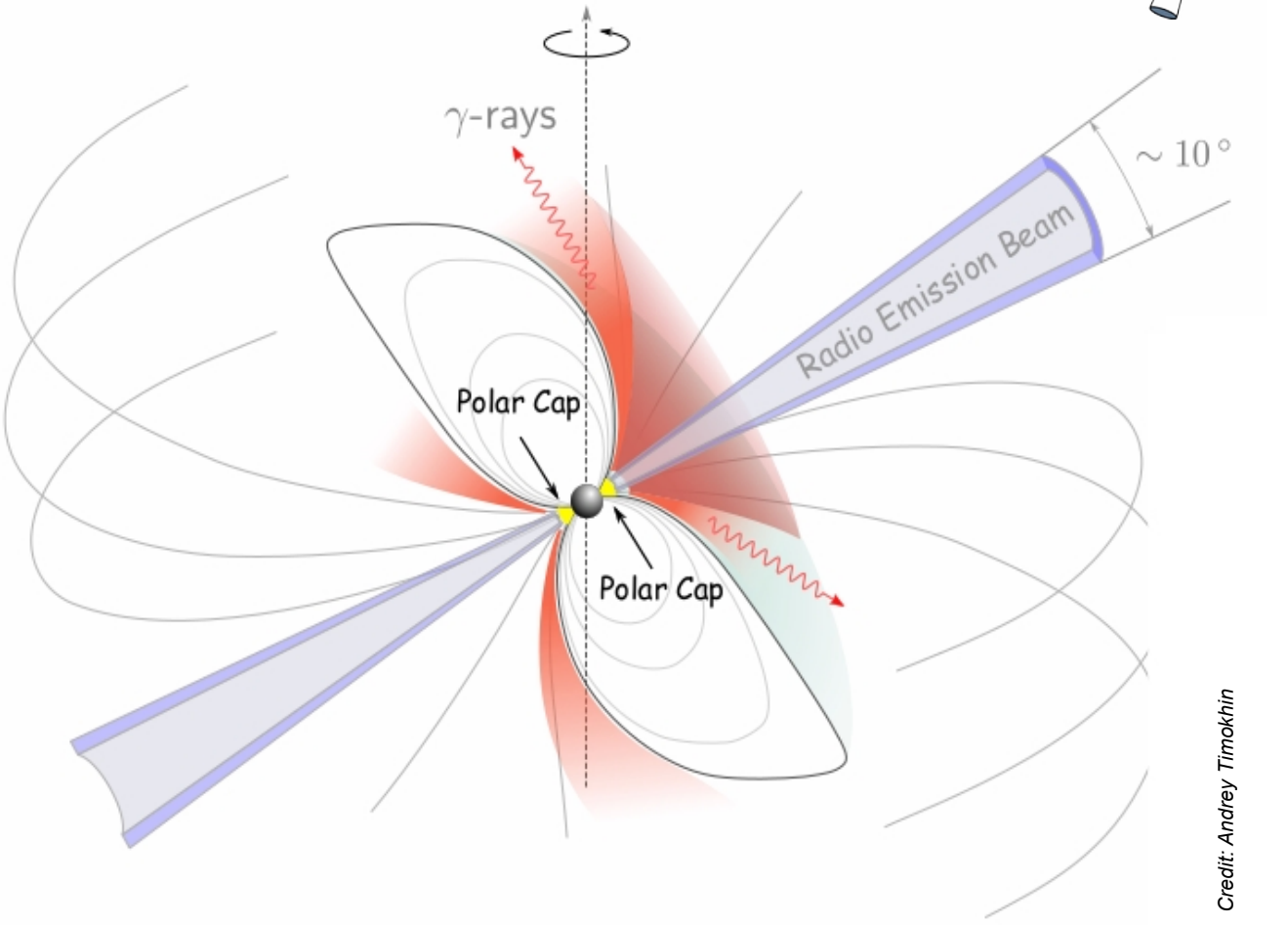
LOFAR software landscape:

# LOFAR2 Pulsar Pipelines

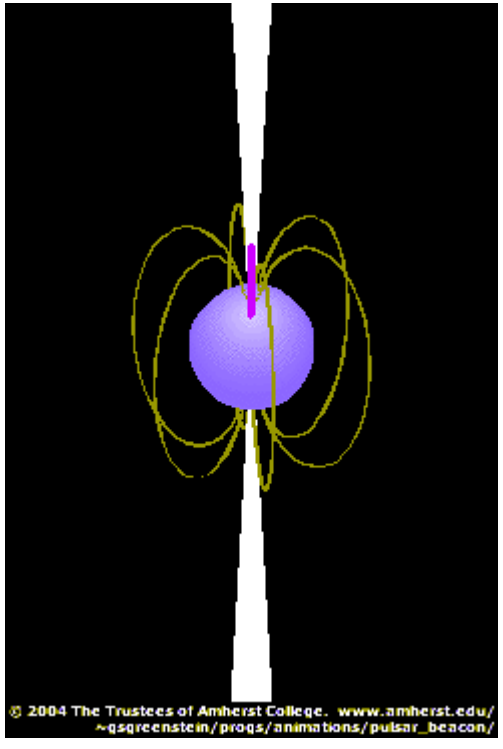
**Vlad Kondratiev**

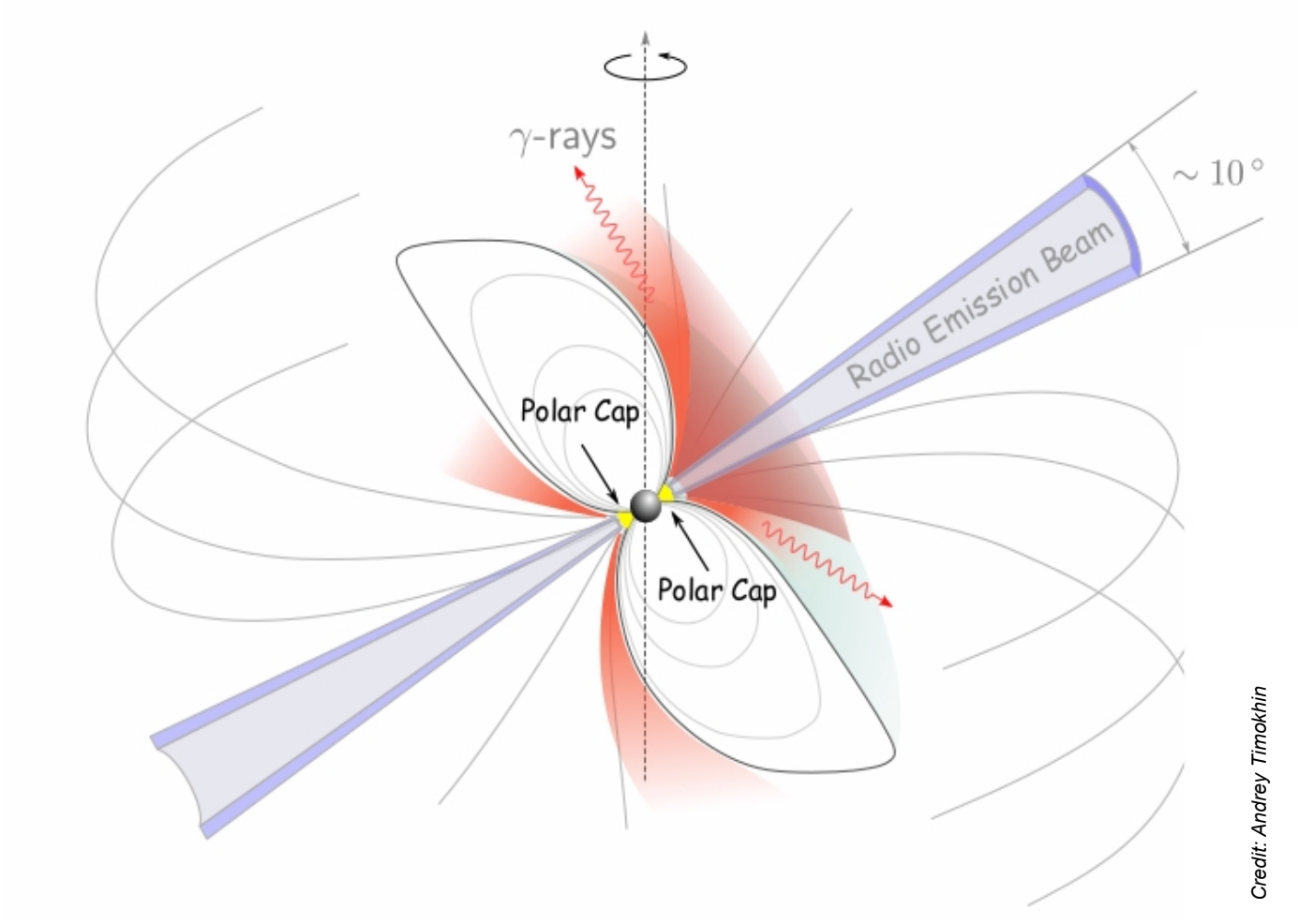
***(ASTRON)***



# What is pulsar?

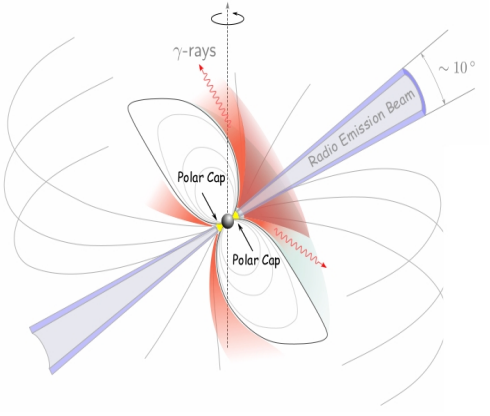
rapidly rotating
highly-magnetised neutron star,
«electric lighthouse»



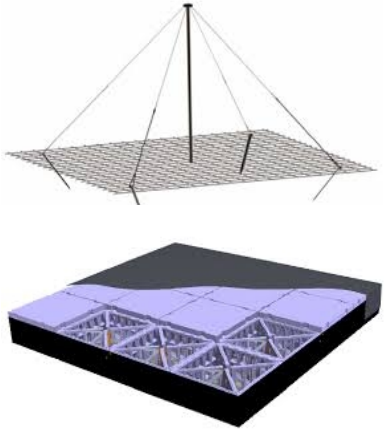




Credit: Andrey Timokhin

# Data flow




radio emission

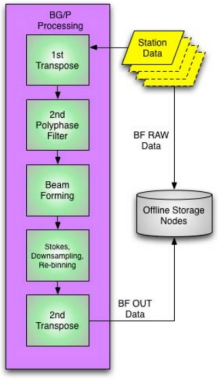


raw data

Cobalt



Cobalt pipeline






CEP6

Pulsar Pipelines



LOFAR Tape Archive

# LOFAR2
# Pulsar Pipelines

COMMON WORKFLOW LANGUAGE

- Pulsar Folding
- Fly's Eye (FE)
- PSRFITS
- Re-digitization
- Gridding
- Dynspec

Centrally run on CEP6

# LOFAR2
# Pulsar Pipelines




*a.k.a.*

**PulP2**

*or*

**PulP2 pipelines**

- Pulsar Folding
- Fly's Eye (FE)
- PSRFITS
- Re-digitization
- Gridding
- Dynspec

Centrally run on CEP6

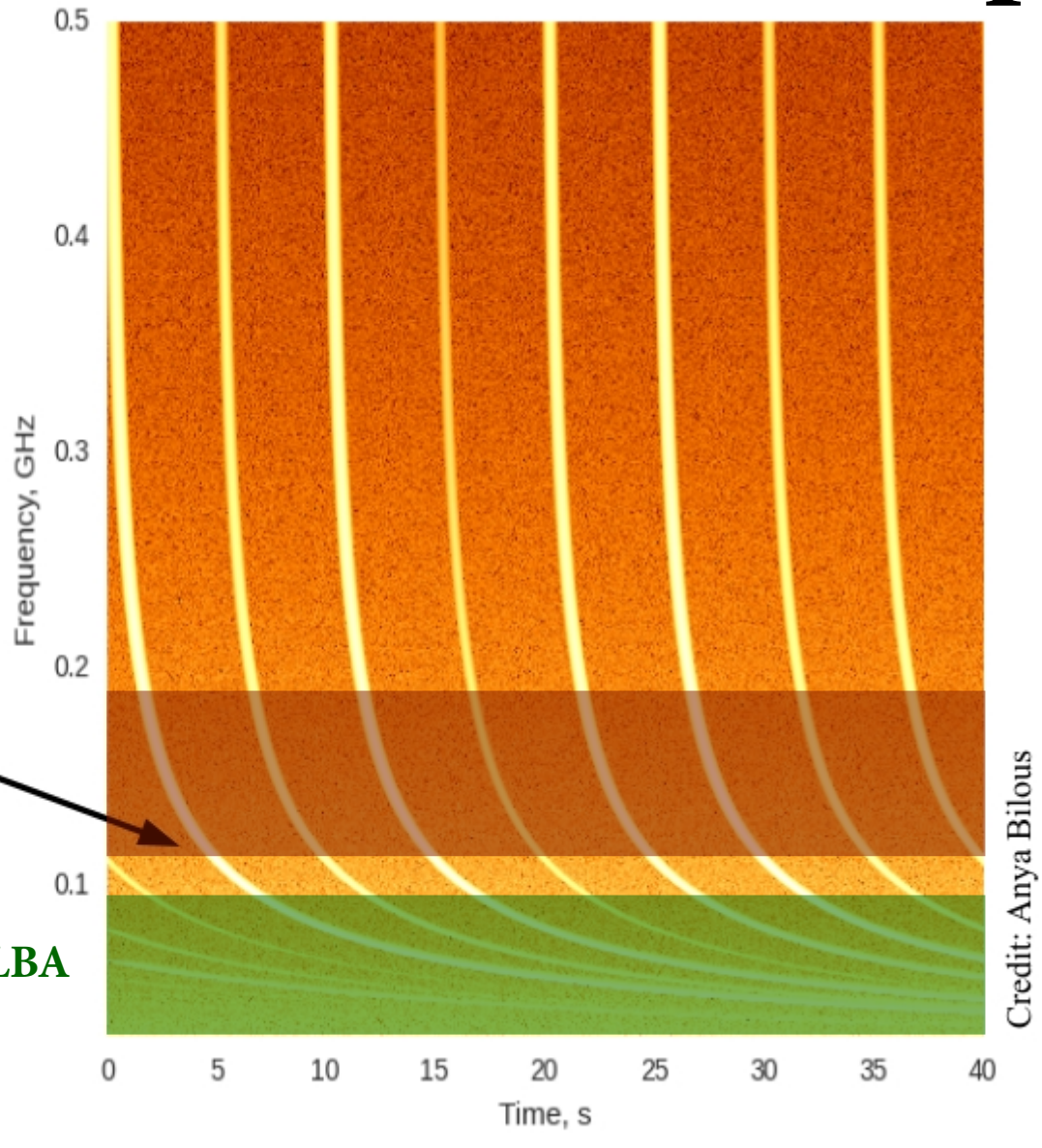
# Dispersion

**Simulated ultra-broadband pulse recording**

DM = 15 pc cm$^{-3}$
P = 5 s

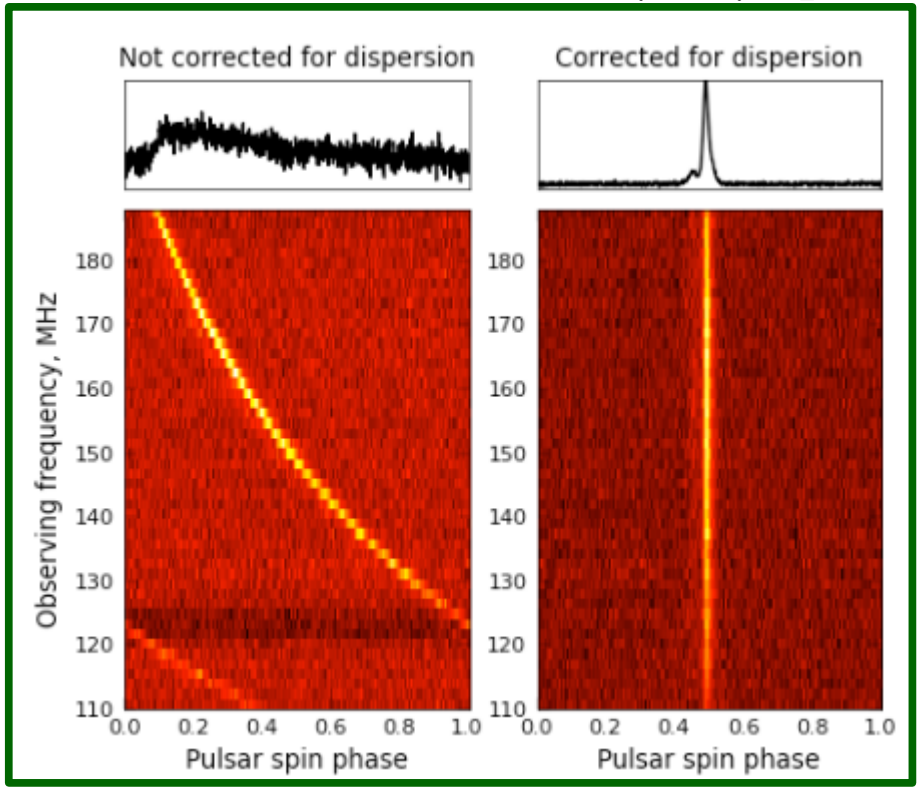
**Dispersive delay**

$$\delta t \sim DM / \nu^2$$



# Dispersion

PSR B2021+51 **DM is off by only 3 pc/cc!**

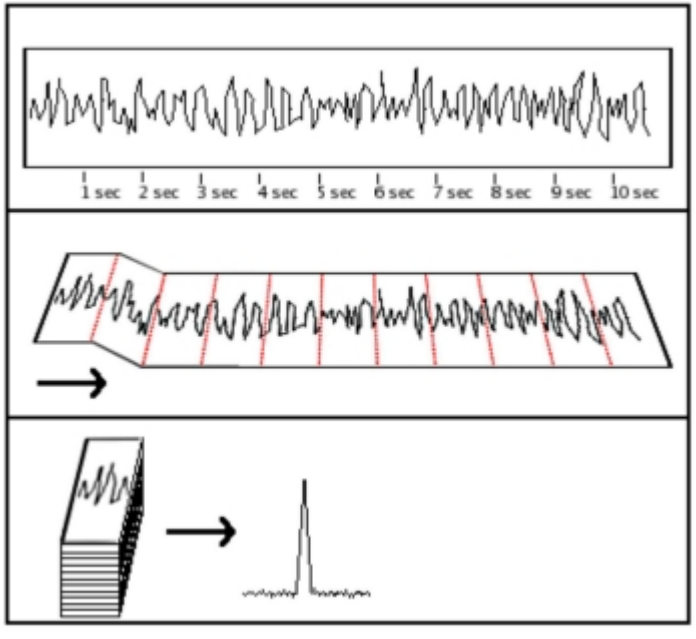



Credit: Anya Bilous

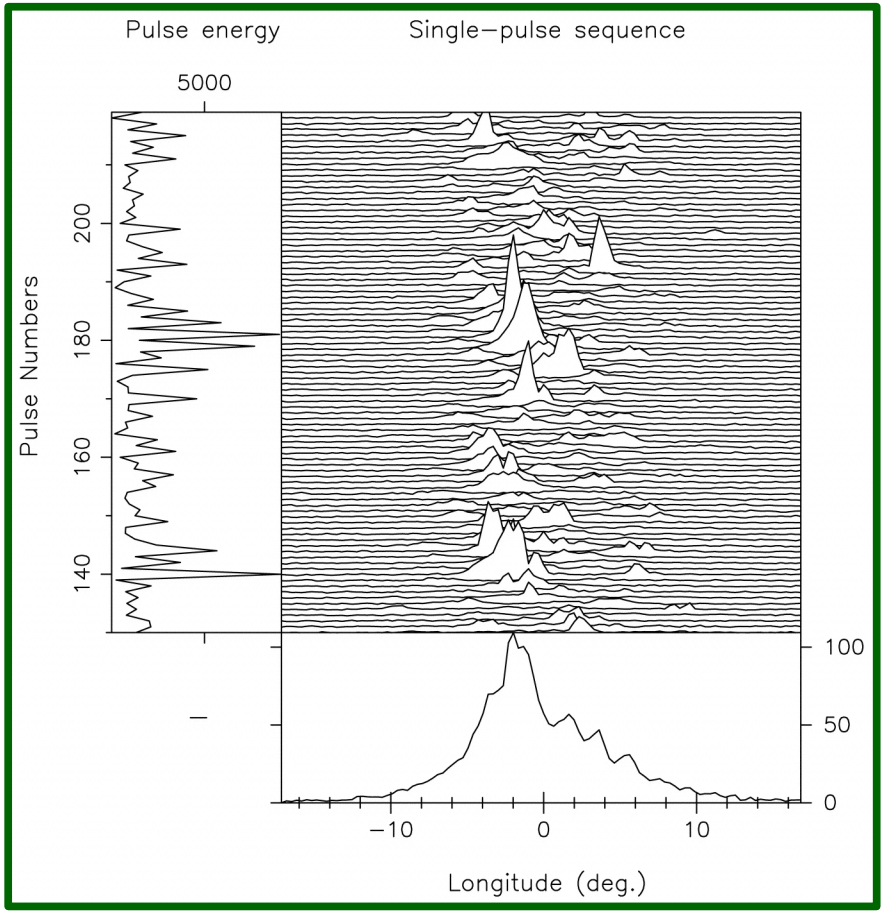
- DM [pc $cm^{-3}$] measures the integrated column density of free electrons along the line of sight
- Can be corrected using (in)coherent dedispersion

# Folding

## in a nutshell




PSR B0943+10



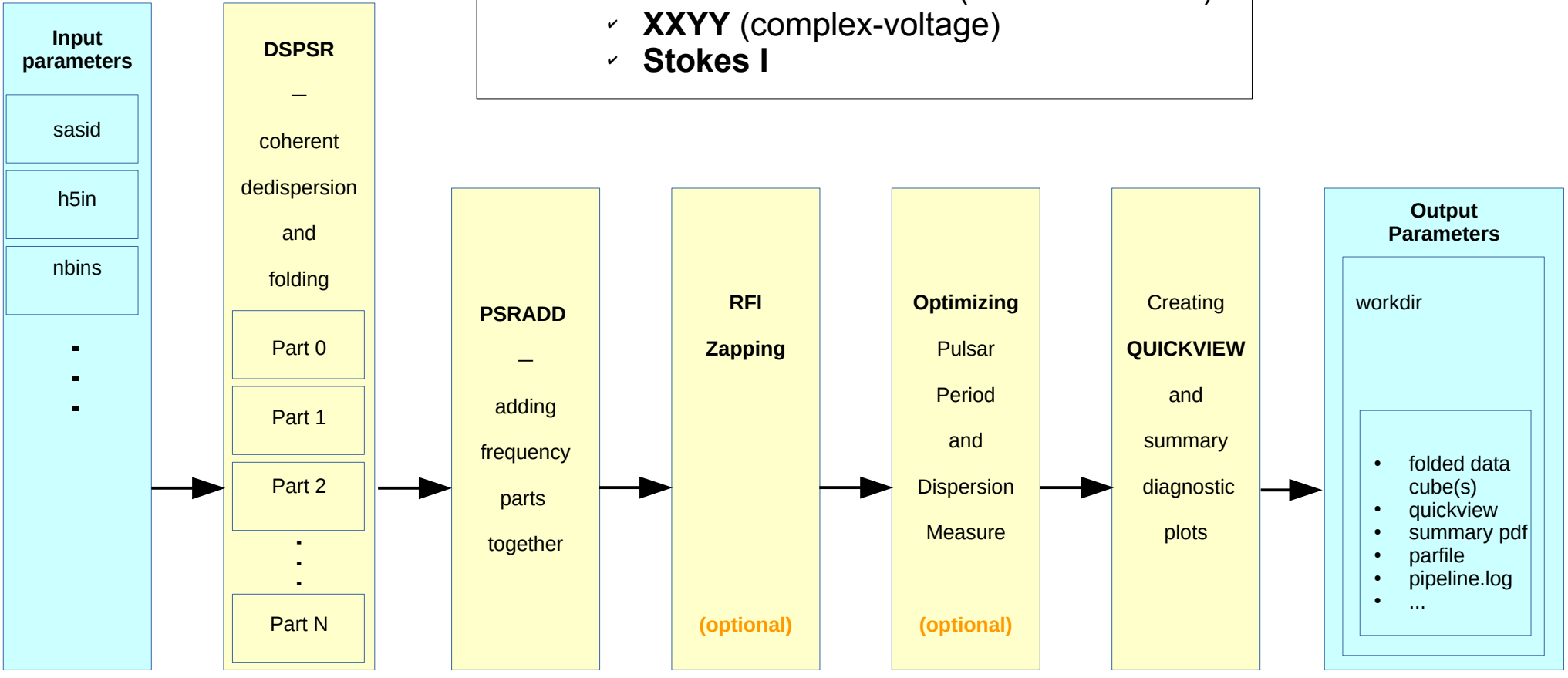

Deshpande & Rankin (1999)

# Pulsar Folding pipeline

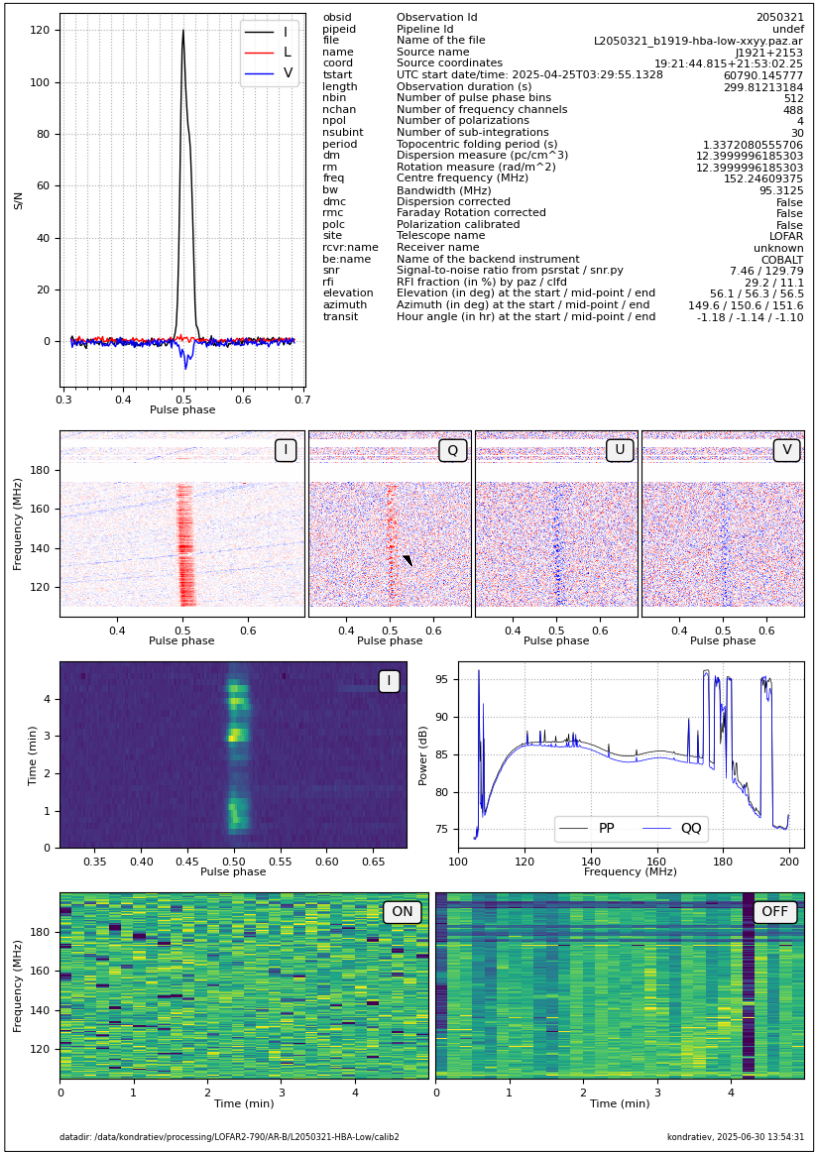
ⓘ pipeline runs per TAB

COMMON WORKFLOW LANGUAGE

ⓘ input files (h5in):
- raw beamformed HDF5 (**32-bit and 8-bit**):
  - ✔ **XXYY** (complex-voltage)
  - ✔ **Stokes I**



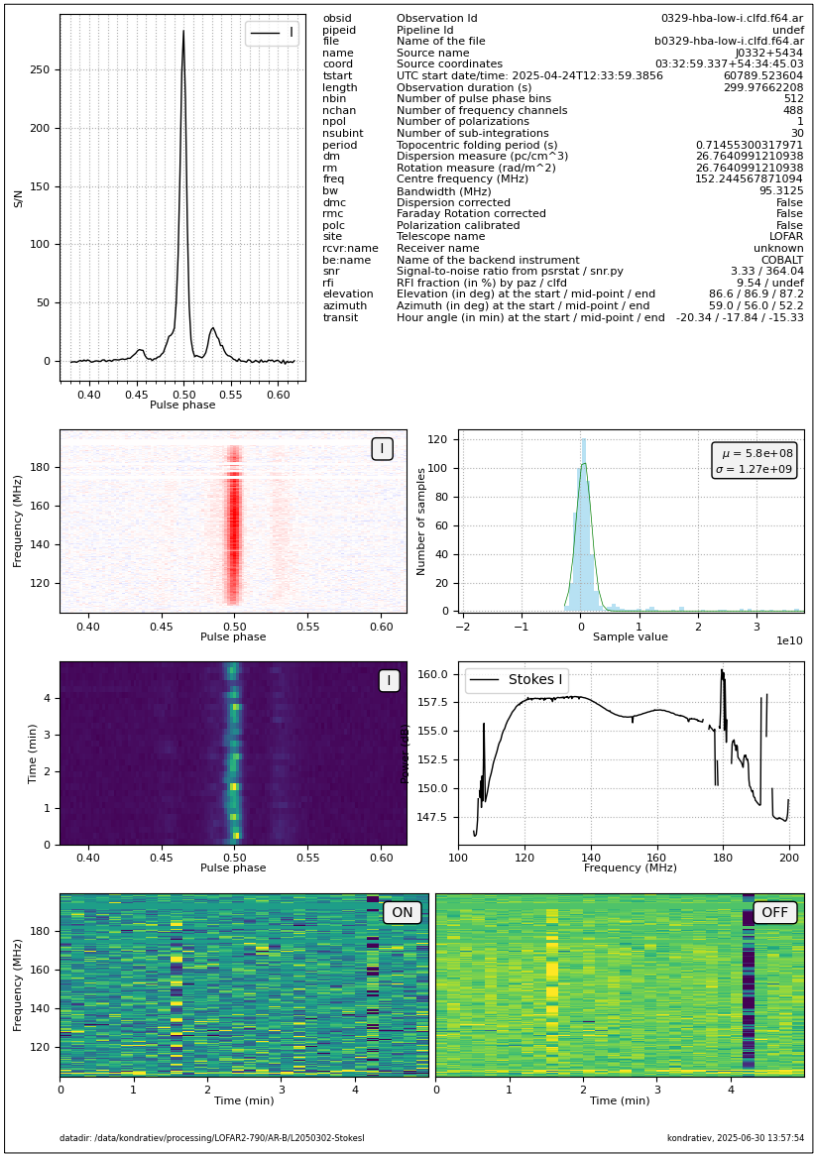
# Quickview diagnostic plot




| | | |
|---|---|---|
| obsid | Observation Id | 2050321 |
| pipeid | Pipeline Id | undef |
| file | Name of the file | L2050321_b1919-hba-low-xxyy.paz.ar |
| name | Source name | J1921+2153 |
| coord | Source coordinates | 19:21:44.815+21:53:02.25 |
| tstart | UTC start date/time: 2025-04-25T03:29:55.1328 | 60790.145777 |
| length | Observation duration (s) | 299.81213184 |
| nbin | Number of pulse phase bins | 512 |
| nchan | Number of frequency channels | 488 |
| npol | Number of polarizations | 4 |
| nsubint | Number of sub-integrations | 30 |
| period | Topocentric folding period (s) | 1.3372080555706 |
| dm | Dispersion measure (pc/cm^3) | 12.3999996185303 |
| rm | Rotation measure (rad/m^2) | 12.3999996185303 |
| freq | Centre frequency (MHz) | 152.24609375 |
| bw | Bandwidth (MHz) | 95.3125 |
| dmc | Dispersion corrected | False |
| rmc | Faraday Rotation corrected | False |
| polc | Polarization calibrated | False |
| site | Telescope name | LOFAR |
| rcvr:name | Receiver name | unknown |
| be:name | Name of the backend instrument | COBALT |
| snr | Signal-to-noise ratio from psrstat / snr.py | 7.46 / 129.79 |
| rfi | RFI fraction (in %) by paz / clfd | 29.2 / 11.1 |
| elevation | Elevation (in deg) at the start / mid-point / end | 56.1 / 56.3 / 56.5 |
| azimuth | Azimuth (in deg) at the start / mid-point / end | 149.6 / 150.6 / 151.6 |
| transit | Hour angle (in hr) at the start / mid-point / end | -1.18 / -1.14 / -1.10 |

← XXYY

Stokes I →




| | | |
|---|---|---|
| obsid | Observation Id | 0329-hba-low-i.clfd.f64.ar |
| pipeid | Pipeline Id | undef |
| file | Name of the file | b0329-hba-low-i.clfd.f64.ar |
| name | Source name | J0332+5434 |
| coord | Source coordinates | 03:32:59.337+54:34:45.03 |
| tstart | UTC start date/time: 2025-04-24T12:33:59.3856 | 60789.523604 |
| length | Observation duration (s) | 299.97662208 |
| nbin | Number of pulse phase bins | 512 |
| nchan | Number of frequency channels | 488 |
| npol | Number of polarizations | 1 |
| nsubint | Number of sub-integrations | 30 |
| period | Topocentric folding period (s) | 0.71455300317971 |
| dm | Dispersion measure (pc/cm^3) | 26.76409991210938 |
| rm | Rotation measure (rad/m^2) | 26.76409991210938 |
| freq | Centre frequency (MHz) | 152.24456787109 |
| bw | Bandwidth (MHz) | 95.3125 |
| dmc | Dispersion corrected | False |
| rmc | Faraday Rotation corrected | False |
| polc | Polarization calibrated | False |
| site | Telescope name | LOFAR |
| rcvr:name | Receiver name | unknown |
| be:name | Name of the backend instrument | COBALT |
| snr | Signal-to-noise ratio from psrstat / snr.py | 3.33 / 364.04 |
| rfi | RFI fraction (in %) by paz / clfd | 9.54 / undef |
| elevation | Elevation (in deg) at the start / mid-point / end | 86.6 / 86.9 / 87.2 |
| azimuth | Azimuth (in deg) at the start / mid-point / end | 59.0 / 56.0 / 52.2 |
| transit | Hour angle (in min) at the start / mid-point / end | -20.34 / -17.84 / -15.33 |

# Pulsar Folding pipeline

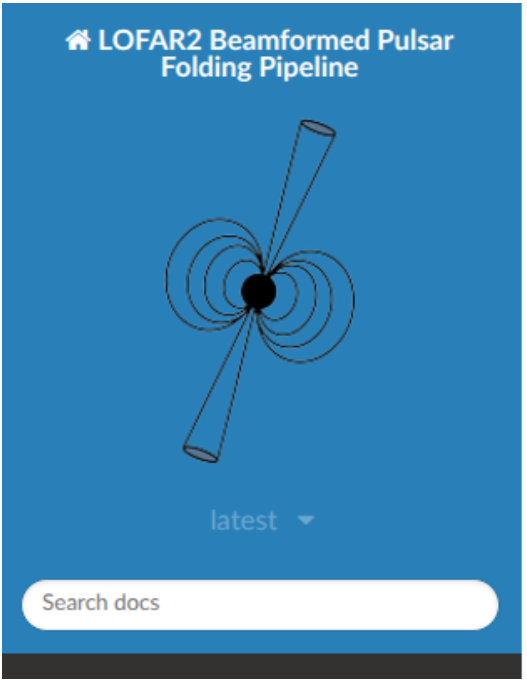
COMMON WORKFLOW LANGUAGE

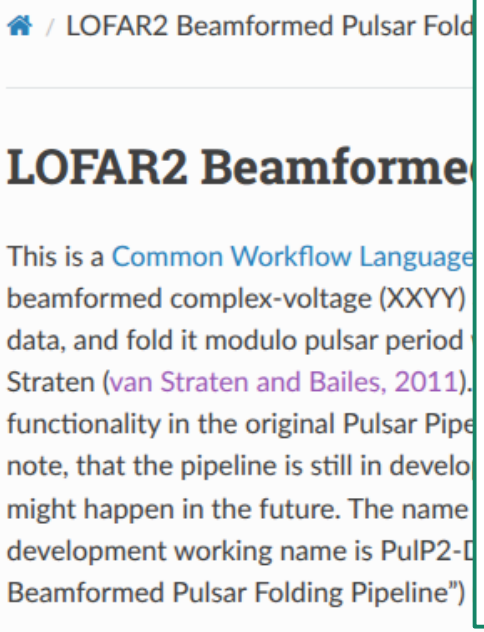
- Development — **done**
  - → https://git.astron.nl/RD/pulp2-cwl-folding
- Integration in TMSS — **done**
  - ingest — **not yet finished** / to be tested

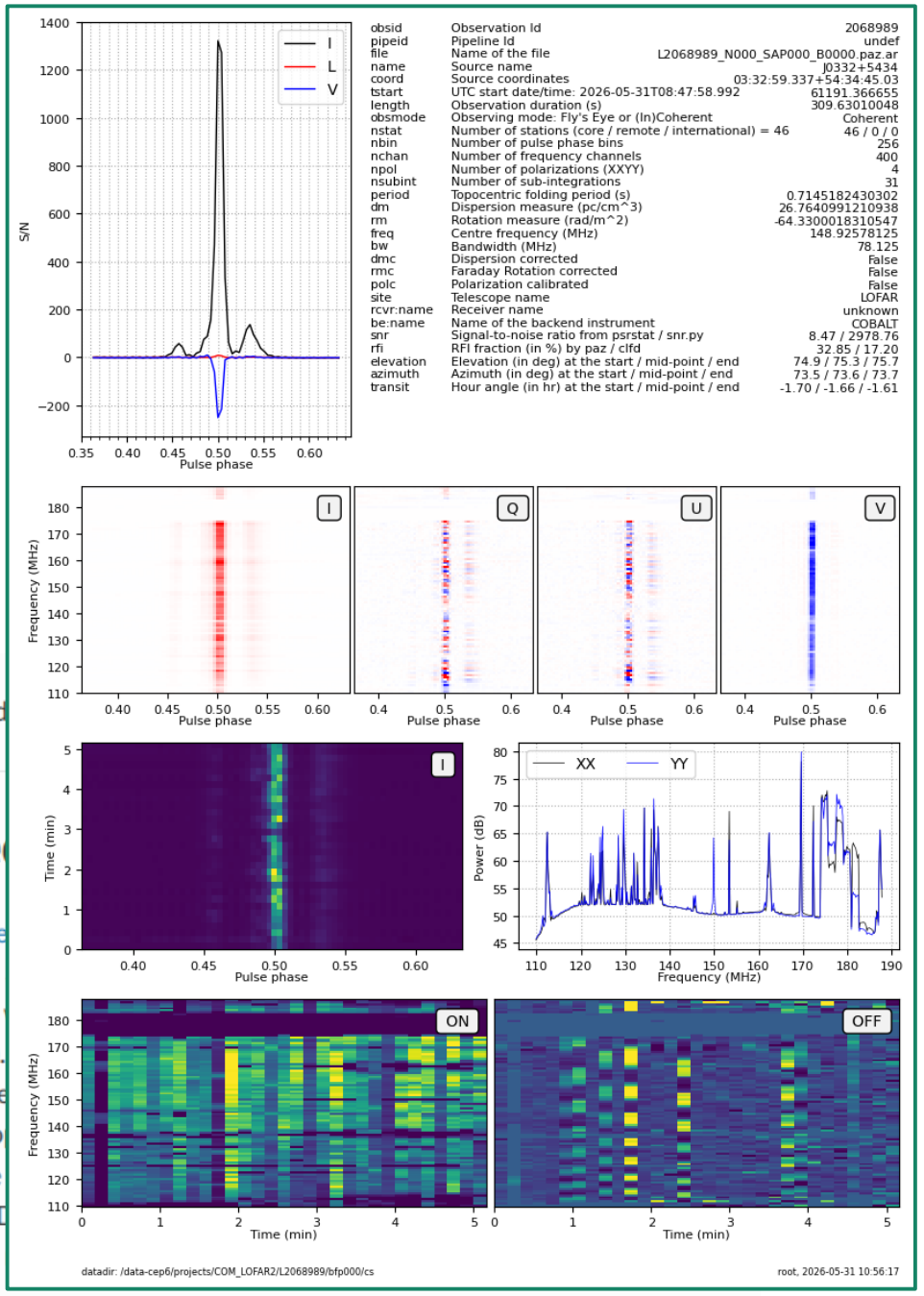
**What is next?**

- support / maintenance
- IQUV support
- calibration (flux & pol)

* TMSS – Telescope Manager Specification System



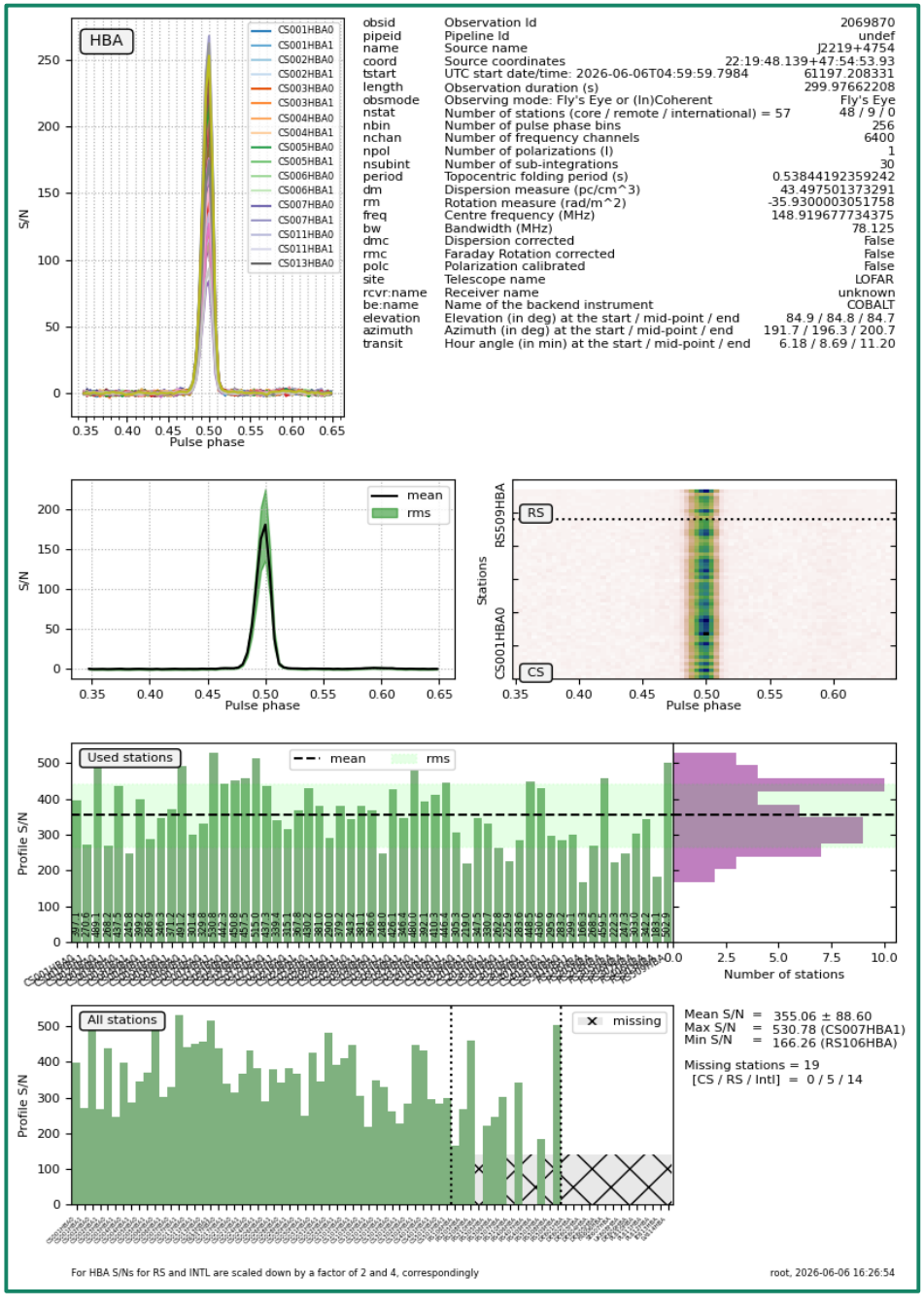



# Fly's Eye (FE) pipeline

COMMON WORKFLOW LANGUAGE

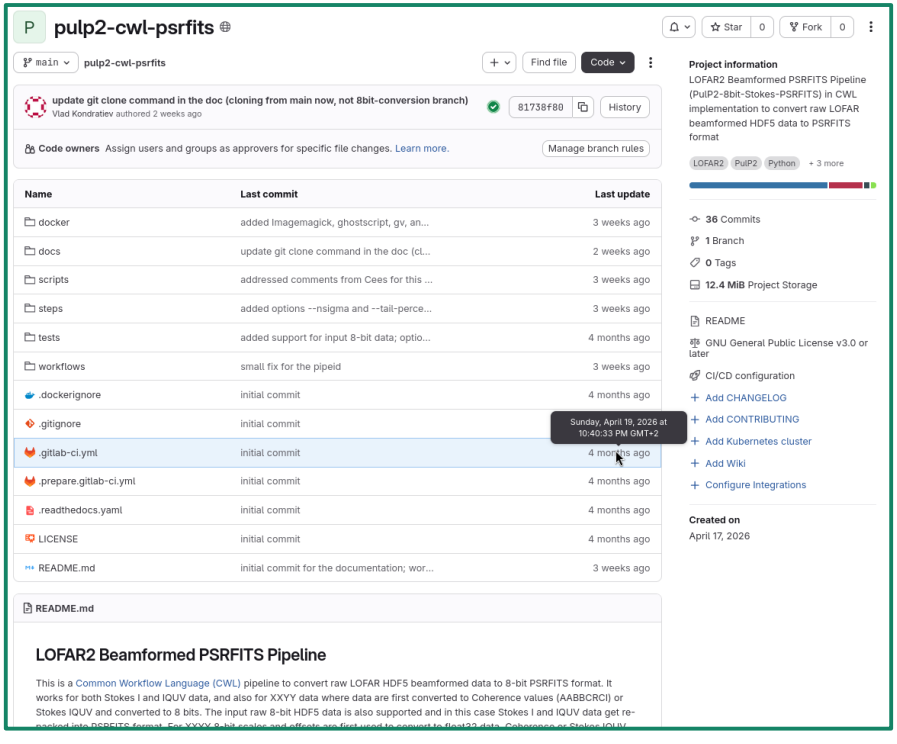
- Extension of the Pulsar folding pipeline for FE observations with multiple station beams:
  - runs folding pipeline for each station beam
  - creates FE diagnostic plot
- To check quickly the station's health during commissioning and operations
- Development — **done**
  → https://git.astron.nl/RD/pulp2-cwl-folding
- Integration in TMSS — **not yet**

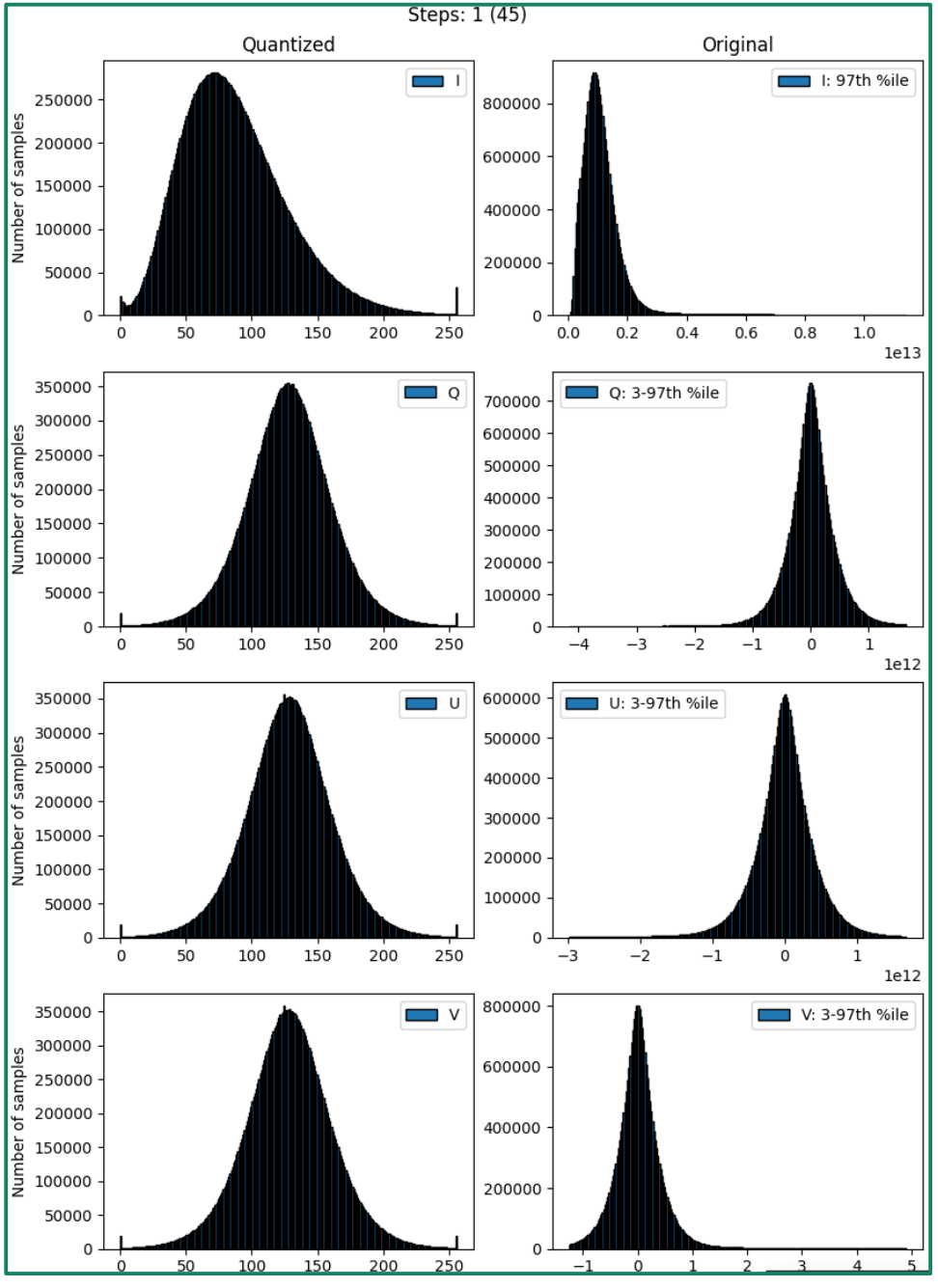


# PSRFITS pipeline

raw beamformed HDF5 data → PSRFITS format
https://www.atnf.csiro.au/research/pulsar/psrfits_definition/Psrfits.html

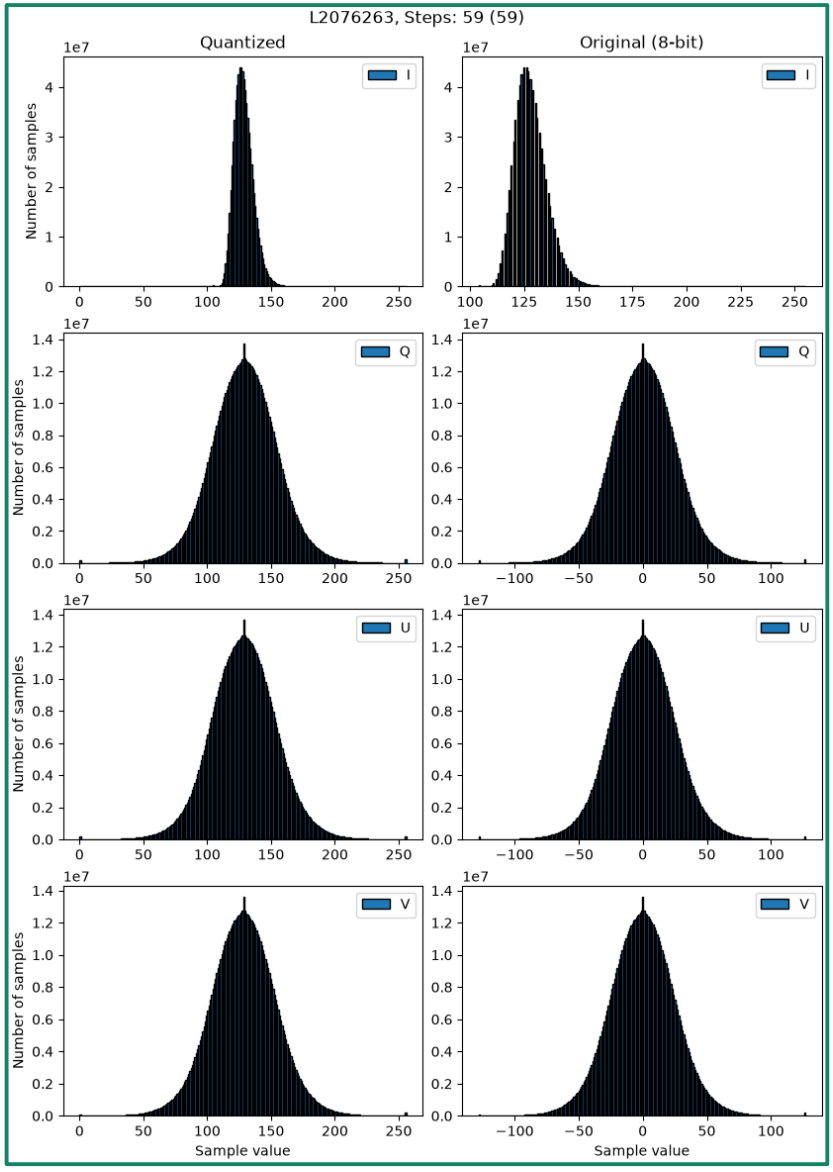
- Development — **done**
  - → https://git.astron.nl/RD/pulp2-cwl-psrfits
- Integration in TMSS — **not yet**
- Diagnostics:
  - samples' histograms
  - dynamic spectrum

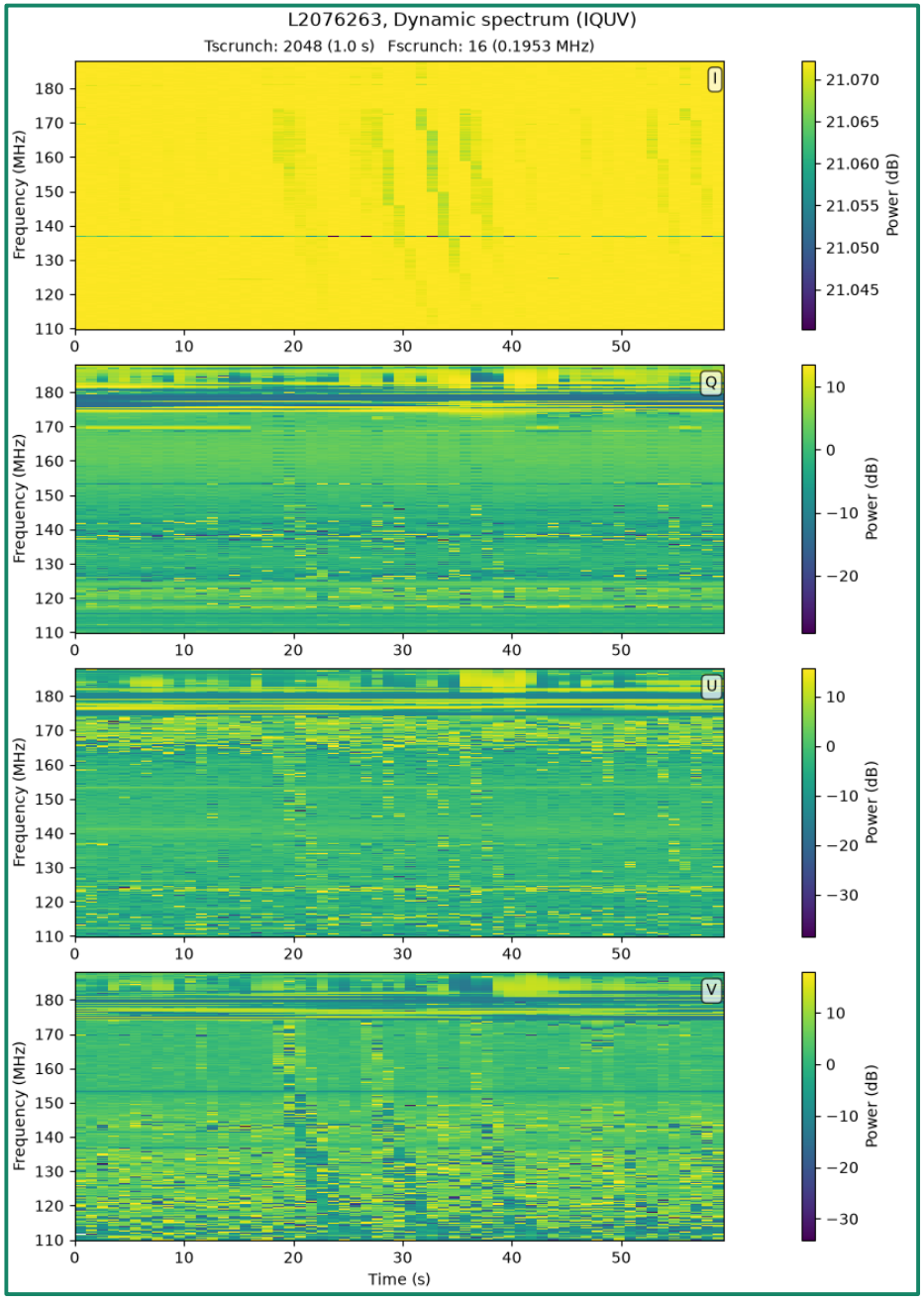


# PSRFITS pipeline

COMMON WORKFLOW LANGUAGE



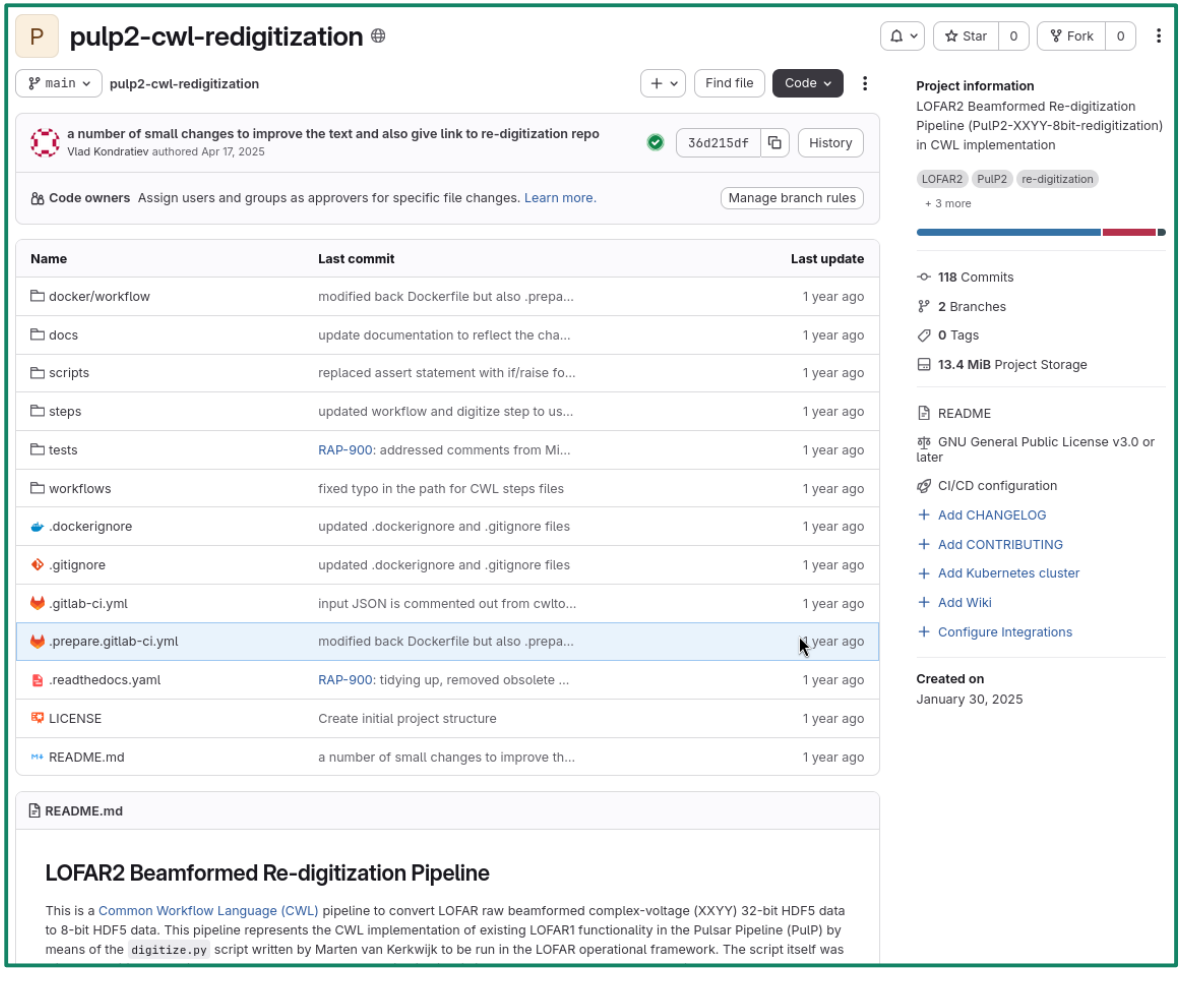
# Re-digitization pipeline

raw beamformed 32-bit XXYY HDF5 data → 8-bit HDF5

- Development — **done**
  - → https://git.astron.nl/RD/pulp2-cwl-redigitization
- Integration in TMSS — **not yet**

Cobalt3 can also record 8-bit data directly.

However, can still be used when recording of 32-bit data is needed for different science cases



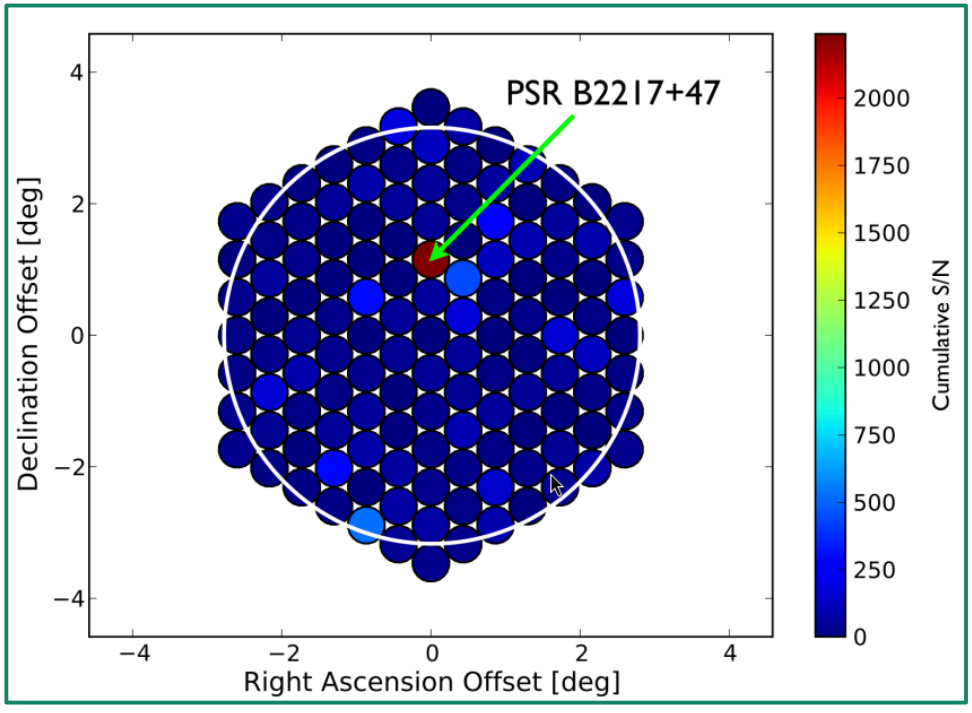
# Gridding pipeline

COMMON WORKFLOW LANGUAGE

extension of Pulsar Folding pipeline for multi-TAB observations

- Development — **later this year (TBD)**
  - will run folding pipeline for each TAB
  - will create tied-array heatmap for source localization

concept example



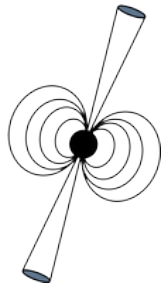

van Haarlem et al. (2013)

# Dynspec pipeline

time-frequency averaged dynamic spectra of the raw beamformed data

- Convert raw beamformed data (for LOFAR1 described by ICD3) to Dynspec data (described by ICD6 in LOFAR1)
- Successor of Dynspec Toolkit Container (DTC) developed by Nicolas Vilchez for LOFAR1
- Development — **TBD**

* ICD — Interface Control Document (data format definition)



**Thank you!**

**Questions?..**