

### The VLBI Mode of the Universal Effelsberg Direct Digitization (EDD) System

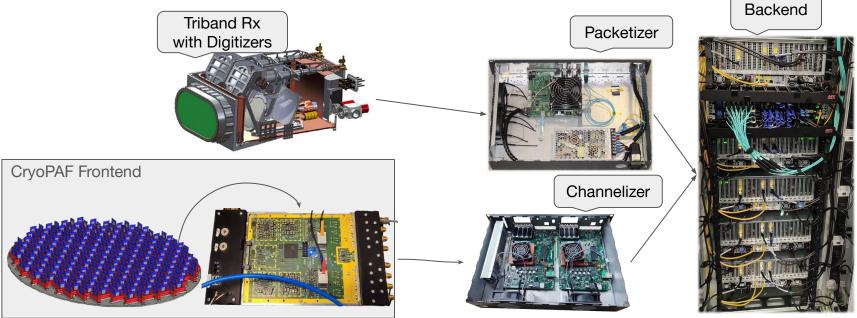
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Max Planck Institute for Radio Astronomy 9th International VLBI Technology Workshop @ MIT Haystack Observatory





# The EDD: From Feed to Disk



The EDD (Effelsberg Direct Digitization) is a modular framework for radio astronomy observing systems, covering receivers, analogue signal conditioning, time distribution units, digitization, packetization and backend signal processing.



# Instruments operating with the EDD



#### Effelsberg Radio Telescope

- Diameter: 100m
- 4 EDD receivers (full)
- 11 other receivers are not direct digitized but can be fed into the EDD backend
- Specifications



#### SKA Prototype Dish

- aka SKAMPI
- Diameter: 6m
- robotic telescope
- 2 EDD receivers
- S-Band 1.8 3.6 GHz
- Ku-Band



#### **Thai National Radio Telescope**

- Diameter: 40m
- 2 EDD receivers
- L-Band 1 1.8 GHz
- K-Band
- EDD compatible Rx planned (Cx-Band)

### **Planned Instruments**

#### **Botswana Telescope**

- SKAMPI Design
- 2 EDD Receiver
- S-Band (TBD)
- C-Band (TBD)

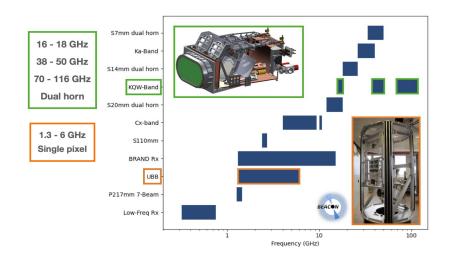
#### **ARGOS (Prototype)**

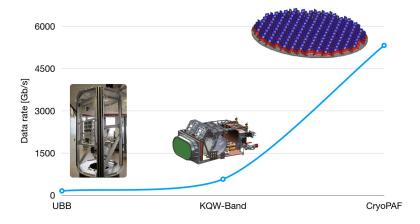
- First Interferometer using the EDD
- 5 Antennas
- Aimed bandwidth
- 1-2 GHz
- 2-3 GHz



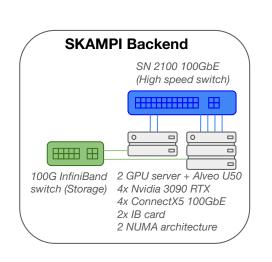


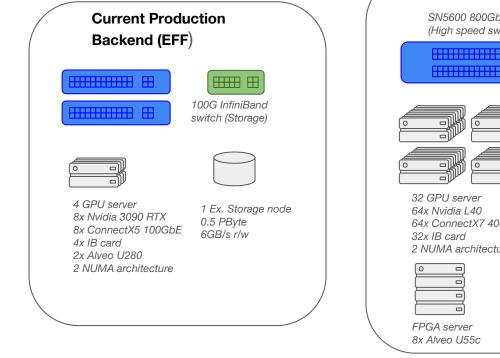
### **Challenging Future Rx Systems**





## More Bandwidth, More Feeds More Computing





#### Scale the cluster to the demands of receivers, scientist and modes



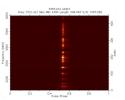
SN5600 800GbE (High speed switch)	QM9700 InfiniBand switch (Storage)
32 GPU server 64x Nvidia L40 64x ConnectX7 400GbE 32x IB card 2 NUMA architecture	4 Ex. Storage nodes 4+ PByte 4x 20GB/s r/w
FPGA server 8x Alveo U55c	VM Farm

EDGAR Cluster (EFF)



### What makes the EDD Backend 'universal'?



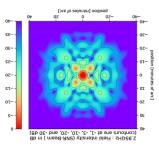


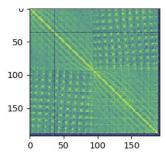
### Science Modes

- Spectroscopy
- Pulsar timing
- Pulsar & Transient
  search recording
- VLBI recording

#### Instruments

- Single pixel feeds
- Multi-pixel feeds
- Phased array feeds (in progress)
- Interferometer (in progress)



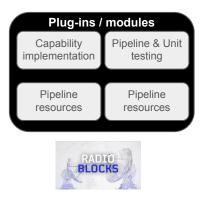




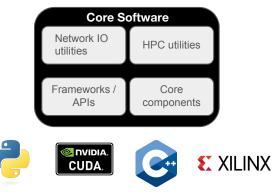
The "EDD backend" is not a specific instance of a backend, but a framework for the development, deployment and operation of radio astronomy backends on COTS hardware.



### **Overview of the EDD Backend Software**



- edd\_dbbc VLBI processing
- edd\_paf Multi-antenna processing
- edd\_pfb Channelization / Synthesis
- edd transient Transient search
- <u>edd moonbounce</u> Educational



- psrdada cpp Graph processing and IPC
- <u>mpikat</u> Python control framework with HPC utilities, CLI wrappers, process management
- <u>mkrecv</u> / <u>mksend</u> CLIs for high speed data capture and transmission

Orchestration Software		
Resource Inventory	Build & Deploy	
System testing	Resource Provisioning	
docker ANS	GitLab	

- Site-specific resource management
- Dockerized service deployment
- Automated CICD Docker image and Debian package builds



#### **Communications** and Services Meta Telescope data Control source Site-specific Site-specific push-to pull-from Monitoring interface interface A deployed and Frontend In-memory provisioned backend key-value store recording VDIF data Master TMI server Not all services shown Controller Grafana redis Long-term time Distributed series DB Filesystem DigPack **Digital Down** Packetizer **VDIF** Packer () influxdb Controller Converter BeeGFS\* CAM Network 0 $\cap$ KATCP High-speed data network sidecars Storage network

Niclas Esser



## **VLBI** plug-in

E edd dbbc

#### EDD Pipelines for VLBI

- Digital down converter
- VDIF packer
- Real-time plotter •
- Recorder / e-VLBI

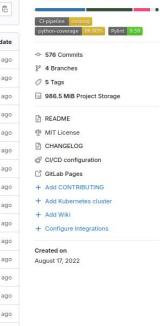
Comprehensive CI Pipeline with build, testing, benchmarks, code quality metric and documentation

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Update .gitlab-ci.yml file · Niclas Esser authored 2 w		Running 🕢 7885e346 🛱	
Name	Last commit	Last update	
🖻 cpp	Included exculded tests, debug CI pipel	1 month ago	
🖹 dbbc	Changes due to mk_tools	3 weeks ago	
🖹 doc	README.md doc; bug fix	1 year ago	
🗅 notebooks	Handle spillover samples in VDIFPacker	1 year ago	
🖹 roles	Bump mpikat version	3 weeks ago	
🖻 scripts	Changes due to mk_tools	3 weeks ago	
🖹 tests	Optimize VDIF unpacking	4 months ago	
Coveragerc	Update .coveragerc	7 months ago	
♦ .gitattributes	Added scripts/ folder	1 year ago	
🚸 .gitignore	2	7 months ago	
😝 .gitlab-ci.yml	Update .gitlab-ci.yml file - do not use in	2 weeks ago	
🕒 .pylintrc	pylint	1 year ago	
M+ CHANGELOG.md	Refactor changes - see CHANGELOG.md	1 year ago	
C LICENSE	Added ansible roles/ and versioing	1 year ago	
M* README.md	Update file README.md	1 year ago	
🖹 galaxy.yml	Added ansible galaxy.yml file	1 year ago	
🌣 pyproject.toml		11 months ago	
皆 requirements.yml	CI	1 month ago	
D run_tests.sh	Pylint	7 months ago	



#### This repository contains VLBI modes implemented within the EDD-system

△ ~ ☆ Star 1 % Fork 0



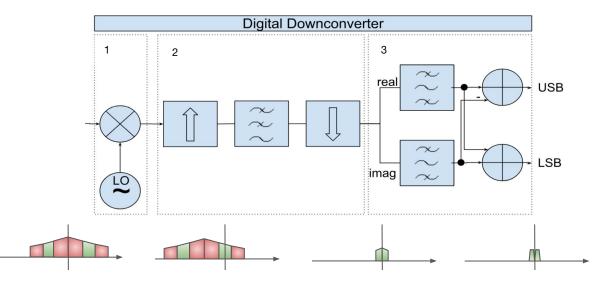
https://gitlab.mpcdf.mpg.de/mpifr-bdg/edd\_dbbc



### **EDD Pipelines: Digital Down Converter I**

An EDD Pipeline selecting arbitrary bands from the baseband signal

- 1. Mixing stage
- 2. Resampling: up-, filtering and downsampling
- 3. Hilbert bandpass filtering





### **EDD Pipelines: Digital Down Converter II**

#### Just downsampling is not enough

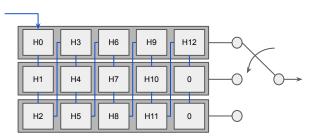
- $\rightarrow$  EDD Rx not always aligned to VLBI bands
- $\rightarrow$  Upsampling is often required

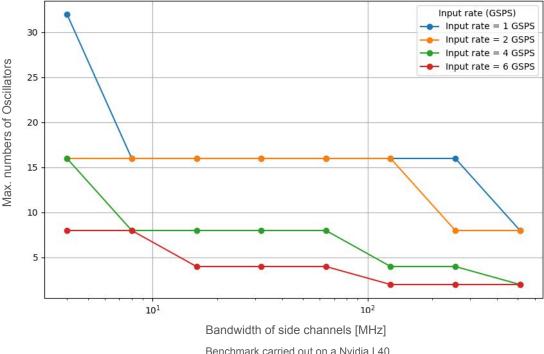
#### Example SKAMPI S-Band:

- Initial sampling rate: 3.6 GHz
- Desired sampling rate: 512 MHz
- Upsample factor U = 32 = Icm(3600, 512) / 3600

#### **Computational Costs:**

- Naive FIR convolution:  $\mathcal{O}(K \times U \times N)$
- Polyphase resample:  $\mathcal{O}(K / U \times N), U^2$  cheaper
- $\rightarrow$  Polyphase resampling saves a lot memory, too







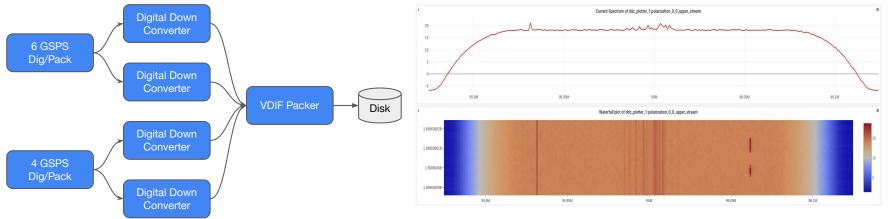
### EDD Pipelines: VDIF Packer

- Re-quantization from float32, 12,10,8-bit int to 2-bit
- Cheap and highly parallelizable operation
- GPU and multi-threaded CPU implementation
- A single VDIF Packer handles multiple DDC streams
- Rudimentary data dumps

### **Real-time Plotter**

- FFTed snapshots from DDC streams
- Sends spectra to Redis
- Grafana live dashboard







### **EDD** Pipelines - Recorder and e-VLBI



We need a proper recording pipeline to fulfill VLBI recording standards



Running and commanding jive5ab from an EDD pipeline



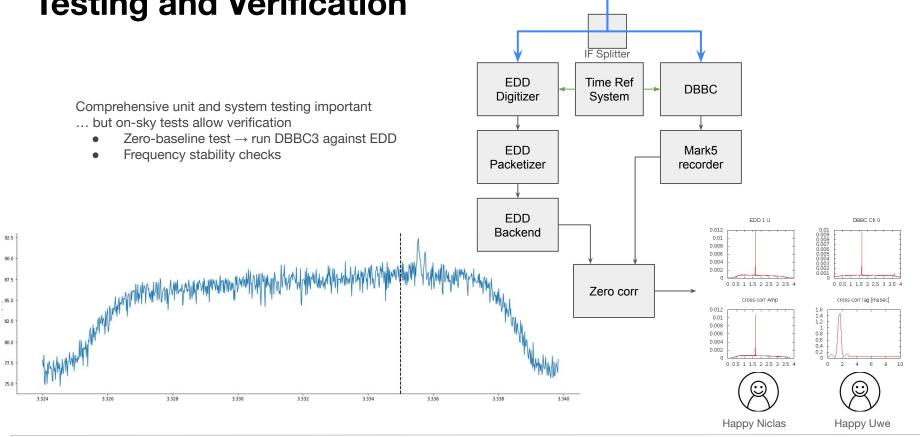
Potentially enables e-VLBI operations



Under construction



### **Testing and Verification**





Slowake

Rumän

Bulgar

Griechenland

Libyen

Zentralafrikanische

Republik

Demokratisch Republik Kong

Athen Aðnyg

Österreich

Niederlande Berline

Niger

Aquatorialquinea

Kone

Frankreich

Mali

Burkina

Faso

Ghana

dian Accra

Benin

Togo

### **First Experiment**

#### **Participants**

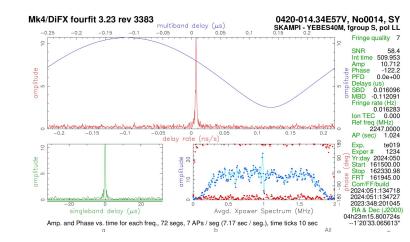
- SKAMPI
- Medicina
- Yebes
- Effelsberg (DBBC/EDD)

SKAMPI's clock offset 130 us  $\rightarrow$  Under investigation

Fringes between all stations and backends!

Longest Baseline: 8800 km

Observed 2 x 4 MHz @ 2.25 GHz



The very first experiment failed due to a typo in the source coordinates



### **Follow-up Experiments**



- Observed various extra galactic sources
- Fringes in all scans
- Frist Fringe detected within Thailand
- Enables international collaborations with TNRT (e.g. EVN)

#### **TANAMI** with SKAMPI

- 24h test observation
- Fringes detected
- Only partially successful as full seconds offsets were found

#### $\rightarrow$ Bug is fixed now

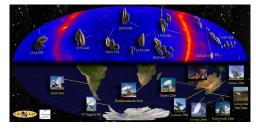
#### **TNRT, FAST** and Tianma

- Thai and Chinese collaboration
- Without support from MPIfR
- Fringes detected













### Outlook

### **Planned Collaborations**

- <u>The Big Milestone</u>: Join the EVN with SKAMPI and EFF
- Contribution to the TANAMI project with SKAMPI

#### **Further Developments (VLBI)**

- Standardized recording with Field System-like meta data logging
- Support for e-VLBI
- Multi-beam VLBI with ARGOS and CryoPAF within RadioBlocks
- Various features...

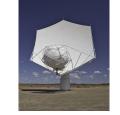




### Take away

- The EDD backend is ready for VLBI operations even not completely automated
- Adaptable and scale computing hard- and software to fulfil the needs of high data rates Rx
- GPUs are suited for VLBI recording
- EDD has proven itself at various stations in different science modes







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### Thank you for listening

All EDD Software is open source, feel free to use https://gitlab.mpcdf.mpg.de/mpifr-bdg

