Simulating radio observations with KARABO

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- Presented by: Rohit Sharma, FHNW, Windisch

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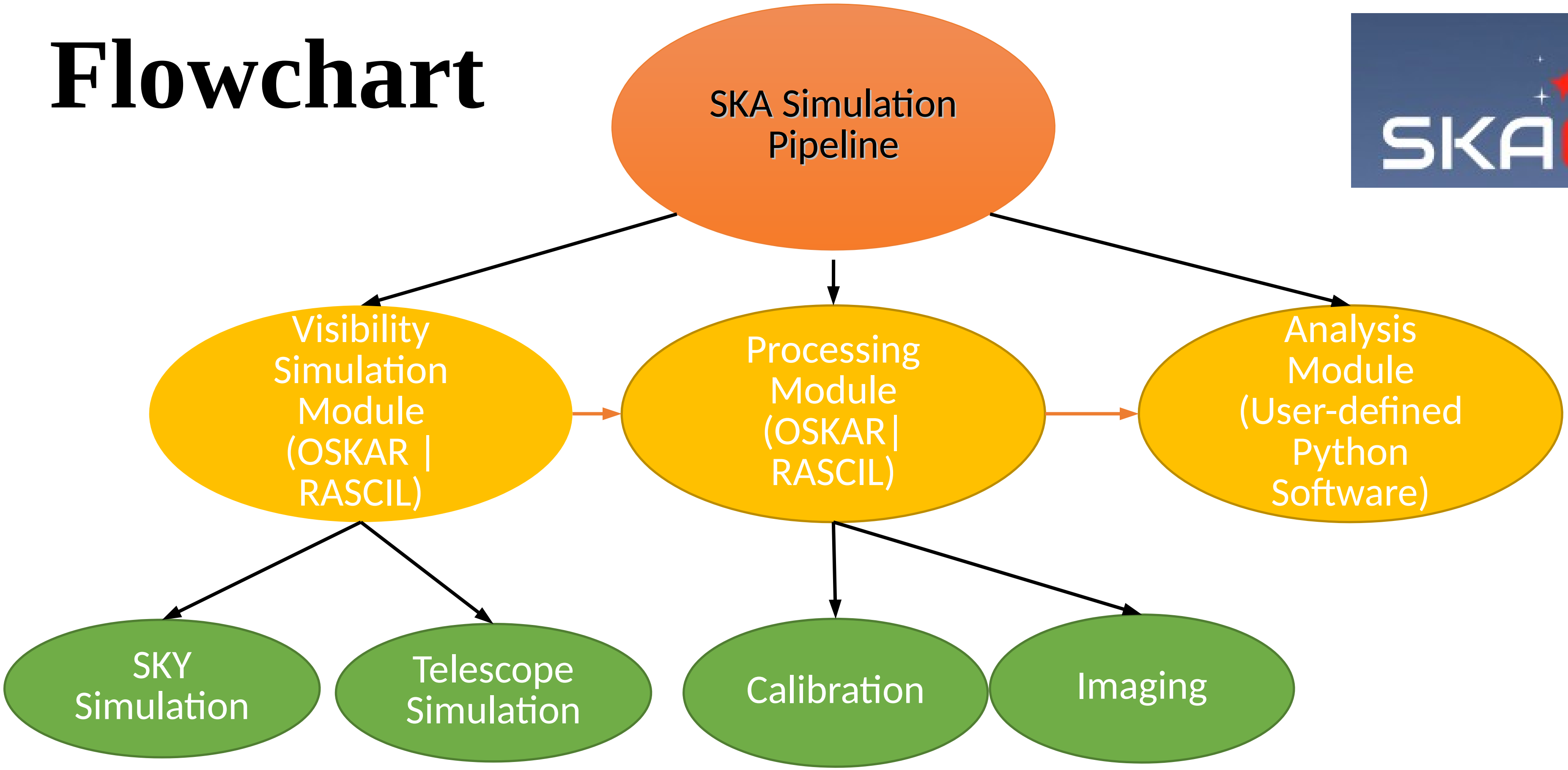
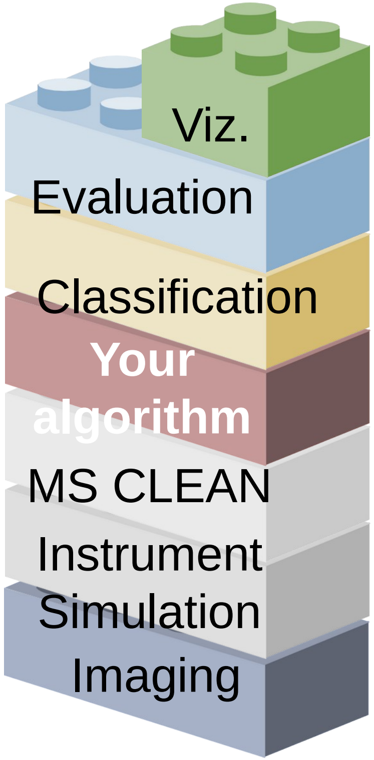
Contents

Flowchart


SKA Simulation Pipeline
Visibility Simulation Module (OSKAR | RASCIL)
Processing Module (OSKAR| RASCIL)
Analysis Module (User-defined Python Software)
SKY Simulation
Telescope Simulation
Calibration
Imaging

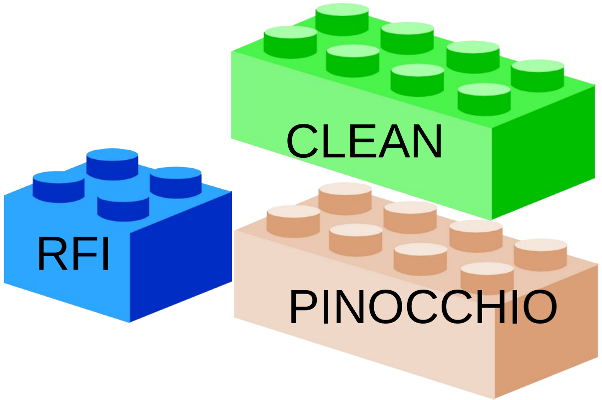
Introduction



Fast and easy ramp-up.

Build **custom** pipelines with our building blocks.

Add your own blocks.



- SKA data simulator
- Karabo is a Square Kilometer Array Digital Twin Pipeline, which is written in Python and set up in an interactive Jupyter Notebook environment.
- Two specific radio telescope packages are used:
- OSKAR: Responsible for the simulation of the sky and the telescope
- RASCIL: Responsible for imaging

Goals of the Karabo Pipeline

- Simulation of the sky, SKA instrument, processing and analysis
- To be used by other teams

  - Ease of use

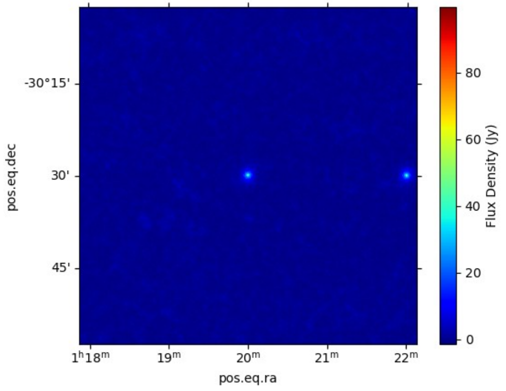
  - Fast ramp up

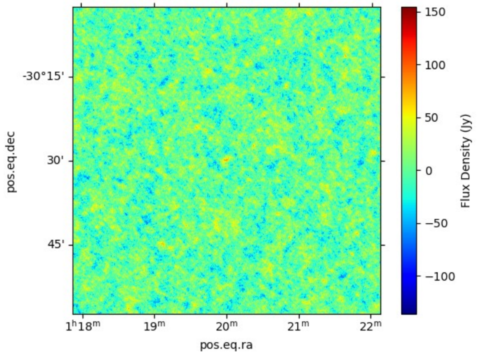
  - Common benchmarks
- Flexible Building Blocks which can be connected, used stand-alone or replaced

Features of Karabo

- System noise
- Primary Beam
- Skymodels from Catalog e.g. GLEAM, MIGHTEE
- Ionospheric Screens
- Integration of Pinnochio (Dark Matter halo Simulation)
- Multiple telescopes (> 10) configuration
- Long observation module

System Noise → Karabo





- Averaged baseline-based RMS noise
- Input RMS noise = 8000 Jy
- For Meerkat nd ~ 2016
- Image RMS ~ 50

Baseline RMS

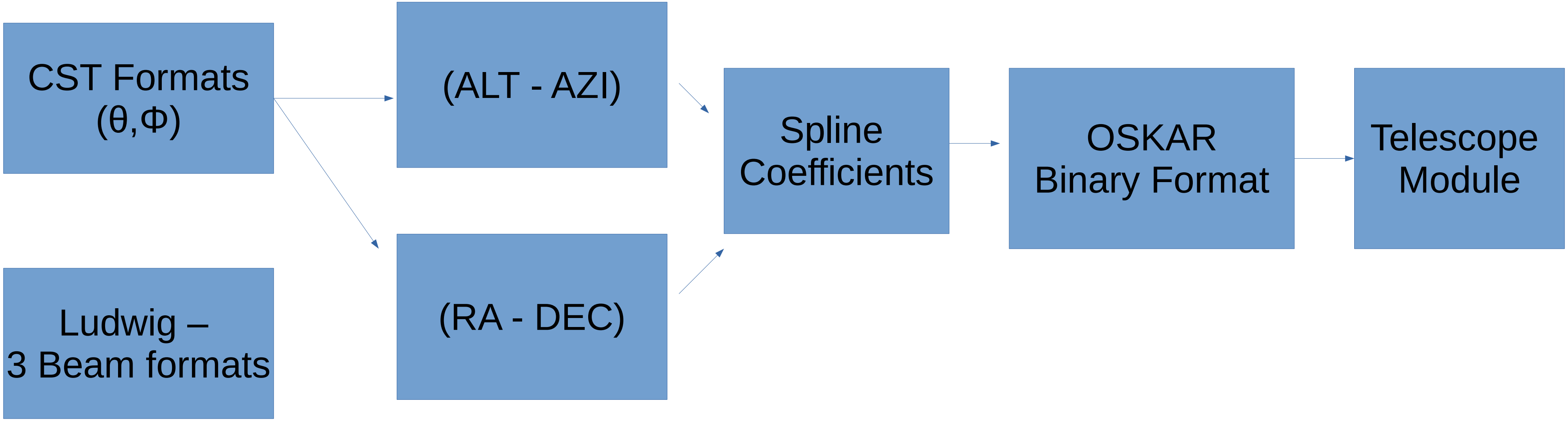
$$\sigma_{p,q} = k_B \sqrt{\frac{2\,T_p T_q}{A_p A_q\ \eta_p \eta_q\ \Delta\nu\ \tau_{acc}}}$$

$$\sigma_{p,q} = \sqrt{\frac{S_p S_q}{2\ \Delta\nu\ \tau_{acc}}}$$

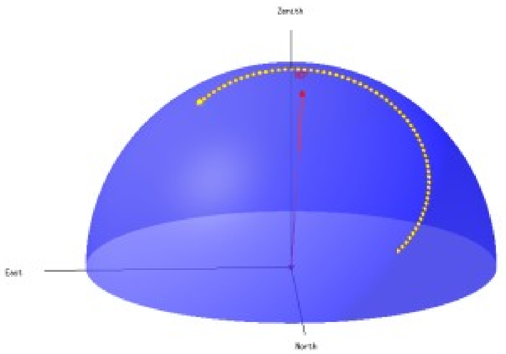
Image RMS

$$\sigma_{im} = \frac{\sigma_{p,q}}{\sqrt{\frac{n_a(n_a-1)}{2}\ \frac{\tau_0}{\tau_{acc}}}} = \frac{\sigma_{p,q}}{\sqrt{n_d}}$$

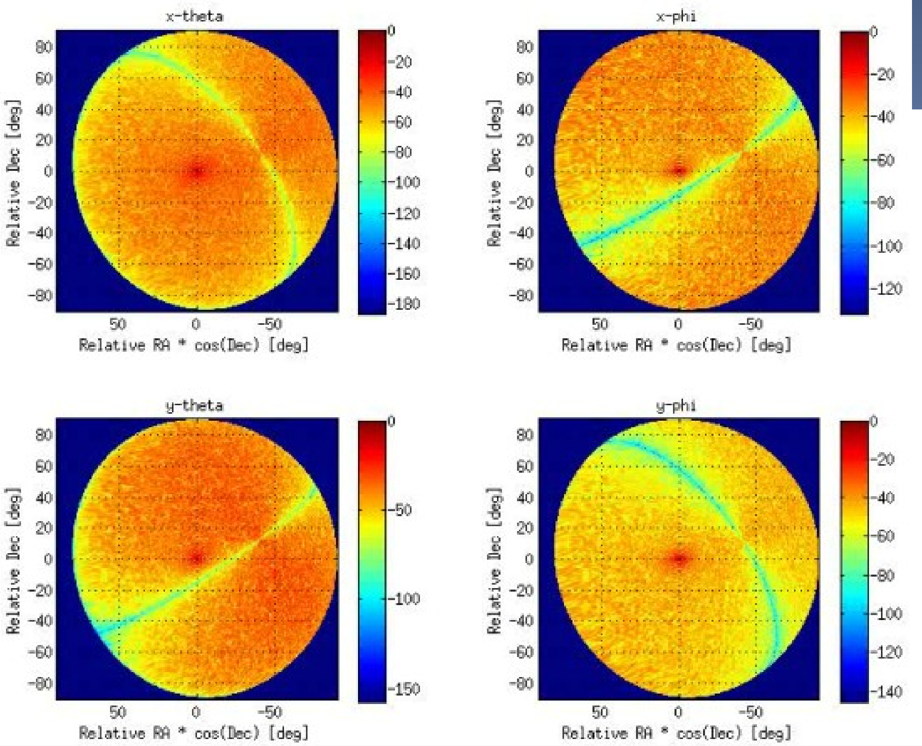
Procedure for Primary Beam Implementation



Theta [deg.]	Phi [deg.]	Abs(Dir.)[dBi]	Abs(Theta)[dBi]	Phase(Theta)[deg.]	Abs(Phi)[dBi]	Phase(Phi)[deg.]	Ax.Ratio[dB]
0.000	0.000	2.071e+001	2.071e+001	218.455	-3.854e+001	330.061	4.000e+001
1.000	0.000	2.064e+001	2.064e+001	218.545	-3.860e+001	330.207	4.000e+001
2.000	0.000	2.046e+001	2.046e+001	218.843	-3.876e+001	330.644	4.000e+001
3.000	0.000	2.015e+001	2.015e+001	219.362	-3.902e+001	331.383	4.000e+001
4.000	0.000	1.971e+001	1.971e+001	220.128	-3.940e+001	332.443	4.000e+001
5.000	0.000	1.914e+001	1.914e+001	221.177	-3.989e+001	333.855	4.000e+001
6.000	0.000	1.843e+001	1.843e+001	222.563	-4.048e+001	335.661	4.000e+001



OSKAR Primary beam



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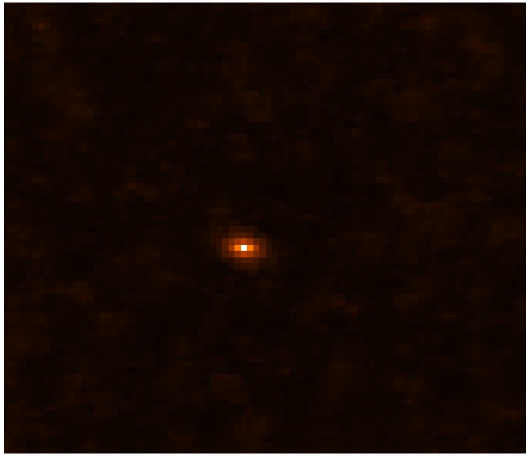
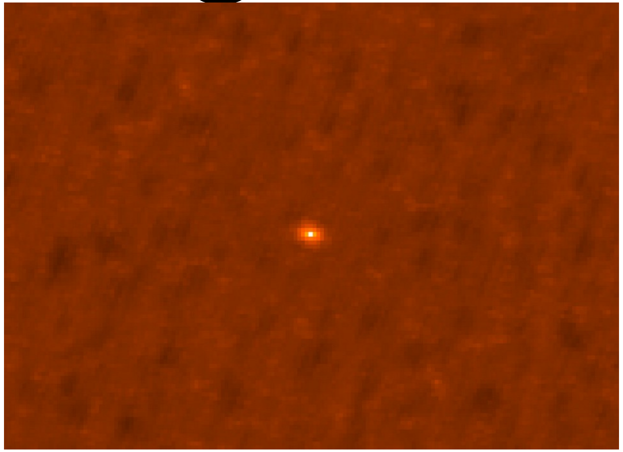
6.000	0.000	1.843e+001	1.843e+001	222.563	-4.048e+001	335.661	4.000e+001

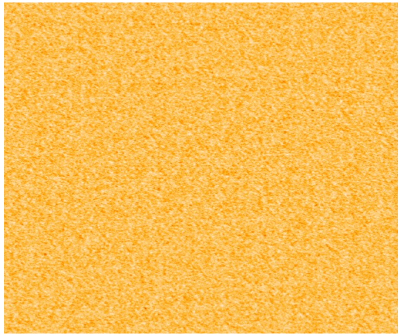
Impact of primary beam on Images



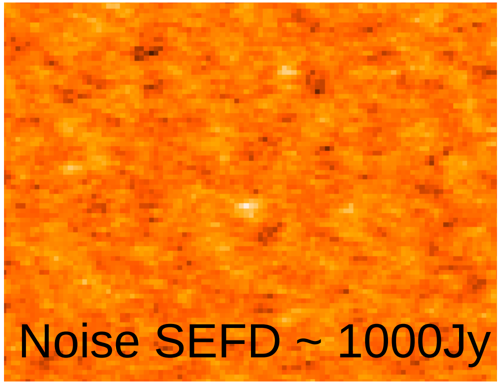
10 Jy source



With Primary Beam



With Primary Beam and Noise SEFD ~ 5000 Jy



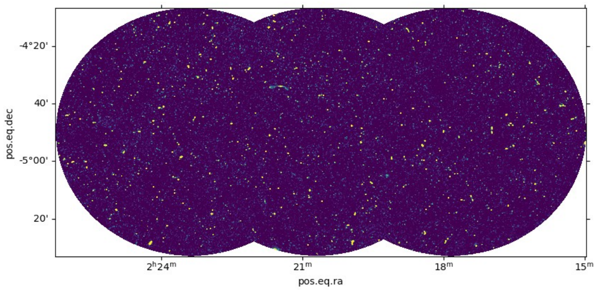
Noise SEFD ~ 1000Jy

Use Cases

- Intensity Mapping
- Mock HI MIGHTEE Catalogue
- Simulated Dark matter halo
- Spectral Line Implementation
- Source Detection
- SKA Data Challenge – 3

Mock-MIGHTEE Survey

MeerKAT International GHz Tiered Extragalactic Exploration (MIGHTEE)



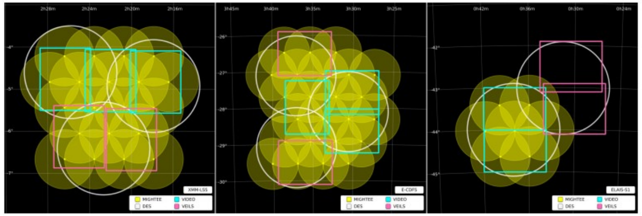


Figure 4: Current plausible pointing strategies for (left-to-right) XMM-LSS (20 pointings, 6.7 deg^2), E-CDFS (24 pointings, 8.3 deg^2) and ELAIS-S1 (7 pointings, 1.6 deg^2). Not shown here is the fourth COSMOS field, which will consist of a single deep pointing. In practice the grid of E-CDFS pointings will be snapped to the LADUMA pointing centre, requiring only 23 additional pointings from MIGHTEE.

Frequency Band	Resolution (arcseconds)	Field of View (degrees)	RMS noise in one hour (microJy)
1.75 – 2.50 GHz	4	0.65	~5
0.90 - 1.67 GHz	6	1.1	4.7
0.58 - 1.01 GHz	10	1.75	9.0

Total FoV	20 deg^2	
Frequency Coverage	900-1670 MHz	
Total Bandwidth	770 MHz	
Nominal sensitivity	1 micro Jy	
Spatial - resolution	~ 6 arcsec	
Observation time per pointing	16 hour	2 micro Jy per beam
Spectral Line	26 kHz	90 micro Jy per beam
Total Channels	32,728	3.27 kHz (Narrowband Extended) 26 kHz (Wideband fine)
Coarse Chanels	4096	208 kHz

L-band: 18cm to 33 cm (910 MHz – 1670 MHz)

S-band Low: 11 cm to 16 cm (1875 – 2727 MHz)

S-band high: 8 cm to 13 cm (2300 MHz - 3750 MHz)

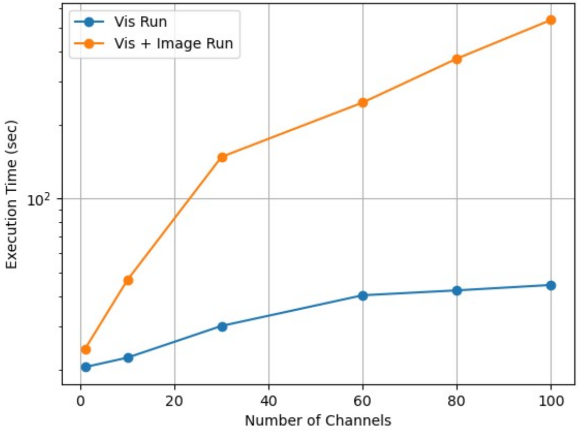
S-band FoV = 4 deg2 in E-CDFS (Chandra Deep Field South) and 1.5 deg2 in COSMOS (Cosmic Evolution Survey)

For 40 pointing and coarse bandwidth, we will have 40*4096 = 163k MS / Images

For fine bandwidth, we have 1.3 million MS / Images

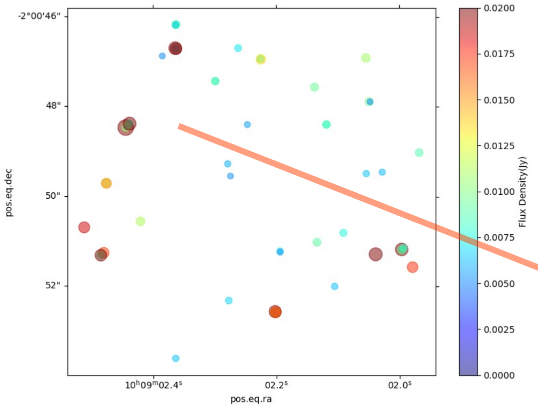
Mock Data Execution time

#	Run	Time until vis run (s) from the start	Time until vis file written (s)	Time until image file written (s)
0	Snapshot Run – 1 channel	20.5	20.6	24.8
1	Snapshot Run – 1 Channel with thermal noise	24.2	24.2	30.3
2	Snapshot Run – 10 Channel with thermal noise	22.4	22.4	46.55
3	Snapshot Run – 30 Channel with thermal noise	30.2	30.2	148.2
4	Snapshot Run – 60 Channel with thermal noise	40.3	40.3	247.2
5	Snapshot Run – 80 Channel with thermal noise	42.2	42.2	373.6
6	Snapshot Run – 100 Channel with thermal noise	44.4	44.4	537.7
7	10 h (1 timestamp) + 1 channel + thermal noise	23.8	23.8	28.8
8	10 h (1 timestamp) + 30 channel + thermal noise	26.7	26.7	148.3
9	10 h (30 timestamp) + 30 channel + thermal noise	111.5	111.6	247.2
10	10 h (100 timestamp) + 30 channel + thermal noise	331	331	469
11	1 channel + 1 timestamp + 13 sources	20.9	20.9	24.2
12	1 channel + 1 timestamp + 1122 sources	25.7	25.7	28.74
13	1 channel + 1 timestamp + 9896 sources	26.8	26.8	30.1



+ For 30,000 channels and 1 channel, the estimated time ~ 161310 sec ~ 2 days
+ For 40 pointing, 80 days with single core!
+ With 80 cores, estimated time ~ 1 days for 1 timestamp
+ For 16h observation with 10 min time-intergation each, we get total 96 timestamps. We get total 96 days with 80 cores. With 1000 cores, we can reduce it to ~ 8 days.
+ For 30 min time-integration, we can reduce execution time by factor 3, i.e. 2-3 days.

Example Simulation of MIGHTEE Survey



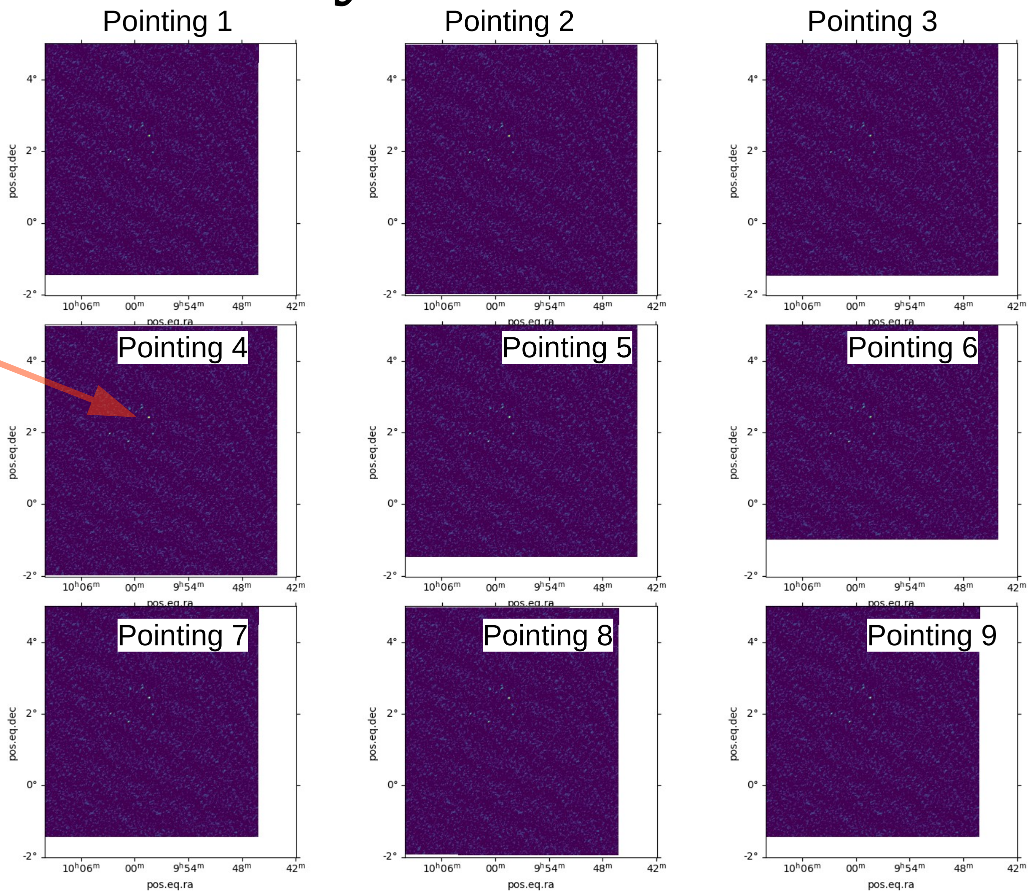


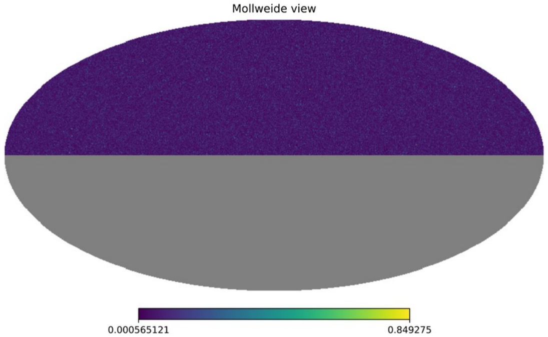
Image Mosaic
See Jennifer's talk

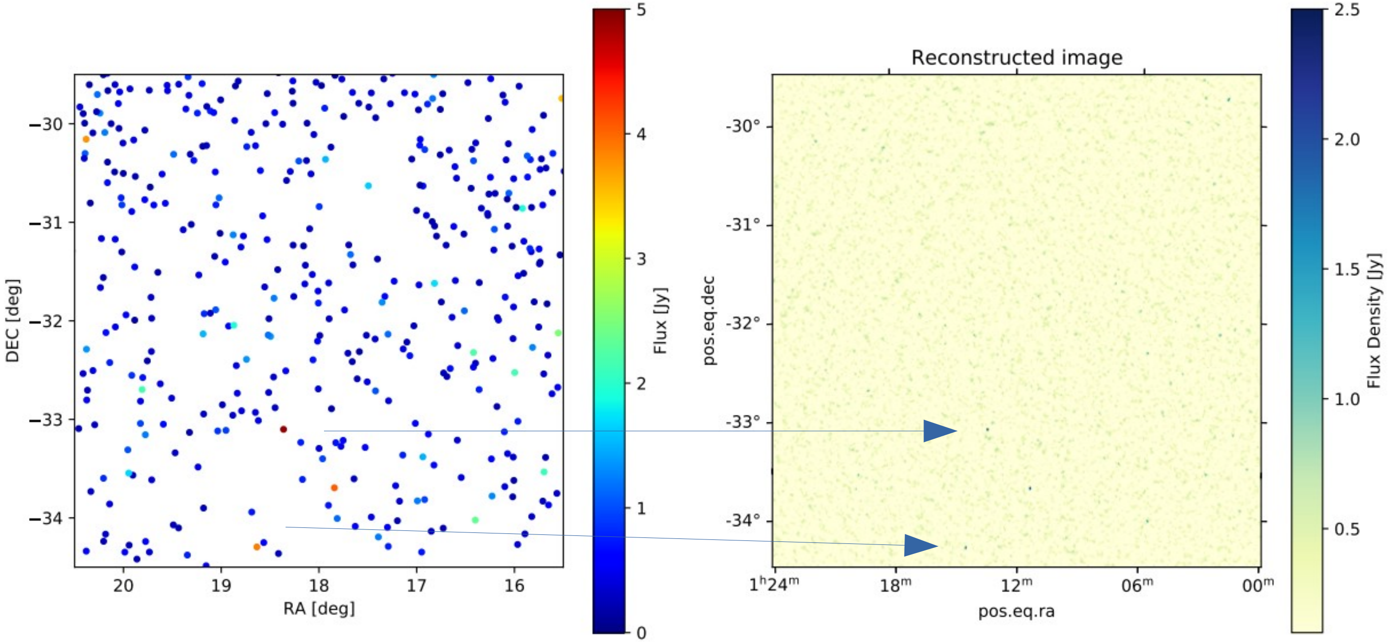
Simulated Dark Matter Halo Skymodels

- Dark matter halo – Pinnochio Simulation
- Halo to HI mass distribution -
- Catalog of simulated HI sources

$$M_{\mathrm{HI}}(M) = \alpha f_{\mathrm{H,c}} M \left(\frac{M}{10^{11} h^{-1} M_{\odot}} \right)^{\beta} \exp\left[-\left(\frac{v_{c,0}}{v_c(M)} \right)^{3} \right]$$

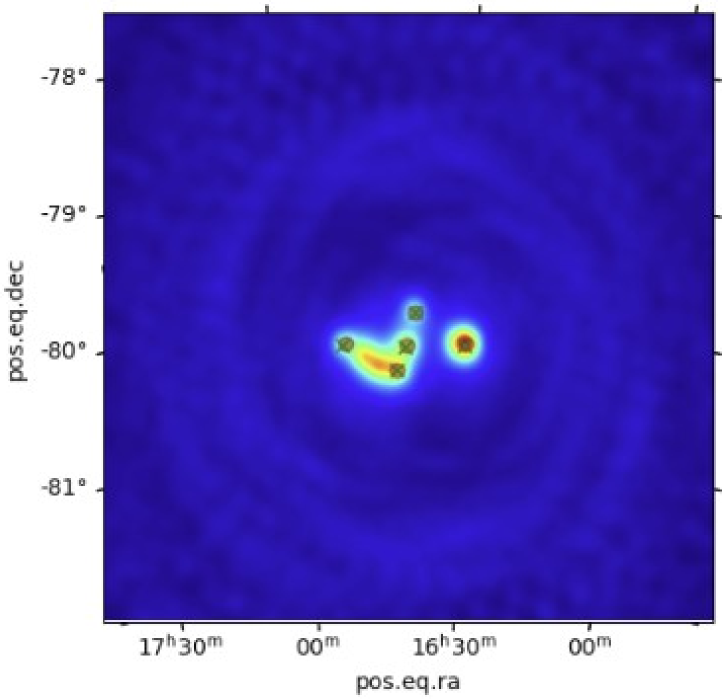
Padmanabhan, Refregier & Amara (2017)





More in Jennifer's talk

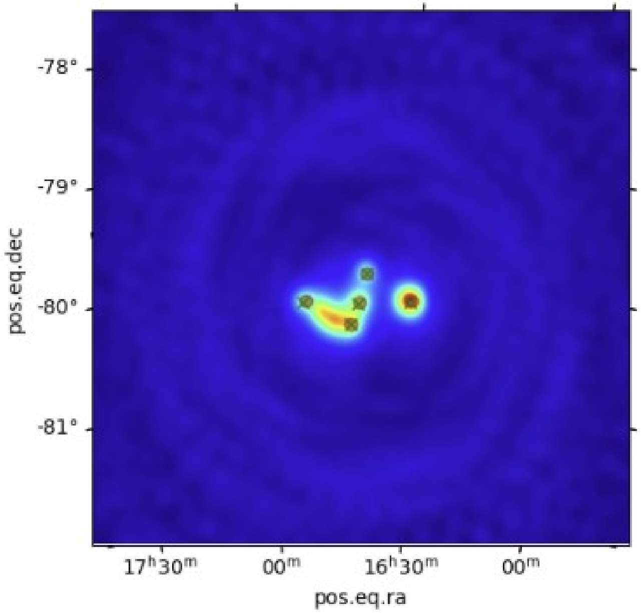
Source Detection Evaluation and Comparisons



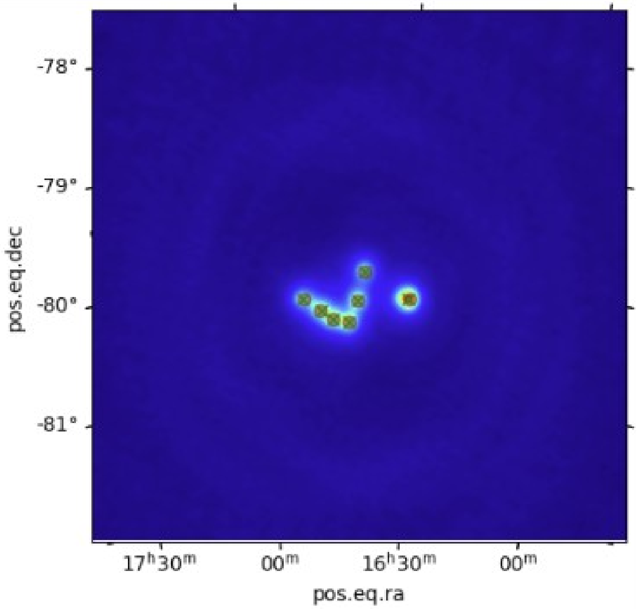
- ***source_detection.ipynb*** shows how to use *detect_sources_in_image*
- Handily callable functions such as *.plot()* allows fast comparisons between different algorithms.

Source Detection Evaluation and Comparisons

Dirty Image



Clean Image

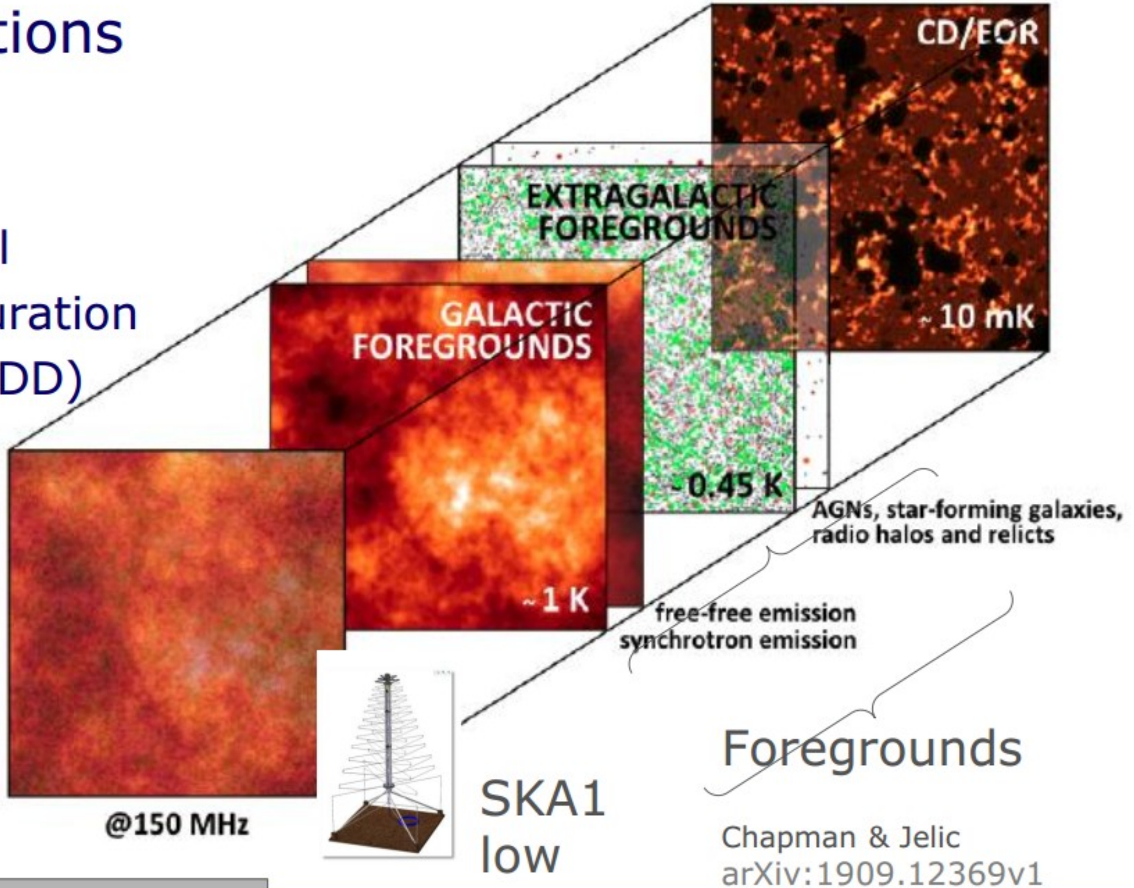


SKA Data Challenge - 3

Synthetic Observations

- Signal Cube
- Foreground model
- Telescope Configuration
- Gain Errors (DI +DD)

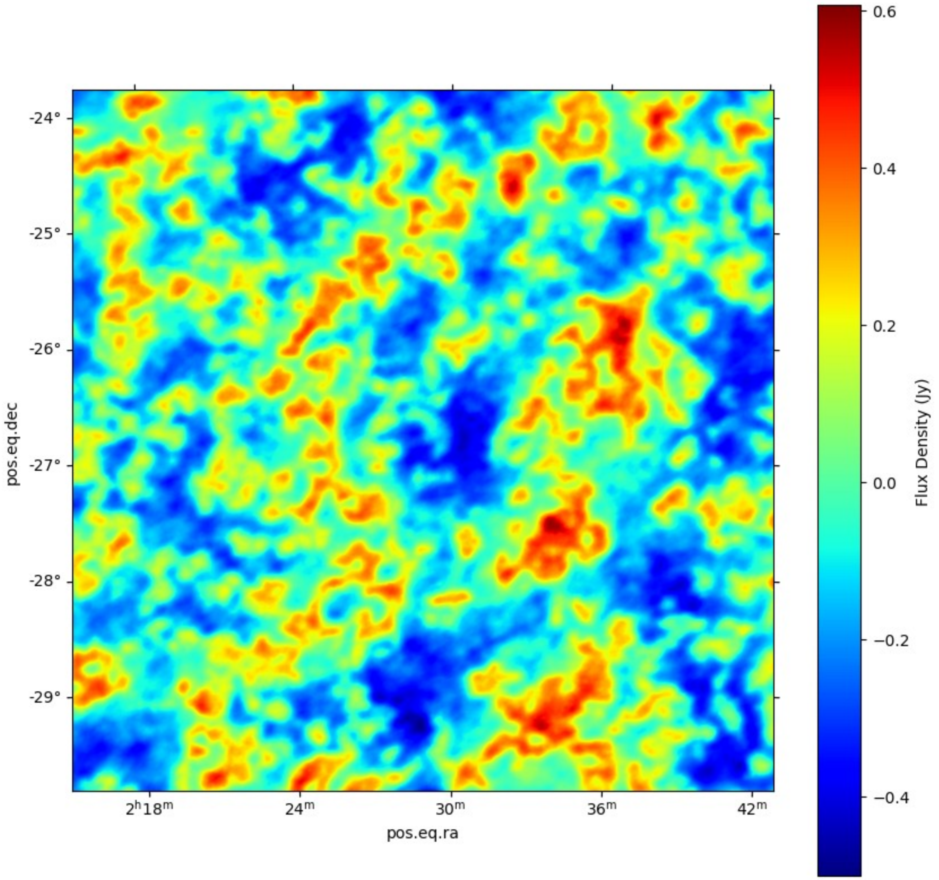
Synthetic
Data Cubes



Chapman & Jelic
arXiv:1909.12369v1

EoR - Simulations

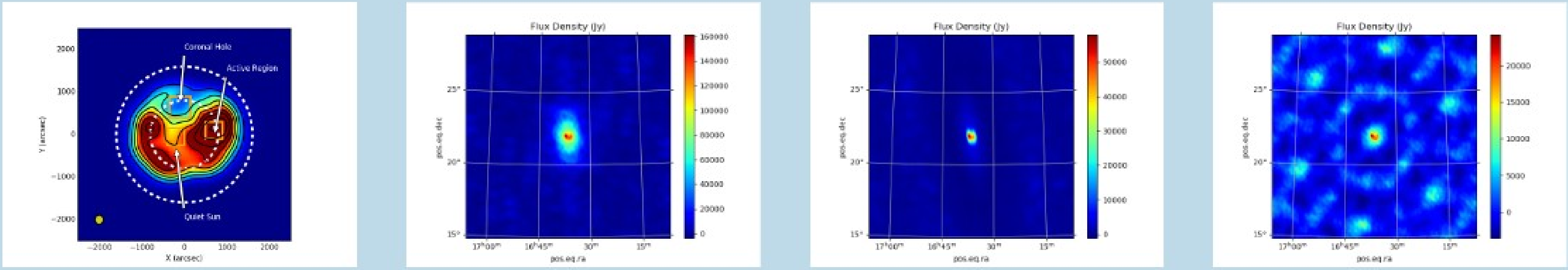
- Karabo provide support to the vis simulations for SKADC-3 and imaging
- Parallisation by Channels
- Parallisation in Skymodels



See Michele’s talk

Solar Observations

- Quiet Sun - Extended and bright
- Radio burst – Compact and brighter
- Skymodel – Free-free emission maps
- Benchmarking with MWA Quiet Sun maps



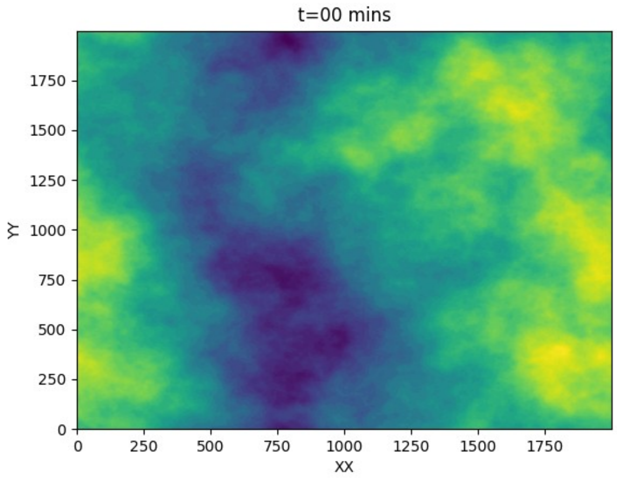
Sun's Model | MWA | SKA-low | LOFAR

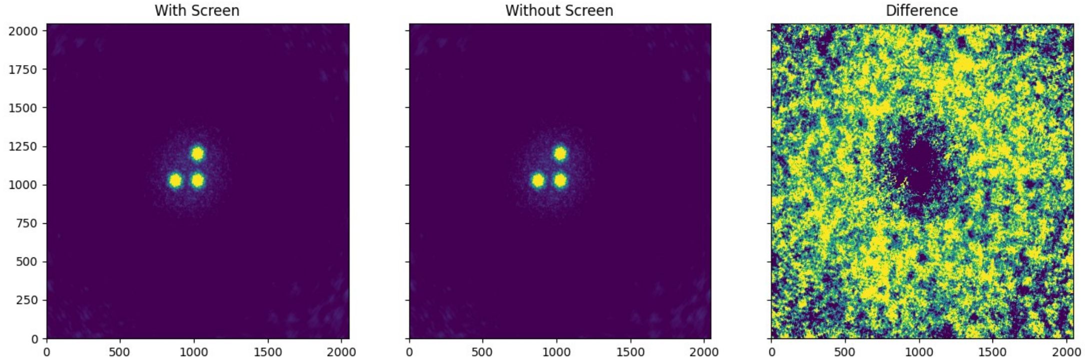
Radio Interferometer Specifications

Instrument	$\nu(GHz)$	$\Delta\nu$ kHZ)	Δt(s)	SEFD (mSFU)
SKA-Low	0.05-0.35	15	0.001	0.5
LOFAR	0.03-0.24	100	0.01	30
MWA	0.08-0.30	10	0.5	5
SKA-mid	0.35-15.3	5	0.001	0.2
MeerKat	0.58-3.5	1.6	8	36
VLA	0.39-45	1000	0.05	42
ngVLA	5-100	200	< 0.001	23

Ionosphere Effects

- Aratmospy: The ionospheric screen was 200 km by 200 km in size, and was modelled as two layers moving in different directions at different speeds to reduce the amount of repetition in the pattern over time: one layer moving at 150 km/h at 300 km altitude, and the other at 75 km/h at 310 km altitude.
- The resolution was 100 metres per pixel. At that altitude, the screen spanned a field of view of almost 40 degrees, so it also covered sources outside the primary beam.





Summary

- Karabo is a versatile tool and user-friendly
- Many use cases have been integrated
- Parallelised via channels
- Workflows are fast and efficient for CSCS deployments
- Many more features will come like wsclean integration, RFI modules, optimally handle extended sources etc.

http://github.com/i4ds/Karabo-Pipeline

Code & Tech Doc.

https://swiss-ska.fhnw.ch/index.php/s/bJWAfTYyoJg3AGx

Files & Documentation

https://swissska.slack.com/

Chat in #digital-twin

Report Issues

Request Features

Get Support

Contribute