Keck laser guide star:
Science case

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Science case: Central issues

- How do Keck NGS and LGS AO compare with AO systems on other 8-10 m telescopes?

- How does Keck AO compare with HST NICMOS?

- What is the unique science that can be done with Keck laser guide star?

- What is the relevant time window?
AO systems on 8–10 m telescopes in next few years

• **Gemini:**
  - N: Hokupaa (curvature, 36 deg's of freedom now, 85 in 2001)
  - S: Hokupaa 85 with ~2 watt CW dye laser (~2003, no funding yet)

• **VLT:**
  - NAOS (Shack-Hartmann, summer 2001)
  - SINFONI (curvature, 60 deg's of freedom, late 2002)

• **Subaru:**
  - Curvature, ≤ 36 degrees of freedom
**AO systems on 8-10 m telescopes in next few years**

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Lasers are all officially estimated for 2003; likely “first science” is probably a year later
NGS Strehl Ratio for Existing AO Systems on Keck and Gemini

- Keck: 250 deg’s of freedom, 0.1% sky coverage
- Gemini N Hokupaa: 36 deg’s of freedom, 5% sky coverage

Guide star magnitude vs. Strehl ratio for K Band.
Predicted NGS Strehl, New AO Systems

- Keck Predicted
- VLT NAOS
- Gemini ALTAIR
- VLT SINFONI
- Gemini Hokupaa 85
- K Band

Guide star magnitude vs. Strehl ratio

- Curvature
- Shack-Hartmann
Lessons from graphs

• Curvature AO systems:
  - Lower Strehl ratios for bright guide stars
  - Retain some performance \((S \sim 0.1)\) for \(M = 17\) stars

• Shack-Hartmann AO Systems:
  - Higher Strehl ratios for bright guide stars \((M < 13)\)
  - Need laser to work well with faint guide stars

Keck AO system was designed to work with a laser
Laser will strongly increase Keck AO sky coverage

From Keck AO “Blue Book”

Current Strehls are 1/2 this value

M ~18  M ~19
Keck AO imaging is better than NICMOS, for bright guide stars

Example: Double nucleus of NGC 6240, a galaxy merger

Hubble Space Telescope:
NICMOS image in J, H, K

Adaptive optics image at Keck:
K band

1.6 arc sec
Keck AO NIRSPEC spectra are unrivaled by NICMOS on HST

NIRSPEC spectrum: dual nucleus of NGC 6240

H₂ emission line 1-0 S(1) from shocked or ionized gas shows clear velocity structure
What unique science can be done with laser at Keck?

• Laser is key enabler for extragalactic work
  - For Keck at K band, laser increases sky coverage from 0.1% to ~ 50% (half-maximum Strehl values)

• Extragalactic science:
  - Extragalactic distance scale (Cepheids, IR surface brightness fluctuations, planetary nebula luminosity functions, supernovae)
  - Galaxy morphology and evolution at high and moderate Z
  - Gravitational lensing by individual galaxies
  - Quasars, starburst galaxies, Seyferts, radiogalaxies, mergers
Galactic science enabled by laser guide star AO

• Globular clusters
  - Central regions, mass segregation, low-mass stars, binaries

• Galactic bulges
  - Stellar populations in Milky Way, nearby galaxies

• Protostellar objects and young stars
  - Could also be done with IR wavefront sensor (if we had one)

• Solar system
  - Io volcanos, asteroids, Pluto spatially resolved spectroscopy
Next-generation laser is too far away

- **Next 3-4 years: dye lasers will be only game in town**
  - VLT’s first laser will probably be pulsed dye laser (Max Planck)
  - Gemini’s first laser will probably be commercial CW dye

- **Next generation: solid-state sum-frequency lasers**
  - Full-up lab prototypes should be working in 1 - 2 years
  - After lab prototype, anticipate another 1 - 2 years for engineering, facilitization (Dee Pennington @ Keck; Bob Byer + Lightwave @ LIGO)
  - All-fiber lasers are a couple of years behind “bulk” lasers
What is relevant time window?

- Gemini, VLT: goal is to have lasers ready in 2003
  - I think 2004 is probably more realistic for first science

- Next-generation technology ready for summit ~2005

- If Keck laser commissioning can be done within ~ 1 yr, Keck will be primary 8 - 10 m telescope with laser for 2 - 3 years

- Allows us to do important science; allows CARA to build up expertise needed for next-generation laser
Conclusions

- Keck laser guide star will access unique science
- Timeliness is important
  - Unique time window for LGS science at Keck
  - In my judgement it will not be possible to keep LLNL + CARA laser team together unless laser goes to summit promptly
  - Timeliness is also important to lay foundation for next-generation laser at Keck
    • Next generation is ~ 5 years away, but won’t be accessible unless there is a knowledgeable CARA team in place