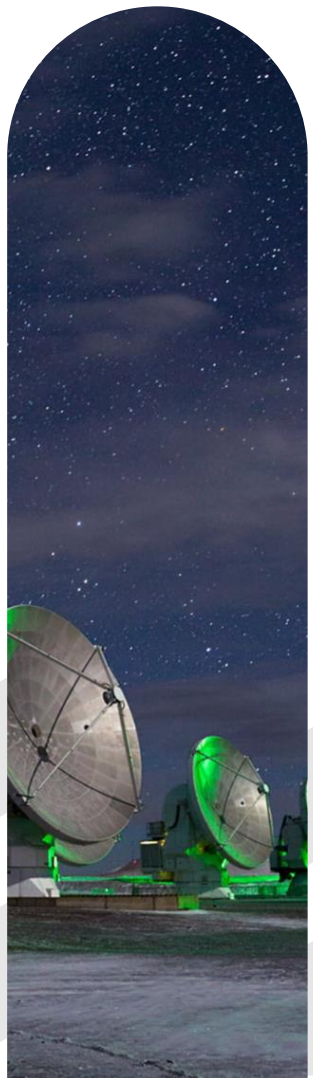
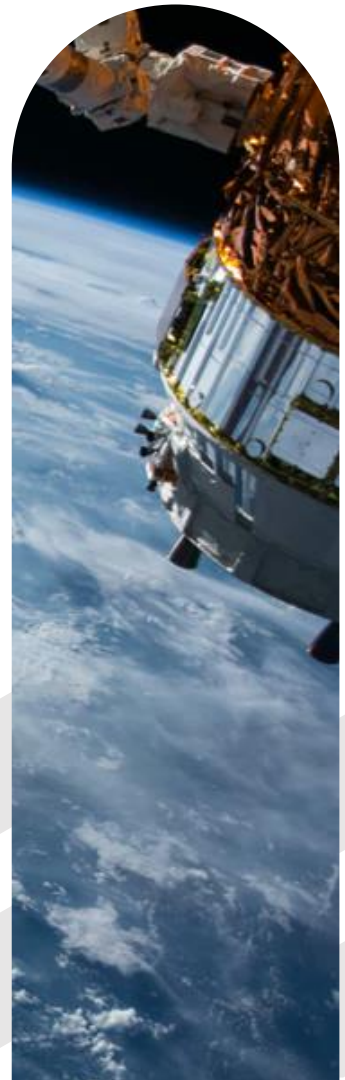
ADAPTIVE ANGULAR TRACK ESTIMATION FOR RESIDENT SPACE OBJECT ORBIT DETERMINATION

M. Montaruli, **P. Di Lizia**,
L. Facchini, M. Massari,
G. Pupillo, G. Naldi, G. Bianchi





OUTLINE

01 BIRALES data processing

From multibeam to adaptive beamforming with MATER algorithm

02 MATER: Catalogued object

MATER pipeline for the observation of catalogued objects

03 MATER: Uncatalogued object

MATER pipeline for the observation of uncatalogued objects

04 Conclusions

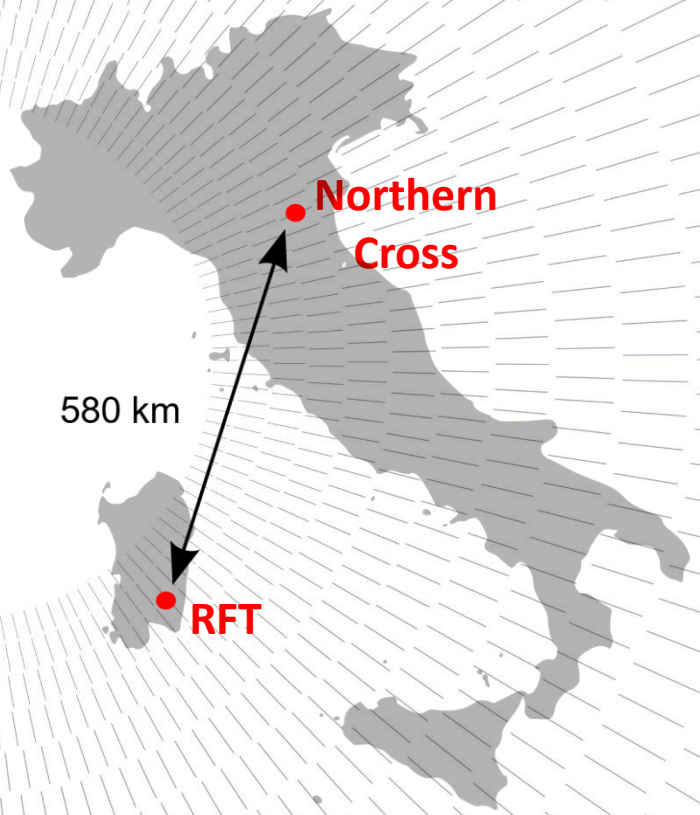
Conclusions and future developments

01 BIRALES
DATA PROCESSING

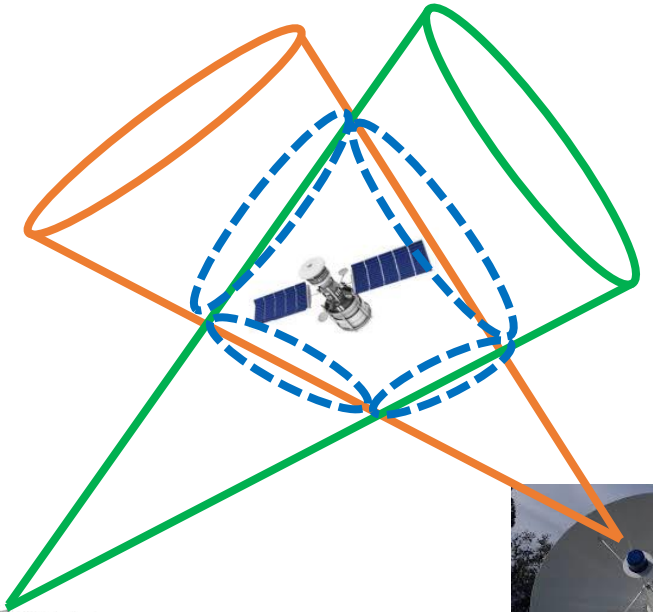
S4U

POLITECNICO MILANO 1863

BIstatic Radar for Leo Survey (BIRALES)



Northern Cross
(Bologna)

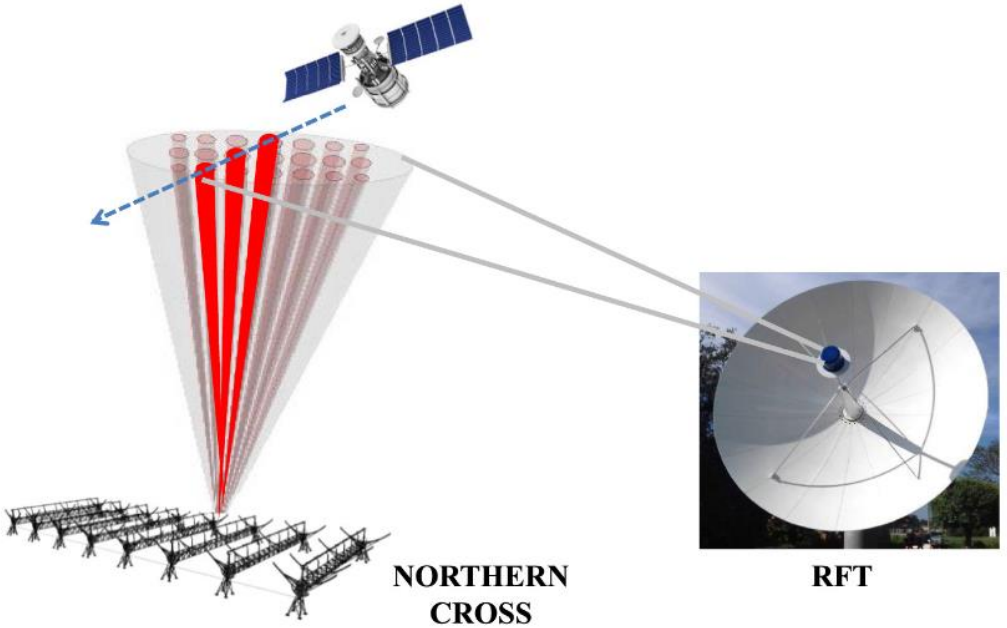


RFT
(Sardinia)

- Angular profile
- Slant Range
- Doppler Shift

BIRALES: MULTIBEAM APPROACH

Static beamforming [1]

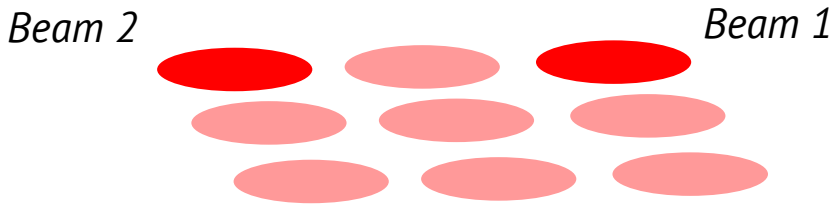


Medicina
(Bologna)

Salto di Quirra
(Sardinia)

Angular profile

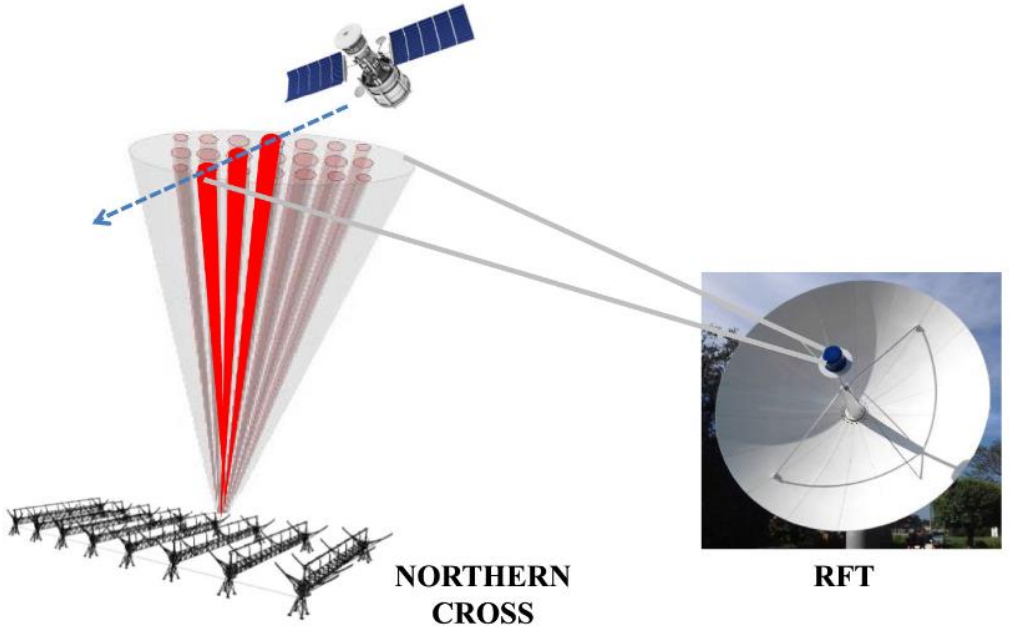
Disadvantage: both main lobes and grating lobes appear in sensor FoV



[1] *M. Losacco et al., Acta Astronautica, 2020*

BIRALES: MULTIBEAM APPROACH

Static beamforming [1]



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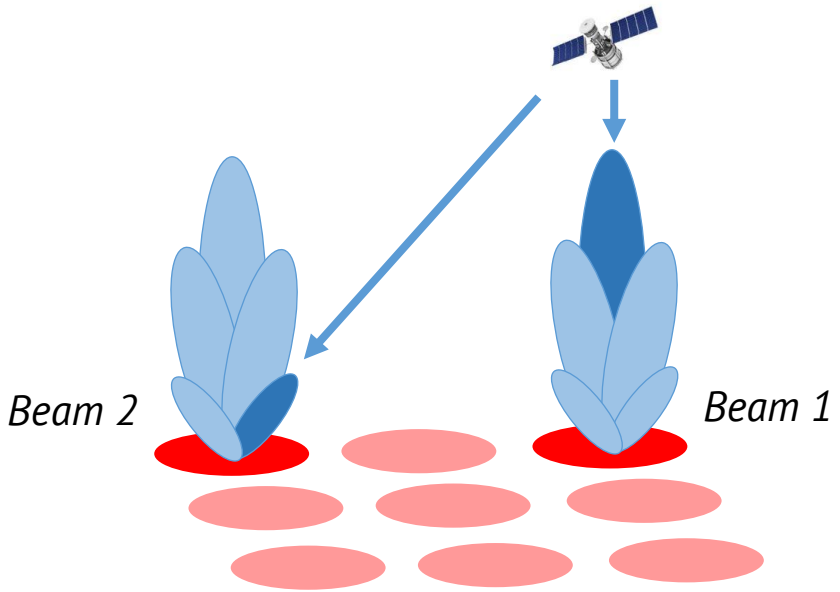

[1] *M. Losacco et al., Acta Astronautica, 2020*

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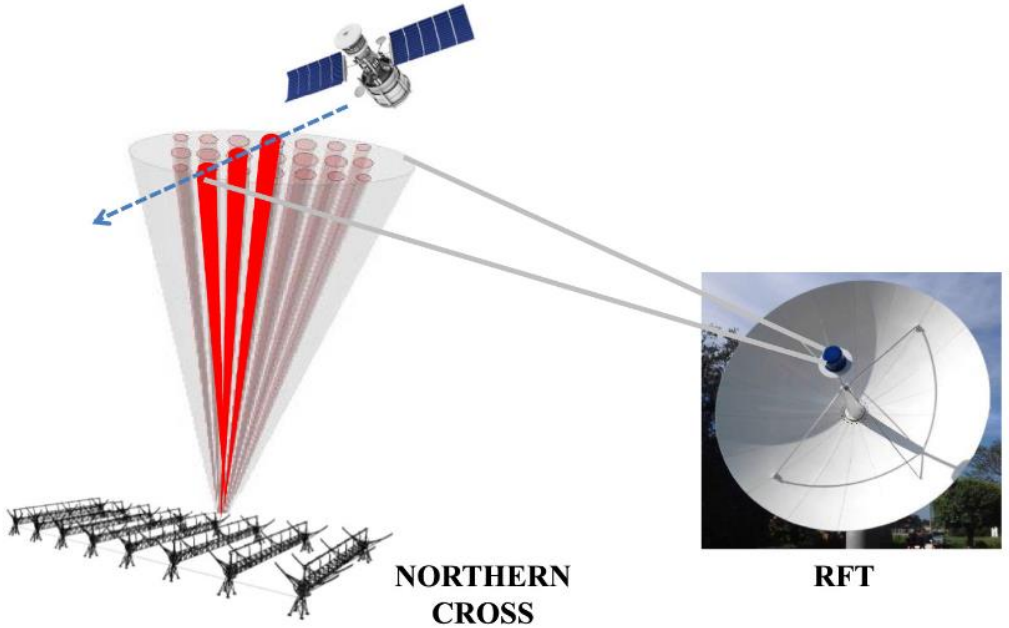

Medicina
(Bologna)

Salto di Quirra
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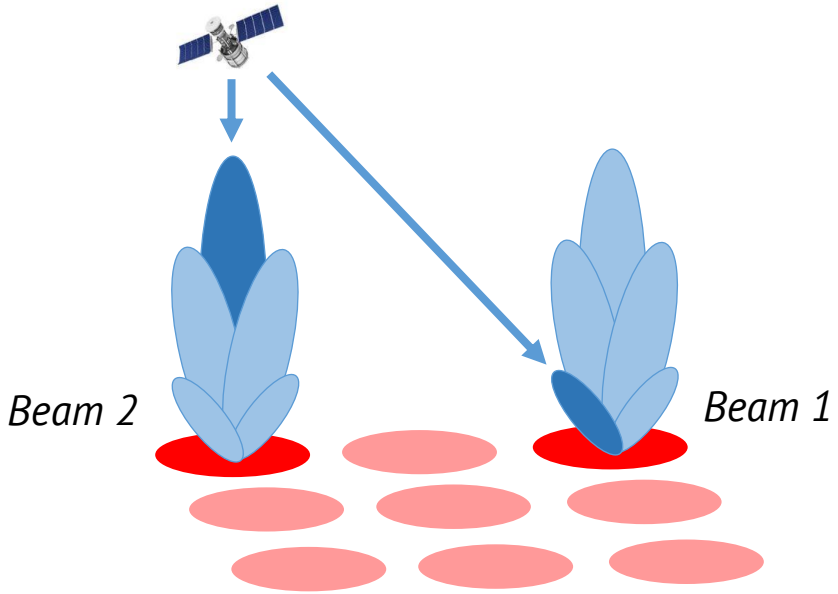
Angular profile

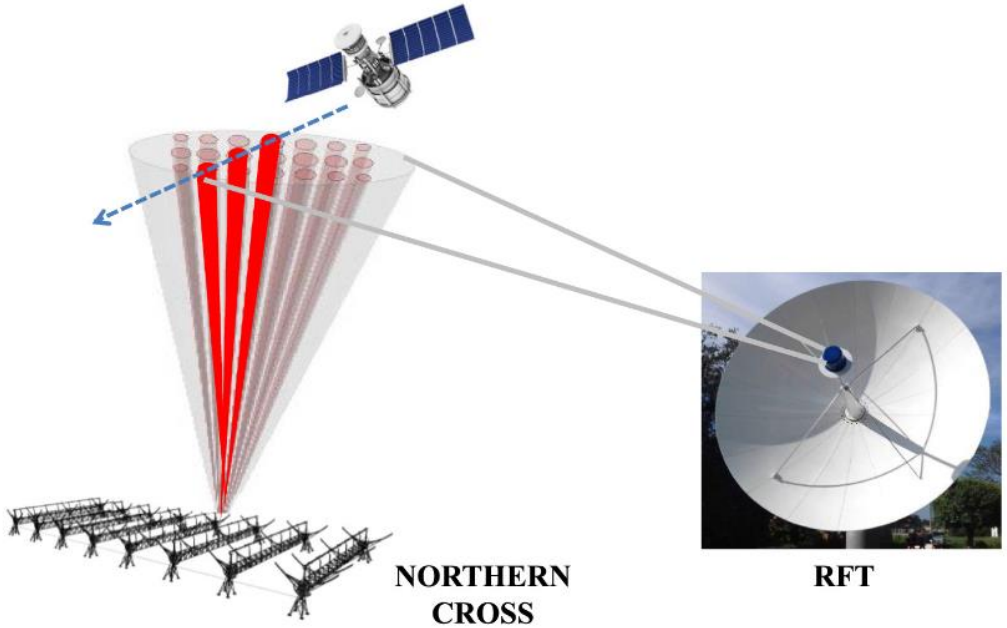
Disadvantage: both main lobes and grating lobes appear in sensor FoV



[1] *M. Losacco et al., Acta Astronautica, 2020*

BIRALES: ADAPTIVE BEAMFORMING APPROACH

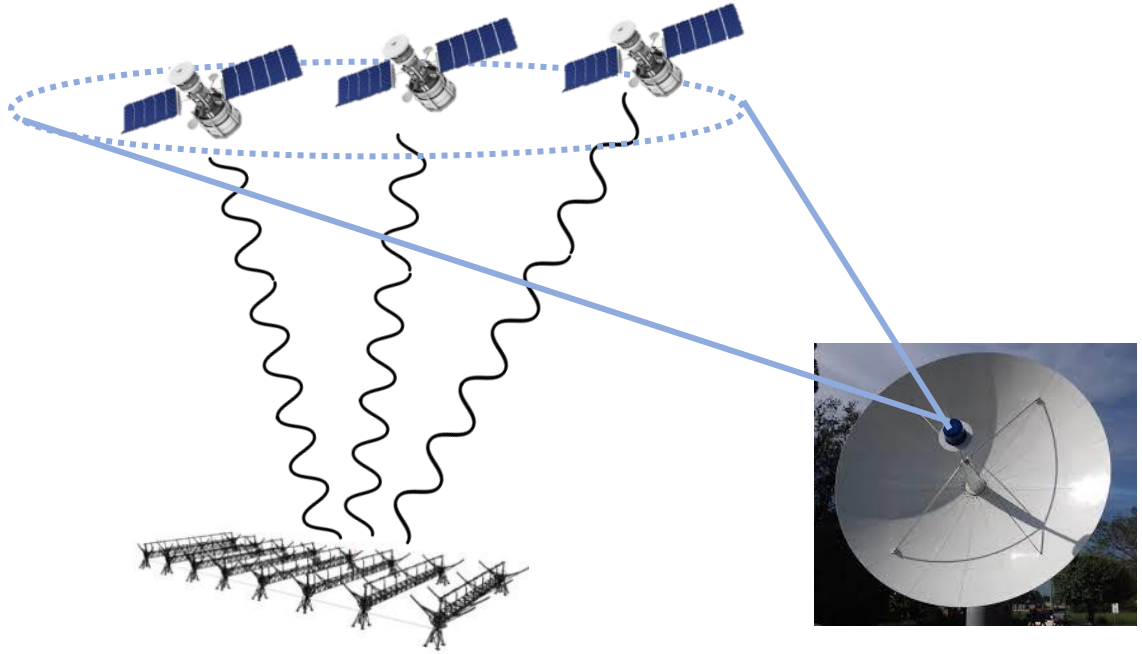
Static beamforming [1]



Medicina
(Bologna)

Salto di Quirra
(Sardinia)

Adaptive beamforming



[1] *M. Losacco et al., Acta Astronautica, 2020*

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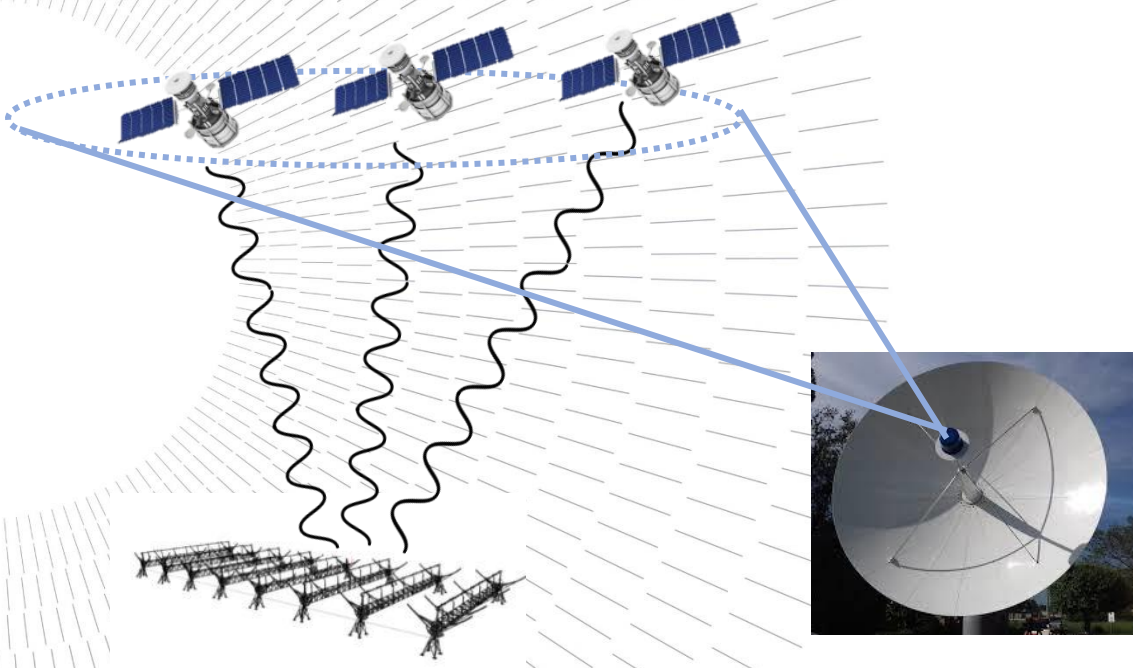
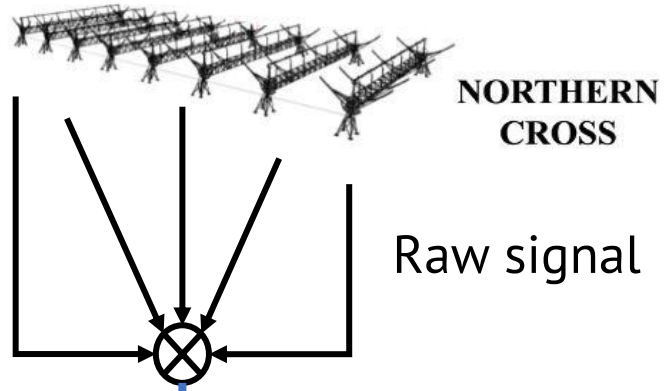
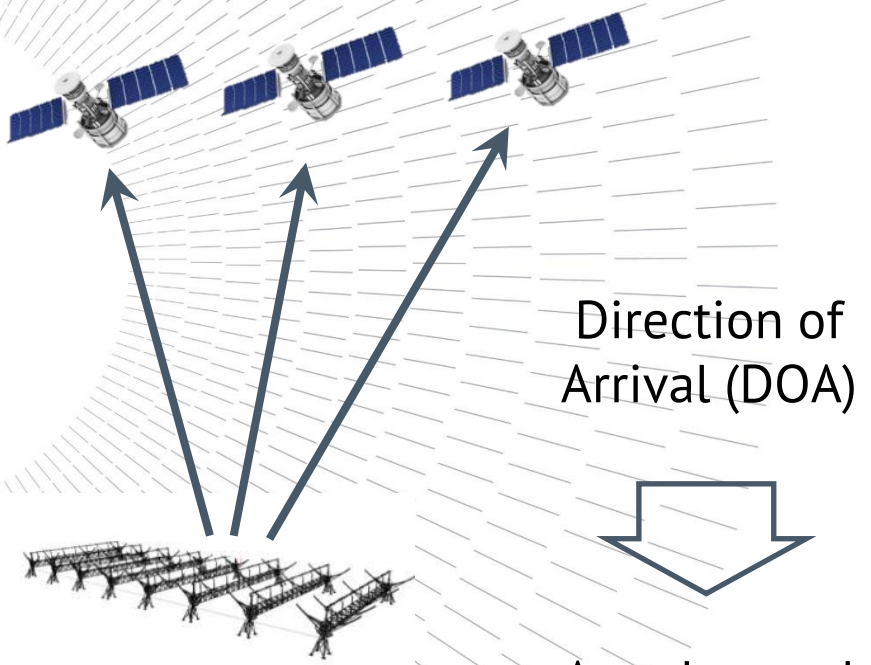


MUSIC - *MUltiple SIgnal Classification* [2]



[2] *R. Schmidt et al., IEEE Transactions on Antennas and Propagation, 1986*

BIRALES: ADAPTIVE BEAMFORMING APPROACH



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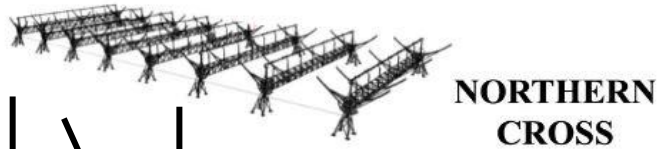
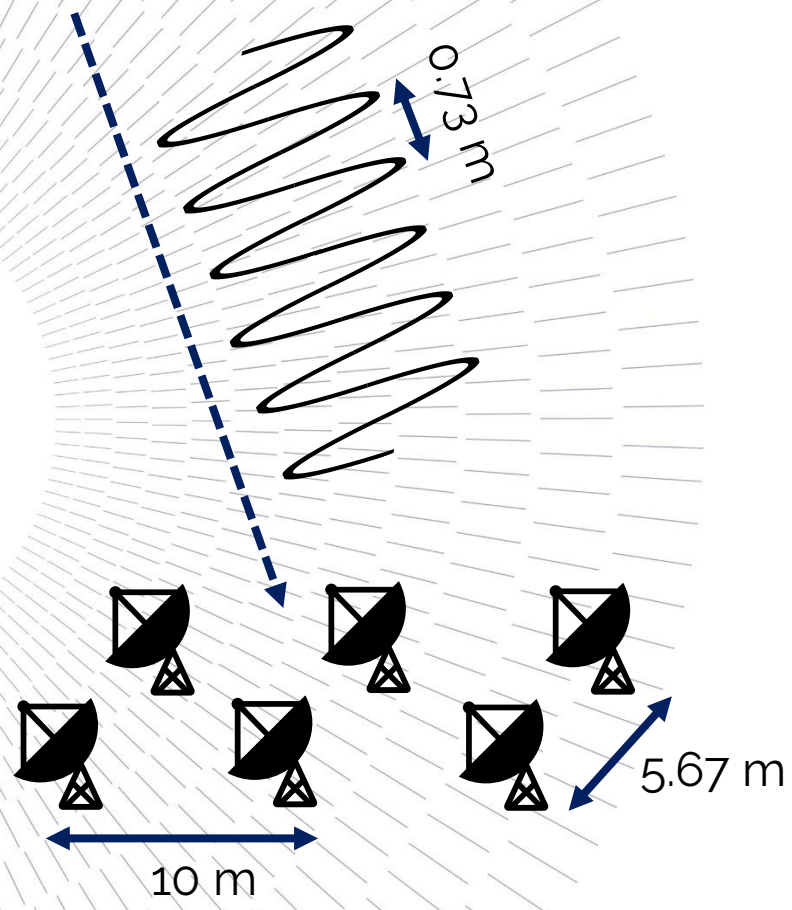


Raw signal

[2] *R. Schmidt et al., IEEE Transactions on Antennas and Propagation, 1986*

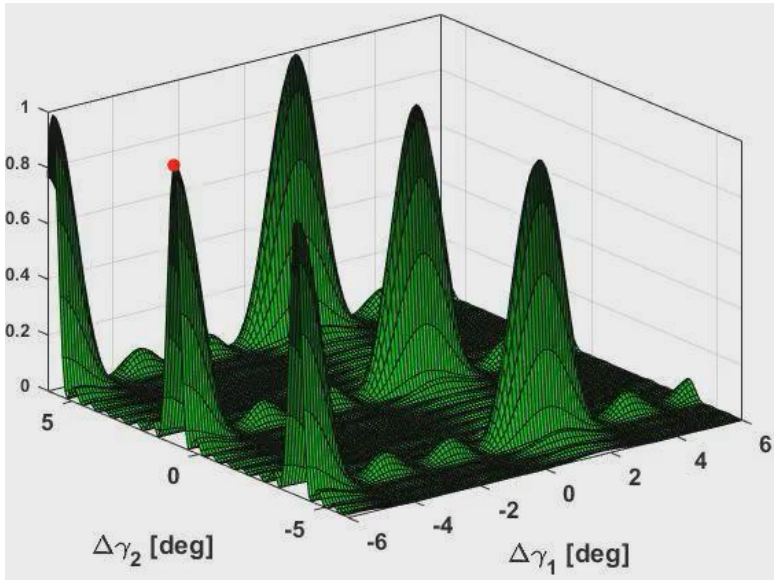
DOA AMBIGUITY PROBLEM



DOA solution is unique if distance between antennas is less than $\lambda/2$

⇨ Presence of multiple DOA estimates

⇨ Ambiguity solving criteria needed



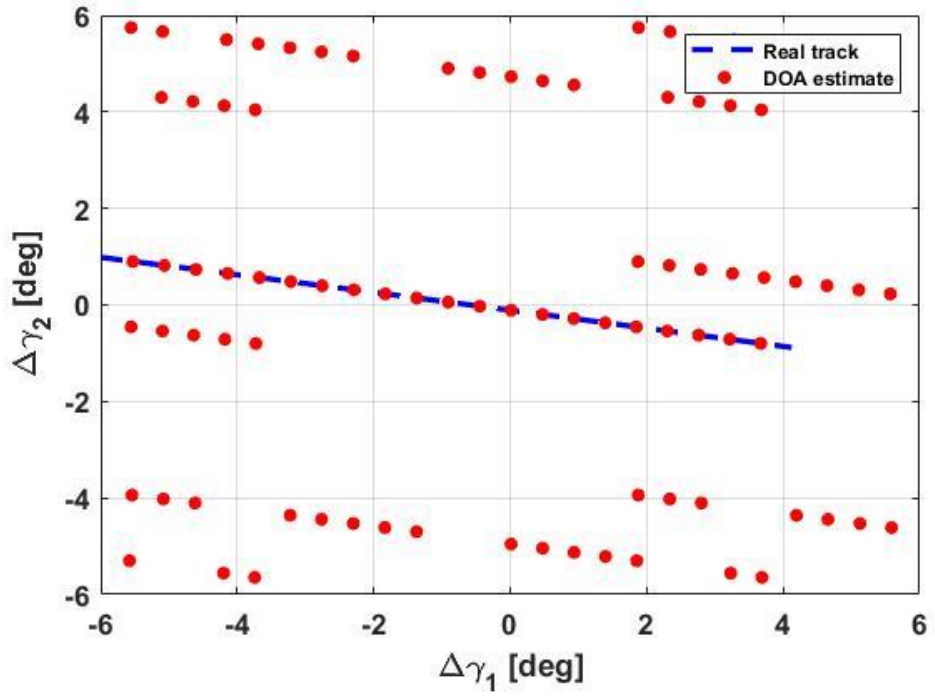
● Signal DOA

02 MATER
CATALOGUED OBJECT

Music Approach for Track Estimate and Refinement (MATER)

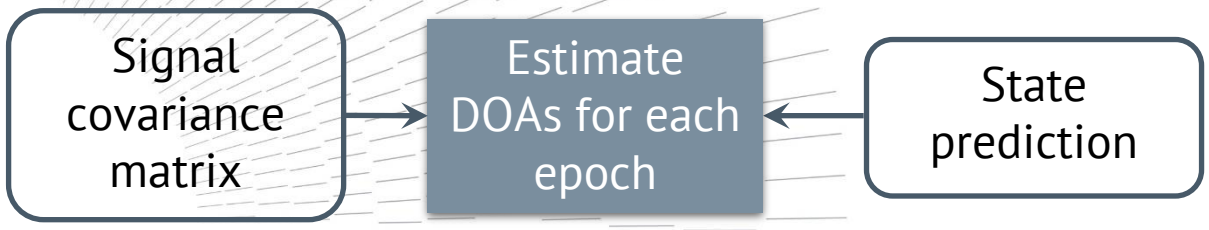
Catalogued case

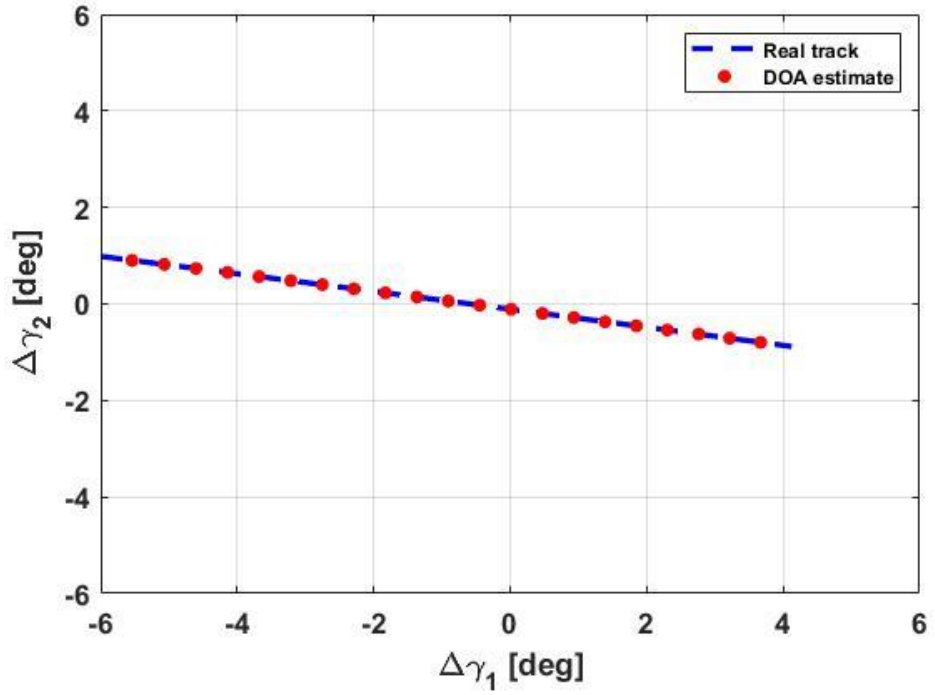
Signal covariance matrix → Estimate DOAs for each epoch



Music Approach for Track Estimate and Refinement (MATER)

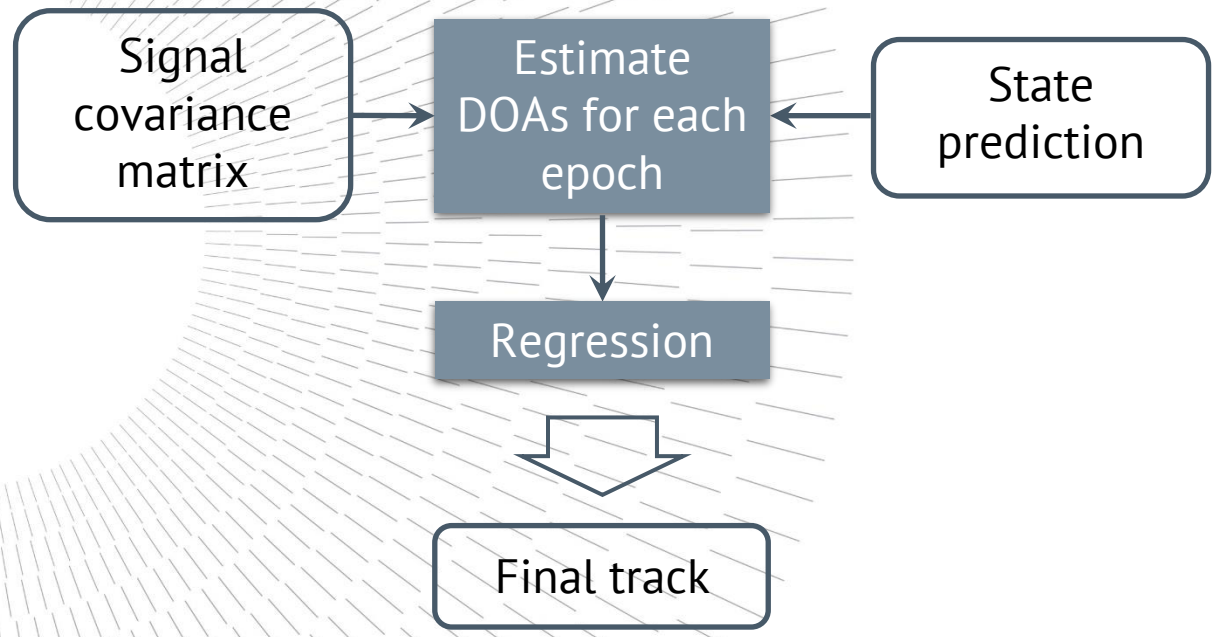
Catalogued case

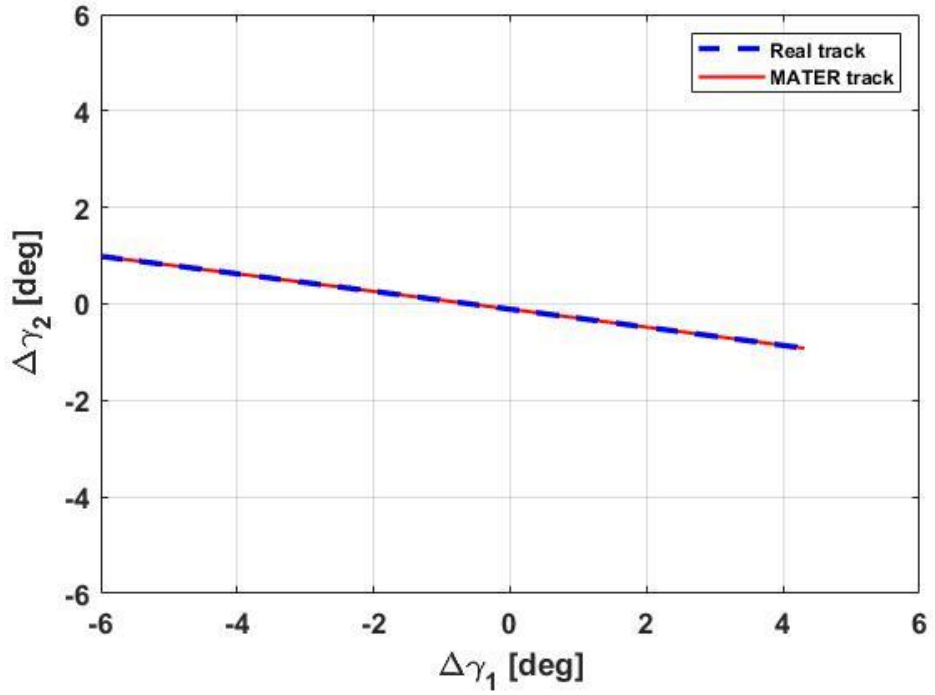




Music Approach for Track Estimate and Refinement (MATER)

Catalogued case





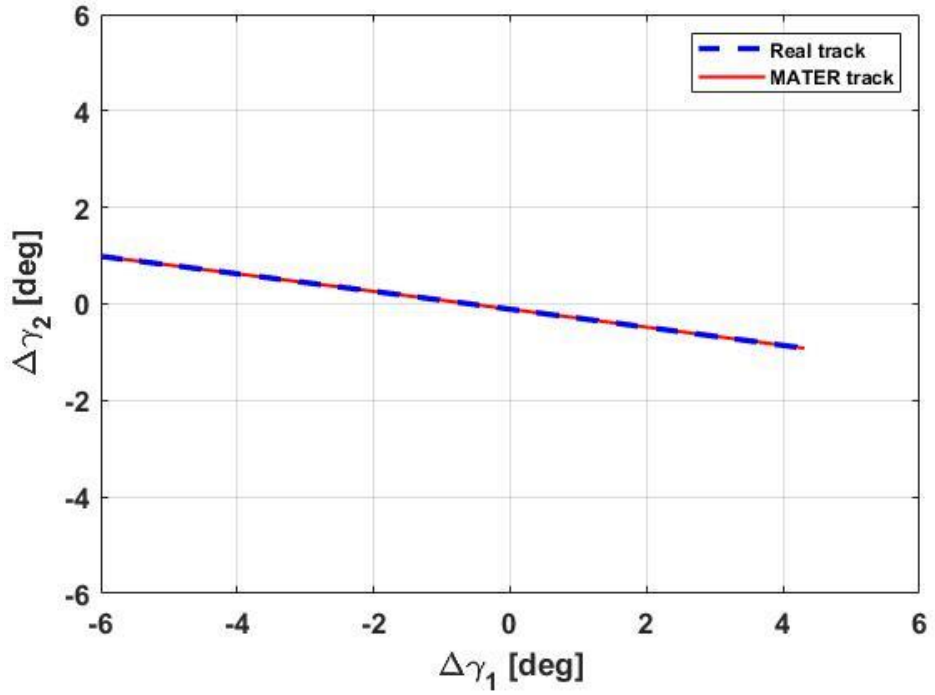
MATER: PERFORMANCE

Synthetic Data:

- 899 NORAD LEO passages, Entire FoV involved
- Transitted power: 10 kW
- Noise levels:
  - Slant range (SR) ~N[0, 30 m]
  - Doppler Shift (DS) ~N[0, 10 Hz]
  - SNR ~N[0, 0.5 dB]

Success rate: 100%

Percentile:	25%	50%	75%
$\Delta\gamma_1$ RMSE [deg]:	0.0033	0.0056	0.0110
$\Delta\gamma_2$ RMSE [deg]:	0.0060	0.0119	0.0129



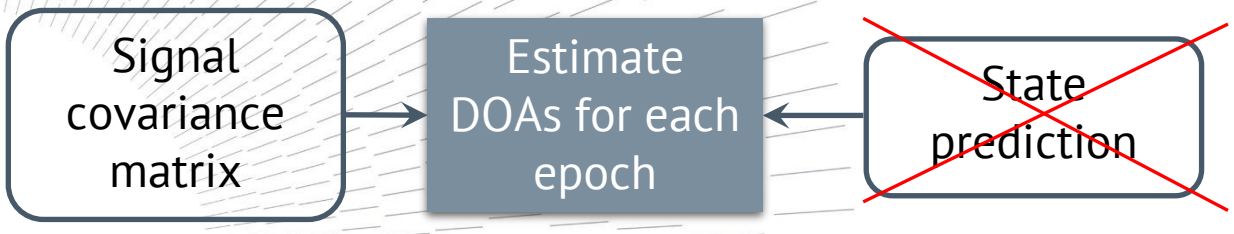
0 MATER
UNCATALOGUED OBJECT

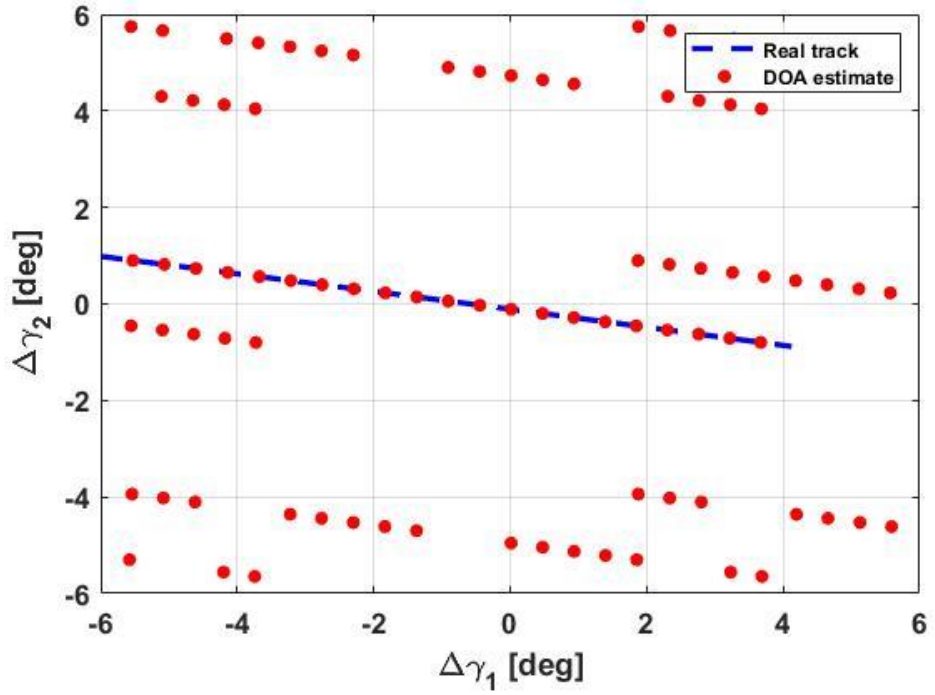
3

POLITECNICO MILANO 1863

Music Approach for Track Estimate and Refinement (MATER)

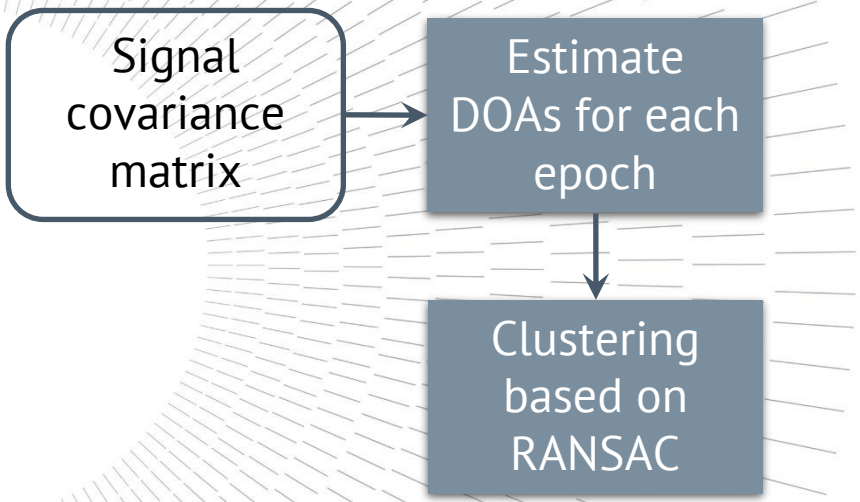
Uncatalogued case

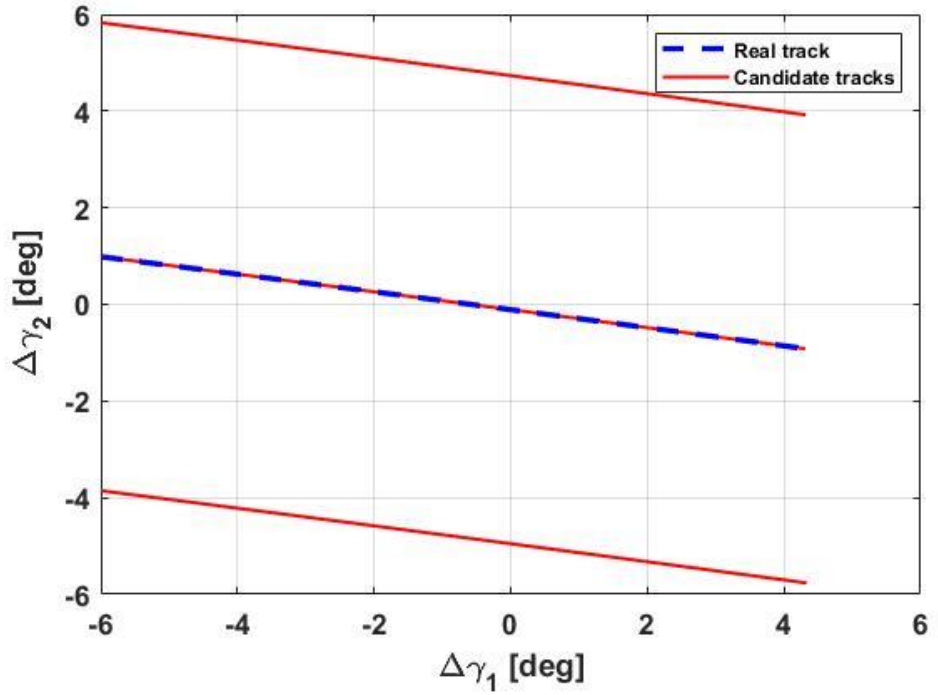




Music Approach for Track Estimate and Refinement (MATER)

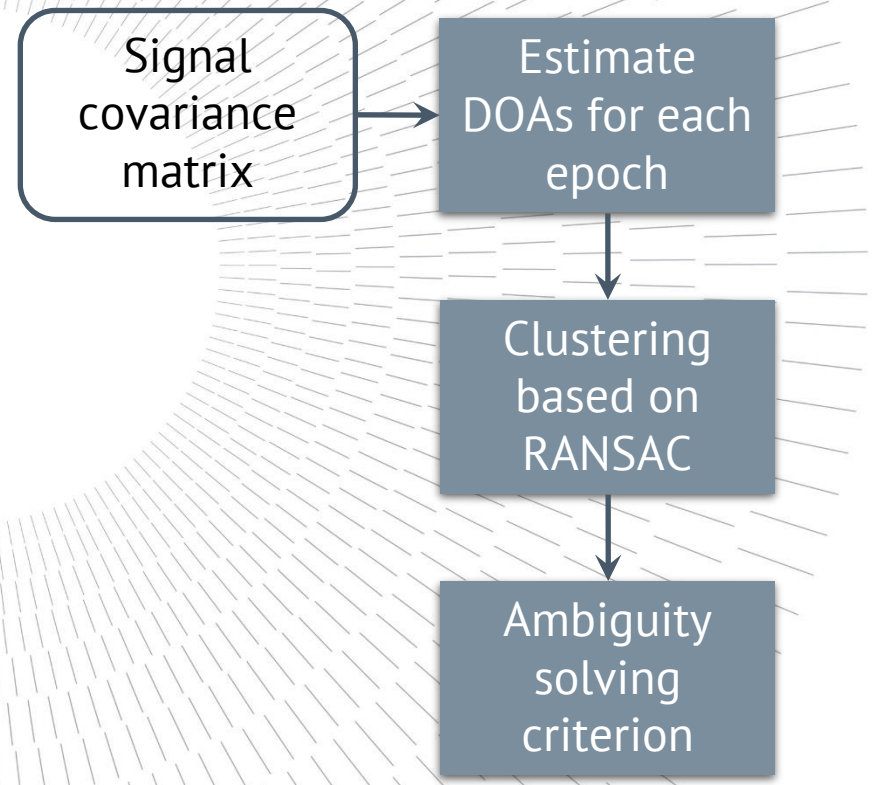
Uncatalogued case

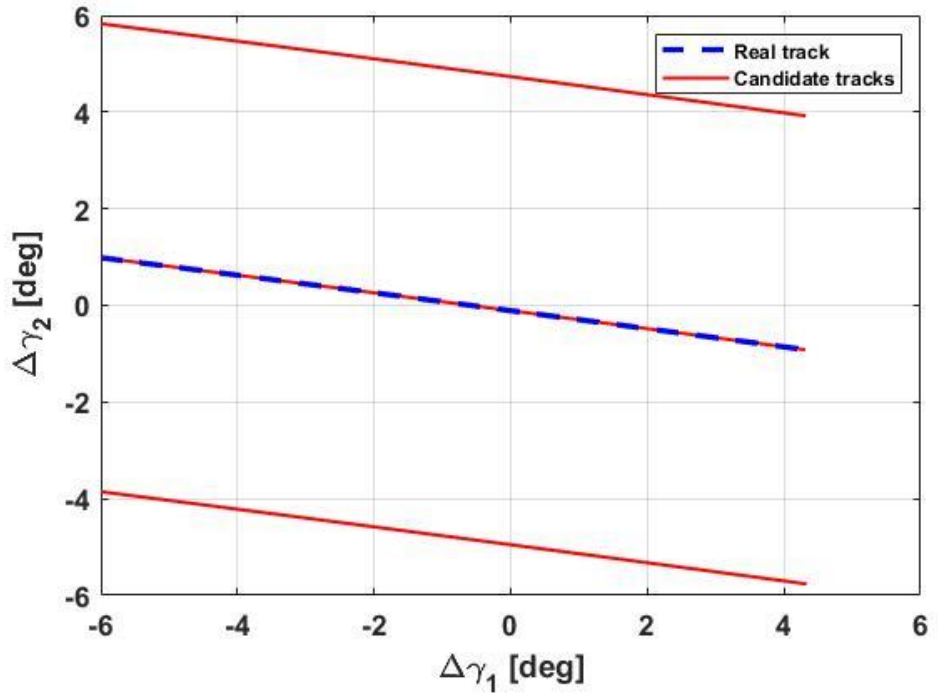




Music Approach for Track Estimate and Refinement (MATER)

Uncatalogued case





Music Approach for Track Estimate and Refinement (MATER)

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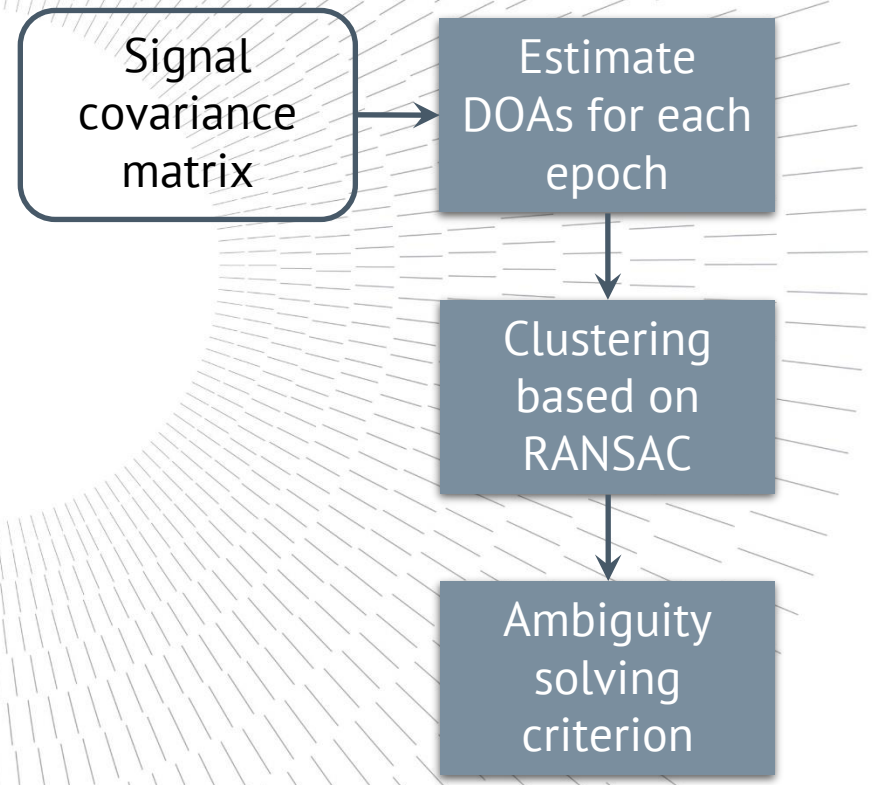
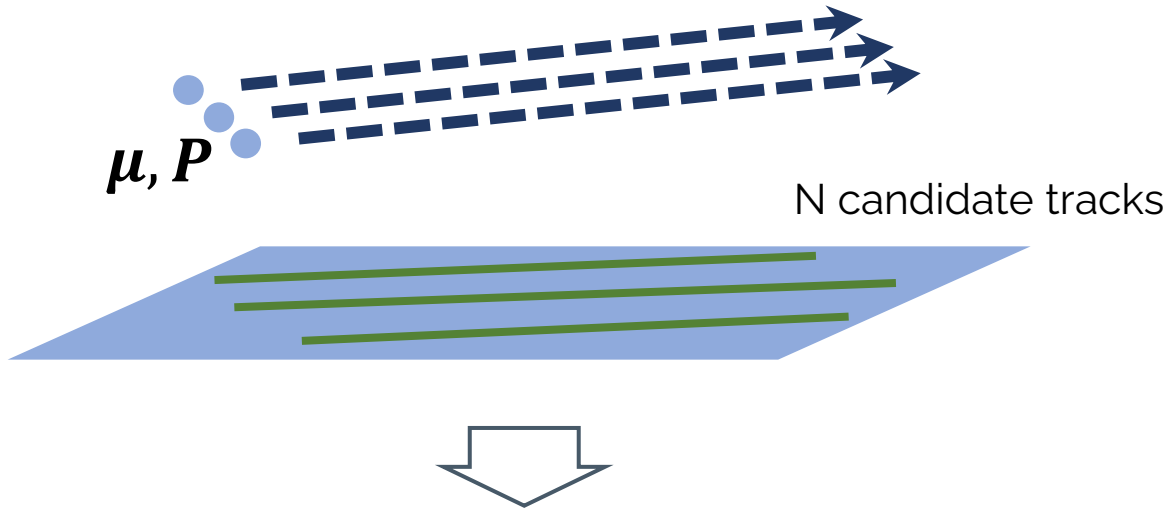


Proposed approach:

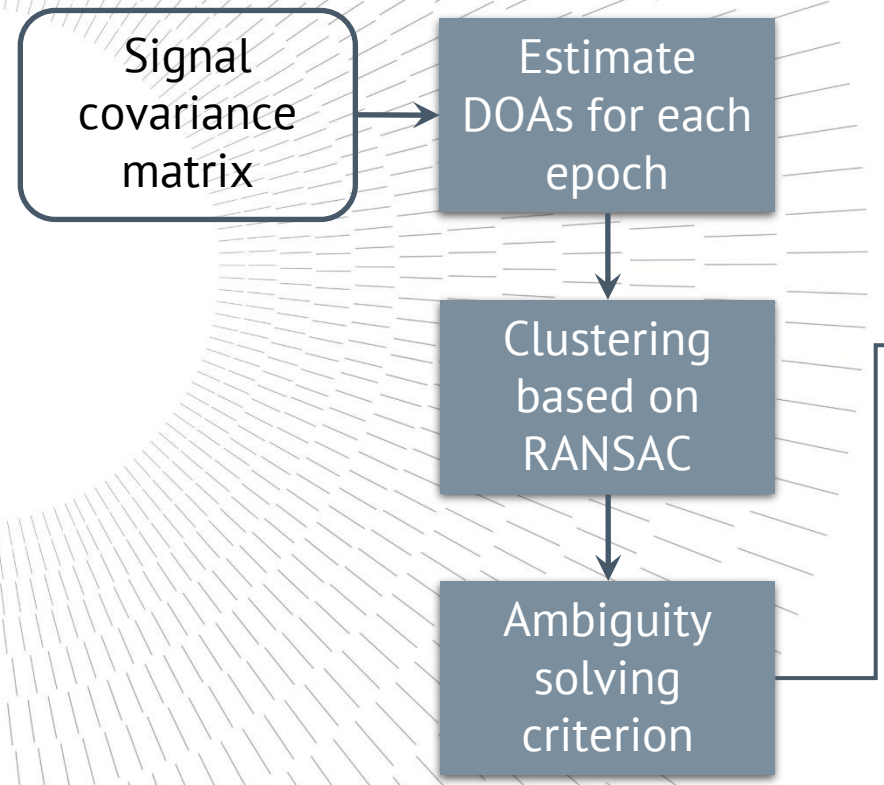
- For each candidate track, use measured DS and SR to perform an initial orbit determination (IOD)



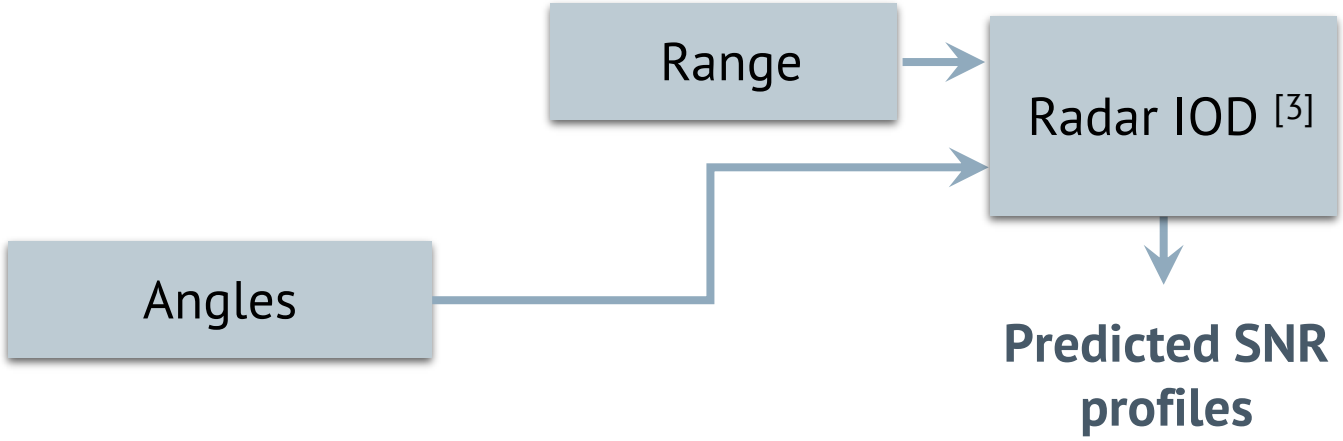
- Compute all predicted SNR profiles and compare with measured SNR

Music Approach for Track Estimate and Refinement (MATER)

Uncatalogued case



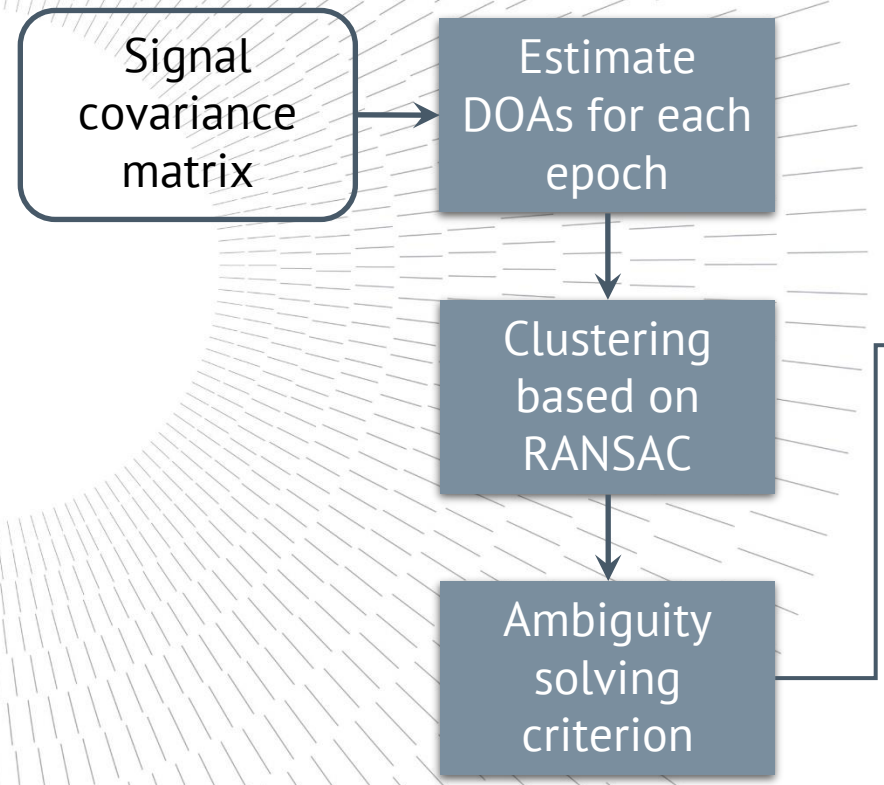
For each angular track, if range is available:



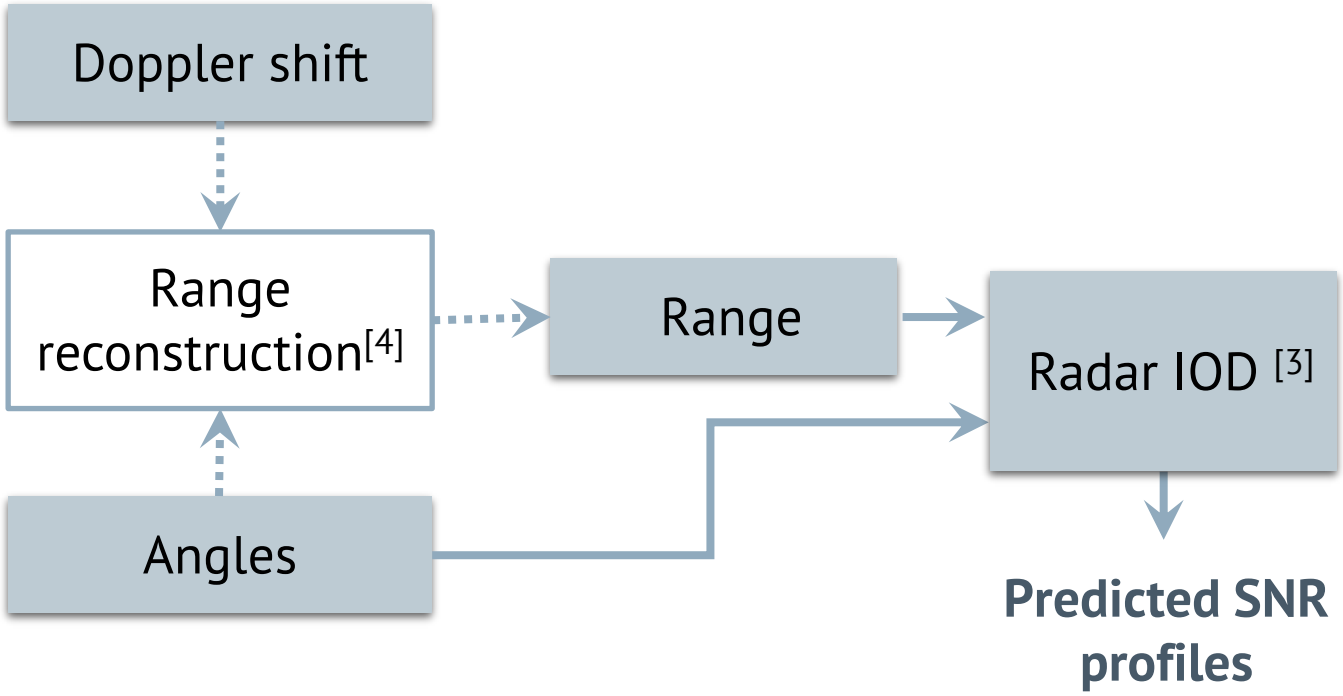
[3] J. Siminski, 6th International Conference on Astrodynamics Tools and Techniques (ICATT), Darmstadt, Germany, 2016, 14-17 March

Music Approach for Track Estimate and Refinement (MATER)

Uncatalogued case



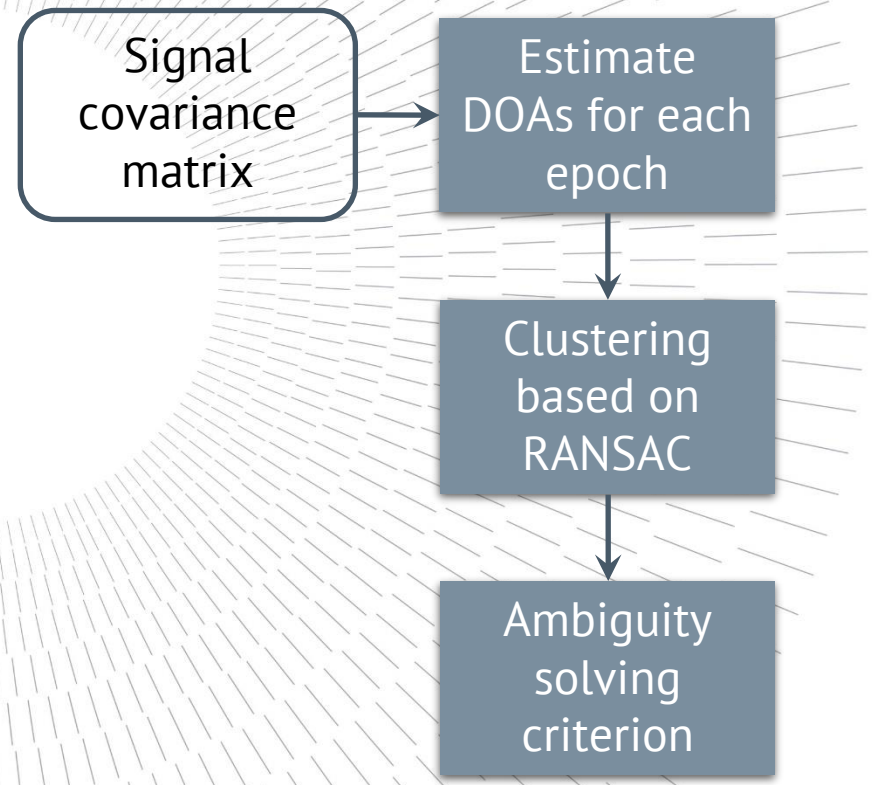
For each angular track, if only Doppler is available:



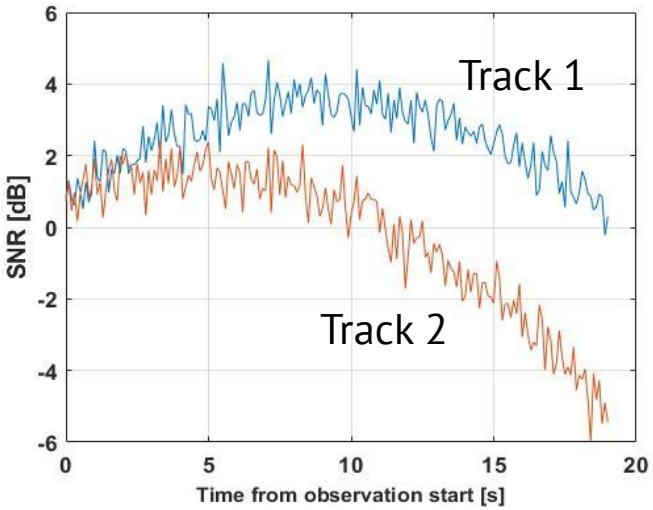
[4] C. Yanez et al, 7th European Conference on Space Debris, 2017

Music Approach for Track Estimate and Refinement (MATER)

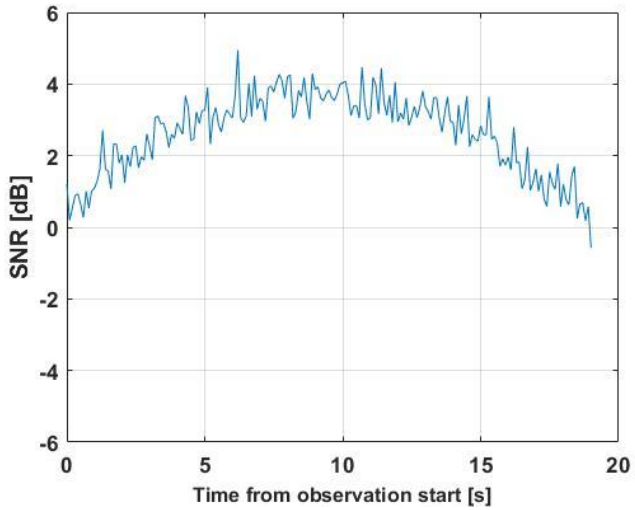
Uncatalogued case



Predicted



Measured



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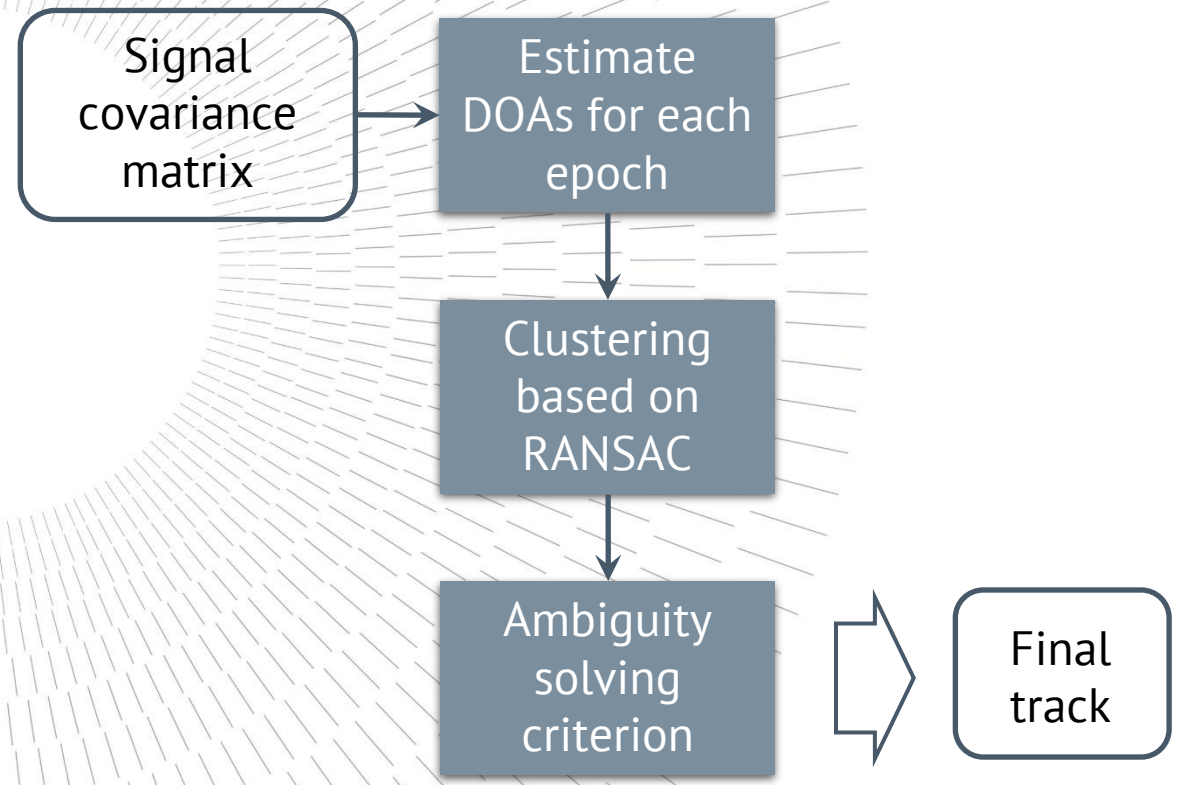
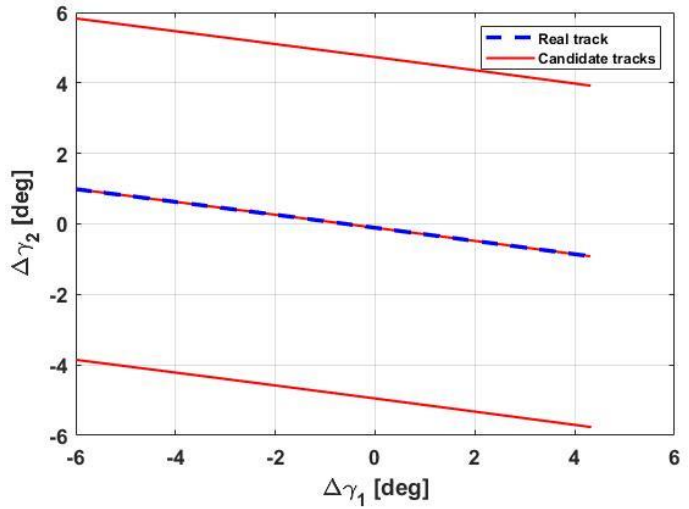
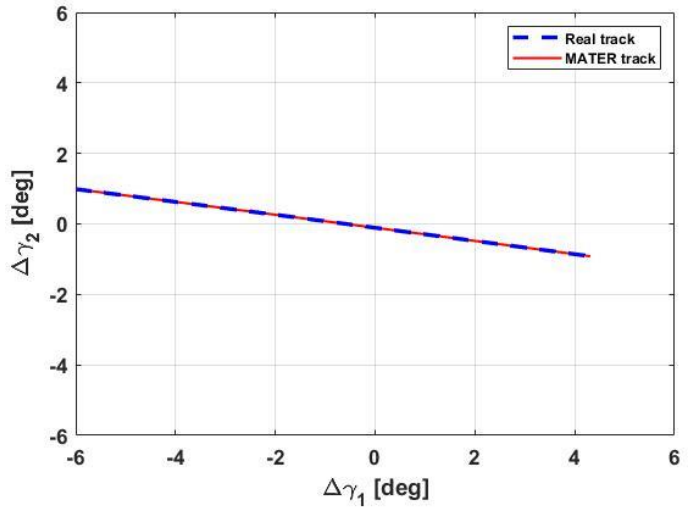
Uncatalogued case







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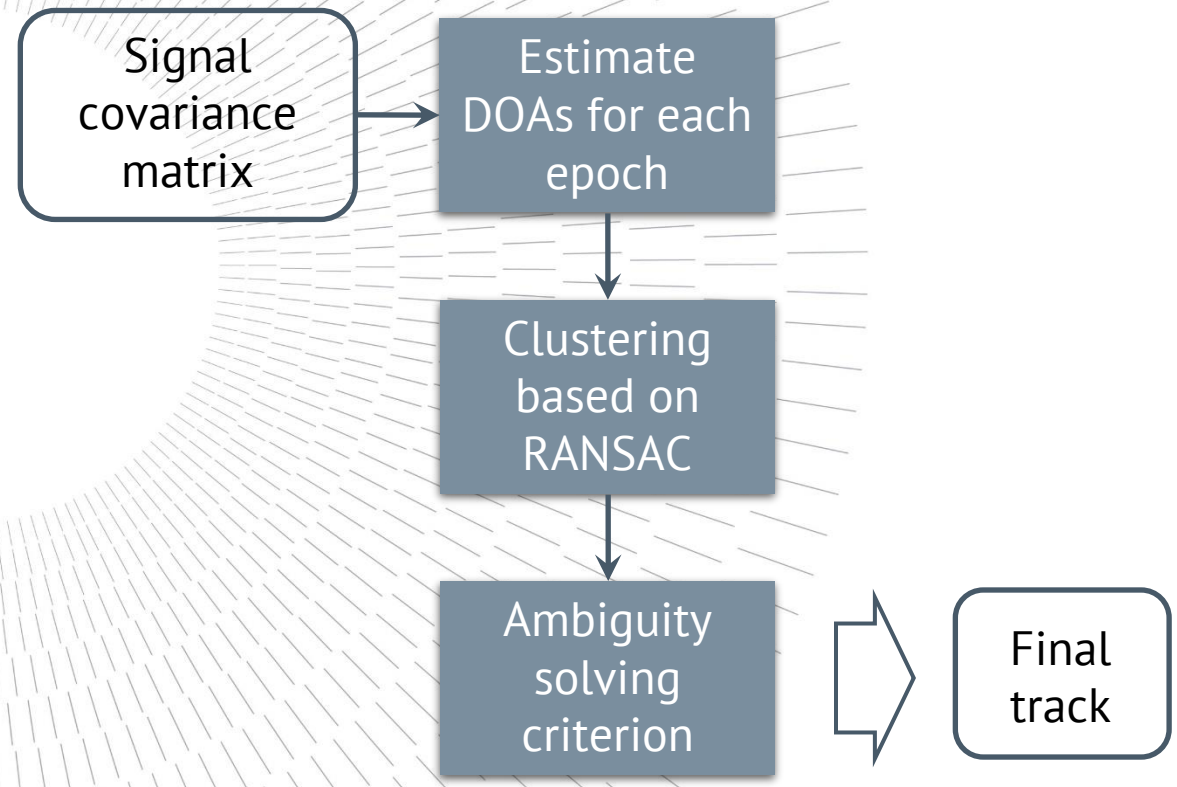


Synthetic Data:

- 899 NORAD LEO passages
- Entire FoV involved

Success rate	100%
Accuracy (RMSE)	10^{-3} – 10^{-2} deg

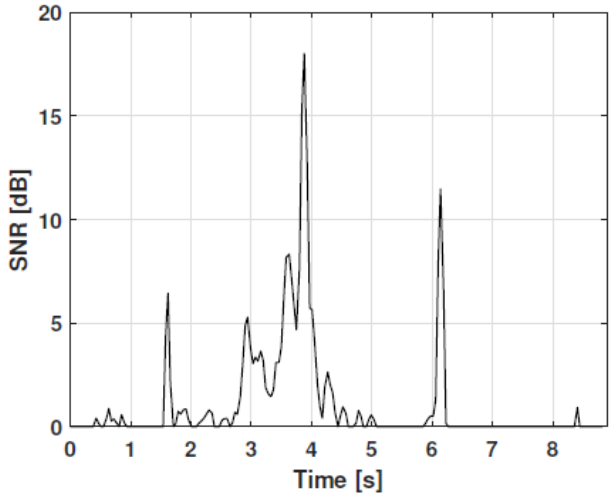
MATER PERFORMANCE: SENSITY ANALYSIS

Sensitivity analysis on the uncatalogued case:

Deterioration of transmitter power	✓
Signal interruption during the passage	✓
RCS fluctuations during the passage	✓
Mismatching between real and assumed RCS	✓
Signal from uncontrolled reentry	✓

⇨ Different signal noise levels

⇨



Success rate: 100 %
RMSE: 10^{-3} – 10^{-1} deg

REAL OBSERVATIONS

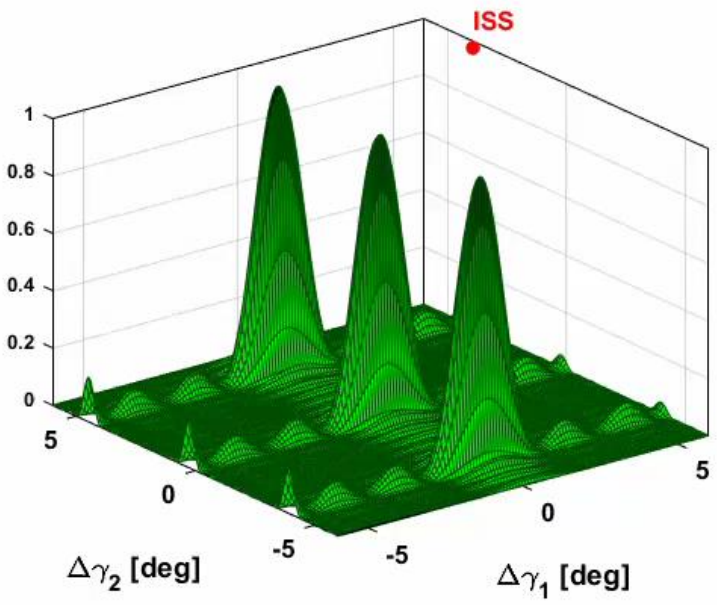
ISS passage (April 28, 2021)

Current signal processing chain not suitable:

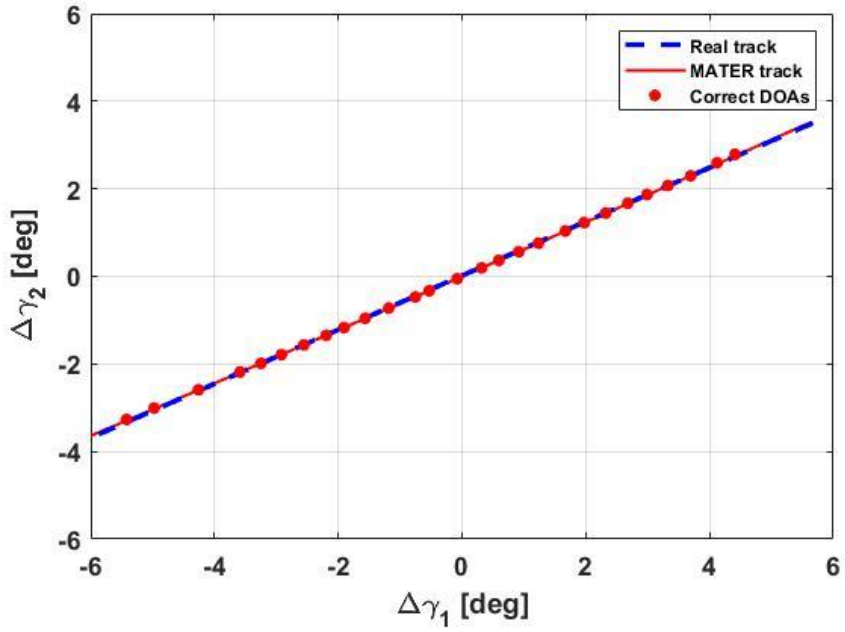
- Still designed for a multibeam logics
- Very noisy covariance matrices

Only large objects with small SR

MUSIC pattern



Accuracy	1e-02 - 1e-01 deg



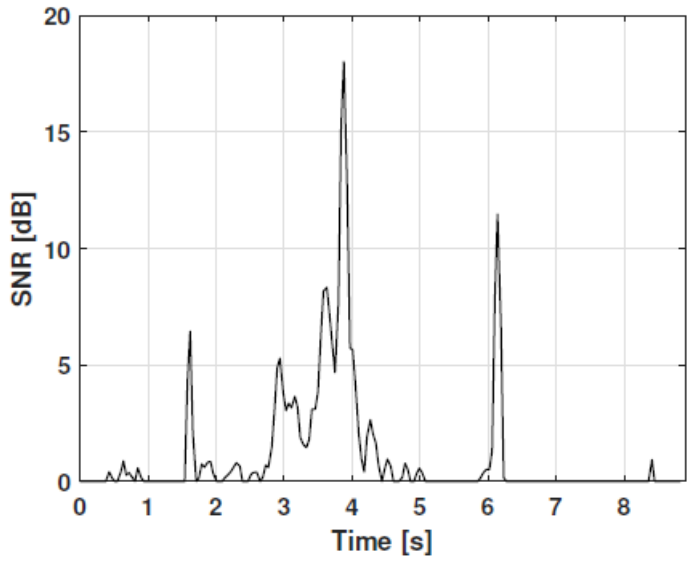
REAL OBSERVATIONS

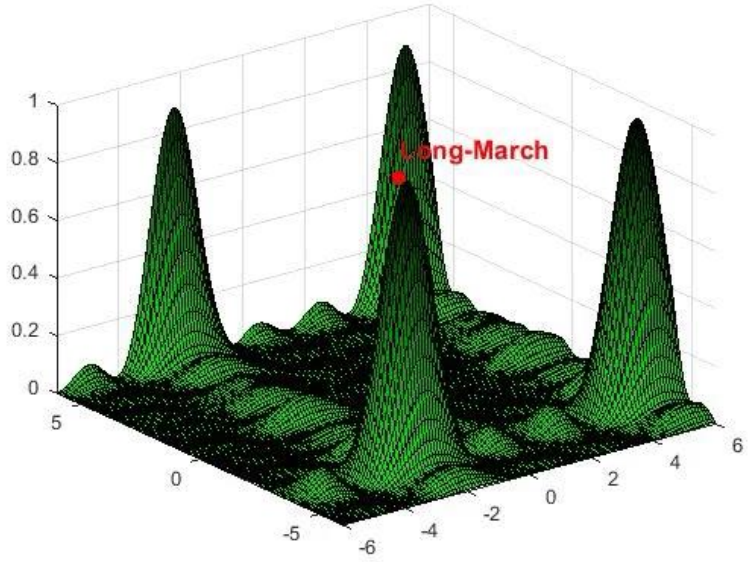
Long March reentry (May 9, 2021)

Challenging conditions:

- No reliable passage prediction
- Weak signal
  - Transit was low on the horizon
  - No proper signal processing chain

✓ Compliant source angular positions





04 CONCLUSIONS

CONCLUSIONS

- Promising results from the new BIRALES data processing pipeline
  - Excellent performance of MATER on synthetic data
  - Good results on real data
  - Current back-end not suitable for MATER ⇨ Much room for improvement

Ongoing activities:

- Extension to simultaneous passages of multiple sources (just completed)
- BIRALES backend upgrade

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Adaptive track estimation on a radar array system for space surveillance

Acta Astronautica, 198, 2022, 111-123

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THANK YOU FOR THE ATTENTION!

ANY QUESTION?

Acknowledgments

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