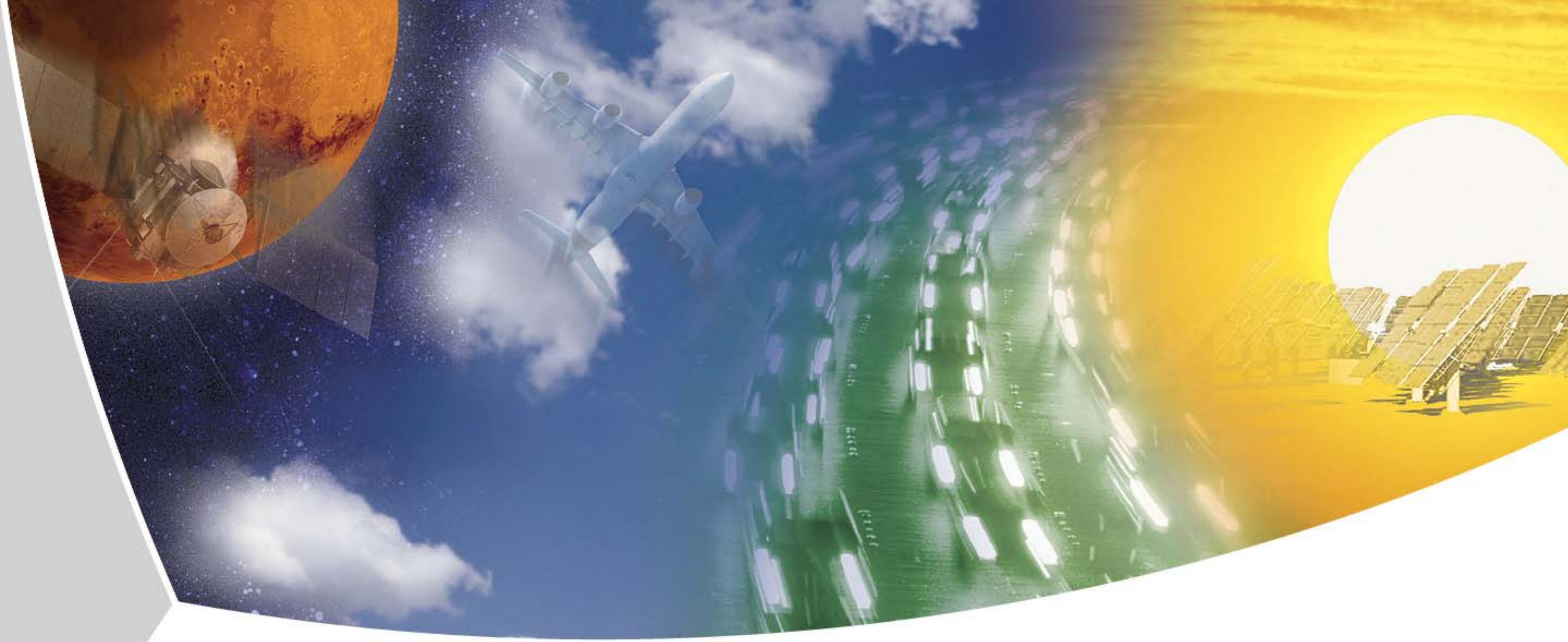
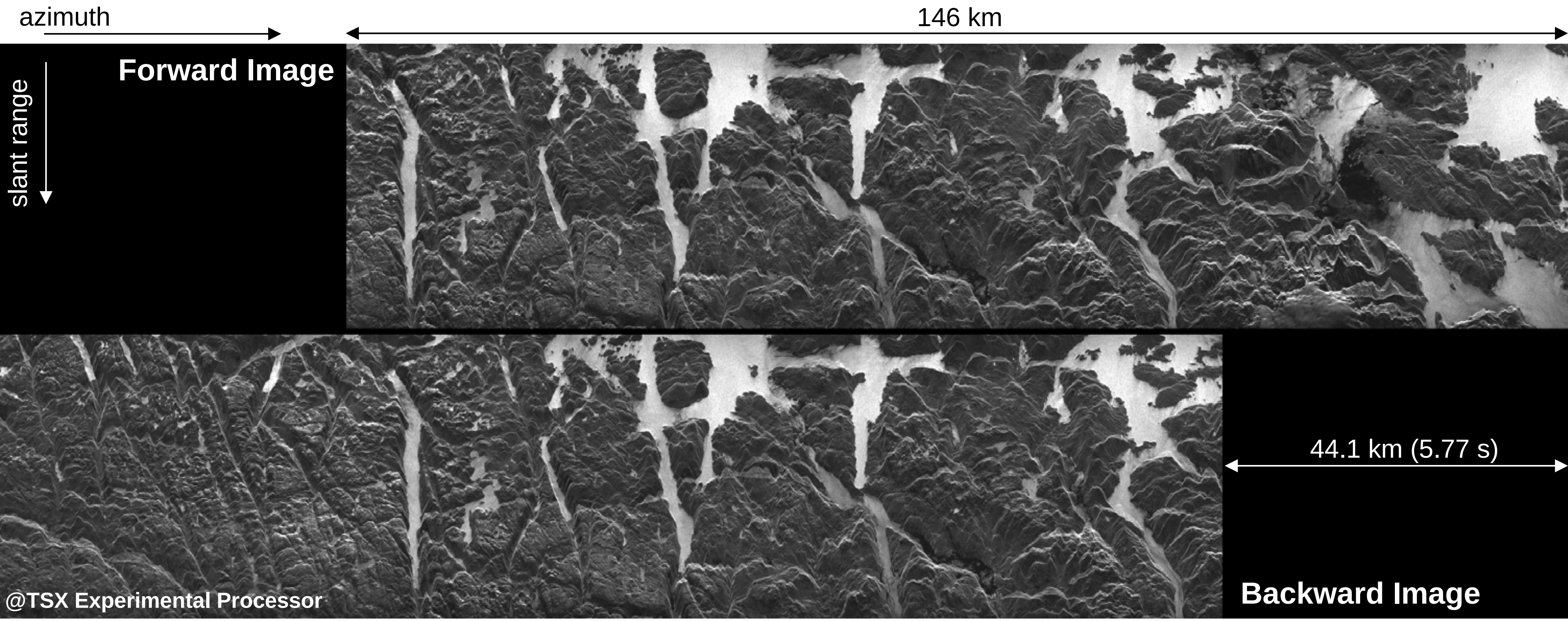


Bi-directional Interferometric SAR Acquisition with TanDEM-X

Monday, September 19, 2011

J. Mittermayer, Pau Prats, Steffen Wollstadt, Paco Lopez-Dekker and Gerhard Krieger

Bi-directional SAR Experiment (July 2009)



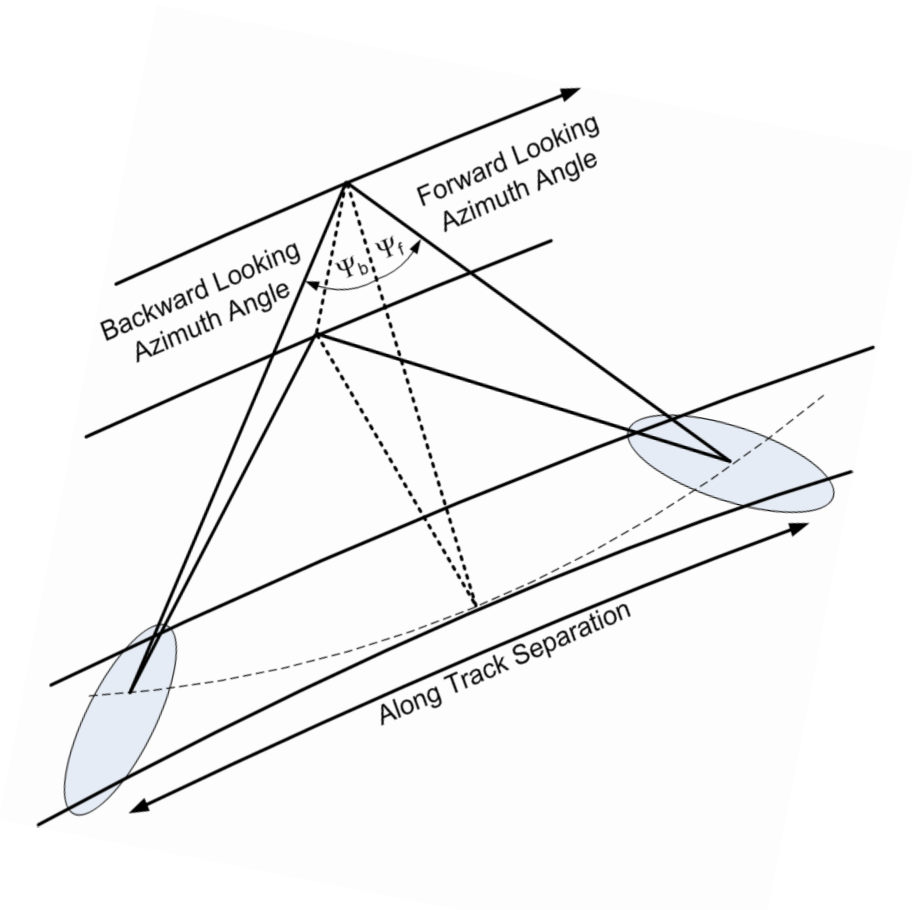
BiDi provides repeated acquisitions with one satellite and one channel within seconds

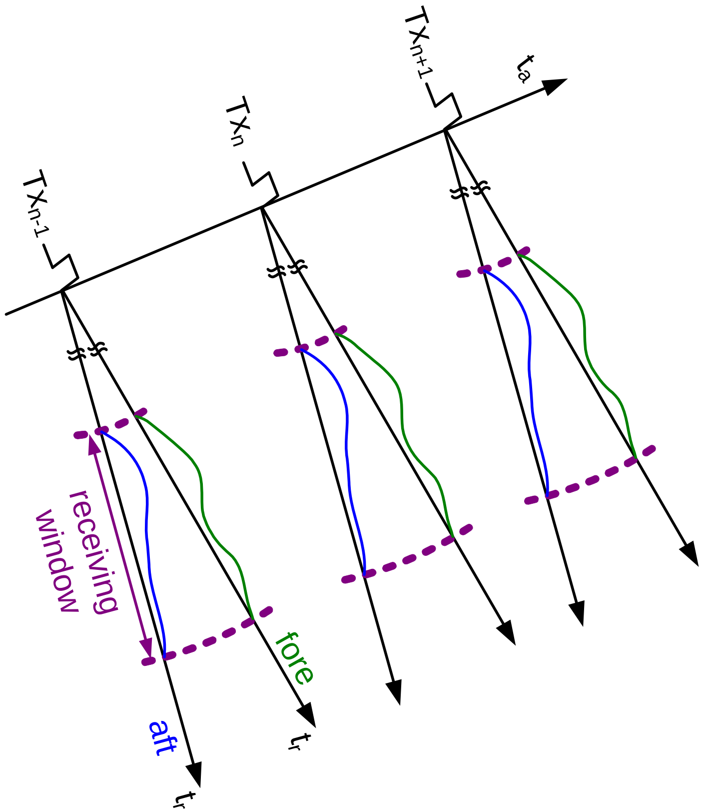
Ref.: J. Mittermayer, S. Wollstadt, "Simultaneous Bi-directional SAR Acquisition with TerraSAR-X", Proc. of EUSAR 2010, Aachen, Germany.

Outline

- Di-directional (BiDi) Mode
- BiDi Acquisition in TanDEM-X Pursuit Monostatic Configuration
- Motion Measurement
- Ship Fringes in Fore and Aft Interferograms

Bi-directional SAR (BiDi)

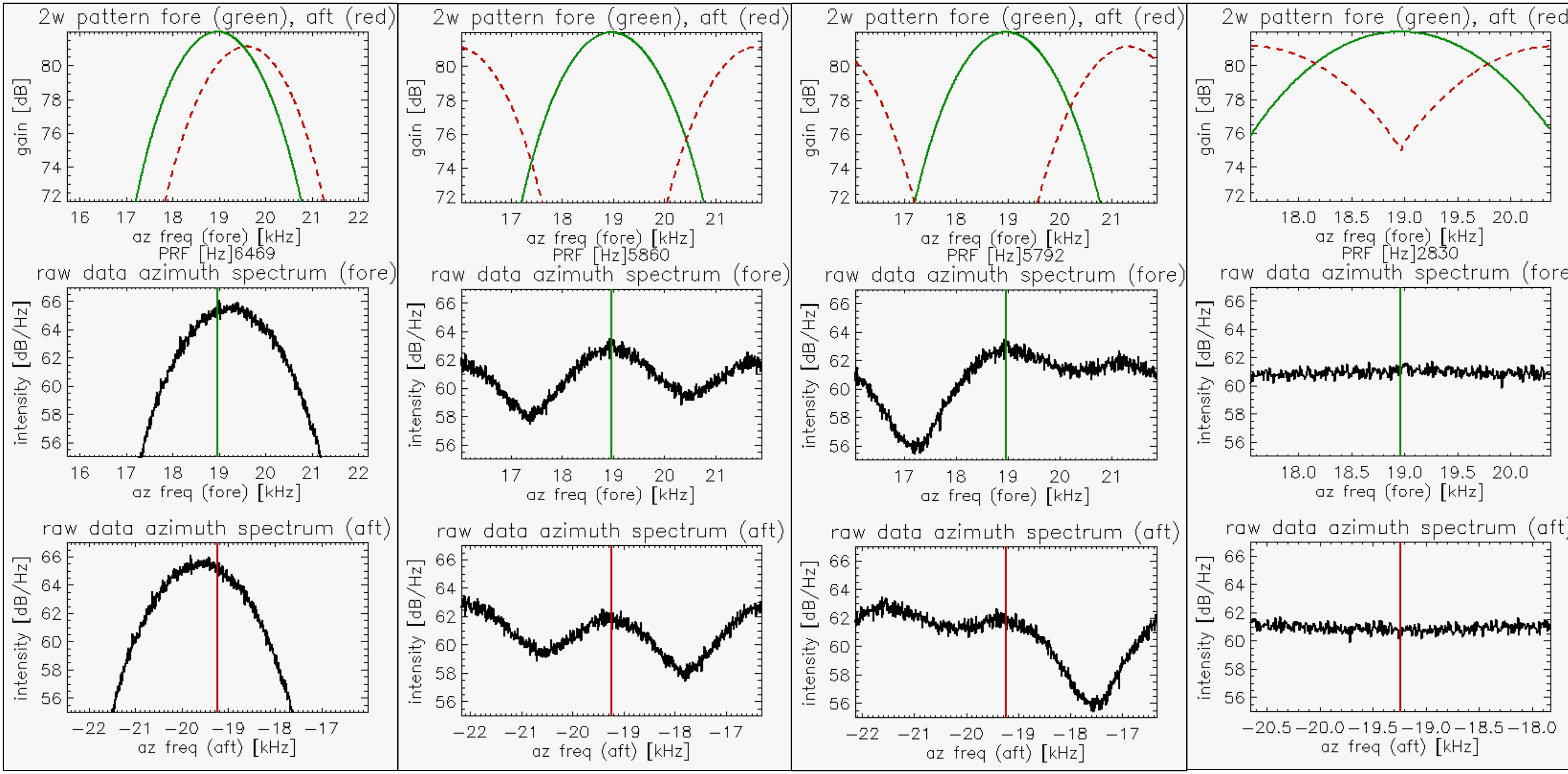




- azimuth beam shaping into two (or more) directions, e.g. forward and backward
- simultaneous reception of both images

Fore & Aft Image Separation in Azimuth Spectra

6469 Hz | 5860 Hz | 5792 Hz | 2830 Hz



- main lobe steering (e.g. TSX 2.1°) results in and grating lobe (e.g. TSX -2.1°)
- coincident or divergent folding position of grating lobe depends on PRF
- low PRF provides less spectra differentiation

BiDi SAR – Singapore Acquisition Example

<u>acquisition Singapore, Aug 2010, ascending</u>

overlaping images: 2

azimuth extension: 150 km

azimuth separation: 41.8 km (5.9s)

slant/ground range: 10.8 km / 33 km

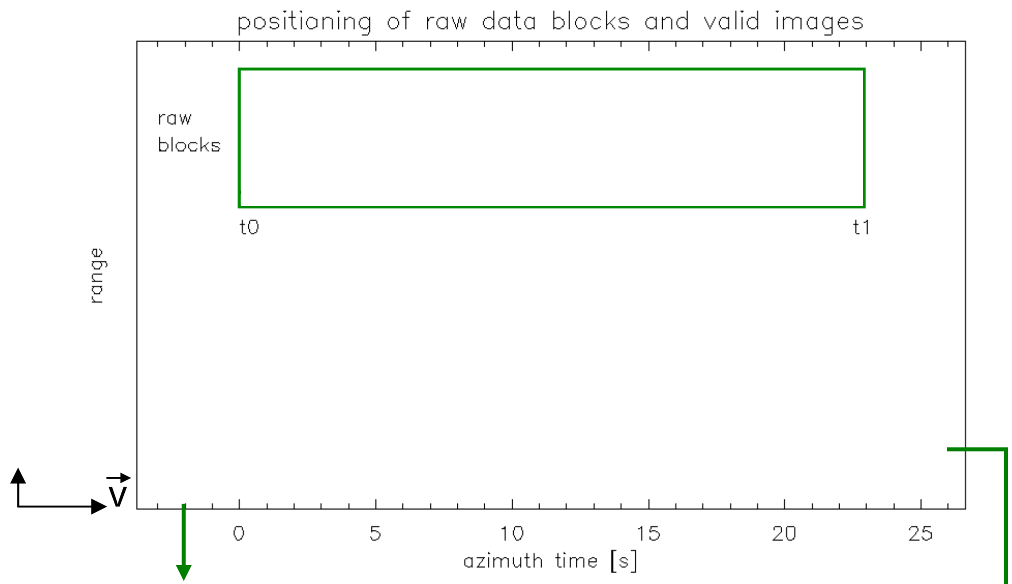
incidence angle: ≈ 22°

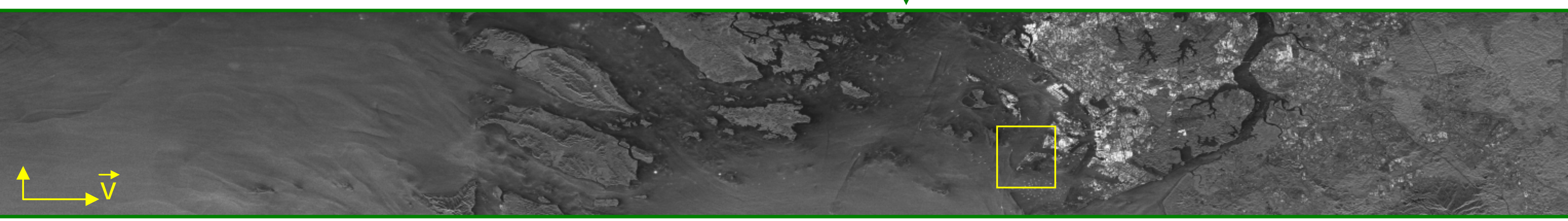
forward/backward **squint: 2.19°/-2.25°**

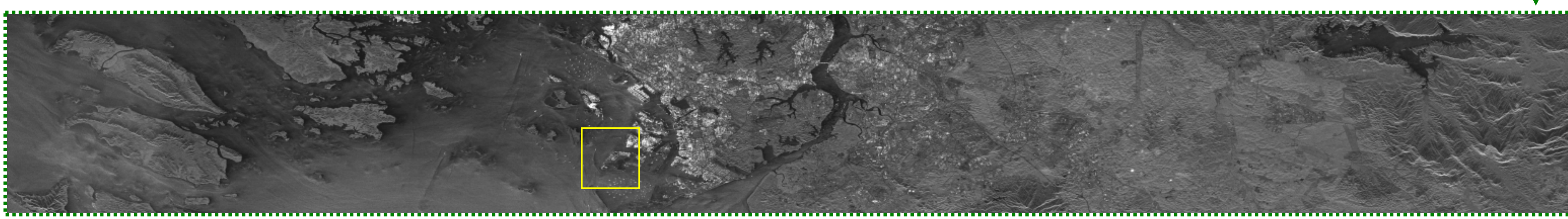
azimuth/slant range resolution: 3.2 m/1.9 m

BW: 2850 Hz az / 100 MHz rg / **PRF 5860 Hz**

azimuth/range Hanning (alpha): 0.54 / 0.54



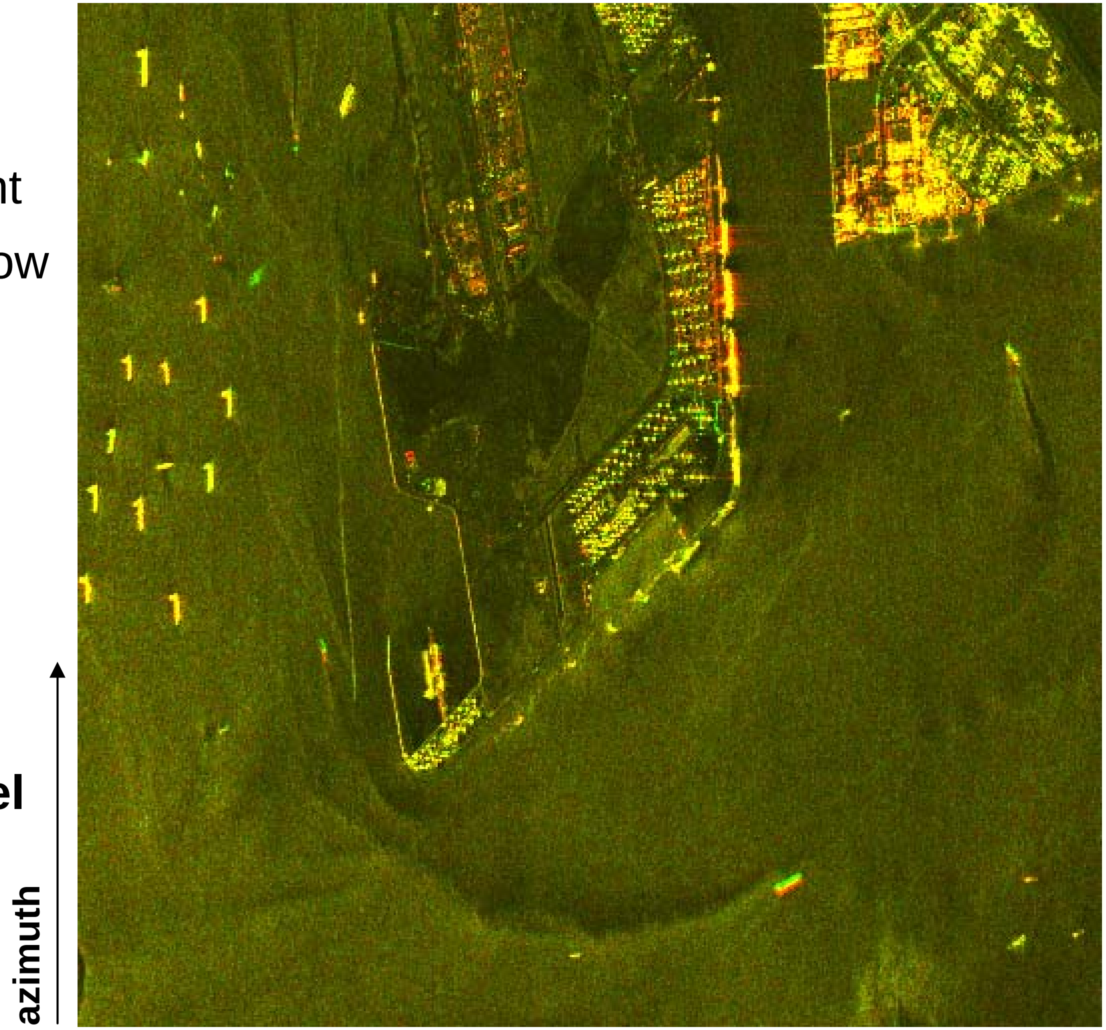




Fore and Aft Image Overlay

- colour composite of fore (red) and aft (green) image sections from single TerraSAR-X overflight
- equal backscatter combines yellow
- considerably differences in backscatter behaviour at 4.4° aspect angle difference
- motion of ships visible

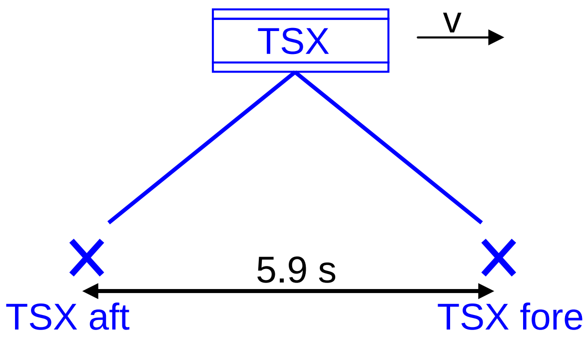
- **2D motion measurement is principally possible with one satellite, one pass, one channel**



BiDi Acquisition in TanDEM-X
Pursuit Monostatic Configuration

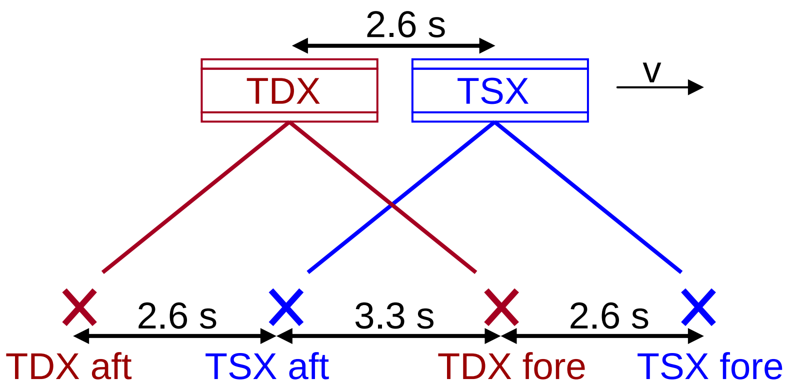
BiDi in TanDEM-X Pursuit Monostatic Configuration

Single-Sat Fore / Aft:



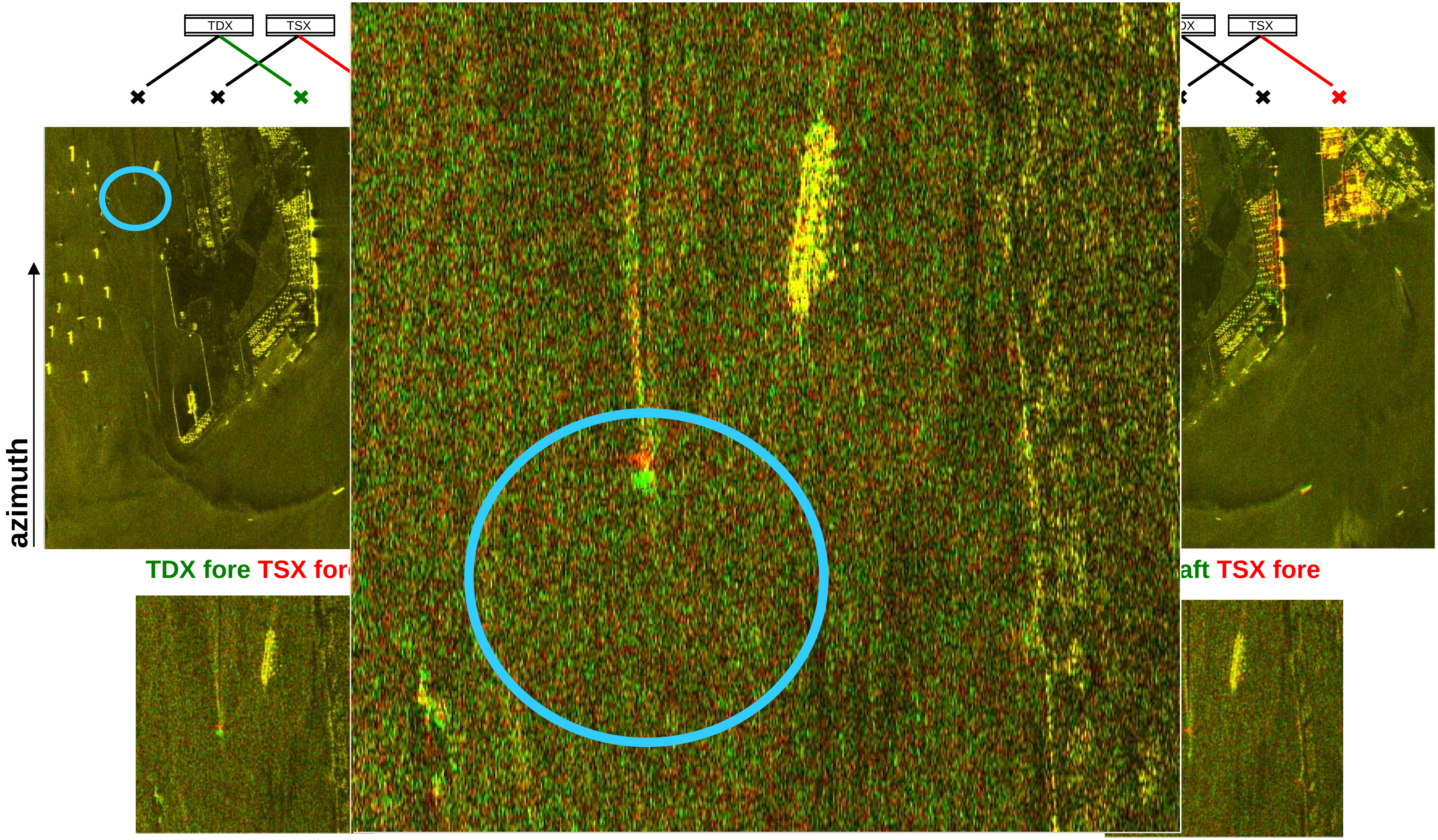
- short-term time series
- time lag of seconds

TanDEM-X



- during pursuit monostatic TanDEM-X commissioning phase TDX satellite followed TSX satellite in 20 km along-track distance
- more acquisitions for time series
- interferometric time series
- repeated motion measurements

TSX TDX BiDi Time Series – Motion Detection



19 pixel, 6.1 m/s , 11.5 kn

42 pixel, 5.9 m/s , 11.9 kn

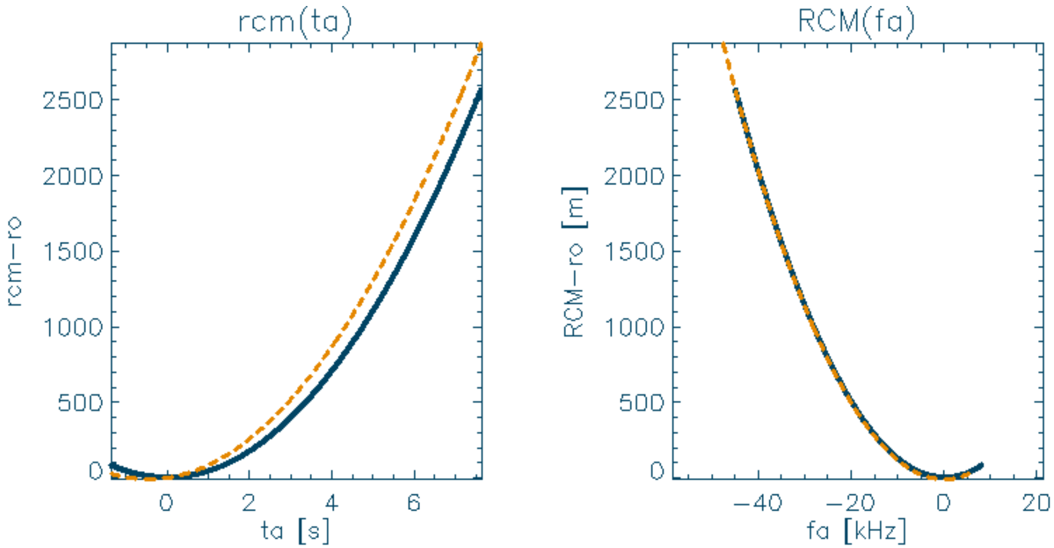
62 pixel, 6.0 m/s , 11.7kn

Velocity Simulation in Azimuth or Range

la [m] 0.03
ro [km] 600.
Vs [m/s] 7600.0
Vg [m/s] 7000.0

sq [°] 2.1
Vr [m/s] 40.
Va [m/s] 0.
ta shift [s] −0.45
ro shift [m] −9.02

blue: no velocity
orange: veloctiy

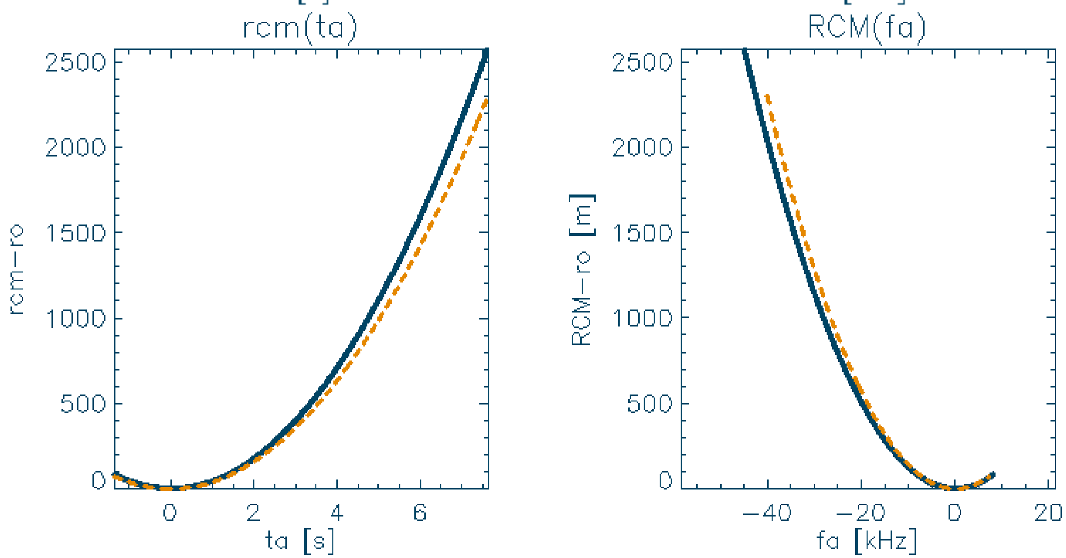


range velocity
- => az shift
- => no rg shift (almost)
- => shift in az spectrum

la [m] 0.03
ro [km] 600.
Vs [m/s] 7600.0
Vg [m/s] 7000.0

sq [°] 2.1
Vr [m/s] 0.
Va [m/s] 400.
ta shift [s] −0.00
ro shift [m] −0.00

blue: no velocity
orange: veloctiy



azimuth velocity
- => no az shift
- => no rg shift
- => curvature change

Velocity Measurement

Moving vs. stable target in one image:

- azimuth velocity causes no position change
- range velocity causes
  - -> azimuth displacement
  - -> azimuth spectrum shift
  - -> no range displacement

Moving target in BiDi fore and aft images (one satellite, one channel):

- range velocity causes identical azimuth displacement

  => azimuth velocity measurement by pixel estimation and time lag
- due to identical RCM history no difference in range position

  => no range velocity measurement by pixel estimation

Range velocity

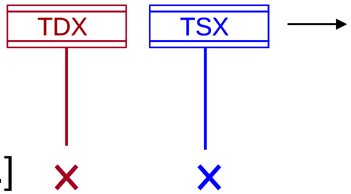
- detectable from azimuth spectral shift in one image
- in BiDi potential for more accurate measurement due to high Doppler centroid and two measurements (to be demonstrated)

Discussion on 2D Velocity Measurement

Two satellites

can measure azimuth & range velocity (pixel estimation)

[Ref: Stefan V. Baumgartner, Gerhard Krieger, “Large Along-Track Baseline SAR-GMTI: First Results with the TerraSAR-X/TanDEM-X Satellite Constellation”, Proc. of IGARSS ‘11.]

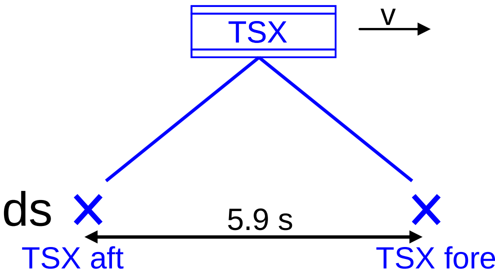


Single satellite BiDi

can measure azimuth velocity (pixel estimation)

& range velocity (e.g. spectral shift)

-> more accuracy due to large time lag and high Doppler centroids

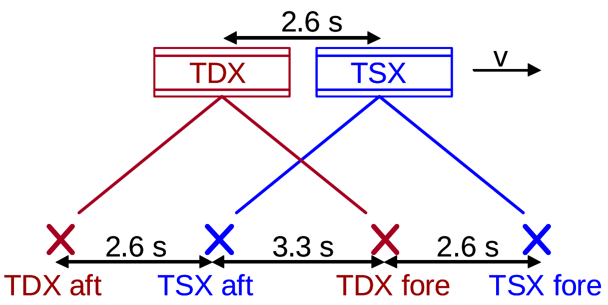


Two satellite BiDi

can measure azimuth & range velocity (pixel estimation)

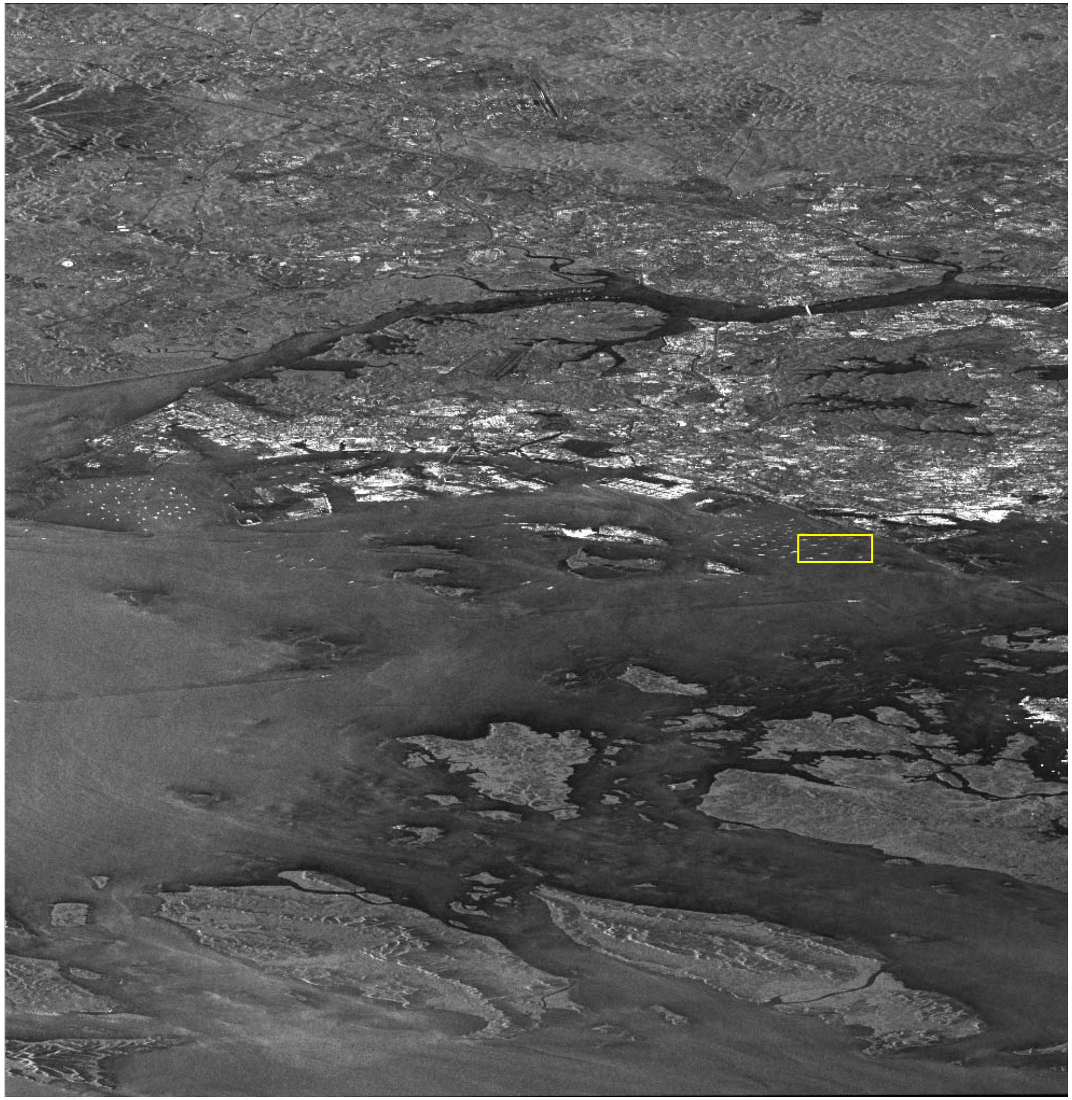
-> repeated measurements

-> has potential for 2D acceleration measurements

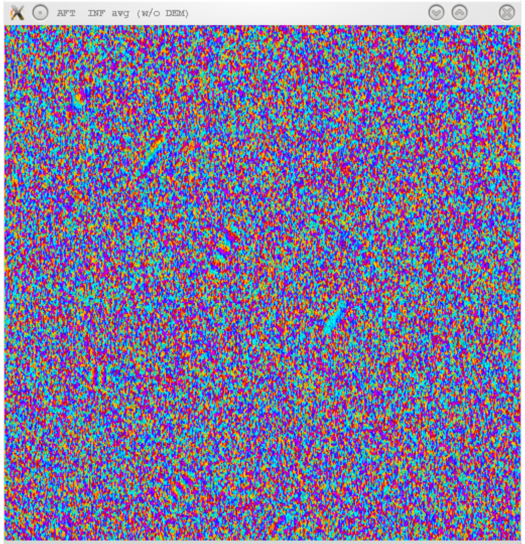


Fringes of Ships in Fore and Aft Interferograms

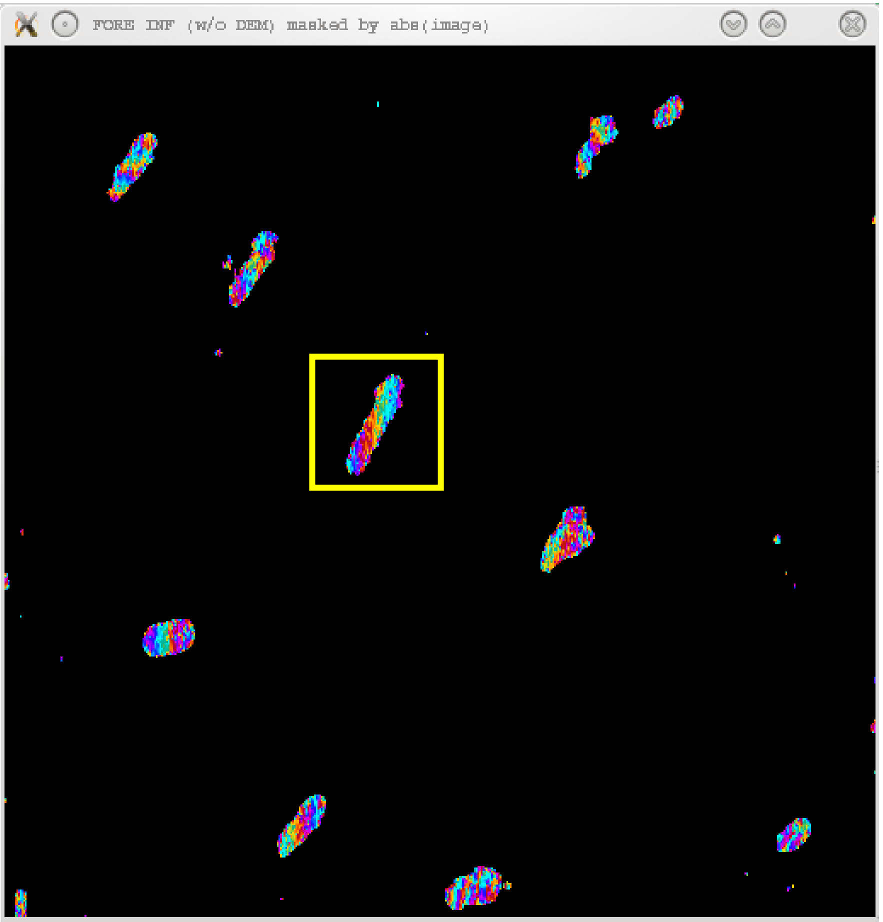
Ships in Singapore Harbour Area

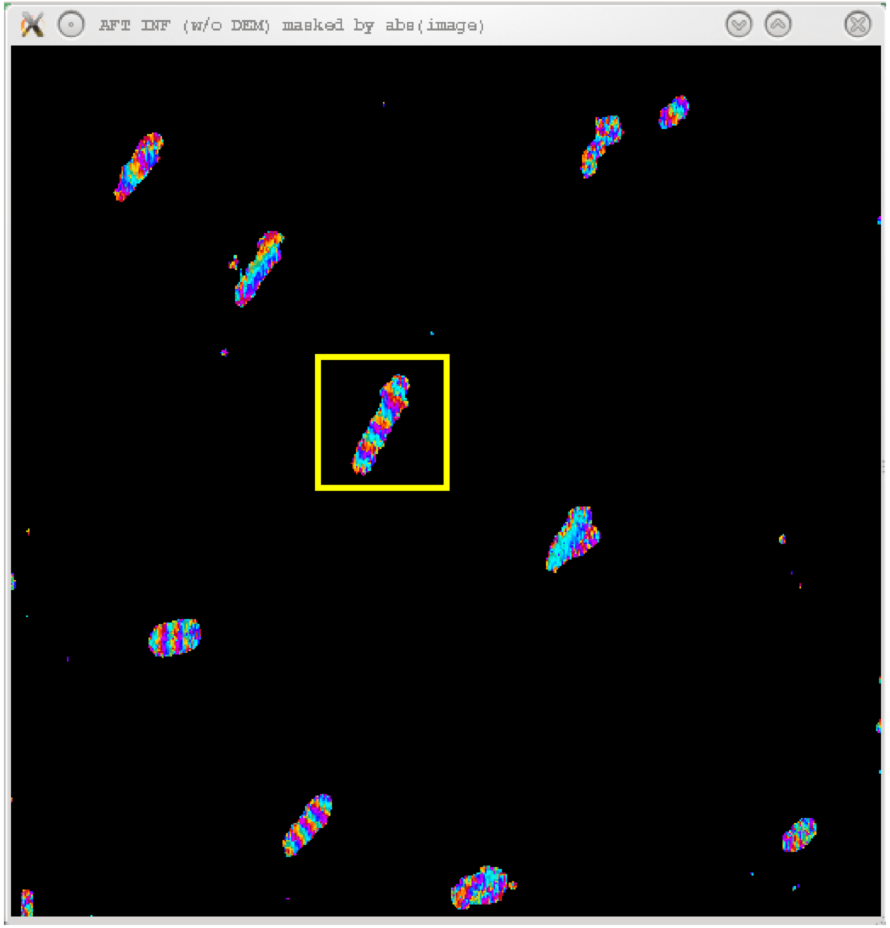


azimuth



Fringes of Ships in Fore / Aft Interferograms

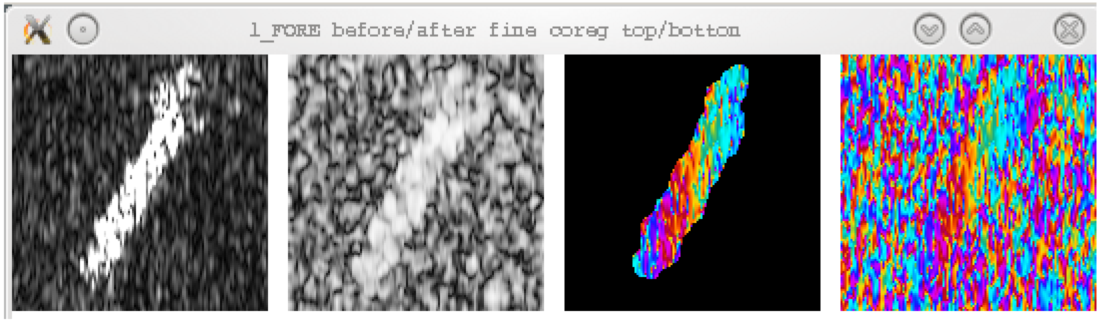




- DEM phase (flat earth over the sea) subtracted
- remaining ship fringes allow for ship rotation measurement
- fringe pattern is different in fore and aft interferograms

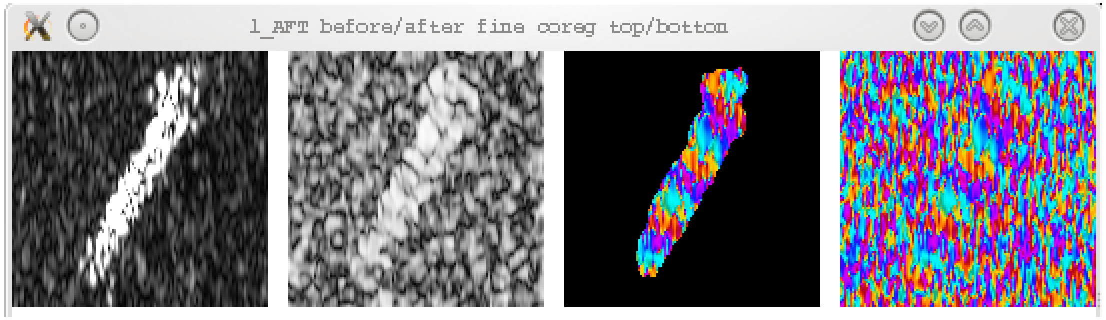
Difference in For and Aft Fringe Pattern

FORE



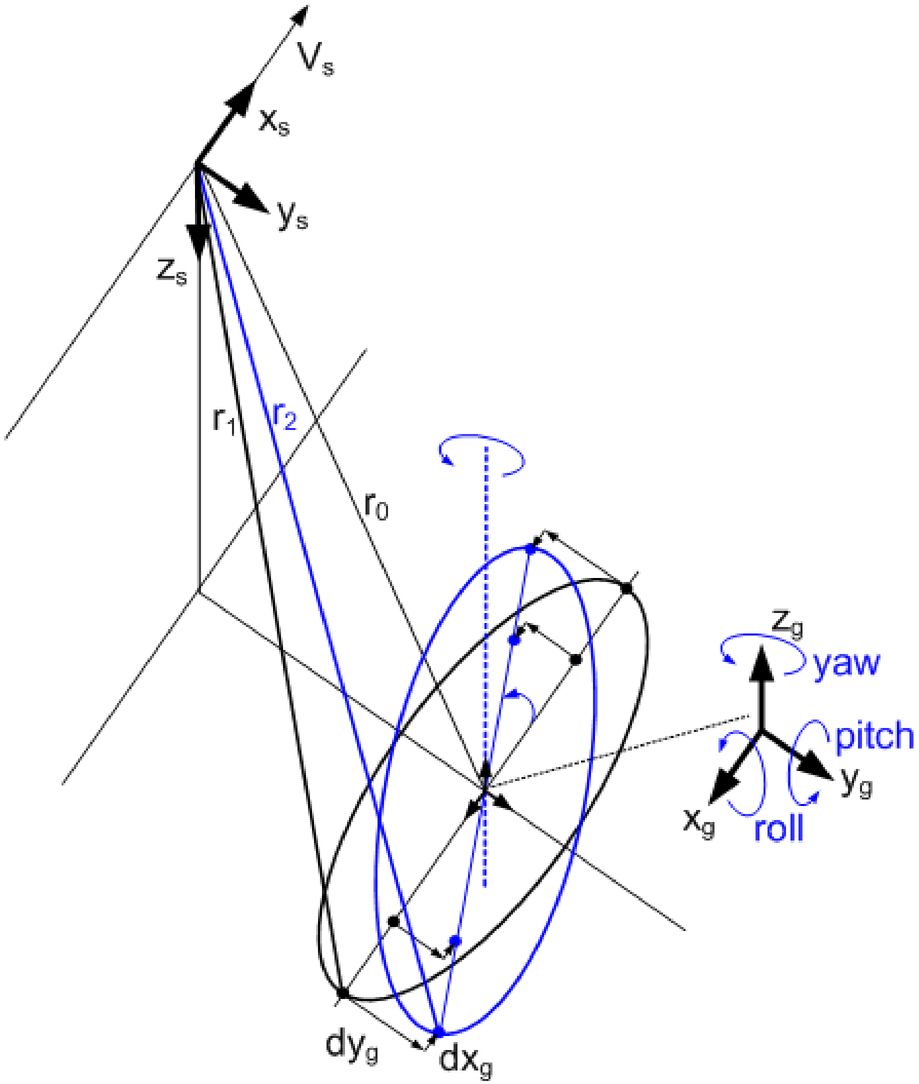
Amplitude Coherence Phase Ship Phase

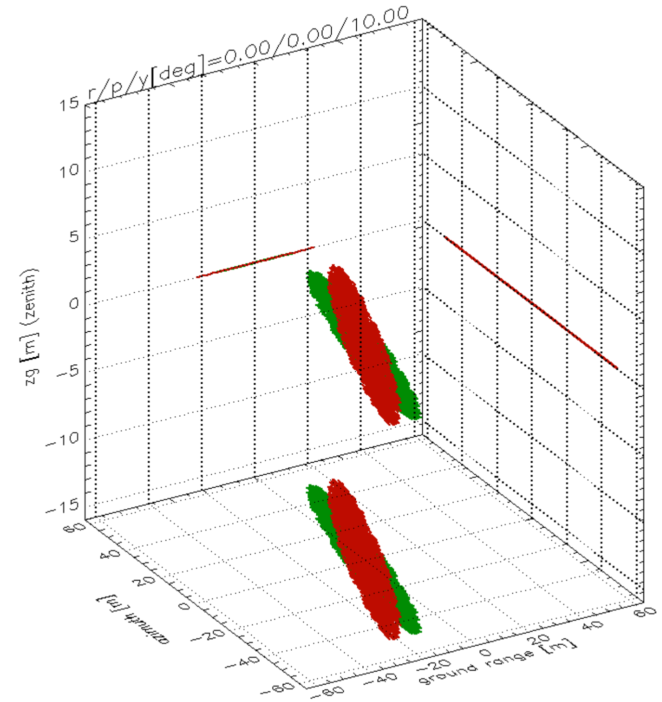
AFT



- a constant ship translational movement causes a constant phase offset
- residual fringes may be induced by a ship rotation due to waves, current, wind, etc.
- the difference in the fringe pattern indicates different rotation velocities

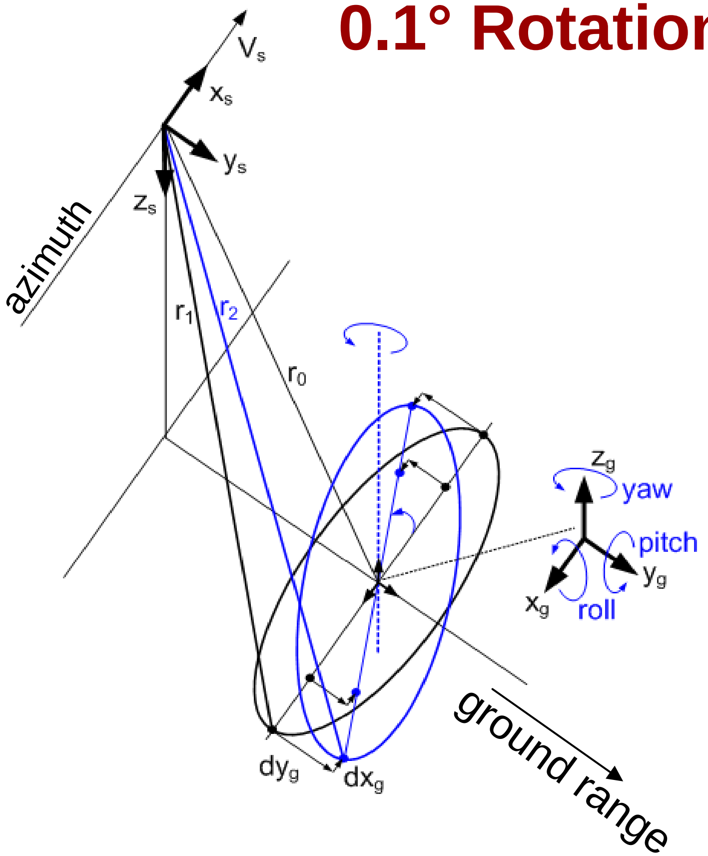
Simulation of Ship Rotational Fringes

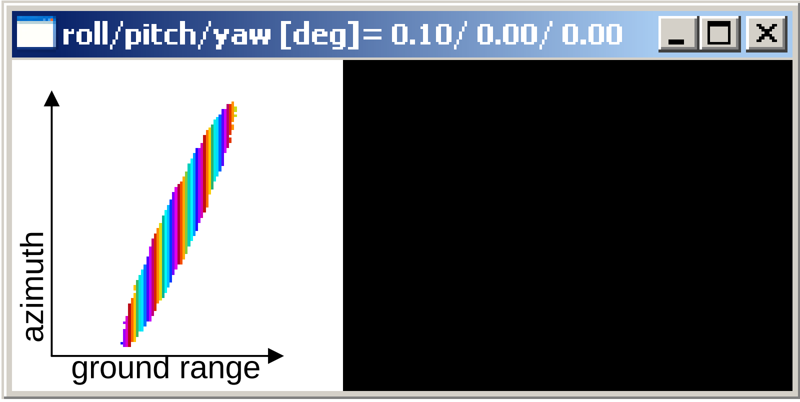


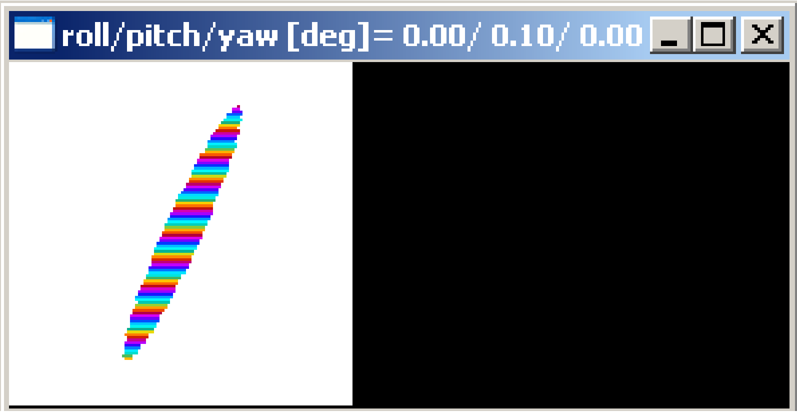


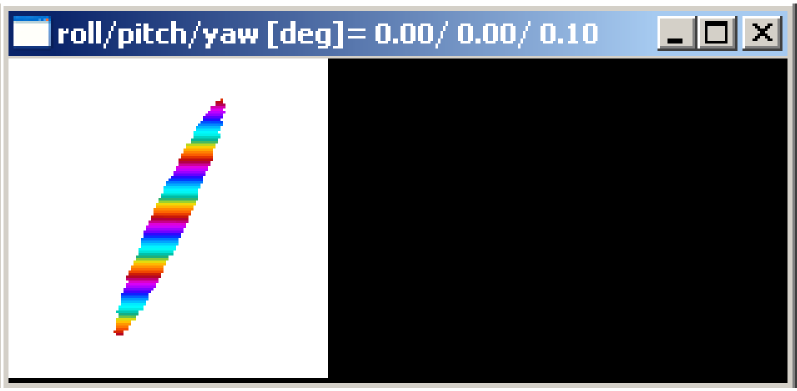
- ship simulated as flat ellipse
- ship oriented w.r.t. azimuth / ground range as in real interferogram
- rotations around xg, yg, and zg simulated to be aligned with azimuth/ground range
- rotations are not related to ship axes

0.1° Rotation Fringes



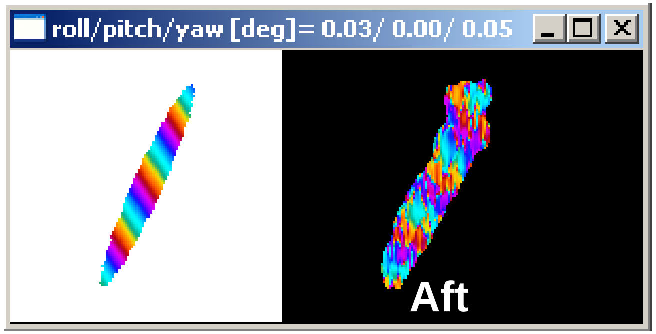






- fringes are very sensitive to rotation
- roll rotation around “azimuth” causes range fringes
- yaw rotation around “zenith” causes azimuth fringes
- pitch rotation around “ground range” causes azimuth fringes

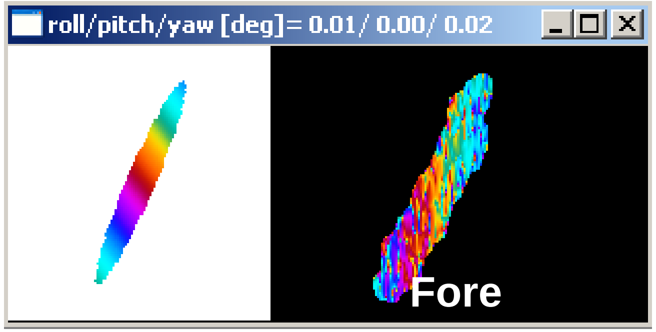
Simulated and Real Fringes



Aft Fringes:

0.03° roll and 0.05° pitch generates similar fringe pattern

(pitch set to 0°)



Fore Fringes:

0.01° roll and 0.02° pitch generates similar fringe pattern

- constant rotation velocity would result in same fringe pattern
  => rotation velocity changed (e.g. acceleration)
- roll and pitch up to now not separated

Discussion Ship Rotation Fringes

- TanDEM-X interferometry with short repeat pass time allows for measurement of ship rotations (due to high geometrical resolution)
- roll angle rotation can be estimated in the single interferograms (range fringes)
- similar rotational effect was detected e.g. with ERS-1 /2 and sea-ice
- BiDi reveals angular accelerations

Conclusion

BiDi single satellite allows for:

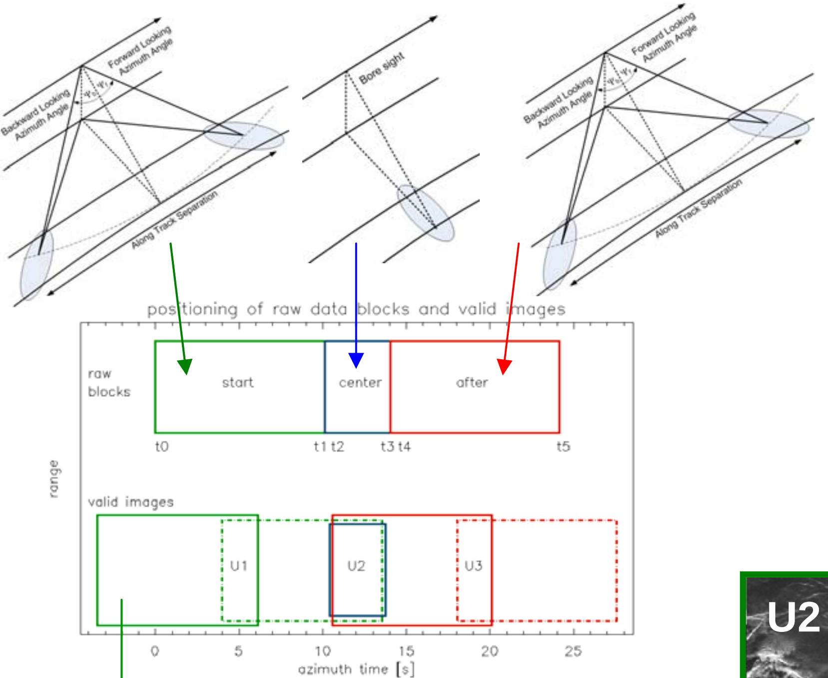
- short-term time series
- 2D velocity measurement

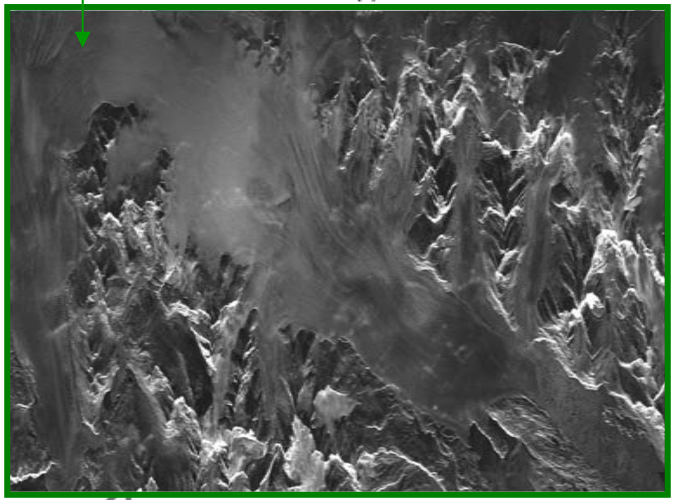
BiDi satellite formation allows for

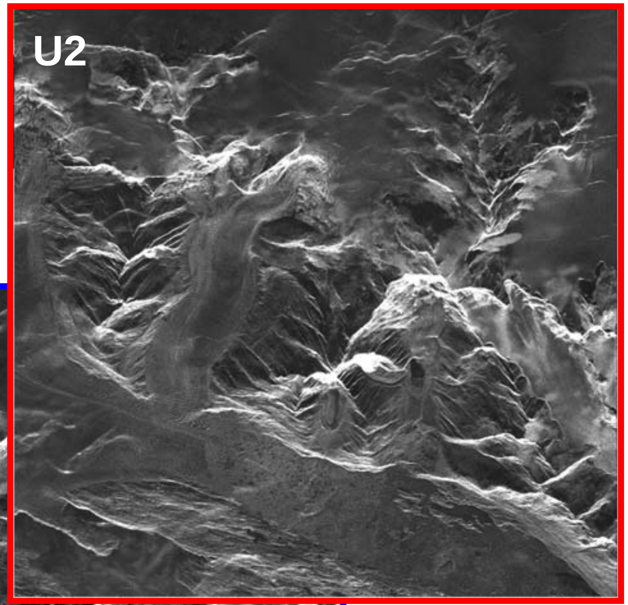
- repeated interferograms
- 2D velocity and acceleration measurement
- measurement of rotational velocities and accelerations

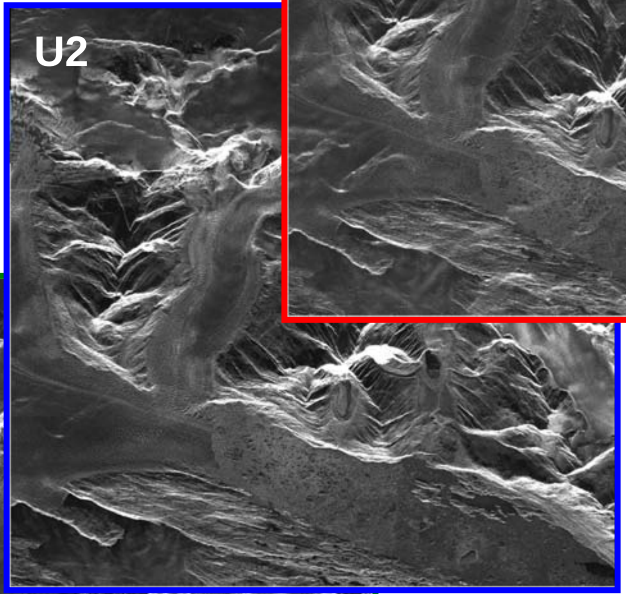
A combined TanDEM-X *BiDi -boresight* acquisition resulted in 3 repeated short-term interferograms

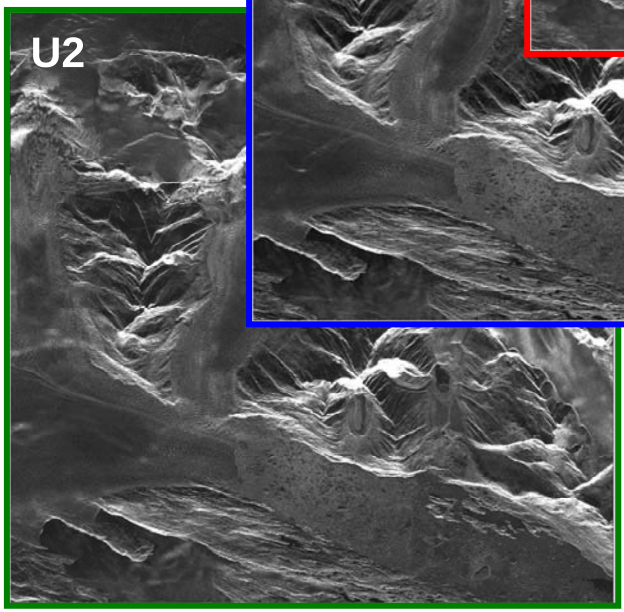
BiDiSAR TSX/TDX Short Time Series - Upsala Glacier





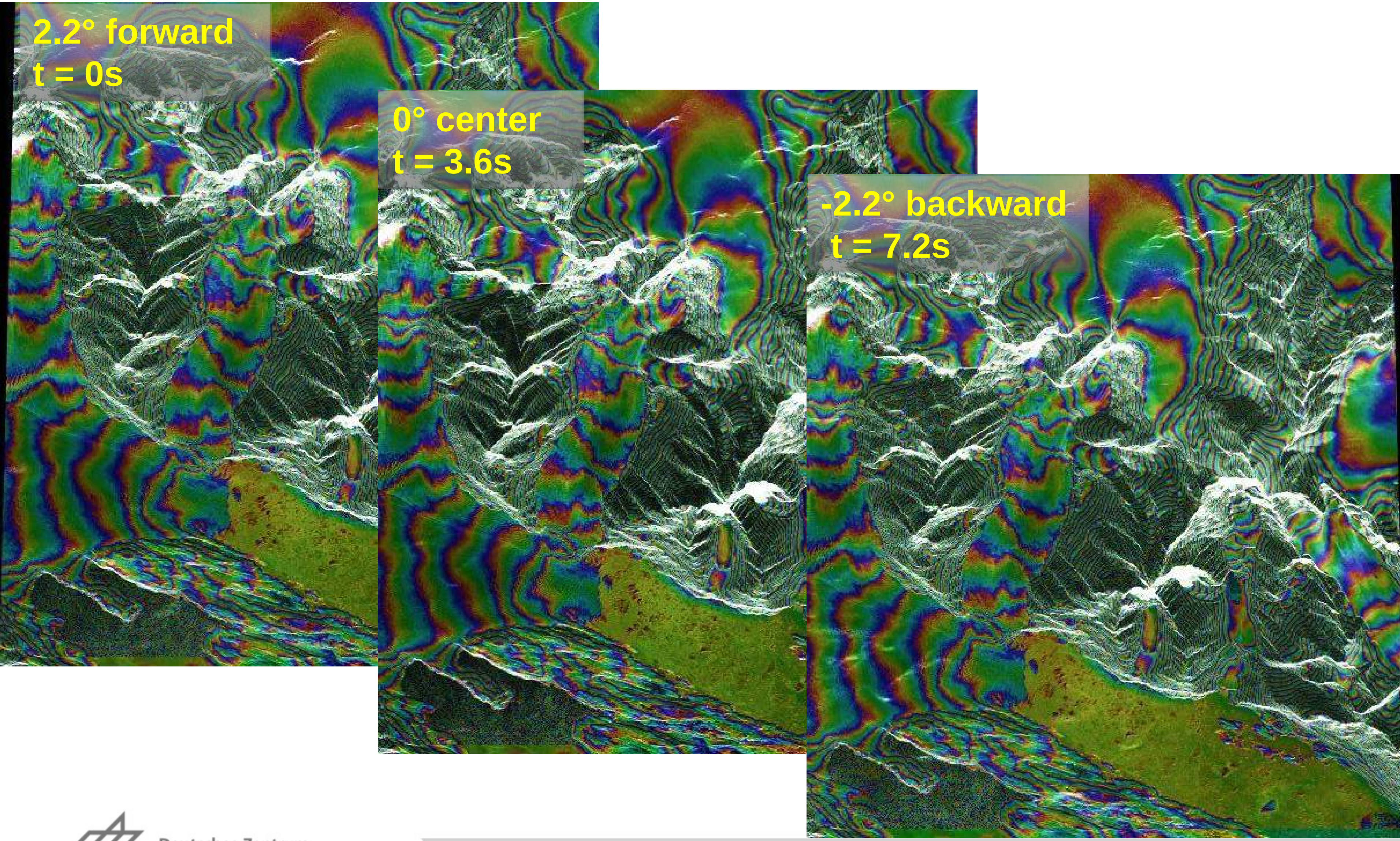






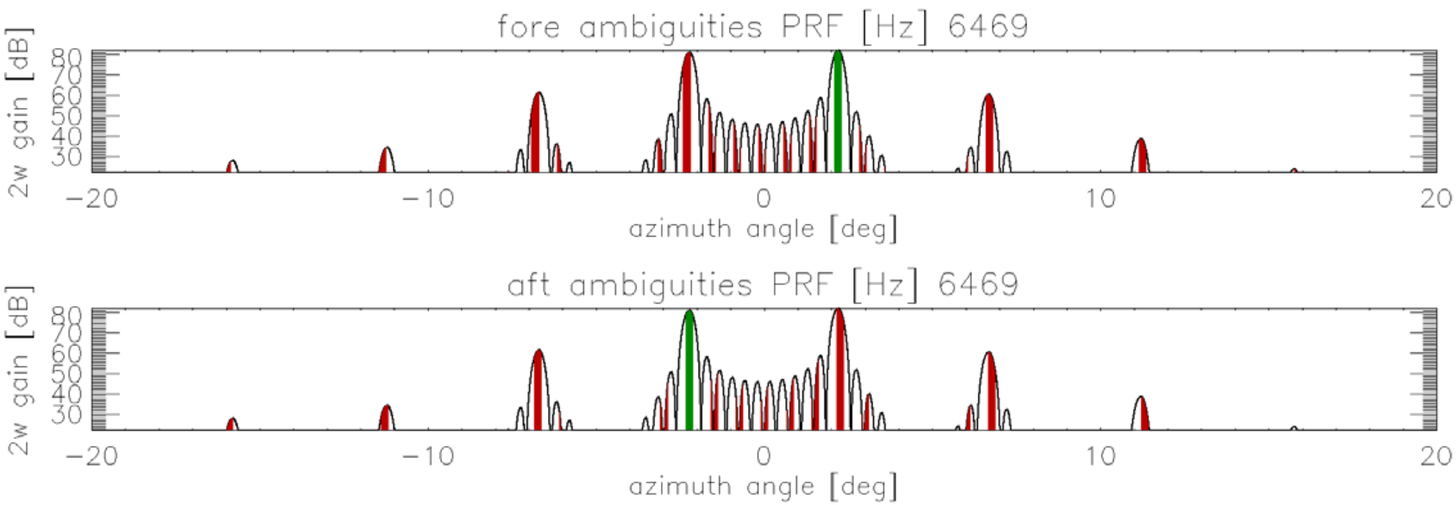
<u>TSX Acquisition</u>
42° inc.
PRF 5800 Hz
<u>short time series</u>
0s 3.6s 7.2s

BiDiSAR Interferogram Time Series - Upsala Glacier (U2)



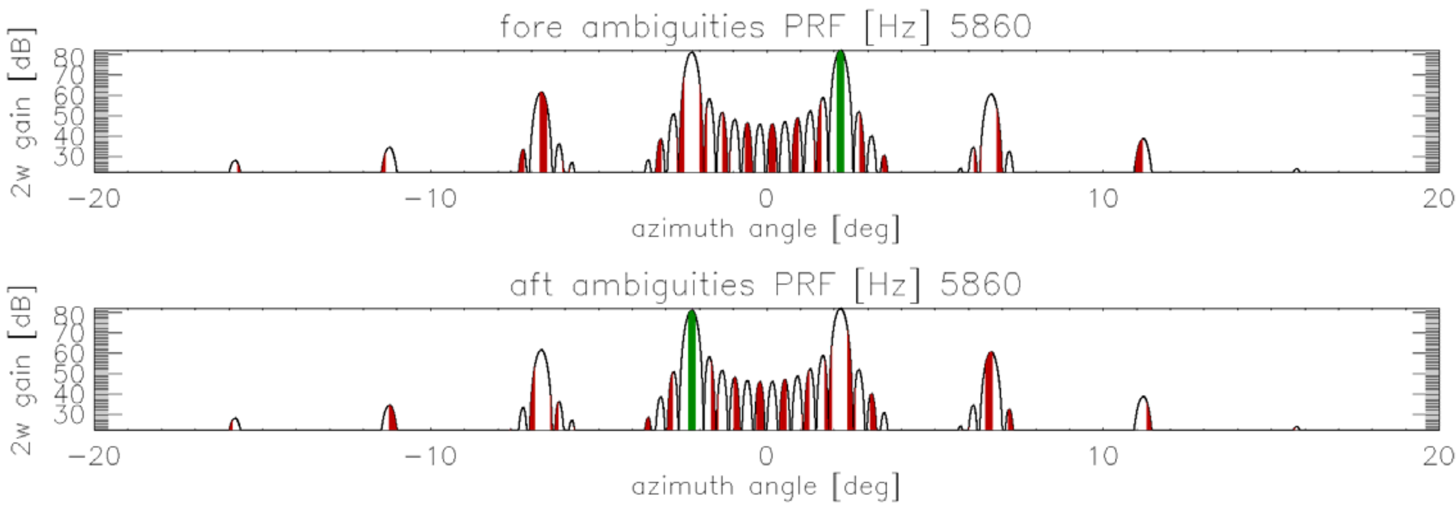
Supplementary Slides

Azimuth Ambiguities



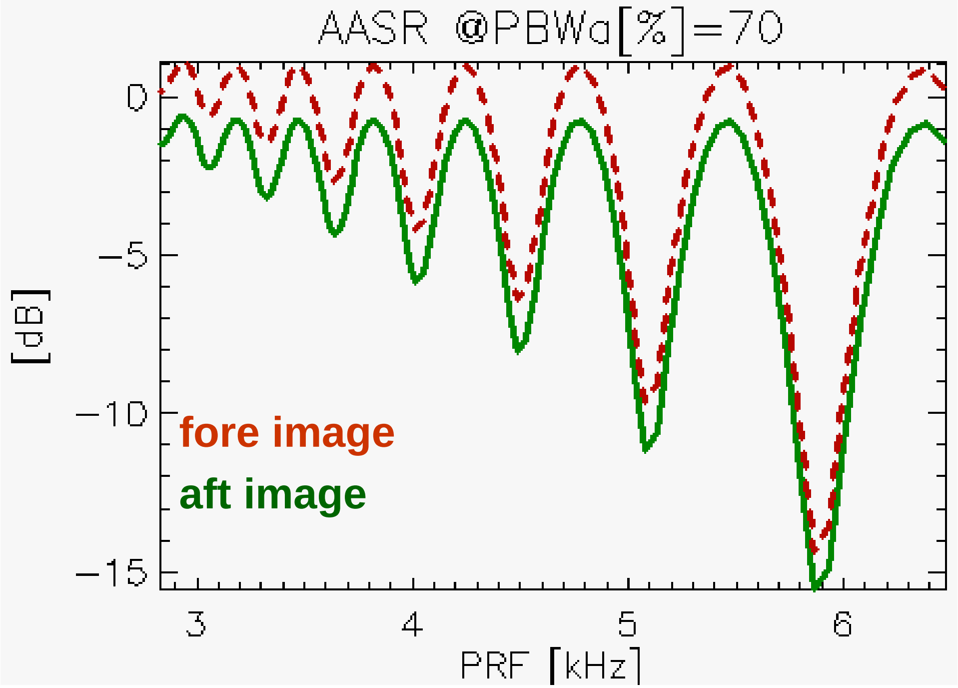
- divergent folding
- processed bandwidth 1995 Hz (70% of 3dB)

- coincident folding



- grating lobe is strongest contribution of ambiguous energy to main lobe and vice versa
- PRF with good spectral separation is also favorable in terms of azimuth ambiguity

Azimuth Ambiguities vs. PRF



- cyclic divergent and coincident folding
- as grating lobe moves relative to main lobe the AASR oscillates between high and low values
- high value keeps constant since it reflects coincident folding
- low value becomes lower with PRF since in divergent folding separation improves with PRF

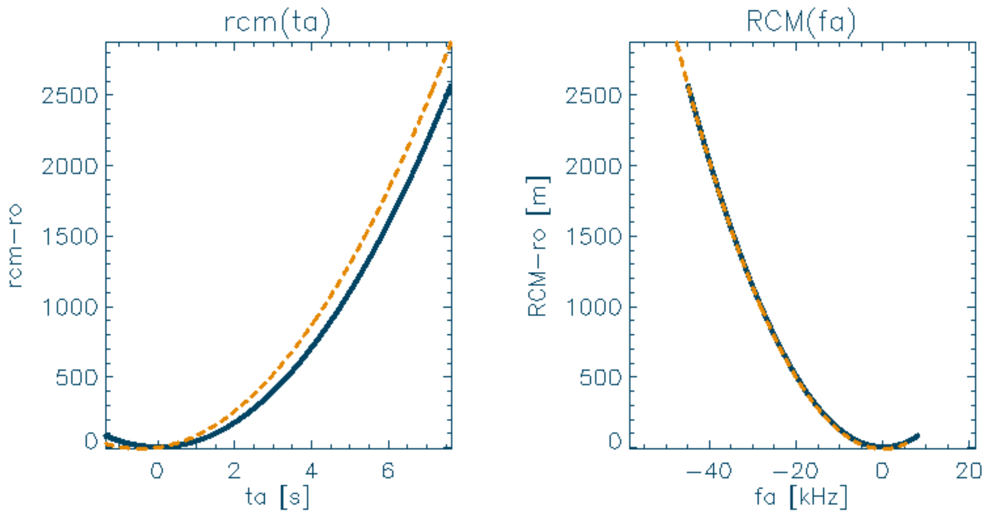
- aft grating lobe is 0.8 dB lower than fore main lobe
- perfect gain equalized main and grating lobe result in identical AASR into fore and aft

BiDi Velocity Simulation V_{LOS} and $V_{azimuth}$

la [m] 0.03
ro [km] 600.
Vs [m/s] 7600.0
Vg [m/s] 7000.0

sq [°] 2.1
Vr [m/s] 40.
Va [m/s] 0.
ta shift [s] −0.45
ro shift [m] −9.02

blue: no velocity
orange: veloctiy

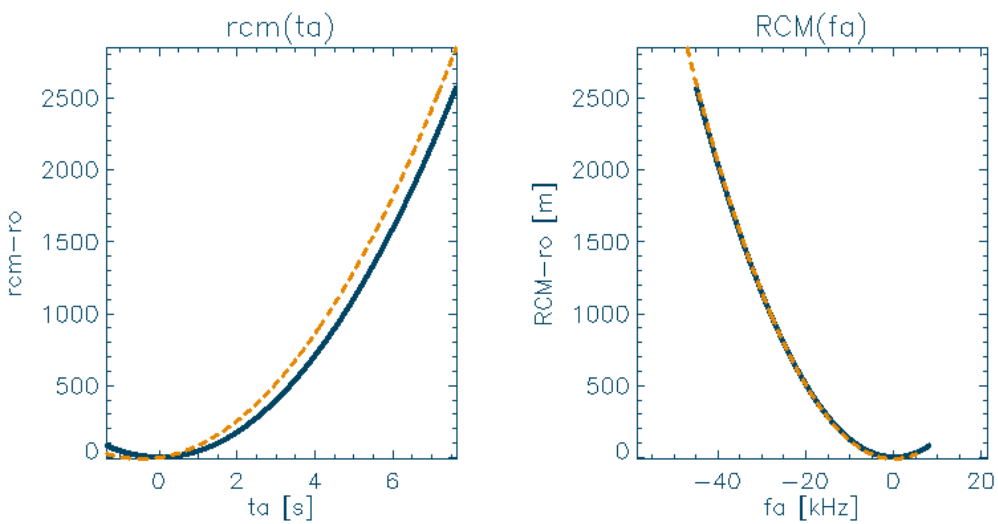


- V in LOS only

la [m] 0.03
ro [km] 600.
Vs [m/s] 7600.0
Vg [m/s] 7000.0

sq [°] 2.1
Vr [m/s] 40.
Va [m/s] 40.
ta shift [s] −0.46
ro shift [m] −9.12

blue: no velocity
orange: veloctiy



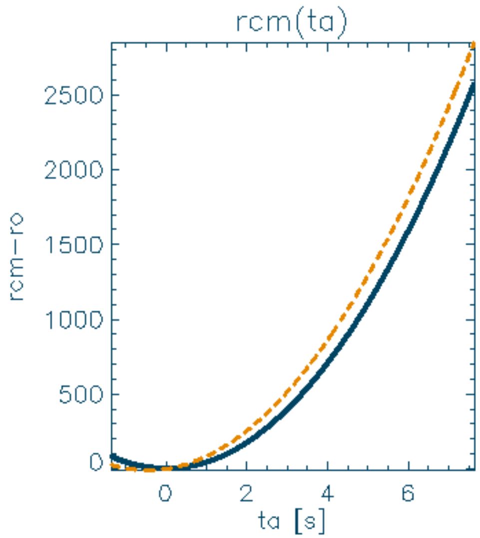
- V in LOS and azimuth
  => both 40 m/s
  => V LOS dominates
  => very small shift in azimuth and range (0.01 s, 0.1m)

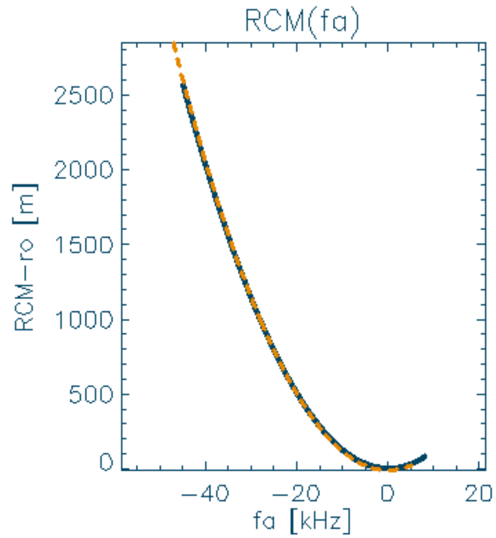
BiDi Velocity Simulation Fore and Aft Images

la [m] 0.03
ro [km] 600.
Vs [m/s] 7600.0
Vg [m/s] 7000.0

sq [°] 2.1
Vr [m/s] 40.
Va [m/s] 40.
ta shift [s] −0.46
ro shift [m] −9.12

blue: no velocity
orange: veloctiy



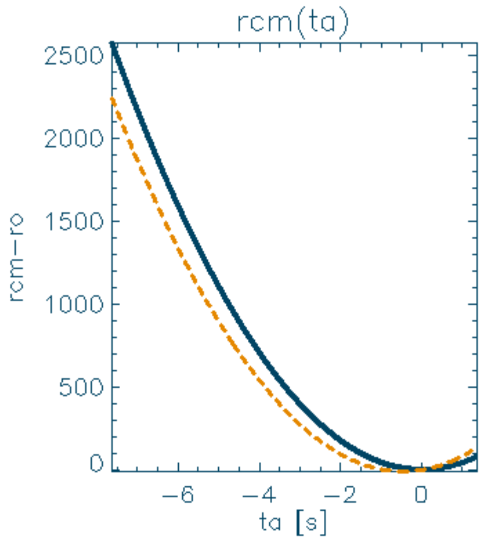


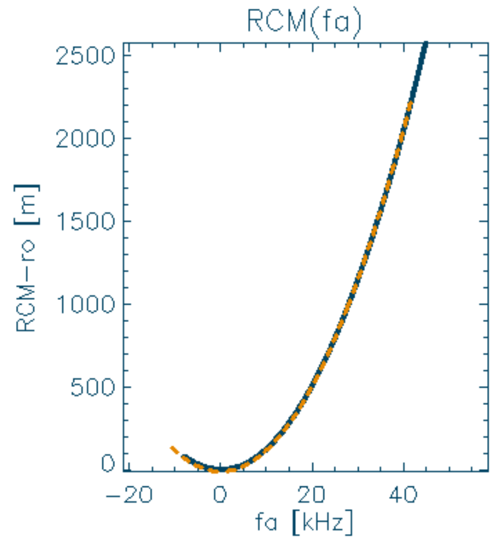
- Fore Image

la [m] 0.03
ro [km] 600.
Vs [m/s] 7600.0
Vg [m/s] 7000.0

sq [°] −2.1
Vr [m/s] 40.
Va [m/s] 40.
ta shift [s] −0.46
ro shift [m] −9.12

blue: no velocity
orange: veloctiy





- Aft Image
  => same azimuth and range shift as in Fore

=> for this Vaz measurable!

- aber az vel measurement due to time lag