Exoplanet High Contrast Imaging: Space

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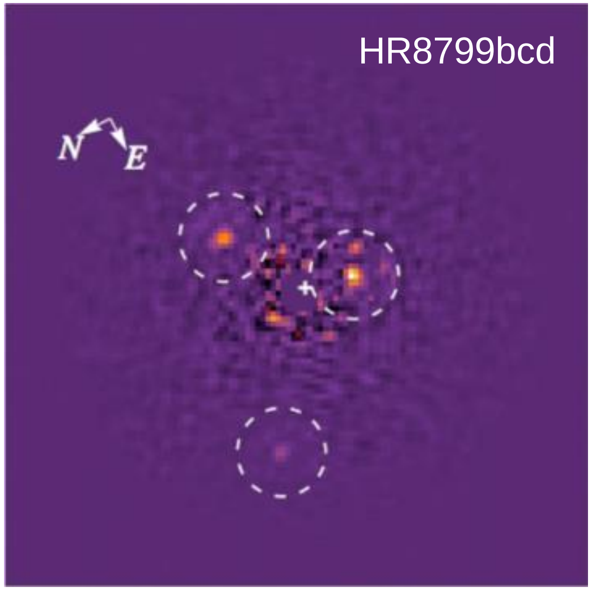
KISS Short Course: Mastering the Wave - The Whys and Hows of Exoplanet Imaging

August 22, 2016

Overview

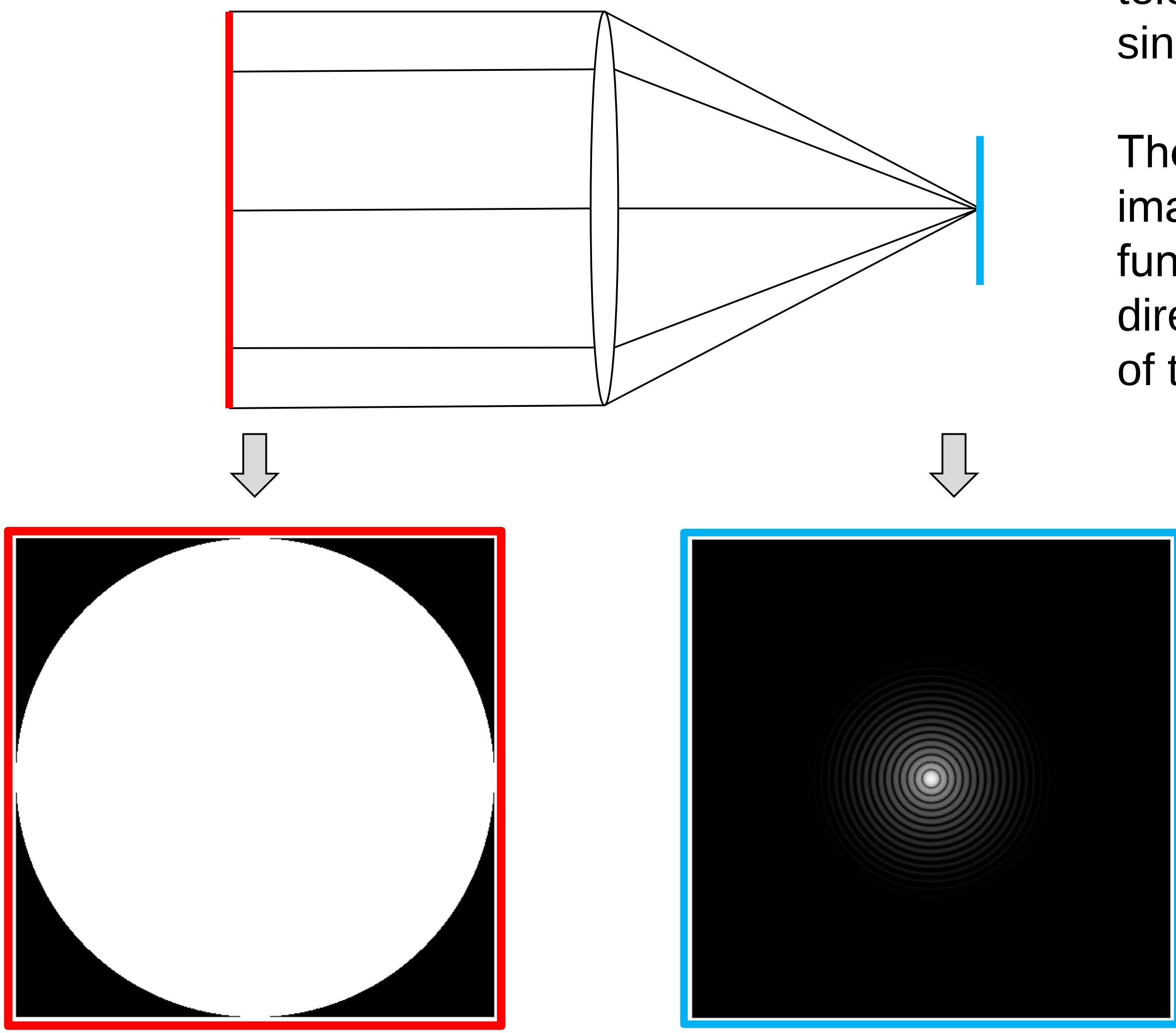


Soummer *et al.* 2011

Outline:

- A brief discussion of diffraction
- The Lyot coronagraph
- Imaging planets from space today
- Coronagraph technology development
- Starshades
- Imaging planets from space in the near future

Diffraction in action



A star imaged by a telescope *never* focuses to a single point.

The shape of the star’s image (“point spread function” or “PSF”) can be directly related to the shape of the telescope aperture.

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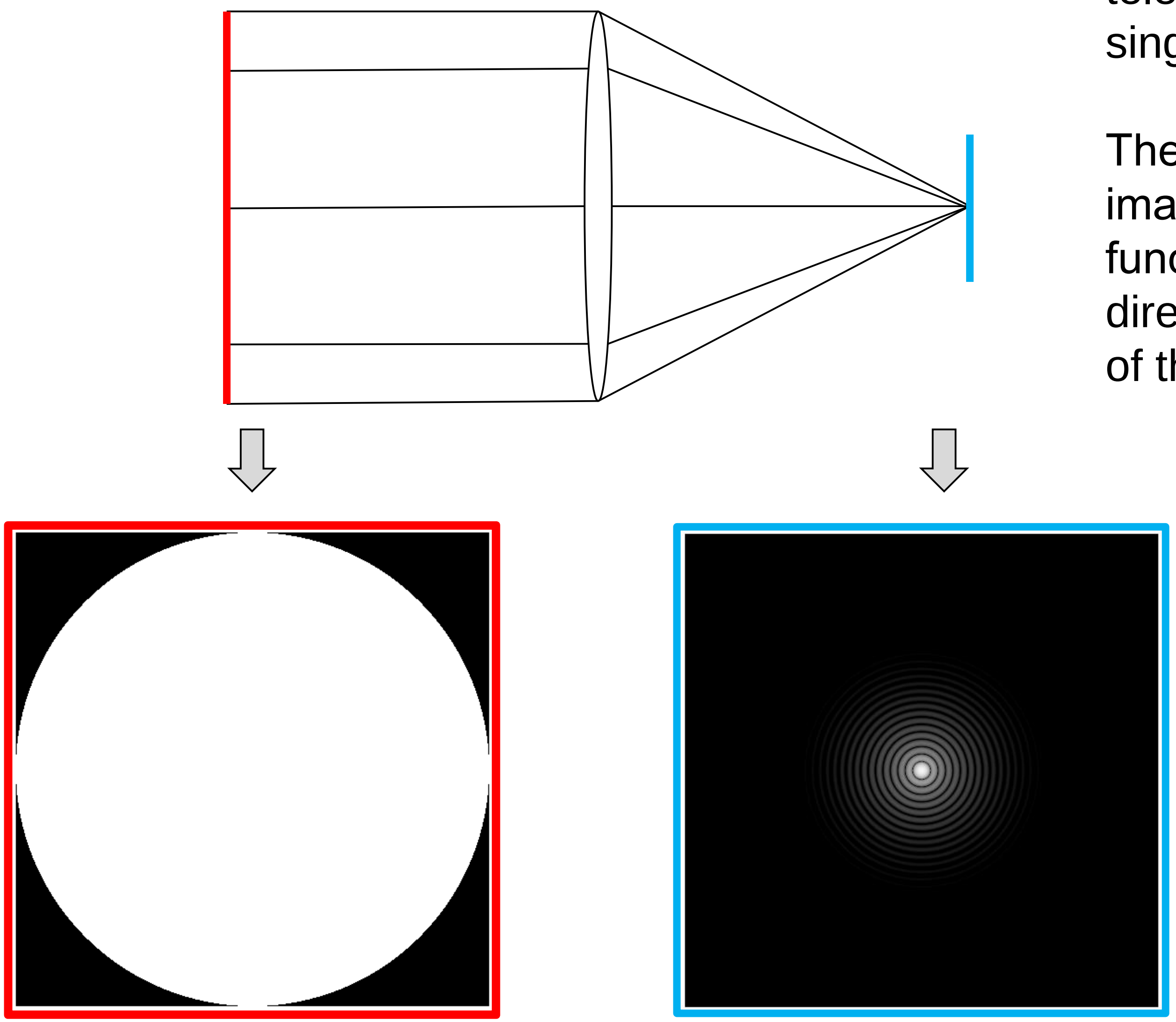
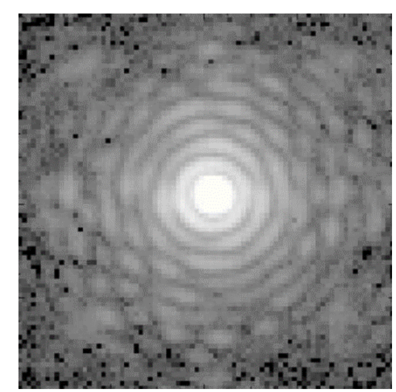
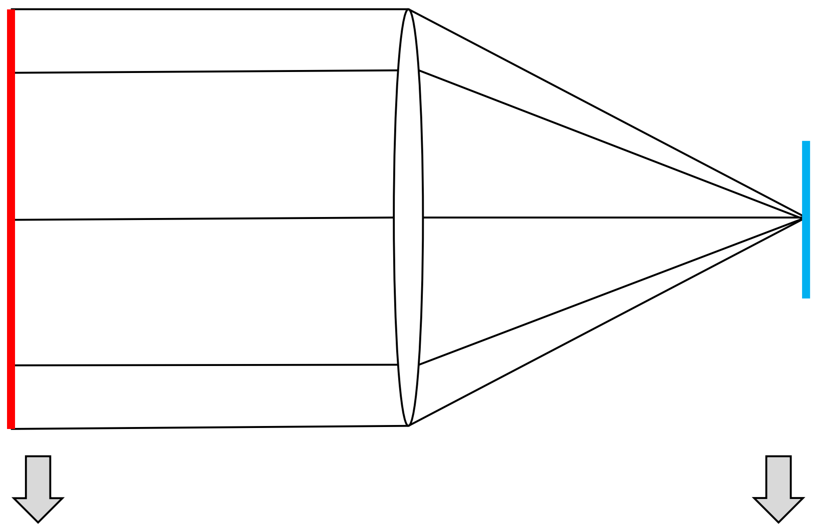


"Airy pattern"



HD121107 with Palomar WCS,
Serabyn *et al.* 2007

Diffraction in action



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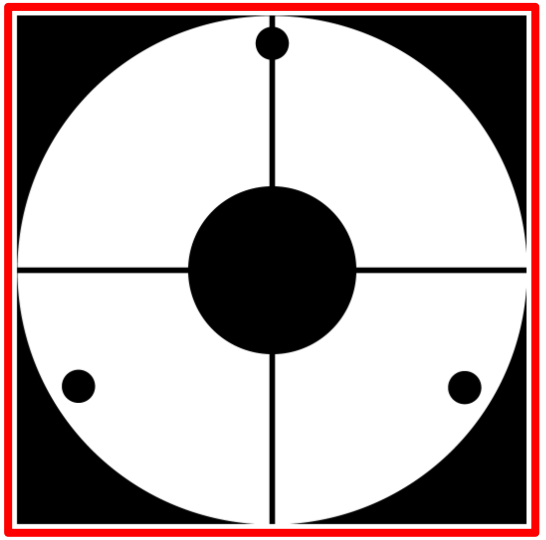
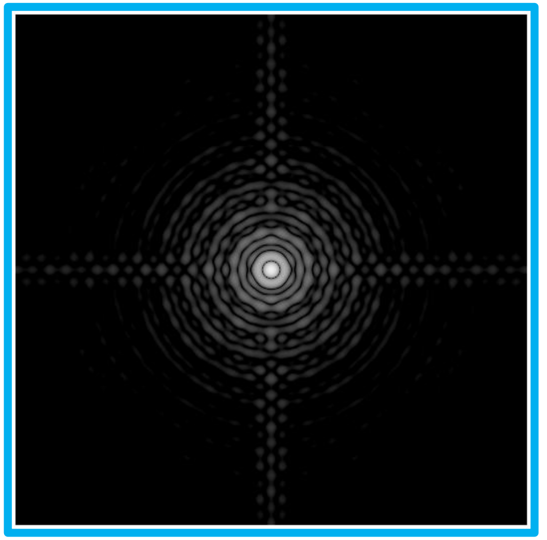
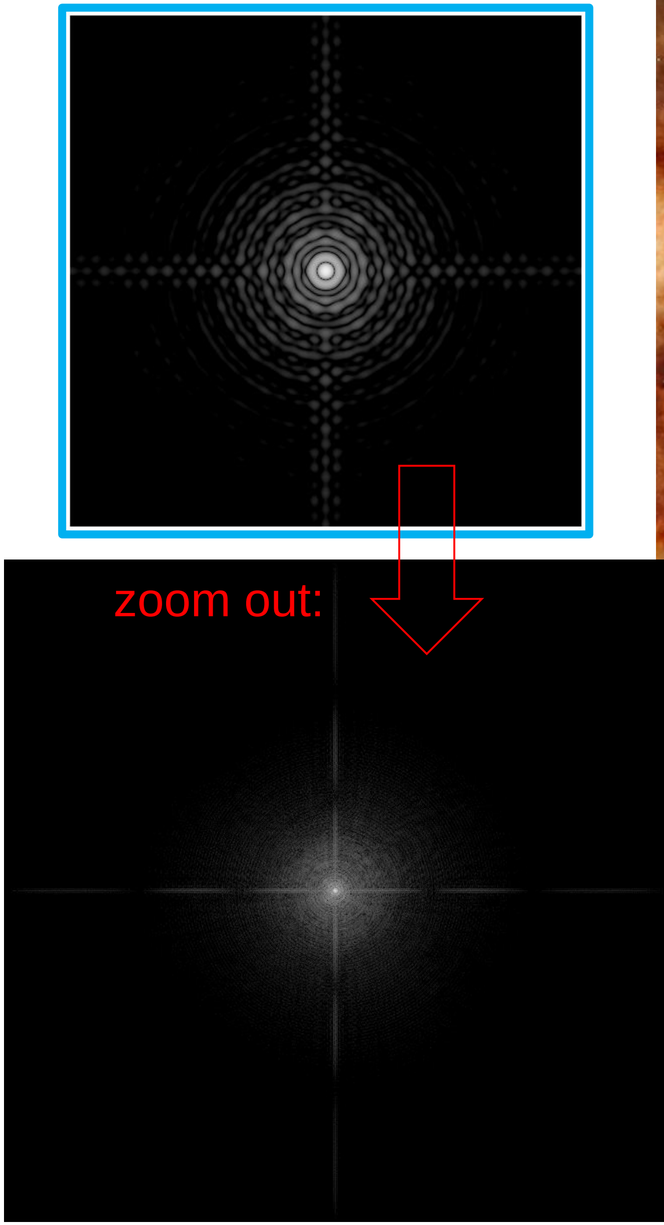


Courtesy of J. Krist



Hubble PSF

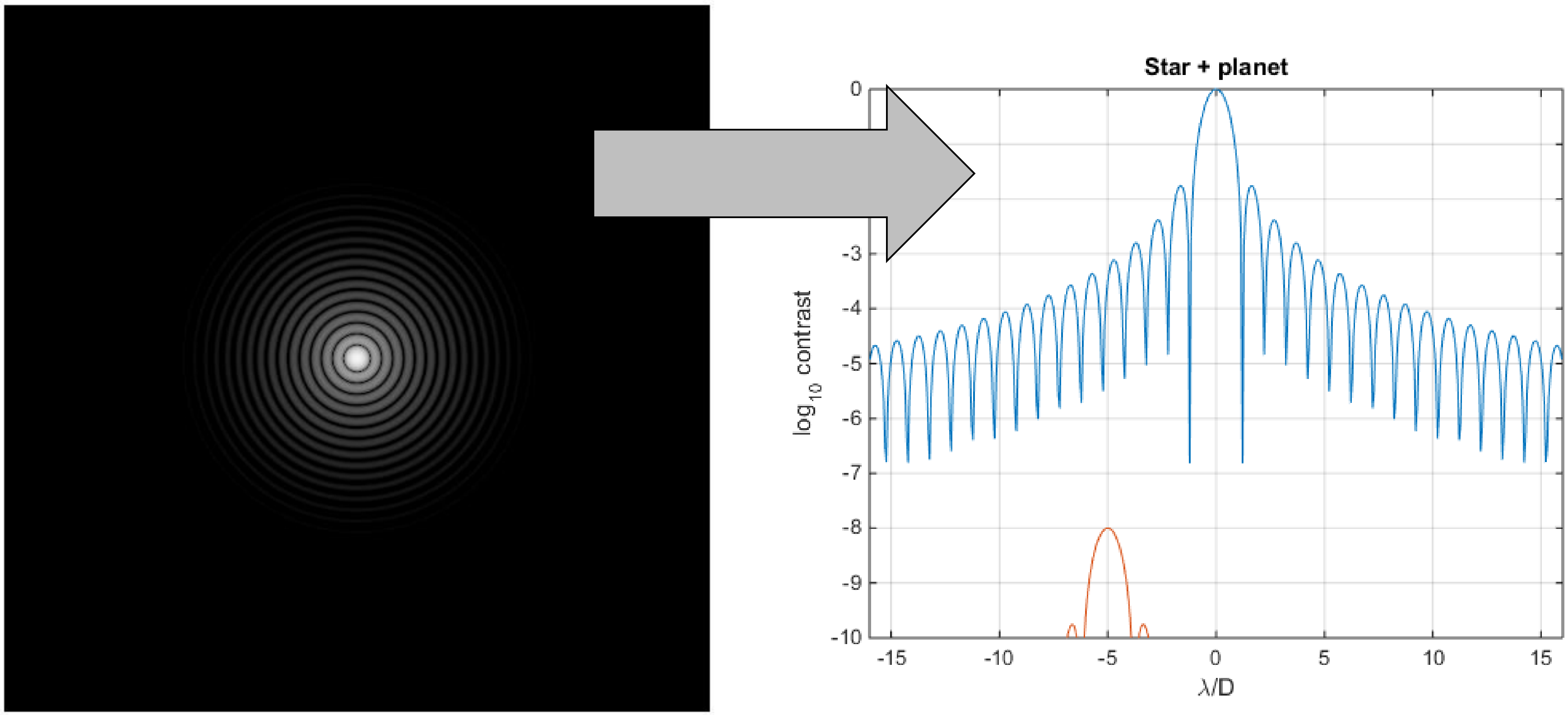
Diffraction spikes in Hubble



30 Doradus with Hubble WFC3, Credit: NASA, ESA, F. Paresce (INAF-IASF, Bologna, Italy), R. O'Connell (University of Virginia, Charlottesville), and the Wide Field Camera 3 Science Oversight Committee

The challenge: faint and close

Unfortunately, most planets are buried under the “wings” of a telescope PSF.



The challenge of high-contrast imaging: *get rid of the diffracted starlight to see those faint nearby objects.*

The challenge: faint and close

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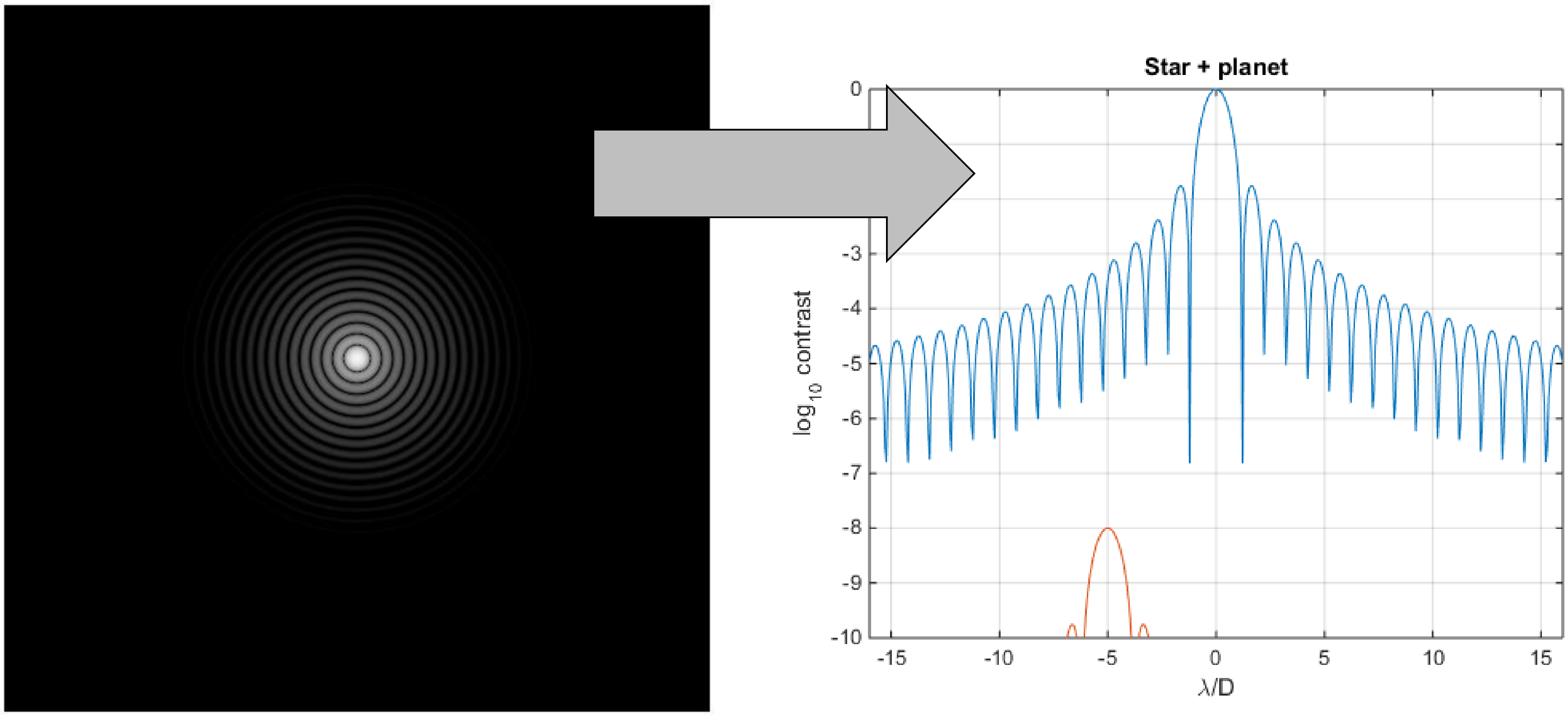


The challenge of high-contrast imaging: *get rid of the diffracted starlight to see those faint nearby objects.*

PSF depends on aperture → different telescopes may need different solutions!

Enter the coronagraph

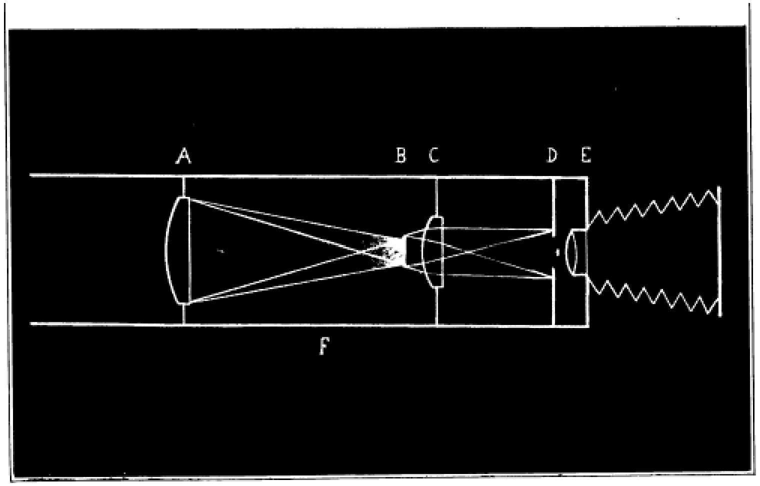
One method for doing this: the coronagraph

A class of instruments that:

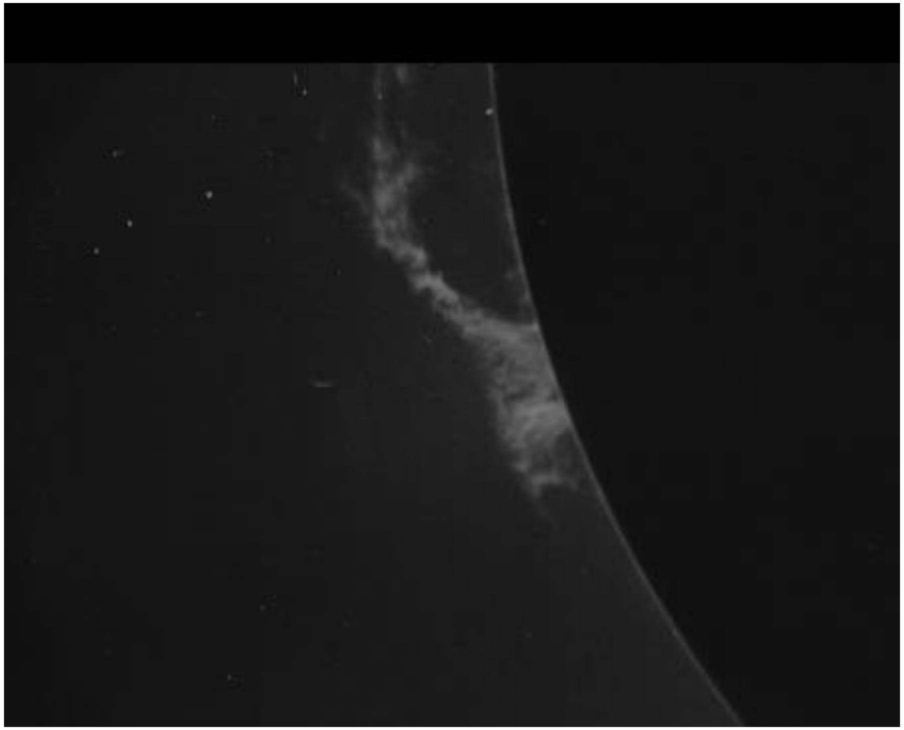
- use diffraction to block, redirect and cancel the starlight inside the telescope
- have a minimal effect on the planet light

First invented by Bernard Lyot to study the solar corona in 1930s

- another faint astrophysical feature right next to a bright one

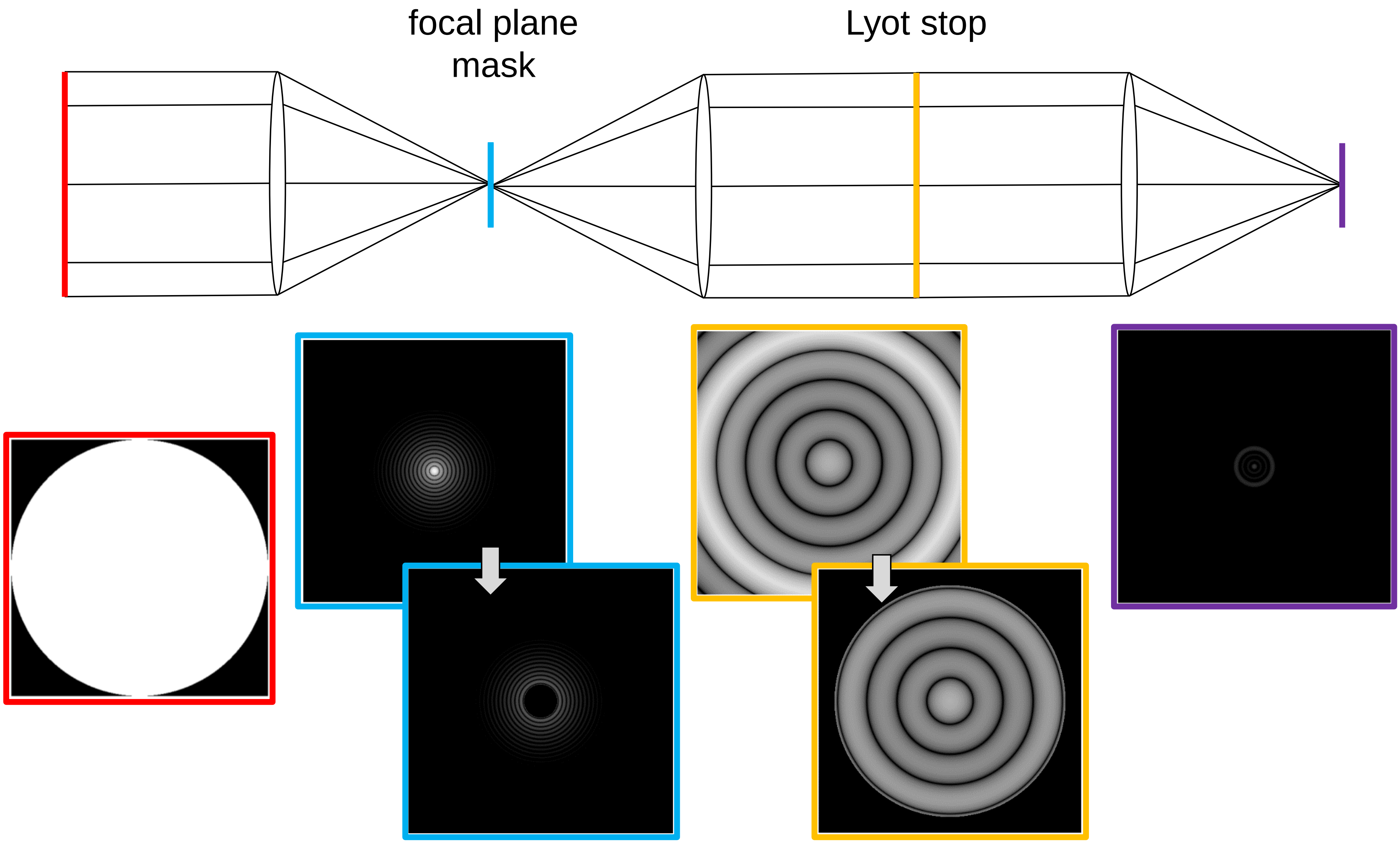


Lyot 1939



Lyot 1935

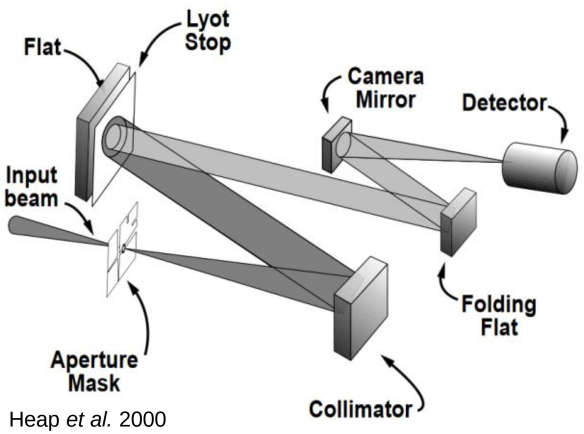
The “classical” Lyot coronagraph



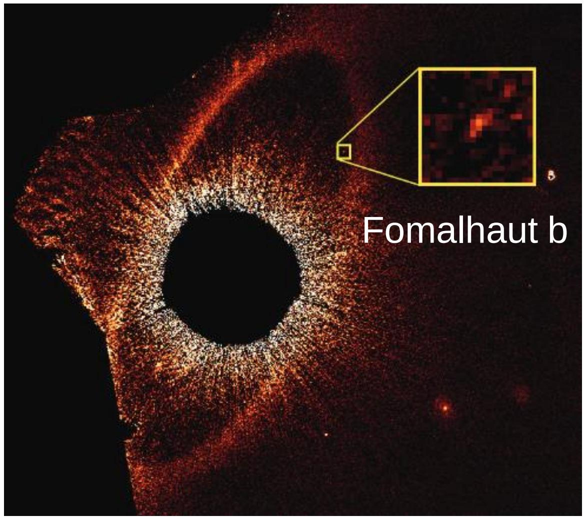
Space coronagraphy, today

Hubble has had three Lyot coronagraphs used in its instruments to look at planets:

STIS

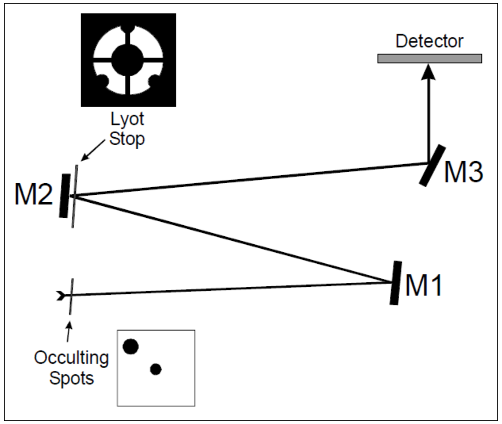


Heap *et al.* 2000

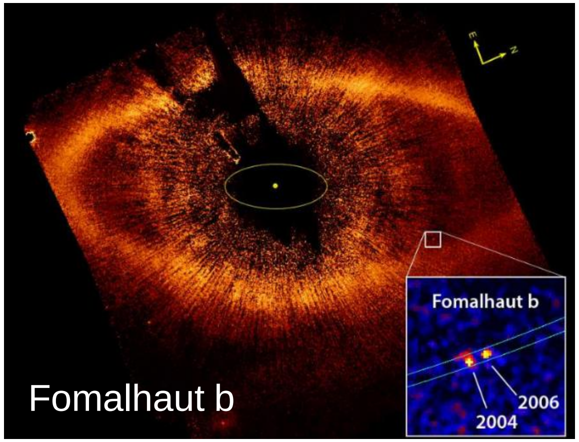


Kalas *et al.* 2013

ACS/HRC

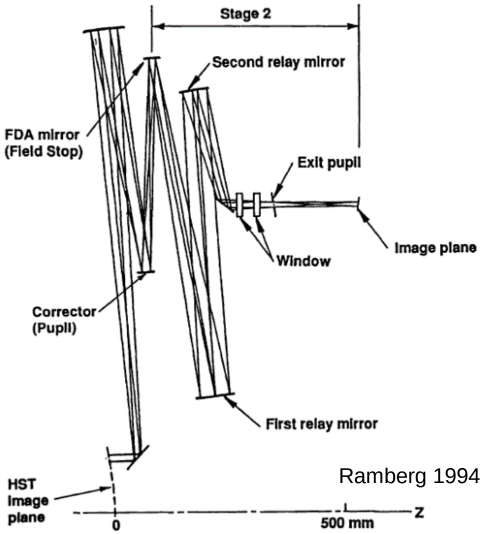


Krist *et al.* 2003

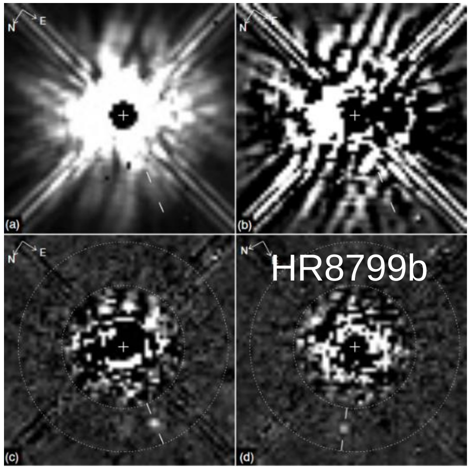


Kalas *et al.* 2008

NICMOS



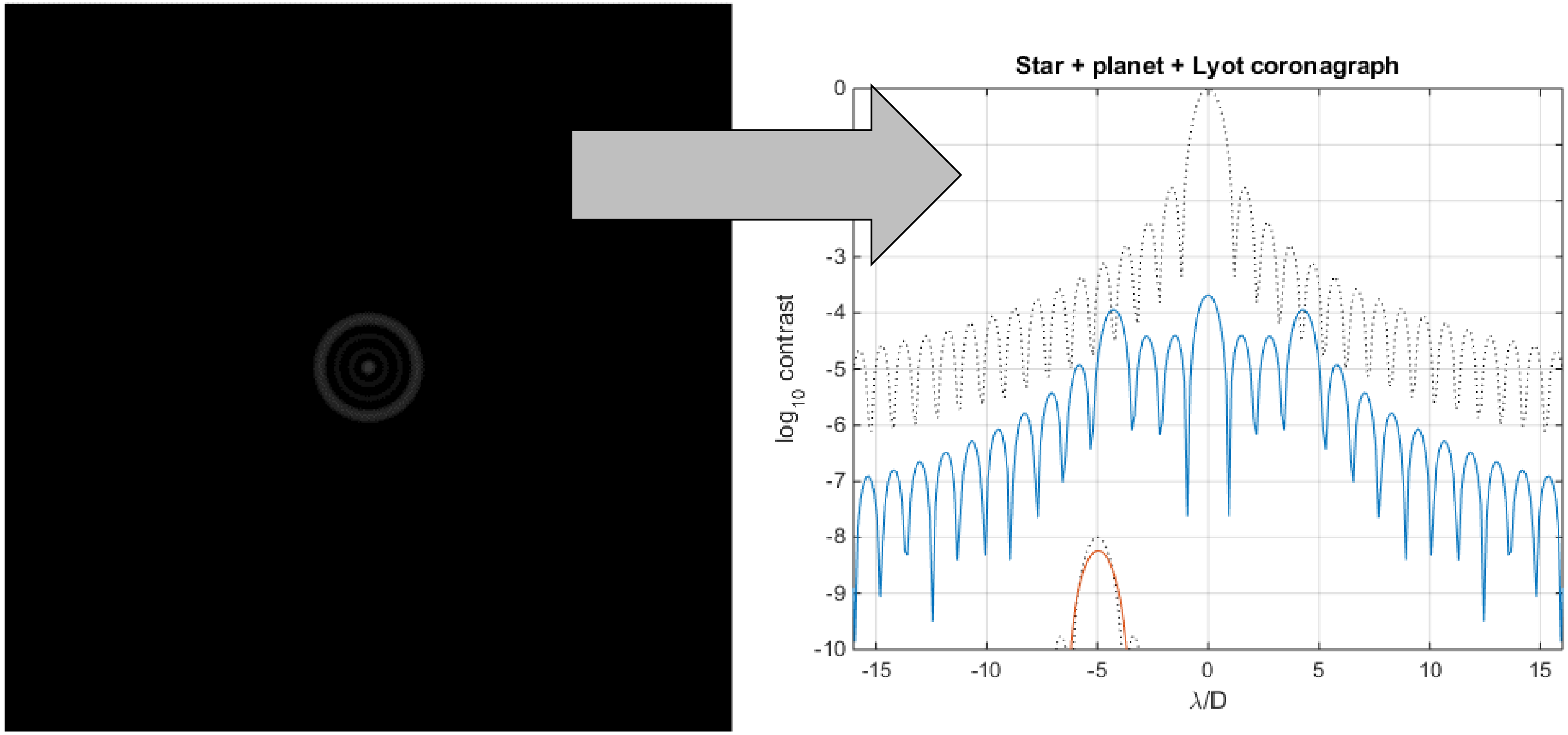
Ramberg 1994



Lafrenière *et al.* 2009

A slice through the PSF

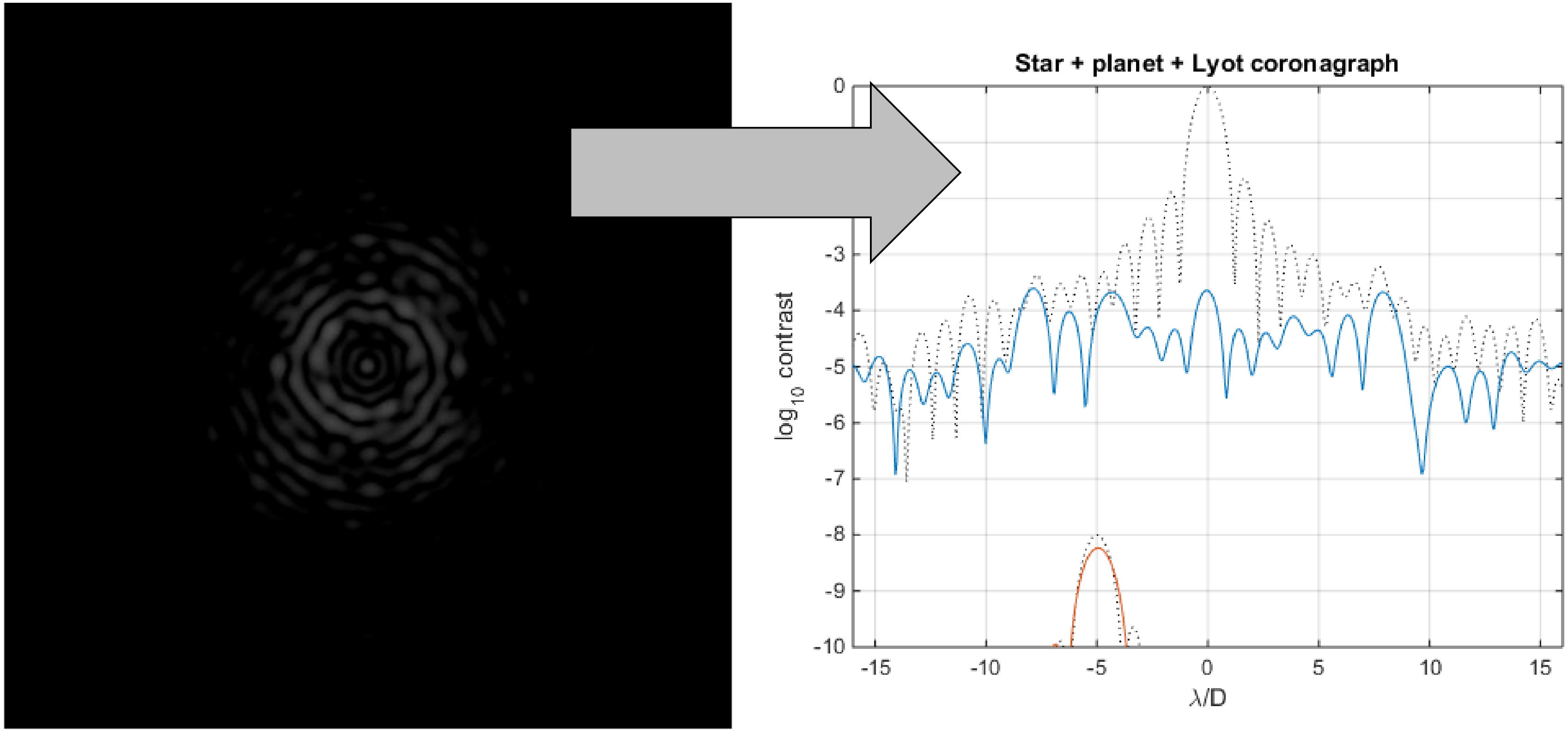
Let’s look at a slice through that post-coronagraph PSF:



1. Wings of PSF are suppressed by mask + Lyot stop, not just center
2. Coronagraph affects planet slightly as well, but not as much as star
3. …even given that, our planet is still too faint for this coronagraph!

It gets worse

If our mirrors are not perfect:



- We get features ("speckles") all over the place
- We don't have those wings suppressed anymore

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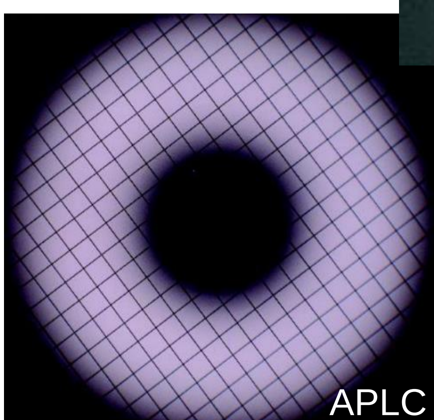
How do we fix this?

1. Better coronagraph designs

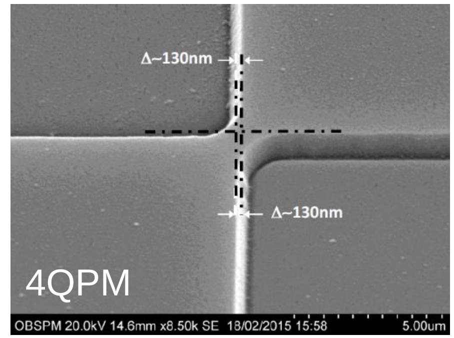
Balasubramanian *et al.* 2016

Change the pupil

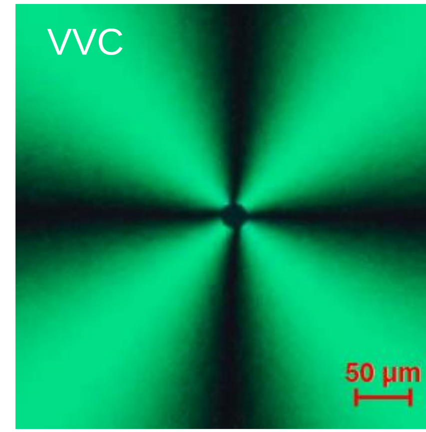
Otten *et al.* 2014



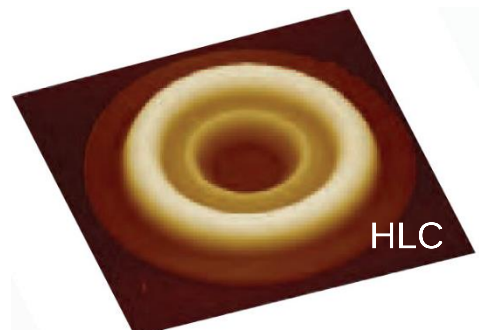
Macintosh *et al.* 2008



Bonafous *et al.* 2016



Mawet *et al.* 2009



Trauger *et al.* 2016

Change the focal plane mask

PIAA

Guyon *et al.* 2012

Introduce additional optics

How do we fix this?

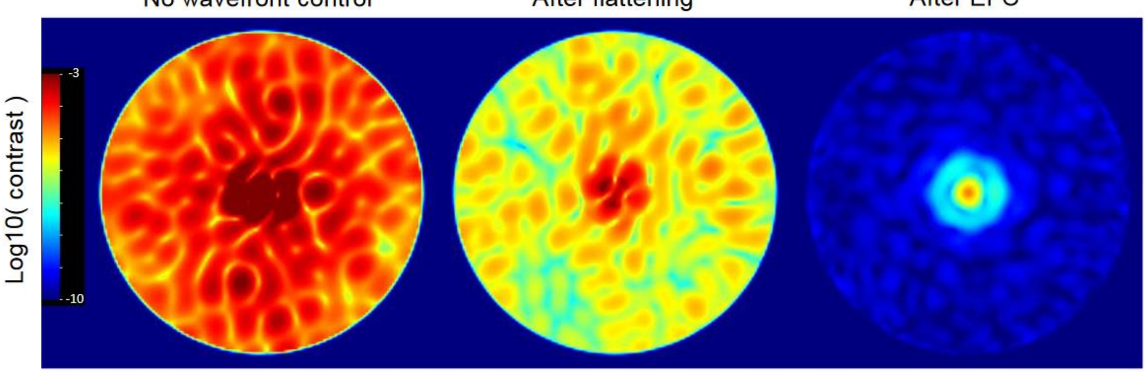
1. Better coronagraph designs
2. Wavefront control

Use wavefront sensors to measure how the starlight was changed ("aberrated")

- Science camera is often best for this

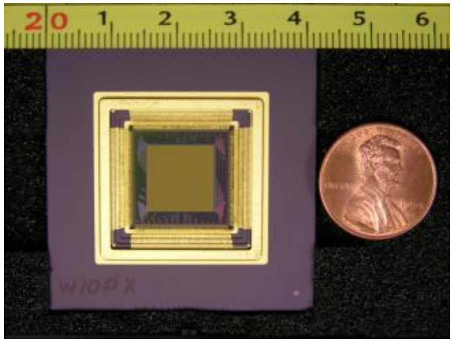
Use deformable mirrors (DMs) to correct those aberrations

The combination is very effective at reducing speckles within a limited area near the star ("dark hole")

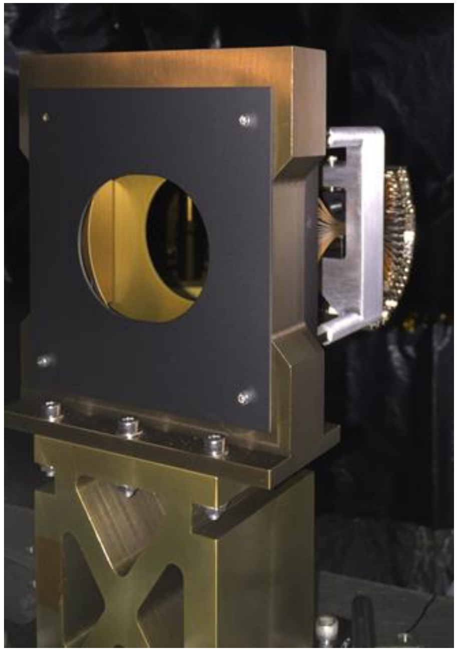


Krist, Nemati, and Mennesson 2015

DMs



Morzinski *et al.* 2006



Courtesy of B.-J. Seo

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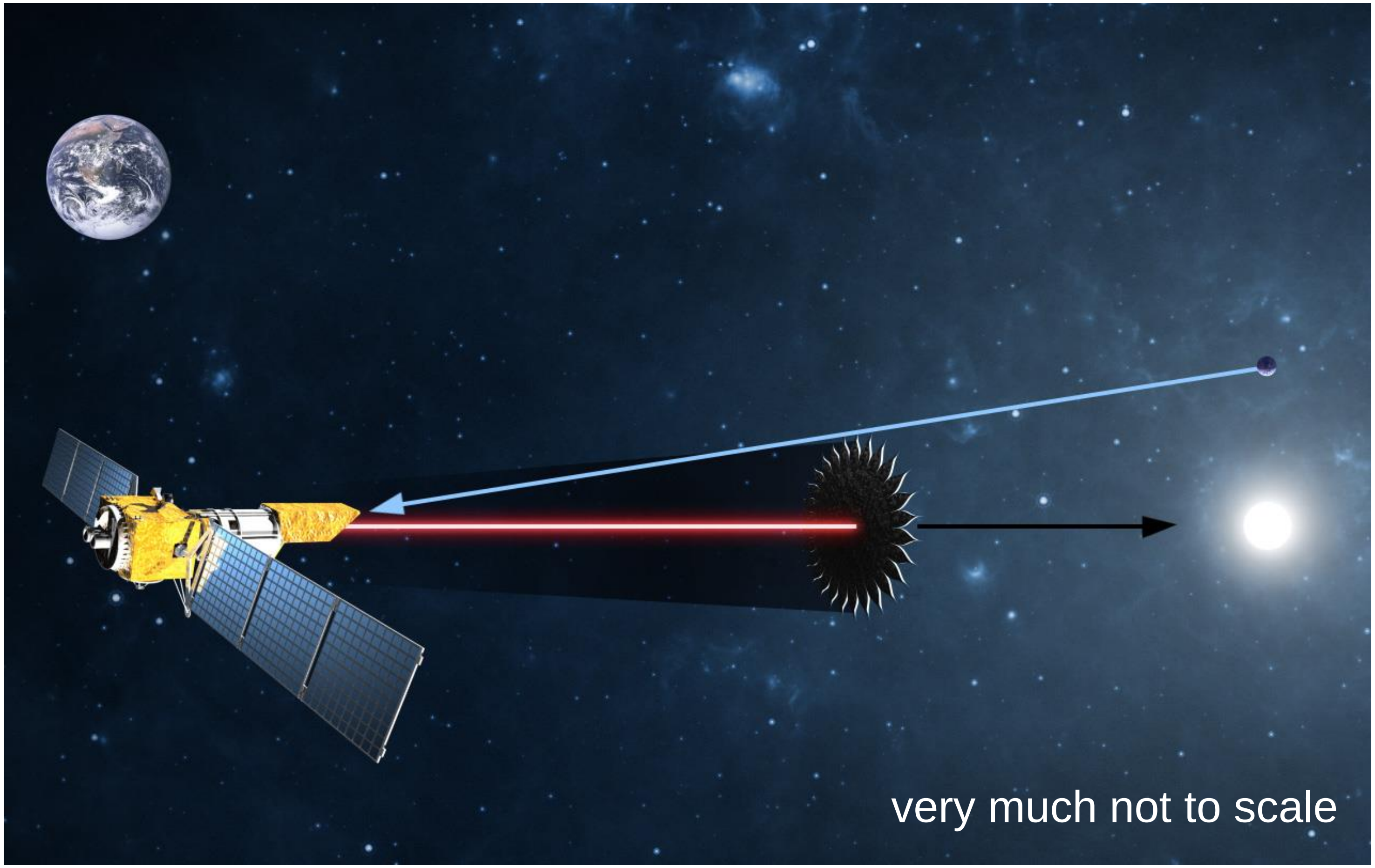
Take it outside

An alternate approach: use a starshade to block the light before it enters the telescope. ("external coronagraph")



Exo-S final report, 2015

Right size not to block the planet. No wavefront control needed!

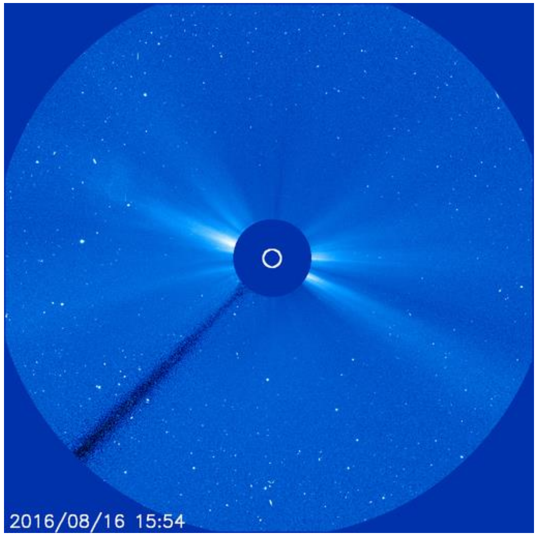
Starshades

Like coronagraphs, the starshade concept was developed for solar observations

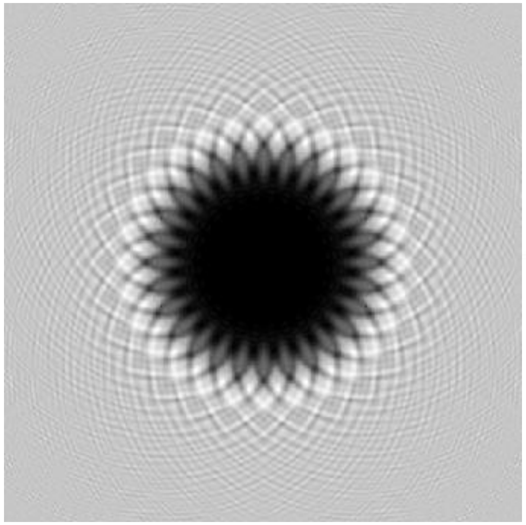
- LASCO on SOHO has two "external coronagraphs" right now looking at sun

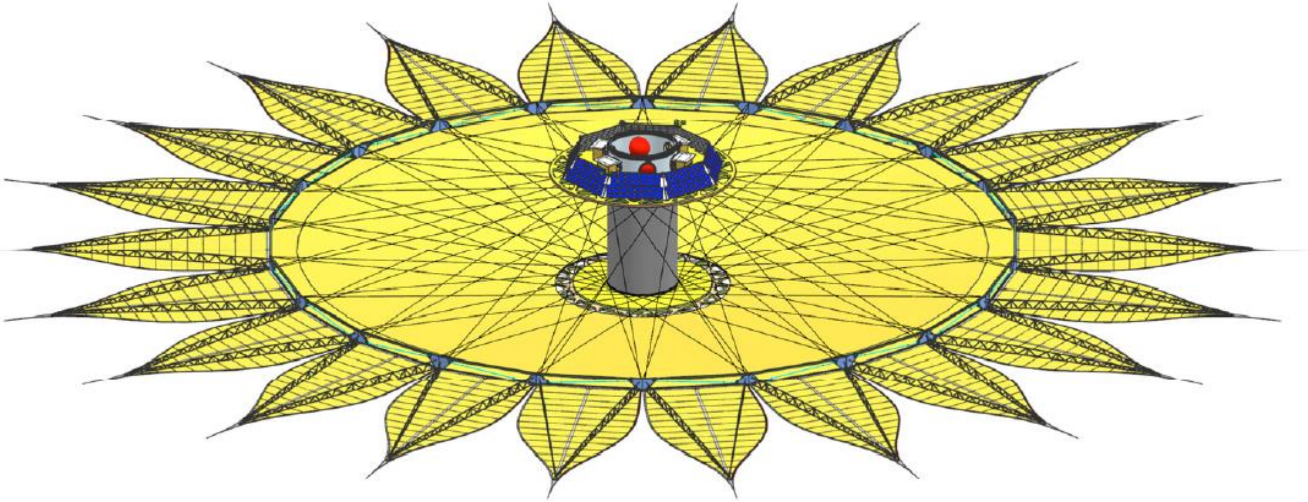
Starshade is external to *telescope*

- Flown in formation at distances of tens of thousands of kilometers
- Creates a shadow where telescope must remain
- Edge is shaped to control diffraction



From C3 on LASCO realtime feed





Exo-S final report, 2015

Still a concept, but a promising one.

Future of space high-contrast imaging

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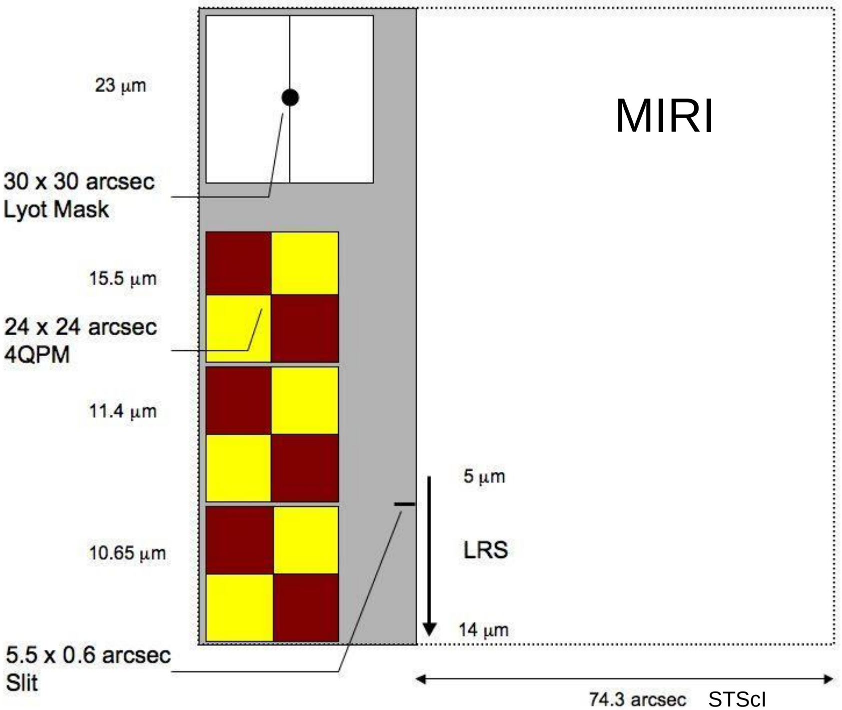
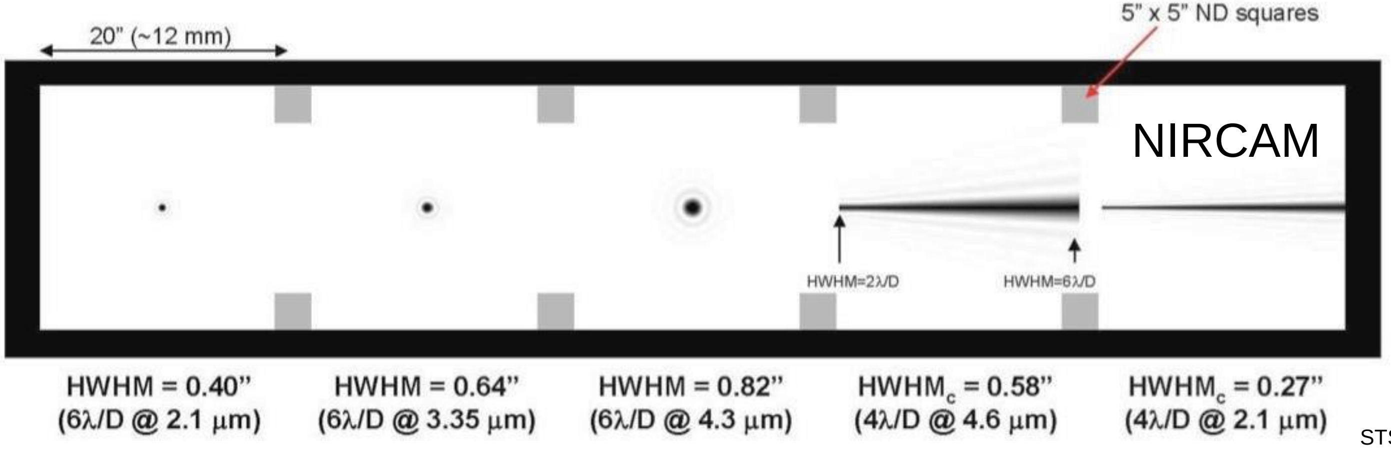
jwst.nasa.gov

JWST: coronagraphs in two instruments

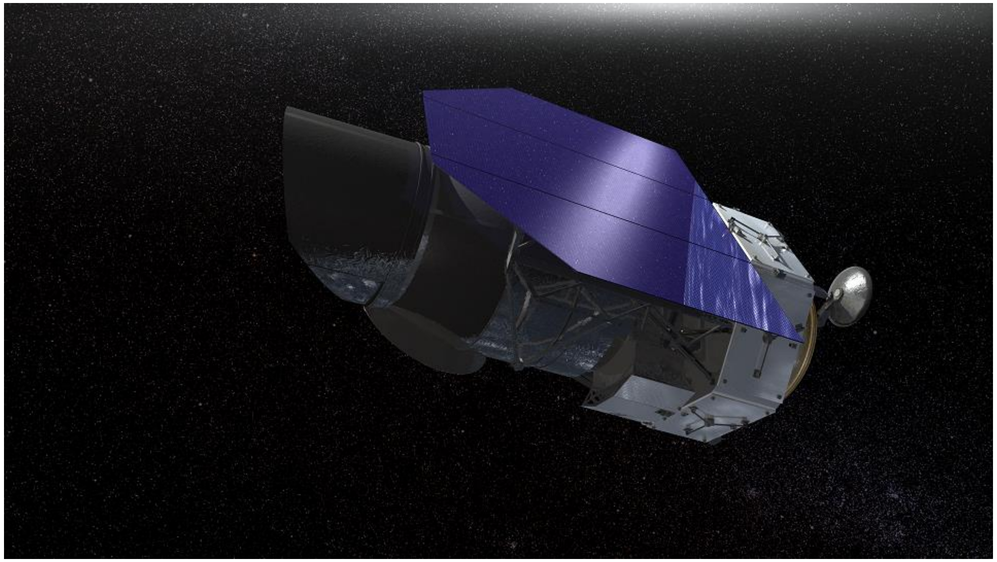


STScI

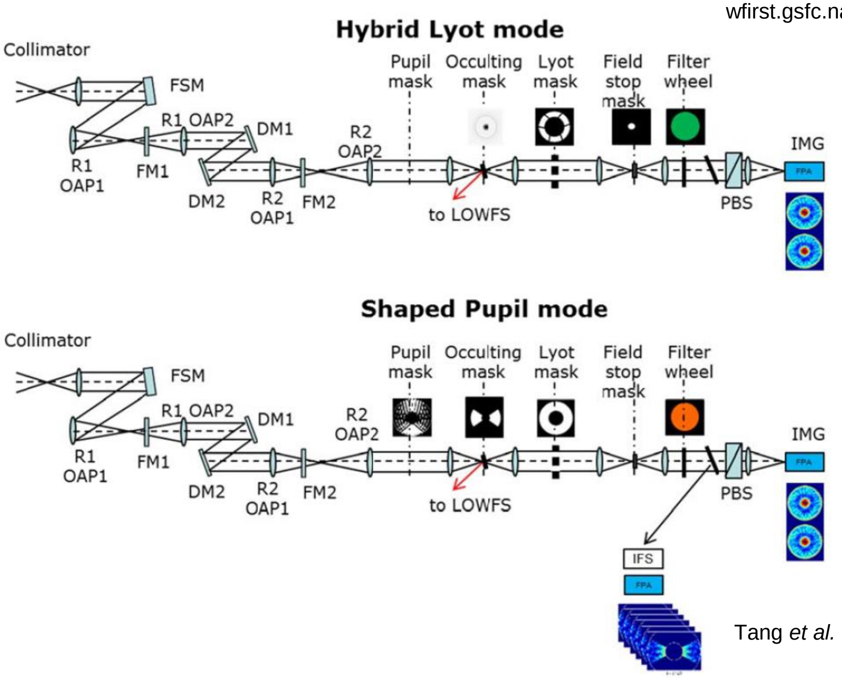


STScI

Future of space high-contrast imaging



wfirst.gsfc.nasa.gov



Tang *et al.* 2015

WFIRST: dedicated coronagraph instrument

Other possible missions:

- HabEx and/or LUVOIR?
- Starshade with WFIRST?

And of course, plenty of imaging to be done on the ground…