LBT PROJECT
2x8,4m TELESCOPE

Doc.No.  : 640s020
Issue   : a
Date     : 4 Jan 2011

LBT PROJECT
2 X 8,4m OPTICAL TELESCOPE

LBTO AO Demonstrator

Feasibility Study
1. Revision History

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<th>Issue</th>
<th>Date</th>
<th>Changes</th>
<th>Responsible</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>4-Jan-2011</td>
<td>Issue a; prepared with input from: Simone Esposito, Armando Riccardi, Richard Green, Dave Thompson, Dave Ashby, Don McCarthy, Craig Kulesa, Gerd Weigelt, Mark Wagner, Andrew Rakich, Doug Miller</td>
<td>Joar Brynnel</td>
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3. About this document

3.1. Purpose

This document is meant to aid in deciding on whether a campaign to offer early AO science at the LBT should be officially launched. The decision should be based on technical and operational feasibility, and an overall cost-benefit analysis for such a campaign. The document is the result of discussions with several people at the LBTO, Steward Observatory, Arcetri Observatory and within LBTB.

Richard Green made the following statement to the STC on December 7, 2010:

The assumption is that LUCI 2 will be commissioned for AO imaging in fall of 2011, after which the capability will be available for science, probably near the end of the year. The question is whether any options for obtaining AO-corrected imaging earlier would be worth the cost. A likely approach would be one or two campaigns with expert observers collecting data on the basis of partner-wide proposals. With the exception of the IR Test Camera and accelerating access to LUCI 2, other options would involve extra effort from the AO team, LBTO staff, and the providers of the science cameras. Should one or more of those options be of scientific interest, the cost, effort, and impact on schedule will be estimated. Steward astronomers are willing to support both the PISCES and CLIO camera options, should the partnership be interested. Responsibility for hardware interface production must be determined.

3.2. Scope

An executive summary is given in section 4. The campaign goals are presented in section 5. A schedule and cost summary can be found in sections 6 and 7. Section 8 through 11 show a detailed assessment of status and required preparatory work. Finally, a risk analysis is discussed in section 12.

3.3. Reference Documents

[RD1] 640aXXX AO system #1 commissioning report (Arcetri) – not yet released
[RD2] 640s015 LBT AO System #1 On-telescope system verification plan

Appendix 1: “PISCES on LBT”, Don McCarthy and Craig Kulesa, December 24, 2010
4. Executive summary

It appears possible to carry out an AO demonstration campaign at the LBT during the 2011A observing semester. This campaign would offer up to 8 nights of service-mode AO assisted imaging science with a science-grade PI instrument at the LBTO Right Front Bent Gregorian focal station.

The campaign will come at an estimated cost of 11 man-weeks of Arcetri staff effort, and 13 man-weeks of LBTO AO group effort, plus a small contribution from the LBTO SciOps group. This diversion of AO resources in Arcetri and Tucson may slow down the completion of LBT AO system #2, which is currently under system test at Arcetri.

Cash costs are estimated to $71K which consists of interface engineering, interface hardware, labor and travel costs for the Arcetri team.

Don McCarthy has offered to make his PI instrument available essentially without direct cost, see also Appendix 1.

Telescope time would have to be allocated for installation, calibration and testing. It is estimated that a total of 15 days and 14 nights of telescope time are required (including the actual science run). This time would be taken from LBTO engineering and commissioning time.

Risks are mostly in the schedule domain. Moderate risks in the technical area are software integration and cryostat LN2 venting configuration.

5. Campaign goals

The AO demonstrator campaign shall serve to meet the following objectives:

   i. Imaging only for high contrast observations over a wide range of exposure times
   ii. Deliver a powerful demonstration of AO performance comparable to AO commissioning results
   iii. Try science driven operating modes of the Telescope and its AO system
   iv. Allow science users to process data exploring the full parameter space during science conditions
   v. Provide opportunity for training of the LBTO AO group for science support
   vi. Measurement of Telescope + AO observing efficiency during science-like observing
6. Schedule

The proposed high-level schedule is as follows:

- Jan/Feb 2011: Interface engineering (instrument interface to telescope)
- Mar 2011: Installation on telescope
- Apr/May 2011: System testing (off-sky and on-sky)
- June 2011: AO Demonstration Science campaign – up to 8 nights

7. Cost

This cost analysis has been done with the following assumptions:

- LBTO will reimburse Arcetri staff on mission to Mt Graham (salary, travel and subsistence) at the rate of regular AO commissioning missions.
- LBTO staff time is not charged explicitly to this project.
- Cost of camera team member’s time (McCarthy and Kulesa) is not part of cost estimate (this aspect needs confirmation).

7.1. Manpower requirements

This proposal does not put significant burden on LBTO Engineering, Mountain and Software groups. It does however require participation of LBTO AO group, Arcetri group, and the LBT SciOps group. Table 1 summarizes the required manpower (estimates given in man-days).

<table>
<thead>
<tr>
<th>Task</th>
<th>Source 1</th>
<th>Source 2</th>
<th>Source 3</th>
<th>Source 4</th>
<th>Task Description</th>
<th>Effort</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>LBT AO group</td>
<td>Table 4</td>
<td>Table 4</td>
<td>Table 5</td>
<td>Table 6</td>
<td>Demonstration run on-sky support</td>
<td>2x8 nights</td>
<td>65 days</td>
</tr>
<tr>
<td></td>
<td>Table 6</td>
<td>Table 6</td>
<td>Table 6</td>
<td>Table 6</td>
<td>Program pre-screening</td>
<td>10 days</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Software integration (IRAF/IDL)</td>
<td>5 days</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Installation of camera on the LBT</td>
<td>2 days</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Daytime preparation</td>
<td>2x10 days</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Nighttime preparation</td>
<td>2x6 nights</td>
<td></td>
</tr>
<tr>
<td>Arcetri AO group</td>
<td>Table 6</td>
<td>Table 6</td>
<td>Table 6</td>
<td>Table 4</td>
<td>Daytime preparation</td>
<td>3x10 days</td>
<td>56 days</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Nighttime preparation</td>
<td>3x6 nights</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Demonstration run on-sky support</td>
<td>8 nights</td>
<td></td>
</tr>
<tr>
<td>LBTO SciOps group</td>
<td>Table 4</td>
<td></td>
<td></td>
<td></td>
<td>Archive setup and coordination</td>
<td>3 days</td>
<td>3 days</td>
</tr>
<tr>
<td>Camera group</td>
<td>Table 4</td>
<td>Table 6</td>
<td>Table 6</td>
<td>Table 6</td>
<td>Demonstration run on-sky support</td>
<td>8 nights</td>
<td>24 days</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Installation of camera on the LBT</td>
<td>5 days</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Daytime preparation</td>
<td>5 days</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Nighttime preparation</td>
<td>6 nights</td>
<td></td>
</tr>
<tr>
<td>Partner observers</td>
<td>Table 4</td>
<td></td>
<td></td>
<td></td>
<td>Demonstration run on-sky support</td>
<td>2x8 nights</td>
<td>16 days</td>
</tr>
<tr>
<td>LBTO SW group</td>
<td>Table 6</td>
<td></td>
<td></td>
<td></td>
<td>Installation of camera on the LBT</td>
<td>2 days</td>
<td>2 days</td>
</tr>
<tr>
<td>Program management</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Coordination and Management</td>
<td>25 days</td>
<td>25 days</td>
</tr>
</tbody>
</table>

Table 1: Summary of manpower
Manpower allocation for the Arcetri team will compete with work towards completion of LBT AO System #2 in Arcetri. No assessment of schedule impact for AO system #2 has been made.

Time spent by the LBTO SciOps group is competing with partner science support. For the LBTO AO group this effort is, in general, beneficial as a preparation activity for commissioning of Lucifer 2 + AO. It may however impact preparations for acceptance of LBT AO System #2, and its deployment schedule.

The task of project management needs to be assigned at the time of official project start.

### 7.2. Direct cost

Below is a summary of the estimated direct cost for hardware and labor. This table summarizes all the detailed cost estimates in this document.

<table>
<thead>
<tr>
<th>Cost</th>
<th>Source</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interfaces</td>
<td>Table 5</td>
<td>$40K</td>
</tr>
<tr>
<td>System testing</td>
<td>Table 6</td>
<td>$31K</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>$71K</strong></td>
</tr>
</tbody>
</table>

Table 2: Summary of direct costs

### 7.3. Telescope time

The following telescope time should be allocated for the AO demonstration effort.

<table>
<thead>
<tr>
<th>Task</th>
<th>Source</th>
<th>Days</th>
<th>Nights</th>
</tr>
</thead>
<tbody>
<tr>
<td>Camera installation</td>
<td>Table 6</td>
<td>5</td>
<td>-</td>
</tr>
<tr>
<td>Daytime preparation</td>
<td>Table 6</td>
<td>10</td>
<td>-</td>
</tr>
<tr>
<td>Nighttime preparation</td>
<td>Table 6</td>
<td>-</td>
<td>6</td>
</tr>
<tr>
<td>Demonstration on-sky run</td>
<td>Table 4</td>
<td>-</td>
<td>8</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>15</strong></td>
<td>14</td>
</tr>
</tbody>
</table>

Table 3: Summary of required telescope technical time
8. Readiness for campaign – Current status

8.1. Telescope Focal Station

The RFBG (Right Front Bent Gregorian) focal station is not yet fully commissioned. Focal station commissioning encompasses seeing limited observing performance, such as pointing, guiding, active optics and delivered image quality characterization. A final commissioning campaign in December 2010 was weathered out, and it was not possible to collect the data required for the formal focal station commissioning report.

8.2. AO system

The LBT AO System #1 is installed at the LBT DX side, and is still under commissioning. Following installation in early 2010, the AO system has consistently shown high reliability, and it has delivered truly spectacular results. Although no major performance-limiting issues or deficiencies are known, some off-sky and on-sky commissioning remain to be done before AO system #1 can be released for routine partner science. An AO commissioning run is scheduled in January 2011. Commissioning reports are pending.

9. Effort required to prepare for AO demonstration

9.1. Science Operation

9.1.1. Concept

To facilitate efficient operation and coordination of Telescope, AO system and Science camera, and at the same time minimizing software development effort, LBTO scientists have proposed to operate the system from IRAF or IDL scripts, analog to how telescope commissioning with the IRTC is done successfully for years at the LBT. This would mean almost zero impact on the LBTO TCS group. The proposal is to use a simple Lucifer-like script for each observing program; this script would be parsed by the IRAF/IDL routines that send the relevant commands to TCS and control science camera exposures. Camera setup (Exposure time, NDIT etc.) must be done manually for each exposure on the camera stand-alone GUI.

9.1.2. Program pre-screening

Approved observing programs should be carefully pre-screened for mistakes before execution. This pre-screening should be done by an experienced LBTO astronomer in advance of program execution. Careful review of submitted programs is considered essential to the success of this effort.

9.1.3. Archive

LBTO archive compliant headers would be added by IRAF/IDL scripts for data ingestion into the LBT science archive. Some effort is required to set up the archive for these
images. It is considered important to use well established and efficient means of distributing science data to allow for PI’s to quickly assess quality of their data.

Relevant AO parameters for image headers must be well defined.

### 9.1.4. Program execution

The recommendation is that the programs are executed by LBTO experienced astronomers in service mode, supported by AO experts, and science camera support personnel. To avoid adding work load to the LBTO Science Operations group, the expectation is to rely on two volunteers from the pool of experienced partner observers to run the queue and execute the programs in service mode.

<table>
<thead>
<tr>
<th>Task</th>
<th>Duration</th>
<th>Responsible</th>
<th>Resources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Archive setup and coordination</td>
<td>3 days</td>
<td>LBTO</td>
<td>1 person</td>
</tr>
<tr>
<td></td>
<td></td>
<td>INAF</td>
<td>1 person</td>
</tr>
<tr>
<td>Program pre-screening</td>
<td>10 days</td>
<td>LBTO Scientist</td>
<td>1 person</td>
</tr>
<tr>
<td>Demonstration run on-sky support</td>
<td>8 nights</td>
<td>Service mode observers</td>
<td>2 people</td>
</tr>
<tr>
<td></td>
<td></td>
<td>AO support</td>
<td>2-3 people</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Camera support</td>
<td>1 person</td>
</tr>
</tbody>
</table>

Table 4: Operations effort

### 9.2. Telescope Focal Station

In order to complete the RFBG focal station commissioning, it is estimated that three nights of data collection is needed, and after this about three to four weeks of data reduction and reporting. It is conceivable to release the focal station as-is for the AO demonstration, but this adds some risk to the effort.

### 9.3. AO system #1

As discussed above, the formal commissioning of the AO system has not yet been completed. Some on-sky and off-sky work remains to collect data, and the two reports [RD1] and [RD2] shall be released before commissioning is formally concluded.

Arcetri leads Esposito and Riccardi have stated that:

i. AO system #1 would be ready for a demonstration campaign in May or June
ii. They and their team are ready to support the AO demonstration effort
iii. It is their assessment that experience gained through such a campaign would be beneficial for the subsequent Lucifer AO commission campaign
The high-level steps required to deploy a new camera with the AO system are:

1. Optical alignment to the Wavefront sensor
2. Non-common path aberration measurement
3. Re-verify AO system calibration
4. Verify AO performance on sky

10. Science Camera

10.1. Camera alternatives

Two science grade cameras have been proposed for the AO demonstration campaign: the PISCES camera (Steward Observatory, PI Don McCarthy), and a Speckle Camera (MPIfR, PI Gerd Weigelt). Based on instrument availability, and considering logistics, this study assumes that the baseline camera is PICSES. Weigelt’s Speckle Camera remains an interesting alternative.

A minor drawback to PISCES is that it slightly undersamples the diffraction-limited core in J band and shorter wavelengths.

10.2. Camera interface engineering

To integrate PISCES onto the LBT, opto-mechanical engineering/design and fabrication/integration is required. See Attachment 1 for details on opto-mechanical integration issues.

Software integration is discussed in Section 9.1.

Electrical interface is trivial (AC power), and can be solved during installation.

A dedicated fiber connection is required to connect the camera and its computer (in LBT control room).

It has been recommended to provide compressed dry air to avoid condensation on the cryostat entrance window.

<table>
<thead>
<tr>
<th>Task</th>
<th>Duration</th>
<th>Responsible</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Opto-Mechanical interface engineering (labor)</td>
<td>6 weeks</td>
<td>Steward ME(^1)</td>
<td>$15K</td>
</tr>
<tr>
<td>Opto-Mechanical interface engineering (hardware)</td>
<td></td>
<td></td>
<td>$20K</td>
</tr>
<tr>
<td>Software integration (IRAF/IDL)</td>
<td>5 days</td>
<td>LBTO</td>
<td>$5K</td>
</tr>
<tr>
<td>Misc hardware (compressed air installation, data communication fibers etc).</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Total</td>
</tr>
</tbody>
</table>

Table 5: Interface engineering effort

\(^1\) ME = Mechanical Engineer. An individual within Steward Observatory has been identified as a suitable candidate.
10.3. Cabling

To save effort during installation and de-installation, all cabling to the science camera should be done through the LBTO on-axis commissioning cable guide system used for the IRTC. In this way it is not necessary to install cables through the permanent instrument cable chain/de-rotator.

11. System testing

To balance the requirements between optimizing the likelihood of success on one hand, and minimizing overall effort for this short-lived campaign on the other hand, this is the proposed time allocation for preparatory calibration, testing and verification:

<table>
<thead>
<tr>
<th>Task</th>
<th>Duration</th>
<th>Responsible</th>
<th>Resources</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Installation of camera on the LBT:</strong>&lt;br&gt;a) Mechanical, electrical installation&lt;br&gt;b) Network and communication&lt;br&gt;c) Software testing (IRAF/IDL)**</td>
<td>5 days&lt;br&gt;a) 5d&lt;br&gt;b) 2d&lt;br&gt;c) 2d</td>
<td>Camera team&lt;br&gt;LBTO SW&lt;br&gt;LBTO</td>
<td>1 person&lt;br&gt;1 person&lt;br&gt;1 person</td>
<td>TBD</td>
</tr>
<tr>
<td><strong>Daytime preparation:</strong>&lt;br&gt;a) PISCES/AO alignment verification&lt;br&gt;b) non common path aberration measurement and rejection&lt;br&gt;c) test of SW interfaces/commands between AO and PISCES</td>
<td>10 days</td>
<td>Arcetri/LBTO/Camera team</td>
<td>Arcetri: 3 p.&lt;br&gt;LBTO: 2 p.&lt;br&gt;Camera: 1 p.</td>
<td>$18K² TBD</td>
</tr>
<tr>
<td><strong>Night-time on-sky preparation:</strong>&lt;br&gt;a) Alignment of telescope with PISCES and AO&lt;br&gt;b) System operability with provided SW&lt;br&gt;c) System performance for PISCES + AO&lt;br&gt;d) Photometric zero points, Image scale</td>
<td>6 nights</td>
<td>Arcetri/LBTO/Camera team</td>
<td>Arcetri: 3 p.&lt;br&gt;LBTO: 2 p.&lt;br&gt;Camera: 1 p.</td>
<td>$13K TBD</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$31K</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 6: Telescope preparation and System testing effort

Time estimates for tasks in Table 6 are from responsible teams. It shall be noted that time estimates have been assessed separately by the different teams, and that time estimates from different individuals have been very comparable. This should give us good confidence in the estimates.

² Arcetri staff cost include salaries, travel, subsistence.
12. Risk areas

12.1. Schedule

12.1.1. Definition of risk
Many reviewers have pointed out schedule as perhaps the single largest risk. Integrating a new instrument with Telescope and AO system and making it operational in a very short amount of time with limited resources will no doubt be a serious challenge.

12.1.2. Mitigation
It is recommended that the project is managed from the LBT PO. This appears to be the safest approach since this is where the integrated knowledge about Telescope, AO system, and LBT science operations resides. In addition, the LBT PO has a well-established working relationship with Arcetri.

12.2. Dichroic

12.2.1. Definition of risk
A dichroic is required to split the incoming optical beam between science instrument and wavefront sensor. If a dichroic with unknown quality and properties is used, this adds significant performance risk.

12.2.2. Mitigation
It is proposed to use the already installed Lucifer-style dichroic for the campaign.

12.3. Modifications to Camera

12.3.1. Definition of risk
The Camera Team have proposed modifications to the camera (detector replacement and re-engineering of control computer architecture, see also Appendix 1). This may not be compatible with the proposed overall schedule.

12.3.2. Mitigation
Changes to the camera and/or support systems needs to be very well motivated and carefully thought through. Unless absolutely critical to the success of the campaign, modifications should preferably be postponed until after the LBTAO demonstration campaign.
12.4. Non-common path aberrations

12.4.1. Definition of risk

For optimal performance, a careful calibration of non-common path aberrations is essential. During AO commissioning using the LBTO Infrared Test Camera IRTC, compensation for non-common path aberrations is not required. It will however very likely be required for a different science camera.

12.4.2. Mitigation

Allocate adequate time for calibration. Time for non-common path calibration is included in time estimates as presented in Section 11.

12.5. Software interface to camera

12.5.1. Definition of risk

Using a new science camera with a requirement of reasonable high observing efficiency means that it has to be integrated into the LBT software environment. This applies both for camera control and processing of science data. A full SW integration would require significant effort and time.

12.5.2. Mitigation

To avoid a time-consuming full integration of the science camera with the TCS, it is proposed to re-use existing IRAF or IDL scripts developed by LBTO astronomers for the IRTC to control both the camera and telescope. This reduces the SW integration effort to about 5 man-days (including testing).

The Arcetri team recommends a meeting between relevant people very soon after project launch to discuss this aspect.

12.6. Flexure

12.6.1. Definition of risk

Differential flexure between AO wavefront sensor and science camera may negatively impact science performance. This is considered a relatively low risk.

12.6.2. Mitigation

The level of flexure must be quantified during system testing.
12.7. Vibrations

12.7.1. Definition of risk
From AO commissioning, it is known that vibrations are present at the RFBG focal station. It is possible (but unlikely) that the effect of vibrations will be worse with a different camera.

12.7.2. Mitigation
The level of vibrations must be quantified during system testing.

12.8. Camera filters
The Arcetri team feels that a manual filter wheel in the science camera could be a potential source of large observing overheads during scientific observations. They suggest that a study to identify if the filter wheel can be remotely controlled would be very important. As an example, many scientific observations require to observe the objects in K, H and J.

12.9. PISCES LN2 vent tube

12.9.1. Definition of risk
PISCES was not designed for a mounting arrangement like the LBT Bent Gregorian rotator, and so the bath cryostat LN2 reservoir will spill most of its LN2 content if the instrument is rotated around the telescope optical axis. This would lead to unacceptably short cryogenic hold times.

12.9.2. Mitigation
A better LN2 vent arrangement should be developed to reach acceptable hold time, 12 hours or more. Alternatively, a constrained rotator motion range may be considered.
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