Long Baseline Bistatic Radar for Space Situational Awareness

Presented at SCI-SET-297 Space Situational Awareness Specialists’ Meeting

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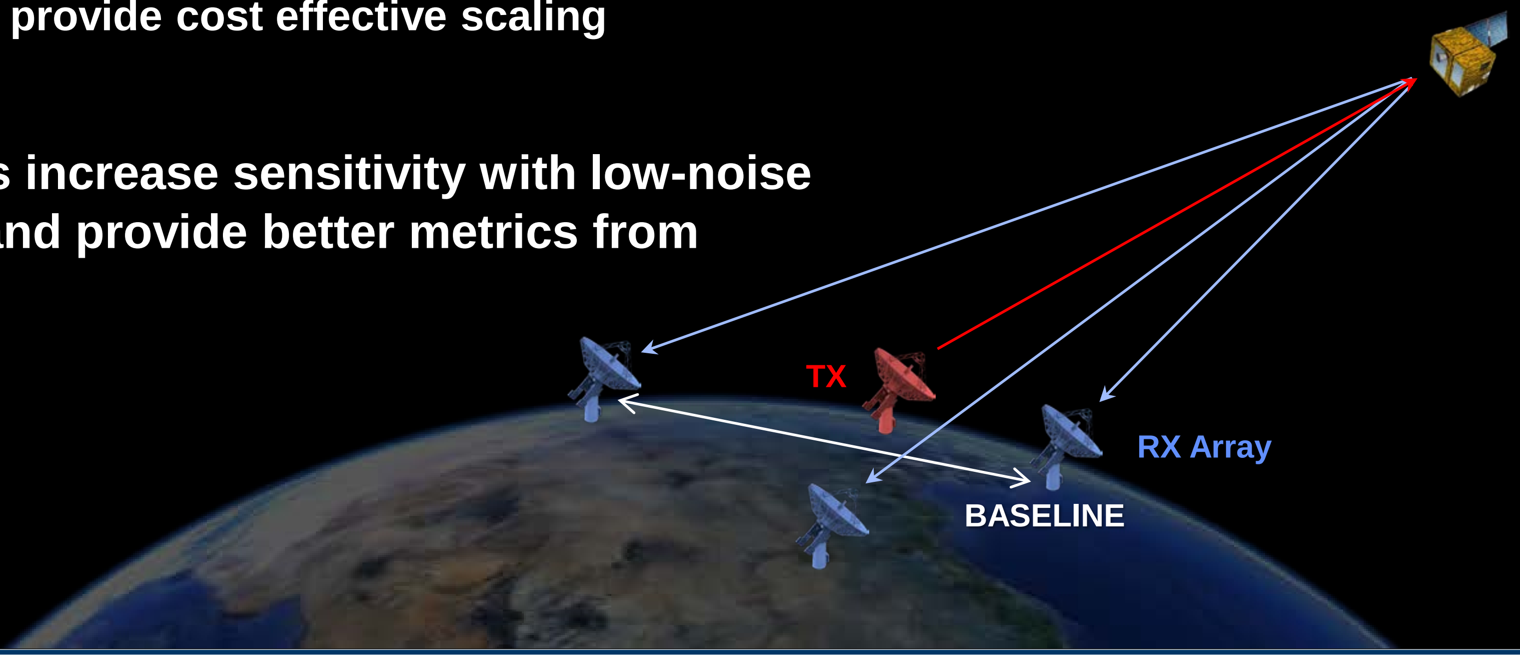
Background & Motivation

- **Space Situation Awareness becoming more challenging**
  - Increasing satellite population in Geosynchronous orbit regime
  - Smaller and maneuvering targets difficult to detect and track

- **Greater sensor sensitivity required to maintain custody**
  - Some gains can be achieved through novel radar signal processing
  - Additional receive apertures can provide cost effective scaling

- **Long baseline radar multistatics increase sensitivity with low-noise temperature receive apertures and provide better metrics from diverse look angles**



NATO SET-293: *RF Sensing for Space Situational Awareness*

Research Objectives

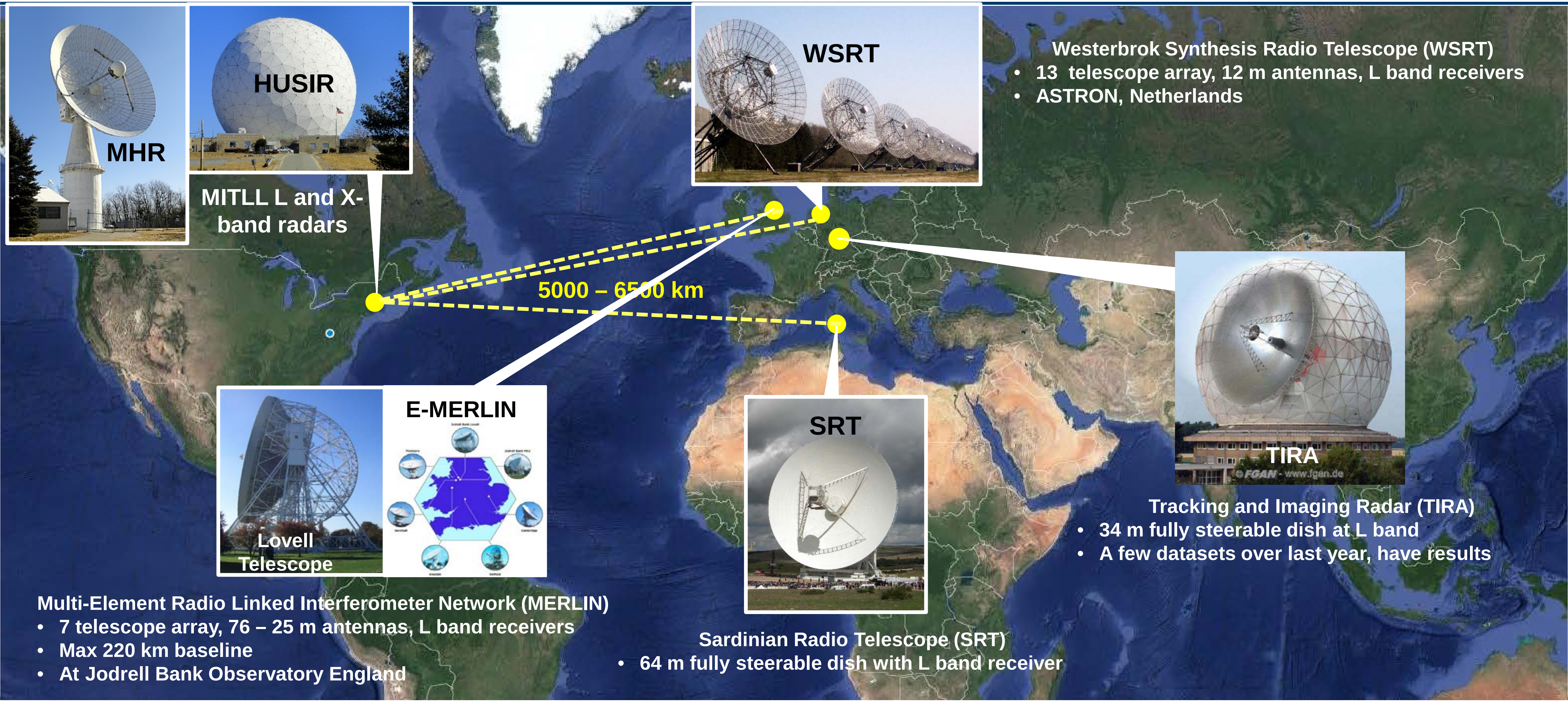
- **Develop and conduct long baseline bistatic radar (LBBR) and multistatic (LBMR) experiments for detection and tracking of GEO Resident Space Objects**
- **Develop algorithms for detection and tracking of GEO RSOs using multi-bistatic radar systems**
- **Investigate a system architecture for a radar network for Space Surveillance and Tracking (SST)**

Participants

- **US, UK, ITA, DEU, NRD, FRA, ESP, TUR**

CTI

Sensors and Experiment Overview



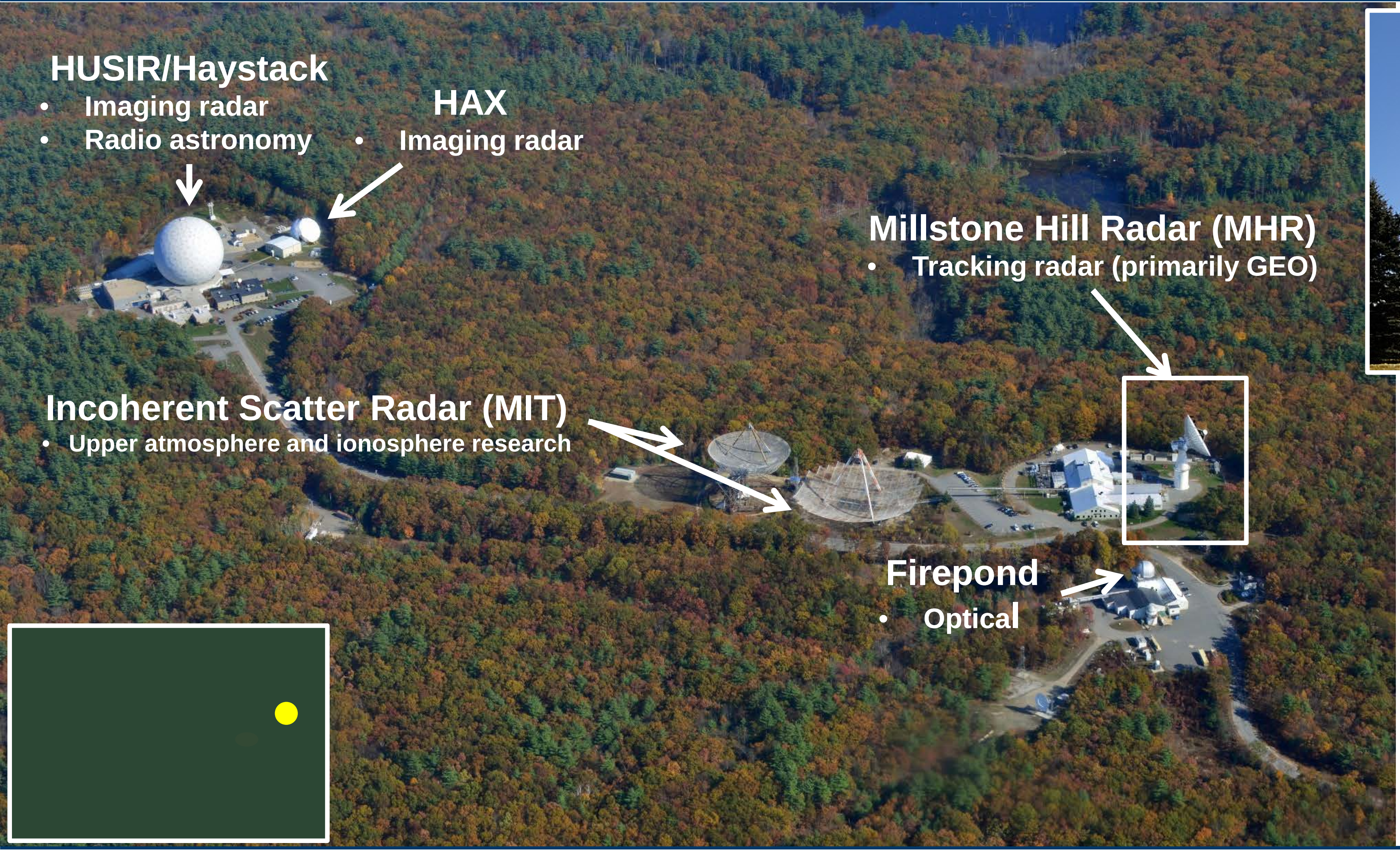
Westerbrok Synthesis Radio Telescope (WSRT)
- 13 telescope array, 12 m antennas, L band receivers
- ASTRON, Netherlands

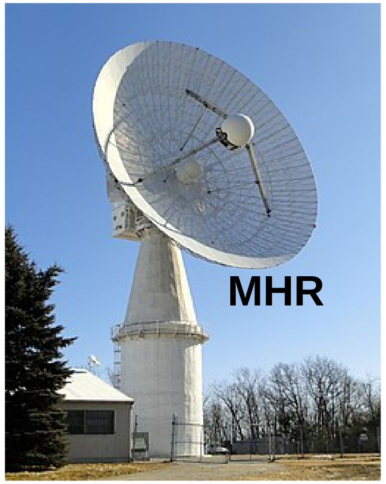
Tracking and Imaging Radar (TIRA)
- 34 m fully steerable dish at L band
- A few datasets over last year, have results

Multi-Element Radio Linked Interferometer Network (MERLIN)
- 7 telescope array, 76 – 25 m antennas, L band receivers
- Max 220 km baseline
- At Jodrell Bank Observatory England

Sardinian Radio Telescope (SRT)
- 64 m fully steerable dish with L band receiver

Lincoln Space Surveillance Complex





Millstone System Parameters

Diameter	25.6 m
Center Frequency	1295 MHz
Max Bandwidth	8 MHz
Peak Power	3 MW
Pulse Repetition Freq.	40 Hz
Pulse Width	1 ms
Duty Factor	5%
Reference SNR*	50 dB

*On a 0 dBsm target at 1000 km

Sensor Parameters and Bistatic Receiver Gain for Millstone Hill & TIRA Radars

Parameter	MHR	TIRA	e-MERLIN (Lovell)	e-MERLIN (Knockin)	SRT	WSRT
	TX	TX	RX	RX	RX	RX
Lat/Lon (degrees)	42.6, 288.5	50.6 7.1	53.0, 357.4	52.8, 357.0	39.5, 9.2	52.9, 6.6
Antenna Diameter (m)	25.6	34	76	25	64	25
Center Frequency (MHz)	1295	1333	[1250-1750]	[1250-1750]	1295	1295
Ref. SNR (dB)	50	47	66	57	65	57
Rx Gain (dB)	–		16 (MHR) 19 (TIRA)	7 (MHR) 10 (TIRA)	15 (MHR) 18 (TIRA)	7 (MHR) 10 (TIRA)

Bistatic Experiment Collections

Date	Sensors	RSO Objects	Outcome
Jan 2020	MHR & WSRT	43039, 27683	Range-Doppler & RCS Measurements
Mar 2021	MHR & SRT	43039, 42950, 41036	Range-Doppler & RCS Measurements
Feb / May 2021	MHR & e-MERLIN	43039, 42950, 27683	Target Detection
May 2021	TIRA & e-MERLIN	43039, 37775	Doppler Processing – multiple targets


Telstar 12V (41036) 15W


Alcomsat 1 (43039) 25W


Intelsat 907(27683) 27W


Intelsat 37E (42950) 18W


Astra 1N (37775)19 E

MHR → WSRT Range-Time & Range-Doppler Processing

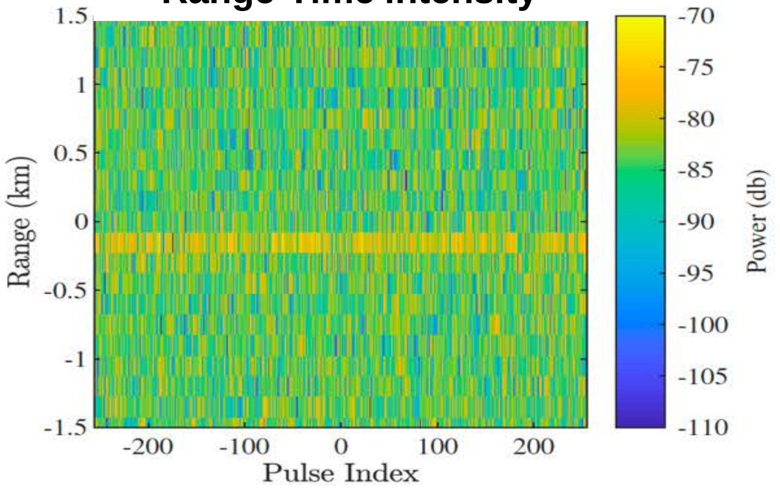
- Coherent Processing
  - 512 pulses / CPI

- Integrate 512 pulses (10 seconds)

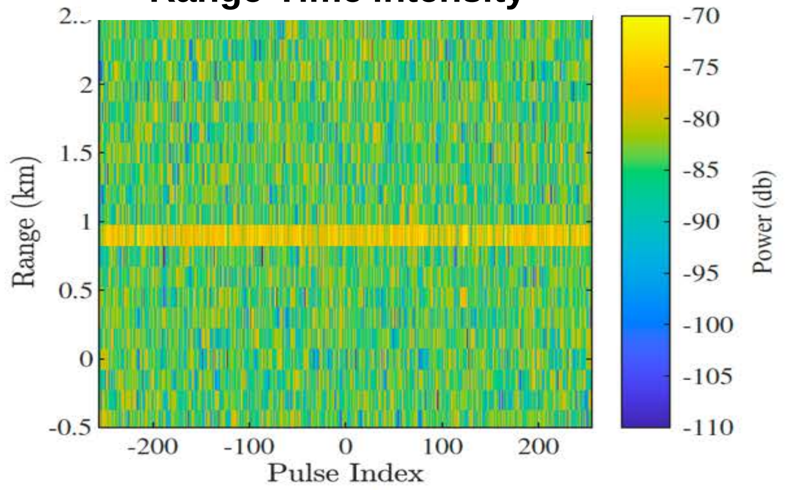
- Reference range and Doppler (0,0) is the bistatic range and Doppler computed from the TLE*
  - A target at exactly (0,0) would be exactly on the TLE, assuming there are no processing errors or other biases

- Doppler spread appears in the response
  - Could be from uncompensated acceleration or slight phase correction errors during pulse compression

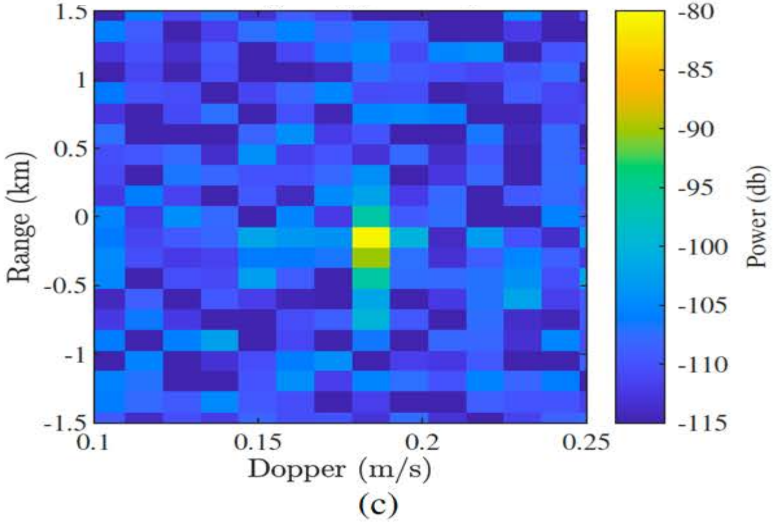
Object 43039
Range-Time intensity



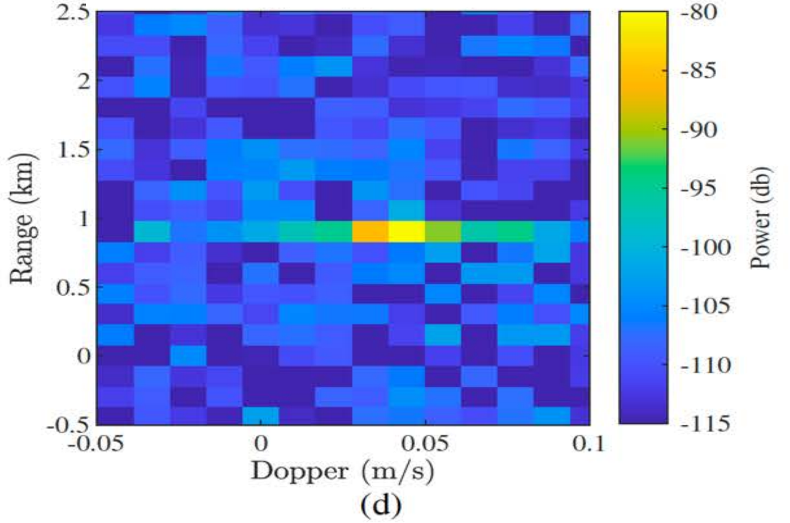
Object 27683
Range-Time intensity



Object 43039
Range-Doppler Map

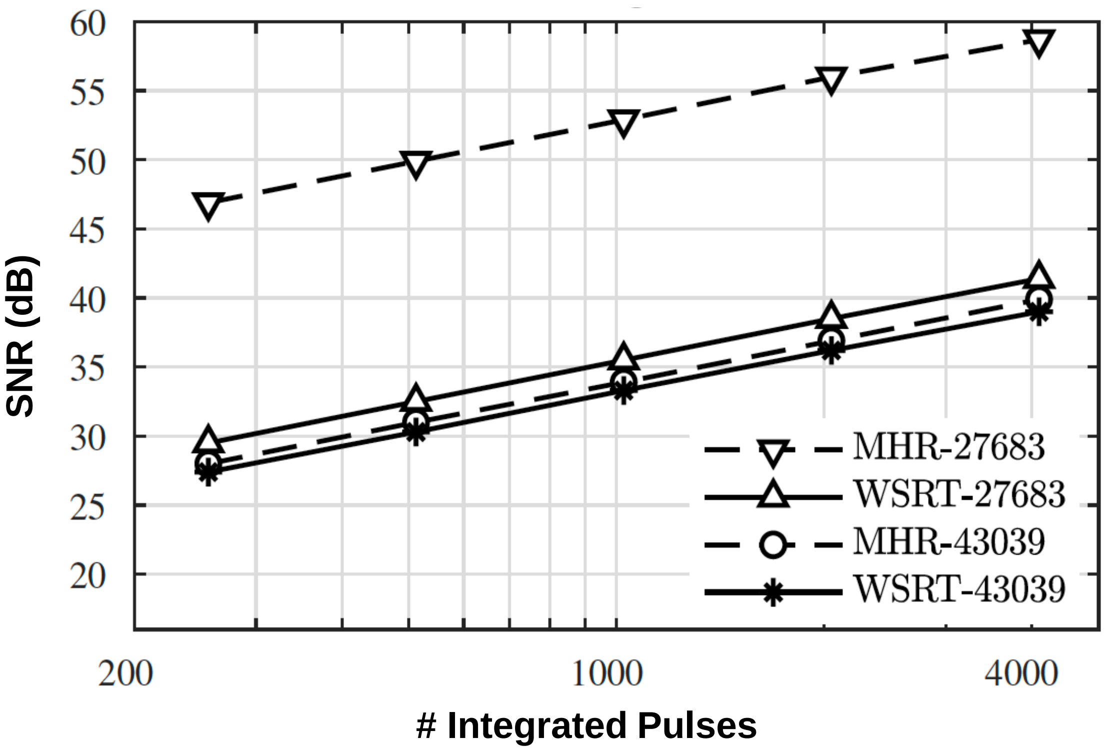


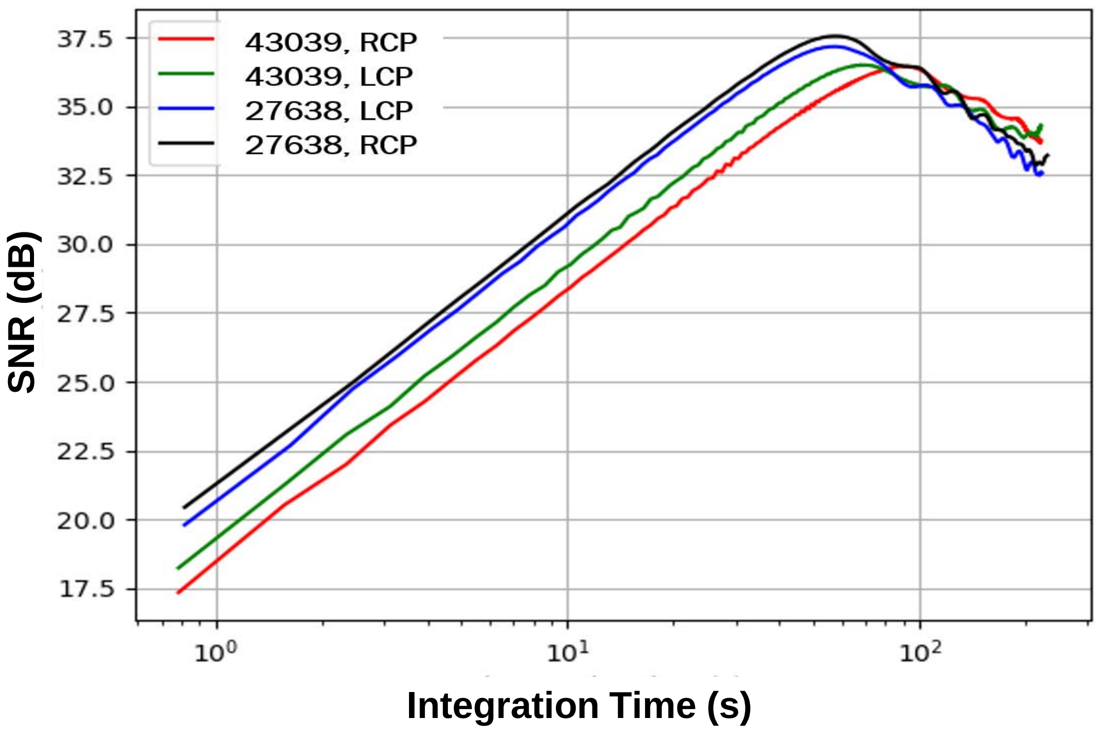
Object 27683
Range-Doppler Map



*TLE = Two Line Element Set

MHR → WSRT Coherent Integration for RSOs 43039 & 27683

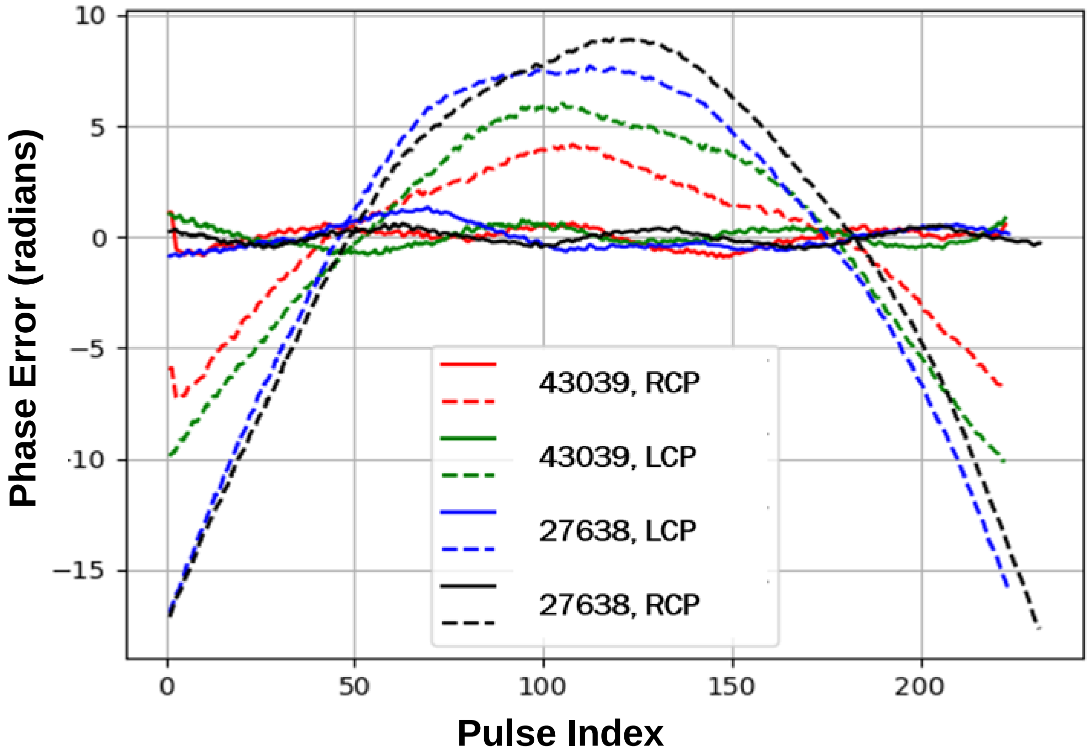


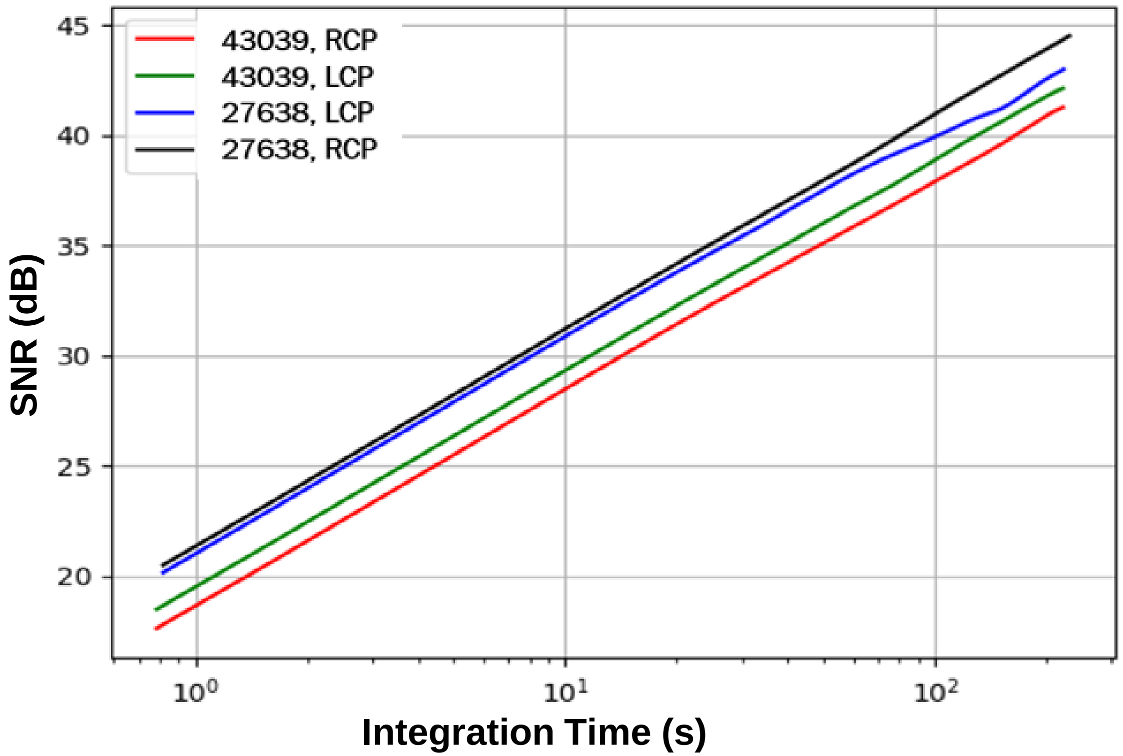


- **Monostatic (MHR) and Bistatic (WSRT) SNR**
  - **Expected SNR gain to ~80 s of integration**
  - **Left circular polarization**

- **Bistatic (WSRT) SNR for both polarizations**
  - **Expected SNR gain to ~80 s of integration**
  - **Decrease in SNR past 80s likely due to inaccurate satellite motion estimation**

Coherent Integration after Adjusting for Range Rate Phase Errors





- **Range rate phase error (dotted curves) seen over time**
- **Quadratic estimation of phase error removed (solid lines)**

- **Full coherent integration observed after phase compensation for entire collection time**

for RSOs 43039 & 27683

MHR → WSRT & SRT: SNR and RCS

- **MHR monostatic RCS comparable with historic measurements**
- **Both SRT and WSRT Bistatic RCS measurements lower than monostatic**
- **Bistatic Receiver gain calculated based on monostatic RCS**

SRT and MHR: SNR and RCS Measurements

Object	43039	42950	41036
Median SNR Gain at SRT (dB)	4.3	3.1	-15.3
Median SRT RCS (dBsm)	11.6	15.2	-5.1
Median MHR RCS (dBsm)	22.9	28.0	26.0
Historical MHR RCS (min,max)	(22,23)	(27,28)	(24,25)

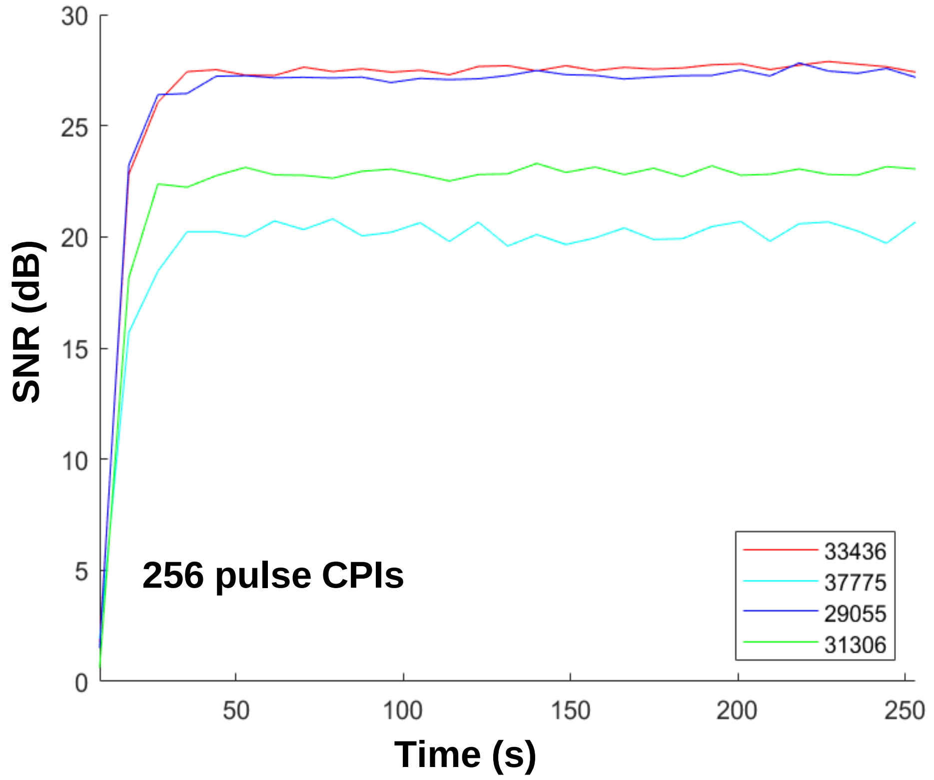
WSRT and MHR: SNR and RCS Measurements

Object	43039	27683
Median SNR Gain at WSRT (dB)	0.6	-17.4
Median WSRT RCS (dBsm)	12.6	14.6
Median MHR RCS (dBsm)	19.4	38.2
Historical MHR RCS (min,max)	(22,23)	(39,40)

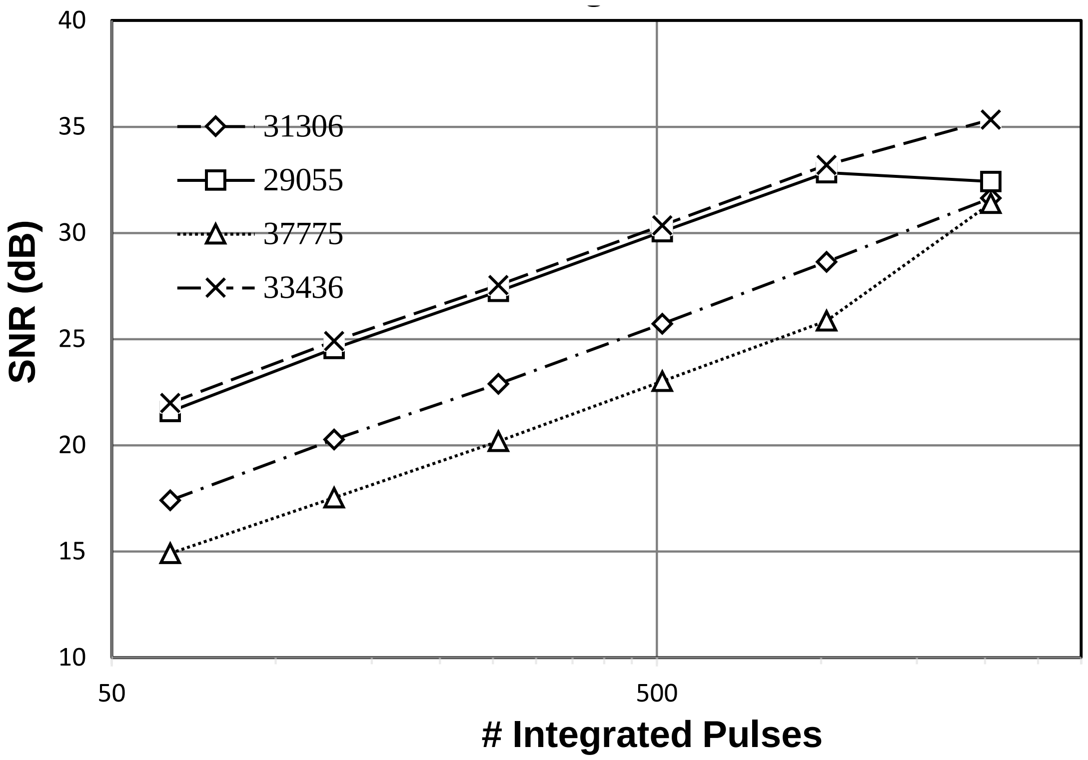
TIRA → e-MERLIN SNR and Coherent Integration

4 GEO Satellites observed in cluster with Astra 1N (37775) at e-MERLIN Knockin Antenna

Similar results seen in TIRA monostatic data



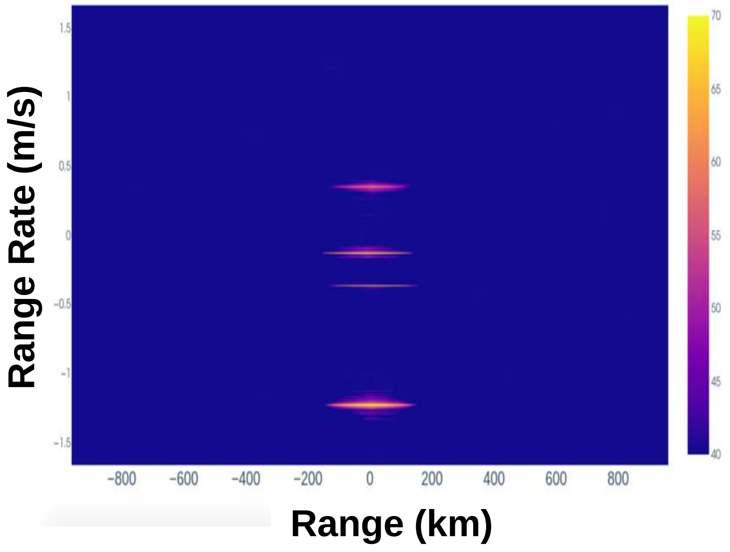
SNR steady over time for all 4 targets

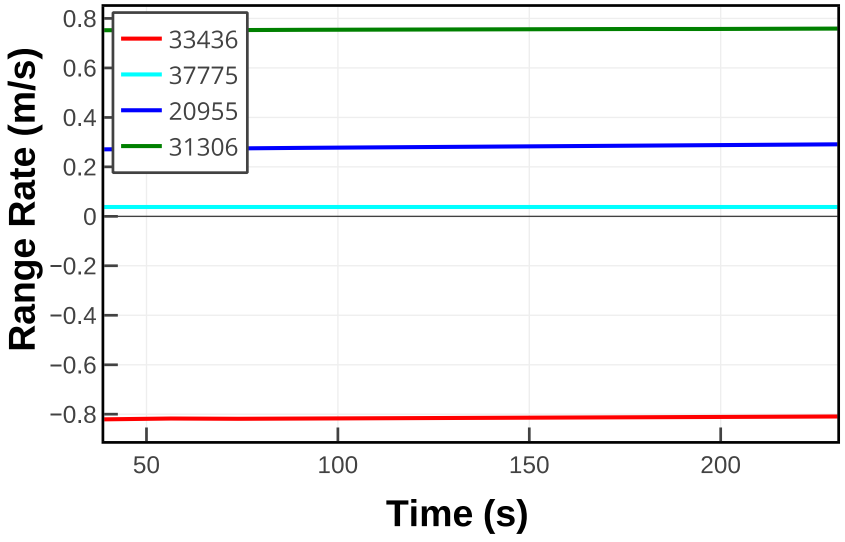


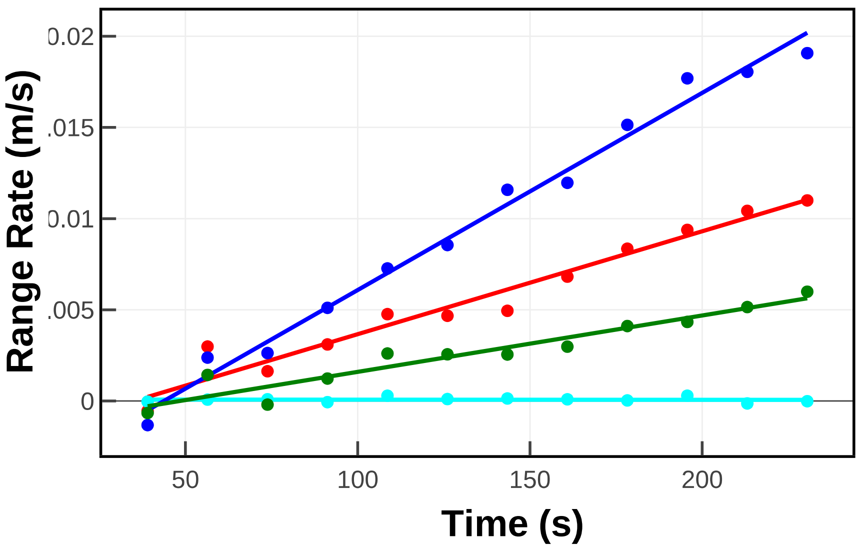
Expected coherent integration gain over ~50s

TIRA → e-MERLIN (Knockin Antenna) Bistatic Analysis

4 GEO Satellites observed in cluster with Astra 1N (37775)







Range-Doppler map

4 RSOs observed

RSO Range Rate over Time

Zoomed in Range Rate vs Time

Different RSO trajectory motions observed

Summary – Next Steps

- **Space Situation Awareness becoming more challenging**
- **Greater sensor sensitivity required to maintain custody**
  - **Additional receive apertures most promising**
- **NATO SET-293, *RF Sensing for SSA*, exploring long baseline radar multistatics**
  - **Two transmitters (US & DEU) and 3 radiotelescope sites (GBR, NLD & ITA)**
  - **Conducted 5 radar measurement collections**
  - **Early results show multi-target detection, achieving long integration times**
- **Additional bistatic collections planned with focus on multiple and closely spaced targets**
  - **Possible collection at X-band**
- **Collaboration with SCI-SET-ET-057 Exploratory** on **‘*Experimental analysis of combined, multistatic RF/EO data for improved Space Situational Awareness (SSA)*’**

Backup Charts

Bistatic Results for MHR and SRT & WSRT

64 m SRT and MHR – 6500 km Baseline - 10°				
	SNRS (dB)	RCS (dBsm)		
Object	Median SNR Gain at SRT (SRT – MHR)	Median SRT RCS	Median MHR RCS	Historical MHR L-Band RCS (min, max)
43039	4.4	11.6	22.9	(22,23)
42950	3.1	15.2	28.0	(27,28)
41036	-15.3	-5.1	26.0	(24,25)

Expect ~16 dB gain

25 m WSRT and MHR – 5700 km Baseline - 9°				
	SNRS (dB)	RCS (dBsm)		
Object	Median SNR Gain at WSRT (WSRT – MHR)	Median WSRT RCS	Median MHR RCS	Historical MHR L-Band RCS (min, max)
43039	-0.6	12.6	19.4	(22,23)
27683	-17.4	14.6	38.2	(39,40)

Expect ~7 dB gain

- SNR gain at both telescopes is lower than predicted and it varies by object
  - Suggests bistatic RCS is lower than monostatic RCS
  - Significant variance in the SNR gain between different objects
- Measured monostatic RCS is consistent with past measurements
- Bistatic RCS for 43039 is similar at SRT and WSRT