Telescope Project Development Seminar

Session 1a: The Project

Matt Johns
1/20/2017
U. Tokyo

Information regarding the course

- **Hi, my name is Matt Johns**
- I am a Project Scientist at the University of Arizona, Tucson AZ, working on optical telescope projects including the primary mirror assembly for the Tokyo Atacama Observatory's 6.5 m telescope.
- This course covers some of the elements that go into the development of ground-based optical/IR telescopes. I focus primarily on the technical/engineering aspects.
- This short course is being conducted in 6 sessions, 2 per day on 3 days over the space of 2^+ weeks.
- Presentations will be available after each session on the Graduate Students' website: http://www.astron.s.u-tokyo.ac.jp/students/news-for-graduate/ .
- Students will be given assignments to complete outside of class hours.
- There will be a final exam during session 6.
- Grades will be based on the submitted assignments, participation in the class, and the final exam.

I look forward to meeting you all. Please feel free to come up and talk with me.

Lecture Series Schedule

- The Project (session 1a) (April 14)
- System engineering (session 1b) (April 14)
- Site, Enclosure & Facilities (session 2) (April 14)
- Telescope Design (session 3) (April 21)
- Telescope Performance (session 4) (April 21)
- Active and Adaptive Optics (session 5a) (April 28)
- Science instruments (session 5b) (April 28)
- Discussion & exam (session 6) (April 28)

Session 1 Outline

Session 1a Introduction

1. Introduction
2. Project Initiation
3. Student Assignment
4. Project Implementation

Session 1b Systems Engineering

1. Systems Engineering Function
2. SE Documents
3. Requirements Flow-down
4. Interfaces
5. Document management system
6. Configuration control
7. Risk management
8. Modeling and analysis
9. Prototyping
10. Hazard management
11. Quality Assurance
12. Reviews
13. Integration and Commissioning
14. Student Assignment

Initial Comments

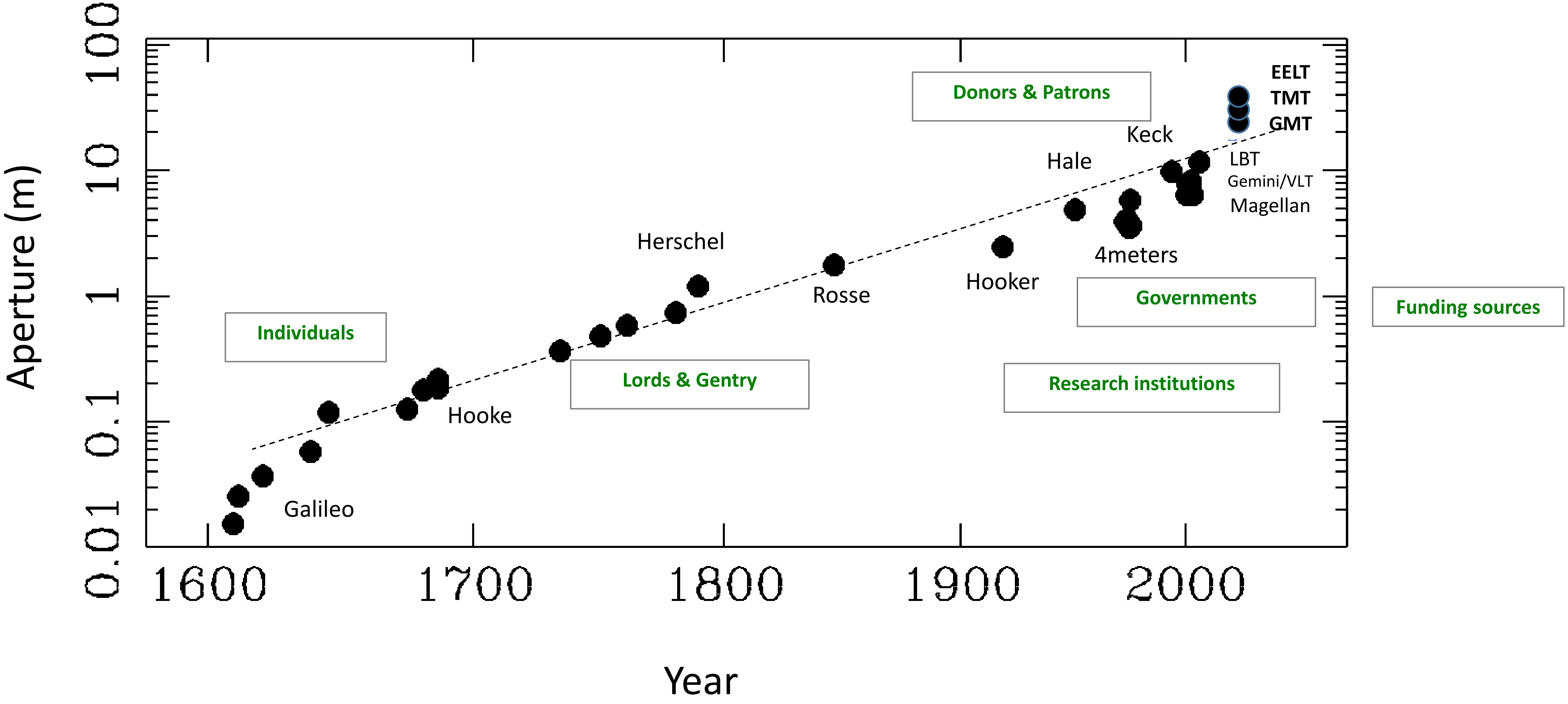
The purpose of this seminar is to step through the process by which a major ground-based optical telescope observatory is conceived, designed, constructed and installed on site. The focus will be on the technical side and the decisions that are taken along the way.

The topics covered are intended as a general discussion but draw heavily on the speaker's experience with the Magellan 6.5m Telescopes Project (Cost = $72M) and the Giant Magellan Telescope (25M) Project (Projected cost >$1B). Both of these projects developed out of an University/Research Institution tradition. GMT has international partners with federal participation.

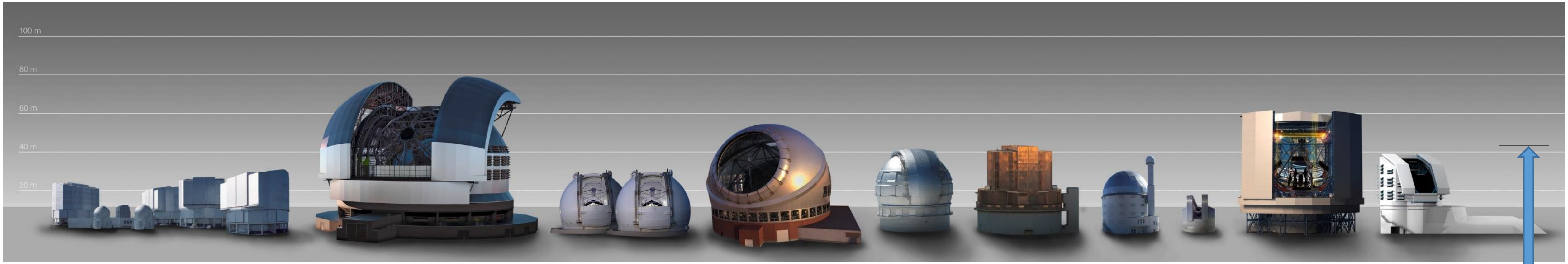
Projects differ in detail but share many features in their organization and implementation. Differences arise from the different management and contracting practices of the managing organization and stakeholders, the degree to which work packages are shared out between various national and international institutions and groups, legal conditions at the site, and the relation of the project to existing facilities and programs.

One size does not fit all. The level of project management and engineering effort required for a $1B project would not be appropriate or cost effective for a $10M project. A balance must the struck but many of the underlying principles guiding the work and management processes are similar.

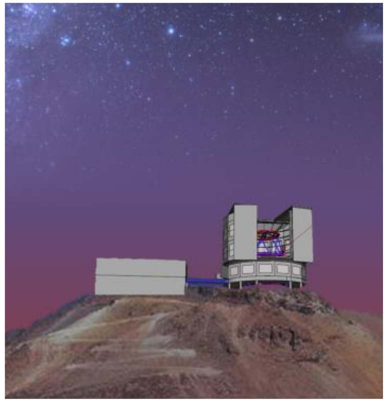
The March of History



Telescopes – Existing and Under Development



VLT *EELT* Keck *TMT* GTC Subaru SALT NTT *GMT* *LSST*

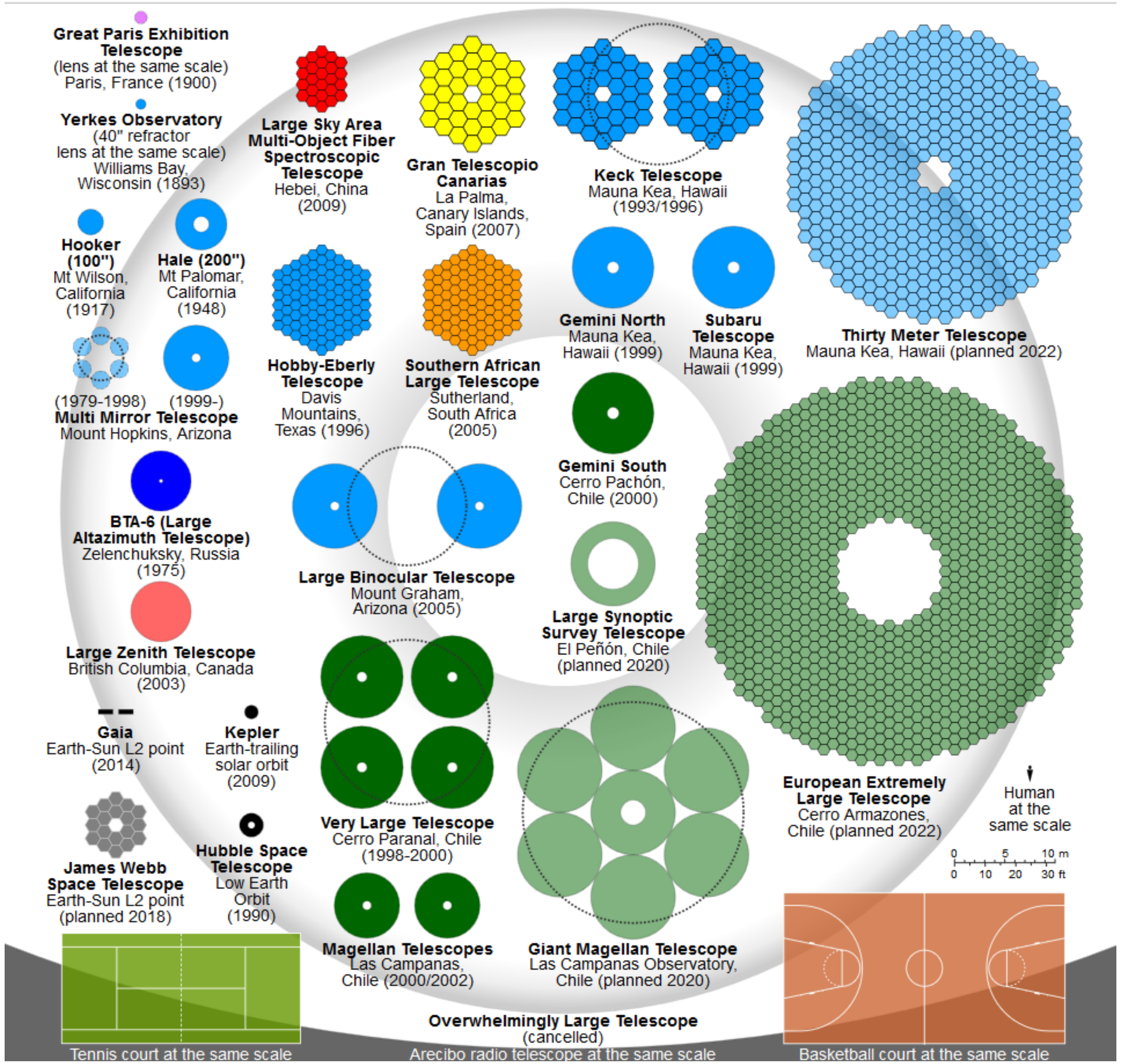


TAO 6.5 m

TSPM 6.5m

LBT

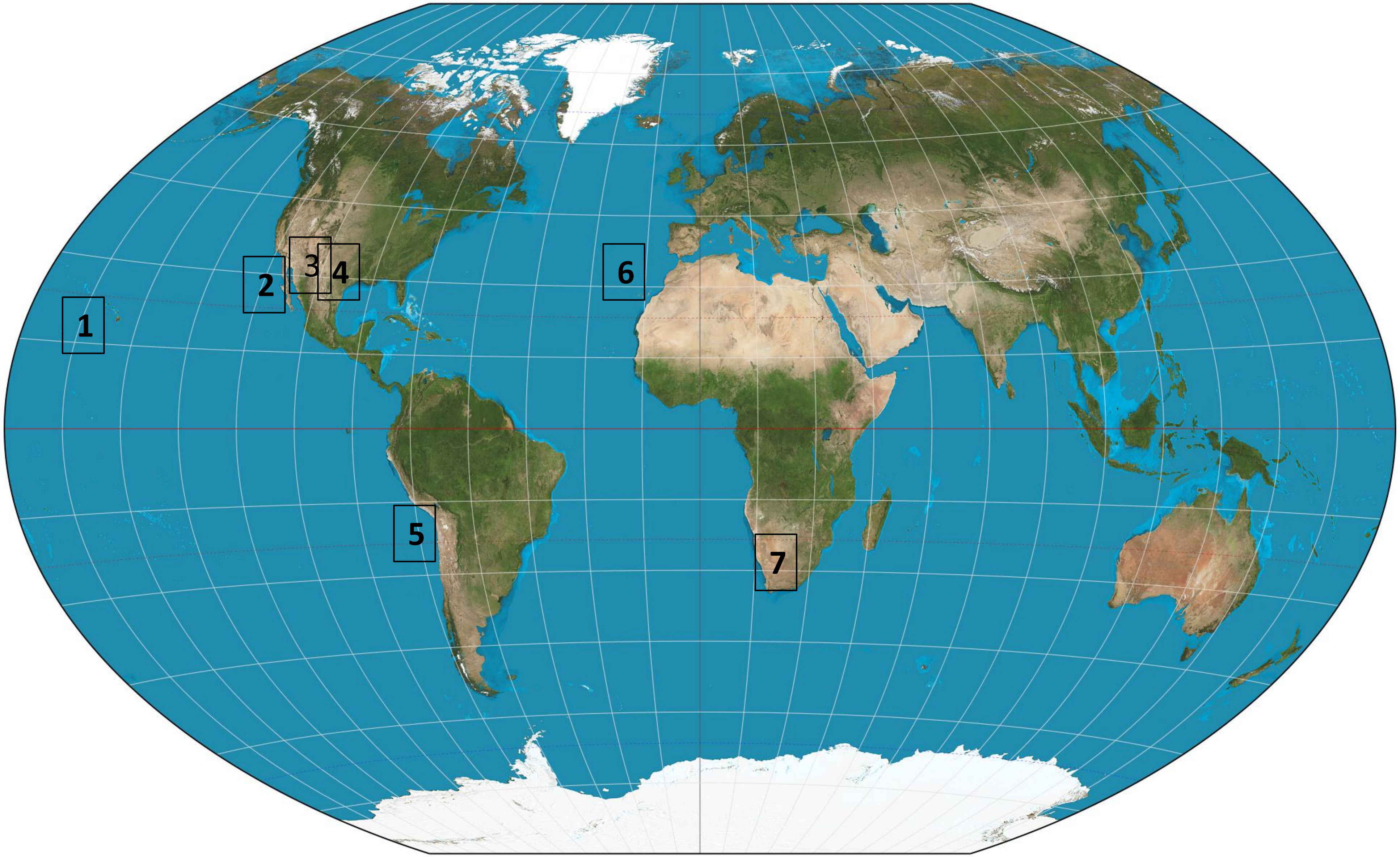
Telescope Comparison by Primary Mirror



Primary Mirror Types

- Monolithic
  - Magellan
  - MMT
  - Gemini
  - Subaru
  - *TAO*
  - *TSPM*
- Large segments
  - LBT
  - VLT (when used in interferometer mode)
  - *GMT*
- Small segments
  - Keck
  - Hobby-Eberly
  - SALT
  - GTC
  - *TMT*
  - *EELT*

World Sites (optical telescopes ≥ 6m)



1. Hawaii US
   - Keck (2 x 10m)
   - Gemini N (8m)
   - Subaru (8m)
   - *TMT (30m)*
2. San Pedro Martir, Mexico
   - *TSPM (6.5m)*
3. Arizona, USA
   - MMT (6.5m)
   - LBT (2 x 8m)
4. Texas, USA
   - Hobby-Eberly (10m)
5. Chile
   - Gemini S (8m)
   - VLT (4 x 8m)
   - Magellan I & II (2 x 6.5m)
   - *LSST (8m)*
   - *GMT (25m)*
   - EELT (39m)
   - *TAO (6.5m)*
6. La Palma, Canary Islands
   - GTC (10m)
7. South Africa
   - SALT (10m)

Italic = under development

Project Initiation

- **Establish Project Goal(s)**
  - Institutional goals (Furtherance of the Institution's Mission, Mission statement)
  - Science themes and objectives
  - Project's place in the global picture
- **Recruit partners**
  - Execute a Memorandum or Partnership Agreement
  - Establish governance (Elect a Board of Directors)
- **Define management structure**
  - Create the legal entity (e.g. a corporation, partnership)
  - Establish organizational structure
  - Secure funding
- **Form project team(s)**
- **Develop Science Case**
- **Project Implementation Plan (PIP)**
- **Begin the conceptualization Phase A**

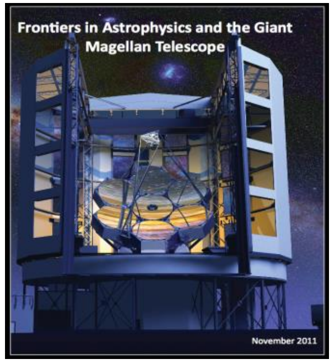
Science Case

- **The Science Case describes the scientific objectives for the telescope facility.**
  - It anticipates the high priority science opportunities that will be topical when the facility goes into operation taking into account the interests of its users (present and future) and considers how these may evolve in the future.
  - It recognizes that much (most?) of the long-term telescope use will involve new science objectives and instruments.
  - It considers technical developments in the state-of-the art that will impact the design of the facility.
  - It considers what other facilities will be operating in the era when this telescope is operational (synergy and competition).
  - It translates the science objectives into general instrument requirements.
  - It may include operational concepts.
- **Facility categories**
  - "Multi-purpose" facilities (Subaru, Keck, Magellan, Gemini, etc.) with broad science capabilites
  - Survey telescopes (Sloan, LSST)
  - Specially optimized telescopes (LBT, TAO)

Four Current Projects

- **Giant Magellan Telescope (GMT)**
  - Next generation extremely large telescope
  - Designed to address science themes identified in the US Decadal Survey
  - International partnership of universities and research institutions
- **Thirty Meter Telescope (TMT)**
  - Next generation extremely large telescope
  - Designed to address science themes identified in the US Decadal Survey
  - International partnership with Japanese participation
- **Large Synoptic Survey Telescope (LSST)**
  - Next generation survey telescope
  - High-cadence high-sky coverage science
  - Funded by the US National Science Foundation
- **Tokyo Atacama Observatory (TAO)**
  - Infrared optimized
  - University of Tokyo Project

GMT Science Case



GMT Science Themes

- From Stars to Planets
- Exoplanets
- Stellar Populations
- Galaxy Assembly & Evolution
- Cosmology and Fundamental Physics
- First Light & Reionization
- Transient Phenomena
- Synergies with other Facilities

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Concept of Operations
Directed key science programs

Science Instruments

- **GMTIFS – AO-fed Integral-Field Spectrograph**
- **GMACS – Optical Multi-object Spectrometer**
- **NIRMOS – Near IR Multi-Object Spectrometer**
- **G-CLEF – Optical high-resolution/precision radial velocity Spectrometer**
- **GMTNIRS – Near-IR High-resolution Spectrometer**
- **MANIFEST – Facility Fiber feed**

GMT SLDR Section 9 – Instrumentation, 2013.

Science Case: GMT-SCI-REF-00482_2_GMT_Science_Book.pdf

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TMT Science Case

Visiting Professor Lecture

TMT Science Themes

- What is the nature and composition of the Universe?
- When did the first galaxies form and how did they evolve?
- What is the relationship between black holes and galaxies?
- How do stars and planets form?
- What is the nature of extra-solar planets?
- Is there life elsewhere in the Universe?

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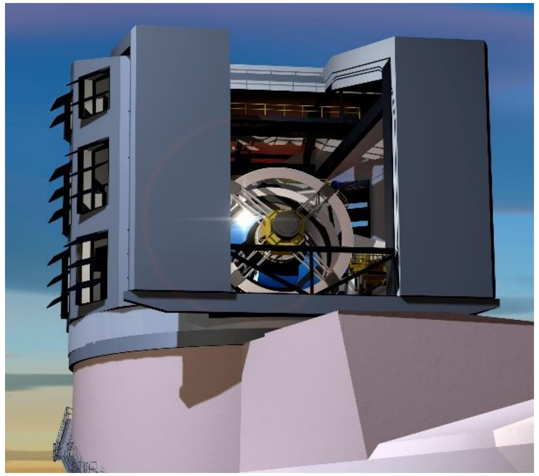
Concept of Operations
Directed key science programs

Science Instruments

- IRIS – Near-IR Integral-Field Spectrometer
- WFOS/MOBIE – optical Multi-Object Spectrometer
- IRMOS – near-IR MOS
- HROS – Optical echelle
- MIRES – Mid-IR echelle
- PFI - High contrast AO imager / spectrograph
- WIRC – Near-IR MCAO imager
- NIRES – Near-IR echelle

Science Case: TMT.PSC.TEC.07.007.REL02

LSST Science Case



Survey Telescope

LSST Science Themes

- **Dark Matter and Dark Energy**
- **The Solar System**
- **The Changing Sky**
- **The Milky Way**

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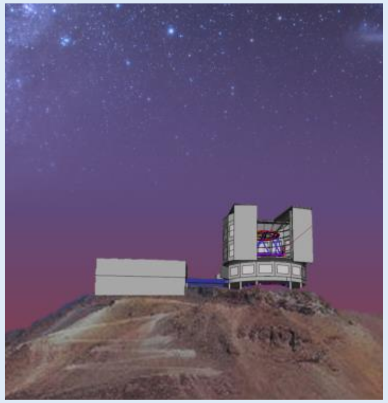
Concept of Operations
High-cadence wide-coverage
Massive data archive

Science Instruments

- **9.6 Sq. Degree multi-band Optical-NIR Camera**

Science Case: (arXiv:0805.2366); version 3.1

Student Assignment



TAO 6.5 m

- Briefly describe the science case for the Tokyo Atacama Observatory 6.5 m Telescope and how that leads to the choice of site and instrumentation.

References & op. cit.

- http://www.ioa.s.u-tokyo.ac.jp/TAO/en/

- SPIE 2016 Proceeding papers
  http://adsabs.harvard.edu/abs/2016SPIE.9906E..4QT
  http://adsabs.harvard.edu/abs/2016SPIE.9906E..2MK
  http://adsabs.harvard.edu/abs/2016SPIE.9906E..0RY

Project (Implementation) Plan

1 Project Partners

2 Project Organization

- 2.1 Partnership Agreement
- 2.2 Organizational structure
- 2.3 Project Office

3 Project Phases

- 3.1 Phase A: Conceptual Design
- 3.2 Phase B: Design Development
- 3.3 Phase C: Construction/Commissioning
- 3.4 Phase D: Operations

4 Implementation Details

- 4.1 Work breakdown structure (WBS)
- 4.2 Systems Engineering
- 4.3 Contracting Strategy
- 4.4 Risk Management
- 4.5 Cost Management
- 4.6 Scope Contingency
- 4.7 Project Meetings
- 4.8 Reports
- 4.9 Reviews
- 4.10 Milestones & Schedule
- 4.11 Staffing plan
- 4.12 Commissioning Plan

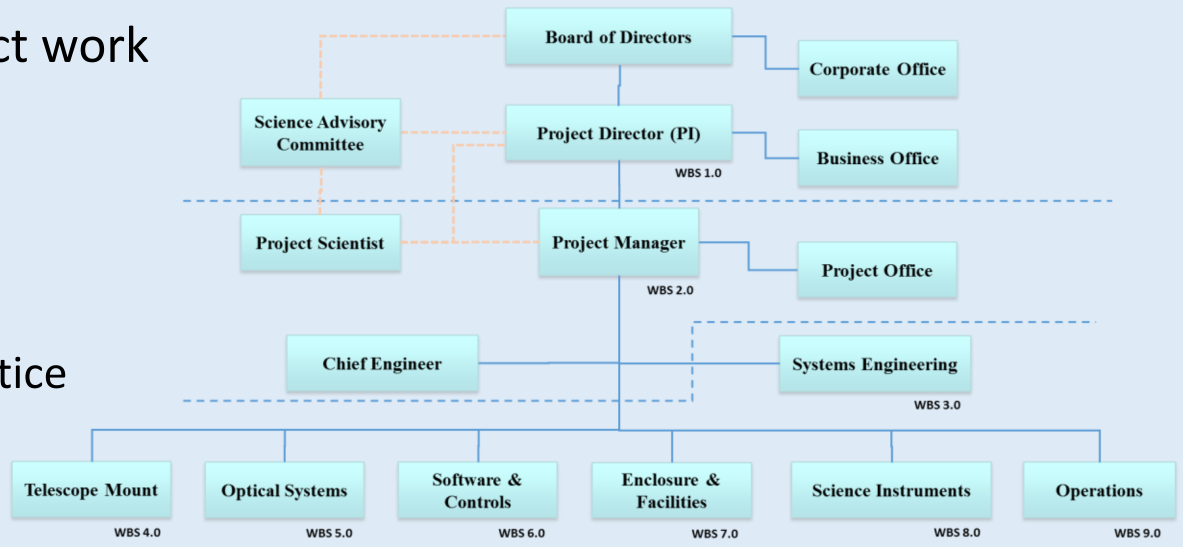
5 Budget

- 5.1 Project Budget
- 5.2 Cash flow

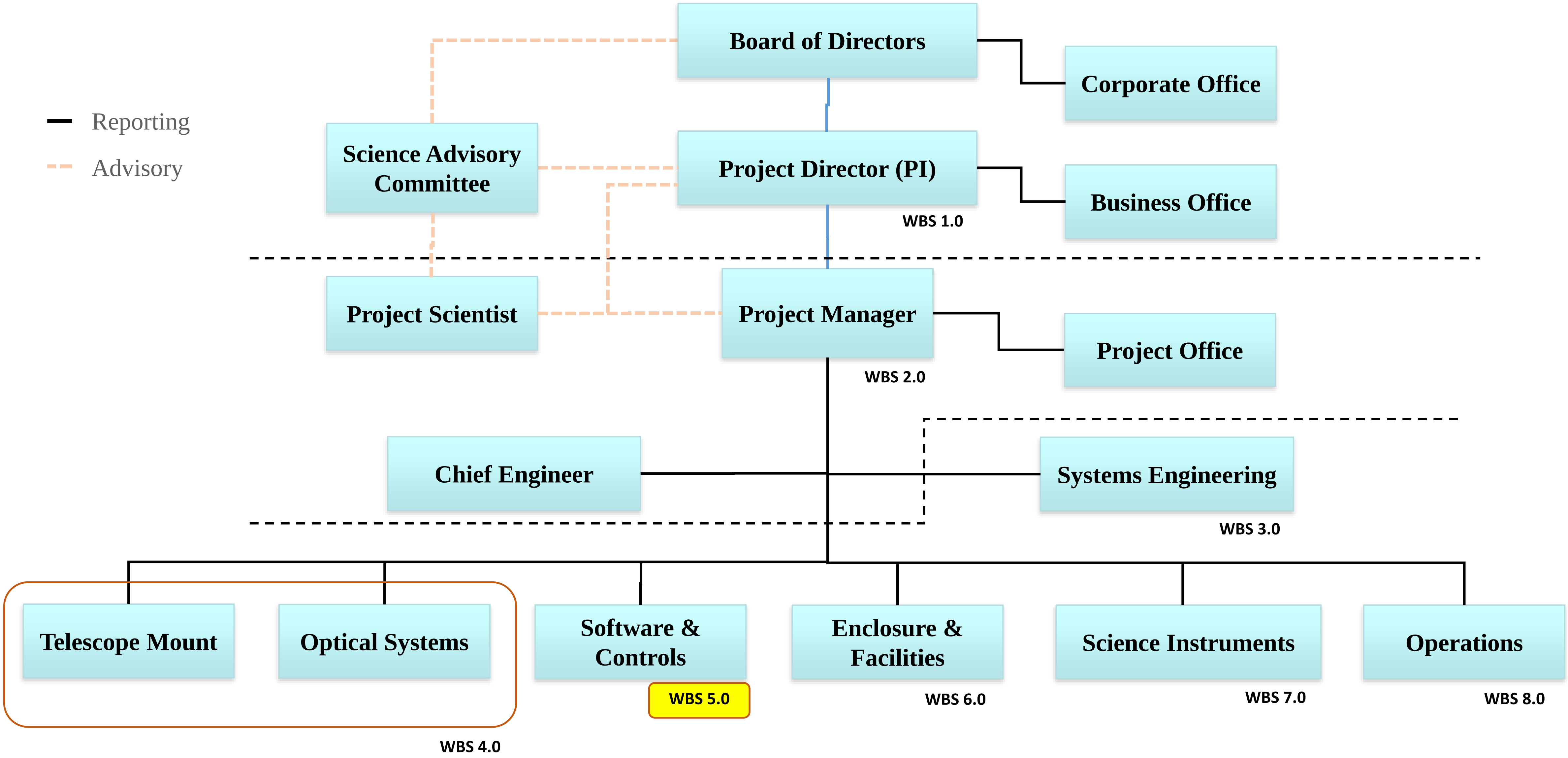
The Project Plan describes how the project will be organized and conducted. It is, in effect, the Project Manager's roadmap.

Project Organization

- An organization chart shows the breakdown of Project work groups and lines of reporting
- It is tailored to accommodate
  - Hosting organization's organization and standard practice
  - Human resources available to the Project
  - Distribution of both internal and external work packages
- Job functions and responsibilities are spelled out in the Project Implementation Plan



Hypothetical Project Organization



Telescope Mount Subsystems

Each group has its own team leader and assigned engineers and defined work breakdown.

Telescope Mount Group Leader

WBS 4.0

- **Mount Structure**
- **Main axis drives**
- **Main axis bearings**
- **Instrument Rotators**
- **Mirror Cover**
- **Counterweights**
- **Cable wraps and Trays**
- **Auxiliary Equipment**
- **Baffles**

<u>Subsystem documents</u>

- Operations Concepts
- Subsystem Requirements
- Interface Control Docs
- Verification Plans
- AITC Plans
- Budgets and schedules

Phase A : Conceptual Design

Phase A: “Conceptual Design”

286 Weeks

- Prepare Science Case - Science Working Group (SWG)
- Draft Top-Level Scientific Requirements
- Execute Memorandum of Understanding with Stakeholders
- Assemble Design Teams
- Develop Conceptual Design
  - **Develop Architecture Concept**
  - **Define Concept of Operations**
  - Identify Major Technical and Cost Risks
  - Conduct Feasibility Studies
  - Draft Instrumentation Plan
- Design, Construct & Deploy Site Testing Stations
  - Begin Testing
- Prepare Draft Phase B/C Implementation Plan
  - Organization/Management Plan
  - WBS, Budget, & Schedule
- Conduct Conceptual Design Review (CoDR)
- Submit Implementation Plan to Stakeholders
  - Revise Plan as Necessary

Phase B: Design Development

Phase B: "Design Development" — *156 Weeks*

- Obtain Design Phase Approval
- Establish Organizational Structure
  - Corporation & Laws of Governance
  - Board of Directors
  - Science Advisory Committee
  - Appoint Director/Project Manager/Project Scientist
- Establish Project Office
- Hire Key Project Staff
- Construct Additional Site Test Stations (as identified)
  - Continue Test Program
- Assemble High-Level Technical Specifications & Error Budgets
- Down-Select First-Generation Instrument Complement
- Assign Work Packages
- Prototype High-Risk/Long Lead-Time Systems
  - Primary Mirror Supports
  - AO System Components
- Complete Site Selection
- Prepare Detailed Phase C/D Implementation Plan
  - Update WBS, Budget, & Schedule
- Conduct Preliminary Design Review(s)
- Submit Implementation Plan & PDR Results to Shareholders
  - Revise Plan
  - "Freeze" High-Level Technical Specifications & Error Budgets

Phase C: Construction/AITC

Phase C: "Construction/commissioning" *286 Weeks*

- Obtain Approval to Proceed with Construction
- Prepare & Let Design/Fabrication Contracts
  - Assign Construction Management Staff
  - Contract Monitoring
  - Conduct Reviews (Design, Source Inspections, Acceptance)
- Start On-Site Construction
- Construct Base Operations Facility
- Begin Second Generation Instrument Studies
- Assemble & Test Telescope, Subsystems, & Instruments On-Site
- Prepare for Commissioning/Operations
  - Update Commissioning/Operations Plan
  - Assemble Commissioning/Operations Staff
- Commission the Telescope and Instruments
  - Train Operations Staff
  - Characterize System Performance
  - Conduct Acceptance Reviews
- Phase-in Science Operations

Work Breakdown Structure (WBS)

- Projects are typically organized around a work breakdown structure (WBS)
  - The WBS is defined as a "a hierarchical decomposition of the total scope of work to be carried out by the project team to accomplish the project objectives and create the required deliverables." (see https://en.wikipedia.org/wiki/Work_breakdown_structure)
- The WBS captures 100% of the activities required to complete the project in a top-down decomposition of the work and provides a tool for developing the project schedule and cost.
- Tasks required to complete the work are developed from the WBS.
- The WBS is organized by major subsystems (telescope, enclosure, etc.), project management activities, systems engineering, instrument development, and operations planning and preparation.
- "The WBS Dictionary describes each component of the WBS with milestones, deliverables, activities, scope, and sometimes dates, resources, costs, quality."
- If cost and basis-of-estimate (BOE) information is included, the WBS can be used to develop the project budget and contingency.
- The WBS may be implemented in MS Excel or other proprietary software.

WBS example: Telescope Mount

- WBS 4.0 Telescope Mount
  - 4.1 Telescope Engineering & Management
    - 4.1.1 Telescope Group Project Management
    - 4.1.2 Telescope Group Systems Engineering
  - 4.2 Telescope Mount Production
    - 4.2.1 Mount Structure Analysis and Design
    - 4.2.2 Mount Contracting
    - 4.2.3 Mount Fabrication
    - 4.2.4 Shop Assembly, Integration and Test (AIT)
    - 4.2.5 Mount Disassembly, Packing and Shipping
  - 4.3 On-site Assembly, Integration, and Commissioning (AITC)

Dictionary entry

- 4.2.3.1 Mount Structure
- 4.2.3.2 Main axis drives
- 4.2.3.3 Main Axis Bearings
- 4.2.3.4 Instrument Rotators
- 4.2.3.5 Mirror Cover
- 4.2.3.6 Counterweights
- 4.2.3.7 Cable wraps and Trays
- 4.2.3.8 Auxiliary Equipment

Simplified WBS Dictionary Example

WBS 4.2.3.1 Mount Structure

The structural components of the telescope mount will be final designed and fabricated under contract according to the preliminary design and specifications provided by the Project. They will be assembled in the fabricator's shop and tested as part of the overall telescope assembly (cf. WBS 4.2.4).

Structural components of the mount include:

- Azimuth track and pier embedments
- Azimuth disk assembly
- Elevation assembly including upper truss and top frame
- Access platforms
- Primary mirror cell weldments

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- Tasks
- Schedule
- Budget

Does not include:

- Assembly or alignment fixturing
- Drives, bearings, encoders, or controls
- Assembly, integration, and test

Product Breakdown Structure (PBS)

- The Product Breakdown Structure (PBS) provides "an exhaustive, hierarchical listing of all the deliverables (physical, functional or conceptual) that make up the project.”
- Its purposes are
  - Provide a comprehensive list of project deliverables
  - Avoid duplication – a deliverable item appears in only one place in the PBS
  - Aid in developing the WBS ensuring that all deliverables are included in the work plan
  - Provide the structure for the interface control documents cross-matrix
- PBS items are linked to the WBS

PBS Example - Primary Mirror Assembly

WBS 5.0 Optical Systems						
Subsystem			WBS	Assembly	Name	Notes
[Proj]-OP-M1			WBS.n		**Primary mirror subsystems**	
	[Proj]-OP-M1-PM		WBS.n.n		**Primary mirror**	
		[Proj]-OP-M1-PM-MR		Drawing numbers	6.5m primary mirror	1 unit - Includes hardpoint wedges and bonded-on metrology attachments (if any).
		[Proj]-OP-M1-PM-TA			M1 thermocouple array	1 assembly - Thermocouples imbedded in M1 and read-out electronics.
		[Proj]-OP-M1-PM-PS			M1 position sensors	1 set - Dial indicators and cell mounts
	[Proj]-OP-M1-CL				**M1 cell**	
		[Proj]-OP-M1-CL-CW			M1 cell weldment	1 unit - 6.5 m mirror cell UA drawing: 23500
		[Proj]-OP-M1-CL-AR			M1 cell aperture ring	1 unit - Clear aperture stop above M1
		[Proj]-OP-M1-CL-CC			M1 cell central cylinder	1 unit - M3 support column (if required). Also provides a mounting ring for inner M1 front surface seal.
		[Proj]-OP-M1-CL-OA			M1 cell outer air seal assembly	1 unit - Outer M1 front surface seal.
		[Proj]-OP-M1-CL-IA			M1 cell inner air seal assembly	1 unit - Inner M1 front surface seal. No design yet
		[Proj]-OP-M1-CL-SV			M1 cell center blank/off safety valve	1 unit - Upper/lower plenum isolation cover used during re-coating
		[Proj]-OP-M1-CL-UO			M1 cell upper flange o'ring	1 unit - O'ring to seal vacuum chamber to cell. Need to be specified for procurement 1 spare recomended
		[Proj]-OP-M1-CL-LO			M1 cell lower flange o'ring	1 unit - O'ring to seal vacuum chamber to cell. Need to be specified for procurement 1 spare recomended
		[Proj]-OP-M1-CL-BC			M1 cell bottom covers	28 units - Var. sizes to fit cell openings
		[Proj]-OP-M1-CL-IC			M1 cell inspection port vented covers	6 units - Located in the cell inside
		[Proj]-OP-M1-CL-BP			M1 cell inspection port blank-off plates	6 units - Port blank-off covers for use during mirror coating
		[Proj]-OP-M1-CL-PC			M1 cell vacuum flange protective covers	2 units - Port blank-off covers to protect the vacuum flanges during shipping
		[Proj]-OP-M1-CL-BP			M1 cell utilities port blank-off plate	3 units - Used to blank off the port during re-coating
		[Proj]-OP-M1-CL-VC			M1 cell utilities port vacuum flange covers	3 units - Protective covers used in operation when the blank off plates are not installed

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3 level PBS for a UA 6.5m Primary Mirror Assembly

Entries for each deliverable

Further breakdown into subassemblies as required

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Schedule

Visiting Professor Lecture

1	2	3	4	5	6
1.04.10 Auxiliary Equipment		1560	04/02/12 A	03/23/18	
1.04.10.01 M1 Lifting Fixture		1450	04/02/12 A	10/23/17	
TS_1182	Define M1 lifter design requirements	5	04/02/12 A	04/06/12 A	100%
TS_1183	M1 lifter ICD's	5	04/09/12 A	04/13/12 A	100%
TS_1184	Obtain design drawings and specifications from the UofA	40	01/02/17*	02/24/17	0%
TS_1186	M1 lifter requirements, SOW and RFP doc's	10	02/27/17	03/10/17	0%
TS_1187	Procure M1 Lifter fabrication services contractor	40	03/13/17	05/05/17	0%
TS_1188	M1 Lifter fabrication services contract award	0	05/08/17*		0%
TS_1189	M1 Lifter fabrication	120	05/08/17	10/20/17	0%
TS_1189A	Spreader Bar	120	05/08/17	10/20/17	0%
TS_1190	M1 Lifter FAT	0	10/23/17		0%
1.04.10.02 Auxiliary Equipment		1347	11/01/12 A	12/29/17	
TS_1194	Auxiliary Equipment Conceptual Design Completed	11	11/01/12 A	11/15/12 A	100%
TS_1197	Auxiliary Equipment preliminary design requirements & ICD's	5	11/12/12 A	01/28/13 A	100%
TS_1199	Auxiliary Equipment preliminary Mechanical/structural design	20	11/15/12 A	02/25/13 A	100%
TS_1200	Mechanical/structural design of M2 handling fixture(s) interface	20	11/15/12 A	03/25/13 A	100%
TS_1201	Auxiliary Equipment electrical and controls designs	20	03/26/13 A	04/22/13 A	100%
TS_1202	Auxiliary Equipment systems level analyses	10	04/23/13 A	05/06/13 A	100%
TS_1204	Auxiliary Equipment preliminary design documentation	5	05/07/13 A	05/13/13 A	100%
TS_1205	Auxiliary Equipment internal PDR	1	05/14/13 A	05/14/13 A	100%
TS_1206	Auxiliary Equipment internal PDR report completed	0		05/21/13 A	100%
TS_1207	Auxiliary Equipment internal PDR action plan completed	11	05/22/13 A	06/05/13 A	100%
TS_1210	Auxiliary Equipment Final Design	160	10/03/16*	05/12/17	0%
TS_1218	Auxiliary Equipment internal CDR	0		05/12/17	0%
TS_1224	Auxiliary Equipment fabricaiton Contract Award	0		05/19/17	0%
TS_1225	Auxiliary Equipment Fabrication/Top End Lifter/Access Gantry	160	05/22/17	12/29/17	0%
1.04.10.03 Aux. Equipment Packing and Shipping		110	10/23/17	03/23/18	
TS_1191	M1 Lifter Shipped	60	10/23/17	01/12/18	0%
TS_1227	Auxiliary Equipment Components Shipped	60	01/01/18	03/23/18	0%

1. WBS/Task/milestones
2. Description
3. Duration (days)
   Start date
4. Finish Date
5. Percent completion

The work is broken down into tasks with durations short enough to effectively monitor progress and flag delays that could result in project schedule slip.

End of Session 1a

Backup