Adaptive Optics for Astronomers: The Basics

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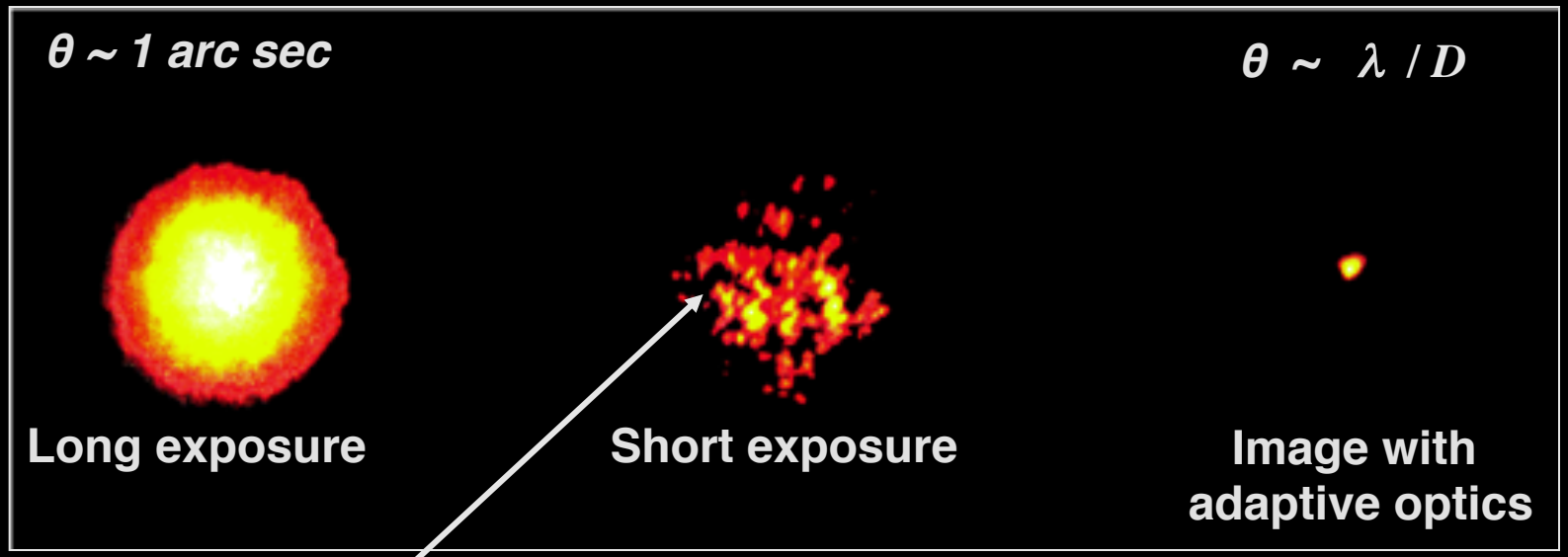
Topics

1. Adaptive optics – the technology
2. What kinds of astronomy are helped by AO?
3. For users of AO: how to plan your observations?
4. For readers of AO papers in journals: how to assess AO results in the literature

Three images of Arcturus, a bright star

Lick Observatory, 1 m telescope



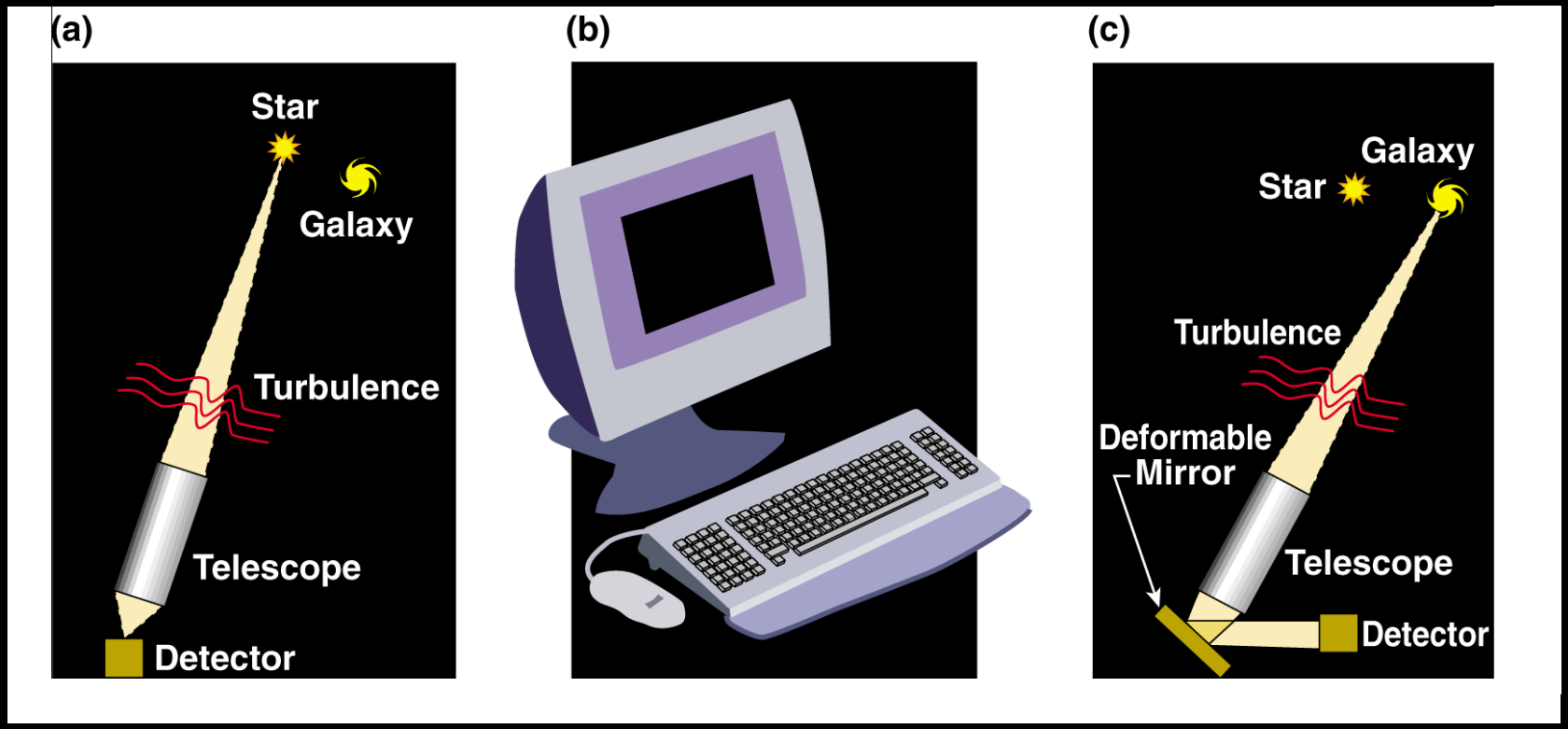
Speckles (each is at diffraction limit of telescope)

Adaptive Optics corrects for blurring due to turbulence in the atmosphere

Measure details of blurring from "guide star" near the object you want to observe

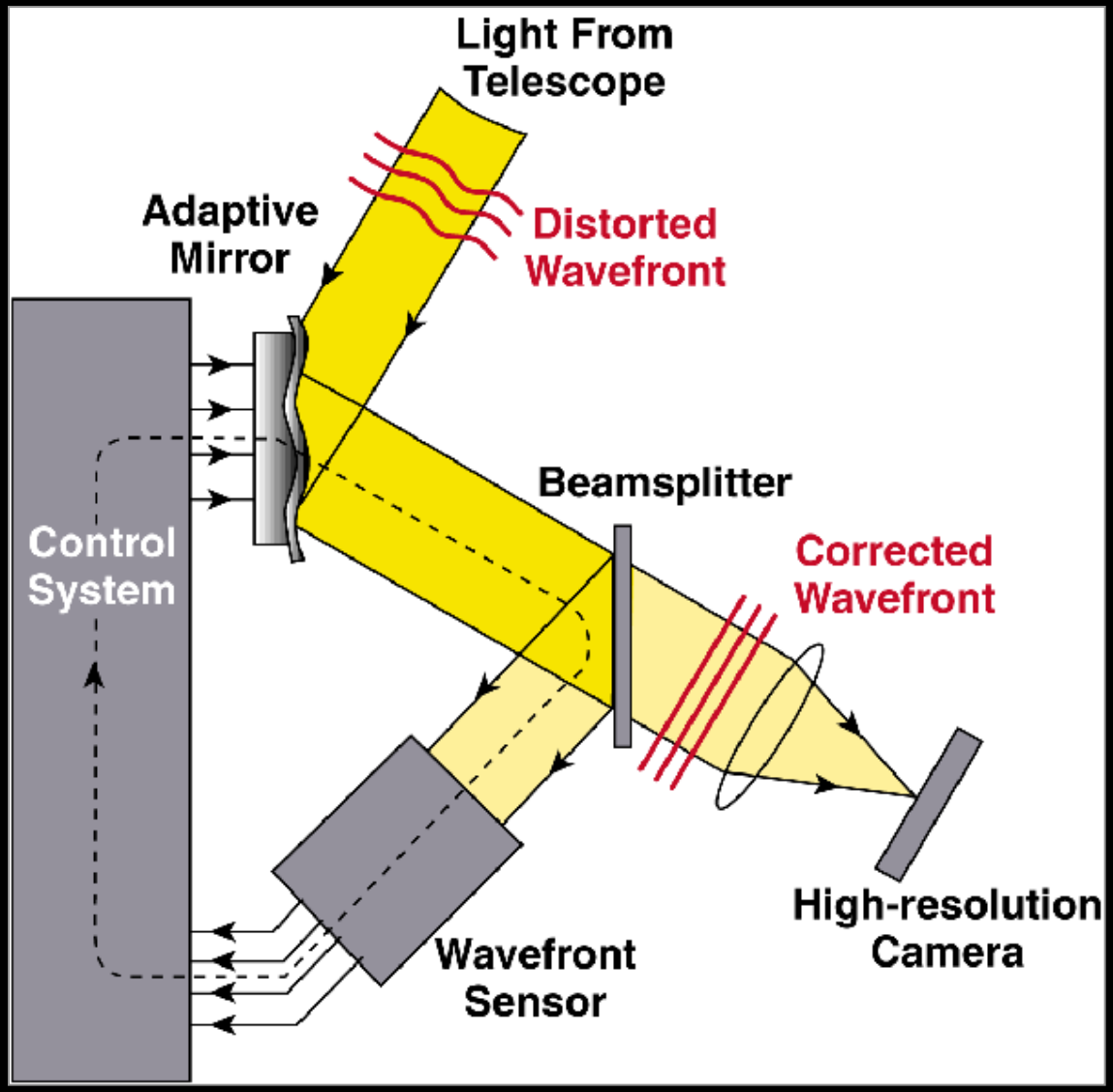
Calculate (on a computer) the shape to apply to deformable mirror to correct blurring

Light from both guide star and astronomical object is reflected from deformable mirror; distortions are removed

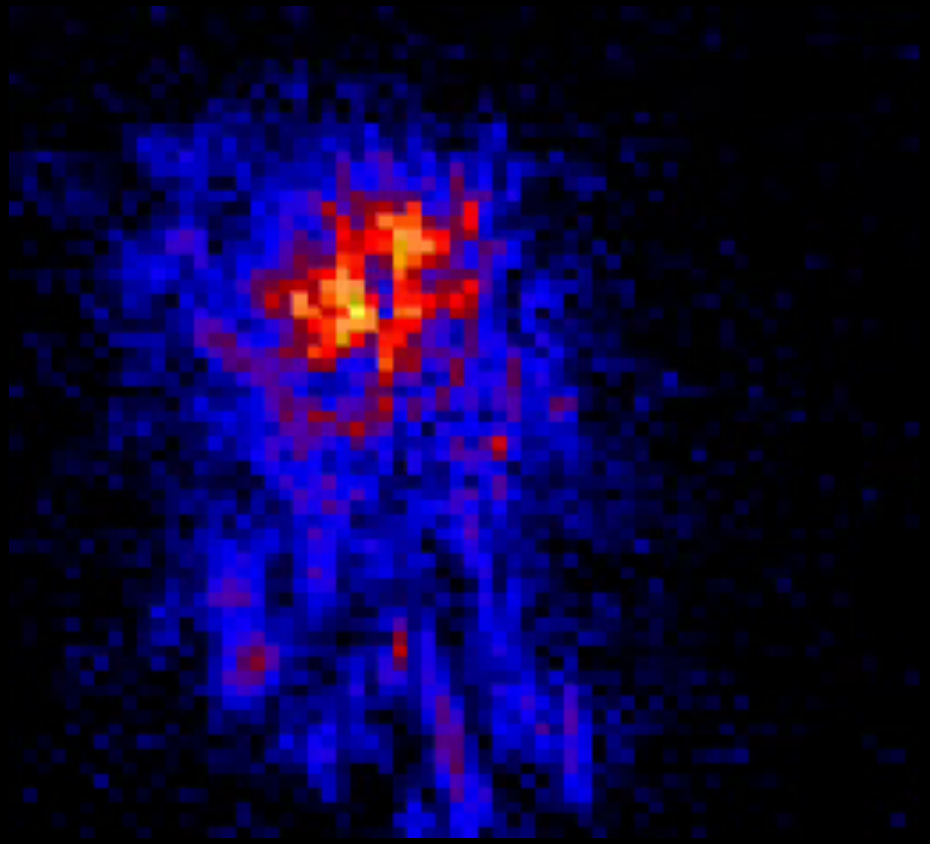


Schematic of adaptive optics system

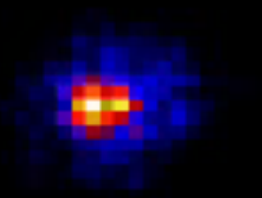
Feedback loop: next cycle corrects the (small) errors of the last cycle



A bright star, without and with adaptive optics correction



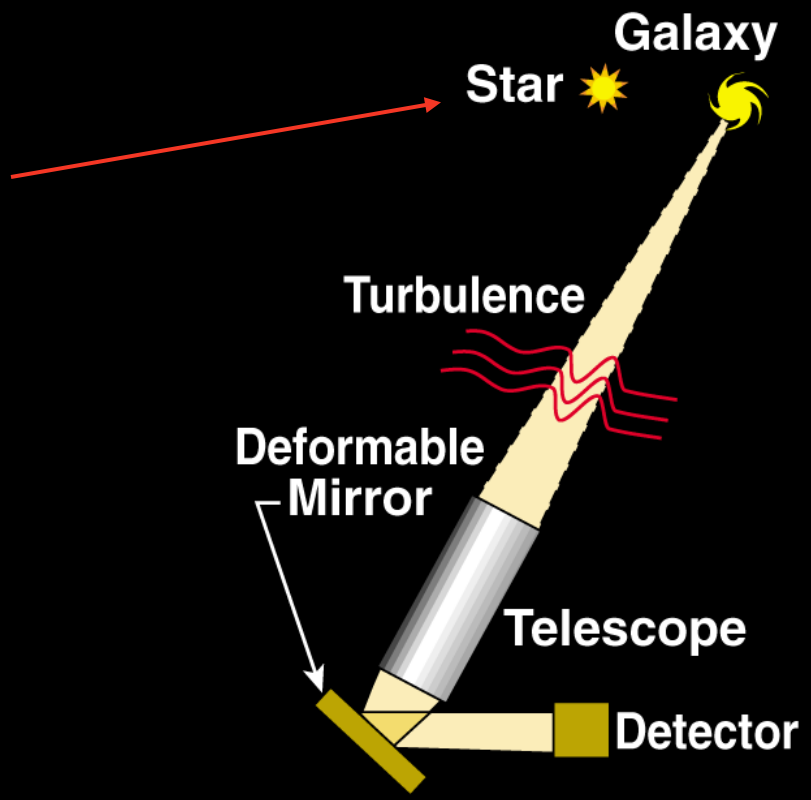
No adaptive optics



With adaptive optics

If there's no close-by "real" star, create one with a laser beacon

- Use a laser beam to create artificial "star" at altitude 15 - 100 km in atmosphere



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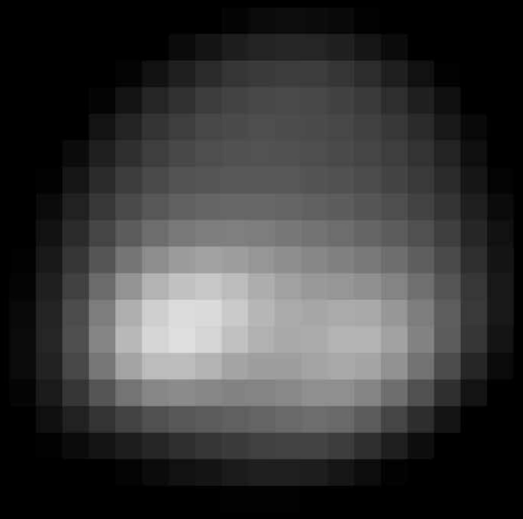
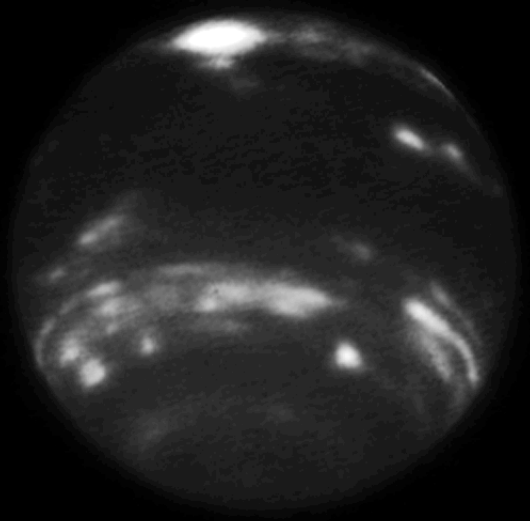
What kinds of observations will be helped by AO? (1)

- See details that were not previously present
  - Qualitative: new morphological statements
  - Quantitative: need to understand Point Spread Function
  - Spatial resolution can improve by x 10-30
- Detect fainter objects/features
  - Works excellently for point sources
  - But: IR AO systems can inject more thermal background.
  - Faint extended objects can actually be harder to see with AO. Limiting factor is background.

See new details and structure



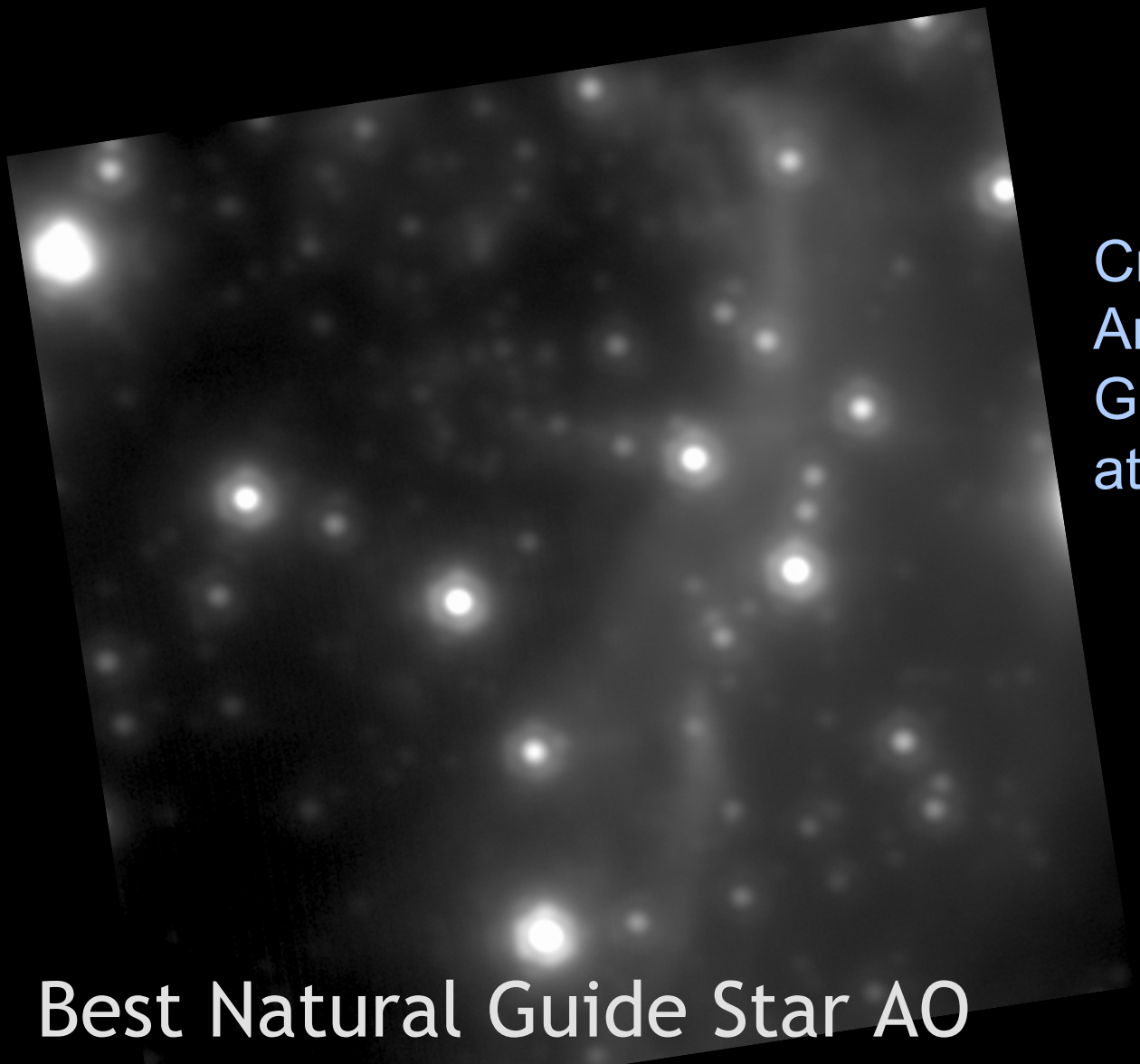
Neptune, Keck, no AO



Neptune, Keck, AO

- Structure is dramatically clearer
- Can be hard to measure quantitative brightness of extended features
  - AO PSF “spills” light from bright features into faint ones

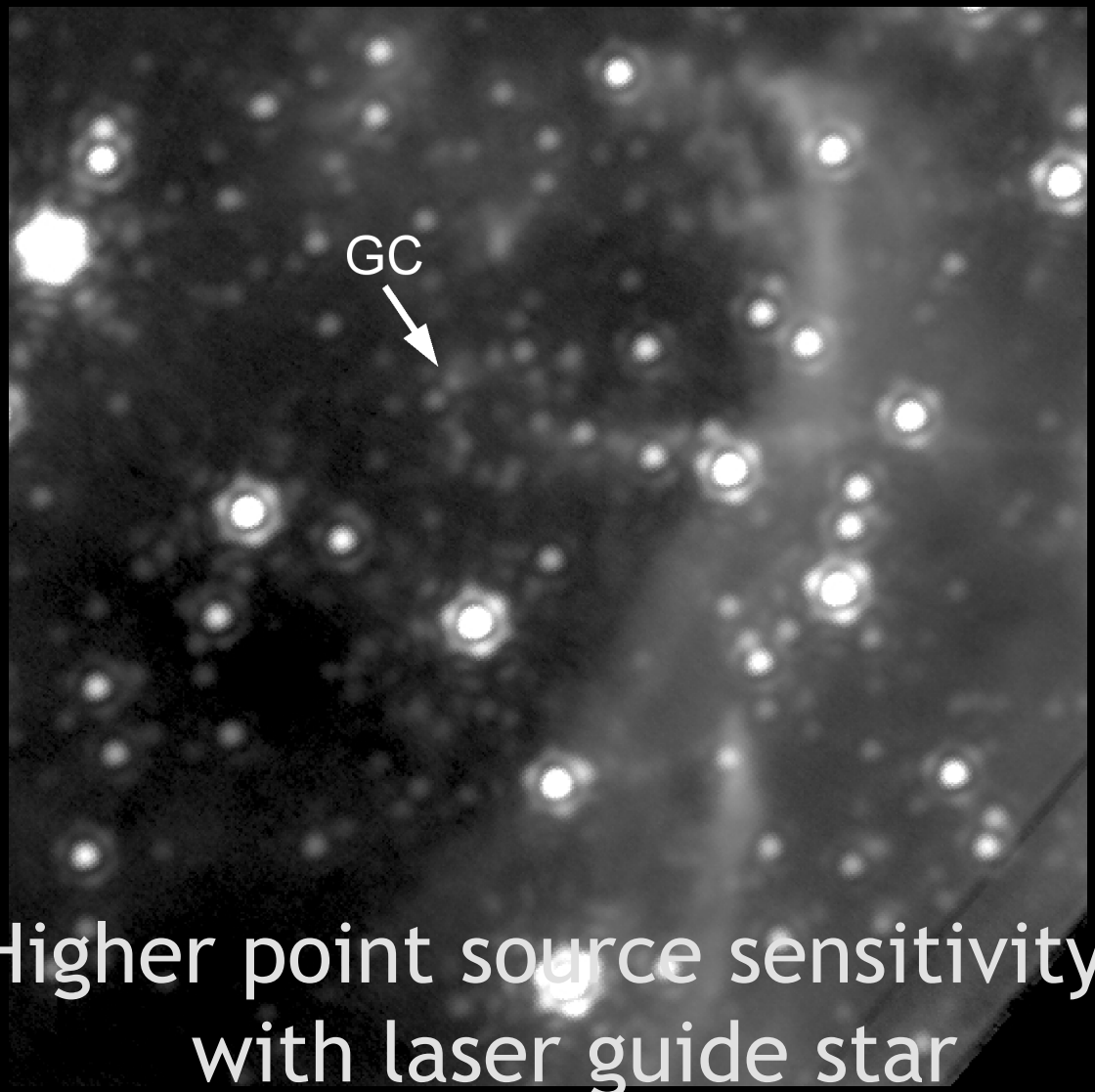
Example of fainter objects with improved AO: Galactic Center



Credit: Andrea Ghez's group at UCLA

Best Natural Guide Star AO

Example of fainter objects with improved AO: Galactic Center



Credit: Andrea Ghez's group at UCLA

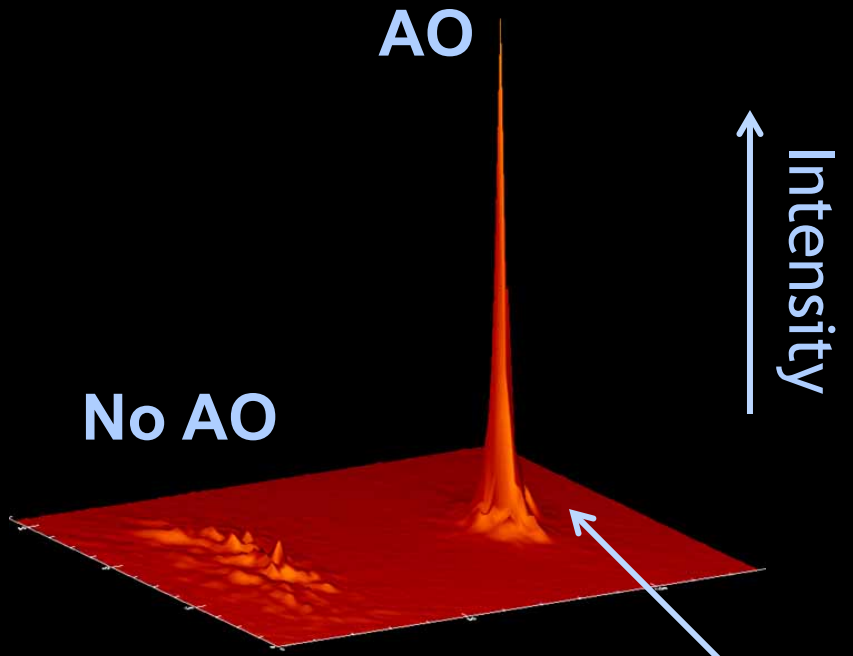
Higher point source sensitivity with laser guide star

What kinds of observations will be helped by AO? (2)

- AO increases image contrast:
  - Sharper edges, brighter features (if they are close to diffraction limit)
  - Detecting faint things close to bright things:
    - companions to bright stars; host galaxies of quasars; stellar and protoplanetary disks

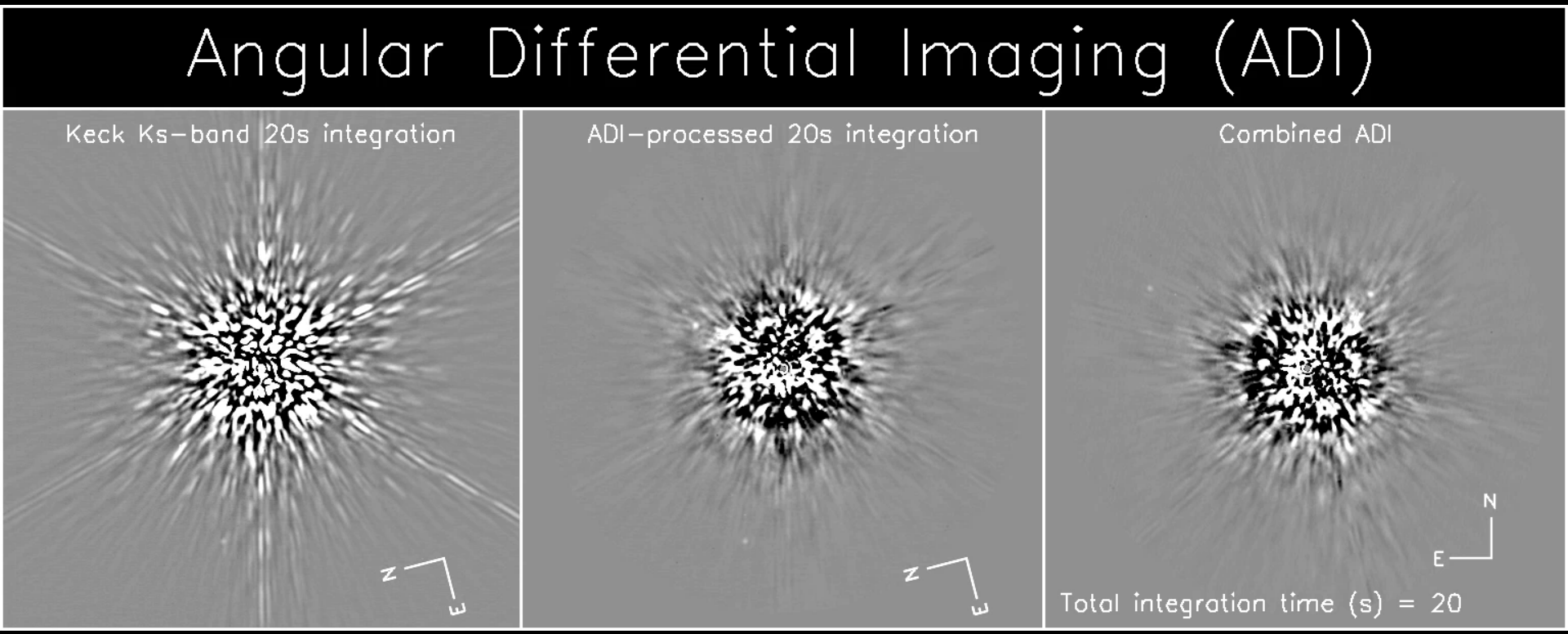
- AO permits more precise astrometry
  - Can measure position of a point source more accurately if a) it is smaller, and b) it is brighter
  - But need other stars in the field for reference frame

Increased image contrast with AO



Much easier to detect a faint companion here

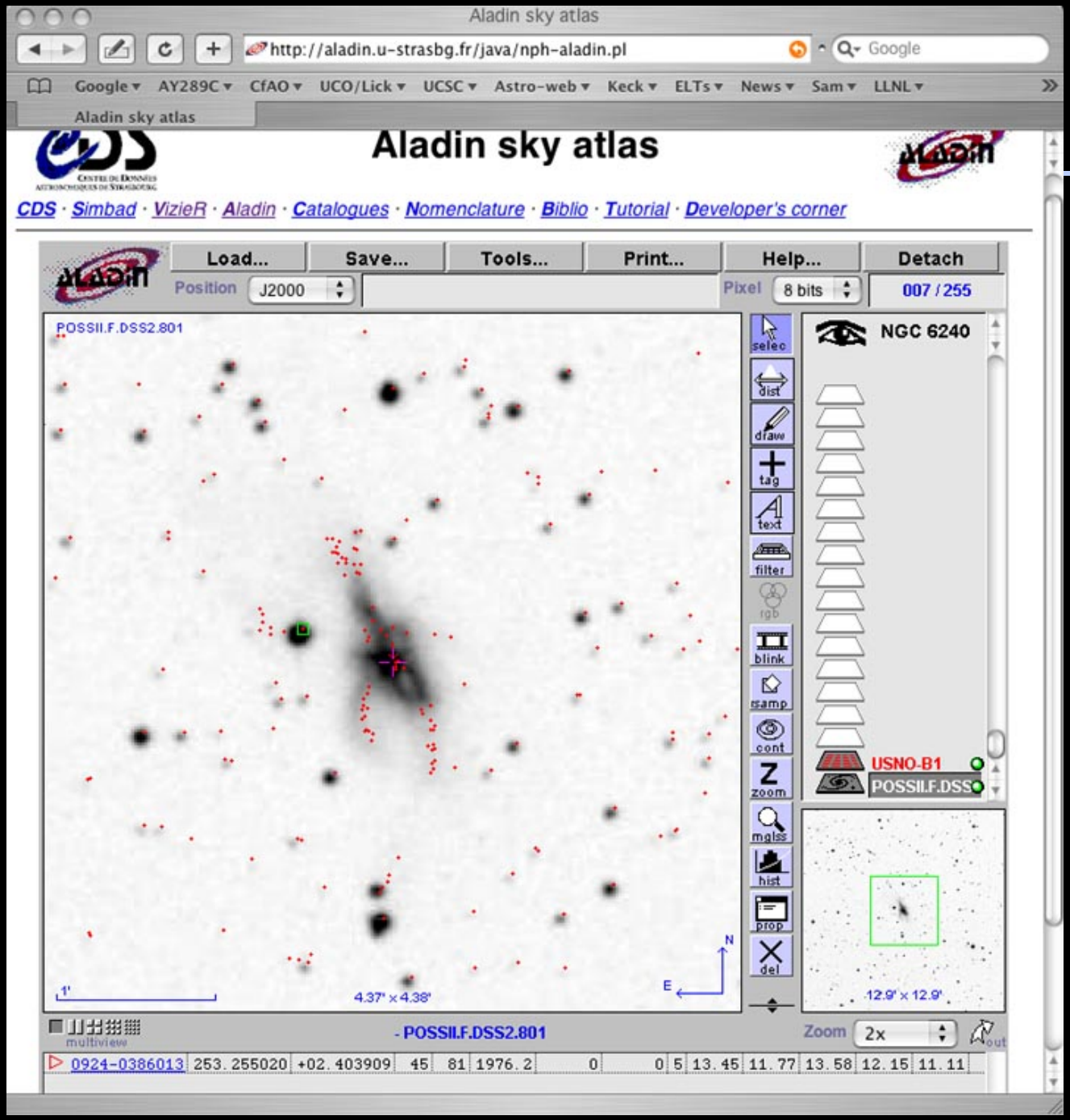
Even with AO, need sophisticated methods to clearly detect planet



Movie thanks to Christian Marois

How to plan observations ahead of time

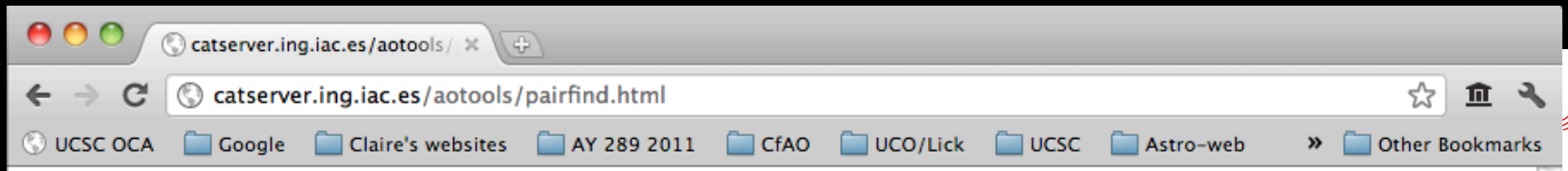
- Understand what AO performance (Strehl) you will need for your science project
- Estimate exposure time needed to achieve good SNR
- Refer to web pages to see what brightness guide star, at what angular offset, at what zenith angle, you will need
- Search star catalogues to find guide stars or use automated observatory tools



- Aladin and USNO B1 catalog: virtues and pitfalls
- Great user interface, many surveys
- But gets confused near galaxies, nebulosity, diffraction spikes
- Check out potential guide stars by eye!

But what was my AO Point Spread Function?

- To obtain quantitative results, need to know AO Point Spread Function (PSF)
- Before, after, and during observing science target, can observe “PSF stars”
- In practice this is a research area in its own right: how to know the PSF that obtained while you were observing your target
  - Research at UCLA, Keck, ESO using real-time information from the AO system



AO PSF pair finder

Target coordinates	**RA (J2000)** **DEC (J2000)** **Coordinate system** sexagesimal
Sky search radius	2.0 **degrees**
V magnitude limit	**PSF star:** 16.0 **Guide star:** 13.0
Guide star distance	**arc seconds**
Distance tolerance	**arc seconds**
Position Angle	**degrees E of N**
PA tolerance	**degrees**

Plain text output SEARCH Reset Form ***Help...***

Laser guide star observing requires further advance preparation

- US observatories have to submit target list to US Space Command (satellite avoidance) in advance
  - Not good form to destroy the detector on a billion dollar satellite
- Specific formats required
- Check observatory web pages for instructions

How to assess the reality of AO results reported in the literature

- Which data should you take seriously?
- What are “danger signs” that should make you doubtful?

Taking data seriously: main issues

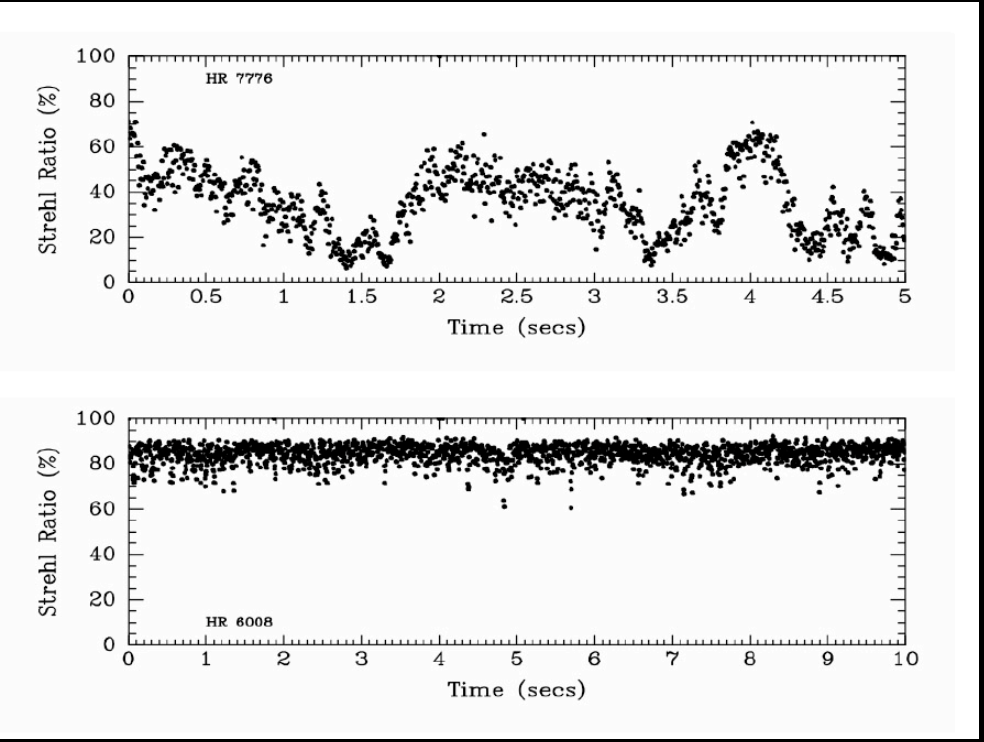
1. Strehl ratio and variability
2. Effect of using a non-point-source as a guide star or tip-tilt star

Closely related to:

1. What was the point spread function?
2. What was the signal to noise ratio?

1) Strehl ratio

- Don't trust low-Strehl results
- How low is low? My rule of thumb: "low" is S < 10%
- Problems: unstable photometry, variable PSFs



2) Finite-size object used as guide star

- Can produce artifacts on point spread function
  - Sometimes “double-star” PSF
- Example: using bright nucleus of a galaxy as the tip-tilt reference
  - The more point-like it is, the better
  - No firm rules: examine results with great care
- Look for independent measurement of PSF

Conclusions

- Very large gains in spatial resolution for IR AO on 8-10m telescopes. Factors of 10-30.
- AO systems can yield flakey results if:
  - Guide star is extended, or too faint
  - Strehl is too low or too variable
- As usual, need good signal to noise
- Need thoughtful preparation before a run
- But…. RESULT IS OFTEN WORTH THE TROUBLE!