The Good, the Bad and the Ugly

A biased overview of the LOFAR interferometric software and how to use it

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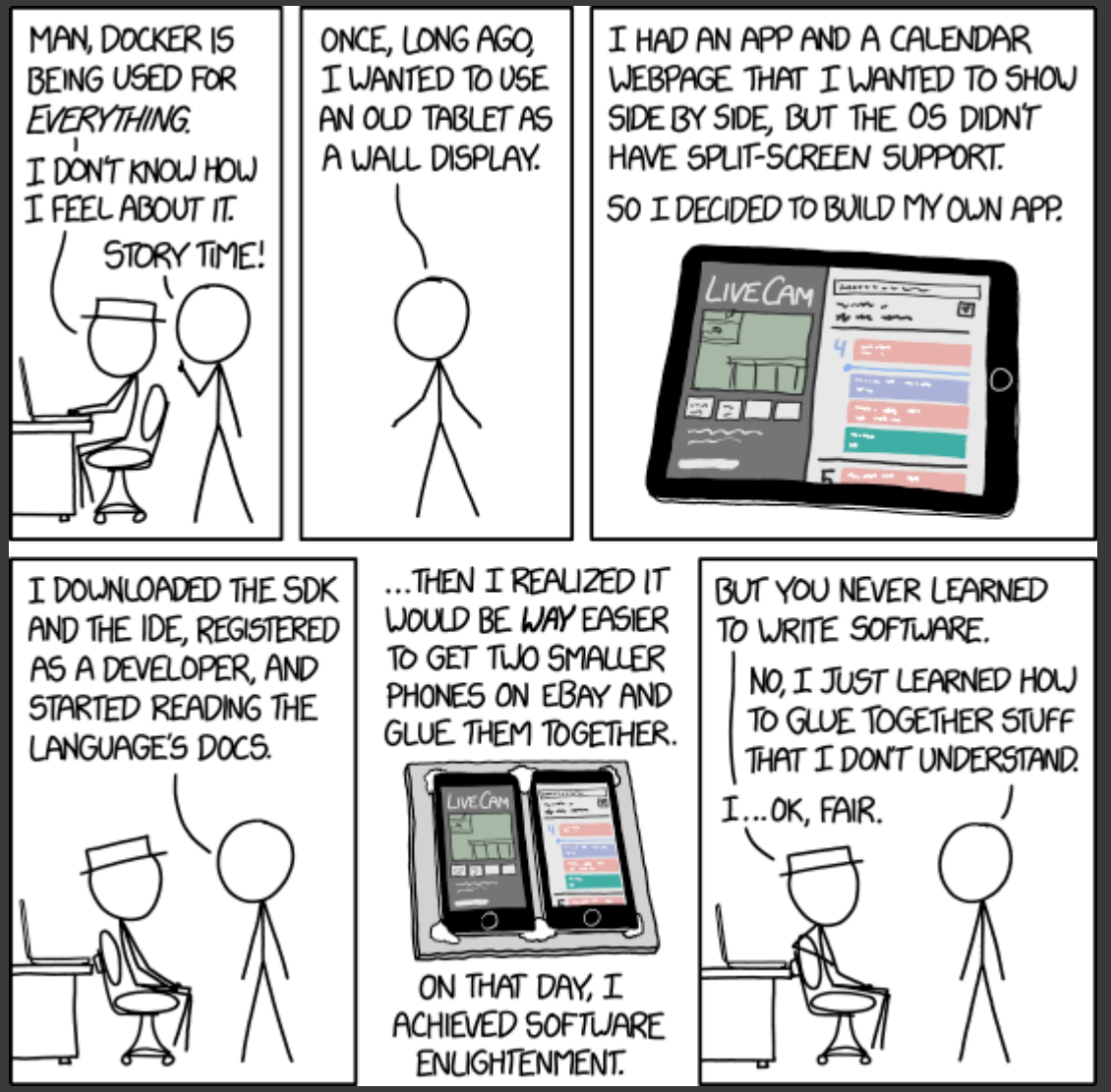
LOFAR Data School 2024



XKCD 1988

Contents

What this talk is about

LOFAR has three "observing modes"

- Direct storage: direct dump of TBB voltages for e.g. cosmic ray air showers
- Beam-formed: station-level beam-formed data before correlation for e.g. puslar studies (see Vlad's talk)
- Interferometric: data correlated between stations for e.g. imaging

I will discuss most commonly used sofware

relevant to processing interferometric data

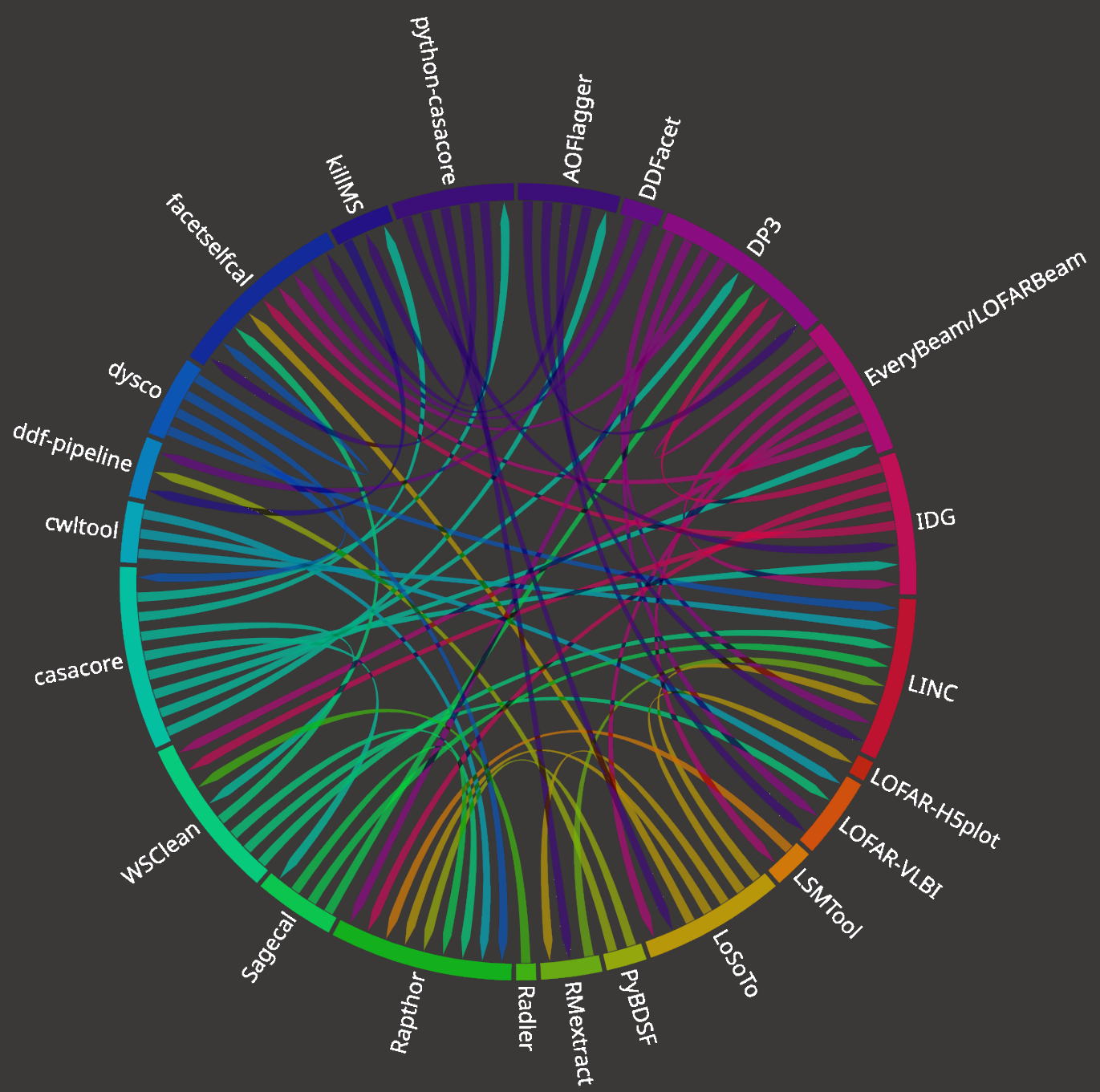
LOFAR software landscape

Many different libraries, programs, packages and pipelines

- C++ for core components
- Python for utilities/pipelines and glue
- Workflow languages for pipelines

Many inter-dependencies

Partly community-maintained, partly ASTRON-maintained



LOFAR software landscape

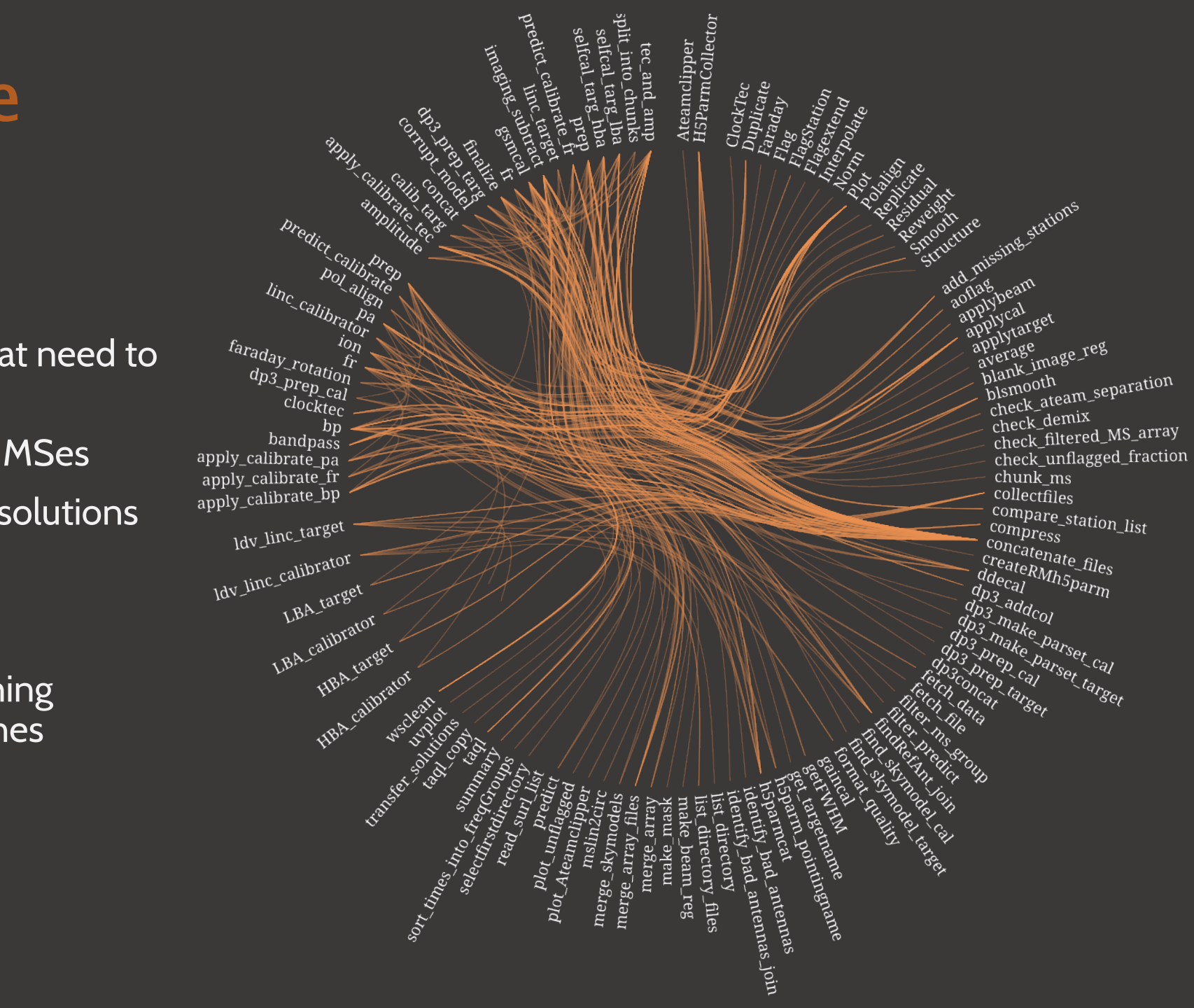
Pipelines are complicated

- Dozens of individual steps that need to talk to each other
- Dozens to hundreds of input MSes
- Many output datasets, plots, solutions

Common Workflow Language

- Declarative language for running programs and creating pipelines

COMMON
WORKFLOW
LANGUAGE



LOFAR user software landscape – pipeline components

Calibration: correct visibilities for systematics, ionospheric distortions and other corruptions

- Derive calibration solutions and correct datasets
- AOFlagger, DP3, facetselfcal, killMS, LoSoTo, RMextract

Imaging: transform data from visibilities into an image of the sky

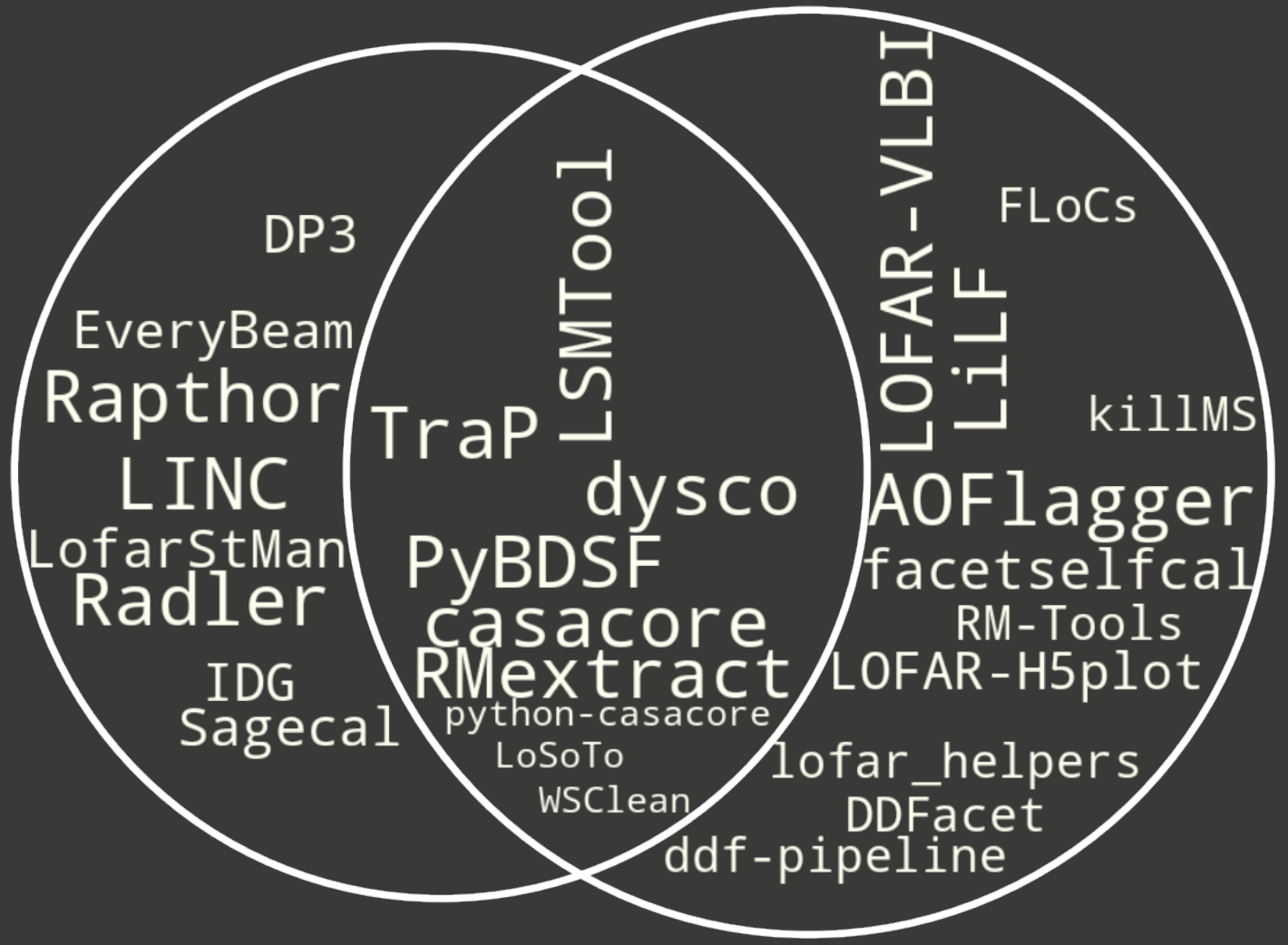
- Deconvolution of the image
- DDFacet (SSD), WSClean (IDG, wgridder)

Utility: tools that do not fit in either category or are generally useful

- Manipulation or inspection of images, MSes, calibration solutions etc.
- facetselfcal, LOFAR-H5plot, lofar_helpers, LSMTool, shadems

LOFAR software landscape

ASTRON
developed/maintained



externally
developed/maintained

LOFAR user software landscape – pipelines

LINC (de Gasperin+2019); https://linc.readthedocs.io/en/latest/index.html

ddf-pipeline (Shimwell+2017, Tasse+2018); https://github.com/mhardcastle/ddf-pipeline

VLBI-CWL (Morabito+2021); https://git.astron.nl/RD/VLBI-cwl

– Wiki coming: https://github.com/LOFAR-VLBI/lofar-vlbi-pipeline/wiki

LiLF (de Gasperin+2019,2020); https://github.com/revoltek/LiLF

facetselfcal (van Weeren+2021) https://github.com/rvweeren/lofar_facet_selfcal

TraP (Swinbank+2015); https://github.com/transientskp/tkp

LOFAR user software landscape – pipeline components

Calibration

- DP3 (ASTRON; Dijkema+2023)
- killMS (Tasse+2014)
- LoSoTo (de Gasperin)
- RMextract (Mevius 2018)

Imaging

- DDFacet (Tasse+2018)
- Radler (ASTRON)
- WSClean (Offringa+2014)

Utility/data editing

- lofar_helpers (de Jong)
- LOFAR-H5plot (Sweijen)
- LoSiTo (Rafferty, Edler, de Gasperin)
- PyBDSF (Mohan & Rafferty 2015)
- shadems (RATT-RU)

Pipelines

Pre-processing

- Averaging to 12 kHz, 1 s
- RFI excision
- Dysco compression
- Ran after observing by the observatory

Initial an direction-independent calibration

- LOFAR Initial Calibration Pipeline (LINC)
- Instrumental effects: polarisation alignment, clock drifts, bandpasses
- Direction-independent ionospheric effects

Pipelines

Direction-dependent calibration and imaging

- DDF-pipeline: direction-dependent calibration and imaging with the Dutch array using killMS + DDFacet
- Rapthor: direction-dependent calibration and imaging with the Dutch array using DP3 + WSClean
- LOFAR-VLBI: calibration and imaging with the full international array
- LiLF: direction-dependent calibration and imaging for LBA with the Dutch array using DP3 + DDFacet + WSClean

Time/frequency-domain

- DynSpecMS: time-frequency search for variability "dynamic spectrum"
- Transient Pipeline "TraP": image-plane searches of transients

Solar and space weather

- Solar imaging pipeline

Calibration

DP3 (https://dp3.readthedocs.io/en/latest/; https://git.astron.nl/RD/DP3)

– Find or apply calibration solutions (in H5parm format); can exploit frequency coherency

killMS (https://github.com/saopicc/killMS)

– Find or apply calibration solutions (in npz format); can exploit time coherency

LoSoTo (https://github.com/revoltek/losoto)

– LOFAR Solution Tool for manipulating and plotting H5parms

RMextract (https://github.com/lofar-astron/RMextract)

– extract TEC, vTEC, Earthmagnetic field and Rotation Measures from GPS and WMM data

Imaging

DDFacet (https://github.com/saopicc/DDFacet)

– Facet-based radio imager supporting full-polarisation DD corrections and smearing corrections

WSClean (https://wsclean.readthedocs.io/en/latest/; https://gitlab.com/aroffringa/wsclean)

– Imager supporting various gridders (w-stacking, IDG, wgridder) and multi-scale deconvolution

Image Domain Gridder (IDG; https://git.astron.nl/RD/idg)

– Can apply smooth screens or include the primary beam during gridding

– Use through WSClean

Utilities

LOFAR-H5plot (https://tikk3r.github.io/lofar-h5plot/; https://github.com/tikk3r/lofar-h5plot)

– Interactively explore calibration solutions in H5parm format

lofar_facet_selfcal (https://github.com/rvweeren/lofar_facet_selfcal)

– Advanced calibration tool

lofar_helpers (https://github.com/jurjen93/lofar_helpers)

– h5_merger and many other utilty scripts for dealing with MSes, FITS files, DS9 regions

LoSiTo (https://losito.readthedocs.io/en/latest/; https://github.com/darafferty/losito)

– LOFAR Simulation Tool for simulating various effects and corruptions into a dataset

shadems (https://github.com/ratt-ru/shadeMS)

– Efficiently plot data in MSes, e.g. uv coverage

PyBDSF (https://pybdsf.readthedocs.io/en/latest/; https://github.com/lofar-astron/PyBDSF)

– Source finder through gaussian fitting

Software distribution

Containers and how to use them

Containerisation

Installing large software stacks is painful

- Many dependencies
- Some libraries are hard to install

Helping people with unknown setups is hard

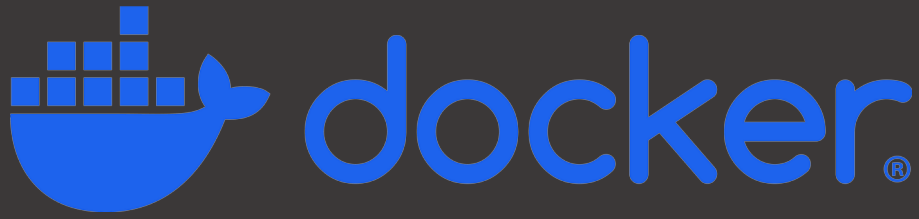
- What hardware, OS, library versions etc.?
- How was it built?

Most people just want to do science, not become sysadmin

Containerisation

Docker

- Industry standard mostly for cloud and VM
- Requires root access



Singularity

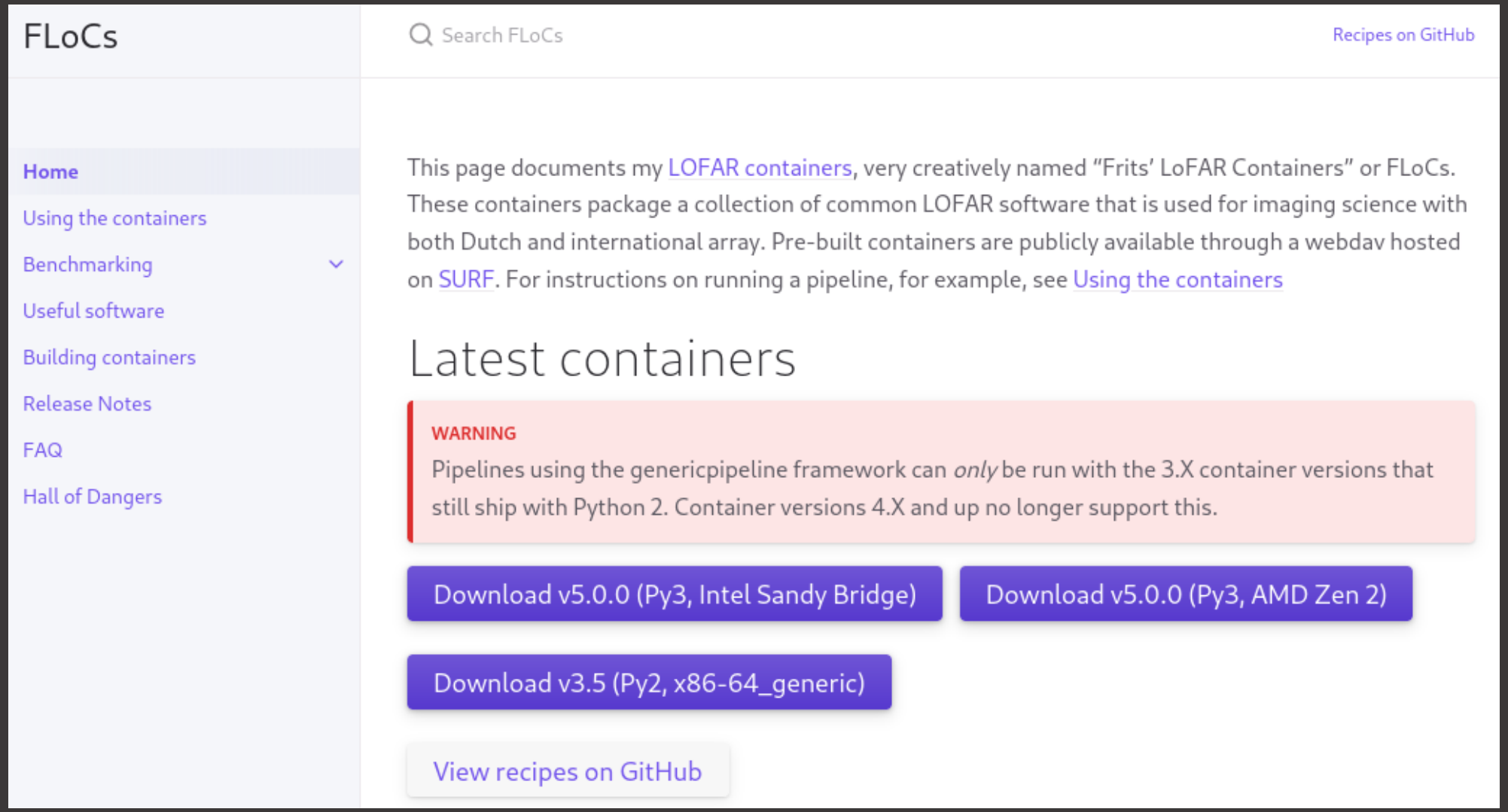
- HPC oriented favouring integration over isolation
- Single file
- No root access required
- Supports Docker

LINC and Rapthor offer Dockers

DDF-pipeline and FLoCs are Singularity

My “machine” becomes your “machine”

Frits' LOFAR Containers a.k.a. FLoCs



https://tikk3r.github.io/flocs/

Frits' LOFAR Containers a.k.a. FLoCs

Monolithic container with a large software stack

- All core components such as AOFlagger, DDFacet, DP3, killMS, LoSoTo, RMextract, WSClean
- Additional utilities such as LOFAR-H5plot (interactive inspection of H5parms), LSMTool (skymodel manipulation), PyBDSF (source finding), shadems (plotting of e.g. uv coverage)
- Support for lofar_helpers and facetselfcal
- Many Python packages for LOFAR and general included

Support for running main calibration/imaging pipelines

- LINC not included, but supported, including user-friendly wrappers handling setup for you (see https://github.com/tikk3r/flocs/tree/fedora-py3/runners)
- DDF-pipeline included
- Rapthor not included, but supported
- facetselfcal not included, but supported

Frits' LOFAR Containers a.k.a. FLoCs

Things to keep in mind

- Do not mix host and container environment
- Paths that need to be accessible should be bound explicitely (and works recursively)
- CPU architecture still matters. If you see `Illegal instruction (core dumped)` let us/me know.
- Singularity is now called Apptainer. Depending on your system's installed version the command is either `singularity` or `apptainer`

apptainer container usage

Downloading a Docker container

```
apptainer pull /path/to/container.sif docker://astronrd/linc:latest
```

Downloading FLoCs

```
wget ‘https://lofar-webdav.grid.sara.nl/software/shub_mirror/tikk3r/lofar-grid-hpccloud/intel/flocs_v5.0.0_sandybridge_sandybridge_mkl_cuda.sif’
```

Not as nice, but illustrates that Singularity containers are just big files.

apptainer container usage

Interactive use

```
apptainer shell -B /my/dir,/other/dir /path/to/container.sif
```

Non-interactive use

```
apptainer exec -B /my/dir,/other/dir /path/to/container.sif <command>
```

apptainer container usage

Interactive use

```
apptainer shell -B /my/dir,/other/dir /path/to/container.sif
```

launch a shell in the container

Non-interactive use

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make these directories accessible

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launch a shell in the container

make these directories accessible

use this container

Non-interactive use

```
apptainer exec -B /my/dir,/other/dir /path/to/container.sif <command>
```

execute a command in the container

apptainer container usage

Interactive use

```
apptainer shell -B /my/dir,/other/dir/path/to/container.sif
```

launch a shell in the container

make these directories accessible

use this container

Non-interactive use

```
apptainer exec -B /my/dir,/other/dir /path/to/container.sif <command>
```

execute a command in the container

execute this command

Wrap up points

When calibrating, inspect your solutions carefully!

- Pipelines produce “inspection plots”
- LoSoTo for automated plotting, LOFAR-H5plot for interactive plotting

CPU architecture matters

If you see `illegal instruction`, see `#software` channel for a generic container

https://tikk3r.github.io/flocs/

https://github.com/tikk3r/flocs/

Thank you for your attention!