# REPORT ON SAM SCIENCE VERIFICATION PROGRAM

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## 1 Introduction

The SOAR Adaptive Module (SAM) is a laser-assisted ground-layer adaptive optics (AO) system designed to improve seeing-limited resolution at optical wavelengths over a 3-arcmin. field. It is equipped with a 4Kx4K CCD imager, SAMI.

The SAM LGS loop was first closed in April 2011. Substantial seeing improvement with SAMI was reached on March 6, 2012. The instrument was commissioned in September 2013 [8]. By that time, the first science paper based on the 2011 commissioning data was published [3]. Data on some other objects collected during commissioning period could be eventually used by the PIs who proposed those objects in advance of the formal SAM science verification (SV) call for proposals (CfP).

The SAM SV CfP was issued on January 18, 2013.[1]. The goals were defined as follows: *"The SAM SV program is intended to demonstrate the ability of the instrument to produce scientifically useful images. Ideally an SV proposal would test as many aspects as possible of SAM's performance, such as image quality and its uniformity over the field, gain in limiting magnitude, photometric accuracy, and astrometric calibration. This SV process is complementary and parallel to shared risk proposals to use SAM during 2013B, which may be submitted in response to the normal 2013B CfP to be released on 1 March 2013 (NOAO) and 15 March 2013 (Brazil and Chile)."*

## 2 Summary of the SV proposals

We received some proposals by mid-February, in time for the SAM February engineering run. A total of 16 proposals were received in response to the CfP by the March 15 deadline. They are labeled as SV1 to SV16 in Table 1, in order of reception. In addition, two more programs SV17a and SV18a were included later informally, as explained below. The last column of Table 1 indicates the number of hours spent on the corresponding proposal. Two SV proposals marked by asterisks were accepted later as regular science programs by the Chilean and Brazilian TACs (CN2013B-57-SAM and S02013B-021, respectively) and allocated observing time in the 2013B semester; both programs were executed successfully.

The total SV time requested by the programs SV1 to SV16 is 61.4 h. Considering the diverse nature of targets, their visibility, and requirements, it was decided not to reject any proposal, but to get useful data whenever possible by flexible selection from the whole SV program. Some programs turned out to be a poor match to the SAM capabilities.

[1] http://www.ctio.noao.edu/new/Telescopes/SOAR/Instruments/SAM/science/sv.html

Table 1: SAM SV proposals summary

| SV# | Title | PI<br>e-mail | Filt | Moon | Req.<br>(h) | Obs.<br>(h) |
|---|---|---|---|---|---|---|
| SV1 | Gravitational arcs | G.Caminha<br>gbcaminha@cbpf.br | g'r'i' | D | 4 | 1.6 |
| SV2 | IRAS cluster | D.Clemens<br>clemens@bu.edu | R,I | D | 5.6 | 0 |
| SV3 | Green-bean galaxies | M.Schirmer<br>mschirme@gemini.edu | R | D | 5 | 4.2 |
| SV4 | M5 globular cluster | K.Kraemer<br>kathleen.kraemer@bc.edu | g'i' | B | 3.4 | 7.3 |
| SV5 | UW Cen nebula | E.Montriel<br>edward.j.montiel@gmail.com | BVRI | D | 3 | 0 |
| SV6 | Polar-ring galaxies | P.Freitas<br>priscila@univap.br | V,R | D | 5.2 | 0 |
| SV7 | Pulsar bow shock | R.Romani<br>rwr@astro.stanford.edu | H$\alpha$ | D | 2 | 3.0 |
| SV8 | Compact pl. nebulae | R.Shaw, L.Stranghellini<br>shaw@noao.edu | H$\alpha$, OIII | B | 3 | 2.4 |
| SV9* | Cosmic Skidmark | D.Murphy<br>dmurphy@astro.puc.cl | g'r'i' | D | 5 | 14.2* |
| SV10 | Pluto | J.Camargo<br>camargo@on.br | I | B | 3 | 1 |
| SV11 | Clumpy galaxy | Z.Zheng<br>zhenya.zheng@asu.edu | 4687/19 | D | 4.5 | 0 |
| SV12* | Star-form. galaxies | L.Martins, A.Ardila<br>aardila@lna.br | V,R,H$\alpha$ | D | 2.4 | 7.2* |
| SV13 | Compact groups | J.McBride<br>mcbridej@physics.unc.edu | q'r'i' | D | 5.3 | 2.0 |
| SV14 | LHS1070 | L.Almeida<br>leonardo...@gmail.com | I | B | 1.5 | 0 |
| SV15 | Gravitational lensing | P.Spinelli<br>pfspinelli@usp.br | I | D | 5.5 | 0 |
| SV16 | Comets | K.Meech<br>meech@ifa.hawaii.edu | I? | D | 5 | 0 |
| SV17a | L-dwarf | S.Dieterich<br>dieterich@chara.gsu.edu | I,R | B | – | 1.1 |
| SV18a | Young binaries | C.Briceño<br>cbriceno@ctio.noao.edu | g'r'i'z' | B | – | 9.8 |

# 3 Execution of the SV program

The original plan was to execute the SV program in the 2013A semester: *"The SAM SV program will use up to 6 nights of engineering time during the 2013A Semester (March to July) including some*

*nights which will be partly dark. Observations will be executed in service mode, with a possibility of remote participation by the proposers."* In fact the SV was extended to the 2013B semester.

Table 2: SAM SV runs and time spent on the SV programs

| Run | Obs. | SV1 | SV3 | SV4 | SV7 | SV8 | SV9* | SV10 | SV12* | SV13 | SV17a | SV18a |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Feb.13 | 12h | | | 0.5 | 1.5 | 0.9 | | | | | | |
| Mar.13 | 5 | | | | 1.5 | | | | | | | |
| Jun.13 | 6 | | | 1.0 | | 1.5 | | | | | 0.7 | |
| Sep.13 | 23 | 1.6 | 3.5 | | | | 14.2 | 1.0 | 1.7 | 2.0 | | 4.7 |
| Jan.14 | 16.5 | | 0.7 | | | | | | 5.5 | | 0.4 | 5.1 |
| Total (h) | 64.5 | 1.6 | 4.2 | 1.5 | 3.0 | 2.4 | 14.2* | 1.0 | 7.2* | 2.0 | 1.1 | 9.8 |

The SV program was executed during 6 SAM observing runs summarized in Table 2. It lists in the 2nd column the total amount of hours when SAM acquired science data in each run, and approximate time spent on each of the 11 programs that were attempted or executed, including the two proposals SV9* and SV12* that were allocated 3 "regular" nights during this period. Four SV runs were combined with the SAM engineering and were scheduled during the full-Moon periods, the remaining two runs Sep.13 and Jan.14 were a "grey" time with the Moon in the last quarter. The "dark" SV time scheduled in April 2013 was lost to telescope failure. Comments on each SV run follow. Of the 64.5 h when SAM was taking science data, 48 h were used to observe the SV program and two proposals; the rest was spent on engineering and on observations of technical or PR targets.

**Feb. 26 and Mar. 2, 2013.** Two nights with favorable seeing conditions and full Moon (the first night was interrupted by clouds, however). SAMI worked with 3" $BVRI$ filters and the 3" H$\alpha$ filter of questionable quality. Most SV proposals were not yet received before the run.

**Mar 27 2013.** Half-night (the rest lost to clouds), full Moon. Only the SV7 program could be addressed, but did not produce results because of the bright sky and clouds.

**April 17-18, 2013.** The two dark nights allocated for the SAM SV work were lost to the hexapod failure in SOAR.

**Jun 21,23 2013.** Of the 3-night allocation, most was lost to clouds, with the bright Moon and poor seeing in the remaining clear half-night. The SOI filter wheel was installed, loaded with the SDSS *gri* 4" filters and the two emission-line filters, enabling partial execution of the SV8 program. Another bright-time program, SV4, got some low-quality data.

**Sep. 26-30, 2013.** Part of the 5-night allocation was lost to clouds. Moon in the last quarter with poor seeing conditions. Two semi-dark nights were ear-marked for the execution of the SV9* program. The remaining time was used mostly for the "bright-sky" SV programs such as SV18a.

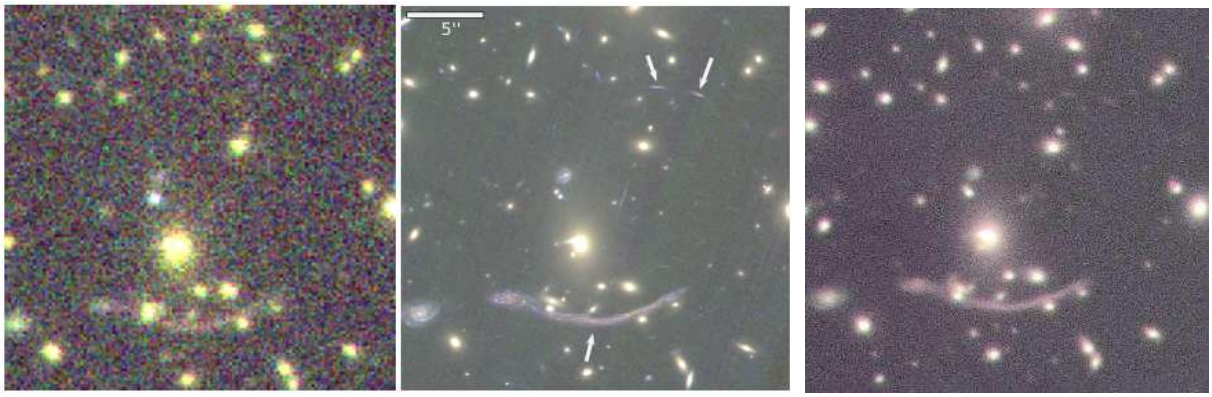
**Jan 20-23, 2013.** Substantial fraction of the 3-night allocation was lost to transparent clouds. One night was allocated to the SV12* proposal, which was in fact executed in the first halves of two nights. The remaining time with the Moon above horizon (last quarter) was mostly used by the SV18a program.

Technical data and problems encountered in SAM operation are reported in the *System Design Notes* posted at the SAM web site.[2] The problems were numerous, but did not prevent regular operation of SAM. Execution of the SAM SV program shows that the SAM system is operational.

[2]http://www.ctio.noao.edu/new/Telescopes/SOAR/Instruments/SAM/sdn/ao_sdn.html [password-protected]

# 4 Overview of the programs and results

## 4.1 SV1: Gravitational Arcs




SDSS HST SAM

Figure 1: Images of the gravitational arcs in the galaxu cluster Abel 370 from SDSS, HST, and SAM. The first two pictures are extracted from the SV proposal. The SAM data were taken on Sep. 29, 2013. Five 5-min exposures in the $i'$ and $r'$ filters each are median-combined and presented as a false-color image; resolution $0.5''$.

High-resolution imaging of gravitational arcs around galaxy clusters. This is a strong proposal which matches the original SAM science case. The two selected arc systems have both ground-based and HST images, enabling to ascertain the SAM niche in-between. This is part of a large project, SOGRAS [4], with data from SOAR and CFHT. One target, Abel 370, was observed in Sep.2013, but interrupted by the clouds (Fig. 1). The full image[3] shows many arcs. Almost all sources are galaxies, and are resolved (their FWHM is larger than the FWHM of few stars in this field). **Data delivered to the proposer, no feedback received.**

## 4.2 SV2: Competitive Accretion in the IRAS19297+1954 Star Cluster

Deep imaging and photometry of a young cluster to $I \sim 21$ and $R \sim 23$. The project is a good match to the SAM capabilities, but the declination of $+20°$ makes it difficult to achieve the requested DIQ of $0.4''$. The cluster could be observed only under good FA seeing and dark sky in June, 2013, but these conditions were not met in that run.

## 4.3 SV3: Ionization Echoes in Active Galaxies

"Green beans" are galaxies with ionization echoes, presumably created by an extinct quasar. Observations of 6 targets with a resolution of $< 0.4''$ in the $R$ filter were requested to better define their morphology (images with $0.6''$ resolution were already available from the Magellan telescope). The list below shows targets covered in the Sep.13 and Jan.14 runs, and the range of FWHM resolution on each target. On two targets, SAM could reach the desired resolution, the remaining targets were observed under poor seeing. Note that the last 2 targets were not part of the SV proposal, they were

[3] http://www.ctio.noao.edu/new/Telescopes/SOAR/Instruments/SAM/pics/abel370a.jpg

communicated to us by M. Schirmer. **Feedback was expected from M. Schirmer by March 1, 2014 but not received.**

| Target | Ra,Dec(2000) | FWHM | Run |
|---|---|---|---|
| SDSS_2050 | 20:50:58 +05:50:12 | 0.7"-0.9" | Sep.13 |
| SDSS_2135 | 21:35:43 -03:14:08 | 0.4" | Sep.13 |
| SDSS_2240 | 22:40:24 -09:27:48 | 0.6"-0.8" | Sep.13 |
| SDSS_0113 | 01:13:41 +01:06:08 | 0.6"-0.8" | Sep.13 |
| SDSS_0800 | 08:00:02 -09:58:41 | 0.4"-0.5" | Jan.13 |

### 4.4 SV4: SAM Observations of the M5 Globular Cluster

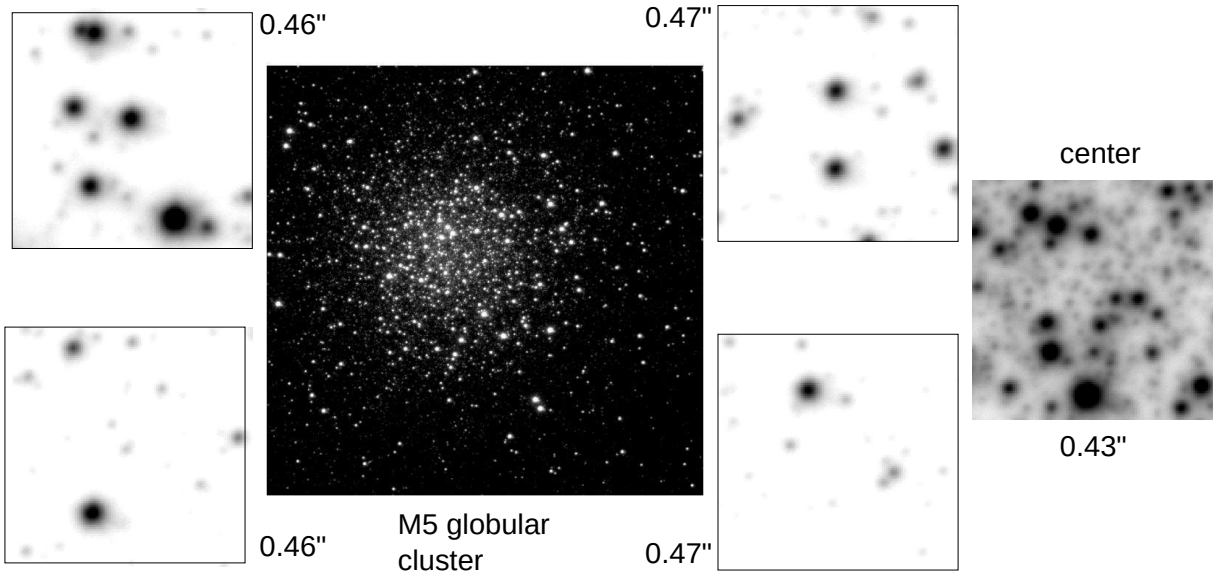



Figure 2: Image of the M5 globular cluster taken on March 2, 2013 (6×10-s exposures in $i$, median-combined). The square fragments are amplified 64 times and demonstrate stability of the PSF over the entire field (the FWHM measured on several stars in each zone is indicated).

Imaging of the core of M5 globular cluster with short exposures was requested to find long-period variable stars among bright AGB cluster members, with several epochs already covered by HST and from the ground. The advantage of SAM was to overcome the crowding in the cluster center and the associated photometric errors. This is a good "bright-time" project for SAM. Images in the $g'$ and $i'$ bands were taken in the Feb.13 and Jun.13 runs with a resolution of $0.4'' - 0.6''$ (Fig. 2) and $0.5'' - 1''$, respectively. Dithers were implemented and used in June. Together with other globular clusters imaged during SAM engineering and SV runs, this is a good material for testing astrometric potential of SAM, given that accurate astrometry of these clusters is available from the HST. **Data delivered to the proposer, no feedback received.**

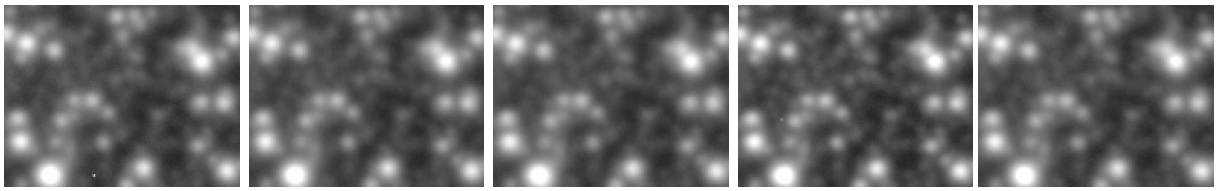


Figure 3: Dithers on the M5 cluster on June 21, 2013. "Movie" of the re-centered and distortion-corrected images #84-88 (M5-SW pointing, $i$ filter). Fragments of the lower-right image corner with maximum distortion are displayed on the same logarithmic intensity scale and show a good registration, despite dithers (from SDN 7134).

### 4.5 SV5: Reflection nebula around UV Cen

This program aims at imaging a very faint reflection nebula surrounding the R CrB-type variable star UV Cen. Here, the increased resolution of SAM brings no gain in the detectivity (the surface brightness of the reflection nebula is $\sim 21 - 22\,\mathrm{mag/arcsec}^2$). The author assumed a 10x10 binning to get an "effective pixel" of $0.5''$, which gives SAM no advantage over seeing-limited imagers. This program was not executed.

### 4.6 SV6: Morphology and Kinematics of Polar-Ring Galaxies

Optical imagery of 5 polar-ring galaxies was requested, with the goal to *"study their morphology and optical colors."* It was not clear from the proposal how the SAM data could be used to advance these goals. This program required a substantial amount of dark time, which we did not have. The targets were included in the observing program of each run, but no data resulted.

### 4.7 SV7: Observations of PSR J0742-2822

Observations of the faint bow-shock around a pulsar in the H$\alpha$ band were requested, in hope of studying the shock morphology. The nebula was barely detected in the SOI deep image presented in the proposal. The target was observed twice, but under bright time, with the sky background noticeable even in H$\alpha$. A good resolution of $0.3'' - 0.4''$ was reached in the Feb.13 run. The shock was not detected against the bright sky. Better results could be obtained from deep exposures under dark sky – the conditions that we did not have. The quality of the 3" H$\alpha$ filter used in these observations is questionable (non-uniform transmission over the field). The PI agreed that very faint nebulae are not good targets for SAM, as their detection would require binning and a loss of resolution, unless there are small and bright details to be resolved.

### 4.8 SV8: High Dynamic Range Observations of Compact Galactic PNe

High dynamic-range observations of compact Galactic planetary nebulae in two emission lines H$\alpha$ 6563Å and OIII 5007Å were requested. The list contained 7 compact PNe with angular diameters $< 3''$, with the expectation that at least 3-4 could be observed with SAM. All these targets have HST images, so the goals of this program were purely technical: to evaluate the dynamic range of SAM. In fact, low-order AO correction provided by SAM concentrates the light into the core of the PSF but has no effect on its wings or even degrades them by light scattering from the small-scale optical defects, including those of the DM. So, from the outset this SV program was not well justified. Yet,

we did obtain a spectacular image of the planetary nebula NGC 2440[4] in the Feb.13 run and were keen to take more.

This program presented a programmatic challenge for SAM, as it required the use of 4" filters, hence the use of the SOI filter wheel (the generic SAM filter wheel has 3" filters). The change of the SAMI software allowing to work with the SOI wheel was implemented only before the Jun.13 run. Two targets were covered in this run (PN_G 285.4+01.5 and PN_G 307.5-04.9), with resolution between 0.7″ and 1″ (poor seeing).

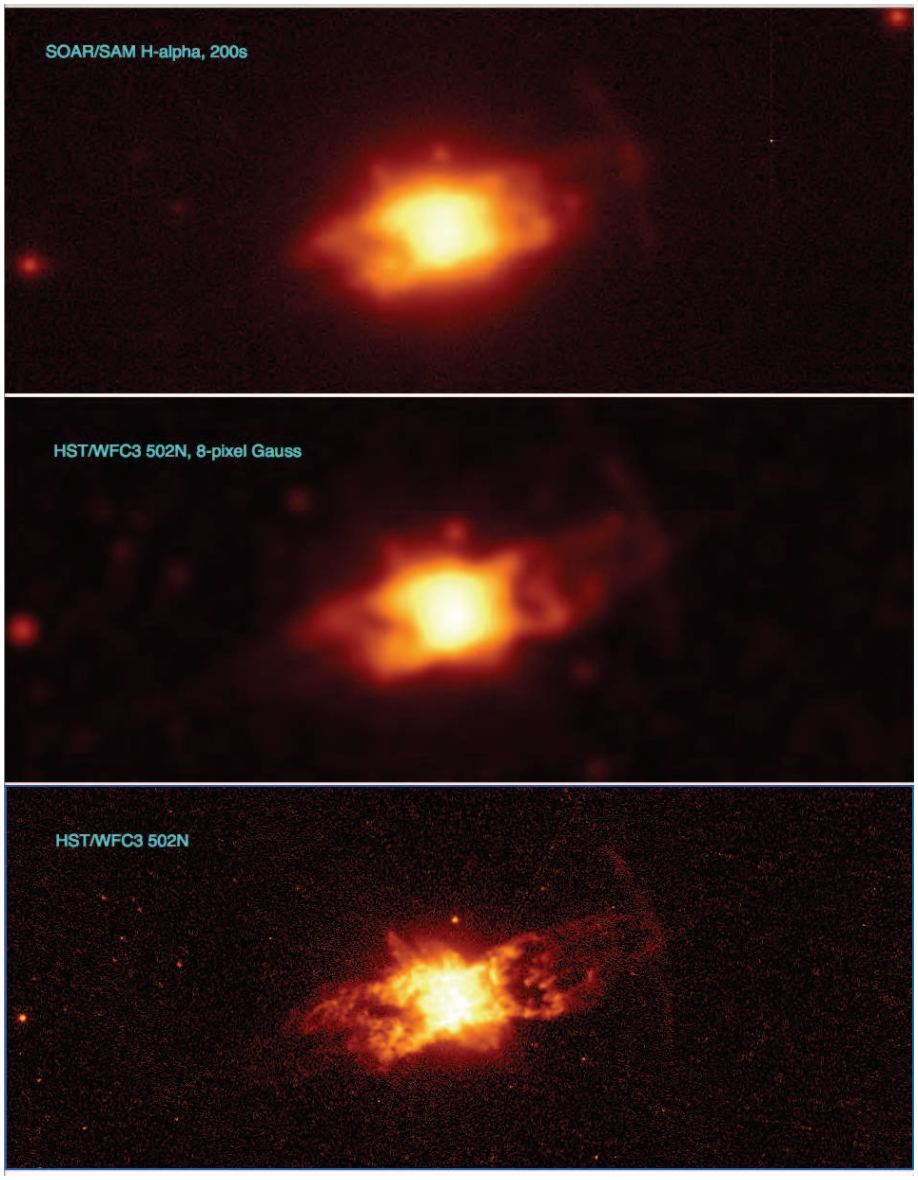



Figure 4: Images of PN PNG285.4+01.5 taken by SAM (top) and HST (fottom), with the resolution-degraded HST image in the middle (image credit: R. Shaw).

Feedback from R.A. Shaw was received on June 28, 2013: *I'd like to share with you some prelim-*

[4]http://www.ctio.noao.edu/new/Telescopes/SOAR/Instruments/SAM/pics/SAM-NGC2440a.png

*inary analysis of SAM data on PNG285.4+01.5, a compact Galactic PN with a bipolar shape. I'm attaching two PDF files comparing the SAM/H-alpha image (where I combined two 100s exposures) with an [O_III] 5007 image from HST/WFC3, and also with a SOAR/Goodman image in H-alpha. Here is what I found:*

*I compared the morphological structure that is evident in the SAM (top) and HST (bottom) images (Fig. 4). The ratio of surface brightness of the faint arc on the right vs. the central bright portion of the nebula is about the same in both images, ∼500, which is good. The structural detail is also similar, except in the inner region where, for instance, background stars and nebulosity become confused. I was expecting somewhat better definition of the structure in the SAM images, considering the widths of point-sources in the field. For a better comparison, I convolved the HST image with a Gaussian, with width of 8 pixels (about 4x the HST resolution), which is in the center panel. It is clear that structural detail is somewhat washed out in the SAM image. It looks like the SAM PSFs have considerably more power in the wings than one would expect compared to natural seeing with a similar PSF half-width.* Note that SAM PSF is modeled by a Moffat function with $\beta \sim 2$, see the Commisioning Report [8].

The PI compared the SAM image with the Goodman acquisition image, showing that the latter detects extended features of low brightness which are not visible in the SAM image (the corresponding Figure and text are omitted here). The PI concludes that SOI is preferred over SAM for this program because the PSF of SOI is better understood.

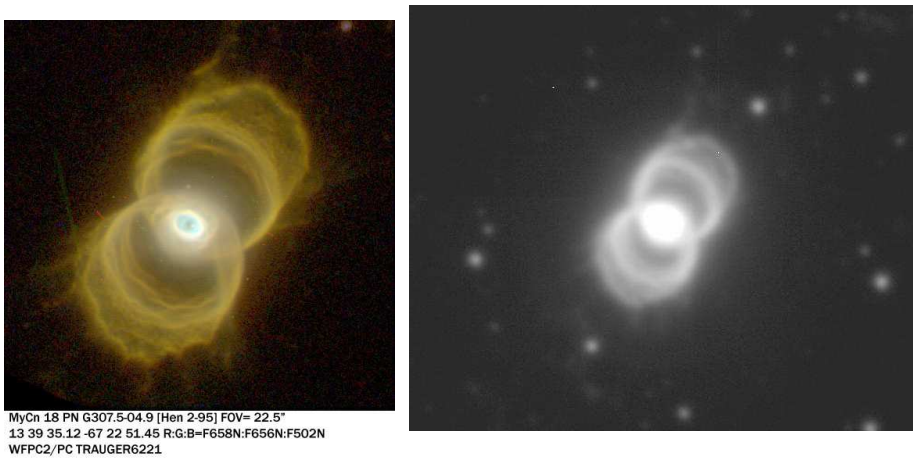



Figure 5: Images of the planetary nebula PN_G_307.5-04.9 (Hen 2-95) taken with the HST (left) and SAM (Right, June 21, 2013, resolution 0.8″, H$\alpha$ filter, poor seeing conditions).

Figure 4 compares the HST image[5] of another compact planetary nebula from this program, PN_G_307.5-04.9, with the data from SAM (combined 5×100-s exposures in H$\alpha$). Both images reveal faint details around the nebula's rim.

### 4.9 SV9*: Exploring the "cosmic skidmark"

The program requested deep high-resolution images of a galaxy in a cluster that showed signs of ram-pressure stripping – the Skidmark. Parallel observations with VIMOS-IFU at VLT were planned. This program received observing time in 2013B through the Chilean TAC and was executed in September 2013 during two nights. The seeing conditions were below optimum. On Sep.27, the FWHM resolution

[5] http://www.astro.washington.edu/users/balick/PNeHST/

was $0.8'' - 1''$. However, on the next night the best images had FWHM of $0.6''$, adequate for this program. The data are proprietary to the PI, D. Murphy, who was satisfied with their quality.

### 4.10 SV10: Astrometry and Photometry of Dwarf Planet Pluto

Observations of the Pluto+Charon were requested to pursue multiple goals, mostly photometry and astrometry. It was not clear from the proposal how this effort compares with other ground-based observations of Pluto, a well-studied target. Images were obtained in the Sep.13 run on 2 nights, with resolution of $0.5''$ on the first night and $1.0''$ on the second night. The Pluto-Charon system is not resolved in these images. The field is very crowded, possibly a good test of astrometry. **Data retrieved by the PI, wait for feedback.**

### 4.11 SV11: Clumpy galaxy at z=2.81

Very deep images of distant Ly$\alpha$-emitting galaxies in the 4697/196 4" CTIO filter were requested. HST image of this field with 16h exposure is available, so the SAM observations could be only of technical interest ("how much worse?"). The proposal for 2013B was submitted but not accepted by the NOAO TAC. No data were taken, as this program required a large amount of dark time and the object with RA=3h was no longer visible in 2013A.

### 4.12 SV12*: Looking for Circumnuclear Star-Formation in HII Galaxies

Deep imaging of star-formation galaxies in the "redshifted" H$\alpha$ filter 6600/75 and SDSS $g', r', i'$ filters was requested, focusing on the central regions. This program received time in 2013B and was executed by covering 3 targets in September 2013 and January 2014. Observations of NGC 520 on September 21, 2013 yielded a resolution of $0.7'' - 1.0''$. Similar resolution was reached on NGC 1482 on Jan. 21, 2014. However, the images of NGC 1232 taken on January 22 have FWHM resolution of $0.4'' - 0.7''$ and are quite spectacular. The data are proprietary.

### 4.13 SV13: Compact Groups of Galaxies

Deep images of a compact galaxy group 2114-2301 were requested, to complement the work with the experimental IFU done at Goodman by the UNC group (J. McBride, G. Cecil). The data taken on September 21, 2013 have resolution of $0.6'' - 0.9''$. Feedback was received from the PI, stating that these images are not deep enough to advance their project. As the target was visible only in the evening, we could not spend the requested 5h on it.

### 4.14 SV14: Improving individual masses determination in LHS1070

Imaging of the nearby triple system LHS1070, previously studied at VLT with NACO, was requested to get relative positions of the outer $\sim 1''$ binary A,B and to resolve the inner sub-system B,C. Compared to NACO [6], SAM would provide measurements of much lower accuracy and could hardly resolve the close pair B,C ($0.2''$ separation) even under the best conditions. The target was visible only in September 2013, but was not observed because of non-optimal seeing and questionable value of the SAM data.

### 4.15 SV15: Gravitational lensing analysis of CODEX clusters with SAMI

This program attempts to evaluate the potential of SAM for weak lensing study by targeting two fields with existing imaging at CFHT. The targets with a declination of +33° required very deep images under dark sky, which could not be obtained with SAM. An alternative target with +9° declination was supplied on our request, but was not observed.

### 4.16 SV16: Small Solar System Bodies and the Early Solar System

Observations of solar-system bodies (comets and asteroids) to detect faint nebulosity around them were proposed. Non-siderial tracking is not implemented in SAM and is not planned. Two targets with a slow motion could be imaged in April 2013 using siderial tracking and 2-min exposures, but this did not happen. The inner coma of Chiron was expected to be 5-6mags fainter than the peak surface brightness of Chiron itself, making its detection with SAM problematic even under optimal conditions.

### 4.17 SV17a: Binary L-dwarf

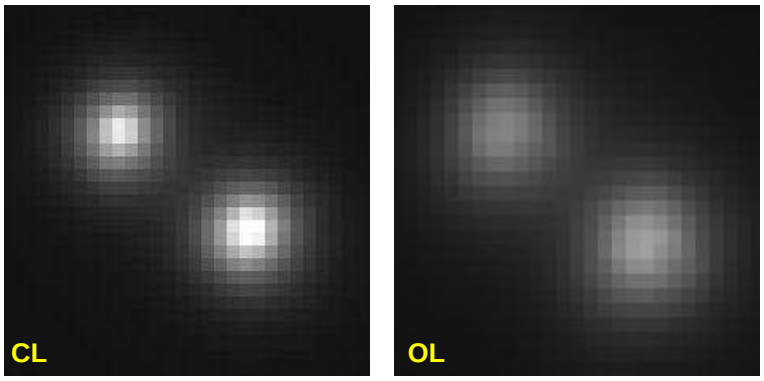



Figure 6: Images of the binary L-dwarf in the $z'$ SDSS filter obtained on Sep. 26, 2013 at UT 7:30 with 30-s exposure and displayed on the same linear intensity scale. Left: image #199, closed loop, FWHM 0.44″. Right: open loop, #200, FWHM 0.64″ (from SDN 7136)

A binary L-dwarf WISE J1049-5319 at 3 pc distance was announced in April 2013 [5] and attracted attention of observers all over the world. S. Dieterich observed this field at CTIO 0.9m and proposed to image the object with SAM, which was done in June and September 2013. Even under mediocre conditions, the 1.5″ binary was easily resolved (Fig. 6). SAM could be used to monitor brightness of the components, using reference stars around it in the large field. Such monitoring was in fact done at other facilities (with seeing-limited resolution) and led to the discovery of "weather" on one binary component [2]. SAM data could be also useful for astrometry (parallax, proper motion).

### 4.18 SV18a: Young binaries

Observations of pre-main-sequence stars with SAM were proposed by C. Briceño who joined the SAM instrument team in September. Although the resolution of SAM is substantially inferior to the AO instruments like NACO, it has a discovery potential for faint stars. This program turned out to be a good "filler" for bright-sky conditions.

During the SAM SV program, we have observed a number of pre-main sequence low-mass stars in the nearby Orion OB1 association to detect its binary or multiple members. Among the newly discovered probable binary systems is CVSO-28, an M1-type T Tauri star located in the young (∼8 Myr) 25 Ori cluster [1]. Its image (Fig. 7) reveals an object at a separation of 1.2″, roughly 4 magnitudes fainter than the primary. If this is a physical companion, its feeble brightness would imply it is a young brown dwarf at a projected separation of ∼400 AU.

As a test, we also observed a know T Tauri binary in the Chamaeleon I association, the M2-type star T43, with a separation of 0.8″. The image in the SDSS $z$ band clearly resolves the pair of stars.

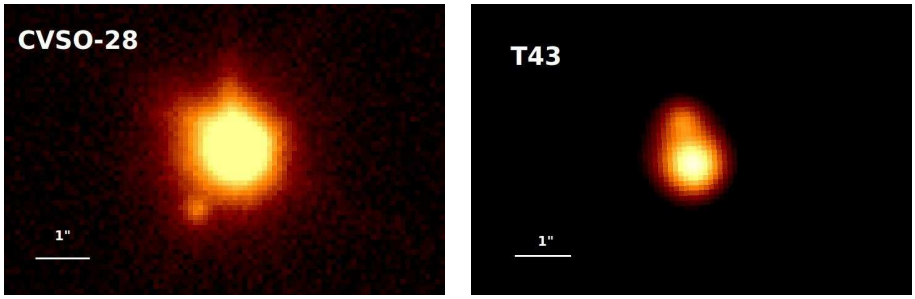



Figure 7: Left: image of the newly discovered binary CVSO-28 in the SDSS $z$ band, with a FWHM=0.36″. Right: image of a known 0.8″ binary T43 in the Chamaeleon association in the SDSS $z$ band (FWHM=0.4″).

# 5 Discussion: science with SAM

## 5.1 Productivity

The execution of the SAM SV program (partly combined with the engineering) has demonstrated that SAM is an operational system capable of getting high-quality data. It also highlighted critical dependence of SAM's delivered image quality on the free-atmosphere seeing (see also the SAM Commissioning Report [8]). Operationally, SAM is less productive than a classical imager because of its dependence on high-atmosphere seeing and thin clouds, and because the increased complexity of the laser-assisted AO instrument translates into the increased loss of time to technical failures and the need to prepare target lists in advance to authorize laser propagation. On the other hand, the overhead in target pointing is reasonably small (nominally 15 min, sometimes as small as 5 min). Most of the overhead time is spent to slewing, pre-imaging of the field, and acquisition of the guide stars. Once this is done, the laser acquisition and closing the LGS loop takes less than a minute.

SAM is different from a classical imager in another important way. Its science programs request high resolution (or maximum acceptable FWHM) that is better than the median seeing (otherwise, why use the AO?). The science goals can't be met in about half of scheduled time because atmospheric conditions do not allow this. Although SAM does improve the natural seeing, the user's expectations often go beyond the achievable gain and make SAM to appear inefficient.

The experience of the SAM SV program shows that SAM should always have a back-up program using some other instruments (or SAM in the open-loop mode) to cover the conditions of low resolution gain, cirrus clouds, and technical failures. So far, speckle interferometry was used mostly as a backup. The science productivity of SAM would be increased by a flexible scheduling, where a block of time

would be shared between SAM and other instruments so that each program could use optimum conditions.

### 5.2 Science cases of SAM

The SV program helped to identify science cases that can be addressed by the instrument, as well as programs where SAM should not be used. The SAM science can be divided in several categories.

- Dense stellar fields, where increased resolution reduces crowding and improves the quality and depth of the photometry. The first SAM paper [3] illustrates this case. The programs SV2 (not executed) and SV4 belong to this class.
- Morphology of faint objects, mostly extragalactic. The programs SV1, SV3, SV9*, SV12*, SV13 (addressed) and SV6, SV11, SV15 (not executed) are typical of this use case.
- Binary and multiple stars. The resolution of SAM cannot compete with classical (diffraction-limited) AO systems like NACO or NICI. Its advantage is access to the faint stars and to visible wavelengths. This is illustrated by programs SV14 (not addressed), SV17a, and SV18a.
- Astrometry. Potentially, SAM can improve accuracy of coordinate measurements owing to its sharper images, reduced crowding, and moderately large field (hence availability of reference stars). The SV10 program pursued such goals. However, the astrometric potential of SAM (its ultimate accuracy and limitations) remains unexplored. Data on several globular clusters collected during the SV program can be used to study astrometric accuracy.

Projects where SAM *should not be used* were also identified clearly. First, this applies to objects of low surface brightness, where the increased resolution brings no gain in the detectivity or S/N (programs SV7, SV5). Second, the dynamic range is not increased by SAM, so objects with high contrast, like faint nebulosity around stars, get no gain from the use of SAM (programs SV8, SV16). Third, SAM is not designed to observe solar-system bodies.

### 5.3 User base and competition

The SAM SV program was essential in starting to gather the user base for this instrument. Two extragalactic programs SV9* and SV12* evolved into regular proposals accepted by the Chilean and Brazilian TACs, got data, and should lead to publications. Some other SV proposals were submitted to the NOAO TAC, but did not get observing time; their PIs might feel discouraged from using SAM.

Potential users of SAM face a choice between SOAR+SAM, other ground-based imaging instruments, and HST. The latter is least accessible, but skimmed most of the high-impact science where high-resolution imaging is the key. Accessibility of SOAR+SAM (especially to the SOAR partners) will likely play major role in attracting scientific projects where imaging with "superb seeing" is required to reach the science goals.

### 5.4 Speckle interferometry

The capability to do diffraction-limited (30 mas resolution) imaging of bright stars at SOAR by speckle interferometry appeared as a by-product of the SAM project (it uses the High-Resolution Camera mounted on SAM). The observational method and data reduction pipeline are fully developed [7]. Up

to 150 stars per night can be covered (also under cirrus clouds), and several thousand measurements of binary stars were performed at SOAR since 2008. The speckle instrument at SOAR opened a unique high-resolution "window" on the southern sky and is presently the major source of data on the orbits of binary stars. Several dozens new close pairs were discovered at SOAR. So far, the speckle camera was used in open loop, but the LGS correction (without tip-tilt) can sharpen the images and increase the limiting magnitude. The sensitivity of speckle at SOAR is adversely affected by the 50-Hz vibration of the telescope.

Although speckle interferometry got time allocations through NOAO TAC (in addition to recovering observing time unsuitable for SAM), it is still *not recognized as an official SOAR instrument* and is not publicized. Its wider use will increase the SOAR scientific productivity by attracting new interesting projects and widening the user base.

## References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