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Preparing for the era of ELTs: precursor surveys, coordinated campaigns and operations planning

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Abstract. We illustrate the need for planning surveys and coordinated observations, using representative science cases developed for ELTs by the GSMT Science Working Group. We conclude that enabling surveys and coordinated observations is critical to ELTs and that ground-based optical and radio and space-based facilities are needed. A world-wide systems approach is needed to support ELT campaigns. We discuss early planning for ELT operations, based on discussions in progress within the TMT partnership. We conclude that developing an architecture to accommodate end-to-end observation and data management will be essential to achieving near-term and legacy goals.

Keywords. telescopes, surveys, astronomical data bases: miscellaneous

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1. GSMT Science Working Group

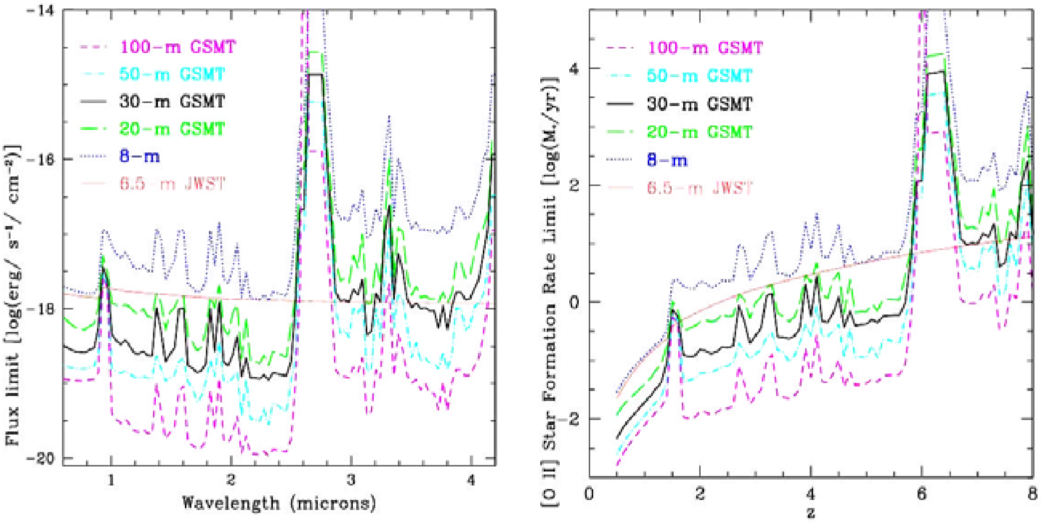
The Giant Segmented Mirror Telescope (GSMT) SWG is a broad community-based group convened by NOAO to:

- Formulate a powerful science case for funding the GSMT recommended by the U.S. National Academy of Science (AASC 2001)
- Identify key science drivers
- Develop clear and compelling arguments for GSMT in the era of JWST and ALMA
- Discuss realization of key science as a function of design parameters: aperture, field of view, point spread function (PSF)...
- Generate unified, coherent astronomy community support

Membership of the SWG is listed in Table 1.

Table 1: GSMT SWG Members

Rolf-Peter Kudritzki	U Hawaii (Chair)	Terry Herter	Cornell
Jill Bechtold	U Arizona	Michael Liu	U Hawaii
Mike Bolte	UCSC	Jonathan Lunine	UA LPL
Ray Carlberg	U of Toronto	Claire Max	UCSC
Matthew Colless	AAO	Chris McKee	UC Berkeley
Irene Cruz-Gonzales	UNAM	Francois Rigaut	Gemini
Alan Dressler	OCIW	Doug Simons	Gemini
Betsy Barton	UC Irvine	Chuck Steidel	Caltech
Paul Ho	CfA	Steve Strom	NOAO
Masanori Iye	NAOJ	Kim Venn	Macalester Coll.



(10,000 seconds, high-order AO, R=3000)

Figure 1. Predicted sensitivity of telescopes including ELTs of different aperture. Courtesy of Elizabeth Barton.

The GSMT SWG has written two white papers and is preparing a third.

- Frontier Science Enabled by a GSMT – July 2003
- GSMT Synergy with the JWST – July 2005

written in collaboration with the JWST SWG

- Science as a function of aperture: 20-30/50-60/100 metres – TBD

to be written in collaboration with European ELT SWG members

These are to be found on the NOAO website.

The key science cases developed by the GSMT Science Working Group are similar to those discussed at this meeting.

- Formation of the first stars and pre-galactic systems
- Tomography of the IGM at $z > 3$
- Stellar population mixes in nearby galaxies spanning a range of types
- Formation and early evolution of planetary systems
- Characterization of mature planets

This work has required detailed simulations of telescope performance (e.g. Barton *et al.* 2004), including the estimated PSFs of adaptive optics (AO) systems, illustrated in Figure 1.

2. Surveys

We illustrate with some examples the need for surveys to enable ELT science.

2.1. *Lyman break galaxies*

To probe the Intergalactic Medium (IGM) at the redshifts of galaxy formation, we need a denser grid of pencil beams. This can be furnished by Lyman break galaxies (LBGs).

At $R < 25$, there are ∼3–4 LBGs per square arcminute at $2.5 < z < 3.5$; ∼1 at $z > 3.5$. The target list should be developed from surveys with 4–8-m class telescopes. ELTs will do the spectroscopy with deployable IFUs.

2.2. *Early mergers and young galaxies*

To understand the epoch of major star formation in the Universe, a large volume sample is required that is immune to cosmic variance. The goals are to:

- Map out large scale structure for $z > 3$ over a $5^\circ \times 5^\circ$ volume, equivalent to the Sloan survey at large redshifts
- Link the emerging distribution of gas and galaxies to the fluctuation scales of the CMB
- Determine metal abundances, so that chemical evolution is also revealed.

The sample required is several $\times\ 10^4$ galaxies from deep, wide-field 4-m imaging surveys.

2.3. *Deconstructing stellar populations among galaxies of all morphologies*

The study of stellar populations with ELTs presents the opportunity to learn about star formation history and chemical evolution in two ways, examining the fossil record and directly looking back in time. The goal of colour magnitude diagram (CMD) studies and high resolution spectroscopy of stars in nearby galaxies is to:

- Quantify ages and [Fe/H] for stars in nearby galaxies spanning all types
- Use the 'archaelogical record' to understand the galaxy assembly process
- Quantify the IMF in different environments

The required measurements are

- CMDs for selected areas in local group galaxies
- Spectra of samples as large as 10^5 stars in galaxies, matching those to be obtained in the Milky Way (Freeman & Bland Hawthorn 2002).

The key to success is to break crowding limits by exploiting diffraction-limited images delivered by AO used in conjunction with ELTs. CMD work will benefit from previous surveys of these galaxies, possibly including calibration photometry with JWST.

2.4. *Formation and early evolution of planetary systems*

ELT goals are to:

- Understand where and when extra-solar giant planets (EGP) form
- Infer initial the EGP distribution via observation of gas kinematics and locating tidal gaps

The measurements include

- Spectra of 10^3 accreting Pre-Main Sequence stars ($R \sim 10^5$, $\lambda \sim 5\mu$m)
- Spanning the expected broad range of accretion disk conditions from massive, high surface density disks (did massive planets form early?) and low mass, low surface density disks (did only low mass planets form late?)
- Understanding whether solar-system-like systems are common or rare.

Precursor surveys needed to identify candidates covering the full range of disk initial conditions. Large ALMA + SMA surveys of young stellar objects (YSOs) (d < 1 kpc) will identify accretion disks, spanning a wide range of disk gas and dust masses.

2.5. *Detecting and characterizing extrasolar planets*

The goals here are to image and/or characterize exo-planets' mass, radius, albedo, atmospheric structure, and chemistry. The measurements include:

- R $\sim$ 10 imaging and R $\sim$ 200 spectra of spatially-resolved planets in the near-infrared (reflected light) and mid-infrared (thermal emission).
- High S/N spectroscopy of unresolved transiting planets

The precursor surveys are radial velocity surveys, transit surveys with 2-m to 8-m class telescopes and transiting planet results from Kepler and other missions. It will be possible to characterize transiting extrasolar planets, including close-in (r << 1 AU) planets, and to observe spectra in and out of eclipse (S/N $\sim$ 1000).

2.6. *Summary of survey requirements*

Subject area	**GSMT role**	**Survey/Coordinated Observations**
3D map of gas & galaxies ($z > 2$)	WF spectroscopy of 5 × 5 degree (SDSS) volume	LBGs to $R = 24$, galaxies $R < 26$ with LSST or Dark Energy Camera
Star/galaxy formation during reionization	Survey and spectroscopy	JWST imaging; ALMA surveys
Stellar populations in nearby galaxies	Crowded field photometry	HST WFC3/JWST imaging
Planet formation environments	HiRes infrared spectroscopy	ALMA +SMA survey of accretion disk properties (masses, sizes)
Characterization of extrasolar planets	High contrast imaging and spectroscopy	Existing Doppler surveys, Ongoing occultation surveys

In addition, it is worth considering survey science that requires follow-up observations with 30-m class ELTs.

Subject area	**LSST + other role**	**Followup requirement**
1st light objects, Pop III massive stars	Detect GRBs & SNe at $R = 24$	ELT spectra (single object)
AGNs & black holes	Detect variability for e.g. reverberation mapping	ELT spectra (MOAO or MCAO)
Supermassive black hole evolution	Detect lensed variability	ELT spectra and GLAO imaging
Galactic archaelogy	Find population III stars	HiRes spectroscopy

Things that go bump in the night	Detect transients	Multiwavelength spectroscopy
Dark energy	Weak lensing and SNe	Baryon acoustic fluctuations (wide-field 8-m class project)

We provide a separate summary for larger aperture implementations.

Subject area	**OWL role**	**Survey/Coordinated Observations**
Terrestrial planet detection	Image	Synergy: Darwin
Planet forming environments	HR infrared spectroscopy	ALMA survey of outer disks
Stellar populations in galaxies to Virgo	Crowded field photometry	JWST imaging (calibration)
Supermassive black holes	Kinematics	
First stars, first elements, reionization	Survey and spectroscopy Optional: JWST imaging	Synergy: SKA
Dark sector	Measure H(z)	Supernovae

3. Initial TMT operations planning

The motivation for TMT operations planning at this early stage is to maximize scientific productivity, minimize technical down-time within affordable limits, minimize annual operations cost, and to enable a graceful evolution from a capable starting point. The general goals are to build on the operations experiences and “lessons learned” within the TMT (Keck, Gemini, NOAO,...) and world (Magellan, VLT, Subaru,...) communities, leading to the creation a system-wide framework for sub-system design and implementation.

Initial assumptions include that it:

- Must allow classical (visitor) observing
- Must allow exploitation of optimal atmospheric conditions
- Must allow optimization of desired observation with conditions
- Must allow rapid and efficient switch between instruments
- Must maintain system performance within nominal range
- Must calibrate instruments
- Must have self-descriptive (VO compliant) Data products
- Must provide data reduction and analysis tools

The implications are that a wide range of explicit and implicit services are required.

With these points in mind, TMT operations implementation challenges are seen to be:

(1) establishing design and concept frameworks early

- It is less expensive to build in hooks early than to retro-fit.

- System engineering and IT design exercises must be employed.

- The possibility for evolution must be built-in.

- Complete implementation of the entire system is not mandatory from the beginning.

(2) exploiting existing end-to-end science operations experience and tools

- Appropriate use of latest (riskiest) technology.

- Adopt tried-and-true industry standards (e.g. banking).

- Minimize re-implementation whenever possible.

- Explore re-use of technology from existing end-to-end systems (e.g HST, Gemini) and data centers (e.g. MAST, IPAC, CADC).

(3) analyzing incremental annual operations costs vs. anticipated benefit for each additional service before committing to implementation.

4. Science operations framework

TMT is working towards a framework with a core of required capabilities, a set of intermediate enhancements, and an advanced level with full-up end-to-end science operations with dynamic scheduling.

Core science operations capabilities include

- Facility + on-site night-time operations team
- Observer (PI or collaborator) at (or near) site
- Observer can decide in real-time what to observe
- Data calibration/reduction tools available for all instrument modes

There are many working models for these core capabilities, such as the 4 metres and the Keck telescope.

Enhanced science operations involve

- complete real-time meteorology (what is happening outside the dome),
- complete science and technical data telemetry,
- trend analysis tools and process for telemetry,
- observatory-based instrument calibration,
- data quality assurance process.

In sum, this enhanced level of capabilities facilitates the near real-time monitoring of system performance, allowing the early detection and correction of problems. This level also provides services critical to a robust legacy science program as well as the creation of a useful science archive.

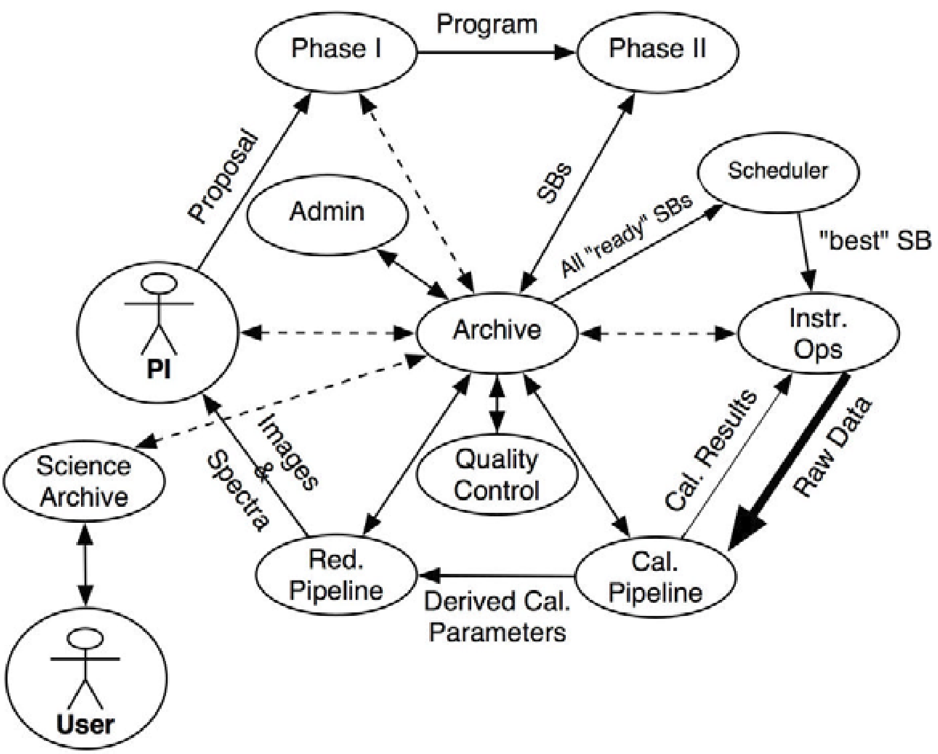


Figure 2. ALMA high-level E2E architecture. Figure courtesy of J. Schwarz.

The features of advanced science operations include

- dynamic scheduling to respond to current and/or predicted atmospheric conditions
- semi-automatic systems to support the science data QA process
- automatic data calibration
- a TMT Science Center
- a Virtual Observatory compliant data center

As already demonstrated at existing facilities (e.g. VLT, Gemini, various space observatories), these advanced capabilities not only allow for the management of a wide-range of project sizes and real-time adaptation to atmospheric conditions and/or science priorities, they produce also science data of a more uniform quality for the current investigator as well as future users of archival data.

5. End to End: a systems approach

The services implemented for ELT operations should be driven not by technology, but by the operational requirements as derived from the high-level science mission of the facility. Once the latter is well-understood, the design vocabulary is workflow, tasks, and interfaces. The implementation strategy is that of integrated information management, where tools are derived from processes, not visa versa.

Within the observatory operations community, this process-driven approach using information technology has become known as data flow or end-to-end (E2E) systems. The technological goal of such systems is integrated science and technical operations, including one IT/computing framework, one problem reporting system, and easy-to-use user tools. An important feature is an archive through which all science and technical information flows, not just bits from science detectors. To be most effective, it is important that such IT systems be embedded within a unified command and control structure with clear lines of authority. Thus, process development and management is just as important as IT development and management. Although the Data Flow System of the ESO Very Large Telescope is the most widely recognised ground-based system, E2E systems are common features in most current generation space and ground astronomical facilities (e.g. the exemple of ALMA shown in Fig. 2). We expect TMT to follow this path.

6. Conclusions

Enabling surveys and coordinated observations will be important to ELTs. Ground-based optical and radio and space-based facilities will be needed. A world-wide systems approach is needed to support ELT campaigns. Developing an architecture to accommodate end-to-end science operations is essential to achieving the near-term and legacy goals of ELTs.

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Discussion

Longhair: I would suggest that a key element of the programming of the ELTs will be the continued availability of Director's Discretionary Time. This has proved to be a key element in the success of the current generation of 8-10 meter telescopes and HST.

Bergeron: On the first set of slides mention is made of real time decision by the PI, whereas in a later one emphasis is given to the efficiency of observations. Those are different operation modes, although complementary approaches.

Mould: If one has a full end-to-end System, queue observing is efficient. It is also expensive. In addition, no observatory wants to cut itself off from the beneficial and critical presence of occasional visiting observers. Visitor mode and queue mode are indeed complementary.

Hook: Have you considered requirements for rapid identification of GRBs prior to follow-up with ELTs, e.g. a rapid-reaction 8m (!) telescope?

Mould: The recent high impact GRB results have made good use of high energy X-rays to locate GRBs. But it will depend on what we have flying at the time. We'll have to complement from the ground whatever we happen to have in space. LSST will help find afterglows with or without gamma-ray detections.