Search for Dark Energy

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What is Dark Energy?

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.
The map will allow HETDEX astronomers to measure how fast the universe was expanding at different times in its history. Changes in the expansion rate will reveal the role of dark energy at different epochs. Various explanations for dark energy predict different changes in the expansion rate, so by providing exact measurements of the expansion, the HETDEX map will eliminate some of the competing ideas.

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

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 18 ton robot that positions the HET Prime Focal Instrument Package.*
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
## Performance Requirements

<table>
<thead>
<tr>
<th></th>
<th>Value 1</th>
<th>Value 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Payload mass (kg)</td>
<td>440</td>
<td>3,156</td>
</tr>
<tr>
<td>Bridge minimum natural frequency (Hz)</td>
<td>10.0</td>
<td>9.4</td>
</tr>
<tr>
<td>Bridge maximum deflection with payload (mm)</td>
<td>2.0</td>
<td>1.5</td>
</tr>
<tr>
<td>Range of motion along X and Y axis (mm)</td>
<td>3,900</td>
<td>4,000</td>
</tr>
<tr>
<td>Range of motion along Z/W axis (mm)</td>
<td>178.0</td>
<td>480.0</td>
</tr>
<tr>
<td>Angular motion about X and Y axis (+/-deg)</td>
<td>8.5</td>
<td>9.0</td>
</tr>
<tr>
<td>Angular motion about Z/W axis (+/-deg)</td>
<td>115.0</td>
<td>24.0</td>
</tr>
<tr>
<td>Slewing speed in X and Y (mm/s)</td>
<td>70.0</td>
<td>80.0</td>
</tr>
<tr>
<td>Slewing speed in Z/W (mm/s)</td>
<td>3.0</td>
<td>6.5</td>
</tr>
<tr>
<td>Max. tracking speed in X and Y (mm/s)</td>
<td>1.30</td>
<td>3.00</td>
</tr>
<tr>
<td>Max. tracking speed in Z/W (mm/s)</td>
<td>1.30</td>
<td>0.50</td>
</tr>
</tbody>
</table>

### Closed Loop Tracking Accuracy

<table>
<thead>
<tr>
<th></th>
<th>Value 1</th>
<th>Value 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Along X and Y axis (mm)</td>
<td>0.005</td>
<td>0.005</td>
</tr>
<tr>
<td>Along Z/W axis (mm)</td>
<td>0.005</td>
<td>0.005</td>
</tr>
<tr>
<td>Rotation about X and Y axis (asec)</td>
<td>-</td>
<td>4.0</td>
</tr>
<tr>
<td>Rotation about Z/W axis (asec)</td>
<td>-</td>
<td>3.0</td>
</tr>
</tbody>
</table>
Integrated Design and Analysis

FMEA UMBRELLA

SolidWorks: Design package; Bill of materials; Component mass and CG’s; Interferences; Visualize obscuration; Fabrication drawings; Enforce constraints

PDM Works: Drawing and documentation configuration management

CosmosWorks: Structural analysis from SolidWorks models

MasterCam: Computer aided manufacturing interface for SolidWorks models

CosmosFloWorks: Fluid and air flow analysis from SolidWorks models

CosmosMotion: Dynamic motion analysis/visualization for SolidWorks models
Tracker Motion in Solid Works
Tracker Controller Block: Actual control code that migrates via auto-code generation to tracker controller hardware – simplified modification process with proven industry standard Matlab-Simulink GUI driven code development process.

Control Algorithms: Proven in realistic simulation environment before transferring to hardware.

Controller Documentation: MS Word documents embedded in Simulink blocks for easy reference.


Component Specifications: Performance “proven” in realistic coupled simulation environment.
Integrated Model of Tracker and Controller
Tracker Bridge

- Designed in SolidWorks
  - driven by stiffness requirement (>9 Hz first mode)
- FEA performed with Simulation:
  - frequency response, deflection, stress & buckling
- Fabrication in progress (ETA June 24th)
- Overall dimensions (L x W x H): 10.86 x 2.73 x 1.93 m
- Total mass: 7577 kg
Bridge Key Results

<table>
<thead>
<tr>
<th></th>
<th>HET</th>
<th>HETDEX</th>
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</thead>
<tbody>
<tr>
<td>Bridge [kg]</td>
<td>2154</td>
<td>7577</td>
</tr>
<tr>
<td>Science payload [kg]</td>
<td>440</td>
<td>3156</td>
</tr>
<tr>
<td>Bridge payload [kg]</td>
<td>1313</td>
<td>9045</td>
</tr>
<tr>
<td>% bridge to tracker mass</td>
<td>59</td>
<td>40</td>
</tr>
<tr>
<td>1st mode nat. freq. [Hz]</td>
<td>11.53</td>
<td>9.40</td>
</tr>
<tr>
<td>Added deflection w/ load [mm]</td>
<td>1.00</td>
<td>1.51</td>
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</tbody>
</table>

1st Mode Natural Frequency
(deformation scale = 125)

Top view:

Side view:

Full solid model:

Beam model for analysis:
Lower Hexapod Frame Structural Analysis

- **Structure analysis description**
  - Performed solid mesh analysis
  - Analyzed two configurations
    - Hexapod force model
      - Calculates deflection at discrete travel locations using hexapod forces
    - Payload mass model
      - Verifies deflection results obtained from force model
      - Determines loads distributed to the bearings

- **Analysis goals**
  - Limit resultant deflection to < 2 mm
  - Limit delta deflections across 4 m travel range to < 0.5 mm
LHF Analysis Results

Analysis Results

- Hexapod Force Model
  - 1.433 mm Resultant Deflection
- Payload Mass Model
  - 1.439 mm Resultant Deflection
  - 410 μm of Delta Deflection Across 4 m Travel Range

<table>
<thead>
<tr>
<th></th>
<th>X (mm)</th>
<th>Y (mm)</th>
<th>Z (mm)</th>
<th>Res. (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Force Model</td>
<td>0.092</td>
<td>-1.234</td>
<td>-0.722</td>
<td>1.433</td>
</tr>
<tr>
<td>Mass Model</td>
<td>0.091</td>
<td>-1.279</td>
<td>-0.652</td>
<td>1.439</td>
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Conclusions

- The stiffness of the lower hexapod frame is adequate to meet the design goals*

*Based on FEA Results
Study # 40 selected as baseline design. Best compromise of low frame displacement and low strut force requirements.
Collision Study

• HETDEX Hexapod Motion
  – Six independent actuators
  – Infinite actuator length possibilities
  – ‘Manually’ moving model to investigate collisions severely limits positions that can be investigated

• Collision Detection Tool
  – Uses SolidWorks programming interface to automate positioning of hexapod and check for collisions
  – Allows very large number of position evaluations

• ‘Optimization’ Study
  – MS Excel solver seeks near collisions, given initial starting position
  – Random hexapod positions used as starting points

~A dozen new problematic actuator position combinations identified.
Available Volume Study

- Needed understanding of available space for additional hardware
- Hexapod motion and number of potential positions too complex to manually determine available volume
- SolidWorks programming interface used for the study
  - Initial volume was defined for evaluation
  - Hexapod exercised thru it’s range of extreme positions
  - Remaining volume was determined that did not collide with existing hardware
IFU Accelerated Life Cycle Test
Pre-Assembly, De-Bugging, and Process Development at CEM

• Full scale Tracker and FMS installation with mock (surrogate) Telescope hexagon, mock elements of VIRUS and mock payloads in CEM’s high bay in 2010

• Tracker, FMS, and control system debugged, tested and validated against test matrix at CEM

• Prior to installation at Telescope
  – Assembly and installation procedures and tooling refined at CEM
  – Telescope personnel training at CEM
  – Tracker-Telescope Control System software integration trials at CEM
  – Documentation completed/updated with “as-built” data and procedures

• CEM team provide on-site support during installation and debugging at Telescope
## Upcoming SPIE Publications

<table>
<thead>
<tr>
<th>Title</th>
<th>Authors</th>
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</thead>
<tbody>
<tr>
<td>Integration of VIRUS spectrographs for the HET dark energy experiment</td>
<td>James T. Heisler, John M. Good, Richard D. Savage, Brian L. Vattiat, Richard J. Hayes, Nicholas T. Mollison, Ian M. Soukup,</td>
</tr>
<tr>
<td>Wind Loading analysis and strategy for deflection reduction on HET dark energy experiment upgrade</td>
<td>South, Good, Booth, Worthington, Zierer, Soukup</td>
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<tr>
<td>Kinematic optimization of upgrade to the Hobby-Eberly Telescope through novel use of commercially available three-dimensional CAD package</td>
<td>Gregory A. Wedeking, Joseph J. Zierer, Jr., John R. Jackson</td>
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<tr>
<td>Tracker controls development and control architecture for the Hobby-Eberly Telescope dark energy experiment</td>
<td>Jason Mock, Joe Beno, Joey Zierer, Tom H. Rafferty, Mark E. Cornell</td>
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<tr>
<td>Design and analysis of the Hobby-Eberly Telescope dark energy experiment (HETDEX) bridge</td>
<td>Michael S. Worthington, Steven P. Nichols, John M. Good, Joseph J. Zierer, Jr., Nicholas T. Mollison, Ian M. Soukup</td>
</tr>
<tr>
<td>Design and development of a high-precision, high-payload telescope dual-drive system</td>
<td>Michael S. Worthington, Timothy A. Beets, John M. Good, Brian T. Murphy, Brian J. South, Joseph H. Beno</td>
</tr>
<tr>
<td>Design of the fiber optic support system and fiber bundle accelerated life test for VIRUS</td>
<td>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</td>
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<tr>
<td>Collaborative engineering and design management for the Hobby-Eberly Telescope tracker upgrade</td>
<td>Nicholas T. Mollison, Richard J. Hayes, John R. Jackson, Richard D. Savage, Marc D. Rafal, Joseph H. Beno</td>
</tr>
<tr>
<td>Design of Performance Verification Testing for HETDEX Tracker in the Laboratory</td>
<td>Hayes, Good, Jason Mock, Rich Savage, John Booth, Beno</td>
</tr>
<tr>
<td>An alternative architecture and control strategy for hexapod positioning systems to simplify structural design and improve accuracy</td>
<td>Beno, Booth, Mock,</td>
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*Plus 3 Master’s Thesis and 1 Master’s Report.*
Questions & Discussion