Funding for Adaptive Optics in the US:
An Overview (060614)

(revised since presented at ACCORD)

Prepared for the ACCORD Meeting
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Purpose

- 2005 September ACCORD meeting:
  - Richard Ellis proposed that ACCORD give NSF strong arguments in support of AO funding in addition to what Gemini and the AO centers receive now.
    - Secondarily, ACCORD asked can successful proposals for AODP be encompassed within TSIP?
- This presentation presents an overview of the funding situation in the US and a comparison with ESO.
- My presentation last year gave the science case for AO.

Outline

- The Historical context
  - Decadal Surveys
  - AO Roadmaps
- Major sources for AO funds
- Major recipients for AO funds
- Are we meeting recommended goals?
- How do we compare with ESO?
- Addenda
  - Listing of individual NSF PI grants for AO R&D and Implementation 1995-present
  - AODP details
  - Other funding details

Acknowledgements

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  - Mike Bolte – Lick, TMT
  - Andy Pickles – Palomar
  - Norbert Hubin, Tim deZeeuw – ESO, OPTICON
  - Doug Simons, Jean-Rene Roy – Gemini
  - Jeremy Mould, Todd Boroson – NOAO
  - Tom Rimmele - NSO

Decadal Survey Reports - 1

- Bahcall Report (1990s)
  - "*The highest priority* [moderate program for ground based astronomy] *is to apply technologies collectively called adaptive optics*."
  - *"… adaptive optics techniques be developed and implemented on existing and planned large telescopes such as … the new generation of 8- and 10-m telescopes."*
  - The Report recommends implementing AO on existing solar telescopes and on LEST (the antecedent of ATST).
  - The recommendation is to spend $35M over next decade on AO.
  - Support is requested for both R&D and science instruments with no recommended fractional split.

Decadal Survey Reports - 2

- **McKee-Taylor Report (2000)**: *"The large size of GSMT means that substantial advances in …adaptive optics will be required."*
  - In the Panel Reports (but not in the main report):
    - *"The utility of a 30-m or larger aperture telescope depends crucially on its near-diffraction limited performance, particularly in the 1 to 25 μm range."*
    - *"…the AO effort associated with the development of GSMT should be funded at $5M per year for the next 10 years."*
    - *"The AO development work will also greatly help existing large telescopes by … allowing them to work at the diffraction limit at shorter wavelengths and thereby increasing their scientific power."*
  - AODP established as a result of the recommendation above.
    - Initially emphasis is on AO R&D for a GSMT, not instruments.
  - TSIP should bring AO instruments to private observatories to make this technique available to all astronomers on the largest telescopes.
  - AO implementation on solar telescopes
  - The main report does not explicitly call for nor prioritize an AO program.

NSF AO Roadmap (2000)
Basis and Targets for AODP Support

- Allocation of new funds reserved for AO technology development:
  - Robust and scaleable laser systems
  - multiple approaches to deformable mirror implementation
  - low-noise, rapid readout detectors for wavefront sensors
  - techniques for atmospheric tomography, MCAO, and wavefront prediction
- Innovative development projects with high potential payoff
- Key goal: ensure needed AO capability for a GSMT (>30M)
- Provide technical advances to support greatly improved performance of AO on existing telescopes.
- Review and update roadmap periodically – costing and prioritization
- Focus is on technology and proof of concept demonstrations (development), *not* science instruments (implementation).
- AODP based on this roadmap TSIP cannot pick up slack (see Addenda to this presentation)

NSF AO Roadmap (2004) Addendum

- Major 2004 recommendation: alter the balance between component development and system concept verification
  - Current AODP funding inadequate to support major investment in both.
- Next AODP solicitation should emphasize in priority order:
  - Concept validation of AO systems critical to current design efforts and associated technologies required (eg. GLAO, MCAO, MOAO, ExAO, MEMS, DMs, etc)
  - Low cost risky systems with high payoff potential
  - Engineered components or subsystems necessary for the next generation of AO systems.
  - Education and training of the next generation of AO scientists
- Only one round of AODP funds have been awarded (2003)
- Second round in 2004 following addendum recommendation cancelled by NSF after proposals solicited, reviewed and ranked
- For FY 2007 NSF budget has a request for ~$1.5M of new funds

Primary Avenues for AO funding from NSF

- Standard NSF peer reviewed grants: $22.6M since 1995
  - Nearly all through MRI and ATI programs (AST & ATM)
  - Data for 2006 is incomplete
  - Does not include funds moved through TSIP, AODP, or CfAO
- AODP: Flow-through via NOAO for NSF/AST funds
  - Peer reviewed proposals open to all
  - ~$8M in 2003 for multi-year grants – 6 awarded
  - Budget zeroed out for new starts in 2004, 2005, 2006
  - May be $1.5M new funds for FY07.
- TSIP: Flow-through via NOAO for NSF/AST funds
  - Peer reviewed, restricted to private observatories with telescopes of 3-m or greater aperture.
  - No R&D, just new instruments and upgrades to existing ones
  - Only one AO instrument so far: $2.75M for OSIRIS on Keck

Primary Avenues for AO funding from NSF - 2

- CfAO: Flow-through for funds from NSF Centers budget.
  - Peer reviewed, restricted to researchers at member institutions
  - $4M/yr for 10 years, ~ $2M/yr for astronomical AO applications
- Gemini: a fraction of NSF's contribution for observatory ops and instrumentation goes to AO activities at Gemini
  - For period 1995-2009 average ~$1.7M/yr from NSF for AO; an equal amount comes from the international partners' share (50%) of observatory ops and instrumentation.

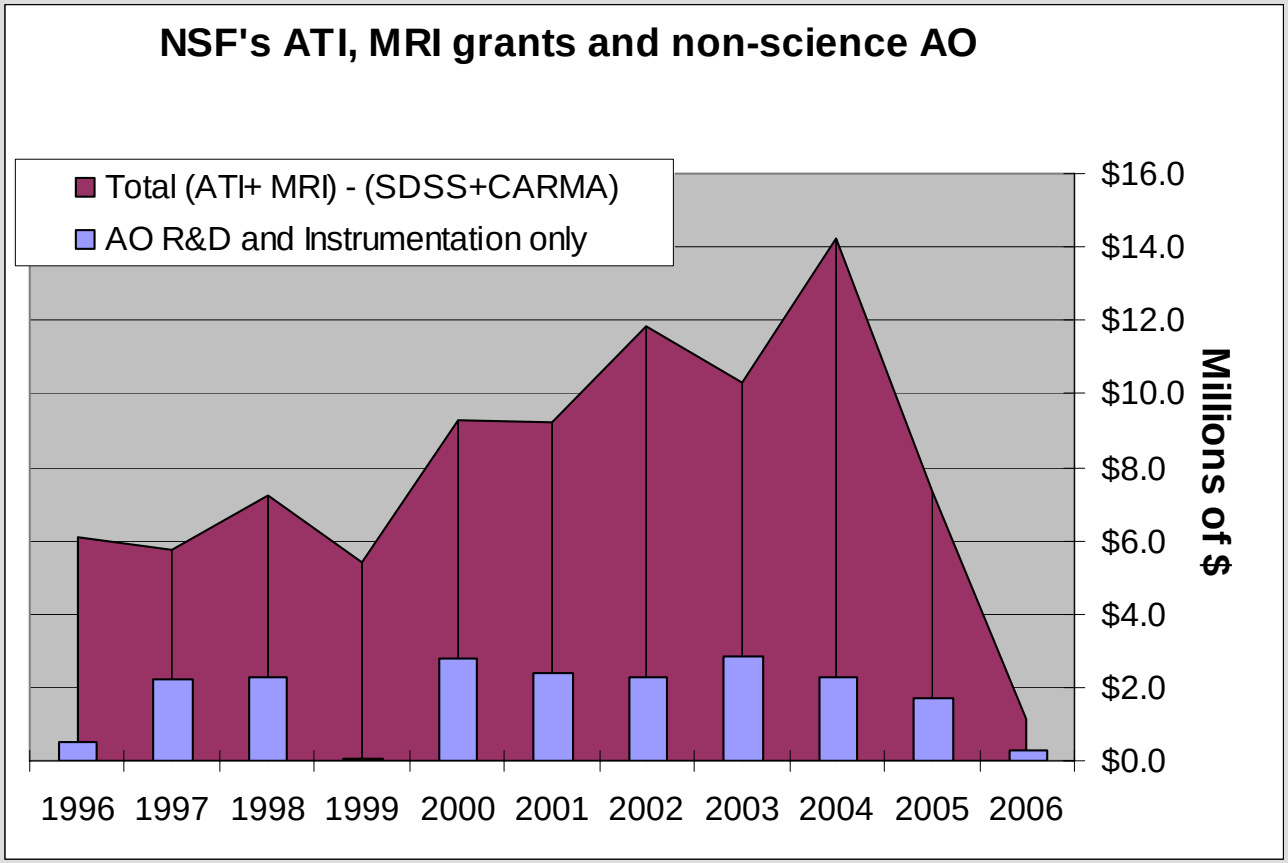
Summary of AO related awards in NSF's ATI, MRI and other PI grants programs

- Awards that support AO astronomy related activities: R&D and construction of AO instruments.
- Awards primarily supporting science observing not included.
- One ATM division MRI award for solar AO development
- See Addenda for details
- **Caveats**:
  - 2006 data incomplete

	ATI MRI only		Other programs	
Year	# AO awards	M $	# AO awards	M $
1996/5	2	$0.512	2	$.709
1997	3	$2.246	0	0
1998	4	$2.285	0	0
1999	1	$0.071	0	0
2000	4	$2.797	0	0
2001	3	$2.378	2	$0.430
2002	5	$2.295	2	$0.238
2003	4	$2.852	1	$0.100
2004	2	$2.288	1	$1.241
2005	2	$1.692	1	$0.266
2006	>2	>$0.258	?	
Total	**32**	**$19.61**	**9**	**$2.984**

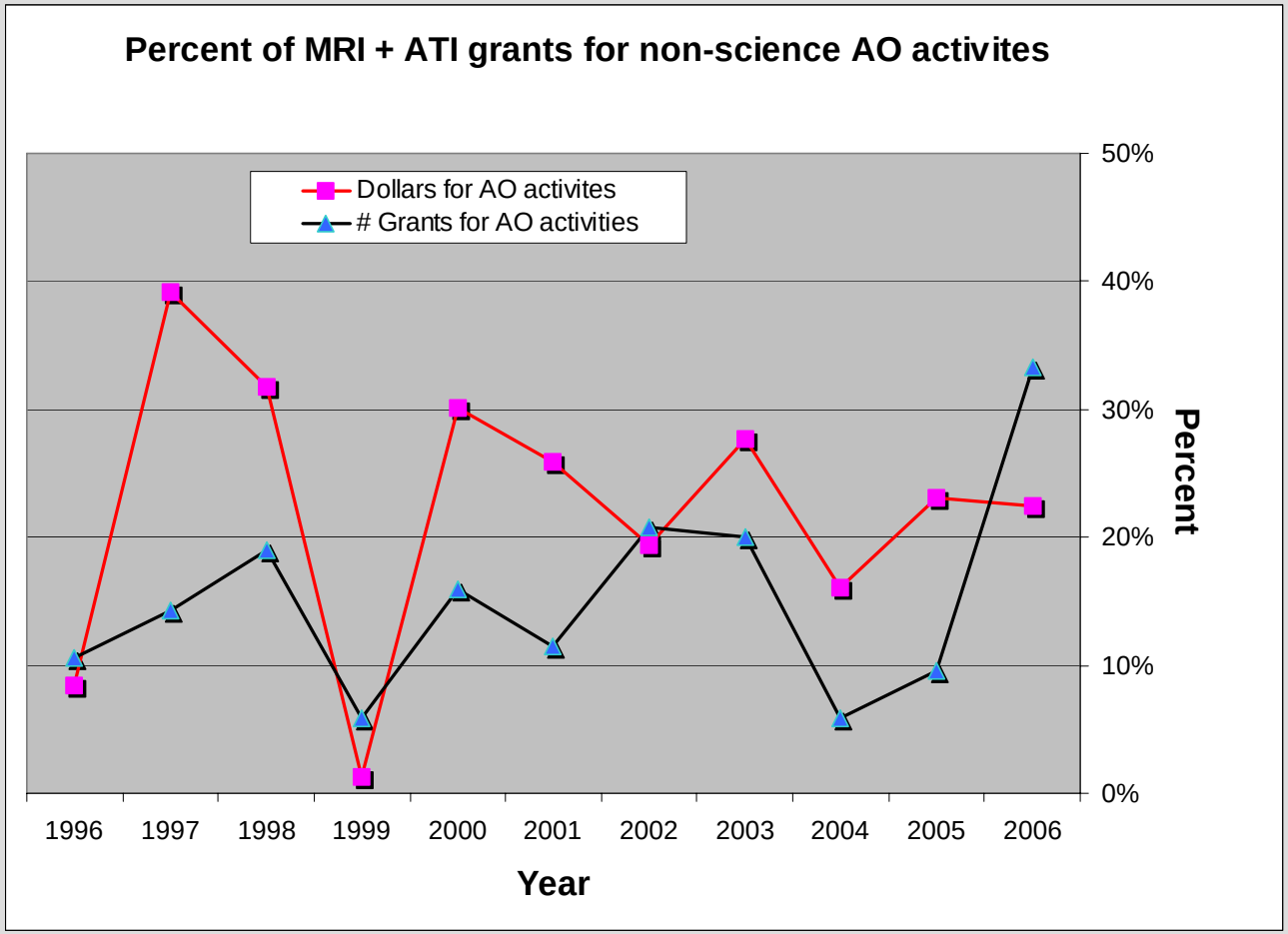
Total ATI, MRI monies and Amount to AO R&D and Instruments (non-science)

Note the sharp drop from 2004 to 2005. Not clear if 2006 will be better



Fractional ATI, MRI funds and grants to AO

~25% of MRI+ATI funds go to AO R&D and instrumentation (non-science). This has been ~ constant except for 1999.



AO related awards in NSF's PI grants programs: Major Recipients (1995-2005)

Institution:	# Awards	Amount	% of Total
U of A	7	$6,067,321	27%
U of H	6	$5,921,295	26%
AMNH:	4	$2,364,045	10%
NJIT	3	$2,186,630	10%
PI	**# Awards**	**Amount**	**% of Total**
Ftaclas	3, UH, MTU	$3,009,987	13%
Oppenheimer	4, AMNH	$2,364,045	10%
Lin	1, UH	$1,978,755	9%
Angel	1, UofA	$1,898,586	8%
Rimmele	1, NJIT	$1,821,322	8%
Lloyd-Hart	3, UofA	$1,791,435	8%
Close	1, UofA	$1,280,516	6%
Simons	1, Gem	$1,241,000	5%
Thompson	1, U Ill	$1,228,138	5%
Kibblewhite	1, U Ch	$1,161,843	5%

- This table examines the distribution of funds for the 41 AO R&D and instrumentation grants in the NSF PI programs considered for 1995-2005 (see addenda).
- NSF PI grants awarded in AO are concentrated:
  - 20 institutions have been recipients of 40 grants for AO work; 63% of the funds have gone to 3 of these.
  - 32 different PIs have been recipients of these 41 grants; 57% of funds have gone to 6 PIs
- This table does not include funds dispersed by Gemini to US institutions to build Gemini AO instruments and sub-systems (eg, FLAMINGOS-2, NICI)

AO related awards in NSF's PI grants programs: Major Recipients 1994 and earlier

- Between 1990 and 1994 there were several major NSF awards for AO R&D and instrumentation:

PI	# Awards	Inst.	Total
Roddier	2	UH	$1.77M
Kibblewhite	3	U Chi	$4.17M
Thompson, L.	2	U Ill	$3.81M
McCarthy	1	UA	$1.05M

AODP (from NOAO data)

- NOAO funded 6 of 17 AODP proposals in 2003: $8.5M
  - Detailed list at end of presentation
  - All but one were multi-year efforts with funding profile in table.
- For 2004 submitted proposals were ranked but not funded because no new NSF funds to AODP.
  - List is at end of presentation
- In 2006 NSF announces $1.5M in new funds (start in 2007?)

Year	2004	2005	2006	2007	2008
Award Obligations	2,461,000	2,053,000	1,492,000	1,527,000	431,000

The CfAO

- Established in 1999 as a NSF Science and Technology Center with a $20M 5-year grant. Renewed for 2nd 5-year period at same level.
  - Has 11 member institutions (5 units of the UC system, Caltech, U of Chicago, Houston, Rochester, Indiana U., Montana State
    - Researchers at member institutions can apply directly for peer reviewed project funding.
  - Works closely with other labs and institutes (e.g. Gemini, NSO, HIA, Keck,) and industrial associates.
- Only two of its 4 main activities are astronomy related
  - AO for Extremely Large Telescopes (ELTs, Theme 2)
  - Extreme AO for planet finding (Theme 3)
  - Typical total budget for the astronomy themes is $2M/year

Major Recipients of AO funding from all sources

- Keck: ~$34M for ~1996-2009 from NASA, Keck Foundation, UC, LLNL, CfAO, NSF, AODP,
  - Does not include funding for AO related activities from these same sources to other UC units (eg, UCLA, UCSC, LLNL) for use on Keck
  - Does not include future instruments with unidentified funds
- Palomar: ~$10.4M in non-NSF funds, 2002 - 2009
- Lick: ~$4.5M from LLNL for AO on the 3m plus the laser
- TMT Project: $4.7M for AO studies 2004-2008. Moore Foundation
- UCSC: Laboratory for AO (LAO) for 2004 - 2009 with $9.1M in seed funds from Moore Foundation, mostly for R&D (MEMS, LGS, etc)
- Gemini Observatory: $55M (<1995 – 2009) from all partners ~half of which, $29.5M, is from US ($25M NSF, $4.5M NASA)
  - Includes future instrument with identified funding - ExAOC
- CAAO/U of A: From AFOSR and from NSF: $13.2M since 2001
- Others? AO funding not examined for IfA, MMT, LBT, Magellan, HET, SOAR ...

AO at Keck Observatory - Summary

- Sources of funding of AO at Keck (total for 10 years):
  - Keck Foundation: $8.3M, 24%
  - UC Operating monies: $12.85M, 38%
  - NSF (ATI, MRI, AODP, TSIP): $6.65M, 20%
  - NASA: $5.1M, 15%
  - CfAO: $0.3M, 1%
  - LLNL: $1.1M, 3%
- Total on AO at Keck for R&D, systems, and instrument: 1996 – 2008 ~$34M, or $2.62M/year
- Total minus (NSF, CfAO) to give only “non-public” funds: $27.05M, or ~$2.1M/year.
- Breakdown slide in Addenda

AO at Palomar Observatory

- Sources of Funding for AO and LGS development :
  - Caltech gifts, budget for ops and instrumentation, and from partners – JPL, Cornell
  - NSF (U Chi, Kibblewhite, Dekenny), CfAO, AFOSR grants
  - U Oxford for SWIFT ($2.3M, 2005-2008)
- For 2002-2009 non-NSF funds received and projected in support of AO R&D and instruments at Palomar are ~$10.4M with a strong ramp up beginning in 2005.
  - Most of these funds are from Caltech Ops, gifts, and partners.

AO at Gemini Observatory

- Gemini is an international partnership ***only half of the expenditures listed below (with exceptions noted) are US/NSF***
- Over the past 10 years Gemini has spent $55M on AO activities :
  - MCAO system for Gemini South - $17.1M
  - ALTAIR for Gemini North - $7.0M
  - Other related AO expenditures (R&D, etc) - $0.9M
  - From NASA (all US): $4.5M to build NICI (UH Hilo, prime)
- Gemini spent $150K (half from US/NSF) to modify and operate Hokupa'a-36 as a visitor instrument on G-N.
  - K-36 was built with ~$800K in NSF funds to UH, originally for use on CFHT
- Two AO exclusive instruments will come on line shortly:
  - NIFS to be used on G-N, cost ~$3.0M
  - GSAOI to be used on G-S, cost ~$3.5M

AO at Gemini Observatory - 2

- ExAO Coronagraph for G-S: built by LLNL (prime), CfAO, et al.
  - CfAO pays for R&D and development of key broadly enabling technologies for ExAO (~half of MEMS DM work with GSMT applications, or $0.5M)
  - Gemini pays for ExAO***C*** as an instrument to go on telescope.
    - Cost for 4-5 years will be $19M to LLNL with $6M held in reserve at Gemini (only half of this is from NSF).
- Collaborative AO R&D on lasers for general use (in concordance with AO Roadmap):
  - Gemini/Keck collaboration on powerful lasers :
    - Contract with Lockheed Martin (also involves USAF)
    - NSF share of funds from ATI/MRI program
    - Gemini's share is $3.59M from partnership ($1.8M from NSF); Keck's is $2.81M from NSF
    - Gemini gets a 50W laser, Keck a 20W;
  - Small $600K NSF grant for Na laser technology risk reduction activities at CTI. Not Gemini specific – Gemini is a "flow through" for funding
    - Overseen by Jerry Nelson, Bob Fugate, Brent Ellerbroek

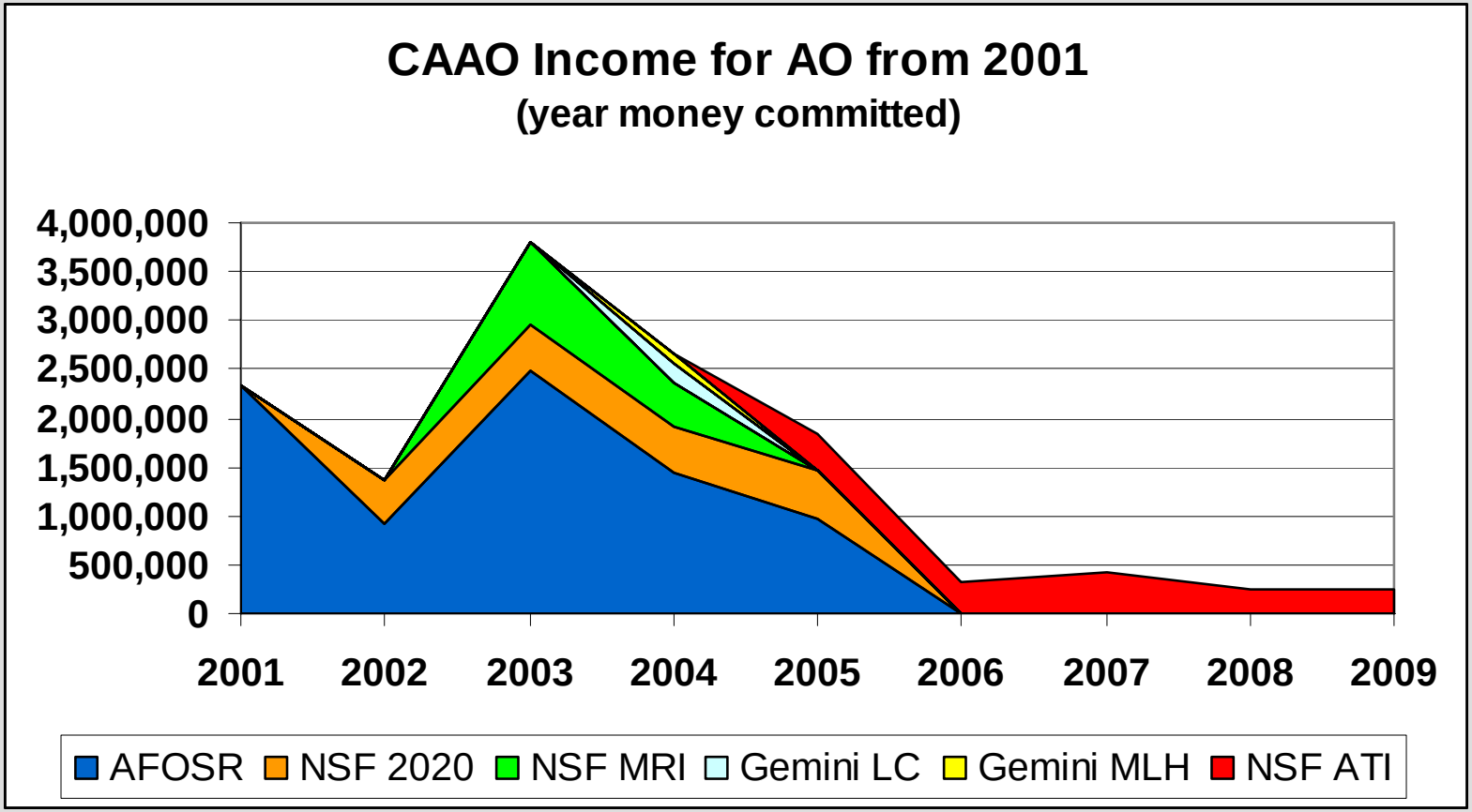
Univ. of Arizona - CAAO

- Founded in 1994 after a 3 year 1992 NSF seed grant of $1M
- Major source of funding is AFOSR - $8.2M since 2001
- Major broadly applicable R&D developments:
  - Development of deformable secondary mirror technology for AO (community has access via UA/Microgate team)
    - Deployed and operational on MMT
    - Nearing completion to both M2s on LBT
  - First multiple laser AO system was demonstrated on MMT
    - Both tomographic and GL wavefronts reconstructed.
- NSF funding: Since 2002, $3.9M AO specific PI grants
  - AO design for GMT
  - Adaptive secondary for the Magellan telescope
  - Partial support for development of multiple laser tomography.
- Support from AFOSR is ending in 2006.
- NSF monies are *peer reviewed targeted PI grants* for specific projects, not for discretionary spending as at CfAO.

CAAO details - 2

- AO funding goes to astronomical applications and training of grad students in astronomical AO
  - UA has excellent track record with students' future success
- On the following slide note the following:
  - Only half of 20/20 money was for AO – the rest was for investigating other aspects of twin 20m and single (GMT) GSMT concepts.
  - The Gemini awards to CAAO were small "CoDR" PI grants to investigate GLAO (PI Lloyd-Hart) and to develop an ExAOC (PI L. Close) concept. Both were "heavily subsidized" by CAAO.
  - Future of CAAO uncertain given significant drop in public peer reviewed funds available for AO.

CAAO details - 3

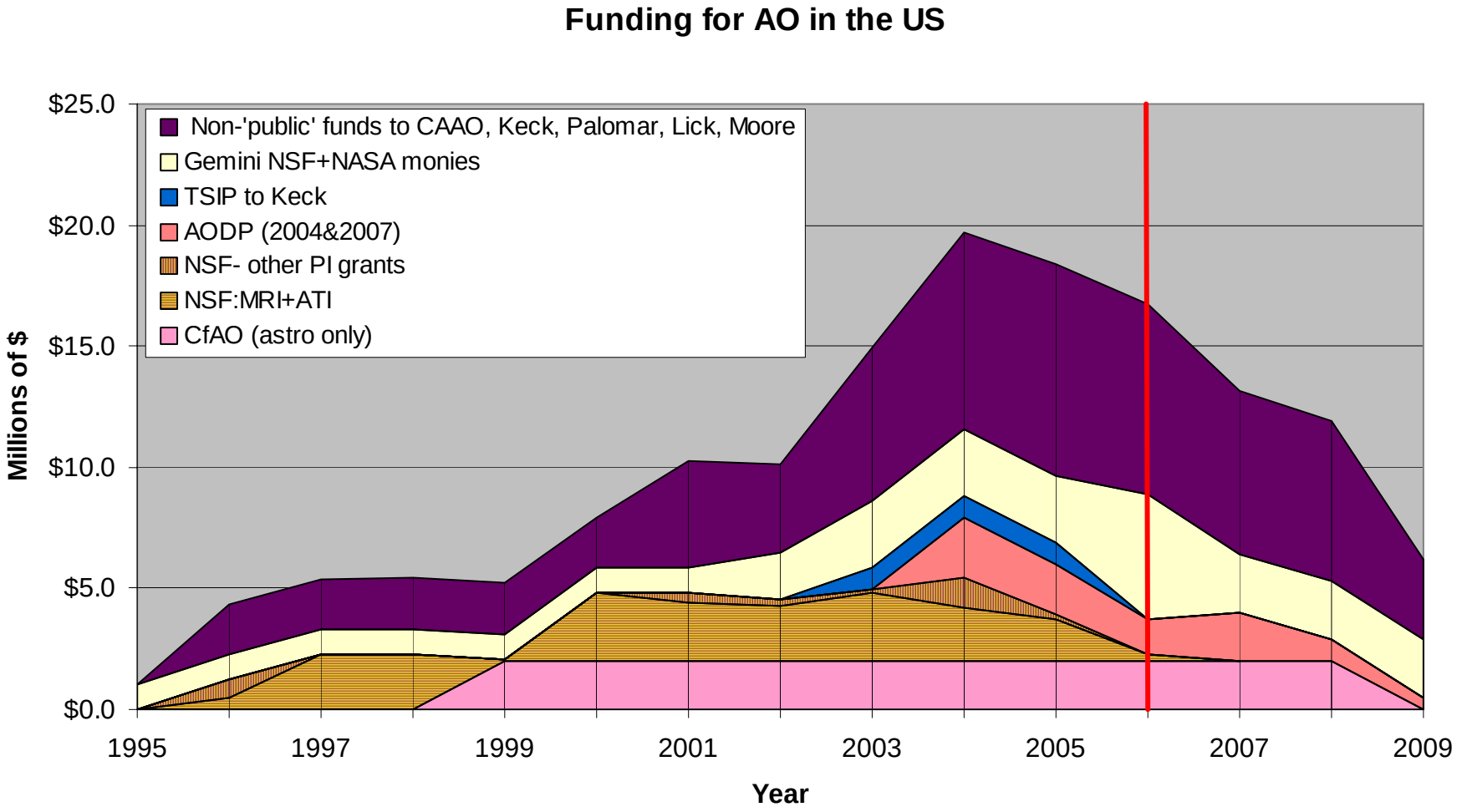


	2001	2002	2003	2004	2005	2006	2007	2008	2009	Totals
AFOSR	2,328,943	926,057	2,480,750	1,442,250	977,000					8,155,000
NSF 2020		449,997	471,625	482,741	494,223					1,898,586
NSF MRI			838,250	442,266						1,280,516
Gemini LC				200,000						200,000
Gemini MLH				101,300						101,300
NSF ATI					358,848	318,022	420,616	253,356	253,720	1,604,562
Totals	**2,328,943**	**1,376,054**	**3,790,625**	**2,668,557**	**1,830,071**	**318,022**	**420,616**	**253,356**	**253,720**	**13,239,964**

AO funding in the US - Summary

- The next slide summarizes the history of funding of AO in the US for R&D and instrumentation only. No science projects are included. Note the following:
  - Except for the “non-public” funds, all monies come directly or indirectly from NSF.
  - AODP money includes the $1.5M that is in the new NSF budget
  - In several cases I have used an average over time rather than actual yearly expenditures.
  - “Non-public” estimate is a lower limit as it only includes Keck, Palomar, Lick, LAO, TMT, and CAAO.
  - I have not been able to get detailed data from AFOSR beyond grants I already knew about.

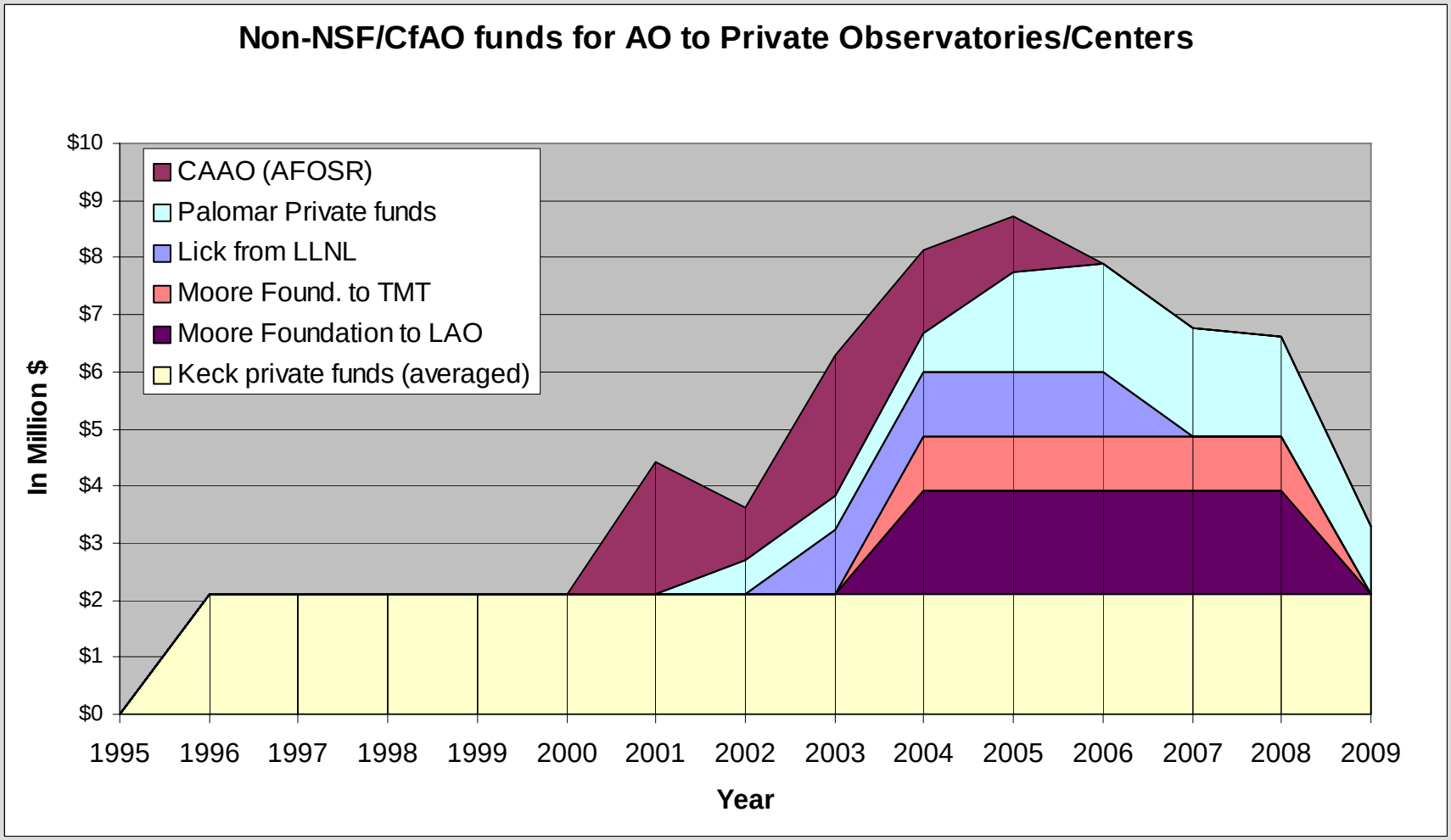
“Best estimate” of current AO funding in US



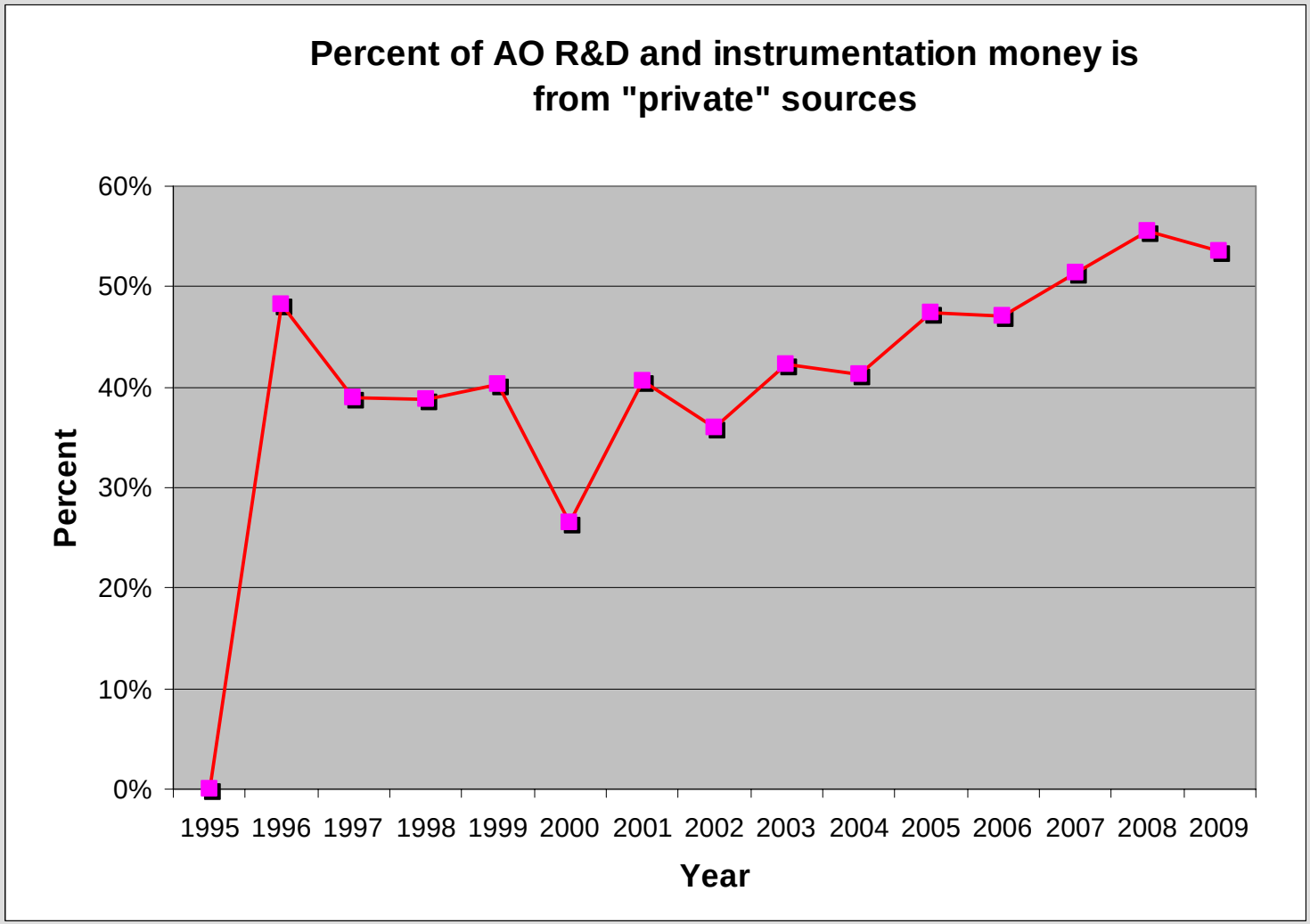
Non-NSF funds to Private Observatories

- The next slide shows data for the private observatories and centers for which I have data
- This plot represents funding sources that by and large are unavailable to the general community, for example
  - Univ. Calif operating funds
  - Keck Foundation
  - Caltech operating funds and gifts
  - AFOSR
  - LLNL
  - Moore Foundation

Non-NSF monies to the "Privates"



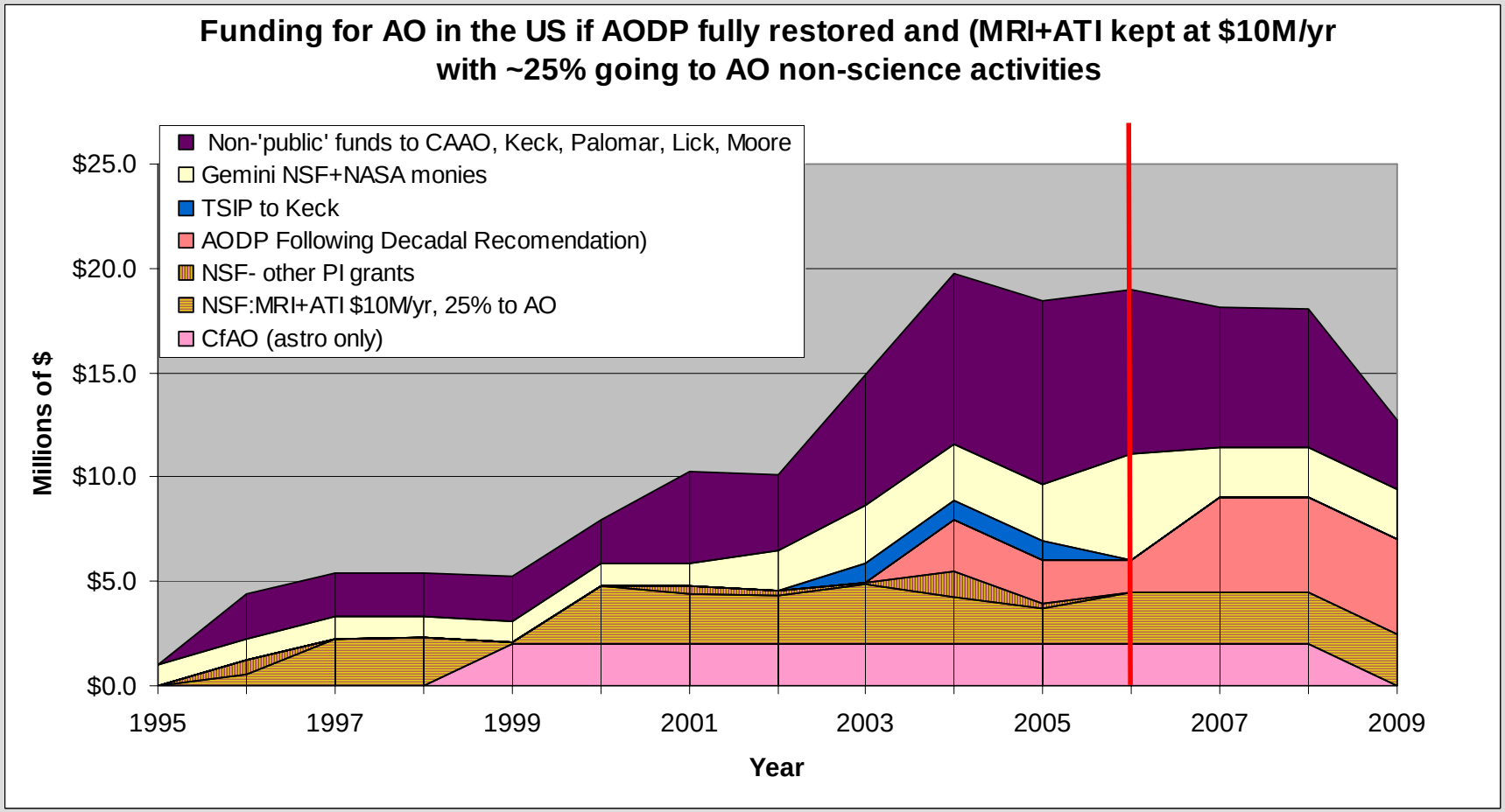
Private Funding now Accounts for more than 50% of all AO Funding:



AO funding with assumptions

- This is similar to plot showing actual funding for AO R&D and instrumentation with two differences:
  - AODP funding is at a steady state of $4.5M/yr as recommended by Decadal Survey starting in 2007
  - ATI & MRI funding is restored to level it was 2000-2004 of ~$10M/yr with amount going to AO R&D and instrumentation of 25% as it has been historically

If AODP and ATI, MRI fully "restored"



NSF AO Funding for R&D Compared with Recommendations

- The Recommendations:
  - Bahcall Report: Spend $35M on AO in the 1990s - $3.5M/yr
  - McKee-Taylor Report: Spend $5M/yr on AO R&D related to GSMT during 2000s.
- Reality – Public spending for AO R&D:
  - NSF PI grants for "non-science" AO:
    - $22.6M for 1995-2006 (data for 2006 incomplete)
    - $7.6M of this for R&D ($0.7M/yr)
    - $15.1M of this for instruments to go on telescopes ($1.4M/yr)
  - AODP - $8.5M (2004-2008) – average of $1.7M/yr for R&D
  - CfAO - $2M/yr for astronomy themes (1999-2009) – ~41% of this is for AO R&D based on years 6 and 7 of CfAO budget, so R&D, ~$0.8M/yr.
  - NSF/Gemini AO expenditures are almost all for instruments
  - AO R&D public average 2004-2006: $3.2M/yr; for 2000-2003 $1.5M/yr.

AO Efforts in Other Countries

- France and Canada primary support for AO at CFHT (adaptive optics bonnette project, AOB)
- Swedish 1-m Solar Telescope (NSST) on La Palma, Spain
- Italy and Germany efforts support LBT
- UK – on the WHT
- Spain/Germany – LGS AO system on 3.5-m Calar Alto
- German Solar Telescopes (Tenerife, Spain):
  - On VTT: AO (KAOS), MCAO (MultiCAOS)
  - Gregor: AO and (planned) MCAO
- Probably more
- ESO – details follow

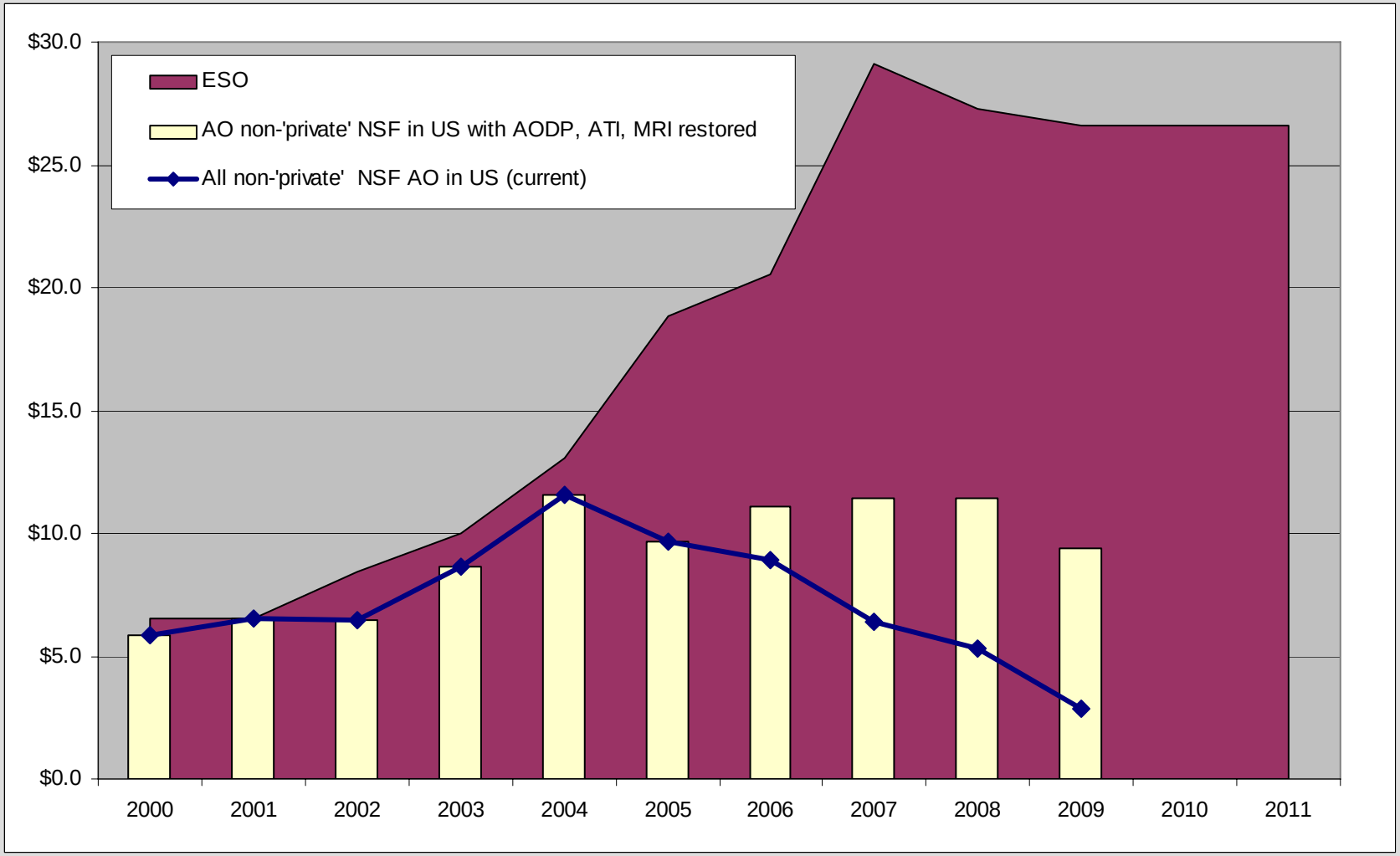
What ESO is doing for AO

- Currently available for AO:
  - NAOS: Nasmyth AO System
    - AO for all apps in the 1-5 micron range on UT4; NGS now, LGS at end of 2006
    - Visible and IR wavefront sensors with CONICA, near IR imager and spectrograph
  - MACAO (now): Multi-Application Curvature AO for VLTI
    - At the Coude focus of all 4 UTs; NGS
  - SINFONI: Spectrograph for Integral Field Observations in the Near-IR
    - Attached AO module uses NGS or LGS
  - MAD: Multi-Conjugate AO Demonstrator
    - Nasymyth focus; part of OWL planning
- In the works for AO:
  - HAWK-I (2007): High Acuity Wide field K-band Imager
    - Near IR wide field imager for use with Adaptive Secondary
  - 4 x LGS facility (2010)
  - Planet Finder (2010?): ExAO system
  - FALCON (concept study - 2010): MOAO IFU system
  - Adaptive Secondary (2012): 1170 actuators
  - MUSE (2012): Multi Unit Spectroscopic Explorer (24 IFUs)
    - Panoramic integral field spectrograph in the visible
    - GLAO, 4 x LGS, Adaptive Secondary
- And several major non-AO instruments (KMOS, XShooter)

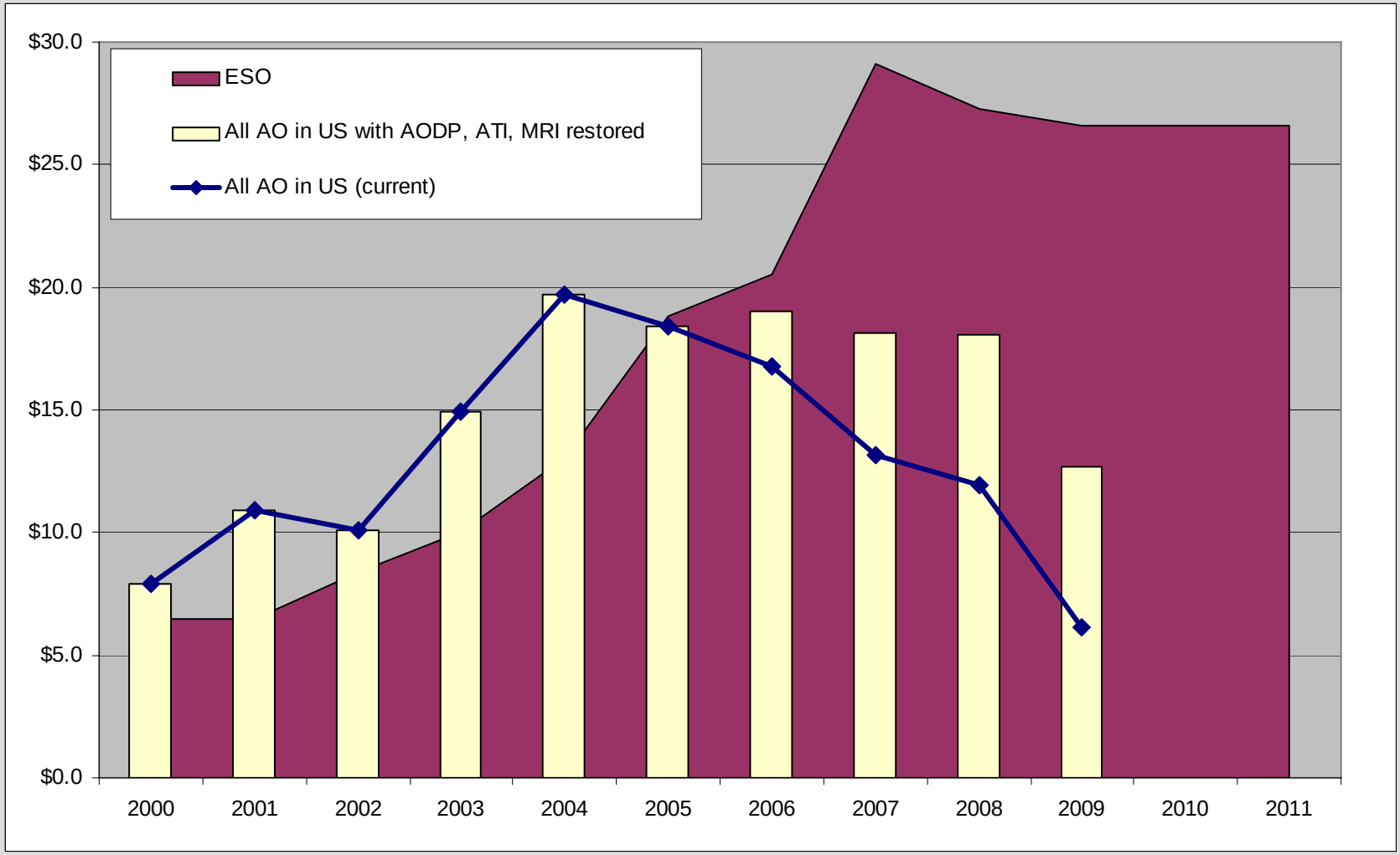
Comparison with ESO

- ESO figures are for VLT and OPTICON efforts
  - May only be a lower limit on funds expended by the partner countries for AO related R&D and instrumentation.
  - Constant Euro/dollar exchange rate of 1.27 used.
  - There is a distinct upward trend projected from actual expenditures on instrumentation.
  - Does not include ops costs (science or general)
- US spending is from two previous plots.
  - This includes expenses for two Gemini telescopes, NSO, two Kecks, Palomar, Lick, CAAO, NSF grants for work on the Air Force's telescope, etc.
  - The only significant US "non-private" source of funding is the NSF

ESO vs. *All NSF* US expenditures on AO



ESO vs. *All* US expenditures on AO



What's to Conclude?

- **If consider just public, NSF funds, ESO is now and projected over the next few years outspending the US effort by factors of two to three in even the "ideal assumptions" scenario.**
- By 2007 ESO will be outspending the *total* (public + private) US effort significantly even with the "ideal assumptions" scenario.
- ESO effort is strongly concentrated – only one observatory with 4 8-m telescopes one of which will be dedicated to AO.
- For US, we have 2 x Gemini, 2 x Keck, LBT, MMT, Lick, Palomar, solar telescopes, 2 x Magellan, etc. etc.
- Concentrated effort has distinct advantages – economy of scale.
  - Norbert Hubin pointed out to me that having one line of production for 6 AO systems in the MACAO program "*was quite cost & labor effective as all key components are mostly identical for MACAO-VLTI, SINFONI, & CRIRES.*"
- What's to be done? More funding? More coordination more integrated approach?

Addenda to presentation

- Listing of individual AO related grants in NSF's ATI, MRI, other PI grant programs and AODP 1995-2006
- Further details on some observatory ops.
- These do not include grants primarily aimed at doing science, i.e. observational research projects

AODP Proposal Solicitations - Rationale

- Objectives for 2003:
  - Need a 5-year period of 2nd generation AO development followed by a ~5-year period of implementation of AO systems.
  - Transition between two periods to be determined by progress.
  - AODP similar to TSIP in philosophy:
    - Results from development awards to be disseminated to the entire US community.
    - Telescopes benefiting from AODP implementation awards will make observing time available to the entire US community as in TSIP.
  - Implementation proposals are not solicited in 2003. Only proposals for AO system concepts and associated critical ELT technologies (see AO Roadmap (2000).
- For 2004:
  - Same as above except follow recommendation in addendum to roadmap.

AO related awards in NSF's ATI, MRI programs 1995-present - 1

- 100-inch Adaptive Optics Program, Jastrow, MWO, 1995, $358K
- Wavefront Sensing and Image Motion Compensation for the Hiltner Telescope, Tonry, UH, 1996, $154K
- High-Performance AO Imager for Astronomy, Ftaclas, UH, 1997, $1,744K
- A Unified Approach to Deep Circumstellar Imaging, Ftaclas, MTU, 1997, $188K
- Ex Post Facto Diffraction - Limited Imaging Through Atmospheric Turbulence, Martin, Caltech, 1997, $314K
- Catching the Perfect Wave: The Application of AO to Optical Interferometry for the Next Generation of Optical Telescopes: Albuquerque, NM; Junor, UNM, 1998, $13K
- Integration and Testing of a Sodium Beacon AO System for Astronomy, Kibblewhite, UChi, 1998, $1,161K

AO related awards in NSF's ATI, MRI programs 1995-present - 2

- A Near-IR Camera for High-Resolution Studies of Star Formation, Shure, Georgia State (MWO), 1998, $107K
- Advanced Instrumentation for Adaptively Corrected telescopes: Detection of Faint Stellar Companions and High Resolution Spectroscopy, Lloyd-Hart & Angel, U of A, 1998, $1,004K
- Evaluation of New Low-Noise IR Detectors for Wavefront Sensor Applications, McLean, UCLA, 1999, $71K
- A new type of wavefront sensor for AO with pulsed laser beacons, Lloyd-Hart, U of A, 2000, $428K
- **(ATI + MRI)** Development of High Order Solar AO, Rimmele, NJIT, 2000, $1,821K
- Silicon Deformable Mirrors for Astronomy, Byer, Stanford, 2000, $150K
- Astronomical applications of a computed tomography imaging spectrometer with an adaptive optics telescope, Hege, U of A, 2000, $398K.

AO related awards in NSF's ATI, MRI programs 1995-present - 3

- Upgrade of Facility Camera (NSFCAM) for the IRTF, Rayner & Tokunaga, UH, 2001, $750K
- UnISIS - Science Commissioning of a LGS System, Thompson, U of Ill, MWO, 2001, $1,228K
- Tomographic wavefront sensing for adaptive optics, Dekany, Caltech, 2001, $400K.
- NSF/AFOSR: Exo-Planet Detection Using an Apodized Square Aperture and Dark Speckle, Korzennik, SAO, 2002, $264K.
- Polarimetric IR Circumstellar Imaging, Kuhn, UH, 2002, $217K
- The 20/20 Telescope - a new concept for the GSMT, Angel, U of A, 2002, $949K (this is half of award for AO)
- **MRI**: Development of a Precision Stellar Coronagraph to Image Exoplanets, Brown Dwarfs and Disks, Oppenheimer, AMNH, 2002, $524K

AO related awards in NSF's ATI, MRI programs 1995-present - 4

- NSF/AFOSR : Extending the Field of View of AO Telescopes based on Measurements of the Spatial Statistics of Turbulence and Post Detection Image Processing, Roggemann, Mich. Tech U., 2002, $341K
- NSF/AFOSR: Precision Imaging with AO Non-Redundant Masking Interferometry, Lloyd, Caltech, Cornell, 2003, $189K
- High Performance AO for Astronomy in the Southern Hemisphere, Ftaclas & Chun, UH, 2003, $1,077K
- **(ATI + MRI)** Development of an IR Optimized AO System for the Baade 6.5m Telescope, Close, U of A, 2003, $1,281K
- NSF/AFOSR: The Lyot Project: Optimized, Diffraction-Limited Coronagraphy, Oppenheimer, AMNH, 2003, $305K
- Advanced Image Slicer IFU for Diffraction-Limited 3-D Imaging, Spectroscopy, Polarimetry**,** Ren, Penn State, 2004, $309K.

AO related awards in NSF's ATI, MRI programs 1995-present - 5

- **MRI** (ATM, not AST) Development of IR Instrumentation for High-Resolution and High-Precision Solar Magnetic Field Observations, Lin & Kuhn, UH, 2004, $1.979M
- Tomographic AO with multiple LGSs, Lloyd-Hart & Angell, U of A, 2005, $359K.
- **MRI** Development of Integral Field Spectroscopy for Exoplanetary Science, Oppenheimer, AMNH, 2005, $1,333K
- NSF/AFOSR: The Lyot Project Survey for Exoplanets, Brown Dwarfs, Circumstellar Disks, Oppenheimer, AMNH, 2006, $202K
- Adaptive Optics System for 1.6-m Solar Telescope in Big Bear, Wang, NJIT, 2006, $56K

NSF AO related awards in non ATI, MRI programs 1995-present

- **COMP MATH**: Images Degraded by Nonlinear Motion Blurs: Mathematical Models, Algorithms and Applications, Nagy, Emory, 2005, $266K
- **MSI**: Facility Class LGS Systems for Astronomical AO, Simons, Gemini, 2004, $1,241K
- **STTR Phase I**: Advanced Sodium Beacon Laser, Brasseur, Directed Energy Systems, 2003, $100K
- **Postdoc:** MEMS Devices and Astronomical Spectroscopy, Sheinis, UCSC Postdoc, 2002, $135K
- **CONTROL NET:** Enhanced Control Analysis and Design for Adaptive Optics, Looze, UMass, 2002, $103K
- **GOALWI**: Microscale Adaptive Optical Wavefront Correction, Cauwenberghs, JHU, 2001, $300K
- **COMP MATH**: Iterative Methods in Image Reconstruction, Nagy, Emory, 2001, $130K
- **MSI:** High Resolution Infrared Imaging at the 6.5 MMT with Adaptive Optics, McCarthy, U of A, 1996, $669K
- **GOALWI**: GOALI: Control Design, Analysis and Implementation of an AO System for Astronomy, Looze, UMass, 1995, $10K

AODP: Where the 2003 monies went

- Summary of the 6 awards all for R&D:
  - 2 high power Na laser development program
  - 2 large format, low noise detectors for optical wavefront sensors
  - 1 high actuator count macro-deformable mirror
  - 1 study to develop advanced wavefront reconstruction algorithms
- The recipients:
  - Beletic (CARA)
    - *Development of Next Generation of Optical Detectors for Wavefront Sensing*
    - $1.1M in 32 months
  - Allan Hankla – Coherent Technologies
    - *Compact, Modular Scalable Versatile LGS Architecture For 8-100-M Telescopes*
    - $3.3M in 54 months

AODP: Where the 2003 monies went (2)

- Glenn A. Tyler, The Optical Sciences Company
  - *Practical and Analytical Assessment of AO concepts Required to Provide Atmospheric Compensation for Next Generation ELTs*
  - *$200K over 2 years*
- S. Olivier & T. Barbee (UCSC/LLNL)
  - *Development of Large Deformable Mirrors Based on Dense Actuation of Nano-Laminate MEMs*
  - $1.0M over 2 years
- J. Vallerga (UC Berkeley/SSL)
  - *Noiseless Imaging Detector for AO*
  - $900K over 3 years
- D. Pennington (LLNL)
  - *Compact, High Power Pulsed Fiber-Based Sodium LGSs*
  - $2M over 4 years

AODP: 2004 programs ranked but not funded:

- All for R&D as called for by 2000 Decadal Survey
- Concept validation of GLAO and MCAO with Multiple Laser Beacons at the MMT
- Development of a Pathfinder for ELT Adaptive Secondaries
- 256 x 256 Split Frame Transfer CCD/CMOS Hybrid Wavefront Sensor
- Silicon Micro-machined Deformable Mirror Technology for Advanced Astronomical Optics Applications
- Sparse Optimal Adaptive Real-time Construction (SOARTR)
- New approach to modular, scalable, fiber laser guide stars

AO at Keck Observatory - details

- Funds for Keck AO systems: ~$13.5M
  - Keck I NGS AO system (2000) ~$4M (NASA)
  - Keck II NGS/LGS AO (1999/2004): ~$9.5M (Keck Found. $6.3M, NASA $1.1M, LLNL $1.1M, UC $1M, CfAO $0.15M
- Funds for Keck II AO science instruments: ~$11.0M
  - NIRC2 (2002) ~$5.8M (UC operating funds)
  - OSIRIS (2006) ~$5.2M ($2.75M TSIP, $2.5M UC.
- Funds committed to AO projects under development ~$9.5M
  - Keck I laser (Gemini/Keck with L-M) - $2.8M, NSF, FY06-07
  - AO CCD development: $1.1M in FY05-08 (AODP)
  - Keck II LGS AO upgrades: $0.3M in FY07 (UC)
  - Wavefront controller upgrade: $2M in FY05-07 (Keck Found.)
  - Keck 1 LGS AO system: $2.5M in FY06-08 (UC)
  - Next generation AO system: $0.9M in FY05-07 ($0.75M UC, $0.15 CfAO)