$$\Theta = 1.22 \cdot \frac{\lambda}{D}$$

$$\sigma_T = \frac{T_{sys}}{\sqrt{\Delta_\nu \cdot \Delta t}}$$

$$\Theta = 1.22 \cdot \frac{\lambda}{D}$$

Diameter of the telescope

smaller is better (more details)

$$\sigma_T = \frac{T_{sys}}{\sqrt{\Delta_\nu \cdot \Delta t}}$$

snag (noun)

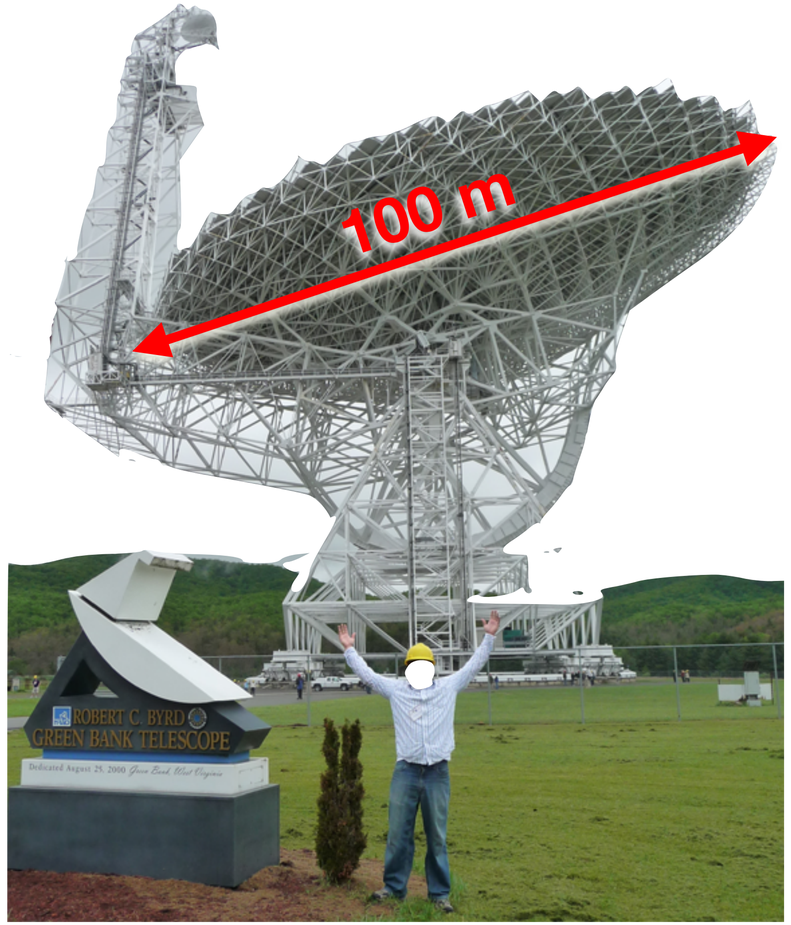
\ ˈsnag \

Definition of *snag*

a concealed or unexpected difficulty or obstacle

The 100m radio telescope in Effelsberg, Germany

The 100m radio telescope in Greenbank, USA



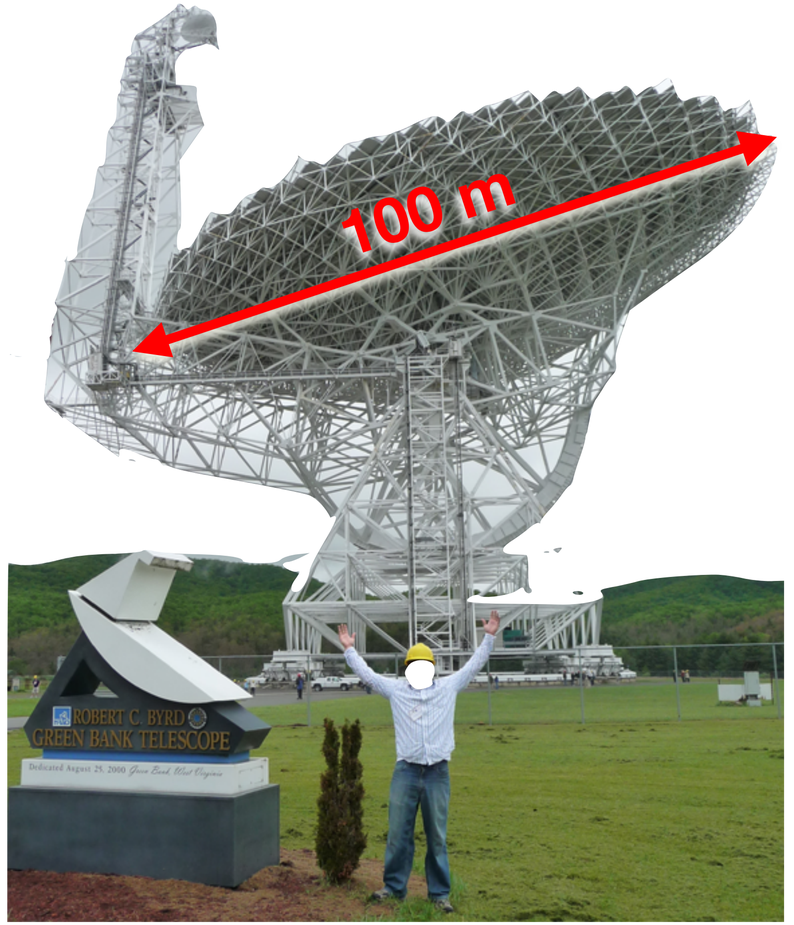
The 100m radio telescope in Greenbank, USA

D = 0,1 m (10 cm)

D = 100 m (10 000 cm)

R=400

D = 0,1 m (10 cm)



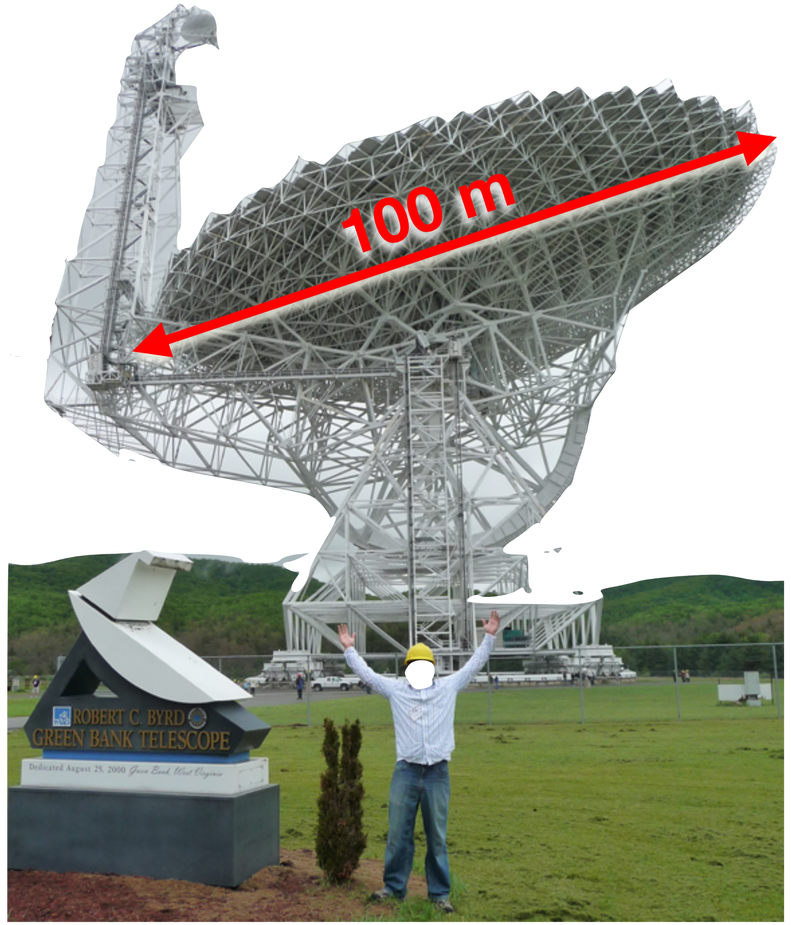
The 100m radio telescope in Greenbank, USA

R=1

D = 100 m (10 000 cm)

D = 0,1 m (10 cm)

λ = 0.0000005 m

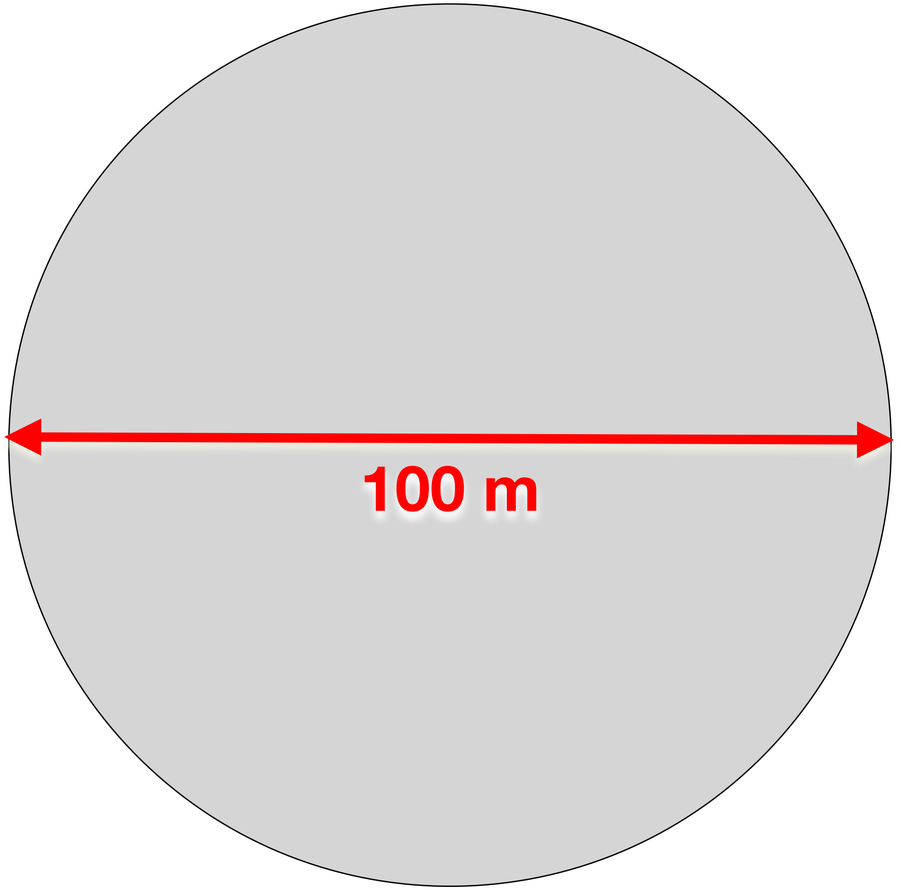


The 100m radio telescope in Greenbank, USA

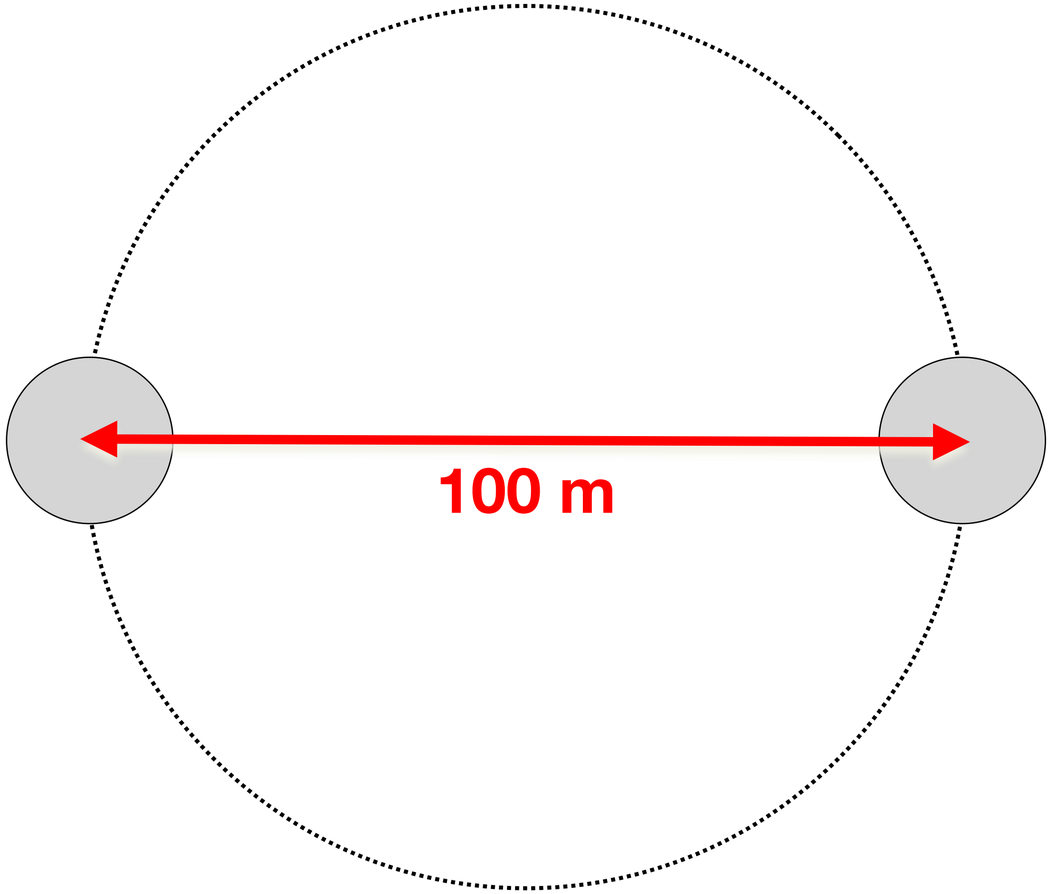
D = 100 m (10 000 cm)

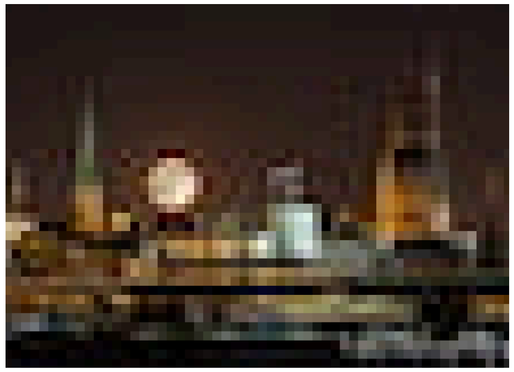
λ = 0.1 m

A Neat Trick™

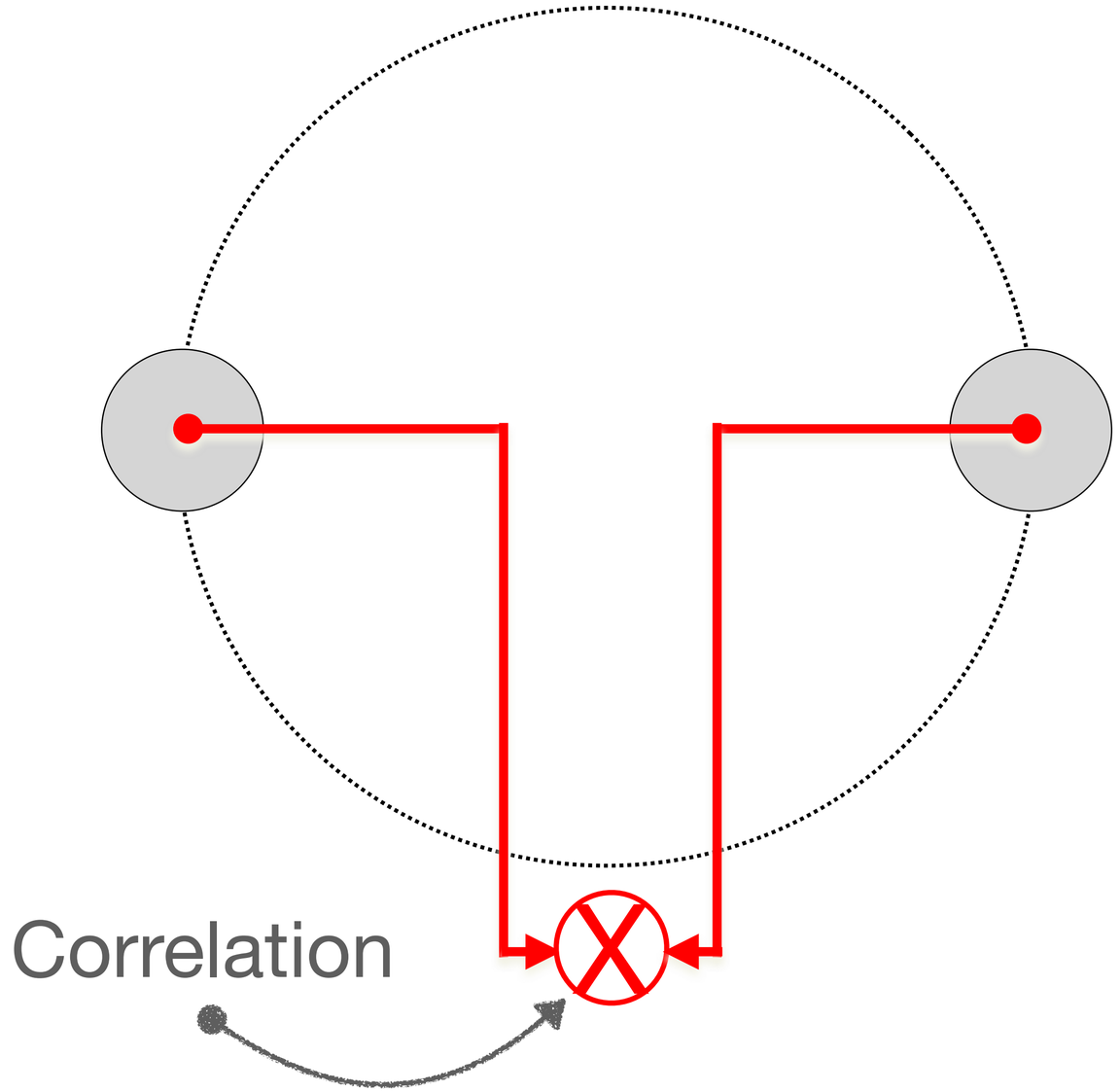


A Neat Trick™

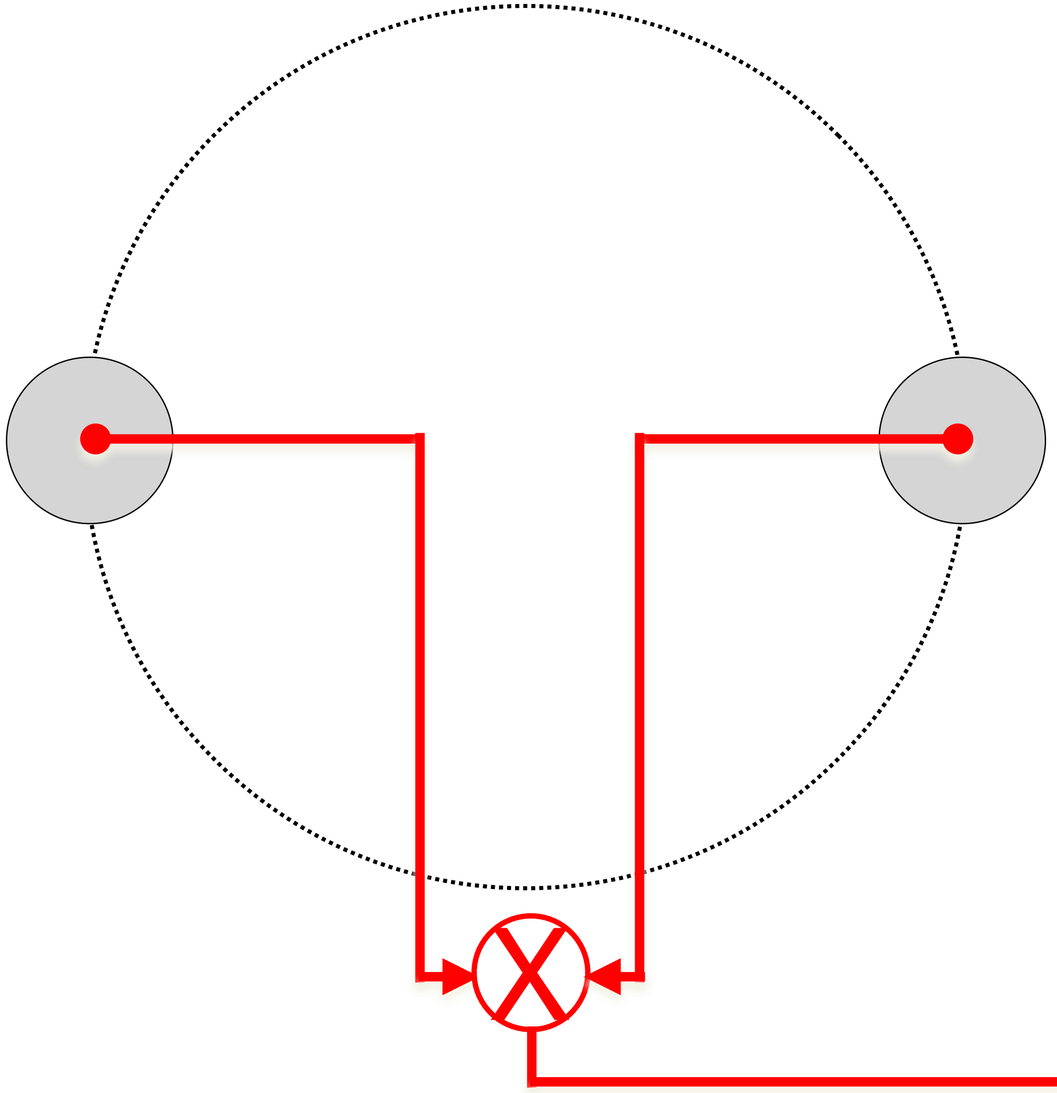




A Neat Trick™

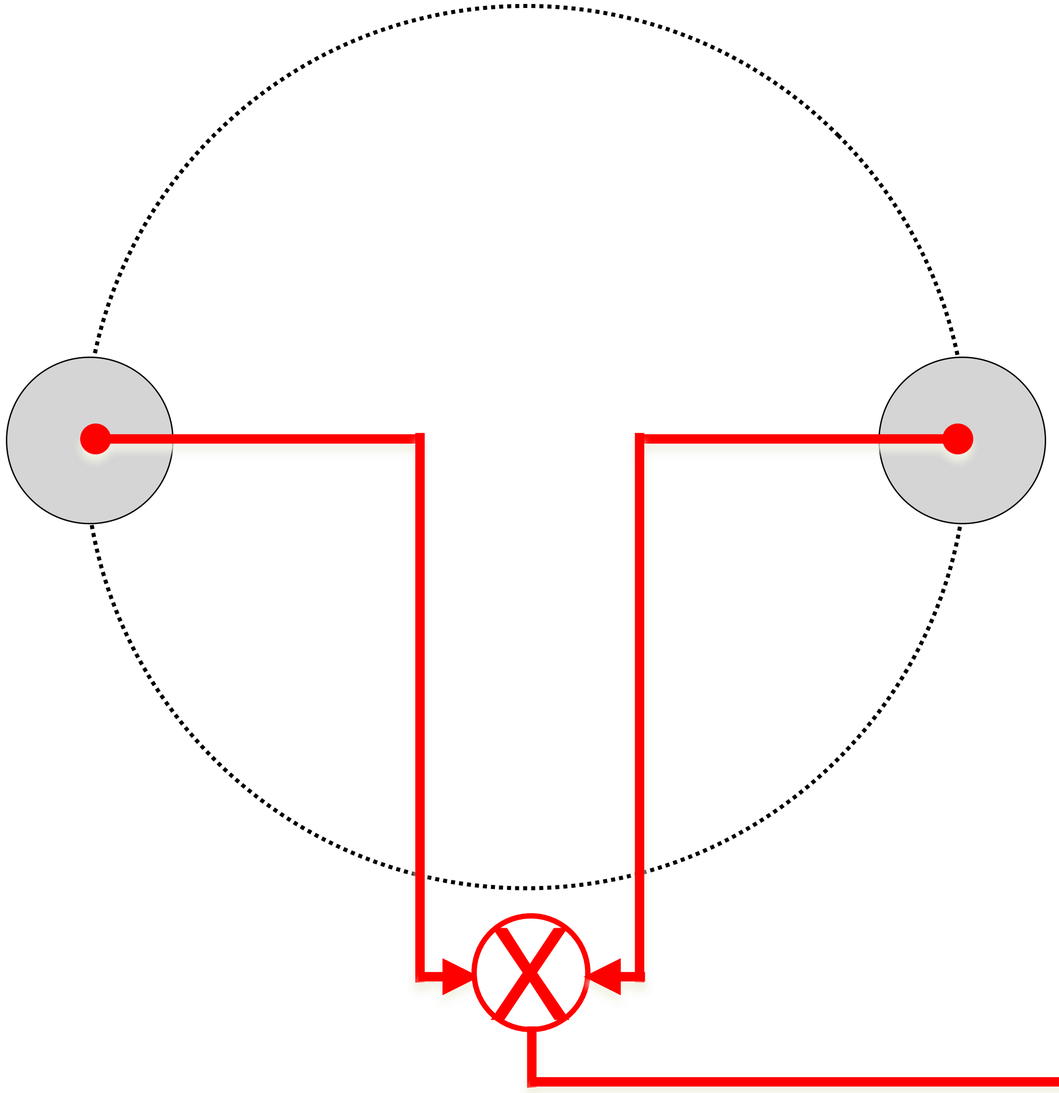


A Neat Trick™



100 !

Interferometry = A Neat Trick™



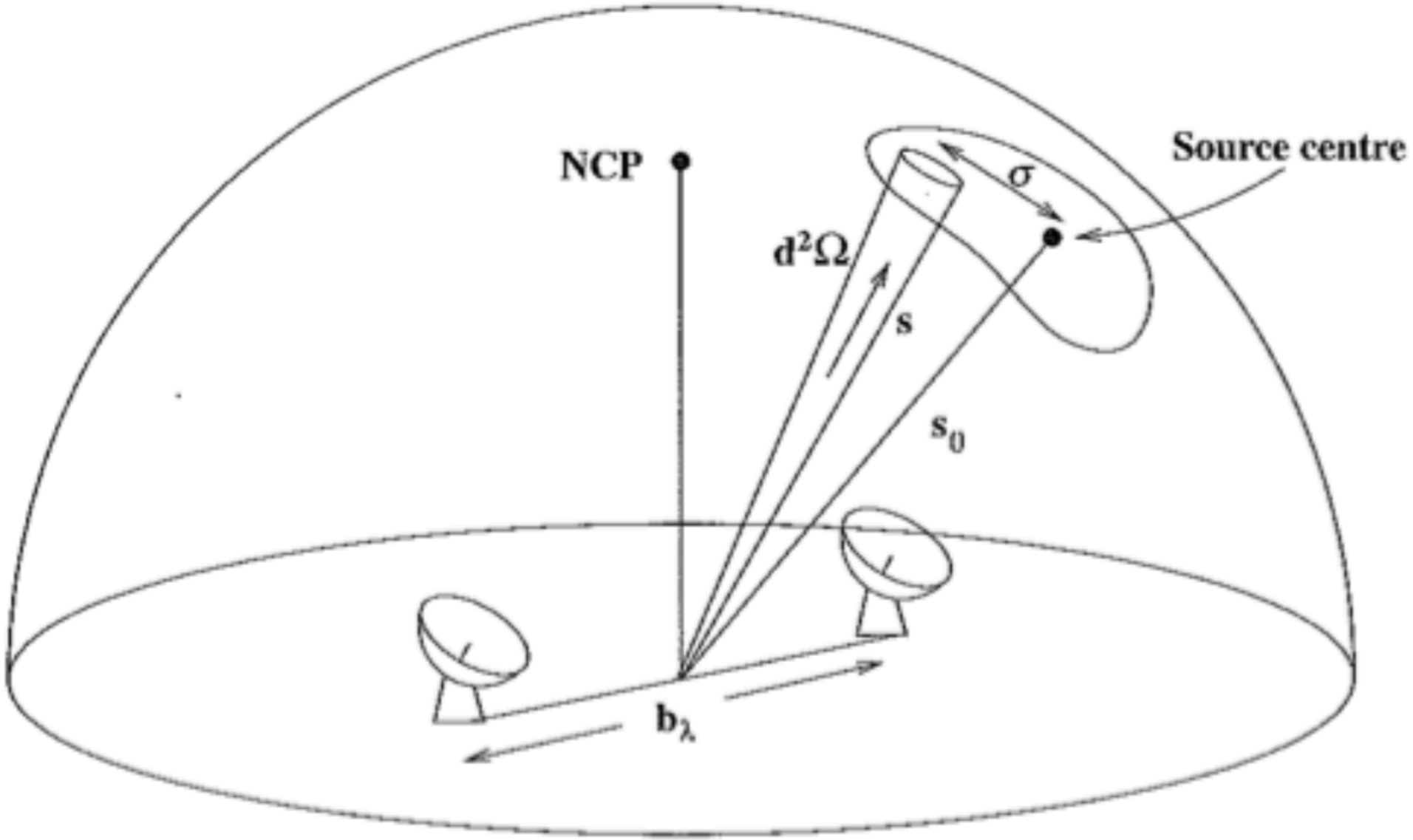
100 !

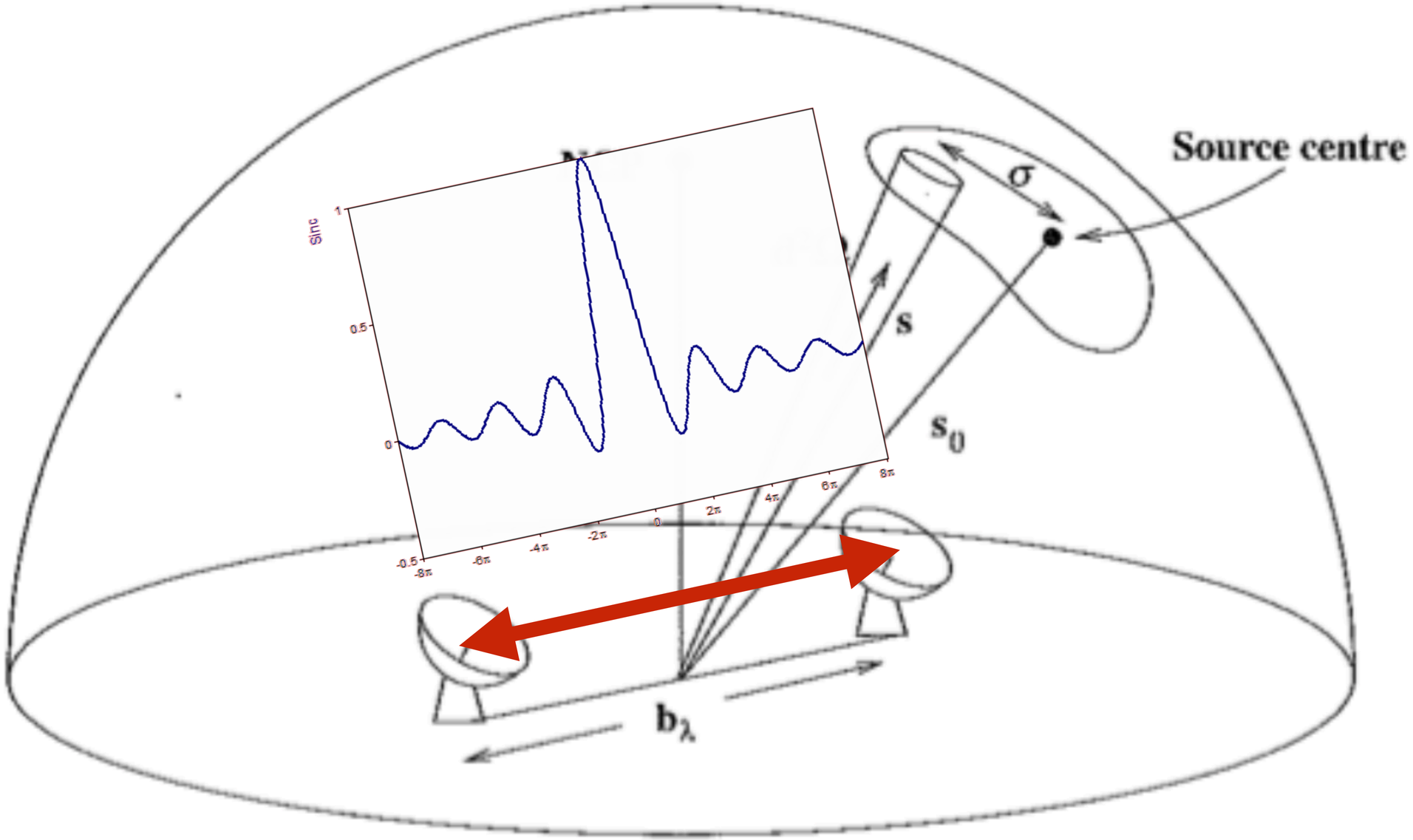
snag (noun)

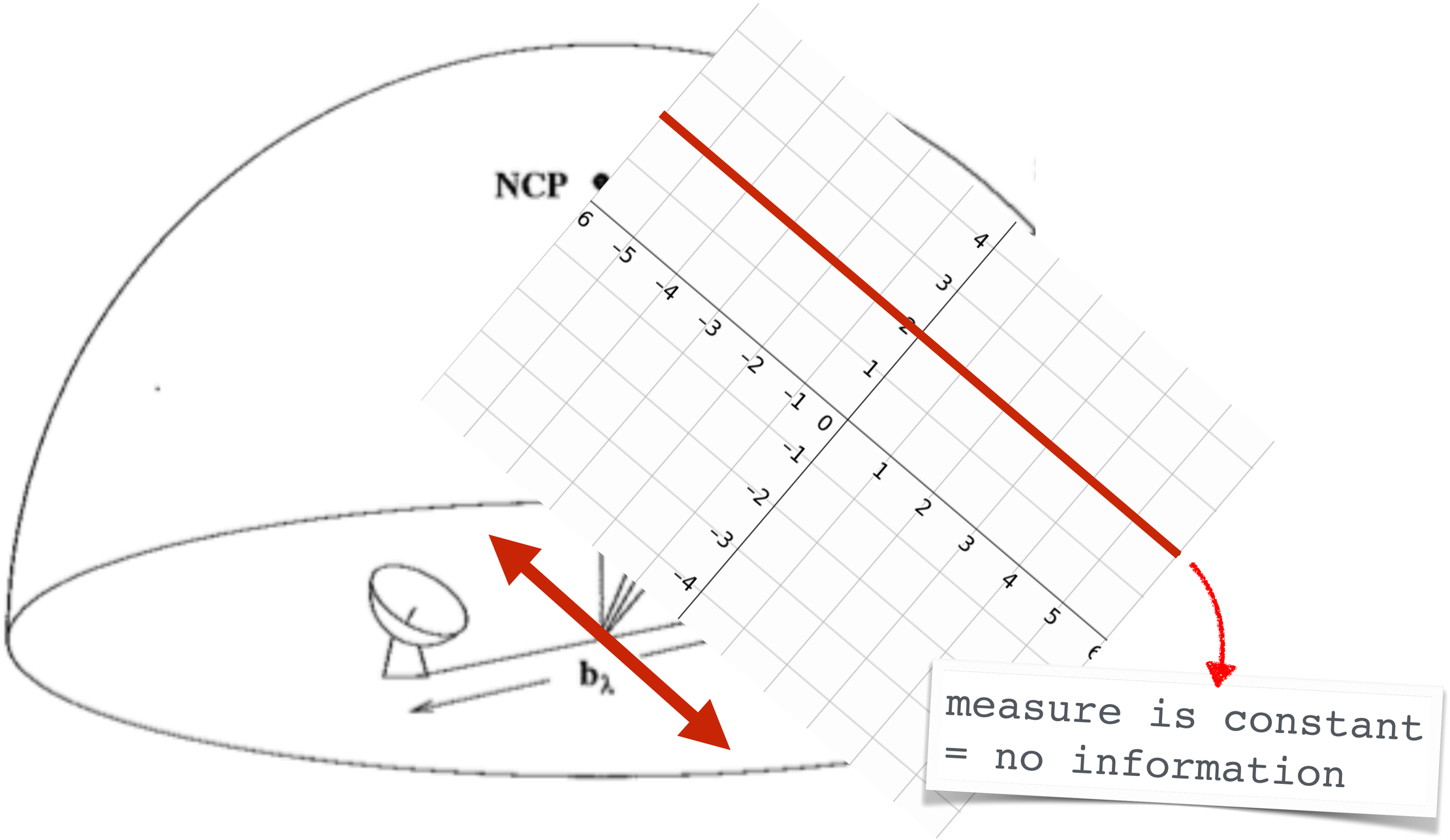
\ ˈsnag \

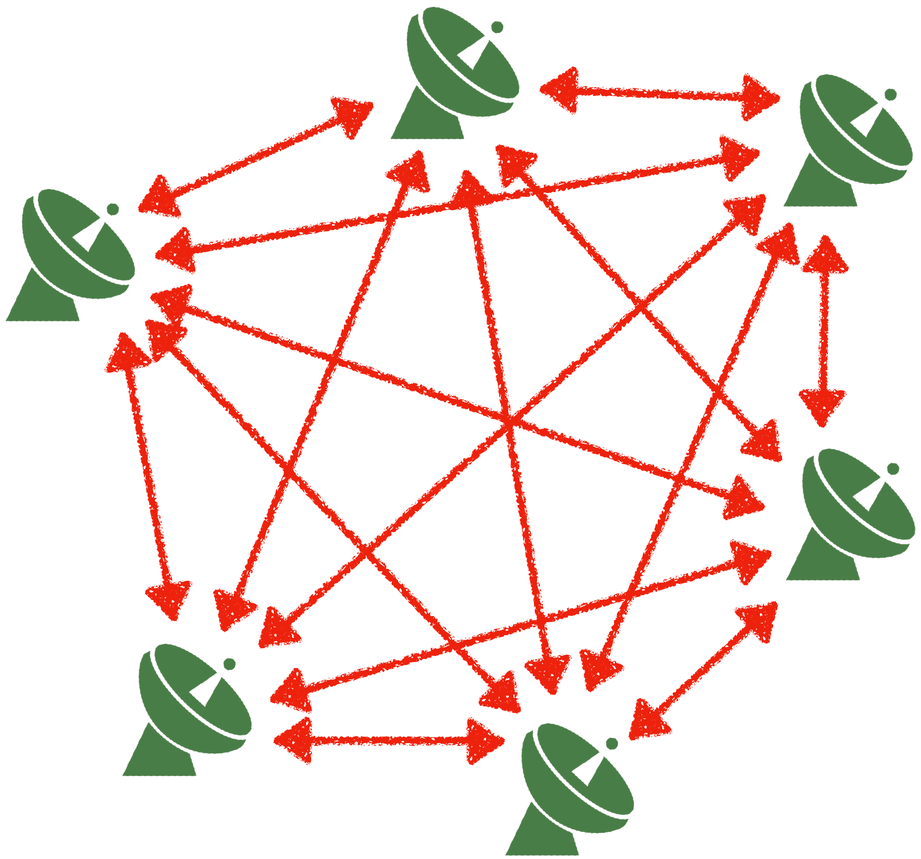
Definition of *snag*

a concealed or unexpected difficulty or obstacle

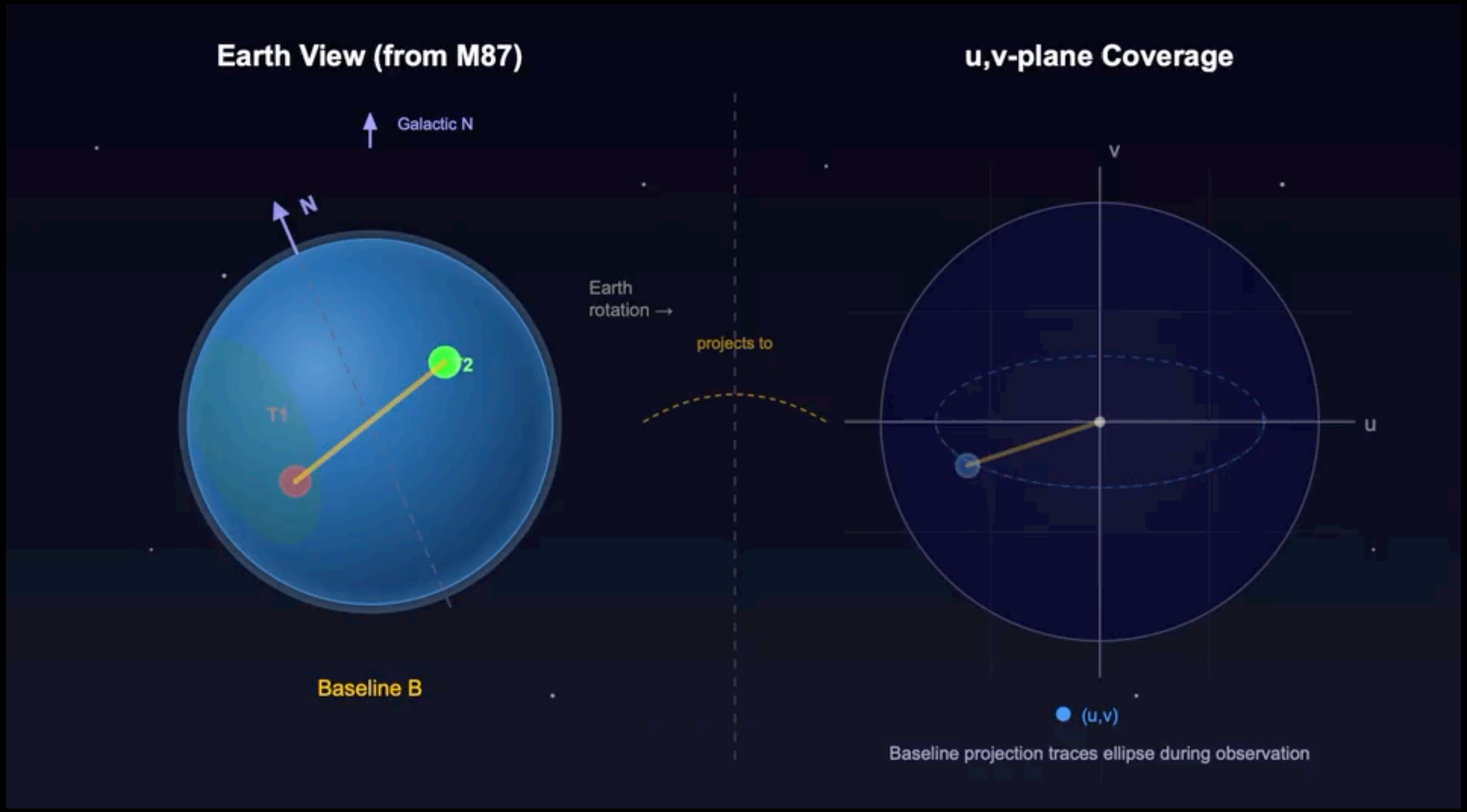

NCP
Source centre
σ
d²Ω
s
s₀
b_λ


Source centre
σ
s
s0
bλ
Sinc
1
0.5
0
-0.5
-8π
-6π
-4π
-2π
0
2π
4π
6π
8π


NCP
b_λ
measure is constant
= no information

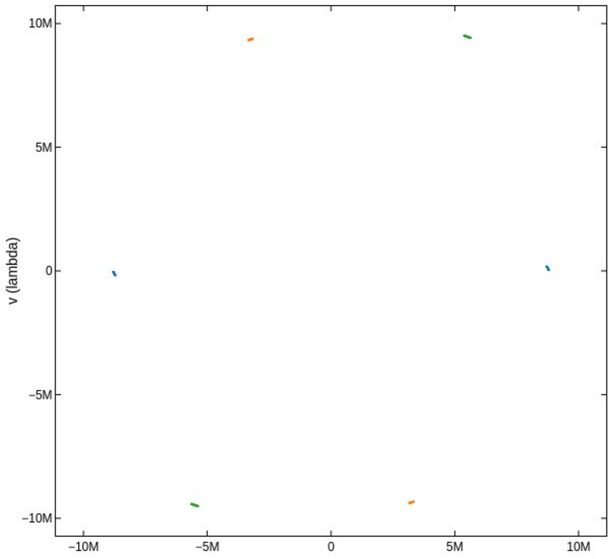


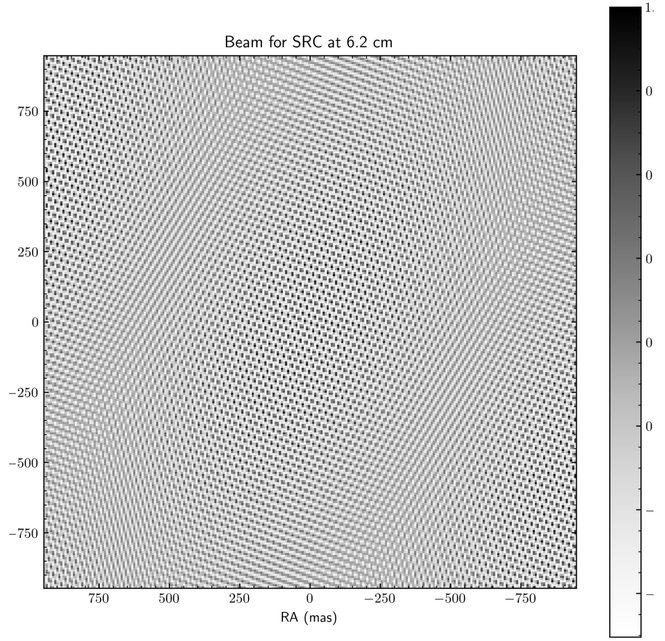
- add telescopes
- correlation impact:
  - all combinations
  - $n_{baselines} \sim n_{telescopes}^2$


Earth View (from M87)
Galactic N
N
T1
T2
Baseline B
Earth
rotation →
projects to
u,v-plane Coverage
v
u
(u,v)
Baseline projection traces ellipse during observation

$n_{ant} = 3$

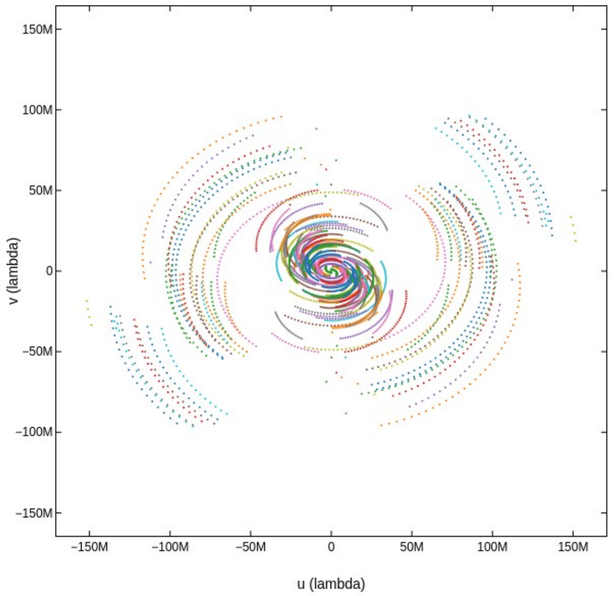
$t_{int} = 5$ min

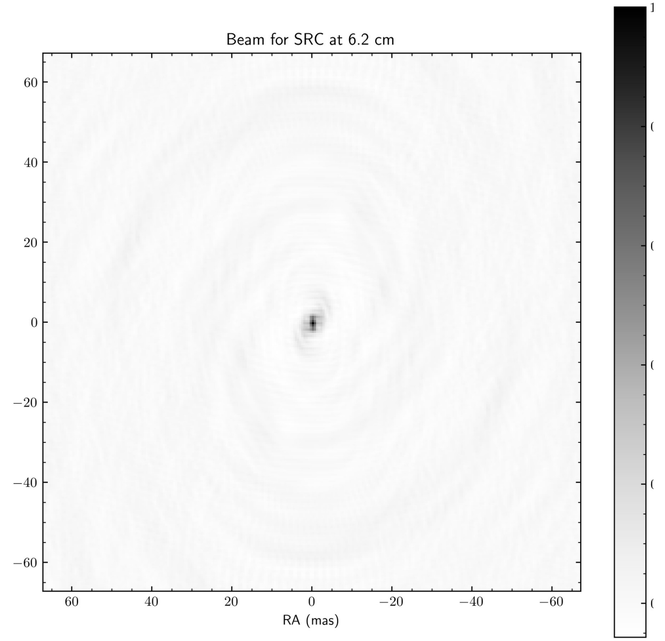


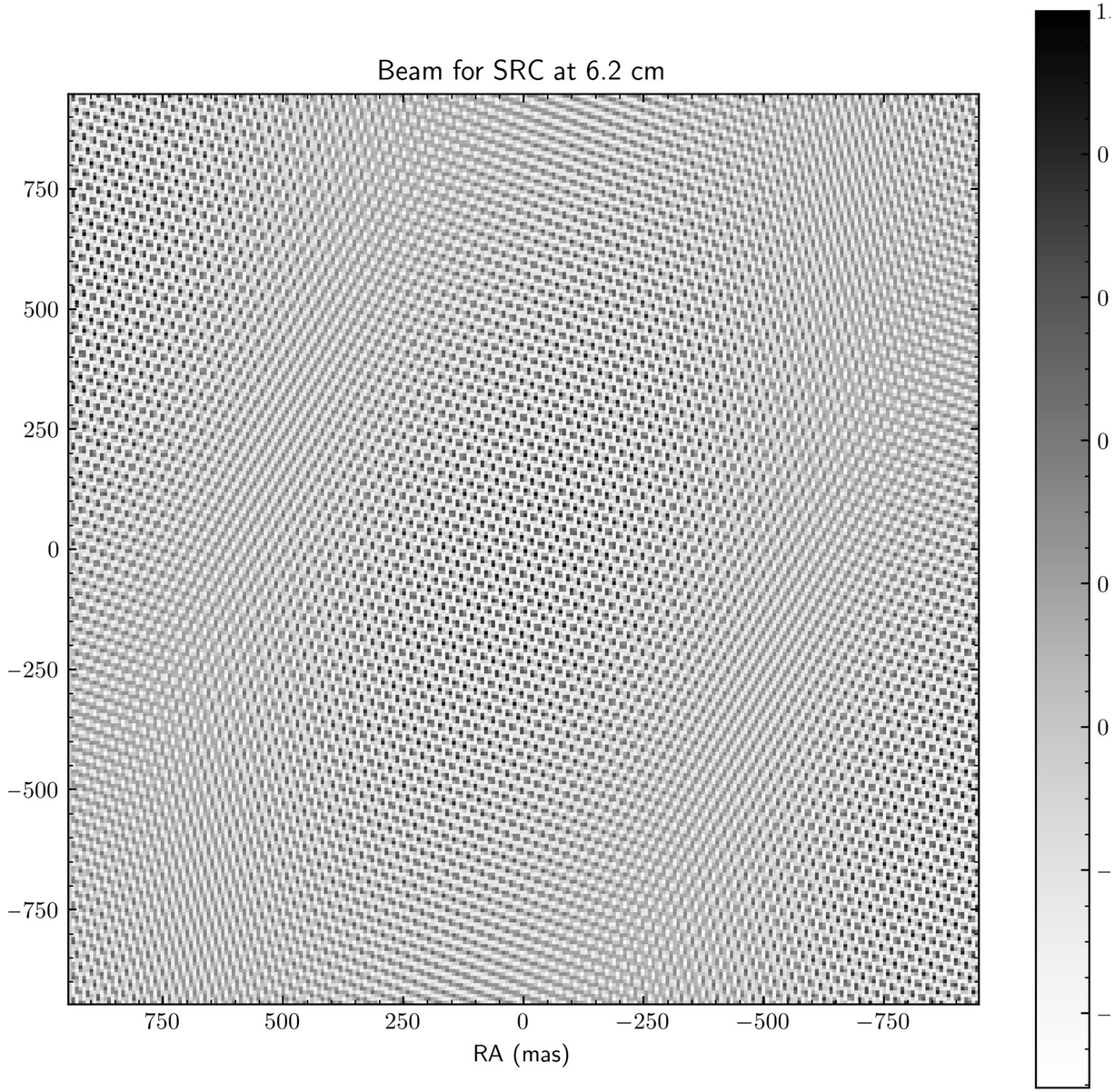


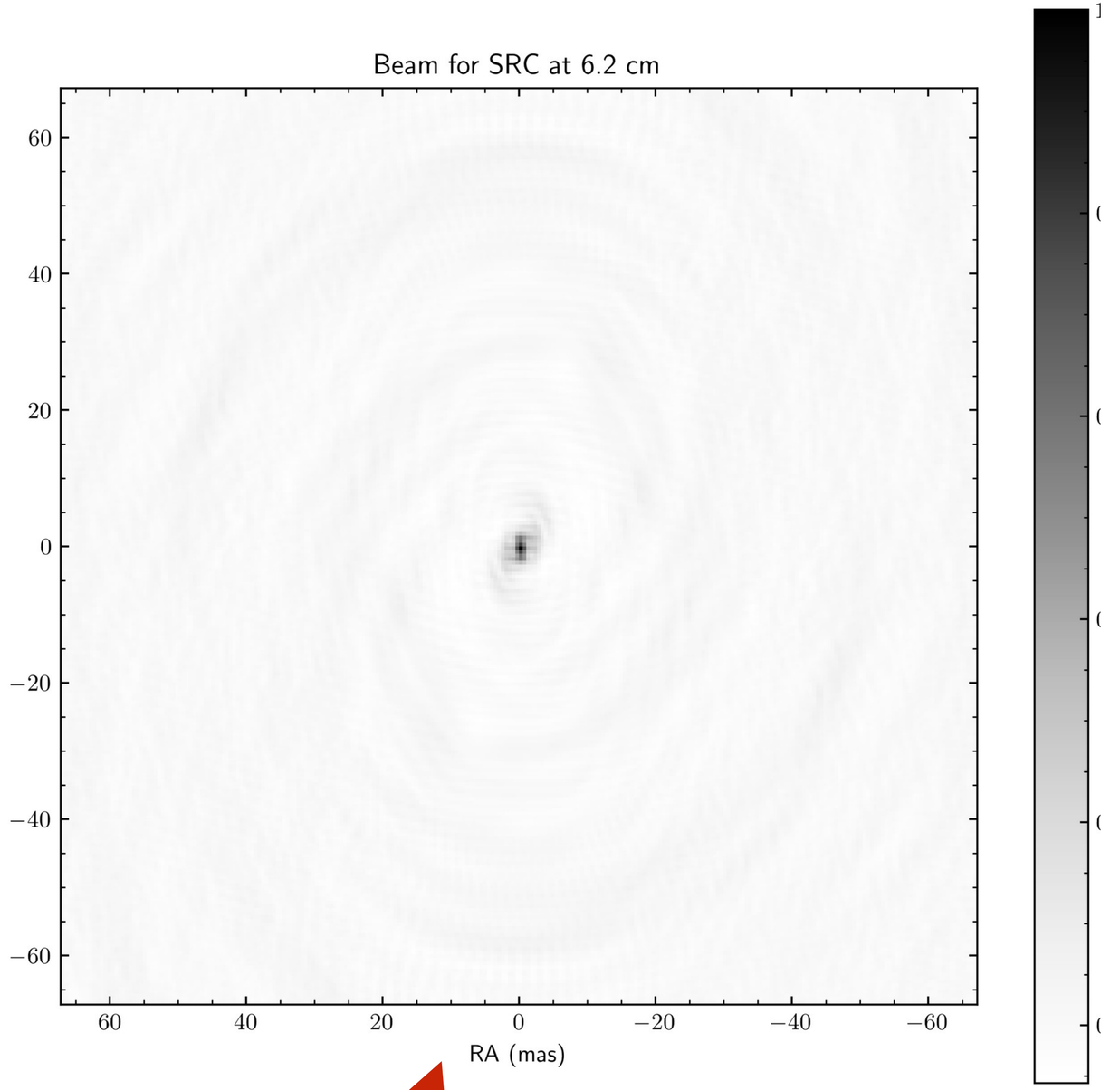
$n_{ant} = 15$

$t_{int} = 8$ hr

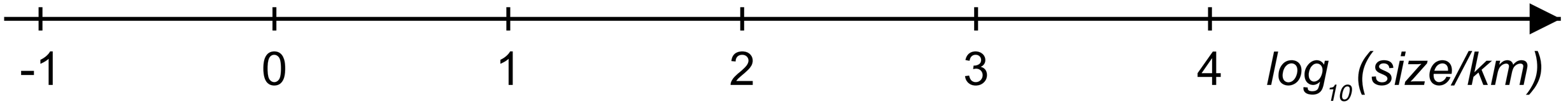








approx. 2500 x more data!


-1
0
1
2
3
4
log10(size/km)

Arcminute Microkelvin Imager - LA (AMI), University of Cambridge (~2005)

Arcminute Microkelvin Imager - SA (AMI), University of Cambridge (~2005)

Sjarjah Radio Telescope, SAAST/UAE, 2020

Millimetre Molecule Array (MMA), Caltech, until 2005

-1 0 1 2 3 4 $log_{10}(size/km)$

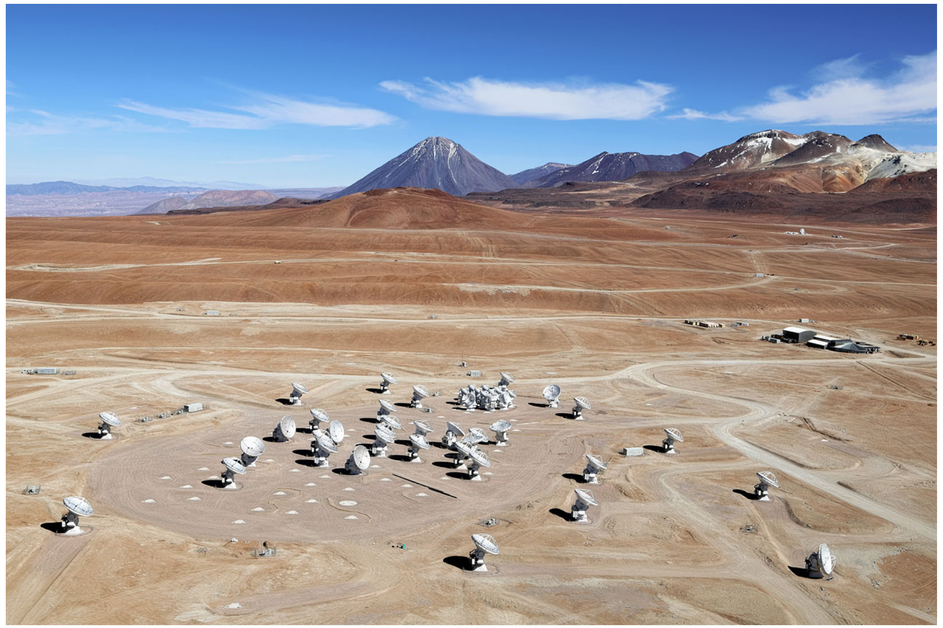
Westerbork Synthesis Radio Telescope (WSRT) ASTRON, 1970's

MeerKAT, SARAO, 2018

Australia Telescope Compact Array (ATCA), ATNF/CSIRO, 1988

Northern Extended Millimeter Array (NOEMA), MPIfR/IRAM, 2018

-1 **0** 1 2 3 4 $log_{10}(size/km)$

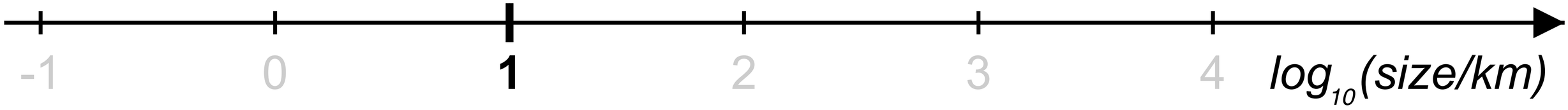


Atacama Large Millimetre Array (ALMA), ESO, 2013

Very Large Array (VLA), NRAO, 1980

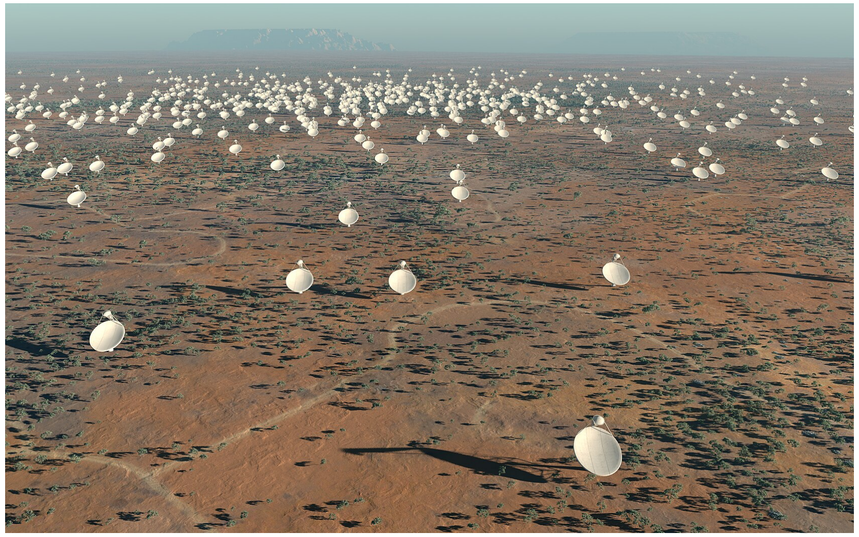
SKA-LOW, SKAO, ~2030?

Giant Metre-wave Radio Telescope (GMRT), NCRA, ~2001

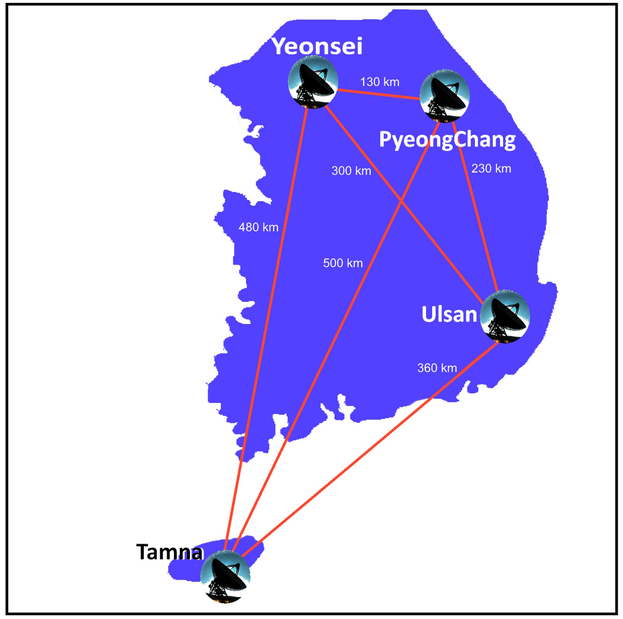


Low Frequency Array (LOFAR) - NL, ASTRON, 2010

enhanced-MERLIN,
University of Manchester, 1980's)

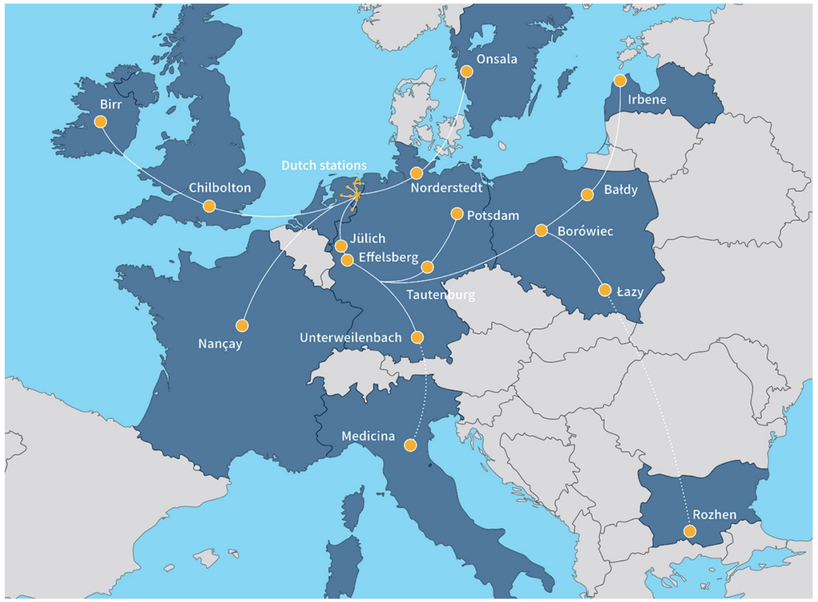


SKA-MID. SKAO. ~2031



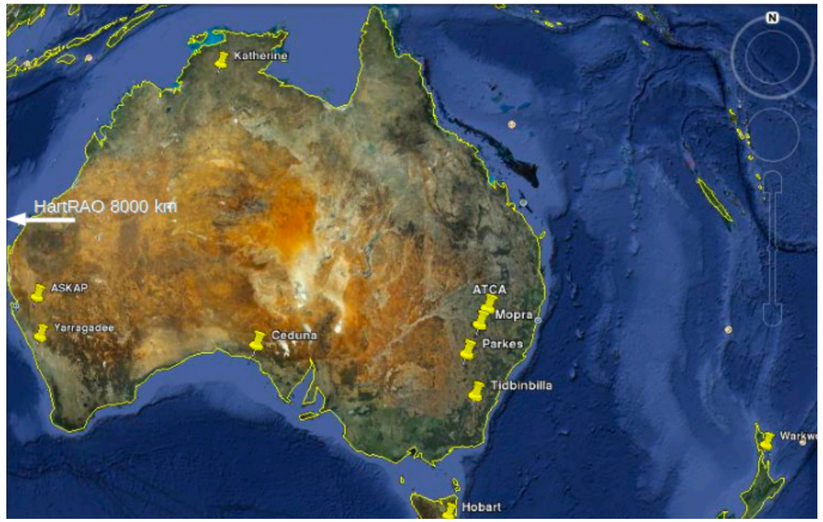
Korean VLBI Network (KVN), KASI, 2010

-1 0 1 **2** 3 4 $log_{10}(size/km)$



Low Frequency Array (LOFAR) - ILT, ASTRON, 2012+

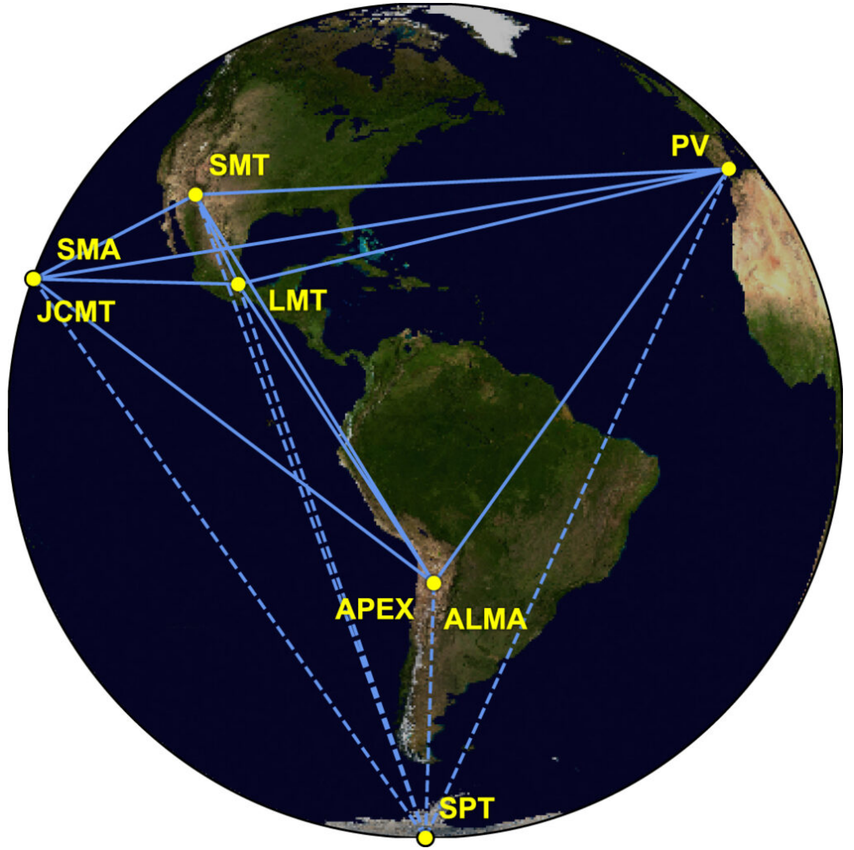
Very Long Baseline Array (VLBA), NRAO, 1998



Long Baseline Array (LBA), CSIRO/ATNF, 1994

-1 0 1 2 **3** 4 $log_{10}(size/km)$

The European VLBI Network (EVN), (many), (1998+)



Event Horizon Telescope Collaboration (EHTC), (many), 2017

-1 0 1 2 3 **4** $log_{10}(size/km)$

JIVE

Joint Institute for VLBI ERIC

Marjolein Verkouter

RADIO BLOCKS

New science in Radio Astronomy: applying cutting-edge technology to enhance the entire data chain, from receiver to final output

This project has receved fundding from the EC under Grant number: 101093934

RADIOBLOCKS partners

First time that **companies** participate in these type of projects. Required by the EU

Grant number: 101093934

RADIOBLOCKS goals

- Building blocks suitable for multiple facilities
- Joint effort to solve common problems
- Enabling new scientific discoveries in mid- and long-term
  - **Increased sensitivity**
  - **Increased bandwidth**
  - **Increased Field-of-View**
- Keeping EU at the front in radio technology developments

Grant number: 101093934

RADIOBLOCKS goals

- Building blocks suitable for multiple facilities
- Joint effort to solve common problems
- **Enabling new scientific discoveries** in mid- and long-term
  - **Increased sensitivity**
  - **Increased bandwidth**
  - **Increased Field-of-View**
- Keeping EU at the front in radio technology developments

Grant number: 101093934

RADIOBLOCKS goals

- Building blocks suitable for multiple facilities
- Joint effort to solve common problems
- Enabling new scientific discoveries in mid- and long-term
  - Increased sensitivity
  - Increased bandwidth
  - Increased Field-of-View

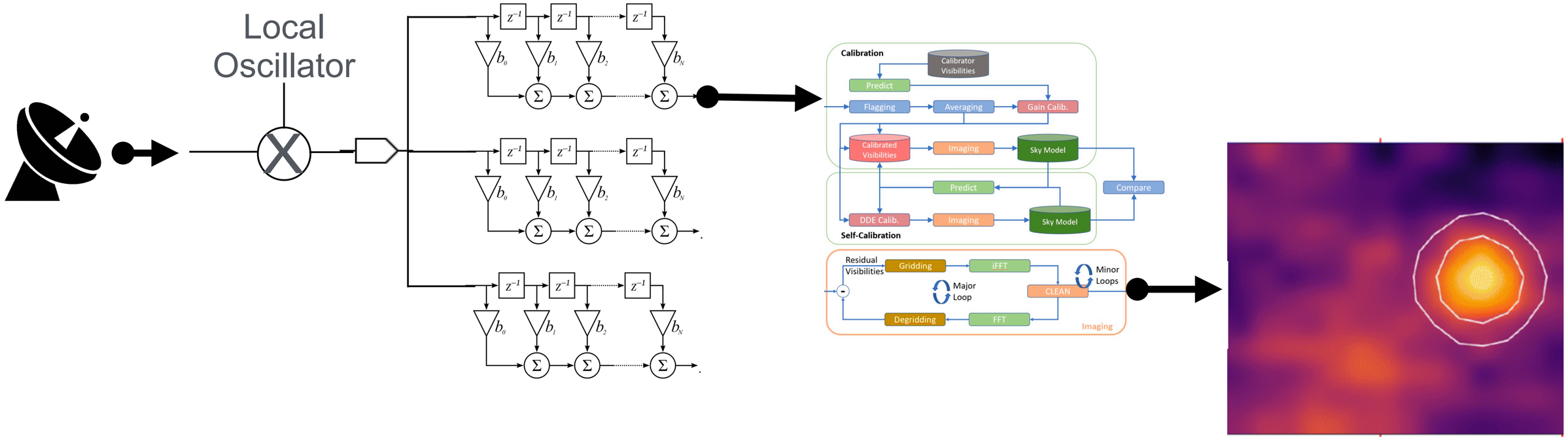
- **Keeping EU at the front in radio technology developments**

Grant number: 101093934

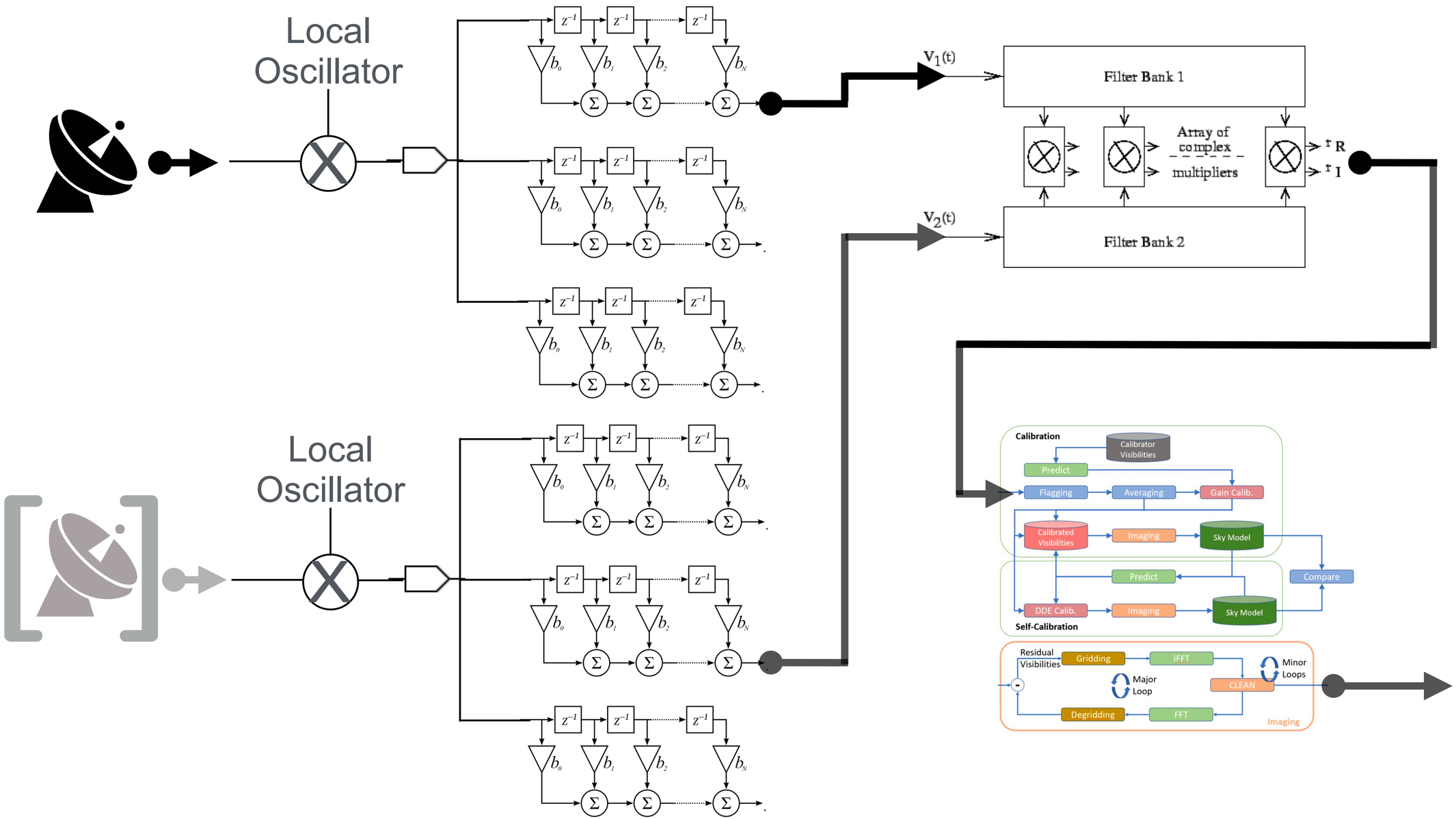
RADIOBLOCKS goals

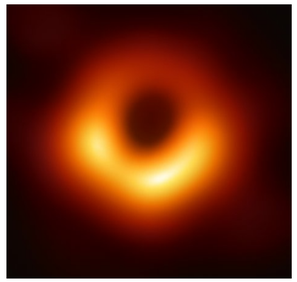
- **Building blocks suitable for multiple facilities**
- **Joint effort to solve common problems**
- Enabling new scientific di… …n
  - **Increased sen…**
  - **Increased ban…**
  - **Increased Field-of-View**
- Keeping EU at the front in radio technology developments

Address the ***whole*** signal chain: from analog to post-processing



Single dish improvements





Supporting the next-generation of VLBI

Science enablers: Increase field of view Increase sensitivity and bandwidth

LOFAR

The International LOFAR Telescope...

... hosted by the ILT

EVN

The European VLBI network (EVN)...

... hosted by the Joint Institute for VLBI

NOEMA

The NOEMA telescope...

... hosted by the IRAM institute

E-Merlin...

... hosted by the University of Manchester

Ef/Srt/Ys

The Effelsberg telescope...

... hosted by the MaxPlanck Institute

The SRT telescope...

... hosted by INAF

The Yebes telescope...

... hosted by CNIG/IGN

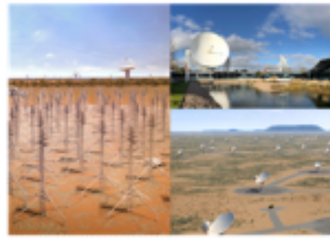
ALMA

The ALMA telescope...

... hosted by the European Southern Observatory for the European part

SKAO

The SKA telescope...



... hosted by the SKA Office

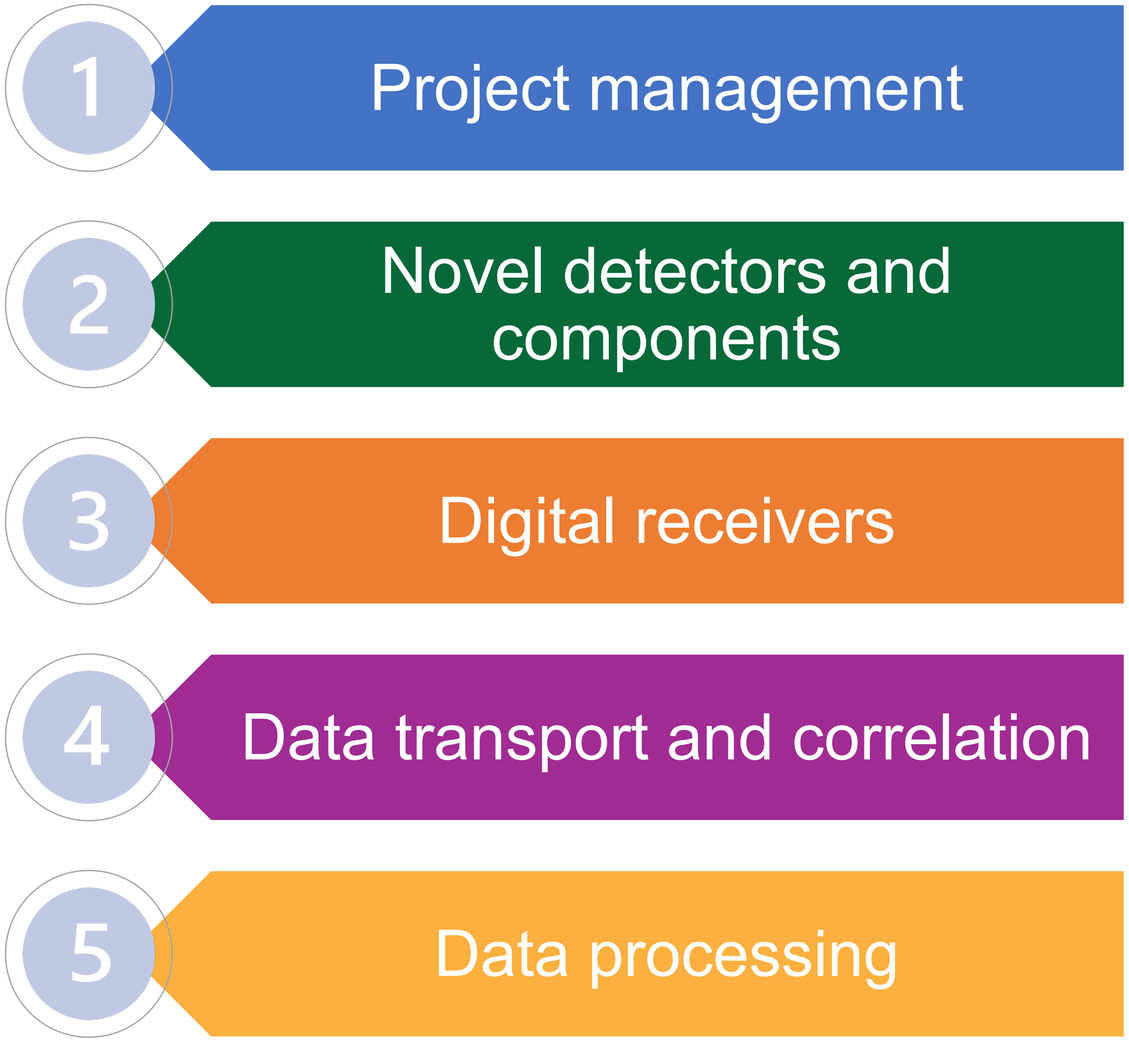
Building blocks:

Novel detectors and components

Digital receivers

Transport and Correlator

Data (post)processing


1
Project management
2
Novel detectors and components
3
Digital receivers
4
Data transport and correlation
5
Data processing

Grant number: 101093934

RADIOBLOCKS goals

- Building blocks suitable for multiple facilities
- Joint effort to solve common problems
- **Enabling new scientific discoveries** in mid- and long-term
  - **Increased sensitivity**
  - **Increased bandwidth**
  - Increased Field-of-View
- Keeping EU at the front in radio technology developments

$$\Theta = 1.22 \cdot \frac{\lambda}{D}$$

lower is better (less noise)

$$\sigma_T = \frac{T_{sys}}{\sqrt{\Delta_\nu \cdot \Delta t}}$$

$$\Theta = 1.22 \cdot \frac{\lambda}{D}$$

- bigger telescope
- higher quality Low-Noise-Amplifier
- more efficient receiver system

$$\sigma_T = \frac{T_{sys}}{\sqrt{\Delta_\nu \cdot \Delta t}}$$

$$\Theta = 1.22 \cdot \frac{\lambda}{D}$$

- ~~bigger telescope~~
- higher quality Low-Noise-Amplifier
- more efficient receiver system

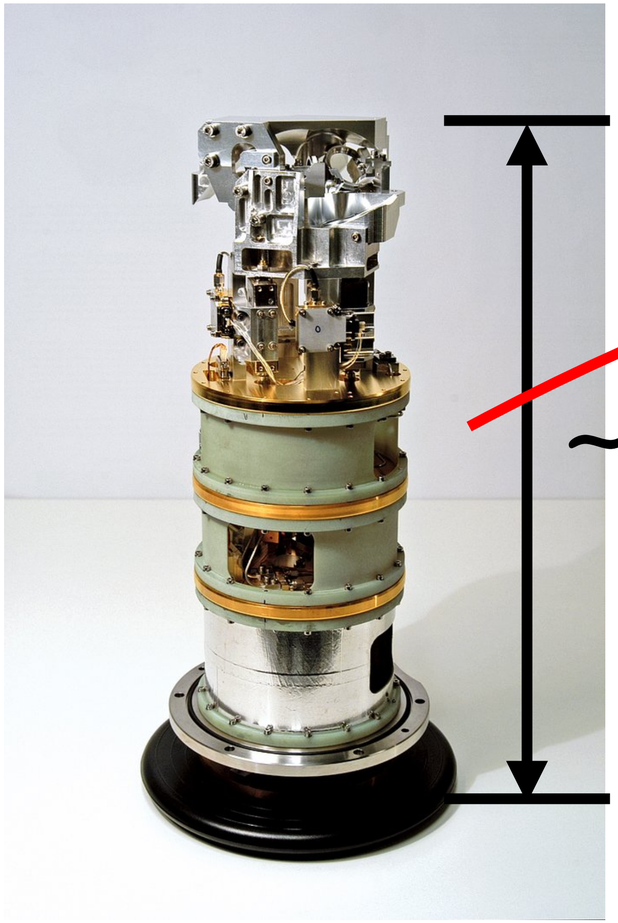
$$\sigma_T = \frac{T_{sys}}{\sqrt{\Delta_\nu \cdot \Delta t}}$$

$$\Theta = 1.22 \cdot \frac{\lambda}{D}$$

$$\sigma_T = \frac{T_{sys}}{\sqrt{\Delta_\nu \cdot \Delta t}}$$

increase bandwidth

Cryo-cooled receiver (4K)

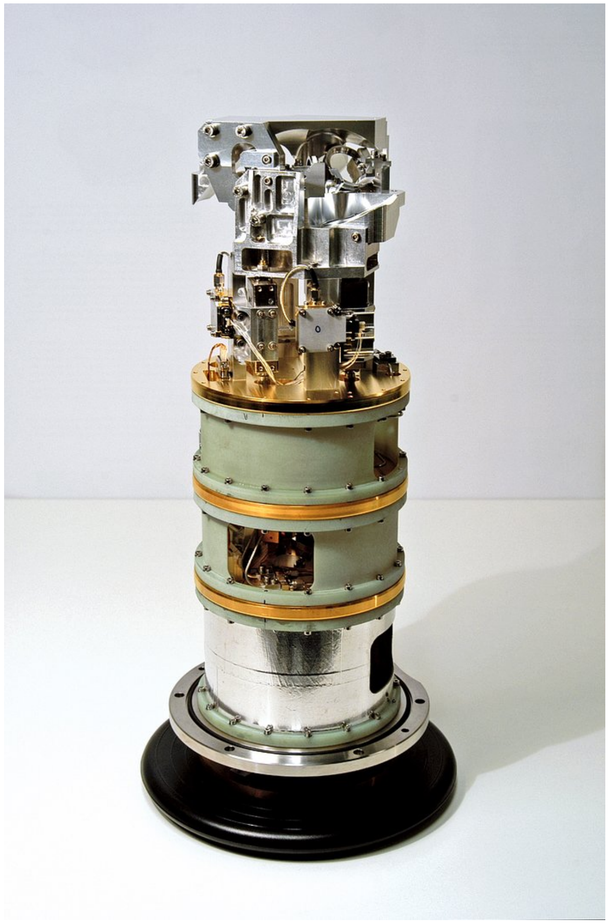


~50 cm

conceptual(!) location

~18 m

Cryo-cooled receiver (4K)

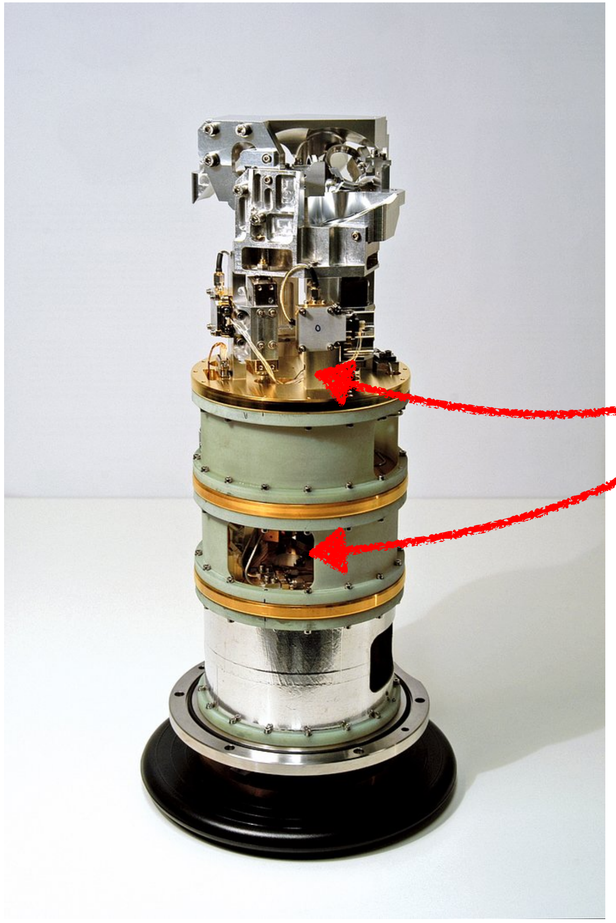


lens(es) separating cooling zones

SiS mixer for downconversion

low-noise amplifiers + horn

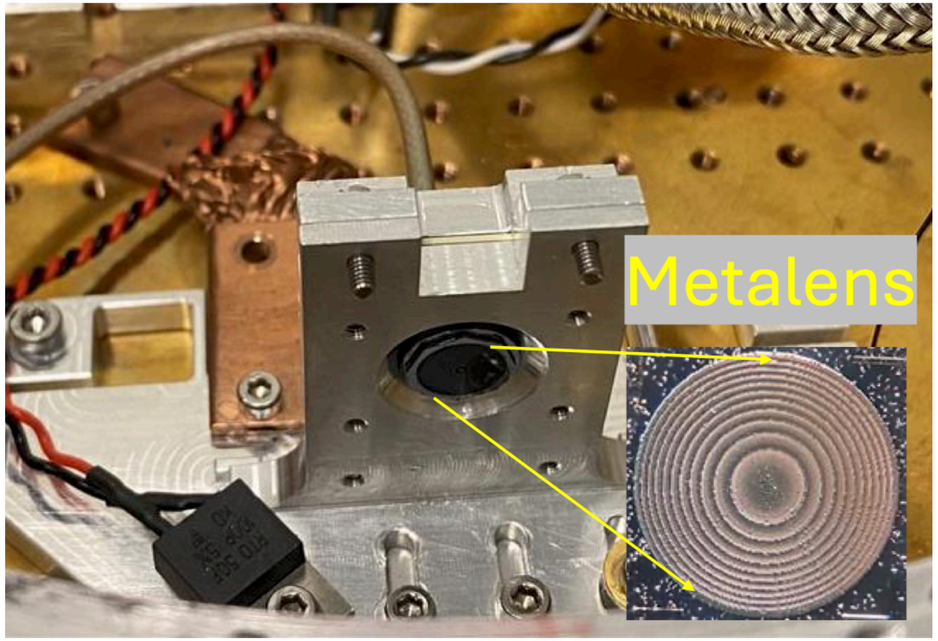
Cryo-cooled receiver (4K)



lens(es) separating cooling zones

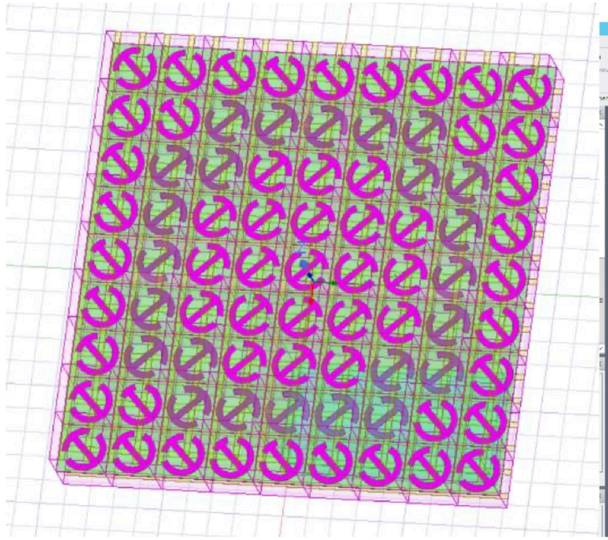
SiS mixer for downconversion

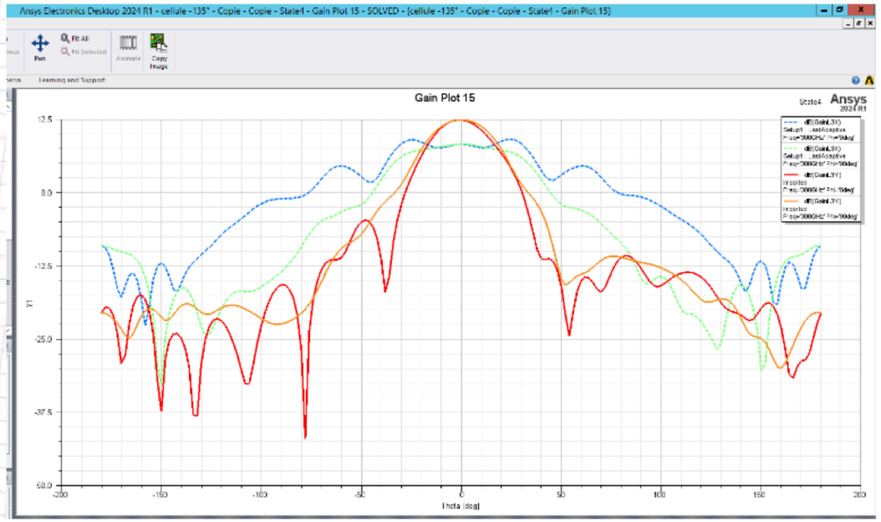
low-noise amplifiers + horn



← prototype

simulation →



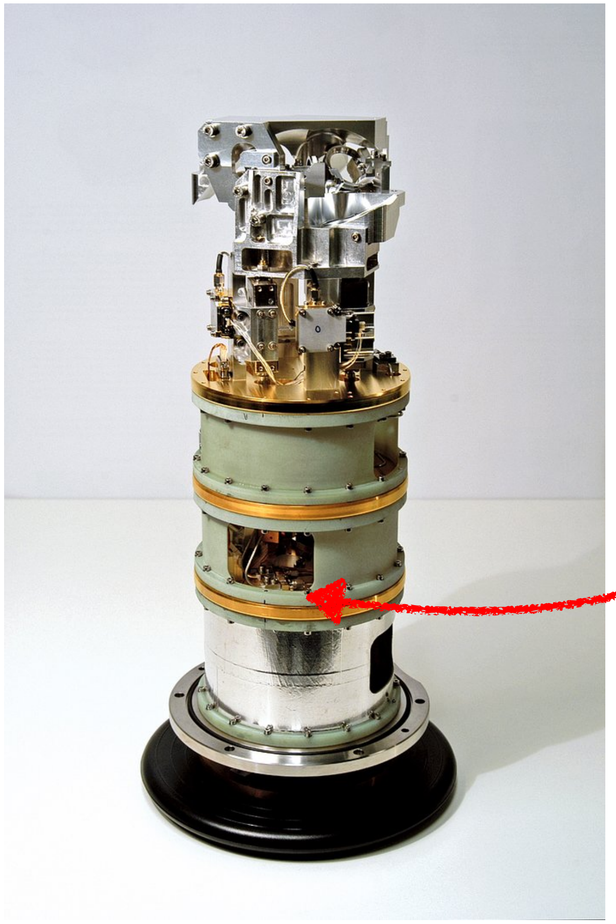


→ enable wider bandwidth
→ better transmission
→ lower noise figure

RADIO BLOCKS

Novel detectors and components

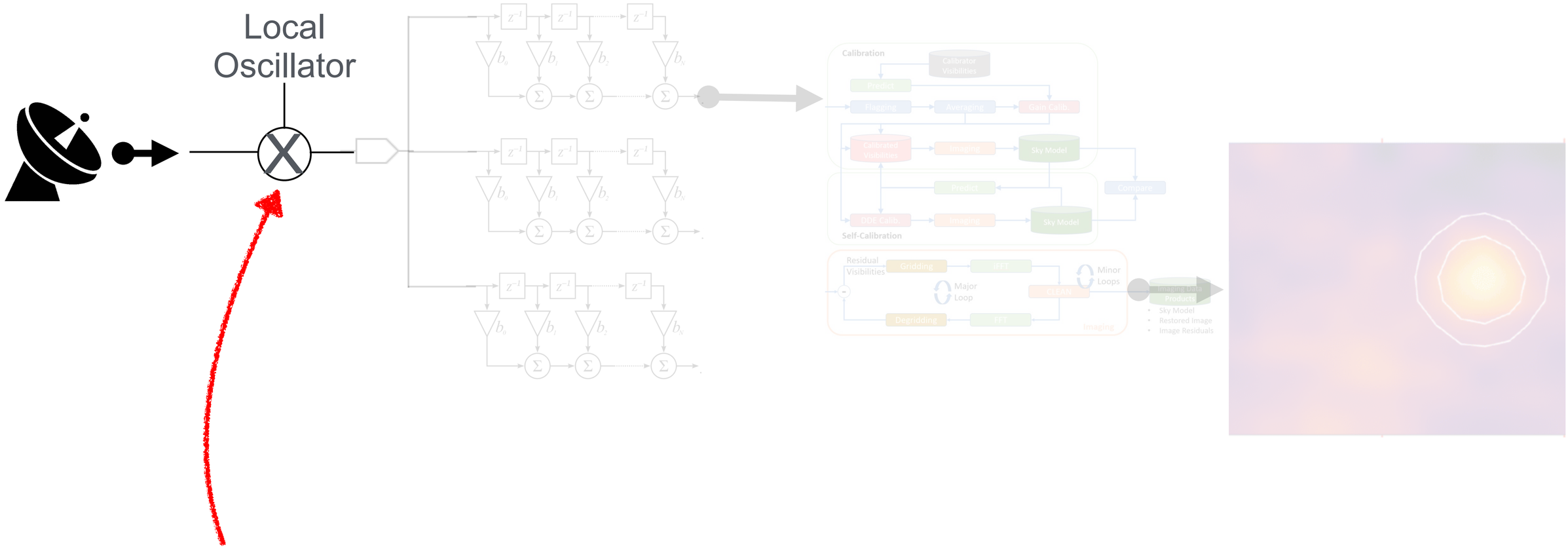
Cryo-cooled receiver (4K)



lens(es) separating cooling zones

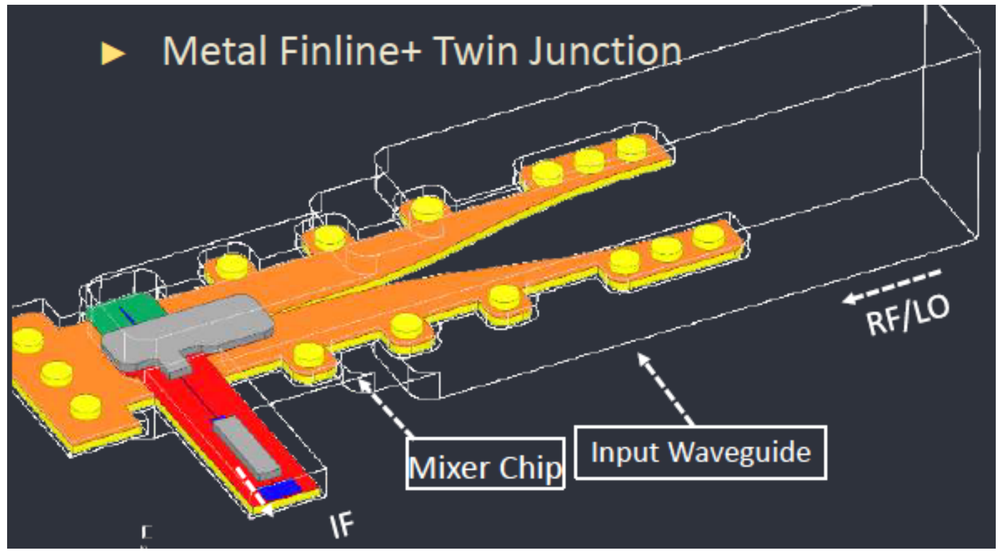
SiS mixer for downconversion

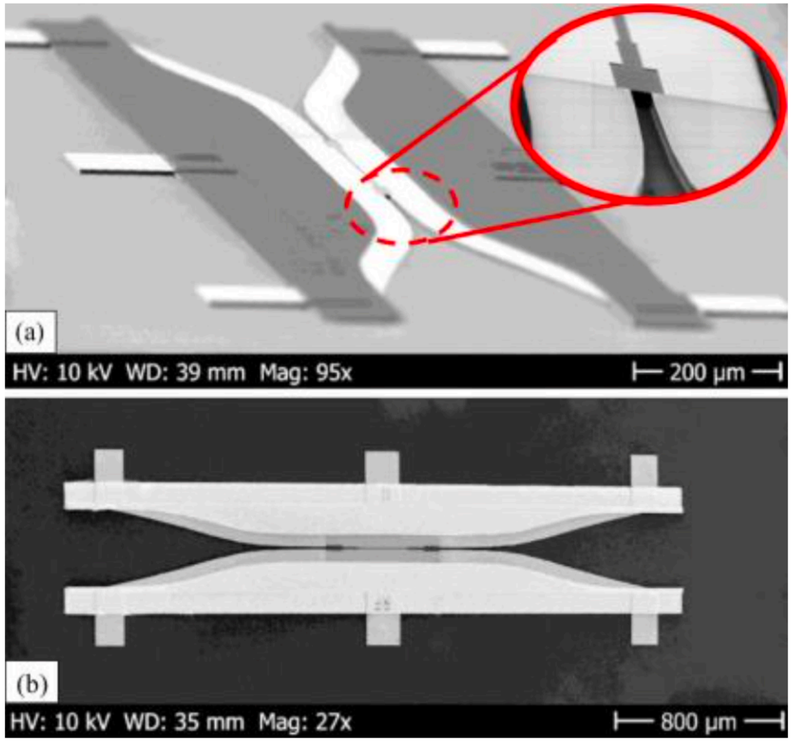
low-noise amplifiers + horn



Mixer: downconvert sky signal to manageable A-to-D bw

Improved SiS mixer(s)





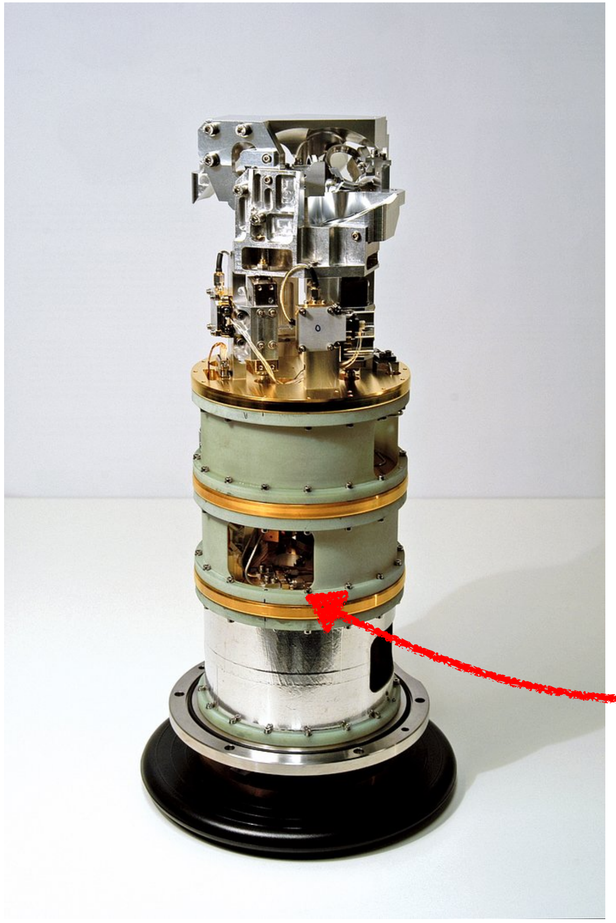
Ultra-wideband waveguide to slotline transition

→ delivers wider bandwidth
→ no impact on noise figure
→ uses less DC power (less cooling required)

RADIO BLOCKS

Novel detectors and components

Cryo-cooled receiver (4K)

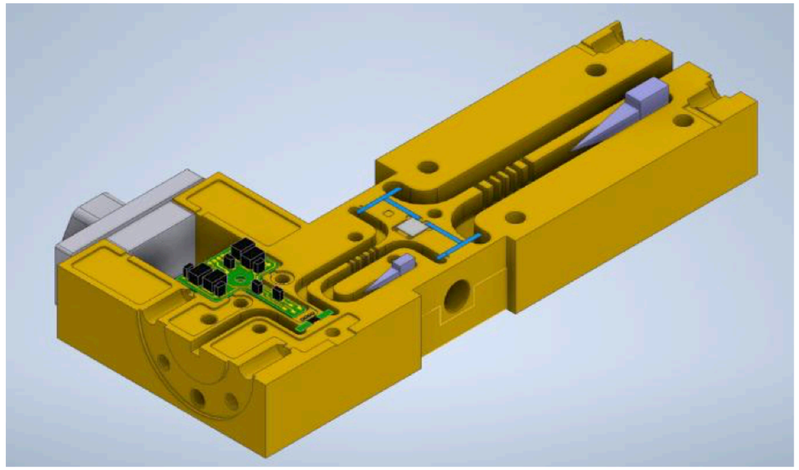


lens(es) separating cooling zones

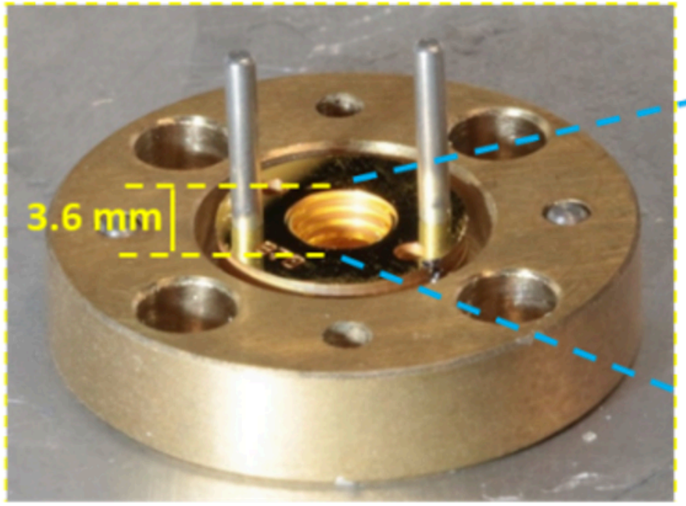
SiS mixer for downconversion

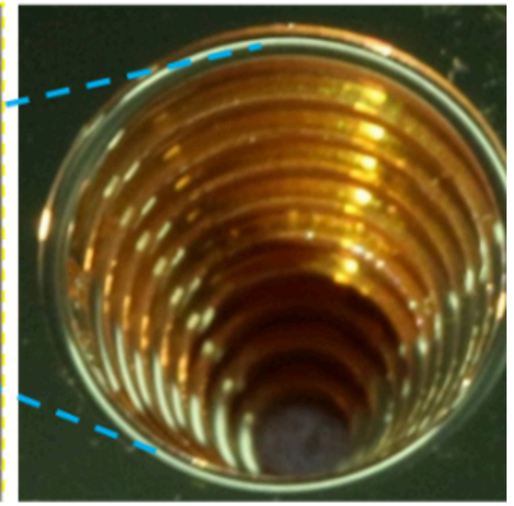
low-noise amplifiers + horn

Ys ALMA NOEMA

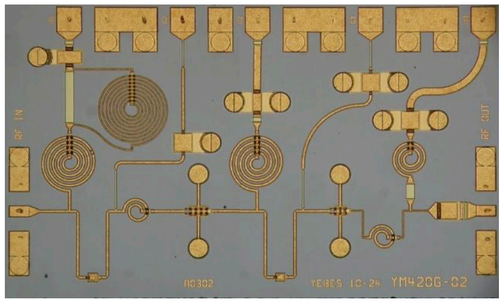


Integrated LNA + Subharmonic Image Rejection Mixers (CAD model)

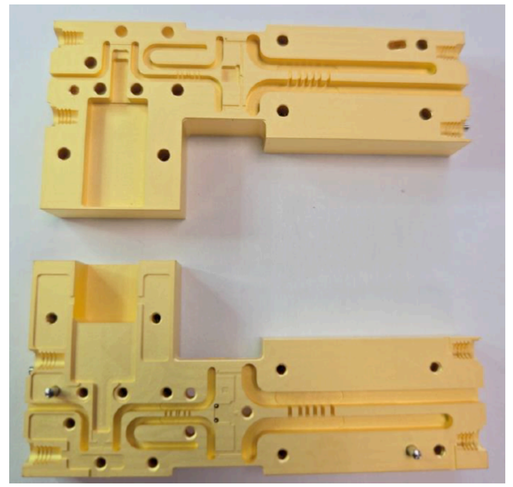




Corrugated horn



LNA (prototype)



LNA up to 150 GHz

→ more compact components (better OMT/mixer/LNA integration)
→ wider bandwidth LNAs
→ enabling higher operating frequencies

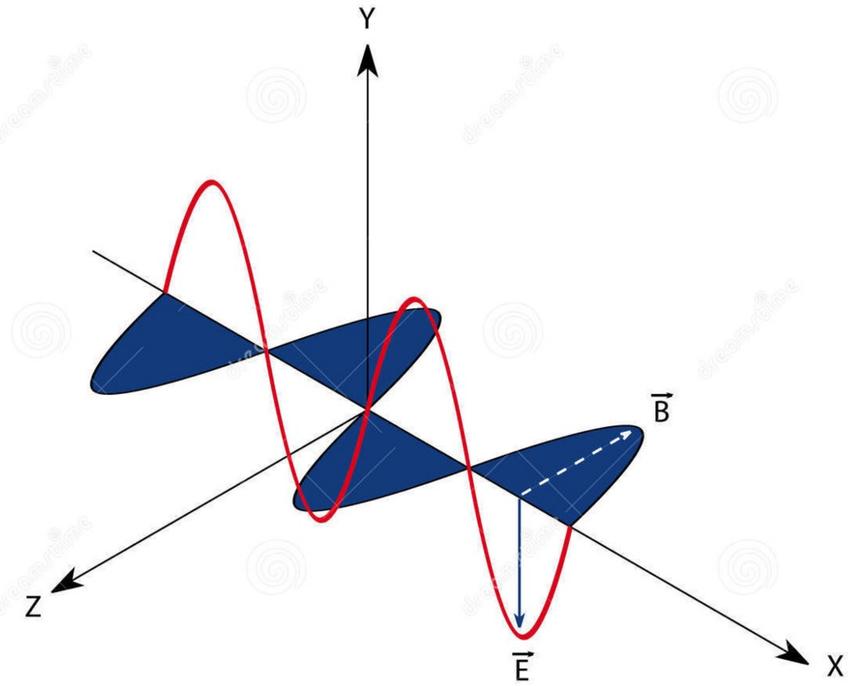
RADIO BLOCKS

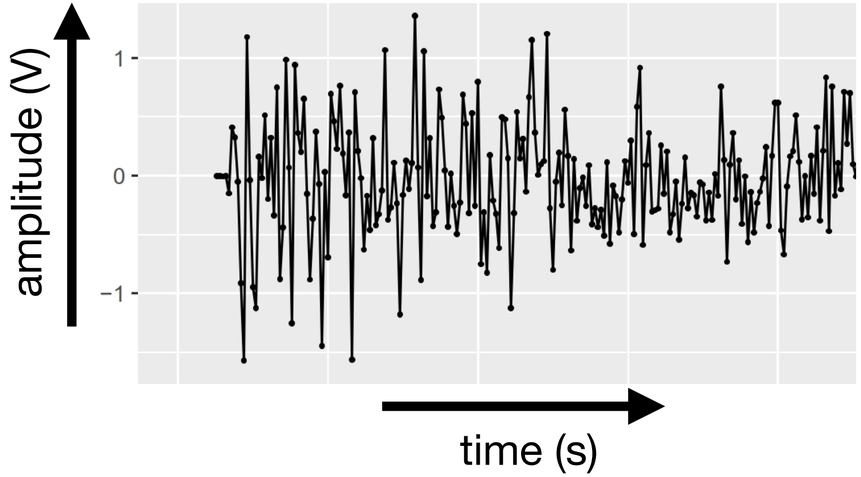
Novel detectors and components

$$\Theta = 1.22 \cdot \frac{\lambda}{D}$$

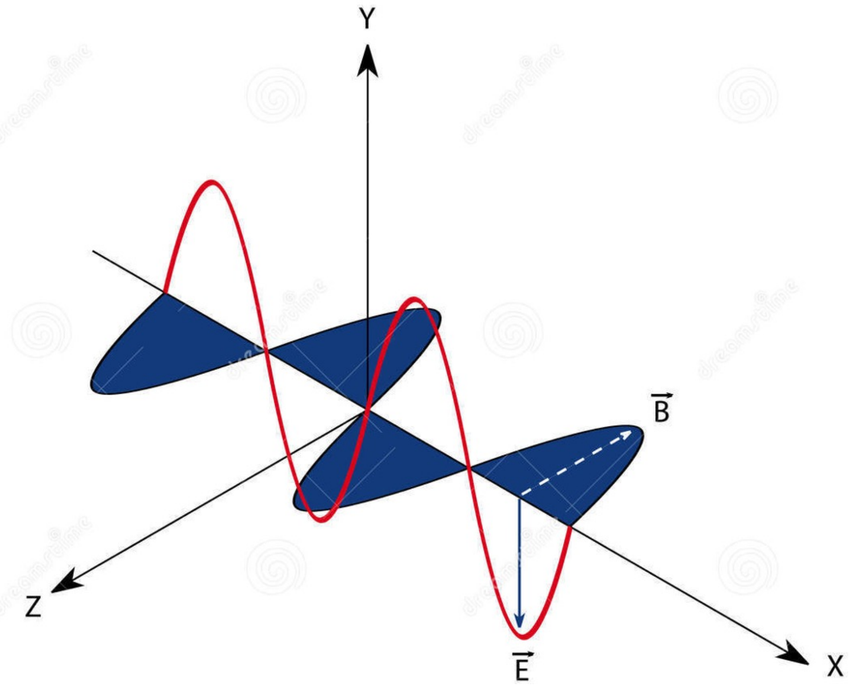
$$\sigma_T = \frac{T_{sys}}{\sqrt{\Delta_\nu \cdot \Delta t}}$$

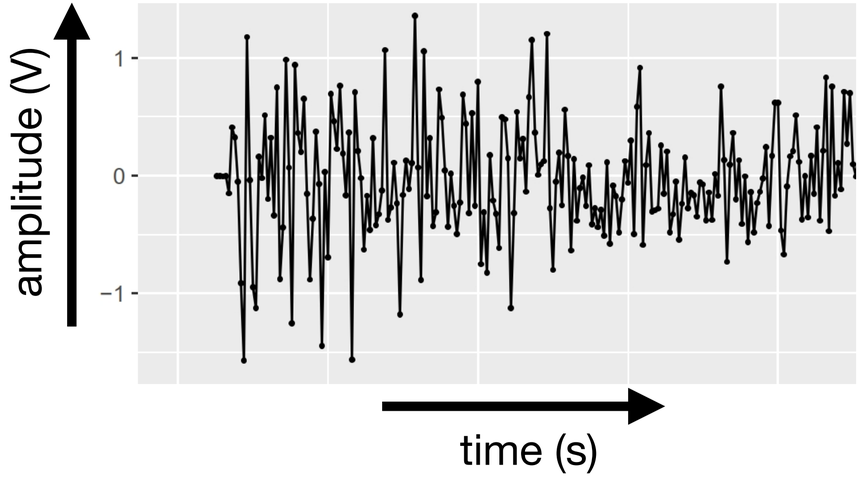
increase bandwidth





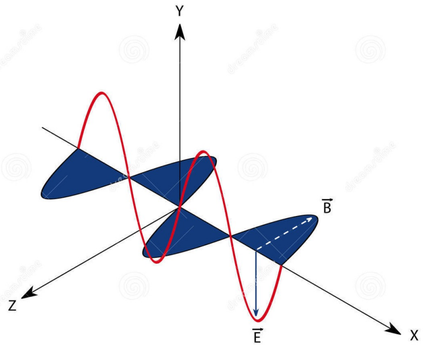
~ a few GHz RF signals



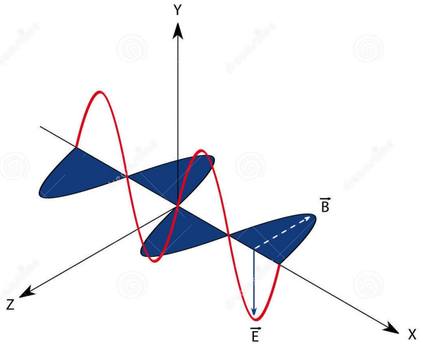


Sample Rate = 2 x BW

Shannon/Nyquist theorem



4 GHz

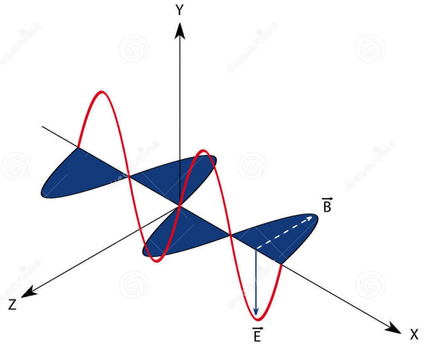


dual polarisation receiver

Nyquist sampling

2-bit per sample
(enough for VLBI)

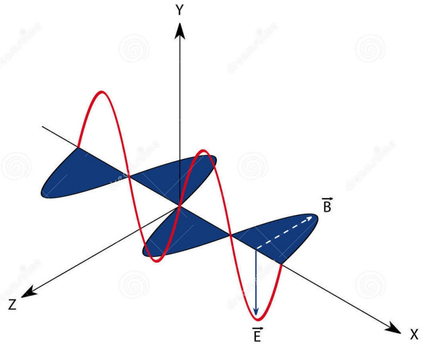
4 GHz x 2 x 2 x 2



2-bit per sample
LOFAR / SKA use 8 or more!

4 GHz x 2 x 2 x 2

= 32 Gbps per telescope (or more)



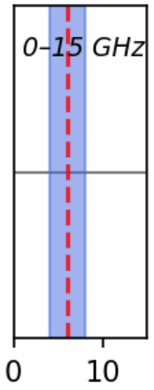
2-bit per sample
LOFAR / SKA use 8 or more!

4 GHz x 2 x 2 x 2 x 8h

≈ 110 TB = 0.1 PB

One (1) telescope
One (1) observation

C-band (6 GHz) — 4 GHz = 66.7% fractional BW

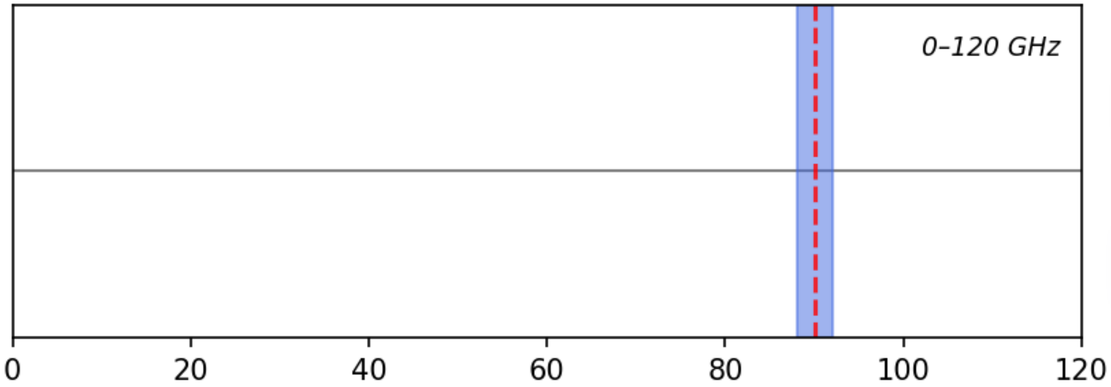


EVN

Ef/Srt/Ys

SKA-MID

W-band (90 GHz) — 4 GHz = 4.4% fractional BW

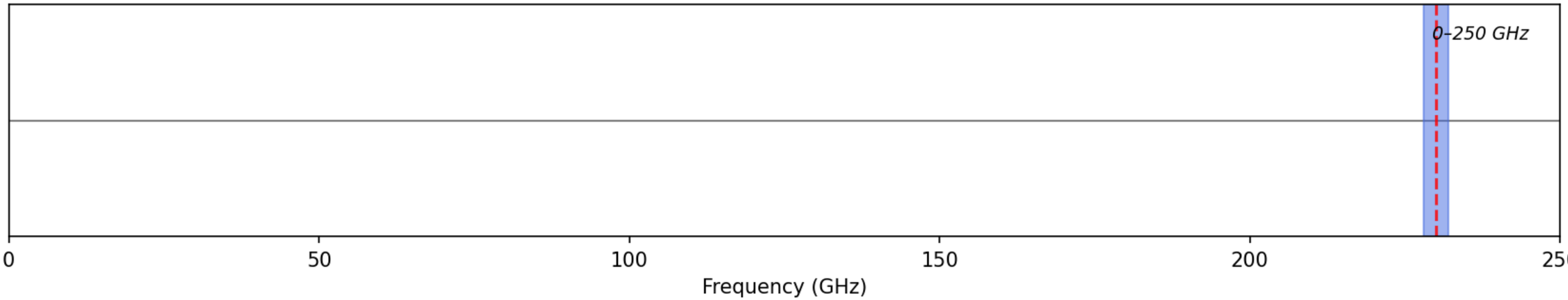


EVN

Ef/Srt/Ys

ALMA

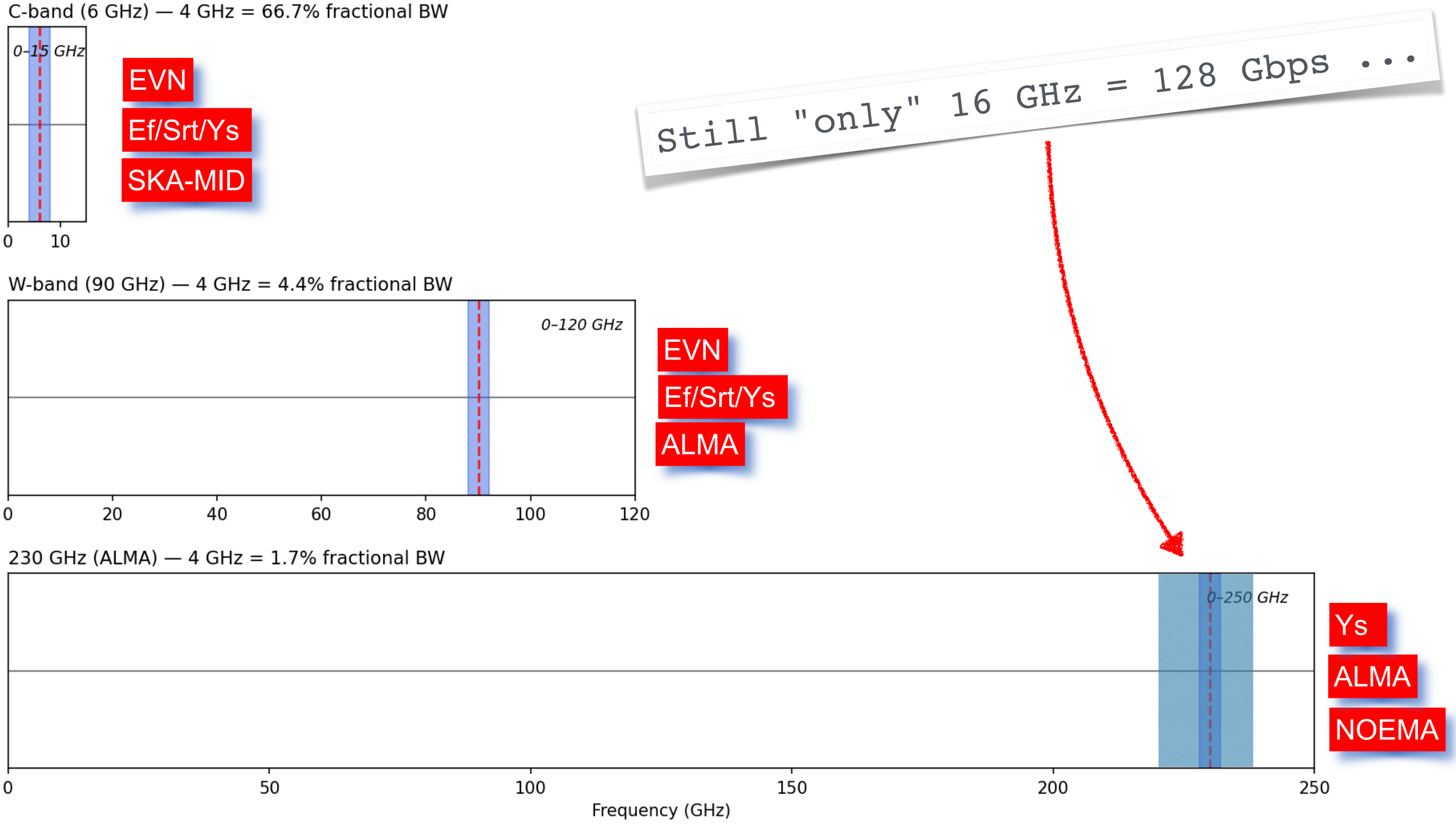
230 GHz (ALMA) — 4 GHz = 1.7% fractional BW



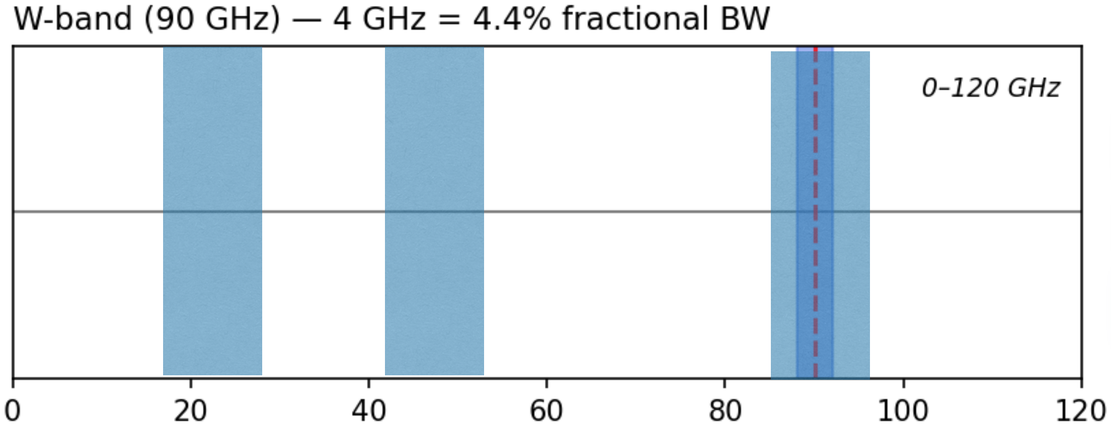
Ys

ALMA

NOEMA


C-band (6 GHz) — 4 GHz = 66.7% fractional BW
0–15 GHz
0
10
EVN
Ef/Srt/Ys
SKA-MID
Still "only" 16 GHz = 128 Gbps ...
W-band (90 GHz) — 4 GHz = 4.4% fractional BW
0–120 GHz
0
20
40
60
80
100
120
EVN
Ef/Srt/Ys
ALMA
230 GHz (ALMA) — 4 GHz = 1.7% fractional BW
0–250 GHz
0
50
100
150
200
250
Frequency (GHz)
Ys
ALMA
NOEMA

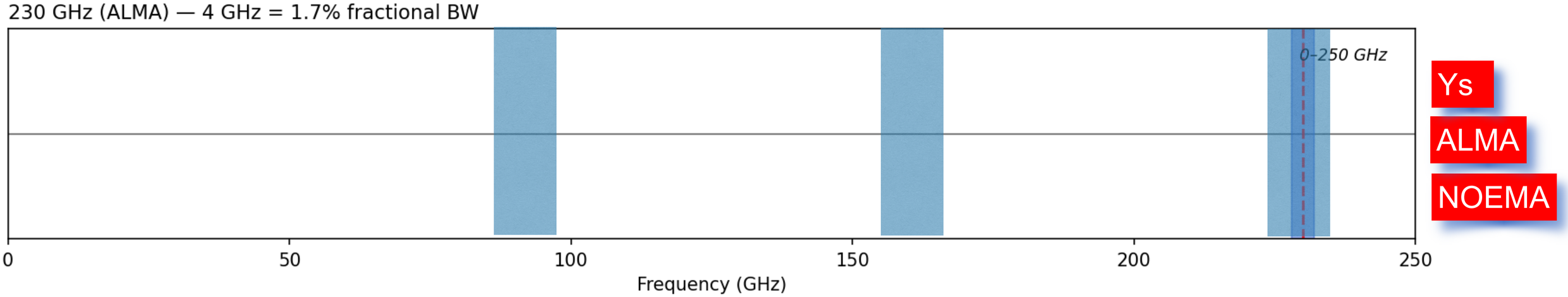
simultaneous(!) multi-band receivers
n x 4(or more) GHz



EVN

Ef/Srt/Ys

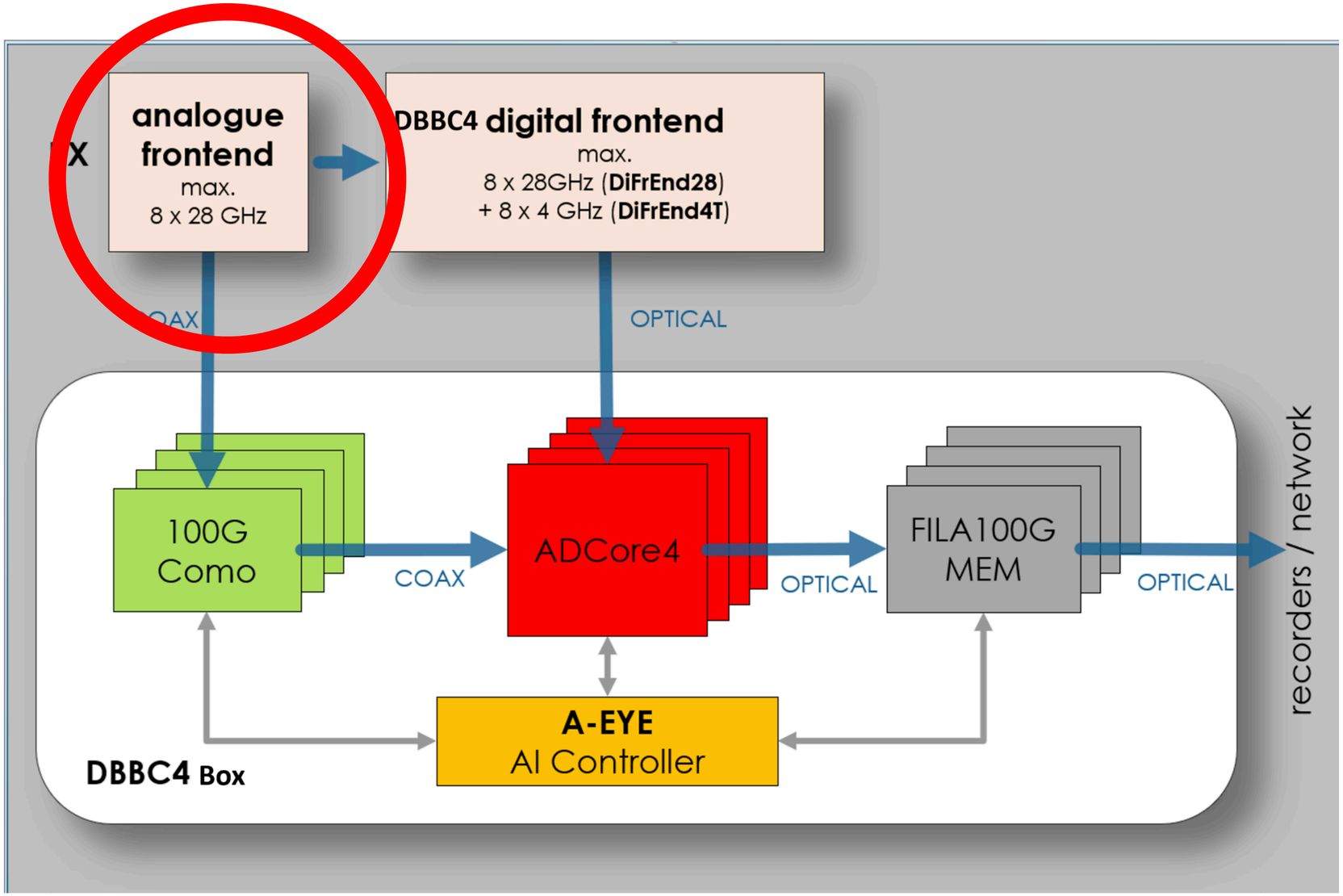
ALMA



Ys

ALMA

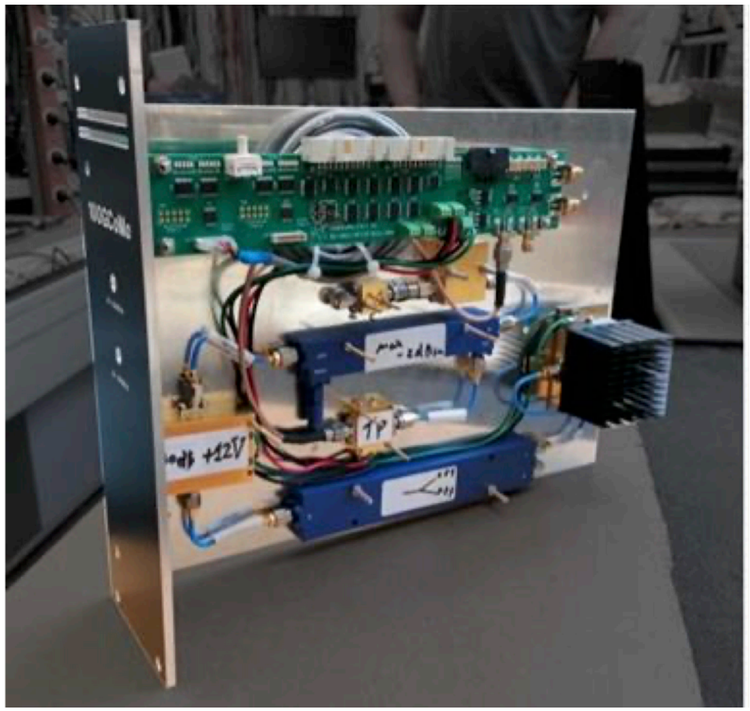
NOEMA

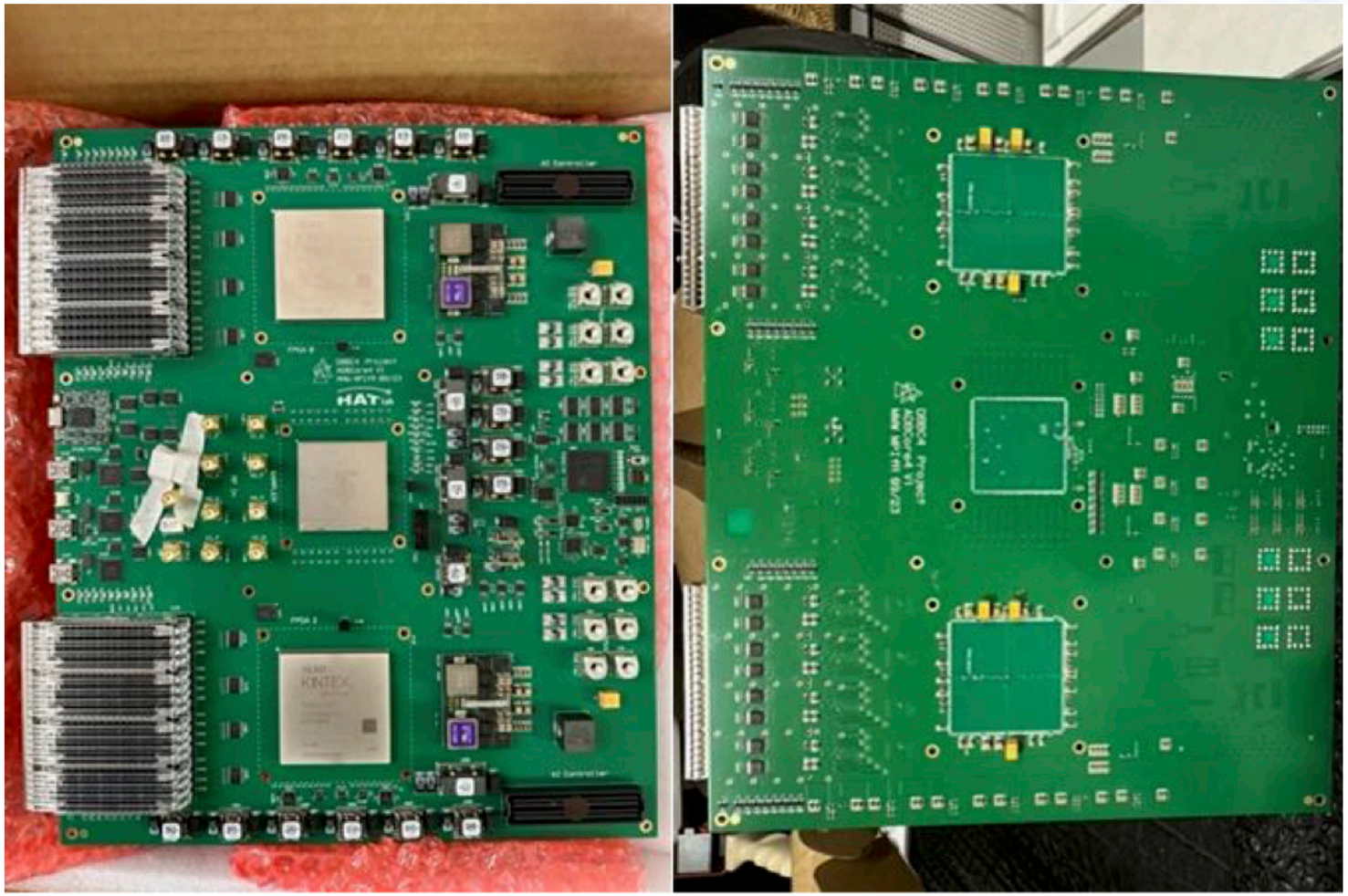


Digital Base Band Converter (v4) schematic

Ys ALMA NOEMA EVN

100G CoMo: analog signal conditioning for best A/D

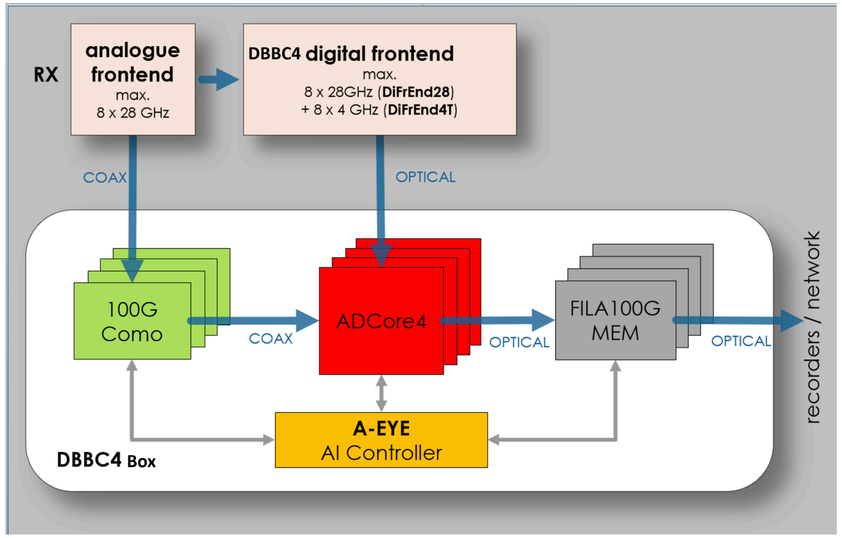




ADCore4 - the FPGA heart of the system

RADIO BLOCKS

Digital receivers



Nyquist sampling

2-bit per sample

8 x 28 GHz x 2 x 2

= 896 Gbps ≈ 1 Tbps ...

Grant number: 101093934

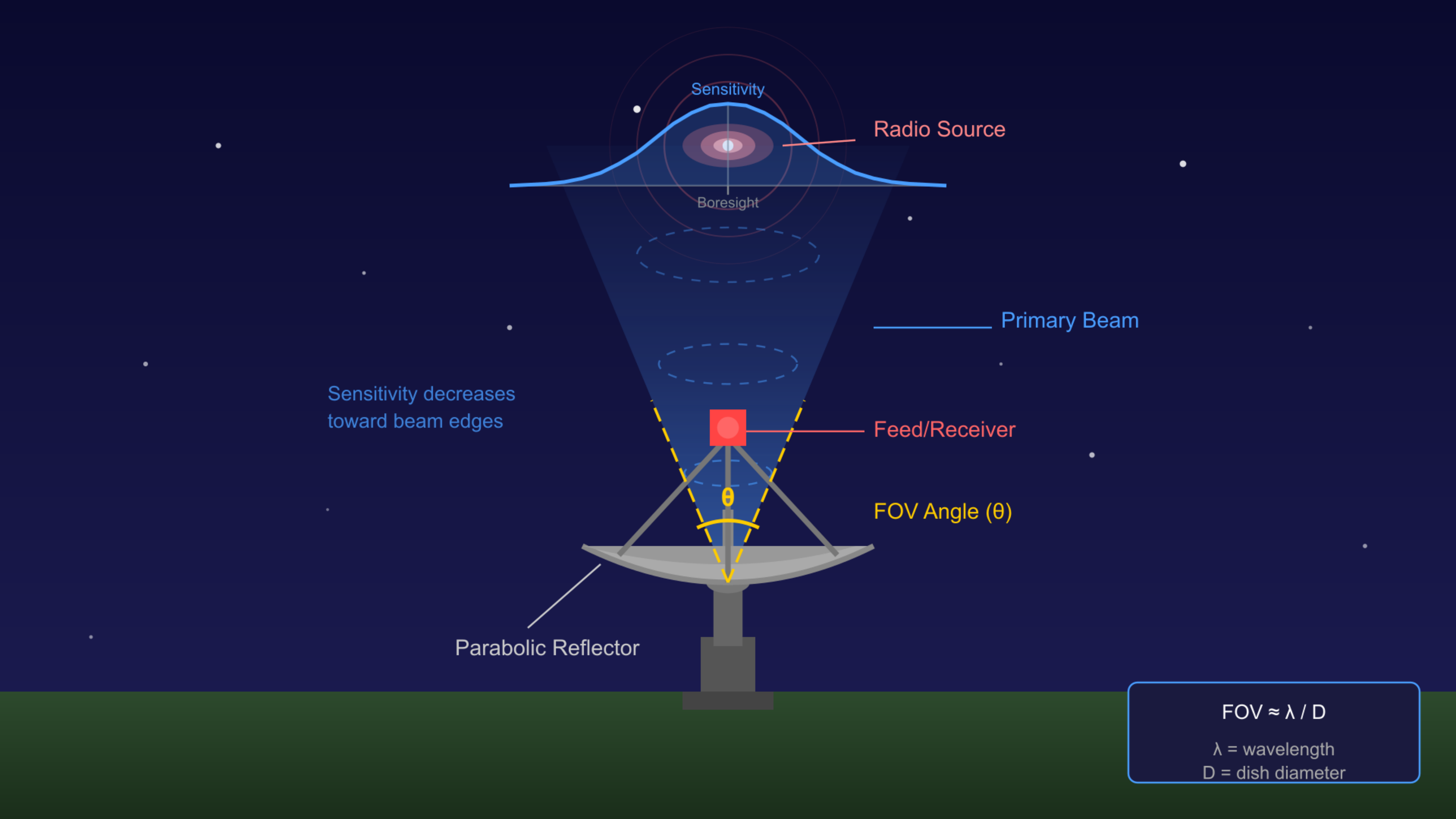
RADIOBLOCKS goals

- Building blocks suitable for multiple facilities
- Joint effort to solve common problems
- **Enabling new scientific discoveries** in mid- and long-term
  - **Increased sensitivity** ✓
  - **Increased bandwidth** ✓
  - Increased Field-of-View
- Keeping EU at the front in radio technology developments

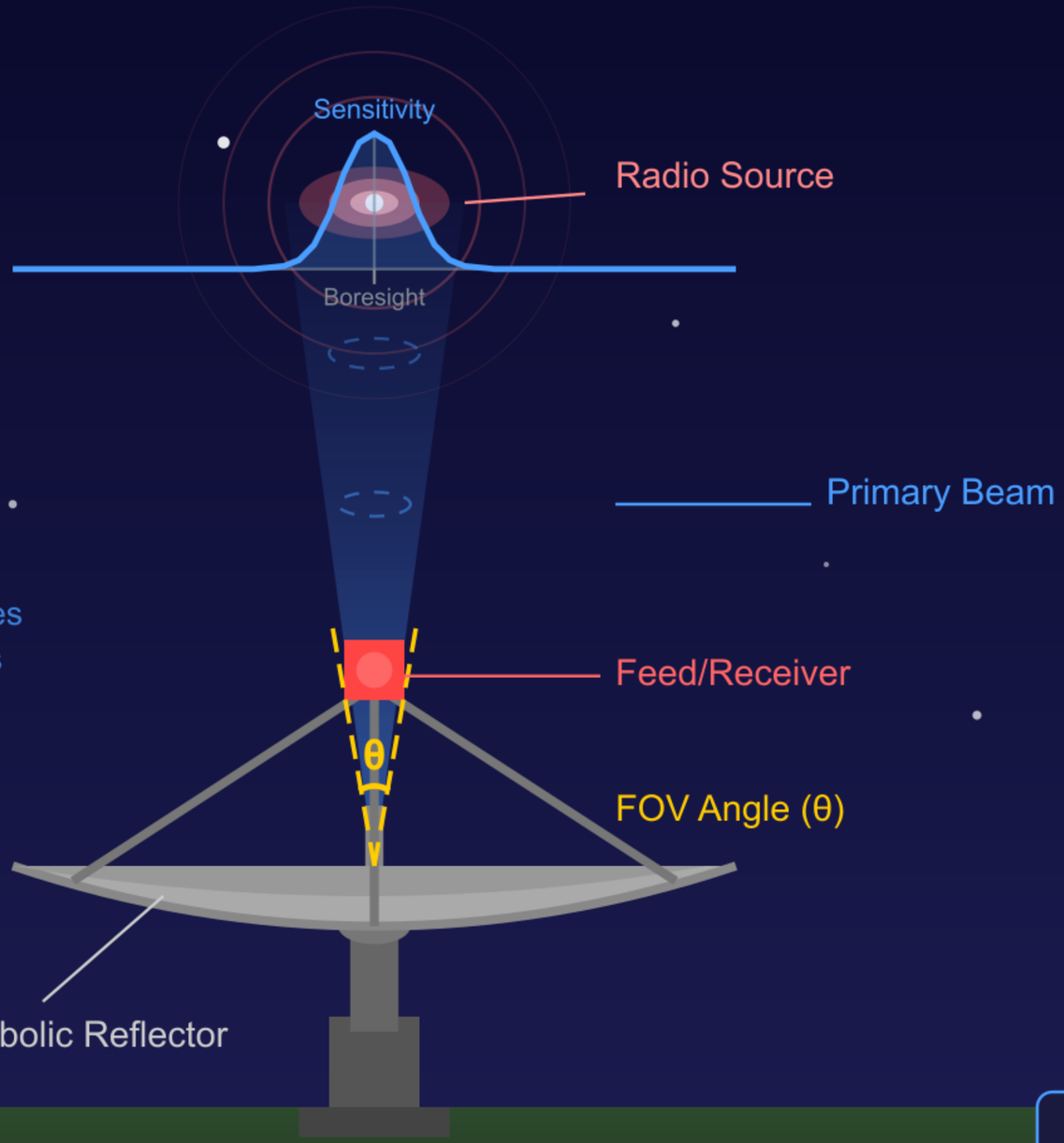
Grant number: 101093934

RADIOBLOCKS goals

- Building blocks suitable for multiple facilities
- Joint effort to solve common problems
- **Enabling new scientific discoveries** in mid- and long-term
  - **Increased sensitivity**
  - **Increased bandwidth**
  - **Increased Field-of-View**
- Keeping EU at the front in radio technology developments

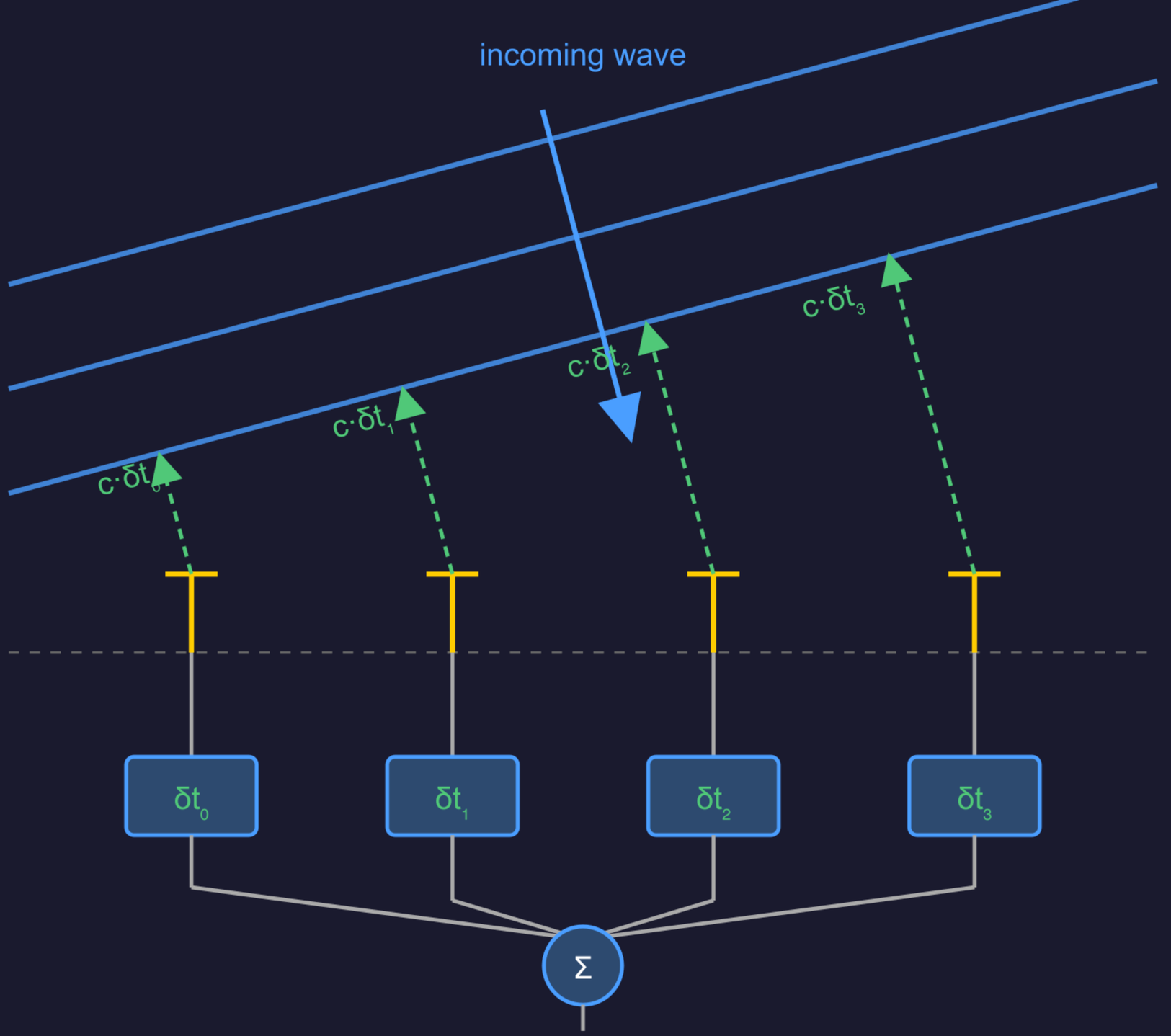

Sensitivity
Radio Source
Boresight
Primary Beam
Sensitivity decreases
toward beam edges
Feed/Receiver
θ
FOV Angle (θ)
Parabolic Reflector
FOV ≈ λ / D
λ = wavelength
D = dish diameter

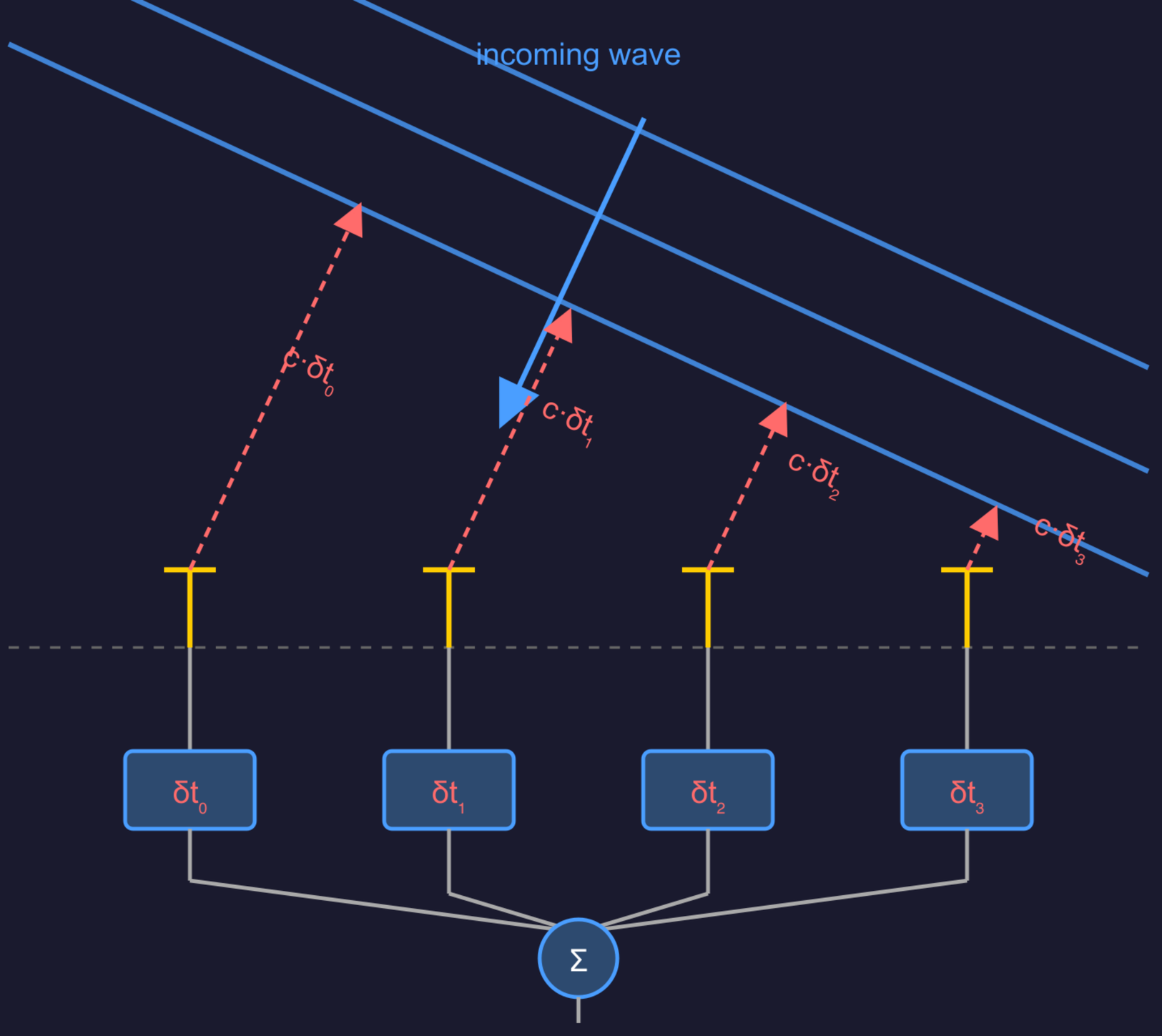
+ sensitivity
+ resolution
- Field of View

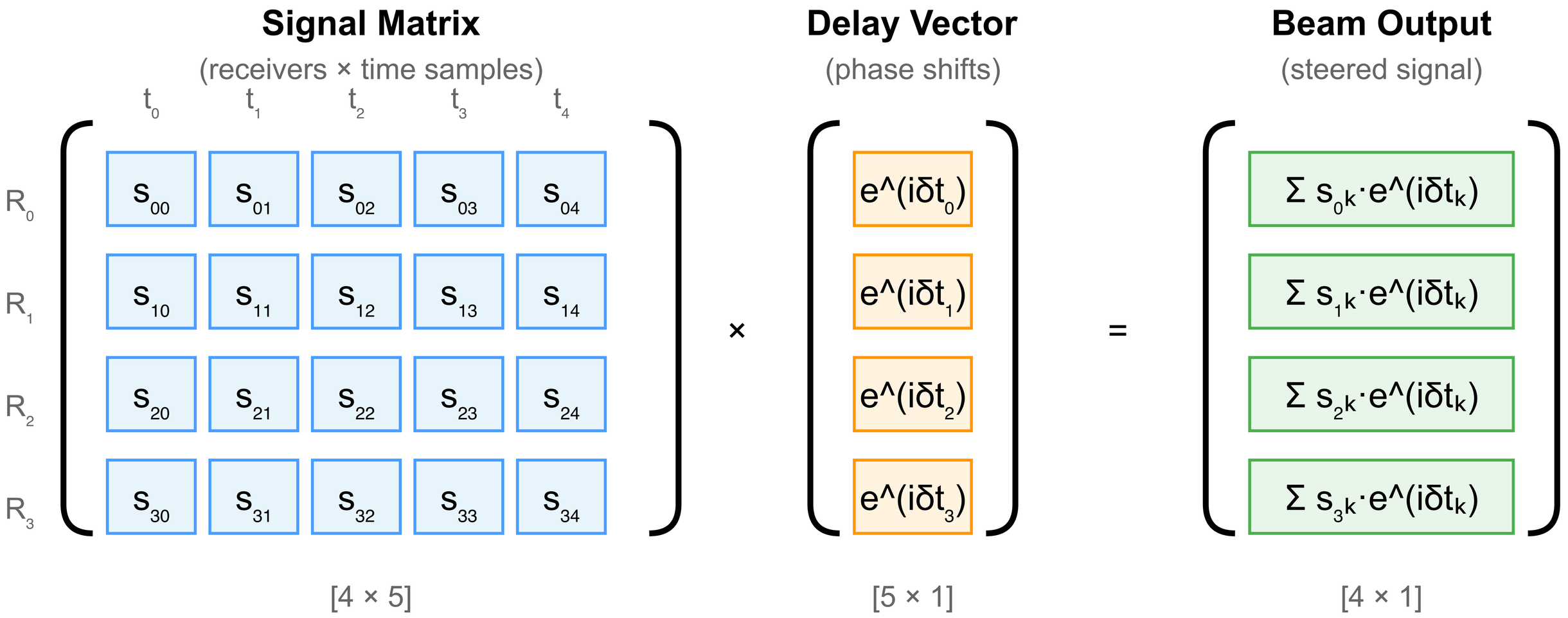


$$FOV \approx \lambda / D$$

λ = wavelength
D = dish diameter

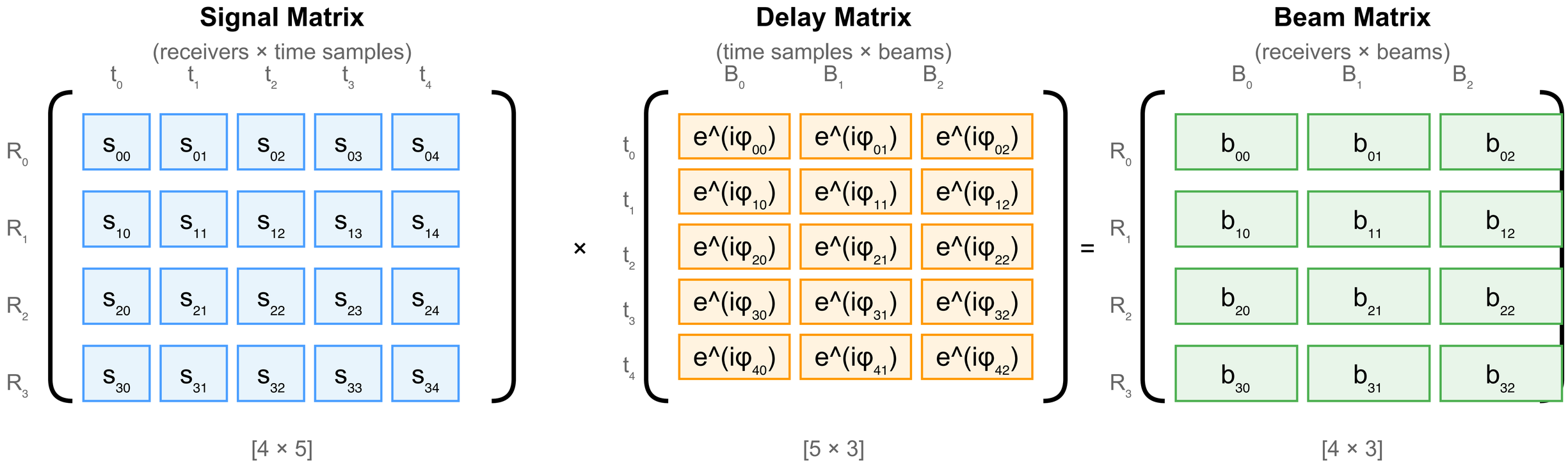

incoming wave
c·δt0
c·δt1
c·δt2
c·δt3
δt0
δt1
δt2
δt3
Σ


incoming wave
c·δt0
c·δt1
c·δt2
c·δt3
δt0
δt1
δt2
δt3
Σ



Beamforming: Apply phase delays to align signals from different receivers

δt_k = geometric delay for receiver k in the desired steering direction

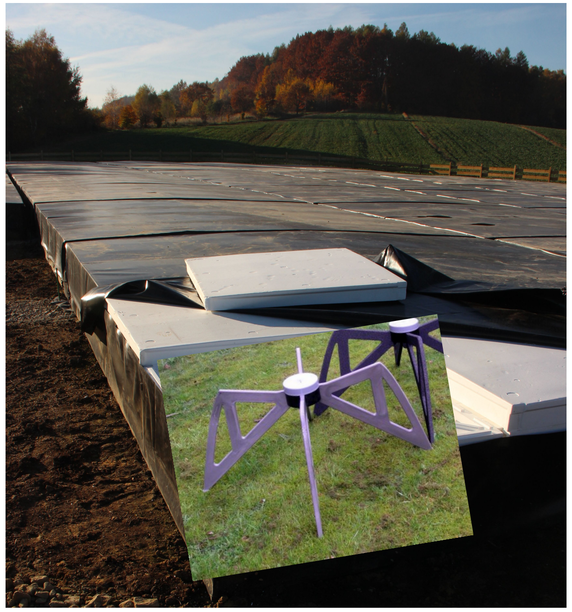


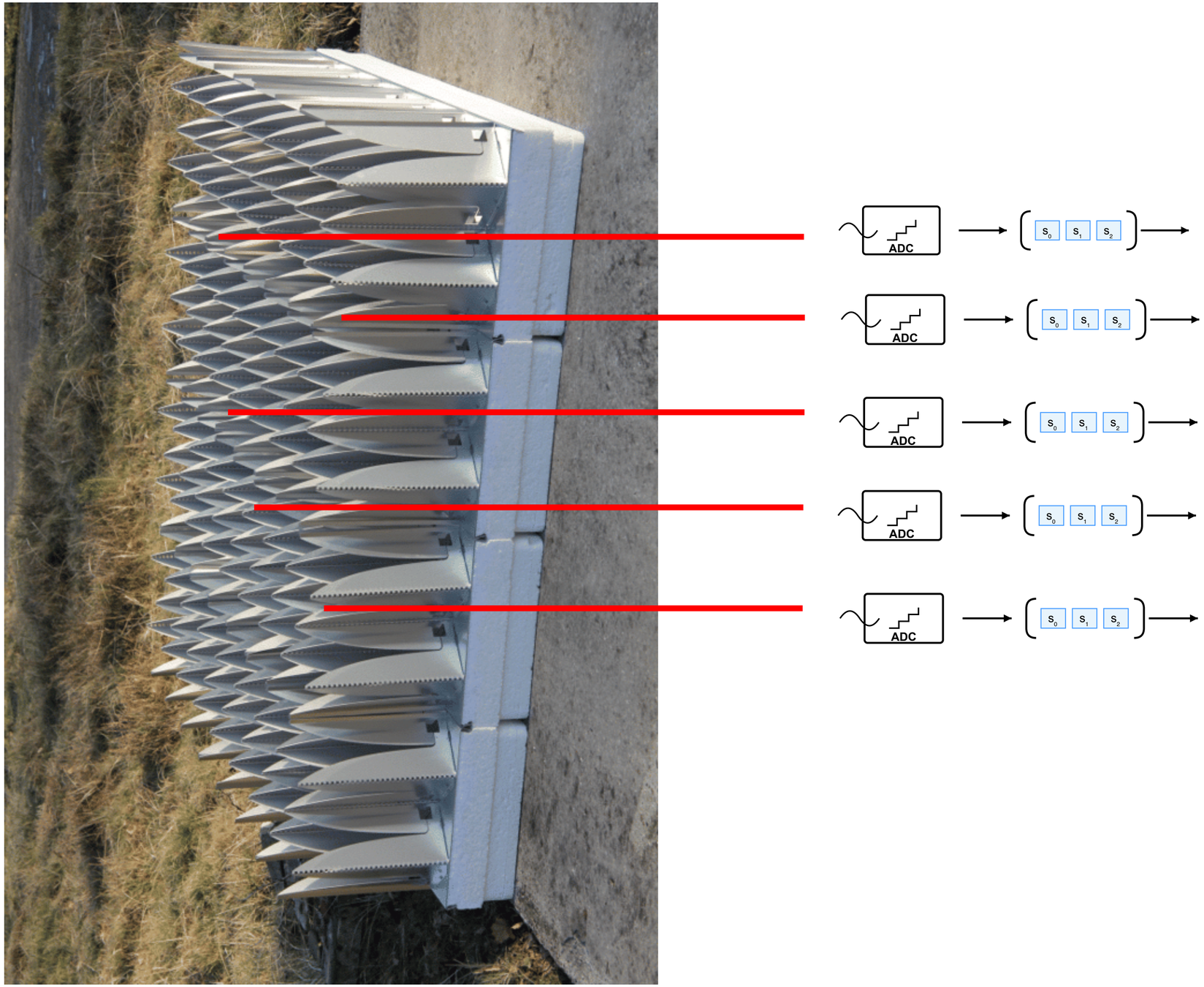
Multi-beam forming: Each column of the delay matrix steers to a different direction

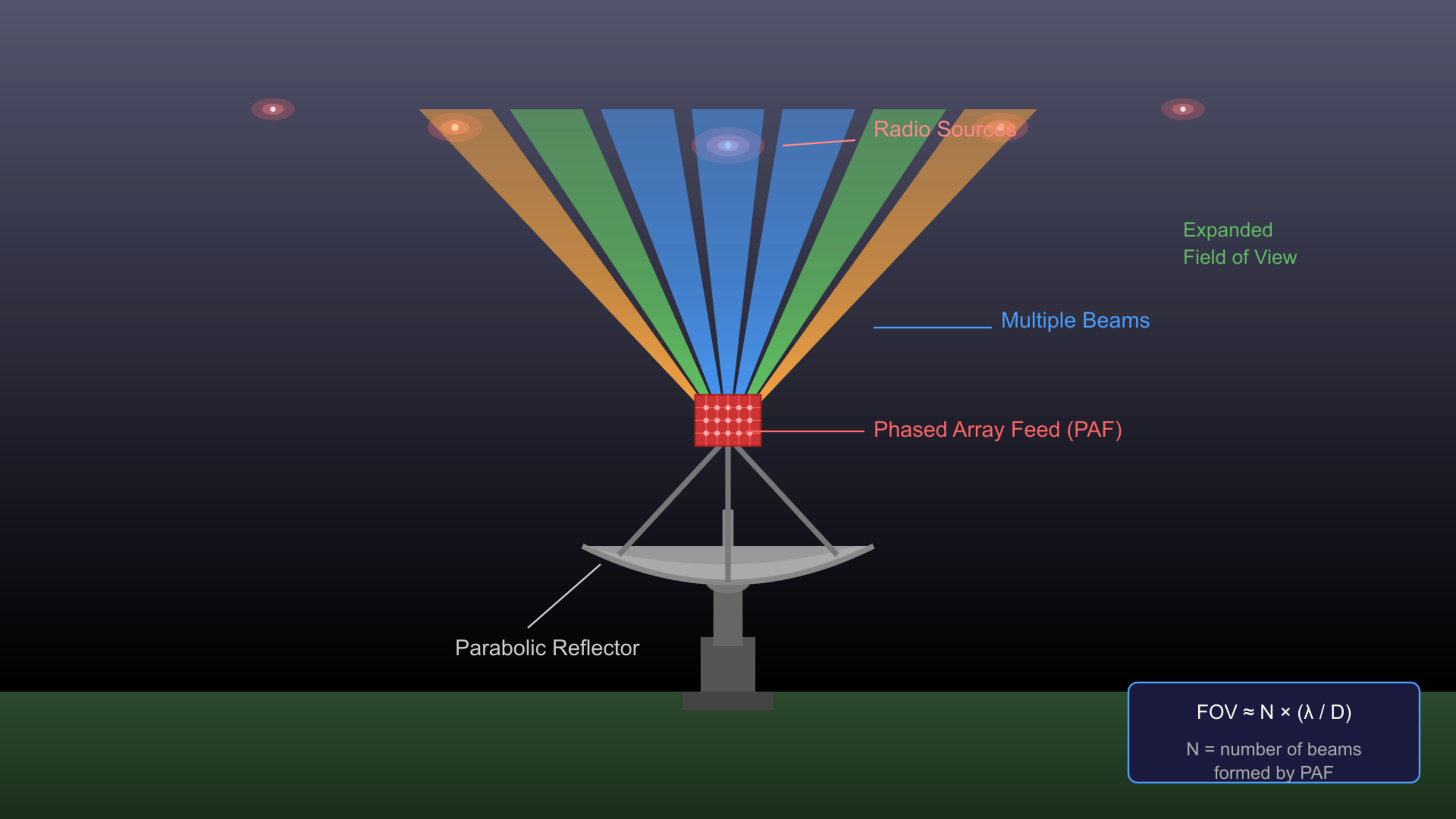
$b_{i\,j} = \Sigma_k\, s_{ik} \cdot e^{(i\varphi_{k\,j})}$ — beam j output for receiver i

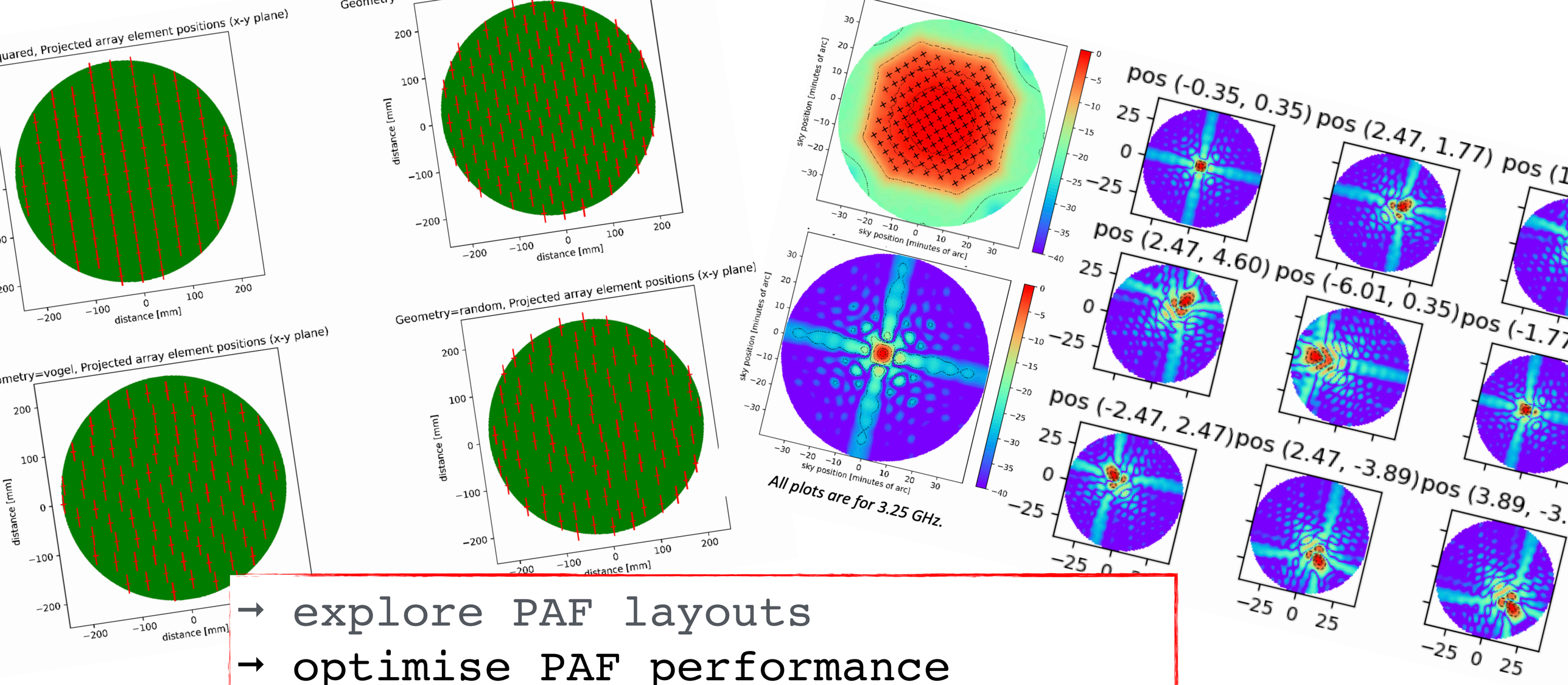
LOFAR

SKA-LOW




ADC
ADC
ADC
ADC
ADC
s_0 s_1 s_2
s_0 s_1 s_2
s_0 s_1 s_2
s_0 s_1 s_2
s_0 s_1 s_2


Radio Sources
Expanded
Field of View
Multiple Beams
Phased Array Feed (PAF)
Parabolic Reflector
FOV ≈ N × (λ / D)
N = number of beams
formed by PAF



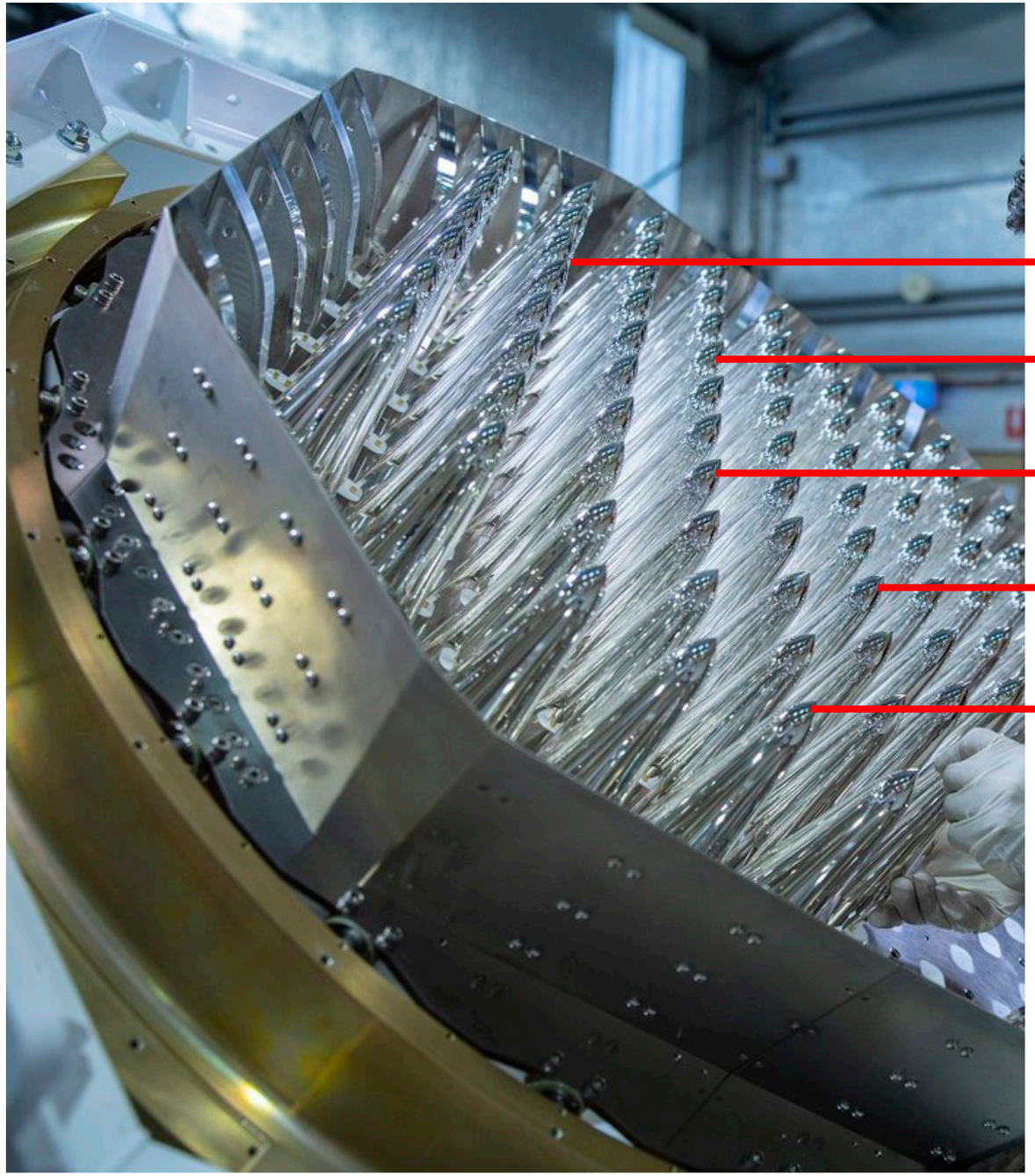
→ explore PAF layouts

→ optimise PAF performance

→ target ≥ 3 GHz (current < 2 GHz)

RADIO BLOCKS

Digital receivers


ADC
s_0 s_1 s_2
ADC
s_0 s_1 s_2
ADC
s_0 s_1 s_2
ADC
s_0 s_1 s_2
ADC
s_0 s_1 s_2

Grant number: 101093934

RADIOBLOCKS goals

- Building blocks suitable for multiple facilities
- Joint effort to solve common problems
- **Enabling new scientific discoveries** in mid- and long-term
  - **Increased sensitivity** ✓
  - **Increased bandwidth** ✓
  - **Increased Field-of-View** ✓
- Keeping EU at the front in radio technology developments

RADIOBLOCKS impact

Focal Plane Arrays require:

- Compactness ⇒ Better integration OMTs, mixers, LNAs
- Easier and faster manufacturing
- DC power (less dissipation ⇒ Lower load for cryogenic cooler)
- uW power (higher LO power needed to feed all pixels)

Larger bandwidth & **Arrays**

- Generate larger volumes of data

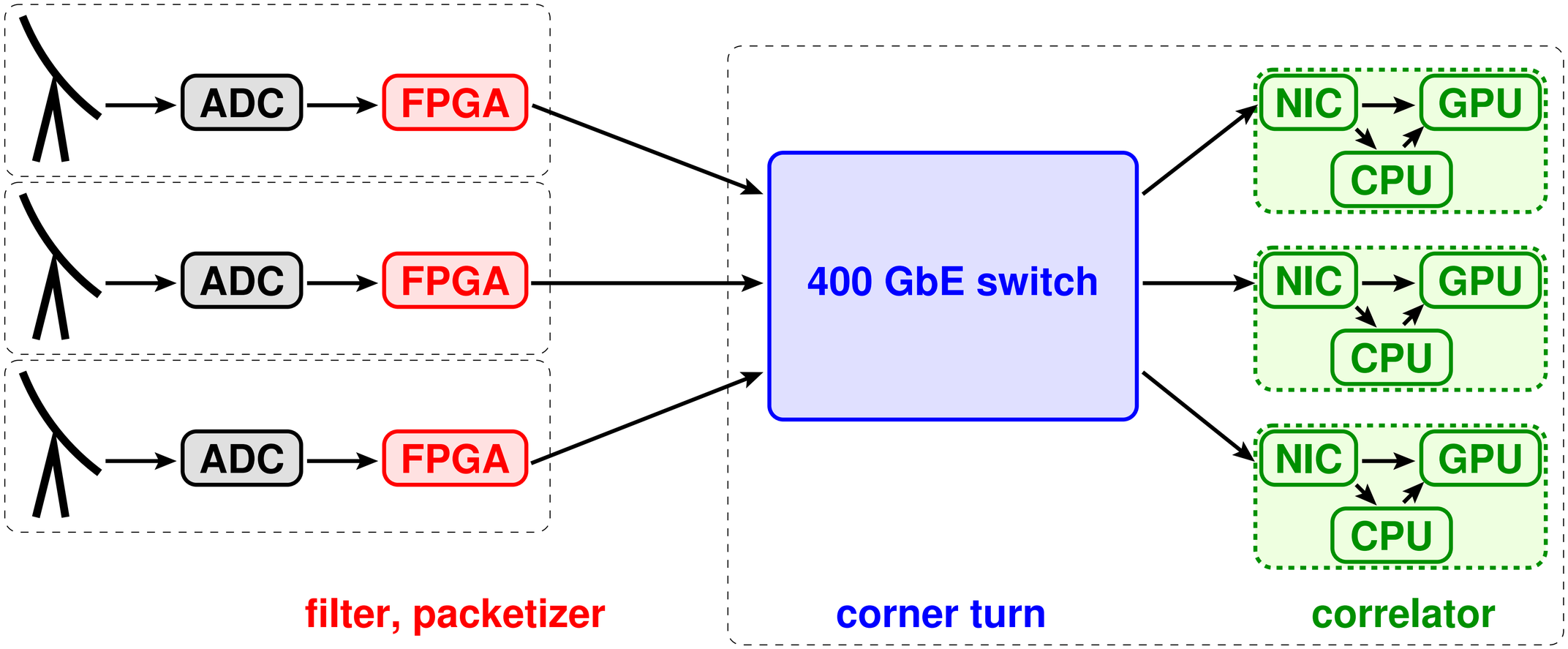
Digitization starting closer to frontend

- Phased Array Feeds.
- Data filtering & no frequency dependent power loss for downconverted signals

Grant number: 101093934

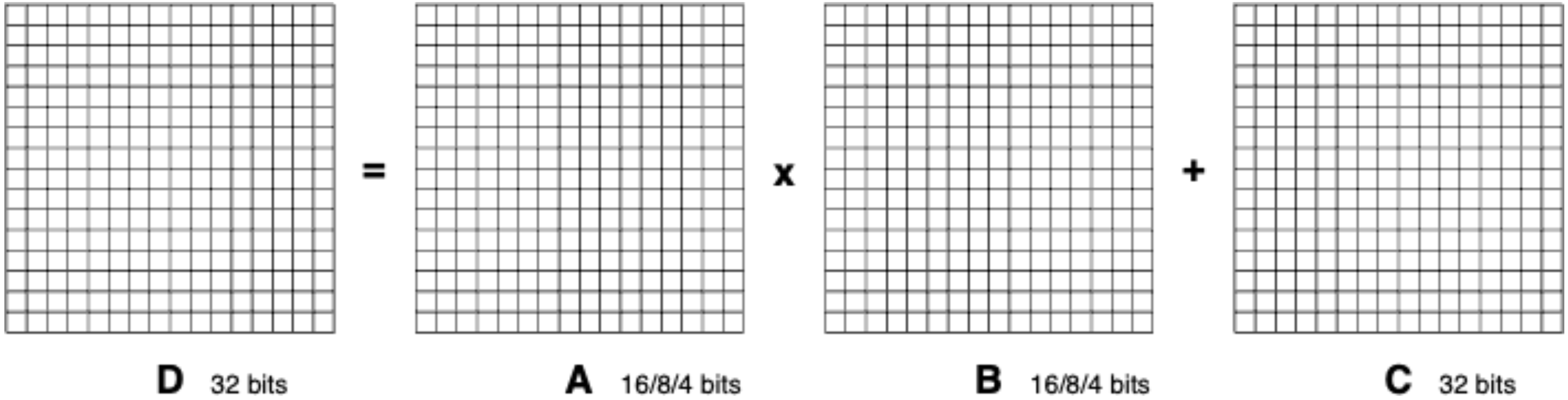
RADIOBLOCKS goals

- Building blocks suitable for multiple facilities
- Joint effort to solve common problems
- **Enabling new scientific discoveries**
  - **Increased sensitivity** ✓
  - **Increased bandwidth** ✓
  - **Increased Field-of-View** ✓
- Keeping EU at the front in radio technology developments

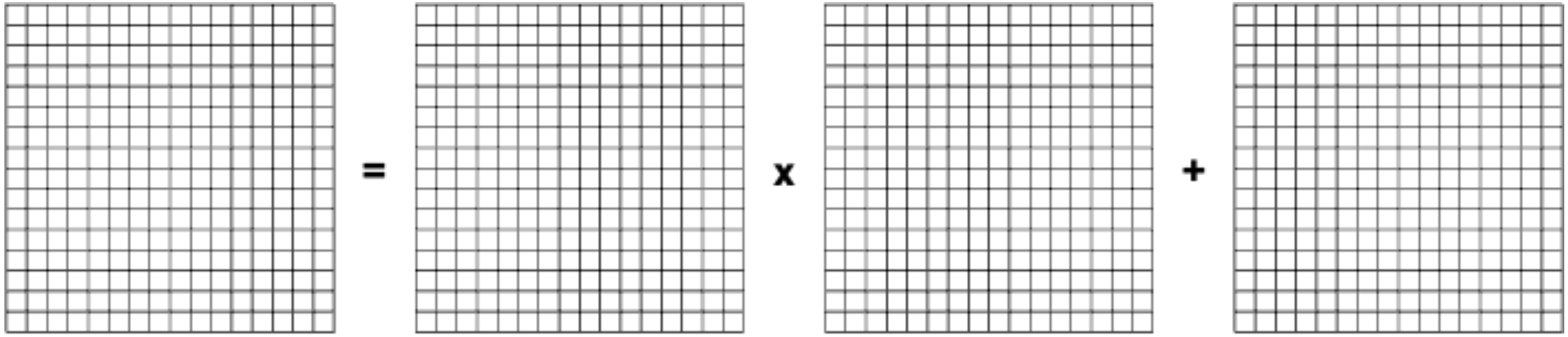

ADC
FPGA
ADC
FPGA
ADC
FPGA
400 GbE switch
NIC
GPU
CPU
NIC
GPU
CPU
NIC
GPU
CPU
filter, packetizer
corner turn
correlator

GPU Tensor Cores!

- hardware matrix-multiplication units
  - limited precision input data
  - ~10x faster than regular GPU cores
- accelerate training and inference
- only in recent GPUs



perform a [16 x 16] * [16 x 16] *in one go*



Signal Matrix

(receivers × time samples)

	t_0	t_1	t_2	t_3	t_4
R_0	s_{00}	s_{01}	s_{02}	s_{03}	s_{04}
R_1	s_{10}	s_{11}	s_{12}	s_{13}	s_{14}
R_2	s_{20}	s_{21}	s_{22}	s_{23}	s_{24}
R_3	s_{30}	s_{31}	s_{32}	s_{33}	s_{34}

×

Delay Matrix

(time samples × beams)

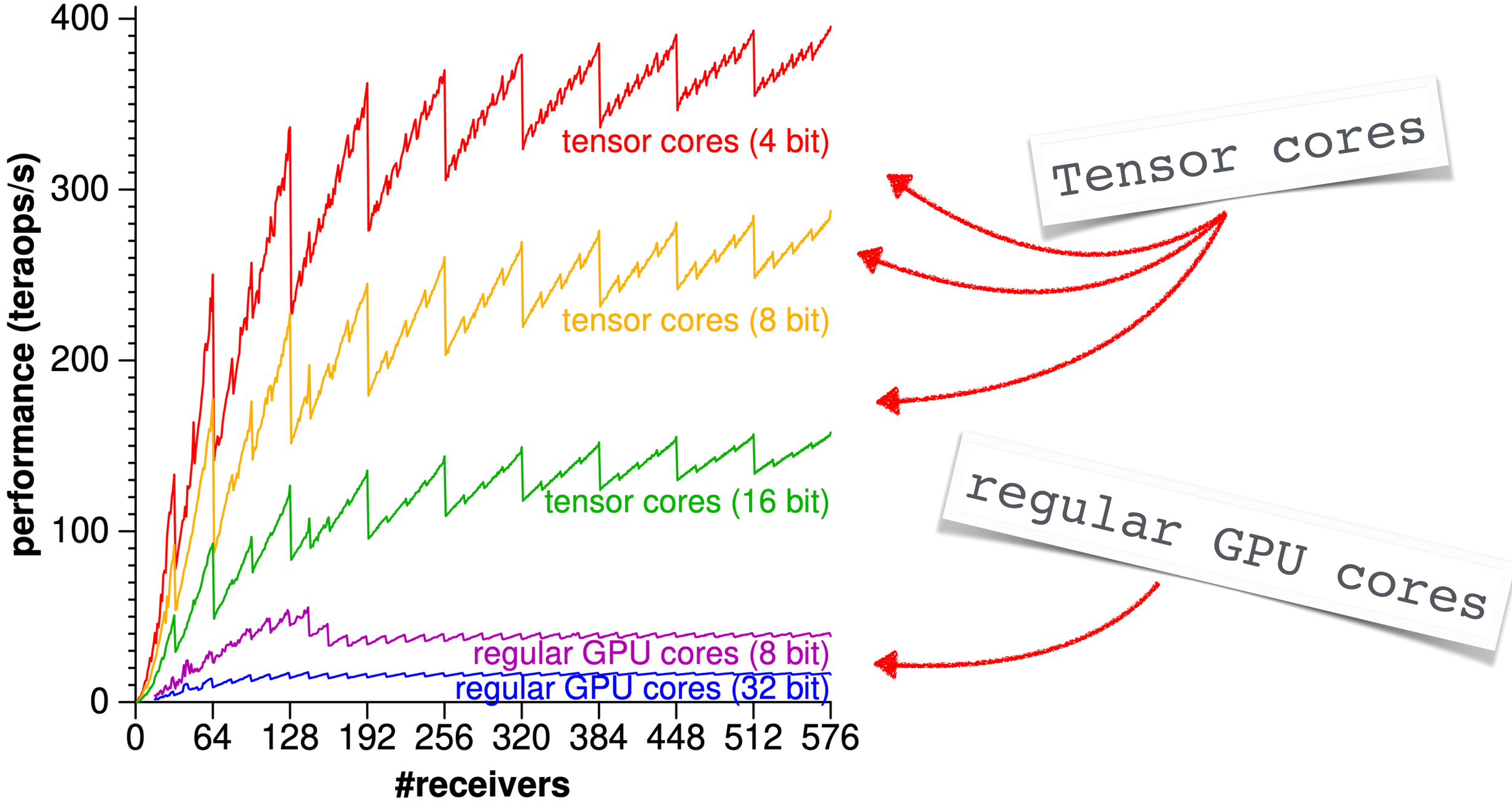
	B_0	B_1	B_2
t_0	$e^{(i\varphi_{00})}$	$e^{(i\varphi_{01})}$	$e^{(i\varphi_{02})}$
t_1	$e^{(i\varphi_{10})}$	$e^{(i\varphi_{11})}$	$e^{(i\varphi_{12})}$
t_2	$e^{(i\varphi_{20})}$	$e^{(i\varphi_{21})}$	$e^{(i\varphi_{22})}$
t_3	$e^{(i\varphi_{30})}$	$e^{(i\varphi_{31})}$	$e^{(i\varphi_{32})}$
t_4	$e^{(i\varphi_{40})}$	$e^{(i\varphi_{41})}$	$e^{(i\varphi_{42})}$

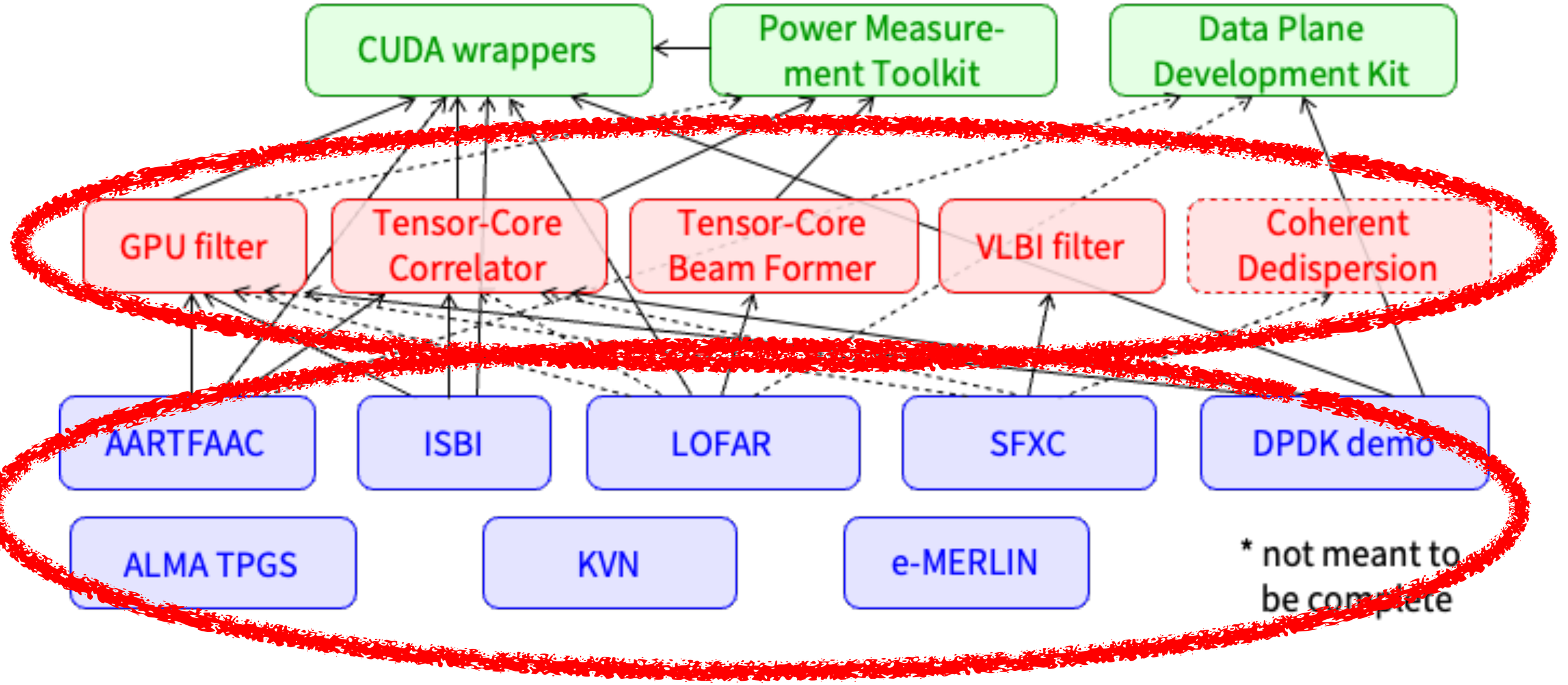
=

Beam Matrix

(receivers × beams)

	B_0	B_1	B_2
R_0	b_{00}	b_{01}	b_{02}
R_1	b_{10}	b_{11}	b_{12}
R_2	b_{20}	b_{21}	b_{22}
R_3	b_{30}	b_{31}	b_{32}


400
300
200
100
0
performance (teraops/s)
0
64
128
192
256
320
384
448
512
576
#receivers
tensor cores (4 bit)
tensor cores (8 bit)
tensor cores (16 bit)
regular GPU cores (8 bit)
regular GPU cores (32 bit)
Tensor cores
regular GPU cores



RADIO BLOCKS

Data transport and correlation

Tensor Core Correlator

Tensor Core Correlator

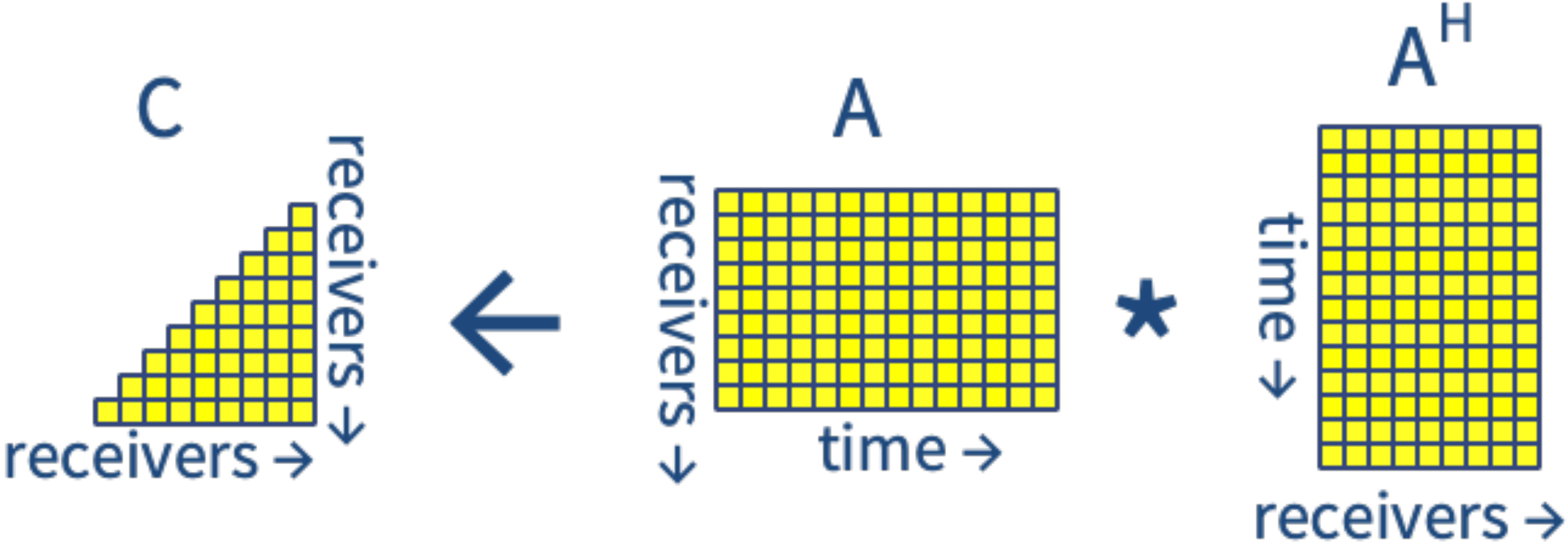
- combines receiver data
- computational ***and*** I/O challenge
- real-time
  - for some instruments *required*
  - others benefit from increased speed/efficiency

Tensor Core Correlator

$$C \leftarrow A * A^{H}$$

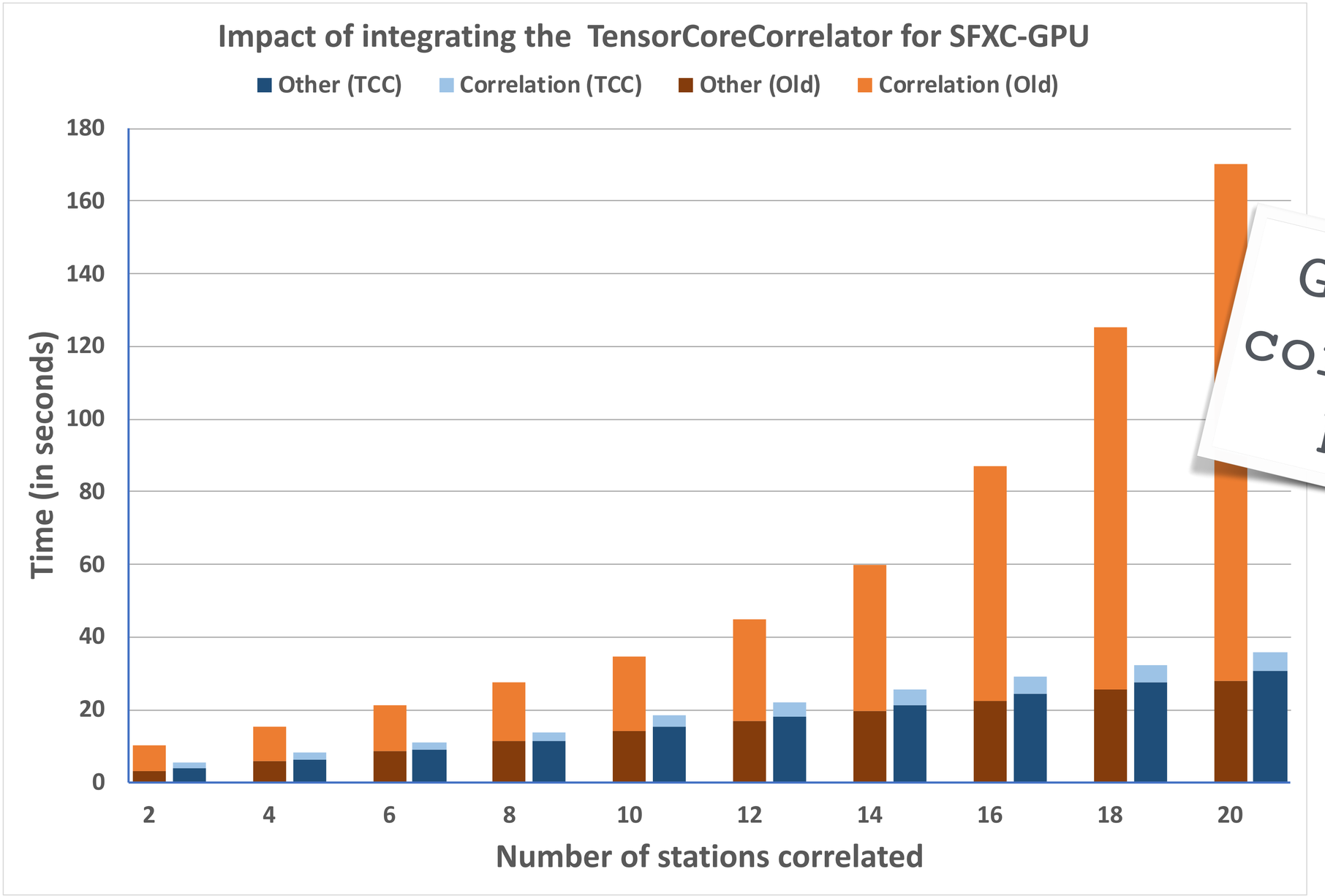
Tensor Core Correlator

$$C \leftarrow A * A^H$$



RADIO BLOCKS

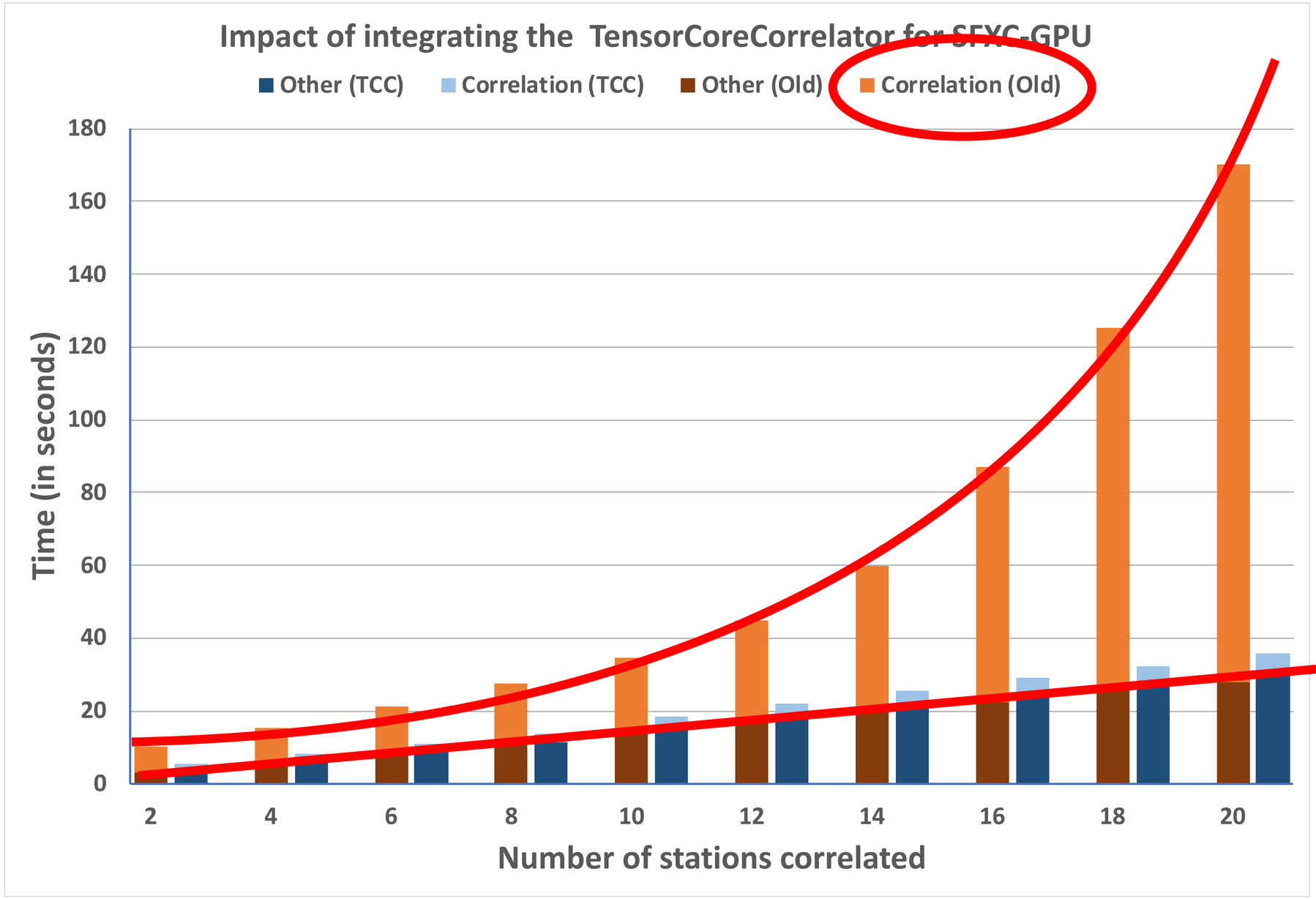
Data transport and correlation



GPU VLBI correlator block

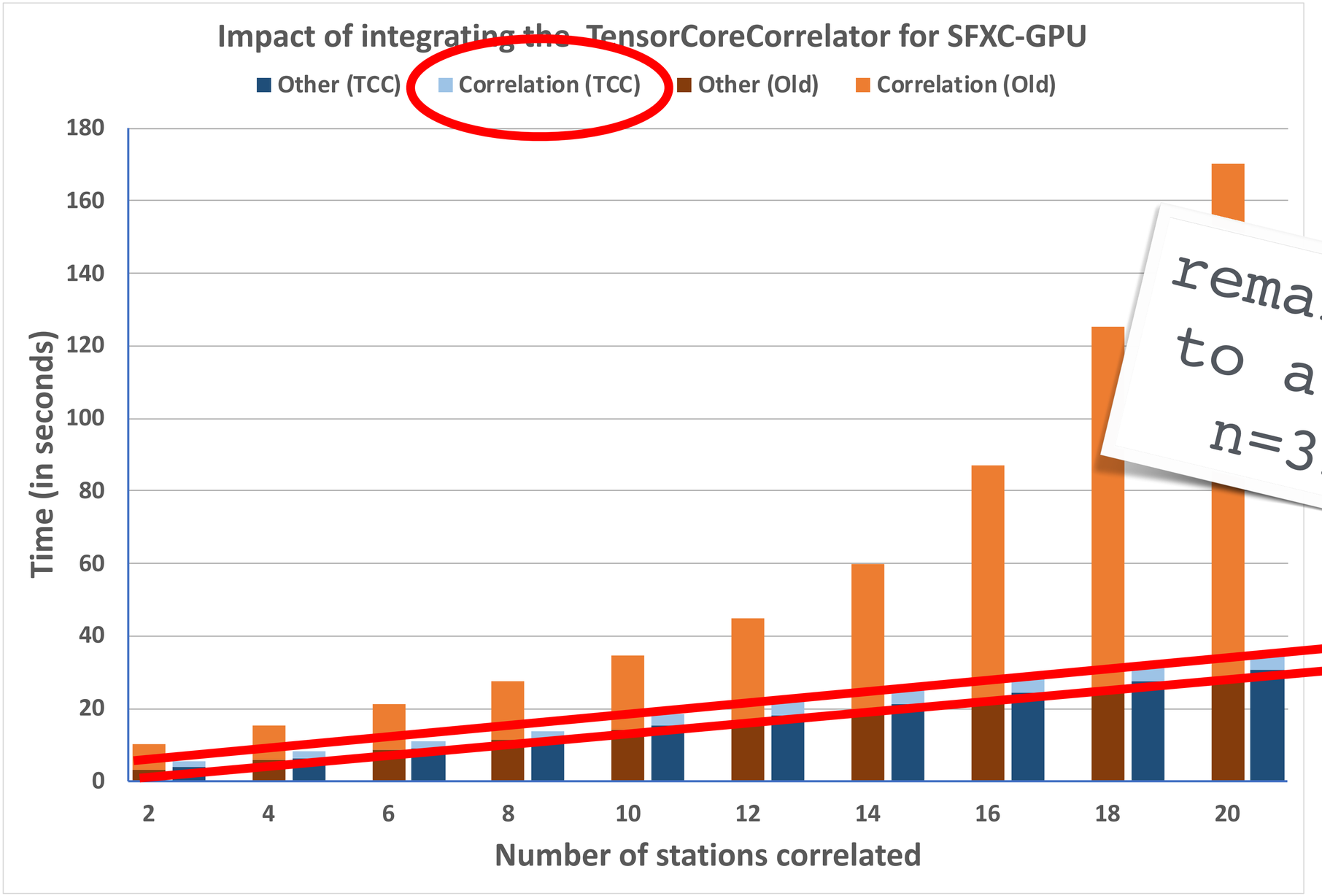
RADIO BLOCKS

Data transport and correlation



RADIO BLOCKS

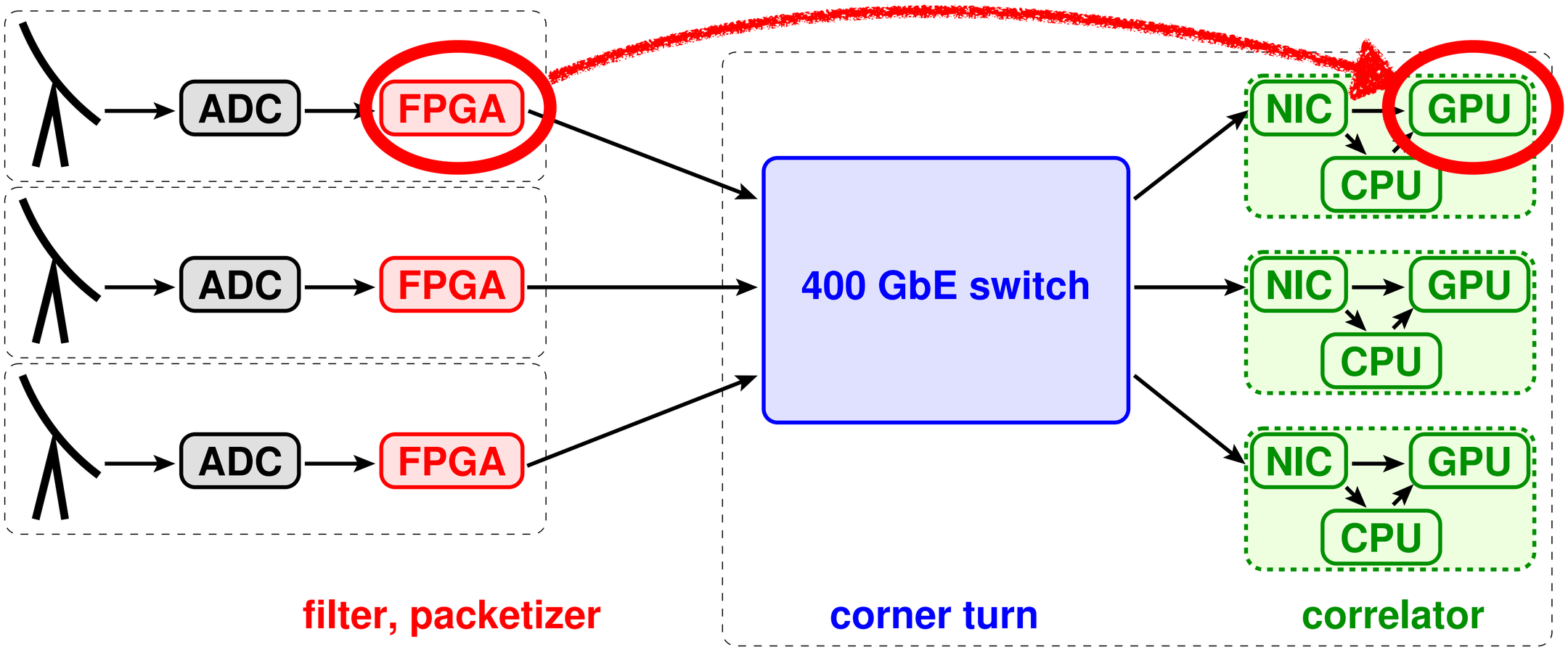
Data transport and correlation

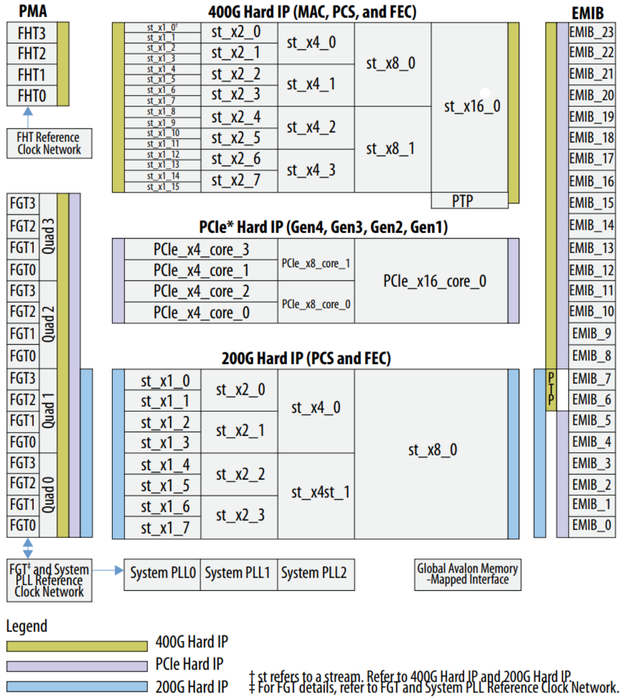


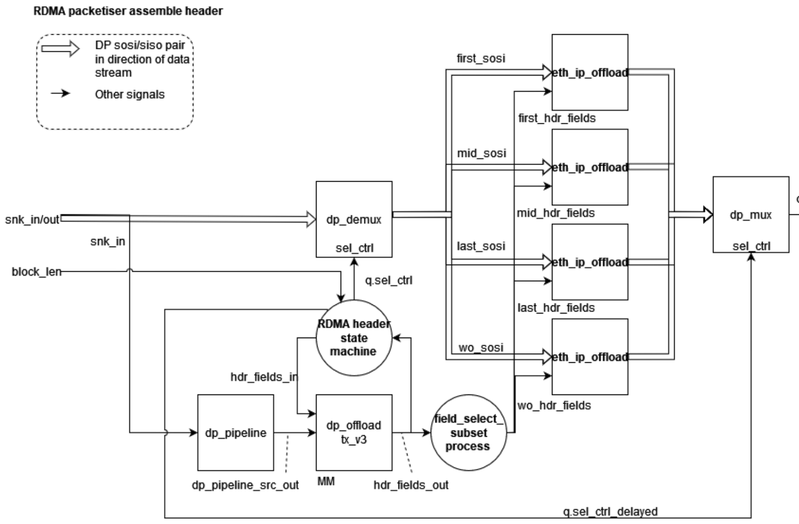
remains flat to at least n=32 ...

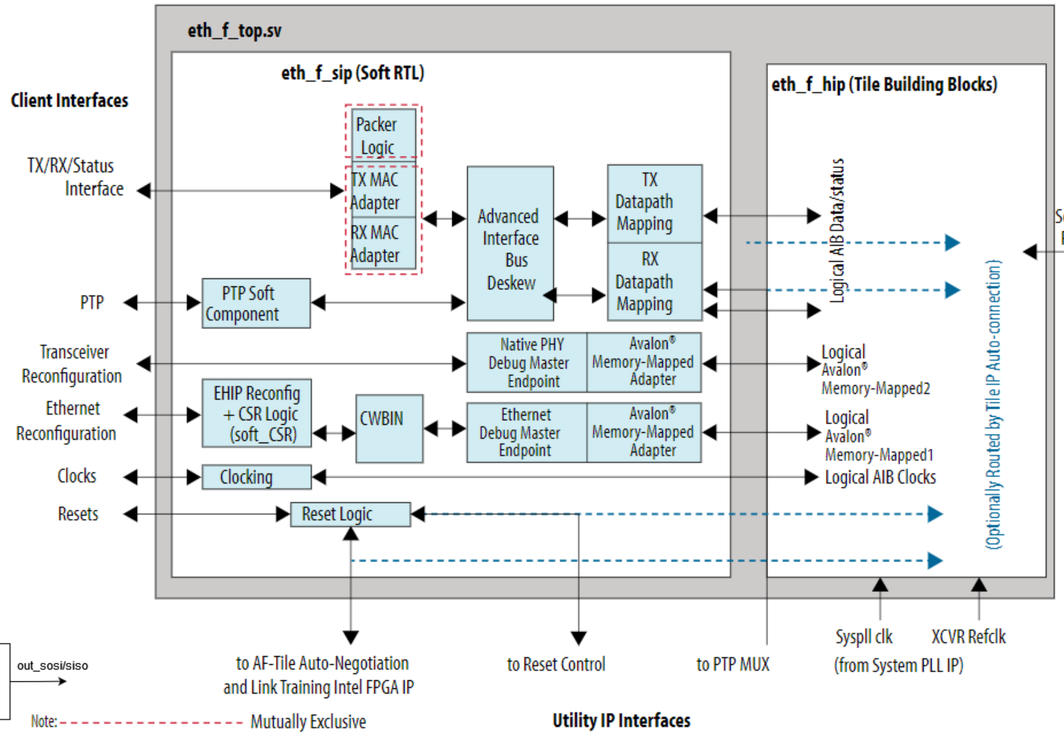
RADIO BLOCKS

Data transport and correlation


ADC
FPGA
ADC
FPGA
ADC
FPGA
400 GbE switch
NIC
GPU
CPU
NIC
GPU
CPU
NIC
GPU
CPU
filter, packetizer
corner turn
correlator





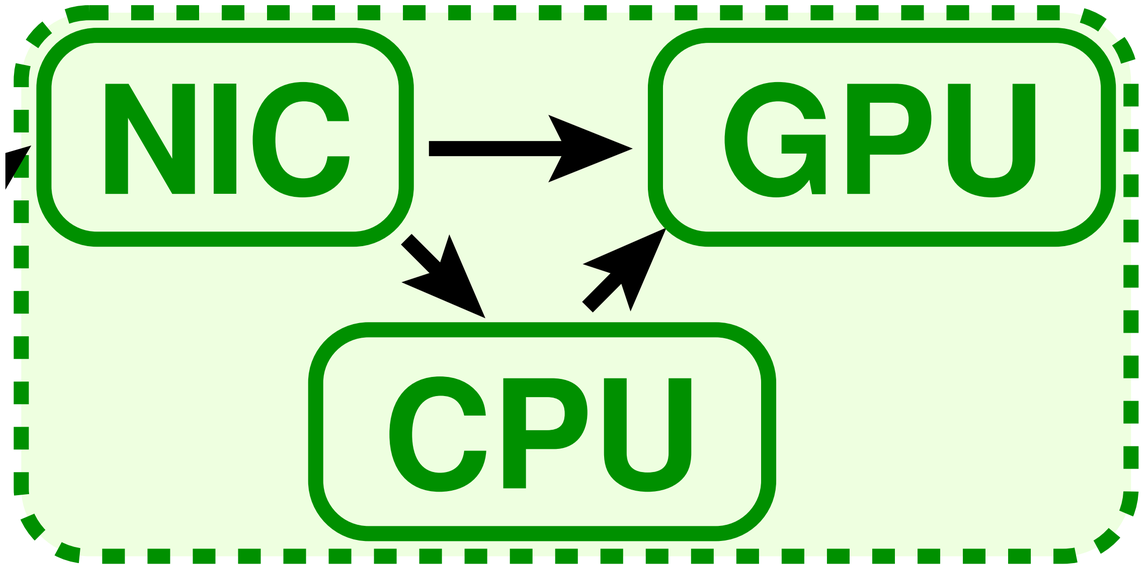


FPGA 200/400 Gbps RDMA implementation

RADIO BLOCKS

Data transport and correlation

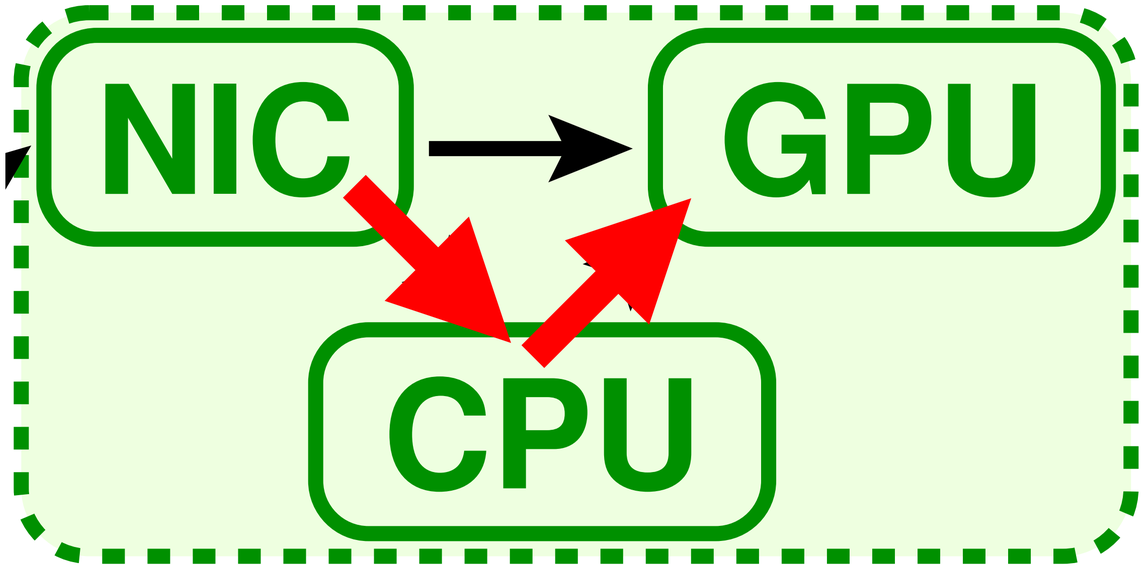
Data Plane Development Kit

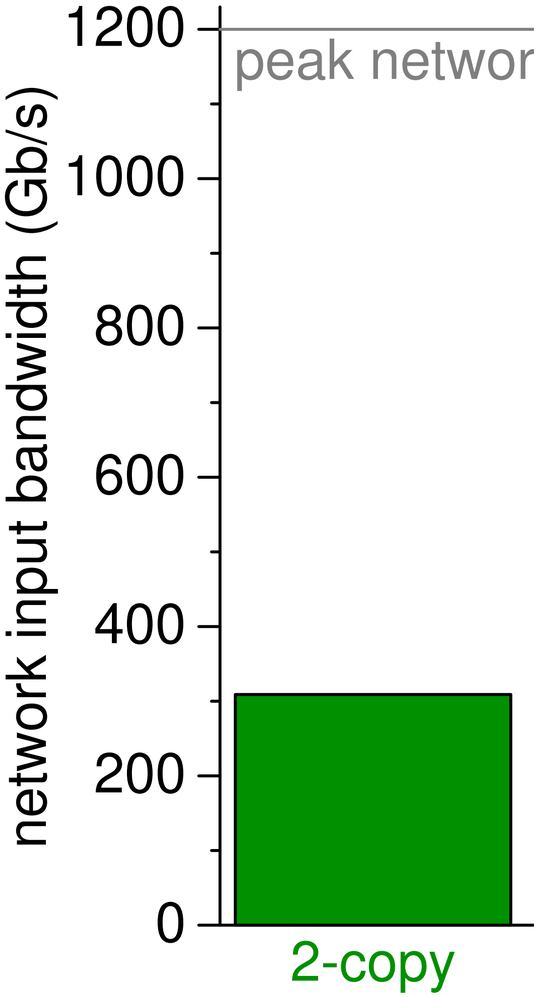


RADIO BLOCKS

Data transport and correlation

DPDK / 2-copy approach



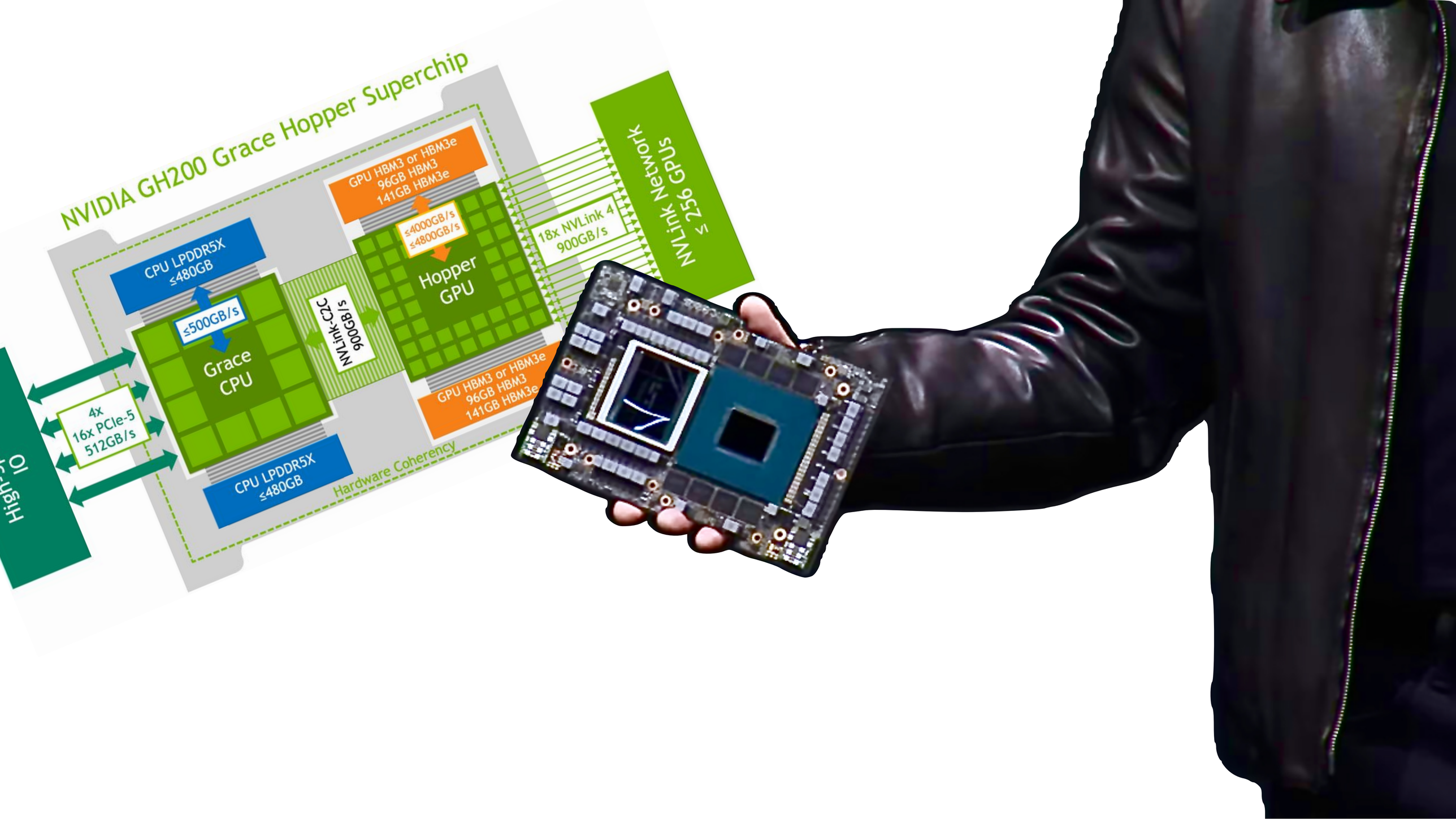


DPDK → RAM

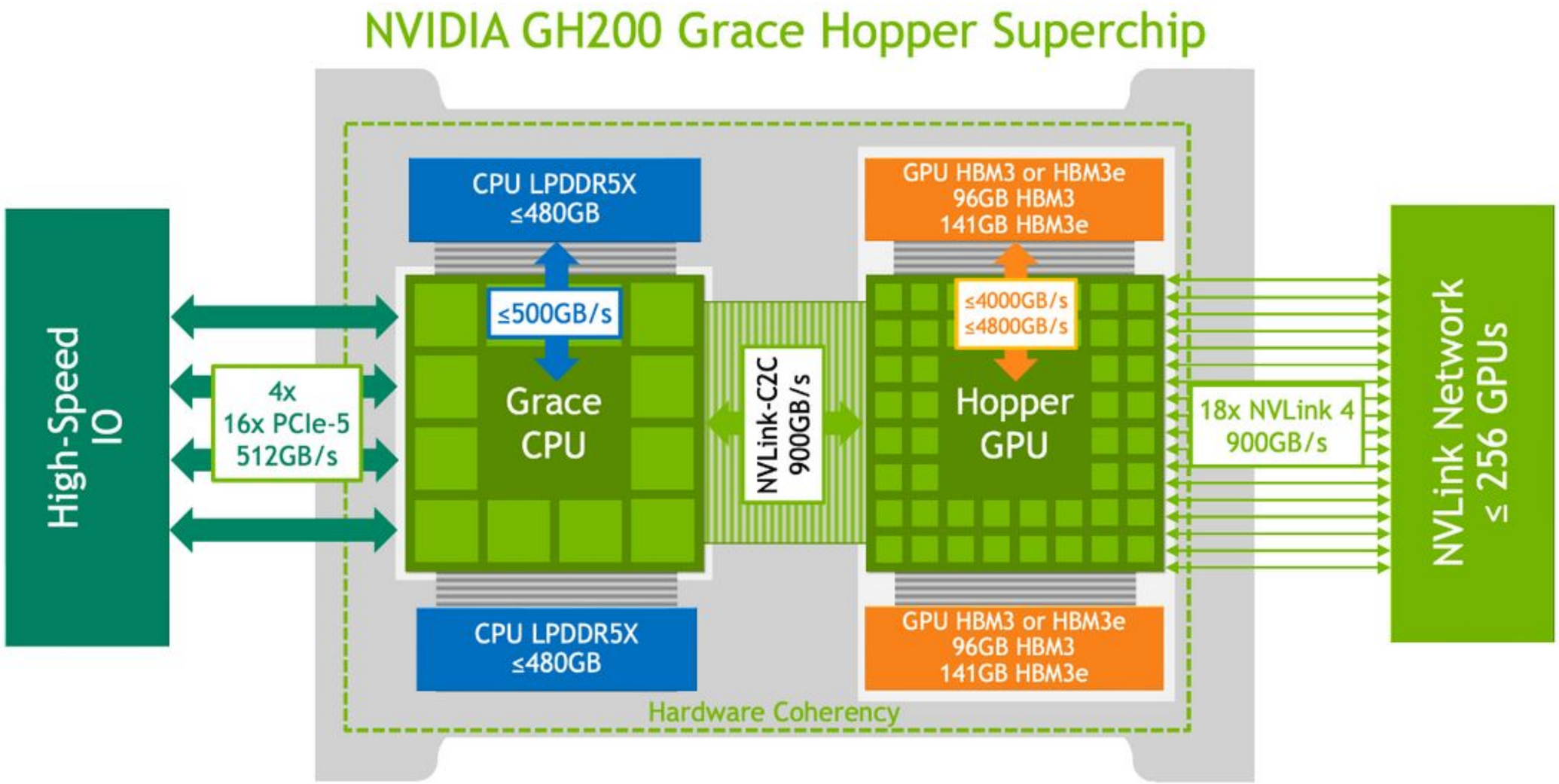
RAM → GPU

RADIO BLOCKS

Data transport and correlation


NVIDIA GH200 Grace Hopper Superchip
CPU LPDDR5X
≤480GB
≤500GB/s
Grace
CPU
NVLink-C2C
900GB/s
GPU HBM3 or HBM3e
96GB HBM3
141GB HBM3e
≤4000GB/s
≤4800GB/s
Hopper
GPU
18x NVLink 4
900GB/s
NVLink Network
≤ 256 GPUs
4x
16x PCIe-5
512GB/s
High-I
IO
CPU LPDDR5X
≤480GB
GPU HBM3 or HBM3e
96GB HBM3
141GB HBM3e
Hardware Coherency

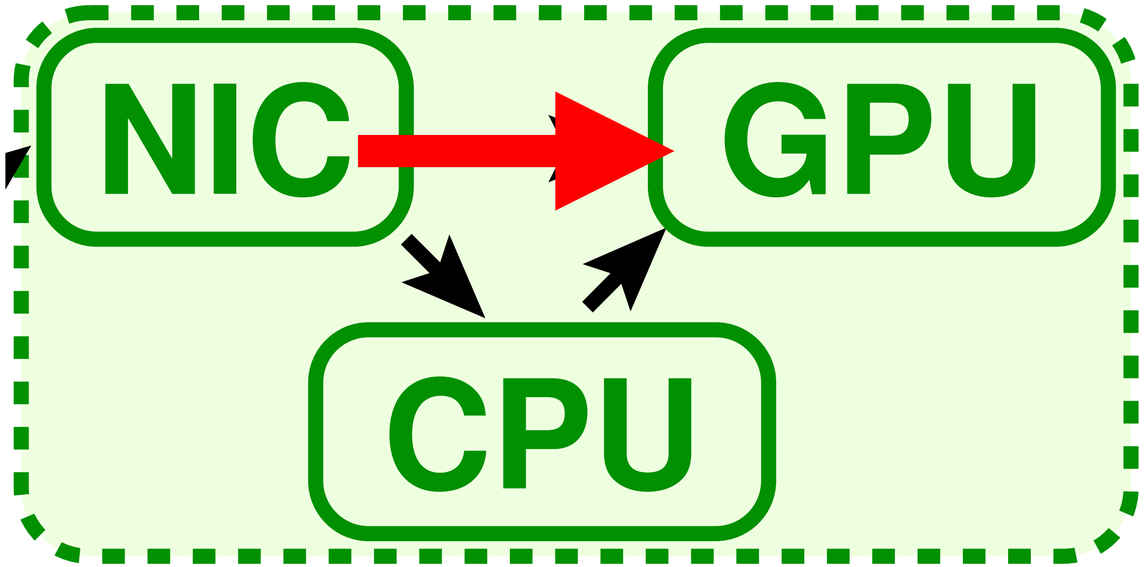
GH200 fast CPU/GPU shared memory

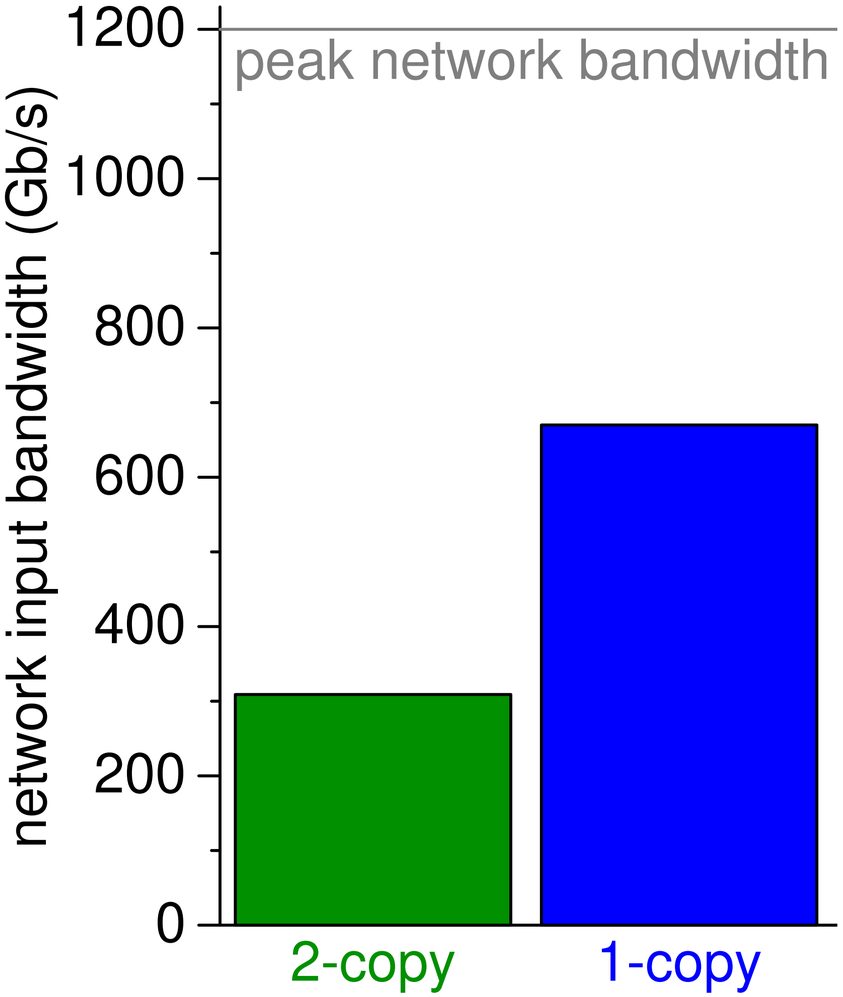


RADIO BLOCKS

Data transport and correlation

DPDK / 1-copy approach





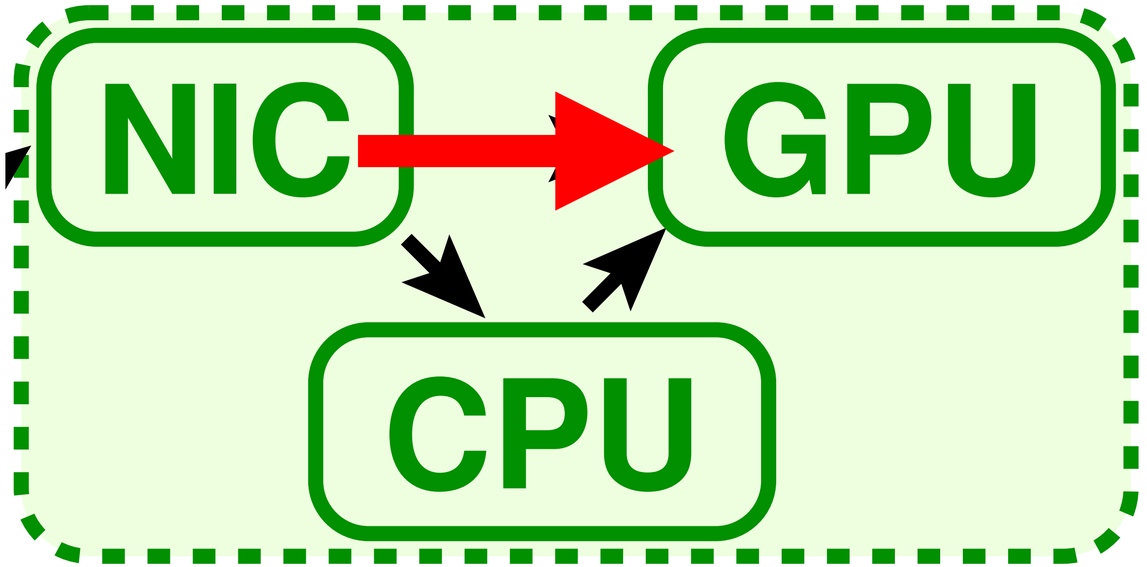
DPDK → GPU

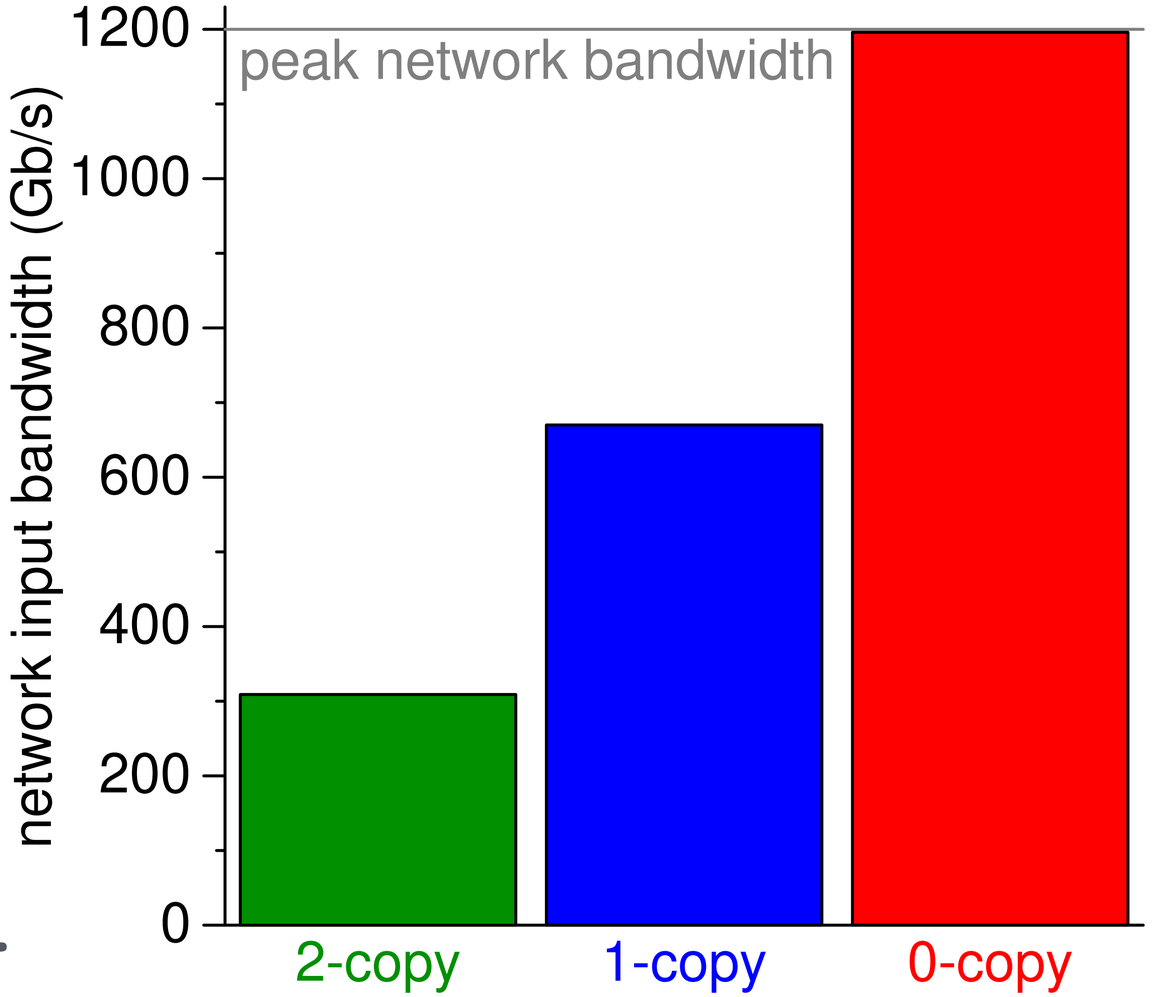
(DPDK ringbuffer in GPU mem)

RADIO BLOCKS

Data transport and correlation

DPDK / 0-copy approach



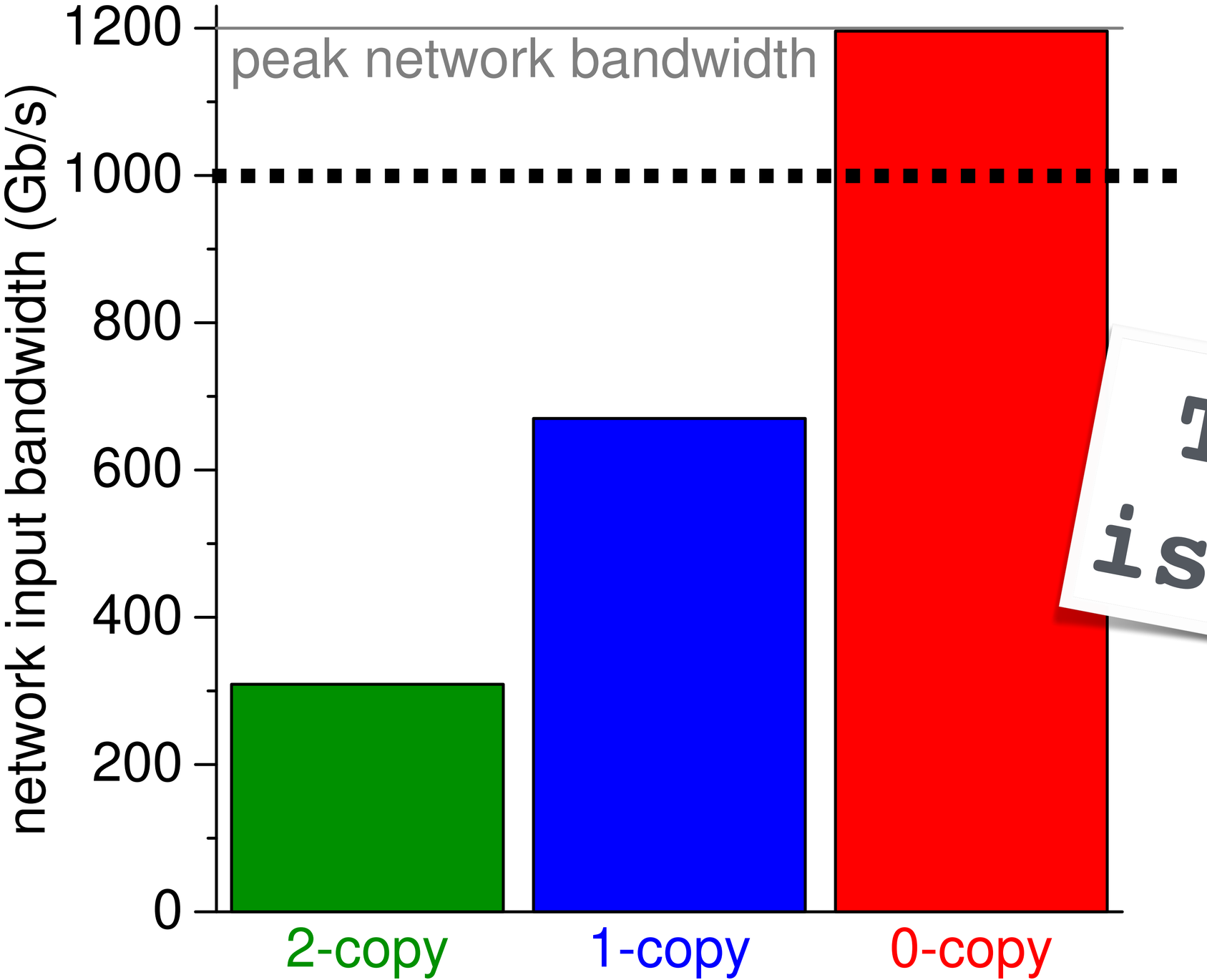


DPDK w/ GPUdev

(DPDK packetbuffer in GPU mem)

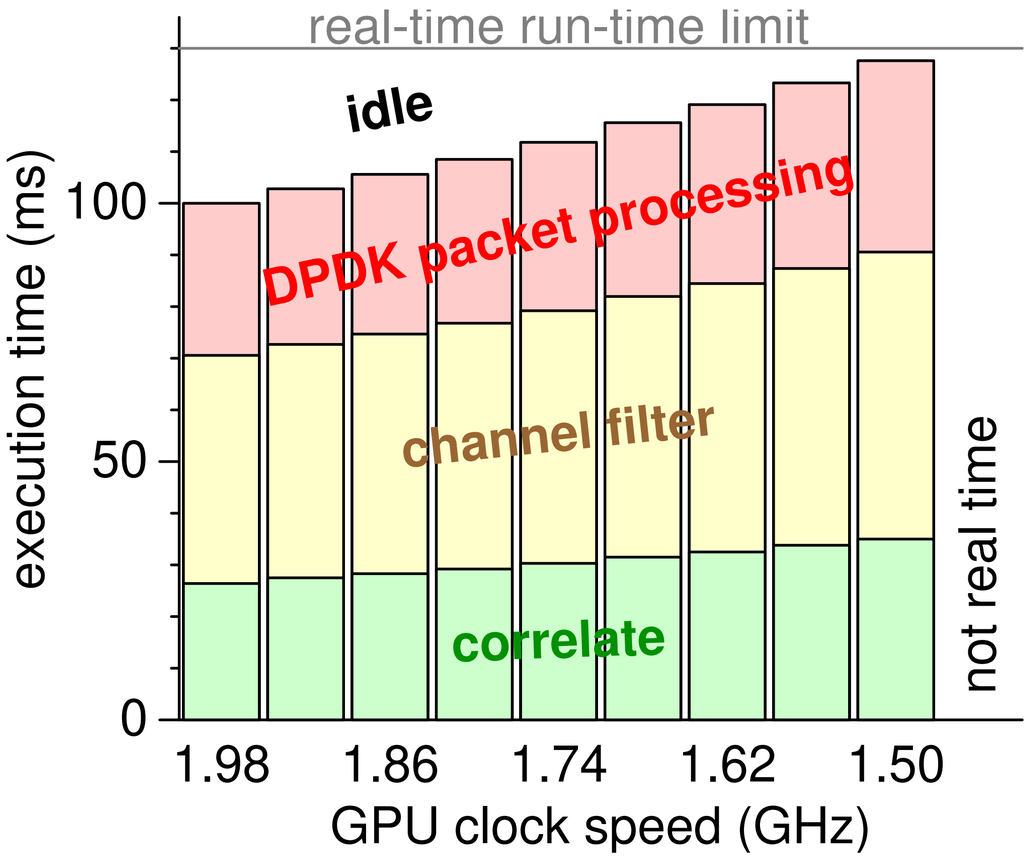
RADIO BLOCKS

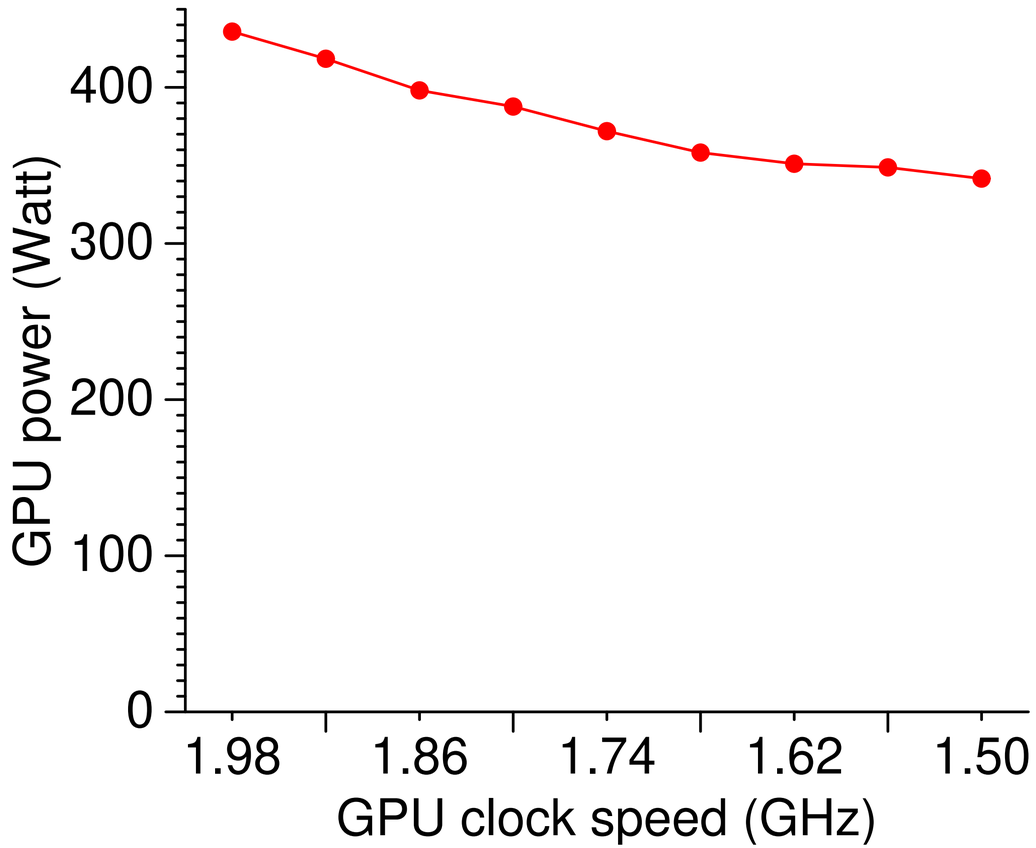
Data transport and correlation



That ...
is 1 Tbps!

Energy efficiency?

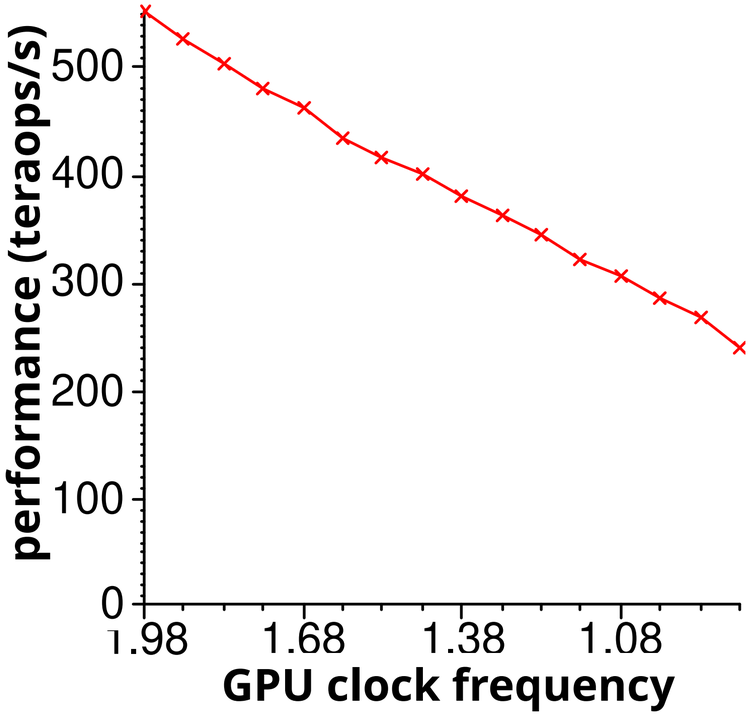


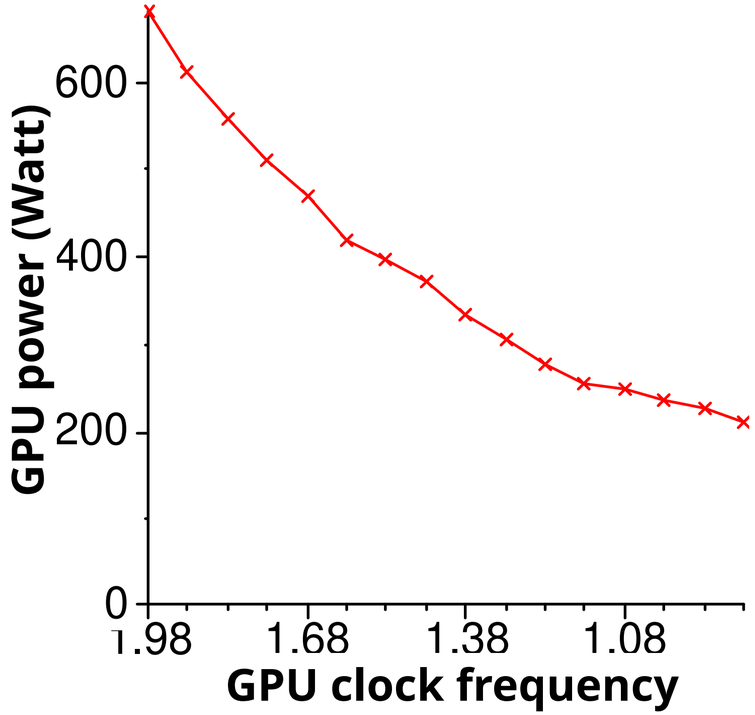


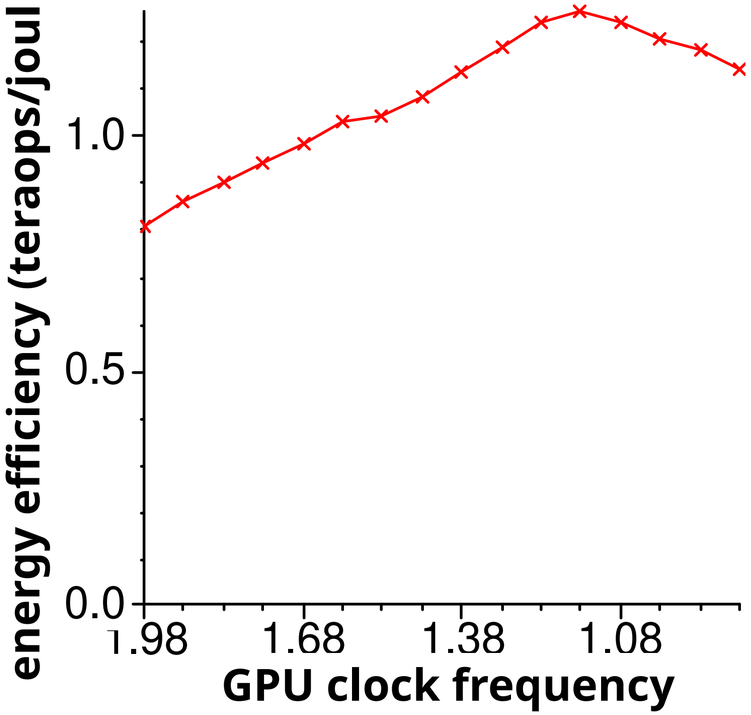
RADIO BLOCKS

Data transport and correlation

Energy efficiency?







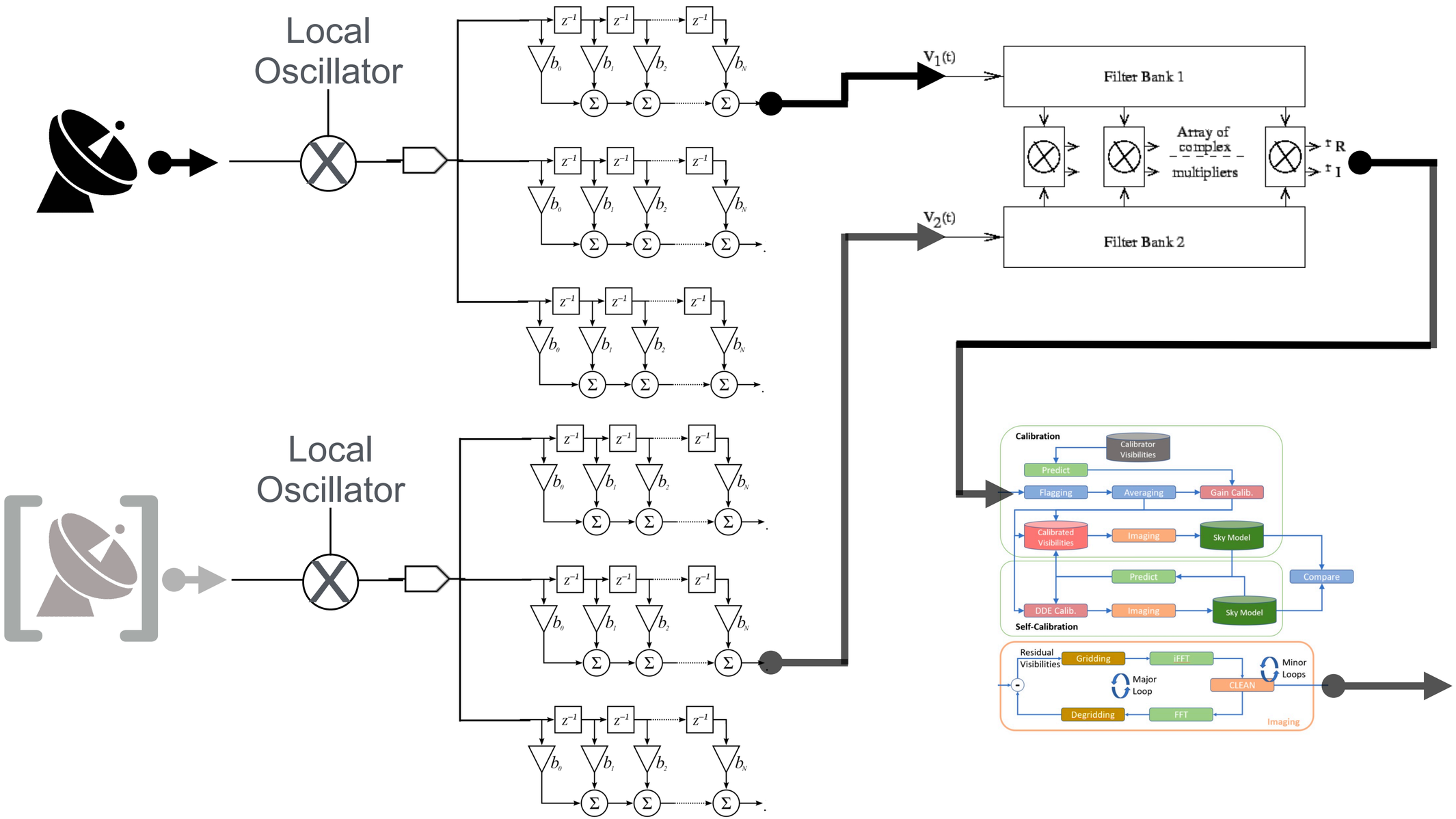
RADIO BLOCKS

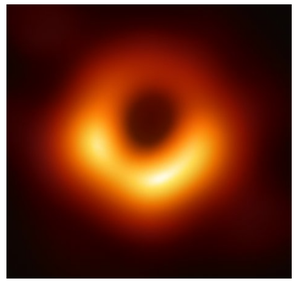
Data transport and correlation

Grant number: 101093934

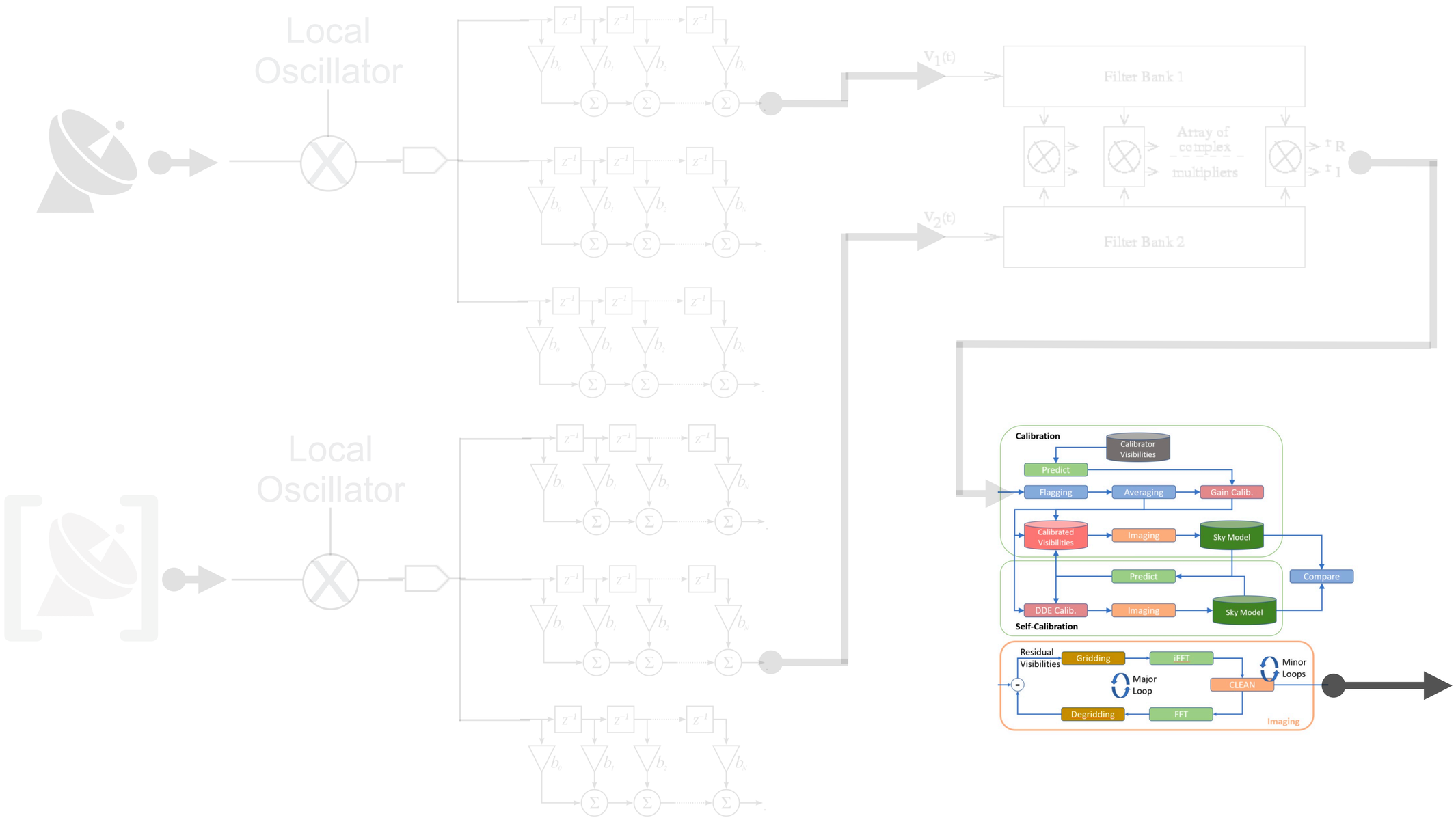
RADIOBLOCKS goals

- Building blocks suitable for multiple facilities
- Joint effort to solve common problems
- **Enabling new scientific discoveries** in mid- and long-term
  - **Increased sensitivity** ✓
  - **Increased bandwidth** ✓
  - **Increased Field-of-View** ✓
  - `Increased DATA PROCESSING!` ✓
- Keeping EU at the front in radio technology developments





Supporting the next-generation of VLBI


Local Oscillator
Local Oscillator
$V_1(t)$
$V_2(t)$
Filter Bank 1
Filter Bank 2
Array of complex multipliers
^{r}R
^{r}I
Calibration
Calibrator Visibilities
Predict
Flagging
Averaging
Gain Calib.
Calibrated Visibilities
Imaging
Sky Model
Predict
Compare
DDE Calib.
Imaging
Sky Model
Self-Calibration
Residual Visibilities
Gridding
iFFT
Minor Loops
Major Loop
CLEAN
Degridding
FFT
Imaging

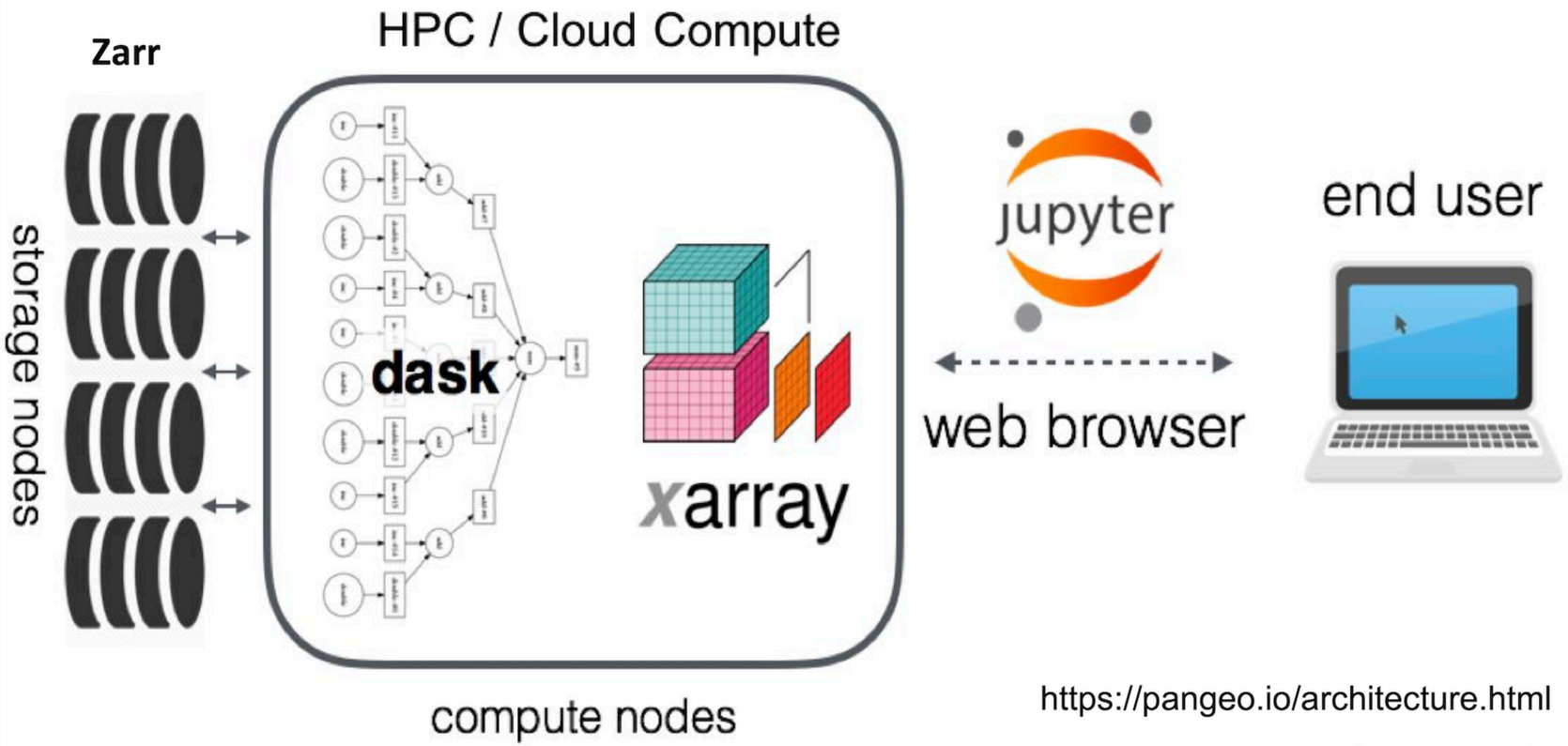
Data processing tool kit

Modular, open-source and flexible components to process interferometry data

More instrument output

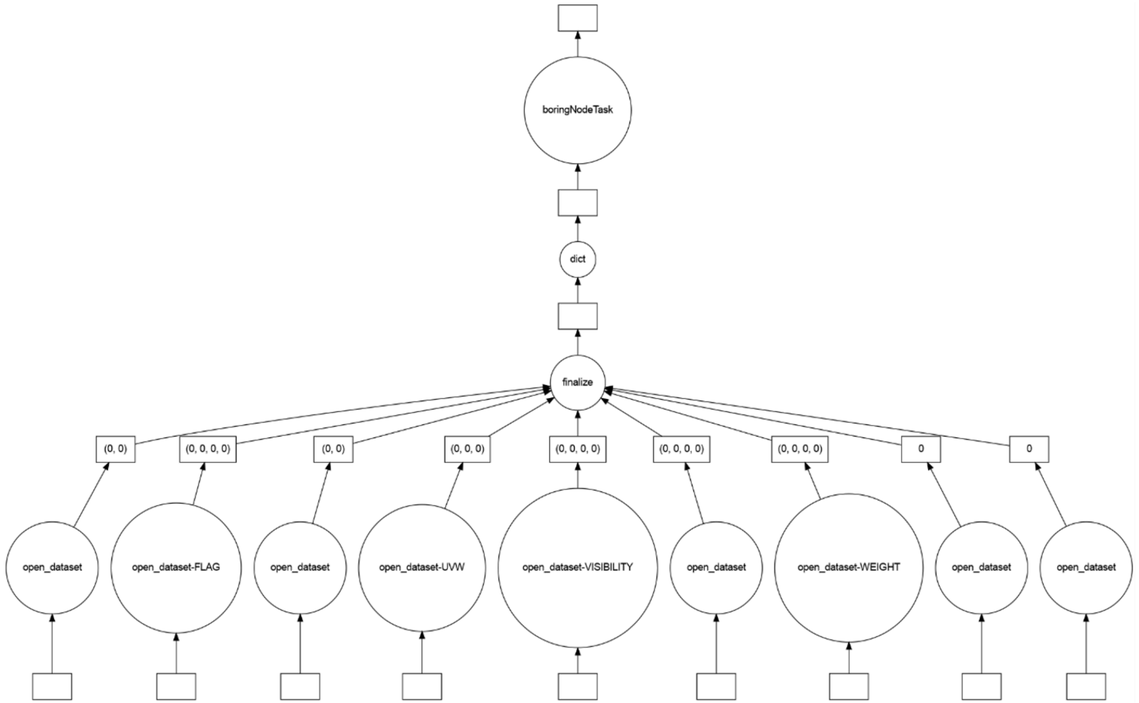
+ more (faster) calibration
+ more (smarter) imaging
+ modern (smarter) analysis
= better science!

Handling more instrument output



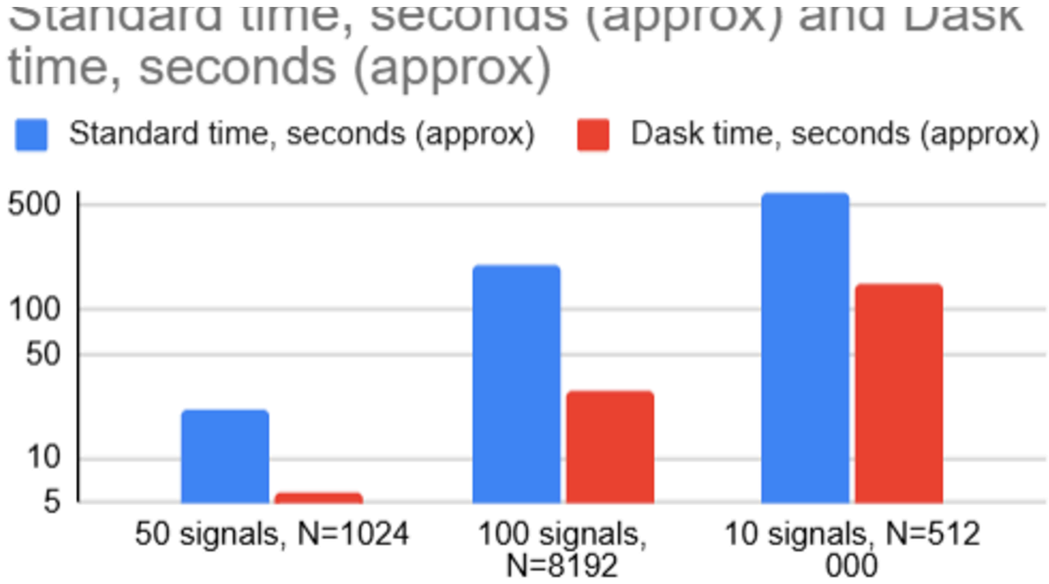
https://pangeo.io/architecture.html

Algorithms ported to Dask



prototype fringefit graph

(instrumental + ionospheric corrections)



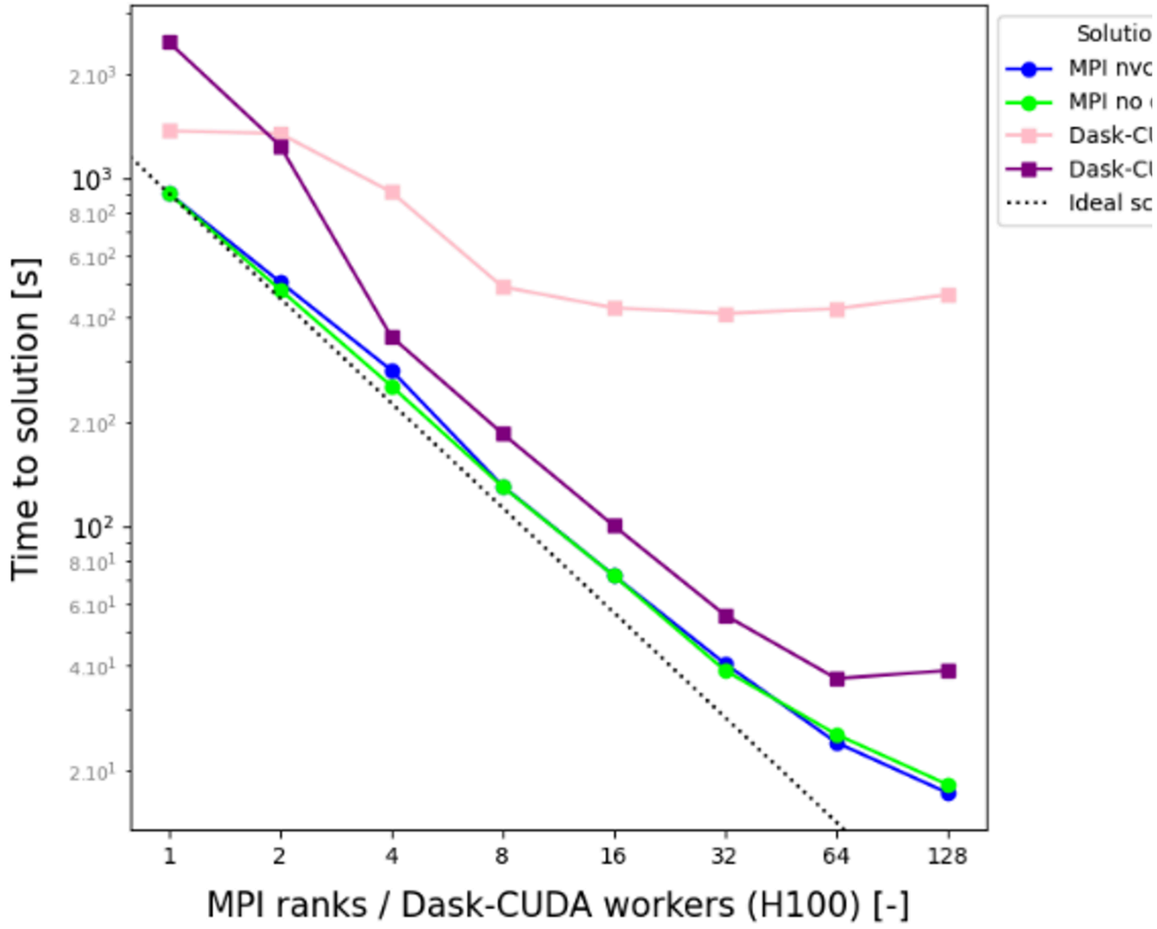
Singular Spectrum Analysis

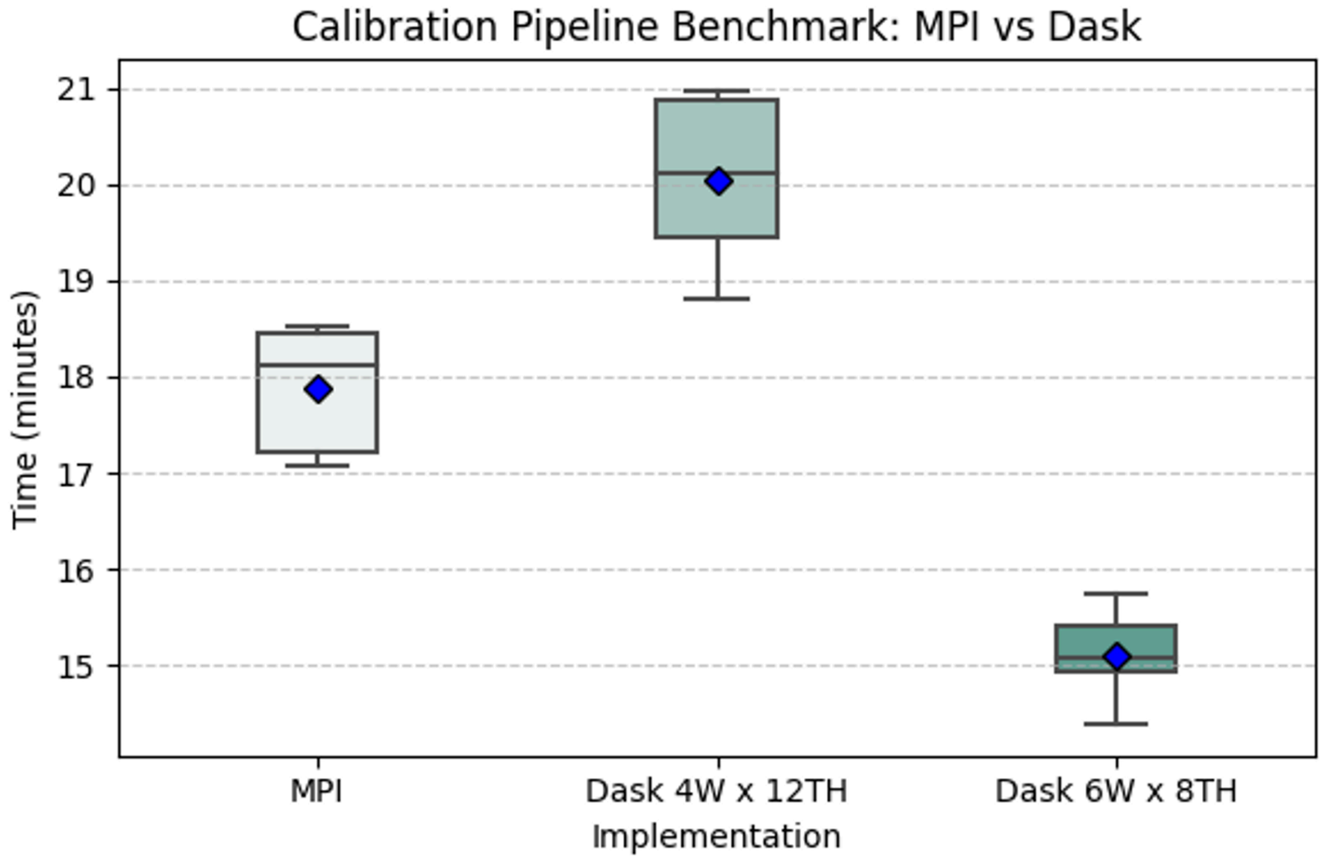
(RFI mitigation)

RADIO BLOCKS

Data processing

Dask vs MPI



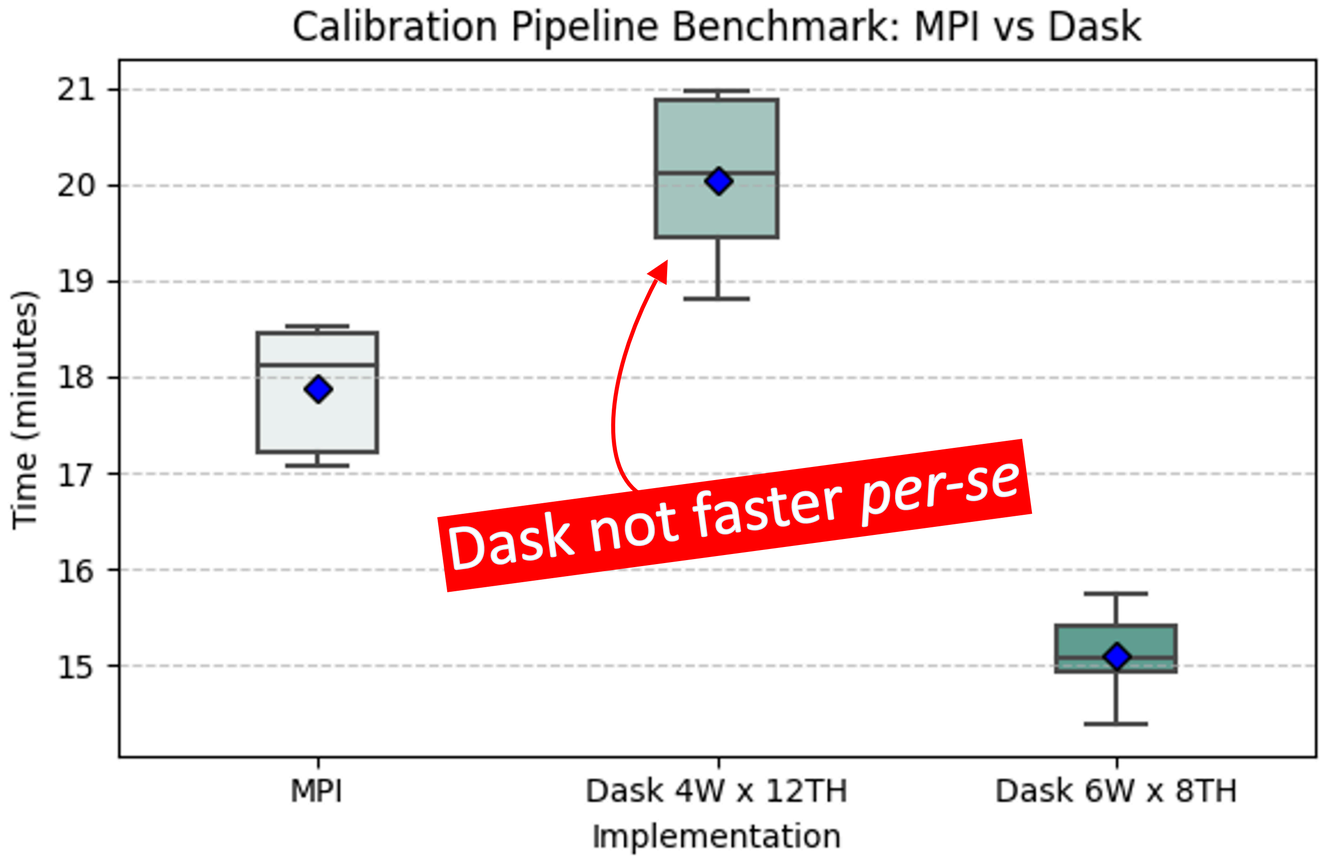


Lower is better

RADIO BLOCKS

Data processing

Dask vs MPI

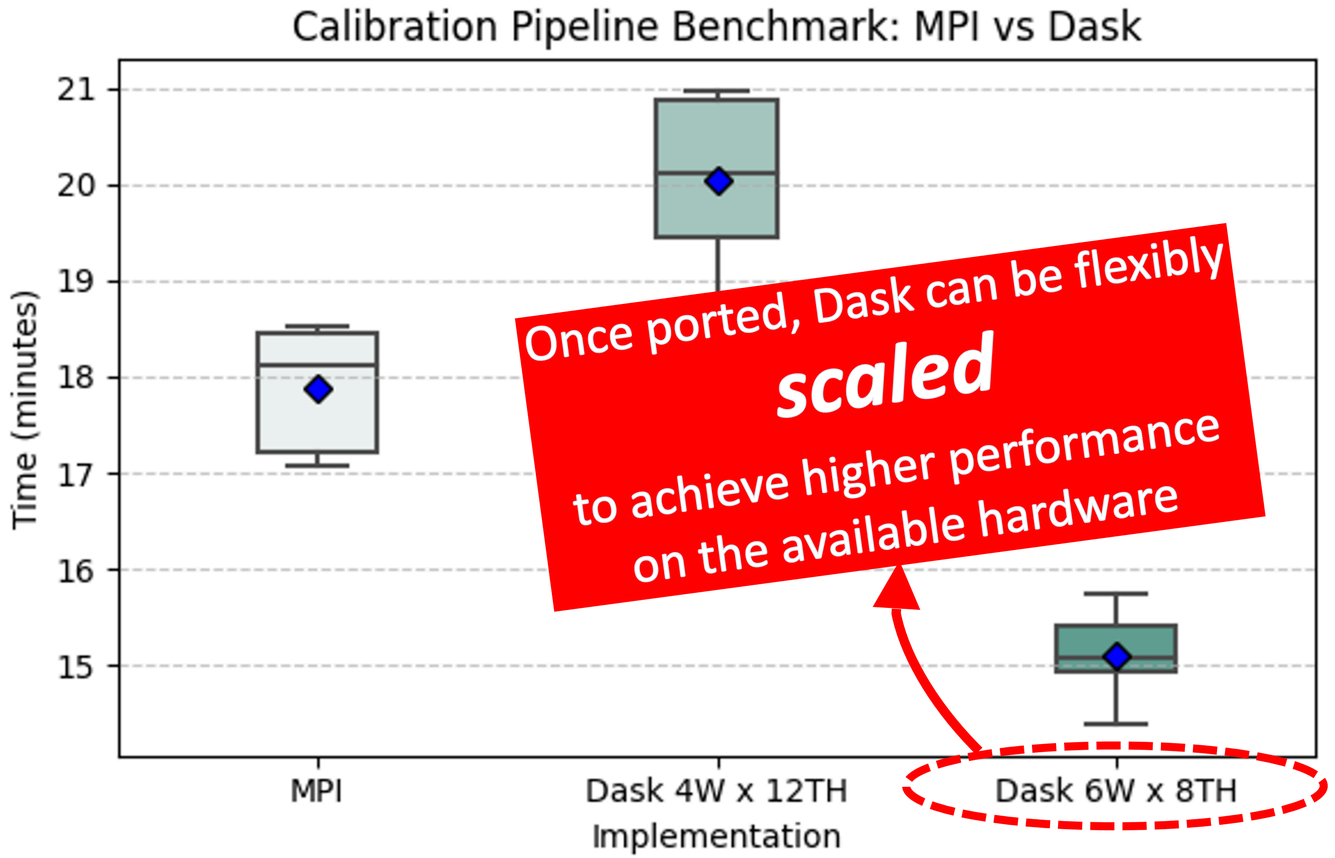


Lower is better

RADIO BLOCKS

Data processing

Dask vs MPI

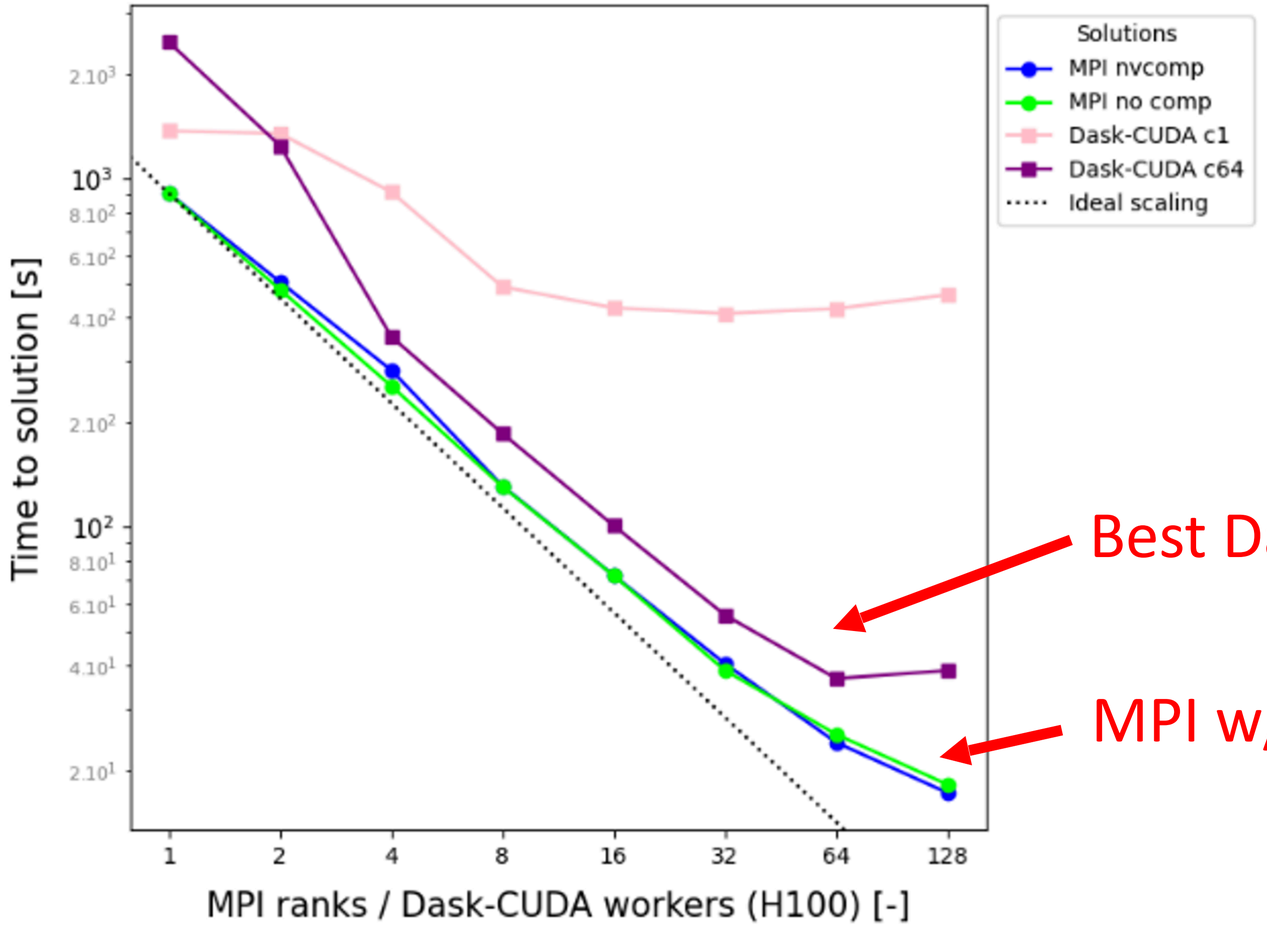


Lower is better

RADIO BLOCKS

Data processing

Dask vs MPI



Dask can not meet MPI performance? Under investigation!

Best Dask performance

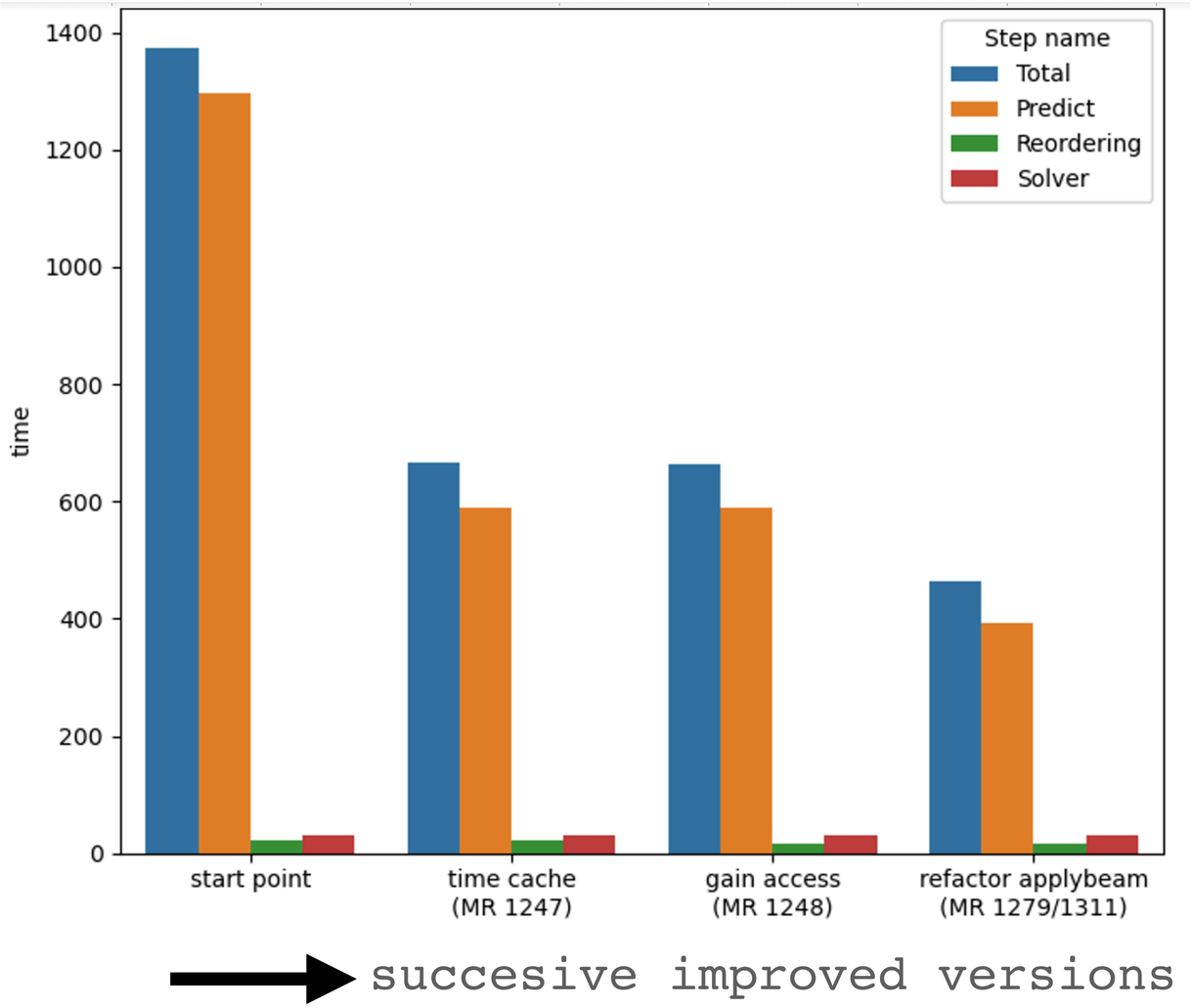
MPI w/wo NVIDIA (de)compression lib

Lower is better

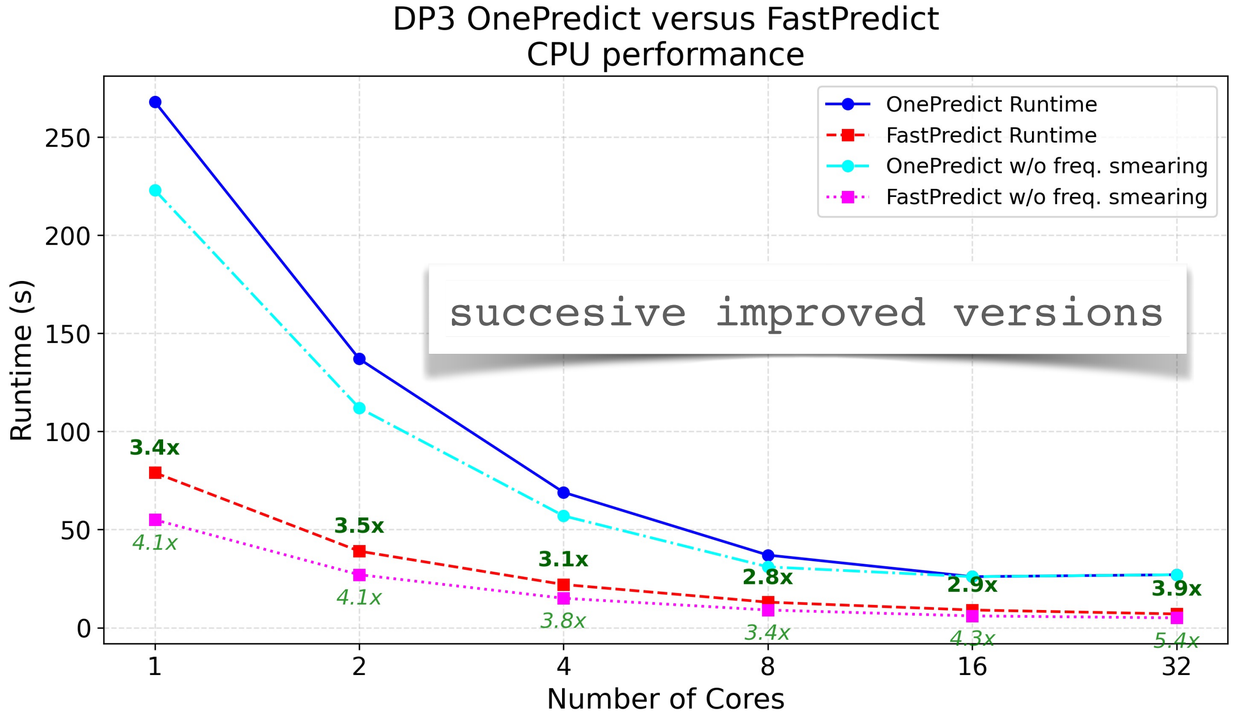
RADIO BLOCKS

Data processing

Computational hotspots



succesive improved versions



Lower is better

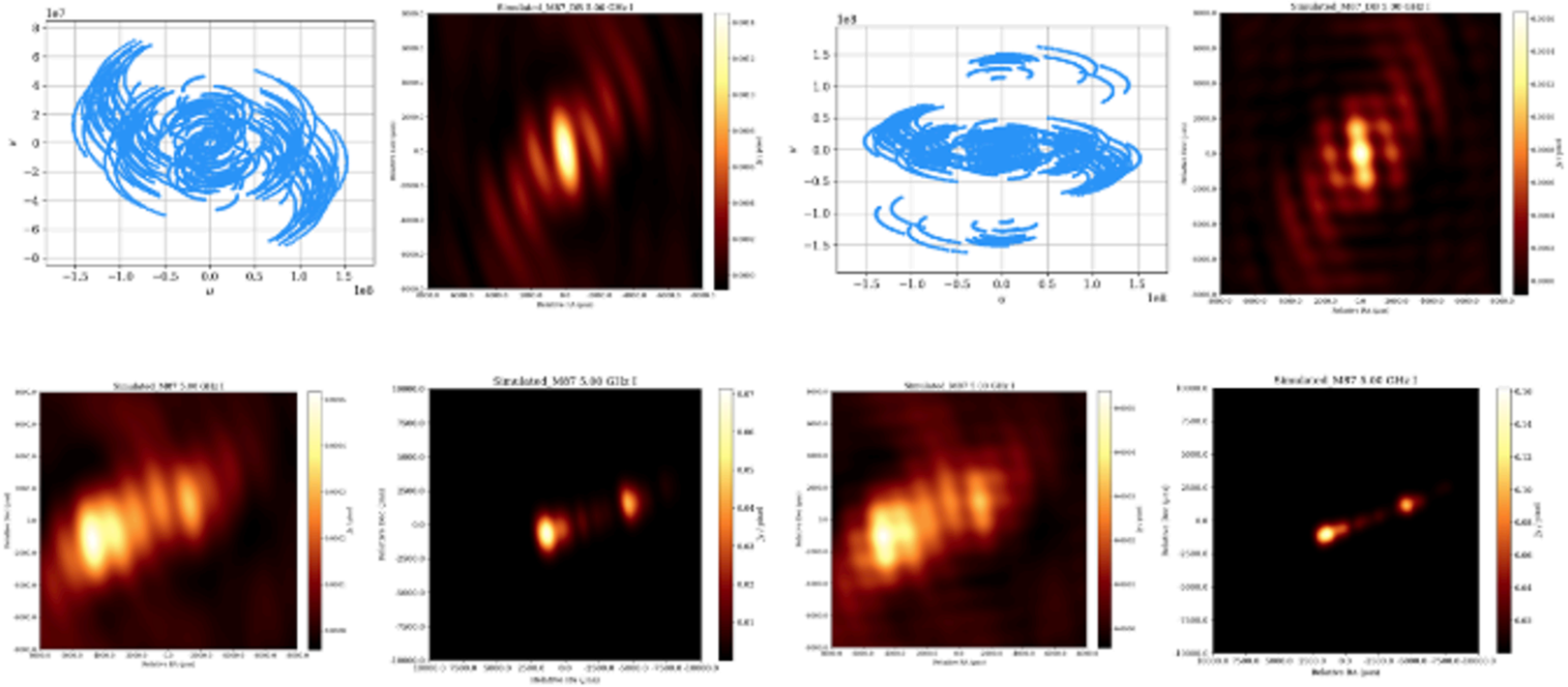
RADIO BLOCKS

Data processing

Synthetic data for instrument(s)

CASE 1:
EVN (only NE antennas)

CASE 2:
EVN + SKA core (4 km)

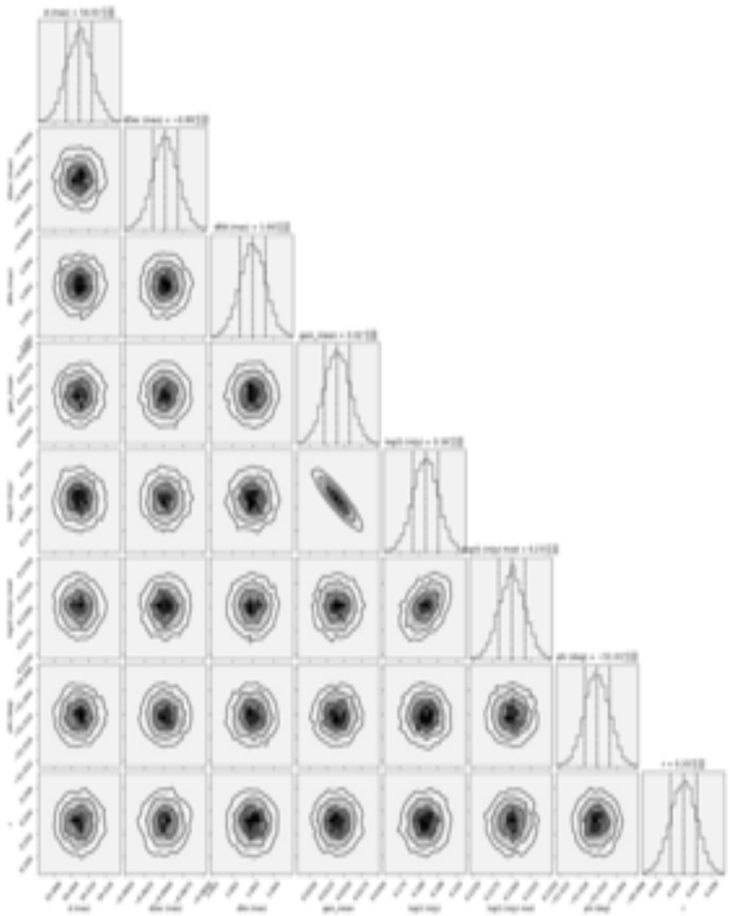


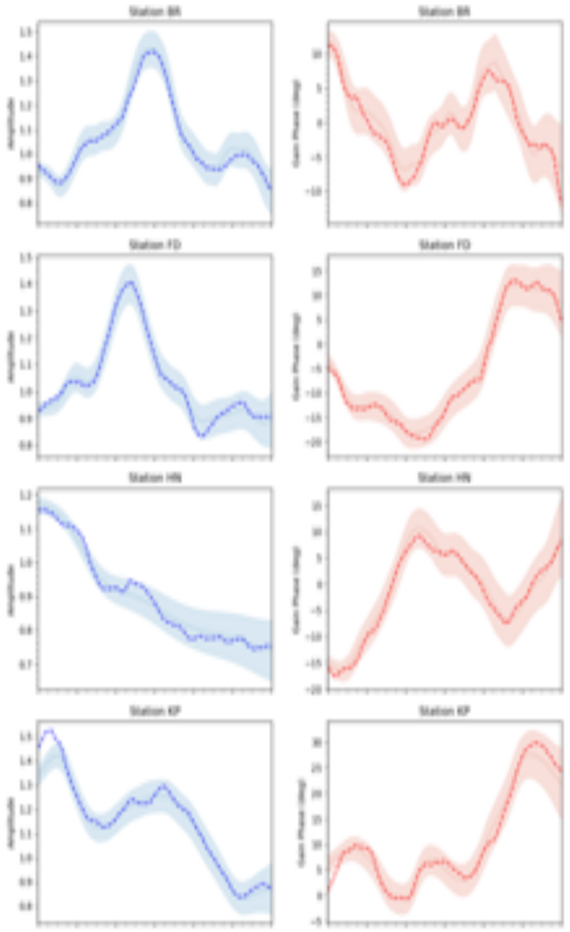
- test calibration algorithms
  (inject controlled error, propagation)
- forward modelling

RADIO BLOCKS

Data processing

More modern VLBI calibration





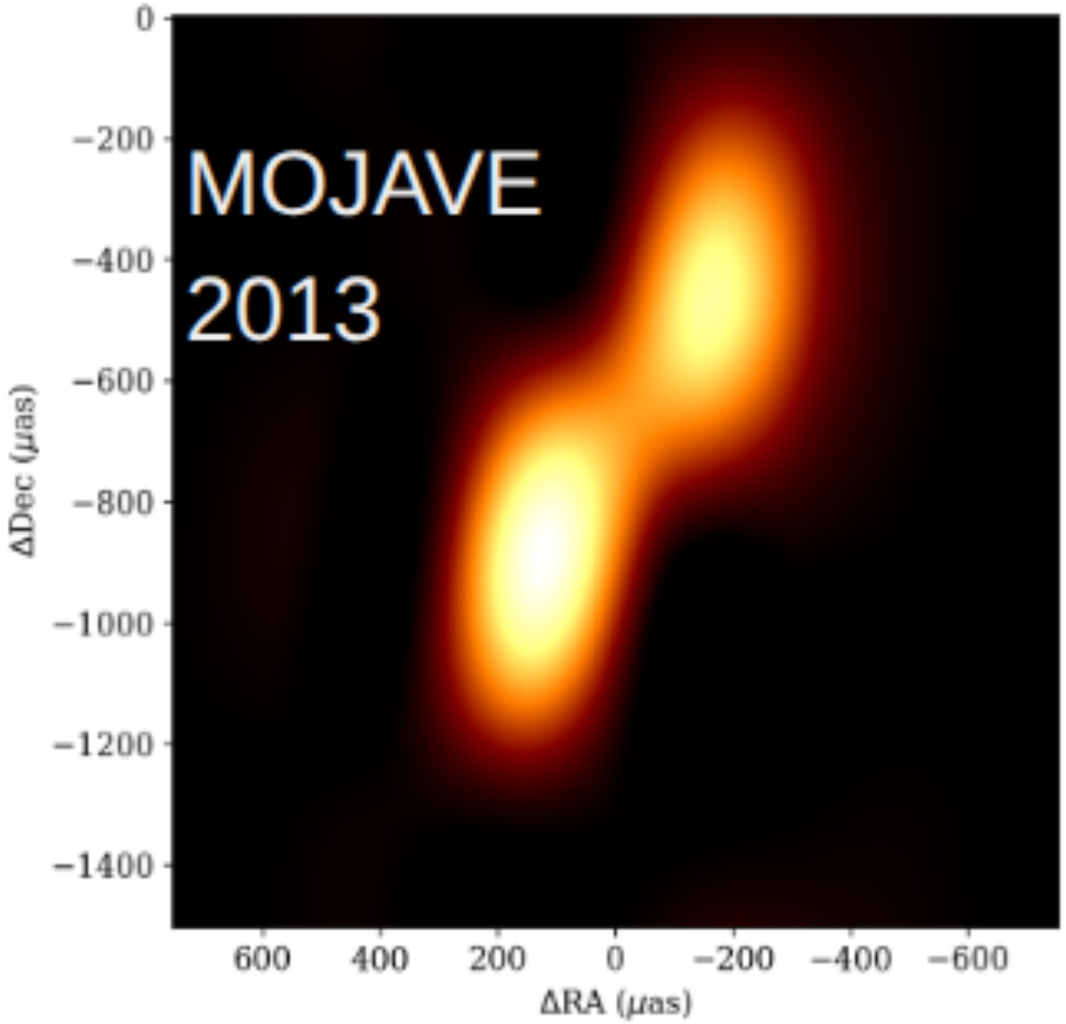
Inference on VLBI data
gives for the first time *qualitative*
gains w/ uncertainty measure

Bayesian inference on VLBI data
- fitting 200 free parameters
(powered by GH200 RADIOBLOCKS cluster!)

RADIO BLOCKS

Data processing

More inference! (EHT tools into cm-λ)

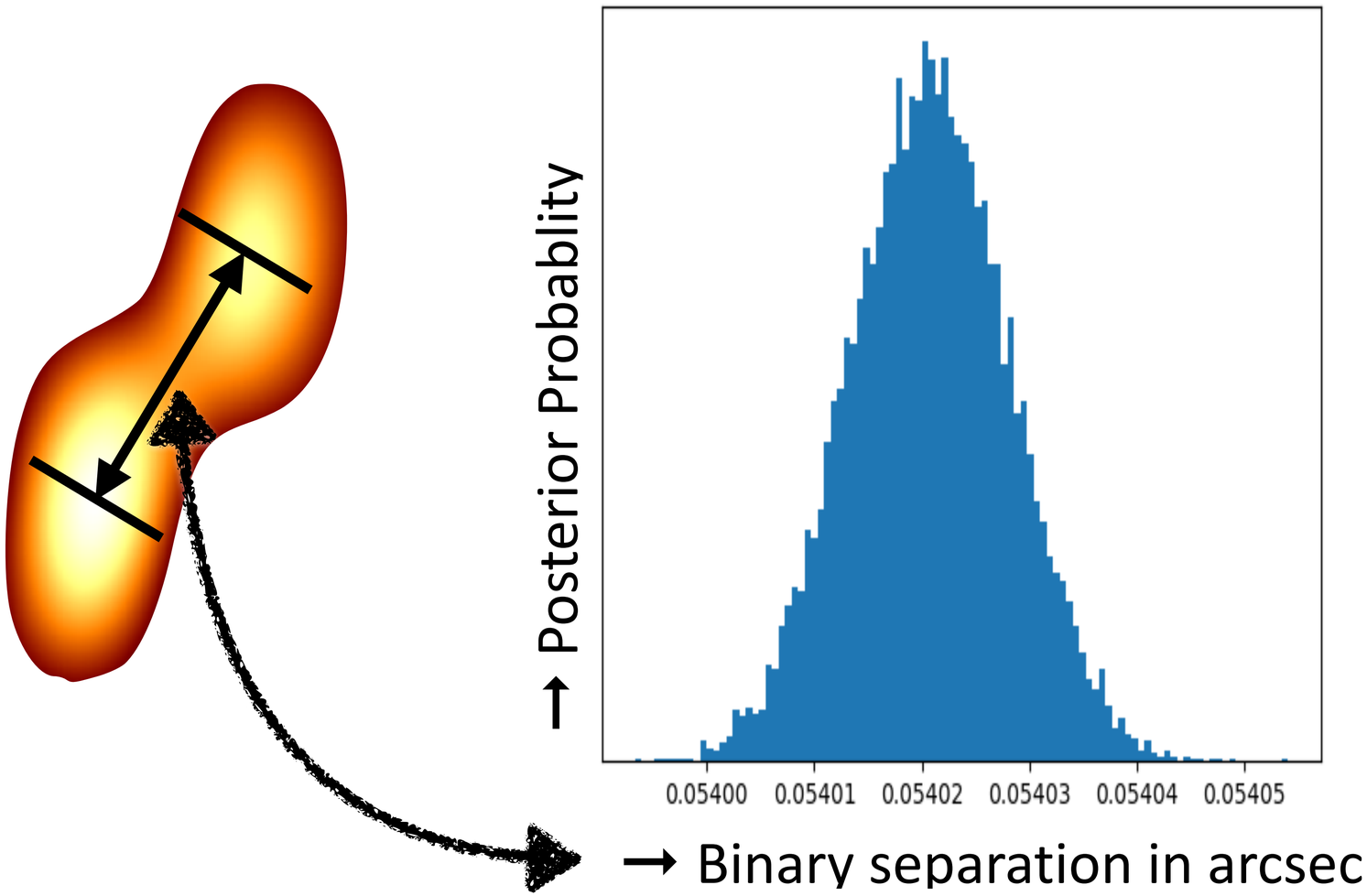


Apply **Themis**
EHT modelling s/w to
cm-VLBI observations (VLBA)

RADIO BLOCKS

Data processing

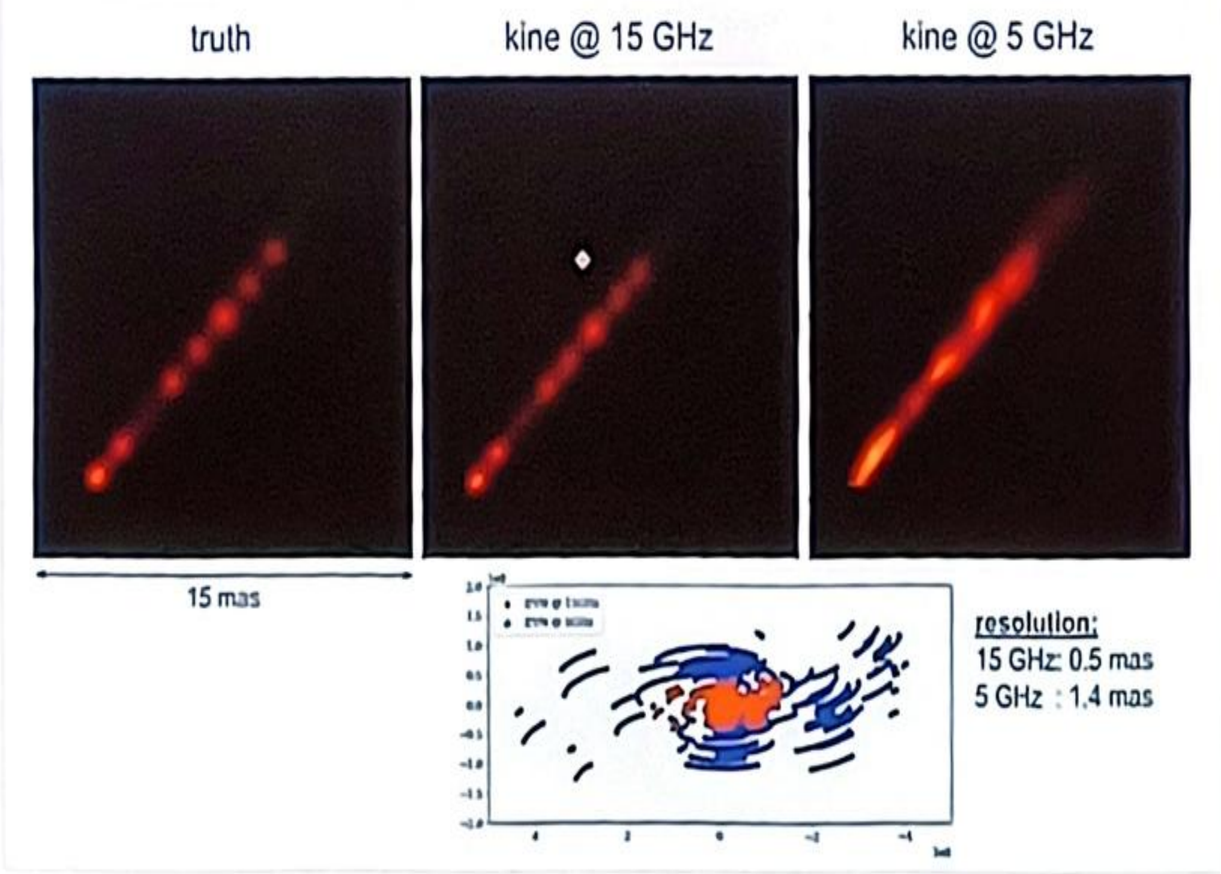
More inference! (EHT tools into cm-λ)



EHT-analysis s/w used for a-posteriori **astrometric PDF!**

Note: used synthetic data

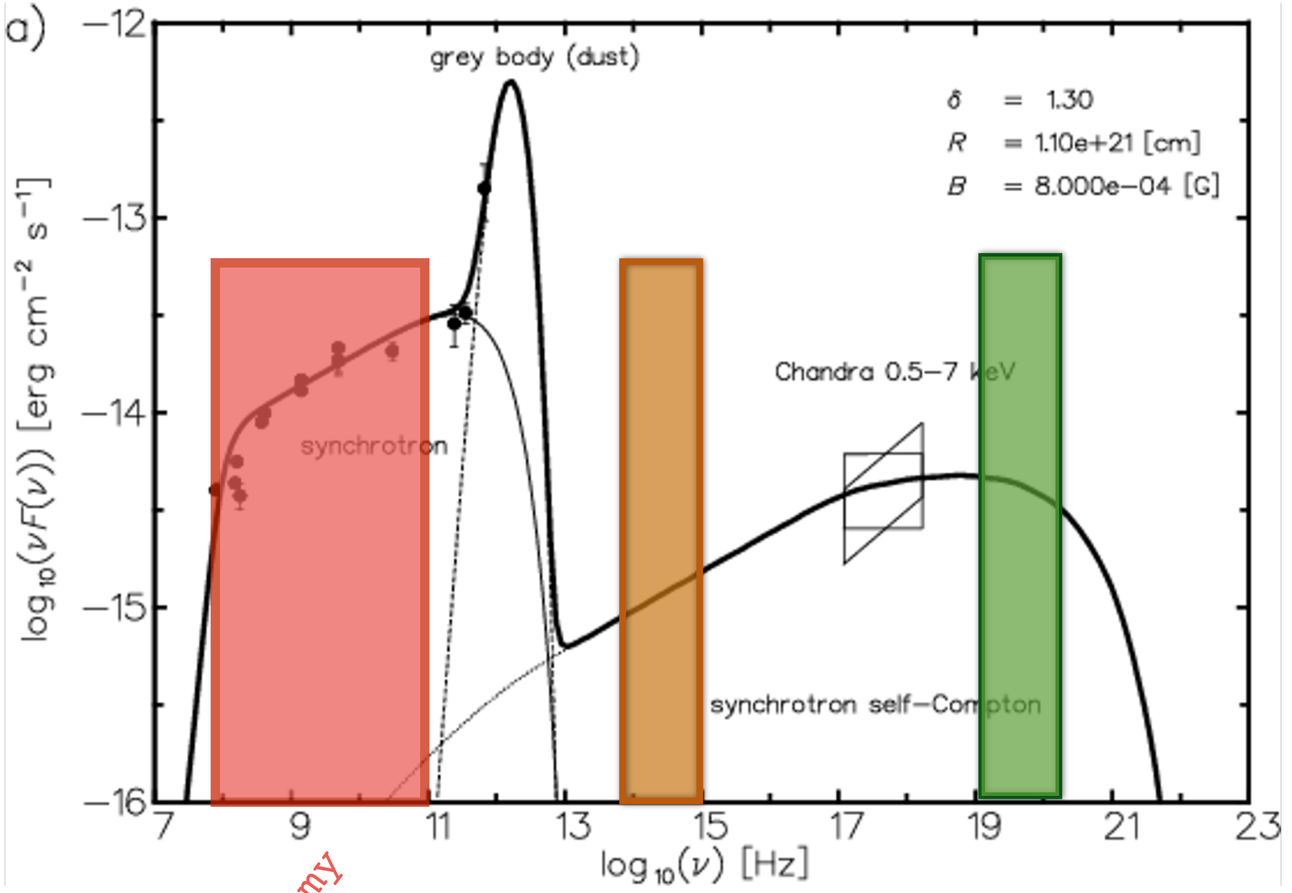
EHT dynamic imaging into cm-λ



Applying
EHT dynamic imaging algorithm
to
simulated EVN data!

RADIO BLOCKS

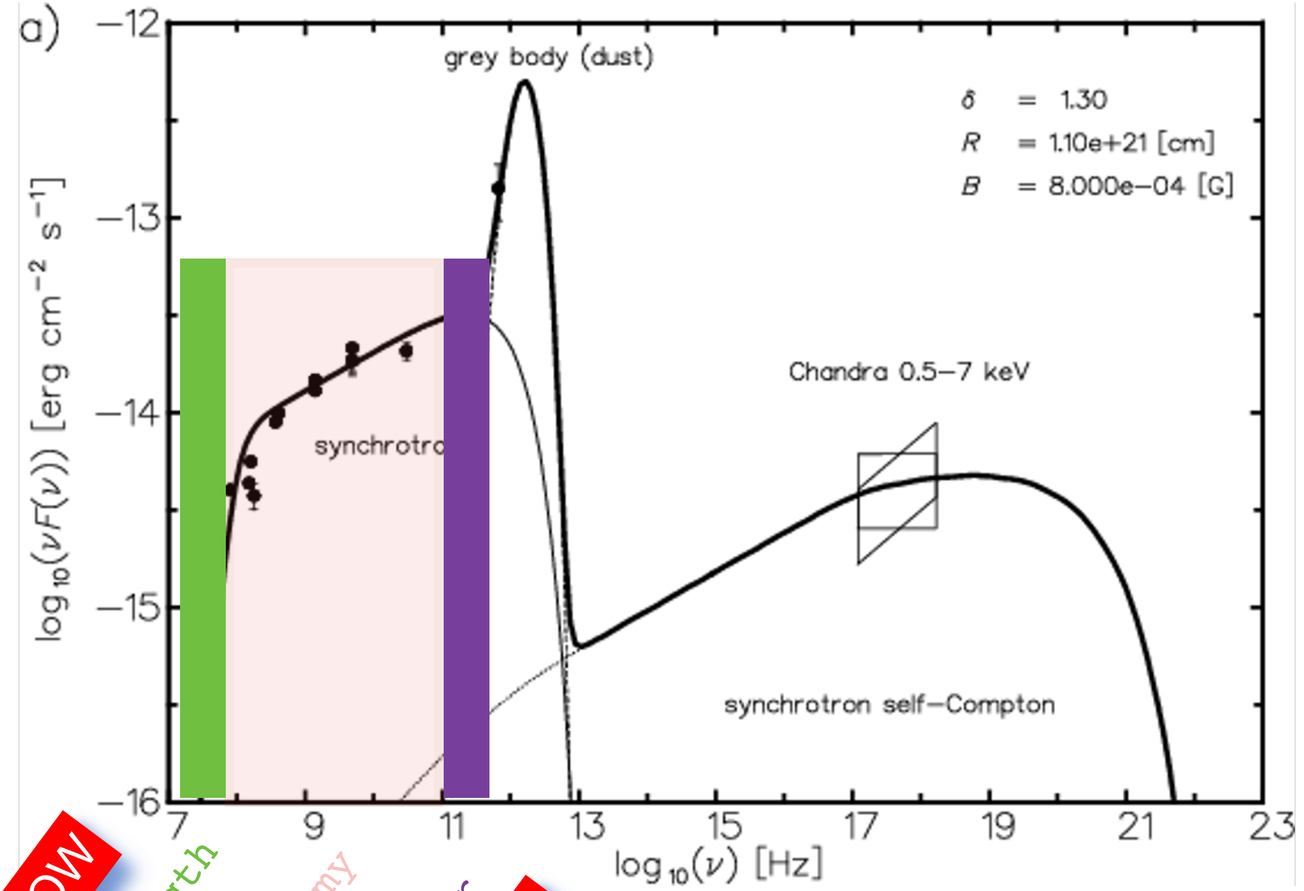
Data processing



radio astronomy

optical

gamma



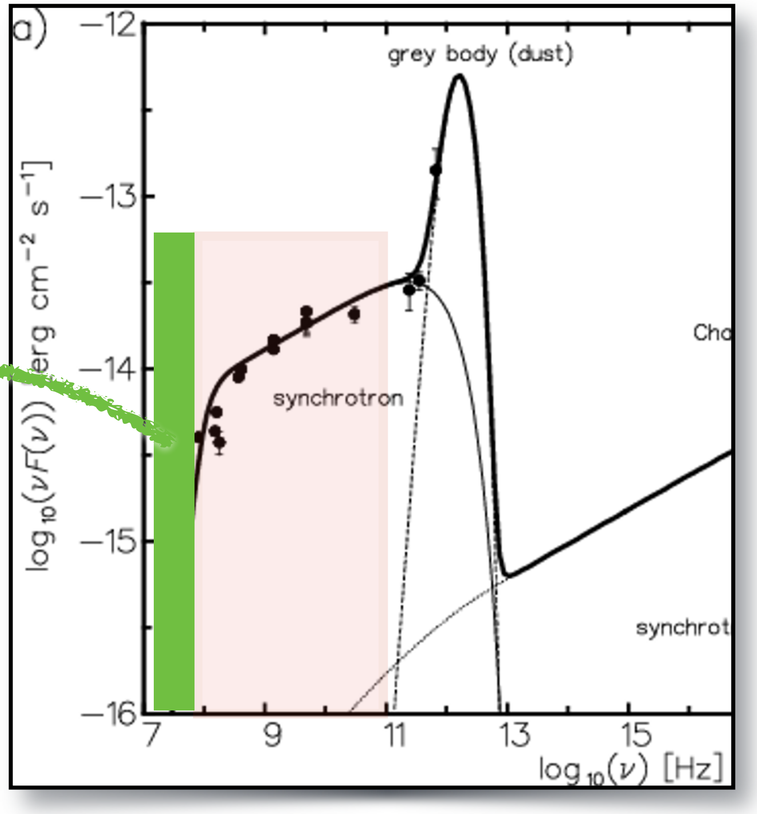
LOFAR SKA-LOW

meter-wavelength

radio astronomy

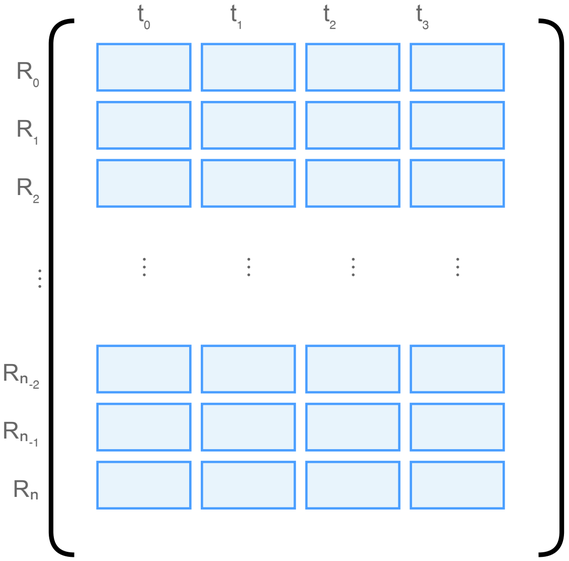
sub-millimeter

NOEMA ALMA



Signal Matrix

(many receivers × time samples)



[n × 4]

n = number of receivers (large)

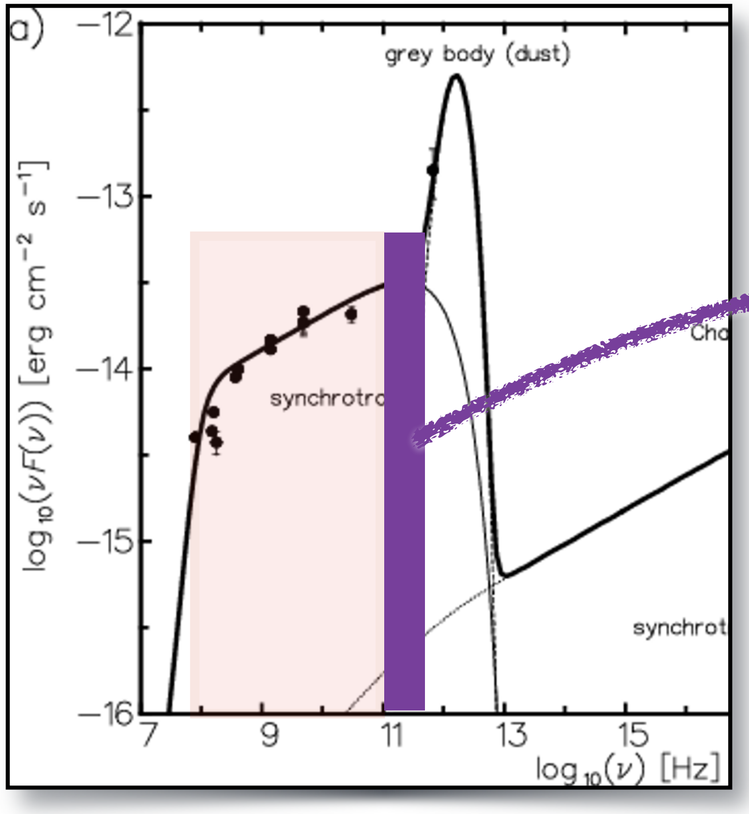
LOFAR SKA-LOW

really large N

(10^4–10^5)

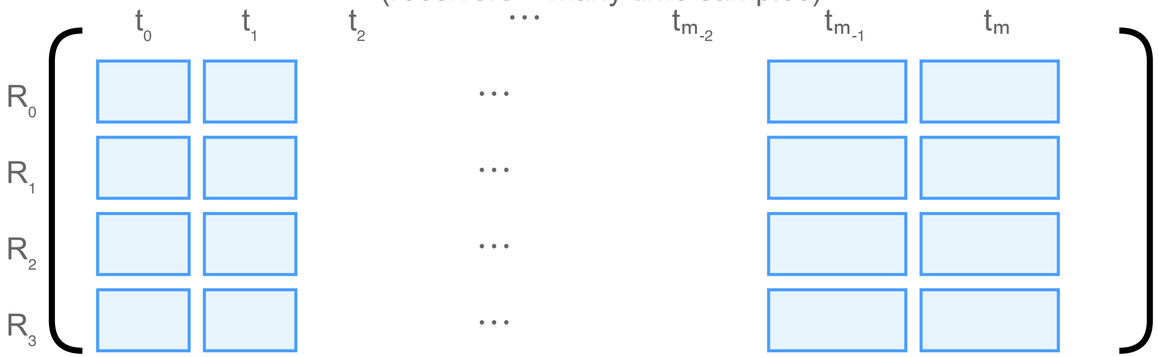
high data rate

(~10^9, > 2 bits/sample)



Signal Matrix

(receivers × many time samples)

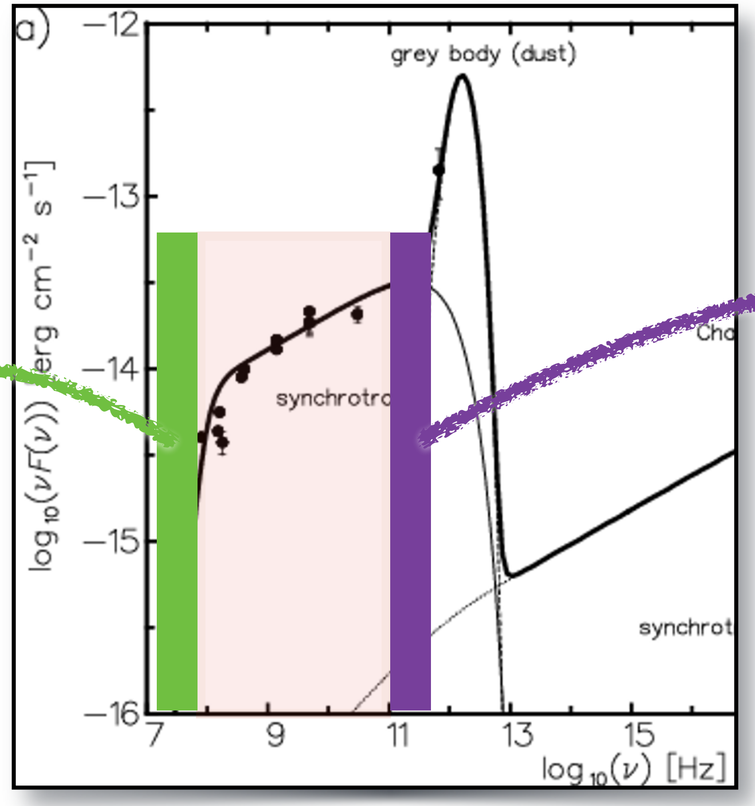


Ys/SRT/Ef EVN NOEMA ALMA

really high data rate

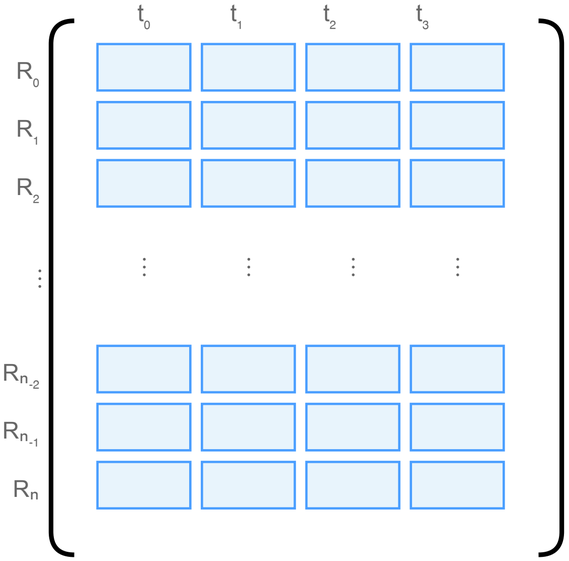
(10^{11}–10^{12} bps)

moderate N (~10^{1})



Signal Matrix

(many receivers × time samples)

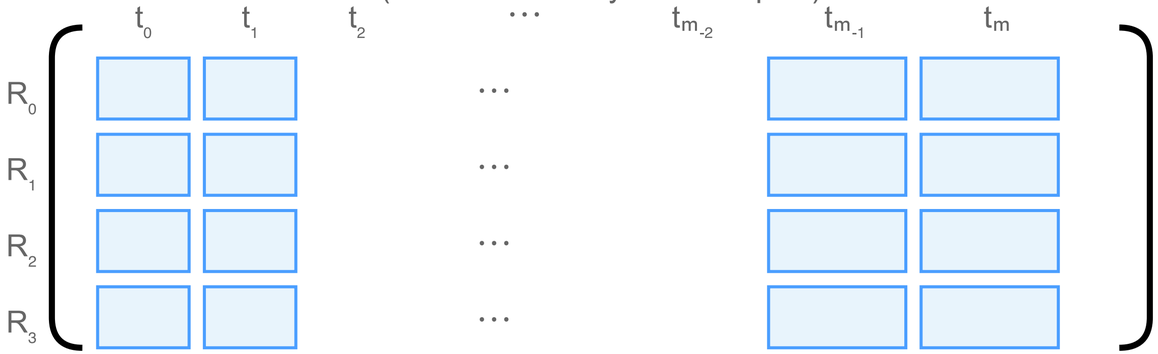


[n × 4]

n = number of receivers (large)

Signal Matrix

(receivers × many time samples)



[4 × m]

m = number of time samples (high data rate)

SKA-MID PAFs

large-ish N (10^2)

large-ish data rate (10^{10})

Science enablers: Increase field of view Increase sensitivity and bandwidth

LOFAR

The International LOFAR Telescope...

... hosted by the ILT

EVN

The European VLBI network (EVN)...

... hosted by the Joint Institute for VLBI

NOEMA

The NOEMA telescope...

... hosted by the IRAM institute

E-Merlin...

... hosted by the University of Manchester

Ef/Srt/Ys

The Effelsberg telescope...

... hosted by the MaxPlanck Institute

The SRT telescope...

... hosted by INAF

The Yebes telescope...

... hosted by CNIG/IGN

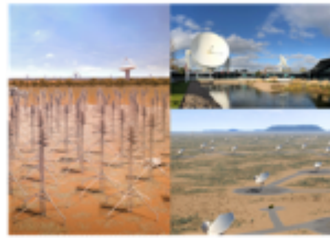
ALMA

The ALMA telescope...

... hosted by the European Southern Observatory for the European part

SKAO

The SKA telescope...



... hosted by the SKA Office

Building blocks:

Novel detectors and components

Digital receivers

Transport and Correlator

Data (post)processing

Thanks for Attention!