→ FRINGE 2015 WORKSHOP

Advances in the Science and Applications of SAR Interferometry and Sentinel-1 InSAR Workshop

Split-Band Interferometric SAR Processing Using TanDEM-X Data

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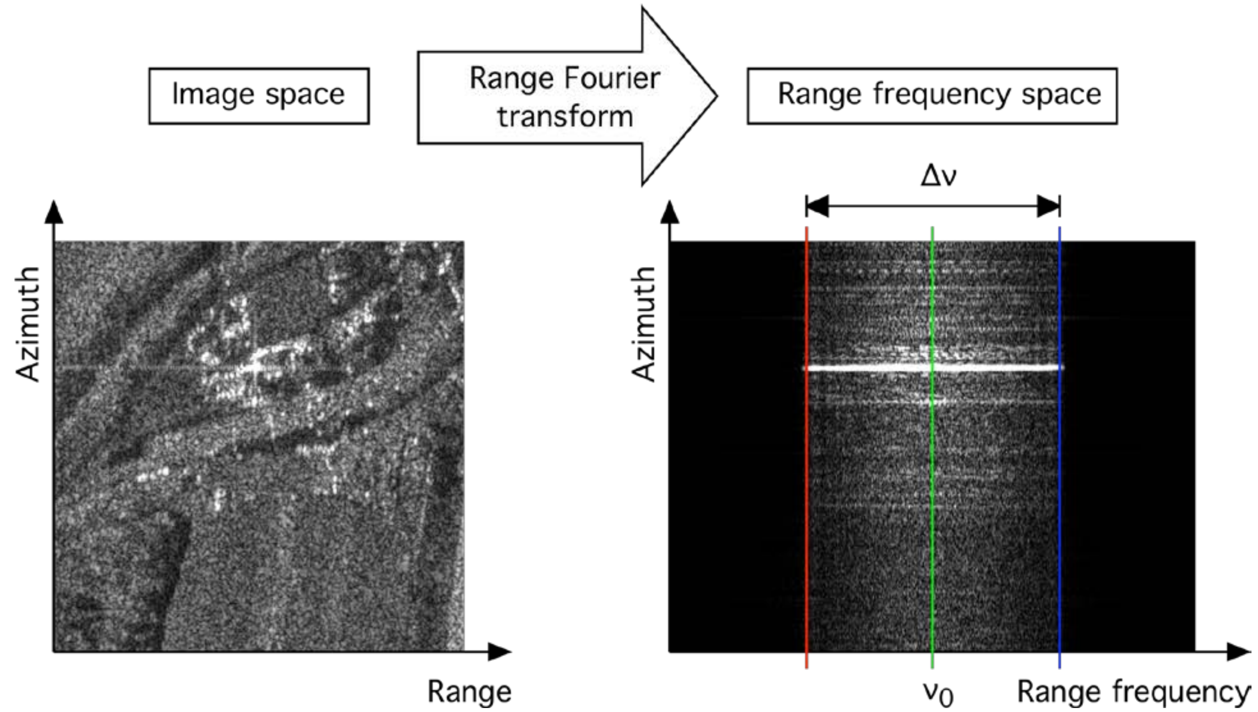
Outline

- SBInSAR?
  - ➯ Split band or Multi-Chromatic Analysis (MCA)
  - ➯ Split band Interferometry
- Test site and project objectives
- SBInSAR results
  - ➯ Accuracy
- Conclusions

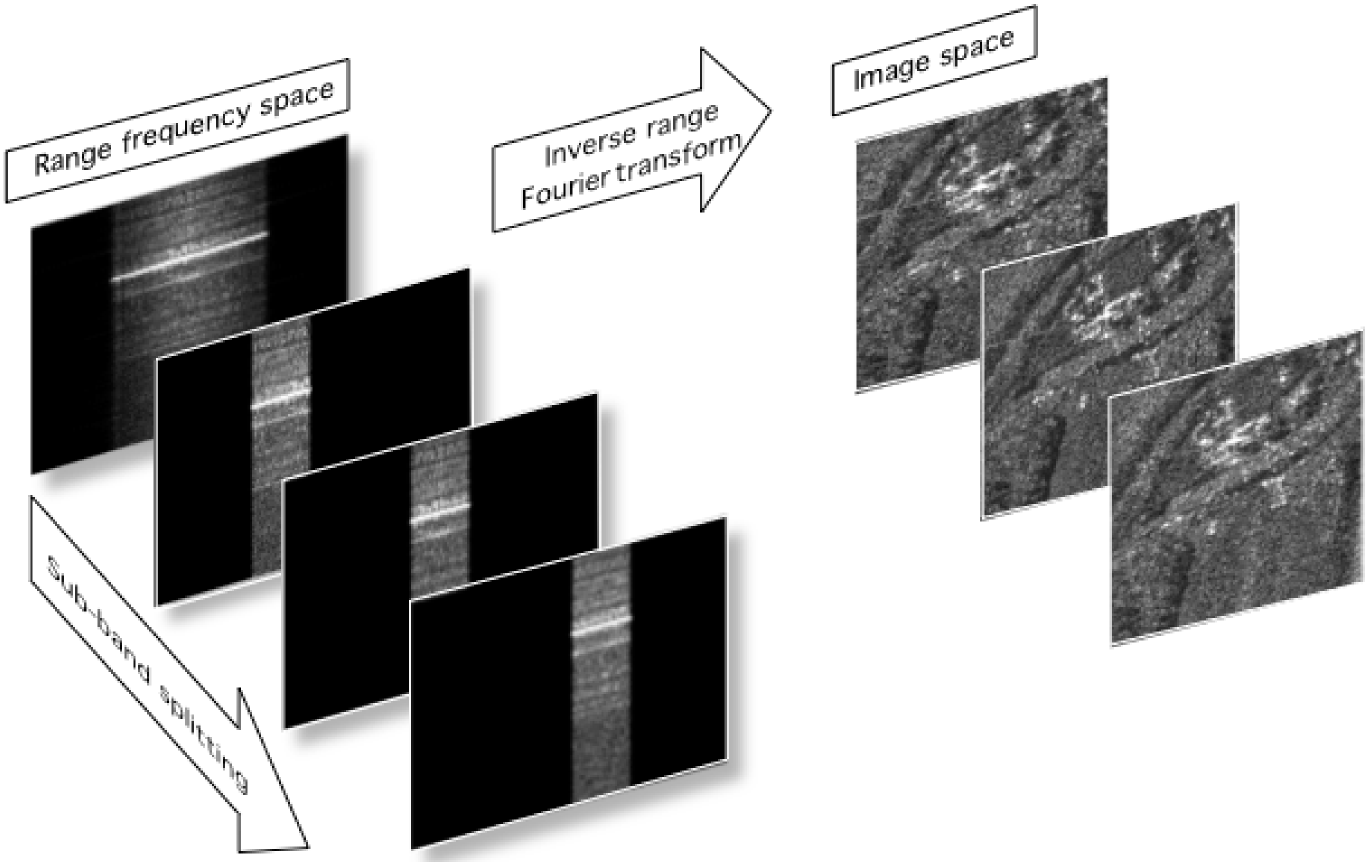
Split band

- Range resolution of SAR images is a function of the emitted radar signal bandwidth.
  - Most recent SAR sensors use wide band signals in order to achieve metric range resolution.
  - By comparison, ENVISAT or ERS sensors used 15MHz bandwidth chirps while TerraSAR-X or Cosmo-SkyMed use nominal signals having 150MHz bandwidth leading to a potentially ten times higher range resolution.



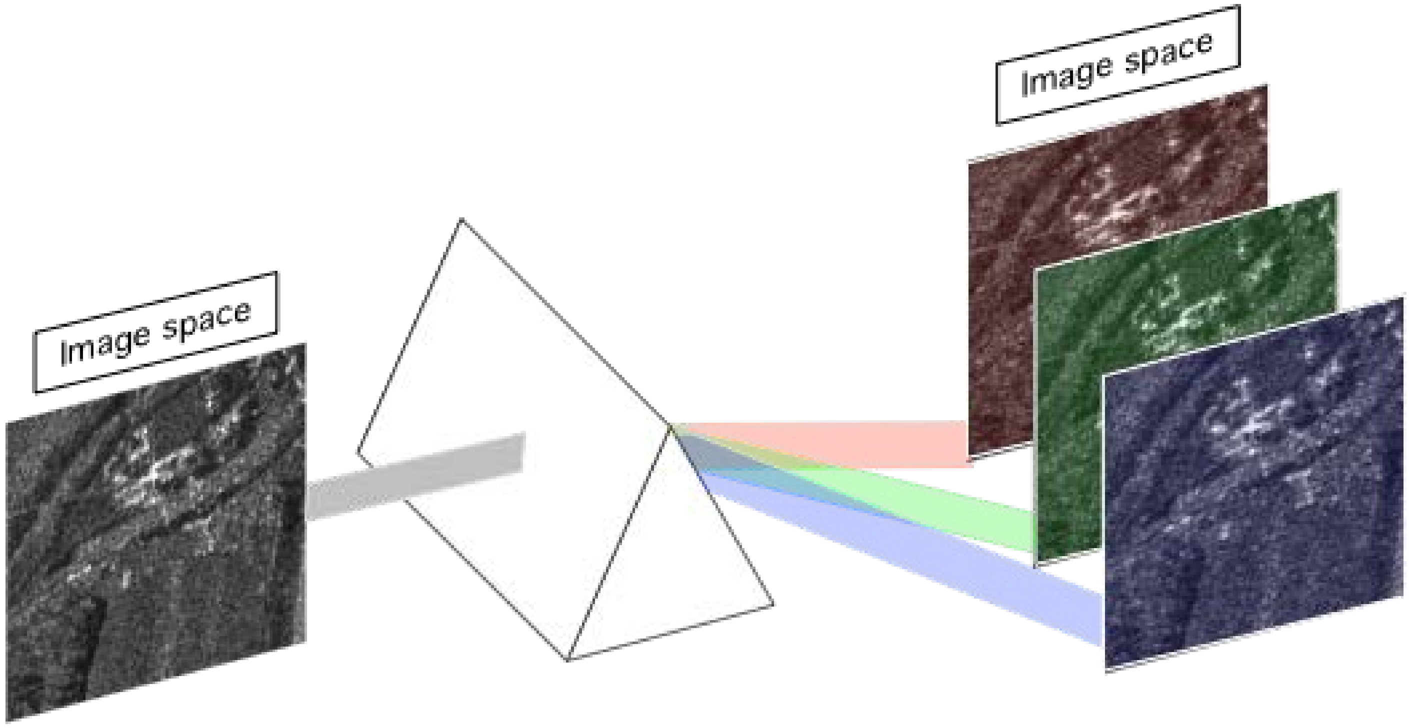
Split band

- When performing an inverse Fourier transform of sub-bands, each one leads to a SAR image of lower resolution when back into the image space



Multi-Chromatic Analysis

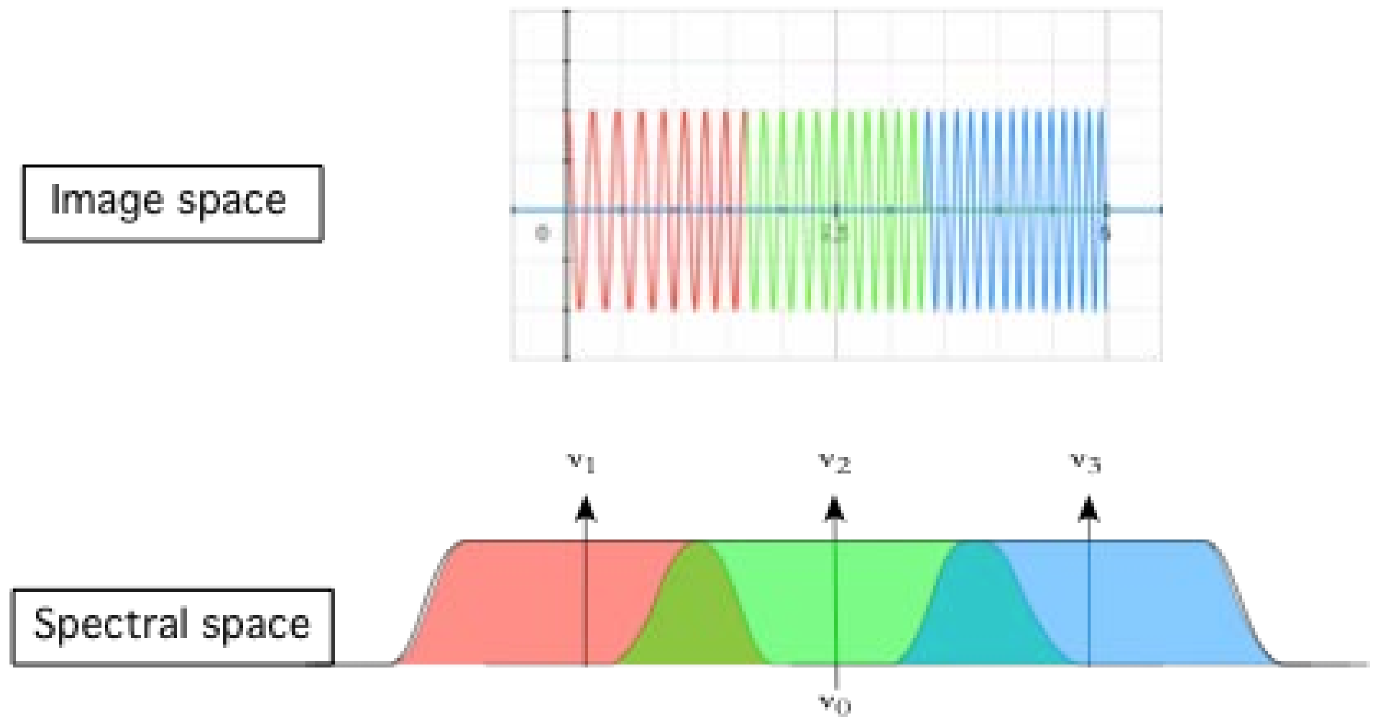
- The process is similar to light decomposition into spectral bands by a prism. Split-band process of SAR images is also known as Multi-Chromatic Analysis (MCA):



➯ Each sub-image or sub-view so generated is centered on its own central frequency (or wavelength) and has a lower range resolution. Range resolution loss is equal to sub-band bandwidth to full bandwidth ratio.

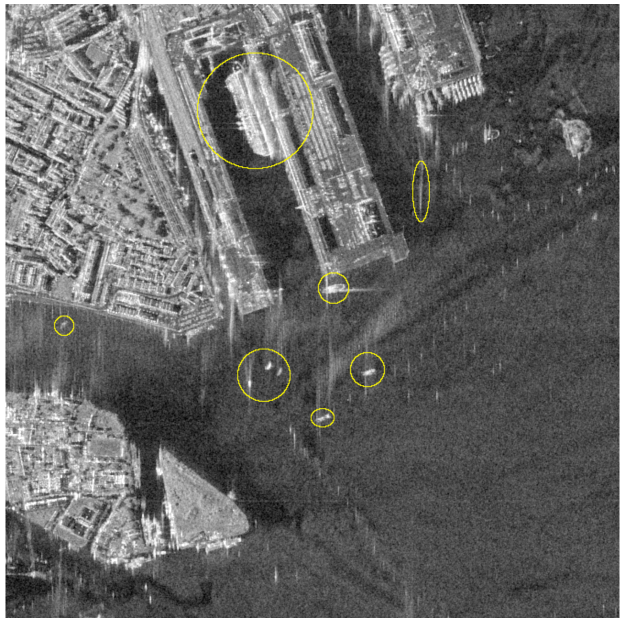
Multi-Chromatic Analysis

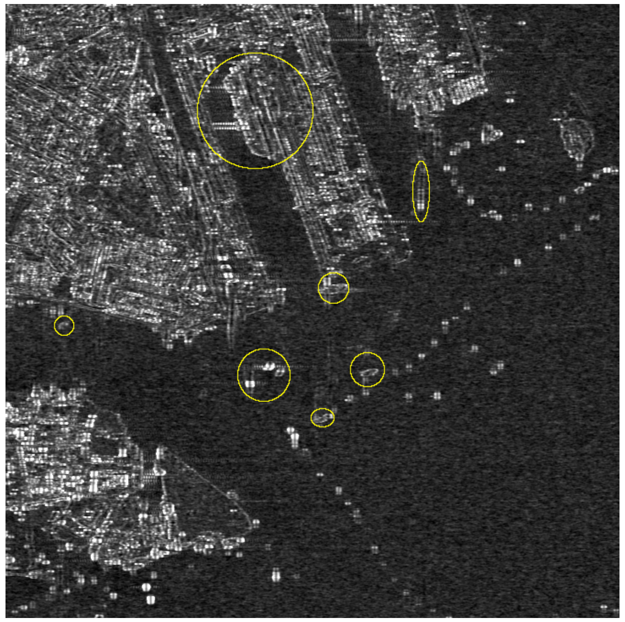
- All the process corresponds to having several SAR beams working simultaneously at slightly different wavelength and sending chirps of shorter bandwidth:



Split band

- What for?
  - ➫ It is possible to analyze the phase stability of scatterers with respect to wavelength:
    - Spectrally stable scatterers can be identified.
    - Spectral coherence may be computed between sub-views.

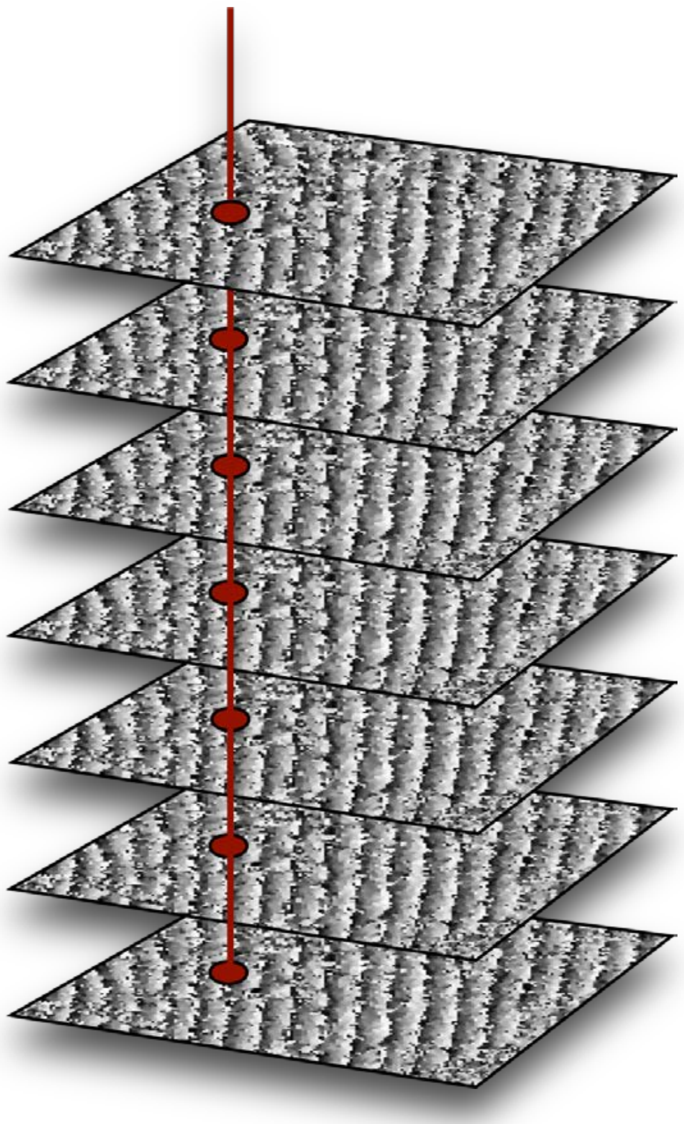




  - ➫ Spilt Band InSAR

SBInSAR

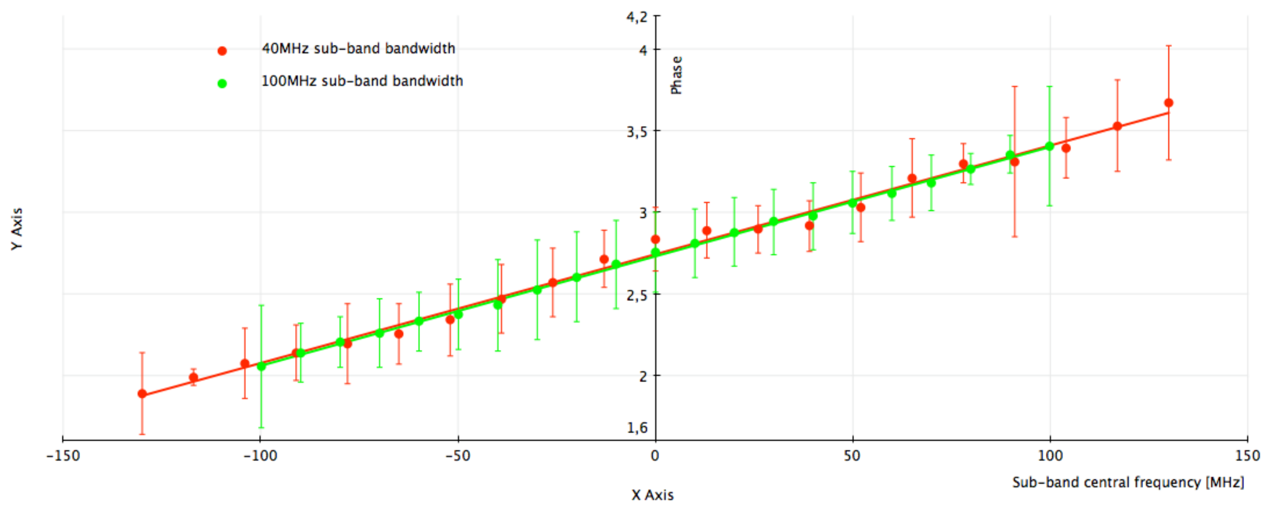
- SBInSAR is based on this spectral analysis
  - to generate several InSAR pairs of lower resolution from a single one.
  - Each sub-band interferometric pair leads to an interferogram generated with its own frequency (or wavelength).
    - Fringe rate will vary with respect to wavelength



SBInSAR

- The interferometric phase of a given point in a stack of split band interferograms will vary linearly with respect to the sub-band central frequency.

$$\Delta\varphi_i = 4\pi\frac{\nu_i}{c}(r_s - r_m)$$



➾ The slope is proportional to the optical path difference

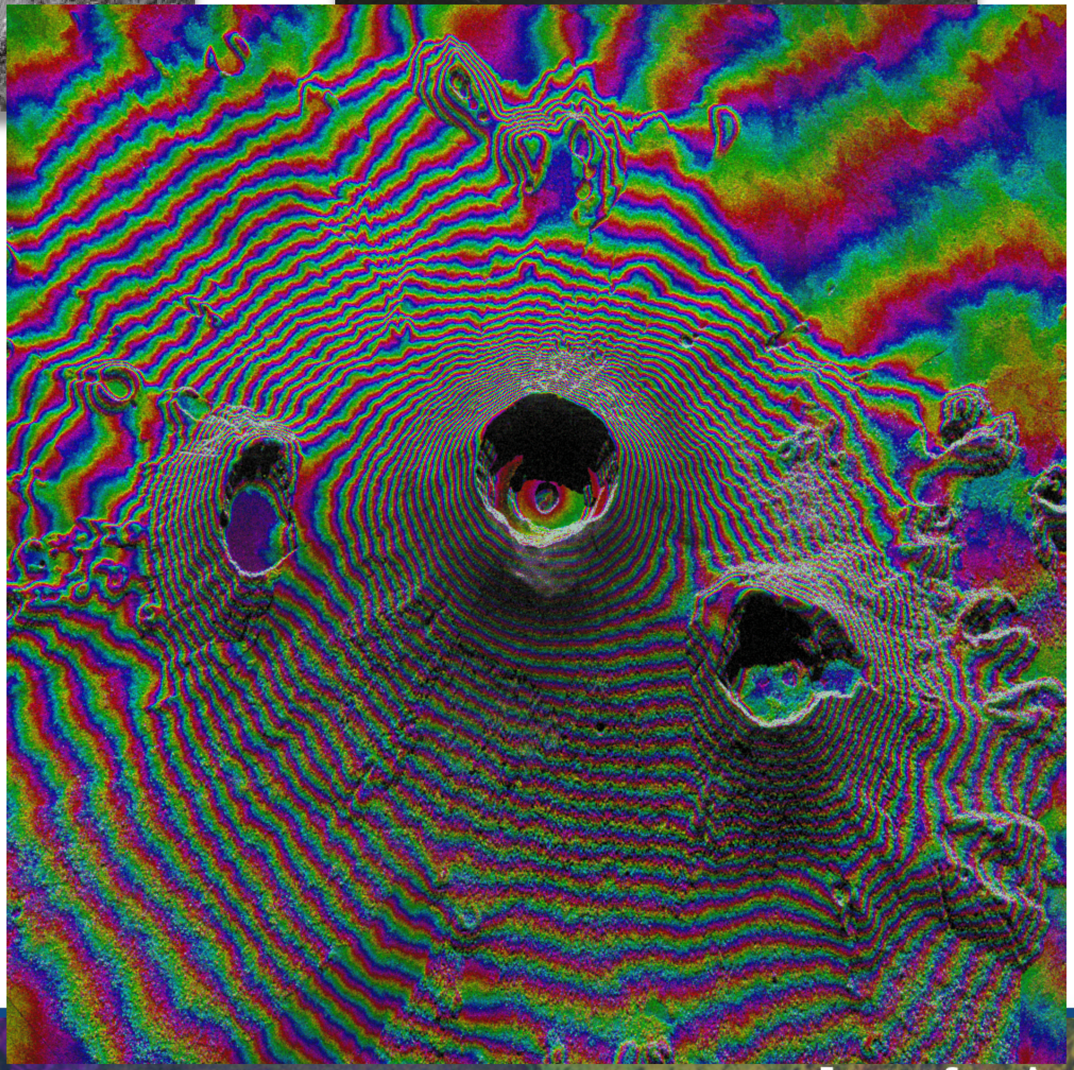
➾ This potentially solves the phase unwrapping problem on point-wise basis

SBInSAR

- SBInSAR advantages and drawbacks
  - SBInSAR allows measuring the absolute interferometric phase.
  - SBInSAR allows unwrapping the interferometric phase on a point by point basis.
    - Unconnected areas, separated by water surface or decorrelating vegetated areas may be connected.
  - Balance must be found between sub-bands bandwidth and explored bandwidth.
  - If the measurement is noisy, SBInSAR may be used to determine the absolute fringe to which belong the considered point; classical InSAR giving the fractional part of the phase.
  - Coherence stays the critical condition to detect and measure phase trends

Test site and objectives

- Nyiragongo volcano, Kivu basin, East RDC



- Objective:
    - Lava lake and lava deposit monitoring
- Data: TanDEM-X 2012-07-21

Co-registered data

- The CSL SBInSAR processor uses co-registered data.
  - It can be shown that, in that case, the phase slope with respect to frequency depends only on the co-registration error e_c:

$$\Delta\varphi_i = 2\pi\nu_0\frac{2}{c}(r_s - r_m) + 2\pi(\nu_i - \nu_0)\frac{2}{c}e_c$$

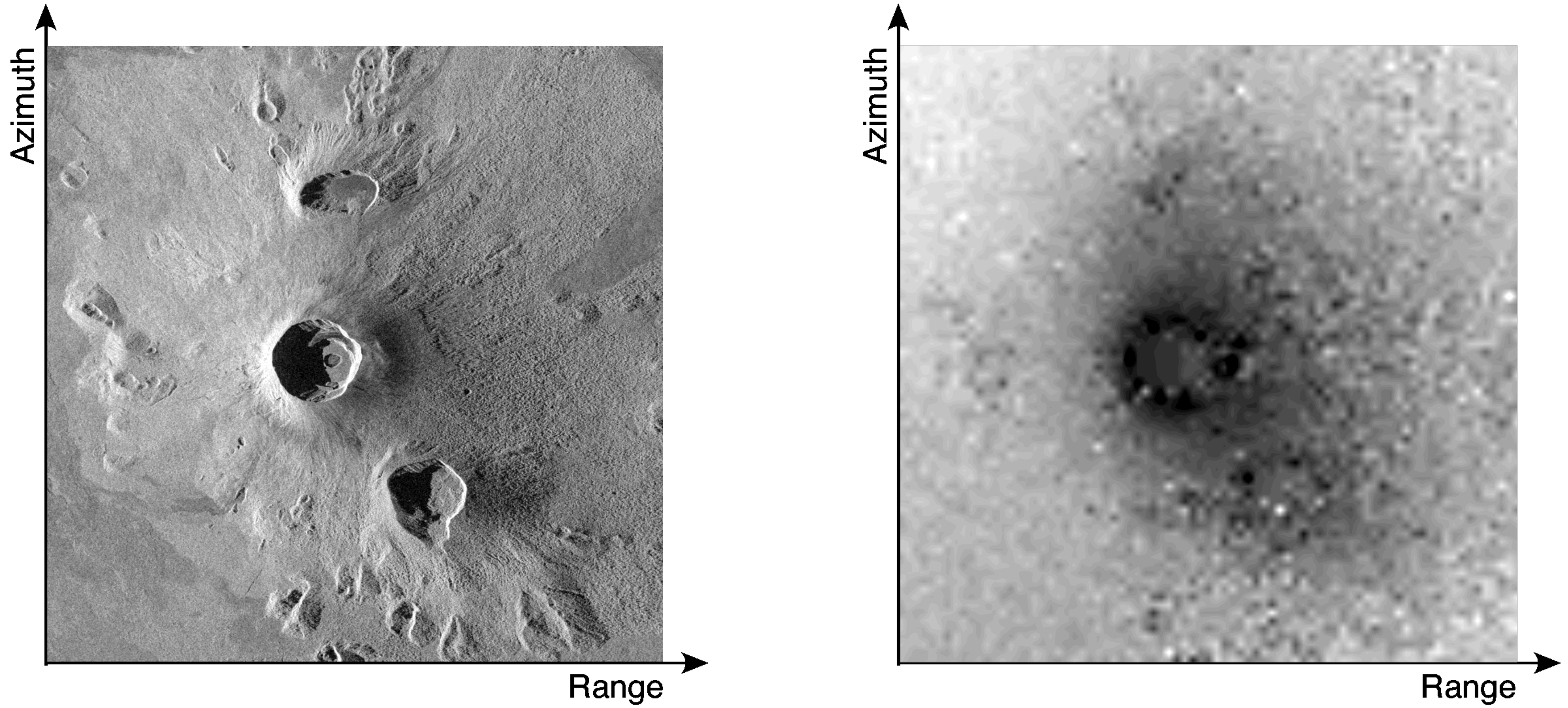
$$\frac{\partial\varphi}{\partial\nu_i} = \frac{4\pi}{c}e_c$$

    - Where co-registration is expressed as: $r_s = r_m + \Delta r + e_c$
  - The co-registration phase must be re-added to recover the full phase and compute the optical path difference:

$$\begin{aligned}\Delta\varphi = \Delta\varphi(\Delta r) + \Delta\varphi(e_c) &= \frac{4\pi}{c}\nu_0\Delta r + \frac{4\pi}{c}\nu_0\, e_c \\ &= \frac{4\pi}{c}\nu_0(r_s - r_m)\end{aligned}$$

TDX case

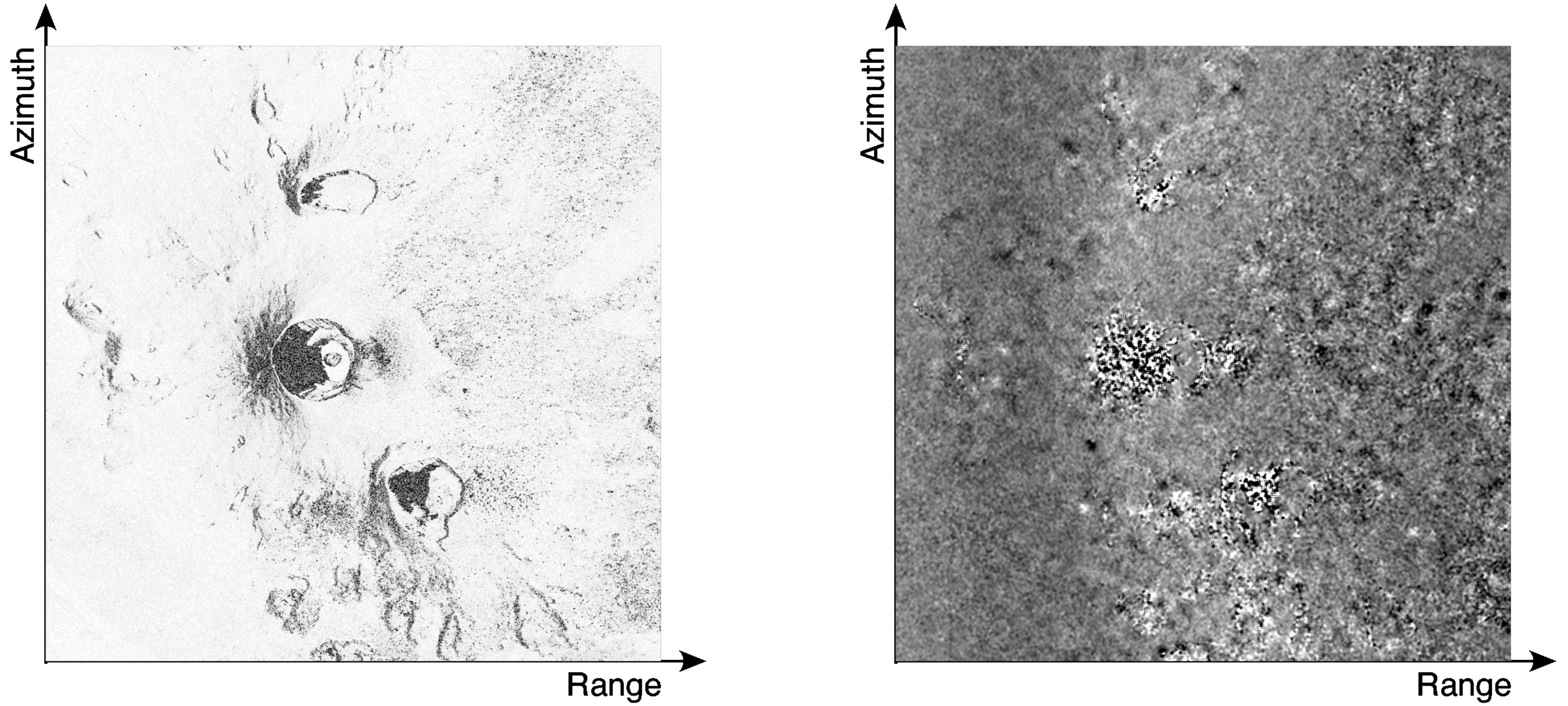
- TanDEM-X data are provided co-registered
  - Co-registration information is provided as a mesh of co-registration values that must be extrapolated to get the applied co-registration in each point
  - Co-registration phase component can be computed using this information



Nyiaragongo test site (left) and corresponding co-registration phase (right)

SBInSAR processing

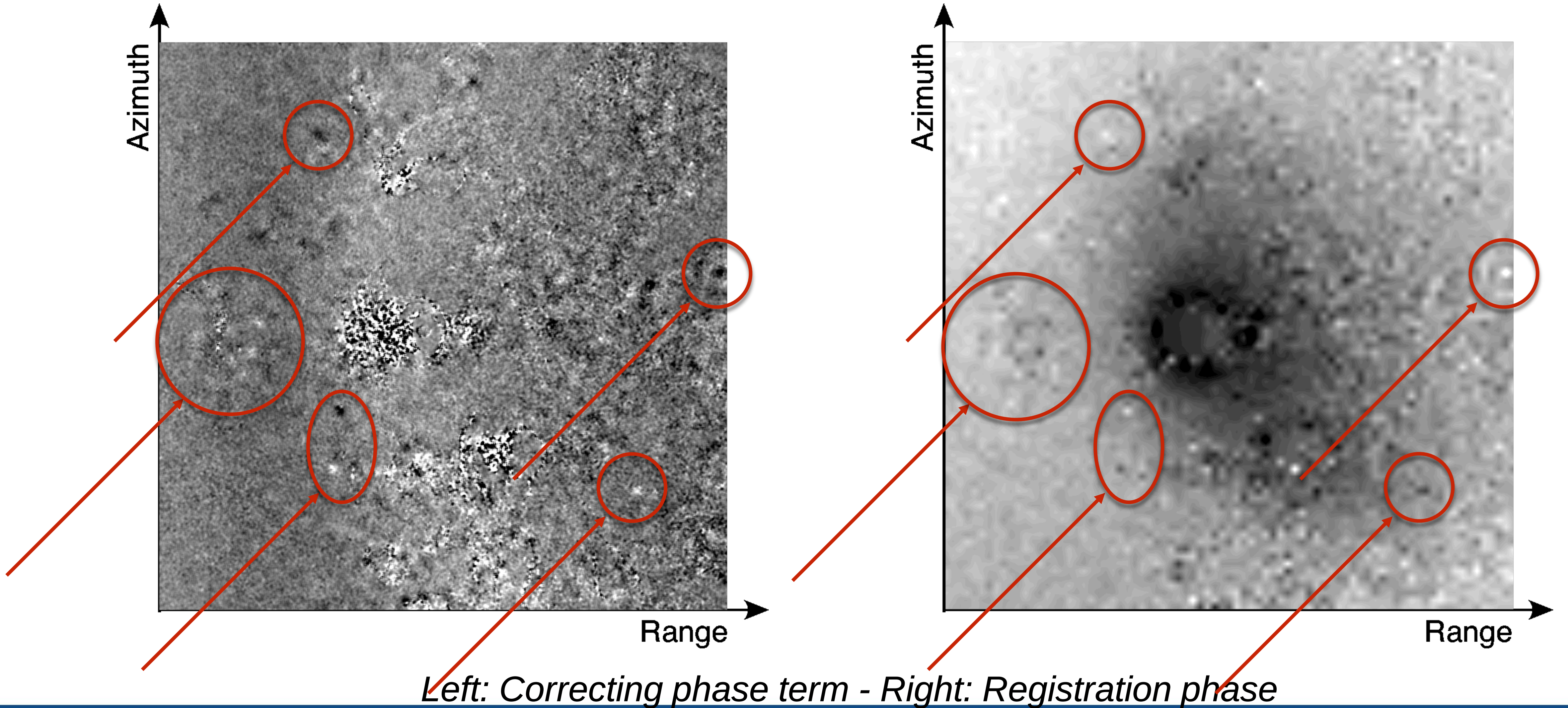
- SBInSAR processing was performed on the July 21 TanDEM-X bistatic pair.
  - The processor computes the correcting phase term



Left: Spectral coherence – Right: Correcting phase term

SBInSAR processing

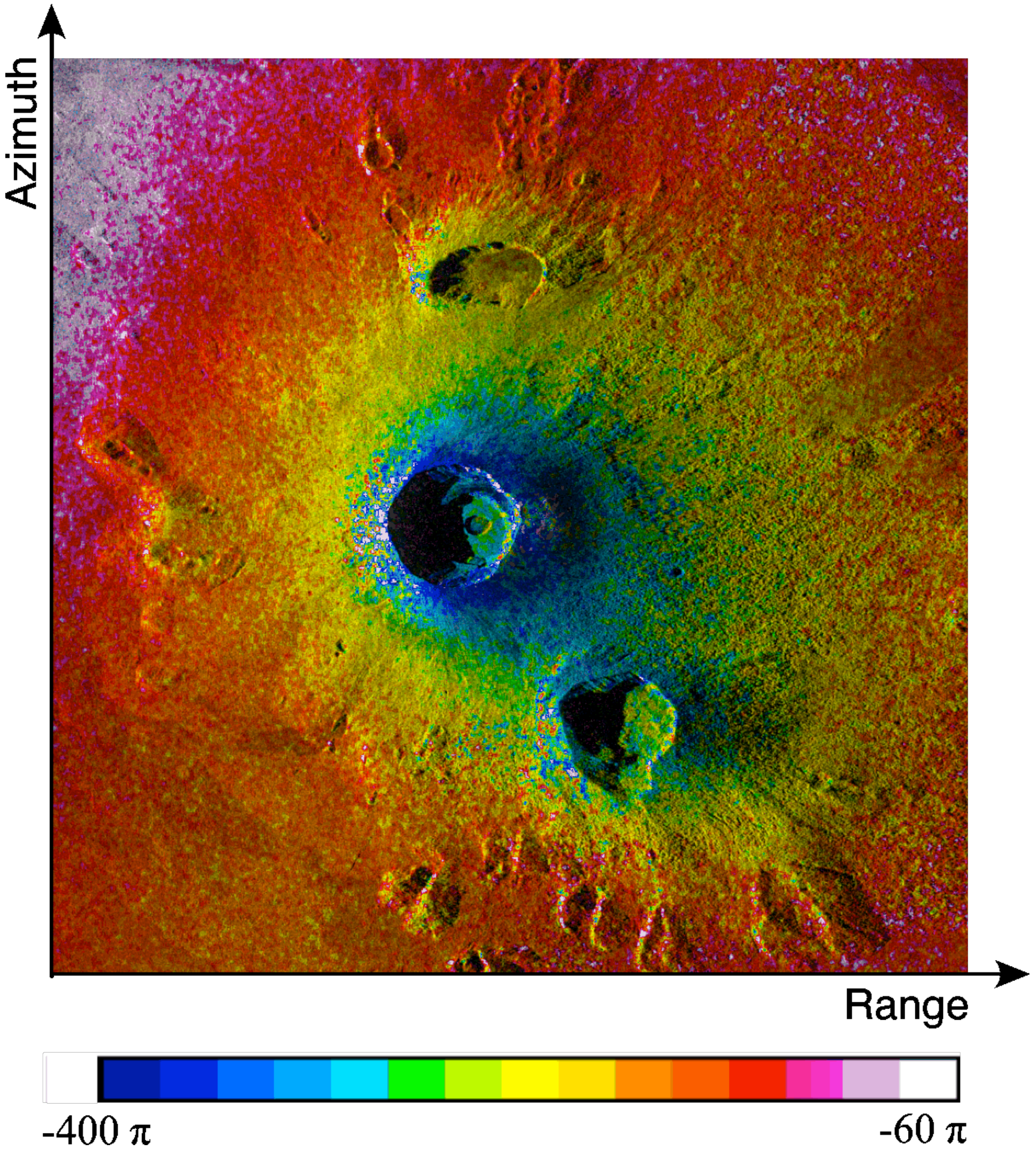
- The correcting phase term appears in many places as a negative of the co-registration phase term
  - ➩ the correcting phase term may also be seen as a local co-registration correction



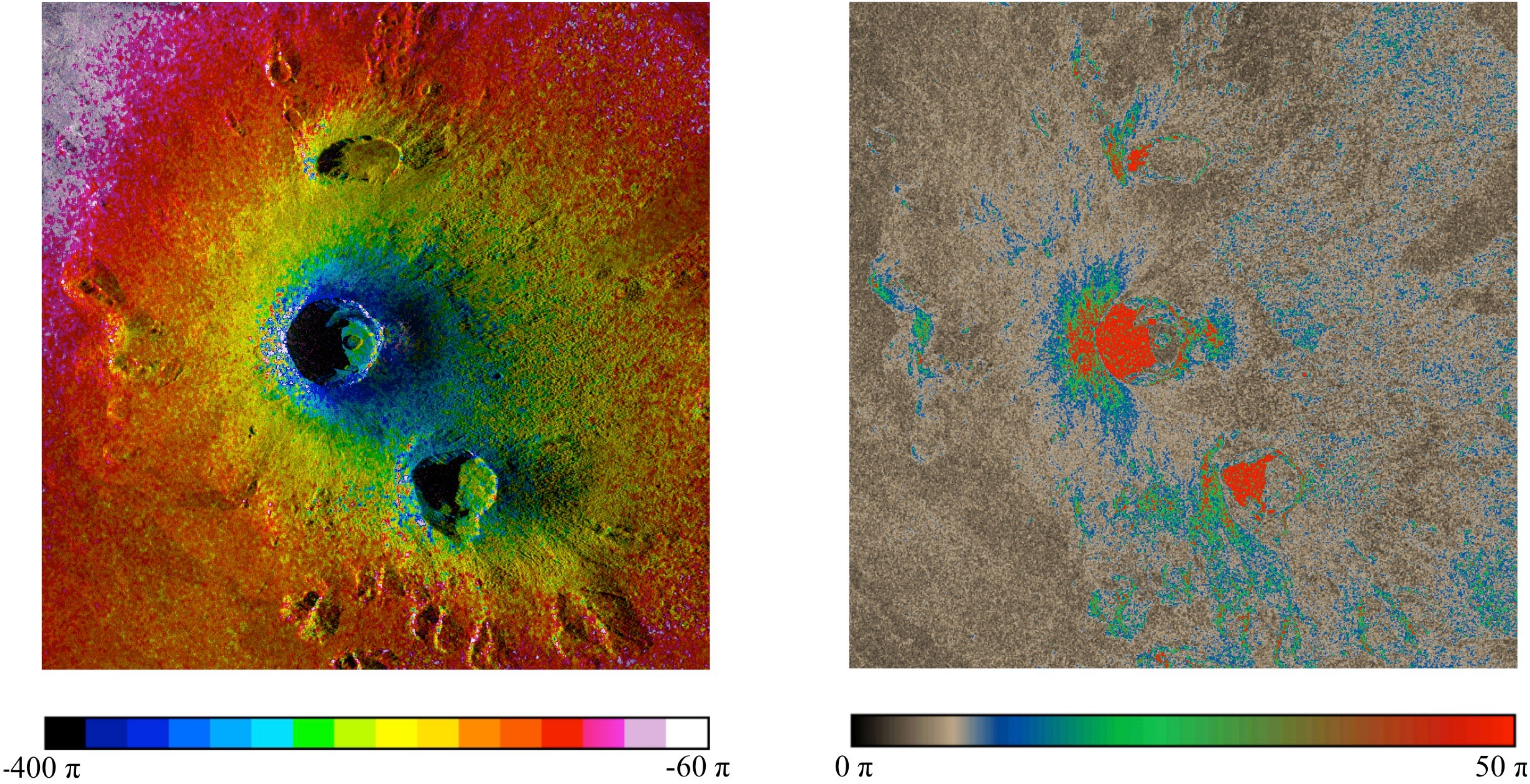
Left: Correcting phase term - Right: Registration phase

SBInSAR processing

- When summing both the registration and the correcting phase term, we obtain the measured absolute phase
  - ➯ No more grainy aspect
    - ✓ The correcting phase term is first a co-registration correction
  - ➯ Bottom platform P3 inside the crater of the Nyiragongo is shown with a phase corresponding to a lower altitude with respect to the crater borders



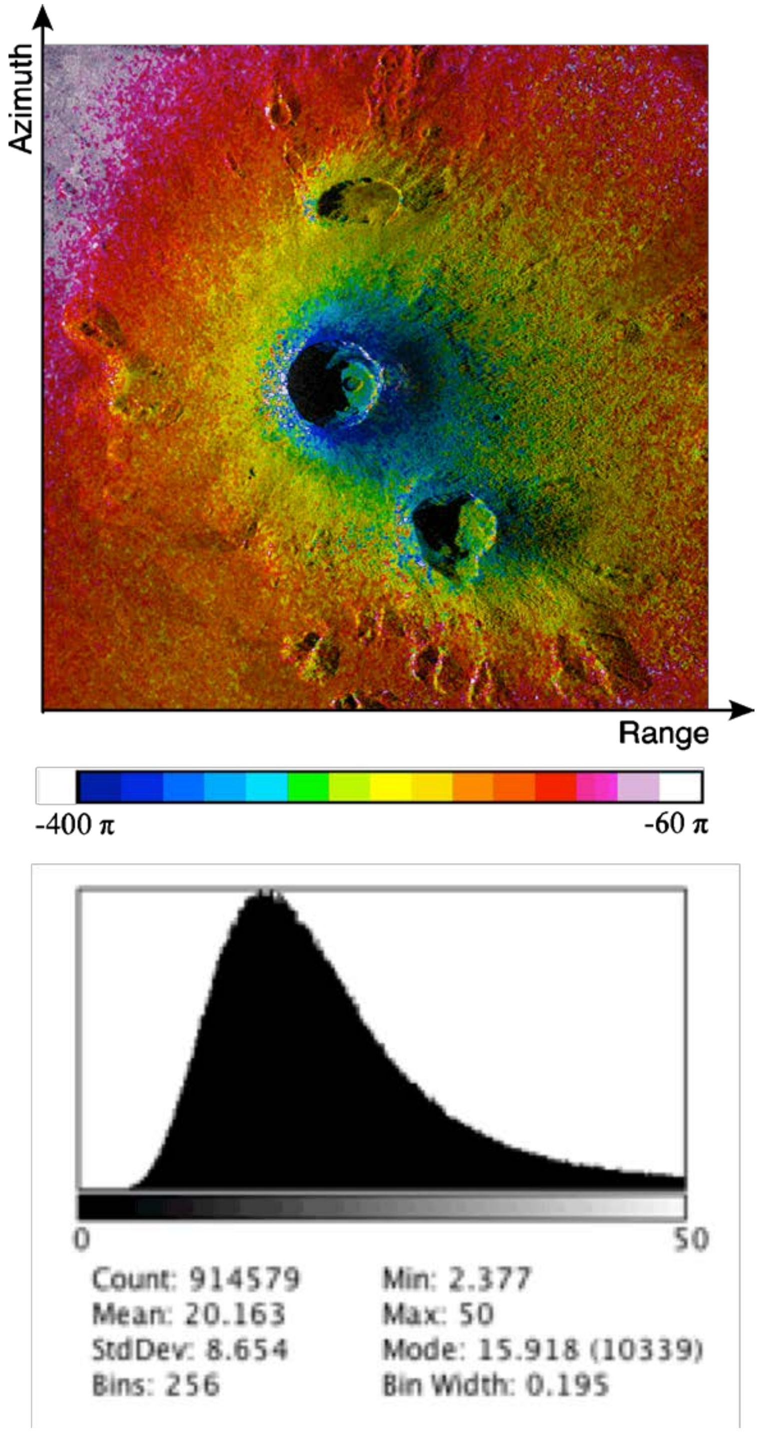
SBInSAR accuracy



Left: Absolute phase (right) and RMS error (right) issued from SBInSAR processing of July 21, 2012 TanDEM-X bistatic pair of the Nyiragongo

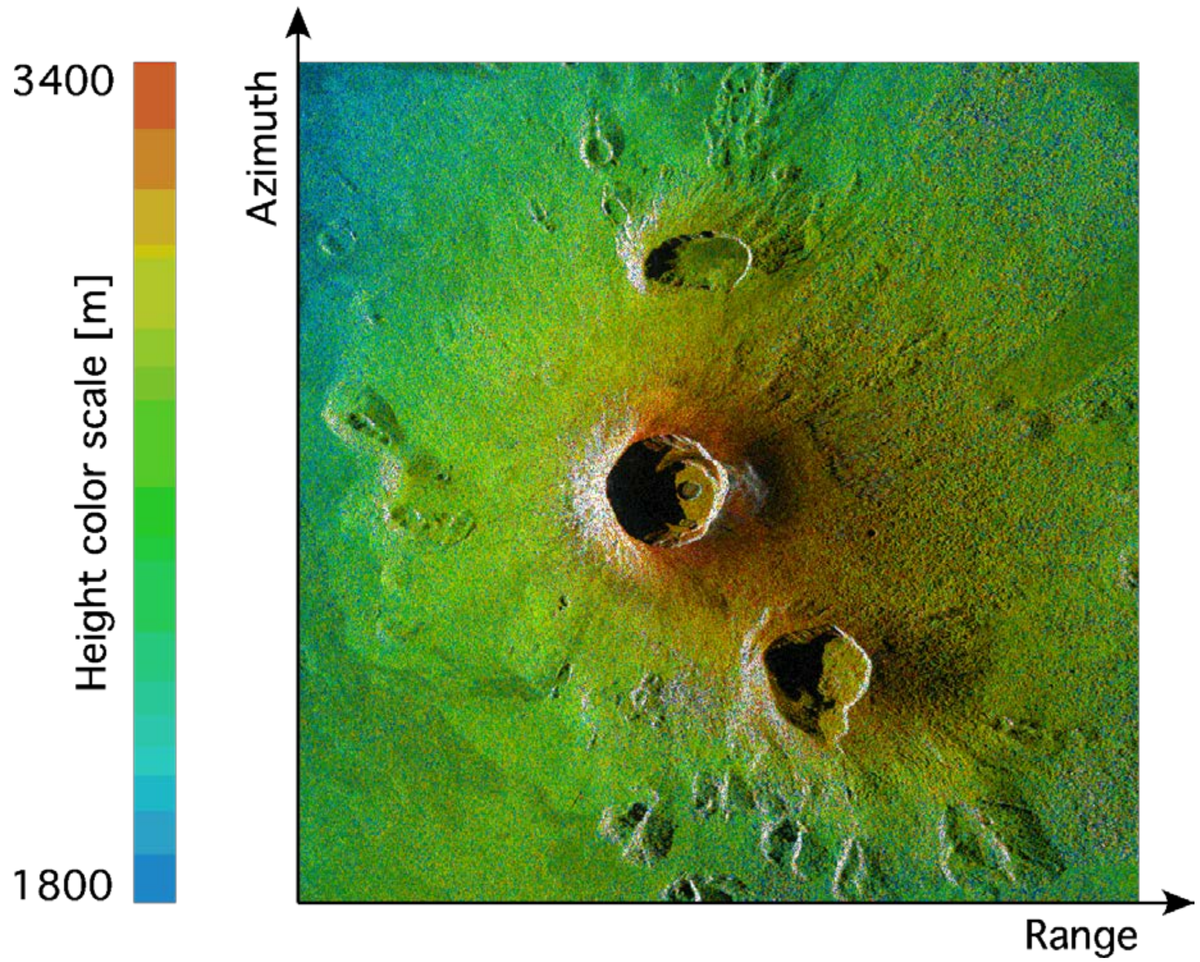
SBInSAR accuracy

- RMS error on slope intercepts:
  - No or very few points offer the sufficient accuracy to obtain almost the absolute fringe number within the interferogram
  - The average error is of about 20 radians (about 3 fringes)
  - Since the altitude of ambiguity is ~41m for the used TanDEM-X bistatic pair, the average 1σ height error is of about 130m.
- A larger signal bandwidth seems necessary to reach the required accuracy



SBInSAR accuracy

- “Absolute” phase was converted into local heights
  - ➯ Despite the relatively poor accuracy, performing a weighted average with respect to spectral coherence, height difference between crater rim and lower crater platform P3 was estimated to be of approximately 410m while the expected value is of about 390m.



Conclusions

- We fully implemented SBInSAR processing, including TanDEM-X co-registration data handling.
- The first phase component, called the registration phase, must be computed, knowing exactly the registration shift applied to the salve image with respect to the master one.
- Adding the residual phase component derived through SBInSAR allows getting the full phase on a point-by-point basis.
- However, the spectral diversity resulting from the bandwidth (100MHz) of TanDEM-X does not allow getting an absolute phase accuracy better than about 3 fringes in the most favorable cases.
- It is expected that one can reach the required precision using either TanDEM-X data in pursuit mode or in bistatic spotlight high-resolution mode