Discovery Channel Telescope
Progress and Status

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ABSTRACT

The Discovery Channel Telescope (DCT) is a 4.2-m telescope being built at a new site near Happy Jack, in northern Arizona. The DCT features a 2-degree-diameter field of view at prime focus and a Ritchey-Chrétien (RC) configuration with Cassegrain and Nasmyth focus capability for optical/IR imaging and spectroscopy. Formal groundbreaking at the Happy Jack site for the DCT occurred on 12 July 2005, with construction of major facility elements underway.

Keywords: DCT, Lowell Observatory, wide field, survey telescope

1. INTRODUCTION

The Discovery Channel Telescope is a project by a partnership between Lowell Observatory and Discovery Communications, Inc. (DCI). The DCT has made considerable progress since last reported on at SPIE Glasgow in 2004.[1,2,3,4,5,6,7,8,9] In July of 2004, a comprehensive conceptual design review (CoDR) was held. The CoDR took place over two days, with presentations made on all aspects of the telescope and facility by DCT staff and contractors, with an invited review committee. Based on comments and issues raised by the review committee, a number of changes to the conceptual approach of the telescope were made in an effort to control cost while improving overall performance. The major changes were to adopt an interchangeable rather than a single tumbling top-end to switch between prime focus and RC configurations, a different layout for the facility buildings, and a refinement of the prime focus instrument design. These changes are detailed in their respective sections below. Construction of the facility and fabrication of the primary mirror are critical path tasks presently underway, with other portions of the project in design phase.

2. SITE

An extended site-testing campaign of the astronomical and environmental qualities at the Happy Jack site began in January 2003 and was completed in October 2004. Differential image motion observations on 117 nights gave median seeing of 0.84 arcsec FWHM, with a first-quartile average of 0.62 arcsec FWHM. A special use permit securing long-term access to this site on the Coconino National Forest was issued by the United States Forest Service in November 2004.

Design work for the site was completed by M3 Engineering and Technology, in November 2004. Site preparations commenced immediately, and the 0.6 mile access road and grading for the telescope site were completed in May 2005. Trenching operations for power and communications was started subsequently, with conduits in place and covered in December 2005.

3. FACILITY

Since last reported, the facility design plan, also by M3 Engineering and Technology, has changed from a single telescope/coating facility building, to a two-building concept. This change was an effort to simplify the design to reduce cost by housing the coating equipment in a prefabricated metal building and better manage waste heat by moving mechanical equipment away from the telescope enclosure. Figure 3-1 shows a section view of the final facility design.

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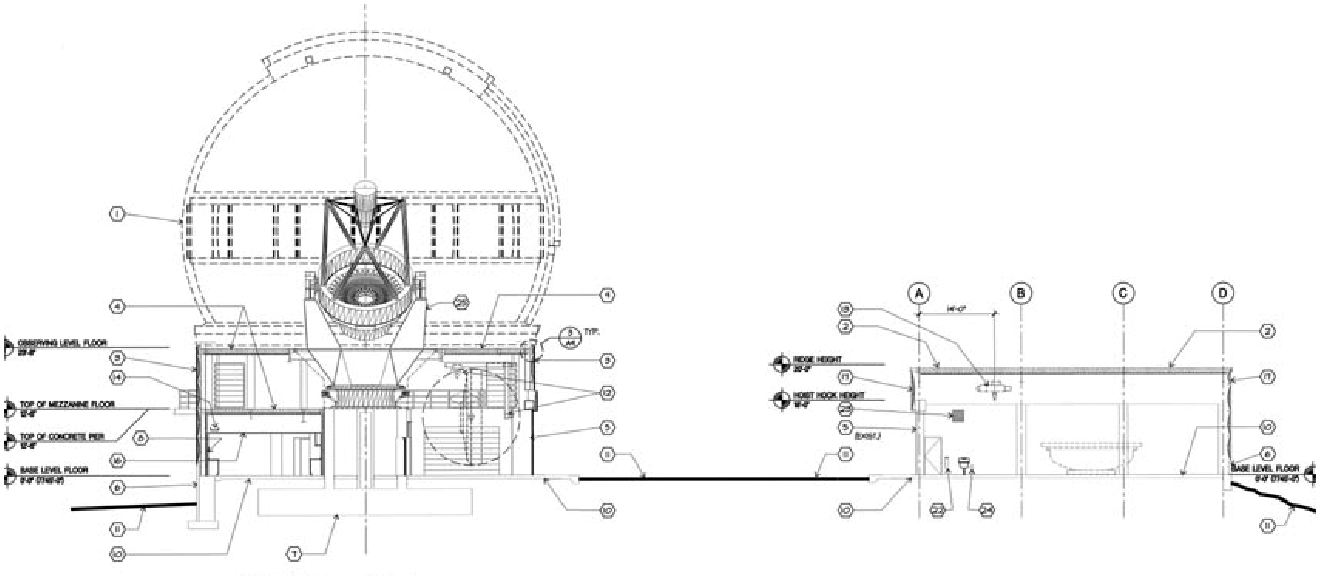

Figure 3-1: DCT Facility Section View

The formal groundbreaking took place in July 2005, with the concrete and structural steel work to be completed by May 2006. Finishing of drywall, plumbing, and electrical installation, and construction of a temporary roof are expected to be completed by the end of 2006.

The facility itself consists of a Telescope Enclosure Building with three levels, and a single level Auxiliary Building. The base level includes spaces for instrument storage, electrical and computer equipment, a control room, a restroom, and an equipment/mirror receiving room. The mezzanine level is largely a buffer zone between the control rooms and the observing space, but provides some instrument storage space, a jib crane for moving instruments, and a clear space for the lift between the base level receiving room and the observing level. The Azimuth motors and mount yoke are also located at the mezzanine level. The observing level is as open as possible for maximum operational space for the telescope structure and provides additional instrument storage areas. This level is serviced by a hydraulic elevator assembly hatch through which the Primary Mirror Assembly and the Prime Focus Instrument can be lowered via the dome crane.

The Auxiliary Building contains spaces for mirror washing and coating, and for mechanical and electrical equipment to support the facility including chillers, HVAC system, electrical transformers, generators, communications, etc. A rail system is included between the two buildings to facilitate a simple process for removing, cleaning, re-coating, and replacing the primary mirror.

Facility construction is consistent with modern observatory practice using steel framed, metal clad buildings designed to equilibrate rapidly and with interior ventilation designed to exhaust waste heat downwind of the observatory. Within the Telescope Enclosure Building only the control room, instrument workspace, and computer room are actively heated and cooled, and these spaces are heavily insulated. The exterior of the building will be white to minimize solar heating. Aerial and geotechnical surveys have been performed, and foundation design for the telescope pier has been completed in concert with finite element and servo-control modeling. Figure 3-2 shows a recent photo of facility construction progress.

Figure 3-2: DCT Enclosure Construction Progress, April 2006

4. TELESCOPE DOME

The telescope dome will employ a steel framework and either aluminum or fiberglass composite panels. This system will provide for a lightweight and cost effective dome. It is anticipated that the dome will rotate via four friction drives diametrically opposed. The shutter will be a nested "over-the-top" design, and driven via chain drives. Ventilation will be provided via twelve 10'x10' ventilation doors, located about the equator of the dome. Although provisions are made for future air conditioning of the dome, thermal management will initially be passive, relying on the well insulated dome panels and rapid temperature equilibration due to the large ventilation openings. Computational fluid dynamics modeling of the telescope facility, including the mount and dome, has been performed by TF Design in Capetown, South Africa. Results are currently being incorporated into finite element modeling, analysis, and design of the telescope mount. Figure 4-1 illustrates the conceptual design of the DCT dome.

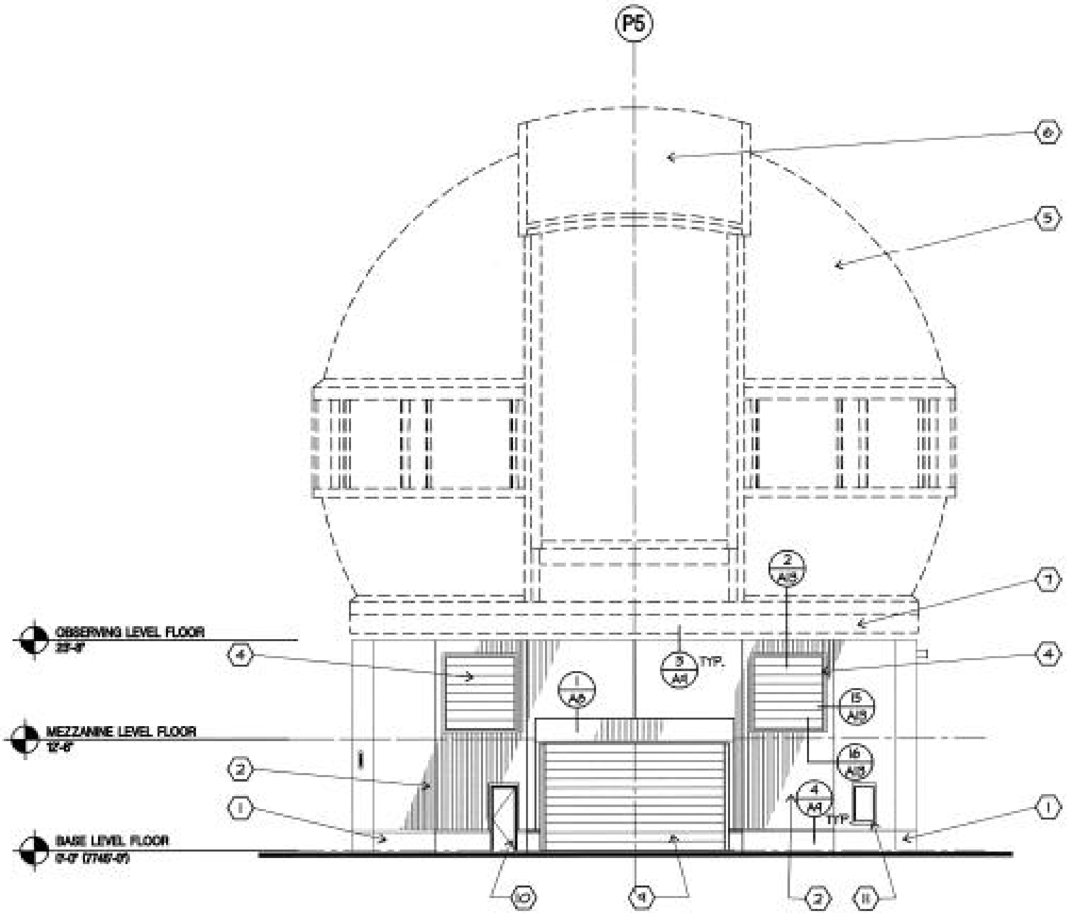

Figure 4-1: DCT Dome Conceptual Design, East Elevation

5. MOUNT

The telescope mount design is currently in development at Vertex-RSI of Richardson, Texas in collaboration with the DCT Project Team. The mount is an Alt-Az gimbal, based on the designs developed for the SOAR and VISTA telescopes. Rolling element bearings are used for the gimbal axes. The Azimuth axis is driven by four counter-torqued motors through helical gears. The Elevation axis uses direct drive torque motors acting on each side of the elevation ring. All motors are glycol cooled to minimize heat sources in the observing environment.

The Mount will support instruments at both Prime and Cassegrain focal positions, with an allowance for future upgrades to accept instruments at the Bent-Cassegrain and Nasmyth positions. Selecting an optical configuration will be accomplished by attaching one of the interchangeable top ends to the Telescope tube; the selected top end will incorporate either the prime focus assembly or secondary mirror and associated spiders.

Preliminary optical alignment will be achieved using a carbon composite and steel truss structure, with strict requirements for parallelism, concentricity, and perpendicularity between optical and mechanical axes. The active optics system will then be used to obtain fine alignment by adjusting M1 tip, tilt, piston, and figure; M2 tip, tilt and piston; and/or Prime Focus Assembly (PFA) tilt. Results obtained with the SOAR telescope mount indicate that tracking accuracy is sufficient for unguided tracking for short, 30-second exposures anticipated for the routine survey work performed by the Prime Focus Camera (PFC). For longer exposures, guiding and low order wavefront sensing are anticipated. Figure 5-1 shows the DCT in its two mount configurations: Prime Focus and Ritchey-Chrétien (RC).

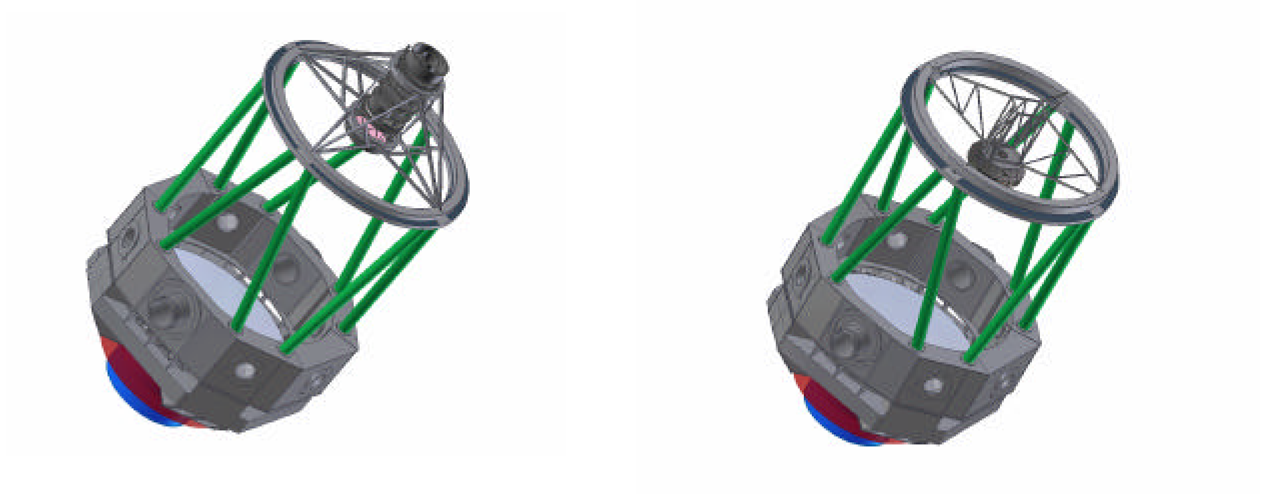

Figure 5-1: Prime Focus Mount Configuration (left); RC Mount Configuration (right)

6. OPTICS

The 4.3m ULE primary mirror blank was fabricated to shape and delivered by Corning, Inc. in September 2005. At this writing, the DCT team is currently evaluating bids for final figuring of the mirror, expected to be completed in 2009.

The active primary mirror system will be similar to that employed by the SOAR telescope. Specifications for the AOS are being developed, and a combination of contracted and internal effort is expected for accomplishing this task. The Primary Mirror will interface to the active optical system and M1 Cell/RC Instrument Adapter with 120 axial actuators, 36 lateral force supports, and 3 tangential defining links. Each support pad will be attached to the mirror using epoxy-adhesive, and fastened to the mirror cell with a pattern of actuators, definers, and retaining bolts.

Actuators are axially stiff and do not permit deformation of the optic due to wind pressure or gravity. To control alignment of the primary mirror, three axial defining actuators will operate in position mode. Open-loop commands will be issued at approximately 1Hz based on lookup tables and temperature sensors. The remaining 117 actuators will operate in force mode, with closed-loop feedback from load cells in each actuator assembly. Lateral support force commands will be issued at a bandwidth of approximately 1Hz, based on the elevation angle of the mount. The three tangential definers will carry nominally zero load. The measured residual load will be used to adjust the relative distributed forces in the four quadrants of the lateral supports, such that the definer loads are zeroed. Closed-loop feedback from optical wavefront sensors may not be available at all focal stations during observations; the bandwidth of the closed-loop system will be approximately 0.1Hz.

The entire primary mirror and M1 Cell assembly will be installed and removed from the telescope mount with the mount pointing to horizon, and the primary mirror assembly lowered to the high bay area in the facility with the dome crane. The secondary mirror will be a fabricated from a light-weight ULE blank. A boule of ULE material has been procured from Corning, Inc. for this 1.4m mirror.

Figure 6-1 shows a photograph of DCT Project Manager, Byron Smith (left) and Lowell Observatory Director, Robert Millis (right) with the completed DCT primary mirror blank.

Figure 6-1: M1 Blank with DCT's B. Smith and R. Millis, September 2005

7. CONTROLS

In order to closely control costs while ensuring compatibility with modern control and programming techniques as well as actual trends in communications, the DCT control system relies heavily on a PC based computing platform and gigabit Ethernet, which at the time of the physical installation is expected to be economically viable to combine with a 10Gb backbone. The diagram in Figure 7-1 shows a condensed view of the computer network and its main components. Several improvements have been introduced in relation to similar solutions:

- Node controllers exclusively handle computations and control strategies, but the related I/O hardware located around the facility is accessed directly only when there are real time constraints and the hardware is completely devoted to that subsystem like in the case of the Telescope mount. By default all the I/O is handled by the Supervisory Control And Data Acquisition controller (SCADA), which has the dual function as engineering maintenance station since all the underlying hardware can be accessed directly regardless of the condition of the Ethernet network or any particular piece of equipment.
- The logger computer also has a dual function acting as messaging server since both functions are very closely related (the logger computer basically records all the details associated to each request or status information in the messaging server database and also the SCADA computer.) Different users may want to look at different sets of data, and maintenance operations may require analyzing some historical trends as well, so in general it is desirable to log as much information as possible.
- Overall, a significant reduction in network traffic shall be achieved, thus increasing the determinism of the system. A further simplification could be introduced by combining the SCADA computer and the messaging server in a single computer, therefore transforming a massive amount of external interaction into internal data exchange. Despite the obvious gain, this would require a thorough analysis of the compatibility of the actual software implementation of the SCADA and messaging portions of the software. Although commercial, each one may have a different origin and specific software environment requirements that could void the integration effort.

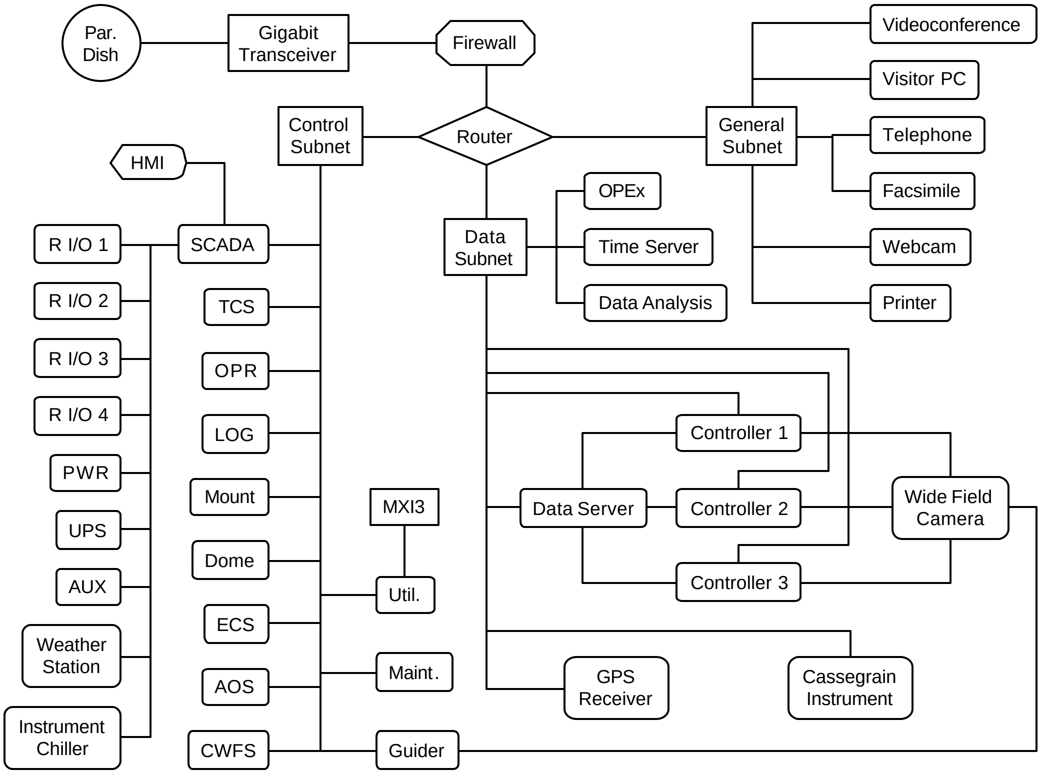

Figure 7-1: View of DCT Control Network Configuration

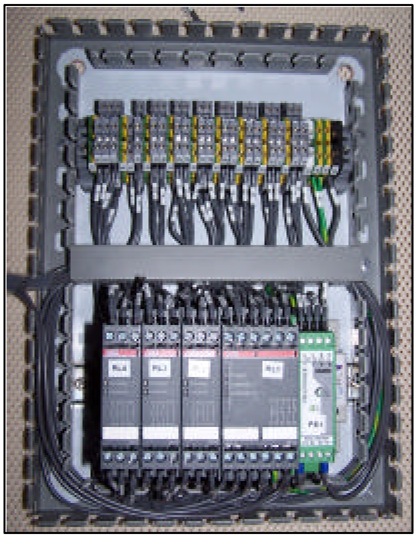

Figure 7-2: DCT Emergency Stop Panel

Such a distributed control system is very cost effective and extremely flexible, providing for simple incorporation of existing algorithms in almost any language and for interface to different hardware standards.

Several electrical panels have already been built in-house for the actual phase of the facility construction: emergency stop (Figure 7-2), emergency lighting, and environmental control system. The Ethernet network will be installed immediately after the completion of the power distribution system, leaving only the external wireless link for a later date in order to take advantage of the latest developments in this fast evolving segment. Other control systems will be implemented to match the delivery schedule of their main parts.

8. SYSTEMS ENGINEERING

Following redesign of the prime focus camera assembly, sensitivities of the system's delivered optical image quality to misalignments of the major assembly optics were derived from Zemax optical models of both the Ritchey-Chrétien and Prime Focus Camera (PFC) configurations. The system error budgets for these two configurations have been realigned to separate the static contributions of design, fabrication, and assembly from dynamic contributions of gravity, wind, and thermal deformations, and facility and mount-induced image smearing. Tolerances derived from the sensitivities and error budget terms for optical misalignments from gravity and wind loads are guiding the current effort by Vertex RSI in the finite element analysis (FEA) of the telescope structure. The early FEA results are helping to define the material and layout of the truss structure supporting separately the RC secondary and PFA top end assemblies. For example, truss tubes made of wound carbon fiber with elastic modulus of 30MPSI, in an eight-leg arrangement, can meet a tight specification of approximately 1mm decenter of the secondary mirror relative to the primary mirror. The comprehensive FEA model also includes the axial and tangential primary mirror supports and will predict the effects of wind as well as gravity loads on the mirror figure.

9. PRIME FOCUS ASSEMBLY

A phase-2 design study of the Prime Focus Assembly (PFA) was initiated at Goodrich Corp. in March 2005 to investigate cost savings through relaxation of select camera requirements; phase-2 design was completed in November 2005. The results of that study are described in these proceedings (MacFarlane and Dunham 2006, 6289-81)[10]. The new operating parameters include relaxation of the image quality requirement to that based on 10% degradation of median seeing rather than 1st quartile average seeing, easing of the U-band requirement, introduction of a tilt/decenter atmospheric dispersion compensator on element L4, rotation of the filters with the CCD mosaic for proper flat-field correction, and repackaging of the PFA without a secondary mirror. The new PFC design uses fused silica in 4/5 elements and standard glass LLF6 in element 4, and utilizes spheres on all but two surfaces, an ellipsoid on L3 and an asphere on L5. The image quality requirements are exceeded over the full 2° field to 80° zenith distance. Figure 9-1 shows the layout of the new conceptual PFA structure, indicating the telescope interface and main mechanized components.

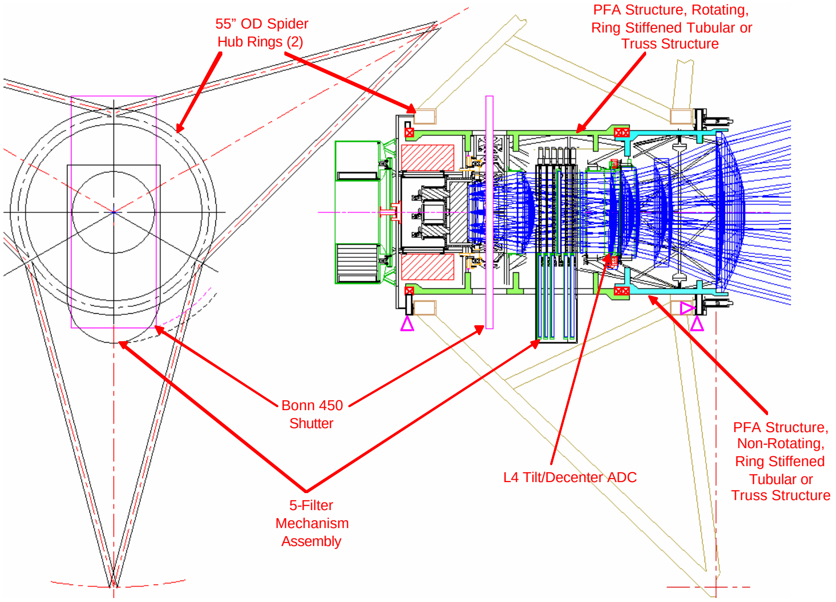

Figure 9-1: The DCT PFA layout showing the optical path and the principal mechanical components. The first camera element, L1 on the far right, is 1.1m diameter. The CCD mosaic is composed of 40 e2v CCD 44-82 2Kx4K CCDs, totaling 1/3 GPx.

10. SCIENCE

The Discovery Channel Telescope holds distinct advantages for survey-based and targeted astronomical research over both current 4m-class and larger aperture telescopes. Implementation of the DCT Prime Focus Camera will introduce a new regime in survey capability through the metric A? , representing telescope collecting area (A, at 13.9m^2) coupled with sky coverage (? , at 2°) in a single exposure. The A? product for the DCT will exceed all existing telescopes with only the planned Pan-STARRS and LSST having greater values. A relatively small user community and flexible operations plan will enable long-term and/or frequent scheduling for programs with precise or dense timing requirements, as well as long-duration scheduling for programs requiring significant sky time.

The DCT astronomical research mission will address fundamental questions about the evolution of the solar system, the formation and evolution of stellar and planetary systems, and the evolution of galactic building blocks such as dwarf galaxies. A set of key observational projects are being defined that in turn address each of these major research categories. Detailed instrumentation specifications to meet the requirements of the key projects are being compiled and extended into conceptual instrument designs. For example, several advanced imaging surveys planned for the wide-field PFC capability have been described[1], including exploration of the Kuiper Belt, extending the search for Near-Earth Objects, and the study of Galactic clusters and OB associations. As noted in section 9, a detailed second-phase conceptual design of the Prime Focus Camera has been completed[10] and this design will meet the requirements of these studies. It is anticipated that the first-light instrumentation complement will not likely include the PFC, therefore RC and Nasmyth-mounted instrumentation, designed to fulfill requirements of DCT key projects, are first under consideration. These instruments include a 30' RC optical imager with field corrector and optional atmospheric dispersion compensator, a high-resolution optical spectrograph, and a dual-purpose near-infrared imager and spectrograph. It is expected that instrumentation goals will be further refined with the addition of another institutional partner to the DCT project.

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