An adaptive approach for the angular track estimation of resident space objects through surveillance radar system

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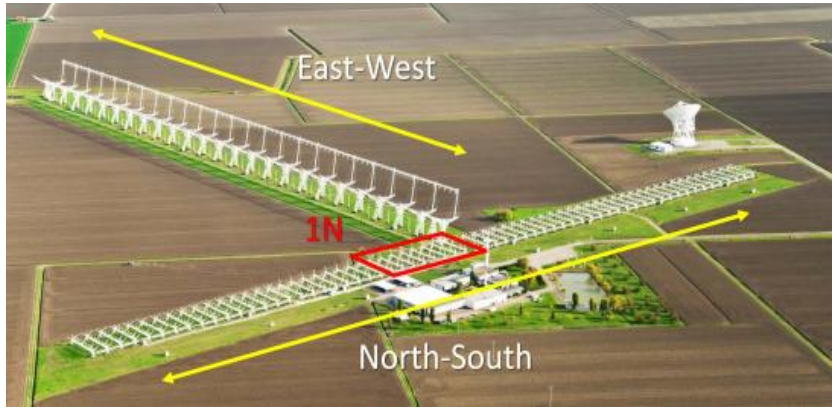
PoliMi[1] INAF[2]

BIRALES - **Bi**static **R**adar for **Le**o **S**urvey

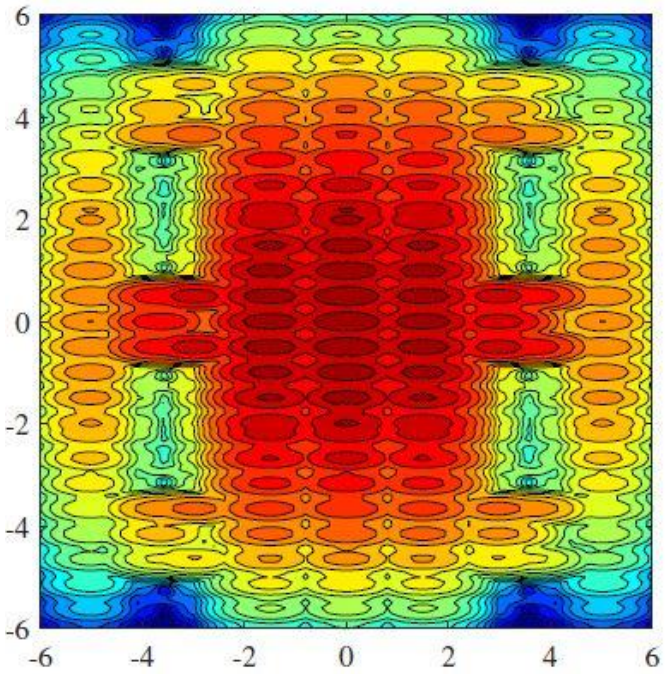
RFT
(Sardinia)

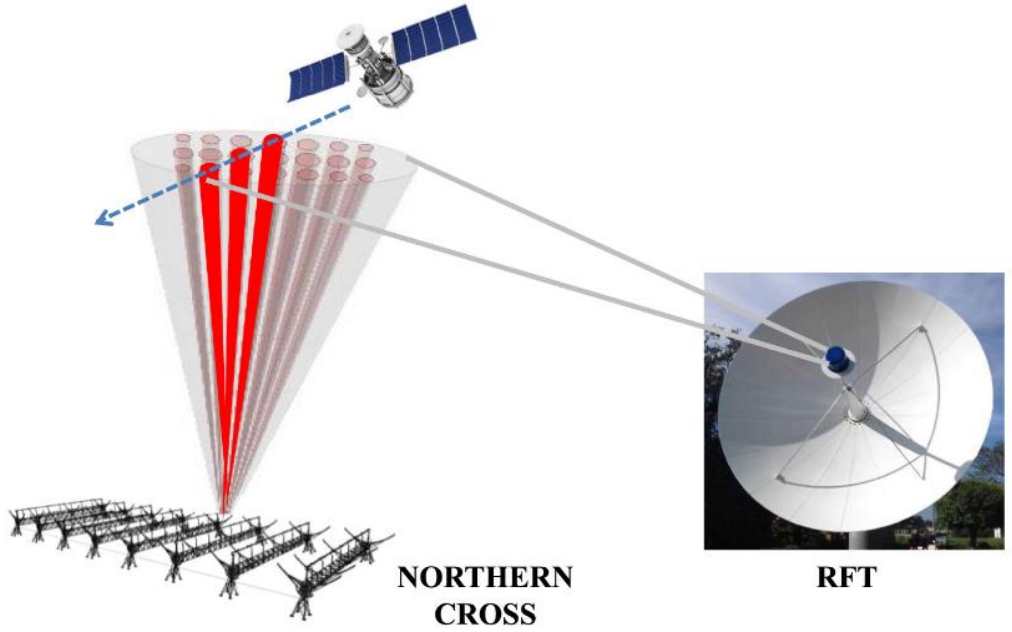


Medicina Radiotelescope
(Bologna)

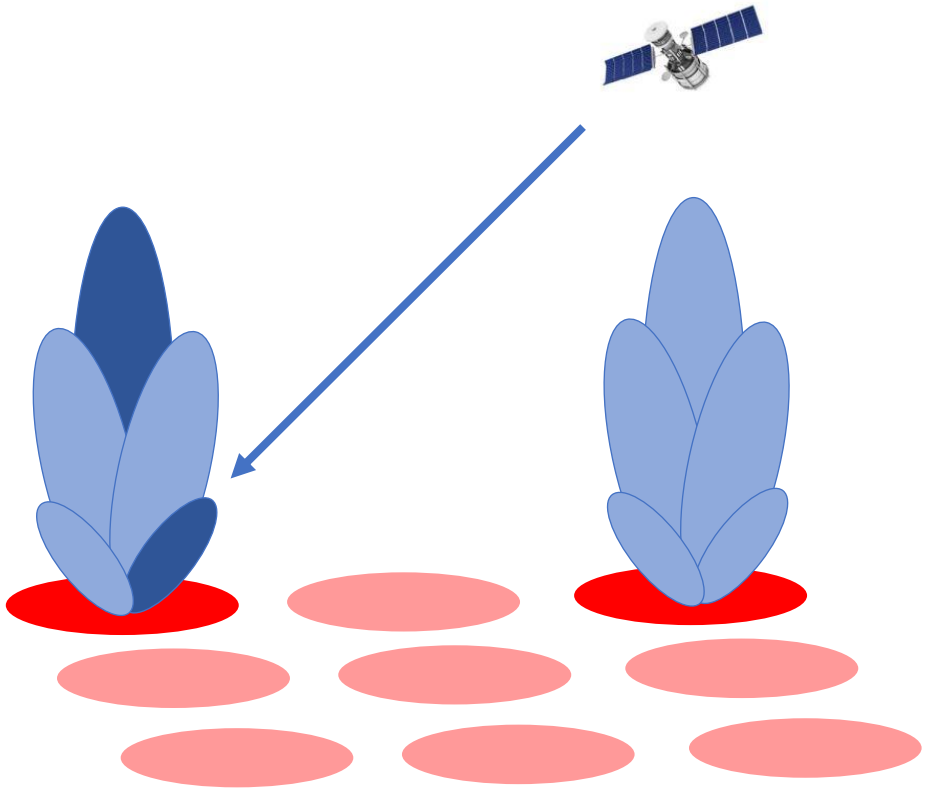
Angular profile | Slant Range | Doppler Shift

Multibeam





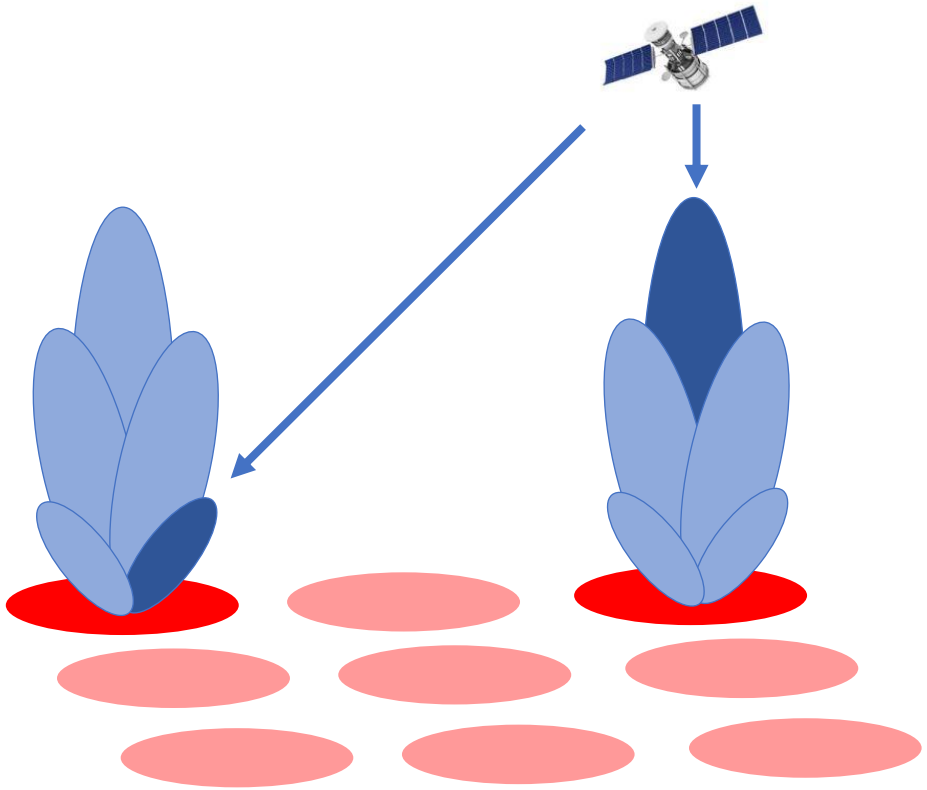
Angular profile | Slant Range | Doppler Shift



Multibeam Orbit Determination [1]

- Lobe ambiguity
- Signal quality

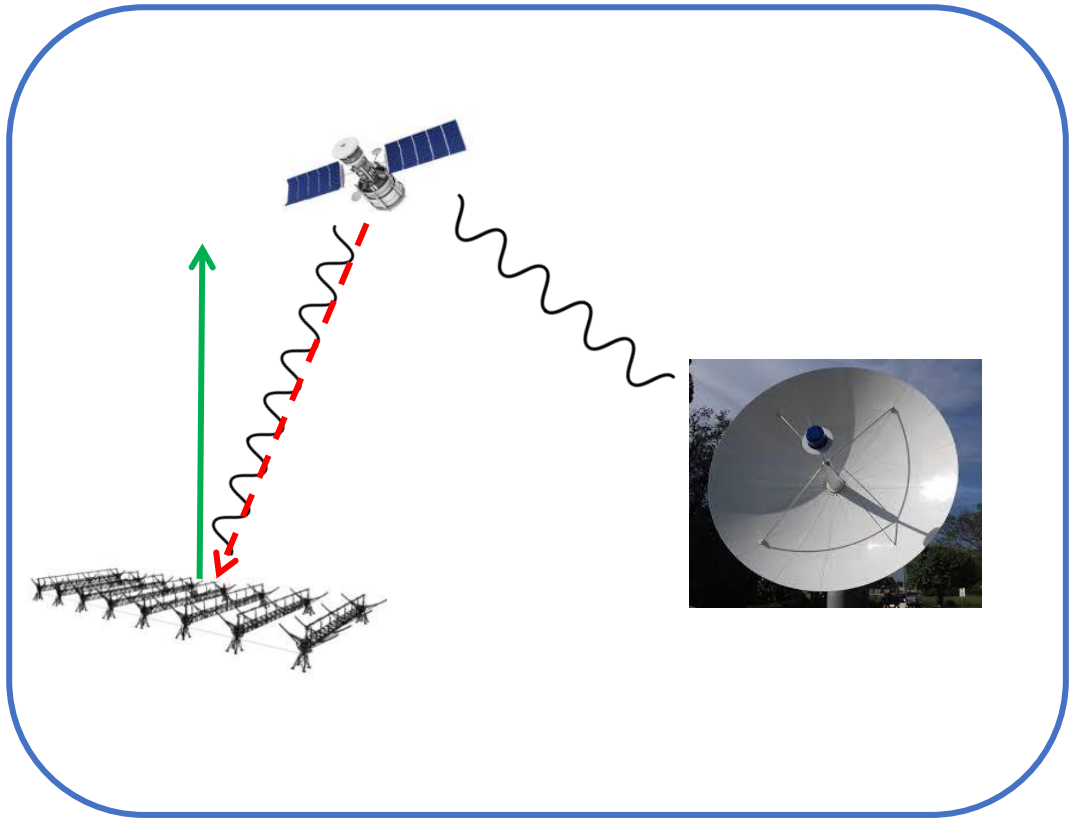
Angular profile | **Slant Range** | **Doppler Shift**

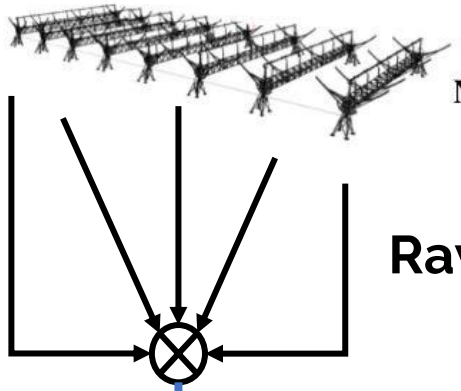


Multibeam Orbit Determination [1]

- Lobe ambiguity
- Signal quality

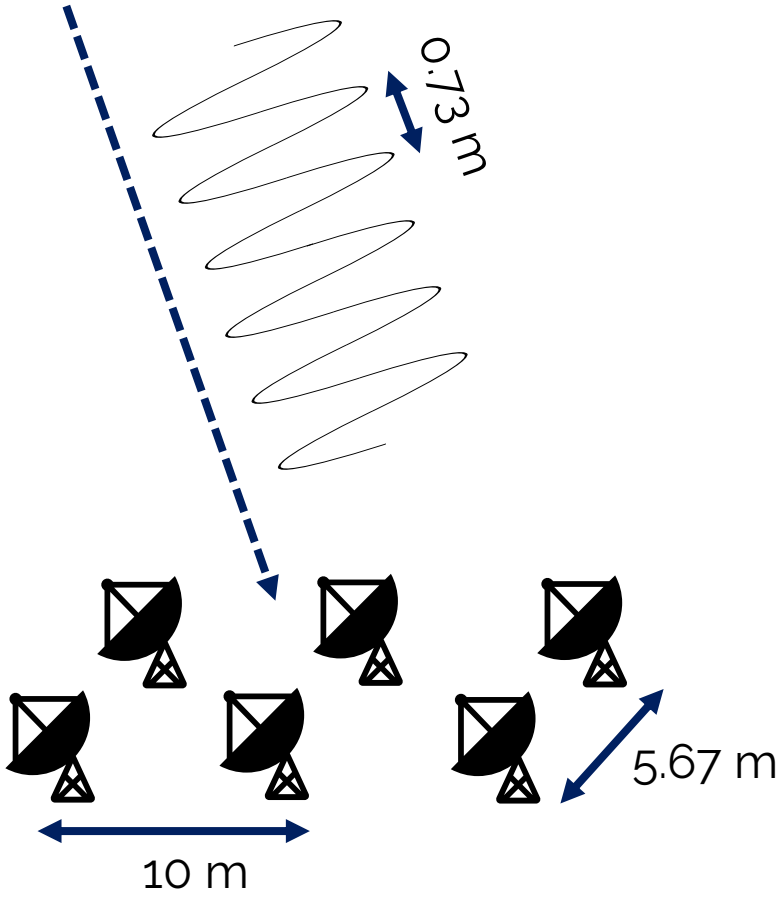
New Approach: Direction of Arrival estimation

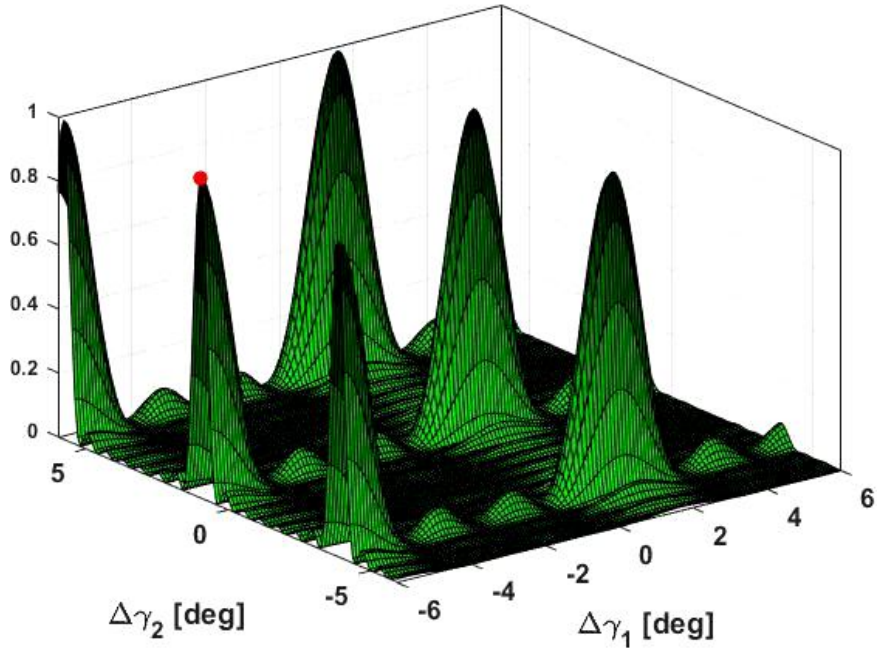




Raw signal

New Approach: Direction of Arrival estimation

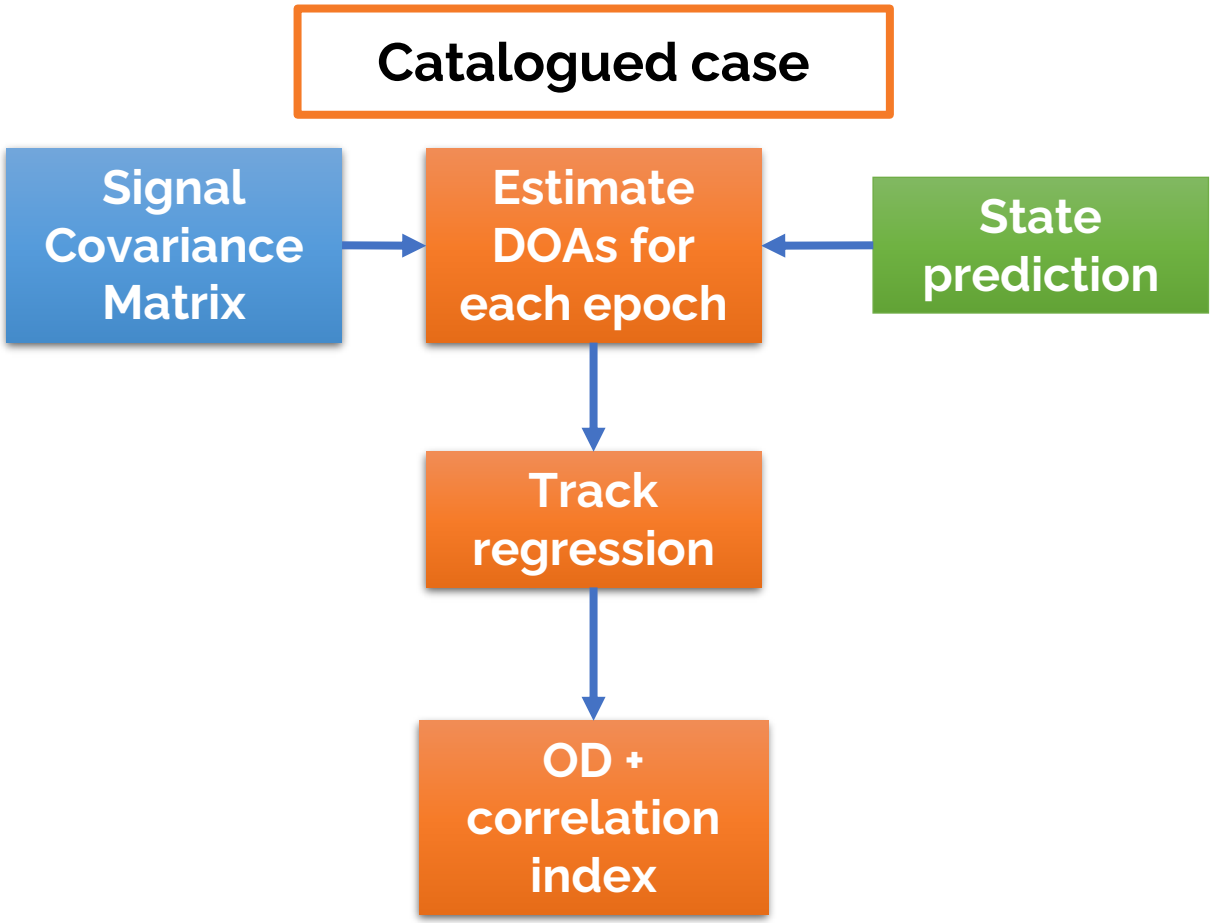


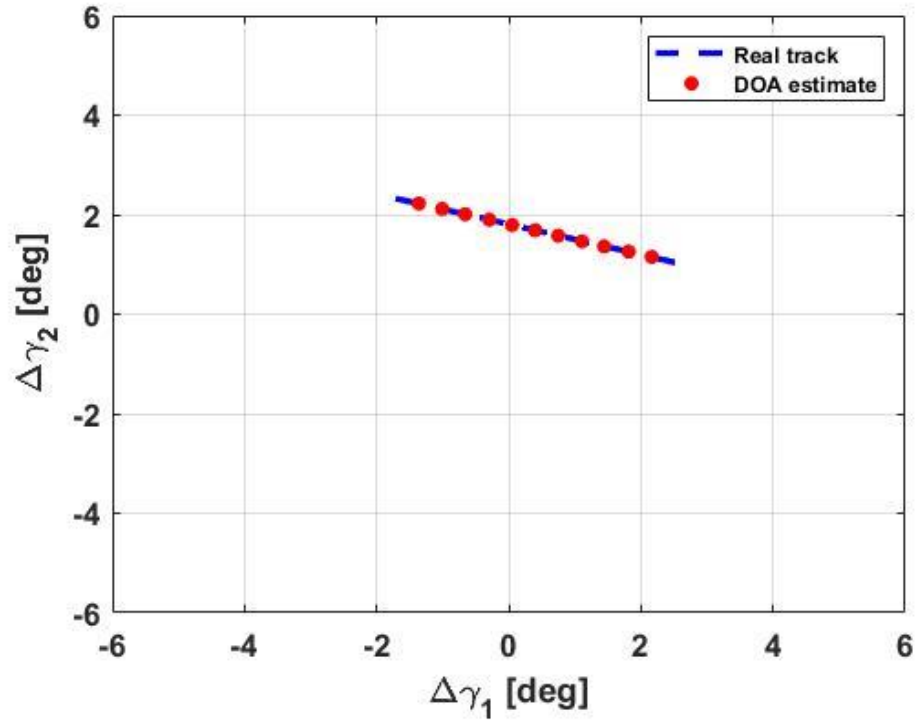


● Signal DOA

- Solution is unique if $d < \lambda/2$
- Presence of multiple peaks
- Ambiguity solving criteria needed

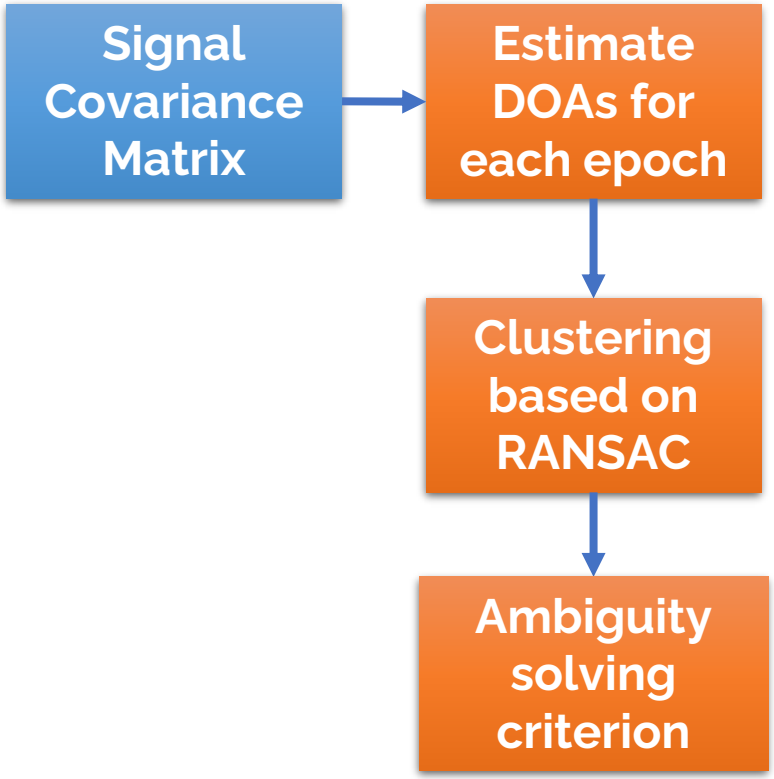
MATER - Music Approach for Track Estimate and Refinement

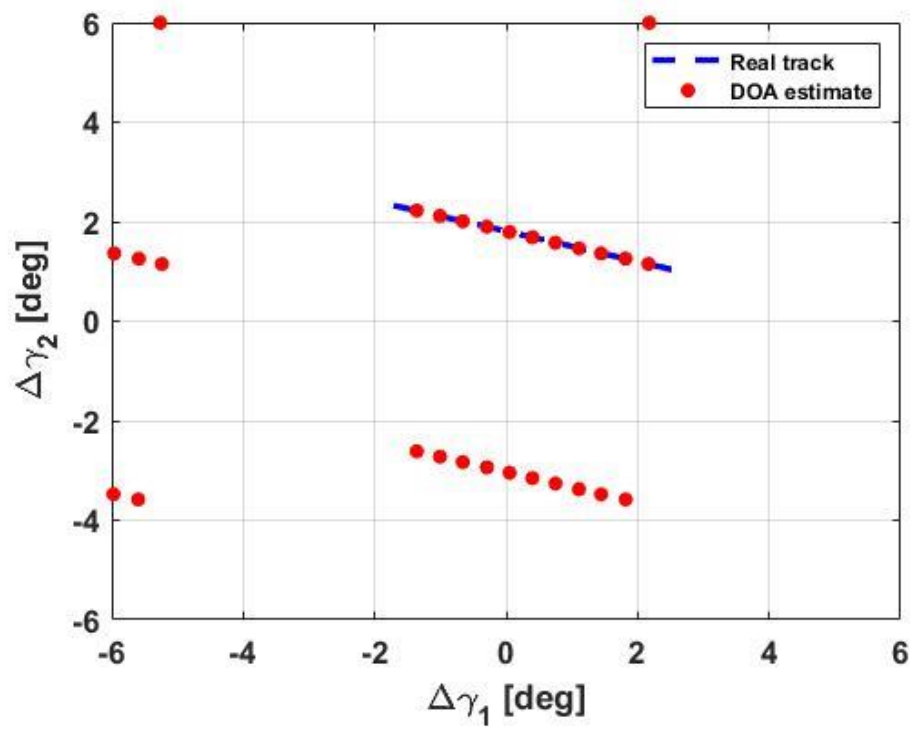




MATER - Music Approach for Track Estimate and Refinement

Uncatalogued case





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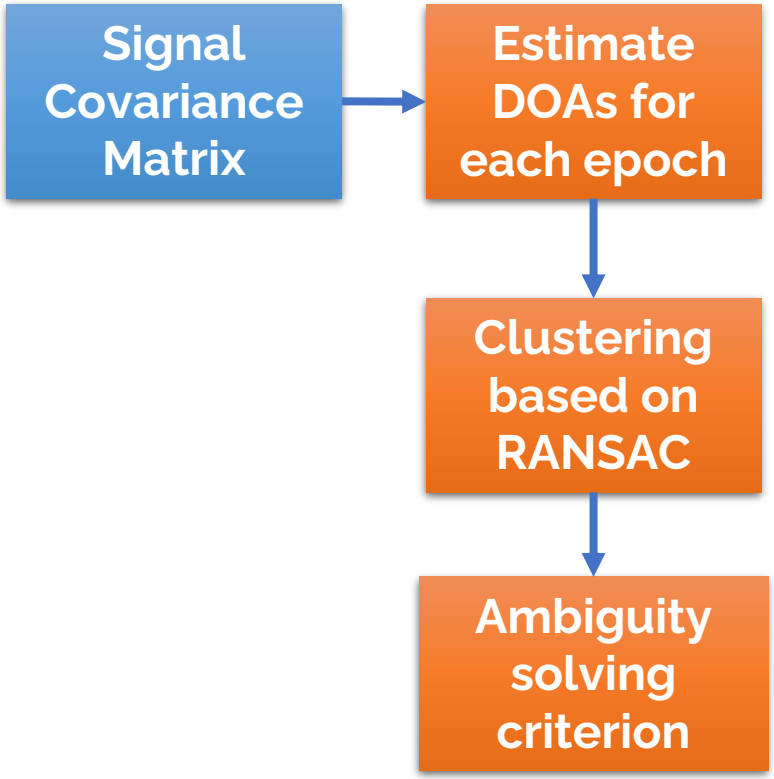
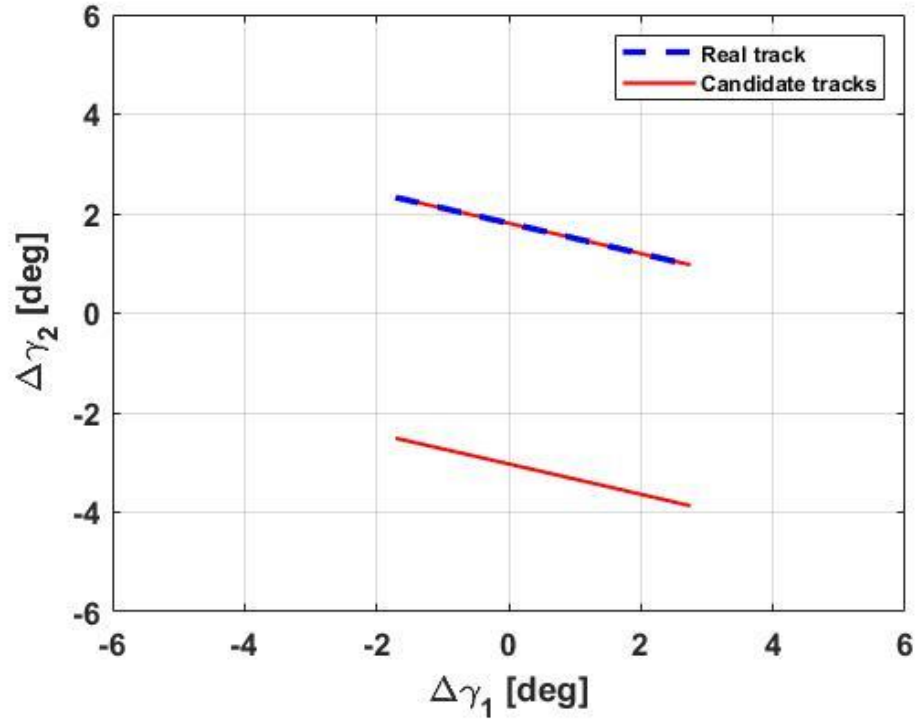




MATER - Music Approach for Track Estimate and Refinement

Uncatalogued case

Signal Covariance Matrix → **Estimate DOAs for each epoch** → **Clustering based on RANSAC** → **Ambiguity solving criterion**

SNR matching

N Tracks **N Tracks**

SNR ⟷ **N SNRs**

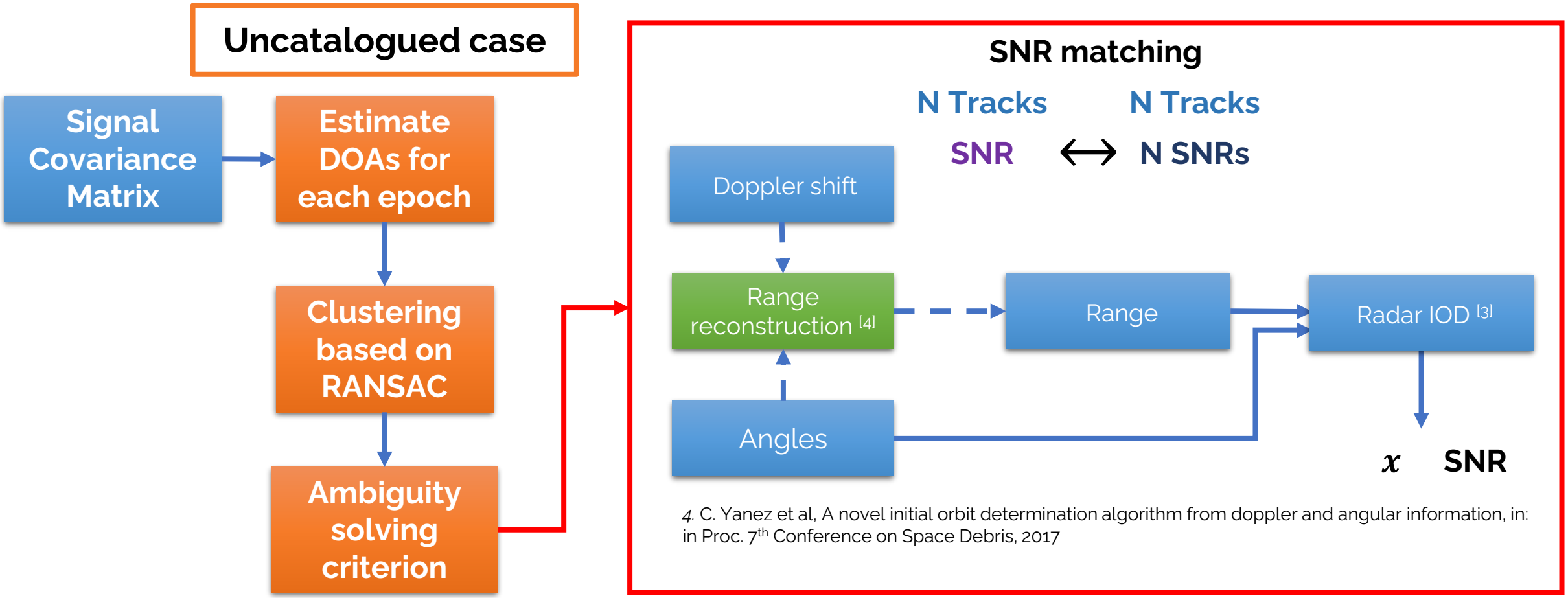
Range → Radar IOD [3]

Angles → Radar IOD [3]

Radar IOD [3] → x **SNR**

3. J. Siminski, Techniques for assessing space object cataloguing performance during design of surveillance systems, 6th International Conference on Astrodynamics Tools and Techniques (ICATT), Darmstadt, Germany, 2016, 14-17 March

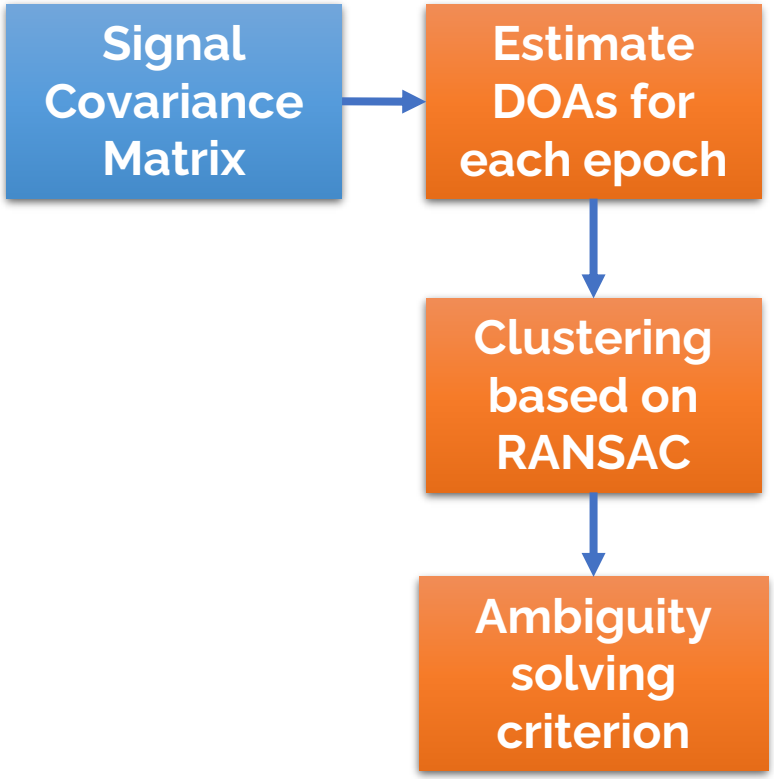
MATER - Music Approach for Track Estimate and Refinement



4. C. Yanez et al, A novel initial orbit determination algorithm from doppler and angular information, in: in Proc. 7th Conference on Space Debris, 2017

MATER - Music Approach for Track Estimate and Refinement

Uncatalogued case

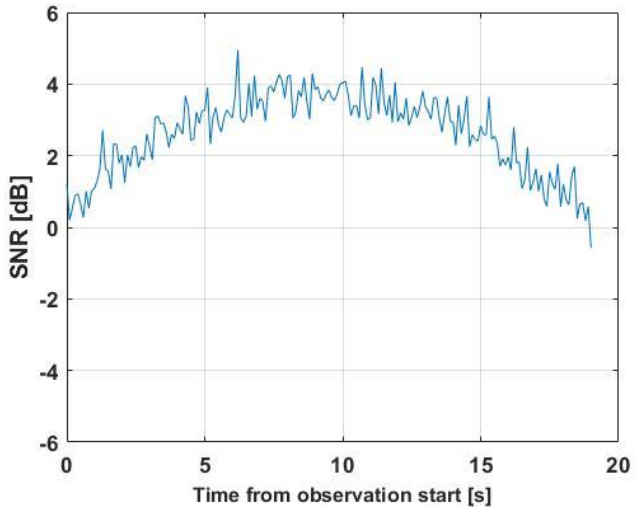


SNR matching

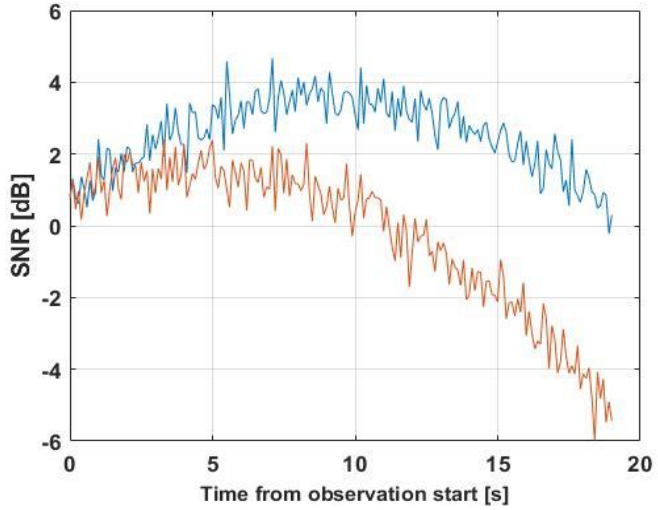
N Tracks **N Tracks**

SNR ⟷ **N SNRs**

Real SNR



Candidates SNR



Nominal performances in uncatalogued case

- 899 LEO synthetic passages from 537 objects
- Gaussian noise consistent with sensor accuracy
- Assumed RCS = 1 m^2

Method	Success %	RMSE (deg)
SNR with DS measurements	100%	1e-04
SNR with SR measurements	100%	1e-04

Sensitivity analysis on the uncatalogued case:

Case	
Different station pointing	✓
Signal interuption during the passage	✓
RCS fluctuations during the passage	✓
Mismatching between real and assumed RCS	✓
Signal from uncontrolled reentry	✓
Receiver channel bandwidth	✓

Success: 100%
RMSE: 1e-04 deg

Sensitivity analysis on the uncatalogued case:

Case	
Different station pointing	✓
Signal interuption during the passage	✓
RCS fluctuations during the passage	✓
Mismatching between real and assumed RCS	✓
Signal from uncontrolled reentry	✓
Receiver channel bandwidth	✓

Different percentage of interruptions considered

Success: 100%
RMSE: 1e-03 deg

*worst case

Sensitivity analysis on the uncatalogued case:

Case	
Different station pointing	✓
Signal interuption during the passage	✓
RCS fluctuations during the passage	✓
Mismatching between real and assumed RCS	✓
Signal from uncontrolled reentry	✓
Receiver channel bandwidth	✓

Different dB RCS fluctuations considered

Success: 100%
RMSE: 1e-03 deg*

*worst case

Sensitivity analysis on the uncatalogued case:

Case	
Different station pointing	✓
Signal interuption during the passage	✓
RCS fluctuations during the passage	✓
Mismatching between real and assumed RCS	✓
Signal from uncontrolled reentry	✓
Receiver channel bandwidth	✓

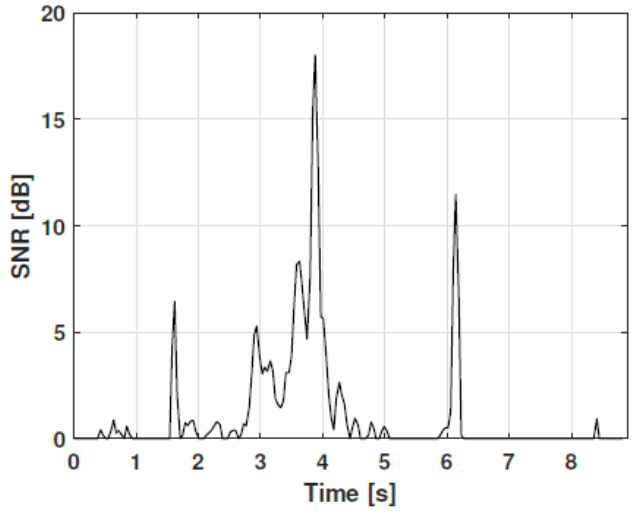
Different real RCS considered

Success: 100%
RMSE: 1e-03 deg*

*worst case

Sensitivity analysis on the uncatalogued case:

Case	
Different station pointing	✓
Signal interuption during the passage	✓
RCS fluctuations during the passage	✓
Mismatching between real and assumed RCS	✓
Signal from uncontrolled reentry	✓
Receiver channel bandwidth	✓



RMSE: 1e-02 deg

Sensitivity analysis on the uncatalogued case:

Case	
Different station pointing	✓
Signal interuption during the passage	✓
RCS fluctuations during the passage	✓
Mismatching between real and assumed RCS	✓
Signal from uncontrolled reentry	✓
Receiver channel bandwidth	✓

Different bandwidth considered

→ Success: 72,2%
RMSE: 1e-01 deg*

✓ Uncatalogued case

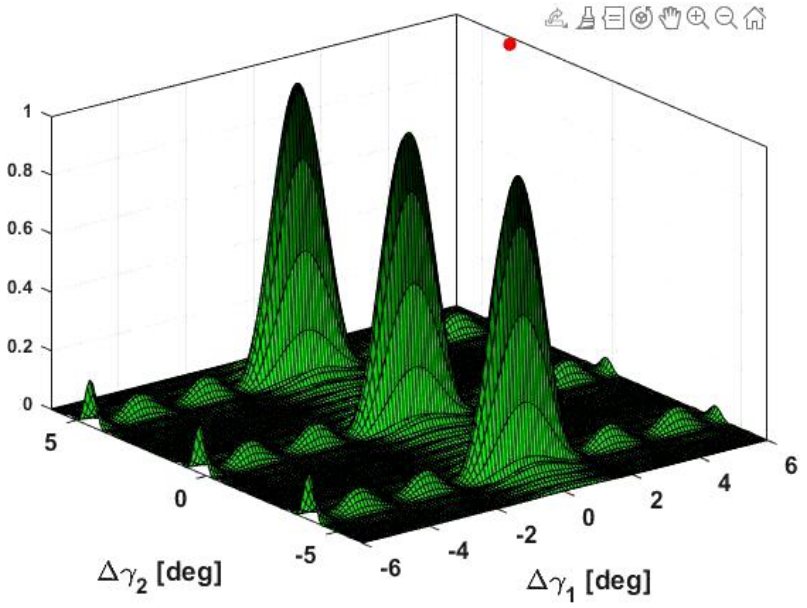
*worst case

Real observation

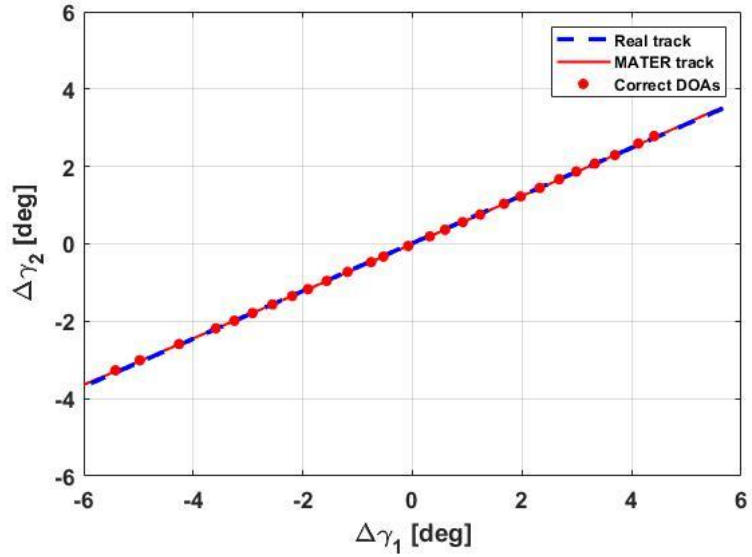
ISS (April 28, 2021)

- Backend not adapted
- Noisy CM

RMSE: 1e-01 deg



● Signal DOA

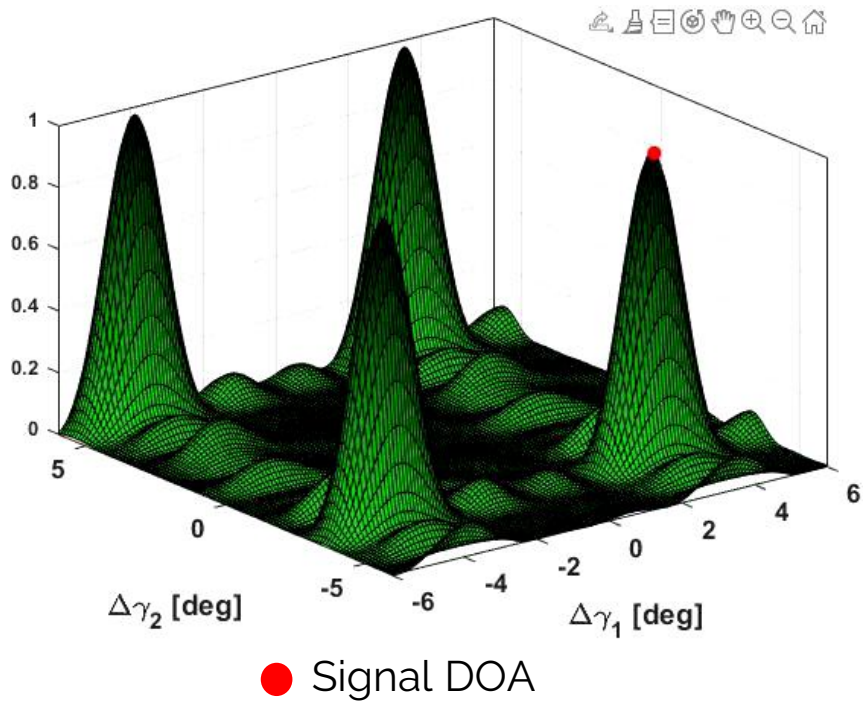


✓ Method works in a real scenario

Real observation

CZ-5B reentry (May 9, 2021)

- Backend not adapted
- Weak signal



✓ Method works in a very challenging real scenario

Conclusions

- ✓ New processing method
- ✓ High accuracy on synthetic data
- ✓ Successful tests on real scenarios

Acknowledgement

Work conducted in the European Commission Framework Programme H2020, Copernicus "SST Space Surveillance and Tracking" and ASI-INAF agreement "Support to IADC and SST activities 2019-2021"

References:

1. *M. Losacco, Orbit Determination of Resident Space Objects Using Radar Sensors in Multibeam Configuration, Politecnico di Milano, 2020.*
2. *H. L. Van Trees, Optimum Array Processing: Part IV of Detection, Estimation, and Modulation Theory, John Wiley & Sons, Inc., 2002*
3. *J. Siminski, Techniques for assessing space object cataloguing performance during design of surveillance systems, 6th International Conference on Astrodynamics Tools and Techniques (ICATT), Darmstadt, Germany, 2016, 14-17 March*
4. C. Yanez, F. Mercier, J. C. Dolado, A novel initial orbit determination algorithm from doppler and angular information, in: in Proc. 7th Conference on Space Debris, 2017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Thank you