THIRTY METER TELESCOPE

Building Instruments for TMT

Luc Simard

Science Instruments Group Leader

TMT Science Forum

Tucson, Arizona, 17-19 July 2014

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Outline

- From science cases to an instrument concept
- Observatory context
- Development process:
  - Community Explorations
  - SAC prioritization
  - Competitive conceptual design studies
- Procurement:
  - Team participation
  - Work package agreements
- Instrumentation Development Office (IDO)
- Funding and incentives
- Instrument phasing scenarios

A Science Case:
Stellar Orbits at Galactic Center

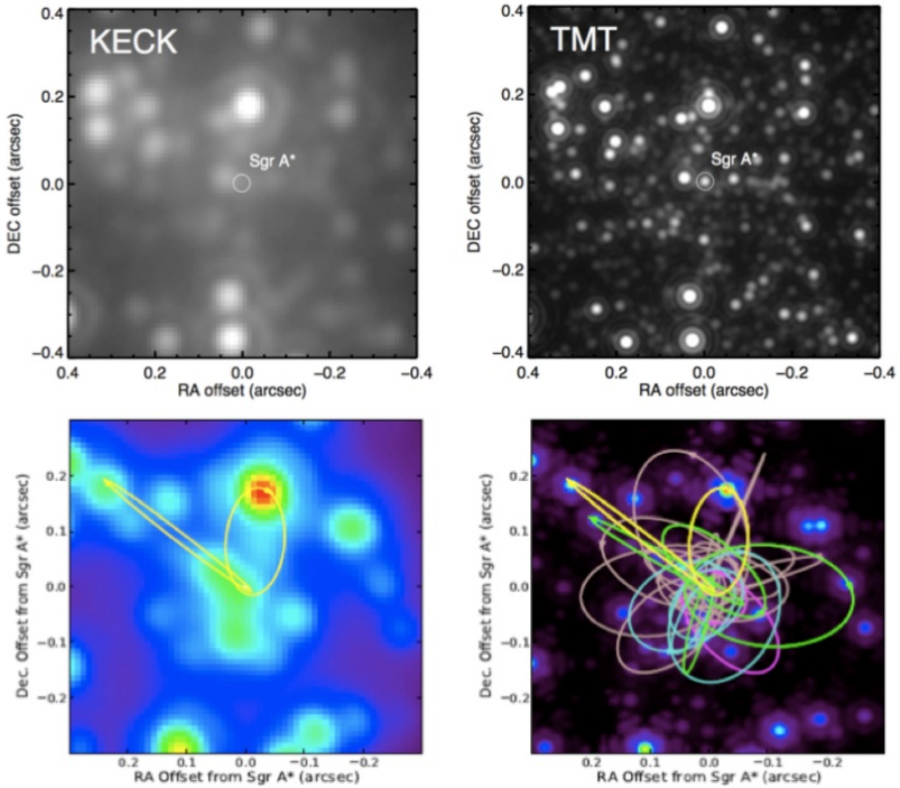
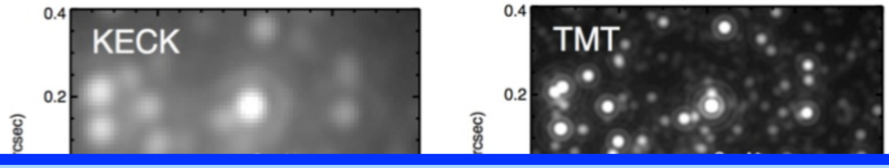


Figure 14. Upper panels: A 0".8 x 0".8 (0.027 x 0.027 pc) region centered on the Milky Way's supermassive black hole (SMBH), as imaged at 2.1 μm with the current Keck + AO system (Strehl = 0.3; left panel), and with TMT/IRIS with a multiple laser AO system (Strehl = 0.7; right panel). Lower panels: Implications for short-period star orbits (note that a different scale and a different point in time has been chosen, meaning the stars are at different positions). Overlaid are all known orbits and examples of expected orbits with periods less than 23 years that are detectable both astrometrically and spectroscopically (14<K<16, yellow; K<17, green; K<18, cyan; K<19, magenta; K<20, tan). TMT/IRIS will not only increase the number of measurable short period orbits by an order of magnitude, but should also find systems that orbit the SMBH much deeper in the central potential, with orbital periods that are a factor of 5 smaller. These systems are particularly helpful for measurements of post-Newtonian effects (GR and extended mass distribution).

A Science Case: Stellar Orbits at Galactic Center



TMT uses <u>full</u> observational scenarios (samples, calibrations, acquisitions, data reductions, etc. etc.) to derive instrument requirements from science cases

The tool used to do this is called an "Operational Concepts Definition Document" (OCDD)

known orbits and examples of expected orbits with periods less than 23 years that are detectable both astrometrically and spectroscopically (14<K<16, yellow; K<17, green; K<18, cyan; K<19, magenta; K<20, tan). TMT/IRIS will not only increase the number of measurable short period orbits by an order of magnitude, but should also find systems that orbit the SMBH much deeper in the central potential, with orbital periods that are a factor of 5 smaller. These systems are particularly helpful for measurements of post-Newtonian effects (GR and extended mass distribution).

Orbits at Galactic Center – Using a Real Image

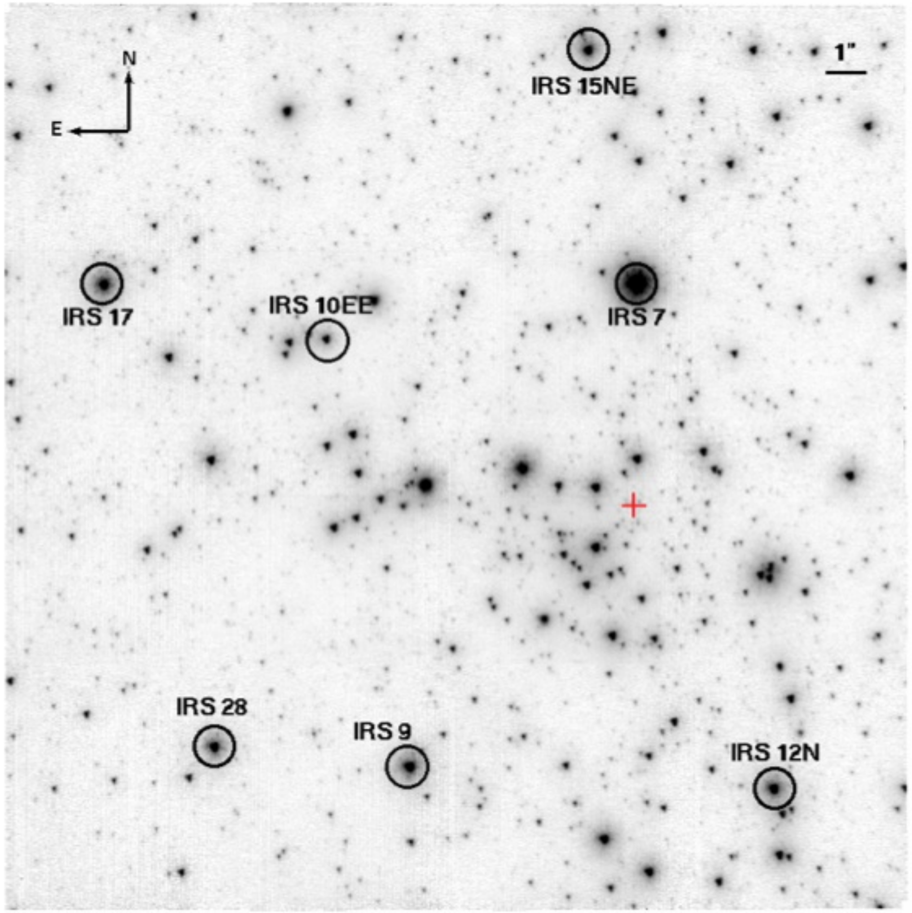


Figure 17. A Keck/NIRC2 22" x 22" mosaic of the Galactic Center. The circled sources are SiO masers that are used for the construction of an absolute reference frame. The red cross marks the SMBH. A large enough field-of-view is therefore crucial to get into a stable reference frame for proper motion studies.

Orbits at Galactic Center – Simulating Expected Results

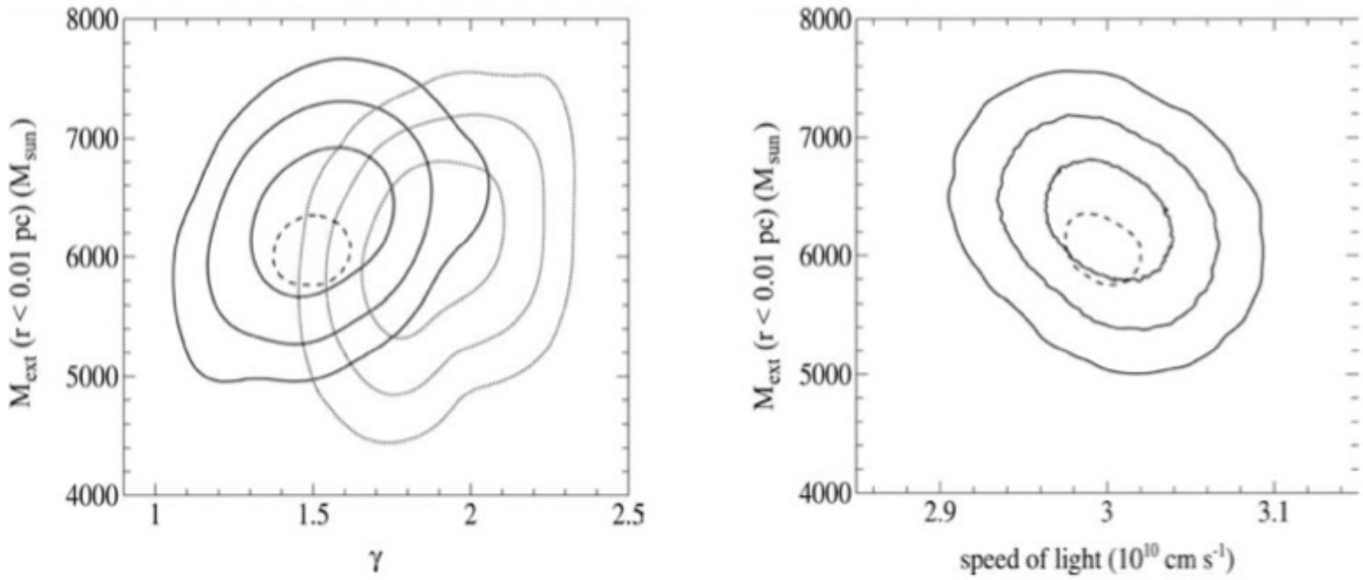


Figure 16. Astrophysical experiments with Galactic Center stellar dynamics measurements. Left panel: constraint on the extended mass distribution obtainable with IRIS/TMT. Shown are the 68%, 95%, and 99.7% confidence levels on the enclosed mass and slope of an extended matter distribution, assuming an astrometric limit of δθ = 0.5 mas and a spectroscopic limit of δ*v* = 10 km s^{-1}. The input models have power-law slope of = 1.5 and 2 and an input enclosed mass of 6000

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Orbits at Galactic Center – Observing Scenario

6.5.5. Example Observing Scenario: Testing General Relativity at the Galactic Center

Science case: Monitoring the orbits of short period stars around the SMBH in the Galactic Center to test General Relativity in an unprecedented regime.

Targets: The nuclear star cluster of the Milky Way.

Desired Observations: Diffraction-limited imaging at K-band and spectroscopy with spectral resolution of R ~ 8000 around the Brγ line for high-precision astrometry (~30 μarcsec) and radial velocities (~5 km/s). A plate scale of 4 marcsec is required for accurate centroiding of point sources. In order to construct a stable reference frame, maser sources at a distance of ~20 arcsec from the SMBH need to be imaged in the same field of view. High Strehl ratios are crucial because of the extreme crowding in the field. IRIS should be able to obtain a spectroscopic S/R = 50 for a K = 21.5 source after five hours of integration. For broadband imaging at a 4 mas sampling scale, a point source with K = 23.5 can be observed to S/N=600 in an hour. Astrometric measurements should scale as $1/\sqrt{t_{\text{int}}}$ as this is the limit of atmospheric noise. Individual exposure times will be short in order to avoid saturating the brightest stars in the field.

Calibration: Flat fields, darks, background skies, and telluric standard stars will be necessary for calibrations. Astrometric fields and a grid are required to calibrate the plate scale. Currently, globular clusters observed with HST have been used at Keck to calibrate the instrumental plate scale and orientation. A device like a fiber source will be useful to calibrate instrumental PSF spatial variability effects.

Challenges: In order to do sub-milliarcsec astrometry over a field of view of 30 arcsec, the spatial stability of the PSF needs to be maximal or very well understood. Low spatial order systematic changes in the field distortion can be fit out (translation, rotation, plate scale), but high spatial order systematic changes should also be limited to ~30 μarcsec (see also Star Formation science case). Due to short individual exposure times low detector read noise is required.

Orbits at Galactic Center – Derived Instrument Requirements

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Table 18: Major Requirements for the Galactic Center

[REQ-2-IRIS-0710]: Wavefront error less than 30 nm. **[REQ-2-IRIS-1310]:** Distortion correctable to 50 μas.	The best possible astrometric accuracy (<< 100 mas) is required to map the orbits of stars in the Galactic center well enough to test general relativity.
[REQ-2-IRIS-0730]: FOV at least 15x15 arcsec for imaging mode	The largest possible field is required to tie the coordinate system of the Galactic center to other frames, and to follow stars out to larger radii.
[REQ-2-IRIS-0760]: Sampling at 0.004 arcsec/pixel for imaging.	The best possible sampling is required for accurate centroiding of stars in the Galactic center. We would like to have 4 samples per diffraction-limited element. H and K are the optimal filter for astrometry depending on the precise AO performance.
[REQ-2-IRIS-0790]: R=2-5 for imaging mode, to 300 in selected bands.	Broad-band and narrow-band imaging may both be used to maximize astrometric sensitivity.
[REQ-2-IRIS-0810]: The instrument should not increase the (inter-OH) background by more than 15% over natural sky + telescope background.	One major advantage of TMT over other instruments is IRIS's ability to detect a much larger number of very faint stars. The sensitivity of the instrument is of key importance to the groundbreaking science goals.
[REQ-2-IRIS-0830]: Detector dark current and read noise should not increase the effective background by more than 5% for an integration time of 2000s. **[REQ-2-IRIS-0800]**: (Goal) The total efficiency of the internal optics and components for the imager and spectrograph in IRIS will be greater than 42% and 35%, respectively.	One major advantage of TMT over other instruments is IRIS's ability to detect a much larger number of very faint stars. The sensitivity of the instrument is of key importance to the groundbreaking science goals.
[REQ-2-IRIS-0780]: Spectral resolution at the smallest pixel scale of R=4,000 or better that covers a field of view of roughly 0."5 x 0."5 with a spectral range of at least 5%. **[REQ-2-IRIS-0780]:** (Goal) Spectral resolution of R=8,000 that covers a field of view of 0."5 x 0."5 with a spectral range of 2.5% or as large a range as possible.	Radial velocity precision of 10 km/sec or better is required for stars that have radial velocities that range from 0 to a few times 10,000 km/sec. The stars of interest will reside within a region that is roughly 0."5 x 0."5. Higher spectral resolution is desirable as it would deblend the Br gamma from the nearby He line, reducing systematic error. We note that spatial and spectral coverage can be increased with a loss of observational efficiency.

MOBIE OCDD – Other Examples

MOBIE OCDD – Requirement Flowdown

Table 7: Flow-down of Science Case Requirements

	White dwarfs	Metal Poor Stars	Resolved populations	Dark matter mapping	IGM Tomography I	IGM Tomography II	z∼ 2 – 5 Galaxies	QSO Pairs	Transients
Slits/mask	140	< 10	140	140	20	90	20	20	1
Masks/night	2	5	2.5,7	6	2	10	2	3	–
Slit width [arcsec]	0.6	0.75	0.8	0.75	0.75-1.0	0.75-1.0	0.75	0.75	0.75
Typical integration time/exposure [s]	1800	1200	1200	1800	1800	1800	1800	1800	1800
Typical integration time/mask [ks]	15	7.2	9,3	3.6	14.4	3.6	14.4	14.4	3.6
Resolution (blue/red)	2000	8000	8000	2000/5000	5000	1000	5000	8000	1000-8000
Minimum wavelength (blue/red) [nm]	340	380/550	370/830	310/550	310/550	310/550	310/550	310/550	310/550
Maximum wavelength (blue/red) [nm]	550	550/800	550/900	550/900	550/750	550/800	550/1000	550/1000	550/1000
ECH mode needed?	✓	✓	✓	✓	✓		✓	✓	✓
Need very precise flux calibration?				✓					
Needs very precise sky subtraction?			✓	✓	✓	✓			
Uses blue and red arms at same time?		✓	✓	✓	✓	✓	✓	✓	✓

Observatory Context

- Requirements, architecture and interfaces
- Common standards and practices

See Scott's presentation

- Definition of development and delivery phases
  - Tasks/steps and deliverables for CDP, PDP, FDP, FAB, INT and AIV
- Planning and management practices
  - Cost estimation and schedule development
  - Cost and schedule tracking
  - Risk management
  - Communications with TMT

TMT Instrumentation Work Breakdown Structure

- TMT.INS: TMT instrumentation
  - TMT.INS.AO – Adaptive Optics
  - TMT.INS.INST – Science instruments
    - TMT.INS.INST.MGT – Science Instruments Management
    - TMT.INS.INST.SYS – Science Instruments Systems Engineering
    - TMT.INS.INST.WFOS – Wide-Field Optical Spectrometer
    - TMT.INS.INST.IRMS – InfraRed Multi-slit Spectrometer
    - TMT.INS.INST.IRIS – InfraRed Imaging Spectrometer
    - TMT.INS.INST.NSCU – NFIRAOS Science Calibration Unit
  - TMT.INS.COOL – Instrumentation Cooling Systems
    - TMT.INS.COOL.REFR – Instrumentation Refrigerant Cooling Systems
    - TMT.INS.COOL.CRYO – Instrumentation Cryogenic Cooling Systems

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WFOS-MOBIE Work Break Down Structure

(Level) WBS Element - Title

(1) WFOS - MOBIE Instrument Installed

(2) WFOS.MGT - MOBIE Management (MGT)

(2) WFOS.SYS - MOBIE Systems Engineering (SYS)

(2) WFOS.STR - MOBIE Instrument Structures (STR)

(2) WFOS.ADC - MOBIE Atmosph. Disp. Corr. (ADC)

(2) WFOS.PFO - MOBIE Pre-Focus Optics (PFO)

(2) WFOS.FPS - MOBIE Mask Exchanger (MEX)

(2) WFOS.COL - MOBIE Collimator Mirror (COL)

(2) WFOS.POS - MOBIE Folding Optical Systems (FOS)

(2) WFOS.SPEC - MOBIE Disp. Optical Systems (DOS)

(2) WFOS.CAM - MOBIE Camera Systems (CAM)

(2) WFOS.DET - MOBIE Science Detector Systems (DET)

(2) WFOS.ICS - MOBIE Instrument Electronics (ELE)

(2) WFOS.MFS - MOBIE Mask Fabrication System (MFS)

(2) WFOS.SWE - MOBIE Software Engineering (SWE)

(2) WFOS.INT - MOBIE Integration and Test (INT)

WFOS-MOBIE WBS Dictionary Entries

(2) **WFOS.COL** - MOBIE Collimator Mirror (COL)

COL encompasses the overall costs associated with the MOBIE collimator mirror, including systems engineering, design engineering, fabrication, procurements, and associated alignment and test tooling, as well as assembly, integration, verification within the collimator sub-system.

The collimator sub-system includes the ~1m x ~2m optical blank (substrate material), optical finishing, and reflective coatings), the mirror cell (quasi-kinematic optical mounting and related reaction structures), stray light controls (baffles and/or aperture stops), the mirror cell motion control system (for control of mirror tip, tilt, and piston), and structural interfaces to the MOBIE main structure. This element includes all integration and test within the collimator sub-assembly.

This element does not include assembly, integration, and test of the collimator within the MOBIE instrument, which is included in the MOBIE.INT element. This element does not include any of the software engineering effort to control tip, tilt, and piston (focus) of the collimator mirror. Software for COL is included in the MOBIE.SWE element. Only local electronics components (motors, encoders, local wiring, etc) are included here. Power supplies, motion controllers, and related electronics are included in MOBIE.ELE.

(2) **WFOS.STR** - MOBIE Instrument Structures (STR)

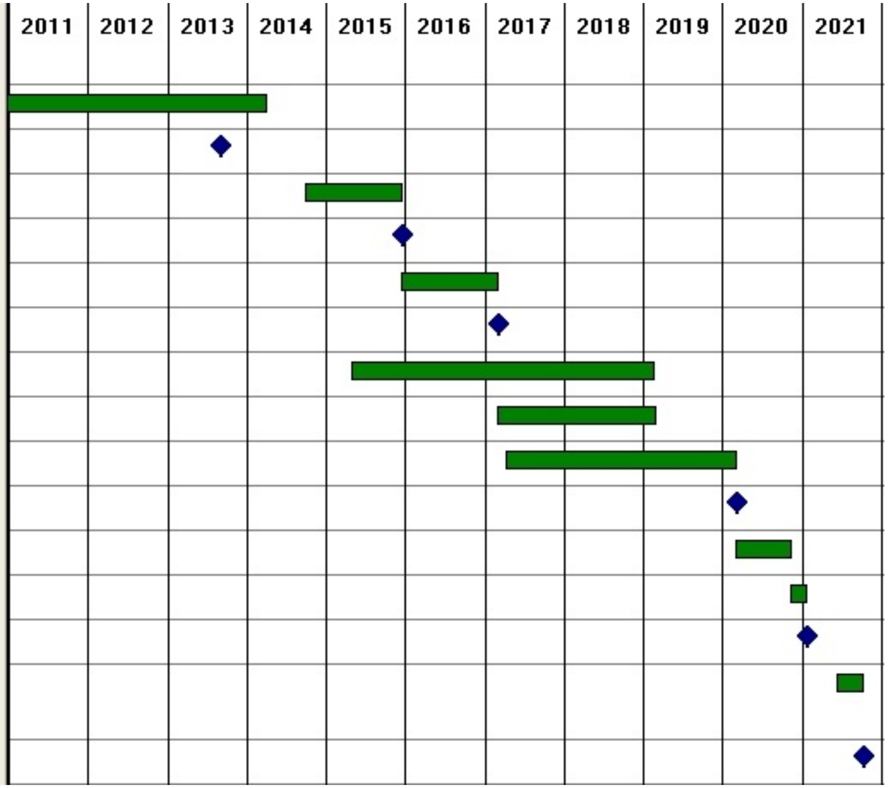
STR encompasses the overall costs and tasks associated with the MOBIE instrument structures, including systems engineering, design engineering, fabrication, procurements, and associated assembly and test tooling, as well as assembly, integration, verification within the structure sub-system.

The structures sub-systems include the instrument rotator, the instrument main structure, the instrument enclosures, and internal stray light controls between the optical sub-systems. The instrument rotator structure includes the mechanical interface to the TMT Nasmyth platform, one side of the rolling mechanical interface between the rotator and instrument, the instrument rotation motion control system, and the non-rotating portion of the instrument utility wrap. The instrument structure is carried by the instrument rotator, and provides the structural back-bone for the support of the rotating instrument sub-systems (ADC, guiders, spectrograph optics, cameras, etc). The structures also provide the supply and return systems (plumbing and wiring harnesses) for compressed air, liquid coolant, and electric power utilities. The instrument enclosure(s) provide light-tight and dust-tight protection for the instrument, and thermal insulation and controls for the instrument and Nasmyth-mounted sub-systems (including stand-alone electronics racks). The STR element includes assembly, integration, and test of the instrument rotator, structure, enclosures, utilities, and stray light controls.

The STR element does not include any intermediate structures between the instrument rotator mechanical interface (approximately 2m below the Nasmyth optical axis) and the TMT Nasmyth platform (presently 7m below the Nasmyth optical axis). The STR element does not include the working area (instrument deck) surrounding the instrument, or the necessary access features (steps, ladders, elevators, lifts) between the instrument deck and the Nasmyth platform, all of which shall be provided by the telescope.

WFOS-MOBIE Top-Level Schedule

Activity Desc.	Early Start	Early Finish	Total Float
WFOS - Conceptual Design Phase	03/02/2009	03/27/2014	184d
WFOS - CoDR	08/26/2013	08/26/2013	184d
WFOS - Preliminary Design Phase	10/01/2014	12/11/2015	54d
WFOS - Preliminary Design Review (PDR)	12/11/2015	12/11/2015	54d
WFOS - Final Design	12/14/2015	02/27/2017	54d
WFOS - Final Design Review (FDR)	02/27/2017	02/27/2017	54d
WFOS - Procure Very Long Lead Time Items	04/28/2015	02/14/2019	64d
WFOS - Procure Long Lead Time Items	02/28/2017	02/28/2019	54d
WFOS - Fabrication	04/11/2017	02/28/2020	54d
WFOS - Pre-Integration Review	03/02/2020	03/02/2020	54d
WFOS - Integration in Test Facility	03/03/2020	11/11/2020	54d
WFOS - Acceptance Testing at I+T Facility	11/12/2020	01/18/2021	54d
WFOS - Pre-Shipment Review	01/19/2021	01/19/2021	54d
WFOS - Integration and System Test at Observatory (Install on Nasmyth Platform)	06/10/2021	10/07/2021	54d
WFOS - Ready for Operations	10/07/2021	10/07/2021	54d

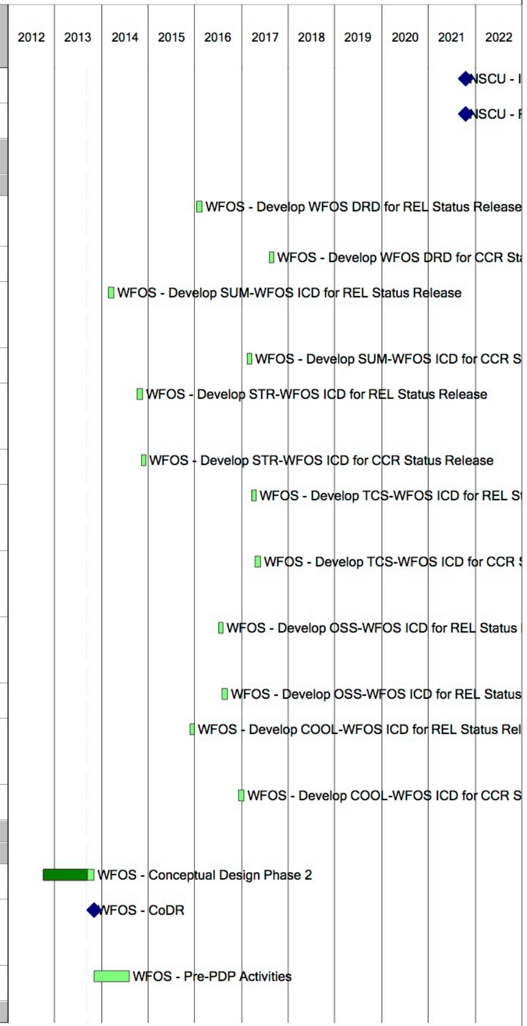


WFOS-MOBIE
Detailed Schedule

Project:	TMT_IPS
Time Now:	09/02/2013
Printed:	09/18/2013
Page:	17 of 20

Thirty Meter Telescope Project
Integrated Project Schedule
INSTRUMENTS
September 1, 2013

Row	Activity ID	Activity Desc.	Dur	Early Start	Early Finish	Total Float	PREDECESSOR_Desc	SUCCESSOR_Desc
212	TMT_INS.NSCU.8.3	NSCU - Integration of Overall Observatory Systems Complete	0	10/07/2021	10/07/2021	128d	TMT_INS.NSCU.8.2, - ,NSCU - Acceptance Testing	TMT_INS.NSCU.8.4, - ,NSCU - Ready for Operations
213	TMT_INS.NSCU.8.4	NSCU - Ready for Operations	0	10/07/2021	10/07/2021	128d	TMT_INS.NSCU.8.3, - ,NSCU - Integration of Overall Observatory Systems Complete	TMT_INS.AO.1.3.15.2.1.20, - ,NFIRAOS AIV: DRD Requirements Verification
214	**TMT_INS.WFOS**	**WFOS (Wide Field Optical Spectrometer)**	**3522c**	**04/30/2008**	**06/14/2022**	**134d**		**TMT_INS.WFOS.1.015, - ,WFOS - Feasibility Study**
215	**TMT_INS.WFOS.0**	**WFOS - Systems Engineering**	**881d**	**02/27/2014**	**08/30/2017**	**67d**		
216	TMT_INS.WFOS.0.001	WFOS - Develop WFOS DRD for REL Status Release	20d	01/19/2016	02/15/2016	134d	TMT_INS.WFOS.3.055, - ,WFOS - Preliminary Design	TMT_SE.SE.9.3.7.05, - ,Wide Field Optical Spectrometer (WFOS) DRD - REL Status Review Process
217	TMT_INS.WFOS.0.002	WFOS - Develop WFOS DRD for CCR Status Release	20d	08/03/2017	08/30/2017	134d	TMT_INS.WFOS.4.075, - ,WFOS - Final Design	TMT_SE.SE.9.3.7.30, - ,Wide Field Optical Spectrometer (WFOS) DRD CCR Review Process
218	TMT_INS.WFOS.0.003	WFOS - Develop SUM-WFOS ICD for REL Status Release	20d	02/27/2014	03/26/2014	69d		TMT_INS.WFOS.0.004, - ,WFOS - Develop SUM-WFOS ICD for CCR Status Release TMT_SE.SE.10.2S.10, - ,SUM-WFOS ICD - REL Status Review Process
219	TMT_INS.WFOS.0.004	WFOS - Develop SUM-WFOS ICD for CCR Status Release	20d	02/13/2017	03/10/2017	242d	TMT_INS.WFOS.0.003, - ,WFOS - Develop SUM-WFOS ICD for REL Status Release	TMT_SE.SE.10.2S.30, - ,SUM-WFOS ICD - CCR Status Review Process
220	TMT_INS.WFOS.0.005	WFOS - Develop STR-WFOS ICD for REL Status Release	20d	10/10/2014	11/06/2014	76d		TMT_INS.WFOS.0.006, - ,WFOS - Develop STR-WFOS ICD for CCR Status Release TMT_SE.SE.10.4S.10, - ,STR-WFOS ICD - REL Status Review Process
221	TMT_INS.WFOS.0.006	WFOS - Develop STR-WFOS ICD for CCR Status Release	20d	11/07/2014	12/08/2014	359d	TMT_INS.WFOS.0.005, - ,WFOS - Develop STR-WFOS ICD for REL Status Release	TMT_SE.SE.10.4S.30, - ,STR-WFOS ICD - CCR Status Review Process
222	TMT_INS.WFOS.0.007	WFOS - Develop TCS-WFOS ICD for REL Status Release	20d	03/23/2017	04/19/2017	217d	TMT_TEL.CONT.TCS.C.9.20, - ,Develop TCS-WFOS ICD for REL Status Release	TMT_INS.WFOS.0.008, - ,WFOS - Develop TCS-WFOS ICD for CCR Status Release TMT_SE.SE.10.11L.10, - ,TCS-WFOS ICD - REL Status Review Process
223	TMT_INS.WFOS.0.008	WFOS - Develop TCS-WFOS ICD for CCR Status Release	20d	04/20/2017	05/17/2017	217d	TMT_INS.WFOS.0.007, - ,WFOS - Develop TCS-WFOS ICD for REL Status Release TMT_TEL.CONT.TCS.C.9.70, - ,Develop TCS-WFOS ICD for CCR Status Release	TMT_SE.SE.10.11L.30, - ,TCS-WFOS ICD - CCR Status Review Process
224	TMT_INS.WFOS.0.009	WFOS - Develop OSS-WFOS ICD for REL Status Release	20d	07/07/2016	08/03/2016	67d	TMT_TEL.CONT.OSS.20.11, - ,OSS Specific Equipment & ICD I/O Parameter Definitions	TMT_INS.WFOS.0.010, - ,WFOS - Develop OSS-WFOS ICD for REL Status Release TMT_SE.SE.10.15H.5, - ,OSS-WFOS ICD - REL Status Review Process
225	TMT_INS.WFOS.0.010	WFOS - Develop OSS-WFOS ICD for REL Status Release	20d	08/04/2016	08/31/2016	67d	TMT_INS.WFOS.0.009, - ,WFOS - Develop OSS-WFOS ICD for REL Status Release	TMT_SE.SE.10.15H.30, - ,OSS-WFOS ICD - CCR Status Review Process
226	TMT_INS.WFOS.0.011	WFOS - Develop COOL-WFOS ICD for REL Status Release	20d	11/23/2015	12/22/2015	547d		TMT_INS.WFOS.0.012, - ,WFOS - Develop COOL-WFOS ICD for CCR Status Release TMT_SE.SE.10.22B.5, - ,COOL-WFOS ICD - REL Status Review Process
227	TMT_INS.WFOS.0.012	WFOS - Develop COOL-WFOS ICD for CCR Status Release	20d	12/06/2016	01/09/2017	309d	TMT_INS.WFOS.0.011, - ,WFOS - Develop COOL-WFOS ICD for REL Status Release	TMT_SE.SE.10.22B.30, - ,COOL-WFOS ICD - CCR Status Review Process
228	**TMT_INS.WFOS.1**	**WFOS - Feasibility Study Phase**	**205d**	**04/30/2008**	**03/02/2009**	**0**		
229	**TMT_INS.WFOS.2**	**WFOS - Conceptual Design Phase**	**1345c**	**03/02/2009**	**07/25/2014**	**180d**		
230	TMT_INS.WFOS.2.037	WFOS - Conceptual Design Phase 2	225d	10/01/2012	10/28/2013	180d	TMT_INS.WFOS.2.035, - ,WFOS - Conceptual Design Phase 1	TMT_INS.WFOS.2.040, - ,WFOS - CoDR
231	TMT_INS.WFOS.2.040	WFOS - CoDR	0	10/28/2013	10/28/2013	180d	TMT_INS.WFOS.2.037, - ,WFOS - Conceptual Design Phase 2	TMT_INS.WFOS.2.HAM1, - ,WFOS - Conceptual Design TMT_INS.WFOS.2.050, - ,WFOS - Pre-PDP Activities
232	TMT_INS.WFOS.2.050	WFOS - Pre-PDP Activities	180d	11/04/2013	07/25/2014	180d	TMT_INS.WFOS.2.040, - ,WFOS - CoDR	TMT_INS.WFOS.3.055, - ,WFOS - Preliminary Design
233	**TMT_INS.WFOS.3**	**WFOS - Preliminary Design Phase**	**385d**	**10/01/2014**	**04/18/2016**	**134d**		



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Risk Management

Project Risk Register

Main Menu | My Risks | All Risks | New Risk | Log Out

Static ID: 77
Risk ID: INST-03

Description: On-instrument wavefront sensor probes may not meet positioning accuracy of 2 milliarcsec in science focal plane
Consequences: IRIS astrometric performance requirements may not be met.
WBS Elements: TMT.INS.INST.IRIS.WFS
Mitigation: Thorough mechanical engineering effort early into OIWFS conceptual study. Mechanical prototype has been built and tested in the cold at HIA as part of the IRIS Preliminary Design Prototyping phase (June 2011-Dec 2012). Detailed report on the OIWFS prototype is on the DCC (https://docushare.tmt.org/docushare/dsweb/Get/Document-26694/). Report includes a number of design improvements.

Probability: Retired (Retired)
Severity: 2 (Moderate Severity)
Overall: 2 (Moderate Risk)

Status: Active
Owner: Luc Simard
Group: INST

Risk Type: B (Risk adjustment sufficient for this risk)
Cost of Risk ($k): n/a
Risk Cost BOE:

Comments: 2 milliarcsec in the TMT science focal plane corresponds to a physical distance of 4.3 microns RMS. https://docushare.tmt.org/docushare/dsweb/Get/Document-11720.
The severity depends on how badly it fails to meet the requirement. OIWFS prototype demonstrated repeatability better than 4.0 microns at a temperature of -30C over a 12-hour period.

Submitted by: Luc Simard, David Crampton on 09/22/2008
Last Updated: 12/03/2013

Edit this risk
View My Risks
View All Risks

Previous Risk: INST-02
Next Risk: INST-04

“Bottom-up” Instrument Costing

Cost Estimating System

Log Out

Main Menu   My Cost   Cost Reports

< Previous Sheet   Next Sheet >

TMT.INS.INST.MGT - Science Instruments Management
CONS - Construction
WBS Owner: Luc Simard
Estimators: Luc Simard, David Crampton

Start Date: Apr 1, 2014
End Date: Dec 24, 2021
Last Updated: Jan 21, 2013

WBS Dictionary:

This task includes in-house project management work for the TMT project office for the TMT science instrument program (WFOS, IRMS, IRIS and NSCU). This includes (i) overall scheduling, cost estimating, and resource allocation for the science instrument program, (ii) project management of the development of all science instruments, (iii) project management of the development of science instrument support facilities and any subsystems such as facility cryogenic cooling, calibration units, detector packages, on-instrument wavefront sensor components (excluding the lenslet to detector package that is the responsibility of the AO group).

The WBS does not include work on any of these topics by TMT partners or suppliers or costs associated with attending conferences and workshops such as SPIE. The WBS does not include management and systems engineering for the combined AO and science instrument program: this is in TMT.INS.MGT.

Phase Description:

This is the TMT in-house oversight and management of the development, testing, integration and commissioning of the first light science instruments that are funded by the construction budget (WFOS, IRMS, IRIS and NSCU). These staff will also have the same responsibilities for successive instruments, some of which will be initiated during the construction phase, but will be funded by post-construction funds.

For more detailed information see the latest version of the Science Instrument Development Plan: Construction Budget Document (TMT.IAO.COR.06.006, https://docushare.tmt.org/docushare/dsweb/Get/Document-7012).

"Bottom-up" Instrument Costing – Labor

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Labor (BOE and line items):

Based on an analysis of the effort required to support the development, integration and commissioning of instruments during the construction phase. This is based on experience gained primarily from delivery of such instruments to CFHT, Gemini and ALMA, and through discussions with other instrumentation managers. The level of project management also reflects the fact that TMT science instruments will be built by international, multi-institution consortia while the Observatory is being built and commissioned.

A total of 4 FTE is required for a Science Instruments Group leader for management/administration/cost/schedule/reviews, and three contract technical managers (one for each first light instrument).

These positions will be located in the TMT project office, with relocation to the Observatory Site envisioned for the INS entire group after the NFIRAOS factory acceptance test, in order to prepare for the delivery of the AO systems and science instruments.

For more detailed information on support of specific activities see the latest version of the Science Instrument Development Plan: Construction Document (TMT.IAO.COR.06.006, https://docushare.tmt.org/docushare/dsweb/Get/Document-7012).

Description	Resource	Org	Start Date	End Date	Hours	FTE	Direct Cost
(1) IRIS Contract Technical Manager	SrEng	PO	Oct 1, 2014	Jun 5, 2020	10,225	1	$763,910
(2) IRIS Contract Technical Manager	SrEng	PR	Jun 5, 2020	Dec 24, 2021	2,796	1	$208,899
(3) IRMS Contract Technical Manager	SrEng	PO	Oct 1, 2014	Jun 5, 2020	10,225	1	$763,910
(4) IRMS Contract Technical Manager	SrEng	PR	Jun 5, 2020	Dec 24, 2021	2,796	1	$208,899
(5) Science Instruments Group Leader	GrpLed	PO	Apr 1, 2014	Jun 5, 2020	11,125	1	$1,015,156
(6) Science Instruments Group Leader	GrpLed	PR	Jun 5, 2020	Dec 24, 2021	2,796	1	$255,147
(7) WFOS Contract Technical Manager	SrEng	PO	Oct 1, 2014	Jun 5, 2020	10,225	1	$763,910
(8) WFOS Contract Technical Manager	SrEng	PR	Jun 5, 2020	Dec 24, 2021	2,796	1	$208,899

Labor summary (*all costs are shown in* ***United States Dollar ($ USD)*** *in base year* ***FY2012*** *economics*)

Total Hours:	**52,985**
Direct Cost:	**$4,188,729**
Benefits:	**$1,089,069**
Facilities & Administrative:	**$527,780**
Labor Subtotal:	**$5,805,578**

“Bottom-up” Instrument Costing – Non-Labor and Travel

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Nonlabor (BOE and line items):

None -- All science instrument hardware are included within their respective instrument WBS elements. Equipment required for the assembly, integration and verification phase of the instruments at the TMT Observatory site are shared with the AO systems and are therefore included under the TMT.INS.MGT WBS element.

(No materials, subcontracts, or other direct costs are included in this estimate)

Travel (BOE and line items):

Based on an analysis of the Travel required to support the development, integration and commissioning of instruments during the construction phase. This is based on experience gained primarily from delivery of such instruments to CFHT, Gemini and ALMA, and through discussions with other instrumentation managers.

For more detailed information on the breakdown of required travel see the latest version of the Science Instrument Development Plan: Construction Document (TMT.IAO.COR.06.006, https://docushare.tmt.org/docushare/dsweb/Get/Document-7012) and the Travel Requirements for Construction Budget spreadsheet (TMT.INS.MGT.10.001, https://docushare.tmt.org/docushare/dsweb/Get/Document-18545/).

Description	Trip Type	Start Date	End Date	Units (Cycles)	Total Trips	Direct Cost
(1) Instrument development phase interim reviews	CONUS - SHORT	Oct 1, 2014	Dec 24, 2021	28 trips	28	$27,341
(2) Instrument development phase reviews	CONUS - SHORT	Oct 1, 2014	Dec 24, 2021	14 trips	14	$13,671
(3) Instrument development phase reviews	CONUS - MID	Oct 1, 2014	Dec 24, 2021	14 trips	14	$21,309
(4) Instrument integration and acceptance at builder site	CONUS - SHORT	Oct 1, 2014	Dec 24, 2021	4 trips	4	$3,906
(5) Instrument integration and acceptance at builder site	CONUS - LONG	Oct 1, 2014	Dec 24, 2021	8 trips	8	$34,001
(6) Instrument integration and acceptance at builder site	Site - LONG	Oct 1, 2014	Dec 24, 2021	8 trips	8	$46,824
(7) International ELT meetings/reviews	Europe - MID	Oct 1, 2014	Dec 24, 2021	8 trips	8	$25,496
(8) Project progress reviews	CONUS - SHORT	Oct 1, 2014	Dec 24, 2021	32 trips	32	$31,247
(9) Site visits prior to Hawaii move	CONUS - MID	Oct 1, 2014	Dec 24, 2021	3 trips	3	$4,566
(10) Site visits prior to Hawaii move	Site - MID	Oct 1, 2014	Dec 24, 2021	1 trip	1	$2,809

Travel summary (*all costs are shown in* ***United States Dollar ($ USD)*** *in base year* ***FY2012*** *economics*)

Total Trips: **120**
Travel Subtotal: **$211,171**

"Bottom-up" Instrument Costing – Risk Factors

Analysis of Risk:

	Factor	%	Risk Adjustment Element Basis of Estimate
Technical	6	2%	Overall instrumentation plan is similar to those at Gemini, ESO and Keck
Cost	4	2%	Estimate is based on prior experience with development and commissioning facility class instruments at Gemini and Keck
Schedule	2	1%	Most of the effort is on the critical path for the early light instruments
Override		*n/a*	
TOTAL		**22%**	

Comments:

(no Comments provided)

Scoping Options:

Reduced scope: the instrument teams could be given more autonomy and much less oversight during the development phases if this is deemed acceptable and could be requested to provide more of the effort during the AIV phases. The membership of the science instrument teams is not yet finalized, and the amount of travel will have to be adjusted as needed by the actual geographical distributions of the final teams.

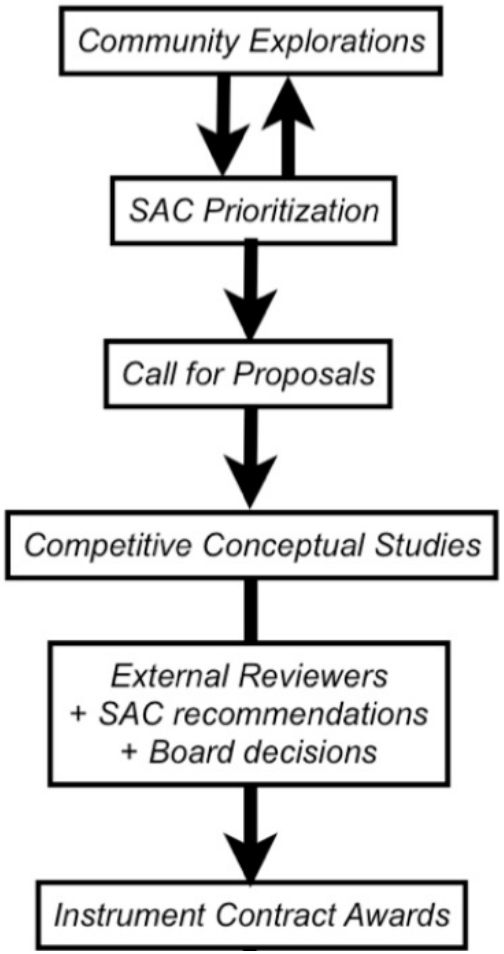
WBS-Phase Summary Cost

Direct Cost:	**$4,399,899**
Benefits:	**$1,089,069**
Facilities & Administrative:	**$527,780**
Budgeted:	**$6,016,749**
Risk Adjustment:	**$1,323,685 @ 22.0%**
Total Risk Adjusted Cost:	**$7,340,433** (USD) FY2012 economics

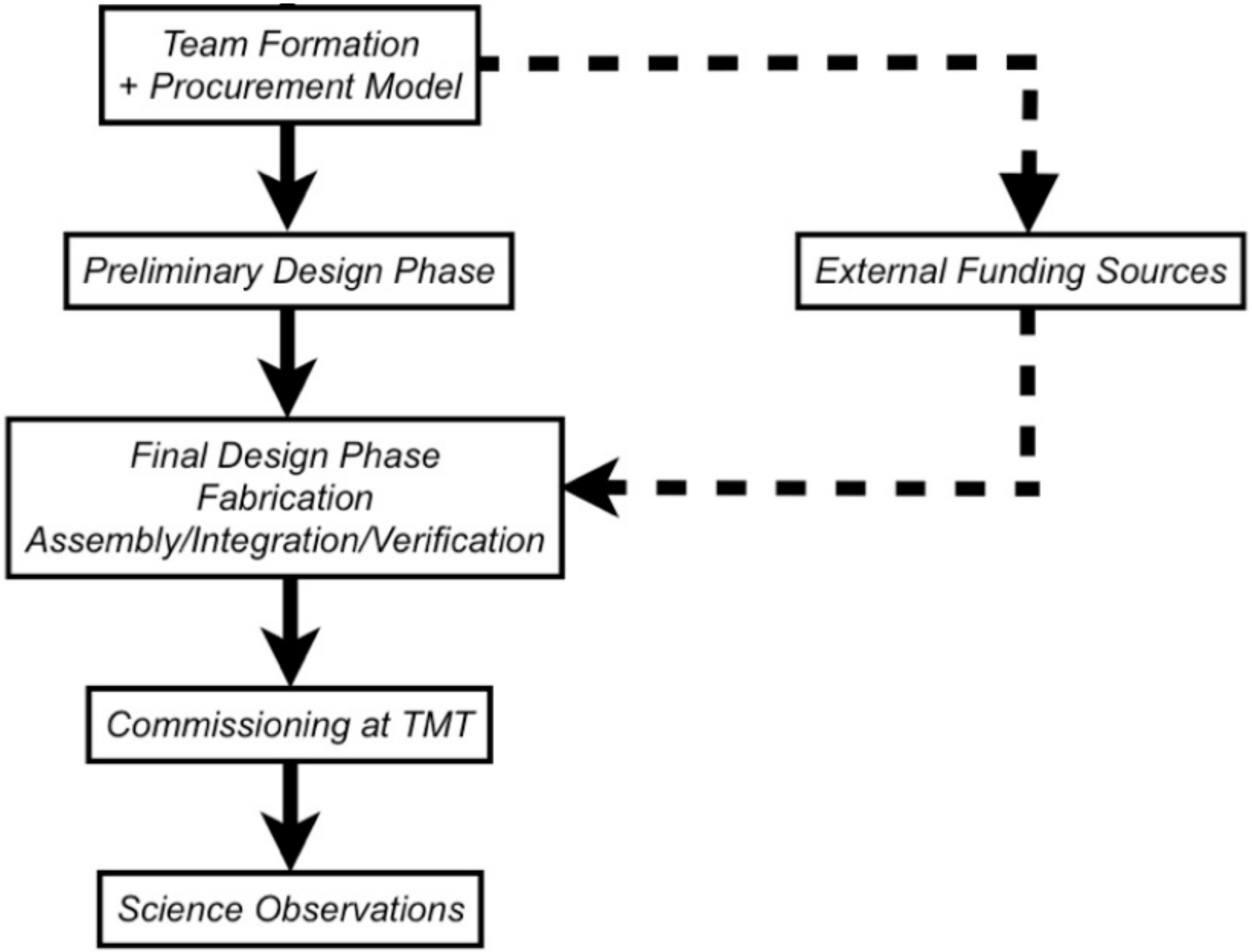
Additional currency options: CAD CNY EUR INR JPY

** items indicate that the line item estimate includes an assessment of the State of Hawaii General Excise Tax*

Future Instrumentation Development Plan



Future Instrumentation Development Plan



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Community Explorations

- Where new instrumentation ideas for TMT are born!
  - Would ideally be a “constant stream”
- Meant to inform the prioritization of desired instrumentation capabilities by SAC
  - Science, technical readiness and risks, rough cost and schedule

    → Draft initial science requirements and their rationale
- Coordinated through SAC and Observatory
- Consultations:
  - Workshops
  - White papers
  - Open to unsolicited proposals

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Community Explorations (cont.)

- "Mini-studies"
  - ≤1 year duration, ~$100k
  - Joint decisions between SAC and Observatory on which studies to fund
  - TMT would also support teams requesting external funding from their agencies, e.g., letters

- Types of mini-studies:
  - Study of science potential of a new instrument capability
  - Technology testbeds such as new coronographs, wavefront sensors, control algorithms, etc. etc.
  - Full instrument feasibility studies

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SAC Instrumentation Prioritization

- **Cornerstone of the instrumentation development program**

- Clearly science-driven but must also factor in all available information on technical readiness, schedule, cost and overall mix of commissioned and planned instrumentation
  - This was a key ingredient in the selection of our early-light instruments in 2006 - it must be preserved

- Balance between AO systems and science instruments:
  - Comprehensive metrics required for science and technical assessment
  - New capabilities versus upgrades to existing systems

SAC Instrumentation Prioritization Metrics

- Should address many scientific areas
- Should open wide regions of discovery space
- Should target high-priority science areas
- Should have broad community support
- Should be complementary with other existing or planned TMT instrument capabilities
- Should enhance telescope and instrument capabilities
- Should be complimentary with capabilities at other observatories
- Should be a good match to expected observing conditions
- Should fill a gap in existing TMT science capabilities

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Competitive Conceptual Design Studies

- Competitive: Often produce different designs in response to same top-level requirements (e.g., IRMOS, HROS)
  - More thorough exploration of system design trade-offs
- Scope and funding established by the TMT Board
  - ~1.5-2 year duration, ~$1-2M range
- Initiated through a formal Call for Proposals:
  - Every ~3 years
  - Ideally two instrument concepts to be studied per cycle
  - Two studies per instrument concept
- Studies to be reviewed by external, expert review panels
- Recommendations made to the Board from SAC and Observatory Directorate

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External Review Criteria

- Concept. Technical description and implementation + How well proposed concept meets science requirements
- Science. Analysis of science cases and list of trade-offs such as bandwidth/resolution
- Modeling. Use of modeling for evaluating different design concepts and trade-offs
- Systems engineering. Adequacy of proposed effort.
- Project plan. Whether proposed development schedule, milestones and task list for the completion of the instrument is realistic and complete
- Management systems. Whether proposed systems for tracking costs and labor and accurately reporting progress will be adequate

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External Review Criteria (Cont.)

- Budget. Whether the budget for the completion of the instrument is realistic given the scope of the work. What opportunities for cost sharing or leveraging might be available.
- Experience, resources and facilities (i.e, “heritage”). The extent of the team’s experience with designing and building astronomical instrumentation, résumés of personnel available to support the team, the percentage of time that key personnel will dedicate to the effort required, and the facilities and other resources available to the team.
- Team Structure. Types of skills, communications, etc. etc.
- Key and High Risk Components. How well have key or high risk components have been identified and what mitigation plans / contingencies are in place
- Cost. A not-to-exceed estimate for the cost of the instrument

Instrumentation Contract Awards

- Following CDP, the selected team is now THE team
  - It is expected to take the concept from here all the way to on-sky commissioning
- Before initiating PDP, TMT will work with SAC, the Board and the instrument team on:
  - Modifications (if any) to requirements and set of capabilities (w/ SAC input)
  - Scope, cost and schedule (approved by Board)
- Beyond this milestone, instrumentation efforts:
  - Are expected to be design-to-cost exercises
  - Will follow TMT procurement models (described later)
- If external funding is needed, TMT will provide bridging funds to support team while their proposal is being processed

  Example: Funding the Preliminary Design Phase (≤ 2 yrs)

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Building Instrument Partnerships

- Each TMT instrument will be built by a multi-institution consortium with industrial partners
- Strong interest from all partners in participating in instrument projects:
  - Primarily driven by science interests of their respective science communities
  - Large geographical distances and different development models
  - Broad range of facilities and capabilities
- Significant efforts are already under way to fully realize the exciting potential found within the TMT partnership
- Goal is to build instrument partnerships that make sense scientifically and technically while satisfying partner aspirations

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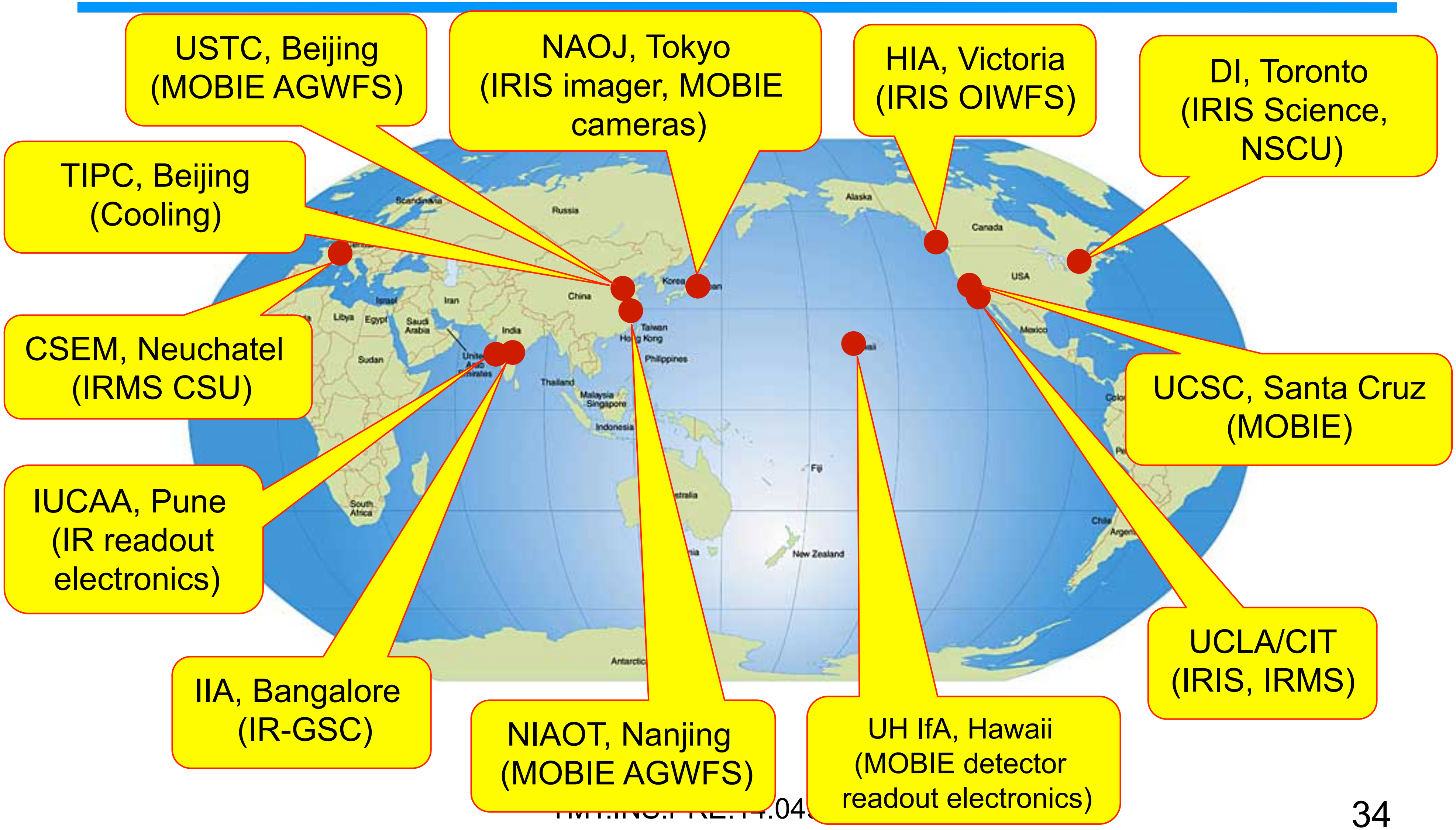
Team Participation

- Every TMT instrumentation project will involve a very sizable investment of resources
  - Must be undertaken by a consortium of institutions and companies
- Already true for recent large instrumentation projects on 8-10m class telescopes: VLT/KMOS, LBT/LINC-NIRVANA, Gemini/ GPI and Keck/MOSFIRE
- "Allowed" mix of institutions in a given consortium needs to be defined:
  - Assumption is that participation of teams from the broader community will be welcome

TMT Global Participants – Science Instruments



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Example of a Timeline

Step	Month No.	Action	Comments
1	0	SAC chooses next 2 or 3 scientific capabilities for consideration, based on prior community consultations (including feasibility studies)	Choice must take into account science *and* technical readiness, schedule and cost
2	4	IDO develops ROM estimates for instruments and options, and solicits interest	Announcements of opportunity issued
3	5	Board (with SAC input) finalizes instrument "package" (including scope and cost targets)	Assume one cheaper (and faster) and one expensive capability
4	7	Issue RFPs that have a 2 month deadline, 2 month review and decision process	Too optimistic?
5	10	Negotiate 2 competitive 15 month studies for each instrument	These studies must be adequately funded[2] in order to understand risks and establish costs
6	25	Review studies	External panels with advice going to SAC, IDO and Board.
7	26	Board (with SAC input) reviews results, decides on general specs and funding cap	Partner issues (if any) addressed at this point
8	28	Negotiate firm price contracts and "the value"	Shared cost and scope contingencies may or may not be included, depending on the model
9	29	Design, build, integrate and test instruments (~6 yrs)	
10	101	Preshipment Review for first instrument.	Ship after final acceptance, install, integrate and commission
11	113	Instrument 1 ready for science	
12	120	Instrument 2 ready	

Total span ~ 10 years → important requirement on team stability

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Work Package Agreements

- Value of instrumentation contributions must be tracked in a fair and consistent way across all participants in the TMT instrumentation program:
  - All efforts (including those funded externally) will be conducted under work package agreements between the Observatory and instrumentation consortia
  - Only efforts accounted for in work packages will be counted towards observing share
- For multi-institutional projects, it will sometimes happen that work within the work package for one partner ends up being done (for convenience or necessity) by another partner
  - Maintenance of work packages will accommodate this
  - All related work packages will be amended accordingly

Work Package Agreements

- Value of instrumentation contributions must be tracked in a fair and consistent way across all participants in the TMT instrumentation program:

All TMT instrumentation efforts are already being conducted under Work Package Agreements

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  towards observing share

- For multi-institutional projects, it will sometimes happen that work within the work package for one partner ends up being done (for convenience or necessity) by another partner
  - Maintenance of work packages will accommodate this
  - All related work packages will be amended accordingly

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Visitor Instruments

- A TMT instrument represents a very sizable investment of money and time
- If a consortium is able to muster resources for such an effort outside the TMT development process and then offers it for use at TMT, should TMT accept this visitor instrument?
- SAC supports visitor instruments at TMT under the following conditions:
  - Must be approved by SAC. Early dialog between the instrument team, SAC and the Observatory is therefore important to avoid creating false expectations
  - Instrument be fully compatible with TMT
  - Visitor instruments will be considered only once TMT is operationally stable
  - The Observatory deems support costs to be acceptable
  - Instrument should be available to all TMT partners

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Procurement Models

- A key aspect of our instrumentation procurement must be flexibility given the diversity of our partnership

  e.g., it may be easier for some partner institutions to provide labor or other in-kind contributions

- Having flexible procurement models will allow TMT to best leverage a broad range of opportunities

- We have detailed four procurement models based on extensive discussions with other observatories
  - Meant to be "boundary conditions"
  - Hybrid models can (and will) be implemented as required
  - Different models can be used within the same instrumentation effort (already done at TMT)

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Model A: Instrumentation funded by TMT with shared contingency

- Contingency is shared between instrumentation consortium and TMT
  - Respective shares to be negotiated on a project-by-project basis
- Team has flexibility at first to use their contingency as they see fit without constantly seeking approval from TMT up to a point
- Once a team has spent its share of the contingency, then it would have to seek the rest from TMT
  - Good way to alert Observatory that significant problems have developed

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Model B: Instrumentation funded by TMT with no contingency

- TMT would provide more funds for an instrument than the value established at the end of CDP
- Team would have to assume financial risk for cost overruns
  - Although options for reduced scope should remain open to negotiation
- "No contingency rule" could be softened by allowing shared contingency for components but not labor say
- Under unforeseeable price increases, negotiations on a price adjustment could be conducted
  - Significant jumps in specific items such as detectors and specialized optics are not uncommon

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Model C: In-kind funding and no contingency

- Some partners will find it easier to provide in-kind funding
- This is the (successful) ESO model:
  - Hardware paid by ESO
  - Labor supplied by instrument consortium institutions in exchange for guaranteed observing time (w/ penalties)
- Main advantage is to get science teams fully engaged and excited about instrument capabilities earlier in the development with the result being a better instrument
- Main disadvantage is the “loss” of observing time for general use
- Variant on this model would be to provide funds not necessarily tied to in-kind labor (e.g., matching funds)
- In-kind contributions will only be allowed for instrumentation projects approved by SAC to avoid “distorting” science priorities

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Model D: Instrumentation funded primarily from external sources

- In this model, partners and/or institutions would seek most if not all the funding from private or government sources (e.g., TSIP in the US)

- Given typical long lead times, the inherent uncertainty in such a process and the uncertainty of continued funding over a ~10-yr period, it would be difficult to adapt this model to a logical, deterministic procurement process

- Must ensure that TMT would maintain a strong voice under such a model by:
  - Funding earlier design phases
  - Establishing work package agreements even for use of external uses

Post-Delivery Instrumentation Support

- Intent is to keep original instrument teams involved in the post delivery instrument support (maintenance and upgrade)
  - TMT does not plan to keep large, in-house teams for this
  - Builders remain the best source of expertise
  - Keeps good teams engaged in long-term health and performance of the instruments
- Depends on having stable instrument teams
  - Not a concern given that teams had to be stable to mount large instrumentation efforts in the first place
- Upgrades will take place as part of "servicing missions":
  - Contingent of expert staff to be sent to Observatory
  - To work in "burst mode"
  - This model is in use at Keck

Instrumentation Development Office (IDO)

- Joint AO and science instrumentation engineering team that provides oversight for all instrumentation activities (except routine support):
  - Initially primarily occupied with early-light instruments (WFOS, IRIS, IRMS, NFIRAOS) and associated AO systems with increasing shift of effort towards support for future instruments and AO systems
  - Example: AO group develops AO requirements, leads performance analysis and coordinates/manages all subsystem and component development
  - Will play a central role within our diverse partnership
- Core staff of 4 FTEs in current operations plan - additional staff to be added as needed by number of on-going projects
- Baseline instrumentation development budget of ~$12M/year

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Development Funding

- Rationale
  - Only funds for first-light AO systems and science instruments are included in the TMT construction budget
  - TMT science community has clearly stated that new capabilities are needed as soon as possible after Early Light
  - Must be able to provide complex, ambitious instruments
- Justification of funding levels based on
  - Phasing scenarios based on First Decade instrument concepts (discussed later)
  - Escalation of costs from one instrument generation to the next on Keck, Gemini and especially VLT (to be done)
- Funding profile must also modulate arrival rate of instruments at Observatory to ensure a realistic commissioning plan

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Possible Sources of Funding

- Base funding
  - TMT partners will contribute a total of $12M / year to a base instrumentation development fund
  - To be kept separate from observatory operations budget
  - Depending on procurement model, it may only be sufficient to fund smaller instruments and/or seeding concept studies
- Supplemental funding
  - Base funding will need to be supplemented
  - Total required appears to be $6M-$20M / year depending on procurement model and phasing scenario
  - Commitments to this funding could be adjusted and renewed on a regular basis (~5 years say)

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Possible Sources of Funding (Cont.)

- External funding opportunities
  - Truly large projects will likely come from specific initiatives at the level of the partners' funding agencies
  - The TMT instrumentation development program should encourage and support such applications
  - However, overall TMT program should not be made to rely heavily on such funding:
    - Hard to maintain funding continuity
    - Difficult to incorporate SAC involvement in establishing priorities, true competition among teams and adequate TMT oversight - One solution here is to use work package agreements to convert value to observing share

Incentives

- How to establish value of an instrumentation contribution
  - Value and cost are not necessarily the same
  - "Common currency" system must be established
    - February 2013 Project Cost Review did this for TMT
    - Will need to establish value for an instrument through an extensive review at the end of CDP
- Should TMT offer observing time as an incentive?
- SAC has recommended ~5 nights for a typical instrument with a maximum of 10 nights:
  - Allocated number of nights should scale as a function of instrument cost and complexity

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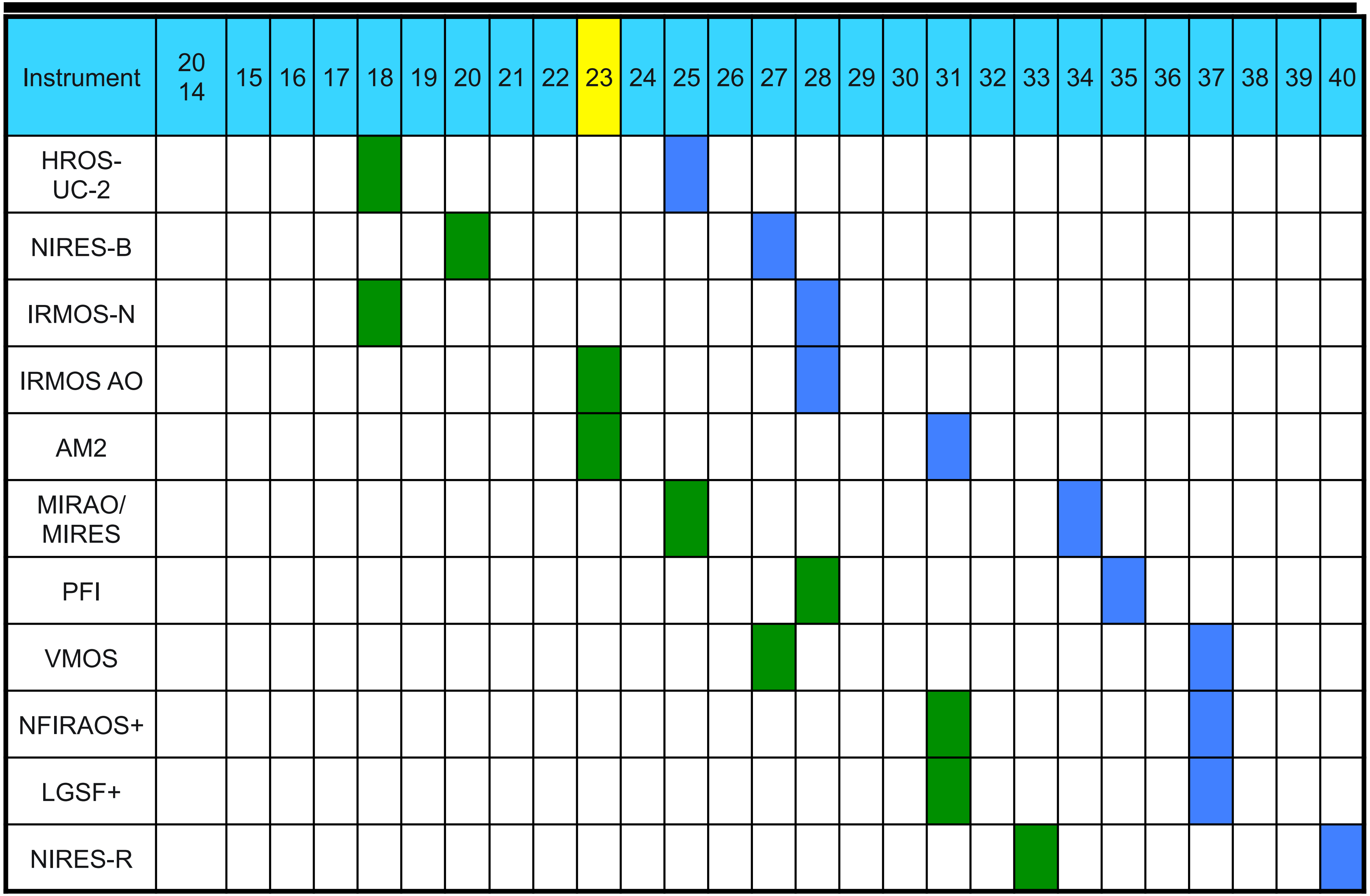
Instrument Phasing Scenarios

- Meant to illustrate the funding profiles required to bring into operations an instrumentation suite as capable as the proposed TMT Instruments
  - Two important variables are the sequence of instruments and the times at which they are delivered to TMT
- Best source of available cost and duration information remains the 2006 instrument feasibility studies
- Costs of development phases (CDP/PDP/FDP) are included
- Nine phasing scenarios were studied looking at science priorities, total costs, total funding required prior to first light, and annual funding after first light
- A SAC preferred scenario was adopted in March 2011

March 2011 SAC Preferred Instrument Phasing Scenario

- Eight instrument capabilities (not "set in stone"):
  1. High-Resolution Optical Spectroscopy (HROS-UC-2)
  2. High-Resolution, Near-IR Spectroscopy (NIRES-B)
  3. Multi-IFU, Near-IR Spectroscopy (IRMOS-N + AO upgrades)
  4. Adaptive Secondary Mirror (AM2)
  5. Mid-Infrared, High-Resolution Spectroscopy (MIRES)
  6. High-contrast imaging (PFI)
  7. Multi-IFU, Near-Optical Spectroscopy (VMOS + AO upgrades)
  8. High-Resolution, 5-18μm Spectroscopy (NIRES-R)
- One new capability every 2.5 years on average
- Starts in 2016 and ends in 2038
- Total cost of $405M at a rate of $21M/yr after first light

One Possible Instrument Phasing Scenario



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Summary

- TMT has a powerful suite of planned science instruments and AO systems that will make the Observatory a world-class, next-generation facility
- Many elements of the instrumentation development program are being defined and discussed including the SAC prioritization process and the instrument phasing scenarios
- Phasing scenarios already raise interesting questions on instrument priorities and timelines
  - And looking beyond the 1st and 2nd gen instruments may raise more
- TMT instruments will offer a wide range of opportunities to all TMT partners!

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Acknowledgments

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