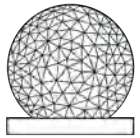
Haystack AeroVista REU

Hirani Sattenapalli, Aparna Rajesh, T. Lucas Briggs



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“Aurora Touching Sunrise” from NASA archives

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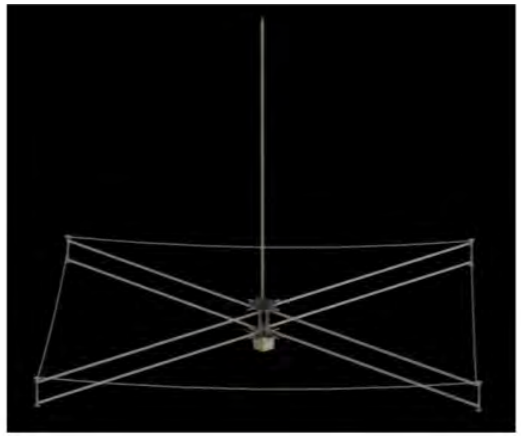
AERO VISTA Mission Introduction

AERO VISTA Payload ←



Antenna after Deployment →

- AERO & VISTA satellites will collect radio frequency (RF) data from the auroral regions
- Data will be used to accomplish science and tech goals
  - Study emissions such as Auroral Kilometric Radiation (AKR), Medium Frequency Burst (MFB), Auroral Roar, and Auroral Hiss
  - Validate usage of Vector Sensor Interferometry and RFI survey

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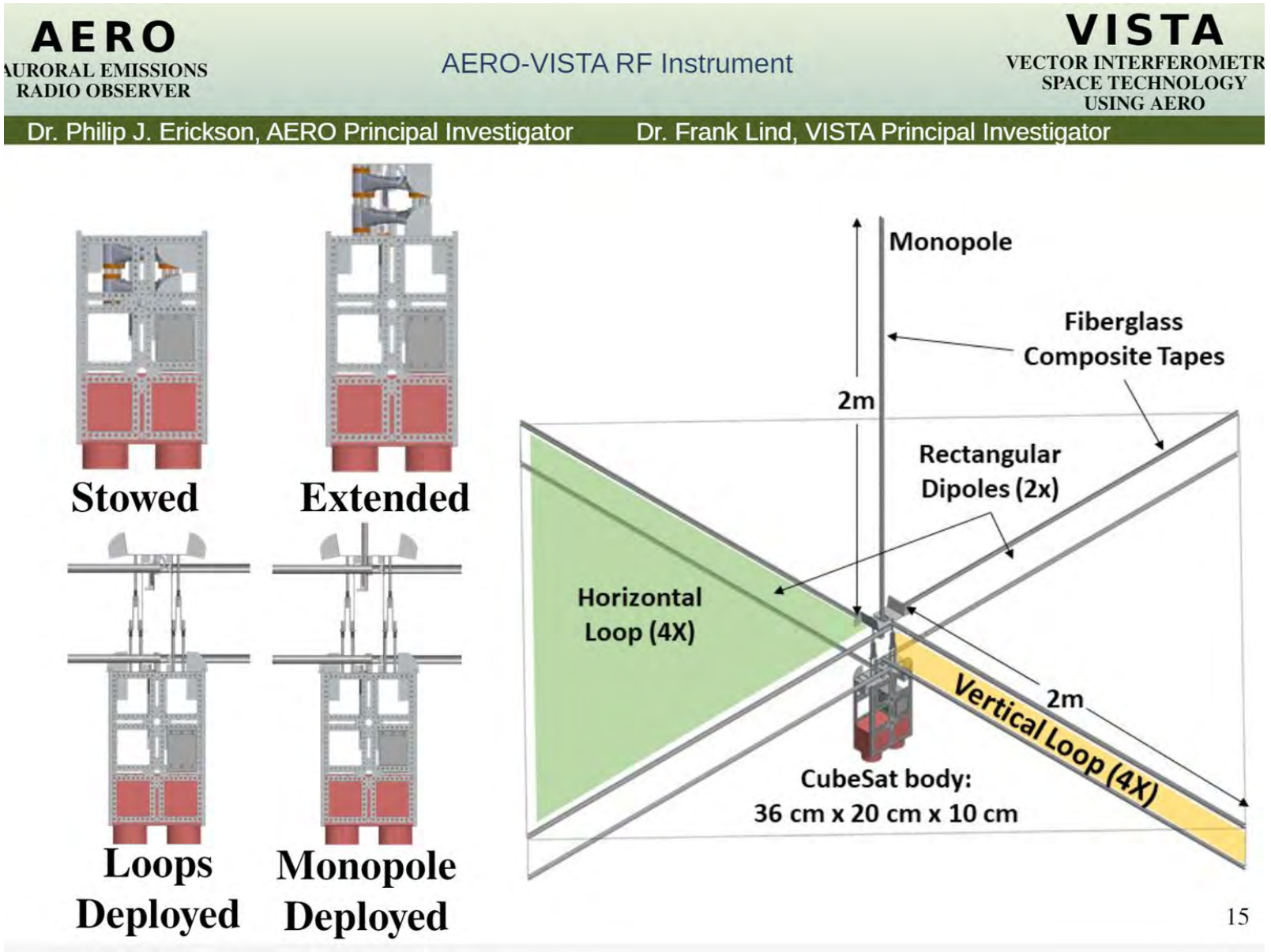
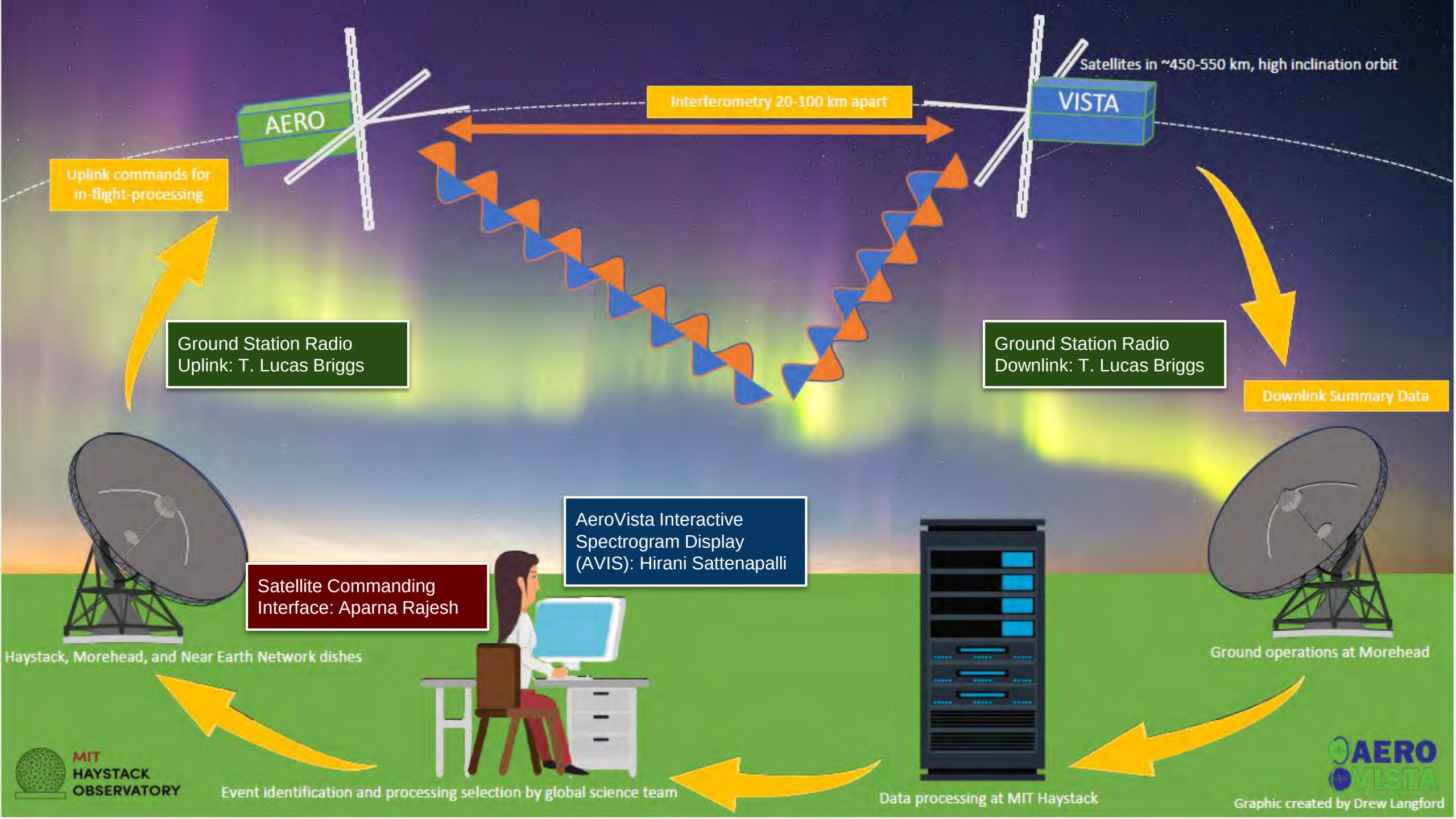


Monopole, Horizontal Loop, and Rectangular Dipoles correspond to channels on spectrogram

Slide from Mary Knapp AERO-VISTA presentation 2021


AERO
VISTA
Satellites in ~450-550 km, high inclination orbit
Interferometry 20-100 km apart
Uplink commands for in-flight-processing
Ground Station Radio Uplink: T. Lucas Briggs
Ground Station Radio Downlink: T. Lucas Briggs
Downlink Summary Data
AeroVista Interactive Spectrogram Display (AVIS): Hirani Sattenapalli
Satellite Commanding Interface: Aparna Rajesh
Haystack, Morehead, and Near Earth Network dishes
Ground operations at Morehead
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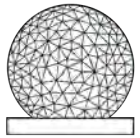
Event identification and processing selection by global science team
Data processing at MIT Haystack
AERO VISTA
Graphic created by Drew Langford

AERO-VISTA Interactive Spectrogram Display

Hirani Sattenapalli



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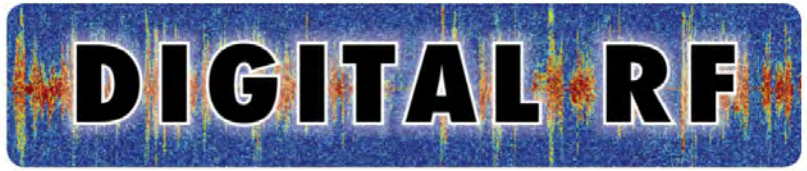
AVIS Display & Objectives

- Provide a tool for the science team to visualize metadata
- Present spectrogram data in plotly graphs
- Allow science team to perform computation on channel data and send commands for in-flight processing

Libraries Used

redis

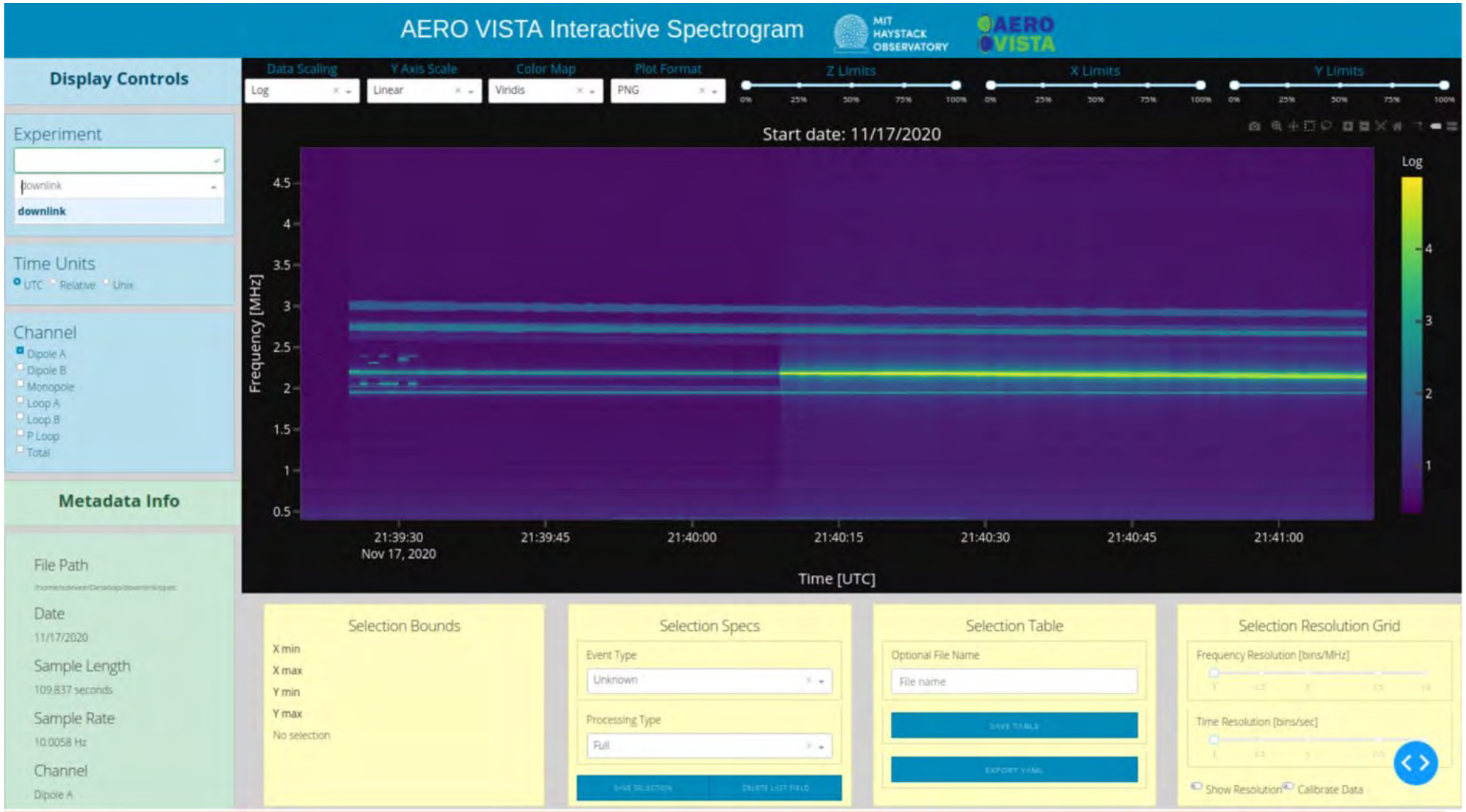


- Plotly
  - Graphing utility used for telemetry maps and spectrogram plots
- Redis
  - In-memory data structure used to store metadata
- Digital RF
  - Software used for reading and writing spectrogram metadata into digital RF format

Libraries Used

- Dash
  - Python framework to build web pages
  - Used to build and style layout and components of the dashboard
- Numpy
  - python library to work with arrays and matrices
- Xarray
  - python package that adds dimensions and coordinates to numpy arrays
  - used to organize metadata to place into redis

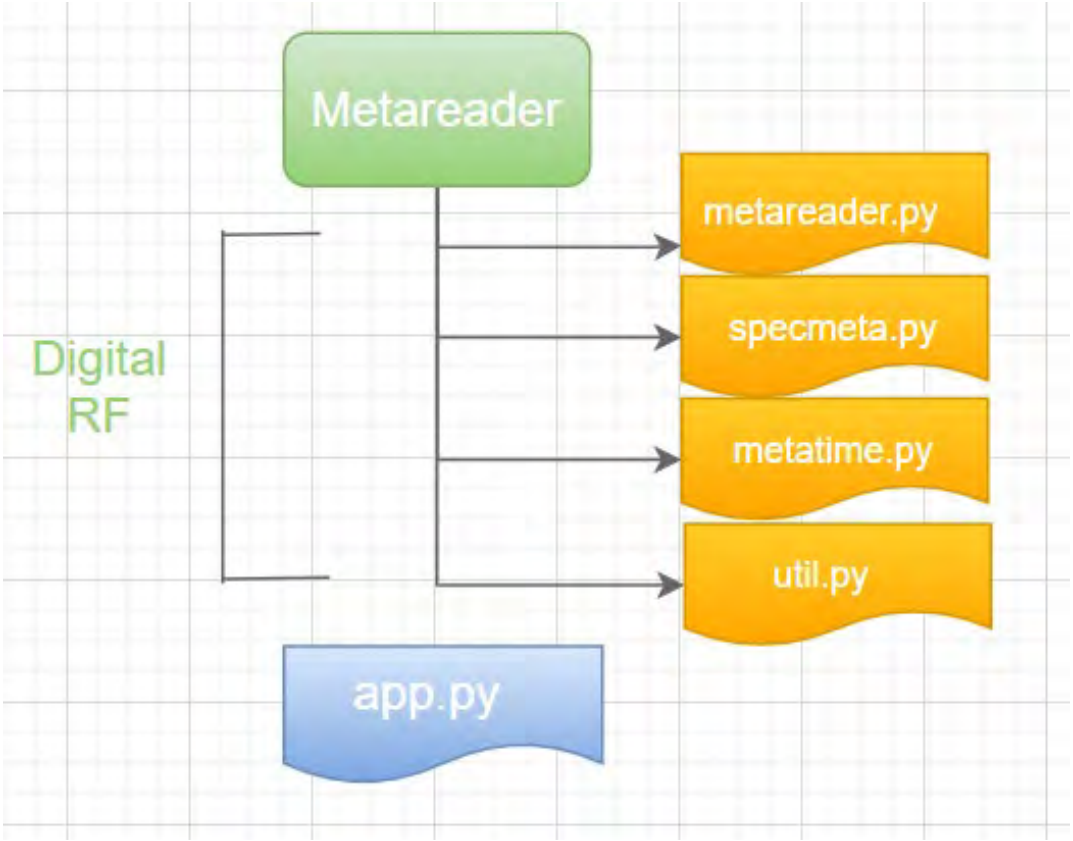
Existing AVIS Display



Goals for Dashboard Version 2.0

- Faster Loading of Data
  - Updating the spectrogram by retrieving and processing the summary data files presents a high computational load
- Display of Telemetry Data
  - Spacecraft speed, location, and altitude
  - Used to provide context for science team
- Generation of Subplots to do computation between channels
- Overall Design Changes to increase visual & user interactibility

File Structure



AVIS Version 1

- Metareader used to read summary data file
- Metatime provides timestamp data
- Specmeta creates spectrogram plot
- Util - creates dash components for the display

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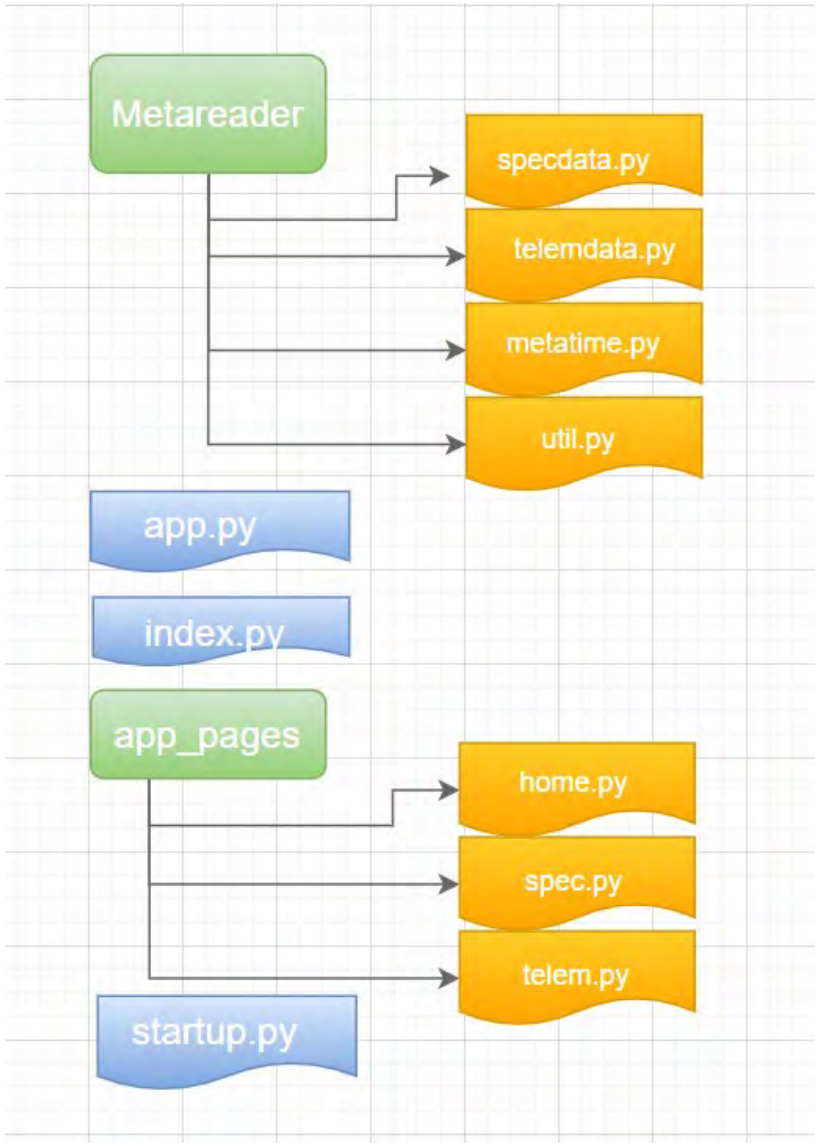
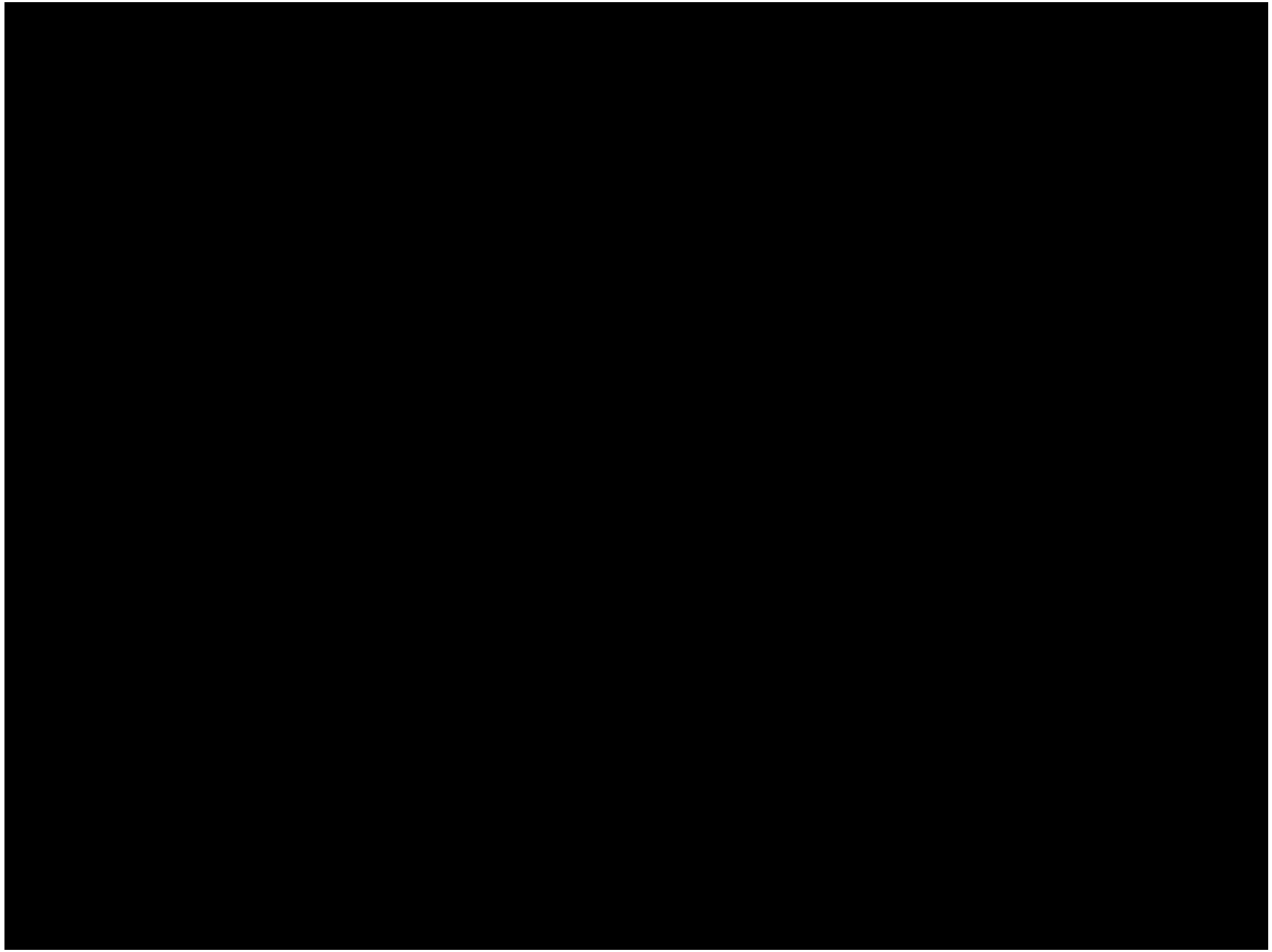
File Structure



AVIS Version 2.0

- Specmeta and Metareader files replaced with Specdata file
- Specdata:
  - used to enter summary data into redis for in-memory storage
- App.py files
  - Split into index.py, app.py, & app pages to accommodate multi-page dash app
  - Easier for future additions

Demo



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Summary of New Layout & Results

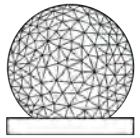
- App.py structure & index.py
  - Allows for easy addition of future improvements
- Redis interface & backend structure
  - Enters all spectrogram and time data into redis
  - Meant for future collaboration between Lucas and Aparna's work
  - Access files in redis and send uplink files into redis
- Speed
  - In memory storage of data did not speed up spectrogram plot generation as desired
  - Data input to redis makes it easier for data to be accessed and exported in the future

Summary of New Layout & Results Cont.

- Telemetry data page
  - Provides a data table of satellite speed, position/ location, & altitude
  - Provides context for science team when analyzing spectrogram data
- Subplots page
  - Continuous regeneration of spectrogram plots to use for computation between different channels (ex. sum(loops), mult(dipoles), division, linear combinations)
  - Used to classify if data is showing electrostatic or electromagnetic phenomena & type of emission

Future Work

- Computation between channels
  - Currently there is subplot generation; computation for channel math needs to be developed
- Improvements on redis structure
  - Data organization in redis and improvements on file access
- Satellite video/ display in home page
  - Future satellite data to be presented on the home page



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Citations

Erickson, et al. “AERO: Auroral Emissions Radio Observer”. *In: Conference on Small Satellites*. Aug. 2018. url: https : / / digitalcommons . usu . edu / smallsat/2018/all2018/453

Knapp, Mary. “AERO-VISTA and Low Frequency Radio Astronomy.” Haystack Observatory, July 2021.

Langford, Drew. (2020). “The AERO-VISTA Interactive Spectrogram Display: An Original Software Solution for Scientific Operations of Twin 6U CubeSats”

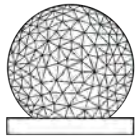
Frank Lind, et al. “AERO & VISTA: Demonstrating HF Radio Interferometry with Vector Sensors”. In: *Small Satellite Conference, Upcoming Missions, SSC19-WKV-09*. Aug.2019.

Volz, R., Rideout, W. C., Swoboda, J., Vierinen, J. P., & Lind, F. D. (2021). Digital RF (Version 2.6.6). MIT Haystack Observatory. Retrieved from https://github.com/MITHaystack/digital_rf

Zell, Holly. “Aurora Video GALLERY.” *NASA*, NASA, 10 Apr. 2015, www.nasa.gov/mission_pages/sunearth/aurora-videos/index.html.

Satellite Commanding API

Aparna Rajesh



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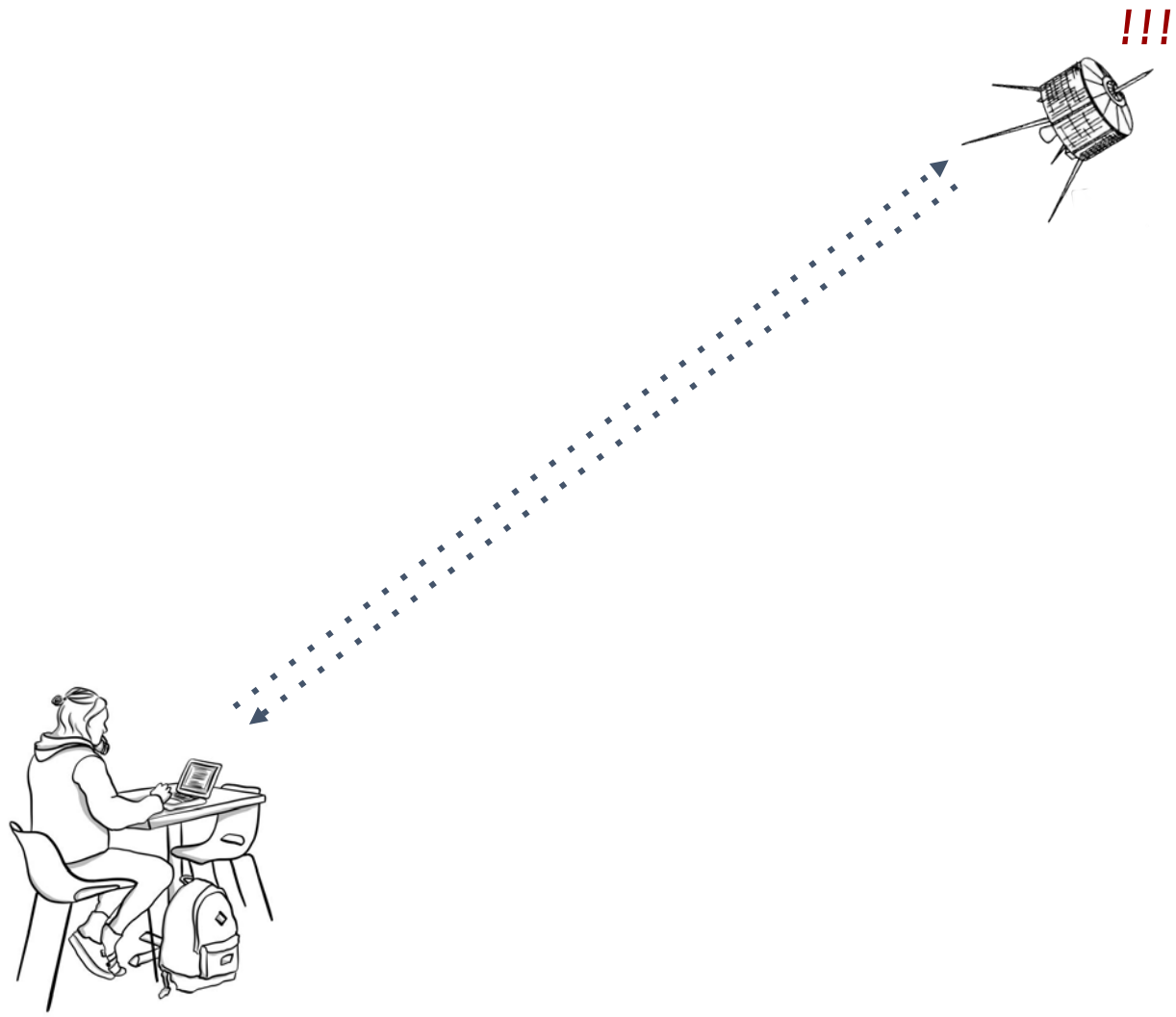
Commanding?

- Once in orbit, satellites must maintain a connection with ground systems
- Example tasks:
  - Ping
  - File transfer
  - Data collection
- Commands are sent up via the uplink & a response is sent back via the downlink



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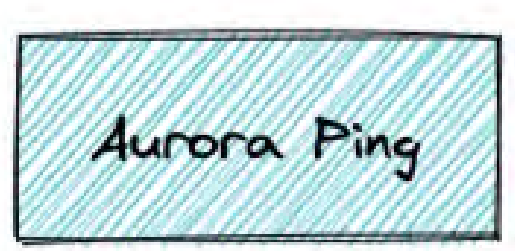
satellite image: https://www.onlygfx.com/wp-content/uploads/2020/05/satellite-drawing-cover.jpg
person at desk image: https://media.istockphoto.com/vectors/thinking-and-typing-vector-id1154317230?k=6&m=1154317230&s=612x612&w=0&h=oVOhCOu4lYlmDjyJNfZIE1V7-giVsVADc7jRJNC_jhg=

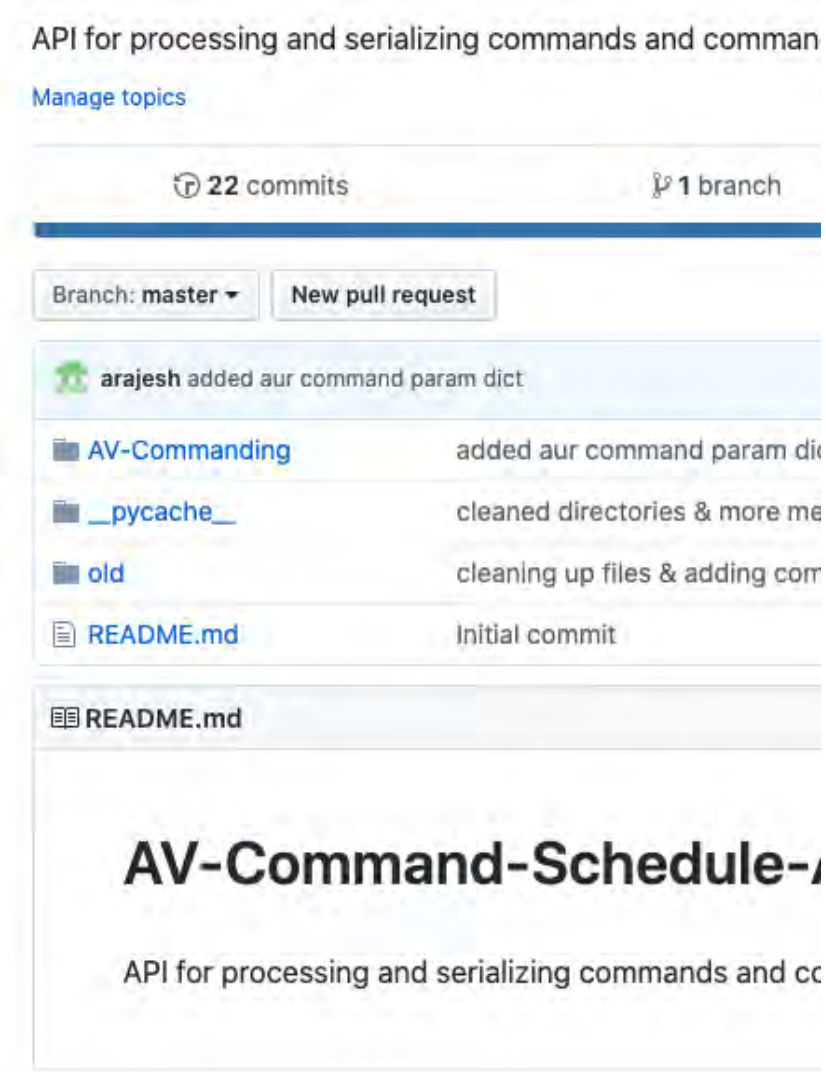
Goals

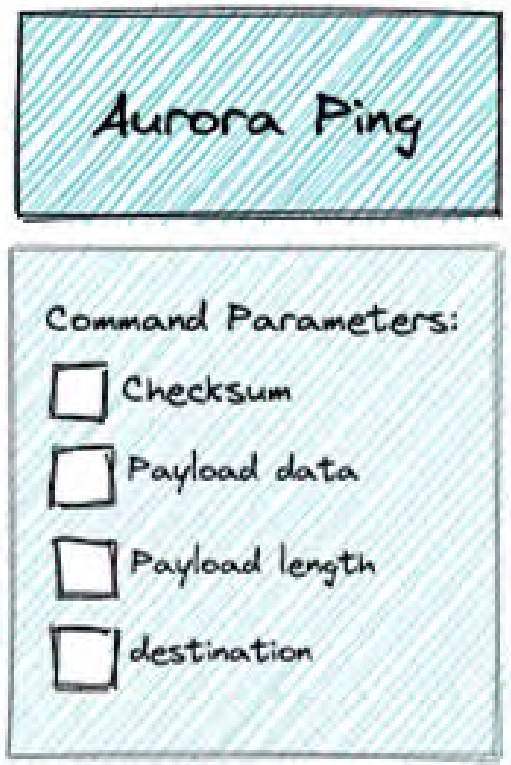
- Develop an API (Application Programming Interface, an intermediary software that takes data from a different software and then sends it to another API or program) that will:
  - neatly package command data and metadata
  - serialize all the information pertaining to a command or command schedule in a predetermined format
    - human readable format
    - hex format for the spacecraft
  - pass this byte stream to another program



AV-Command-Schedule-API

- The AV-Command-Schedule-API:
  - creates a command object with using instance-specific parameters and other data stored in config files
  - establishes a command “connection” using a connection modifier
    - *where will this command be sent?*
  - generates a human-readable component of the command object
  - generates a hex stream that is to be read by the spacecraft






```
test = Connection(ping_aurora(5, 4, 2, 1, 0), "aurora_payload_computer")
```

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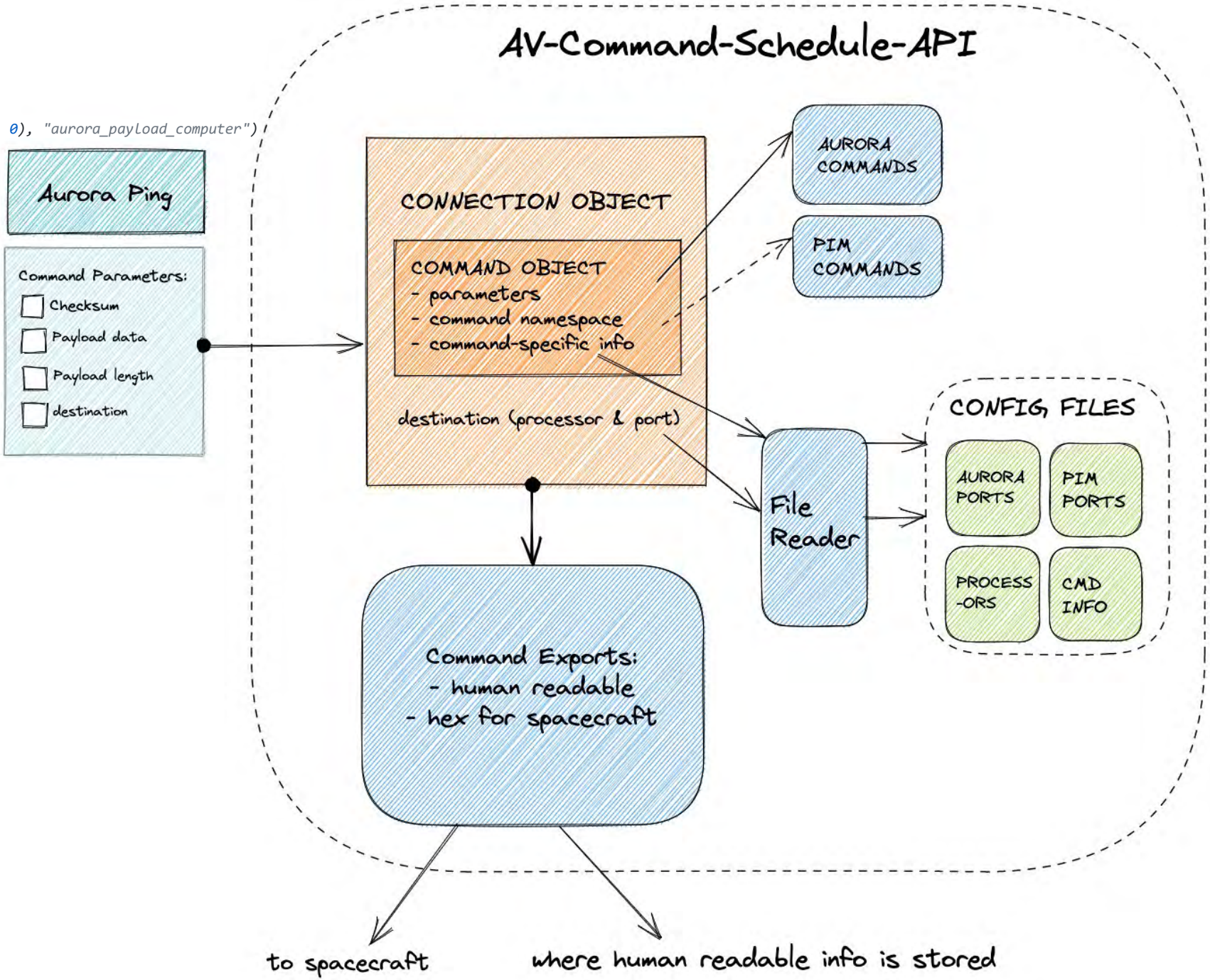
```
test = Connection(ping_aurora(5, 4, 2, 1, 0), "aurora_payload_computer")
```

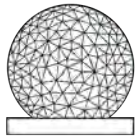


Next Steps

- Command schedules
- Hex headers
- Command dictionary parameter data types
- Config files

Ground Station Radio Communications

T. Lucas Briggs



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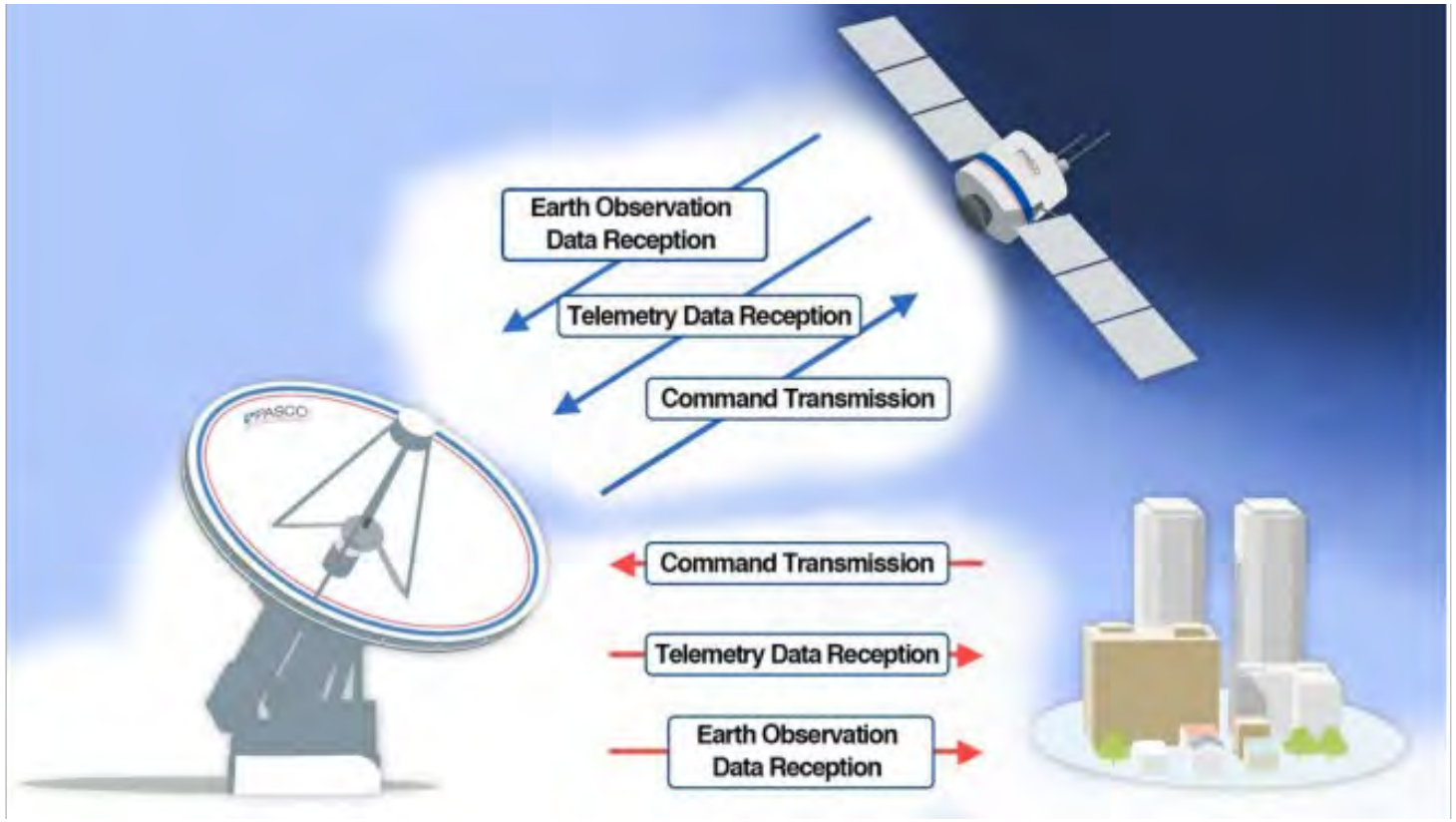
What is a Ground Station?

- Enables communication between spacecraft and mission operations

- Handles all radio operation, command scheduling, and data verification tasks



Source: https://www.gim-international.com/content/news/pasco-provides-rental-service-for-satellite-ground-station-facilities

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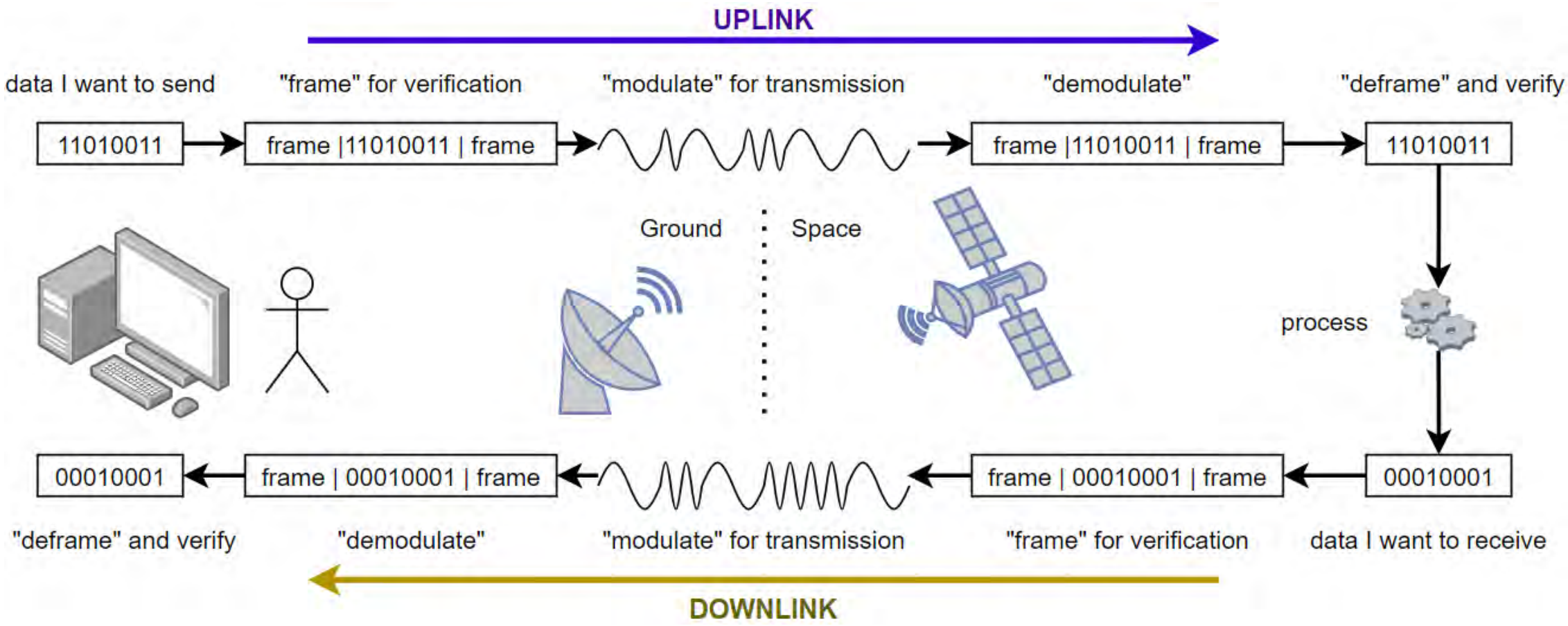
For AERO / VISTA

- Multiple possible Ground Stations in different locations with a wide range of radio configurations
- Many different types of data with varying sizes of payload
  - Commands: small, carries data necessary for spacecraft to execute desired action.
  - Acknowledgements: very small, carries data necessary to say “command received”
  - Telemetry: large, carries as much information as possible about spacecraft state
  - Science: very large, carries a full time-series of spectrum data from auroral emissions

Digital Communications over Radio



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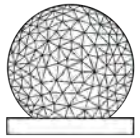
Summary of Requirements

Need a software package that...

- Enables framing/deframing and mod./demod. on uplink/downlink.
- Allows for a wide range of data payload lengths.
- “Drops in”. Can be imported, started, and maintained anywhere.
- Provides a way to access data remotely and asynchronously.
- Is as configurable as possible
- Is as extendable as possible



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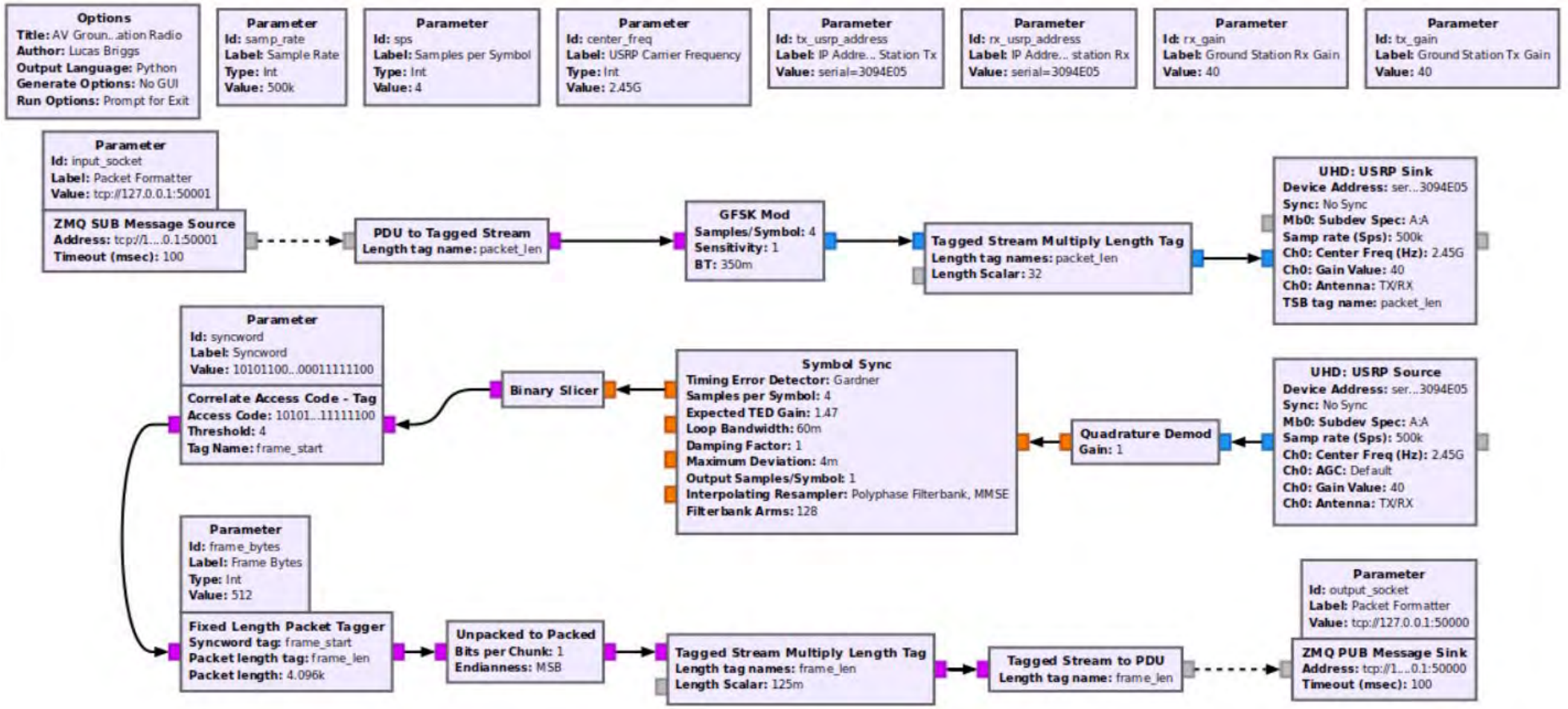
Implementation - GNURadio Flowgraph



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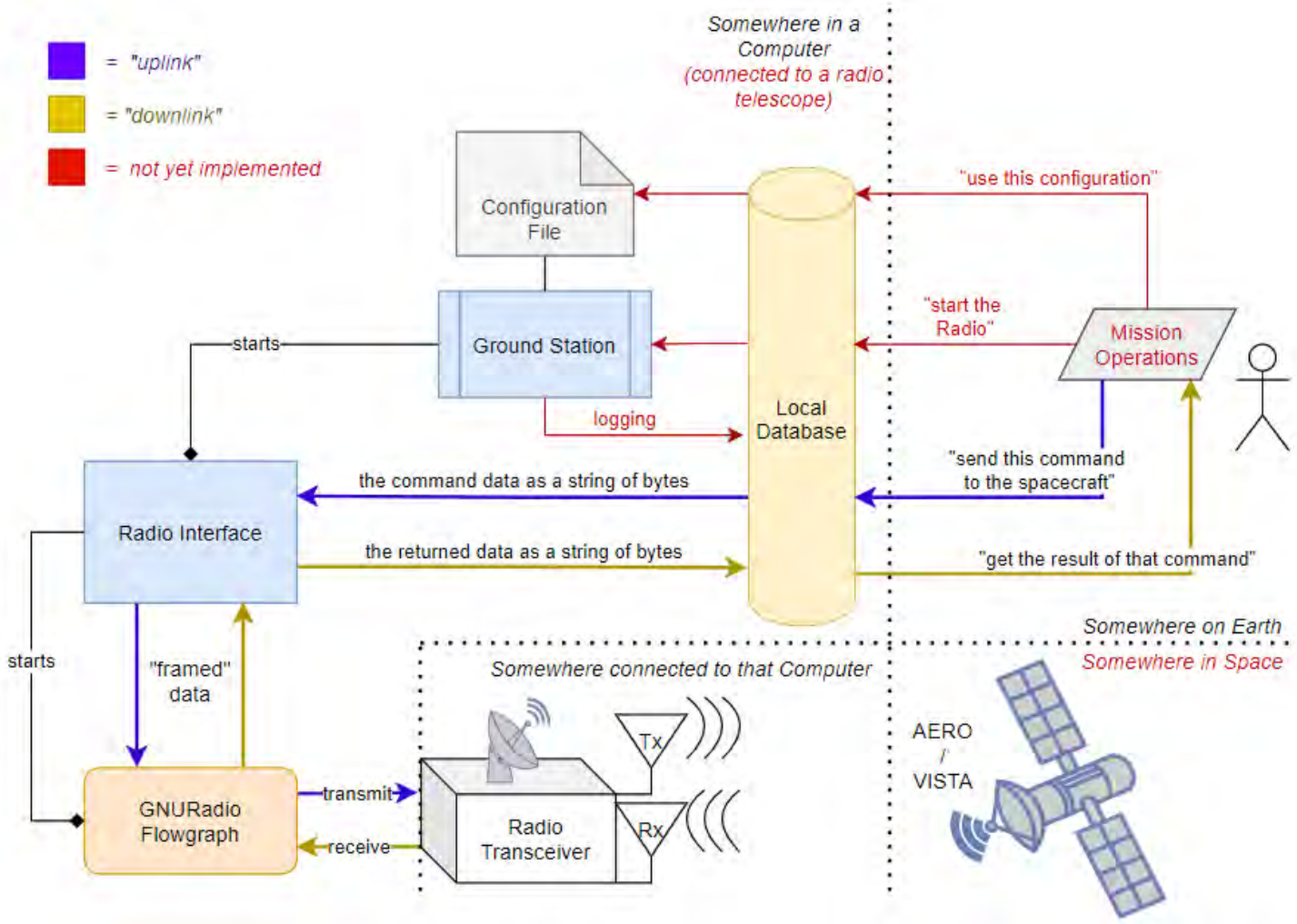
Implementation - Software (simplified)

- Database provides asynchronous remote access.
- Ground Station provides configuration, handles top-level operation.
- Radio Interface manages framing/deframing data, uplinking/downlinking frames.
- Flowgraph operates the Radio Transceiver.



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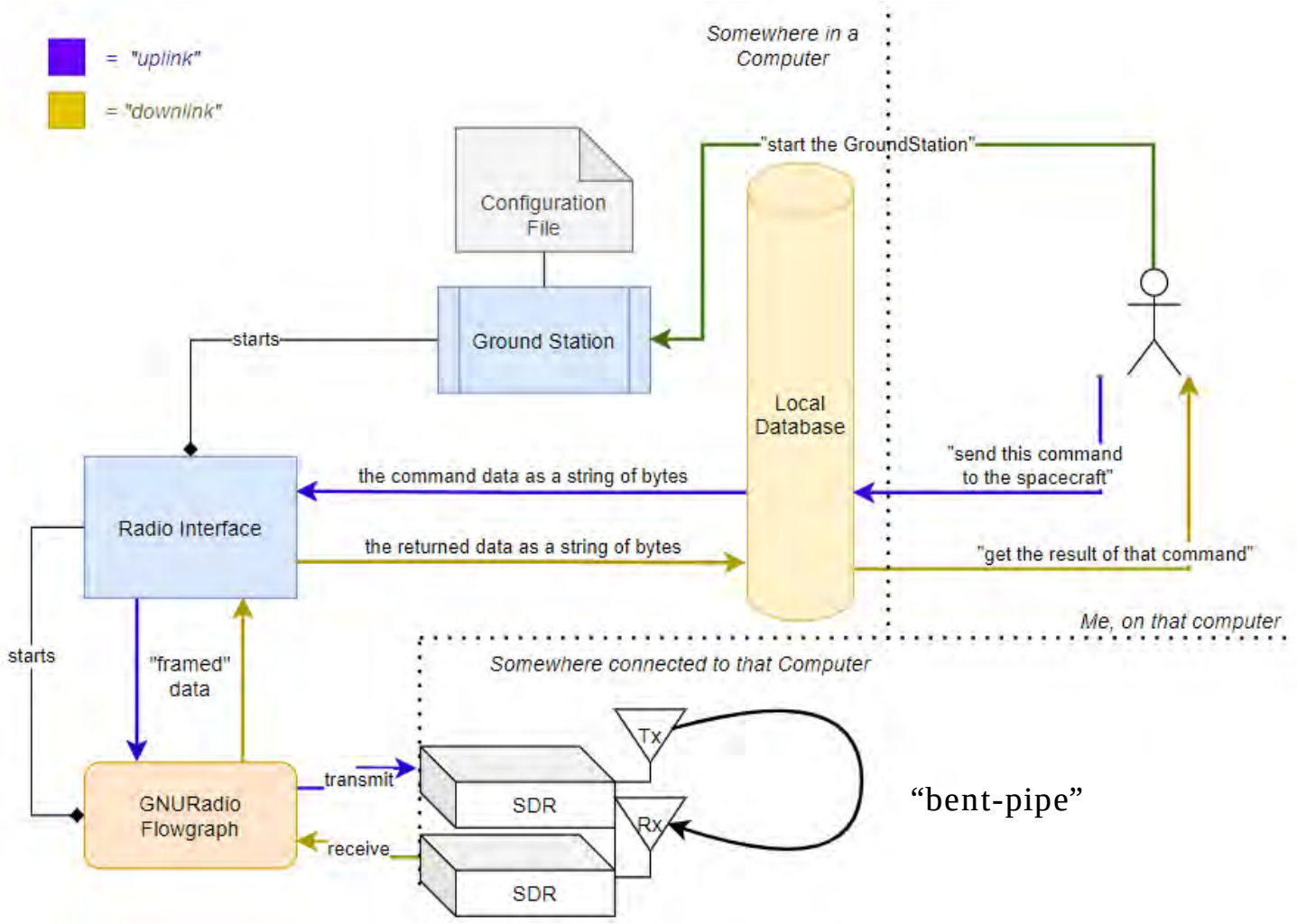

"bent-pipe"

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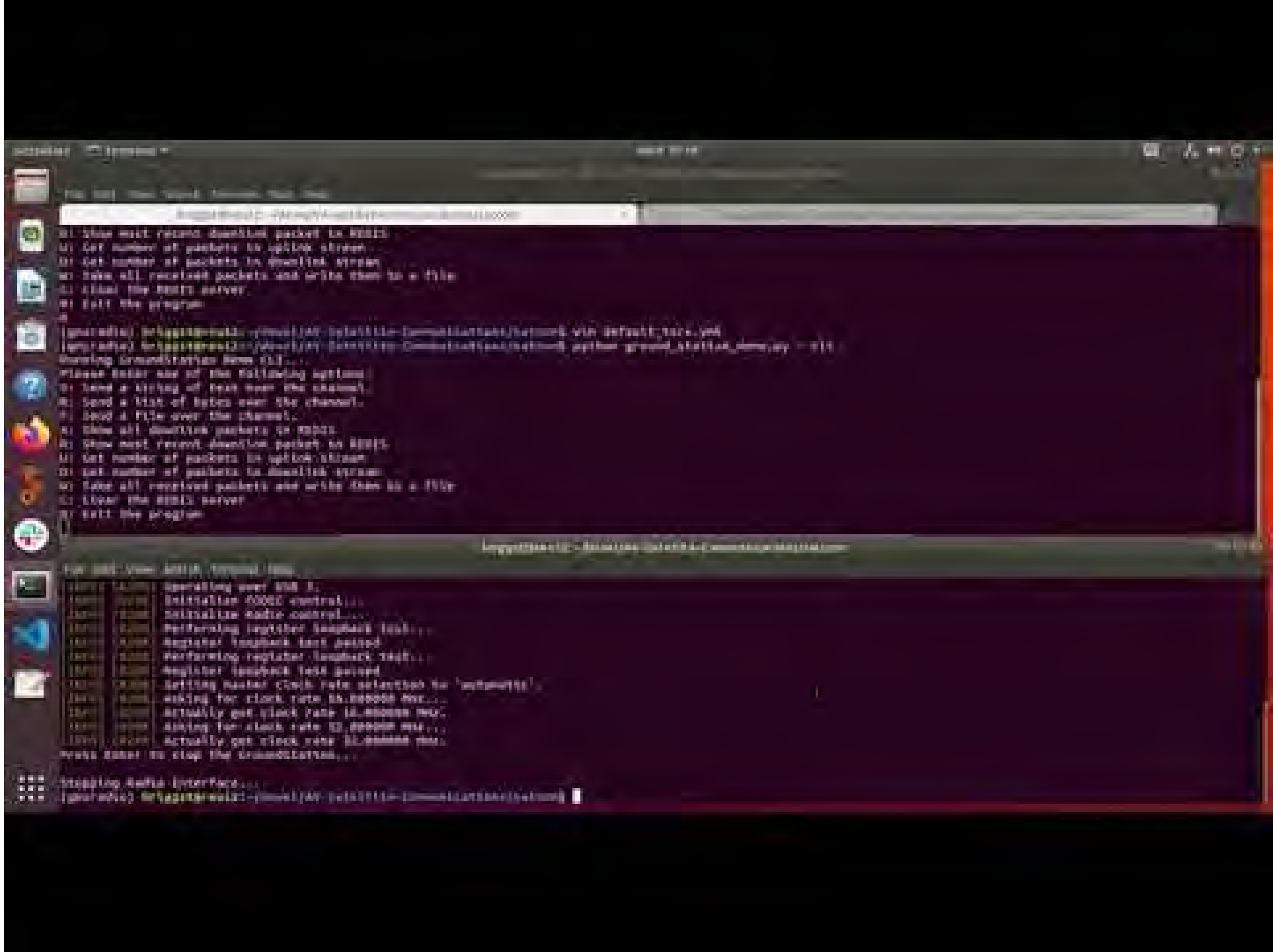
Live Demo - PNG File Transfer



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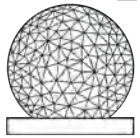
Next Steps

- Interaction of the Ground Station with the Database needs to be expanded
  - Operation commands, logging, configuration, and satellite command scheduling, all remote-asynchronous
- GNURadio Flowgraph needs to be expanded
  - More/better signal processing for higher SNR (configurable)
- Develop a “mock satellite” version of the Ground Station
  - Responds to known commands with dummy data
  - Potentially applies a channel model to the signal to test non-ideal conditions
- Integrate with a real transceiver and satellite engineering model



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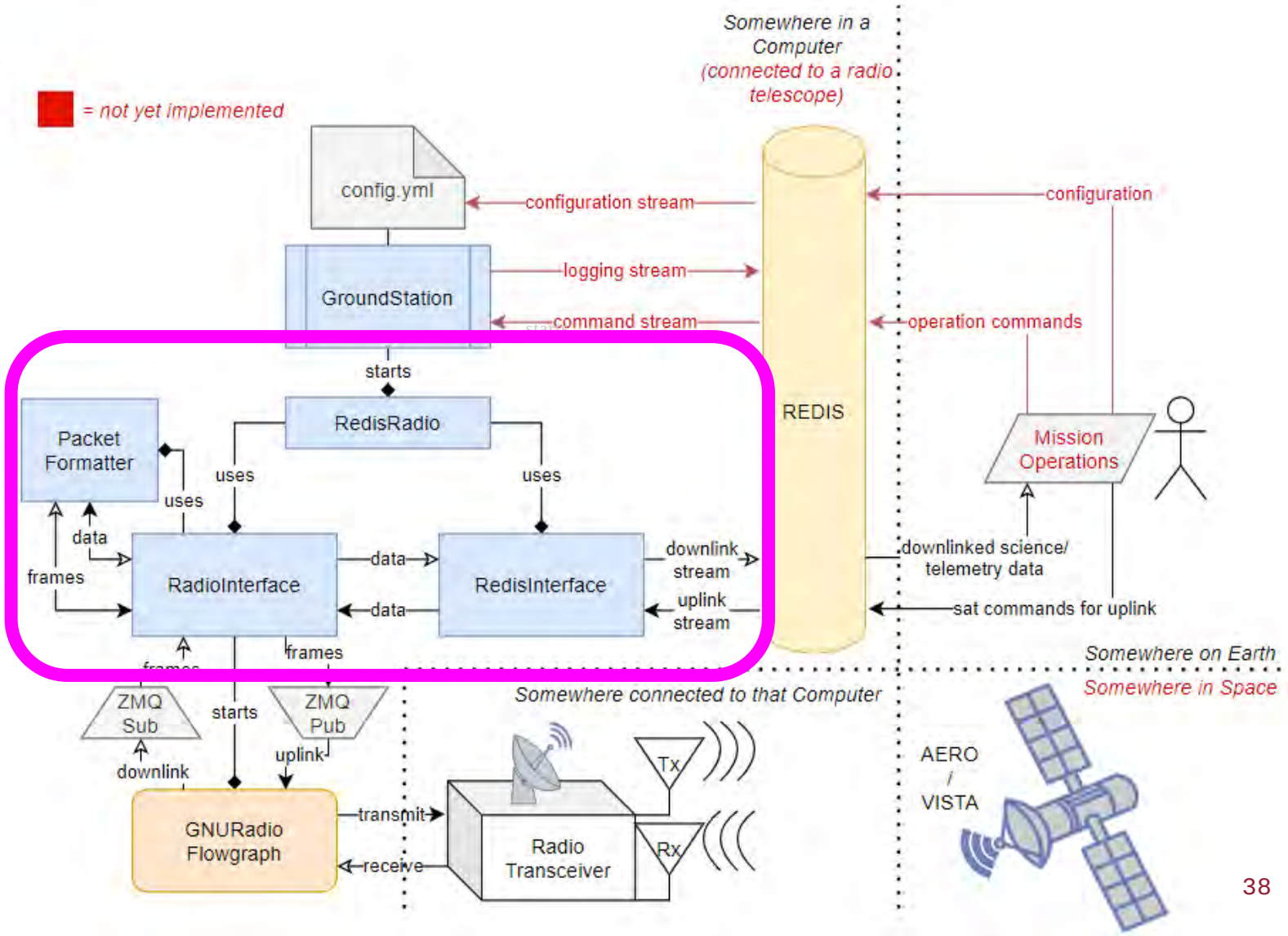
backup

Implementation - Software (expanded)

- Radio Interface exists as 3 important blocks
- Each has a single responsibility, promotes extendability
- See report for more details



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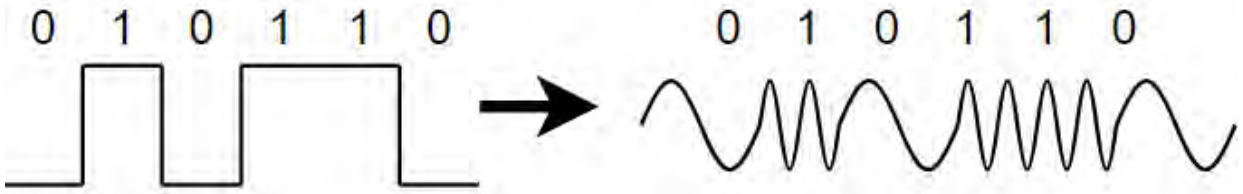
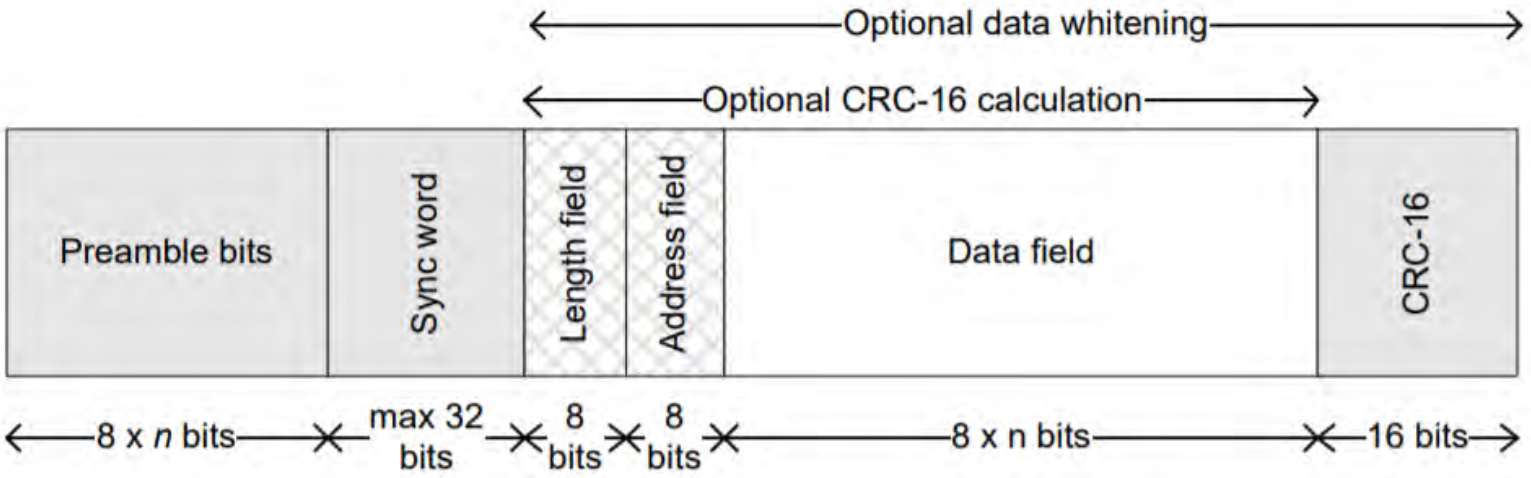
Modulation and Framing for A/V

- Modulation using Gaussian Frequency Shift Keying (GFSK)
  - Looks a bit like this:



- Flexible data framing with the following template:



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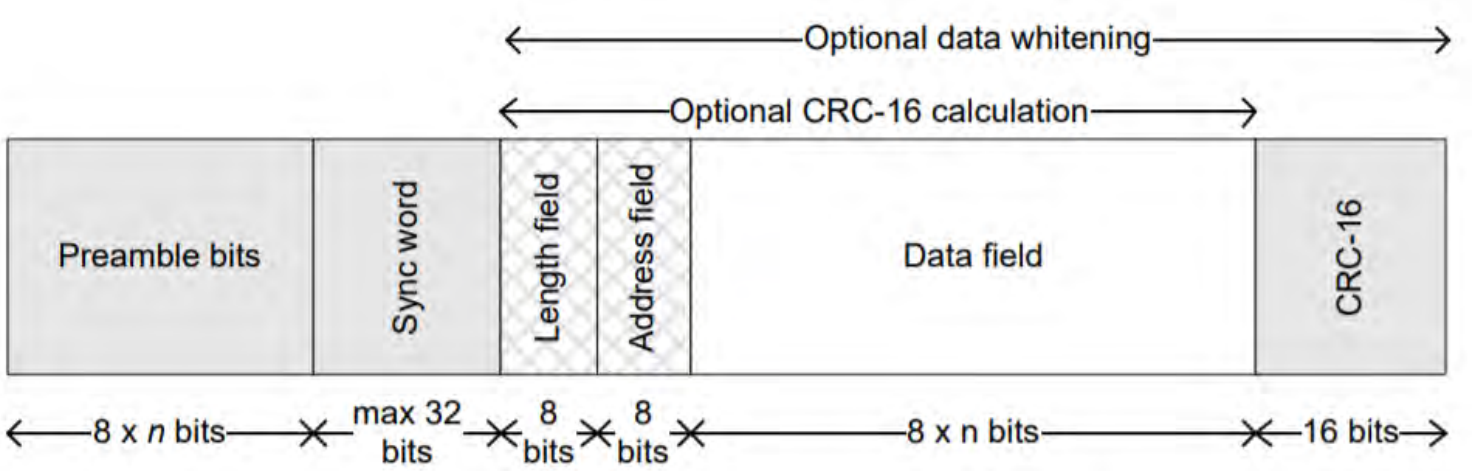
Reliable Data Transfer: Framing

- Preamble: recognize symbols, “lock on” to binary data
- Syncword: find the start of the data packet
- Length: how many bytes to expect in the data
- Address: where should this data go



- CRC (Cyclical Redundancy Check): Verify that the data has not changed
- Whitening: Deterministically randomize the data

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Configuration Through YAML Files

Configurable parameters are categorized into “packet”, “radio”, and “redis” groupings

default_txrx.yml M

AV-Satellite-Communications > satcom > default_txrx.yml

```yaml
packet:
  formatter: "default"
  preamble: "1010010011110010" # ""
  syncword: "10101100110111011010010011100010111100101000110000100000011111100"
  whiten: True
  whitener_offset: 0
  crc: True

radio:
  center_frequency: 2450000000
  sample_rate: 500000
  samples_per_symbol: 4
  rx_gain: 40.0
  tx_gain: 40.0
  # These addresses can be the same (sat-in-the-loop test)
  rx_usrp_address: "serial=3094DF7"
  tx_usrp_address: "serial=3094E05"
  # These addresses must be different
  rx_socket_address: "tcp://127.0.0.1:50000"
  tx_socket_address: "tcp://127.0.0.1:50001"
  receive_waits_s: [0.1, 1, 3, 5]
  max_payload_bytes: 512

redis:
  host: "localhost"
  port: 6379
  db: 0
  pkt_uplink_stream_name: "pkt-uplink"
  pkt_downlink_stream_name: "pkt-downlink"
  clear_on_start: True
```

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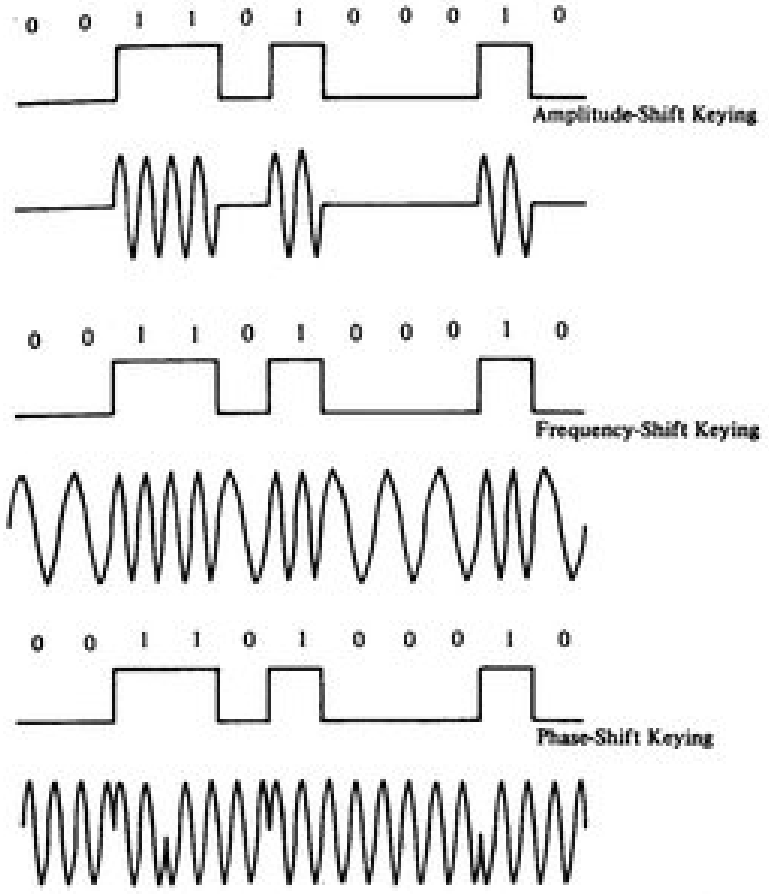
Digital Communications: Modulation

- Binary data representation on a “constant wave”, accomplished through **keying**
  - Amplitude-Shift Keying (ASK)
  - Frequency-Shift Keying (FSK)
  - Phase-Shift Keying (PSK)
  - ...many more
- Our solution: Gaussian FSK (GFSK)
  - FSK with no sudden jumps



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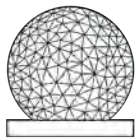
Final Group Demo



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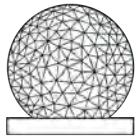
Thank you to our mentors

Mary Knapp, Ryan Volz, John Swoboda, Frank Lind, Phil Erickson, Toby Gedenk, and Geoff Crew



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