Synthetic Aperture Radar

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Historical origins

- the idea of *synthesising* a large antenna from a succession of spatial samples has its origins in radioastronomy;
- but the idea of a synthetic aperture *radar* (i.e.an active system) was conceived by Carl Wiley in the USA in the 1950s, in the context of sideways-looking airborne radar.
- he recognised that the variation in Doppler shift of echoes from a target meant that the beamwidth of a sideways-looking radar could be artificially reduced by filtering (*Doppler beam sharpening* or *unfocused aperture synthesis*).
- the first spaceborne SAR was carried by NASA's SEASAT satellite in 1978. This only lasted for three months, when a power supply fault caused its early demise, but in that time it produced a wealth of data from land, ocean and ice surfaces.
- nowadays SAR is a powerful set of techniques, both for spaceborne remote sensing and for aircraft-borne high-resolution surveillance. Current areas of interest include interferometry, spotlight mode, polarimetry, inverse SAR (ISAR), …..


3,196,436

THE UNITED STATES OF AMERICA

TO ALL TO WHOM THESE PRESENTS SHALL COME:

Whereas Carl A. Wiley, of Phoenix, Arizona, assignor to Goodyear Aerospace Corporation, a corporation of Delaware,

PRESENTED TO THE Commissioner of Patents A PETITION PRAYING FOR THE GRANT OF LETTERS PATENT FOR AN ALLEGED NEW AND USEFUL INVENTION THE TITLE AND A DESCRIPTION OF WHICH ARE CONTAINED IN THE SPECIFICATION OF WHICH A COPY IS HEREUNTO ANNEXED AND MADE A PART HEREOF, AND COMPLIED WITH THE VARIOUS REQUIREMENTS OF LAW IN SUCH CASES MADE AND PROVIDED, AND

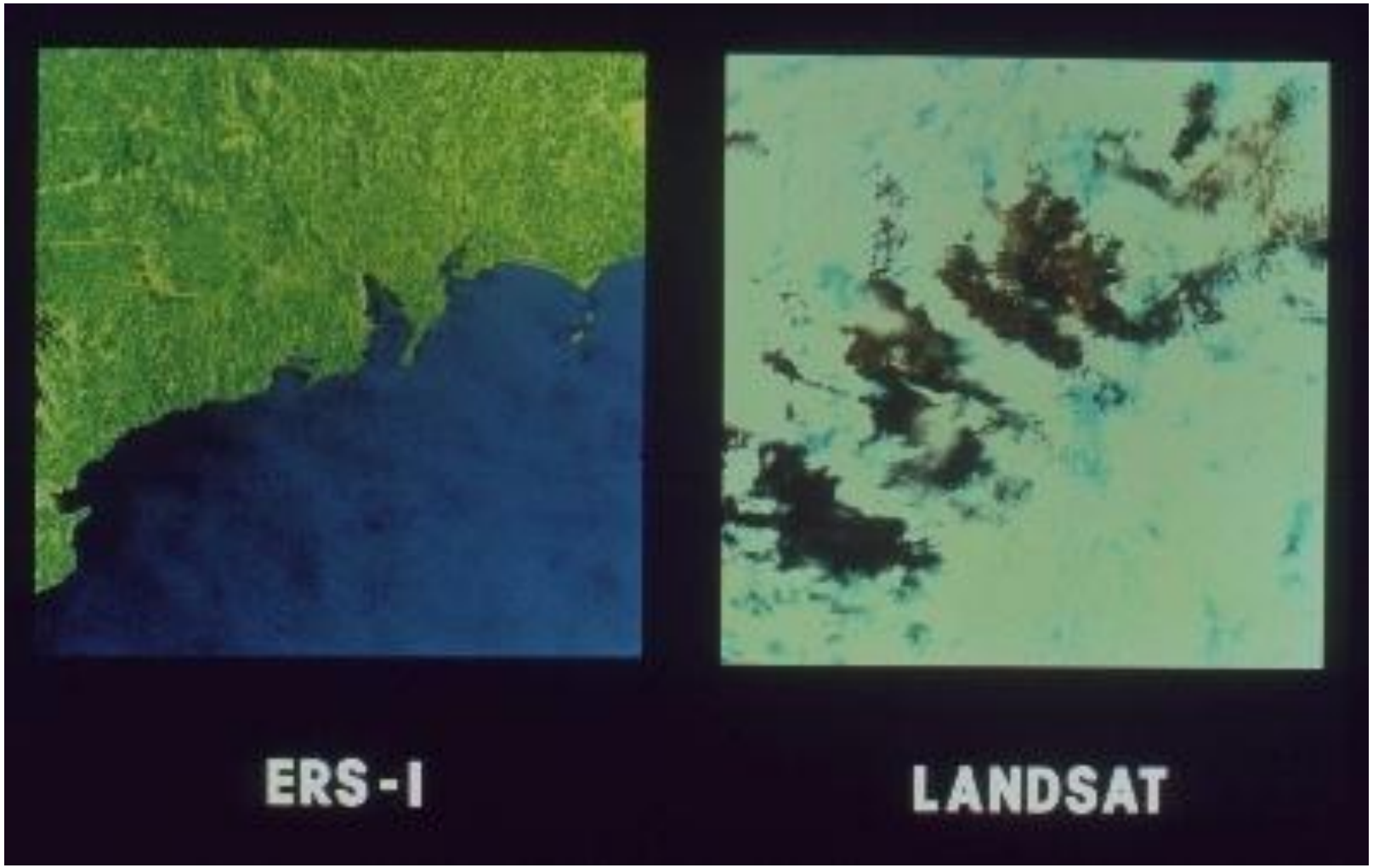
Whereas UPON DUE EXAMINATION MADE THE SAID CLAIMANT is ADJUDGED TO BE JUSTLY ENTITLED TO A PATENT UNDER THE LAW.

NOW THEREFORE THESE Letters Patent ARE TO GRANT UNTO THE SAID Goodyear Aerospace Corporation, its successors OR ASSIGNS FOR THE TERM OF SEVENTEEN YEARS FROM THE DATE OF THIS GRANT

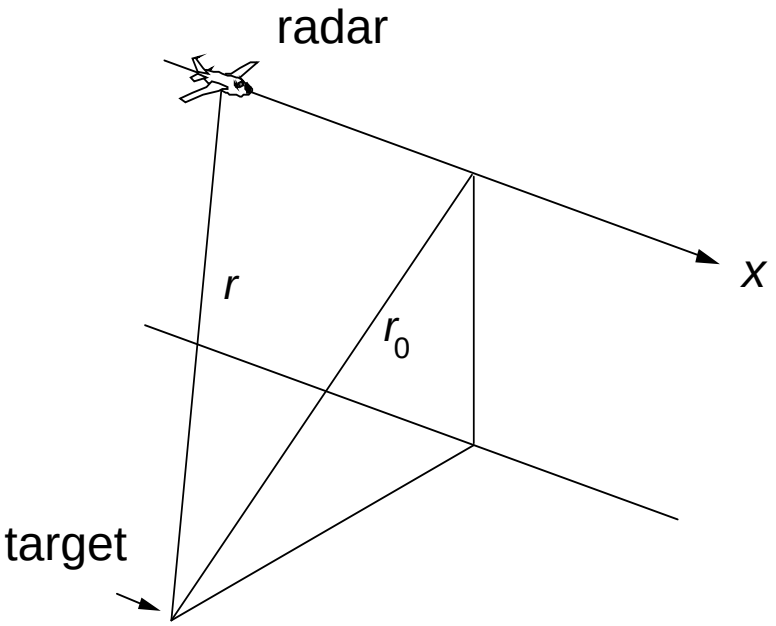
THE RIGHT TO EXCLUDE OTHERS FROM MAKING, USING OR SELLING THE SAID INVENTION THROUGHOUT THE UNITED STATES.

In testimony whereof I have hereunto set my hand and caused the seal of the Patent Office to be affixed at the City of Washington this twentieth day of July, in the year of our Lord one thousand nine hundred and sixty-five, and of the Independence of the United States of America the one hundred and ninetieth.

Attest:

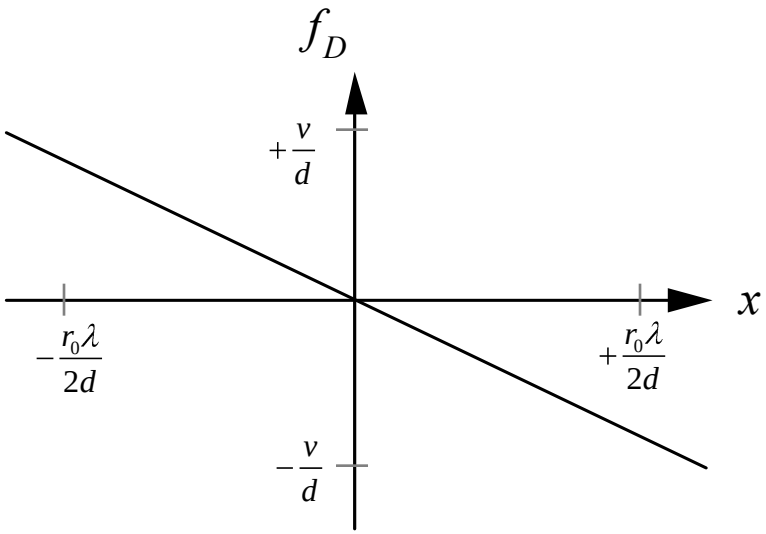

ERS-1
LANDSAT

SAR geometry



$$r \approx r_0 + \frac{x^2}{2r_0}$$

$$\phi\ x = -\frac{2\pi}{\lambda}.2r = \phi_0 - \frac{2\pi x^2}{r_0\lambda}$$



Digital SAR processing

For a medium resolution SAR system where the range compression and azimuth compression functions are independent, we may define the following SAR processor:

Range compression
- FFT data samples in range
- multiply by range compression spectrum replica
- inverse FFT

Transpose data to be azimuth contiguous (corner turn)

Azimuth compression
- FFT data in azimuth
- multiply by azimuth compression spectrum replica
- inverse FFT

Store or display image

SAR imaging of moving targets

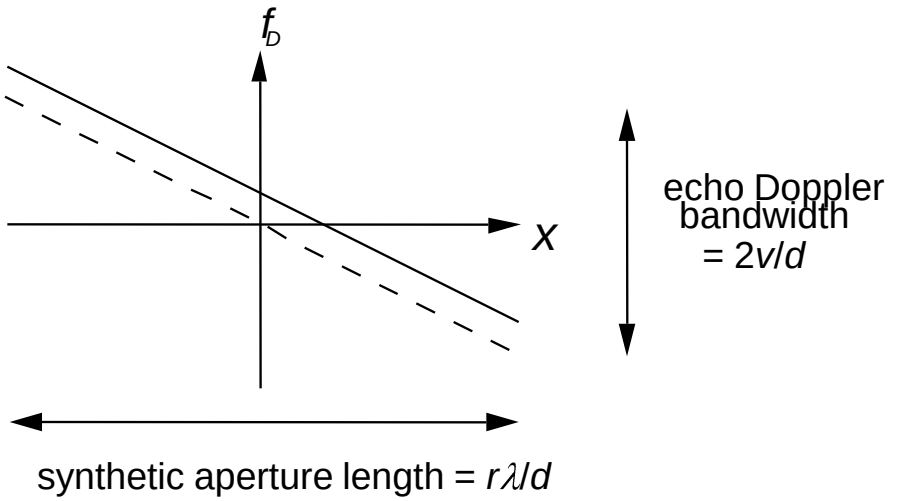
A moving target with a radial component of velocity v_r results in an echo Doppler shift

$$f_{\mathrm{D}} = \frac{2v_r f_0}{c}$$

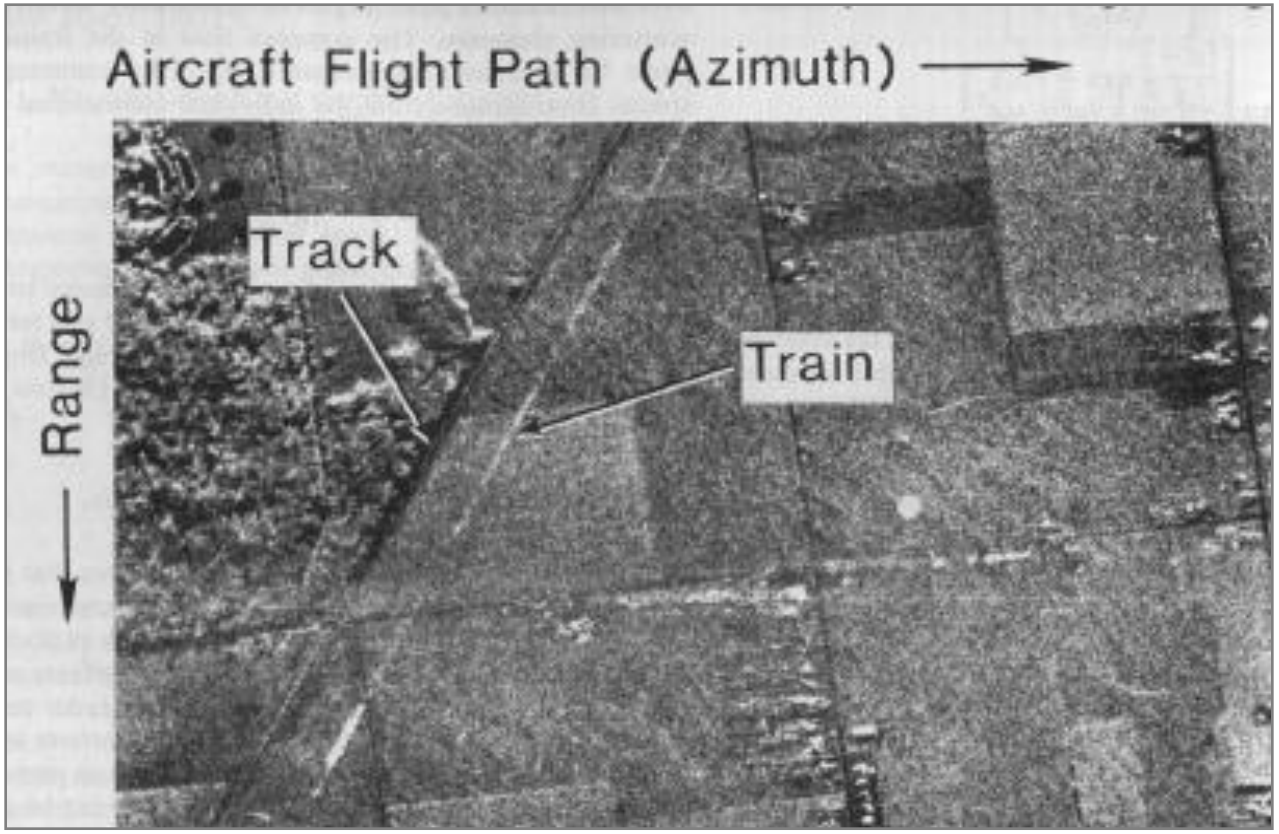
The Doppler-shifted sequence of echoes is matched-filtered (with a small mismatch) with an azimuth shift

$$\Delta x = f_{\mathrm{D}} \cdot \frac{r\lambda/d}{2v/d}$$

$$= \frac{v_r r}{v}$$



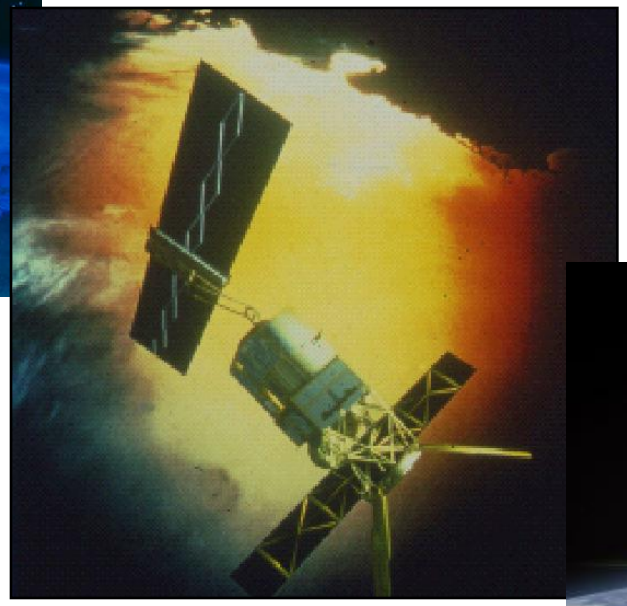
SAR imaging of moving targets



(after Rufenach, C.L. et al., 'Interpretation of Synthetic Aperture Radar measurements of ocean currents', *J. Geophys. Res*., Vol.88 No.C3, February 1983).

Satellite-borne remote sensing radar

SEASAT (1978)



ERS-1 (1991), ERS-2 (1995)

ENVISAT (2002)

ASTOR

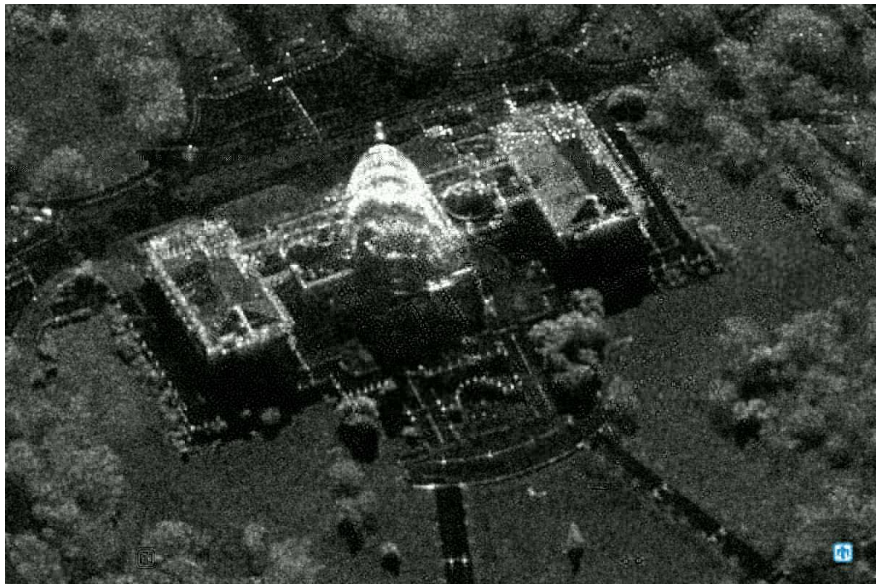
In December 1999, Raytheon Systems Ltd was awarded a contract for the development of the UK Ministry of Defence Airborne Stand-Off Radar (ASTOR). The system, which includes five Bombadier Global Express business jet aircraft fitted with a derivative of the Raytheon ASARS-2 radar, is an airborne battlefield or ground surveillance radar system which will be operational with the Royal Air Force and the British Army in the year 2005.

ASTOR www.airforce-technology.com/projects/astor/

Games we can play ....

- Ultra high-resolution SAR (and target recognition)
- Change detection
- Coherent change detection
- Interferometry
- Polarimetry
- Low-frequency SAR (FOPEN)

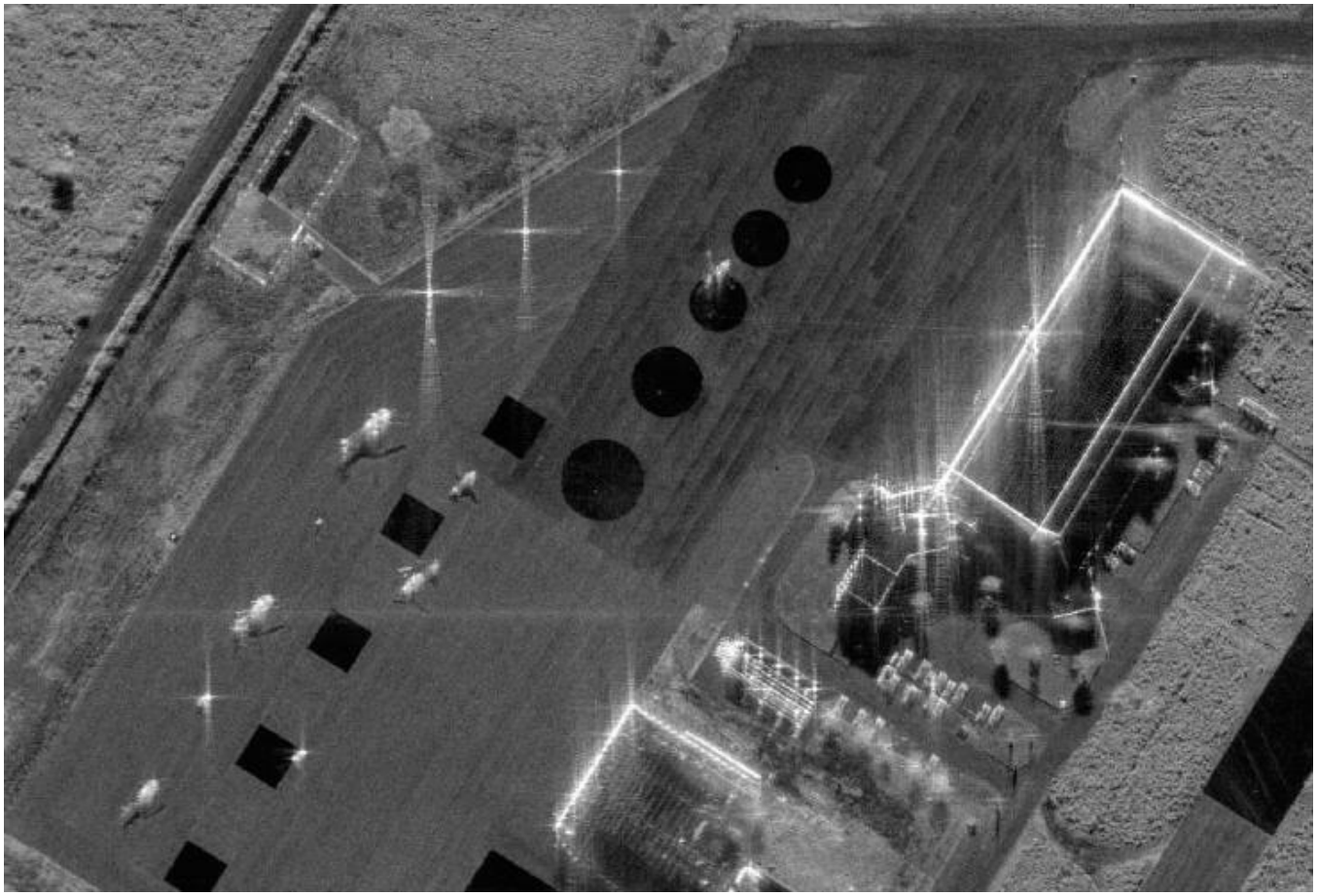
Sandia National Laboratories Twin Otter (Ku-band)



source: Sandia Corporation -http//www.sandia.gov

Sandia National Laboratories

Ultra-high resolution image



Example of 3-look image yielding 10 cm resolution

Cantalloube, H. and Dubois-Fernandez, P. 'Airborne X-band SAR imaging with 10 cm resolution – technical challenge and preliminary results', *Proc. EUSAR 2004* Conference, pp271-274.

Spotlight mode – maximum achievable resolution

Take the expression for spotlight mode azimuth resolution :

$$\Delta x = \frac{\lambda}{4\sin\ \Delta\theta/2}$$

A practical maximum value for $\Delta\theta$ might be 30º, i.e. $\Delta\theta$ = 60º in which case

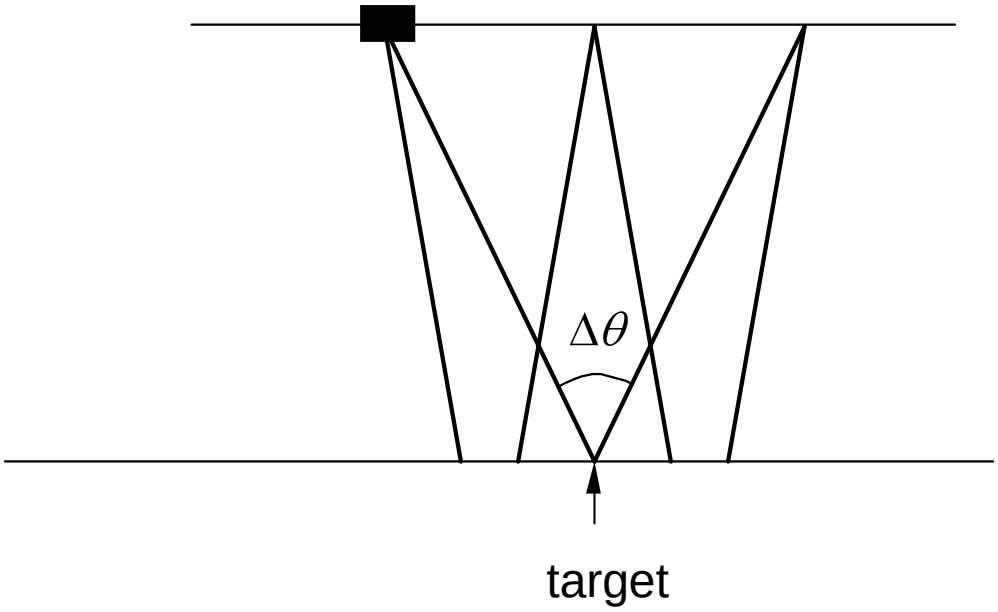
$$\Delta x = \frac{\lambda}{2}$$

In range, $\Delta r = \frac{c}{2B} = \frac{f_0\lambda}{2B}$

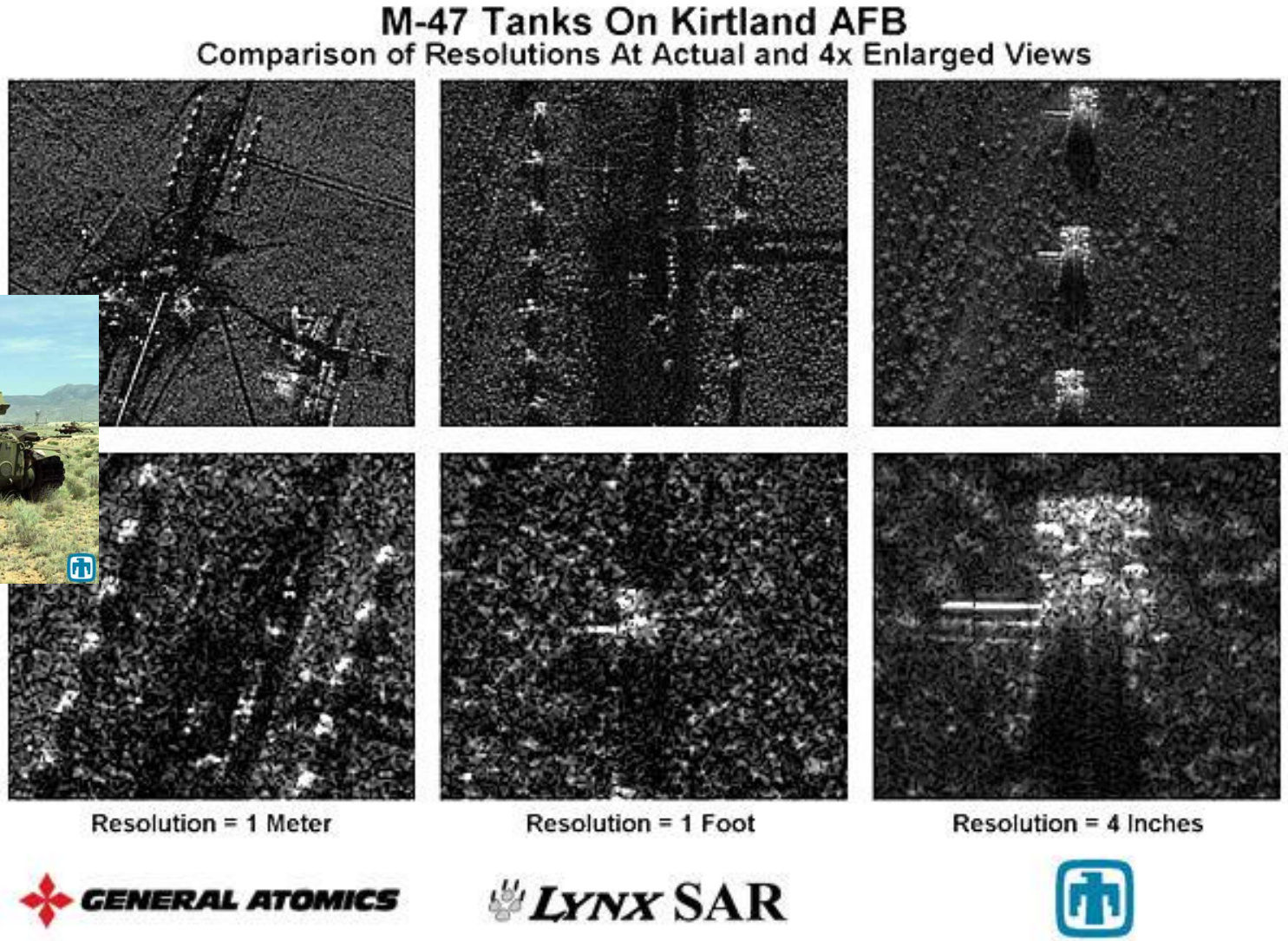
For a fractional bandwidth of 100%

$\frac{B}{f_0} = 1$ so

$$\Delta r = \frac{\lambda}{2}$$



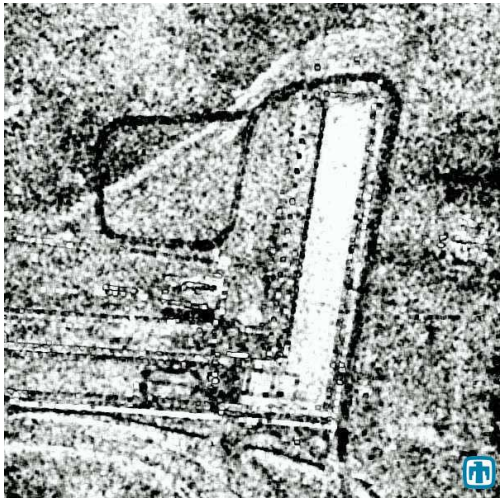
Ultra-high resolution image

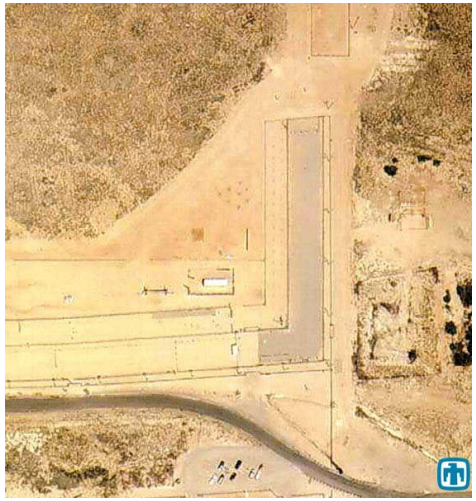


Coherent Change Detection (CCD)

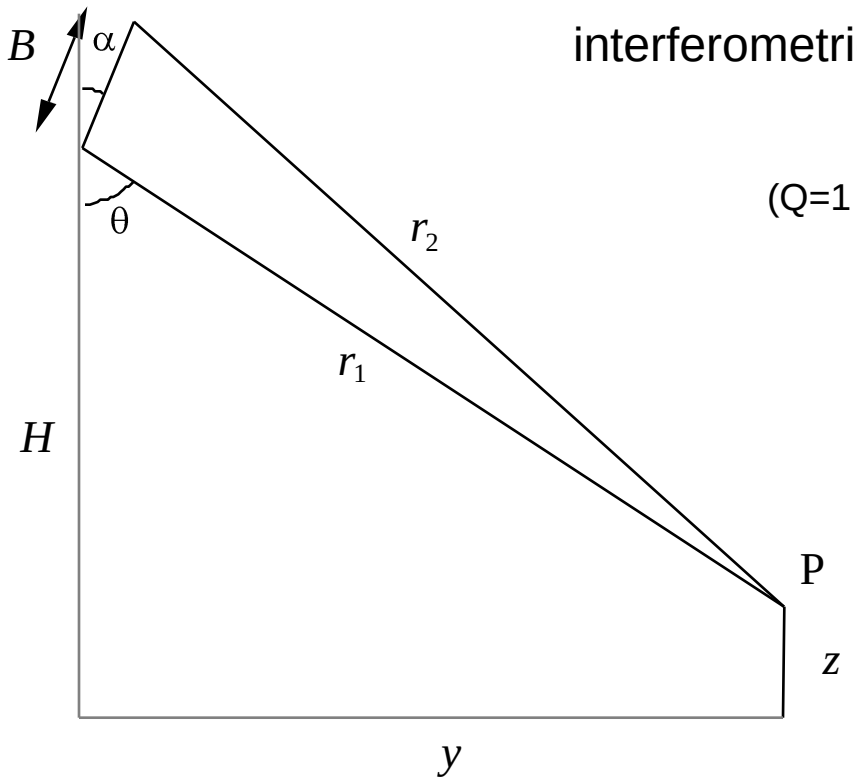
To detect whether or not a change has occurred, two images are taken of the same scene, but at different times. These images are then geometrically registered so that the same target pixels in each image align. After the images are registered, they are cross correlated pixel by pixel. Where a change has not occurred between the imaging passes, the pixels remain correlated, whereas if a change has occurred, the pixels are uncorrelated.

Of course, targets that are not fixed or rigid, such as trees blowing in the wind, will naturally decorrelate and show as having "changed." While this technique is useful for detecting change, it does not measure direction or the magnitude of change.





Interferometric SAR - geometry



interferometric phase $\phi = \frac{2\pi}{\lambda}.\mathrm{Q}.\ r_2 - r_1$

(Q=1 for single-pass, 2 for double-pass)

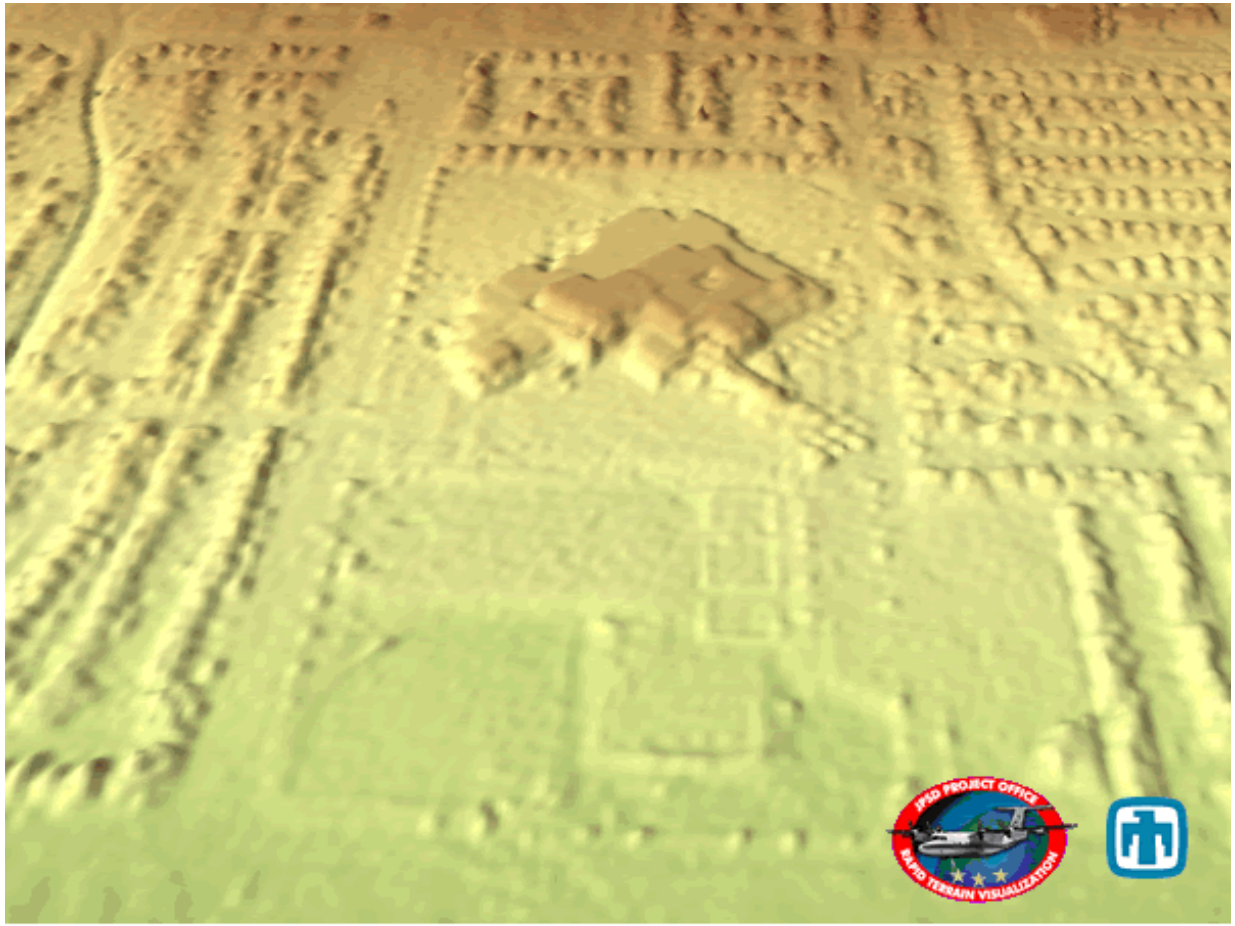
$$\phi = \frac{2\pi}{\lambda}.\mathrm{Q}.\left[r_1^2 - B^2 - 2r_1 B\cos\ \theta+\alpha \ ^{1/2} - r_1 \right]$$

$$\approx \frac{2\pi}{\lambda}.\mathrm{Q}.B\cos\ \theta+\alpha$$

(valid at long range or for θ large)

Interferometric SAR

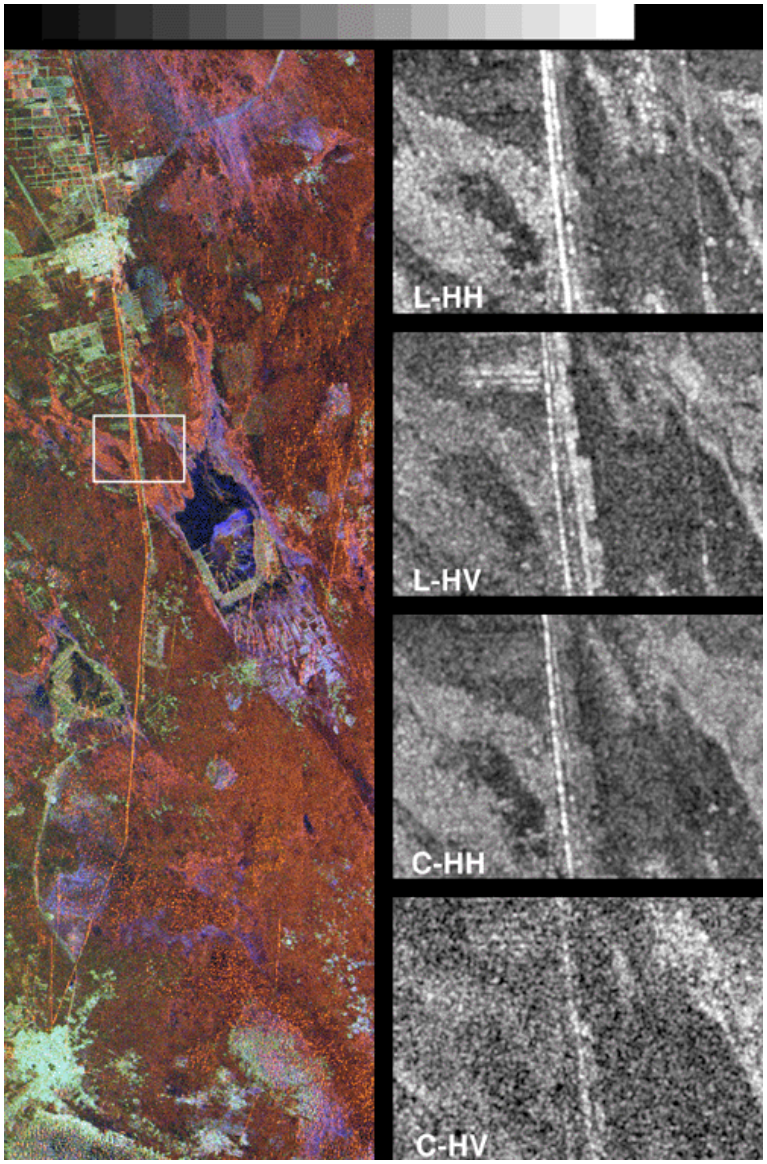
The Rapid Terrain Visualization (RTV) interferometric synthetic aperture radar sensor was designed and developed by Sandia National Laboratories for the Joint Precision Demonstration Project Office of the United States Army (Intelligence, Electronic Warfare & Sensors PEO). This radar provides the ability to generate highly accurate map products in real-time, including digital elevation models (DEMs), orthorectified SAR images, as well as a measure of the data quality.



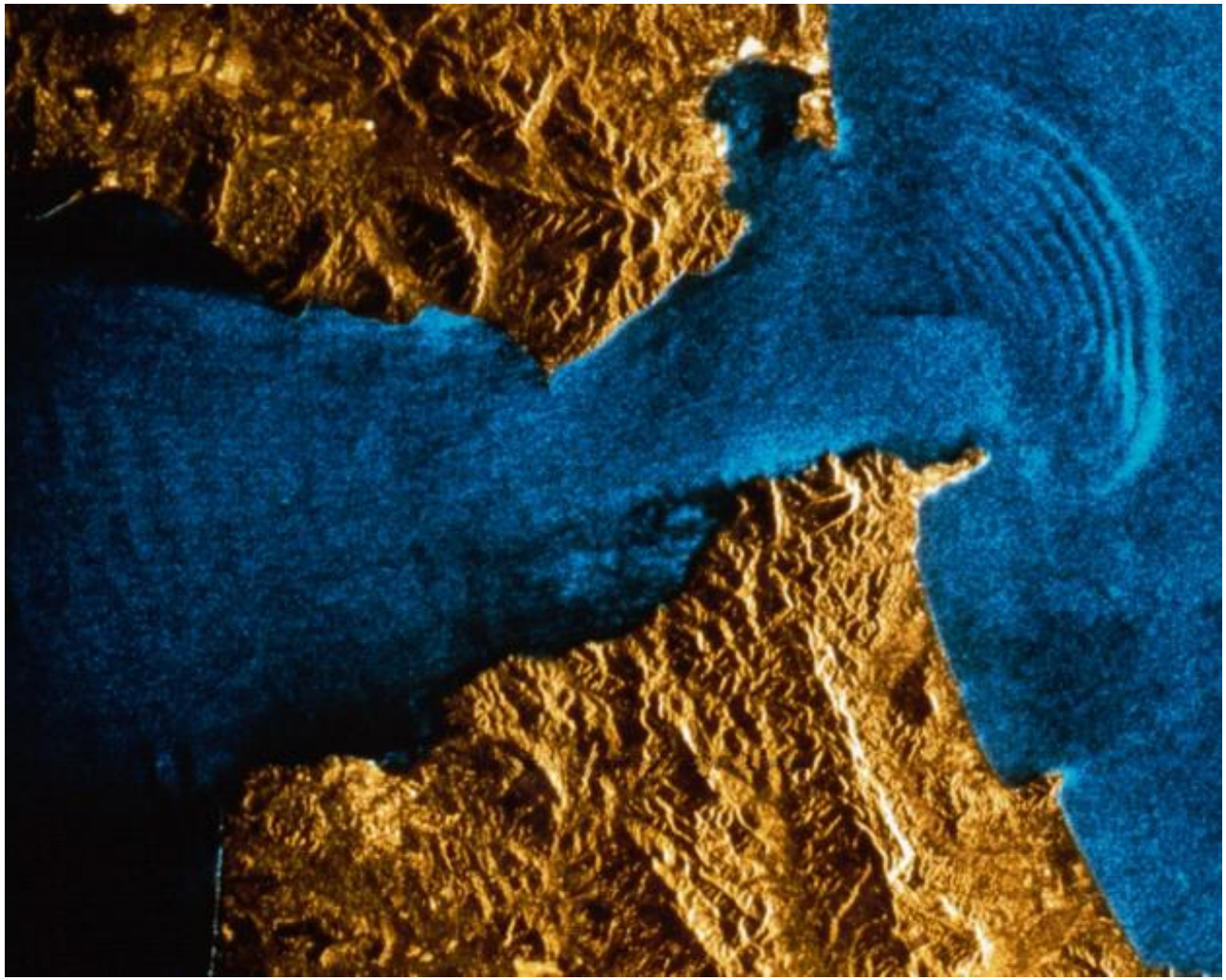
3-D Rendering of La Cueva High School, Northeast Albuquerque, NM
Created from RTV DEM (DTED Level IV)

www.sandia.gov

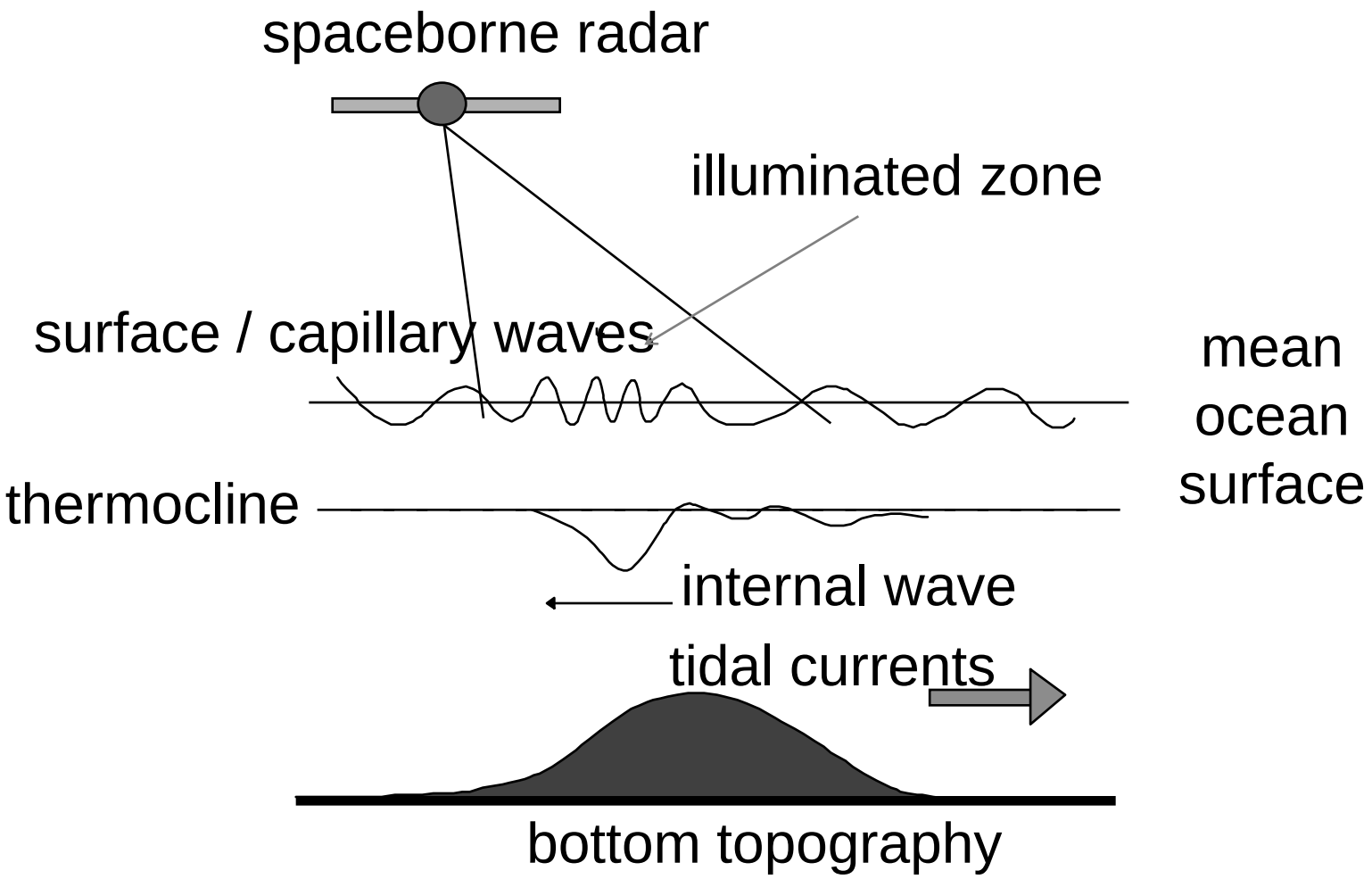
SIR-C SAR images



Internal waves in SAR images



Internal waves in SAR images



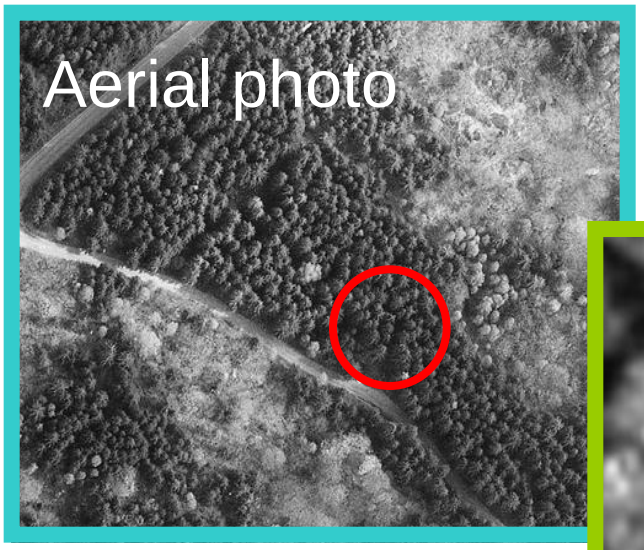
CARABAS I Experimental Demonstrator

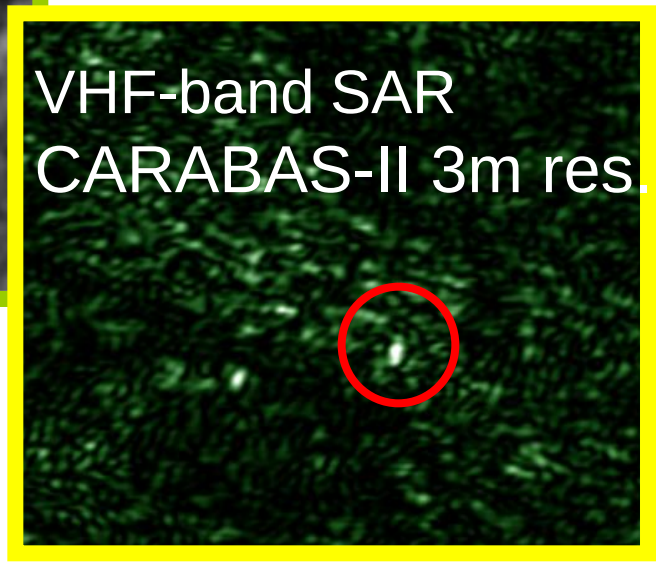
FOI

CARABAS II/LORA

FOI

Detection of Concealed Targets





Attenuation is significantly reduced in VHF-band SAR, but forest clutter is still a problem.

FOI

Conclusions

- SAR is a mature set of techniques, with numerous applications in geophysical remote sensing and in military surveillance
- As well as advances in hardware and techniques, the key thing is the ability to extract information from SAR imagery