



# Shoppinglist

1. phased array
2. digital backend
3. VLBI data recorder
4. internet connection
- 5.
- 6.
- 7.

recorded VLBI

# Shoppinglist

1. phased array
2. digital backend
3. internet connection
4. network engineer
- 5.
- 6.
- 7.

real-time VLBI (e-VLBI)

# snag<sub>noun</sub>

\ 'snag \

## Definition of *snag*

: a concealed or unexpected difficulty or obstacle



**JIVE**

Joint Institute for VLBI  
ERIC

Harro Verkouter



**JIVE**

Joint Institute for VLBI  
ERIC

# Technicalities of doing (e-)VLBI with the EVN

Harro Verkouter

# Phased Array



N18L1

data: n18l1\_no0008\_2x32MHz\_lag\_1.ms [LAG\_DATA]

amplitude versus channel

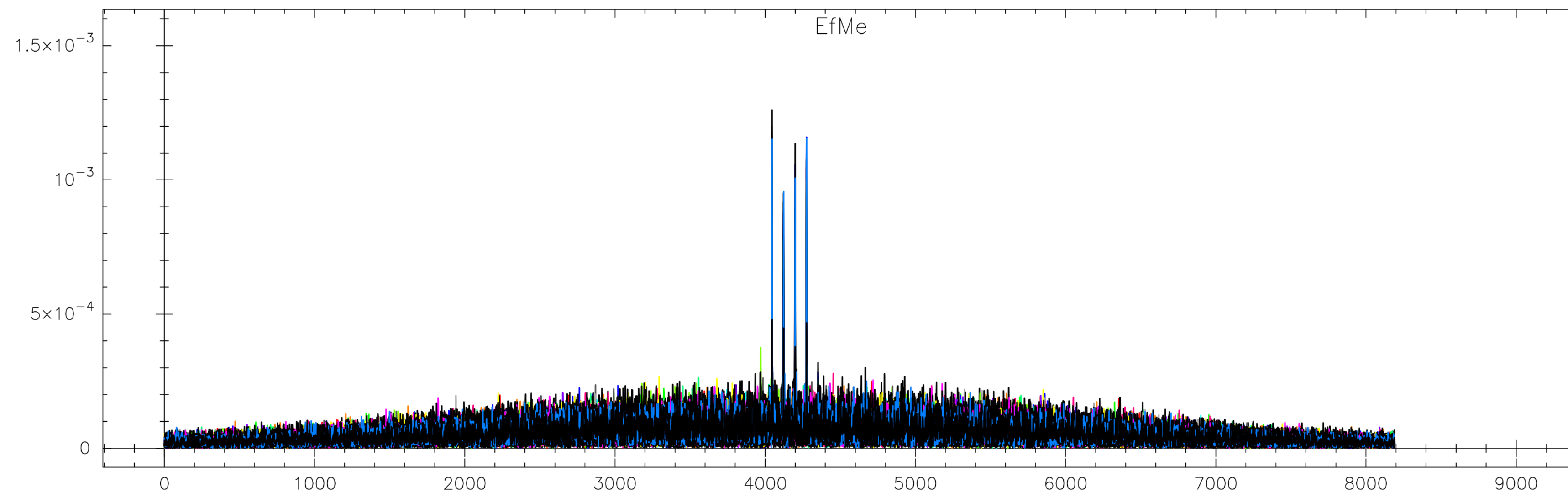
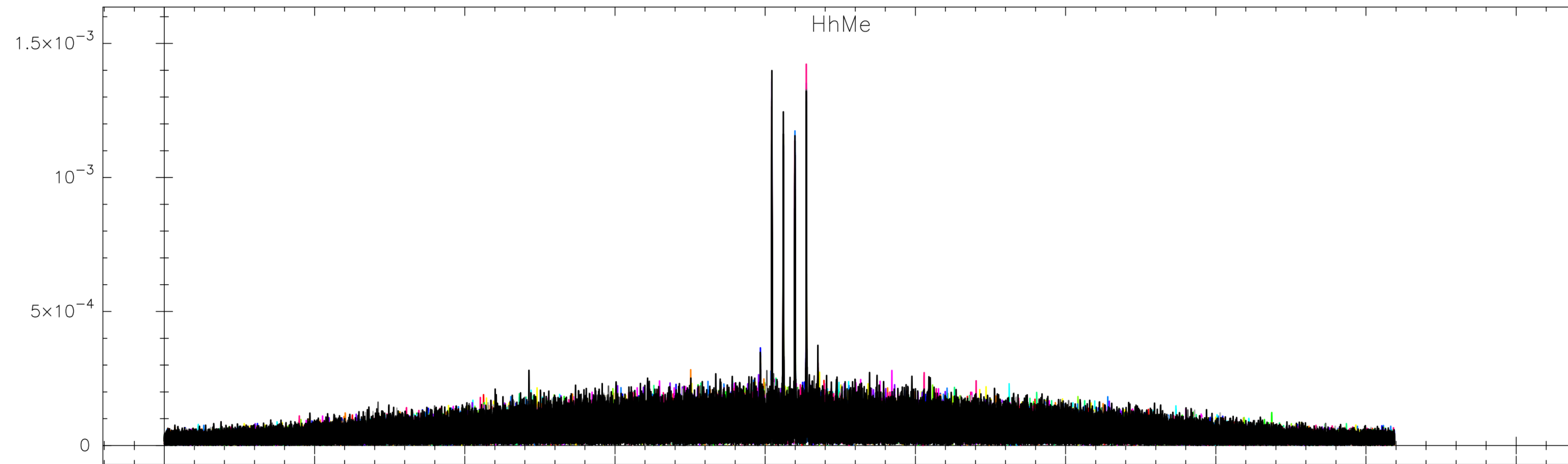
unique: sess118.L512nme/14:48:25.50/J0530+1331

verkouter@<??> 2019-10-24T23:32:13

Pol=RL,LL,LR,RR;Nsub=\*;;

page: 1/1

[ Vector avg'ed 22-Feb-2018/14:48:23.125->22-Feb-2018/14:48:27.875]



LR/SB4	LR/SB5	LR/SB6	LR/SB7	LR/SB0	LR/SB1	LR/SB2	LR/SB3	LL/SB6	LL/SB7	LL/SB4	LL/SB5	LL/SB2
LL/SB3	LL/SB0	LL/SB1	RR/SB2	RR/SB3	RR/SB0	RR/SB1	RR/SB6	RR/SB7	RR/SB4	RR/SB5	RL/SB0	RL/SB1
RL/SB2	RL/SB3	RL/SB4	RL/SB5	RL/SB6	RL/SB7							

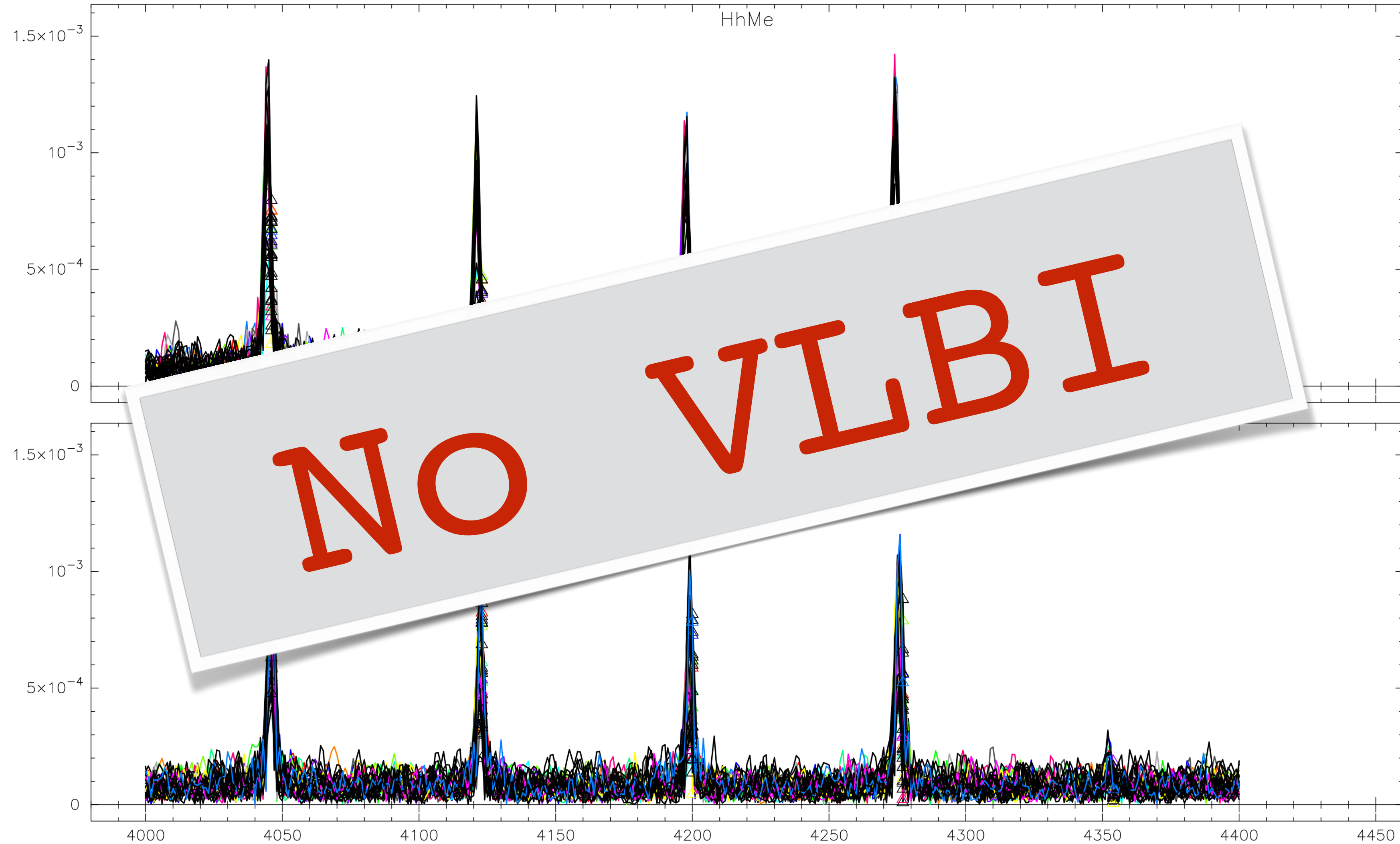
amplitude versus channel  
unique: sess118.L512nme/14:48:25.50/J0530+1331  
Pol=RL,LL,LR,RR;Nsub=\*;;[amplitude: ((x-4046)%77) == 0]  
[ Vector avg'ed 22-Feb-2018/14:48:23.125->22-Feb-2018/14:48:27.875]

N18L1

data: n18l1\_no0008\_2x32MHz\_lag\_1.ms [LAG\_DATA]

verkouter@<??> 2019-10-24T23:33:01

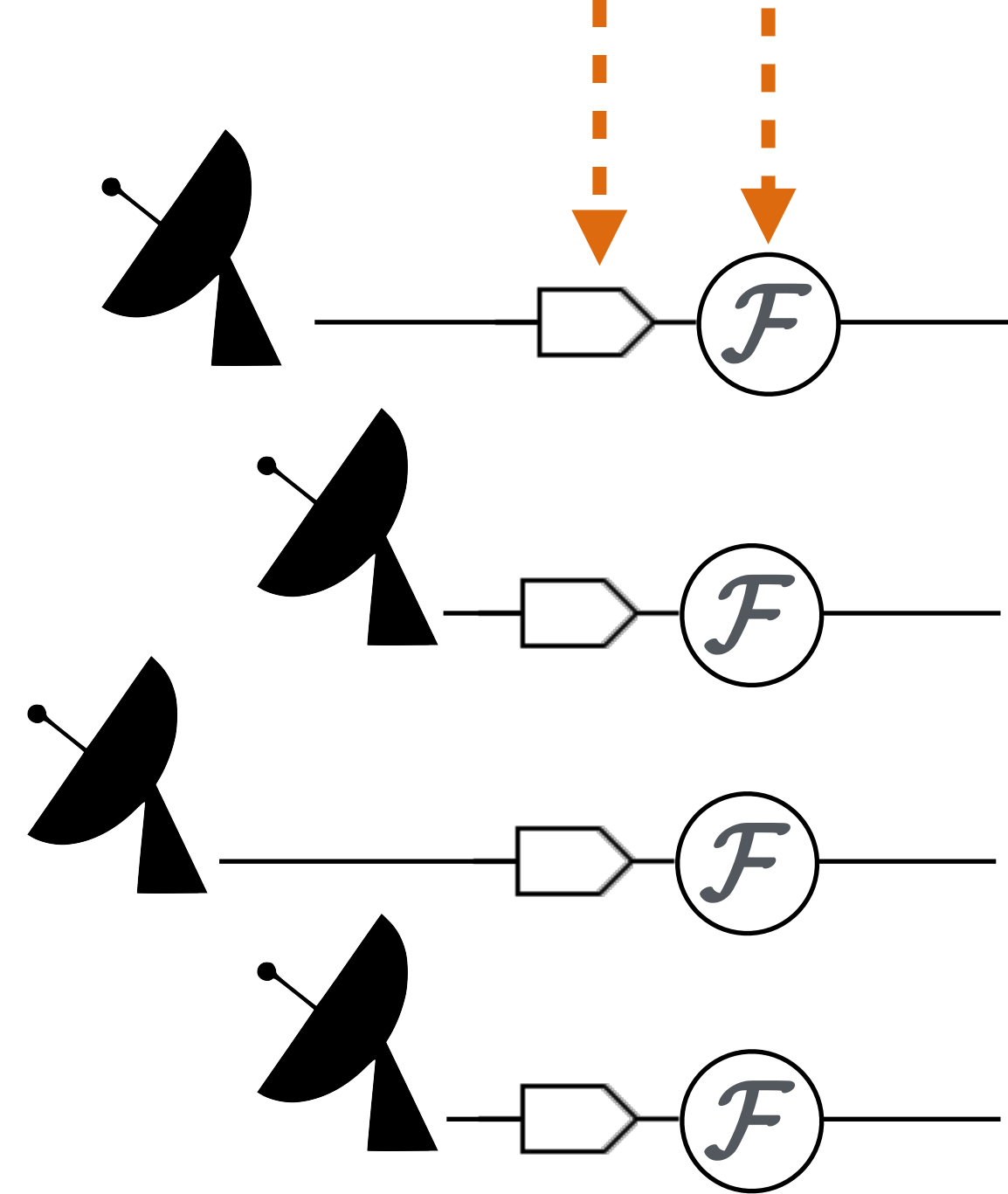
page: 1/1



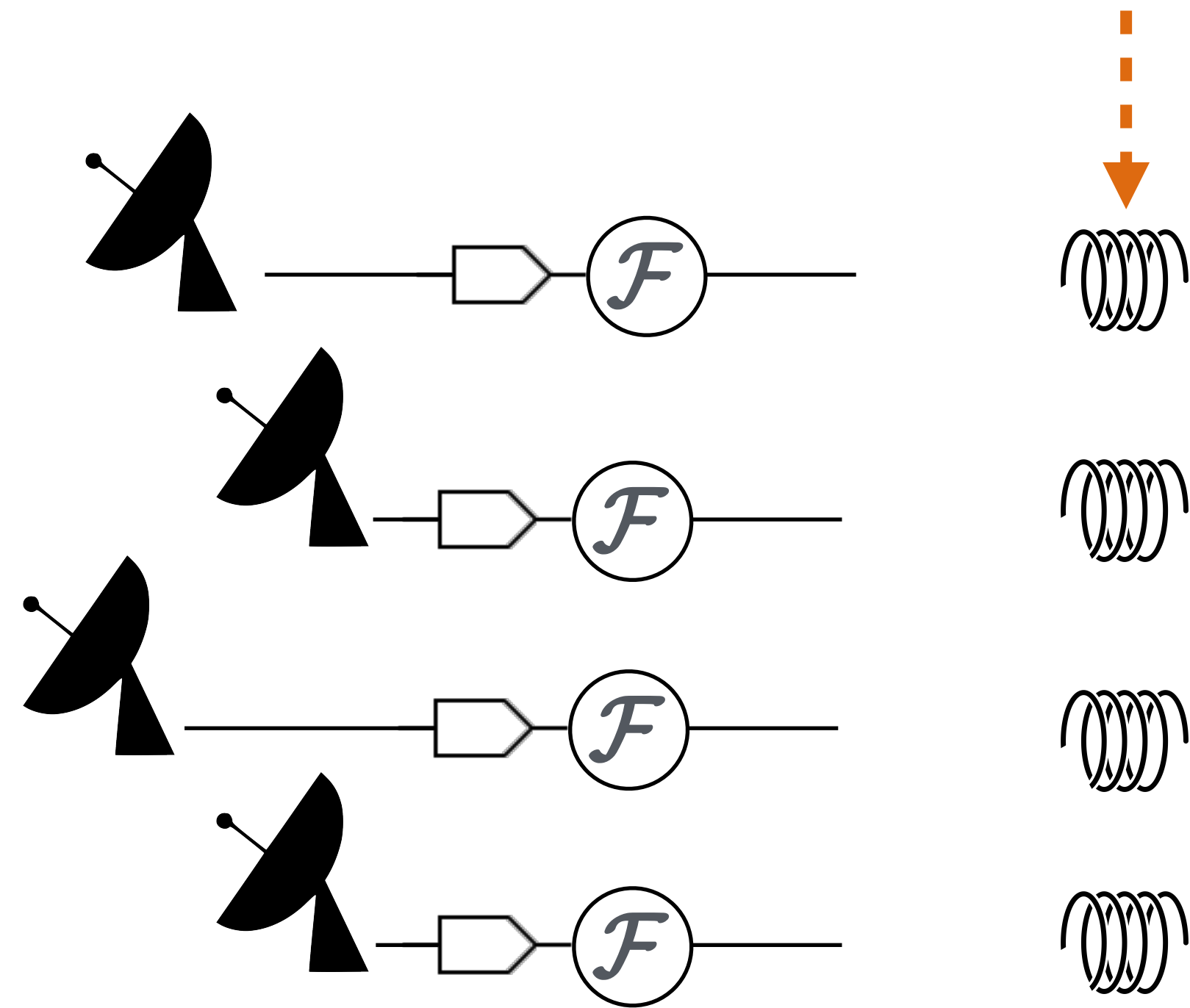


samplers  $\Rightarrow$  time series

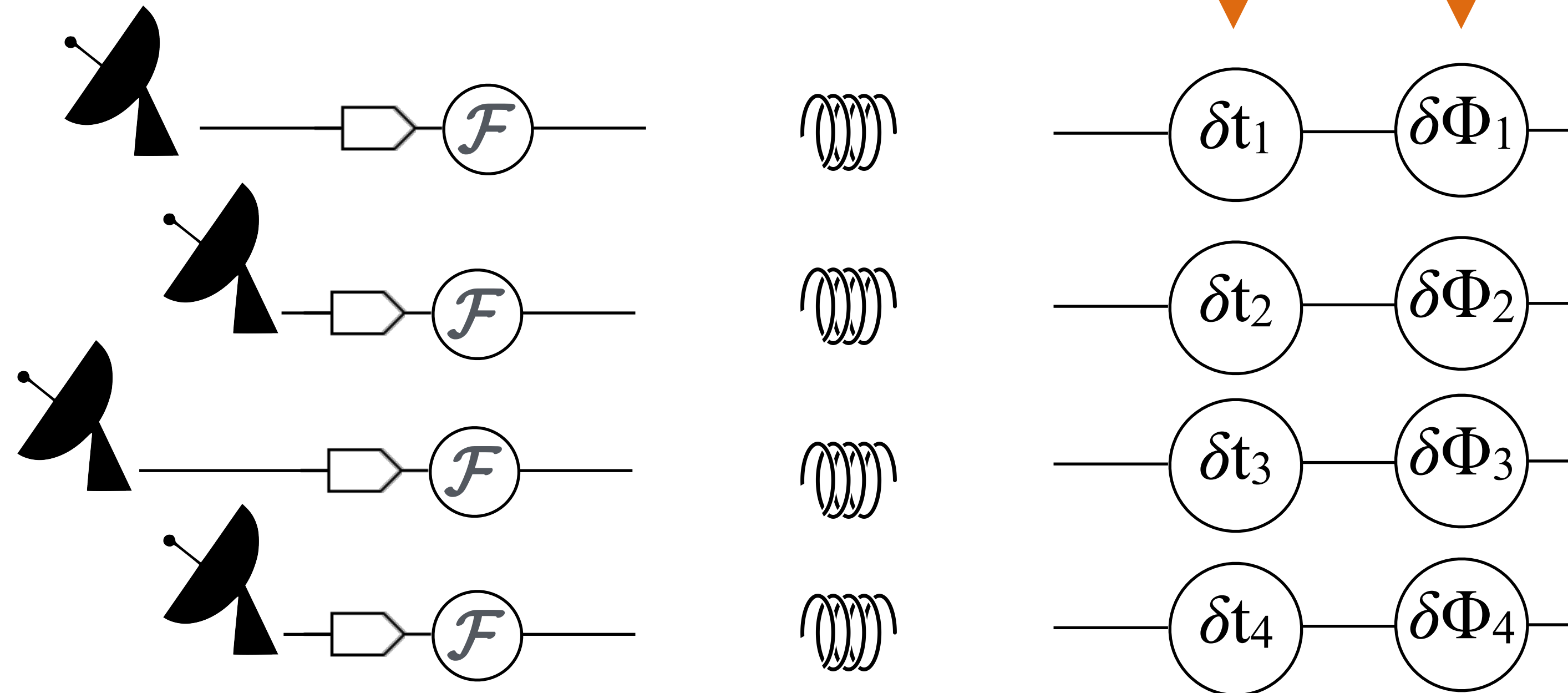
Fourier transform  $\Rightarrow$  complex spectra

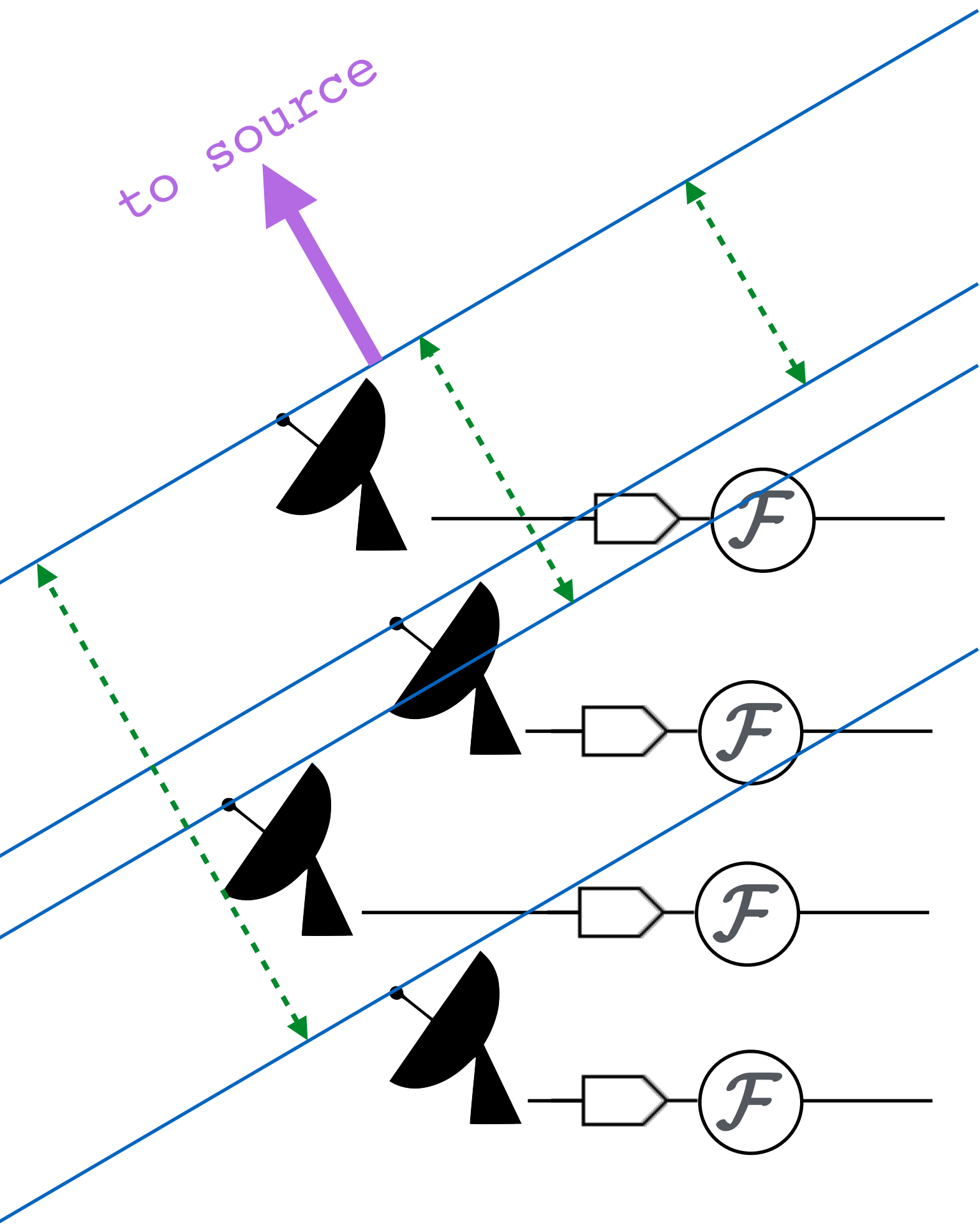


transmission to central processor

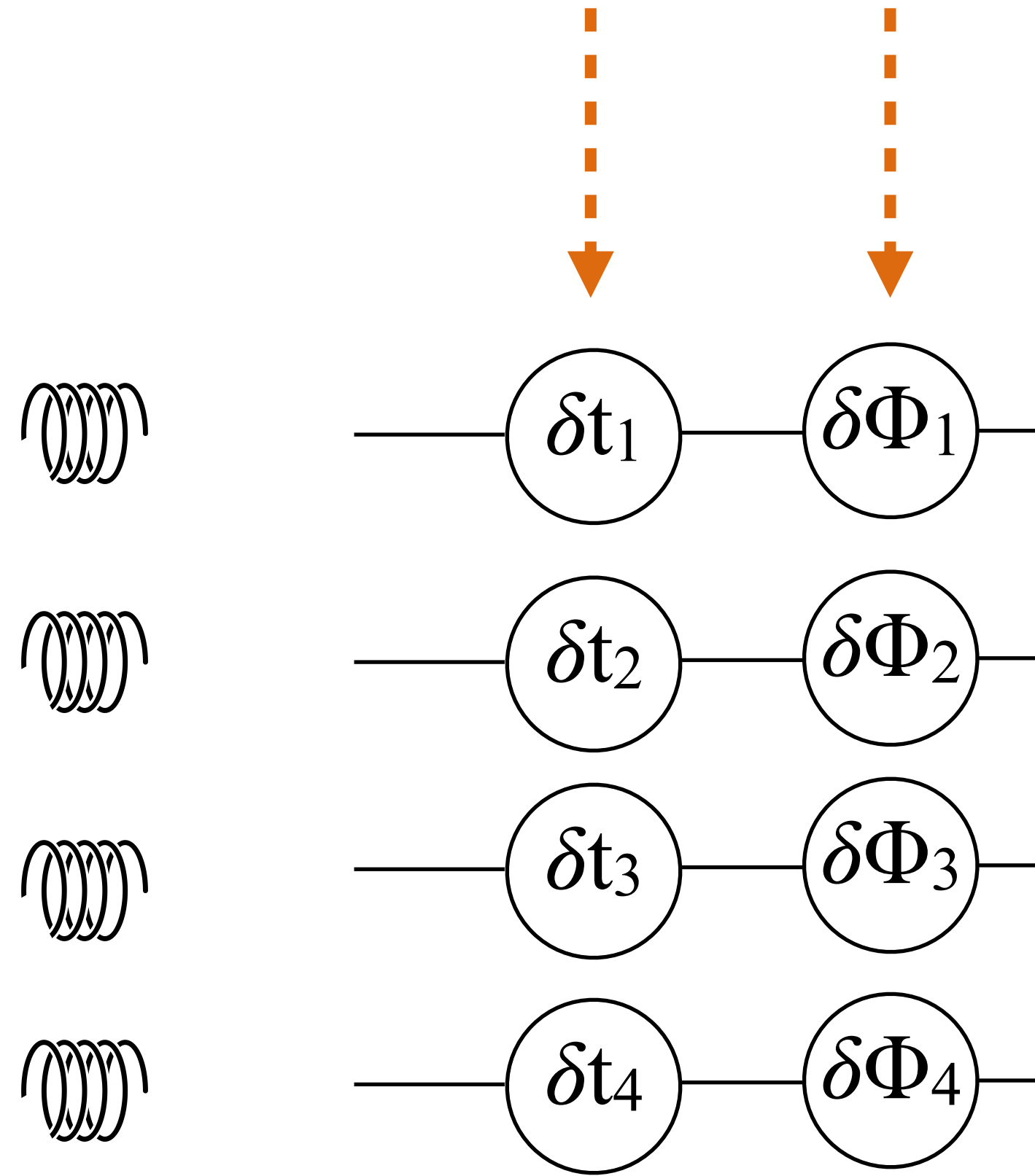


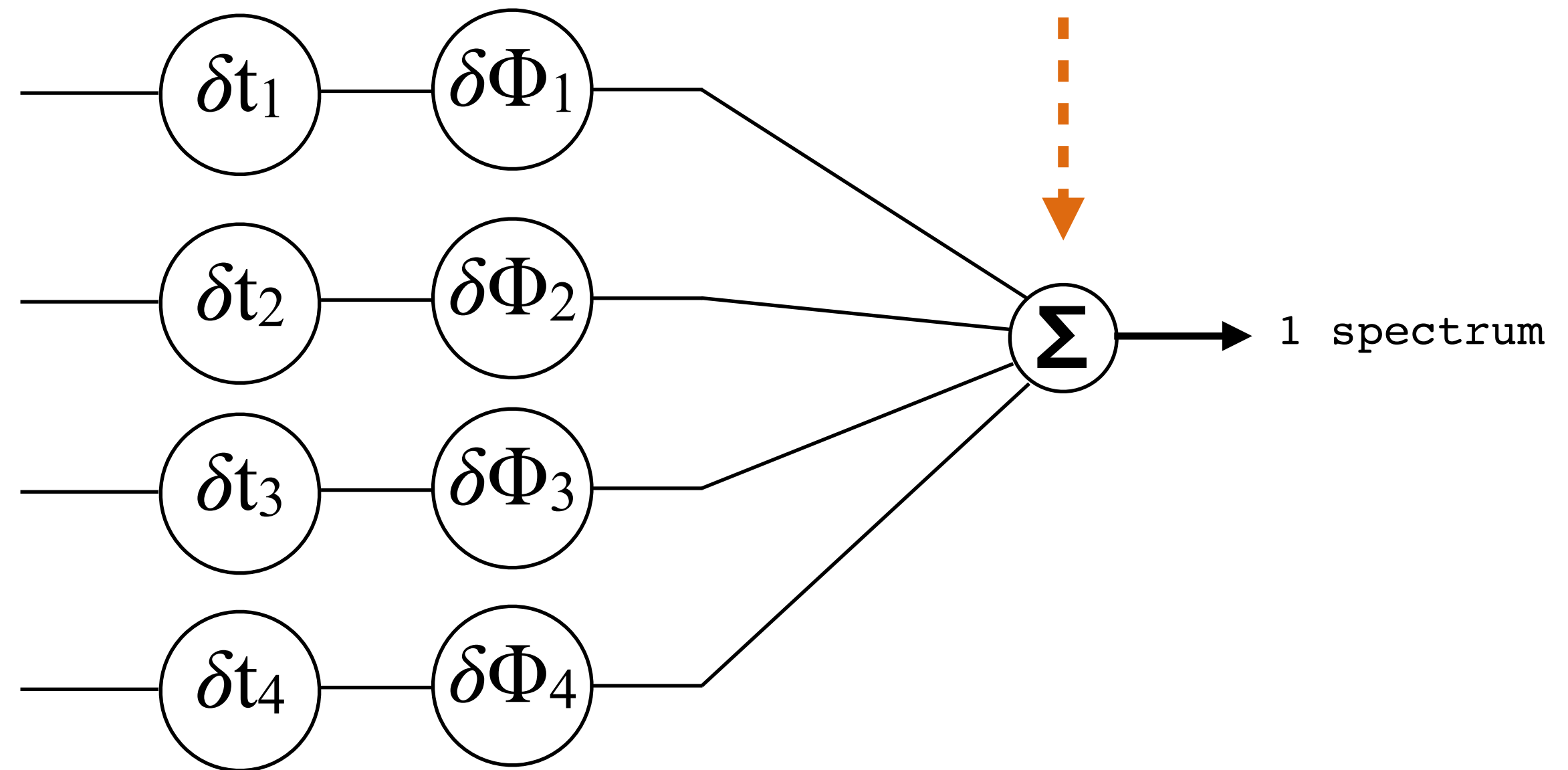
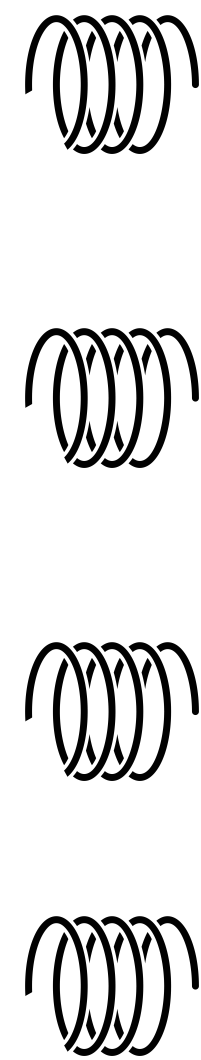
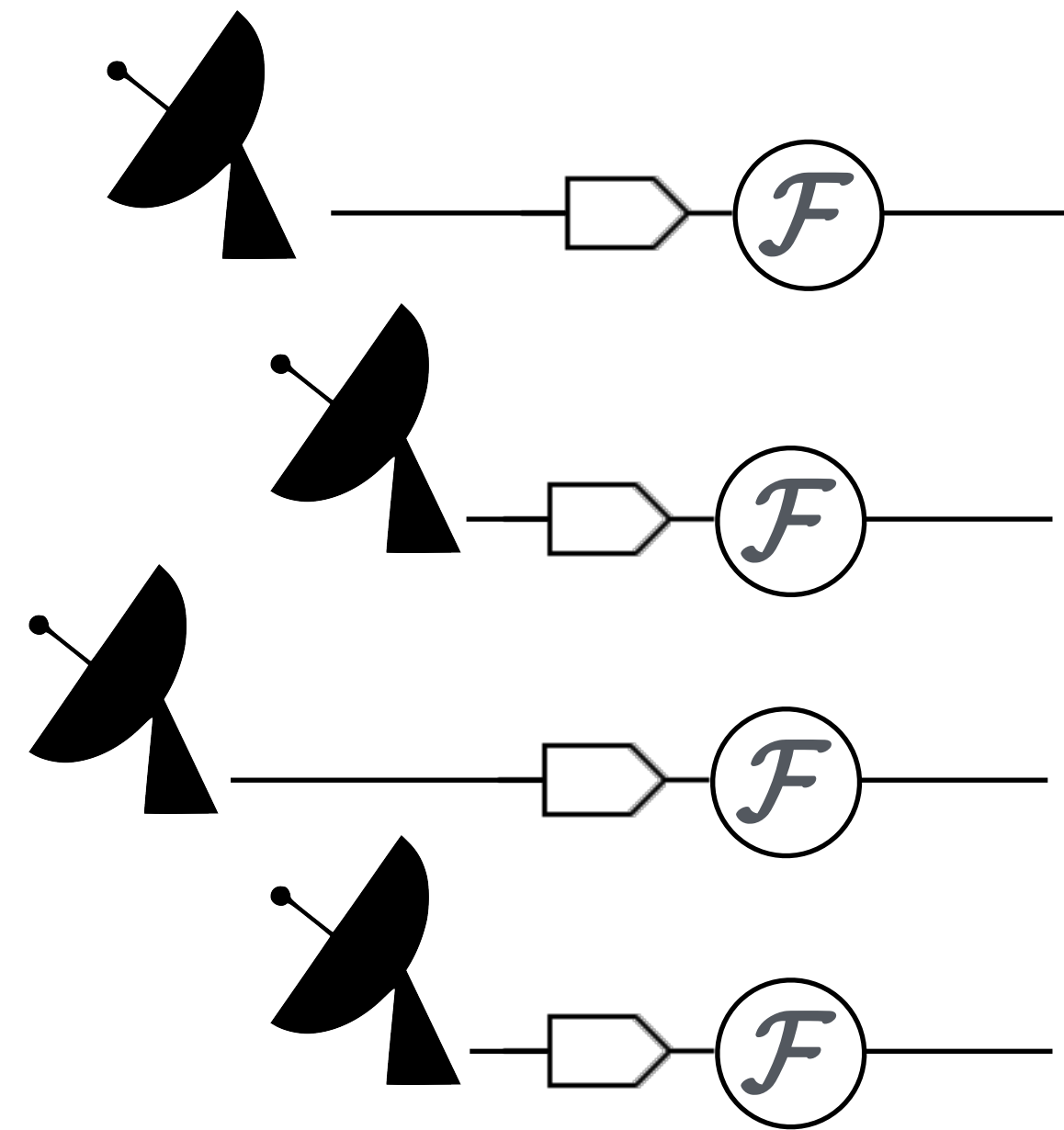
apply delay and/or phase rotation  
(array geometry + source direction

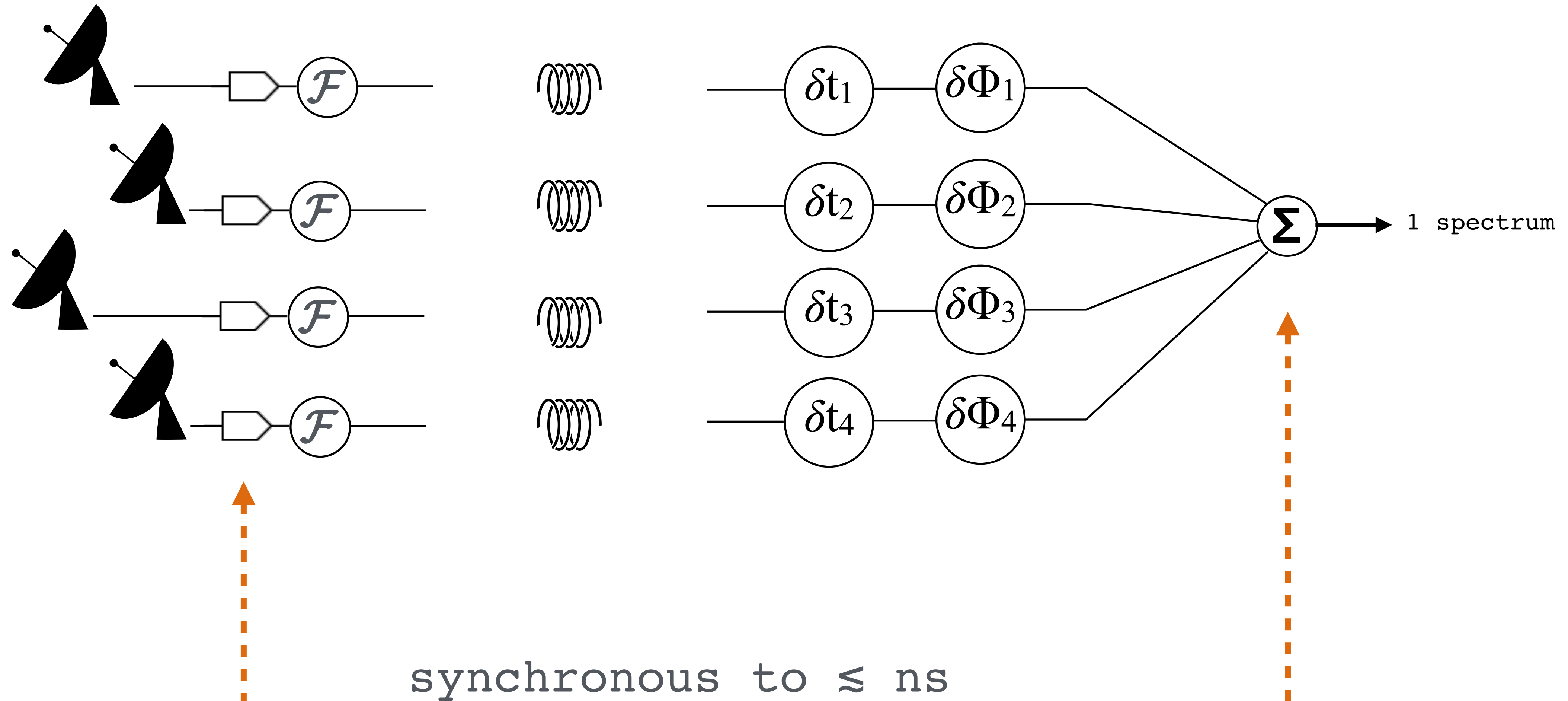




apply delay and/or phase rotation  
(array geometry + source direction)







N18L1

data: n18l1\_no0011\_2x32MHz\_sd\_4\_lag.ms [LAG\_DATA]

amplitude versus channel

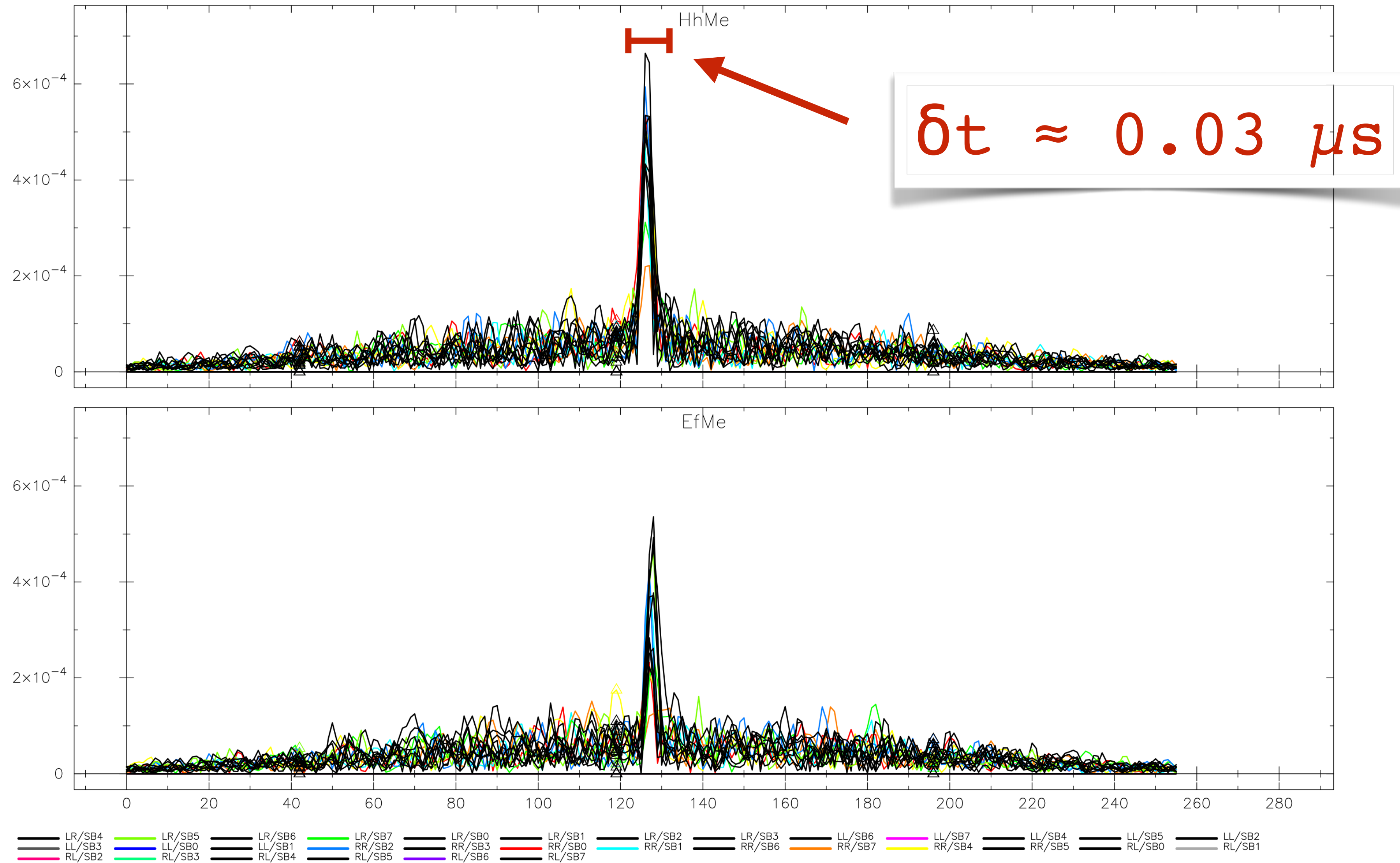
unique: sess118.L512nme/15:30:00.00/J0530+1331

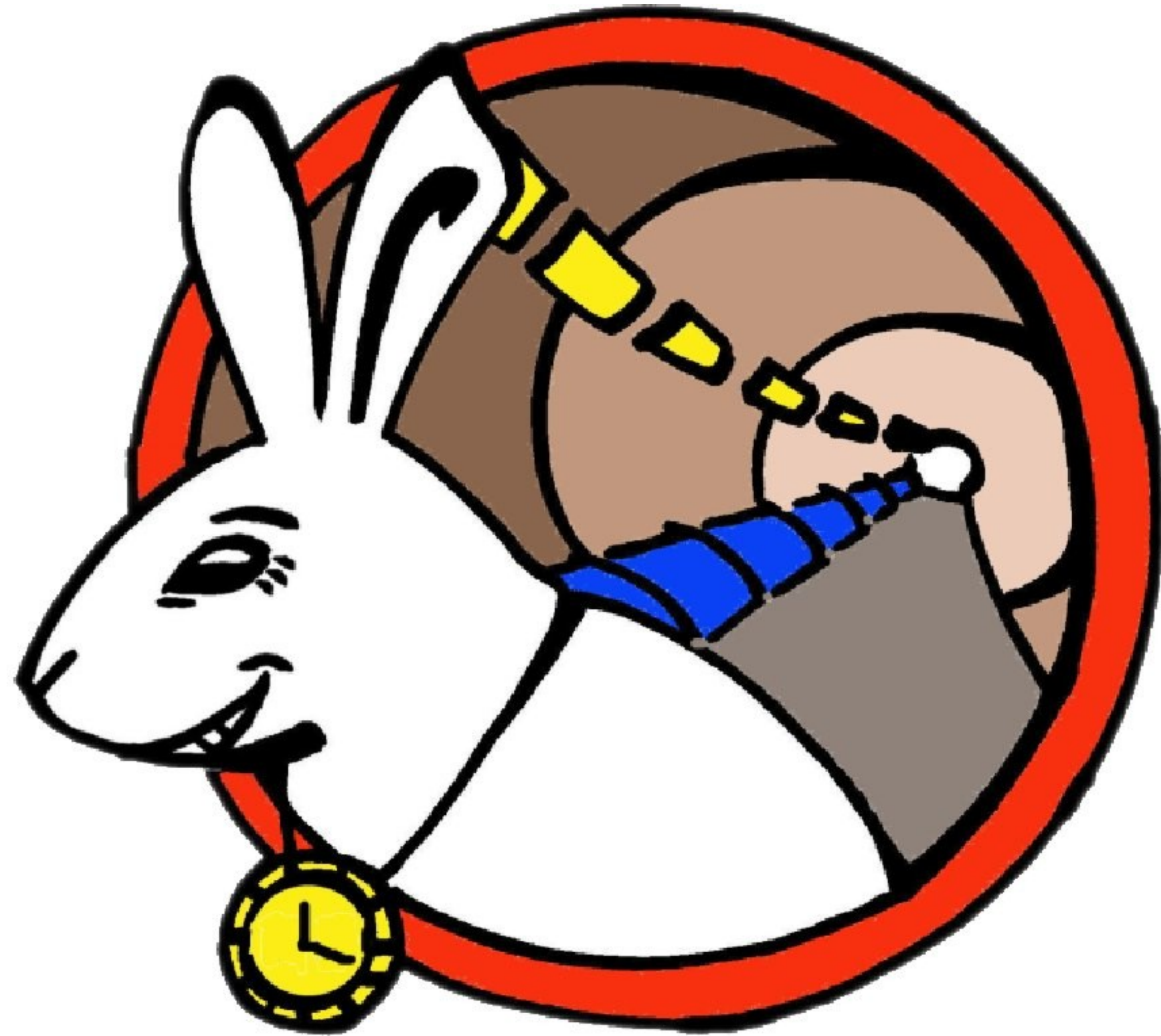
verkouter@<??> 2019-10-24T23:41:05

Pol=RL,LL,LR,RR;Nsub=\*;;[amplitude: ((x-4046)%77) == 0]

page: 1/1

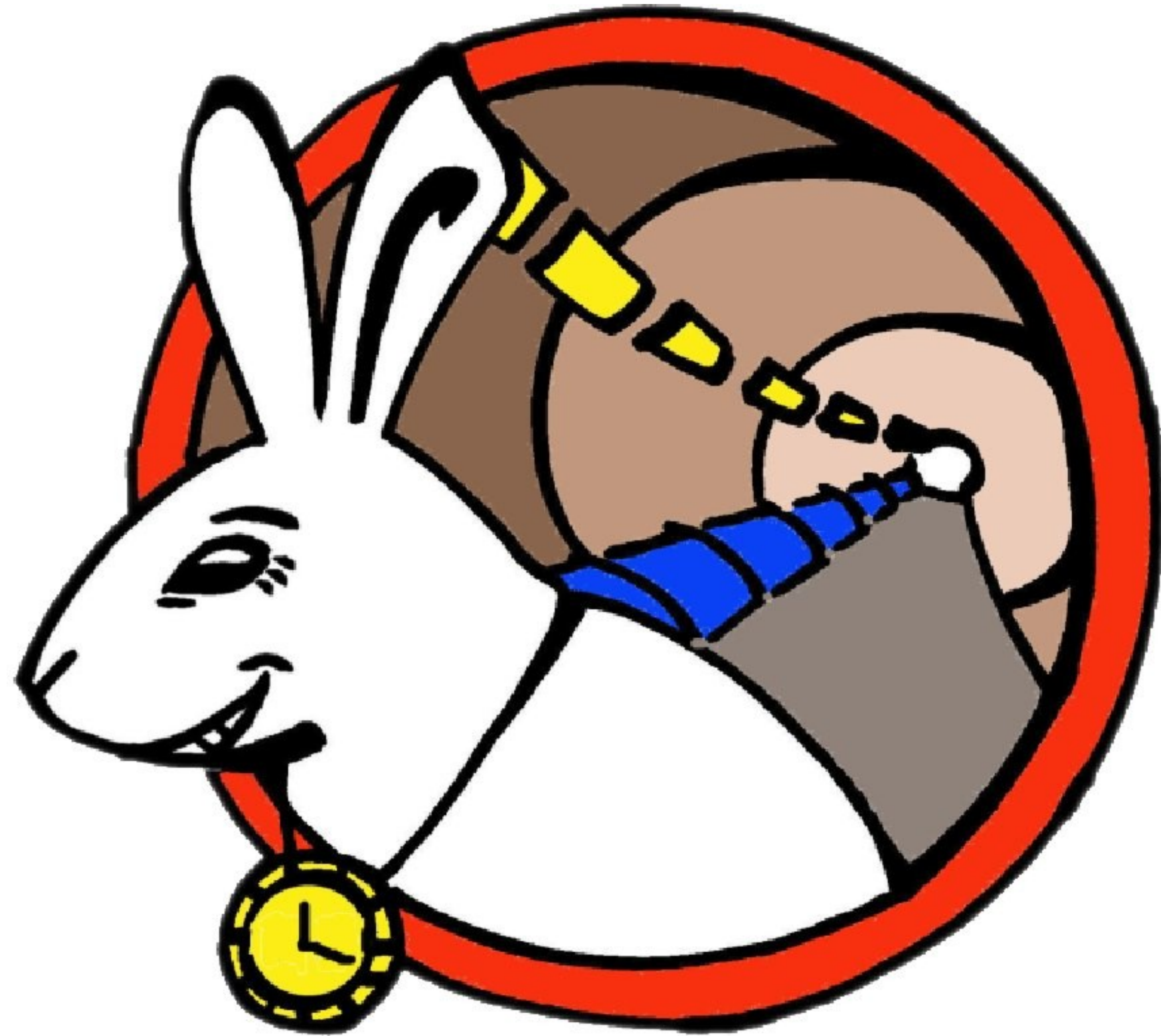
[ Vector avg'ed 22-Feb-2018/15:29:55.125->22-Feb-2018/15:30:04.875]



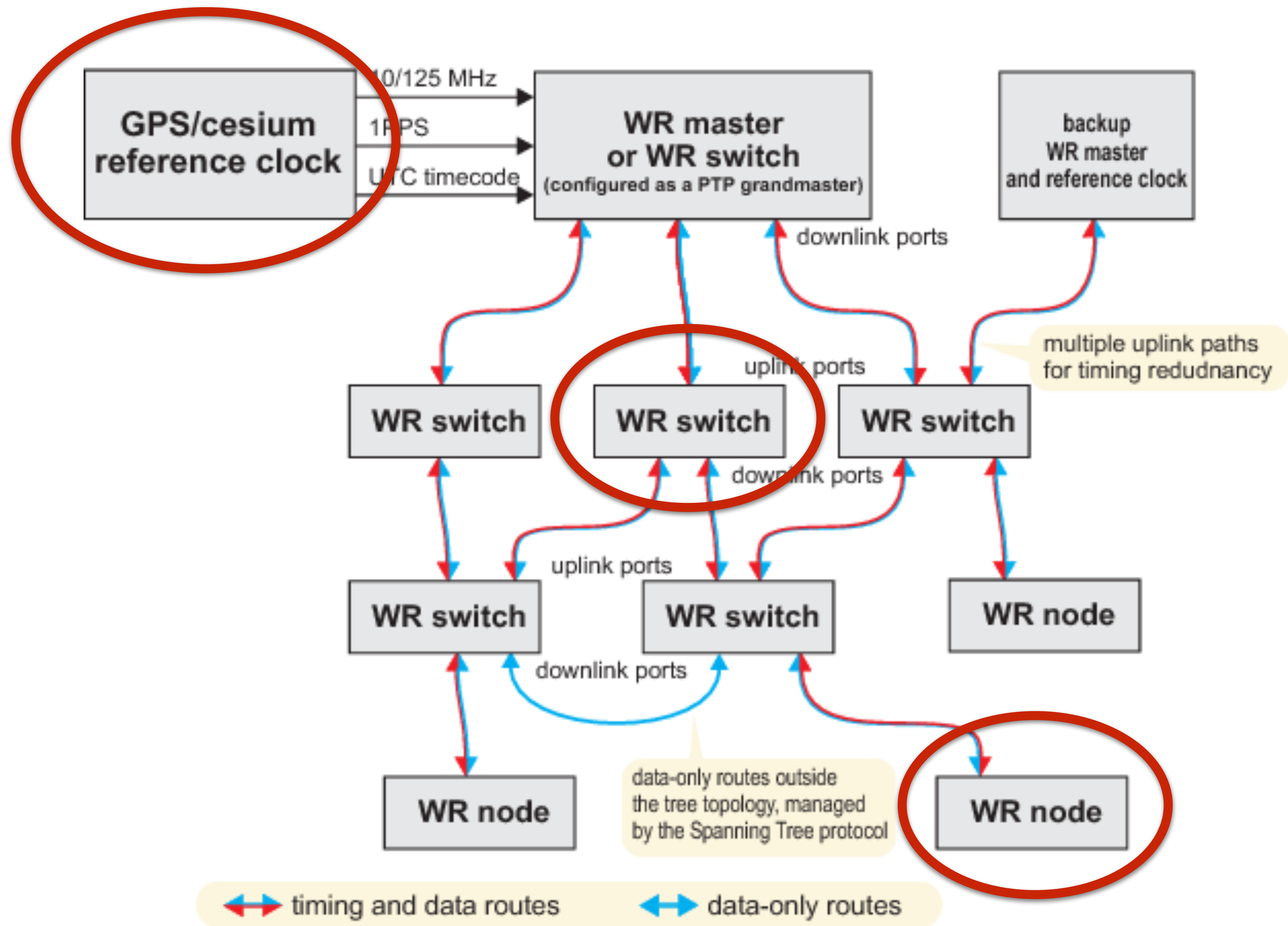


<https://ohwr.org/project/white-rabbit/wikis/home>

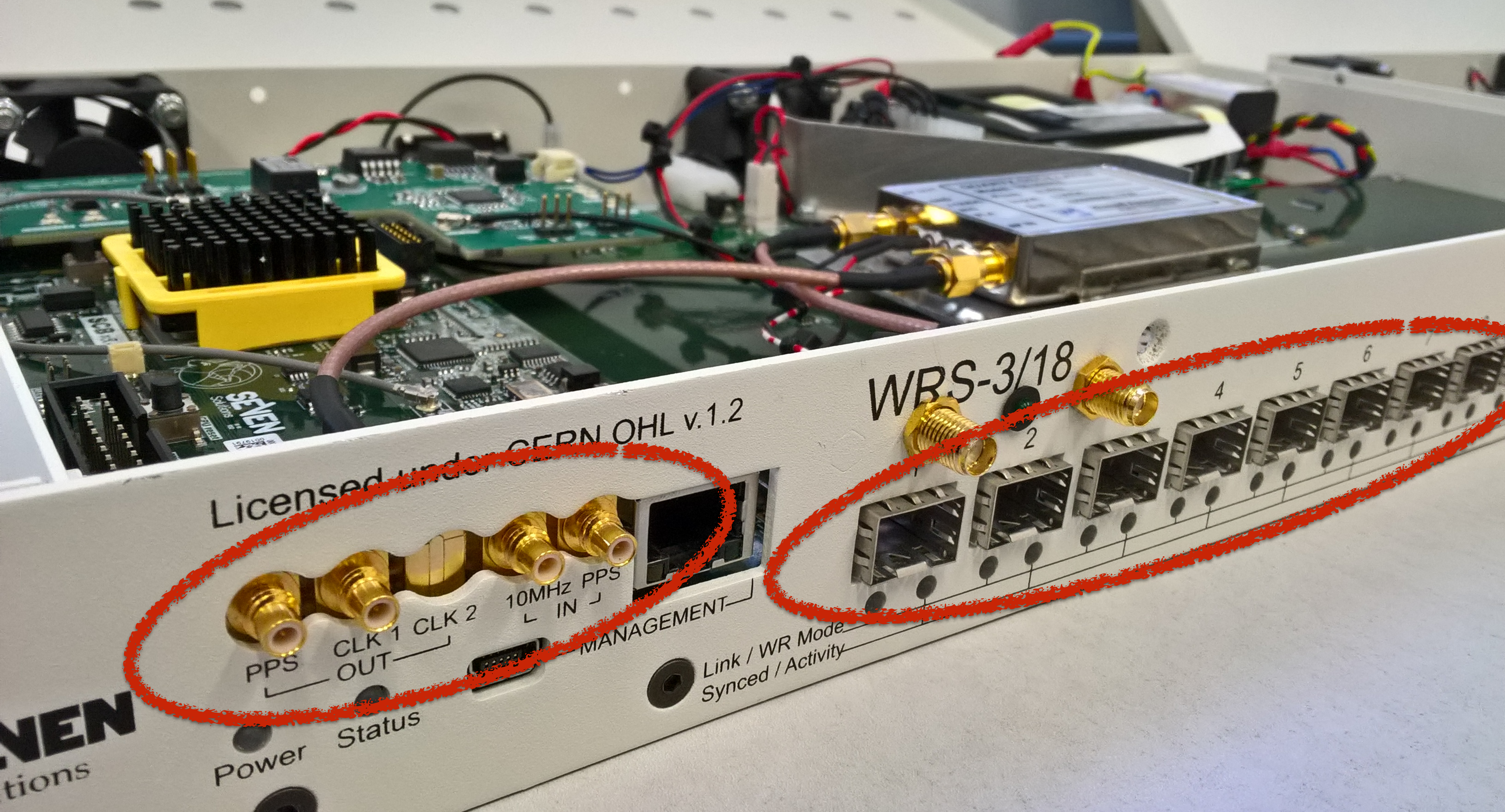




<https://ohwr.org/project/white-rabbit/wikis/home>



<https://ohwr.org/project/white-rabbit/wikis/home>



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WRS-3/18

PPS  
CLK 1 OUT  
CLK 2  
10MHz PPS IN

MANAGEMENT

Link / WR Mode  
Synced / Activity

VEN  
tions

Power Status

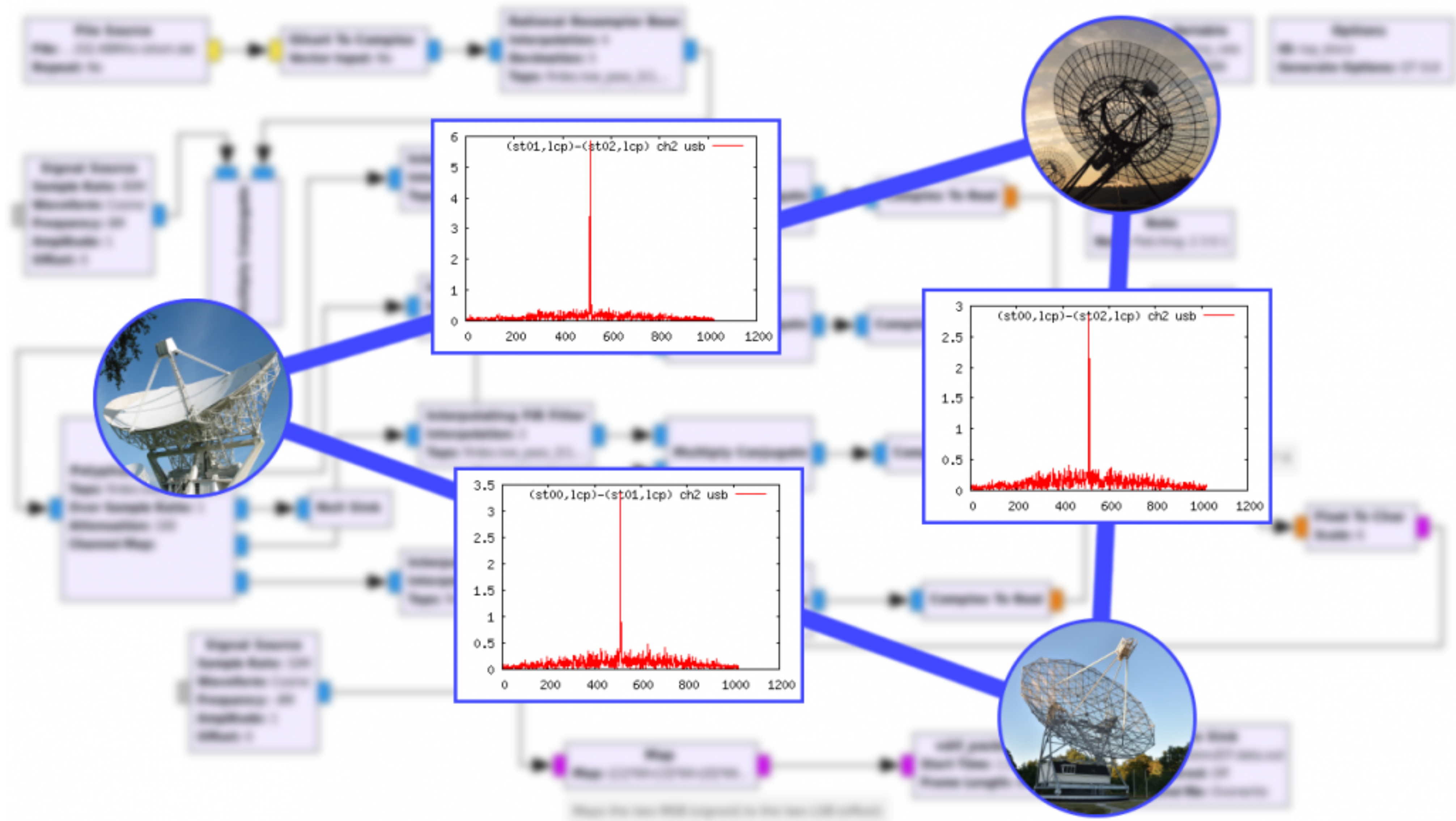
From city of Groningen

To city of Groningen



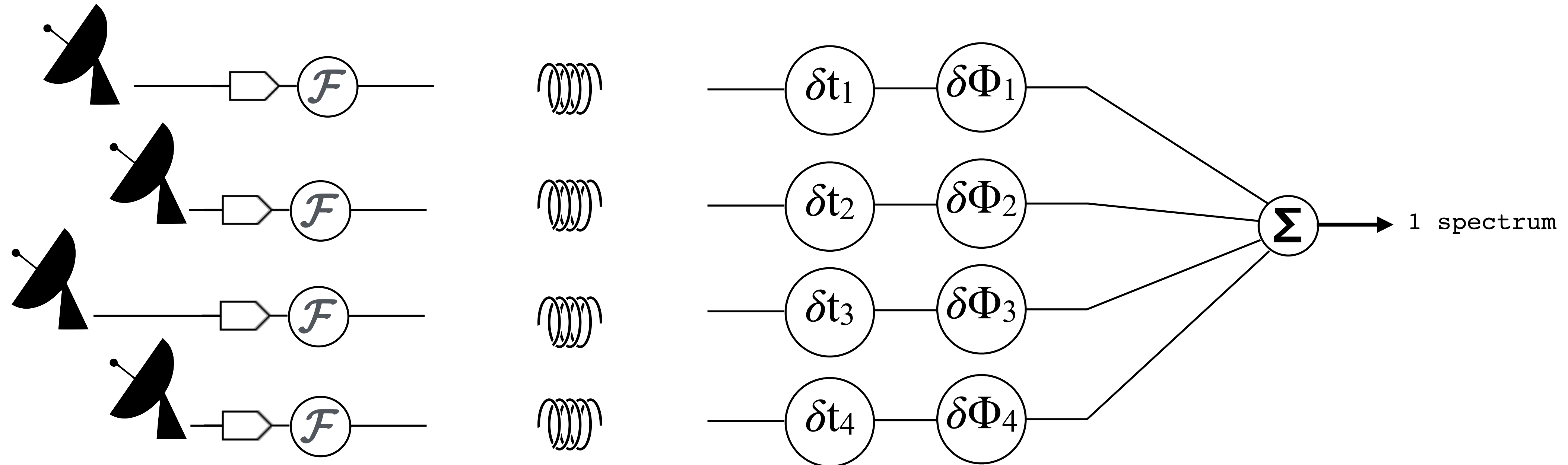
170km of fiber in total

(c) Wim de Vries



(c) Paul Boven

# Phased Array (this way)



# Phased Array (this way)



100%

incompatible

with VLBI

MeerKAT	
<b>Bandwidth</b>	856 MHz
<b>Sky frequency</b>	fixed 856 - 1712 MHz
<b>Sample type</b>	8 bit complex (4 real+4 imag)
<b>Domain</b>	frequency (spectrum)
<b>Data format</b>	HDF5 own structure



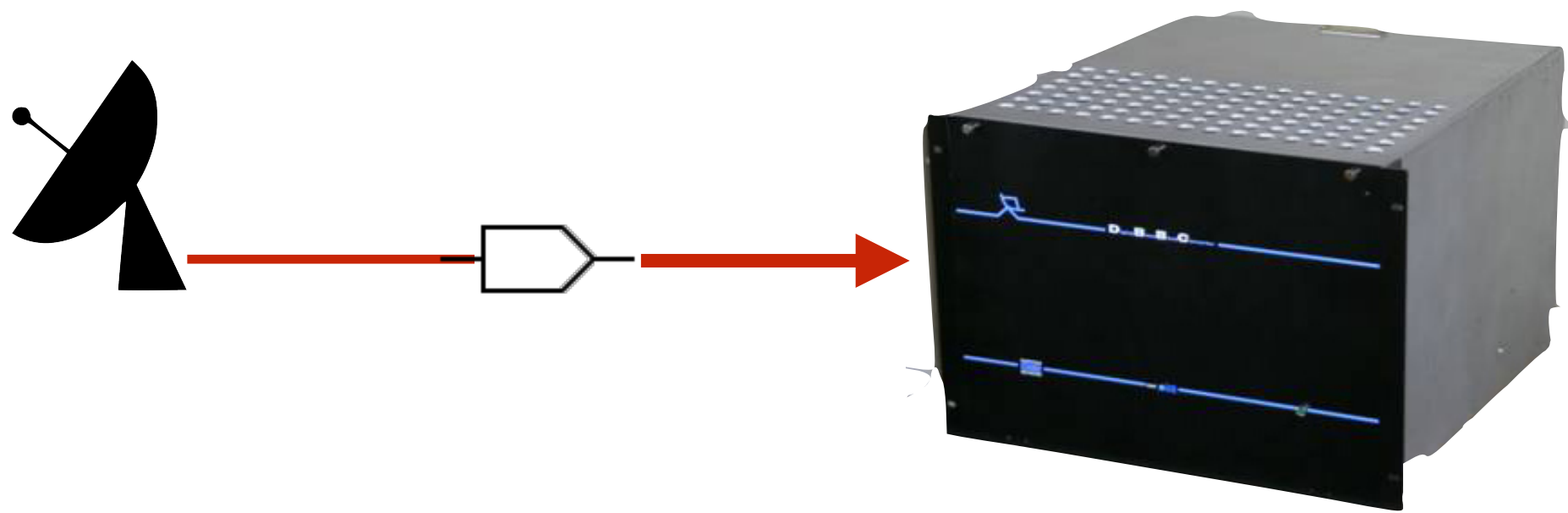
	MeerKAT		VLBI
<b>Bandwidth</b>	856 MHz	≠	2 <sup>n</sup> MHz
<b>Sky frequency</b>	fixed 856 - 1712 MHz	≠	tunable
<b>Sample type</b>	8 bit complex (4 real+4 imag)	≠	2 bit real
<b>Domain</b>	frequency (spectrum)	≠	time (voltage)
<b>Data format</b>	HDF5 own structure	≠	VDIF format(*) international standard

(\*) [https://vlbi.org/wp-content/uploads/2019/03/VDIF\\_specification\\_Release\\_1.1.1.pdf](https://vlbi.org/wp-content/uploads/2019/03/VDIF_specification_Release_1.1.1.pdf)

# Digital back end



# Digital back end

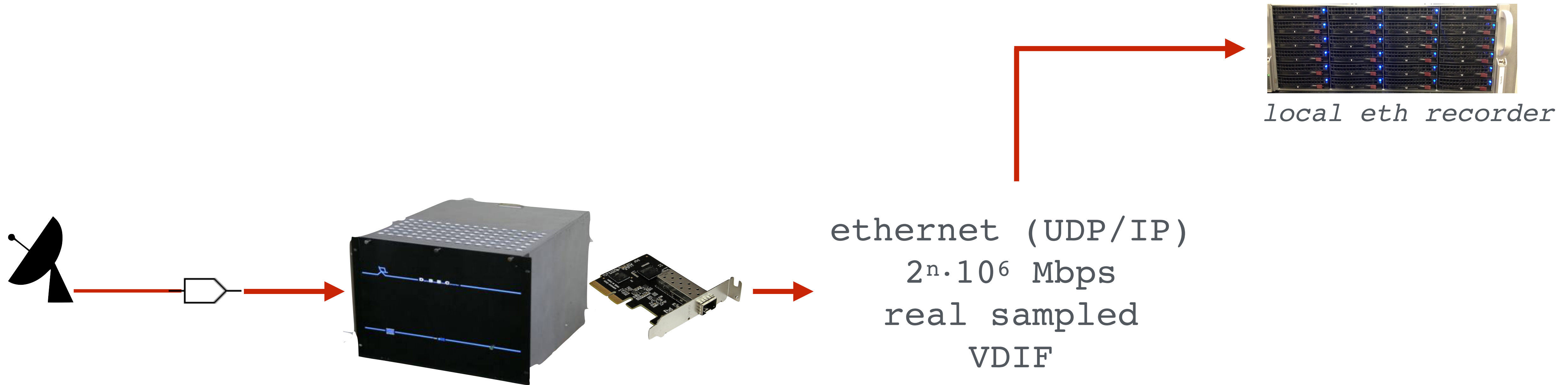


*internet*

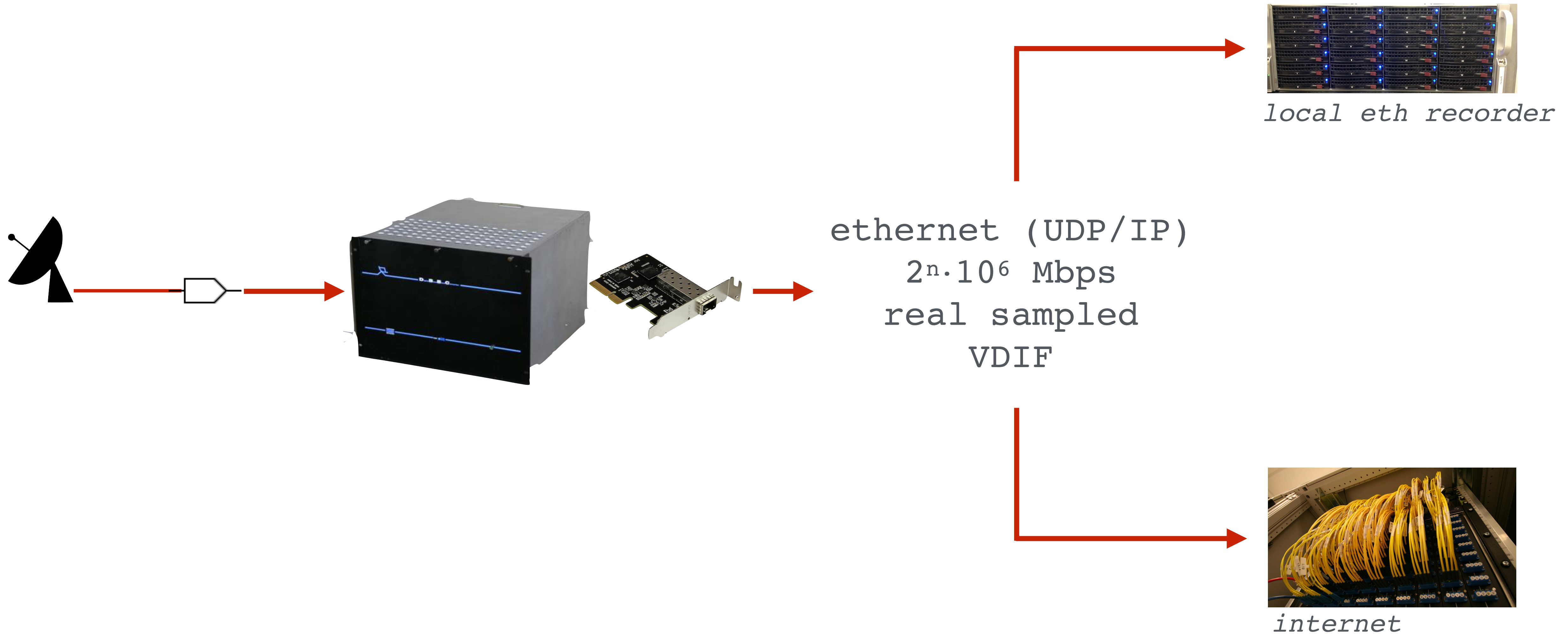
# Digital back end



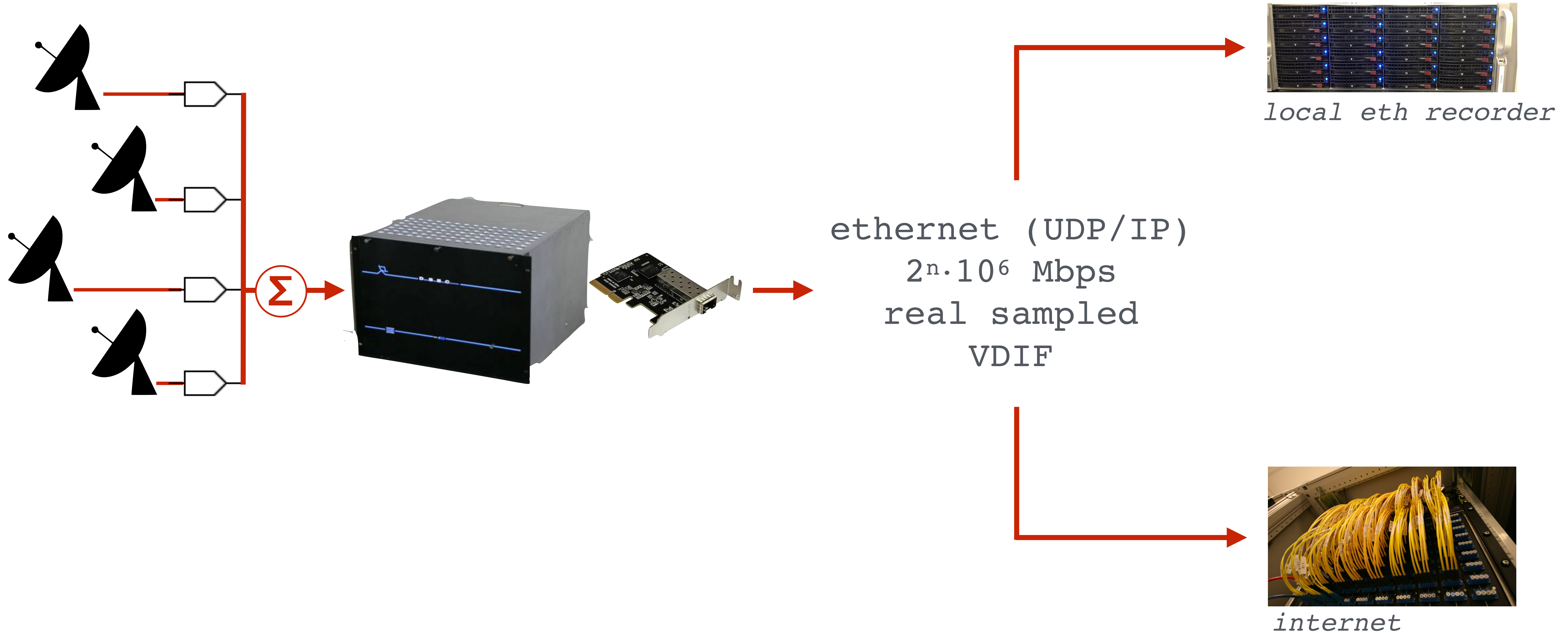
# Digital back end



# Digital back end



# Digital back end

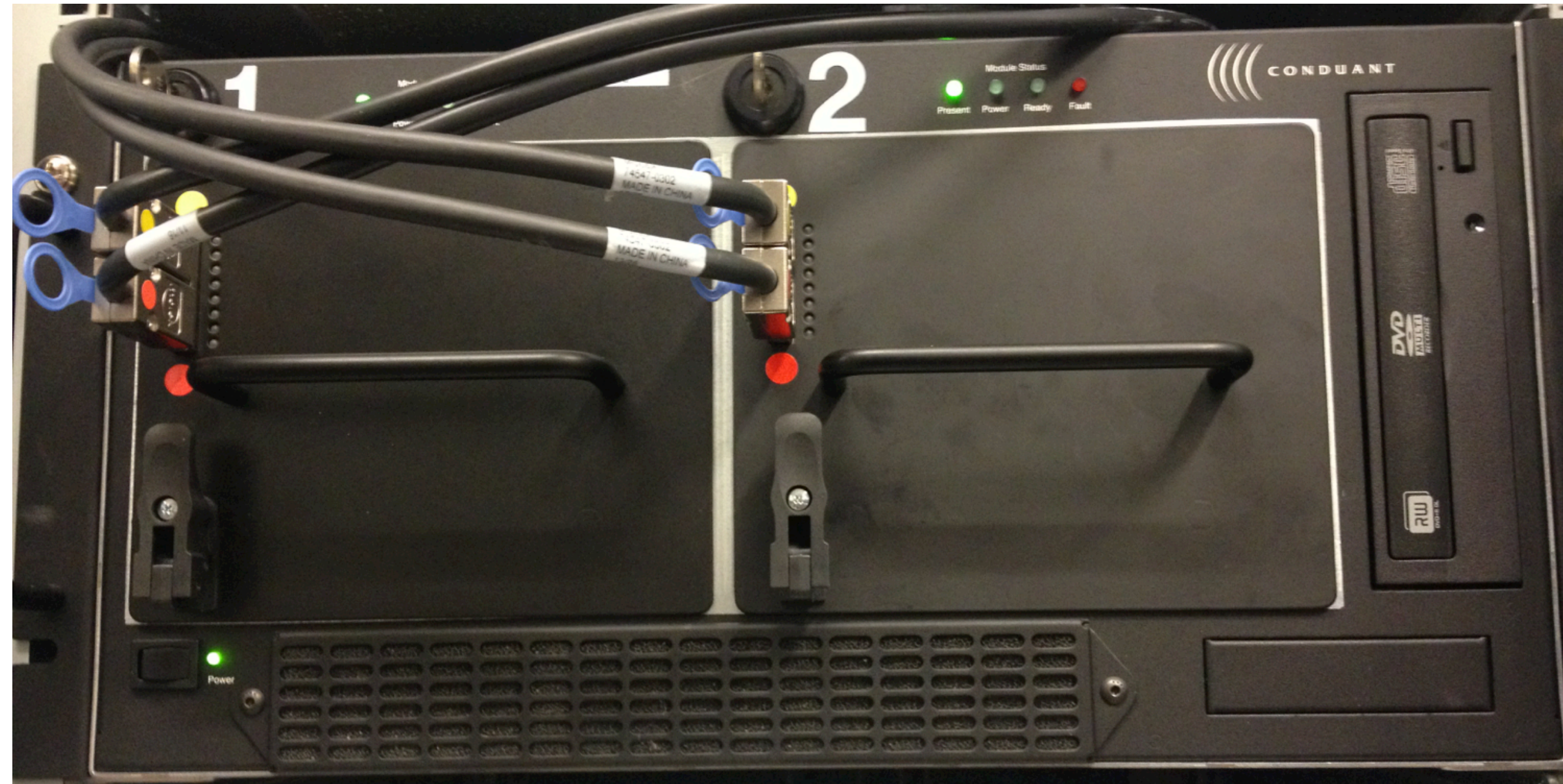


# The ethernet recorder





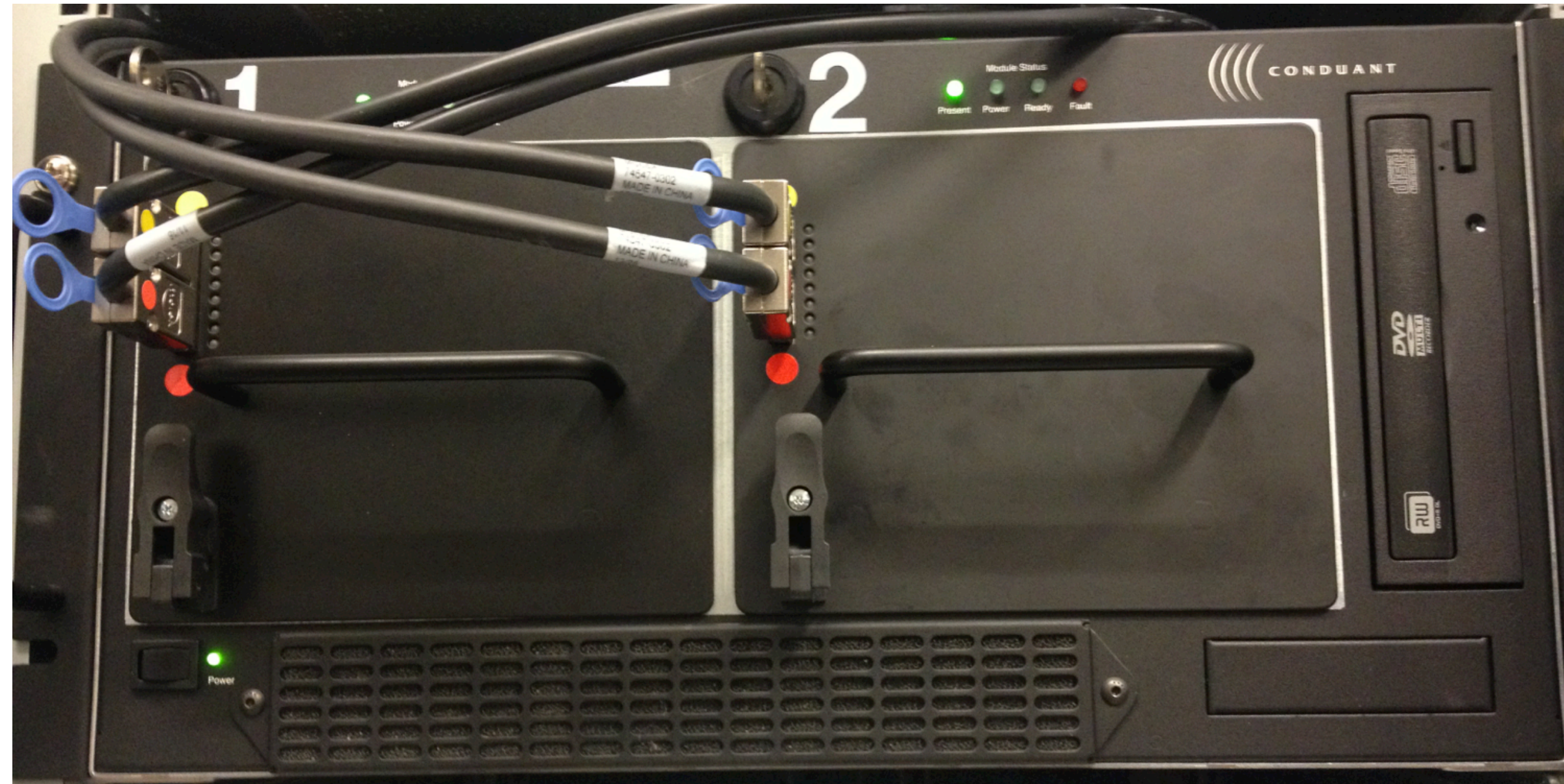
# The ethernet recorder



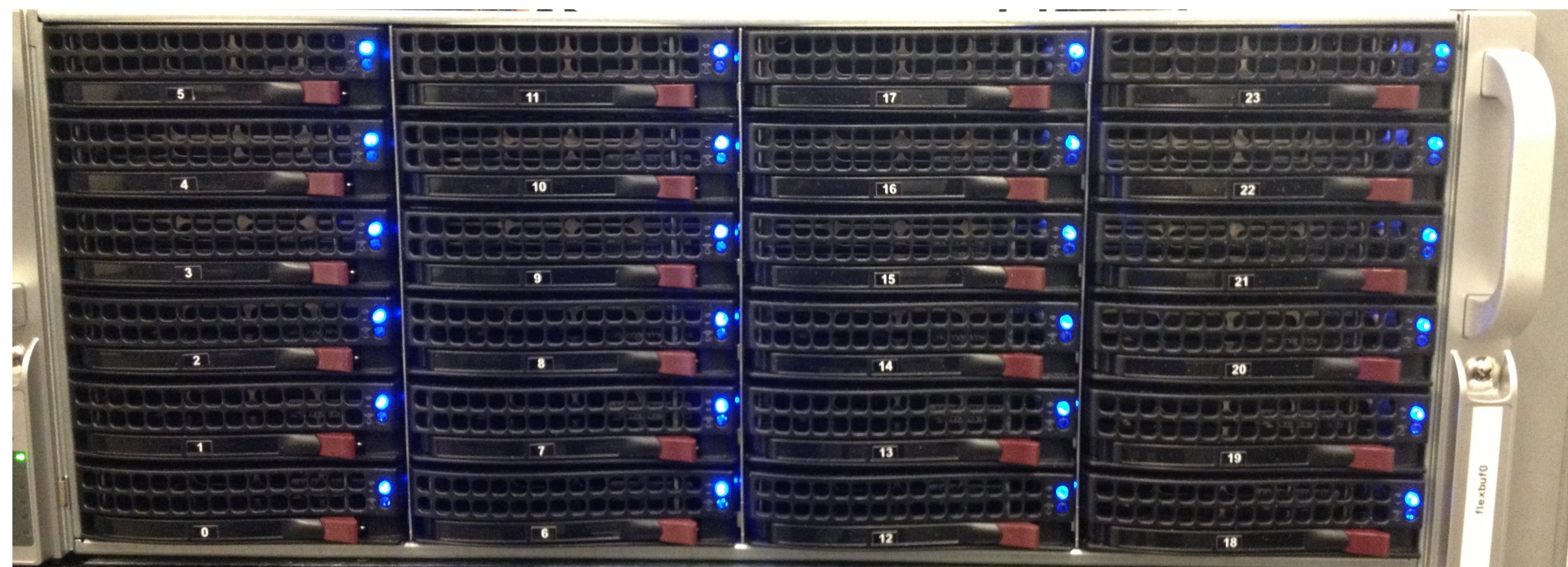
Mark6 (MIT Haystack/Conduant)

- proprietary hardware
- only one supplier (Conduant Corp.)
- $\leq 8$  Gpbs
- 30 k€ (inc. 32 x 10 TB HDD)

# The ethernet recorder



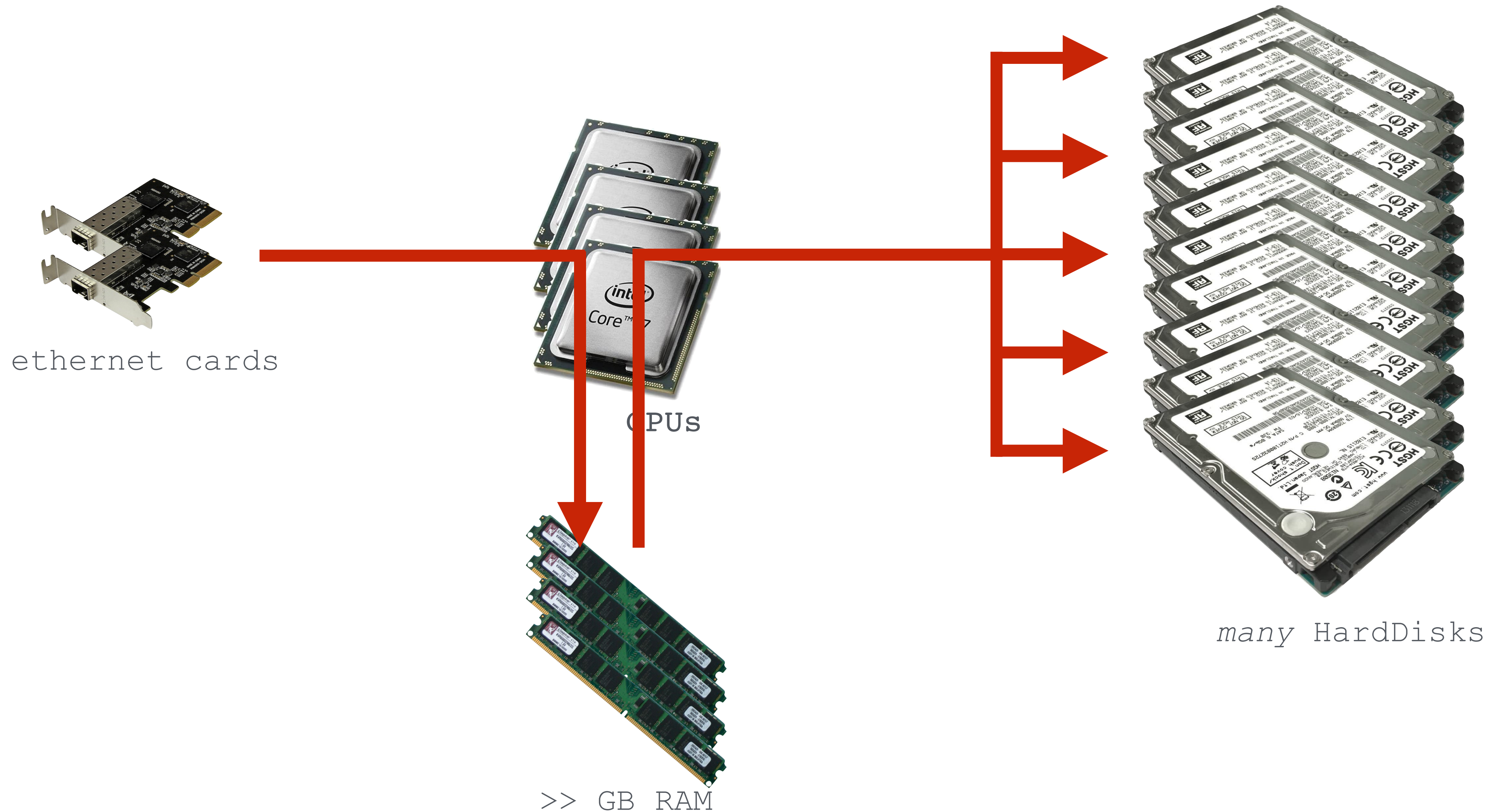
- Mark6 (MIT Haystack/Conduant)
- proprietary hardware
  - only one supplier (Conduant Corp.)
  - $\leq 8$  Gpbs
  - 30 k€ (inc. 32 x 10 TB HDD)



- FlexBuff (Metsähovi / JIVE)
- fully customizable, COTS
  - $n$  Gpbs
  - 16 k€ (inc. 36 x 10 TB HDD)

*Concept: A. Mujunen, Metsähovi*  
*Productionalized: JIVE*

# The ethernet recorder



# The ethernet recorder



The only tangible difference between the systems. The rest is semantics/software.

Mark6 removable disk packs



FlexBuff fixed disks



# EVN: disk-shipmentless



- recorded

- e-VLBI (real-time)

# EVN: disk-shipmentless



- recorded
  - data recorded locally (FlexBuff, Mark5/6)
  - transferred off-line to JIVE over internet
  - correlate when data from all stations rcv'd
- e-VLBI (real-time)

# EVN: disk-shipmentless



- recorded
  - data recorded locally (FlexBuff, Mark5/6)
  - transferred off-line to JIVE over internet
  - correlate when data from all stations rcv'd
- e-VLBI (real-time)
  - real-time over (public) internet
  - direct transfer into correlator

# EVN: disk-shippingless





# EVN: disk-shippingless



# EVN: disk-shippingless



Software Correlator @JIVE



# internet connection



*$\nu \leq L\text{-band} \Rightarrow \text{observing data rate} \lesssim 2 \text{ Gbps}$*

# internet connection



- recorded
- e-VLBI (real-time)

*$\nu \leq L\text{-band} \Rightarrow \text{observing data rate} \lesssim 2 \text{ Gbps}$*

# internet connection



- recorded
  - connection speed  $\geq 0.5$  observing data rate
  - 1 Gpbs and higher ok
- e-VLBI (real-time)

*$\nu \leq L\text{-band} \Rightarrow \text{observing data rate} \lesssim 2 \text{ Gbps}$*

# internet connection



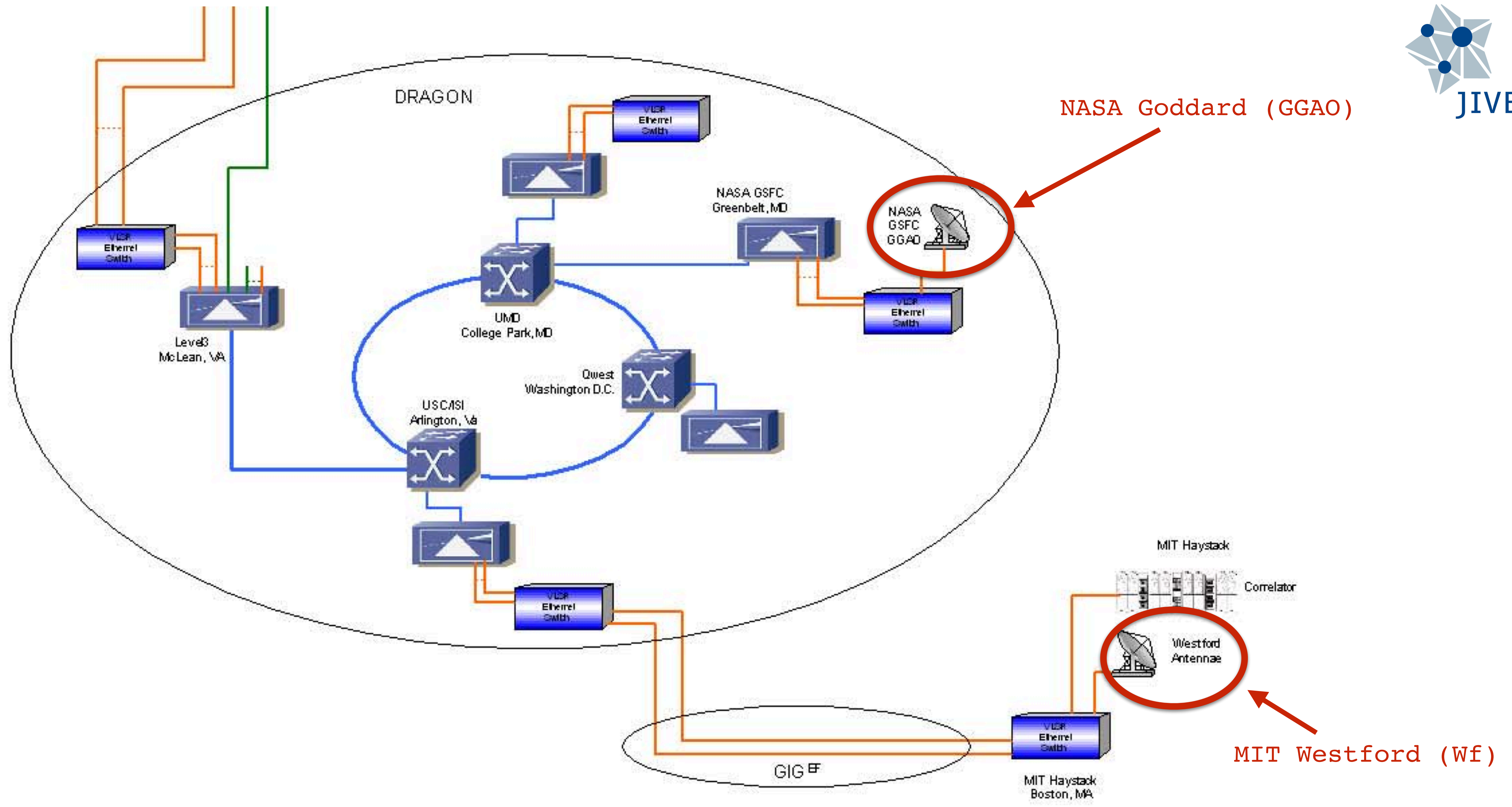
- recorded
  - connection speed  $\geq 0.5$  observing data rate
  - 1 Gpbs and higher ok
- e-VLBI (real-time)
  - connection speed  $\approx 1.5$  observing data rate
  - 2-3 Gpbs and higher ok

*$v \leq L\text{-band} \Rightarrow \text{observing data rate} \lesssim 2 \text{ Gbps}$*

# a network engineer





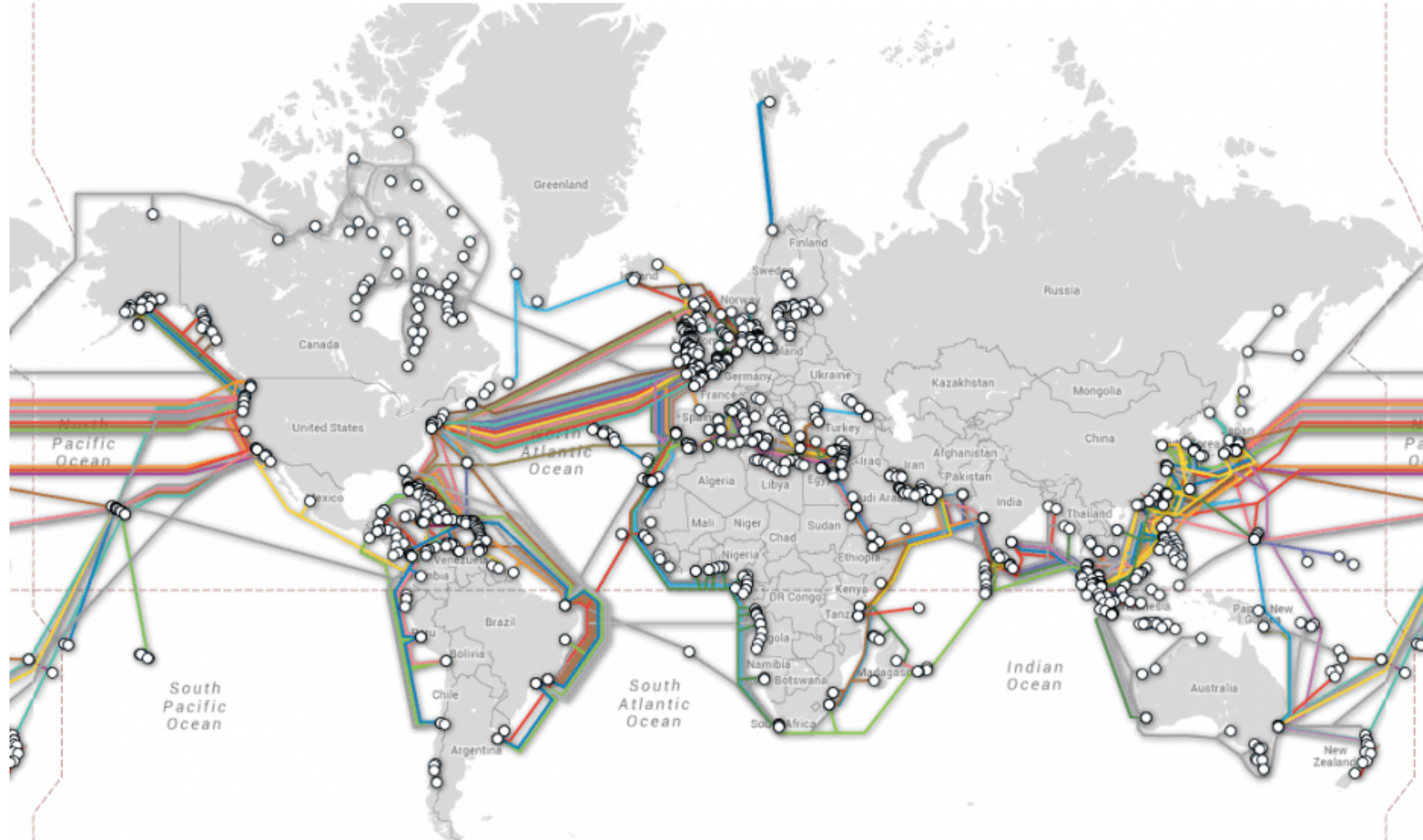


NASA Goddard (GGAO)

MIT Westford (Wf)



# a network engineer



Thanks for  
attention!

# Summarizing



## Requirements for VLBI\*

- ▶ phased up array
- ▶ VLBI compatible “digital back end”:
  - data format
  - sampling rate
- ▶ VLBI data recorder
- ▶ network connectivity
- ▶ access to source of network knowledge

*(\*) Likely applies to all VLBI networks, not just EVN*