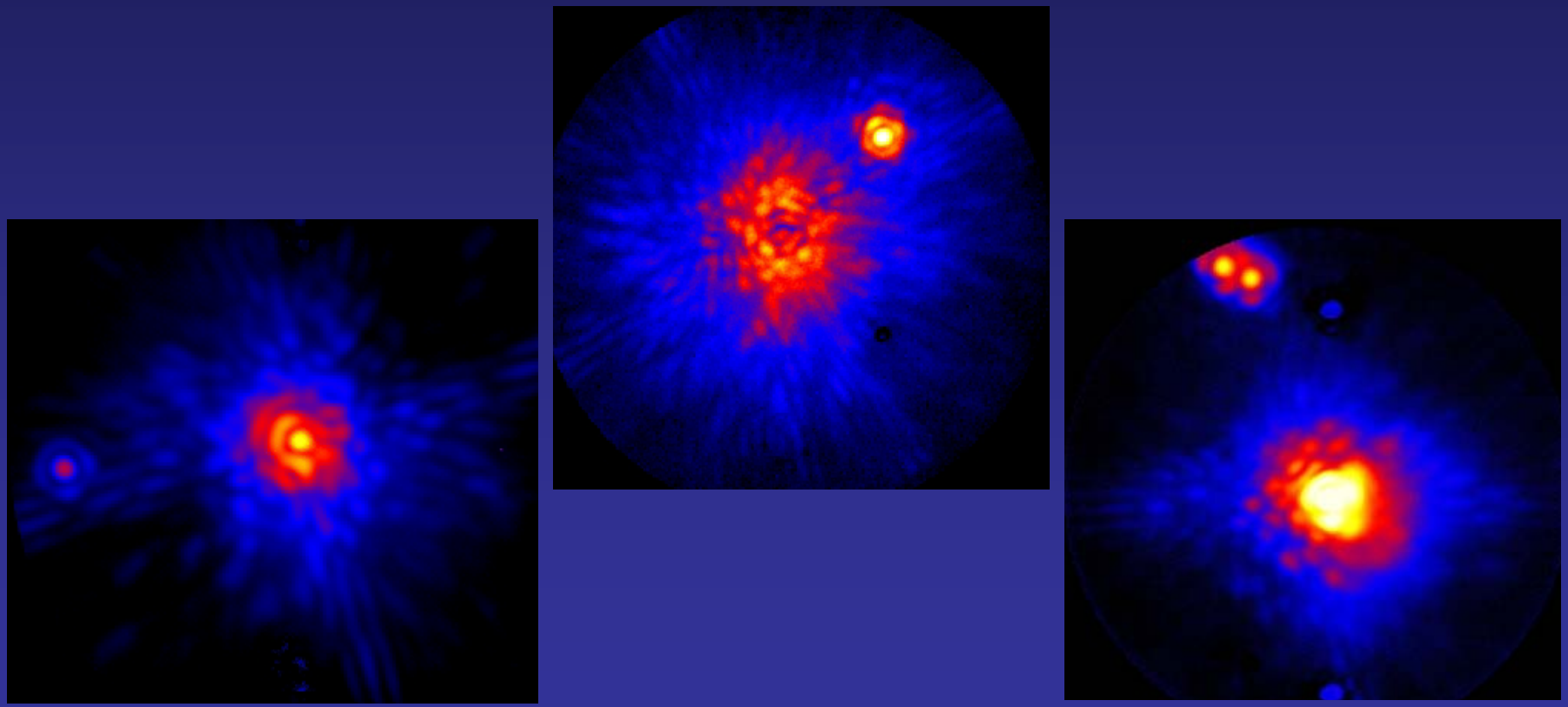
THE LYOT PROJECT

Andrew Digby

AMERICAN MUSEUM of NATURAL HISTORY

The Challenges of Coronagraphic Astrometry



Digby, MFS 2005

The Lyot Project

AMNH:	Ben Oppenheimer, Anand Sivaramakrishnan, Remi Soummer, Sasha Hinkley, Michael Shara, Douglas Brenner, Laura Newburgh
UC Berkeley:	Marshall Perrin, James Graham, Paul Kalas
STScI:	Russell Makidon
Cornell:	James Lloyd
UH:	Jeffrey Kuhn, Kathryn Williams
Boeing:	Lewis Roberts

The Lyot Project

Diffraction-limited, optimized coronagraph and 'Kermit' infrared camera

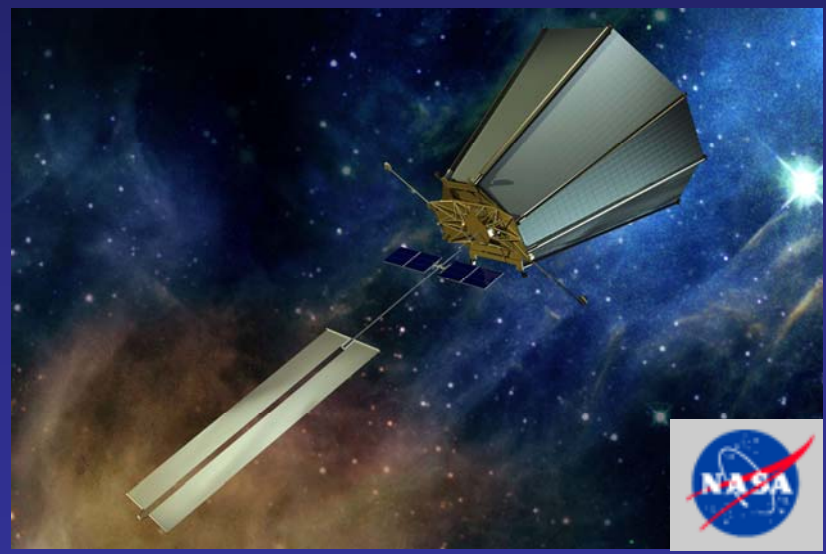
Installed at 3.63m AEOS telescope on Maui in March 2004

Coronagraphy

- Coronagraphy key method for direct imaging of faint companions

But:

- ✕ It’s difficult!
- ✕ Little data



TPF-C

AO Coronagraphy

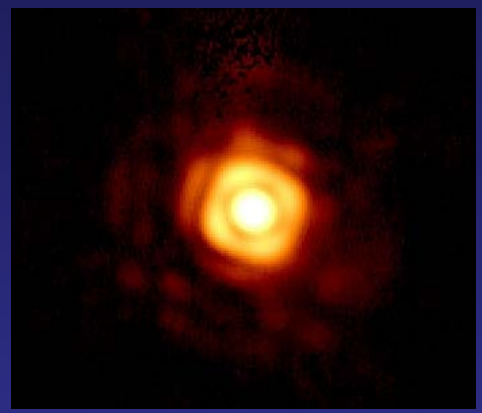
Complex images:

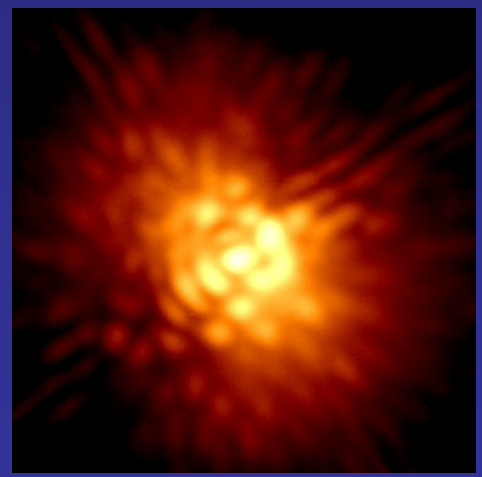
need to fully understand and characterize before can find planets

AO Coronagraphic Astrometry

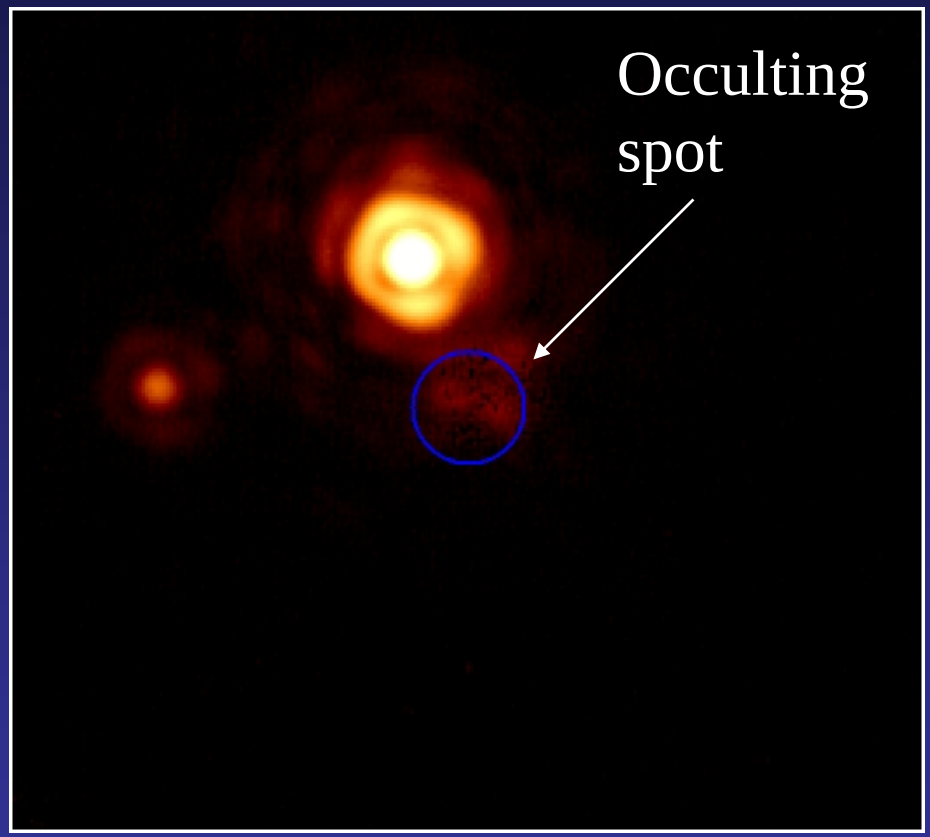
Two main sources of complication:

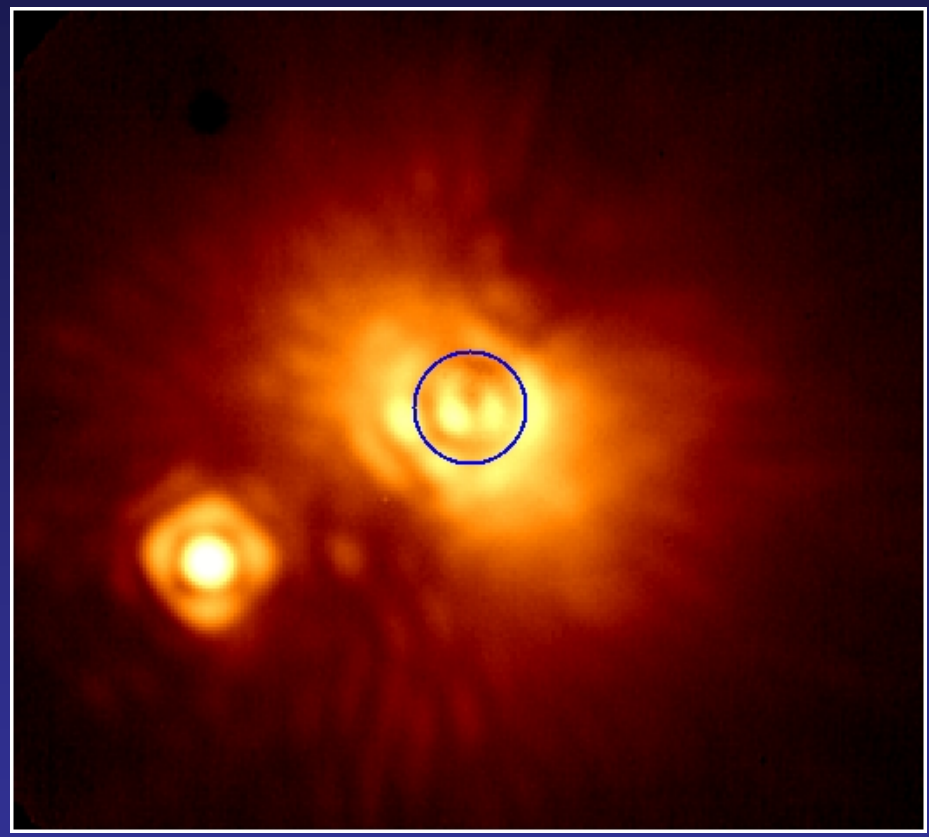
- AO challenges: PSF fitting
- Coronagraphic challenges





Where's the star?



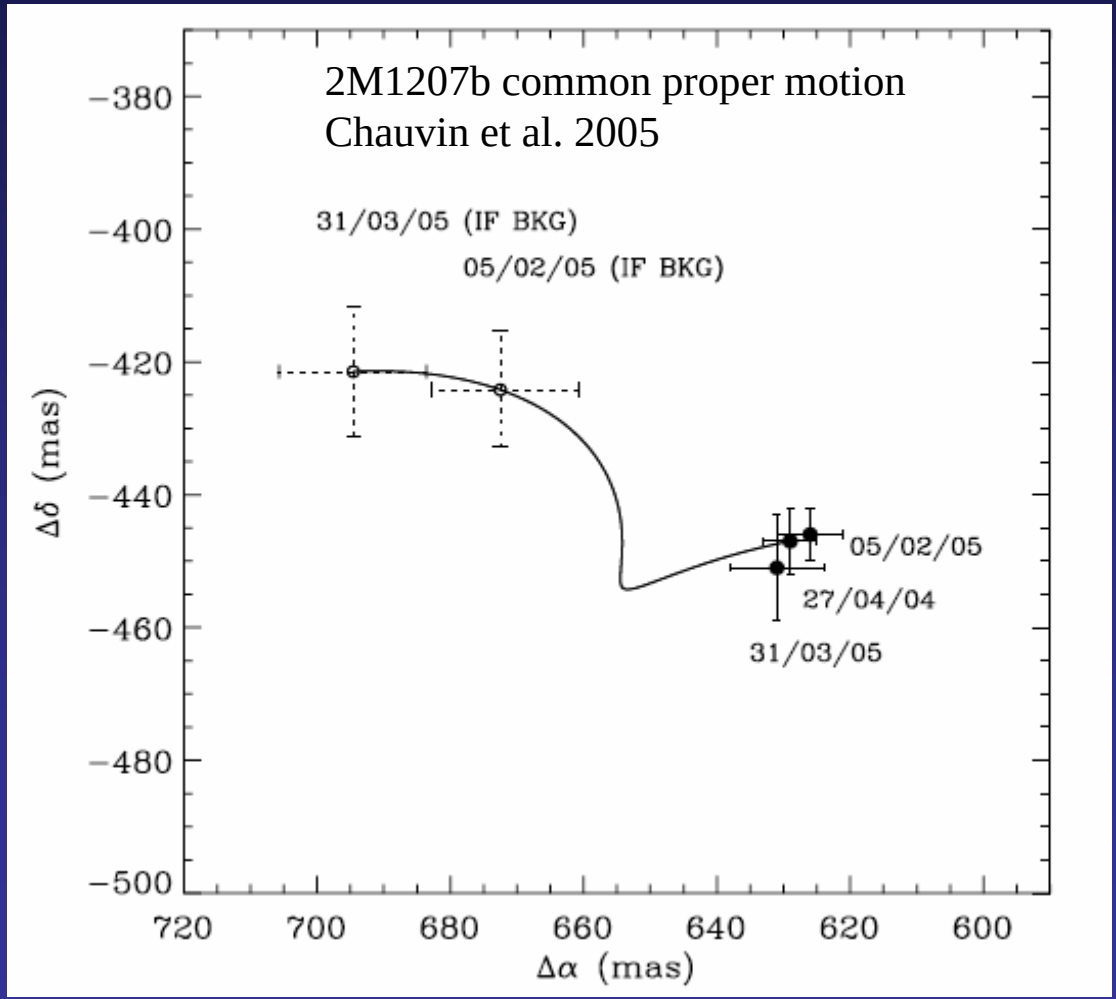


Unocculted

Occulted

Why is astrometry important?

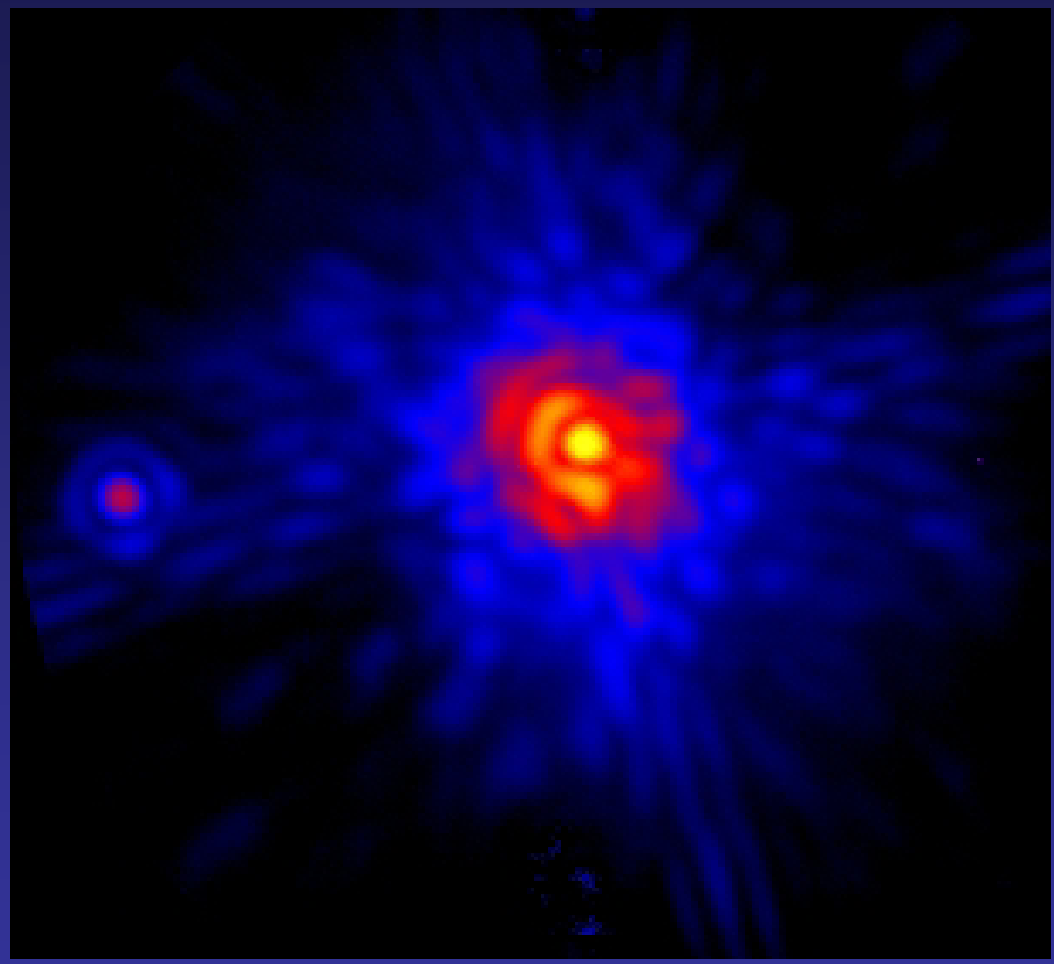
Common proper motion



Why is astrometry important?

Common proper motion

Orbits of companions

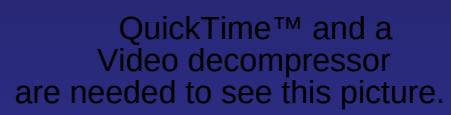


Why is astrometry important?

Common proper motion

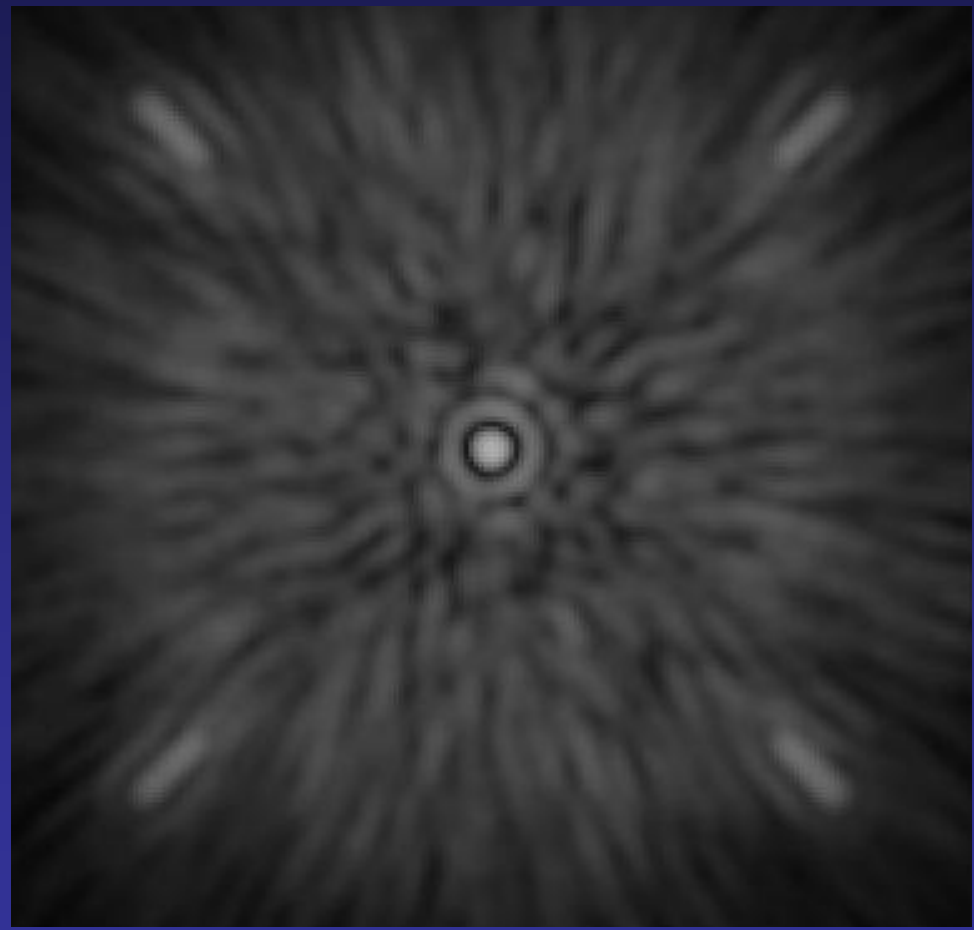
Orbits of companions

Summing and derotating images



Star location difficulty

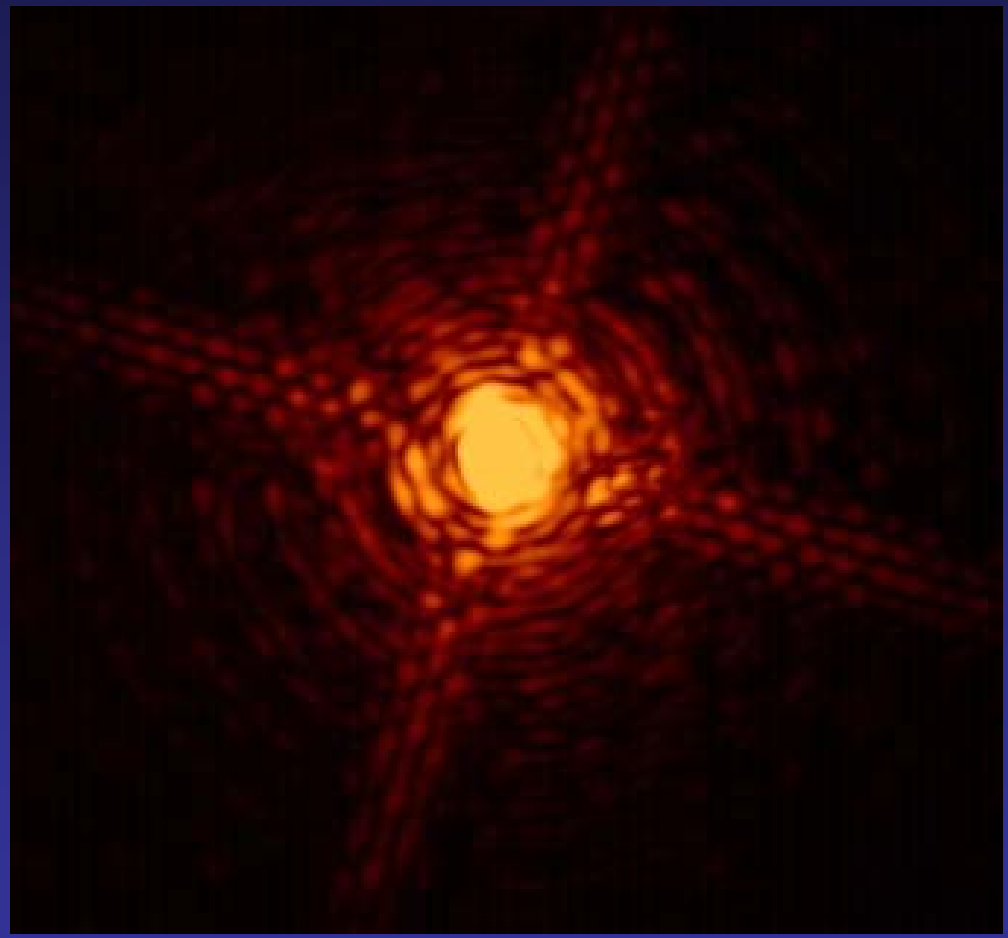
Simulated



Star location difficulty

Simulated

Laboratory

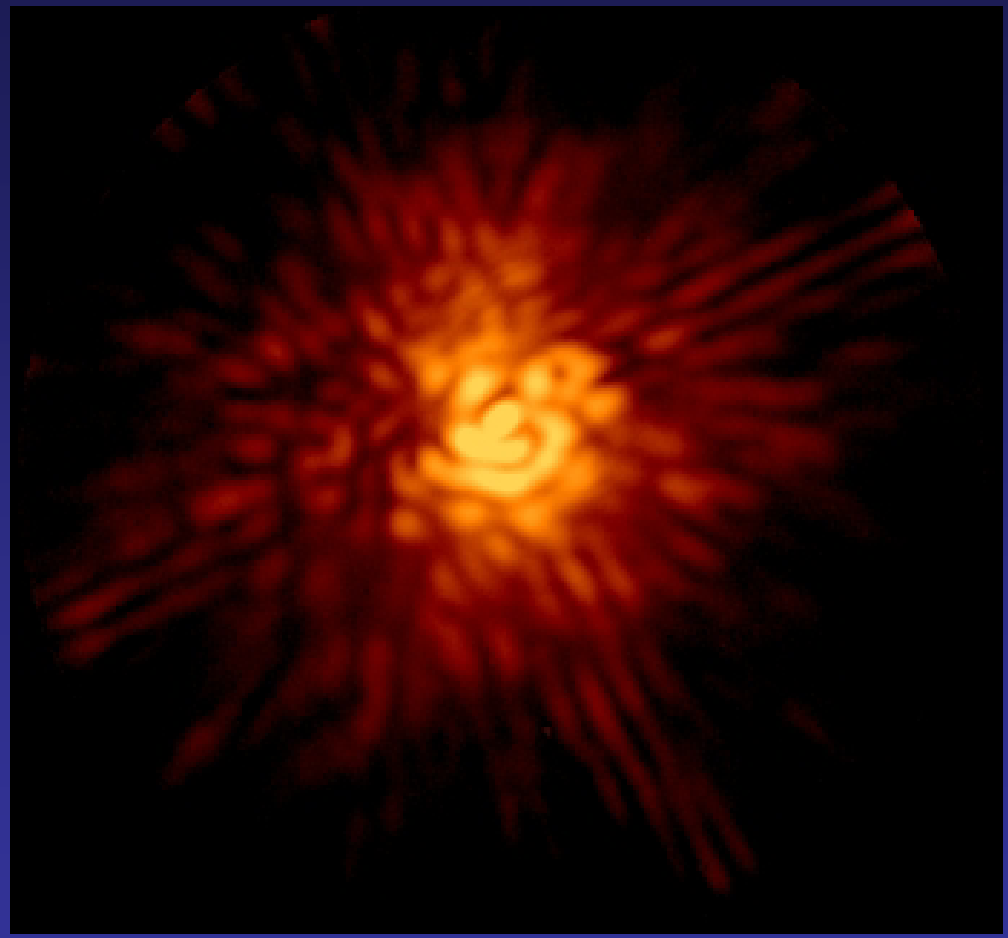


Star location difficulty

Simulated

Laboratory

Observed



Star location difficulty

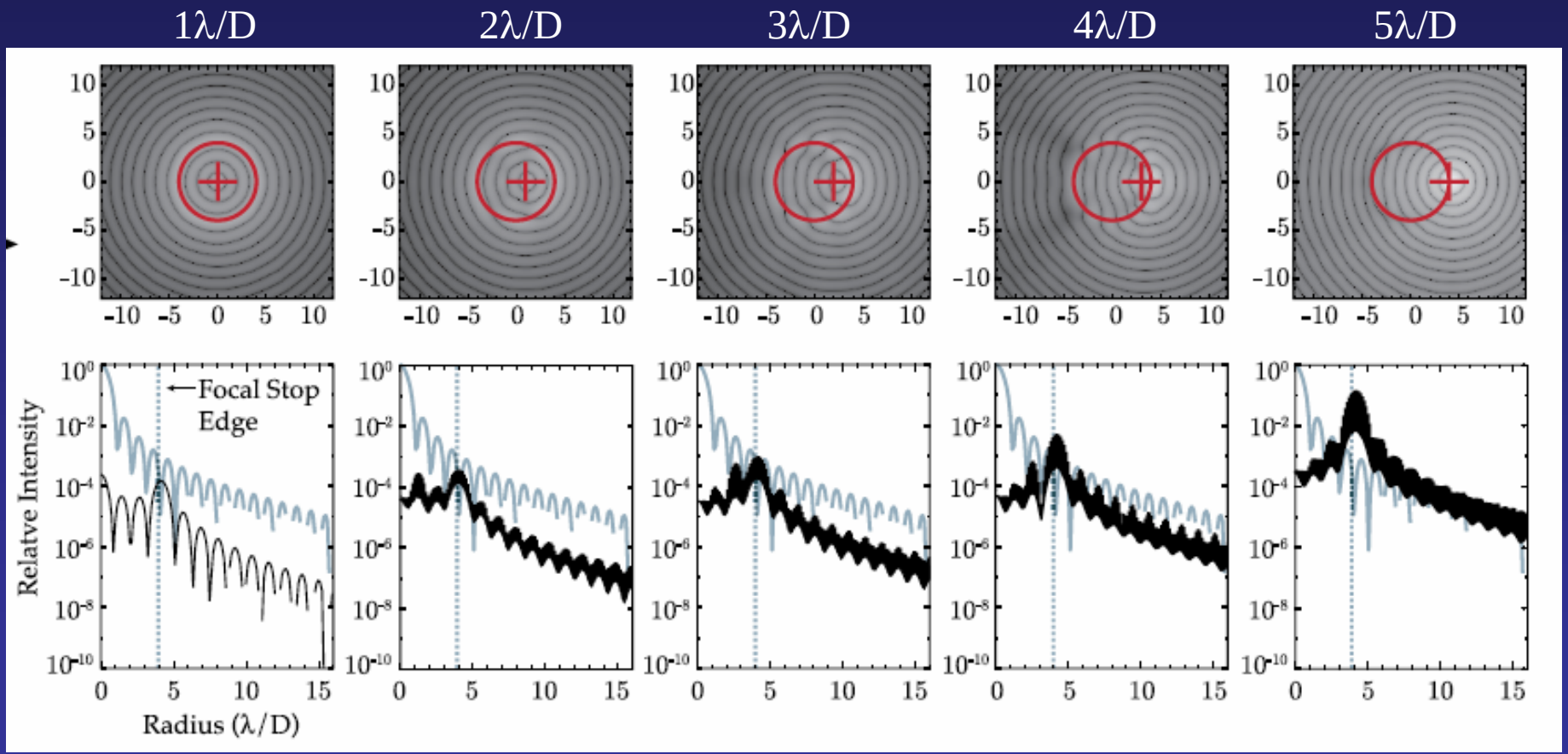
Image distortions:

- Speckles
- Spiders
- Unseen companions

QuickTime™ and a
Video decompressor
are needed to see this picture.

PSF as function of star position: theory

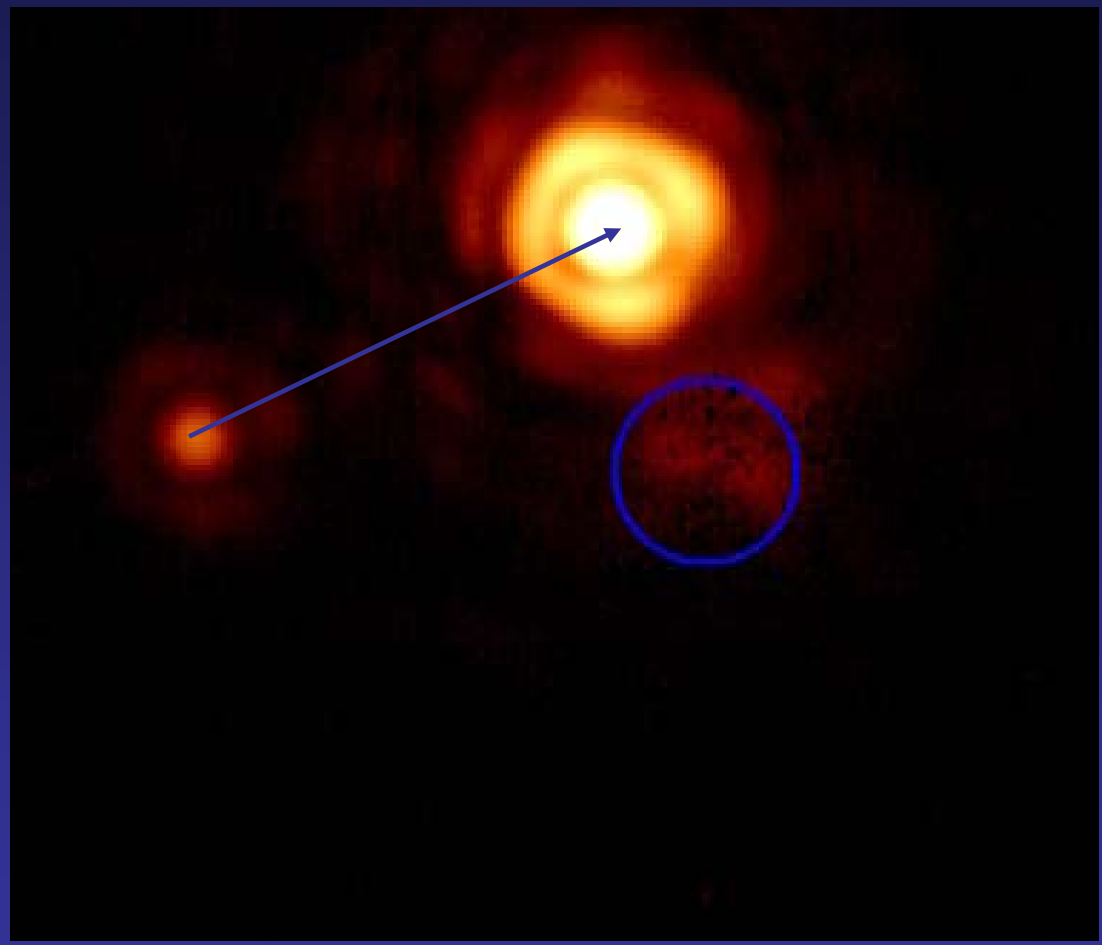
"Fake sources"



Lloyd & Sivaramakrishan 2005 (ApJ, 621, 1153)

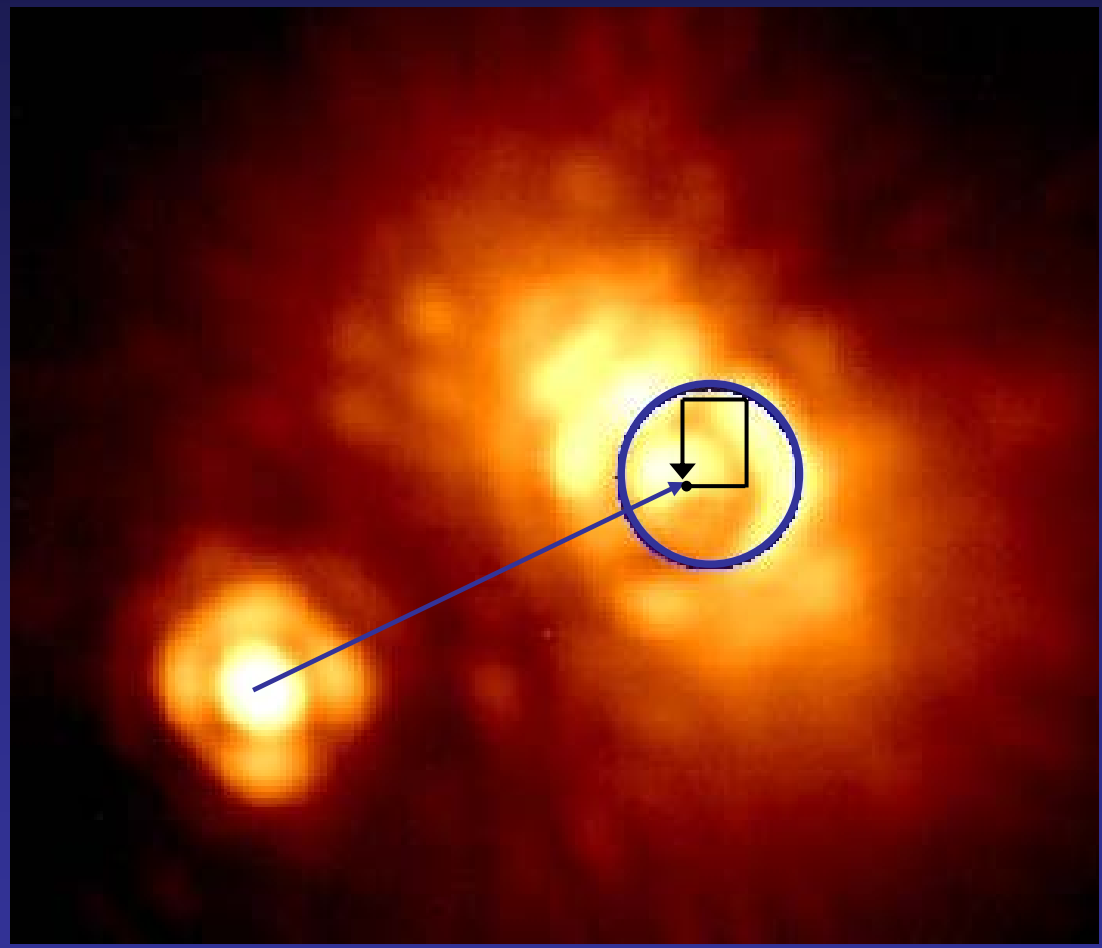
PSF structure: binary tests

- Calibration binary tests
- Can infer star position behind spot from secondary



PSF structure: binary tests

- Calibration binary tests
- Moved star behind spot and observe change in PSF structure



PSF as function of star position: data

Calibration binary tests

QuickTime™ and a
Video decompressor
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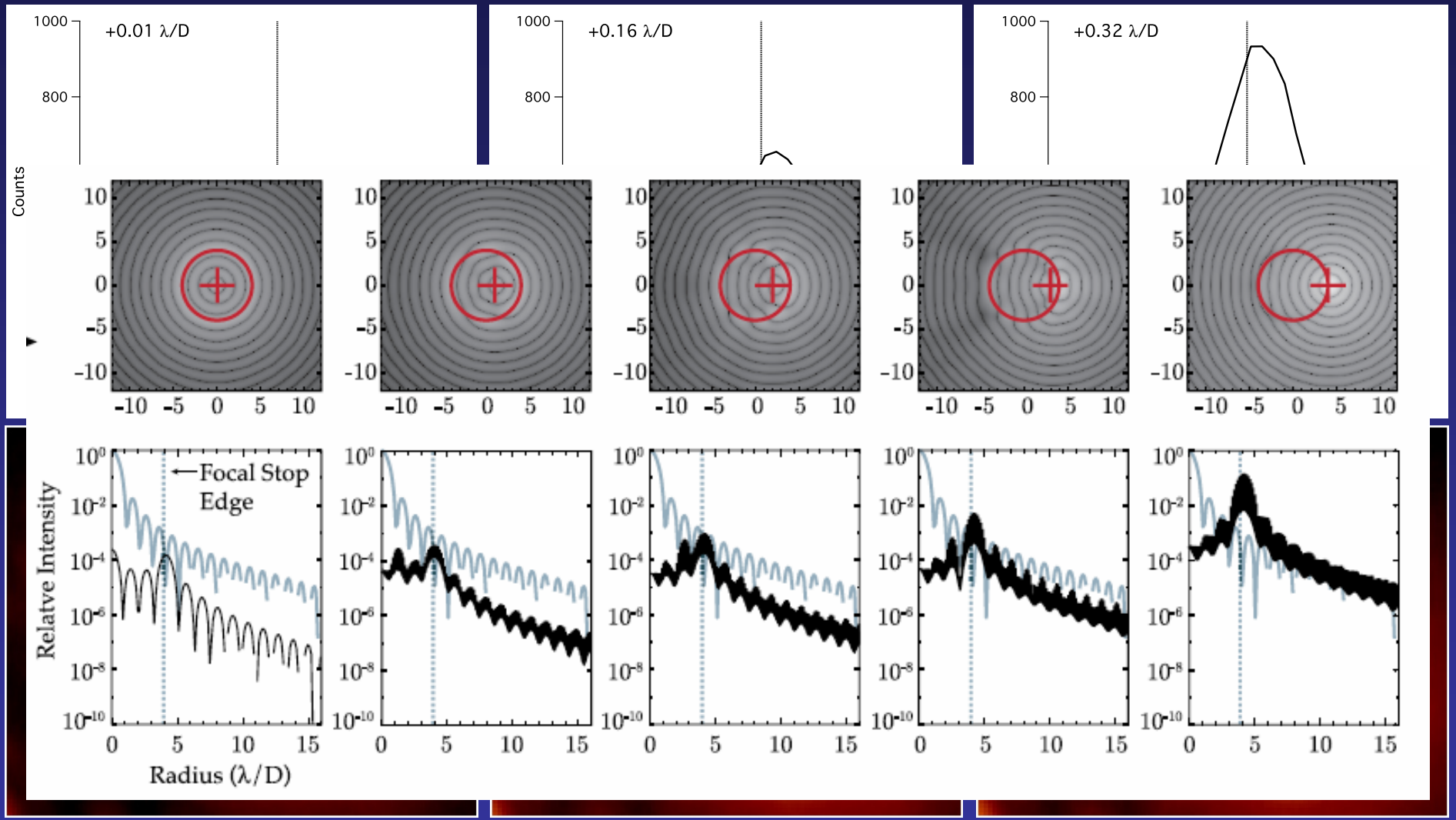
PSF as function of star position: data



PSF as function of star position: data

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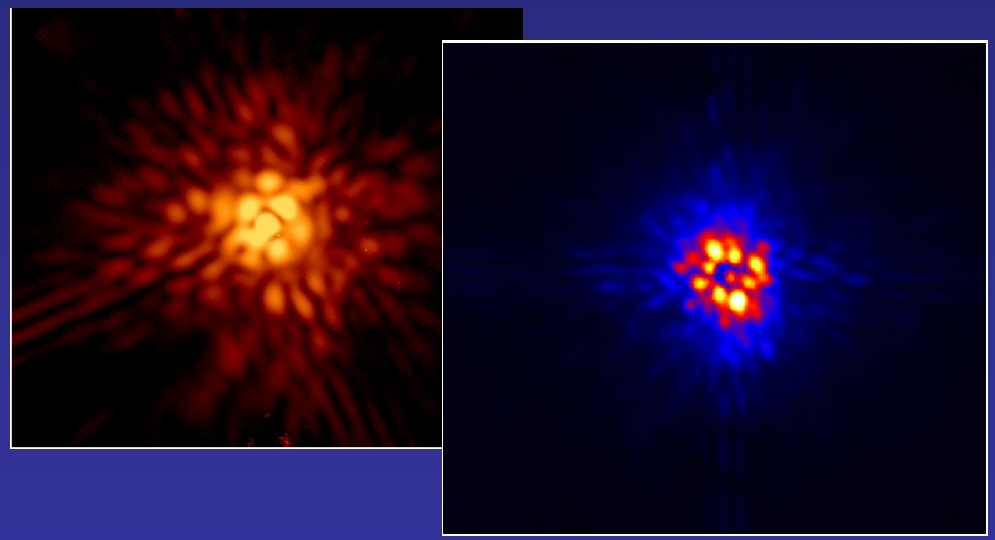
Star location solutions

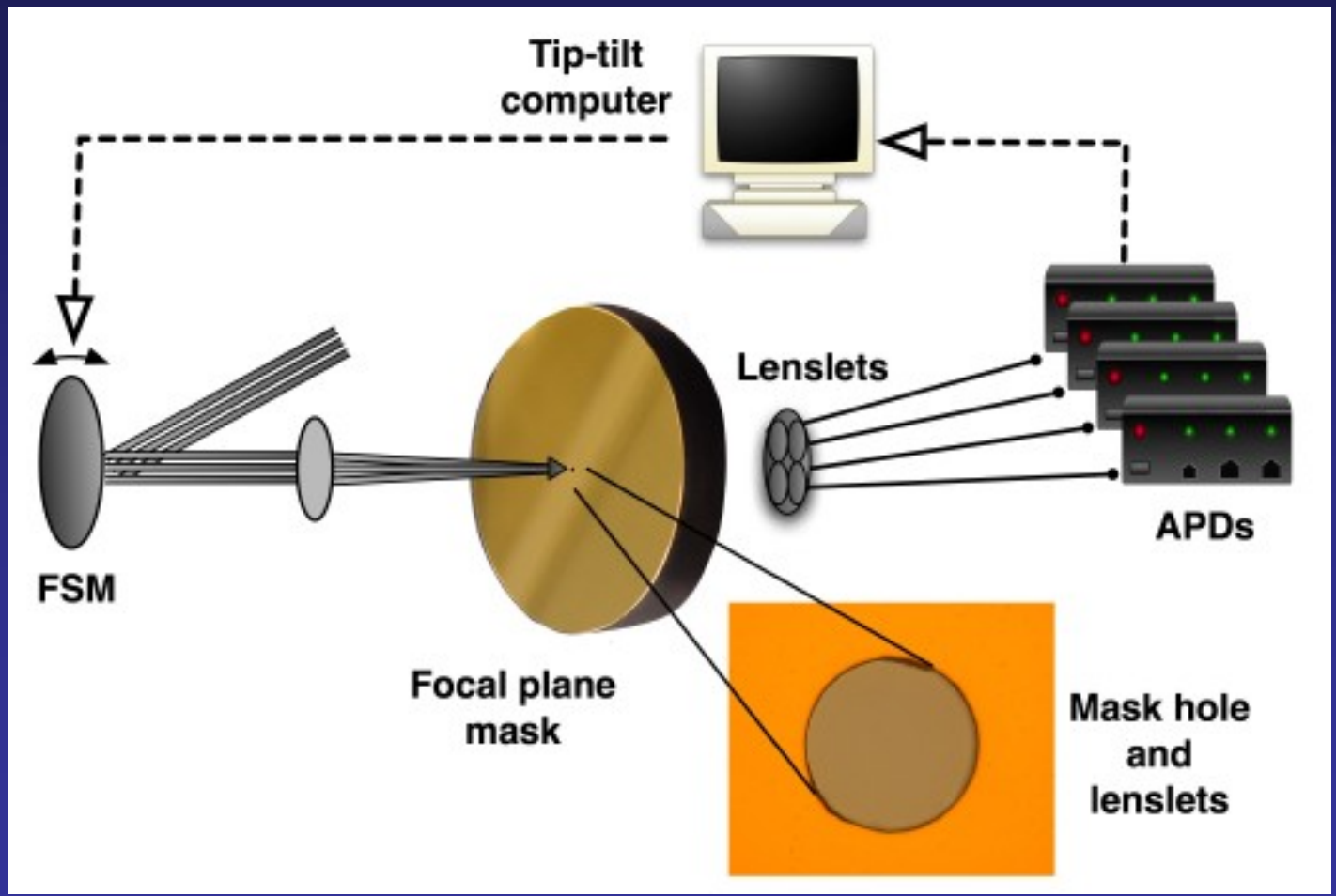
- Instrument metrology

- Image information

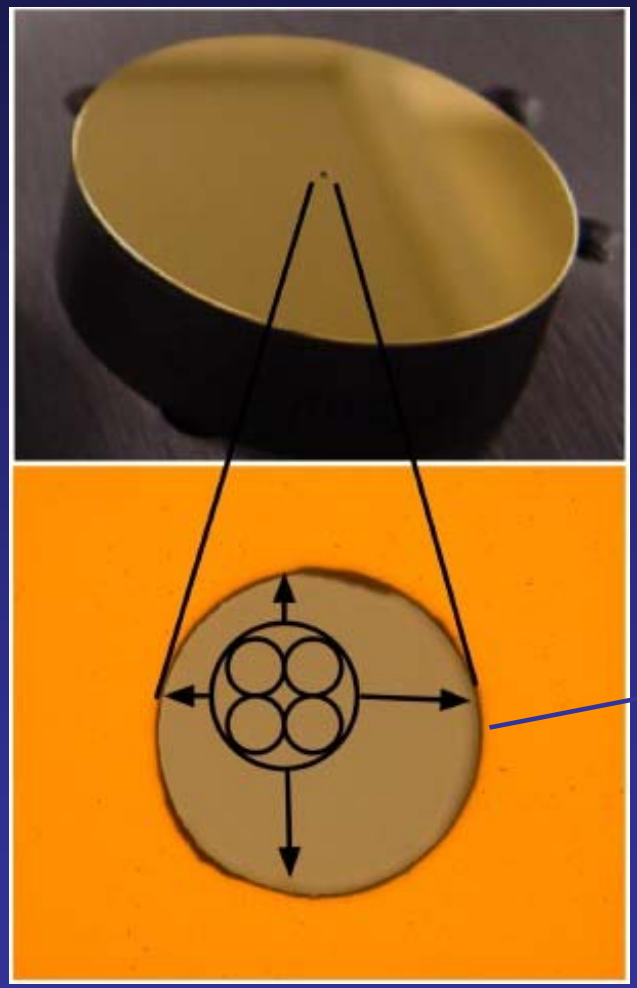


Internal Metrology

Lyot Project coronagraph tip-tilt loop



Internal Metrology



Mask hole

Tip-tilt loop lenslet position can infer star position in image

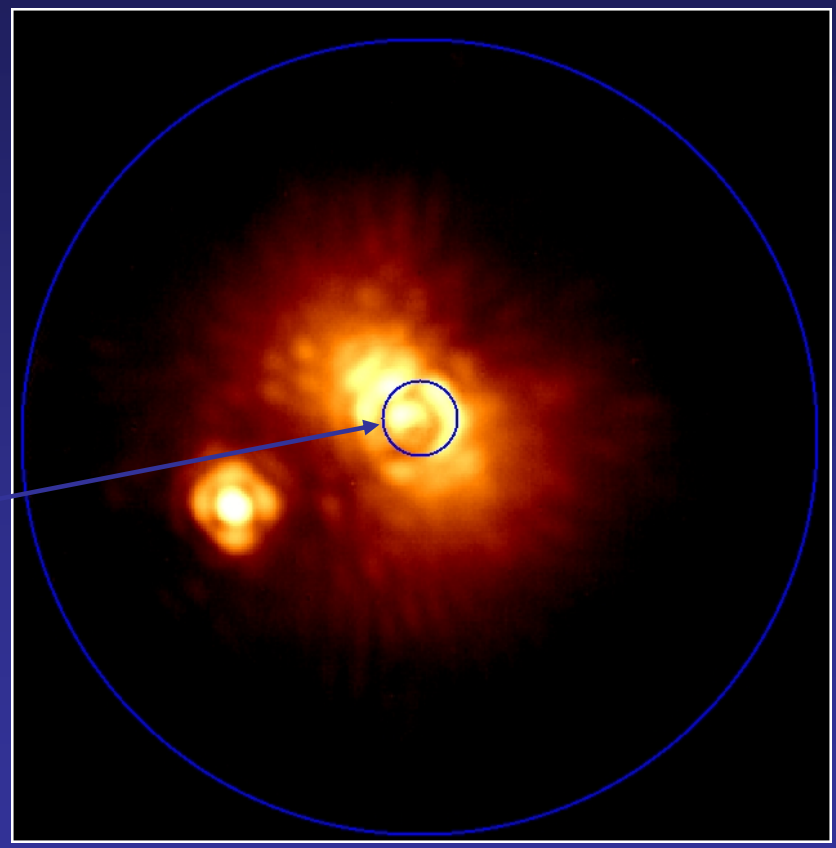
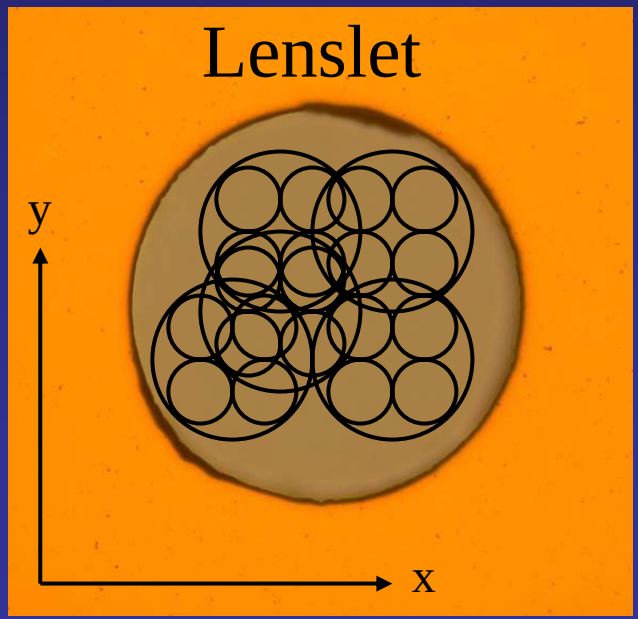


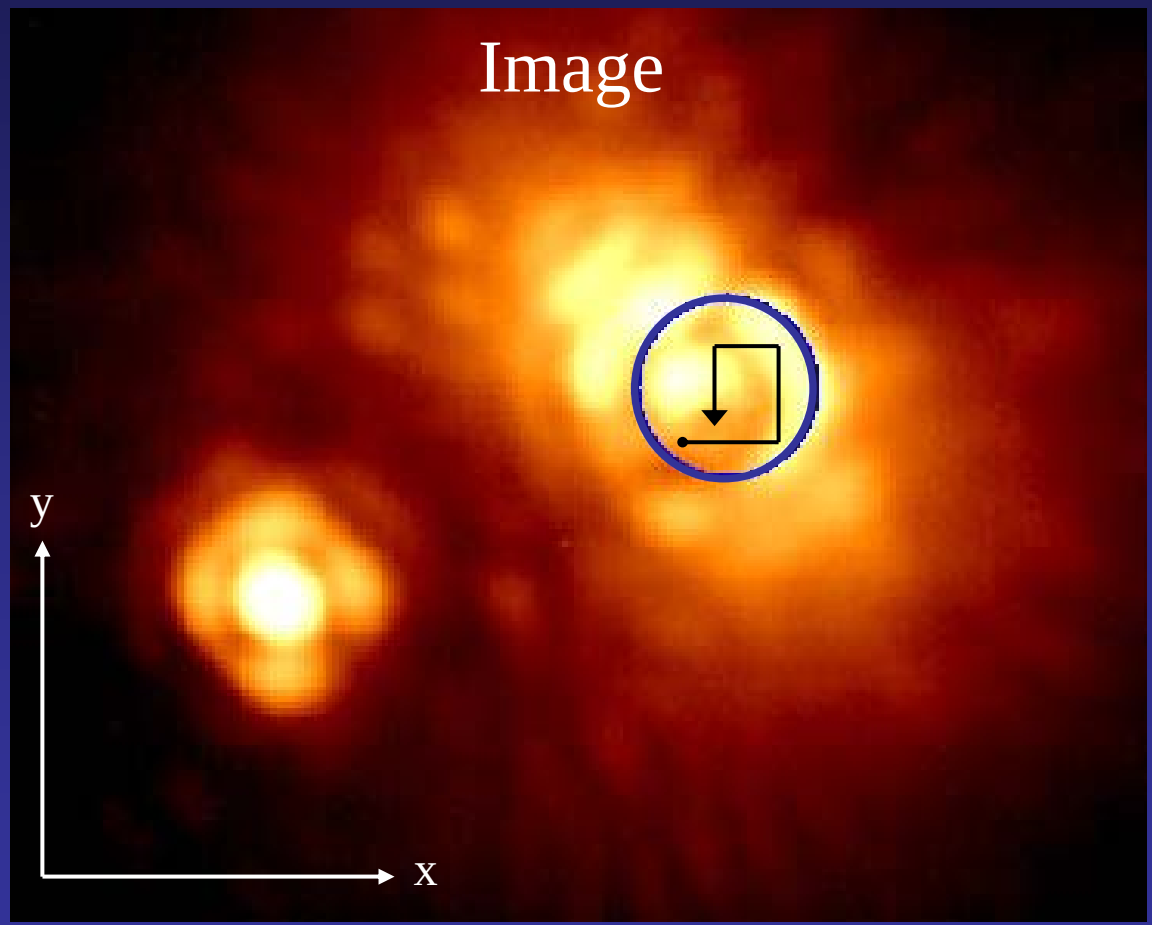
Image plane

Metrology tests

Binary tests

⇨ Moved star behind spot and compared estimated star position with lenslet motor readings

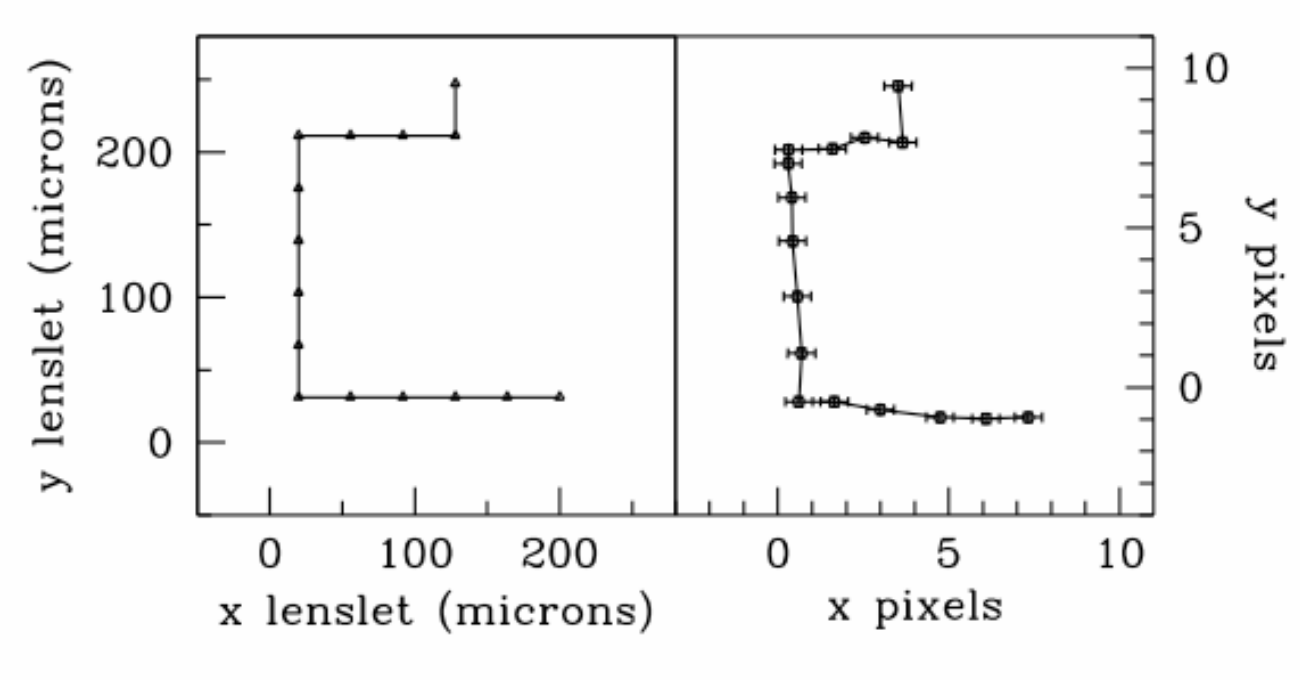




Metrology Results

Results

Relation between lenslet motor position and star pixel location



Internal Metrology

Results

Relation between motor position and star pixel location

Good correlations (0.975, 0.995)

Translations:

- Differential refraction
- Motor zero points

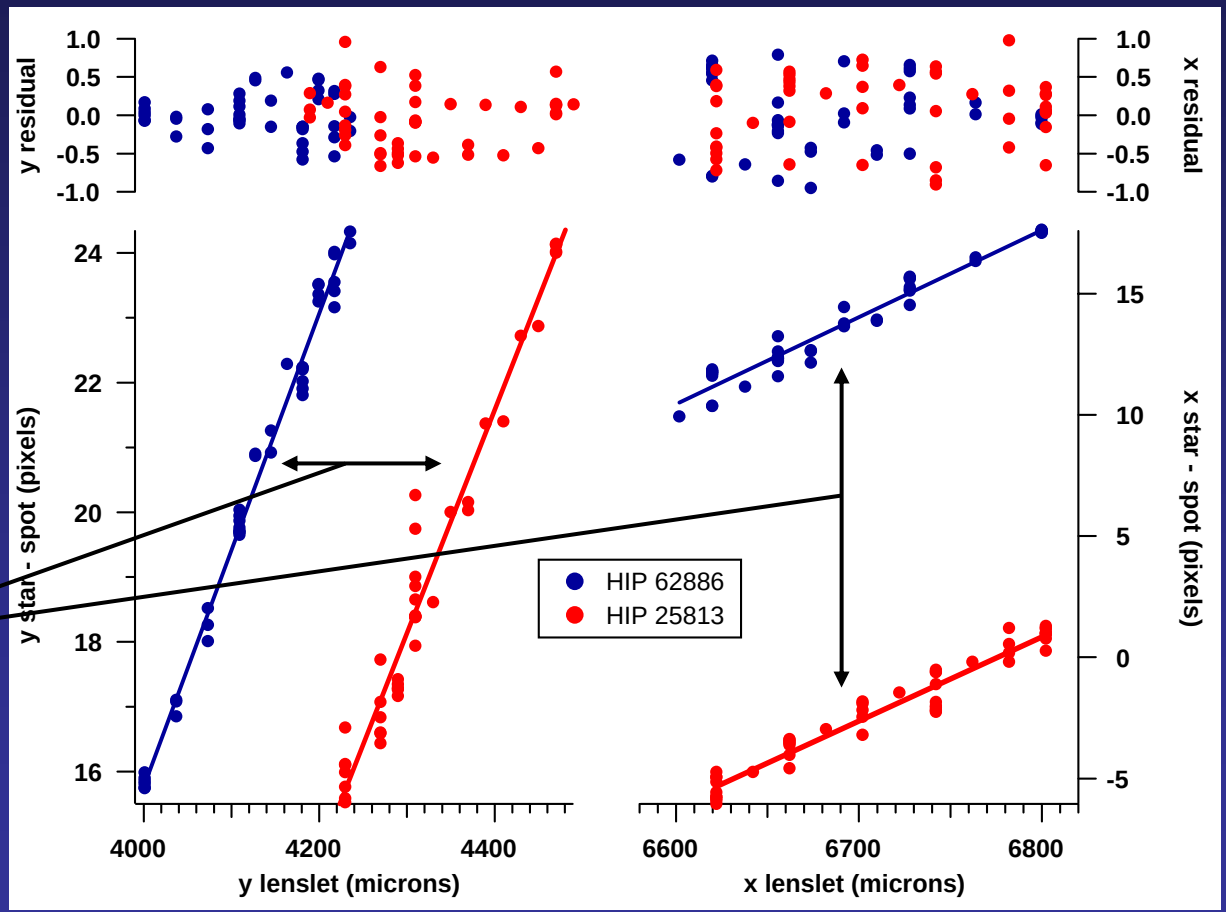


Image info rmation - PSF symmetry

PSF symmetry

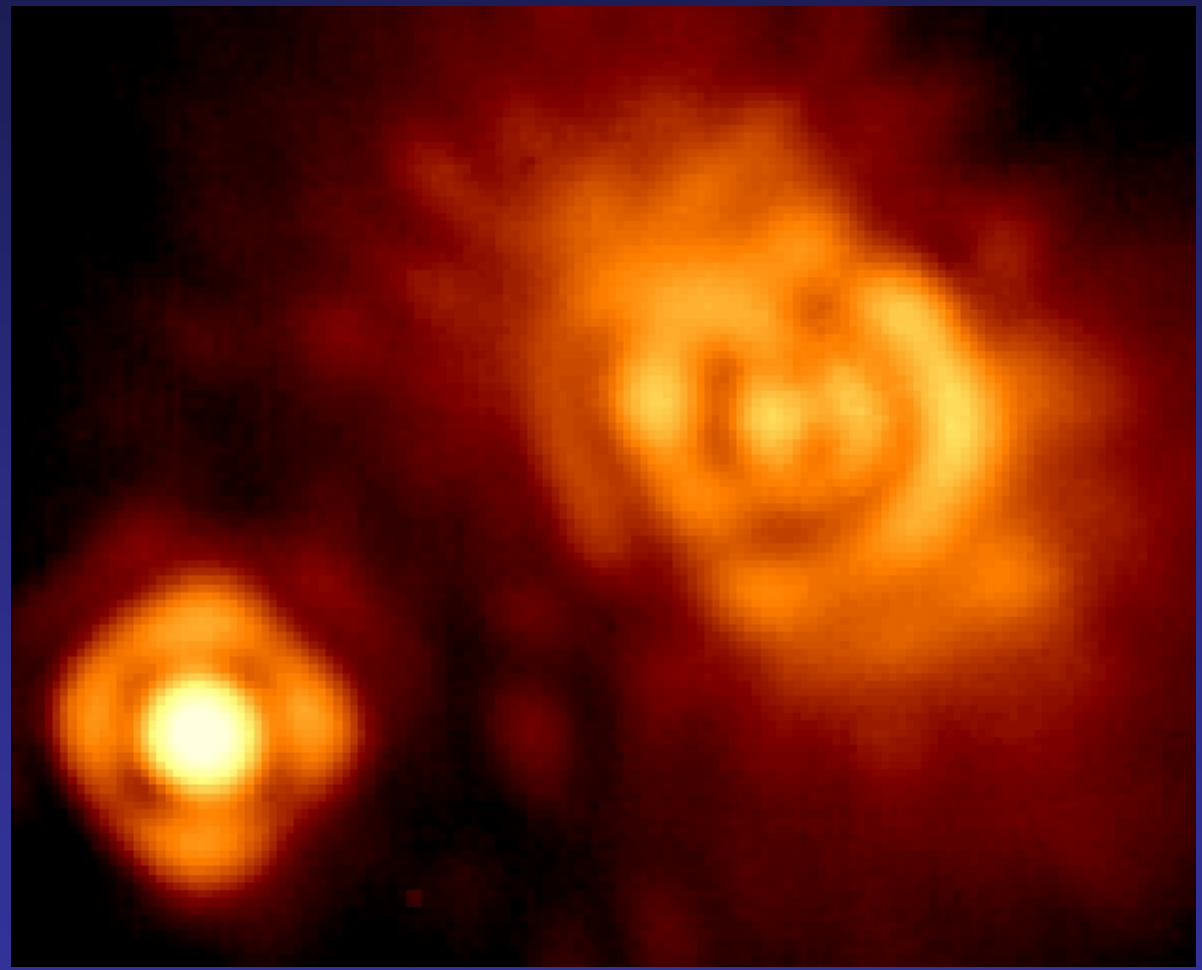
Pupil field:

$$Ae^{i\phi(x,y)} = A\left(1 + i\phi - \frac{\phi^2}{2} + \ldots\right)$$

$$p(\Phi) = aa^* \quad \text{(p0)}$$
$$-i\left[a(a^* * \Phi)(a^* * \Phi^*) - a^*(a * \Phi)\right] \quad \text{(p1)}$$
$$+(a * \Phi)(a^* * \Phi^*) \quad \text{(p2i)}$$
$$-\tfrac{1}{2}\left[a(a^* * \Phi^* * \Phi^*) + a^*(a * \Phi * \Phi\right] \quad \text{(p2ii)}$$

Perrin et al. 2003

p0: perfect PSF
p1: ‘pinned’ speckles
p2(i): halo speckles
p2(ii): 2nd order ‘pinned’ speckles



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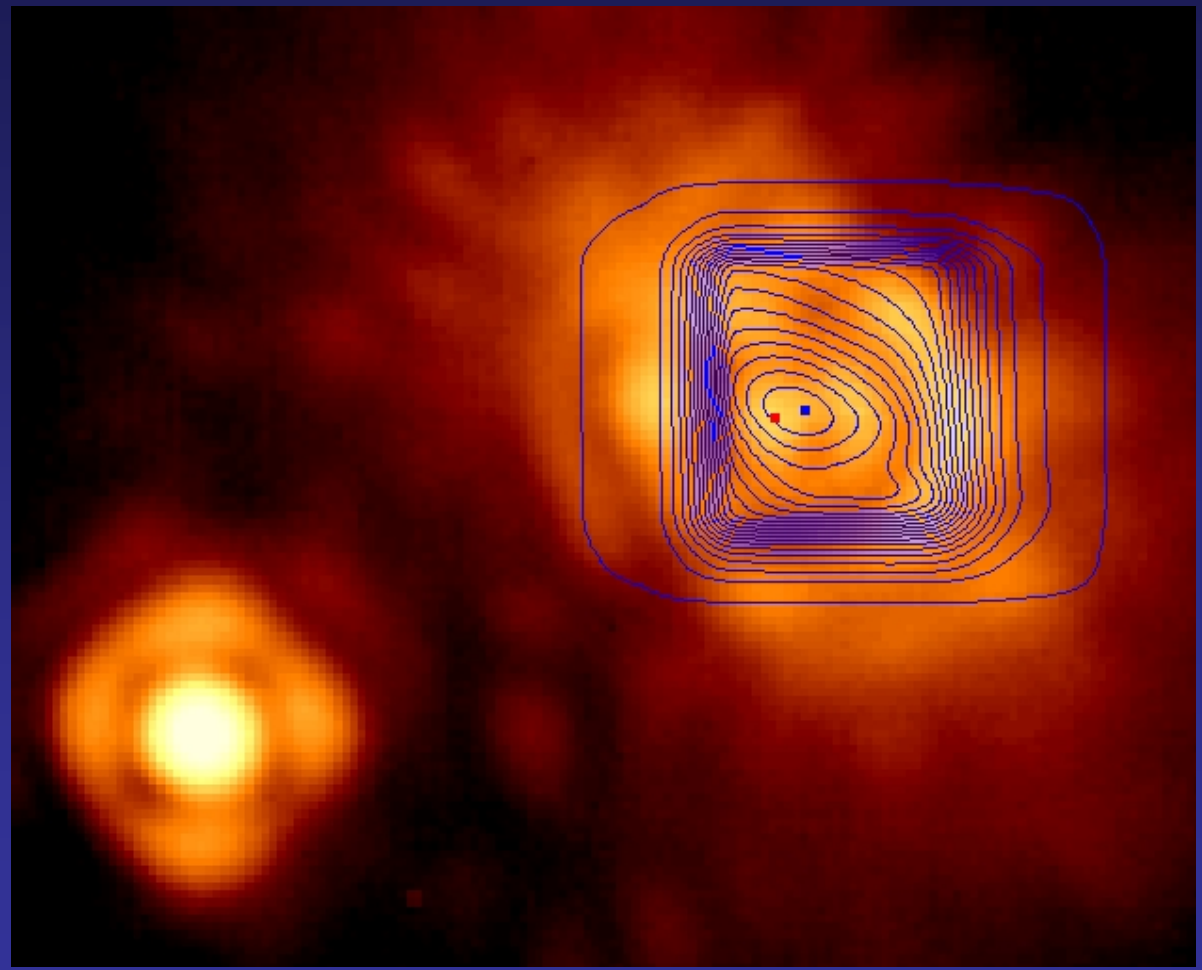
Perrin et al. 2003

Contours:
I = S/(S+A)
S - symmetric
A - positive
anti-symmetric



Summary

- Accurate astrometry central to the success of coronagraphic planet-finding experiments
- Important in future ‘extreme AO’ coronagraphs
- Careful consideration required during instrument design; precise calibration of instrument metrology required