DRAFT 2.1

CELT Project Plan

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Contents

1. Introduction

This document describes the program to design and build a new telescope for research in astronomy at visible and infrared wavelengths. The telescope is currently called the California Extremely Large Telescope (CELT).

We divide the project into the following major categories.

Project Organization
Design and Technology Development
Construction
Commissioning
Operations
Management
Budgets
Schedules
Specifications

2. **Project Organization**

CELT is a joint project between the University of California and the California Institute of Technology. This partnership intends to design, build, and operate CELT for the benefit of its scientists.

The design and development activities are guided by the CELT steering committee, chaired by Joe Miller (University of California, Santa Cruz), and Wal Sargent, (California Institute of Technology).

The following working groups have been formed.

- Telescope
- Adaptive Optics
- Science
- Instrumentation
- Dome and Building
- Site

3. Design and Technology Development Overview

We divide these activities into three major phases.

Phase	Activity	duration (months)	cost ($M)
Phase 1	Conceptual Design / Development	12-18	1-2
Phase 2	Preliminary design/ Development	18-24	2-4
Phase 3	Detailed design/ Development	24-48	5-10

Each of these three design phases aims to improve upon the preceding cost estimates and designs.

In Section 4 we list the key categories of these Design and Technology Development phases. In Section 5 we summarize the conceptual design studies that will be undertaken in each of the categories. We describe the product (usually a report) and a rough estimate of the duration and cost. Some work will be carried out by astronomers, and much will be carried out by consultants and staff engineers, guided by the CELT steering committee and working groups.

The aim of Phase 1 (Conceptual Design / Development) is to find a plausible design for CELT with enough detail that the feasibility is established. In this phase, optimization of the design will be extremely limited, but of course we will start from our best estimates on optimal configurations. When necessary, prototyping will be carried out to establish feasibility. Phases 2 and 3 will improve on the efforts of Phase 1, and by the end of Phase 3 we will have a design that is detailed enough to begin construction. A series of reviews both during and at the conclusion of each phase will be used ensure the quality of each activity and also to ensure that the design of each aspect is well integrated into the project as a whole.

Of the many aspects of CELT, adaptive optics is the most difficult to establish feasibility. Here we expect the development activities will occur over a much longer period and will require the efforts and funds of other groups and individuals in addition to those of CELT.

4. Design and Technology Development Topics

In this section we list the detailed topics to be addressed by the Design and Technology Development program. We have organized them as follows;

1. Scientific Motivation
2. Performance Goals
3. Telescope Configuration
4. Telescope Design
5. Adaptive Optics
6. Scientific Instruments
7. Dome
8. Building
9. Site
10. Operations

4.1 Scientific Motivation

Solar system Studies
Planets, young stellar objects
Our Galaxy
Galaxies
Cosmology
Exotic Objects
Unique Opportunities

Seeing-limited observations
Diffraction-limited observations
- AO with Natural guide stars
- AO with laser beacons
- Multi-conjugate AO

Single object work
Multiple object or extended field work

Imaging
Spectroscopy

Visible observations

Near IR observations
Thermal IR observations

4.2 Performance Goals

Collecting area
Throughput
Emissivity
Sky access
Wavelength range
Image quality
    Seeing limited
    Diffraction limited
Field of view
Instrument support
Telescope motion control
    Pointing
    Tracking
    slewing and settling
Dome
    Motion
    Wind protection
    Seeing preservation
Servicing
Reliability
Operations and efficiency

4.3 Telescope Configuration

Arrays of telescopes
Stationary primary zenith pointing
Stationary primary –siderostat
Quasi stationary telescope
Spherical primary telescopes
Ritchey-Chretien two mirror telescopes

4.4 Telescope Design

Error Budgets
External Design Drivers

- Wind
- Temperature
- Seismic

Optical Design

Primary Mirror
- Segments
  - Geometry
  - Fabrication
  - Testing
  - Passive Support
- Active Control Performance
  - Active control system algorithms
  - Error propagation
- Active Control Hardware
  - Sensors
  - Actuators
  - Computing, electronics
  - Alignment Camera
- Role in adaptive optics

Secondary Mirror
- Design
- Fabrication
- Testing
- Support and motion control
- Possible role in adaptive optics
- Multiple secondaries?

Tertiary Mirror
- Design
- Fabrication
- Testing
- Support and motion control
- Multiple tertiaries?

Global Optical Control
- Installation and alignment
- Interactive Control of Primary, Secondary, and Tertiary

Handling and Maintenance of Optics

Telescope Structure
- Conceptual design
  - Stiffness, mass, segment handling, instrument support

Bearings and Drive

4.5 Adaptive Optics

- Modes of operation
  - Near IR
  - Thermal IR
  - Other
- Error budgets
- Alternative Design Concepts
- Natural guide star uses
- Technology Issues
- Baseline design
  - Optical design
  - Wavefront sensors
  - Deformable mirrors
  - Laser beacons
  - Multi-conjugate AO

4.6 Scientific Instruments

- Imaging Systems
  - Seeing limited
    - Visible
    - Near IR
    - Thermal IR
  - Diffraction limited (AO)
    - Near IR
    - Thermal IR
- Spectrographs, single object
    - Seeing limited
    - Visible
    - Near IR
    - Thermal IR
  - Diffraction limited (AO)
    - Near IR
    - Thermal IR
- Multi-Object spectrographs
  - Seeing limited
    - Visible
    - Near IR

Thermal IR
Diffraction limited (AO)
Near IR
Thermal IR
High Resolution
Low Resolution
Other

4.7 Dome

Protection of the Telescope (safety)
Thermal environment of telescope
Wind effects on telescope
Support of telescope/optics maintenance
Support of scientific instruments
Performance specifications

4.8 Building

Support of telescope maintenance
Support of optics maintenance
Support of instrument maintenance
Support of staff
Support of astronomers

4.9 Site

Possible sites
For each site
Fraction of clear nights
Fraction of spectroscopic nights
(cirrus may bear on use of AO)
Wind speed and direction distributions
Temperature distributions
Mean temperatures
Diurnal range distributions
Evening cooling rate distributions
Humidity distributions
Access
Soil Properties
Seismic conditions
Initial site development, infrastructure costs

Political issues
Construction costs at site

4.10 Operations

- Expected mode of operations
  - Queue scheduling
  - Service observing
  - Remote observing
  - Local observing
- Local facility needs
- Cost mitigating strategies
  - Telescope maintenance
  - Dome maintenance
  - Instrument support
  - Astronomer support
- Estimated staffing and cost of operations

5. Technology Development: Milestones and Costs

During Phase 1 an intense program of conceptual design and technology development must move forward together. The results of the technology development will strongly influence the selection of design options. We propose design / technology programs in the following areas. Detailed budgets for each activity are not included here; we only list the total estimated cost. The working group that will be reviewing each program is indicated. Where possible we have given an estimated duration and responsible party.

Activity	Working Group	Responsible Person	Estimated Duration	Estimated Cost ($K)
Scientific Motivation	**Sci**	**Steidel**	**x**	**50**
Performance Goals	**SC**	**SC/Nelson**	**x**	**5**
Telescope Configuration	**T**	**Nelson**	**x**	**5**
Optical design		**Nelson**	**x**	**5**
Error budgets		**Nelson**	**x**	**5**
Segment				
Geometry		**Nelson**	**x**	**10**
Fabrication		**Nelson/Mast**	**x**	**200**
Testing		**Mast**	**x**	**100**
Support		**Nelson**	**x**	**50**
Telescope structure	**T**	**Medwadowski**	**x**	**65+65**
Wind loading	**T**	**Nelson**	**x**	**20**
Active Control Hardware	**T**			
Sensors		**Mast**	**x**	**100**
Actuators		**Mast**	**x**	**50**
Active Control Performance	**T**	**Chanan**	**x**	**100**
Secondary	**T**			
Design		**x**	**x**	**10**
Fabrication		**x**	**x**	**50**
Testing		**x**	**x**	**40**
Wavefront Sensing	**T**	**Chanan**	**x**	**30**
Vibration	**T**	**x**	**x**	**10**
Adaptive Optics	**AO**	**Dekany**	**x**	**100**
Scientific Instruments	**Inst.**	**Mclean**	**x**	**250**
Dome	**D & B**	**Tytler**	**x**	**50**
Building	**D & B**	**Tytler**	**x**	**10**
Site	**Site**	**x**	**x**	**50**
Operations	**T**	**x**	**x**	**20**

Grand Total	**1450**

Notation:

Working Groups	**SC**	Steering Committee
	T	Telescope
	AO	Adaptive Optics
	Sci	Science
	Inst	Instrumentation
	D & B	Dome and Building
	Site	Site

Phase 1 Milestones and Deliverables

Optical Design
    Document the initial design — Report
        Discuss trade offs: FOV vs f/#, back focal distance, curvature vs .. linear field size
    Research and document coatings options — Tech. Note

Error Budgets
    Image size error budget using rms wavefront errors
        1) Telescope — Report
        2) primary mirror — Report
        3) secondary mirror — Report
    Image size error budget using geometric optics
        4) Telescope — Report
        5) primary mirror — Report
        6) secondary mirror — Report

Segment
    Geometry
        Establish size & thickness based on cost tradeoffs — Tech Note
    Fabrication
        Develop PSMP — prototype / Report
        Develop Deep Ion Figuring — prototype / Report
    Testing
        segments testing during fab + error budget — Tech Note
        tradeoffs for holographic, profilometry, interferometry at focus
    Support
        Radial (no holes) — FEA / Tech Note
        Axial (whiffletrees) (no holes) — FEA / Tech Note

Active Control Hardware

Sensors	
Develop non-interlocking, low cost	Tech Note
Focus mode (and other low modes) sensing	Tech Note
Actuators	
Develop low cost	Tech Note
Active Control Performance	
Model error propagation for all modes	Report

Secondary
Design
Fabrication
Testing

Wavefront Sensing	Report

Structure
response to wind loads, natural resonant frequencies,
segment exchange system, cleaning system,
Vibration
Dome and Building ???
Adaptive Optics - CfAO will work on this ??

6. Construction

The construction phase should not begin until the telescope technology program has clearly demonstrated the feasibility of both the cost and the schedule. Since site approval and preparation and building and dome construction have long lead times, they can begin before all of the detailed design is completed.

7. Commissioning

The commissioning phase will follow the construction phase, but due to the complexity of such an Observatory, there will probably be significant overlap between construction, commissioning, and operations phases. Since the primary mirror is segmented, a great deal of commissioning work can be achieved while the primary is being fabricated and assembled. To take advantage of the this, a number of alignment, wavefront control, active system control, and an initial suite of instruments need to be completed well before the primary mirror is completed. A detailed and integrated commissioning plan needs to be developed early in the project to guarantee the required instruments are available.

8. Operations

Given the size and level of technology of the CELT Observatory, the operations costs might be high. The site will likely be distant from California and expensive to support, compounding the problem. It is absolutely critical that during the design and development phases every effort must be made to estimate the impact on operations and minimize those future costs.

It is a central aspect of the design and construction activities that potential costs of maintenance and repair be considered early and often.

Additional design and construction costs may be required to minimize the future costs of operations, maintenance, and repair.

9. Management

During the design and development stage, the CELT Steering Committee will provide oversight for the activities. As we enter preliminary design and detailed design phases, we expect that a more dedicated management structure will be developed. This will involve a Project Manager, a Project engineer, as well as managing engineers for the major parts of the Observatory.

10. Budgets

A major goal of the design and development work is to produce a cost and budget estimate for CELT. For now we will emphasize the likely costs of carrying out the initial/conceptual development work.

11. Schedules

Project schedules through commissioning need to be developed. At this time we will concentrate on the schedules for the design and development activities. Out of this work will come the schedules for construction and commissioning.

12. Requirements / Specifications

In order to proceed with the design of CELT, the astronomical requirements and needs must be specified in a fashion that can guide the designers. Inevitably these specifications will be set by the dynamic process of balancing what the astronomer would like in principal against what the designers and engineers establish as practical and affordable. Thus the specifications will evolve through the design and development phases.

13.1 Scientific Requirements

- Telescope
  - General statement of purpose
  - Primary aperture
  - Optical foci
  - Telescope instrument support (guiders, focus, baffles, rotators, ADC's)
  - Operating conditions
  - Telescope motion
  - Instrument support (size, location, facilities for each focal station)
  - Servicing (mirror coating, segment exchange, maintenance)
- Dome
  - Range of motion
  - Thermal environment
  - Dome motion control
  - Differential dome-telescope motion
- Nasmyth Deck

13.2 Support Facilities Requirements

- Building
- Site
- Headquarters
- Intermediate level facilities
- Communications

Thoughts on studies

Optical Design tradeoffs for an RC telescope

- Primary f#
- Final f#
- Field of view
- Plate scale, size of FOV
- Focal curvature
- Length of telescope
- Location of foci
- Baseline design

The design of planetary stressed mirror polishing fixtures

- What is the geometry of the system
- How many levers are needed
- How much oversize does the mirror need to be
- How large are the stresses
- How accurately do the forces need to be applied
- How accurate does the geometry need to be
- How should levers be attached to glass
- How should forces be generated? Manual, electronic adjustment of springs

Segment fabrication with planetary polishing

- Laboratory tests of prototype stressing fixtures
- Design studies with potential polishers
- Prototype polishing experiments at potential polishers

The design of the passive support of segments

- What thickness is needed for an 18 point axial support
- Where should the points be and what forces are needed
- Layout of the whiffletree geometry
- What advantage comes from spreading out the support "point"
- What is the effect of gluing onto the back- glue shrinkage, metal shrinkage, slits?
- Flexure requirements at pivots and attachments to mirror
- Lateral support design
  - Gravity deformations
  - Thermal issues
  - Attachment to subcell

Actuator options for CELT

- Possible commercial actuators with full range
- Ball screw raft actuators
- Fine resolution 2 stage actuator commercial options

Telescope structural design alternatives

- Gravity deflection of primary
- Resonant frequencies
- Effect of wind loads on top end
- Mass
- Segment handling
- Geometry for bearings
- Geometry for encoders
- Secondary mirror/top end instrument handling
- Tertiary mirror handling
- Bent Cass instrument accomodation and handling

Edge sensors for the ACS

- Requirements
- Capacitive options
- Inductive options
- Attachment technique and accuracy
- Stability
    - Thermal
    - Aging
    - Uncontrolled segment motions

Active control system

- Noise propagation
- Computer needs
- Sensor calibration
- Two stage control philosophy
- Wavefront measurements
- Combining wavefront measurements with edge sensor data
- Separating primary and secondary alignments

Error budget for CELT optics

Error budget for CELT AO

Value and use of warping harnesses on CELT

Dome design concepts

Building requirements

Mirror coating options

Secondary mirror options

Adaptive
Field of view
Material
Segments?