

TARGET VELOCITY VECTOR ESTIMATION FROM DUAL PLATFORM

DUAL-CHANNEL SQUINTED SYNTHETIC APERTURE RADAR

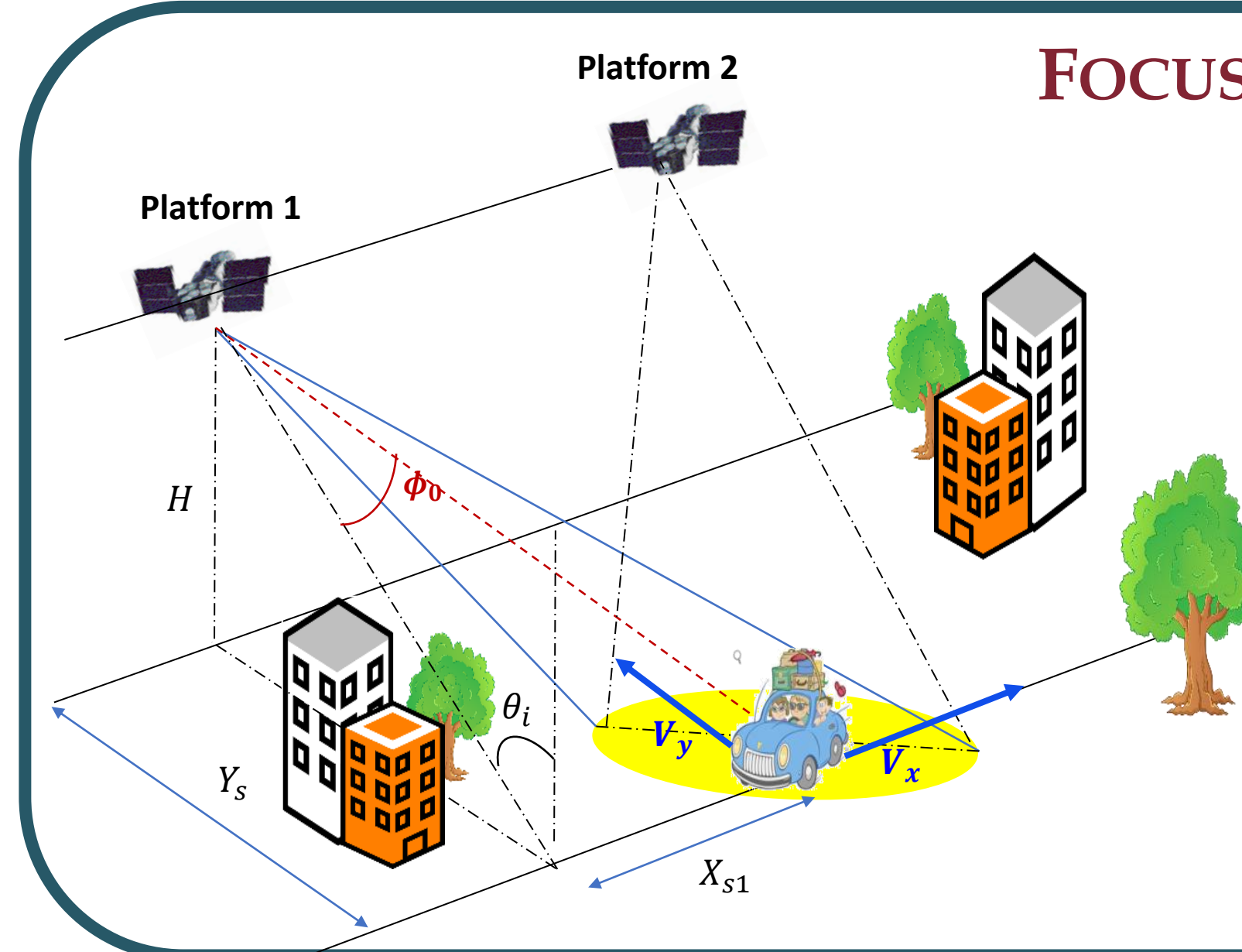
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This study was carried out within the Space It Up! project and received funding from the ASI and the MUR - Contract n. 2024-5-E.0 - CUP n. I53D2400060005. This manuscript reflects the views and opinions of the authors only; the funding bodies cannot be held responsible for them.

1. INTRODUCTION AND OBJECTIVES OF THE WORK

Synthetic Aperture Radar (SAR): all-weather and all-day image capabilities for continuous monitoring of **Surface moving target**

- **Degradations experienced by targets moving in SAR images:**
Along-track velocity → Defocusing effect
Radial velocity → Azimuth mislocation
- **Traditional motion estimation techniques:**
Single platform, multi-channel with very long baselines
→ Unsuitable for constellations of small satellites
- **New Space Era:**
Miniaturization of SAR platforms → Attention focused on constellations of small satellites

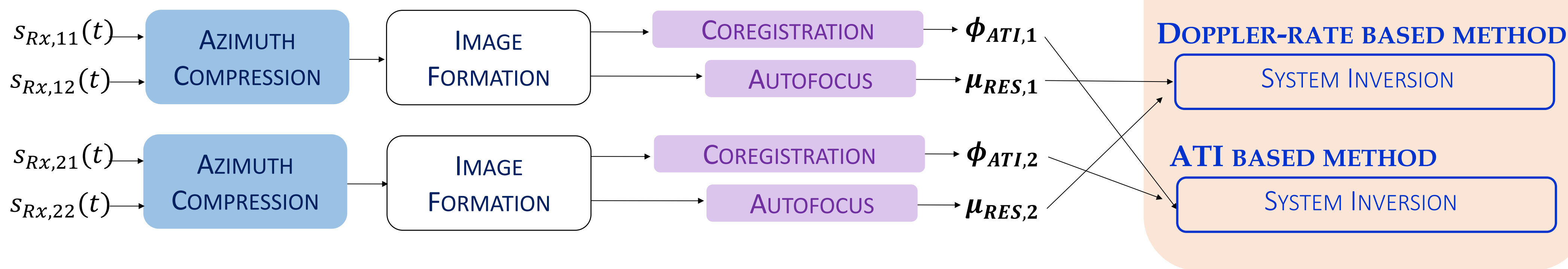


FOCUS OF THE WORK

- **Full velocity vector estimation** of surface movers already detected in SAR images. The satellites operate in **squinted geometry**.
- **Dual platform (k=1,2), dual-channel acquisition** → **Along-track interferometric phase (ATI)** based estimation technique.
- **Dual platform (k=1,2) single-channel acquisition** → **Doppler rate based** velocity estimation technique.

2. ESTIMATION ALGORITHM AND PERFORMANCE ANALYSIS

1. ESTIMATION ALGORITHM



2. PERFORMANCE ANALYSIS

- Complex SAR image corrupted by **zero mean additive white gaussian disturbance**
- Estimation accuracies $\sigma_{\delta V_x}$ and $\sigma_{\delta V_y}$ given by:

$$\begin{bmatrix} \sigma_{\delta V_x}^2 & 0 \\ 0 & \sigma_{\delta V_y}^2 \end{bmatrix} = Z_{ATI}^{-1} \begin{bmatrix} \sigma_{\phi_{ATI1}}^2 & 0 \\ 0 & \sigma_{\phi_{ATI2}}^2 \end{bmatrix} Z_{ATI}^{-1T}$$

$$\begin{bmatrix} \sigma_{\delta V_x}^2 & 0 \\ 0 & \sigma_{\delta V_y}^2 \end{bmatrix} = Z_{\mu_{RES}}^{-1} \begin{bmatrix} \sigma_{\mu_{res1}}^2 & 0 \\ 0 & \sigma_{\mu_{res2}}^2 \end{bmatrix} Z_{\mu_{RES}}^{-1T}$$

3. PERFORMANCE ASSESSMENTS RESULTS

DOPPLER-RATE BASED METHOD

$$\mu_{RES,k} \approx \frac{2V^2}{\lambda R_F} \left(1 - \frac{X_{sk}^2}{R_F^2} \right) - \frac{2V_y^2 + (V - V_x)^2}{\lambda R_{Fk}} + \frac{2[X_{sk}(V - V_x) - Y_s V_y]^2}{\lambda R_{Fk}^3}$$

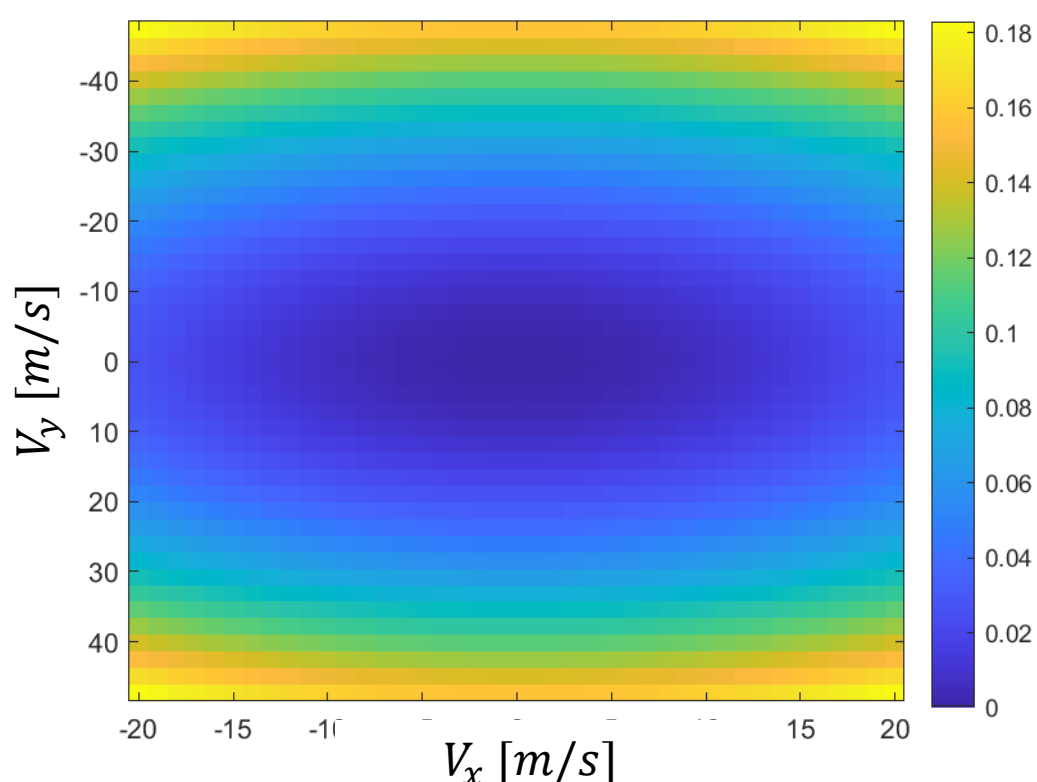
CASE STUDY : MONOSTATIC ACQUISITION IN LEO

H	570000 m	d	6/4 m
Y _s	265795,36 m	λ	0,03 m
θ _i	25°	V	7,5 km/s
SNR	1000 cos φ ₀ ⁴	φ ₀	26°

ATI BASED METHOD

$$\phi_{ATI,k} \approx \angle I_{k1} I_{k2}^* \approx \frac{4\pi}{\lambda V} d \left(\frac{-\left(X_{sk} + \frac{(V - V_x)x_{pk}}{V}\right)V}{R_{Fk}} + V_{radial,k} \right)$$

Linearization error of \widehat{V}_x



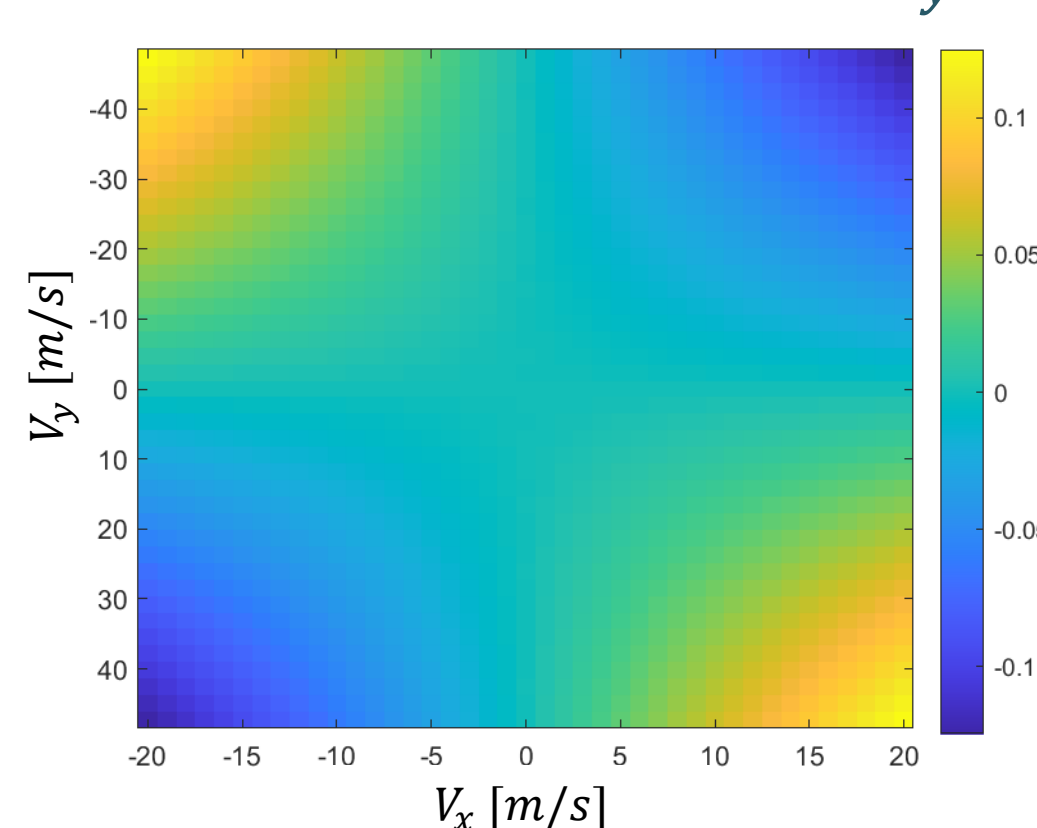
Precision limits due to linearization

$$\begin{bmatrix} \widehat{V}_x \\ \widehat{V}_y \end{bmatrix} = Z_{\mu_{RES}}^{-1} \begin{bmatrix} \mu_{RES,1} \\ \mu_{RES,2} \end{bmatrix}$$

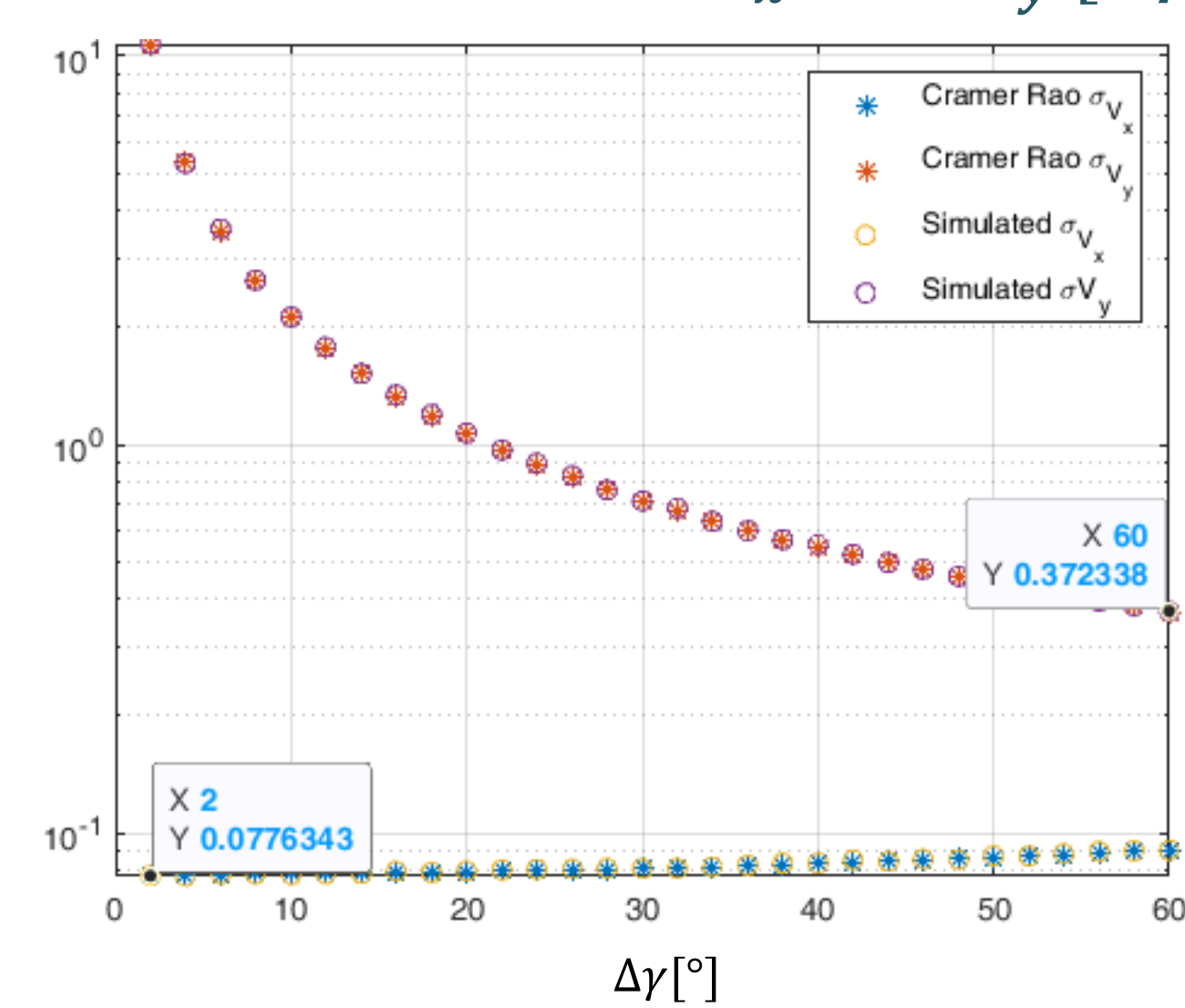
- Inversion of the system implies a **linearization error**
- Linearization errors are **proportional to the target velocity** → negligible errors for slow movers (e.g. ships) while higher errors experienced for faster targets (e.g. vehicles)

In all cases limited impact of the linearization error

Linearization error of \widehat{V}_y



Standard Deviation of \widehat{V}_x and \widehat{V}_y [m/s]

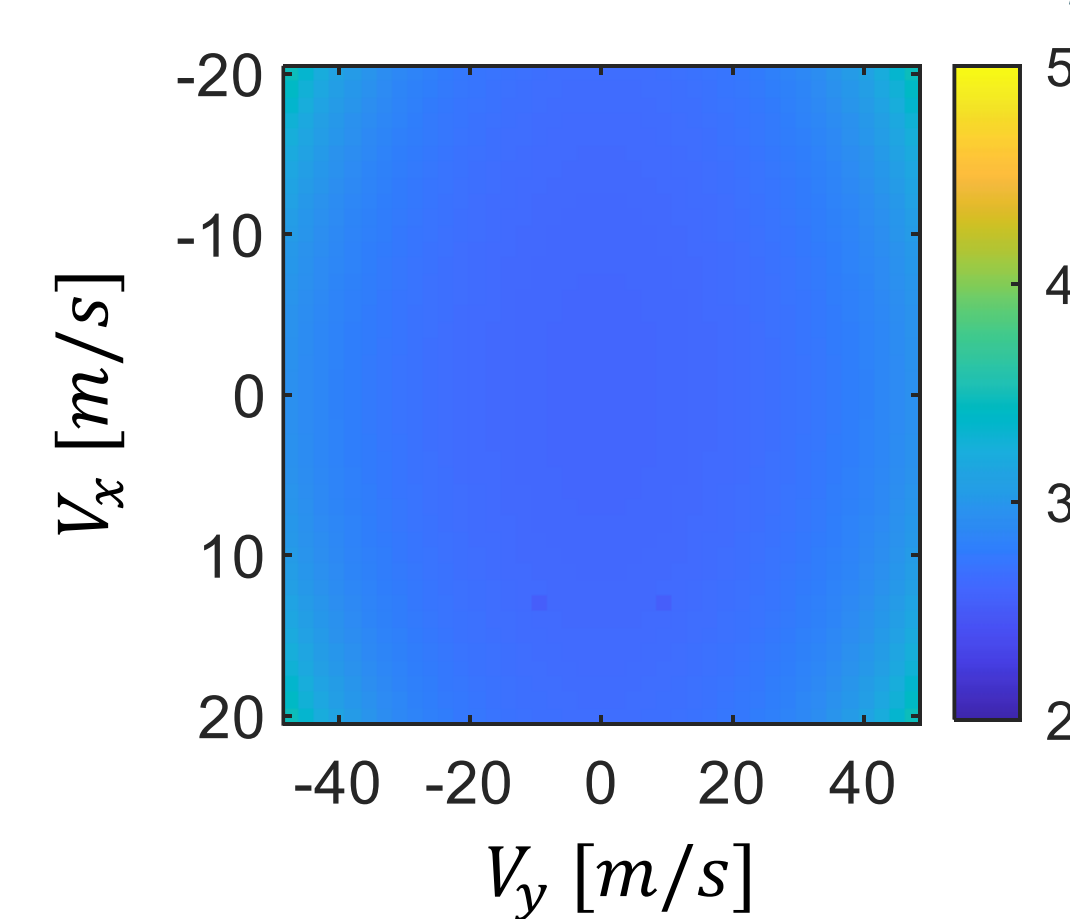


Validation of theoretical analysis → large agreement with Monte Carlo simulations

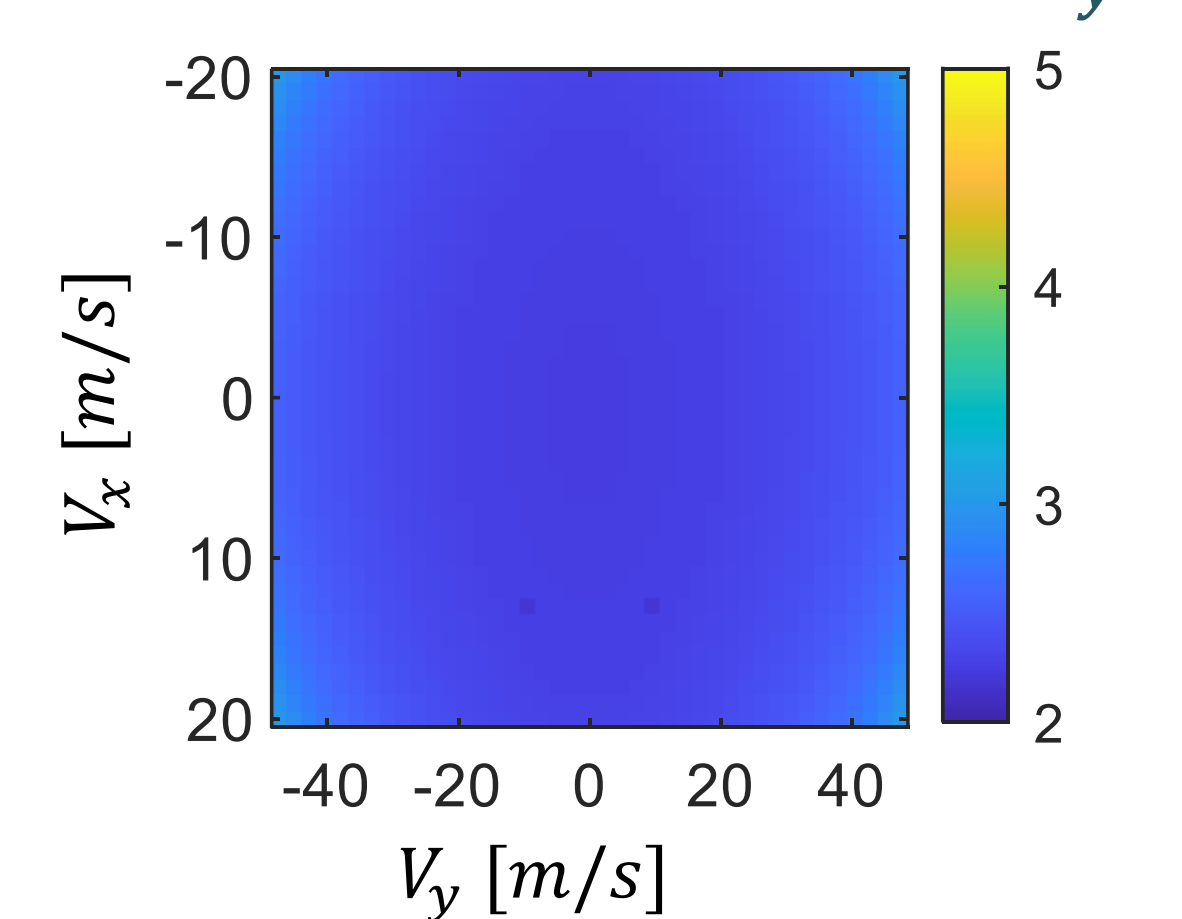
Achievable accuracy in presence of noise

- The accuracy of the y-component improves when **angular separation Δγ** increases → higher sensitivity to V_y
- The estimate of V_x is **less sensitive** to changes in angular separation
- Proposed technique guarantees **good performance** in the estimate of the velocity → possibility to estimate **velocity components with single-channel SAR platforms**

Standard Deviation of \widehat{V}_x

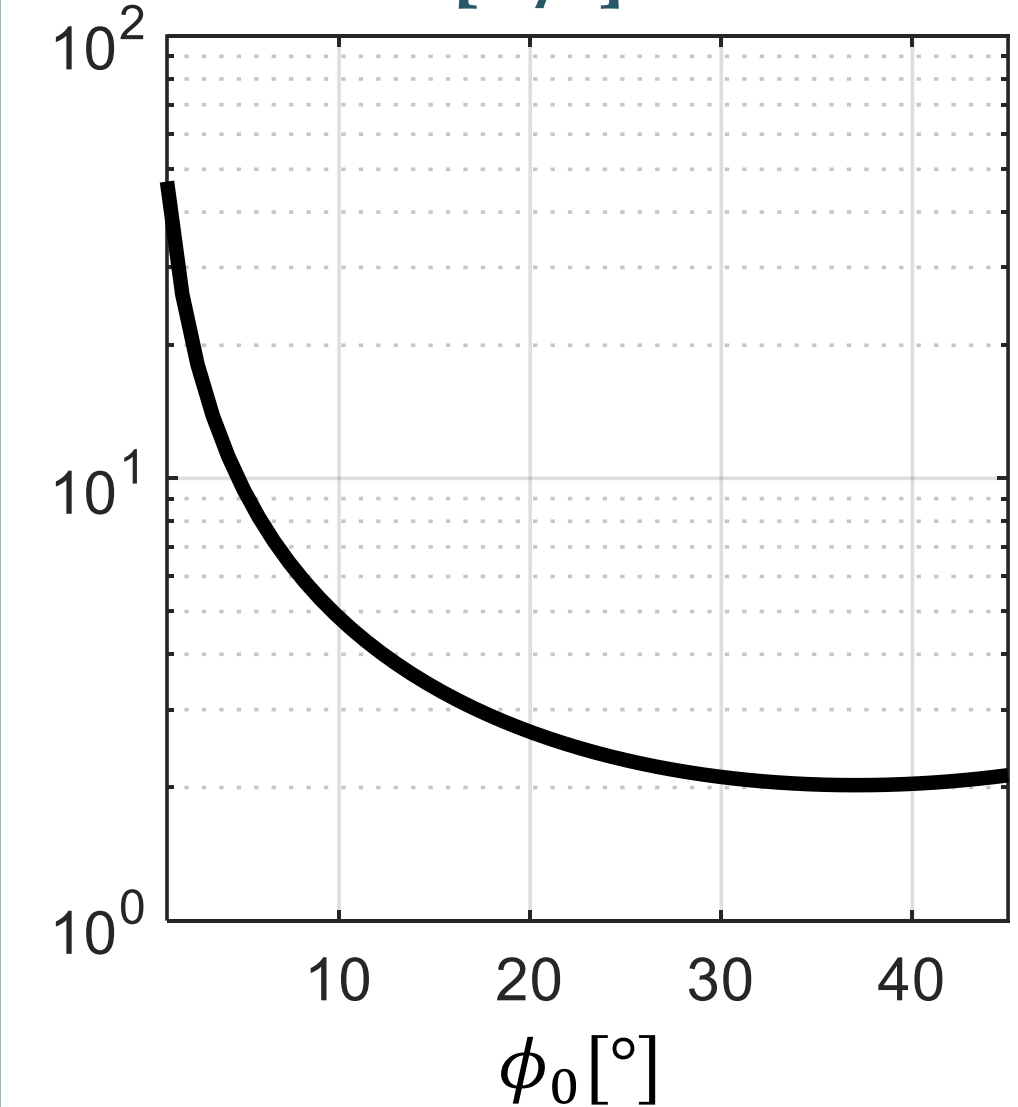


Standard Deviation of \widehat{V}_y

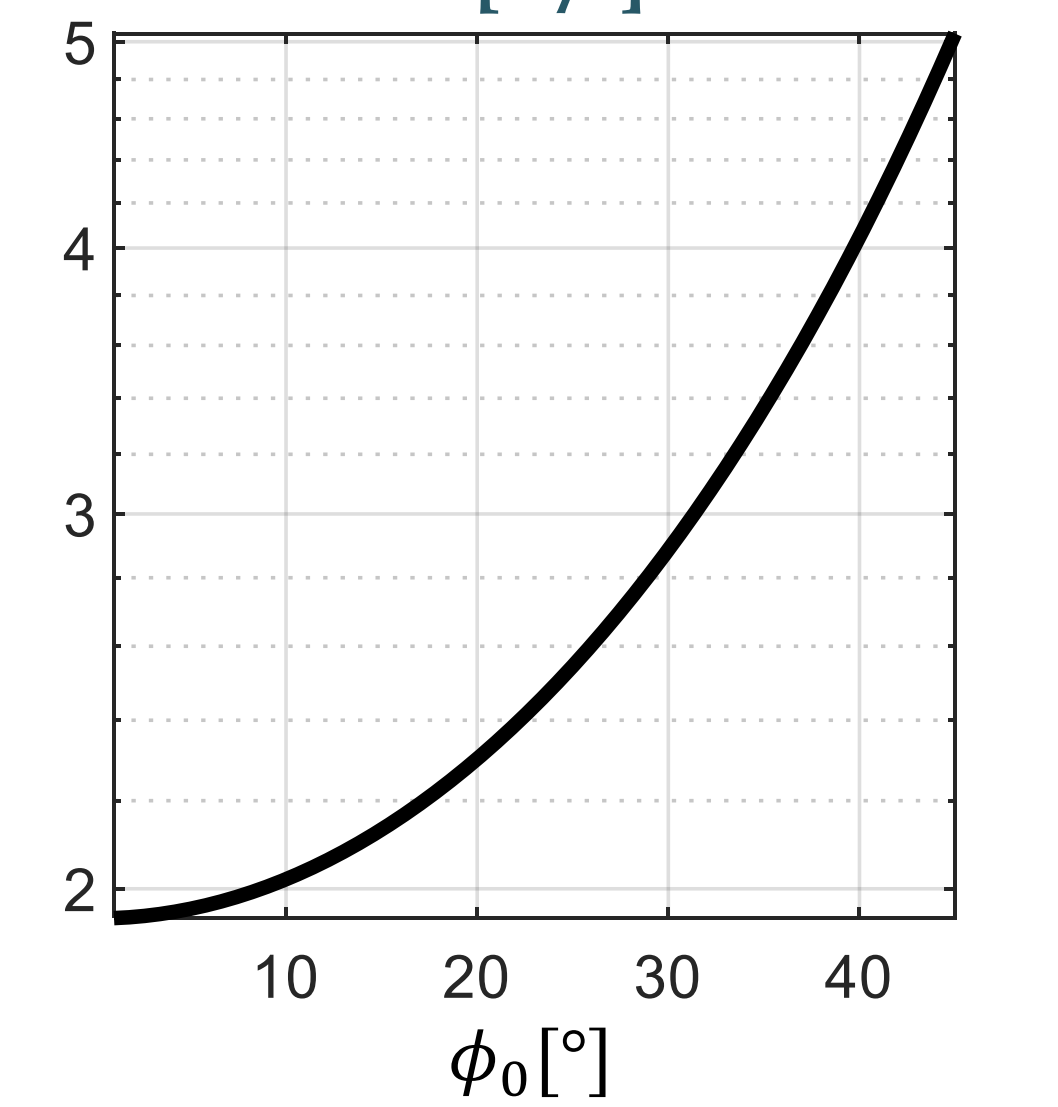


- Refocusing **before** ATI → maximize the SNR₀ and defocusing loss compensation, general **improvement** at high velocities
- ✓ Validation of theoretical analysis → large agreement with Monte Carlo simulations
- Estimation variances independent of velocity → searching for **optimum configuration**

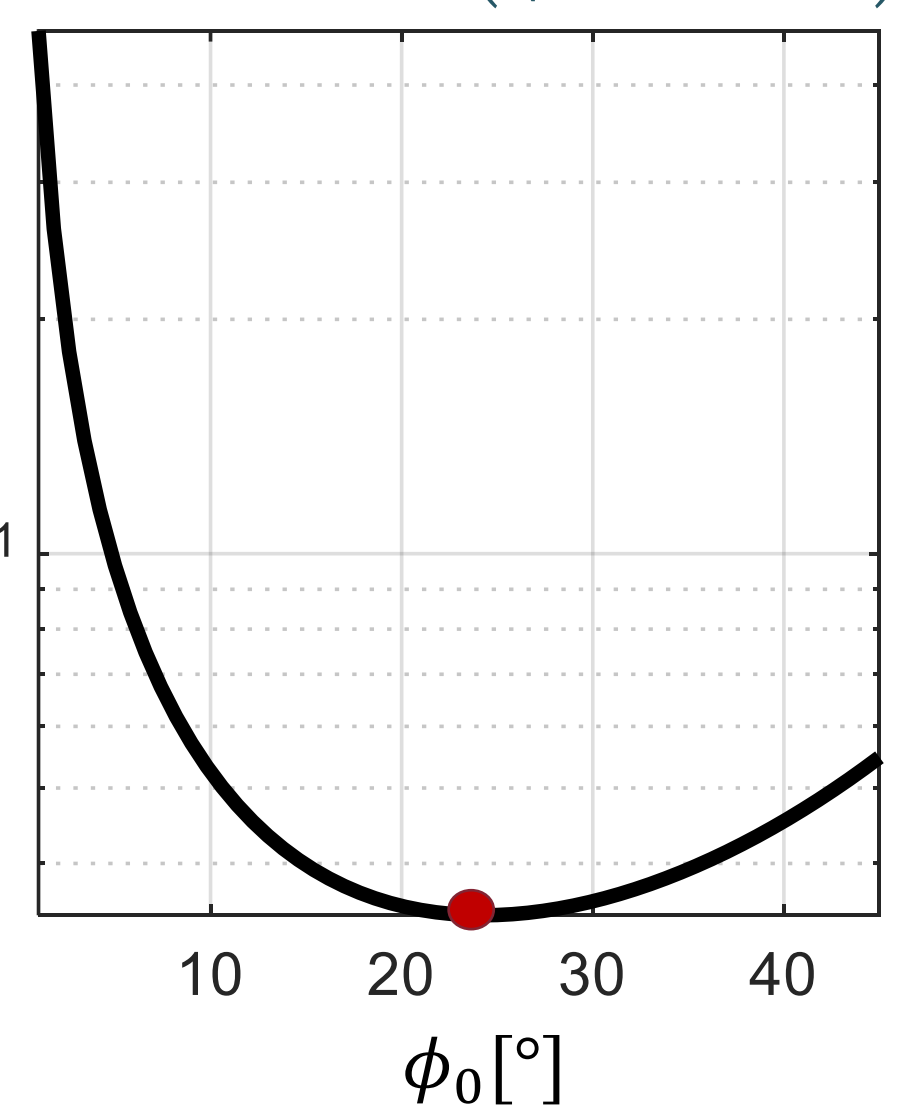
Standard Deviation of \widehat{V}_x [m/s]



Standard Deviation of \widehat{V}_y [m/s]



Optimal Squint Angle



- Higher sensitivity to along-track velocity
- Worse cross-track estimation capabilities

Optimal Squint Angle 24°

4. CONCLUSIONS

- ATI based method → high sensitivity to V_y (accuracy ≈ 2 m/s)
- Doppler-rate based method → high sensitivity to V_x (accuracy ≈ 10 cm/s)
- **Joint exploitation** of ATI and Doppler rate from both platforms to enhance the performance