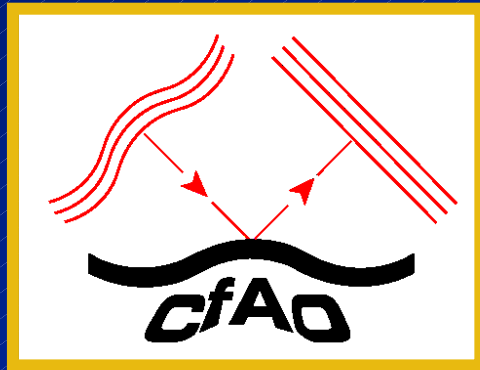


Astronomical Research at the Center for Adaptive Optics



Sandra M. Faber, CfAO

SACNAS Conference

October 4, 2003



Science with “Natural” Guide Stars

Any small bright object can be a “natural” guide star:

Examples:

Planets

Bright moons of planets

Random nearby stars near the line of sight



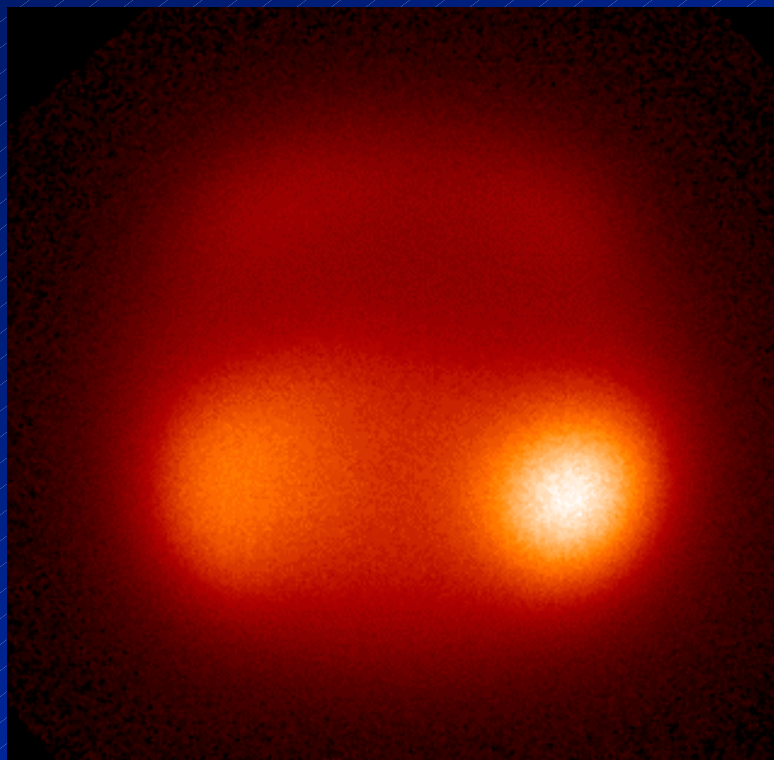
Solar System Research at UCB and UCSC

- Imke de Pater (UCB):
Planetary weather and rings
- Claire Max (UCSC):
Volcanoes on Jupiter's moon Io



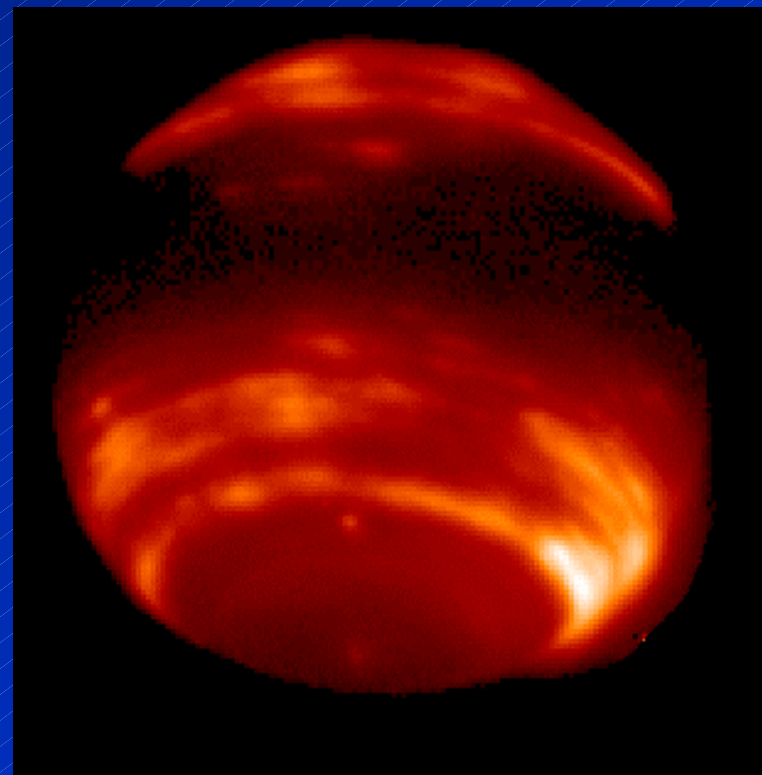
Neptune in Infrared Light

Without adaptive optics



May 24, 1999

With Keck adaptive optics



June 27, 1999

2.3 arc sec

$\lambda = 1.65$ microns

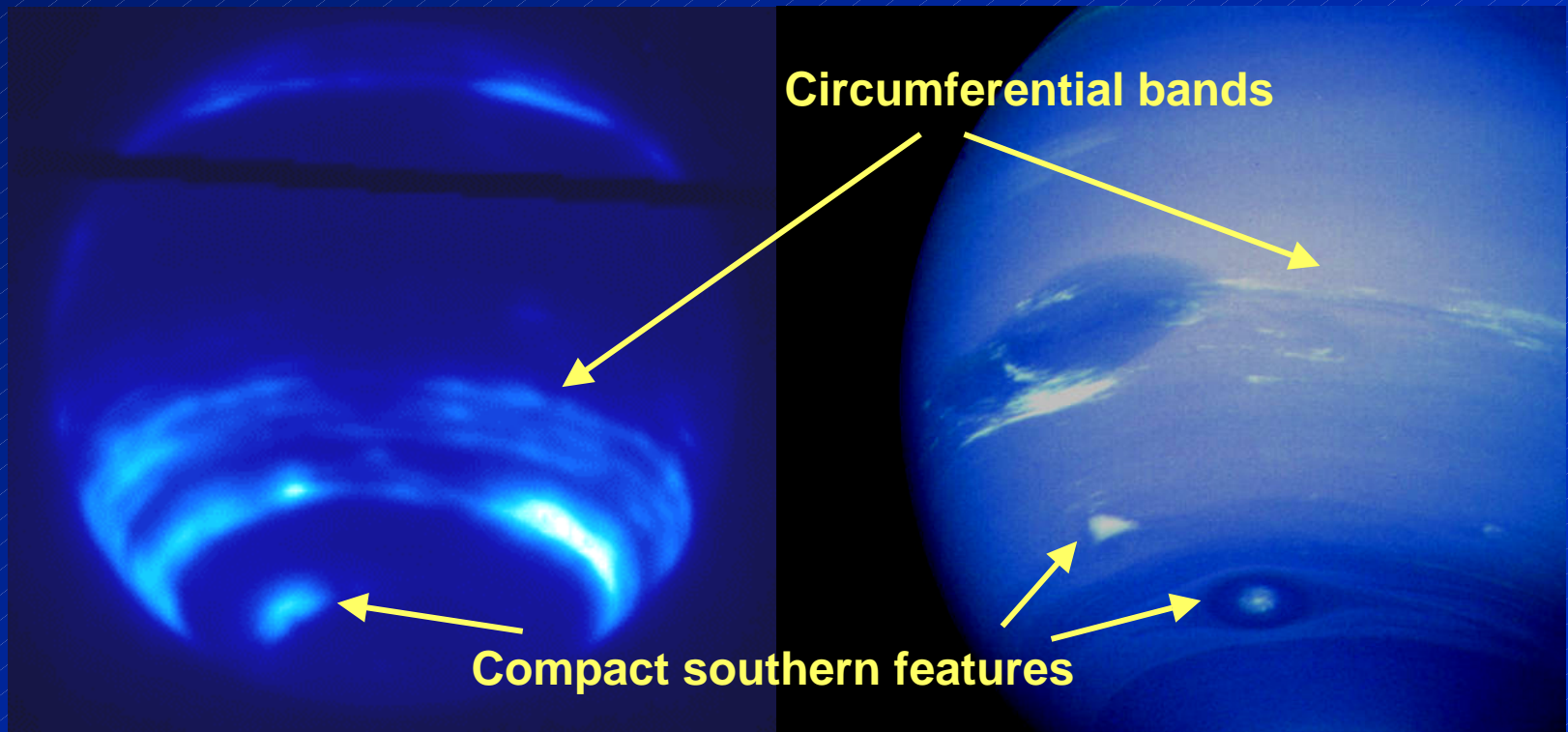
I. De Pater,



Neptune: Ground-based AO vs. Voyager Spacecraft

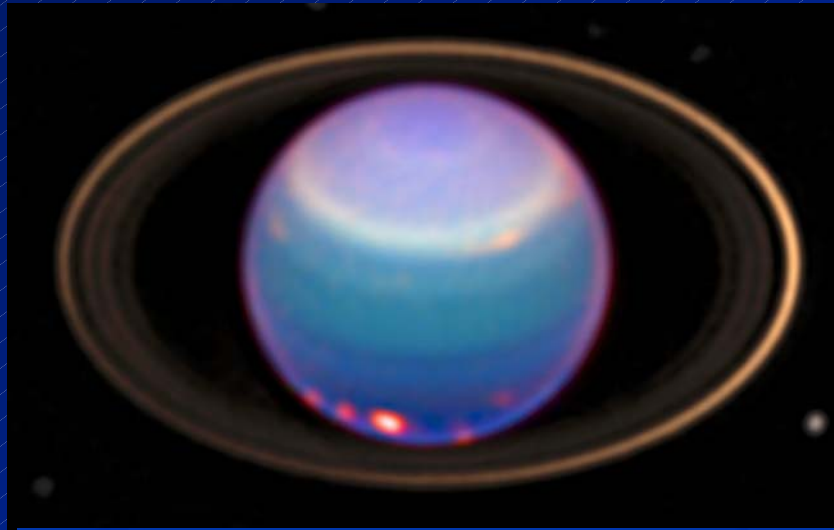
Infrared: Keck adaptive optics,
2000

Visible: Voyager 2 fly-by, 1989

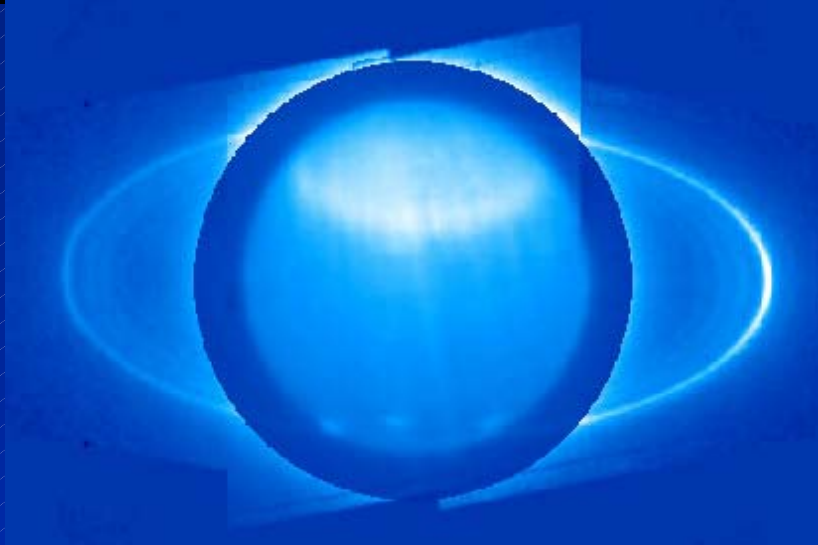




Uranus as seen by Hubble Space Telescope and by Keck AO



Hubble Space Telescope
false-color image
(1.1, 1.6, 1.9 μ m)

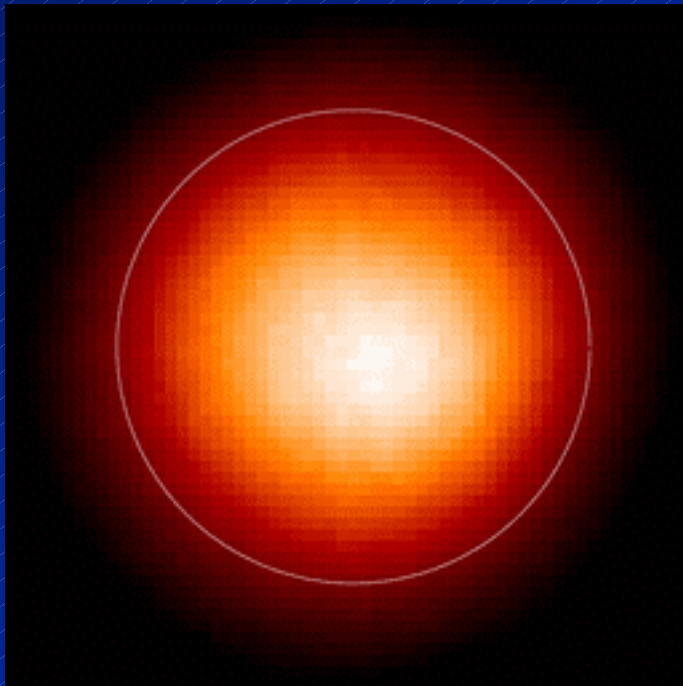


Keck adaptive optics
image (2.1 μ m)



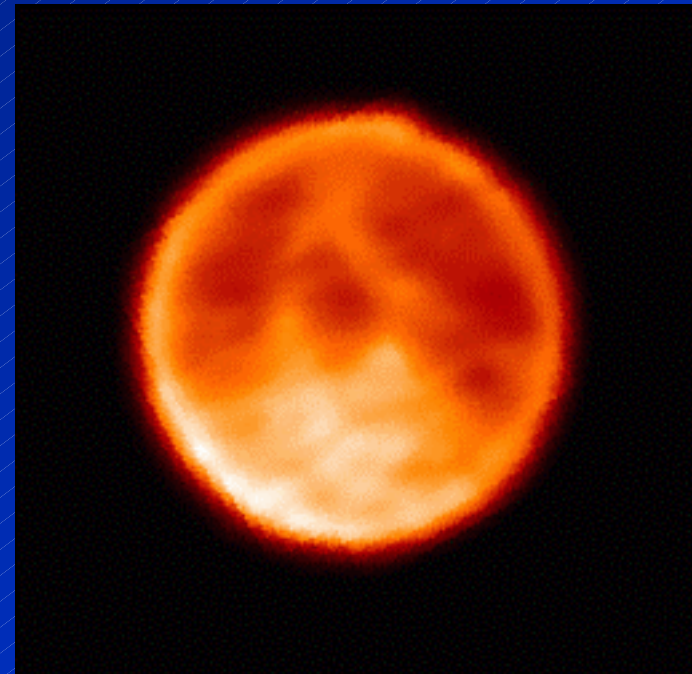
Saturn's moon Titan at Keck: with and without adaptive optics

Titan without adaptive optics



Typical @ wavelength 1.65 mm

Titan with adaptive optics

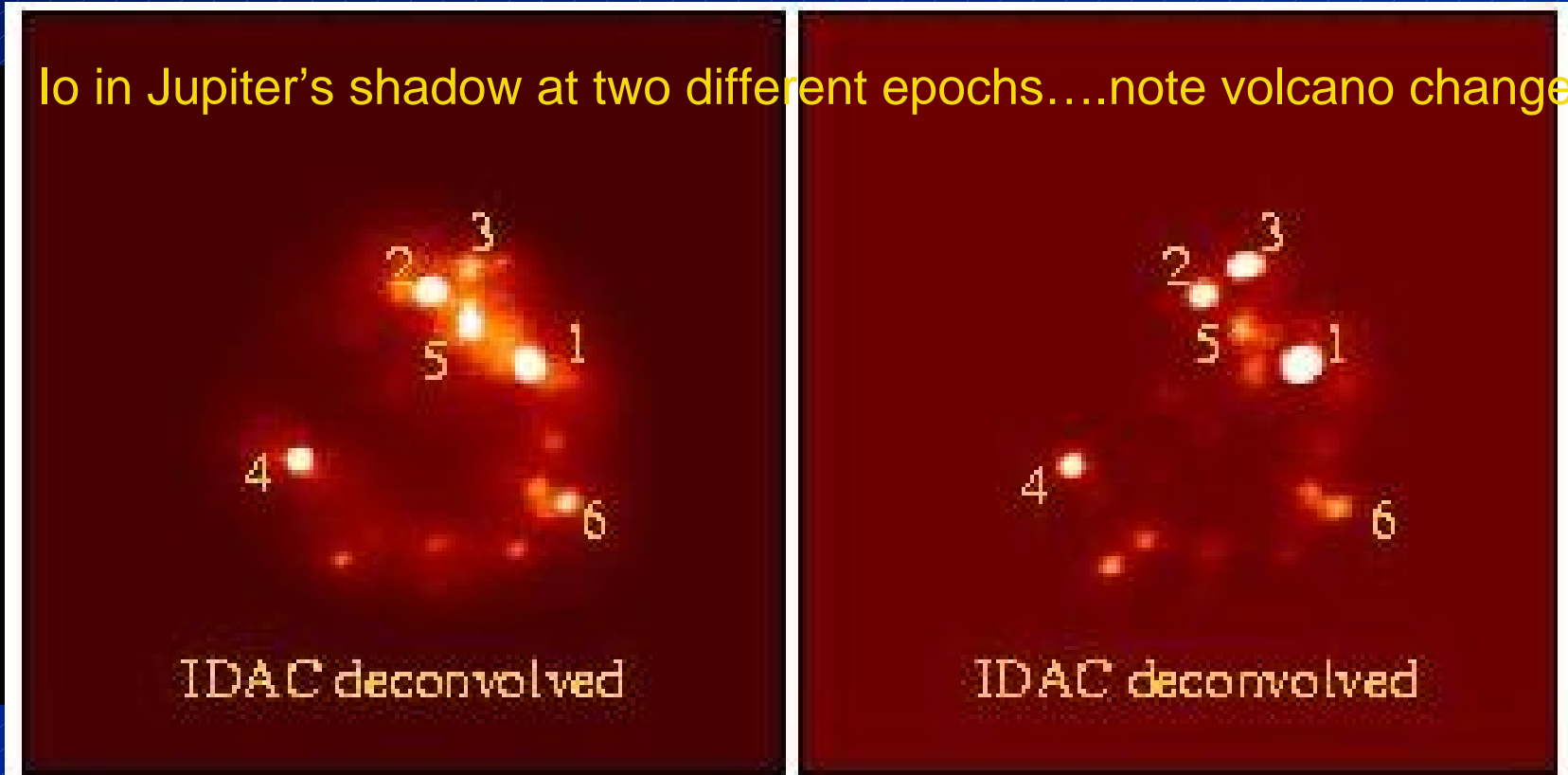


February 26-27, 1999



Io with adaptive optics sees most of the volcanic features seen by Galileo

Io in Jupiter's shadow at two different epochs....note volcano changes



Same volcanoes

Same volcanoes

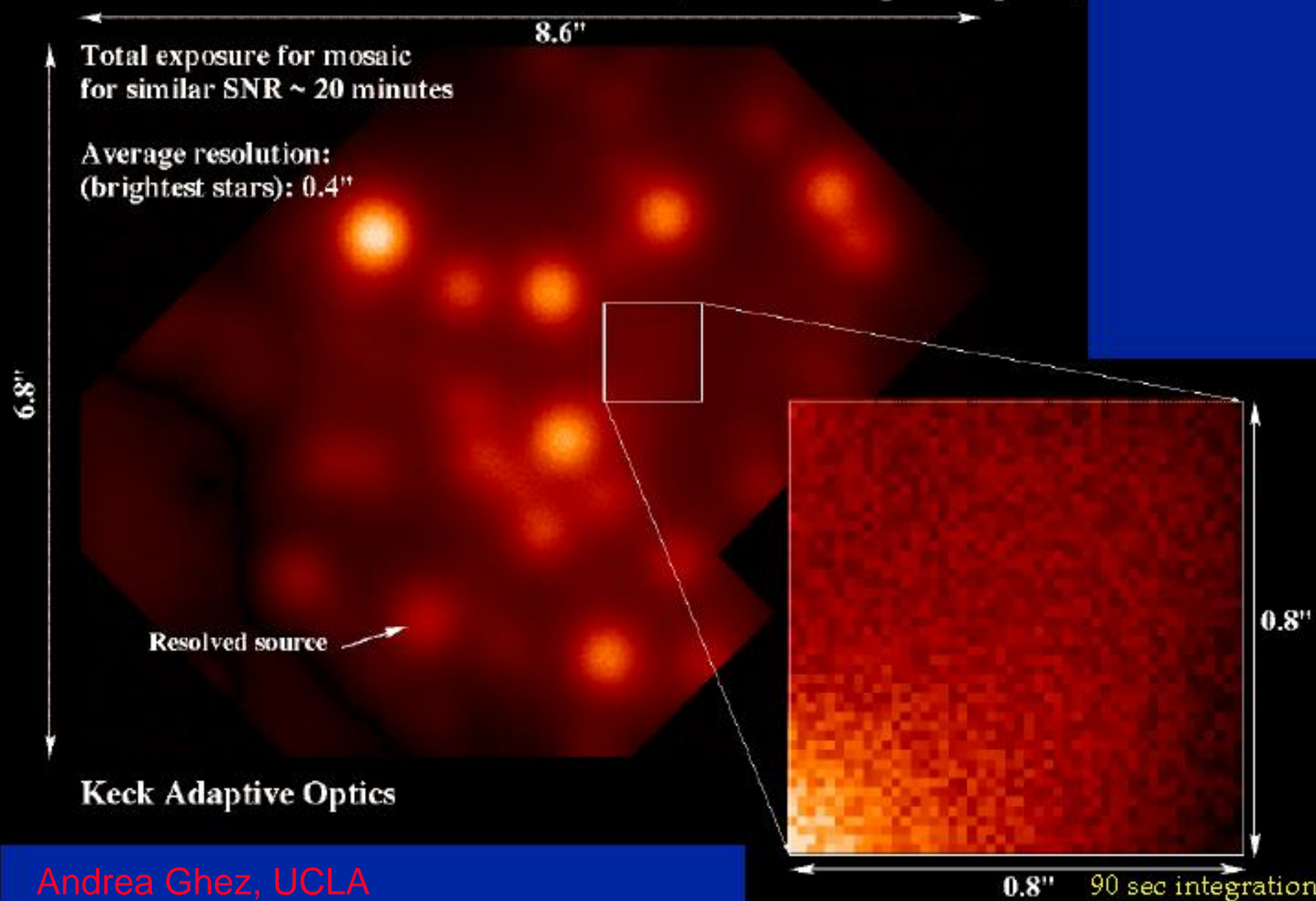


Massive Black Holes at the Centers of Galaxies

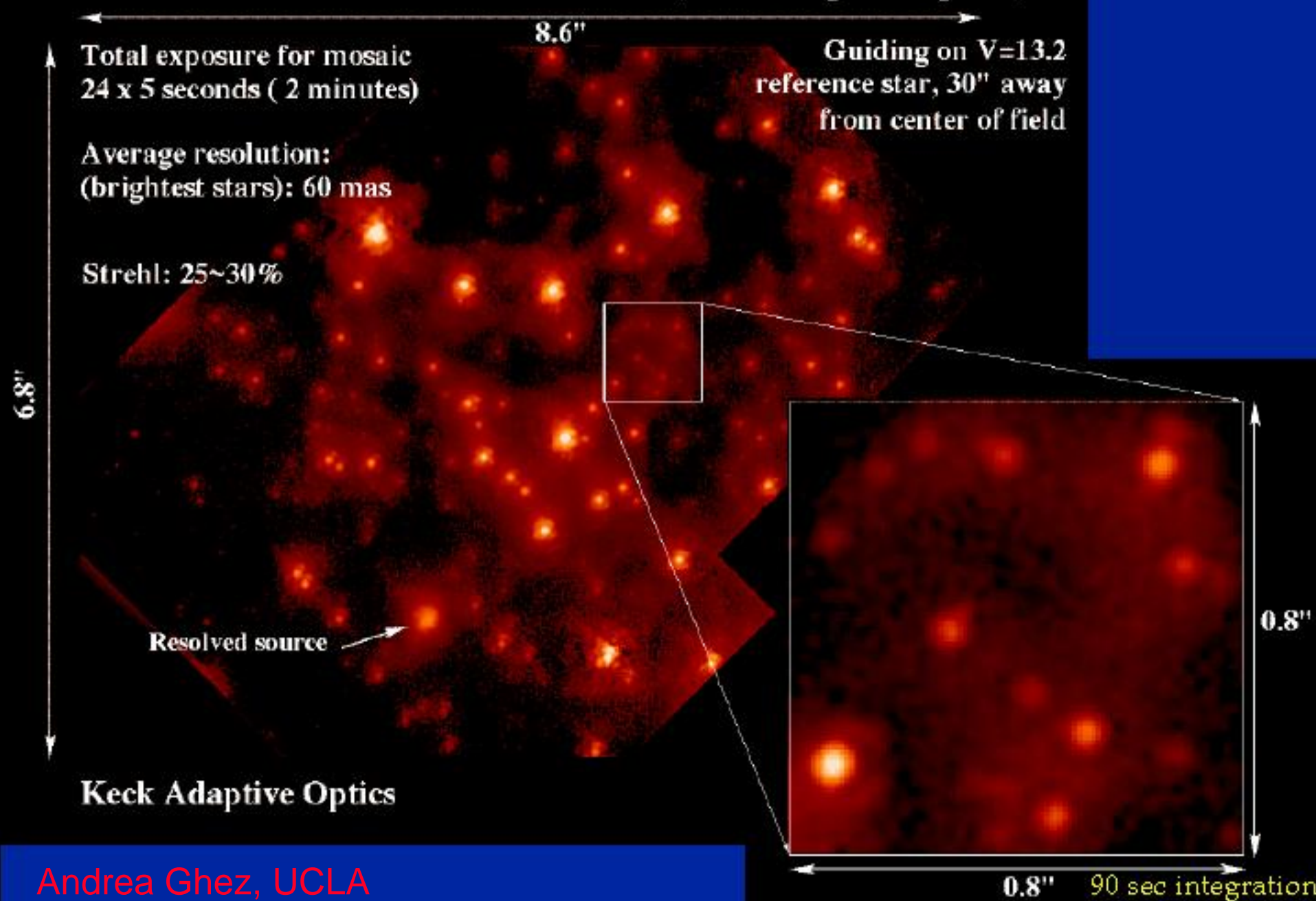
A natural guide star exists near our Galactic center.

Andrea Ghez of UCLA has been following stellar motions to detect an invisible massive black hole.

The Galactic Center at 2.2 microns (without adaptive optics)

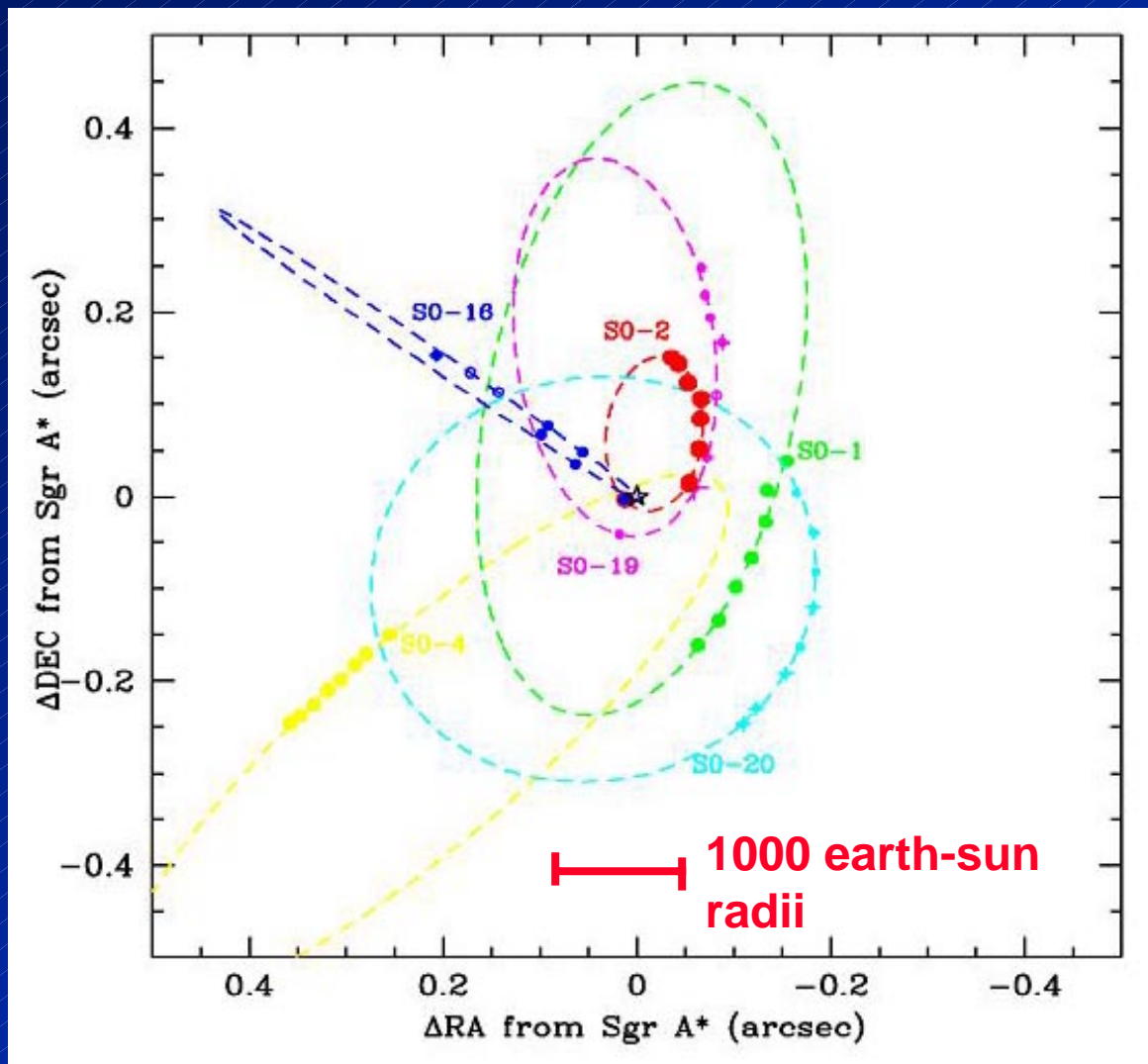


The Galactic Center at 2.2 microns (with adaptive optics)





Stars in orbit about the BH at the Galactic Center



From stellar orbits, the BH is accurately located at the black dot, with mass 3×10^6 solar masses

Recently, IR light has been detected from the BH for the first time, using Keck AO

Andrea Ghez, UCLA



Active Galactic Nuclei

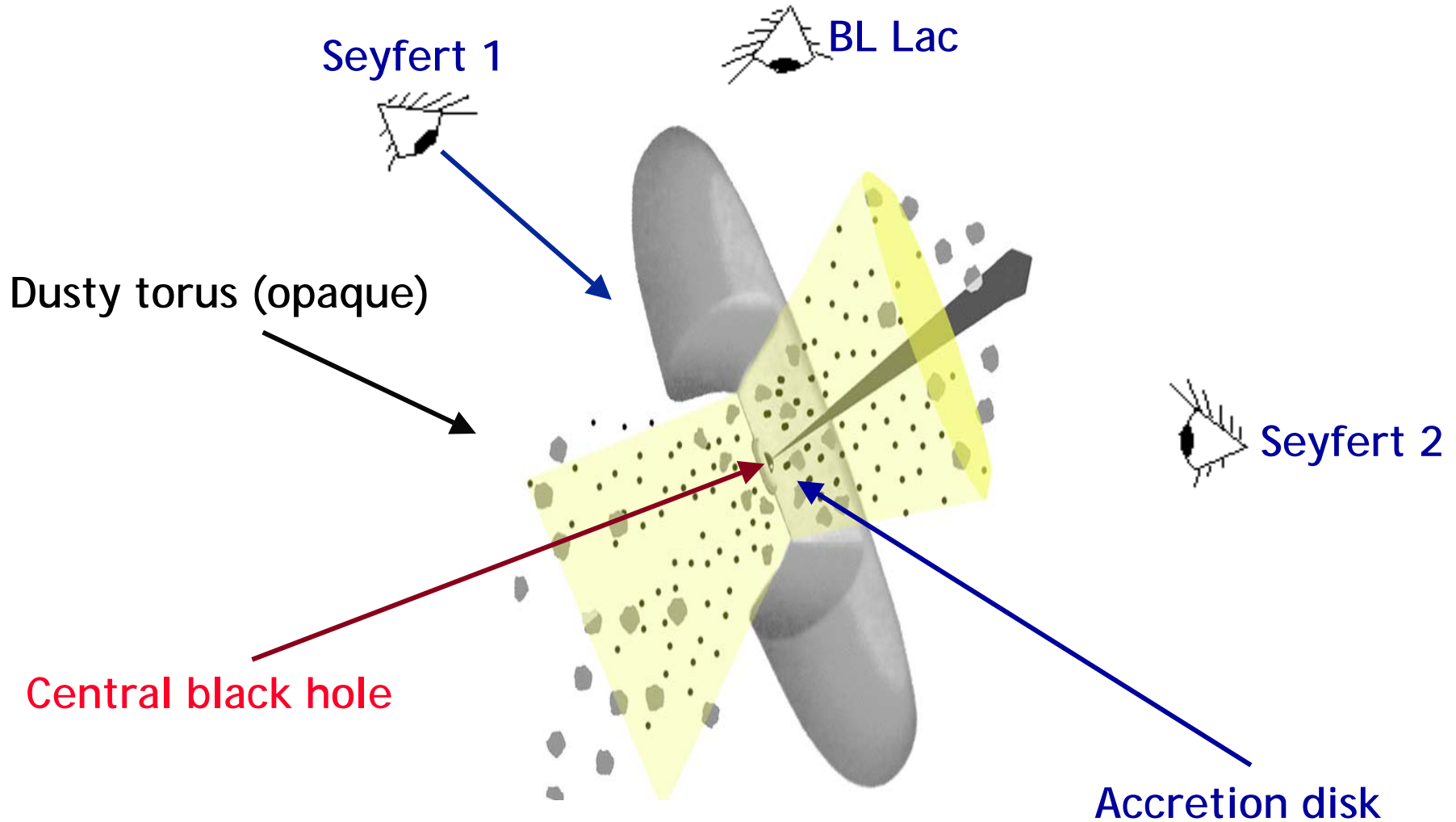
Active galactic nuclei include quasars, Seyfert galaxies, and radio galaxies.

They are powered by gas falling onto massive central black holes, which can weigh up to several billion solar masses.

Claire Max and grad student Lynne Raschke at UC Santa Cruz are studying star formation near AGNs using both Keck AO and Hubble Space Telescope.



What are AGN's? the “cartoon approximation”





Cygnus A: Nearby prototype of a powerful radio galaxy

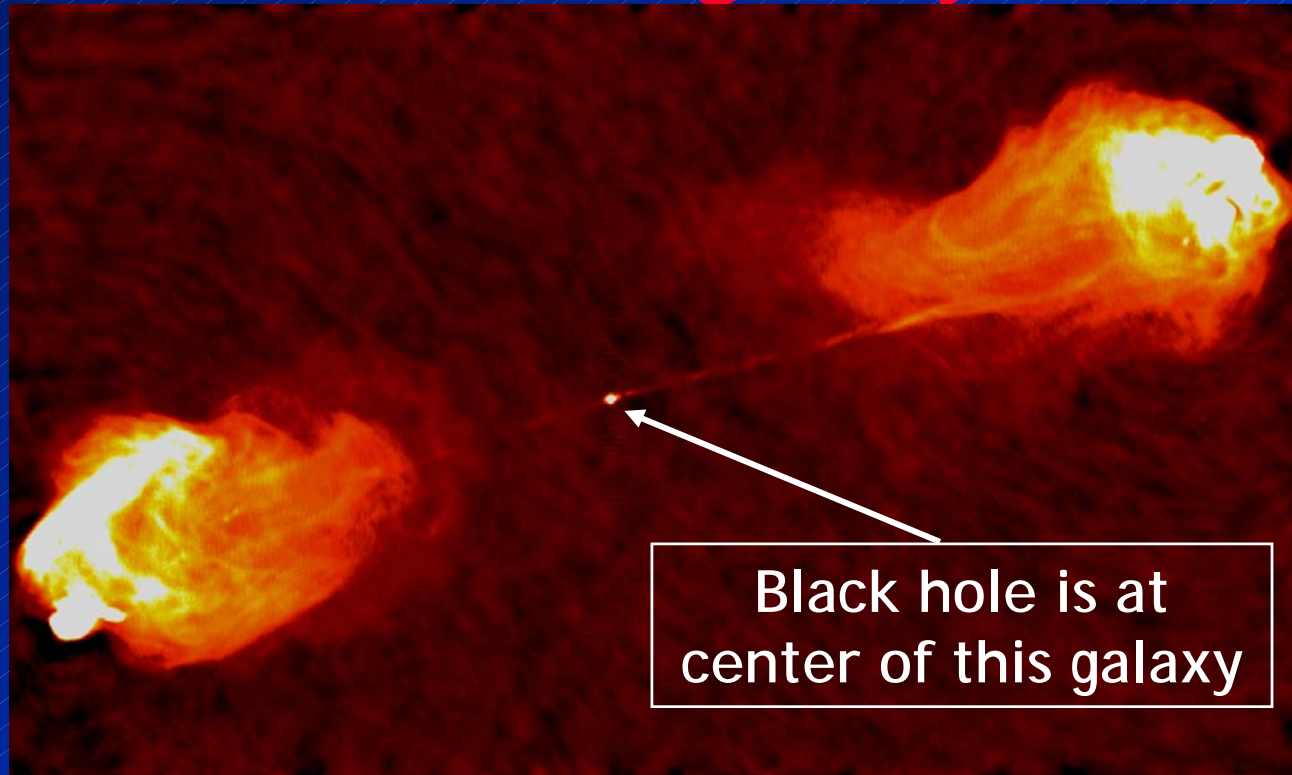


Image from VLA radio
interferometer: powerful double-
lobed radio source



Keck AO: H-band 40" field

Cygnus A:
the whole
galaxy

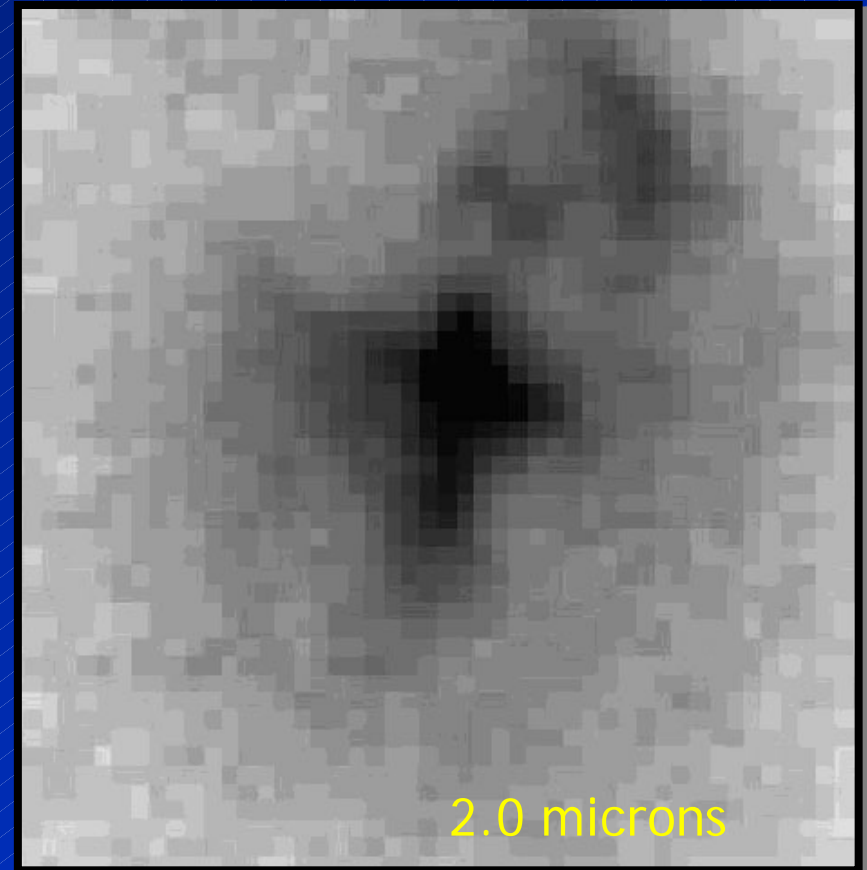
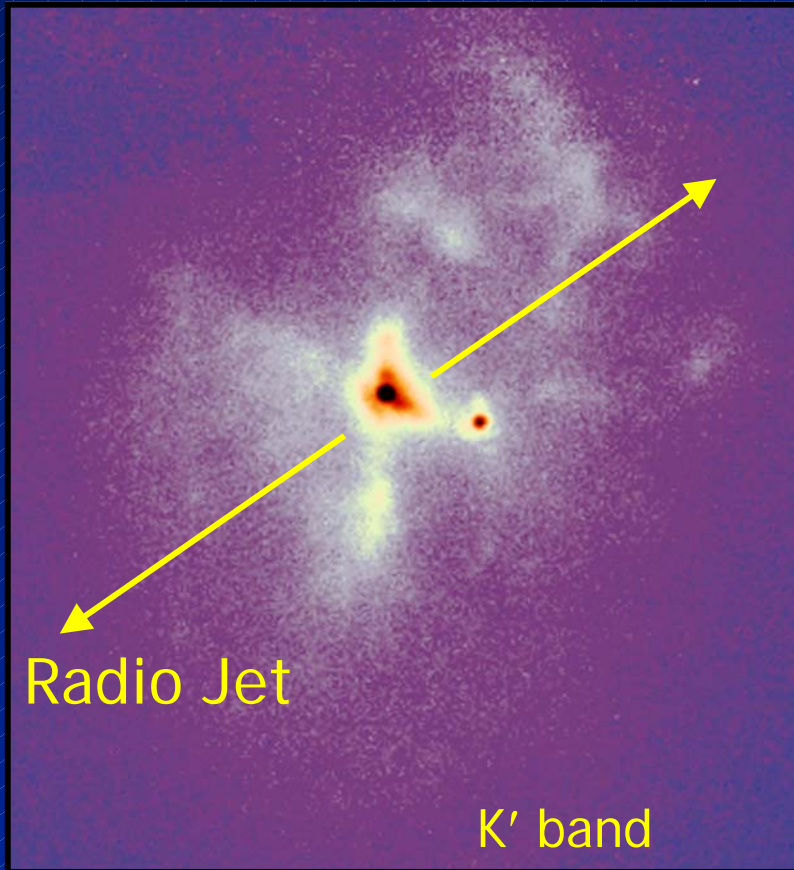
Redshift
 $z = 0.056$



AO guide star
(over-exposed)



Inner core of Cygnus A

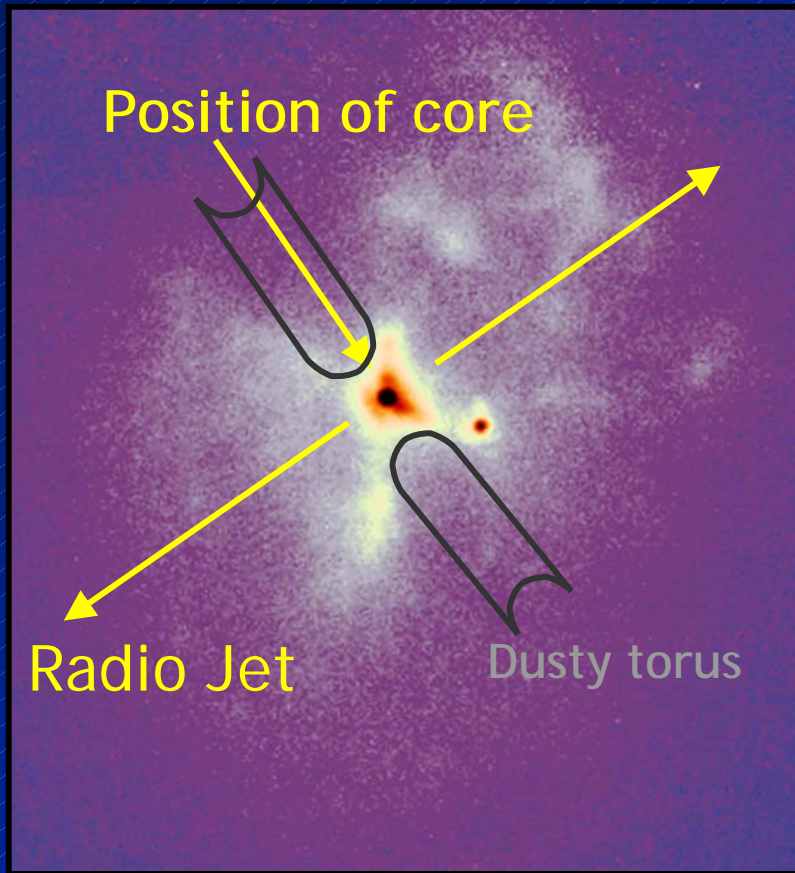


Keck AO with NIRC2 camera
Telescope:
Spatial resolution ~ 0.05 arc sec (50 pc)

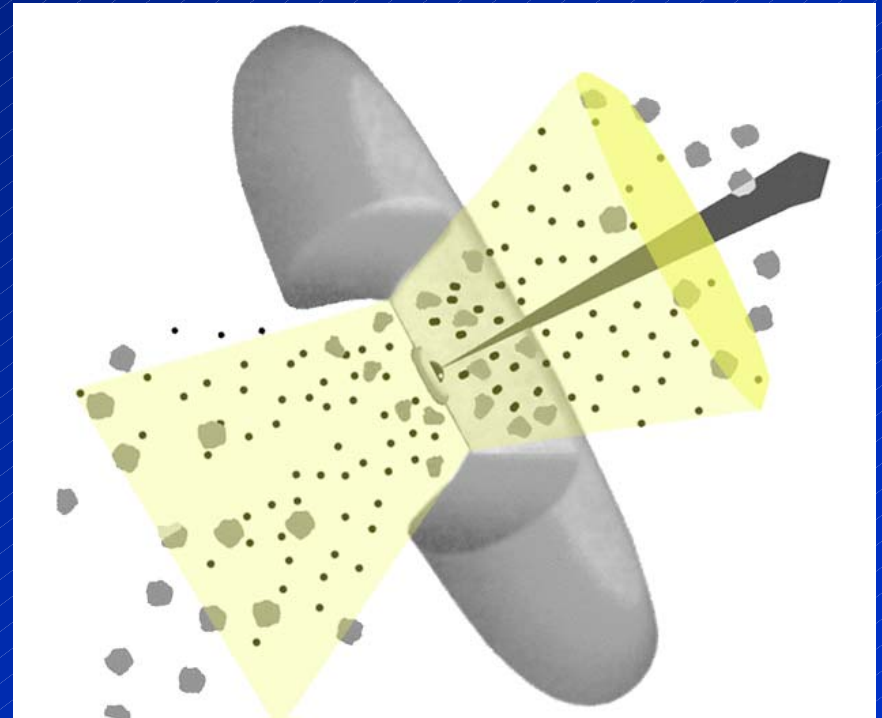
Hubble Space
NICMOS IR image
Claire Max,



Inner core of Cygnus A



Keck AO with NIRC2 camera
K' band

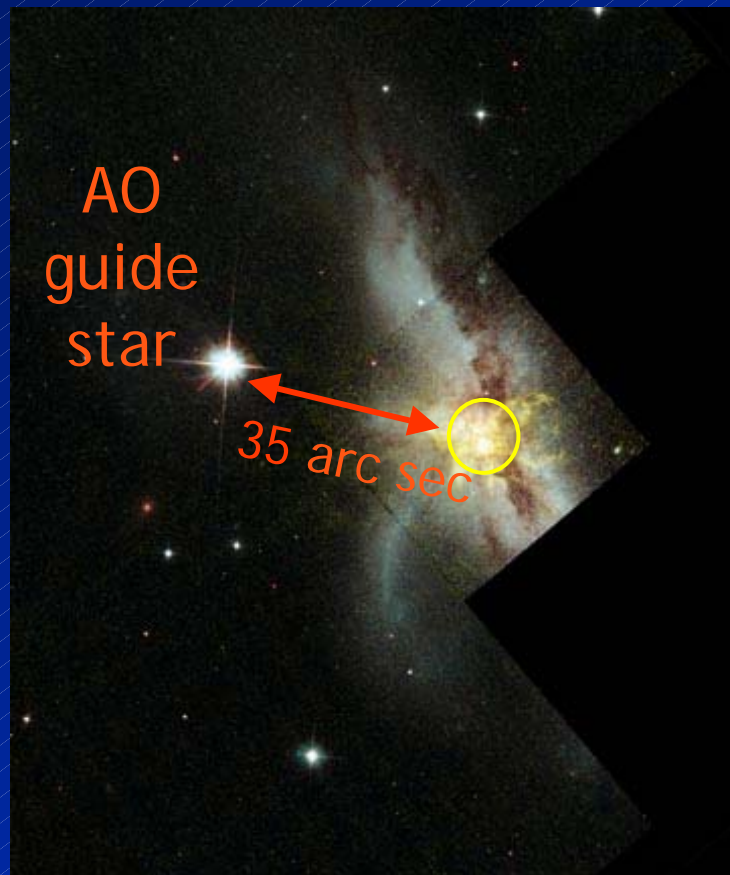


Cartoon of ionization cones
and dusty torus around black hole



NGC 6240: two AGNs *plus* a merger-driven starburst

It's a merger of 2 disk galaxies, it's a starburst galaxy, it hosts not one but 2 black holes

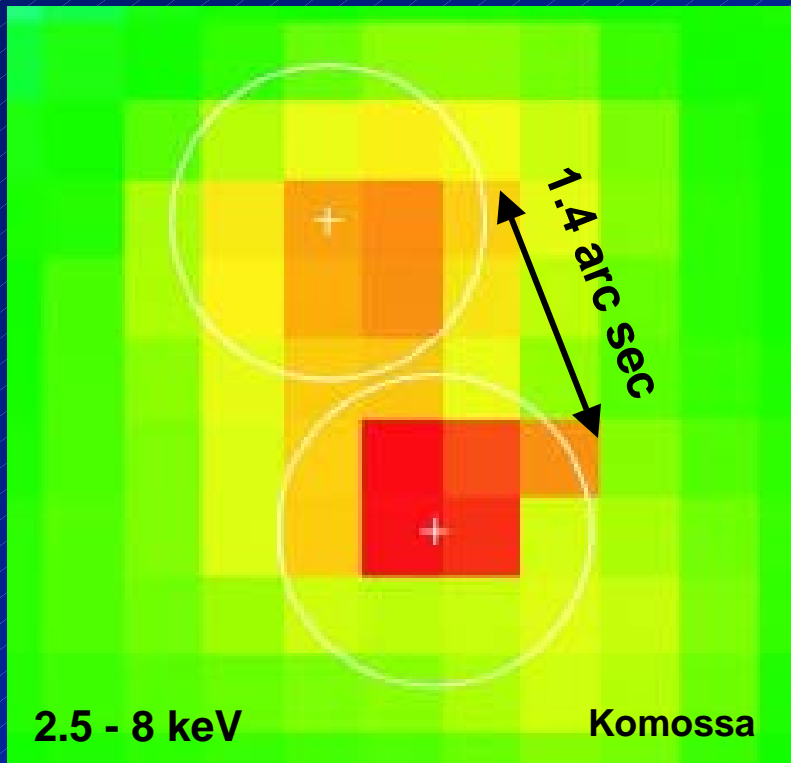


- Relatively nearby:
Redshift $z = 0.0245$
(~ 100 Mpc for $H_0 = 75$)
- Galaxy is most luminous source of near-IR line emission:
 $L_{\text{H2lines}} \sim 10^9 L_{\odot}$
- Double nucleus
- Tidal tails due to merger (“bow-tie”)

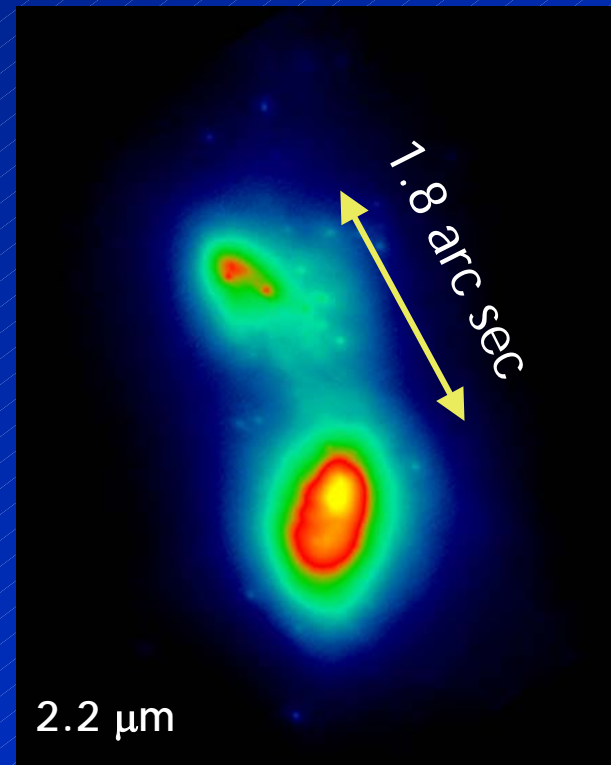


Keck adaptive optics shows details of the two nuclei

1 arc sec = 470 pc



CHANDRA: High energy x-rays from region near black holes

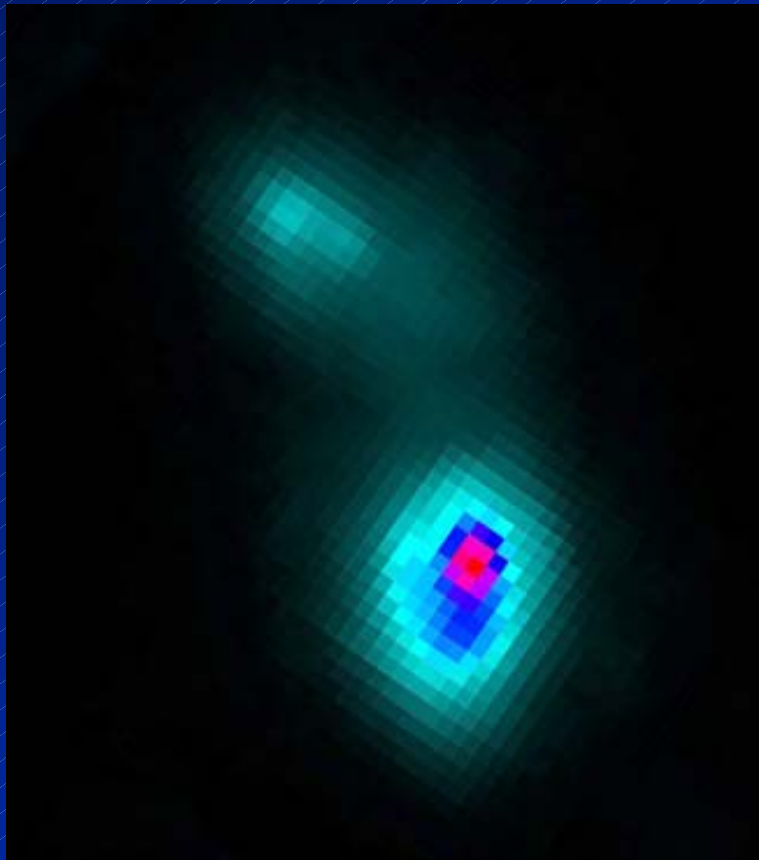


Keck AO: infrared emission from the two nuclei

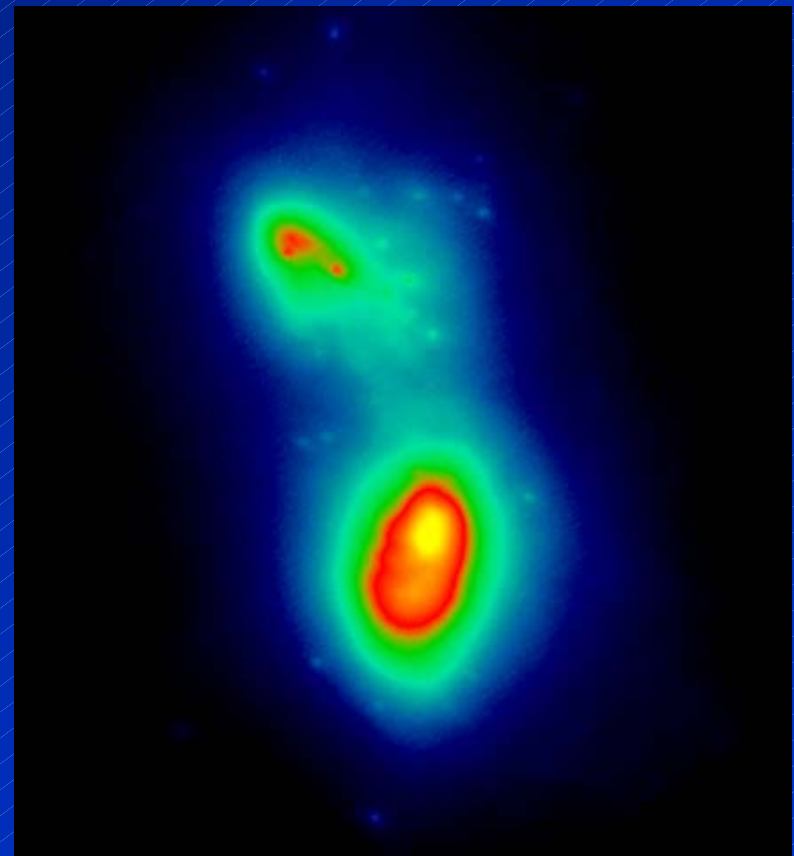


Comparison of Keck AO and NICMOS on Hubble

Hubble, NICMOS, 2.2 micron



Keck AO: NIRC2, 2.2 micron



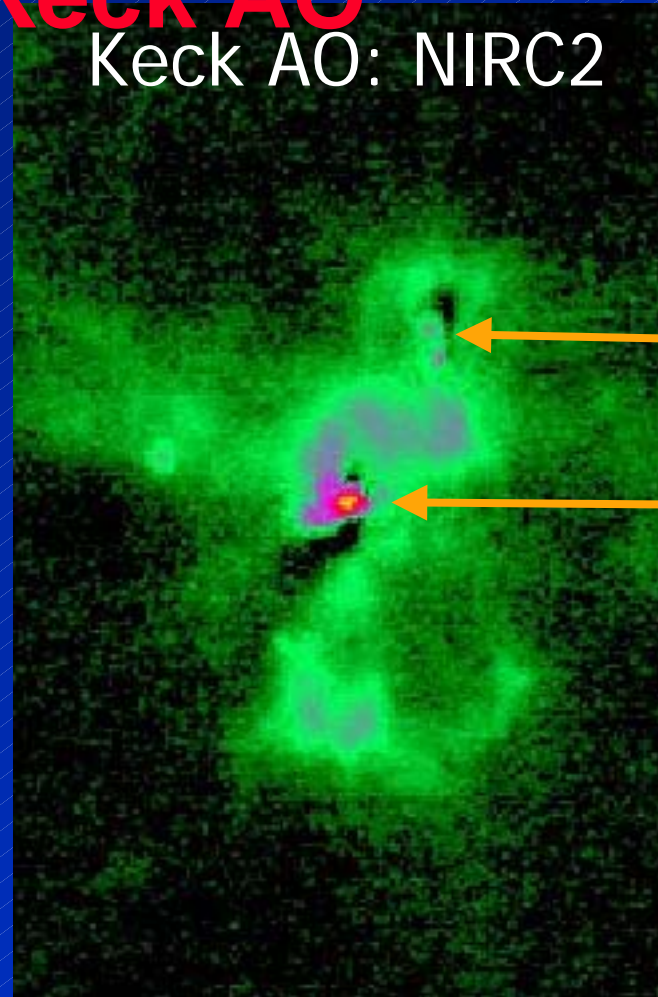


Detailed interior structure of H₂ “superwind” seen with

Keck AO

Image in H₂ 1-0 S(1) line

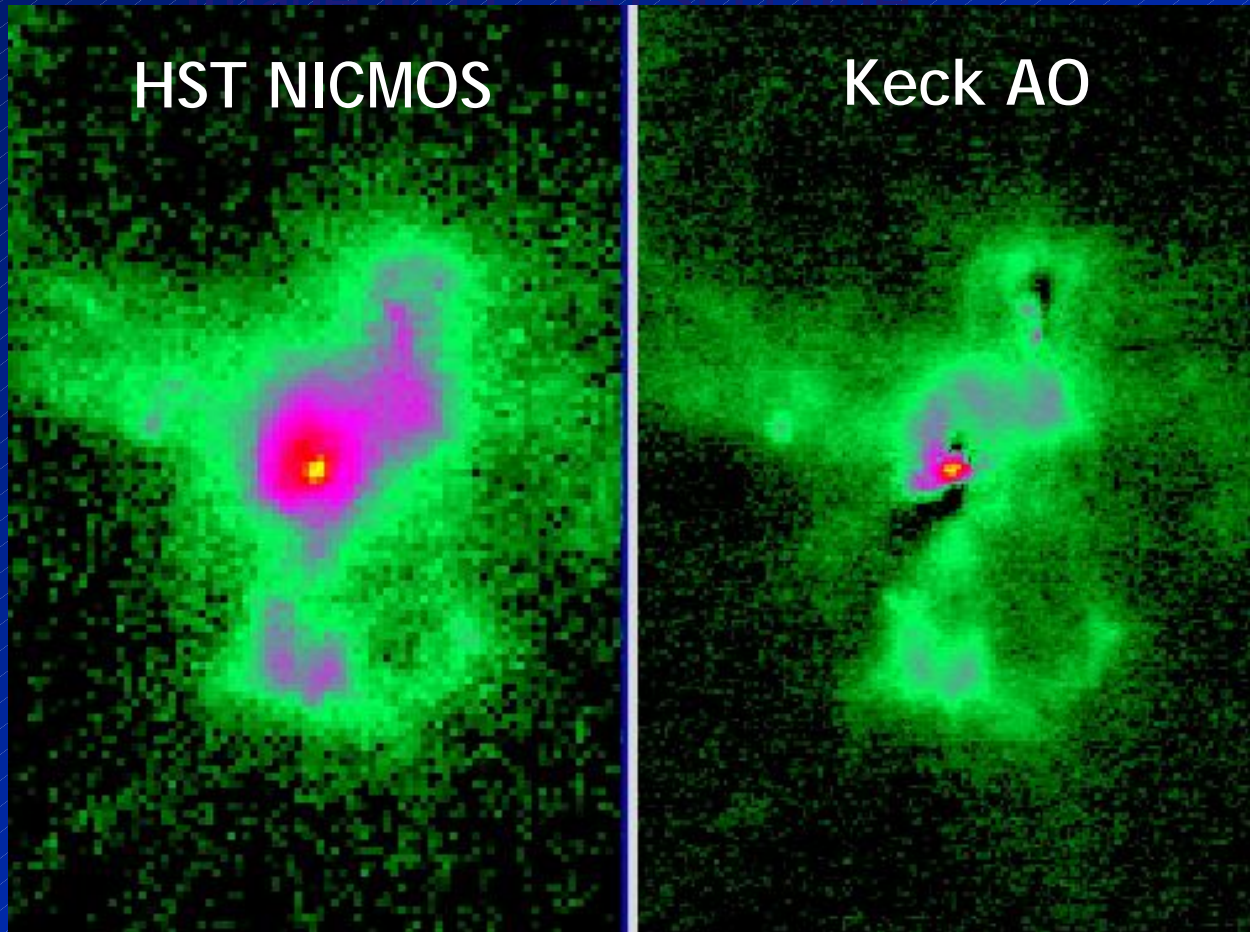
- Streamers of excited H₂ driven by starbursts
- “Bubbles” (due to multiple supernovae)
- “Ribbon” of excited H₂ between S and N nuclei



Claire Max,

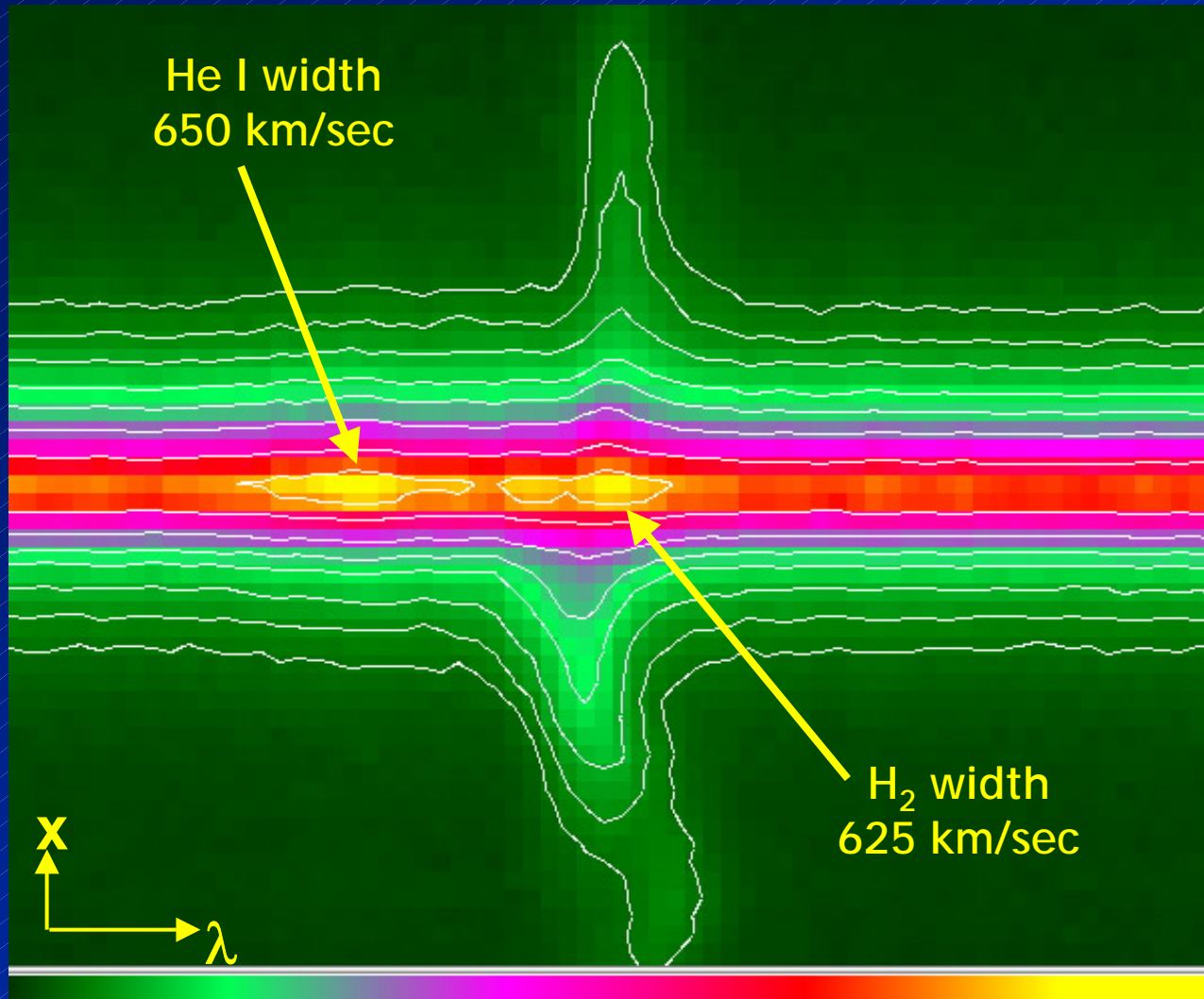


Comparison of Keck adaptive optics with HST NICMOS





AO spectroscopy shows gas velocities nearest BH



AO spectroscopy using He I and H₂ lines at 2 microns.

Broadened H₂ and He I lines extend over only 2 pixels (~56 pc)

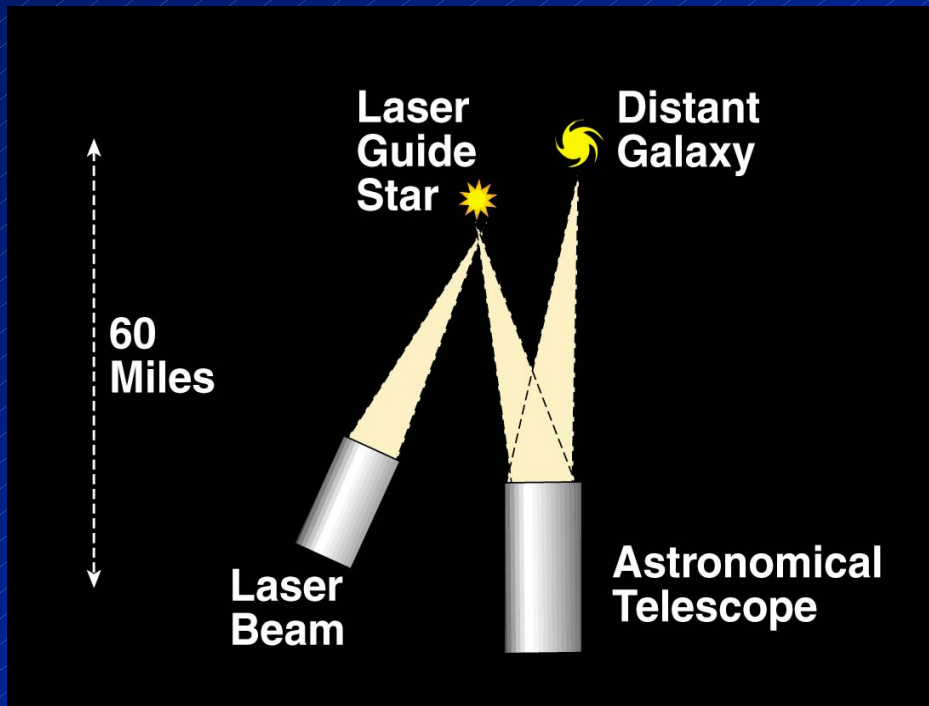
Not seen in a spectrum taken a few 10th of an arc sec away

Claire Max,

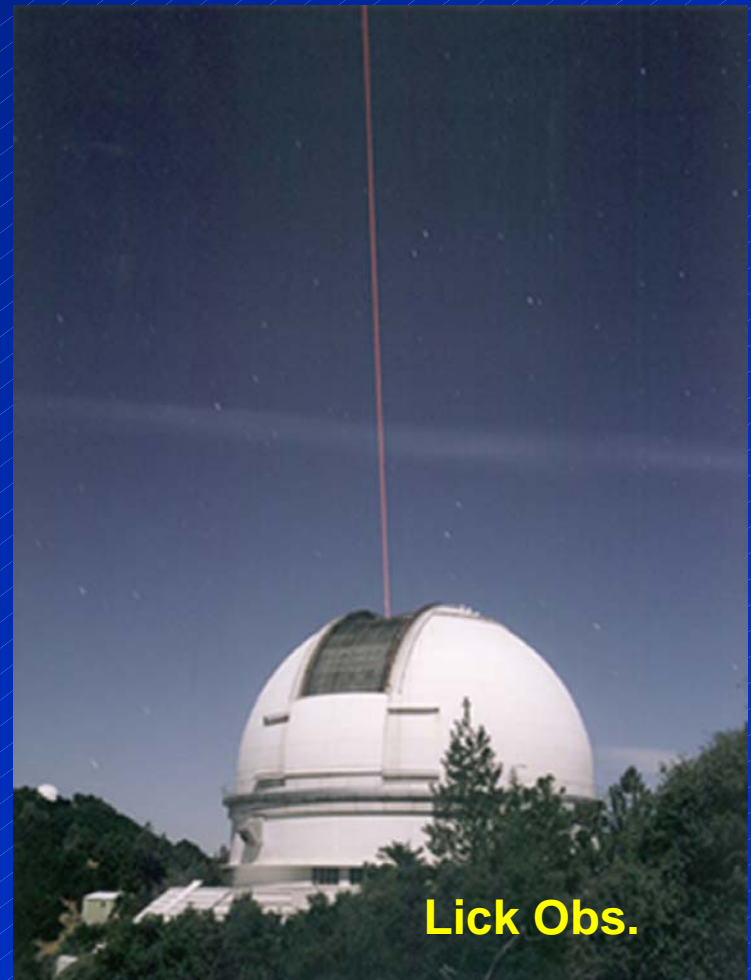


If there is no nearby star, make your own “star” using a laser

Concept



Implementation



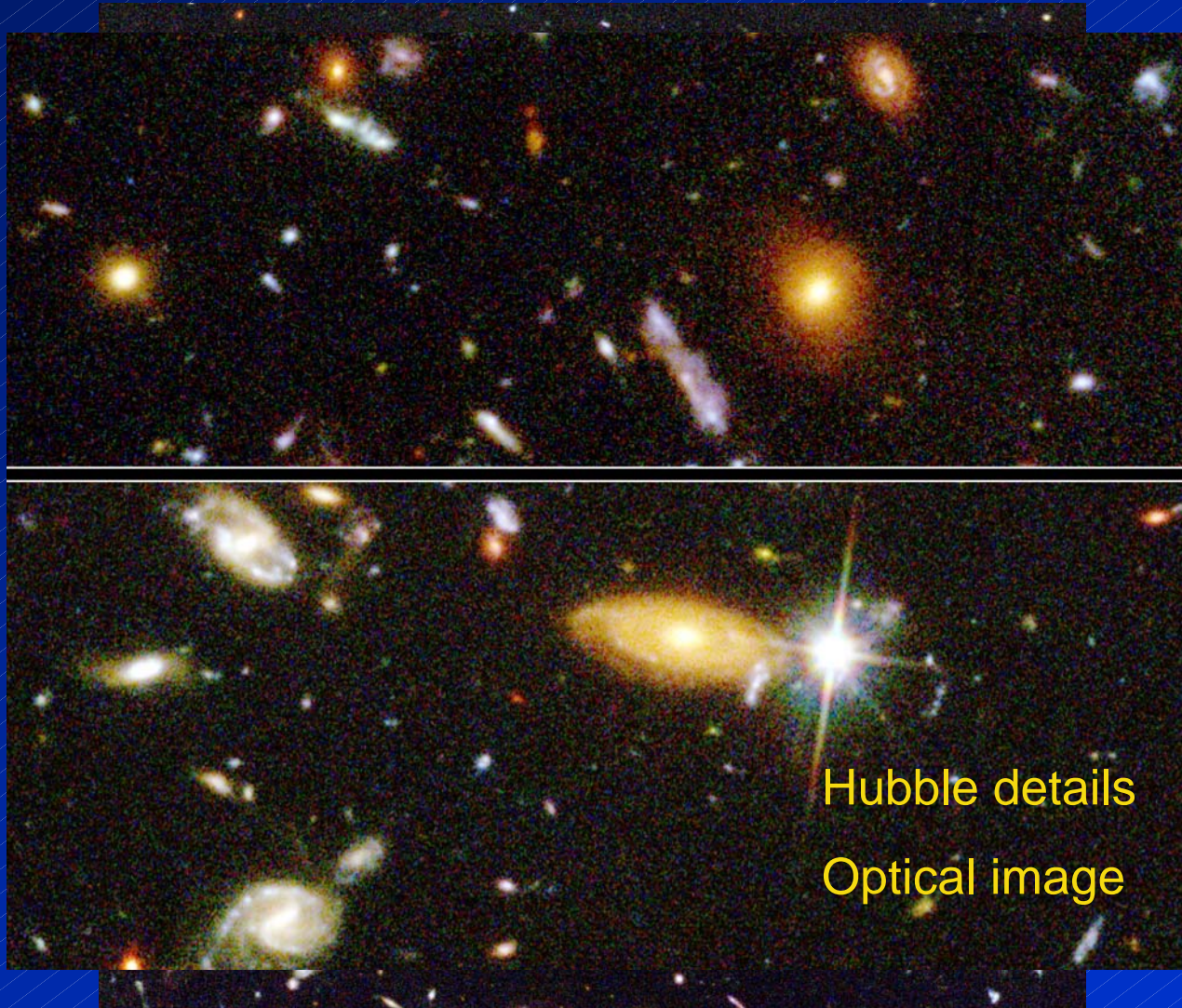


New Laser at Keck: Ready Next Year





The Hubble Deep Field: Distant Galaxies to 12 Billion Lyr

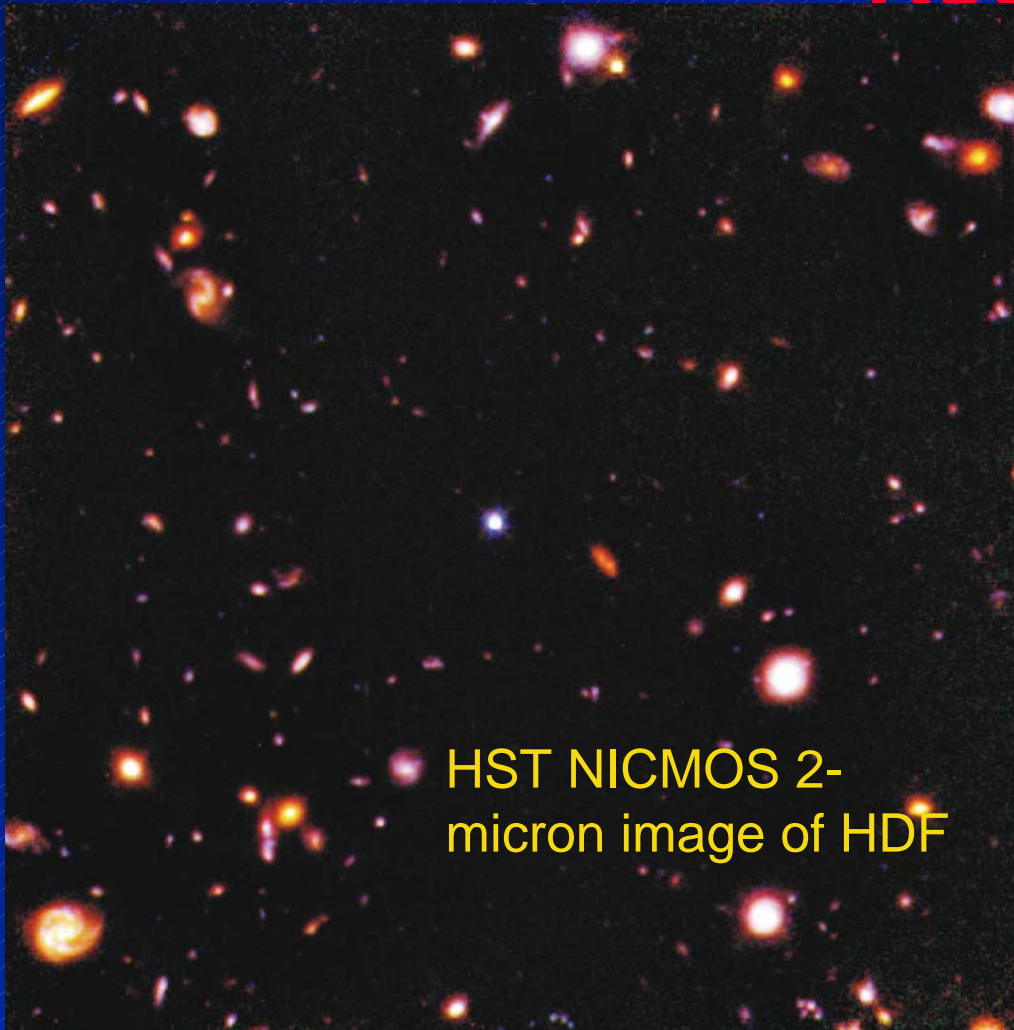


Hubble details

Optical image



The CATS AO Survey of the GOODS-North Field at Keck



HST NICMOS 2-
micron image of HDF

GOODS-North is a larger region surrounding the Hubble Deep Field

CATS will be a major Treasury survey of GOODS-N by CfAO and Keck

Led by Profs. James Larkin (UCLA) and David Koo (UCSC)



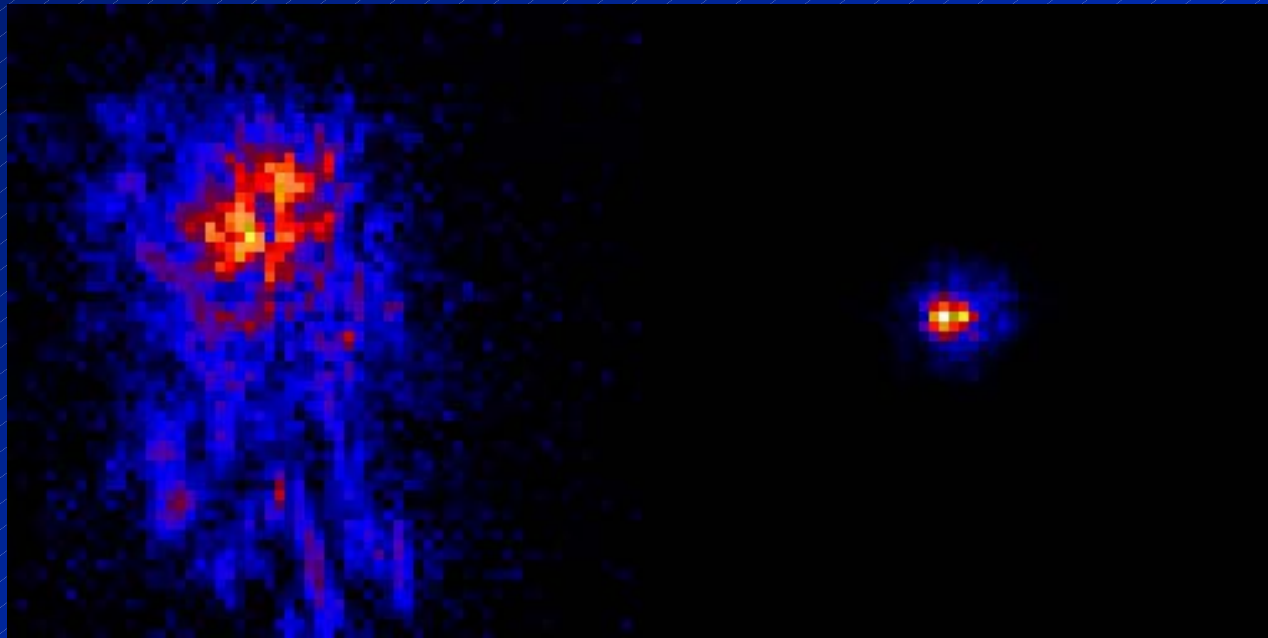
Future Opportunities at CfAO

- High-resolution studies of Solar System objects, AGNs, and the Galactic center are already underway using natural guidestars
- Roughly six PhD theses are completed or are underway, plus numerous undergraduate projects
- The coming laser will make Keck AO a general-purpose tool applicable to every kind of astronomical object
- The CATS Treasury survey will yield a gold-mine of near-IR data on distant galaxies that won't be equaled until NASA's JWST satellite observatory roughly 10 years from now



Adaptive optics in action

Lick Observatory adaptive optics system

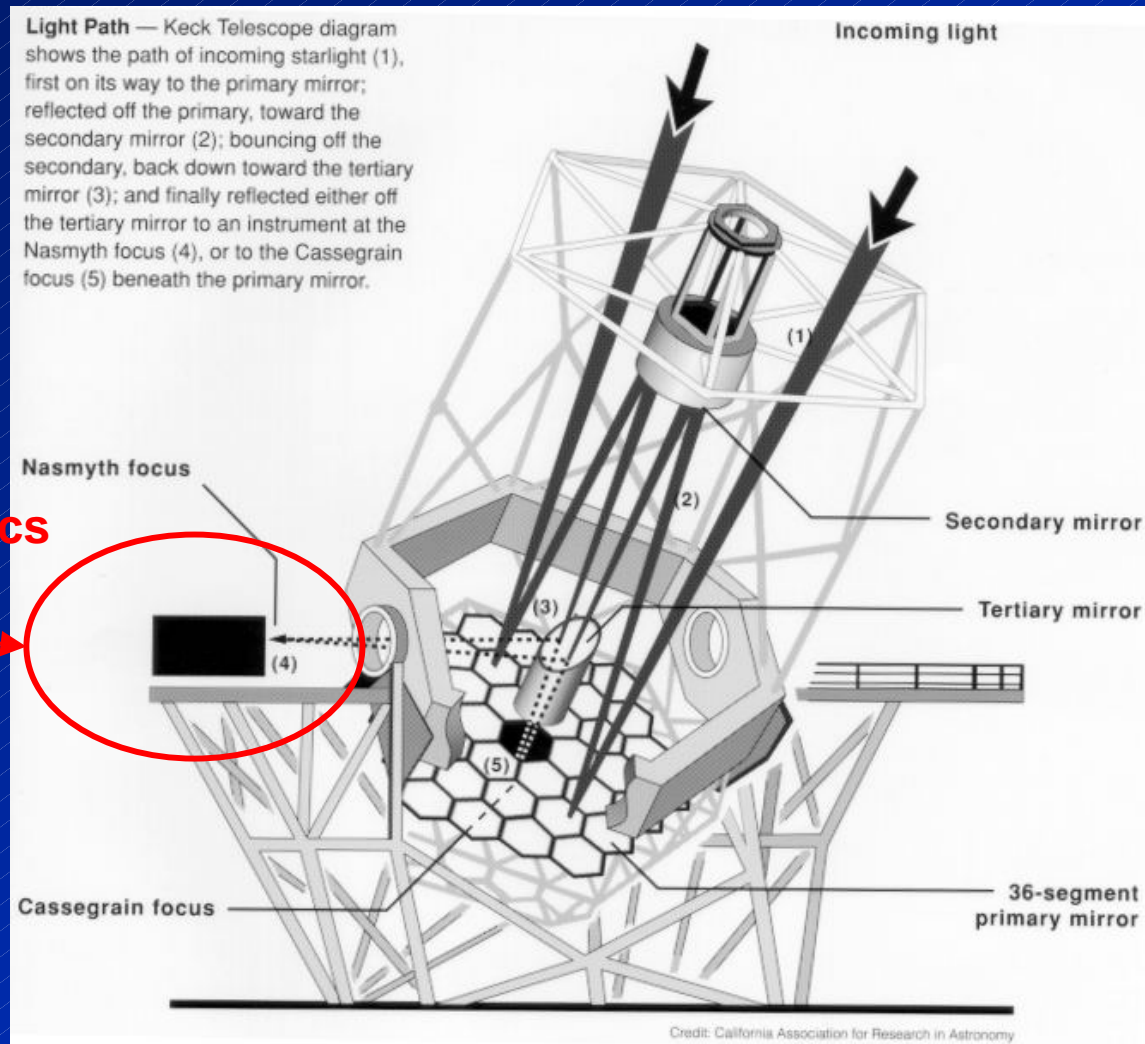


Star without adaptive optics

Star with adaptive optics



AO at the Keck 10 m Telescope

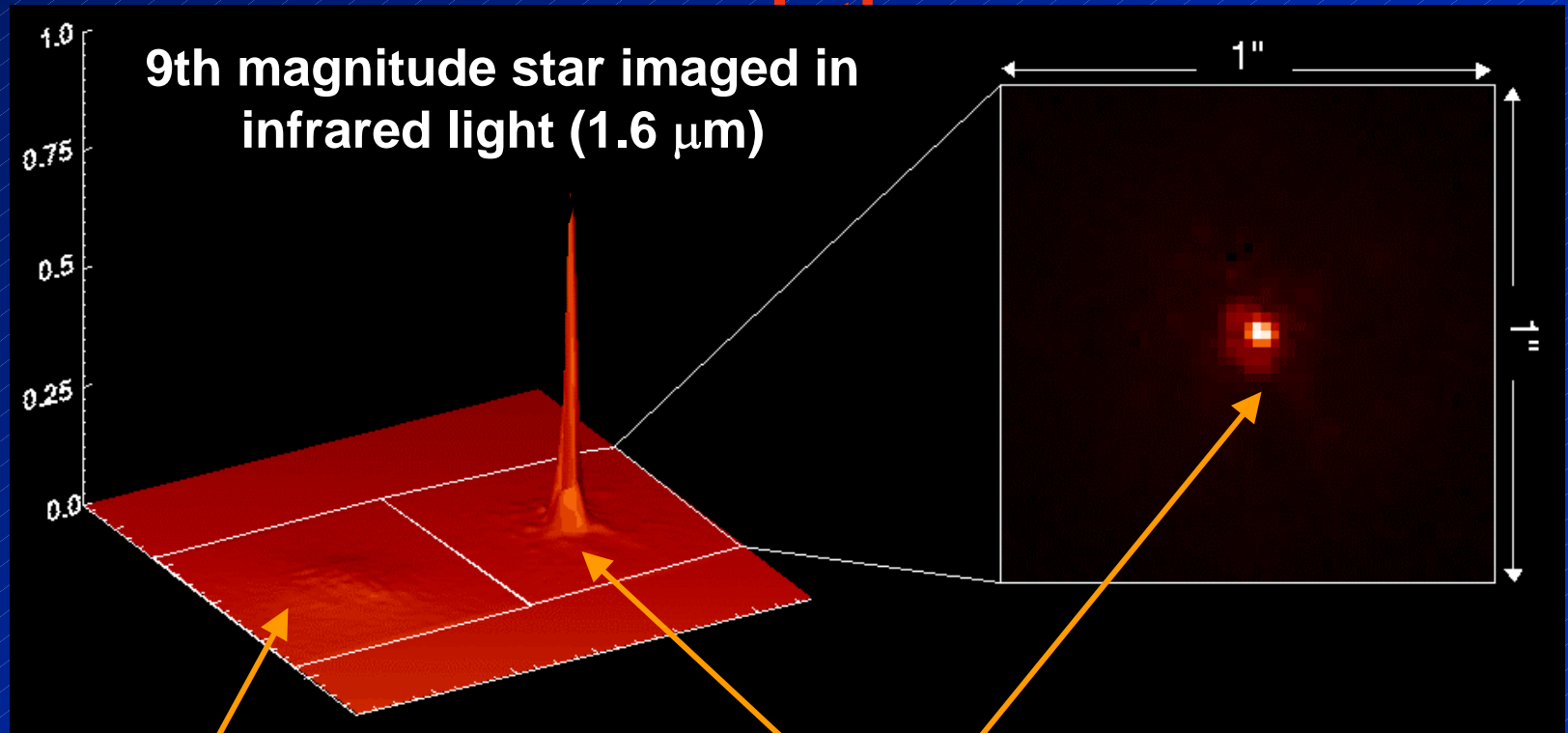






Adaptive optics on 10-m Keck II Telescope:

Factor of 10 increase in spatial



Without AO
width = 0.34 arc sec

With AO
width = 0.039 arc sec