



recorded VLBI

real-time VLBI (e-VLBI)

# snag noun

\ ˈsnag \

## 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 European VLBI Network

Harro Verkouter

Beam Wave Guide System[1]:

## 2.3 GHz – 26 GHz

Receivers:

| | |
|---|---|
| C-Band | 4.7 - 7.6 GHz |
| K-Band | 20 - 25 GHz |

## EVN Bands[2] (approx):

| | |
|---|---|
| L-Band | 1.4 - 1.7 GHz |
| C-Band | 4.0 - 6.0 GHz |
| M-Band | 5.7 - 7.7 GHz |
| X-Band | 8.0 - 9.9 GHz |
| K-Band | 18 - 26 GHz |

[1] http://spacecenter.gov.ua/contents/pdf/Ulyanov_New_Ukrainian_RT-32-Zolochiv-2019.pdf

[2] https://deki.mpifr-bonn.mpg.de/Working_Groups/EVN_TOG/Frequency_ranges_for_2%2F%2F4_Gbps/Old_Frequency_range_table

# Site requirement

Phase-coherent system:

- local oscillator
- sampler
- backend
- …
- recorder*

[*] Depending on actual recorder type

# Site requirement

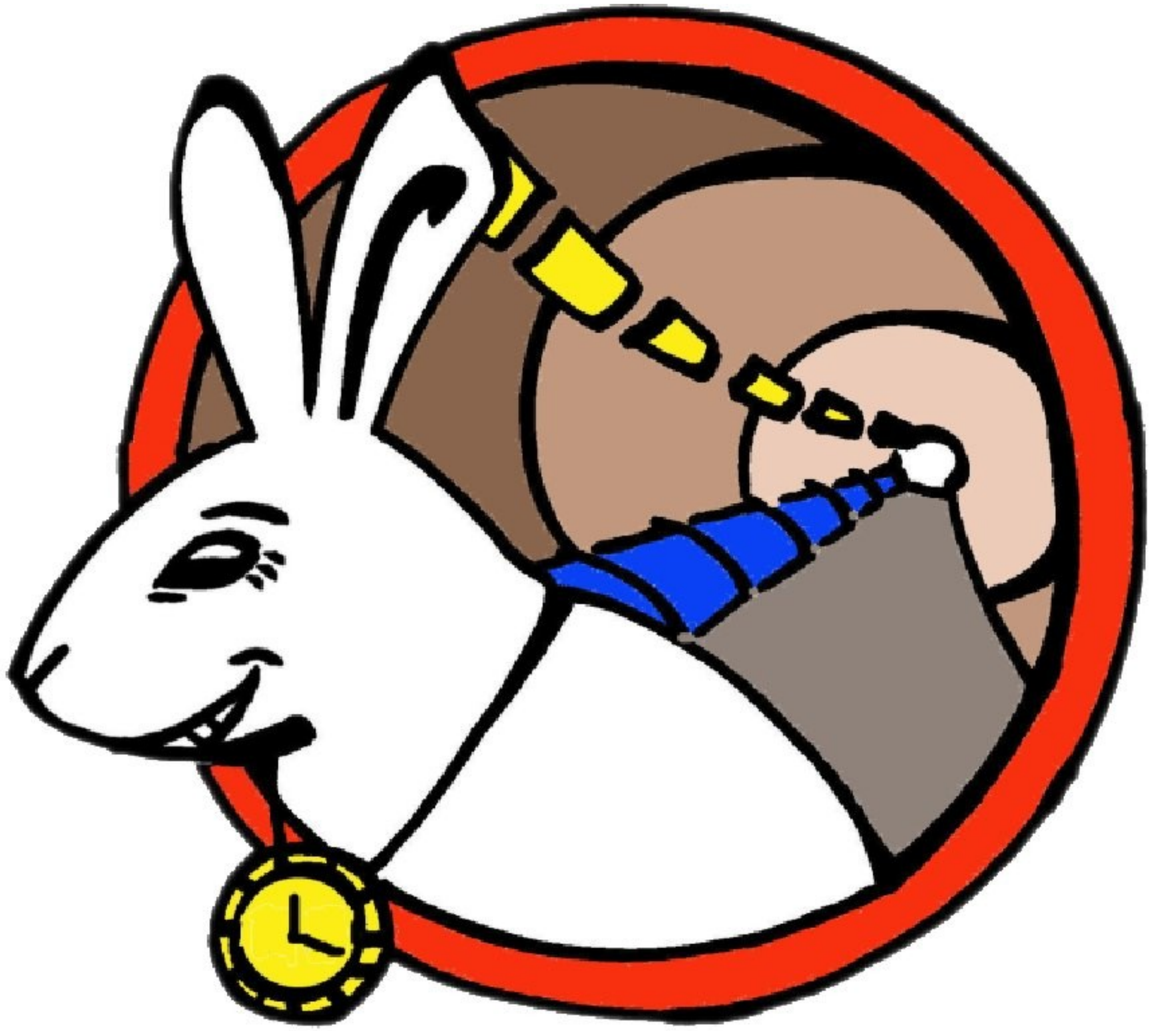
Phase-coherent system:

- local oscillator
- sampler
- backend
- …
- recorder*

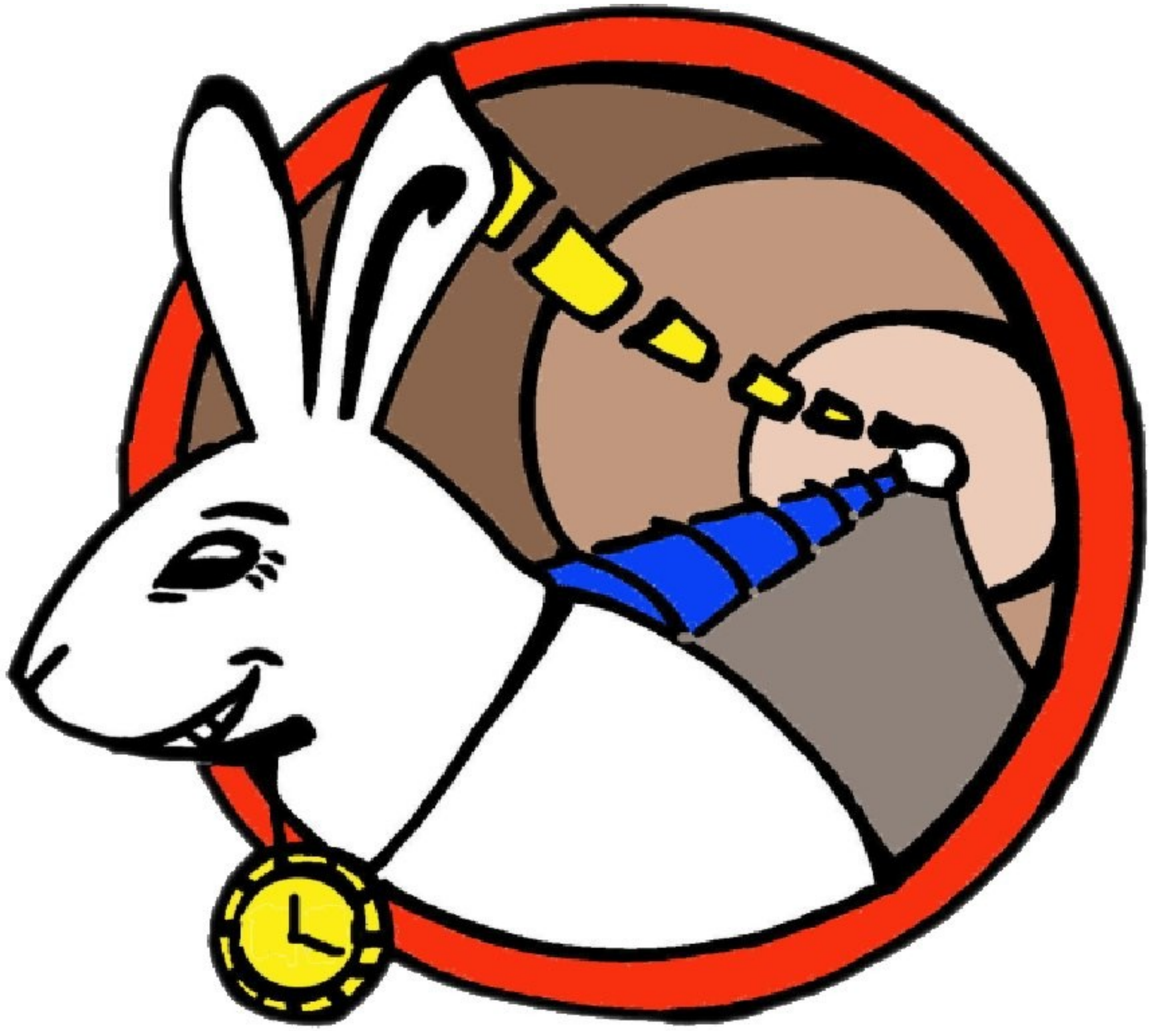
⇒ common time/frequency standard

[*] Depending on actual recorder type

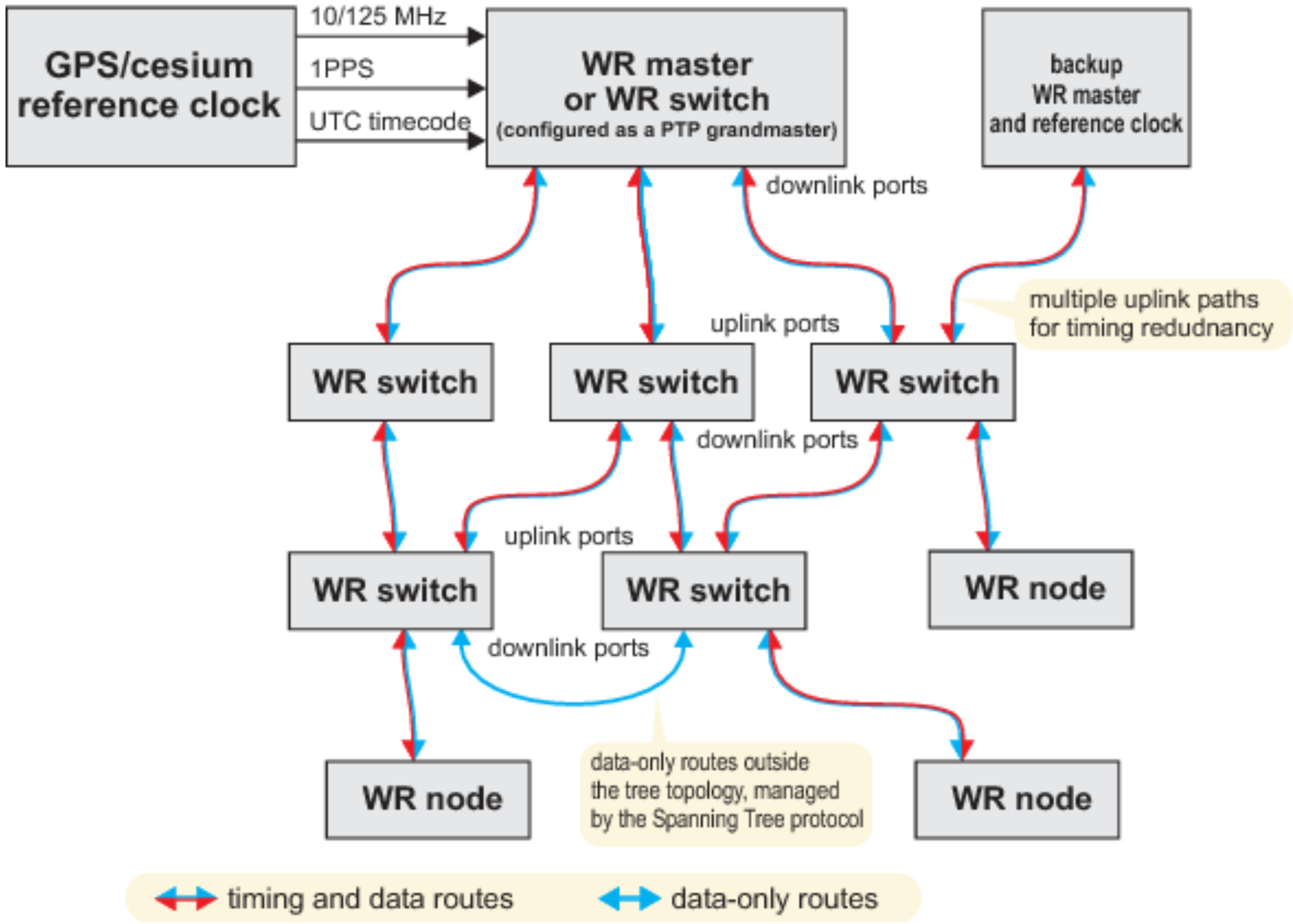
# H-maser, Cs clock



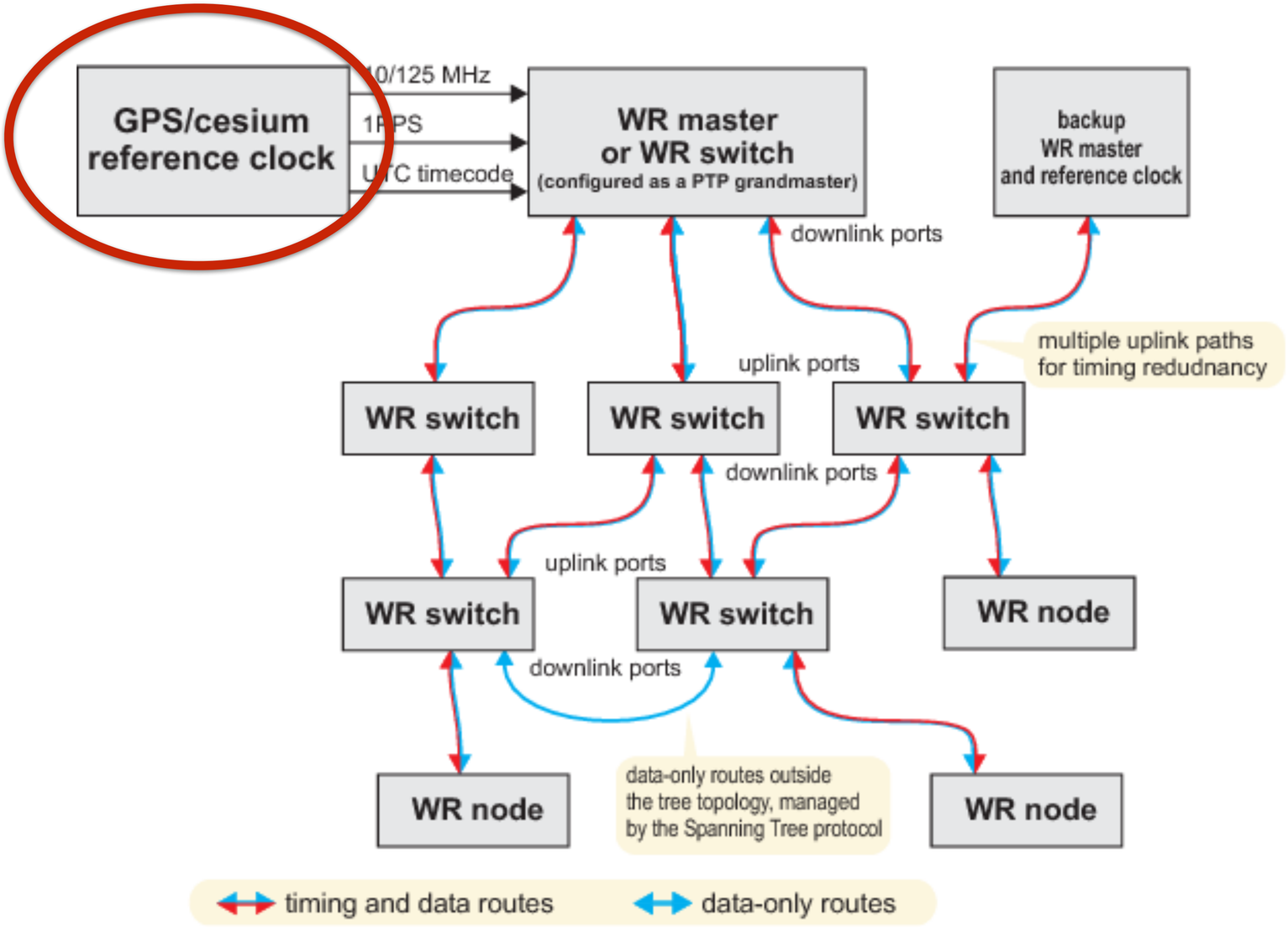
*https://ohwr.org/project/white-rabbit/wikis/home*



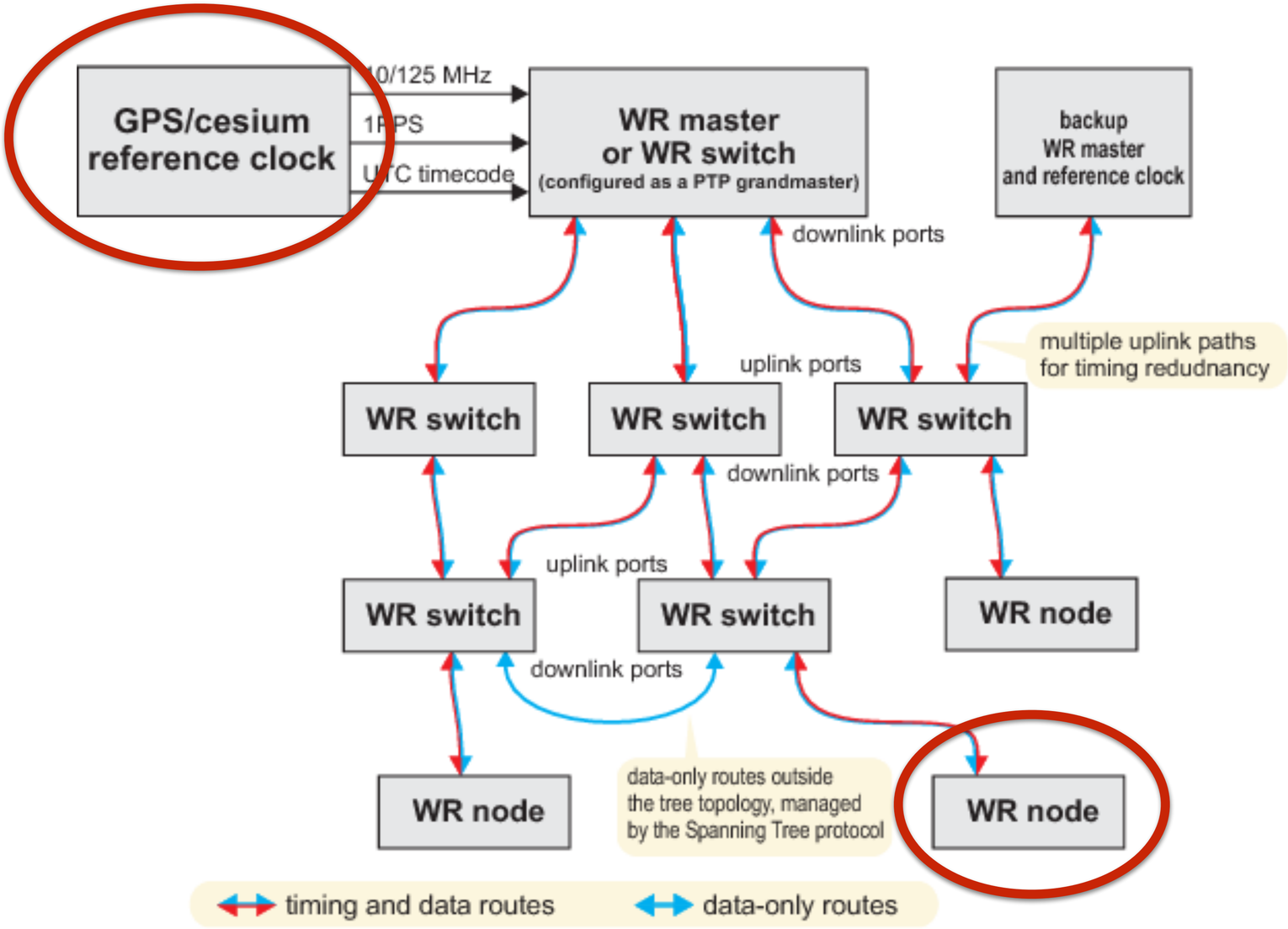

*https://ohwr.org/project/white-rabbit/wikis/home*



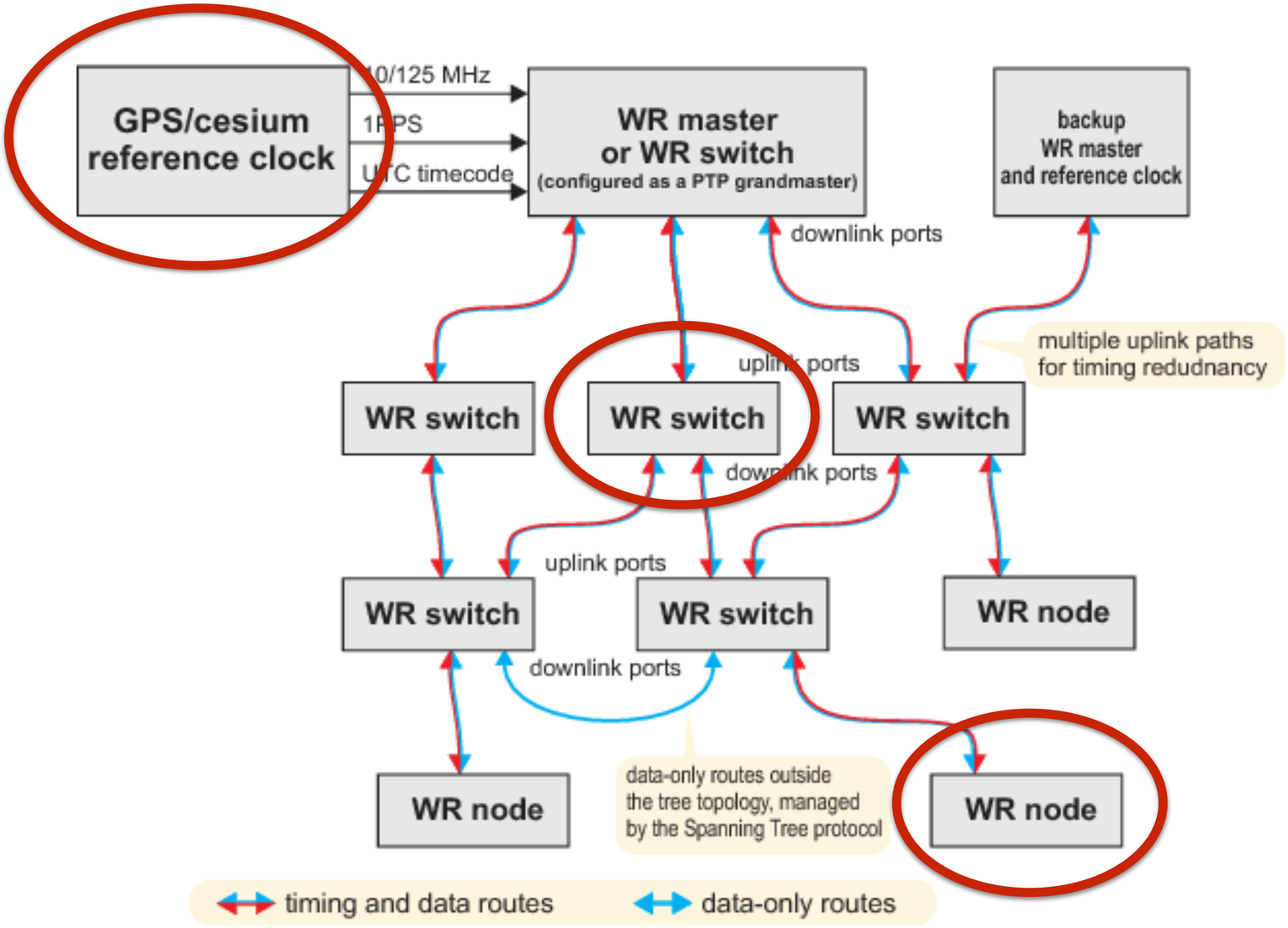

*https://ohwr.org/project/white-rabbit/wikis/home*



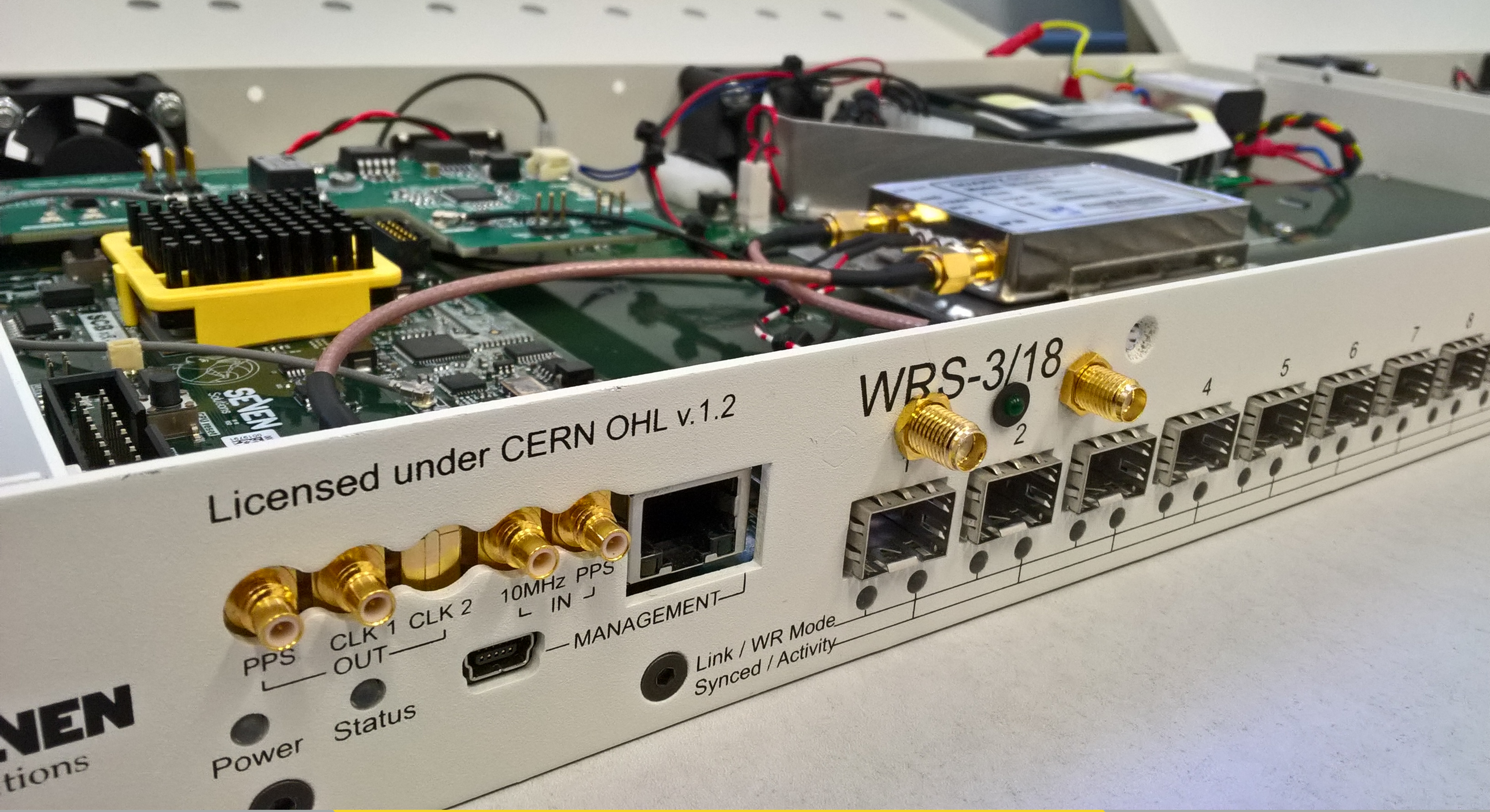

*https://ohwr.org/project/white-rabbit/wikis/home*

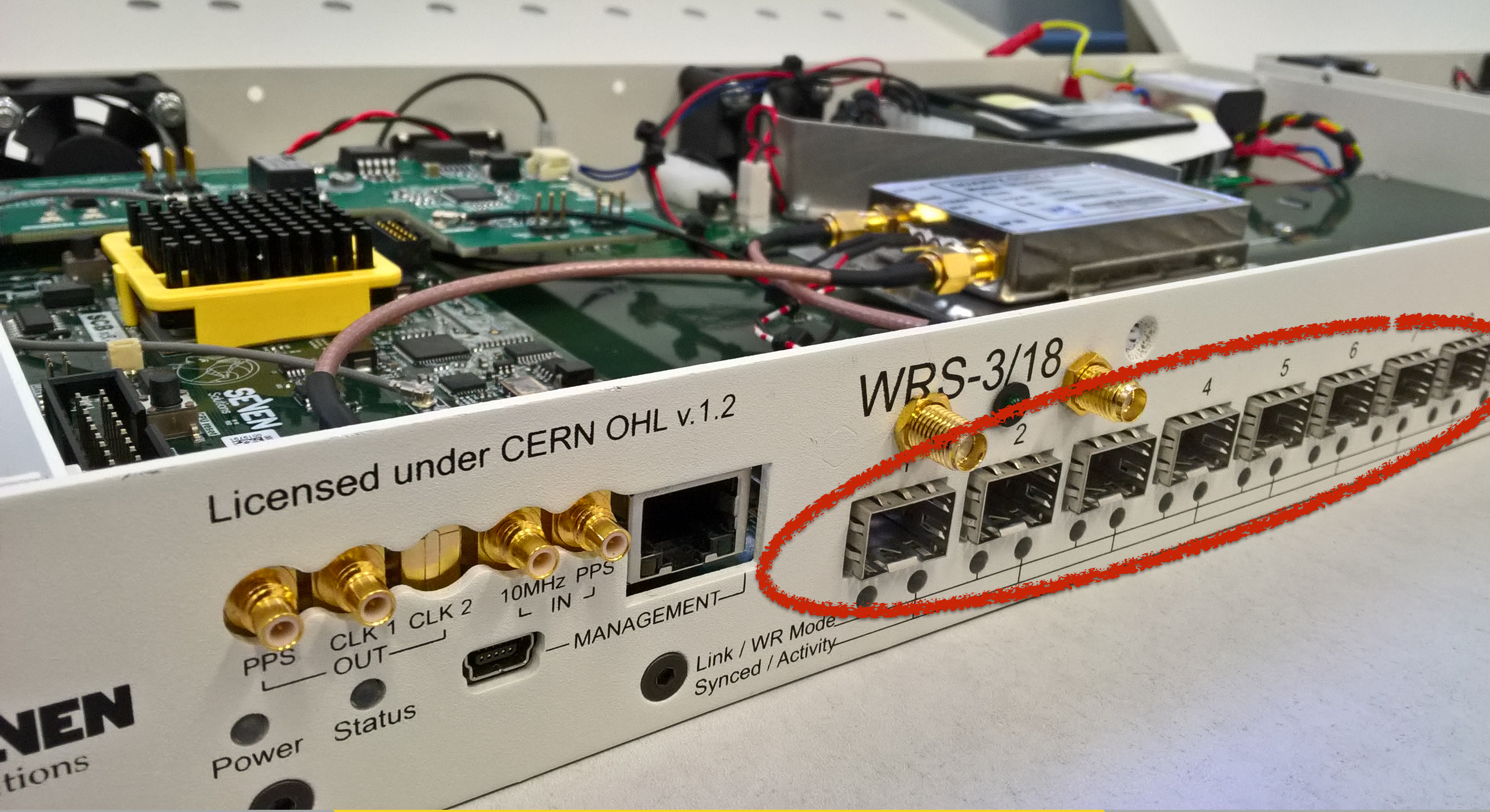


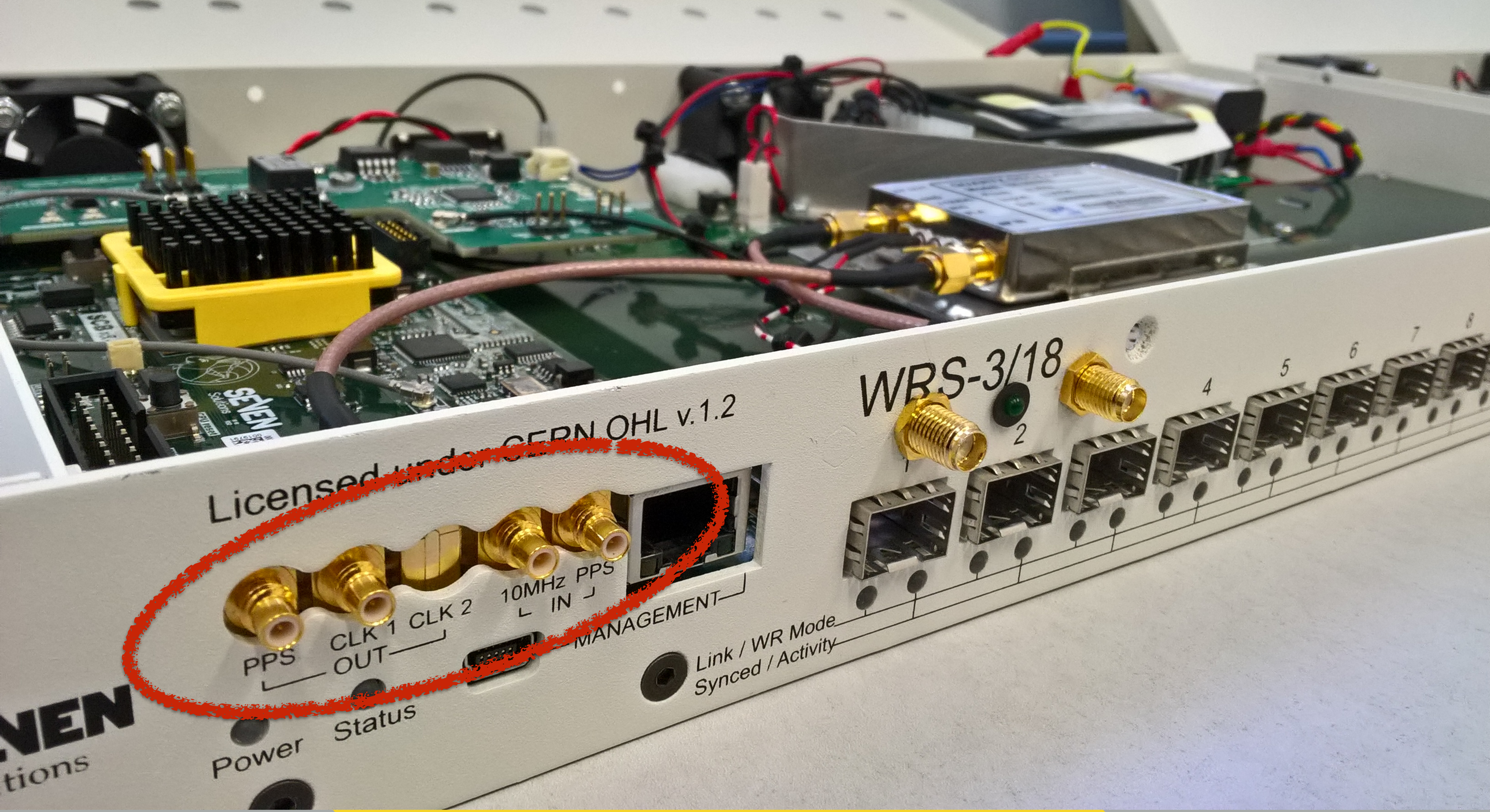

*https://ohwr.org/project/white-rabbit/wikis/home*

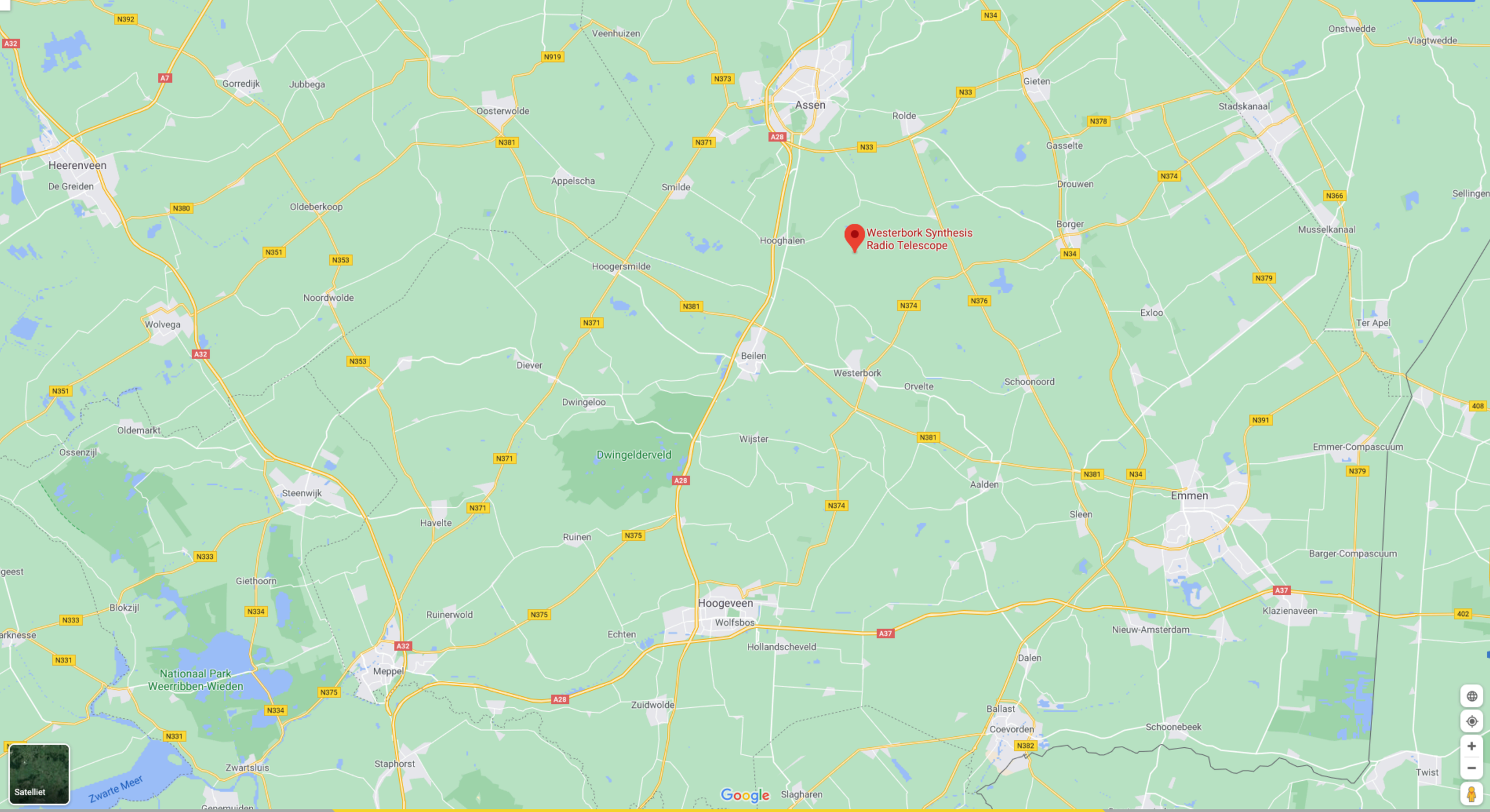



*https://ohwr.org/project/white-rabbit/wikis/home*


Licensed under CERN OHL v.1.2
WRS-3/18
PPS
CLK 1
CLK 2
OUT
10MHz
PPS
IN
MANAGEMENT
Power
Status
Link / WR Mode
Synced / Activity


Licensed under CERN OHL v.1.2
WRS-3/18
1
2
4
5
6
PPS
CLK 1
CLK 2
OUT
10MHz
PPS
IN
MANAGEMENT
Link / WR Mode
Synced / Activity
Status
Power


WRS-3/18
Licensed under CERN OHL v.1.2
PPS
CLK 1
CLK 2
10MHz
PPS
OUT
IN
MANAGEMENT
Power
Status
Link / WR Mode
Synced / Activity


Westerbork Synthesis
Radio Telescope
Assen
Heerenveen
Emmen
Hoogeveen
Meppel
Nationaal Park
Weerribben-Wieden
Dwingelderveld
Satelliet
Google


(c)Wim de Vries

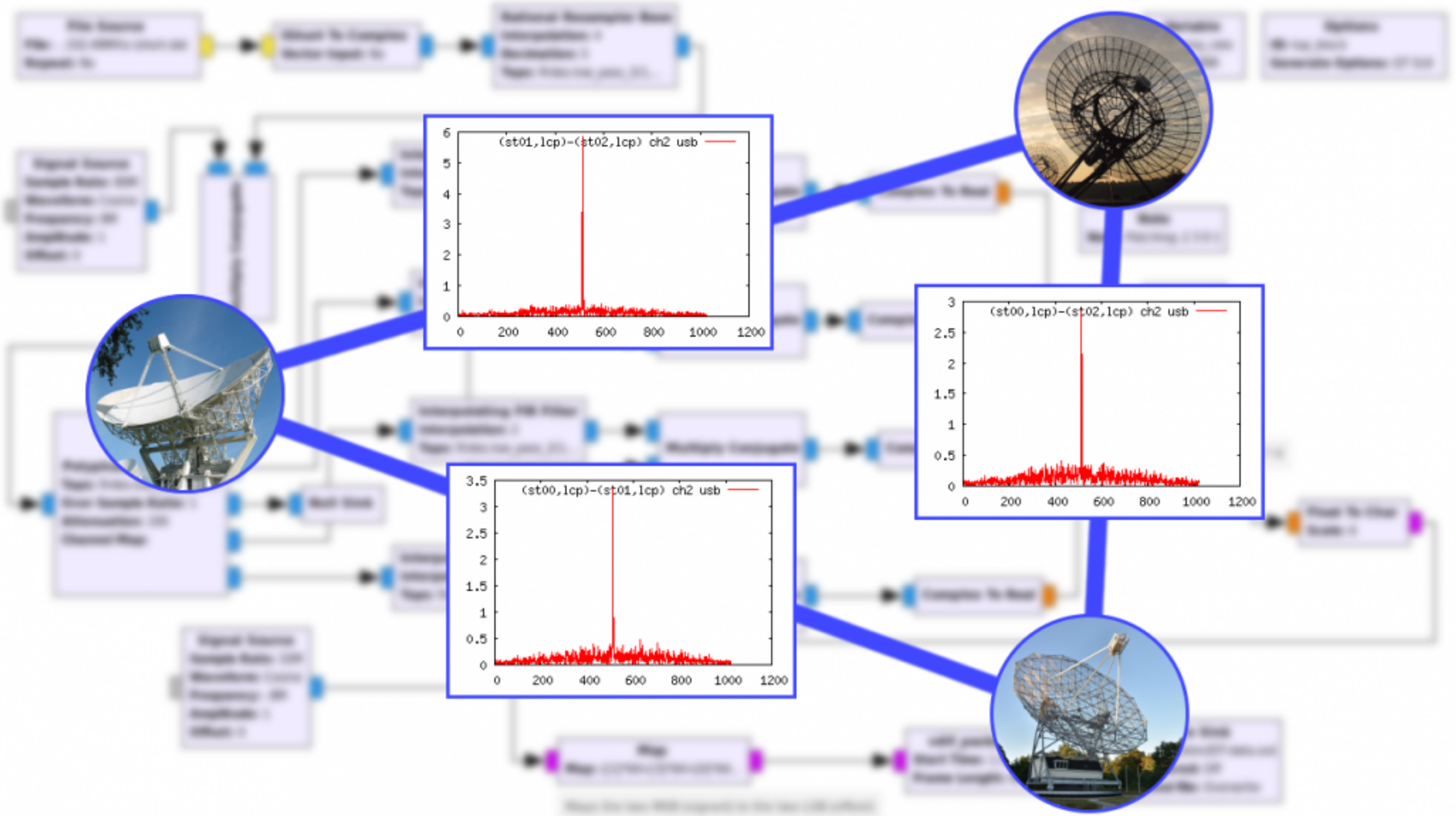
(c)Wim de Vries

From city of Groningen

To city of Groningen

(c)Wim de Vries

170km of fiber in total


(st01,lcp)-(st02,lcp) ch2 usb
(st00,lcp)-(st02,lcp) ch2 usb
(st00,lcp)-(st01,lcp) ch2 usb

*(c)Paul Boven*

# Generating PI data

EVN = (off-line) interferometer

- bring station data to central location
- only then compute coherence/correlation

# Generating PI data

EVN = (off-line) interferometer

- bring station data to central location
- only then compute coherence/correlation

Only if same frequency sampling

| | Zolochiv RT32 |
|---|---|
| **Sample rate** | $2^n \cdot 10^6$ s/s |
| **Sky frequency** | 100 Hz tunable |
| **Sample type** | 16 bit (real or complex) |
| **Domain** | waveform or spectra |
| **Data format** | NADR Data Format<br>own structure |

| | Zolochiv RT32 |
|---|---|
| **Sample rate** | $2^n \cdot 10^6$ s/s |
| **Sky frequency** | 100 Hz tunable |
| **Sample type** | 16 bit (real or complex) |
| **Domain** | waveform or spectra |
| **Data format** | NADR Data Format<br>own structure |

| | Zolochiv RT32 |
|---|---|
| **Sample rate** | $2^n \cdot 10^6$ s/s |
| **Sky frequency** | 100 Hz tunable |
| **Sample type** | 16 bit (real or complex) |
| **Domain** | waveform or spectra |
| **Data format** | NADR Data Format<br>own structure |

| | Zolochiv RT32 |
|---|---|
| **Sample rate** | $2^n \cdot 10^6$ s/s |
| **Sky frequency** | 100 Hz tunable |
| **Sample type** | 16 bit (real or complex) |
| **Domain** | waveform or spectra |
| **Data format** | NADR Data Format<br>own structure |

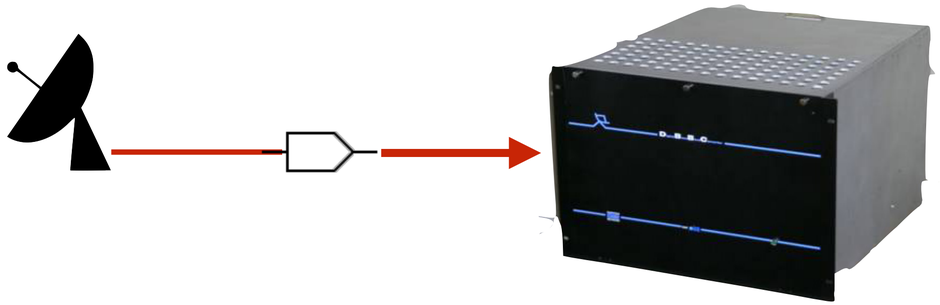
| | Zolochiv RT32 |
|---|---|
| **Sample rate** | $2^n \cdot 10^6$ s/s |
| **Sky frequency** | 100 Hz tunable |
| **Sample type** | 16 bit (real or complex) |
| **Domain** | waveform or spectra |
| **Data format** | NADR Data Format<br>own structure |

| | Zolochiv RT32 | | VLBI |
|---|---|---|---|
| **Sample rate** | $2^n \cdot 10^6$ s / s | ✓ | $2^n \cdot 10^6$ s / s |
| **Sky frequency** | 100 Hz tunable | ✓ | tunable |
| **Sample type** | 16 bit (real or complex) | ≠ | 2 bit real |
| **Domain** | waveform or spectra | ≈ | time (voltage) |
| **Data format** | NADR Data Format<br>own structure | ≠ | VDIF format(*)<br>international standard |

(*) https://vlbi.org/wp-content/uploads/2019/03/VDIF_specification_Release_1.1.1.pdf

# Digital back end

# Digital back end



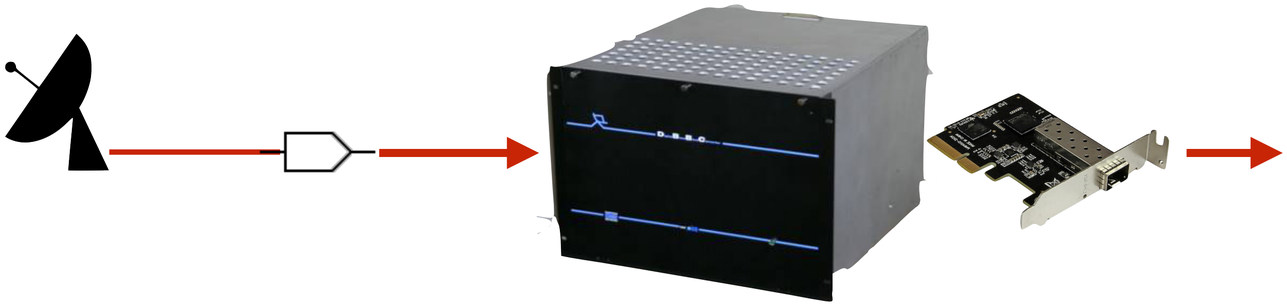
*internet*

# Digital back end

ethernet (UDP/IP)
$2^n \cdot 10^6$ Mbps
real sampled
VDIF

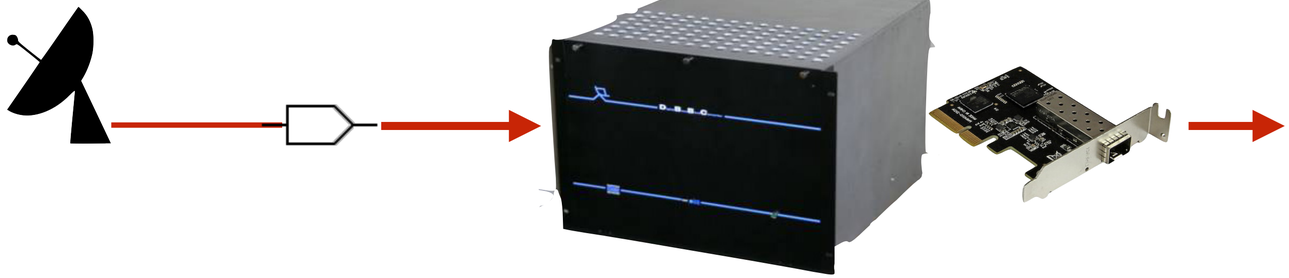
# Digital back end

*local eth recorder*



ethernet (UDP/IP)
$2^n \cdot 10^6$ Mbps
real sampled
VDIF

# Digital back end



ethernet (UDP/IP)
$2^n \cdot 10^6$ Mbps
real sampled
VDIF

*local eth recorder*

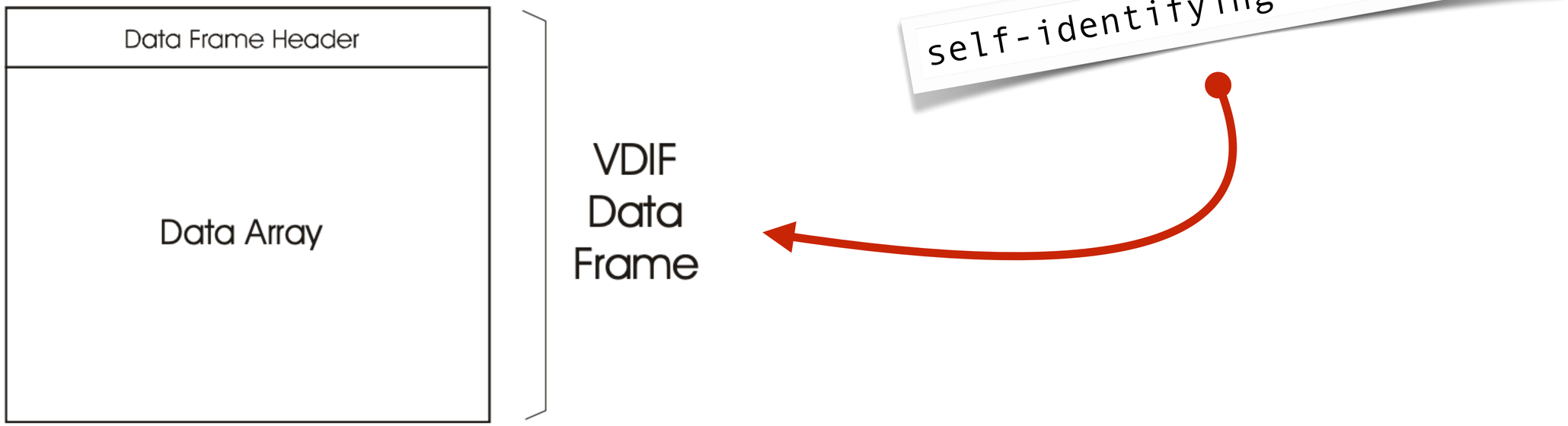
*internet*

# The VDIF format*

VLBI
Data
Interchange
Format

*(*) Ratified in 2009, following community discussion at IVTW (International VLBI Technology Workshop)*

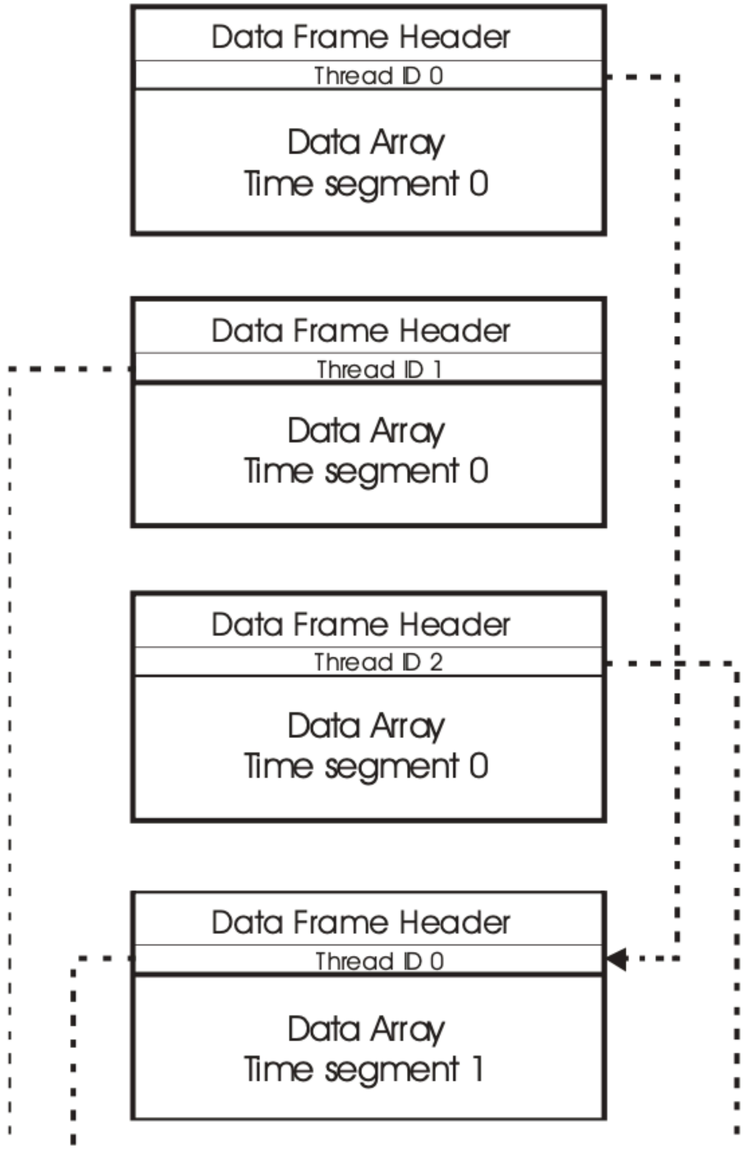
# The VDIF format




*https://vlbi.org/wp-content/uploads/2019/03/VDIF_specification_Release_1.1.1.pdf*

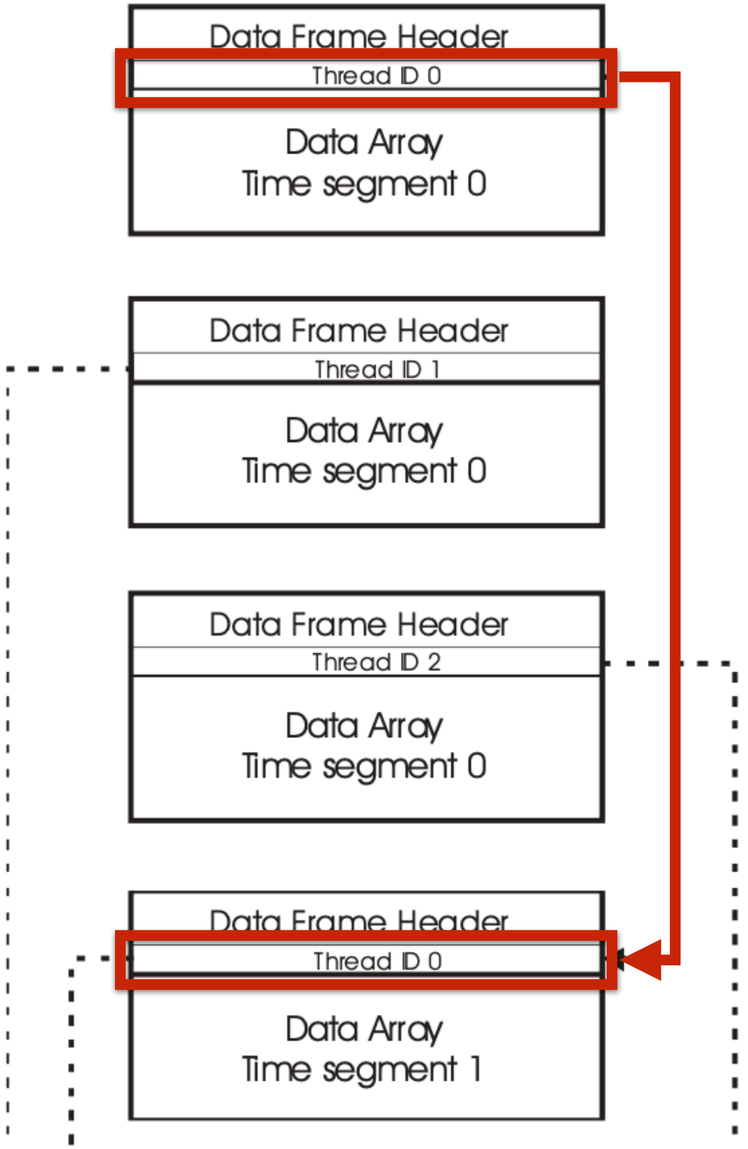
# "THREAD"

In the VDIF concept, each time-series of Data Frames from the same set of sub-bands(s) is known as a 'Data Thread', where each Data Thread is identified by a 'Thread ID' embedded in the Data Frame Header.



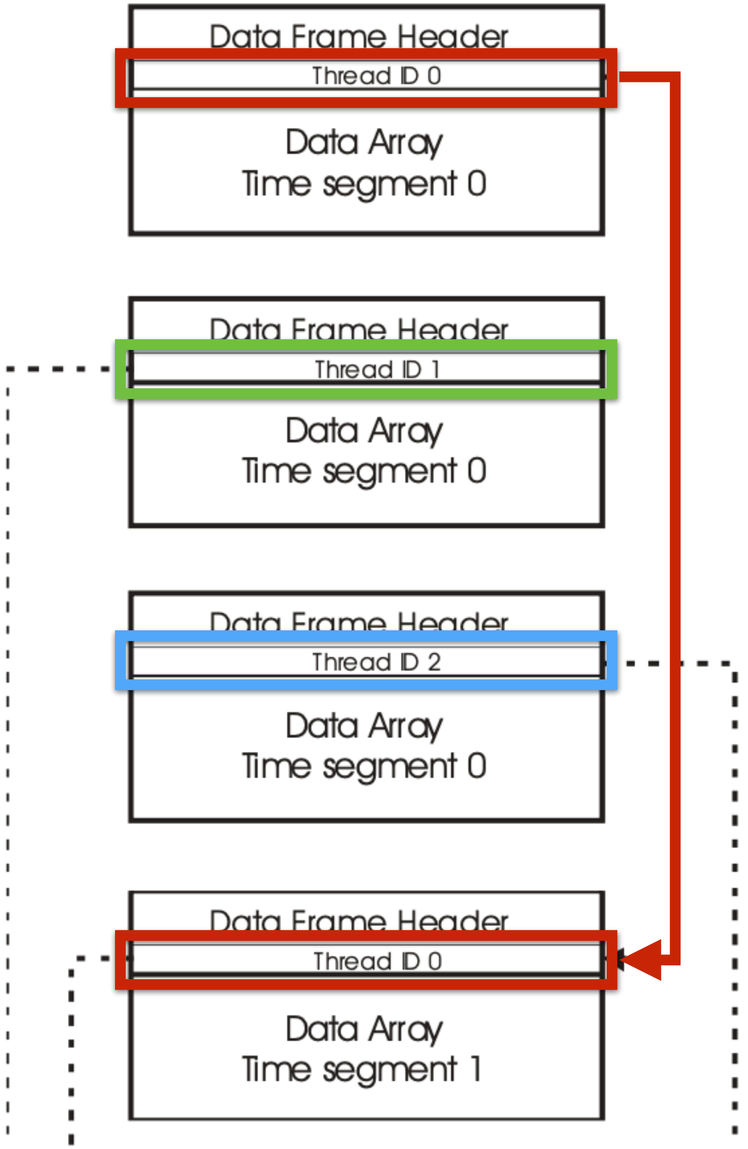
# "THREAD"

In the VDIF concept, each time-series of Data Frames from the same set of sub-bands(s) is known as a 'Data Thread', where each Data Thread is identified by a 'Thread ID' embedded in the Data Frame Header.



# "THREAD"

In the VDIF concept, each time-series of Data Frames from the same set of sub-bands(s) is known as a 'Data Thread', where each Data Thread is identified by a 'Thread ID' embedded in the Data Frame Header.



# Other (useful) VDIF properties

sampling rate $2^n \cdot 10^6$ samples / sec

time stamp accuracy + longevity

- can describe ≥ 128 Gbps data rates w/o problems
- can take data for ~33 years continuously before wrap

supports:

- odd number of channels (one channel per VDIF thread is OK)
- real and complex sampling
- 1-32 bit / sample*

*(*) Subject to other constraints some sample widths are impossible, though*

# EVN software correlator

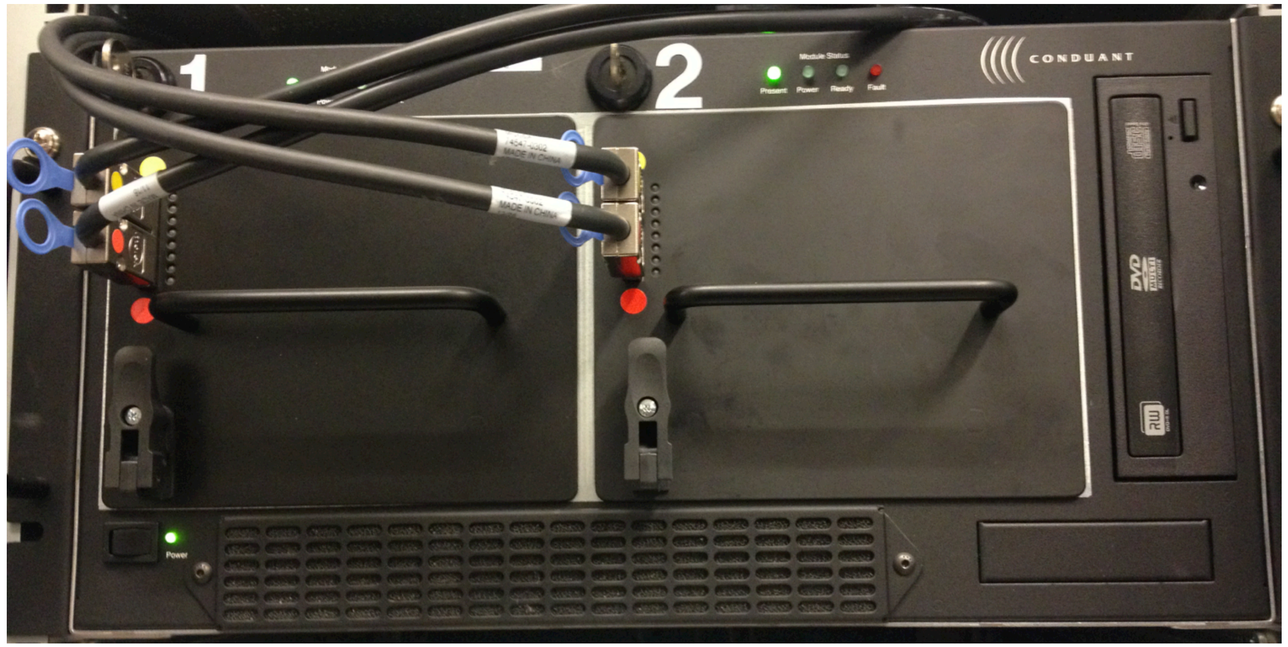
Accepts standard VLBI VDIF
- 2 bit / sample
- real data

Optimized (supported) flavours:
- single thread with all channels
- each channel in separate thread

*The VDIF standard allows many more configurations and supporting all of them is unpractical*

# The ethernet recorder

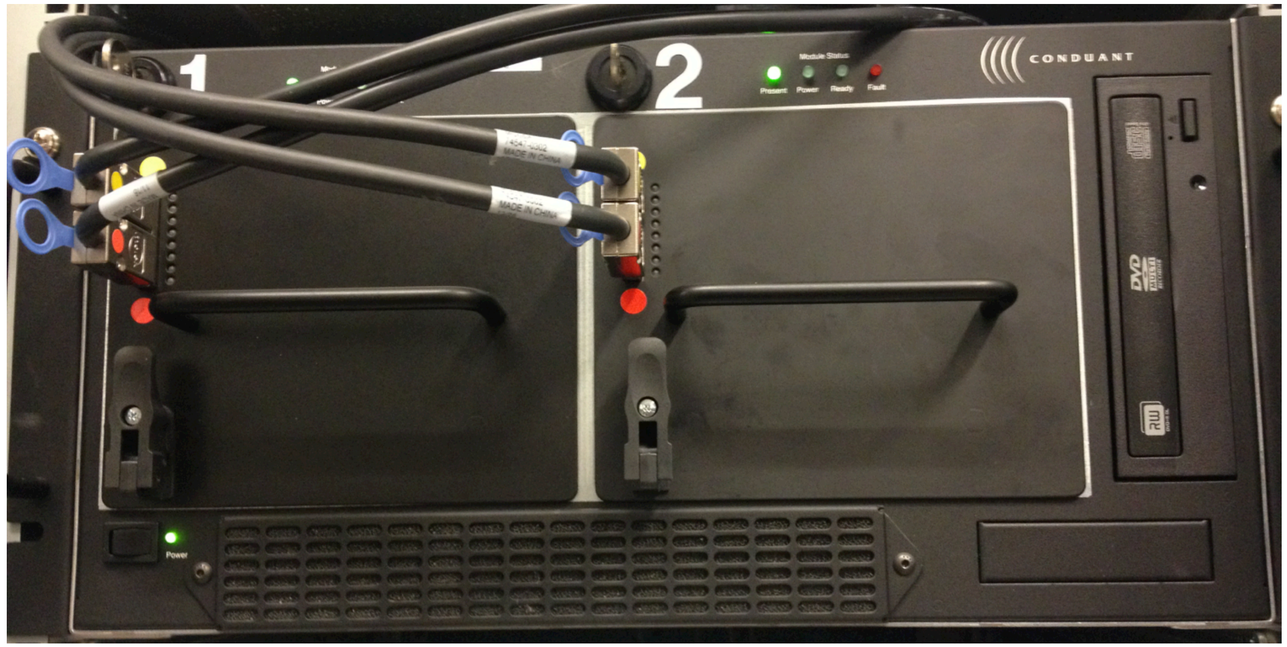
# The ethernet recorder




Mark6 (MIT Haystack/Conduant)

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

# The ethernet recorder




Mark6 (MIT Haystack/Conduant)
- proprietary hardware
- only one supplier (Conduant Corp.)
- ≦ 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*

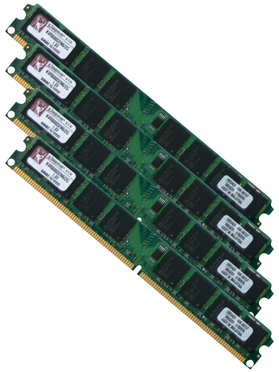
# The ethernet recorder

# The ethernet recorder


CPUs

# The ethernet recorder


CPUs

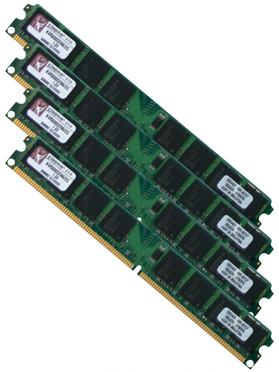


>> GB RAM

# The ethernet recorder

ethernet cards


CPUs

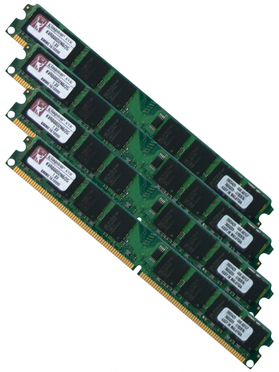


>> GB RAM

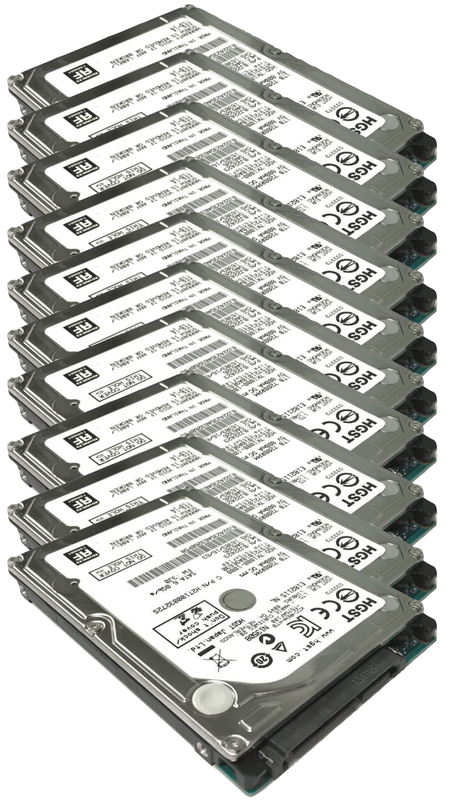
# The ethernet recorder

ethernet cards


CPUs



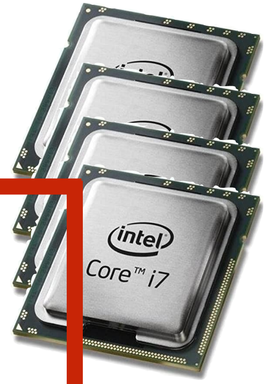
>> GB RAM



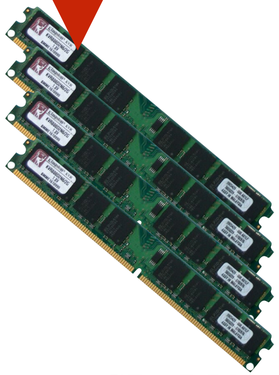
*many* HardDisks

# The ethernet recorder

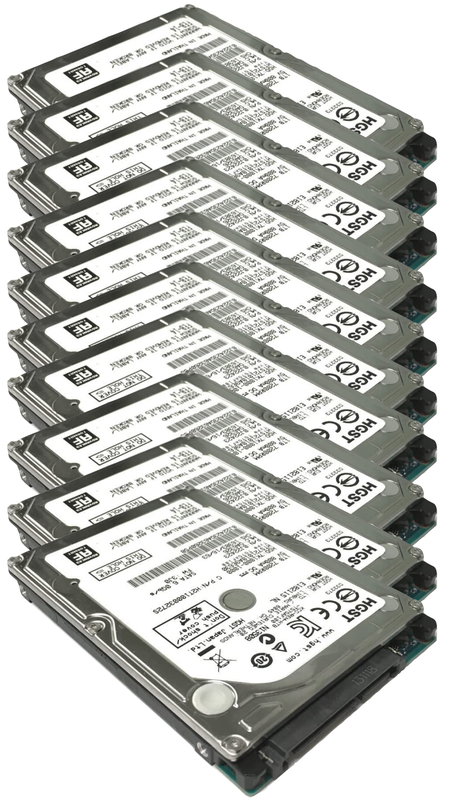
ethernet cards




CPUs



>> GB RAM

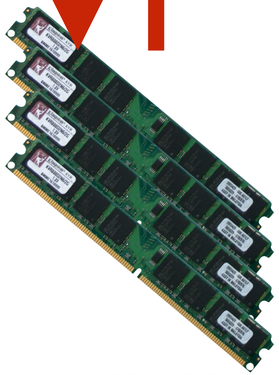


*many* HardDisks

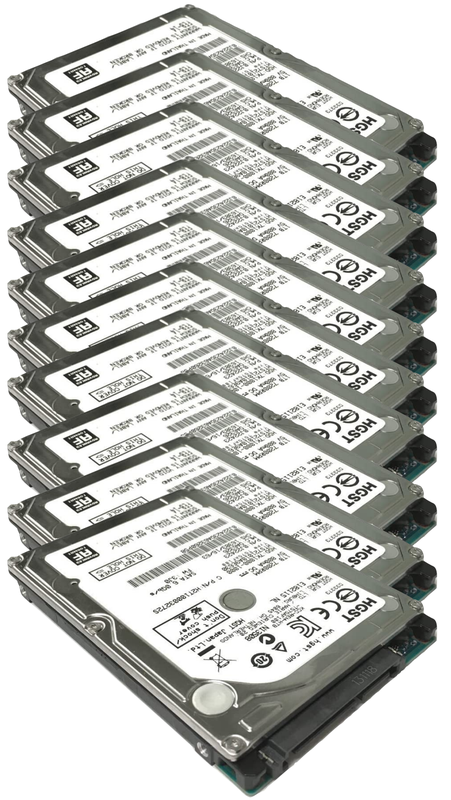
# The ethernet recorder

ethernet cards

CPUs



>> GB RAM



*many* HardDisks

# The ethernet recorder

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

Mark6

FlexBuff

# The ethernet recorder

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

Mark6 removable disk packs

FlexBuff

# The ethernet recorder

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

Mark6 removable disk packs

FlexBuff fixed disks

# EVN: disk-shippingless


- recorded

- e-VLBI (real-time)

# EVN: disk-shippingless

- 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-shippingless

- 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

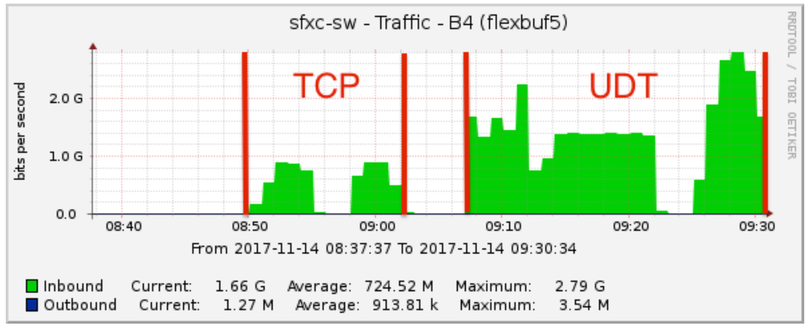
# EVN: disk-shippingless


- Use **jive5ab**[1] software
  - high-speed local recording
  - supports all VLBI recorders / data formats
  - built-in high speed network protocol UDT[2]

*[1] https://github.com/jive-vlbi/jive5ab*
*[2] e.g. https://udt.sourceforge.io/doc/udt-ccc-sc05-v10.pdf*

# EVN: disk-shippingless

- Use **jive5ab**[1] software
  - high-speed local recording
  - supports all VLBI recorders / data formats
  - built-in high speed network protocol UDT[2]



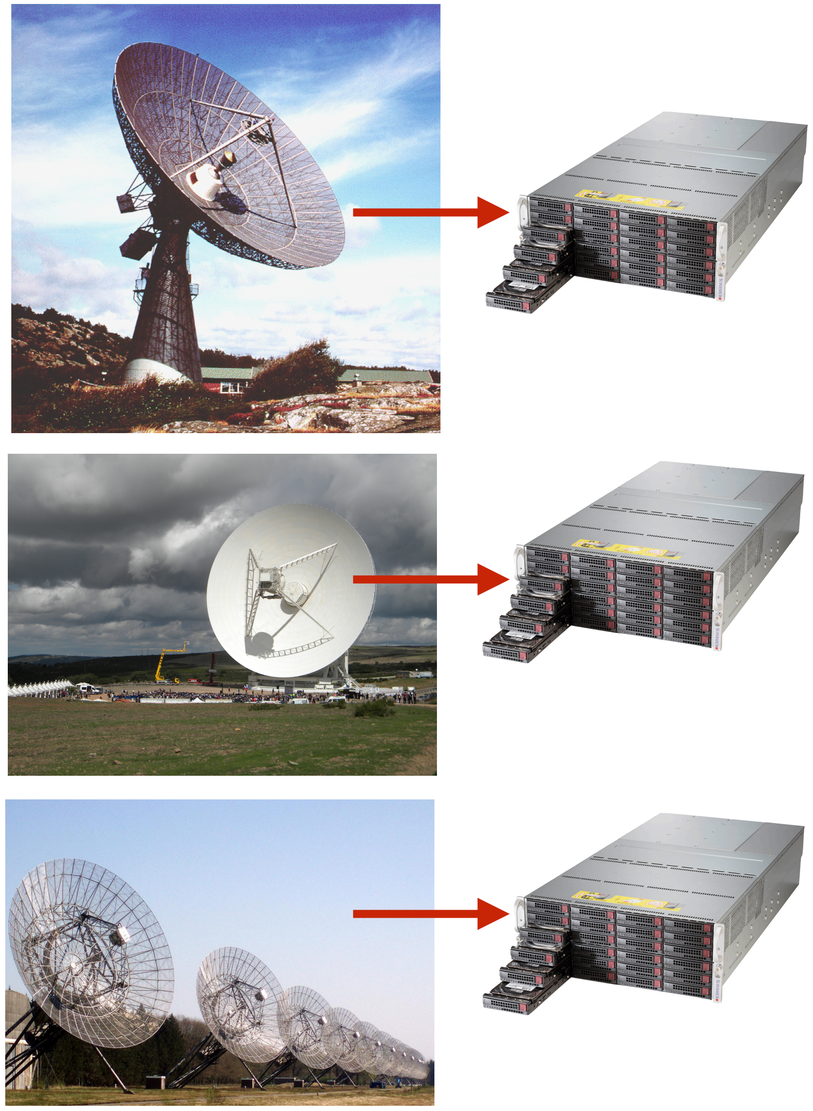

Throughput between Netherlands and New Zealand

*[1] https://github.com/jive-vlbi/jive5ab*

*[2] e.g. https://udt.sourceforge.io/doc/udt-ccc-sc05-v10.pdf*

# EVN: disk-shippingless

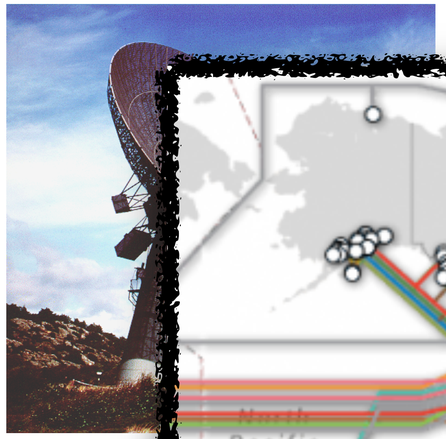
# EVN: disk-shippingless

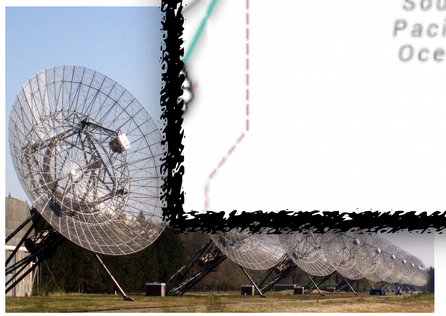


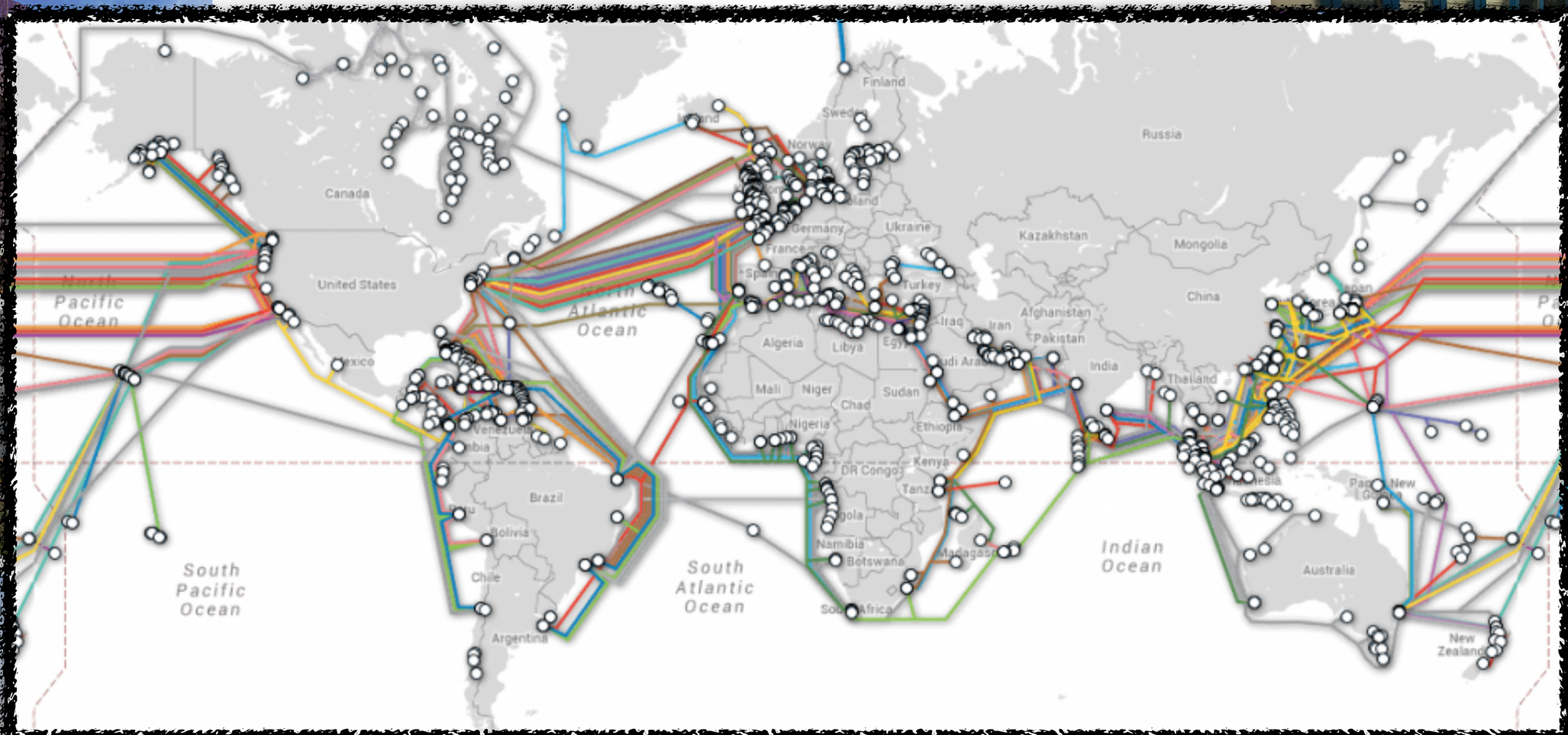
# EVN: disk-shippingless

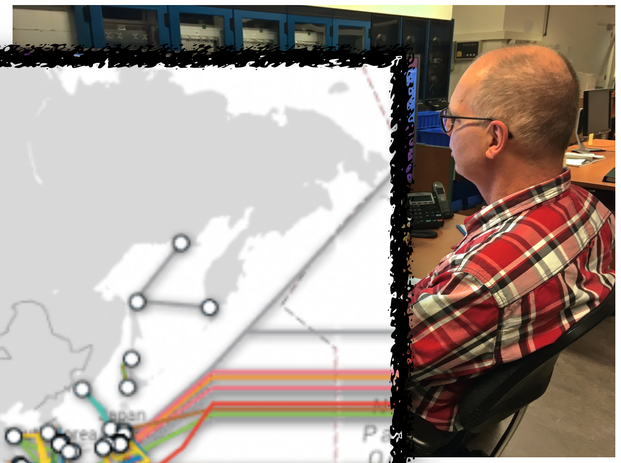

Software Correlator @JIVE

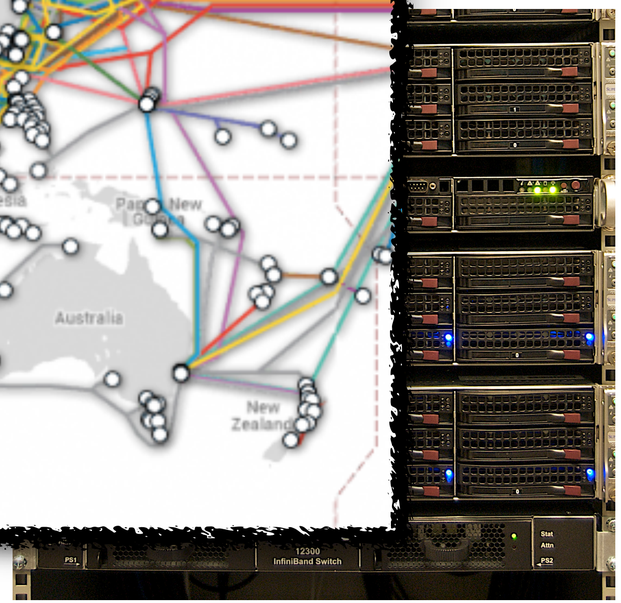
# EVN: disk-shippingless










Software Correlator @JIVE

# internet connection

$\nu \leq$ L-band $\Rightarrow$ observing data rate $\lesssim$ 2 Gbps

# internet connection

- recorded

- e-VLBI (real-time)

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

# internet connection

- recorded
  - connection speed ≥ 0.5 observing data rate
  - 1 Gpbs and higher ok

- e-VLBI (real-time)

*ν ≤ L-band ⇒ observing data rate ≲ 2 Gbps*

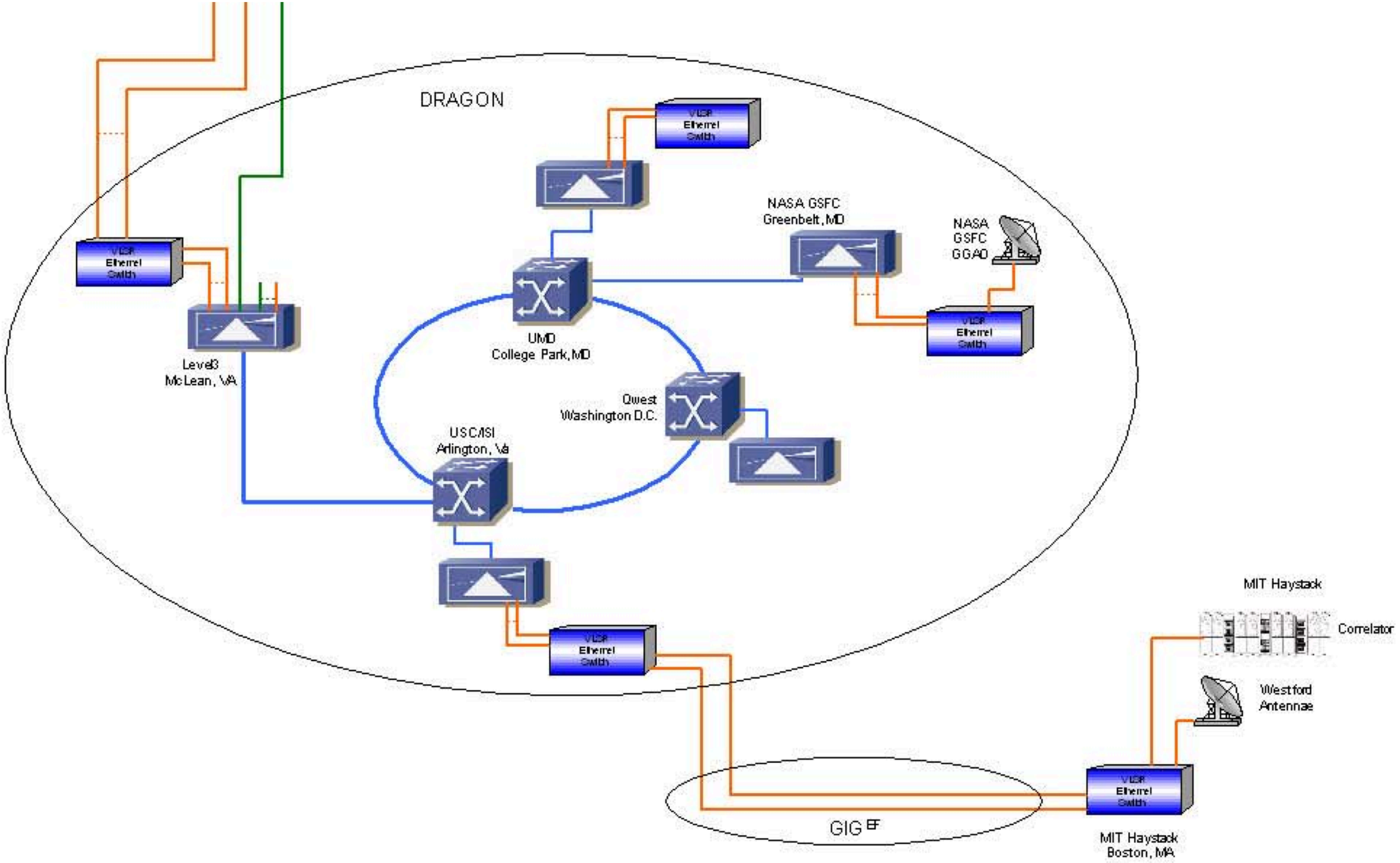
# internet connection

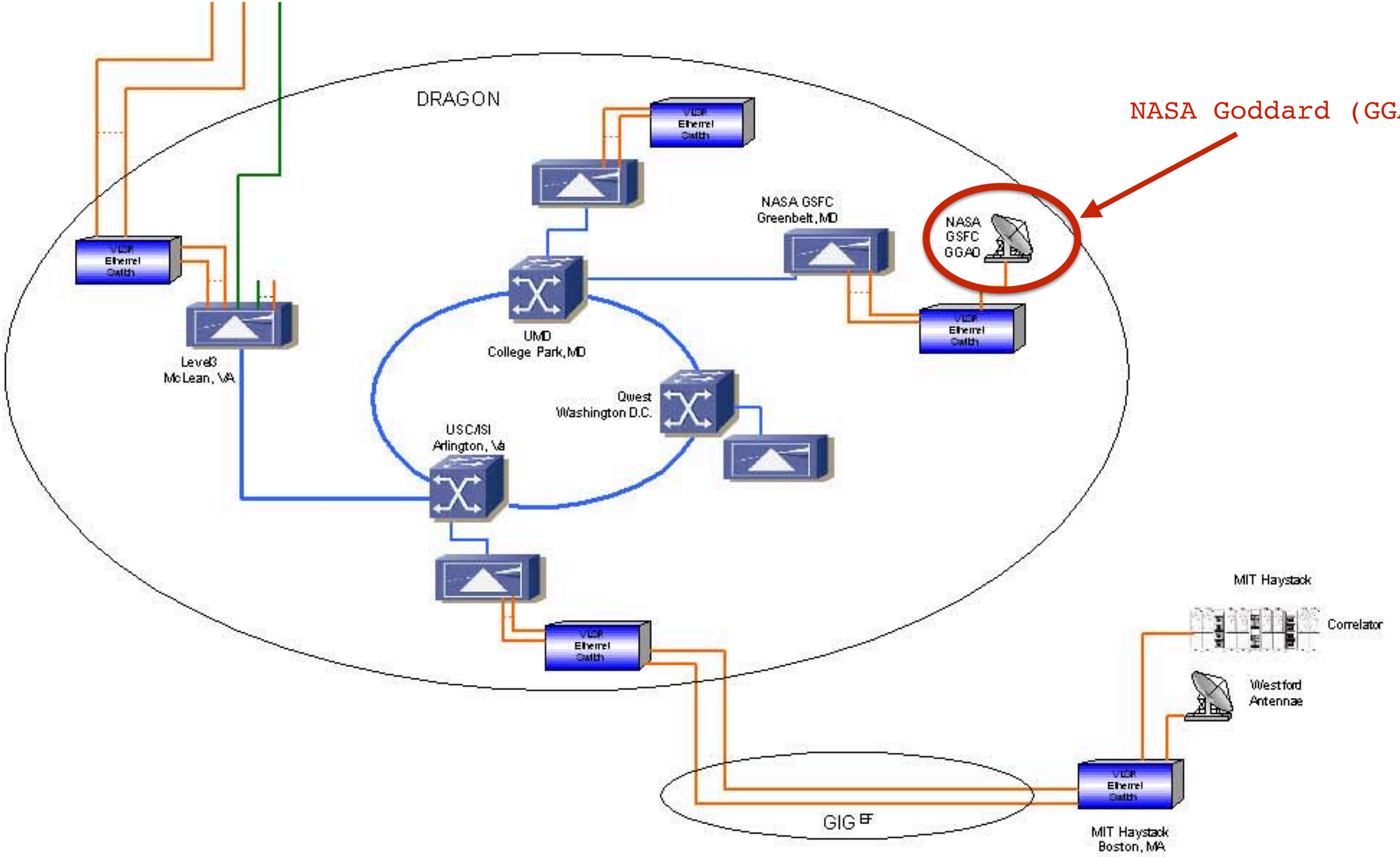
- recorded
  - connection speed ≥ 0.5 observing data rate
  - 1 Gpbs and higher ok

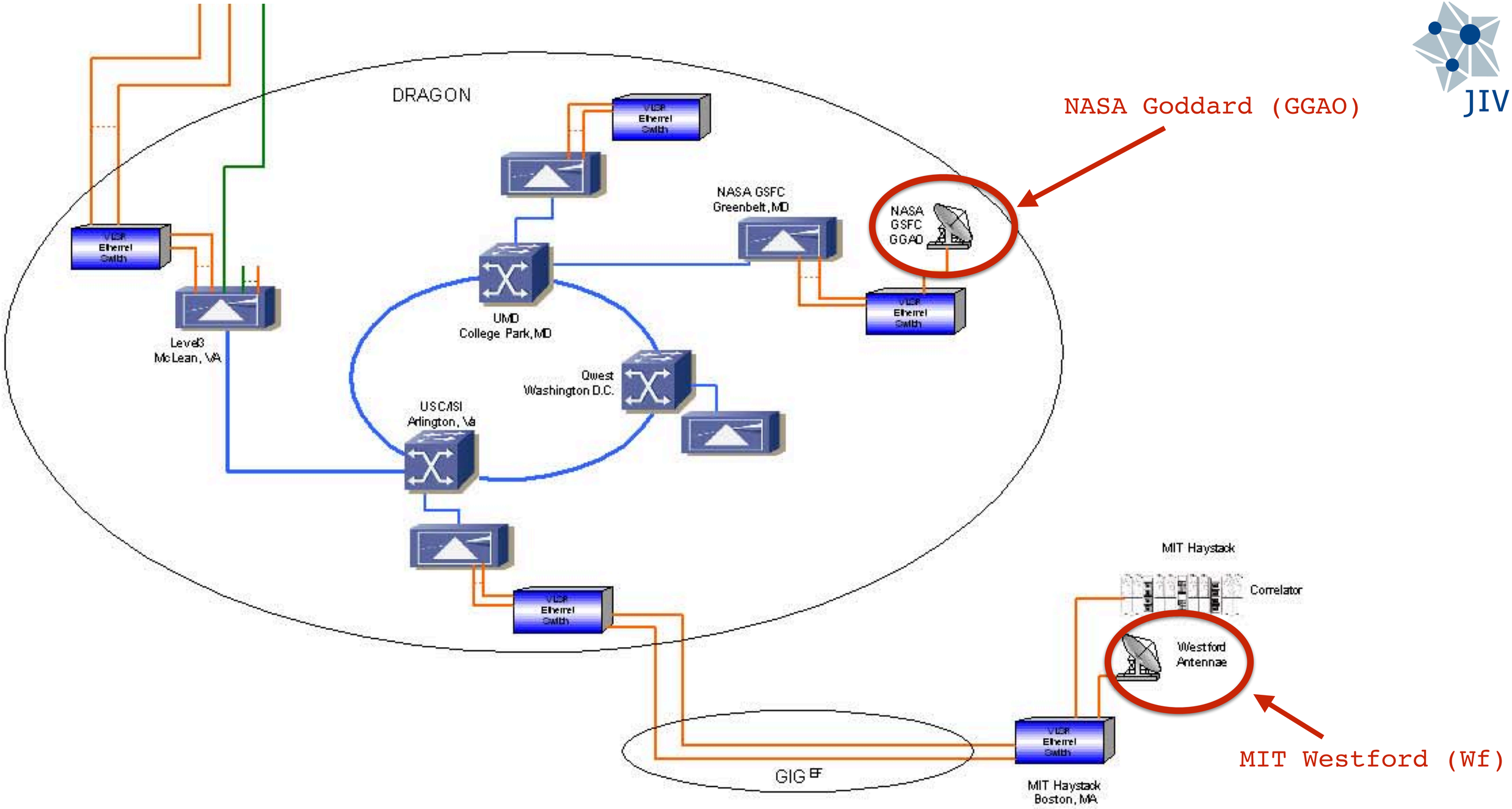
- e-VLBI (real-time)
  - connection speed ≈ 1.5 observing data rate
  - 2-3 Gbps and higher ok

*ν ≤ L-band ⇒ observing data rate ≲ 2 Gbps*

# a network engineer

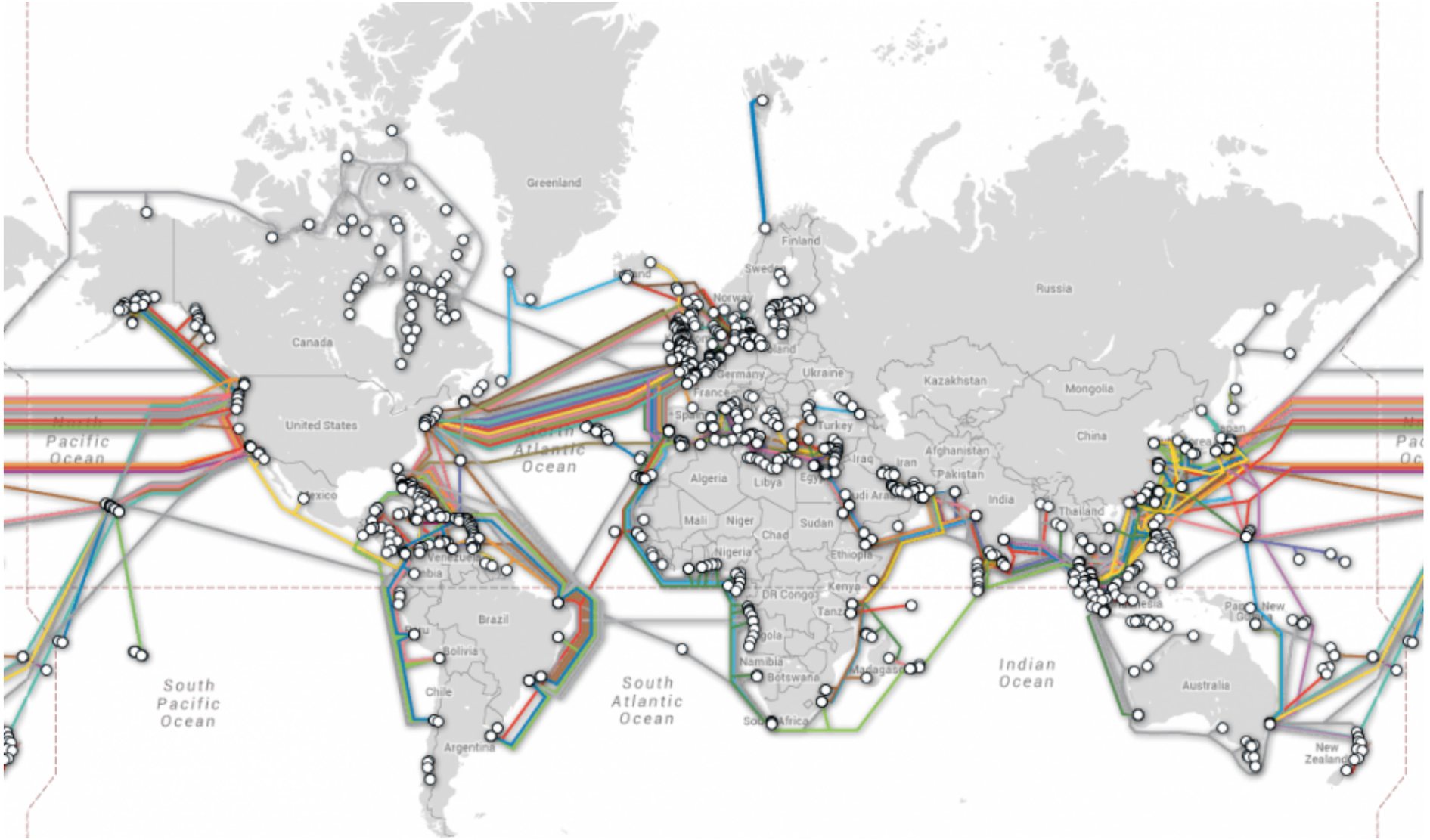

DRAGON
VLBI Ethernet Switch
NASA GSFC Greenbelt, MD
NASA GSFC GGAO
VLBI Ethernet Switch
VLBI Ethernet Switch
Level3 McLean, VA
UMD College Park, MD
Qwest Washington D.C.
USC/ISI Arlington, Va
VLBI Ethernet Switch
MIT Haystack
Correlator
Westford Antennae
VLBI Ethernet Switch
GIG E
MIT Haystack Boston, MA


NASA Goddard (GGAO)
DRAGON
VLBI Ethernet Switch
NASA GSFC Greenbelt, MD
NASA GSFC GGAO
UMD College Park, MD
Level3 McLean, VA
Qwest Washington D.C.
USC/ISI Arlington, Va
GIG BF
MIT Haystack
Correlator
Westford Antennae
MIT Haystack Boston, MA


DRAGON
VLSR Ethernet Switch
NASA GSFC Greenbelt, MD
NASA GSFC GGAO
NASA Goddard (GGAO)
VLSR Ethernet Switch
UMD College Park, MD
Level3 McLean, VA
Qwest Washington D.C.
USC/ISI Arlington, Va
VLSR Ethernet Switch
VLSR Ethernet Switch
GIG EF
VLSR Ethernet Switch
MIT Haystack Boston, MA
MIT Haystack
Correlator
Westford Antennae
MIT Westford (Wf)


Logan International Airport
United States
Mexico
Bermuda
The Bahamas
Gulf of Mexico
Gulf of California
Regina
Winnipeg
Vancouver
Victoria
Seattle
Portland
Minneapolis
Toronto
Québec City
Ottawa
Montreal
Detroit
Chicago
Denver
Kansas City
Indianapolis
Nashville
Charlotte
Atlanta
Dallas
Houston
San Antonio
Austin
El Paso
Tucson
Phoenix
Los Angeles
San Diego
San Francisco
Sacramento
San Jose
Las Vegas
New York
Philadelphia
Jacksonville
Orlando
Tampa
Miami
New Orleans
Havana
Monterrey
WASHINGTON
OREGON
CALIFORNIA
NEVADA
IDAHO
MONTANA
WYOMING
UTAH
COLORADO
ARIZONA
NEW MEXICO
NORTH DAKOTA
SOUTH DAKOTA
NEBRASKA
KANSAS
OKLAHOMA
TEXAS
MINNESOTA
IOWA
MISSOURI
ARKANSAS
LOUISIANA
WISCONSIN
ILLINOIS
MICHIGAN
INDIANA
OHIO
KENTUCKY
TENNESSEE
MISSISSIPPI
ALABAMA
GEORGIA
NORTH CAROLINA
SOUTH CAROLINA
FLORIDA
NEW YORK
PENNSYLVANIA
WEST VIRGINIA
MARYLAND
DE
NJ
CT
RI
VERMONT
NEW HAMPSHIRE
MAINE
NEW BRUNSWICK
PRINCE EDWARD ISLAND
NOVA SCOTIA
BAJA CALIFORNIA
BAJA CALIFORNIA SUR
SONORA
CHIHUAHUA
COAHUILA
NUEVO LEON
SINALOA
DURANGO
TAMAULIPAS

# a network engineer



# Technical Operations Group*

## Techies @ stations and correlator

- meet in person (~9 month duty cycle)
- since COVID-19 also on-line/Zoom
- mail exploder
  https://mailman.astron.nl/listinfo/evntech
- perfect opportunity to share
  - performance of the EVN
  - (technical/social) information
  - new developments
  - procedures
  - experiences
  - drinks …

*[*] https://www.evlbi.org/TOG*

# Technical Operations Group*

Techi… …nd correlator

…nth duty cycle)

…-line/Zoom

…/evntech

…share

…drinks …

[*] https://www.evlbi.org/TOG

# Technical Operations Group*


[*] https://www.evlbi.org/TOG

# Technical Operations Group*

## Techies @ stations and correlator

- meet in person (~9 month duty cycle)
- since COVID-19 also on-line/Zoom
- mail exploder
  https://mailman.astron.nl/listinfo/evntech
- perfect opportunity to share
  - performance of the EVN
  - (technical/social) information
  - new developments
  - procedures
  - experiences
  - drinks …

*[*] https://www.evlbi.org/TOG*

# Thanks for attention!

# Summarizing

## Requirements for VLBI*

- phase-coherent system at site
- 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*