HIRAX - Commissioning

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SKACH Winter Meeting 2025

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Swiss National
Science Foundation

HIRAX Overview

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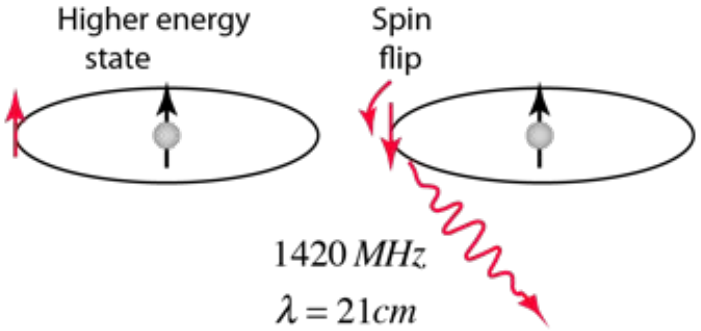
- **H**ydrogen **I**ntensity and **R**eal-time **A**nalysis e**X**periment
- Radio interferometer with a compact, redundant layout
- To be co-located with SKA in the Karoo, South Africa
- Funded up to ~128-256 element deployment. Plans to extend to 1024.
- 6 m diameter dishes instrumented to operate 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



Line Intensity Mapping (LIM)

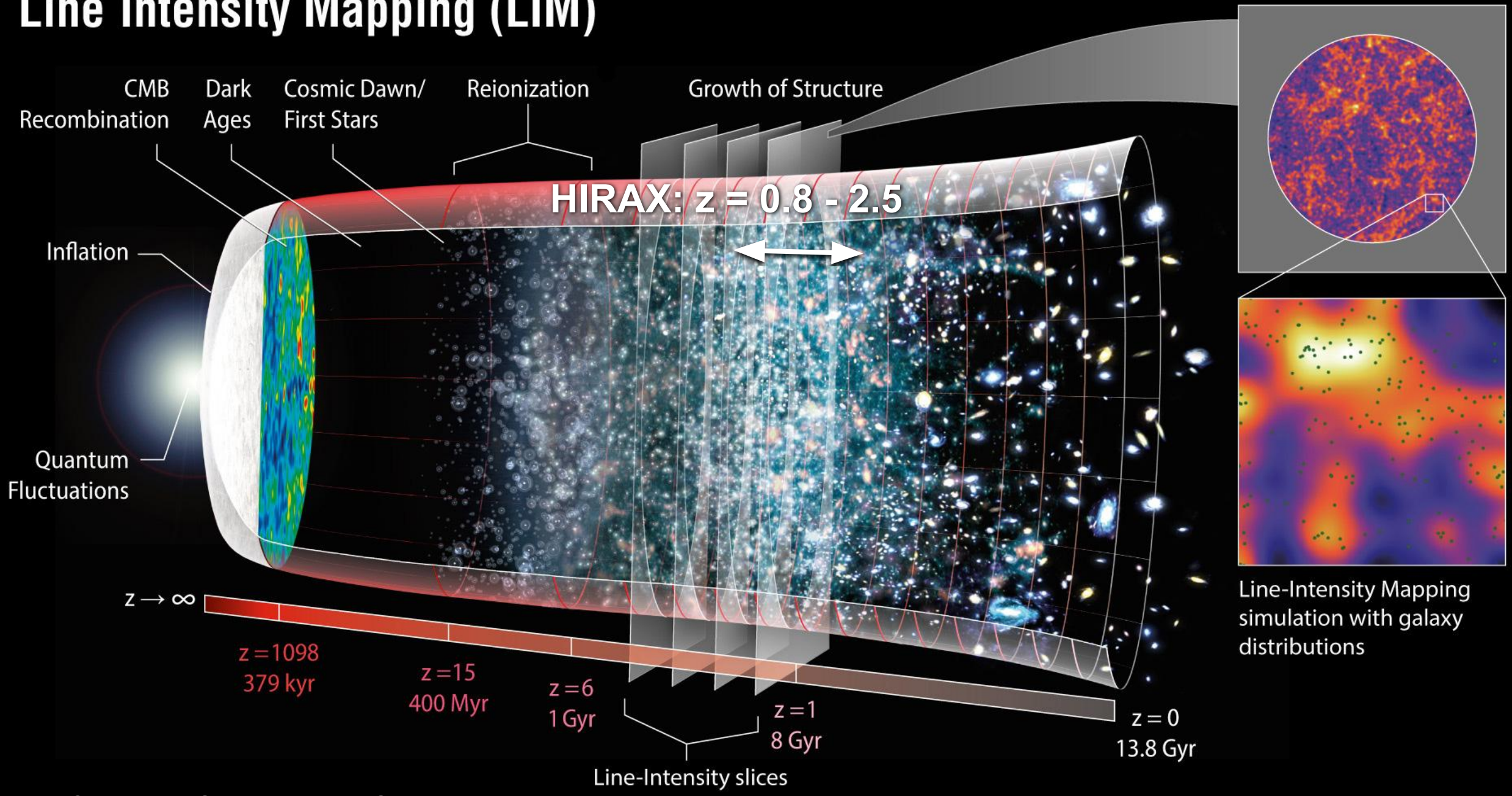
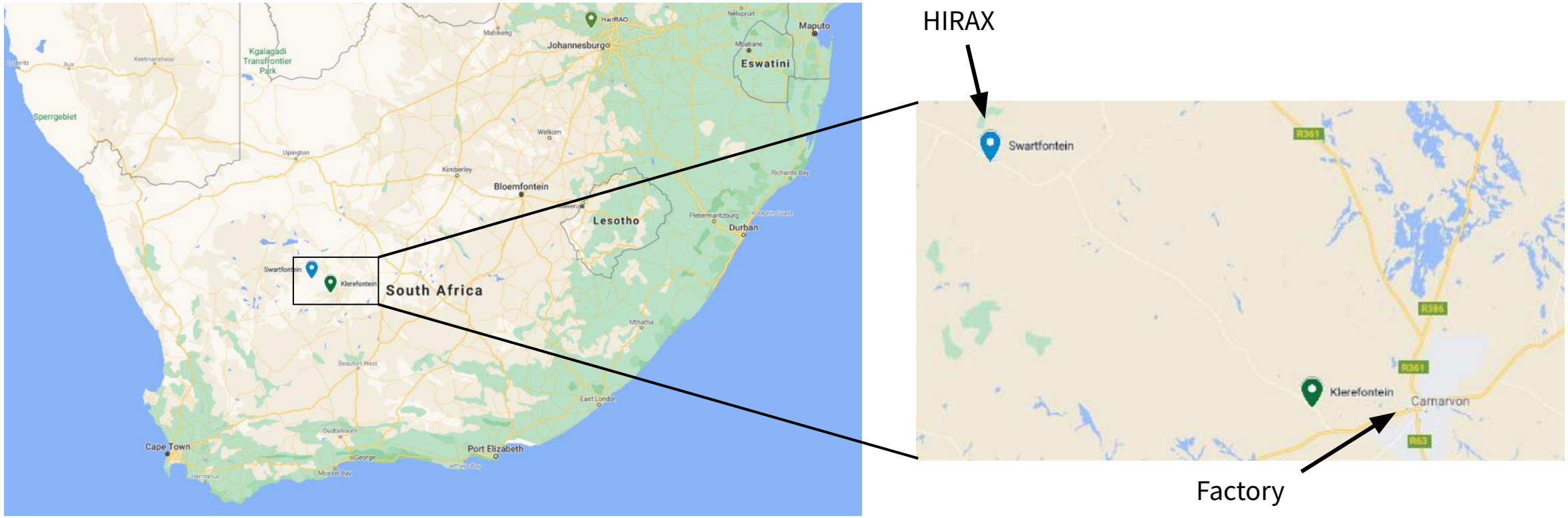


Image Credit: NASA / LAMBDA Science Team

HIRAX Site

- 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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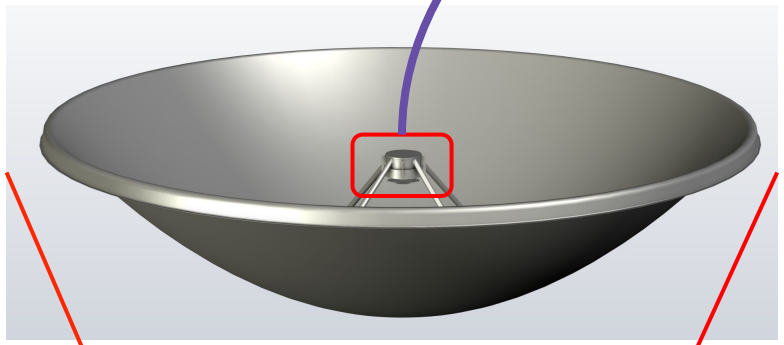
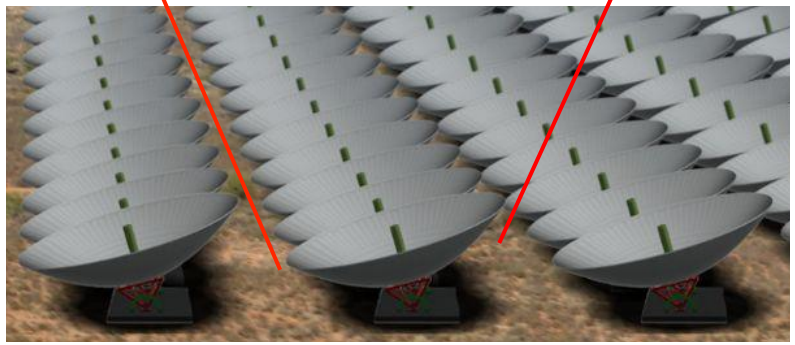
RF Frontend
dual-polarized feed
RFOF transmitter



dish diameter: 6 m
f/D = 0.21



256 antennas

RFOF receiver

F-Engine

32 boards:
1 board per 4 antennas

X-Engine

Process about 1.6
Tb/s of raw data

V_{ij}

Systematics

HIRAX Systematics Focus

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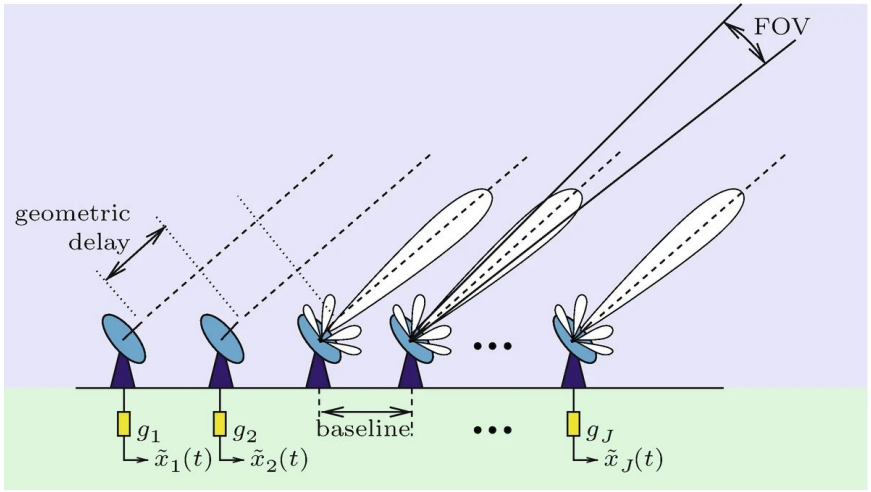
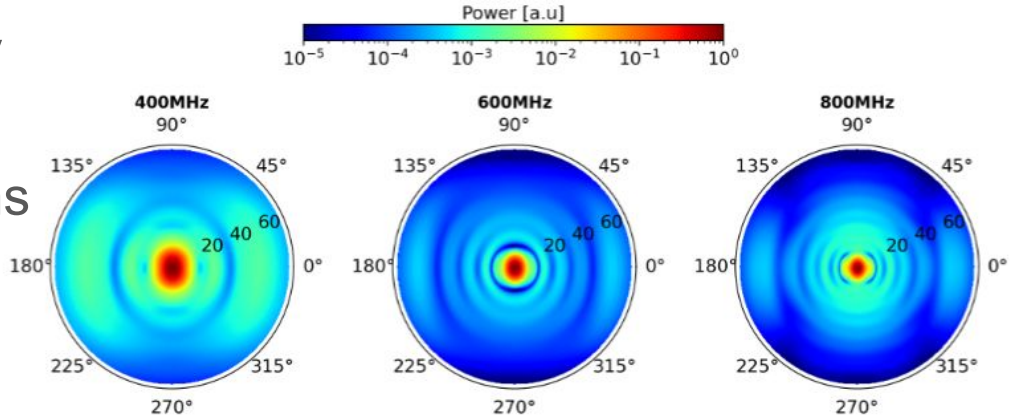
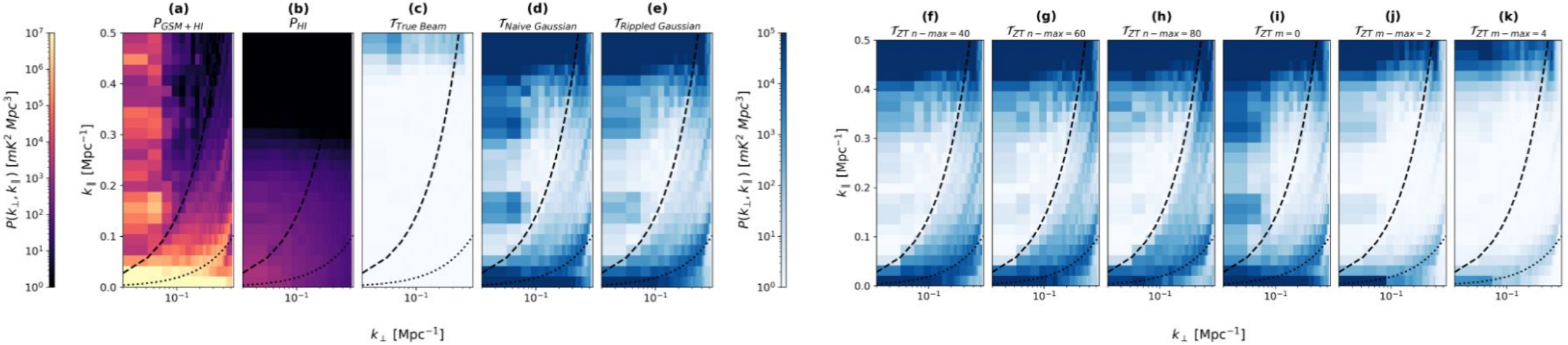
- Electromagnetic simulations of system to determine primary beams
  - And extensions to full array to capture coupling and embedding effects
- Modeling primary beams
  - Finding compact spaces of basis functions that can capture chromaticity efficiently
- Direct measurements of primary beams (e.g. with drones or holography)
- **Measuring aspects of the system that affect primary beams (Metrology)**
- Evaluating impact of non-redundancies in primary beams on calibration plans
- Propagating systematics to data and cosmological pipeline
  - Many degrees of freedom in data space if fully non-redundant





Systematics induced Wedge Leakage



Wedge leakage effects

- Beam Chromaticity, non-redundancy from physical perturbations of dish-feed system
- Can significantly impact otherwise clean regions
- Simulations backed by measurements required for mitigation strategies to be motivated and evaluated

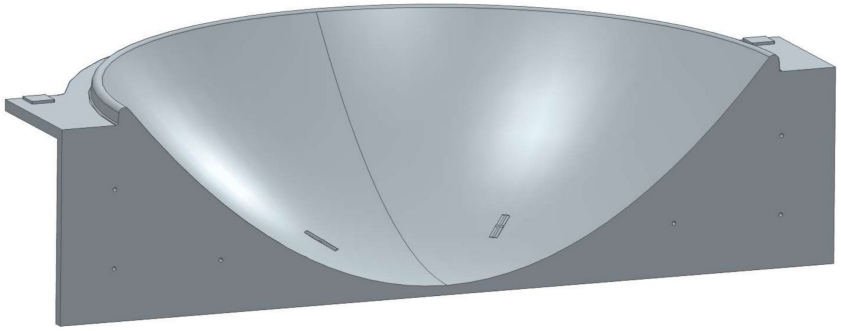
Ajith Sampath + HIRAX Collaboration 2024 - arXiv: 2412.09527

Commissioning and Metrology

HIRAX Dish Production

Reflector Plug

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



Reflector Mold

- Split molds manufactured and measured in Cape Town
  - Produce prototype and outrigger dishes
- Final monolithic dish molds in production / QA
  - Cosmology-ready surface accuracy

Reflector Dish

- Fiberglass with an embedded aluminium mesh
- Split mold dishes in production and deployment
- Two element array deployed in Klerefontein
- Gearing up for monolithic dish production ~ weeks

Instrument Requirements

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	$1'$

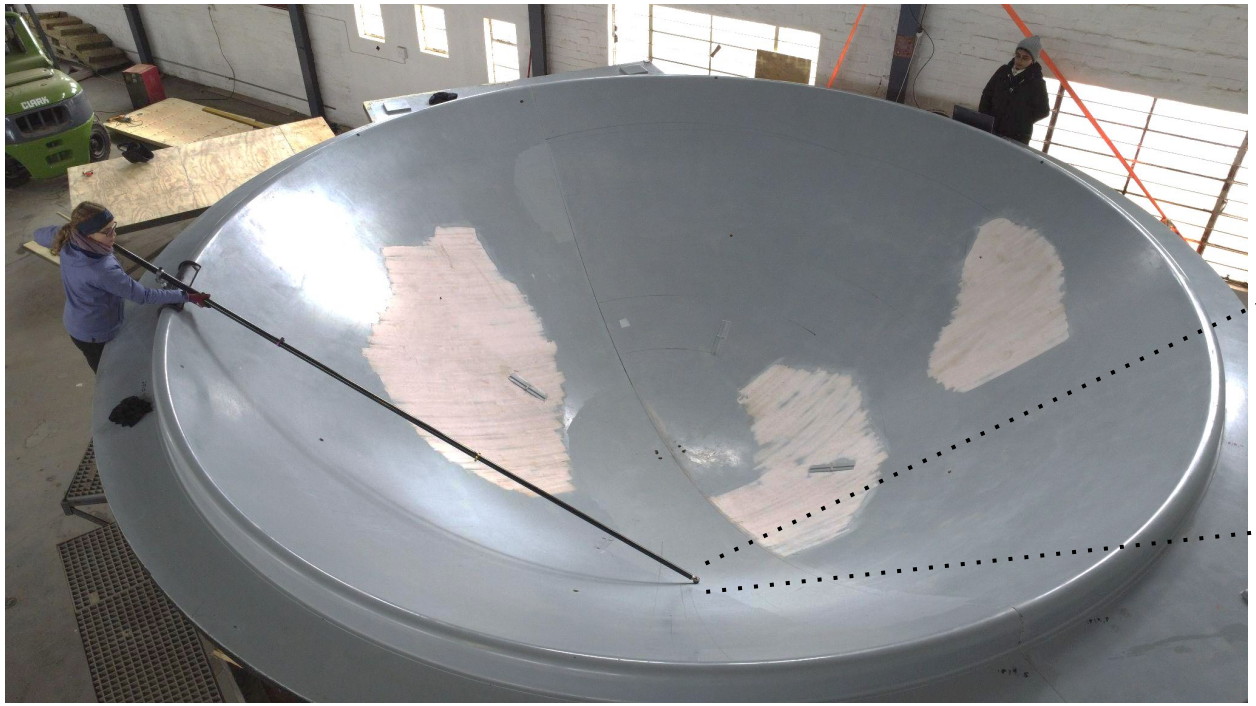
Table 4 Target precision values for HIRAX telescope mechanical structure

Credit: D. Crichton et al. (2022)

Laser Tracker

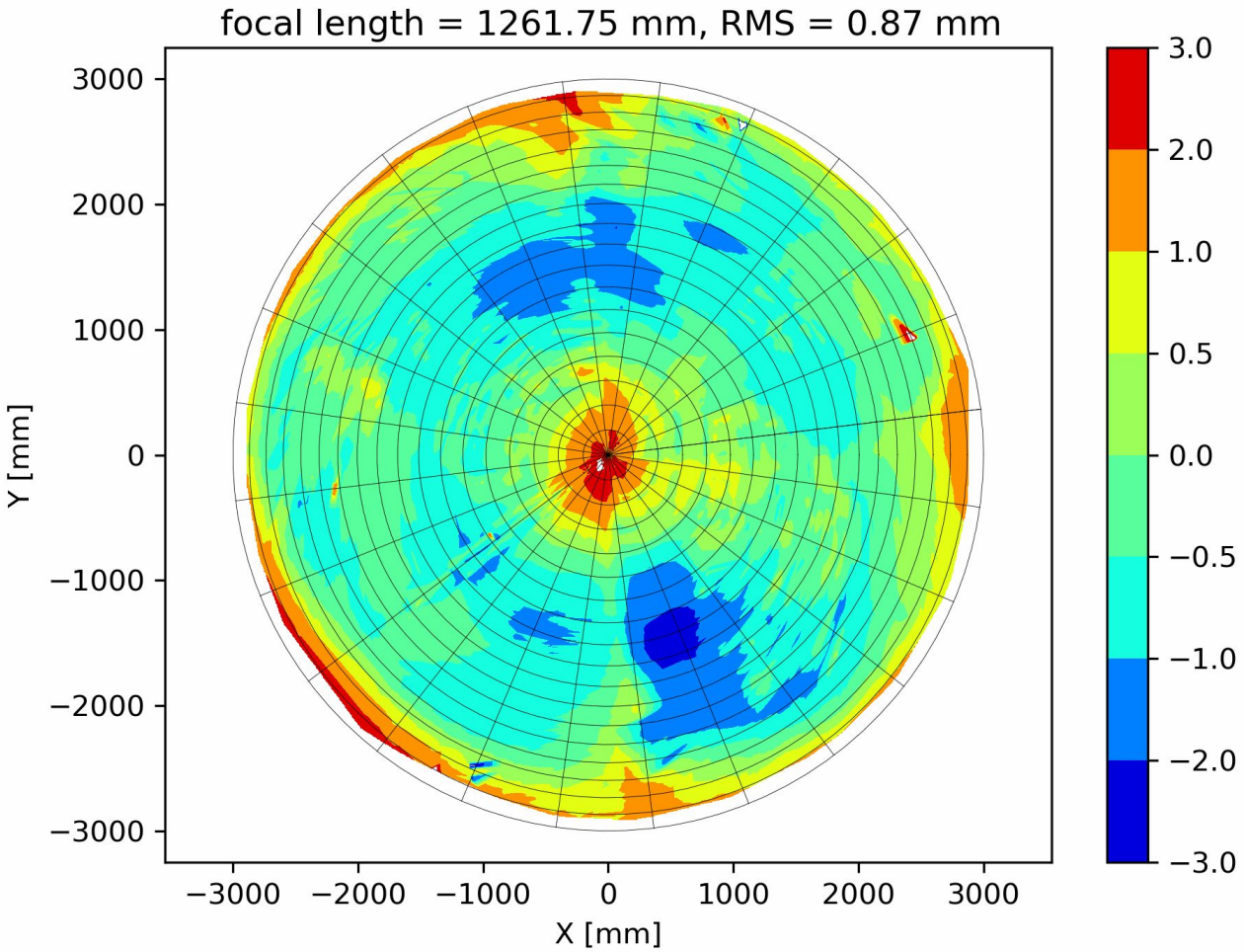
Measurement procedure:

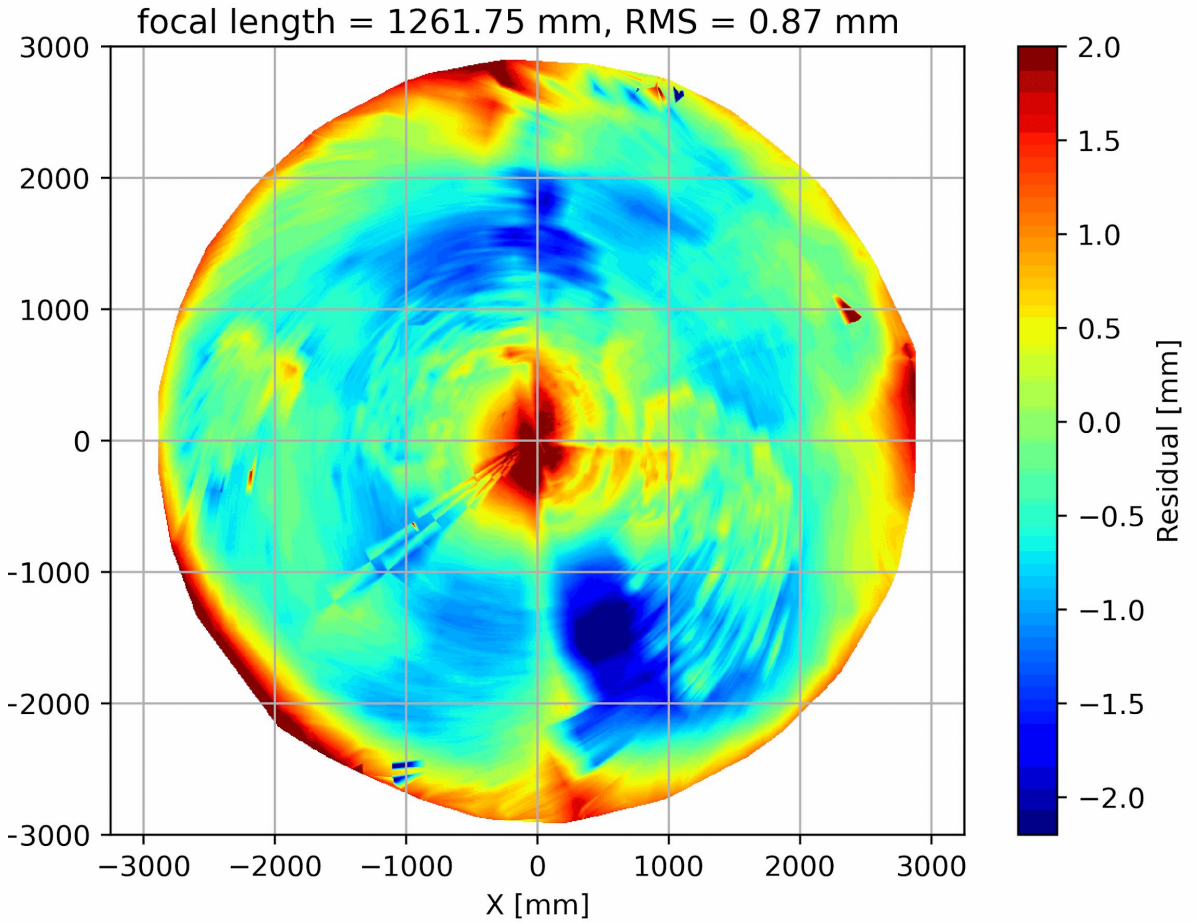
1. Sweep the reflector over the surface of the device under test while the laser tracker tracks it
2. Analyze the resulting 3D point cloud



Plug Improvement

June 2024





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

Laser Tracker - First Monolithic Mold

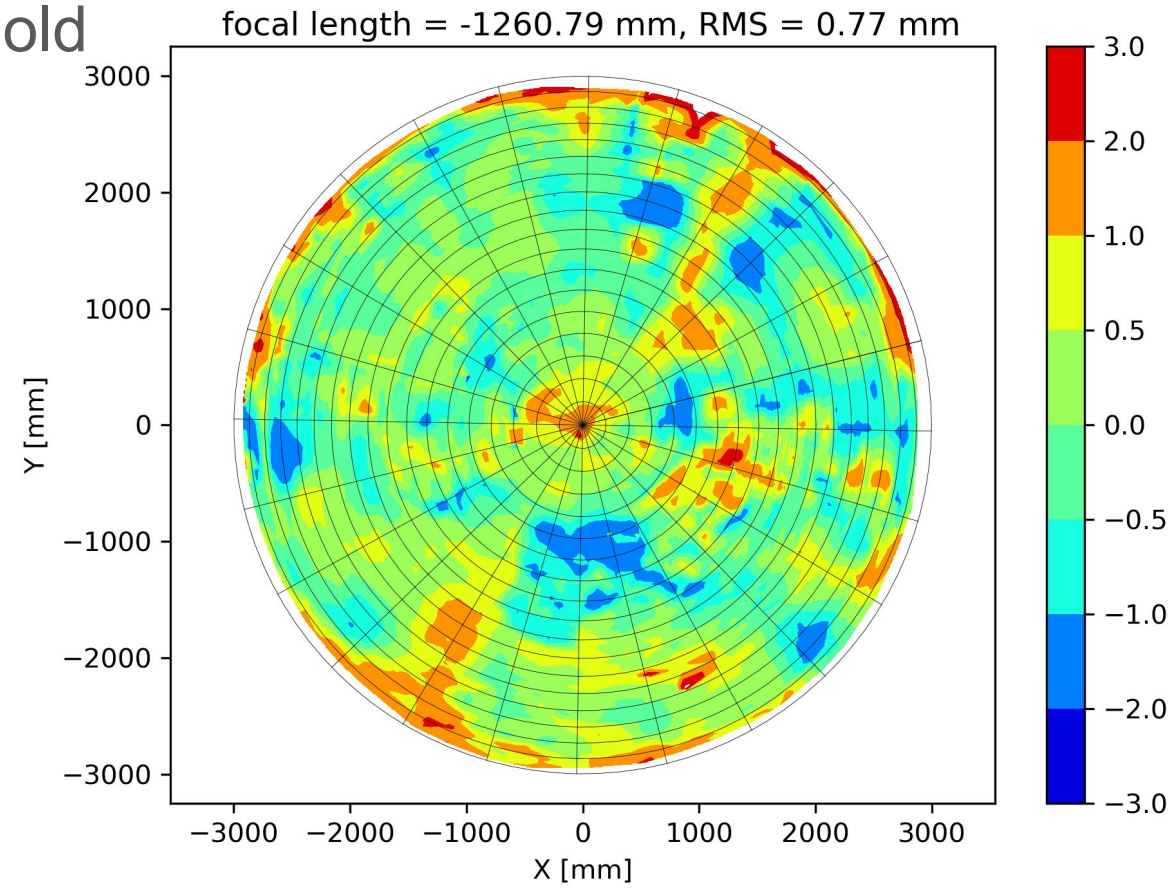
December 2024

Laser Tracker - First Monolithic Mold

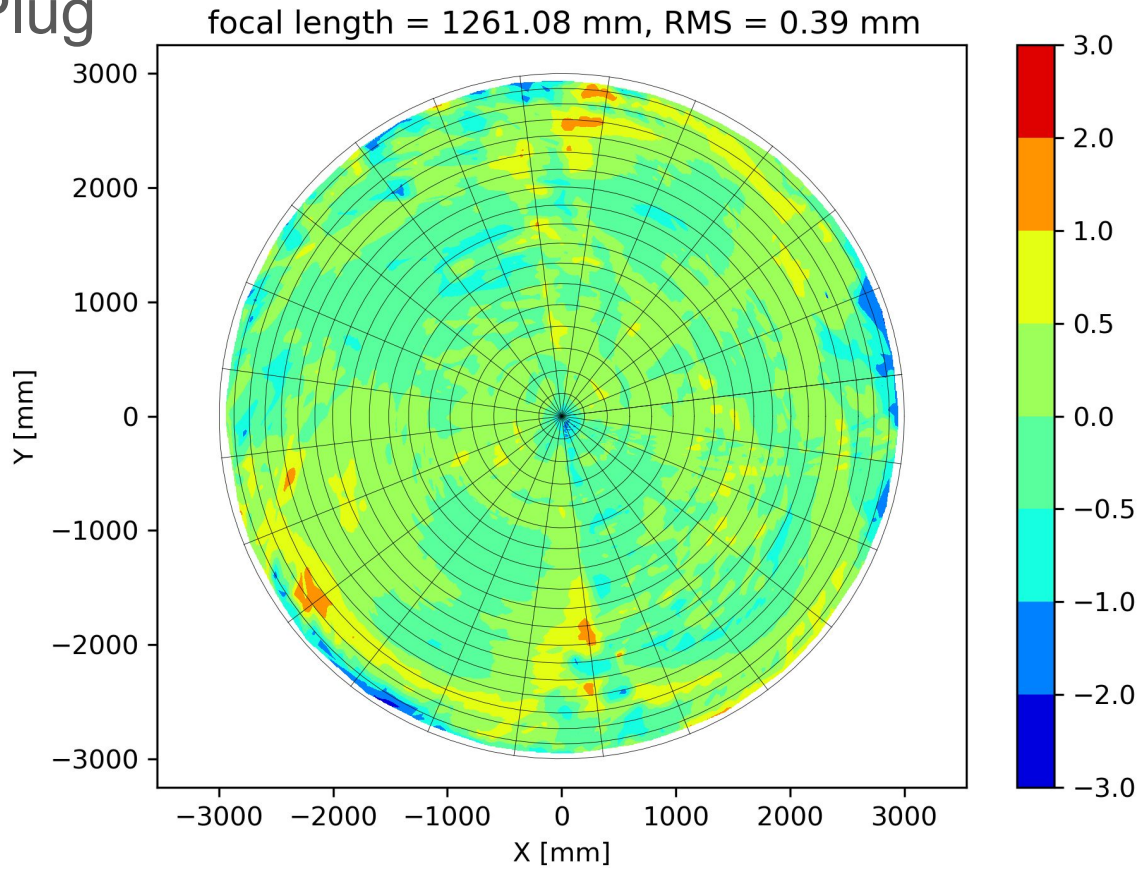
As of end of last week. Jennifer Studer and Thierry Viant in Carnarvon currently.

Polar RMS = 0.60

Mold



Plug



Klerefontein Prototype Commissioning

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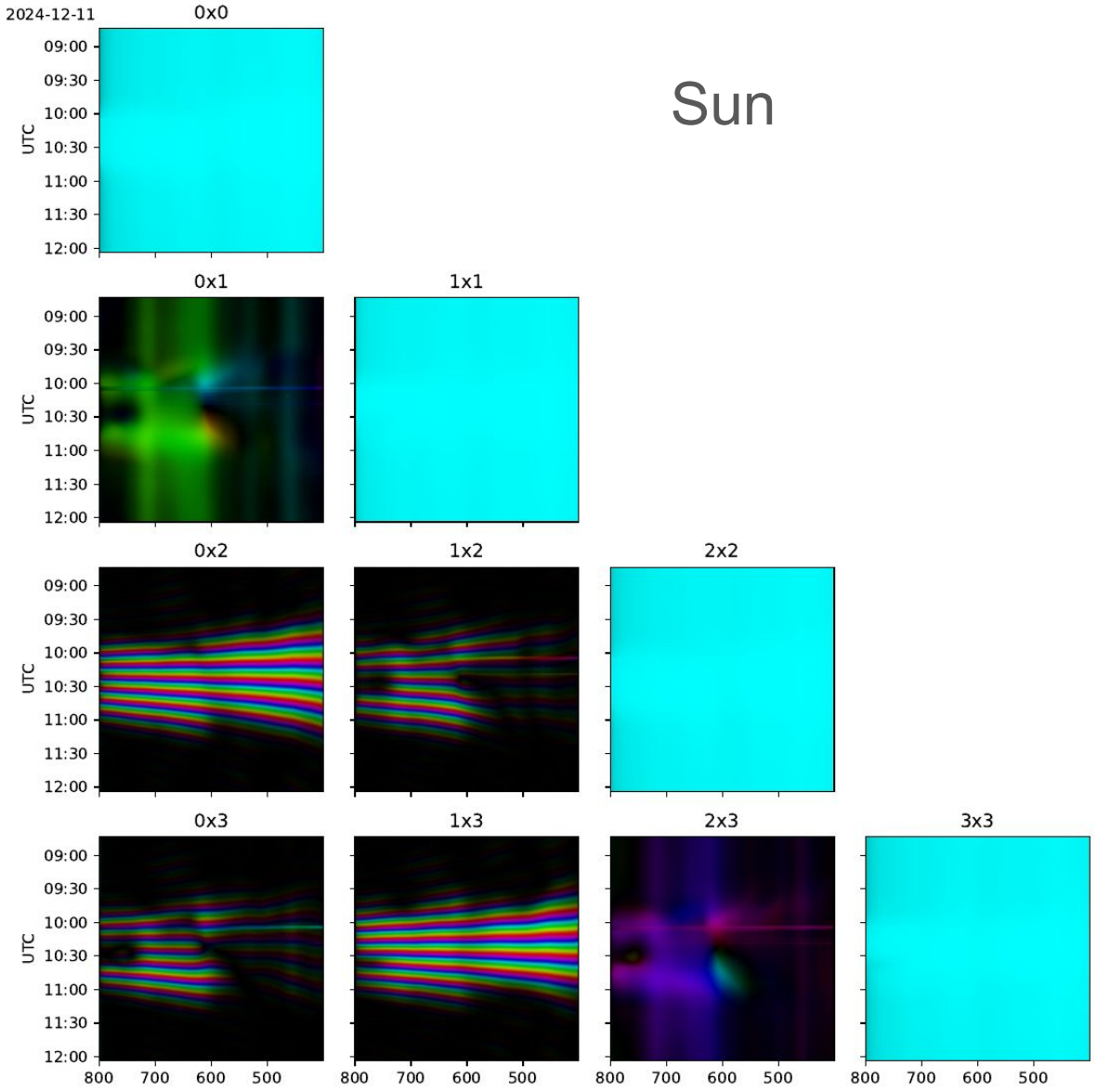
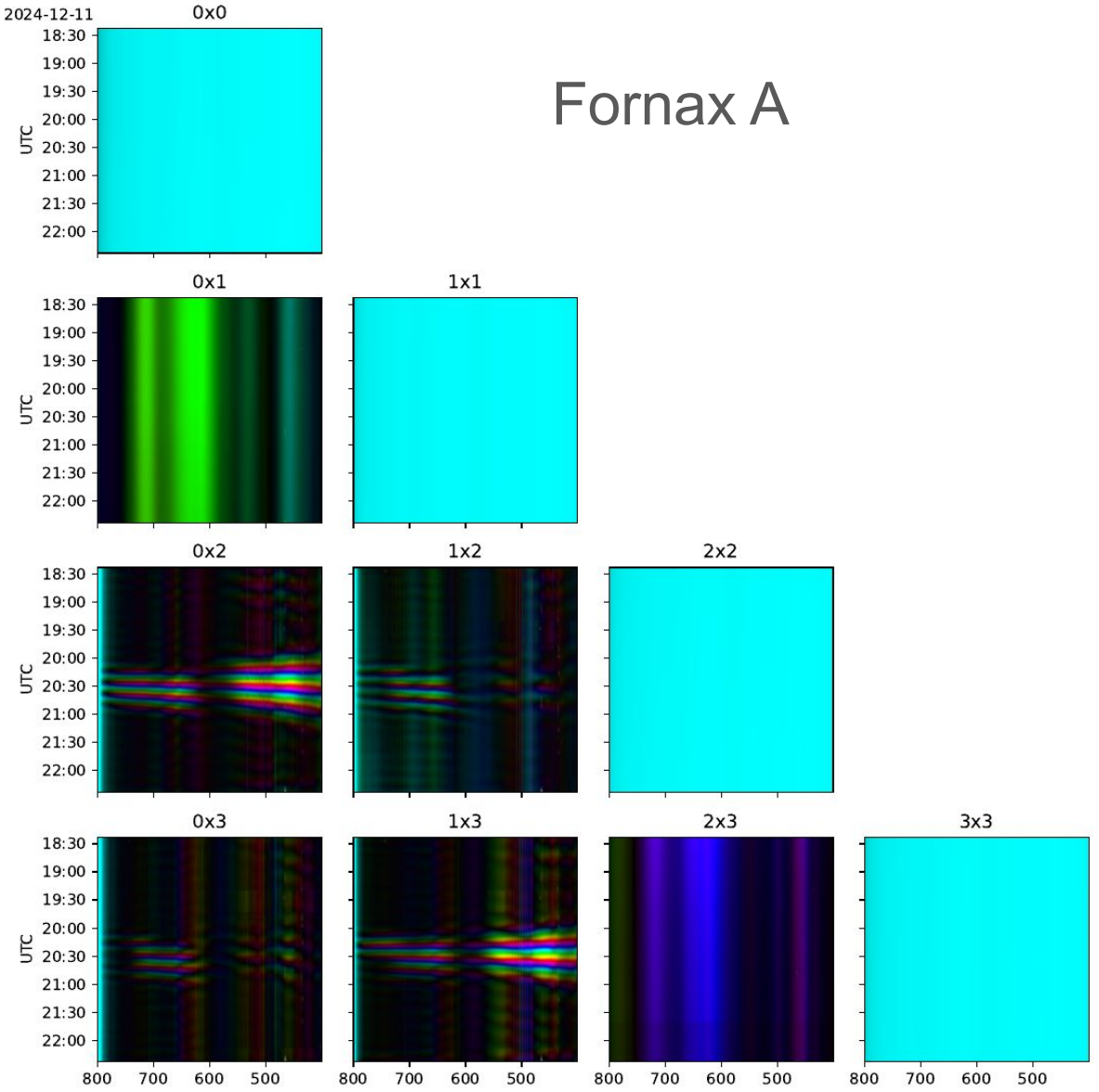
December 2024 - January 2025

- Two dishes instrumented with backend
- Low RFI but not fully RFI restricted area
- Full system integration test
- Verify subsystems and performance
- Generally operating well
- Some temperature dependent gain effects being tracked down

Klerefontein Prototype - First Fringes

11.12.24





Conclusions

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- HIRAX is entering the final stages of tooling development for final dishes
- Careful accounting of mechanical requirements on dish-feed system
  - Critical to reach systematics targets for cosmology
  - Lots of hard work in remote factory in Carnarvon
- End-to-end systems integration test operating in Klerefontein
- First light achieved with two-element prototype in end of 2024
- Finalising molds for full dish production in ~ weeks
- Lots more to come in 2025! Goal: 32-element array at Swartfontein

Thanks!