

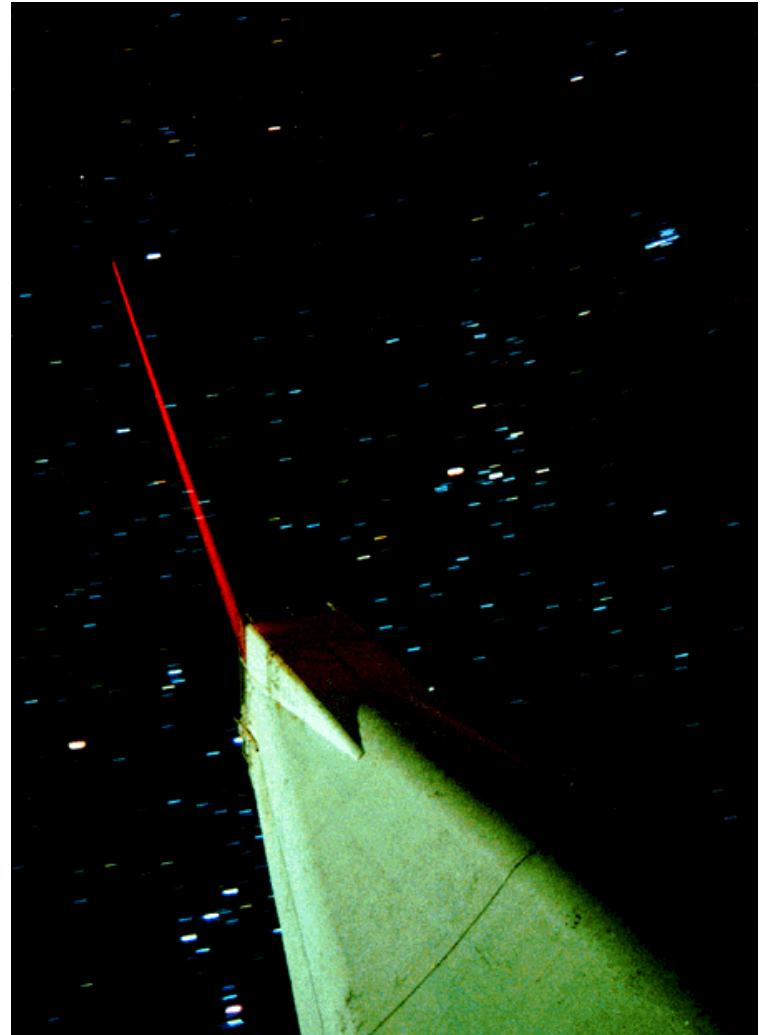
Examples of major developments/inventions at Sac Peak

Solar Adaptive Optics - Many

Quantum Accounting - Keil

Adaptive Optics at the Dunn Solar Telescope:

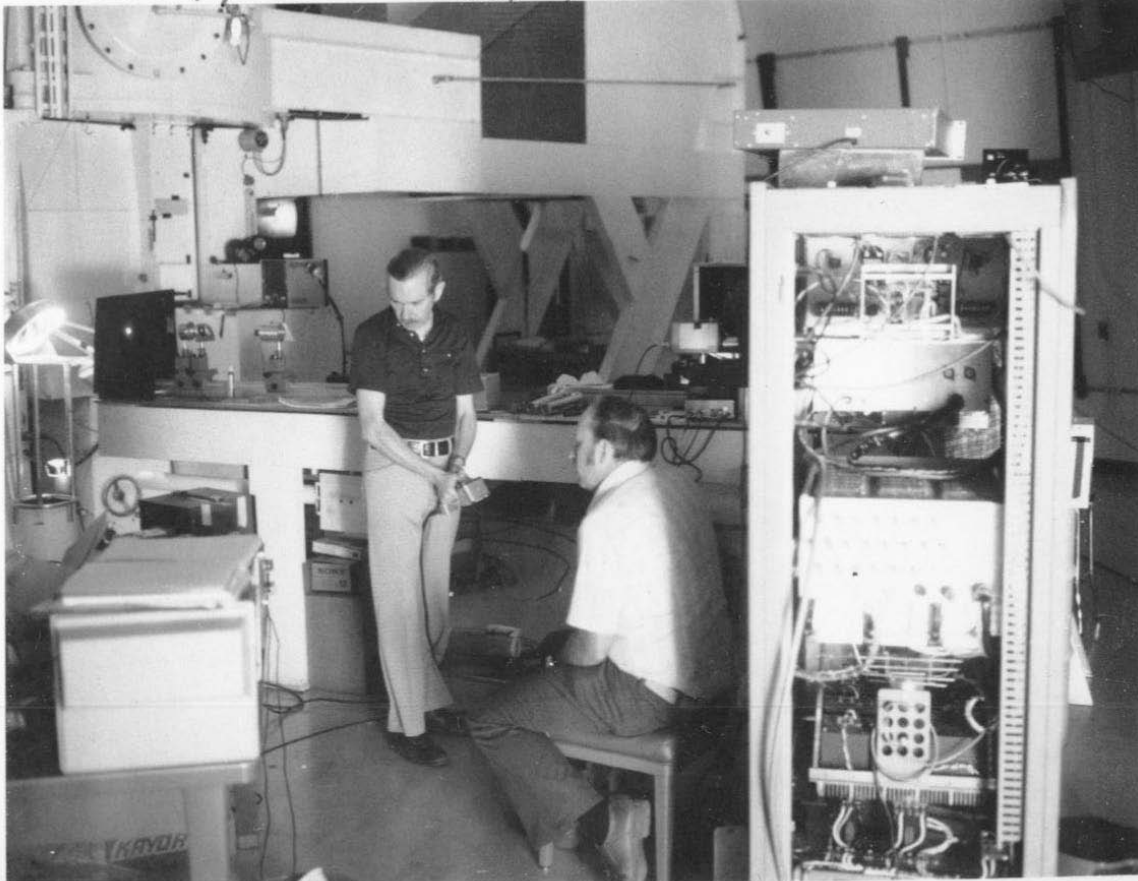
AO, AO – it's off to work we go!



AO – the early beginnings Sac Peak VTT – 1979!

15 Jun 79

ITEK 'FIXING' SEEING @ F2H



JOHN HARDY

STEVE MOODY

OXFORD SERIES IN OPTICAL
AND IMAGING SCIENCE

Adaptive Optics for
Astronomical Telescopes

JOHN W. HARDY

Hardy 1979 at Sac Peak

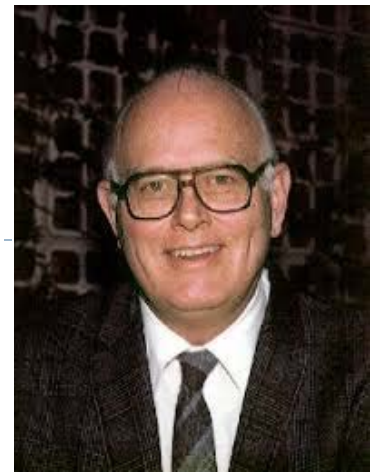
The first on-sky AO experiments

- ▶ ...the expected improvement in image sharpness due to the deformable mirror was obtained only on some occasions ...
- ▶ These results appear to be due to atmospheric parameters, primarily the small size of the isoplanatic patch and the small values of turbulence coherence length during the day.
- ▶ This experiment has confirmed the feasibility of real-time compensation of solar images.
- ▶ **However, much work remains to be done to refine the technique.**

It took until 1998 to get the first operational (for science) solar AO system commissioned!!



Solar AO History



▶ Hardy 1979-1980 at the DST

- ▶ Shearing interferometer
- ▶ 21 actuator continuous faceplate DM
- ▶ stars and sunspots

▶ NSO AO system (Dunn 1987, Dunn et al. 1988, Dunn 1990)

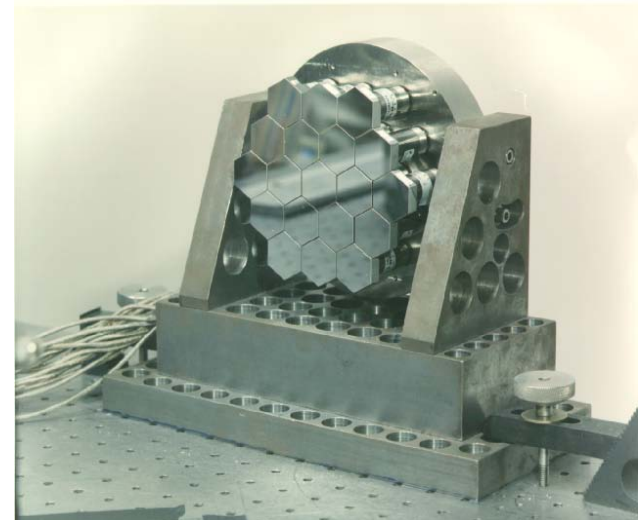
- ▶ modified knife-edge WFS using an focal plane LCD mask (von der Luehe 1988)
- ▶ 61 actuator continuous faceplate DM

▶ Lockheed AO system (Acton&Smithon 1992, Acton&Dunn 1993)

- ▶ 19 element Shack-Hartmann WFS
- ▶ 19 element segmented mirror
- ▶ Worked on pores only

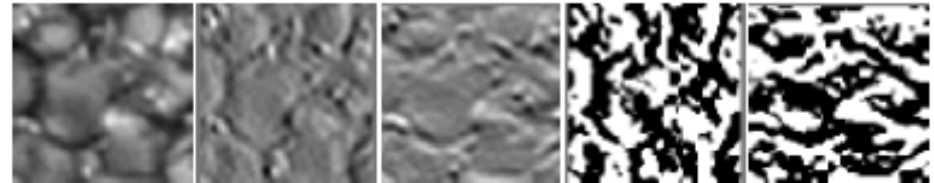
▶ DST AO w/correlating SHWFS

- ▶ 76 element SHWFS
- ▶ 97 actuator Xinetics DM
- ▶ Operational vs. Optics experiment



NSO AO at Sac Peak

4. Wellenfrontmessung mittels optischer Differentiation



(a) Referenzbild
 $I(\xi, \eta)$:
Sonnengrammatur.
Ausschnitt von
 $10'' \times 10''$

(b) Horizontale
Maske für
 x -Richtung.
Entspricht der
horizontalen
Ableitung des
Referenzbildes von
rechts nach links.

(c) Vertikale Maske
für y -Richtung.
Entspricht der
vertikalen Ableitung
des Referenzbildes
von oben nach unten.

(d) Quasibinare
horizontale Maske

(e) Quasibinare
vertikale Maske

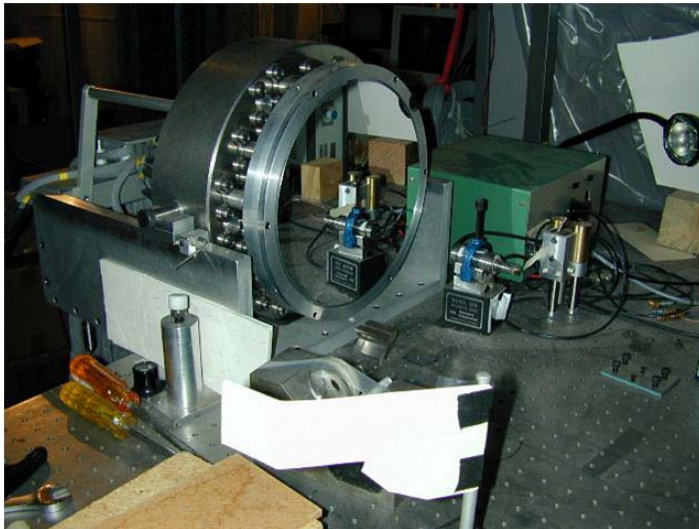


Abbildung 4.3.: Die Masken (b) u. (c) werden nach Gl. (4.7) u. (4.8) mit $\Delta = 0.16''$ aus dem Referenzbild (a) erzeugt. Die Erstellung der quasibinären Masken (d) u. (e) aus den normalen Masken (b) u. (c) wird in Abschnitt 4.3.2 erläutert.

Oskar's Focal Plane WFS:
So far not demonstrated
on sky – but we ought to!!

Solar AO History

▶ Hardy 1979-1980 at the DST

- ▶ Shearing interferometer
- ▶ 21 actuator continuous faceplate DM
- ▶ stars and sunspots

▶ NSO AO system (Dunn 1987, Dunn et al. 1988, Dunn 1990)

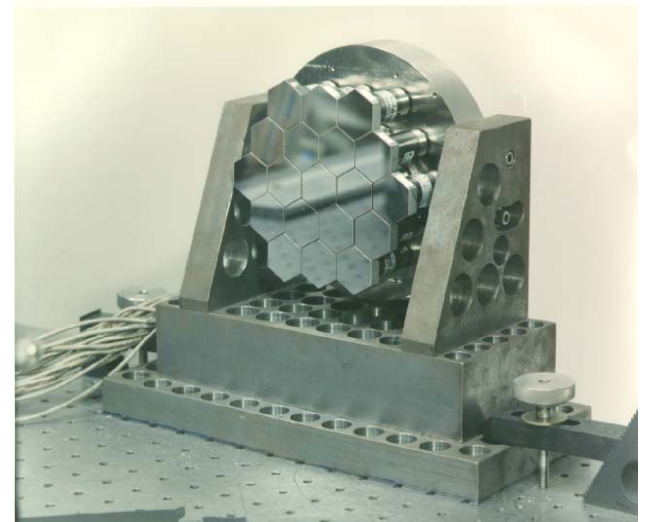
- ▶ modified knife-edge WFS using an focal plane LCD mask (von der Luehe 1988)
- ▶ 61 actuator continuous faceplate DM

▶ Lockheed AO system (Acton&Smithon 1992, Acton&Dunn 1993)

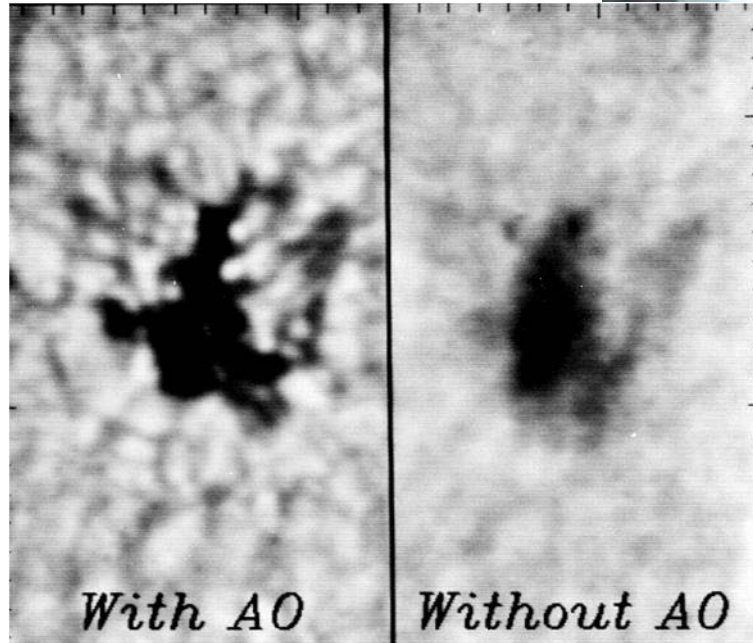
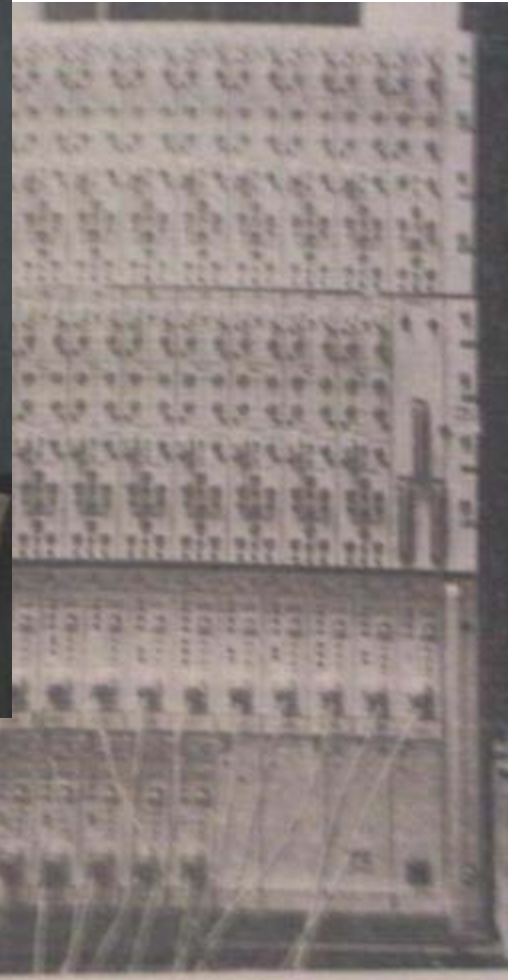
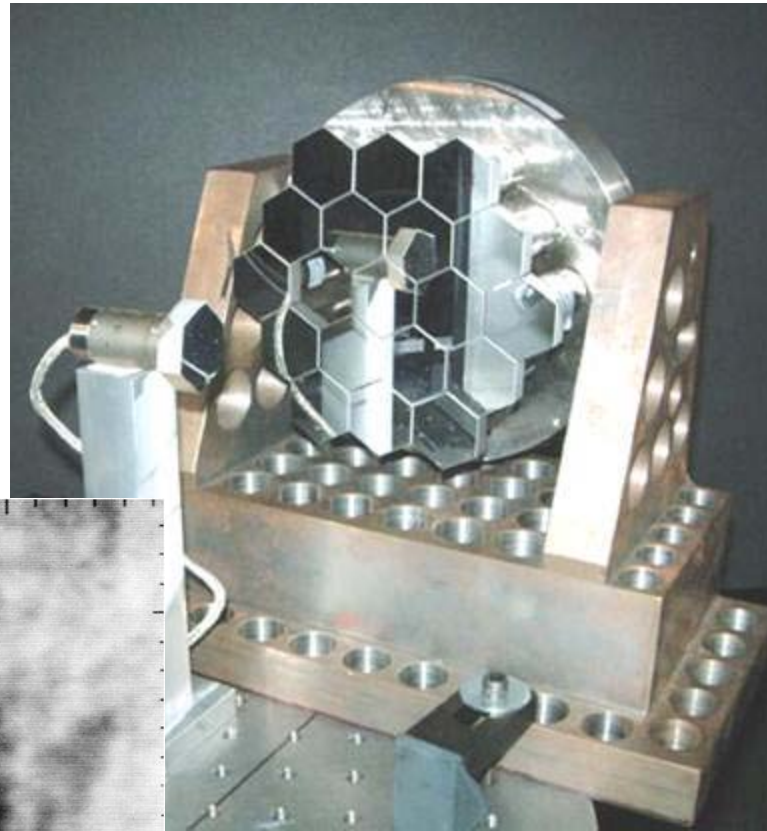
- ▶ 19 element Shack-Hartmann WFS
- ▶ 19 element segmented mirror
- ▶ Worked on pores only

▶ DST AO w/correlating SHWFS

- ▶ 76 element SHWFS
- ▶ 97 actuator Xinetics DM
- ▶ Operational vs. Optics experiment



Lockheed AO - at Sac Peak and Teneriffe



Correlation Tracker
Celebration July 1988

J. Christou	Dick Ounn
Phil Wiborg	Domenico
Charley Miller	Thomas Rianale
Oskar	

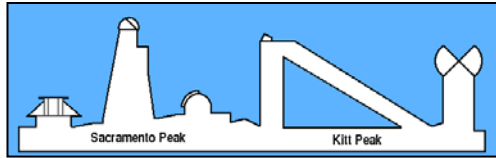


... and more celebration



Solar AO History

- ▶ Hardy 1979-1980 at the DST
 - ▶ Shearing interferometer
 - ▶ 21 actuator continuous faceplate DM
 - ▶ stars and sunspots
- ▶ NSO AO system (Dunn 1987, Dunn et al. 1988, Dunn 1990)
 - ▶ modified knife-edge WFS using an focal plane LCD mask (von der Luehe 1988)
 - ▶ 61 actuator continuous faceplate DM
- ▶ Lockheed AO system (Acton&Smithon 1992, Acton&Dunn 1993)
 - ▶ 19 element Shack-Hartmann WFS
 - ▶ 19 element segmented mirror
 - ▶ Worked on pores only
- ▶ DST AO w/correlating SHWFS (low order 1998 & high order 2002)
 - ▶ 76 element SHWFS
 - ▶ 97 actuator Xinetics DM
 - ▶ Operational vs. Optics experiment

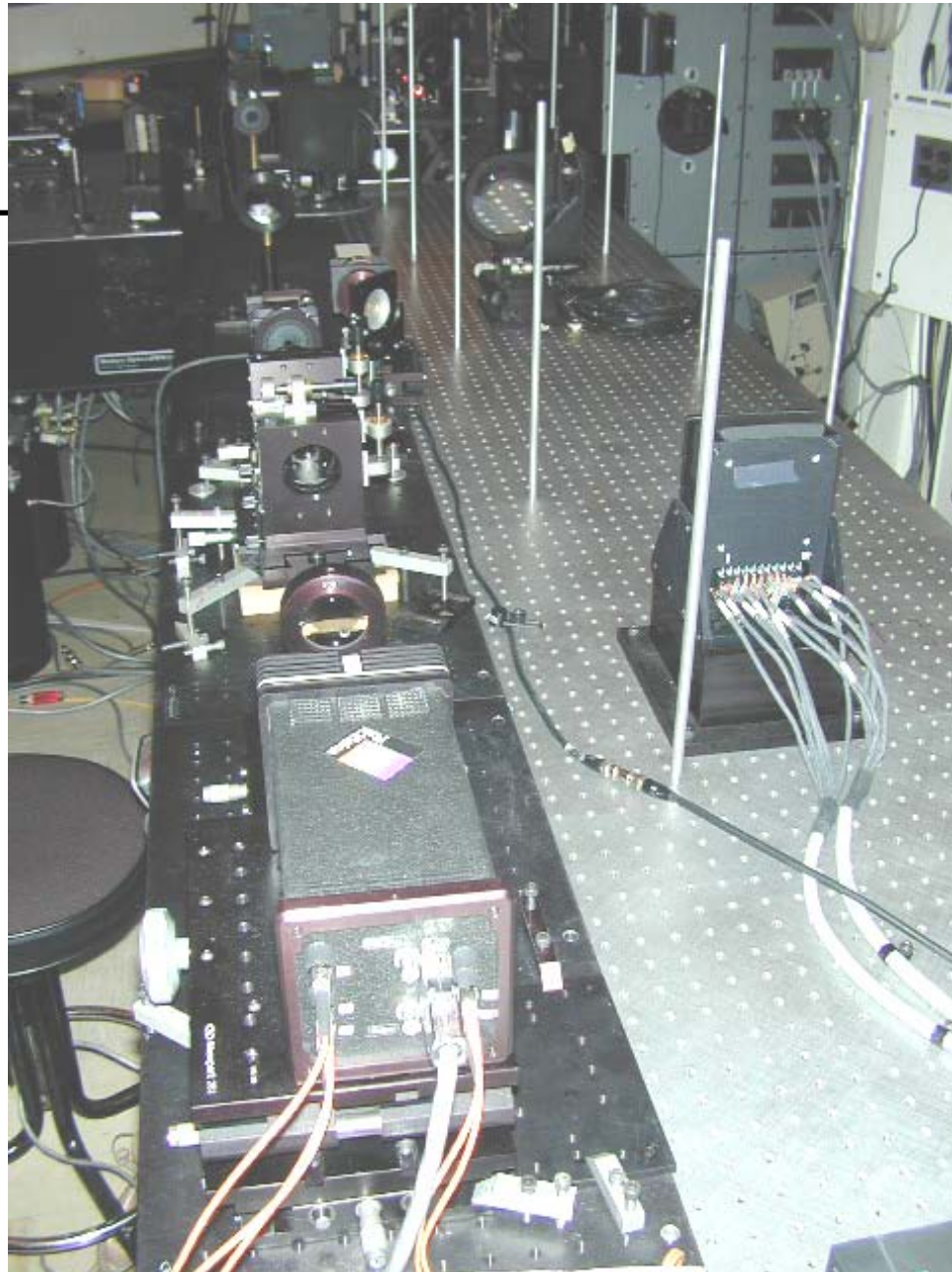
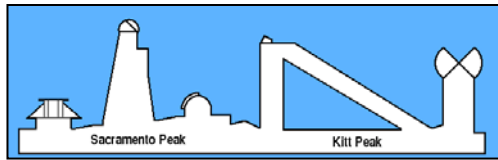


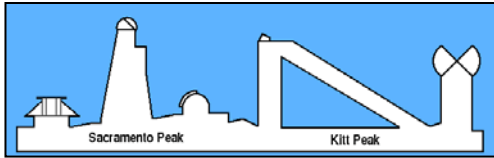
National Solar Observatory

Solar Adaptive Optics

Low-Order AO System Components

- **Correlating Shack-Hartmann WFS**
 - 24 subapertures , 16x16 pixels per subaperture
 - 2kHz sampling rate (target), achieved 800 Hz
 - parallel processing using off-the-shelf DSPs
- **DM: 97 actuators (Xinetics)**
- **Reconstructor: Modal, off-the-shelf DSPs**





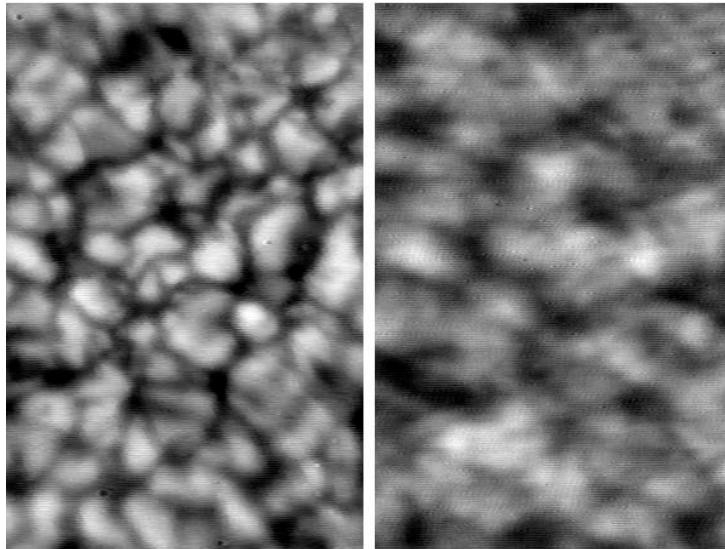
National Solar Observatory

Solar Adaptive Optics

Results

Corrected

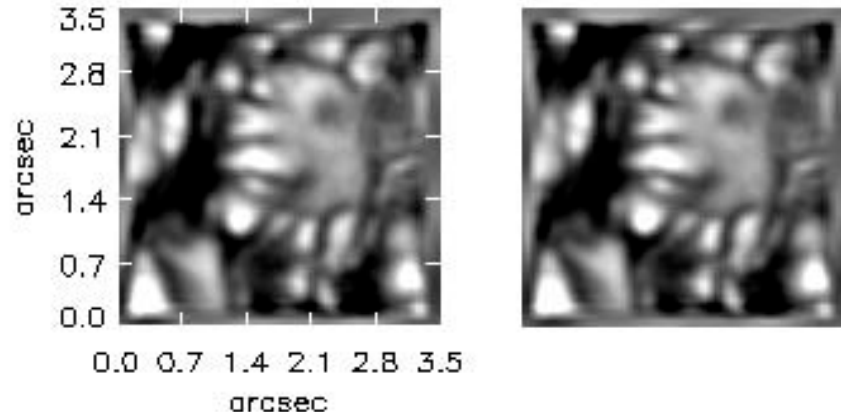
Uncorrected



- Diffraction Limited Images fed to Horizontal Spectrograph at the DST (D=76cm).
- First diffraction Limited Long Exposure Narrow-Band Images and Spectra.
- First diffraction Limited ($<0.2''$) Maps and Time Sequence of Velocities in Sunspots and Magnetic Field Maps of Pores and "Quiet" Sun Granulation.

W/ AO: 1
sec exposure

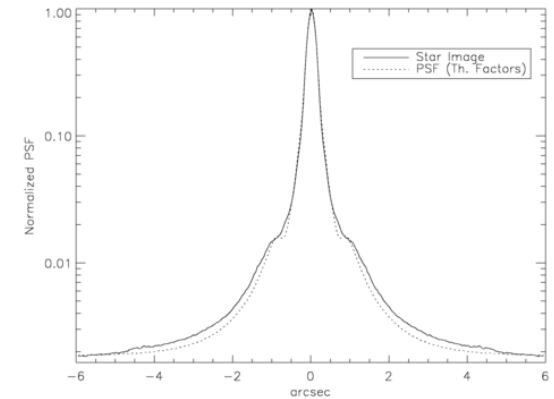
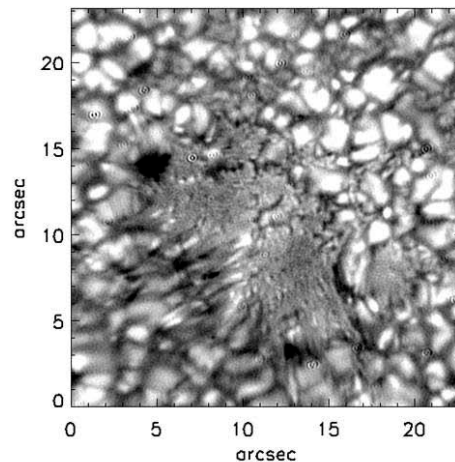
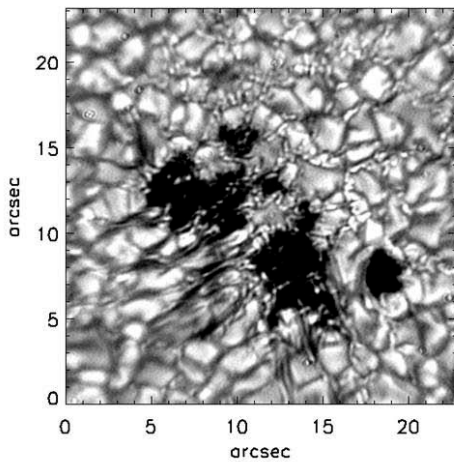
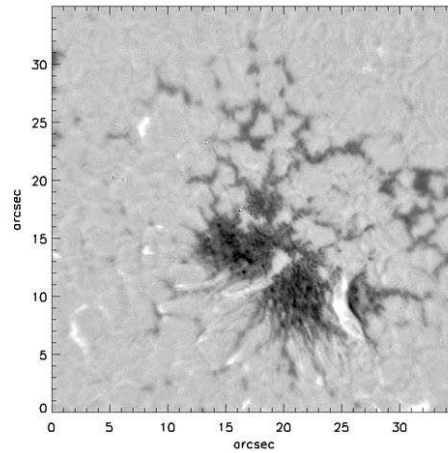
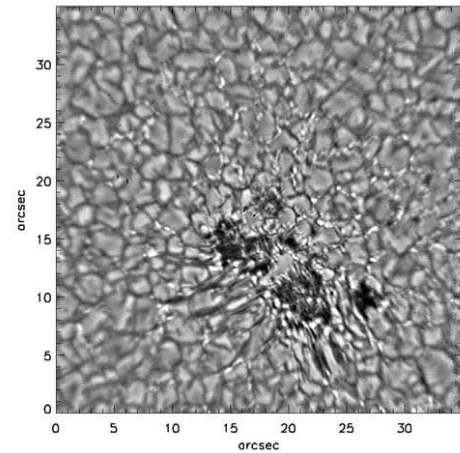
W/ AO:
10 sec exposure



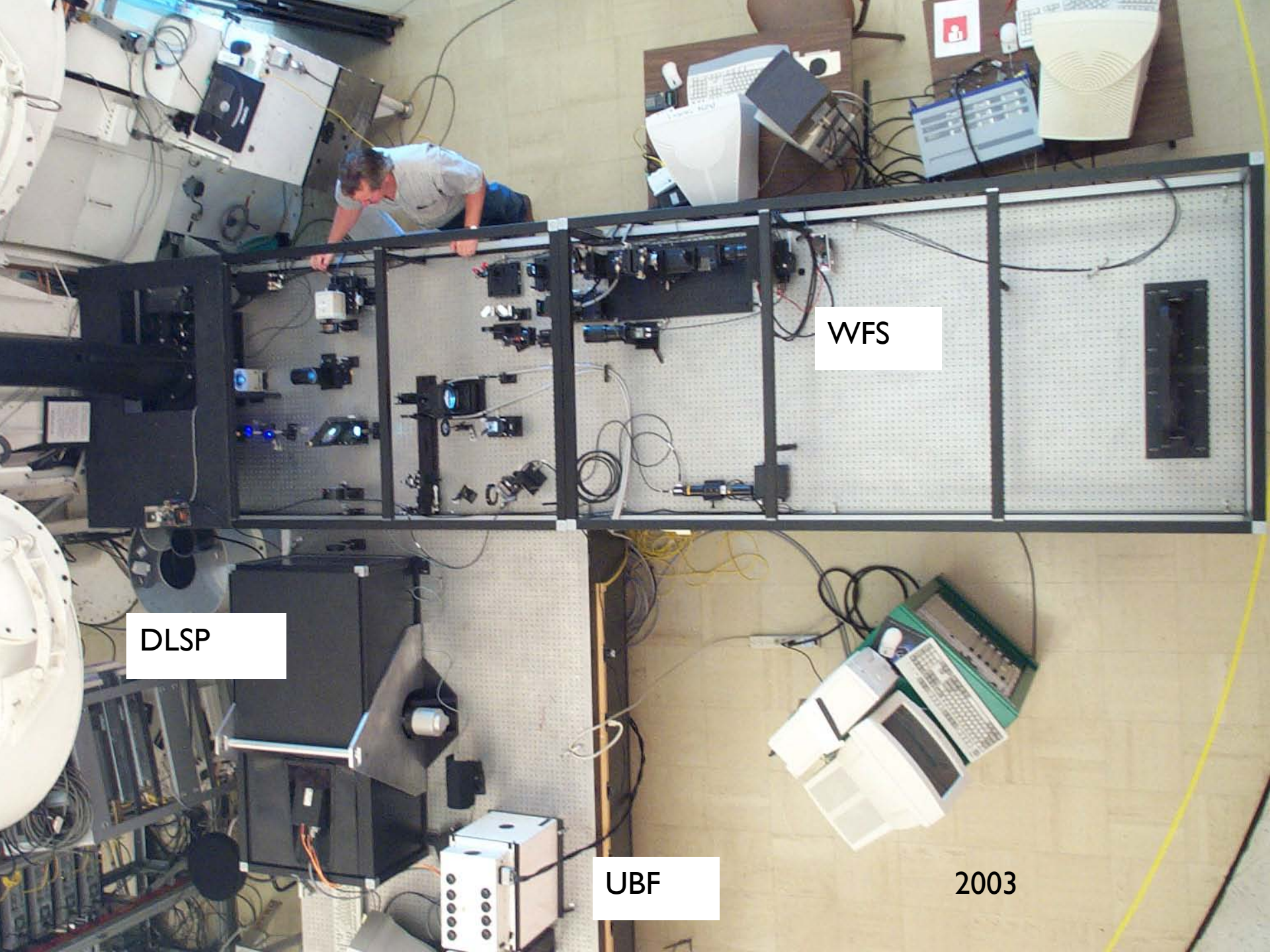
AAS 1999

▶ LOAO – first system based on correlating SHWFS

Timing crucial for US
decadal survey ~2000
A(T)ST - recommendation



18 sec. exposure

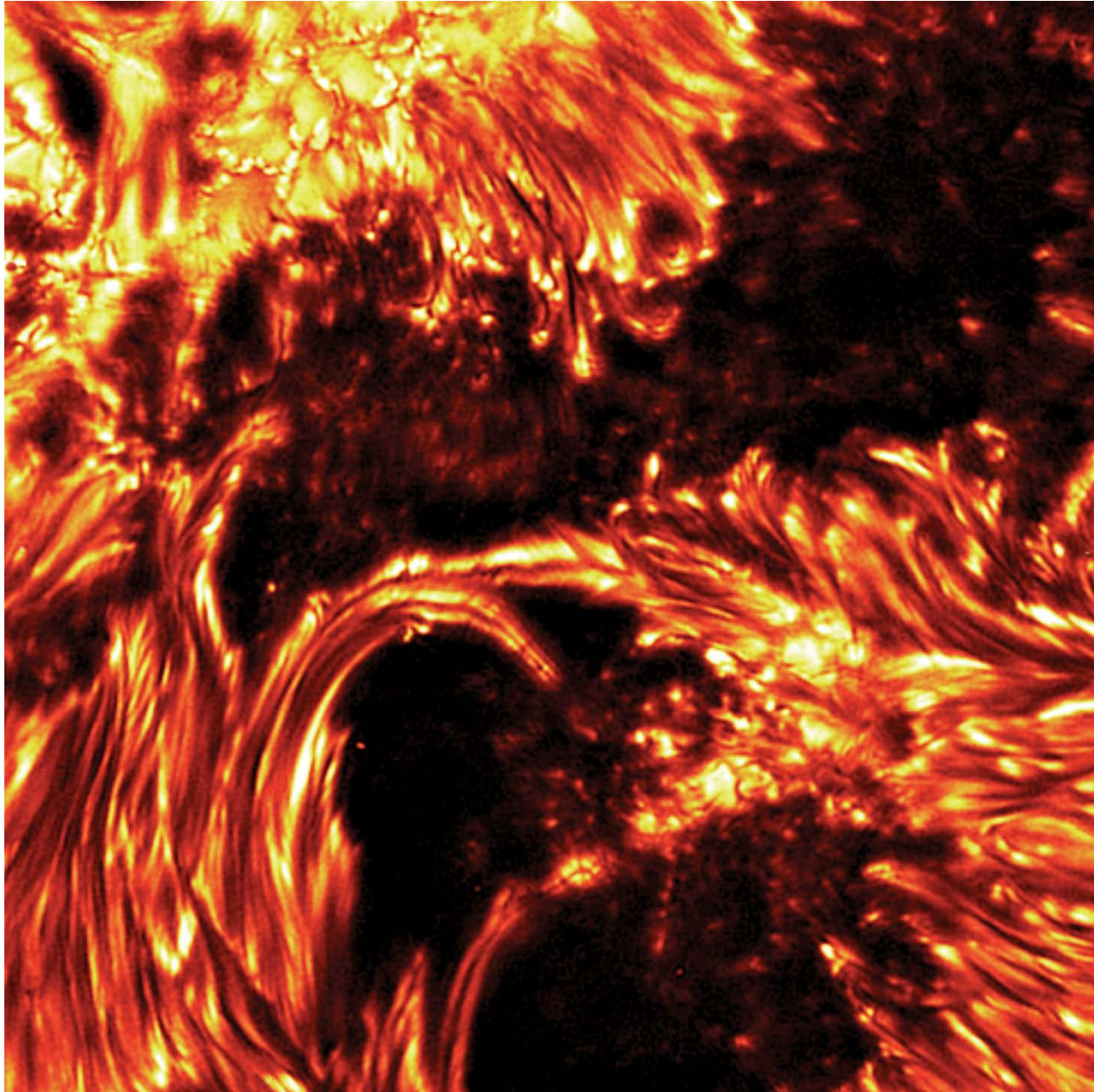


DLSP

UBF

WFS

2003



G-band
430 nm



Past & Current Results

Multi-Conjugate Adaptive Optics

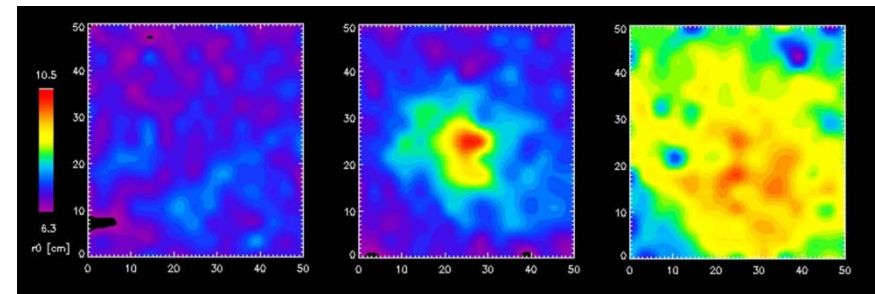
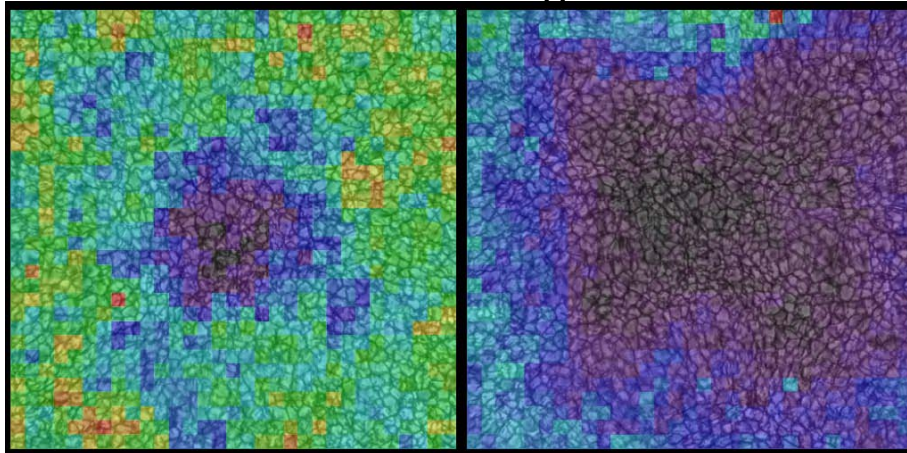
▶ DST

▶ VTT/GREGOR & NST

However, much work remains to be done to refine the technique!!

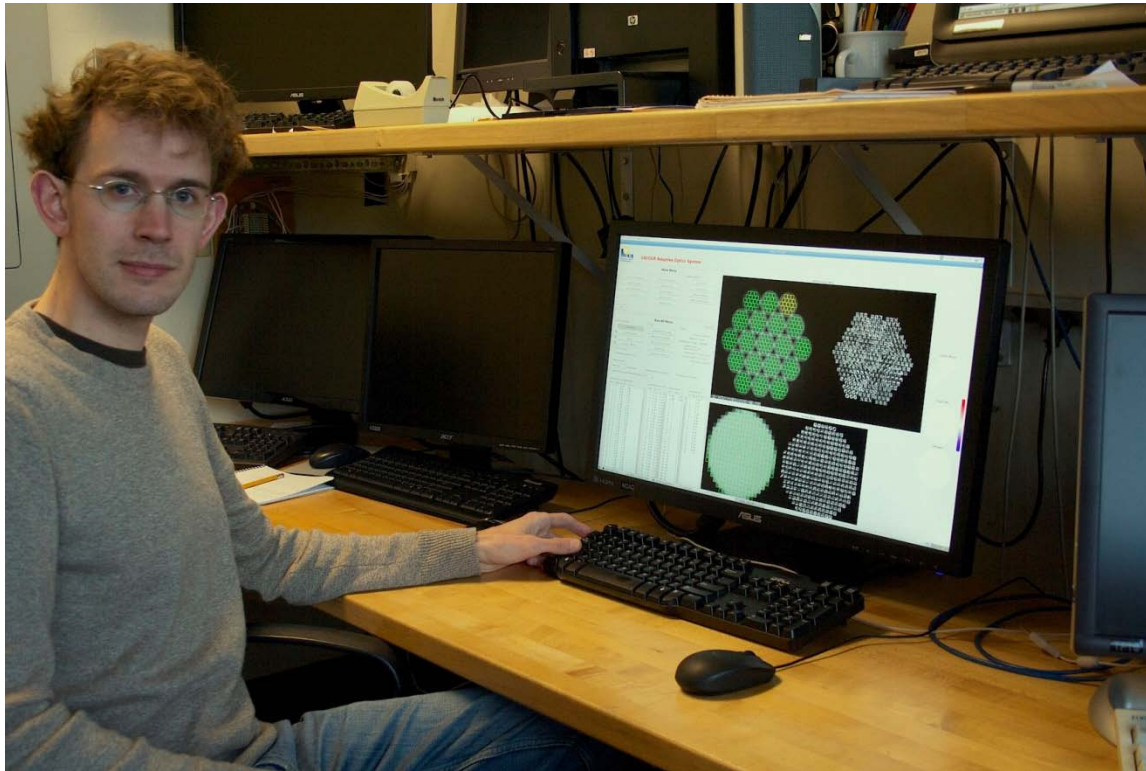
Conventional AO

5 guide “stars” MCAO



The next generation is taking over ...

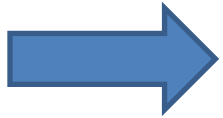
Dirk Schmidt at BBSO
Working on MCAO





Steve's Brilliant Management Skills

- Budget, budgets and more budgets
- Thousands of excel budget spreadsheets
- Ever increasing budget pressures



- the need to be (very) creative!

Table 8.4-2. Detailed Long-Range Budget Estimates

FY14 or Nonrecurr	FY14		FY15		FY16		FY17		FY18		FY19		FY19		
	Agency	NSF	Agency	NSF	Agency	NSF	Agency	NSF	Agency	NSF	Agency	NSF	NISP	AT&T	
NSO HQ															
Director's Office	462	33	495	468	33	501	460	190	679	490	260	750	495	100	505
HQ Development & Relocation	46	9	74	190	762	800	112	800	912	464	464				
HQ Lease and Utilities	825	825		830	830		834	834		850	838	838			
Administrative Support	120	40	160	230	80	310	500	90	590	500	80	580			
Science Staff															
AT&T Science Staff	661	80	561	650	114	764	1,200	190	1,390	1,220	190	1,410			
AT&T Fellow	120	21	141	120	7	127									
Synoptic Science Staff							501	40	541	510	50	560			
Data Center/Software/Computing	406	330	1,730	1,220	1,640	2,860	1,241	2,188	3,448	1,280	2,310	3,500			
Instr Program/Maintenance	300	111	391	531	200	731	895	400	1,295	1,270	506	1,666			
Synoptic Program							500	300	800	520	310	830			
EPO							200	30	230	200	30	230			
ROB Utilities															
Total NSO	3,277	421	4,099	3,097	2,172	6,244	3,963	3,991	7,481	5,677	4,778	10,360	6,080	4,100	10,589
AT&T Mail Operations															
Science Staff Supporting Ops	190	40	190	225	42	267	300	70	370	350	130	480			
Operations Staff	140	40	180	220	24	244	250	90	340	700	170	870			
Administrative Support	110	30	140	200	40	240	210	70	280	400	120	520			
Engineering/Technical Support							320	142	462	700	360	1,100	1,800	220	2,220
Computing/IT Staff	100	70	170	200	400	490	270	360	630	320	490	900			
Mountain Facility Support							884	884	887	887	510	510	354	354	
Remote Ops Building (ROB) Lease							100	100	100	100	100	100			
ROB Utilities/Lease/Insurance							100	100	100	100	100	100			
Total Mail Ops	520	180	700	525	1,214	3,441	1,810	1,827	3,741	2,880	2,921	6,740	3,020	2,921	6,740
NSO Science															
Scientific Staff	234	13	247	241	13	254	35	3	38						
Software Support							7	7	7						
Instrument Development/Maint.							3	3	3						
Telescope Ops	82	9	90	42	6	48	41	6	47	21	12	33			
Administrative Support															
Miss. Revenue															
Total NSF Science	316	22	328	283	29	308	76	16	85	21	12	33			
NSO/MoMP															
Scientific Staff	1,275	54	1,329	833	48	881	50	44	694						
Software Support	1,058	107	1,164	1,123	106	1,229	800	100	900						

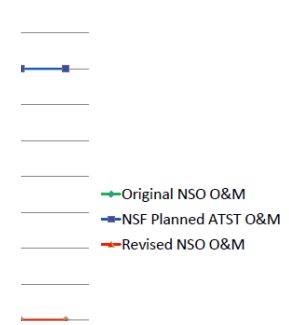
Long Range Plan

0.001

0.105263 0.894737

	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY19	FY19
									NISP	AT&T
Directors Office	405	358	329	478	800	850	820	660		
HQ Development + Reloc	22	22	44	770	875	460	-	-		
HQ Lease and Utilities	-	-	-	800	1,050	1,050	1,150	1,200		
Admin	-	-	-	180	310	600	860	695	73	622
Science Staff										
AT&T Science Staff	120	284	482	541	814	1,395	1,415	1,500		1,500
AT&T Fellow	-	-	-	141	127	-	-	169		169
Synoptic Science Staff	-	-	-	-	-	546	560	570	570	570
Data Center - Software/Computing	-	-	-	690	1,800	2,500	2,760	1,550	163	1,387
Instr Program/Maintenance	-	-	-	500	800	1,400	1,970	2,080	219	1,861
IT Support	-	-	-	540	550	470	300	41	41	340
Synoptic Operations	-	-	-	-	-	800	830	850	850	850
EPO	-	-	-	250	360	300	300	300	32	268
AT&T Operations										
Science Staff supporting Ops	-	-	-	190	267	370	991	1,473		1,473
Operations Staff	-	-	-	180	254	440	730	794		794
Admin	-	-	-	140	280	280	570	723		723
Eng/Technical	-	-	-	362	1,110	2,220	2,906	2,906		2,906
IT Support	-	-	-	170	450	760	960	620		620
Mountain Facility Support	-	-	-	-	-	-	-	2,024		2,024
Building Lease	-	-	-	900	900	900	900	900		900
Tucson & MoMP Operations	565	290	293	288	130	-	-	-		-
NISP	4,043	3,366	3,418	2,937	2,006	-	-	-		-
Sao Peak	2,623	2,160	1,994	2,181	2,125	1,412	790	-		-
Bonuses	100	100	100	100	100	100	100	100	105	895
General NOAO Supp	960	1,100	1,100	1,100	1,200	1,297	1,100	1,000		
Utilities on Kitt Peak	80	60	80	80	40	-	-	-		-
AURA Management Fee	282	260	260	396	440	480	504	506	63	533
Total NSO Costs (after revenues)	9,100	8,000	8,000	13,000	16,000	17,500	19,500	21,000	2,716	17,024

ility Ramp-down



Long Range Plan

0.001

	FY14	FY15	FY16	FY17	FY18	FY19	FY19
Directors Office	328	478	870	730	595	680	
HQ Development + Reloc	44	770	875	480	-	-	
HQ Lease and Utilities	-	760	790	810	820	845	
Admin	-	180	310	580	630	840	87
Science Staff							
AT&T Science Staff	473	641	784	1,386	1,415	1,741	
AT&T Fellow	-	141	127	-	-	-	
Synoptic Science Staff	-	-	-	548	680	670	670
Data Center - Software/Computing	-	770	2,810	3,449	3,690	2,160	228
Instr Program/Maintenance	-	311	881	1,295	1,888	2,835	277
Synoptic Operations	-	-	-	800	830	860	860
EPO	-	220	260	280	285	300	32
AT&T Operations							
Science Staff supporting Ops	-	190	267	370	891	1,085	
Operations Staff	-	180	254	440	730	888	
Admin	-	140	280	280	670	719	
Eng/Technical	-	-	482	1,210	2,125	2,680	
IT Support	-	170	450	835	825	877	
Mountain Facility Support	-	-	-	-	-	2,018	
ROB	-	1,089	1,089	1,089	1,089	1,089	
ROB Utilities	-	100	100	100	106	106	
Tucson & MoMP Operations	293	288	130	39	-	-	
NISP	3,418	2,937	2,008	-	-	-	
Sao Peak	2,003	2,181	2,126	1,412	790	-	
Bonuses							
General NOAO Supp	1,100	1,100	1,100	1,100	1,100	1,000	106
Utilities on Kitt Peak	80	80	40	20	-	-	
AURA Management Fee	280	386	440	480	604	680	68
Total NSO Costs (after revenues)	8,000	13,000	16,000	17,500	19,500	21,000	2,716

	FY18	FY18	FY18	FY18	FY18	FY18	FY18	FY18	FY18	FY18	FY18	FY18
Directors Office	(89)	(175)	(282)	(414)	(228)	(35)	(133)					
HQ Development + Reloc	(38)	(40)	(1,656)	(1,030)	175							
HQ Lease and Utilities	-	-	(350)	(350)	(360)	(340)	(380)					
Admin	-	-	(180)	(110)	(480)	(180)	(180)					
Science Staff												
AT&T Science Staff	120	284	(7)	(132)	(531)	65	(39)					
AT&T Fellow	-	(16)	(141)	14								
Synoptic Science Staff	-	-	-	-	(868)	(382)	(453)					(463)
Data Center - Software/Computing	-	-	(124)	(180)	422	1,284	2,026					1,367
Instr Program/Maintenance	-	-	(500)	(429)	(590)	(267)	(267)					888
IT Support	-	-	-	-	#REF!	#REF!	#REF!					(178)
Synoptic Operations	-	-	-	-	(1,010)	(300)	(394)					895
EPO	-	-	(350)	(140)	(15)	(10)	(35)					(23)
AT&T Operations												
Science Staff supporting Ops	-	-	(170)	(2)	(103)	(490)	(482)					(482)
Operations Staff	-	-	(140)	31	(196)	(120)	(84)					(84)
Admin	-	-	(140)	(15)	(290)	(153)	(163)					(163)
Eng/Technical	-	-	(20)	(153)	(518)	(590)	(781)					(781)
IT Support	-	-	(20)	(260)	(210)	(265)	300					300
Mountain Facility Support	-	-	-	-	-	(2,180)	(2,180)					(2,180)
Building Lease	-	-	(900)	189	189	189	189					189
Tucson & MoMP Operations	(241)	(506)	(526)	(338)</								

Steve's Nobel Prize worthy invention: Quantum Accounting & The Quantum Dollar

