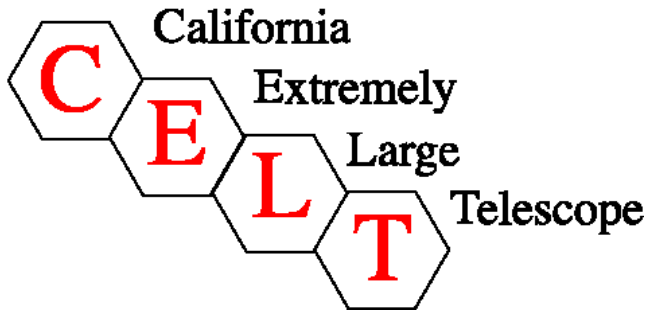


The Potential of Ground Based Telescopes

Jerry Nelson

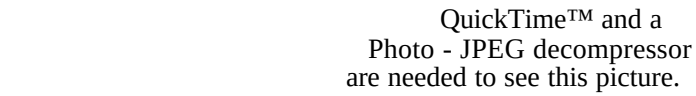
UC Santa Cruz

5 April 2002

California Extremely Large Telescope

Contents

- **Present and Future Telescopes**
- **Looking through the atmosphere**
- **Adaptive optics**
- **Extragalactic astronomy**
- **Planet searches**


QuickTime™ and a
Photo - JPEG decompressor
are needed to see this picture.

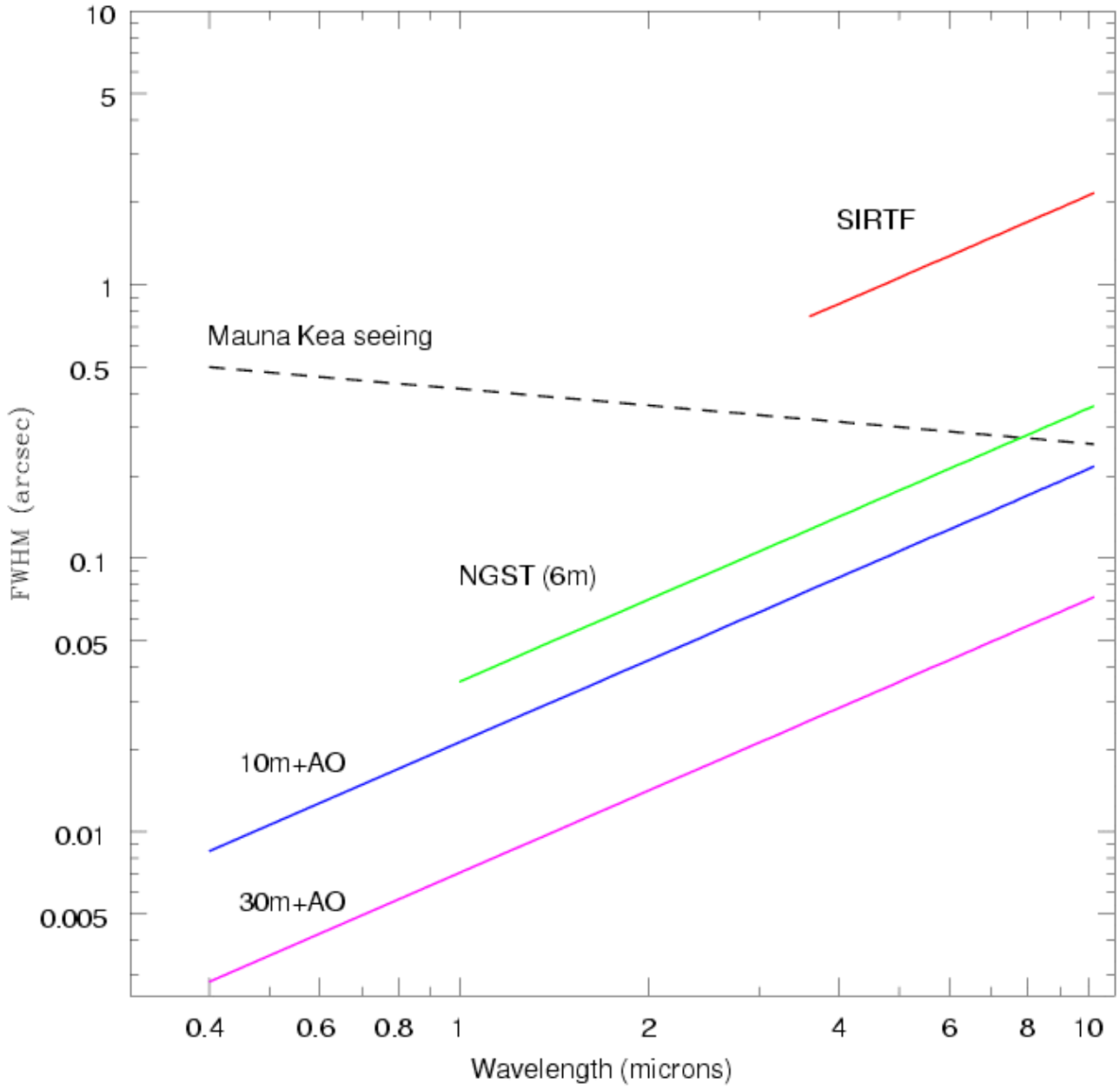
California Extremely Large Telescope

Desire for larger telescopes

- **History shows largest telescope diameter doubles every 31 years**
  - 2.5m 1917 Hooker
  - 5m 1948 Hale
  - 10m 1993 Keck
- **2001 NAS decadal astronomy and astrophysics survey committee (AASC) recommended a 30-m telescope (GSMT) as its highest ground based priority**
- **Other groups in the US and in Europe are thinking and talking about giant telescopes (up to 100-m) on the ground**
- **Advances in adaptive optics makes this particularly exciting**

California Extremely Large Telescope

- **CELT is a study to build a 30-m telescope**
- **UC and Caltech are partners**
- **Funding is not yet in hand (proposal submitted)**
- **Site is unknown (several candidates)**


10
5
1
0.5
0.1
0.05
0.01
0.005
FWHM (arcsec)
SIRTF
Mauna Kea seeing
NGST (6m)
10m+AO
30m+AO
0.4
0.6
0.8
1
2
4
6
8
10
Wavelength (microns)

California Extremely Large Telescope

Science Potential for CELT

- **Increased angular resolution**
  - With AO can reach 0.007 arc second resolution (100x improvement)
  - Study morphological details of most distant galaxies (cosmology)
  - Study details for star and planet formation
  - Study stellar evolution in globular clusters
  - Quasars and Active Galactic Nuclei (black holes)
  - Solar system objects
- **Increased light gathering power**
  - With CELT can collect 9x the energy from an object (over Keck)
  - Spectroscopy of most distant objects known
  - Planet searches and their study

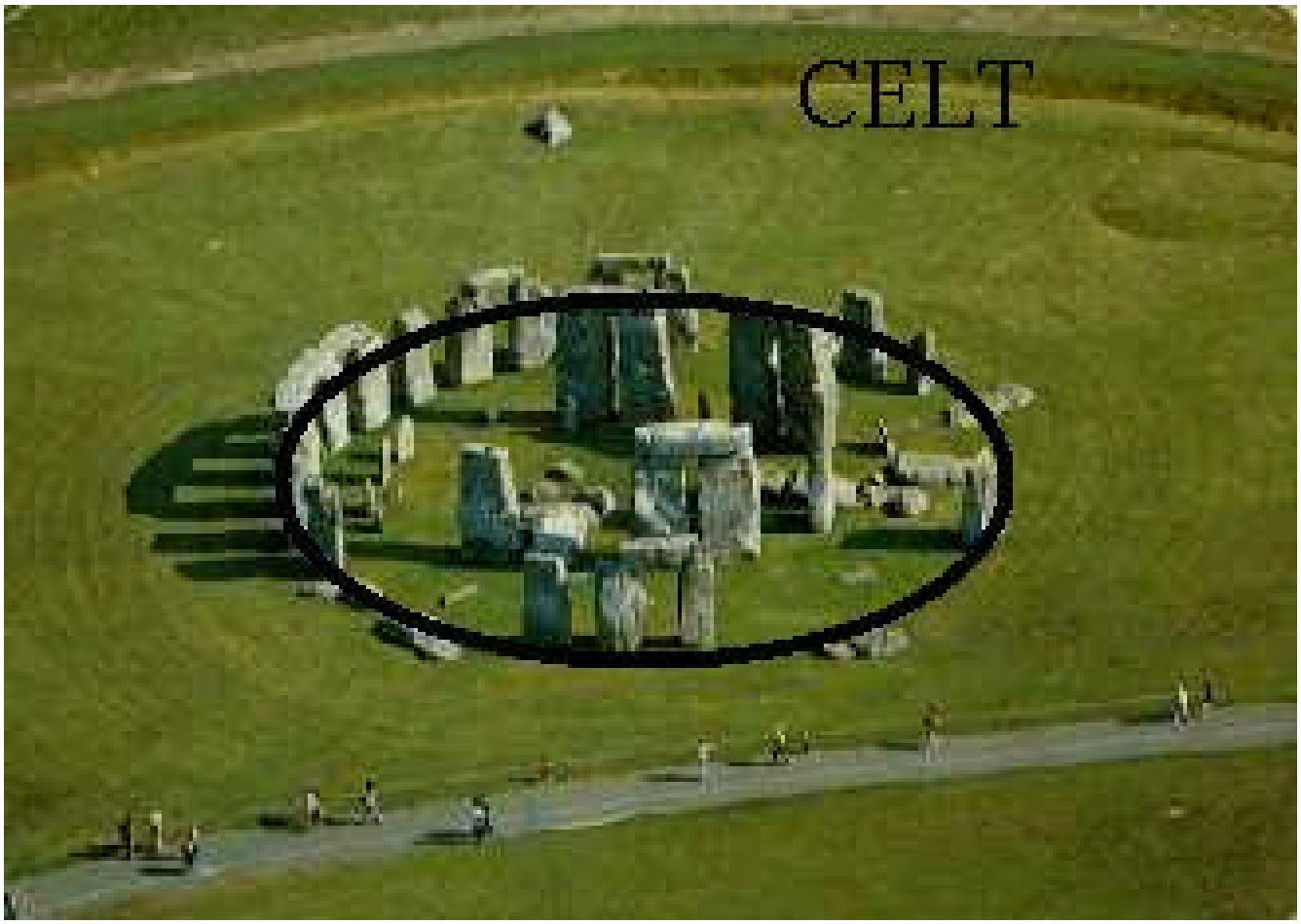
California Extremely Large Telescope

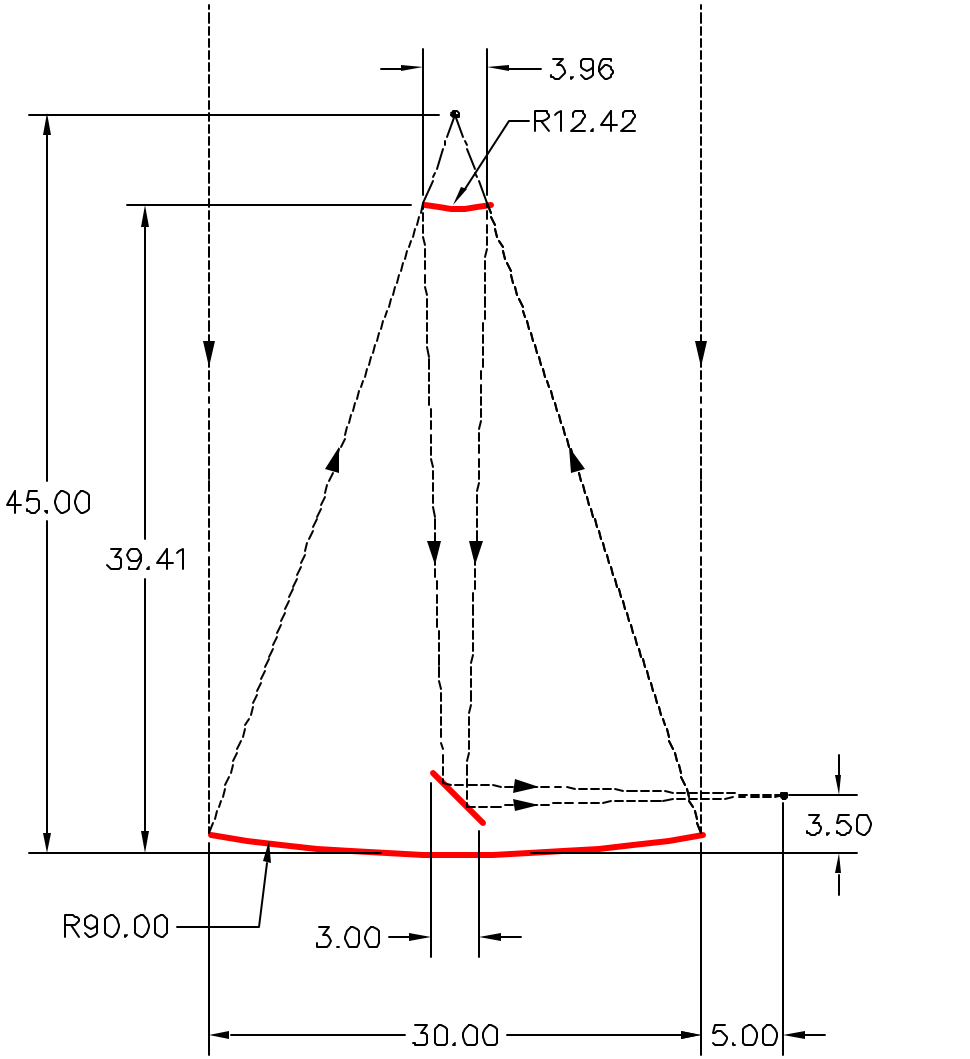
Scientific Potential

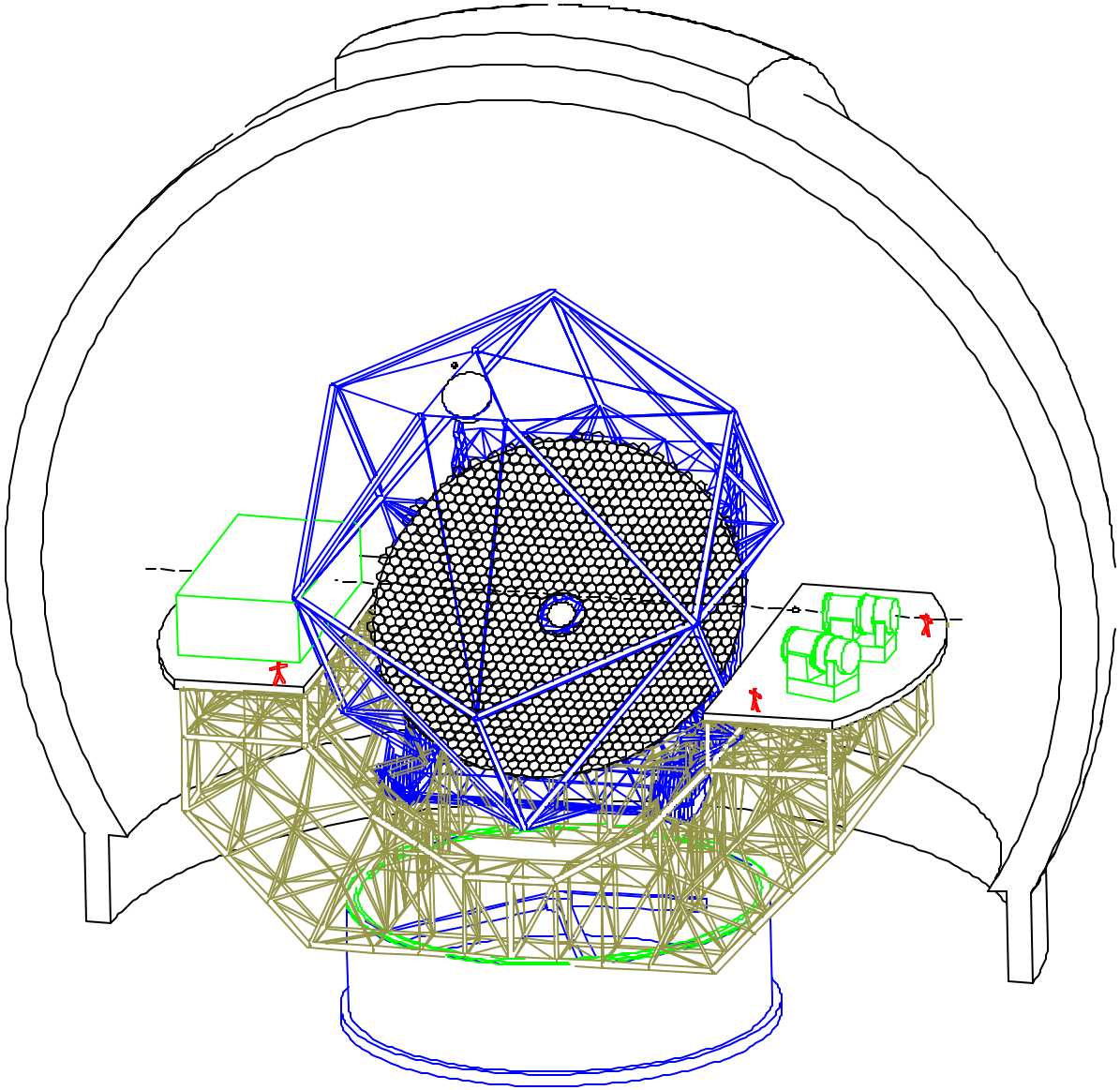
- **Seeing limited observations**
  - 0.3-1.0 µm
  - Scale 2.18 mm/arc second (f/15)
  - Wide field of view available: 20 arcminutes
- **Diffraction limited observations**
  - 1-25µm, mainly 1-2.5µm
  - Thermal IR possible, but not most important
  - At 1 µm angular resolution of 7 mas
  - Resolution element size: 15µm (at f/15, 1 µm wavelength)
  - Large field of view: 1 arc minute at 1 µm with multi conjugate AO

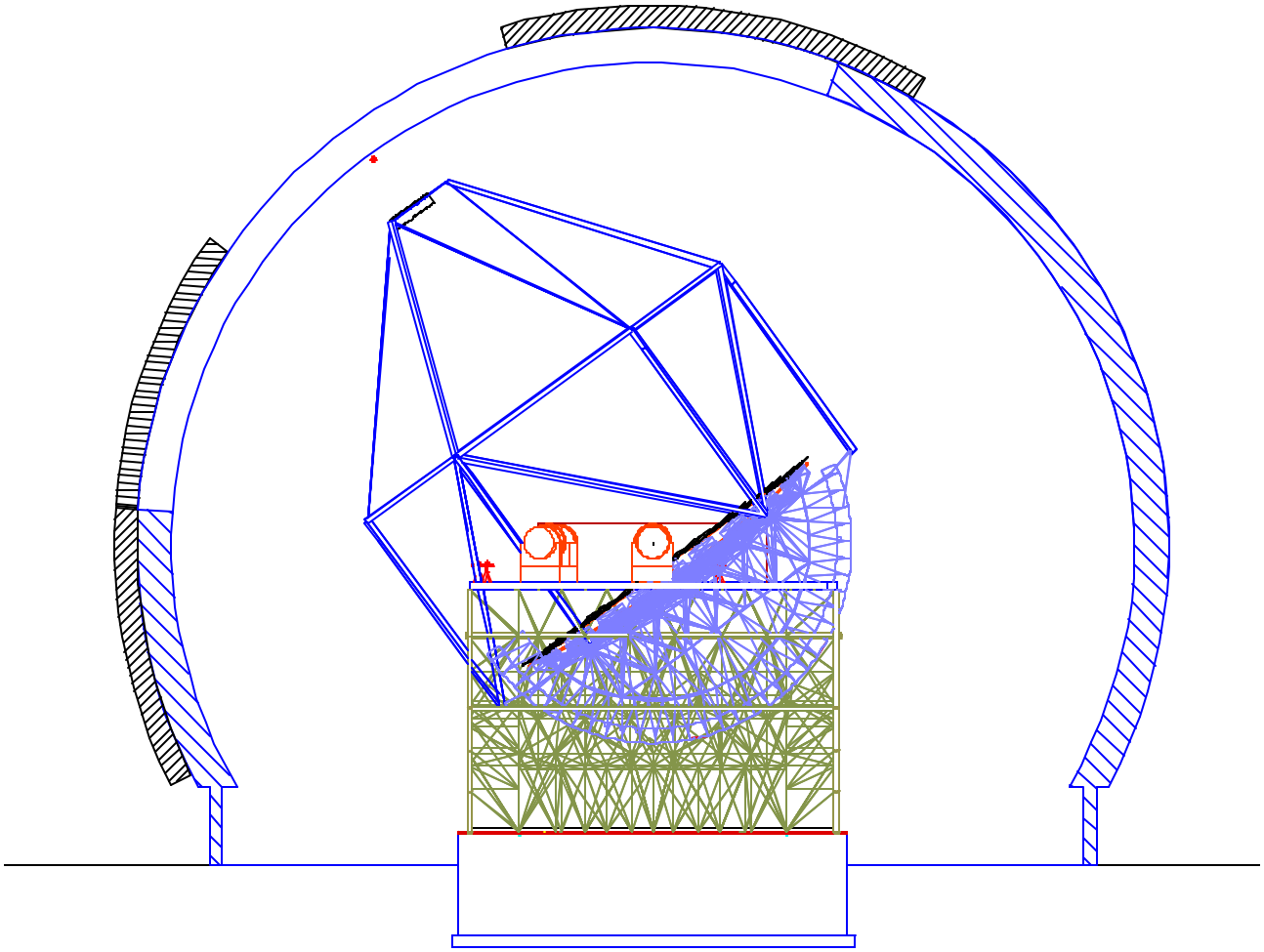
California Extremely Large Telescope

CELT and Stonehenge

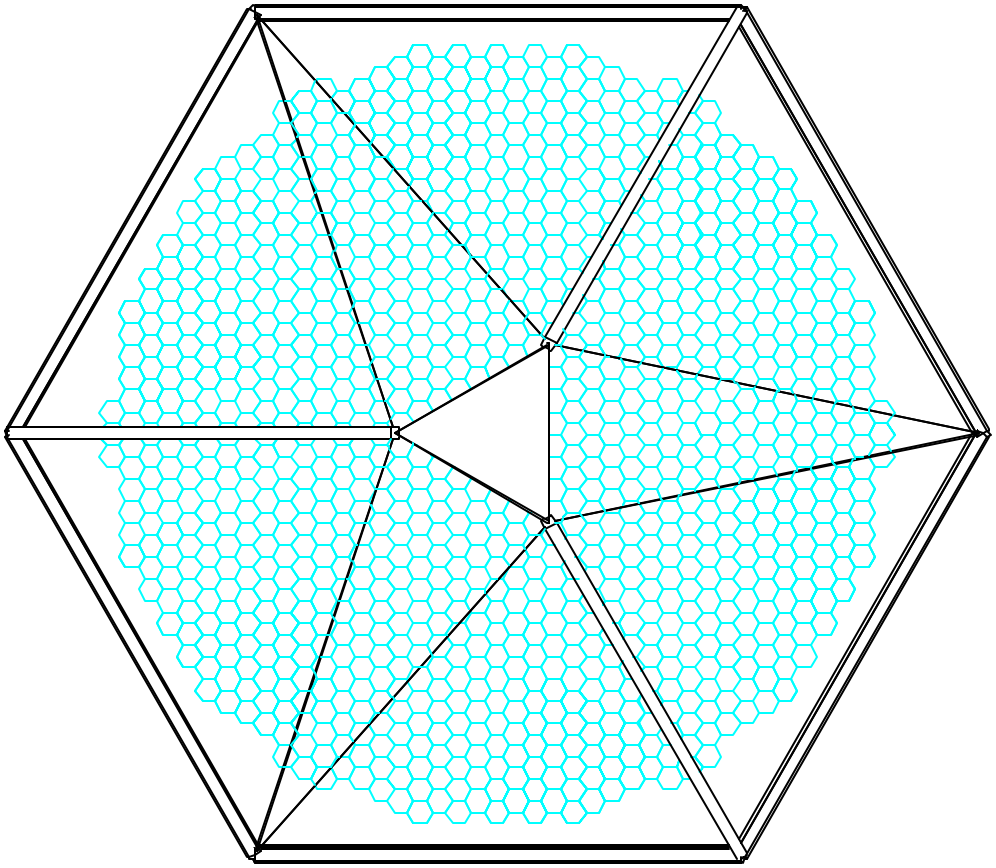



3.96
R12.42
45.00
39.41
3.50
R90.00
3.00
30.00
5.00
------- light path
units = meters

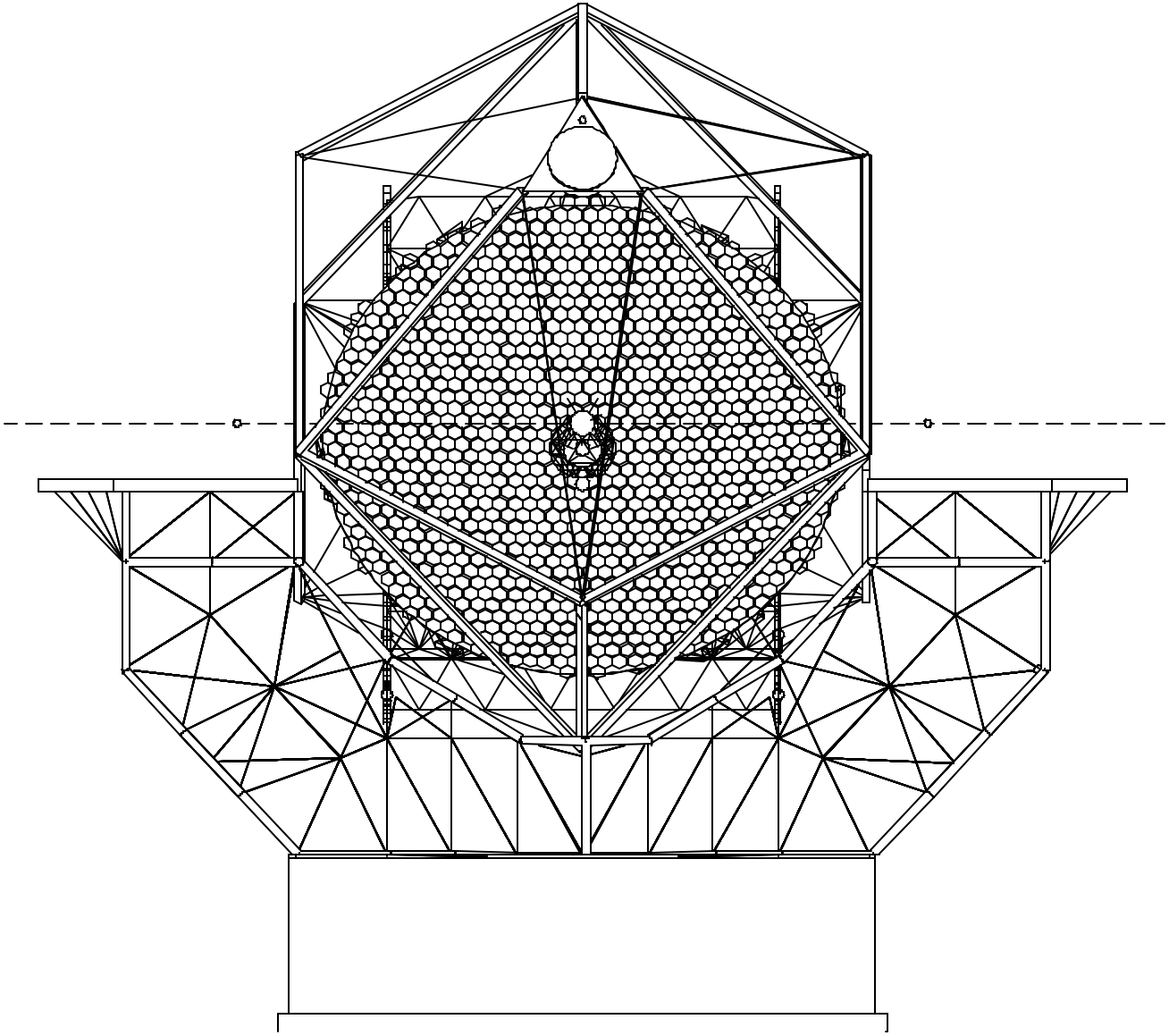




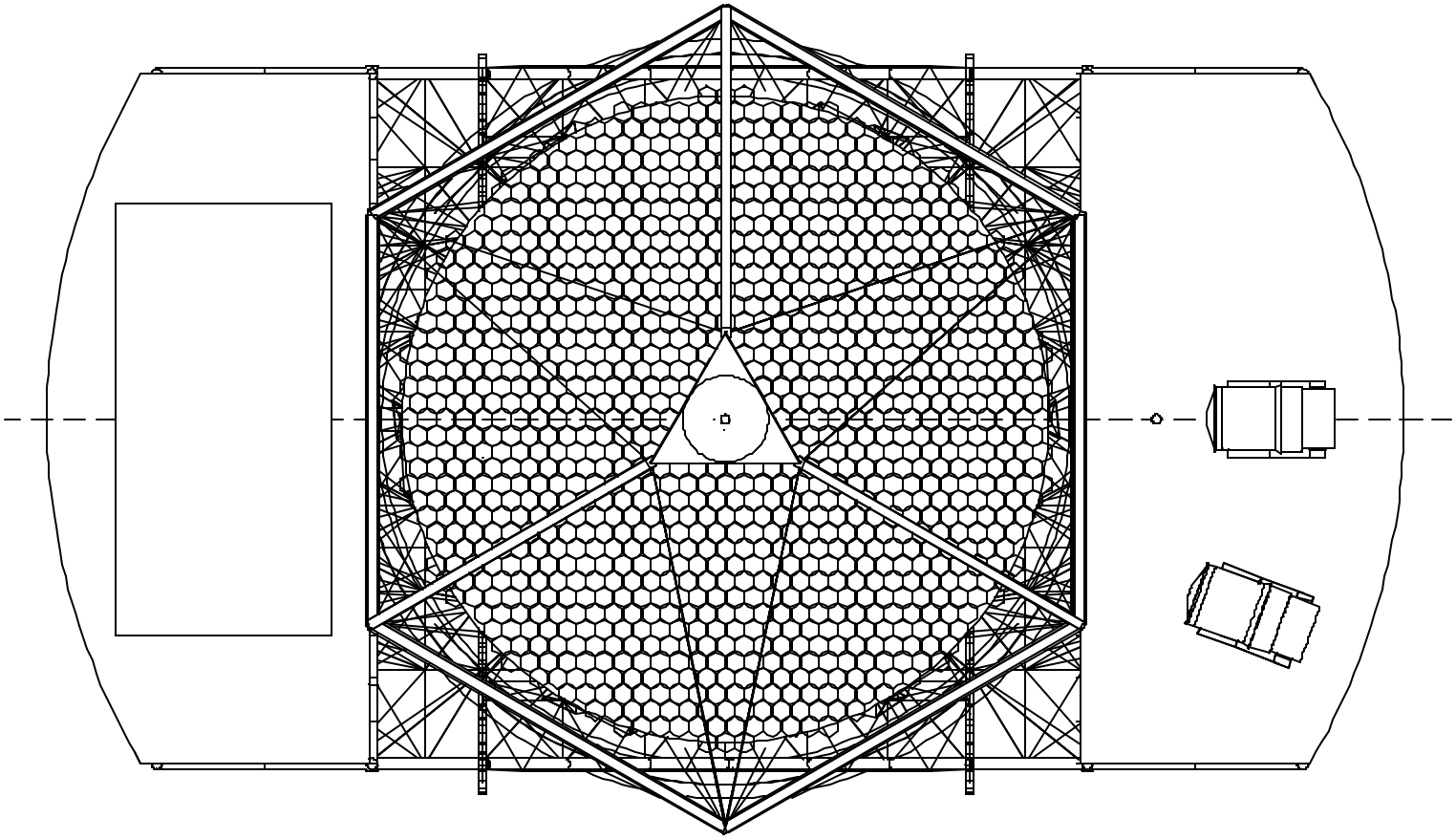
Observing at 54° Elevation


30 meters

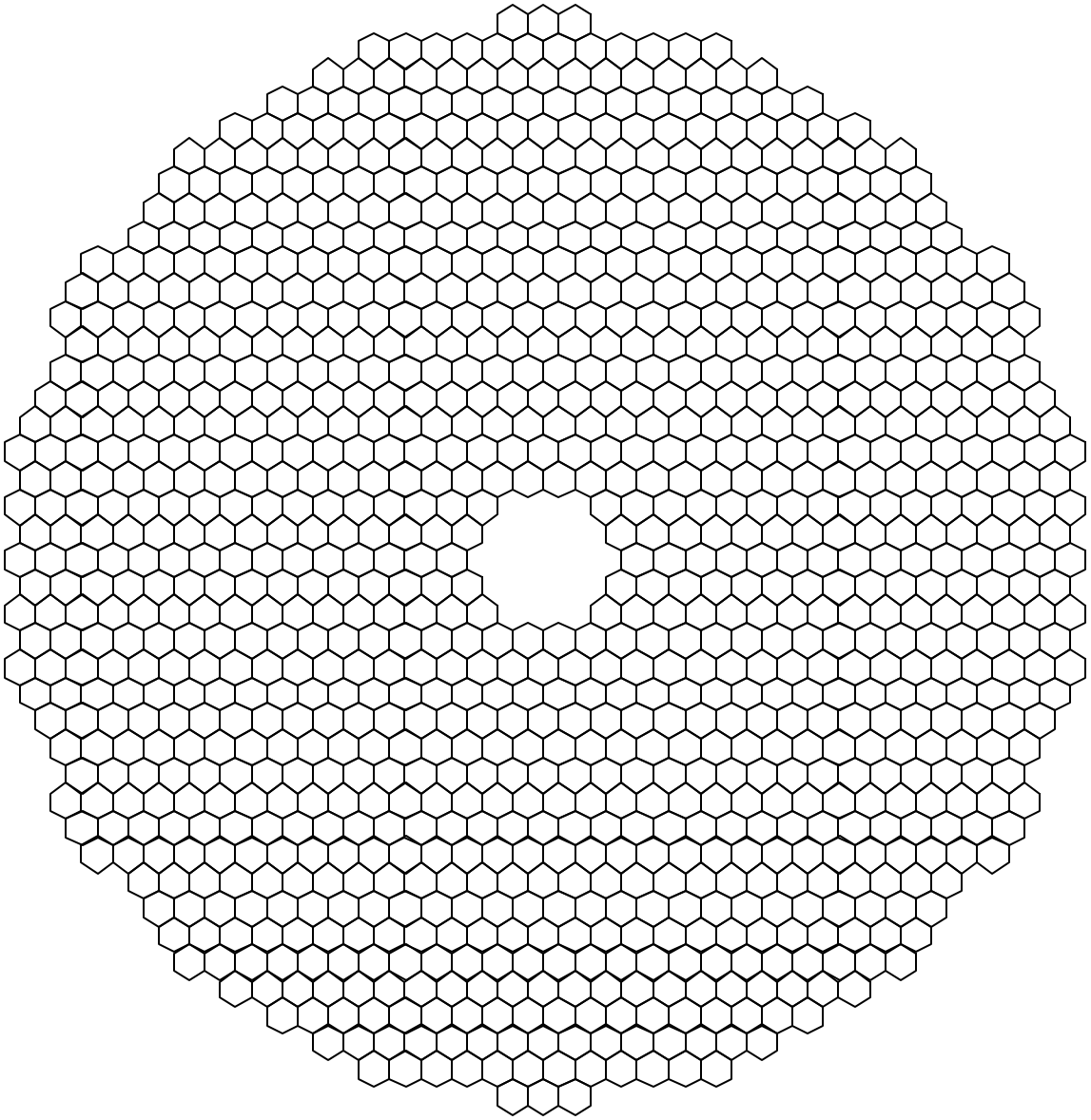
Front view of CELT



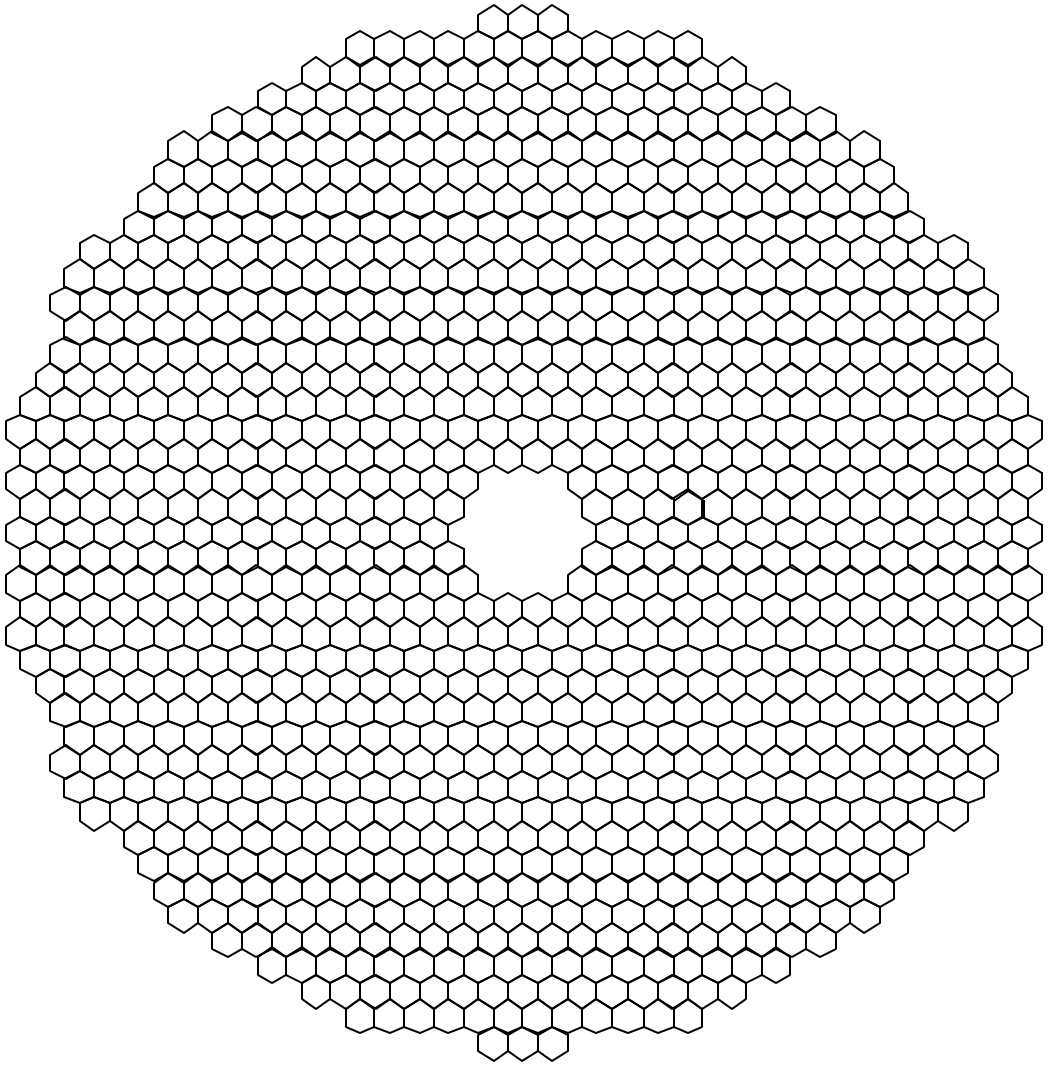
Plan view of CELT showing Nasmyth platforms and instruments



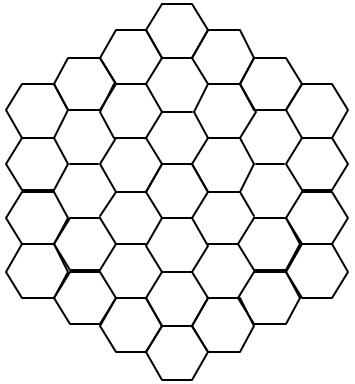
CELT basic layout-1080 segments

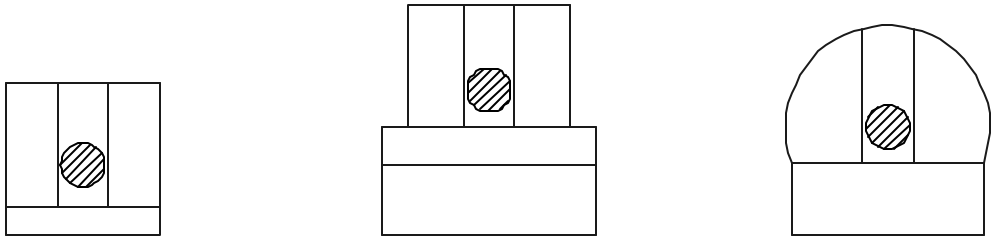


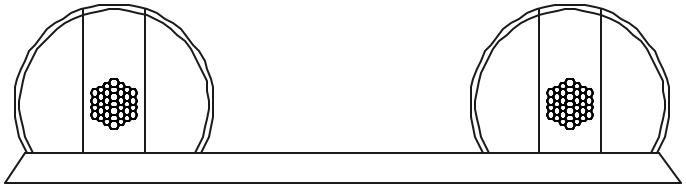
CELT

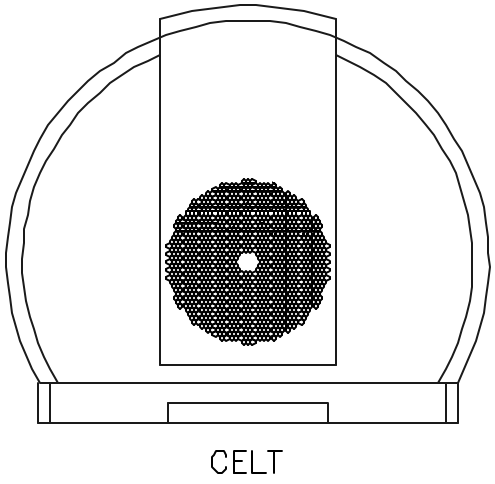


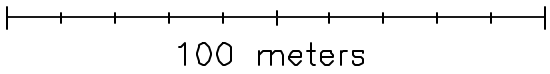
Keck

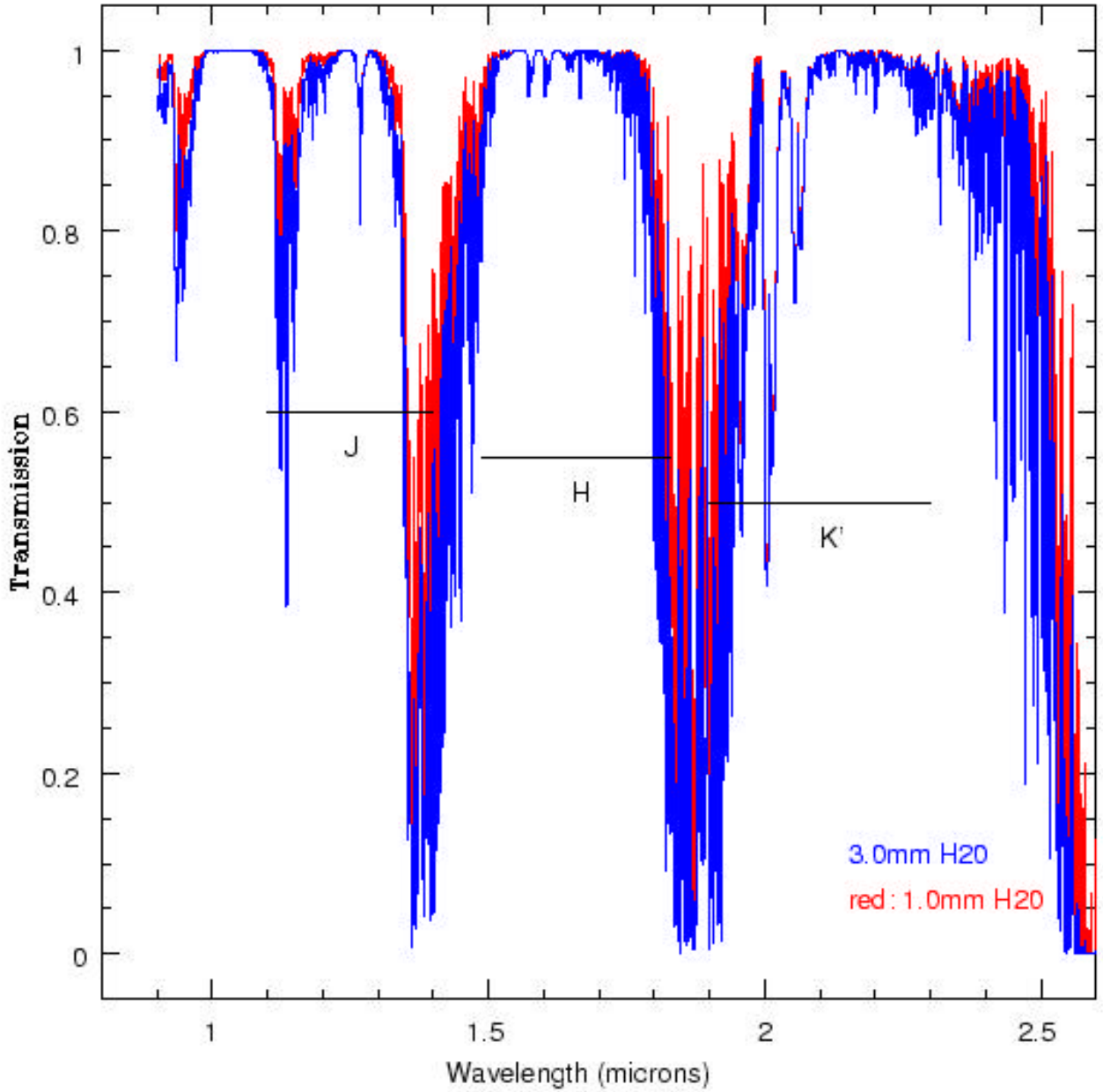


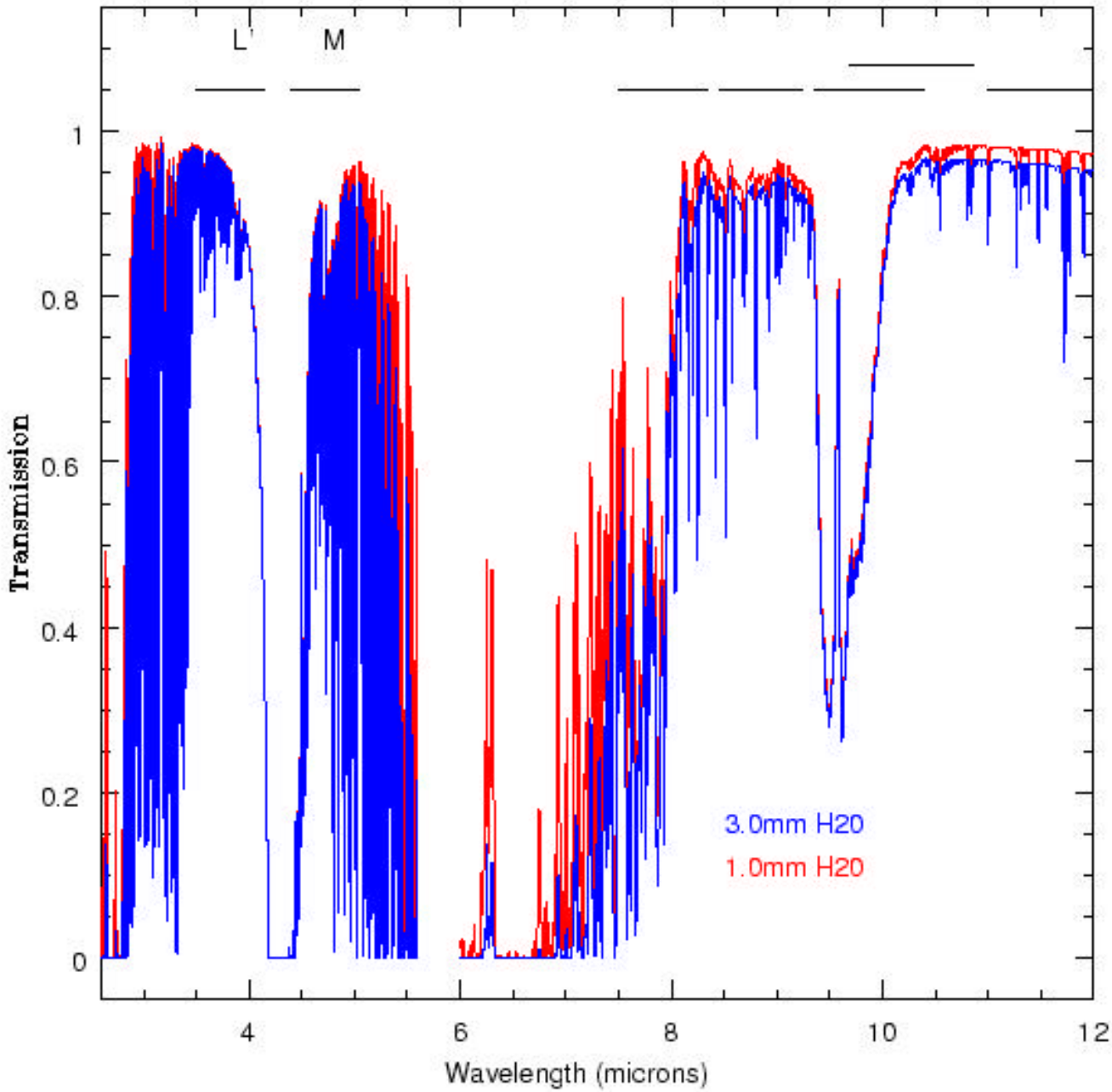

VLT
Subaru
Gemini

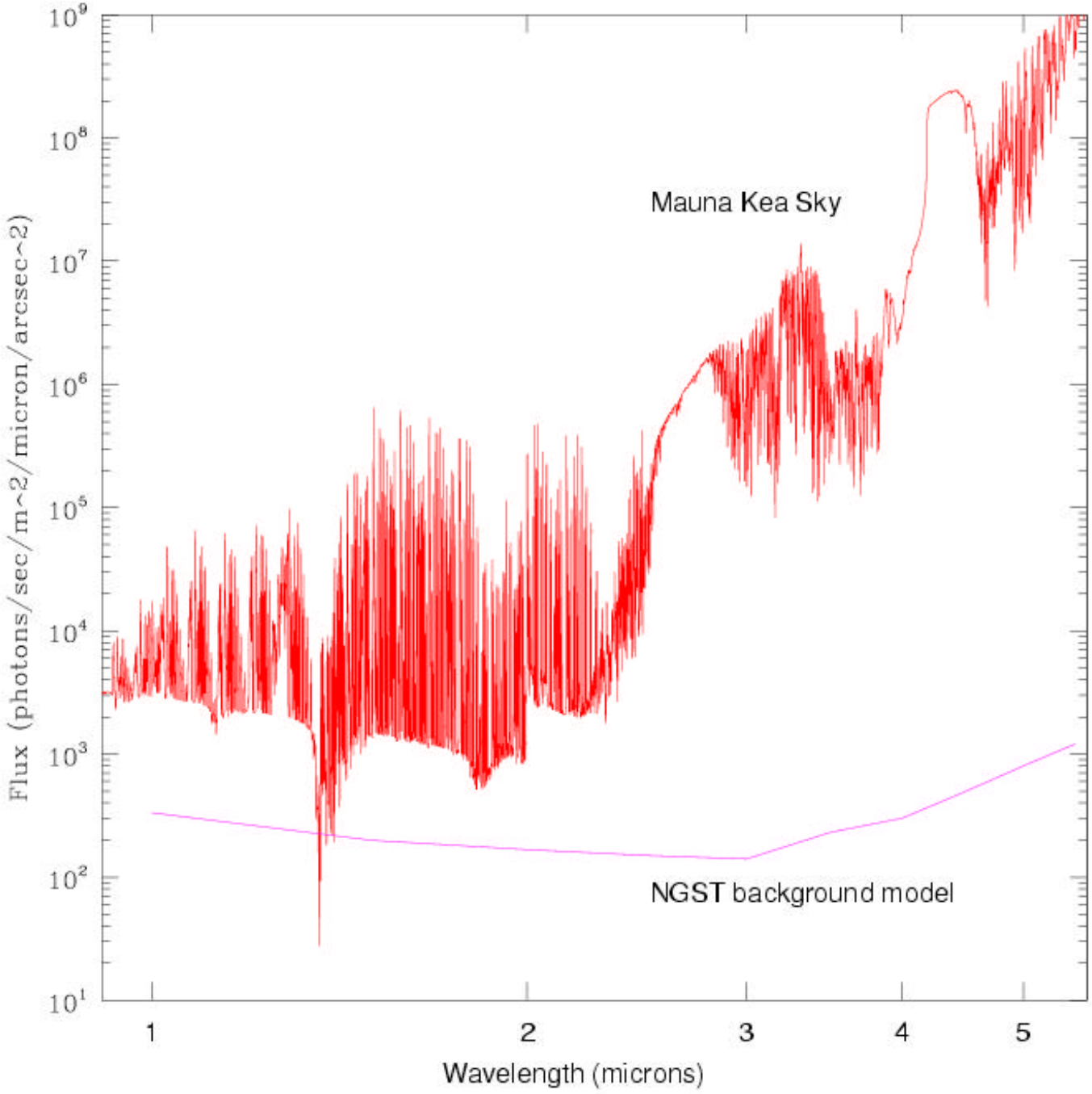

Keck


CELT


100 meters


Transmission
Wavelength (microns)
J
H
K'
3.0mm H20
red : 1.0mm H20
0
0.2
0.4
0.6
0.8
1
1
1.5
2
2.5


L'
M
1
0.8
0.6
0.4
0.2
0
Transmission
4
6
8
10
12
Wavelength (microns)
3.0mm H20
1.0mm H20

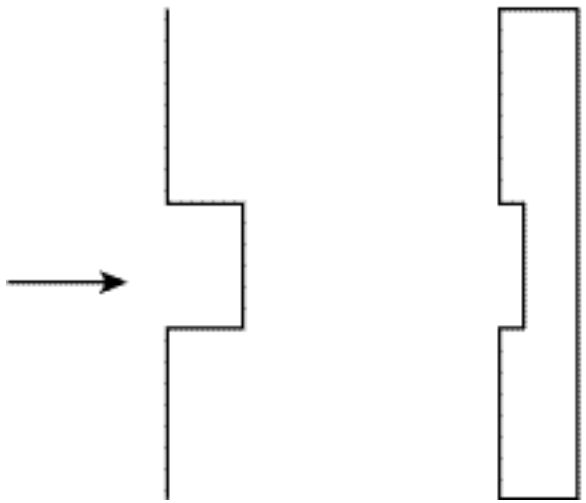

Flux (photons/sec/m^2/micron/arcsec^2)
10^9
10^8
10^7
10^6
10^5
10^4
10^3
10^2
10^1
Mauna Kea Sky
NGST background model
1
2
3
4
5
Wavelength (microns)

California Extremely Large Telescope

How a Deformable Mirror Works

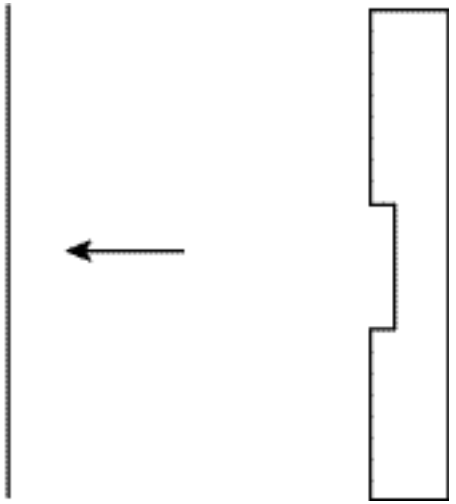
BEFORE

AFTER



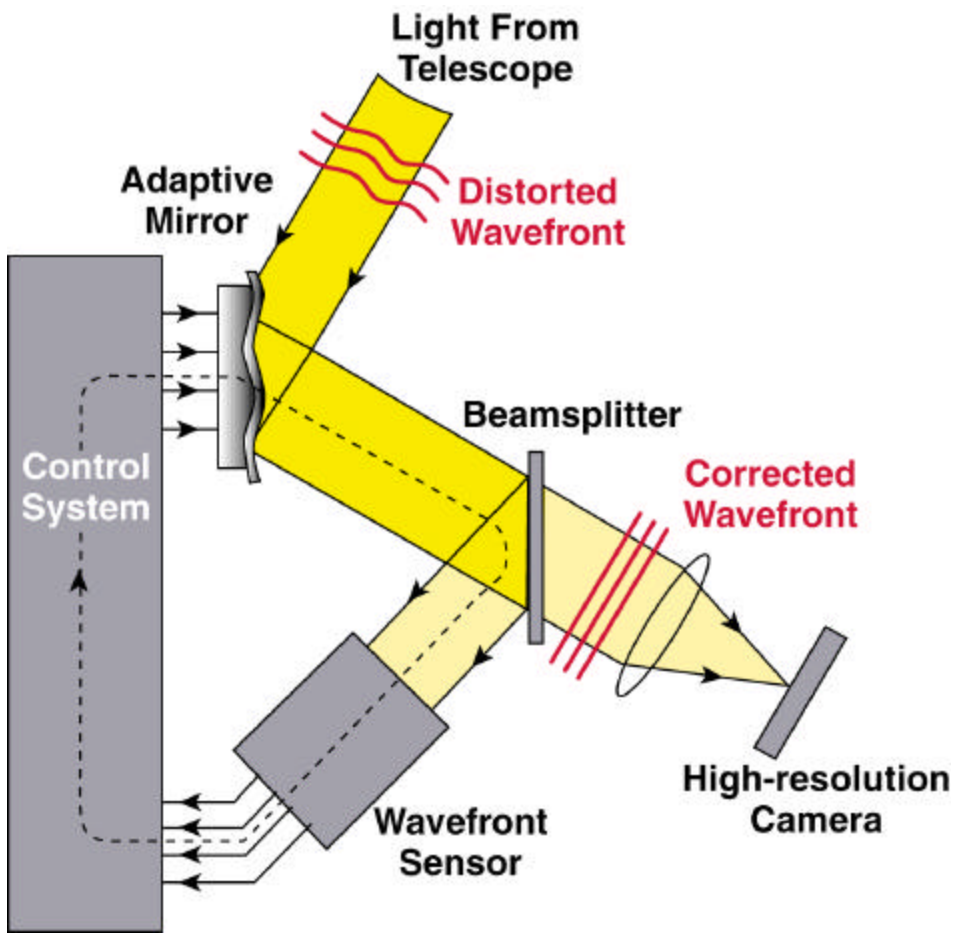
Incoming Wave with Aberration

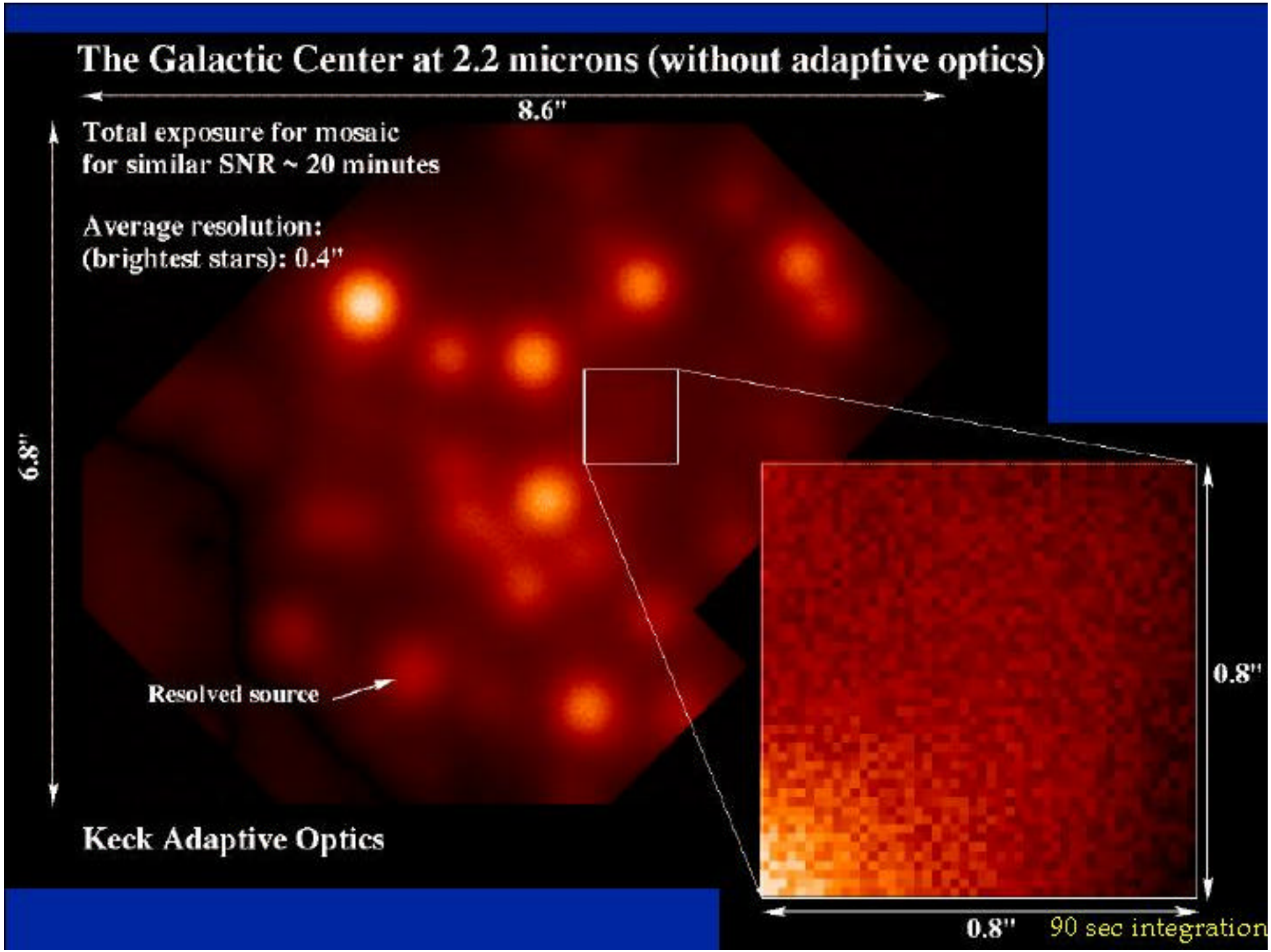
Deformable Mirror

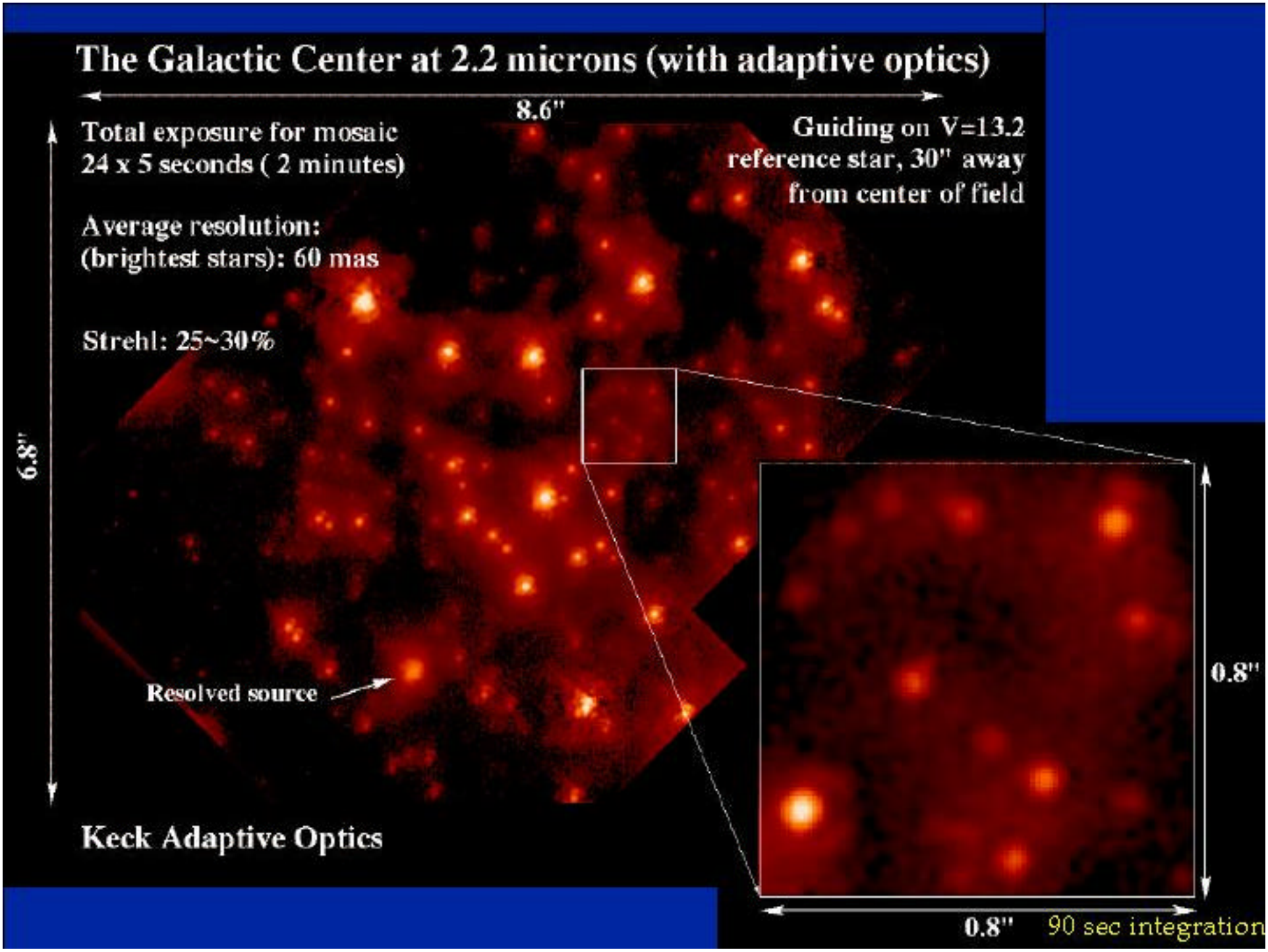


Corrected Wavefront

Deformable Mirror


Light From
Telescope
Adaptive
Mirror
Distorted
Wavefront
Beamsplitter
Control
System
Corrected
Wavefront
High-resolution
Camera
Wavefront
Sensor

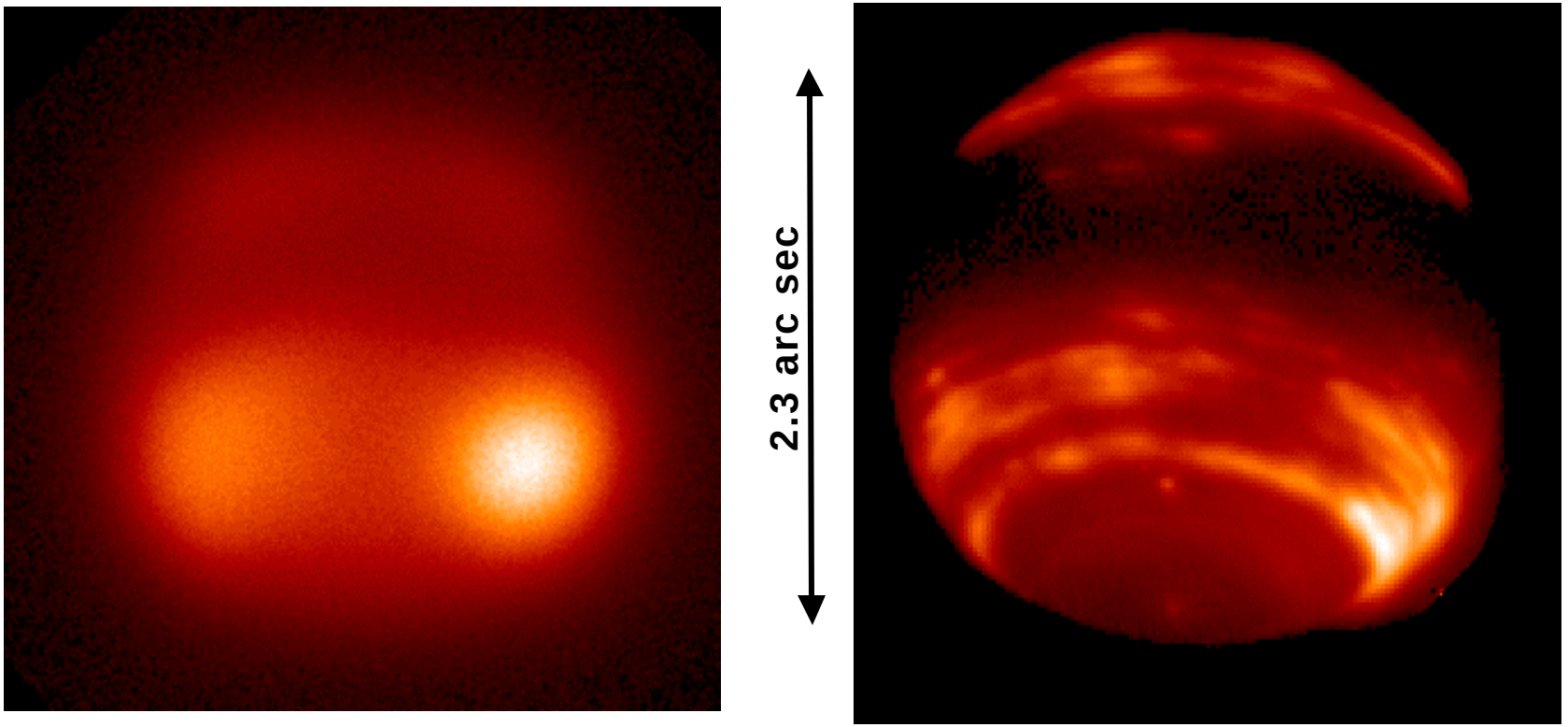

The Galactic Center at 2.2 microns (without adaptive optics)
8.6"
Total exposure for mosaic
for similar SNR ~ 20 minutes
Average resolution:
(brightest stars): 0.4"
6.8"
Resolved source
Keck Adaptive Optics
0.8"
0.8"
90 sec integration


The Galactic Center at 2.2 microns (with adaptive optics)
8.6"
Total exposure for mosaic
24 x 5 seconds (2 minutes)
Guiding on V=13.2
reference star, 30" away
from center of field
Average resolution:
(brightest stars): 60 mas
Strehl: 25~30%
6.8"
Resolved source
0.8"
0.8"
90 sec integration
Keck Adaptive Optics

Neptune at 1.65 microns

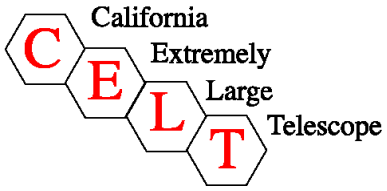
Without adaptive optics

With adaptive optics



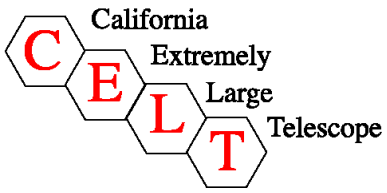
May 24, 1999

June 28, 1999



The future of AO in astronomy

- **More powerful AO systems**
  - More energy concentrated into diffraction limited image
  - Better resolution at shorter wavelength
- **Larger diffraction-limited fields of view**
  - Multi-conjugate AO systems to cancel aberrations “where they occur”
  - Multiple laser beacons
- **Larger telescopes with AO**
  - NAS AASC recommended a ground based 30-m telescope
- **California Extremely Large Telescope (CELT)**
  - University of California-Caltech partnership
  - 30-m diameter
  - Adaptive optics working down to 1 μm ($\lambda/D = 0.007$ arcsecond resolution)


California
Extremely
Large
Telescope
C
E
L
T

California Extremely Large Telescope

CELT Adaptive Optics Issues

- **AO system requirement: wavefront residual 133 nm**
  - Strehl= 0.84 at 2 µm
  - Strehl = 0.50 at 1 µm
  - Strehl = 0.24 at 0.7 µm
- **Native atmosphere is roughly 2000 nm rms (tilt removed)**
- **System will require ~ 5000 actuators**
- **MCAO will require ~ 3 layers, each with 5000 actuators**
- **Wavefront sensing will require 80x80 lenslet arrays, advanced detectors**
- **Sky coverage will require ~5 Na laser beacons**
- **Computations currently impractical (need better algorithms and computers)**

California Extremely Large Telescope

CELT Plans

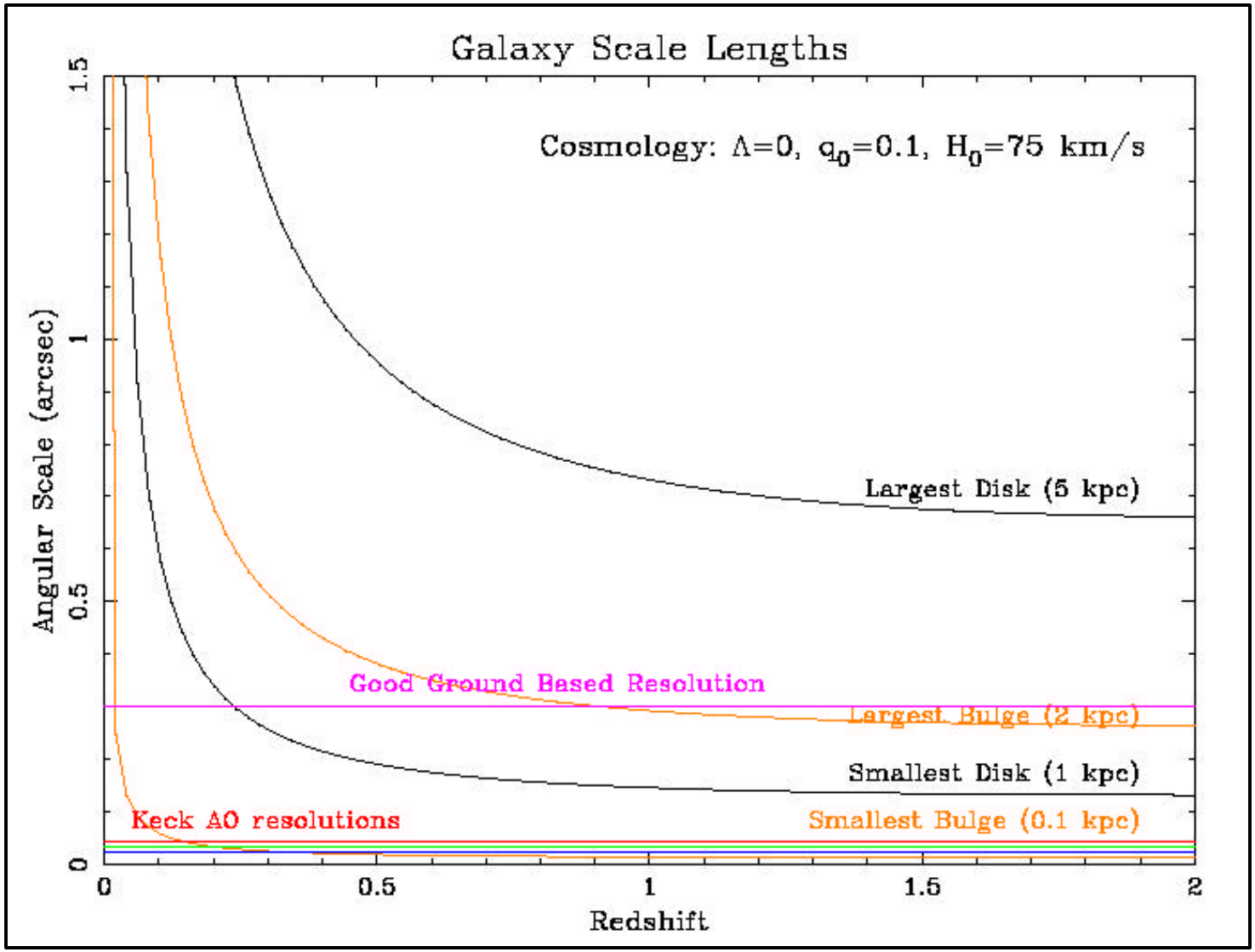
- **Conceptual design study underway**
  - Started September 2000
  - End March 2002
  - + fund raising
- **Preliminary Design should start end of 2002**
  - + fund raising
- **Detailed design should start mid 2004**
- **Construction may begin 2006**
- **Completion ~ 2012**

Galaxy Evolution

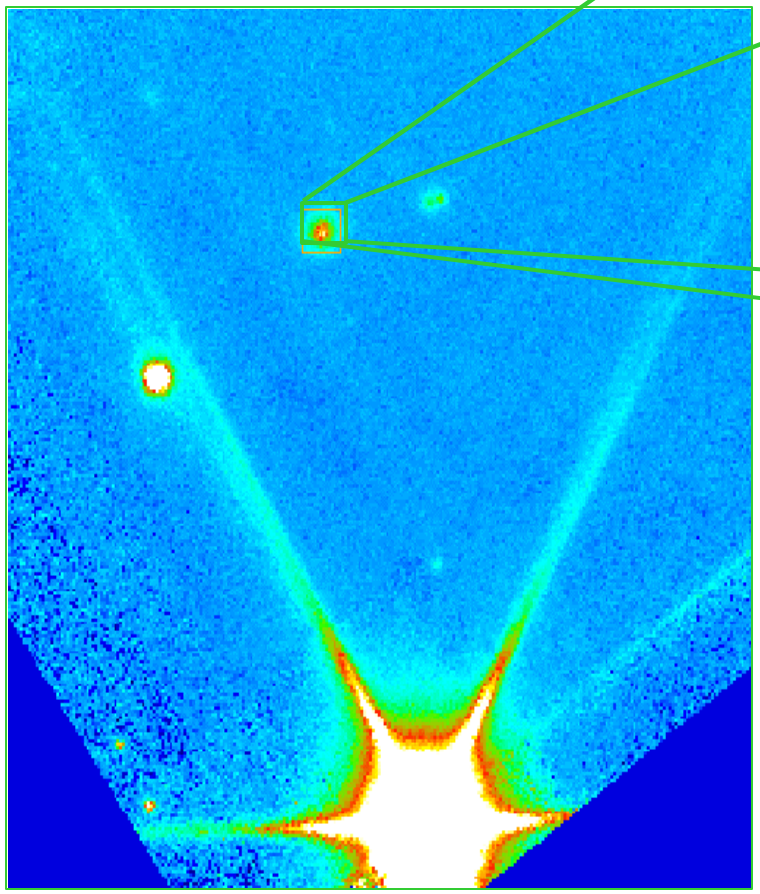
- When did galaxies form?
- When did disks stabilize?
- When and how did bulges form?

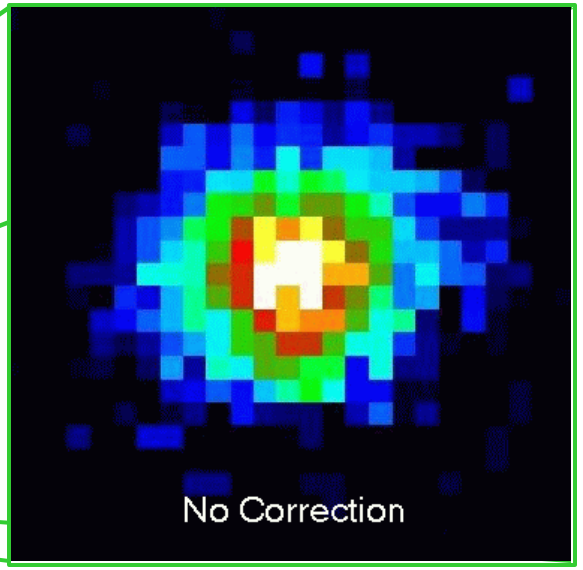
- When was the Hubble sequence in place?
- What is the merger rate as a function of time?
- What caused the sharp decline in star formation since a redshift of 1?
- What was the Galactic environment at the time of the formation of the solar system (z~0.4)?

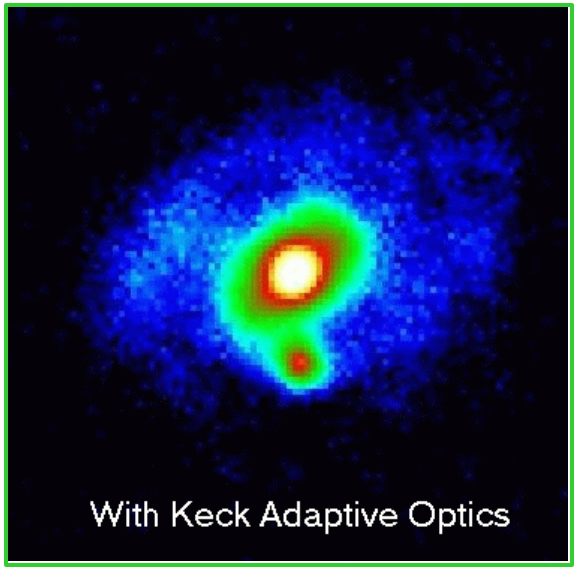
Galaxy Evolution



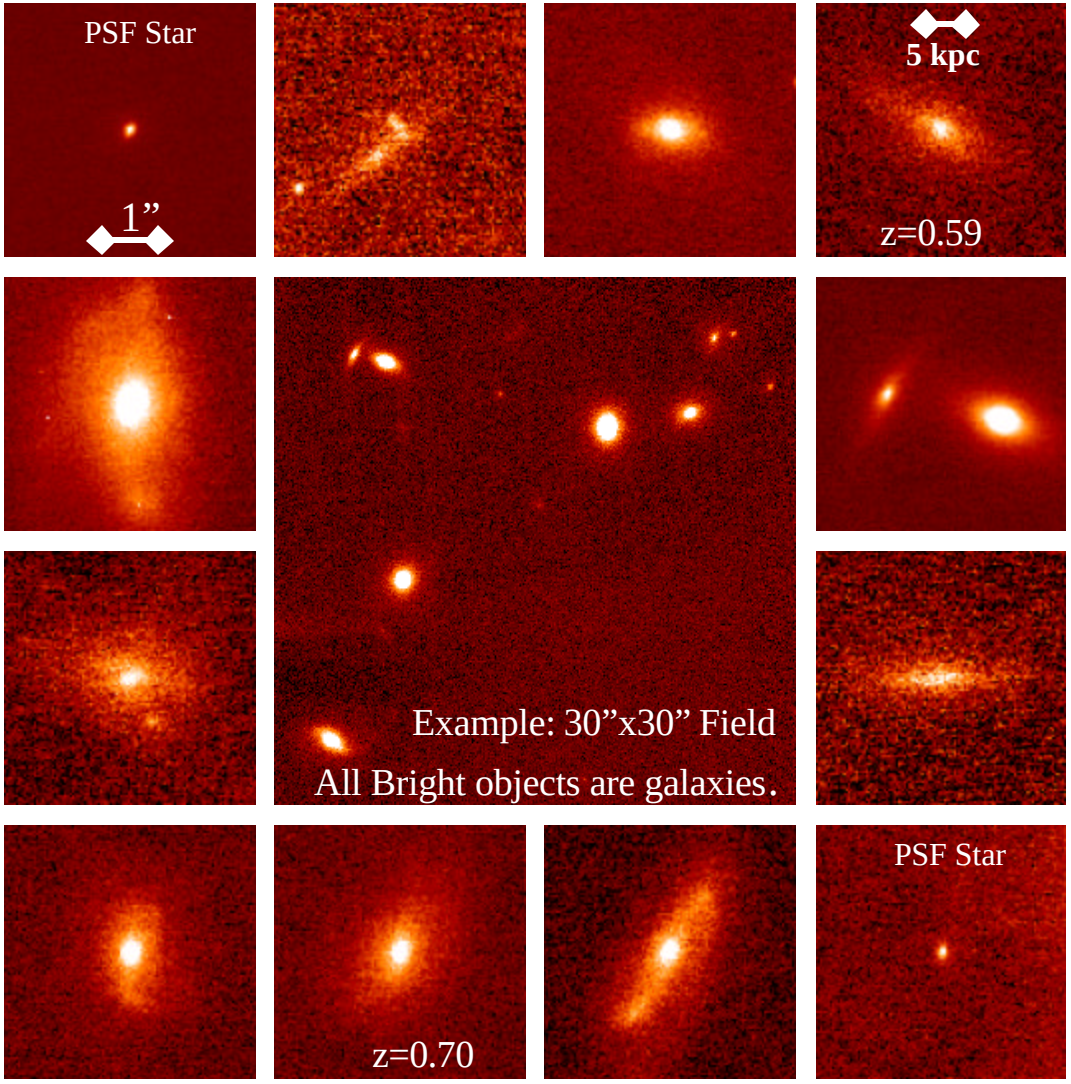
Field Galaxy Studies





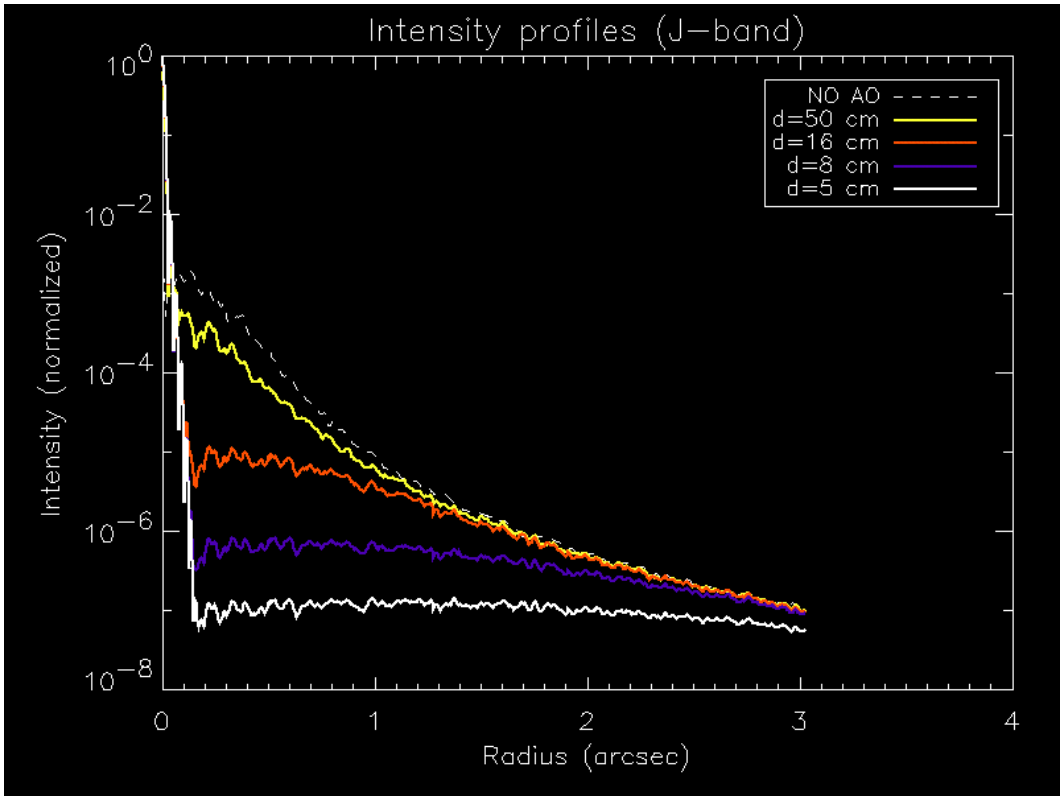


New Sample of >200 galaxies.



“Extreme” Adaptive Optics[1]: ExAO

- **Science driver: Direct detection of extrasolar planets**
- **“Extreme AO”: systems powerful enough to control the scattered light halo at large radii**



[1]R. Dekany, JPL

ExAO System Phase Space

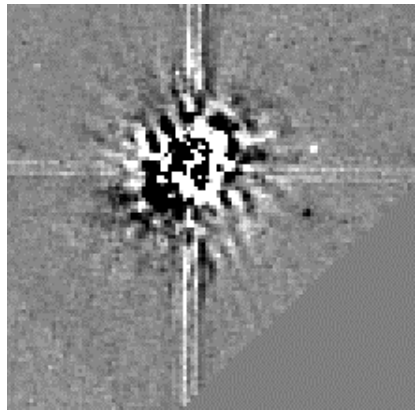
Target stars	Contrast goal	m_r	distance	# of stars	$d_{subaperture}$
Young: 1-20 MYr	10^5 @ 0.2”	8-10	30-60 pc	100	~30 cm
Medium: 0.1-5 GYr	10^6 - 10^7 plus diffuse dust	5-8	<50 pc	100s	~20 cm
Mature 5 GYr	10^9 @ 1”	<4	4-8 pc	10s	~5-10 cm

- **Three areas of phase space:**
- **Young stars: identified through space motions, X-ray emission, etc.**
  - –Planets are warm (500-1000K) and very bright in the near-IR
- **Field stars: detection of massive (2-10 M_J) planets around older field stars**
- **Reflected-light: detection of reflected sunlight at < 1 micron**

Young Extrasolar Planets

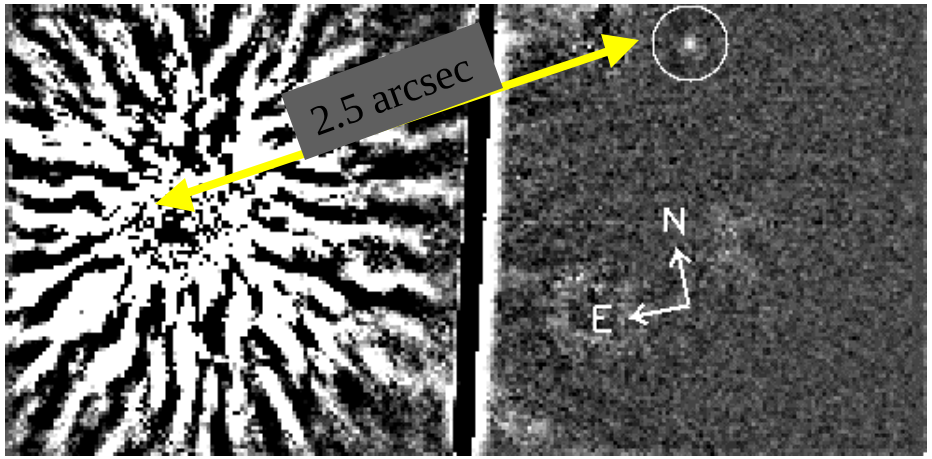
- **Low-mass planets (the most exciting ones) cool and dim extremely rapidly (Burrows et al 1997)**
- **Planets are most detectable at ages < few 10^7 years**
- **A (surprisingly?) significant population of stars of appropriate age exists close (50 pc) to earth (Zuckerman et al, Webb et al)**
- **Current AO and HST can detect young planets orbiting these stars at wide (50-100 AU) separations**
- **ExAO could probe solar-system-like scales (5-20 AU, 0.2-0.4")**

TWA6 and candidate m_H=20 object @ 2.5" separation (=150 AU?)

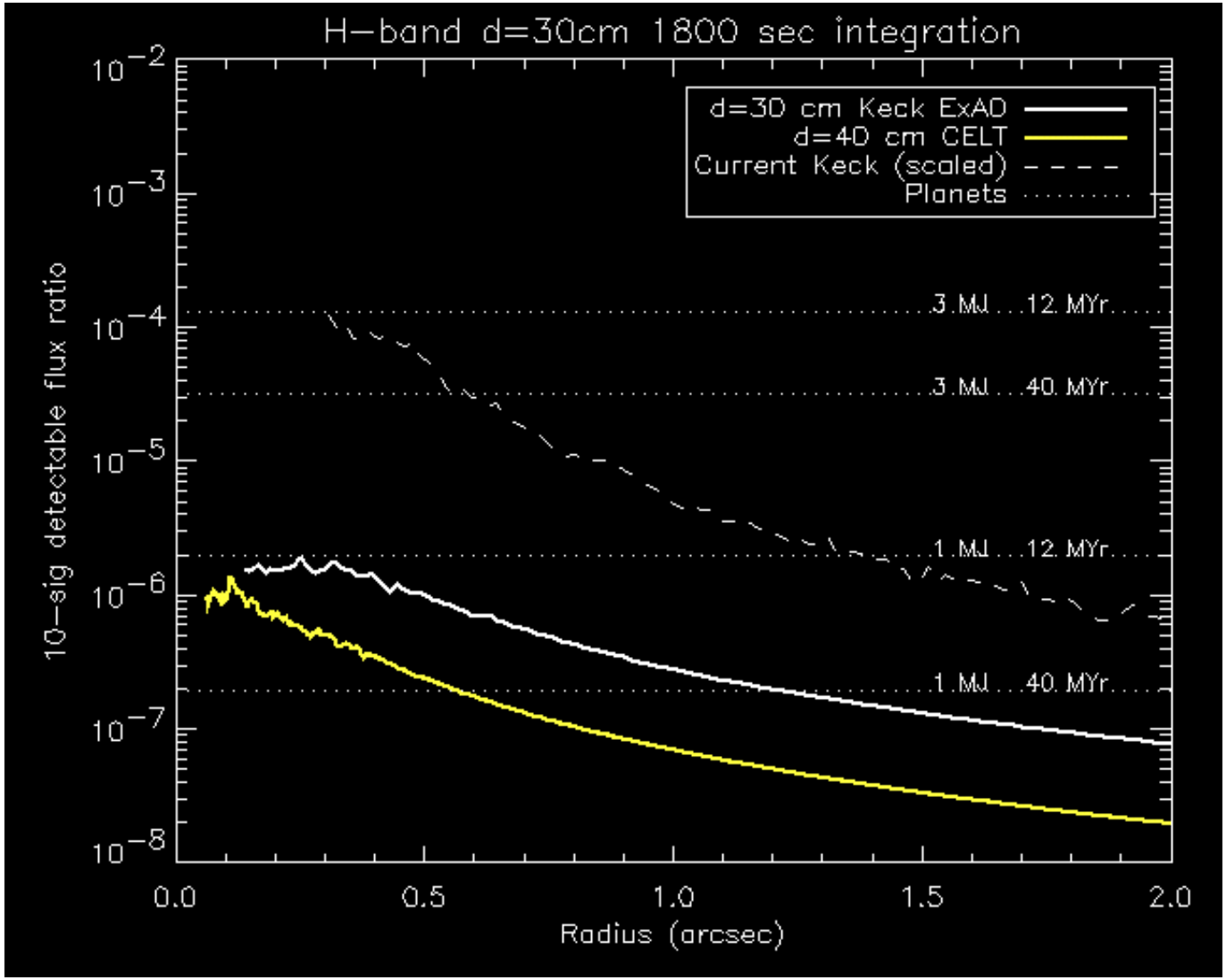


HST/NICMOS

Keck AO Image Feb 2001 (NIRSPEC/Scam)

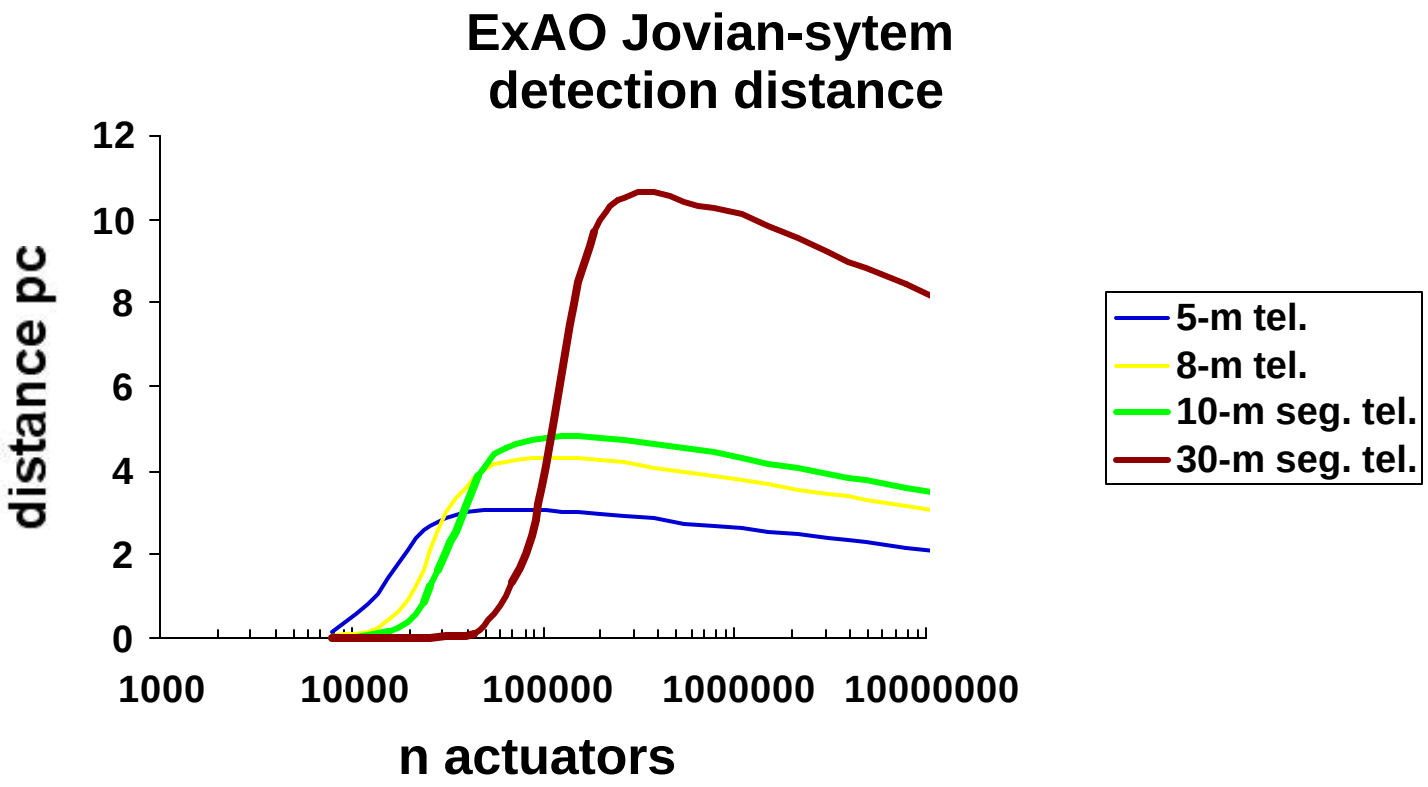


Detectable young-planet flux ratios for Keck and CELT



Detection of mature Jovian planets in reflected sunlight

- Performance can be expressed in terms of the distance at which a Jupiter in a solar system like ours could be detected in a four-hour integration
- Performance predictions based on refined version of Angel (1994) scaling laws (more pessimistic than Angel's original paper)



California Extremely Large Telescope

Conclusions

- **Large, diffraction limited telescopes are here**
- **Larger, diffraction limited telescopes are coming**
- **AO with good sky coverage and interesting fields of view are coming soon (laser beacons, MCAO)**
- **Jovian planets will be detectable**