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An infusion of new blood using the Toptica laser with GeMS: results of the commissioning and science performance

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ABSTRACT

Adaptive Optics (AO) systems aim at detecting and correcting for optical distortions induced by atmospheric turbulences. The Gemini Multi Conjugated AO System GeMS is operational and regularly used for science observations since 2013 delivering close to diffraction limit resolution over a large field of view. GeMS entered this year into a new era. The laser system has been upgraded from the old 50W Lockheed Martin Coherent Technologies (LMCT) pulsed laser to the Toptica 20/2W CW SodiumStar laser. The laser has been successfully commissioned and is now used regularly in operation. In this paper we first review the performance obtained with the instrument. I will go then into the details of the commissioning of the Toptica laser and show the improvements obtained in term of acquisition, stability, reliability and performance.

Keywords: Adaptive Optics, Multi-Conjugated Adaptive Optics, GeMS, astrometry, Laser Guide Star

1. INTRODUCTION

GeMS,[1–3] the Gemini Multi Conjugated Adaptive Optics (AO) System is a Multi Conjugated AO (MCAO) facility installed at the Cassegrain focus of the 8.1m Gemini South telescope at the top of Cerro Pachón (Chile). GeMS delivers a uniform, close to diffraction limit, corrected image in the near infrared (from $0.95\mu m$ to $2.5\mu m$) over a wide field of view (FoV) of 2'. GeMS is the first sodium laser assisted MCAO instrument and is currently still the only one in regular operation. GeMS uses 5 Laser Guide Stars (LGSs) placed on a 60" diameter squared constellation with one star in the center. The LGS light goes then to five 16×16 Shack-Hartmann wavefront sensor to measure the distorted wavefront. These measurements are then used to drive two deformable mirrors, one conjugated to the ground, one conjugated at 9km at a speed up to 800 Hz (depending on the sodium photon return). To correct for tip-tilt (TT) errors, GeMS uses up to three Natural Guide Stars (NGSs) using a second set of wavefront sensor. Currently GeMS has three probes that can move in the technical FoV in order to catch

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the light from the NGS and sense the TT. One of these probes has also a second functionality, it sends 30% of the light into a Slow Focus Sensor (SFS) in order to compensate the slow altitude drift of the sodium layer altitude in the mesosphere. The magnitude limit for this NGSWFS system is about 15.5 in the V-band.

Since GeMS is in operation, it has been combined with the 85”^{2} near infrared imager GSAOI.[4] GSAOI has 4 2048×2048 pixels Hawaii-2RG detectors and is equipped with a decent number of wide and narrow band filters. GeMS, being an AO facility, could also be used with other facilities instruments available at Gemini South, such as Flamingos-2[5] (a near infrared spectro-imager) or GMOS-S[6] (a multi-objects spectrograph in the visible).

2. PERFORMANCE STATUS OF GEMS

GeMS performance have been consistent and stable since the commissioning. Under good seeing conditions, GeMS can deliver up to 40% SR in K-band all over the science field of view (see figure 1).

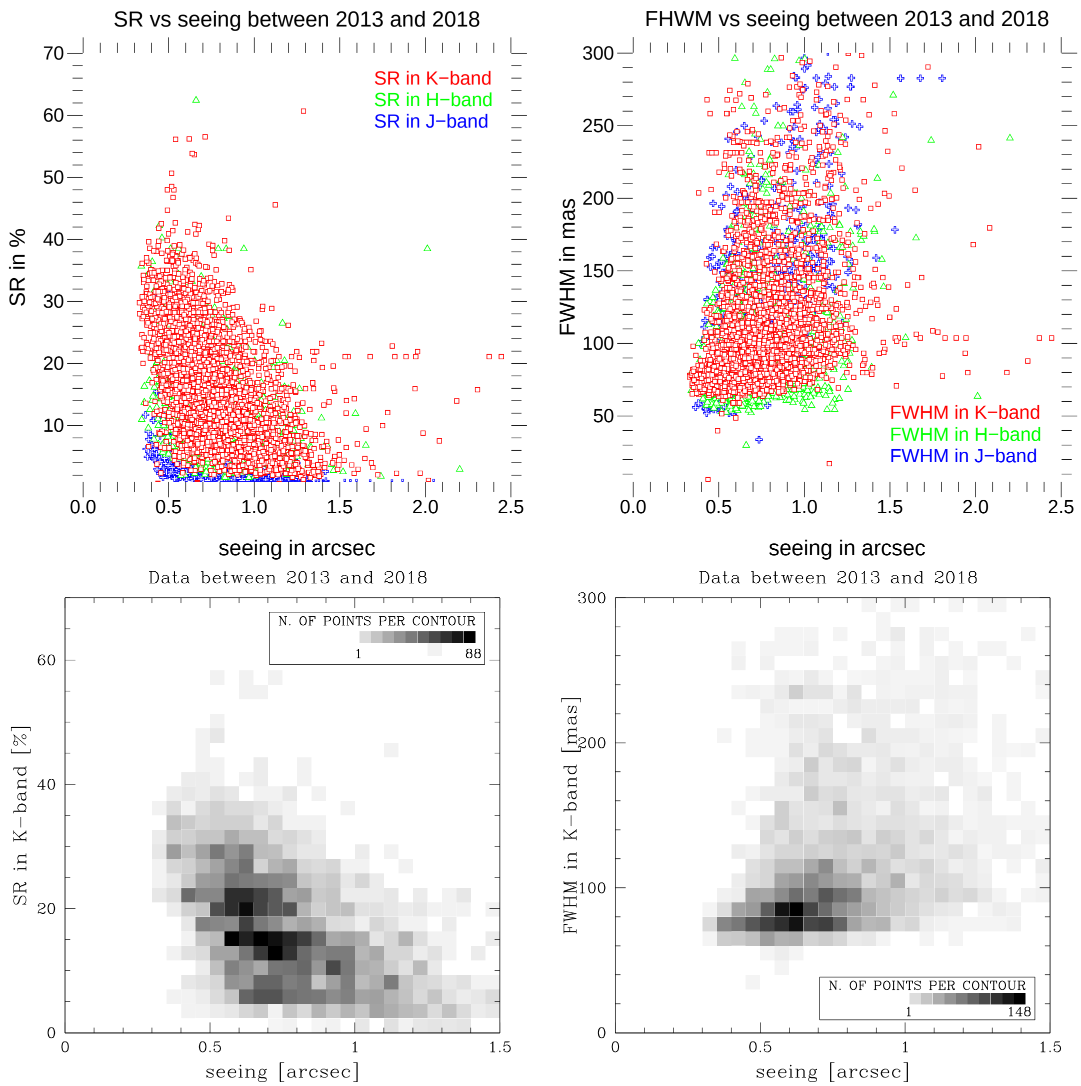

Figure 1. Performance obtained with GeMS during the period 2013-2018 in term of Strehl ratio (left) and full width half maximum (right) as a function of the seeing condition (Red: K-band. Green: H-band. Blue: J-band). On the top we see the data points and on the bottom the density of probablity.

The figure 2 shows the uniformity of the correction over the large field of view.

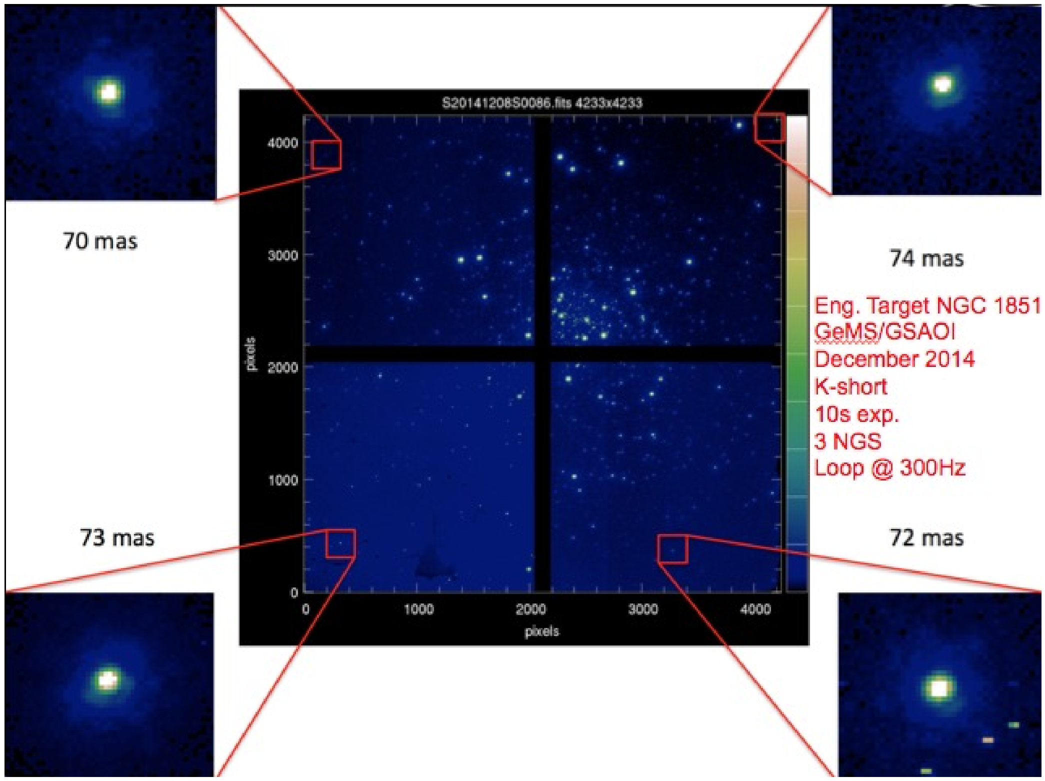

Figure 2. Example of uniformity of the correction obtained with GeMS-GSAOI .

Maintaining good performance for GeMS under mediocre to bad seeing conditions (worse than 0.8" seeing) has been a challenge over the past years mainly due to the lack of power of our solid state laser system developed by Lockheed Martin Coherent Technologies. To overcome this issue at Gemini, we decided to replace our laser system with a newer, more stable and more reliable laser. After we conducted a feasibility study and reviewed the possible candidate, we did select the SodiumStar 22W Toptica laser[7] to replace our laser system. We present in the section 3 the reason of such a change and the challenge of installing a new laser into a working instrument.

3. A NEW LASER FACILITY: THE TOPTICA SODIUMSTAR 20/2

The laser subsystem is one of the most important components of the full GeMS facility. Our current laser, a 50W solid-state laser delivered by Lockheed Martin Coherent Technologies (LMCT) in March 2010, has seen its first light on-sky in January 2011.[8] Two infrared laser arms are independently amplified several times before being mixed into a sum frequency generation birefringent crystal to produce a laser line centered at the D2a sodium resonance frequency. This very complex system is located inside a container box mounted on the side of the telescope platform providing a control environment in a gravity invariant area. Since its first light in 2011, a very non negligible amount of staff and time has been required to keep the system in a working state for operations. The laser power has been very unstable and rarely at nominal working values. The figure 3 shows the output laser power as a function of time. We can see that since 2012, the laser keeps dropping and this affects directly the performance achievable with GeMS and was never back to full performance after a strong earthquake that we suffered in 2015.

In 2014, we started to work internally at Gemini, to see if it was possible to find a replacement for this laser system that would allow us to reach the performance level needed for our science but also being a much more reliable laser. The main requirements were delivering a similar photon return but with an increased robustness and ease of use in order to reduce significantly the man power required and the engineering workload and provide a sustainable long term operation for GeMS. Based on a successful internal feasibility study within the AO team, the Gemini board endorsed the procurement of a new laser system. The procurement phase was done via a

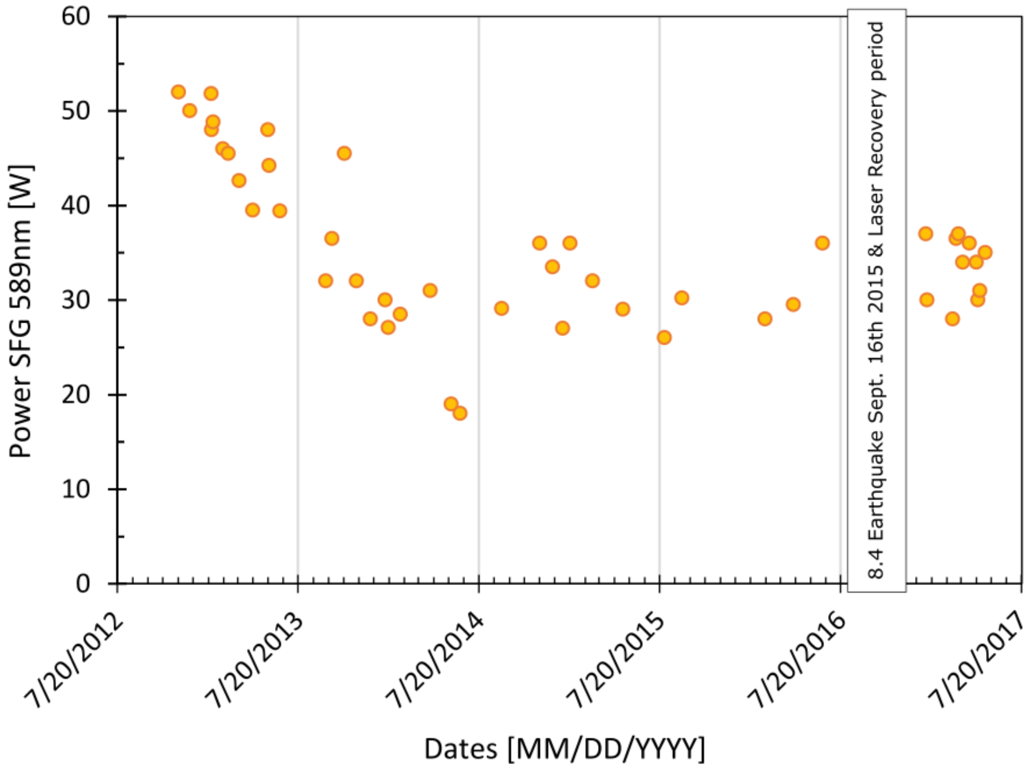

Figure 3. LMCT laser output power as a function of time .

public request for quotes and after reviewing the answers, the internal committee with the help of 2 external reviewers, have decided to select the Toptica SodiumStar 20/2 laser.[7] In 2017, the laser has been tested in the laboratory, and integrated on the telescope. In October 2017, the Gemini AO team has successfully performed the commissioning of the toptica laser and the system is since fully operational for science operations. No downtime for GeMS was required during this whole process which consists of a great success for the entire team. The results of the commissioning are presented in the next section (section 4).

The main challenge for the installation of this new laser was that we had to keep the system available for science operation while upgrading the laser, meaning that the old LMCT had to be working while we install the new Toptica laser. The second challenge was also that nothing had to be modified downstream the BTO entrance. For this we had to install the Toptica laser on the side of the LMCT, on top of the gravity invariant platform and add a Beam Injector Module (BIM) that allows to select which laser we want to have in use and align the Toptica into the BTO. The second functionality of the BIM is to provide a low power mode for the Toptica laser. Indeed, the Toptica laser cannot be used at low power since the electronic does not provide this mode. The low power mode is required for GeMS since we do need to align the BTO at every slew to correct for flexures. The BTO is equipped with cameras that we use during the alignment step. To do so, we put in or out a beam splitter cube inside the BIM path to either send the light to the BTO fully (operation mode) or to a beam dump and let 1% of the light going through the BTO and align it. An illustration is presented in the figure 4.

4. SCIENCE PERFORMANCE AND TOPTICA PHOTOMETRY

Since October 2017, the new laser is available for science operation. We did (to date of this paper June 2018) perform 3 laser runs for science operations for a total of 12 nights on-sky. We present below the performance obtained in the figure 5.

We can see in the figure 5 that the system is delivering the same science performance than the old laser. The working point in K-band is between 15 to 20 % SR and 75 to 85 mas FWHM. Regarding the photometry, the

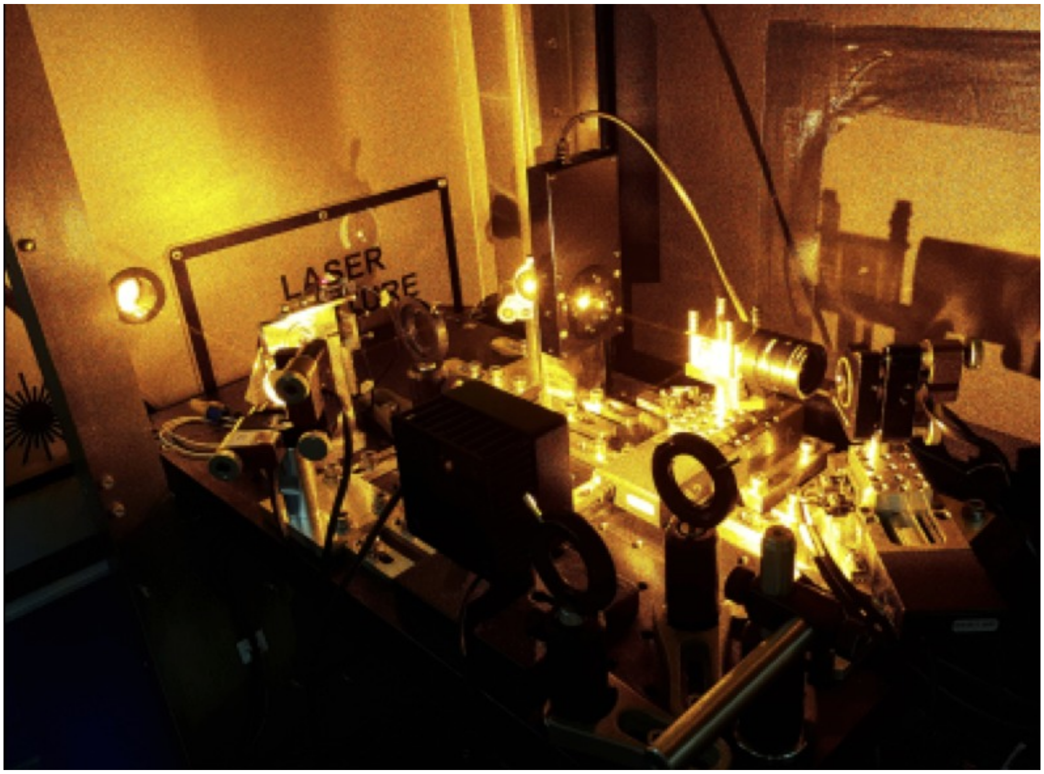

Figure 4. Photography of the Beam Injector Module illuminated with the Toptica laser.

requirements for the new laser was to deliver at least $5e6$ photons/m^2. We did perform a photometry analysis of the Toptica laser using images recorded thanks to the Gemini acquisition camera. The results are shown in the figure 6. In this figure, we did stack a set of 5 images of the constellation at zenith and removed the Rayleigh scattering for background cleaning. Using the zero point calibration of the acquisition camera and the ADU conversion we estimate that each spot has a magnitude of about 10 in V-band and delivers more than $1e6$ photons. Our requirements are met and are in agreements with the data analysis done at Keck[9] and ESO[10] for their toptica laser.

5. CONCLUSION

GeMS is in operation and delivering very good new exciting science since 2012. While we are still in operation and working on maintaining the system, we are actively working on strong upgrades that will bring GeMS into a more reliable system and helping our community to reach for the first time resolution on several important science cases. GeMS has been upgraded with a new, more reliable and easier to use laser guide star system using the toptica laser. This new laser improved significantly the operations of GeMS and the availability of the system for science. Other upgrades are on the roadmap of GeMS. We are working on a new NGS WFS that will help us reach a better sky coverage to overcome the limitation we are currently facing. This new NGS will also be much easier to use and help the acquisition to be much faster. GeMS also requires 4 trained staff to operate currently. We are working in modernizing the BTO in order to simplify operation and reduce the staff needed to be at most 3. Finally, we are looking into a new RTC facility to bring higher computer power to the system, make available a minimum variance controller that will help improve the AO performance and most of all, have a simpler RTC platform that could be maintained by our software group and have also an easier component for this critical part of the system. Reshaping GeMS will definitely bring the instrument as a worldwide recognised AO workhorse. A detailed comparison of the 2 laser guide star system has been done in term of photometry, sodium return characterisation with respect to telescope pointing, and AO parameters such as spot size, spot shapes, centroiding accuracy and phase reconstructions. These results are presented in a refereed paper in preparation

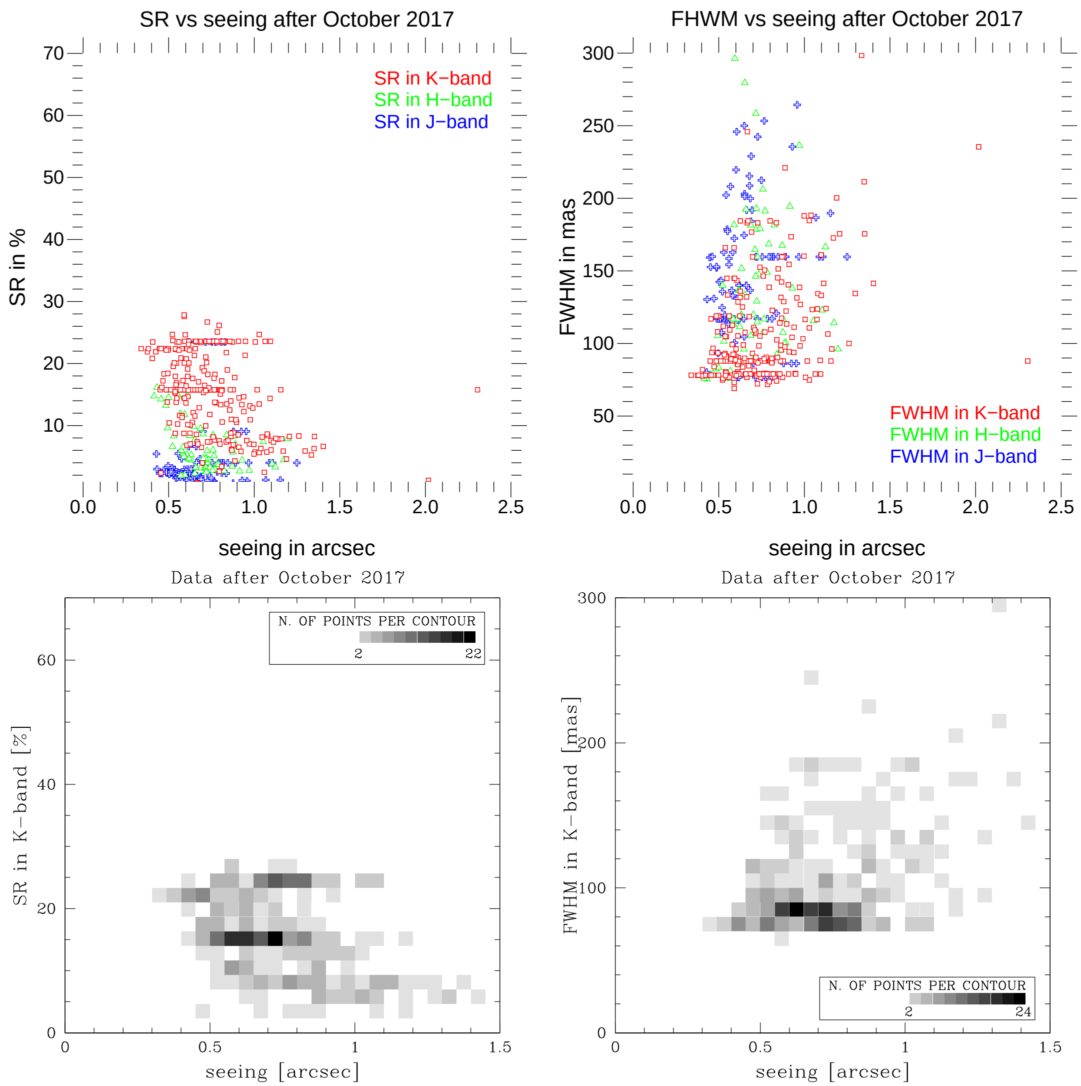

Figure 5. Performance obtained with GeMS during the period October 2017 - March 2018 using the Toptica laser in term of Strehl ratio (top) and full width half maximum (bottom) as a function of the seeing condition (Red: K-band. Green: H-band. Blue: J-band). On the left we see the data points and on the right the density of probability.

to be submitted by the end of 2018 (Sivo et al 2018 in prep.).

6. ACKNOWLEDGMENTS

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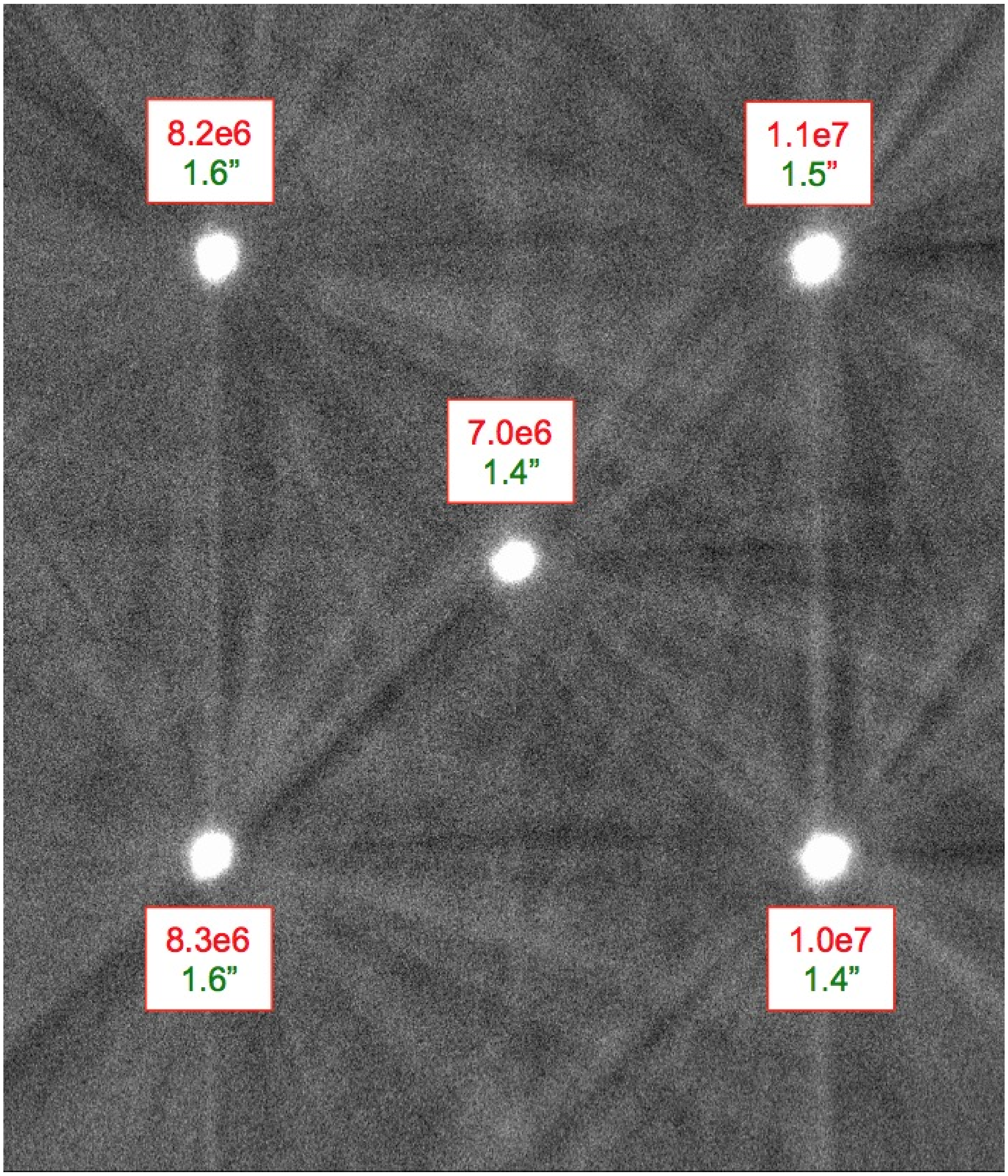

Figure 6. Acquisition camera image of the Toptica laser constellation on-sky. In red we give the ADU record of the spot and in green the spot size on-sky.

REFERENCES

[1] Rigaut, F., Neichel, B., Boccas, M., d'Orgeville, C., Vidal, F., van Dam, M. A., Arriagada, G., Fesquet, V., Galvez, R. L., Gausachs, G., Cavedoni, C., Ebbers, A. W., Karewicz, S., James, E., Lührs, J., Montes, V., Perez, G., Rambold, W. N., Rojas, R., Walker, S., Bec, M., Trancho, G., Sheehan, M., Irarrazaval, B., Boyer, C., Ellerbroek, B. L., Flicker, R., Gratadour, D., Garcia-Rissmann, A., and Daruich, F., "Gemini multiconjugate adaptive optics system review - I. Design, trade-offs and integration," *MNRAS* **437**, 2361–2375 (Jan. 2014).

[2] Neichel, B., Rigaut, F., Vidal, F., van Dam, M. A., Garrel, V., Carrasco, E. R., Pessev, P., Winge, C., Boccas, M., d'Orgeville, C., Arriagada, G., Serio, A., Fesquet, V., Rambold, W. N., Lührs, J., Moreno, C., Gausachs, G., Galvez, R. L., Montes, V., Vucina, T. B., Marin, E., Urrutia, C., Lopez, A., Diggs, S. J., Marchant, C., Ebbers, A. W., Trujillo, C., Bec, M., Trancho, G., McGregor, P., Young, P. J., Colazo, F.,

and Edwards, M. L., "Gemini multiconjugate adaptive optics system review - II. Commissioning, operation and overall performance," *MNRAS* **440**, 1002–1019 (May 2014).

[3] Sivo, G., Marin, E., Garrel, V., Neichel, B., van Dam, M., Rigaut, F., Moreno, C., Chirre, E., Perez, G., Ebbers, A., Collins, P., Vergara, V., Toro, E., Diaz, P., Chinn, B., Figueroa, C., Donahue, J., Gigoux, P., Price, I., Herrald, N., Bennet, F., Carrasco, R., Andersen, M., Angeloni, R., Lazo, M., Montes, V., Rutten, R., d'Orgeville, C., and Hirst, P., "Getting ready for GeMS 2.0: A workhorse AO facility," in [*Fith International Conference on Adaptive Optics for Extremely Large Telescopes.*], (2017).

[4] McGregor, P., Hart, J., Stevanovic, D., Bloxham, G., Jones, D., Van Harmelen, J., Griesbach, J., Dawson, M., Young, P., and Jarnyk, M. A., "Gemini South Adaptive Optics Imager (GSAOI)," in [*Ground-based Instrumentation for Astronomy*], Moorwood, A. F. M. and Iye, M., eds., *Proc. SPIE* **5492**, 1033–1044 (Sept. 2004).

[5] Elston, R., Raines, S. N., Hanna, K. T., Hon, D. B., Julian, J., Horrobin, M., Harmer, C. F. W., and Epps, H. W., "Performance of the FLAMINGOS near-IR multi-object spectrometer and imager and plans for FLAMINGOS-2: a fully cryogenic near-IR MOS for Gemini South," in [*Instrument Design and Performance for Optical/Infrared Ground-based Telescopes*], Iye, M. and Moorwood, A. F. M., eds., *Proc. SPIE* **4841**, 1611–1624 (Mar. 2003).

[6] Crampton, D., Fletcher, J. M., Jean, I., Murowinski, R. G., Szeto, K., Dickson, C. G., Hook, I., Laidlaw, K., Purkins, T., Allington-Smith, J. R., and Davies, R. L., "Gemini multi-object spectrograph GMOS: integration and tests," in [*Optical and IR Telescope Instrumentation and Detectors*], Iye, M. and Moorwood, A. F., eds., *Proc. SPIE* **4008**, 114–122 (Aug. 2000).

[7] Enderlein, M., Friedenauer, A., Schwerdt, R., Rehme, P., Wei, D., Karpov, V., Ernstberger, B., Leisching, P., Clements, W. R. L., and Kaenders, W. G., "Series production of next-generation guide-star lasers at TOPTICA and MPBC," in [*Adaptive Optics Systems IV*], *Proc. SPIE* **9148**, 914807 (July 2014).

[8] d'Orgeville, C., Diggs, S., Fesquet, V., Neichel, B., Rambold, W., Rigaut, F., Serio, A., Araya, C., Arriagada, G., Balladares, R., Bec, M., Boccas, M., Duran, C., Ebbers, A., Lopez, A., Marchant, C., Marin, E., Montes, V., Moreno, C., Petit Vega, E., Segura, C., Trancho, G., Trujillo, C., Urrutia, C., Veliz, P., and Vucina, T., "Gemini South multi-conjugate adaptive optics (GeMS) laser guide star facility on-sky performance results," in [*Adaptive Optics Systems III*], *Proc. SPIE* **8447**, 84471Q (July 2012).

[9] Chin, J. C. Y., Wizinowich, P., Wetherell, E., Lilley, S., Cetre, S., Ragland, S., Medeiros, D., Tsubota, K., Doppmann, G., Otarola, A., and Wei, K., "Keck II laser guide star AO system and performance with the TOPTICA/MPBC laser," in [*Adaptive Optics Systems V*], *Proc. SPIE* **9909**, 99090S (July 2016).

[10] Bonaccini, D., "Laser Guide Star return flux at Cerro Paranal and at the Canary Islands," in [*Fith International Conference on Adaptive Optics for Extremely Large Telescopes.*], (2017).