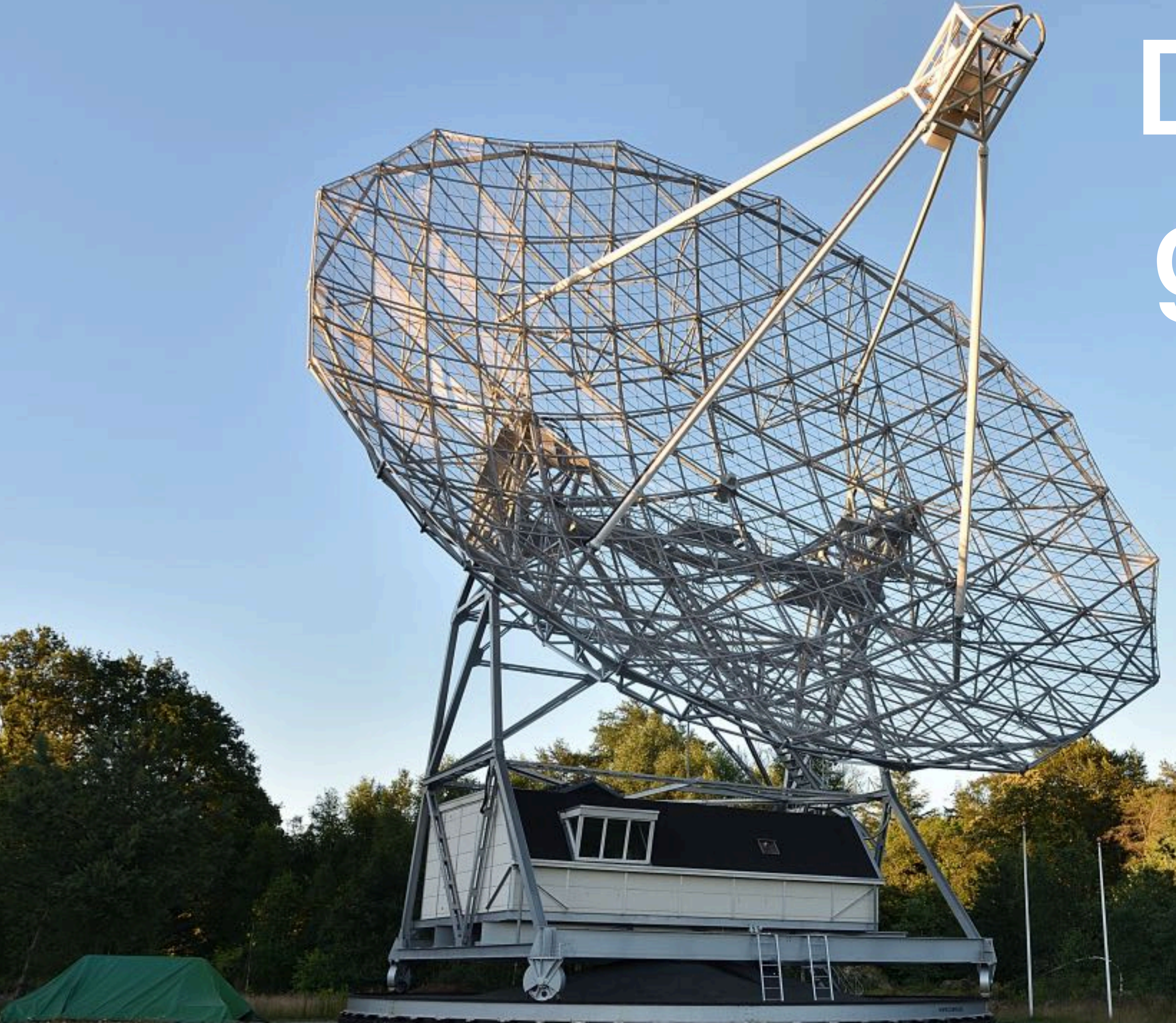
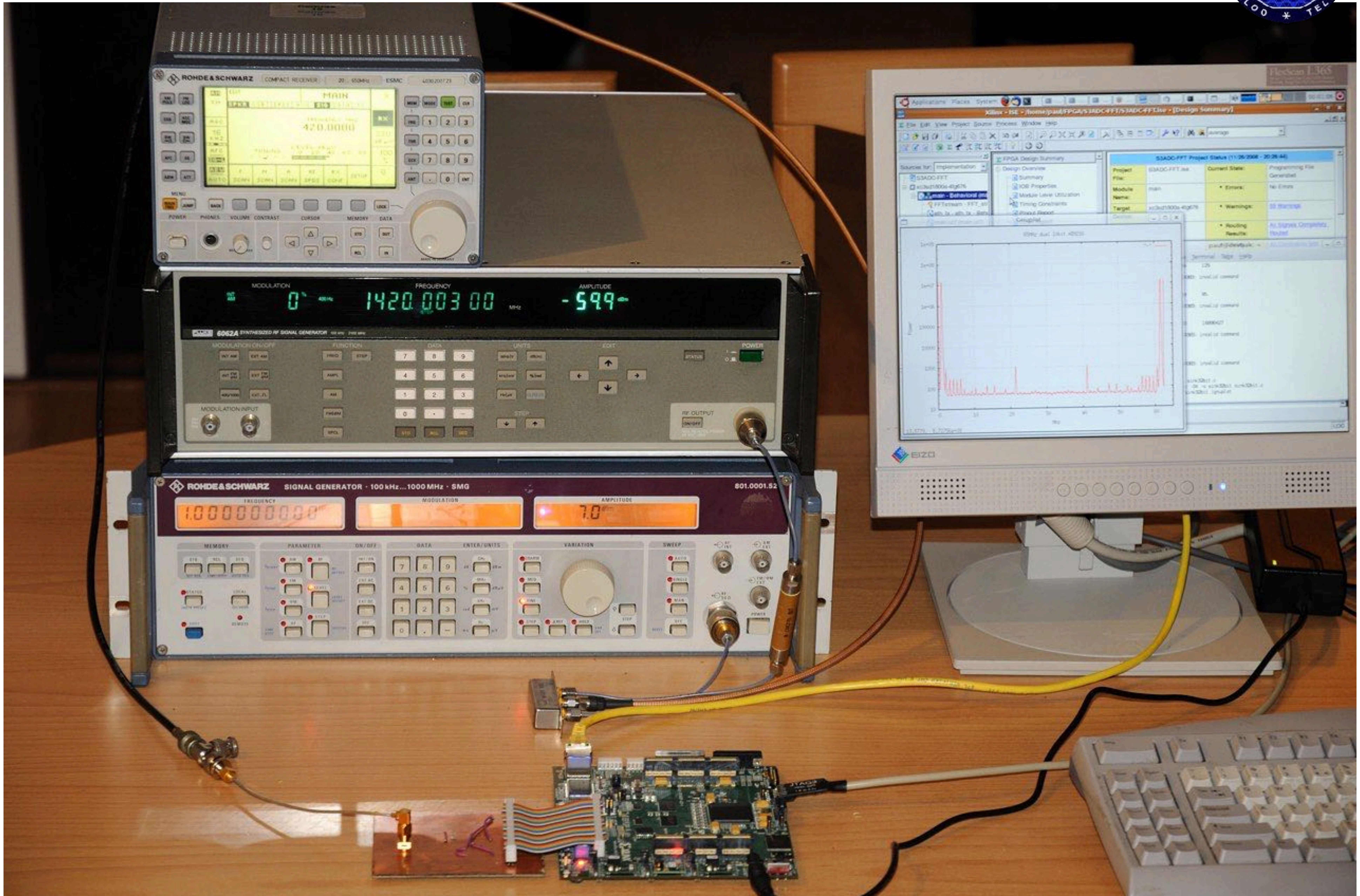
Dwingeloo goes SDR

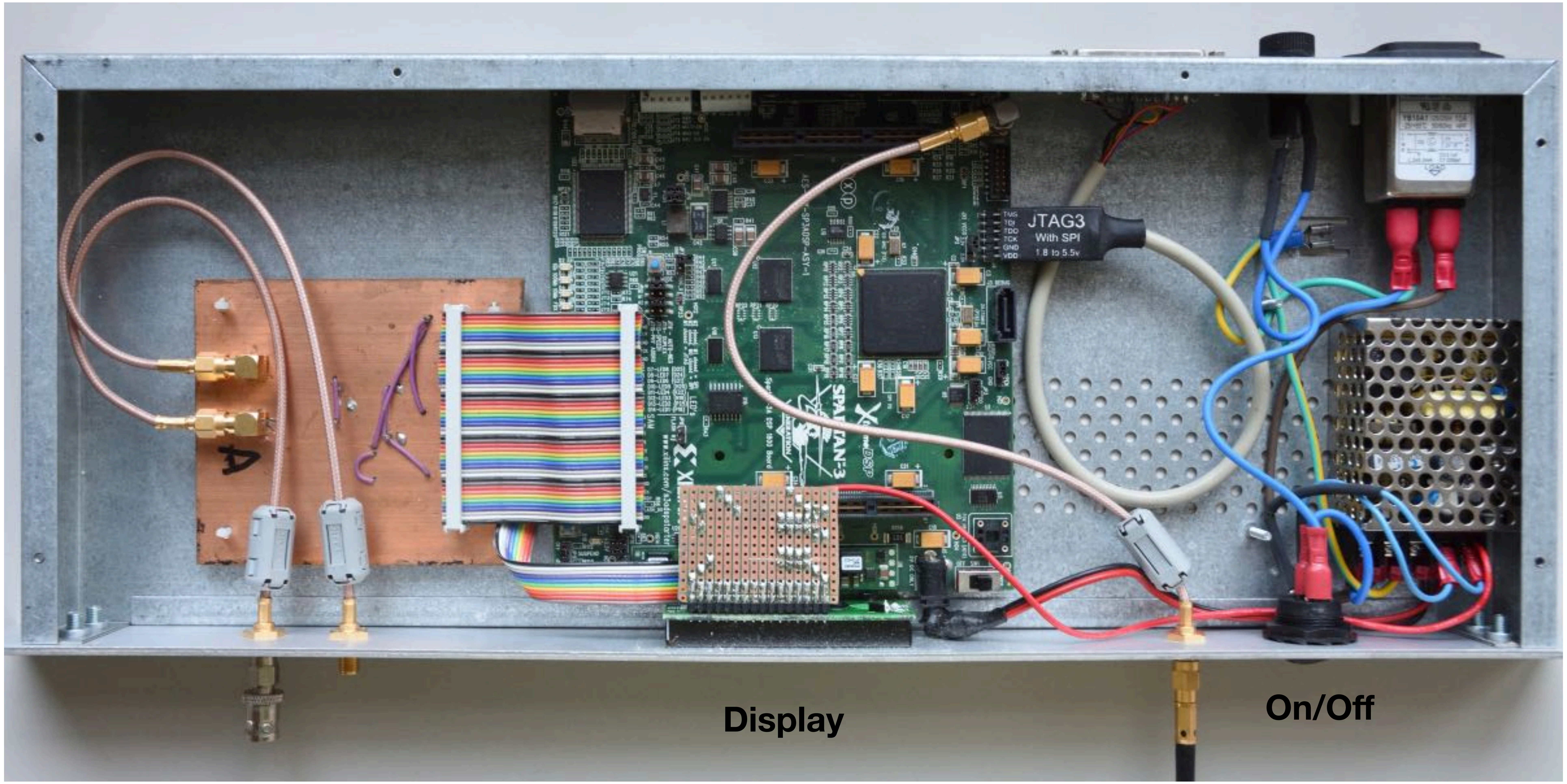
Paul Boven
PE1NUT



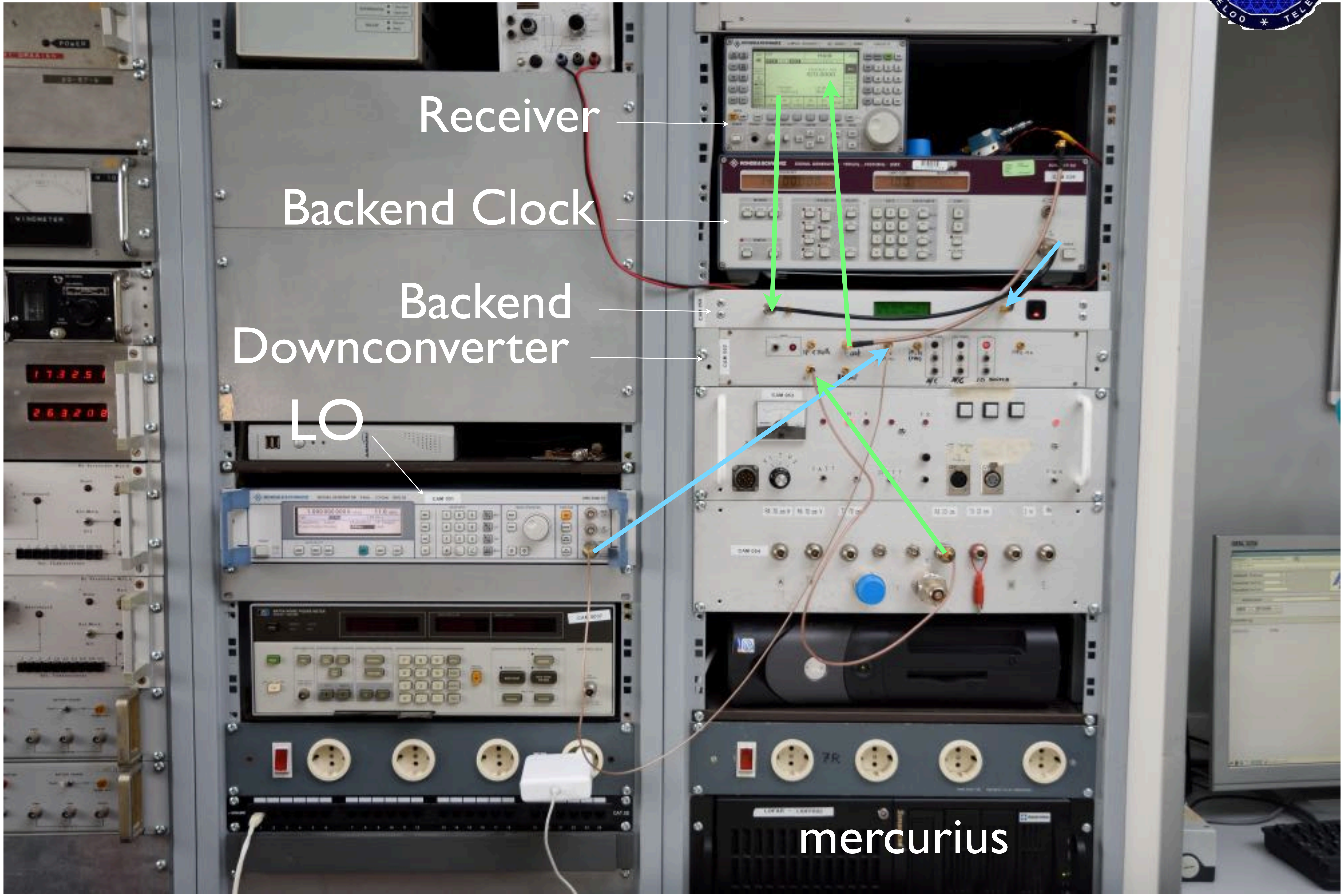
On my Kitchen Table (2008)



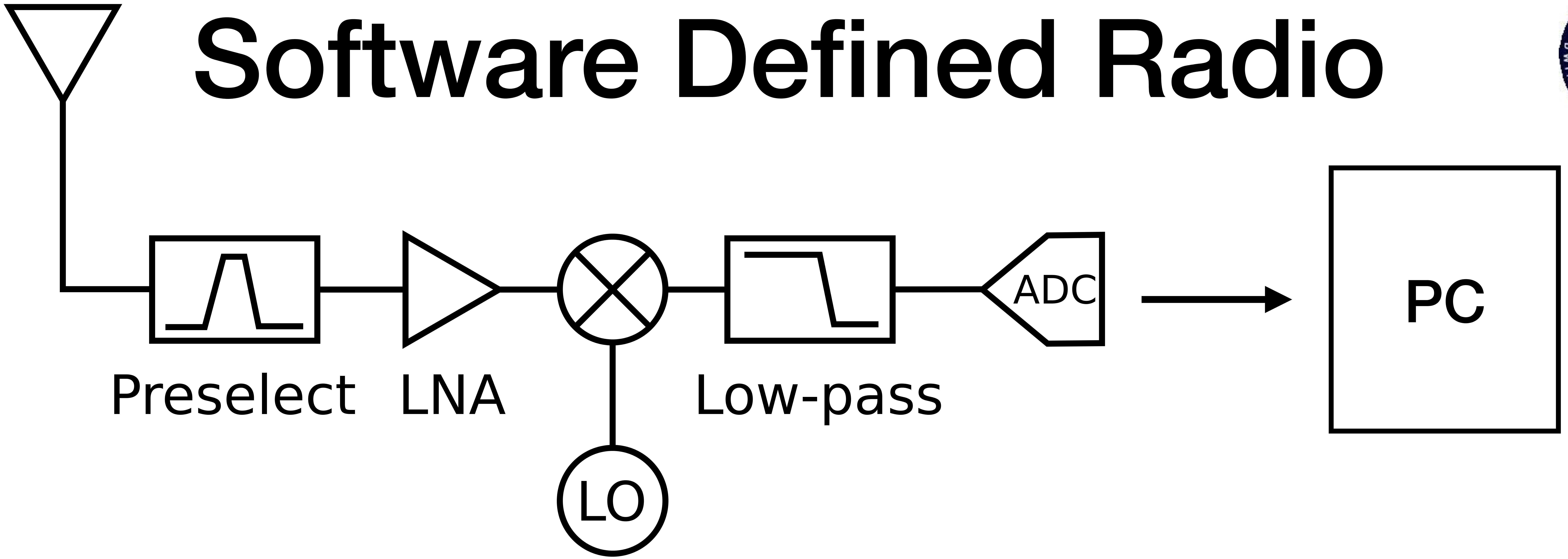
Boxed (2010)


Ethernet
JTAG
(Parallel)
Fuse
Mains
JTAG3
With SPI
1.8 to 5.5v
Display
On/Off
Inputs
Clock

Signal Chain



Software Defined Radio



- Antenna signal or IF signal is digitised at high rate
- Demodulation or measurement is done in software
- Advantages: Flexibility, stable and steep filters
- Disadvantages: Computational Requirements

Some SDRs

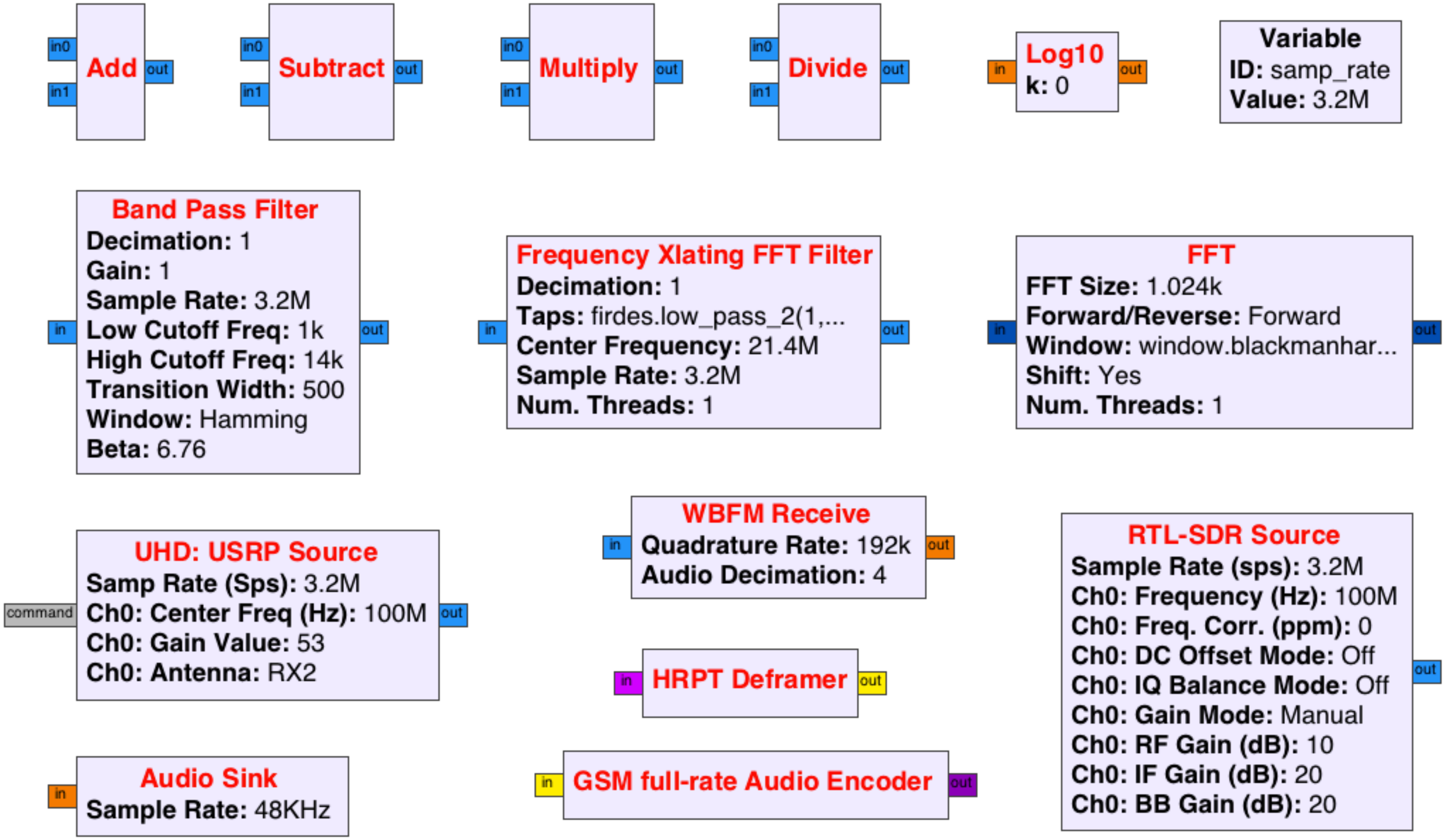
- Differences in:
    - Frequency Coverage
    - Bandwidth / Sample Rate
    - Sensitivity
    - Price

GNU Radio

THE FREE & OPEN SOFTWARE RADIO ECOSYSTEM

- Free and open source development system for signal processing
- Radio tinkering with Python and/or flowgraphs
- Available on most operating systems

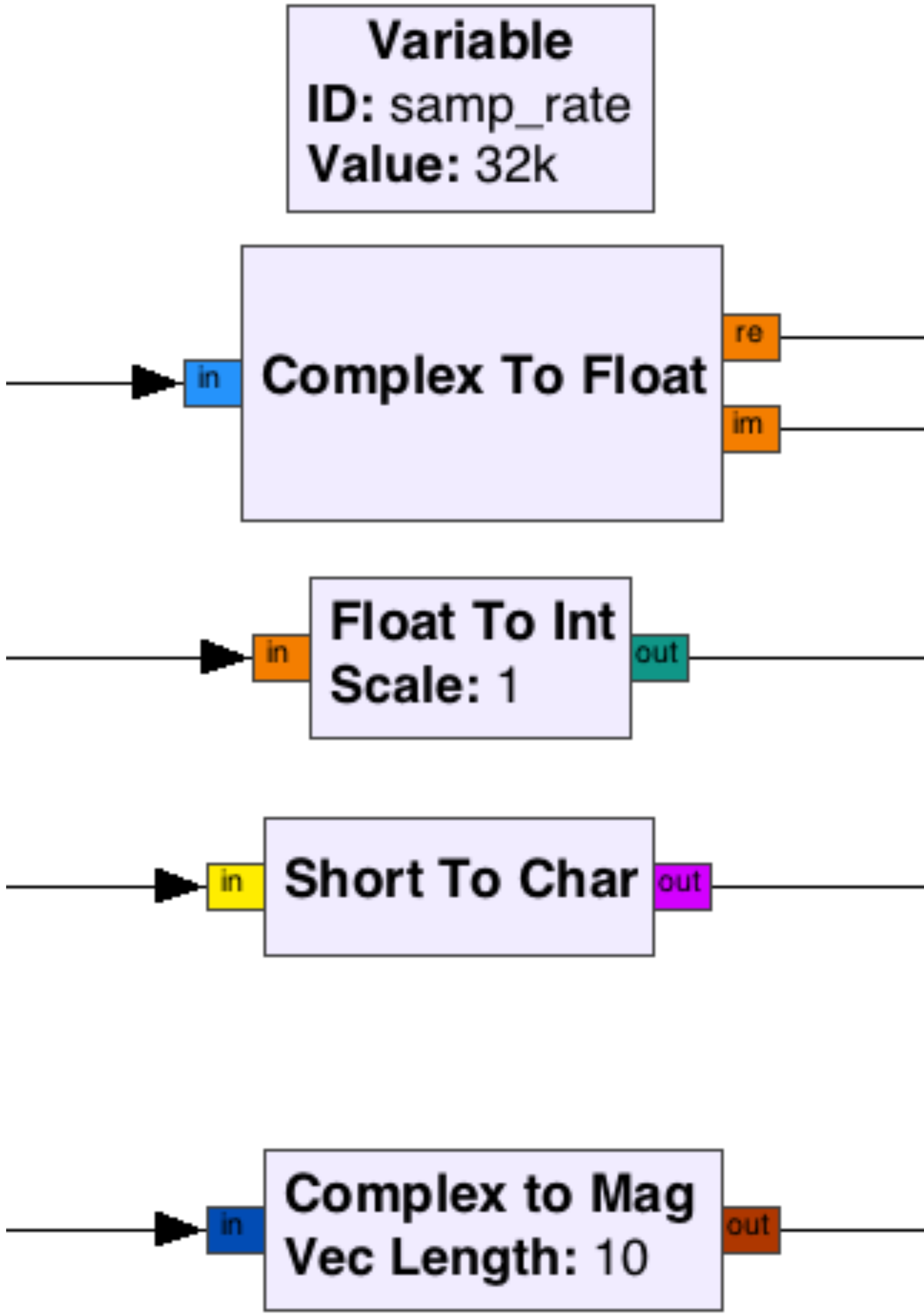
GnuRadio Blocks



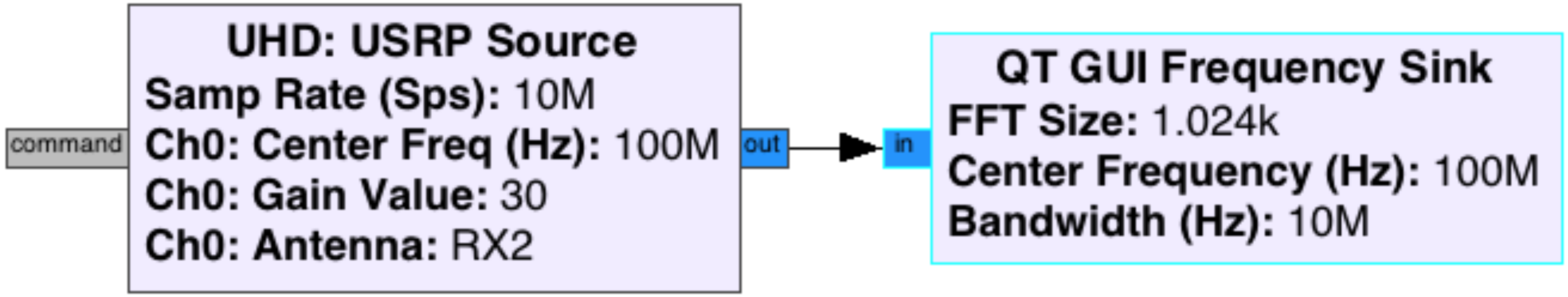
Signal Types

- Blue: Complex, IQ data, floating point
- Orange: Float, (32 bit)
- Green: Int, 32 bit
- Yellow: Short, 16 bit
- Purple: Char/UChar/Byte, 8 bit

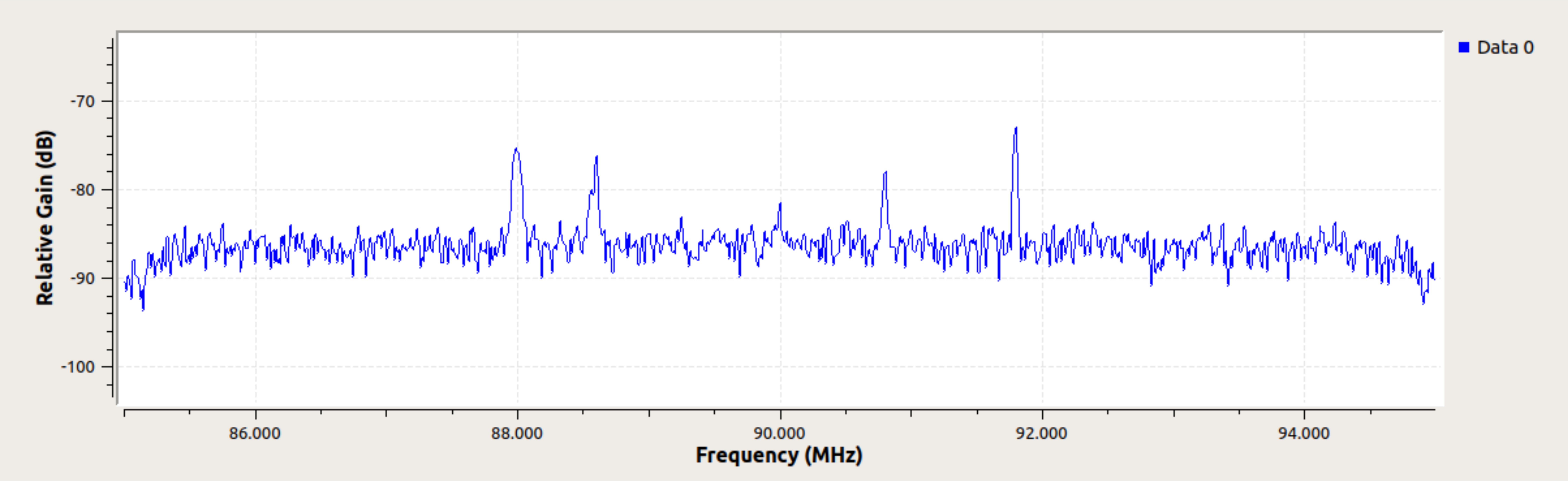
- Vector: List of samples grouped together
  - Darker colour shade



‘Hello World’

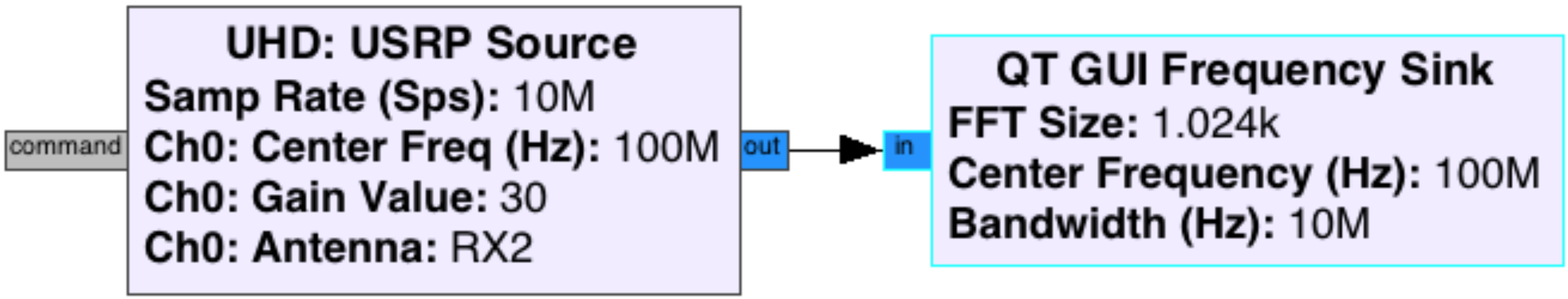


UHD: USRP Source
Samp Rate (Sps): 10M
Ch0: Center Freq (Hz): 100M
Ch0: Gain Value: 30
Ch0: Antenna: RX2
command
out
in
QT GUI Frequency Sink
FFT Size: 1.024k
Center Frequency (Hz): 100M
Bandwidth (Hz): 10M



Data 0
-70
-80
-90
-100
Relative Gain (dB)
86.000
88.000
90.000
92.000
94.000
Frequency (MHz)

FFT Display

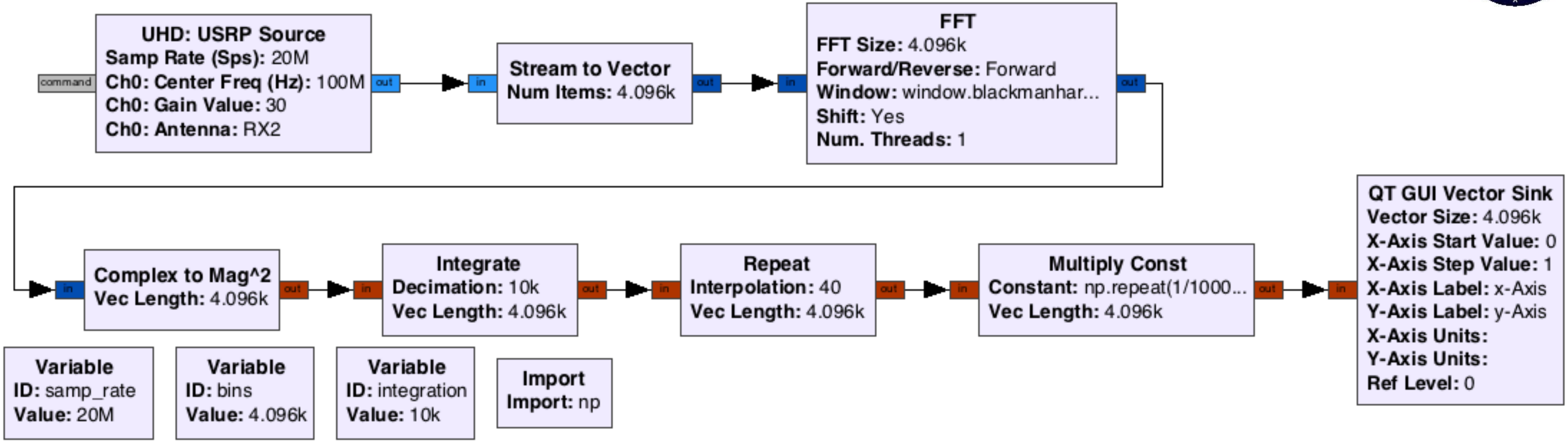


- Good for high dynamic range (log scale)
- Low CPU impact (runs only 10 times per second)
- This example: only 0.1% of samples get used
  - 1024 bins, 10 Hz, 10MS/s
- Poor sensitivity
- Long time averaging required

FFT all the samples

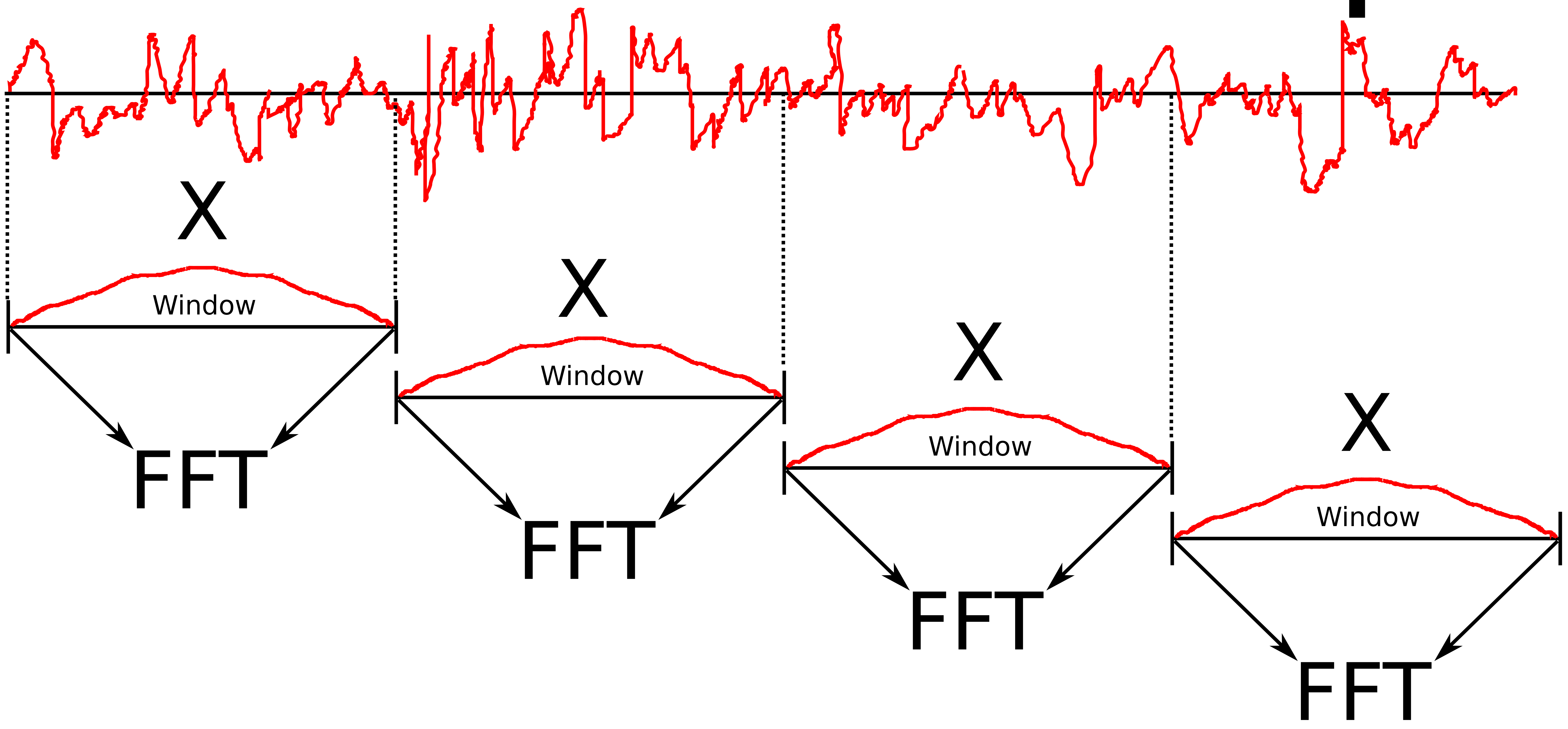
- Resolution: 20MHz / 4096 = 5 kHz
- 1% power uncertainty (10,000 power samples for each bin)
- Update rate is samp_rate / bins / integrations = 2s
- Due to block-based processing: display lag is tens of seconds !

Flushing the Pipeline



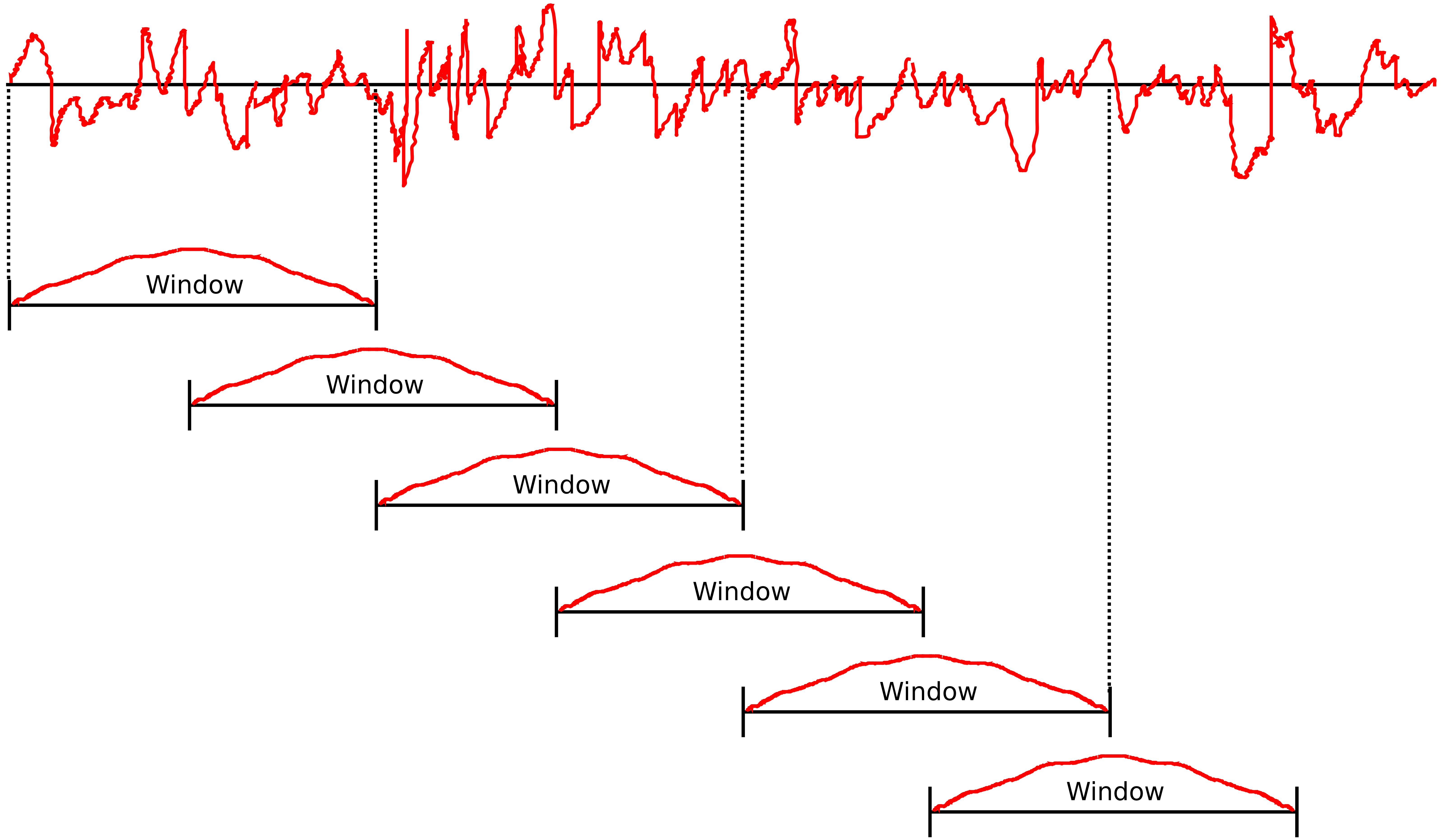
- Repeat the output of the integrator
- Only happens every 2 seconds anyway
- Flushes buffers so Vector Sink updates immediately
- Also introduced normalisation, after integration

FFT without Overlap



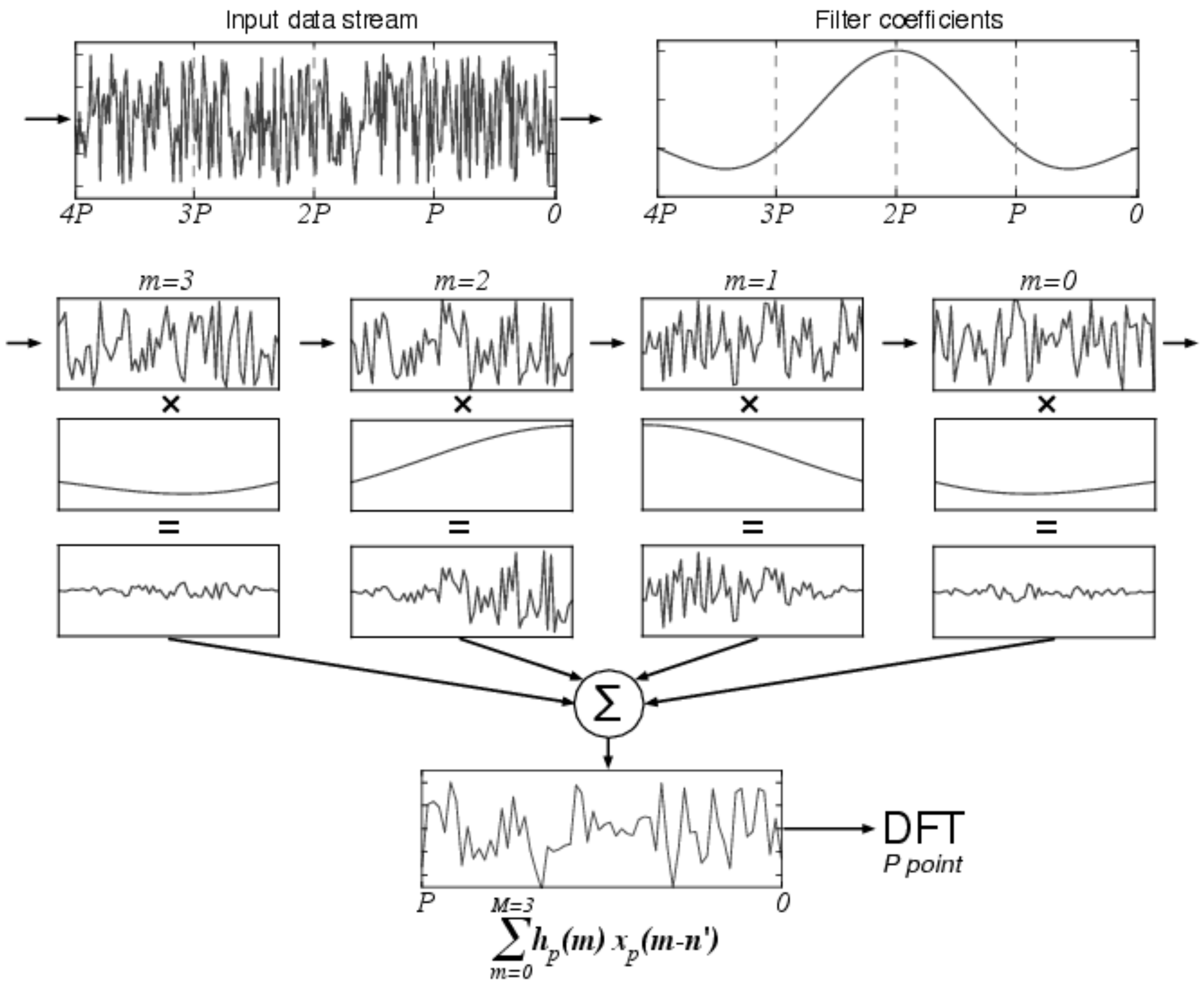
- Low (zero) weight for samples at window edge
- Loss of sensitivity, as samples are thrown away

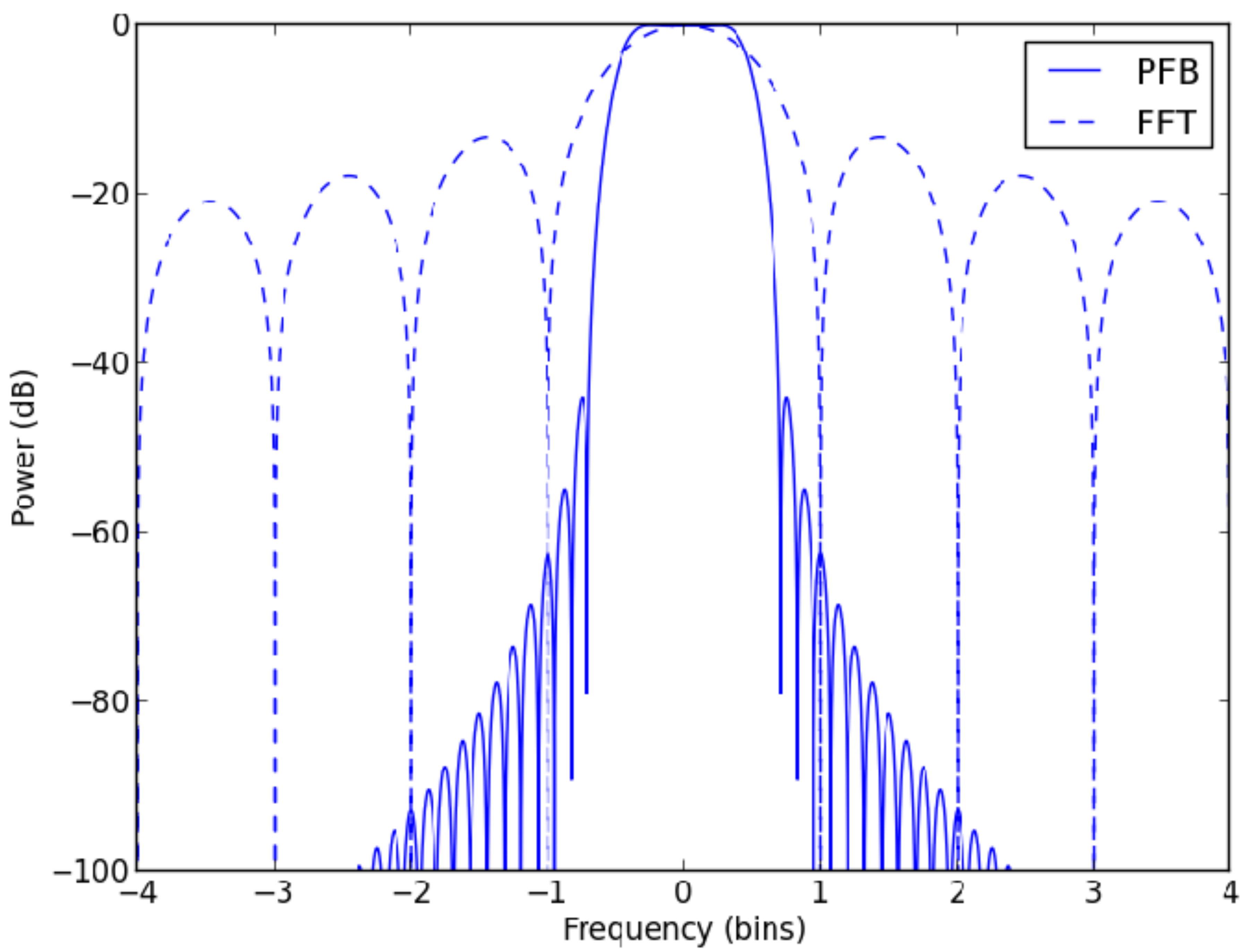
FFT with Overlap



- Increase in CPU resources scales with overlap factor !

Weight Overlap Add

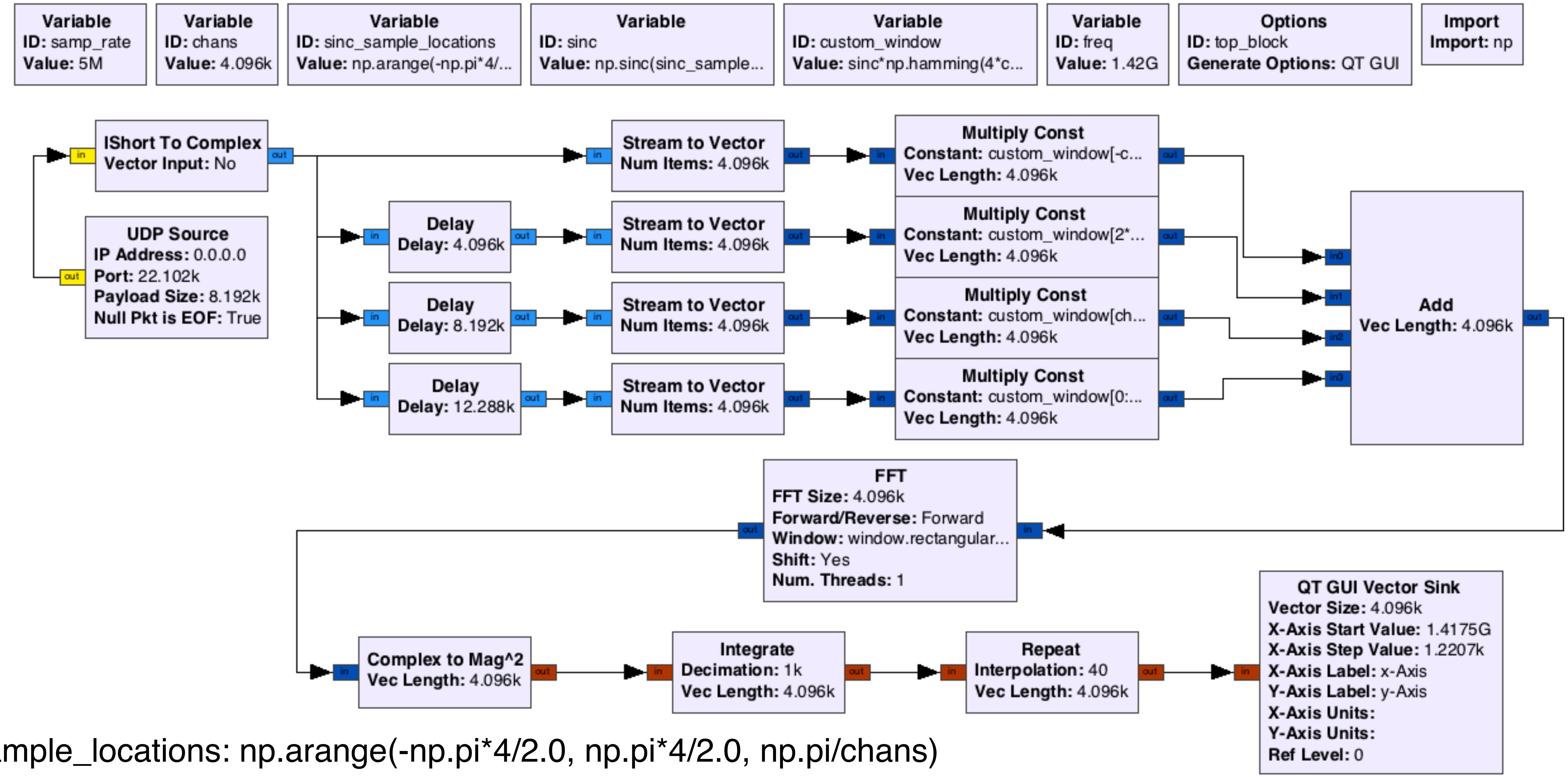




Source: https://arxiv.org/pdf/1607.03579.pdf

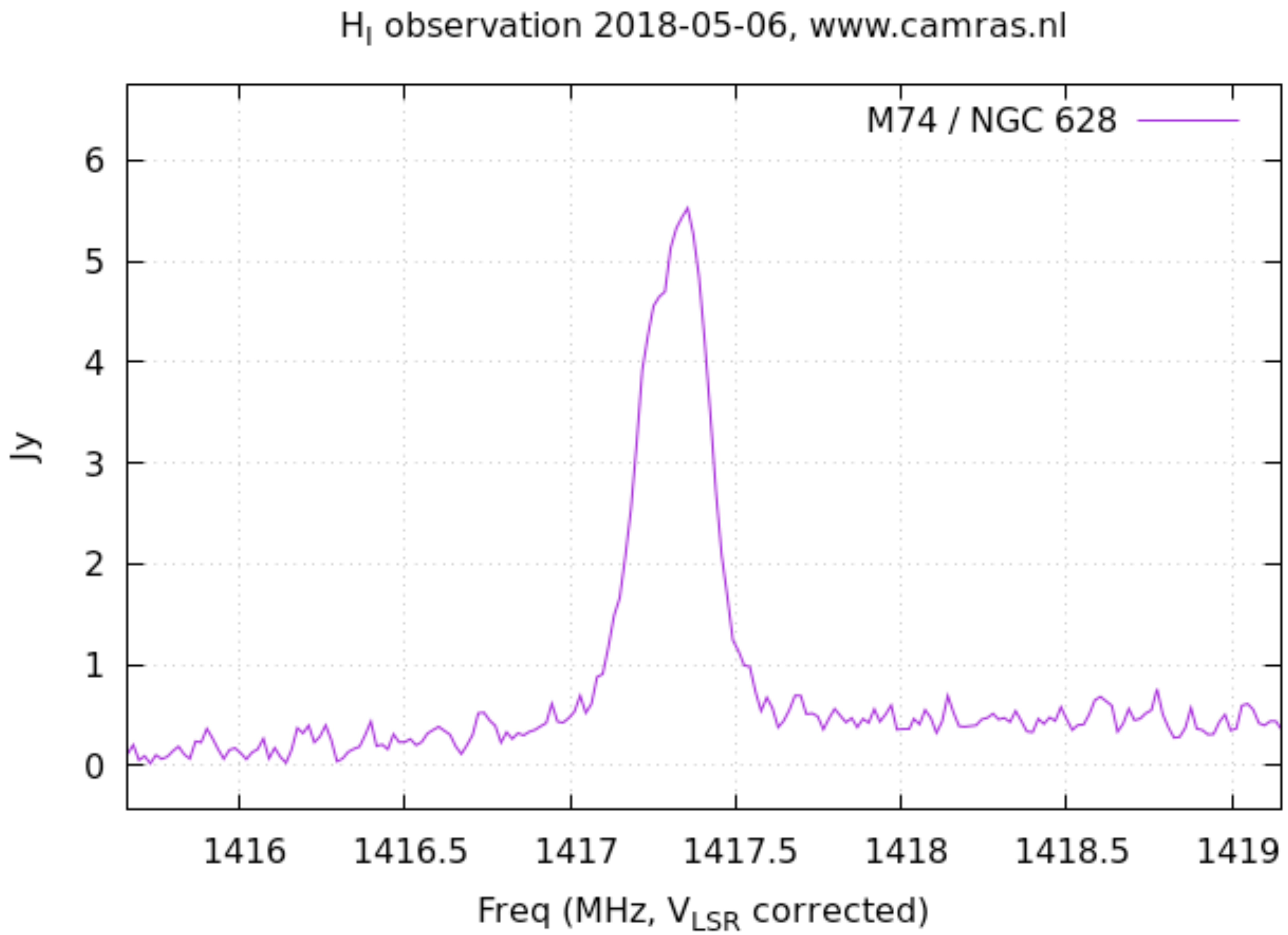
- Sinc window (perhaps multiplied with e.g. hamming)
- More overlaps allows less truncated sinc(x)
  - Better frequency box shape
  - Worse time resolution

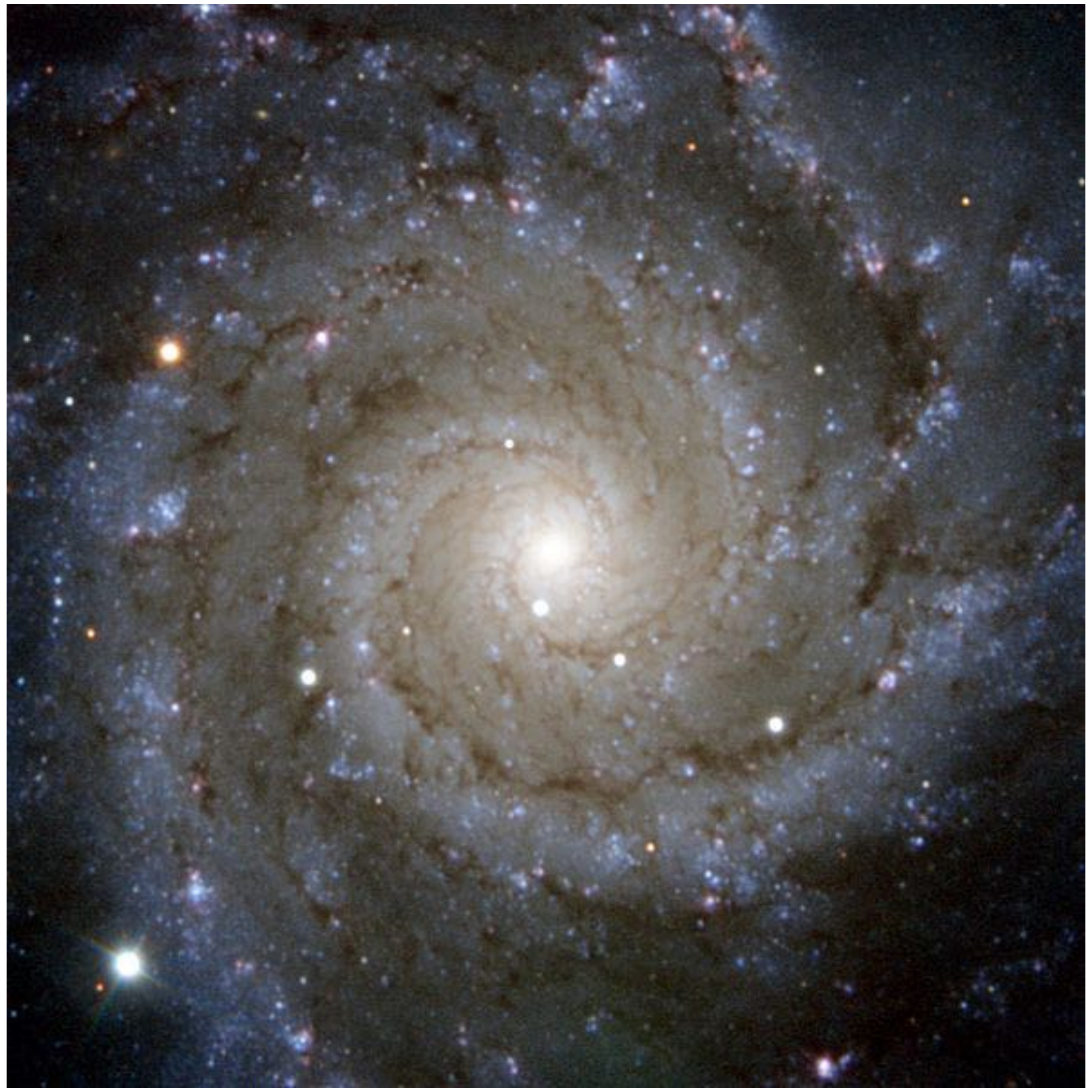
Weight Overlap Add (WOLA)



- sinc_sample_locations: np.arange(-np.pi*4/2.0, np.pi*4/2.0, np.pi/chans)
- sinc: np.sinc(sinc_sample_locations/np.pi)
- custom_window: sinc*np.hamming(4*chans)
- Top to bottom: custom_window[-chans:], [2*chans:3*chans], [chans:2*chans], [0:chans]
- Based on: http://wvurail.org/dspira/labs/05/

M74 / NGC 628





ESO/PESSTO/S. Smart

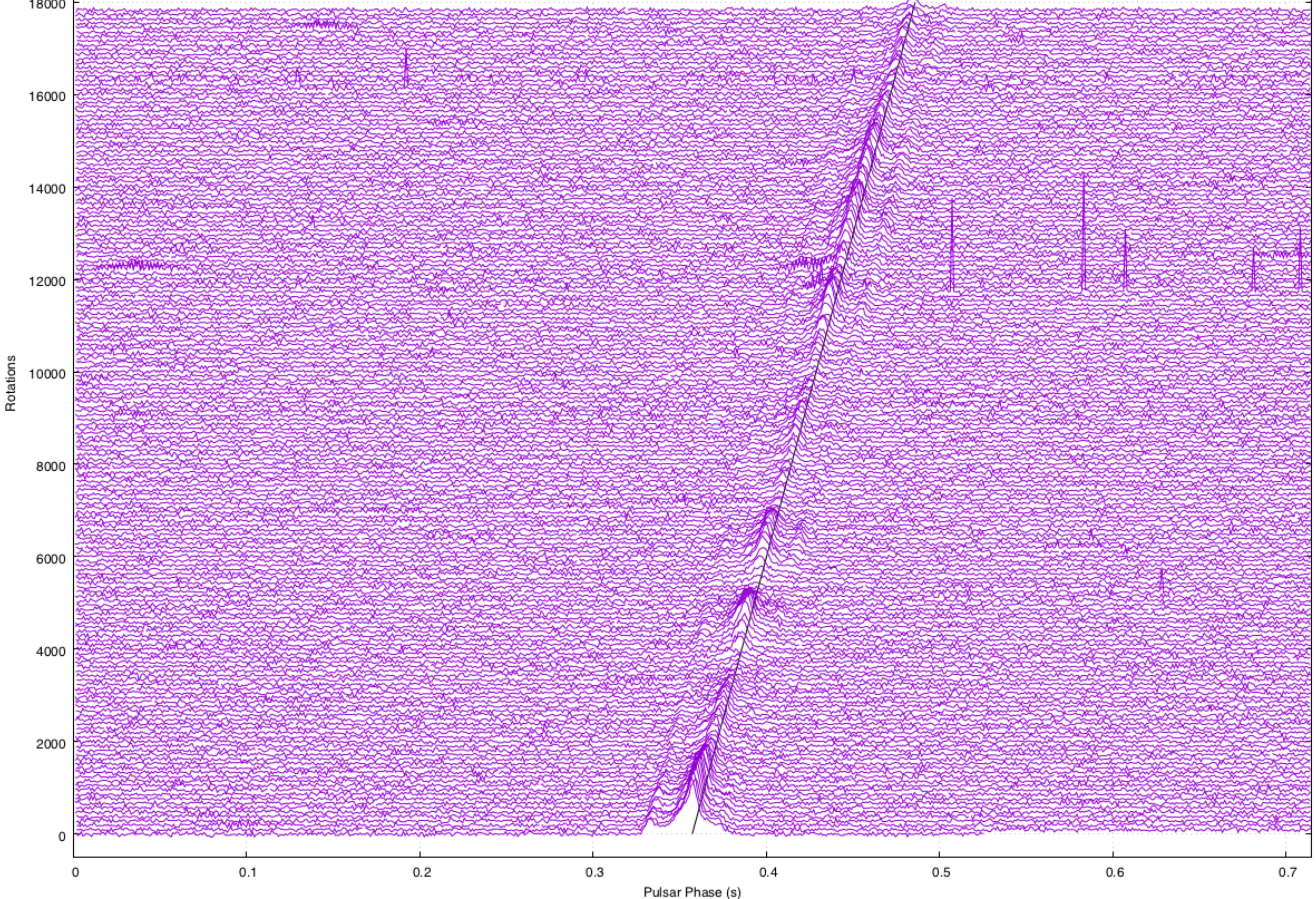
- 2300s on-source, 2400s off-source (100s integrations)
- Red-shift: 657km/s (3.1 MHz)
- Distance: 30 (±6) Million Lightyears

Timing


GPS
GPS Timing RX
PPS
STANFORD RESEARCH SYSTEMS
Rubidium (SRS FS725)
PPS
10MHz
USRP B210
SDR
Astronomy Workstation
‘mercurius’
NTP, GPS Locked
RS232
Data + Control + Time
(USB/Ethernet)

Pulsar Flowchart

- Automatically record scans of 1 minute
- Perform folding (without de-dispersion) with above flowchart
- Read start time (ns resolution) from metadata

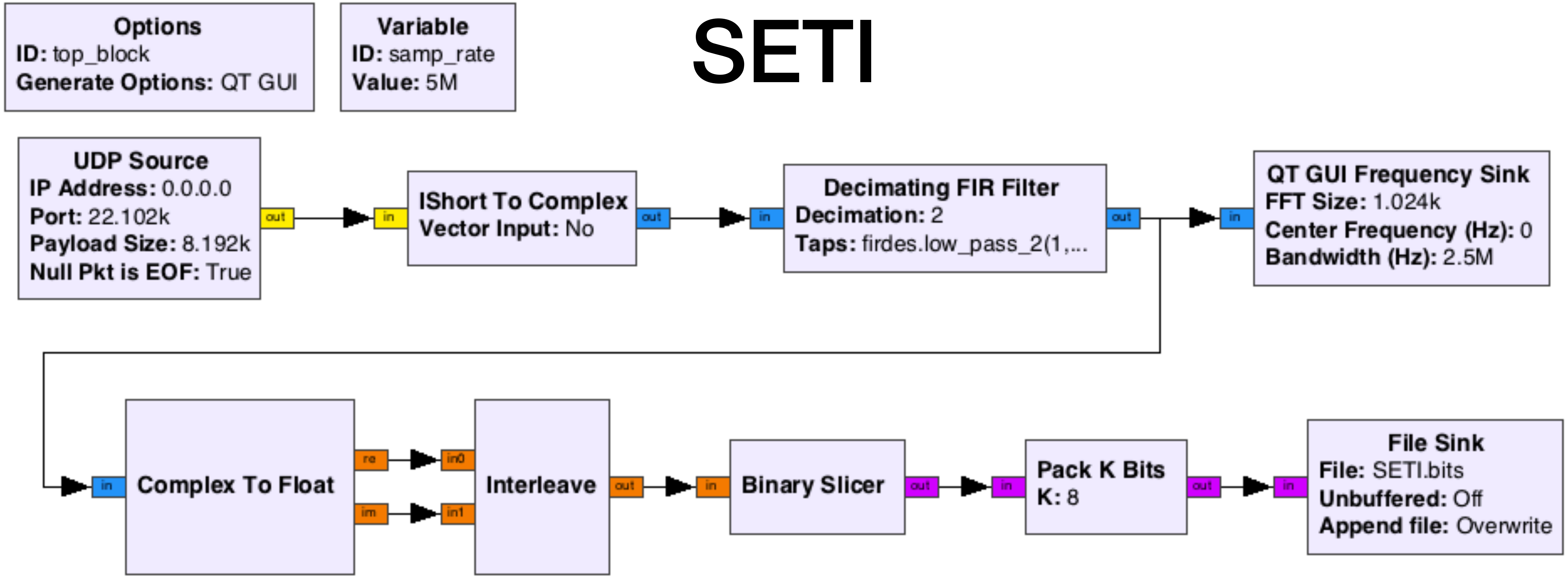


B0329+54

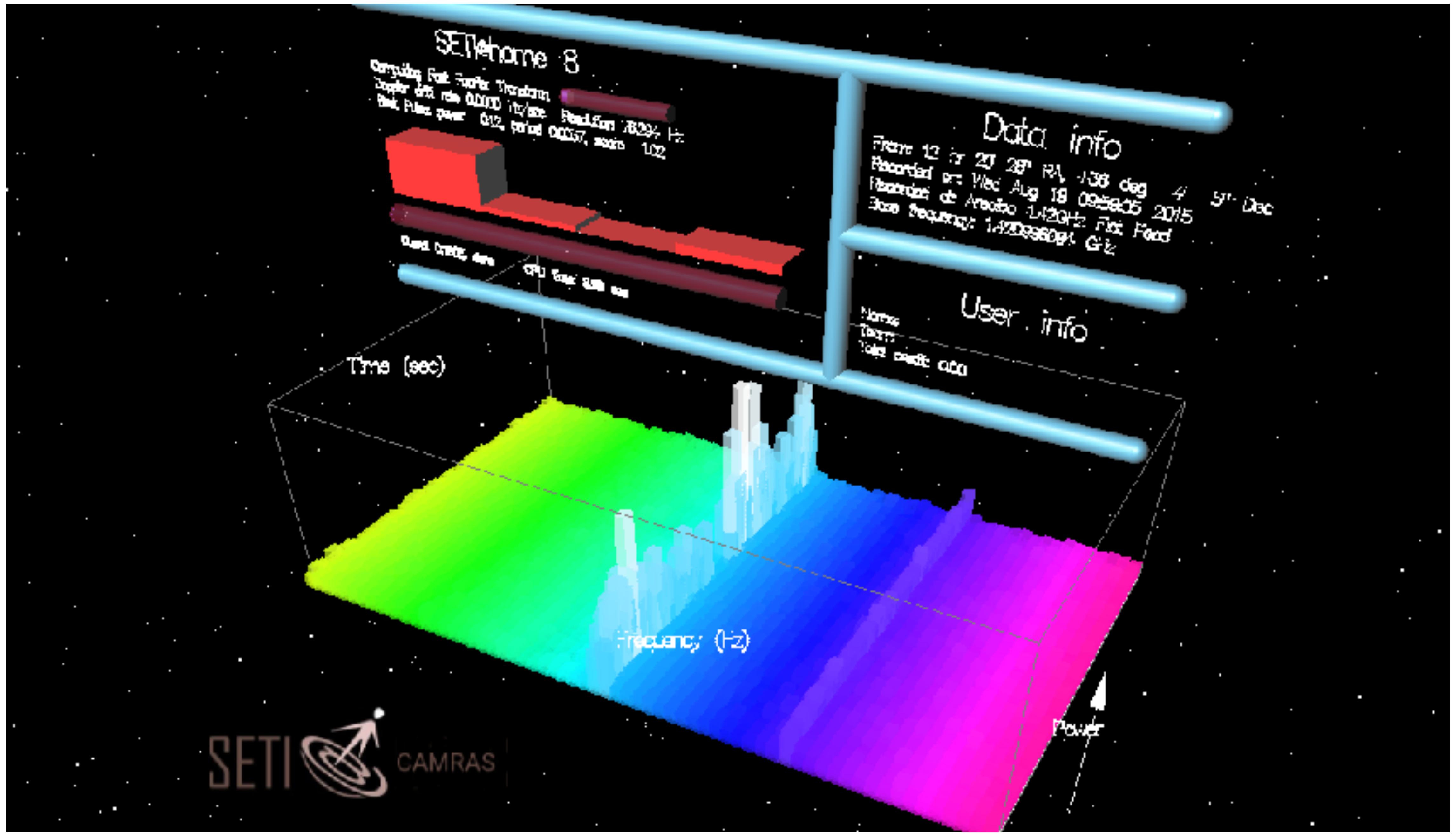
2018-06-28
1330 MHz
10MHz wide
No de-disp.
4 hour obs.
188 records,
1 minute each

P=0.7144921s

SETI



- 2.5 Ms/s IQ data
- 1 bit quantised
- Compatible with SETI@HOME (Berkely) format and tools
- CAMRAS is launching a SETI project



Astronomy and Resolution

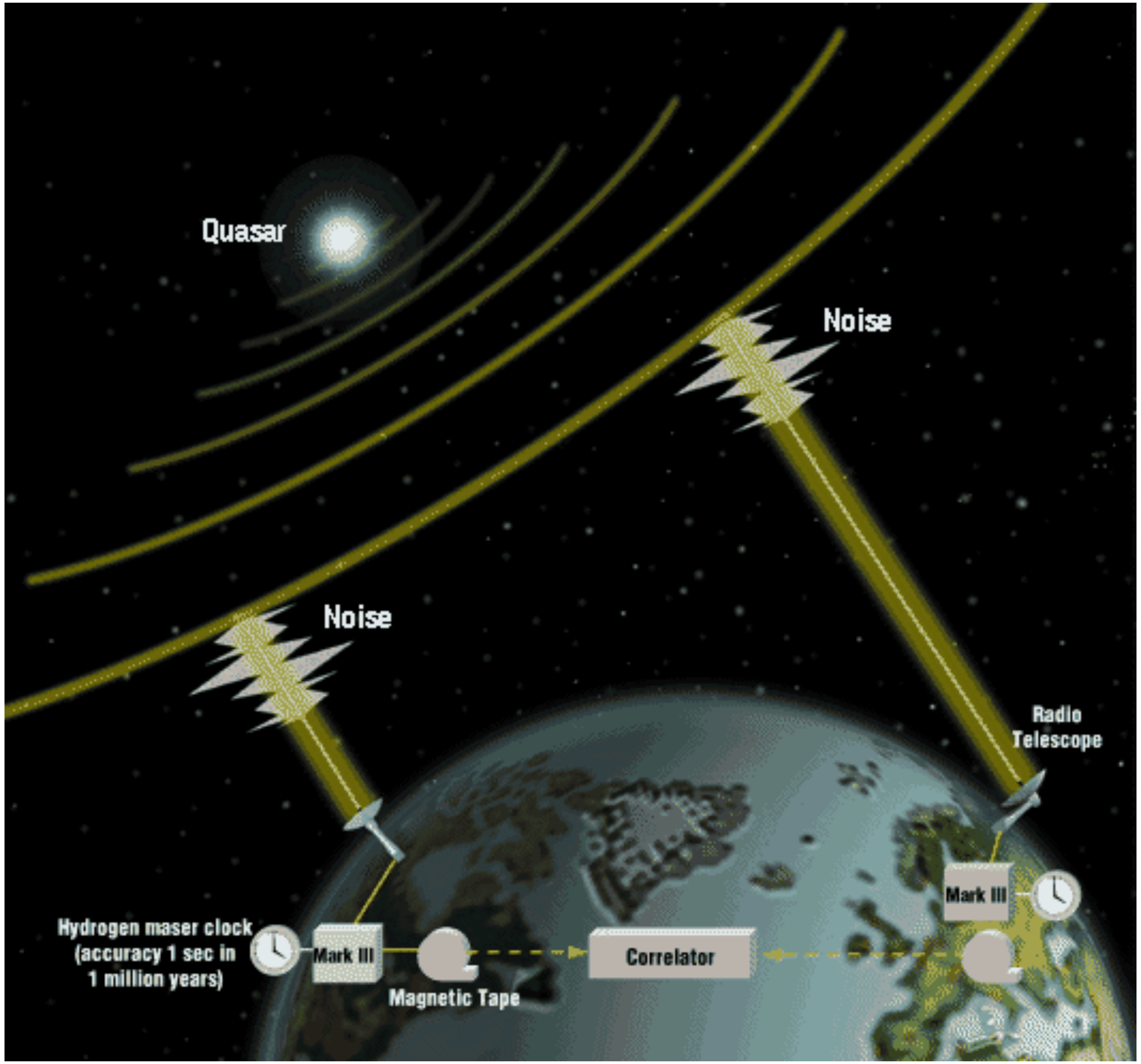
$\theta \approx 1.2\ \lambda/D$ (λ = wavelength, D = diameter)

- λ = 600nm (visible light)
- D = 2.4 m
- θ = 0.06 arcsecond

- λ = 6cm (5 GHz)
- D = 25 m
- θ = 600 arcsecond

Wanted: Dish of 240km ?

Interferometry - VLBI



- Very Long Baseline Interferometry
- Highest Resolution in Astronomy
- Sensitivity goes with √Bandwidth
- Needs very high clock stability:
  - H-maser at every dish
- A virtual dish the size of the Earth
  - And beyond…
- Data recording and transport:
  - 2 bit samples for efficiency
- 1Gb/s or more per dish

JIVE
Joint Institute for VLBI
ERIC

EUROPEAN vlbi NETWORK

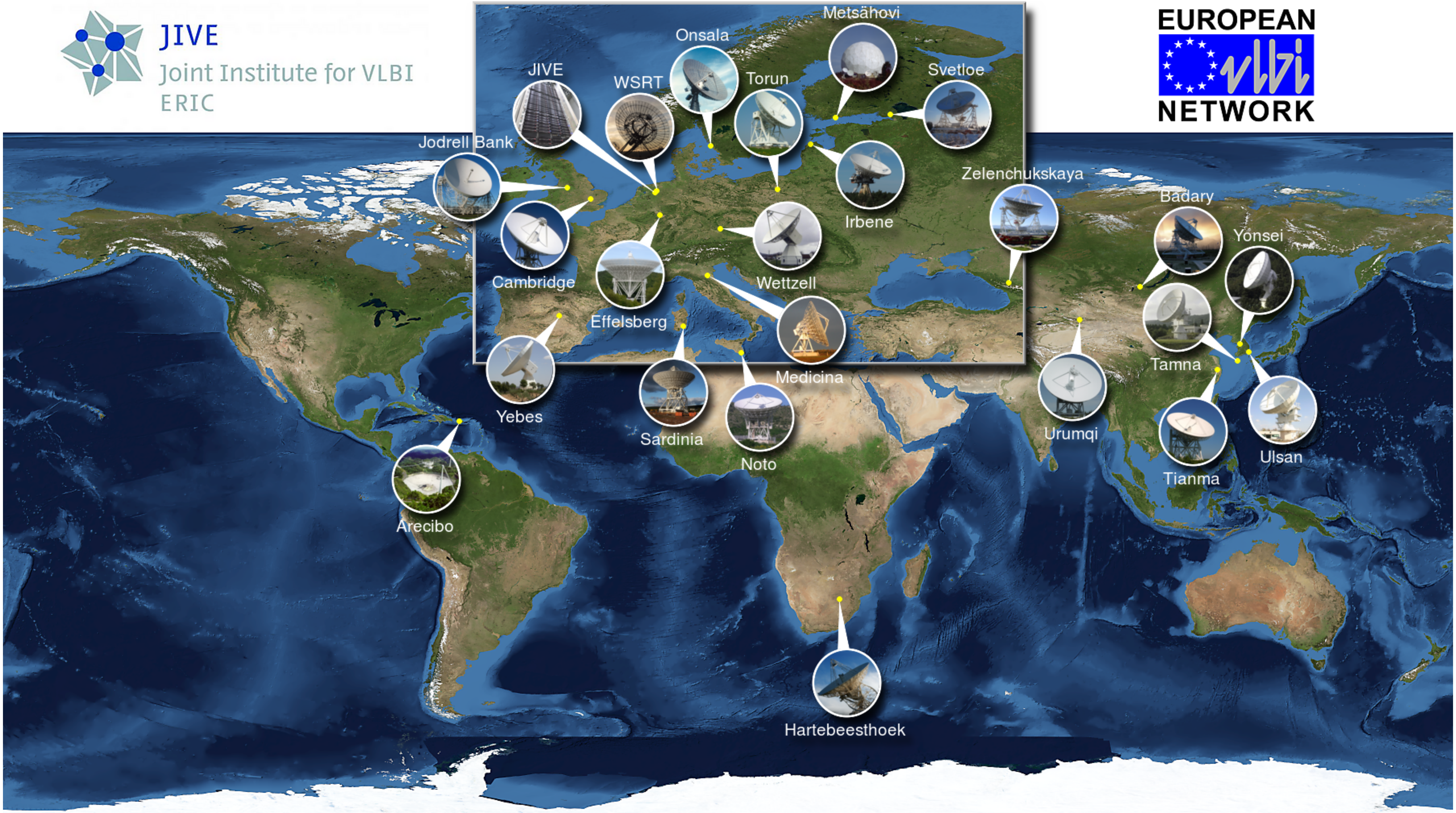
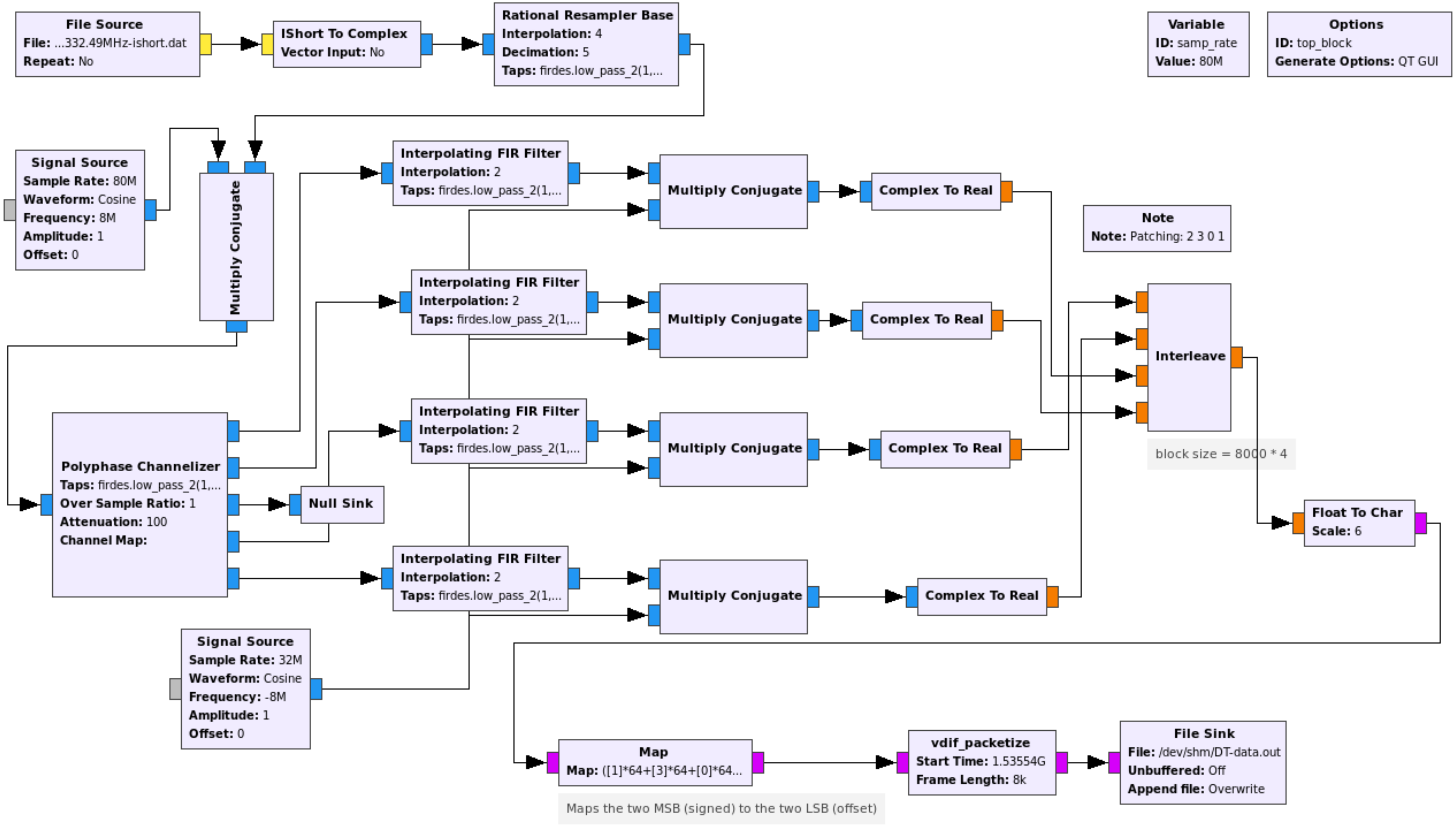


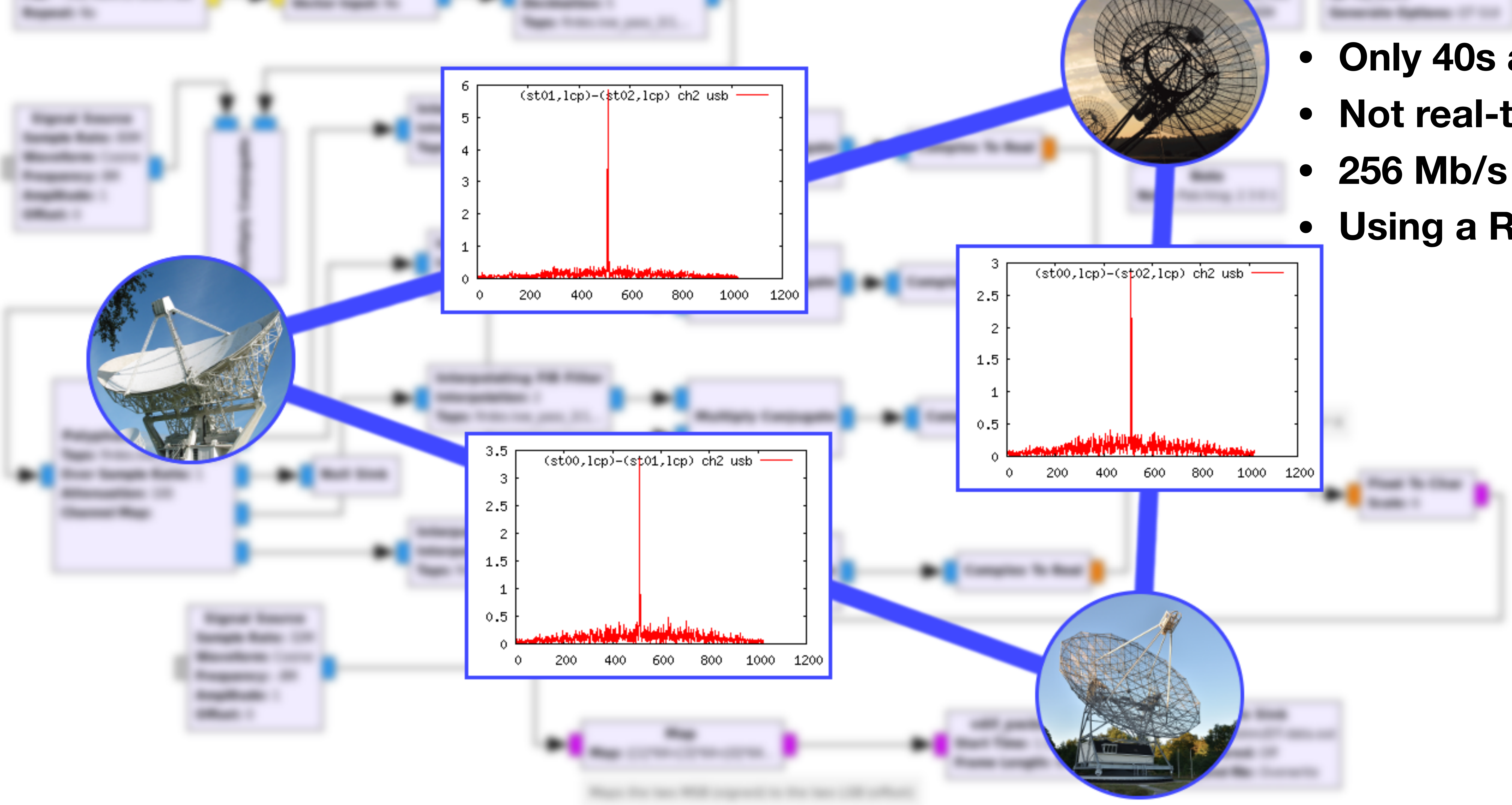
Image by Paul Boven (boven@jive.eu). Satellite image: Blue Marble Next Generation, courtesy of Nasa Visible Earth (visibleearth.nasa.gov).

Dwingeloo VLBI



Dwingeloo VLBI fringes (again) !

2018-08-25



- Only 40s at a time
- Not real-time
- 256 Mb/s (for now)
- Using a Rubidium

White Rabbit

- An open protocol/standard for distributing time and frequency, accurate to 1ns over 10km, to 1000s of nodes

- Initial design at CERN for beam control of the LHC

- ASTERICS project, CLEOPATRA work-package:

- Improvements to add even more stability and longer distance:
  - 165km test, H-maser at
  - WSRT connected to Dwingeloo telescope using shared fiber

ASTERICS is a project supported by the European Commission Framework Programme Horizon 2020 Research and Innovation action under grant agreement n. 653477

New Backend

Ettus X310

- Dual 10Gb/s SFP+
- Big FPGA
- Two TwinRX modules
  - 10 MHz - 6GHz
  - Each 2x 80 MHz Bandwidth

X310

Usage:

- VLBI
  - This will require RFNOC
  - H-Maser clock via White Rabbit
  - Part of H2020 Asterics project
- All our usual observations, and much more

TwinRX

Upcoming Work

- Dig 300m fiber
  - Connect Astron to DT
- 510m fiber, 144 strands
- Connect H-Maser to DT

- Firmware for real-time VLBI


Questions?