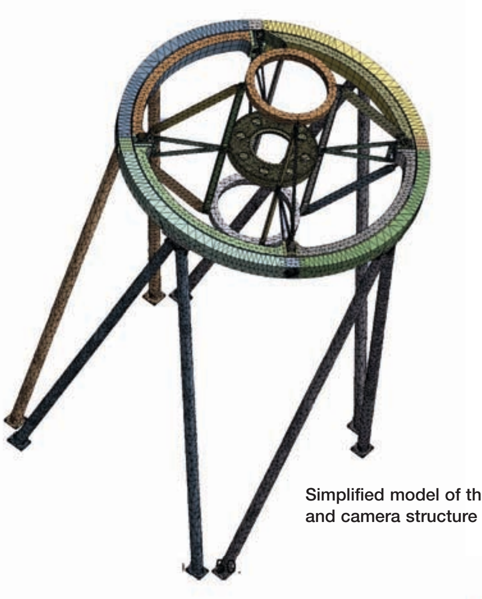
Exploring the Dark Side of the Universe



Simplified model of the telescope and camera structure

Engineers at the Fermi National Accelerator Laboratory use ANSYS technology in developing a precision camera for studying the far reaches of the universe.

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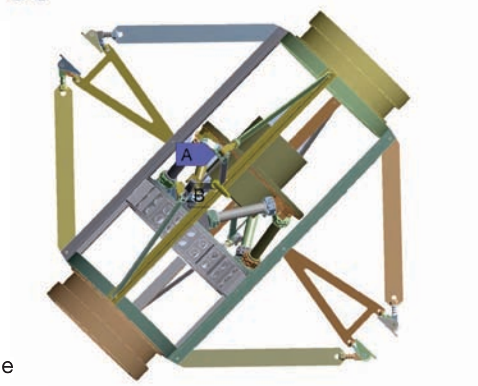


Detailed model of the primary focus cage

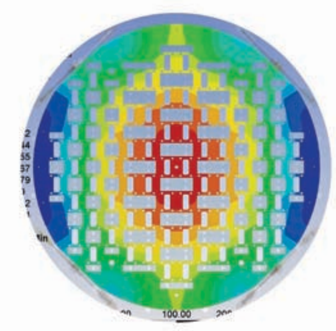
From observations of distant exploding stars called supernovae, astrophysicists know that the universe is expanding at an accelerating rate, driven outward by what they speculate is the push of negative gravity from so-called dark energy that uniformly fills otherwise empty space. Because of its cosmological significance, scientists are eager to learn all that they can about dark energy, which has yet to be directly observed because of its extremely low density and lack of interaction with most fundamental forces of the universe. Essentially, the only way to probe the properties of dark energy is to make extremely precise measurements of the expansion rate of the universe.

This challenge is being addressed by a project called the Dark Energy Survey, which is aimed at determining the history of the expansion rate of the universe by taking images of roughly 300 million galaxies and measuring their shape and redshift — the change in frequency of light and other electromagnetic radiation as the heavenly bodies move outwardly away from Earth. By making such measurements, scientists will be able to investigate the expansion of the universe over two-thirds of its total life — from the time when the universe was only a few billion years old.

Scientists will photograph these distant galaxies using a Dark Energy Camera (DECam) — one of the largest cameras ever built using charge-coupled devices (CCDs), the same imaging technology used in conventional digital cameras. With an end-to-end length of 2.5 meters and weight of 3.6 metric tons, the 500-megapixel DECam will be placed on an existing 4-meter telescope at the National Optical Astronomy Observatory's Cerro Tololo Inter-American Observatory in north-central Chile.

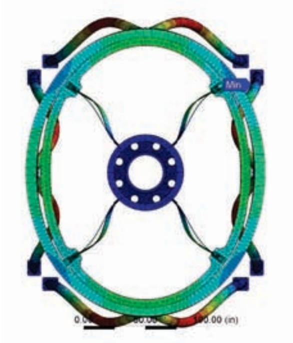
Obtaining proper measurements requires that the DECam's CCDs be precisely aligned with the telescope's lenses and primary mirror. An "alignment budget" was created to allocate 10 to 15 microns of allowable misalignment for each subsystem in the camera.

The more than 300 parts and subsystems of the DECam were developed by individual members of a design team. The author's specific contribution was to perform detailed analysis of these parts and subsystems using ANSYS Mechanical software to ensure that dead-weight deflections, vacuum deformations, thermal distortions and vibration modes of the camera were within these limits. The software also was used for thermal studies to determine temperatures of individual parts as well as total heat load on the cooling system. All calculations were



Temperature distribution at focal plane for 20-degree C ambient temperature

Barrel and imager Z direction displacement under vacuum load, thermal load and gravity load at 20-degree C ambient temperature



Telescope and camera assembly at mode 6 natural frequency of 14.006 Hz

made at two ambient temperatures: 20 degrees Celsius (C) and -5 degrees C based on climate conditions at the telescope site. Due to the complexity of the DECam, two separate analysis models were created. A full model of the camera — which contained 679 higher-order solid elements but without all component details — computed displacements. These displacements were used as input to a detailed cage model having 3,112K elements.

Fermilab employed the ANSYS Workbench platform with ANSYS Mechanical software to reduce the time required to create analysis models using CAD integration, automatic meshing and fully parametric modeling capabilities. They imported native CAD geometry directly into ANSYS software and used the ANSYS DesignModeler tool to simplify the geometry. The ANSYS Workbench environment automatically detected and set up contacts and joints between parts of the assembly, with the engineer modifying contact settings and entering additional manual contact definitions.

ANSYS Workbench saved much time on the project because its graphical tools greatly streamlined the process of editing geometry and applying boundary conditions, loads, contacts and more. In contrast, the traditional approach requires selecting all of the nodes on a surface in order to define it. With the ANSYS Workbench platform, the engineer simply clicks on the surface or volume to apply the boundary condition, load or contact.

Analysis results provided detailed information on the deflection of the structure and temperature of the CCD readout printed circuit boards. Project engineers for individual subsystems examined the results and made design changes to mitigate any issues. Models were then changed and resimulated in an iterative process until the design was finalized to ensure that each subsystem maintained proper alignment. This guaranteed that the DECam would deliver the accuracy needed to trace back two-thirds of the way to the beginning of the universe.

The Dark Energy Survey Collaboration consists of scientists from Fermilab, University of Illinois at Urbana-Champaign, University of Chicago, Lawrence Berkeley National Laboratory, University of Michigan, University of Pennsylvania, The Ohio State University, Argonne National Laboratory, NOAO/CTIO, CSIC/Institut d'Estudis Espacials de Catalunya (Barcelona), Institut de Fisica D'Altes Energies (Barcelona), CIEMAT (Madrid), University College London, University of Cambridge, University of Edinburgh, University of Portsmouth, University of Sussex, Observatorio Nacional, Centro Brasileiro de Pesquisas Fisicas, Universidade Federal do Rio de Janeiro, and Universidade Federal do Rio Grande do Sul. Funding has been provided by U.S. DOE, NSF, STFC (UK), Ministry of Education and Science (Spain), FINEP (Brazil), and the collaborating institutions.

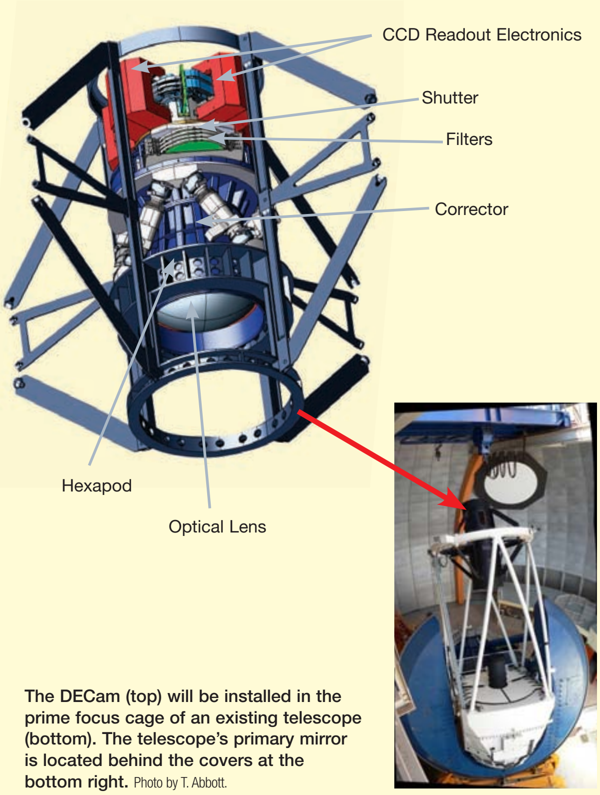
Anatomy of the Dark Energy Camera

As designed, the Dark Energy Camera consists of complex optical components that must properly align to accurately measure the distorted shapes and redshift of distant galaxies.

A set of five fused-silica optical lenses and related filters comprise a corrector assembly that focuses the light and separates out the relevant frequencies. Focusing is done with a hexapod assembly that aligns the camera with the telescope's primary mirror and also performs lateral correction to compensate for structural deflection as the telescope moves. A shutter mechanism controls CCD exposure time.

Attached to the end of the corrector is an imager system containing an array of charge-coupled devices (CCDs) cooled with liquid nitrogen. Readout circuit boards that process signals from the CCD array are mounted in electronic crates at the end of the imager.

To check the alignment of components, Fermilab engineers used ANSYS Mechanical software to accurately determine deformations, thermal distortions and vibration modes of the camera. The team also used the software for thermal studies to determine the temperature of individual parts as well as total heat load of the cooling system.



The DECam (top) will be installed in the prime focus cage of an existing telescope (bottom). The telescope's primary mirror is located behind the covers at the bottom right. Photo by T. Abbott.