Techniques for direct imaging of exoplanets

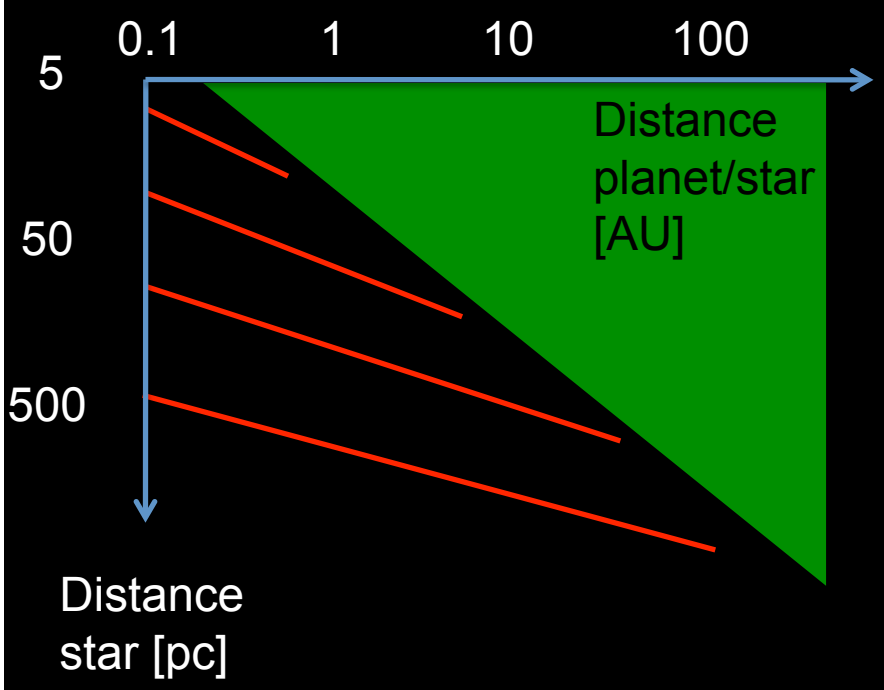
Aglaé Kellerer
Institute for Astronomy, Hawaii

1. Where lies the challenge?
2. Contrasts required for ground observations?
3. Push the contrast limit – Recycle!

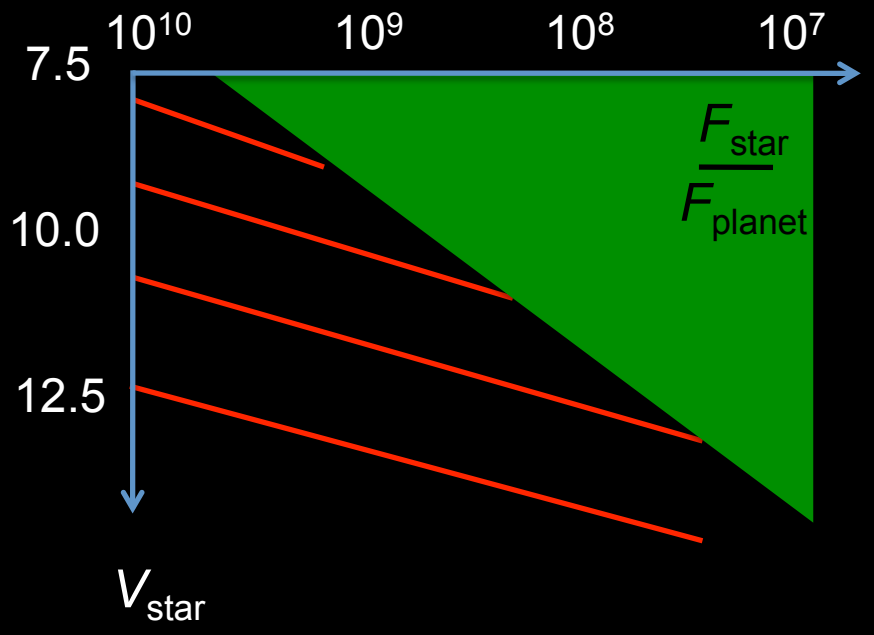
1. Where lies the challenge?
The telescope aperture?

Take an 8m telescope observing at 1μm wavelength.

Can it resolve the planet and its host star?

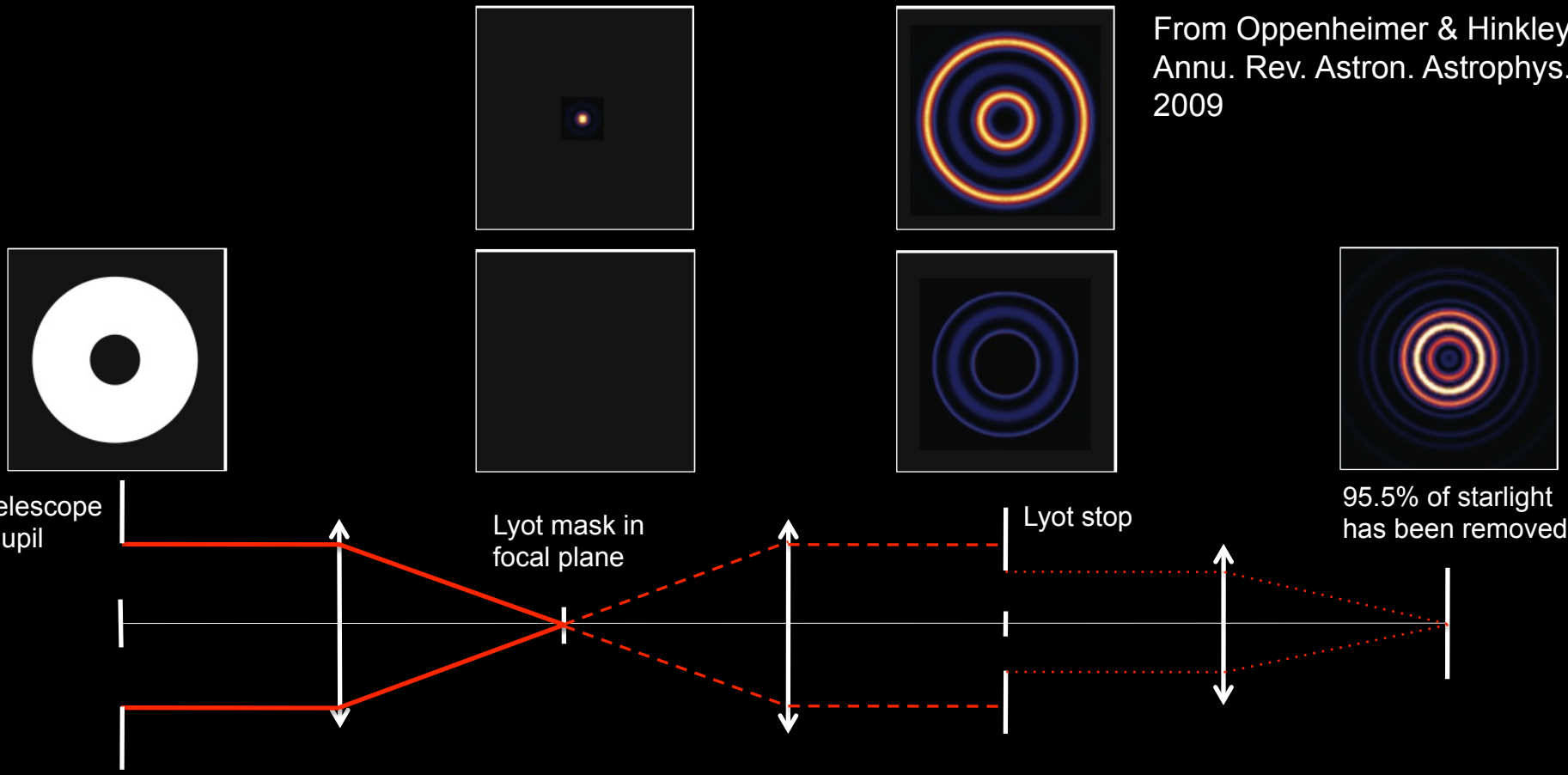


Can it collect enough photons from the planet?



Telescope aperture is not the primary challenge
(except for the coolest exoplanets)

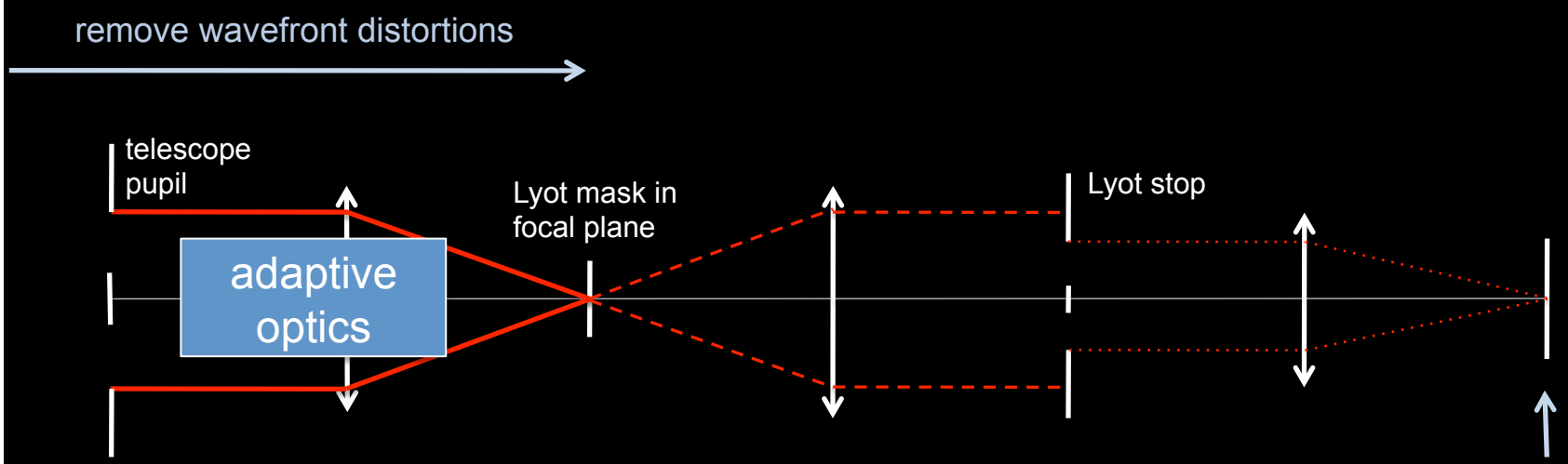
1. Where lies the challenge?
The coronagraph?



From Oppenheimer & Hinkley, Annu. Rev. Astron. Astrophys., 2009

Current coronagraphs achieve contrast levels up to 10^{-10} for diffraction limited wavefronts.

1. Where lies the challenge?
Adaptive optics & speckle suppression techniques



For the speckles that made their way to the detector:
Spectral Differential Imaging (Racine et al., PASP 1999)
Angular Differential Imaging (Marois et al, ApJ 2006)

The primary difficulty of high-contrast imaging is

~~get a large telescope,~~

~~design a coronagraph,~~

flatten the wavefront and suppress the residual speckles.

Techniques for direct imaging of exoplanets

1. Where lies the challenge?

- Large telescopes are only required for the coolest exoplanets
- The primary issue for exoplanet imaging is scatter in the atmosphere and on the imperfect telescope optics

2. Contrasts required for ground observations?

2. What are the contrasts achievable from ground?

Comparison of 4 exoplanet surveys

4m telescope
Adaptive Optics
Lyot coronagraph

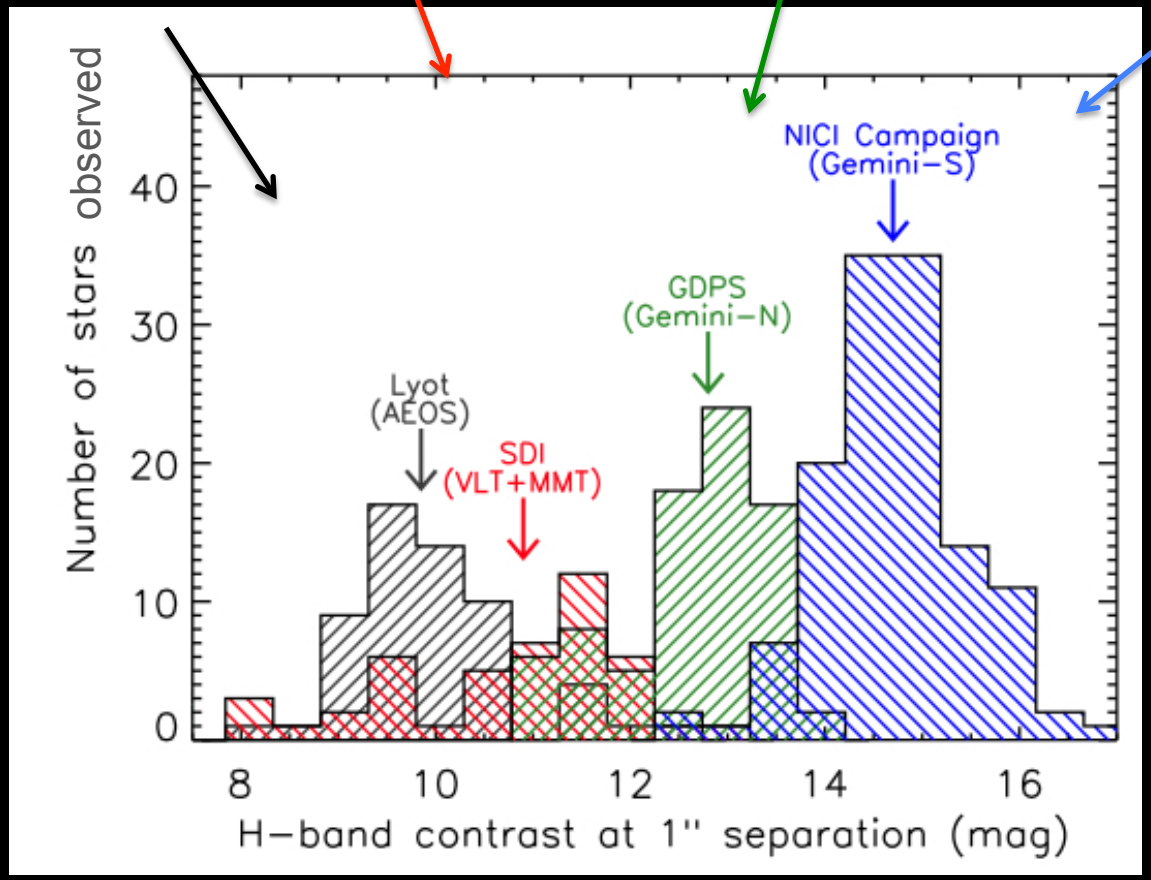
6m & 8m telescopes
Adaptive optics

• Spectral Differential Imaging

8m telescope
Adaptive optics

• Angular Differential Imaging

8m telescope
Adaptive optics
Lyot coronagraph
• Spectral Differential Imaging
• Angular Differential Imaging



The most sensitive survey (NICI) :
contrasts down to ~$10^{-6.5}$

Liu et al, SPIE 2010

2. What are the contrasts achievable from ground?

The ultimate limit

Contrast at 0.5" separation	Acceptable wavefront error Single exposure	Acceptable wavefront error 2500 exposures	Required AO correction frequency [Hz]	Required magnitude (H band)
10^{-6}	λ /4400	λ /88	930	6.9
10^{-7}	λ /14000	λ /280	2900	3.2
10^{-8}	λ /44000	λ /880	10^4	-0.6
10^{-9}	λ /140000	λ /2800	$3 \cdot 10^4$	-4.3
10^{-10}	λ /440000	λ /8800	10^5	-8.1

Stapelfeldt, IAU symposium, 2006

The ultimate contrast limit for a solar type star at 10pc (H=3) is 10^{-7}
With added speckle subtraction techniques : 10^{-8}

Techniques for direct imaging of exoplanets

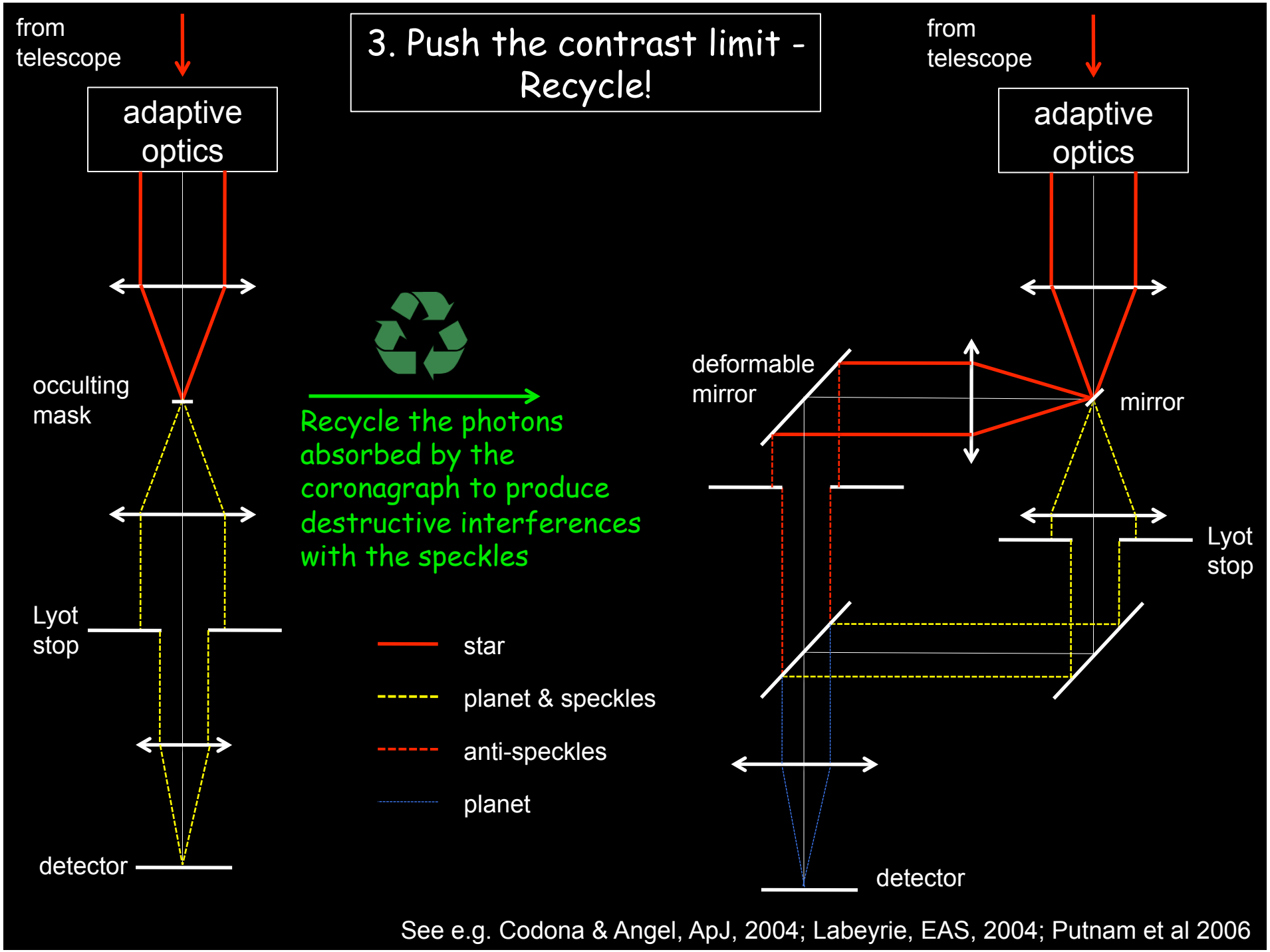
1. Where lies the challenge?

   (correction of residual speckles)

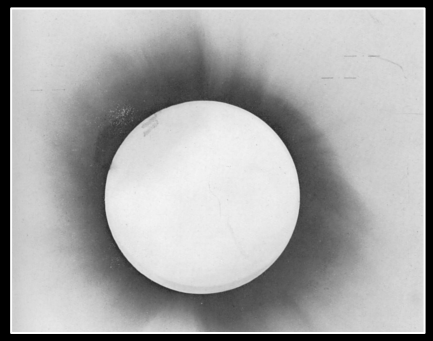
2. Contrasts required for ground observations?

   For a solar twin at 10pc, required contrast > 10^{-8}

3. Push the contrast limit – Recycle!

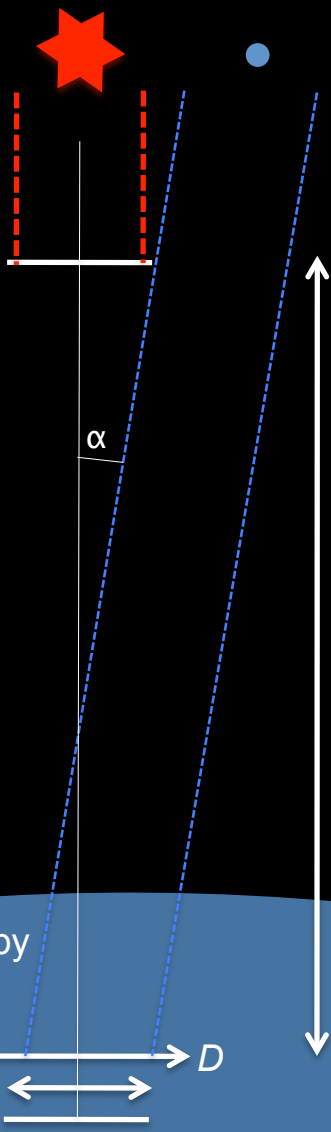

3. Push the contrast limit - Recycle!
from telescope
adaptive optics
occulting mask
Lyot stop
detector
Recycle the photons absorbed by the coronagraph to produce destructive interferences with the speckles
star
planet & speckles
anti-speckles
planet
from telescope
adaptive optics
deformable mirror
mirror
Lyot stop
detector
See e.g. Codona & Angel, ApJ, 2004; Labeyrie, EAS, 2004; Putnam et al 2006

3. Push the contrast limit



We reached contrasts above 10^{-12} back in 1919…

Stellar wavefront is blocked …



8m telescope
α = 1 arcsec
H > 2000 km

… before it is distorted by atmospheric turbulence

… and imperfect telescope optics.

See e.g. Cash et al., SPIE, 2007

External occulters: stellar light never enters the telescope.

Conclusions

1. Where lies the challenge?

   Large telescopes are only required for the coolest exoplanets

   The primary issue for exoplanet imaging is scatter in the atmosphere and on the imperfect telescope optics

2. Contrasts required for ground observations?

   For a solar twin at 10pc, the maximum achievable contrast from ground is 10^{-8}

3. Push the contrast limit – Recycle!

   The contrast limit can be increased to ~10^{-10} by recycling the photons absorbed by the coronagraph, and producing destructive interferences with the speckles.