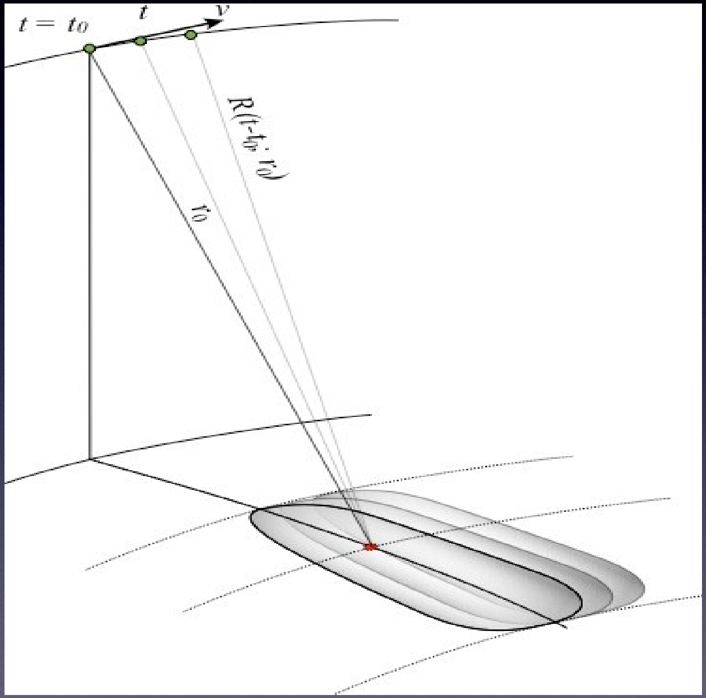
InSAR

A very very quick introduction…

… though quite complete.

Dominique Derauw
dderauw@uliege.be
dderauw@unrn.edu.ar

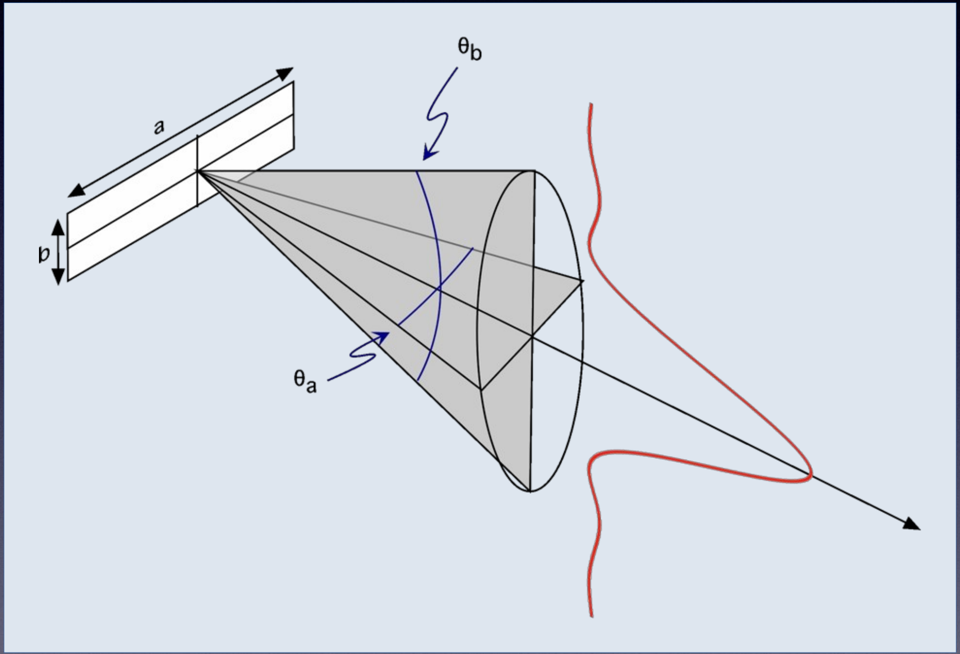
SAR acquisition



- Radar pulses are emitted at regular pace (~1 a 3kHz)
  - ☞ The signal is back-scattered by the illuminated part of the scene.
  - ☞ Natural resolution of the system corresponds to beam pattern on the ground.
- Echoes are recorded along the satellite orbit.
  - ☞ A point target is recorded on numerous echoes but at varying distance

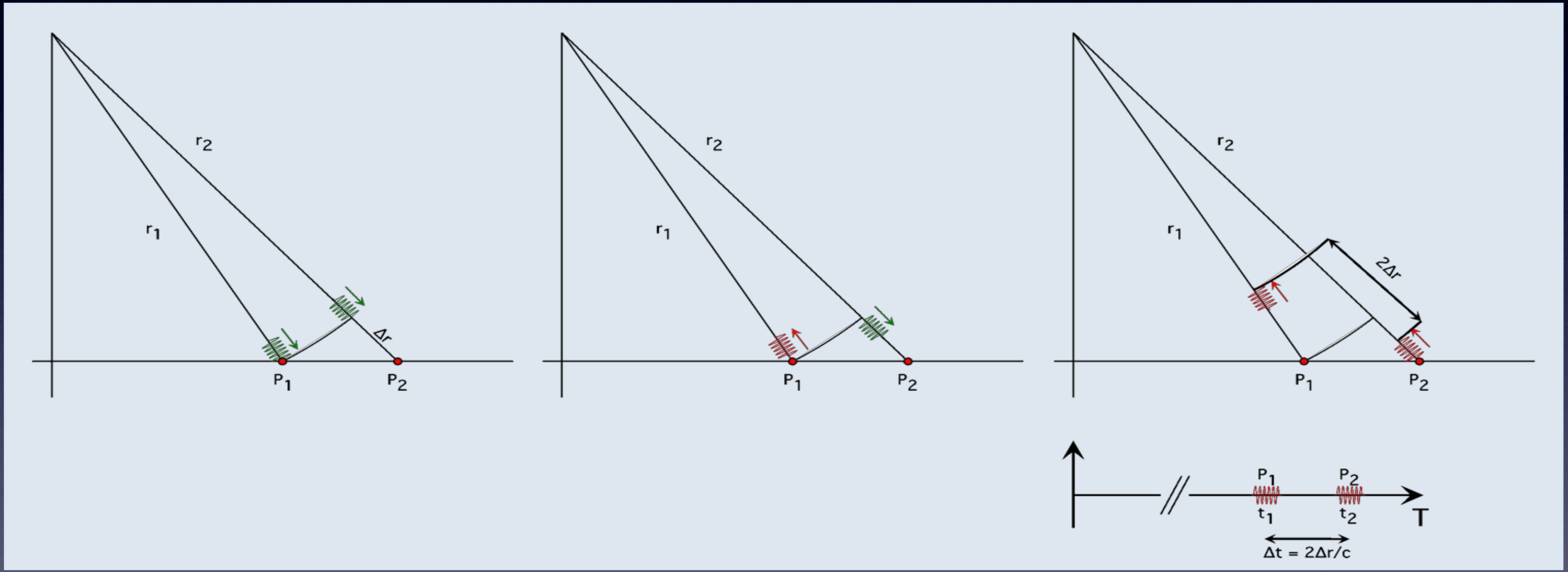
Real aperture radar

- Earth observation radar generally use rectangular antennas
- The angular aperture of the diffraction pattern of a rectangular antenna diminish with increasing antenna dimensions and increase with used wavelength.
  - ☞ We do need a huge antenna to get a high resolution.



Range resolution improvement

- If we use pulses of duration δt, range resolution will be equal to the distance traveled by the pulse in δt.



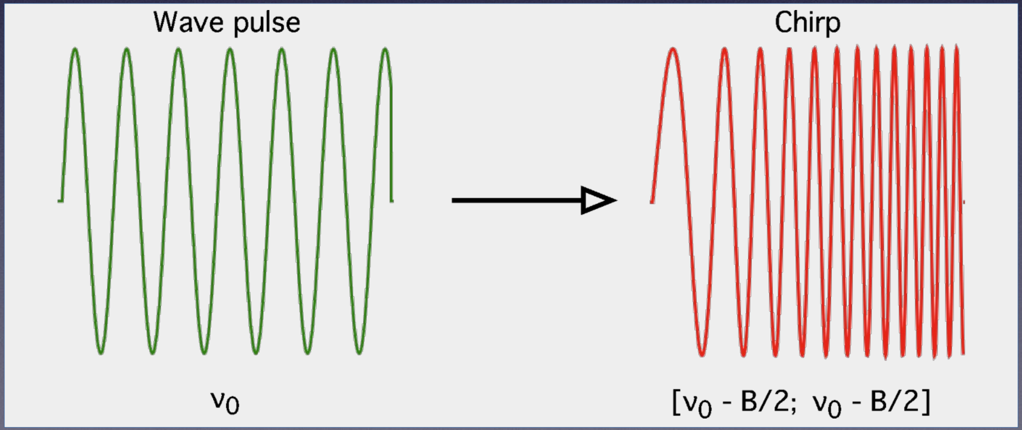
☞ Two points can be distinguished if the traveling time separating them is larger than the pulse duration.

Range resolution improvement

- Range resolution can be improved using high energy – short duration pulses:
  - ☞ LIDAR
- Due to radar wavelength and antenna size, the diffraction pattern lead to energy dispersion on a very large illuminated surface.
  - ☞ Short duration pulses of high energy lead to very low energy per unit surface.
  - ✓ Back-scattered energy intercept by the antenna is even lower.

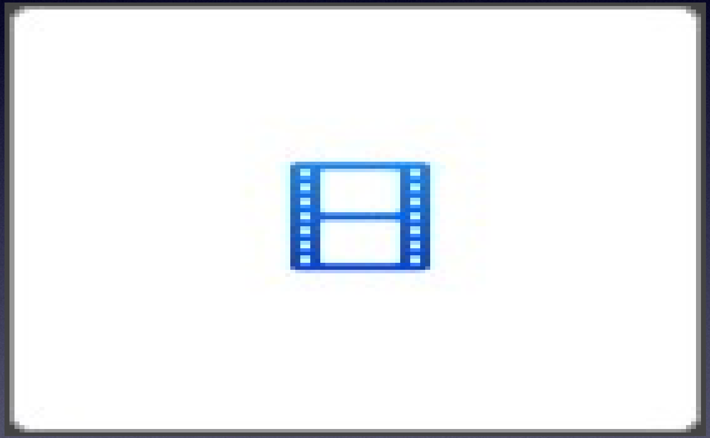
Range resolution improvement

- Solution consist in:
  - ☞ Sending pulses of long duration to raise energy received per unit surface.
  - ☞ Use coded pulses to preserve high resolution through matchin at detection level.
  - ✓ SAR is not purely monochromatic.
  - ✓ The less monochromatic, the better the range resolution.

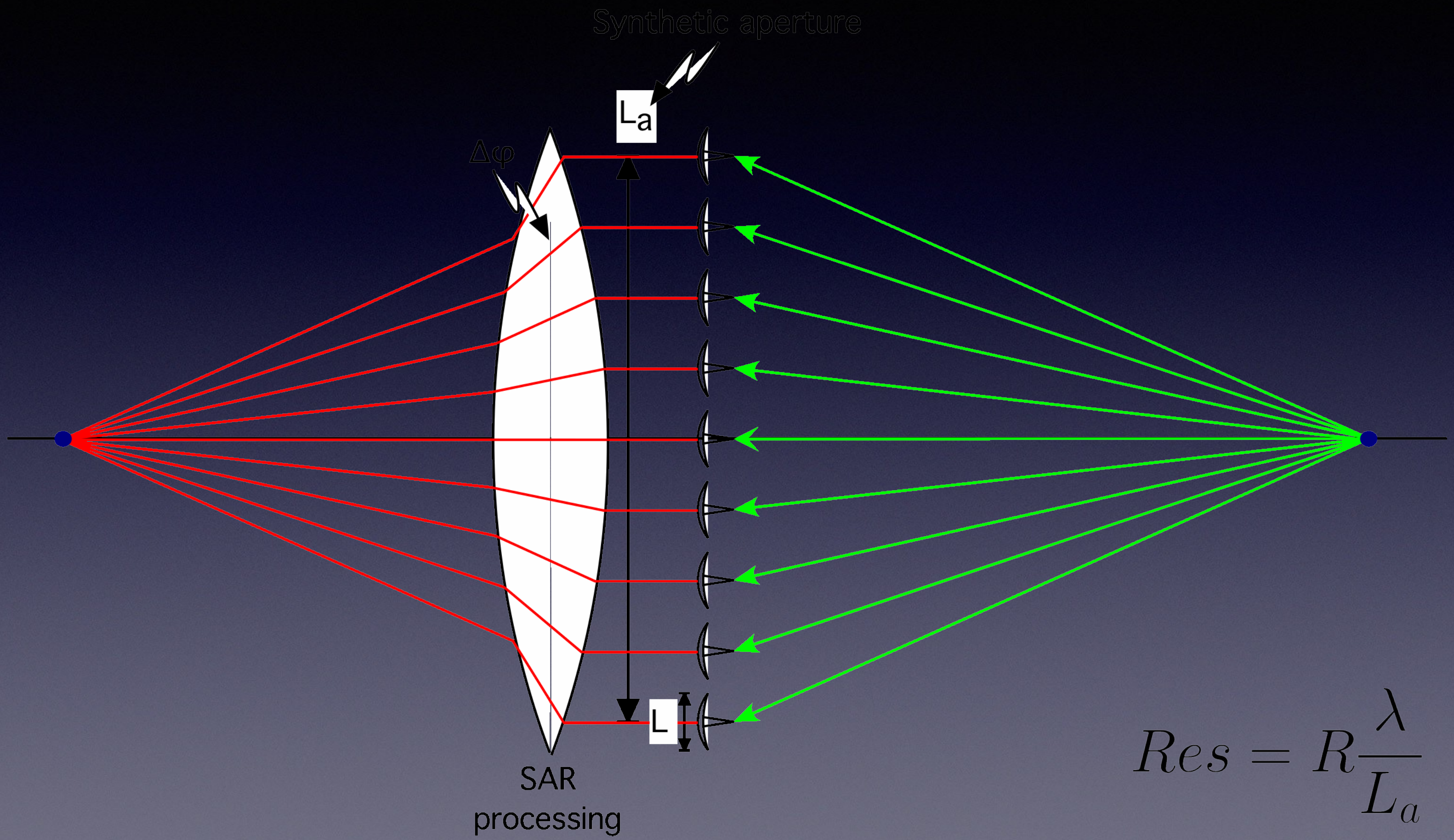


Azimuth resolution improvement

- Through antenna displacement, a point target is observed at varying distance:
  - ☞ Recorded signal will bear a varying phase leading to an azimuth chirp



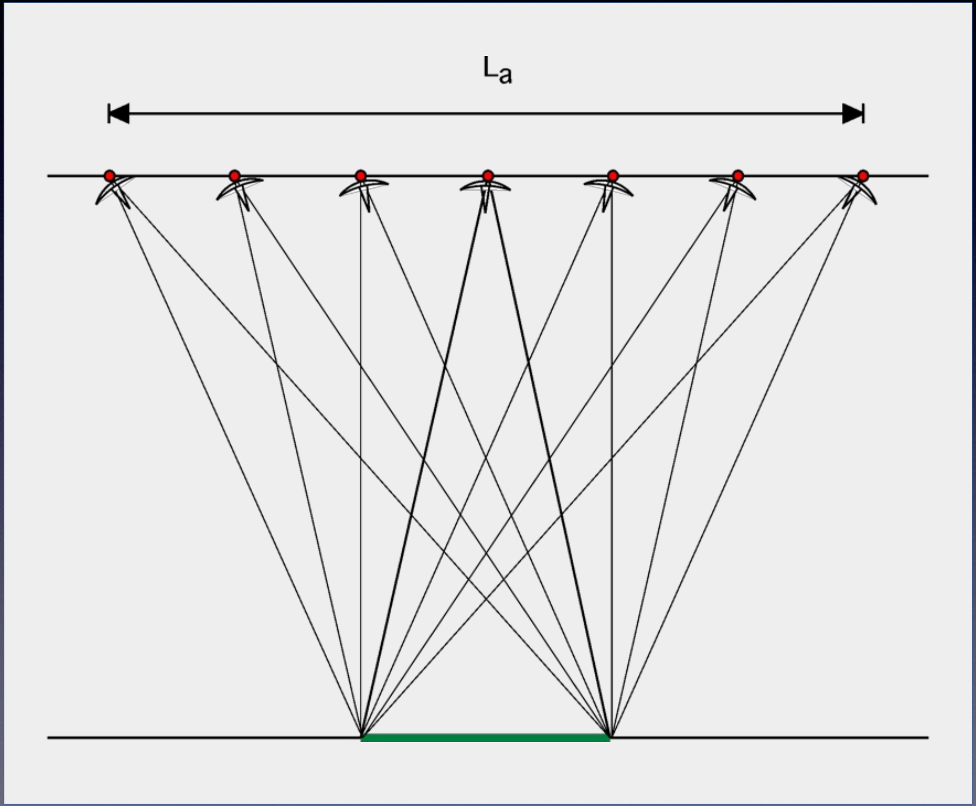
Azimuth resolution improvement



$$Res = R\frac{\lambda}{L_a}$$

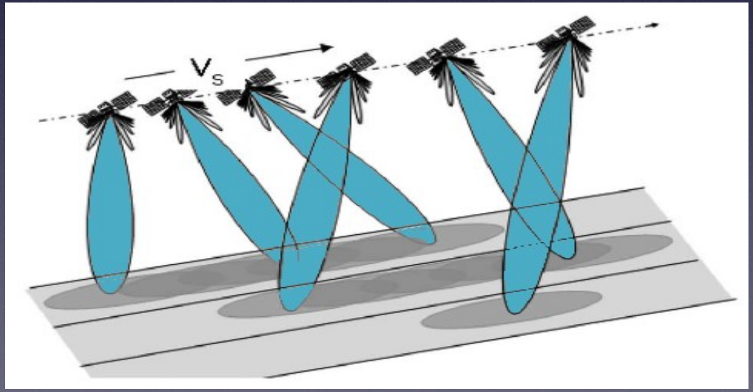
Spotlight

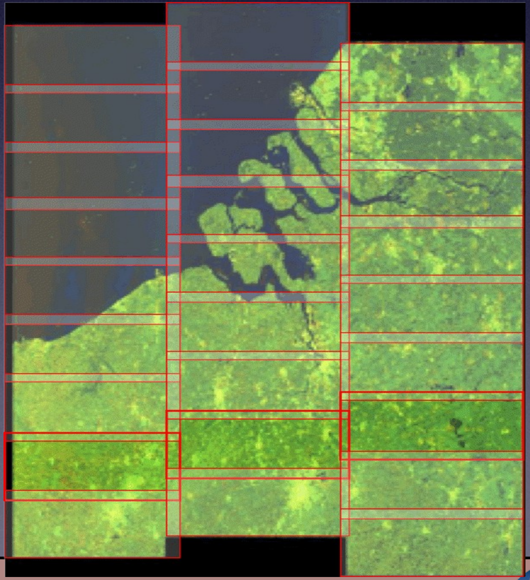
- A way to still increase the azimuth resolution is to increase the synthetic aperture:
  - ☞ Using a smaller antenna!?
  - ☞ Aiming the antenna beam toward the scene centre during satellite displacement



TOPSAR

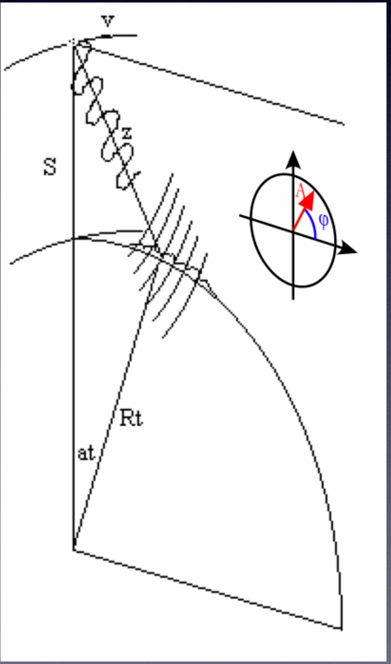
- Sentinel1: To increase coverage the reverse process is used. The beam is electronically steered from forward to backward during satellite displacement:
  - ☞ Freed time is used to steer the beam in range dimension.
  - ☞ TOPSAR : burst by burst acquisiton.

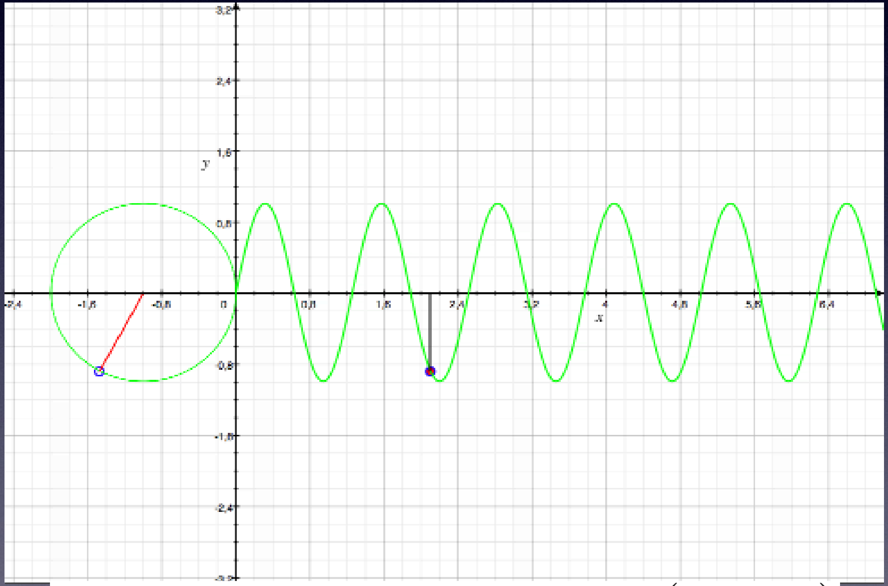




SAR Image characteristics

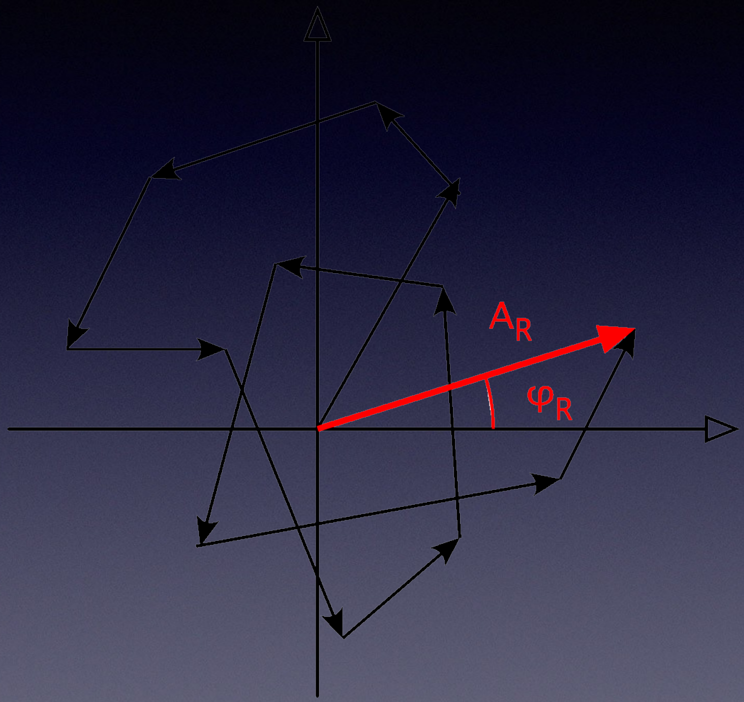
- SAR images are complex
  - ☞ In the mathematical sense





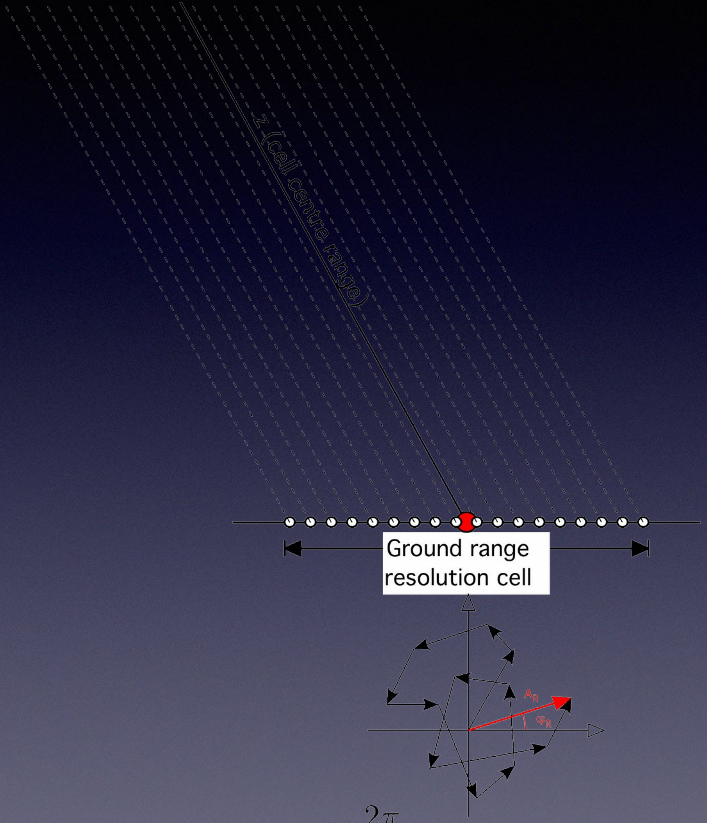
$$s(x,z) = A(x,z)e^{\left(\frac{2\pi i}{\lambda}2z\right)}$$

The speckle



- The back-scattering signal of a resolution cell is made of the coherent superposition of the response of each back-scattering centers within the cell.
- The amplitude and the phase from one resolution cell to another can vary a lot, which leads to an apparent noise.
  - ☞ This apparent noise is named the speckle.
  - ☞ The speckle IS NOT NOISE!

The interferometric phase



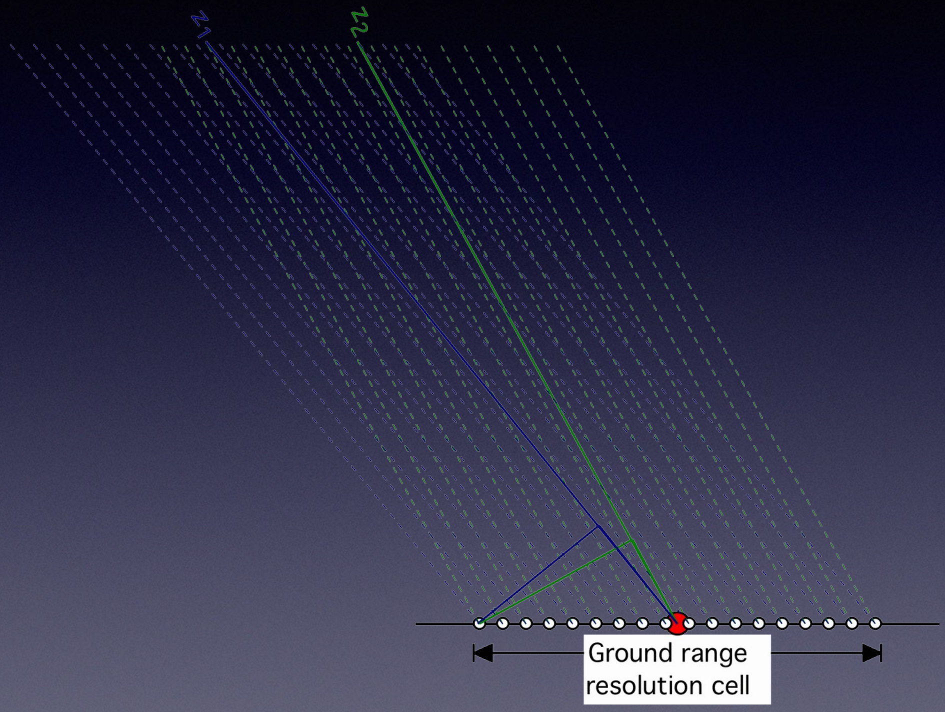
$$\varphi(z) = \frac{2\pi}{\lambda} 2z + \varphi_{speckle} + \epsilon\varphi$$

- The phase in a single image varies very rapidly with range:
  - ☞ One cycle every 2,3 cm in C band.
  - ☞ Each diffusor within the resolution cell is at a different distance to the sensor.
  - ☞ Each diffusor within the resolution cell has its own amplitud and phase response

  - ☞ The phase in a single image is of no direct use.

The interferometric phase

- If we consider two SAR images acquired from two slightly different observation points:
  - ☞ Each phase term has:
  - ✓ Its own optical path phase
  - ✓ Its own speckle component
  - ✓ Its own noise



The interferometric phase

- If we consider two SAR images acquired from two slightly different observation points:
  - ☞ Each phase term has:
  - ✓ Its own optical path phase
  - ✓ Its own speckle component
  - ✓ Its own noise

$$\begin{cases} S_1(z) = A_1 e^{i\varphi(z_1)} = A_1 e^{i\left(\frac{2\pi}{\lambda}2z_1 + \varphi_{speckle_1} + e\varphi_1\right)} \\ S_2(z) = A_2 e^{i\varphi(z_2)} = A_1 e^{i\left(\frac{2\pi}{\lambda}2z_2 + \varphi_{speckle_2} + e\varphi_2\right)} \end{cases}$$

The interferometric phase

- Making the following hypothesis:
  - ☞ Both sensors are close one from the other even if not at the same time.
  - ✓ In such a way the relative positions of diffusers stay stable within the resolution cell.
  - ☞ Diffusers are stable with time.
  - ✓ Intrinsic phase response of each diffuser stays equal.
  - ☞ Measurement noise may be neglected.
- Speckle stays preserved from one acquisition to the other.

$$\varphi_{speckle_1} \simeq \varphi_{speckle_2}$$

The interferometric phase

- Whithin these hypothesis, phase difference makes sense:

$$\varphi_1 = \left(\frac{2\pi}{\lambda} 2z_1 + \varphi_{speckle_1} + e\varphi_1\right)$$

$$\varphi_2 = \left(\frac{2\pi}{\lambda} 2z_2 + \varphi_{speckle_2} + e\varphi_2\right)$$

$$\Longrightarrow \Delta\varphi = \varphi_2 - \varphi_1 = \frac{4\pi}{\lambda}(z_2 - z_1) = \frac{4\pi}{\lambda}\Delta z$$

Phase difference is directly proportional to the **optical path difference**.

The interferometric phase

- Phase is measured modulo 2π: $\Longrightarrow \Delta\varphi = k\,2\pi + \Delta\varphi_w = \frac{4\pi}{\lambda}\Delta z$

☞ What is measured is the wrapped phase: $\Delta\varphi_w$

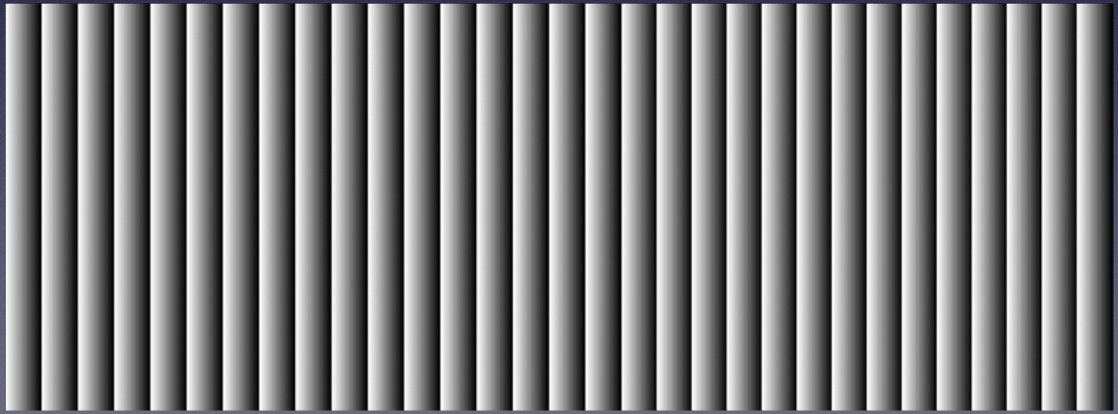
☞ The integer number k of cycles is unknown

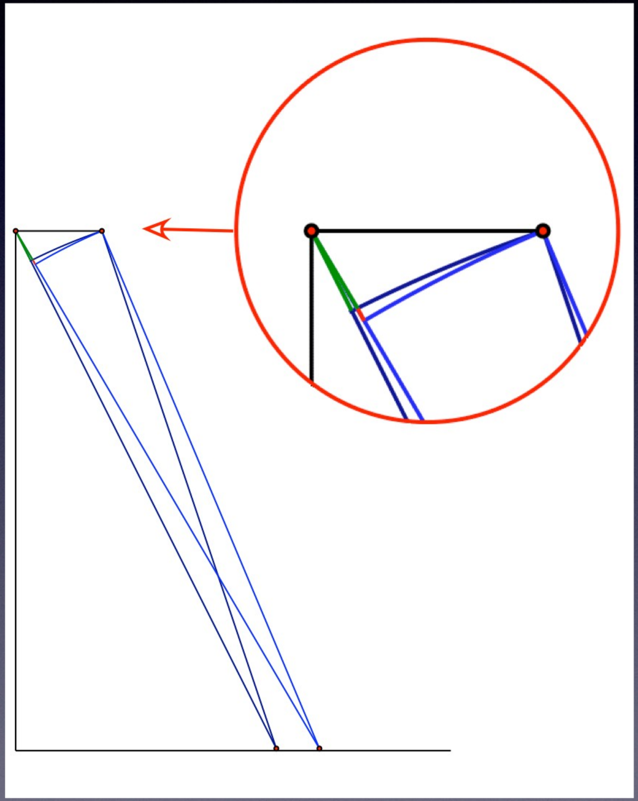
✓ We do have a very precise measure of the optical path variation but only on the ultimate traveled wave cycle.

☞ Phase unwrapping is required

SAR interferometry

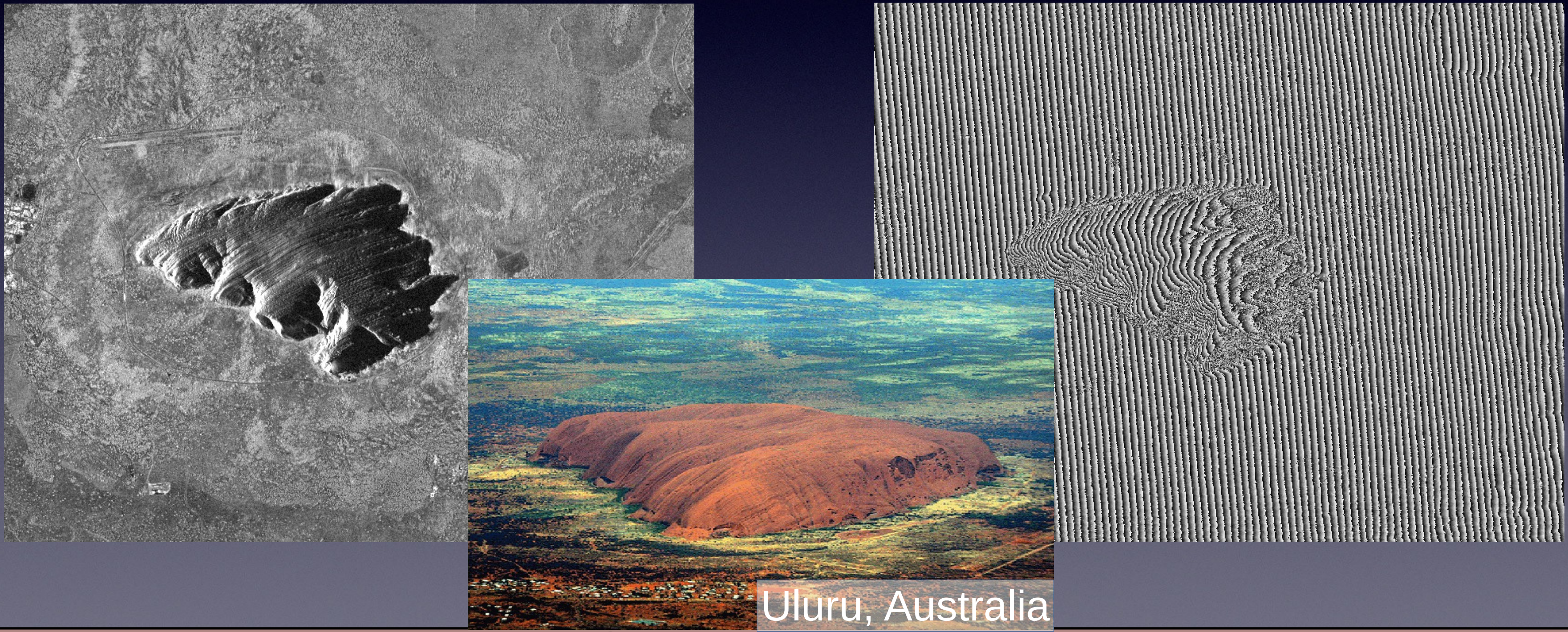
- From two SAR images, we can measure the optical path difference between two observation and form an interferogram





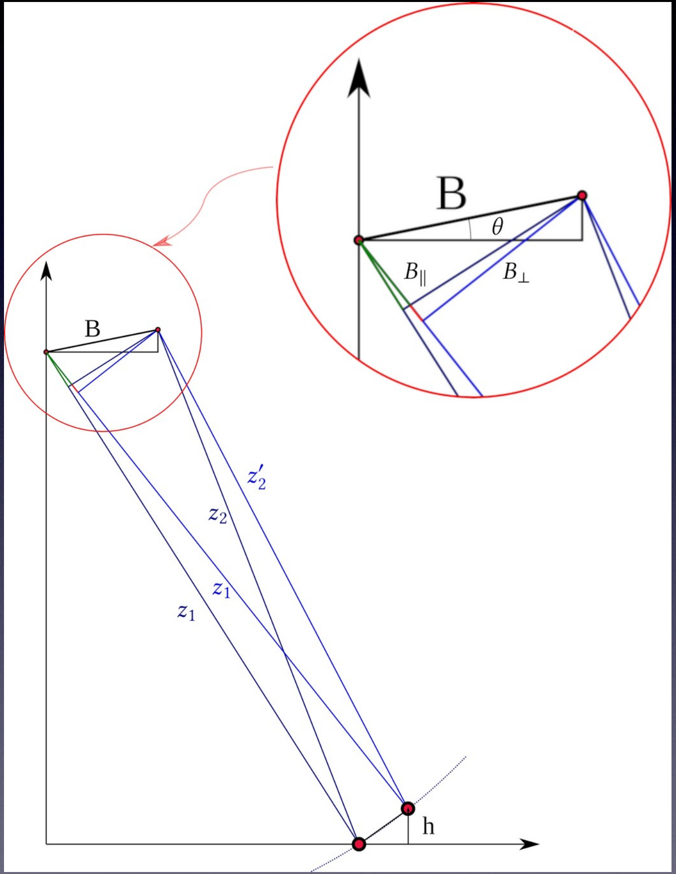
SAR interferometry

- In presence of a relief, the interferometric pattern is perturbed:



Uluru, Australia

SAR interferometry



- In presence of a relief, the interferogram pattern is perturbed.
- Considering the made hypothesis, the interferometric phase contains the orbital phase and a topographic component.
- Objective of SAR interferometry is to estimate the topography above the ellipsoid.

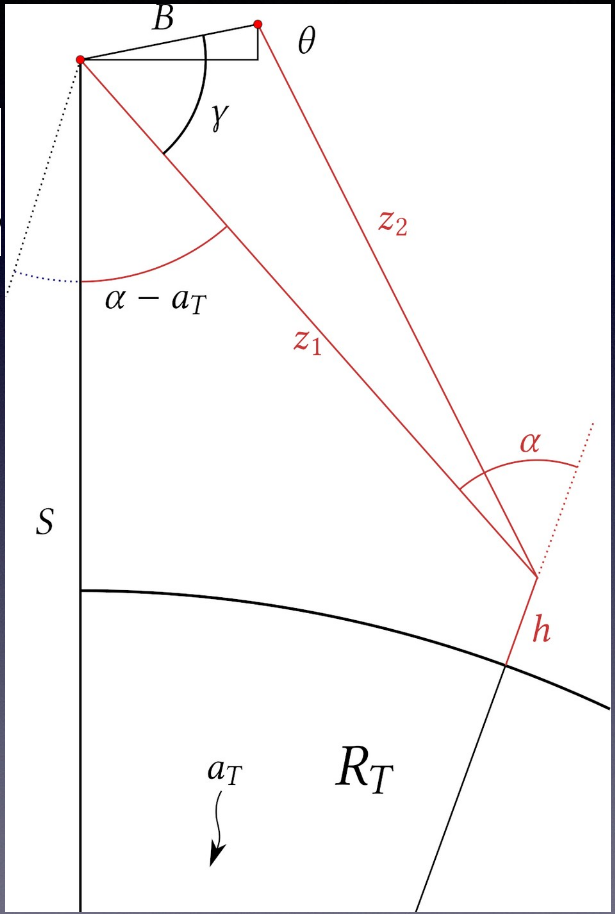
$$\begin{aligned} \Delta\varphi &= k_{z_0}(z_2 - z_1) \\ &= \Delta\varphi_{orb} + \Delta\varphi_{topo} \end{aligned}$$

Local height calculation

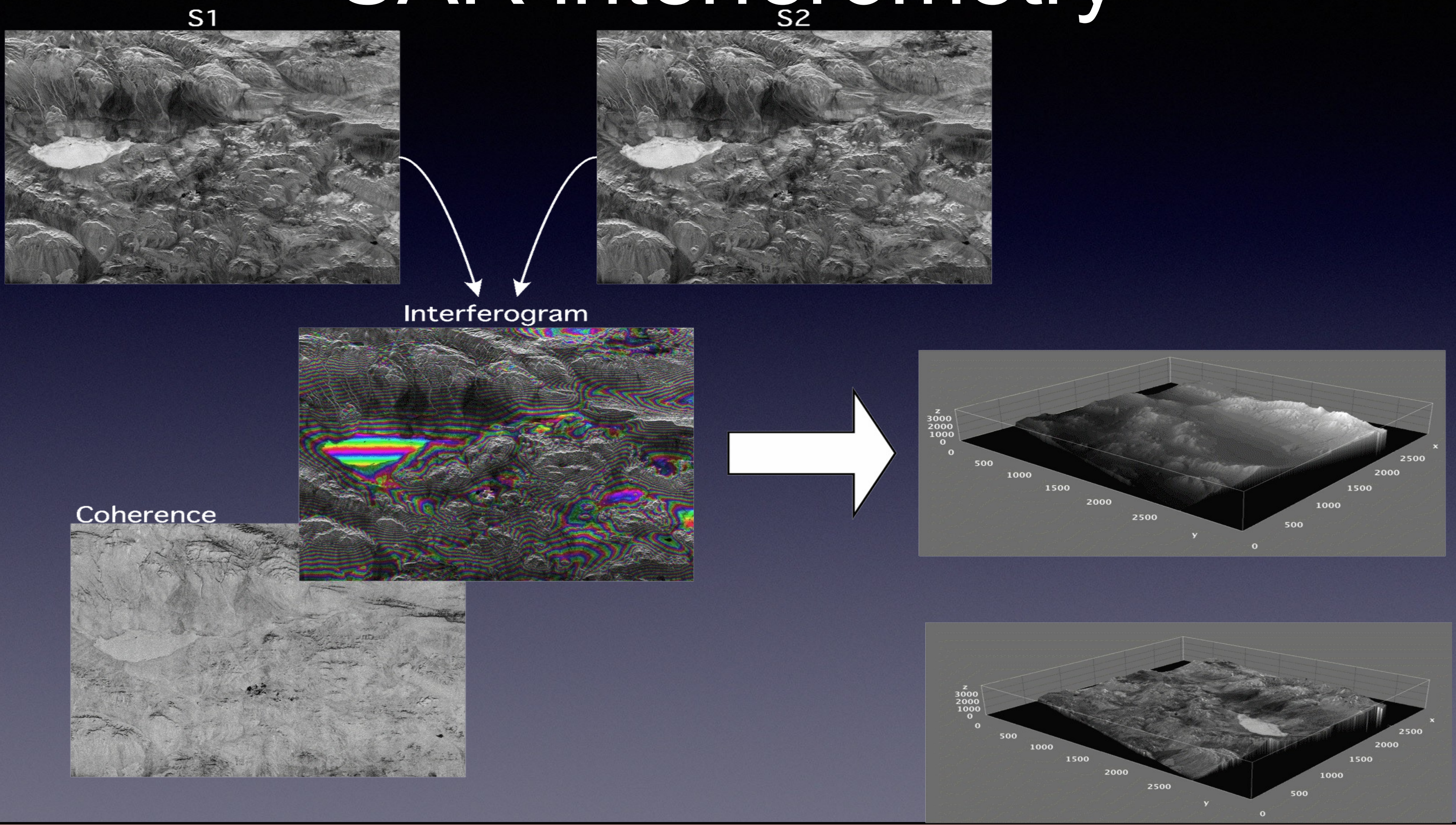
- In practice, exacts equations are used:
  - ☞ Interferometry allows getting optical distance z2 very precisely with respect to z1

$$\Delta\varphi = \frac{4\pi}{\lambda}(z_2 - z_1)$$
$$\Longrightarrow z_2 = z_1 + \frac{\lambda}{4\pi}\Delta\varphi$$

  - ☞ Triangle z1 B z2 allows getting the angle γ
  - ☞ Having γ allows deducing the elevation angle α - a_T
  - ☞ From triangle S z1 (RT + h), we measure R_T + h
  - ✓ Terrestrial radius R_T is recalculated at every point position on the reference ellipsoid to finally get the ellipsoidal height.



SAR interferometry



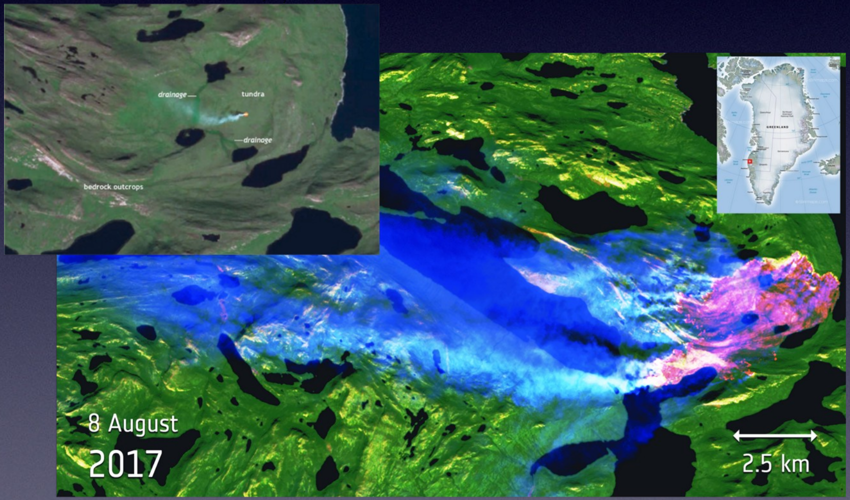
Interferometric coherence

- Coherence is a measure of the validity of our hypothesis.
  - ☞ If speckle is not preserved, phase difference contains speckle difference which this times is noise.
- This information loss is itself an information channel as it is an indicator of difusers instability with time. .
  - ☞ Coherence is a very important information channel
  - ✓ Human activity
  - ✓ Vegetation changes
  - ✓ Forest fires
  - ✓ Floods
  - ✓ …

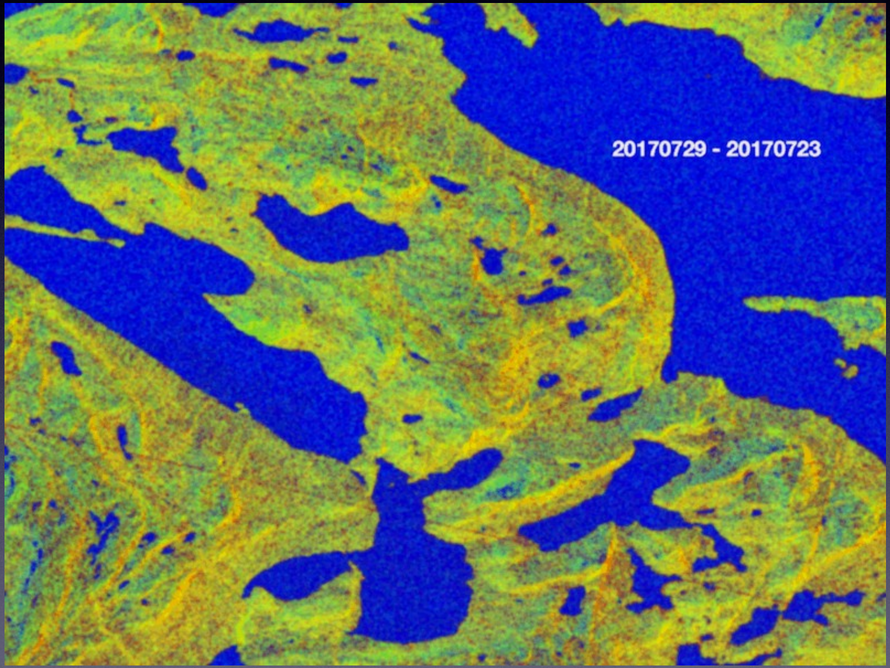
Coherence dynamic monitoring

- Wildfires

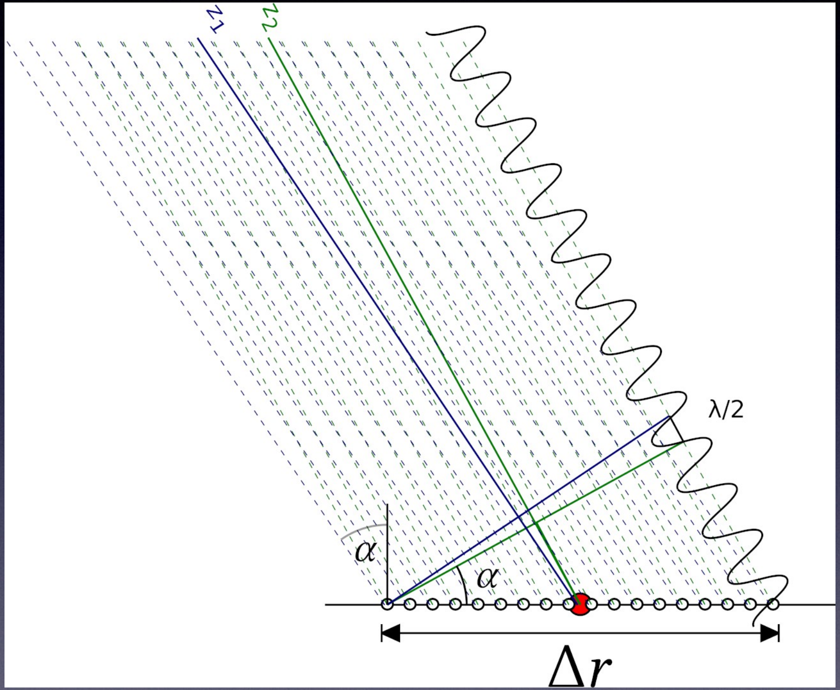
Landsat 8 - First observation - July 31, 2017



Greenland wildfire extend observed by Sentinel2 - August 8, 2017



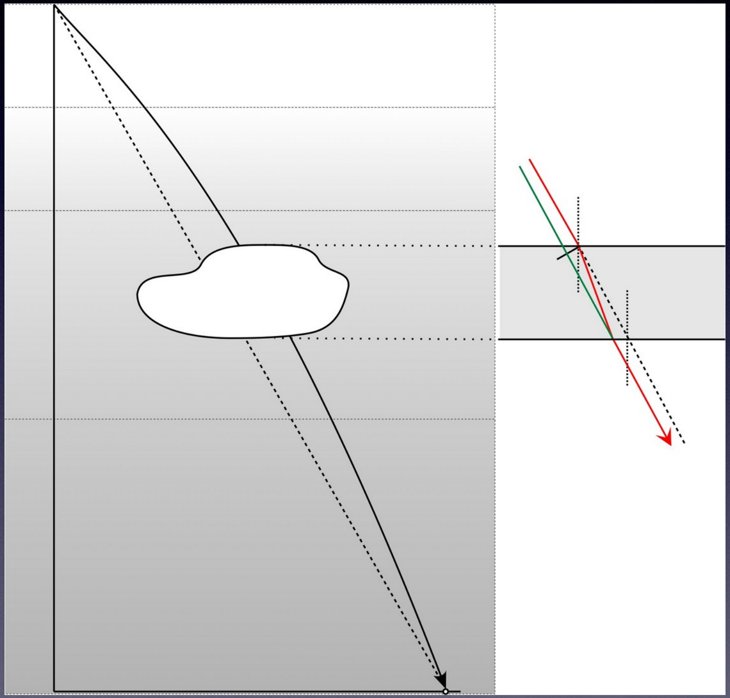
Geometrical decorrelation



- Other hypothesis lack of validity:
  - ☞ Relative position of diffusors within the resolution cell varies with incidence angle from one image to the other..
  - ☞ Speckle cannot be considered as constant and is never perfectly preserved.
  - ☞ Considering a random distribution of diffusers within a plane, it exists a limit baseline leading to total signal decorrelation:
  - ✓ S1 ~ 3600m

$$B_{\perp_c} = z\,\frac{\lambda}{2}\,\frac{tan(\alpha)}{\Delta r}$$

Atmospheric perturbations



- Noise:
  - ☞ Temporal and geometrical decorrelation induce measurement noise.
- Perturbations:
  - ☞ Unexpected additional phase terms if the optical path in one acquisition is larger than it should be in absence of the perturbation:
  - ✓ Refraction index variation due to atmosphere instability in case of asynchronous acquisitions.
- Atmosphere may be considered as a succession of layers of variable refraction index

Atmospheric perturbations

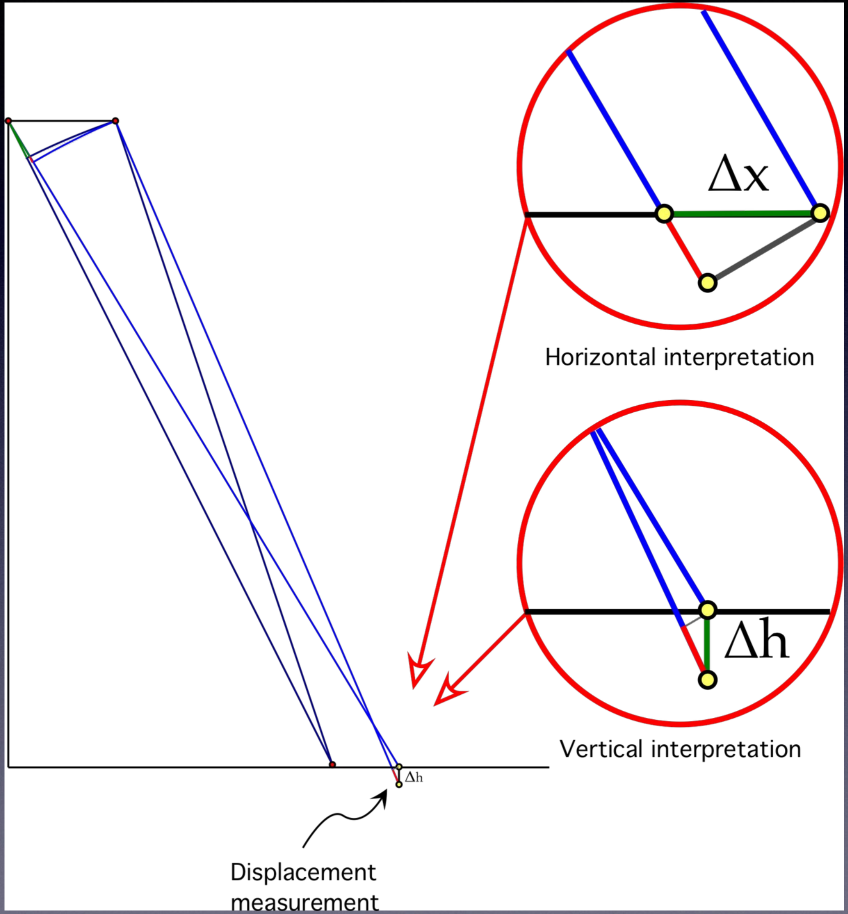
- Local variation of the atmosphere refraction index (clouds) will lead to aditionnal optical path component.
  - ☞ Additional phase term:

$$\Delta\varphi = \frac{4\pi}{\lambda}(z_2 - z_1) + \frac{4\pi}{\lambda}\delta z_2$$

$$\Delta\varphi = \underbrace{\Delta\varphi_{orb} + \Delta\varphi_{topo}}_{geometric} + \underbrace{\Delta\varphi_{ath}}_{optical\ path\ variations} + \underbrace{\epsilon\Delta\varphi}_{noise}$$

  - ☞ Atmospheric perturbation may lead to important topographic measurement errors if considered as part of the topographic phase component.
  - ✓ Data selection is of prime importance!
- Refraction index depends on wavelength:
  - ☞ Less atmospheric perturbations in L band than in C or X band

DInSAR

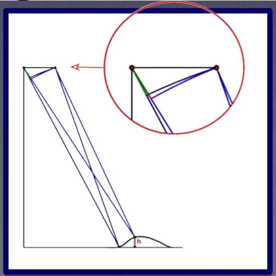


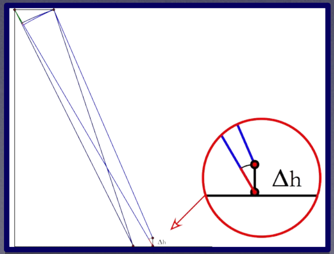
- Local displacements between acquisition also induce optical path variation:
- Additional phase term is directly proportional to the component of the displacement along the line of sight..
  - ☞ Interferometry is much more sensitive to displacement than to topography:
  - ✓ A variation of altitude equivalent to the ambiguity of altitude induce one fringe.
  - ✓ A displacement of half a wavelength $\lambda/2$ lead to an additional fringe.

InSAR summary

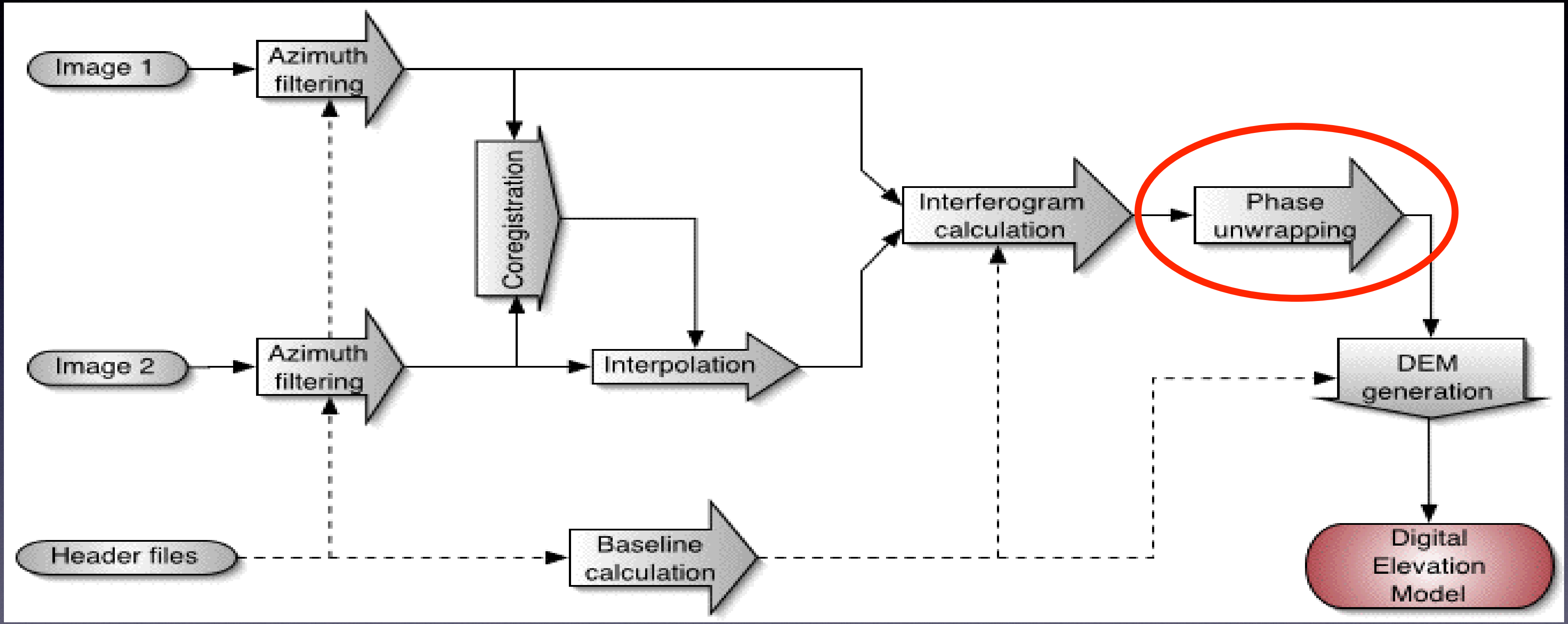
- The interferometric phase contains $\Delta\varphi = ¿$
  - ☞ The orbital phase $\Delta\varphi_{orb}$
  - ☞ The topographic phase $+\Delta\varphi_{topo}$
  - ☞ The atmospheric component $+\Delta\varphi_{ath}$
  - ☞ The displacement phase $+\Delta\varphi_{mov}$
  - ☞ Noise $+\epsilon\Delta\varphi$

$$\Delta\varphi = \underbrace{\Delta\varphi_{orb} + \Delta\varphi_{topo}}_{geometric} + \underbrace{\Delta\varphi_{ath} + \Delta\varphi_{mov}}_{optical\ path\ variations} + \underbrace{\epsilon\Delta\varphi}_{noise}$$

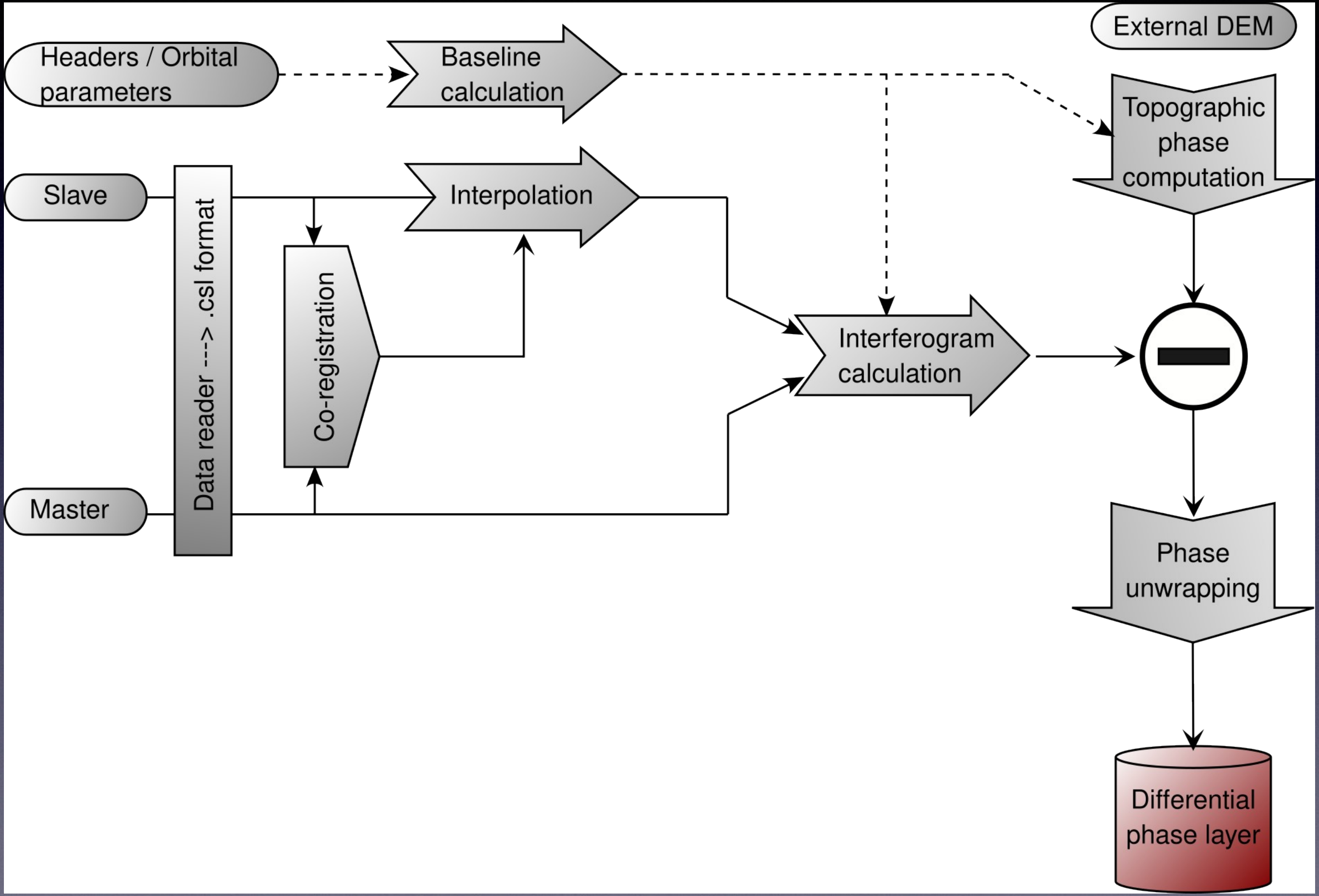




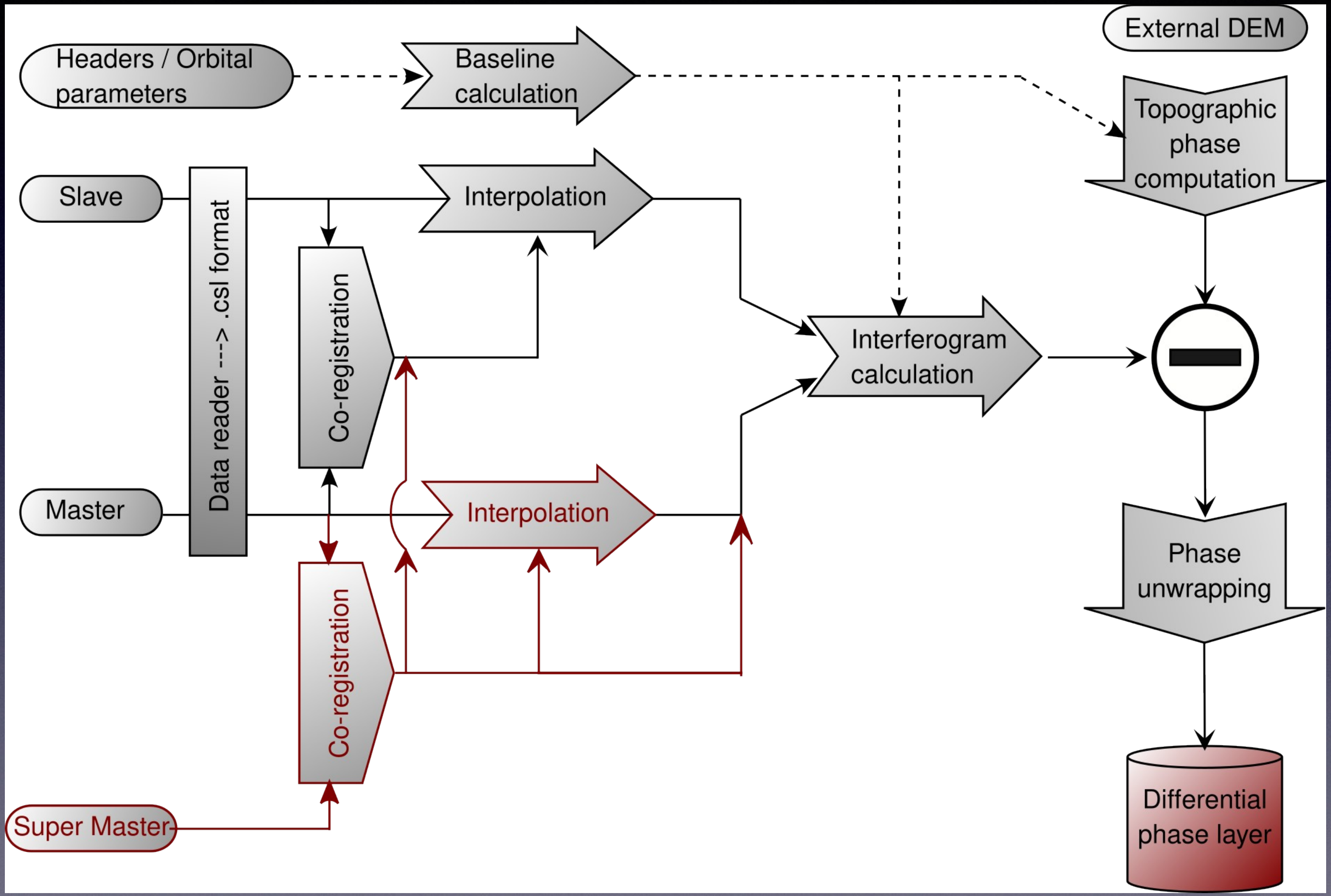
InSAR flowchart



DInSAR flowchart



DinSAR flowchart II



MasTerEngine to MasTer toolbox