interTwin

Detecting pulsar signals in vast real-time data streams with a machine learning / digital twin-based pipeline

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Our Project and Interdisciplinary Team

ML-PPA =
ML-based Pipeline for Pulsar Analysis

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External:

Radio telescope data rates

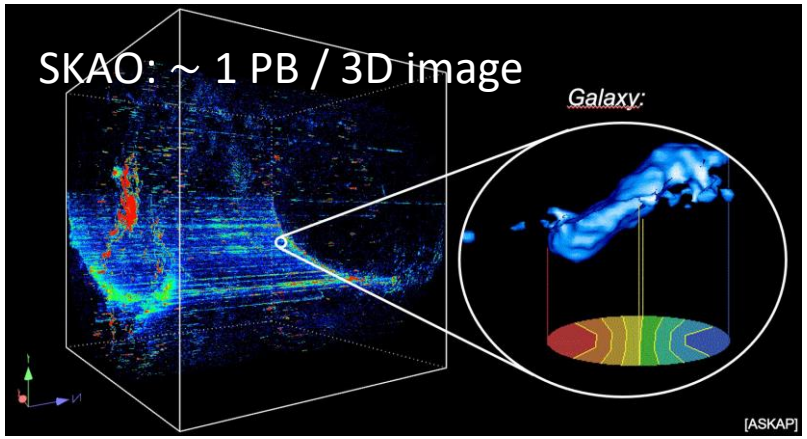
Radio telescope name	Radio telescope exterior	Bitrate per beam	Total bitrate
Effelsberg		P210-7: 11.04 Gb /s	**77 Gb / s (7)**
		UWB: 290 Gb / s	**290 Gb / s (1)**
MeerKAT		107 Mb / s	**0.1 Tb / s (~1024 beams)**
Square Kilometer Array		~ 1 Gb / s	**20 Tb / s (>2200 beams)**

Data Irreversibility

o Only a tiny part of the data can be archived

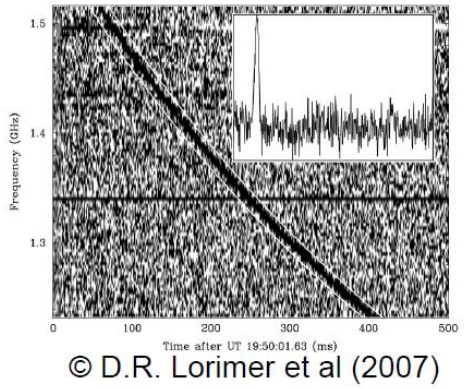
o Decisions on what to keep are based on incomplete information

⇒ irreversible loss of information



Transients & Pulsars

Crab pulsar with surroundings



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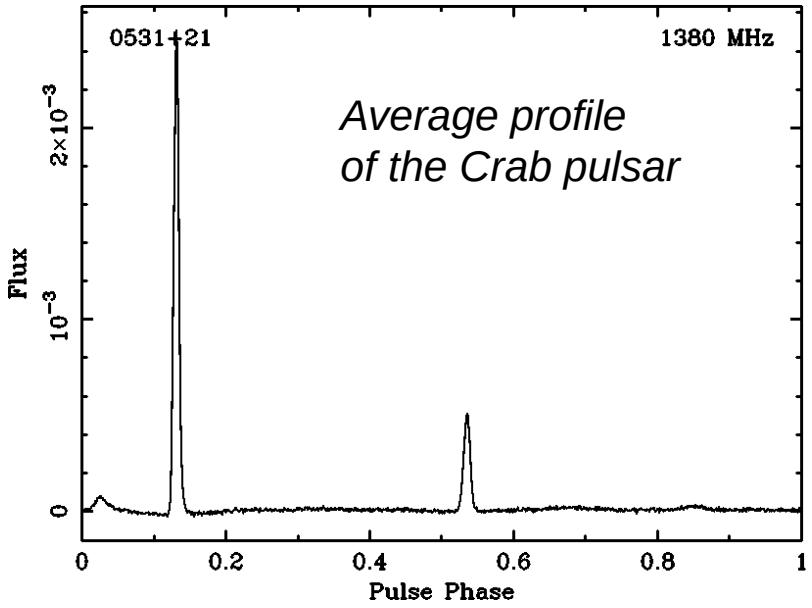
A transient



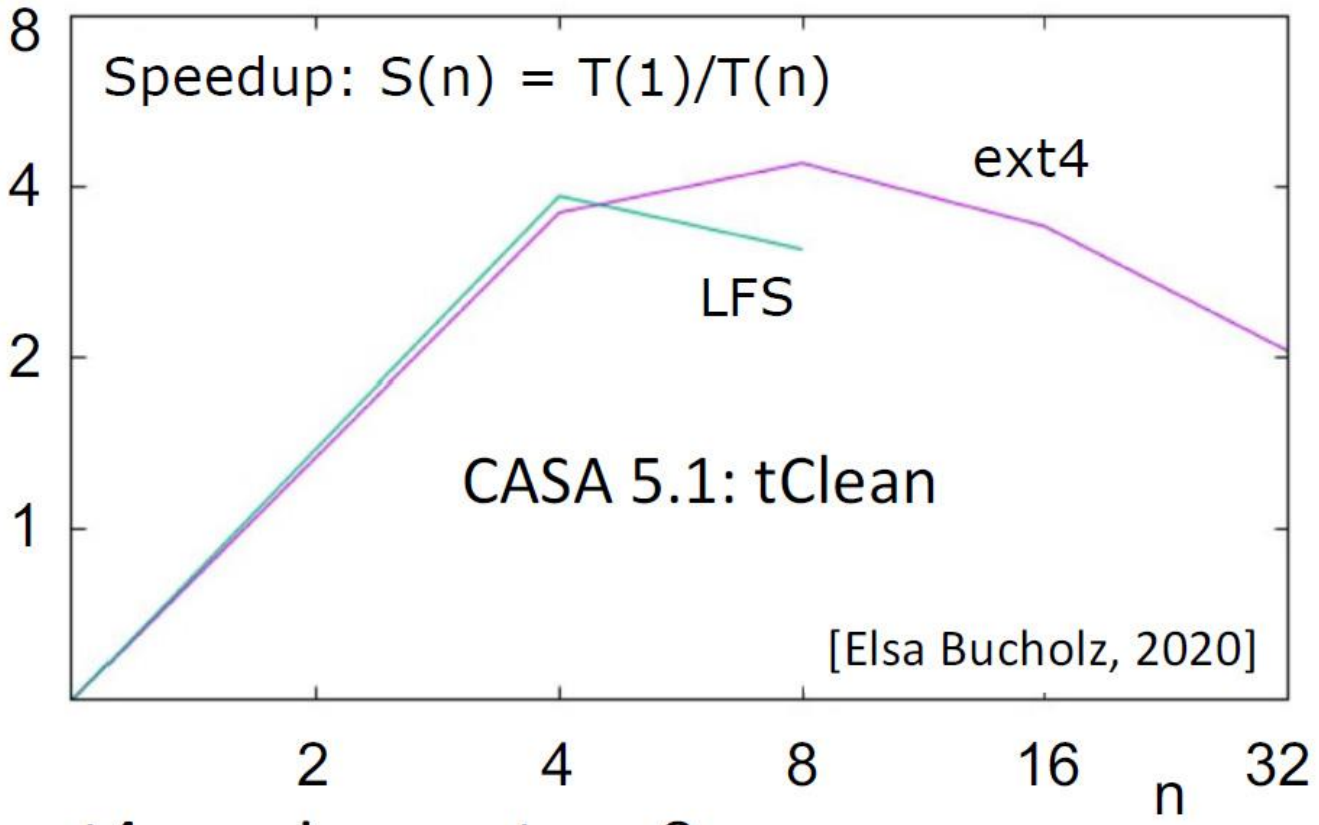
3 focus points:

- **new gen of radio telescopes threatens to flood us with data**
- **search for transients, using pulsars as proxies**
- **scalability of new data pipelines**

100m Effelsberg radio telescope

MeerKAT array (South Africa)

Common Astronomy Software Applications (CASA) testing



ext4: maximum at n = 8 cores

LFS: **CASA crashes for n > 8 cores ⇒ ML-PPA**

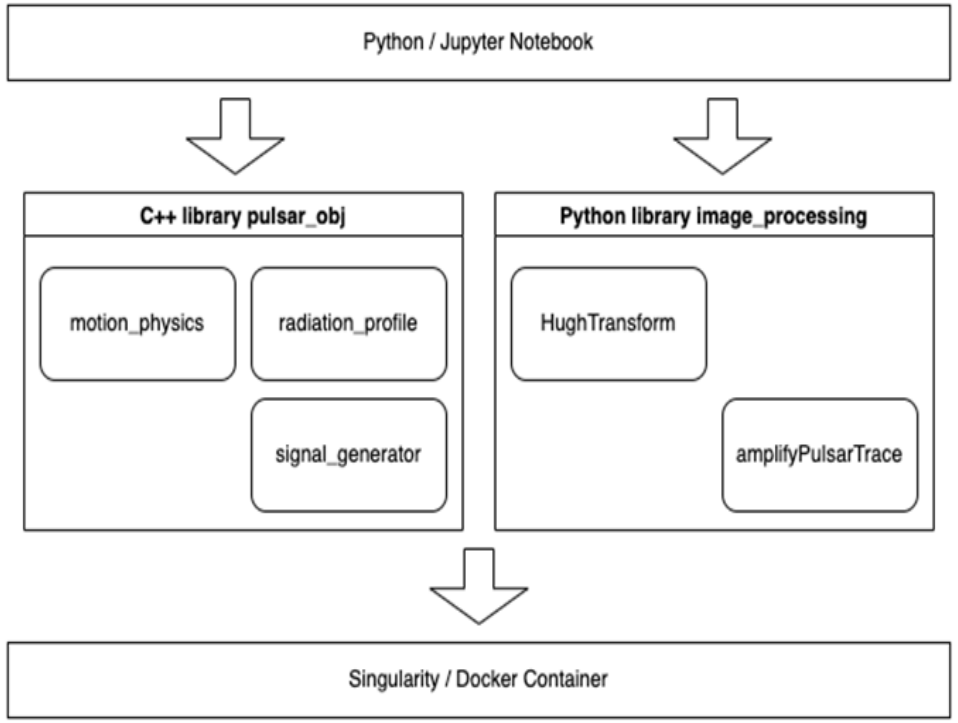
- Standard and universal data reduction software suite for radio astronomy
- Handles scaling poorly,
  need an HPC-capable alternative

ML-PPA v. 0.1

Repository: (https://gitlab-p4n.aip.de/punch_public/ml-ppa)

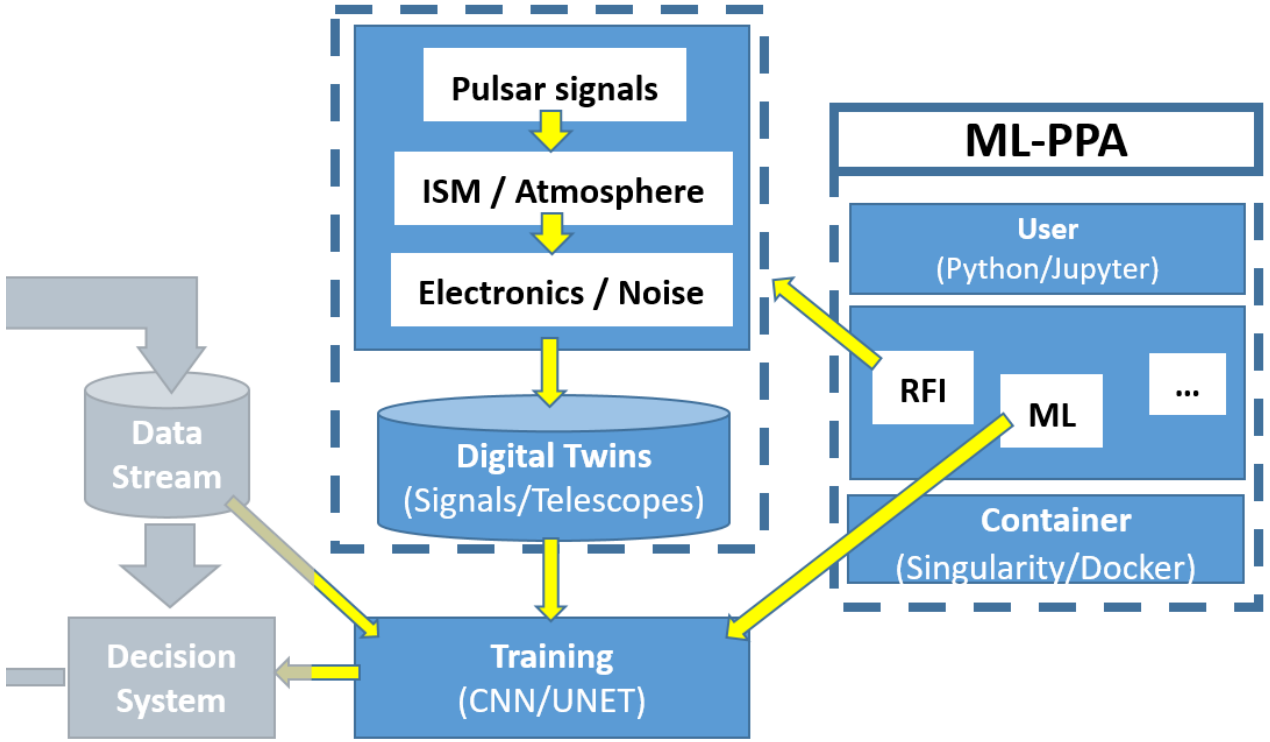
- PulsarDT: physics-based DT (Python)
- PulsarRFI_Gen: empirical DT (Python)
- PulsarRFI_NN: ML-classifier (Python)
- PulsarDT++: C++ implementation of all ML-PPA components => HPC

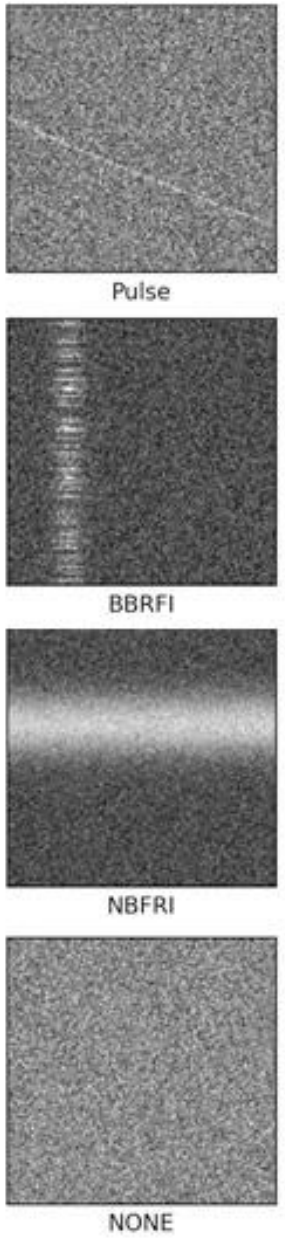
+ ~50 page **paper** with detailed description

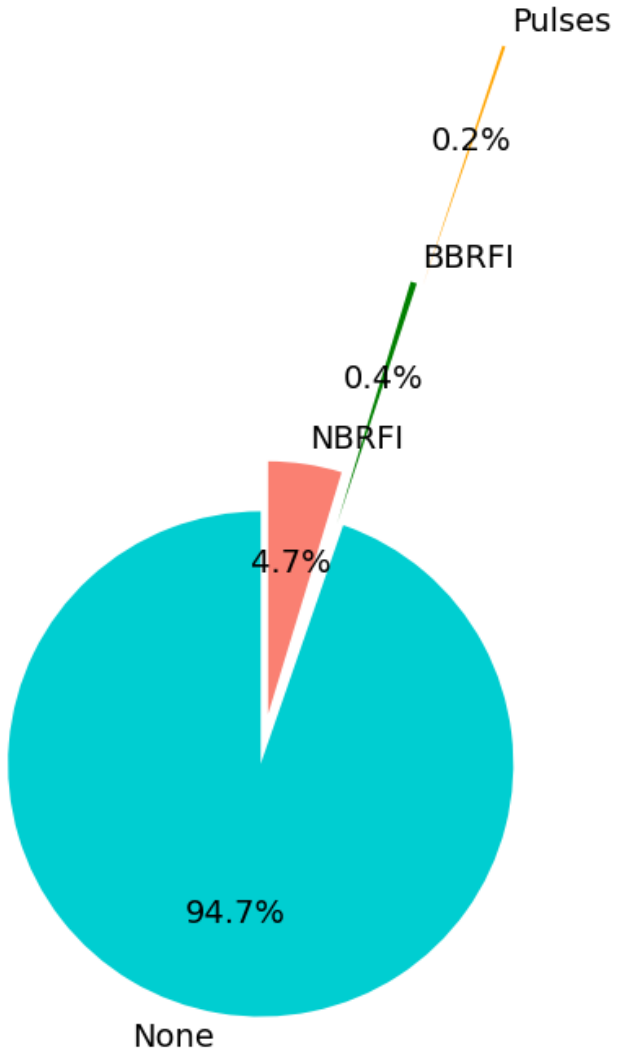


Data Classifier

ML-based **data classifier**, needs **DT** to supply **training data**.

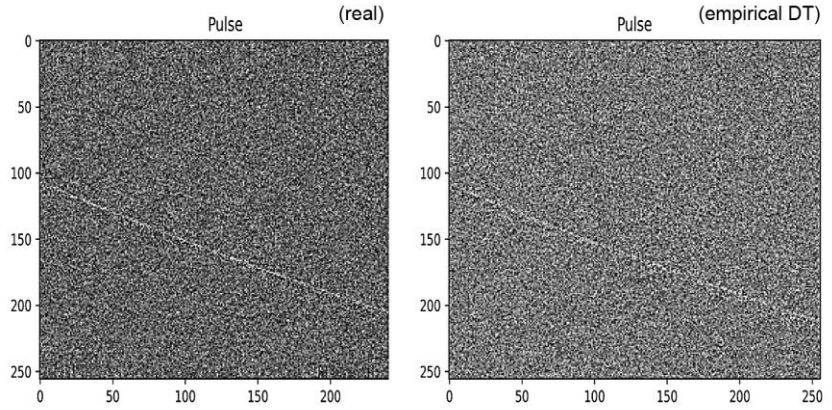


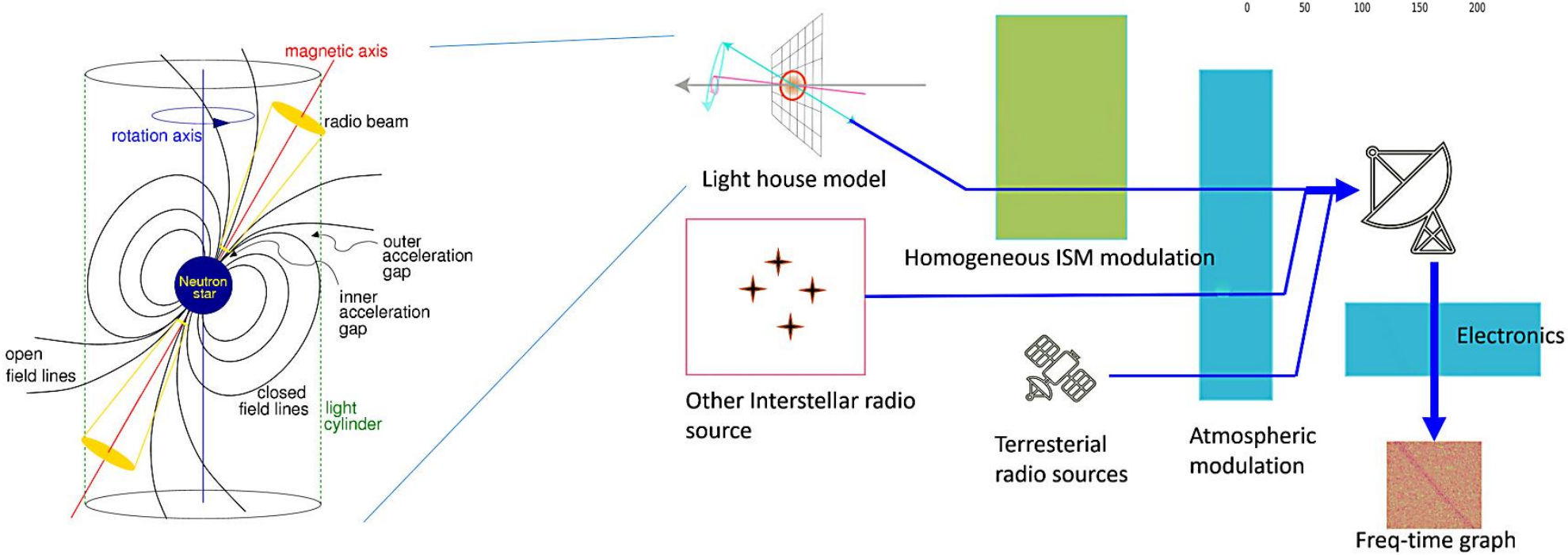




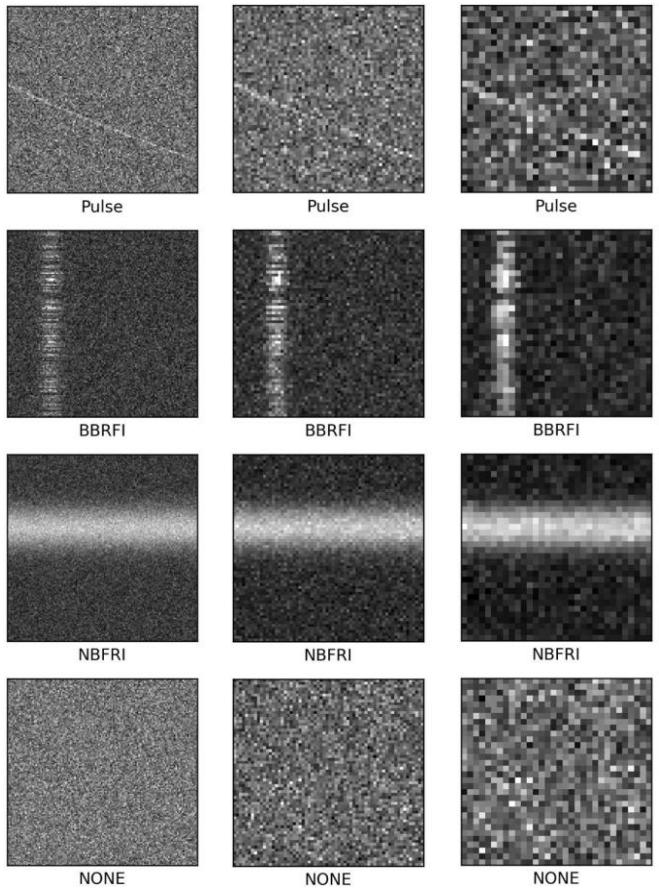
Digital Twins

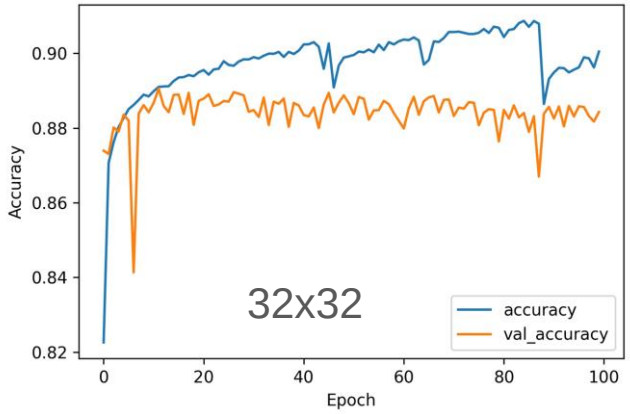
2 types of DT: **physics-driven** (main) and **empirical** (auxiliary)

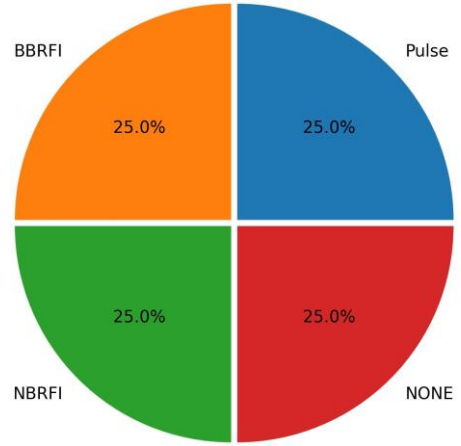


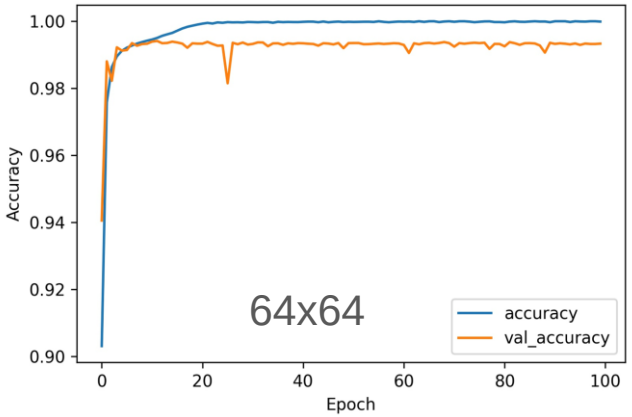


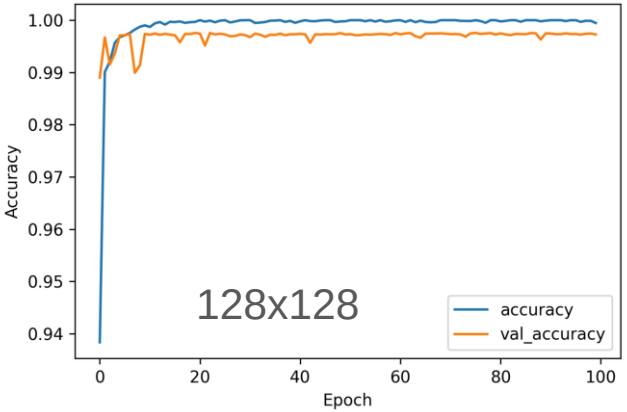
Accuracy of the model trained on synthetic data





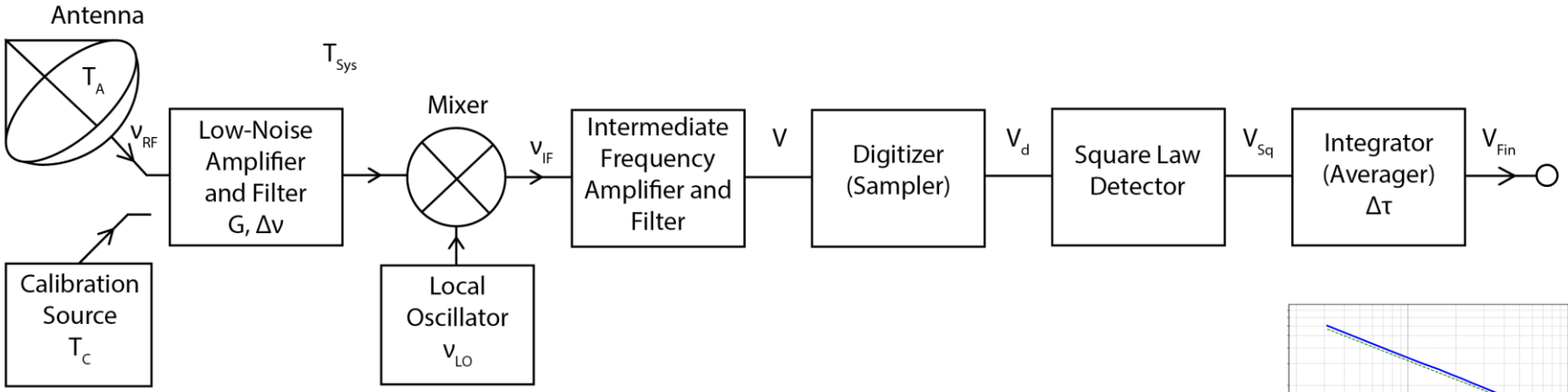






Noise Analysis

Simple Radiometer (Superheterodine Single Sideband) model predicts **white noise**:



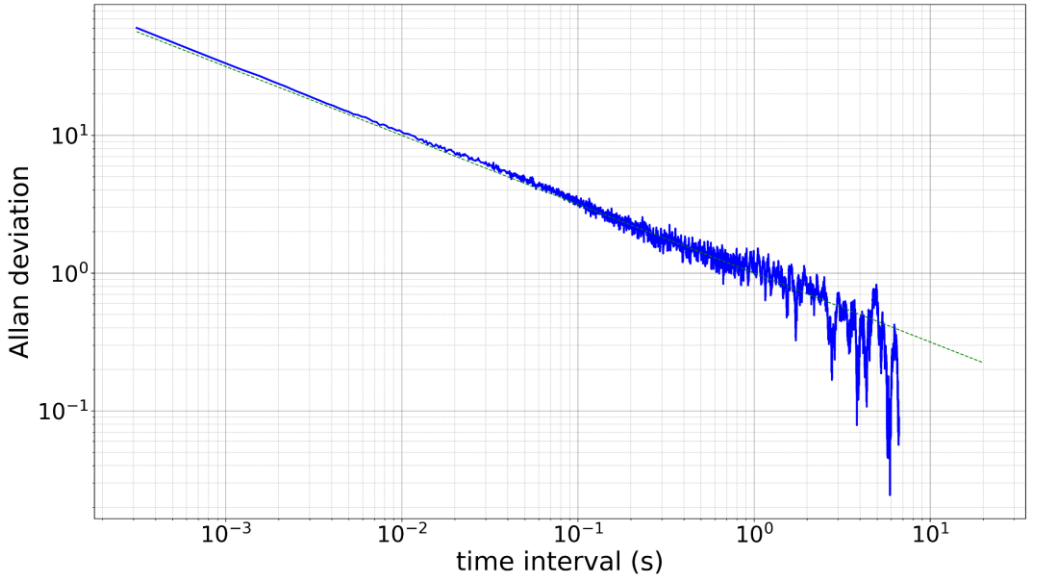
…and it is **confirmed** by statistical analysis of **real data**:

$$T_{\mathrm{Sys}} = T_{\mathrm{rad}} + T_{\mathrm{cmb}} + T_{\mathrm{bg}} + T_{\mathrm{atm}} + T_{\mathrm{spill}} + T_{\Omega}$$

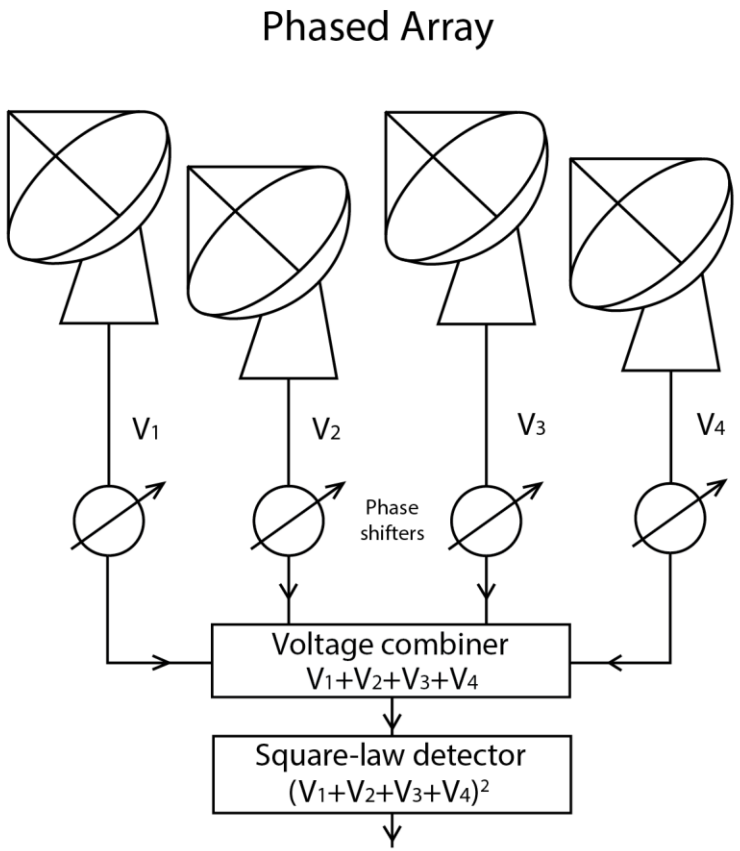
$$\langle V_{\mathrm{Fin}_T} \rangle = T_A + T_{\mathrm{Sys}}$$

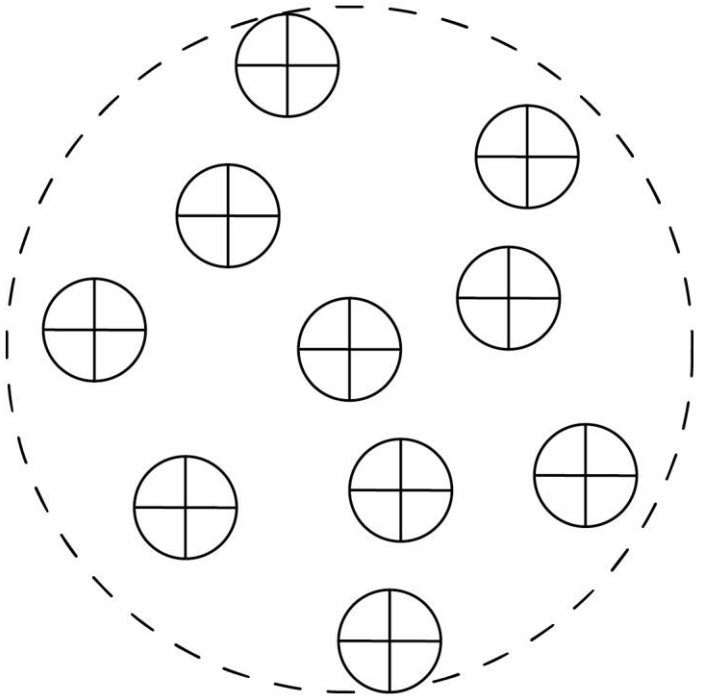
$$\sigma_{\mathrm{Fin}_T} = \frac{T_A + T_{\mathrm{Sys}}}{\sqrt{\Delta\nu\Delta\tau}}.$$

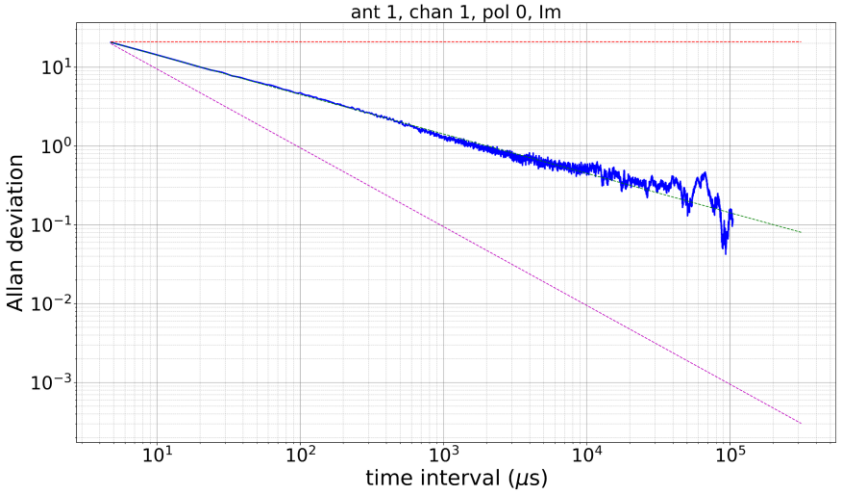
$$\mathrm{SNR} \approx \frac{T_A}{T_{\mathrm{Sys}}} \sqrt{\Delta\nu\Delta\tau}.$$

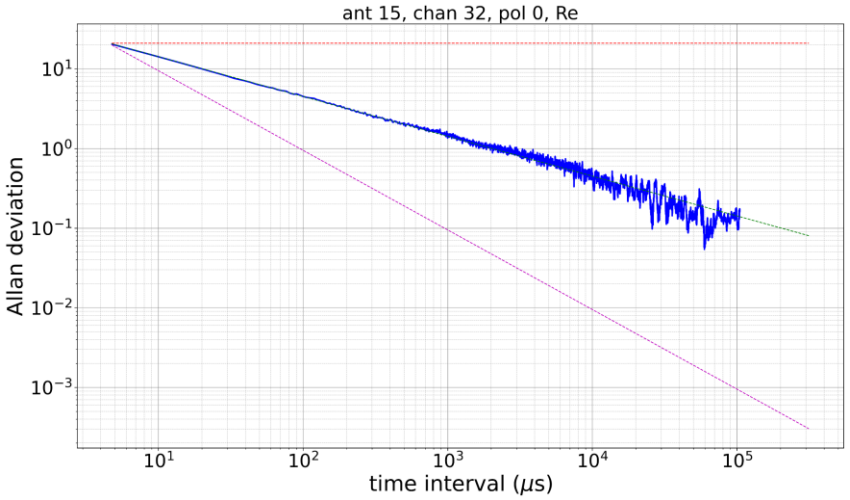


Applicability to arrays (like MeerKAT)



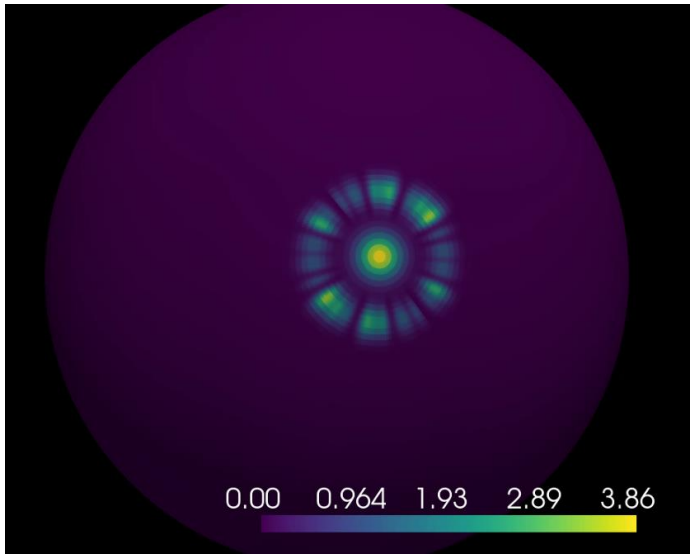


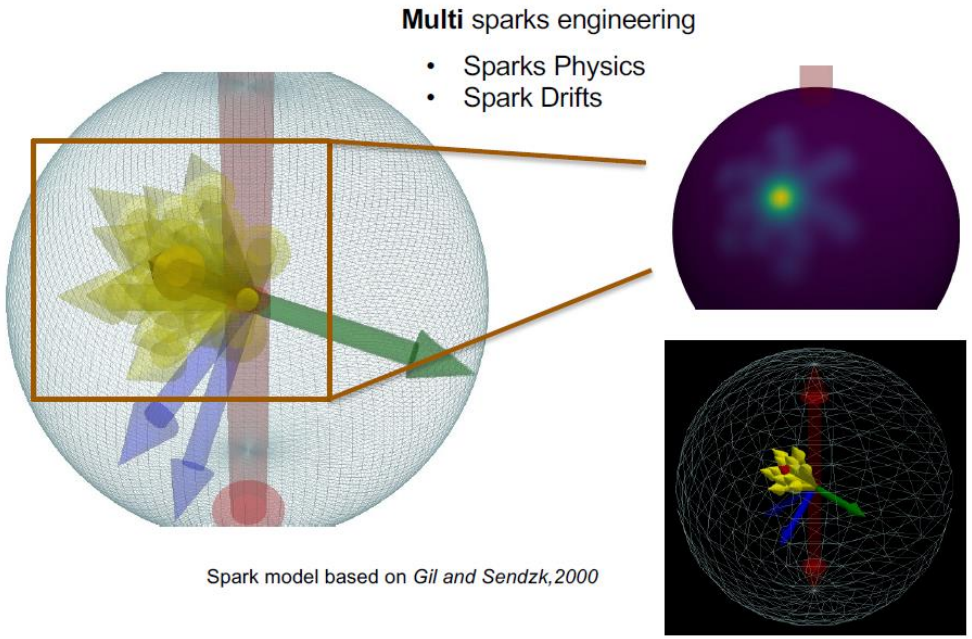




Status & plans

- Data
  - more Effelsberg data (other pulsars)
  - MeerKAT data
- Physics-driven DT
  - better pulsar model (beam properties etc.)
  - improving ISM model
  - interface
- ML-classifier
  - improving low SNR performance (exploring different ML architecture)
  - distributed training (HeAT, Horovod)
  - de-dispersion (TransientX)
- Deployment and HPC testing (different data centers)
- New release (v. 0.2) soon





Thank you!

Questions?

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