

# Using Allen Telescope Array Data on GNU Radio

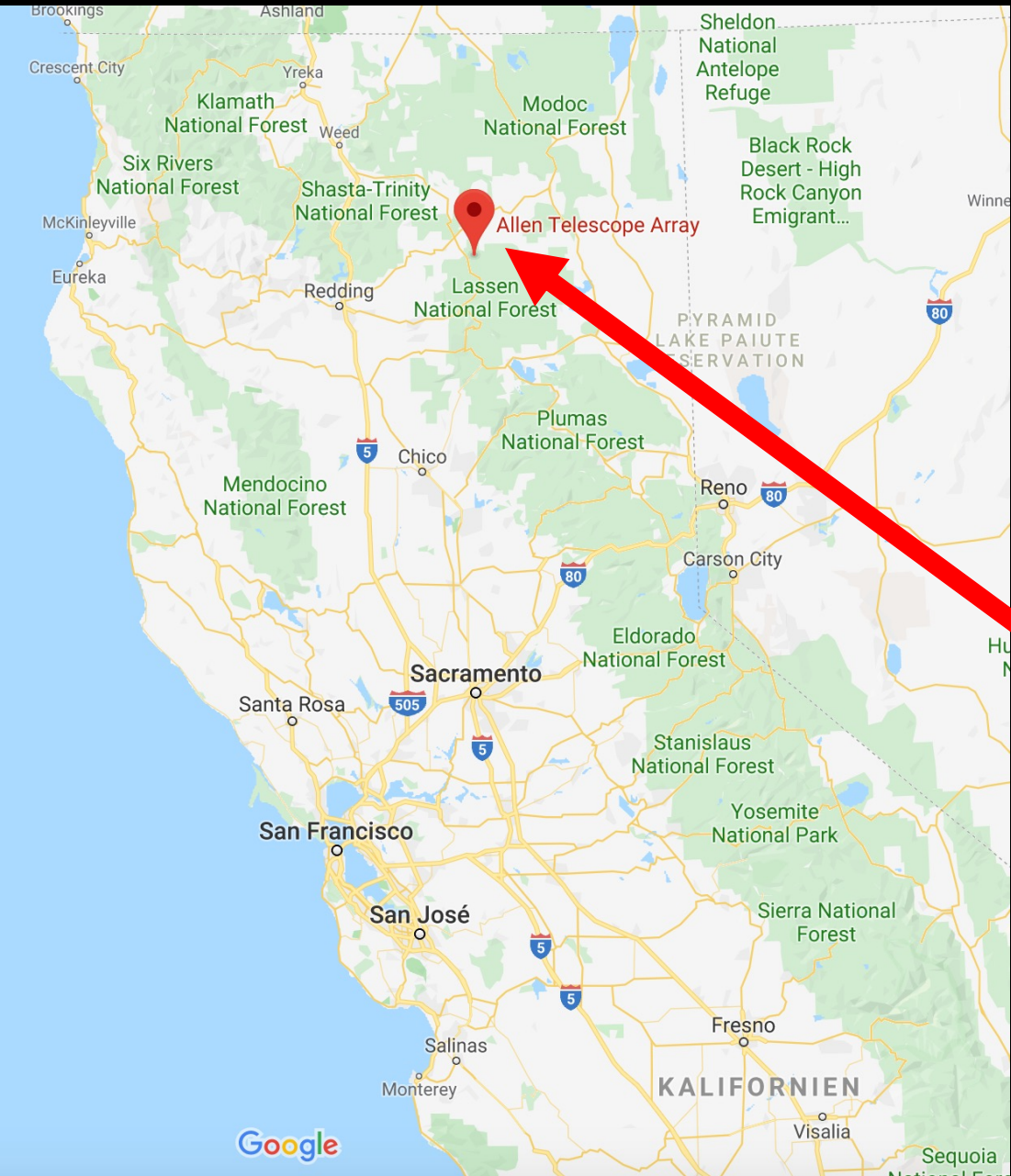


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S. Lang  
J. Kim  
G. Singh





# The Hat Creek Radio Observatory





# History of HCRO & ATA

- 1958: Hat Creek Radio Observatory was founded
- ~1962-2004: Multiple different radio telescopes pass through site
- ~2002 - 2007: Construction of ATA
- 2019: Beginning of the 3-year feed refurbishment program**



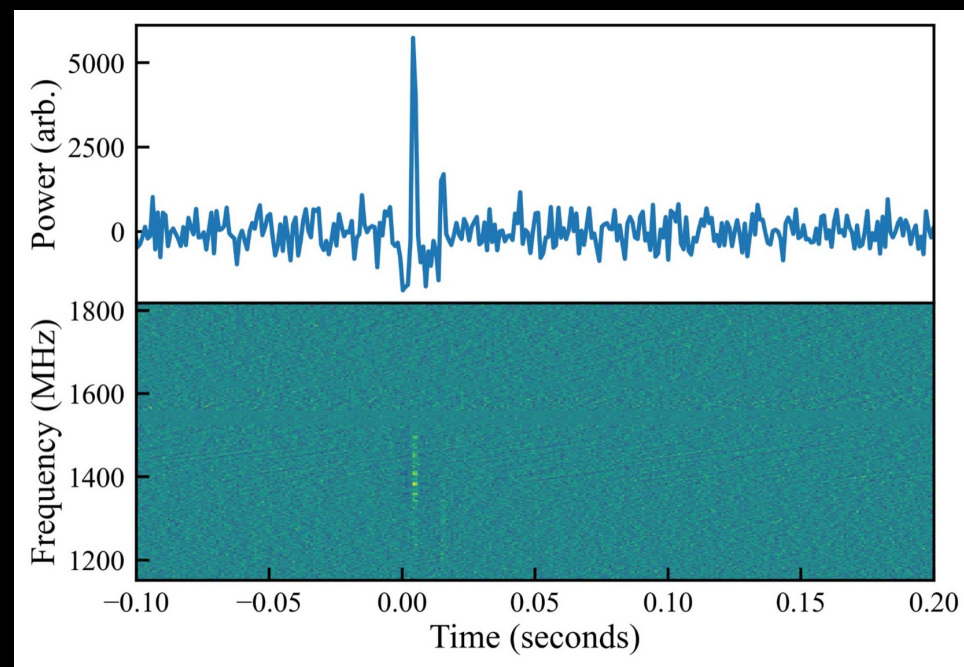
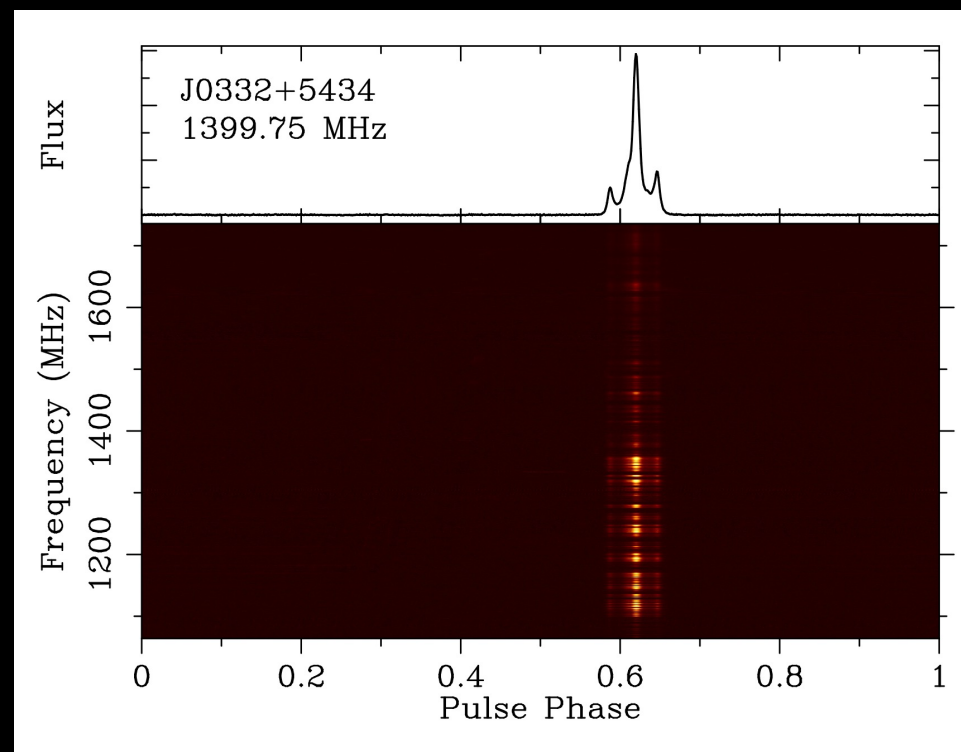
Image Credit: Colby Gutierrez-Kraybill





# Use Cases

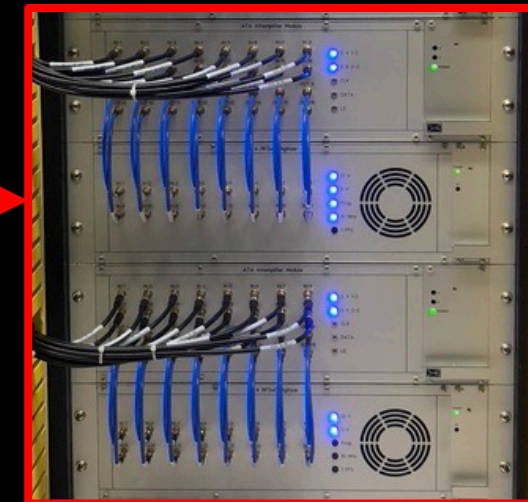
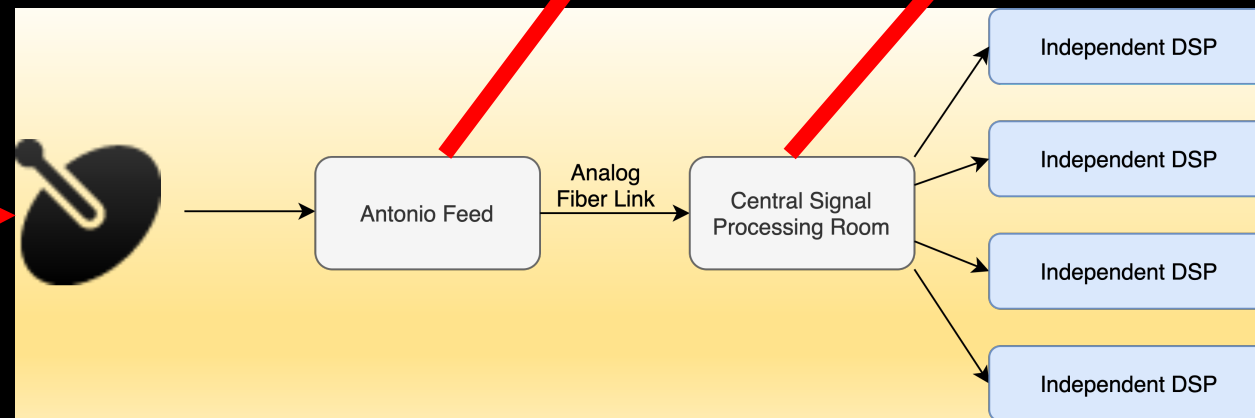
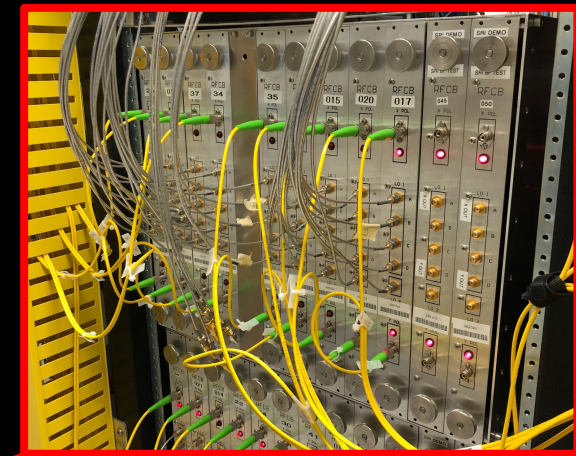
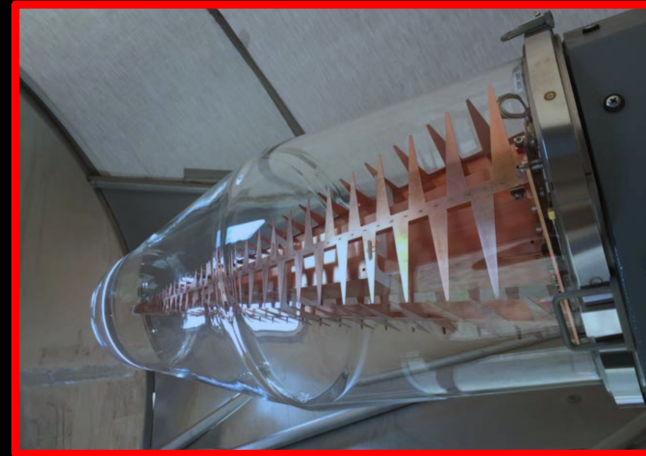
- Pulsars
- Fast Radio Bursts
- SETI Research





# The Allen Telescope Array

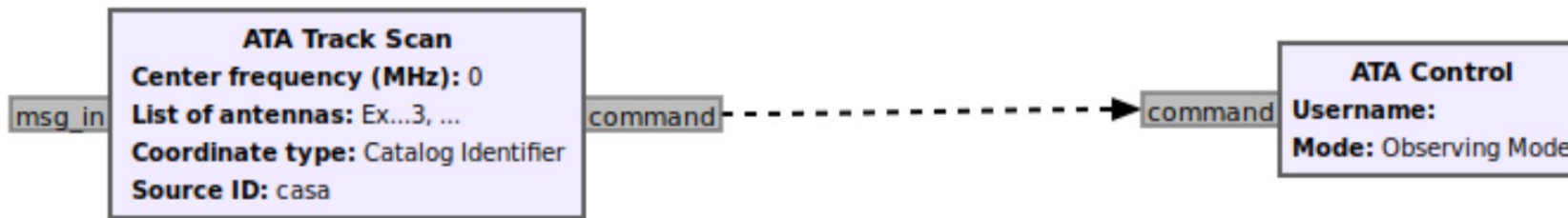
- **Antennas:** 42x 6.1m offset Gregorian  
1 - 11.2GHz bandwidth
- **ATA Signal Path:** Analog RF over fiber link into the central signal processing room
- **Signal Processing Room:** 4 independent tunings with 700MHz each
- **Digital Signal Processing:** Currently three DSP systems deployed. SNAPs, GNU Radio USRPs, and **RFSocCs**





# GNU Radio at the ATA today

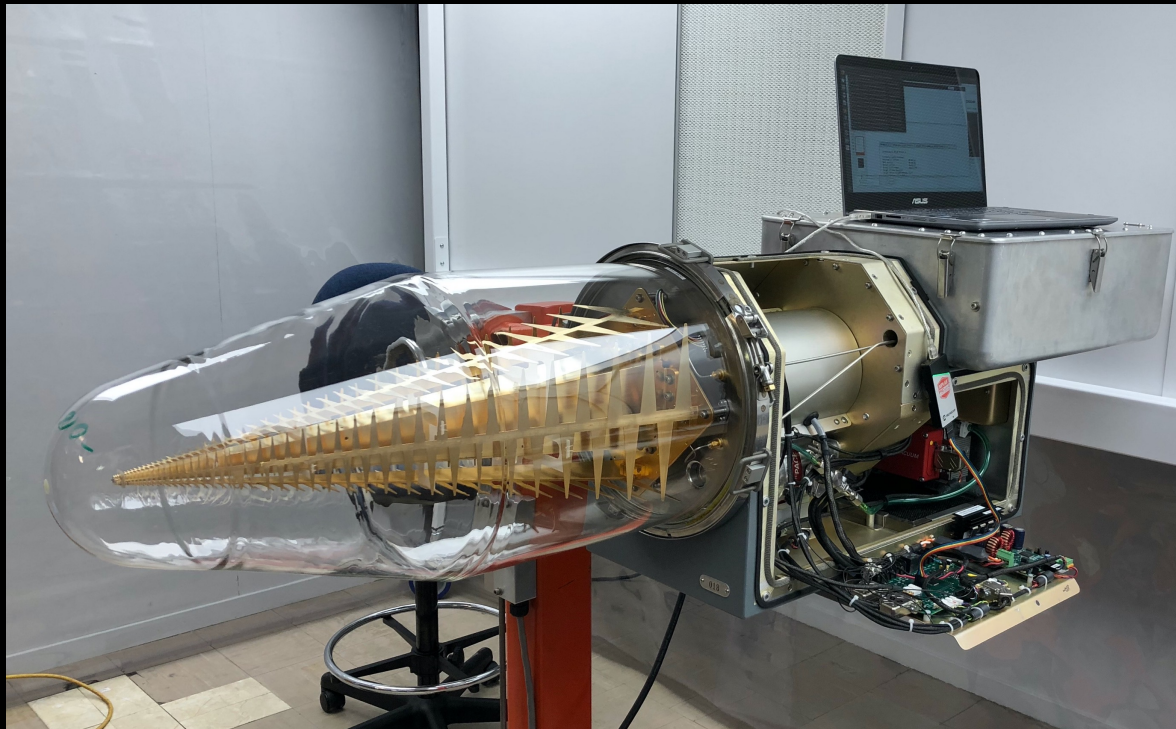
- **GR-ATA:** Control the antennas in GNU Radio Companion
- **2x USRP N320/N321:** 200 MHz of bandwidth with two antennas
- **gnuradio1 server:** Processing of collected data





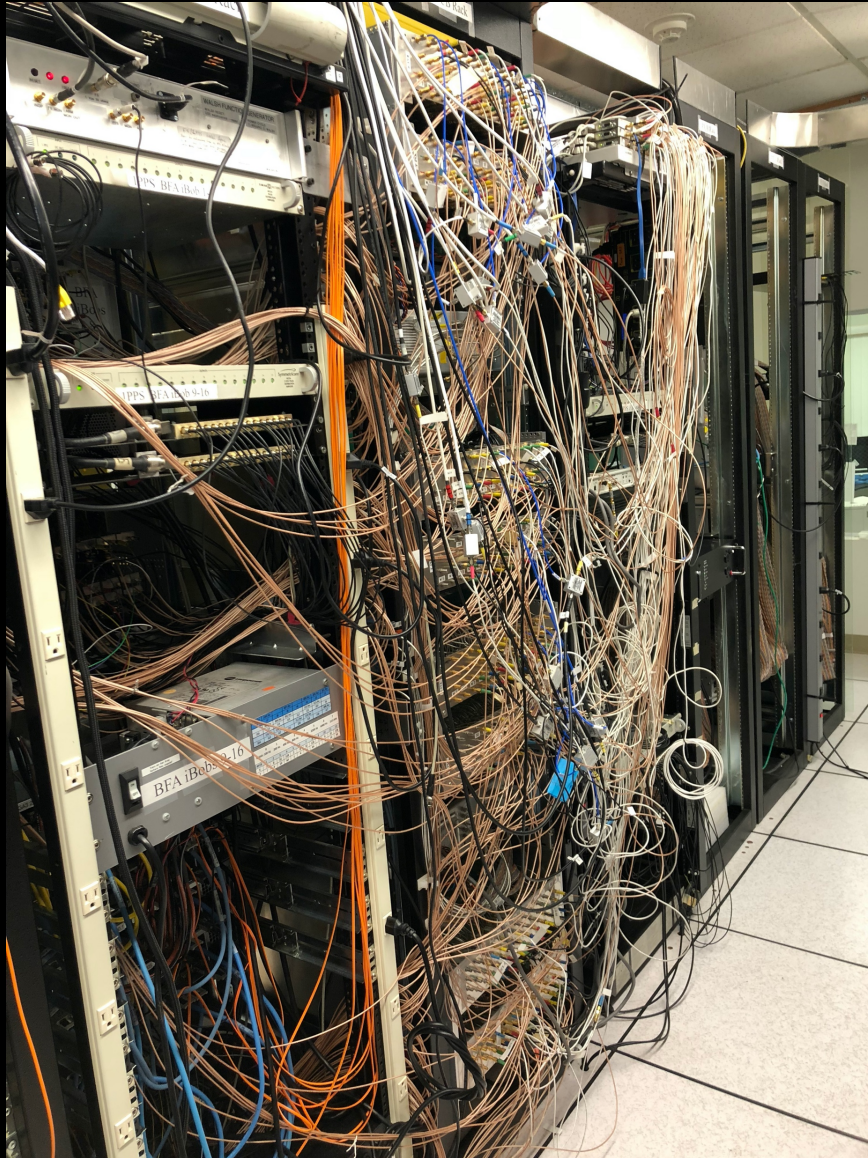
# Summary of Refurbishments

- 21 existing feeds refurbished and operational (cryogenically cooled)
- 4 original feeds in operation (non-cryogenically cooled)
- 30 feeds by the end of this year are planned





# Signal Processing Room



Before

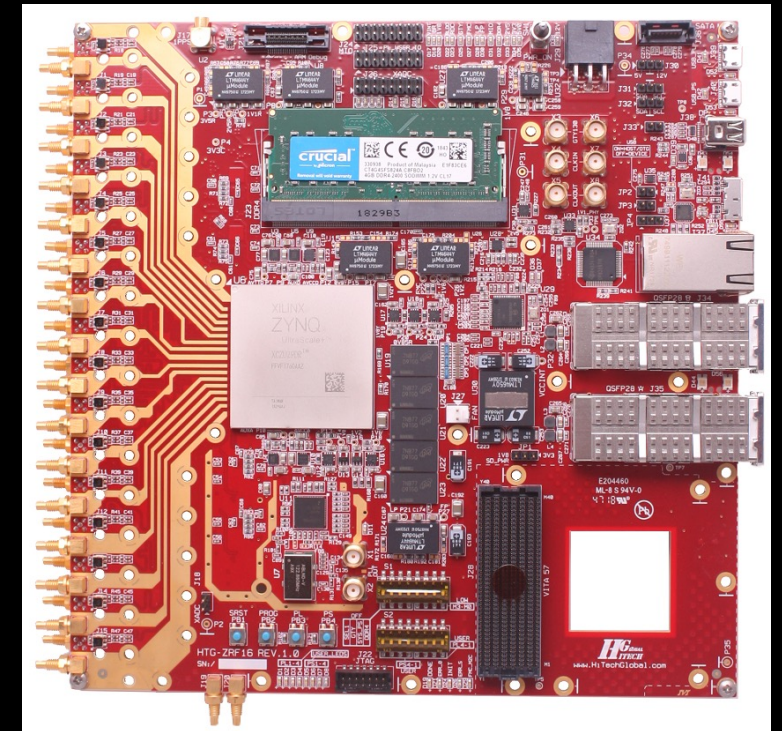
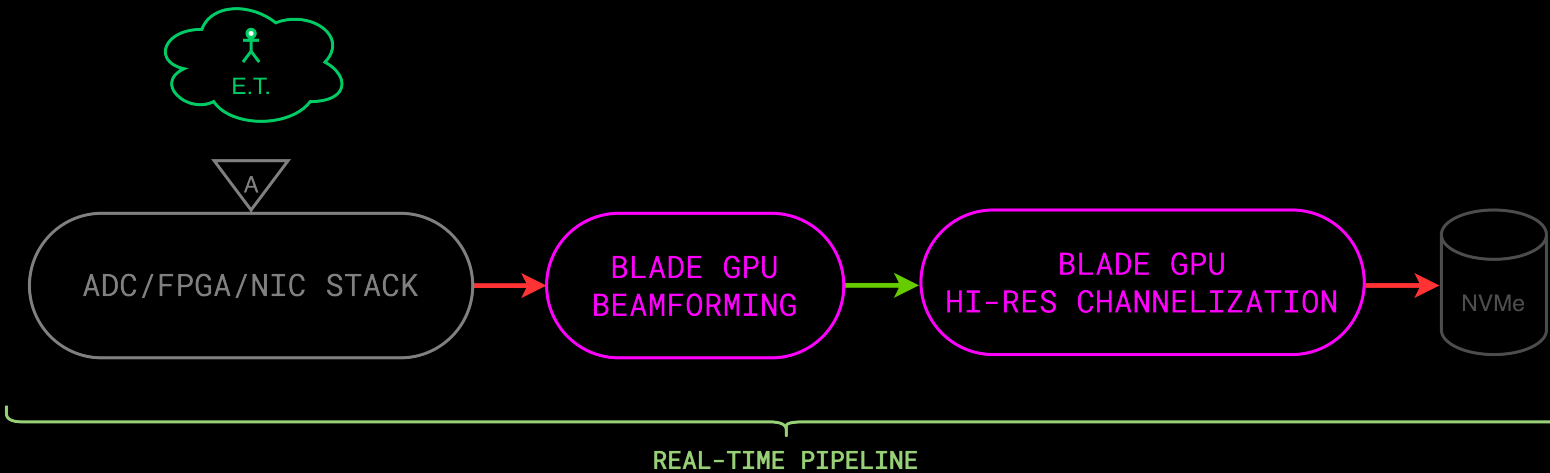
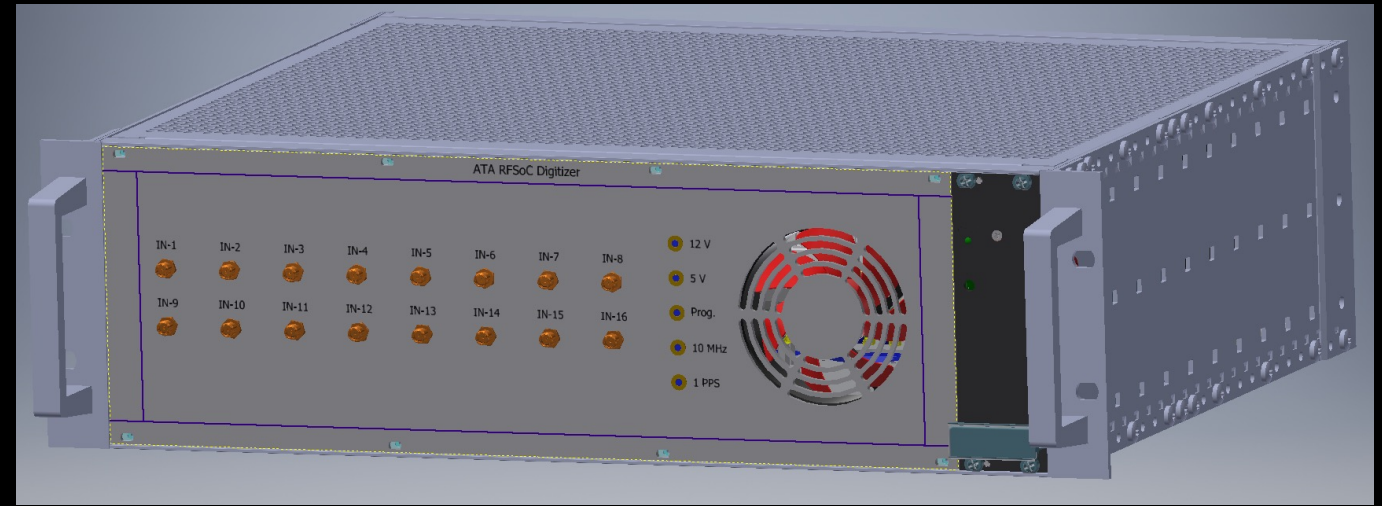


After



# The Telescope's New Backend

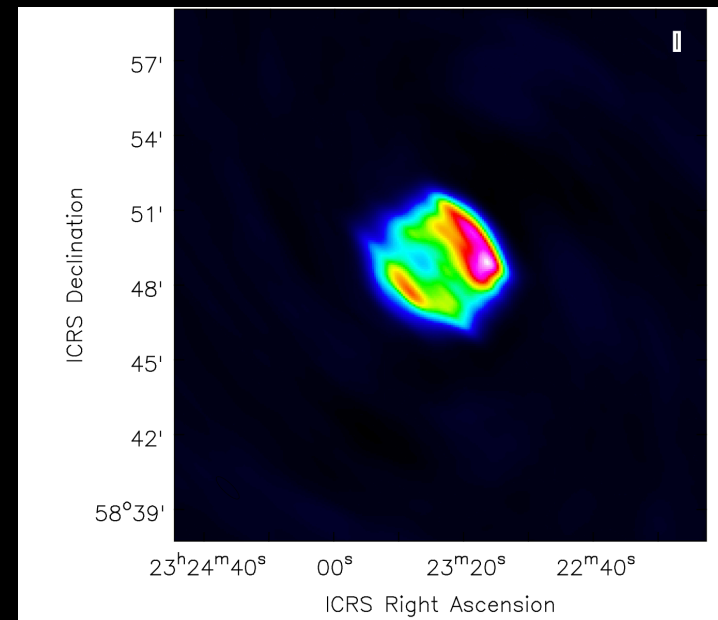
- RFSoc Multi Mode Digital Backend
- Supported operations:
  - Correlation
  - Baseband capture
  - Beamforming
  - ...



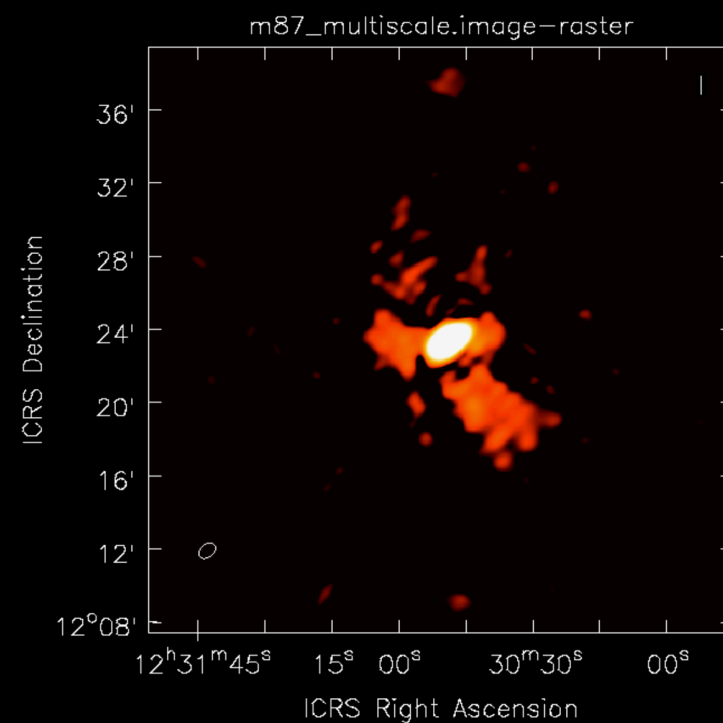


# Correlator

- **N\_ants:** 20 antennas (210 baselines)
- **Integration lengths:** 8ms - X mins
- **Backend:** xGPU-based pipeline.
- **Visibilities:** uvh5 output file format
- **Calibration:**  
Current use of correlator is phase/  
bandpass calibrating of beamformer  
+ tests of delay engine.



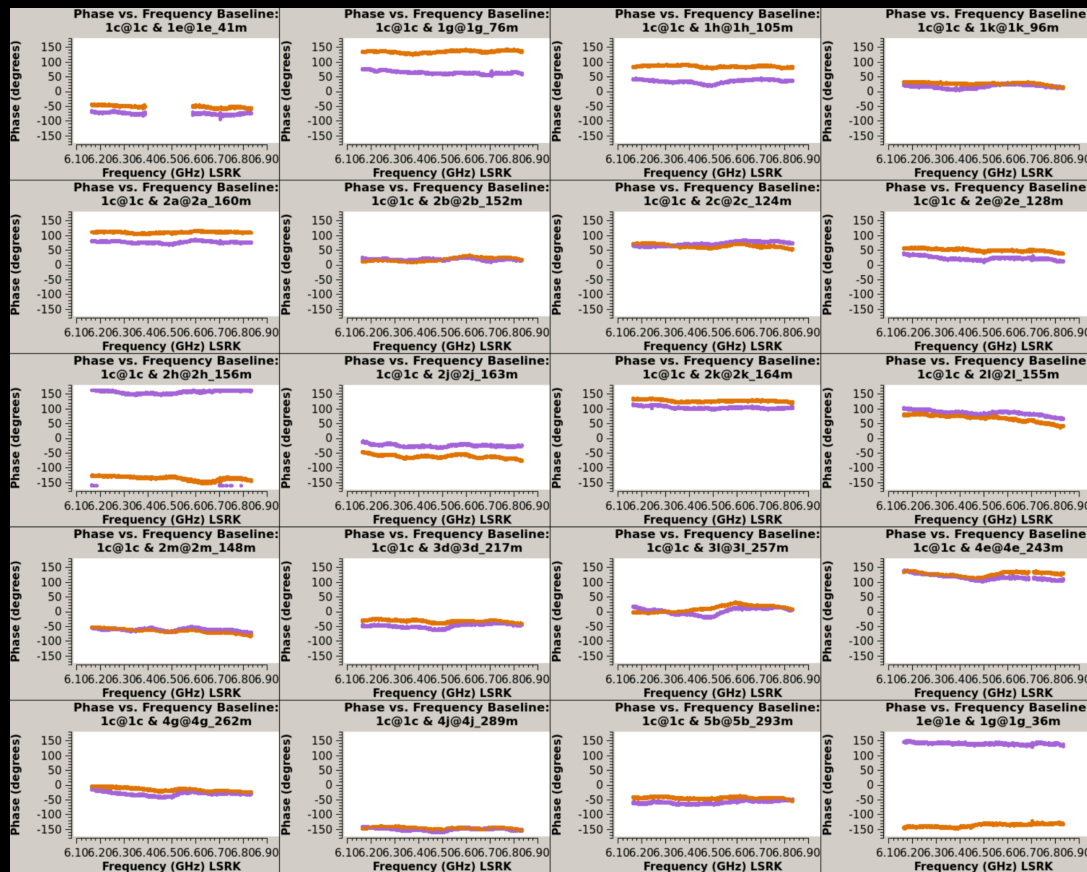
CasA  
8GHz



M87



# Correlator + beamformer calibration

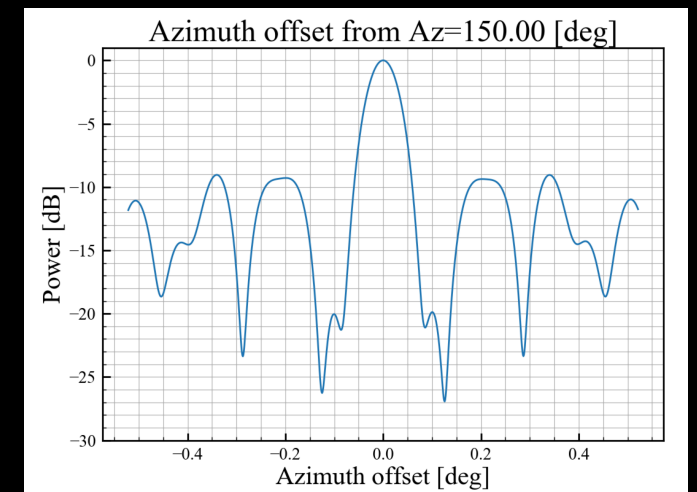
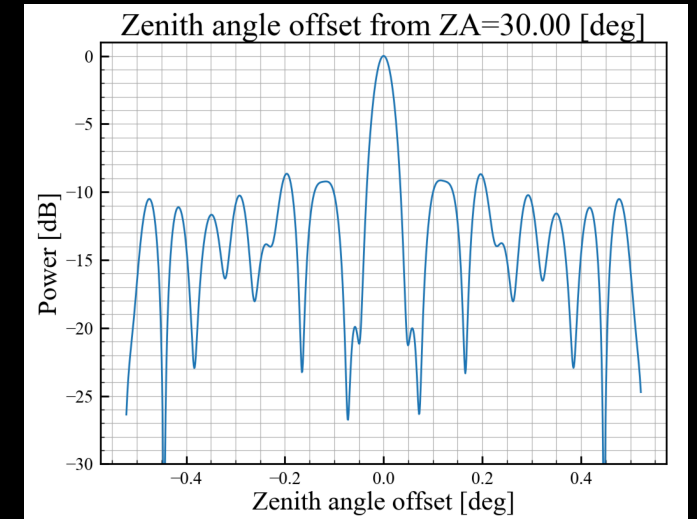
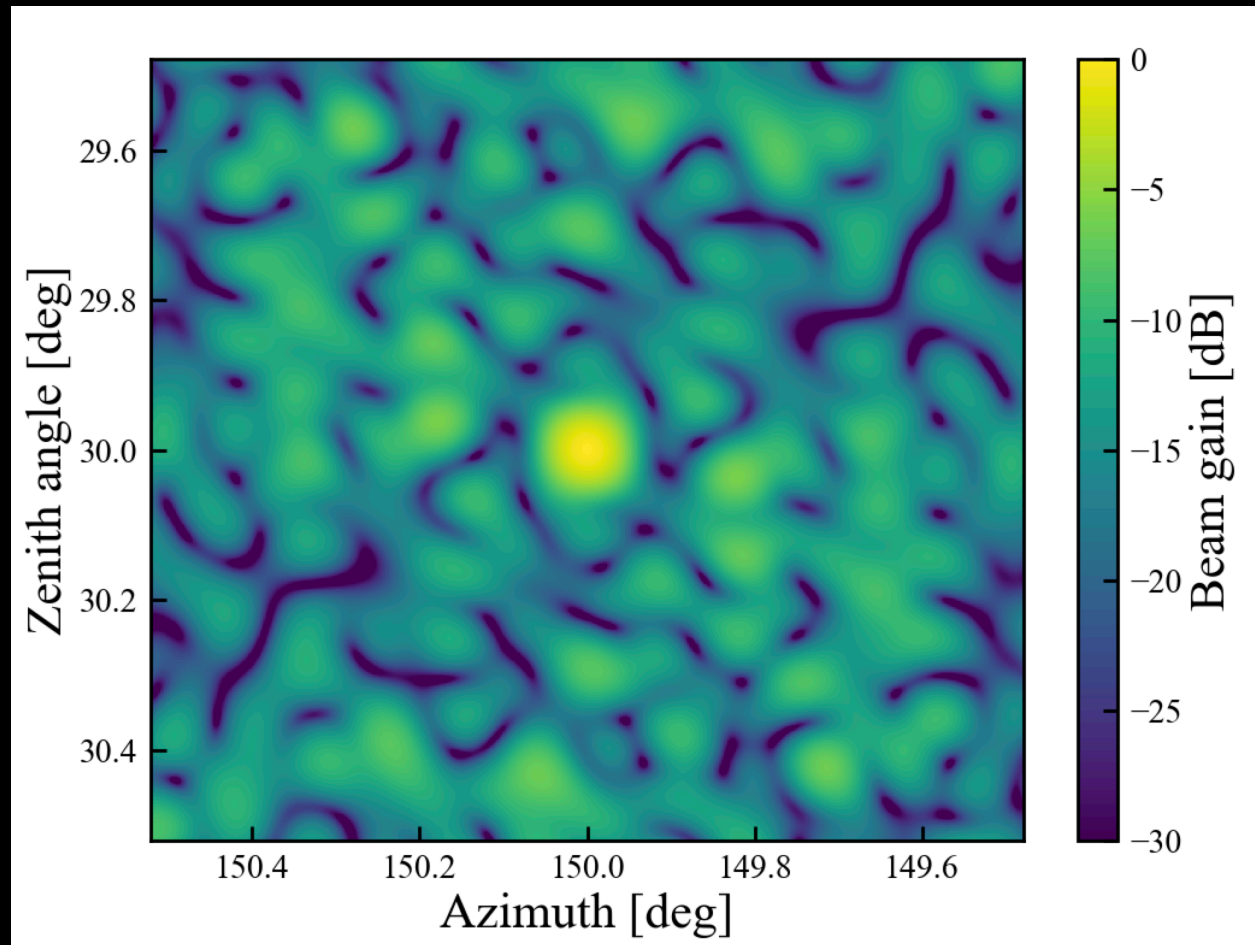


Before delay/phase cal

After delay/phase cal



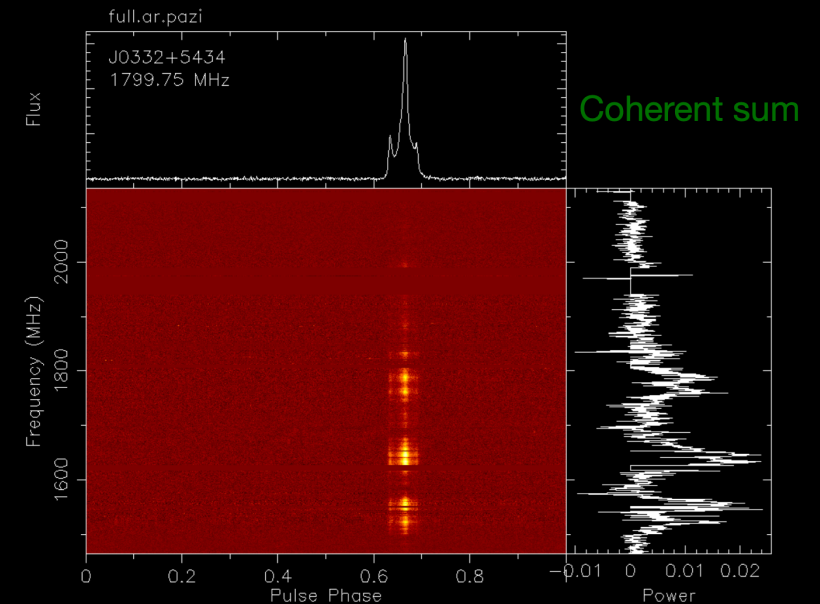
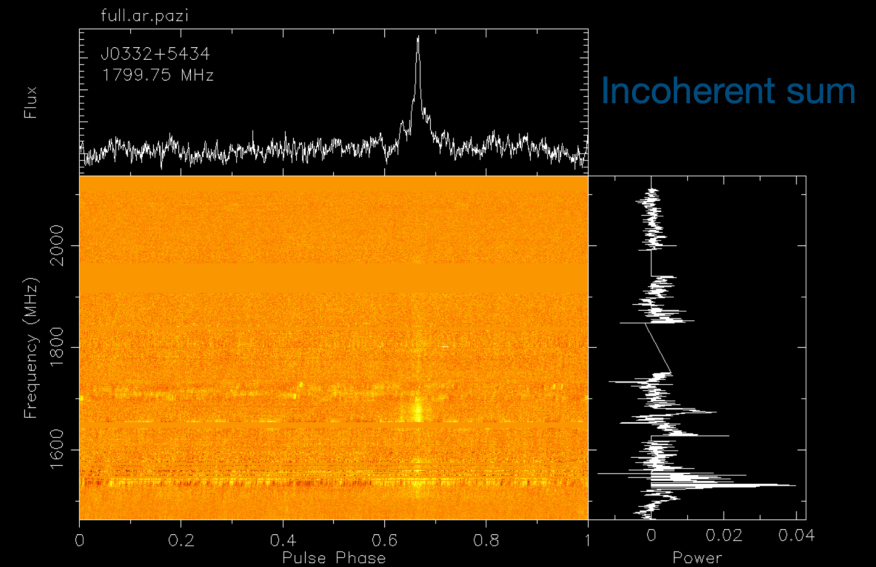
# Beamformer - beam pattern simulation





# Beamformer

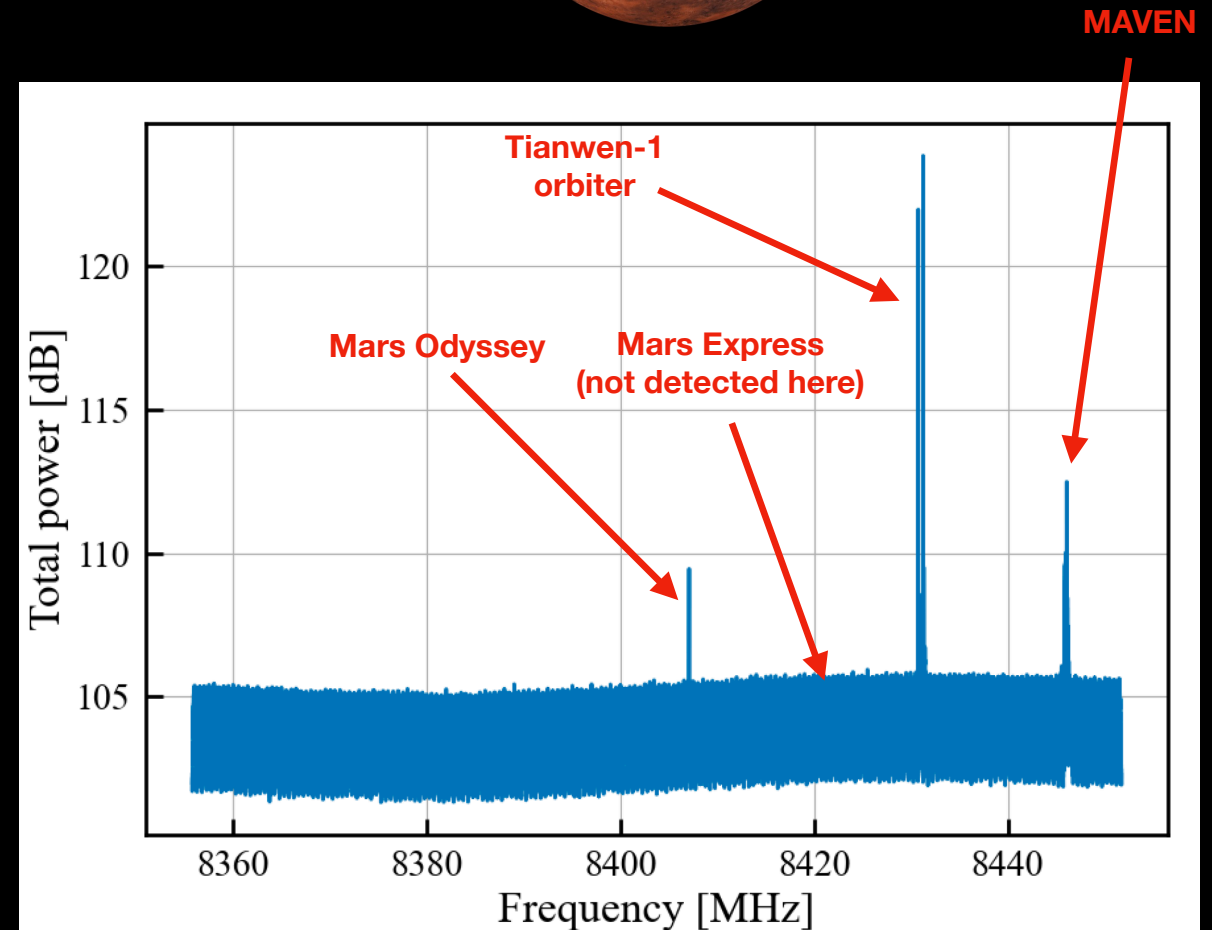
- **First light December 2021**
- **Beamforming library: BLADE;**  
**developer: Luigi Cruz (research intern)**
- **Capabilities constantly improving**
- **Real-time synthesis of up to 8 beams, if outputting complex voltages (io-bound)**
- **Output format:**  
**“modified” GUPPI format**  
**+ sigproc filterbank (under development)**





# Mars observation

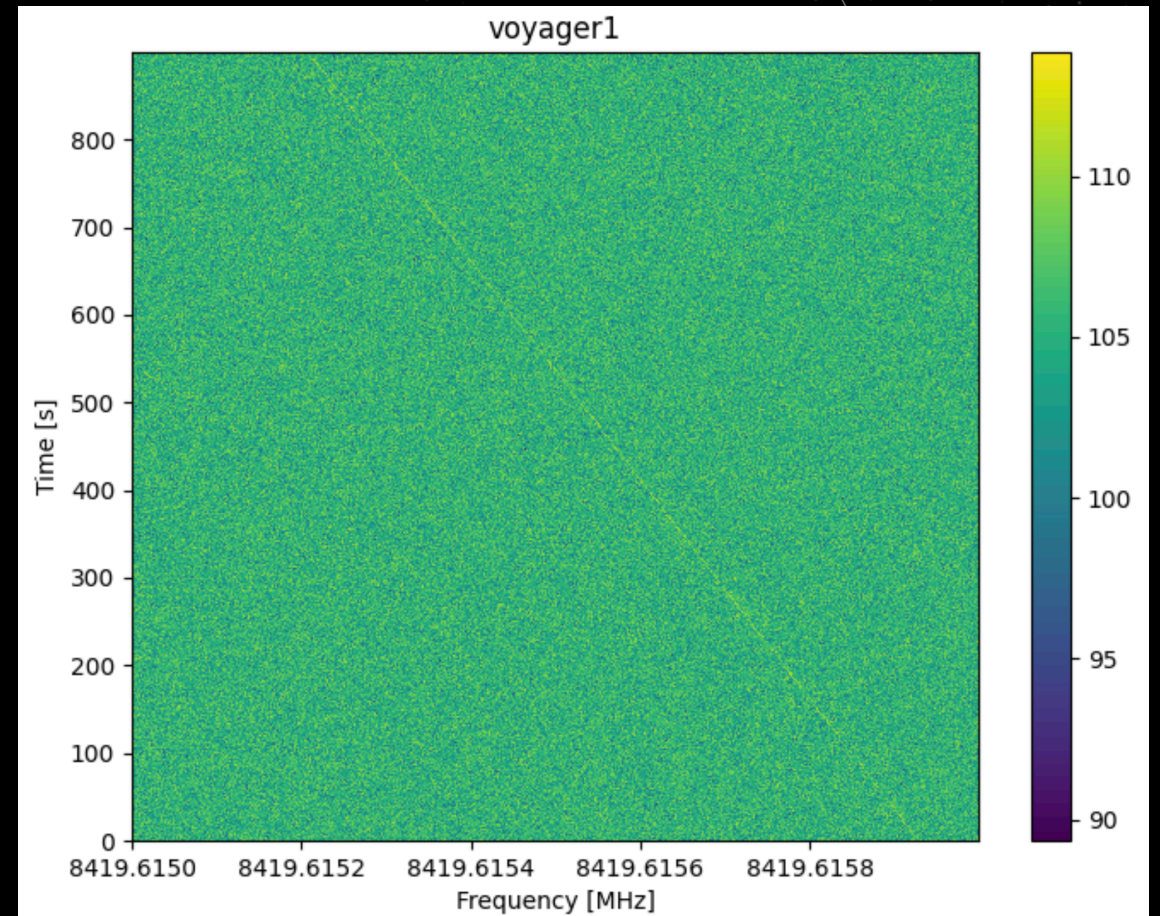
- 60 seconds observation with 20 antenna beamformer, centered at 8500 MHz (where most orbiter downlink frequencies are)
- Beamformer calibrated using the typical correlator observation
- Orbiters were detected (Mars express was detected in an earlier recording)





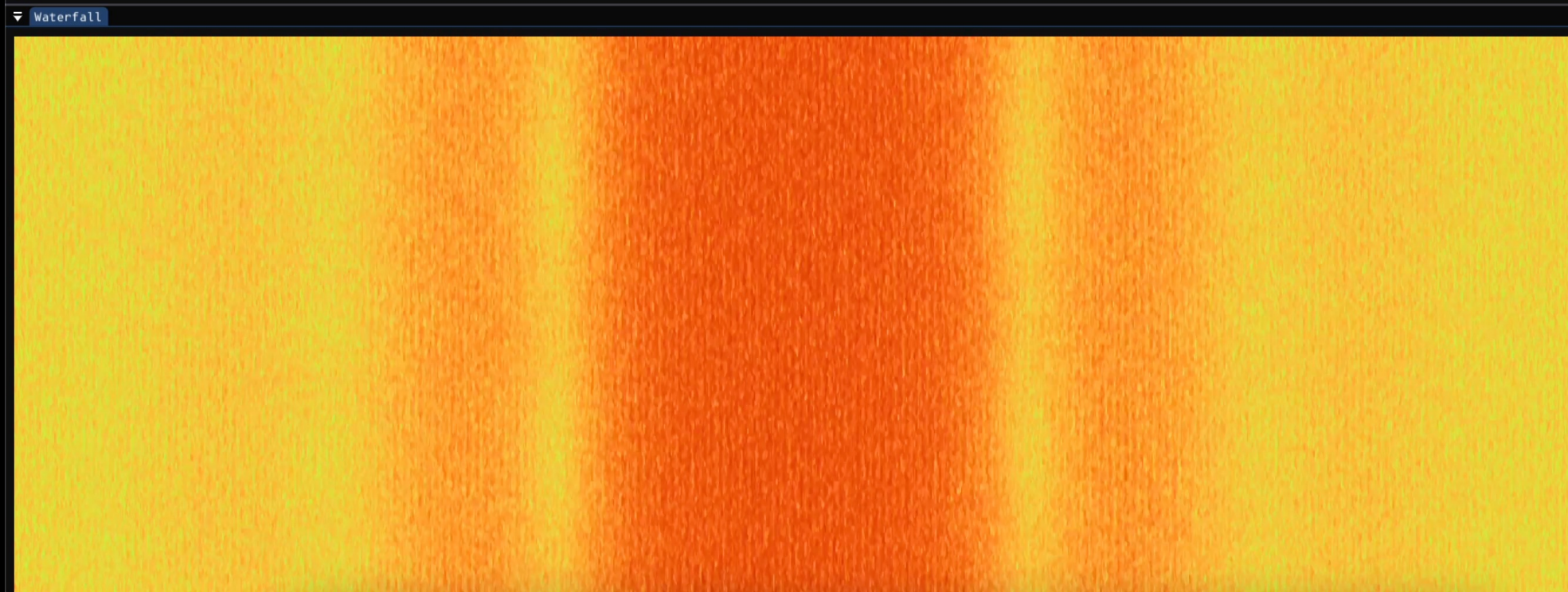
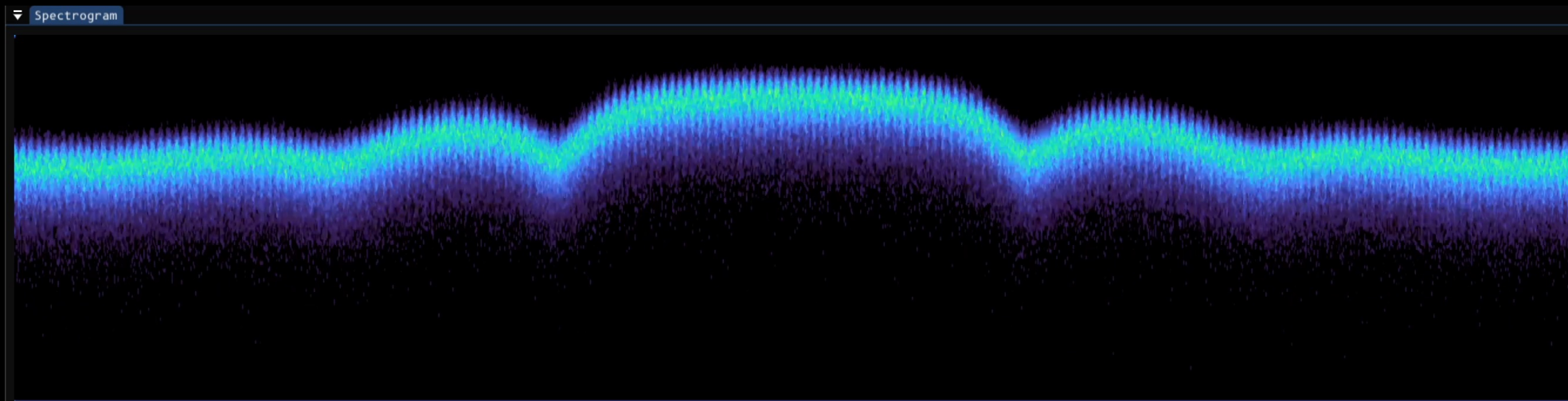
# Voyager observation

- Voyager 1, furthest human-made object, detected by the ATA
- July 9th, 2022, 900 second recording with the beamformer was performed.
- Measured C/N0 ratio is as expected from link budget calculations
- Read more: <https://wfarah.github.io/blog/voyager1/>



# Joint Polar Satellite System (JPSS)

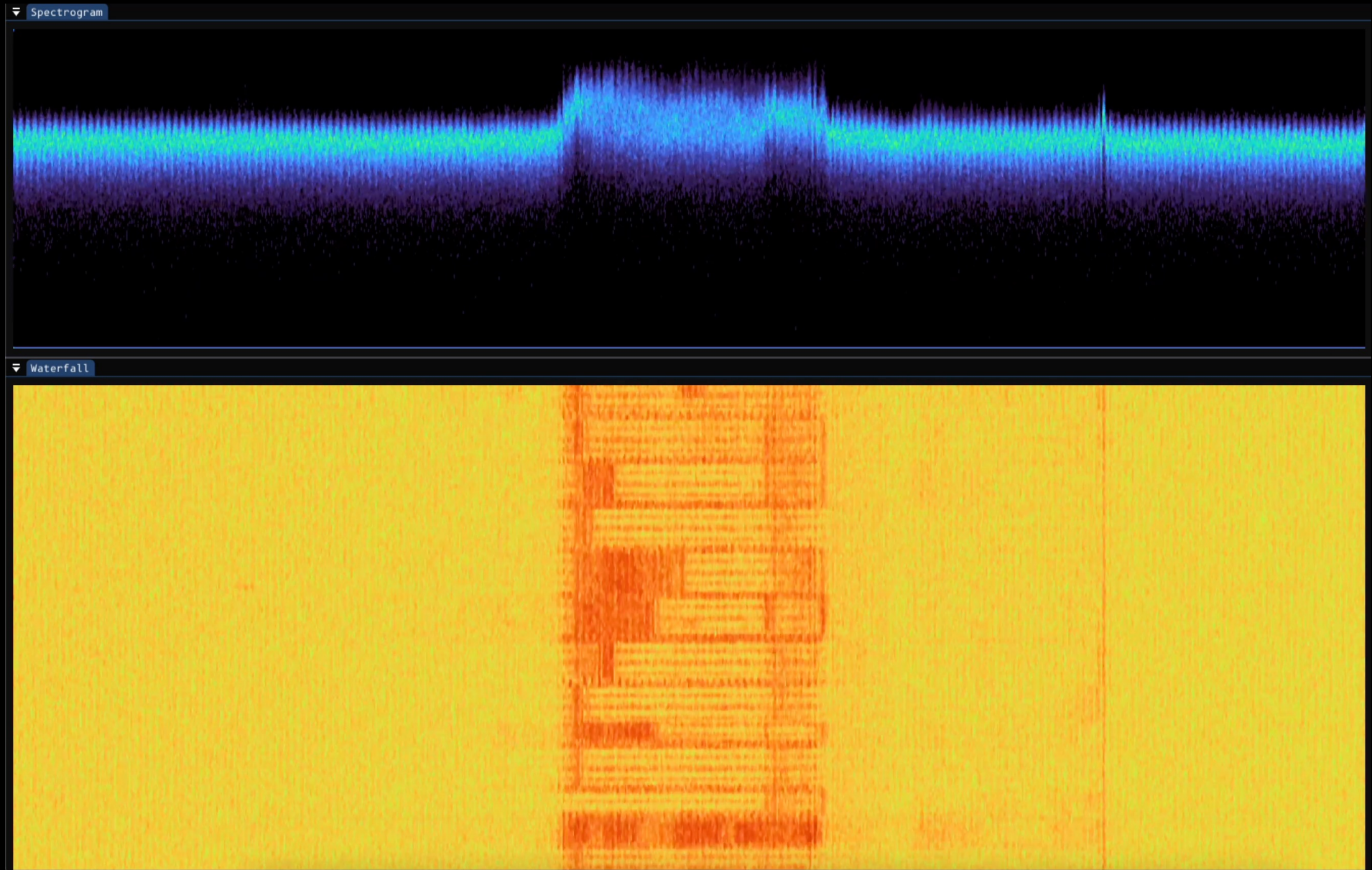
- 30 MHz bandwidth
- X – Band (7812 MHz)





# LTE Downlink

- 20 MHz bandwidth
- LTE Band 2 (1960 MHz)









# GUPPI Files

- Streaming data is stored in blocks.
- Each block is composed of an ASCII metadata header followed by binary data.
- Binary data is laid out as a matrix of mixed-domain data (frequency, time, polarization).
- Multiple beams or antennas can be added as an optional dimension.
- Sample type can be integers or floats

## METADATA HEADER

F0T0	F1T0	F2T0	F3T0	F4T0	F5T0	F6T0	F7T0
F0T1	F1T1	F2T1	F3T1	F4T1	F5T1	F6T1	F7T1
F0T2	F1T2	F2T2	F3T2	F4T2	F5T2	F6T2	F7T2
F0T3	F1T3	F2T3	F3T3	F4T3	F5T3	F6T3	F7T3

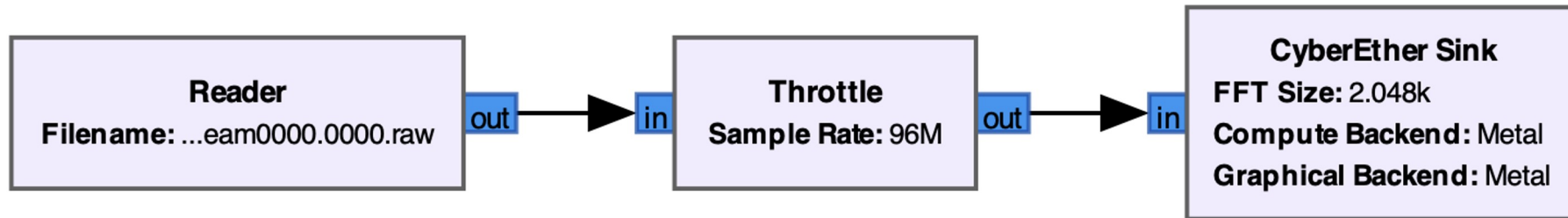


## METADATA HEADER

F0T0	F1T0	F2T0	F3T0	F4T0	F5T0	F6T0	F7T0
F0T1	F1T1	F2T1	F3T1	F4T1	F5T1	F6T1	F7T1
F0T2	F1T2	F2T2	F3T2	F4T2	F5T2	F6T2	F7T2
F0T3	F1T3	F2T3	F3T3	F4T3	F5T3	F6T3	F7T3

# gr-teleskop

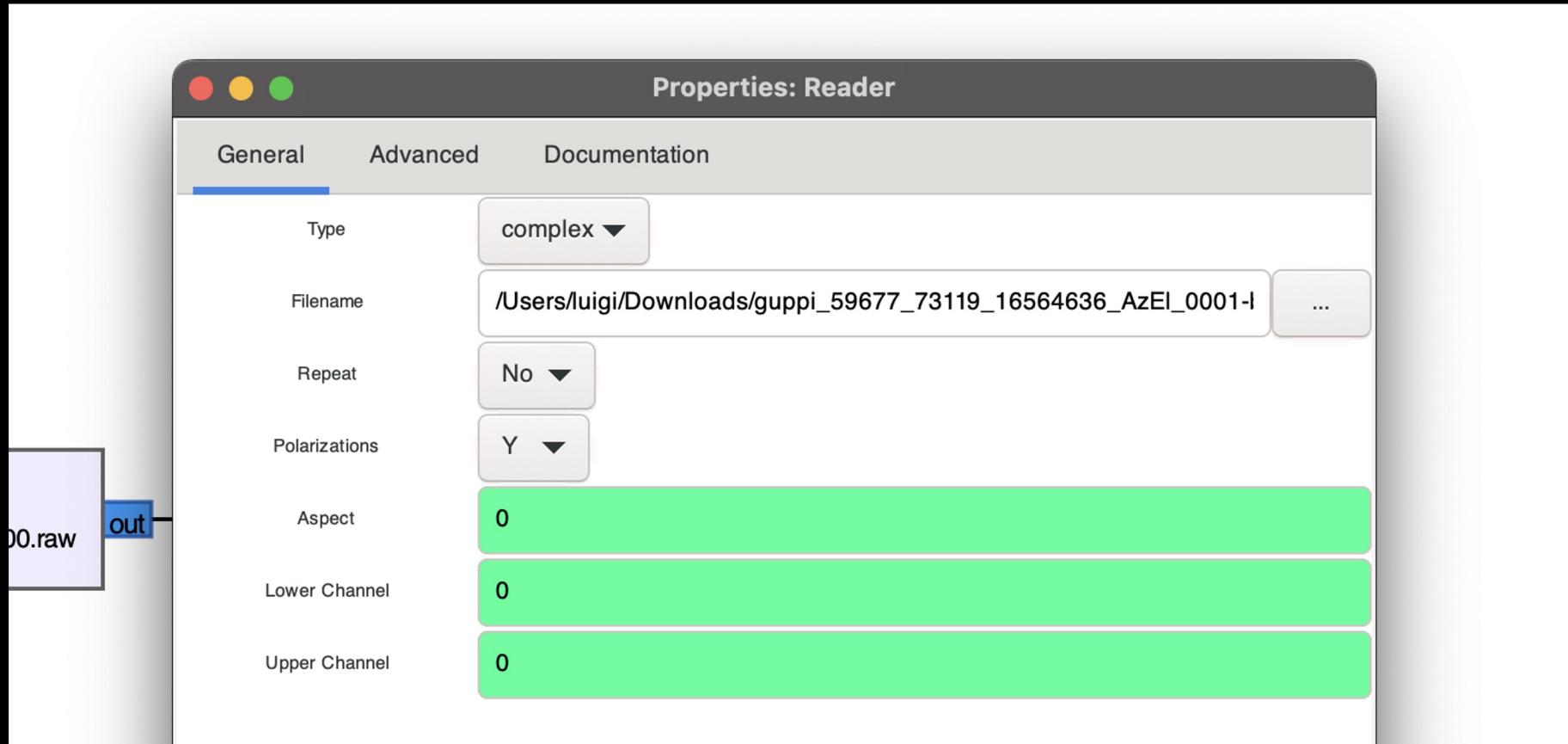
- Provides reader block for ATA-generated GUPPI files.
- Internally converts mixed-domain data into a time-domain stream.
- Fast enough to decode 96 MHz of 16-bits floating-point data in 0.5x real-time.
- Planning to capabilities to other observatories in the future.





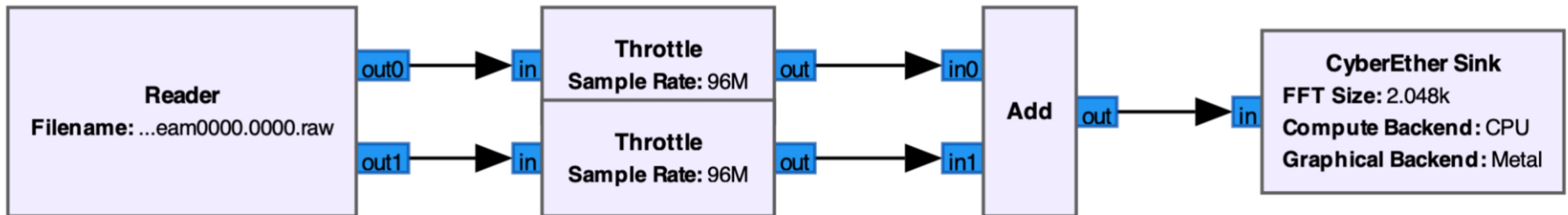
# gr-teleskop

- Type selection (32-bits floating-point output).
- Repeat toggle (just like native file reader).
- Number of Aspects (antennas, beams, or none).
- Channel Binning (lower/upper channel).
- Polarizations (X, Y, XY).



# Circular Polarization

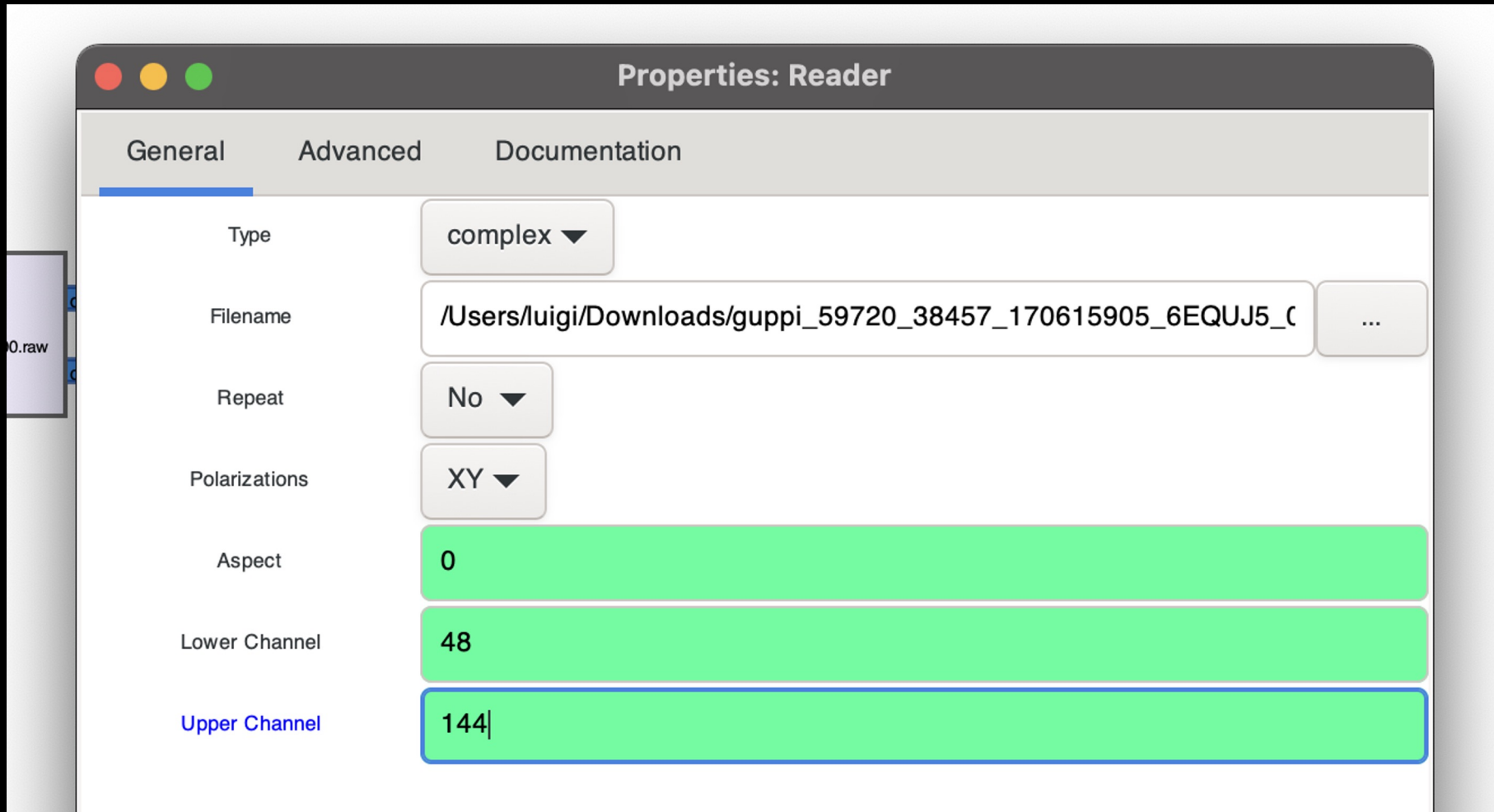
- Circular polarization synthetization by summing (RHCP) or subtracting (LHCP).
- Calibrations for polarizations X and Y are necessary.
- Available soon for the Allen Telescope Array!



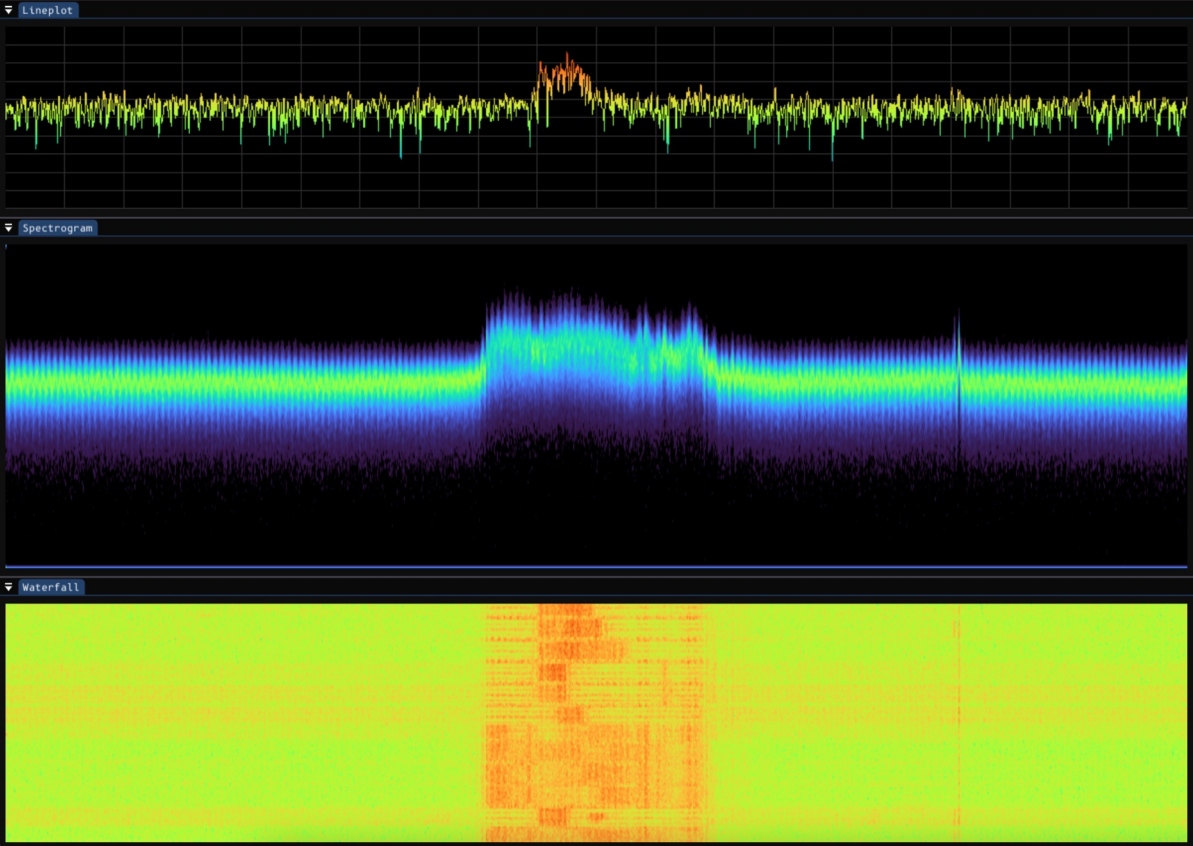


# Channel Binning

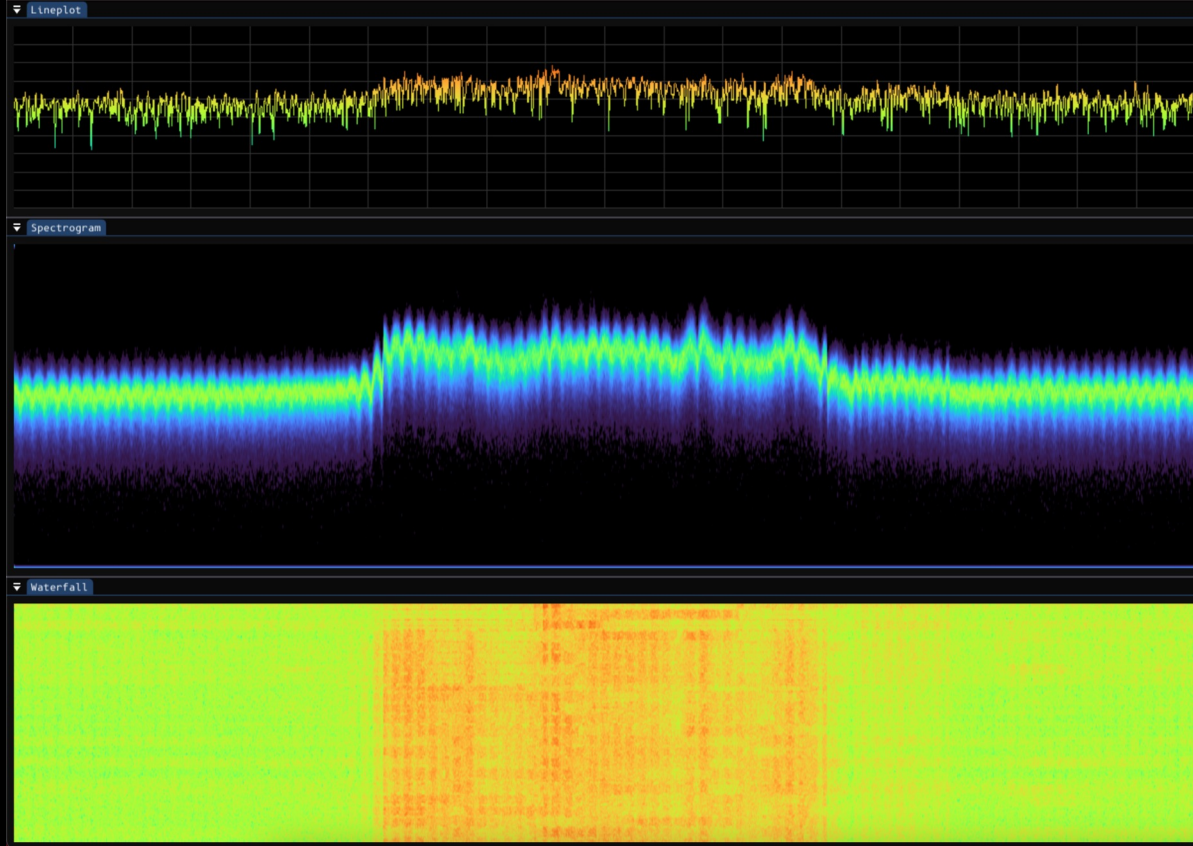
- Channel binning discards frequency channels that aren't necessary.
- Set by the “Lower Channel” and “Upper Channel” parameters.



# Channel Binning



Channel 0 to 192 (96 MHz)  
Full Frequency Range

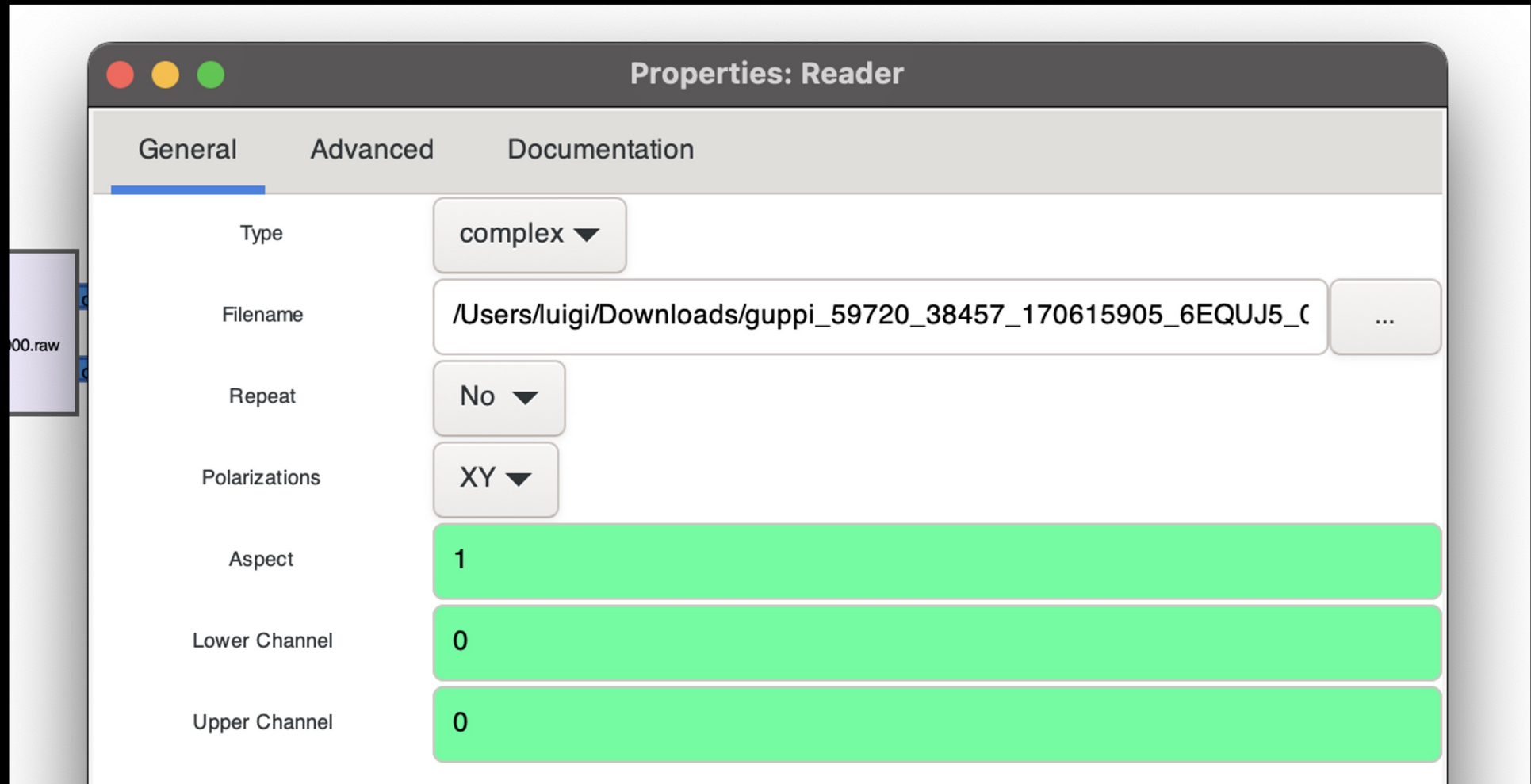


Channel 48 to 144 (48 MHz)  
Binned Range



# Aspects

Optional: Antenna or Beam can be chosen with the “Aspect” parameter.





Thank you for your attention!

<https://github.com/luigifcruz/gr-teleskop>

