ProcessMeerKAT: The IDIA Calibration Pipeline

Srikrishna Sekhar

Jordan Collier
Brad Frank
Russ Taylor

Inter-University Institute for Data Intensive Astronomy

UNIVERSITY OF CAPE TOWN
IYUNIVESITHI YASEKAPA • UNIVERSITEIT VAN KAAPSTAD

SPARCS 2019

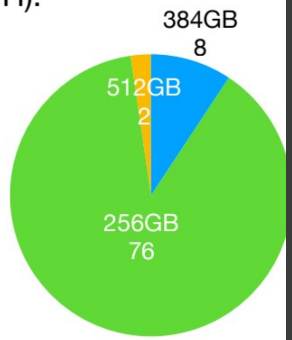
Overview

- ProcessMeerKAT : IDIA Calibration pipeline
- Developments with AW projection

ProcessMeerKAT

IDIA Kit

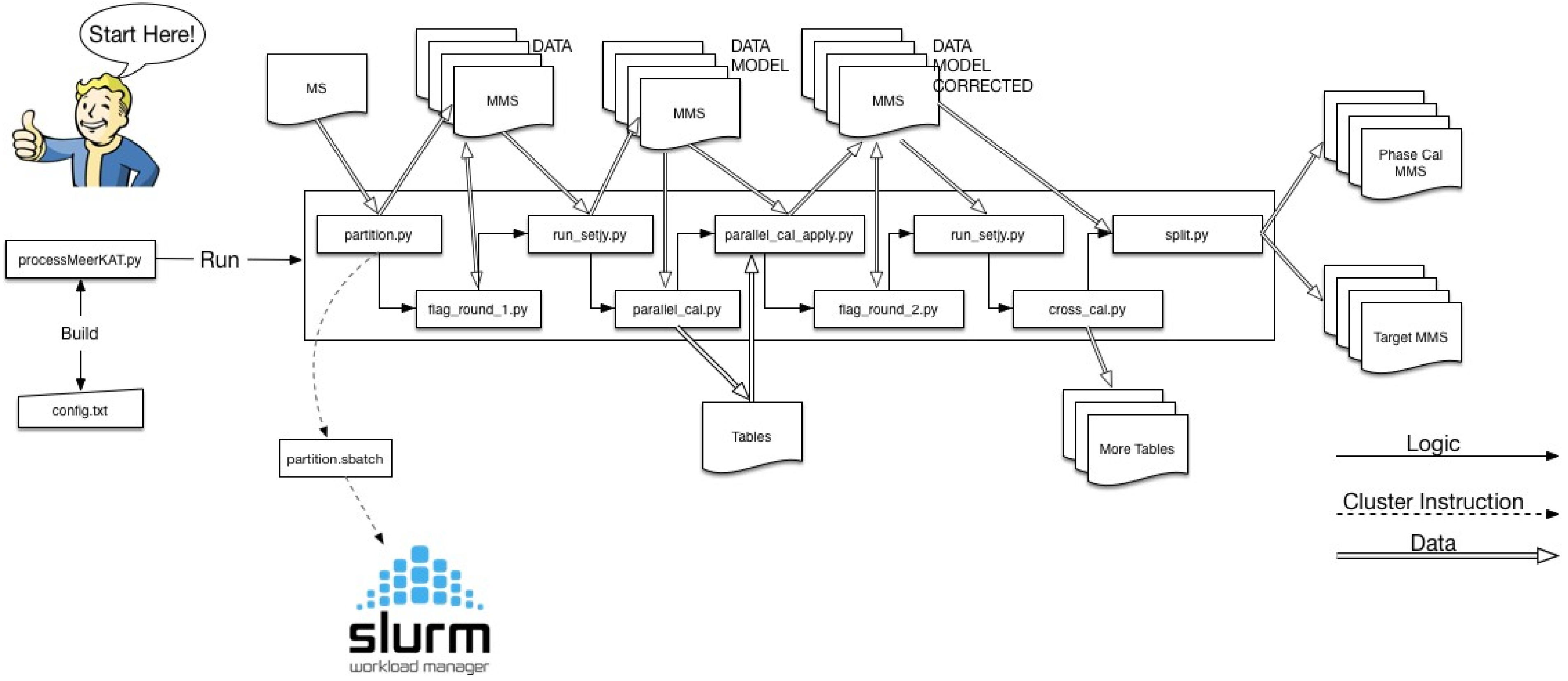
- Current integration into ILIFU.
  - ILIFU: Joint Cloud Centre for Astronomy and Bioinformatics.
  - Compute
    - 127 Nodes, 16-24 cores/node @ 2.6GHz (hyper-threading).
    - VHPC: 50 Nodes (256G/32VCPU) currently available (CEPH).
    - ~ 6 Fat Nodes (256G/32VCPU) — BeeGFS.
  - Storage
    - 19 Nodes, 3.3PB raw (~1PB available to Pipelines/LSP).
    - BeeGFS (OS) / CEPH (LT).



IDIA SKA AFRICA SQUARE KILOMETRE ARRAY NRF National Research Foundation

Slide courtesy Brad Frank

IDIA


Start Here!
processMeerKAT.py
Run
Build
config.txt
MS
DATA
MMS
DATA
MODEL
MMS
DATA
MODEL
CORRECTED
MMS
partition.py
flag_round_1.py
run_setjy.py
parallel_cal.py
parallel_cal_apply.py
flag_round_2.py
run_setjy.py
cross_cal.py
split.py
Phase Cal
MMS
Target MMS
Tables
More Tables
partition.sbatch
slurm
workload manager
Logic
Cluster Instruction
Data

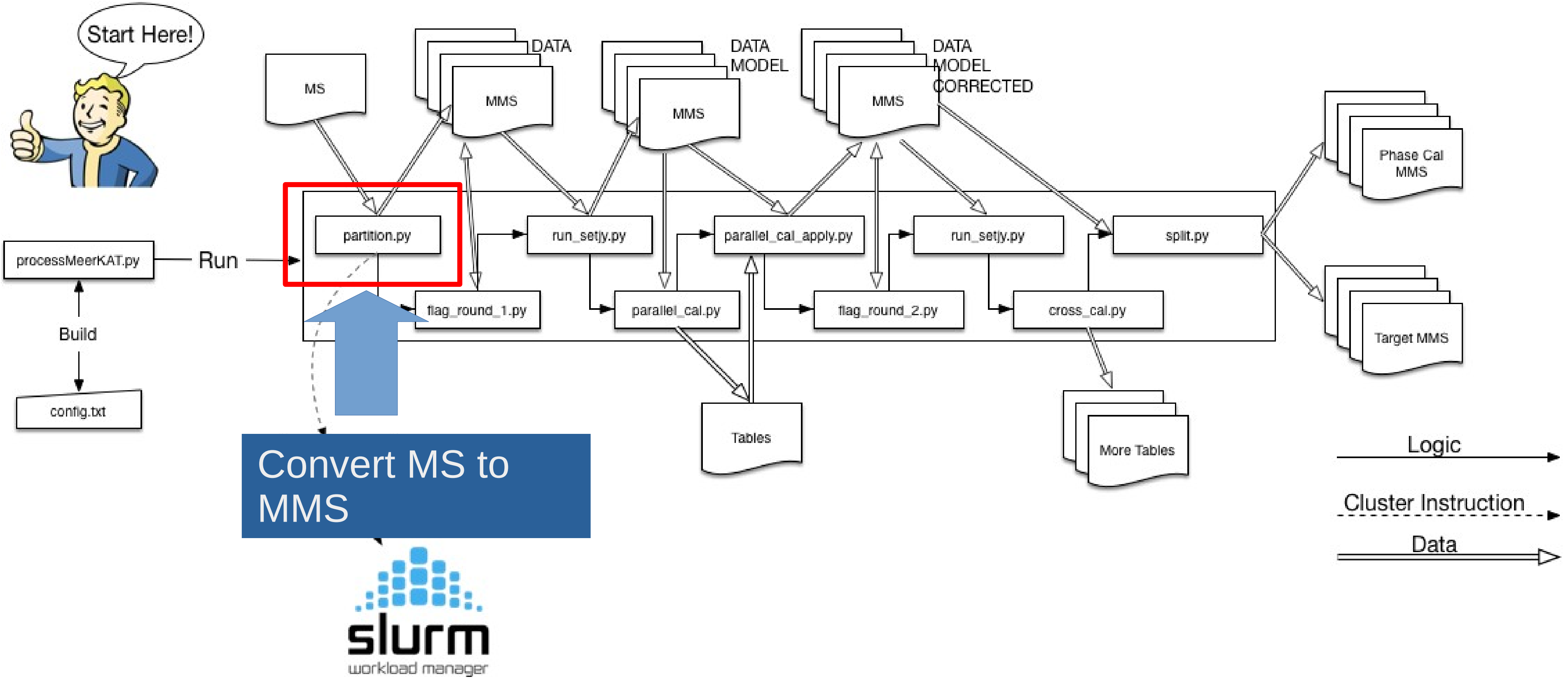
Pipeline Philosophy

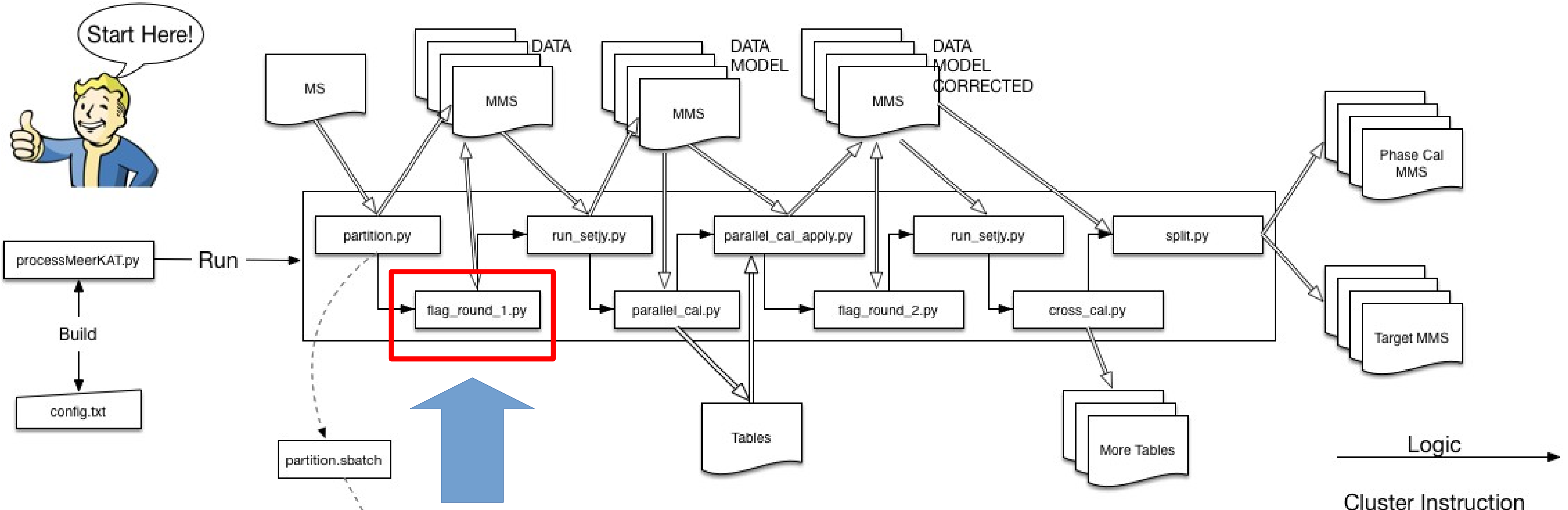
- Use multi-measurement sets (MMS) to parallelize across a cluster, take advantage of MPI aware tasks in CASA
- Do The Right Thing™ - Sensible defaults, get phases, fluxes, and polarizations right

Pipeline goals

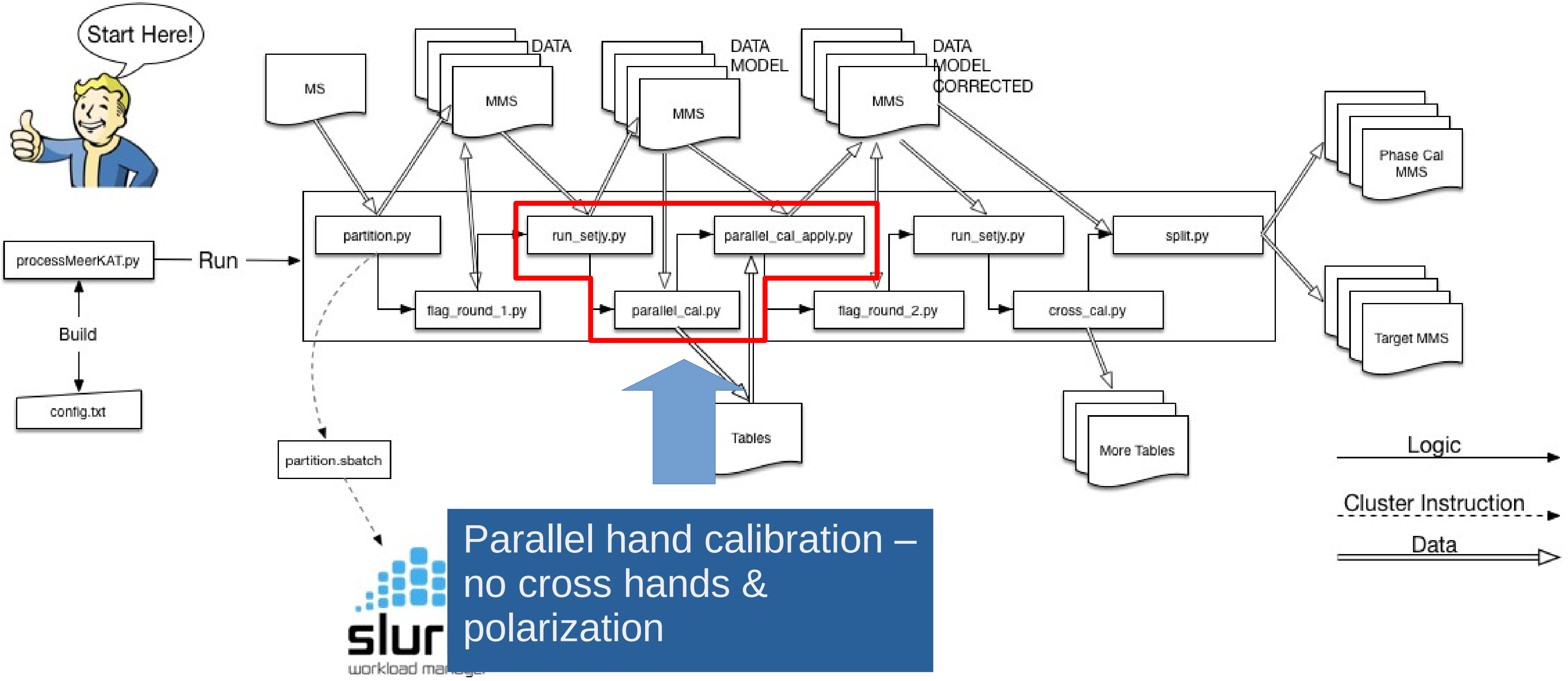
Full Stokes calibration with the aim of producing continuum images/polarization cubes/spectral line cubes

(Full Stokes required for maximizing sensitivity in Stokes I as well)

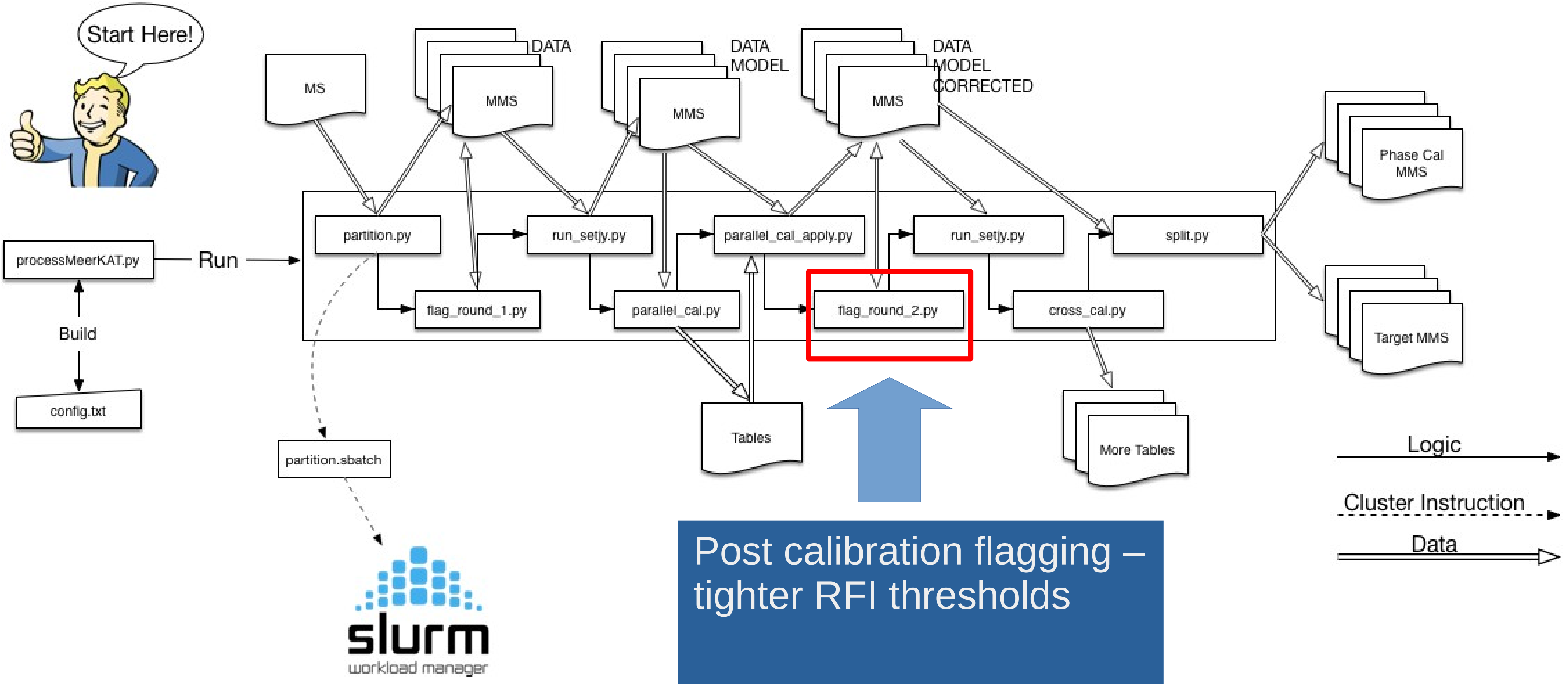

Start Here!
MS
DATA
MMS
DATA
MODEL
MMS
DATA
MODEL
CORRECTED
MMS
Phase Cal
MMS
processMeerKAT.py
Run
partition.py
run_setjy.py
parallel_cal_apply.py
run_setjy.py
split.py
flag_round_1.py
parallel_cal.py
flag_round_2.py
cross_cal.py
Target MMS
Build
config.txt
Tables
More Tables
Logic
Cluster Instruction
Data
Convert MS to MMS
slurm
workload manager



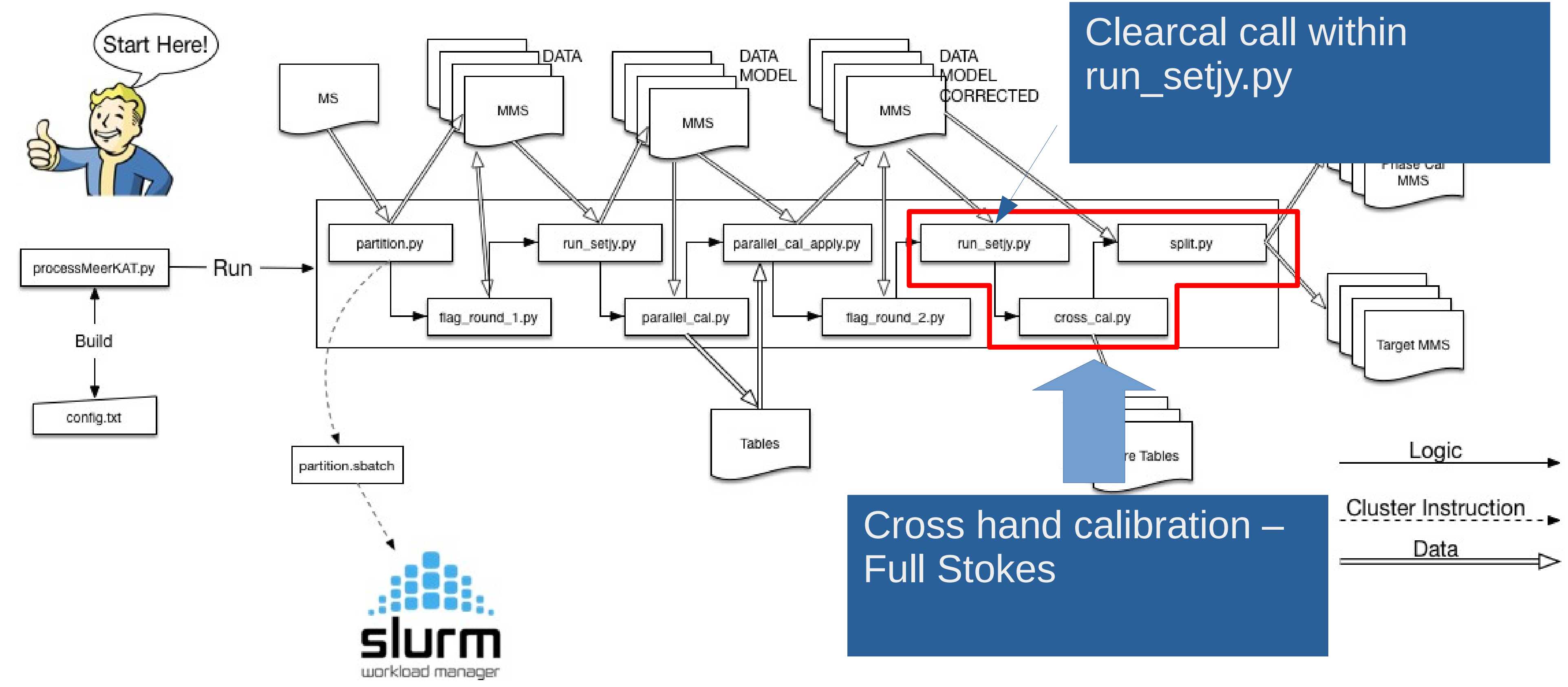
Pre calibration flagging – get rid of the worst RFI



Parallel hand calibration – no cross hands & polarization



Post calibration flagging – tighter RFI thresholds



Clearcal call within run_setjy.py

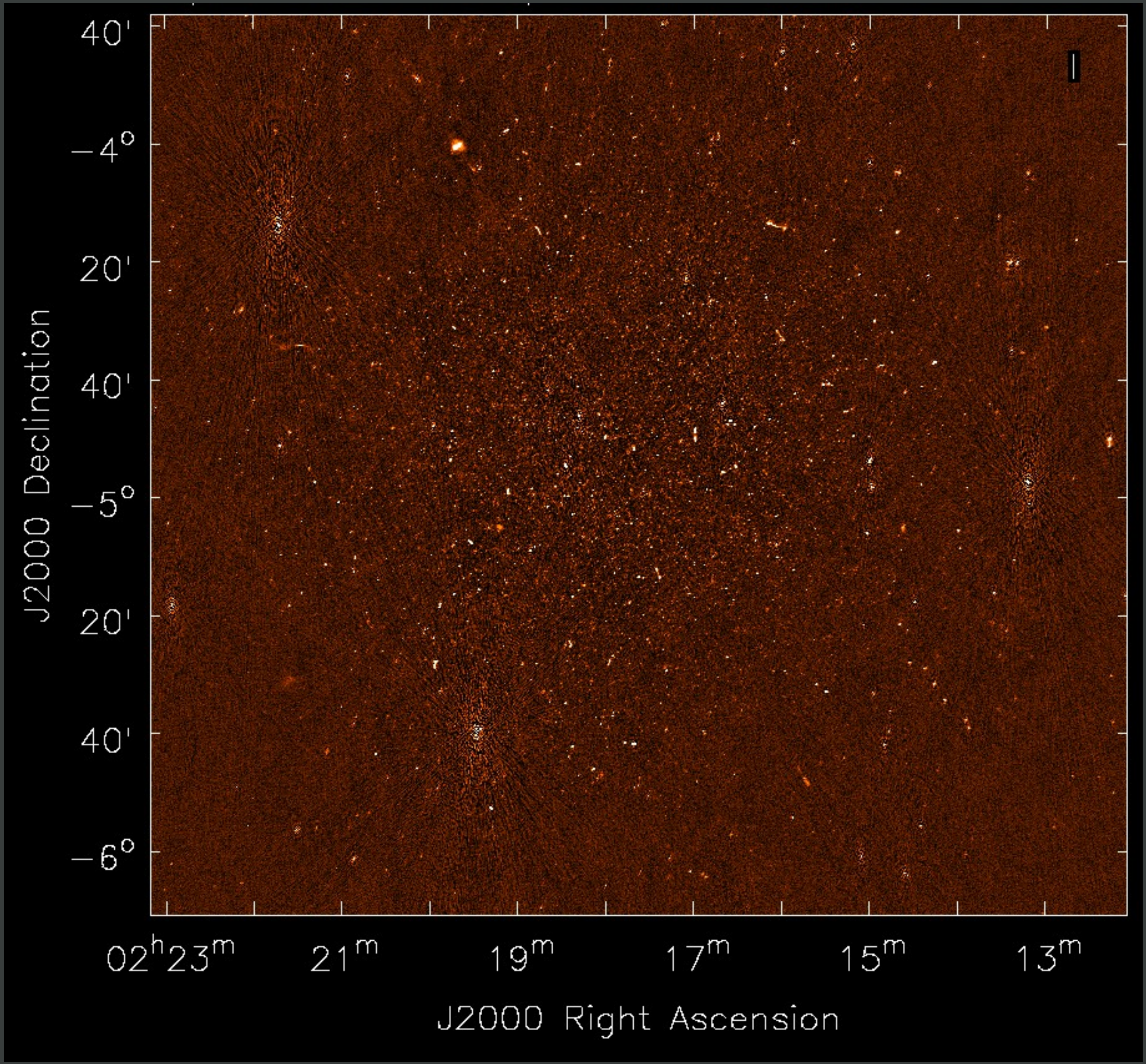
Cross hand calibration – Full Stokes

Polarization calibration

- Need to estimate :
  - Instrumental leakage
  - Calibrator source polarization
- Do both by observing a single source over several parallactic angles

Polarization calibration

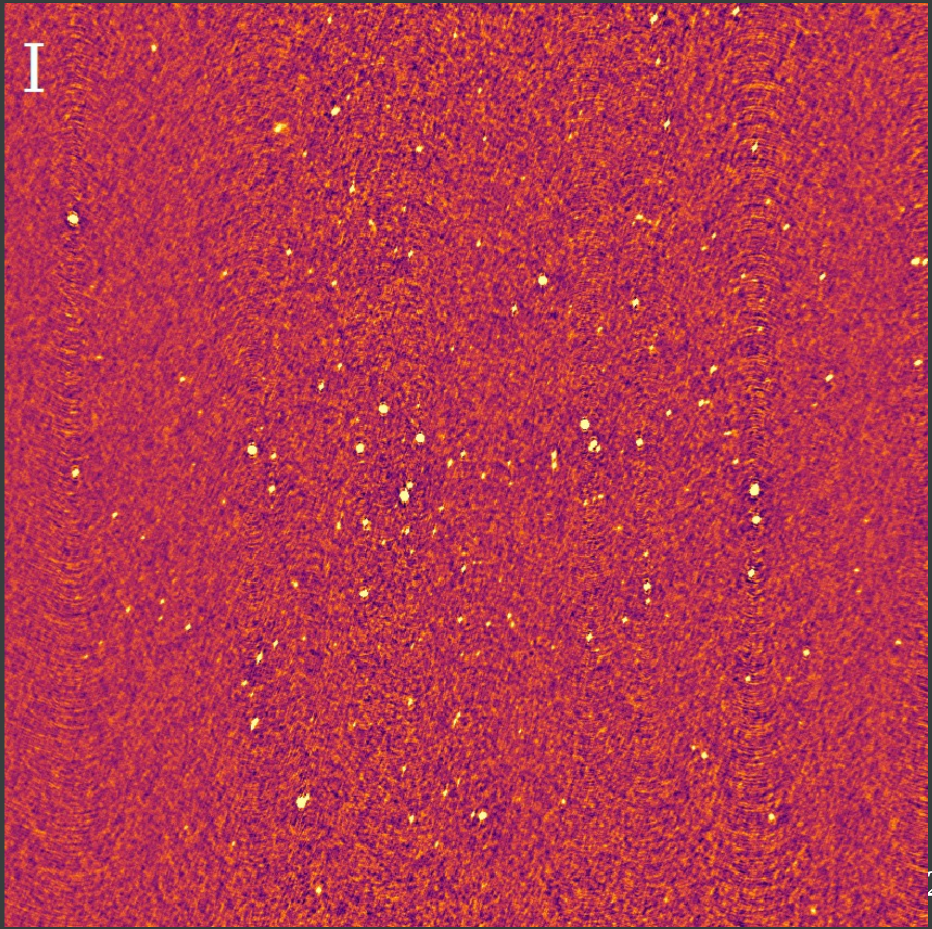
- Limitations: Leakage and QU estimation assume a constant value across an SPW.
  - Reasonable for VLA/ALMA, with several small (~ 64 MHz) SPWs
  - Problematic for MeerKAT with one ~ 800 MHz SPW
- On axis calibration still good, in reasonable agreement with VLA polarization measurements



MIGHTEE XMM LSS 12

RMS : ~ 4 uJy/beam

Polarization cubes



Stokes images of a single channel of the XMM LSS pointing at 1120 MHz

2019

How to get better?

- Split band into SPWs to get better polarization calibration
- AW projection to get off-axis polarizations and leakages (full Mueller)

AW Projection

In collaboration with Preshanth Jagannathan, Sanjay Bhatnagar, and Brian Kirk (NRAO) and Russ Taylor (IDIA)

The problem

- Antenna PBs can be rotationally asymmetric in the parallel hand correlations
- Polarization leakage beams are inherently asymmetric, systematic errors in off axis polarization
- Alt-az mounted antennas rotate, and these rotations cause an apparent variation of source flux

The approach

$$V_{ij}^{\mathrm{Obs}}(\nu, t) = W_{ij}(\nu, t) \int \mathsf{M}_{ij}(\mathbf{s}, \nu, t) \mathbf{I}(\mathbf{s}, \nu) e^{\iota \mathbf{b}_{ij} \cdot \mathbf{s}} d\mathbf{s},$$

$$M_{ij}(\mathbf{s}, \nu, t) = \mathsf{E}_i(\mathbf{s}, \nu, t) \otimes \mathsf{E}_j^*(\mathbf{s}, \nu, t).$$

$$V_{ij}^{\mathrm{Obs}}(\nu, t) = W_{ij}(\nu, t) \mathcal{F} [(\mathsf{E}_i(\mathbf{s}, \nu, t) \otimes \mathsf{E}_j^*(\mathbf{s}, \nu, t)) \cdot \mathbf{I}(\mathbf{s}, \nu)]$$

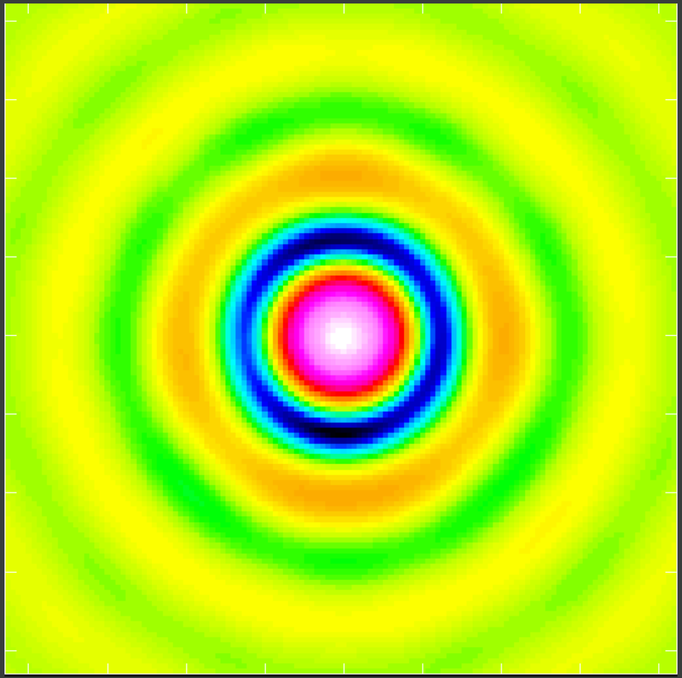
$$= W_{ij}(\nu, t) [\mathsf{A}_{ij} \star \mathbf{V}_{ij}],$$

From Jagannathan et al., 2018

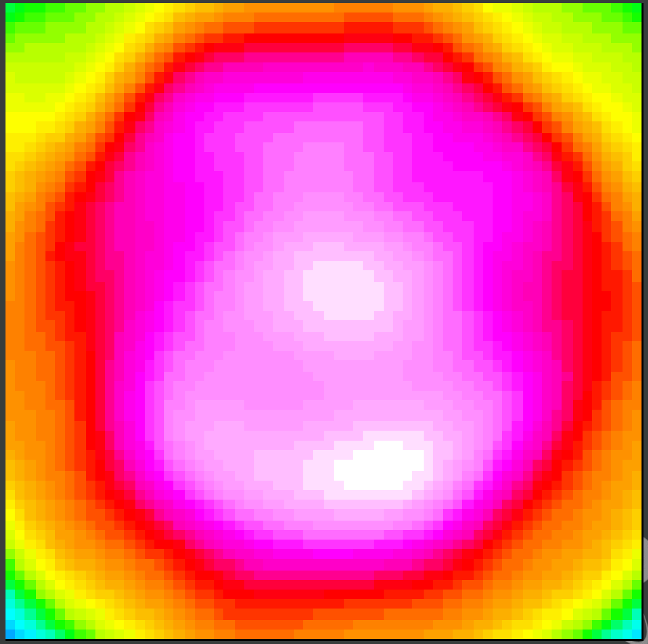
Aperture illumination patterns

- Obtained by Fourier transforming the PB holography measurements

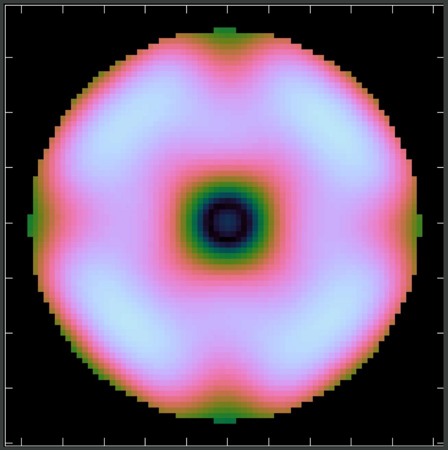
MeerKAT Holography courtesy SARAO

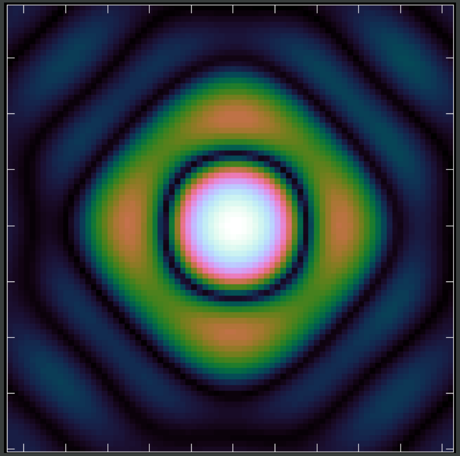


FT



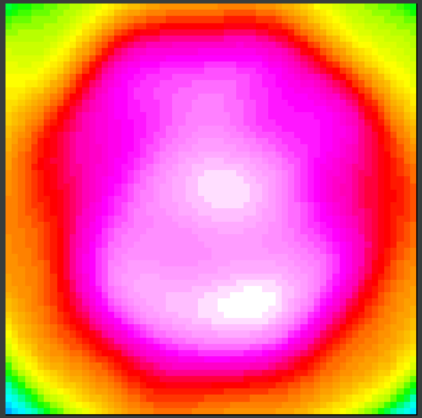
Unblocked apertures are neat

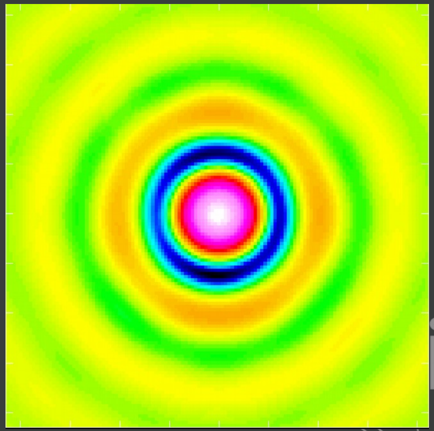




Left: VLA

Right: MeerKAT





A – to – Z solver

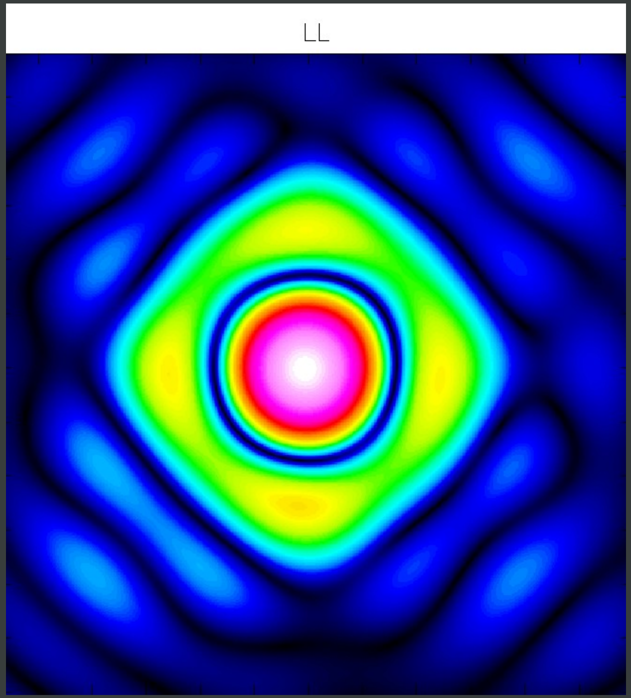
- Use Zernike polynomials to directly model the complex aperture
- Natural domain to model optical aberrations that cause PB weirdness
- Telescope agnostic - does not require ray traced model for different antennas/telescopes, only holography
- Aperture size is fixed, independent of number of measured sidelobes

A – to – Z Solver

- Ray tracer does not capture all optical effects at lower frequencies – model with Zernikes

Squint from ray tracer

Squint from Zernike modeling



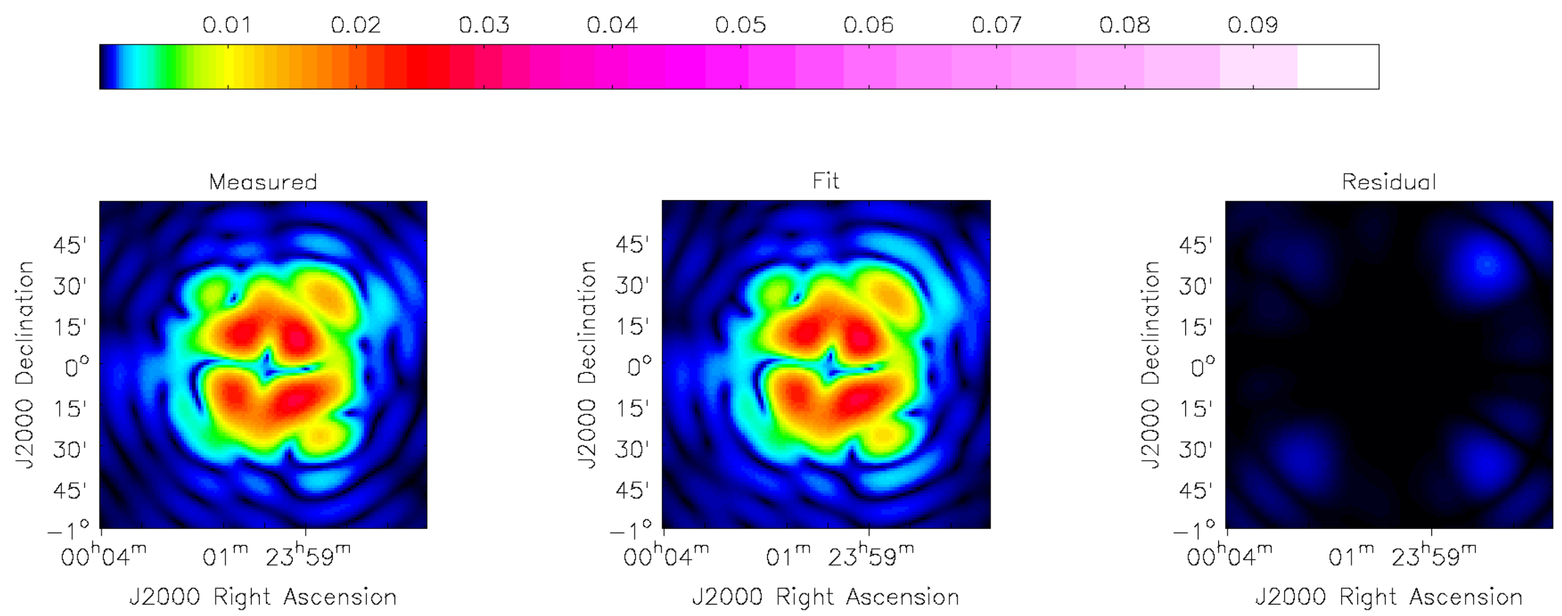
A – to – Z solver : Zernike Fitting

- Fit for the first N orders of polynomials

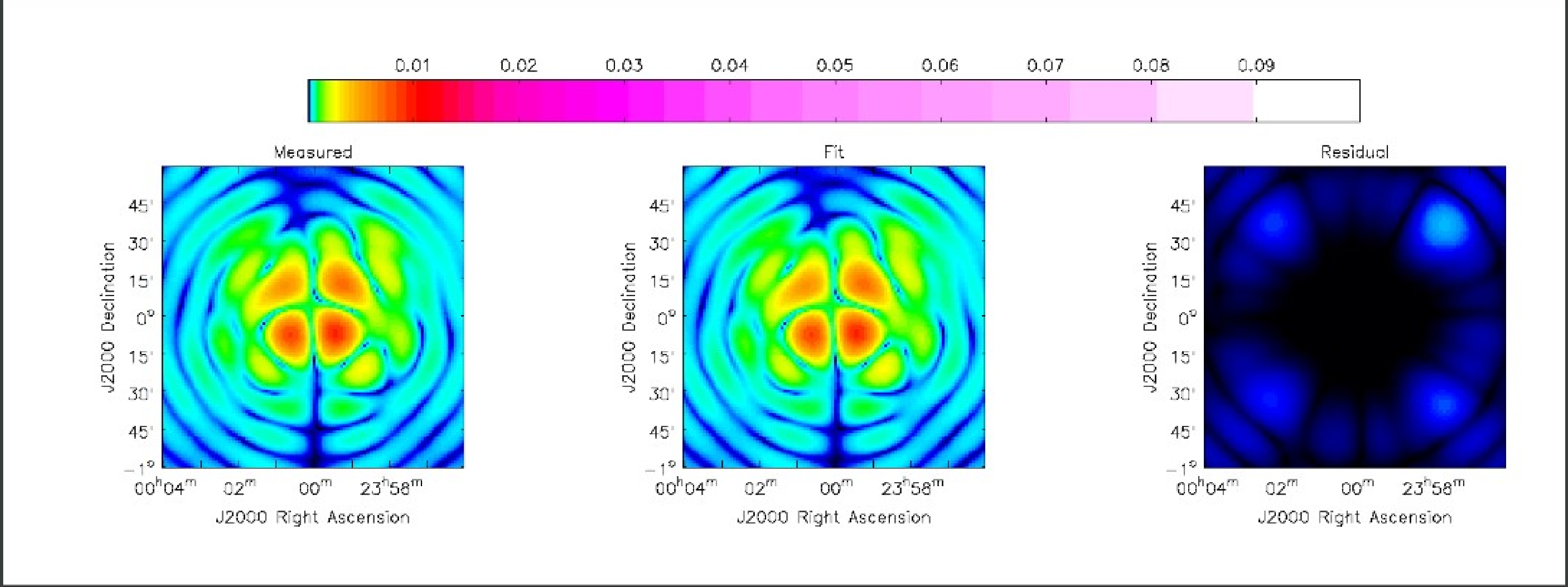
  Non-linear least squares solver (Levenberg-Marquardt)

- Obtain model complex aperture as a function of Stokes, frequency
- Fourier transform to obtain model PB as a function of Stokes, frequency
- Allows for full Mueller matrix corrections

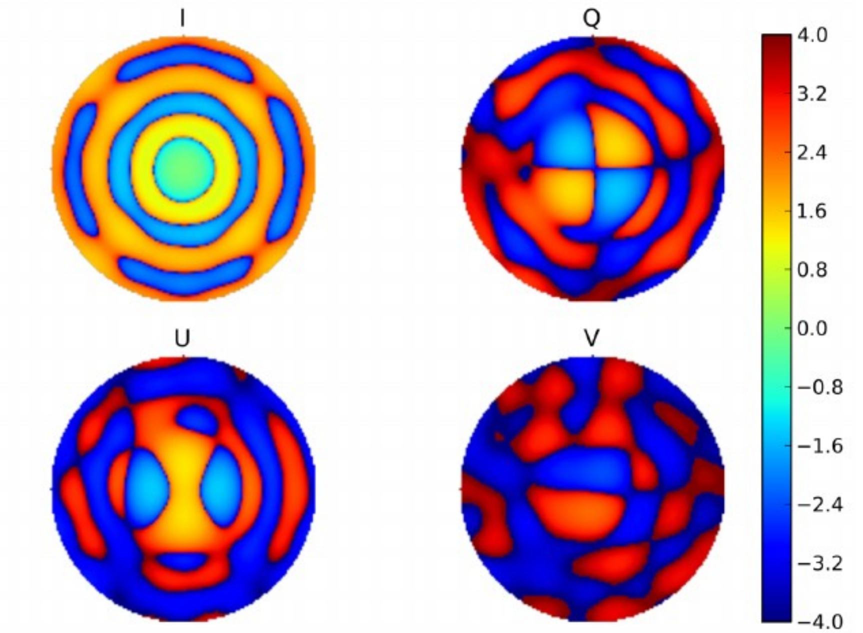
A – to – Z Solver: VLA



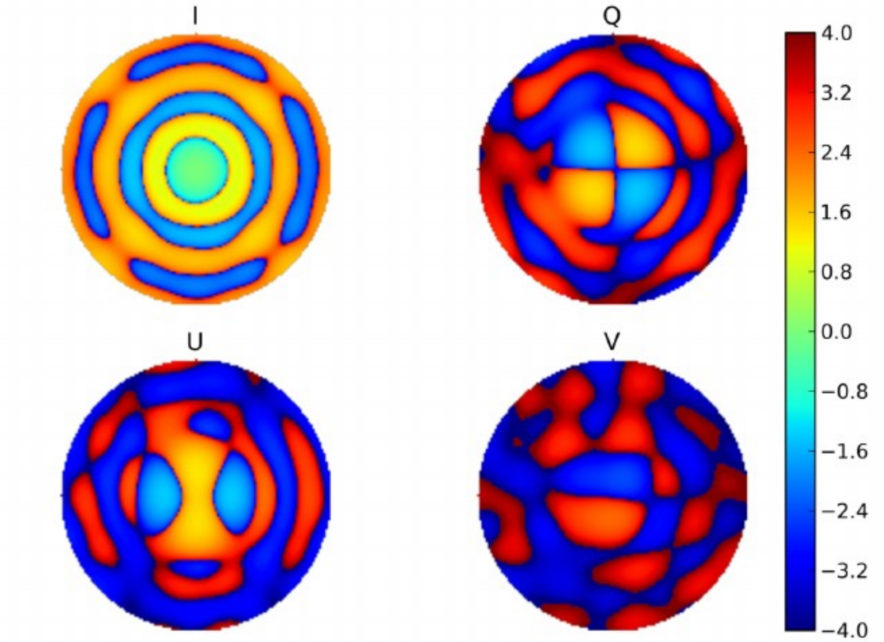
A – to – Z Solver : MeerKAT



A – to – Z Solver : ALMA

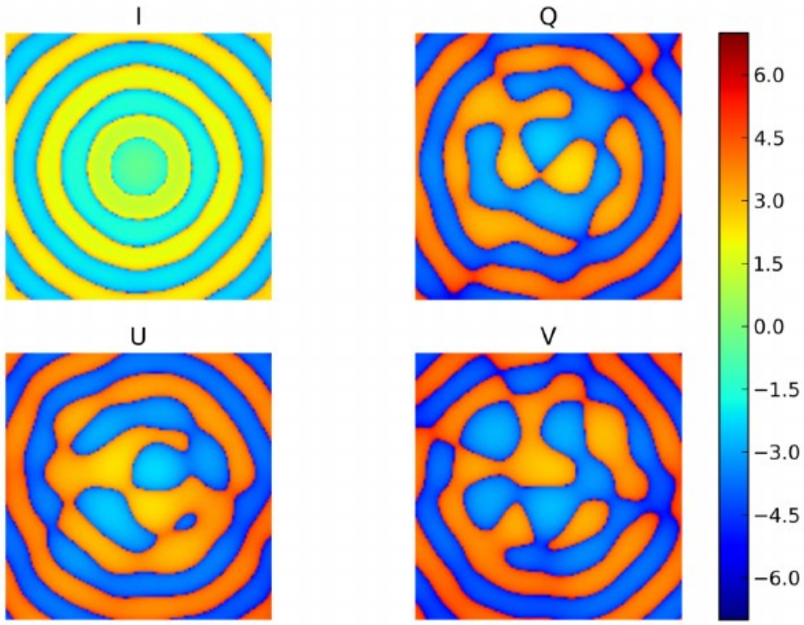


(a) Stokes data, ALMA DA dish

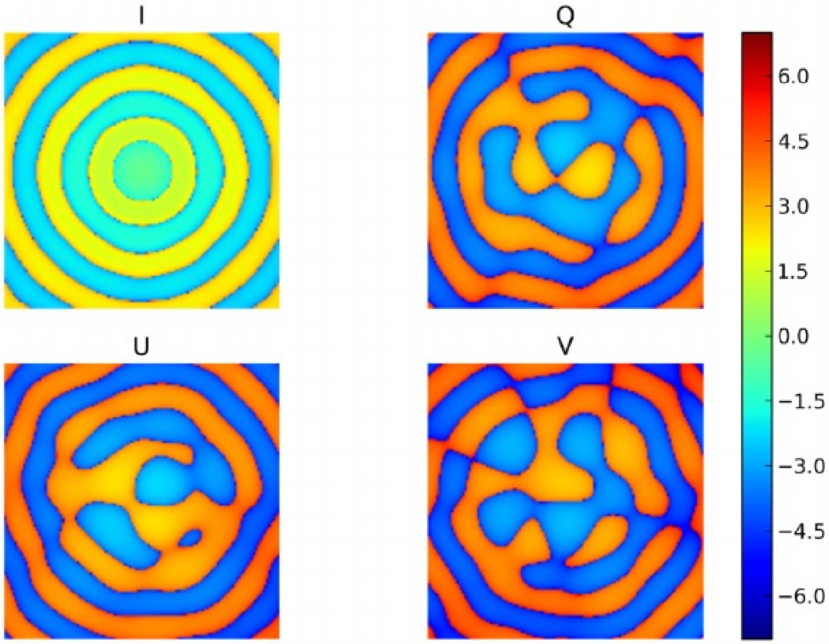


(b) Stokes model, ALMA DA dish

A – to – Z Solver : MeerKAT

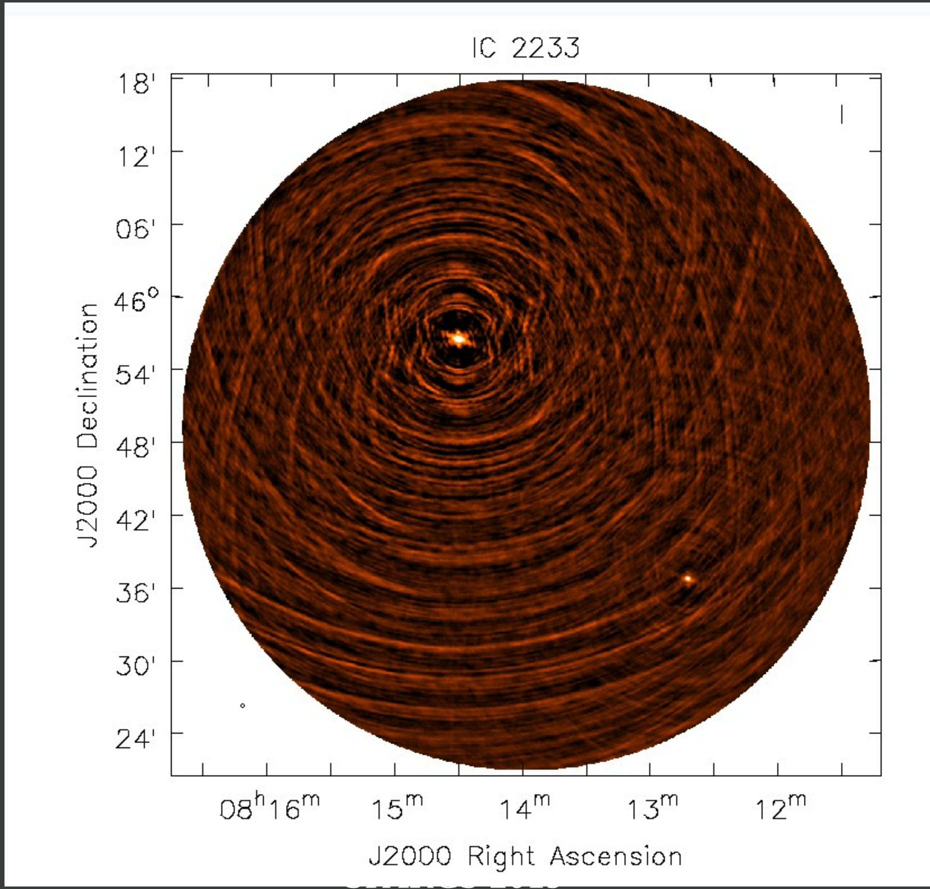


(a) Stokes data, MeerKAT

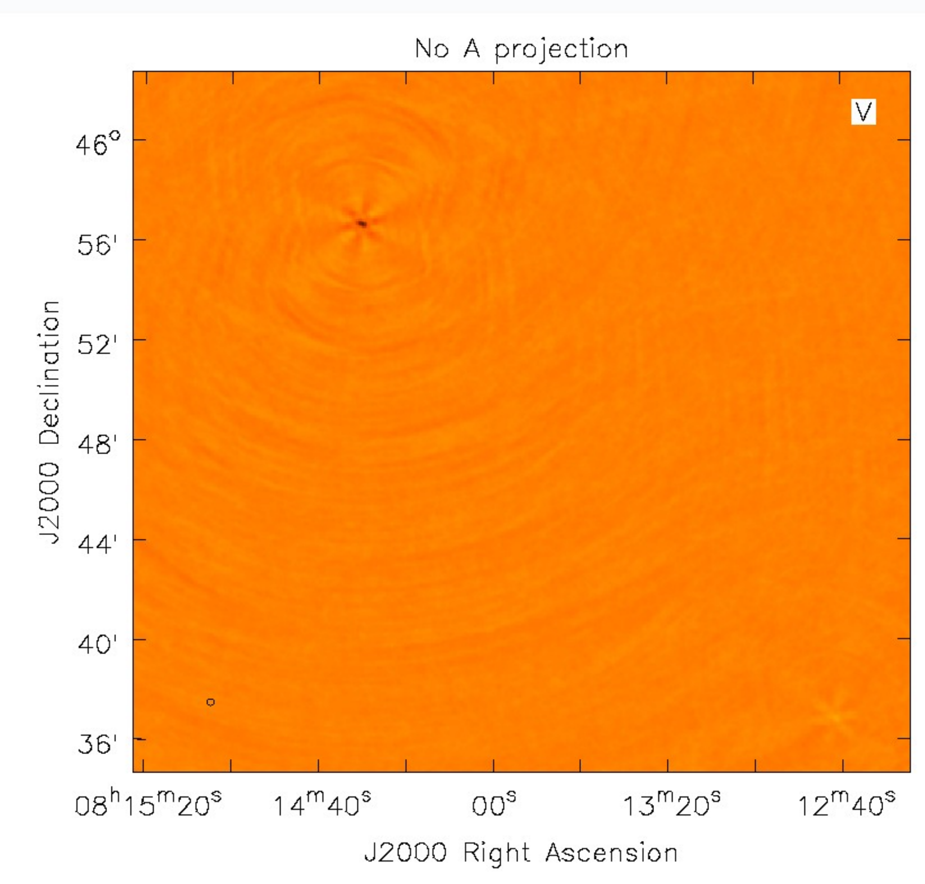


(b) Stokes model, MeerKAT

Test field: IC2233



A projection at the VLA



- IDIA in collaboration with NRAO
- In the process of expanding the framework in CASA to allow for any general Zernike polynomials to be passed in to the A projection framework
- Very close to an initial test with MeerKAT!

Summary

- IDIA Calibration pipeline is fast and flexible
- Only a-priori calibration at the moment – self-cal & DDE calibration coming

- Working on implementing Zernike-based generalized framework for AW projection
- Full Mueller, wideband A corrections within reach
- Telescope agnostic