

# **Theme 2: Adaptive Optics for Extremely Large Telescopes**



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## AO for 30-meter diameter telescopes

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- National Academy of Sciences' decadal study on astronomy and astrophysics recommended a 30-m “Giant Segmented Mirror Telescope” as very high-priority for the next decade
- Adaptive optics for such a telescope will incorporate features significantly more sophisticated than those used today
- **Basic AO scaling and operation not yet well understood**
- A “Problem” and an “Opportunity” for the CfAO



## Outline of Talk

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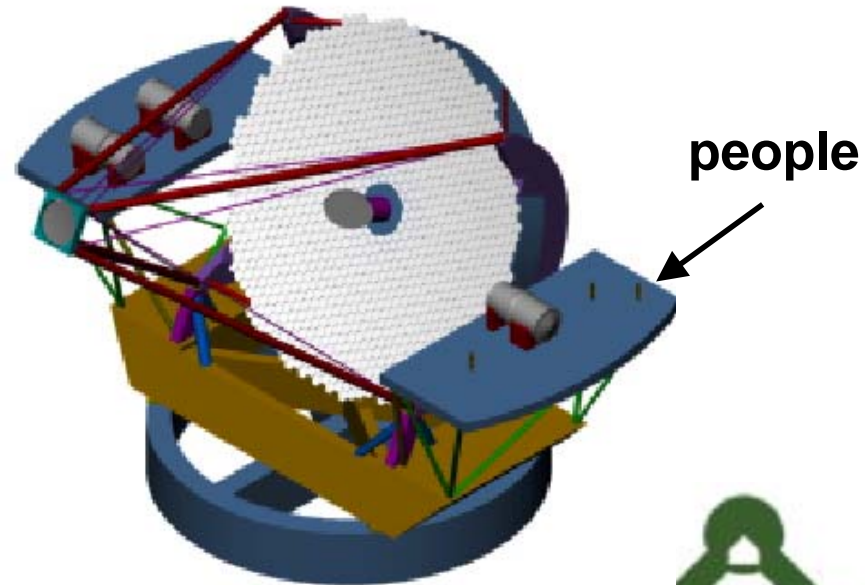
- **Issues for AO on giant telescopes**
- **Goals of Theme 2**
- **Two new initiatives**
- **Summary**



## Example: CELT California Extremely Large Telescope

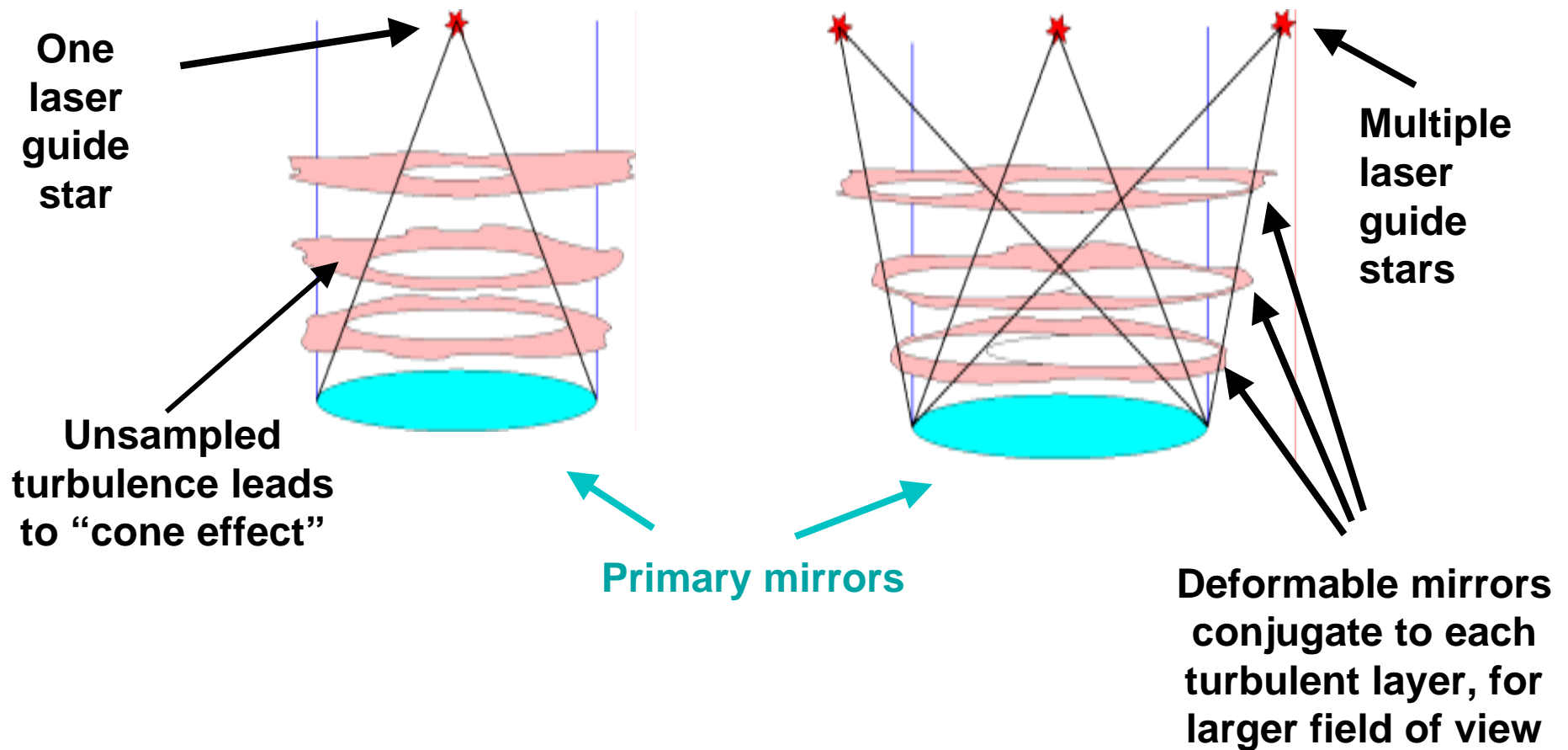
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- 30-m segmented mirror telescope with adaptive optics
- University of California and Caltech initiative
- Compare telescope structure with baseball diamond:





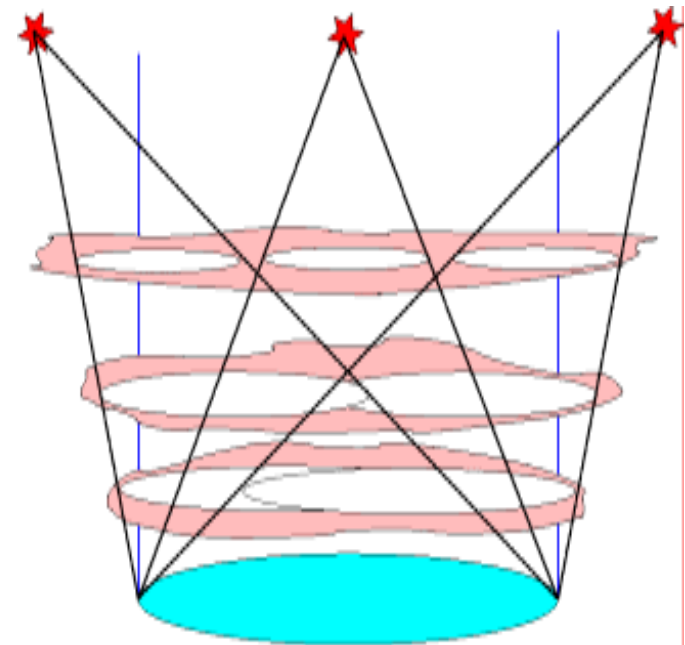
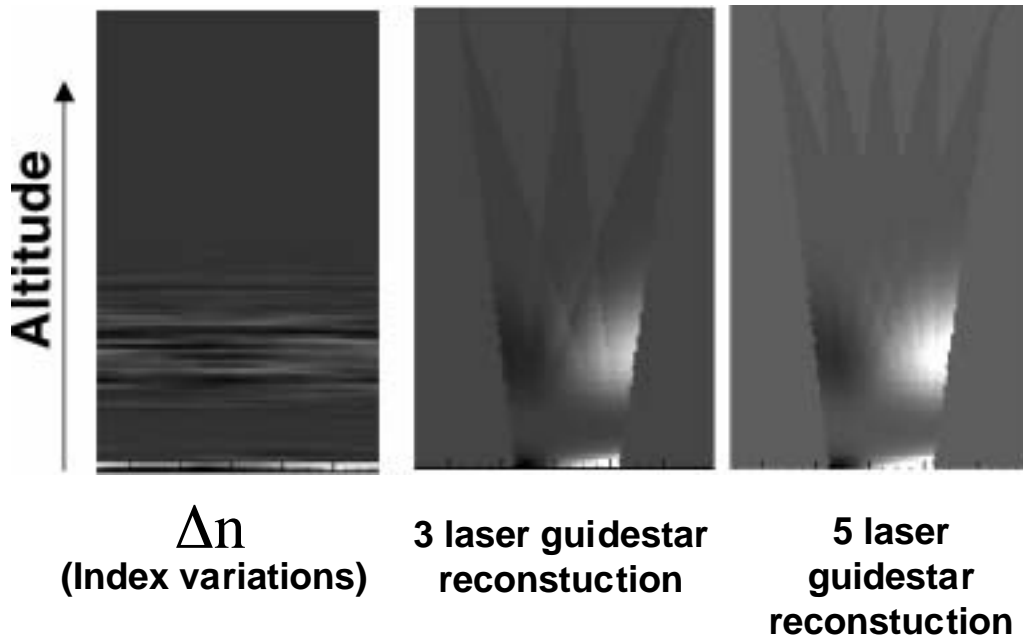
# Extremely Large Telescopes: Why is AO Different?





# Diameter so large that you can use “tomography” on atmosphere

- Multiple guide stars  $\Rightarrow$  multiple “views” through 3D structure of turbulent layers





# Issues of scale, cost, reliability for next generation of giant telescopes

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- **Scale:**

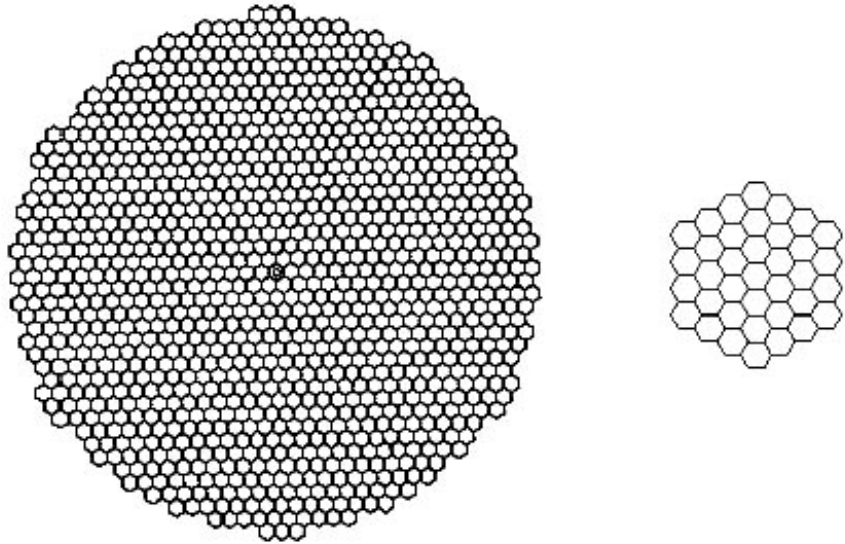
- Keck 36 segments
- CELT ~ 1000 segments

- **Cost:**

- Keck < \$100M / telescope
- CELT: good fraction of \$1B

- **Reliability:**

- Example: laser guide stars
- Keck: 1, can give personal attention
- CELT: 5 to 10, must be robust on an industrial scale
- Importance of systems engineering, industrial-strength hardening of all telescope components and systems



**\$1B facilities are a qualitatively different beast than \$100M facilities**



## Technology developments needed

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- **Fast algorithms for tomography, wavefront reconstruction**
- **Deformable mirrors with many 1000's of degrees of freedom and diameters ~ 30 cm**
- **Fast sensors that can measure wavefront at 1000's of locations at ~ 1 kHz frame rates**
- **Lasers for sodium-layer laser guide stars**
- **AO systems that are robust, not impossibly complex to implement and operate**



## Goals for Theme 2: AO on ELT's

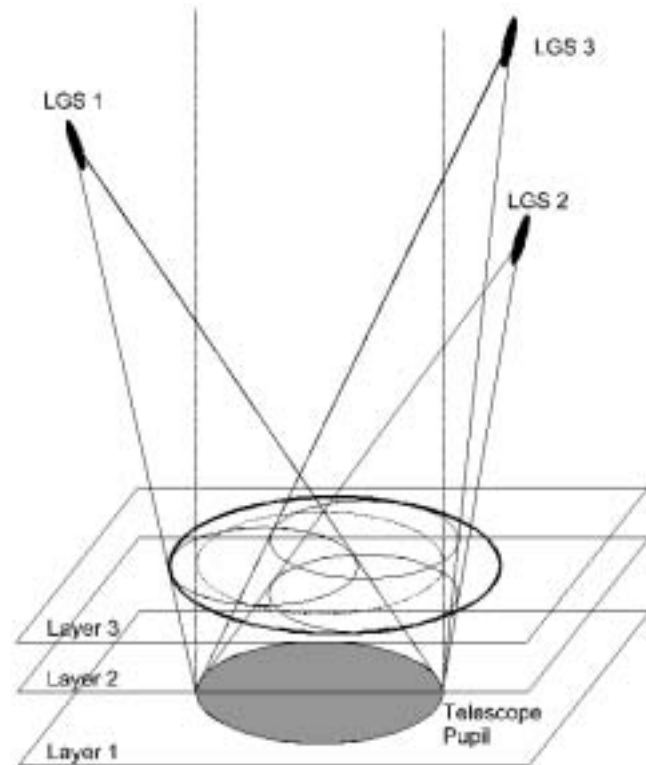
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- **Develop at least one workable point design for multiconjugate AO (MCAO) on a 30-m telescope**
- **Develop partnerships to co-fund hardware technology development for key components, including lasers**
- **Develop techniques for doing quantitative astronomy with laser guide stars**
- **Pursue astronomical science related to AO on 30-m telescopes**



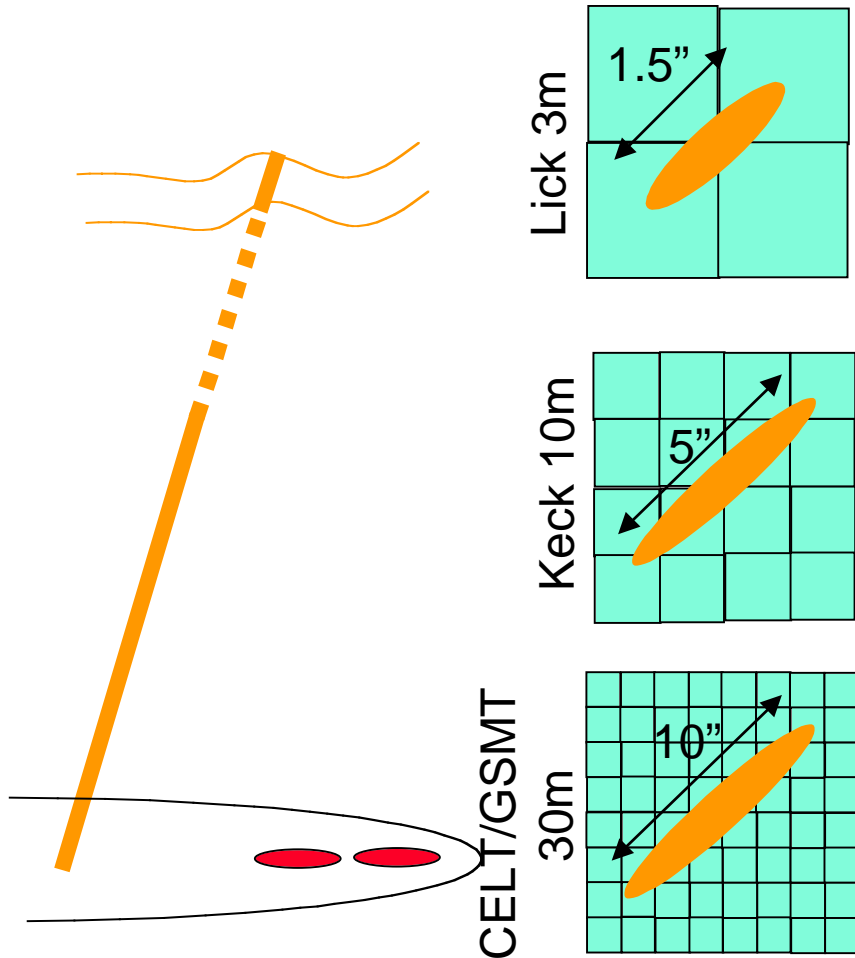
## A. Develop at least one workable point design for MCAO on a 30-m telescope

- Today there are concepts but not quantitative “point designs” for MCAO on 30-m telescopes
- Important issues: tomography vs. layer-oriented, laser guide star spot elongation, optical design, ....
- In Year 4 we initiated a collaborative analysis, modeling, and simulation effort aimed at a “point design” for AO on a 30-m telescope





# Laser Spot Elongation is important problem for 30 m telescope AO



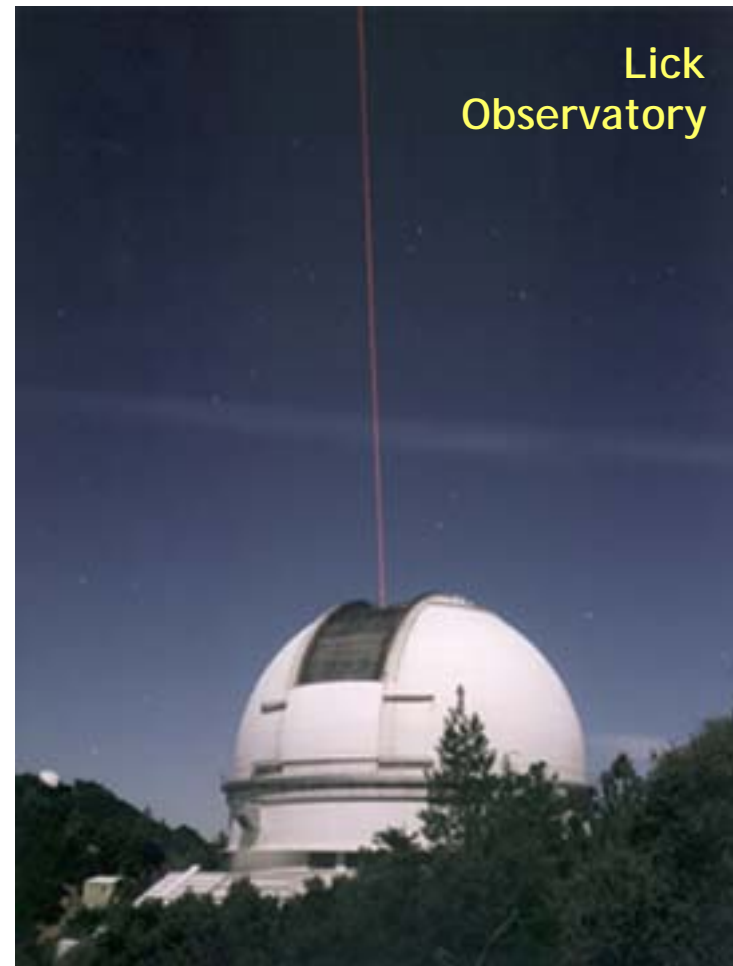
- Laser spot becomes elliptical when viewed far from projection telescope
- Increases measurement error in the “long” direction
  - poor centroiding
- How we can mitigate spot elongation?



## B. Develop partnerships to co-fund hardware technology development for key components

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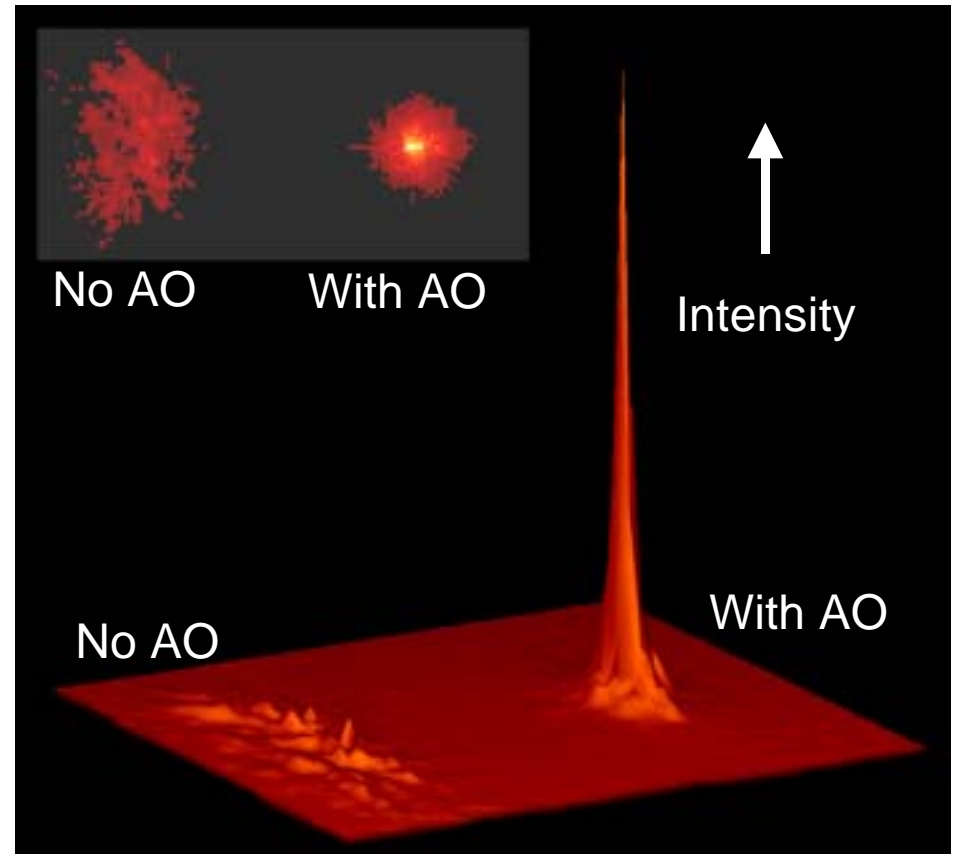
- **Problem: components are VERY expensive**
  - Partner to develop hardware components at meaningful level
- **Laser beacons**
  - Focus on sodium beacons
  - Currently pursuing two laser hardware approaches
- **Deformable mirrors**
  - Focus on MEMS devices, large sizes (> 30 cm)





## C. Develop techniques for doing quantitative astronomy with laser guide stars

- **Key issue: what is “point spread function”**
  - Because turbulence strength, quality of AO correction vary with time, point spread function varies too
- **Crucial to develop methods for tracking variation of point spread function with time, position on sky**

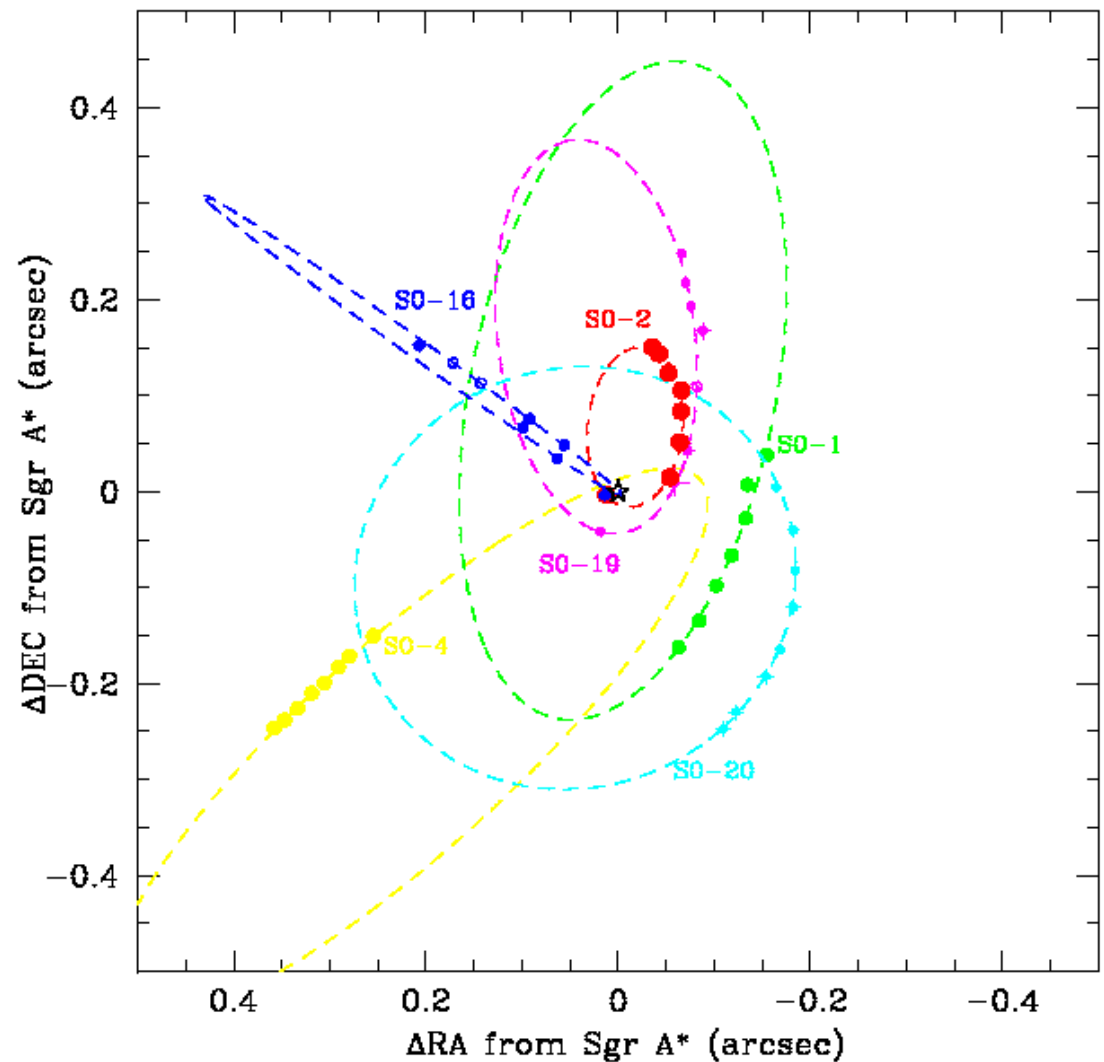


Lick Observatory AO system



## D. Pursue astronomical science related to AO on 30-m telescopes

- Use laser guide stars, develop new data analysis methods, use spectral image slicing with AO (spectra as function of  $x$  and  $y$ ), push state of the art.
- Example: motion of stars very close to the black hole at the center of our own Galaxy (Andrea Ghez)





## New Science Project this year: CfAO Treasury Survey (CATS)

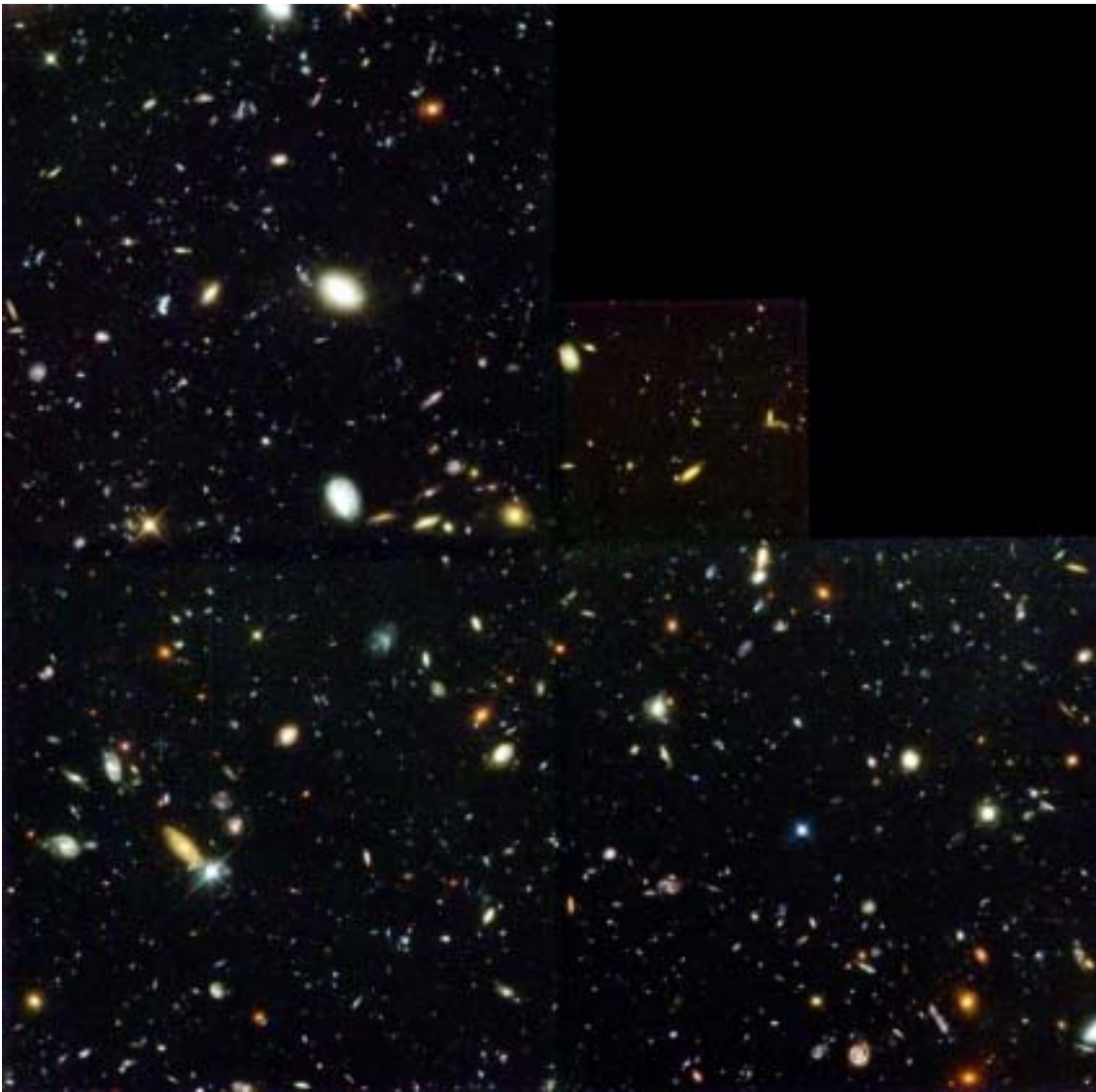
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- **“Legacy project”**
  - Deepest near-IR adaptive optics images ever
  - Young galaxies at redshifts of 0.5 - 1.5
  - Study galaxy formation and evolution,
- **Fields: GOODS, GEMS**
  - Coordinated with spacecraft observations, ground-based telescopes at other wavelengths
- **Team: UCSC, UCLA, Caltech, Gemini**
- **Facilities: State of the art AO at Keck (laser guide star), Gemini, Subaru**
- **Deliverables: public database, analysis tools**



## Hubble Deep Field North (visible light)

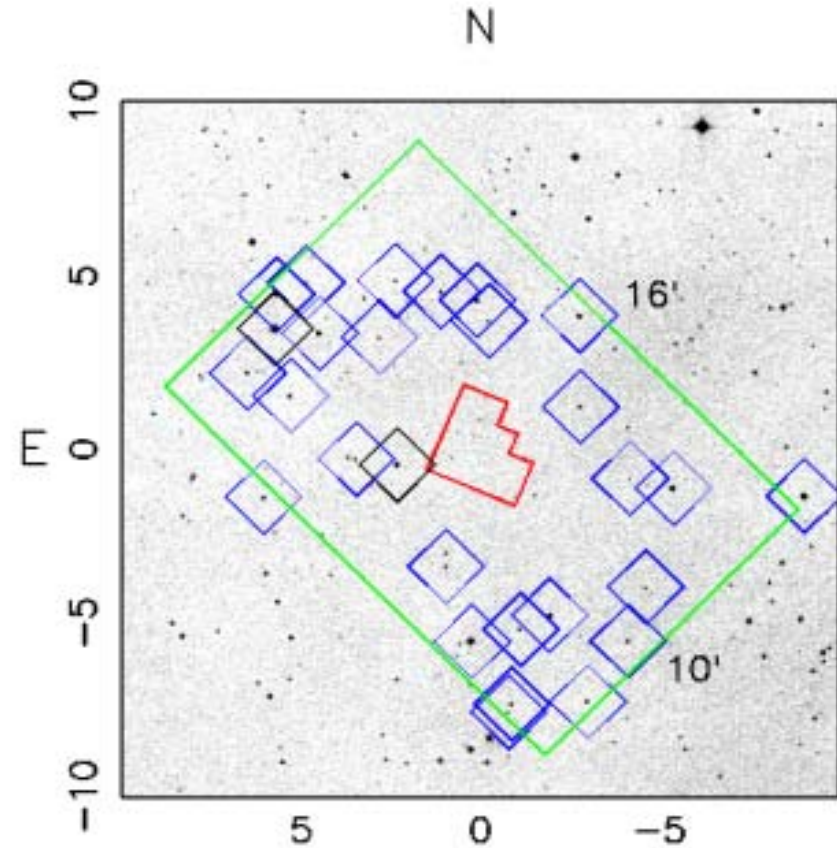
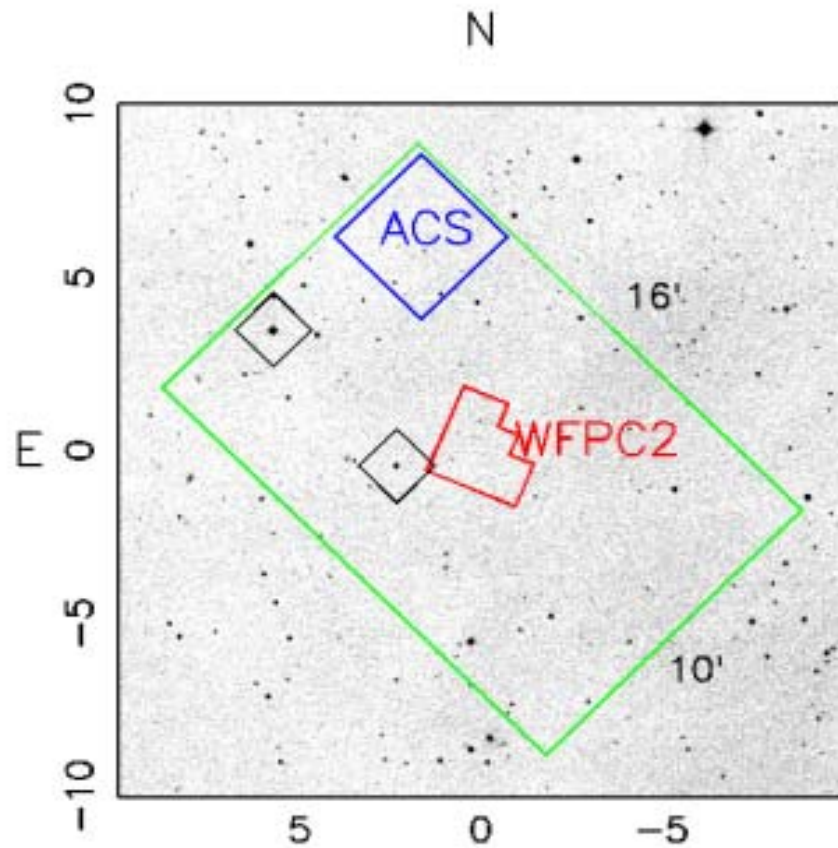
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- Every little dot is a galaxy
- We will take very deep AO images of 2 similar large fields in near IR
- High-redshift galaxies in light that was visible-light in original rest frame



# The GOODS field N: natural and laser guide star adaptive optics coverage



**Green box: GOODS field**

**Red box: Hubble Deep Field N.**

**Black boxes: natural guide star AO**

**Blue boxes: laser guide star AO**



## **New Lab for AO at UCSC: CfAO can test new concepts**

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- **Grant from Moore Foundation (~ \$9M over 5 years)**
- **Outfit labs at UCSC**
  - Test and integrate hardware, train grad students, postdocs
  - Industrial outreach
- **Testbed for AO on 30-m telescopes**
  - Scaled prototype of MCAO system, with mock lasers
  - Phase screens to mock up turbulence in lab
  - Place to test new hardware and algorithm ideas
- **ExAO lab:**
  - Hope to build up and integrate new ExAO system here
- **Component testing lab**



## Summary

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- **Adaptive optics for future 30-m telescopes will incorporate features significantly more sophisticated than those used today**
- **A suitable challenge for the CfAO**
- **We've developed four specific goals, roadmaps**
- **Exploring partnerships for hardware component development**
- **Two new long-term projects this past year: Analysis and Modeling, CATS**
- **New facility for use of CfAO and its collaborators: Laboratory for AO at UC Santa Cruz**