

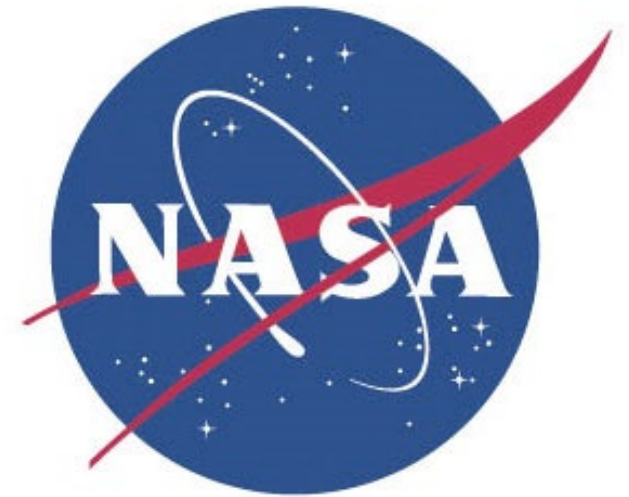
HQ U.S. Air Force Academy

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**U.S. AIR FORCE
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Integrating Machine Learning into the ISS Antenna Management Software



Timothy Giblin*, 511 Space Innovation LLC

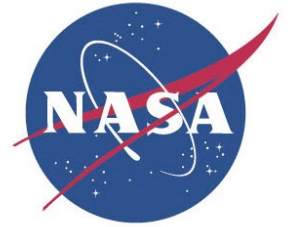
Steven Novotny*, Autonodyne LLC

C25 Margaret Meehan, USAF Academy

Dan Jackson, KBR Technologies & NASA Johnson Space Center

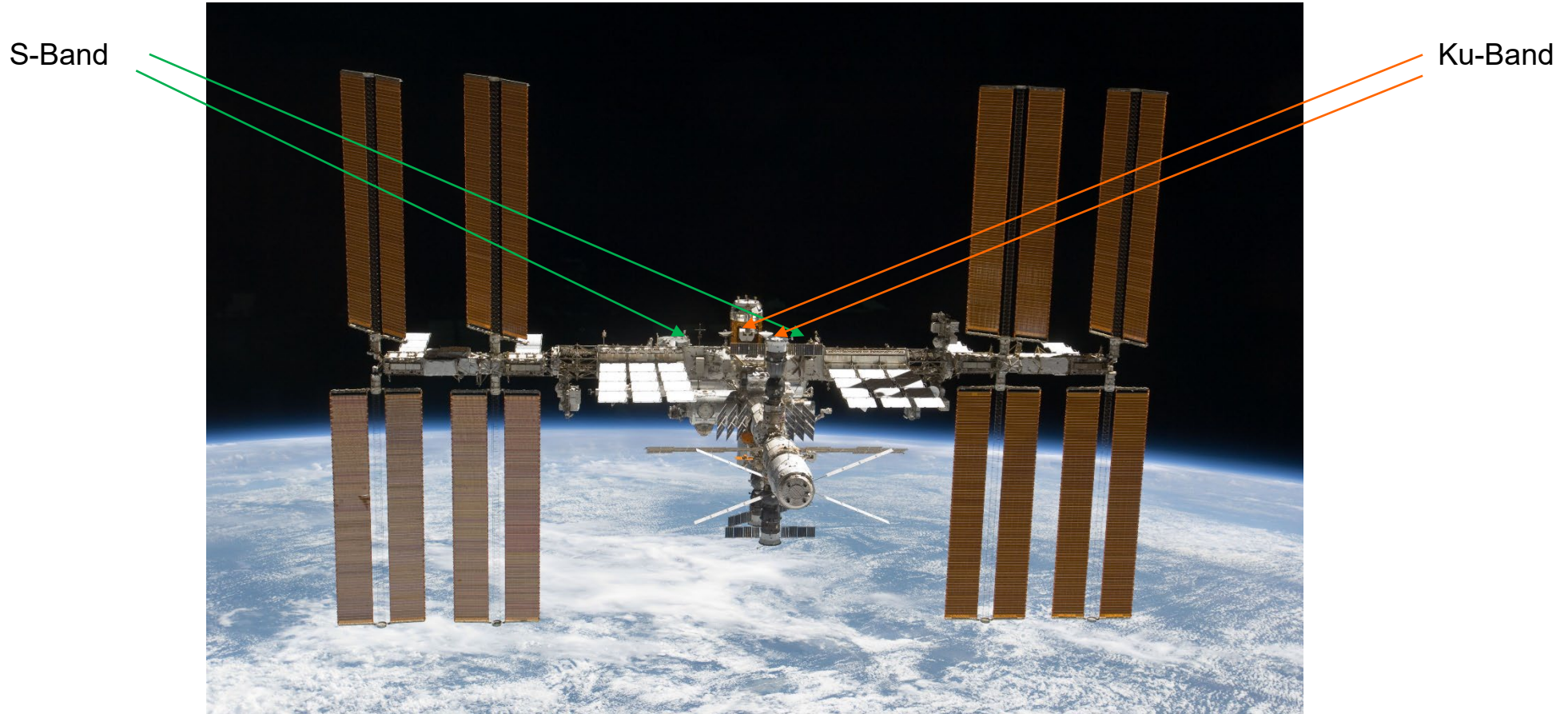
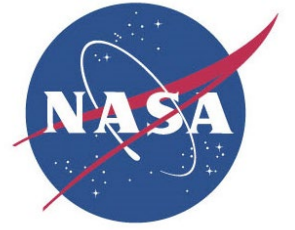
N. Brice Orange, Orangewave Innovative Science, LLC

Del Christman*, Autonodyne LLC

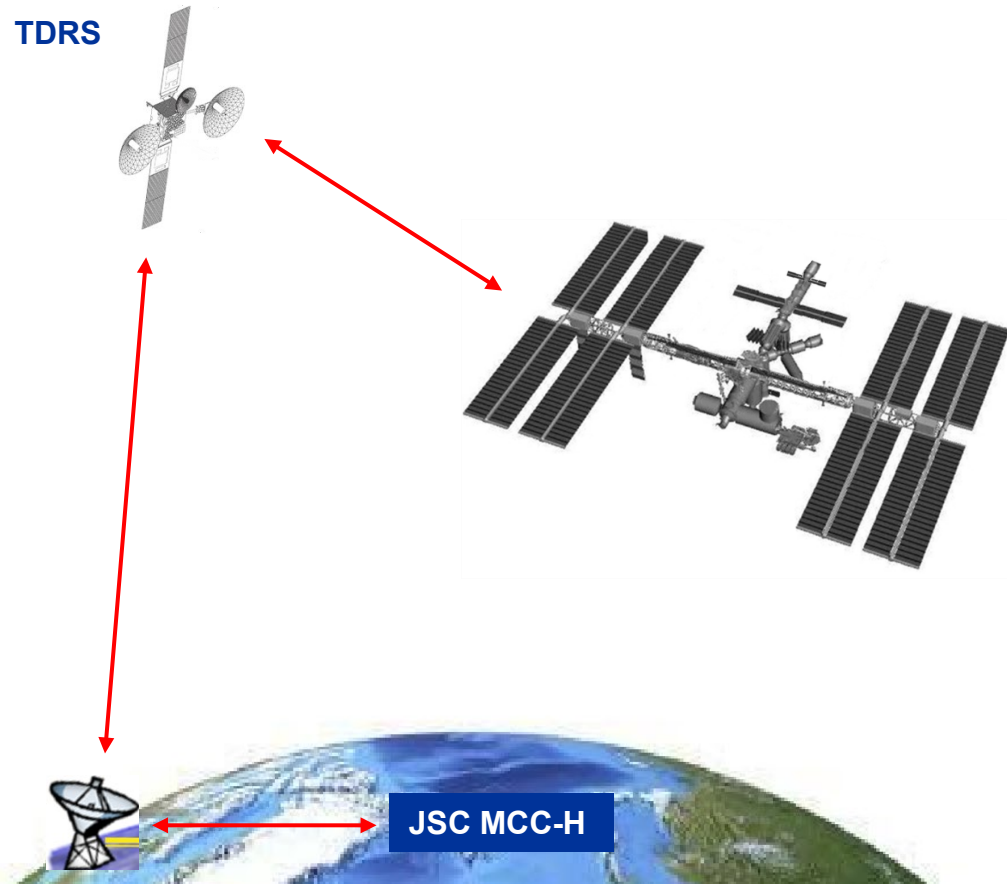
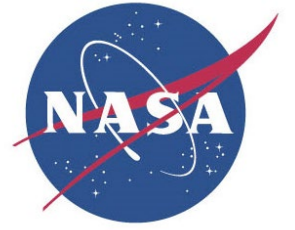


- International Space Station: Comm Systems & Operations
- Statement of the Problem – Loss of Signal
- Machine Learning Signal Classification
- Current Results
- Integration with ISS Antenna Manager
- Discussion & Future Work

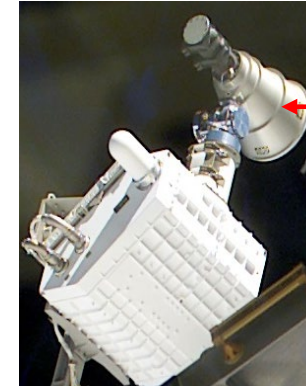
International Space Station



International Space Station: Comm Systems & Operations



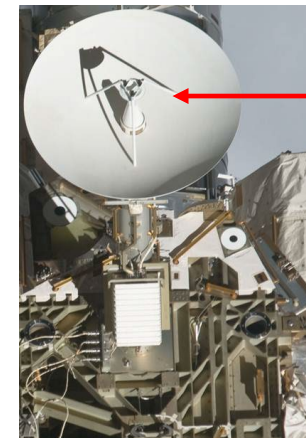
S-Band



High Gain Antenna

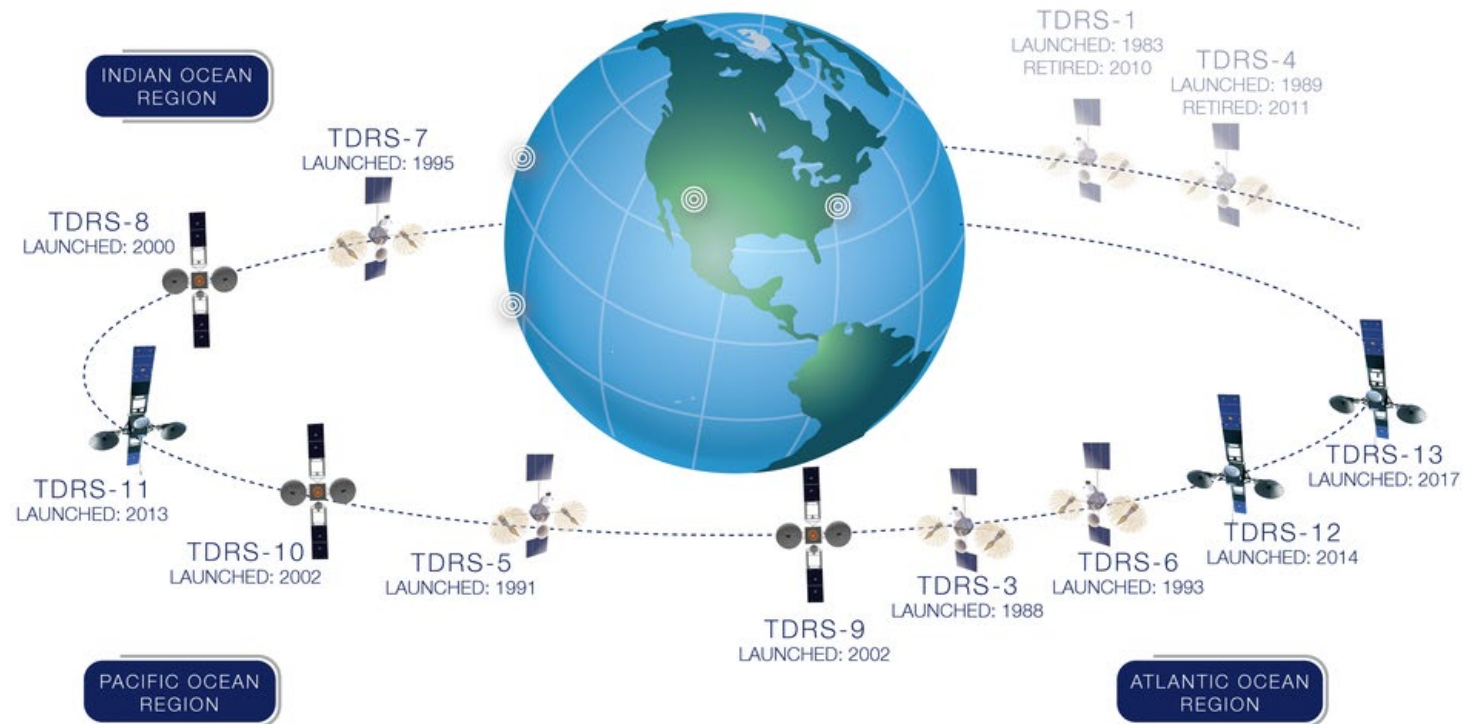
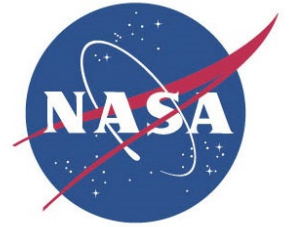
Strongest Signal:
Digital AGC ~22

Ku-Band



Space to Ground
Antenna

TDRSS Topology





CRONUS Flight Controller

- Command & Data Handling
- Communication & Tracking Systems
- Onboard Audio & Video Systems
- ISS Antenna Management Tool
- TDRS Handover
- Loss of Communication

FCR-1 CRONUS Console



Challenge:
Unscheduled Loss of Signal (LOS)



Loss of Signal



CRONUS Systems Overview MSK Display

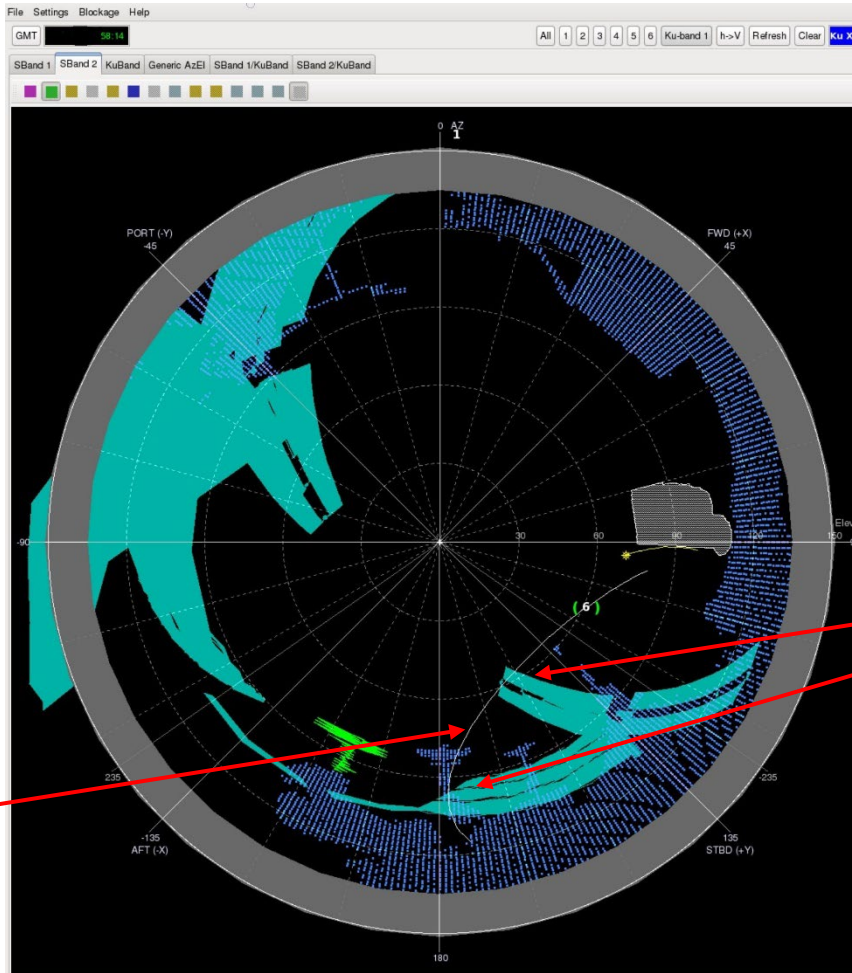
The screenshot displays a complex MSK (Mission Status Key) interface for the CRONUS system. It is organized into several main sections:

- Top Left:** Summary tables for various system components like CCS Wvr, Bc Conn Fail, ENAS, and various operational modes (e.g., P_CCS, B_CCS, S_CCS).
- Top Center:** S-Band 1 and S-Band 2 Overview panels showing active channels, carrier locks, and signal levels.
- Top Right:** Channel Switching and EXT RTs panels, detailing channel configurations and external real-time status.
- Middle Left:** Detailed status for various subsystems including P_INT, P_EXT, P_GNC, P_PMCU, P_PL, P_HCZ, P_NCS, S_NCS, AL-1, LA-1, LA-2, N2-1, N2-2, N3-1, N3-2, and PMM.
- Middle Center:** A large central panel for XMIT (Transmit) status, showing antenna management, current TDRS (Target Data Relay Station) position, and various control parameters.
- Middle Right:** Video Overview and Video Routing panels, showing video feed status and routing paths.
- Bottom Left:** CCSRM (Control System Resource Manager) and NTS (Network Transfer System) status panels.
- Bottom Center:** C2V2 (Control to Vehicle) and UHF (Ultra High Frequency) status panels.
- Bottom Right:** PCS (Power Control System) and various other status panels including P4PV RTs, P4V RTs, and P4V RTs.

The interface uses a color-coded system (green for good, yellow for caution, red for error) to indicate the health of different components. A status bar at the bottom indicates the time basis is set to 2023/12/01 00:17:898.

Real-time S-Band Display

- Graphical User Interface
- S-Band (alt, az) coordinate view
- Articulating & static ISS structure
- Current TDRS location
- TDRS tracking



Optional TDRS Track (solid white curve)

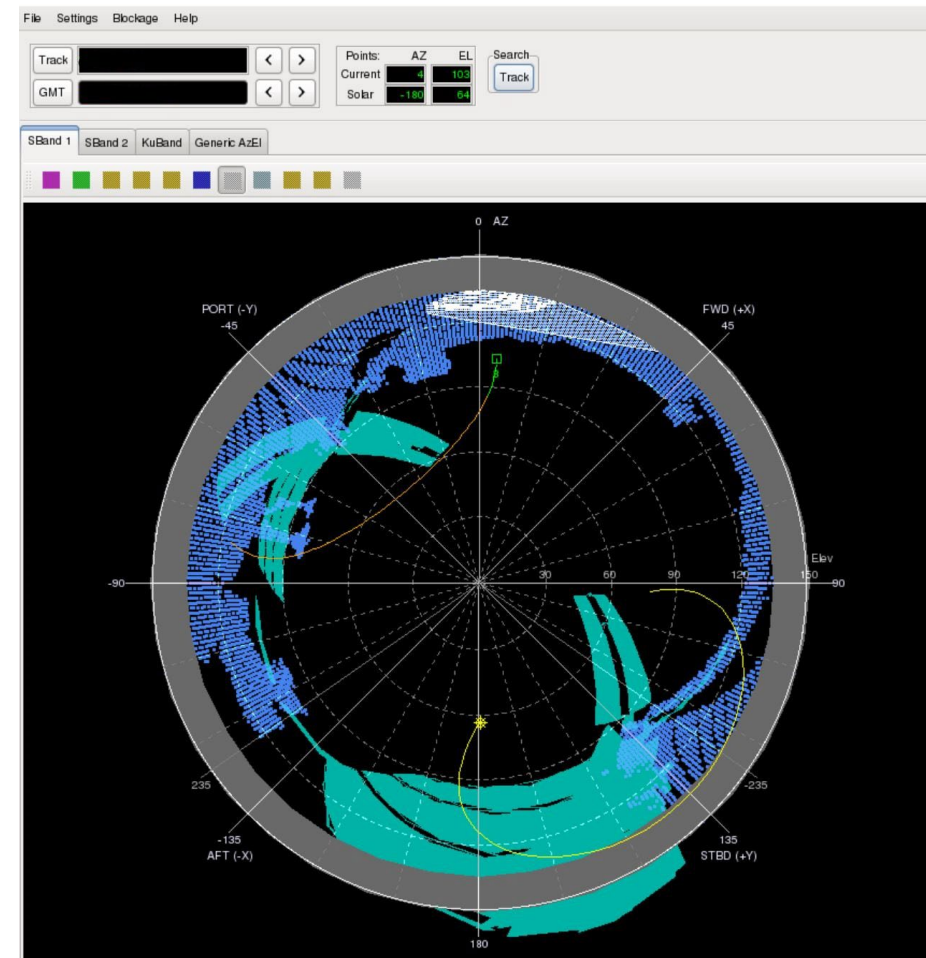
Potential LOS

S-Band Predict Display

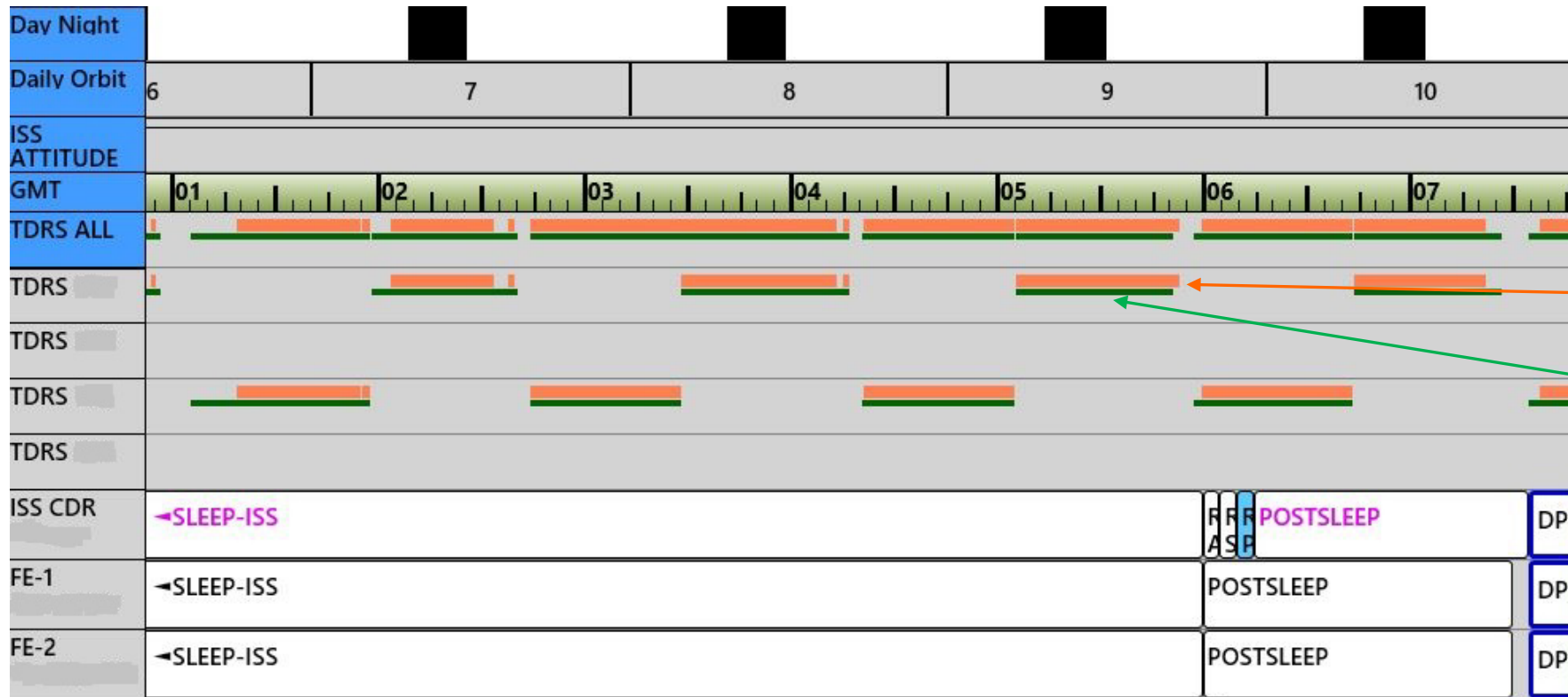
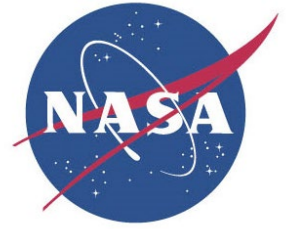
- Graphical User Interface
- S-Band (alt, az) coordinate view
- Articulating & static ISS structure
- Predicted TDRS locations

Predict Data:

- TDRS events + pointing (generated by GC)
- Solar array plan (generated by PRO)
- Elementary blockage estimation
- 3 Files (frequently updated plan)

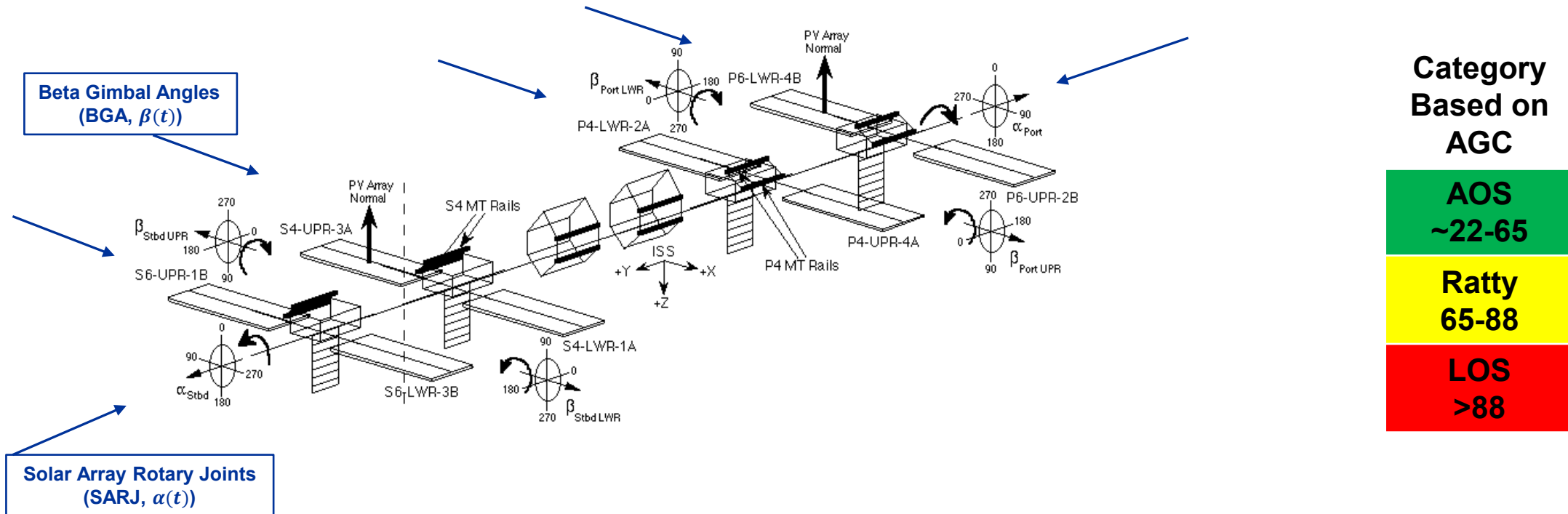


Comm Availability Indicators for Crew



Orange: Ku-band availability
 Green: S-band availability
 Gaps in the color bars indicate structure blockage or scheduled outages

ISS Structural Blockage

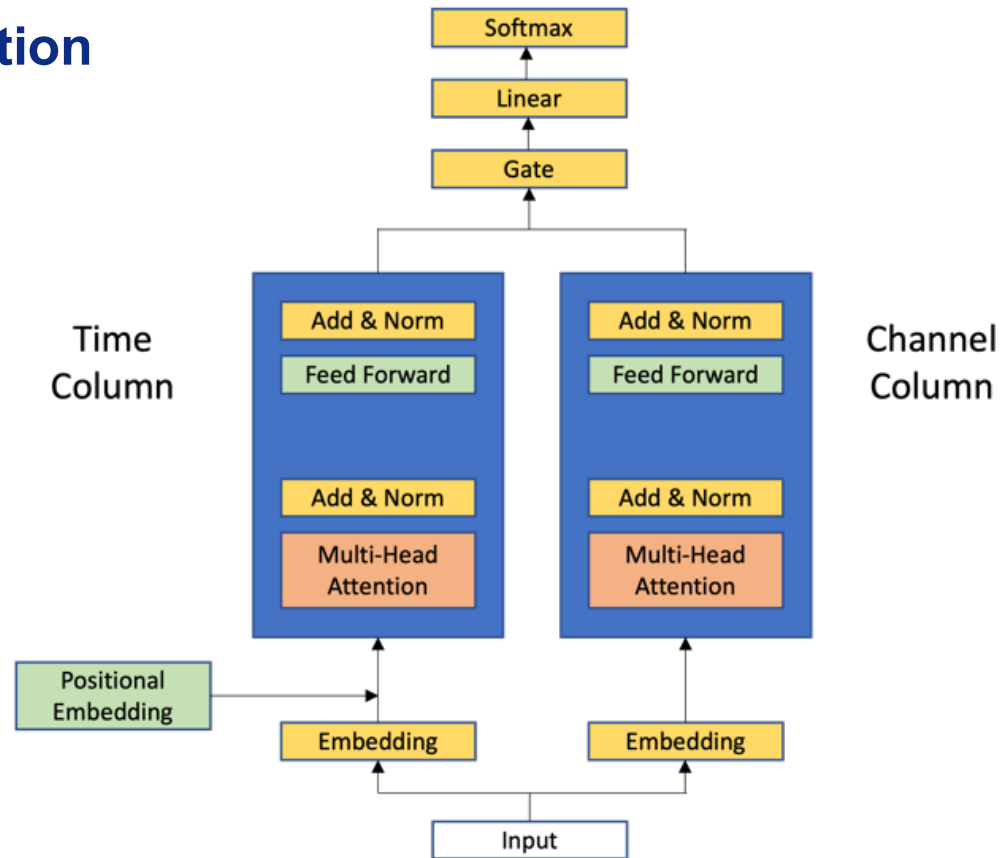


S-Band Signal Strength: Digital Automatic Gain Control (AGC)

$$Digital\ AGC = f(S_{az}, S_{el}, Port\ \&\ Starboard\ SARJ, 8\ BGAs, Port\ \&\ Starboard\ TRRJ)$$

Apply multi-variate time-sequenced classification

- Train on historical telemetry data
 - 14 time dependent telemetry parameters + corresponding comm status (AGC)
- Gated Transformer Network (GTN)
 - Assesses correlations among timesteps and channels
- Inference applied to “Predict” data



ISS S-Band Performance Data Preparation

- MCC-H ISS JMEWS Telemetry Archive: 10+ years
- Parameter Selection

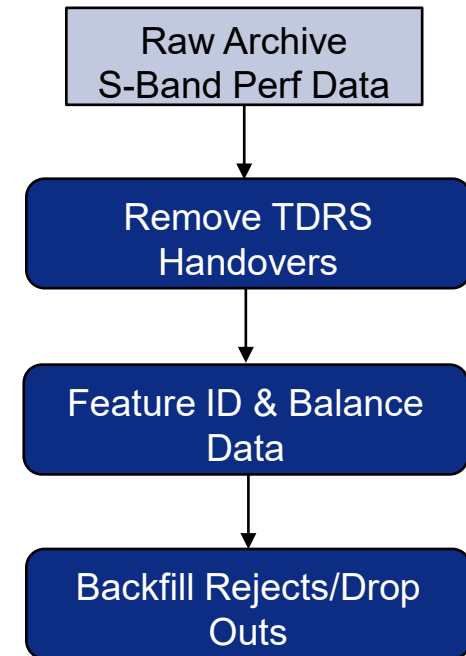
$$\{\alpha_j(t_i), T_j(t_i), \beta_k(t_i), S_{az}(t_i), S_{el}(t_i), AGC(t_i)\} \quad j = [1,2], k = [1,8], i^{th} \text{ row}$$

- Feature Identification and Labeling

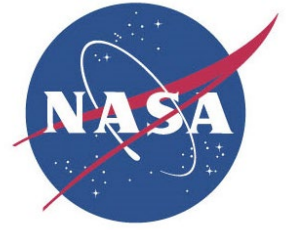
Model Training

- Numerous training runs over increasing length of time
- Winter + Spring 2017

Time Span	Length	Orbits	Rows	Training Samples	Test Samples	Epochs	Training Time
60 days	4 days	64	434,500	300,000	41,000	200	~200 hrs



Comm Class Results



Normalized Confusion Matrix for Test Set

- Approximately 41,000 samples
- Fairly balanced among classes

		<i>Predicted</i>		
		AOS	LOS	Ratty
<i>True</i>	AOS	0.988	0.007	0.005
	LOS	0.000	0.997	0.003
	Ratty	0.004	0.006	0.990

Accuracy:
99.2%

Classification Metrics

	<i>Precision</i>	<i>Recall</i>	<i>F1 score</i>
AOS	0.998	0.988	0.993
LOS	0.991	0.997	0.994
Ratty	0.986	0.990	0.988

Predict Data Files (MCC-H)

- TDRS SHO – forthcoming TDRS events (7-14 days)
- ISS TDRS Pointing – TDRS events & corresponding unit vector in ISS body coords
- ISS Sun ABG – comprehensive time-tagged solar array plan

Predict Data Preprocessing

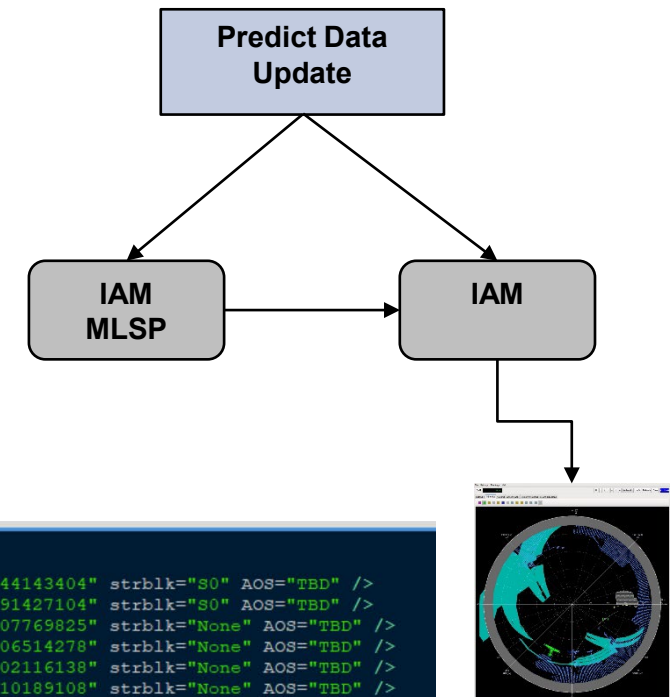
- Coordinate transformation(s)
- Map solar array plan to each TDRS event
- ISS Sun ABG

```

1 <tdrs>
2 <event name="46E" value="2" sho="E-TDRS">
3 <predict time="2018:07:02:12:11:00" GMT_DOY="183" az="-115.606138691" el=" 43.702344799" x=" 0.69091199754" y=" 0.65193631741" z=" 0.31244143404" strblk="S0" AOS="TBD" />
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8 <predict time="2018:07:02:12:16:00" GMT_DOY="183" az=" -96.693973038" el=" 47.931283945" x=" 0.74234178855" y=" 0.66545380274" z=" 0.07810189108" strblk="None" AOS="TBD" />

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IAM MLSP
IAM Machine Learning
Standalone Prototype



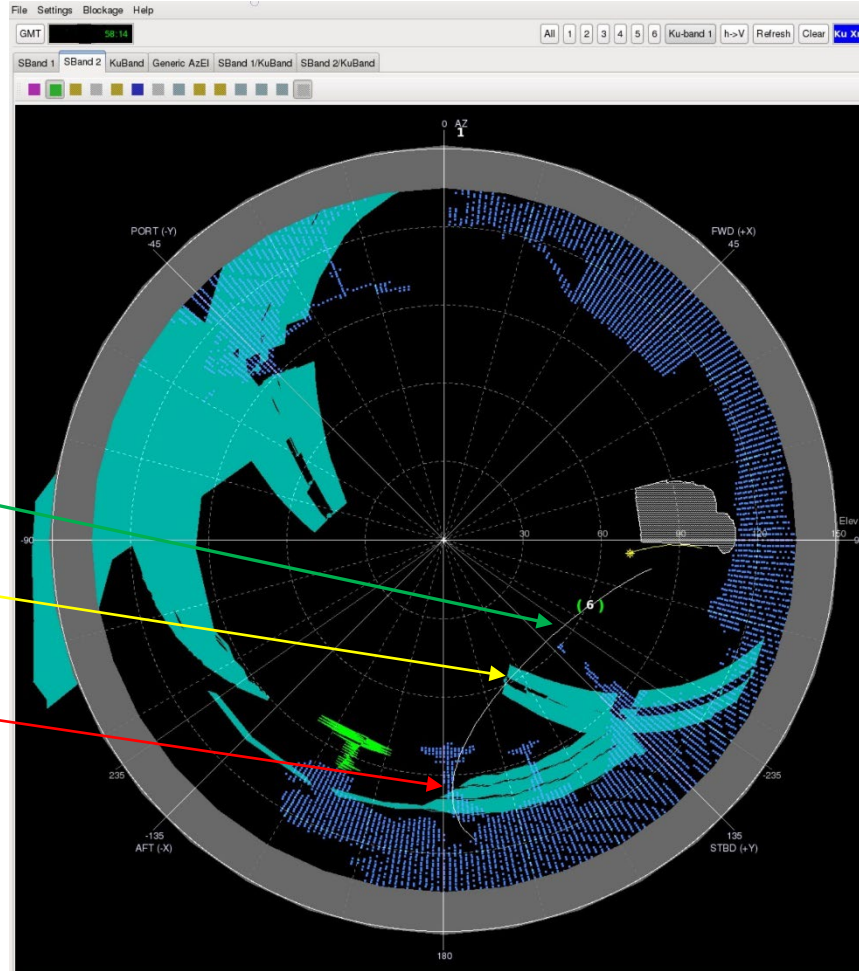
Predicted Comm Display Indicators



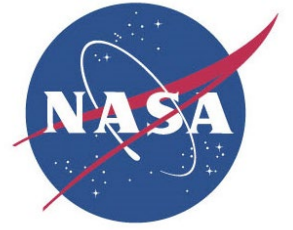
Real-time S-Band Display

Category

AOS ~22-65
Ratty 65-88
LOS >88



Standardizes real-time “comm calls” regarding availability during structure blockage impinging on comm links.



IAM MLSP Development & Deployment

- 3-Phase delivery to MCC-H (Phase I IAM MLSP Preprocessor)
- Have we captured all AOS scenarios? Additional Training: full year's performance data, over multiple years (current training run on 3 seasons)
- Extensive Testing using archived ISS Telemetry: short (~week, ~month) and long (year) timescales
- Generate separate network for S-Band string #2, as well as Ku-Band
- Performance Evaluation: past Predict Data with contemporaneous Digital AGC telemetry

Future Operations

- On console performance assessment during real-time operations – identify where the AI missed LOS events
- Justify using ISS as a testbed for future autonomous space communication systems
- Migration to onboard systems
- Future AI development projects at JSC to pioneer and test elements of cognizant communications management systems
(e.g. Artemis and Lunar Gateway)

Thank you!

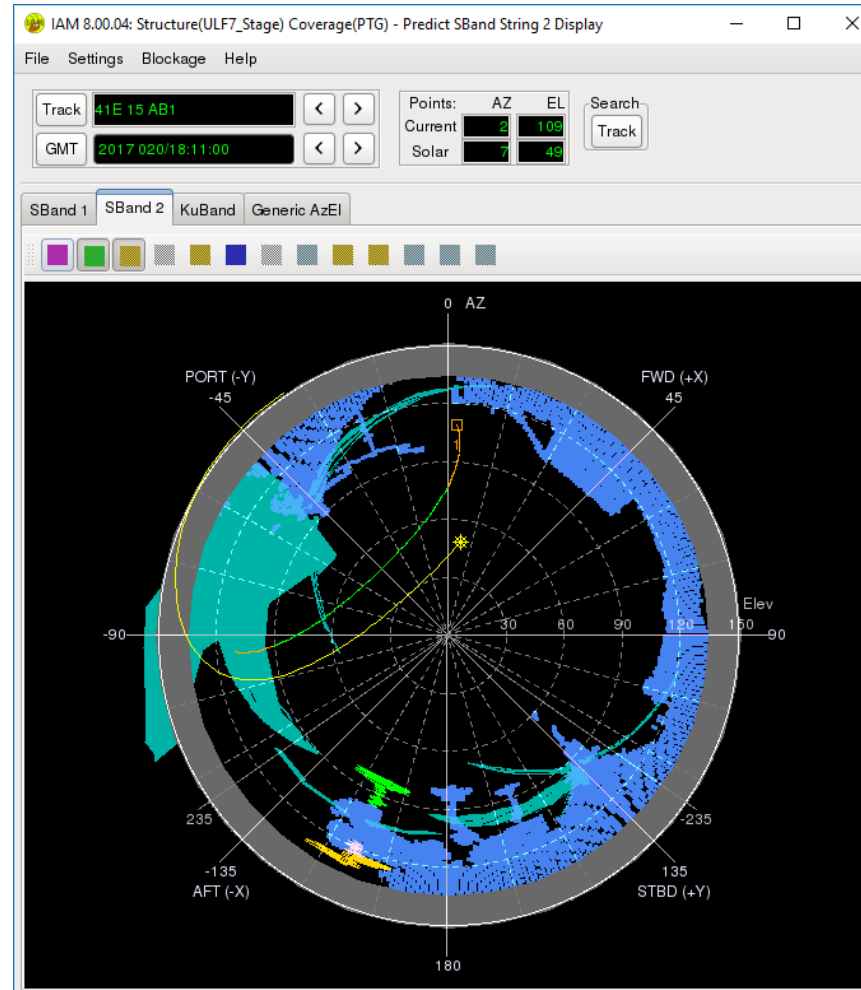
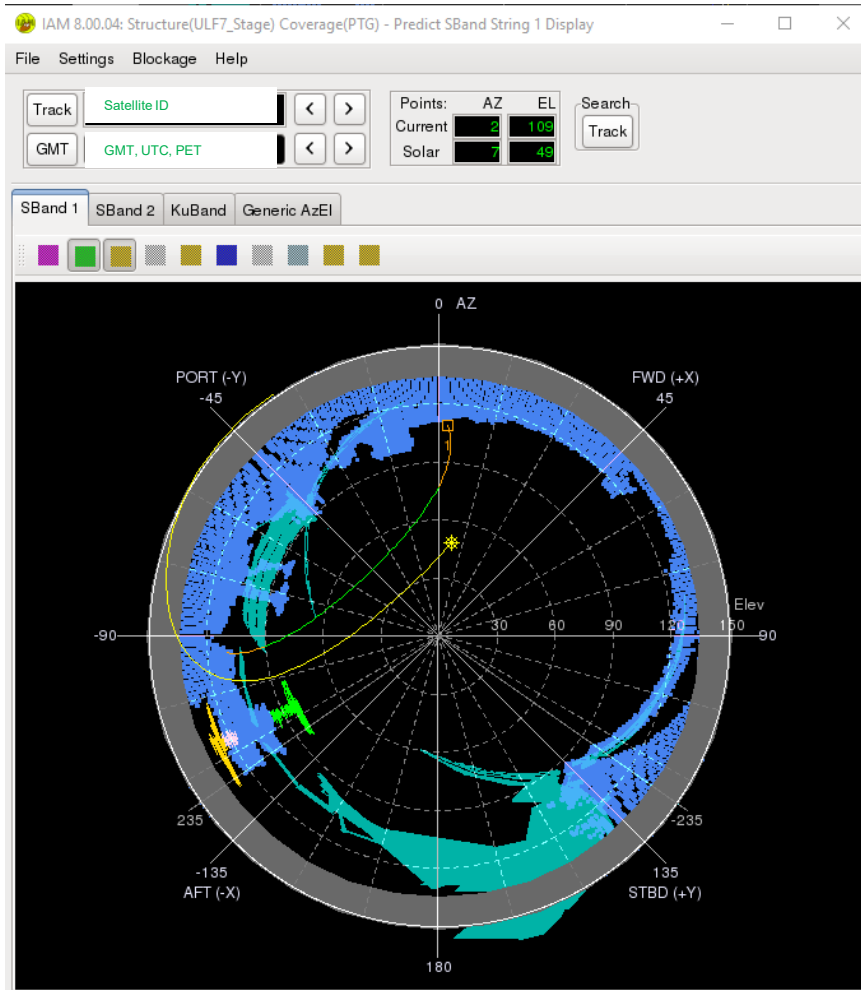
Questions?

Inter Agency Agreement SAA-CA-21-34279

AFOSR Small Grant
Boeing Gift Funds

Back Up Slides

Both S-Band Strings



Ku-Band Display

