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!



OXFORD SERIES IN OFFICAL AND IMAGING SCIENCE

Adaptive Optics for Astronomical Telescopes

JOHN W. HARDY

Hardy 1979 at Sac Peak The first on-sky AO experiments

- In 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&Dunn1993)

- I9 element Shack-Hartmann WFS
- 19 element segmented mirror
- Worked on pores only

DST AO w/correlating SHWFS

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





NSO AO at Sac Peak

4. Wellenfrontmessung mittels optischer Differentiation







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

(b) Horizontale Maske für z-Richtung. Entspricht der horizontalen Ableitung des Referenzbildes von

rechts nach links.

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

(e) Ouasibināre 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)
- (von der Luene 1766)
- 61 actuator continuous faceplate DM

Lockheed AO system (Acton&Smithon 1992, Acton&Dunn1993)

- I9 element Shack-Hartmann WFS
- 19 element segmented mirror
- Worked on pores only

DST AO w/correlating SHWFS

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



Lockheed AO - at Sac Peak and Teneriffe



Comelation Tracker Celebration July 1988 J. Christou Dick Ouna Phil wibers charles milter Domenico Thomas Riam ele Oskan

... 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&Dunn1993)

- I9 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
- 97actuator 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



AAS 1999

Diffraction Limited Images fed to Horizontal Spectrograph at the DST (D=76cm).

Results

- 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: 10 sec exposure



0.0 0.7 1.4 2.1 2.8 3.5 arcsec



LOAO – first system based on correlating SHWFS



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

> Star Image PSF (Th. Factors)





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!!





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!

1			Table	8.4-2. Detail	ed Long-R	ange Budget Es	timates		Long F	Range Plan				0.001					0	.105263	0.894737				
	TV & in the sector	FY14	w. Total Pa	FY15	Total Pagesi	FY16	FY17	FY18 Factor Total				EV40	EV42	EVAA	EVAE	EVAC	EV/47	EV40	EV40	FY1	19				_
	NSO HQ	- spon woor	1 104 11	and some of	1000 1000		apor sorrage total	- Internet and the	Direct	tors Office	_	405	358	329	476	890	850	620	660	NISP	AISI	cility Par	nn-down		Ĺ
	Director's Office HQ Development + Relocation	462 3 65 1	3 495 9 74	468 33 98 702	501 480 800 112	190 670 800 912	490 240 730 466 466	495 100 595	HQ D	evelopment +	Reloc	22	22	44	770	875	460		-			chity Ran	np-down		Ĺ
	HQ Lease and Utilities Administrative Support			825 120 60	825	830 830	834 834 500 80 580	838 838 550 80 635	HQ Le	ease and Utilit	ies			-	800	1,050	1,050	1,150	1,200	72	633				1
	Science Staff								Scien	ice Staff				-	180	510	600	000	095	15	022		-		1
	ATST Fellow			120 21	141 120	7 127	1,210 199 1,399	1,220 195 1,415	AT	ST Science St	aff	120	284	482	541	814	1,395	1,415	1,500		1,500				1
	Synoptic Science Staff Data Canter Software Computing			450 320	770 1 220	1.640 2.860	501 45 546	510 50 560	AT	ST Fellow				-	141	127	-	-	169		169				1
	Instrument Program/Maintenance			280 111	391 531	200 731	895 400 1,295	1,270 596 1,866	Syr	noptic Science	Staff				600	4 000	546	560	570	570	4 207				1
	EPO			200 20	220 220	30 250	230 30 240	235 30 265	Instri	Center - Soltv Program/Main	tenance				500	1,800	2,500	2,700	2,080	219	1,387				1
	Budgeted Indirects Total HQ	527 4	(166)	197 2,172	4,344 3,963	3,891 7,454 1	5,577 4,778 10,355	6,080 4,509 10,589	IT Su	pport					100	540	550	470	390	41	349		-		1
	ATST Maul Operations								Synop	ptic Operation	s					-	800	830	850	850					1
	Science Staff Supporting Ops Operations Staff			150 40 140 40	190 225 180 220	42 267 34 254	300 70 370 350 90 440	950 130 1,080 700 170 870	EPO					-	250	360	300	300	300	32	268	-	-		1
	Administrative Support Engineering/Technical Support			110 30	140 200	60 260 142 462	210 70 280 750 560 1.310	450 120 570 1,400 820 2,220	ATST	Operations															1
	Computing/DataIT			100 70	170 250	200 450	275 340 635	325 600 925	Sci	ence Staff sup	porting Ops			-	190	267	370	991	1,473		1,473		-		1
	Remote Ops Building (ROB) Lease			884	884	897 897	910 910	924 924	Op	erations Staff				-	180	254	440	730	794		794		Original NSO	0&M	1
	ROB Utilities/Taxes/Insurance Total Maui Ops		_	500 1,214	150	152 152	155 155 1.885 2.215 4.100	157 157 3.825 2.921 6.746	Adi	min n/Technical					140	260	280	2 220	2 906		2 906				1
	NSO/Tucson								ITS	Support					170	450	760	960	620		620		NSF Planned	ATST U&M	1
	Scientific Staff Software Support	234 1	247 7 7	241 13	254 35	3 38			Mo	untain Facility	Support			-	÷	÷		÷	2,024		2,024			0&M	1
	Instrument DevelopmentMaint.		3 3		3 4				Bui	ilding Lease				-	900	900	900	900	900		900				1
	Administrative Support	~	• ~	•z •			21 12 20		Tucson	& McMP Oper	ations	565	290	293	288	130	-		-						1
	Miss. Revenue Total NSF Tucson	316 3	(84)	503 28	258 76	16 92	21 12 33		NISP			4,043	3,366	3,418	2,937	2,006	-	-	-				-		1
	NSONSP Scientific Staff	1 275 5	4 1 1 22						Sac Pea	ak	D	2,623	2,160	1,994	2,181	2,125	1,412	790	-						1
	Software Support	1,038 10	17 1,144 1,	123 106	1,229 800	100 900			General	NOAO Supp	Bonuses	960	1 1 1 0 0	1 100	1 100	1 200	1 297	1 100	1 000	105	895		-		1
									Utilities	on Kitt Peak		80	60	80	80	40	-	-	-	105	000				
Long Range F	Plan		0.0	001					AURA N	lanagement F	9e	282	260	260	386	440	480	504	596	63	533				
										Total NSO	Costs (after revenues)	9,100	8,000	8,000	13,000	16,000	17,500	19,500	21,000	2,110	17,024				
			FY	(14	FY15	FY18	EY17	FY18	FTIRE	NISI	Directory Office			/8.01		751	(282)	(414)		261	(25)	FT18	A181	syn MED	
Directors Offic	e		33	28	478	670	730	695	680		NO Developmen	t e Reloo		(20)		400	(1 656)	(1.020)		76	(00)	(155)	100	(40)	
HQ Developm			44	770	875	460				HQ Lease and U	fillfies		(50)		+	(350)	(350)	ä	601	(340)	(380)	(25)	0 (128)		
HQ Lease and Utilities					760	780	810	820	845		Admin						(180)	(110)		601	(180)	(188)	(125	(83)	
Admin	Admin				180	310	580	630	640	87	Solence Staff						1.1.1	1			1	1.1.1			
Solence Staff											ATST Solence	Staff		120	2	84	0	(132)	15	241	65	(39)	(35		
ATST Solen	on the		47	79	644	784	1 195	1 415	1 741		ATST Fellow				- 7	1.61	rian	14	10			(00)	100		
ATST Fellow			-		141	197	1,000	1,414	1,1 41		Synoptic Sole	noe Staff							0	681	(382)	(453)		(453)	
Superile Se	lance tintf		-				6.40	600	670	670	Data Center - 8	offware/Co	mouting				(124)	(180)	4	22	1.284	2.026	1.357	889	
Data Center	Roffware/Computing	-			770	2 810	9 449	9 590	9 160	220	Instr Program/M	aintenano					(500)	(429)	0.	139)	(590)	(267)	(178	(88)	
Instr Brogram	Walotenance	•	-		911	2,010	1 295	1 9 9 9	2,100	277	IT Support							#REF!	#8	EFI	#REF!	#REF!	#REF!	#REF!	
Synophic Oper	rations		-				800	830	850	860	Synoptic Operat	tions							(1.)	910)	(300)	(394)	-	(384)	
EPO					220	250	200	200	200		EPO						(350)	(140)	0	5)	(10)	(35)	(23	3) (12)	
EFU			-		220	200	200	200		92										-			#REF!	#REF!	
ATST Operativ	one										ATST Operation	6													
Solence Sta	ff supporting Ops				190	287	370	991	1.085		Solence Staff	supportin	g Ope				(170)	(2)	0	03)	(490)	(482)	(482	2)	
Operations	Staff		_		180	254	440	730	888		Operations St	afr					(140)	31	<i>a</i>	86)	(120)	(64)	(84	4)	
Admin	o com				140	280	280	670	719		Admin						(140)	(120)	0	5)	(290)	(153)	(153	s)	
Eng/Technik	oal					482	1,210	2,125	2,680		Eng/Teohnica	d .						(153)	(5	18)	(590)	(781)	(781	0	
IT Support					170	450	835	825	877		IT Support						(20)	(260)	(2	10)	(265)	300	300)	
Mountain Er	a lithe Support								2 018		Mountain Fao	liity Suppo	ort				-					(2,180)	(2,180	0	
POP	some support		-		1 099	1 099	1 099	1 099	1 099		Building Leas						(900)	189	10	59	189	189	188		
ROB Utilitie			-		100	100	100	105	105								-						(3,171)	
NOD GUILLE	•					100	100	100			TUOSON & MOMP O	perations		(241)	6	06)	(526)	(338)	a	60)			#REFI	#REFI	
Tuoson & MoMP	Operations		25	93	288	130	39		.		synoptic			(89)		190)	(977)	(1,009)							
NISP			3.4	18	2 937	2 000	-	-			sao Peak			(315)	/ (8	100)	(829)	(360)		,	0				
San Peak			2.0	03	2,007	2,006	1 412	790			General NOAC Av			/201		22	60								
out room		Bonuses	2,00			2,120	1,412	100	-		Utilities on KI# Pa	PP tak		(20)		281	(10)	(13)		101	20	0			
General NOAO a		1.10	00	1,100	1,100	1,100	1,100	1.000	105	AURA Managemer	nt Fee		(14)		45)	(148)	(94)		8)	(54)	(92)				
Utilities on Kitt	Peak			80	80	40	20				Total NSO Co	osts (after	revenued	(691)) /2	090)	(7.390)	(6.000)		0	(1.500)	(2.521)			
AURA Managem	ent Fee		2	80	386	440	480	604	660	68															
Total	NSO Costs (after re	venues)	8,0	00 1	3,000	16,000	17,500	19,500	21,000	2,187										_					
														1											

			I							Curren	t Coop Agre	ement		Perio	d Covered I	by next Coo	p Agreemer	it .
									FY2010	FY2011	FY2012	FY2013	FY2014	FY2016	FY2018	FY2017	FY2018	FY2018
	Curre	nt Coop Agr	reement	Per	lod Covered	by next Coo	p Agreen	NSO Base OSM	9 100	9 100	9 100	8 000	8 000	8000	8 000	4 000	4000	
	FY2012	FY2013	FY2014	FY2016	FY2018	FY2017	FY2018	ATST OAM	0,100	0,100	0,100	0,000	5,000	8.000	11,000	14,000	18,000	
								Total	9 100	9 100	8 100	8 000	13,000	17,000	19.000	18.000	22.000	
NSO Base O&M	8,100	8,000	8,000	8000	8,000	4,000	400	10121	0,100	0,100	0,100	0,000	10,000		10,000	10,000	22,000	
ATST O&M	-	-	6,000	9,000	11,000	14,000	18,000											
Total	8,100	8,000	13,000	17,000	18,000	18,000	22,000	Outyear Numbers in orginal NSF Project	on	FY2011	FY2012	FY2013	FY2014	FY2016	FY2018	FY2017	FY2018	
								NSO O&M		8,610	8,780	10,090	10,390	10,000	8,000	4,000	4,000	
								ATST OBM		-	-	-	6,000	9,000	11,000	14,000	18,000	
Outyear Numbers in orginal NSF Projection	FY2012	FY2013	FY2014	FY2016	FY2018	FY2017	FY2018	Total		8,610	8,790	10,090	16,390	18,000	19,000	18,000	22,000	
NSO O&M	8,790	10,090	10,390	10,000	8,000	4,000	4,000											
ATST O&M	-	-	6,000	8,000	11,000	14,000	18,000	deltal		(410)	(890)	(2,090)	(2,390)	(2,000)	0	0	0	
Total	9,790	10,090	16,380	19,000	18,000	18,000	22,000											
deital	(690)	(2,080)	(2,390)	(2,000)	0	0	0											

se O&M	9,100	8,100	8,100	8,000	8,000	8000	8,000	4,000	4000	
8.M	-	-	-	-	6,000	8,000	11,000	14,000	18,000	
Total	8,100	8,100	8,100	8,000	13,000	17,000	18,000	18,000	22,000	
Numbers in orginal NSF Project	on	FY2011	FY2012	FY2013	FY2014	FY2016	FY2016	FY2017	FY2018	
NSO O&M		9,610	8,790	10,090	10,390	10,000	8,000	4,000	4,000	
ATST OBM		-	-	-	6,000	8,000	11,000	14,000	18,000	
Total	-	9,610	9,790	10,090	16,390	18,000	19,000	18,000	22,000	
		(410)	(890)	(2,080)	(2,380)	(2,000)	0	0	0	

	٨	в	C	D	E	F	8	н	1	J	K	L	M	N	0	P	0	R	8
3			2014			2015			2016			2017			2010			2019	
4	EV (5 in the mandal	Descell	NonDay	Total	Descell	NonDay	Total	Descel	NeeDev	Total	Descoil	No.0	Total	Paural	NonDay	Total	Descell	NonDay	Total
-		- aprox	101110	10.00	- aj tat	and the set	TOBE		100.00	100.00	- Agrica	Later of	10.00		and the set	100.00	- Agrican	and a set	10.00
H÷-	100.00			-	_						<u> </u>								
-	Noong												-						
1	Directors Office	402	33	496	400	33	501	400	190	670	490	240	730	400	100	596	500	60	560
8	HQ Development + Reloc	36	9	-	70	700	770	75	800	875		400	400						
9	HQ Lease and Utilities					750	750		790	790		810	910		820	\$20		945	946
10	Admin				120	60	190	250	80	310	600	00	520	660	00	630	560	00	640
11	Science Staff																		
12	ATST Science Staff				401	90	641	660	114	764	1,200	195	1,395	1,220	195	1,415	1,500	174	1,741
13	ATST Fellow				120	21	141	120	7	127									
-14	Synoptic Science Staff										601	45	546	610	60	500	620	S	670
15	Data CenterSoftware/Computing				450	320	770	1,170	1,640	2,810	1,201	2,193	3,449	1,200	2,010	3,590	1,300	950	2,150
16	Instr Program/Maintenance				200	111	311	401	200	601	995	400	1,295	1,270	606	1,006	1,000	1,005	2,636
17	Synoptic Program										500	300	900	620	510	830	550	300	860
18	DP0				200	20	220	220	30	250	230	30	260	235	30	265	205	35	300
19	Budgeted Indirects			(100)			(26)												
20	Total HQ	497	42	373	2,009	2,095	4,150	3,426	3,051	7,277	6,677	4,740	10,325	6,000	4,491	10,571	6,963	3,429	10,291
21																			
22	ATST Maul Operations																		
23	Science Staff supporting Ops				150	40	190	225	42	267	300	70	370	001	110	991	956	130	1.005
24	Operations Staff			_	540	40	100	220		254	350	90	440	600	100	730	660	200	000
2	Admin			-	110	30	140	200		260	240	20	200	450	120	670	647	102	710
1	EnglTachaical			-		~		100	140	462	200	640	1 210	1.540	705	2 4 26	1005	654	2,500
- 27	Computing Data 17			-	100	70	170	350	200	450	276	340	67.6	100	600	006	373	304	
-	Company Caracter	_		_	144	14	110	-	200			-		-				-	
-20	Mountain Facility Support				_						<u> </u>							2,016	2,016
	ROB LASS				_	1,089	1,009		1,000	1,009		1,009	1,009		1,005	1,009		1,009	1,009
	HOL CEIDE I DIEDITEURIO					100	100		100	100		100	100		100	100		100	100
31	Total Maul Ops				500	1,309	1,009	1,215	1,007	2,002	1,835	2,299	4,124	3,096	2,939	6,536	4,531	4,019	9,149
- 54					_														
33	NSO/Tucaon																		
34	Scientific Staff	204	26	290	241	26	207	36	1	30									
35	Software Support		15	13		13	13		13	13									
36	Instru Devel/Maint		6	6		5	6												
37	Telescope Ops	82	17	90	63	12	76	65	13	73	27	12	30						
38	Admin																		
- 39	Mac Revenue			(14)			(73)												
40	Total NSF Tucson	516	61	295	505	55	200	100	29	130	27	12	59						
41																			
42	NSO/NISP																		
43	Scientific Staff	1,276	54	1,329	833	40	001	660	44	694									
44	Software Support	1,008	107	1,166	1,123	106	1,229	900	100	900									
45	Instru Devel/Maint	472	159	601	443	196	639	200	100	300									
46	Telescope Ops	93	326	420	333	190	613	350	75	425									
47	Admin	219		279	61		61	63	10	72									
48	Indirects Carryover																		
49	Mac Revenue			(305)			(305)			(305)									
50	Total NISP	1,097	706	3,412	2,792	630	2,937	2,063	329	2,006	-								
51				-							<u> </u>								
52	NSO/SP										<u> </u>								
63	Scientific Staff	700	41	741	401	41	612	204		476	250	30	200	-					
1	Sel Support Comput	207		323	244	405	350	264	110	361	47	40	277						
66	Instru Devel Maint	672		607	500		624	500		643	00	40			~				
66	Talascore One	244	20	220	241	34	267	240	27	275	200	34	206	400	-	140			





FY13 - \$8.0M

Program Flat	6	0	-	0		-	-	5		0					2					- 40	K
77.3 # Faseria	Tage of	22		Tagent	101 bally	144	Taged)HH had y	144	Tapal	211 Safe	10	Page 1	and Sealing	100	Tapa	27.,		Paged	21	14
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Steve's Nobel Price worthy invention: Quantum Accounting & The Quantum Dollar



