MUZUBI – Advanced phase unwrapping using split-band interferometry

Denis Defrère
Liège Space Center – University of Liège

A. Radioti, L. Libert, D. DeRauw, Q. Glaude, A. Orban, M. Kirkove, and C. Barbier

MUZUBI partners: F. Kervyn, B. Smets (RMCA), N. d'Oreye (ECGS)

MUZUBI: Project summary

- **MU**lti-**Z**one phase **U**nwrapping using advanced Split **B**and **I**nterferometry

  - Technical/methodological core:
    - *Absolute* phase unwrapping.

  - Application core:
    - Volcanological risk assessment and early warning.

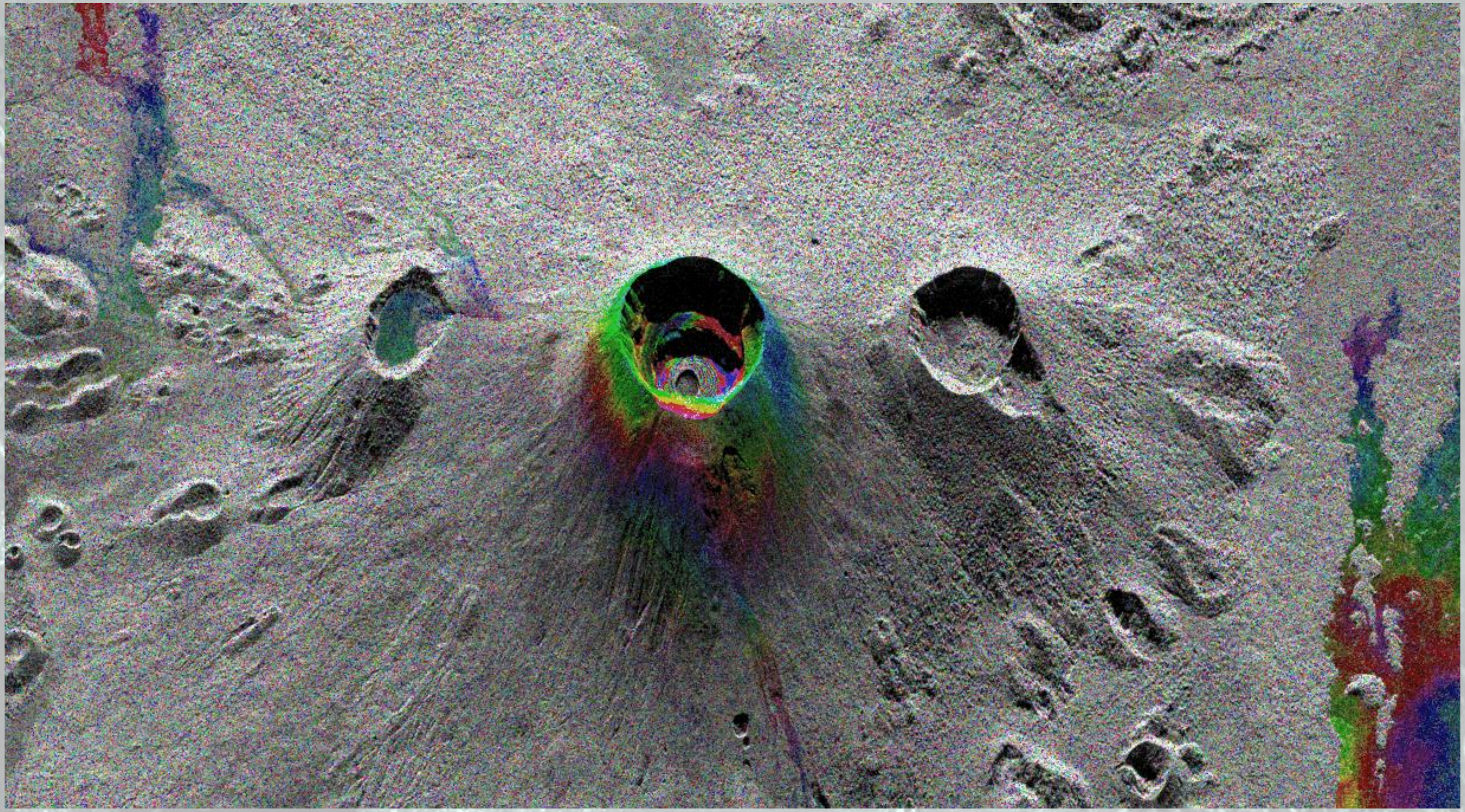
Project main partners

- Belgian partners:
  - ✓ Centre Spatial de Liège (CSL):
    - Responsible for technological and methodological developments.
  - ✓ Royal Museum of Central Africa (RMCA):
    - Responsible for applicative aspects on Virunga Volcanoes.

- International partners:
  - ✓ European Centre for Geodynamics and Seismology / Musée National d’Histoire Naturelle (ECGS/MNHN) – Luxembourg
    - Processing parameters and validation of results

Project motivation

- How to connect independent phase zones to **get continuous measurements?**

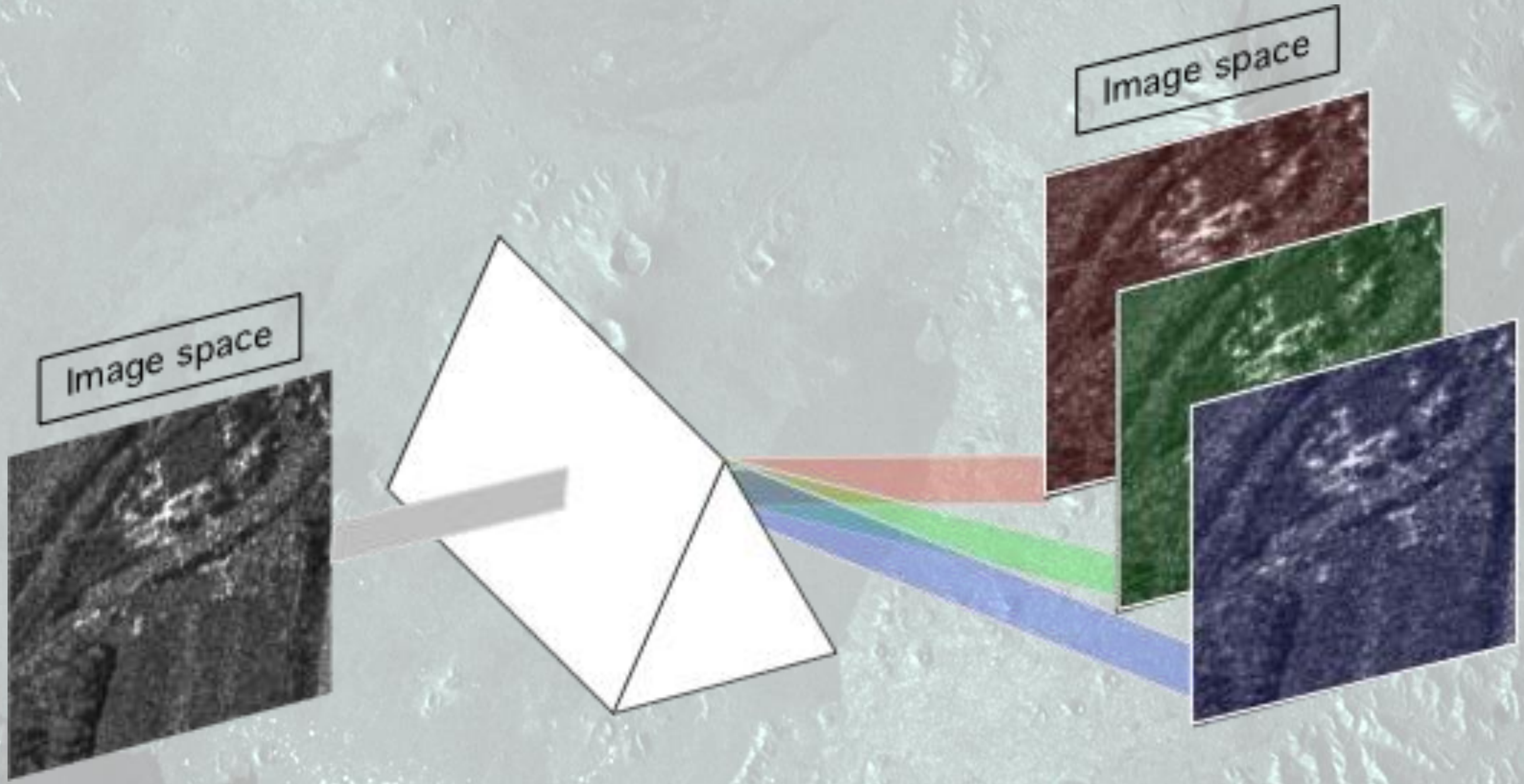


Rationale for SBInSAR

- **Absolute ranging** first proposed by Masden and Zebker (1992)
- Studied by various authors as **Multi-Chromatic Analysis (MCA)** for absolute phase and height retrieval (e.g., Veneziani et al. 2003, de Rauw et al. 2009, Bovenga et al. 2013)
- Solution to assist phase unwrapping and re-connect disconnected regions (MUZUBI: Libert et al. 2017)
- Theoretical limitations investigated in details by Veneziani et al. (2003)
- **Practical limitations and applicability on real test cases** (Defrère et al. in prep)

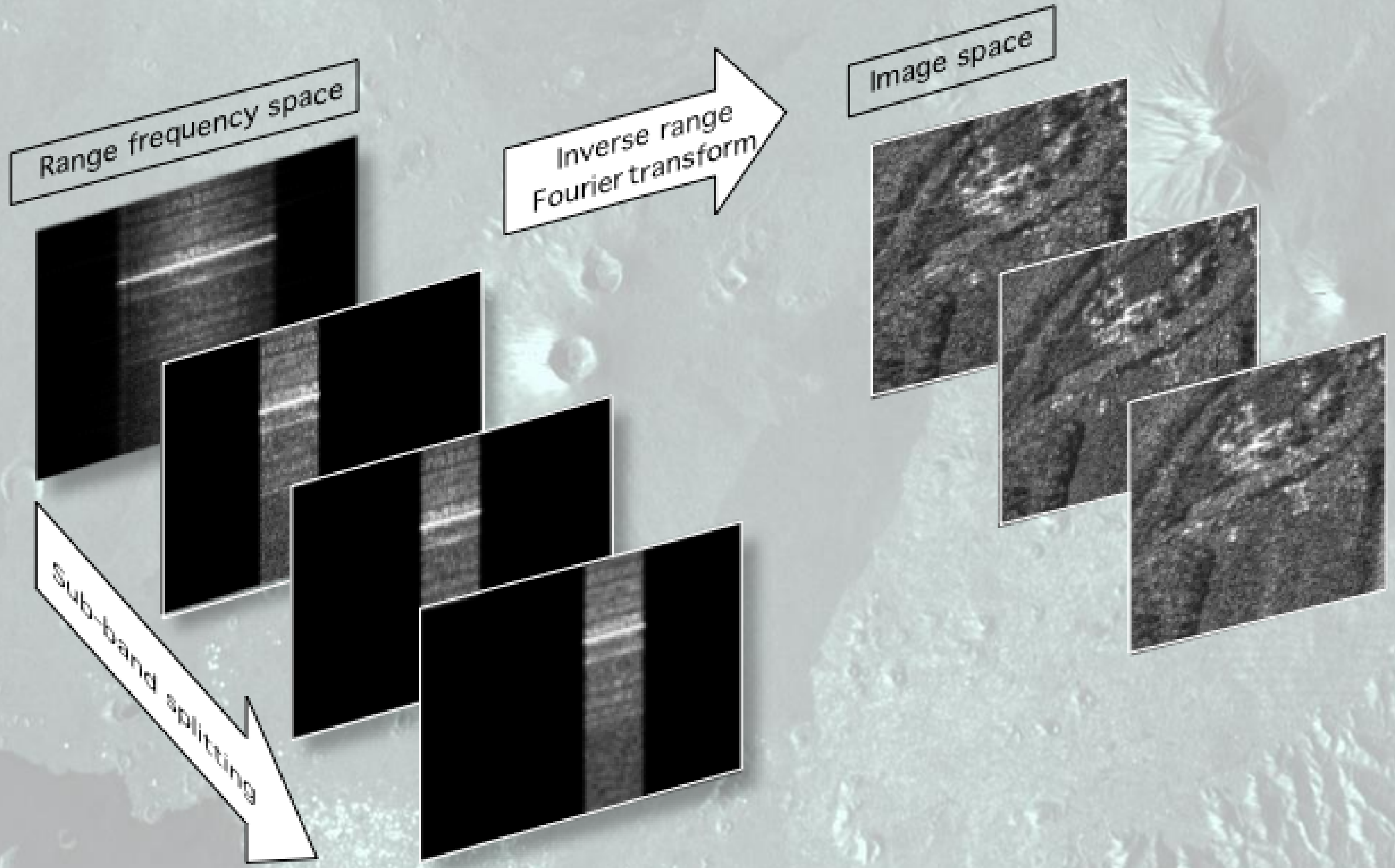
SBInSAR principles

- Bandwidth splitting
- <u>PROS</u>: spectral diversity
- <u>CONS</u>: loss of geometric coherence and spatial resolution



SBInSAR principles

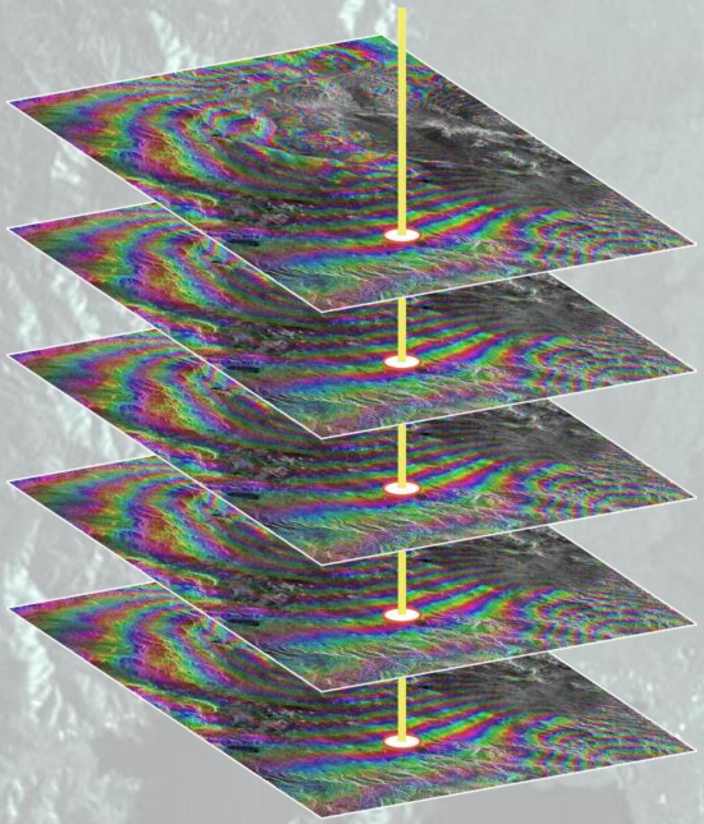
- Bandwidth splitting
- PROS: spectral diversity
- CONS: loss of geometric coherence and spatial resolution

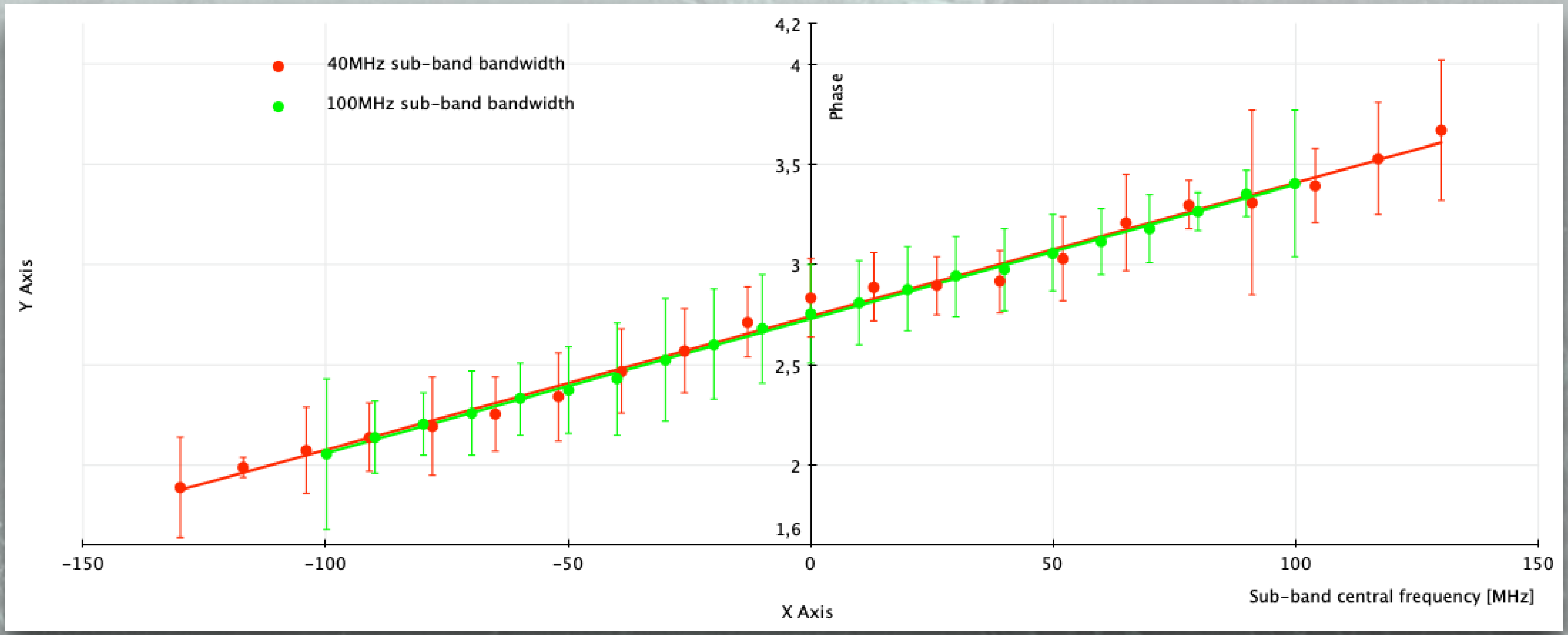


SBInSAR principles

- Fringe rate will vary linearly with respect to frequency
- The **absolute phase** is proportionnal to the slope:

$$\Delta\phi_i \simeq p(\nu_i) = s\nu_i + u$$





SBInSAR principles

- **The precision of the measured absolute phase** is proportional to the precision on the slope or the intercept

- For non overlapping sub bands (Libert et al. 2017):

$$\sigma_{\phi_{sb}} = \frac{\nu_0}{\Delta\nu}\sqrt{\frac{\sum_{i=1}^{N}\frac{1}{\sigma_{\phi_i}^2}}{\sum_{i=1}^{N}\frac{1}{\sigma_{\phi_i}^2}\sum_{i=1}^{N}\frac{\nu_i^2}{\sigma_{\phi_i}^2}-\left(\sum_{i=1}^{N}\frac{\nu_i}{\sigma_{\phi_i}^2}\right)^2}}$$

- Large bandwidth ($\Delta\nu$)
- Small carrier central frequency (ν_0)
- High coherence (i.e. small σ_ϕ)

Practical example

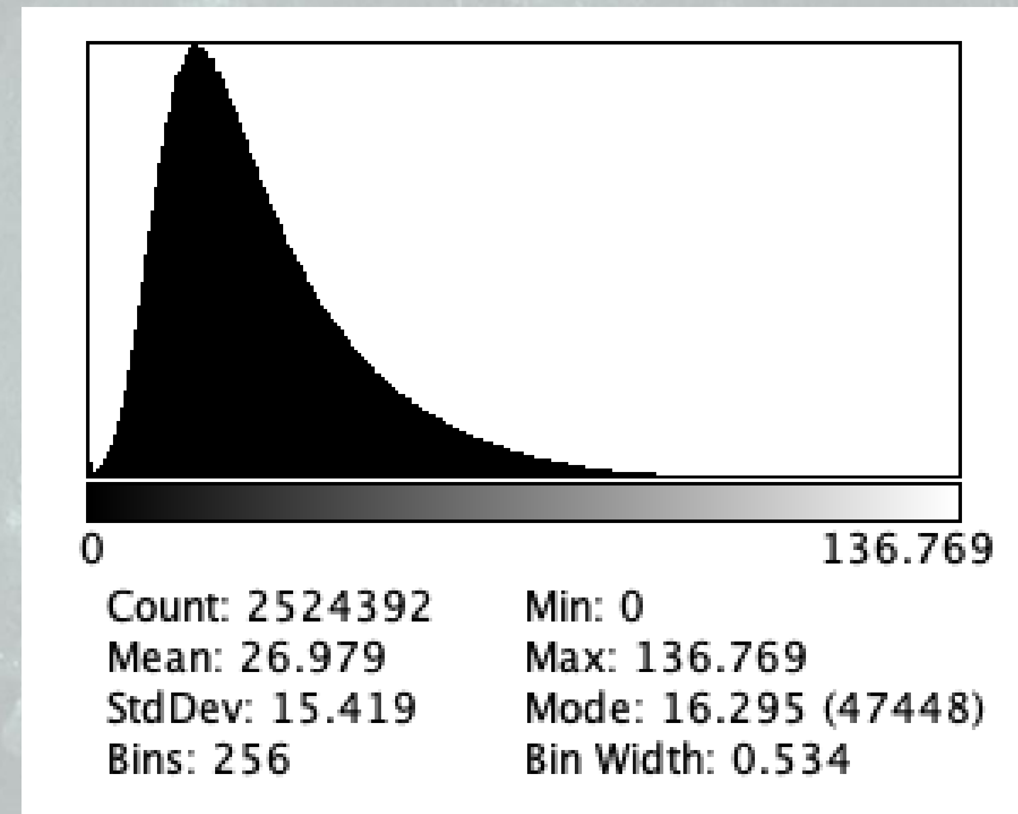
- TANDEM-X monostatic images of Mount Uluru (Australia, 2009/02/12 – 2009/02/23);
- B = 300 MHz

Amplitude of master image

Practical example

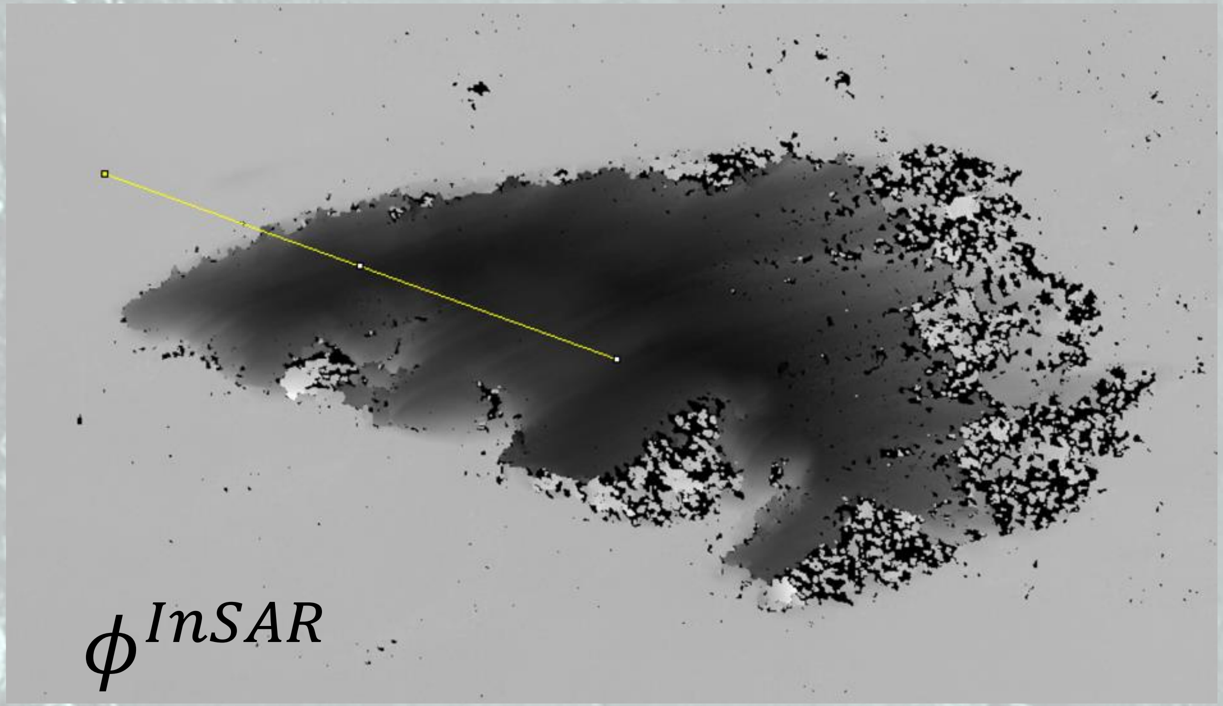
Error on absolute phase from SBInSAR $\sigma_{\phi_{sb}}$

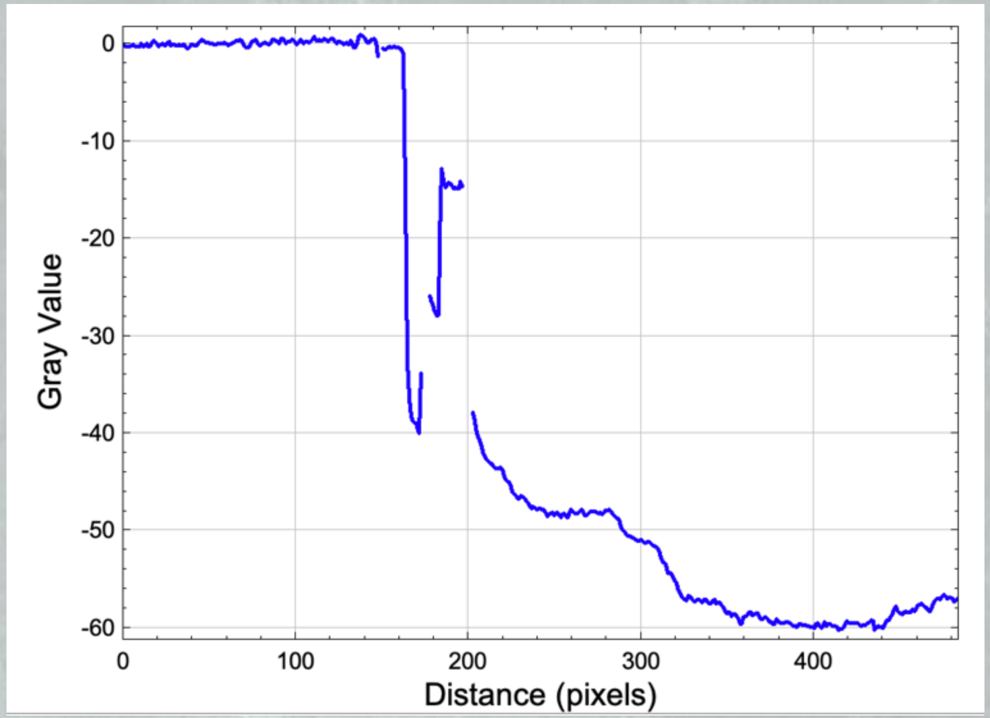
Error distribution

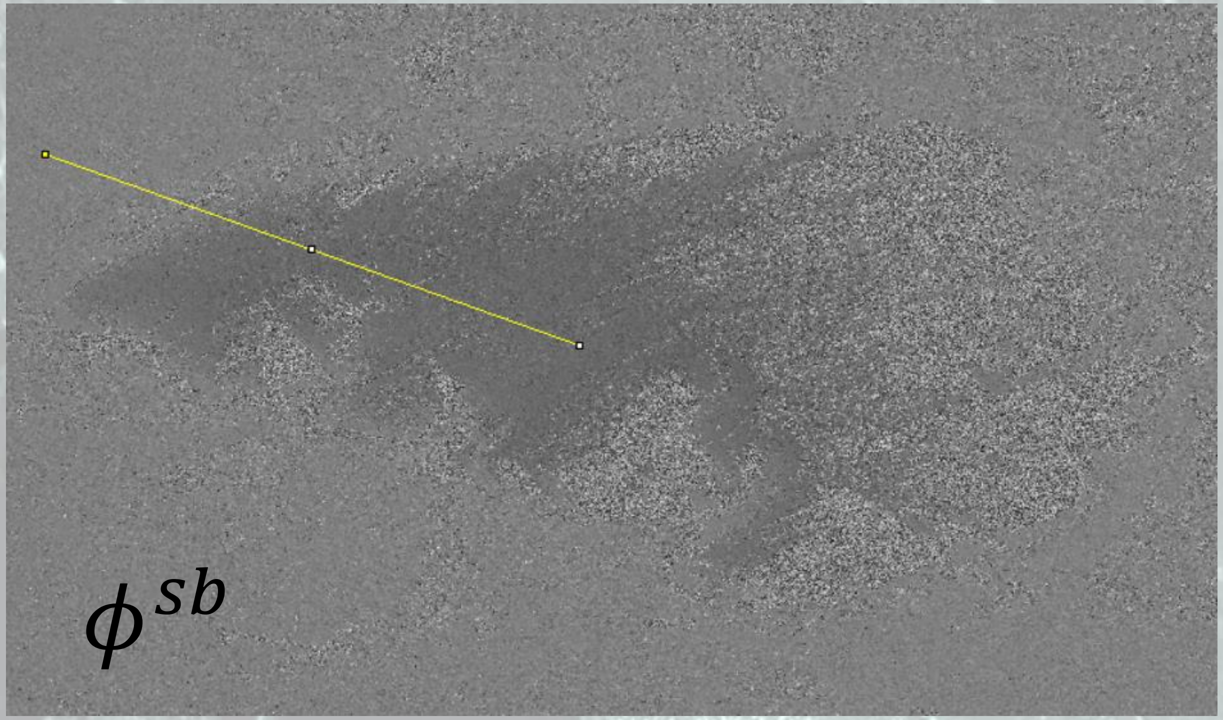


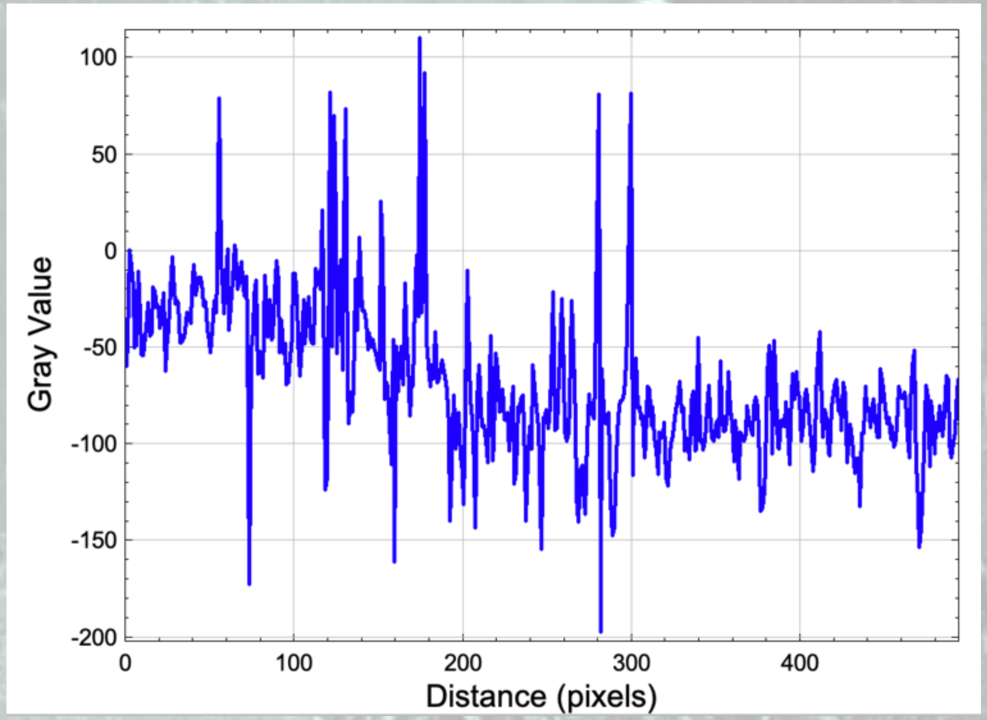
- Mode of error ~5π (per look)
- What about the error for an independently-unwrapped zone?

Phase offset determination





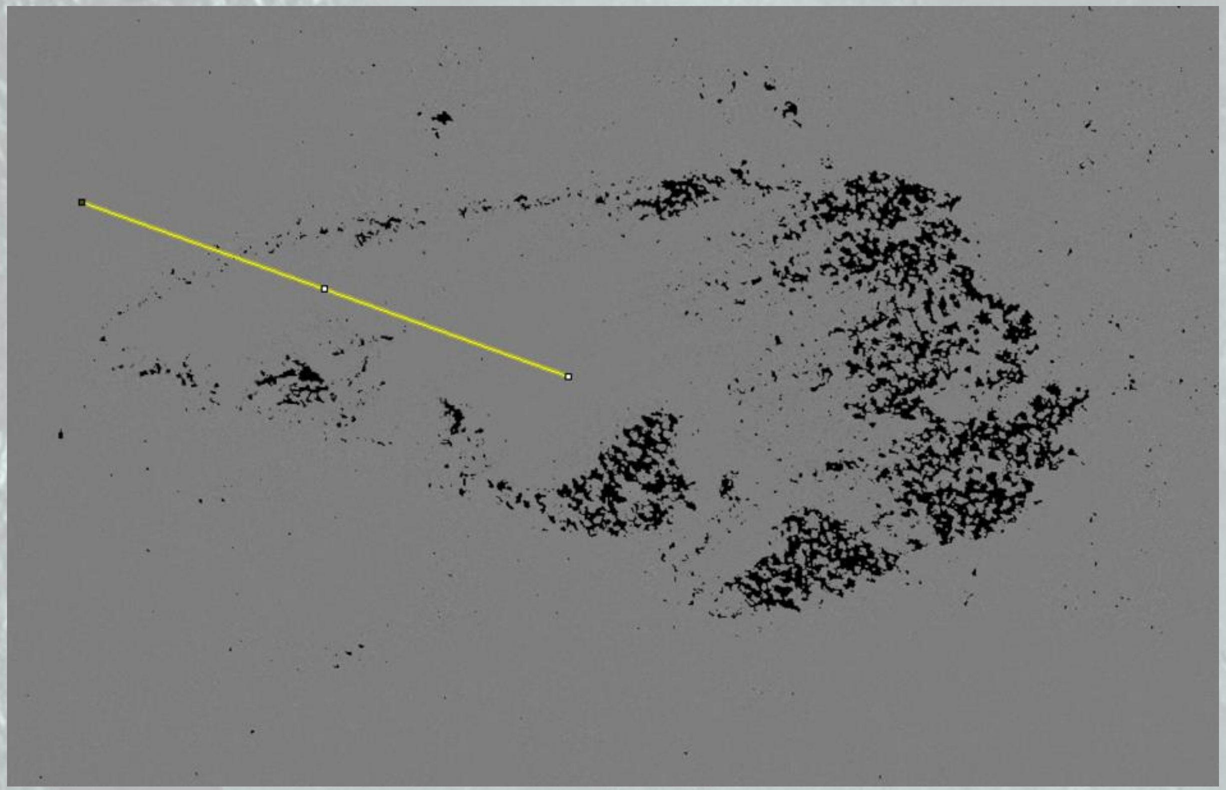


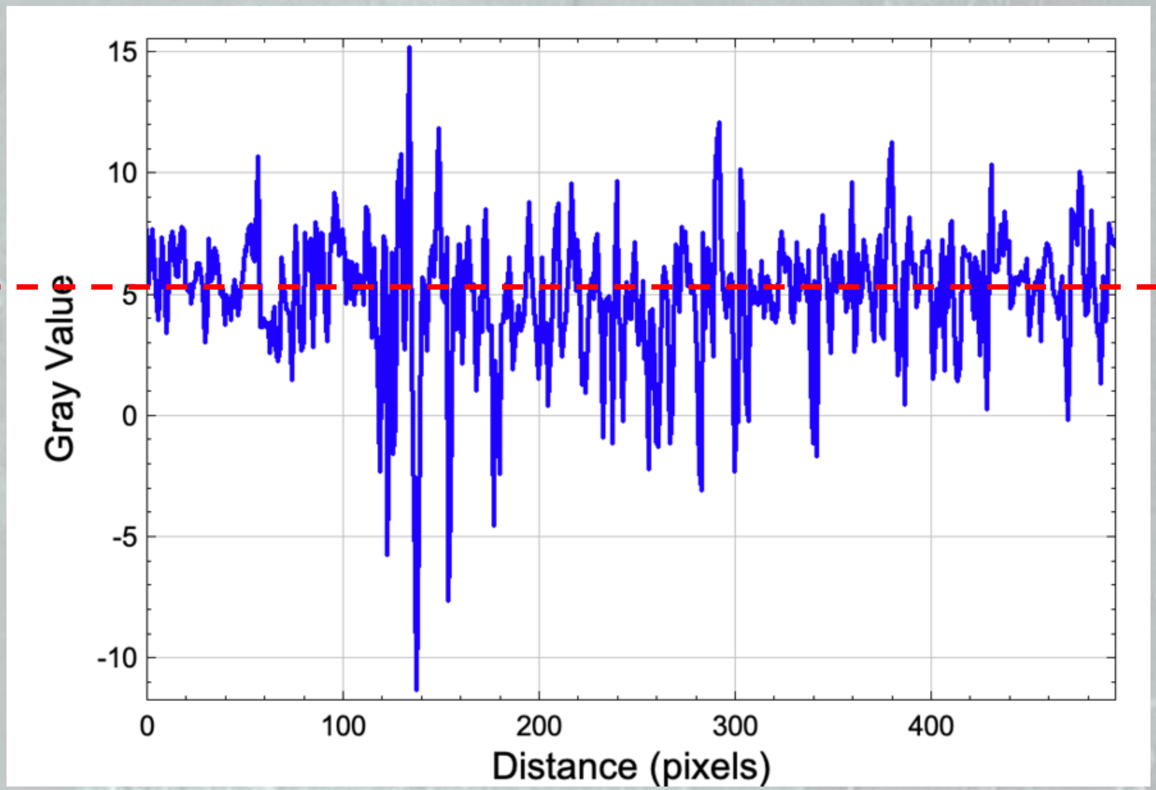


Phase offset determination

$$n \simeq \frac{\phi^{sb} - \phi^{InSAR}}{2\pi}$$

Correction of unwrapped phase





ϕ^{sb} is less precise but more accurate!

Test cases and InSAR processing

- Six different test cases (sensors, bandwidths, modes, and coherence levels);
- Processing using **CSL InSAR suite (CIS), adapted to compute the error for each independently-unwrapped zone**
- InSAR processing using branch-cut algorithm for phase unwrapping and 5x5 multi-looks

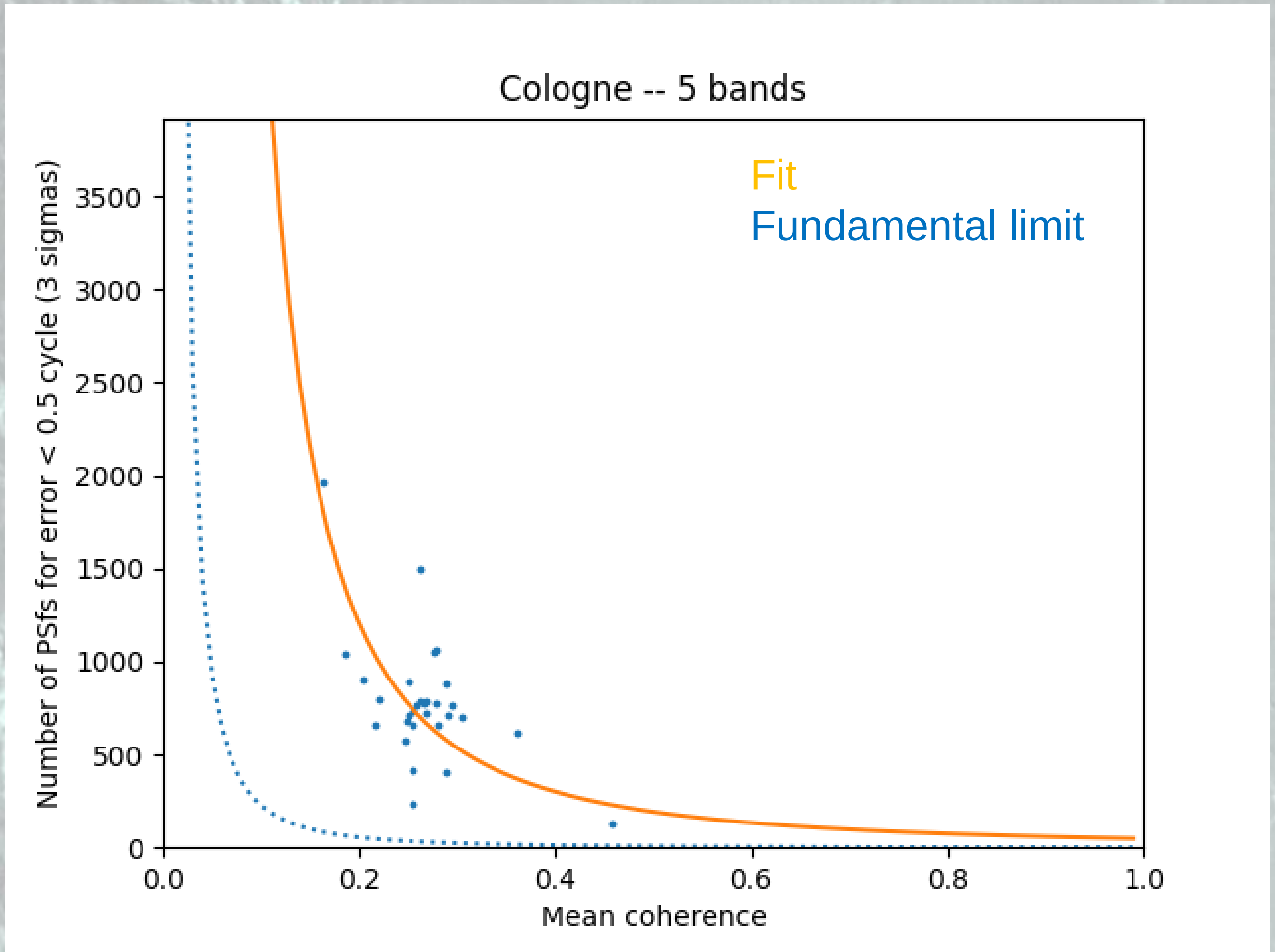
ID	SENSOR	MODE	REGION	DATES	FREQ. [GHz]	BAND. [MHz]	B_p [m]	H_a [m]
1	S1	TOPS	Cologne	2019-03-04/2019-03-16	5.4	56	159	79.7
2	S1	STRIPMAP	Houston	2019-04-15/2019-04-21	5.4	100	60.4	137
3	CSK	SPOTLIGHT	Virunga	2011-07-30/2011-07-31	9.6	130	71	69
4	TSX	STRIPMAP	Nyamuragira	2008-06-22/2008-07-03	9.6	150	13	300
5	TSX	SPOTLIGHT	Uluru	2009-02-12/2009-02-23	9.6	300	233	34
6	TDX	SPOTLIGHT	Copahue	2014-12-15/2014-12-26	9.6	300	32	163

Minimum number of PSfs per zone

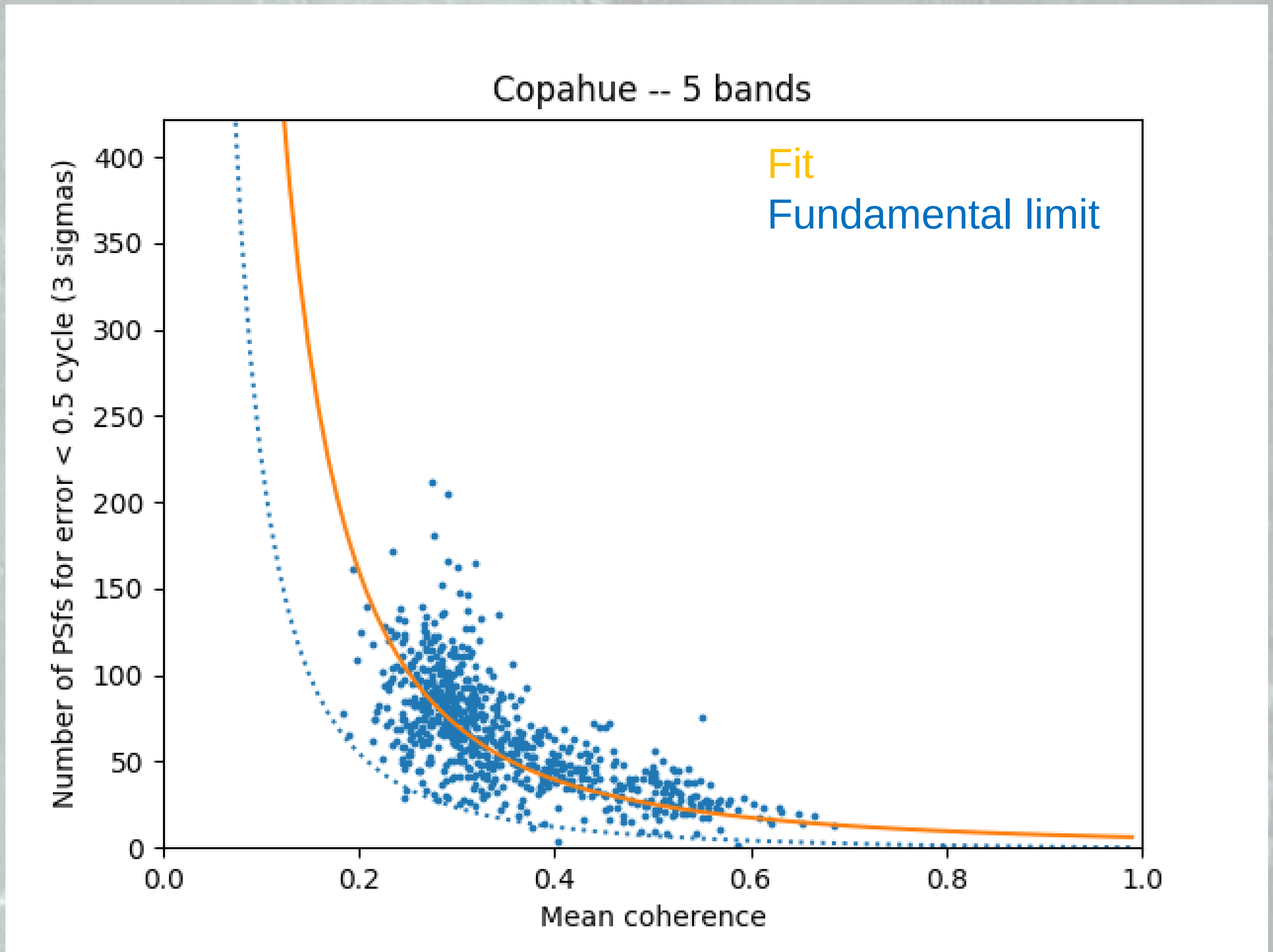
for absolute phase measurement **with a 99.7% confidence (i.e., 3 × σ_n < 0.5 cycle).**

- Typically, 50-100 (resp. 500-1000) PSfs for TANDEM-X (resp. SENTINEL)
- Typically ~3x above fundamental noise limit for TANDEM-X

SENTINEL (B = 56 MHz)



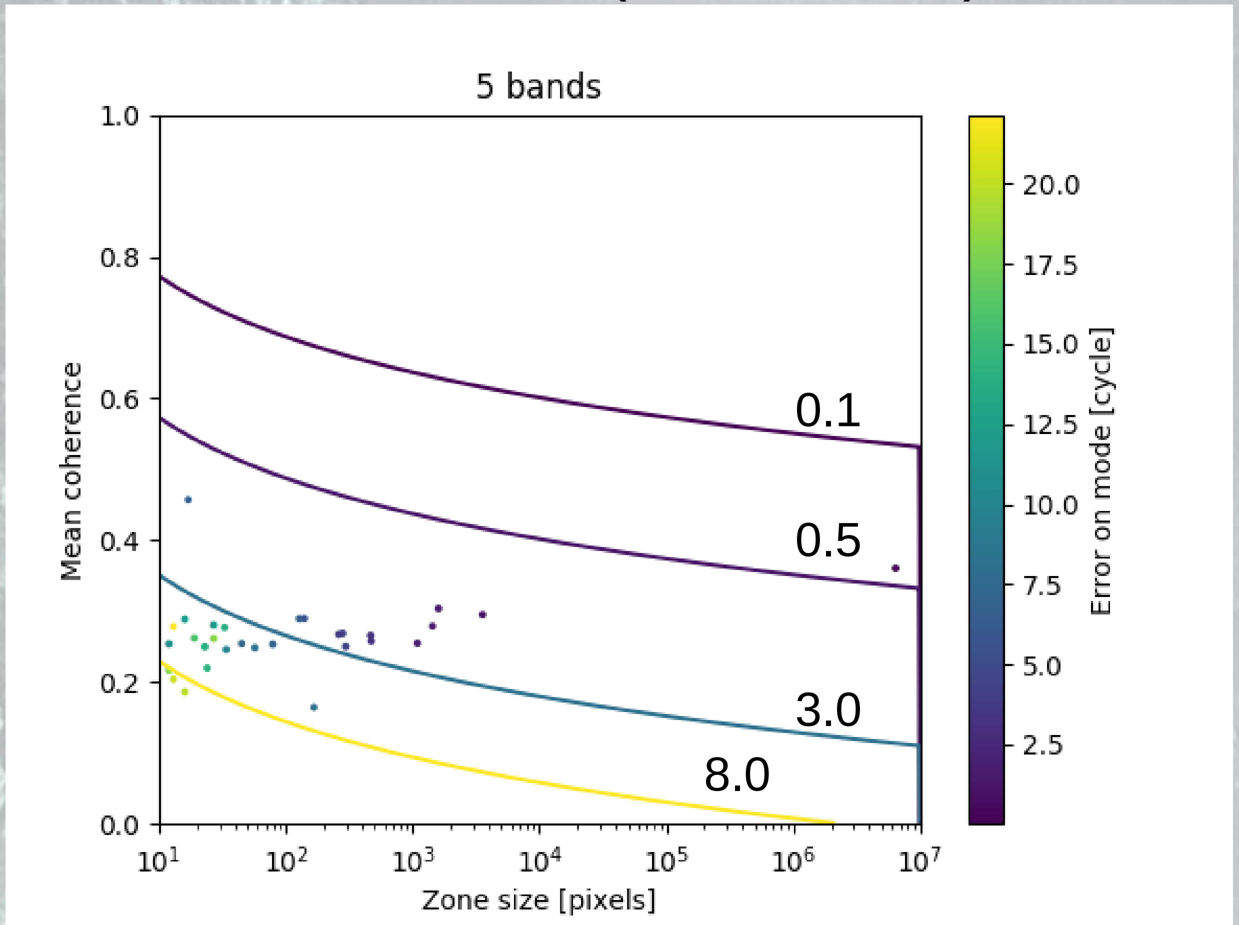
TANDEM-X (B = 300 MHz)



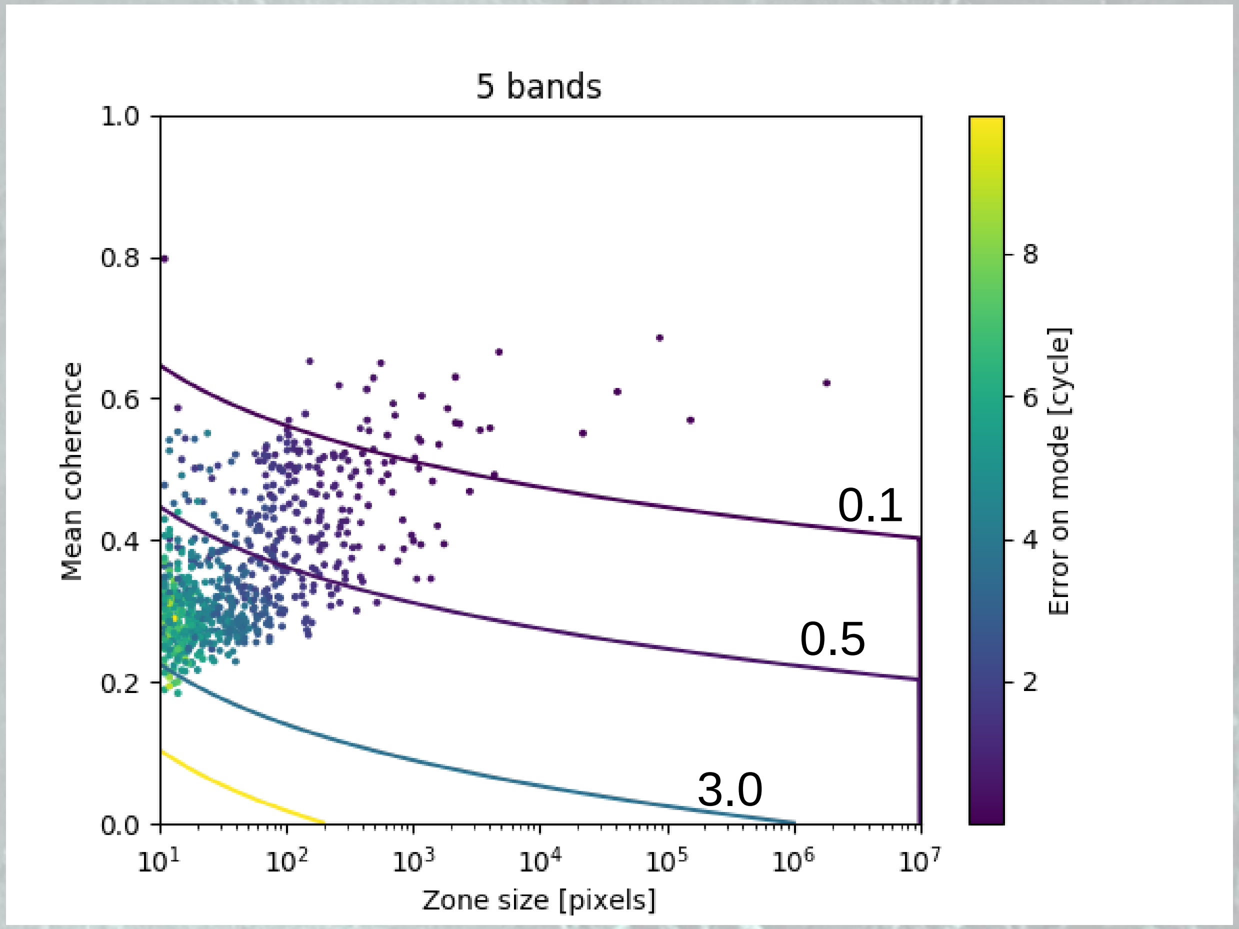
Limits of applicability

- SENTINEL: valid for ~3% of the zones (i.e. correction within 0.5 cycle)
- TANDEM-X: valid for ~30% of the zones

SENTINEL (B = 56 MHz)

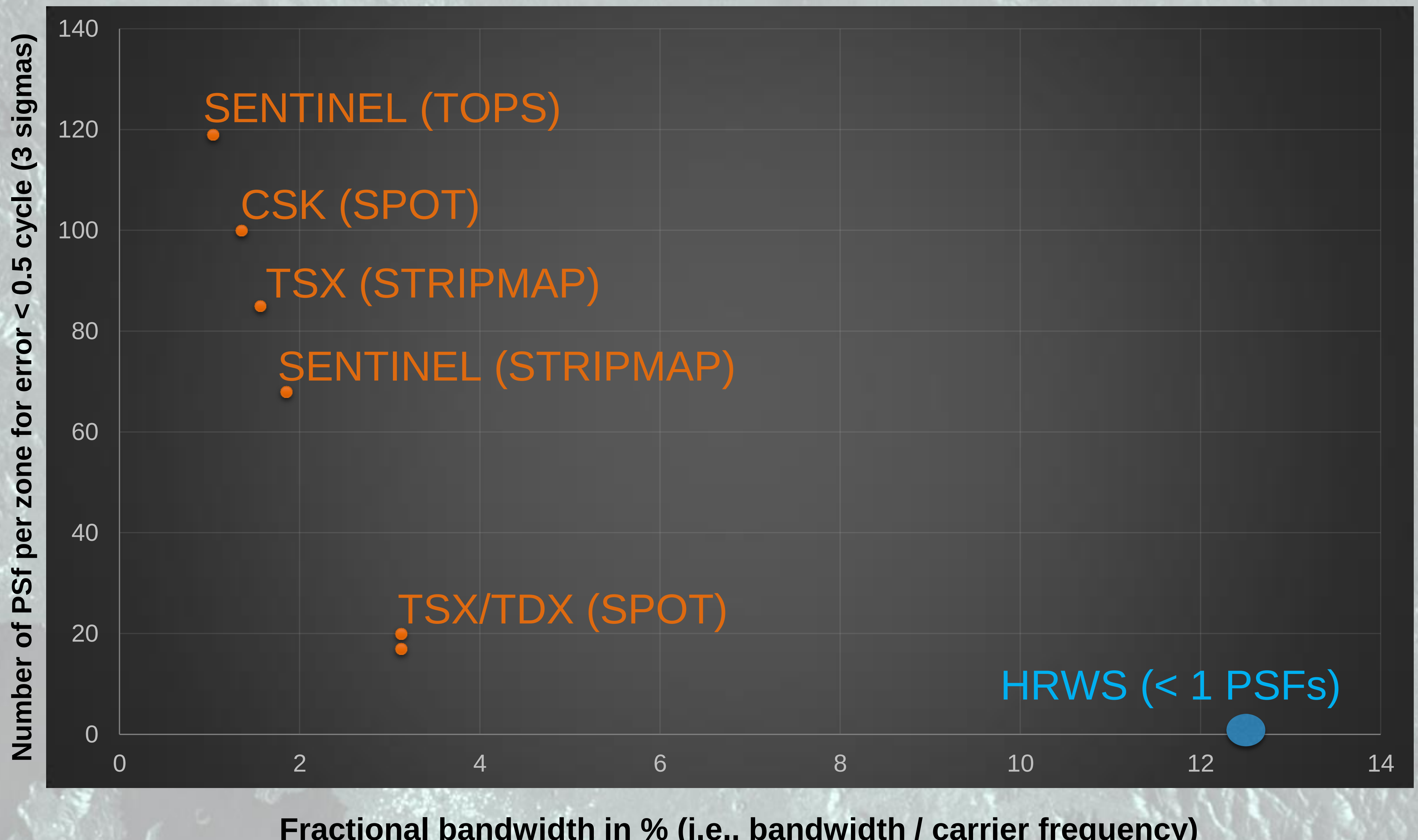


TANDEM-X (B = 300 MHz)



Prediction for HRWS

- High Resolution Wide Swath (HRWS, successor of TANDEM-X): **bandwidth 1200 Mhz**



Conclusions and ongoing work

- **Operational** absolute phase retrieval with **SBInSAR**
- **Typical SBInSAR error of TSX/TDX of ~2.5 cycles per look** (50 to 100 PSfs required per zone for <0.5 cycle at 99.7% confidence)
  - ➫ Method applicable to ~30% of the zones
  - ➫ **~3x above fundamental noise limit**
- **Very promising for future sensors such as HRWS** => accurate DEM and deformation mode
- Ongoing method validation with external DEM, application to bistatic data, and effect of ionosphere