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LBT Beteiligungsgesellschaft
ref: Recent Potsdam meeting

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Dear LBTB:

I am writing to follow up on our discussion of LINC-NIRVANA (LN) upgrades at the recent LBTB meeting in Potsdam. Specifically, I would like to expand and explain the reasoning behind my assessment that wider field MCAO is the more interesting route to pursue, compared to small-field interferometry.

Brief Background

At its March 2015 meeting in Minneapolis, the LBT Board charged the LN leadership, the director of LBT, and the SAC to evaluate upgrade options for LN beyond Lean MCAO. I have attached their complete wording for your reference, but it boils down to a comparison between expanding the field of view for single-eye (but dual telescope) MCAO and focusing on (narrow-field, low sky-coverage) interferometry.

The Options

The “extended field MCAO” option refers to changing the re-imaging scale of our cryogenic optics to produce sampling appropriate to single-eye diffraction limited imaging – 20 mas per pixel, compared to the current 5 mas/pixel, which properly samples the interferometric PSF. The result is a 41” field of view, some 16 times larger than the current configuration. The approach put forward in my letter of 27 June foresees a reversible opto-mechanics swap in the current cryostat.

The “(small field) interferometric imaging” mode corresponds to “Lean LINC,” one of the options that we examined during the re-planning exercise in 2013. While pursuing this route does not require hardware investment, we will have to write, integrate, and test some software modules. It will also require that the “Binocular Gen-2” telescope control software be operating on the mountain.

For your reference, I have attached two tables summarizing the properties of extended field MCAO and small field interferometric imaging.

Why Wider-Field MCAO?

In its most basic form, our opinion boils down to the following: Two years ago, we traded off Lean MCAO versus Lean LINC and found that Lean MCAO is the more compelling choice in terms of science, risk, and programmatics. Both the LBT SAC and Board endorsed this view. Increasing the field of Lean MCAO by a factor of sixteen tips this balance further. In other words, if Lean MCAO is more interesting than Lean LINC, then surely a far more capable MCAO is even more interesting. In addition, the LBT SAC emphasized the importance of such a wider-field capability in their recommendations of October 2013.

The list of pros and cons of each option on the following page should make this clearer.

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Pros and Cons Wider Field MCAO

Pros
• science interest – all Lean MCAO cases strengthened, and several new ones enabled (e.g. surface brightness fluctuations)
• MCAO a unique capability in the northern hemisphere
• science interest – arguably better match to partner science interests
• needs lower level of instrument requirements, alignment compared to Lean LINC
• Lean MCAO will demonstrate all necessary control concepts
• telescope requirements significantly reduced
• In terms of programmatics and expertise, this is a route to E-ELT
• Necessary for NIRVANA

Cons
• New hardware procurement
• Lower alignment and performance requirements of instrument and telescope may jeopardize interferometry (requirements less strict for MCAO)
• Opto-mechanics swap is time consuming and not risk-free (jeopardizes interferometry)

Pros and Cons of Small-Field Interferometric Imaging

Pros
• interferometry, a unique capability of LBT
• no new hardware procurement…can proceed without taking Lean MCAO offline
• necessary for NIRVANA
• Pathfinder has demonstrated effectively all of the AO needed
• Bright, on-axis reference requirement means always operating in the high-Strehl-Ratio regime (>60%)

Cons
• needs a higher level of instrument performance and alignment compared to MCAO
• science interest – For on-axis referencing, the brightness "window" between being bright enough for fringe-tracking and saturating the science detector is small
• science interest – LBTI may do easy K-band bright science
• team readiness – FFTS delivered but not tested at instrument level
• team readiness – Sofware packages missing (and no human resources)
• telescope readiness – beyond the very simplest LINC, need Binocular Gen-2.
• telescope requirements – Zero-piston adjustment (including AOS) an unknown

Wider-Field MCAO Science Cases

The White Paper extract I attached to my June 27th letter describes the wider field MCAO science cases that we prepared in the context of the 2013 re-planning exercise. The evaluations included scientific justification, technical comments, and an assessment of the timeline and competitive landscape from other facilities. We are continuing to work on these in preparation for our Board report in the fall. I list the cases here for your reference and include a table summarizing them. Please refer to the previous attachment for fuller details.

Galactic Science - Star Clusters
- Milky Way Globular Clusters
- Embedded Young Stellar Clusters

Nearby Galaxy Science – Near-Field Cosmology
- Studying the resolved stellar populations in external galaxies.
- Improved distance indicators.

i) Cepheid Variables
ii) Tip of the RGB
iii) Surface Brightness Fluctuations

High redshift Science – Galaxy Evolution & Cosmology

- A K-band deep field
  - i) Formation of Massive Disk Galaxies
  - ii) Galaxy morphology during the peak of star formation
  - iii) The faint end of the luminosity function at z > 3

Further science applications at high redshift

- Deep imaging of proto-clusters at z ~ (2 – 4)
- Searches for over-densities around high-z (z>5) SMGs and/or QSOs
- Searching for Hα emitters at z=2

Science Case	Target Accessibility	Typical Strehl	Depth (Vega)	Exp Time	Total Time	FoV Needed	LINC Mode	Bands	Improvement
Milky Way Star Cluster Science Cases									
GCs Single or Multi Epoch	∼100%	>0.4	K_s = 20	20s, 15s, 10s (J, H, K_s)	1hr per GC 20hrs total[2]	∼90″ to reach R_e	Yes[1]	J, H, K_s	Significant; >10 year proper motion baseline, also resolution 2.5× better than WFC3 in J & H
Embedded clusters single epoch	∼100%	>0.3	K_s = 23	60s, 45s, 30s (J, H, K_s)	108hrs	30″	No	J, H, K_s	Significant/Transformational[3]
Embedded clusters multi epoch	∼100%	>0.3	K_s = 23	30s	60hrs	30″	Yes[4]	K_s	Significant/Transformational[3]
Nearby Galaxy Science Cases									
Stellar Migration in galaxy disks	>30%	>0.1-0.3	K_s = 24	2hrs per field on source	8 hours per galaxy[5]	∼60″	No	J, K_s	Competitive with HST.
Testing models of galaxy halo formation	>30%	>0.1-0.3	K_s = 24	2hrs per field on source	8 hours per galaxy[5]	∼60″	No	J, K_s	Competitive with HST.
Tip of the Red Giant Branch Distances	>30%	>0.1-0.3	K_s = 24	2hr per field on source	8 hours per galaxy[5]	>30″	No	J, K_s	[7]Significant; ∼5% distance errors for galaxies < 15Mpc.
Surface Brightness Fluctuation Distances	>30%	>0.1-0.3	K_s = 24	1hr per field on source	2 hours per galaxy[6]	>30″	No	K_s	[7]Significant; 10% distance errors for galaxies at <100Mpc .
High-z Science Cases									
Deep Field	>30-50%	>0.2-0.3	K_s = 24.65	3hr per field	5[8] nights	150″×150″	No	K_s	Significant[9]; V band morphology @ z=3
QSOs z > 5 SMGs z > 5	>30-50%	>0.2-0.3	K_s = 24.65	3hr per field	6hr 24hr	50″×50″; 100″×100″	No	K_s	Significant

[1] LINC mode provides higher resolution but smaller FoV, limiting it to studies of the inner few arcseconds.
[2] Assuming 50″ FoV and a 20 GC sample size. The exposure times are negligible relative to overheads.
[3] Until JWST there will be no space-based K-band imaging, so that the deeply embedded low-mass population can only be detected by this kind of imaging.
[4] LINC will improve the astrometry by a factor of 3, allowing us to reach 3-4 km/s accuracy. This will allow us to study internal cluster dynamics on shorter timescales.
[5] Assuming 50% overheads and a need for 2 pointings per galaxy to provide adequate spatial coverage.
[6] Assuming 50% overheads.
[7] MCAO mode essential to achieve the required stability of PSF across the FoV.
[8]Assuming a 50% observing efficiency and 11hr long nights
[9]Until JWST no space-based K_s band observations possible

Wider Field MCAO Properties

Item	Value / Comment
Observation Type	Multi-Conjugate Adaptive Optics Near-IR imaging
Wavelength	1.1 – 2.4 μm; broad and narrow band filters
Pixel Scale	20 mas/pixel
Spatial Resolution (see below)	30 mas – J Band (FWHM of diffraction-limited peak) 41 mas – H Band 53 mas – K Band
Field of View	41”square per telescope (1680 square arcsec) with a 2k detector or 82”square (6720 square arcsec) with a 4k detector – see below*
Detector Array	1 x Hawaii-2, 2 x Hawaii-2, 4k arrays – see below*
Adaptive Optics	2-layer, multi-conjugate with 12 NGS for GLAO and 8 NGS for high-layer AO. The deformable mirrors have 672 (ground) and 349 (high) actuators
Strehl Ratio	J-band 20% (based on simulations and H-band 40% GeMS performance) K-band 60%
Sky coverage	Galactic plane 99% North Galactic Pole 48%
Point Source Sensitivity (Johnson)	J-band: 25.6, 5σ 1 hour, assuming 20% Strehl Ratio H-band: 25.0, assuming 40% Strehl Ratio K-band: 24.7, assuming 60% Strehl Ratio, wintertime

*There are optical configurations which overlap the two telescopes on a single detector, as well as those which place the separate telescopes on separate detectors. In the latter instance, the two telescopes can either co-point or point separately, allowing simultaneous two-filter observations or doubling the Field of View. This applies to both 2k and 4k arrays, although adjacent fields 82” square would exceed the delivered AO-corrected field (120” diameter).

Small Field Interferometry Properties

Item	Value / Comment
Observation Type	Near-infrared Fizeau interferometric imaging
Wavelength	1.1 – 2.4 μm; broad and narrow band filters
Pixel Scale	5.11 mas per pixel; Nyquist samples to J band
Spatial Resolution	10 mas – J Band (in direction of the projected baseline) 15 mas – H Band 20 mas – K Band
Field of View	10.5” square (110 square arcsec) – same for all bands
Detector	1 Hawaii-2 array
Adaptive Optics	on-axis, single-conjugate (almost identical to LBT First-Light AO)

	AO secondary as deformable mirror (672 actuators)
Strehl Ratio	J-band 60% (assumes *ca.* 14 mag reference star) H-band 70% K-band 80%
Fringe Tracking	on-axis, near-infrared reference star (*ca.* 14 mag or brighter)
Sky coverage	typical for SCAO Galactic plane < 5% North Galactic Pole <1%
Point Source Sensitivity (Johnson)	J-band: 26.8, 5σ 1 hour, assuming 60% Strehl Ratio H-band: 25.6, assuming 70% Strehl Ratio K-band: 25.0, assuming 80% Strehl Ratio, wintertime

<u>Board Actions from March 2015</u>

Consensus 2015.03.08 (LN Plan): To reaffirm the 2013.10.13 motion on the plan for LINC/NIRVANA.

2015.03.15) With PAE for LN (in its lean MCAO configuration) imminent, the Board charges the LN project leadership, the LBTO director and the LBT SAC, to work out and evaluate the costs, time, risks and scientific benefits of:

(a) an extended MCAO field-of-view, or
(b) (small-field) interferometric imaging,

consistent with the terms of reference enumerated in Board resolution 2013.10.13. Estimate should entail, but are not limited to, an updated science case for these capabilities, an estimate of the FTE, hardware costs, commissioning time estimates, implementation schedule, with resources from both from within LBTO and available from a (possibly extended) instrument consortium. These estimates, along with the progress of the ongoing PAE and the lean MCAO implementation, should form the basis for future Board decisions whether to pursue option a), option b), both, or neither.
Deadline: Sept 27