Keck Adaptive Optics Note 341

Keck Precision AO (KPAO)

SSC Presentation

June 29, 2005

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for the KPAO team

Presentation Outline

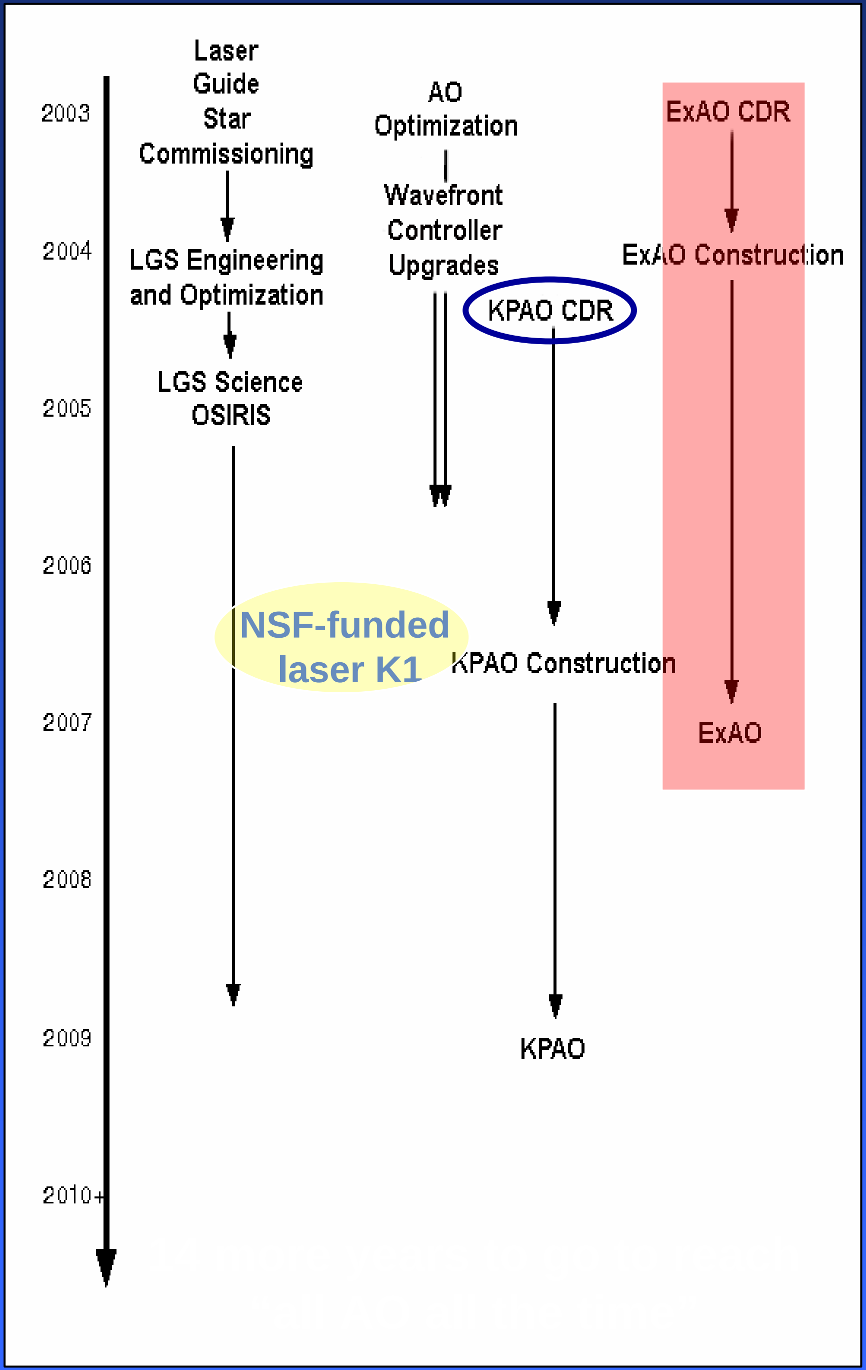
AOWG Strategic Planning Background (Peter)

Draft Science Case (Olivier)

Program & Technical Update (Chris)

AOWG Strategic Planning

- Proposed timeline defined at 11/02 Strategic Planning (SP) meeting.
  - K1 laser added in early 03
- Priorities confirmed at 9/04 SP meeting.
- Mike Brown: "AOWG vision is that high Strehl, single-object, AO will be the most important competitive point for Keck AO in the next decade."
  - Based on science cases presented/discussed by AOWG members
  - Top-level requirements defined by a subgroup & approved by AOWG



KPAO Technical Requirements (KAON 237)

- High IR Strehls -> evaluate 120 & 180 nm rms
  - On-axis LGS & NGS, median seeing, El > 45°, NGS m_v < 17
- High Strehl stability -> ± 15 nm
- Moderate field of view -> 30” radius
- Near complete sky coverage
- Good knowledge of the delivered PSF
- Wavelength coverage -> 0.45 to 14 μm
- Facility-class system
- Sensitivity & angular resolution not yet addressed

AOWG Strategic Planning -> KPAO Science Case

- KPAO team could use a detailed science requirements document & access to a project scientist/science team to interact on design choices
  - Also need a short glossy science document to help seek funding
- Olivier Lai volunteered to flesh out the science case, in collaboration with Mike Brown
  - Olivier has developed similar science cases for next generation CFHT AO & OHANA; & is familiar with Keck from his AO postdoc here
  - Olivier has also helped with initial science requirements input
- Result is a draft science case document that needs community input
  - This is the focus of Olivier's presentation …

In the words of and as a tribute to the great Hunter S. Thompson:

"… The Edge… There is no honest way to explain it because the only people who really know where it is are the ones who have gone over. The others - the living - are those who pushed their control as far as they felt they could handle it, and then pulled back, or slowed down, or did whatever they had to when it came time to choose between Now and Later."

Hunter S. Thompson, 1967: "Hell's Angels: a strange and terrible Saga"

KPAO astrophysical parameters envelope

General purpose instrument delivering:

Translating AOWG requirements into Standard Units

- 120nm rms wavefront error
  - K band Strehl: 89%.
  - Diffraction limited $(\sigma_{\phi}^2 < 1 \text{rad}^2)$ to 750nm
- Laser Guide Star constellation
  - Substantial sky coverage.
  - PSF independent of astrophysical morphology or magnitude.

KPAO astrophysical parameters envelope

General purpose instrument for infrared:

- Higher Strehl, more stable PSF
  - Sky coverage important. Conscious choice to prioritize it with respect to highest Strehl (e.g. extreme AO).
  - High Strehl improves contrast as side effect. But main drive is for PSF calibration and stability issue. Improve quantitative measurements (photometry, source confusion)
  - Sensitivity in IR: gain from increased Strehl, but may impose strict requirement on emissivity.
  - First stage (both scientific and technical) for extreme AO.

KPAO astrophysical parameters envelope

General purpose instrument for infrared:

- Higher Strehl, more stable PSF
    - Lower level of artifacts and speckles
    - PSF calibration and reconstruction for accurate knowledge
  - More accurate photometry, less source confusion.
- “Sweet spot” for redshift z=2.3
    - Hα & NII in K band
    - OIII & Hβ in H band
    - OII, 4000 Break in J band

KPAO astrophysical parameters envelope

General purpose instrument for infrared:

- Higher Strehl, more stable PSF
    - Lower level of artifacts and speckles
    - PSF calibration and reconstruction for accurate knowledge
  - More accurate photometry, less source confusion.
- But limitations
  - PSF stability dominated by non-phase errors
  - PSF structure dominated by diffraction

KPAO astrophysical parameters envelope

General purpose instrument for infrared:

- PSF stability dominated by non phase errors
  - Super speckles
    - Believed to originate from intensity fluctuations or phase errors not in pupil plane (generate intensity fluctuations on pupil).
    - These may propagate through AO system via aliasing
  - Telescope
    - Entire chain from telescope pupil to detector.
    - This is what 120nm r.m.s refers to.
    - May have impact on segment figures, vibrations, etc. (first order included in simulations).

KPAO astrophysical parameters envelope

General purpose instrument for infrared:

- Higher Strehl, more stable PSF
    - Lower level of artifacts and speckles
    - PSF calibration and reconstruction for accurate knowledge
  - More accurate photometry, less source confusion.
- But limitations
  - PSF stability dominated by non phase error
  - PSF structure dominated by diffraction

KPAO astrophysical parameters envelope

General purpose instrument for infrared:

- PSF structure dominated by diffraction
  - E.g. RY Scuti,
    - Blue is V band HST traces ionized gas
    - Red is Lp at Keck traces dust
    - Strehl estimated at 81~ 86%
    - Quantitative photometry of dust inner disk difficult unless
      - Accurate knowledge of PSF
      - And trust in deconvolution
      - Or coronagraph, apodization, pupil densification…?

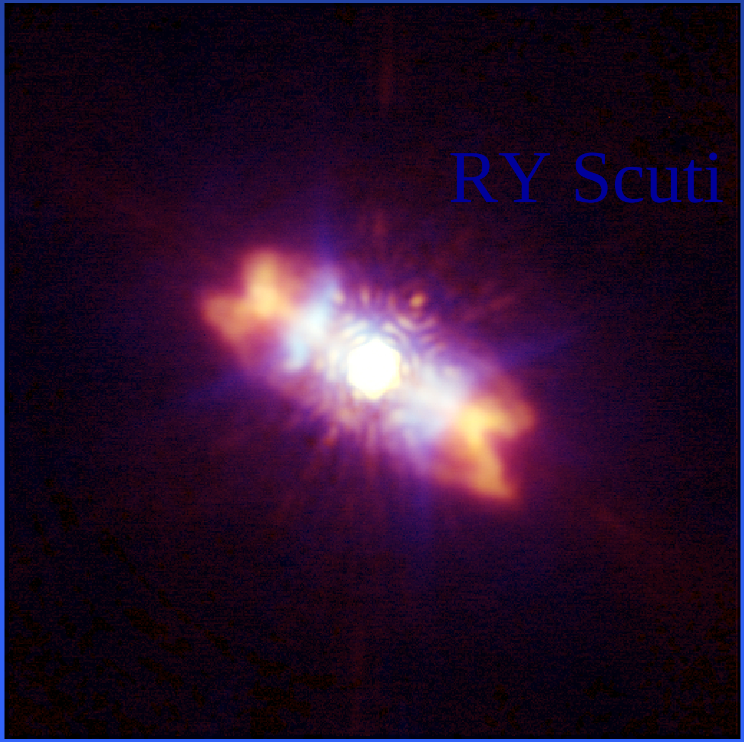


Image Credit: W.M. Keck Observatory and HST

KPAO astrophysical parameters envelope

General purpose instrument for infrared:

- PSF structure dominated by non phase error and diffraction.
  - Note that extreme AO will address these two issues
    - Focal plane wavefront sensing
    - Coronagraph
- So the current system represent limits of what is achievable with given requirements.
  - as long as one requires general purpose (I.e. non specific science case driven).

KPAO astrophysical parameters envelope

General purpose instrument for infrared:

- Higher Strehl, more stable PSF
  - Lower level of artifacts and speckles
  - PSF calibration and reconstruction for accurate knowledge
- Numerous applications including Galactic Center, AGNs, YSOs & disks, faint companion searches.

KPAO astrophysical parameters envelope

General purpose instrument for visible:

- Diffraction limit down to R band
- Complementarity to TMT's spatial resolution in the NIR (although similar spec, 4 years niche)
- Gain in sensitivity S x D/r_0
  - Typically a gain in exposure time of 10 to 15 w.r.t seeing-limited (in the visible)!
  - In case of spectroscopy, slit can be 10 to 15 times smaller
    - But Strehl still small so detailed calculation for sensitivity still needs to be carried out.

KPAO astrophysical parameters envelope

General purpose instrument for visible:

- Diffraction limit down to R band
- Complementarity to TMT's spatial resolution in the NIR (although similar spec, 4 years niche)
- Gain in sensitivity S x D/r_0
  - Typically a gain in exposure time of 10 to 15 w.r.t seeing-limited (in the visible)!
- Polarization studies (stronger (and easier) in visible), YSOs, disks, etc.

KPAO astrophysical parameters envelope

General purpose instrument for visible:

- Diffraction limit ($\sigma_\phi^2 < 1 rad^2$) down to R band
    - But can become a requirement

λ (nm)	450	500	550	600	650	700	750	800
Residual wavefront error requirement (nm rms)	71	80	88	95	103	111	120	127
λ/D (mas)	9.3	10.3	11.3	12.4	13.4	14.4	15.5	16.5

- Or evolution path when TMT comes online.

KPAO astrophysical example

- Only included to stimulate imagination
- But real science cases will come out of the talented and resourceful astronomers of UC/Caltech communities.
- Benefits to many areas of astrophysics.
- See Science case Draft document (KAON 331)

KPAO astrophysical example

- Benefits to many areas of astrophysics:
  - Planetary, 10 to 15mas monitoring of meteorological or volcanic activity, many spectral lines in visible…
  - Star formation, YSOs, disks, low mass companions
  - Area that benefits the most is without a doubt extragalactic.
- See Science Case draft document (KAON 331)

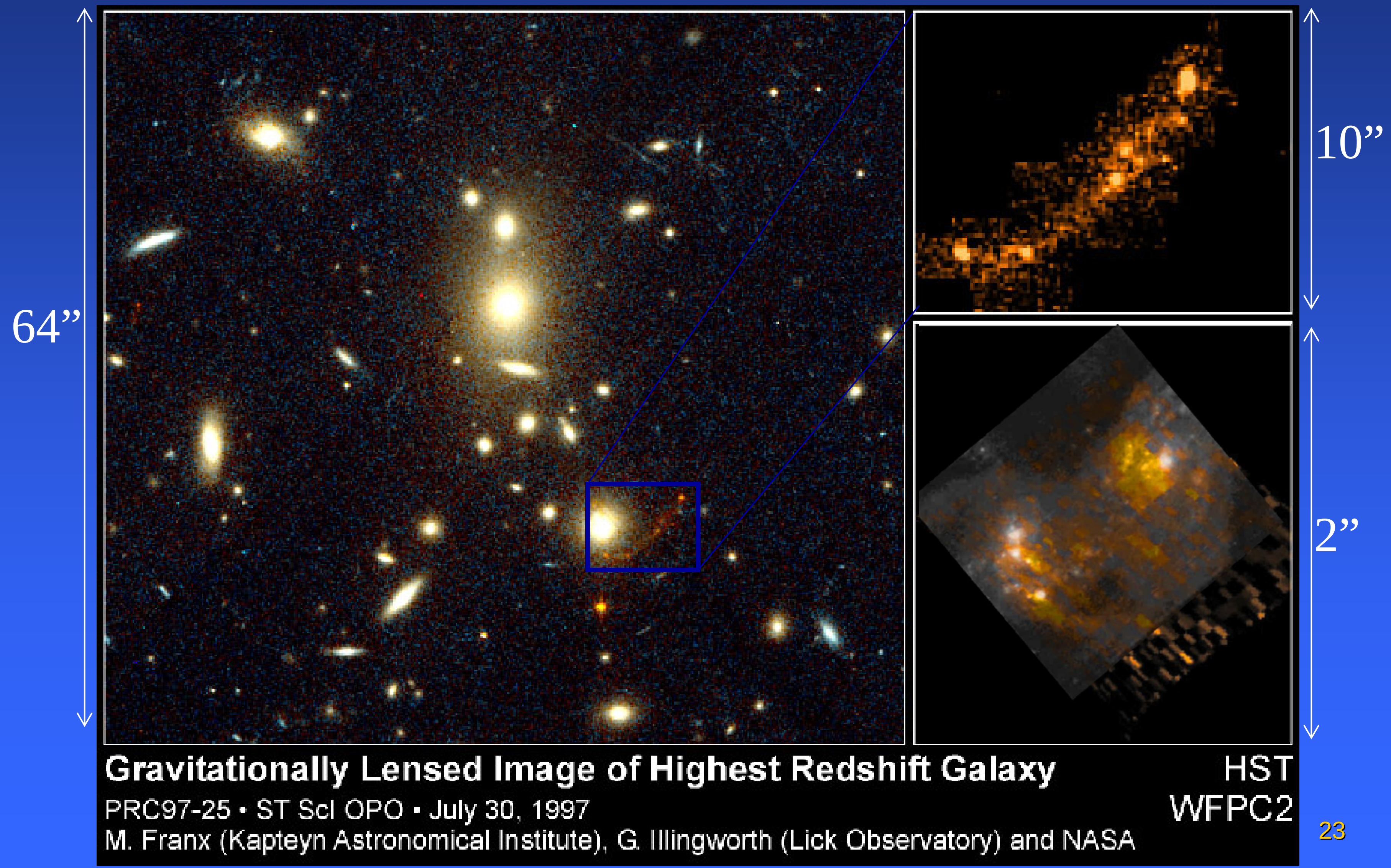
KPAO astrophysical example

- Area that benefits the most is without a doubt extragalactic.
  - Distant quasar hunting
    - unresolved sources in visible where sensitivity increase is greatest
  - Assembly of galaxy masses.
    - Complex kinematics at z~1, Lyman break kinematics at z~3. Modern mass disks at z~2?
  - Variations within NLR of individual AGN, and detailed comparisons of many AGN. Testing standard paradigm.
  - Evolutionary (or not) linkages between ULIRGS, Quasars and normal galaxies.
  - Formation of bulges and tie to central black hole.
    - Central velocity dispersions in local galaxies.
    - Bulge formation tied to quasar epoch?
    - Test new CDM models of galaxy formation.

KPAO astrophysical example

- Gravitational lensing
  - Spectroscopy of “dark ages” galaxies through gravitational amplification and higher sensitivity in visible.
    - E.g. arc in Abell 2218 observed with HST&Keck
      $6.6 < z < 7.1$, gravitational amplification ~ 25.
  - Can even probe morphology and dynamics
    - If arcs are resolved, possible to disentangle arc like structures by modeling deflecting potential.
    - Reconstruct image of galaxy.
    - Many early galaxies have very irregular shapes, probing F-UV (50 to 100nm rest frame wavelength)
  - HST view of CL1358+62

KPAO astrophysical example



KPAO astrophysical example

- Only included to stimulate imagination
  - However, real strategic choices will have to be made soon:What (kind of) instrument(s) will this feed?
    - Visible or IR
      - Which wavelength range, size of the field, with what spatial sampling?
    - Imaging and/or spectroscopy
      - Dedicated Distant quasar imager and ranger?
      - Near IR OSIRIS-like IFS for nearby AGNs, and z=2 evolution scenarios
  - Instrument should be part KPAO design (and vice versa) so requirements are not unduly limited by either one.

KPAO astrophysical example

- Only included to stimulate imagination
- But real science cases will come out of the talented and resourceful astronomers of UC/Caltech communities.
- Help required to fill out Science case document.
  - AOWG restructuring.
  - KPAO Science team.

Program & Technical Update

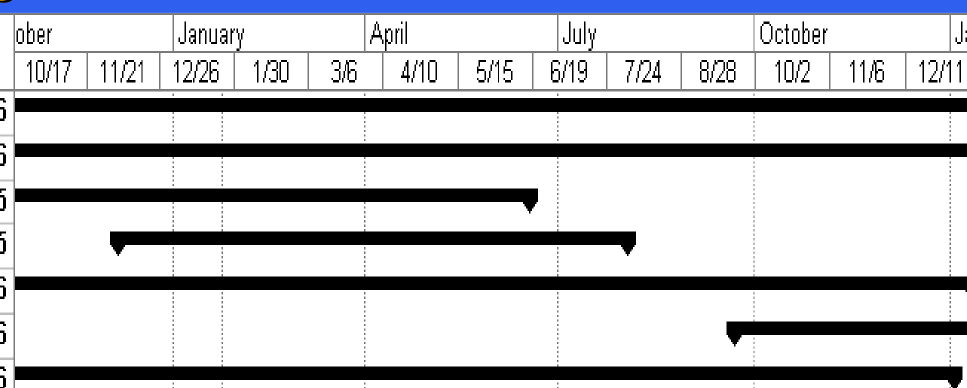
- Goal: produce a well developed proposal by early 2006 to seek external funding to build KPAO.
  - Observatory funding at 1.5 ftes in FY05 & 0.5 in FY06
- This will require:
  - well developed requirements,
  - a sufficiently developed design to have confidence the requirements can be met,
  - a credible budget and schedule,
  - appropriate review & approval.

KPAO Progress to Date (FY05)

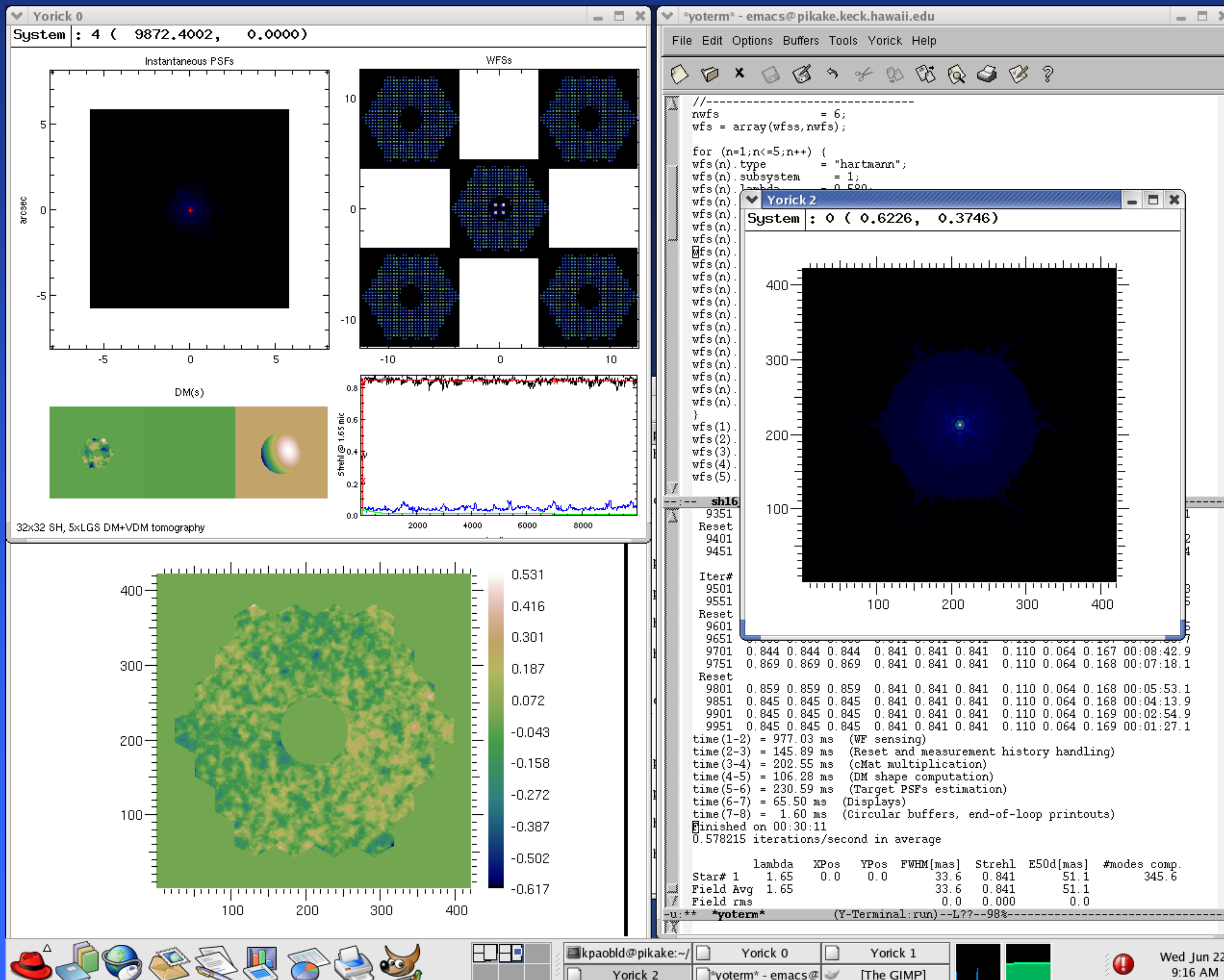
Status of major WBS elements:

1. Science case & requirements (10% complete)
   - Draft science case document prepared for community input
   - SSC working on setting up a KPAO science team
2. Performance prediction (75% complete)
   - Simulations of 120 & 180 nm systems, including vibration & segmented telescope errors, IR background calculations, & Na laser return (including saturation)
3. System design (10% complete)
   - AO bench optical design begun
4. External proposal
5. Management plan including cost/schedule

ID	Task Name	Duration	Start	Finish
1	KPAO system design year one	352 days	Mon 10/4/04	Tue 2/14/06
2	Milestones	352 days	Mon 10/4/04	Tue 2/14/06
15	KPAO science case and requirements	180 days	Mon 10/4/04	Fri 6/17/05
42	KPAO performance	169 days	Mon 12/6/04	Tue 8/2/05
65	KPAO system design	328 days	Mon 10/4/04	Wed 1/11/06
96	KPAO proposal	104 days	Thu 9/22/05	Tue 2/14/06
120	KPAO management	321 days	Mon 10/4/04	Mon 1/2/06

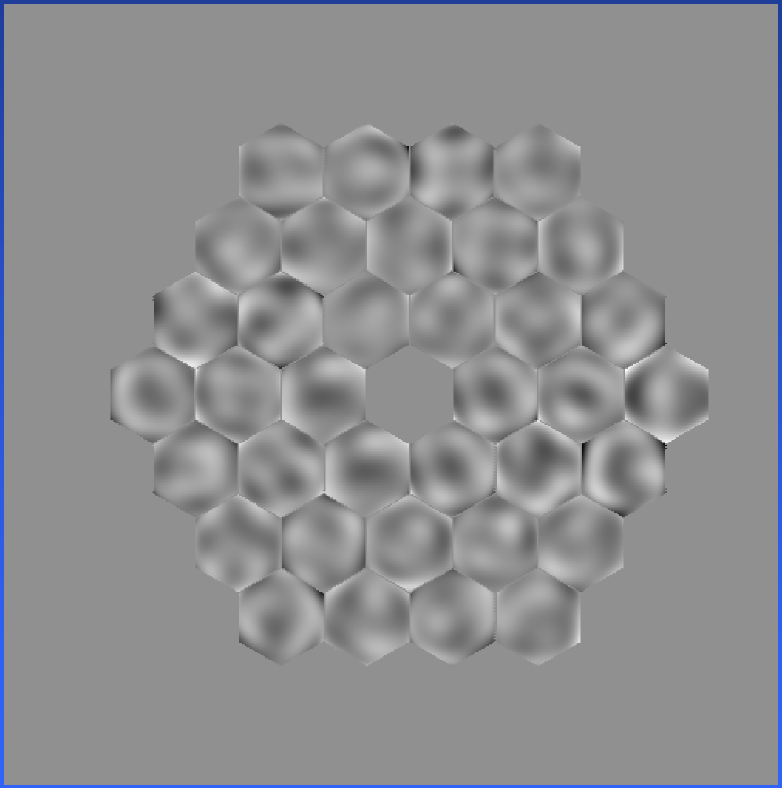


KPAO Simulation Screen Shot

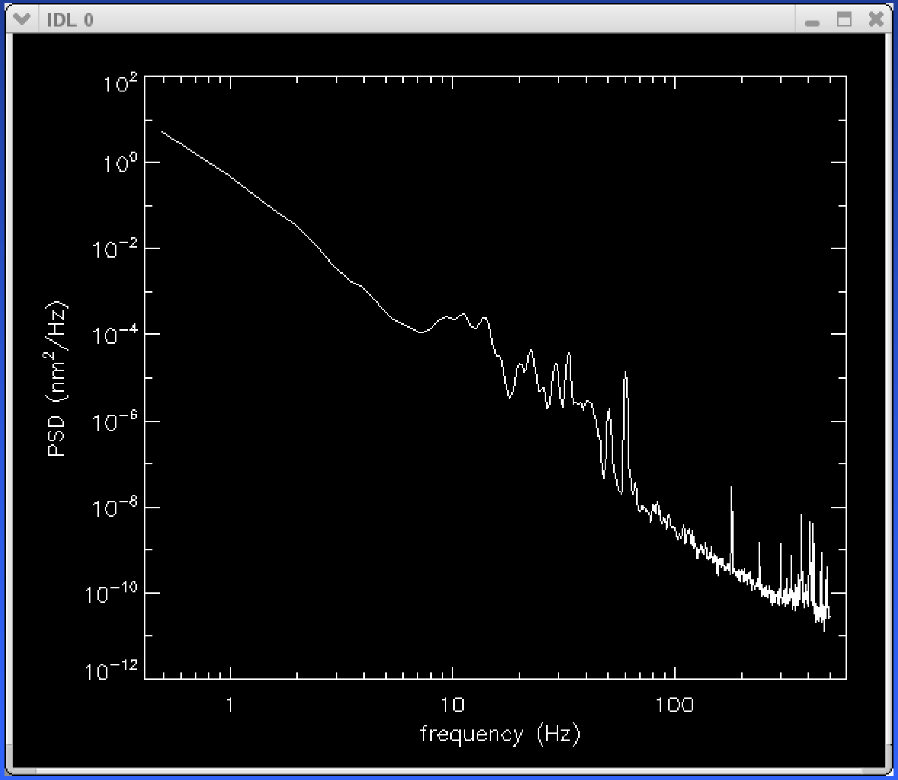


Keck specific simulation inputs

Segment phase errors



Vibration spectrum



Sample KPAO Wavefront Error Budget

Error Type			Simulation parameters	Simulation parameters
Fitting Error	65	54	700 act (32x32)	1300 act (40x40)
Servo Error	45	35	1000 Hz	1500 Hz
Measurement Error (noise)	60	40	15 W (CW) laser, 6e- CCD	20 W (CW), 1e- CCD
Focus Anisoplanatism	58	45	5 LGS (corners + center)	7 LGS (hex. + center)
Alias, reconstruction	48	35	SVD	Estimate from Linear AO model
Total for Higher Order AO	**125**	**95**		
Telescope	70	50	Allocation	Allocation
Instrument	50	35	Allocation	Allocation
Tracking (noise, servo & iso.)	97	40	Allocation	Allocation
Total	**180**	**120**		

Summary

- Important to develop science requirements as part of the conceptual design process.
  - Therefore desire more community involvement.
- Performance analysis tools in place to do science/technical trade studies.
- Emphasis soon to switch to system design issues.