HIRAX - Overview and Metrology

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Swiss Cosmology Days 2025

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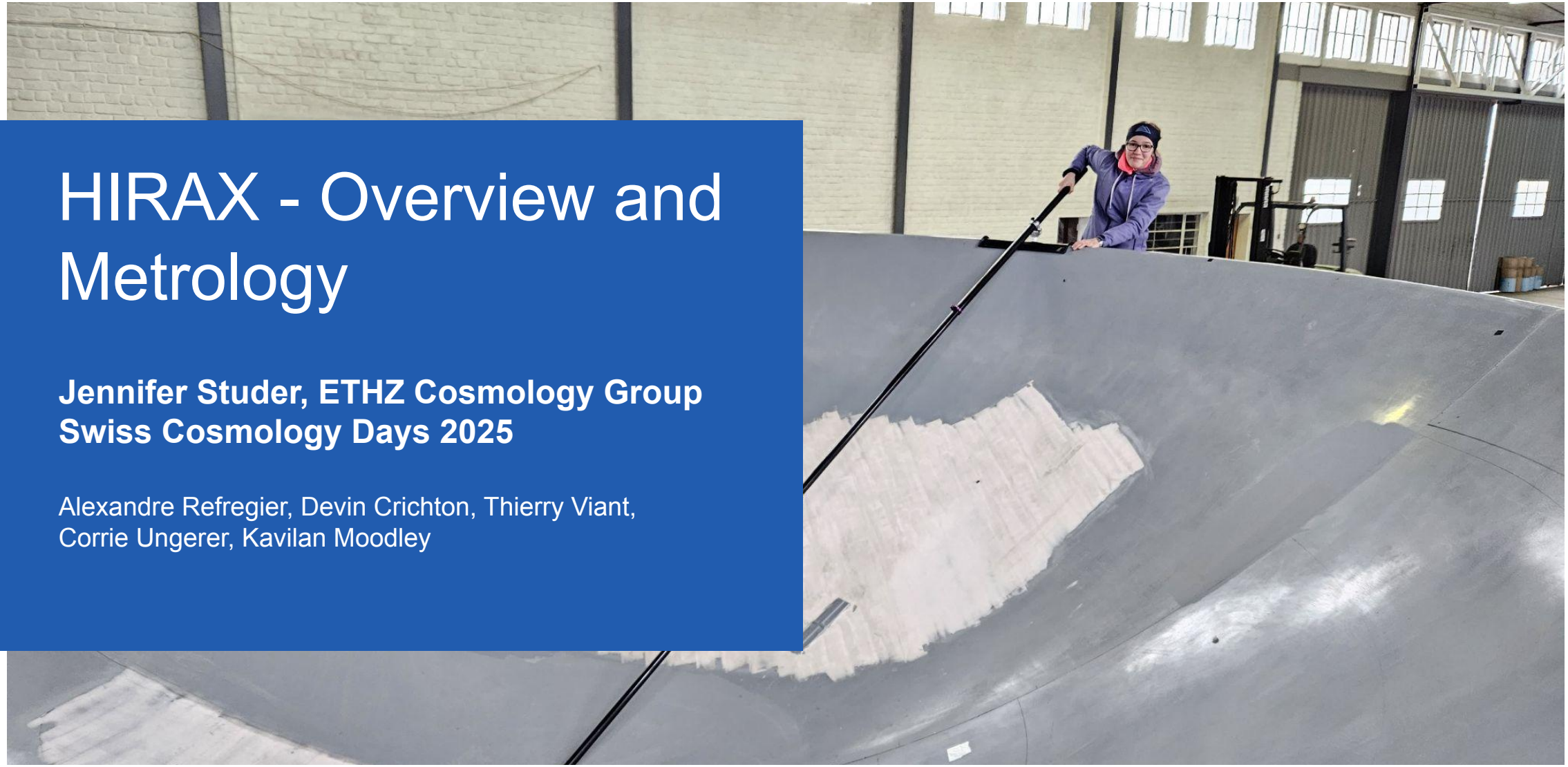
Corrie Ungerer, Kavilan Moodley

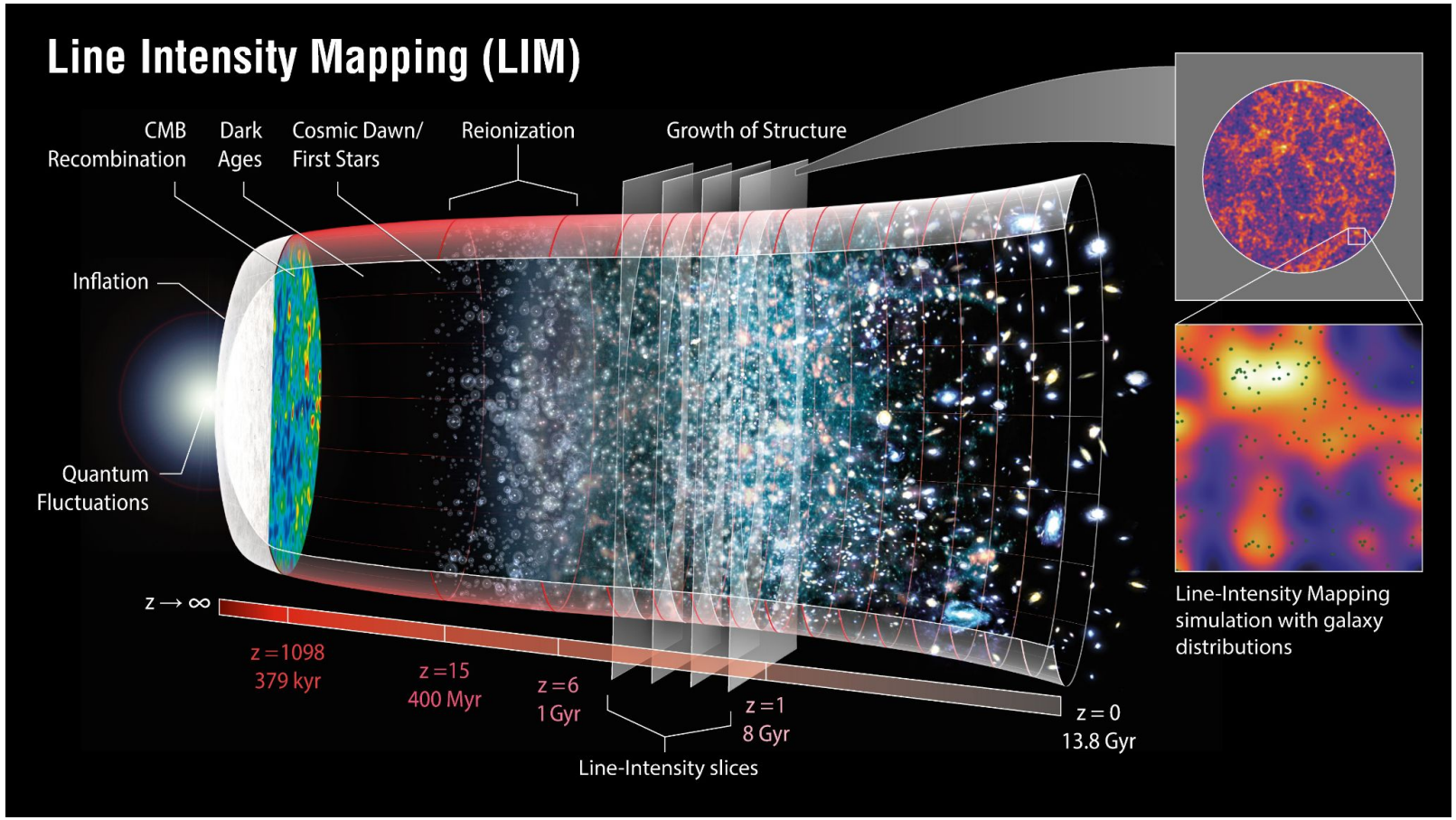


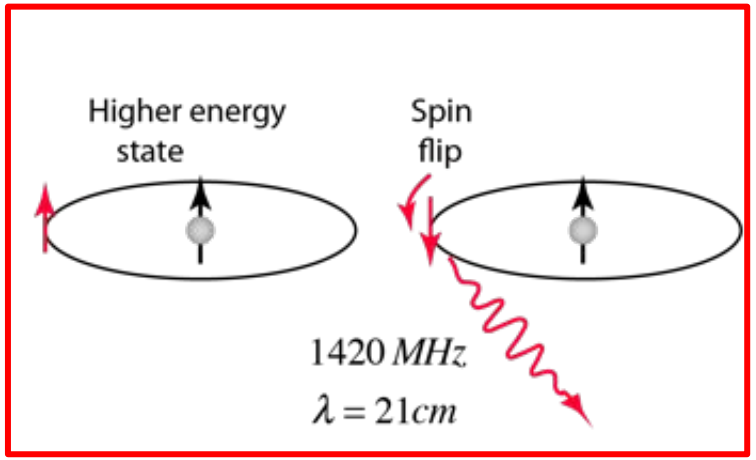
Credit: D. Crichton et al. (2022)

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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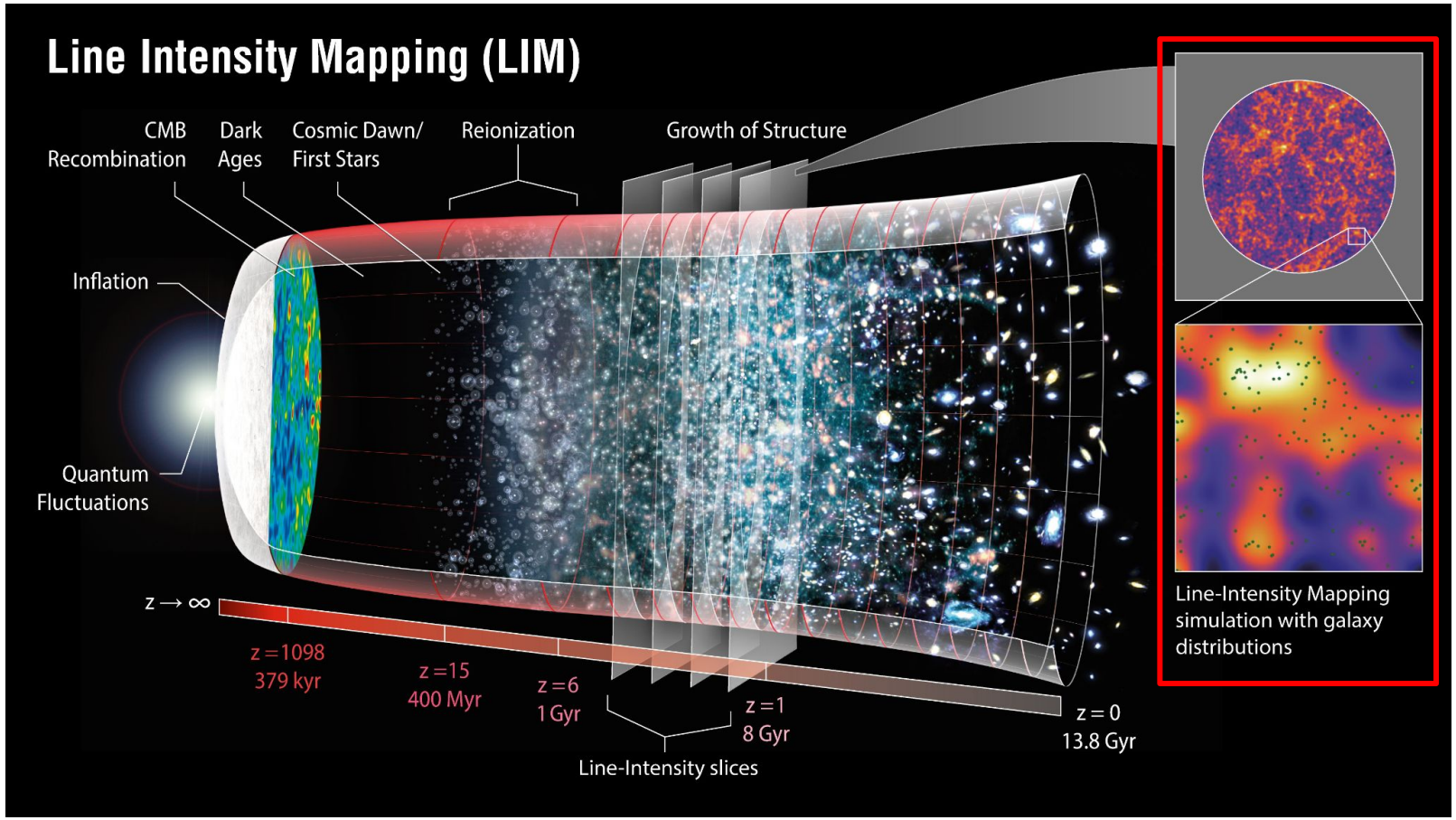

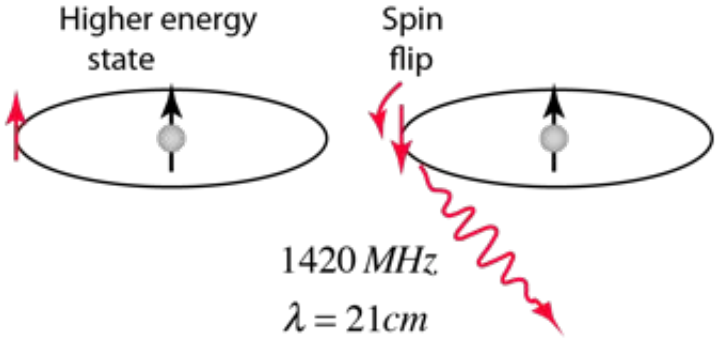

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HIRAX Overview

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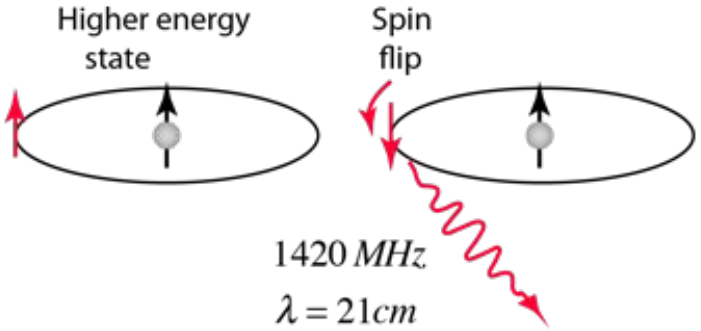
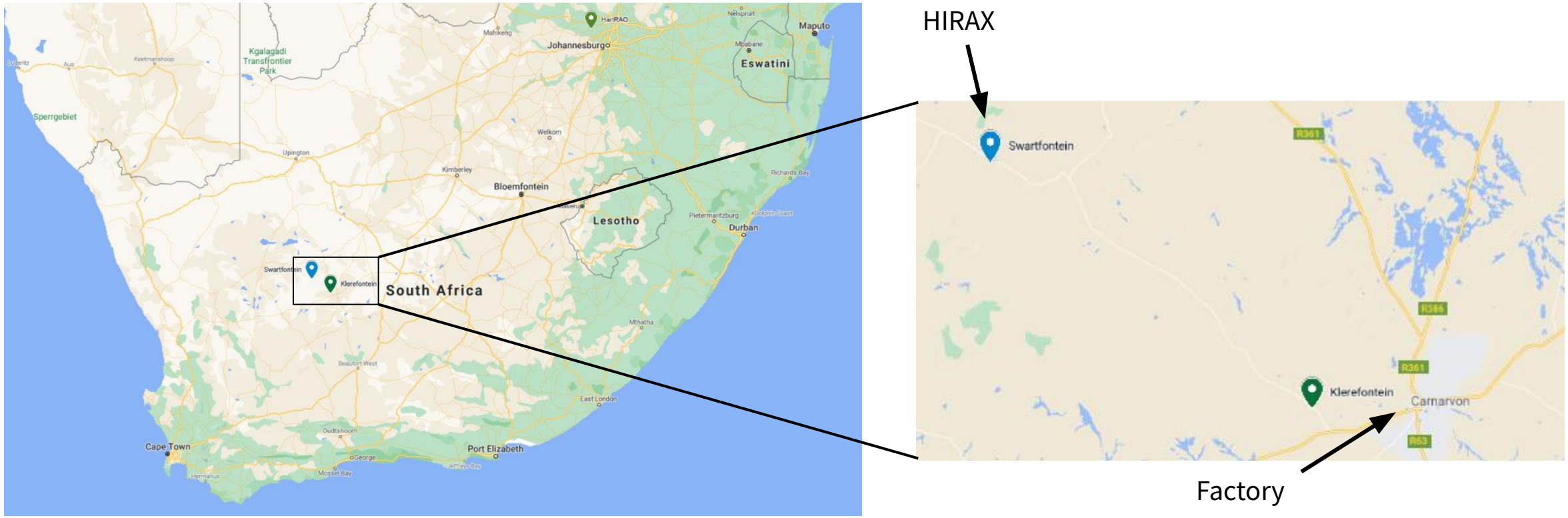
- **H**ydrogen **I**ntensity and **R**eal-time **A**nalysis e**X**periment
- Radio interferometer with a compact, redundant layout
- To be co-located with SKA in the Karoo, South Africa
- Funded up to 256 element deployment
- 6 m diameter dishes instrumented to operate between 400–800 MHz / z = 0.8-2.6
- 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

- 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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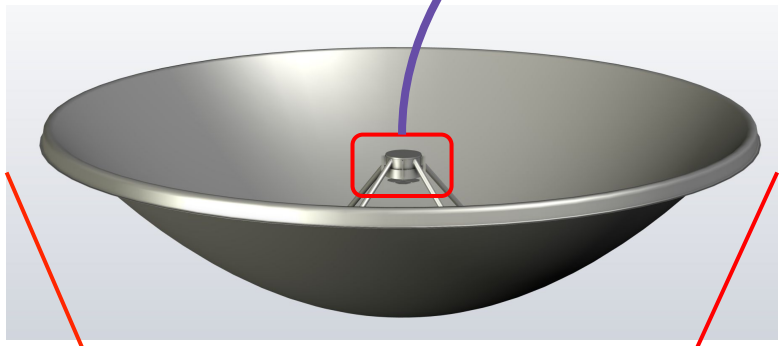
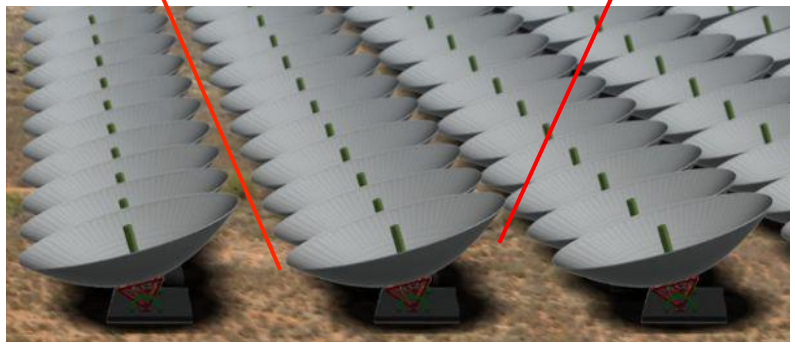
RF Frontend
dual-polarized feed
RFOF transmitter



dish diameter: 6 m
f/D = 0.21



256 antennas

RFOF receiver

F-Engine

32 boards:
1 board per 8 antennas

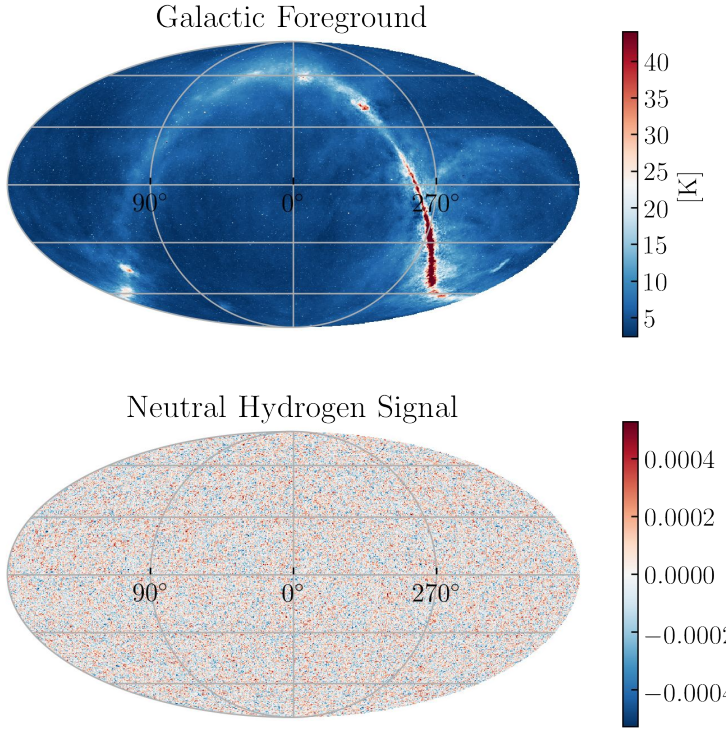
X-Engine

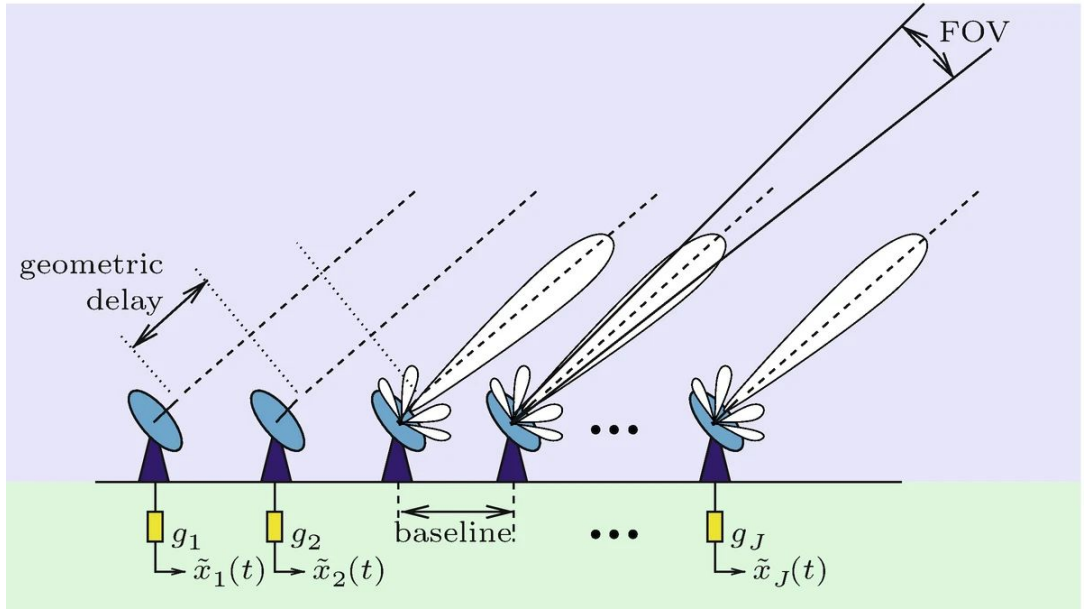
Process about 1.6
Tb/s of raw data

V_{ij}

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



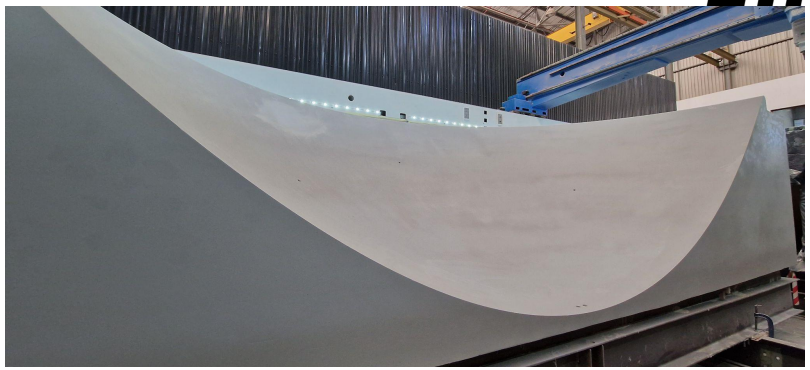


Credit: made with cora by D. Crichton

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
- Monolithic dish production just started

Instrument Requirements

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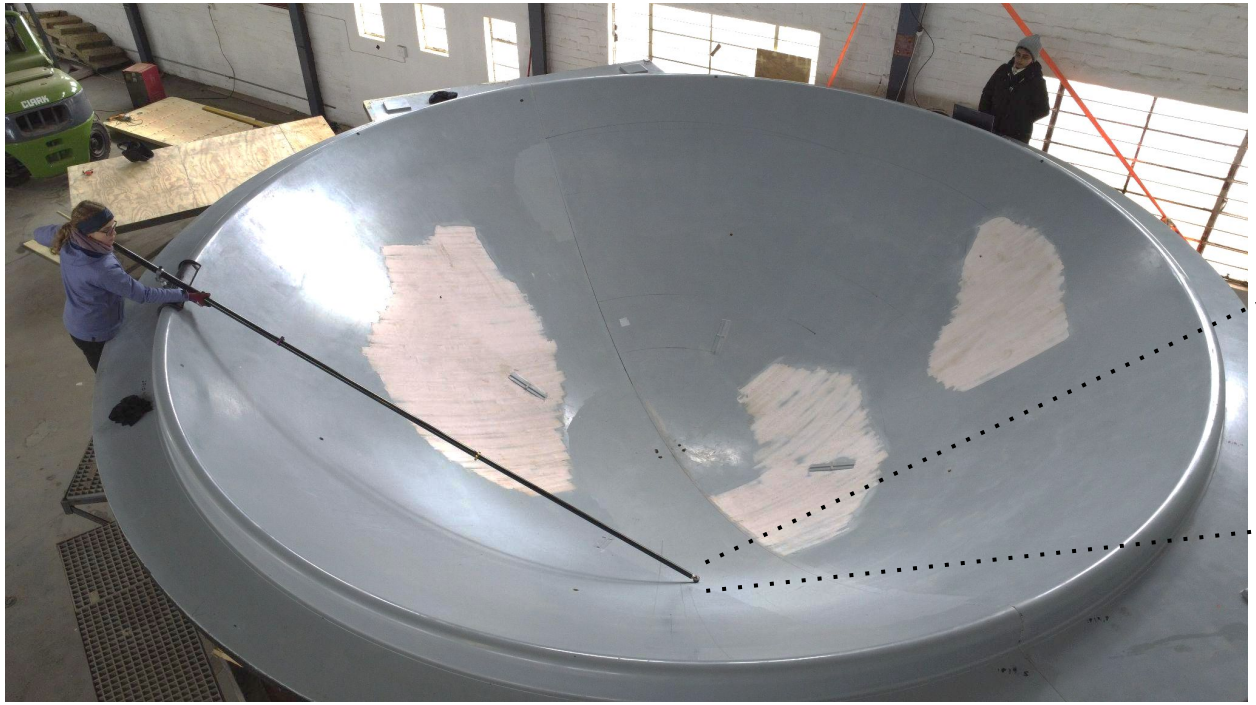
Telescope mechanical parameter	Target precision (RMS)
Receiver position relative to focus	0.5 mm
Receiver orientation relative to boresight vector	$2.5'$ polar and azimuthal
Dish surface deviations	1 mm
Dish vertex position relative to elevation axis	1 mm
Orthogonality of boresight vector and elevation 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

	Point density	Time effort
Laser Tracker	high	~ 1-2 h/dish
Photogrammetry	medium	< h/dish
Reflectometer	very sparse	~ 1 h/dish



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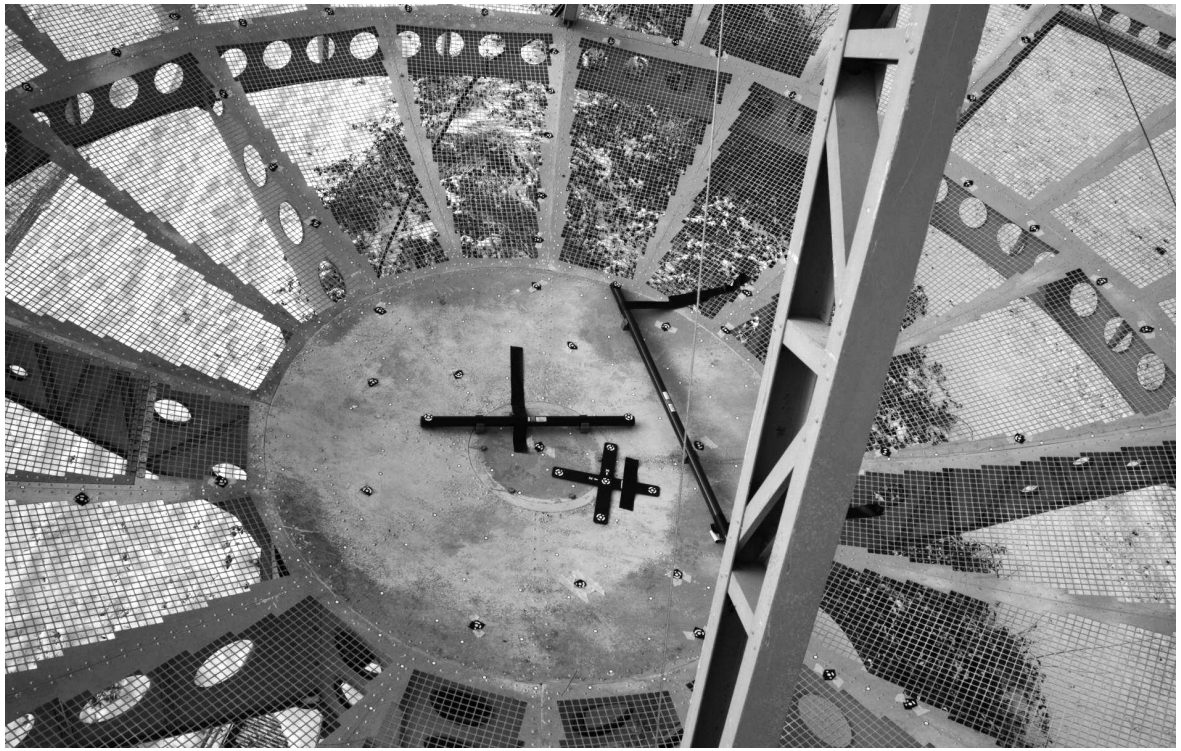
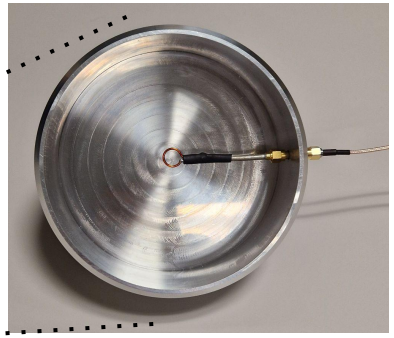
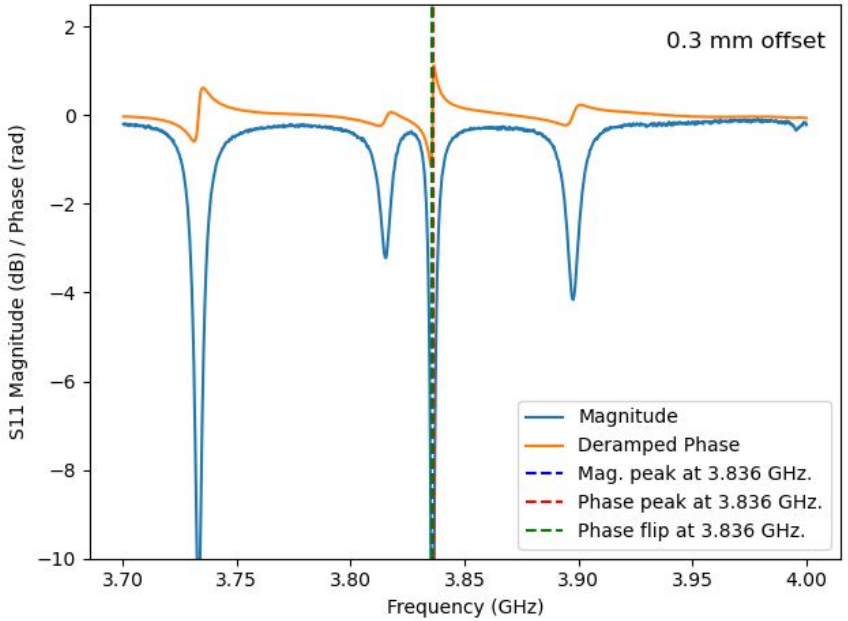


Measurement Equipment to Characterize the Dish

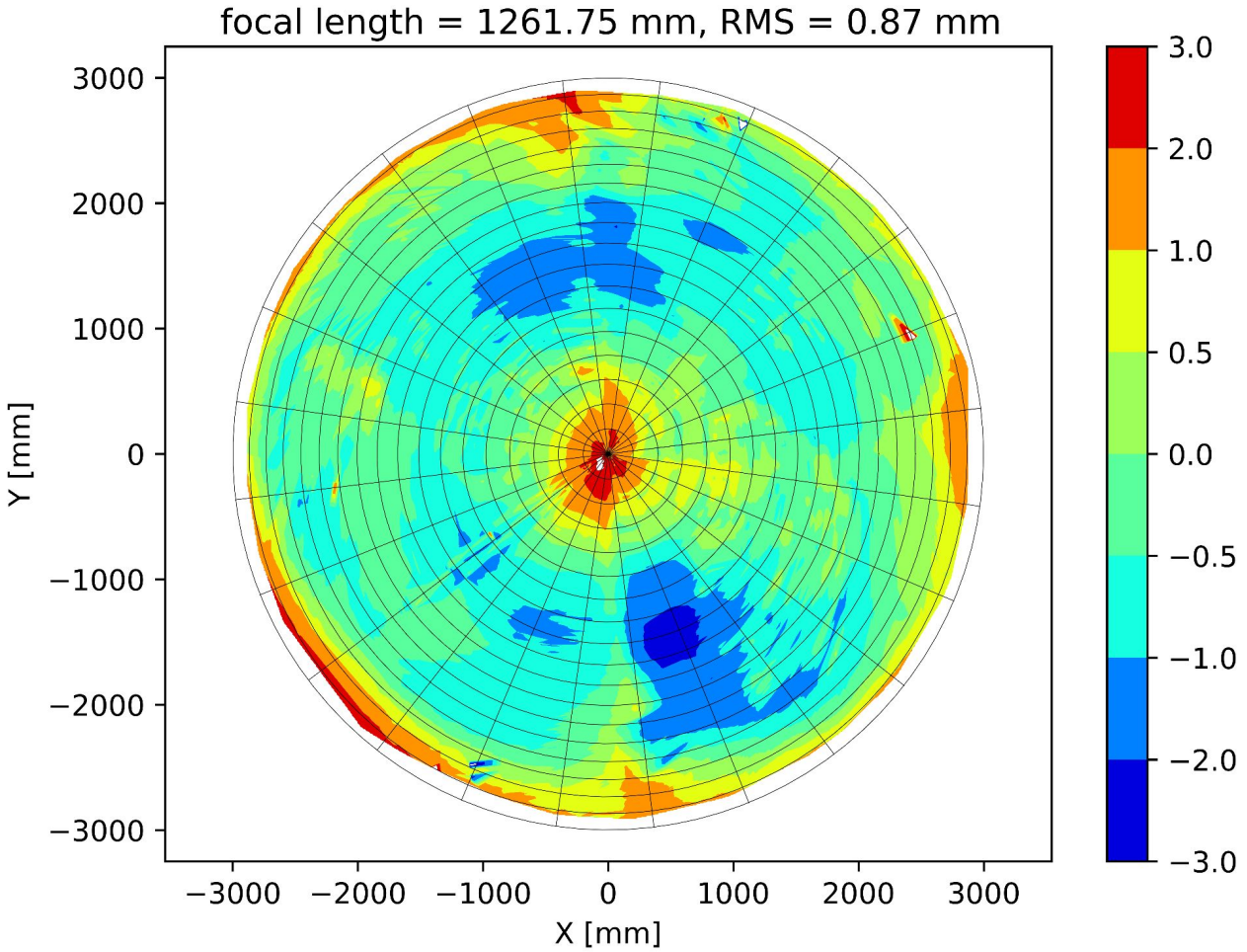
	Point density	Time effort
Laser Tracker	high	~ 1-2 h/dish
Photogrammetry	medium	< h/dish
Reflectometer	very sparse	~ 1 h/dish

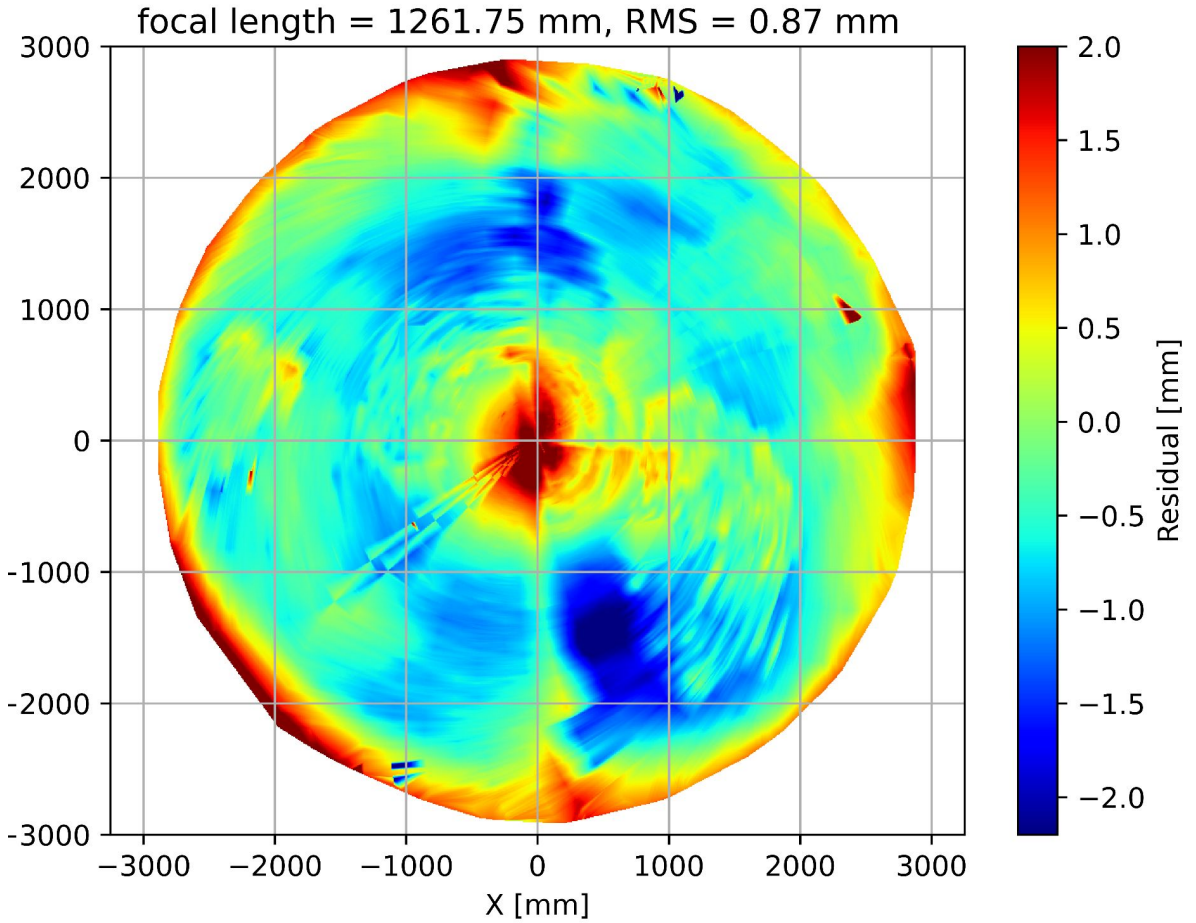




Plug Improvement

June 2024





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

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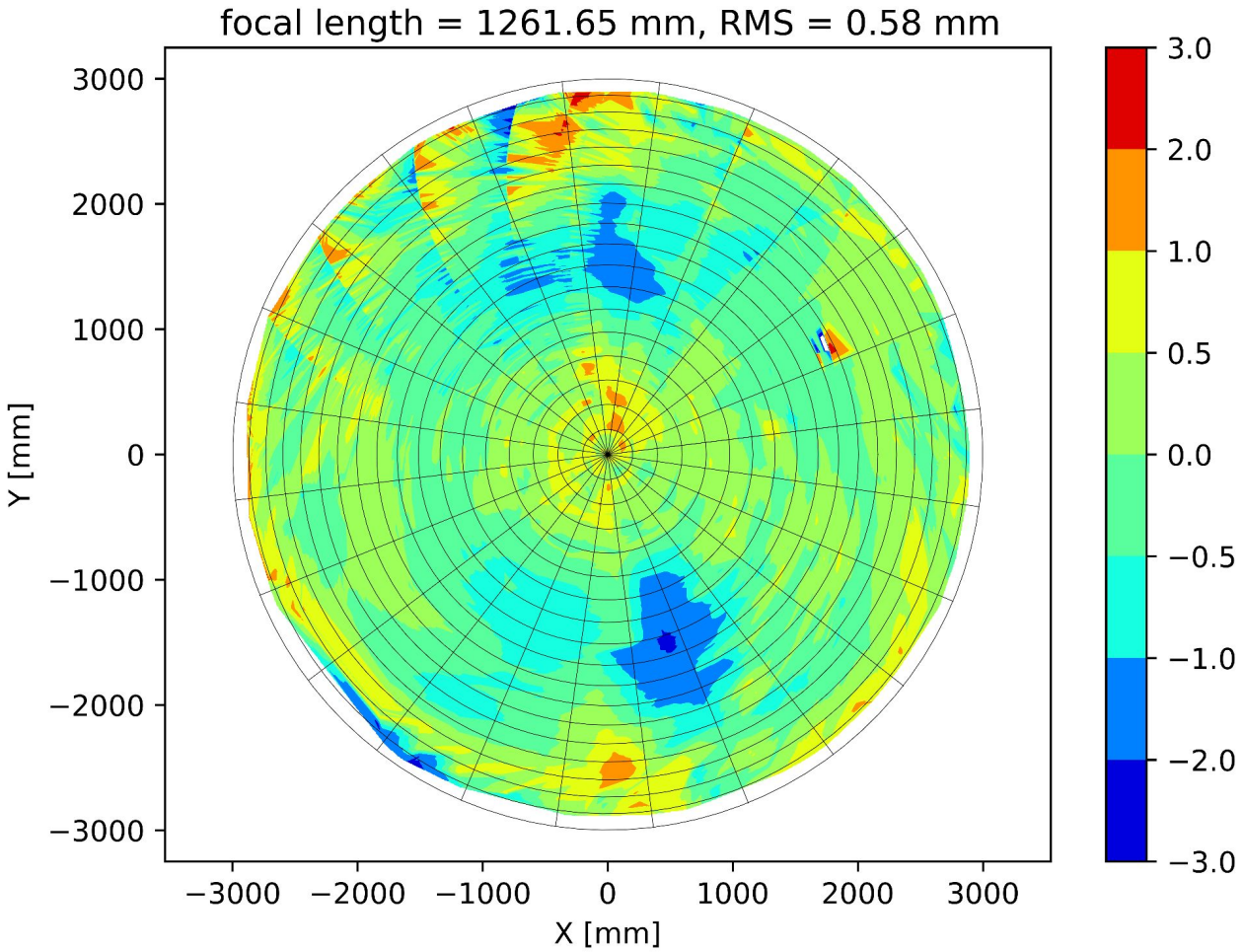

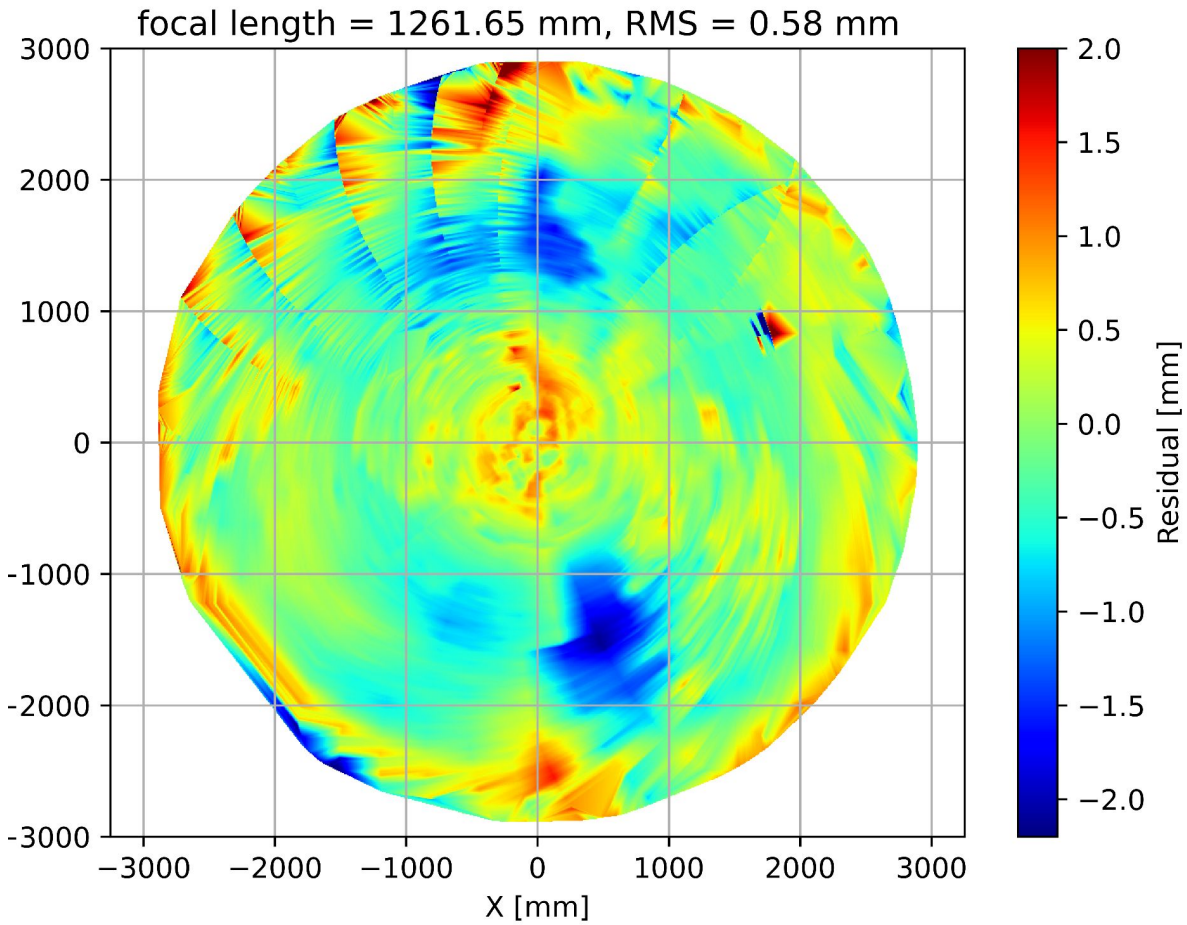

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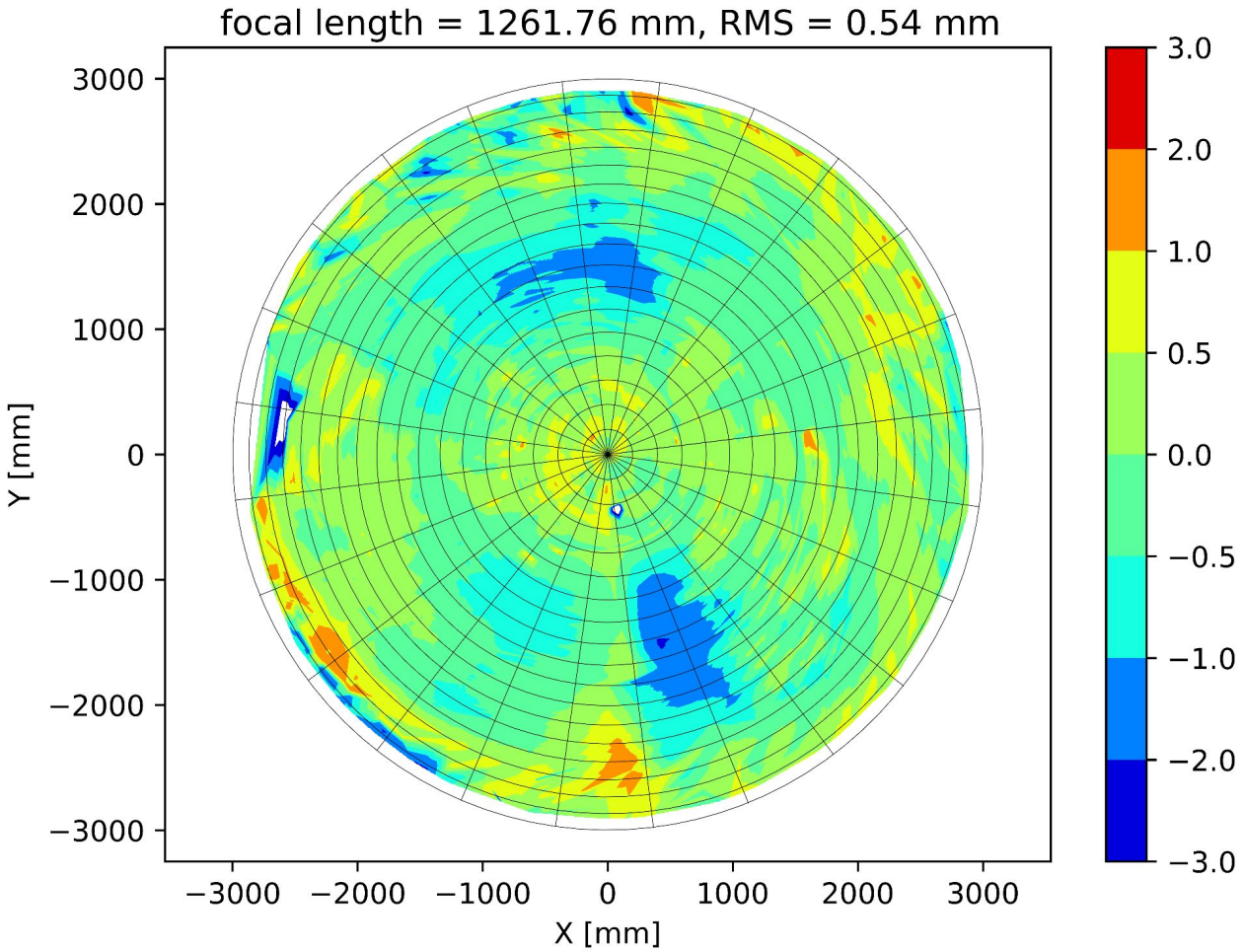

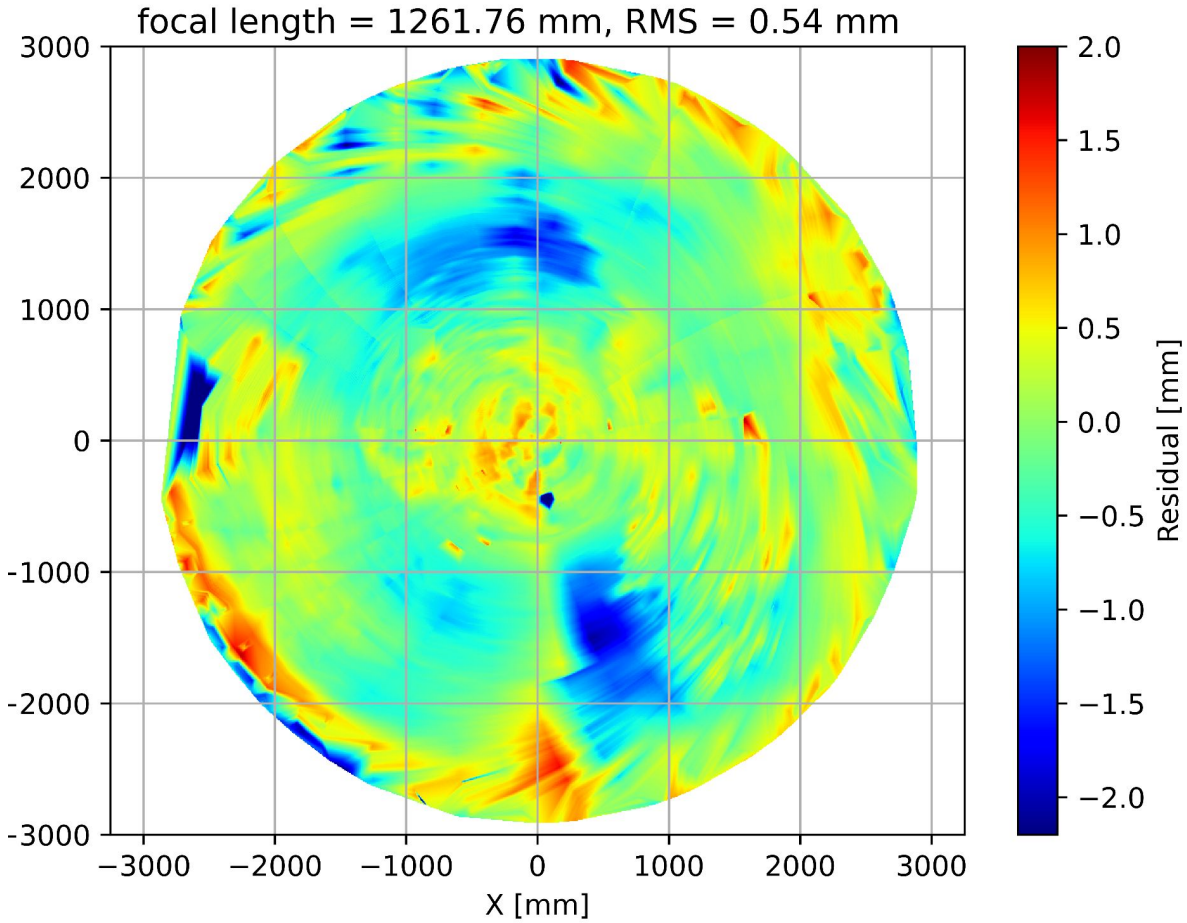

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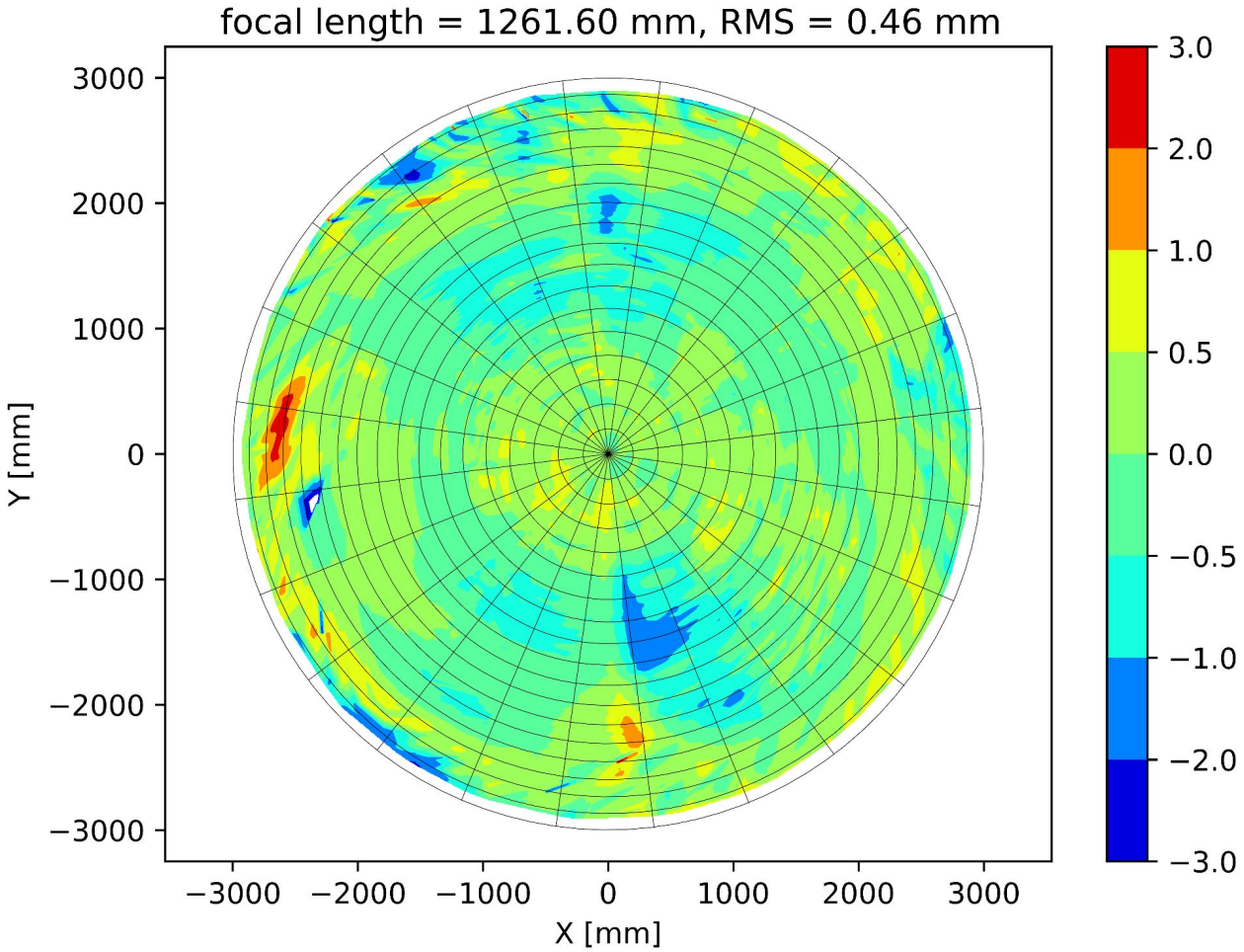

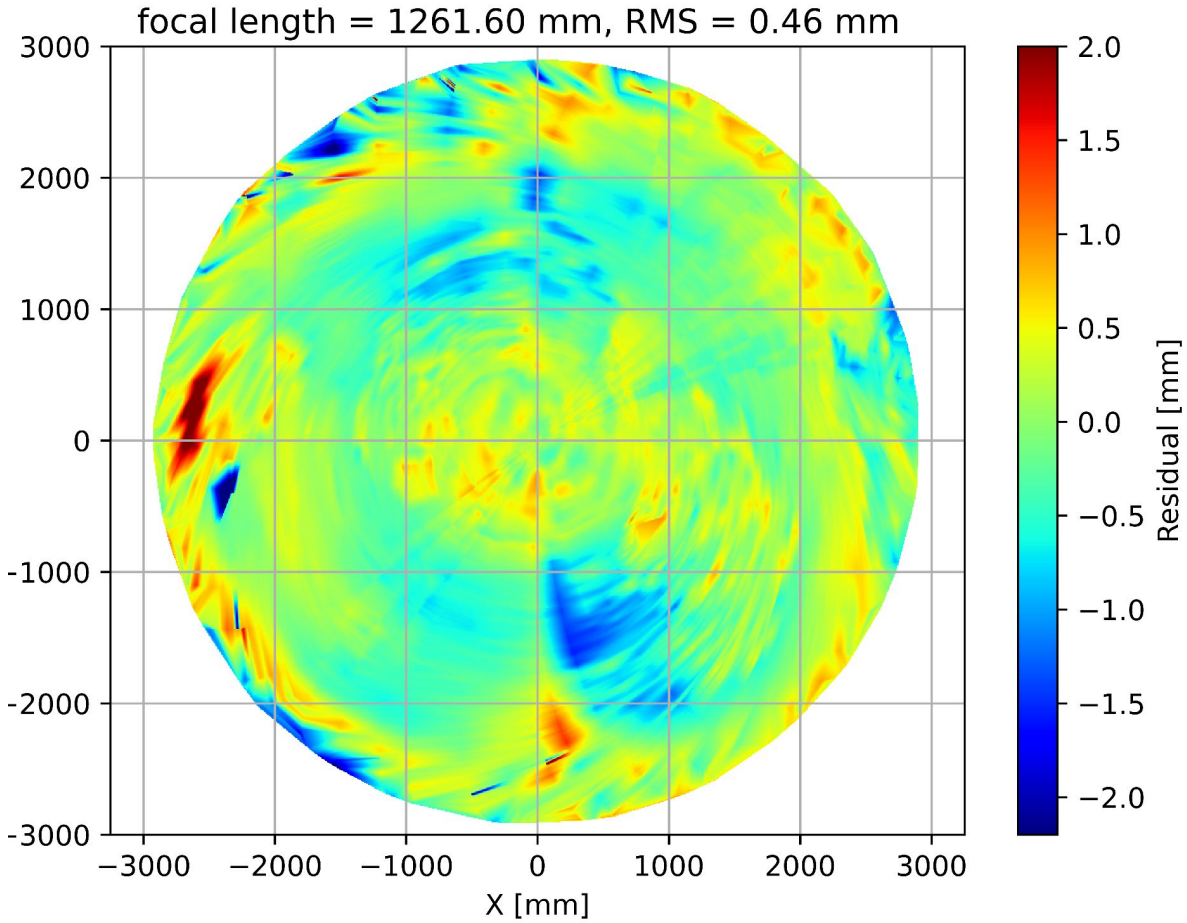

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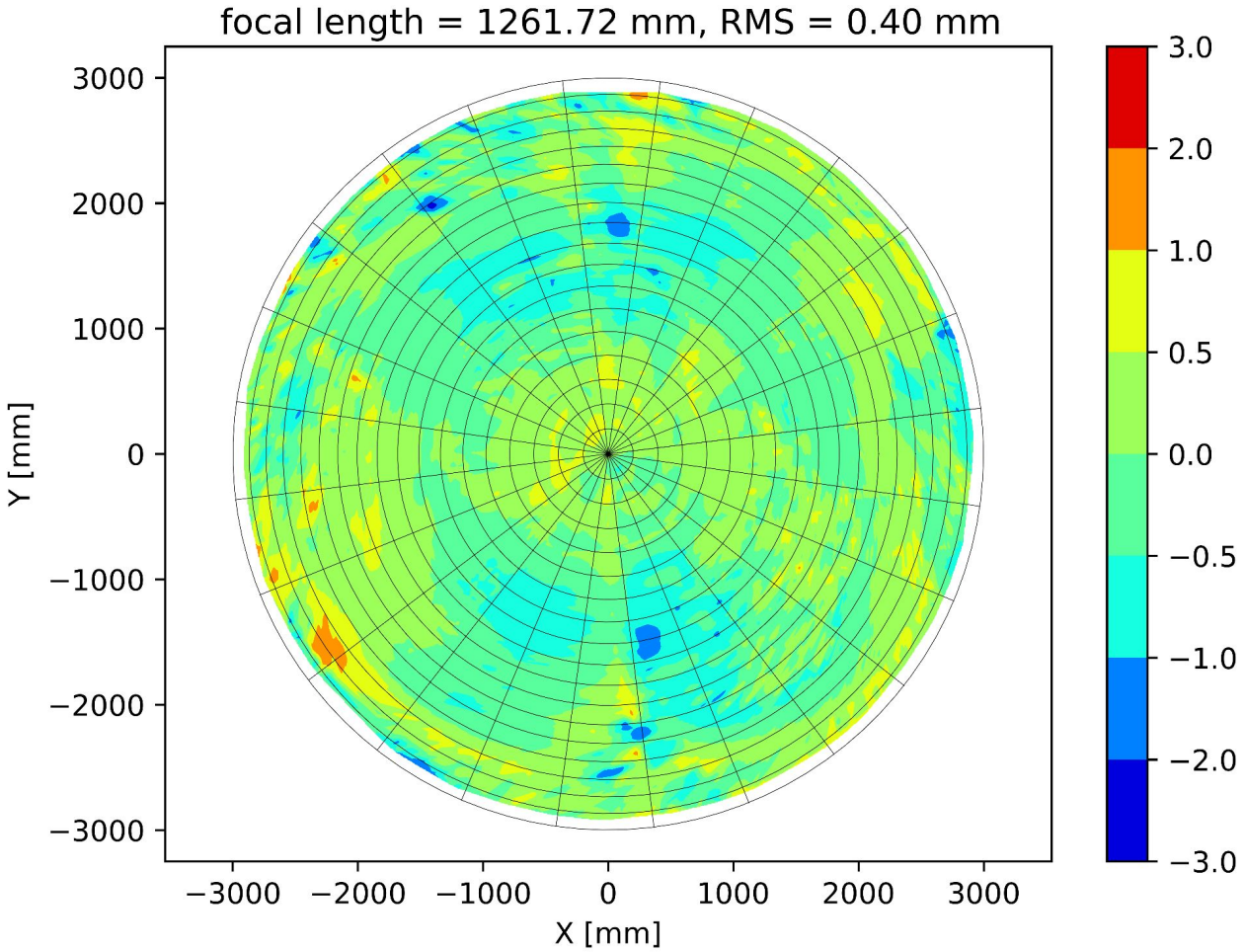

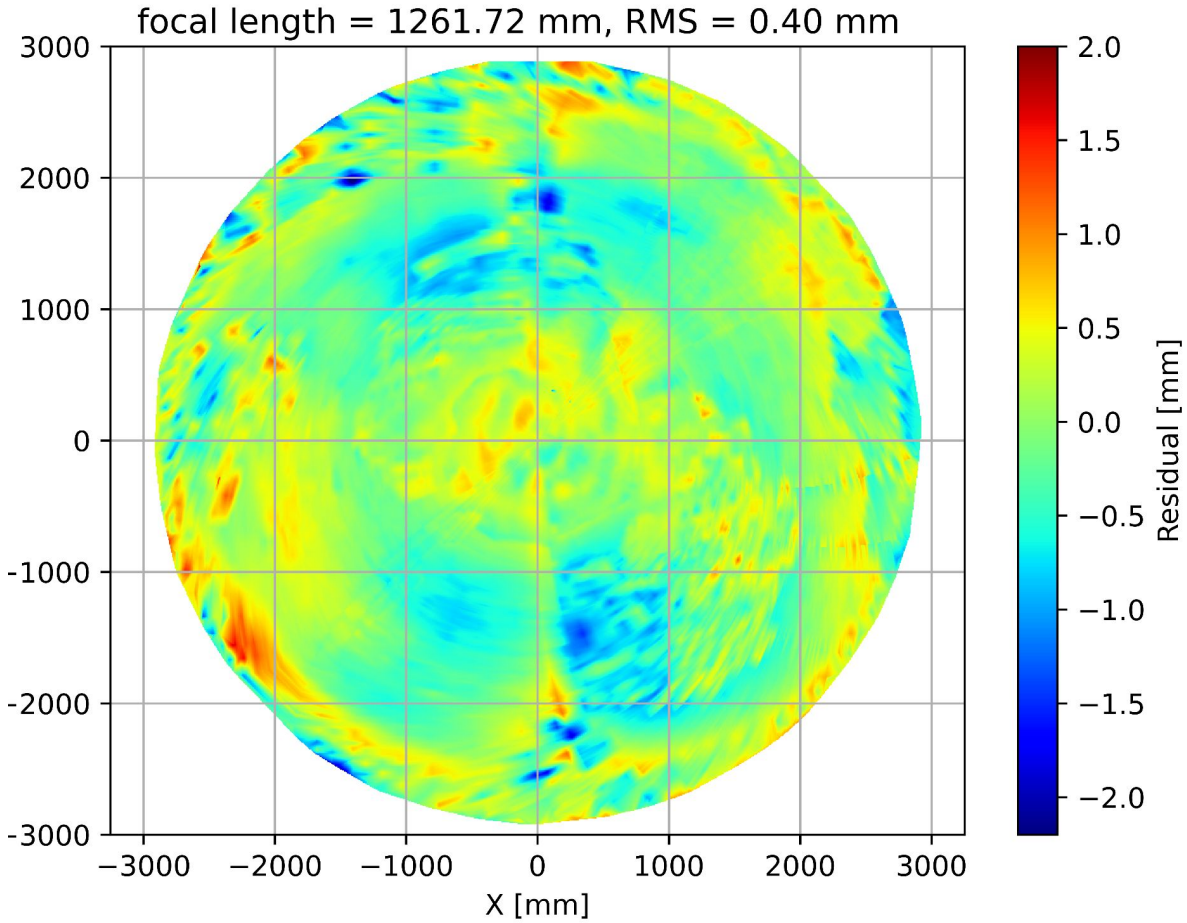

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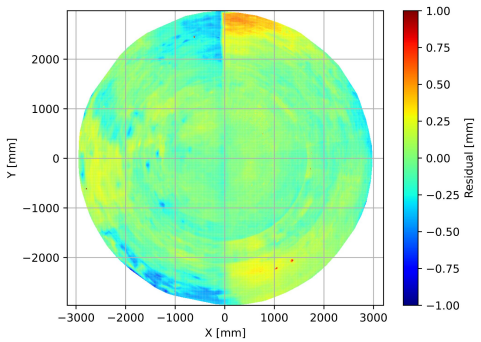
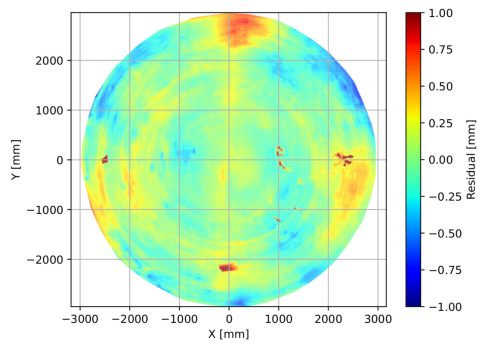
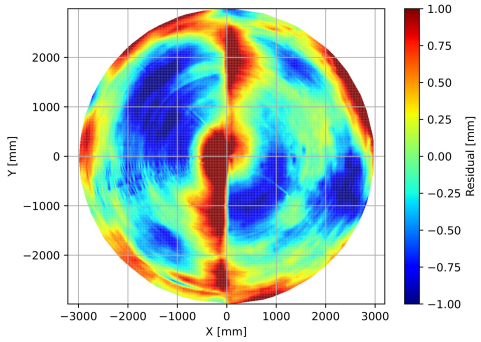
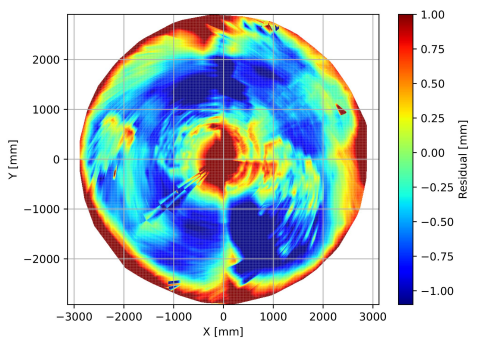
Plug - History

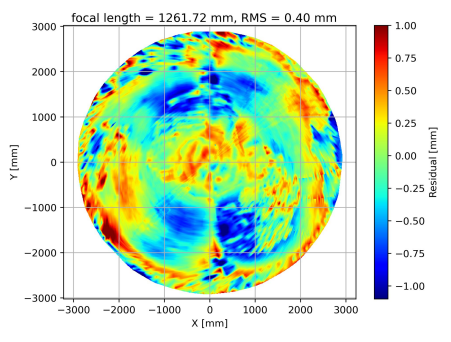
	Focal Length	RMS value
September 2023 - OmegaVerse	1260.0 mm	0.12 mm
November 2023 - AFF in Strand	1260.3 mm	0.21 mm
February 2024 - Carnarvon (~ 40°)	1260.0 mm	0.61 mm
June 2024 - Carnarvon (~ 5°)	1261.8 mm	0.87 mm
June 2024 - Carnarvon after Improvement	1261.7 mm	0.40 mm
November 2024 - Carnarvon (~30°)	1260.97 mm	0.41 mm
May 2025 - After Mold 1 & 2 are pulled	1262.53 mm	0.53 mm











Rework is again required!

Laser Tracker - First Monolithic Mold

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December 2024

Laser Tracker - First & Second Monolithic Mold

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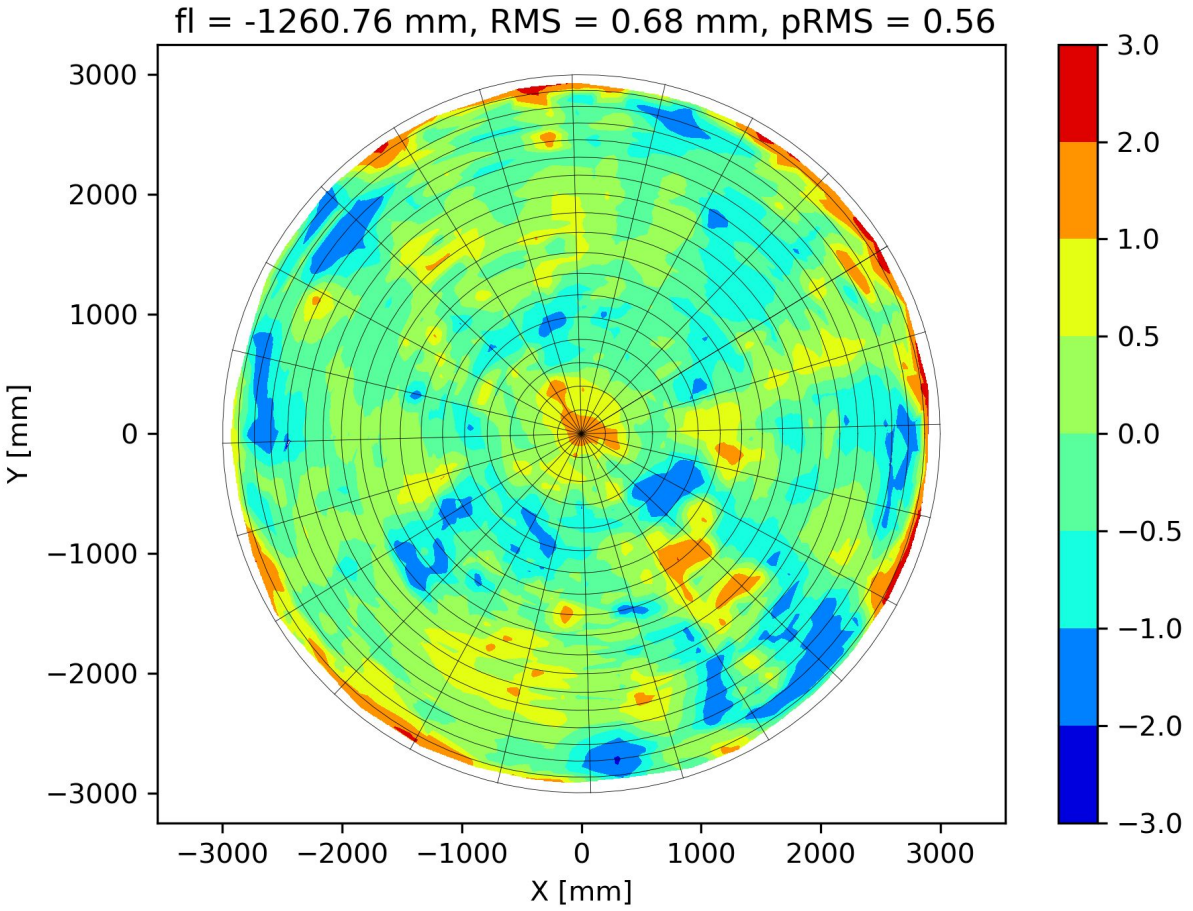
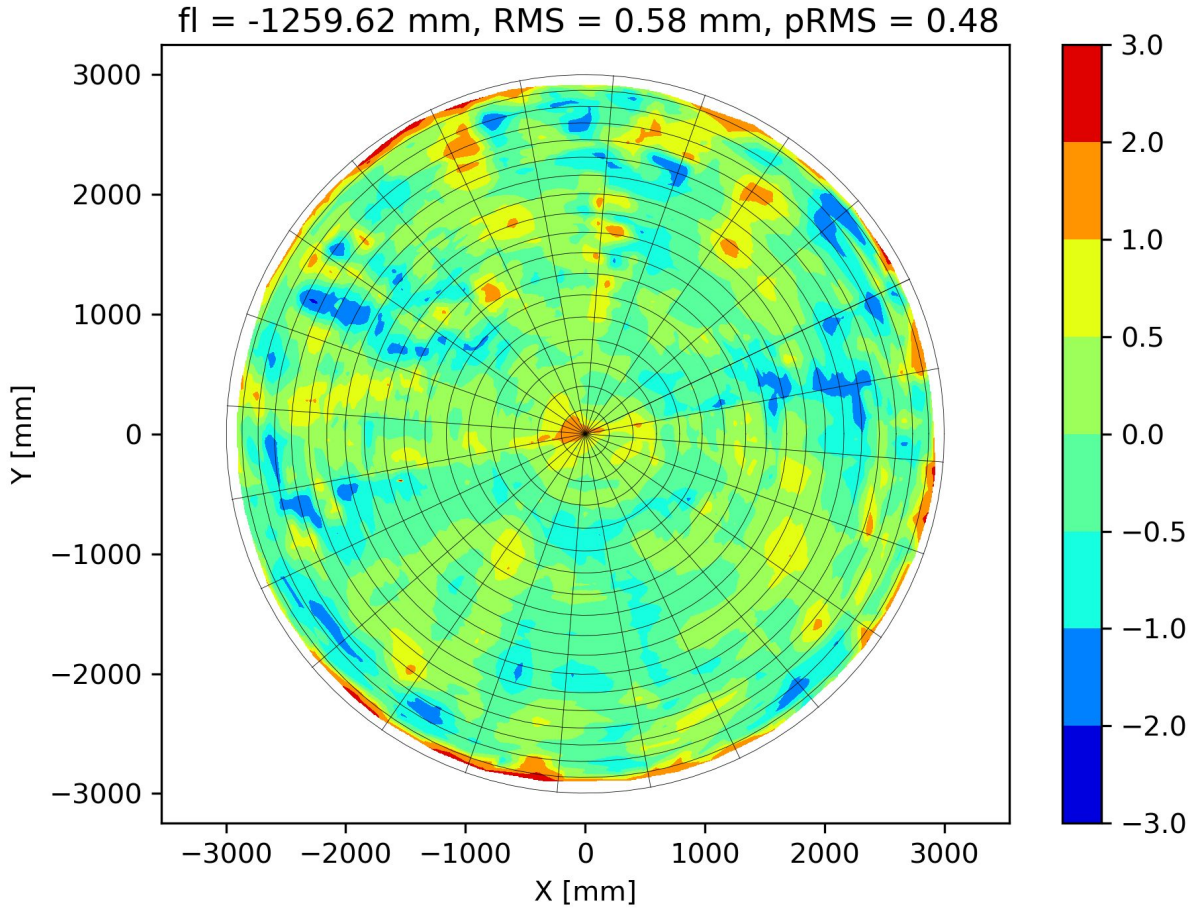
Mold 1



Mold 2



Klerefontein Prototype Commissioning

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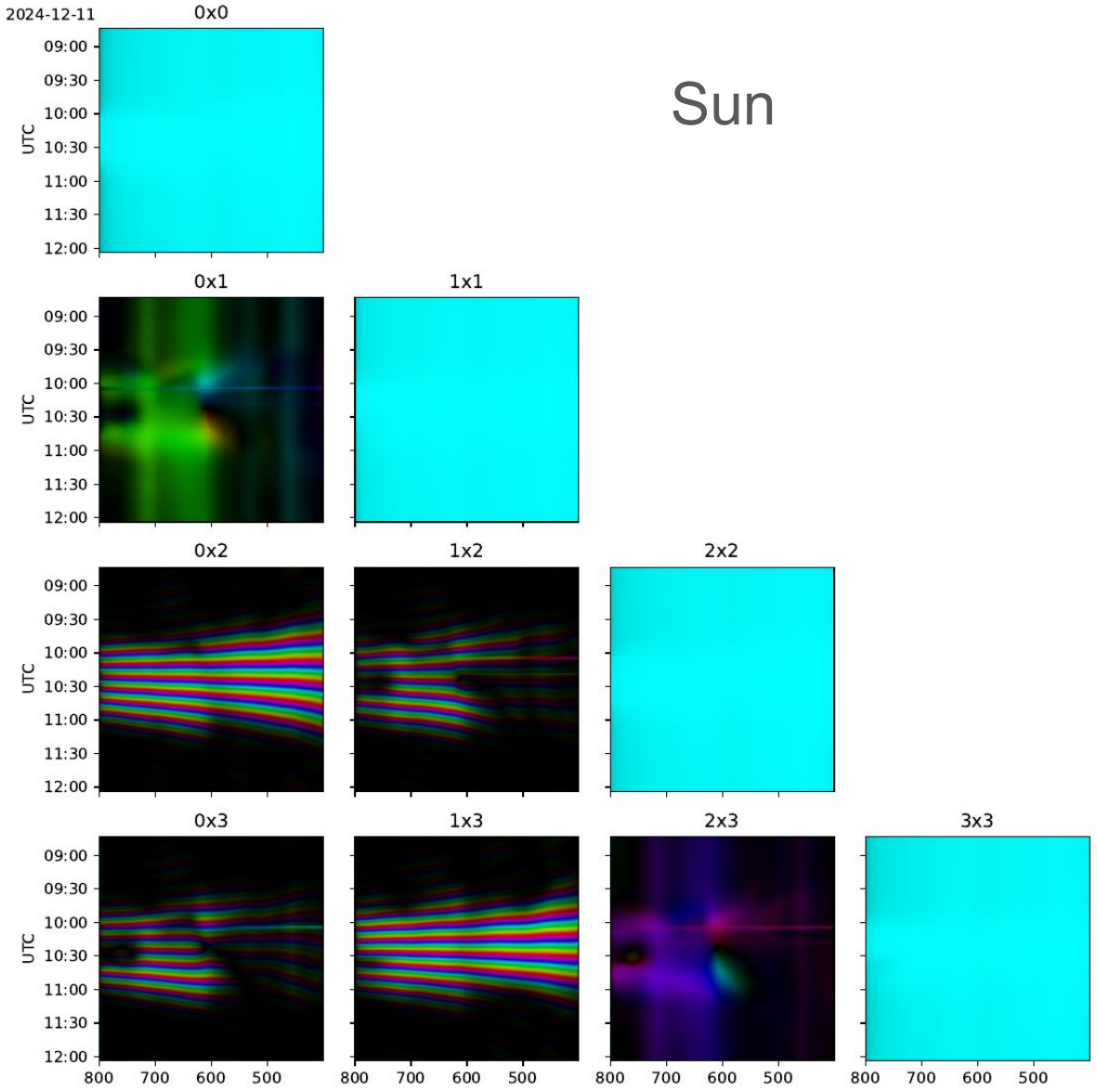
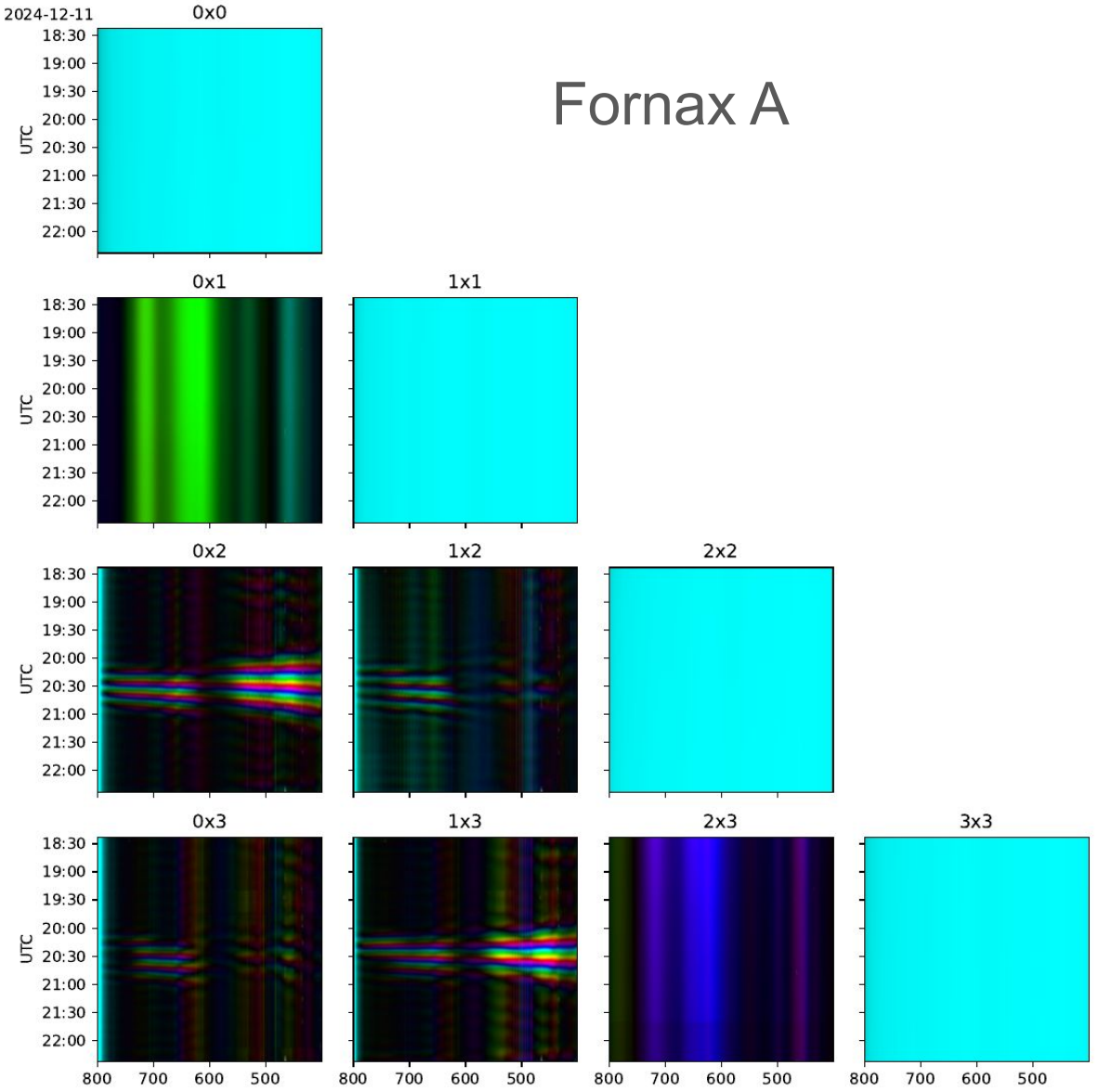
December 2024 - January 2025

- 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 / Outlook

- HIRAX is entering the stage of full production
- Critical to reach systematics targets for cosmology
  - Careful accounting of mechanical requirements on dish-feed system
  - Focus on the dish surface / primary beam
- First light achieved with two-element prototype in end of 2024
- Finalising the first monolithic dishes - Installation at Klerefontein in ~ 3 weeks
- Lots more to come in 2025!
  Goal: 32-element array at Swartfontein