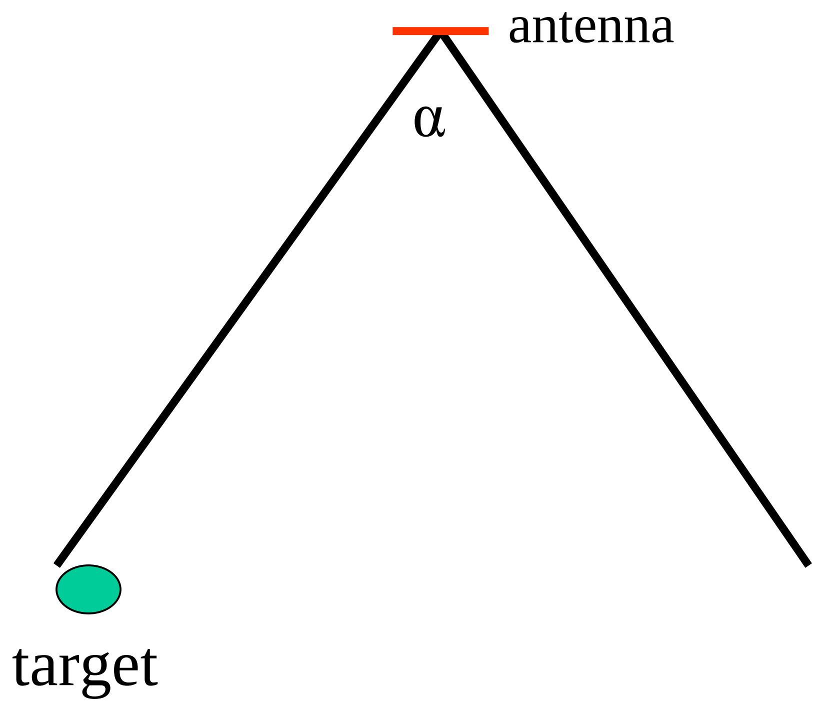


V = platform velocity

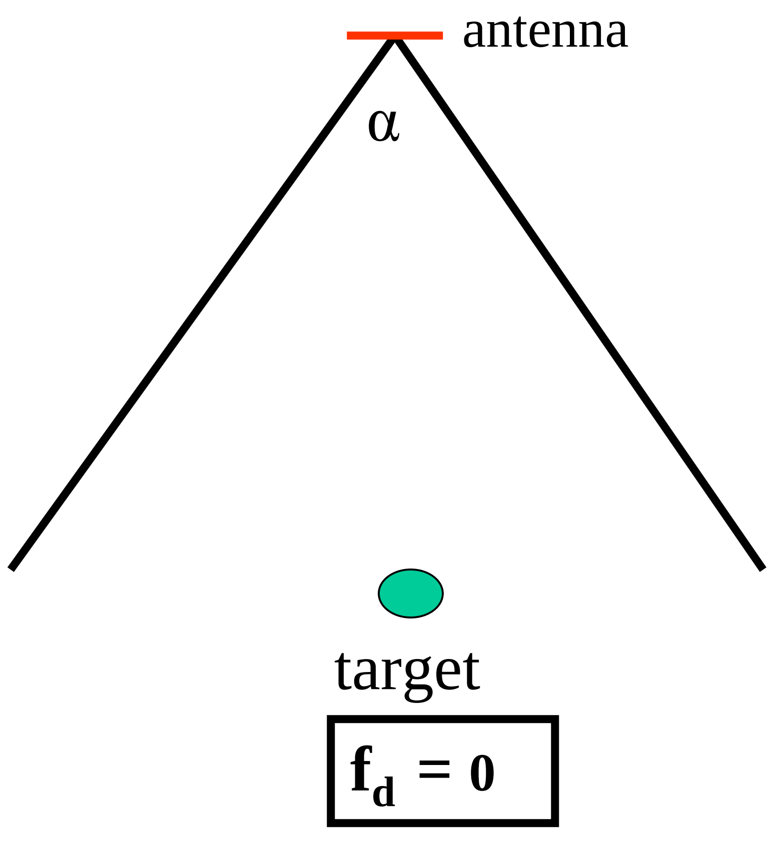
T = integration time

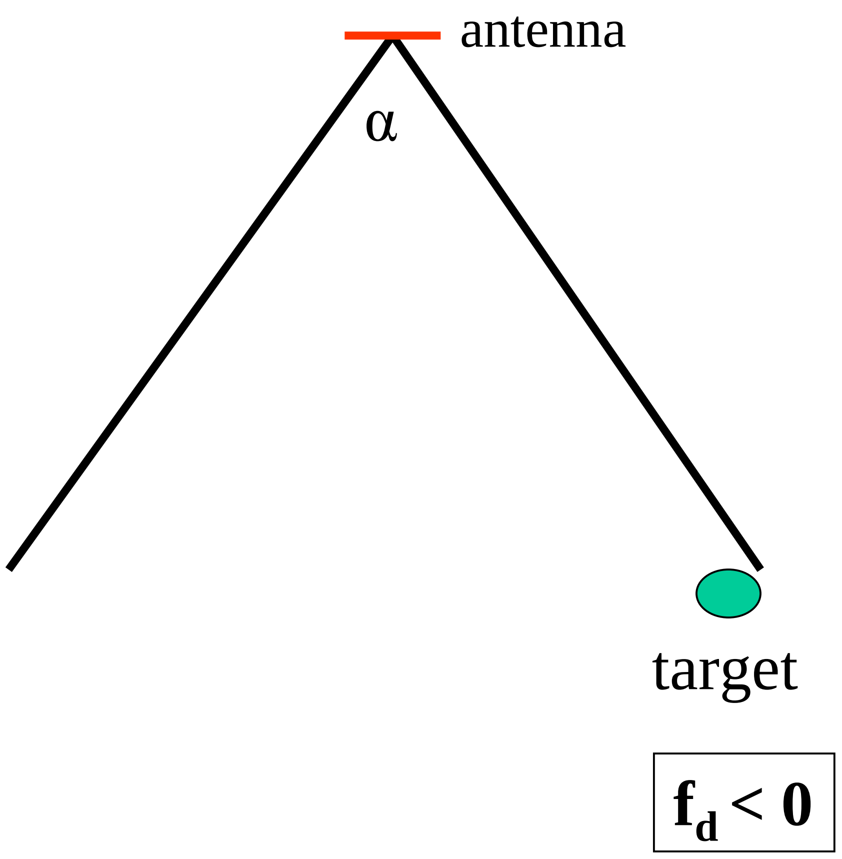
L = length of the synthetic antenna

The target remains for T seconds in the antenna beam

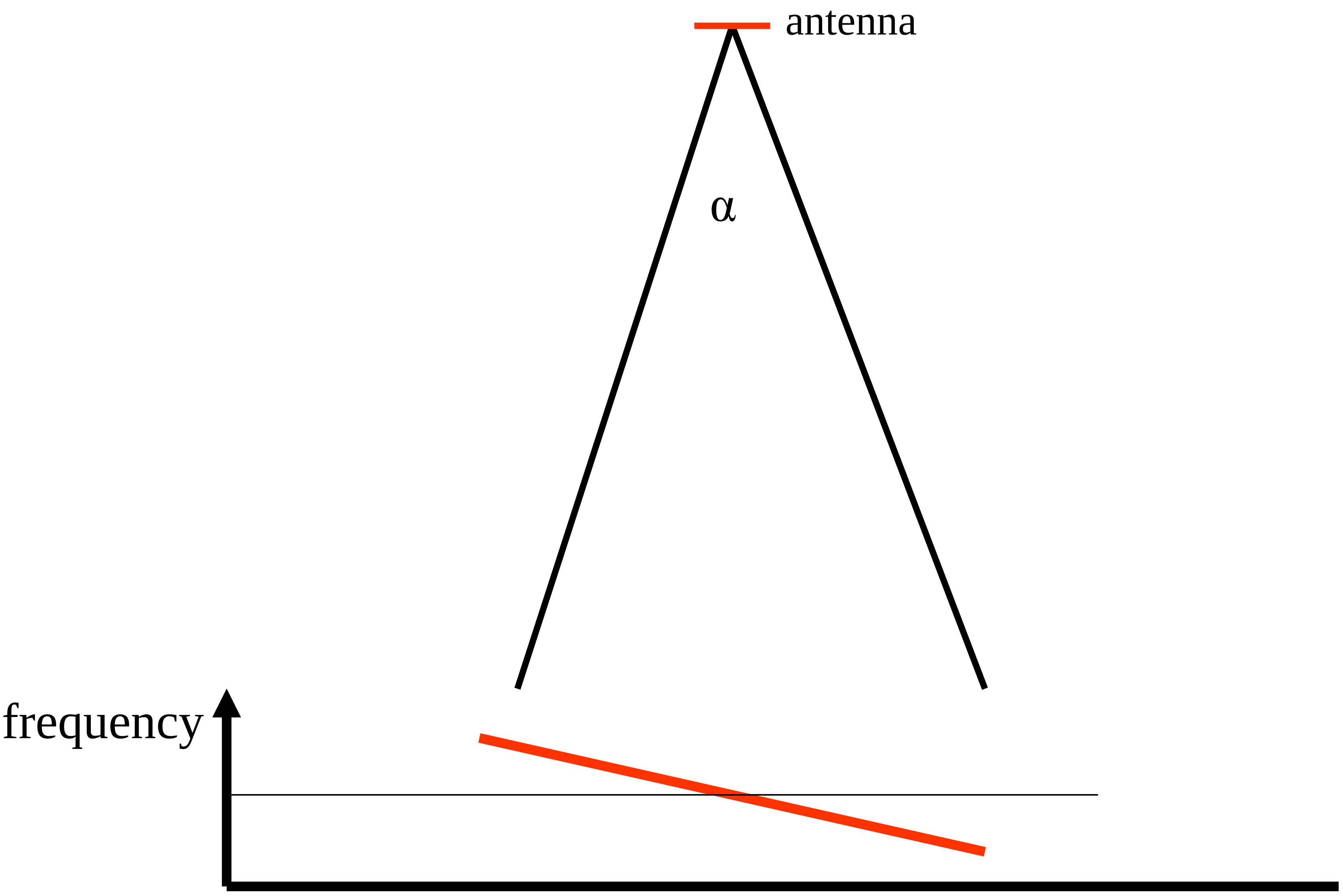


$$f_d > 0$$

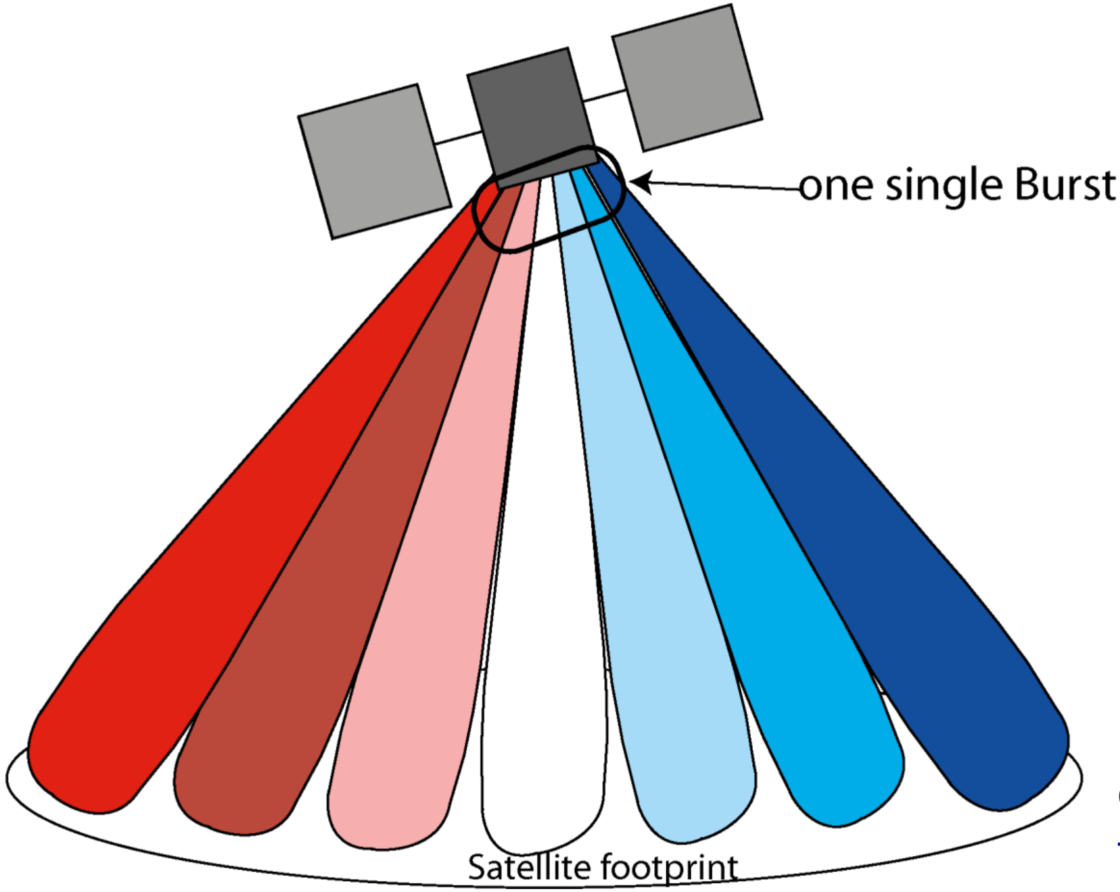

antenna
α
target
$f_d = 0$


antenna
α
target
$f_d < 0$

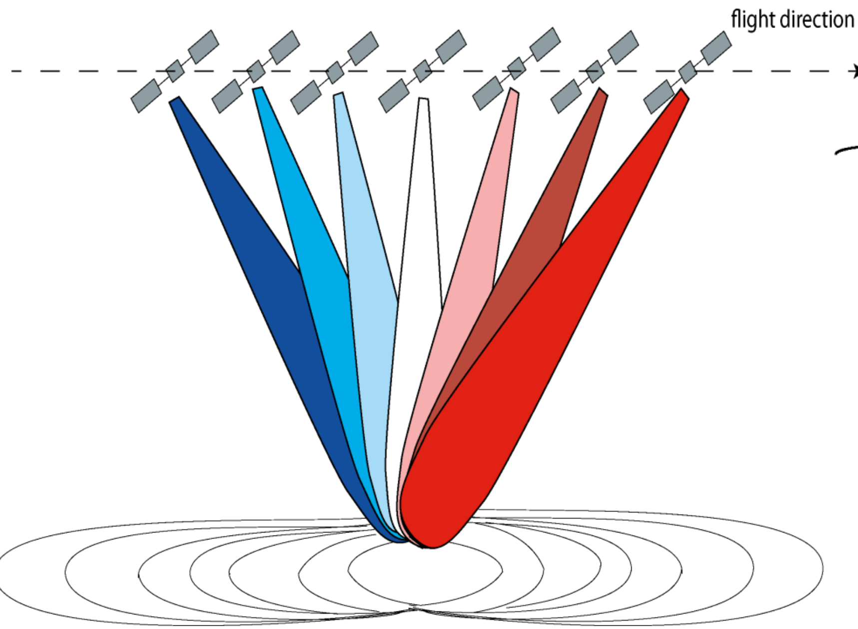
Acoustic anology of a SAR

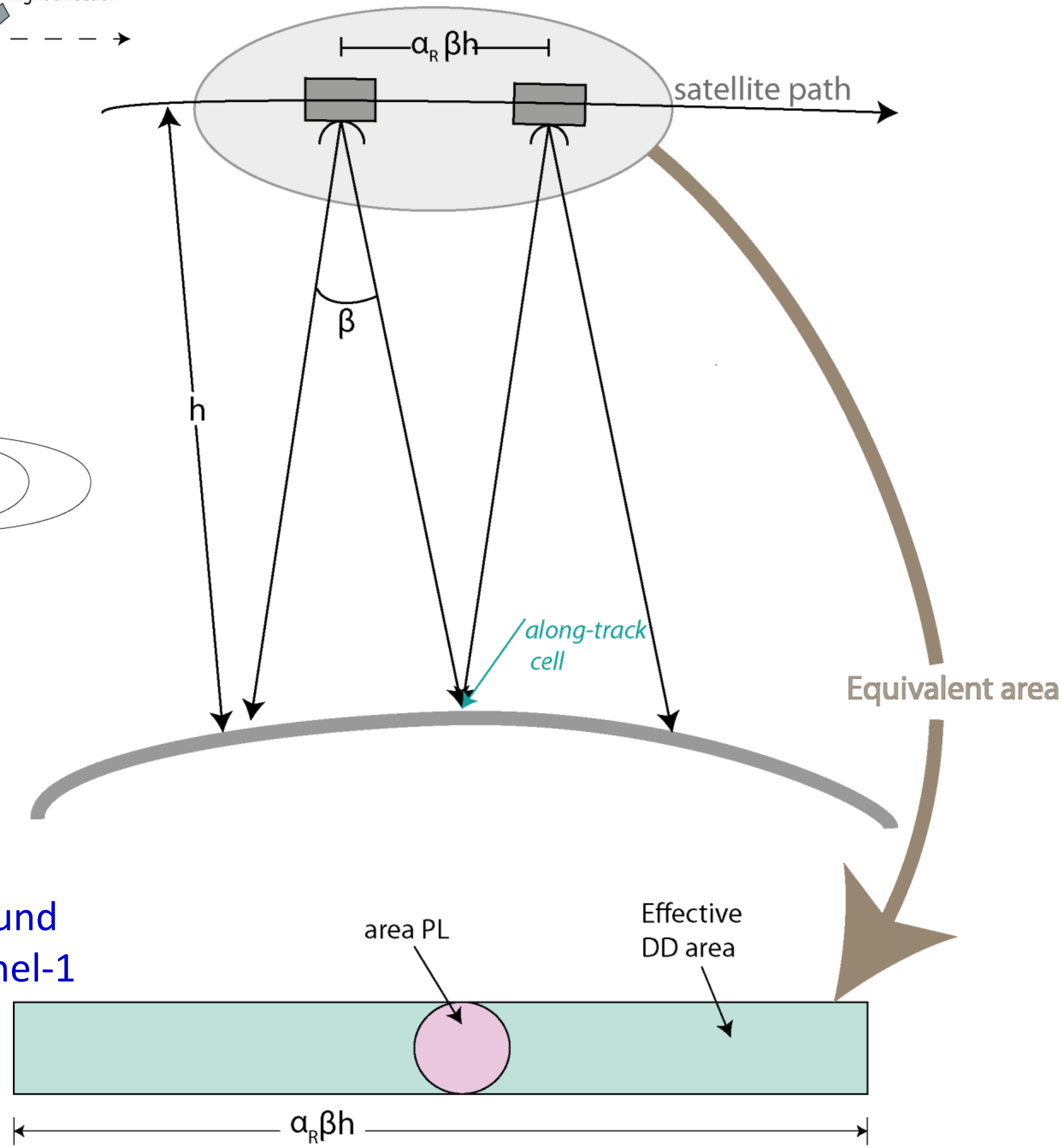


Red shift of
doppler
frequencies



Blue shift of
doppler
frequencies

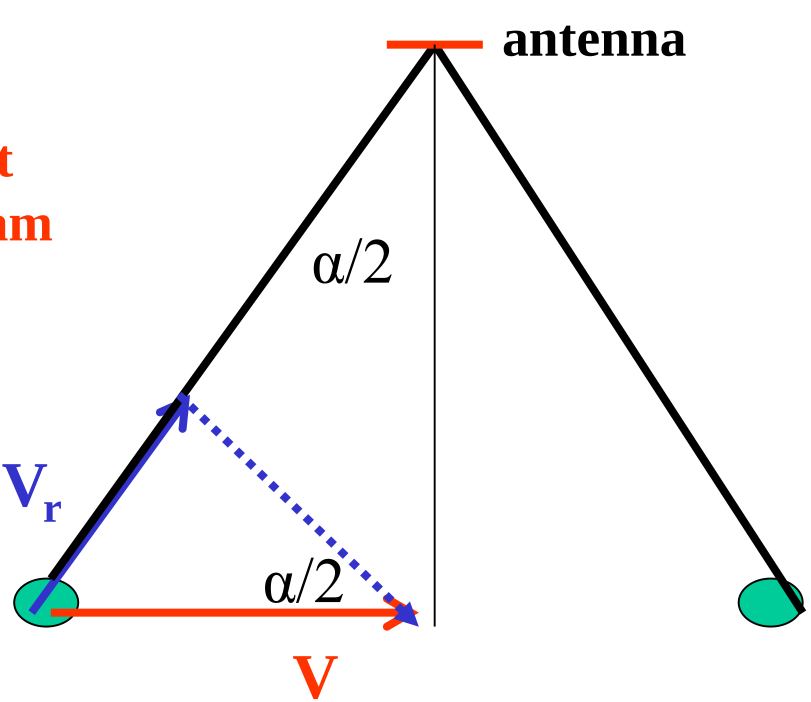




Along-track effective length of ground cell is approximately 7 km for Sentinel-1

Change of the Doppler shift across the aperture

V= velocity of the target through theantenna beam



$V_r = V\sin\alpha/2$

$= V\ \alpha/2$

(approx.)

$f_d = +2V_r/\lambda = +V\alpha/\lambda$

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

$2f_d = B$ is called the azimuthal bandwidth of the SAR

Recall: General rule in signal processing:

If an electrical system has a bandwidth B, then it can resolve a signal that has a time interval of $\Delta t=1/B$.

For SAR azimuthal resolution this implies:

The time interval that can be resolved: $\Delta t=1/B=1/2f_d= \lambda/2V\alpha = D/2V$ (because $\alpha=\lambda/D$).

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

Thus the azimuthal resolution of a SAR is independent of range and is inversely proportional to the dimension D of the antenna

Example: Seasat SAR

Satellite velocity V = 7.5 km/s
Antenna length in flight (azimuth direction): D= 10 m

➡ Bandwidth B = 2V/D = 1.5 kHz

➡ Resolution in azimuth = ρ_a = D/2 = 5 m

The synthetic enhancement of azimuth resolution in a SAR is called: "azimuth compression"

But a SAR also performs “Range Compression”

- **Instead of using a short pulse, one uses a long pulse which is freqency modulated. This enables the power of the emitted pulse to be spread over a longer period, which is technically desirable.**

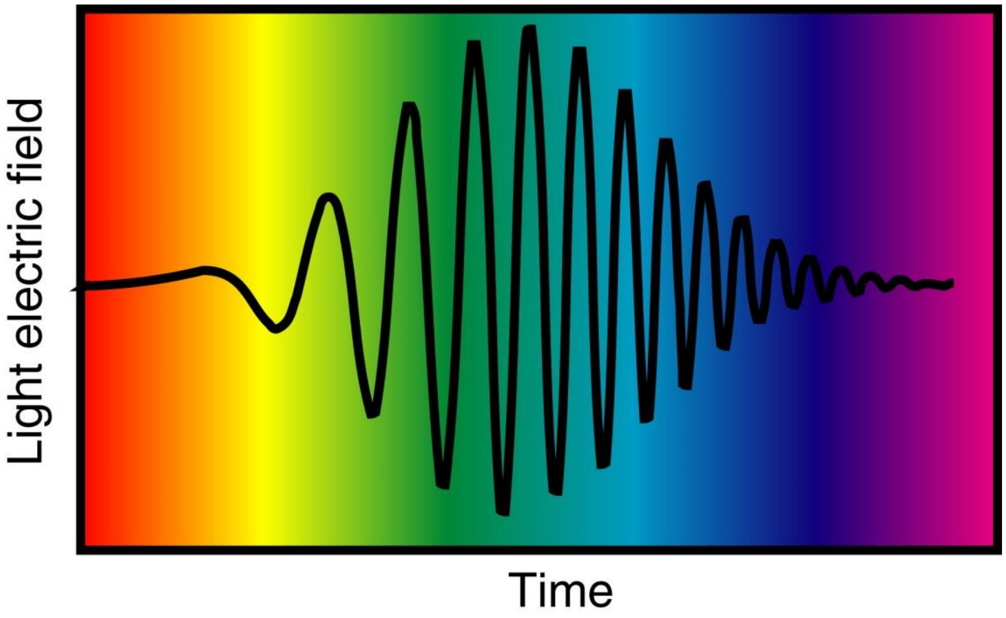
- **The short pulse is later generated in the SAR processing.**

- **Radar engineers call this „range compression“.**

Often a linearly modulated pulse is used, which then is called a „chirped pulse“.

The Chirped Pulse

A pulse can have a frequency that varies in time.



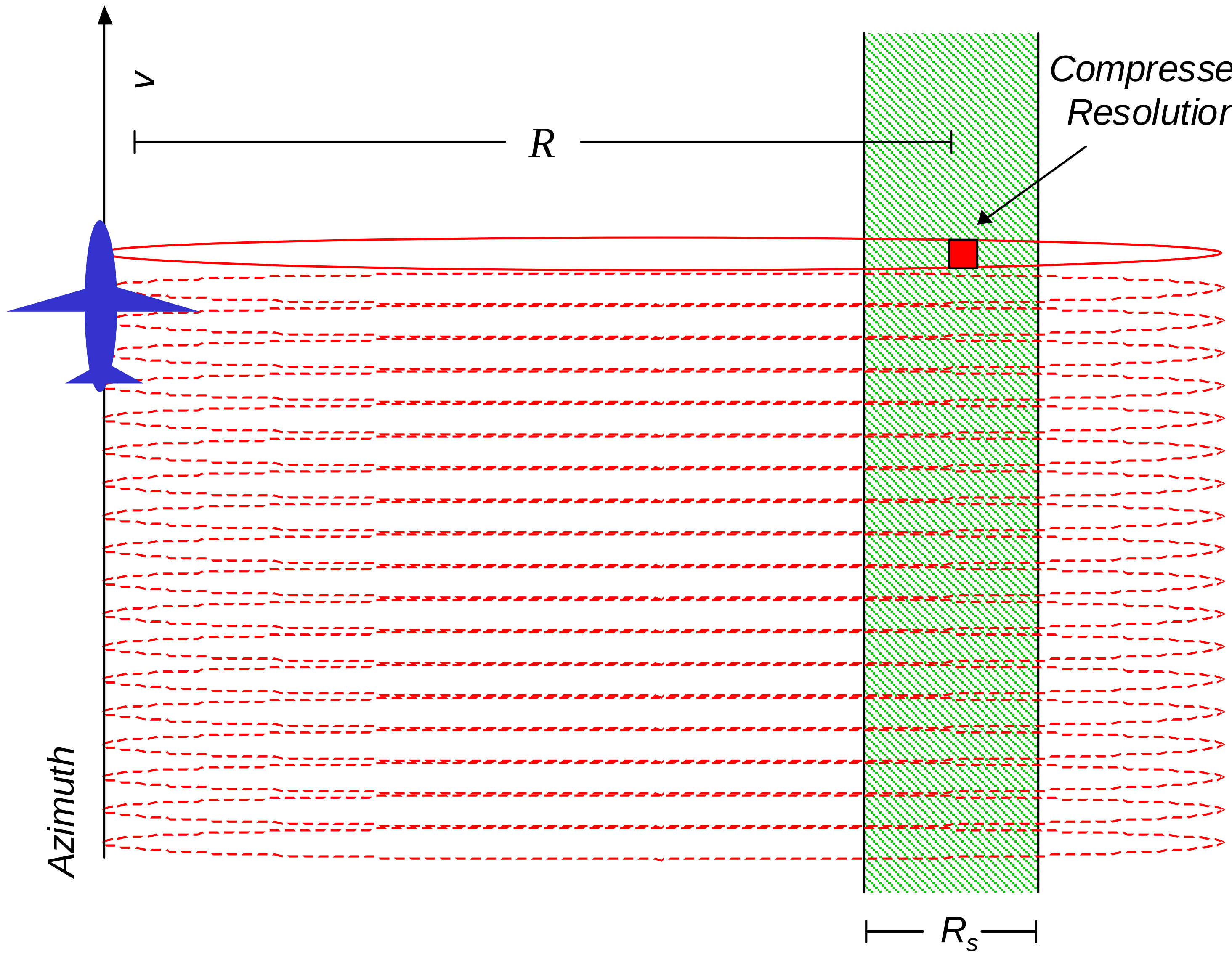
This pulse increases its frequency linearly in time (from red to blue).

In analogy to bird sounds, this pulse is called a "chirped" pulse.

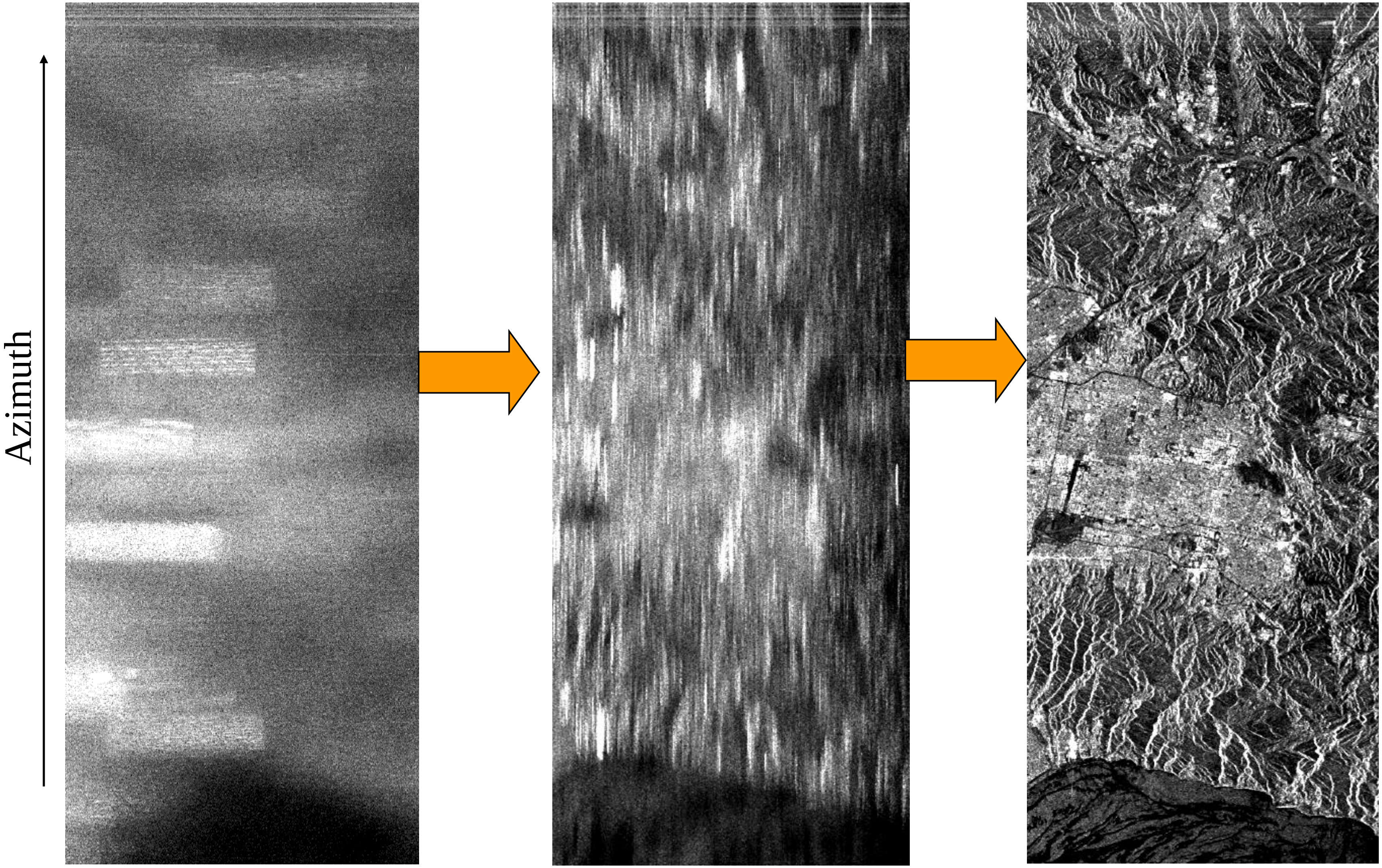
SAR processing is done in two steps:

First the signal is compressed in range direction and then it is compressed in azimuth direction.

Synthetic Beams



SAR pulse compression in range and azimuth

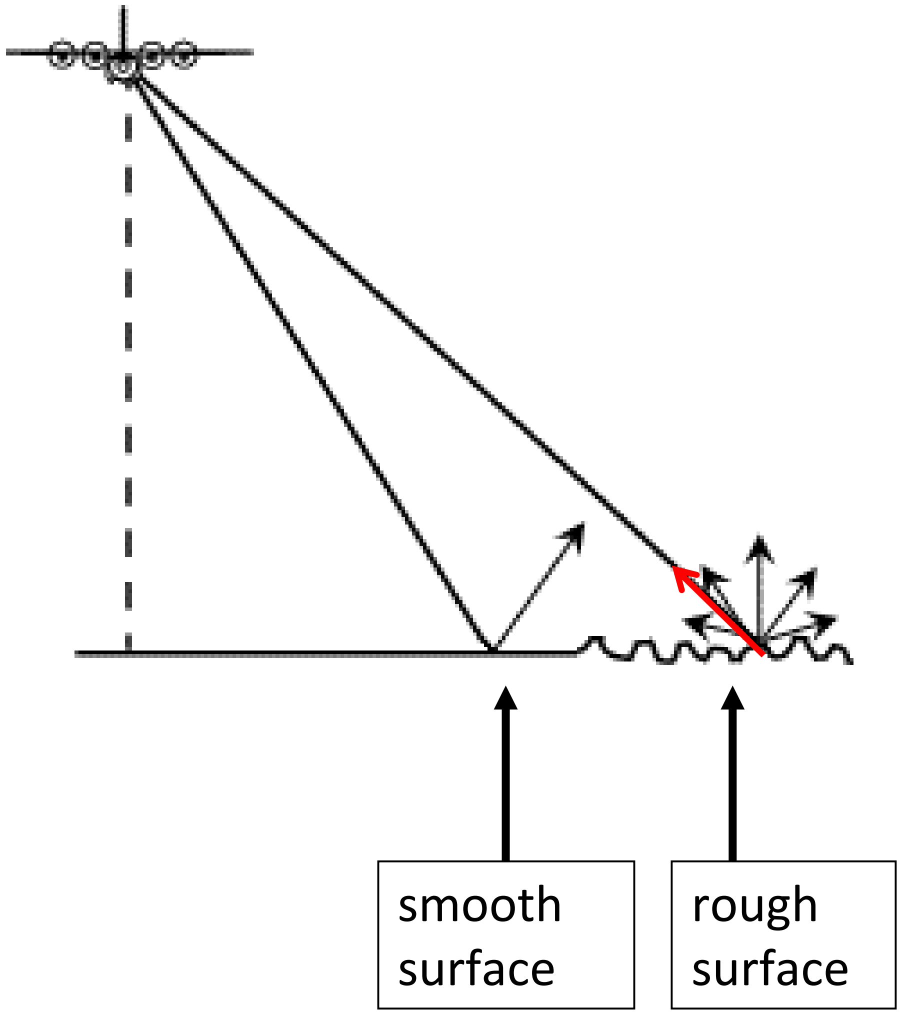


Raw data

After range compression

SAR image

Radar backscattering from the sea surface



- The microwaves (radar waves) do not penetrate into the water.
- Thus, the radar senses only the sea surface roughness.

Example of a low beckscatter SAR

TerraSAR-X 25.10.2008 Stripmap mode HH pol. (3 m resolution)

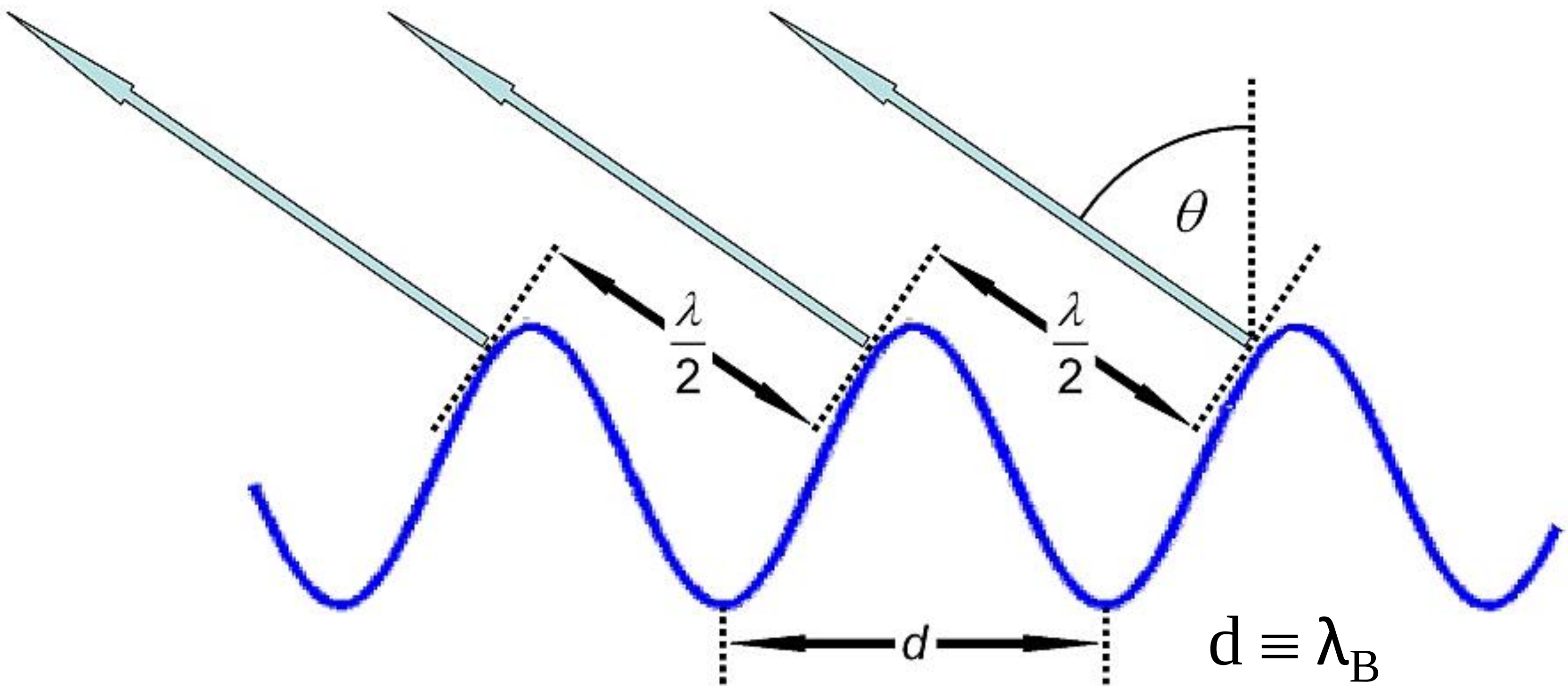
First Order (Resonant) Bragg scattering

$\lambda_B \equiv$ Bragg wavelength

$\lambda \equiv$ Radar wavelength

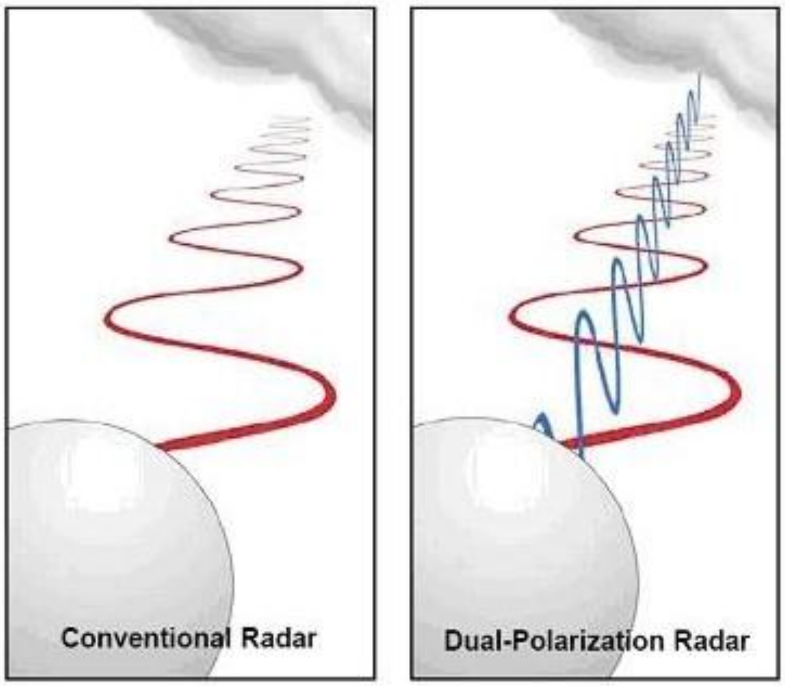
$\lambda_B = \lambda / 2 \sin \theta$

Bragg resonance condition



$d \equiv \lambda_B$

Dual Co-Polarized SAR Measurements of Internal Solitary Waves



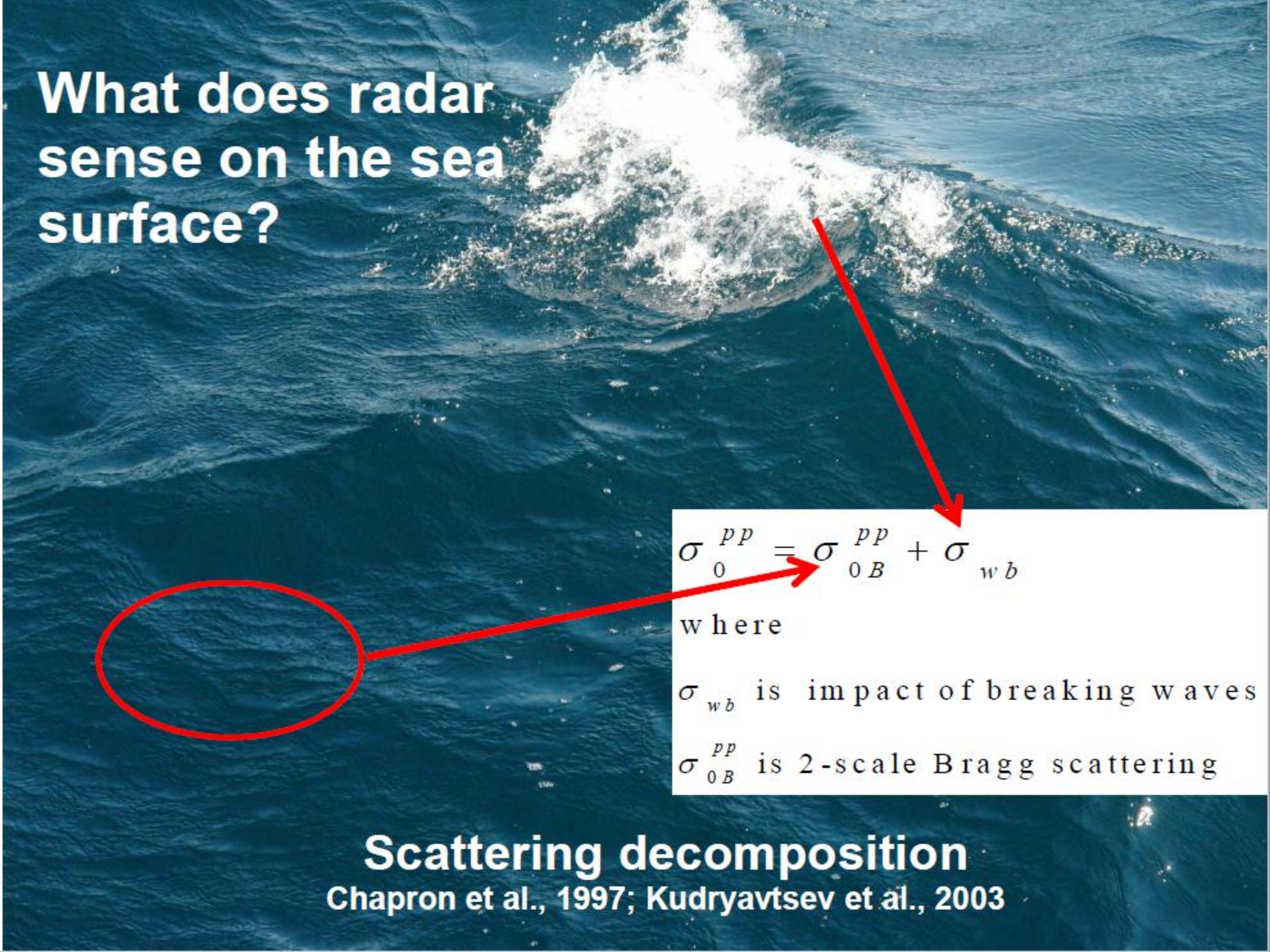
Transmitted waves: H, V

Received waves: H, V

HH ≡ H transmit; H received

VV ≡ V transmit; V received

What does radar sense on the sea surface?



$$\sigma_0^{pp} = \sigma_{0B}^{pp} + \sigma_{wb}$$

where

σ_{wb} is impact of breaking waves

σ_{0B}^{pp} is 2-scale Bragg scattering

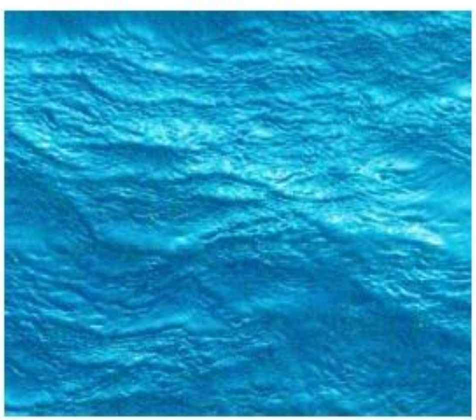
Scattering decomposition

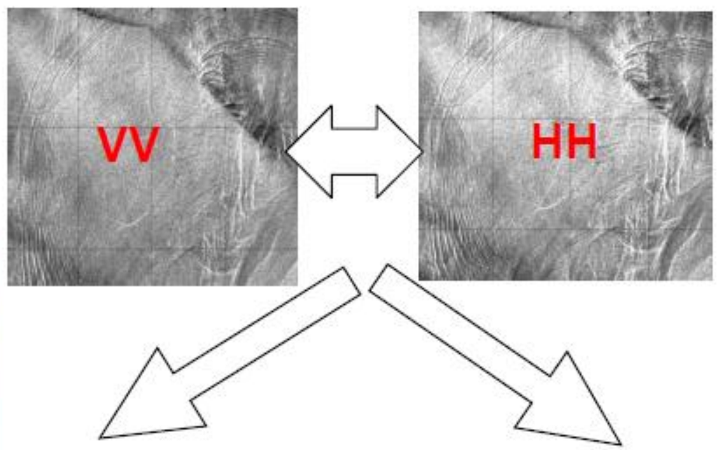
Chapron et al., 1997; Kudryavtsev et al., 2003

The radar backscatter cross section per unit area is the sum of separate contributions from Bragg scattering and sea spikes from wave breaking.

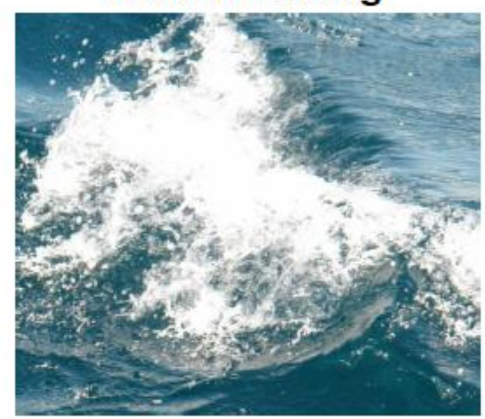
VV and HH polarized images are transformed in 2 other new images describing very different surface properties:

Polarized scattering
Short wind waves





Non-polarized scattering
Wave breaking



$$\sigma_0 = \sigma_{Bragg} + \sigma_{ss}$$

$$\sigma_0^{pp} = \sigma_{0B}^{pp} + \sigma_{0nB}$$

Radar Cross Section is represented as sum of one polarized scattering component associated with conventional two-scale Bragg Scattering (Bragg waves superposed on longer waves):

$$\sigma_{0B}^{pp}$$

and one *nonpolarized* (NP) scattering component due to non-Bragg scattering, i.e.

$$\sigma_{0nB}$$

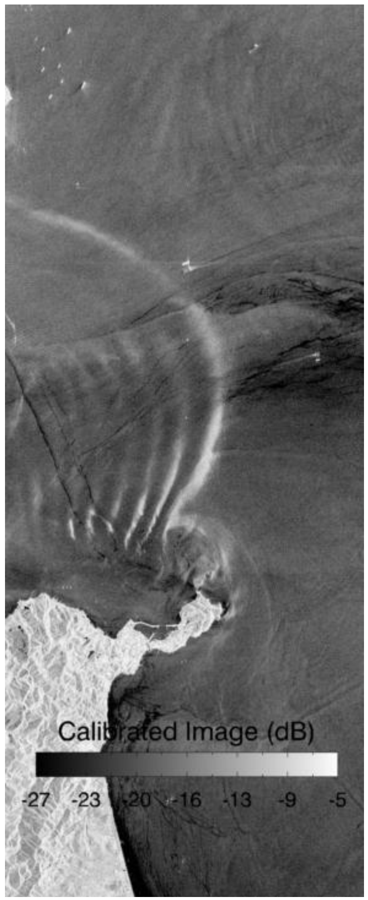
The *NP* component is expressed as:

$$NP = \sigma_{0nB} = \frac{\sigma_0^{VV} - p\sigma_0^{HH}}{1 - p}$$

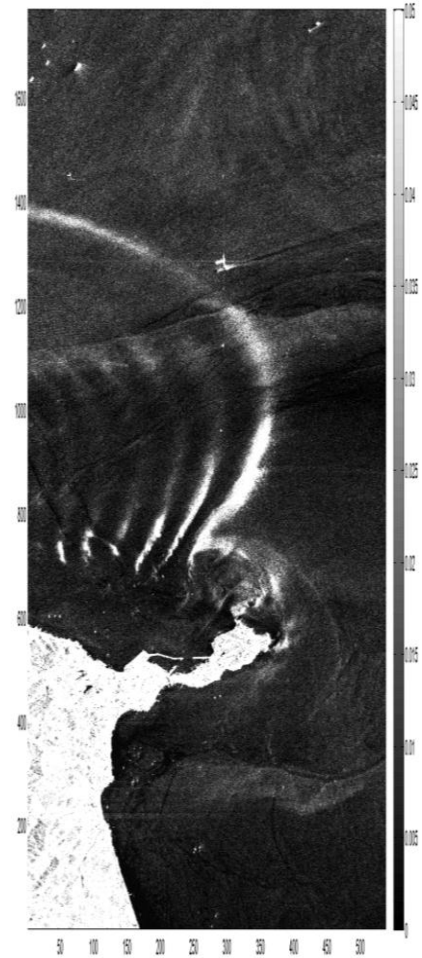
where p is a polarization ratio for the two-scale Bragg scattering model, i.e.

$$p = \frac{\sigma_{0B}^{VV}}{\sigma_{0B}^{HH}} \approx \frac{\left|G_{VV}\right|^2}{\left|G_{HH}\right|^2}\left[1 + \left(g_h - g_v\right)s_i^2\right]$$

This theory has been tested using TerraSAR-X data



TerraSAR-X StripMap image, HH pol.
17 August 2009, 06:29: 59 UTC,
ID: dims_op_oc_dfd2_513403606_1

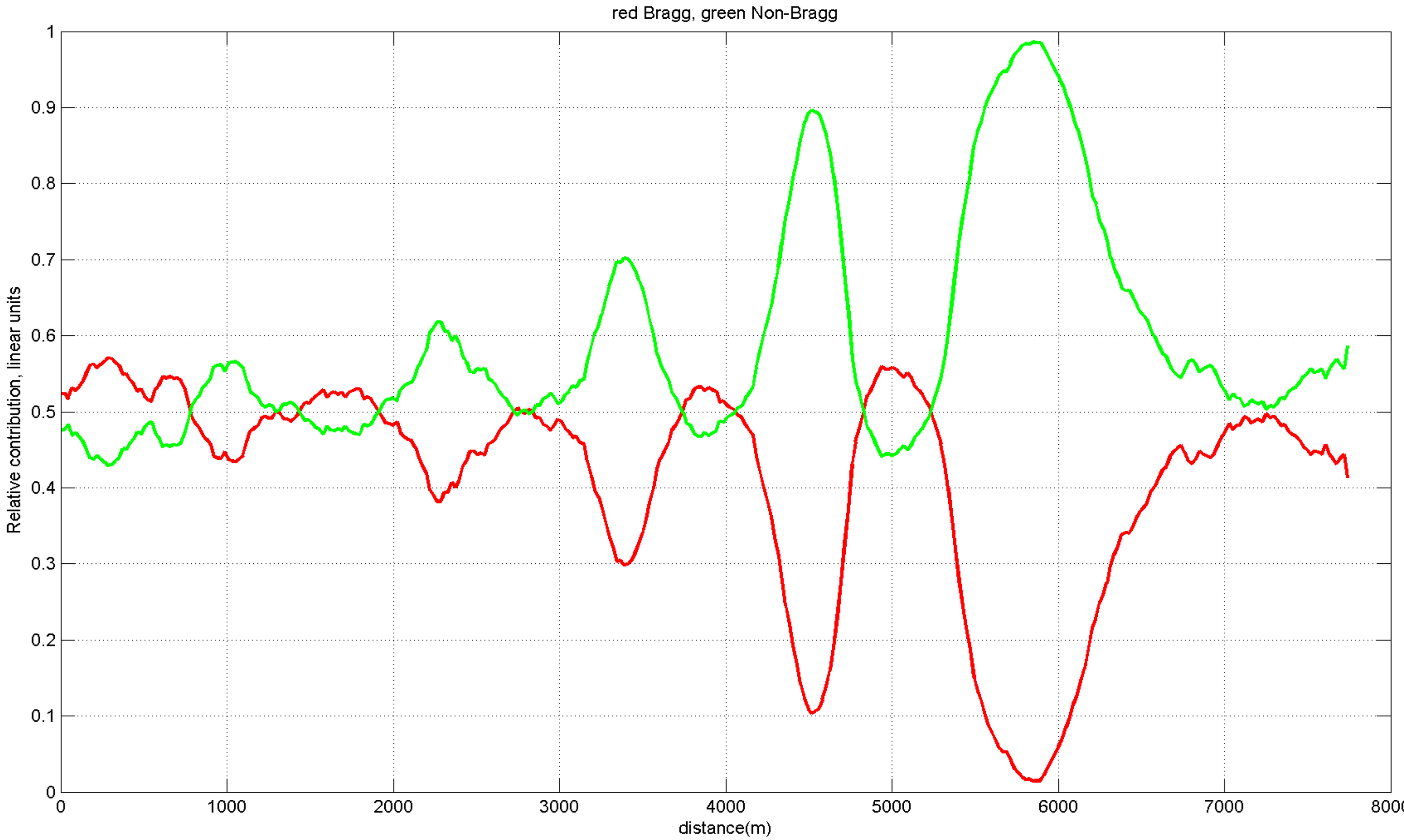


Non-polarized contribution
to radar backscatter

Wave breaking has to be taken into account

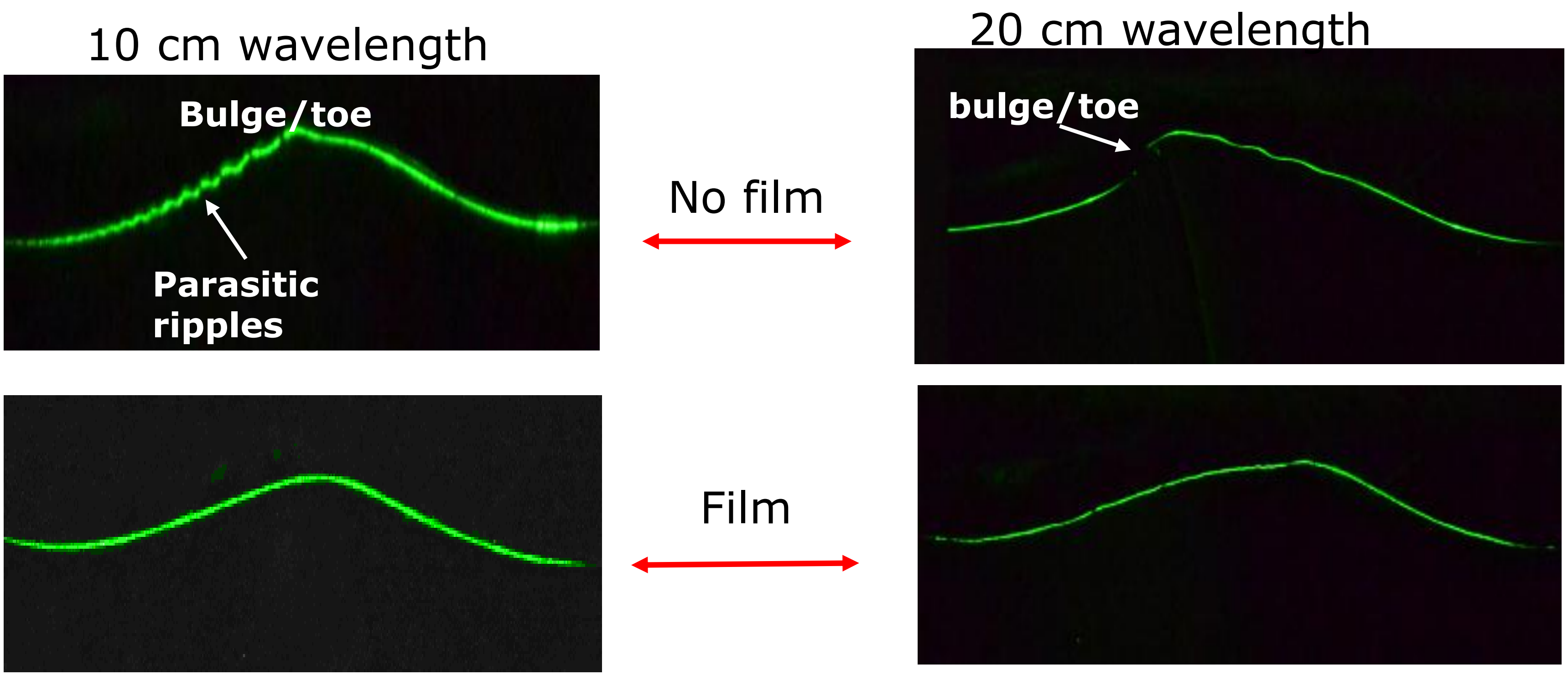
$$\sigma_0^p = \sigma^p_{Bragg} + \sigma_{wb}$$

Percentage of Bragg & non-Bragg backscatter components



Transect along- internal solitary wave profile

Laboratory experiments. Micro wave breaking in the presence of film slicks (Ermakov et al., 2018)

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End of Part II (Active Sensing)

Thank you