
ASTRON
Netherlands Institute for Radio Astronomy

LOFAR: FOSS HPC across 2000 kilometers

Corne Lukken (PD3SU)

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Background

- ASTRON: Dutch government institute for radio astronomy
  - Public money = Public code
  - Telescopes
    - LOw Frequency ARray (LOFAR)
    - Westerbork Synthesis Telescope (WSRT)
- CAMRAS
- JIVE & EVN
- Very Long Baseline Interferometry (VLBI)

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Onsala
Irbene
Birr
Dutch stations
Chilbolton
Norderstedt
Bałdy
Potsdam
Borówiec
Jülich
Effelsberg
Tautenburg
Łazy
Nançay
Unterweilenbach
Medicina
Rozhen


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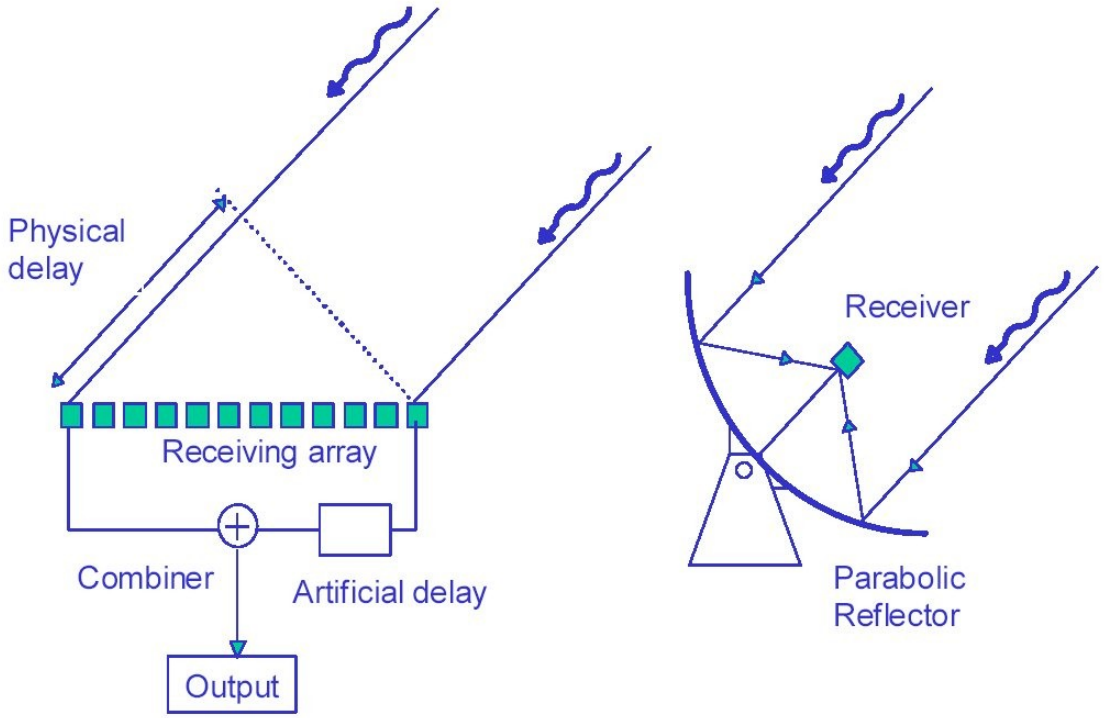
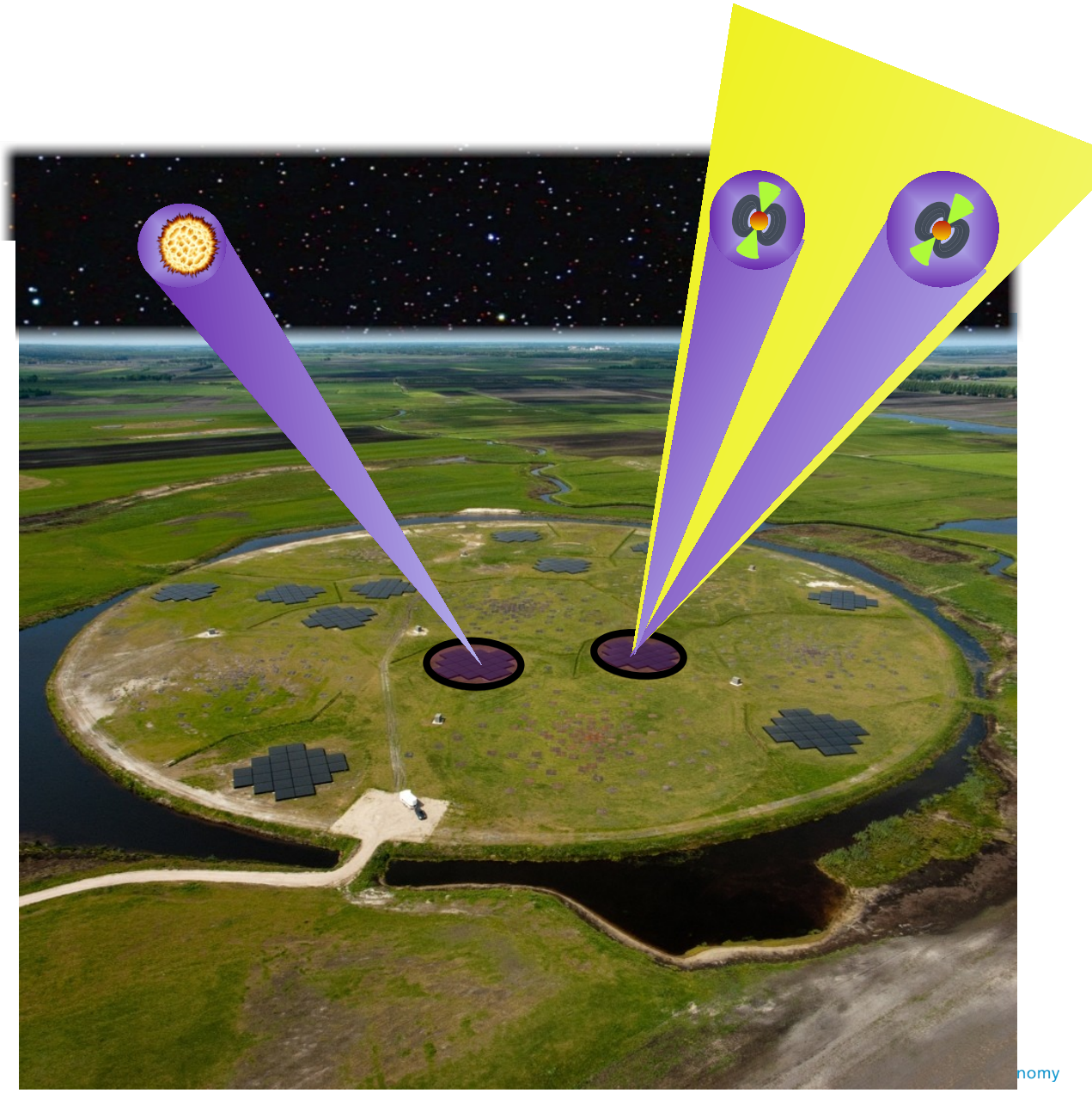
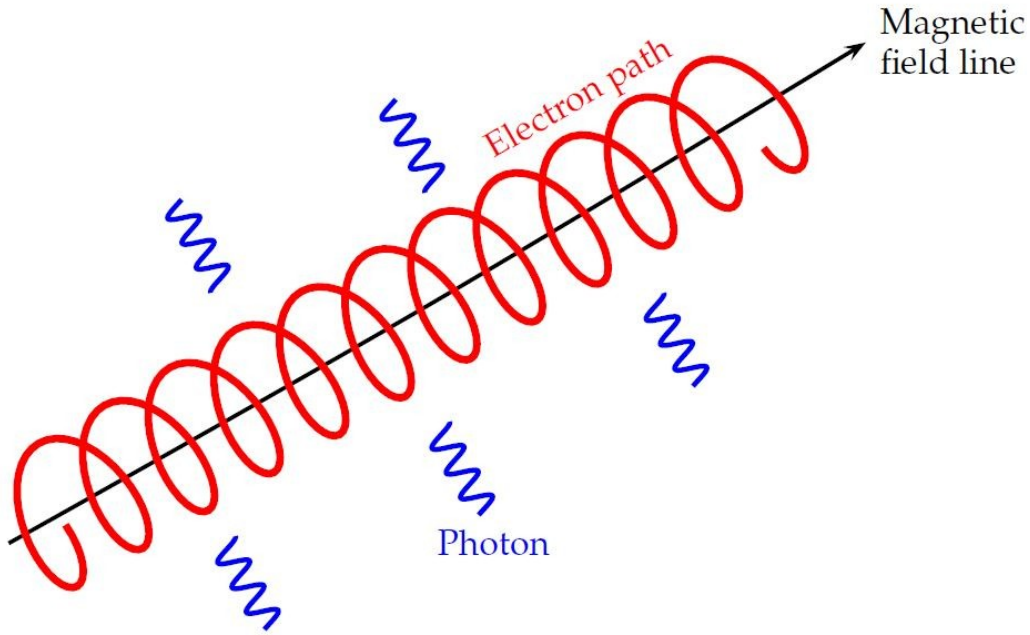
Beamforming

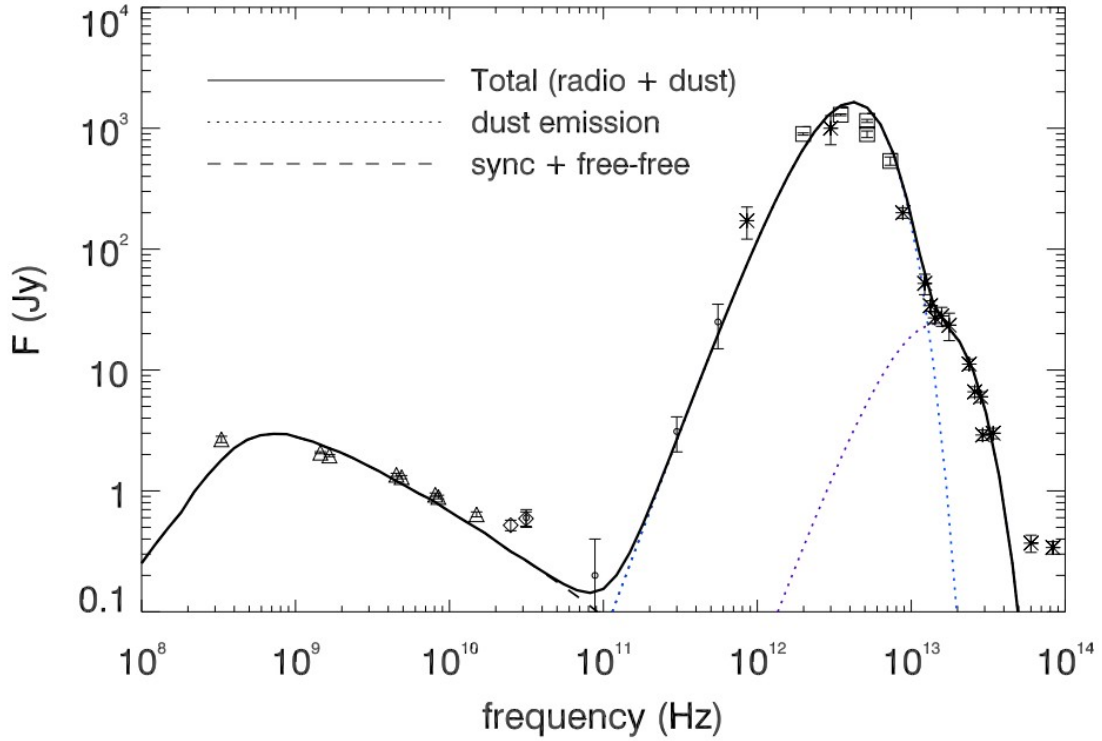




Synchroton Radiation



Accelerated charged particle emission



Pozo, E.D., Torres, D.F., Rodríguez, A., & Reimer, O. (2009). Model analysis of the very high energy detections of the starburst galaxies M82 and NGC 253. arXiv: High Energy Astrophysical Phenomena.

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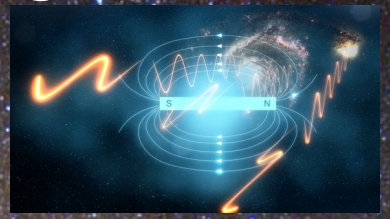
Cosmic magnetism



Supermassive black holes

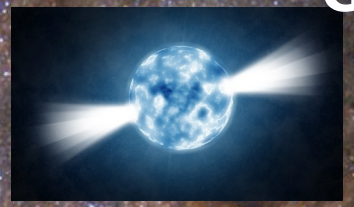
Early Universe

Supernovae

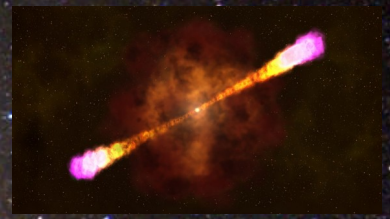
Galaxy clusters

Sun

Pulsars



Gravitational wave events

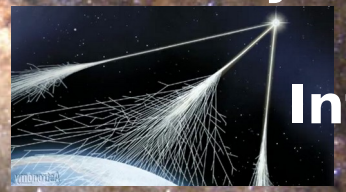


Solar System Planets

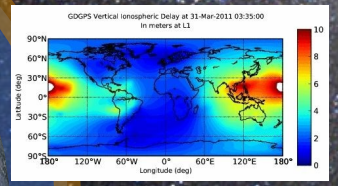
Meteors

Nearby galaxies

Cosmic rays



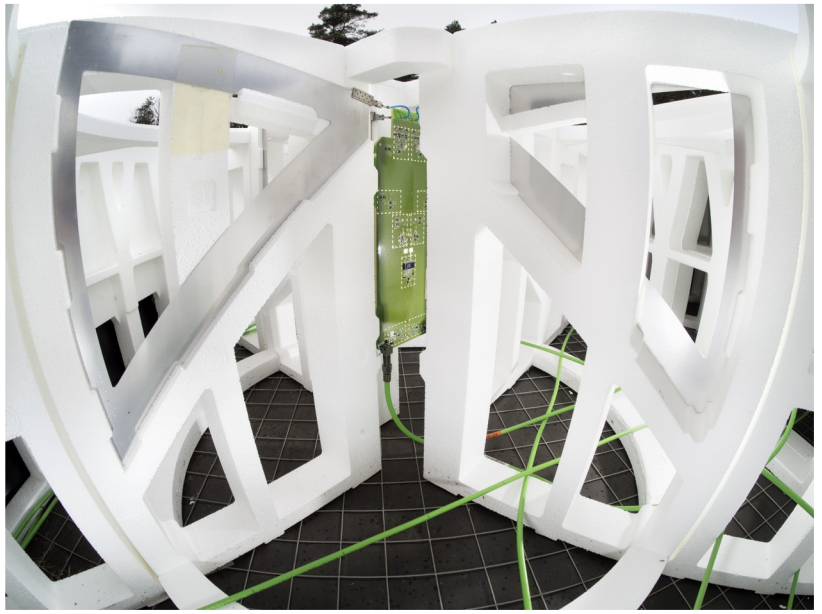
Ionosphere

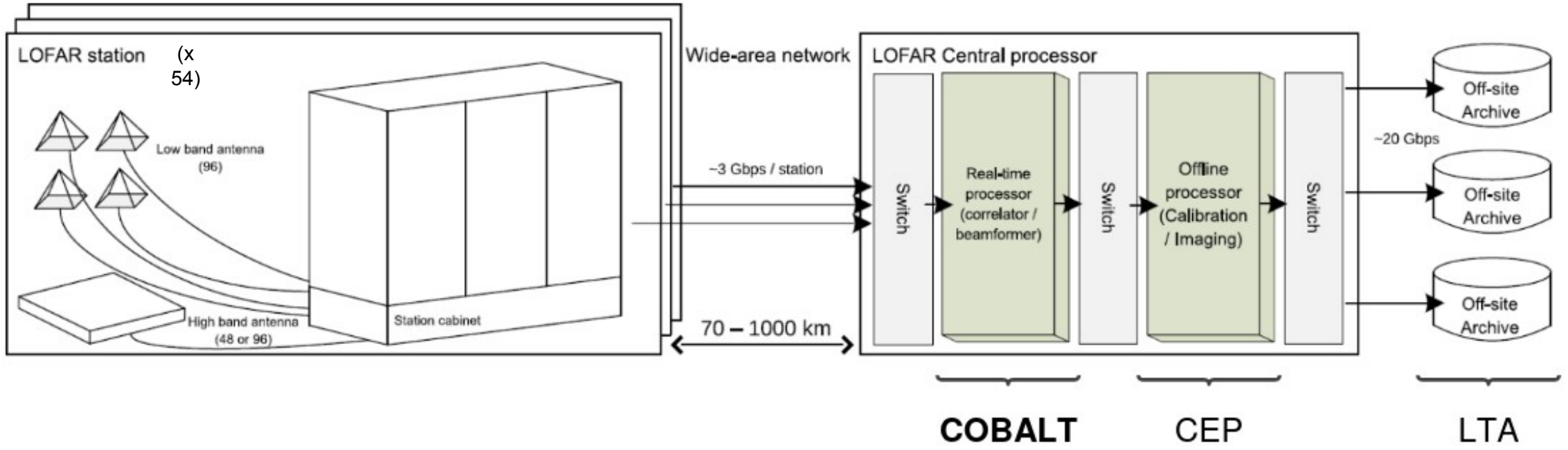


Interstellar medium

Lightning

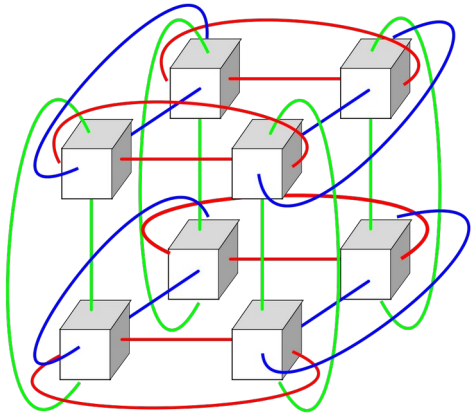
Space weather




LOFAR station (x 54)
Low band antenna (96)
High band antenna (48 or 96)
Station cabinet
Wide-area network
~3 Gbps / station
70 – 1000 km
LOFAR Central processor
Switch
Real-time processor (correlator / beamformer)
Switch
Offline processor (Calibration / Imaging)
Switch
~20 Gbps
Off-site Archive
Off-site Archive
Off-site Archive
COBALT
CEP
LTA

Early days: IBM BlueGene

- 2005: IBM BlueGene/L
  - ~5/6 racks + 2 head nodes
  - 1024x PPC440 @ 700 MHz
- 2008: IBM BlueGene/P
  - ~5/6 racks + 2 head nodes
  - 1024x PPC450 @ 850 MHz
- Fast interconnects
  - 3D Torus + Tree
- I/O: 64x 10GbE



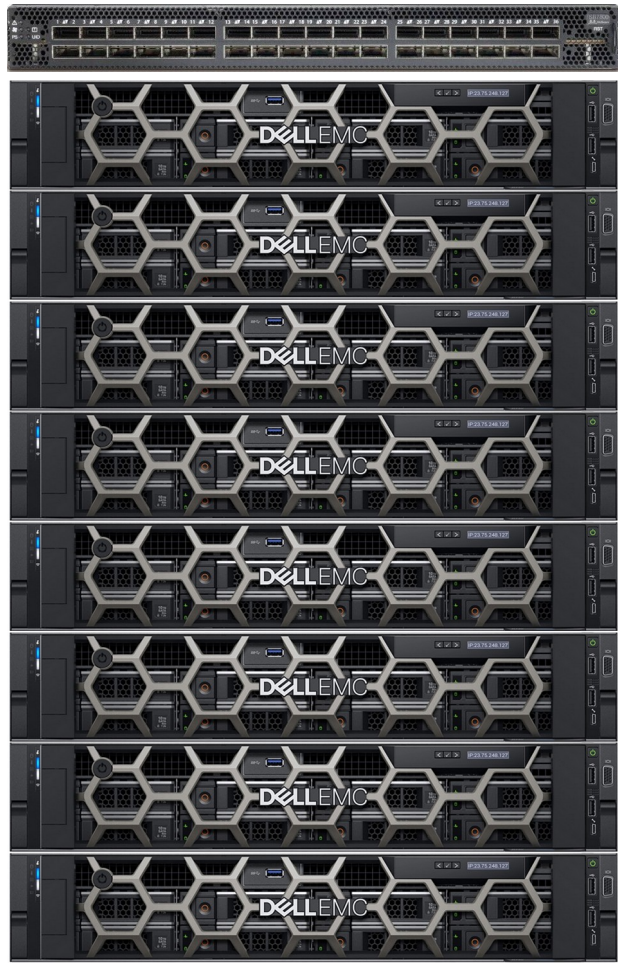
BlueGene/L

BlueGene/P

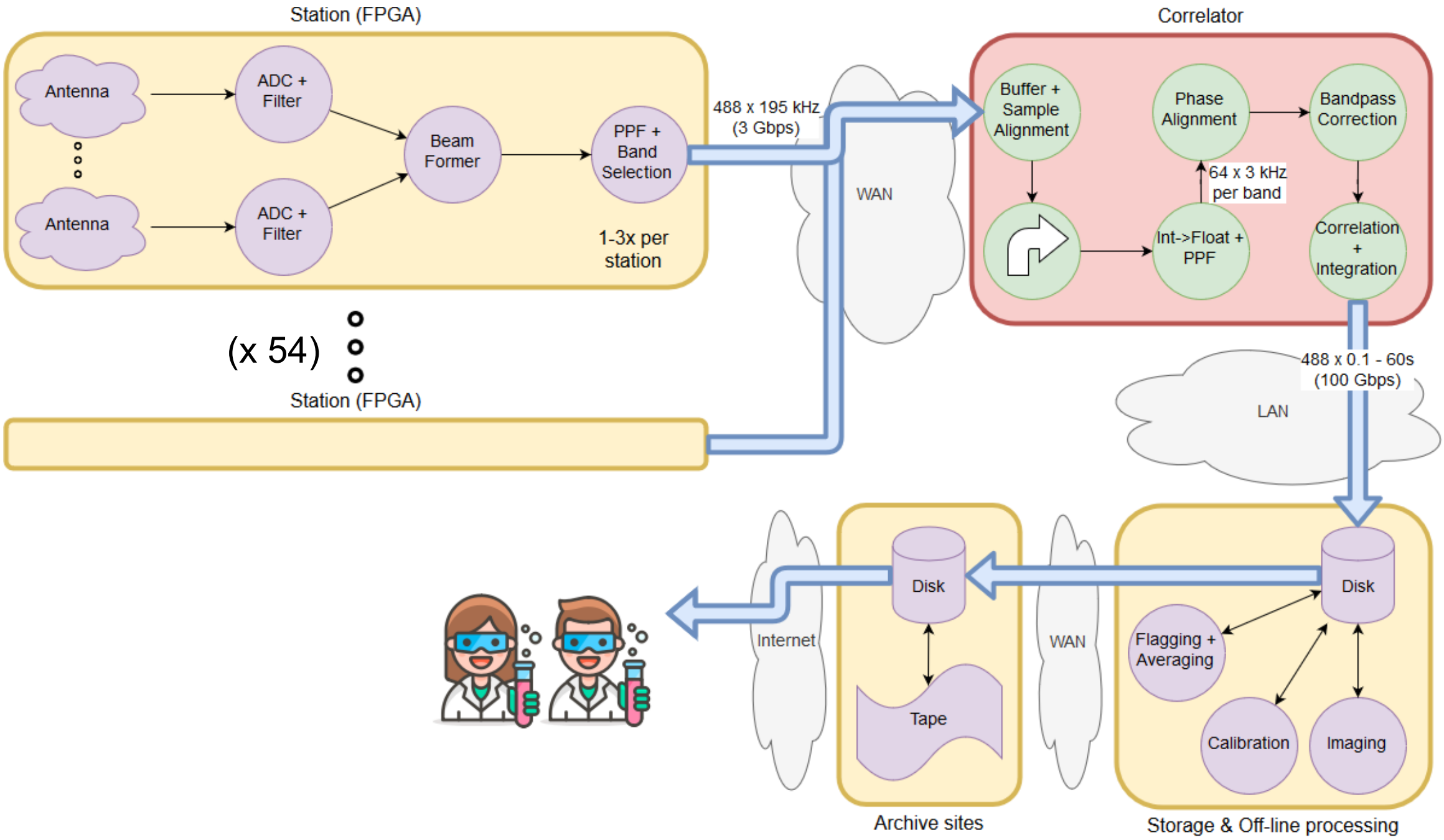
Now: GPU servers (“COBALT”)

- 2013: COBALT1
  - 8x Dell PowerEdge T640 (Xeon E5-2660)
  - 16x NVIDIA Tesla K10
  - 16x FDR Infiniband (56 Gbps)
  - I/O: 32x 10GbE
- Dec 2018: COBALT2
  - 1x Dell PowerEdge R440 (head)
  - 11x Dell PowerEdge R740 (Xeon Gold 6140)
  - 22x NVIDIA Tesla V100
  - 23x EDR InfiniBand (100 Gbps)
  - I/O: 80x 10GbE
    - 3x 10GbE socket 1 + 1GbE
    - 4x 10GbE socket 2

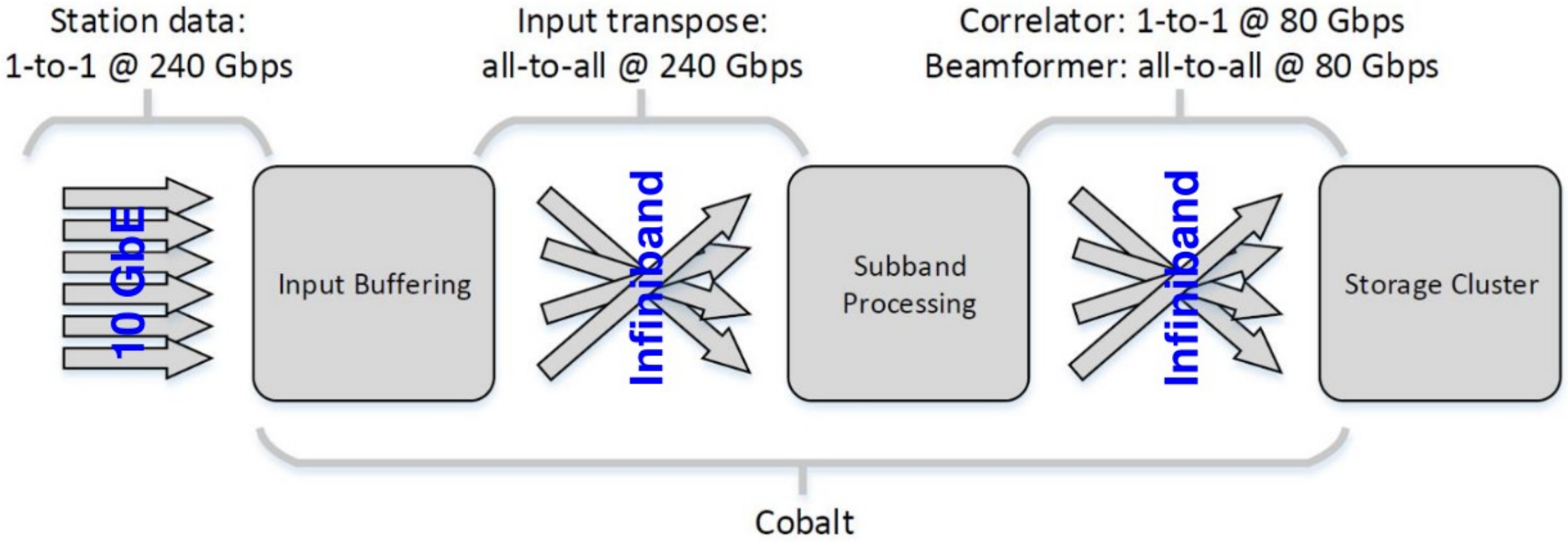
COBALT 1

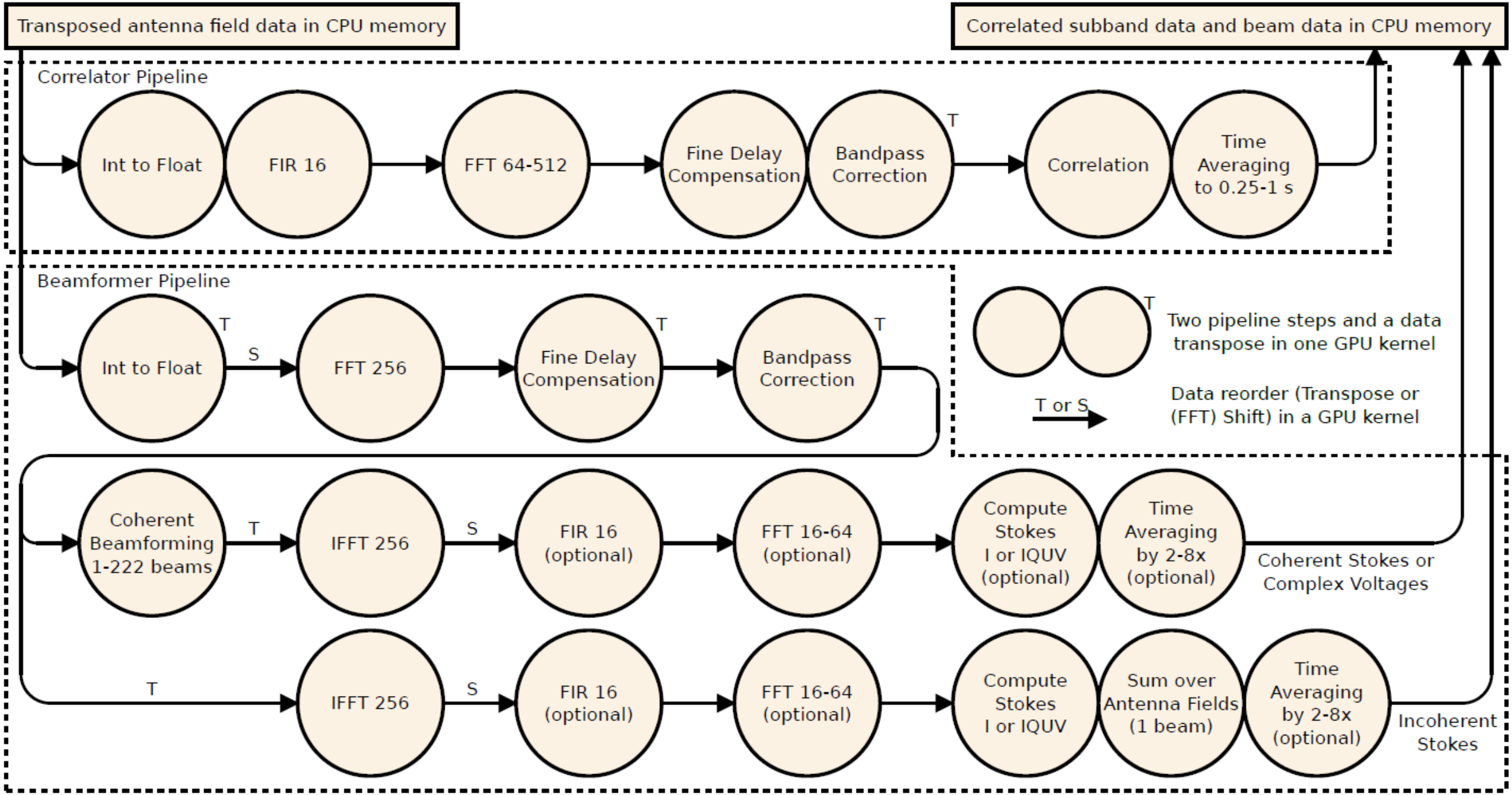


COBALT 2


Station (FPGA)
Antenna
Antenna
ADC + Filter
ADC + Filter
Beam Former
PPF + Band Selection
1-3x per station
(x 54)
Station (FPGA)
488 x 195 kHz (3 Gbps)
WAN
Correlator
Buffer + Sample Alignment
Phase Alignment
Bandpass Correction
64 x 3 kHz per band
Int->Float + PPF
Correlation + Integration
488 x 0.1 - 60s (100 Gbps)
LAN
Internet
Disk
Tape
Archive sites
WAN
Disk
Flagging + Averaging
Calibration
Imaging
Storage & Off-line processing

COBALT data flow




Transposed antenna field data in CPU memory
Correlated subband data and beam data in CPU memory
Correlator Pipeline
Int to Float
FIR 16
FFT 64-512
Fine Delay Compensation
Bandpass Correction
T
Correlation
Time Averaging to 0.25-1 s
Beamformer Pipeline
Int to Float
T
S
FFT 256
Fine Delay Compensation
T
Bandpass Correction
T
T
Two pipeline steps and a data transpose in one GPU kernel
T or S
Data reorder (Transpose or (FFT) Shift) in a GPU kernel
Coherent Beamforming 1-222 beams
T
IFFT 256
S
FIR 16 (optional)
FFT 16-64 (optional)
Compute Stokes I or IQUV (optional)
Time Averaging by 2-8x (optional)
Coherent Stokes or Complex Voltages
T
IFFT 256
S
FIR 16 (optional)
FFT 16-64 (optional)
Compute Stokes I or IQUV
Sum over Antenna Fields (1 beam)
Time Averaging by 2-8x (optional)
Incoherent Stokes

Open Source Software

- Tools By ASTRON (or friends)
  - AOFlagger - https://gitlab.com/aroffringa/aoflagger
  - Radler – https://git.astron.nl/RD/radler
    - WSClean - https://gitlab.com/aroffringa/wsclean/
  - IDG – https://git.astron.nl/RD/idg
  - Casacore - https://github.com/casacore/casacore
  - LOFAR – https://git.astron.nl/ro/lofar
    - DP3 - https://git.astron.nl/RD/DP3
    - Rapthor - https://git.astron.nl/RD/rapthor
    - LINC (Prefactor) - https://git.astron.nl/RD/LINC

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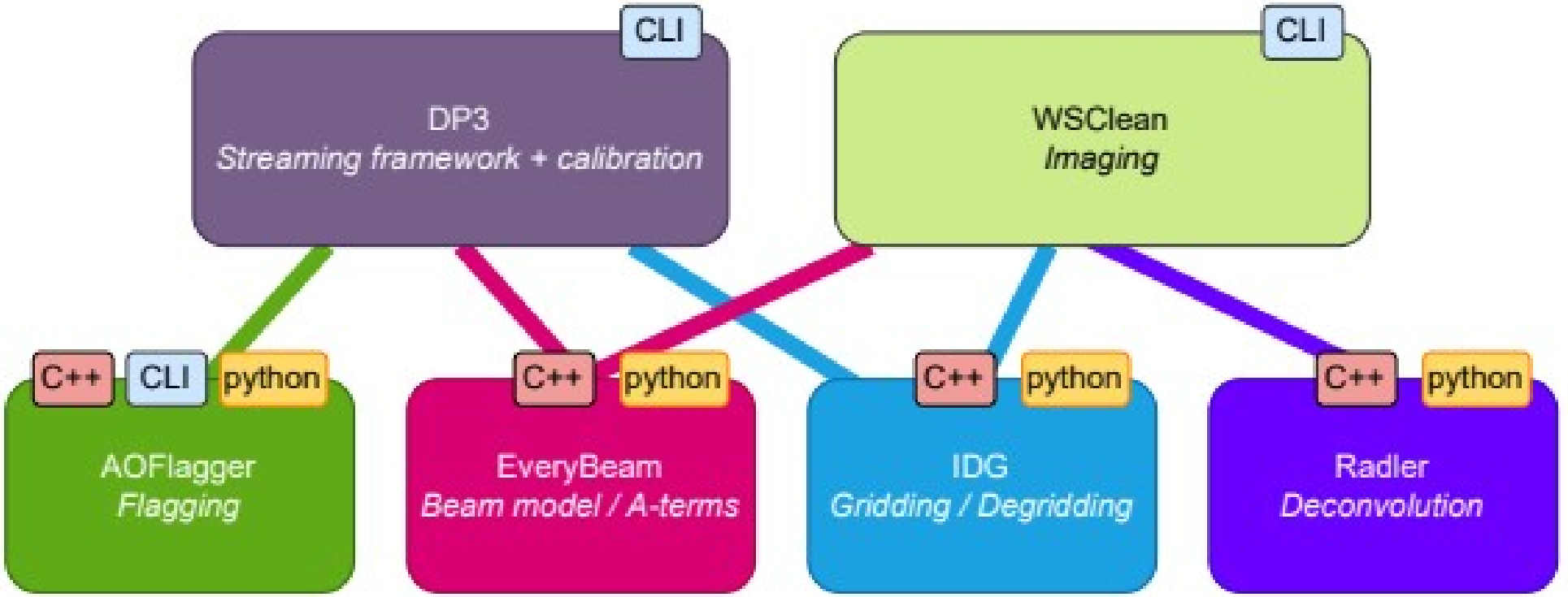
Radio ASTRONomy Toolkit



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Casacore

- Rework of older AIPS/CASA package
  - CASA can still be built now on top of Casacore
- Built of several subpackages with unique features
  - MS (libcasa_ms) – Storing UV-domain data
  - Images (libcasa_images) – N-dim images in world coordinates
  - Measures (libcasa_measures) Values in astronomical reference frame
  - Scimath (libcasa_scimath) N-dim linear and non-linear fitting
- Python bindings: https://github.com/casacore/python-casacore

Open Source Software

- Some (open) tools used by ASTRON
  - OpenMP
  - OpenMPI
  - SLURM
  - Gitlab
  - Grafana
  - (Py)Tango (SCADA)
  - Prometheus
  - Docker

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Open Source Software

- ASTRON potential improvement areas
  - CUDA (OpenCL / Vulkan)
  - WinCC (phasing out)
  - FPGA vendor IP blocks
  - Infiniband firmware
  - Office 365 (Kopano)
  - Slack (Mattermost)
  - Zoom (Jitsi)

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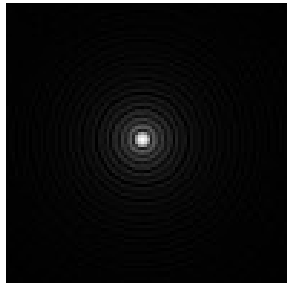
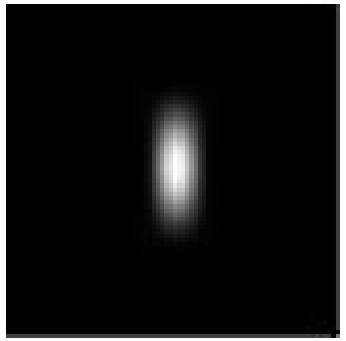
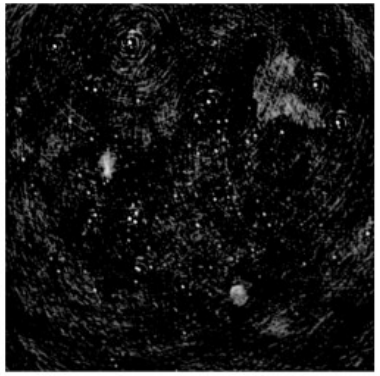
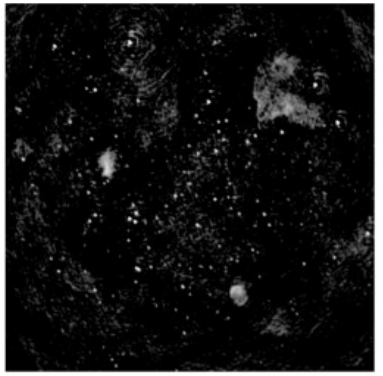
Imaging & Deconvolution

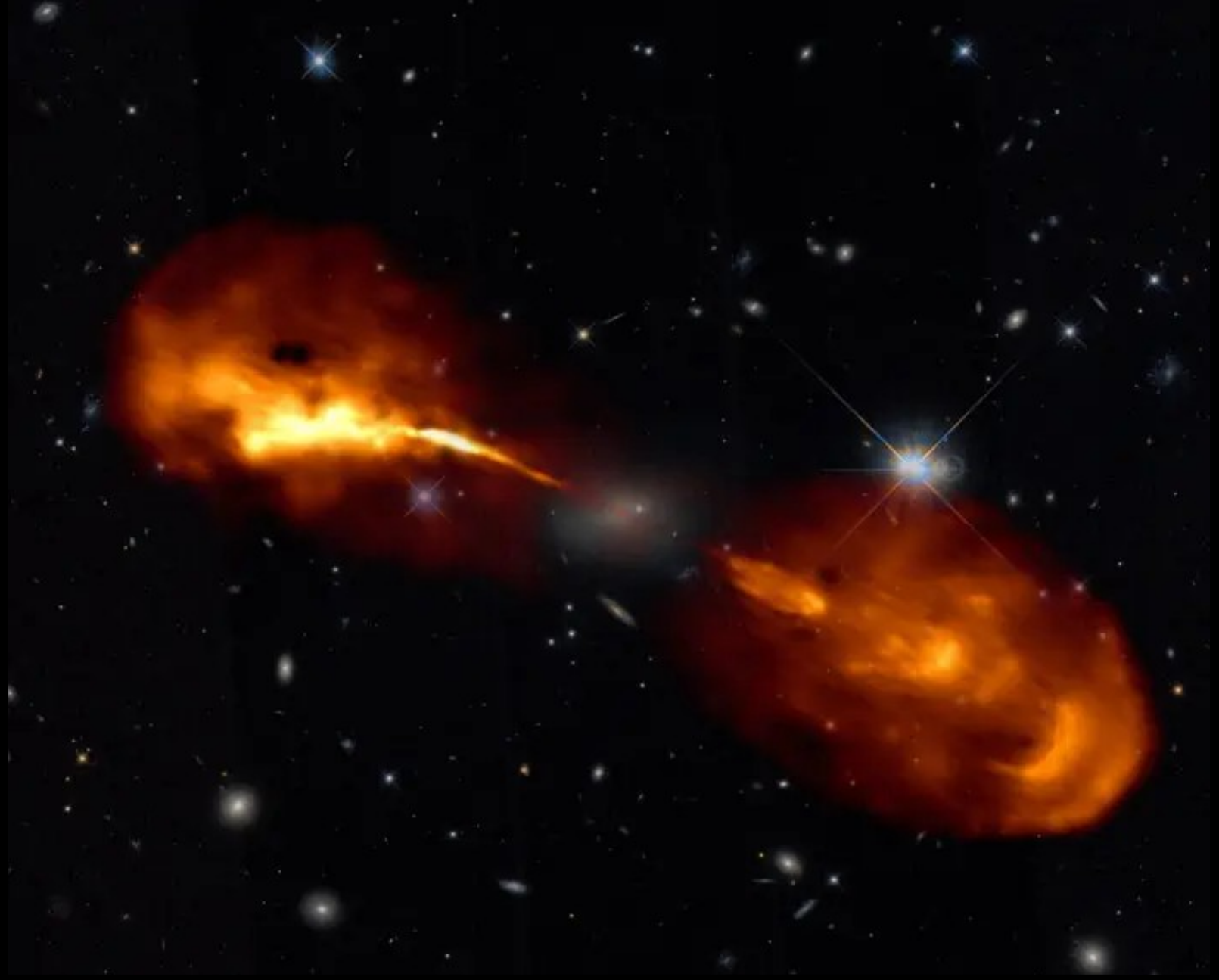








S. Van der Tol et al., "Image Domain Gridding: a fast method for convolutional resampling of visibilities", A&A 2018
A. R. Offringa et al., "An optimized algorithm for multiscale wideband deconvolution of radio astronomical images", MNRAS 2017



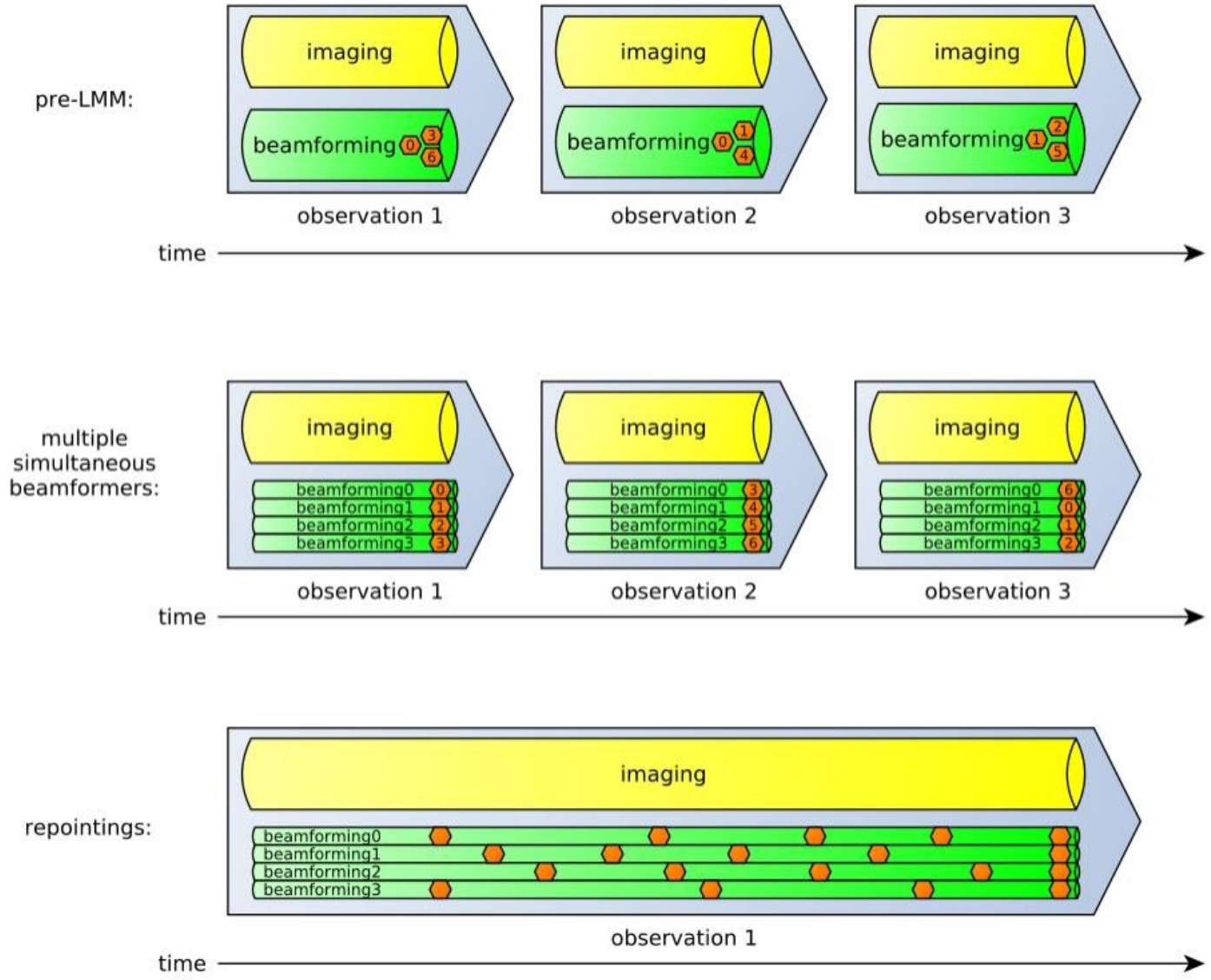
Origin of the ring structures in Hercules A - https://arxiv.org/abs/2108.07287

R. Timmerman; LOFAR & Hubble Space Telescope

LOFAR 2.0

- Big upgrade to LOFAR scheduled for end of 2024
  - Replacing WinCC with Grafana, Alerta & Prometheus
  - Using both LBA & HBA antennae in a single observation
  - Multiple beams / pointings per observation (Mega Mode)
  - Completely new SCADA system using (Py)Tango
  - Upgraded hardware (Uniboard 2)
  - Upgraded timing distribution (White Rabbit)

LOFAR Mega Mode



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Links

- https://git.astron.nl
- https://astron.nl
- https://tinyurl.com/10yearslofar
- https://www.astron.nl/lofartools/lofarmap.html
- https://dantalion.nl/knowledgetransfer.html