Future Instruments: Adaptive Optics

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Nearly Normal Galaxies Conference

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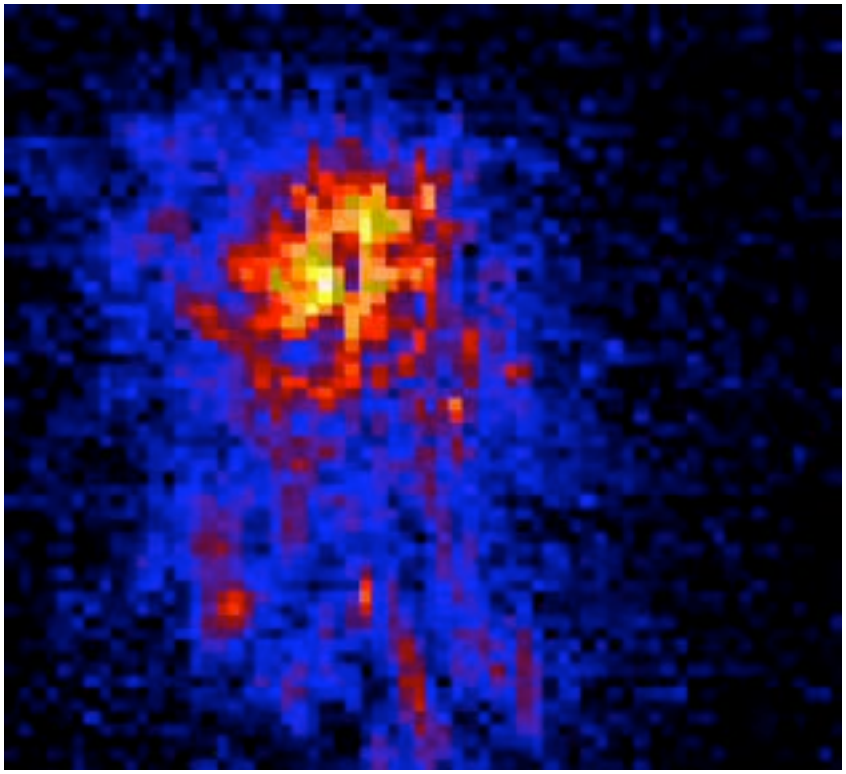
Outline

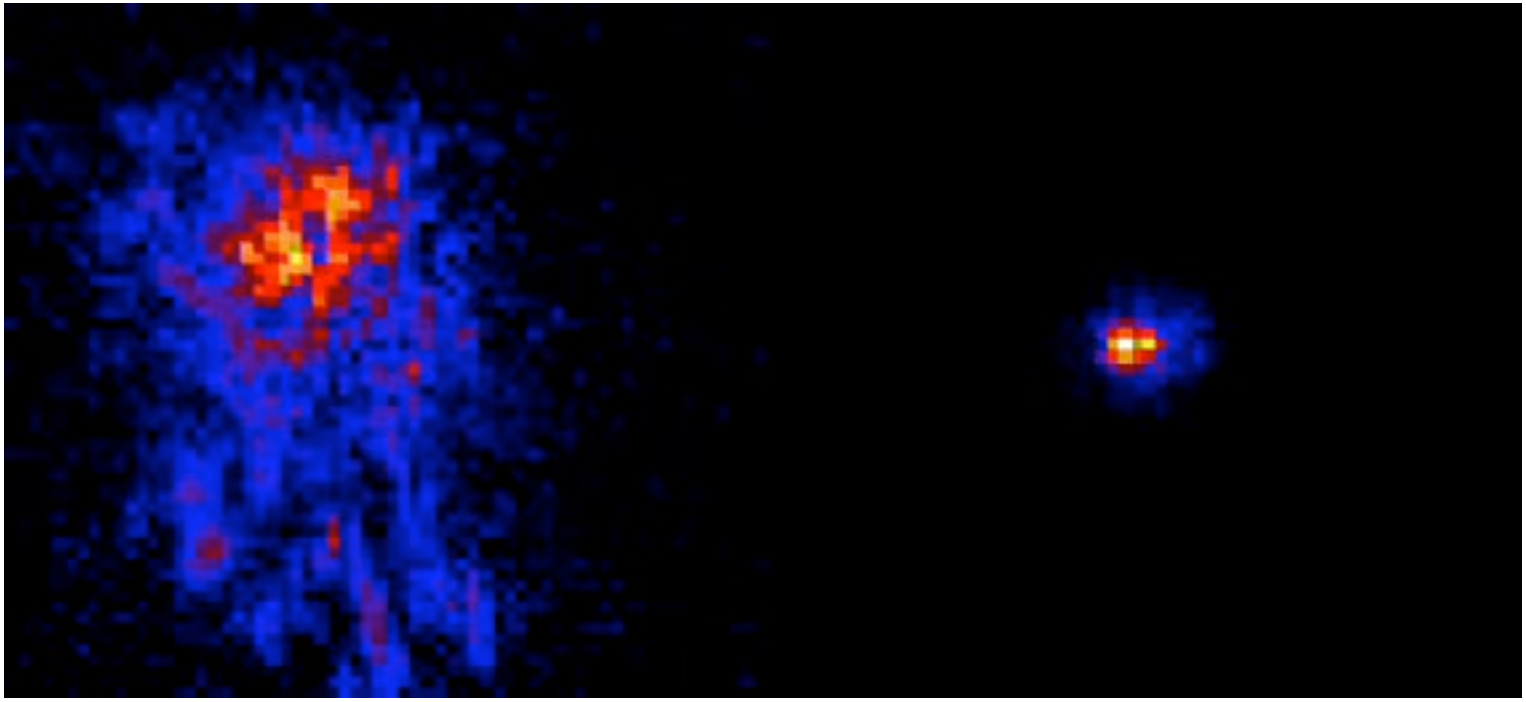
- Introduction to adaptive optics (AO)
- AO issues specific to extragalactic astronomy
- A few examples of current extragalactic projects
- What lies in the future?

Movie of "real" turbulence (vastly slowed down)



Sequence of short snapshots of a star, taken at Lick Observatory using the IRCAL infra-red camera

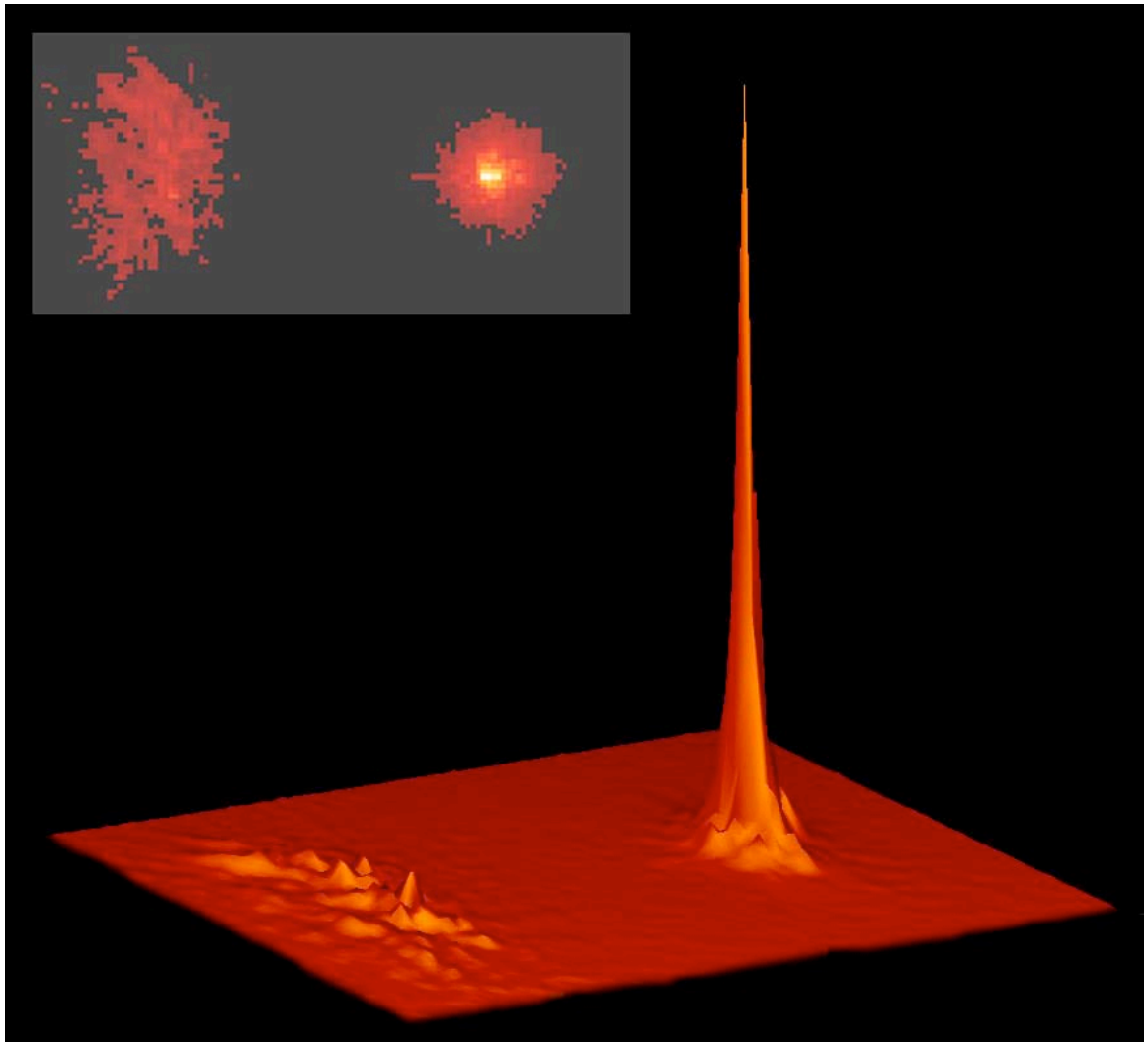
Infra-red images of a star, from Lick Observatory adaptive optics system



No adaptive optics

With adaptive optics

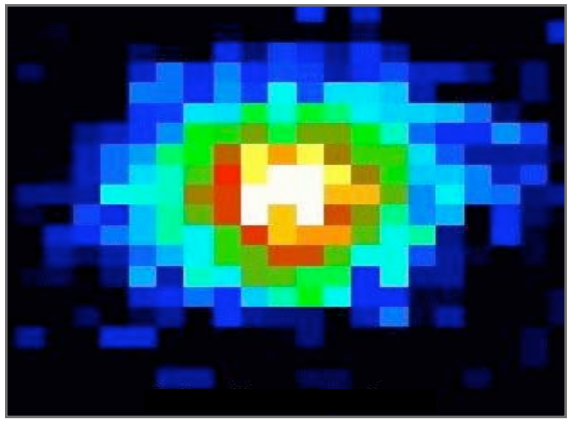
Adaptive optics increases peak intensity of a point source



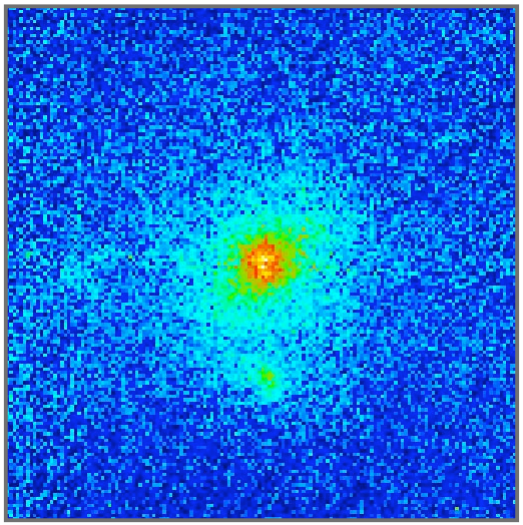
Lick Observatory

A redshift z~0.5 galaxy seen at Keck with three different cameras

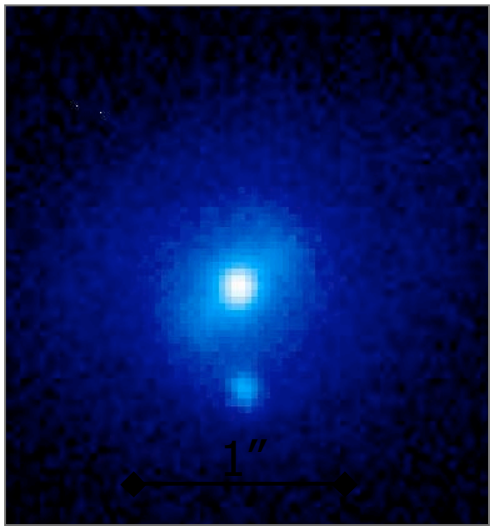
PPM114182+6+27 H-band image (z=0.487)
James Larkin and colleagues, UCLA



Non-AO NIRC

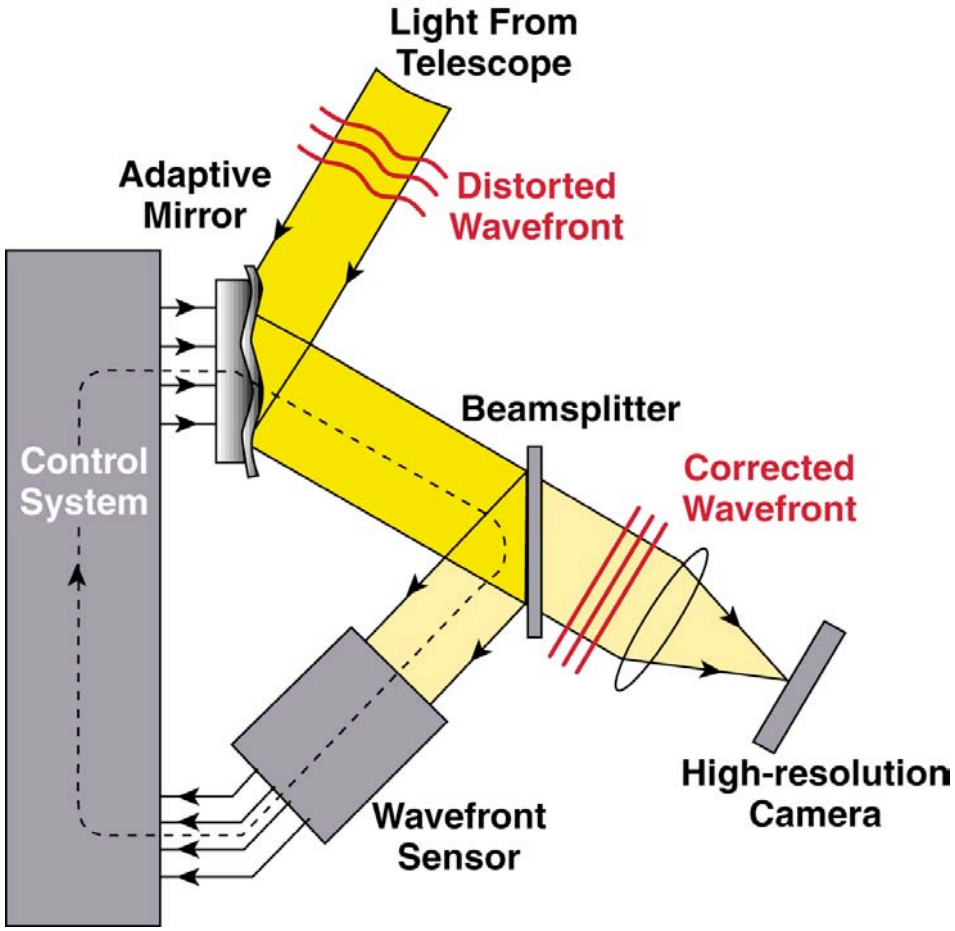


Scam - NIRSPEC
with AO



NIRC2
with AO

Optical schematic of adaptive optics system

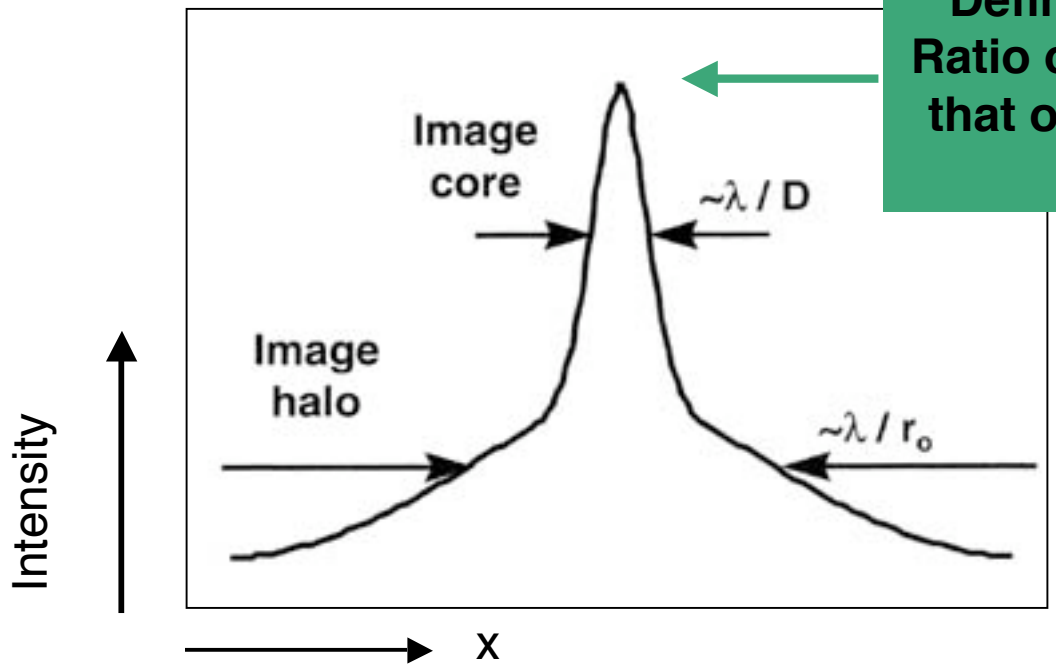


AO issues specific to extragalactic astronomy

- Point spread function is variable
- Sky coverage fraction with natural guide stars is low (less than a few %). Need to use laser guide stars for high sky coverage.
- Corrected field of view will be modest, even with new AO schemes (of order a few arc min at most). Means practical surveys will contain tens - 100 galaxies, rather thousands.
- Best for modest-size surveys, detailed studies of individual objects (e.g. black hole masses)

BUT: Keck AO at K band is producing images with same spatial resolution as HST at V band, on a regular basis.

AO produces point spread functions with a "core" and "halo"



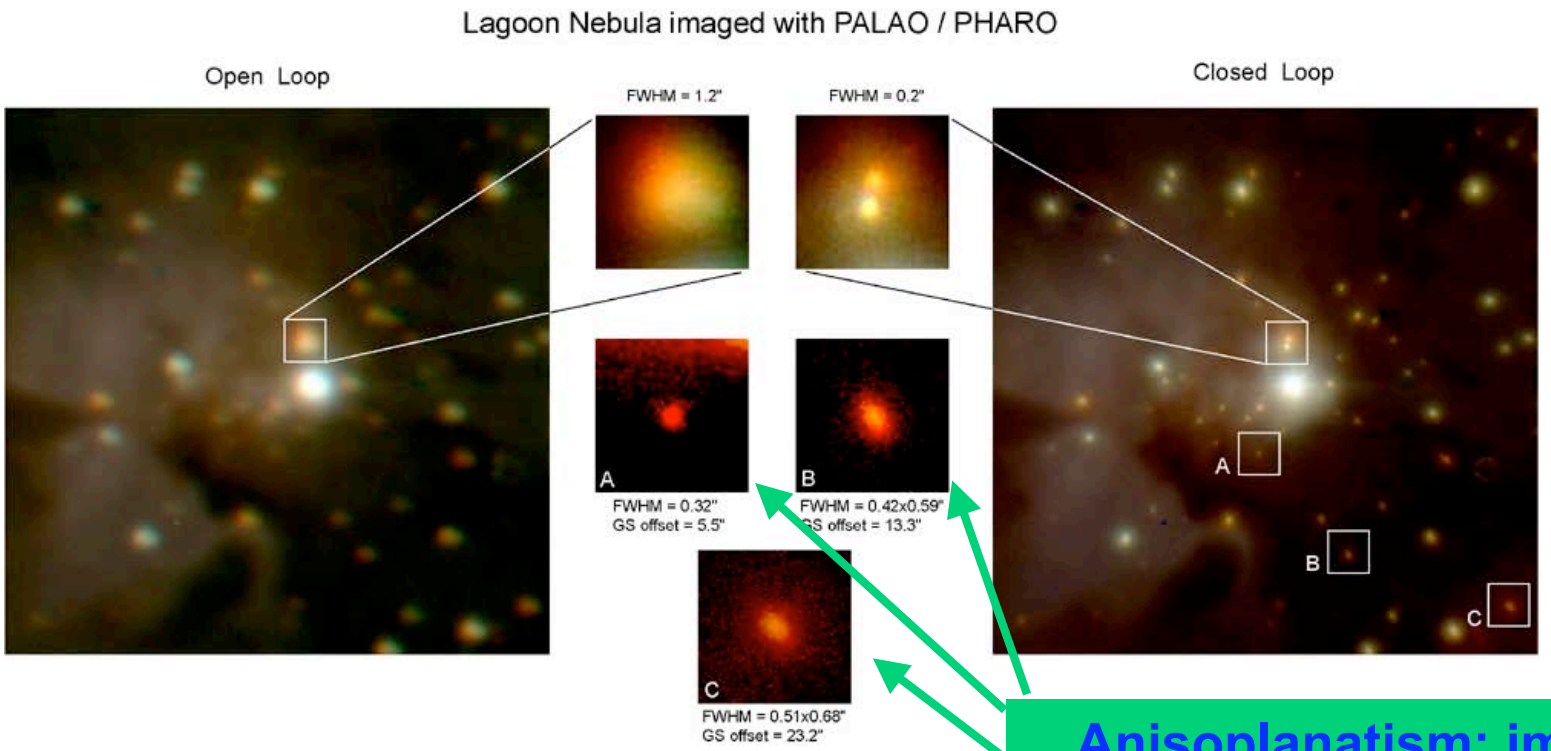
Definition of "Strehl": Ratio of peak intensity to that of "perfect" optical system

- When AO system performs well, more energy in core
- When AO system is stressed (poor seeing), halo contains larger fraction of energy (diameter ~ r_0)
- Ratio between core and halo varies during night
- Key element is measuring the point spread function

Field angle limitations

- Wavefronts measured in one direction do not usually apply in other directions
- This limits the field of view of AO systems
- Also limits the useful sky coverage fraction, because a natural guide star must be quite close to the astronomical object of interest
- Most astronomical objects (e.g. galaxies, asteroids, ...) are not bright enough to use as wavefront reference
- Leads to the need for measurement "beacons": bright natural stars, or artificial stars created by laser beacons

Palomar: anisoplanatism with AO

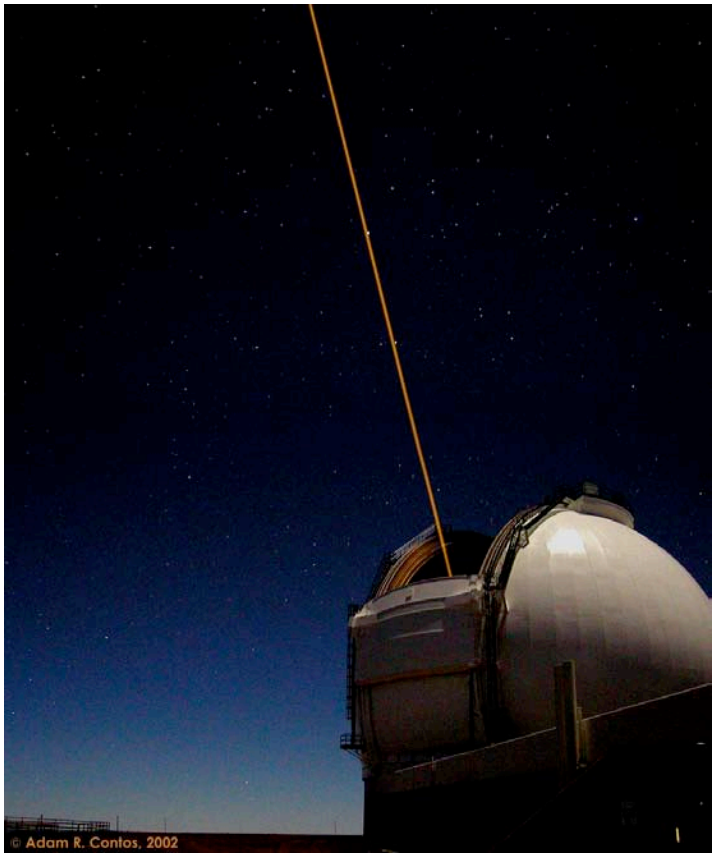


Anisoplanatism: image quality deteriorates farther from guide star

- Composite J, H, K band image
- Field of view 40”x40” (at 0.04 arc sec
- On-axis K-band Strehl ~ 40%, falls to 25% at corner

Laser guide stars at Lick and Keck Observatories

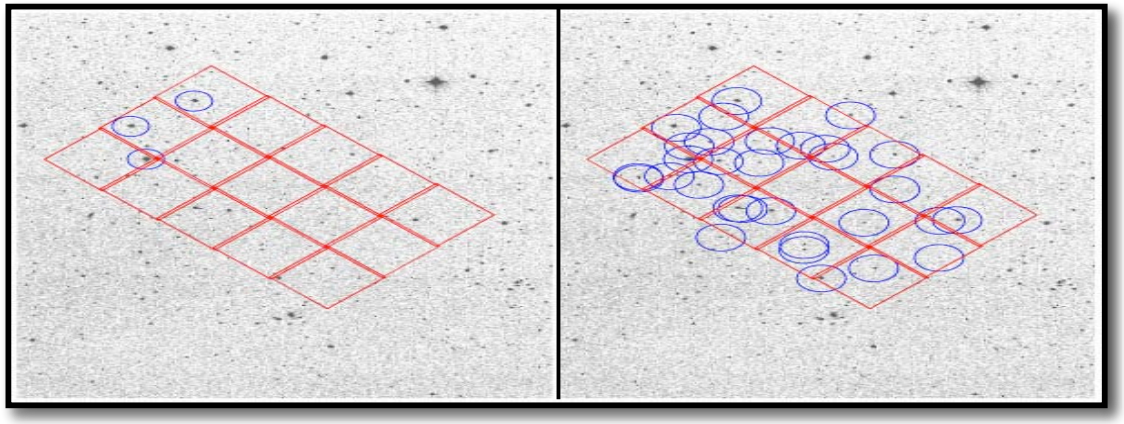
Lick Observatory
photo: Laurie Hatch



Keck Observatory
photo: Adam Contos

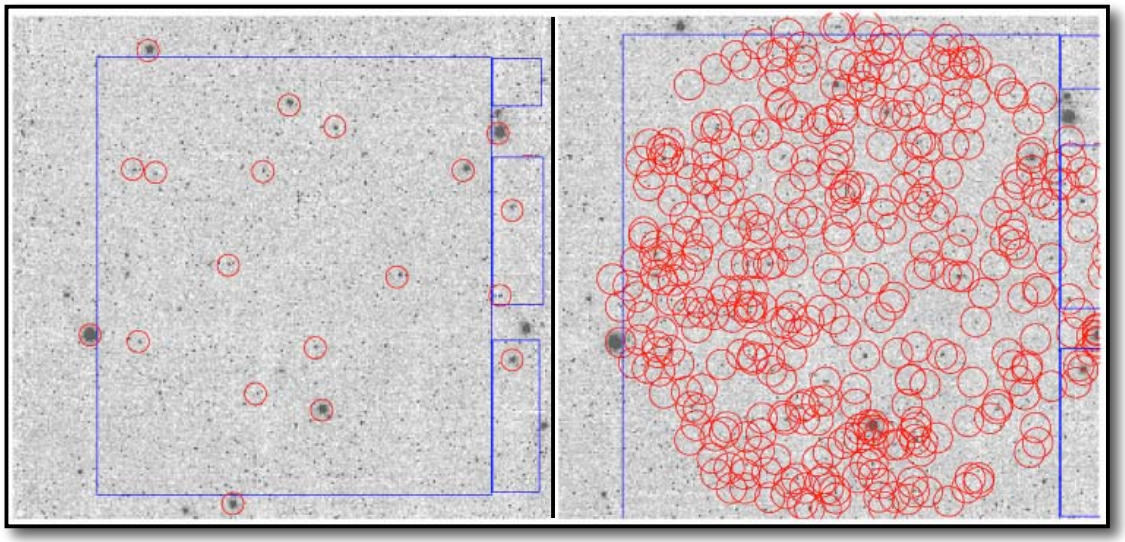
GOODS Field (North) and GEMS Field (South)

GOODS



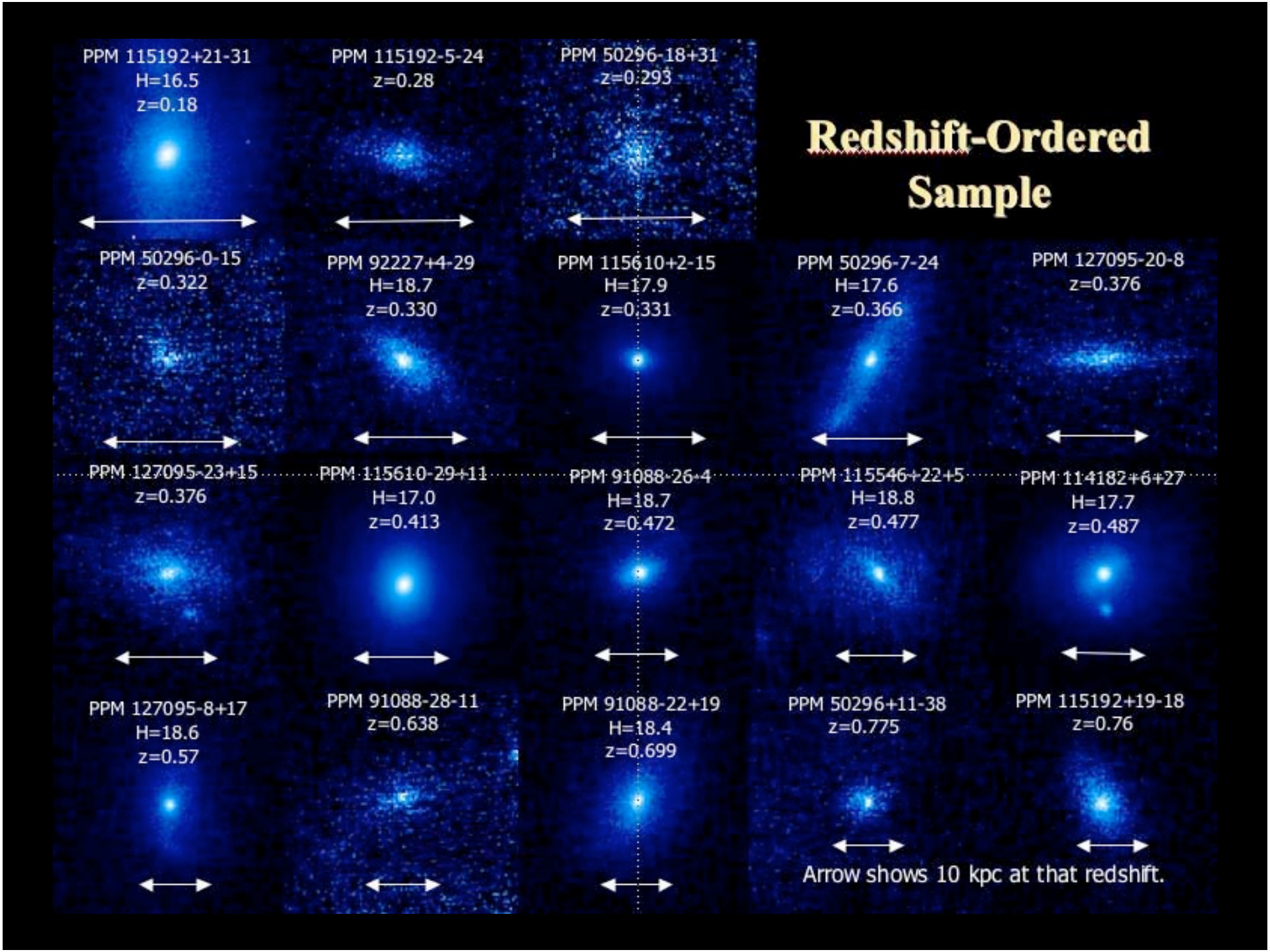
Natural AO coverage Laser AO coverage

GEMS



A few current extragalactic AO projects

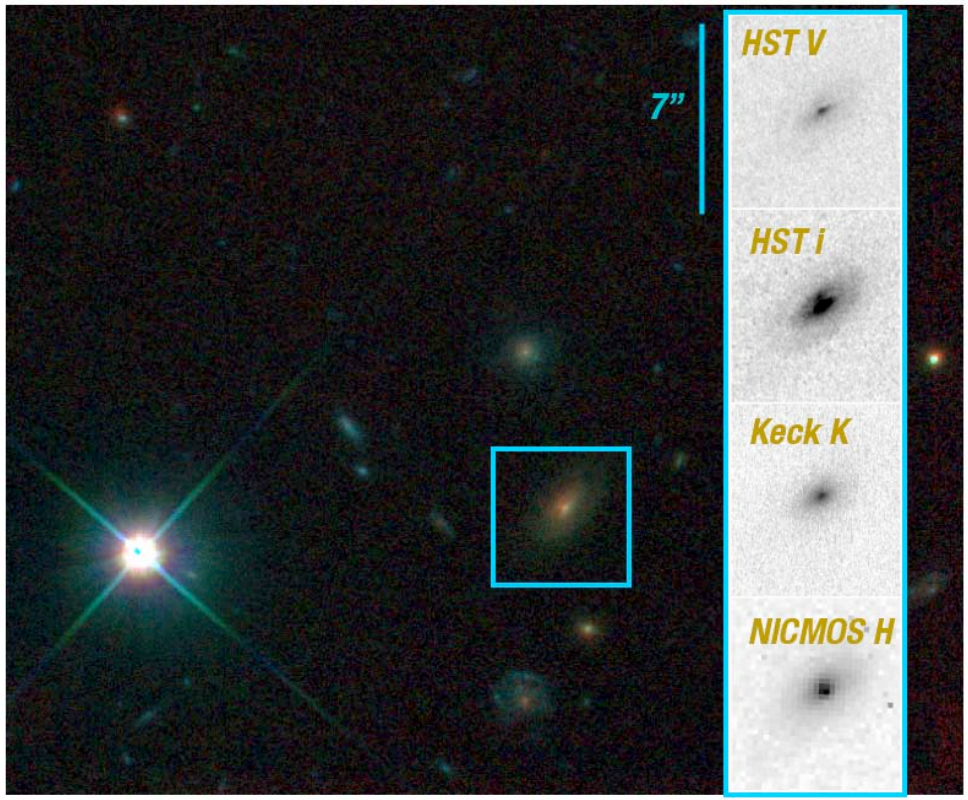
- Larkin et al. galaxy survey using natural guide stars (Looking Under the Lamp-post)
- CfAO Treasury Survey (CATS):
  - GOODS, GEMS, EGS at K-band at Keck, mostly with laser guide star AO
- Black hole masses and feedback in nearby AGNs


PPM 115192+21-31
H=16.5
z=0.18
PPM 115192-5-24
z=0.28
PPM 50296-18+31
z=0.293
Redshift-Ordered Sample
PPM 50296-0-15
z=0.322
PPM 92227+4-29
H=18.7
z=0.330
PPM 115610+2-15
H=17.9
z=0.331
PPM 50296-7-24
H=17.6
z=0.366
PPM 127095-20-8
z=0.376
PPM 127095-23+15
z=0.376
PPM 115610-29+11
H=17.0
z=0.413
PPM 91088-26+4
H=18.7
z=0.472
PPM 115546+22+5
H=18.8
z=0.477
PPM 114182+6+27
H=17.7
z=0.487
PPM 127095-8+17
H=18.6
z=0.57
PPM 91088-28-11
z=0.638
PPM 91088-22+19
H=18.4
z=0.699
PPM 50296+11-38
z=0.775
PPM 115192+19-18
z=0.76
Arrow shows 10 kpc at that redshift.

The Center for Adaptive Optics Treasury Survey (CATS)

The Goal

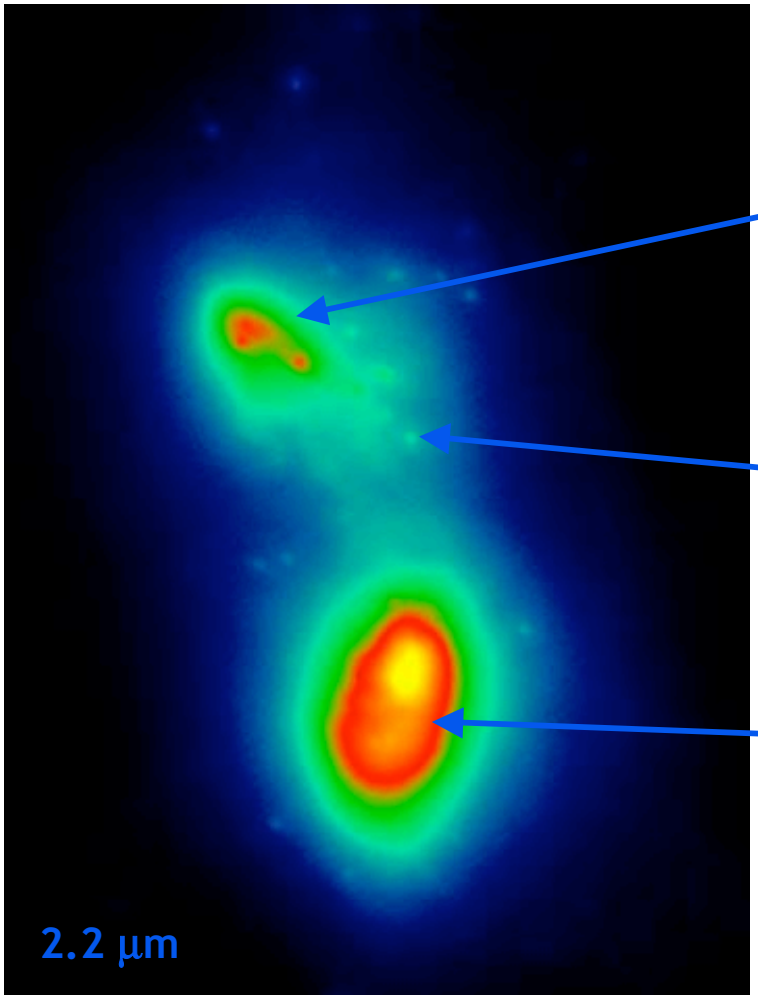
CATS is following up deep HST survey fields (GOODS, GEMS, EGS) with adaptive optics imaging in the near IR to study the evolution of galaxies and their sub- components over the last 10 Gyr.



Galaxy Decomposition

- Are distant bulges red or blue?
- If red, are they old, or young and dusty?
- Are disk galaxies forming from the inside out?
- Are the outer parts of galaxies blue because they are metal poor or young?

The core of NGC 6240: a massive disk-galaxy merger containing two black holes



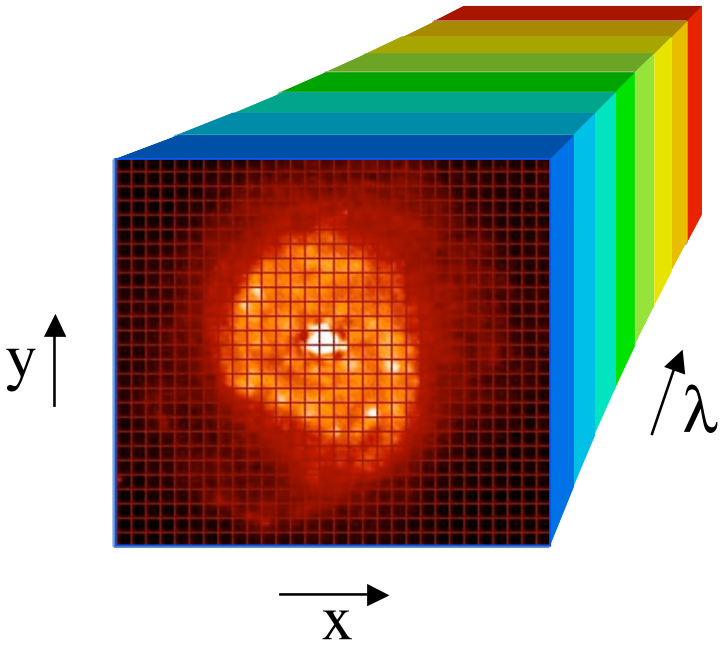
North nucleus: at least 3 point sources

Each “dot” is an unresolved star cluster < 30 pc in diameter

South nucleus: at least 2 resolved sources

Use galaxies such as this as testing ground for "feedback" recipes in cosmological simulations

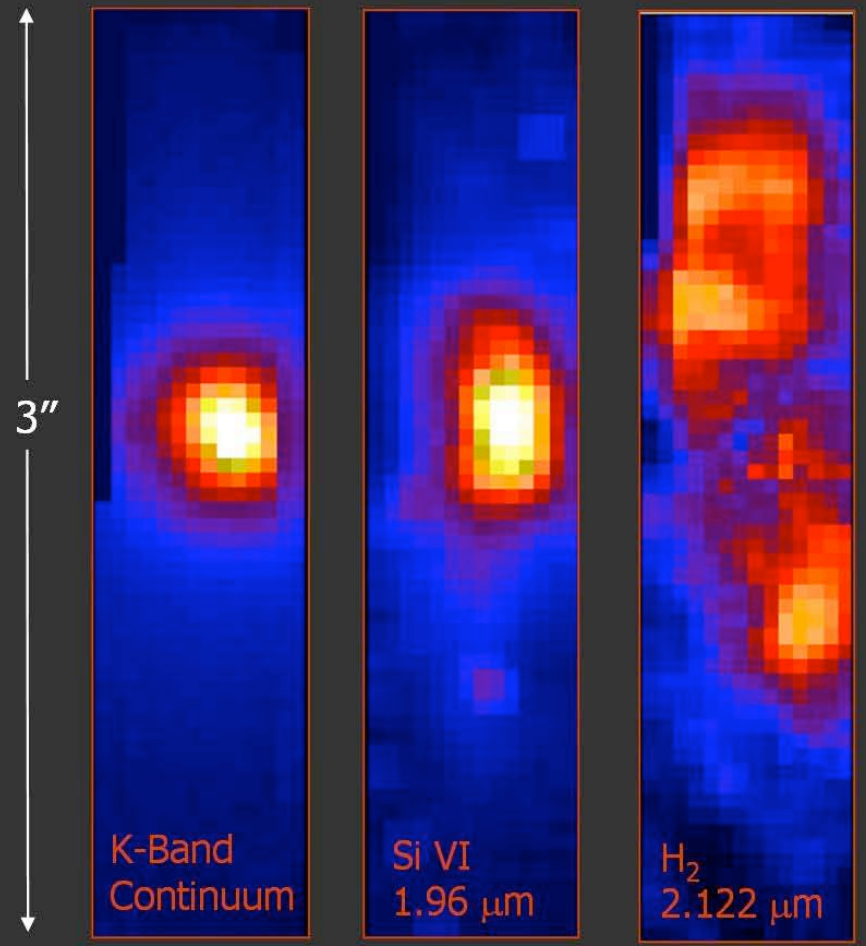
Future AO Technology



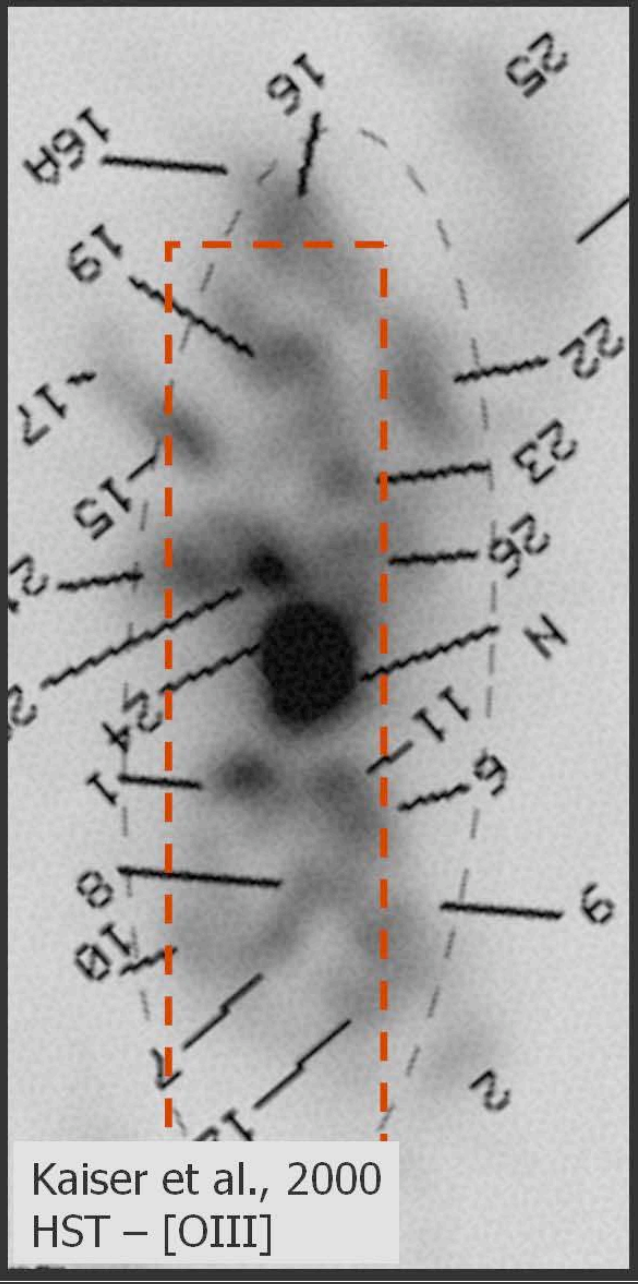
Integral Field Spectroscopy:
OSIRIS at Keck
SINFONI at VLT

Multi-Conjugate and multi-object AO for wider fields

NGC 4151



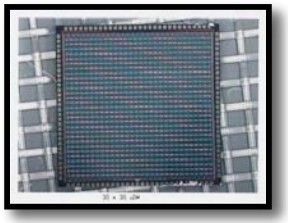
Iserlohe and OSIRIS team, 2005

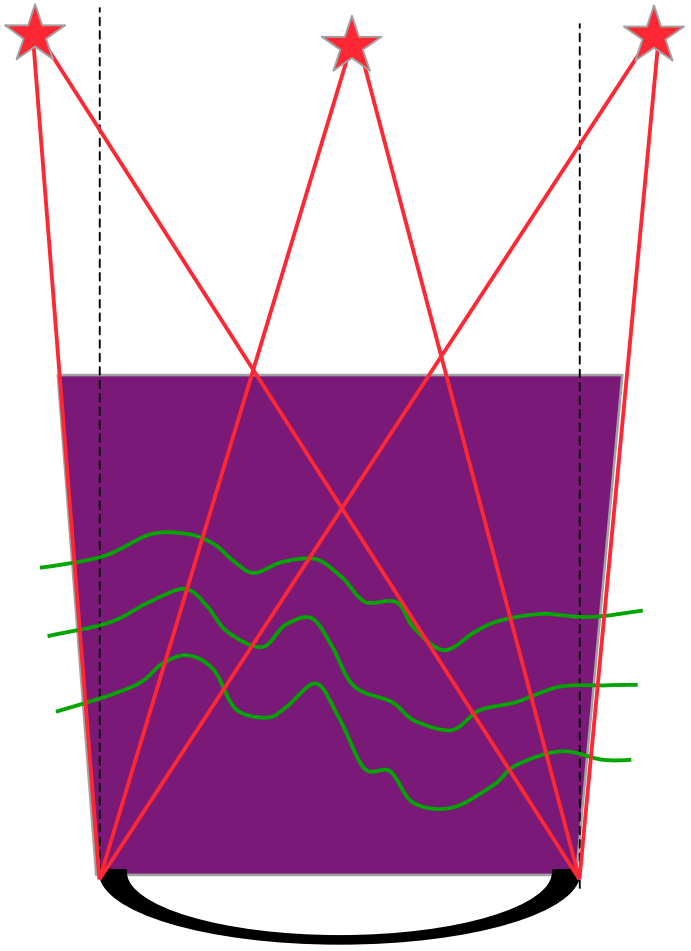


Kaiser et al., 2000
HST – [OIII]

For AO over wider fields, use "tomography" on atmosphere

- Multiple guide stars ⟹ multiple "views" through 3D structure of turbulent layers
- Starting at Gemini and VLT in a couple of years (multi-conjugate AO)
- New concept for TMT: Multi-Object AO
  - Place a tiny MEMS deformable mirror under every galaxy in the GOODS field





Summary

- Current AO systems at Keck, VLT, etc give same spatial resolution at K-band as HST in the visible
- Till now most of work has been imaging and long-slit spectroscopy
- Have entered era of laser guide star AO (Keck, Lick)
  - Lasers soon to be running at Palomar, Gemini N, VLT
- Next step: wider corrected fields of view
  - Multi-conjugate AO, Multi-object AO