Development of the Optical Communications Telescope Laboratory for Lasercom Missions

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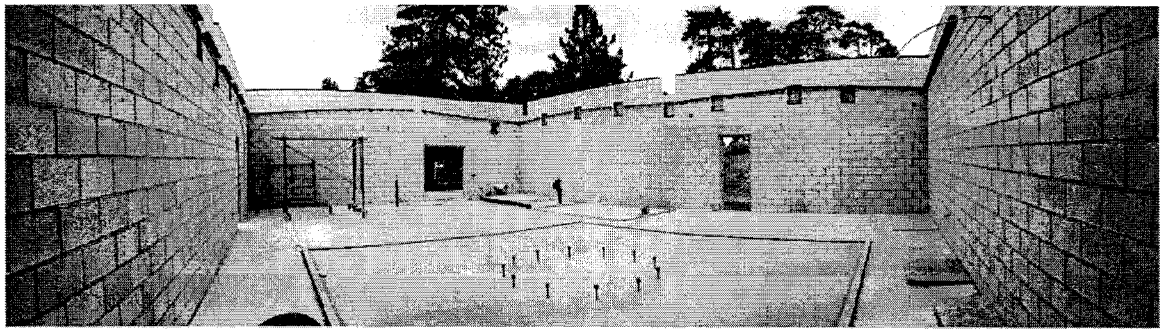
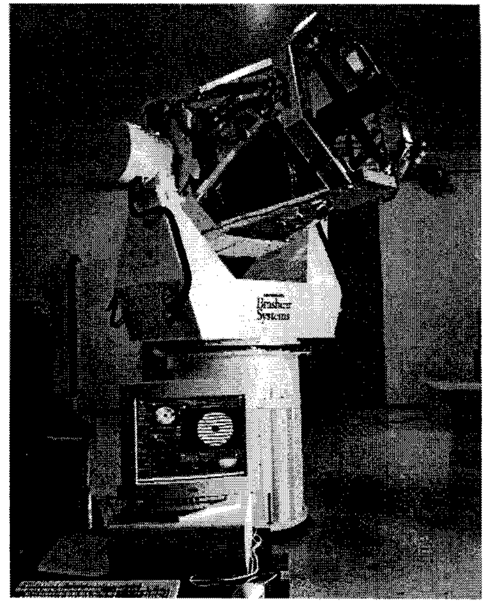
Introduction

- The Telecommunications and Mission Operations Technology Office at JPL has commissioned the construction of a 1-m Optical Communications Telescope Laboratory (OCTL)
- OCTL is NASA's first dedicated optical telescope for technology development and demonstrations to accelerate the state of the art in optical space communication for cost-effective support of missions at high data rates



D090199a JPL PhotoLab

Photo shows a 200 square meter OCTL facility being built at Table Mountain in California. The coude isolation concrete pad with imbedded bolts for installation of the telescope pier shown at center is anchored into the granite bedrock. The building is to be completed by October 1999.



Contraves Brashear Systems has been competitively selected to provide the 1-m tracking telescope; photo shows similar 1-m tracking telescope built by the contractor for the Airforce Research Lab

OCTL OBJECTIVES

- The primary objective of OCTL is to provide an R&D 1-meter optical communications telescope facility to:
  - Support optical communications demonstrations with spacecraft from low Earth orbit (LEO) to deep space
  - Validate optical communication technology for space applications in support of NASA missions
  - To the extent possible provide a testbed for developing operational strategies useful for an eventual optical ground network

OCTL DEVELOPMENT APPROACH

- First, the objectives and high level requirements of OCTL were developed with participation of the optical communication community at JPL and guidance from the program office
- Then, detailed requirements were developed at JPL and refined through an RFI (Request for Information) with leading telescope vendors
- A key decision was made to procure the telescope system, dome, and pier as an integrated turnkey system but to design and build the OCTL building as a separate item
  - Procurement of the entire system (building and telescope) as a turnkey project was not favored by telescope vendors as it is not the norm in this industry and would have resulted in increased bid preparation costs to telescope vendors
  - The design of the telescope, dome, pier and OCTL building have been coordinated to insure mechanical, optical, and thermal integrity of OCTL
- The OCTL building was competitively awarded to Dumarc Corp; construction started in May 99 and is expected to be completed by October 1999
- The turnkey telescope system has just been awarded to Contraves-Brashear; delivery is expected by February 2001.

High Level Functional Requirements

- Image objects from 1 km to infinity at coude focus and be compatible with laser beam uplinks
- Be able to acquire and track spacecraft from LEO to deep space
- Provide easy-to-use operator interfaces, operational reliability and safety, and be easy to maintain.

Major Elements of the Optical Telescope Systems

- The Optical Telescope System Consists of :
  - A 1-m telescope with coude focus to support optical communications
    - The telescope system design has been designed to allow future addition of wide-field/Cassegrain foci as an option to support astrometry and/or asteroid survey.
      - There is strong program office desire to have these options open
      - It is envisioned that separate coude and wide-field/Cassegrain secondary mirrors would be provided that can be manually switched out of, or placed into, the field of view.
  - A telescope tracking and pointing system
  - A dome
  - A pier
  - A 20 cm acquisition aid telescope
  - Associated hardware and software for control/operations/safety

Telescope Design and Key Specifications

- The selected design is a long focus Cassegrain that manages to focus 66% of the energy at coude in a 1.54 μrad (Airy disk) while conforming to vendor's basic 1-m telescope design
  - The requirement for multi-gigabit communications for LEO missions is main driver to focus coude energy in a small disk to avoid pulse smearing
  - The main optical form is:
    - 1.0 m f/1.5 primary mirror
    - 170 m m secondary mirror
    - 75.8 m focal length
    - Aperture obscuration is set by M3- 203 mm equivalent at primary mirror
    - Coude path is conventional (M4-M7) with a 150 mm clear aperture
    - Optics designed to operate at any polarization in the 500 nm to 2200 nm wavelength range
    - At least 72 % of energy incident on aperture will be received at coude focus, (product of unobstructed aperture ratio and end-to-end mirror efficiencies >72 %) for $\lambda>600$ nm, and greater than 67 % for 500 nm$>\lambda>$600 nm).
    - The telescope has at least an unvignetted 500-μrad diameter flat field-of-view

Telescope Design and Key Specifications, continued

- The Telescope System is designed for night and day operations; will survive when operating at sun separation angles >10 degrees and meets operational specifications at any sun separation angle >30 degrees.
  - The control system includes a sun avoidance routine to prevent the telescope from pointing to within an angle of 10 degrees to the sun
  - When operated 30 degrees from the sun the total scattered light from coated mirrors and window surfaces will be less than 10 pW/A ° per square 100 µrad (=10E-8 steradian) field of view at the coude focus at the operating wavelength of 1060 nm and less than 20 pW/A ° for all other wavelengths in the 500-2000 nm range under the following conditions and assumptions:
    - Sun's flux density is assumed to be 0.1 $W/M^2/A^o$; sunlight scattered by the atmosphere is assumed to have a flux density of 0.01 W/M^2/sterad/A °
    - Includes contribution of the sunlight and scattered sunlight by the atmosphere after scattering by the mirrors and all other telescope surfaces but excludes scattered sunlight from the portion of the atmosphere directly in the field of the view of the telescope which would contribute an additional 100 pW/A ° per square 100 µrad

Telescope Design and Key Specifications, continued

- The telescope pointing and tracking system provides the capability to track from LEO satellites to deep-space probes and will also be able to point to fixed AZ and EL positions, in the following modes:
  - Local mode: Telescope will point to fixed AZ and EL position (-5° to 185°).
  - Planetary mode: Telescope will track planets, asteroids and other solar system bodies from a vendor-supplied catalog.
  - Orbital mode: Telescope software will generate pointing predicts and telescope will track objects in Earth orbit based on NORAD two-line orbital element set.
  - Predict mode: Telescope will track objects from LEO to deep space spacecraft from externally provided state vectors (time-stamped AZ/EL values) and start/ stop times.
  - Sidereal mode: Telescope will be able to track in sidereal mode to develop a star file for mount calibration
- Telescope slew rate: The Optical Telescope System has a slew rate (acceleration) of 25 deg/s (3 deg/s/s) in azimuth and 10 deg/s (0.5 deg/s/s) in elevation.
  - The telescope will be able to track for a non-tracking keyhole no greater than 4 degree radius for spacecraft in low earth orbit at 250 km altitude. The nontracking keyhole is halved for each doubling of the spacecraft orbit altitude.

Telescope Design and Key Specifications, continued

- Telescope pointing/tracking limits and tolerances:
  - Telescope elevation travel limit: -5° to 185° for pointing and and 0° to 180° for tracking.
  - Telescope azimuth travel limit for pointing and tracking: ±200°.
  - Blind-pointing accuracy: After all sky mount model, the maximum blind pointing error will be less than 15 μrad at coude focus over the operating temperature range of -10°C to 40°C.
  - For telescope travel within 5 degrees of a calibration reference, the line of sight will retain a relative accuracy of 2.5 μrad.
  - M-7 control: M-7 mirror is motorized and remotely controlled and allow 360° rotation; positioning is repeatable to within 10 μrad.
  - Line-of-sight variation due to focus travel is < 10 μrad (nominal TMF nighttime seeing disk) over total range of travel of secondary mirror

Telescope Design and Key Specifications, continued

Table 1: Maximum RMS line of sight (LOS) jitter error specifications for OCTL for tracking LEO to deep-space spacecraft including spacecraft in medium Earth orbit (MEO) and high Earth orbit (HEO). Also given are the requirements for sidereal tracking and for pointing to a fixed Az/El direction, such as would be used for tracking satellites in geostationary orbit (GEO) and for ground-to-ground demonstrations. Typical elevation axis angular velocities (dθ/dt) are also given for a trajectory plane above 10 degree elevation and outside the tracking keyhole

Elevation Velocity (dθ/dt) in deg/s	RMS LOS Jitter in Bandwidth of 0.1–20 Hz	RMS LOS Jitter in Bandwidth of >20 Hz
Stationary to Planetary 0.0<dθ/dt<0.007	Required <10 μrad	<1 μrad
Stationary to Planetary 0.0=dθ/dt<0.007	Desired <2 μrad	<1 μrad
MEO to HEO 0.0071<dθ/dt<0.54	<10 μrad	<1 μrad
LEO 0.5<dθ/dt<2.0	<10 μrad	<1 μrad

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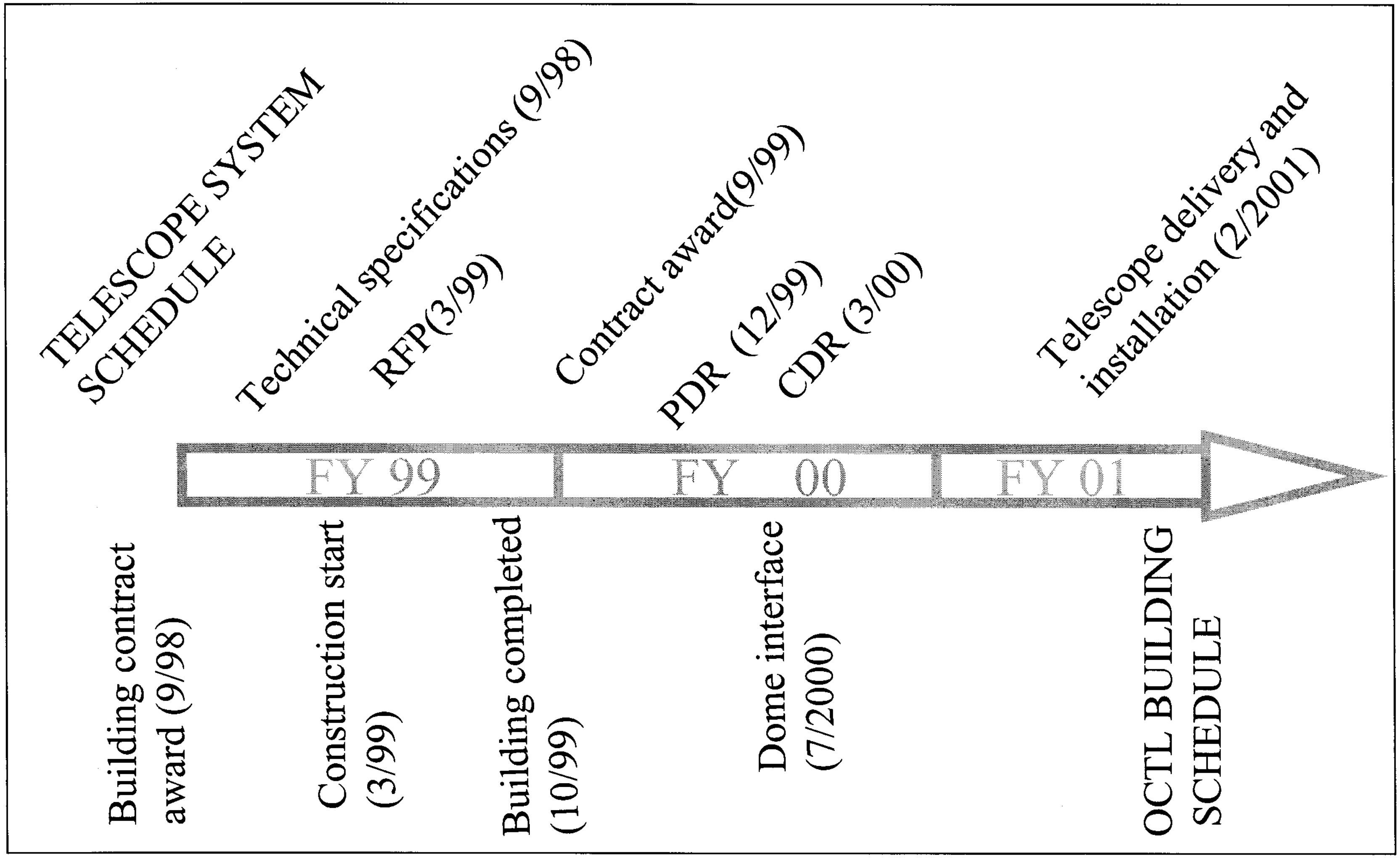
Schedule



Conclusions

- This presentations has reported on a major commitment by NASA for a dedicated Optical Communications Telescope Laboratory to support development and demonstrations of optical communications technology for cost effective support her missions program.
- The laboratory is being built at NASA's Table Mountain Facility near Wrightwood, California. Building construction is expected to be completed by October 1999 and the telescope to be installed by February 2001.

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