HIRAX - Overview and Status

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SKA Days 2024

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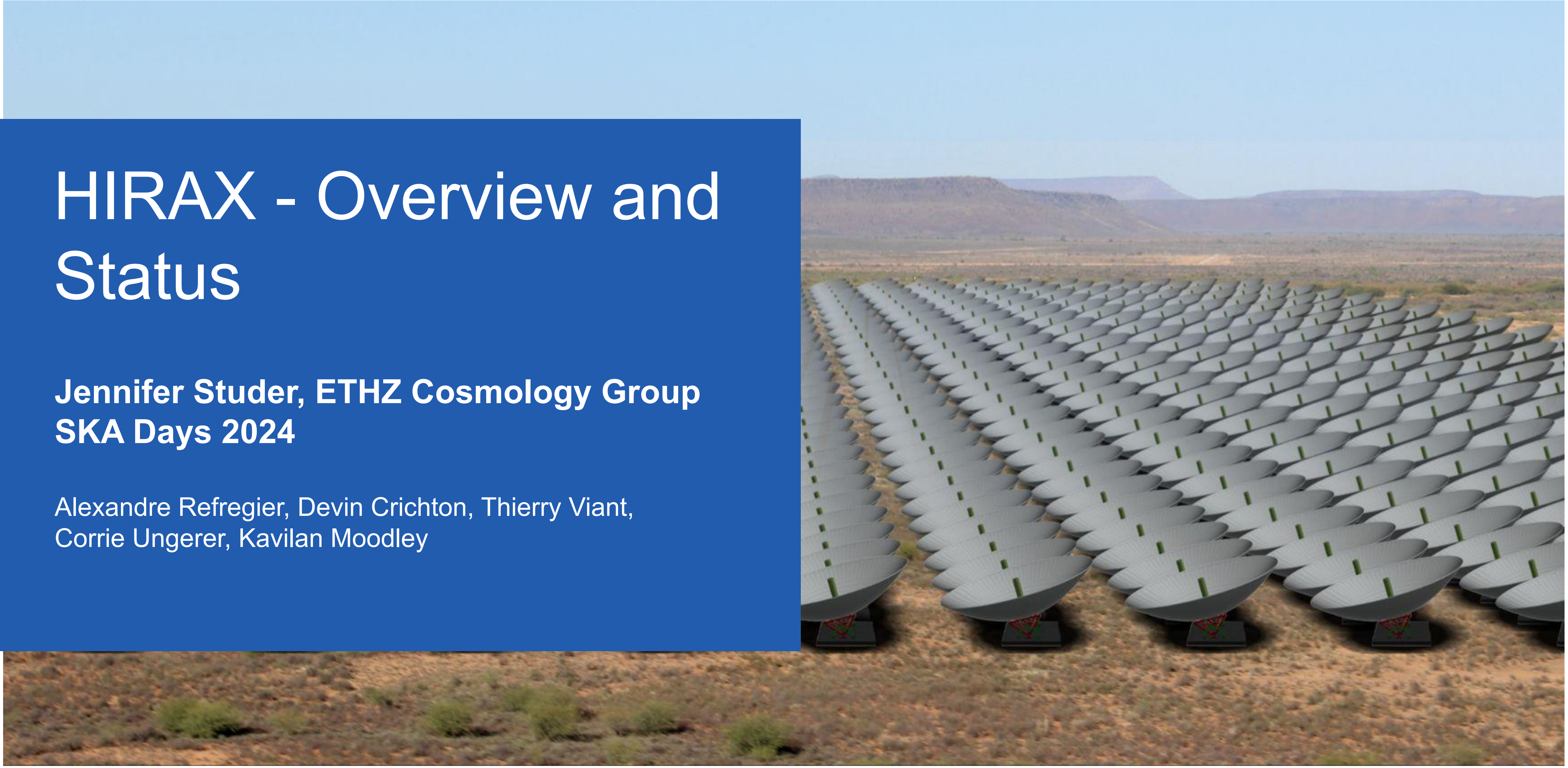
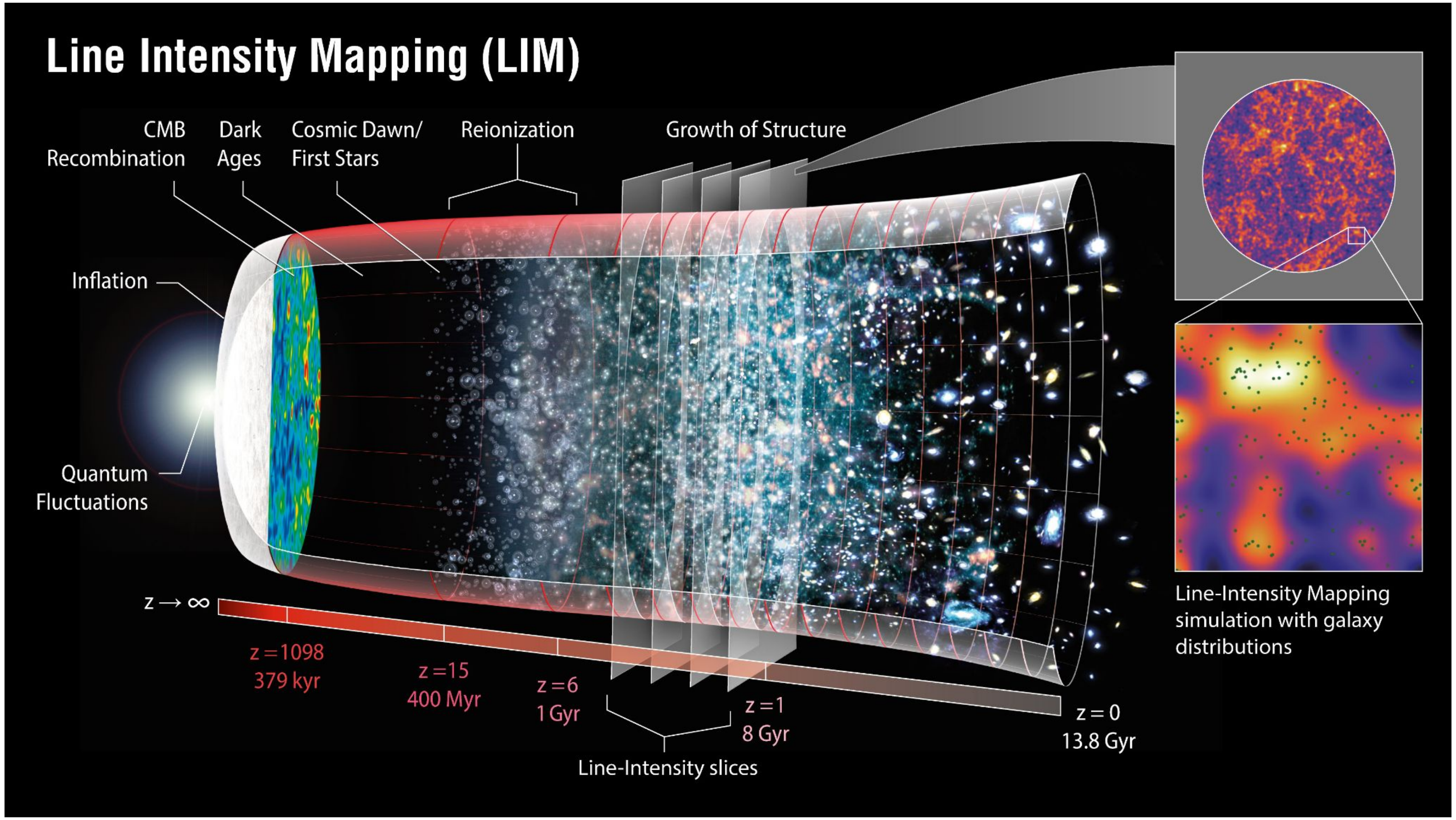


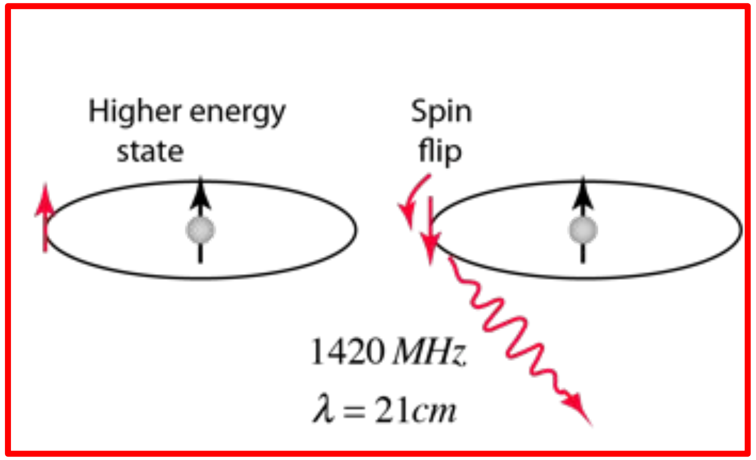
Credit: D. Crichton et al. (2022)

Swiss National Science Foundation

HIRAX Overview

- **H**ydrogen **I**ntensity and **R**eal-time **A**nalysis e**X**periment
- Radio interferometer with a compact, redundant layout





Credit: https://lambda.gsfc.nasa.gov/education/graphic_history/intensitymapping.html
http://hyperphysics.phy-astr.gsu.edu/hbase/quantum/h21.html

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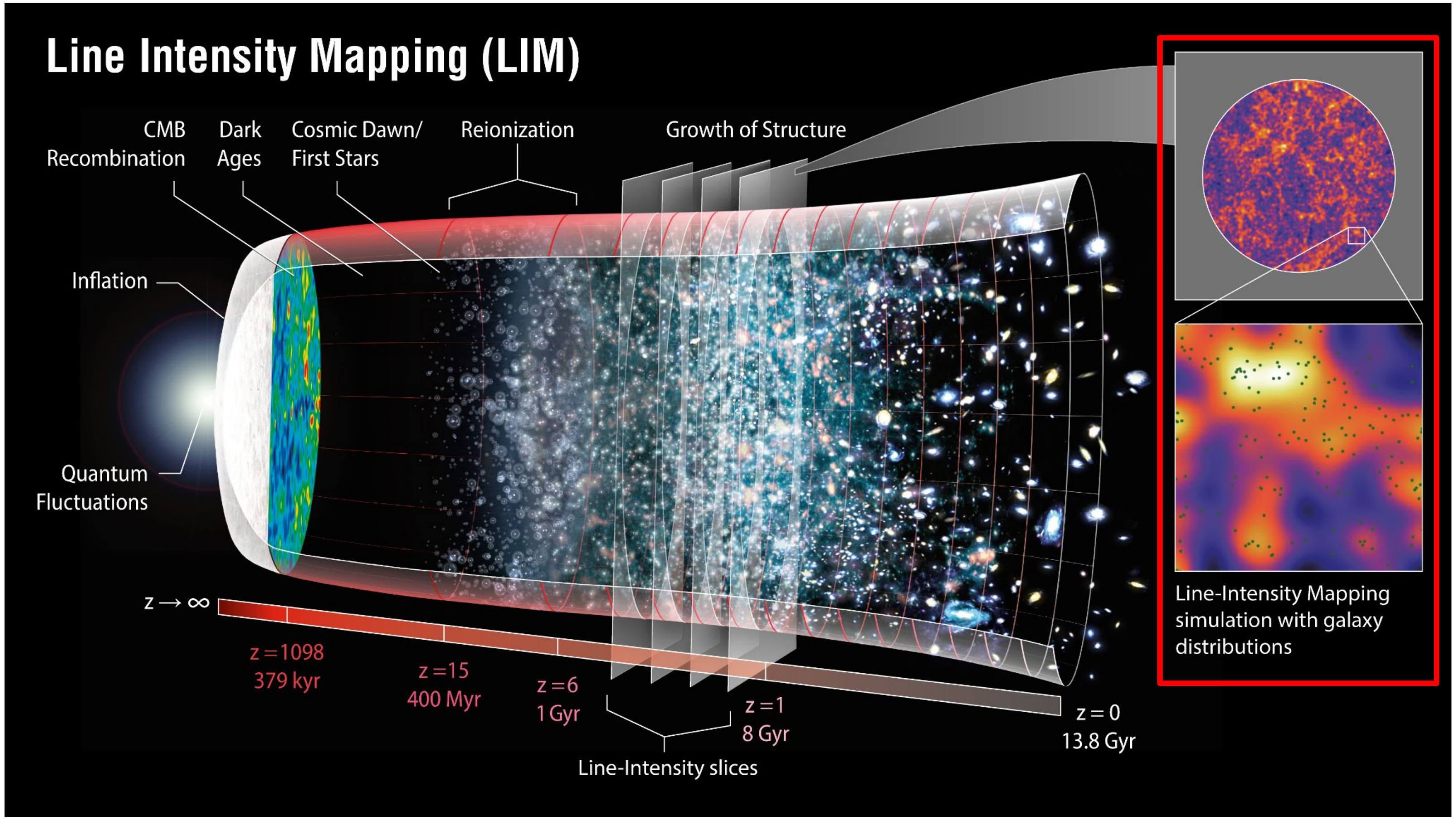

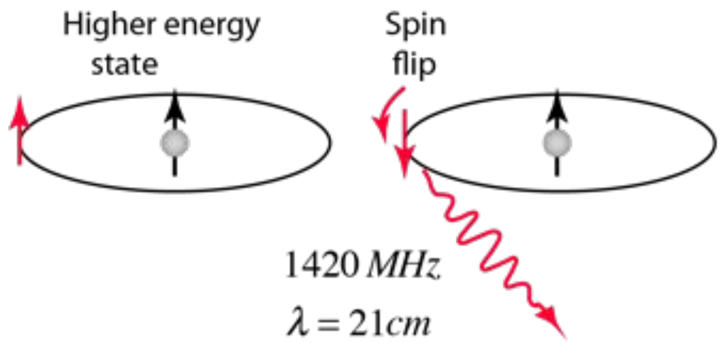

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HIRAX Overview

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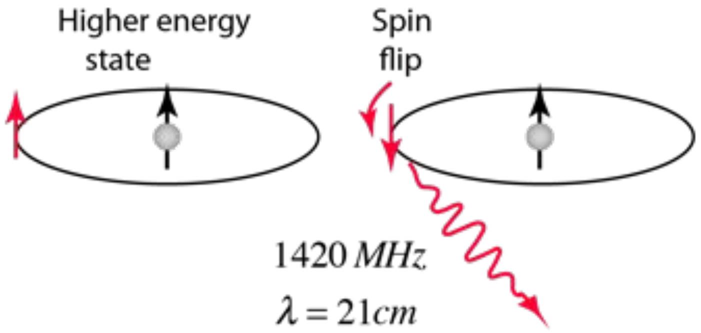
- **H**ydrogen **I**ntensity and **R**eal-time **A**nalysis e**X**periment
- Radio interferometer with a compact, redundant layout
- To be co-located with SKA in the Karoo, South Africa
- Funded up to 256 element deployment. Plans to extend to 1024.
- 6 m diameter dishes instrumented to operate between 400–800 MHz / z = 0.8-2.6
- Intensity mapping survey of ~⅓ of the sky over 4 years
- Field of view: 5°-10°
- Primary Science Goals:
  - Observationally probe the evolution of dark energy
  - Survey the transient radio sky



Credit: D. Crichton et al. (2022)

HIRAX Site

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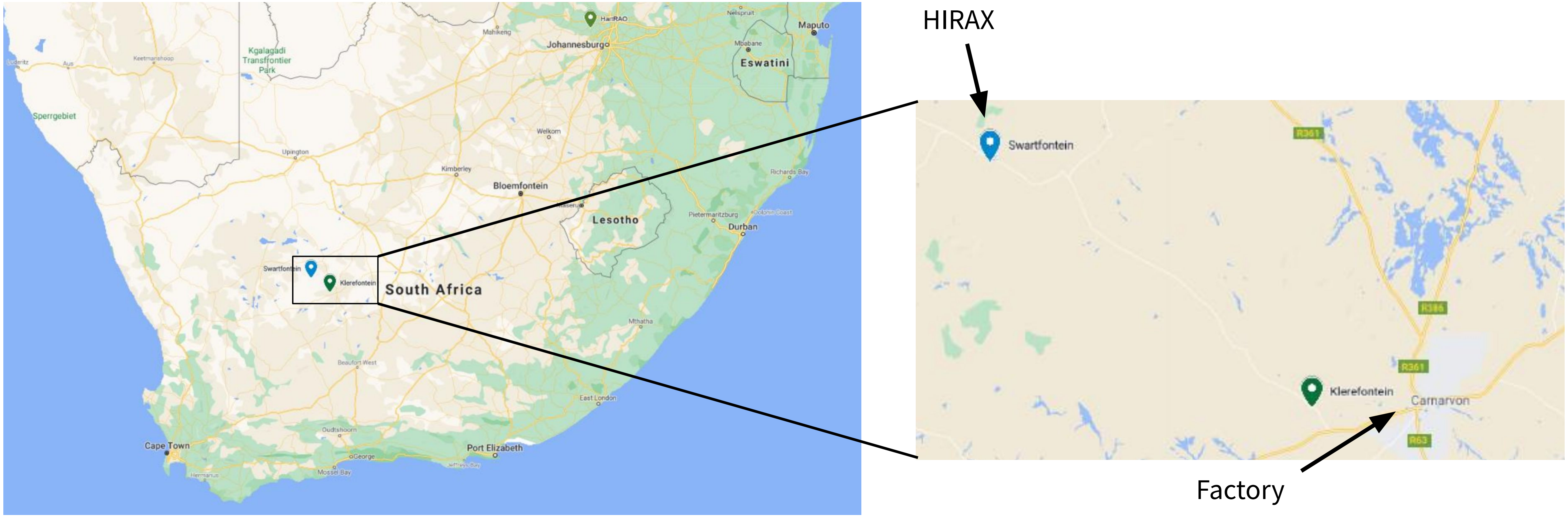
- Guest instrument on SKA site in the Karoo, South Africa
- Low RFI (radio frequency interference) site - protected by government regulations
- Access to roads, power supply, external network connection, and SKA infrastructure



Credit: The Hydrogen and Real-time Analysis eXperiment (HIRAX) HYDROGEN INTENSITY AND REAL-TIME ANALYSIS EXPERIMENT TELESCOPE MECHANICAL ASSEMBLY REQUIREMENTS DOCUMENT. (n.d.).

HIRAX Schematic

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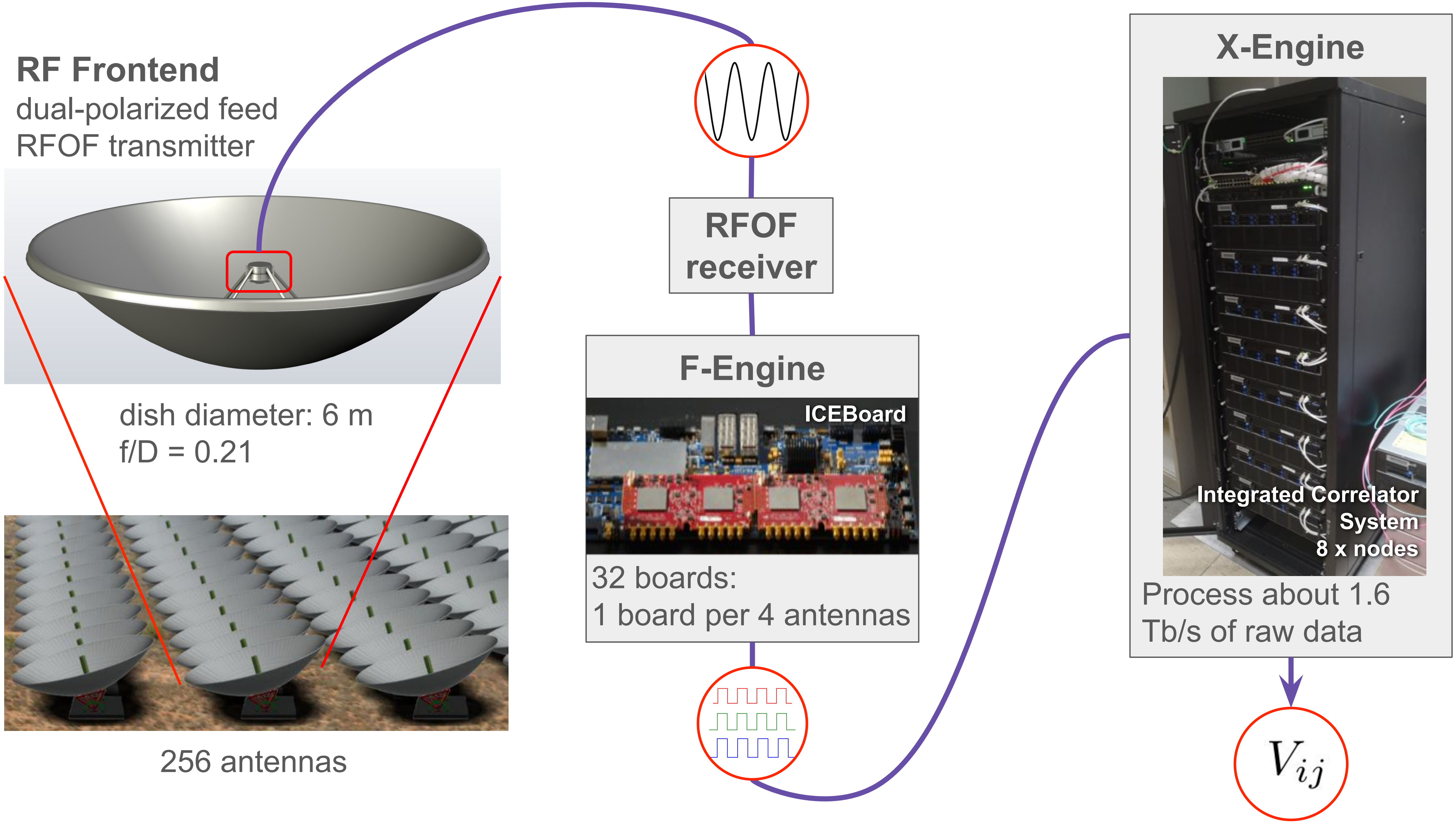

HIRAX Dish Production

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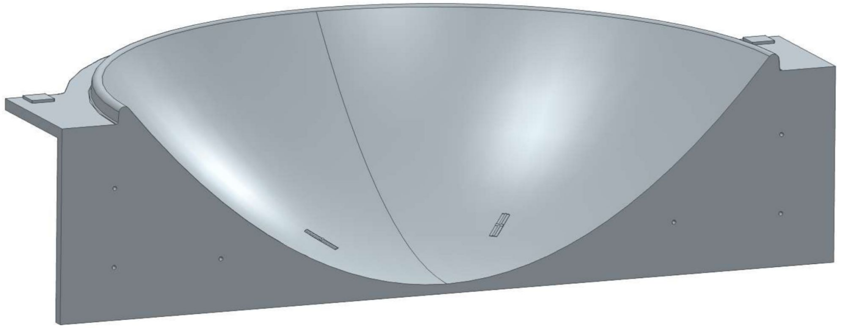
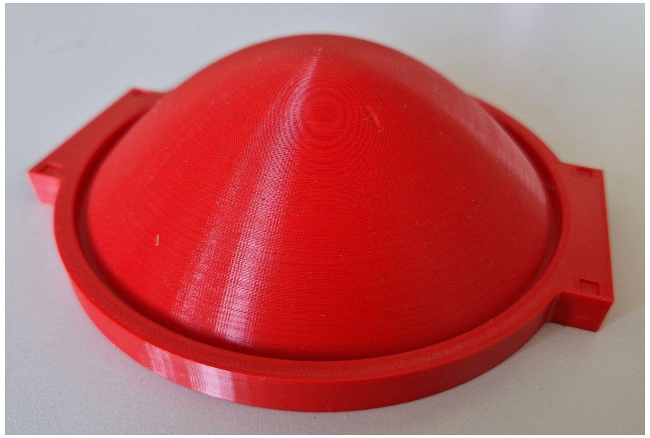


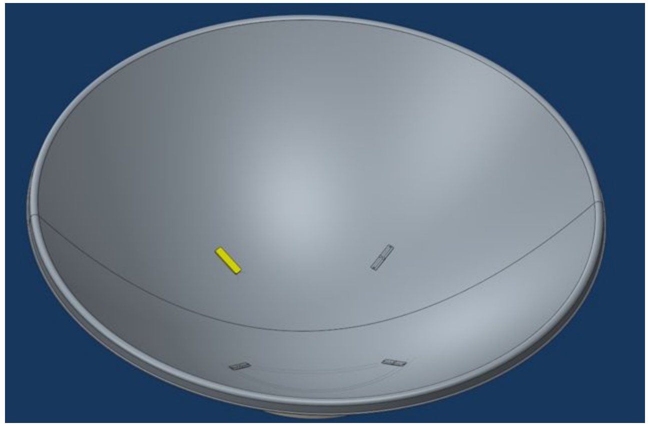
Reflector Plug

- Manufactured in two halves
- Manufactured and measured in Cape Town
- Combined, measured and finished in Carnarvon



Reflector Mold

- Half molds manufactured and measured in Cape Town
- 4 molds for main dishes



Reflector Dish

- First half dish prototype measured
- First 2 prototypes planned in October/November
- Fiberglass with an embedded aluminium mesh

Telescope Mechanical Assembly - Fibreglass

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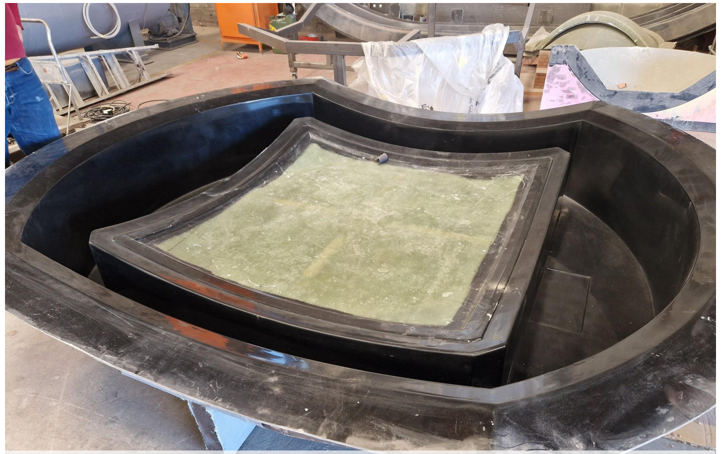
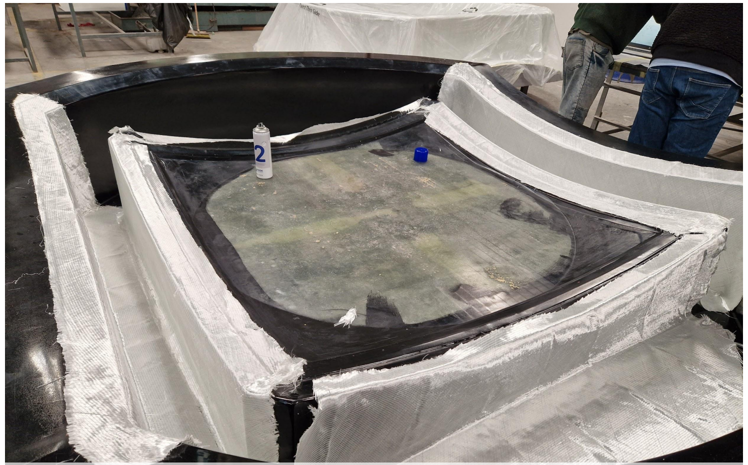
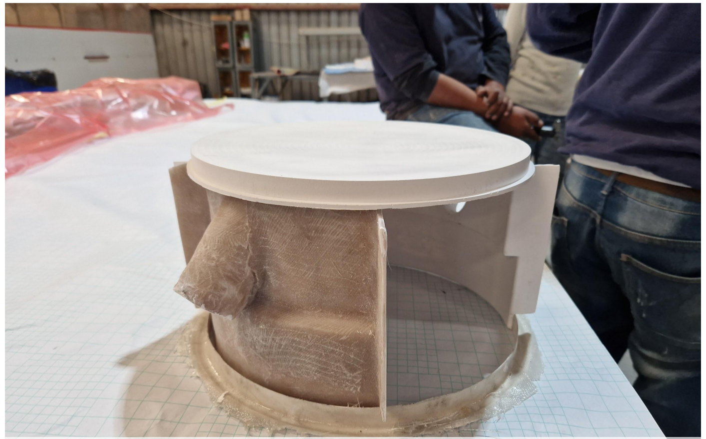

Backing ring mould


Backing ring built on a mould


Backing ring mould infusion


Scalar model of plug and mould


Feedleg assembly jig

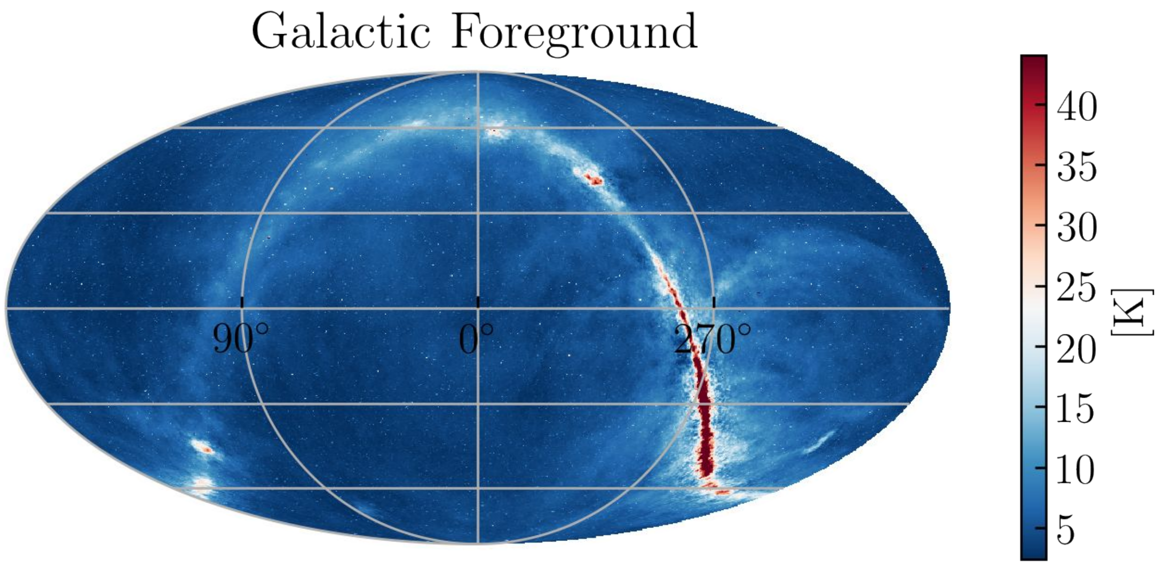

Feed assembly jig

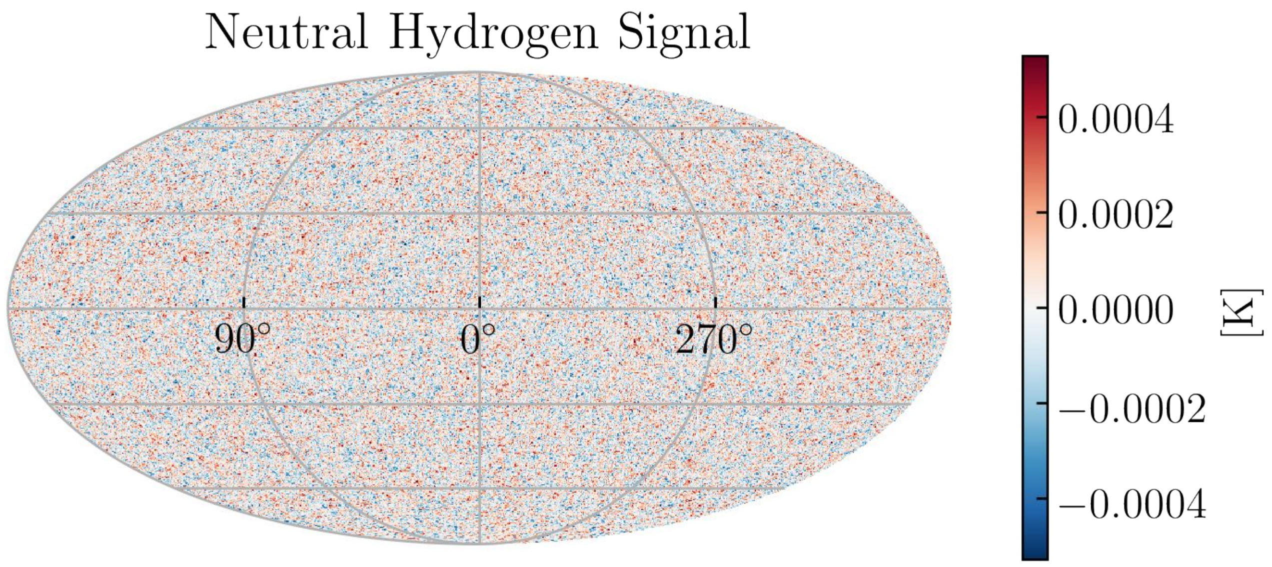
First assembled Dish

First Split Dish; Cape Town, June 2024

Systematics

- Foreground highly dominates
  - Smooth in frequency
  - HI is correlated over small ranges in frequency
  - Instrument systematics are frequency dependent
- Imperfect knowledge of the instrument leads to foreground leakage
- Need instrument with very low systematics and a very good understanding of it





more in Devin's talk

Credit: made with cora by D. Crichton

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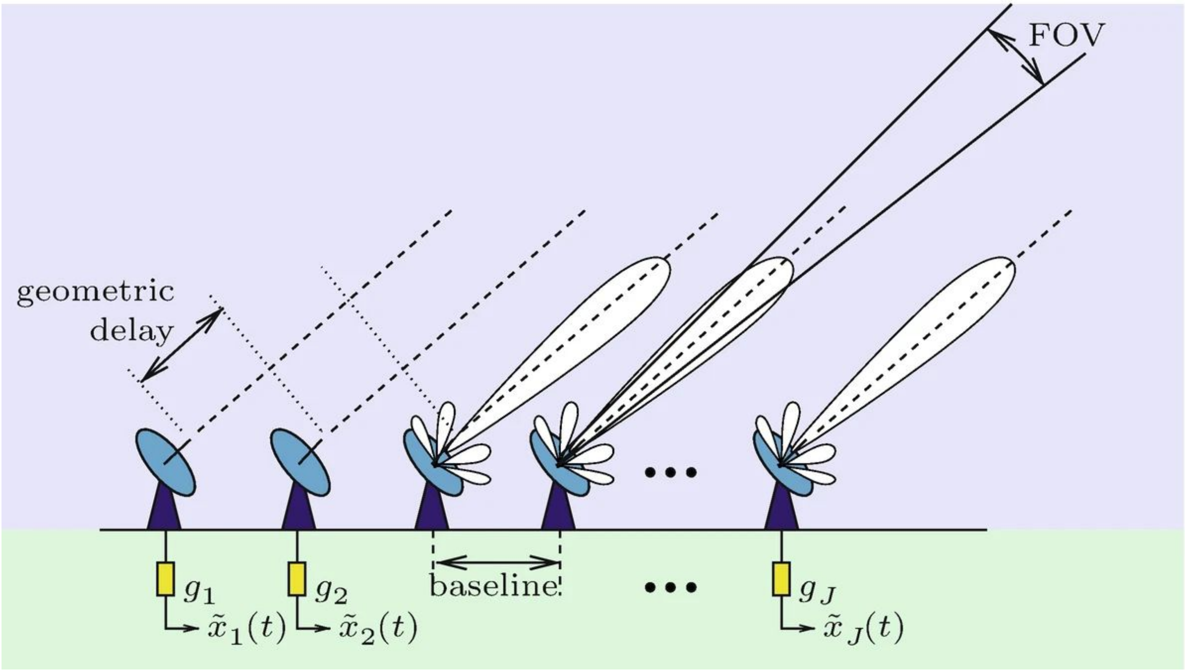

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more in Devin's talk

Instrument Requirements

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Telescope mechanical parameter	Target precision (RMS)
Receiver position relative to focus	0.5 mm
Receiver orientation relative to boresight vector	$2.5'$ polar and azimuthal
Dish surface deviations	1 mm
Dish vertex position relative to elevation axis	1 mm
Orthogonality of boresight vector and elevation axis	$1'$
Elevation axis position within the array	0.5 mm in array plane 1 mm out of array plane
Elevation axis alignment within the array	$1'$
Elevation pointing angle	$1'$

Table 4 Target precision values for HIRAX telescope mechanical structure

Credit: D. Crichton et al. (2022)

Measurement Equipment to Characterize the Dish

- Laser tracker
  - Very dense point cloud
  - ~ 1-2 hours/dish

- Photogrammetry system
  - Medium dense point cloud
  - < hour/dish
  - Survey over time

- Reflectometer
  - Very sparse point density
  - ~ 3 hours/dish
  - Measures the actual EM surface relative to the dish surface

Laser Tracker

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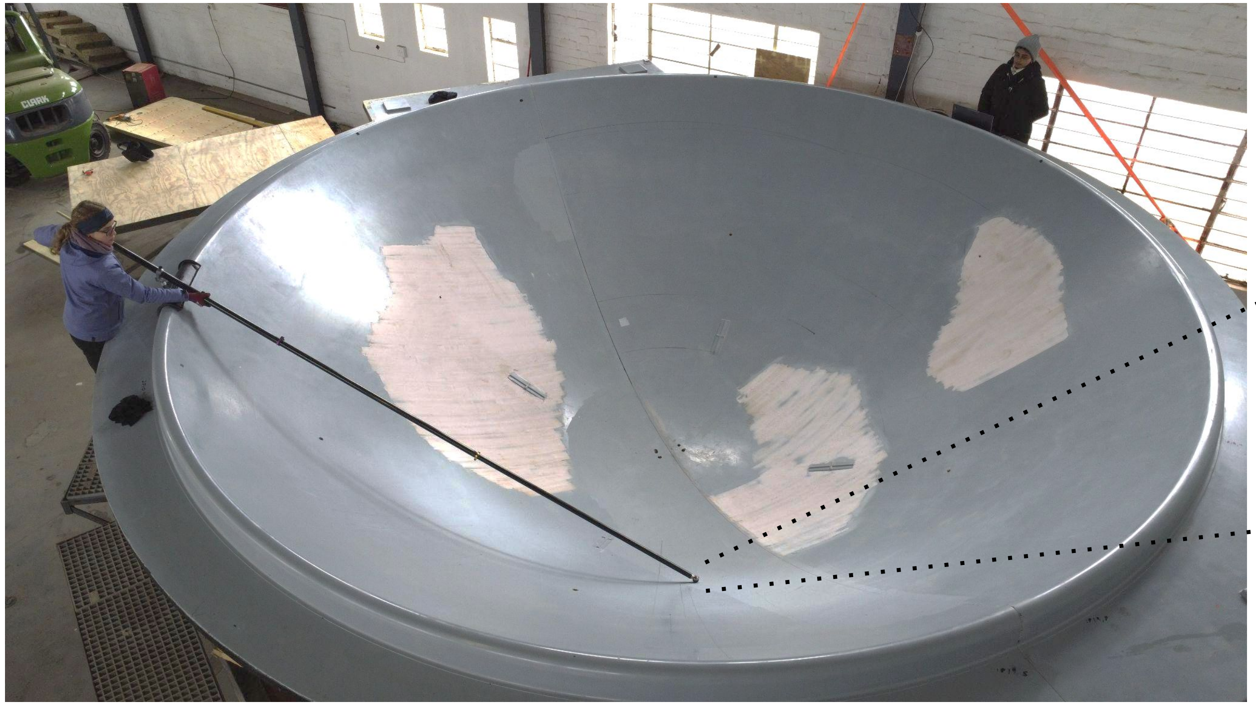
Measurement procedure:

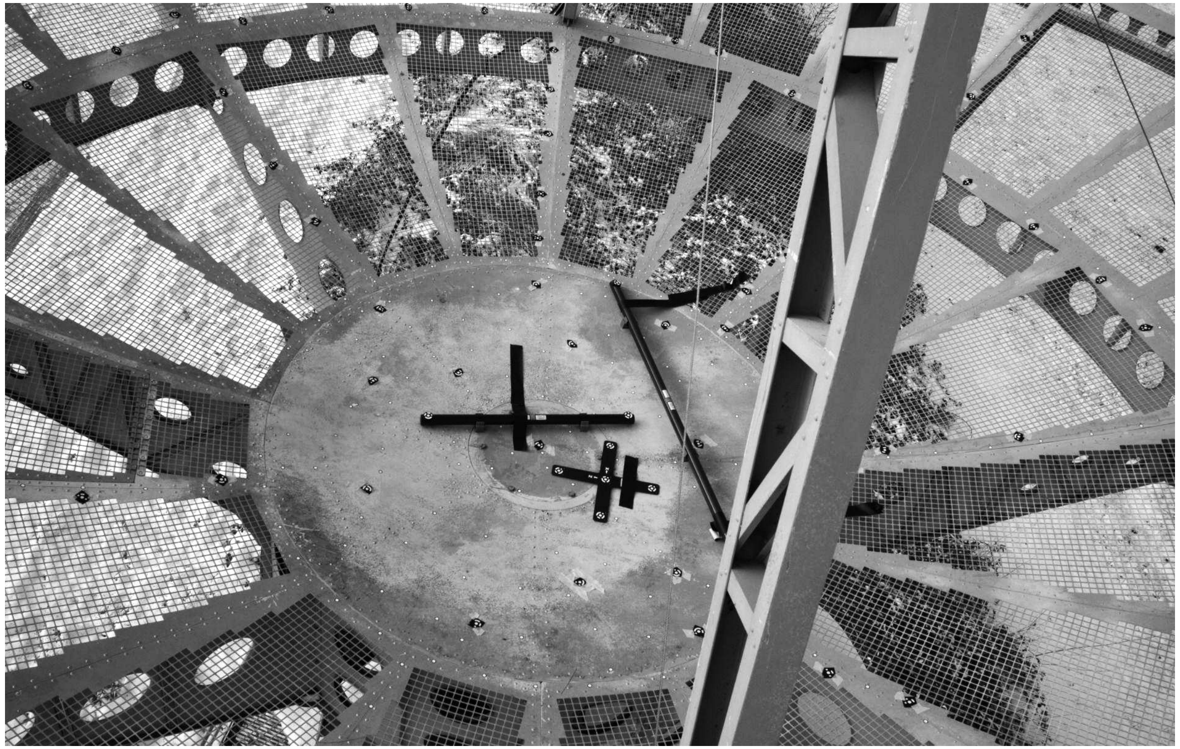
1. Sweep the reflector over the surface of the device under test while the laser tracker tracks it
2. Analyze the resulting 3D point cloud

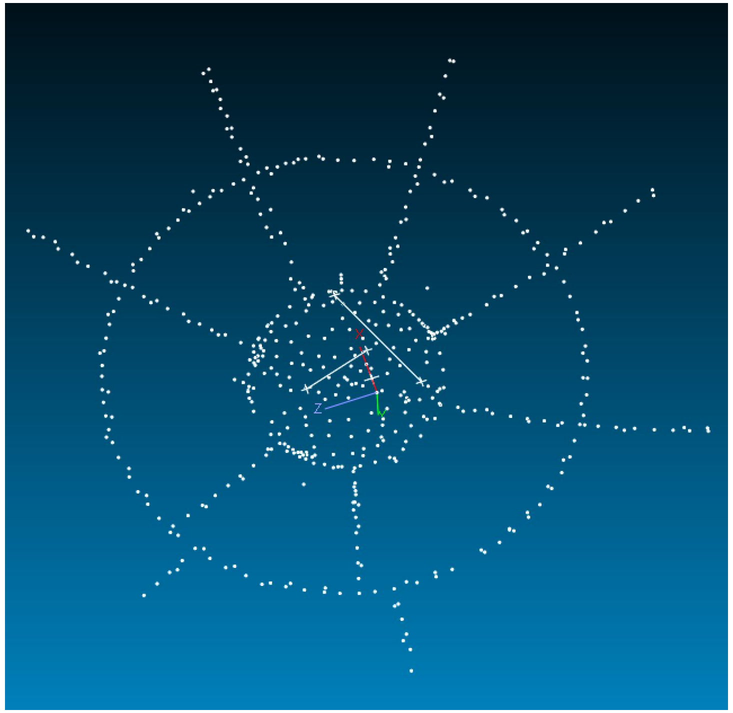


Photogrammetry System

Measurement procedure:

1. Glue coded and uncoded targets
2. Take pictures from different angles
3. Feed the pictures into the software to get the 3D point cloud



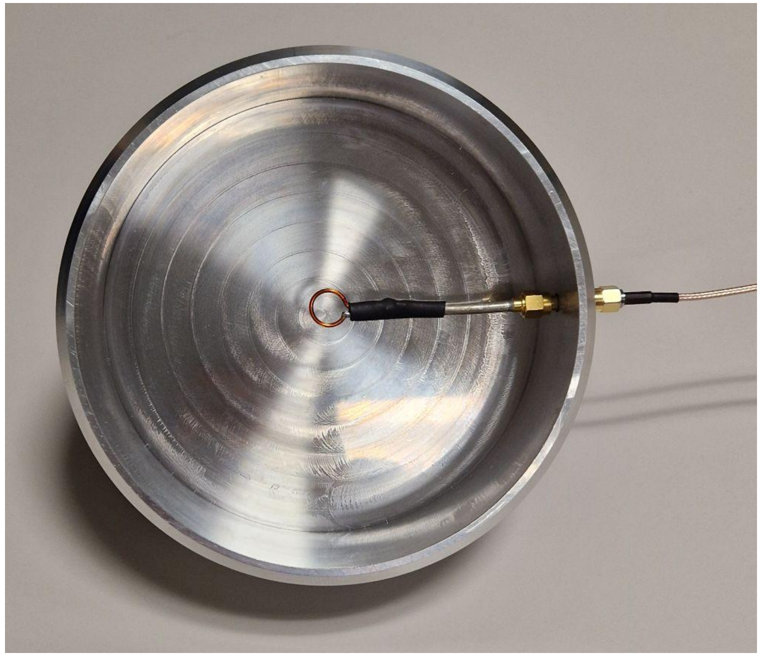


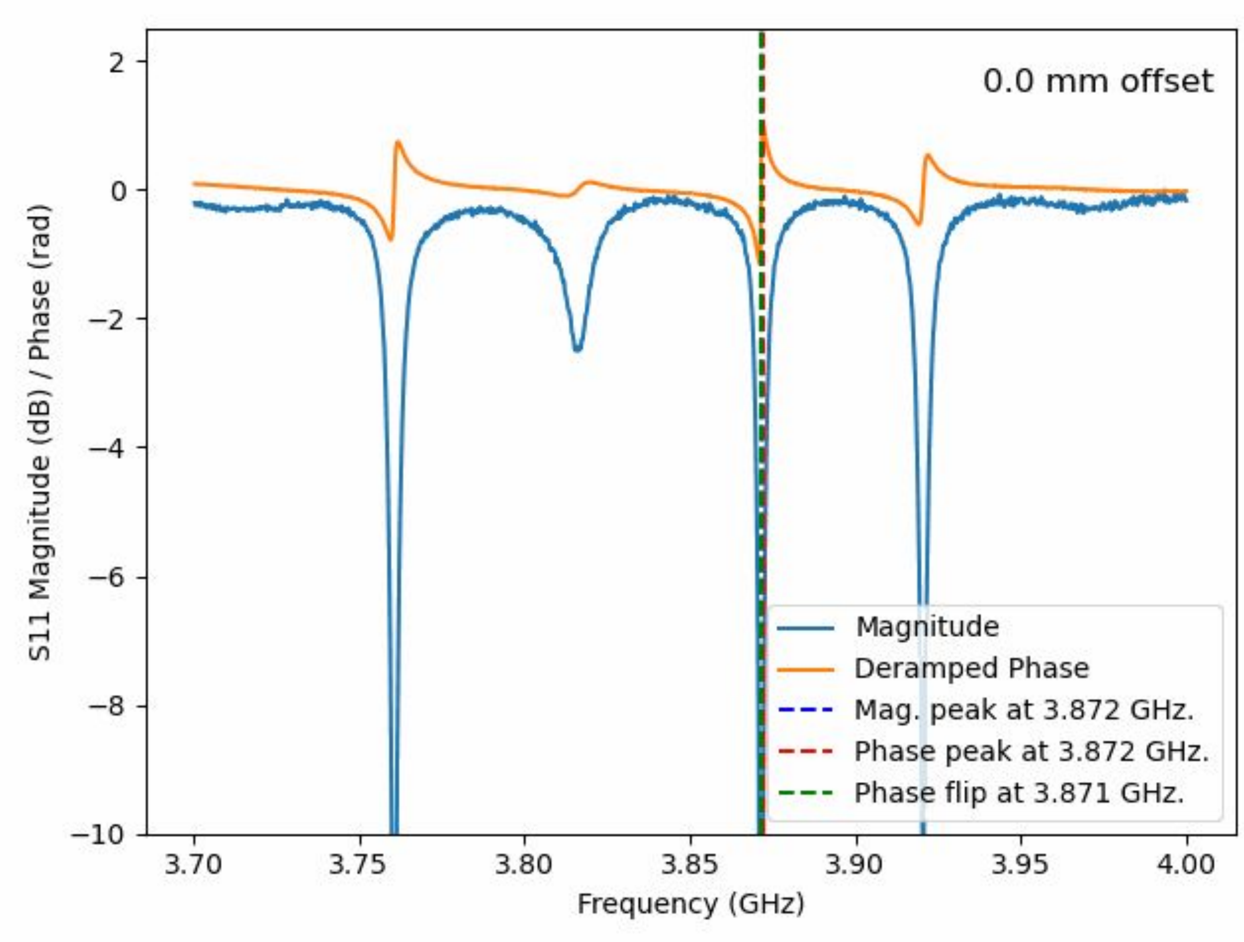
Reflectometer

Tracks distance offset through shifting resonant frequency

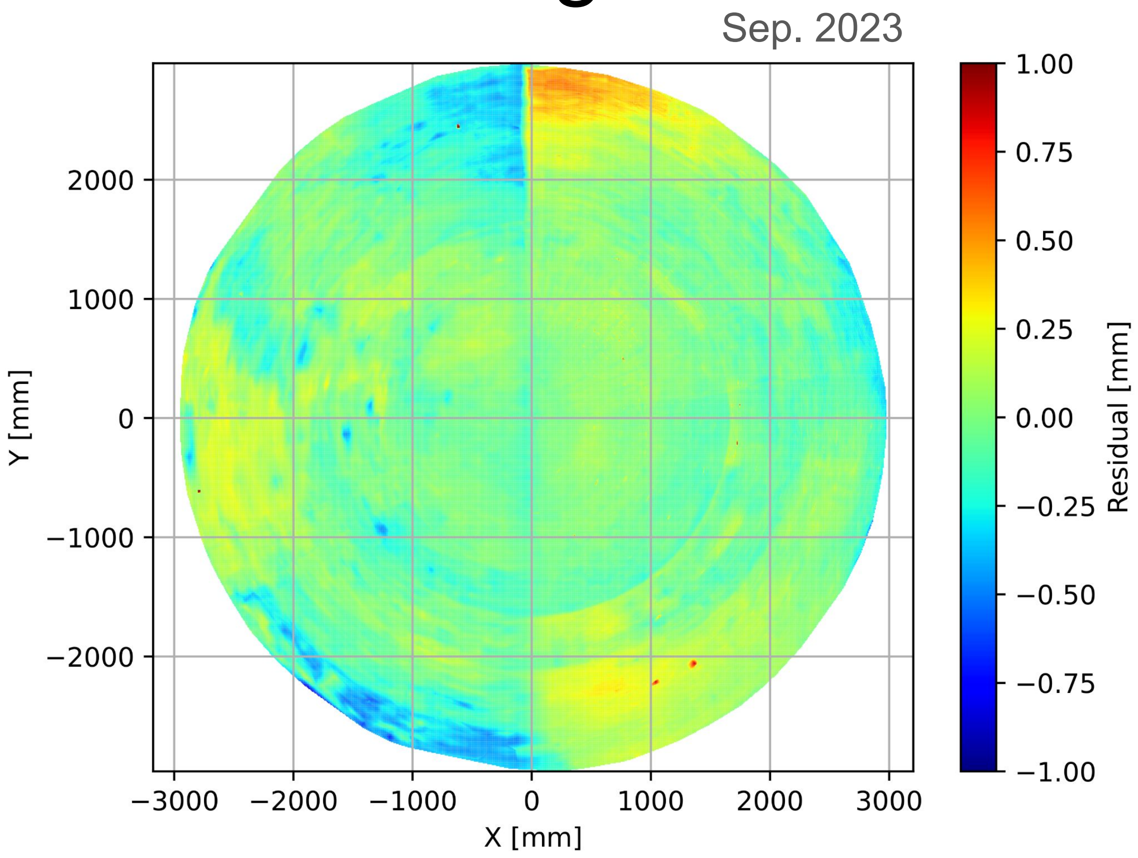
Measurement procedure:

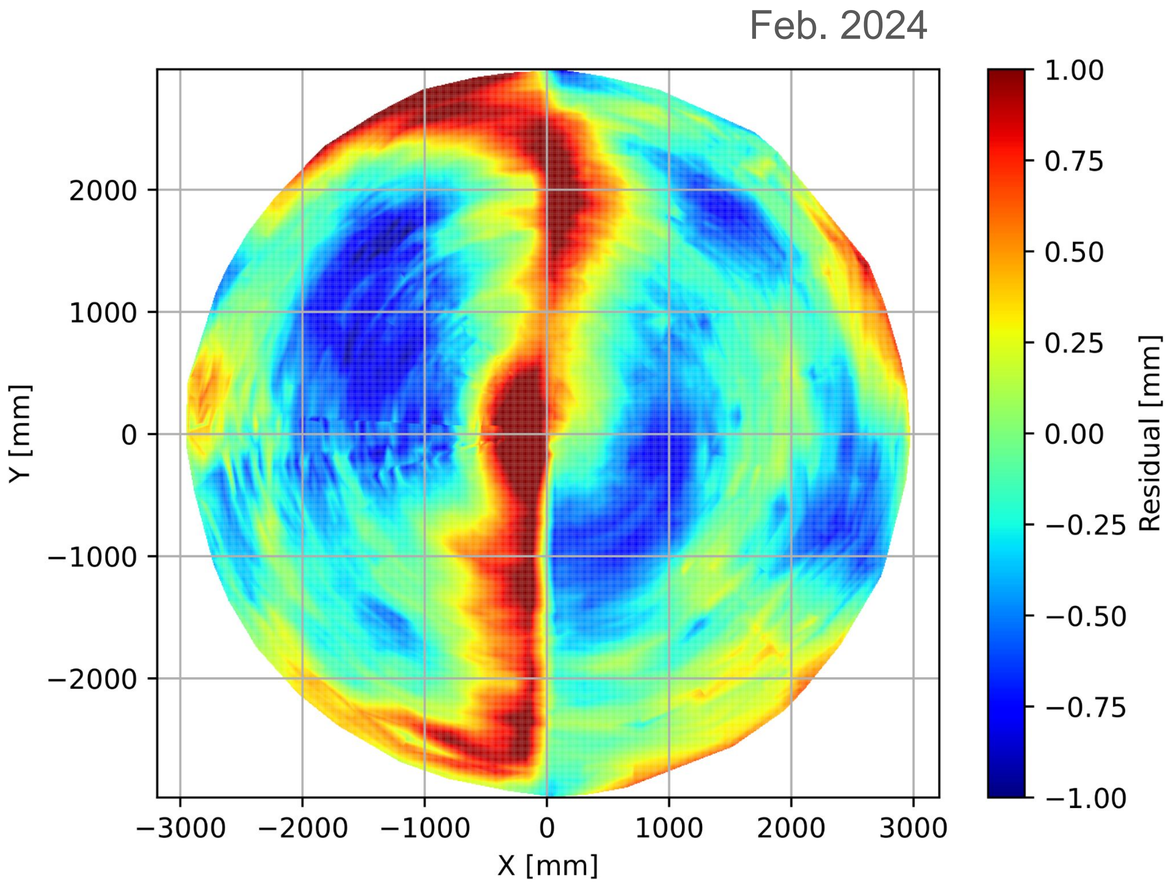
1. Calibrate with aluminium mesh
2. Take measurements at locations of interest
   a. Measure the arc length/height
3. Analyze data





Transport from OmegaVerse to Carnarvon
Effect on Plug





The **RMS** value is **0.123 mm < 0.6 mm**
The **focal length** is **1260.0 mm**

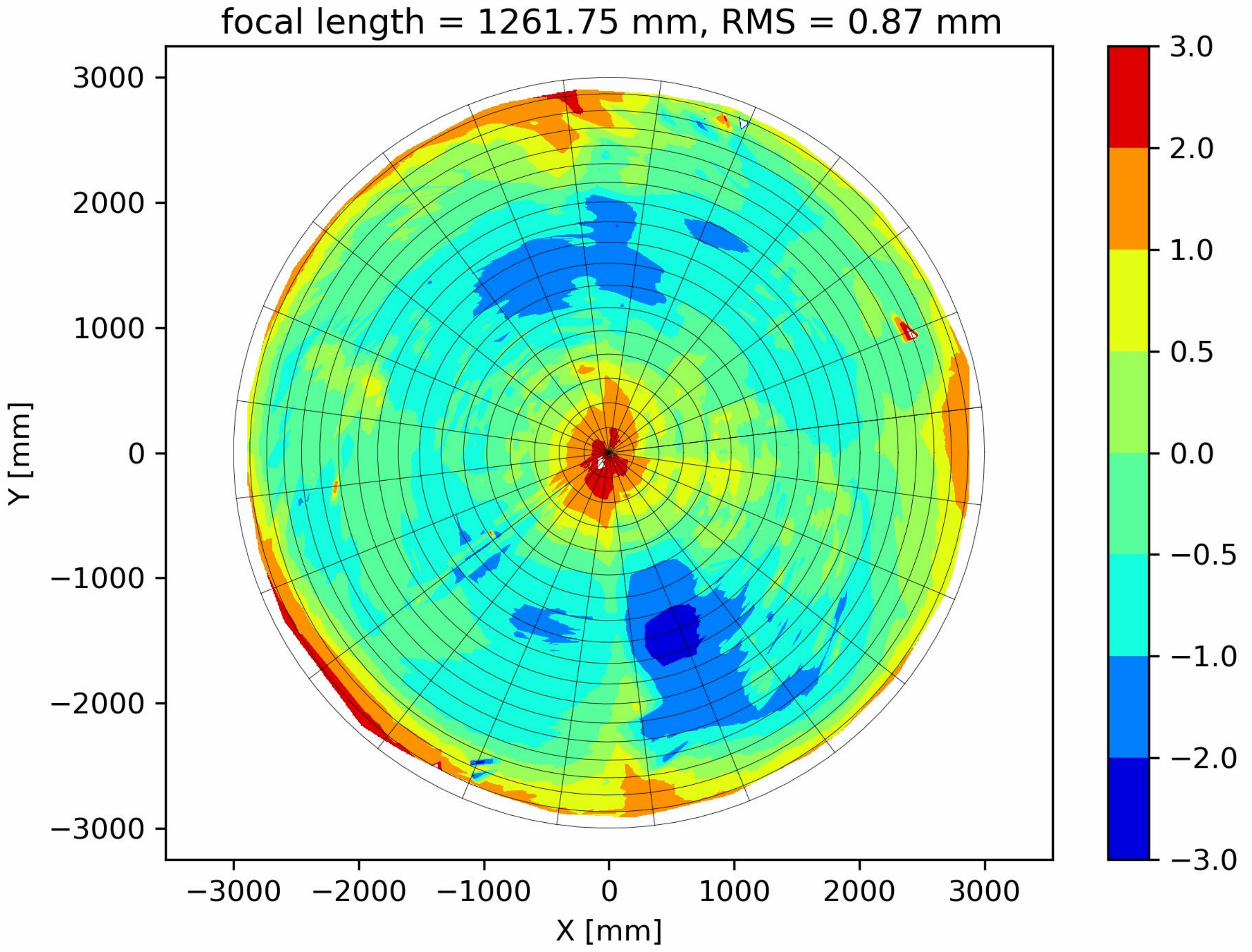
→

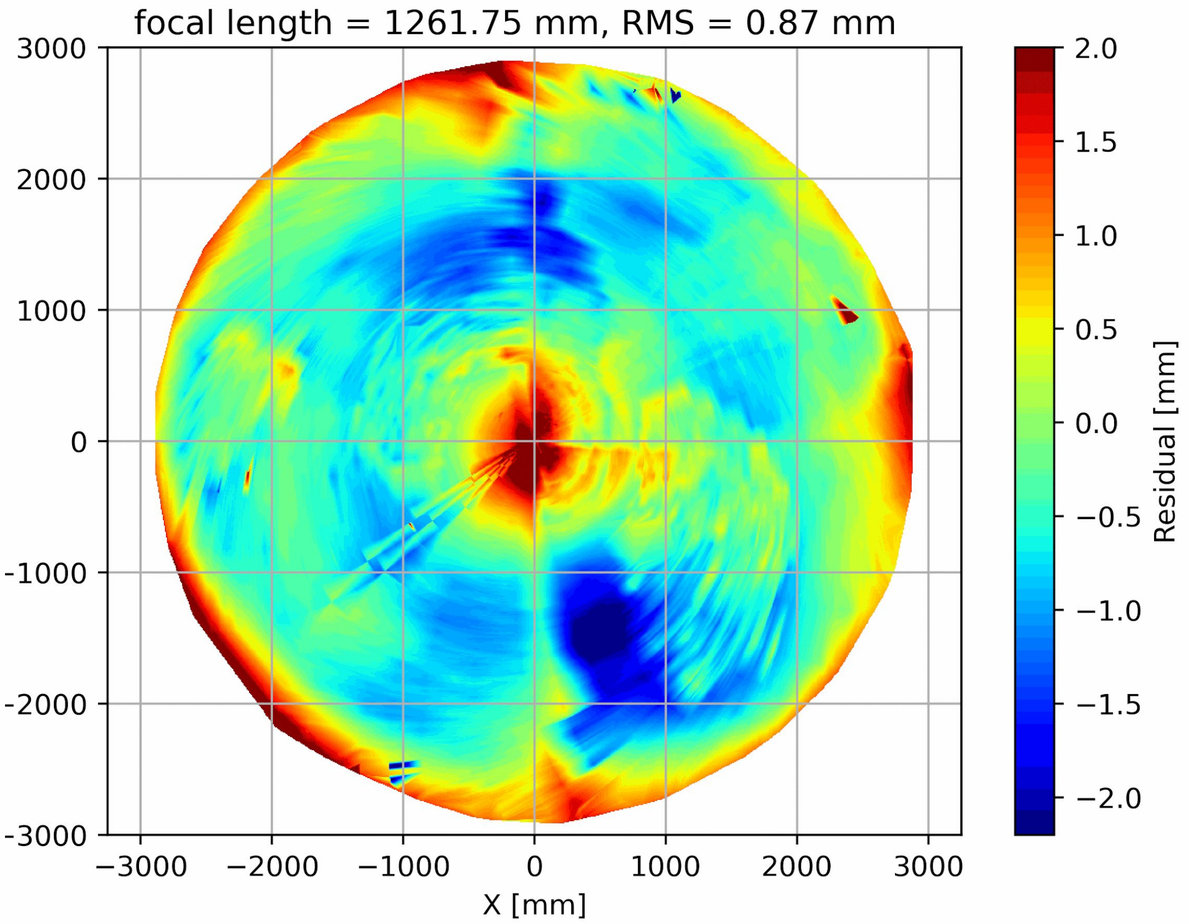
The **RMS** value is **0.510 mm < 0.6 mm**
The **focal length** is **1260.7 mm**

with the support of Keshav Bechoo,
Tasmiya Papiah, Thierry Viant, and others

Plug Improvement

June 2024





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Calibration

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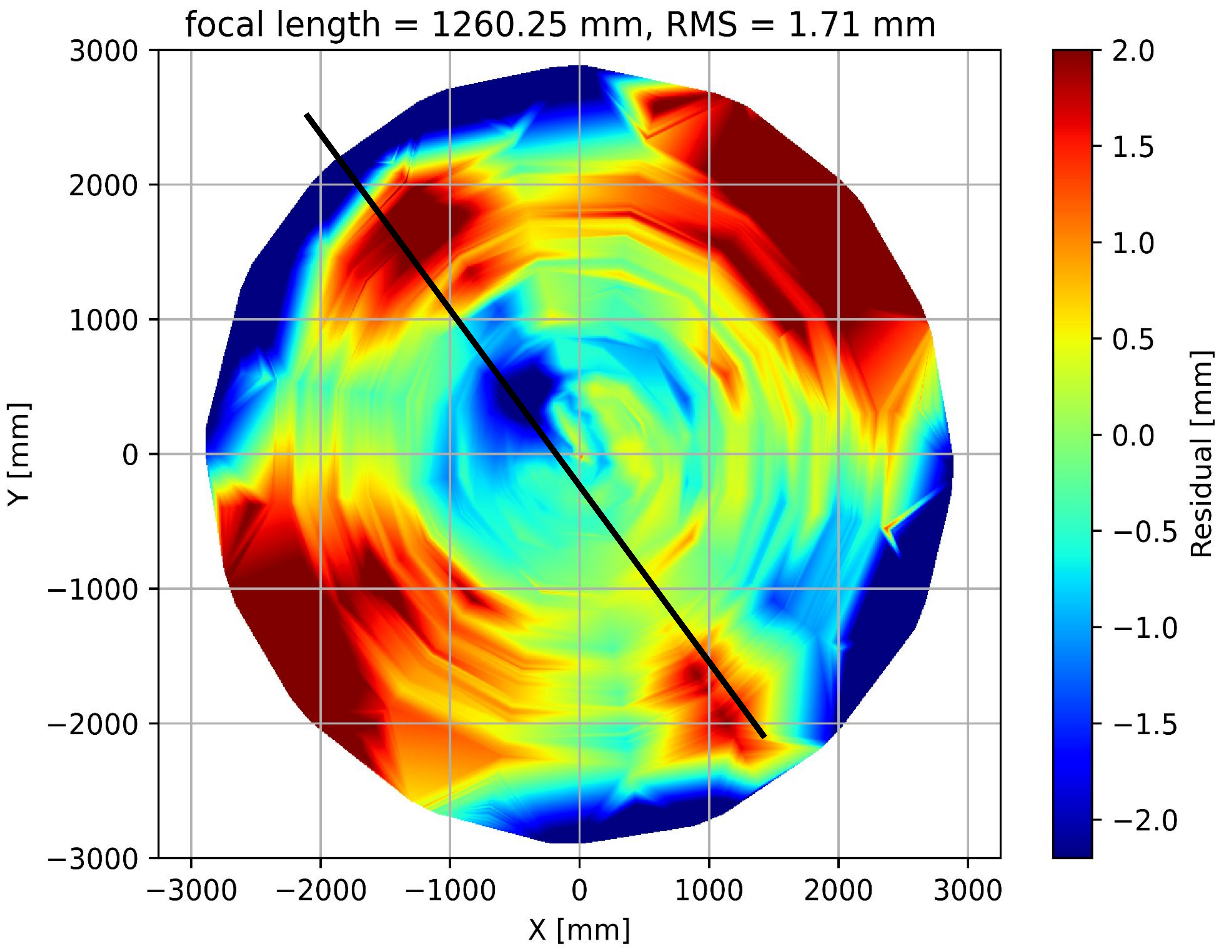
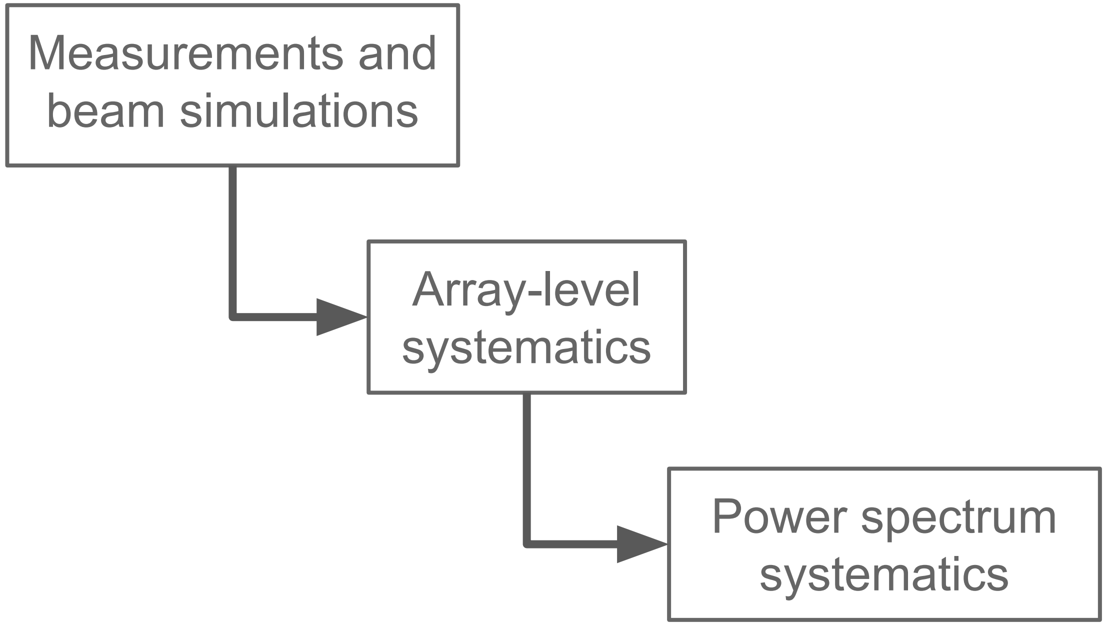
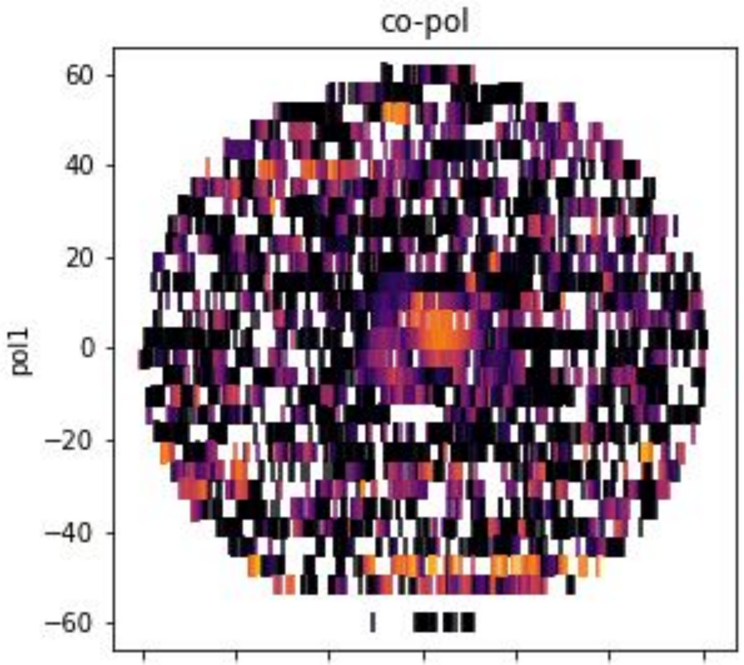
June 2024





Drone Beam Mapping and Holography

- Drone mounted transmitter for direct beam mapping of
- Test flights at Bleien Observatory in Switzerland
  - Also with other groups at Green Bank CHIME outrigger and DRAO
- Multiple parallel efforts
- Exploring feasibility of flights at Karoo site
  - RFI characterisation and testing
- Comparing with holography and metrology based reconstruction



Christian Monstein, Thierry Viant,
Tony Walters, Tasmiya Papiah and others

Klerefontein test side ready in October!

Klerefontein, June 2024

Conclusions

- HI IM provides access to large cosmological volumes
- Systematics need to be controlled
  - Focus on the dish surface / primary beam
- Manufacturing process is in progress
  - Plug is ready for production
- Propagate dish surface deviations into beams
  - Understand the effects and combine with other methods
  - Enable the mitigation of systematics in the HI IM measurement to constrain cosmological parameters
- HIRAX will have first light in 2025

RMS Error Propagation

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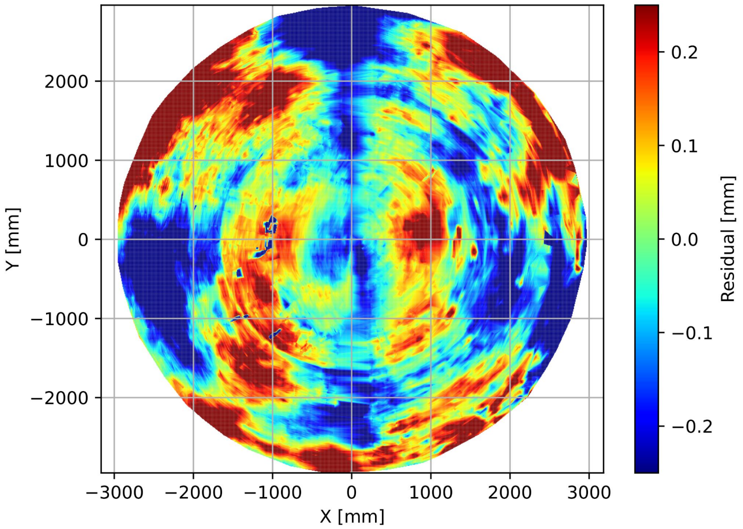
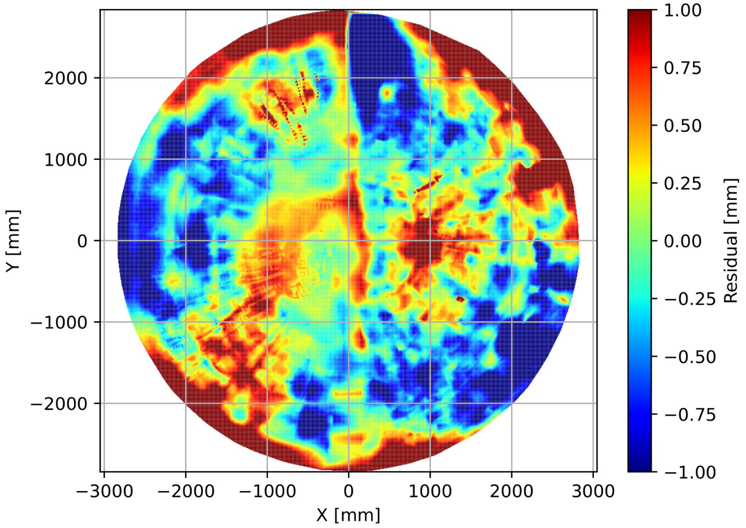
Plug (Split, Cape Town)



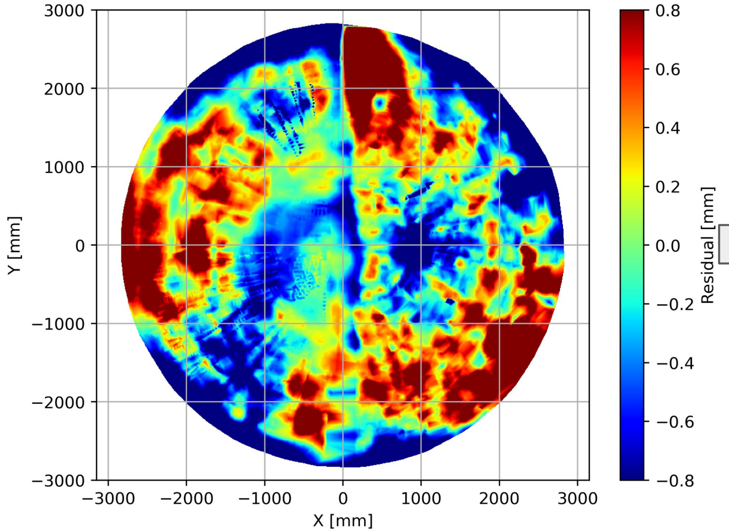
RMS = **0.205 mm**
focal length = 1260.3 mm

x4

Mold (Split)



RMS = **0.7 mm**
focal length = 1258.6 mm



x2.4

Split Dish 1

RMS = **1.7 mm**
focal length = 1260.25 mm