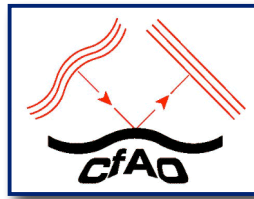


AO Working Group Report: Planning for Next-Generation Adaptive Optics at Keck



Claire Max and Mike Liu

on behalf of Keck AO Working Group

Antonin Bouchez (Caltech), Rich Dekany (Caltech),
David Koo (UCSC), Bruce Macintosh (LLNL), Franck
Marchis (UCB), Keith Matthews (Caltech)

Outline



- Role of AO Working Group
- Near-term Keck AO
- External landscape
- Strategic planning:
 - Previous strategic plans
 - What should next-generation AO system look like:
 - High Strehl over narrow field? (narrow-field AO)
 - Moderate Strehl over wider field? (MCAO)
 - High Strehl over multiple narrow fields (MOAO)
- Next steps

We are working with the Keck community to compare science cases for future AO options

AO Working Group



- Second-generation AO Working Group
- Co-chairs: Mike Liu (UH) and Claire Max (UCSC)
- Members: Antonin Bouchez (Caltech), Rich Dekany (Caltech), David Koo (UCSC), Bruce Macintosh (LLNL), Franck Marchis (UCB), Keith Matthews (Caltech)
- Charter: "To assist in prioritization and advocate the optimization of the scientific output of the Keck adaptive optics facilities, in conjunction with the adaptive optics science instruments."

Near-term Keck AO



- **Current Status:**
 - Keck II laser guide star doing shared-risk science
 - Working VERY well (!)
- **Near-term upgrades:**
 - Wavefront controller upgrade (KI and KII) under way
 - Procurement of laser for KI under way
- **77 Keck AO papers to date (!)**
- **8 laser guide star science papers published or submitted in the past 6 months**
- **Oversubscribed LGS session at January '06 AAS mtg, "Early Science Results"**

External landscape

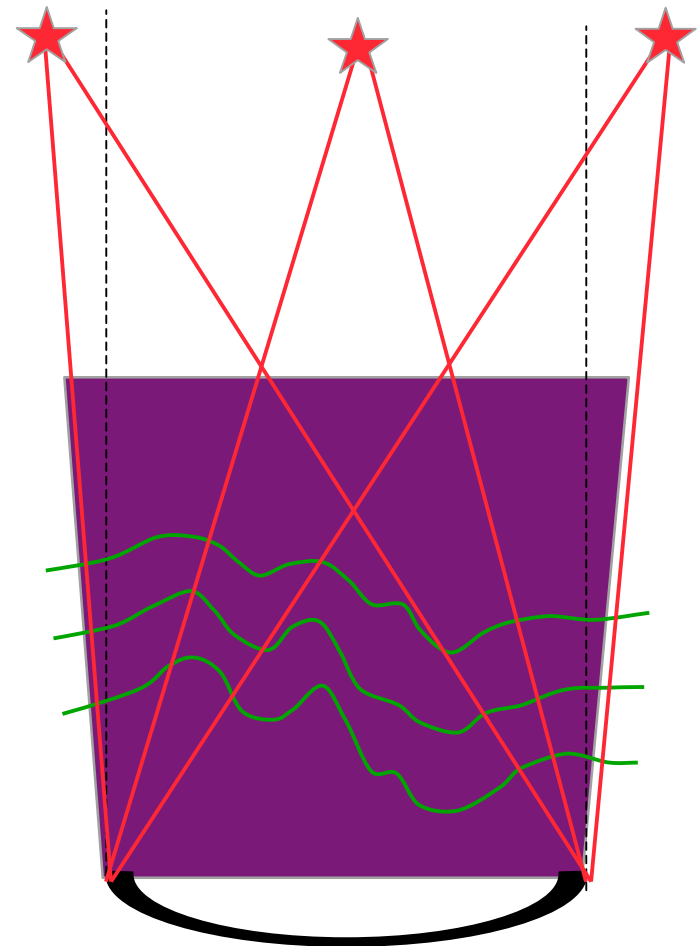


- HST is possibly/probably going to die in 3-5 years
 - After that, Keck AO would be the best/only high resolution system available.
- In the optical, Keck could deliver 4x the resolution as HST
 - Currently does this in the IR
- Laser technology is making significant strides
 - Lasers for Gemini MCAO are being built today
 - Lasers for optical AO are no longer a pipe dream
- TMT is a long way in the future
 - There is ample time for at least one next-generation Keck AO system (and likely more).
 - Even once TMT is operational, Keck with AO will play crucial role
- For planetary science, next-generation Keck AO will happen a lot sooner than any new space missions (except Moon-Mars!)

Work has been proceeding on KPAO: Keck Precision AO



- Chris Neyman, Ralf Flicker
- “Tomography Engine”: Use multiple laser guide stars to reconstruct 3D atmosphere
- Basis of ANY future AO: corrects for cone effect, info about multiple lines of sight
- Original concept: High level of AO correction, narrow FOV, some correction in optical



Recent developments have lead to reconsideration of Science Case



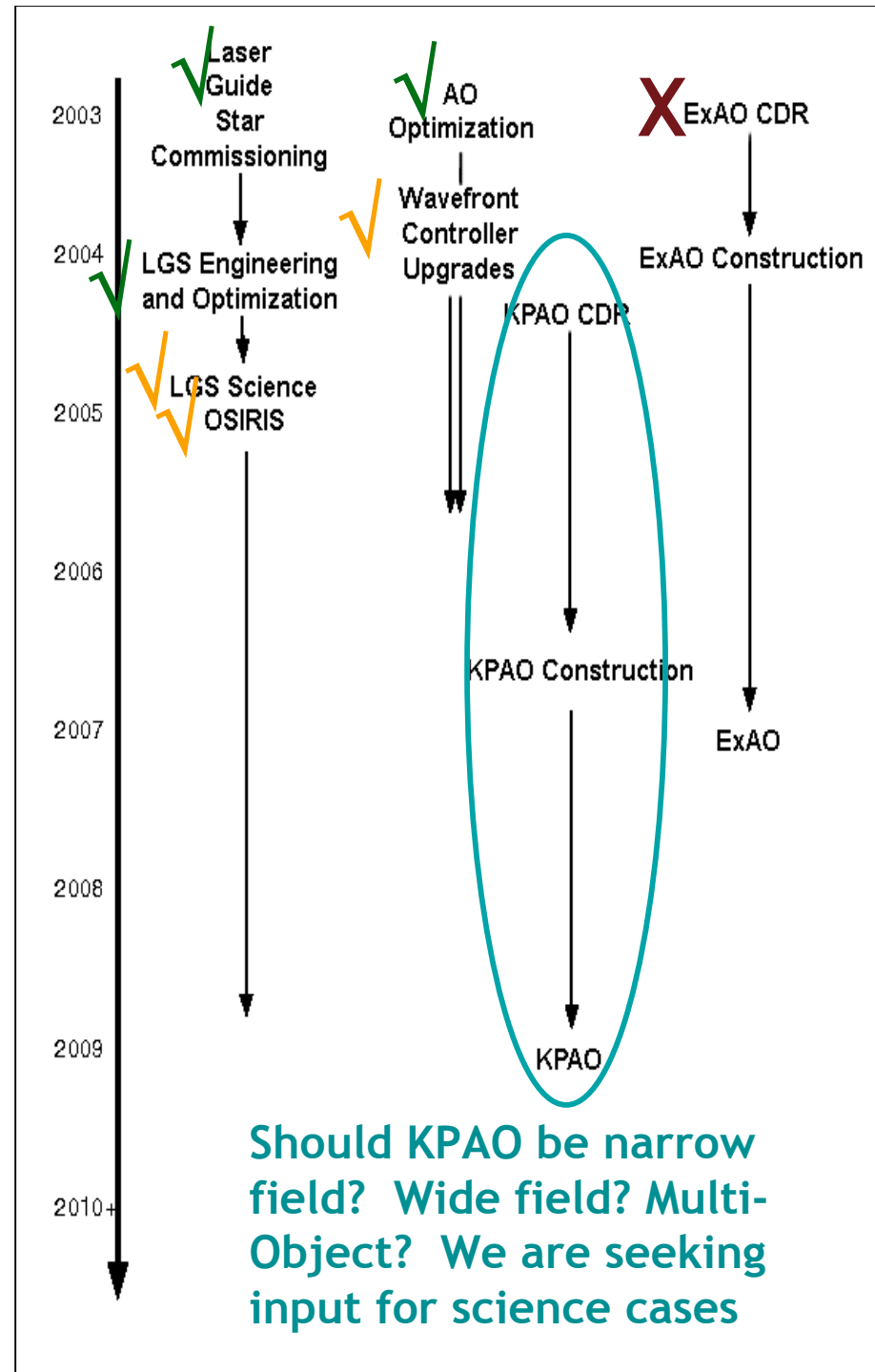
- Since previous strategic plan, we've learned a LOT more about tomography (CfAO, TMT analysis, simulations)
- KPAO as a powerful “tomography engine”
- KPAO as potential “front end” for:
 - Narrow-field high-Strehl (original concept): one camera, one IFU
 - Multi-object AO: deployable MEMS AO systems with their own IFUs
 - Multi-Conjugate AO: AO correction over whole (wide) field
- We want to consider science case (cost-benefit) for the two wider-field implementations, in comparison with narrow-field KPAO concept

Previous strategic plan

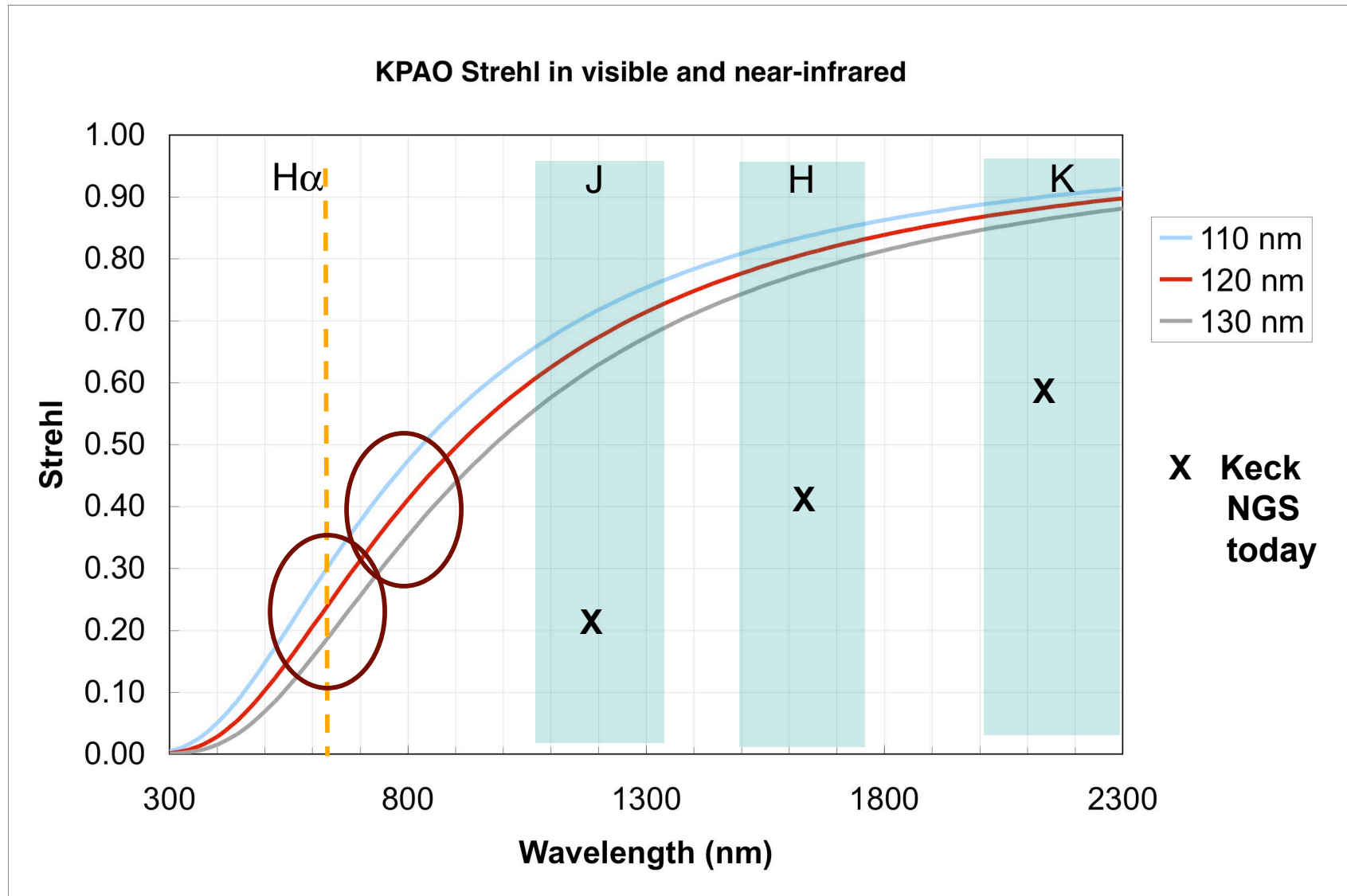
✓ Complete

✓ In progress

X Went to Gemini



KPAO as originally conceived would have important capabilities in the visible



Notional performance at J-band



	<u>Strehl</u>	<u>FOV diam</u>
• KPAO narrow-field	60%	~ 20"
• MCAO wide-field	~ 20%	1.5 arc min
• MOAO multi-object	60%	N x 20" within 7' field of regard

Should we head toward wide field AO?



- Comparison of KPAO with Gemini MCAO

KPAO advantage

	K band	J band	8000A	H α
KPAO Strehl	90%	65%	40%	22%
MCAO Strehl	60%	20%	2%	very low

Table 3: *MCAO and CAO compensated surface area*

	J	H	K
MCAO FoV Diameter [arcsec]	90	110	120
CAO FoV Diameter [arcsec]	20	30	40
Area gain	20	13	9

MCAO advantage

First cut at science case, narrow-field vs. wide-field



Preference

- Solar System narrow field
 - Galactic narrow field
 - Planet detection narrow field
 - Extragalactic it depends....
-
- The following slides will give examples

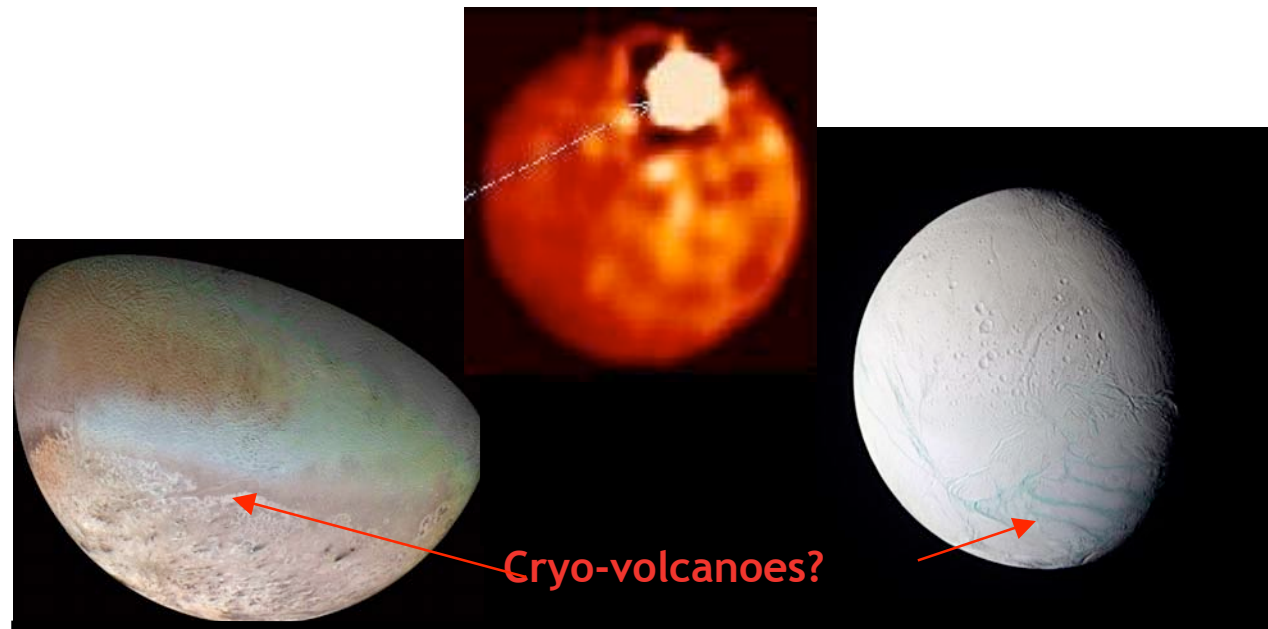
Planetary Science: narrow-field KPAO is the most promising technology



Jovian moons, asteroids, trans-neptunian objects are small enough to fit into KPAO's field of view
KPAO in visible has high potential for asteroids, TNO's

Volcanism: variable phenomenon

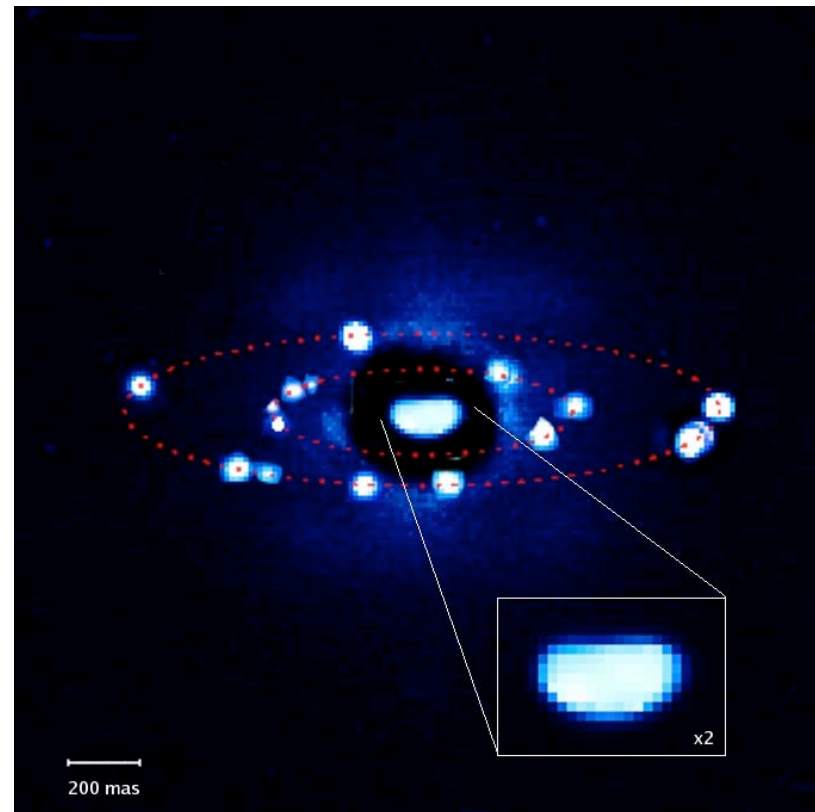
- Io
- Triton
- Enceladus



KPAO in visible has high potential for asteroids, TNO's



- Better angular resolution
- Better sensitivity
 - > find smaller fragments around asteroids and TNO's (multiple systems)
 - > Bulk-density and formation scenario
- PSF quality and stability will be important
 - Higher performance AO system more likely to have stable PSF

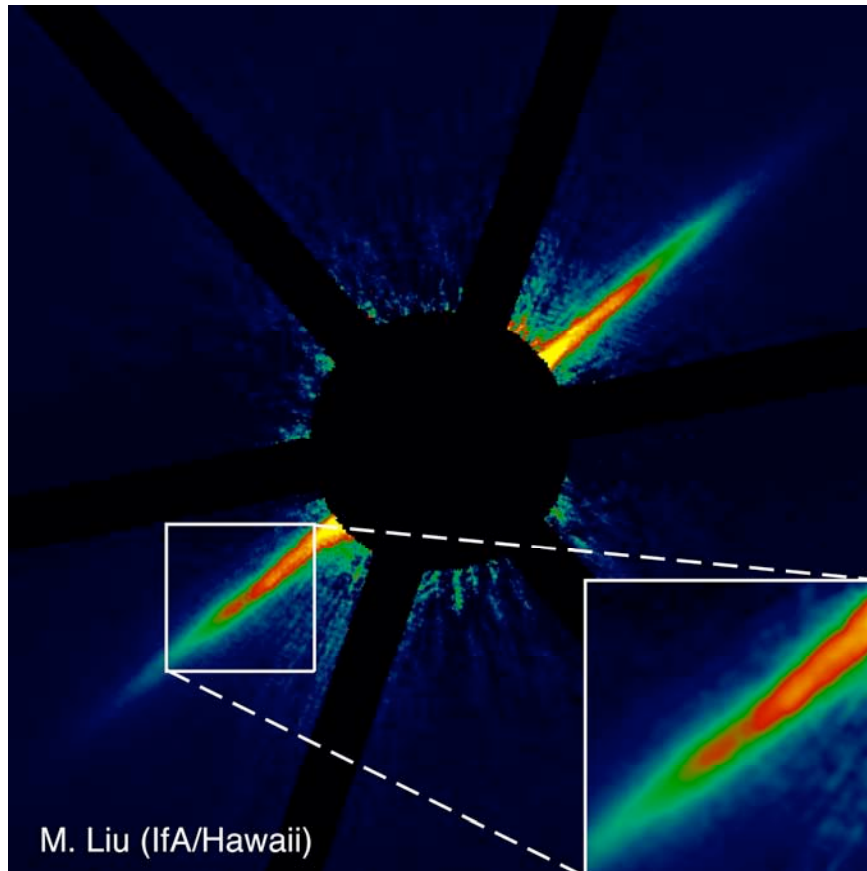


87 Sylvia and its two moonlets
(Marchis et al. 2005)

KPAO can fulfill needs of most Galactic Astronomy programs

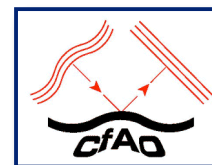


What is the diversity of planetary systems?
Imaging of dusty circumstellar disks



- Disk sub-structure tells about the **planet formation process**.
- Low-mass planets too faint to directly image can be studied by the **dynamical signatures** they produce in the dust.
- Multi-wavelength optical + IR colors tell us about grain growth.
- KPAO AO @ I-band: resolution $\sim 0.015''$ (0.1-0.5 AU scales).

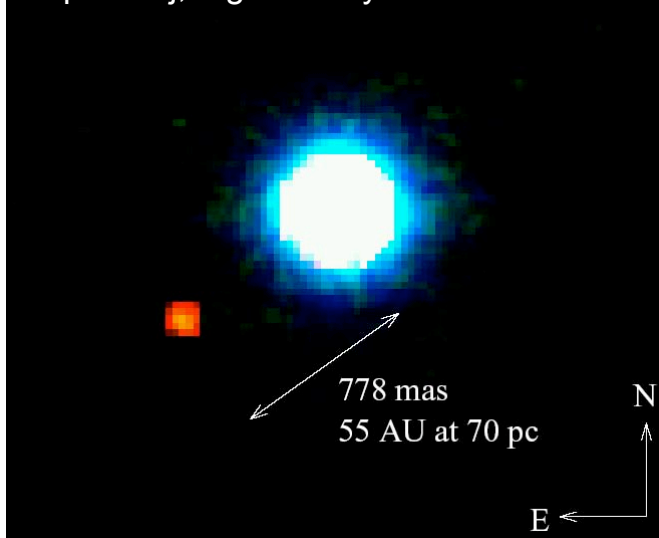
KPAO: Imaging of planets around low-mass stars and brown dwarfs



- KPAO would be able to detect $1 M_J$ companion to $40 M_J$ 10 GYr brown dwarf
- Can detect 1 MJ companion to T Tauri star @ 50 AU
- These targets are inaccessible to bright-star ExAO systems

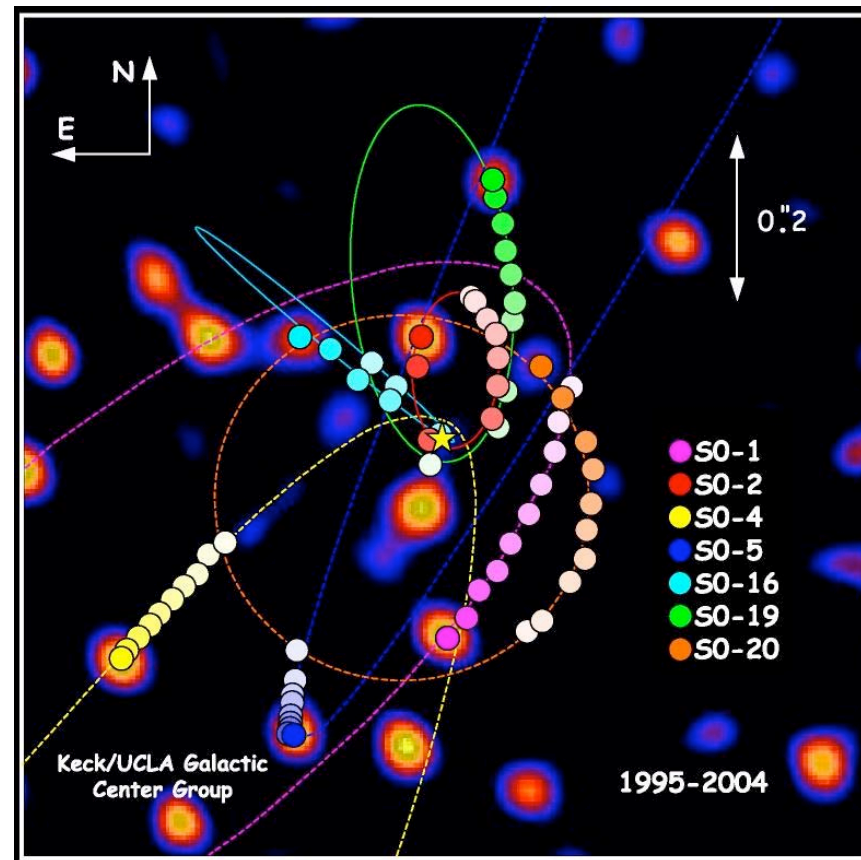
2MASSWJ1207334–393254

$M_p \sim 5 M_J$, age ~ 8 My



System	Detectable contrast @ 0.5"	Mag. Limit
Current AO	10^4 - 10^5	$R < 18$ mag
Extreme AO	10^7 - 10^8	$I < 9$ mag
KPAO	10^5 - 10^6	? Closer to current AO

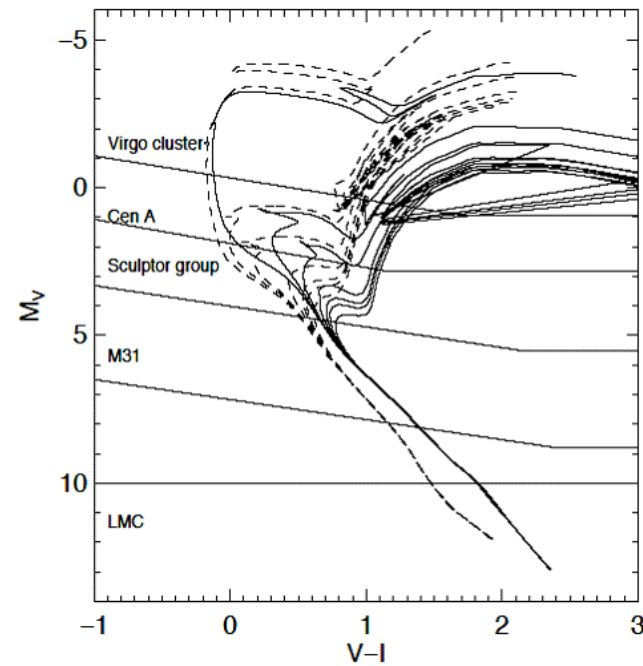
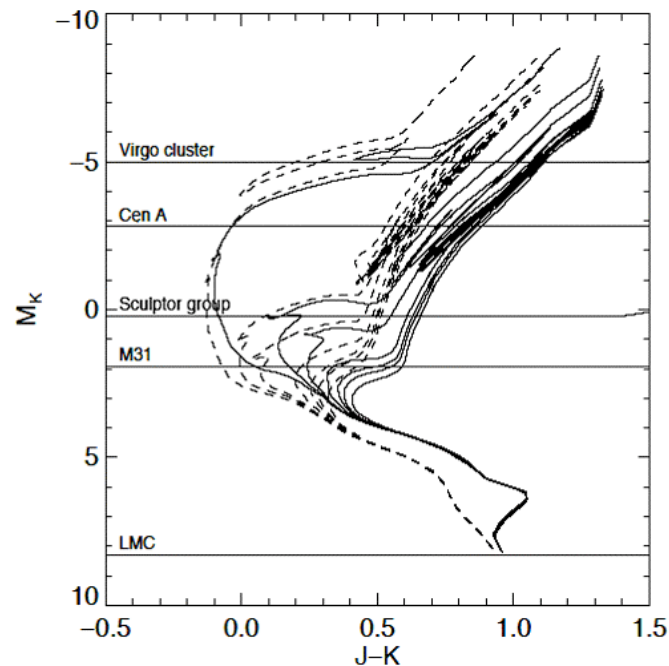
KPAO: better orbits for stars around Galactic Ctr $\Rightarrow$ General Relativity



Extragalactic astronomy: some science cases would prefer narrow field, high Strehl AO



- Stellar populations in confusion limit: Narrow field AO
 - Favors high Strehl
 - Advantage of V-band in constructing color-magnitude diagrams
 - Examples for 30 m telescope (Olsen et al.)

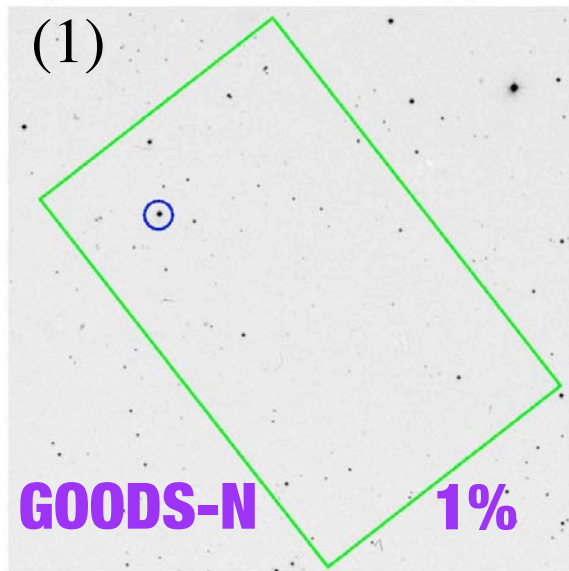


Extragalactic astronomy: some science cases would prefer wide field IR AO

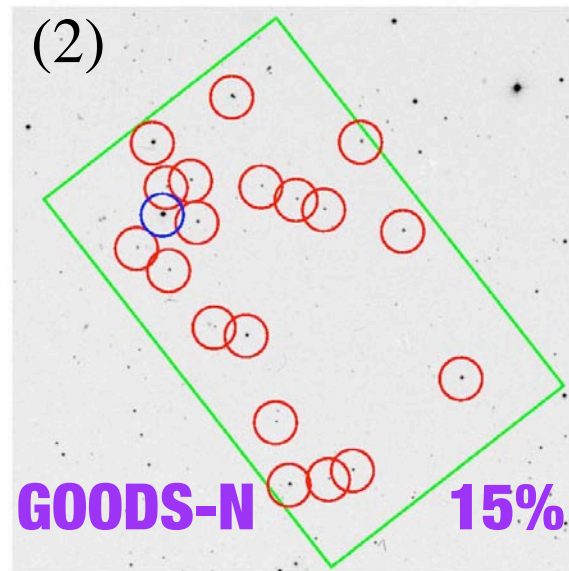


- Morphology, astrometry, spectroscopy: Wide field AO (2' - 7')
 - For high-z galaxies, IR AO correction
 - Higher astrometric accuracy likely with MCAO (needs wide field imager)
- For spectroscopy at high z, don't want to waste pixels in blank spots between galaxies $\Rightarrow$ deployable IFUs
 - Both MCAO and MOAO can take advantage of deployable IFUs
 - MOAO would deploy little MEMS AO system along with each IFU
- Even with deployable IFUs, would need to image first in order to find target galaxies
 - Is it sufficient to image without AO?
 - If not, what is best way to image wide field with AO?

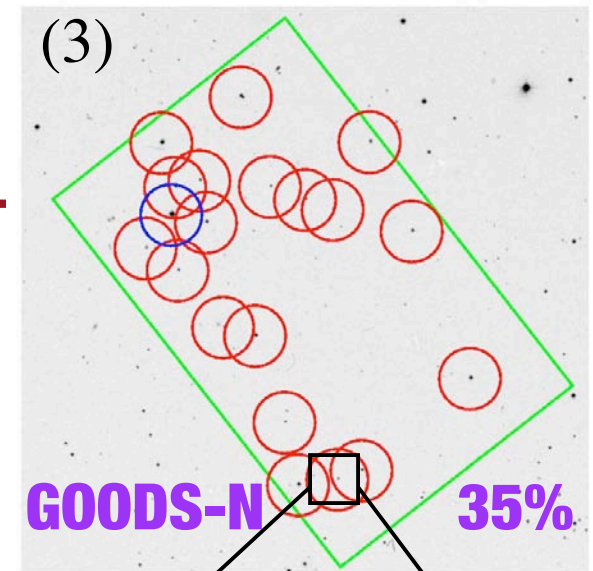
NGS A0



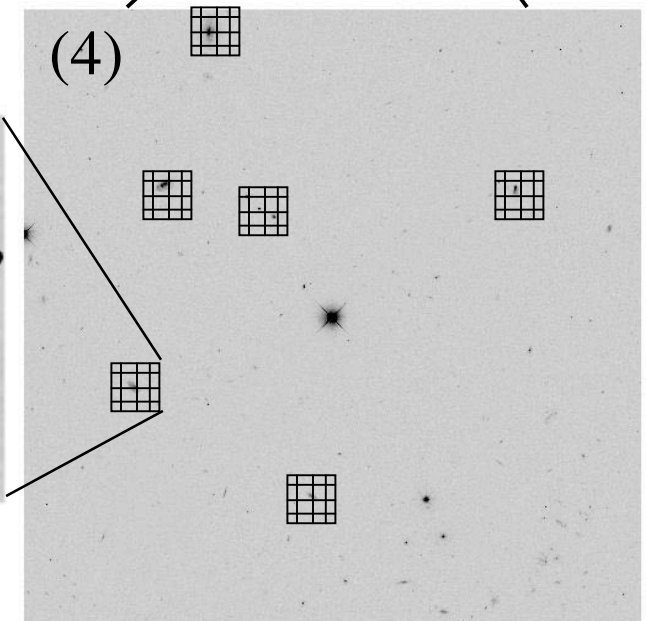
LGS A0



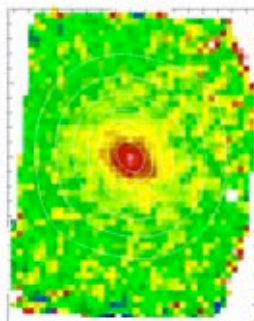
MCAO A0



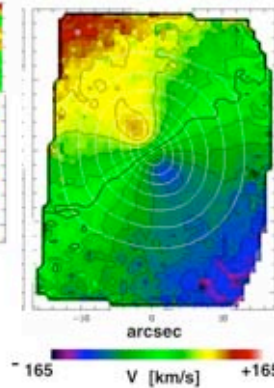
MOAO A0



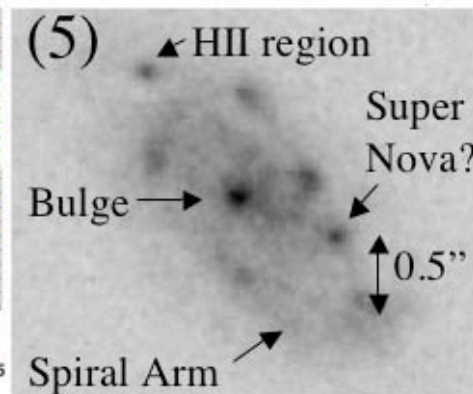
Metallicity Gradients



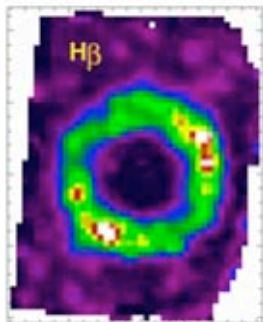
Velocity Kinematics



z=1 Galaxy



Star Formation Rates



(6)

Note: Sauron Data from local galaxies, de Zeeuw et al. 2002

Potential synergy between KPAO and wide field AO options



KPAO
Narrow FOV
High IR Strehl
Visible capability

KPAO will measure turbulence using multiple laser guide stars and tomography

Wide field AO can use these meas'ts to correct atmosphere

Multi-Conjugate AO
~2' FOV
Moderate IR Strehl

Multi-Object AO, ~7' field of regard
Many small postage stamps within field of regard
High Strehl in IR

Back-end instruments



- **KPAO:**
 - IR is well covered by NIRC2, OSIRIS
 - To take advantage of performance in the visible, would need new back-end instrument
 - Consider a dual-channel optical-near IR imager
- **MCAO or MOAO**
 - Need deployable IFUs to take advantage of wide field
 - Need to think about wide-field camera (either AO or non-AO) to detect and select high-z targets for IFUs



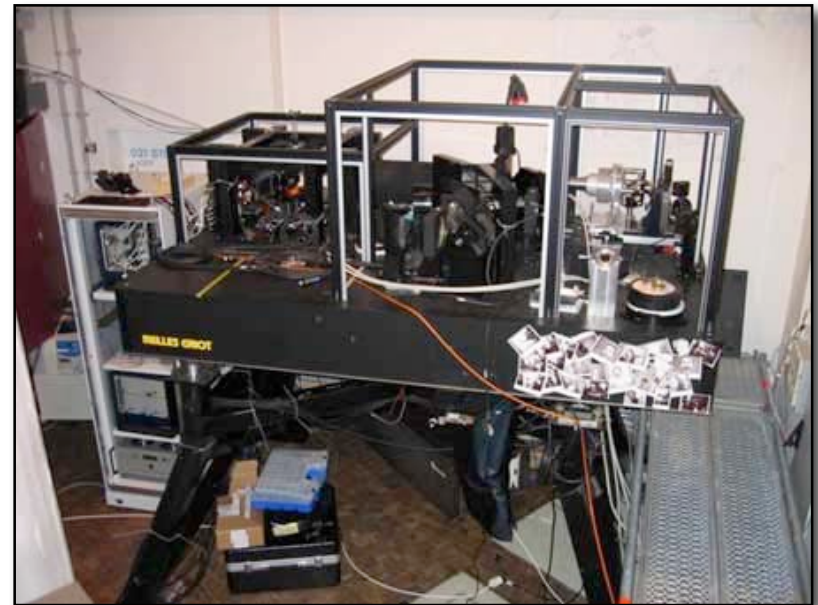
Phasing is possible, and may be desirable

- Notional phases:
 - Design full wide-field AO system (KPAO, plus MCAO or MOAO)
 - Build KPAO part first
 - Use with OSIRIS/NIRC2
 - Build visible-light instrument
 - Add wide-field capability at later date
 - MCAO: add large deformable mirror(s), deployable IFUs
 - MOAO: add deployable MEMS AO systems with IFUs
- Obviously cost will be a crucial consideration: KPAO very preliminary estimates are \$25-30M (Neyman and Dekany) without back-end instrument
- Preferable if we can interest a donor in doing the whole project (?)

Our competition is forging ahead



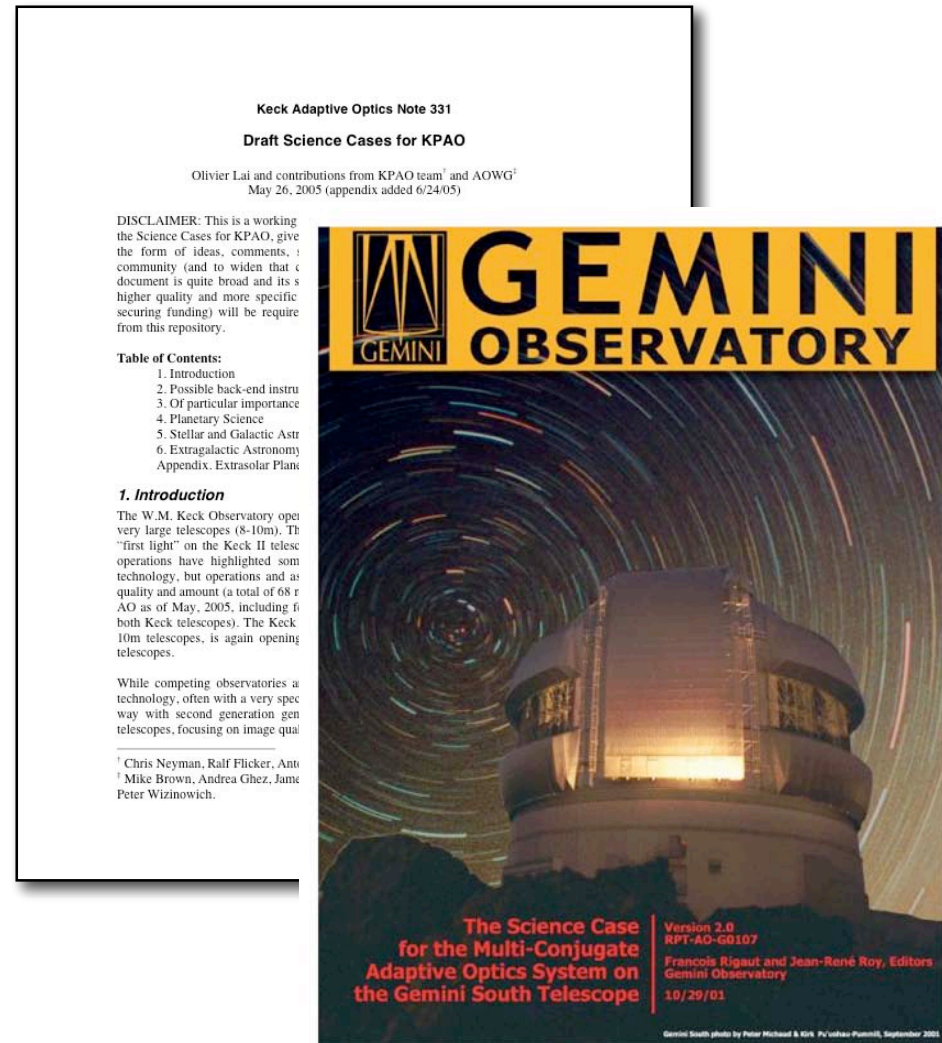
- Gemini South MCAO system:
 - Operational in ~ 2007 with multiple lasers
 - Facility class AO system
 - New wide-field camera (GSAOI): 4 Hawaii-2 detectors, 85" FOV
 - Spectrograph (HRNIRS) under study
- ESO VLT:
 - Multi-Conjugate AO Demonstrator (MAD)
 - Functioning in lab at ESO, will go on telescope in ~ 1 year
 - No laser
 - Will test alternative MCAO concepts for OWL
 - Use results to decide on next step for VLT



We need to compare key science cases for KPAO, wide field AO



- AOWG has put together a few example science cases
- Gemini MCAO Science Case is much more extensive
- TMT/GSMT science cases contain valuable examples
- **We plan to work with Keck community to flesh out a science-case comparison between KPAO with and without and wide-field AO**



Slide from Keck Strategic Planning Mtg: We are seeking input



- What capabilities would you need from a next-generation Keck AO system for your own science?
 - NOW is the time to begin planning this
 - Are you most excited about a high Strehl, modest FOV AO system with some optical (red?) wavelength capability?
 - Would a larger field of view with lower Strehl but only IR wavelength coverage be of most interest to you?
- HST users: what does HST provide for you that Keck AO doesn't (aside from funding)?
- Please help us work on comparing science cases!
 - Form a mini-working group
 - CfAO and Keck could co-sponsor a workshop
 - Science closely tied with AO and instrument capabilities

Next Steps



- CfAO Retreat in two weeks
 - Session on next-generation Keck AO and science cases
 - Hope to generate lots of discussion, interest in follow-up work
- Form a mini working-group, flesh out a few key science cases and compare
 - Both astronomers and AO folks
 - Simulations needed (e.g. how well can you do astrometry?)
 - Hold a small retreat (?)
- AO Working Group will digest results, discuss with CARA and the community, report back to SSC