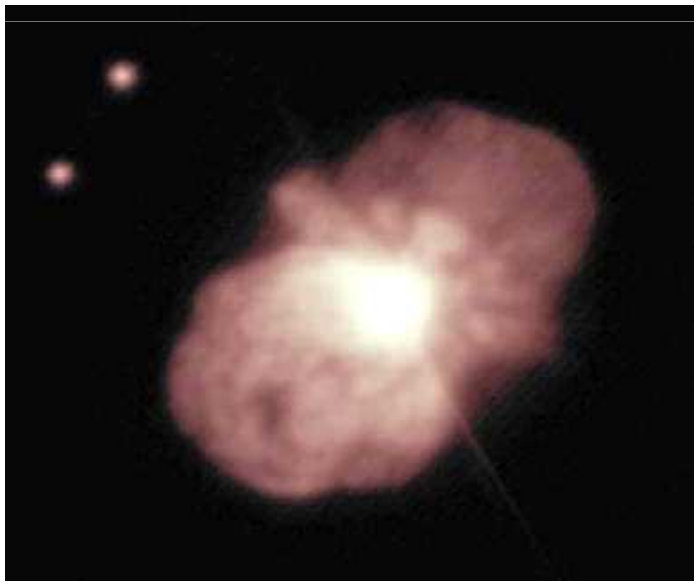
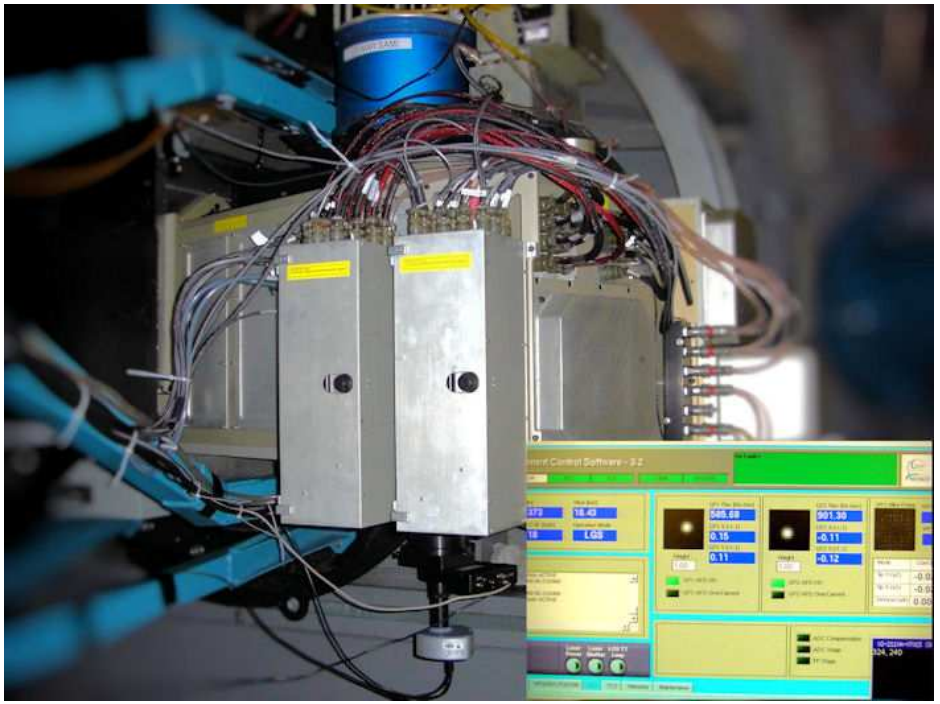
Science with the SOAR Adaptive Module

A. Tokovinin (CTIO)

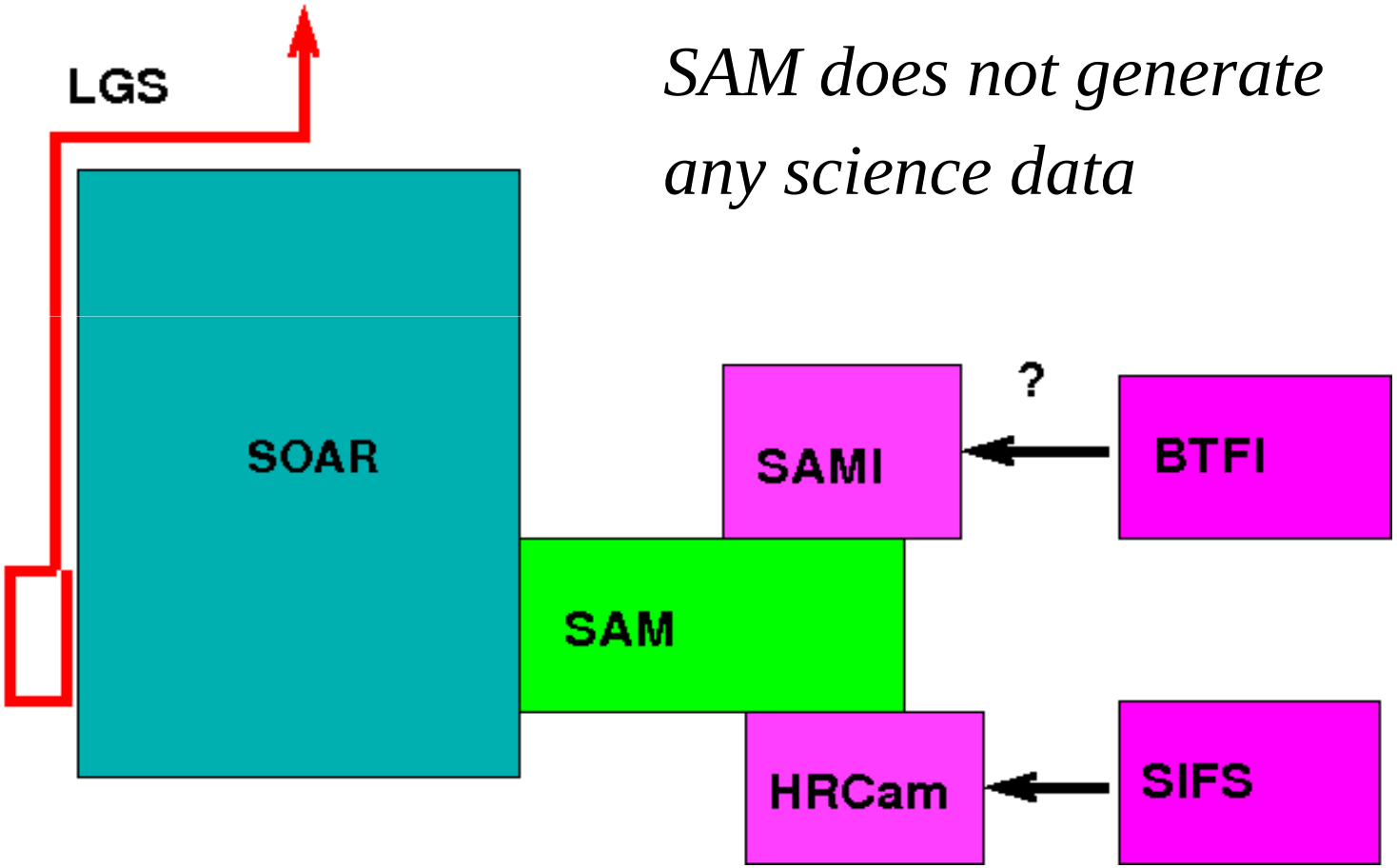




Outline

- What do we expect from SAM?
- SAM as a system: hardware, software, and operation
- Current SAM status and perspective
- International competition
- Science case and call for SV programs
- Diffraction-limited science at SOAR

SAM is not a science instrument!



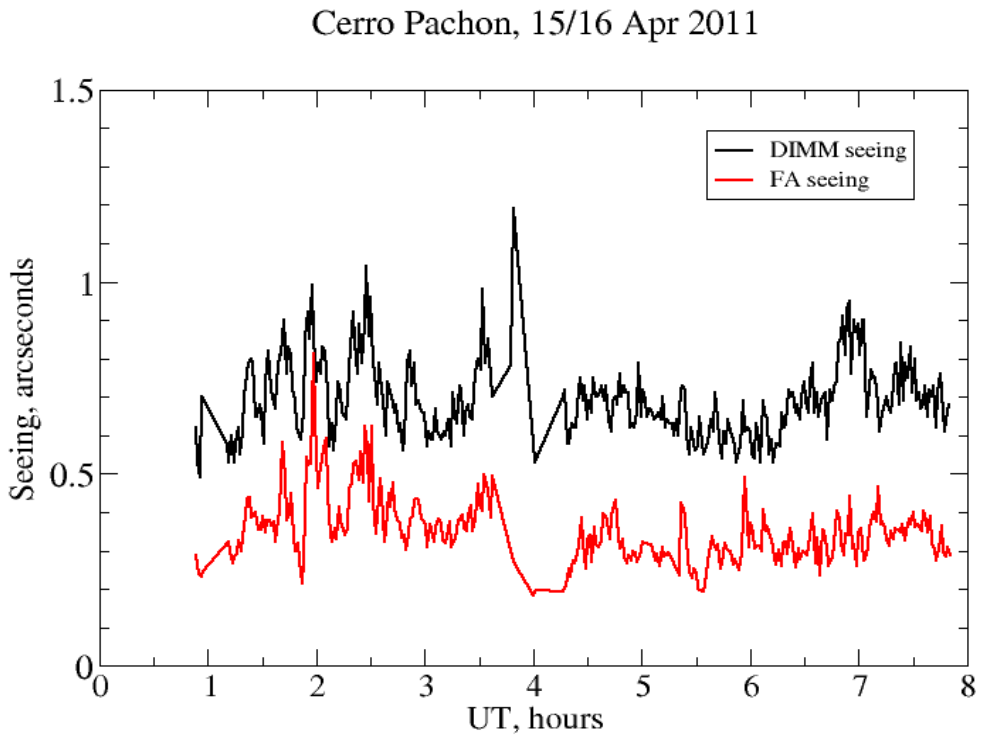
SAM does not generate any science data

What SAM can do?

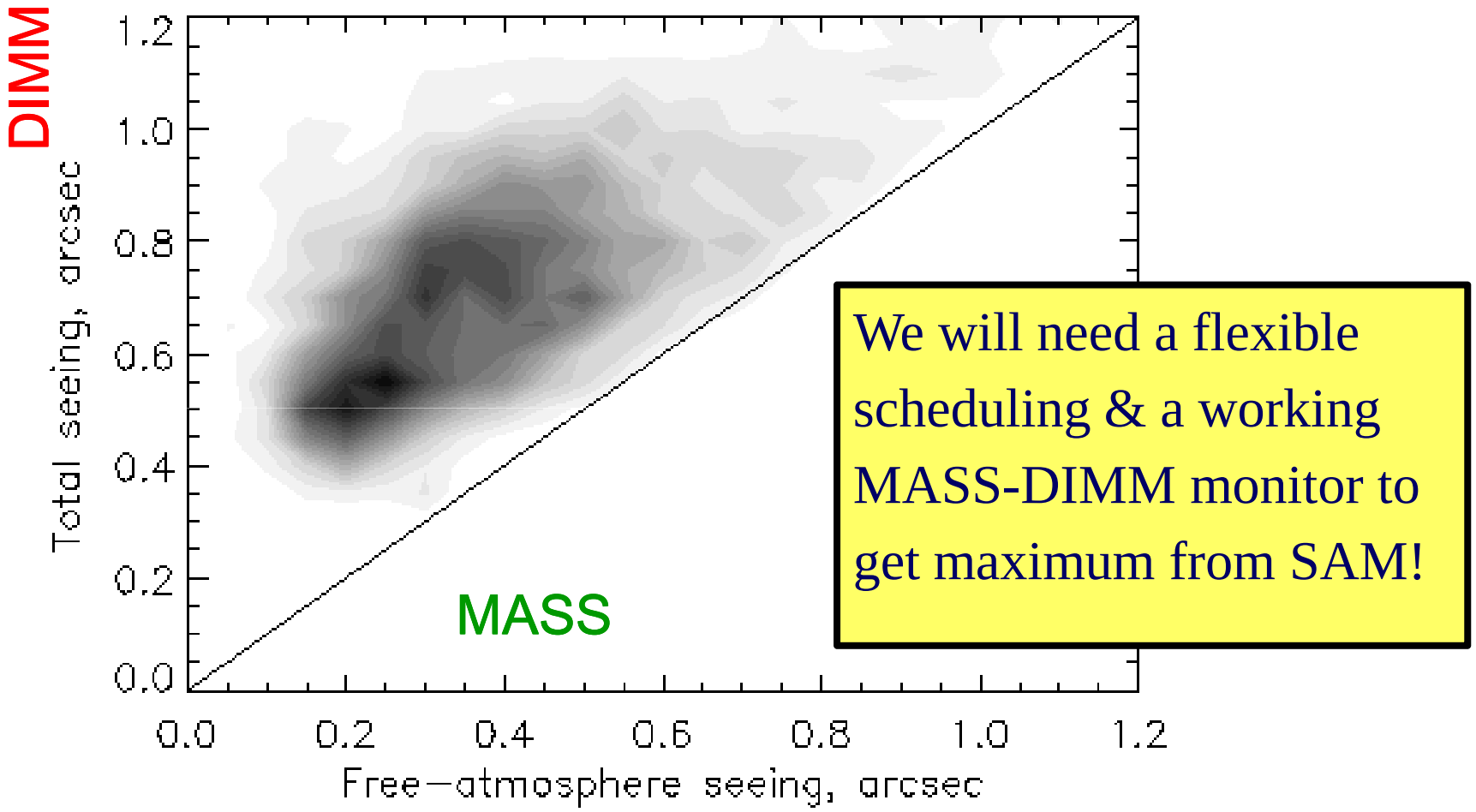
- Compensate near-ground turbulence

(including dome seeing) → half-way to space?

- Compensate residual aberrations

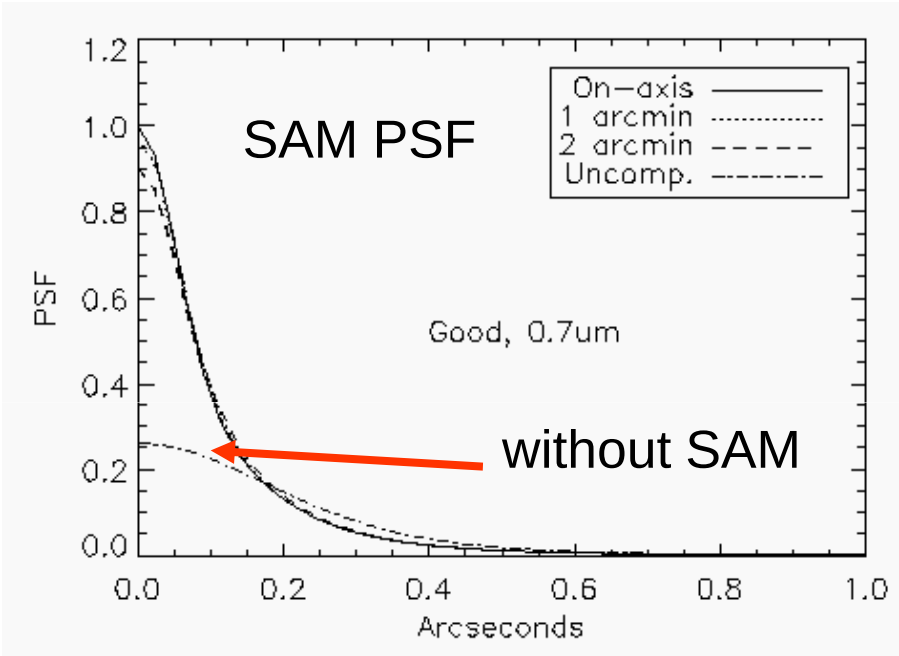


MASS-DIMM: turbulence @ Cerro Pachon, 2005

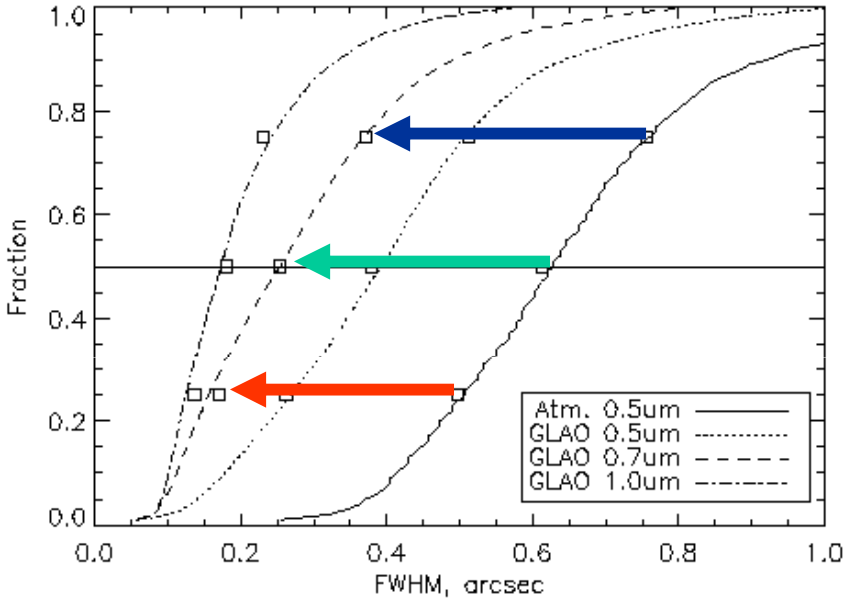


Calm nights with FA seeing <0.25” happen regularly

Expected performance of the ideal SAM



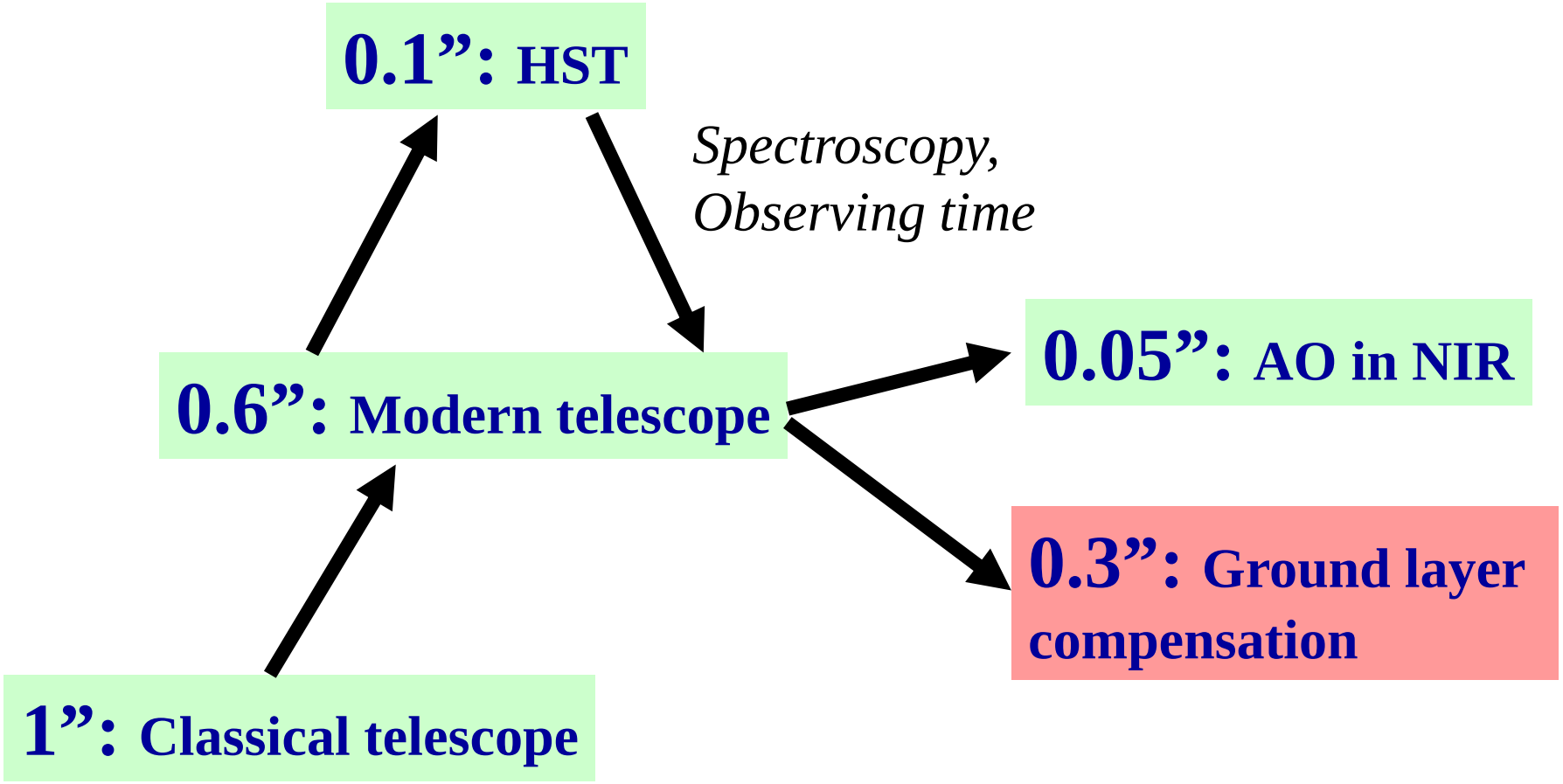
FWHM histograms



More details at: …SAM/ao_sam_performance.html

Modern astronomy is a struggle for

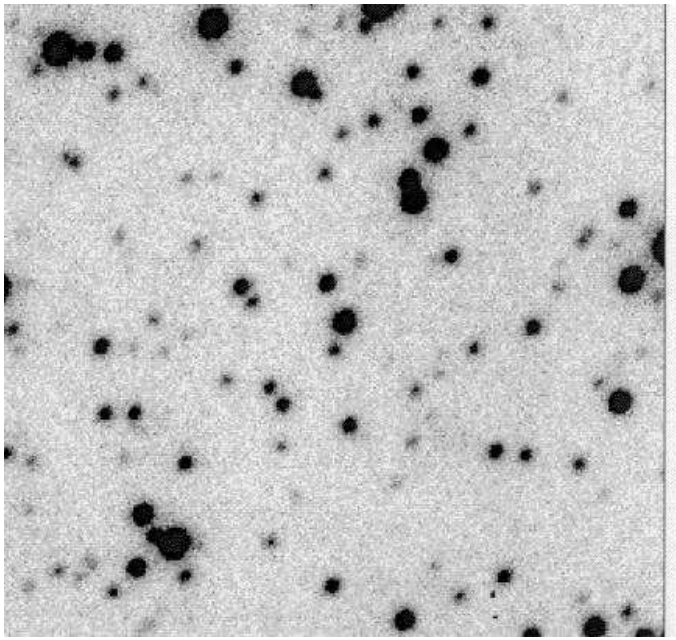
angular resolution

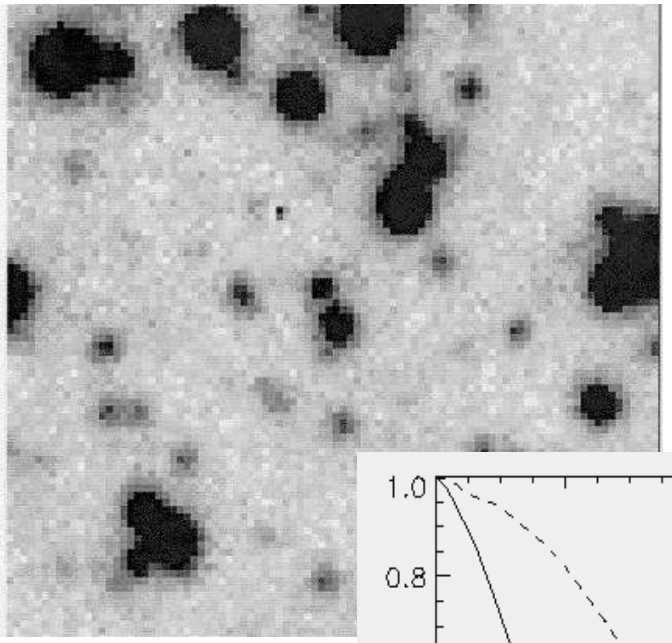


Other GLAO systems

- GLAS (ING): Rayleigh 512nm, H=25km, 25W, VIS/IR (1st light 2008. Not working now.)
- MMT: 5 Rayleigh LGS, adaptive secondary. 0.2” in K.
- MUSE (ESO): 4xNa-LGS, 1’, VIS (in progress)
- LBT: 4xRayleigh 532nm, 4’, IR
- IMACA: NGS, 1-degree field @ CFHT (proposal)

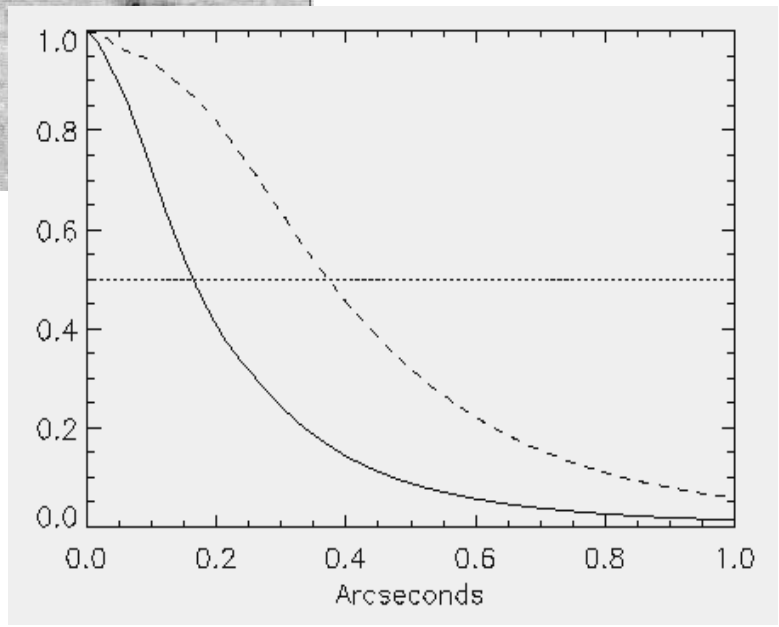
Angular resolution is crucial





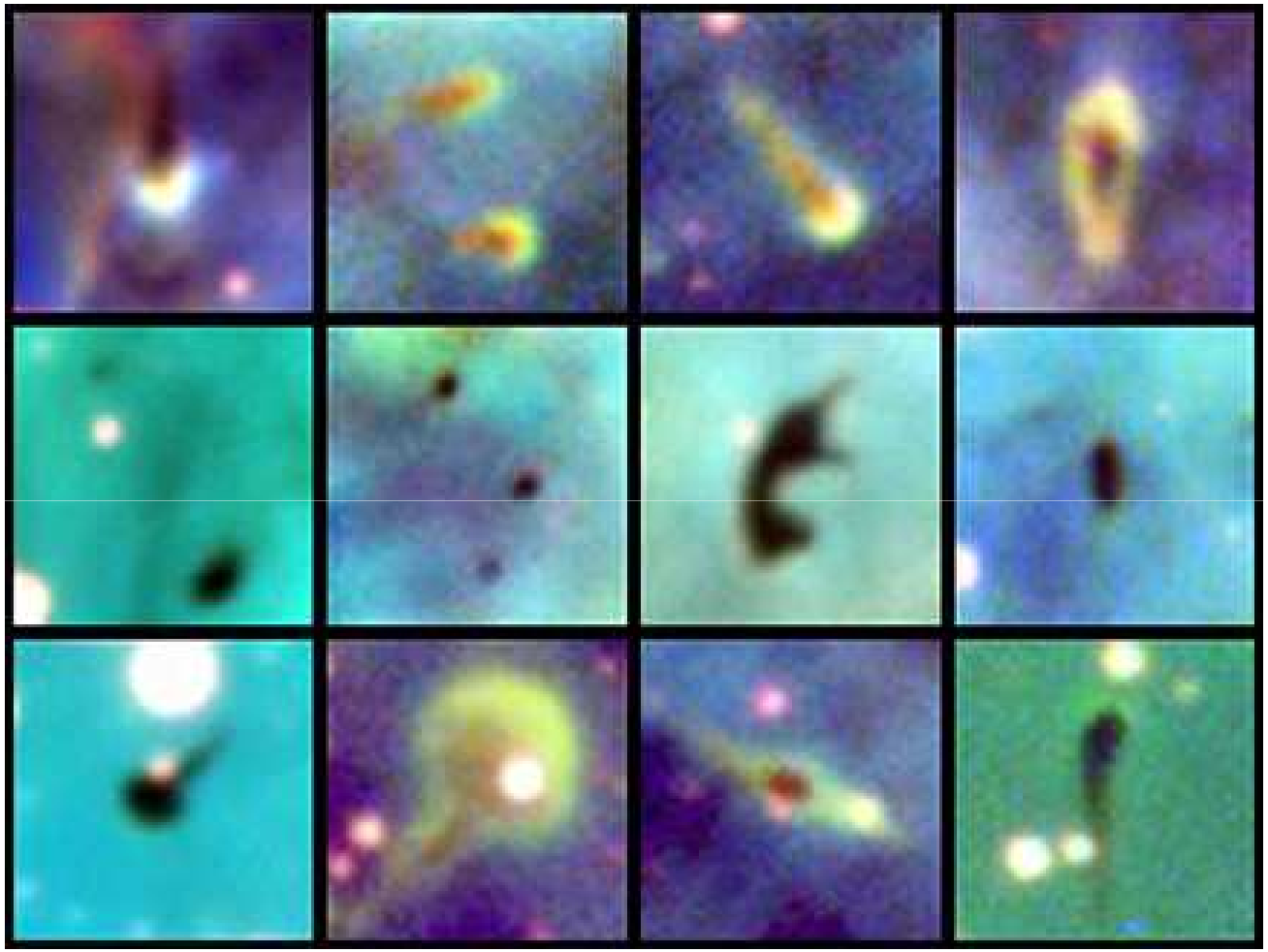
0.3 arcsec **0.7 arcsec**

Images from Magellan



SAM+LGS, April 18, 2011, *I*-band

At the limit of 0.6” resolution…



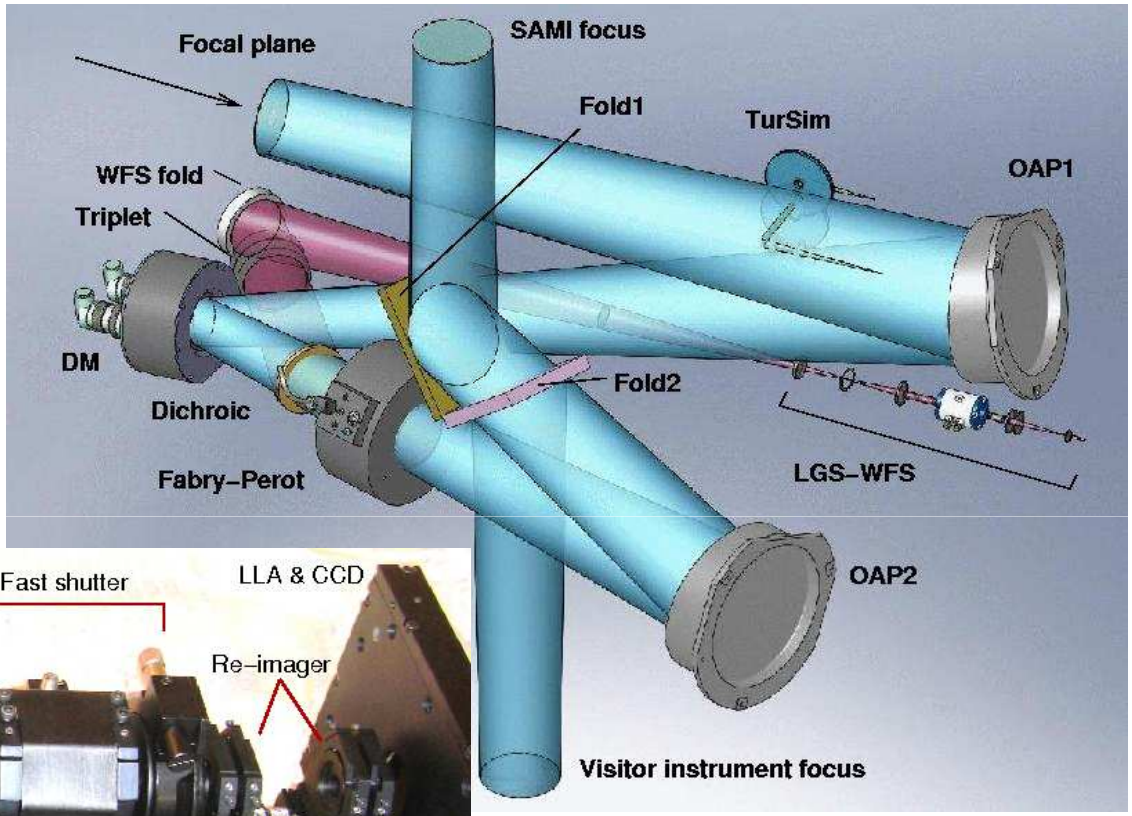
Proplyds in Eta Car (N.Smith et al. 2003)

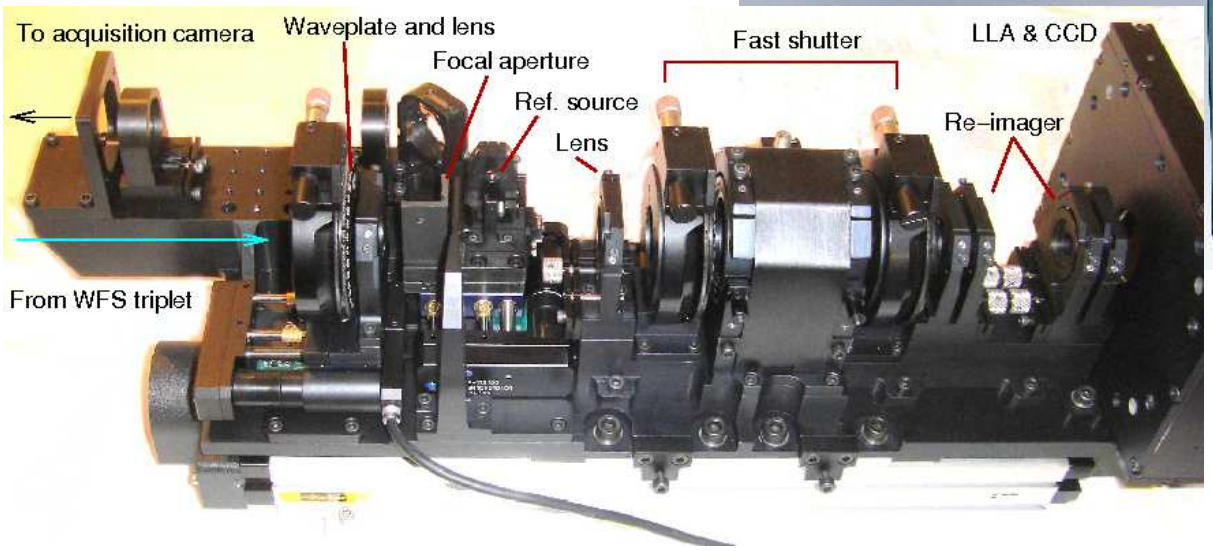
SAM complexity 1: hardware

- AOM: 19+2 motions (5 of which TurSim)
- LGS: UV laser, CCD, 6 motions
- 2+1 CCD detectors, 8 APDs, 5 photo-diodes
- Optics, mechanics, electronics, cables

SAM is more complex than any instrument built at NOAO
It must be extremely reliable to be useful

Optics


Focal plane
SAMI focus
Fold1
TurSim
OAP1
WFS fold
Triplet
DM
Dichroic
Fabry–Perot
Fold2
LGS–WFS
OAP2
Visitor instrument focus


To acquisition camera
Waveplate and lens
Focal aperture
Ref. source
Lens
Fast shutter
LLA & CCD
Re–imager
From WFS triplet

SAM complexity 2: software

- 6 programs running on 3 PC computers

  (AOM, LGS, LCH, ICSoft, RTC, SAMI) +TCS.

- All connections by sockets

- Four servo loops (AO, tt, mount, LLT)

Crushes of RTC and bad connection to TSC are recurrent
User control through 6 GUIs → need a better interface

SAM complexity 3: operation

- LCH (Laser Clearing House)

  Target list >3 work days in advance

- Airplanes (reduce efficiency to ~50-70%?)

  but SAM is airplane-safe!

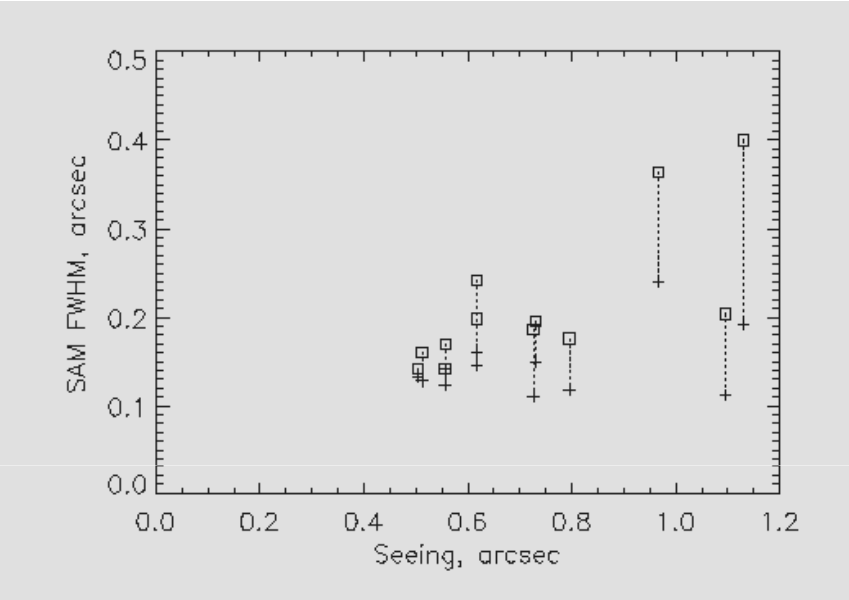
- Avoid bad FA seeing and thin clouds below 7km
- Instrument failures

SAM must be operational without LGS, in open loop

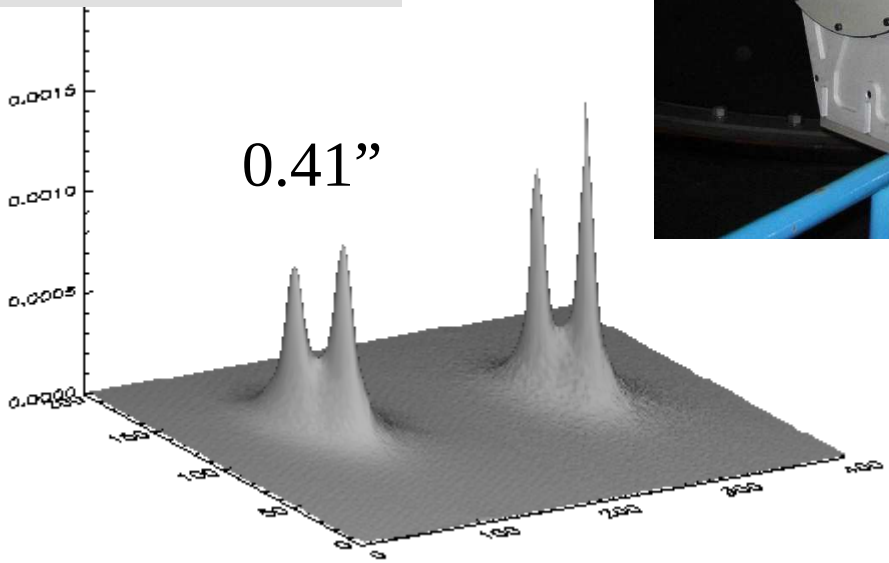
Operation scenario

- Prepare targets in advance (need an “observing tool”)
- Slew to a target
- Acquire SAMI picture (offset). Acquire GS in the probes, center. Close tip-tilt loop, mount loop
- Propagate laser, center in the WFS Acquis. Camera
- Close LLT and AO loops
- Take science data with interrupts (planes, satellites,...)
- Open LGS loops, laser off
- Open tt loop, APD HV off. Ready for the next target!

SAM First Light (August-October 2009)



October 2/3, 2009



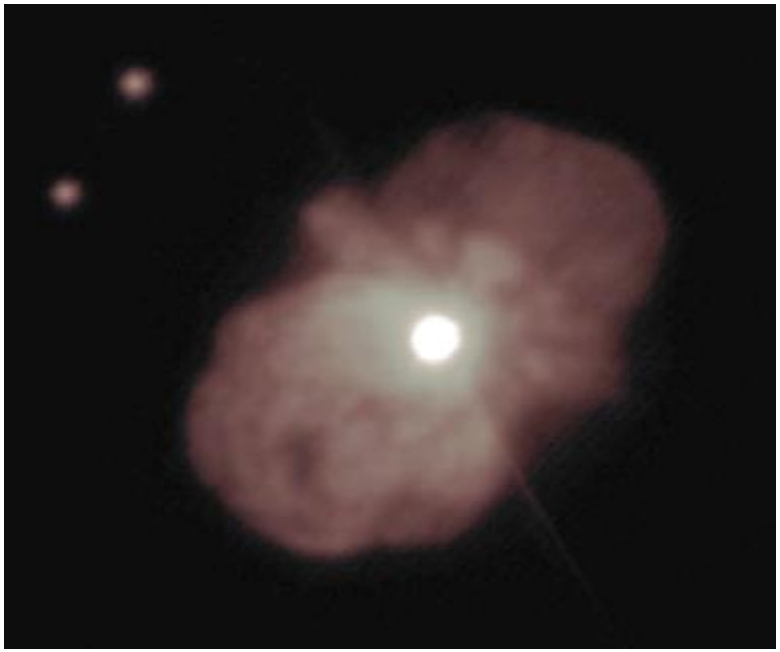
SAM was still incomplete

SAM in NGS mode (Nov 2010 – Jan 2011)

- Test and tune tt guiders
- Test ADC
- Test SAMI (not complete)
- Practice AO and tt loops. Emulate LGS.
- Demo images
- Technical data (50-Hz vibration, DM flexure)

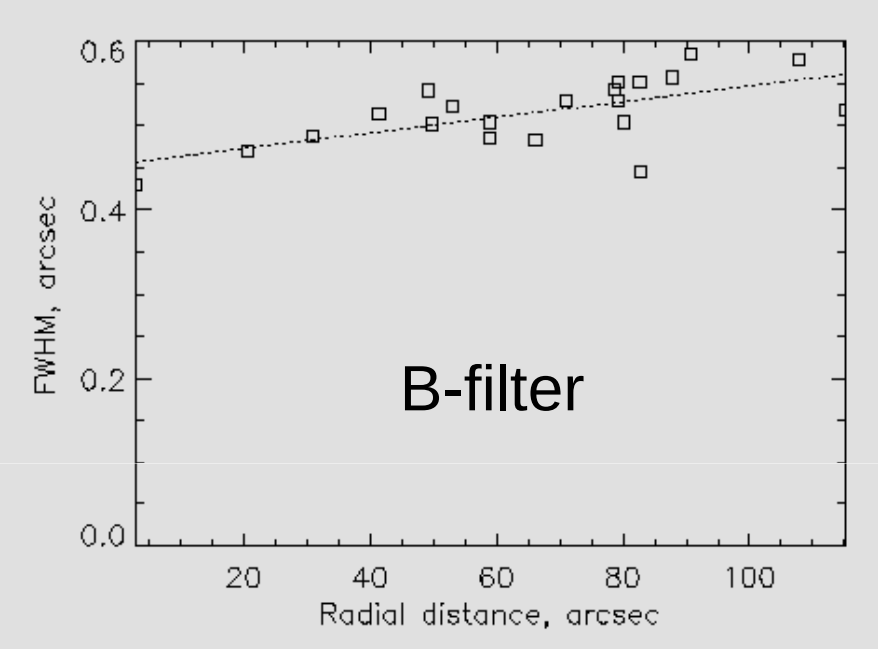
SAM first NGS run (November 2010)

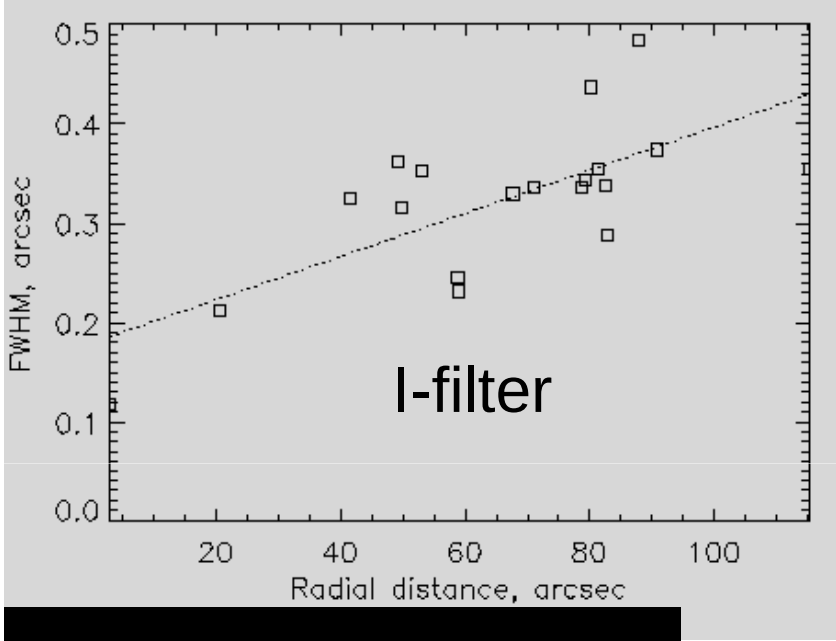
Nov 23: calm free atmosphere permitted seeing improvement over the full SAMI field

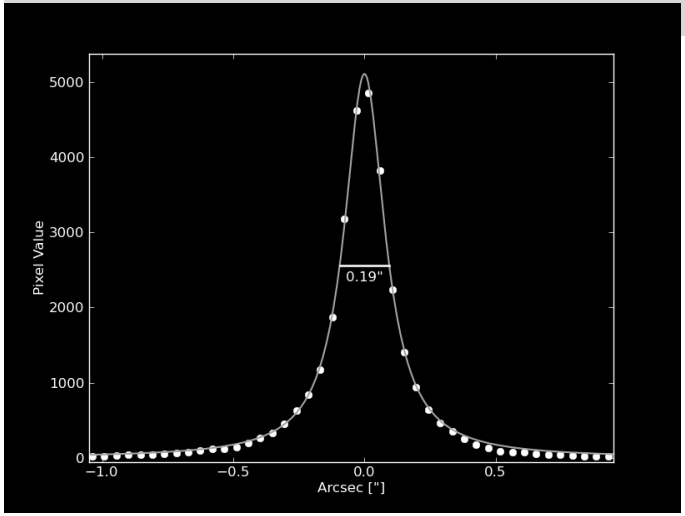


1-s VRI composite (L.Fraga)
Resolution ~0.3”

Feel the taste of SAM+LGS…

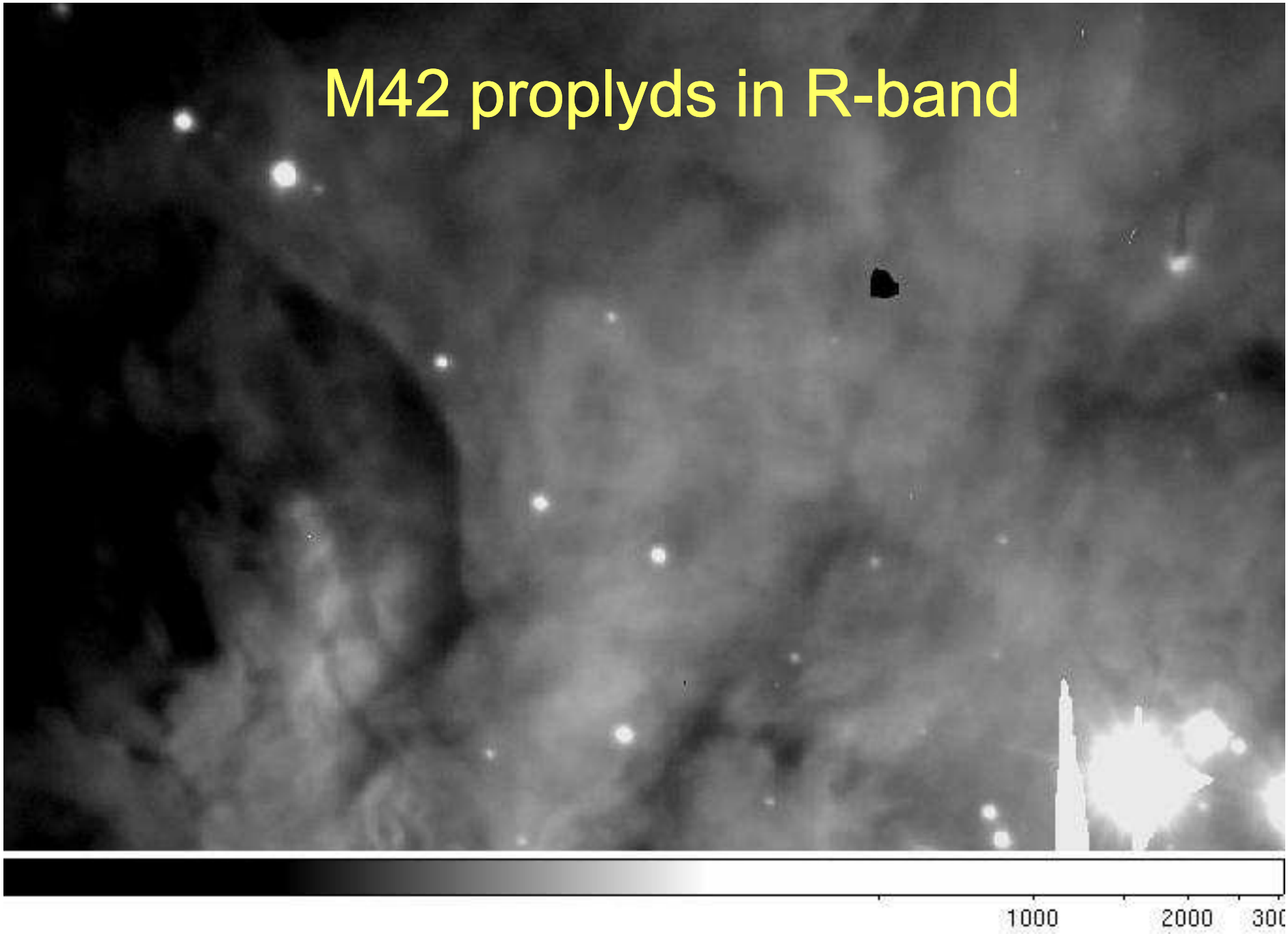




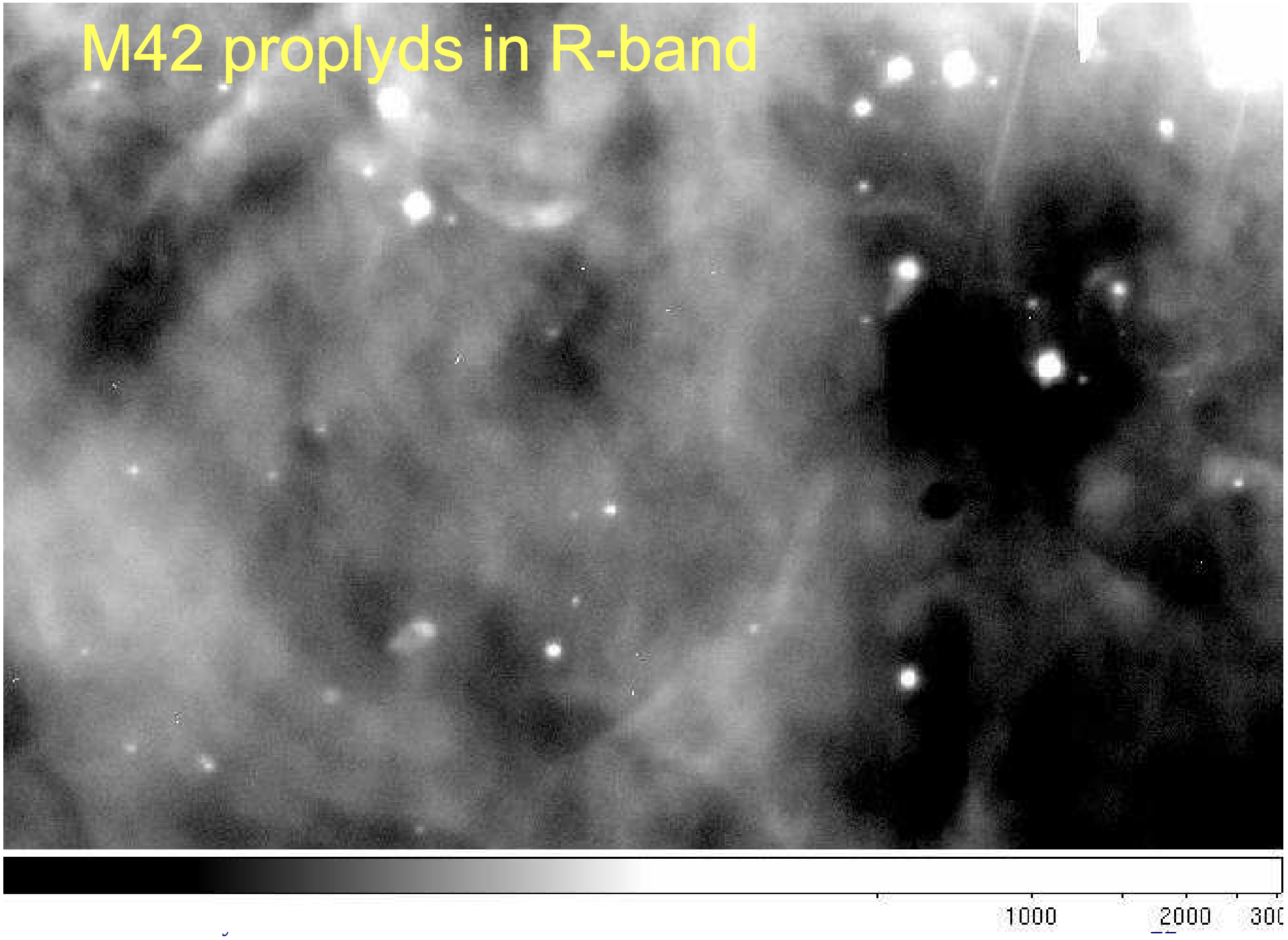


Data on Orion (M42)

M42 proplyds in R-band



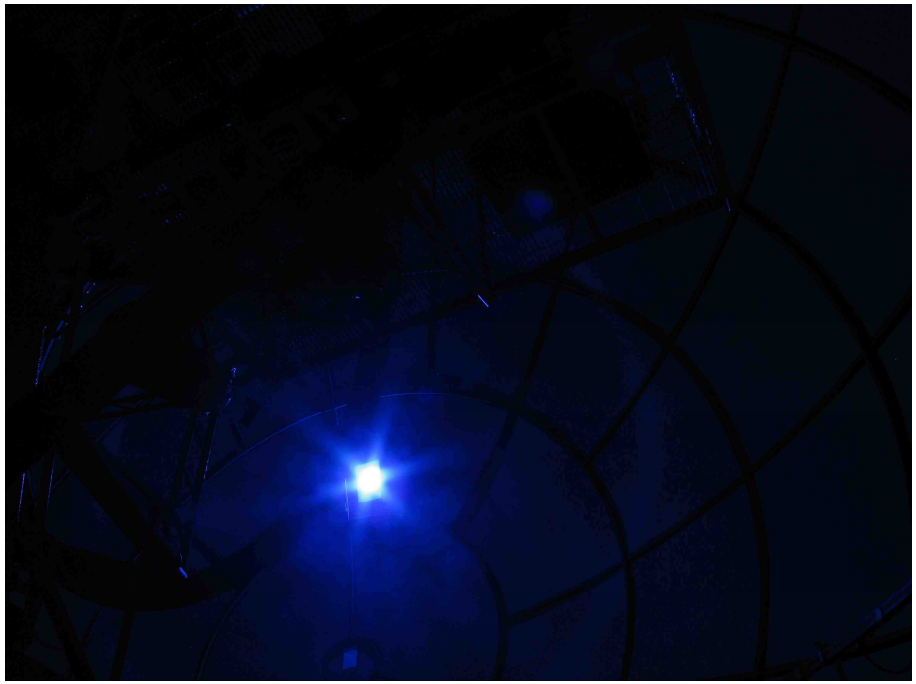
M42 proplyds in R-band



LGS commissioning

- January 28 2011: first laser light in the dome
- February: LLT tests. Flexure 16” (zenith-30deg)
- March: first laser propagation on the sky
- April: close the LGS loop

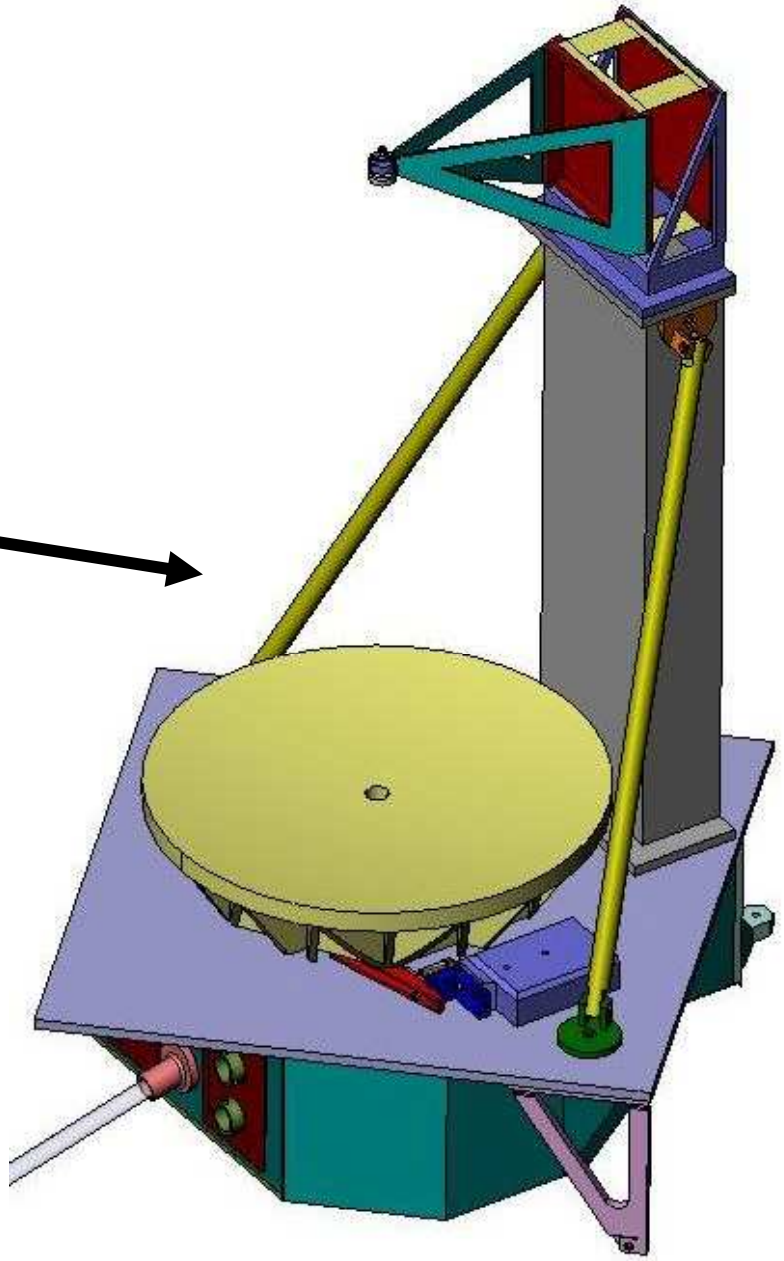
(3 nights)



“Quick & dirty” phase

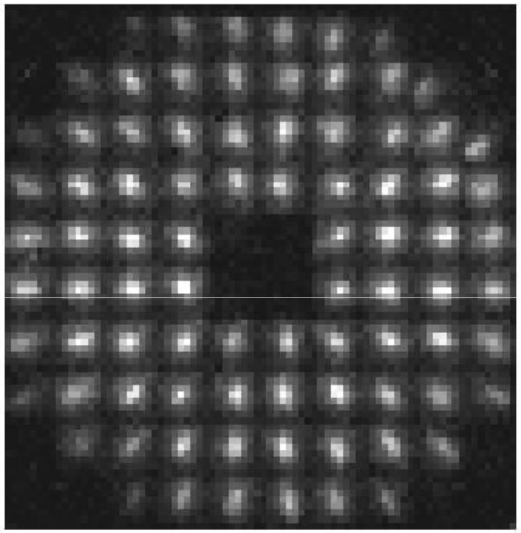
SAM laser system

- Nd:YAG
  laser, 10W, 355nm, commercial
- LLT: D=250mm behind SOAR secondary
- WFS with a Pockels-cell fast shutter
- Simple beam transport

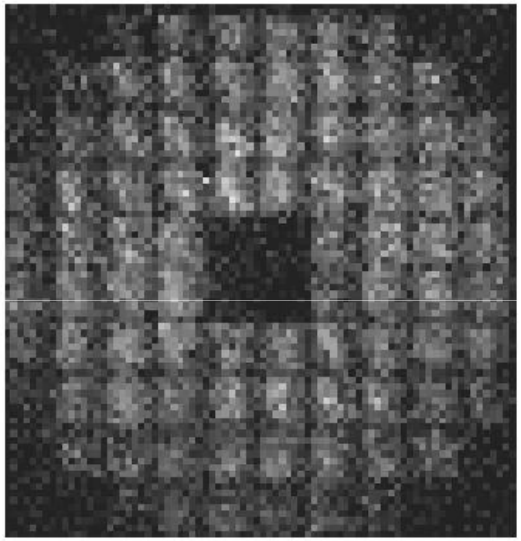


Closing the loop with LGS

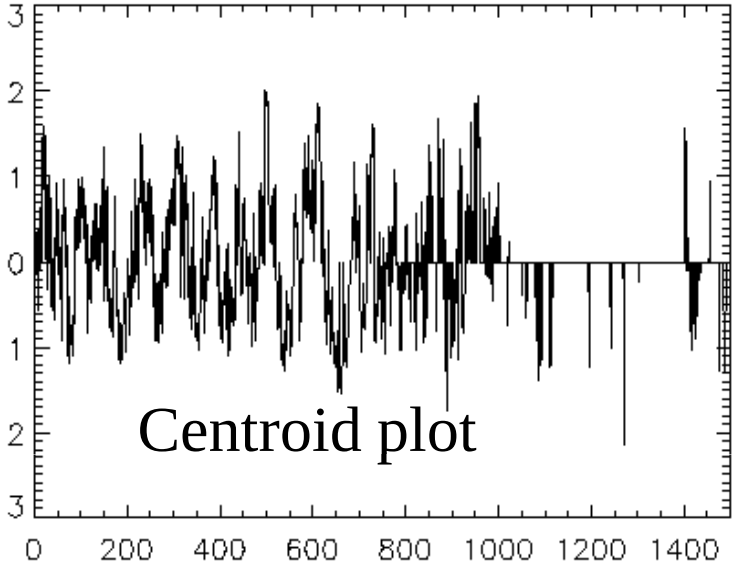
- WFS spot size 1.9”-2.4”.



spot6, 3:31UT

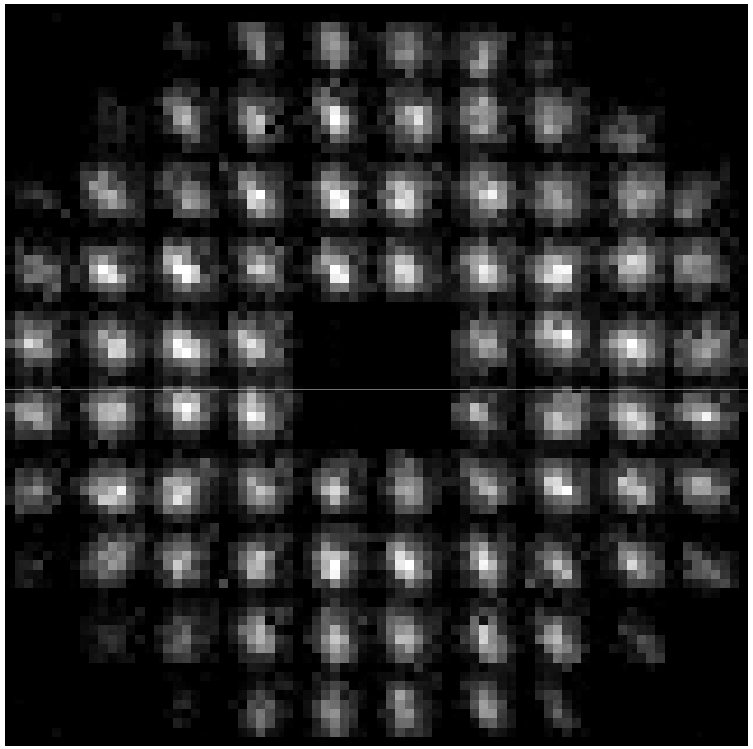


spot10, 7:15UT

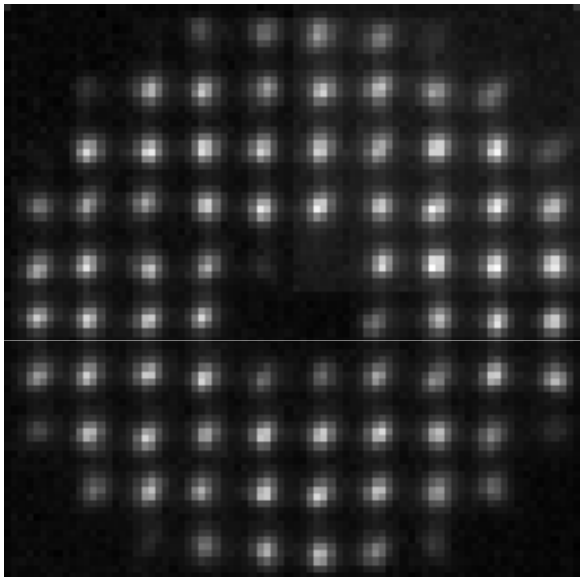


Return flux is high enough (~1000 ph/loop), but the centroid calculation fails when the spots are too fuzzy

Living LGS spots

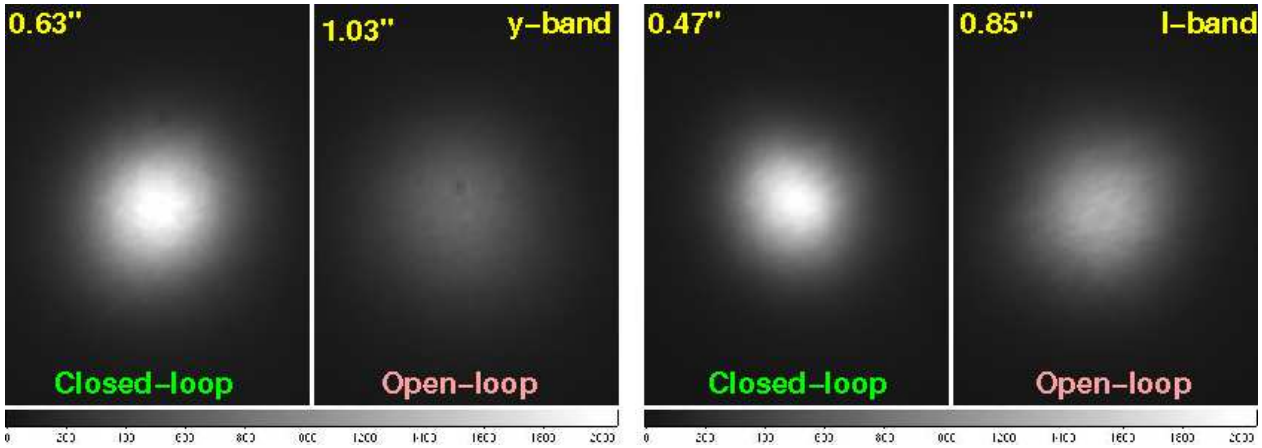


April 18/19 2011

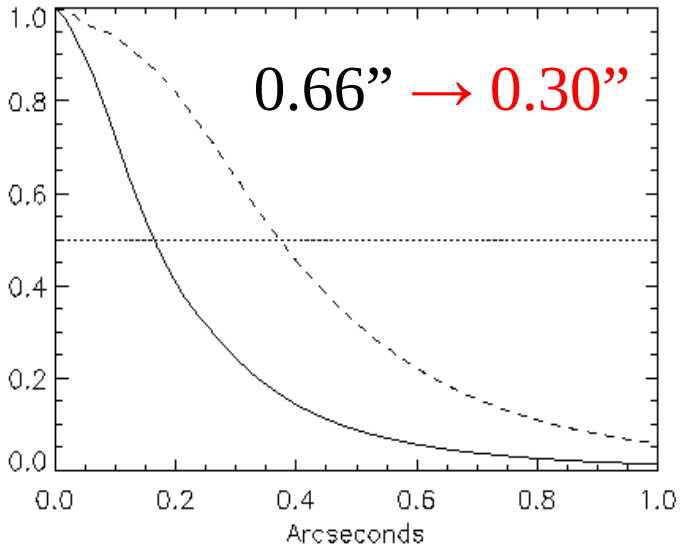


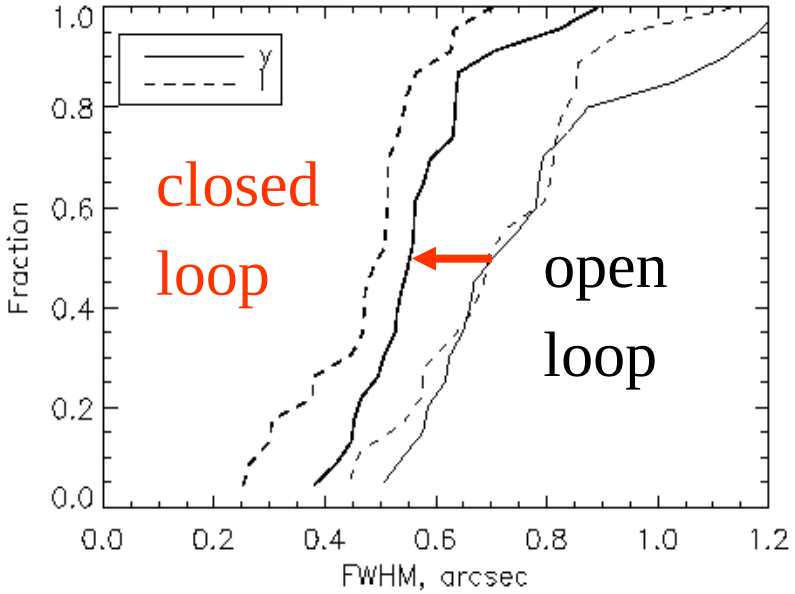
NGS, Oct 2009

First LGS results



Pseudo
long-exposure



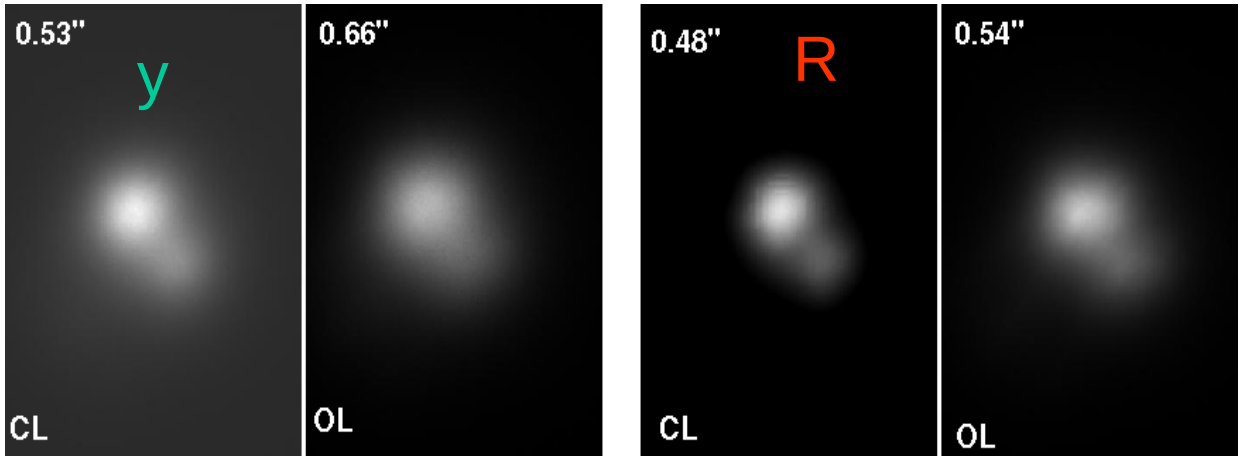


LGS problems

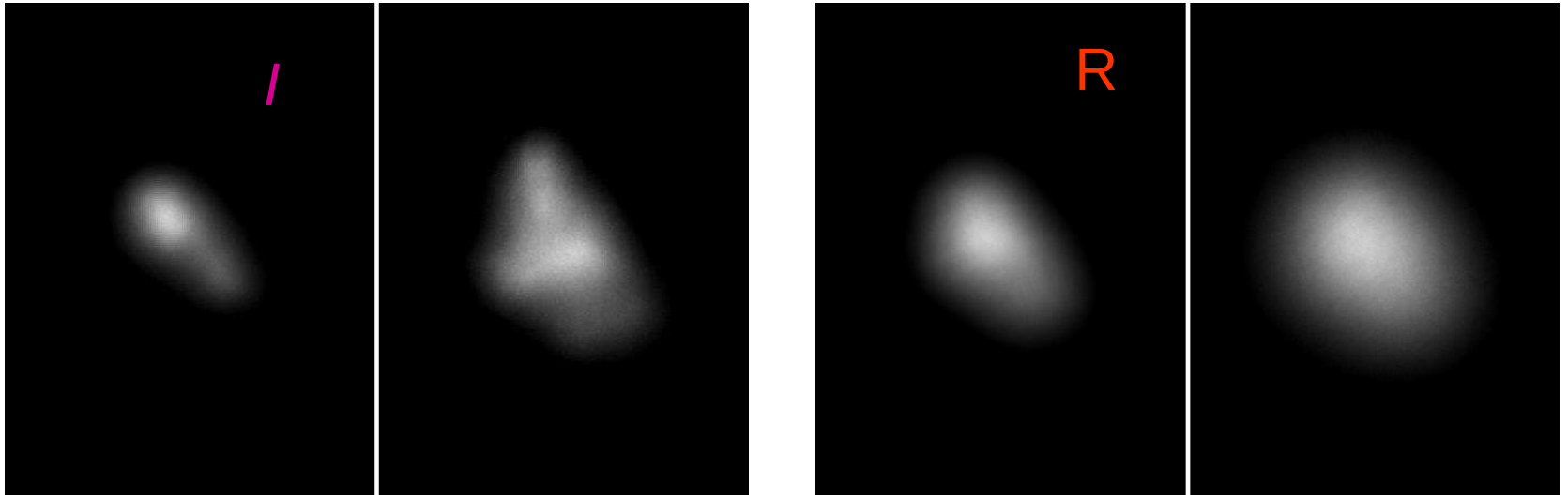
- Spot size 1.9”-2.4” FWHM; must be <1”.
- Tune the polarization of the emitted and received LGS
- Many things to improve in the LLT, some are essential
- LGS control SW is preliminary
- WFS is not optimal (change the lenslets?)

To address these issues, the LGS hardware must be removed from the SOAR

SAM works or not?

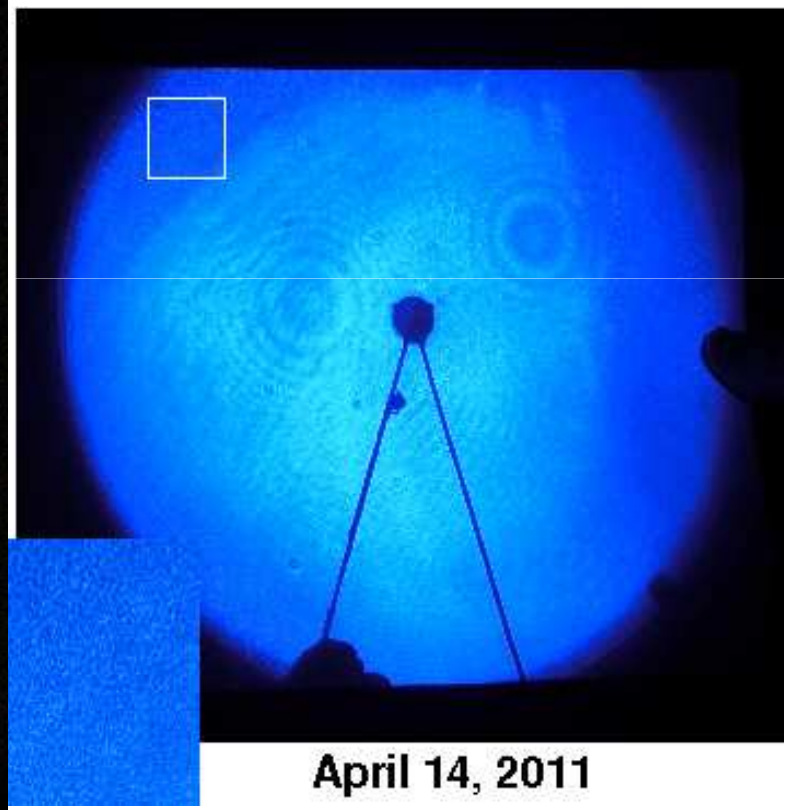


Apr. 18.
0.61”



May 10. 0.40”

Damaged M2 coating



Perspectives of SAM

- Finish SAM design (documentation!) and accept the SAM instrument and SAMI
- SAM shutdown: fix LGS hardware issues
- Remaining SW work to get reasonable instrument control, diagnostic, logging
- Commission SAM in the LGS mode
- Science verification (produce a paper!)

Gains offered by SAM

- Resolution: 2-3 times
- Limiting magnitude [sky]: gain 0.5-1 mag (rival 8-m telescopes)
- Limiting magnitude [confusion]:

  gain 1-2 mag (half-way to HST)
- Light in 0.3” IFU: 1-2 mag.

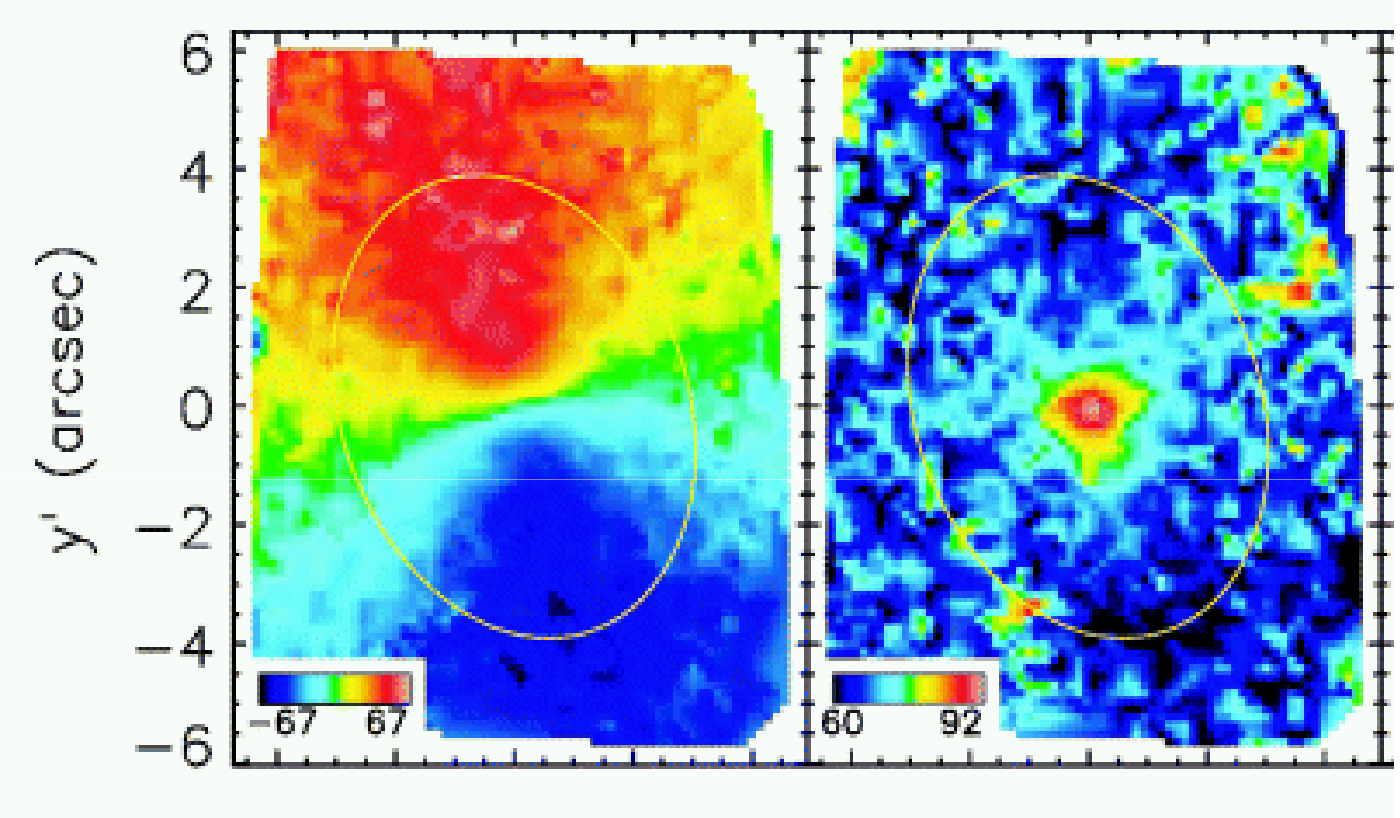
The largest SAM impact is expected from IFU, but early science (SV) must be done in the imaging-only mode

Examples of SAM science

- Dynamics and kinematics of galaxies (IFU)
- Clusters in Galaxy, LMC (CMD)
- Morphology of lensed galaxies and arcs
- Resolved nearby galaxies (CMD, star formation, distance scale, post-AGB)
- Nebulae (proplyds, PN, HH, jets, etc.)

Need input from the SOAR community to the SAM SV program!

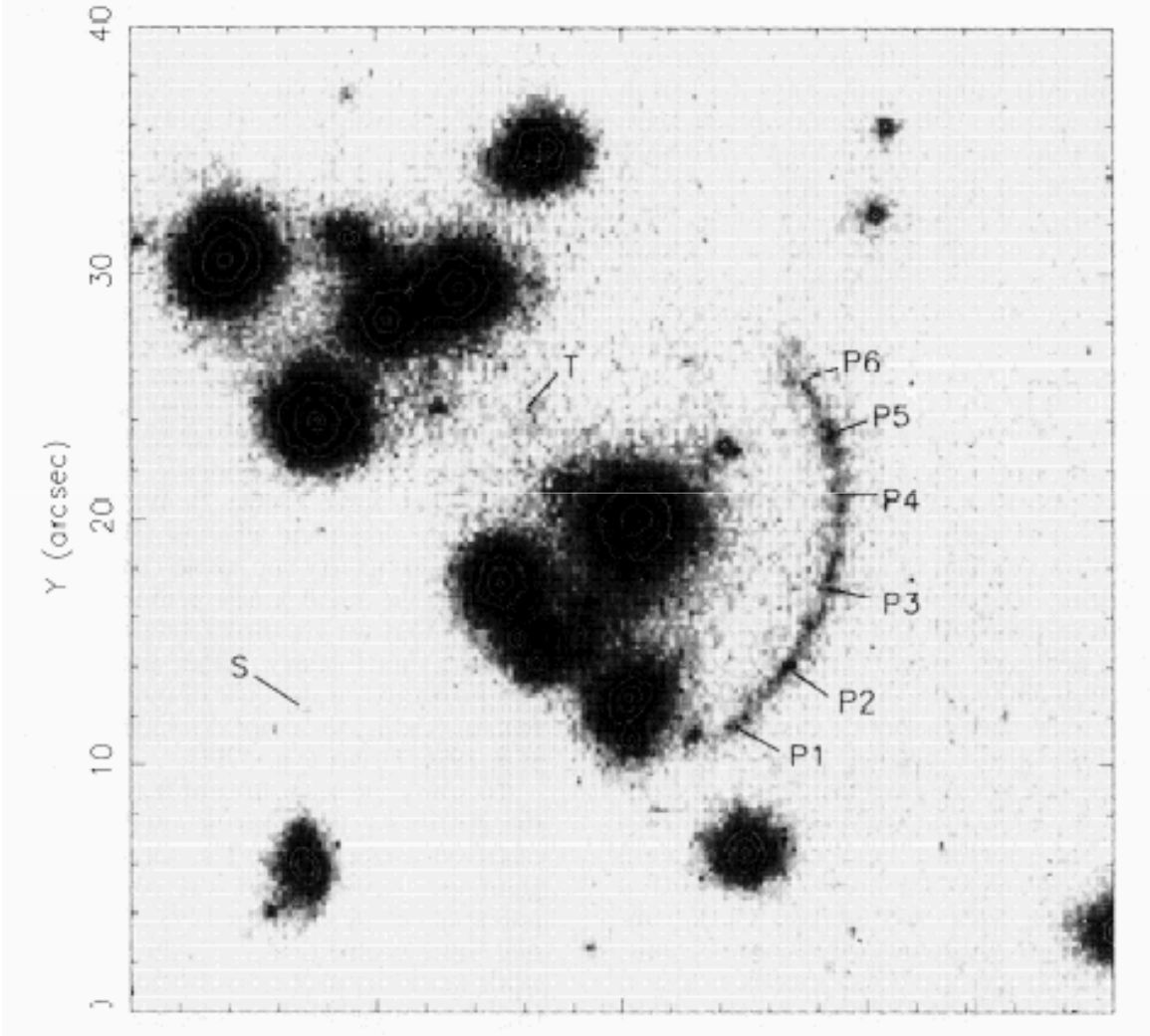
Black holes are sub-arcsecond



Velocity map **Dispersion map**

Black hole in M32 (OASIS+PUEO)

Morphology of lensed galaxies



Goal: study normal galaxies at very high z using lensing as an amplifier

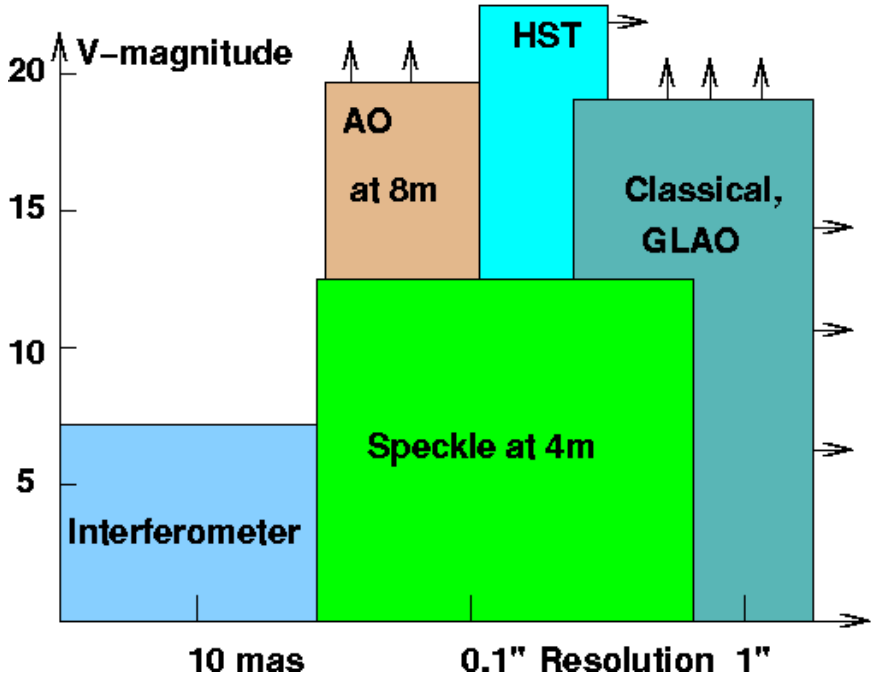
1996 ApJ 469 508

Partially resolved galaxy at 1 Mpc

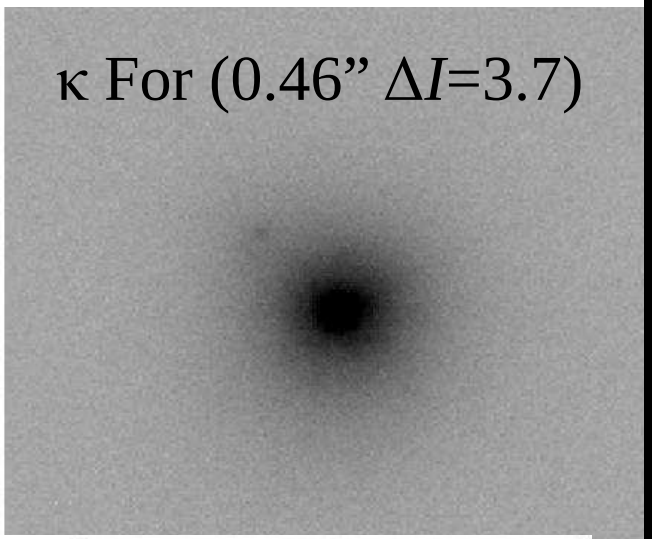
Diffraction-limited science at SOAR

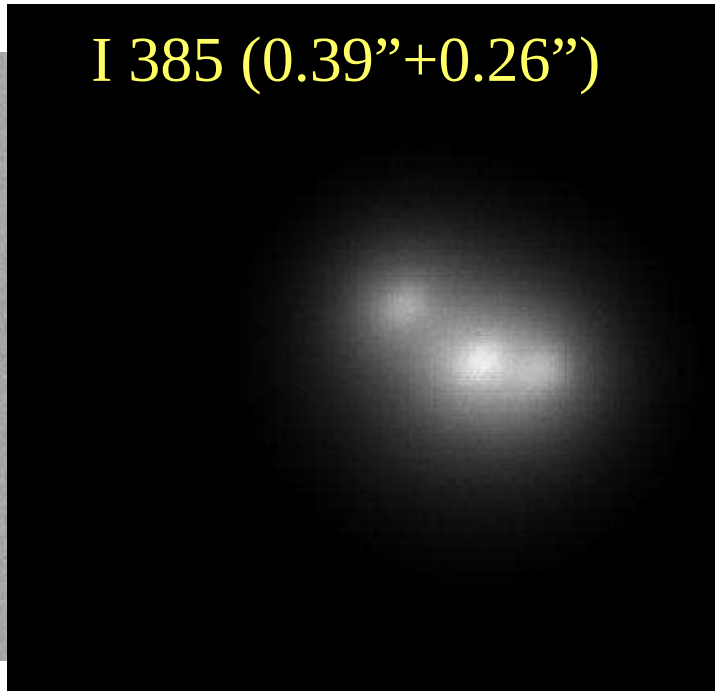
- SAM NGS mode was abandoned. The HRCam was implemented
- Now: >1000 speckle measures, >30 discoveries
- Imaging of planets (Cecil & Rashkeev 2007)
- “Lucky”+SAM

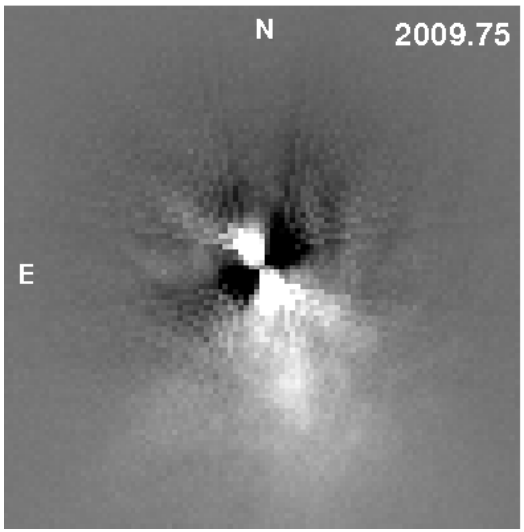
Palomar: AO+”Lucky”



“Lucky” images of multiple stars with SAM







ζ Aqr Aa,Ab
(0.48”, Δ*I*=5.3)

HARI = High Angular Resolution Imager

- Simple imager on the side-port
- EM CCD 2Kx2K and a small AO system
- Space for experiments (imaging polarimetry, coronagraph)