White Rabbit for VLBI

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White Rabbit in a Nutshell

WR: 1ns accuracy for distances up to 10 km

Open Source Hardware/Software project

Initiated at CERN (LHC beam timing and control)

Already in use in several instruments, very active community

Images: SevenSolutions and FiberStore

- 1Gb/s Ethernet ports (Synchronous Ethernet)
- Transports 10MHz reference frequency, 1PPS, Time-of-Day
- 125 MHz Ethernet Carrier at far end tracked by Phase-Locked Loop
- PTP (IEEE1588v2) for precise timing information
- BiDi SFPs so outbound and return signal is on the same fiber
    - Standardized on 1000base-BX10 SFPs (10km, 1310nm/1490nm)

UTC Distribution in the SKA1

SIGNAL AND DATA TRANSPORT

One of the SADT (Signal and Data Transport) work packages:

Deliver local realisation of UTC from the central atomic clocks to the receptors in the field

- Phasing up the (sub)-arrays (aid in fringe search)
- Tying measurements to absolute time (e.g. pulsar timing)

Challenges:

- Distance (up to 173 km)
- Climate
- Overhead Fiber in South Africa
- Mixed fiber types
- Accuracy: 2 ns (1σ) over decades

Effects on stability and accuracy

- Reach depends on optical wavelength. 1310nm works up to 60km, 1550nm can reach up to 120km (fiber attenuation is lowest @1550 nm)

- Temperature of the end-points
  - Changes SFP laser wavelength (~0.1nm/ºC)
  - Due to fiber dispersion, changes the delay (17ps/nm/km @1550nm)
  - Use temperature stabilised (DWDM) SFPs for longer links (needs external DWDM filter)

- Fiber type: G.652.D has low dispersion at 1330nm, but high at 1550nm
  - G.655 (non-zero dispersion shifted) has less dispersion at 1550nm but slightly more attenuation, and is more expensive

- Temperature of the fiber
  - Changes index of refraction, which WR compensates for (α)
  - Residual effect: ratio of refractive indices changes
Remedy: Use wavelengths that are close together
SKA design: C21/C32, i.e. 1560.61nm / 1558.98nm (1.63nm)

Worst Case PPS Error

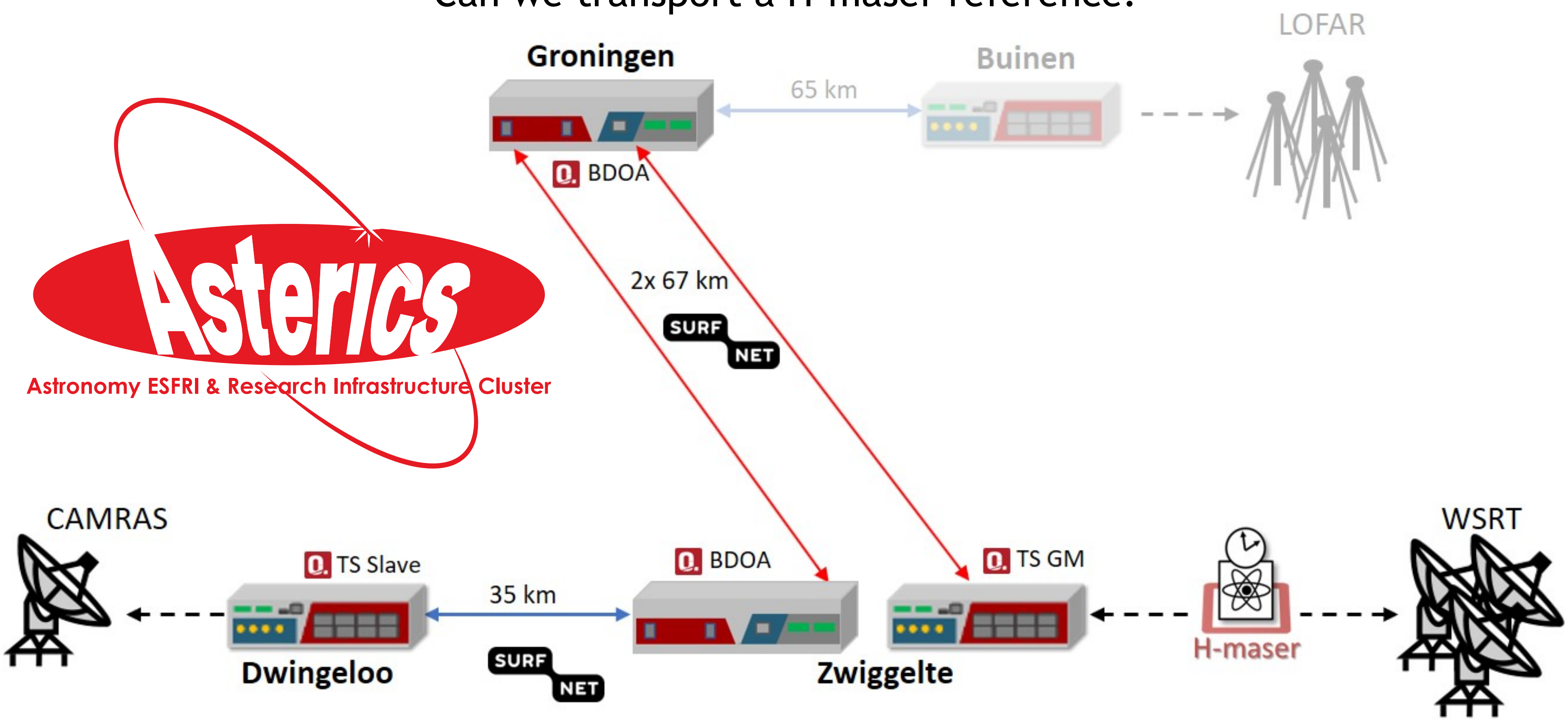
- 80 km: Longest link in SKA1-Low
- 173 km: Longest link in SKA1-Mid, with 2x repeater

(all values in ps)	1310/1490 20 km	1490/1550 80 km	1490/1550 173 km	1490/1550 + TC 80 km	1490/1550 + TC 173 km	DWDM 80 km	DWDM 173 km
Delay Calibration	10	10	30	10	30	10	30
Link Restart	75	75	225	75	225	75	225
Received Power Var.	30	30	90	30	90	30	90
Determination of α	75	75	225	75	225	165	375
Wavelength Uncert.	141	1240	2682	1240	2682	160	346
Temp. dependence α	25	100	216	100	216	3	6
TC of WR-Zen (25K)	94	94	94	94	94	94	94
TC of WR-Switch (1K)	8	8	8	8	8	8	8
Uplink SFP temp	2.5	1400	1580	280	460	0	0
Downlink SFP temp	14	68	422	68	136	0	0
Total	**475**	**3100**	**5550**	**1915**	**4600**	**545**	**1174**

See: P. Boven, DWDM stabilised optics for White Rabbit
DOI: 10.1109/EFTF.2018.8409035 IEEE Proceedings, EFTF 2018

Frequency Stability

Can we transport a H-maser reference?



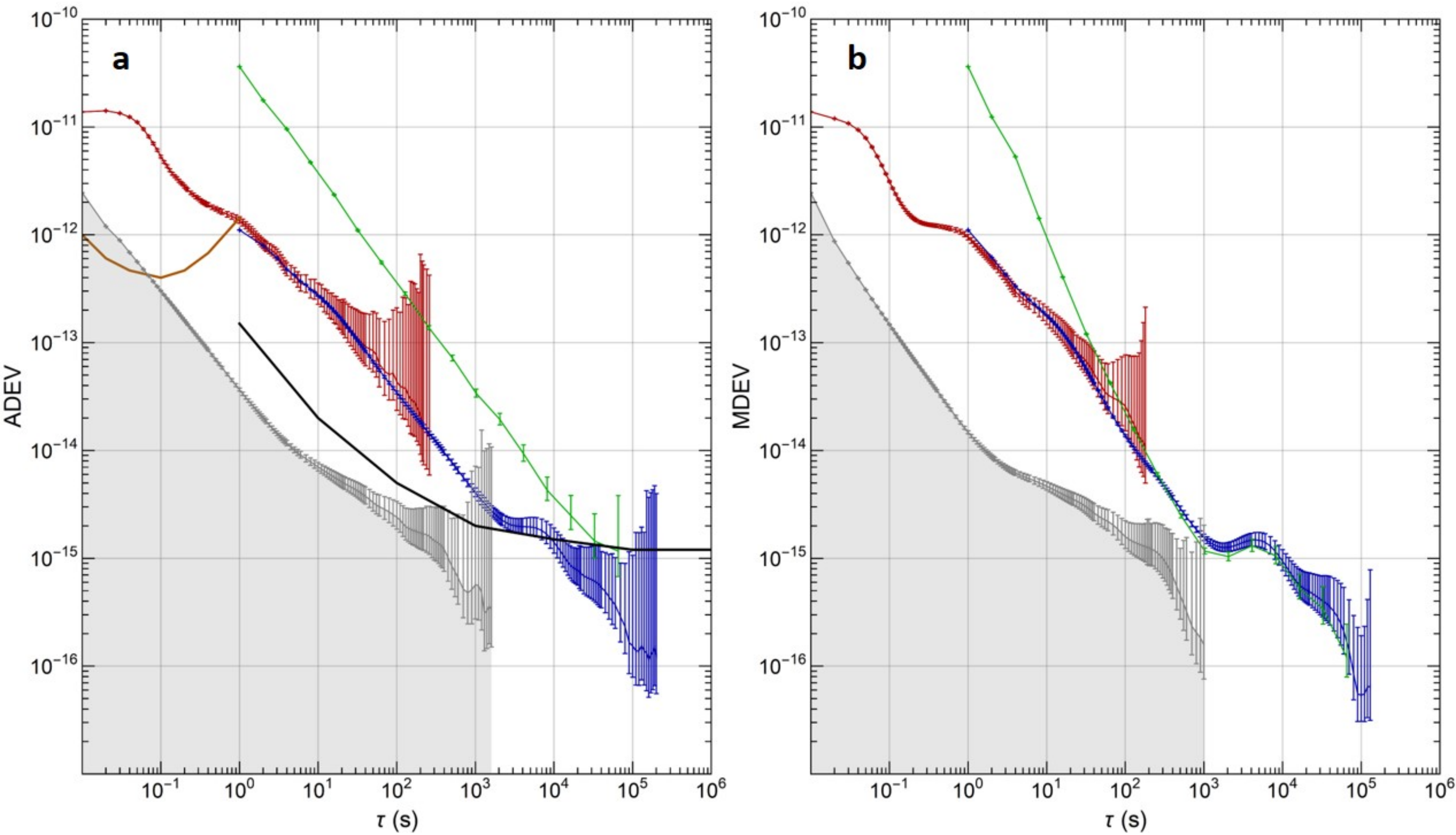
Astronomy ESFRI & Research Infrastructure Cluster

- Uses WR devices with ‘Low Jitter Board’ improvement
- WR in Dwingeloo Telescope also has a high quality cleanup oscillator
- Bi Directional Optical Amplifiers to extend the link
- Runs on existing SURFnet production DWDM network

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

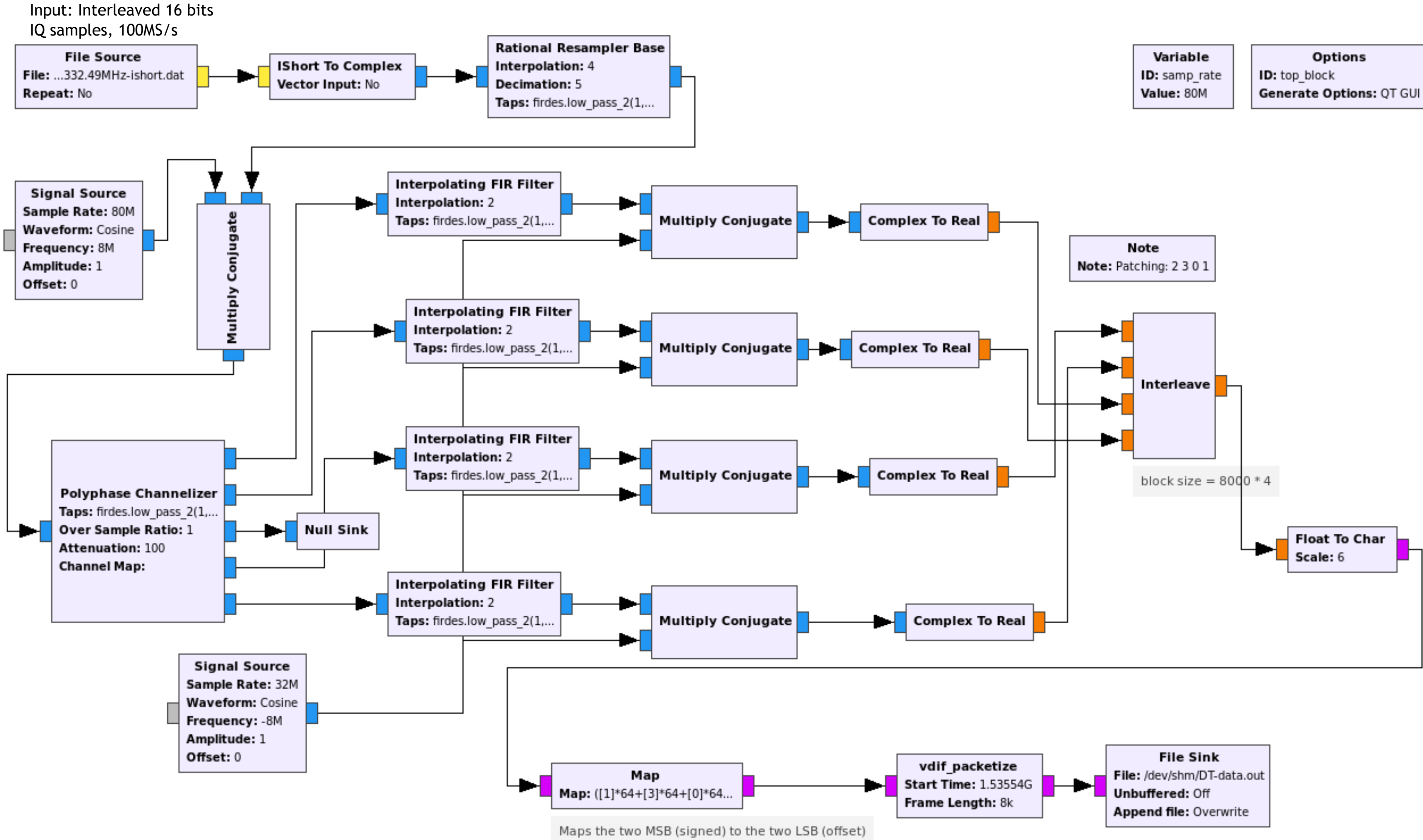
Results over 2x 67km

WSRT - Groningen - WSRT



Red: ADEV/MDEV, 50 Hz. Blue: ADEV/MDEV, 0.5 Hz. Green: ADEV/MDEV 1PPS
Black: H-maser specifications. Brown: Cleanup Oscillator. Grey: noise floor

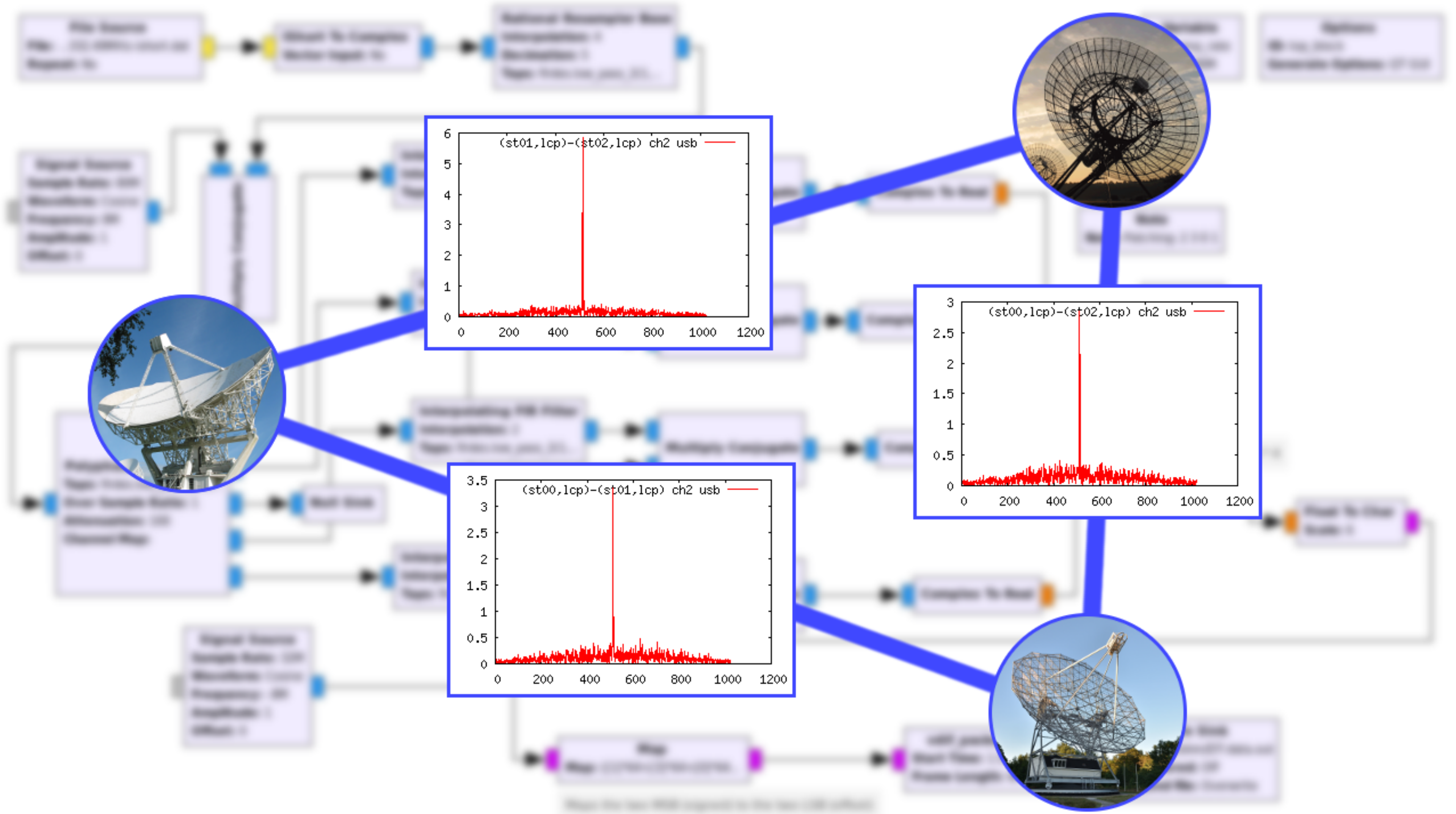
A VLBI Formatter in GNURadio



Takes 80 MHz of spectrum (oversampled at 100 MHz, 12 bit I/Q).
PFB, creates 4 sub-bands of 16 MHz each, 2 bit sampled, single thread VDIF format.
SDR hardware is capable of 1024 Mb/s. Currently a batch process, 40s at a time.

Fringes with the Dwingeloo Telescope

2018-08-29: 4C39.25, 1332 MHz



Recorded 10 s of data (LCP only) using SDR, locked to Rubidium + GPS
Correlated at JIVE using the SFXC correlator.
Next: Dig 300m fiber to complete WR link!