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

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on behalf of Keck AO Working Group

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Outline

- External landscape
- Strategic planning:
  - 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

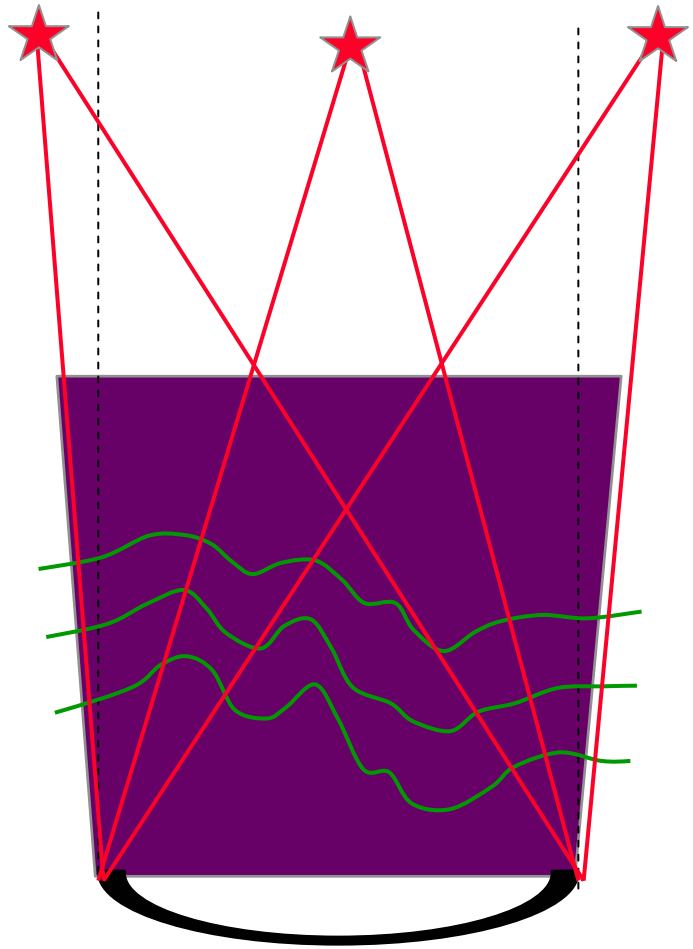
We want to work closely with the science community (you) to compare science cases for the future AO options

External landscape

- HST is possibly/probably going to die in 3-5 years
  - After that, Keck AO would be the best high resolution system available.
- In the optical, Keck could deliver 4x the resolution as HST
  - Currently does this in the IR
  - Want to consider pros and cons of visible AO at Keck
- Laser technology is making significant strides
  - Lasers for Gemini MCAO and Keck 1 are being built today
  - Laser for optical AO exists at Starfire Optical Range
- TMT is a long way in the future
  - There is ample time for at least one next-generation Keck AO system
  - Even once TMT is operational, Keck with AO will play crucial role
- For planetary science, next-generation Keck AO will happen a <u>lot</u> sooner than any new space missions (except Moon-Mars!)

Work has been proceeding on KPAO: Keck Precision AO

- Chris Neyman, Ralf Flicker
- Selected for study by AOWG in its strategic plan, 2002
- "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 (KPAO)



Potential synergy between KPAO and wider-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
Multiple DMs
Moderate IR Strehl

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

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 potential "tomography front end" for:
  1. Narrow-field high-Strehl (original concept): one IFU
  2. Multi-object AO: deployable MEMS AO systems with their own IFUs
  3. Multi-Conjugate AO: AO correction over whole (wide) field, deployable IFUs
- We want to consider science case (cost-benefit) for these three concepts

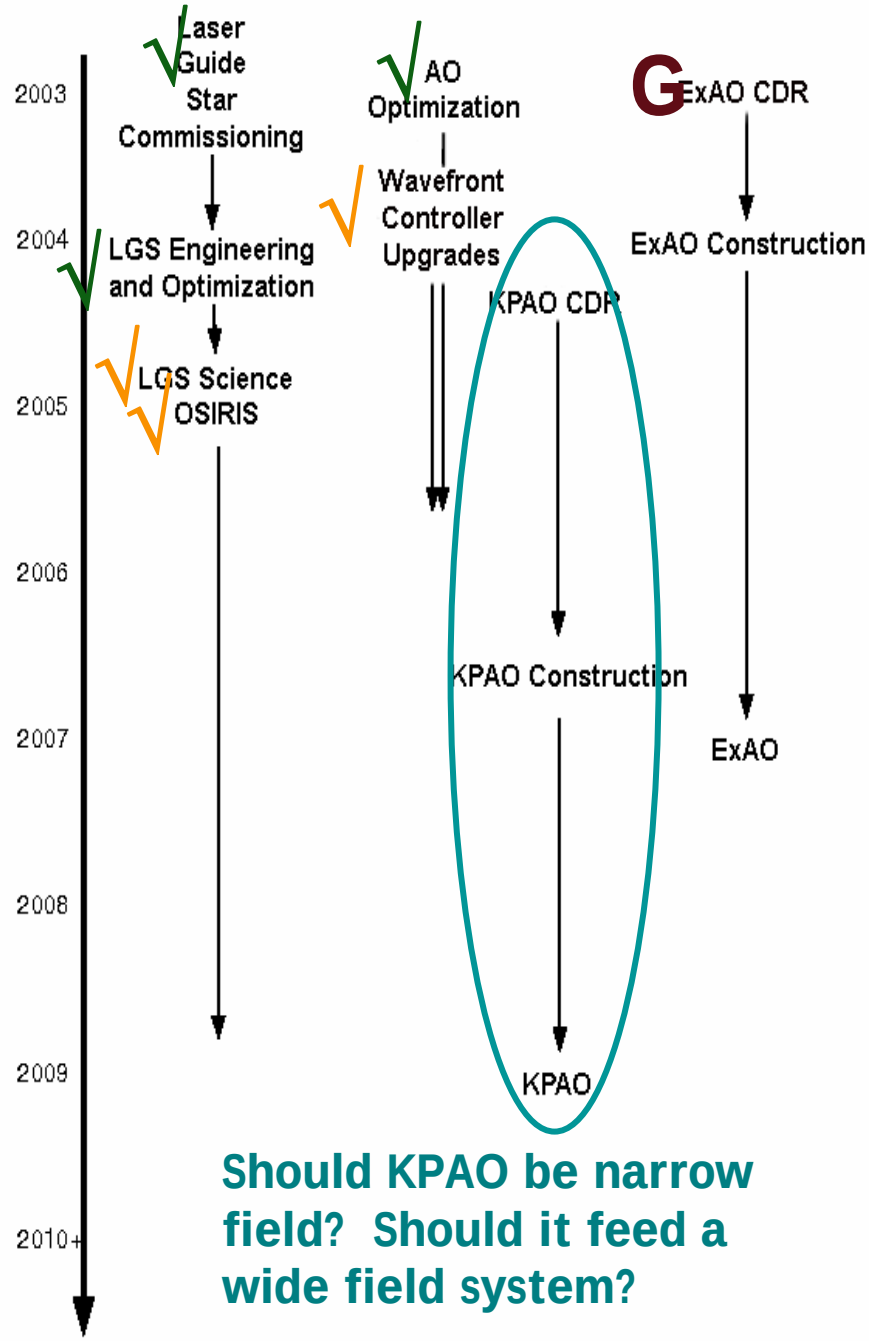
Previous strategic plan

√ Complete

√ In progress

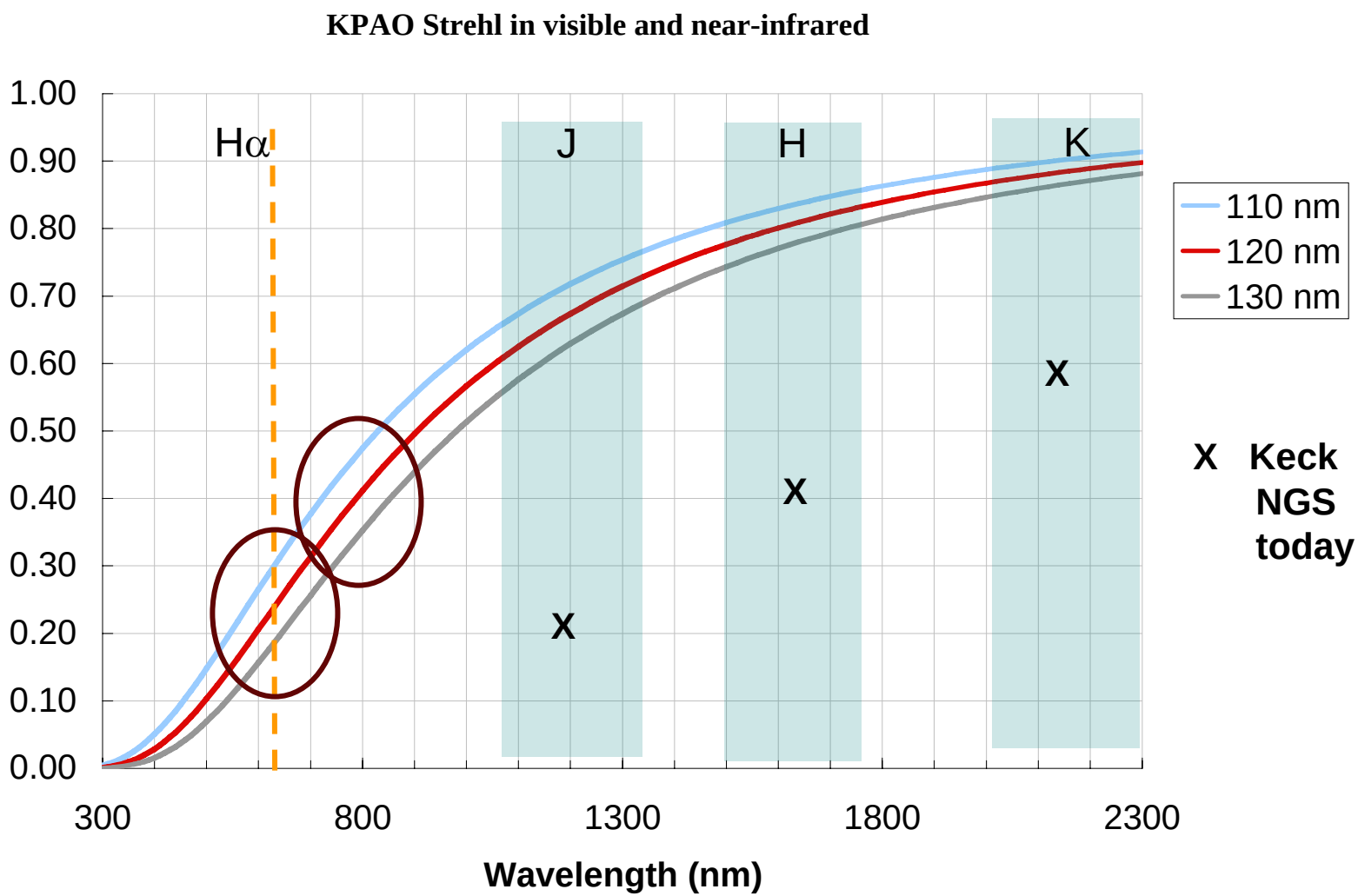
G Went to Gemini

- 80 Keck AO papers to date (!)
- 8 laser guide star science papers published or submitted in the past 6 months



Should KPAO be narrow field? Should it feed a wide field system?

KPAO as originally conceived would have important capabilities in the visible



Zero'th 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 seems 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**

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

KPAO can fulfill needs of most Galactic Astronomy programs

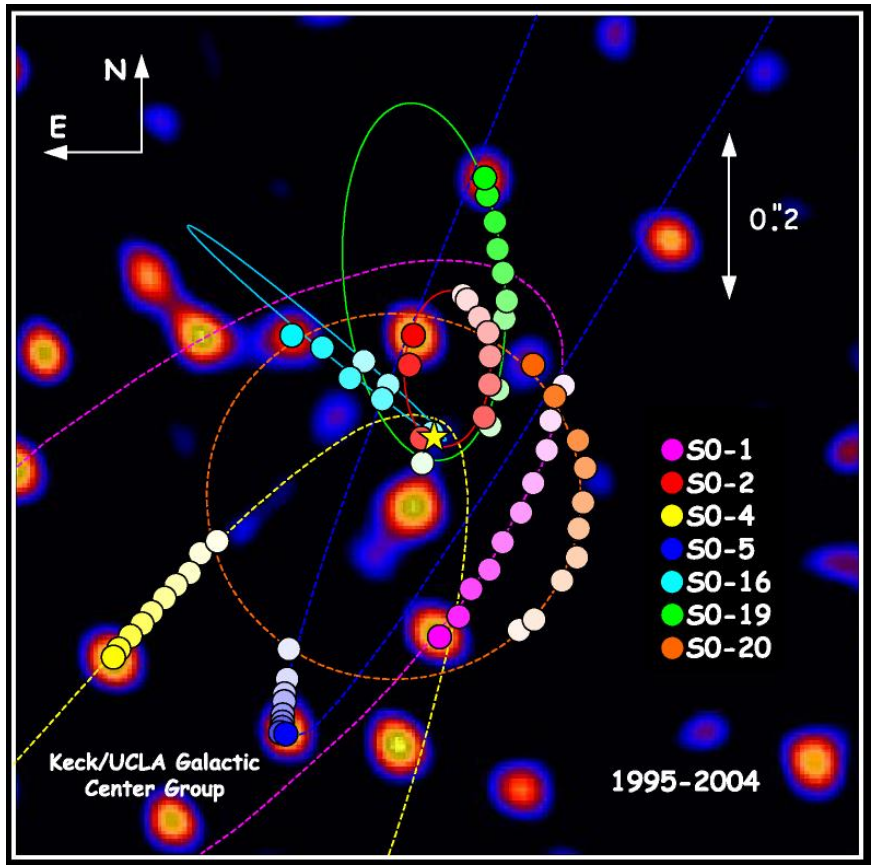
Example: What is the diversity of planetary systems?

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

- **Imaging 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 will resolve 0.1-0.5 AU scales for nearby stars**

KPAO: better orbits for stars around Galactic Ctr ⇒ General Relativity

- Confusion limited field: best photometry at highest Strehl
- Astrometry: in principle better with wider field, but in this case can get joint solution for many stars within narrow field



Extragalactic astronomy: a complex tradeoff between wide field and narrow field

- Examples of some science cases, in order of distance from us:
  - Cores of nearby AGNs
  - Nearby dwarf galaxies
  - Stellar populations in galaxies out to Virgo cluster
  - Quasar host galaxies
  - High-redshift supernovae
  - Evolution of high-z galaxies (small and faint, red-shifted)
    - Dynamical masses
    - Metallicity history
    - Star formation rate
    - Merger history
    - Lyman α clouds around young (high-z) galaxies

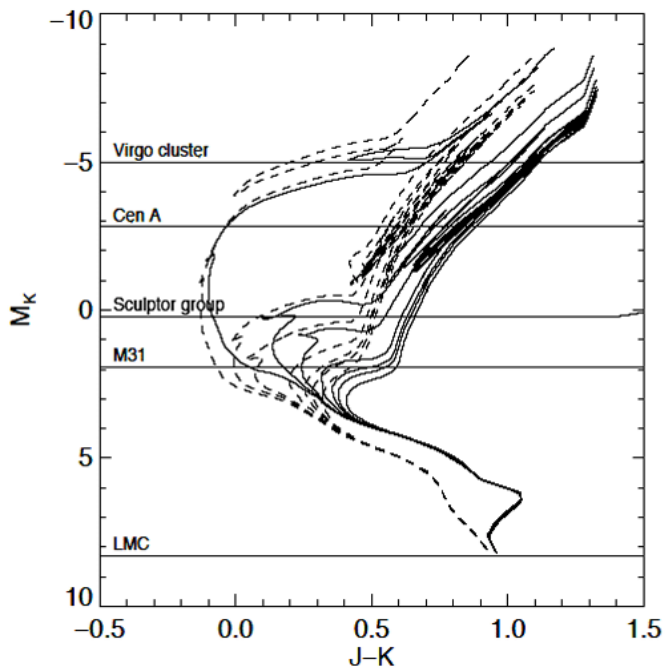
Mostly narrow field

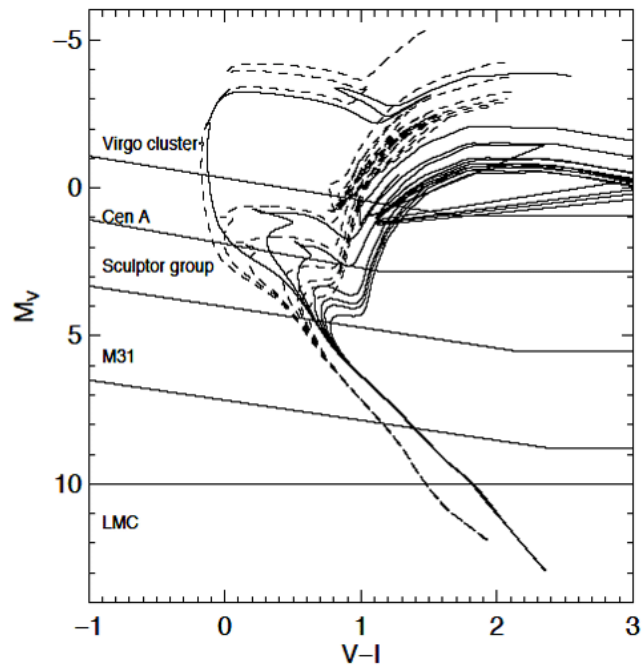
Mostly wide field: multiplex advantage, 5-10 objects per square arc minute

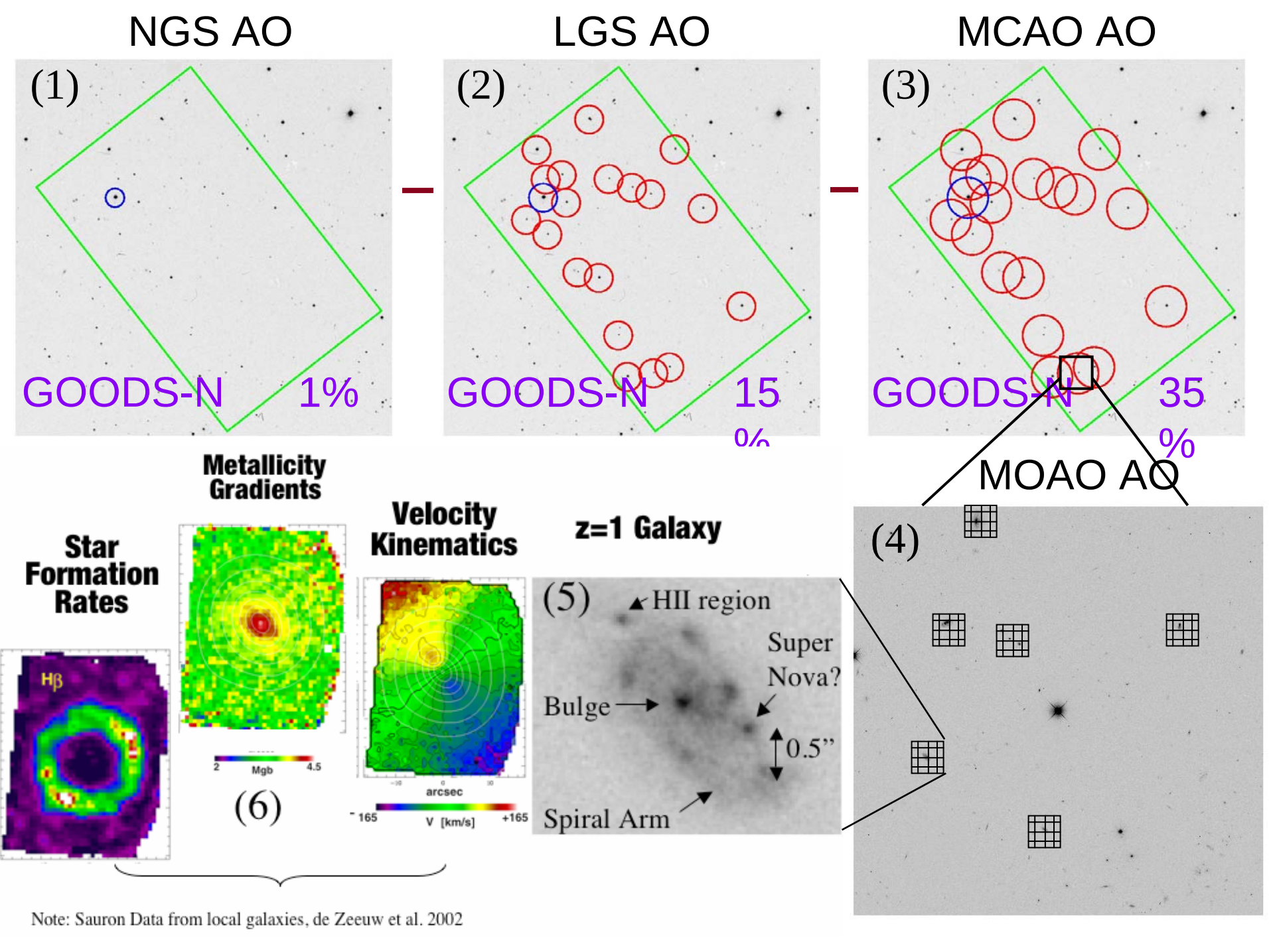
- Each has different considerations for optimal AO system.
- Examples to follow.

Stellar populations in confusion limit: narrow field, high Strehl AO preferred

- Photometry in confusion limit favors high Strehl
- Advantage of V-band in constructing color-magnitude diagrams
- Examples for 30 m telescope studies (stellar evolutionary tracks from Olsen et al.):

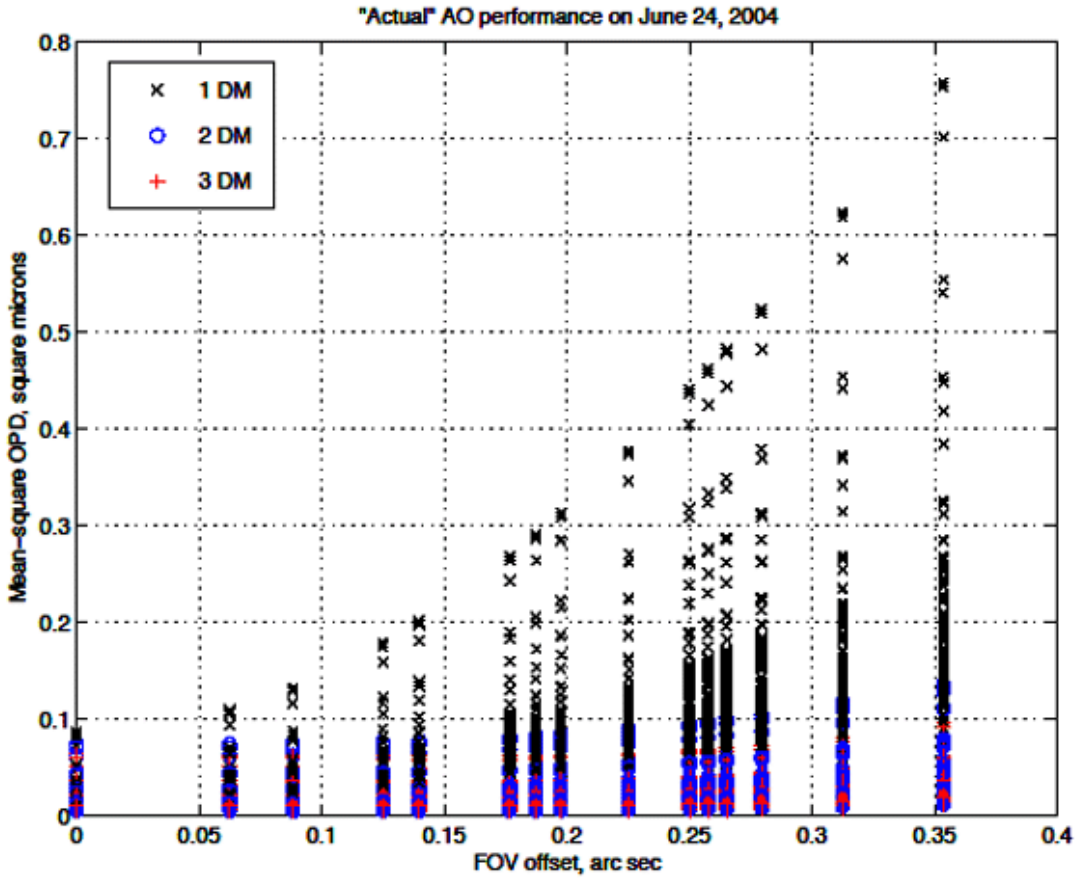





NGS AO
LGS AO
MCAO AO
(1)
(2)
(3)
GOODS-N
1%
GOODS-N
15 %
GOODS-N
35 %
MOAO AO
(4)
Metallicity Gradients
Velocity Kinematics
z=1 Galaxy
Star Formation Rates
Hβ
2
Mgb
4.5
(6)
arcsec
-165
V [km/s]
+165
(5)
HII region
Super Nova?
Bulge
0.5"
Spiral Arm
Note: Sauron Data from local galaxies, de Zeeuw et al. 2002

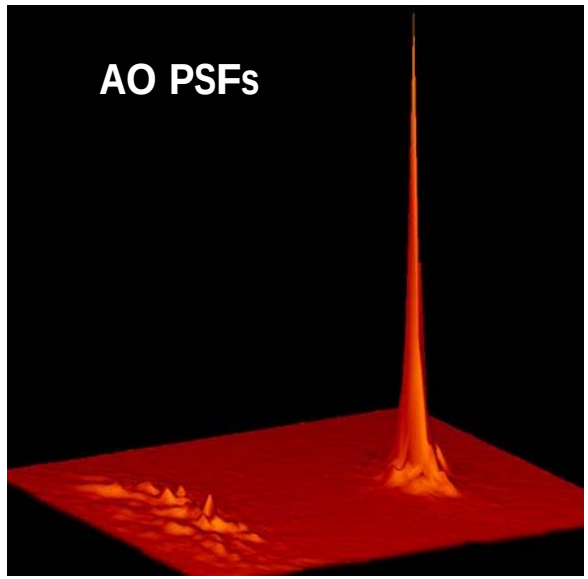
Photometric accuracy: a key issue

- Two science examples:
  - Color-magnitude diagrams to determine stellar ages and metallicities
  - Photometric redshifts
- Accurate photometry means you must know your PSF, and it must be stable
- Simulation for TMT by Brent Ellerbroek: stability advantage for 2 or more DMs
- We need to examine PSF stability for Keck (10m instead of 30m) and for KPAO



Astrometry and AO

- Science examples:
  - Proper motions for Galactic Center stars
  - Proper motions of stars in rest of Galaxy
  - Apparent proper motions due to gravitational microlensing
  - Planet detection (in conjunction with other methods)
- 1 mas/year = 4.5 km/s at 1kpc. Many applications need to do better than this.
- Rule of thumb has been that you can centroid an image to accuracy given by FWHM / signal to noise ratio.
  - AO should help with both, for point sources
  - But we don't know if AO has in fact been able to stay on this curve



AO off AO on

Science instruments need thought

- **KPAO:**
  - OSIRIS could provide a first-generation IFU instrument; ideally would want an IFU with a larger field of view
  - Consider rebuilding NIRC2 camera (too high a wavefront error)
  - To take advantage of performance in the visible, would need new back-end instrument
- **MCAO**
  - Spectroscopy: deployable IFUs to take advantage of wide field
  - Imaging: needs a wide field camera
- **MOAO**
  - Multiple AO-IFUs
  - Select targets based on seeing-limited images

Next Steps

- **Form mini working-groups, flesh out a few <u>key science cases</u> and compare different AO implementations**
  - **Both astronomers and AO folks are needed**
  - **Simulations and "data analysis" needed. Examples:**
    - **How well can you recover a color-magnitude diagram?**
    - **How well can you do astrometry?**
    - **What is the PSF stability for narrow-field high-Strehl AO, compared with MCAO or MOAO?**
    - **How crucial is visible-light AO for the science?**
- **AO Working Group will digest results, discuss with CARA and the community, report back to Keck Science Steering Committee**

If you think you *might* be interested in participating, please talk to me or Peter Wizinowich or Chris Neyman. We need your input!

Multiplexing: surface density of targets (from Gemini study)

Object class	N/arcmin^2
All galaxies (K<20)	10
HDF Irr (z=0.5-1)	5-6
Lyman break gals (R<25)	3
Gravitational lens arcs	10
Super star clusters (B<23)	10
Orion stars M<0.1 M_{sun}	2
T-Tauri stars	0.1
Proplyds/microjets in Orion	1

Extragalactic survey work: N ~ 5 - 10. Implies about 10 deployable IFUs in a wider field of regard.

Should we head toward wide field AO?

- **Comparison of KPAO with Gemini MCAO**

KPAO advantage

	K band	J band	8000A	Hα
KPAO Strehl	90%	65%	40%	22%
MCAO Strehl	60%	20%	3%	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

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

- KPAO would be able to detect 1 M_J companion to 40M_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
- Only a narrow field of view is needed