SOAR Adaptive Module (SAM): the user's perspective

Andrei Tokovinin
Outline

I: What is SAM?
II: Capabilities: why use SAM?
III: Science with SAM
IV: Before, during, and after your observations
V: Using SAM data for science
VI: Broader perspective (competition, active optics, speckle)
Why SOAR needs AO?

- “Small” (4-m) telescope with a narrow field. Its niche was declared to be high angular resolution.
- “Classical” AO: NO (poor sky coverage, narrow field, IR only, competition with 8-m)
- Ground-Layer AO: YES (optical wavelengths, full sky coverage, moderate field).
- SAM was built as a GLAO instrument. First laser light: Apr 2011, commissioned: Nov 2013, science verification: Jan 2014. Cost: ~4.5M USD, time: 12 calendar years, manpower: ~20 man-years.
Ground-layer adaptive optics

Selectively compensate only low turbulent layers to improve the “seeing” over a wide field (F. Rigaut, 2001)

SAM uses one UV Rayleigh laser to selectively sense the ground layer. The compensation is partial.

SAM is a “sandwich” between telescope and instrument, it does not produce science data by itself!

SAMI (built-in imager) and visitor instrument (SIFS?)
I: What is SAM?

- AO module on optical ISB relays image 1:1 with partial seeing correction
- SAMI: built-in CCD imager (4096x4112, 45mas pixel, FoV 3 arcmin, 1 filter wheel)
- UV laser and its projection system
- Software, computers, documents

www.ctio.noao.edu/new/Telescopes/SOAR/Instruments/SAM/
Documentation available

- User guide (short instruction)
- Manuals on SAMI and its software
- Several SAM manuals
- Commissioning report
- Science verification report
- SPIE papers on SAM

To-to:
Refereed paper
Complete description

www.ctio.noao.edu/new/Telescopes/SOAR/Instruments/SAM/
Optics of SAM
SAM at a glance

DM tilt is not controlled and it works!
Rayleigh LGS (λ=355nm)

Range gate defines the spot elongation and flux

- Laser plume
- 15 km
- 7.12 km
- 7 km
- WFS focal plane
- Time
- t=0 Laser pulse (34 ns)
- t=46.7 μs Range gate start
- t=47.5 μs Range gate end
- t=100 μs Next pulse
Seeing: total (DIMM) and free-atmosphere (MASS)

We need a flexible scheduling & a working MASS-DIMM monitor to get maximum from SAM!

Calm nights with FA seeing <0.25” happen regularly
II: SAM capabilities

- Improve FWHM resolution (close to free-atmosphere seeing in the I and z bands)
- Guide stars to R=18 in 5' FoV (full sky cov.)
- Wavelength >400nm (no UV!)
- As efficient as SOI, but no gap between CCDs
- ADC is available
- Can work without laser, in open loop
Performance: two good nights

Cerro Pachon, 26/27 Feb 2013

Median FA seeing at Pachon 0.40”
Performance: a poor night (with good seeing)

Cerro Pachon, 31/1 Oct 2012

Small gain in FWHM

No direct correlation between SAM resolution and site seeing
Correction uniformity over the field

UT 4:08
0.369" (I, 60s)

UT 7:13
0.280" (I, 15s)
SAM performance metrics

- FWHM uniformity over the field (often <2%)
- PSF: Moffat profile with $\beta \sim 2$
- Energy gain $\frac{1}{2}$ of FWHM gain (e.g. 1.4 instead of 2)
- Ellipticity small (typ. <0.05)

SAMI parameters: gain 2.1 el/ADU, RON 4 el, Readout time ~5s (with 2x2 binning), pixel scale 45mas, no bad columns
III: Science with SAM

- Stellar: clusters, crowded fields, binaries
- Nearby galaxies (star formation, globular-cluster systems, AGNs)
- Distant galaxies (clusters, weak and strong lensing)
- Follow-up of DECAM, LSST (e.g. Supernovae)
- Astrometry? To be studied

- NO: Low surface brightness
- NO: high dynamic range
SAM science 1: stars

- Stellar populations in crowded fields

L. Fraga et al., AJ
ArXiv:1304.4880
globular cluster
NGC 6496

Competition with HST
Collaboration with GEMS

Non-uniform PSF is OK
SAM science 2.

- Nebulae,
- star formation
- (proplyds etc)

Feb. 26, 2013
Exp. 60s
(H\textalpha,V,B) \rightarrow (rgb)
FWHM 0.35"
Fragment
(nebula 72"

Best ground-based image of NGC 2440
SAM science 3.

- Small targets: galaxies, gravitational arcs, lensed quasars, solar-system bodies (Pluto, asteroids, comets), binary companions. Only on-axis FWHM matters!

- Future: imaging+spectroscopy (IFU and/or MOS)

Lensed quasar SDSS_0924 (0.5” in B, 0.4” in I). Jan. 2013, 5-min. exp
SAM science verification program

- 16 proposals for ~60h, mostly dark time
- 20h allocated (Apr. 17,18), lost to telesc. failure
- Galactic: clusters, planetary nebulae, pulsar shock, triple star
- Extragalactic: polar-ring galaxies, compact groups, gravitational lenses, “green beans”
- Solar system: Pluto, comets (non-siderial track?)
SAM looks at gravitational arc

Abel 370

SDSS  HST  SAM
Comparative imaging of NGC 1232

VLT (ESO PR 9845)  SAM

Image credit: ESO, LNA
NGC 1232: SAM vs. SOI

SAM project by A. Ardila (January 2014)
“Skidmark”
SAM project
by D. Murphy
(September 2013)

SAMI vs.
SOI:
Better guider
No gap
As efficient

Cons: no UV, 3' FoV
IV: Before, during, & after observations

- Laser propagation is subject to the Laser Clearing House restrictions.
- Target list submitted to LCH 3 days in advance, in special format, by CTIO. No last-minute changes!!!
- LCH sends PAM files on the day of observation. SAM operator loads the file. Beware of blanket closures!
Before...

- Why use SAM? Plan your work!
- Send the instrument setup form (filters) to SOARops
- Send target list to CTIO (→ LCH), plus standards
- Select position angle of SAM, guide stars
- Think of backup program for poor FA seeing
During observations

- SAM is prepared for the run by the instrument scientist (check, calibration of AO)
- Take sky flats (dome flats not good) and biases
- SAM is supported. Observer takes science data and interacts with SAM operator.
- Setup overhead <15min (can be 5-7min)
- Center your target before acquiring guide stars!
- Dithers: pros and cons. Small dithers OK.
Observing procedure with SAM

- Point the target, take pointing exposure, determine field offset (identify 1 star with known coordinates in the image)
- Acquire two guide stars (USNO, 2MASS, “wobble tool”)
- Acquire the LGS (<1min), close all loops
- Take science exposures. Large dither=new target
- Pause during LCH closures or other problems
Focusing with SAM

- Check/tune
- focus once per night
Acquisition of guide stars

Identify star in the pointing image!
SAMI GUI

ds9+IRAF to display images & evaluate
Scripting with SAM

- SAM has scripting (example: dithers). Hide the complexity of AO operation behind scripts.
- SAMI has scripting. Can control SAM, but this has not been tested, problems likely.
- LUA scripting language is very uncomfortable. Poor diagnostic and weird behavior.
SAM ADC: pros and cons

- ADS is available in SAM
- Deviates image by ~2": complicates guide-star acquisition
- Extra light loss and reflections (in parallel beam)
- Used extensively for speckle, not with SAMI, so far
What can go wrong?

- Poor free-atmosphere seeing (50% chance): no gain!
- Cirrus clouds or blanket closure: no laser!
- SAM technical failure. Sometimes open-loop possible.
- Telescope failure
- Clouds, wind, snow,...
After observations

- Data are processed at CTIO (bias subtraction and flat field, join 4 extensions in a single frame)
- Get your data (no standard procedure yet, use FTP). NOAO archive?
- Extract what is needed (e.g. photometry)
- Publish! Publish! Publish!
V. Science use of SAM data

- Artifacts
- Photometric calibration
- Distortion
- Astrometry
- Binary stars
Artifacts in SAM+SAMI

- “Blue leak” (strong in B-filter, weak in SDSS g')
- Scattered light: as in SOI (filters!)
- Parasite light in g' (switch off camera)

10^{-5} at 20''
Artifacts 2.

- “Tails” of the PSF (SAM DM)
- Strong saturation: “ghosts” and after-glow
Artifacts 3 (SIFS dewar)

- Mysterious “Arcs” and fringing in z'
- Overscan changes vertically
Photometric calibration of SAMI

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<tr>
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<td>25.3</td>
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<tr>
<td>z'</td>
<td>24.8</td>
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 Flux [ADU/s] = 10^{-0.4(mag - mag0)}

BVRI calibration: Fraga et al. 2013, AJ
Distortion

SAM’s optical relay introduces quadratic distortion up to 40 pixels or 1.8” (amplified 20x in the picture)
Photometric error 2%
Dealing with the distortion

- Do nothing --> coordinate error ~1”
- Correct measured X,Y (work with the text file)
- Use RA-TNX, DEC-TBX non-linear WCS (not FITS standard)
- “Un-warp” the image (samiwarp.pro, dcombine.pro)

M5 with 2” dithers
Astrometry with SAM

- **Step 1:** `samiqastrometry.py` to get correct WCS origin and orientation (does not change the pixel scale!) RMS ~0.7” before distortion correction, down to 0.15” after. SOAR rotator has variable offsets in angle!

- **Step 2:** fit to the reference catalog using quadratic and higher terms. So far, only 2MASS...
Astrometry with SAM: future

- Best seeing-limited astrometry: 0.3mas (VLT), 1-3 mas (many wide-field imagers). These are relative errors.
- Best AO astrometry: 0.15 mas (Keck, Galactic Center)
- SAM: use HST-observed cluster. TBD accuracy.

Need a tool with variable PSF (Starfinder, DAOPHOT, custom)
Example: binary stars

March 4, 2014: images of faint distant companions to nearby solar-type stars: are the companions binary?

Mediocre conditions, resolution ~0.5” only

21 targets, 7 min. median overhead

HIP 50895
i' band,
binary 42”,
V=8.12+16.3
FWHM 0.7”

PSF match to ~5%
Result: one binary discovered

HIP 53172B, 0.2", equal components
To SAM or not to SAM?

- Use SAM if you do not need blue wavelengths and wide field (it does not make things worse!) Open-loop?
- Not to SAM: low surface brightness or high-contrast objects, U/B filters.
- SAM for crowded fields and when resolution is critical
Everything has its cost...

- Resolution depends on wavelength, poor in the blue
- Dependence on FA seeing: need a backup program and flexible scheduling
- PSF has strong wings (Moffat function with beta ~ 2)
- Laser targets submitted to LCH 3 days in advance
- Complexity: SAM operation is simple, but the system is complex and requires maintenance and discipline
- Future failures...
Active optics, please!

- SAM often “sees” little ground-layer turbulence
- Still useful to correct focus and astigmatism
- Need real-time active optics for ALL SOAR instruments!
- Use regular guiders to adjust between exposures?
- Optimize dome environment

No AO correction, only tip-tilt
SAM's competitors

- HST: most high-res. optical imaging and best science!
- GEMS: IR complement, rather than competitor
- Mag-AO: NGS system, PI instrument only.
- MUSE @ VLT: real competitor: GLAO, visible, 8-m!
- ARGOS @ LBT (IR only)

SAM with its UV laser and 3' FoV is unique and can bring SOAR ½ way to space!
Future II: AO spectroscopy

- Default plan (SAM+SIFS) is not happening
- SAM+BTFI: two monsters, not practical. Space for F-P!
- IFU for SAM+Goodman? (~350 fibers, 0.3” spaxel, 6”x6” FoV, efficiency ~70%)
- SAMOS (multi-slit)?
Diffraction-limited science @ SOAR

- Original SAM science case included NGS mode, dropped for simplicity. But it worked during commissioning!
- HRCam → speckle interferometry
- Resolution ~25mas (better than 8-m with AO!)
- SOAR offers unique high-resolution optical “window”
End