# LINC-NIRVANA

The **L**BT **IN**terferometric **C**amera and
**N**ear-**I**nfra**R**ed / **V**isible **A**daptive
i**N**terferometer for **A**stronomy

A collaborative project of the MPIA Heidelberg, INAF-Arcetri,
Universität zu Köln, and MPIfR Bonn

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# LINC-NIRVANA

## Implementation, Commissioning, and Acceptance: Plans and Procedures



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# Contents



# List of Figures



# List of Tables

# 1 Scope

This document presents the plans and procedures for implementation, commissioning, and acceptance of LINC-NIRVANA (LN) at the Large Binocular Telescope (LBT), as far as they have been established at the time of writing.

# 2 Applicable Documents

| No. | Title | Number and Issue |
|---|---|---|
| 1 | Scientific and Technical Requirements | LN-MPIA-FDR-GEN-003 1.0 |
| 2 | Operations and Maintenance Requirements | LN-MPIA-FDR-GEN-004 1.0 |
| 3 | External Requirements | LN-MPIA-FDR-GEN-005 1.0 |
| 4 | Assembly, Integration and Testing Plan | LN-MPIA-FDR-AIT-002 1.0 |
| 5 | Alignment Plan | LN-MPIA-FDR-AIT-003 1.0 |
| 6 | Management | LN-MPIA-FDR-PM-001 1.0 |
| 7 | Handling and Shipping | LN-MPIA-FDR-AIT-005 1.0 |
| 8 | Memorandum of Understanding for the Design, Construction and the Usage Rights of LINC-NIRVANA, an Interferometric Beam Combiner with Multi-Conjugated Adaptive Optics for the Large Binocular Telescope | n.a. 1.2 |
| 9 | LBT SAC Activities 2000-2004 | n.a. 1.0 |

# 3 External Interfaces

| Item | Short description |
|---|---|
| LBTO | LBT Observatory interactions |

# 4 Acronyms and Abbreviations

| | |
|---|---|
| AIT | Assembly, integration and testing |
| AO | Adaptive optics |
| DM | Deformable Mirror |
| GWS | Ground-layer Wavefront Sensing System |
| LBT | Large Binocular Telescope |
| LBTO | LBT Observatory |
| LN | LINC-NIRVANA |
| MCAO | Multi-conjugate adaptive optics |
| MHWS | Mid-high-layer Wavefront Sensing System |
| MoU | Memorandum of Understanding |
| n.a. | Not applicable |
| OPD | Optical path difference ("piston") |
| PDR | Preliminary Design Review |
| SAC | Scientific Advisory Committee |

# 5 Introduction

LINC-NIRVANA (LN) will be implemented at the LBT in a step-wise fashion. Each of a total of four implemenation steps realizes a distinct operation mode. The final instrument configuration attained after successful completion of all four implementation steps is defined as the baseline configuration of LN in the Memorandum of Understanding (MoU) of the LN consortium partners.

Each implementation step is connected with its own commissioning phase(s) and followed by a period of routine science observations. In this document, the major commissioning goals are described for each implementation step, together with a time schedule, whereas a detailed commissioning plan at task level will be prepared by the time the instrument is shipped to Arizona (cf. LN-MPIA-FDR-AIT-005).

Plans and procedures for instrument acceptance are addressed and described as far as they have been established at the time of writing (spring 2005).

# 6 Implementation Steps

Due to the great complexity of the baseline configuration of LN, the instrument will be implemented in a stepwise fashion.

1. LINC mode:
   Diffraction limited near-infrared interferometric imaging with a pair of single on-axis natural guide stars, adaptive optics (AO) sensing systems. The goal here is to obtain scientifically useful data as soon as possible and to aim for a performance level qualified for routine science operation. This implementation level will use a single pyramid and star enlarger in each of the two mid-high layer wavefront sensors (MHWS) to perform AO corrections with the adaptive secondary mirrors of the LBT or (alternatively) with the deformable mirrors (DM) of LN.

2. GWS demonstration:
   Demonstration of Ground Level Wavefront Sensors (GWS) driving the adaptive secondaries of the telescope, with a best effort to obtain interferometric measurements.

3. MCAO (single-arm):
   Multi-conjugate Adaptive Optics (MCAO) using a single telescope aperture (non-interferometric). This mode uses the GWS and MHWS simultaneously. The goal here is to demonstrate the enhanced field of view and sky coverage afforded by MCAO. Optionally, a three-layer experiment will be performed employing an additional LN DM.

4. NIRVANA mode (MCAO interferometry):
   This is the final operating mode of LN, with scientific interferometric observations and MCAO with both GWS (driving the adaptive telescope secondaries) and both MHWS (driving one LN DM per arm).

Even though the stepwise implementation at the telescope is the key to managing the complexity of LN, it is foreseen to ship the complete final hardware and infrastructure (see LN-MPIA-FDR-AIT-005), i.e. the baseline instrument configuration in the MCAO interferometry (NRIVANA) mode. This is for financial and manpower reasons. Therefore, the instrument will be fully assembled, integrated, and tested in the MPIA integration facility (see LN-MPIA-FDR-AIT-002) followed by a final test phase leading to preliminary acceptance Europe.

Afterwards, the instrument will be disassembled to unit level and shipped to Arizona. On Mt. Graham an initial, preparatory phase of (re-)assembly, system integration, and functionality testing is foreseen to take place in a dedicated instrument preparation/integration area on the ground floor of the LBT building. Details of this integration facility are still under discussion with LBTO, but see LN-MPIA-FDR-GEN-005 for requirements from the LN project. The assembled instrument will then be lifted by crane to the instrument platform, followed by a phase of final alignment and integration with the telescope. In the subsequent implementation phase, the instrument may have to be returned to the integration/preparation area for specific tasks, thereby optimizing the time during which the implementation team can access the instrument. This will be coordinated with LBTO.

# 7 Requirements for implementation

## 7.1 Early routine scientific observations

Periods of routine scientific observations are foreseen between the individual implementation/commissioning phases of the instrument.

The LINC mode is therefore considered to be a regular operation mode of the instrument. The other implementation levels must preserve this mode of instrument operation with switch-over from one night to the next.

## 7.2 LBTO support, logistics, and infrastructure

LN imposes a number of requirements on LBTO for support, logistics, and infrastructure. This includes the permanent mounting at the foreseen focal station, the personnel support to be provided by LBTO, the instrument integration/preparation area, services such as ethernet, power, and cooling, access to the control room, requirements on instrument handling, and on accomodation for the implementation/commissioning team and observers.

These high-level requirements towards LBTO are described in LN-MPIA-FDR-GEN-005 (FDR chapter 2) and shall not be repeated here in full detail. However, one particular requirement shall be emphasized here which is the option to bring the instrument back from the telescope platform to the integration/preparation area (see Section 6). As far as realistically possible, the preparation area should be ready for access by LN during the time scheduled for implementation and commissioning.

Table 1: Manpower for the implementation/commissioning team

| **Phase** | Engineers | | | | | | | Astronomers/ physicists | Total |
|---|---|---|---|---|---|---|---|---|---|
| | Optics | Electr-onics | Detect-ors | Soft-ware | Mech-anics | Cryo-mech-anics | Total Engin-eers | | |
| **AIT at LBTO:** | | | | | | | | | |
| peak activity | 2 | 2 | 2 | 2 | 2 | 1 | 11 | 4 | 15 |
| routine activity | 1 | 1 | 1 | 1 | 1 | 1 | 6 | 3 | 9 |
| **Commissioning:** | | | | | | | | | |
| peak activity | 1 | 1 | 1 | 1 | 1 | 1 | 6 | 3 | 9 |
| routine activity | 1 | 1 | 1 | 1 | | | 4 | 3 | 7 |
| **Science:** | | | | | | | | | |
| early phase | 1 | 1 | | 1 | | | 3 | 2 | 5 |
| routine observations | | 1 | | 1 | | | 2 | 1 | 3 |

### 7.3 Implementation team

The composition of the LINC-NIRVANA implementation/commissioning team is summarized in Table 1. In the early phases, the various categories of engineers have two people assigned (except cryo-mechanics) in order to permit day and nighttime work. In the later phases, several categories are not represented, but their engineers will provide remote support via internet, VideoCon or phone. Several of the foreseen astronomers have also good knowledge in various engineering aspects or laboratory physics and will therefore provide support already in the early integration phases.

# 8 Implementation Plan

We intend to ask the LBTO for commissioning time for LINC-NIRVANA as follows:

For each of the four implementation steps of LINC-NIRVANA we will request 12 nights within a three-week time interval which will be subdivided as follows:

| | | |
|---|---|---|
| First week: | 1 night arrival+setup | — telescope access not needed |
| | plus 6 nights of commissioning | — on telescope |
| Second week: | resting, evaluation of results, and preparations for the remaining week | — commissioning team will leave the mountain |
| Third week: | 1 night arrival+setup | — telescope access not needed |
| | plus 6 nights of commissioning | — on telescope |

The four inmplementation and commissioning periods are separated by intervals of 3 – 4 months which will be devoted to evaluation and documentation of results at the home institutions of the LINC-NIRVANA partners. Also scheduled between the commissioning phases will be periods of routine science observations. The allocation of these scientific nights will be coordinated by the Italian and German partners in the usual way.

This approach leads to the tentative schedule presented in Table 2 and Fig. 1 for the activities related to implementation, commissioning, and acceptance (see also LN-MPIA-FDR-PM-001, FDR Chapter 14).

This schedule is preliminary and depends not only on progress with LN, but also on the allocation by LBTO of time slots for the planned activities.

Within the allocated nights at the telescope, each run will have a beginning-of-run alignment phase in both daytime and nighttime. In LINC mode, the GWS units will be installed, but will not necessarily need to be aligned. Twice per year, dedicated summer-winter alignment phases are foreseen.

Note that $4 \times 12$ nights of commissioning of the several LINC-NIRVANA modes will most likely not be sufficient to achieve a performance level similar to that expected from a fully commissioned instrument. This is in line with the strategic character of LINC-NIRVANA within the LBT instrument ensemble. We will certainly have to re-evaluate the needs for further test time at the telescope after the first allocated commissioning runs.

Table 2: Implementation schedule

| Phase | Time interval | Activity | Nights* |
|---|---|---|---|
| • Assembly, integration and testing (AIT) at LBTO | 2007-01-15 — 2007-03-18 | AIT in LBTO integration facility | 0 |
| | 2007-03-19 — 2007-04-01 | AIT on LBT platform | 0** |
| • Implementation Step 1: LINC mode | 2007-04-02 — 2007-04-22 | Commissioning LINC mode | 12 |
| | 2007-04-22 | Readiness LINC mode | |
| | 2007-04-23 — 2007-09-06 | Evaluation/documentation of results 1 | 0 |
| • Implementation Step 2: GWS demonstration | 2007-09-07 — 2007-09-29 | Commissioning GWS | 12 |
| | 2007-09-29 | Readiness GWS | |
| | 2007-09-30 — 2007-12-30 | Evaluation/documentation of results 2 | 0 |
| • Implementation Step 3: MCAO (single-arm) | 2007-12-31 — 2008-01-21 | Commissioning single-arm MCAO | 12 |
| | 2008-01-21 | Readiness single-arm MCAO | |
| | 2008-01-22 — 2008-04-20 | Evaluation/documentation of results 3 | 0 |
| • Implementation Step 4: NIRVANA mode | 2008-04-21 — 2008-05-12 | Commissioning NIRVANA mode | 12 |
| | 2008-05-12 | Readiness NIRVANA mode | |
| | 2008-05-13 — 2008-08-10 | Evaluation/documentation of results 4 | 0 |
| • Instrument delivery | 2008-08-11 — 2008-09-25 | Documentation update appropriate to facility instruments | 0 |
| | 2008-09-26 | Acceptance by LBTO for facility instrument | 0 |

∗ The number of nights we will request from LBTO for commissioning.
∗∗ During initial instrument installation at the LBT platform, it may happen in one or two instances that the telescope will not be ready for nighttime operations.

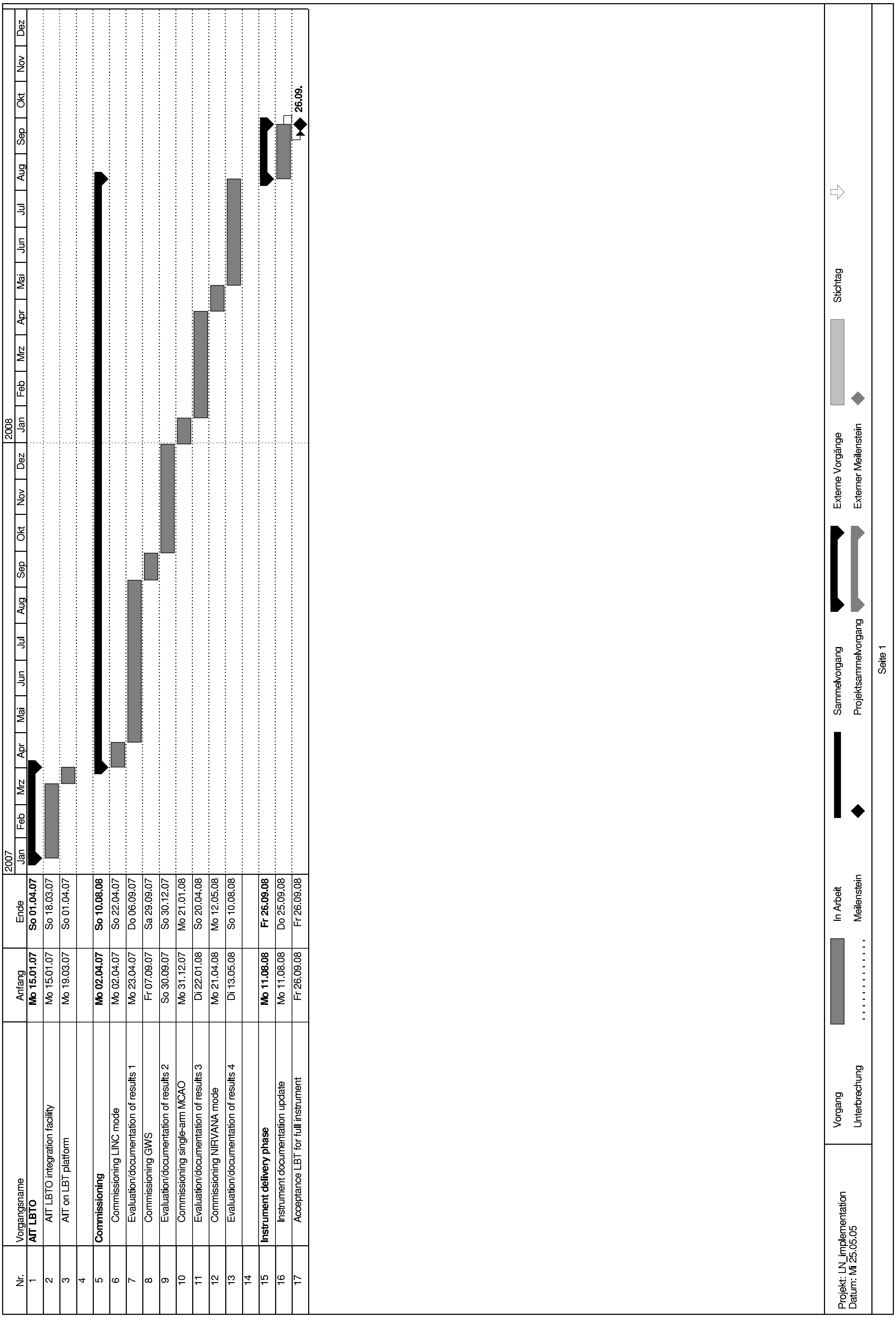


Figure 1: Implementation schedule

# 9 Commissioning Goals

Primary verification items (main drivers) are

- high fringe contrast,
- a field of view (FoV) as large as possible.

In turn these depend on

- Strehl ratio (wavefront error)
- homotheticity (the less fulfilled the smaller the FoV)
- iso-planatic patch size (an-iso-planatism, asterism dependent)
- differential piston (OPD $< \lambda/10$, where $\lambda = 1.13\mu$) and iso-pistonic patch size
- field overlap (from both telescopes) < PSF
- derotation smearing (max. 30° in parallactic angle) implies alignment of the optical axes of telescope and detector to better than 2 pixels

The principal verification and characterisation goals for the commissioning of the instrument in its four implementation modes are listed in Table 3.

Other characterisation items (on-sky):

- Image scale science detector (specified is 5.11 mas per pixel to achieve 2-pixel sampling at $1.13\mu$ given single telescope $f/87.9$ beams, i.e. FoV is $10.5'' \times 10.5''$ with a $2048 \times 2048$ pixel detector)
- Characterisation of fringe tracker FoV (specified $1' \times 1.5'$) with respect to iso-pistonic patch size; done via fringe contrast measurements over the FoV
- Fringe tracking stability (depending on seeing)
- On-sky check of pyramid sensor stability for both GWS and MHWS
- On-sky optimization of pyramid sensor positioning algorithm for both GWS and MHWS
- Differential piston "caused by" AO residuals: (a) spatial vaiation, (b) temporal variation
- Differences in the images of the two telescopes affecting individual image scales, different distortions, rotations (homotheticity differences)
- On-sky development of a strategy to minimize these differences
- Performance tuning of MCAO and fringe tracking loops
- Astrometric error, asterism dependent
- Photometric error

An attempt will be made to study several of these items as a function of telescope inclination (flexure tests).

Table 3: Major characterisation/verification items for the commissioning of LINC-NIRVANA

| | |
|---|---|
| Pre-conditions: | (1) Reference wavelength K-band<br>(2) Elevation $\geq 30°$ above horizon<br>(3) Seeing in R-band $\leq 1''$ at employed elevation<br>(4) Suitably selected asterisms (appropriate to instrument modes 1–3) |

| Impl. step | Instrument mode | Item | Commissioning goal |
|---|---|---|---|
| 1 | LINC | • Bright reference sources: | |
| | | Time-averaged on-axis Strehl ratio | 30% |
| | | Time-averaged on-axis interferometric performance | 50% of target routine performance |
| | | Overall throughput | 30% |
| | | Thermal background (accumulated emissivity) | Characterize, isolate contributors, and correct (when possible) |
| | | Isopistonic patch at site | Characterize interferometric performance a function of off-axis distance |
| | | Image scale | $\approx 5.11$ mas/pixel |
| | | • Faint reference sources: | |
| | | Fringe contrast as a function of brightness (fringe tracking star) | Characterize fringe contrast as a function of J-magnitude |
| | | Limiting magnitude for fringe tracking | Determine J-magnitude for 50% fringe contrast degradation; verify pertinent J-magnitude. Goal: J=17 mag |
| | | • Operations: | |
| | | Fringe tracker usable field | Goal: $30'' \times 30''$ |
| | | Duration of continuously closed loop (with above performances) | 30 min |
| | | Duration of startup, i.e setup of complete instrument plus first target acquisition | < 1 hr night time |
| | | Re-acquisition time | Goal: 7 min, maximum 20 min |
| | | Instrument recovery time (full re-boot and re-acquisition) | < 1 hr |
| | | Speed of closed-loop nodding up to an amplitude of $5''$ | Goal: 1 sec/arcsec, max. 5 sec/arcsec |
| 2 | GWS demo | • Bright reference sources: | |
| | | Ground-layer correction | FWHM reduction 0.5, minimum 0.7 |
| | | Turbulence strength/variance of phase fluctuation above site | Characterize the $C_N^2$ profile as a function of height |
| | | • Faint reference sources: | |
| | | Limiting magnitude for ground-layer correction | Determine R-magnitude (integrated over all reference stars) for 50% degradation of Strehl ratio. Goal: R=15 |
| | | • Operations: | |
| | | Continuous operation | 30 min |
| | | Re-acquisition time (target and asterism) | Goal: 10 min, maximum 30 min |
| | | Interferometric observations | Best effort, no requirement |

Continuation of Table 3

| Impl. step | Instrument mode | Item | Commissioning goal |
|---|---|---|---|
| 3 | Single-arm | • Bright reference sources: | |
| | | Time-averaged Strehl ratio in field | 30% |
| | | Strehl variation over FoV ($10.5'' \times 10.5''$) | 5% |
| | | Isoplanatic patch | Characterization for selected asterisms |
| | | • Faint reference sources: | |
| | | Limiting magnitude for mid-high layer correction | Determine R-magnitude (integrated over all reference stars) for 50% degradation of Strehl ratio. Goal: R=15 |
| | | • Operations: | |
| | | Closed-loop operation | 30 min |
| | | Re-acquisition time (target and asterism) | Goal: 10 min, maximum 30 min |
| | | Setup time to change layer height (movement of DM, MHWS) | Goal: 1 min, maximum 5 min |
| 4 | NIRVANA | • Bright reference sources: | |
| | | Same as for LINC mode | |
| | | • Faint reference sources: | |
| | | Limiting magnitude for fringe tracking | Verifiy goal of J=17 mag (50% degradation of interferometric performance) |
| | | Limiting magnitude for MCAO | Verify goal of R=15 mag for both GWS and MHWS (50% Strehl ratio degradation) |
| | | • Operations: | |
| | | Fringe tracker usable field | Goal: $1' \times 1.5'$ |
| | | Re-acquisition time (target and asterism) | Goal: 10 min, maximum 30 min |
| | | Other items: same as LINC mode | |

Table 4: Acceptance milestones for instrument categories

| | Strategic instruments | Facility instruments |
|---|---|---|
| Preliminary Acceptance Laboratory | × | × |
| Preliminary Acceptance Mt. Graham | × | × |
| Final Acceptance Mt. Graham | | × |

## 10 Commissioning Plan

For the purpose of this document, the fundamental verification and characterisation items and goals have been identified in the previous section. A more detailed commissioning plan at task list level will be prepared in due time, presumably before preliminary acceptance Europe and at the latest before implementation activities on Mt. Graham commence.

## 11 Requirements for acceptance

The requirements for acceptance by LBT have yet to be established in detail by LBTO. Here, it is assumed that the milestones summarized in Table 4 will have to be passed.

This assumption follows the recommendation that the Scientific Advisory Committee (SAC) made on its meeting on 3–4 May 2002 (LBT SAC Activities 2000-2004, p. 77):

> *The Project should establish a "preliminary" and "final" acceptance procedure based on the following general steps:*
>
> 1. *Preliminary Acceptance Laboratory — The instrument is deemed safe, useful, and reliable enough to bring to the telescope for commissioning.*
> 2. *Preliminary Acceptance Mt. Graham — The instrument meets minimum, non-negotiable, performance requirements. These requirements correspond to the performance specifications set out in the procurement contract.*
> 3. *Final Acceptance Mt. Graham — The instrument meets support, maintainability, and negotiable scientific performance targets. These targets correspond to the performance goals laid out in the contract.*
>
> *The LBT Director should have the authority to grant final acceptance.*

# 12 Acceptance Plan and Procedures

## 12.1 Preliminary Acceptance Laboratory

This is for strategic instrument status.

- Instrument fully assembled in lab
- Alignment procedures successfully established, applied as far as they correspond to lab level, and documented
- Fringe tracking on lab level within requirements and documented
- MCAO lab experiment performed and results documented using as much as possible of the original LN hardware
- A list of instrument characteristics determined (this list will be compiled)

## 12.2 Preliminary Acceptance Mt. Graham

This is for strategic instrument status.

Successful commissioning and documentation of LINC mode, i.e. implementation step 1.

## 12.3 Final Acceptance Mt. Graham (optional)

This is for facility instrument status. To achieve it is desired after implementation step 4, NIRVANA mode.