

Dwingeloo
goes SDR

Paul Boven
PE1NUT

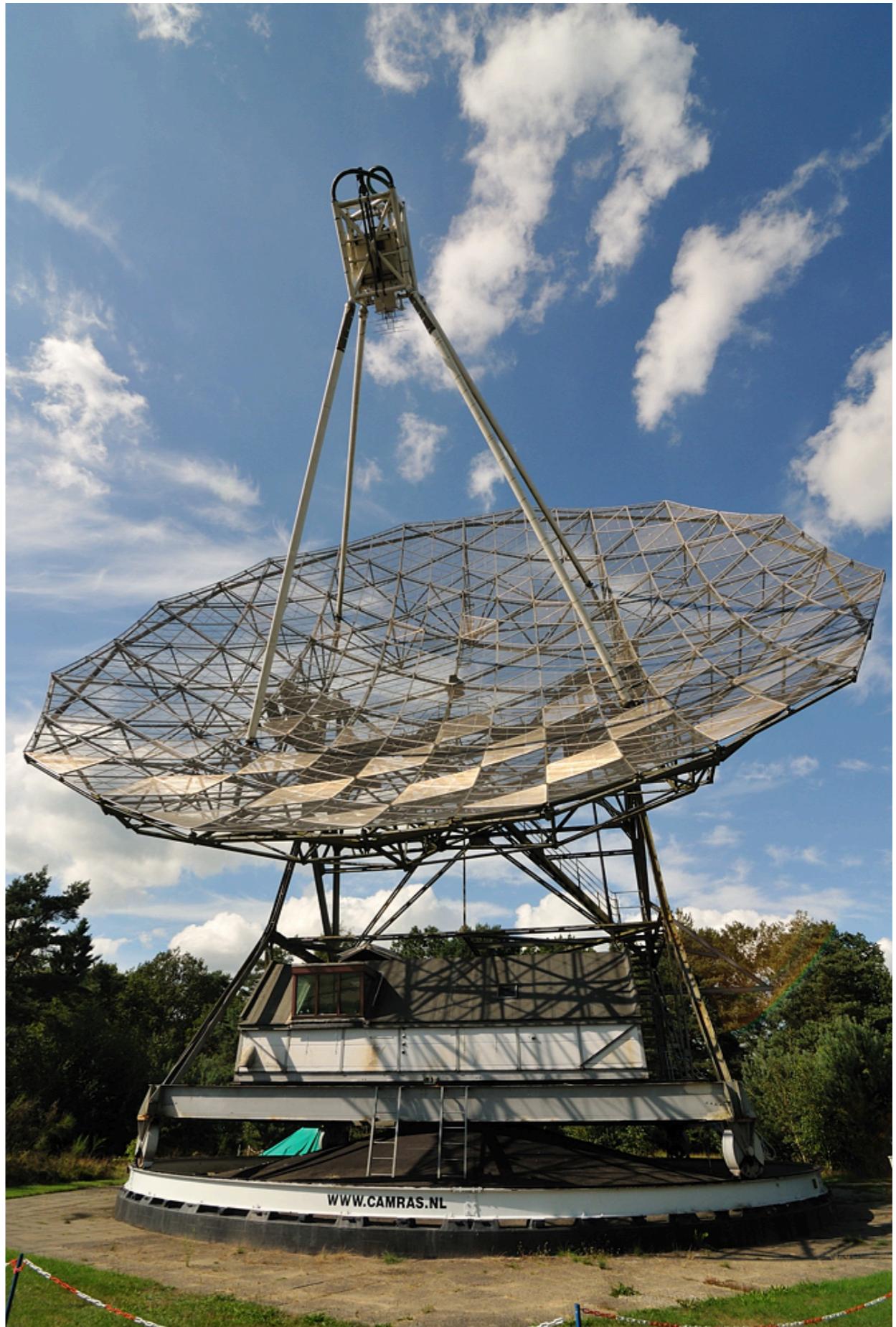
The Dwingeloo Radiotelescope

- 12 April 1956:
Opening by Queen Juliana
- 25m Diameter
- Stainless mesh 7.7mm
- Rails: 12m diameter
- 120 ton
- Azimuth: 540°
- Elevation: 0° - 90°



CAMRAS

- Foundation: C.A. Muller Radioastronomy Station
- Named after prof. Lex Muller (PA0CAM)
- Founded in 2007
- Over 300 sponsors
- About 50 volunteers
- Radio amateurs, amateur astronomers, mechanics, teachers, ...



(Some of) Our Volunteers



Telescope restoration completed, reopened in 2014

CAMRAS

C. A. Muller Radio Astronomy Station

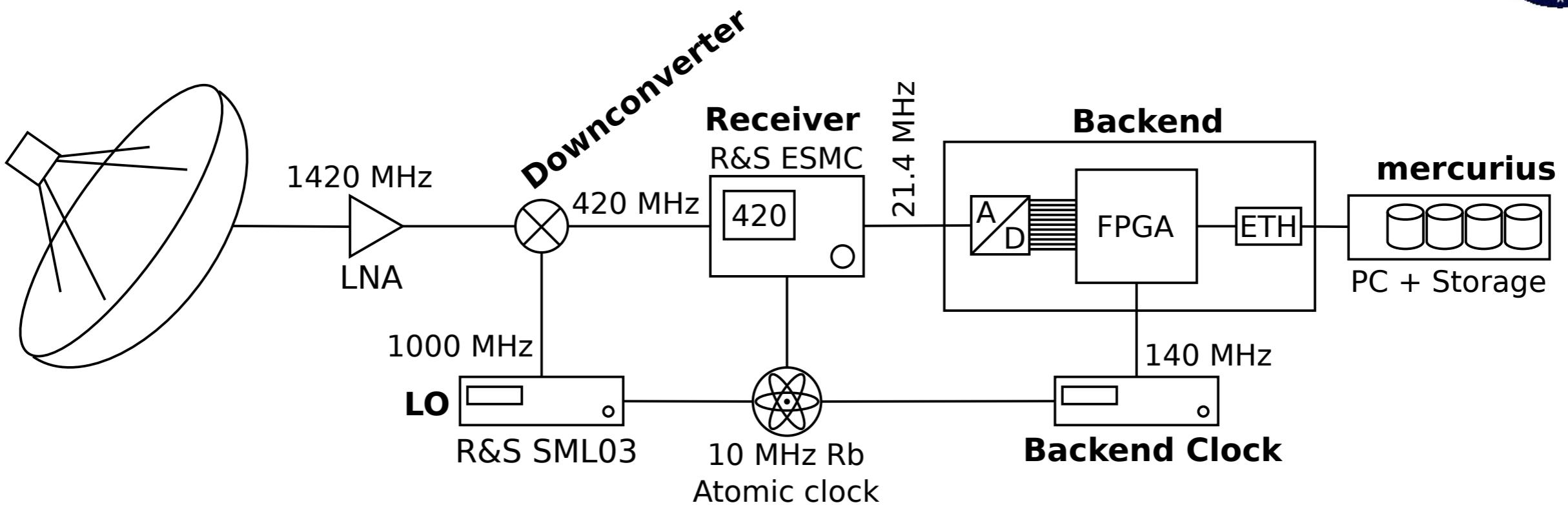


Our three goals:

- Making the Dwingeloo Radio telescope available to the communities of amateur astronomers and radio amateurs
- Stimulating interest in science and technology, in particular for youth, by offering access to the Dwingeloo Telescope
- Preserving and maintaining the Dwingeloo Telescope as an industrial and scientific monument

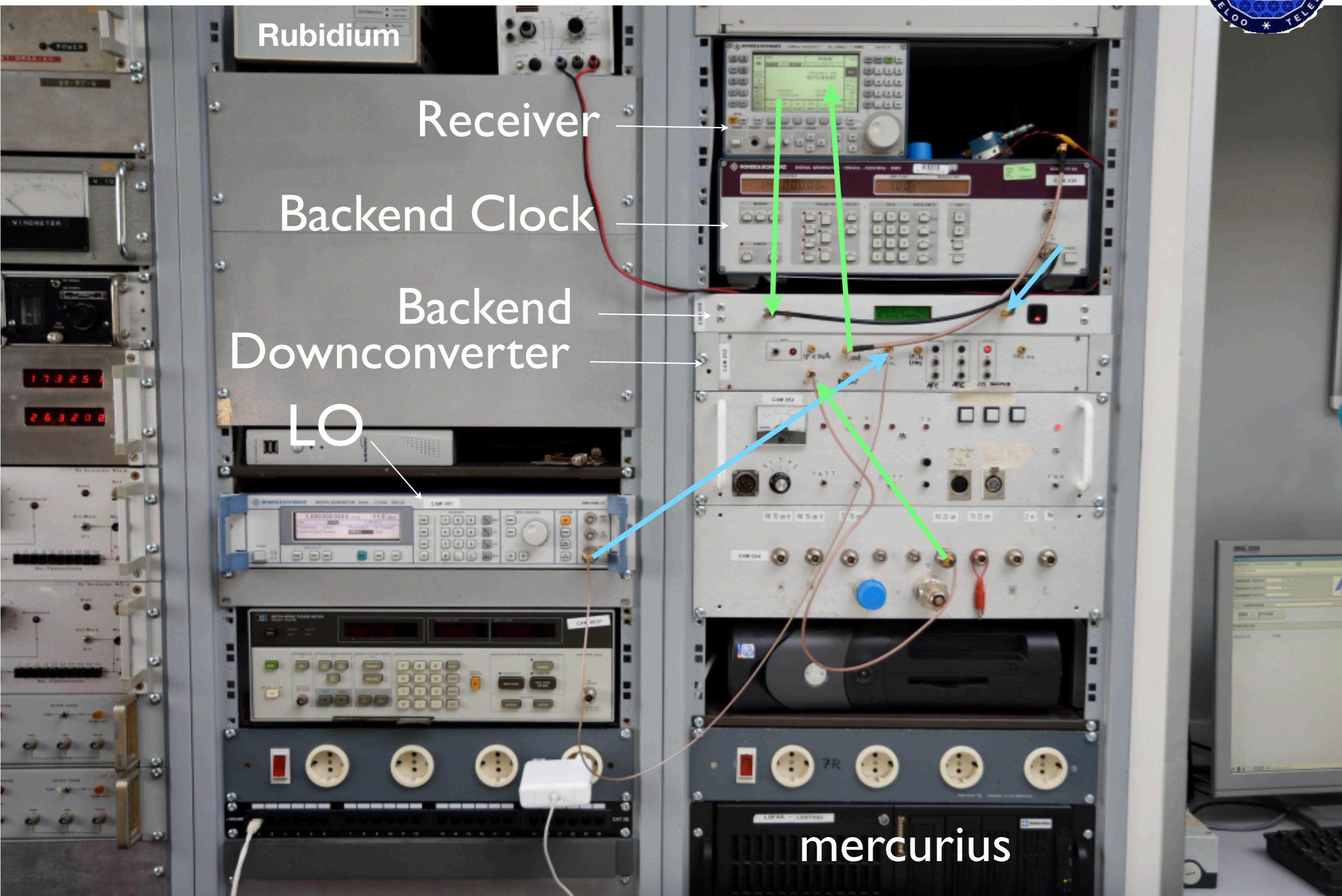


Signal Flow

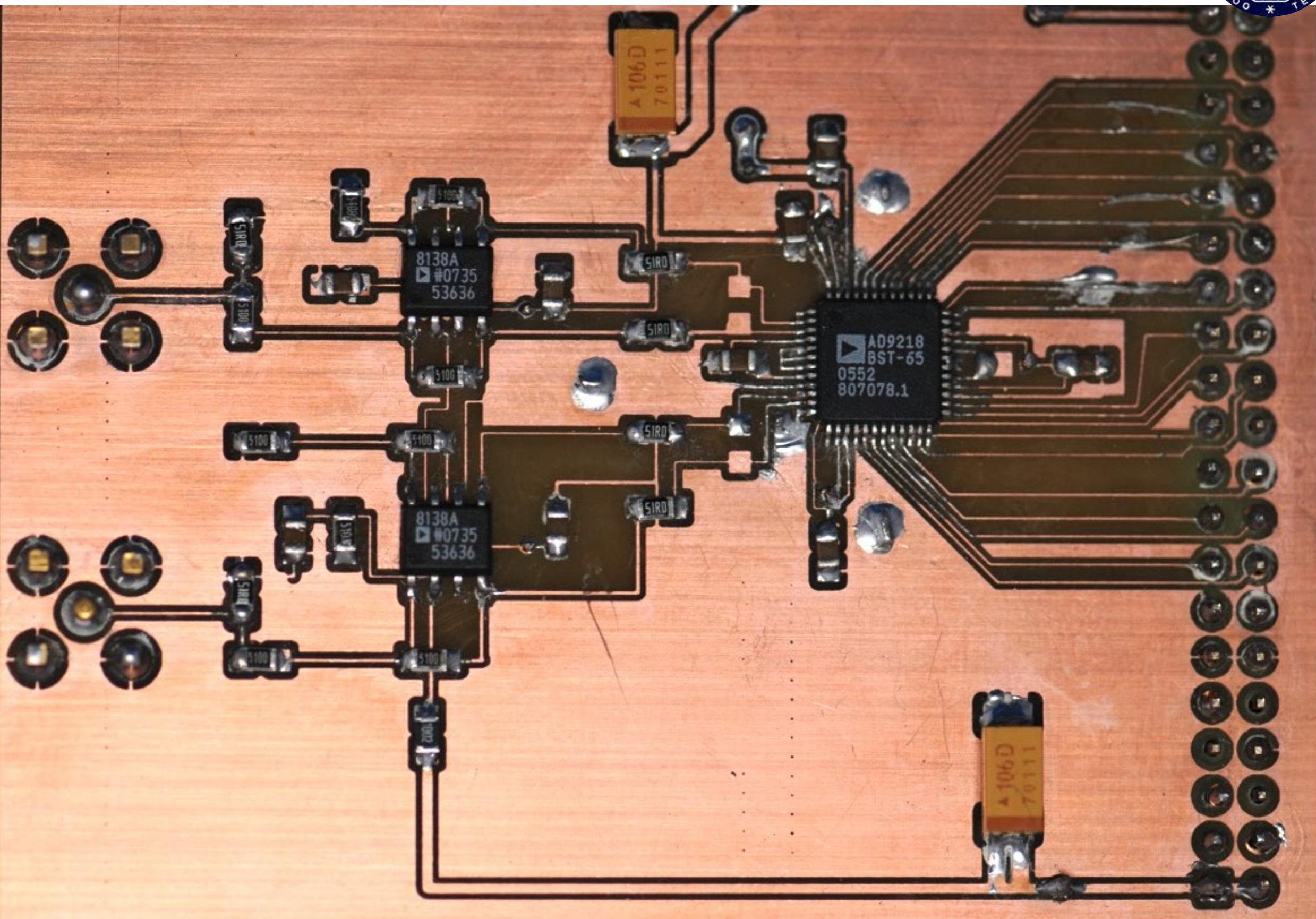


- Signal gets converted from 1420 MHz to 21.4 MHz
 - Intermediate step of 420 MHz
- IF Bandwidth: ~25 MHz centered at 21.4 MHz
- Backend: Sampling at 70 MHz

Signal Chain (inside the telescope)

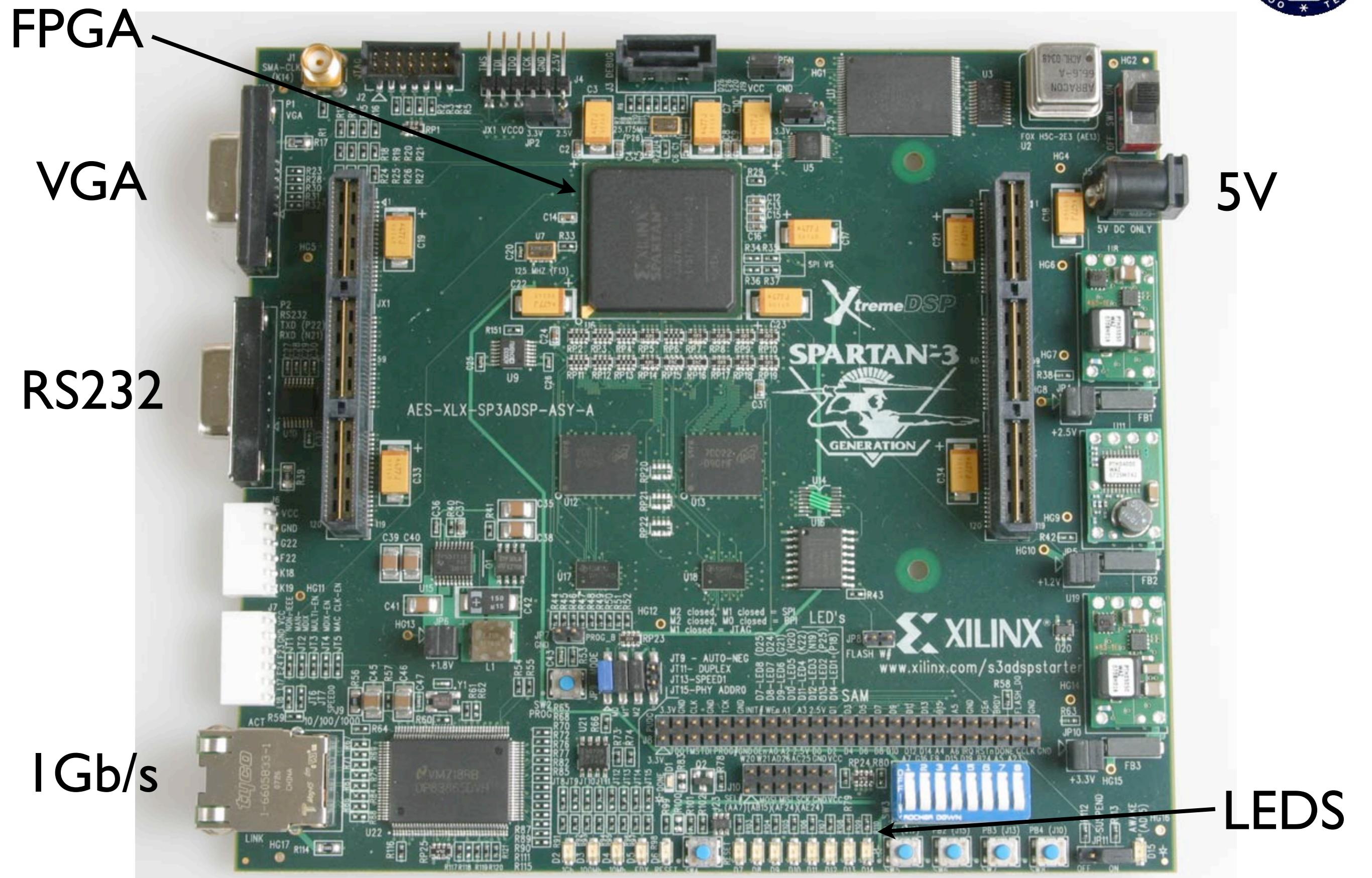


AD9218 65MHz dual 10bit A/D converter



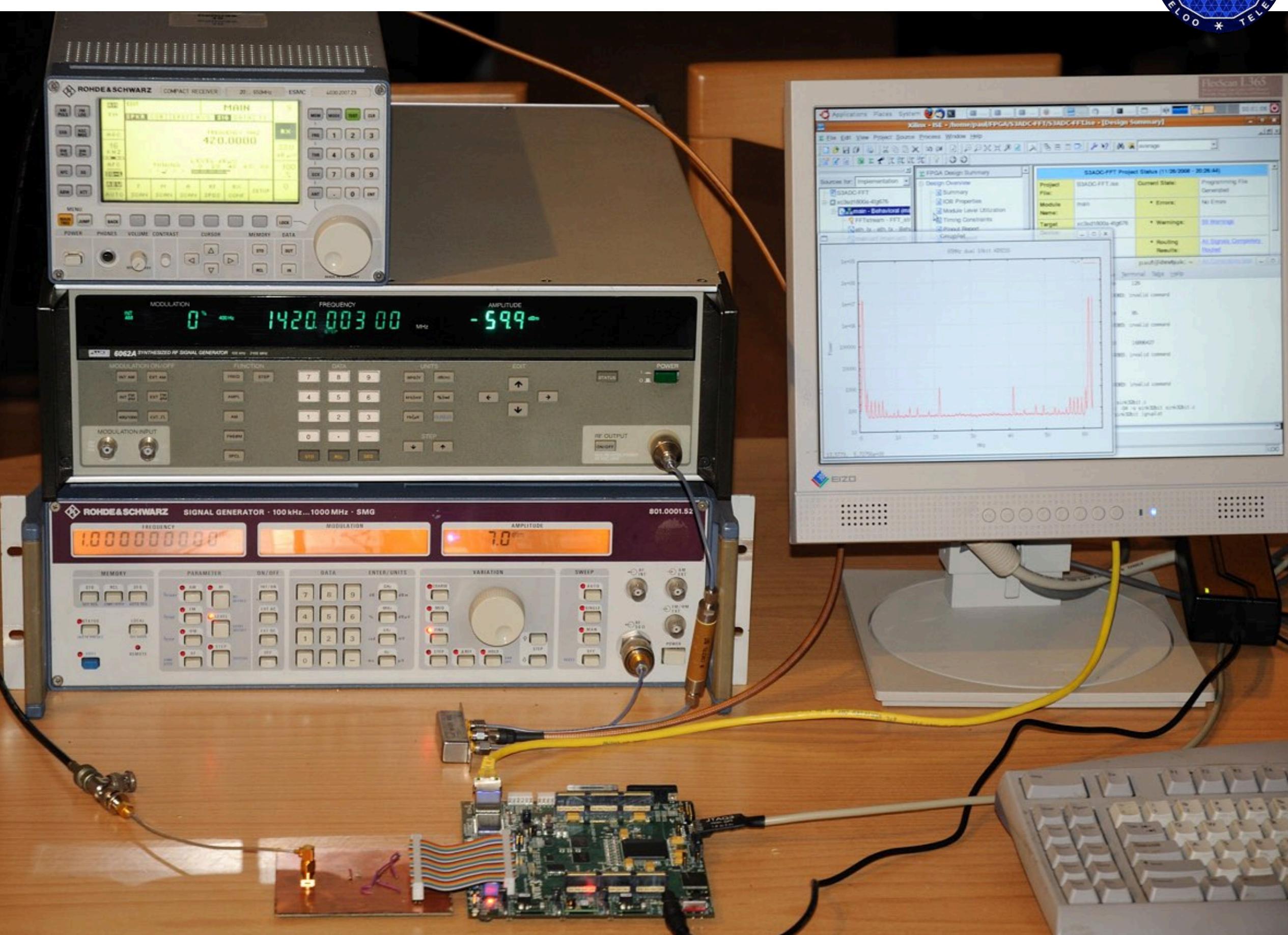


Xilinx Spartan-3A DSP starter kit





On my Kitchen Table (2008)





Boxed (2010)

JTAG
(Parallel) Fuse Mains

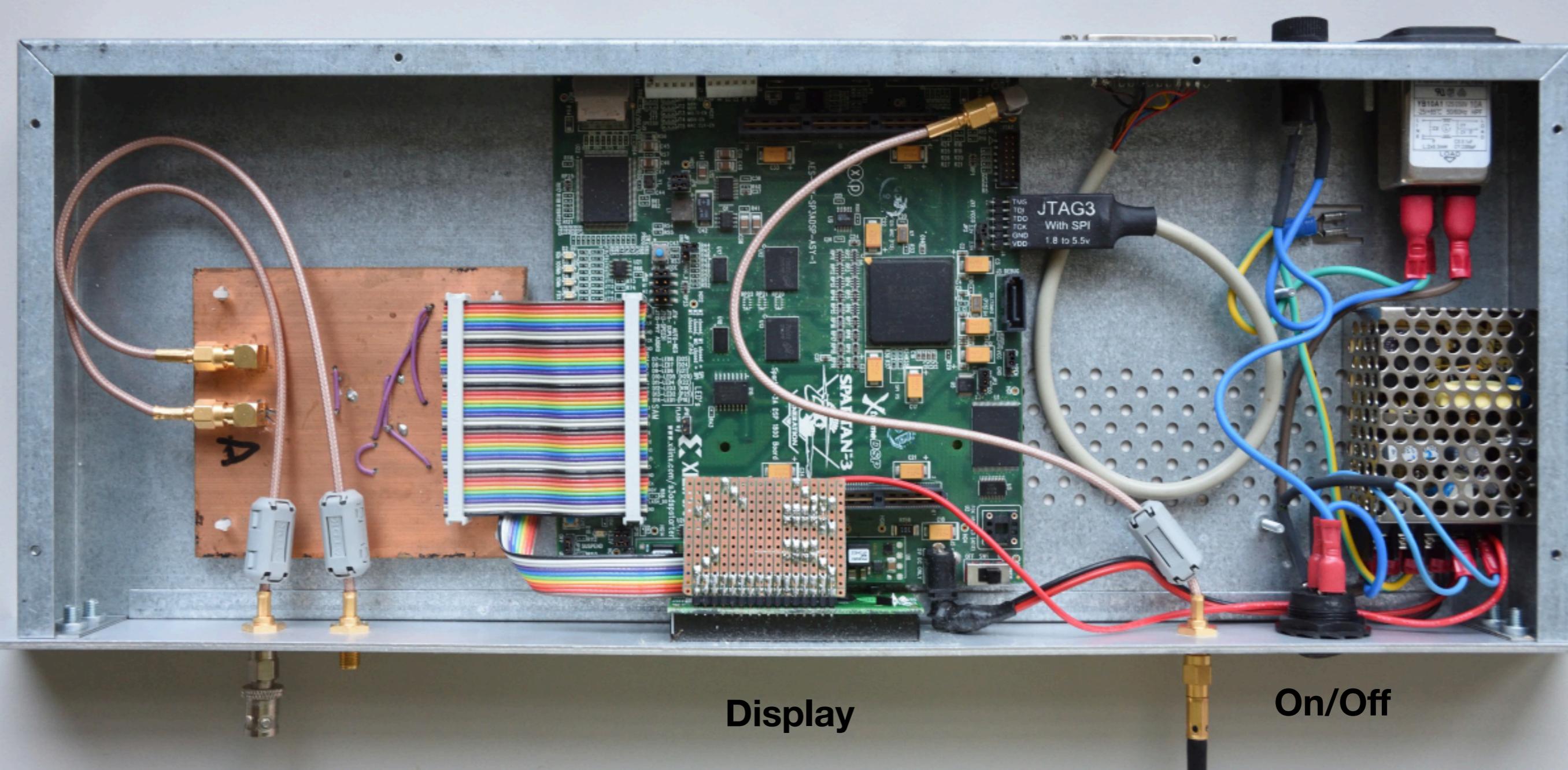
Ethernet

Inputs

Display

Clock

On/Off



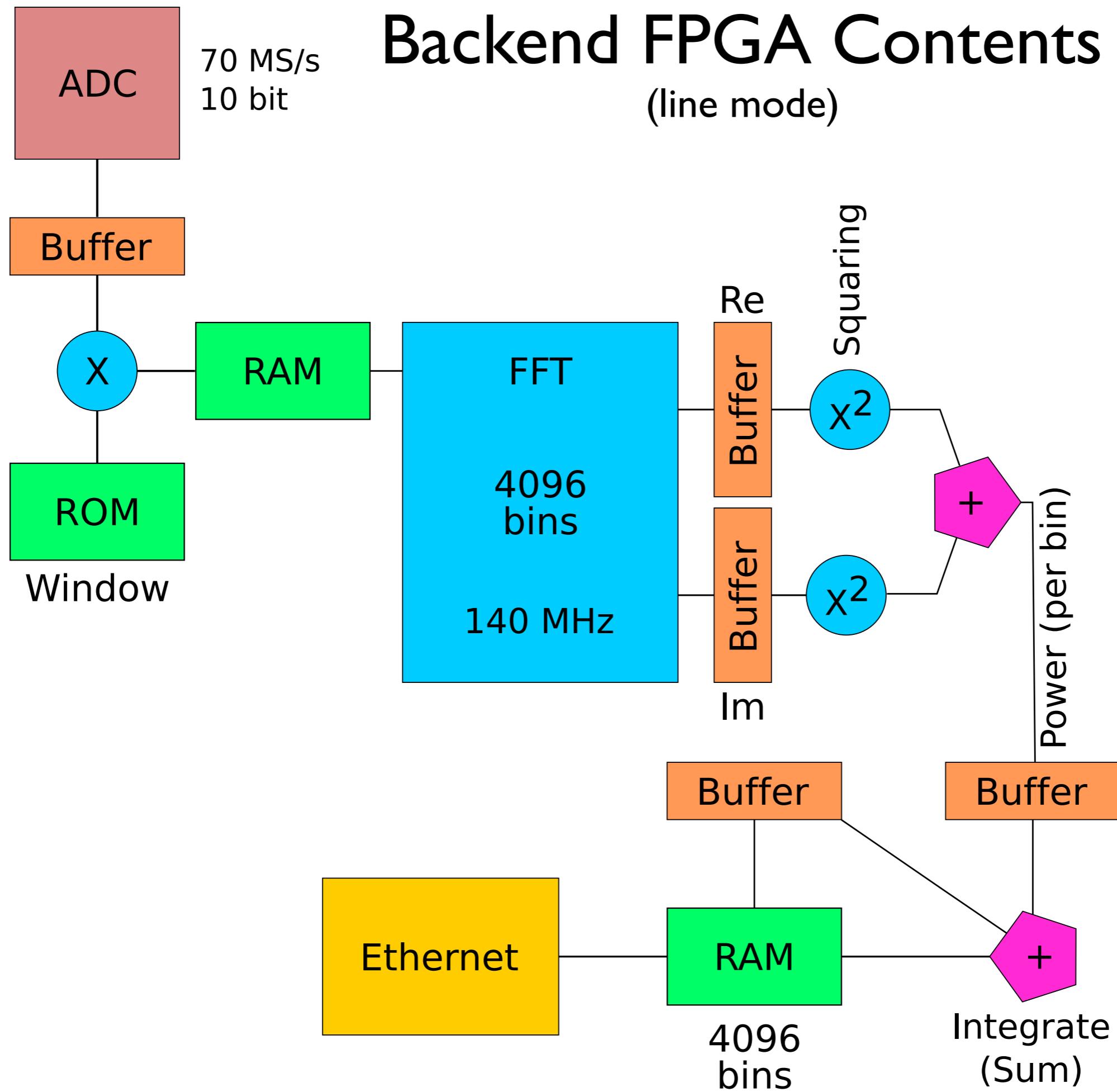


Pulsar Mode v0.2
256bins 140MHz /



Backend FPGA Contents

(line mode)



Personalities for the Backend



Pulsar mode

- 512 samples, 256 bins, 64 integrations
- 137 kHz resolution
- 2136 spectra per second

Pulsar Mode v0.2
256bins 140MHz -

Line mode

- 4096 samples, 2048 bins, 64 integrations
- 17.1 kHz resolution
- 267 spectra per second

Line Mode v0.2
4k bins 140MHz -

Raw mode (ADC mode)

- 70M samples / second, 10 bit
- Sends 700Mb/s to RAID server
- 300GB per hour

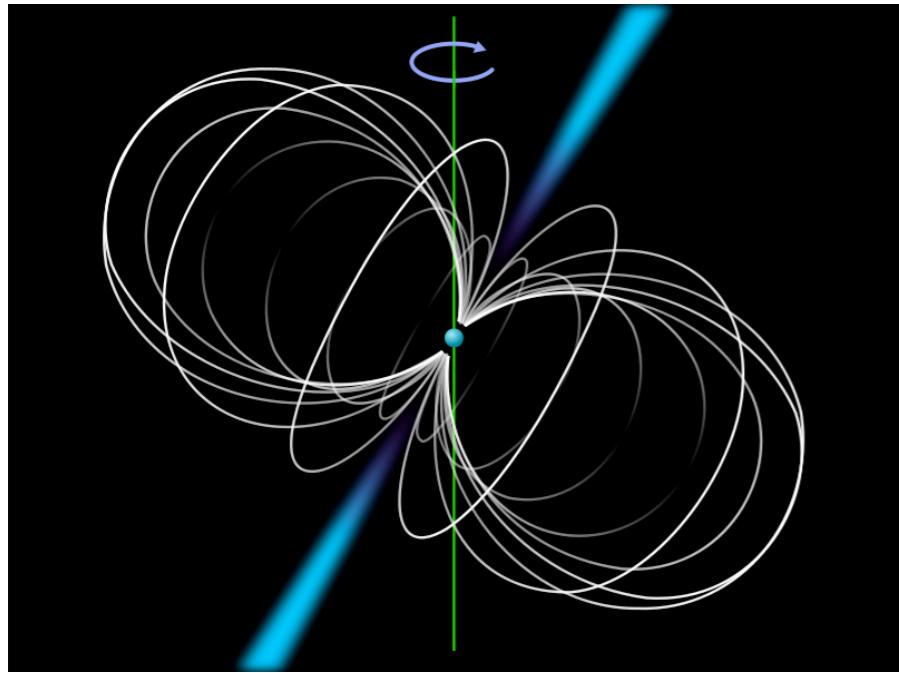
ADC Mode v0.1
1Gb/s 140MHz



Rotating line shows that
the backend is active

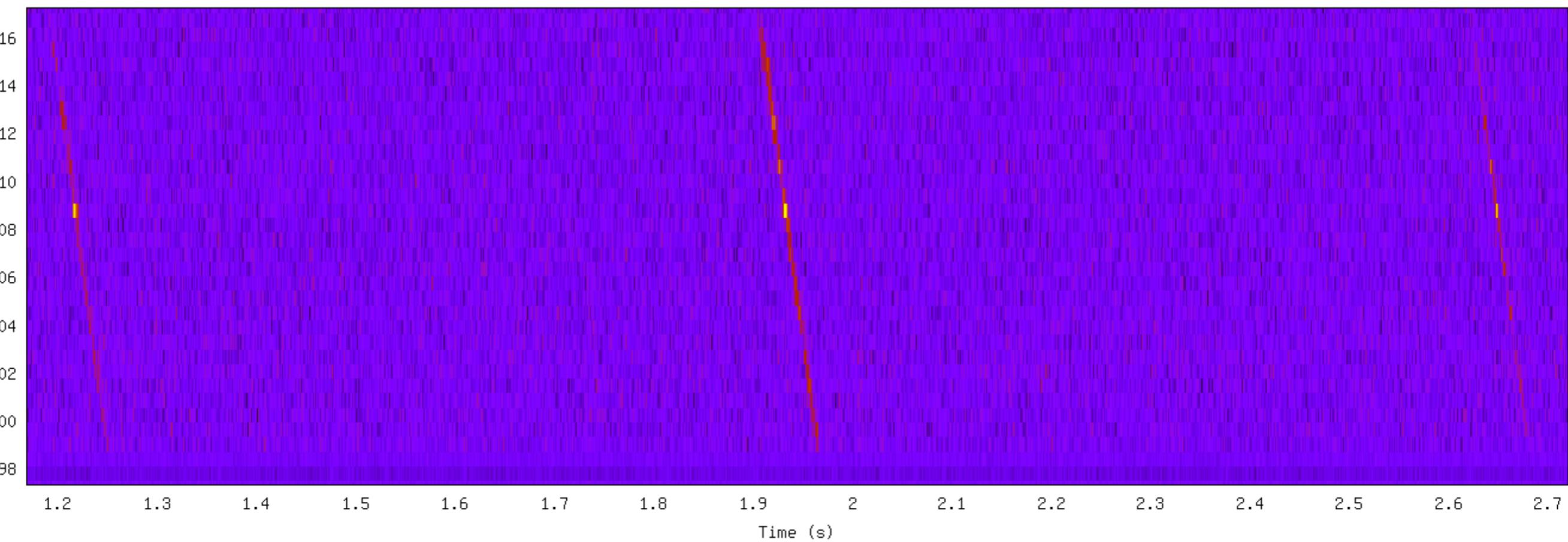


Pulsars



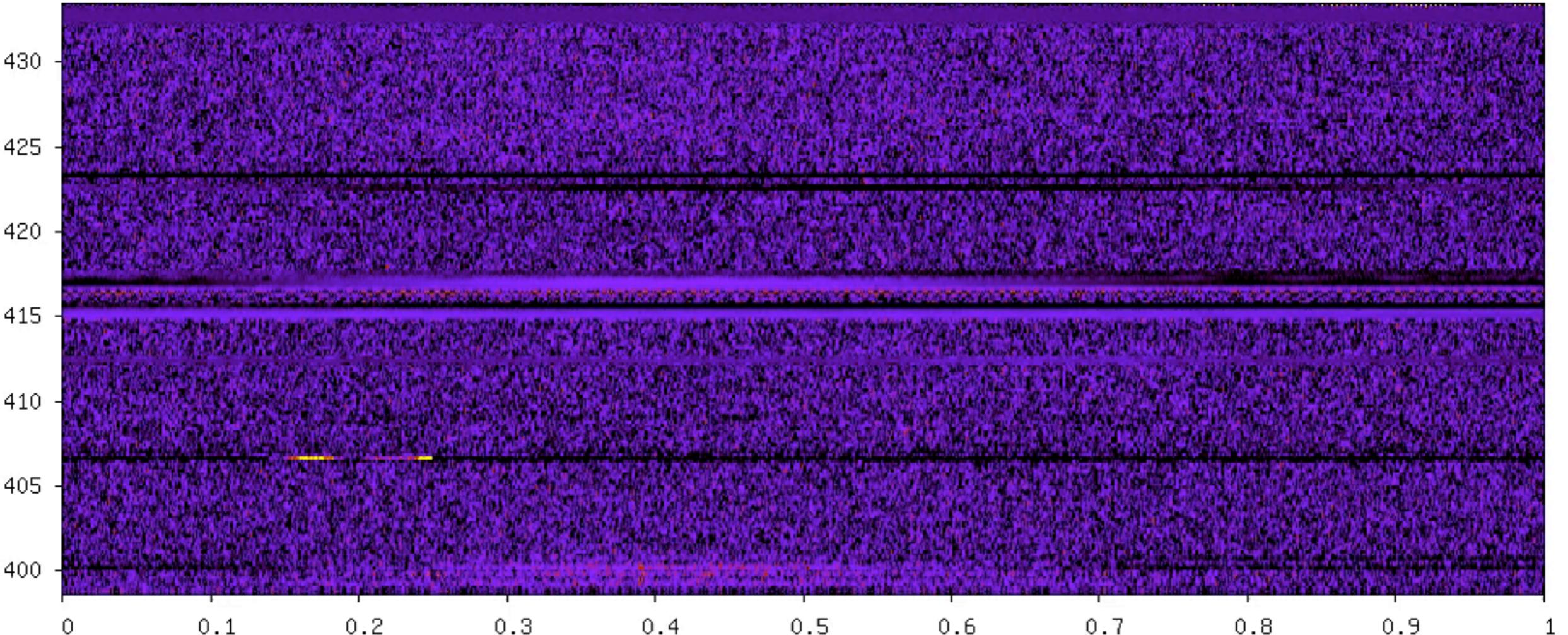
- Stellar Core Remnant
- Result of Supernova Explosion
- Mass: app 1.4 x Sun
- Diameter: 20km
 - Extremely Dense
- Rotating Lighthouse
- Delay depends on frequency (dispersion)

PSR B0329+54 single pulses, 610kHz bins - 2009-10-15 www.camras.nl



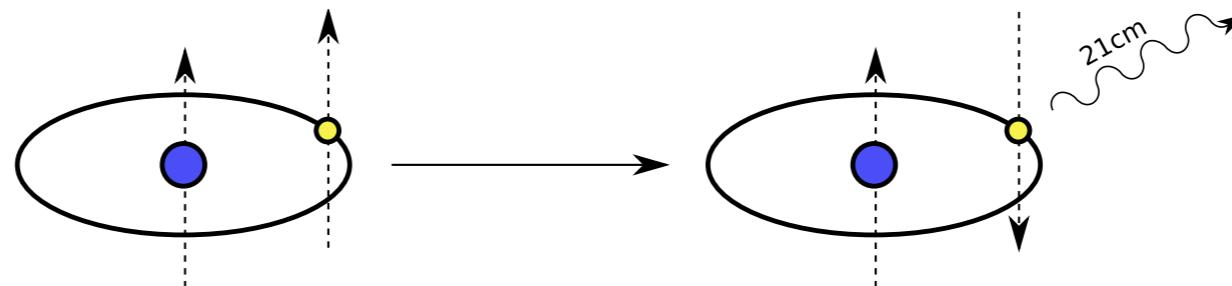
B0329+54

B0329+54 2010-03-15, sec. 0.00



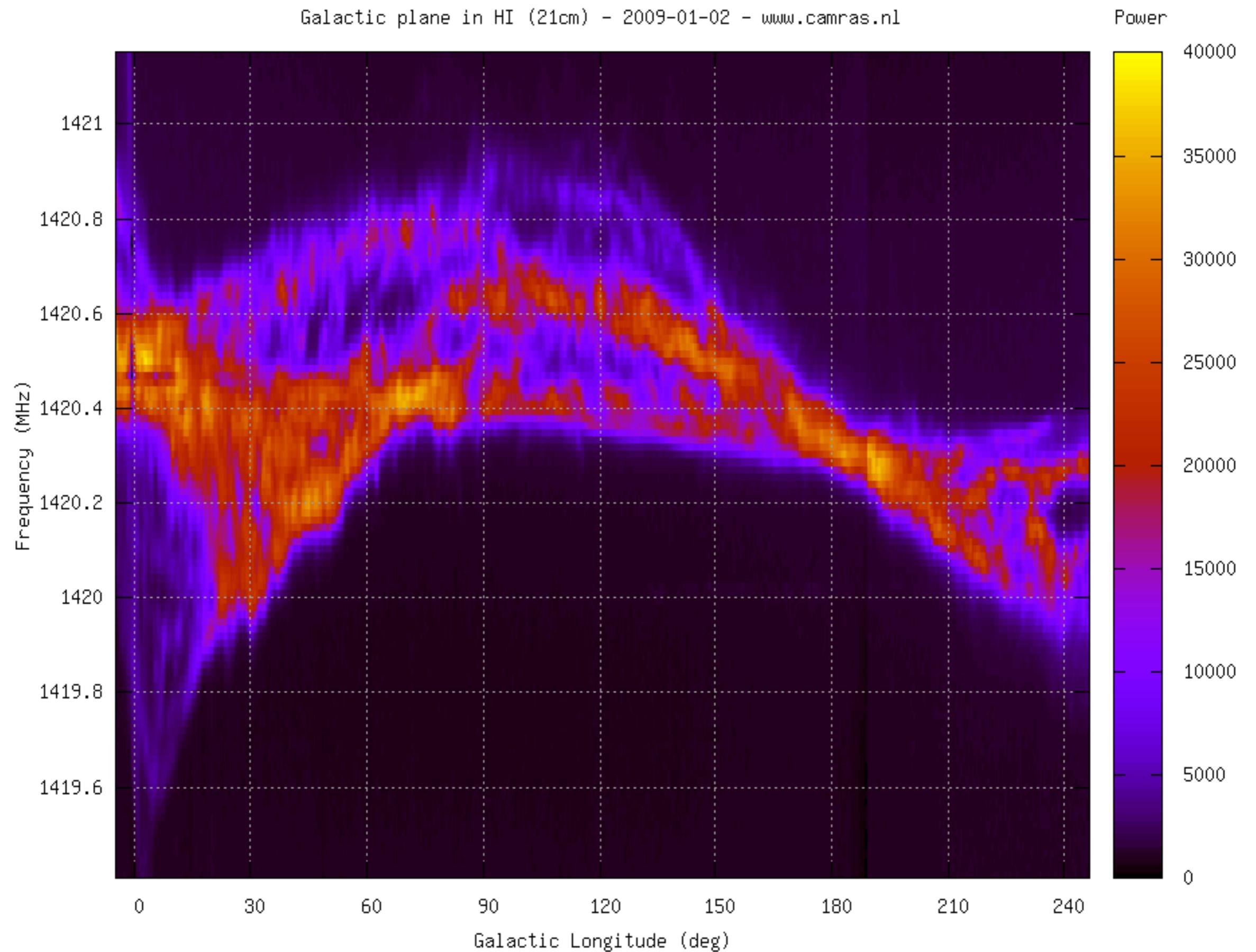
- Brightest Pulsar of the Northern Hemisphere
- Distance: 3460 lightyears
- $P = 0.71452\text{s}$
- We can detect single pulses
- And make them audible

Hydrogen (HI)



- Most abundant element in the universe
- Concentrated in Galaxies, low density ($1 / \text{cm}^3$)
- Two spin states with very small energy difference
- ‘Forbidden’ transition: half-life 11 million years
- 1.420.405.575 Hz (21cm)
- Predicted by H. C. van de Hulst
- Observed Frequency depends on Doppler Shift

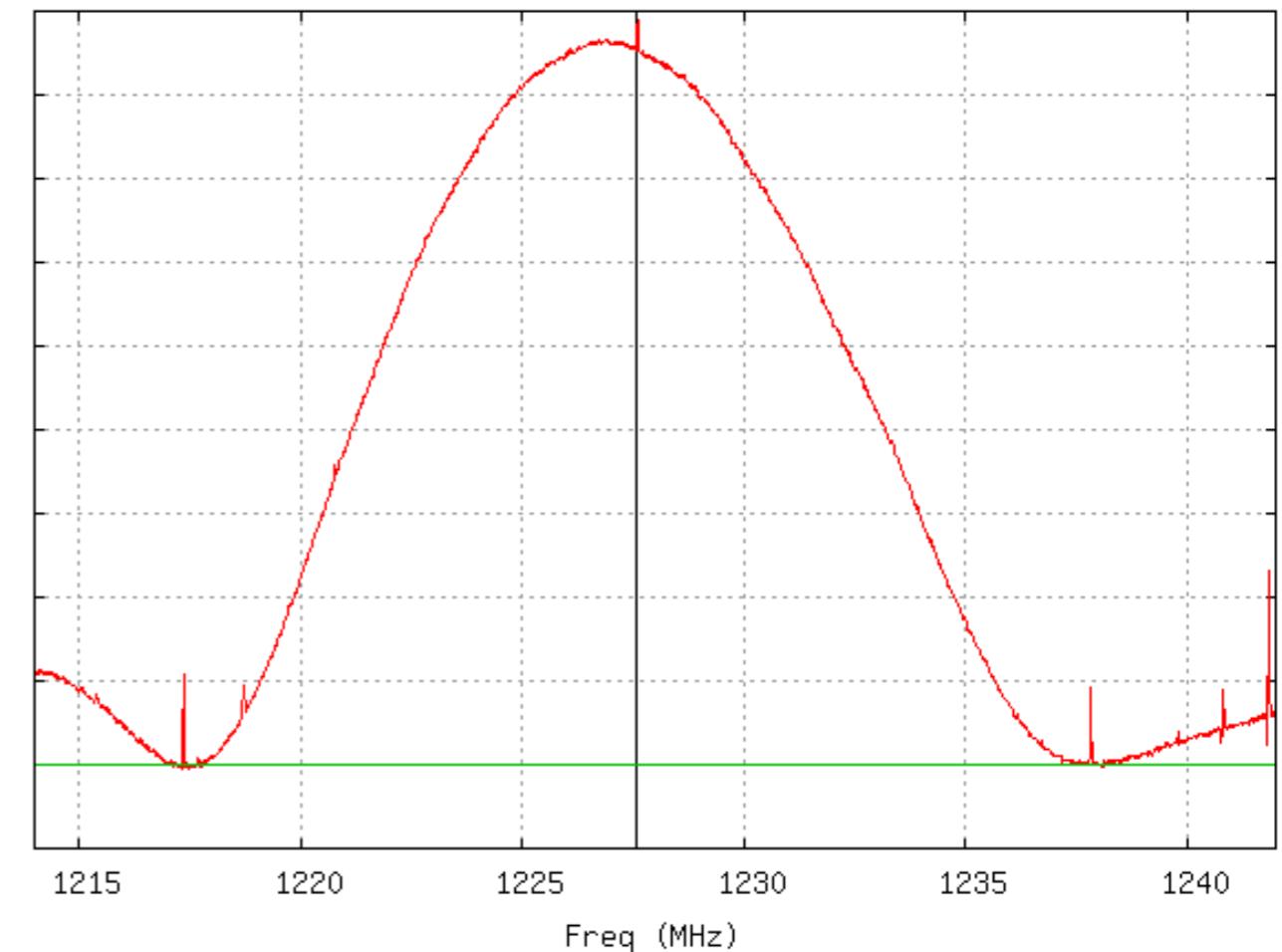
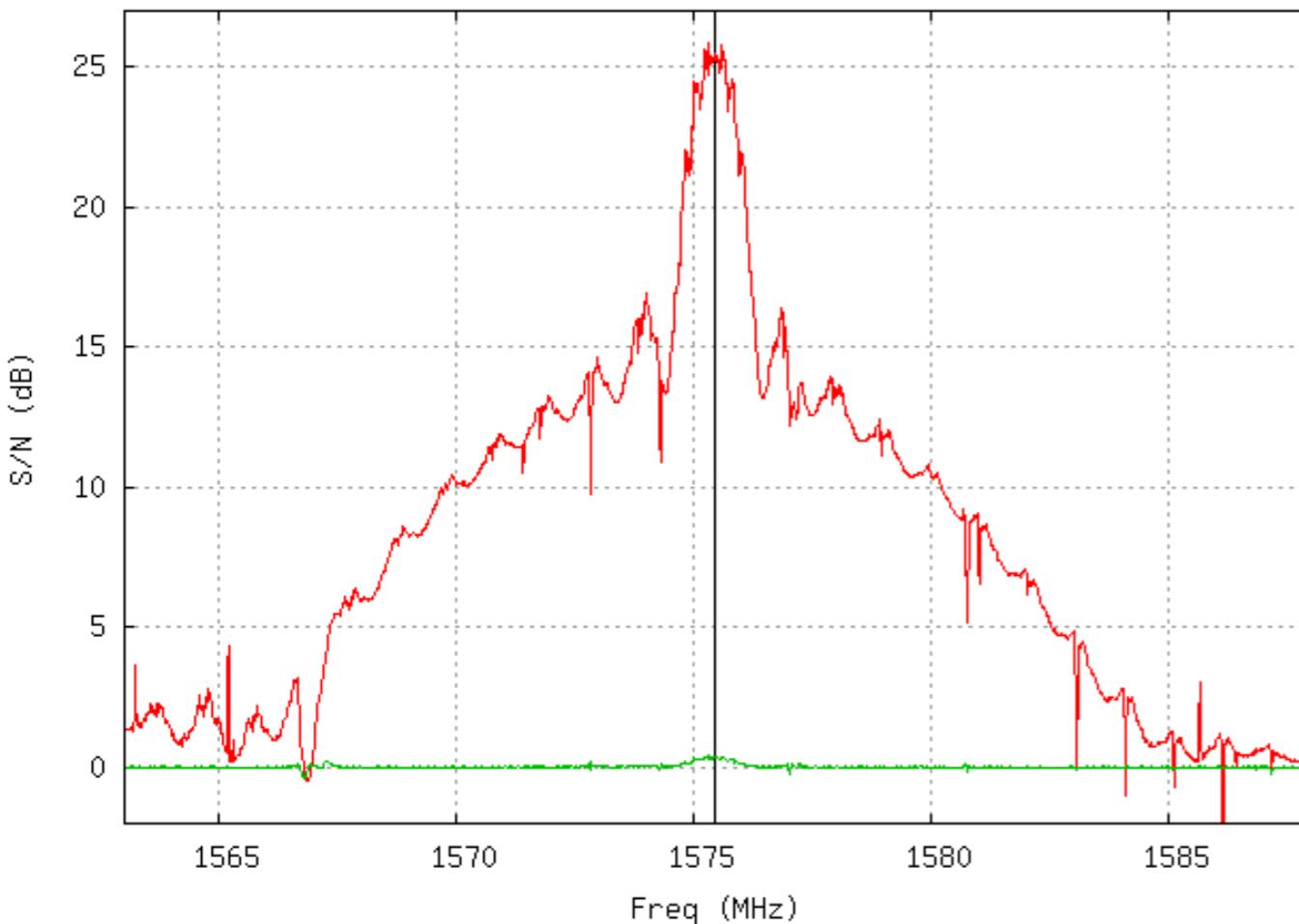
Hydrogen Signal in the Galactic Plane



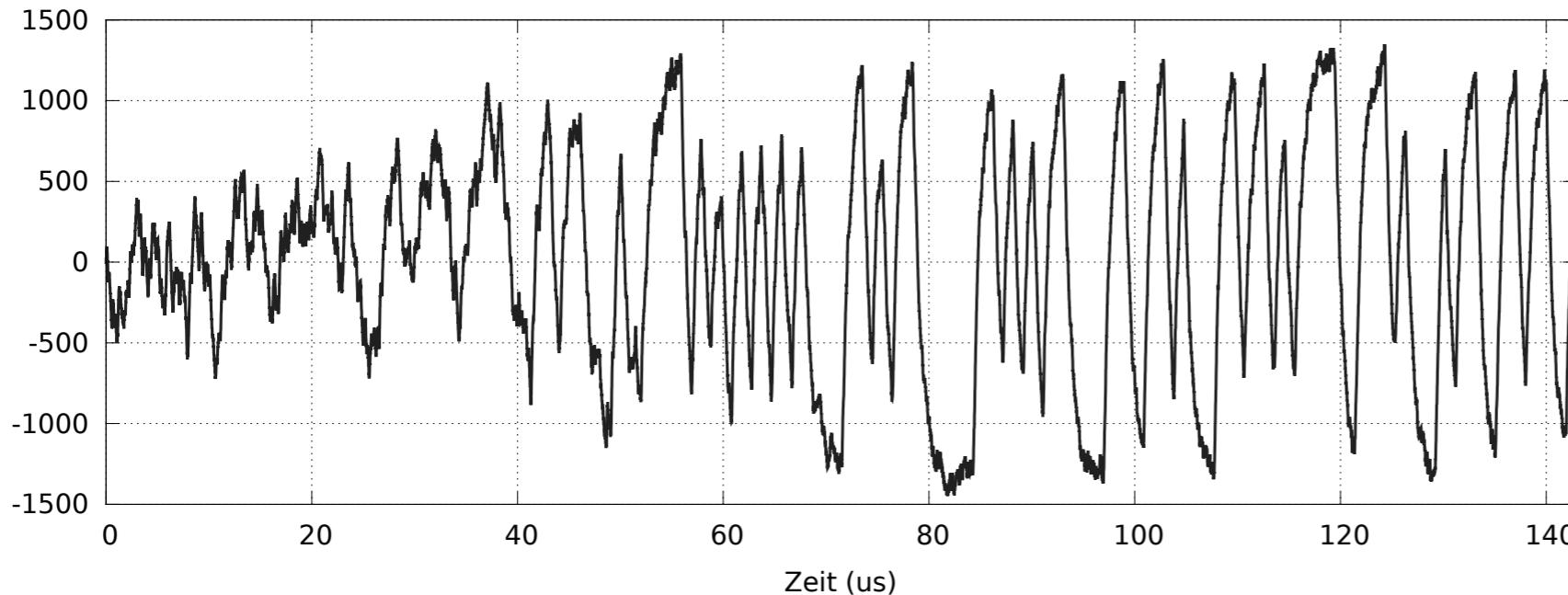
GPS L1 and L2 signals

GPS Navstar 43 2011-21-15 www.camras.nl

GPS Navstar 43 2011-12-21 www.camras.nl

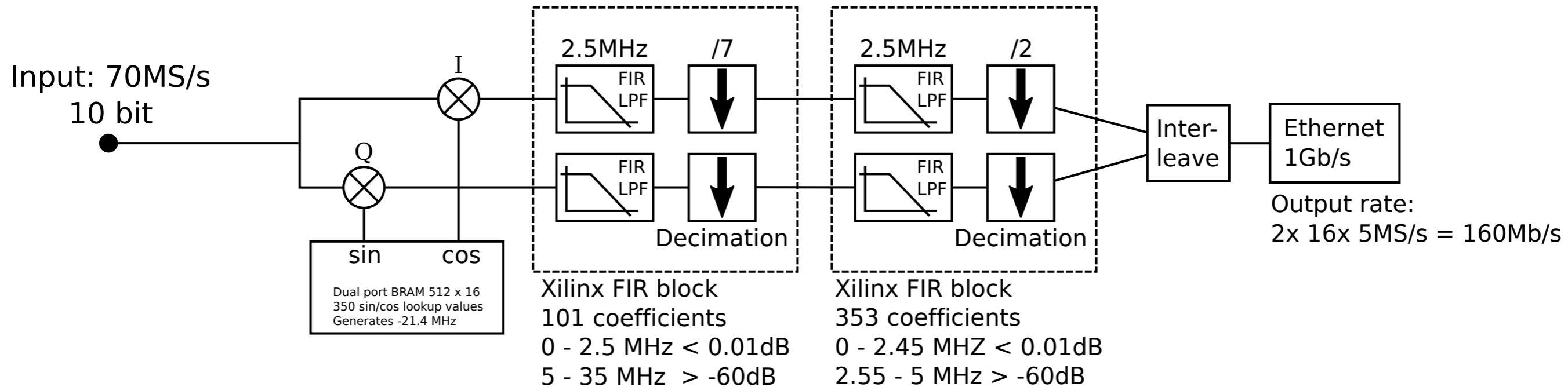


- We can see individual bits - before de-spreading using a simple COSTAS

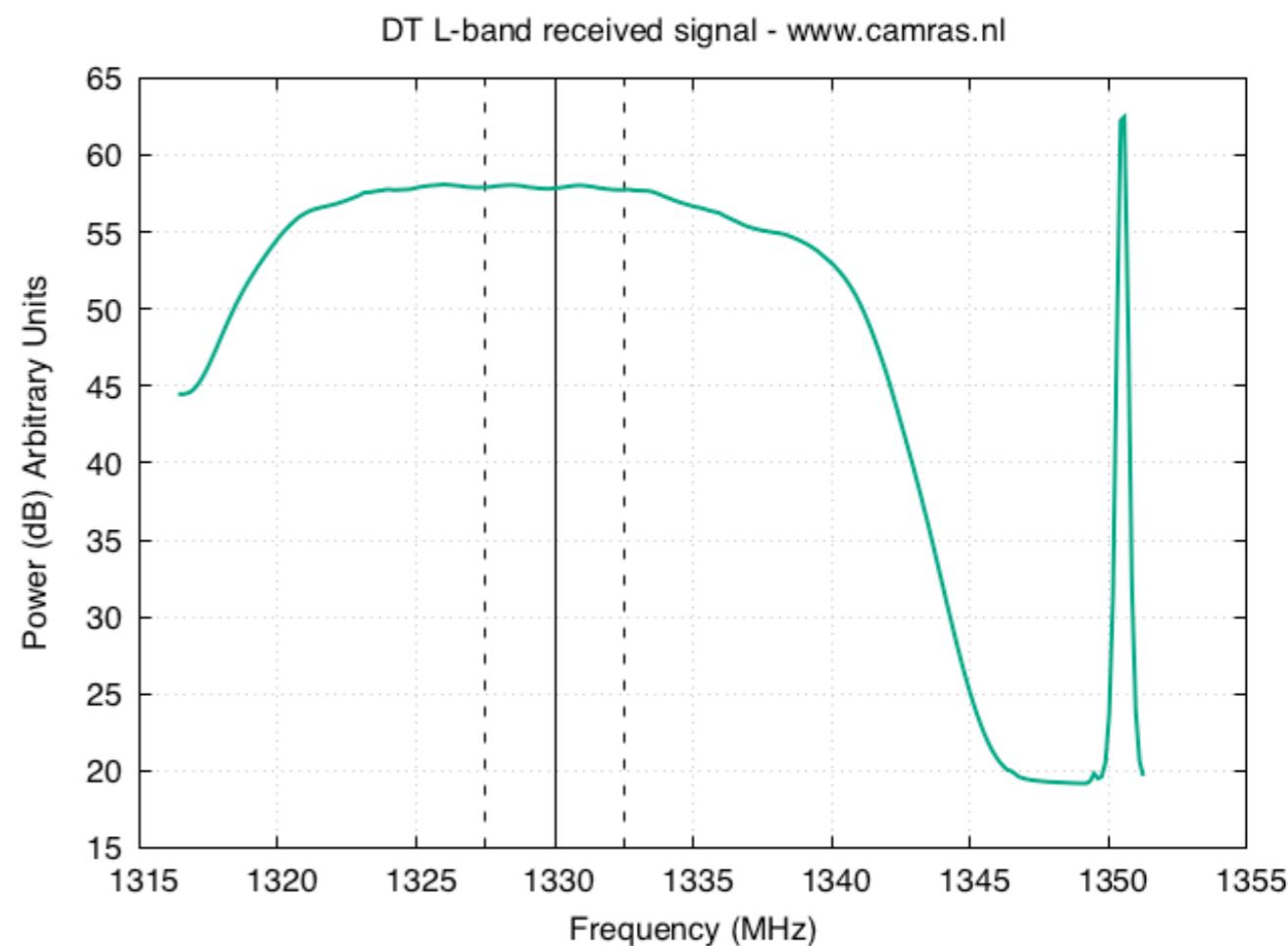




GnuRadio Mode

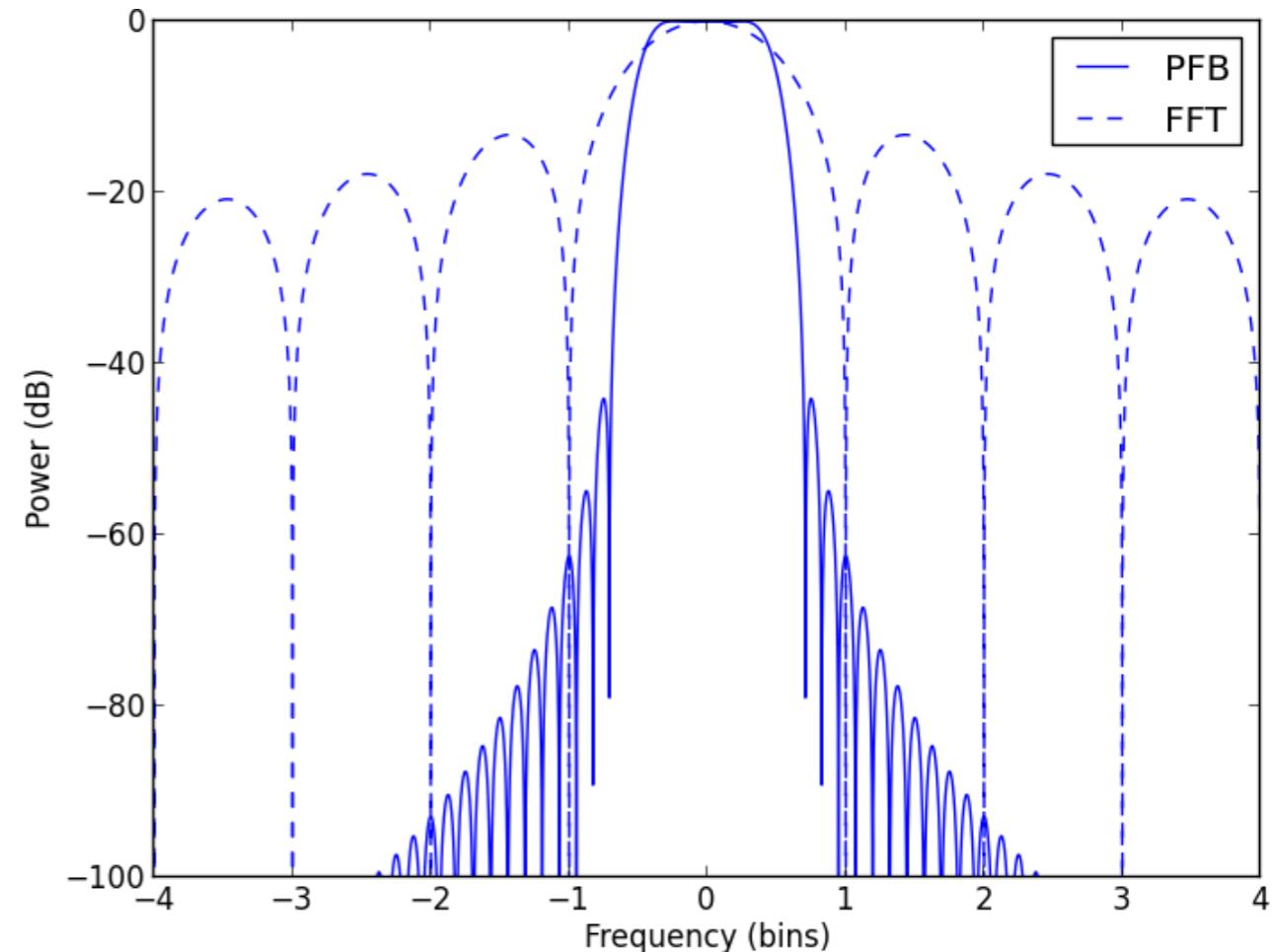
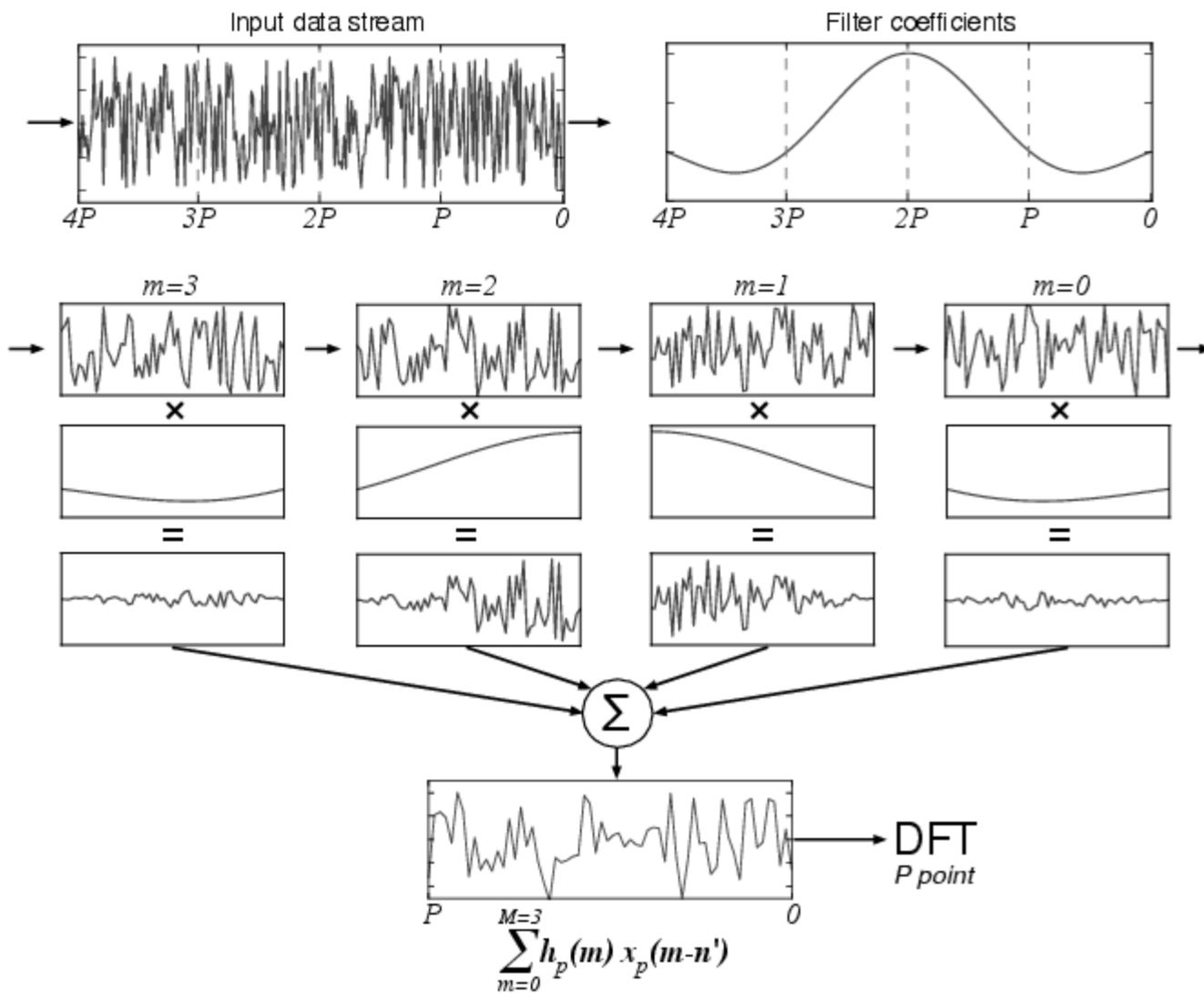


- Cascaded FIR filter
 - First Filter: Large transition band
 - Second filter: steep halfband
- Implemented in FPGA
- Input: 70Ms/s real samples
- Output: 5Ms/s complex data
- GnuRadio compatible:
 - Interleaved 16 bits ints
 - Ethernet UDP Jumbo Frames
- 160Mb/s traffic





Weight Overlap Add

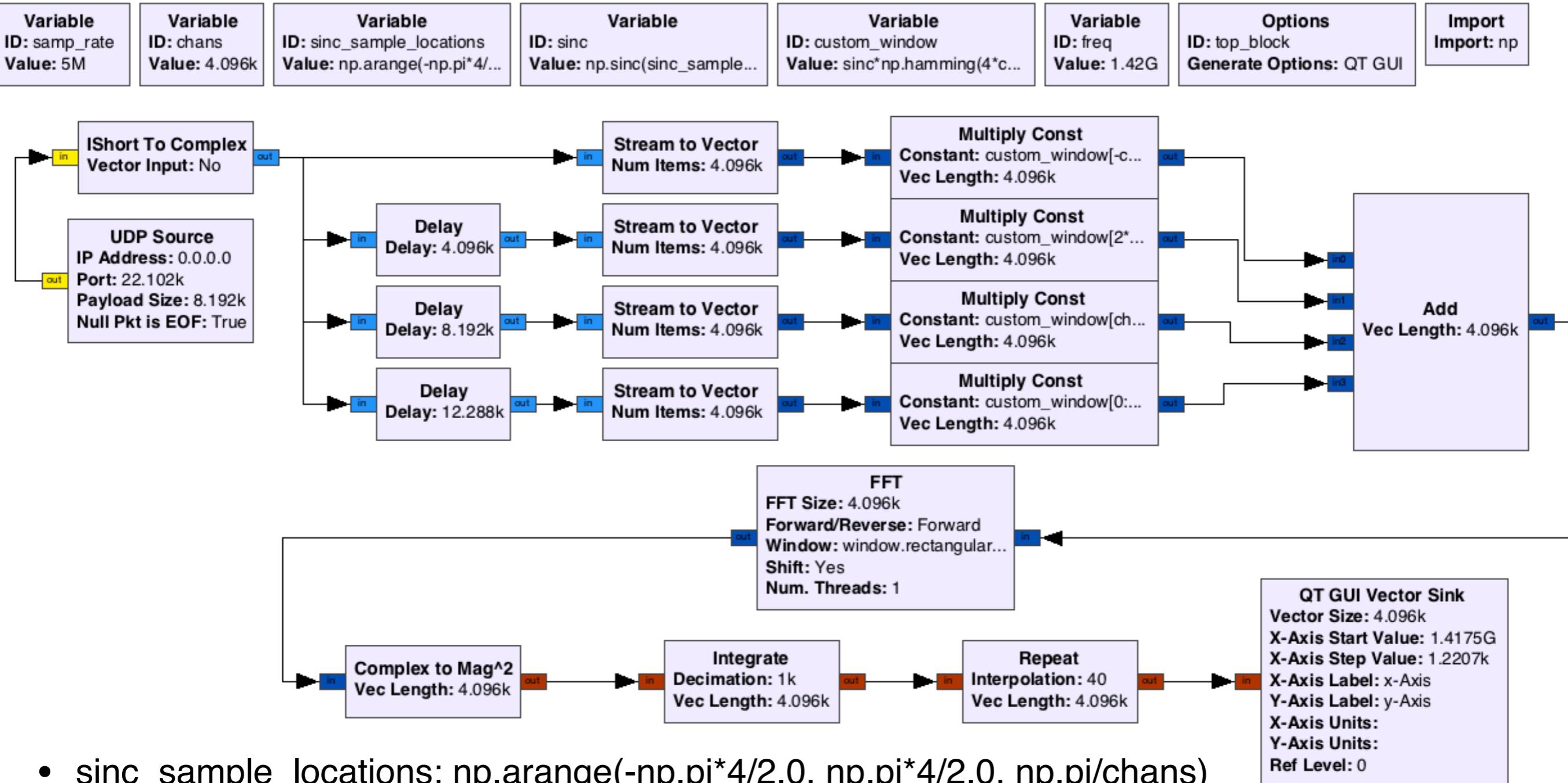


Source: <https://arxiv.org/pdf/1607.03579.pdf>

- Sinc window (perhaps multiplied with e.g. hamming)
- Same behaviour as polyphase, just different implementation
- More overlaps allows less truncated sinc(x)
 - Better frequency box shape
 - Worse time resolution



Weight Overlap Add (WOLA)

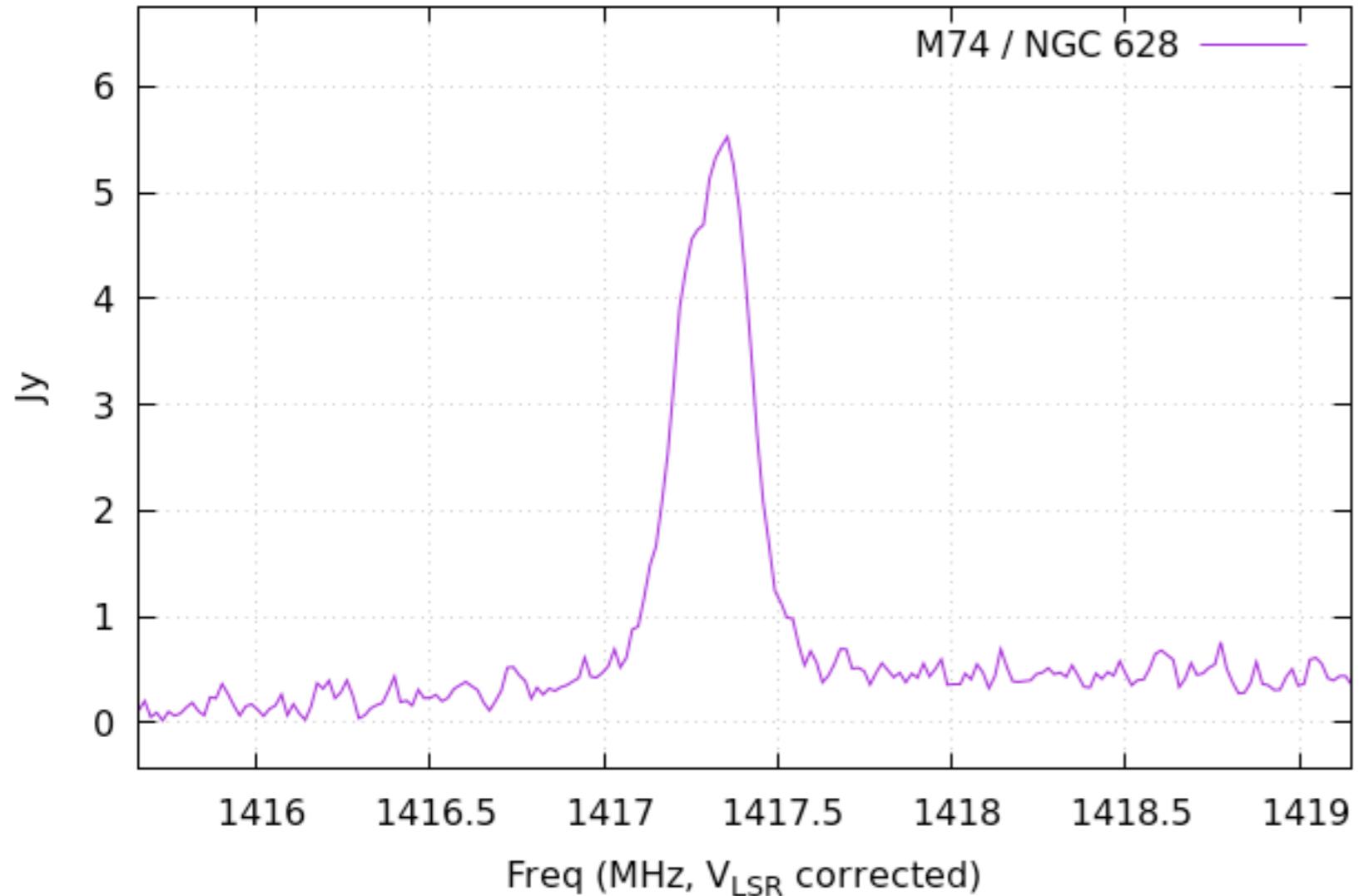


- `sinc_sample_locations: np.arange(-np.pi*4/2.0, np.pi*4/2.0, np.pi/chans)`
- `sinc: np.sinc(sinc_sample_locations/np.pi)`
- `custom_window: sinc*np.hamming(4*chans)`
- Top to bottom: `custom_window[-chans:]`, `[2*chans:3*chans]`, `[chans:2*chans]`, `[0:chans]`
- Based on: <http://wvurail.org/dspira/labs/05/>



M74 / NGC 628

H_I observation 2018-05-06, www.camras.nl

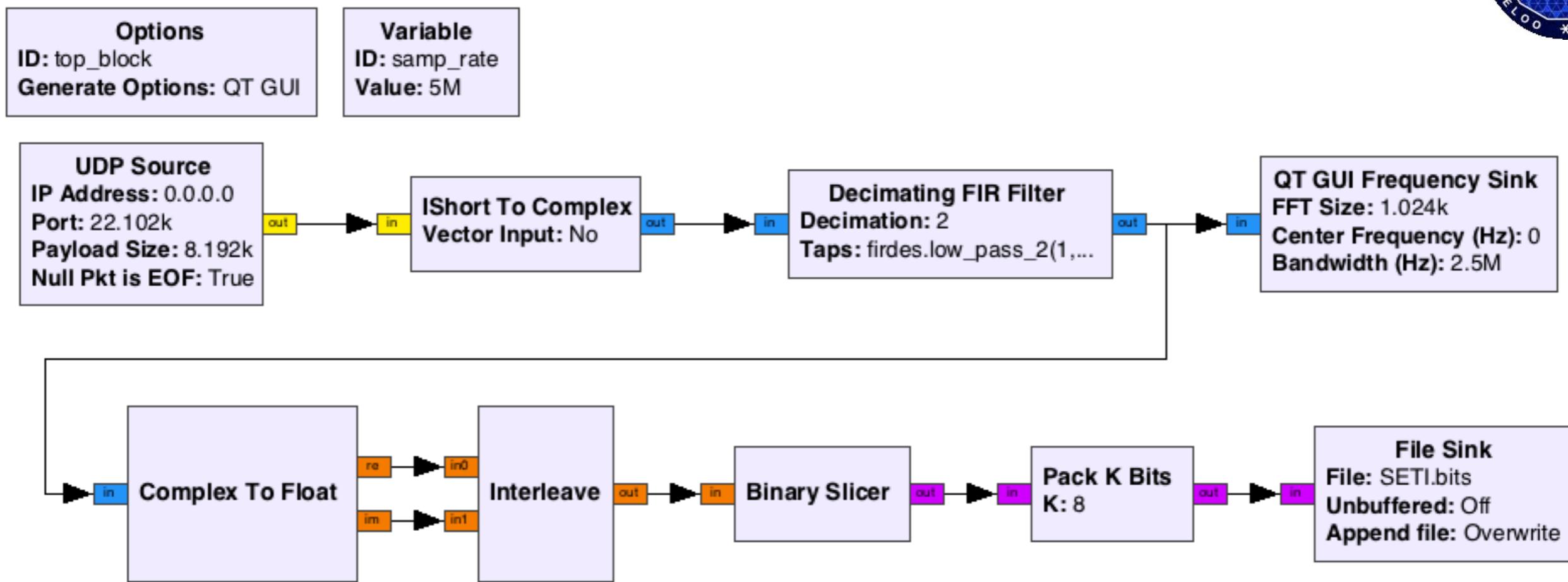


ESO/PESSTO/S. Smart

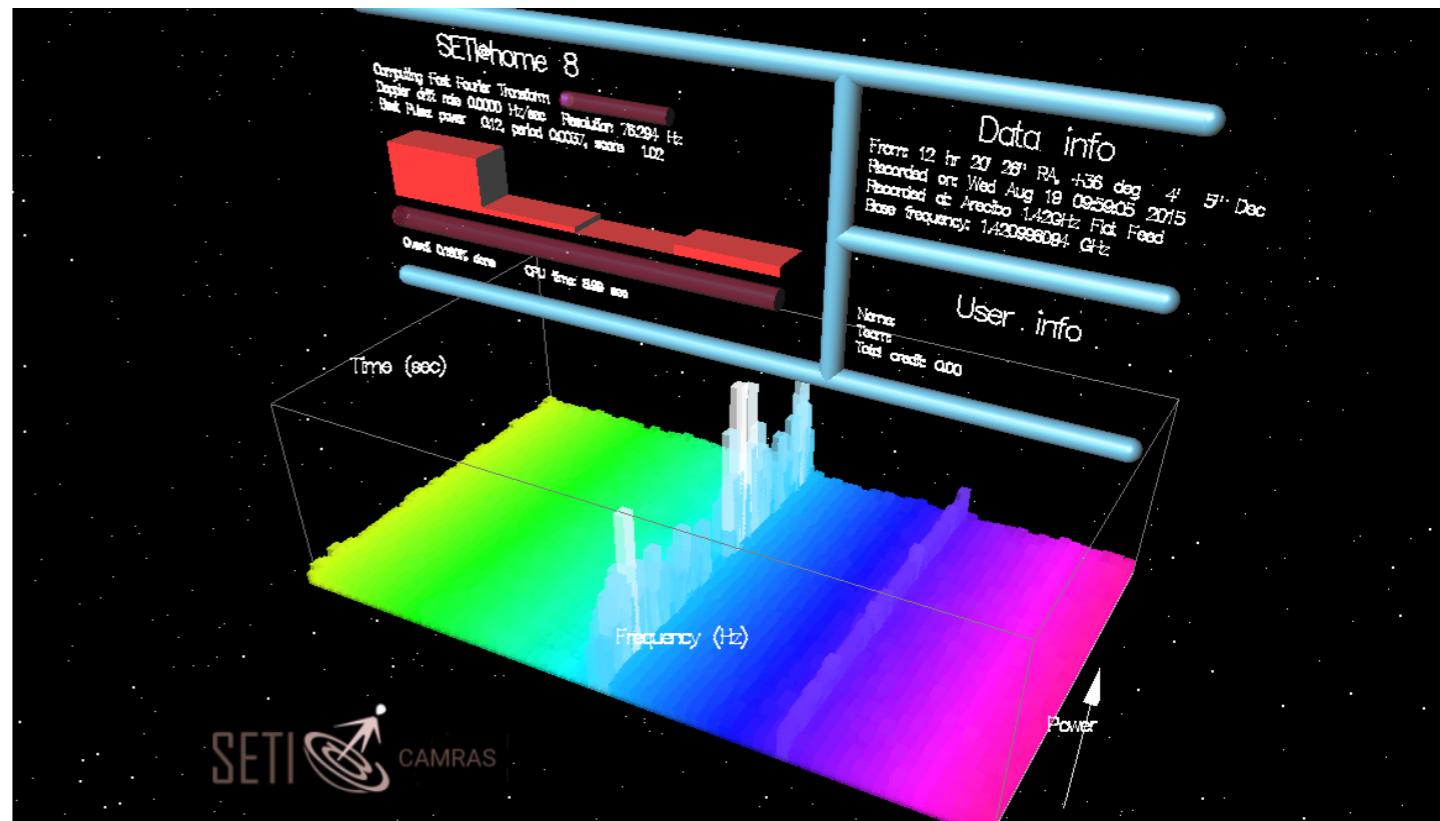
- 2300s on-source, 2400s off-source (100s integrations)
- Red-shift: 657km/s (3.1 MHz)
- Distance: 30 (± 6) Million Lightyears



SETI



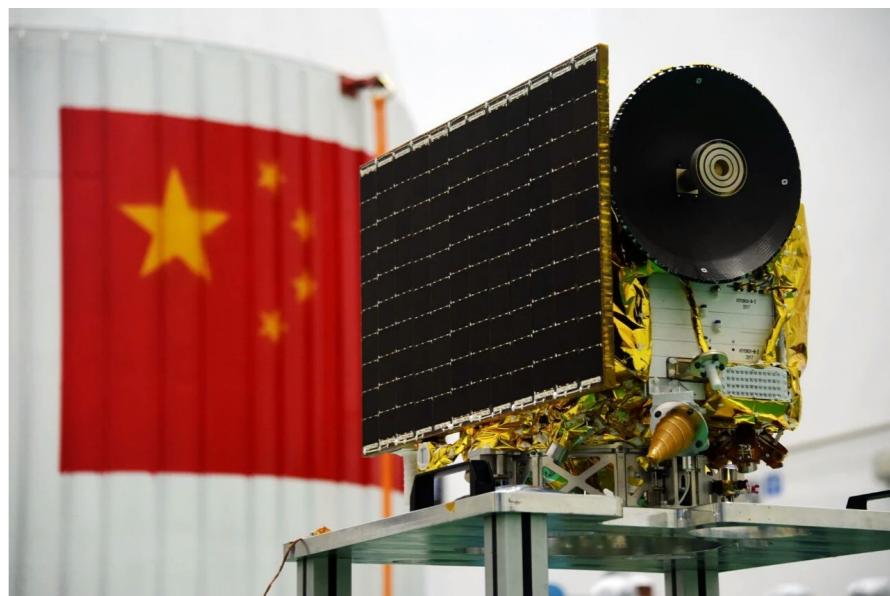
- 2.5 Ms/s IQ data
- 1 bit quantised
- Compatible with SETI@HOME (Berkeley) format and tools
- CAMRAS is launching a SETI project





DSLWP-B

- A Chinese satellite orbiting the Moon, with an amateur radio payload
- We often track DSLWP-B and stream the downlinks live



Flowgraphs for receiving DSLWP-B: <https://github.com/bg2bhc/gr-dslwp>
Images and telemetry: http://lilacsat.hit.edu.cn/dashboard/pages_en/telemetry-b.html

Astronomy and Resolution



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



- $\lambda = 600\text{nm}$ (visible light)
- $D = 2.4\text{ m}$
- $\theta = 0.06\text{ arcsecond}$

- $\lambda = 6\text{cm}$ (5 GHz)
- $D = 25\text{ m}$
- $\theta = 600\text{ arcsecond}$



Wanted: Dish of 240km ?

Very Long Baseline Interferometry



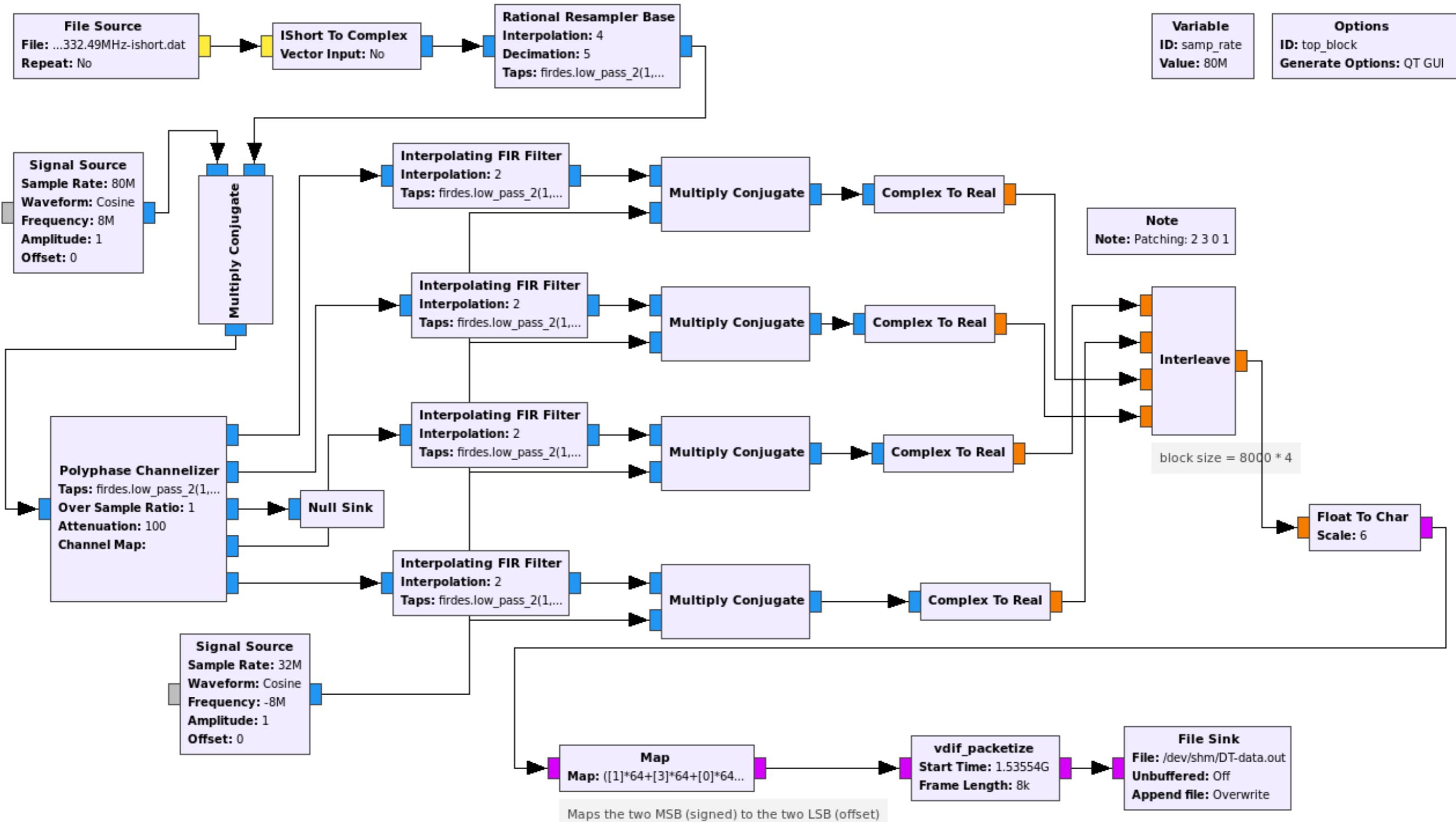
JIVE

Joint Institute for VLBI
ERIC



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

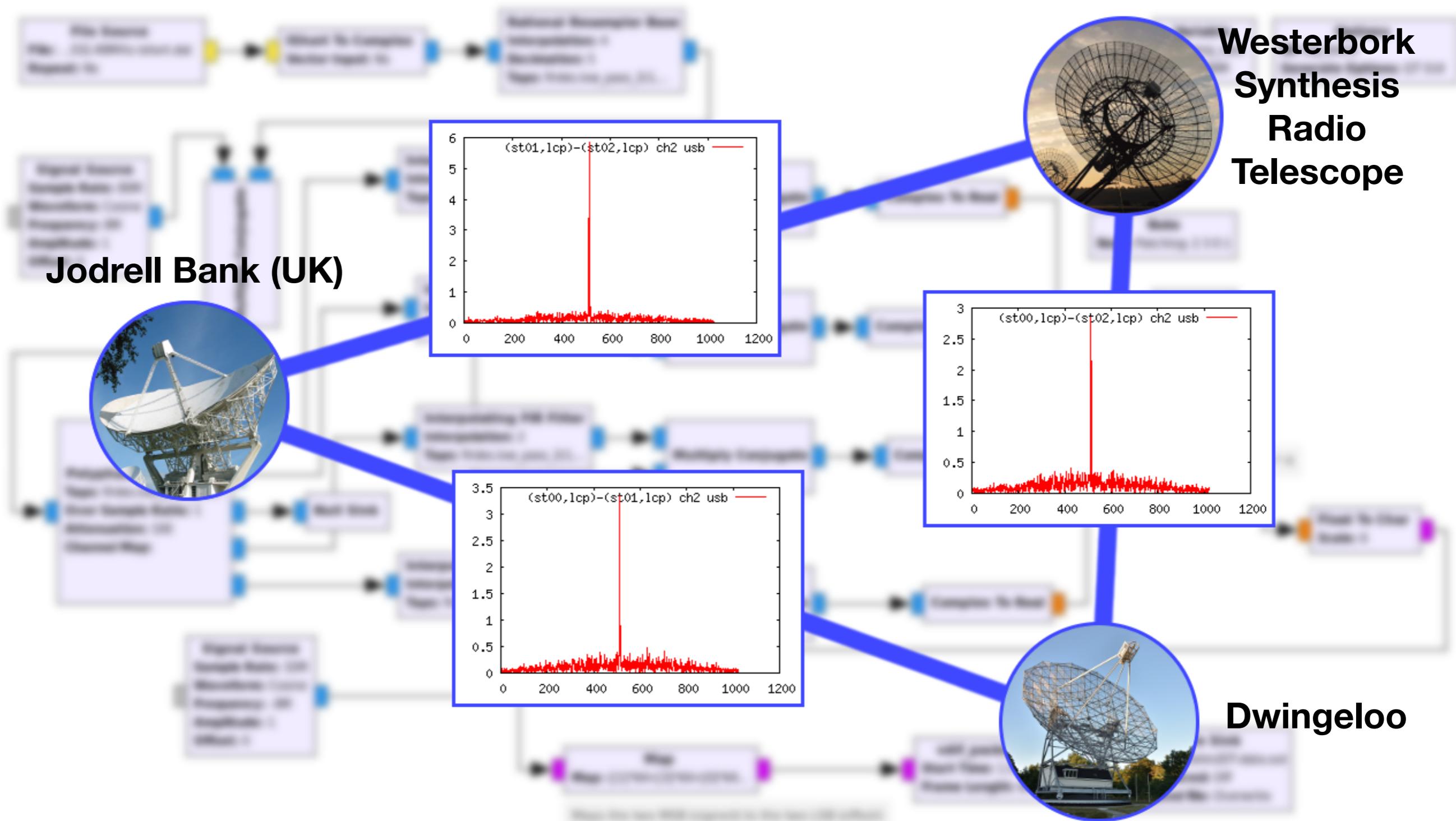
Dwingeloo VLBI



- Runs on Ettus X310 with dual TwinRX
- Four of these flowcharts to get 256MHz of spectrum, 1024Mb/s data

Dwingeloo VLBI fringes (again) !

2018-08-25



- Using a Rubidium (Todo: White Rabbit link to H-Maser in WSRT)
- batches of 40s (making RFNoC version for real time use)

Keep in Touch

- Website: <http://www.camras.nl/>
- Mail: info@camras.nl
- Gitlab: <http://gitlab.camras.nl/public>
 - Including Backend design
- Twitter:
 - @Radiotelescoop (Dutch, general public)
 - @PI9CAM (English, more technical)
- Observation data:
 - <http://charon.camras.nl/public>
 - Pulsars, SETI, DSLWP-B
- We welcome new members!

