EnVision M5 Orbiter Proposal

Opportunities and Challenges

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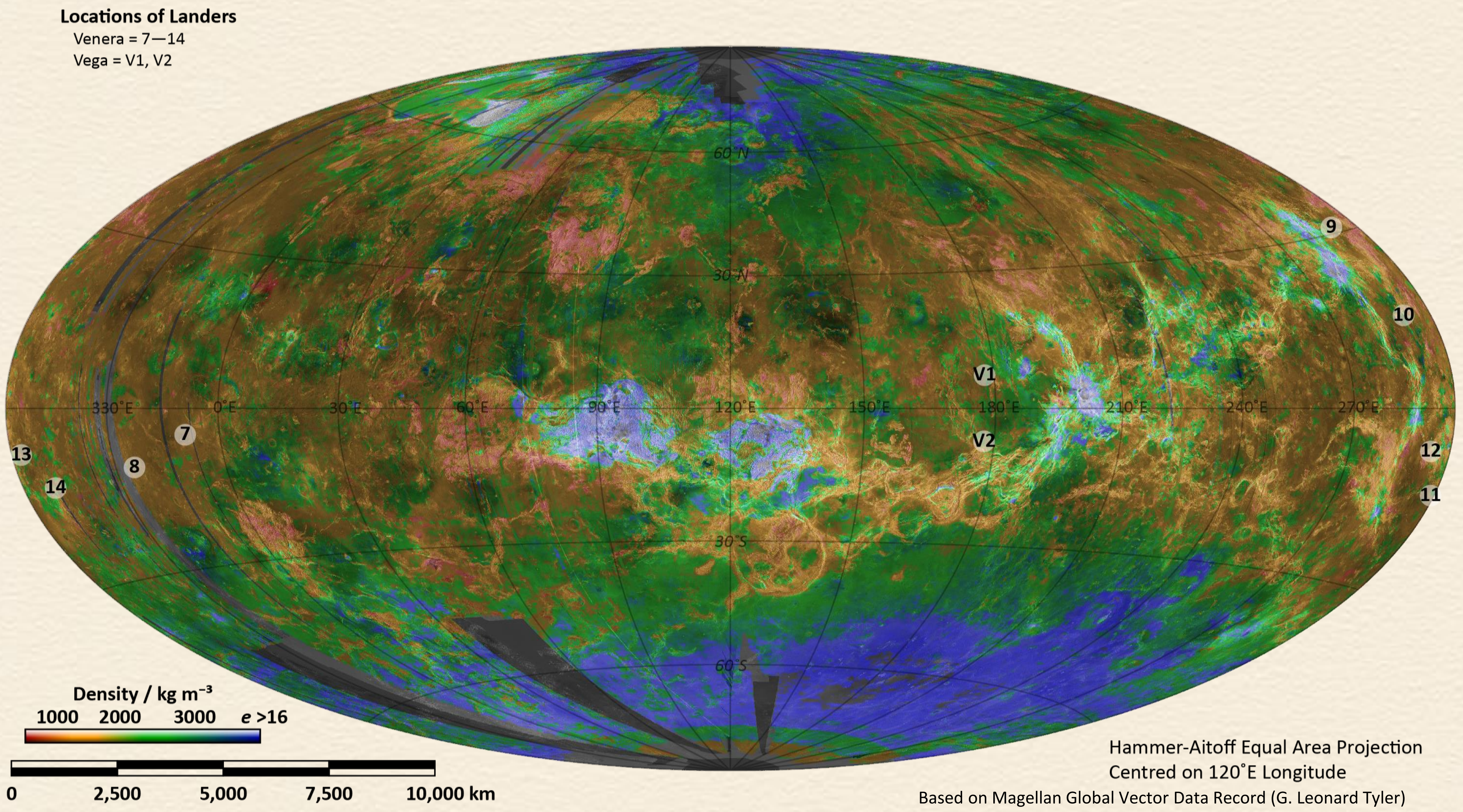
Venus: Current Knowledge

Outstanding Questions and Debate:
- Almost nothing known about the Venus interior
- Why is the crater distribution at odds with the geology?
- Are tesserae old or special?
- Is large scale deformation a thing of the past?
- How active are the volcanoes?

Recent Observations:
- Some evidence for pyroclastic materials
- Sulphur cycle probably most important
- Evidence for a weathering and sedimentary cycle



What new data are required?
- Higher resolution imagery and topography
- Constraints on interior structure
- Exchange rate between the interior and exterior
- Rates of surface change/activity

Venus: Data Requirements

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Goal	Measurement Resolution	Coverage
Surface change	< ±1 cm a^{-1} at 10–50 m spatial	>20% global
Geomorphology	Images at 10–50 m spatial	Global
	Topography at 10–50 m vertical, 100–500 m spatial	Global
Specified targets	Images at 1–10 m spatial	As required
Subsurface structure	Profiles at 10–50 m vertical and 100–500 m spatial	Global
Thermal emissivity	Signal to noise >100 at <50 km spatial	Global
SO_2 concentration	< ±1% at <300 km spatial and 30–40 km altitude	Global
H_2O concentration	< ±10% at <300 km spatial and <15 altitude	Global
D/H ratio	< ±10% at <300 km spatial and <15 altitude	Global
Gravity field	Spherical harmonic degree and order 120	Uniform
Spin Rate	< $\pm 10^{-8}$ (1 minute in one Venus day)	Global
Spin Axis	< ±0·001° in right ascension and declination	North Pole

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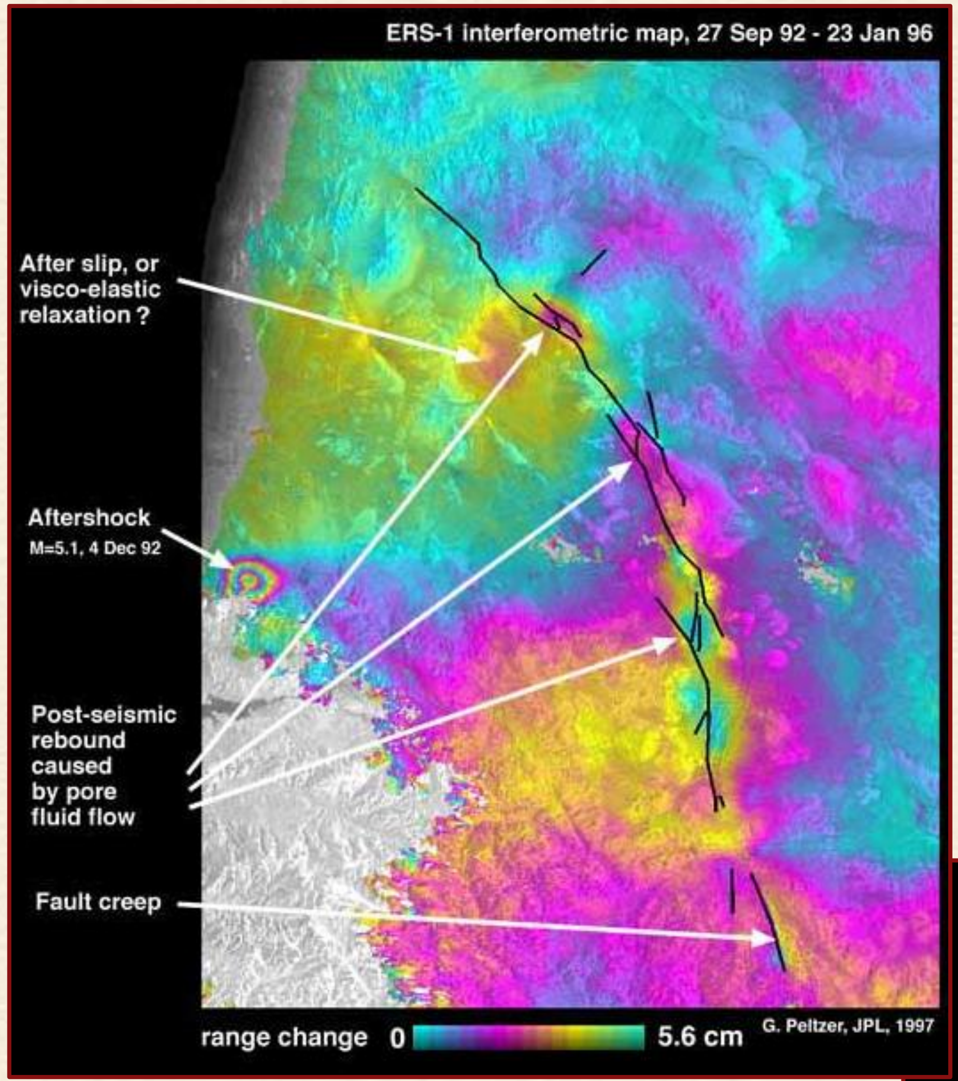
VenSAR: Interferometric Change Detection

Pass to Pass InSAR:

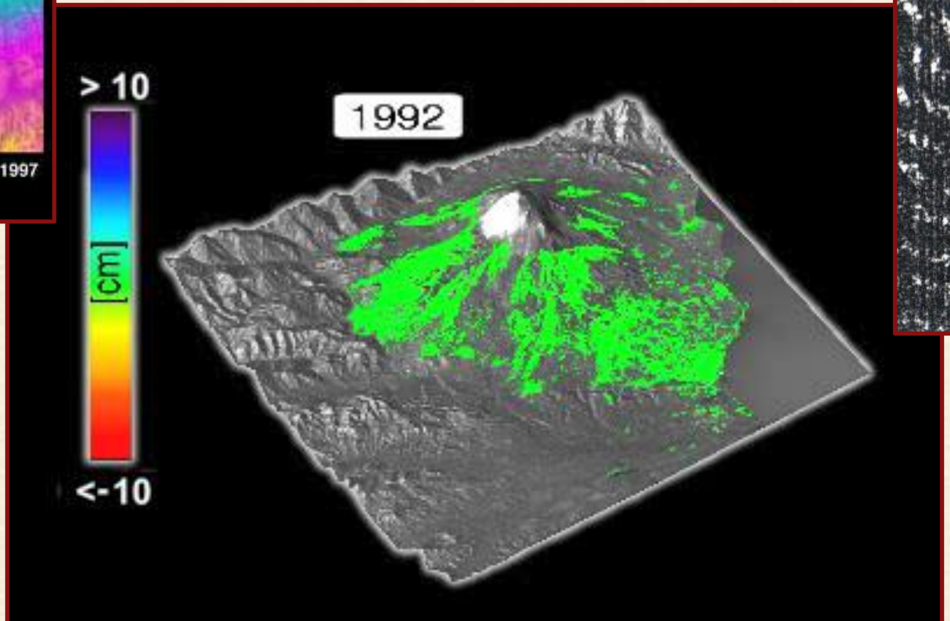
- Increases the quality of InSAR observations by minimizing atmospheric phase distortions while maximizing coherence
- Variance of estimated topography and deformation parameters can be reduced
- Long spatial baselines increases topographic resolution
- Helps separate topographic and deformation related phase components
- Can be achieved using electronic shift in transmitted frequency, reducing bandwidth and data rates

Provides initial results in hours not months



InSAR detection of post-seismic deformation.
[Peltzer 1997]

7½ hour interferogram of Venus north pole from Magellan
[Goldstein et al. *pers. comm.*]



Magmatic inflation at Etna (ERS data)

Venus: Challenges and Design Drivers

Shrouded in permanent clouds, the 90 bar, 750 K Venus atmosphere is prohibitive for surface rovers and effectively opaque at wavelengths < ~3·5 cm

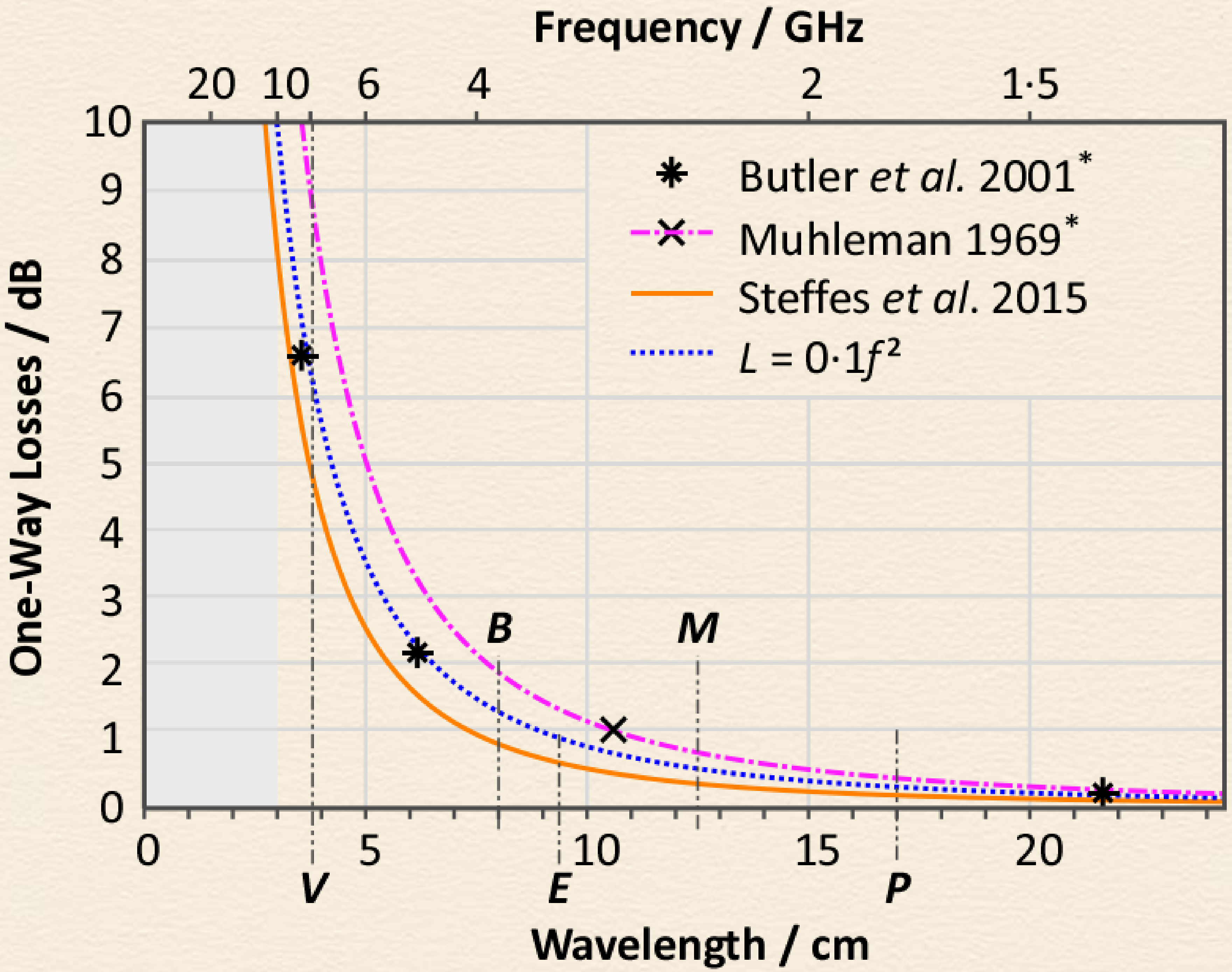
Total one-way losses:

- 6·20 dB at 3·8 cm, 8·4 GHz X/C-band
- 1·69 dB at 5·6 cm, 5·4 GHz C-band
- 0·55 dB at 9·4 cm, 3·2 GHz S-band

EnVision's InSAR coherence requirement drives our choice for an S-band radar

In other respects the atmosphere is benign:

- The total electron count is <1 TeV
- IR brightness temperature ~50 K cooler than Earth
- Drag-free orbits above 220 km altitude



V=VERITAS B=Venera 15/16 E=EnVision M=Magellan P=Pioneer Venus

1 & 2 include data points beyond the range of the graph

Venus: Challenges and Design Drivers

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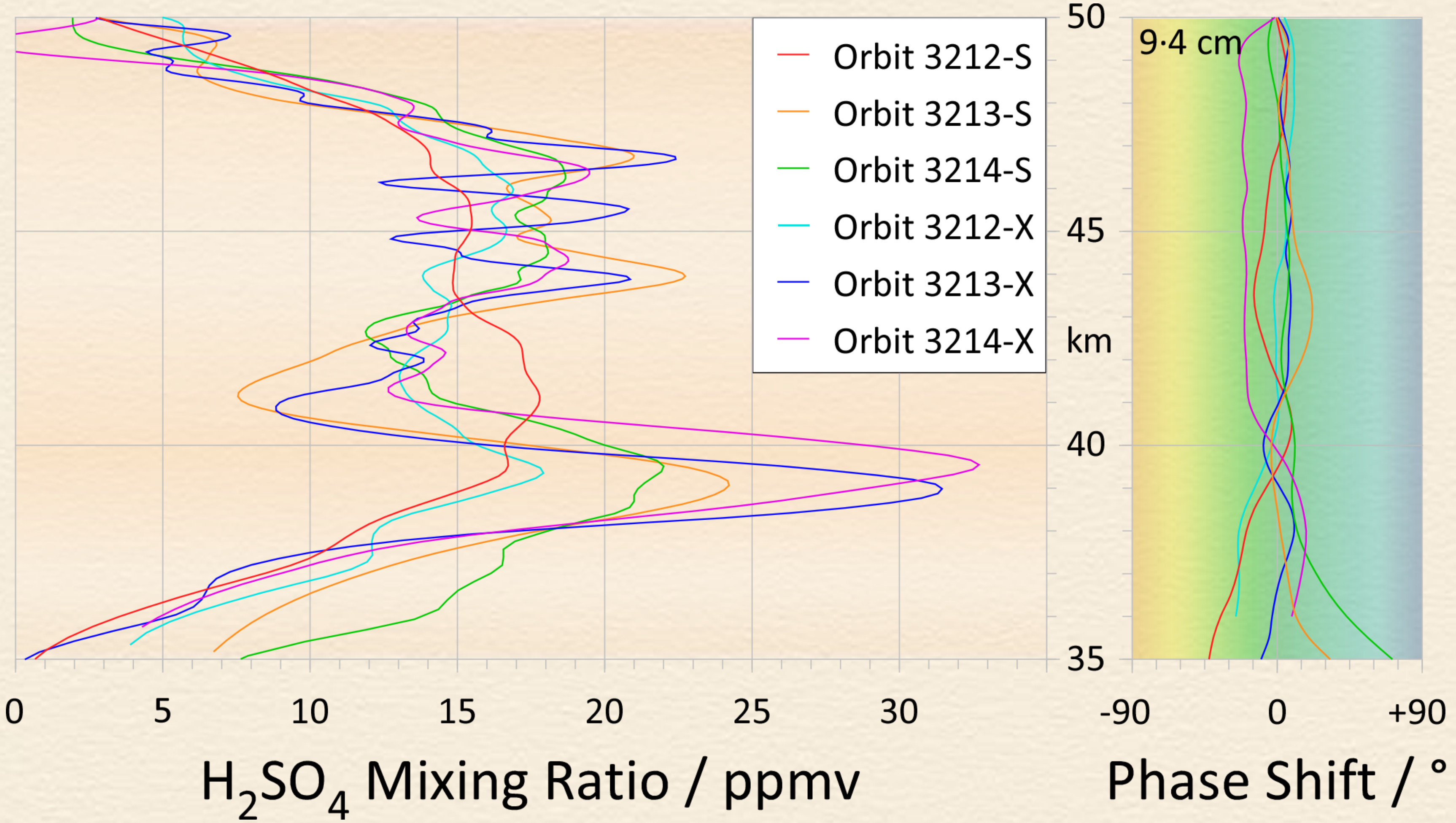


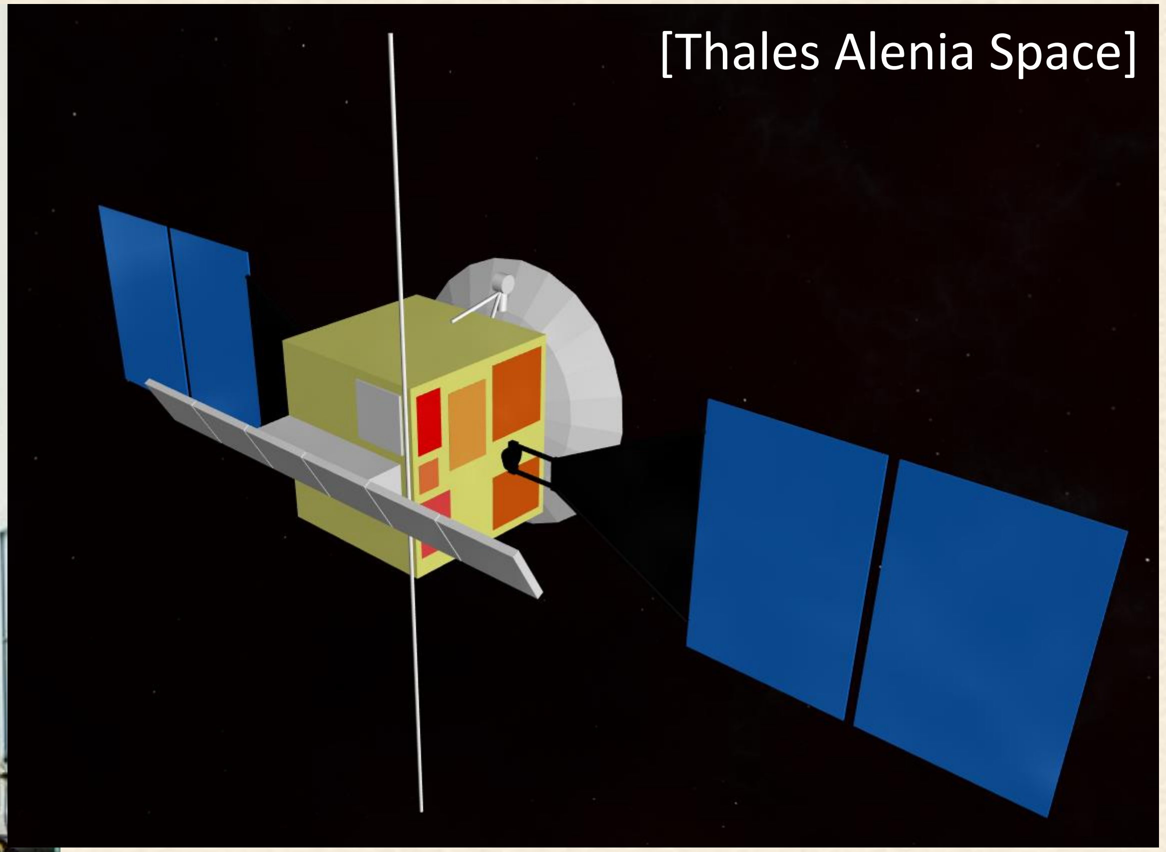
Dataset: MGN-V-RSS-5-OCC-PROF-ABS-H2SO4-V1.0
Jenkins, 1994

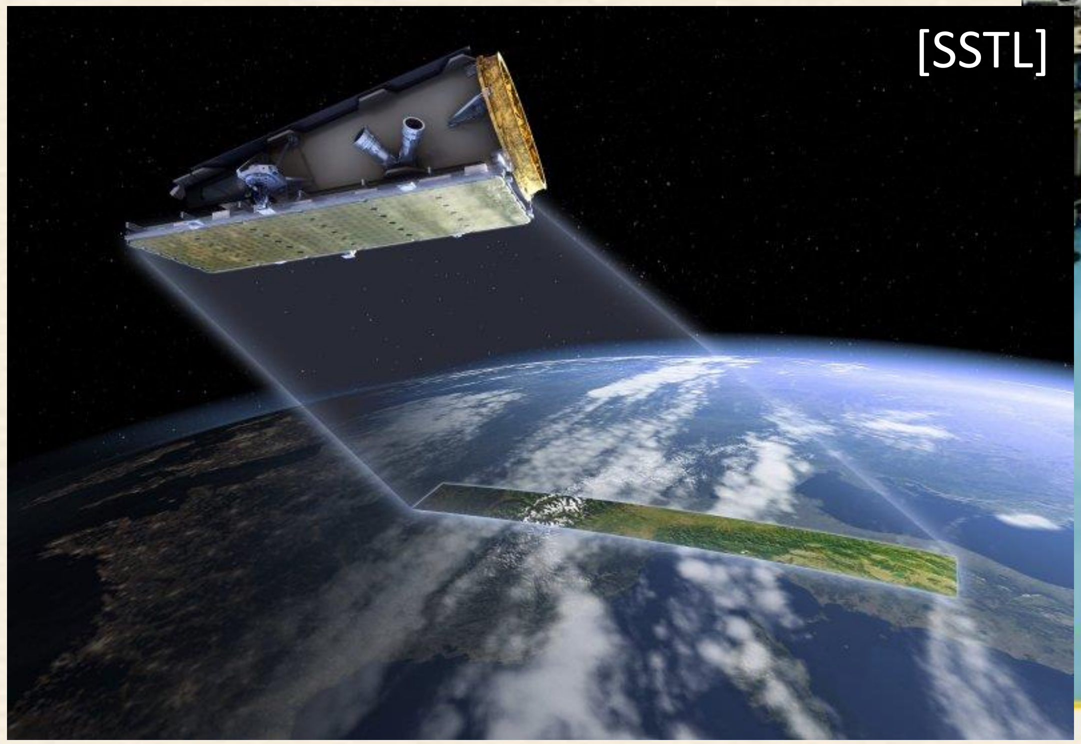
VenSAR: Adapted from NovaSAR-S

NovaSAR will consist of four small low cost SAR satellites providing continuous global environmental management and disaster monitoring.

The first is being funded by the UK government for launch in 2016.

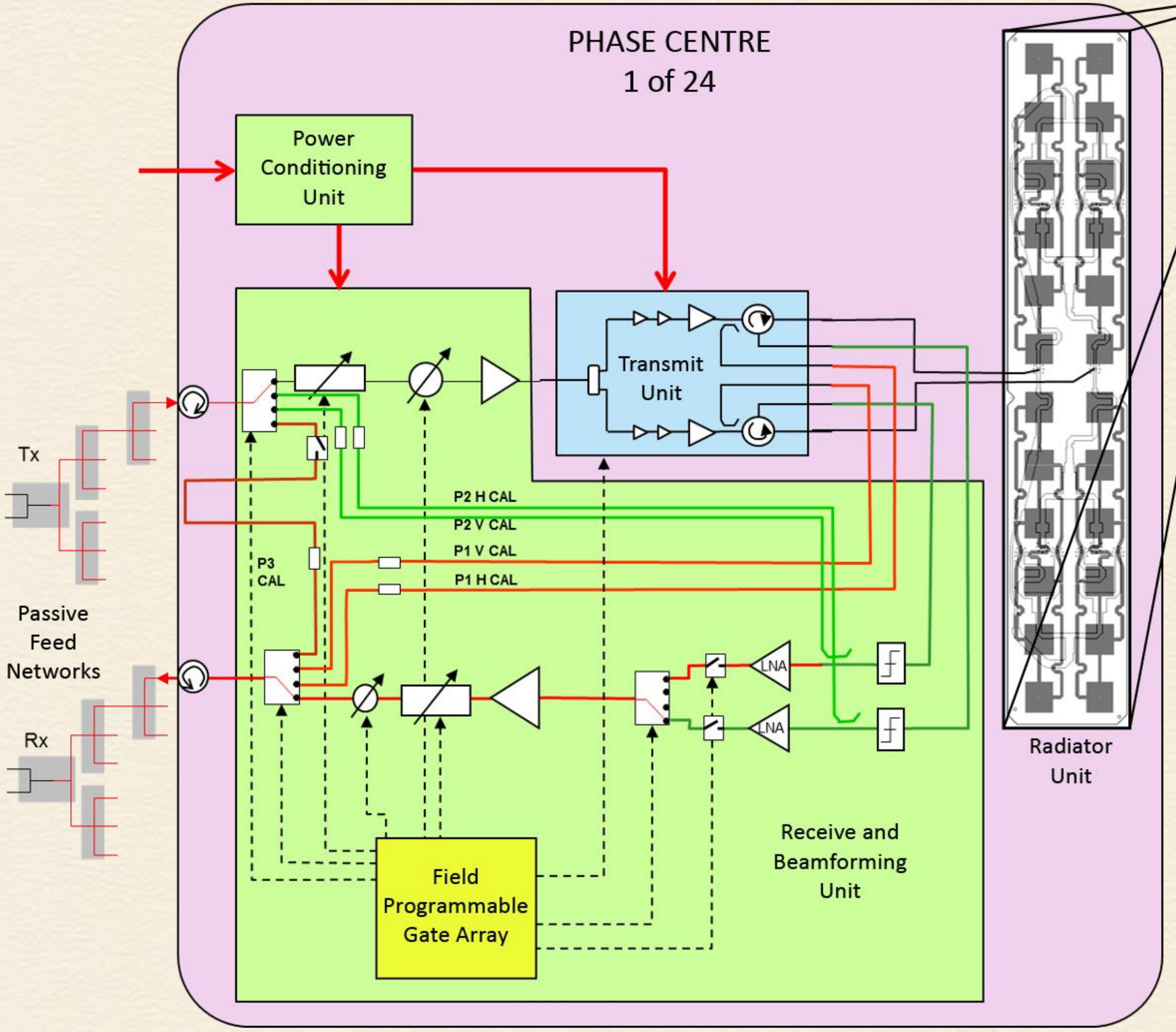

NovaSAR being assembled at SSTL


[Thales Alenia Space]


[SSTL]

EnVision is a proposed ESA M-class mission to Venus designed to find out what made Earth's closest neighbour so different. It will carry a subsurface sounder, emissivity mapper and spectrometer, and its primary instrument, the NovaSAR-S based VenSAR.

VenSAR: Phased Array SAR



The reverse side of each phase centre has:

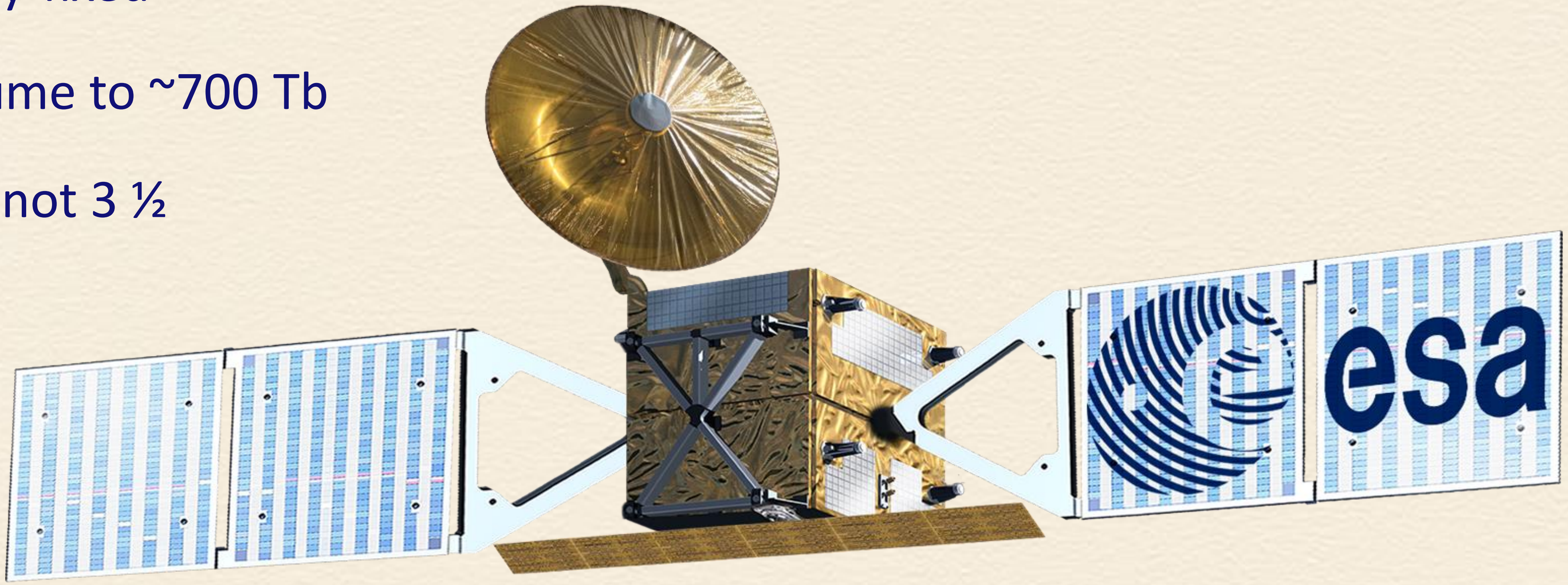
- a power conditioning unit,
- a 115 W RF transmit unit,
- a radiator unit, and
- a receive/beam control unit,

making for an independently controllable, fully scalable array.

The VenSAR antenna consists of 24 of these phase centres arranged in 6 columns of 4 rows spread over 3 panels (2 columns per panel), oriented with the orbit track along the major axis.

M5 Call: Key Changes

- 550M€ cost on completion provides significant margin for EnVision (M4 was 450M€)
- VenSAR is already optimised for Venus and will not fundamentally change
- VEM gains a UV spectrometer channel for mesospheric SO_2
- 3 m HGA antenna becomes body-fixed
- 25% reduction in total data volume to ~700 Tb
- Nominal mission length 5 years not 3 ½
- Suggested launch opportunity is October 2029



VenSAR: Spatial vs Radiometric Resolution

5·47 m x 0·6 m (6 columns x 4 rows)

S-band, 3·2 GHz, upto 182 MHz Tx bandwidth

DC Power: 820 W at 5% Tx duty ratio

1874 W at 20% Tx duty ratio

Selectable single polarisation: HH, VV and HV

Along track (azimuth) resolution is fixed at ~3 m

Across track (range) resolution is a trade off between data rate and resolution:

9 looks is the ideal compromise:

27 m square pixels at 86 Mbps at 4% Tx

High resolution is achieved by maximising bandwidth: 2 x 3 m single look for 6 m square pixels at 6 looks at 901 Mbps at 20% Tx

Sliding spotlight can achieve 1 m resolution

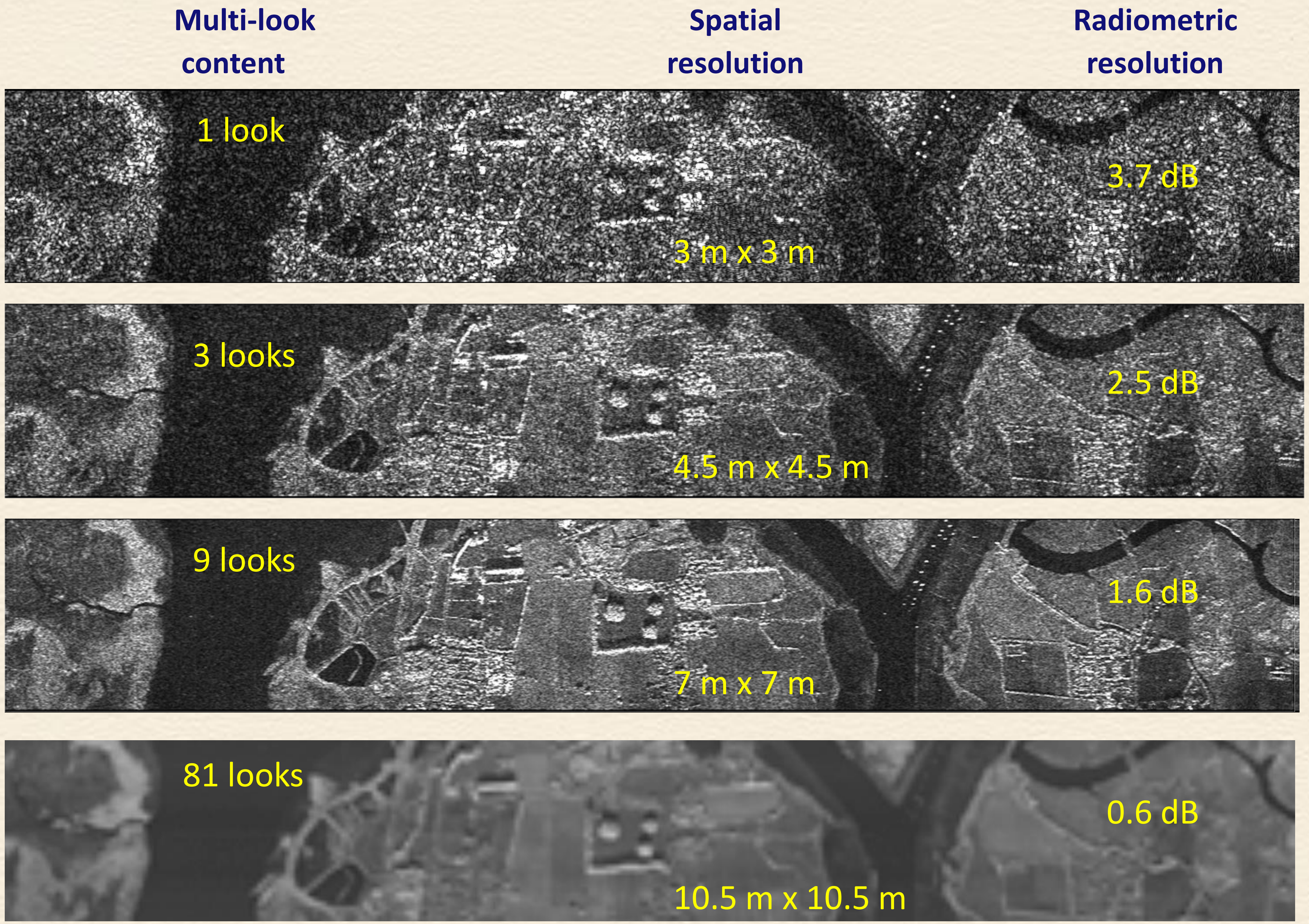
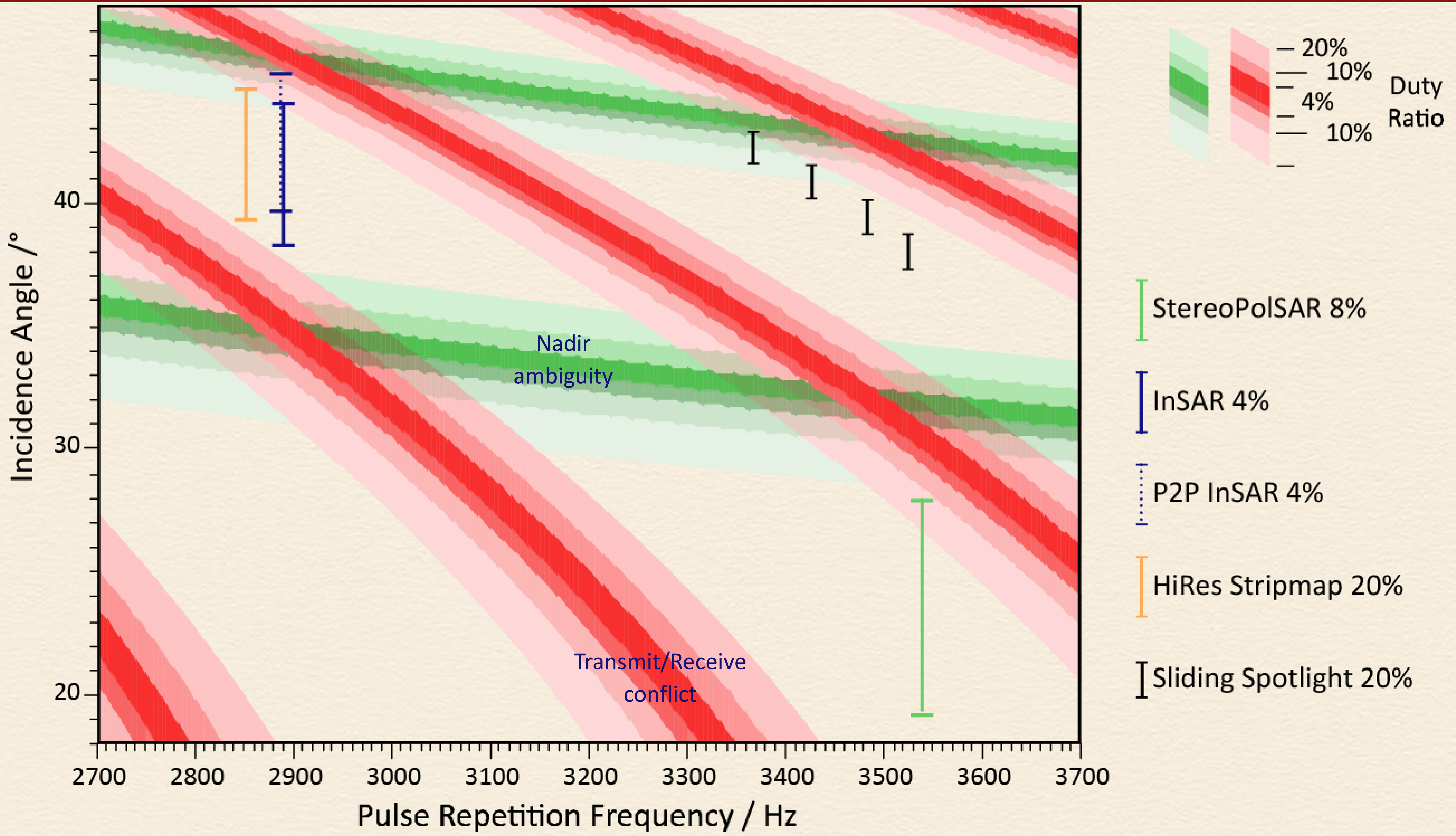
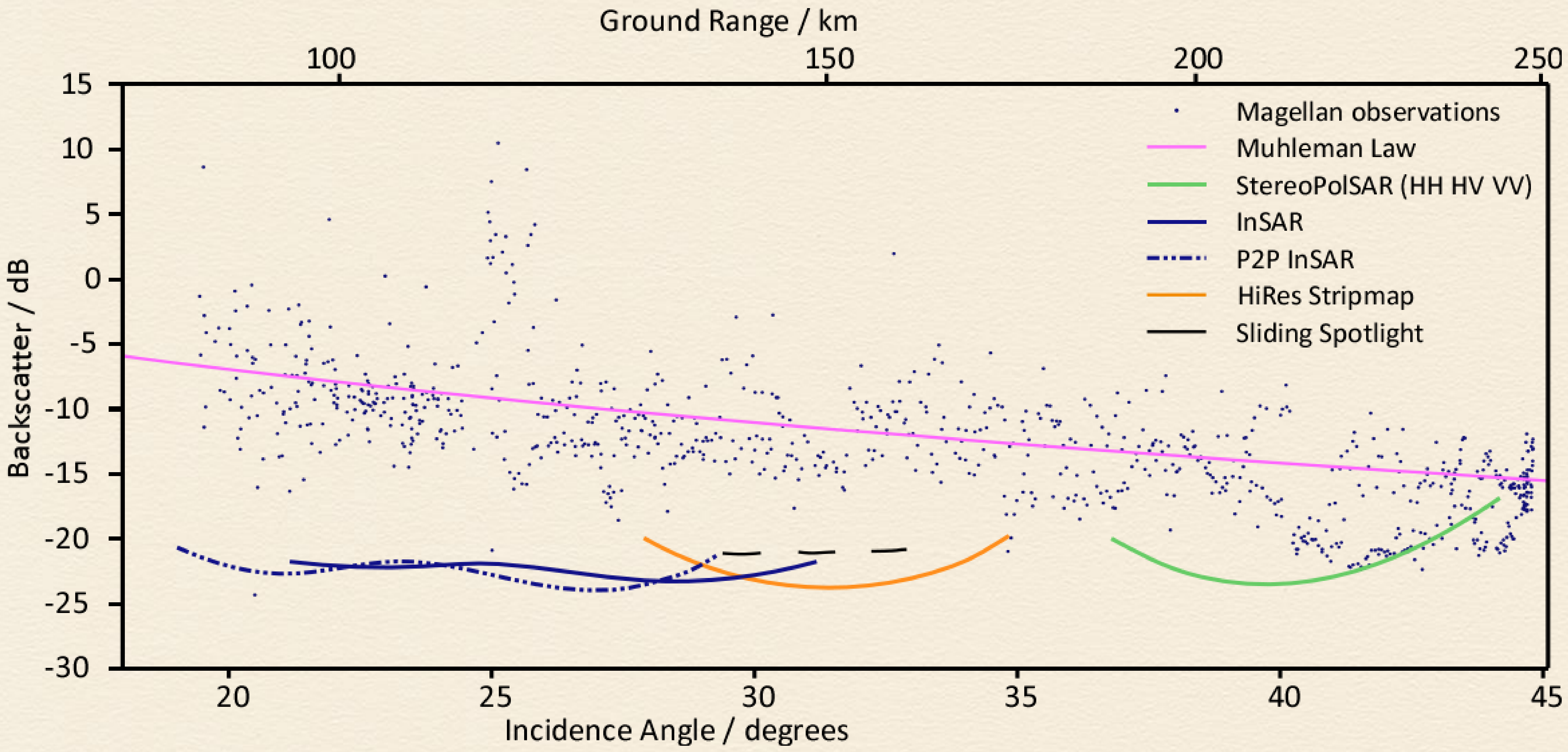


Image sequence showing impact of multi-looking; normally higher spatial resolution reduces number of looks possible. Simulation based on airborne NovaSAR-S test data. [© Airbus Defence and Space]

VenSAR: Modes and Swath Selection

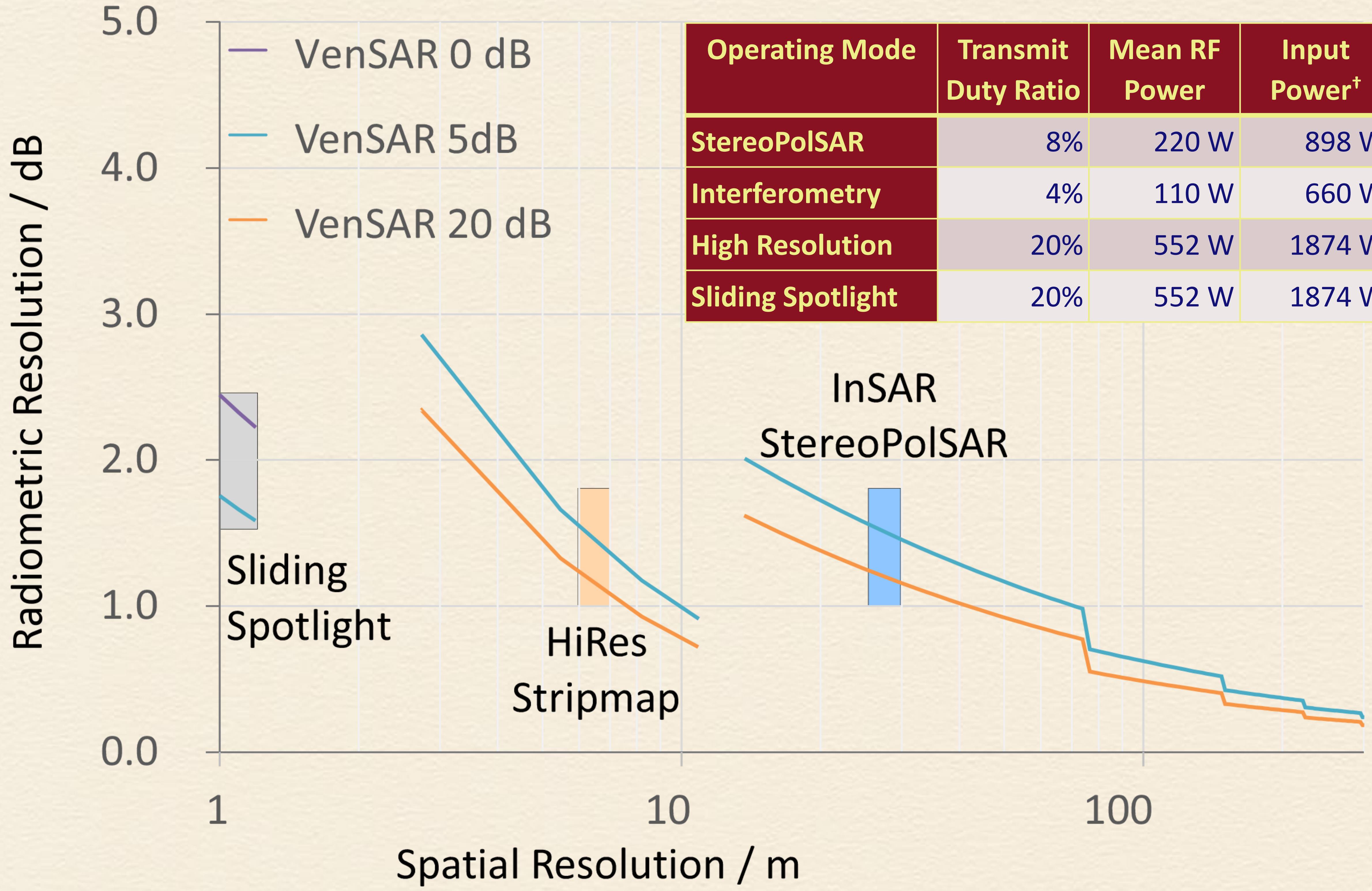


VenSAR: Sensitivity

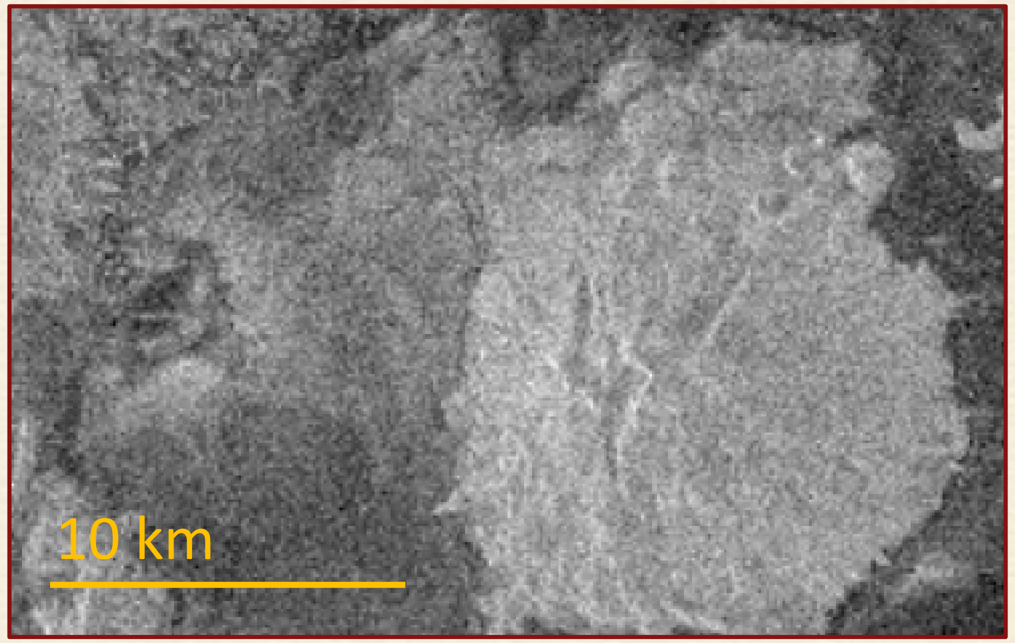


VenSAR: Sensitivity

Operating Mode	Transmit Duty Ratio	Mean RF Power	Input Power†	Image Duration	Swath Width	Data Rate
StereoPolSAR	8%	220 W	898 W	9·2 min	45 km	162 Mbps
Interferometry	4%	110 W	660 W	9·2 min	53 km	65 Mbps
High Resolution	20%	552 W	1874 W	3·1 min	40 km	856 Mbps
Sliding Spotlight	20%	552 W	1874 W	2·184 s	10 km	591 Mbps



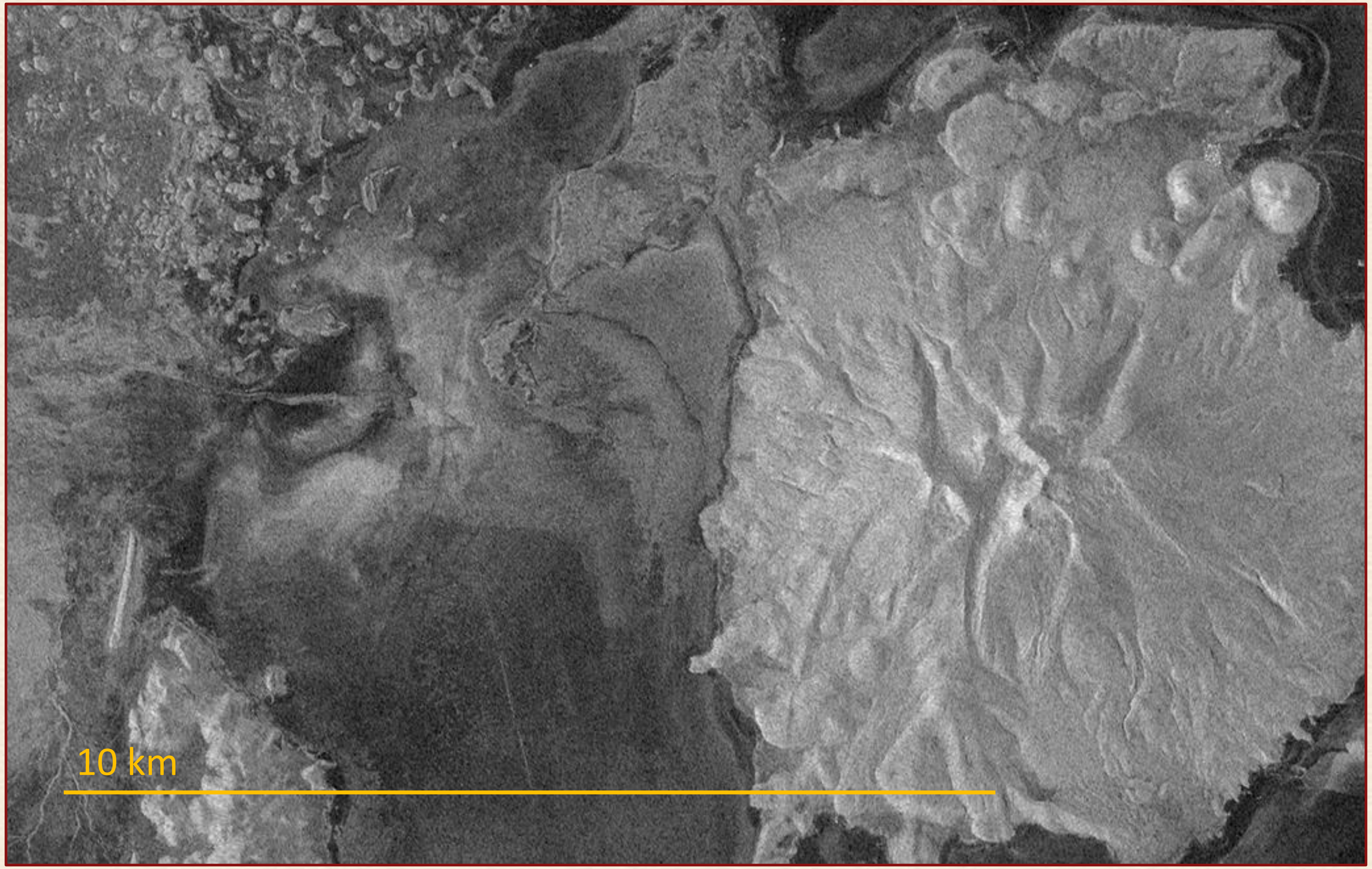
VenSAR: Comparison with Magellan



Left: 110 m resolution, 5-look image posted at 75 m per pixel to simulate a Magellan image from Venus. Note that the volcanic cone suffers from layover.

Right: Simulated standard resolution (27 m) 9-look VenSAR image. Layover is corrected using the stereo-derived 135 m resolution DEM. In addition to higher spatial resolution and reduced noise, the image has greater sensitivity and a factor of 4 improvement in radiometric resolution.

[All images derived from Sentinel 1a data]



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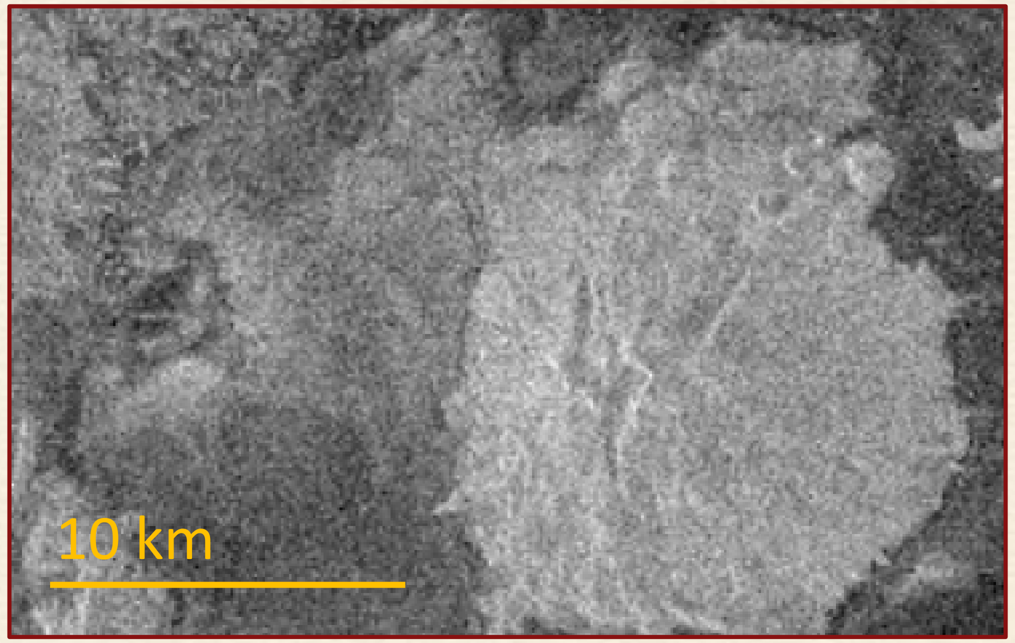

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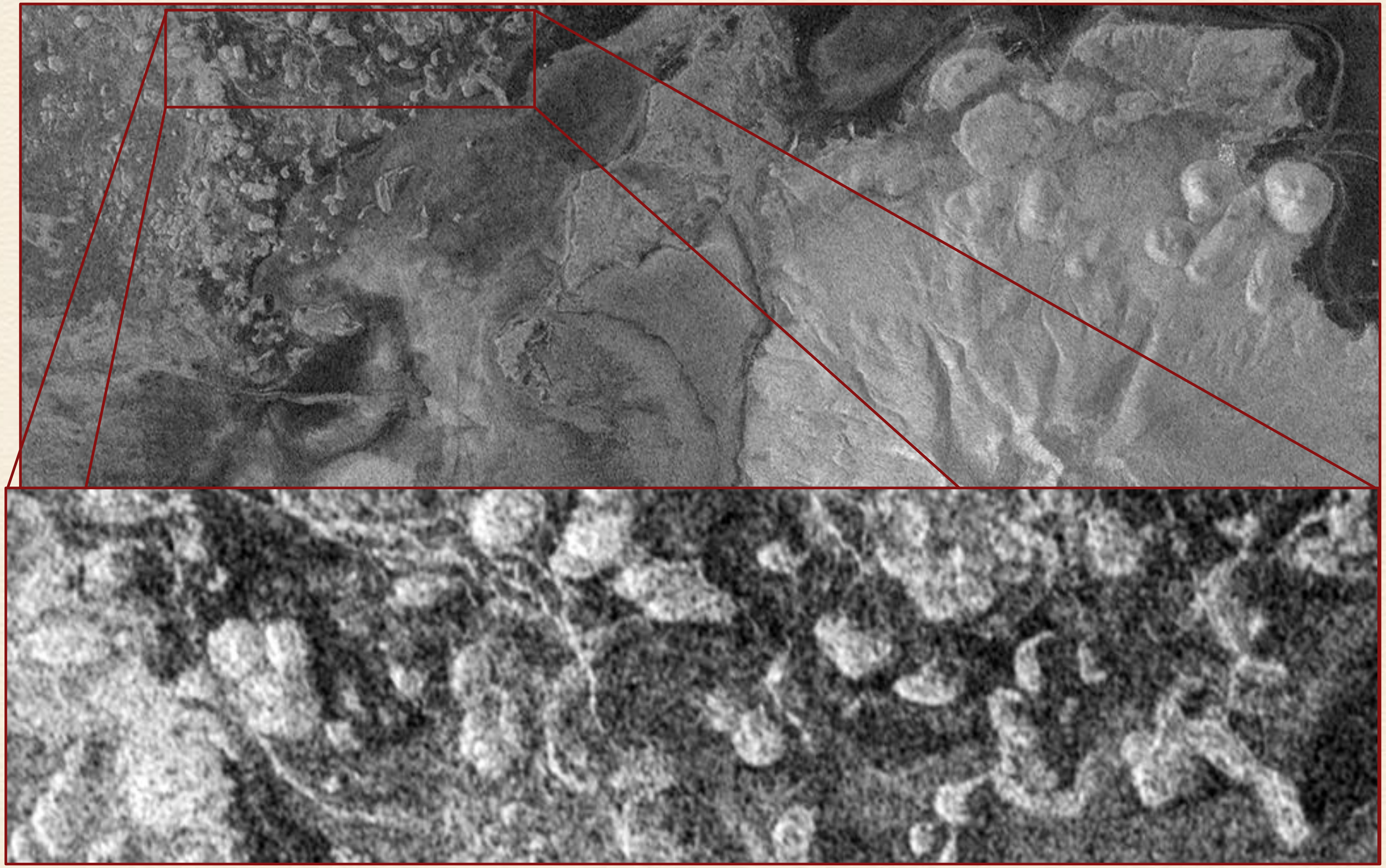


Right: Simulated high resolution (6 m) 6-look VenSAR image. This simulation uses scaled 3-look 14 m Sentinel-1 data; VenSAR will achieve better spatial and radiometric resolution.

[All images derived from Sentinel 1a data]

VenSAR: StereoPolSAR

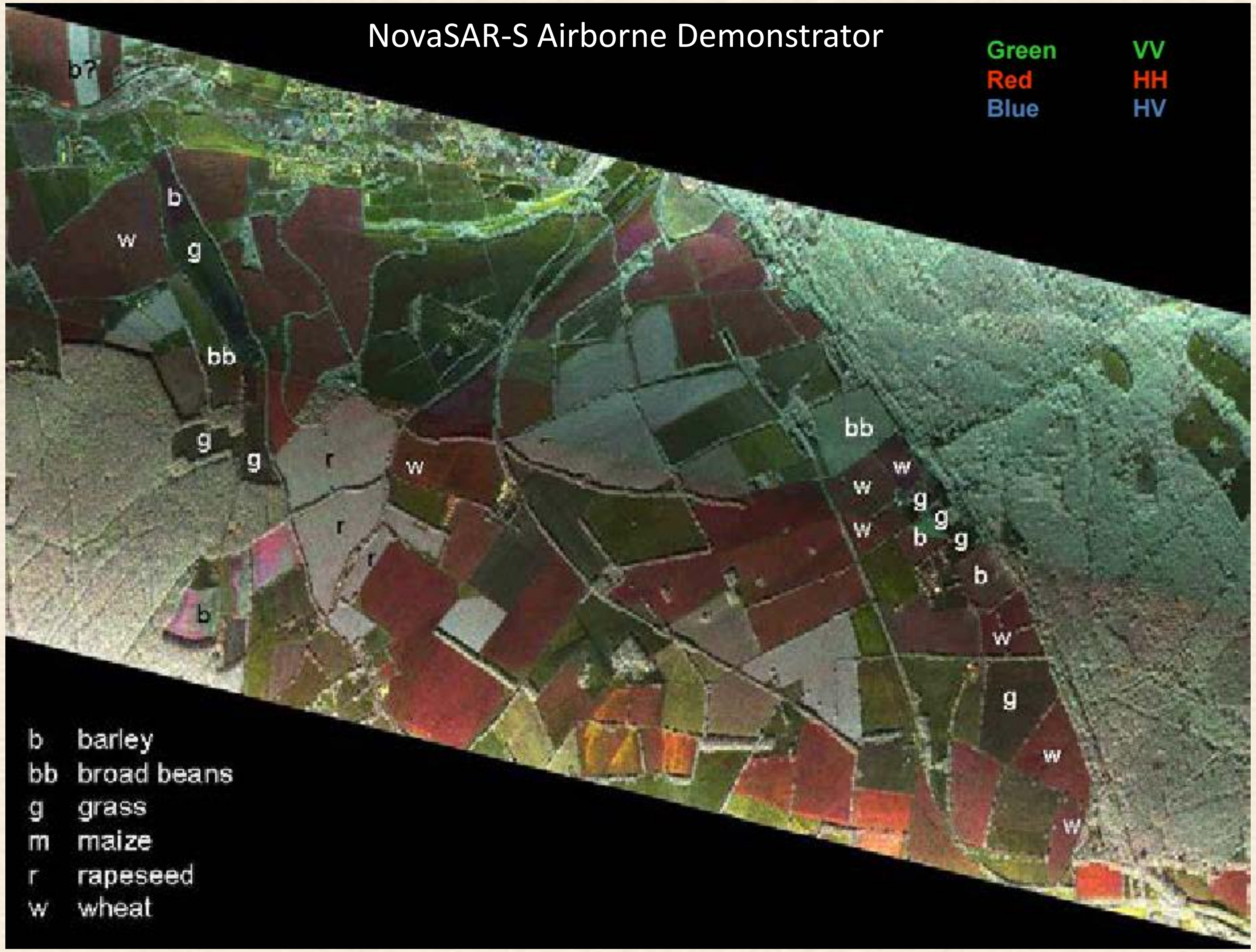
Understanding the character and extent of different surface materials requires polarimetric data.

Terrestrial studies show that the HV and VH polarisations states are almost identical, so that only HH, VV, and HV polarised data are required.

VenSAR can transmit and receive bursts of both horizontal and vertical polarisations, allowing a mix of HH, VV, HV polarised images to be obtained.

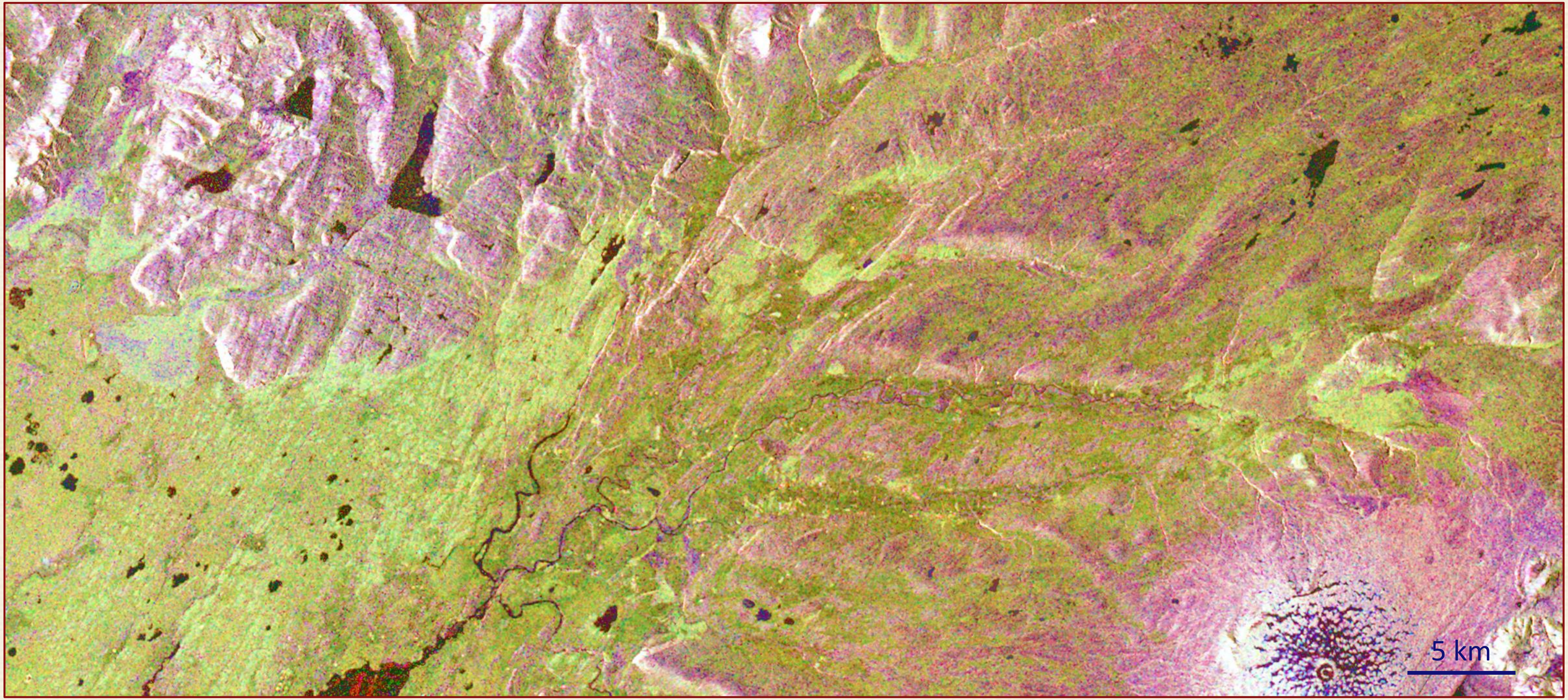
Burst mode causes scalloping that degrades the along track image resolution by a factor of 2N + 1, where N is the number of polarisation states, hence the degradation is a factor of 7.

Polarimetric data will be collected at a lower incidence and at a resolution of 30 m to form complementary stereo pairs to the InSAR image swaths.



Although Venus lacks vegetation, Venera lander images show a variety of surface materials that can be distinguished in multipolar imagery.

VenSAR: StereoPolSAR



Simulated VenSAR 9-look 30 m StereoPolSAR VV-VH-HH image of north east Iceland (based on Sentinel-1 data).

VenSAR: StereoPolSAR

Resolution requirement:

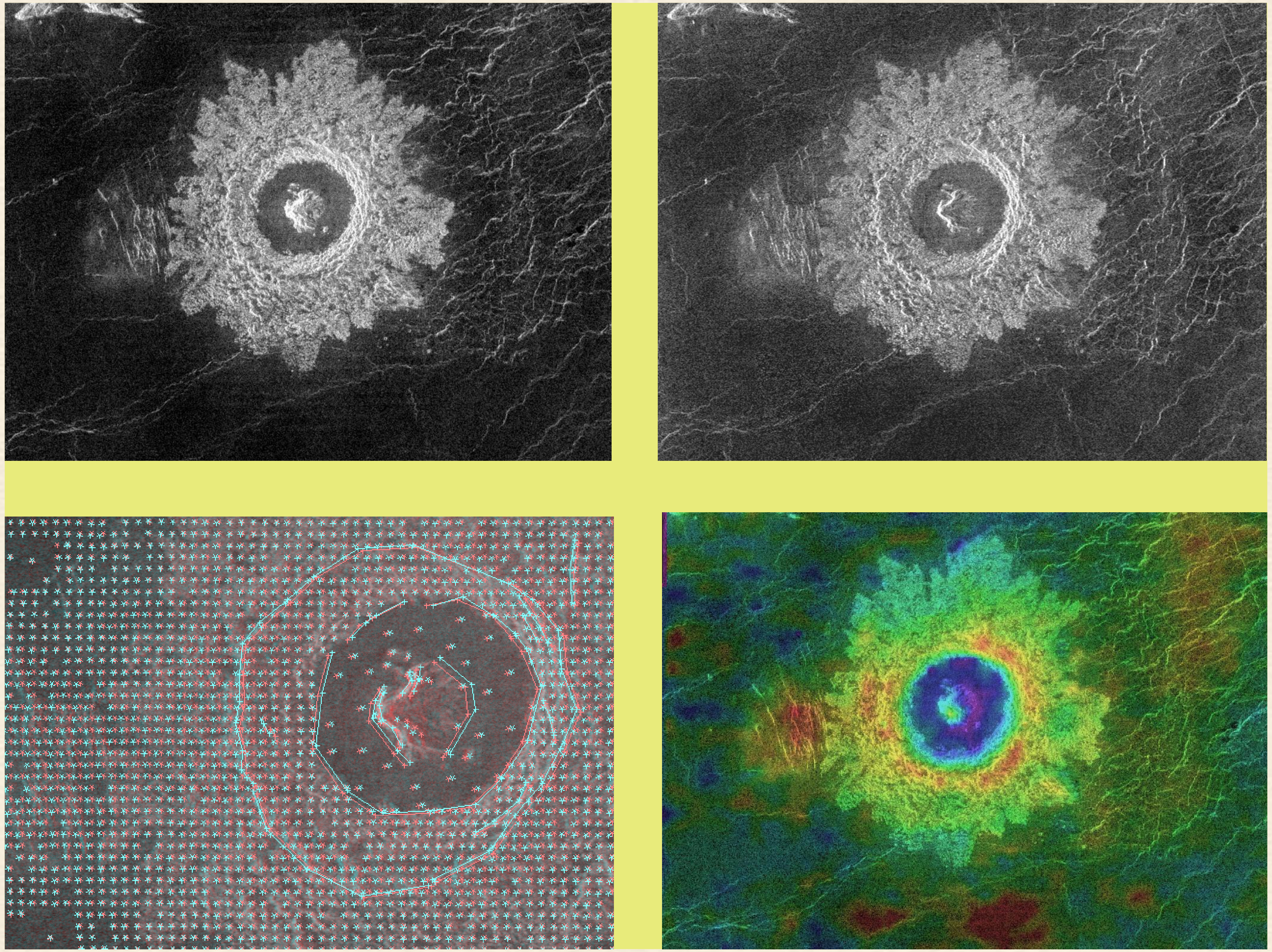
- Globally to better than a few tens of metres (Magellan was >100 m)
- Resolve flow boundaries, tesserae fault blocks, crater floor darkening
- Individual lava flows, canali, boundaries, etc. in apparently featureless areas

InSAR:

- Unwrapped DEM at 27 m spatial and ~5 cm vertical resolution
- Most suited to smooth terrain; fails if coherence lost over ~90 minutes

Stereo:

- Achieves topographic data at better than 250 m spatial and 20 m vertical resolution
- Works best in rough areas, complementing interferometric topography

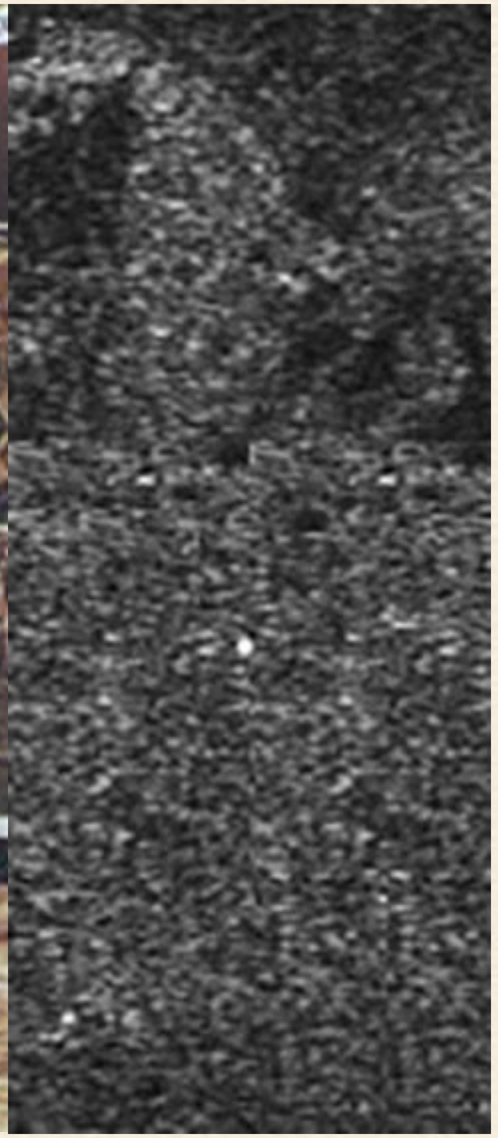


[R Herrick]

Ground Truth: Venera Lander Detection

The 2 m diameter metallic body and coiled antenna array of the Venera landers will contrast strongly with the Venus surface.

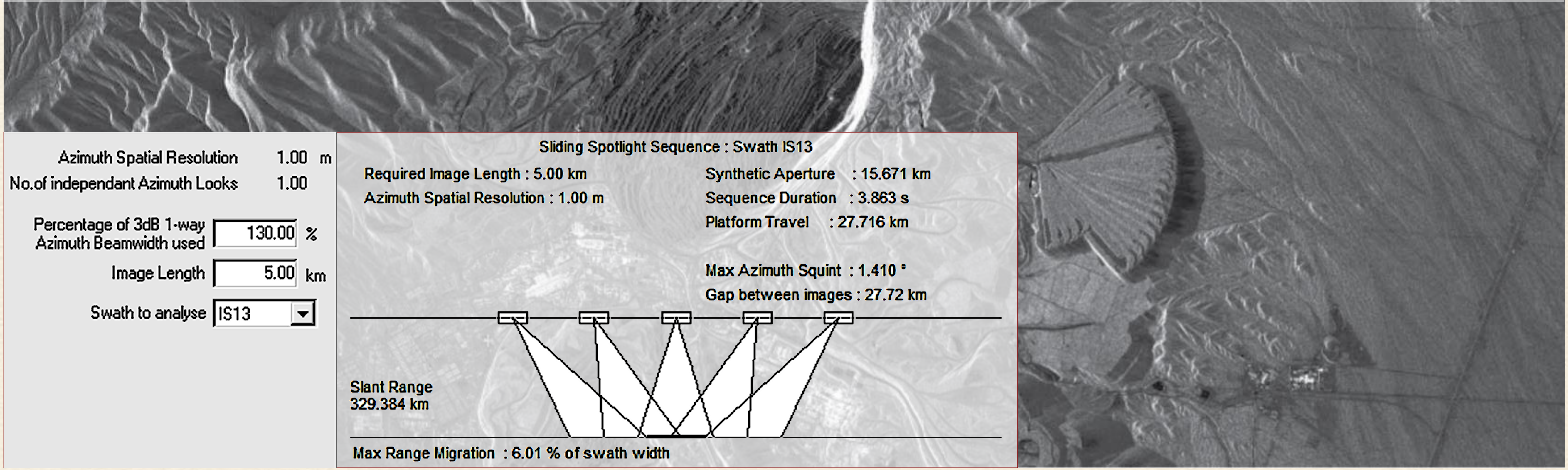
Increasing the transmit power and bandwidth to the maximum sustainable permits a 40 km wide swath at 2·0 m resolution (1 look), in which the landers will be identifiable as a very bright spot in the terrain.



This high resolution mode will also be useful for imaging canali, tesserae and other features of geological interest.

Ground Truth: Sliding Spotlight

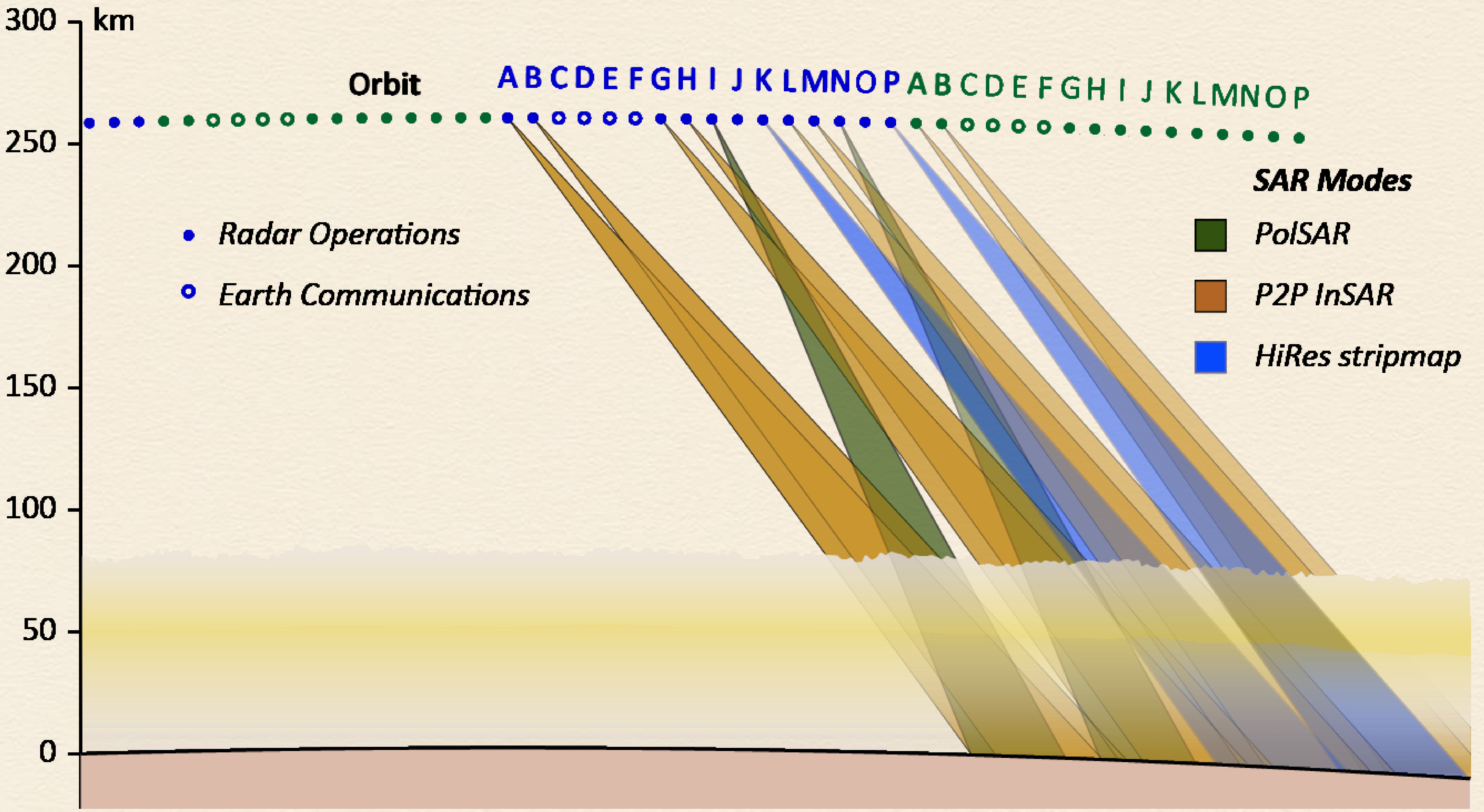
Sliding spotlight mode allows imaging of a 5 x 5 km at just 1 m resolution, sufficient to identify the landers and discriminate human-scale features at other selected targets. Up to 20,000 1-m resolution images covering a total of 500,000 km² may be obtained.



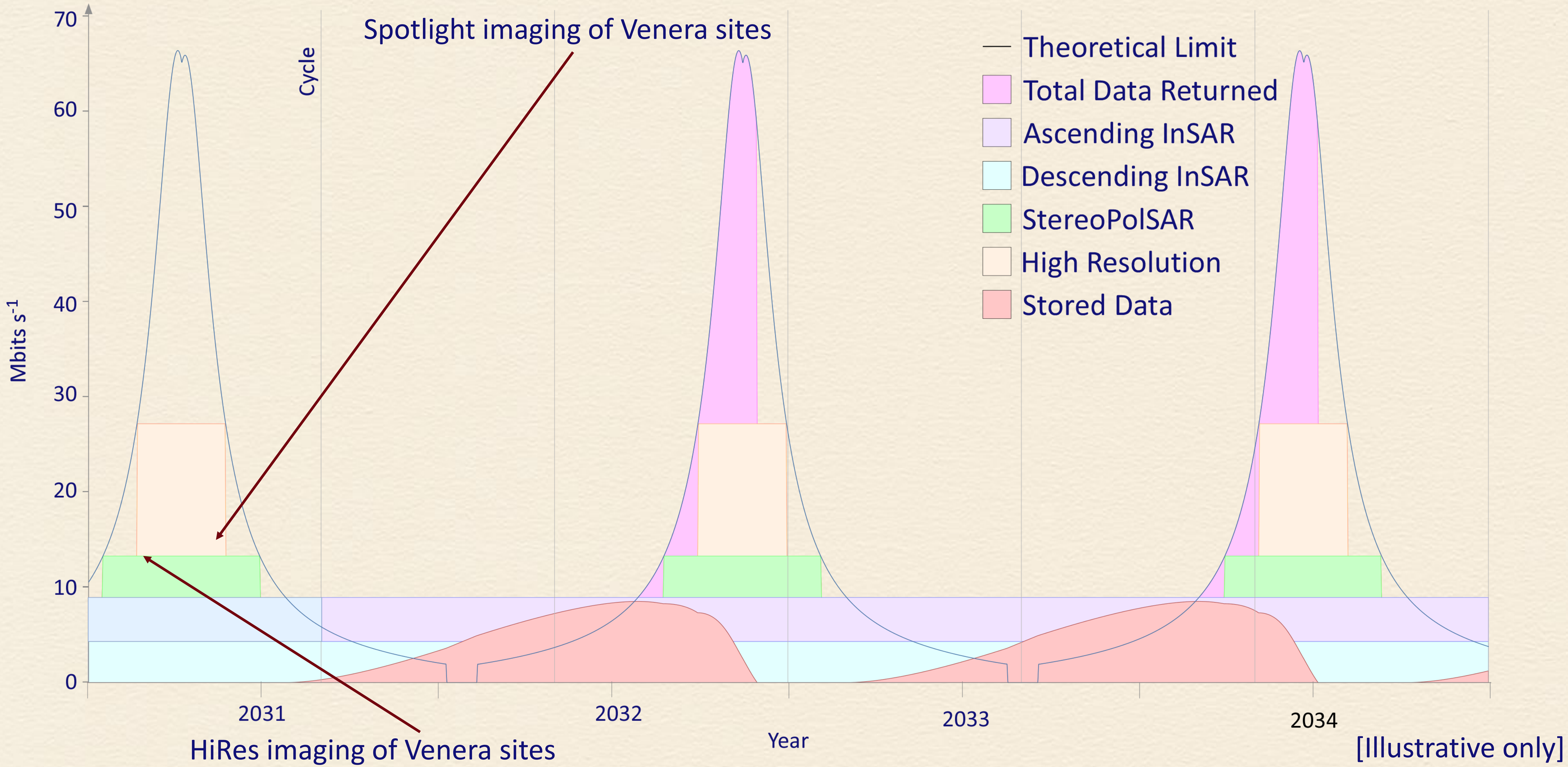
Sliding spotlight image acquired by TerraSAR-X over the Chuquicamata copper mine, Chile. The range is horizontal, and the azimuth is vertical, with near range on the left side. The image dimensions are 6·8 km × 10·9 km (azimuth × slant range).

[Prats et al. 2010]

EnVision: Mapping Strategy



EnVision: Data Return and Coverage

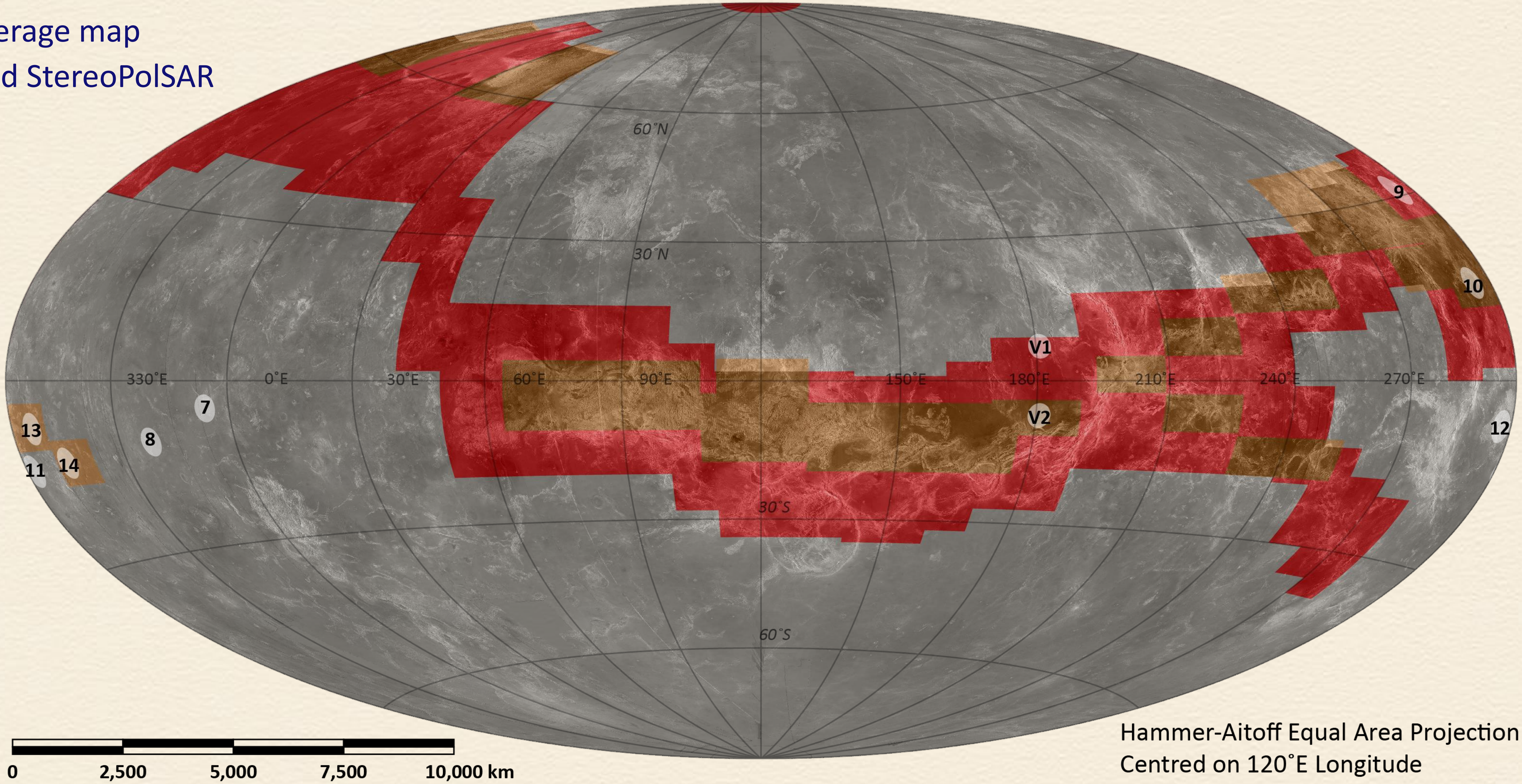


EnVision: Data Return and Coverage

Illustrative coverage map

Red = InSAR and StereoPolSAR

Brown = HiRes



Hammer-Aitoff Equal Area Projection
Centred on 120˚E Longitude

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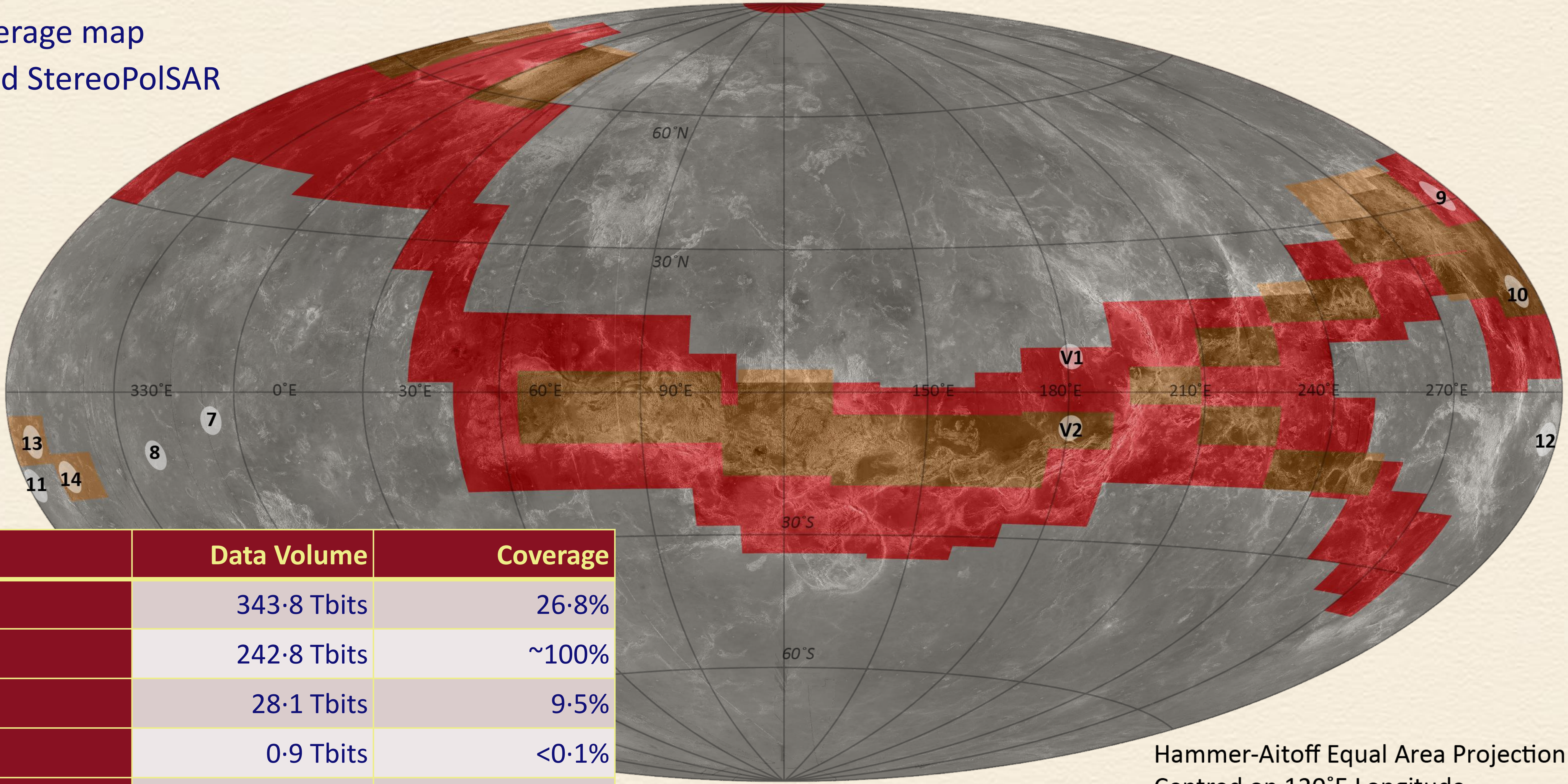


Hammer-Aitoff Equal Area Projection
Centred on 120˚E Longitude

Data Type	Data Volume	Coverage
Interferometry	343·8 Tbits	26·8%
Polarimetry	242·8 Tbits	~100%
High Resolution	28·1 Tbits	9·5%
Sliding Spotlight	0·9 Tbits	<0·1%
Subsurface Sounder	23·9 Tbits	~100%
VEM-M	11·1 Tbits	~100%

Conclusions

We have a *very poor* understanding of Venus, particularly its surface materials

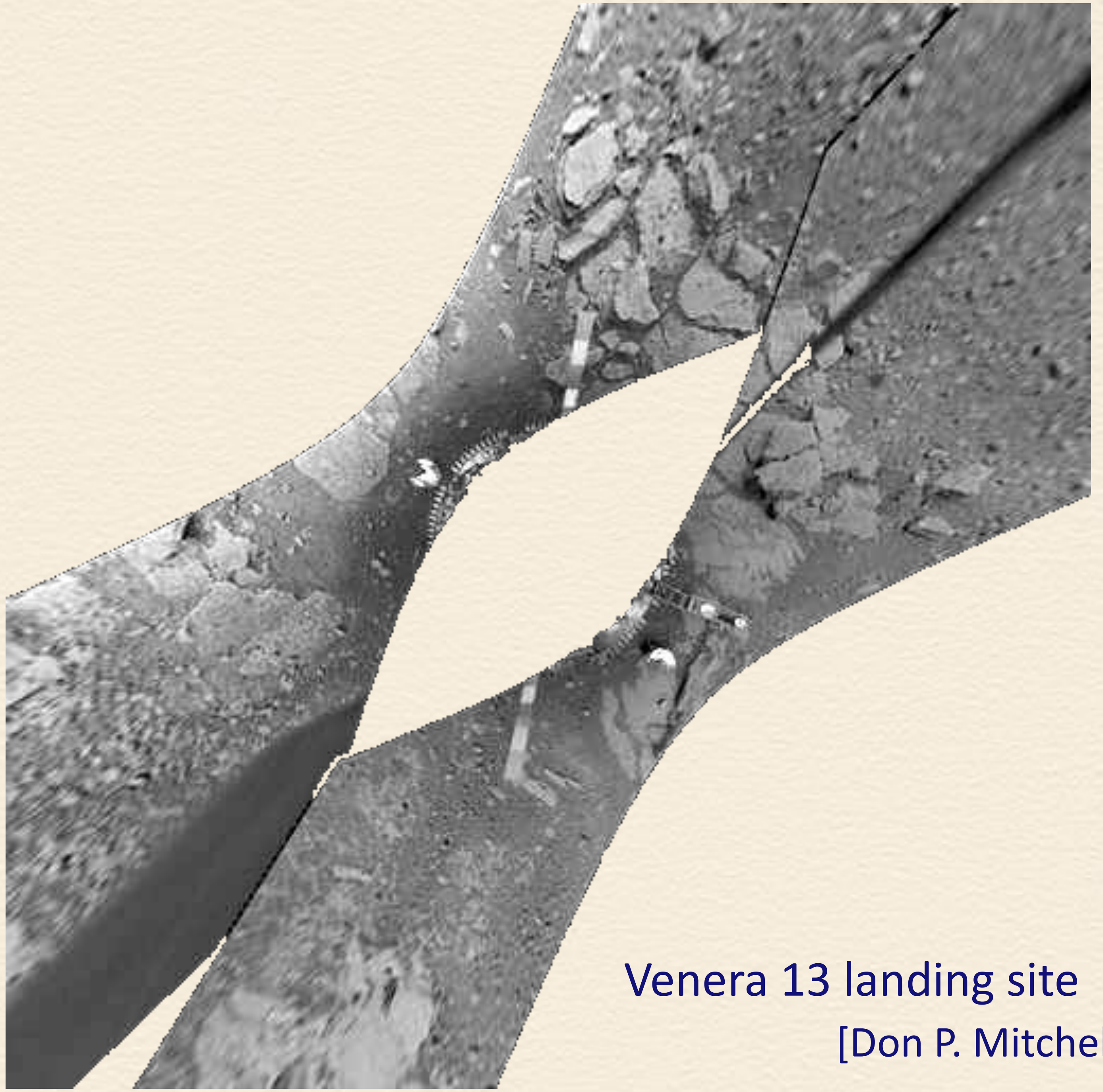
High resolution imagery, topography and compositional data are needed to understand

D-InSAR change detection will determine the location and nature of geological activity on Venus today

Surface, tropospheric and mesospheric volatile measurements will characterise geochemical cycles

Calibrated polarimetric and high resolution contextual imagery of the Venera landing sites is needed to understand what the landers imaged

EnVision will take our knowledge of Venus towards that of Mars today



Venera 13 landing site
[Don P. Mitchell]