The University of Texas at Austin
Center for Electromechanics

2016 ADVISORY PANEL
INSTRUMENTS FOR SCIENCE

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5/10/2016

Development of an in-situ hot calibration source for the ITER-ECE diagnostic system

Project summary

UT - CEM

- UT-CEM Task definition:
  - Develop an in-situ hot calibration source for an optical instrument used in ITER tokamak.
- ITER Tokamak: International Thermonuclear Experimental Reactor
  - World largest machine designed to harness fusion energy
  - Bridge between present laboratory machines and future fusion power plants
  - 35 countries
  - Under construction in France
  - US participants: DOE labs, universities, industry
- ITER-ECE diagnostic system:
  - Provides information on electron temperature and other plasma parameters by detecting and processing the electron cyclotron radiation emitted from ITER plasmas.
  - Major diagnostic system: critical for successful operation of ITER.
- Calibration source:
  - In-situ hot calibration source periodically calibrates the ITER-ECE diagnostic system.
  - Crucial for successful operation of the ITER-ECE system.

Project Collaborators

- US collaboration:
  - PPPL (Princeton Plasma Physics Laboratory): DOE contractor / US-DA / Project monitor
    - ➢ Responsible for integrating all US diagnostics in ITER including ITER-ECE system
  - UT-IFS (UT Institute for Fusion Studies) : Prime Subcontractor
    - ➢Project management, component testing, optical instruments
  - MIT: Contributing subcontractor
    - ➢ Analysis and control software, data acquisition, optical instruments
  - **UT-CEM**: Contributing subcontractor:
    - ➢Hot calibration source development, controls, monitoring, and other engineering support tasks.

- International collaboration:
  - INDIA: (Indian Institute for Plasma Research): Contributing partners
    - ➢ Develop\contribute ITER-ECE system components
  - ITER Organization: Cadarache, France (ITER site)
    - ➢ Project lead, system integration, operation, regulation, and safety

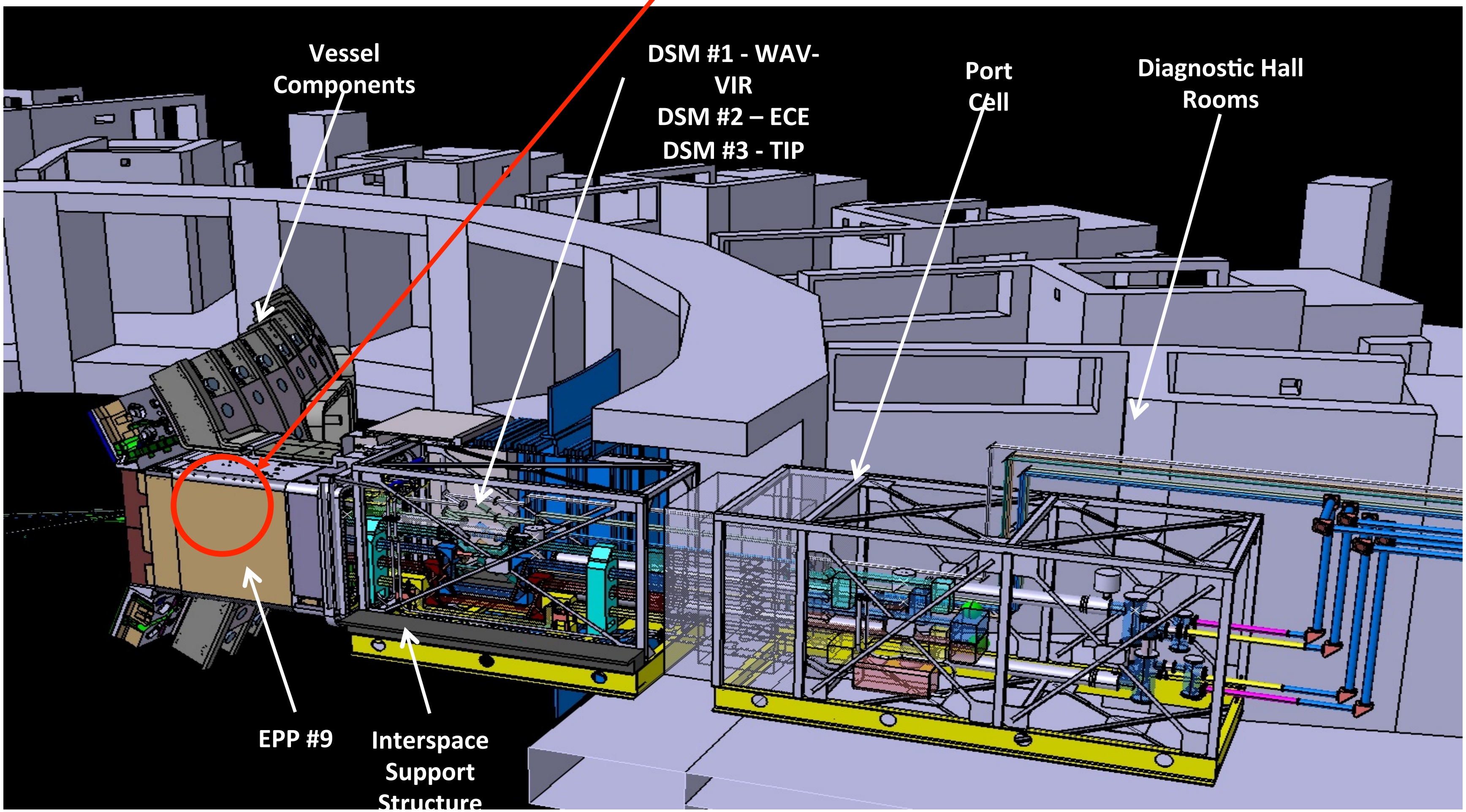
- Project Duration: ~ 30 months
- Start: 2 July 2014
- PDR: November 2016
- CEM Budget: $2.7M

Hot calibration source specifications

1. Emitter surface temperature = 700 ^{0}C +/- 10 ^{o}C
2. Temperature stability 24 hours = 3 ^{o}C
3. Temperature uniformity over surface = 10 %
4. High vacuum compatible ~ 10^{-7} Torr
5. Presence of static magnetic field during calibration: 4 T
6. Possible transient B-field during faults: dB/dt ~ 10 T/s
7. Compact size = 250x250x250 mm^3
8. Heating current limit = 40 A
9. Target efficiency = 70%
10. Very long life: operation spread over 20 years
    1. > 5000 operating hours
    2. > 100 calibrations
    3. Continuous operation > 24 hours
11. Survive many off-normal events
    1. Plasma disruptions
    2. Flooding
    3. others
12. Vibration specs include plasma disruptions, vertical displacement and seismic events

In-situ hot calibration source is part of large system

To be permanently installed inside diagnostic shield module



In-situ hot calibration source

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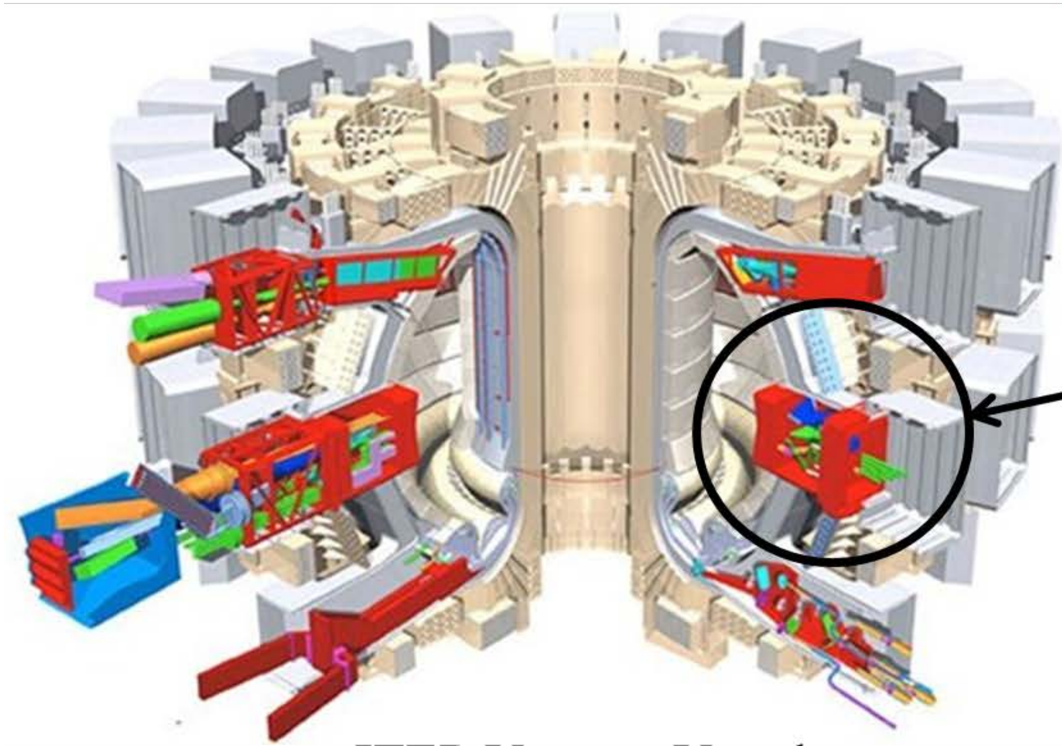
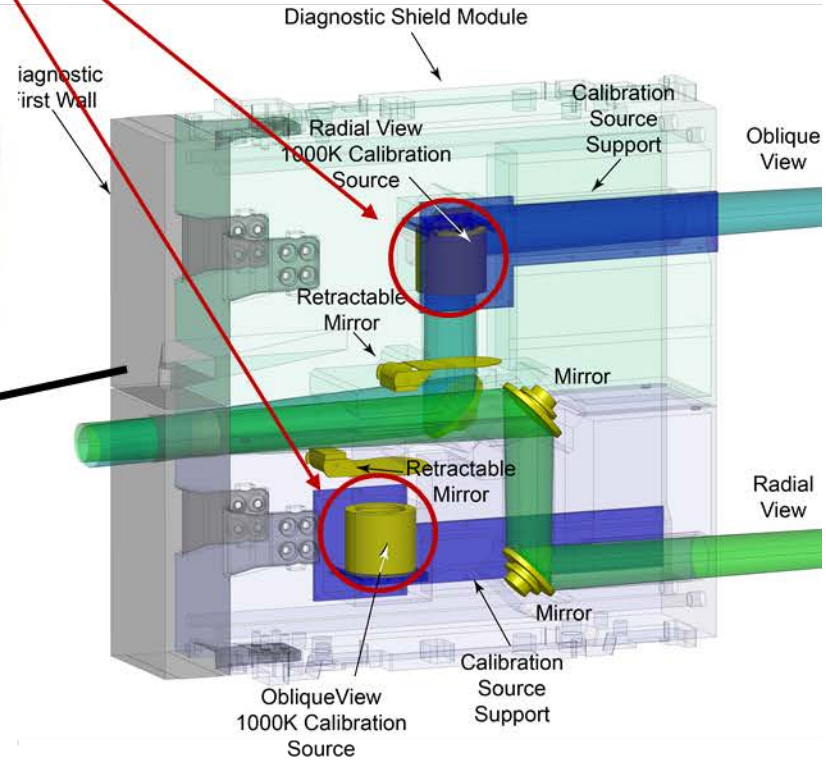
- Location: Near the plasma, within diagnostic shield module (DSM)
- Operation: Provides calibration signal through retractable mirrors\shutters



ITER Vacuum Vessel



Hot calibration source: design evolution

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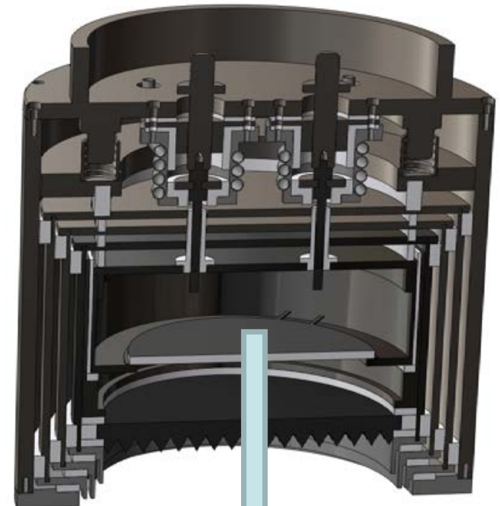
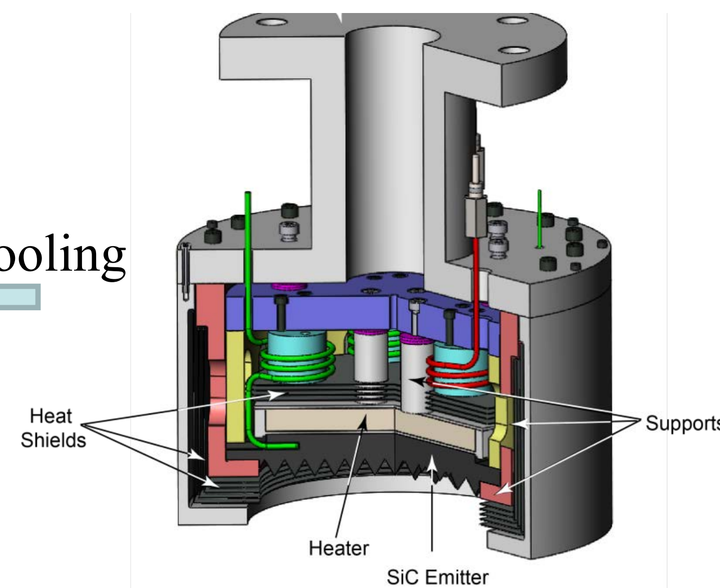
Conceptual design

Add magnetic field

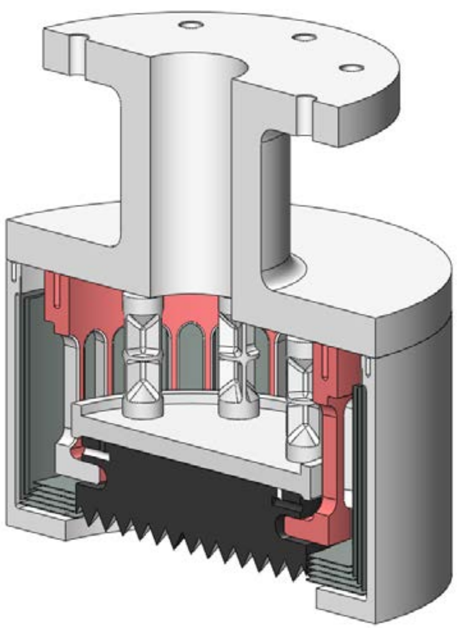


Add vibration specs



Avoid water cooling

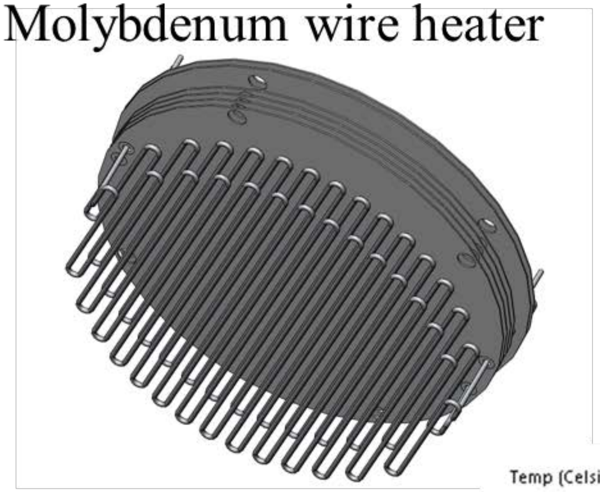
Current design



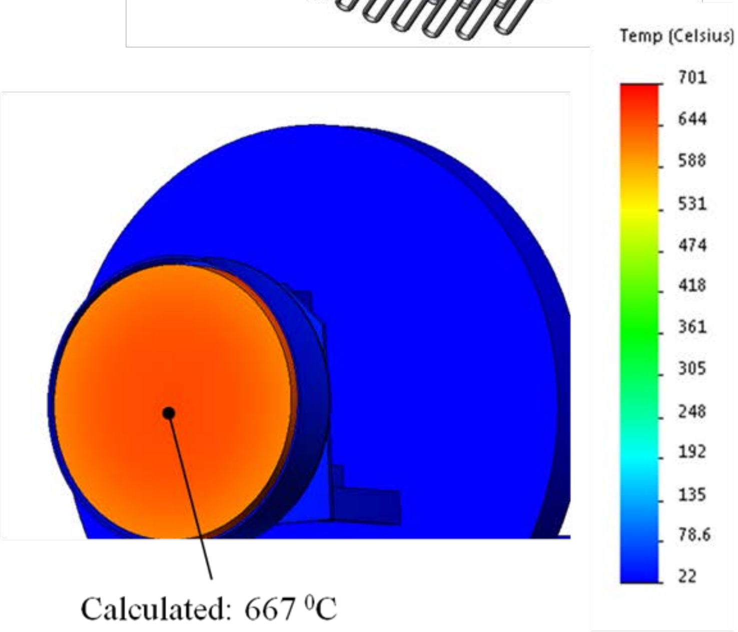
Heater selection and testing

COTS Inconel heater

Molybdenum wire heater



Measured: ~ 670 ^{0}C



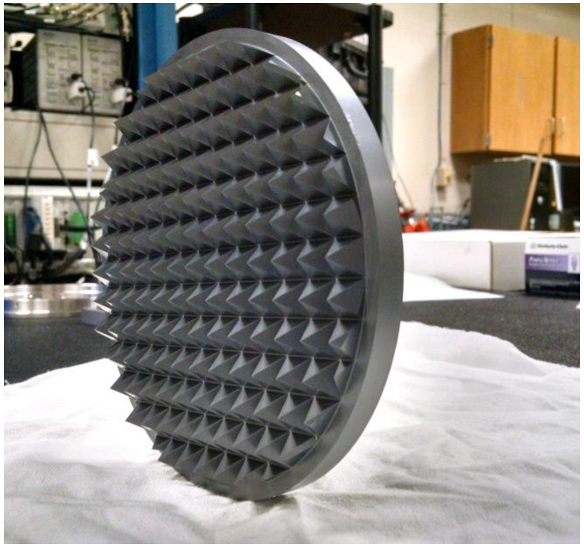
Calculated: 667 ^{0}C

Prototype development

Prototype assembly ready for testing

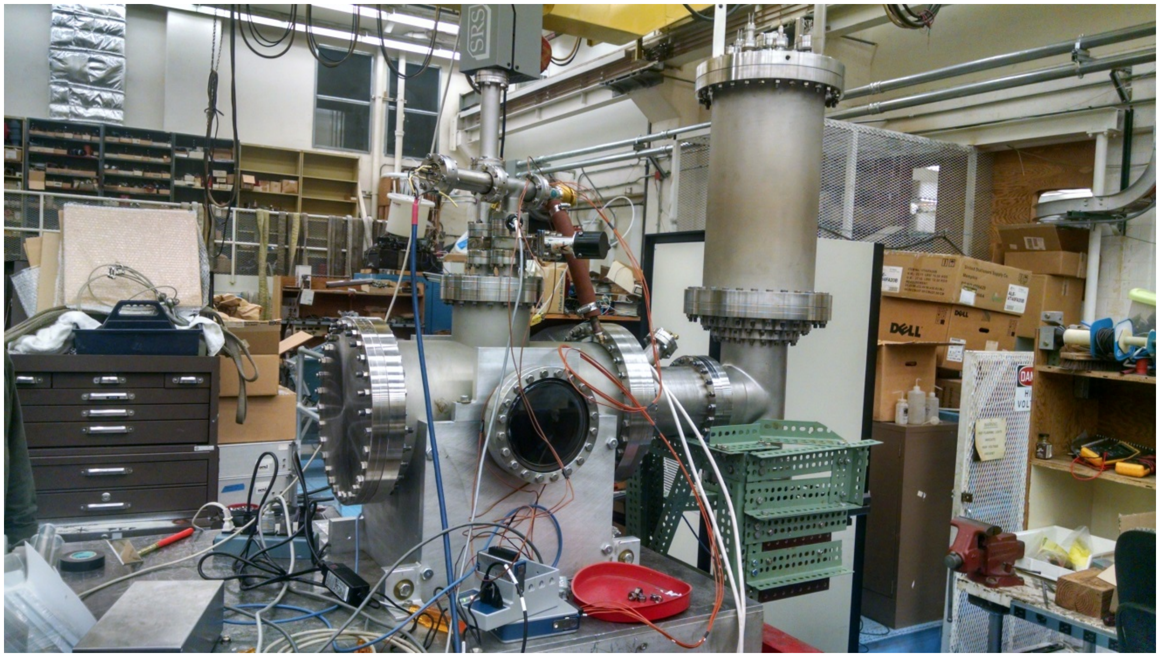
Inconel heater

SiC calibration surface

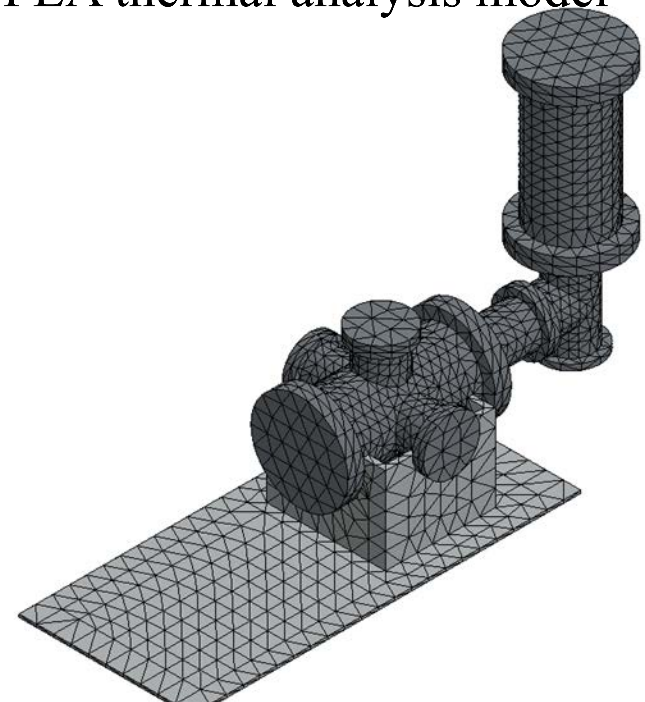


Prototype currently under testing at IFS lab (main campus)

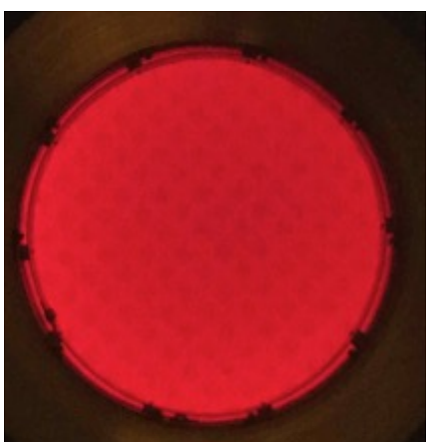
Prototype calibration source test set-up

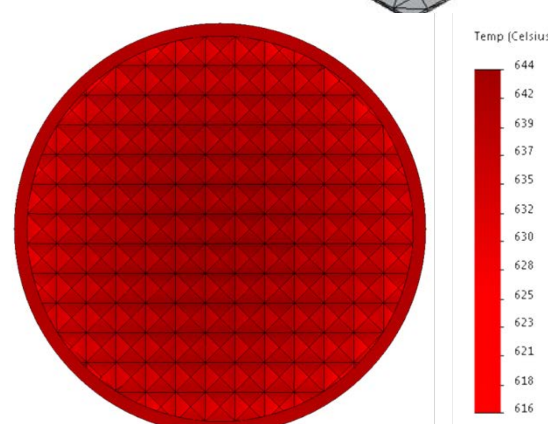


FEA thermal analysis model



Heated SiC emitter

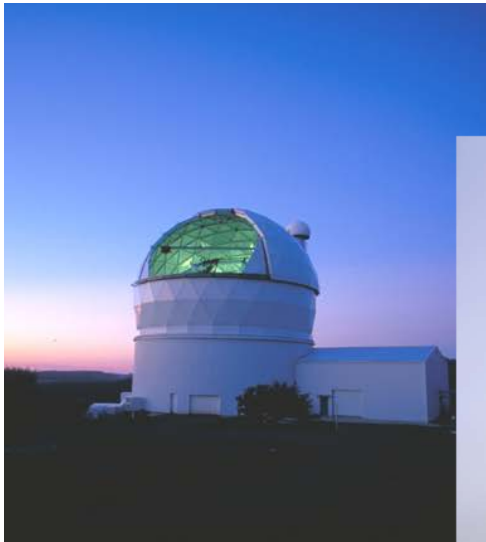




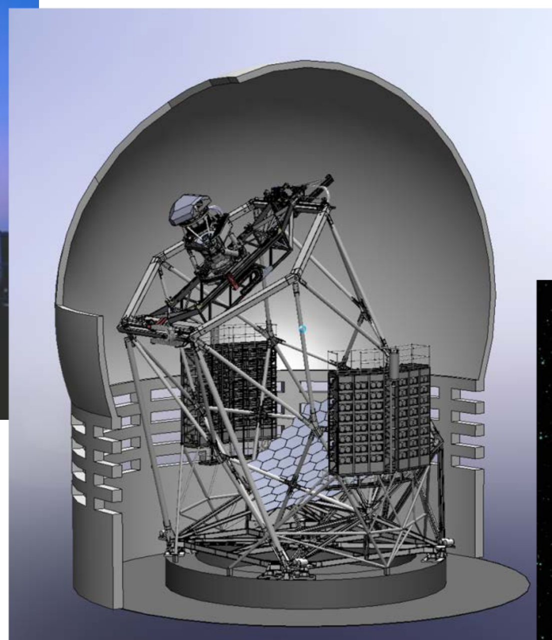
Thermal simulation result

Search for Dark Energy

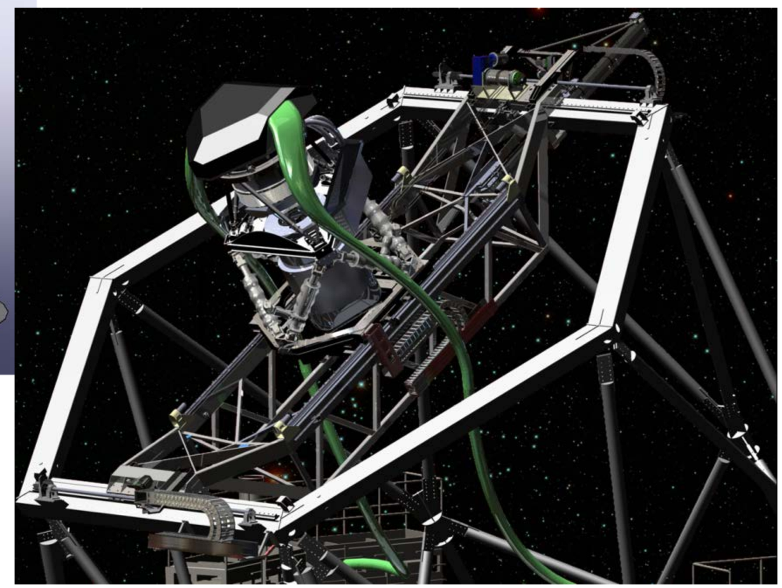
Overview



Scientists can't explain 70% of the apparent energy in the Universe.

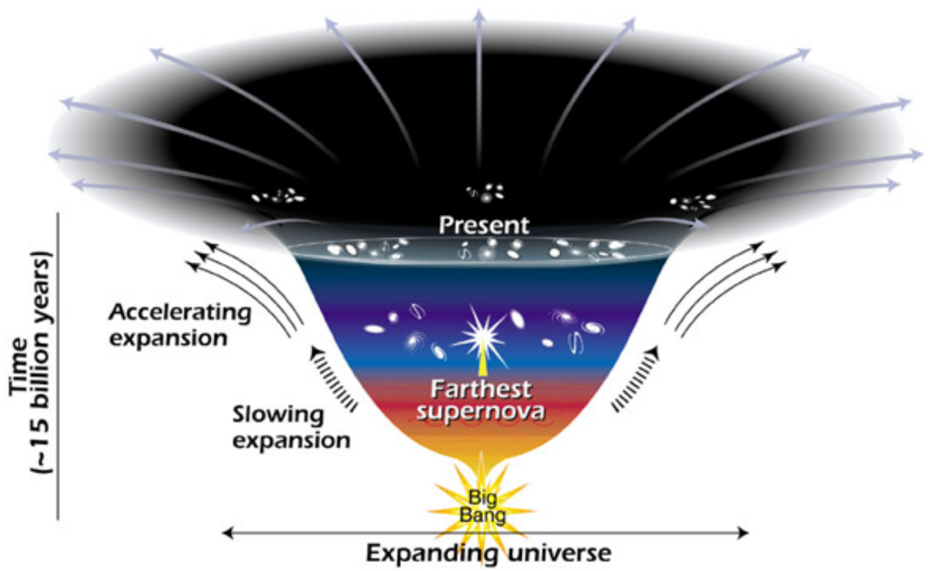


UT's Hobby Eberly Telescope Dark Energy Survey will look for answers.



CEM's 20 ton precision robot will do the work.

What is Dark Energy?



This diagram reveals changes in the rate of expansion since the universe's birth 15 billion years ago. The more shallow the curve, the faster the rate of expansion. The curve changes noticeably about 7.5 billion years ago, when objects in the universe began flying apart at a faster rate. Astronomers theorize that the faster expansion rate is due to a mysterious, dark force that is pushing galaxies apart.

News Release Number: STScI-2001-09
http://hubblesite.org/newscenter/archive/releases/2001/09/image/f/

More is unknown than is known. We know how much dark energy there is because we know how it affects the Universe's expansion.

Other than that, it is a complete mystery. But it turns out that roughly 70% of the Universe is dark energy. Dark matter makes up about 25%.

The rest - everything on Earth, everything ever observed with all of our instruments, all normal matter - adds up to less than 5% of the Universe.

The thing that is needed to decide between dark energy possibilities - a property of space, a new dynamic fluid, or a new theory of gravity - is more data, better data.

Dark Energy, Dark Matter - NASA April 2010.mht

HET Dark Energy Experiment

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http://hetdex.org/hetdex/search_area.php

HETDEX will be the first major experiment to probe dark energy.

During three years of observations, HETDEX will collect data on at least one million galaxies that are 9 billion to 11 billion light-years away, yielding the largest map of the universe ever produced.

http://hetdex.org/hetdex/index.php

HET Scale Up IS Necessary To Reduce Viewing Time From Decades to Years

This diagram shows HET's current (right) and upgraded field of view compared to the size of the full Moon. [Tim Jones]

During each observation, HET will see an area of the sky that is more than 30 times greater than it sees today.

CEM is responsible for upgrading the Tracker – an 20 ton robot that positions the HET Prime Focal Instrument Package.

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HET Tracker Upgrade in CEM Lab

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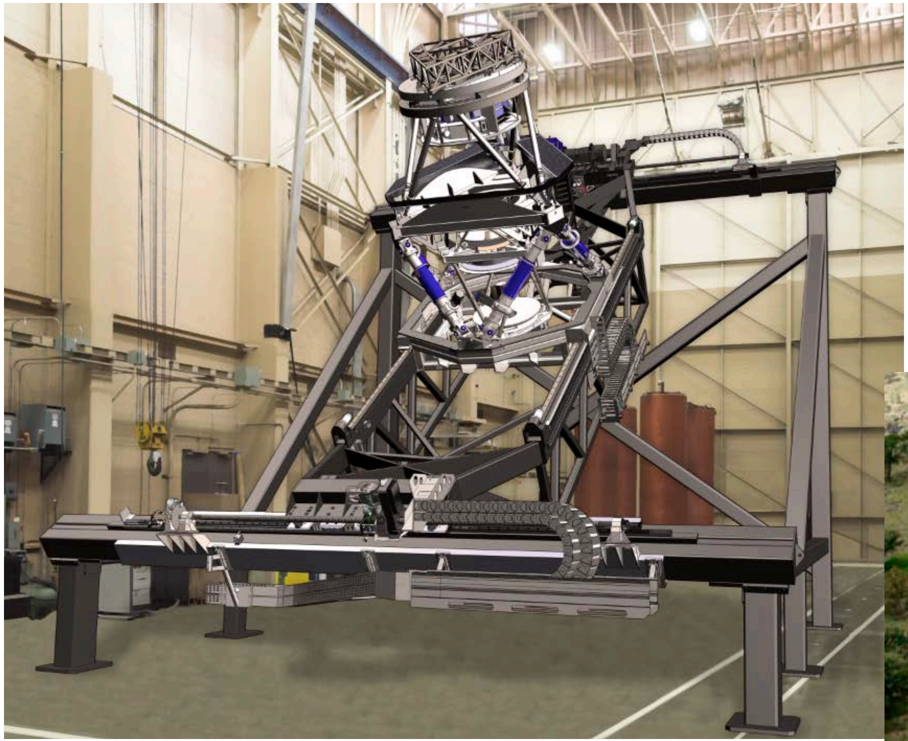
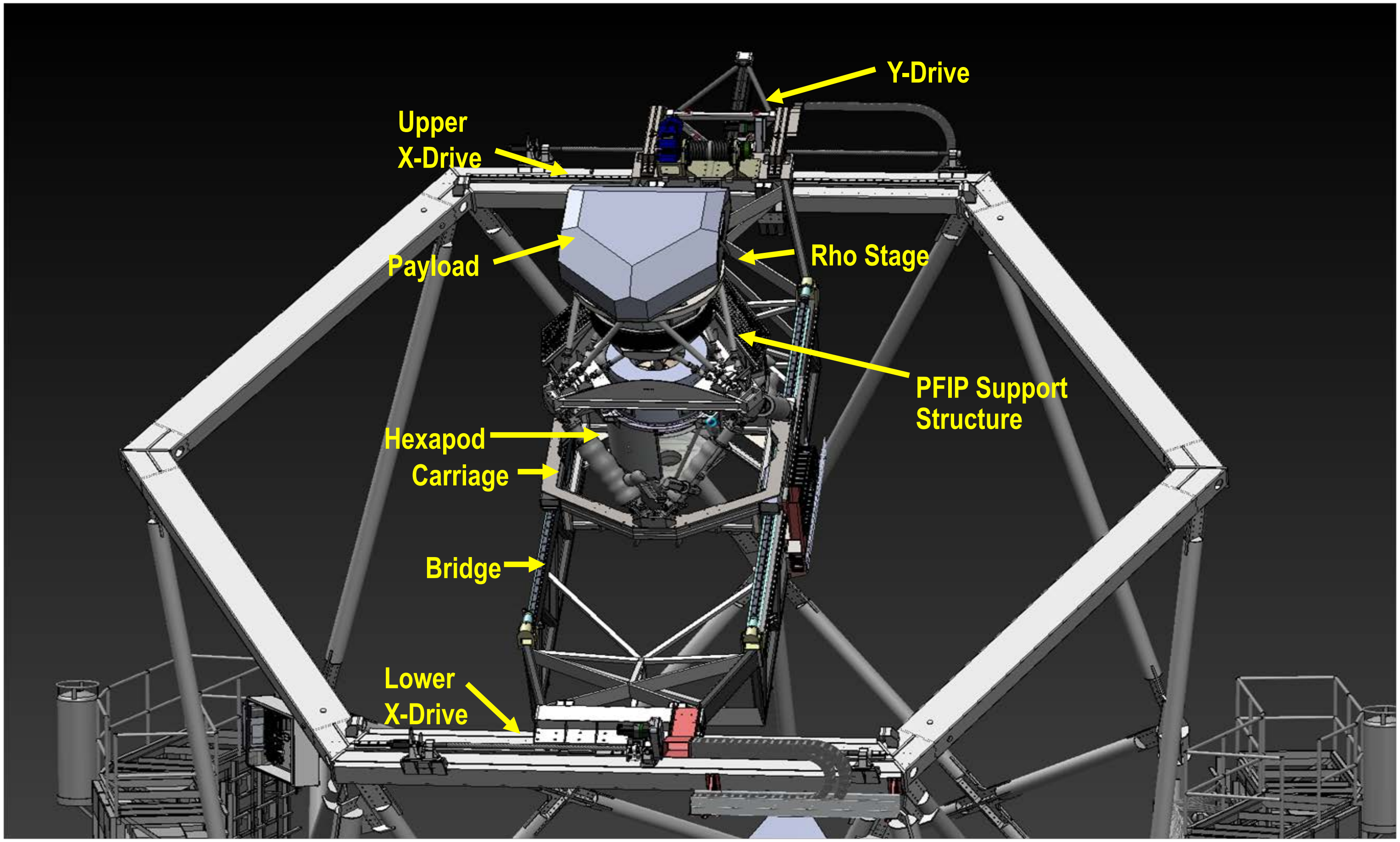


Tracker Subsystems

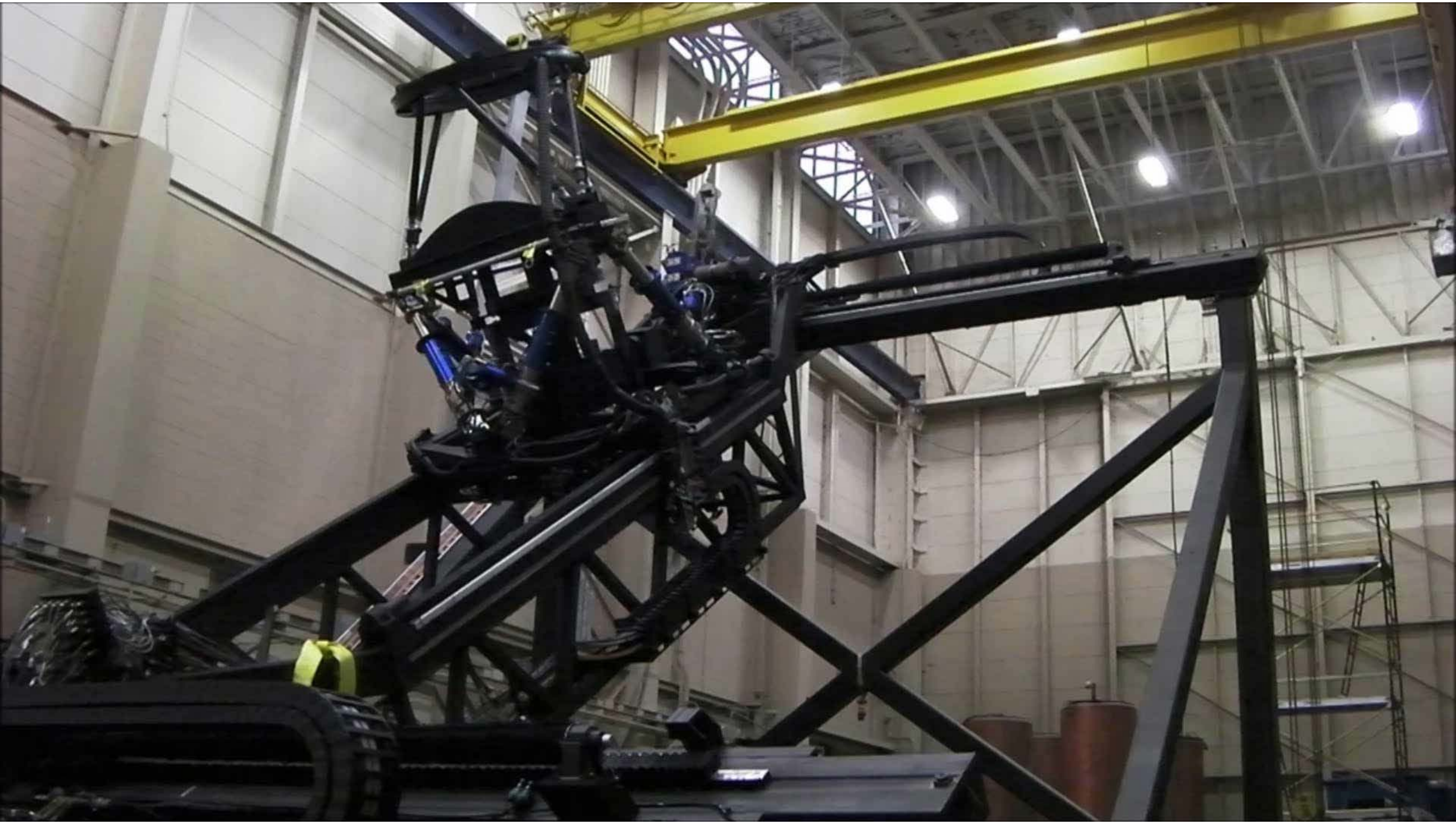


Tracker Function: Position optical package (payload) where commanded and align it perpendicular to primary mirror

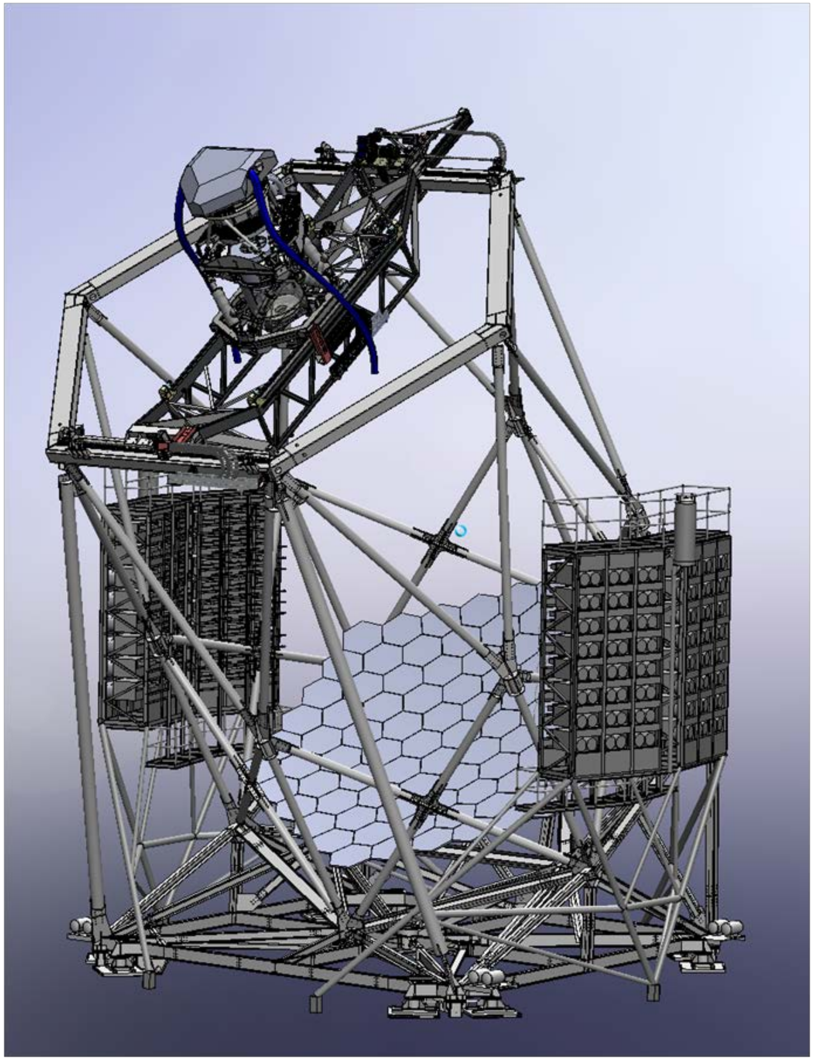
Payload: 3.5 tons

Tracker: 55' above floor; 35' long; 18' high; 18 tons

HET Tracker in CEM's Lab



HET Tracker is a large robot. . .

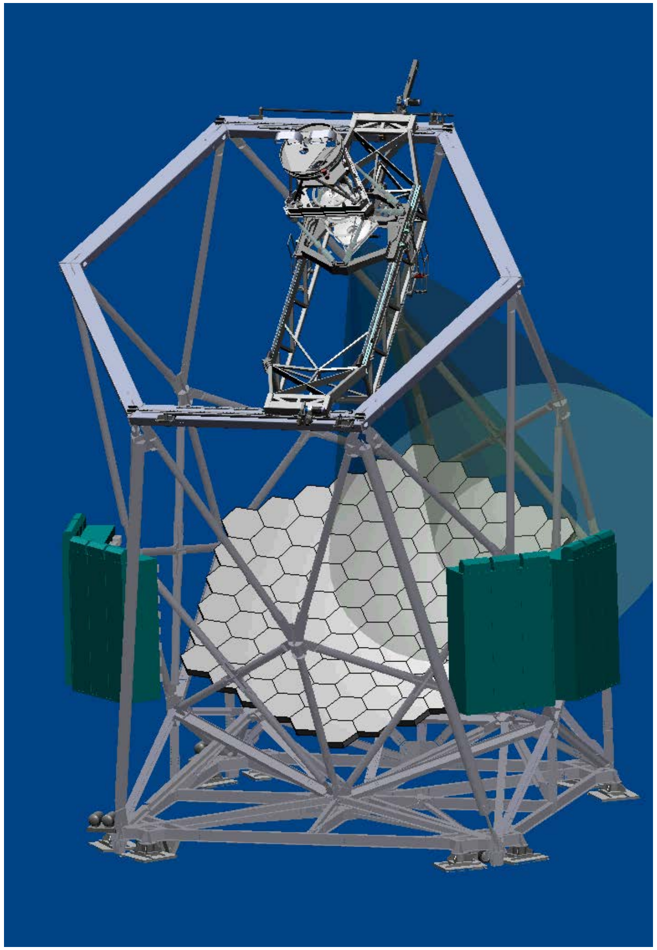


Major Component	Major Component Masses in kg	Mass Supported at Base of Component in kg
IFU Mass Loading on PFIP	260	
Focal Surface Assembly	584	
Rho-Stage	403	1,247
Pupil Assembly	116	
Wide Field Corrector	953	
Electronics on Strongback	353	
PFIP Support Structure	1,507	4,175
Tracker Hexapod System	2,079	6,254
Thermal Control System	90	
Work Platforms/Handrails	400	
Tracker Carriage	2,300	
Y- Drive System	913	9,957
Fiber Management System Loading on Bridge	610	
Constant Force Drive	597	
Tracker Bridge	7,718	18,882
X-Drive System (Load on Telescope Structure)	1,827	20,709

~ Size: 55’ above floor; 35’ long; 20’ high.

Performance Requirements

Tracker Parameter	Original HET	HETDEX Design
Payload mass (kg)	440	3,156
Bridge minimum natural frequency (Hz)	10.0	9.4
Bridge maximum deflection with payload (mm	2.0	1.5
Range of motion along X and Y axis (mm)	3,900	4,000
Range of motion along Z/W axis (mm)	178.0	480.0
Angular motion about X and Y axis (+/-deg)	8.5	9.0
Angular motion about Z/W axis (+/-deg)	115.0	24.0
Slewing speed in X and Y (mm/s)	70.0	80.0
Slewing speed in Z/W (mm/s)	3.0	6.5
Max. tracking speed in X and Y (mm/s)	1.30	3.00
Max. tracking speed in Z/W (mm/s)	1.30	0.50
Closed Loop Tracking Accuracy		
Along X and Y axis (mm)	0.005	0.005
Along Z/W axis (mm)	0.005	0.005
Rotation about X and Y axis (asec)	-	4.0
Rotation about Z/W axis (asec)	-	3.0



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SPIE Publications

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Integration of VIRUS spectrographs for the HET dark energy experiment	James T. Heisler, John M. Good, Richard D. Savage, Brian L. Vattiat, Richard J. Hayes, Nicholas T. Mollison, Ian M. Soukup,
Wind Loading analysis and strategy for deflection reduction on HET dark energy experiment upgrade	South, Good, Booth, Worthington, Zierer, Soukup
Design and development of a long-travel positioning actuator and tandem constant force actuator safety system for the Hobby-Eberly Telescope wide-field	Nicholas T. Mollison, Jason R. Mock, Ian M. Soukup, Timothy A. Beets, John M. Good, Joseph H. Beno, Herman J. Kriel, Sarah E. Hinze, Douglas R. Wardell
Kinematic optimization of upgrade to the Hobby-Eberly Telescope through novel use of commercially available three-dimensional CAD package	Gregory A. Wedeking, Joseph J. Zierer, Jr., John R. Jackson
Tracker controls development and control architecture for the Hobby-Eberly Telescope dark energy experiment	Jason Mock, Joe Beno, Joey Zierer, Tom H. Rafferty, Mark E. Cornell
Design and analysis of the Hobby-Eberly Telescope dark energy experiment (HETDEX) bridge	Michael S. Worthington, Steven P. Nichols, John M. Good, Joseph J. Zierer, Jr., Nicholas T. Mollison, Ian M. Soukup
Design and development of a high-precision, high-payload telescope dual-drive system	Michael S. Worthington, Timothy A. Beets, John M. Good, Brian T. Murphy, Brian J. South, Joseph H. Beno
Design of the fiber optic support system and fiber bundle accelerated life test for VIRUS	M. Soukup, Nicholas T. Mollison, Jason R. Mock, Joseph H. Beno, Gary J. Hill, John M. Good, Brian L. Vattiat, Jeremy D. Murphy, Seth C. Anderson, Eric P. Fahrenthold
Collaborative engineering and design management for the Hobby-Eberly Telescope tracker upgrade	Nicholas T. Mollison, Richard J. Hayes, John R. Jackson, Richard D. Savage, Marc D. Rafal, Joseph H. Beno
The Development of high-precision hexapod actuators for the Hobby-Eberly Telescope Dark Energy Experiment (HETDEX)	Joey Zierer, Jason Mock, Joseph H. Beno, Paolo Lazzarini, P.Fumi, E.Anaclerio (ADS International), John Good, John Booth
Design of Performance Verification Testing for HETDEX Tracker in the Laboratory	Hayes, Good, Jason Mock, Rich Savage, John Booth, Beno
An alternative architecture and control strategy for hexapod positioning systems to simplify structural design and improve accuracy	Beno, Booth, Mock,

Plus 3 Master's Thesis and 1 Master's Report.