HQ U.S. Air Force Academy

Integrity - Service - Excellence

Integrating Machine Learning into the ISS Antenna Management Software

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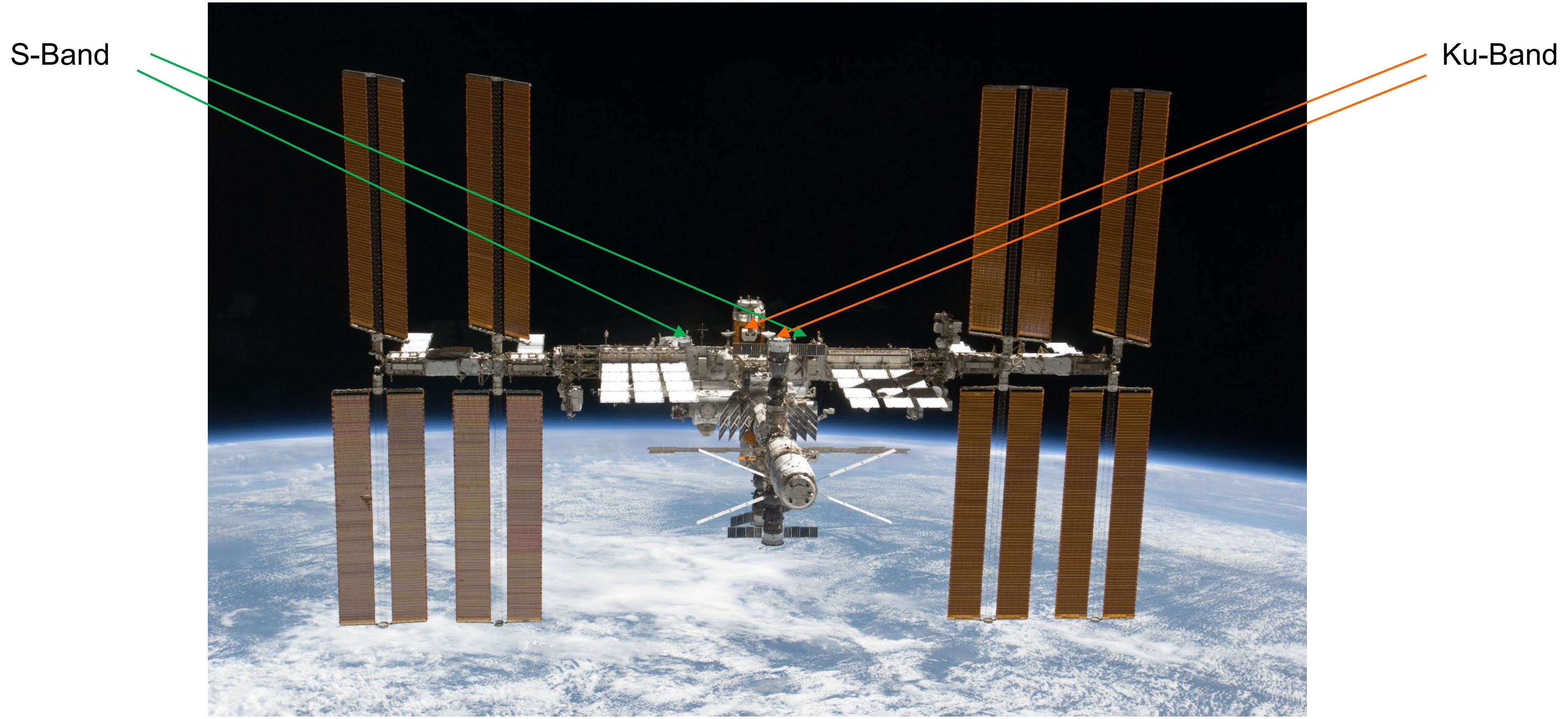
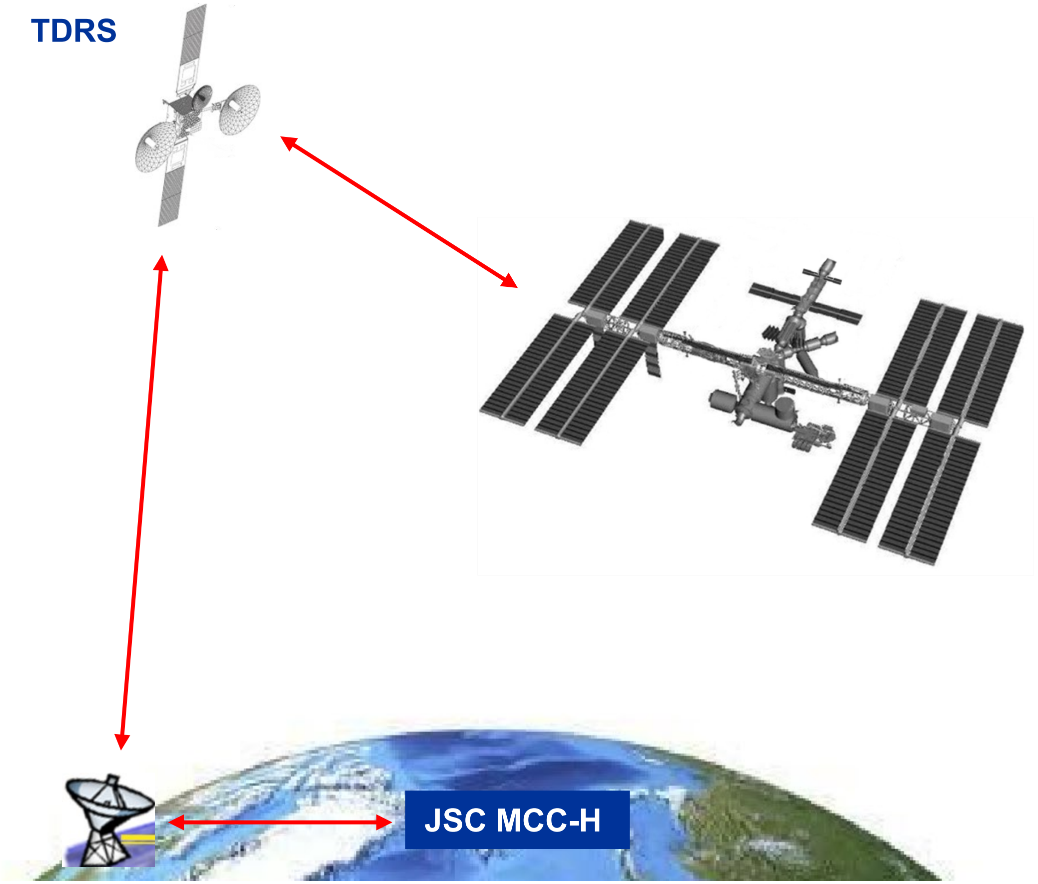
Overview

- 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

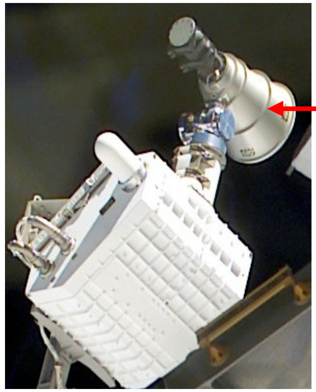
International Space Station



International Space Station: Comm Systems & Operations



S-Band



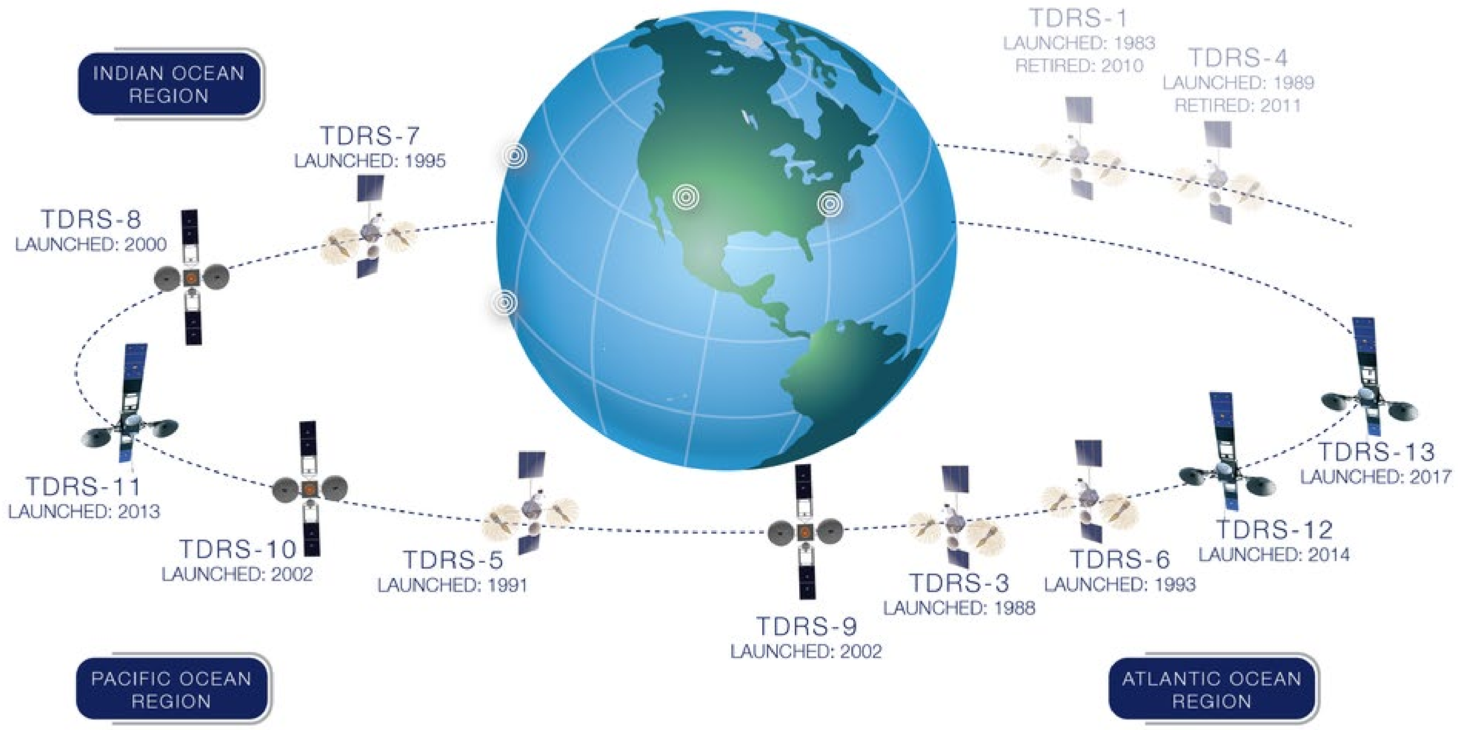
High Gain Antenna

Strongest Signal:
Digital AGC ~22

Ku-Band

Space to Ground Antenna

TDRSS Topology



Statement of the Problem

CRONUS Flight Controller

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

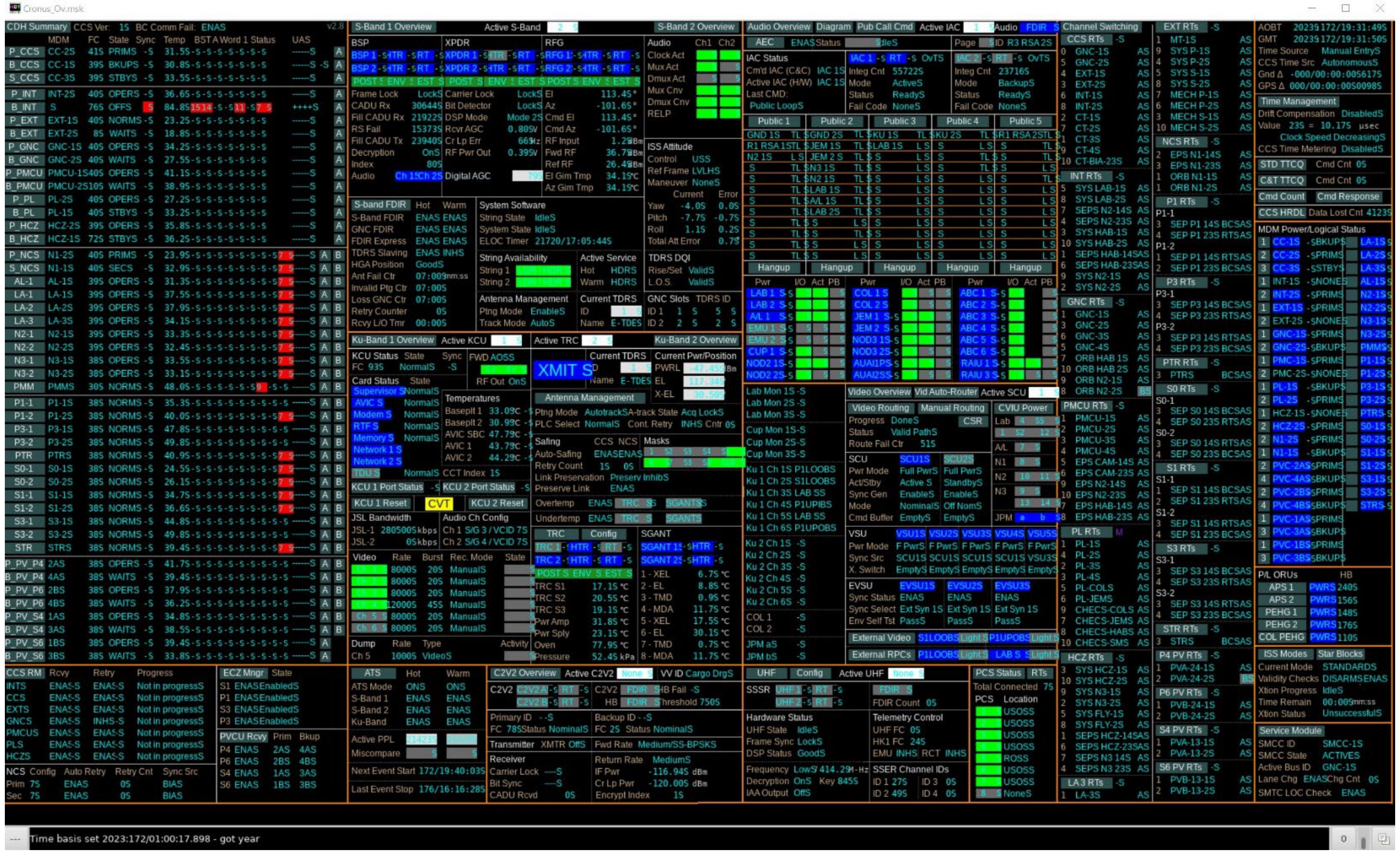
FCR-1 CRONUS Console

Challenge:

Unscheduled Loss of Signal (LOS)

Loss of Signal

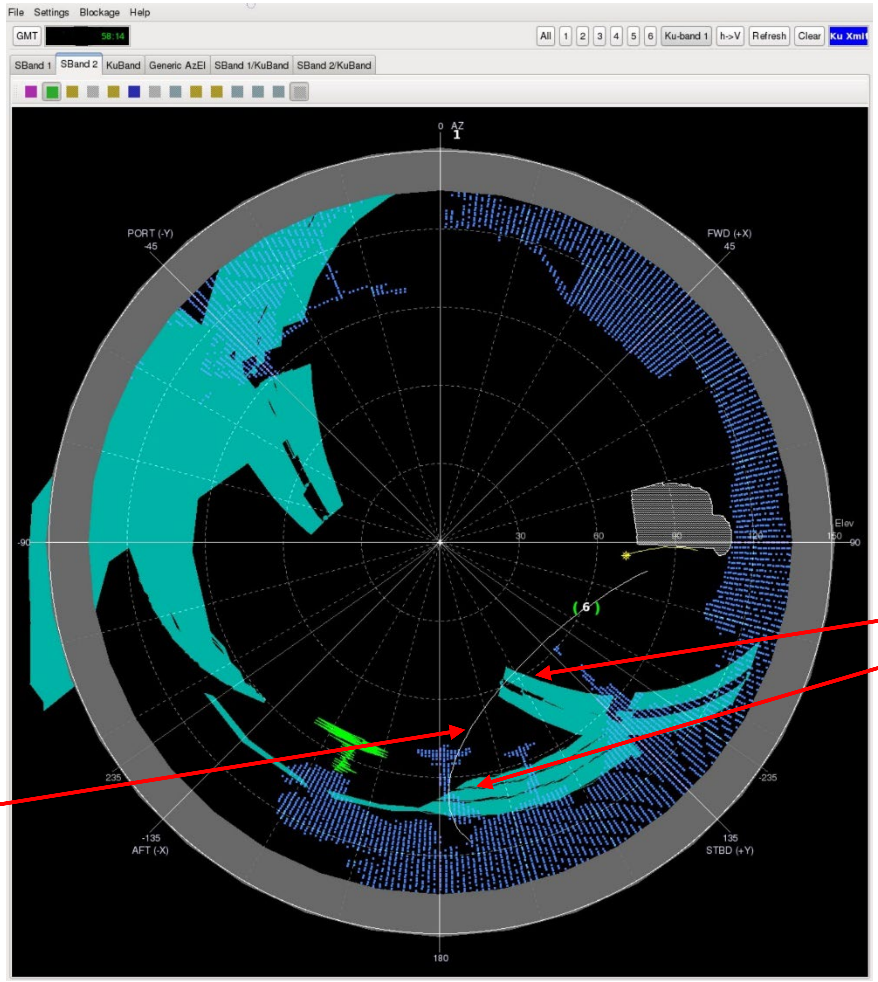
CRONUS Systems Overview MSK Display



ISS Antenna Manager

Real-time S-Band Display

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



Potential LOS

Optional TDRS Track (solid white curve)

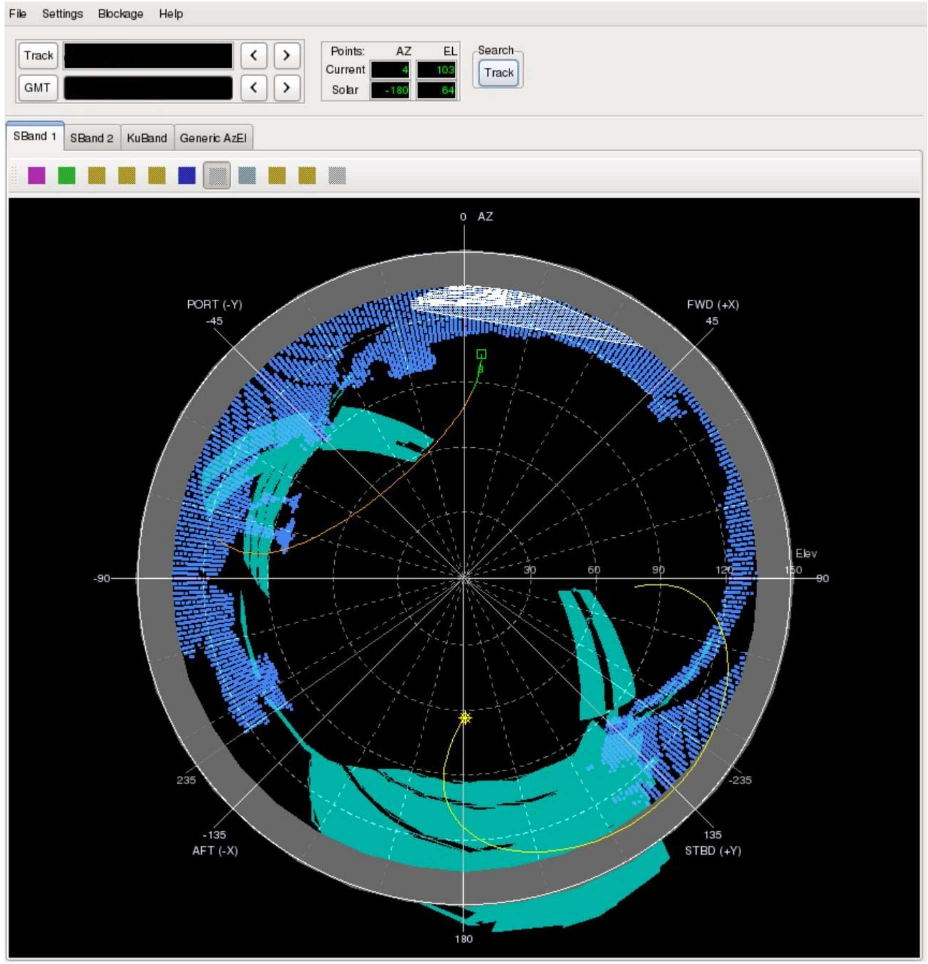
ISS Antenna Manager

S-Band Predict Display

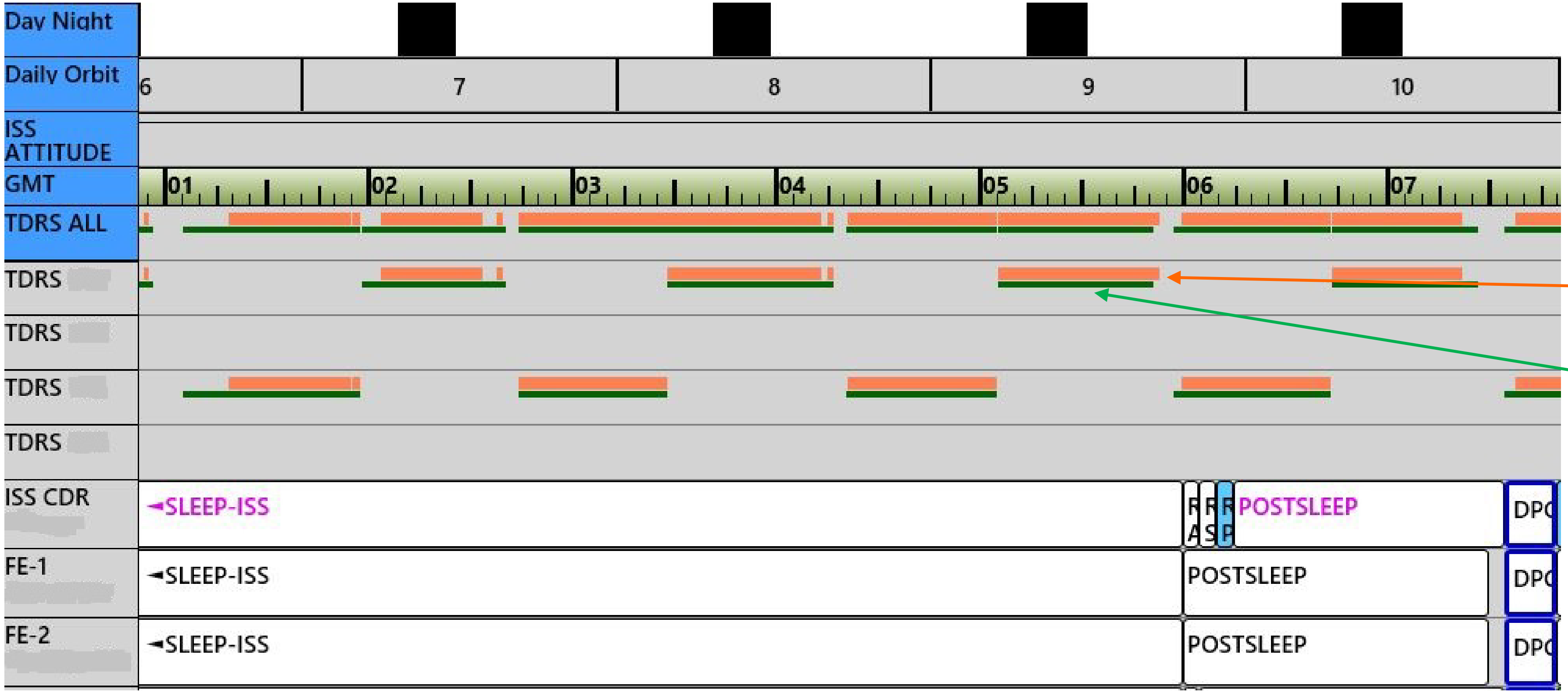
- Graphical User Interface
- S-Band (alt, az) coordinate view
- Articulating & static ISS structure
- Predicted TDRS locations

<u>Predict Data:</u>

- 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

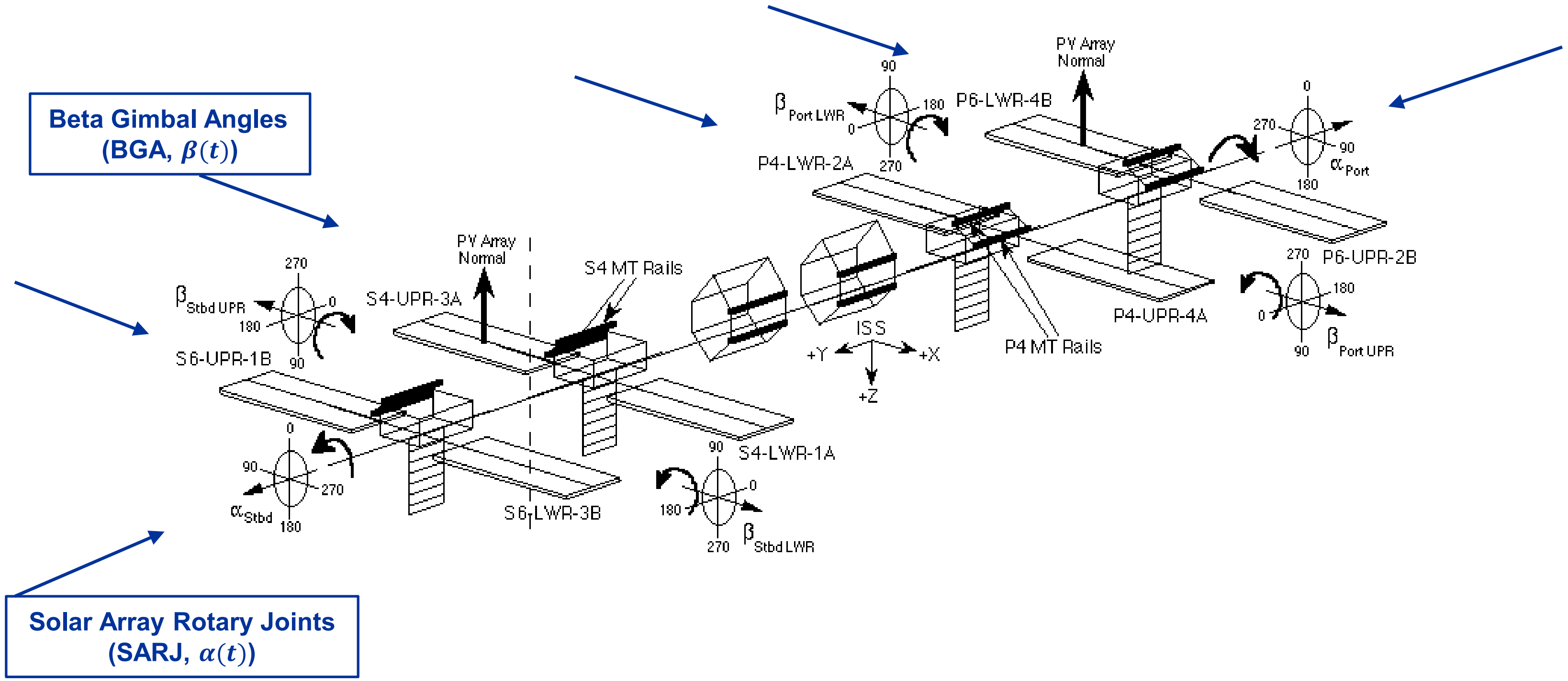


Orange: Ku-band availability

Green: S-band availability

Gaps in the color bars indicate structure blockage or scheduled outages

ISS Structural Blockage



Category Based on AGC
AOS ~22-65
Ratty 65-88
LOS >88

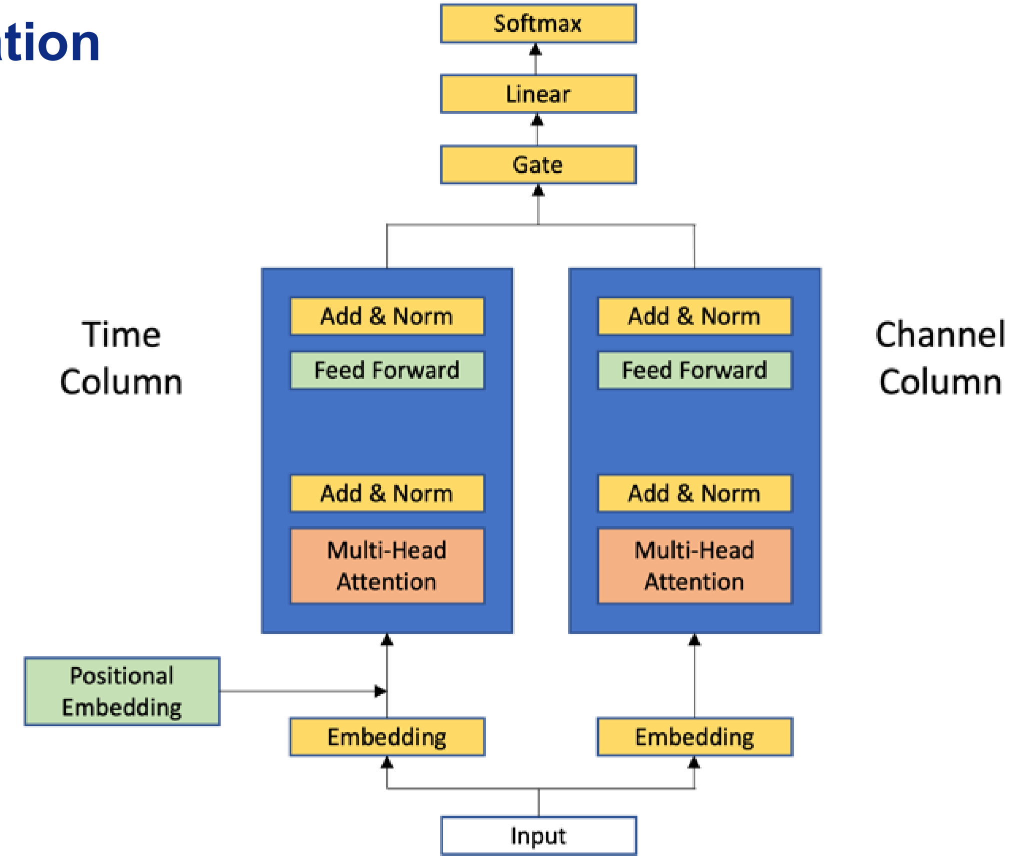
S-Band Signal Strength: Digital Automatic Gain Control (AGC)

$$Digital\ AGC = f(S\_az, S\_el, Port\ \&\ Starboard\ SARJ, 8\ BGAs, Port\ \&\ Starboard\ TRRJ)$$

ML for Communication Classification

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



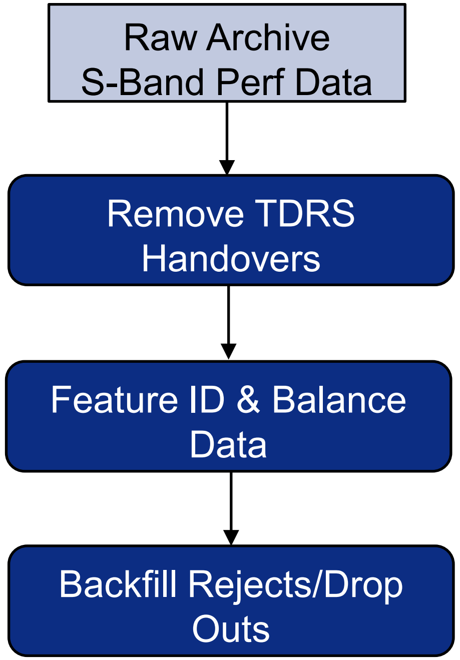
GTN Training

ISS S-Band Performance Data Preparation

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

$$\{\alpha_j(t_i), T_j(t_i), \beta_k(t_i), S\_az(t_i),\ S\_el(t_i),\ AGC(t_i)\}\quad j = [1,2], k = [1,8],\ i^{th}\ row$$

- 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

True \ *Predicted*	AOS	LOS	Ratty
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

	Precision	*Recall*	*F1 score*
AOS	0.998	0.988	0.993
LOS	0.991	0.997	0.994
Ratty	0.986	0.990	0.988

Predict Data Processing

Predict Data Files (MCC-H)

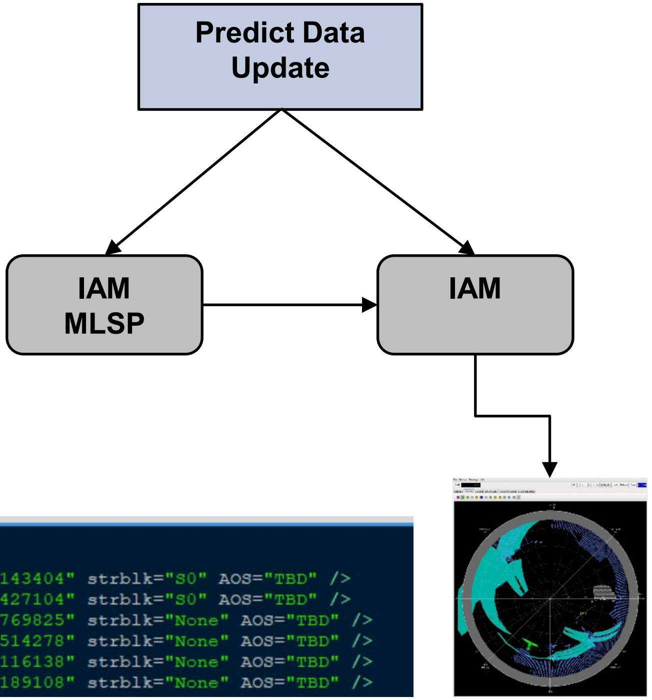
- TDRS SHO – forthcoming TDRS events (7-14 days)
- ISS TDRS Pointing – TDRS events & corresponding unit vector in ISS body coords
- ISS Sun ABG – comprehensive time-tagged solar array plan

Predict Data Preprocessing

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

IAM MLSP

IAM Machine Learning Standalone Prototype

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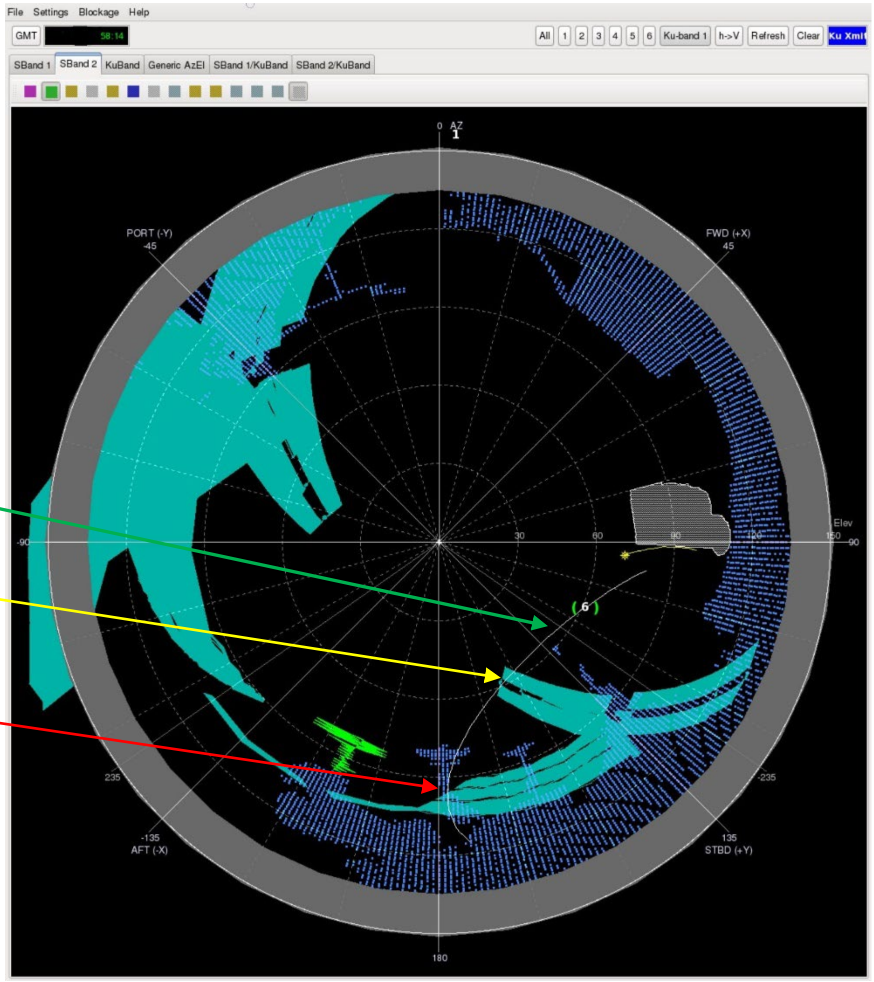
Predicted Comm Display Indicators

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.

Discussion & Look-Ahead

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!

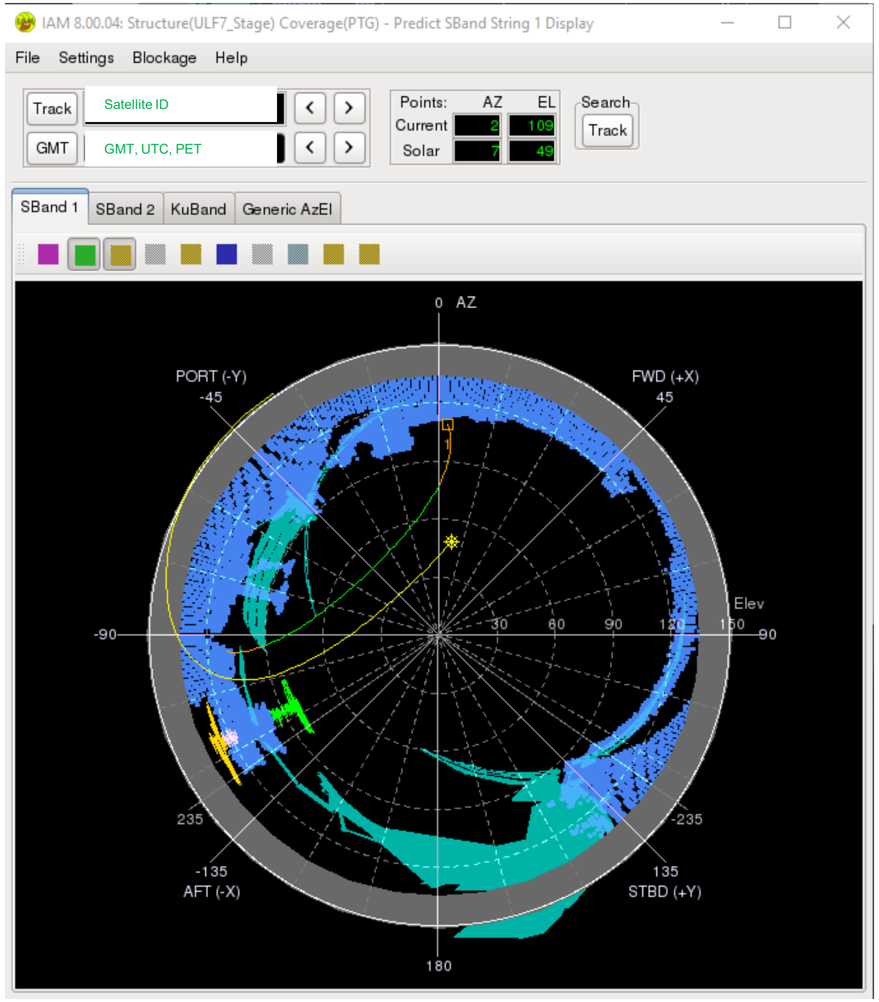
Questions?

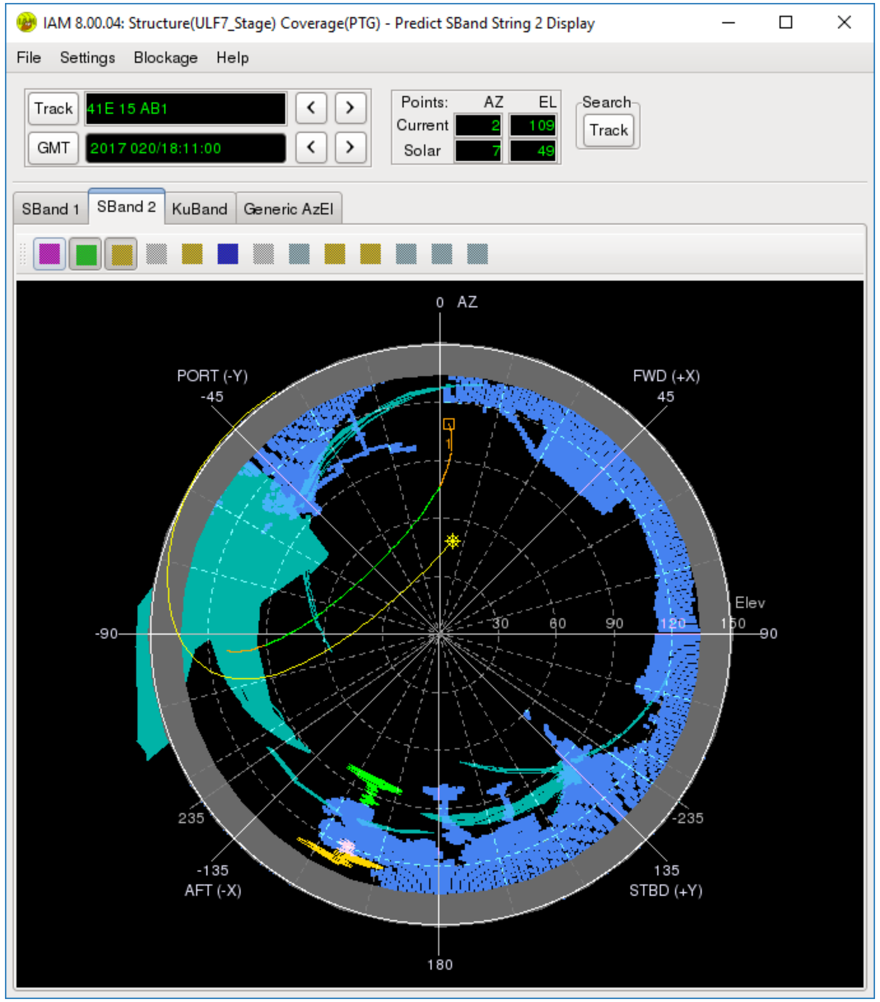
Inter Agency Agreement SAA-CA-21-34279

AFOSR Small Grant
Boeing Gift Funds

Back Up Slides

Both S-Band Strings





Ku-Band Display