GEOS 639 – INSAR AND ITS APPLICATIONS

GEODETIC IMAGING AND ITS APPLICATIONS IN THE GEOSCIENCES

Lecturer:

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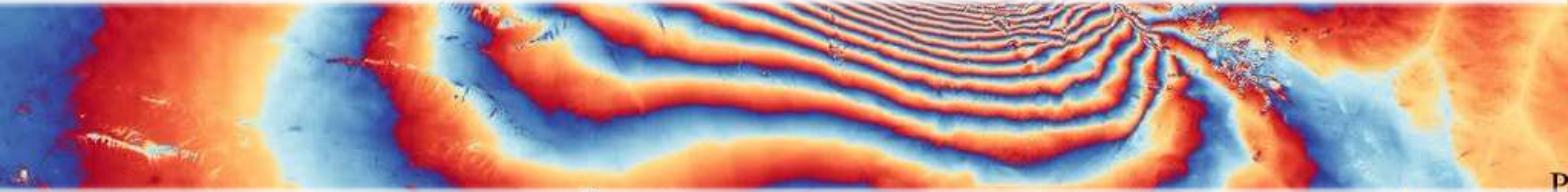
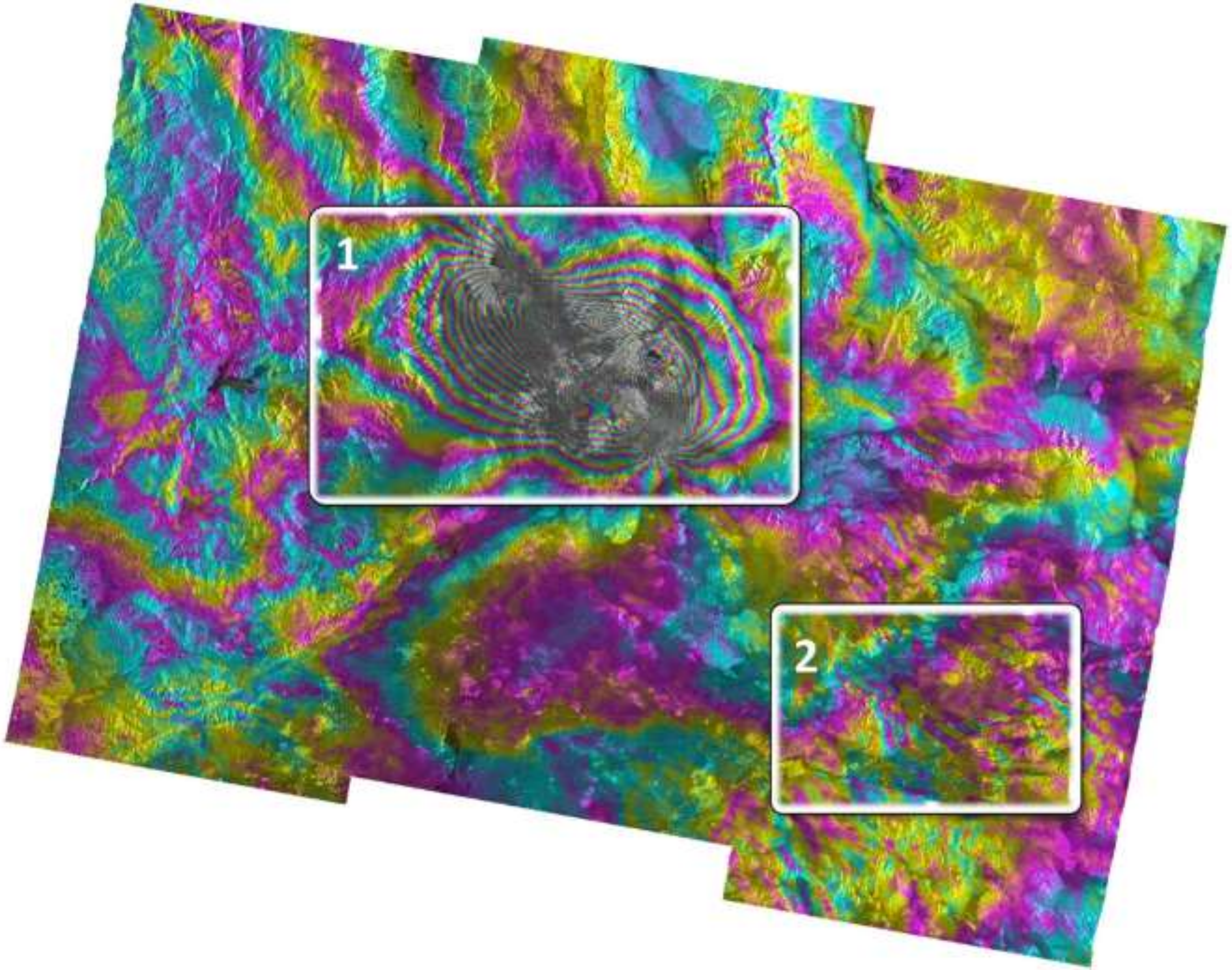
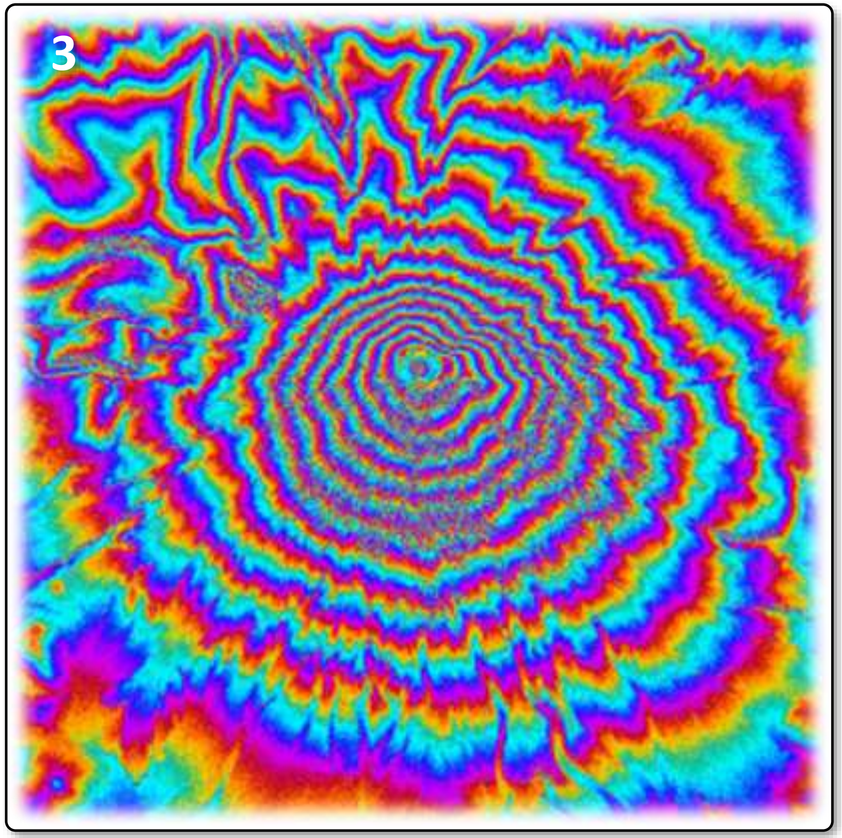
Lecture 5: Interferometric SAR Techniques - Concepts

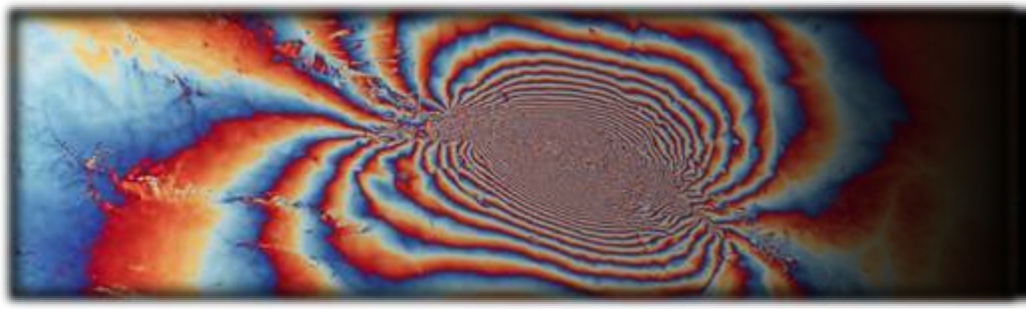


Think – Pair – Share

What is the stuff you see in these interferograms (sites 1-3)?







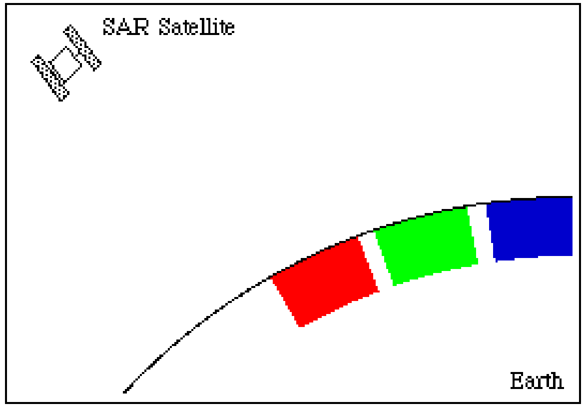
THE GENERAL CONCEPTS OF INTERFEROMETRIC SAR (INSAR)

Different Components of the SAR Measurement

SAR Systems record **Amplitude** and **Phase** of the reflected **polarized** microwave signals

Amplitude forms SAR Image

Phase measures the range to objects on ground



Polarization for analyzing surface types

SAR Interferometry ....

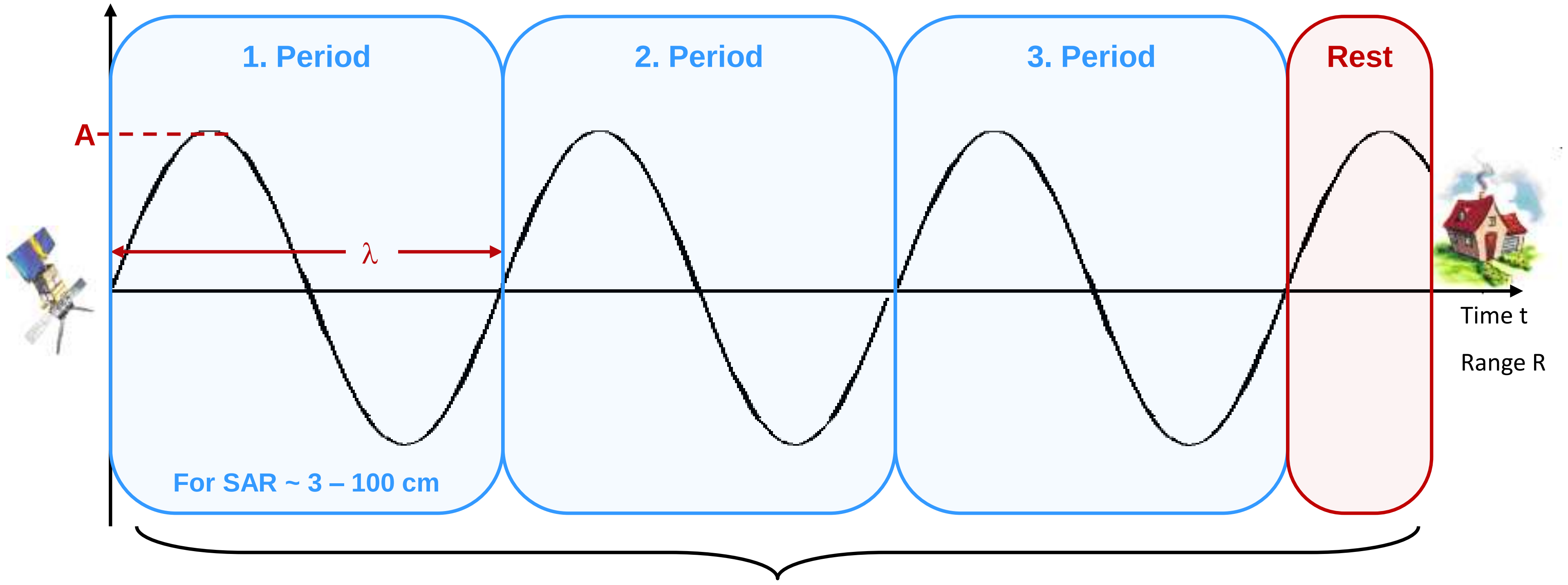
... combines two or more complex-valued SAR images to derive more information about the imaged objects (compared to using a single image) by exploiting phase differences.

$\Rightarrow$ Images must differ in at least one aspect (= “baseline”)

baseline type	known as ...	applications: measurement of ...
$\Delta\theta$	across-track	topography, DEMs
$\Delta t = \text{ms} \quad \text{to} \quad \text{s}$	along-track	ocean currents, moving object detection, MTI
$\Delta t = \text{days}$	differential	glacier/ice fields/lava flows, SWE, hydrology
$\Delta t = \text{days} \quad \text{to} \quad \text{years}$	differential	subsidence, seismic events volcanic activities, crustal displacements
$\Delta t = \text{ms} \quad \text{to} \quad \text{years}$	coherence estimator	sea surface decorrelation times land cover classification

What is the Phase of a Radar Signal

- A radar transmits electromagnetic waves in the radar spectrum
- The following schematic sketch illustrates a propagating radar wave



Distance = 3 full periods + a fraction of a period

The length of the fractional period is described by the term **"Phase"**

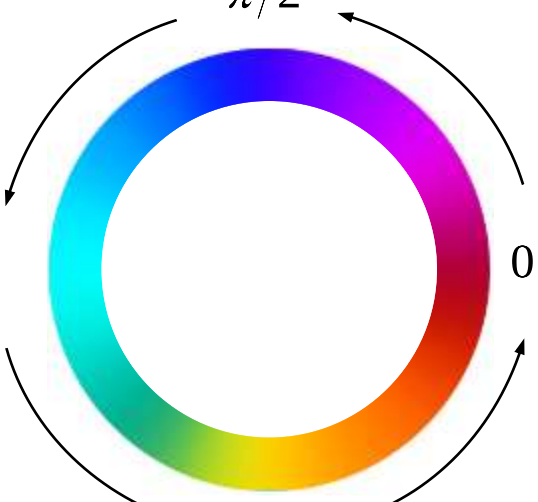
Phase Representation

Phase is always ambiguous w.r.t. integer multiples of 2π

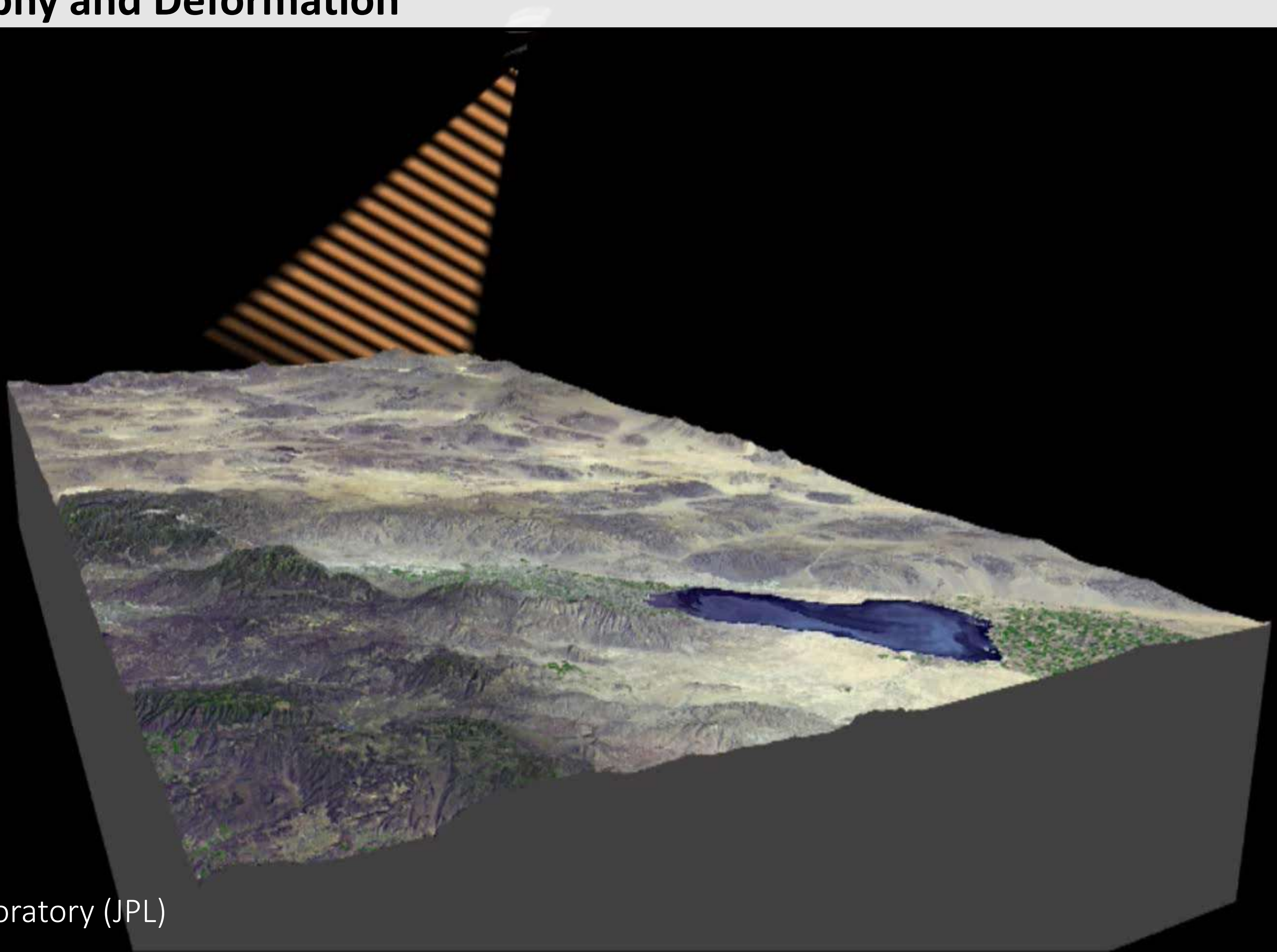
pictorial representation of phase:

grey value

color wheel



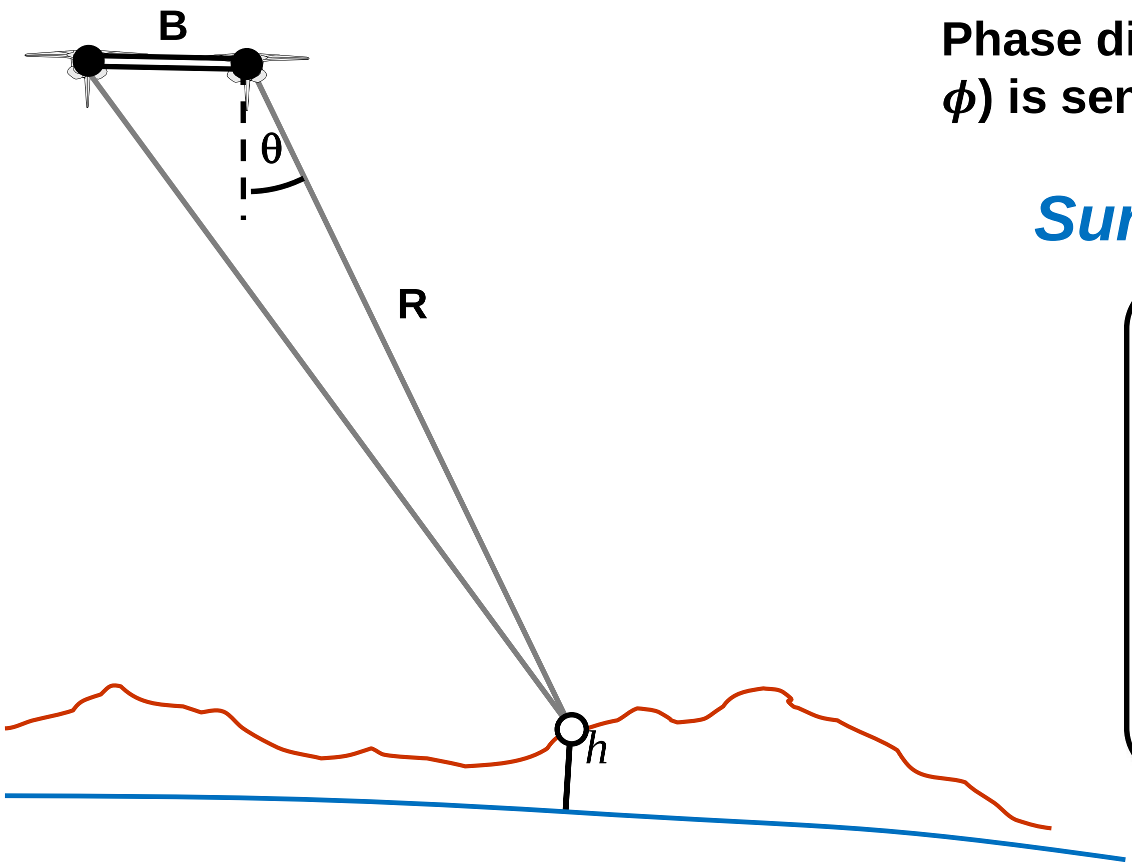
Interferometric SAR Measures Phase Differences Between Repeated Observations to Measure Topography and Deformation



Source: Jet Propulsion Laboratory (JPL)

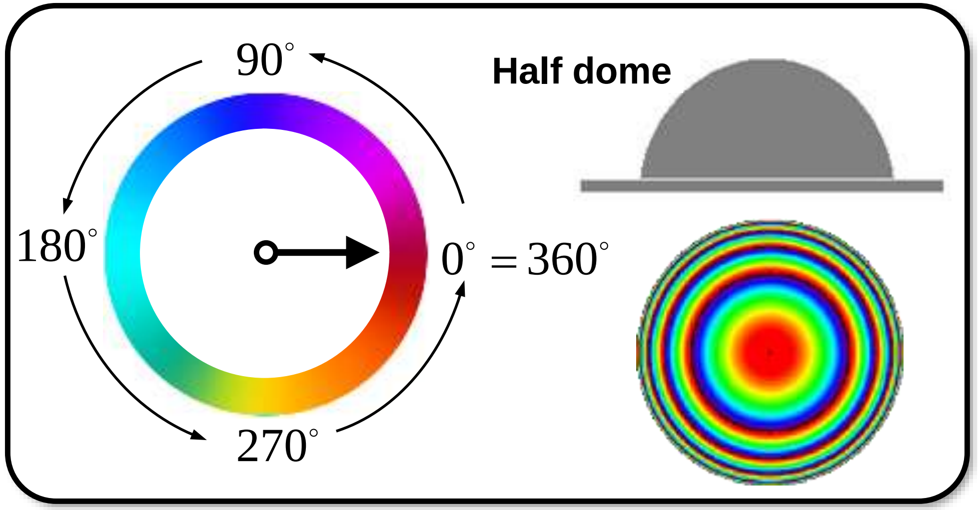
The Concept of Interferometric SAR (InSAR)

- Calculation of Phase Difference between Pairs of Radar Remote Sensing Images acquired from similar vantage points



Phase difference measurement (interferometric phase ϕ) is sensitive to:

Surface Topography $\boldsymbol{\phi}(\boldsymbol{h}, B, R, \theta)$



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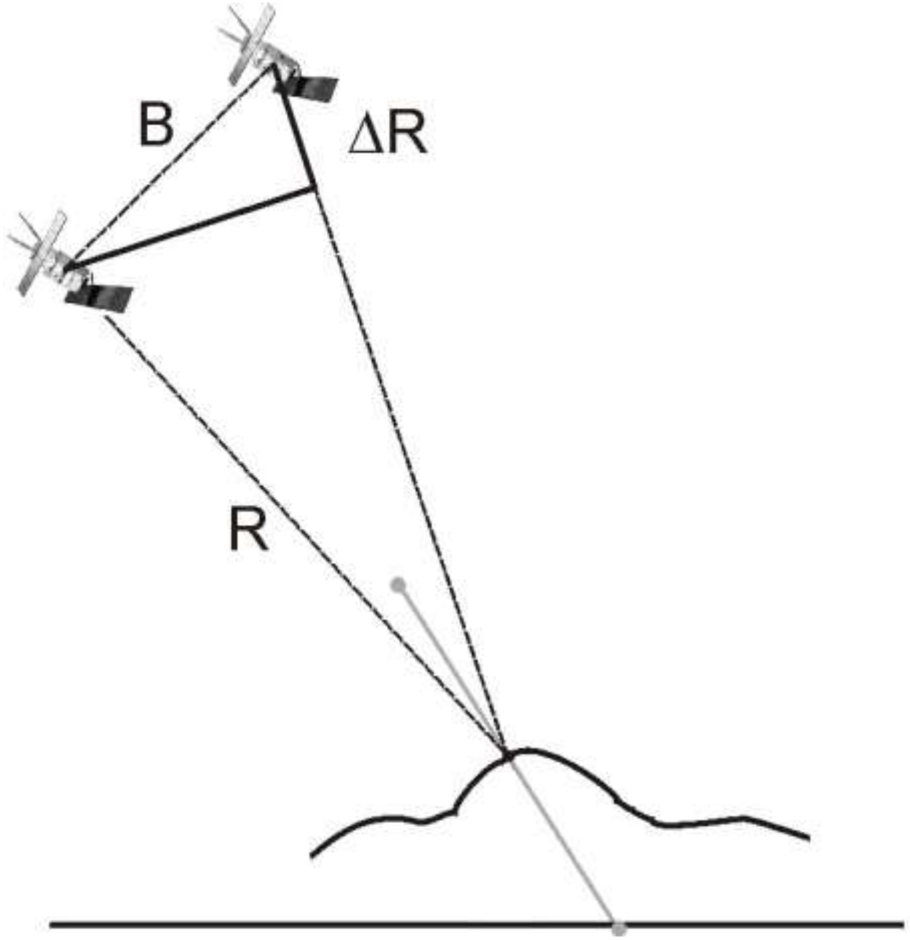

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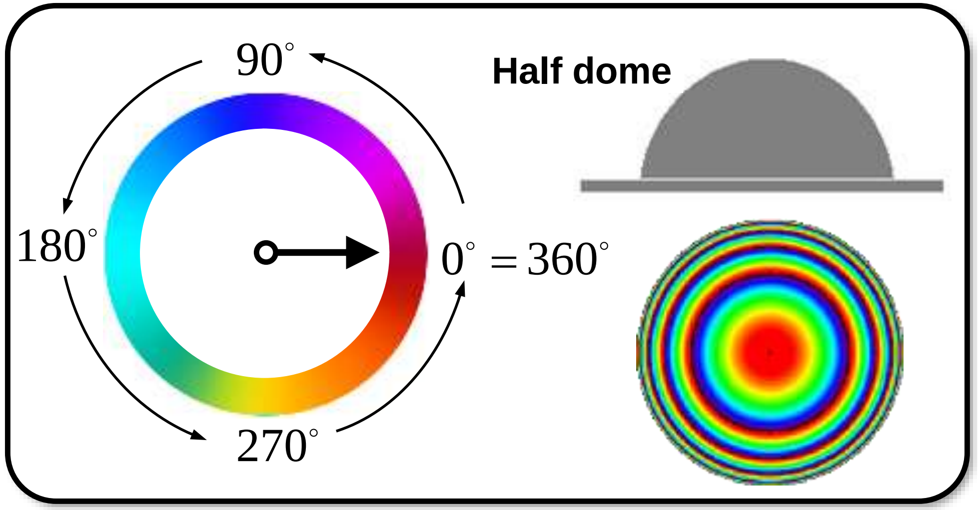
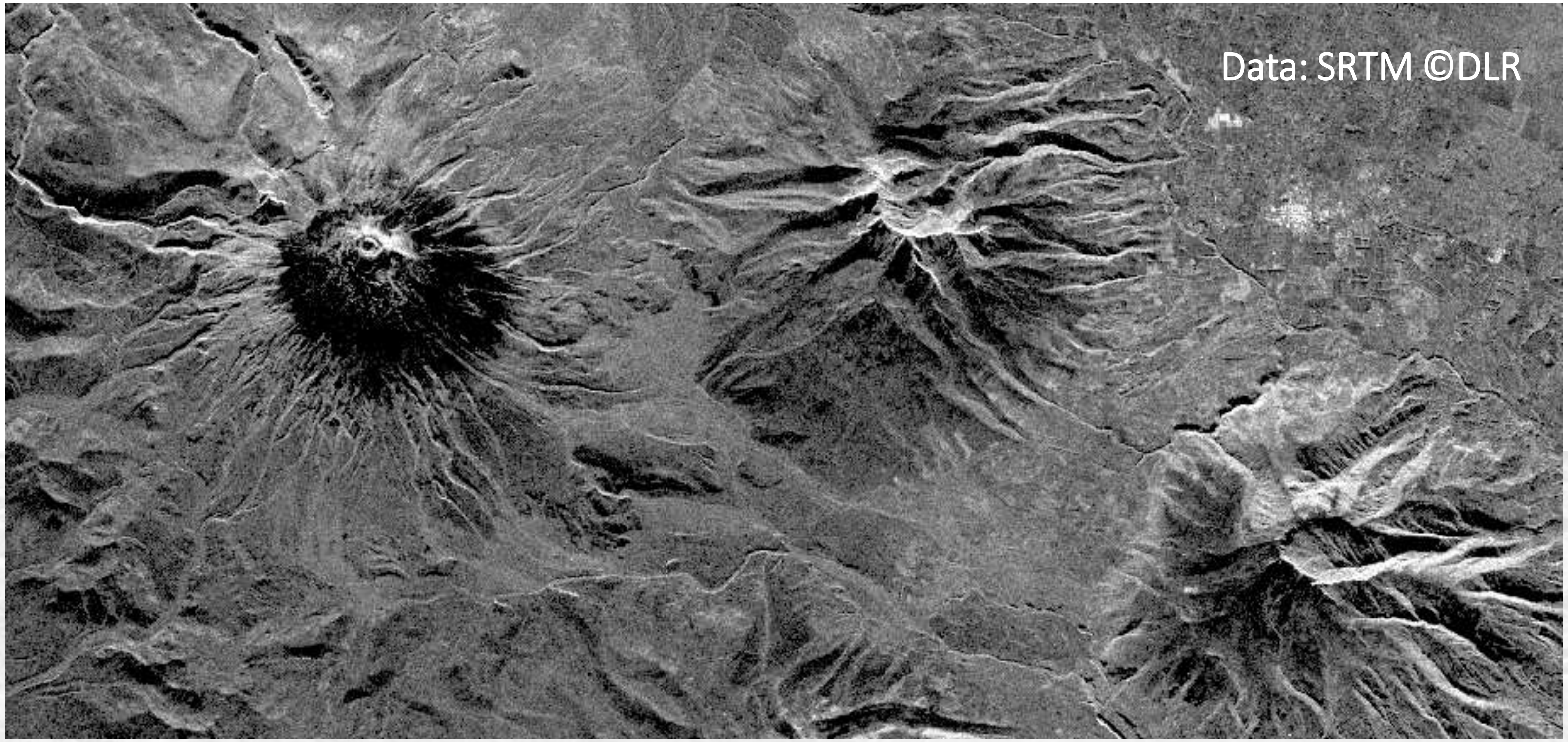
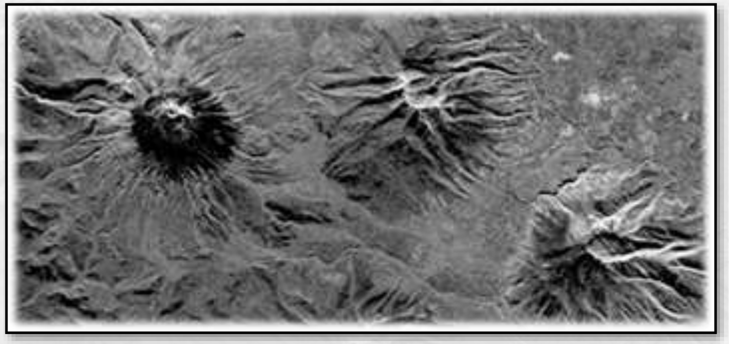


Example of a Spaceborne SAR Image

Cotopaxi Volcano, Ecuador

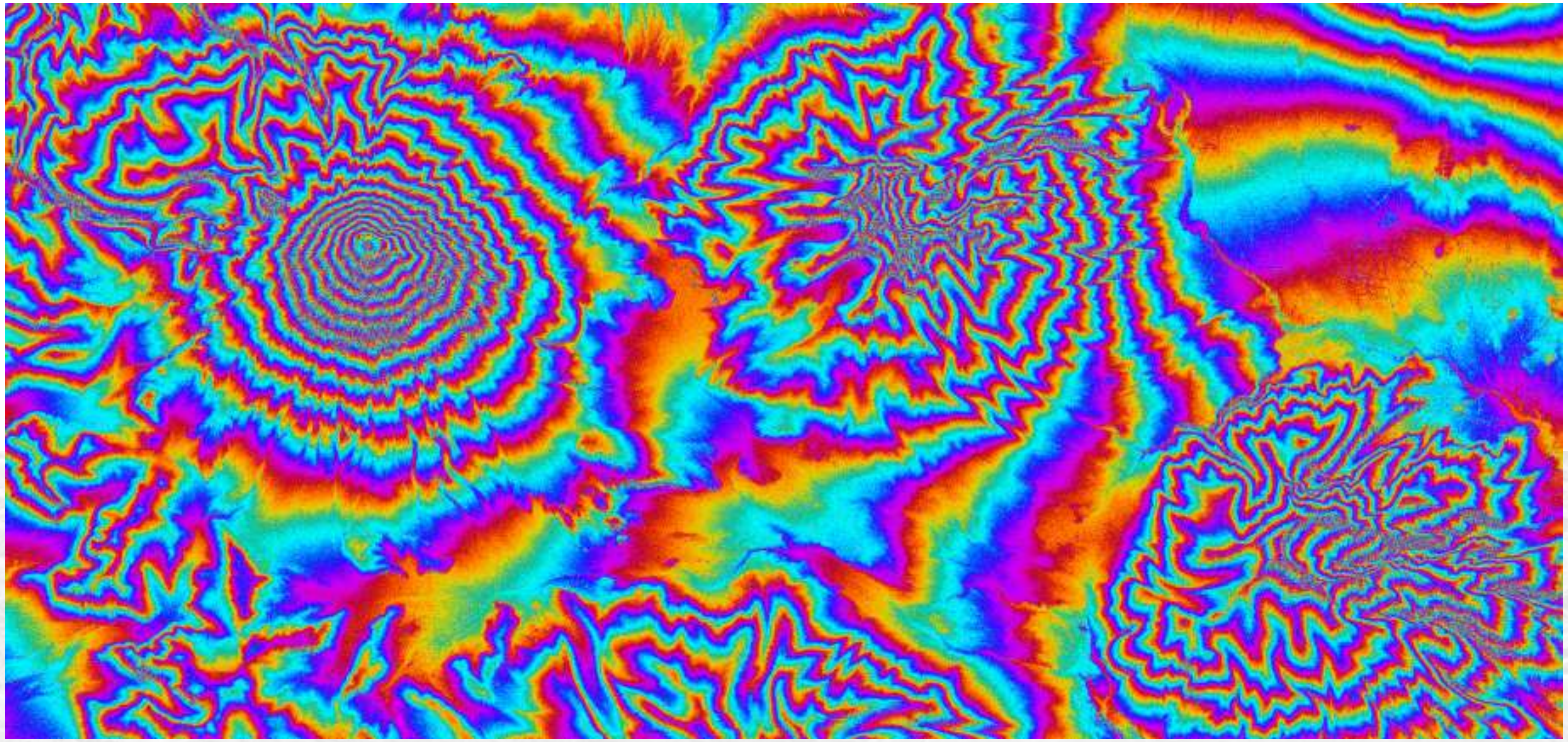


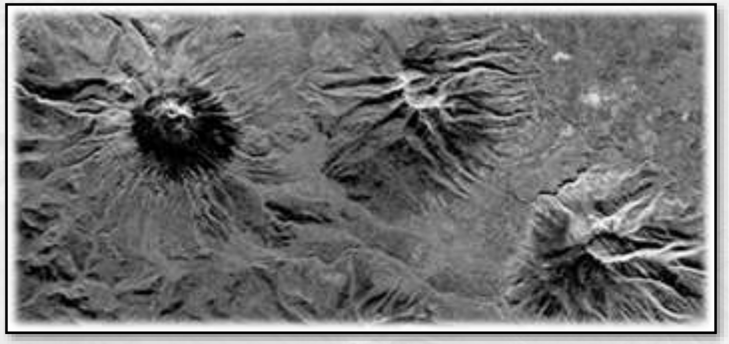


Data: SRTM ©DLR

Example of the Corresponding Interferometric Phase Image

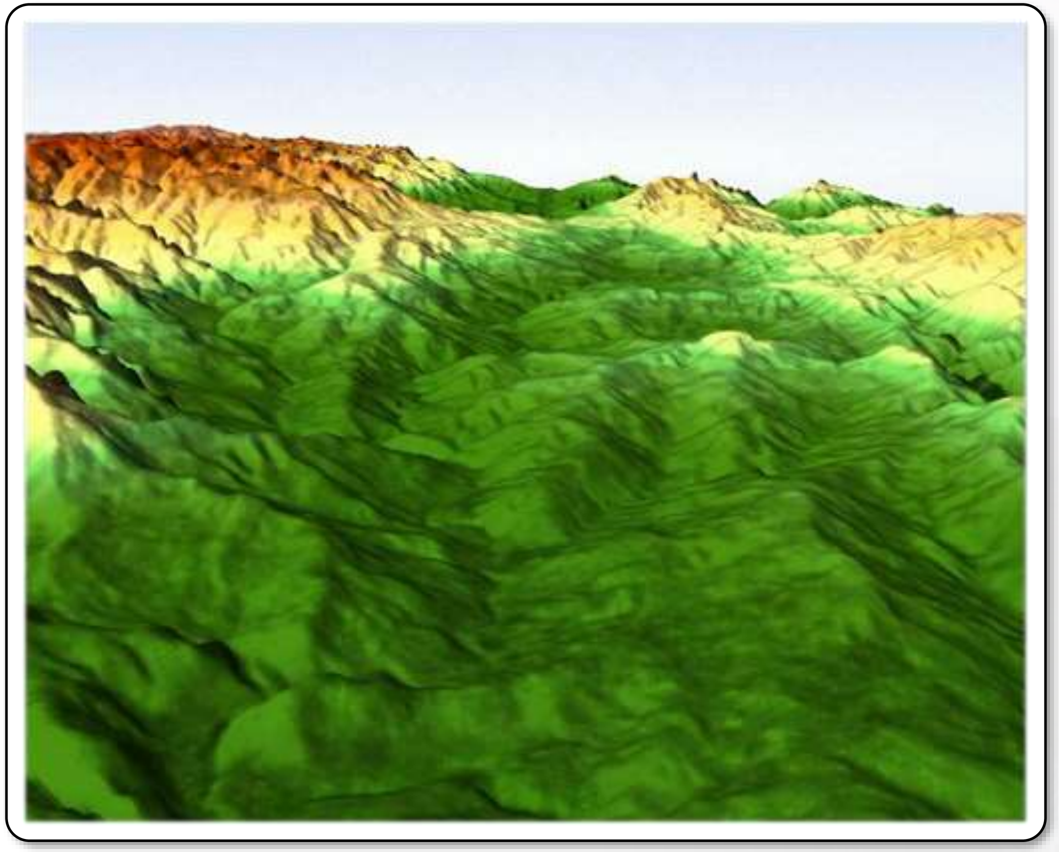
Cotopaxi Volcano, Ecuador





Data: SRTM ©DLR

InSAR-derived DEM, Cotopaxi Volcano, Ecuador



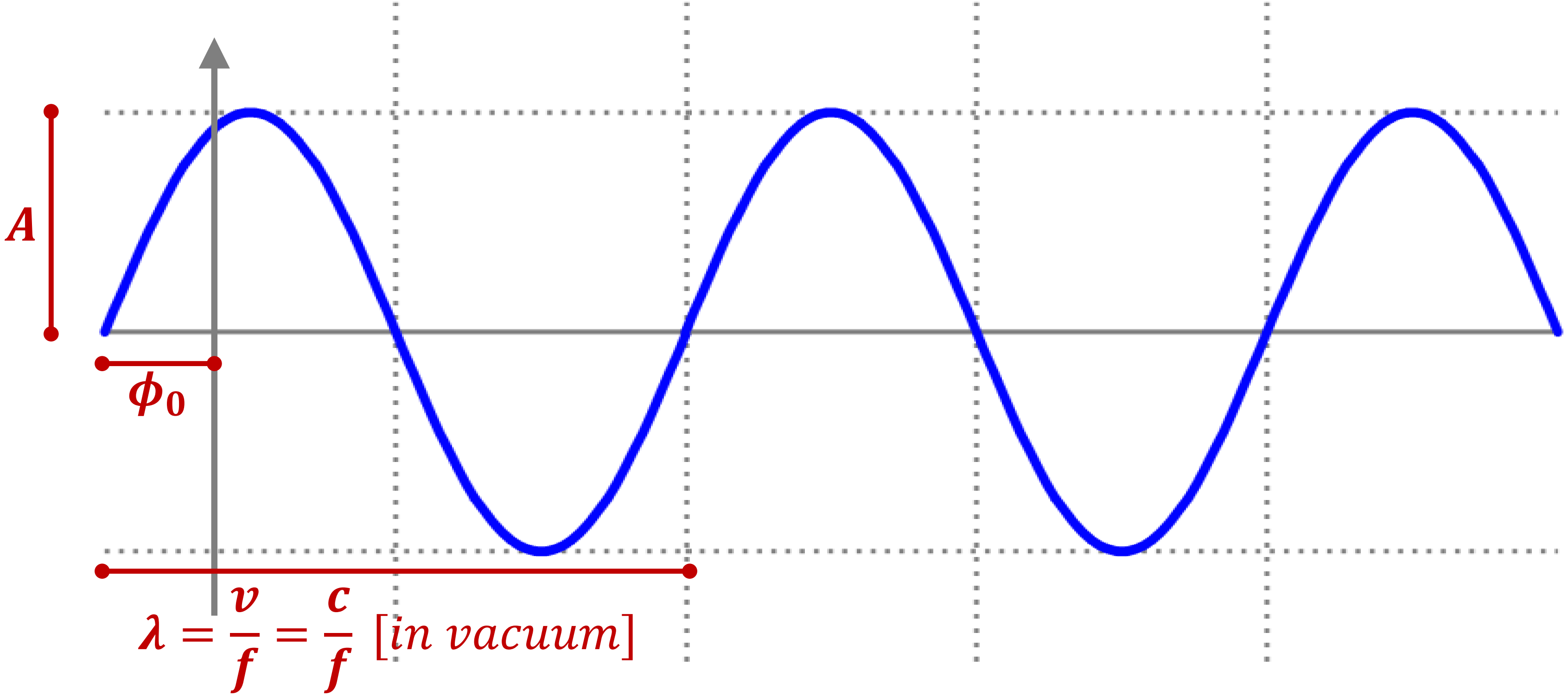
A SHORT EXCURSION INTO WAVE PROPAGATION, WAVE INTERFERENCE, AND COHERENCE

Wave Description of EM Signals

- Simplest way of describing a wave: Harmonic waves (= sine wave)

- Typically we use three parameters to describe harmonic waves:

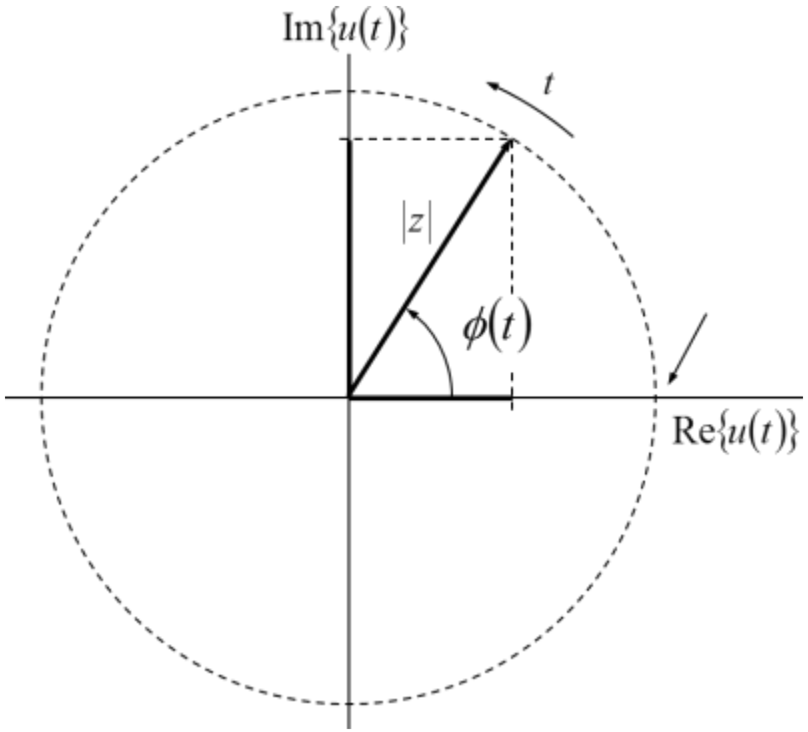
$$\Psi(t) = \boldsymbol{A} \cdot sin(2\pi \boldsymbol{f} t + \boldsymbol{\phi_0})$$

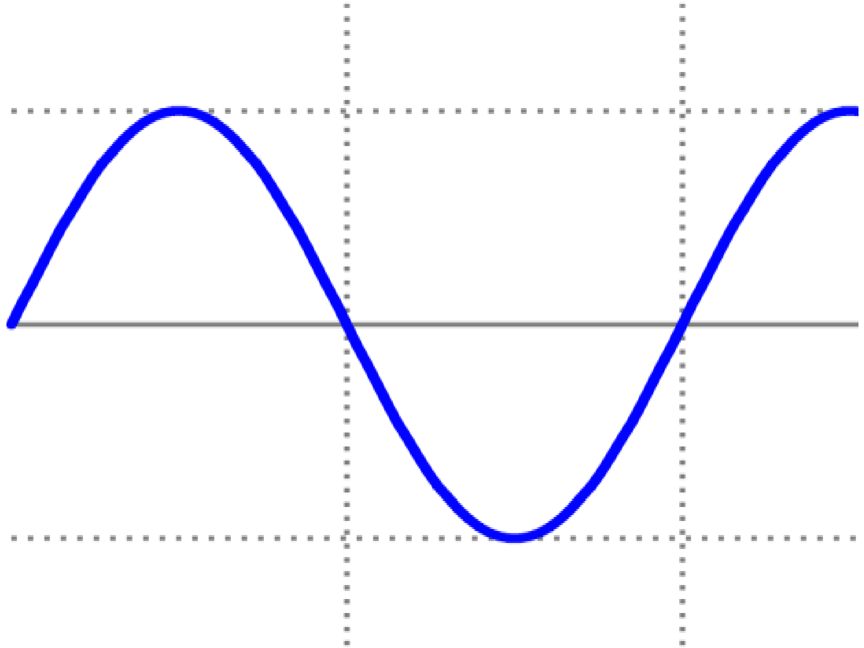


A Compact Way to Visualize Propagating EM Waves

- **Imagine a propagating EM wave as a vector rotating in a plane**
  - The length of the vector describes the amplitude of the signal
  - The orientation describes the phase of the signal
  - The rotation speed describes its frequency

This visualization is a handy way of thinking about propagating waves



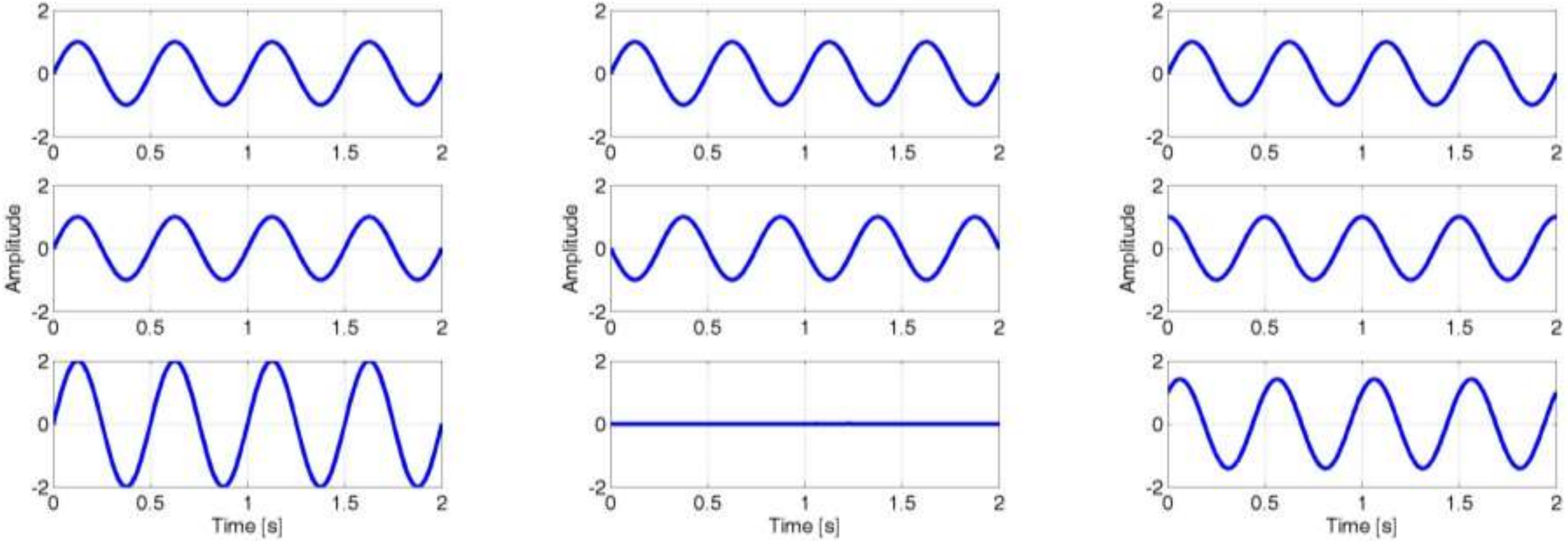


Combination of Waves

- Superposition of waves called *interference* (e.g., two waves: $\psi = \psi_1 + \psi_2$)
- As ψ_1 and ψ_2 can have different amplitude, frequency, and phase, the shape of ψ is not straightforward

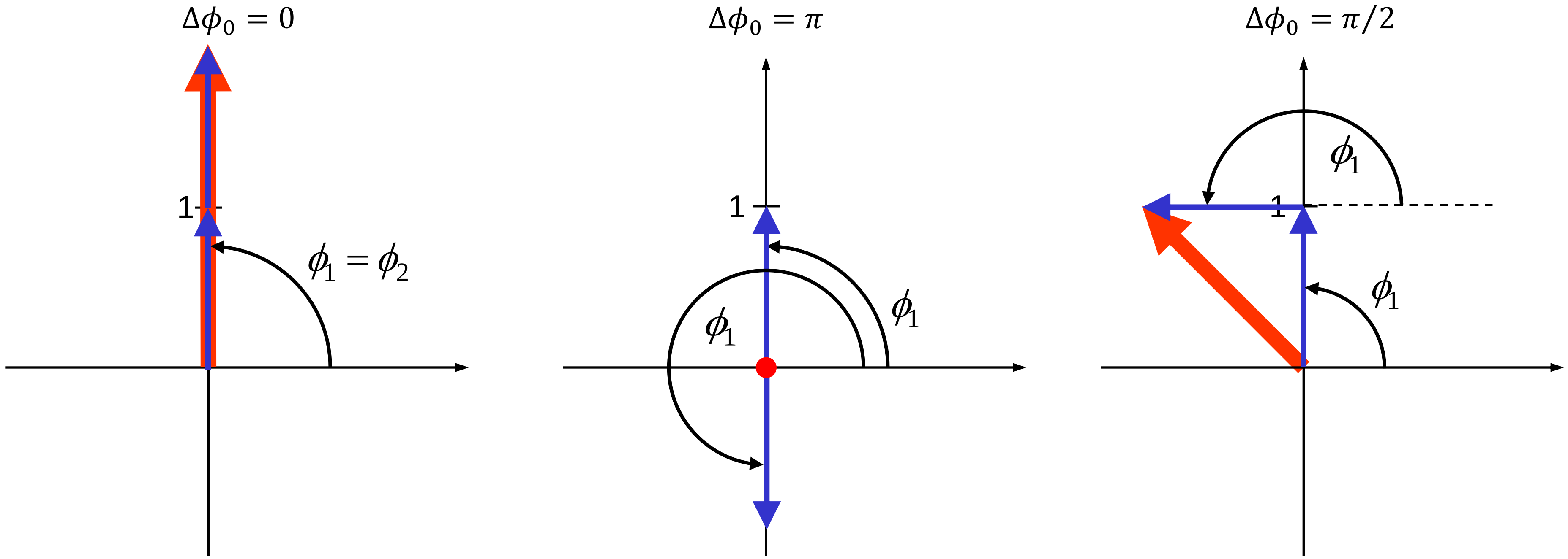
  - **Examples:** A and f of waves kept the same; ϕ_0 can vary

$\Delta\phi_0 = 0$ $\Delta\phi_0 = \pi$ $\Delta\phi_0 = \pi/2$



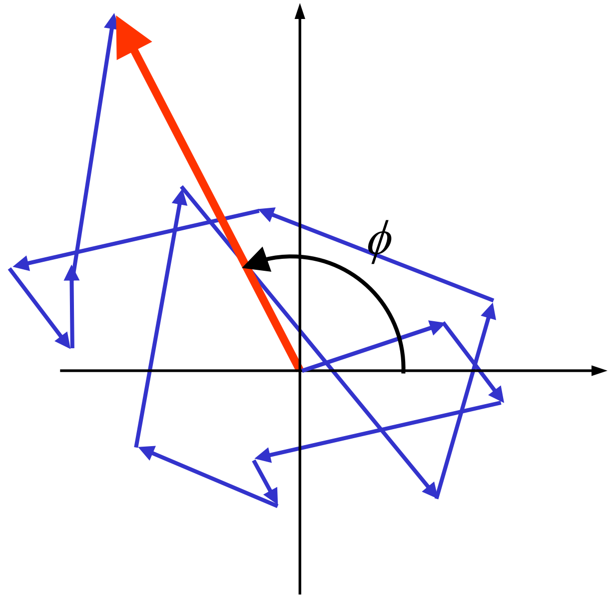
Combination of Waves

- **The result of interference can be easier calculated in the complex plane**
- In the complex plane, the addition of two waves ψ_1 and ψ_2 is simply their vector sum



Interference and Coherence

- Waves with phase differences that remain constant over time (or space) are said to be ***coherent***
- Coherent waves → combined wave vector is stationary
- If coherence is low, interference effects are less predictable



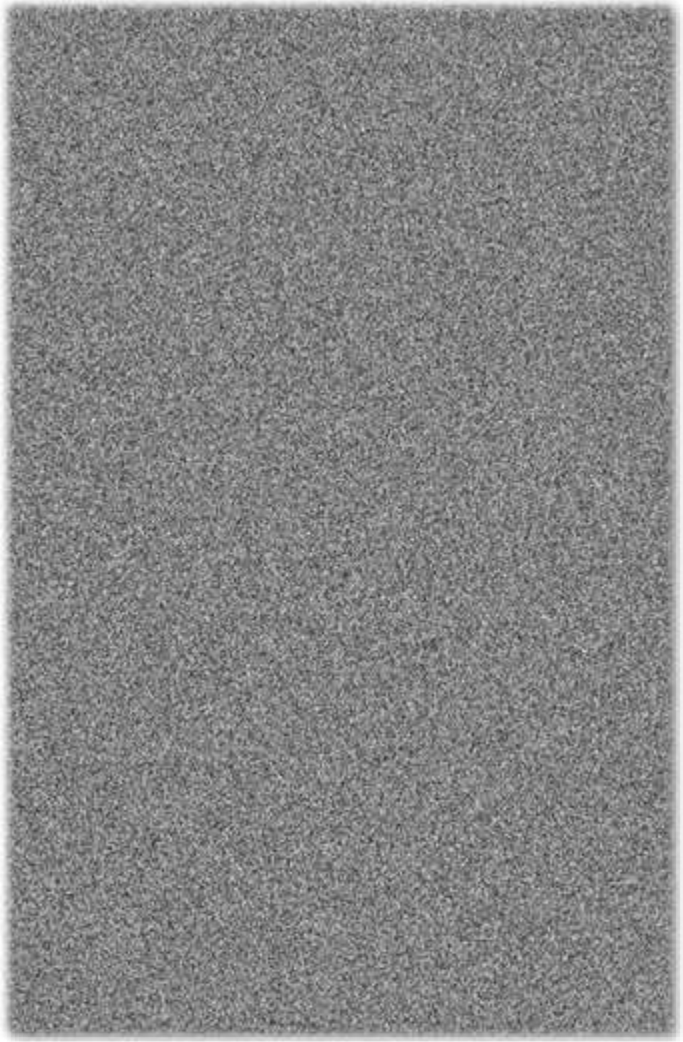
- Coherence can be seen as measure of predictability

How InSAR Really Works

Think – Pair – Share

InSAR, a differential technique (or, interference & coherence is back … again):

- InSAR analyzes the phase difference between two or more SAR images in order to map surface topography and monitor surface deformation.
  - **Q1**: We have to rely on phase differences as the phase of a single SAR image appears spatially random and does not allow access to information. Use the concept of interference to explain why that is.
  - **Q2**: We calculate phase differences between SAR images to extract information about surface topography and/or deformation. For this approach to be successful, we require the data to have sufficient coherence. From your knowledge about coherence, explain how coherence affects this process.



Phase signature of a single SAR image

How InSAR Really Works:

1. What is Contained in a SAR Image's Phase Signal

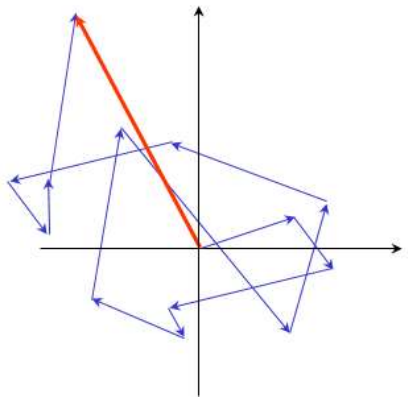
- **Phase in a pixel of a SAR image is sum of two components:**
  1. A **deterministic** component that is a function of the distance R between satellite and pixel on ground ($\psi(R)$)
  2. A **random** phase change ψ_{scatt} caused by how all scattered signals from one pixel combine together

- **Therefore, the phase signal measured in a SAR pixel is:**

$$\psi = \psi(R) + \psi_{scatt}$$

- As ψ_{scatt} is different for every pixel (every pixel contains different combination of scatterers), the **phase in a single SAR image ψ looks random**

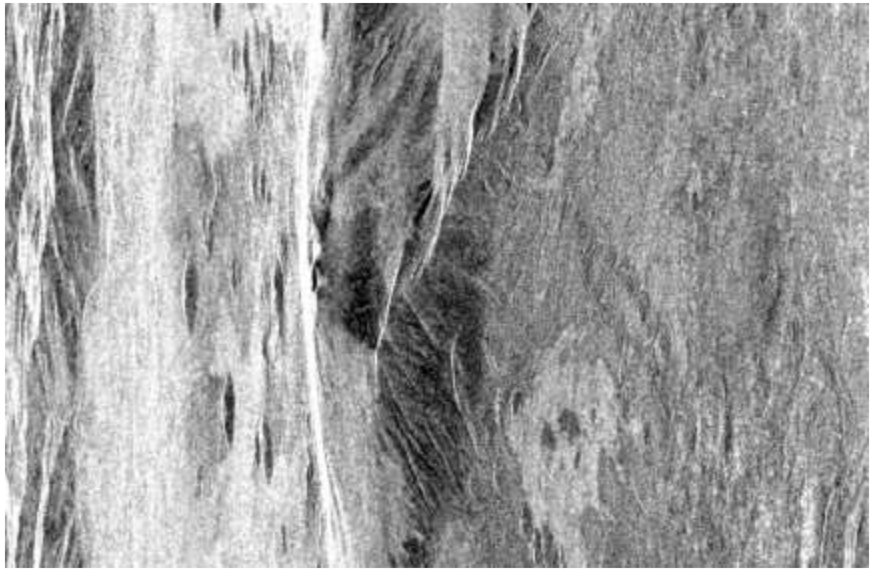
Remember how individual scatterers sum up to final signal received from a pixel:



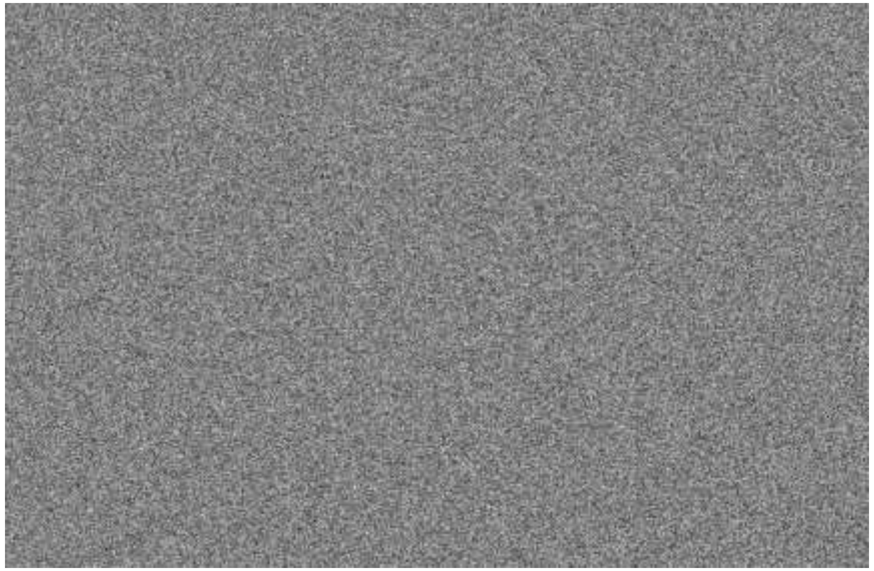
Blue: contribution by one single scattering event
Red: final amplitude and phase of received signal

Example: Amplitude and Phase of a SAR Image of Mount Etna

Amplitude of a segment of an ERS-1 image over Mount Etna, Italy



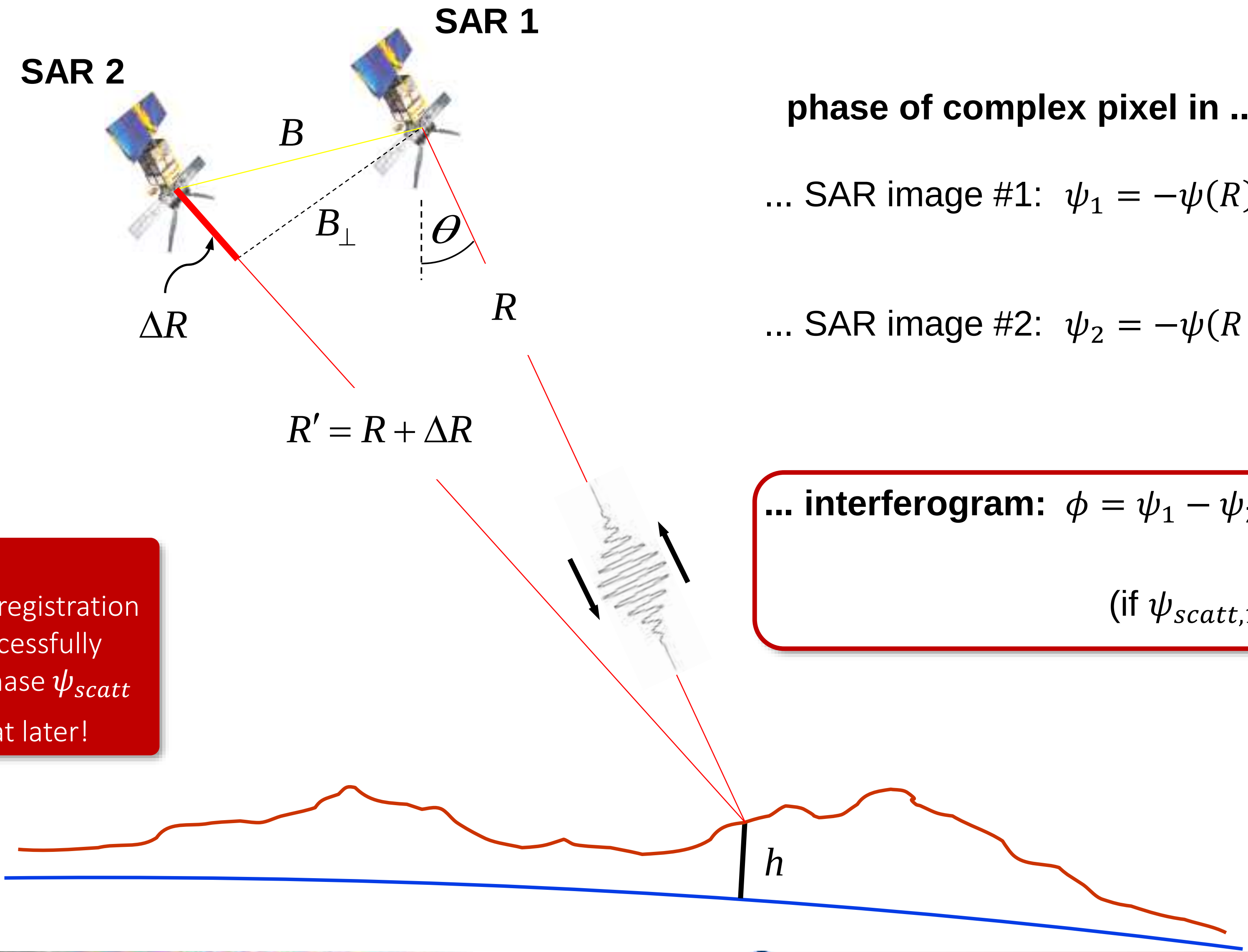
Phase ψ of a segment of an ERS-1 image over Mount Etna, Italy



$$\psi = \psi(R) + \psi_{scatt}$$

How InSAR Really Works:

2. Form Interferogram to Remove Random Phase ψ_{scatt}



phase of complex pixel in ...

... SAR image #1: $\psi_1 = -\psi(R) + \psi_{scatt,1}$

... SAR image #2: $\psi_2 = -\psi(R + \underline{\Delta R}) + \psi_{scatt,2}$

... interferogram: $\phi = \psi_1 - \psi_2 = \phi(\Delta R)$

(if $\psi_{scatt,1} = \psi_{scatt,2}$!)

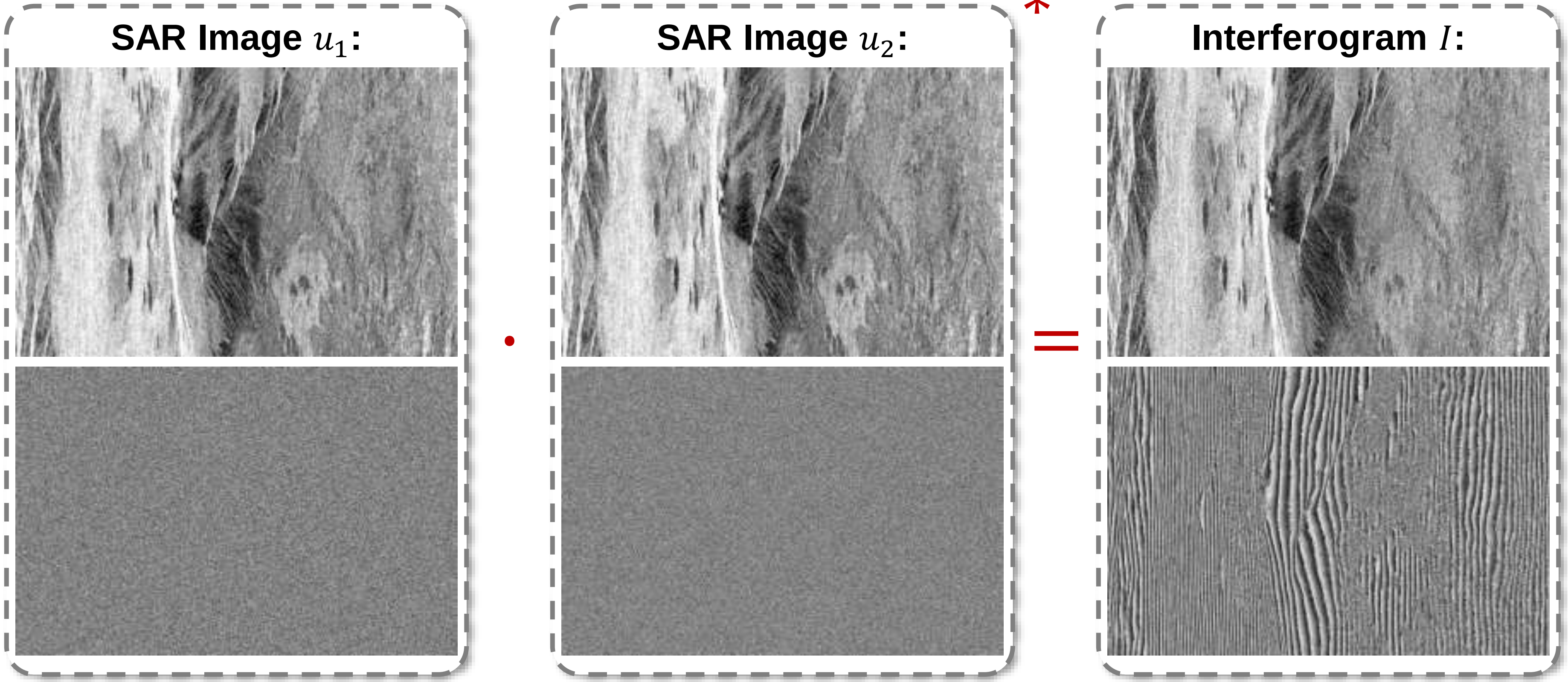
Note:

Accurate Image co-registration is needed to successfully remove random phase ψ_{scatt}

More about that later!

Example: Form Interferogram to Remove Random Phase Component ψ_{scatt}

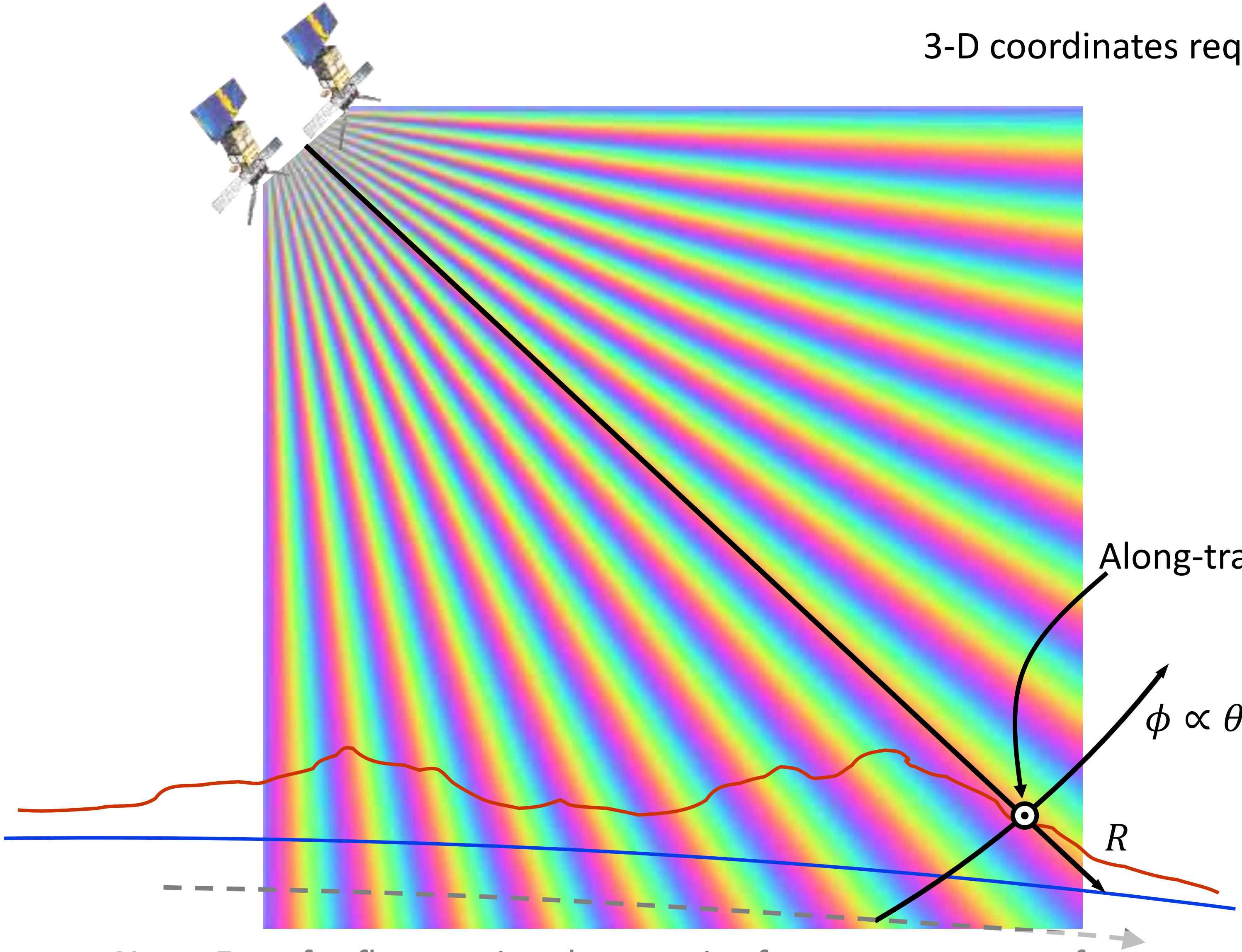
- **To form interferogram, we calculate:** $I = u_1 \cdot u_2^*$ ($\blacksquare^*$ is complex conjugate)



How InSAR Really Works:

3. Interferometric Phase ϕ as a Measurement of Angle

3-D coordinates required: R, t, θ

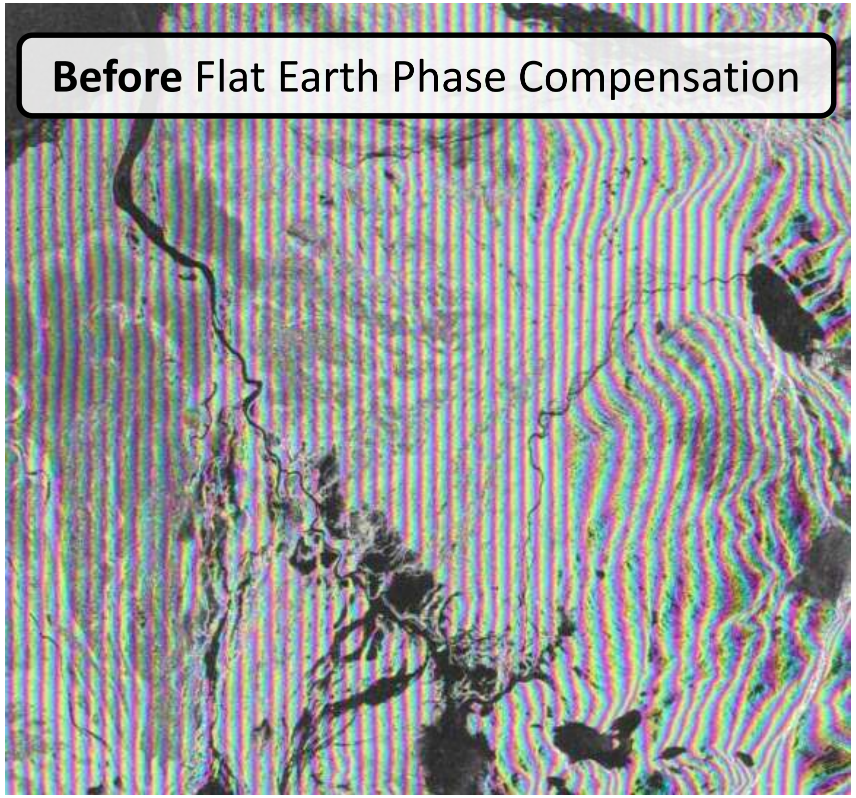


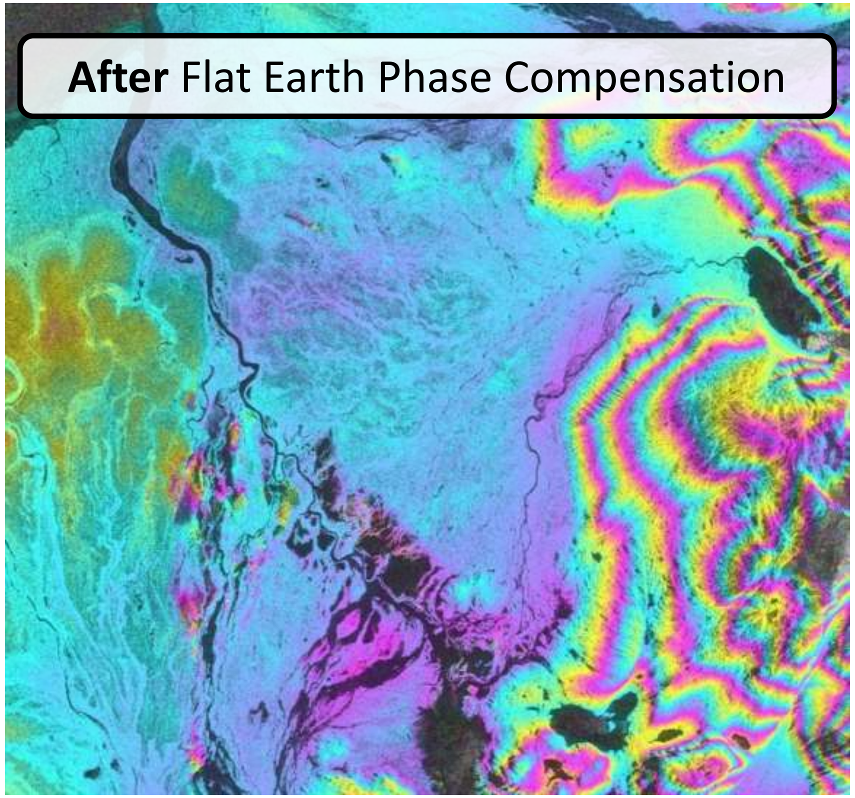
Note: Even for flat terrain: phase varies from near-range to far-range

How InSAR Really Works:

4. Subtraction of Flat Earth Phase

- **Example:**
  - ALOS PALSAR Interferogram near of Drift River Valley, AK (Baseline ~ 400m)

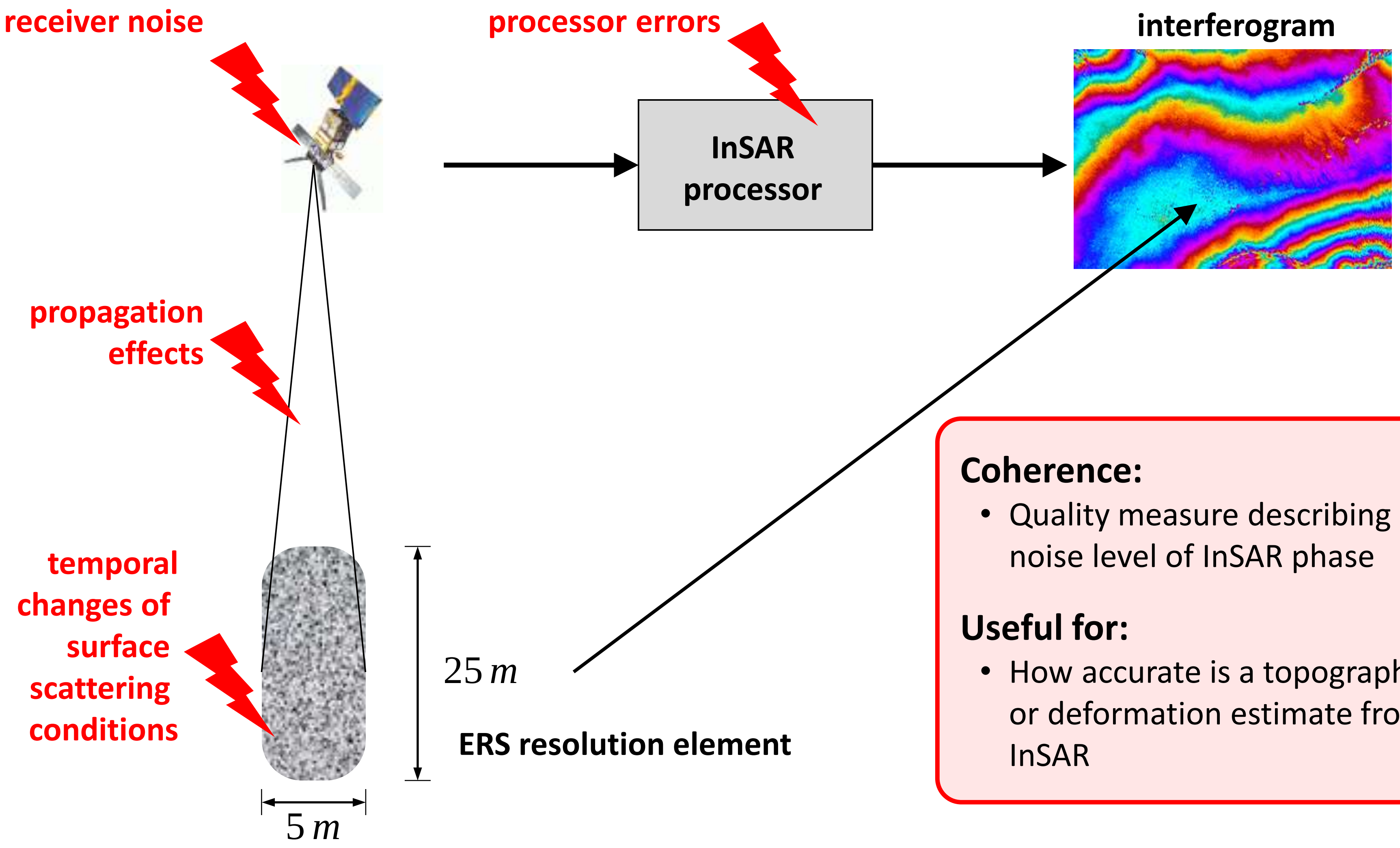




How InSAR Really Works:

5. Coherence: A Phase Quality Descriptor

- **Contributions to Phase Noise:**



Coherence:
- Quality measure describing noise level of InSAR phase

Useful for:
- How accurate is a topography or deformation estimate from InSAR

How InSAR Really Works:

5. Coherence: A Phase Quality Descriptor

- **We can calculate coherence using the following approach:**

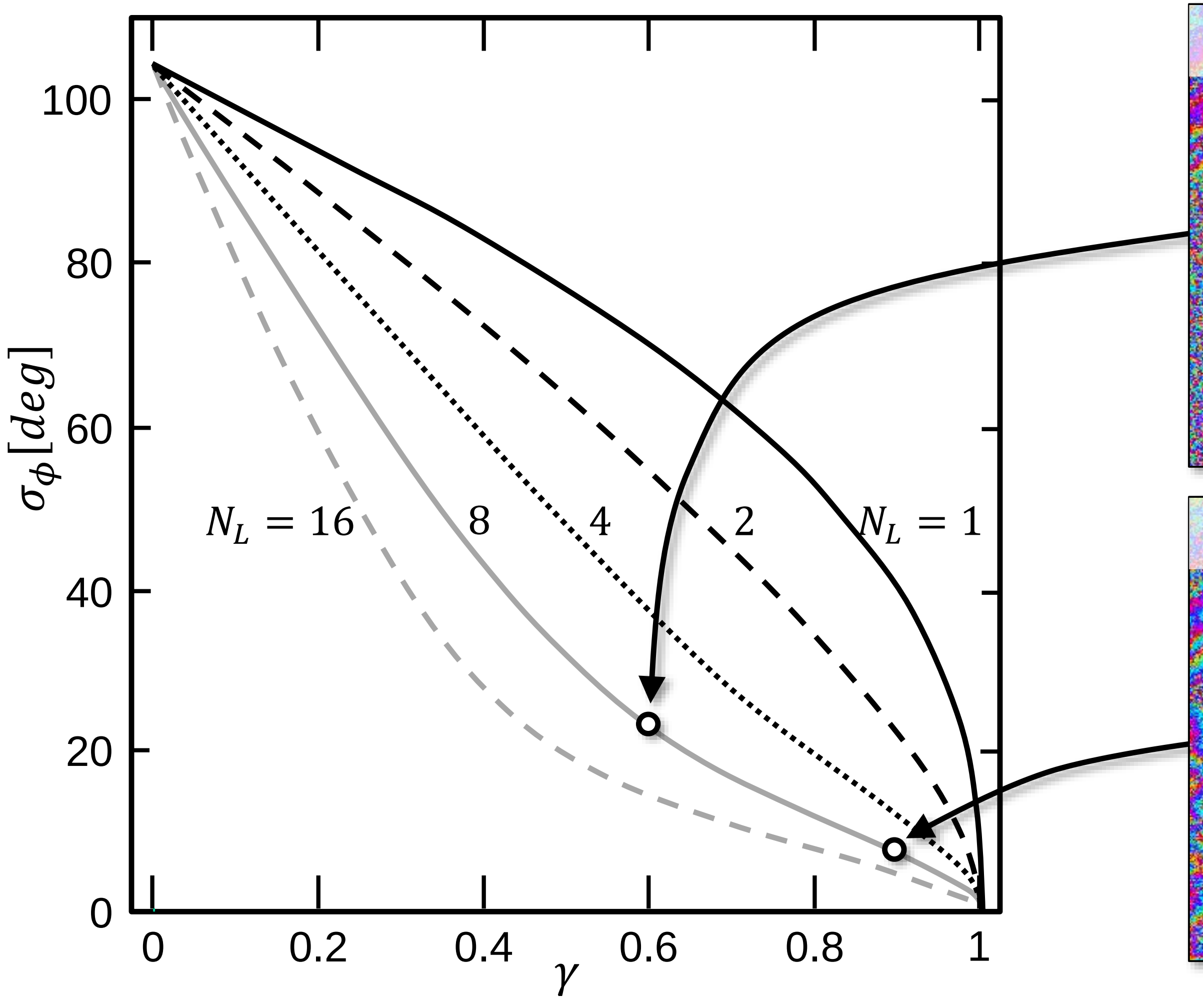
$$|\hat{\gamma}[i,k]| = \frac{\left|\sum_W u_1[i,k] \cdot u_2^*[i,k]\right|}{\sqrt{\sum_W |u_1[i,k]|^2 \cdot \sum_W |u_2[i,k]|^2}}$$

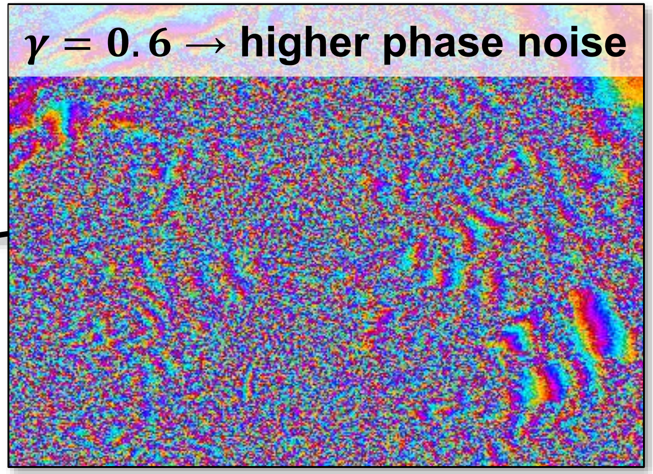
W: small window centered around pixel $[i,k]$

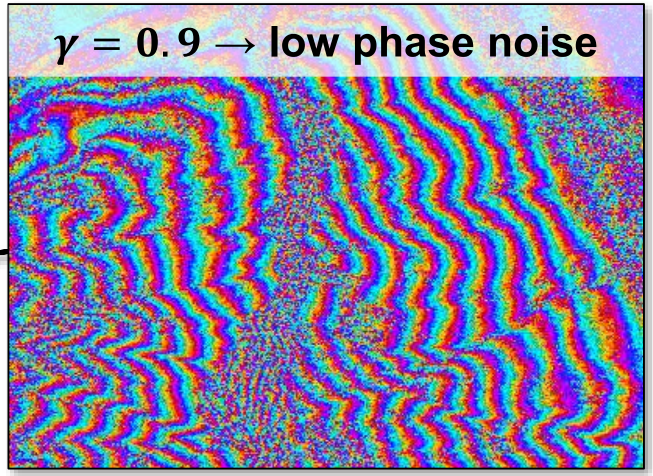
- **Coherence** is an indicator for the **level of noise in phase** $\phi[i,k]$ of interferogram pixel $[i,k]$
- **Coherence is defined between 0 (high phase noise) and 1 (low phase noise)**
- **Coherence can be converted to a phase standard deviation** $\sigma_\phi[i,k]$

Coherence and Phase Noise - Theory

- How Coherence γ converts into phase standard deviation σ_ϕ depends on the number of looks N_L (how much we average)

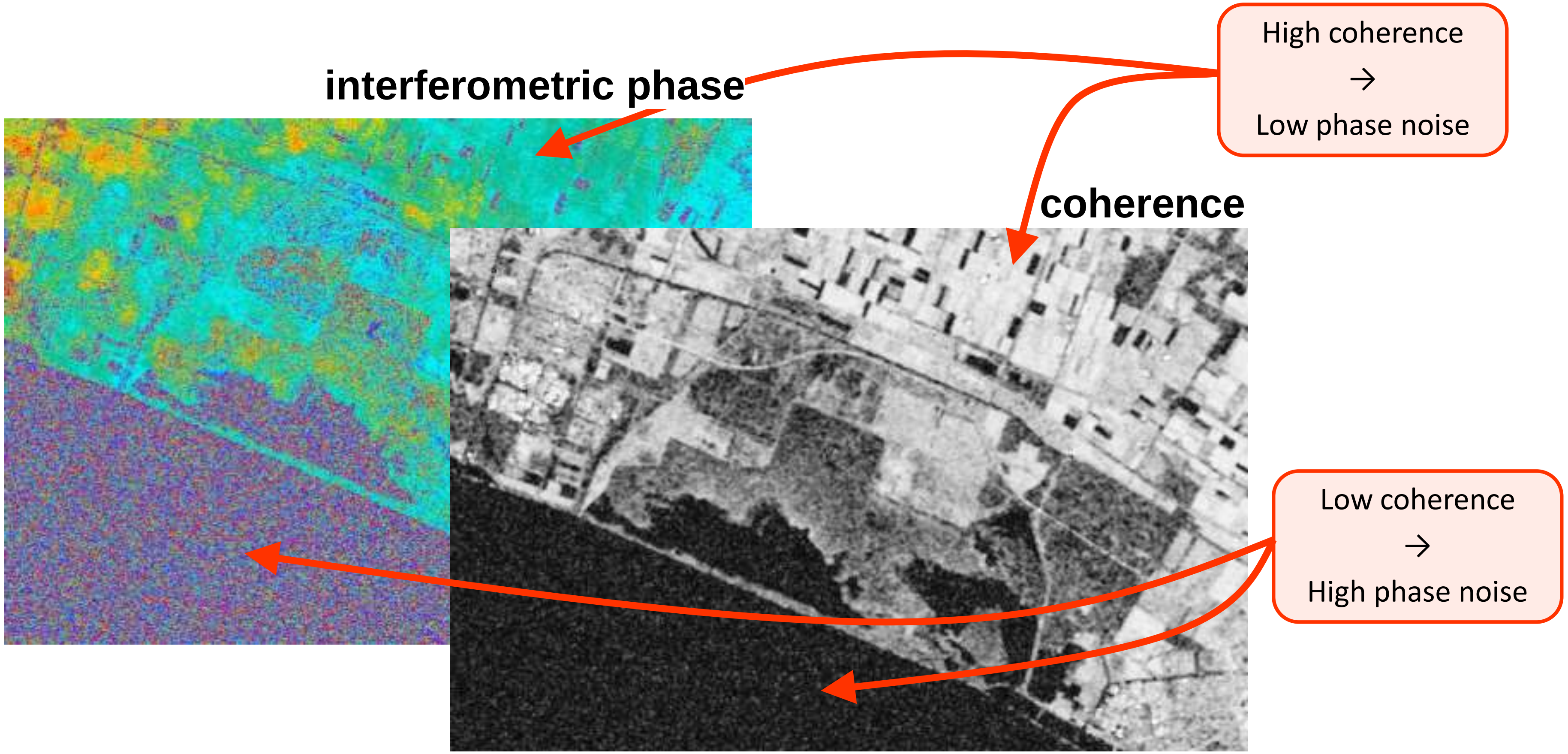






Interferometric Coherence - Example

- **This example compares interferometric phase quality and coherence side-by-side**



What’s Next?

- **This is what awaits next:**
  - **InSAR for Topographic Mapping**

- **Preparatory Reading:**
  - For this lecture, please continue to read (or re-read) up to the start of Section 3.3.1 in the following document (10 pages): FerrettiBook_Chapter3.pdf