Gemini North Adaptive Optics (GNAO) facility overview and status updates

Gaetano Sivo, Julia Scharwächter, Manuel Lazo, Célia Blain, Stephen Goodsell, Marcos van Dam, Martin Tschimmel, Henry Roe, Jennifer Lotz, Kim Tomassino-Reed, William Rambold, Courtney Raich, Ricardo Cardenes, Angelic Ebbers, Tim Gaggstatter, Pedro Gigoux, Thomas Schneider, Charles Cavedoni, Stacy Kang, Stanislas Karewicz, Heather Carr, Jesse Ball, Paul Hirst, Emmanuel Chirre, John White, Lindsay Magill, Molly Grogan, Anne Jordan, Suresh Sivanandam, Masen Lamb, Adam Muzzin, Eduardo Marin, Scott Chapman, Jennifer Dunn, Dan Kerley, Jean-Pierre Vérant, Morten Andersson, Franck Marchis, Ruben Diaz, John Blakeslee, Michael Pierce, Rodrigo Carrasco, Hwihyun Kim, Anja Feldmeier-Krause, Alan McConnachie, James Jee, Wesley Fraser, Mark Ammons, Christopher Packham, John Bally, Trent Dupuy, Daniel Huber, Marie Lemoine-Busserole, Thomas Puzia, Paolo Turri, Chadwick Trujillo, and Janice Lee

 NSF’s NOIRLab - Gemini Observatory, Colina El Pino s/n Casila 603, La Serena, Chile
 b NSF’s NOIRLab - Gemini Observatory, 670 N’Aohoku Place, Hilo, Hawaii, USA
 c NSF’s NOIRLab - Gemini Observatory, 950 N Cherry Avenue, Tucson, Arizona, USA
 d Durham University, Stockton Road, Durham, UK
 e Flat Wavefront, 21 Lascelles Street, Christchurch, New Zealand
 f University of Toronto, 27 King’s college Sir, Toronto, Canada
 g York University, 4700 Keel Street, Toronto, Canada
 h Keck Observatory, 65 Mamalahoa Hwy, Waimea, Hawaii, USA
 i Dalhousie University, 6299 South Street, Halifax, Canada
 j NRC Herzberg Astronomy and Astrophysics Research Centre, 5071 West Saanich Road, Victoria, Canada
 k European Southern Observatory, Karl-Schwarzschild-Straße 2, 85748 Garching bei München, Germany
 l SETI Institute, 339 N Bernardo Ave Suite 200, Mountain View, California, USA
 m NSF’s NOIRLab, 950 N Cherry Avenue, Tucson, Arizona, USA
 n University of Wyoming, 1000 E University Avenue, Laramie, Wyoming, USA
 o University of Chicago, 5801 S Ellis Avenue, Chicago, Illinois, USA
 p Max Planck Institute for Astronomy, Königstuhl 17, Heidelberg, Germany
 q Yonsei University, 50 Yonsei-ro, Seodaemun-gu, Seoul, South Korea
 r Lawrence Livermore National Laboratory, 7000 East Avenue, Livermore, California, USA
 s University of Texas at San Antonio, 1 UTSA Circle, San Antonio, Texas, USA
 t University of Colorado, Boulder, Colorado, USA
 u University of Edinburgh, Old College, South Bridge, Edinburgh, UK
 v University of Hawai‘i, 200 W Kawili Street, Hilo, Hawaii, USA
 x Pontifica Universidad Católica, A v. L libertador Bernardo O’ Higgins 3 40, Santiago, Chile
 y University of British Columbia, Vancouver, Canada
 z Northern Arizona University, S San Francisco Street, Flagstaff, Arizona, USA

Further author information: (Send correspondence to Gaetano Sivo)
Gaetano Sivo: E-mail: gaetano.sivo@noirlab.edu, Telephone: +56 51 2205 642
ABSTRACT

The Gemini North Adaptive Optics (GNAO) facility is the upcoming AO facility for Gemini North providing a state-of-the-art AO system for surveys and time domain science in the era of JWST and Rubin operations. GNAO will be optimized to feed the Gemini infrared Multi Object Spectrograph (GIRMOS). While GIRMOS is the primary science driver for defining the capabilities of GNAO, any instrument operating with an f/32 beam can be deployed using GNAO.

The GNAO project includes the development of a new laser guide star facility which will consist of four side-launched laser beams supporting the two primary AO modes of GNAO: a wide-field mode providing an improved image quality over natural seeing for a 2-arcminute circular field-of-view and a narrow-field mode providing near diffraction-limited performance over a $20 \times 20$ arcsecond square field-of-view. The GNAO wide field mode will enable GIRMOS’s multi-IFU configuration in which the science beam to each individual IFU will be additionally corrected using multi-object AO within GIRMOS. The GNAO narrow field mode will feed the GIRMOS tiled IFU configuration in which all IFUs are combined into a “super”-IFU in the center of the field.

GNAO also includes the development of a new Real Time Controller, a new GNAO Facility System Controller and finally the development of a new AO Bench. We present in this paper an overview of the GNAO facility and provide a status update of each product.

Keywords: GNAO, Gemini Observatory, GLAO, LTAO, Laser Guide Star, GIRMOS, Adaptive Optics

1. INTRODUCTION

One of the main limitations for optical and near-infrared ground-based astronomy is the presence of Earth’s atmosphere. It works both to absorb light as a function of wavelength and also to blur the images. Adaptive Optics (AO) has been developed to mitigate the blurring of the atmosphere by compensating the image motion caused by atmospheric turbulence using deformable mirrors (DMs). Natural guide star (NGS) AO uses a bright natural reference source to measure the wavefront distortions introduced by turbulence and to compute the corresponding corrections to be applied to the DM. NGS AO works best in the near infrared and the reference source has to be sufficiently bright for the AO correction to be possible. A strong restriction for single source AO is the small field that can be corrected. Under good conditions, even a 20″-25″ field of view (FOV) is challenging, and the quality of the correction will strongly vary within this field. Many science cases require larger FOVs and more homogeneous corrections across the FOV than achievable with single natural guide star (NGS) AO.

Science fields frequently lack sufficiently bright, nearby stars for wavefront sensing. This limitation can be overcome by using laser guide stars (LGSs). However, by passing the atmosphere twice, LGSs cannot provide any information about the tip and tilt of the wavefront, i.e. the positional offsets seen for light from a star passing the atmosphere only once. This means that LGS AO systems typically still require an NGS for tip/tilt measurements but the requirements for this NGS can be relaxed for the benefit of larger sky coverage. Another limitation of that, in contrast to NGS, the LGS is located at a finite altitude. The turbulence layers probed with an LGS are, therefore, not identical with the ones probed with NGSs. This effect – which is called the “cone effect” - can be mitigated by using multiple LGSs at different angular positions instead of a single LGS.

Various flavors of multi-guide star AO have been developed to support different types of scientific applications. We will describe the two modes that will be designed and implemented for GNAO and the added AO mode coming from the science instrument fed by GNAO.

- Laser Tomography AO (LTAO)$^1$-$^2$ is based on multiple LGSs and a single DM to provide high Strehl ratios over a narrow FOV. The data from the wavefront sensors are used to perform a tomographic reconstruction. Compared to single-LGS AO - as e.g. provided by ALTAIR at Gemini-North$^3$ -, the use of multiple LGSs, probing the atmospheric turbulence along multiple lines-of-sight, helps to reduce the cone effect.

- Ground Layer AO (GLAO)$^4$ uses multiple guide stars distributed over a relatively large FOV and a single DM to provide a moderate but uniform correction. The guide stars are used to determine an average correction which is then sensitive to the common area probed by the different guide stars, i.e. the ground
layer. This type of AO is most efficient if the dominant fraction of the turbulence is associated with
the ground layer. This is well known for Maunakea\(^5\) and thus well suited for GNAO. GLAO results in
a seeing enhancement by concentrating the energy in the peak of the PSF. Implementations of GLAO
include, e.g., GRAAL\(^6\) and GALACSI\(^7\) at ESO, which feed the wide-field (7.5'x7.5') NIR imager HAWK-I
and the optical large-format (1'x1') integral field spectrograph MUSE,\(^8\) respectively, and use the adaptive
secondary mirror of UT4 at the VLT to apply the AO correction.

- Multi-Object AO (MOAO)\(^9\) aims to provide an AO correction over small fields around multiple science
targets selected from a large patrol field. This technique overcomes the limitations of the before-mentioned
AO types to provide an efficient correction over the full patrol field. Multi-object spectroscopy (MOS) is a
powerful technique for many survey-type science cases because of its multiplexing advantage. While MOS
has commonly been in use under natural seeing conditions, first implementations with MOAO have only
been available over recent years. The Raven instrument\(^10\) demonstrated MOAO at the 8-meter Subaru
Telescope with some performance limitations because of the NGS requirements. The Gemini Infrared
Multi-object Spectrograph GIRMOS,\(^11\) built as the first-light instrument behind GNAO by a Canadian
consortium, will take advantage of the GNAO LGS facility to provide an advanced implementation of
MOAO, feeding multiple integral field spectrographs across the patrol field.

GNAO is developed as part of the National Science Foundation-funded “Gemini in the era of multi-messenger
astronomy” (GEMMA) program, in parallel with the other two GEMMA projects on Time Domain Astronomy
and Public Information and Outreach. The original design for GNAO focused on a general purpose MCAO
system for imaging and spectroscopic modes provided by visiting and facility instruments.\(^12\) During 2020, the
scope of the GNAO project was refocused towards towards LTAO and GLAO using a single DM only.\(^13\) This
design was optimized to support the innovative first-light instrument GIRMOS\(^11\) while reducing complexities
compared to an MCAO system.

The design of GNAO is jointly driven by the science cases developed by the GIRMOS team and the large
fraction of science cases originally developed for the GNAO MCAO system that will remain feasible within
the GNAO+GIRMOS scope. A potential use of GNAO with GMOS at visible wavelengths is considered an
upscope.\(^13\)

2. GIRMOS: THE GEMINI INFRARED MULTI OBJECT SPECTROGRAPH

The Gemini InfraRed Multi Object Spectrograph (GIRMOS) is designed as a multiplexed Near InfraRed (NIR)
Integral Field Unit (IFU) spectrograph using MOAO to feed four IFUs deployable over the 2'-diameter patrol
field provided by the GNAO GLAO mode. The IFUs are based on an image-slicer design offering spatial sampling
options of 0.025", 0.05", and 0.1" per spaxel and FoVs of 1"x1", 2"x2", and 4"x4", respectively. Each individual
IFU will be paired with a DM to perform the MOAO correction based on the GNAO ground-layer corrected
field. GIRMOS offers wavelength coverage from 0.95 to 2.4 microns at spectral resolutions of 3000 or 8000.
The IFUs can be used in a tiled mode offering a total IFU FoV size that is unprecedented among current NIR IFUs
at AO spatial resolutions. The resulting tiled FOV of up to 8"x8" can take advantage of the GNAO LTAO
mode to achieve high Strehl ratios. In addition to the IFU modes, GIRMOS will include a NIR imager based on
a HAWAII-4RG 4K x 4K detector, which provides an 85" x 85" FOV with a spatial sampling of 0.021" /pixel.
More updated informations on GIRMOS can be found in the SPIE proceeding from this conference.\(^11\)

3. SYNERGIES WITH OTHER FACILITIES

At the time of GNAO’s commissioning, there will be many new facilities either in operation or close to coming
online. Among the major ones are James Webb Space Telescope (JWST), the Vera C. Rubin Observatory’s
Legacy Survey of Space and Time (LSST), the Nancy Grace Roman Space Telescope, and Euclid. GNAO is
envisioned to complement and work in unison with these facilities.

The time domain capabilities planned for GNAO will play a key role in the follow-up of the enormous
number of variable and transient objects detected with the Rubin Observatory’s LSST together with the Roman
Space Telescope, and Euclid. Many of these discoveries will require rapid follow-up, both spectroscopically
and photometrically, at wavelengths not covered by the Rubin Observatory/LSST camera and at higher spatial resolution (e.g., or isolating the flux from a transient against the flux of an underlying background galaxy).

A GNAO system with queue scheduling flexibility, fast proposal routes (like the Gemini Fast Turnaround program\textsuperscript{14}), and short acquisition times for rapid target-of-opportunity triggers will be highly competitive in this context.

JWST’s launch happened on Christmas day 2021. The first data from JWST have just started to revolutionize near-to-mid-infrared astronomy. With a JWST mission lifetime goal of more than 10 years and an expected GNAO first light in the second quarter of the US fiscal year 2028, both facilities are likely going to be in operation simultaneously for several years.

GNAO cannot compete with JWST’s sensitivity, but will be substantially more flexible than JWST for rapid follow-up and long-term monitoring. The survey capabilities enabled by GNAO and GIRMOS offer major synergy potential between the two facilities. In particular, the multi-object IFU mode will provide an important multiplexing advantage, for example for spatially-resolved spectroscopy of galaxies around cosmic moon. GNAO-enabled instrument modes may provide a larger flexibility in narrow-band imaging filters, or provide medium-to-high spectral resolution complementary to JWST’s capabilities. The availability of these modes depends on the backend instrument design.

4. GNAO’S SCIENCE CASES SUMMARY

The GNAO science team has supported the development of GNAO, to ensure the best use of the facility by the community. The team is led by Gemini/NSF’s NOIRLab and has strong participation from the Gemini Observatory community with experts in many areas of astrophysics. A collaboration with the GIRMOS team is provided through joint team members.

The development of GNAO+GIRMOS focuses on three key science capabilities that enable a wide range of science cases from solar system science to extragalactic science and cosmology.

- High Resolution facility for multi messenger events. With a rapid response mode, GNAO will be a premier facility for high-angular resolution follow-up studies of gamma-ray bursts and other transients.

- Powerful capabilities for Survey Science. The spectroscopic multiplexing provided by GNAO+GIRMOS will provide a powerful capability for spectroscopic surveys of galactic and extragalactic sources.

- Flexible for Solar System science and multi-epoch studies. By offering a queue-scheduled system with a non-sidereal tracking option, GNAO will have key capabilities to support a wide range of solar system science and monitoring studies.

We present here a couple example of science cases enabled with GNAO+GIRMOS.

4.1 High Resolution Facility for Multi-Messenger events

The example of the famous 2017 gravitational wave event GW170817 has demonstrated the power of multi-messenger astronomy as an important driver of astrophysical discoveries. GW170817 was the first gravitational wave event detected with an electromagnetic counterpart through a major worldwide observing campaign.\textsuperscript{15} The gravitational wave signal together with the subsequent short gamma-ray burst (GRB) and follow-up detections across the electromagnetic spectrum have provided unprecedented insights into the physics of neutron star mergers, including their association with short GRBs as well as kilonova emission from radioactive decay during the synthesis of heavy elements. Characterizing the kilonova emission after a short GRB is a high-priority science driver for the GNAO narrow field mode, where high angular resolution will improve the detection of the transient against the background host galaxy light. As a queue-operated facility, GNAO is being developed to offer a rapid response mode to support this science case and early follow-up of other targets of opportunity, such as Solar System transients or new, unknown transients discovered with Rubin Observatory’s Legacy Survey of Space and Time.
4.2 Powerful capabilities for survey science

GNAO, in conjunction with GIRMOS, will provide powerful capabilities for spectroscopic surveys at high angular resolution. The multiplexing capabilities offered by the GIRMOS spectroscopic modes will be complementary to many aspects of galactic and extragalactic research conducted with the JWST. The GIRMOS spectroscopic modes are well suited to study targets such as star clusters, galaxy nuclei and supermassive black holes, lensed galaxies, and in the study of galaxy evolution from low to high redshift. Two of the primary science drivers for GIRMOS are a survey of galaxies between redshifts of 0.7 and 2.7 and a survey of globular clusters, taking advantage of the multi-IFU and tiled-IFU configurations, respectively. The galaxy survey will provide unprecedented sample sizes of high-angular-resolution IFU data to study the role of mergers, star formation, and feedback processes in the build-up of galaxy mass around redshift 2. Globular clusters are candidates for hosting intermediate-mass black holes, which are expected to exist in the mass range between stellar-mass and supermassive black holes but have remained difficult to detect. The spatially resolved spectroscopy obtained with the GIRMOS globular cluster survey will provide new opportunities to systematically search for observational signatures of the much sought-after intermediate-mass black holes.

4.3 GNAO+GIRMOS characteristics and Image Quality requirements

We present here the characteristics of GNAO + GIRMOS both in imaging and spectroscopic mode.

|                     | Imaging | FoV | K-band (2.2\(\mu\)m) performance | H-band (1.65\(\mu\)m) performance | J-band (1.25\(\mu\)m) performance |
|---------------------|---------|-----|-----------------------------------|-----------------------------------|-----------------------------------|
| GNAO WFM (GLAO)     | 60% sky coverage | 85” x 85” | 120 mas FWHM                       | 150 mas FWHM                       | 200 mas FWHM                       |
| GNAO NFM (LTAO)     | 60% sky coverage | 20” x 20” | SR 35%                            | SR 20%                            | SR 10%                            |
| GNAO on-axis (LTAO) | 12 mag R-band limit | on-axis | SR 60%                            | SR 45%                            | SR 25%                            |

| Detector            | Hawaii-4RG 4k×4k |
|---------------------|------------------|
| Pixel Scale         | 0.021”           |
| Wavelength (\(\mu\)m) | 0.83-2.4         |

5. GNAO TECHNICAL CONFIGURATION

In this section, we present a brief overview of the different products for GNAO. The GNAO facility is divided into 4 main technical work packages:

- the laser guide star facility;
- the real time controller;
- the system controller;
- and the adaptive optics bench.

We describe these four products in the subsections below. In the figure 1, we can see the current functional diagram of the full GNAO facility. This is not a design solution but a representation of all the functionalities required to build GNAO and perform all the different required tasks.
Figure 1. GNAO system control integration
5.1 Laser Guide Star Facility

The LGSF is responsible for generating the 4 laser guide stars that will be used for GNAO and it must also be capable of producing 4 laser guide stars in a wide field mode to support a future GLAO Adaptive Secondary Mirror system for Gemini independent of GNAO. In order to ensure the system meets requirements, the first trade study that was completed for the GNAO LGSF was the number of lasers that would be required. Due to the efficiency of the 3rd generation fiber lasers built by Toptica photonics and also due to improvements in detector technology it was determined that two Toptica lasers would be sufficient to generate four guide stars with adequate photon return for GNAO in both wide and narrow field mode.

The three main components of the LGSF are the Toptica SodiumStar high-power guide star laser at 589nm, the Beam Expander and Control Node (BEaCoN), the LLTs. The 589nm lasers and LLTs will both be purchased as turn key systems through vendors, while the BEaCoN will be developed in-house. The lasers are provided by Toptica Projects GmbH. Officina Stellare has been selected to build the Laser Launch Telescopes. This design is similar to the LLTs that are currently in use at the European Southern Observatory (ESO) Very Large Telescope (VLT). The LLTs are transmissive reverse Galilean telescopes, as opposed to the reflective off-axis parabola LLTs that are currently in use at Gemini. One key element of these LLTs is their large patrol field of 14.4 arcminutes in diameter. This allows them to support both narrow-field and wide-field constellations. The BEaCoN is the only element of the LGSF that is being developed in-house, apart from the laser coolant system.
More information on the LGSF for GNAO is presented in this conference paper from Thomas Schneider\textsuperscript{17}

5.2 Real Time Controller

The Real Time Controller for GNAO is based on the HEART toolkit\textsuperscript{18}. Herzberg Extensible Adaptive Real-Time (HEART) software is a framework and collection of utility tools that can be used to create an AO Real-Time Controller (RTC). It consists of generalized RTC code blocks in modular, flexible and configurable structure that allows for development of an RTC with reduced effort, which is what everyone really wants, especially when it is an observatory that will be upgrading instruments regularly. Also, HEART comes with extensive testing of the common code base which improves the quality because it will be used across multiple projects. HEART is also unique because years ago it was decided by not tying to specific hardware it would be easier to develop if a CPU-based architecture with off-the-shelf hardware. The code is largely written in C, with some Python and JavaScript. HEART is the baseline for several AO systems:

- GNAO on Gemini, both wide and narrow field mode. (GLAO, LTAO);
- NFIRAOS on Thirty Meter Telescope, MCAO;
• GIRMOS on Gemini, MOAO;
• GPI2.0 on Gemini, XAO;
• REVOLT on Dominion Astrophysical Observatory Telescope.

HEART is also considered for MORFEO (MCAO on ELT) and ANDES (SCAO on ELT). More details can be found in Jennifer Dunn’s proceeding from this conference.\textsuperscript{18}

5.3 System Controller
As the current GNAO effort is ongoing, we are developing the core components for the System Control (SYSCO) facility. The System Control architecture was devised so that the different major components can reuse a basic design, divided in a number of discrete, highly configurable agents that deal with different tasks: abstracting the SYSCO-hardware interface, discrete command execution and monitoring, reactive control (subsystem coordination), and sequence execution and control. This paper describes the components providing control logic, with focus on the sequencing one, which is central to the ”One Button” philosophy guiding GNAO’s software design. This philosophy follows from design goals of the GNAO system: improving field resolution and operating in the Gemini queue scheduled environment. From the operative point of view, GNAO strives to be a system that is simple to operate, with a single person being able to handle it without the need for an intimate knowledge of the underlying system. To achieve these goals, the GNAO Control System is designed to support a functional decomposition of the primary actions (creating guide stars, correcting atmospheric distortion, etc), assigning them to subsystems, and then to functional components in each subsystem. Patterns of abstraction and encapsulation are used throughout the design to provide functional interfaces which ensure that each component hides the complexity and details of its underlying implementation.

In the past, Gemini’s facility software has been heavily based on EPICS IOCs written in C and C++. Early on we decided against this though, first because we were looking for something more extensible. Because of that we decided to use a general-purpose language for scripting, and in order to leverage our expertise Python was the choice. More information on the detail design of the SysCo can be found in the proceeding from Ricardo Cardenes presented in this conference.\textsuperscript{19}

5.4 Adaptive Optics Bench
The GNAO AOB is currently under competitive conceptual design phase studies. 3 teams have been selected to conduct the conceptual design study of the AO bench. The current plan is to held the conceptual design review early June and soon after a down selection to one team to continue the design until the delivery and integration to the telescope. More information to come later once the competitive phase has passed.

ACKNOWLEDGMENTS
The authors would like the thank the National Science Foundation for the funding of the GEMMA program under the Contract Support Agreement number AST-1839225. The Gemini Observatory is operated by the Association of Universities for Research in Astronomy, Inc., under a cooperative agreement with the NSF on behalf of the Gemini partnership: the National Science Foundation (United States), National Research Council (Canada), CONICYT (Chile), Ministerio de Ciencia, Tecnología e Innovacion Productiva (Argentina), Ministério da Ciência, Tecnologia e Inovação (Brazil), and Korea Astronomy and Space Science Institute (Republic of Korea).

REFERENCES
[1] Tallon, M. and Foy, R., “Adaptive telescope with laser probe: isoplanatism and cone effect,” \textbf{235}, 549–557 (1990).
[2] Le Louarn, M., \textit{Laser guide stars for large telescopes : cone effect and astrophysical implications}, PhD thesis, CRAL - Observatoire de Lyon and European Southern Observatory - Garching (2000).
[3] Herriot, G., Morris, S., Anthony, A., Derrall, D., Duncan, D., Dunn, J., Ebbbers, A. W., Fletcher, J. M., Hardy, T., Leckie, B., Mirza, A., Morbey, C. L., Pfieger, M., Roberts, S., Shott, P., Smith, M., Saddlemenyer, L. K., Sebesta, J., Szeto, K., Wooff, R., Windels, W., and Veran, J.-P., “Progress on Altair: the Gemini North adaptive optics system,” in [Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series], Wizinowich, P. L., ed., Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series 4007, 115–125 (July 2000).

[4] Rigaut, F., “Ground-conjugate wide field adaptive optics for the elts,” in [Beyond Conventional Adaptive Optics], Ragazzoni, R. and Esposito, S., eds., Astronomical Observatory of Padova (2001).

[5] Tokovinin, A., Vernin, J., Ziad, A., and Chun, M., “Optical turbulence profiles at mauna kea measured by mass and scidair,” Pub. Astron. Soc. Pacific 117, 395–400 (2005).

[6] Paufique, J., Madec, P.-Y., Kolb, J., Kuntschner, H., Argomedo, J., Kiekebusch, M. J., Donaldson, R. H., Arsenault, R., Siebenmorgen, R., Soenke, C., Tordo, S., Conzelmann, R. D., Jost, A., Reyes-Moreno, J., Downing, M., Hibon, P., Valenzuela, J. J., and Haguenauger, P., “GRAAL on the mountain top,” in [Adaptive Optics Systems V], Marchetti, E., Close, L. M., and Veran, J.-P., eds., Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series 9909, 99092H (July 2016).

[7] Oberti, S., Kolb, J., Madec, P.-Y., Haguenauger, P., Le Louarn, M., Pettazzi, L., Guesalaga, A., Donaldson, R., Soenke, C., Jeram, B., Suarez Valles, M., Kiekebusch, M., Argomedo, J., La Penna, P., Paufique, J., Arsenault, R., Hubin, N., and Vernet, J., “The AO in AOF,” in [Adaptive Optics Systems VI], Close, L. M., Schreiber, L., and Schmidt, D., eds., Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series 10703, 107031G (July 2018).

[8] Bacon, R., Bauer, S.-M., Bower, R., Cabrit, S., Cappellari, M., and al., “The second generation vlt instrument muse: science driver and instrument design,” in [Ground-based instrumentation for astronomy], 5492-1145. (2004).

[9] Hammer, F., Sayede, F., Gandron, E., Fusco, T., Burgarella, D., Cayatte, V., Conan, J.-M., Courbin, F., Flores, H., Guinouard, I., Jocou, L., Lançon, A., Monnet, G., Mouline, M., Rigaud, F., Rouan, D., Rousset, G., Bunt, V., and Zamkotsian, F., “The FALCON Concept: Multi-Object Spectroscopy Combined with MCAO in Near-IR,” in [Scientific Drivers for ESO Future VLT/VLTI Instrumentation], Bergeron, J. and Monnet, G., eds., 139 (2002).

[10] Lardi`ere, O., Nash, R., Markes, J.-P., Andersen, D., Bradley, C., Blain, C., Desmarais, R., Gamroth, D., Ito, M., Jackson, K., Lach, P., and Pham, L., “Final opto-mechanical design of Raven, a MOAO science demonstrator for Subaru,” in [Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series], 8447 (July 2012).

[11] Sivanandam, S., Chapman, S., Simard, L., Hickson, P., Venn, K., Thibault, S., Sawicki, M., Muzzin, A., Erickson, D., Abraham, R., Akiyama, M., Andersen, D., Bradley, C., Carlborg, R., Chen, S., Correia, C., David, C., Ellison, T., El-Sankary, K., Fahlman, G., Lamb, M., Lardi`ere, O., Lemoine-Busserolle, M., Moon, D.-S., Murray, N., Peck, A., Shafai, C., Sivo, G., Veran, J.-P., and Yee, H., “Gemini infrared multi-object spectrograph: instrument overview,” in [Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series] 10702, 107021J (Jul 2018).

[12] Sivo, G., Palmer, D., Scarrywachter, J., Andersen, M., Provost, N., Marin, E., van Dam, M., Chinn, B., Chirre, E., Cavedoni, C., Schneider, T., Kang, S., Hirst, P., Rambold, W., Ebbbers, A., Gigoux, P., Catala, L., Hayward, T., Blakeslee, J., Roe, H., Lotz, J., Kleinman, S., Sivanandam, S., Krause, A., Ammons, M., Trujillo, C., Packham, C., Marchis, F., Christou, J., Lee, J., Bally, J., Pierce, M., Puzia, T., Turri, P., Kim, H., Schwamb, M., Dupuy, T., Diaz, R., Carrasco, R., Neichel, B., Correia, C., Steinbring, E., Rigaut, F., Yervis, J.-P., Chun, M., Lamb, M., Chapman, S., Esposito, S., and Fusco, T., “GNAO: an MCAO facility for Gemini North,” in [Advances in Optical Astronomical Instrumentation 2019], Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series 11203, 112030N (Jan. 2020).

[13] Sivo, G., Scharrwächter, J., and Sivanandam, S., “The Next-Generation Adaptive Optics Facility for Gemini North,” The NOIRLab Mirror 3, 17 (June 2022).

[14] Andersen, M., Mason, R., Geballe, T. R., Chiboucas, K., Salinas, R., Lundquist, M. J., scharrwachter, J., Schirmer, M., and silva, K., “The first two years of the Gemini Fast Turnaround Proposal Program,” in [American Astronomical Society Meeting Abstracts #229], American Astronomical Society Meeting Abstracts 229, 237.12 (Jan. 2017).
Proc. of SPIE Vol. 12185  1218536-12
[18] Jennifer Dunn et al, t. c., “,” in [Advances in Optical Astronomical Instrumentation 2022], Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series (2022).

[19] Ricardo Cardenes et al, t. c., “A Flexible Automation Solution for the Gemini North Adaptive Optics Facility,” in [Advances in Optical Astronomical Instrumentation 2022], Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series (2022).