ZTF Hardware Update

March 19, 2018

Richard Dekany

Caltech Optical Observatories
California Institute of Technology

Outline

- ZTF Observing System overview
- H/W commissioning activities
  - Filter exchanger commissioning – Porter, Feeney, Hale, Riddle
  - Science CCD optimization – Kaye, Greffe, Smith
  - Open-loop flexure mapping – Dekany, Graham, Masci
  - Robotic Observing System (ROS) commissioning – Riddle
  - Observational efficiency improvements – Kaye, Smith, Zolkower, Riddle
  - Linearity – Cunningham
  - Filter band leakage – Frederick
  - Star flats – van Sistine et al.
  - Astrometry – Ho
  - Ghost analysis – Cunningham, Cenko
  - and more…
- Remaining development activities
  - Filter Exchanger operational readiness review
  - Guide/Focus CCD and GF loop commissioning
  - Telescope maintainability / infrastructure improvements

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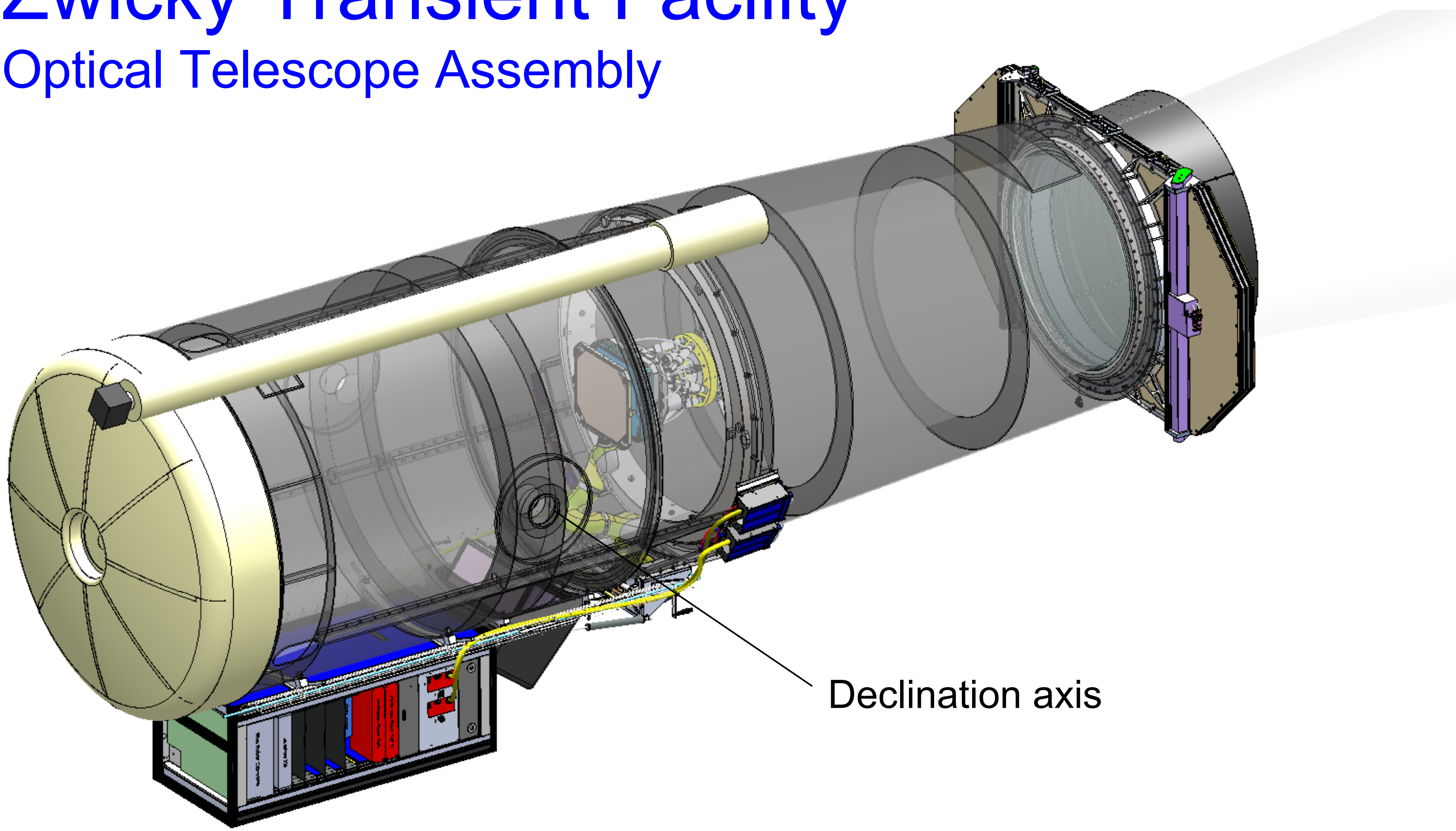
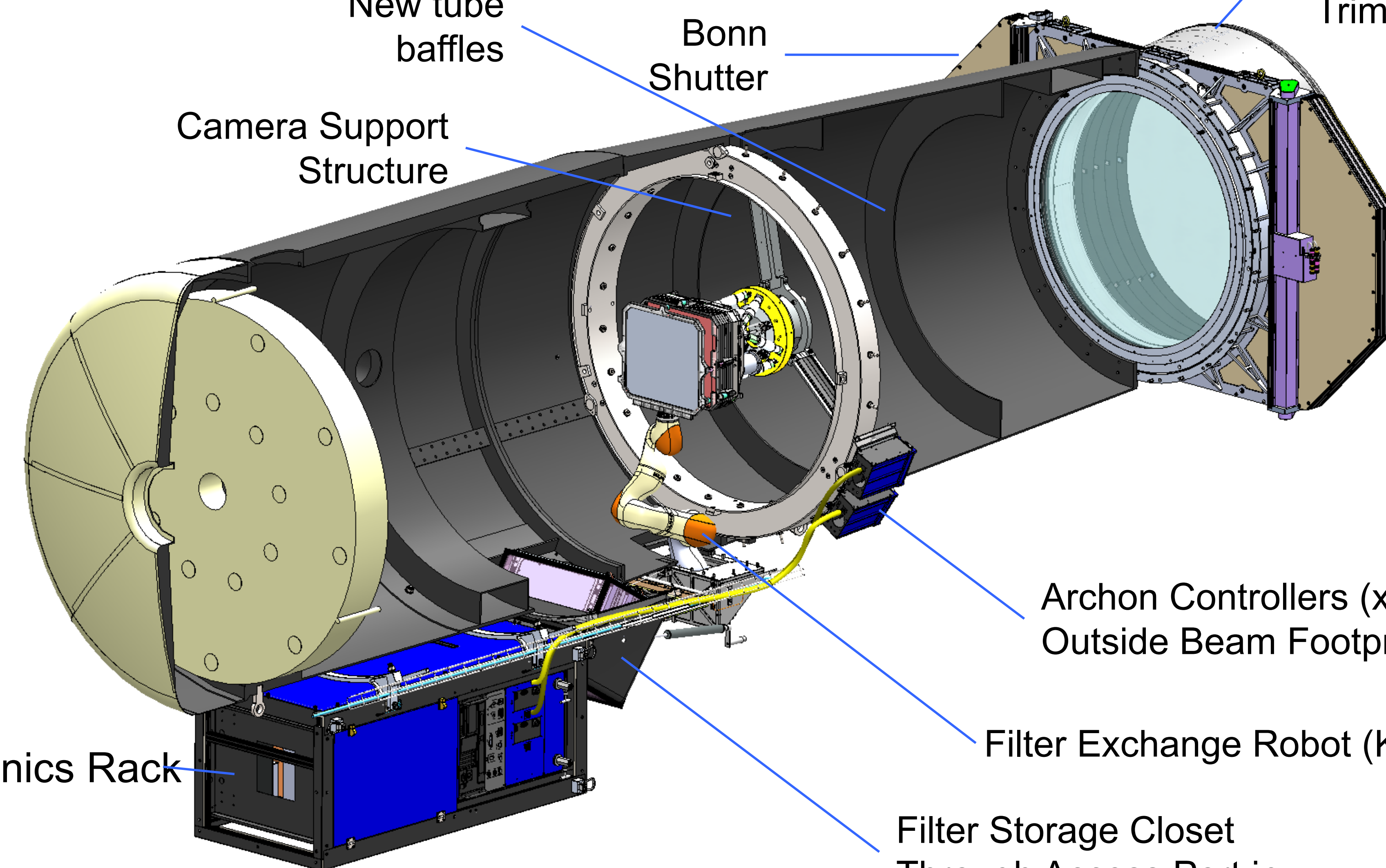
ZTF Observing System Overview

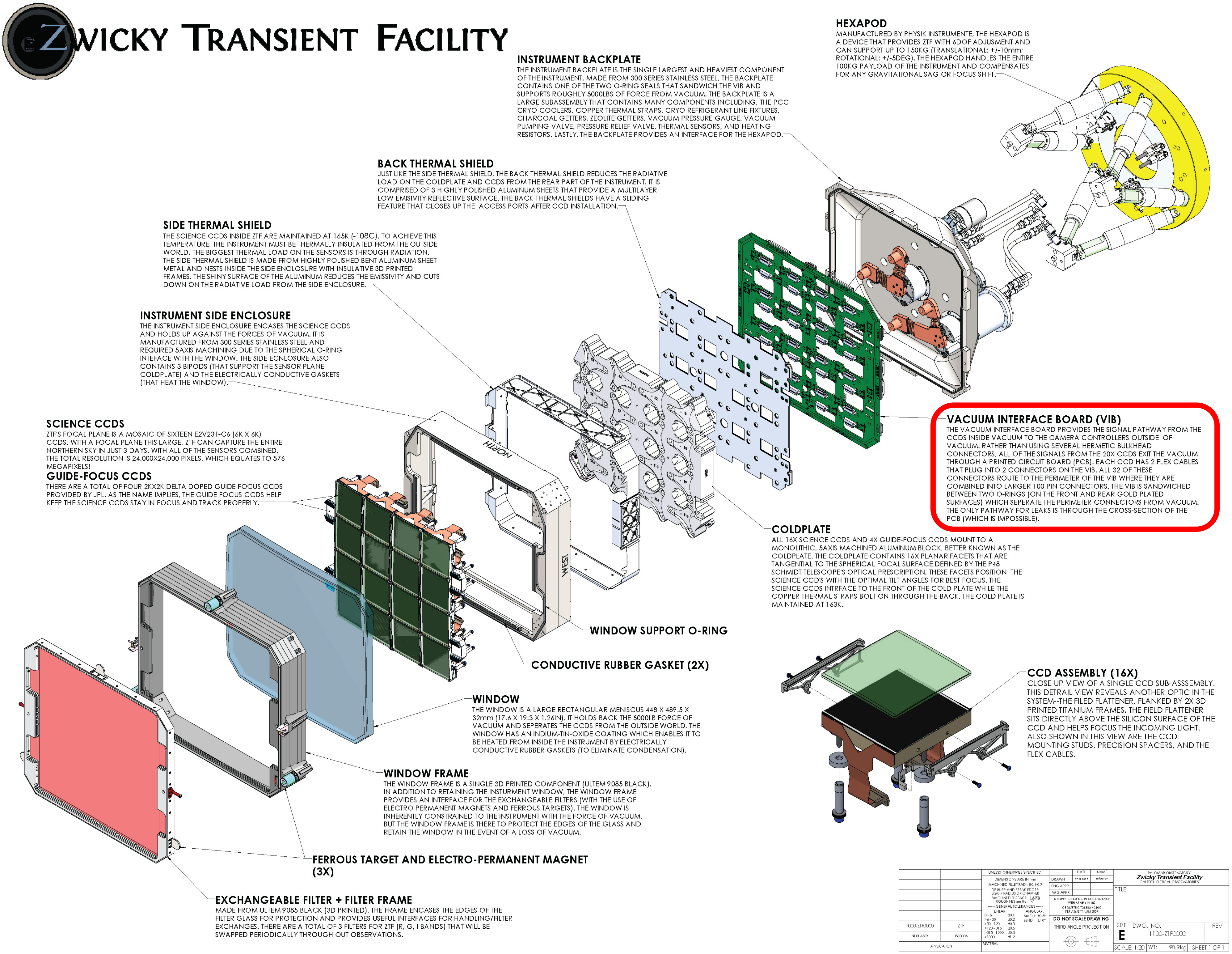
Zwicky Transient Facility

Optical Telescope Assembly

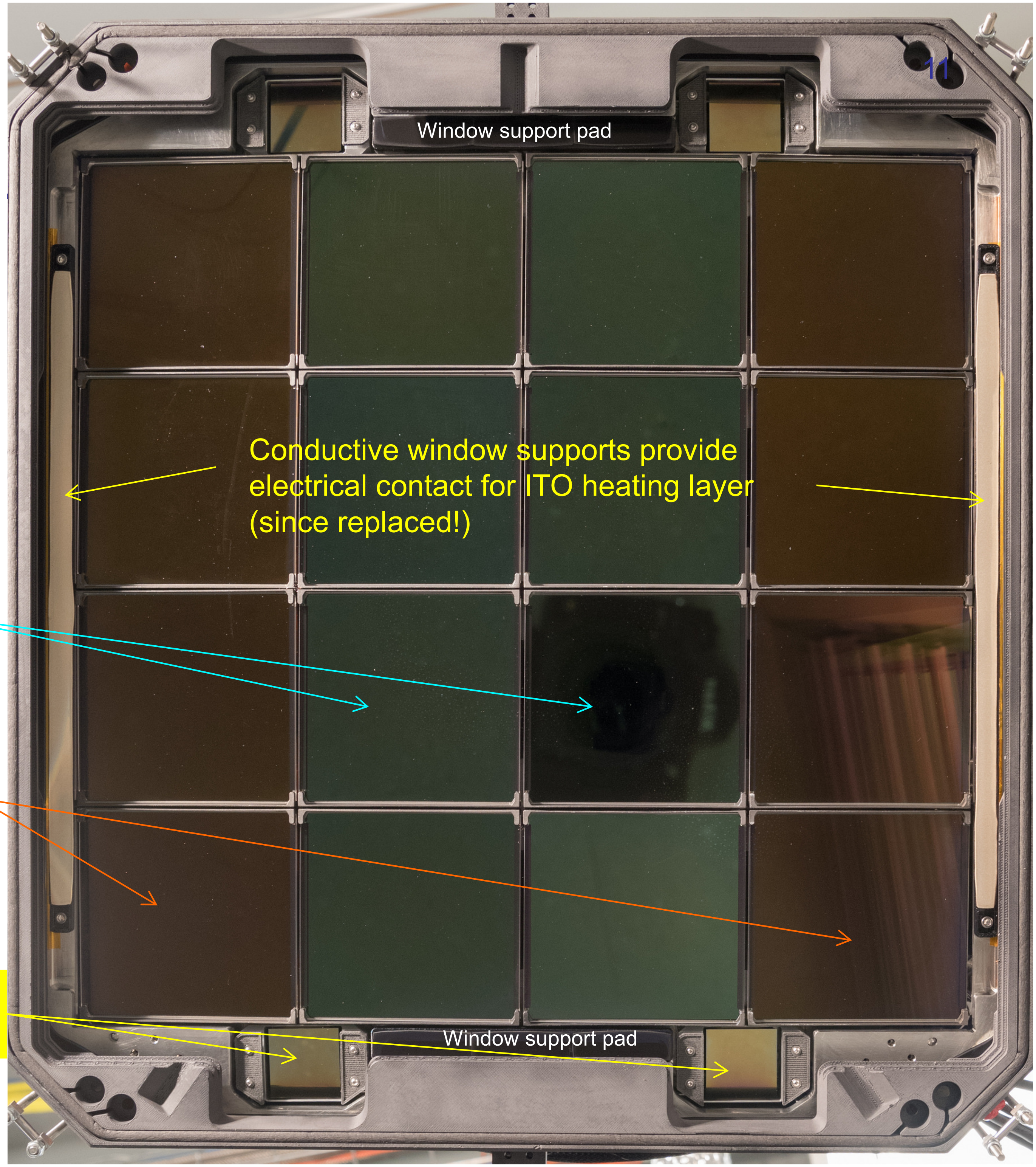


ZTF elements on the 48” Schmidt




ZWICKY TRANSIENT FACILITY
HEXAPOD
MANUFACTURED BY PHYSIK INSTRUMENTE, THE HEXAPOD IS A DEVICE THAT PROVIDES ZTF WITH 6DOF ADJUSMENT AND CAN SUPPORT UP TO 150KG (TRANSLATIONAL: +/-10mm; ROTATIONAL: +/-5DEG). THE HEXAPOD HANDLES THE ENTIRE 100KG PAYLOAD OF THE INSTRUMENT AND COMPENSATES FOR ANY GRAVITATIONAL SAG OR FOCUS SHIFT.
INSTRUMENT BACKPLATE
THE INSTRUMENT BACKPLATE IS THE SINGLE LARGEST AND HEAVIEST COMPONENT OF THE INSTRUMENT. MADE FROM 300 SERIES STAINLESS STEEL, THE BACKPLATE CONTAINS ONE OF THE TWO O-RING SEALS THAT SANDWICH THE VIB AND SUPPORTS ROUGHLY 5000LBS OF FORCE FROM VACUUM. THE BACKPLATE IS A LARGE SUBASSEMBLY THAT CONTAINS MANY COMPONENTS INCLUDING, THE PCC CRYO COOLERS, COPPER THERMAL STRAPS, CRYO REFRIGERANT LINE FIXTURES, CHARCOAL GETTERS, ZEOLITE GETTERS, VACUUM PRESSURE GAUGE, VACUUM PUMPING VALVE, PRESSURE RELIEF VALVE, THERMAL SENSORS, AND HEATING RESISTORS. LASTLY, THE BACKPLATE PROVIDES AN INTERFACE FOR THE HEXAPOD.
BACK THERMAL SHIELD
JUST LIKE THE SIDE THERMAL SHIELD, THE BACK THERMAL SHIELD REDUCES THE RADIATIVE LOAD ON THE COLDPLATE AND CCDS FROM THE REAR PART OF THE INSTRUMENT. IT IS COMPRISED OF 3 HIGHLY POLISHED ALUMINUM SHEETS THAT PROVIDE A MULTILAYER LOW EMISIVITY REFLECTIVE SURFACE. THE BACK THERMAL SHIELDS HAVE A SLIDING FEATURE THAT CLOSES UP THE ACCESS PORTS AFTER CCD INSTALLATION.
SIDE THERMAL SHIELD
THE SCIENCE CCDS INSIDE ZTF ARE MAINTAINED AT 165K (-108C). TO ACHIEVE THIS TEMPERATURE, THE INSTRUMENT MUST BE THERMALLY INSULATED FROM THE OUTSIDE WORLD. THE BIGGEST THERMAL LOAD ON THE SENSORS IS THROUGH RADIATION. THE SIDE THERMAL SHIELD IS MADE FROM HIGHLY POLISHED BENT ALUMINUM SHEET METAL AND NESTS INSIDE THE SIDE ENCLOSURE WITH INSULATIVE 3D PRINTED FRAMES. THE SHINY SURFACE OF THE ALUMINUM REDUCES THE EMISSIVITY AND CUTS DOWN ON THE RADIATIVE LOAD FROM THE SIDE ENCLOSURE.
INSTRUMENT SIDE ENCLOSURE
THE INSTRUMENT SIDE ENCLOSURE ENCASES THE SCIENCE CCDS AND HOLDS UP AGAINST THE FORCES OF VACUUM. IT IS MANUFACTURED FROM 300 SERIES STAINLESS STEEL AND REQUIRED 5AXIS MACHINING DUE TO THE SPHERICAL O-RING INTEFACE WITH THE WINDOW. THE SIDE ECNLOSURE ALSO CONTAINS 3 BIPODS (THAT SUPPORT THE SENSOR PLANE COLDPLATE) AND THE ELECTRICALLY CONDUCTIVE GASKETS (THAT HEAT THE WINDOW).
SCIENCE CCDS
ZTF'S FOCAL PLANE IS A MOSAIC OF SIXTEEN E2V231-C6 (6K X 6K) CCDS. WITH A FOCAL PLANE THIS LARGE, ZTF CAN CAPTURE THE ENTIRE NORTHERN SKY IN JUST 3 DAYS. WITH ALL OF THE SENSORS COMBINED, THE TOTAL RESOLUTION IS 24,000X24,000 PIXELS, WHICH EQUATES TO 576 MEGAPIXELS!
GUIDE-FOCUS CCDS
THERE ARE A TOTAL OF FOUR 2KX2K DELTA DOPED GUIDE FOCUS CCDS PROVIDED BY JPL. AS THE NAME IMPLIES, THE GUIDE FOCUS CCDS HELP KEEP THE SCIENCE CCDS STAY IN FOCUS AND TRACK PROPERLY.
NORTH
WEST
VACUUM INTERFACE BOARD (VIB)
THE VACUUM INTERFACE BOARD PROVIDES THE SIGNAL PATHWAY FROM THE CCDS INSIDE VACUUM TO THE CAMERA CONTROLLERS OUTSIDE OF VACUUM. RATHER THAN USING SEVERAL HERMETIC BULKHEAD CONNECTORS, ALL OF THE SIGNALS FROM THE 20X CCDS EXIT THE VACUUM THROUGH A PRINTED CIRCUIT BOARD (PCB). EACH CCD HAS 2 FLEX CABLES THAT PLUG INTO 2 CONNECTORS ON THE VIB. ALL 32 OF THESE CONNECTORS ROUTE TO THE PERIMETER OF THE VIB WHERE THEY ARE COMBINED INTO LARGER 100 PIN CONNECTORS. THE VIB IS SANDWICHED BETWEEN TWO O-RINGS (ON THE FRONT AND REAR GOLD PLATED SURFACES) WHICH SEPERATE THE PERIMETER CONNECTORS FROM VACUUM. THE ONLY PATHWAY FOR LEAKS IS THROUGH THE CROSS-SECTION OF THE PCB (WHICH IS IMPOSSIBLE).
COLDPLATE
ALL 16X SCIENCE CCDS AND 4X GUIDE-FOCUS CCDS MOUNT TO A MONOLITHIC, 5AXIS MACHINED ALUMINUM BLOCK, BETTER KNOWN AS THE COLDPLATE. THE COLDPLATE CONTAINS 16X PLANAR FACETS THAT ARE TANGENTIAL TO THE SPHERICAL FOCAL SURFACE DEFINED BY THE P48 SCHMIDT TELESCOPE'S OPTICAL PRESCRIPTION. THESE FACETS POSITION THE SCIENCE CCD'S WITH THE OPTIMAL TILT ANGLES FOR BEST FOCUS. THE SCIENCE CCDS INTRFACE TO THE FRONT OF THE COLD PLATE WHILE THE COPPER THERMAL STRAPS BOLT ON THROUGH THE BACK. THE COLD PLATE IS MAINTAINED AT 163K.
WINDOW SUPPORT O-RING
CONDUCTIVE RUBBER GASKET (2X)
WINDOW
THE WINDOW IS A LARGE RECTANGULAR MENISCUS 448 X 489.5 X 32mm (17.6 X 19.3 X 1.26IN). IT HOLDS BACK THE 5000LB FORCE OF VACUUM AND SEPERATES THE CCDS FROM THE OUTSIDE WORLD. THE WINDOW HAS AN INDIUM-TIN-OXIDE COATING WHICH ENABLES IT TO BE HEATED FROM INSIDE THE INSTRUMENT BY ELECTRICALLY CONDUCTIVE RUBBER GASKETS (TO ELIMINATE CONDENSATION).
CCD ASSEMBLY (16X)
CLOSE UP VIEW OF A SINGLE CCD SUB-ASSSEMBLY. THIS DETRAIL VIEW REVEALS ANOTHER OPTIC IN THE SYSTEM--THE FILED FLATTENER. FLANKED BY 2X 3D PRINTED TITANIUM FRAMES, THE FIELD FLATTENER SITS DIRECTLY ABOVE THE SILICON SURFACE OF THE CCD AND HELPS FOCUS THE INCOMING LIGHT. ALSO SHOWN IN THIS VIEW ARE THE CCD MOUNTING STUDS, PRECISION SPACERS, AND THE FLEX CABLES.
WINDOW FRAME
THE WINDOW FRAME IS A SINGLE 3D PRINTED COMPONENT (ULTEM 9085 BLACK). IN ADDITION TO RETAINING THE INSTURMENT WINDOW, THE WINDOW FRAME PROVIDES AN INTERFACE FOR THE EXCHANGEABLE FILTERS (WITH THE USE OF ELECTRO PERMANENT MAGNETS AND FERROUS TARGETS). THE WINDOW IS INHERENTLY CONSTRAINED TO THE INSTRUMENT WITH THE FORCE OF VACUUM, BUT THE WINDOW FRAME IS THERE TO PROTECT THE EDGES OF THE GLASS AND RETAIN THE WINDOW IN THE EVENT OF A LOSS OF VACUUM.
FERROUS TARGET AND ELECTRO-PERMANENT MAGNET (3X)
EXCHANGEABLE FILTER + FILTER FRAME
MADE FROM ULTEM 9085 BLACK (3D PRINTED), THE FRAME ENCASES THE EDGES OF THE FILTER GLASS FOR PROTECTION AND PROVIDES USEFUL INTERFACES FOR HANDLING/FILTER EXCHANGES. THERE ARE A TOTAL OF 3 FILTERS FOR ZTF (R, G, I BANDS) THAT WILL BE SWAPPED PERIODICALLY THROUGH OUT OBSERVATIONS.
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN mm
MACHINED FILLET RADII: R0.4-0.7
DE-BURR AND BREAK EDGES: 0.2-0.7 RADIUS OR CHAMFER
MACHINED SURFACE ROUGHNES μm Ra 1.6 0.8
------ GENERAL TOLERANCES ------
LINEAR: 0 - 6 ±0.1, >6 - 30 ±0.2, >30 - 120 ±0.3, >120 - 315 ±0.5, >315 - 1000 ±0.8, >1000 ±1.2
ANGULAR: MACH: ±0.5°, BEND: ±1.0°
DATE NAME
DRAWN 07.17.2017 mfeeney
ENG APPR.
MFG APPR.
INTERPRET DRAWING IN ACCORDANCE WITH ASME Y14.100
GEOMETRIC TOLERANCING PER ASME Y14.5M-2009
DO NOT SCALE DRAWING
THIRD ANGLE PROJECTION
1000-ZTF0000
ZTF
NEXT ASSY
USED ON
APPLICATION
MATERIAL
PALOMAR OBSERVATORY
Zwicky Transient Facility
CALTECH OPTICAL OBSERVATORIES
TITLE:
SIZE E
DWG. NO. 1100-ZTF0000
REV
SCALE: 1:20
WT: 98.9kg
SHEET 1 OF 1

ZTF focal plane

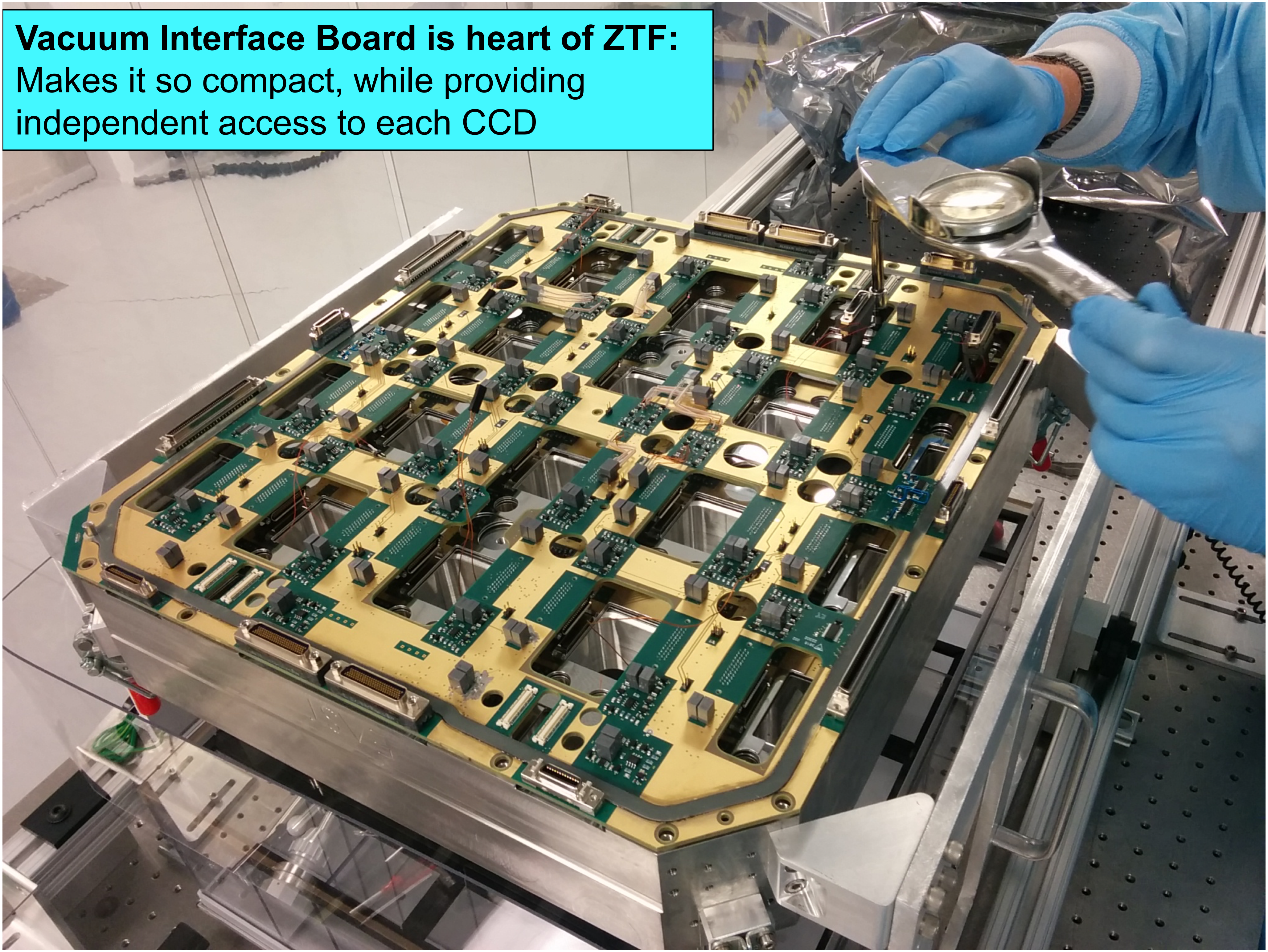


2 layer AR coating

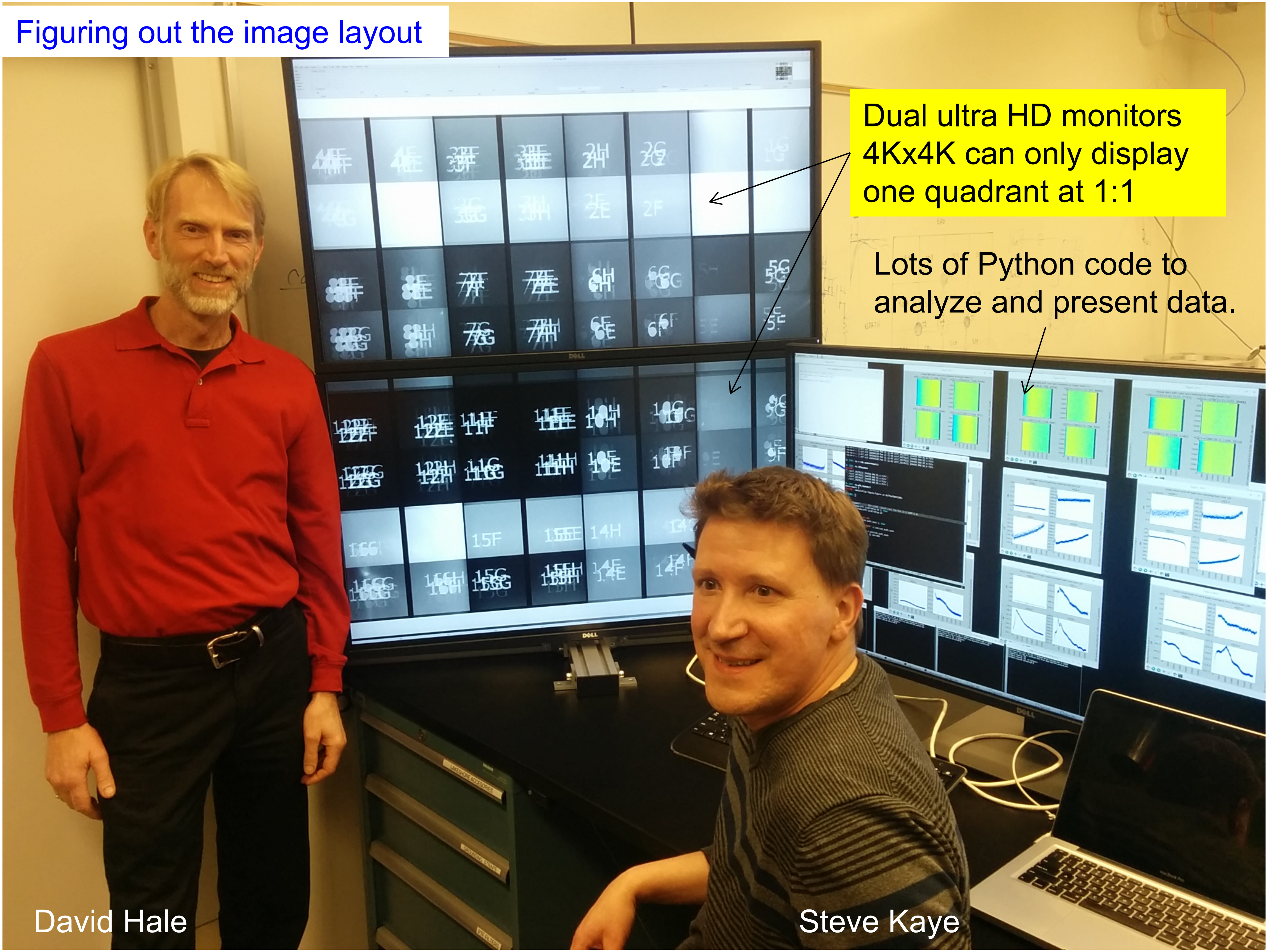
Single layer AR coating

Delta doped, multi-layer AR coating, fully depleted thick CCDs

Vacuum Interface Board is heart of ZTF:
Makes it so compact, while providing independent access to each CCD



Figuring out the image layout



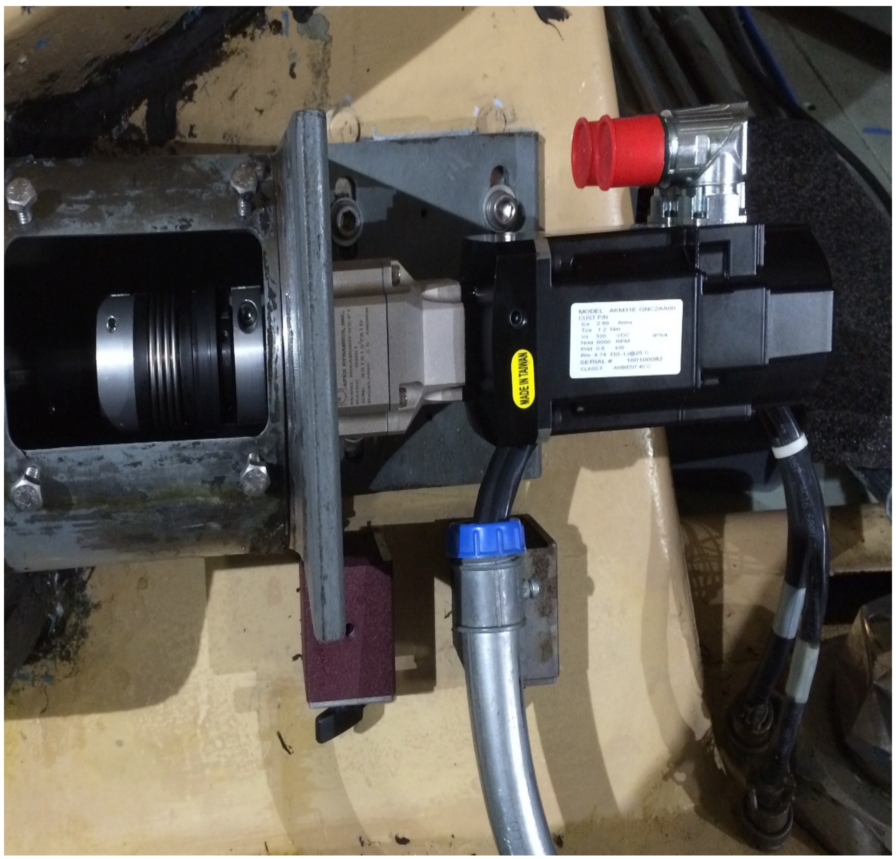
Observatory Facility Upgrades

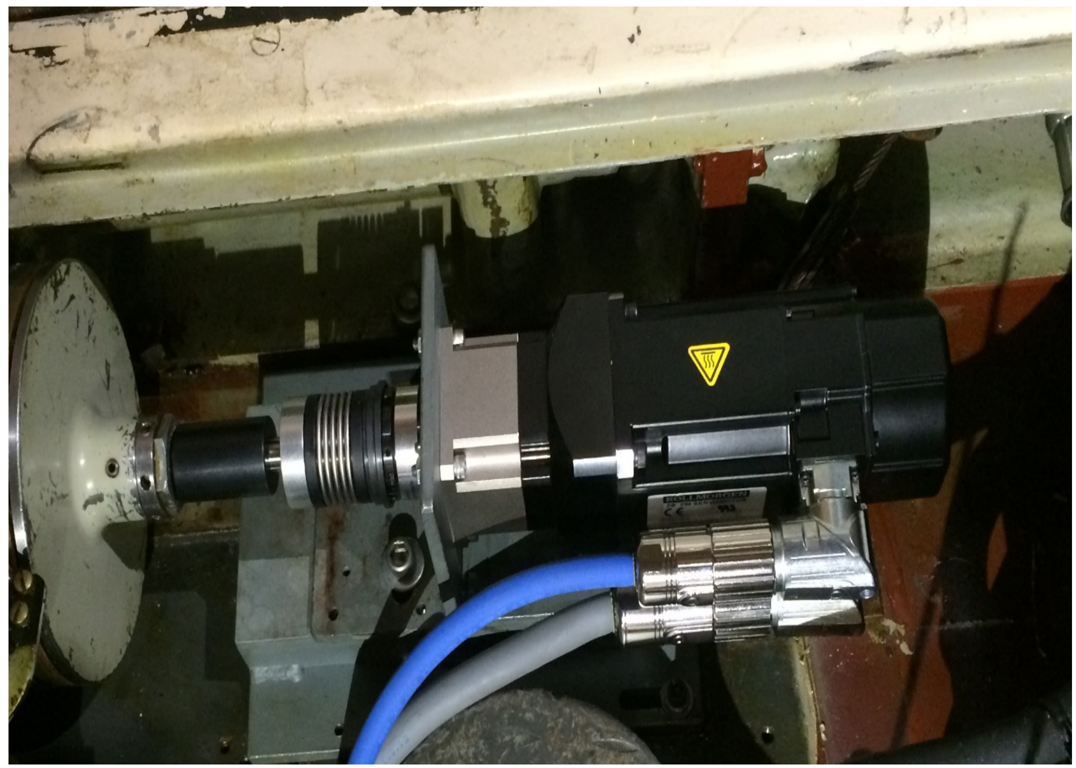
- ✓ **New telescope drives:** J. Zolkower, J. Henning, B. Baker
- ✓ **New Telescope Control Software:** J. Henning → ability to tune P48 motion.
- ✓ **New dome servo drive:** J. Zolkower, J. Henning, POMO staff
- ✓ **New trim plate lens:** Xu Chen (NIAOT), D. Reiley
- ✓ **New shutter and forward baffles:** Bonn Shutter, R. Smith, M. Feeney
- ✓ **New trim plate and corrector cells; cleaning infrastructure:** M. Feeney
- ✓ **New filter exchanger:** M. Porter, D. Hale, J. Belicki
- ✓ **New Flat Field Illuminator:** D. Hover, R. Smith
- ✓ **Electrical upgrades and equipment annex:** J. Zolkower, POMO staff
- ✓ **New high capacity dry air system:** J. Zolkower, POMO staff
- ✓ **New Robotic Observatory Software (ROS):** R. Riddle, J. Cromer

RA & Dec drive upgrades

Modern Variable Frequency drives provide flatter torque-speed curve: Acceleration up to: 0.5 deg/s^2

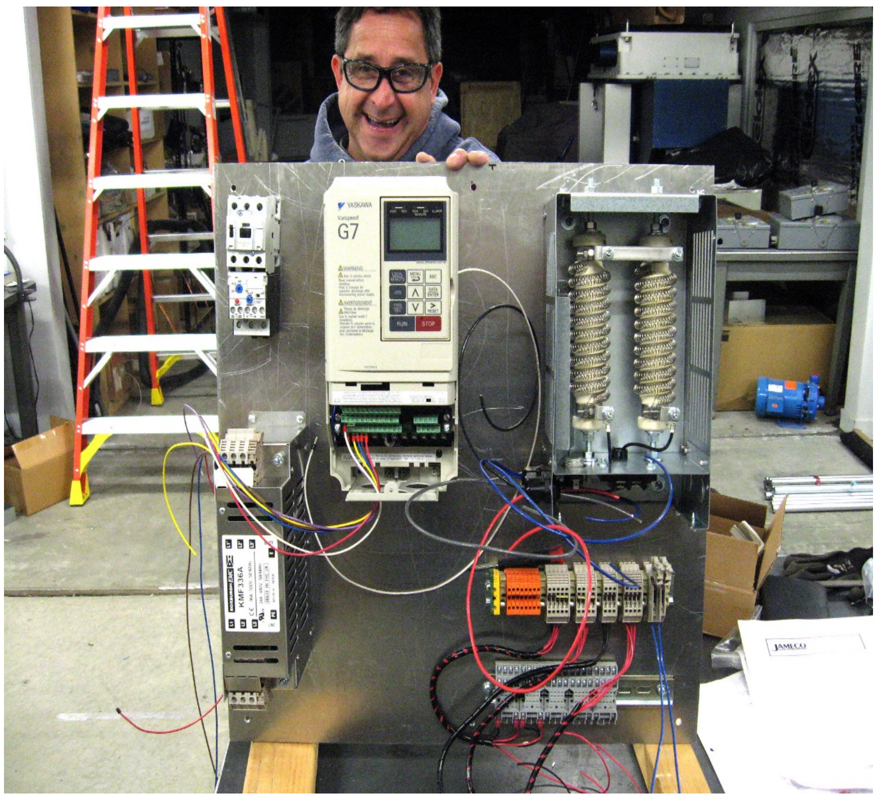
Top speed up to: 3 deg/s





Dome drive upgrade

New variable frequency controller
→ Increased acceleration and top speed (up to 5° /sec)
→ Dynamic braking
→ Optimal settling

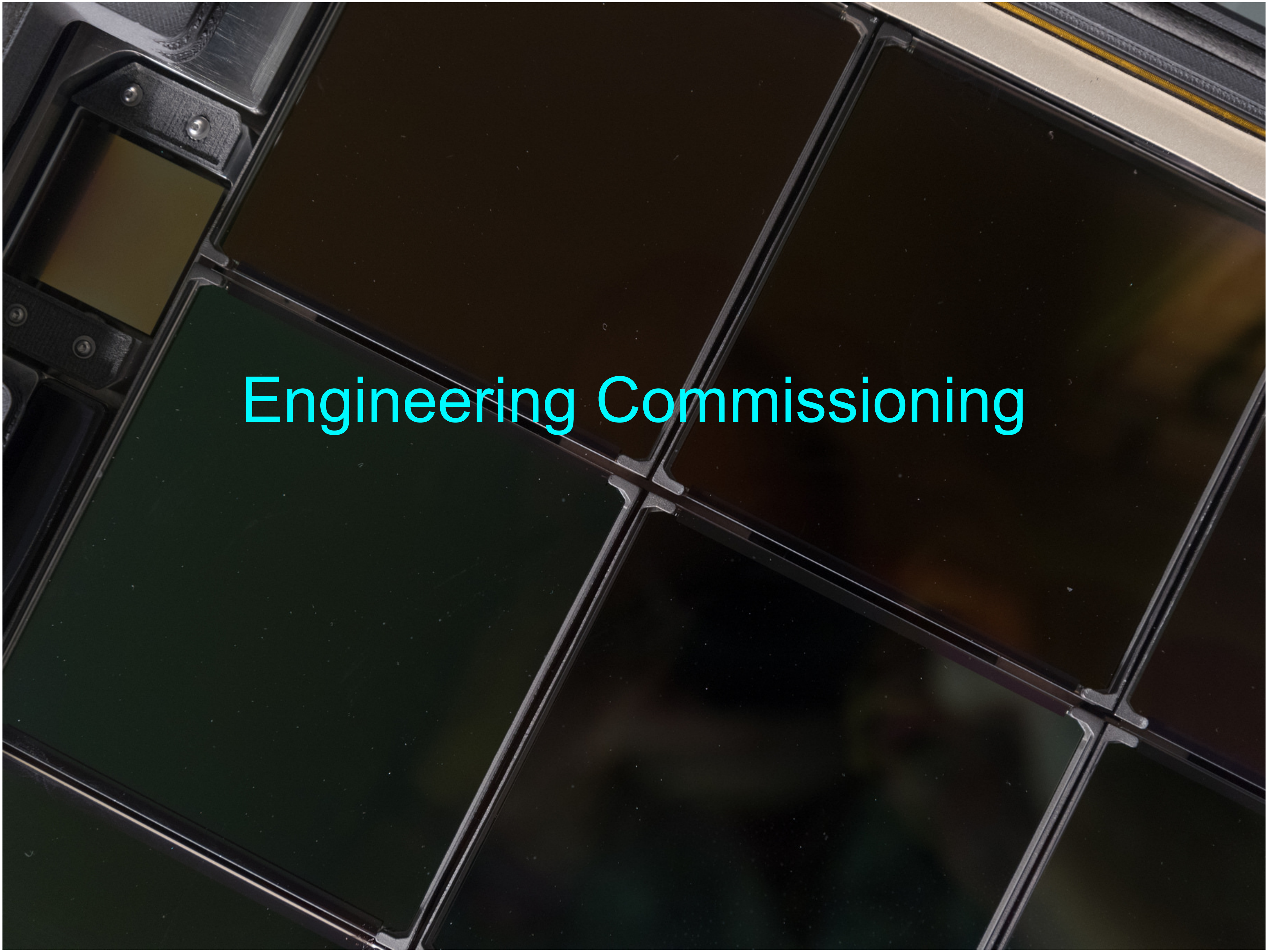


New dome drive motor/gearbox:
→ More powerful, 5 HP
→ Servo controlled to give flat torque vs. speed
→ New gearbox and tire

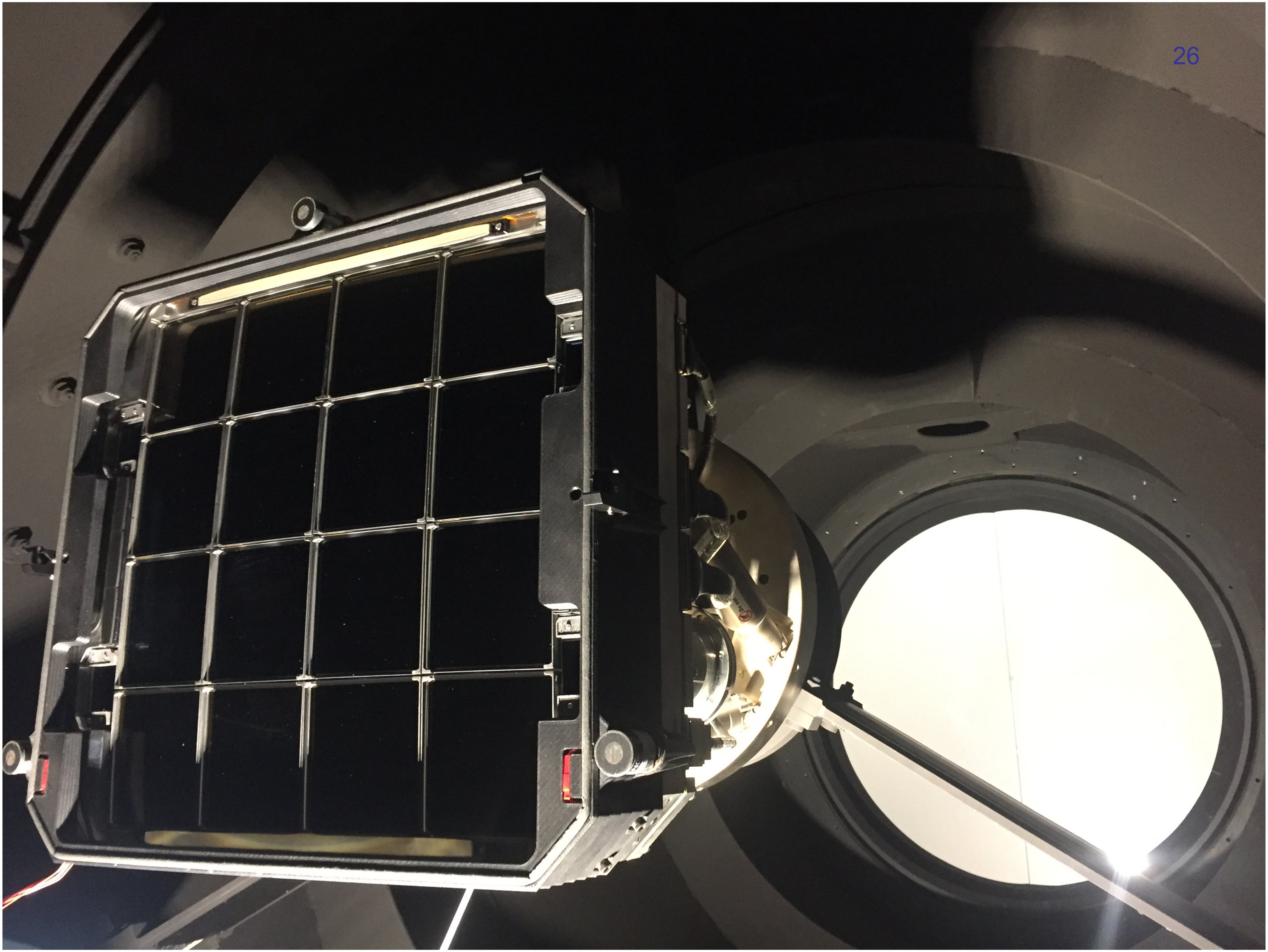
Observatory Facility Upgrades (cont.)

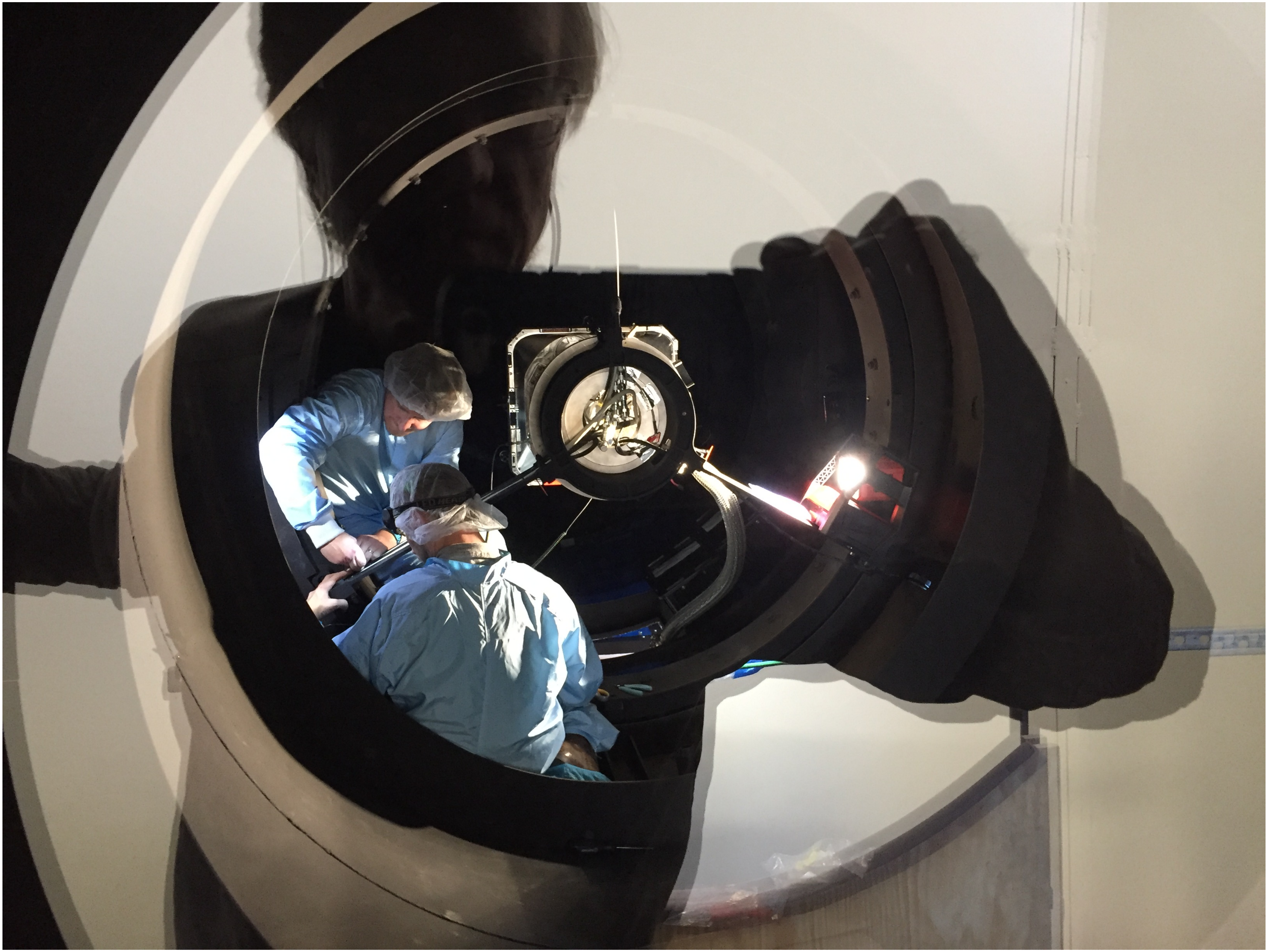
- ✓ **New lightning protection:** ground ring in trenches, etc., J. Zolkower
- ✓ **Improved building thermal management:** HVAC upgrades, J. Zolkower
- ✓ **Re-aluminized primary:** POMO staff
- ✓ **Mods to P48 steel tube:** POMO staff
- ✓ **New black paint inside tube:** Avain Black-S, 3% Lambertian reflectance
- ✓ **P48 data room upgrades:** POMO staff
- ✓ **Windscreen automation:** POMO staff
- ✓ **Removal of obsolete equipment from dome floor:** POMO staff
- ✓ **…and a punch-list of > 100 items more**


FLIR
~28.5°C

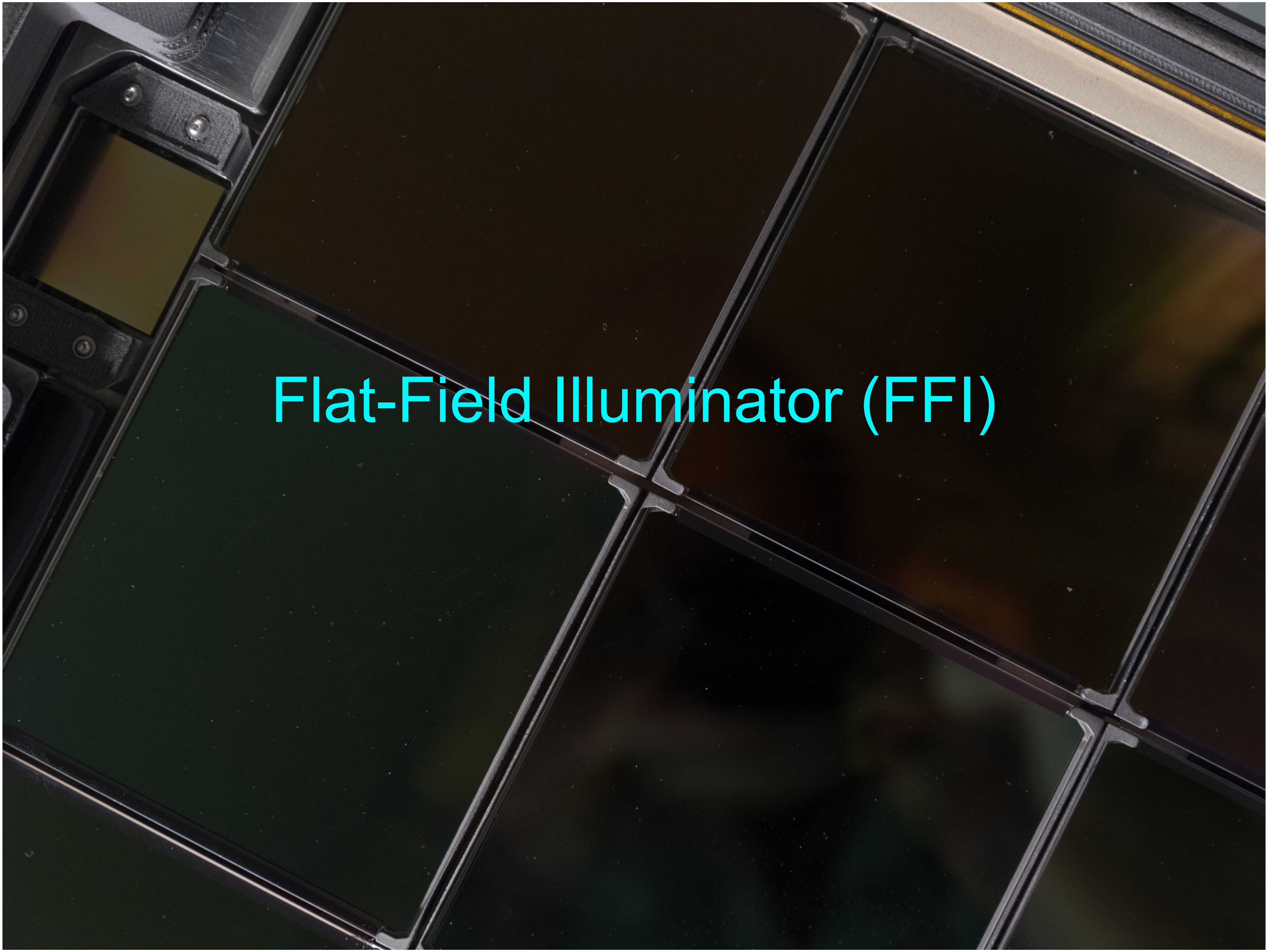

Engineering Commissioning


CAT
CATERPILLAR
Johnson Lift / HYSTER



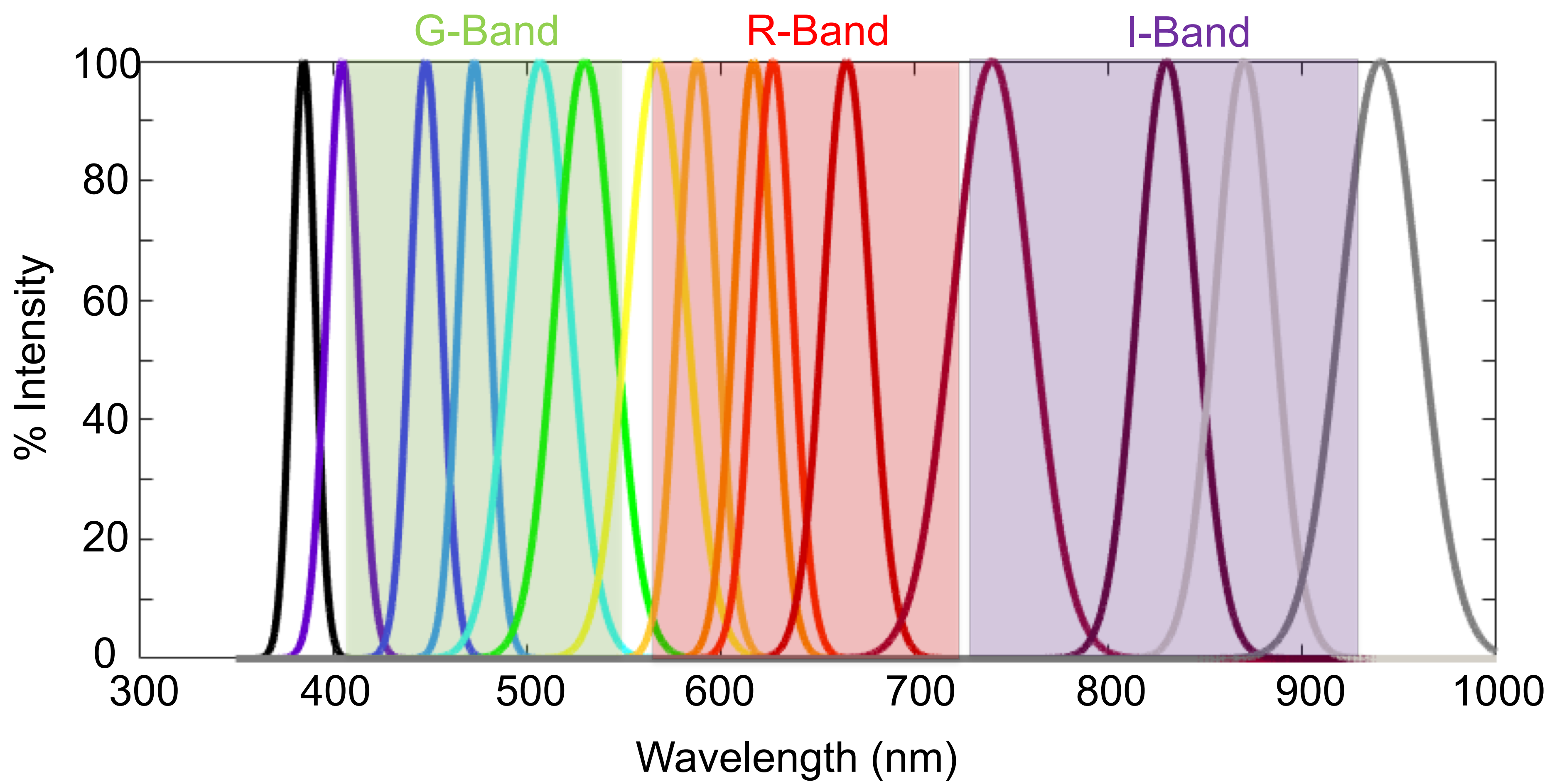



STOP
DO NOT ADJUST
ABC


Flat-Field Illuminator (FFI)

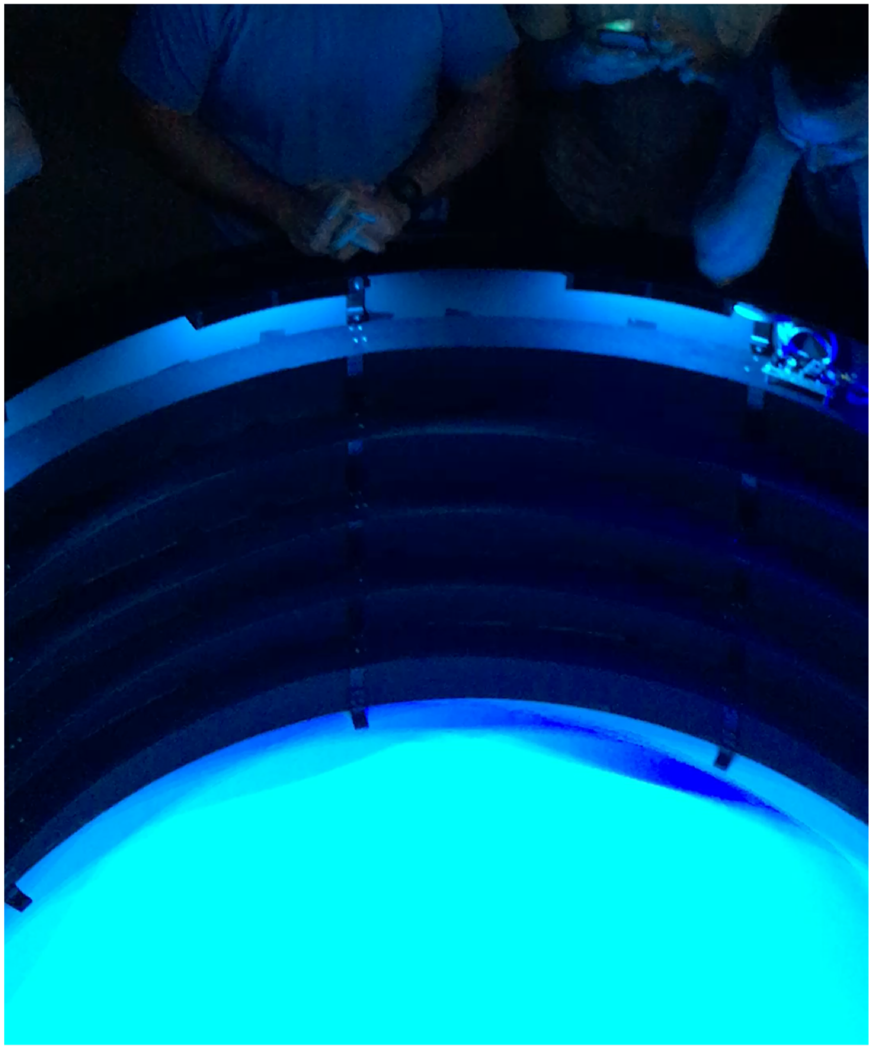

Flat Field Illuminator

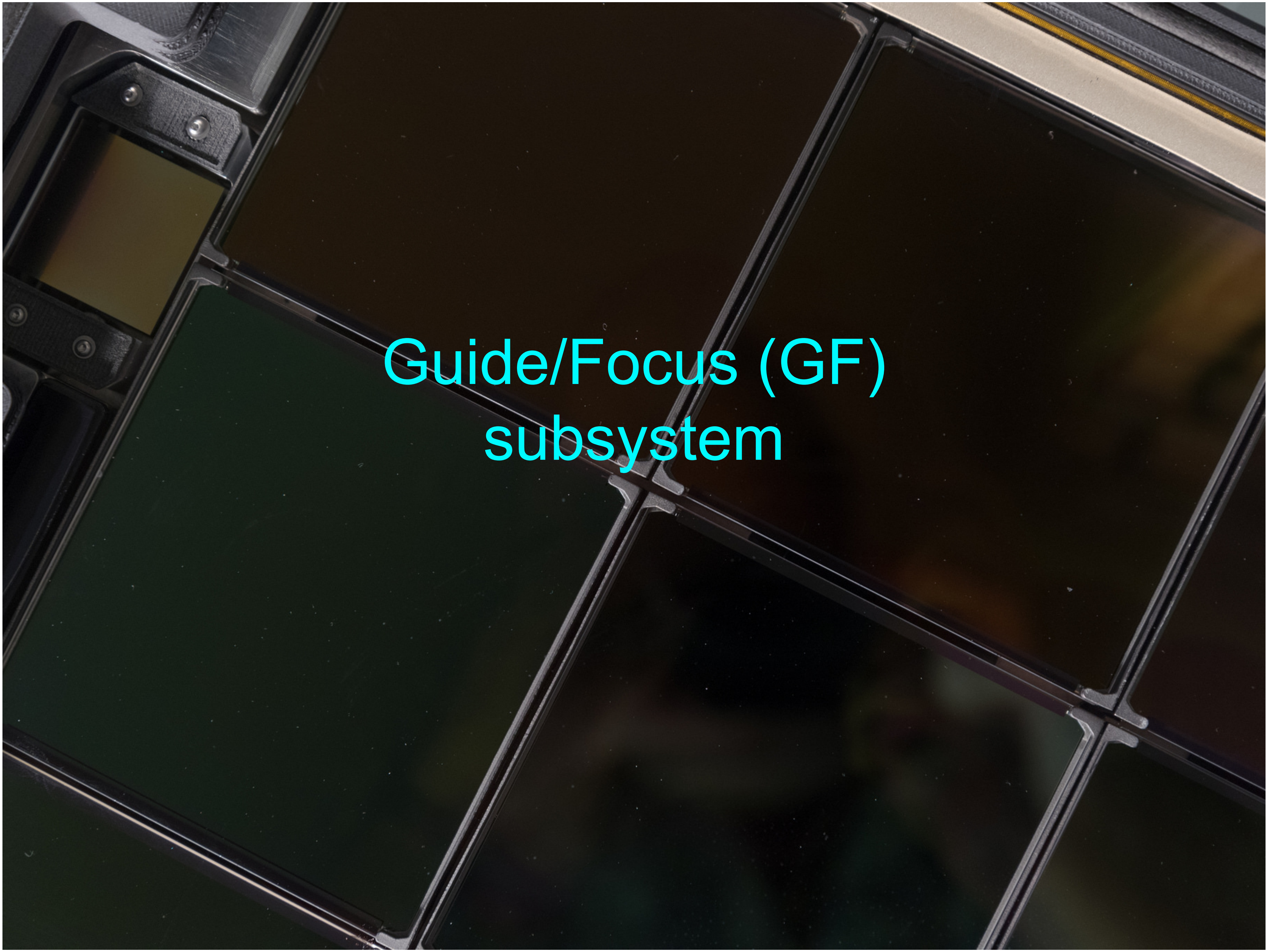
LED Wavelengths



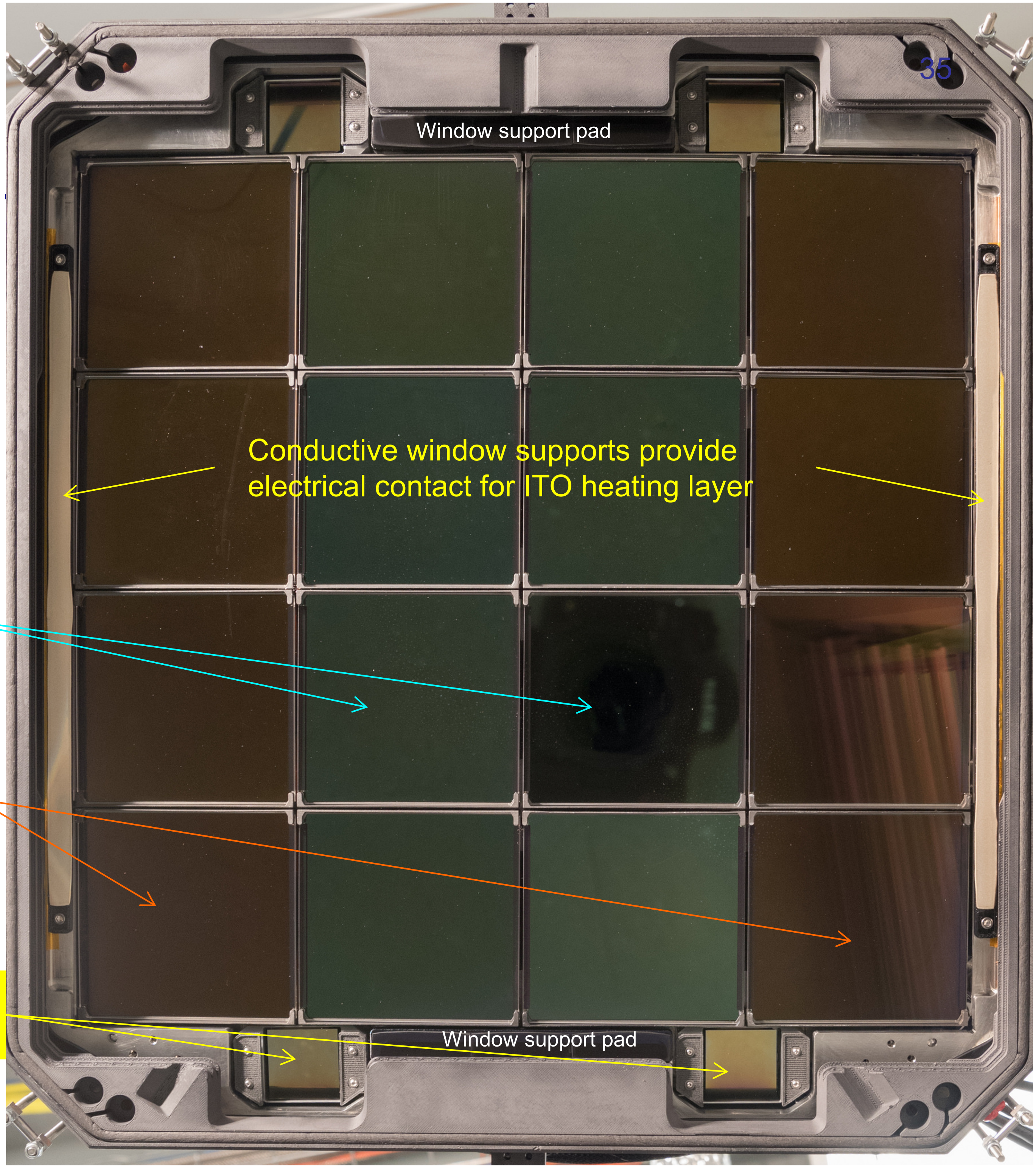
LED illumination test

- Laboratory evaluation of ZTF flat-field illuminator LEDs
  - LEDs mounted along the inside perimeter of the FFI baffle flash briefly in sequence
  - Verify
    - Custom control board functionality (D. Hover)
    - Illumination uniformity
    - Baffle shadowing




Guide/Focus (GF)
subsystem

ZTF focal plane



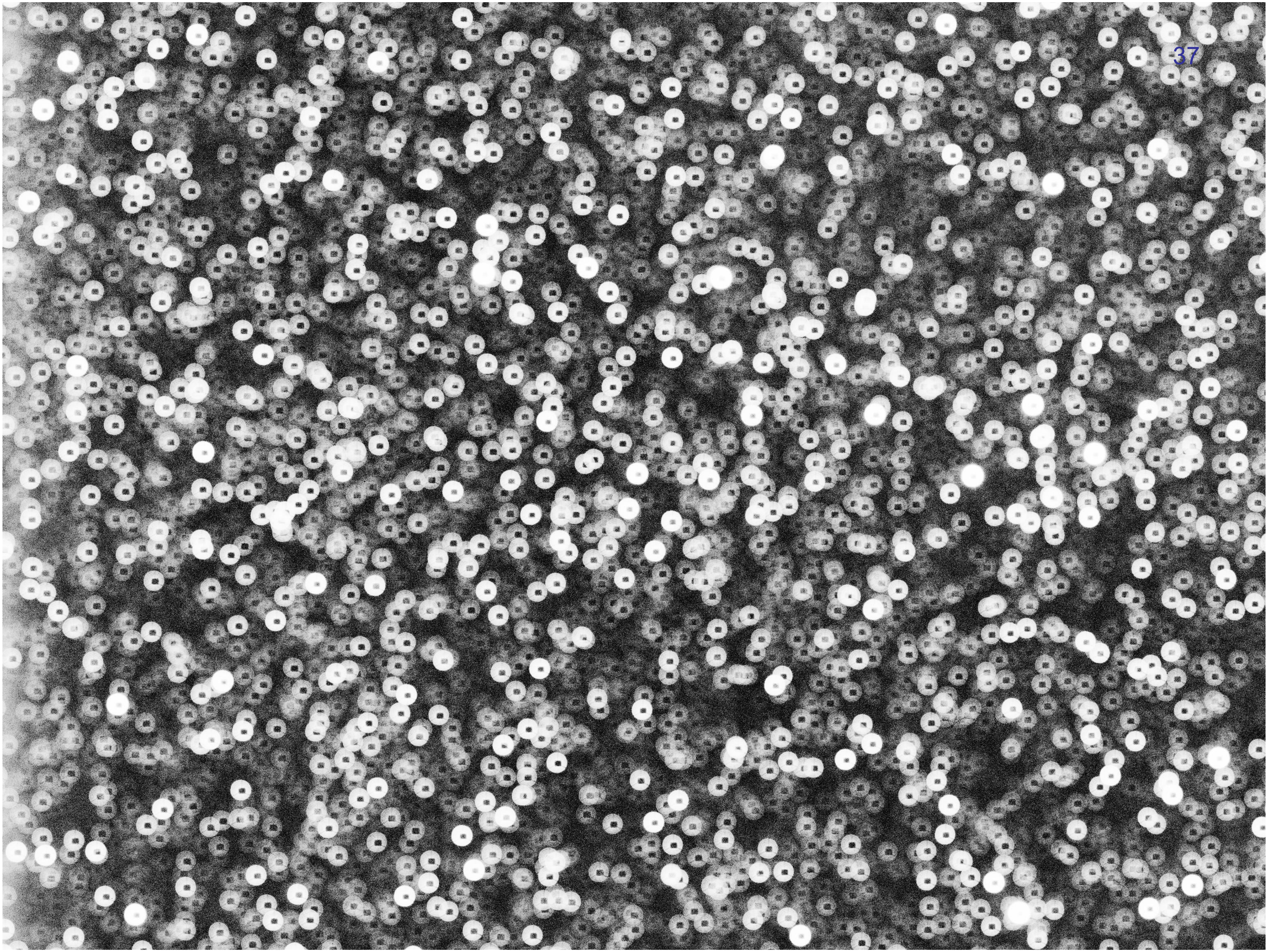
2 layer AR coating

Single layer AR coating

Delta doped, multi-layer AR coating, fully depleted thick CCDs

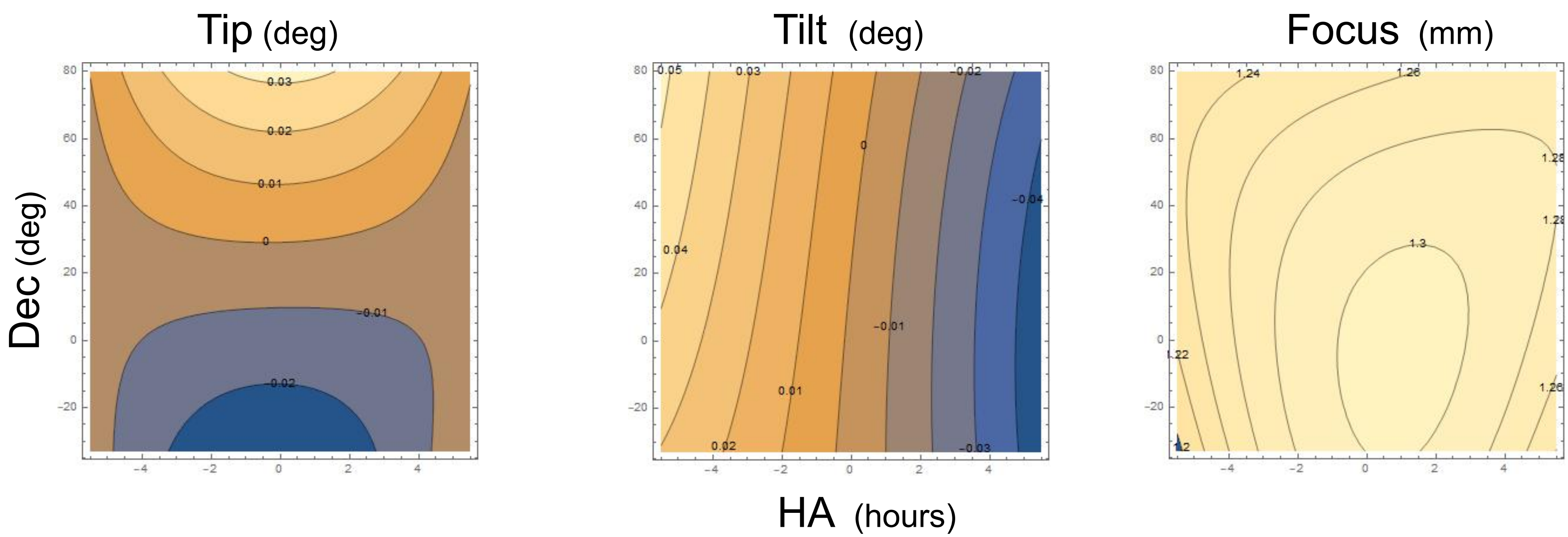
ZTF guide/focus subsystem

- The fast F/2.4 Schmidt focus makes ZTF susceptible to gravity- and thermally-induced flexure
  - Relative motions of ~ 30 microns induce measureable defocus
  - Foresight of this issue led to inclusion of 3+1 auxiliary CCDs within the ZTF camera cryostat
    - One guide CCD: to be read out every few seconds, provides signal to correct for ~ 3 mas/sec telescope tracking errors
    - Three out-of-focus CCDs: read out at science mosaic cadence to maintain tip, tilt, and focus optimization of science CCDs
  - ROS maintains open-loop model of system flexure for use during 1st science exposure following large telescope slew



ZTF open-loop flexure calibration

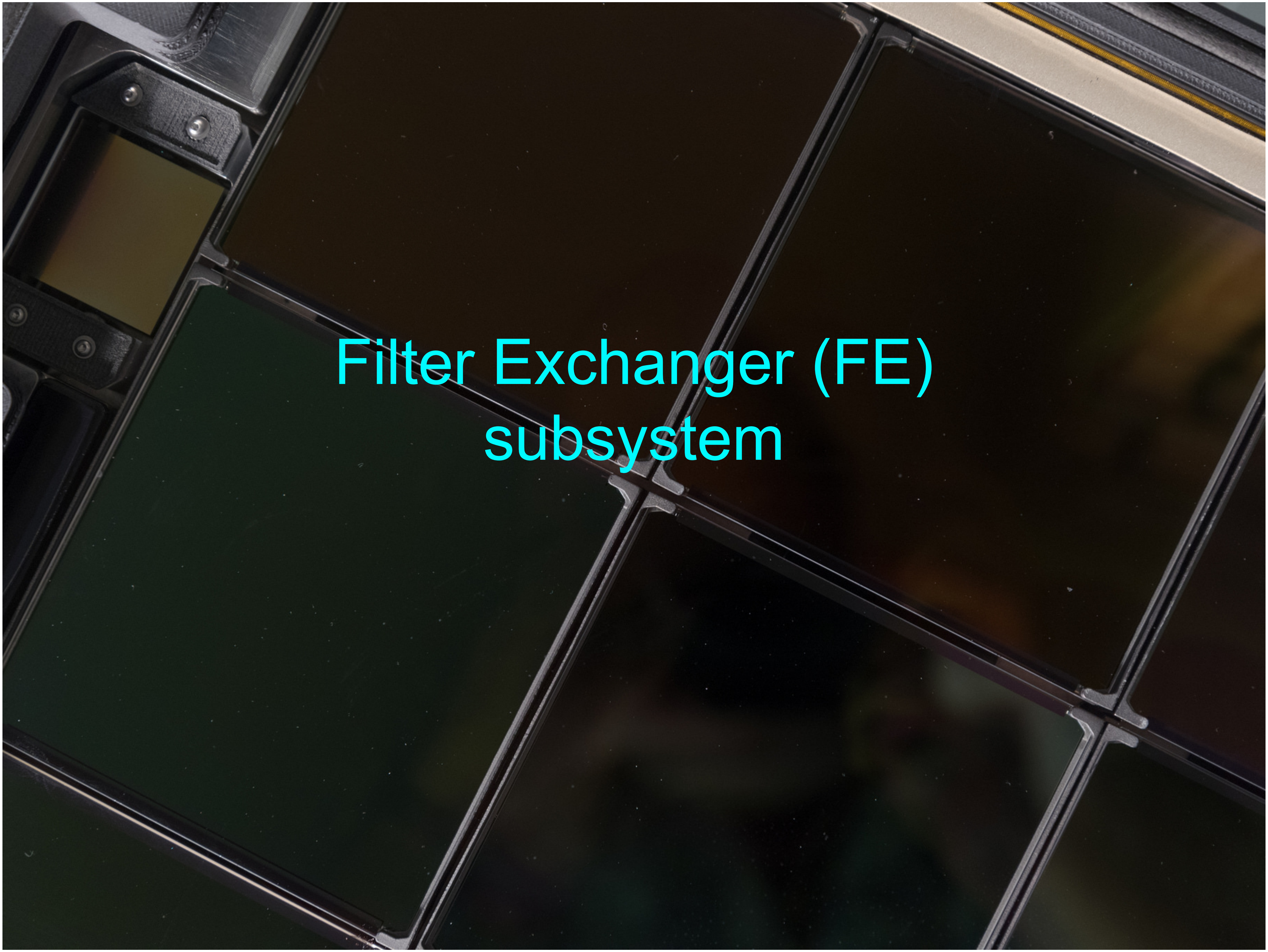
We measured camera flexure using out-of-focus images obtained across the entire sky (HA = (-5,5) hours; Dec = (-28, 78) deg)

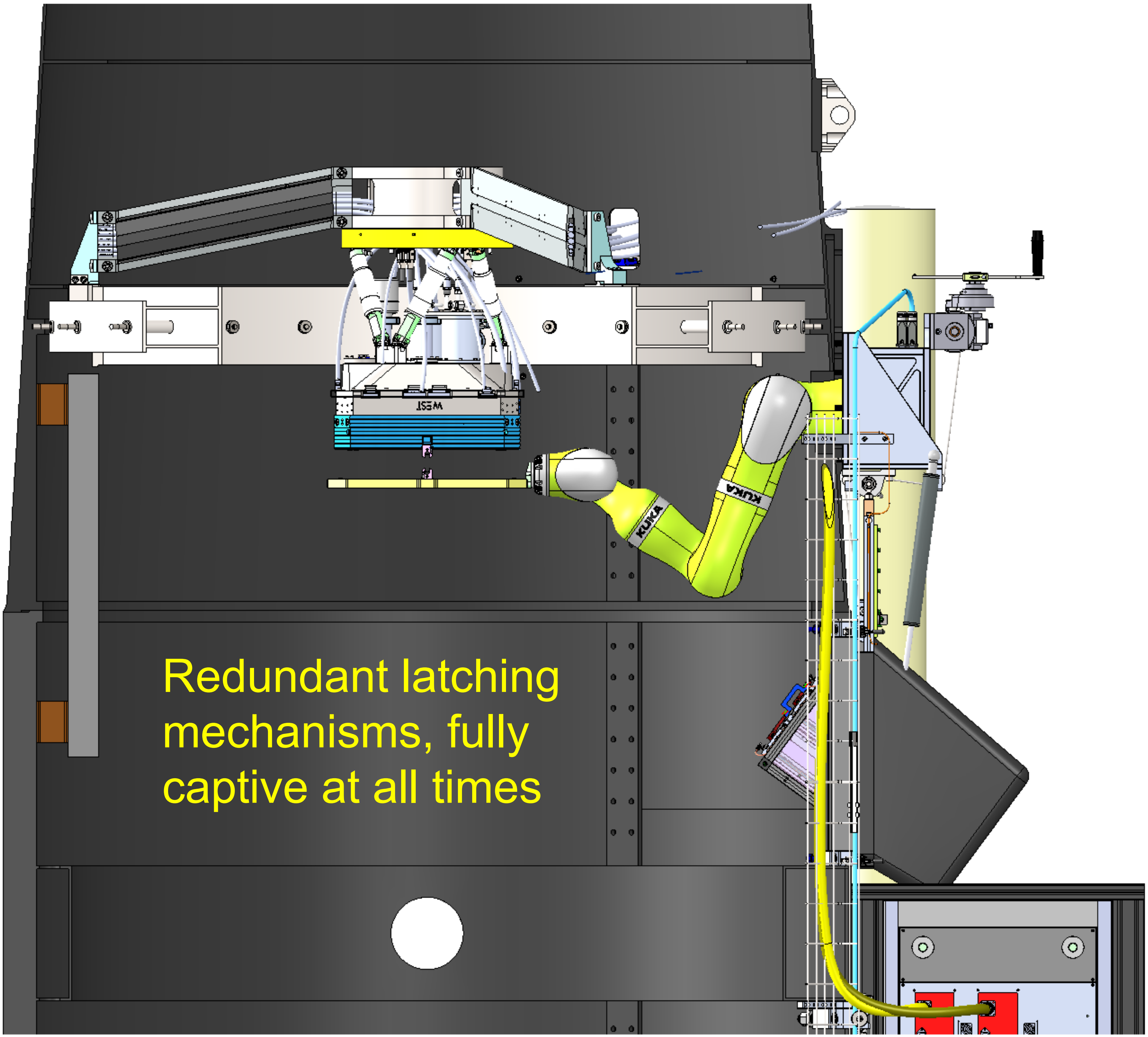


These models are polynomial fits to much noisier data and are generally good fits for zenith angles > 45 degrees.
At large airmass, flexure model has been troublesome and less repeatable.
Awaiting active guide/focus control to maintain active tip/tilt/focus…

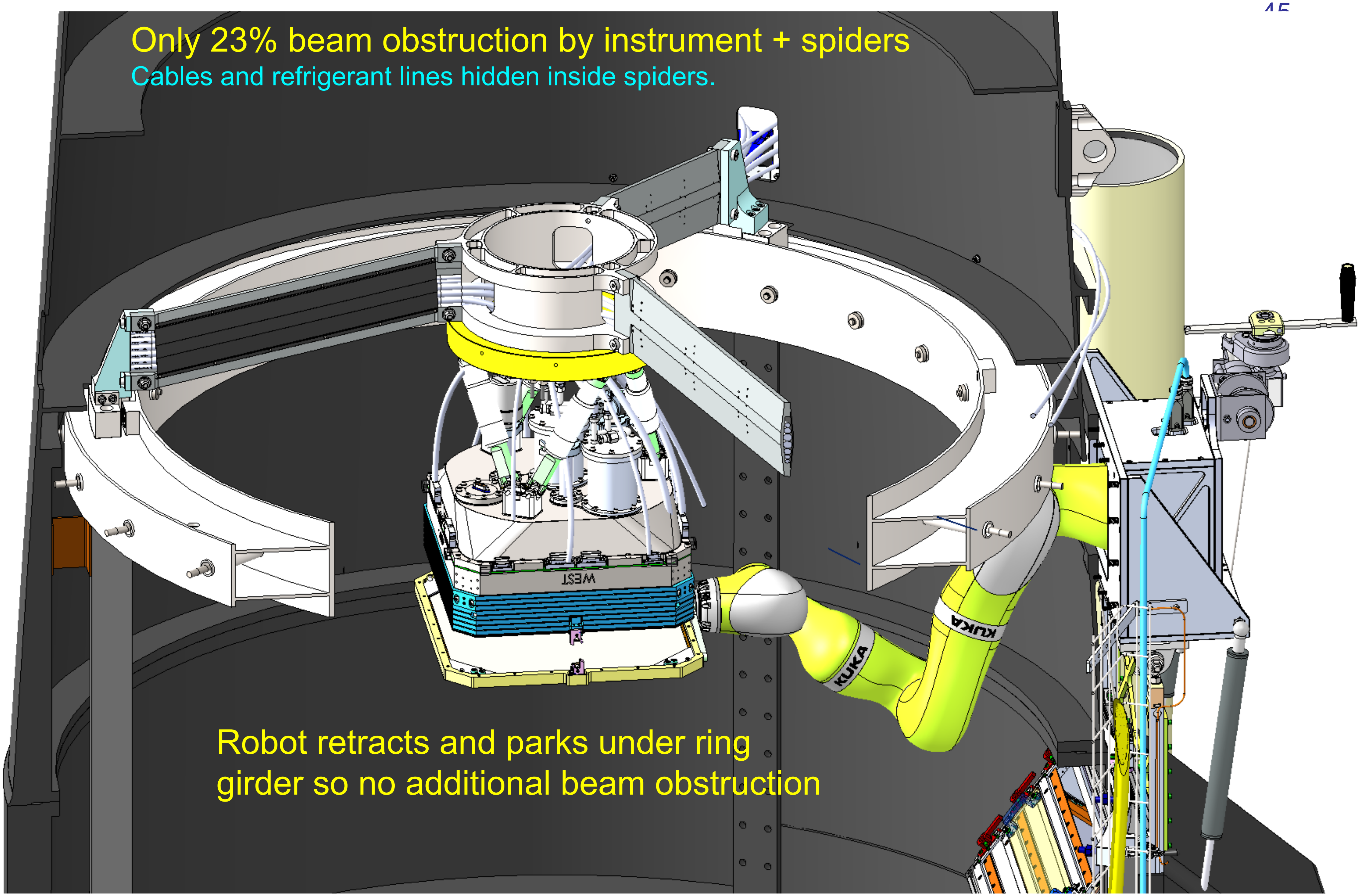
GF subsystem expected early April

- GF CCD readout is currently being integrated for synchronous operation
  - We’ve verified operation does not impact science mosaic
  - On-sky GF images obtained using engineering interface
  - Tip/tilt/focus calibration data expected shortly
  - Servo loop under development
  - ROS implementation under development
  - Expected roll-out in early April 2018 (bright/twilight time)


Filter Exchanger (FE)
subsystem

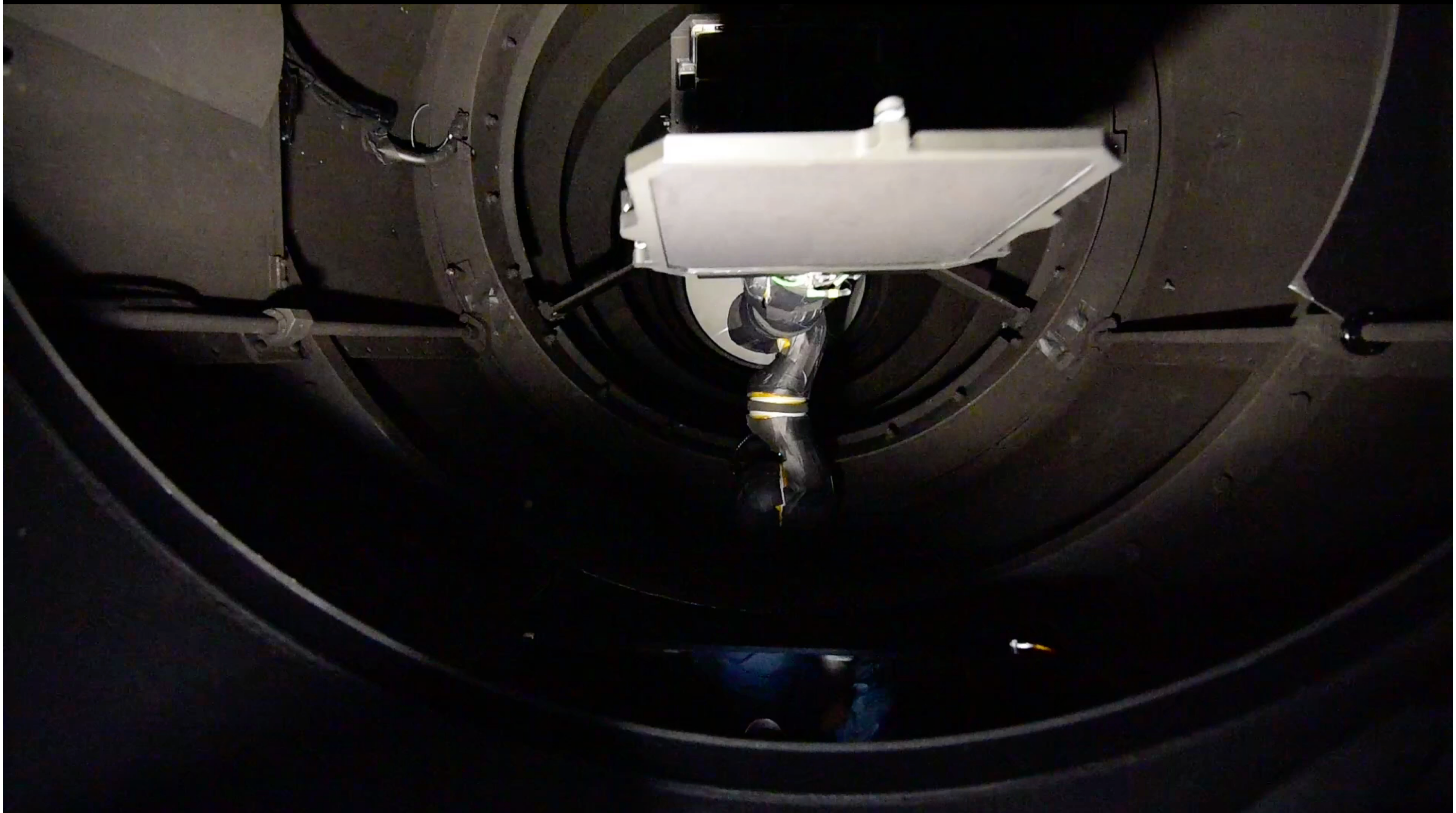


Redundant latching mechanisms, fully captive at all times
WEST
KUKA
KUKA


Only 23% beam obstruction by instrument + spiders
Cables and refrigerant lines hidden inside spiders.
KUKA
KUKA
Robot retracts and parks under ring
girder so no additional beam obstruction

FE expected by end of March

- Due to criticality of filter exchanger (FE) safety and reliability, we have been performing extensive testing
  - Upgraded filter frames from Delrin to metal for improved latch sensor performance
  - Installed insulation and heaters to overcome < 5C firmware operations limit
    - So far, thermal behavior has been excellent; no discernable impact on DIQ (so far)
- Recently demonstrated 300+ exchanges without FE subsystem fault of any kind
  - Behind this is hundreds of hours of testing, robotic fault handing software, and built-in KUKA robotic arm diagnostics
- FE Operational Readiness Review next week



The amaZing ZTF Team

Observing System - Caltech

- Roger Smith – Observing System Lead
  Richard Dekany – Project Manager
  Justin Belicki – Electronics
  John Cromer – Instrument Software
  Alex Delacroix – Cryo & FPA Mechanical
  Gina Duggan – FPA Metrology
  Michael Feeney – Cryo & P48 Mechanical
  David Hale – Camera & Filter Exchanger Software
  David Hover – FFI Electrical and System Design
  Steve Kaye – VIB & Detector Testing
  Peter Mao – Detector Test Automation
  Jennifer Milburn – Autoguider Software
  Patrick Murphy – Electronics & Cryo
  Reston Nash – Exchanger Mechanical
  Michael Porter – Filter Exchanger Lead
  Dan Reiley – Optics Lead
  Reed Riddle – Software Lead
  Hector Rodriguez – Integration and Test
  James Wincentsen – ZTF Documentation

  Jeff Zolkower – P48 Chief Engineer
  Bruce Baker – P48 Supervisor
  Tom Barlow – P48 Operations
  Rick Burruss – P48 Site Supervisor
  Jamey Eriksen – P48 Operations
  John Henning – P48 TCS
  Dan McKenna – P48 Telescope Engineering
  Victor Tapia – P48 Engineering
  Richard Walters – P48 Operations

Observing System – DESY/Bonn

- Klaus Reif – Shutter Lead
  Philipp Mueller – Systems Engineering
  Martin Polder - Mechanical

Data System

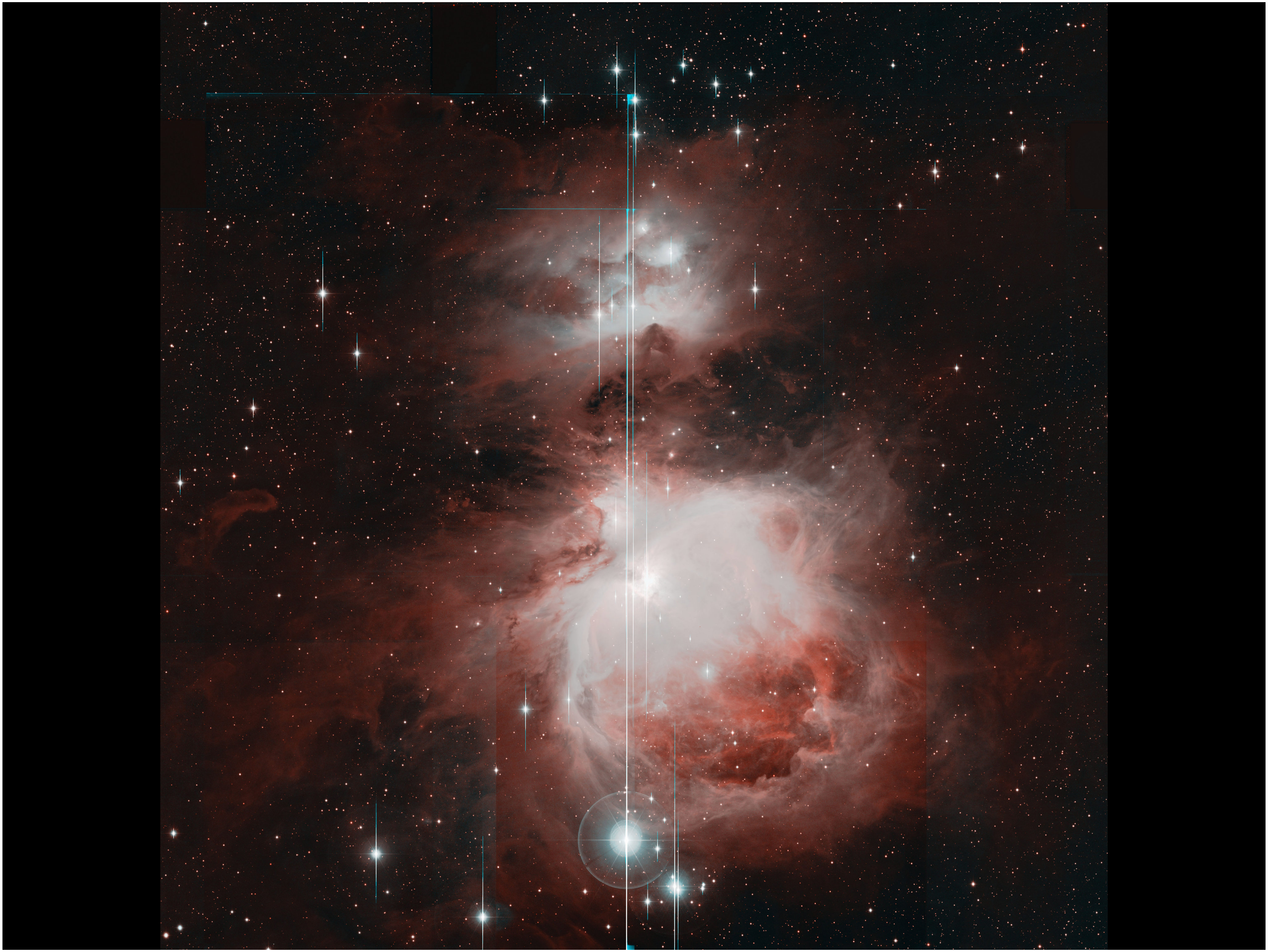
- Frank Masci – Data System Lead
  Ron Beck – Pipeline Operations
  Lee Bennett – Systems Engineering
  Imel David – IPAC Manager
  Steve Groom – Archive Architect
  George Helou – IPAC Director
  Ed Jackson – Database Mngt
  Russ Laher – Pipeline Infrastructure; Ingest; Test
  Ben Rusholme – Data xfre; Pipeline; Config. Mngt
  David Shupe – Source Matching; Astrometry
  Jason Surace – Image Simulation; Data Analysis
  Lin Yan – Marshal Planning & Summer School

Commissioning

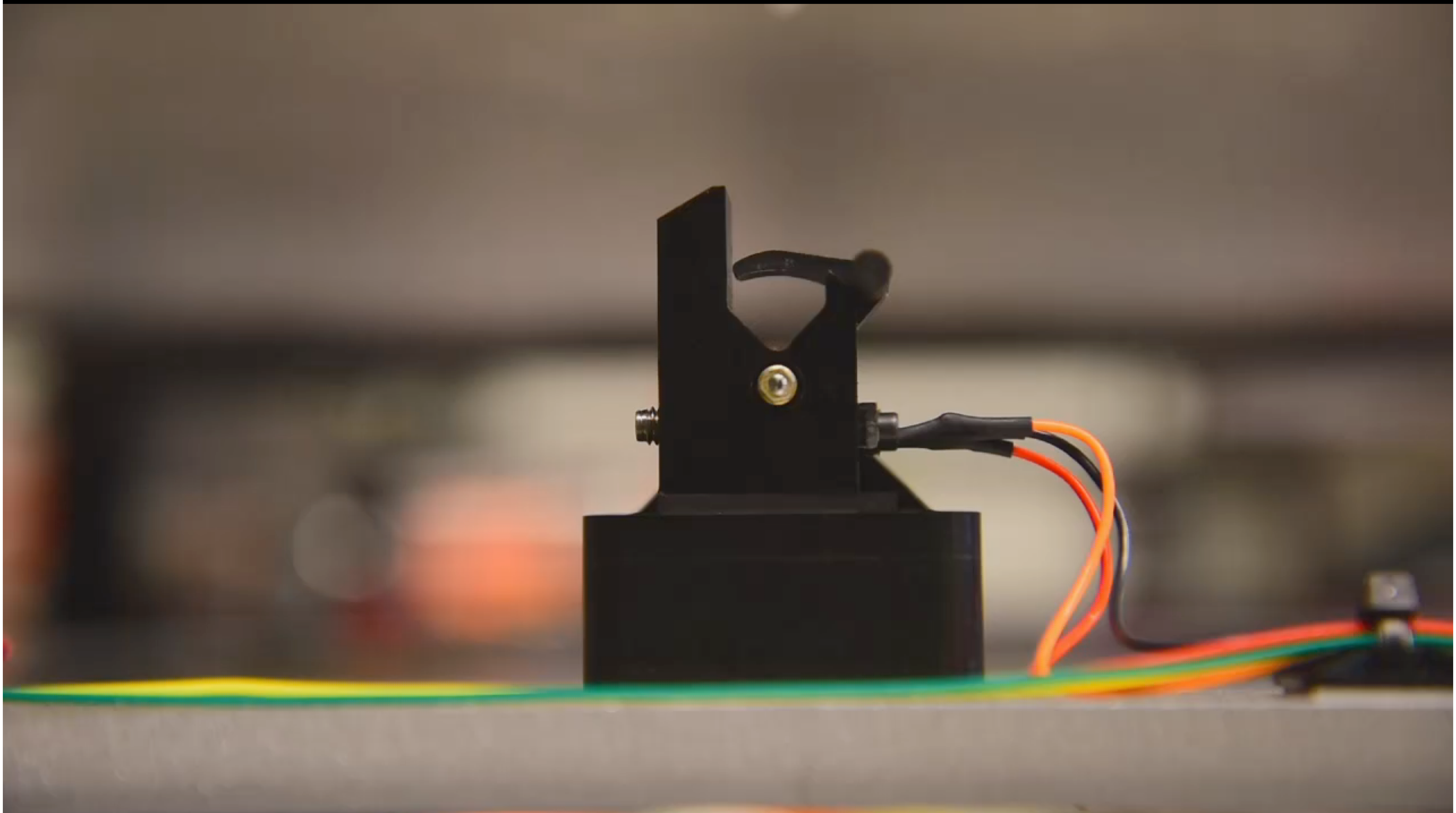
- Angie van Sistine, Thomas Kupfer, Ginny Cunningham, Brad Cenko, Kishalay De, Jakob Nordin, and a rapidly growing list of many, many people in this room…

THANK YOU!

Shri Kulkarni, Principal Investigator; Matthew Graham, Project Scientist; Eric Bellm, Survey Scientist

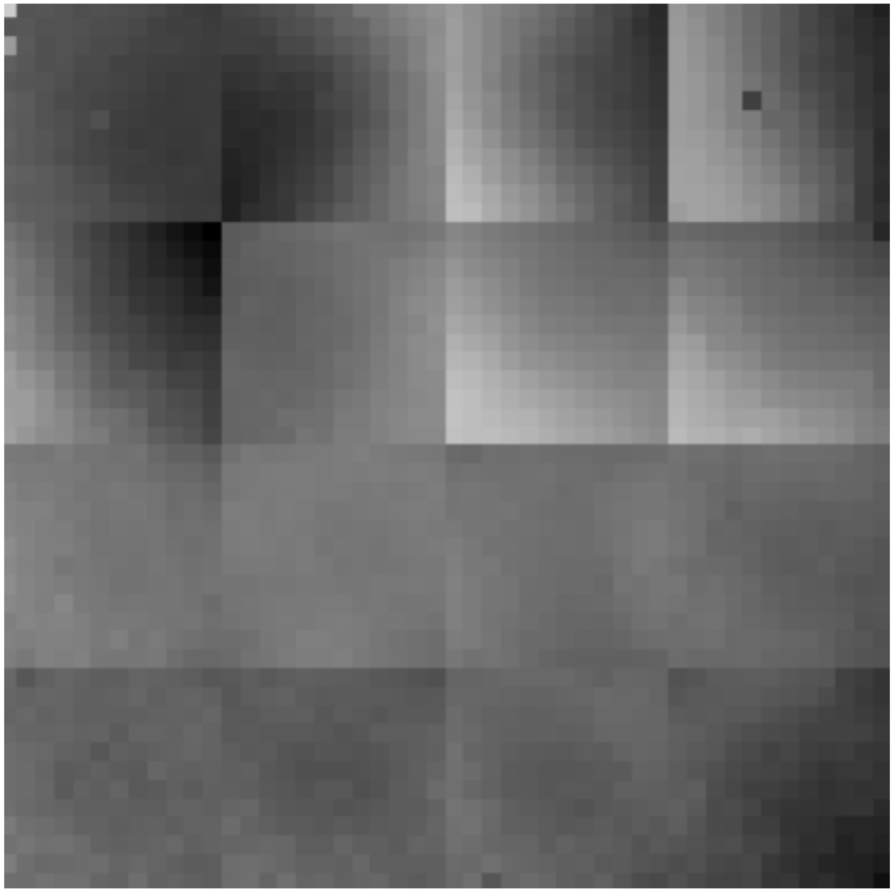


BACKUP SLIDES

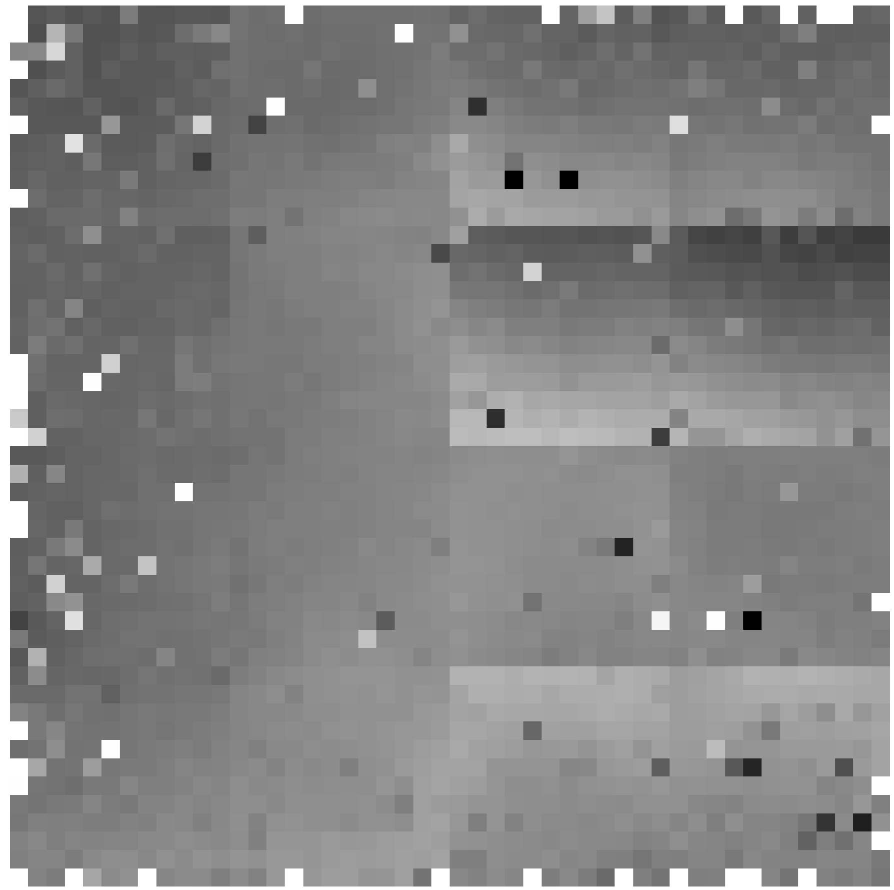


Focal plane leveling imperfect

Height maps for 16 science CCDs

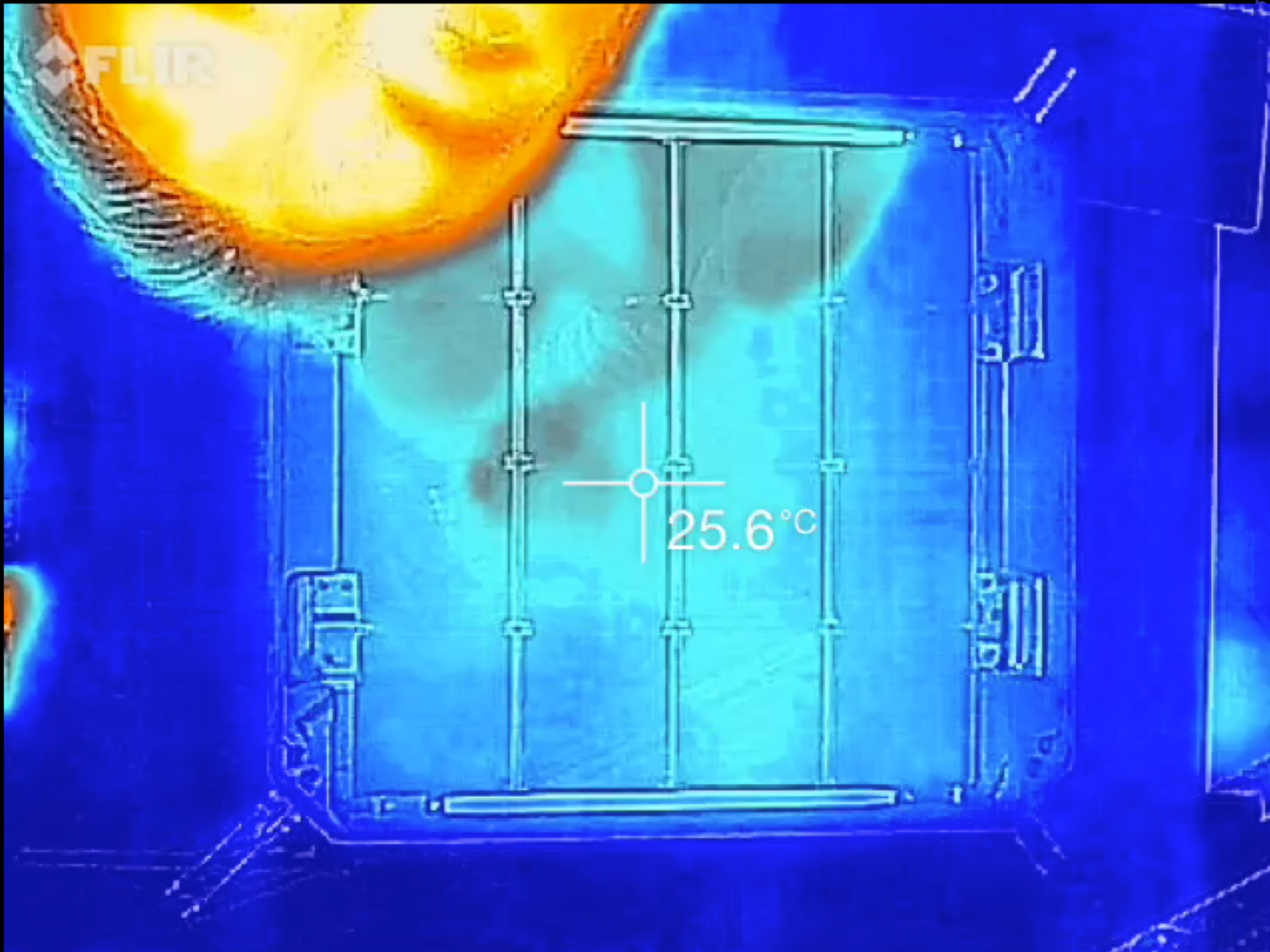


October 2017



February 2018

- RMS CCD height variations remain ~ 17 microns (noticeable CCD-to-CCD FWHM variation)
- Limited resources (time and $) led project to accept CCD state and direct remaining funding toward guide/focus system, which is having larger impact on DIQ


25.6°C