Direct Imaging Of Planets

AST 205

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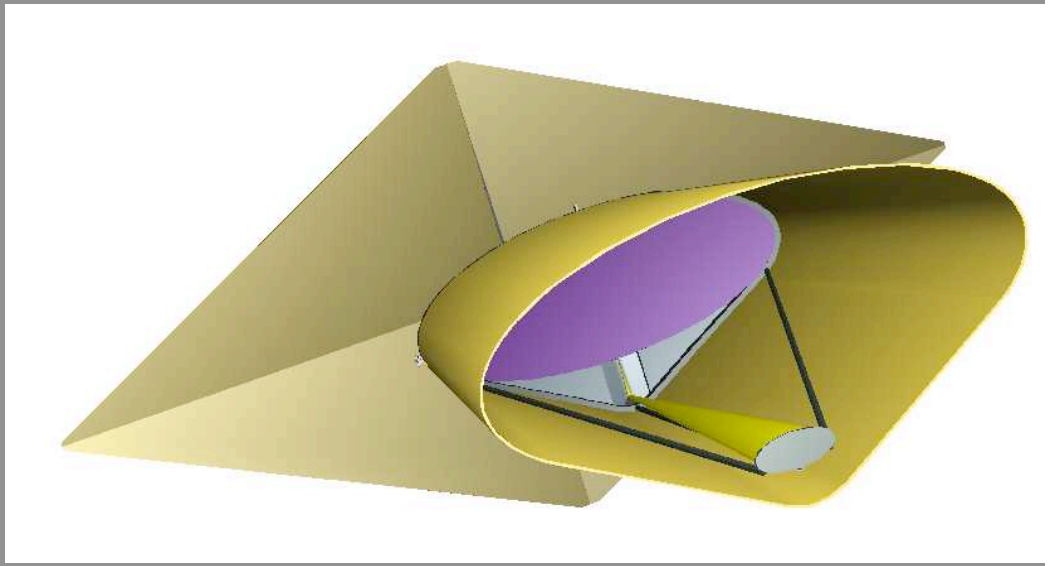
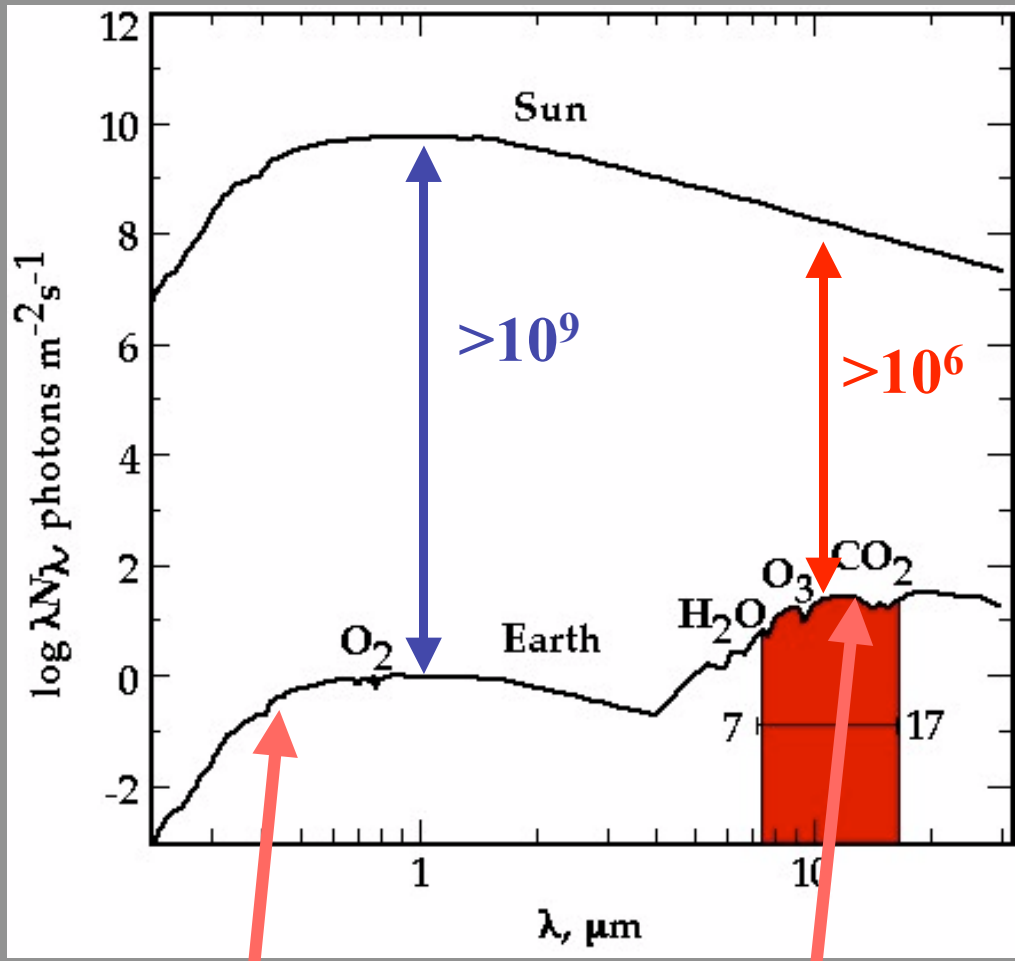
Advantages

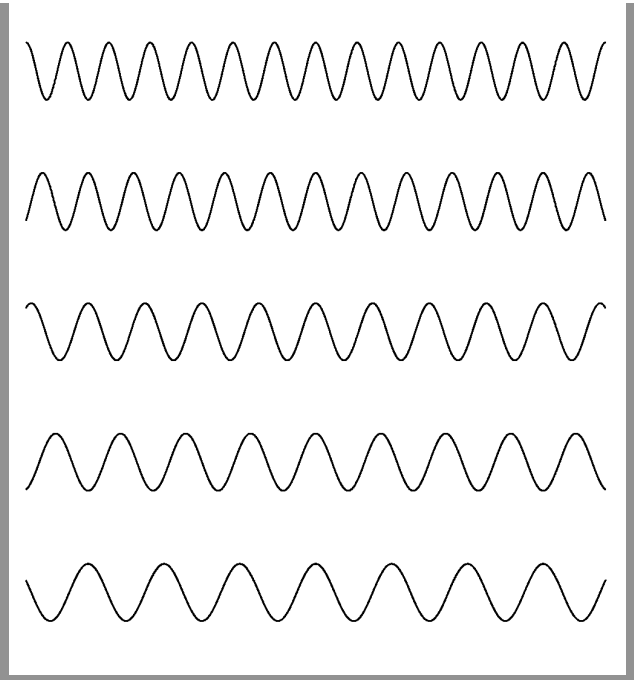
- Much faster detections
- Immediate detection of entire system
- Enormous additional science
  - Size and Albedo
  - Spectroscopy
  - Biomarkers



Why is this hard?

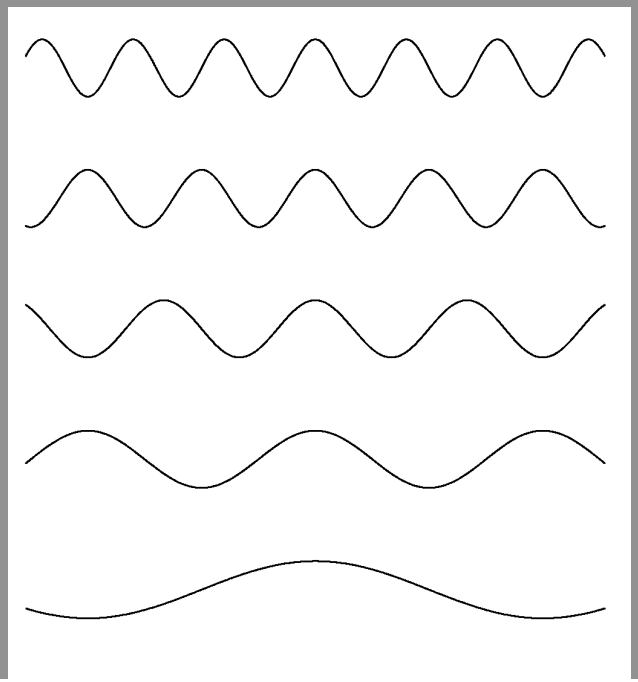
- Detecting light from planets beyond solar system is hard:
  - Planet signal is weak but detectable (few photons/sec/$m^{2)}$
  - Star emits million to billion more than planet
  - Planet within 1 AU of star
  - Dust in target solar system 300 brighter than planet
- Finding a firefly next to a searchlight on a foggy night





Fourier Transform

Any function can be represented as a sum of cosine (and sine) waves



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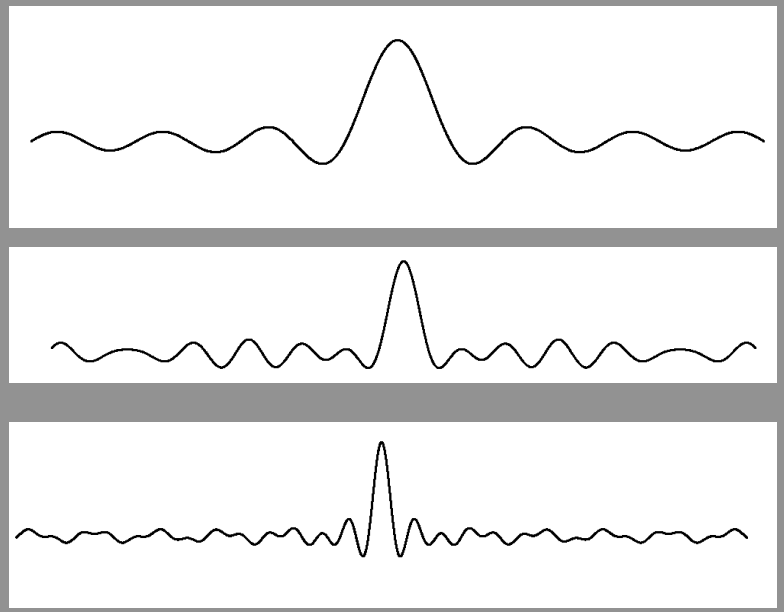
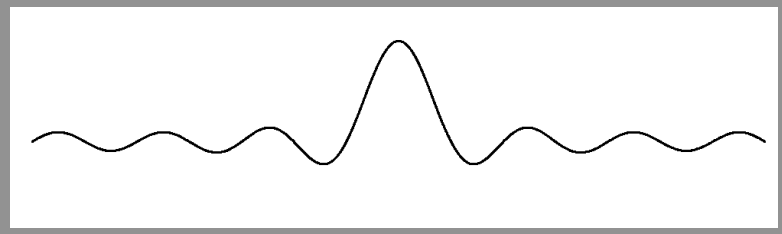


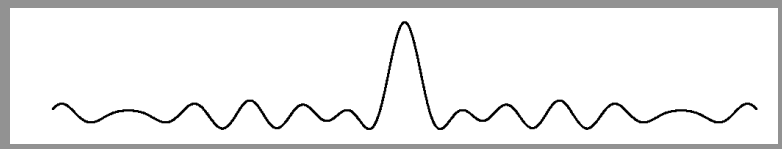
Telescope Size Sets Resolving Power

$\theta = \lambda/d$

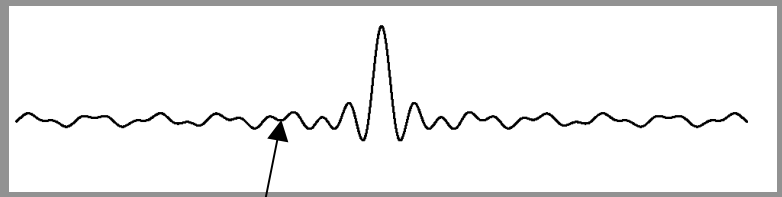
d=1



d=2

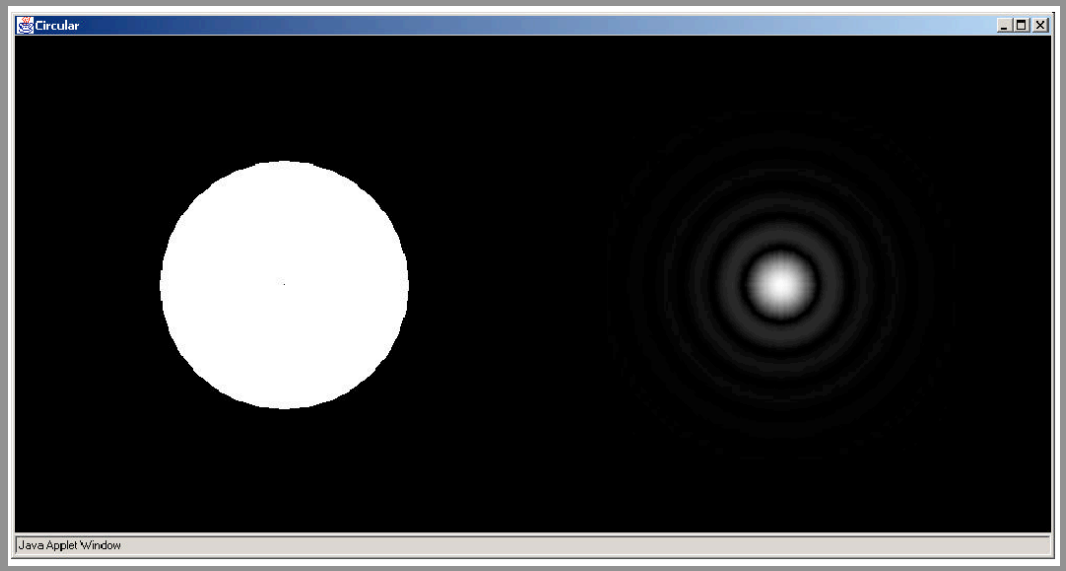


d=4

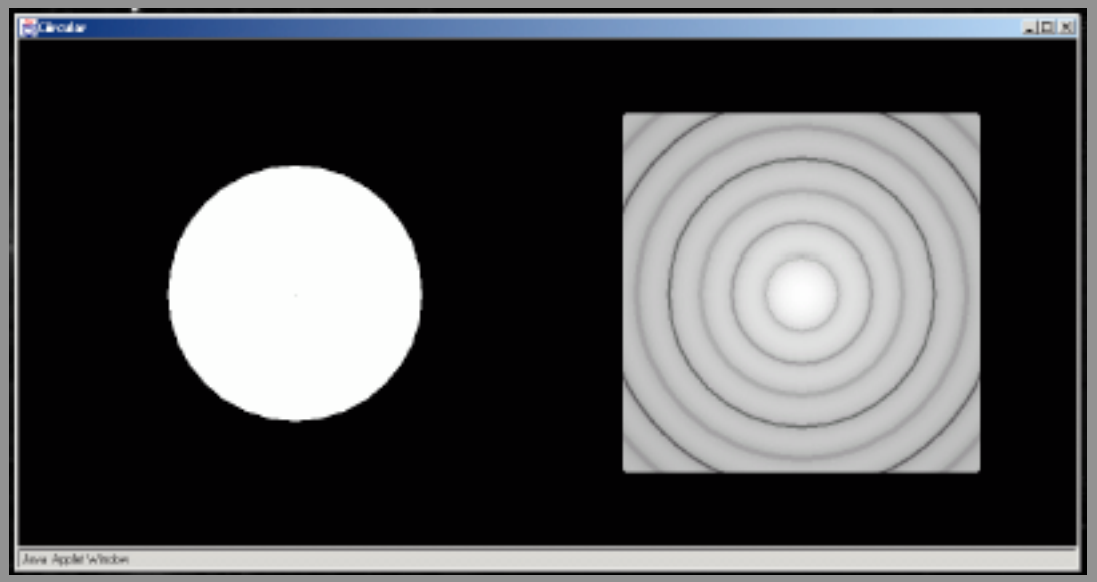


Ringing

Airy Rings

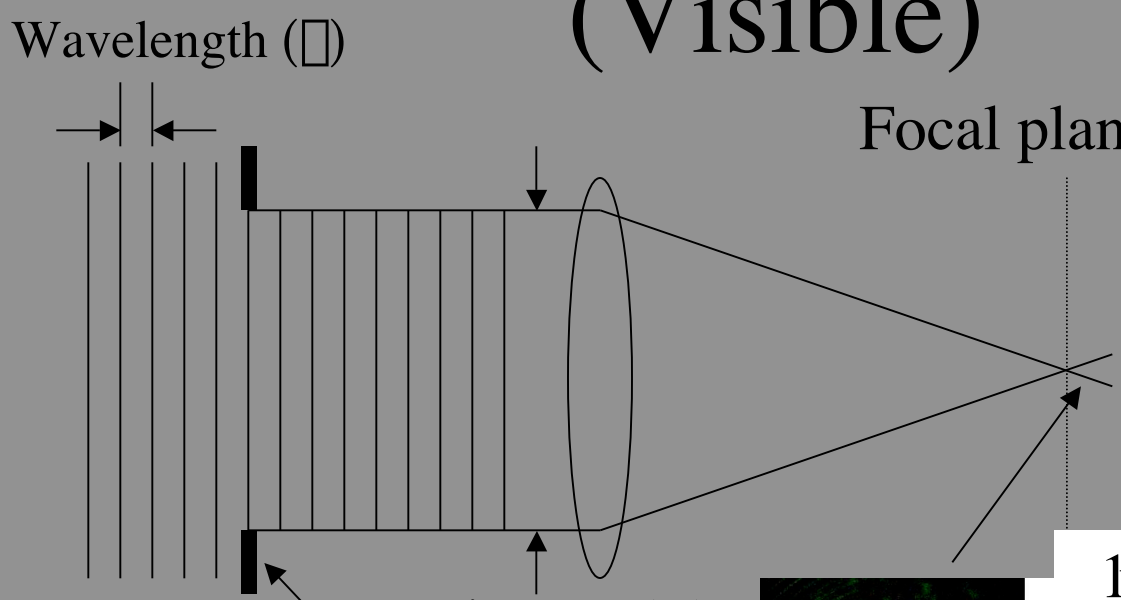


Linear Scale

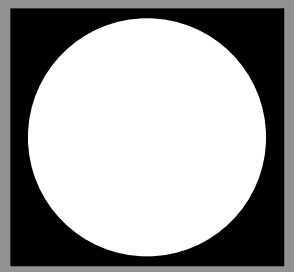


Log Scale
(1e-10 is black)

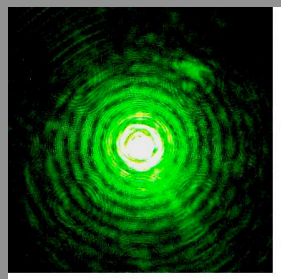
The Diffraction Problem (Visible)

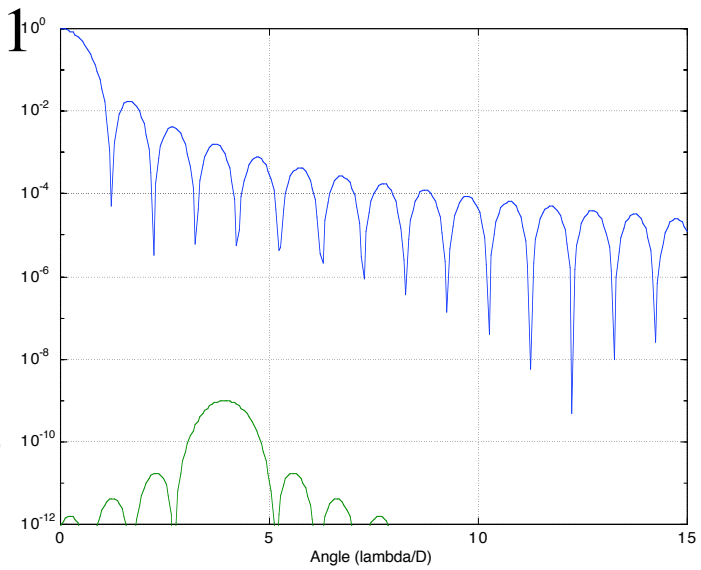


The image in the focal plane is the spatial Fourier transform of the entrance field



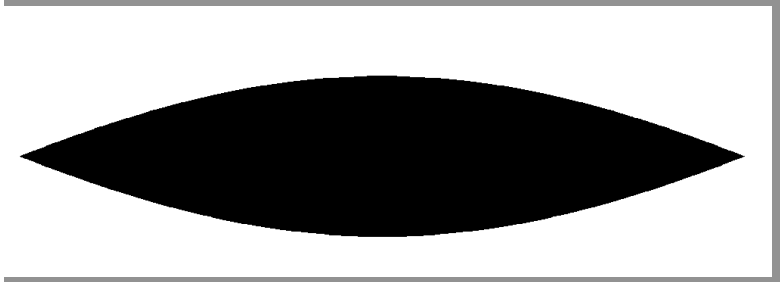
Entrance Pupil

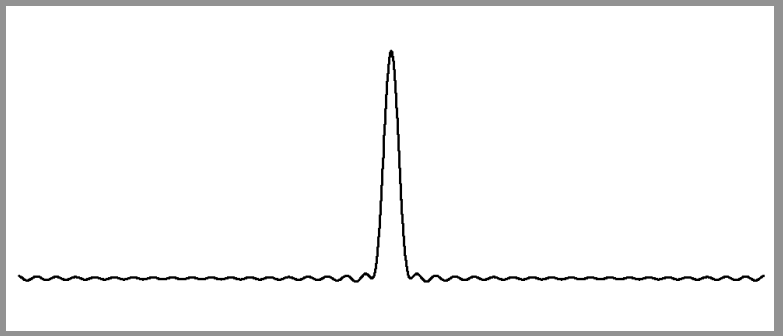




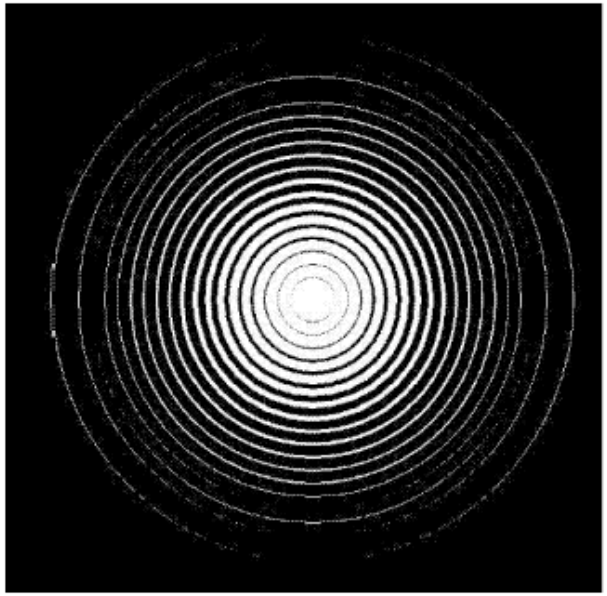
Pupil Coronagraph

What if we don't give equal weight to each Fourier mode?

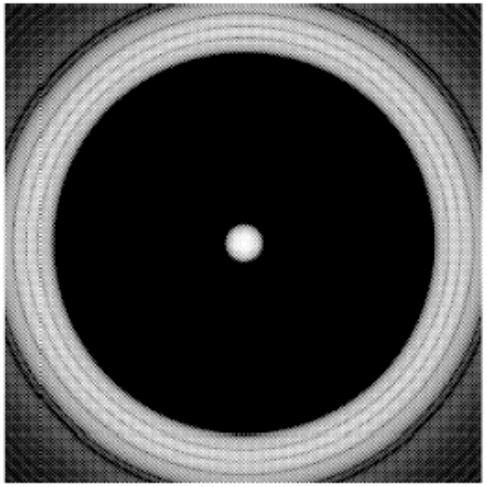


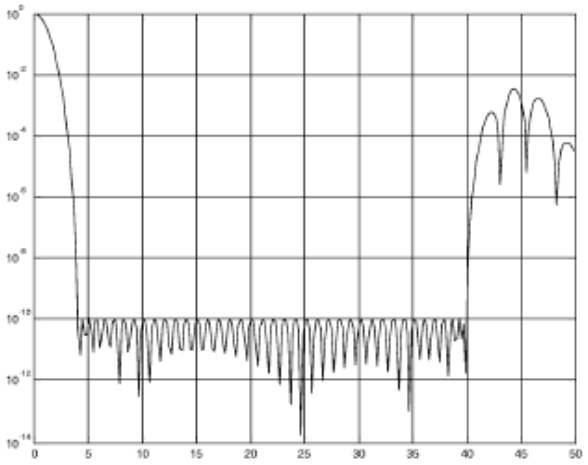


Pupil Design

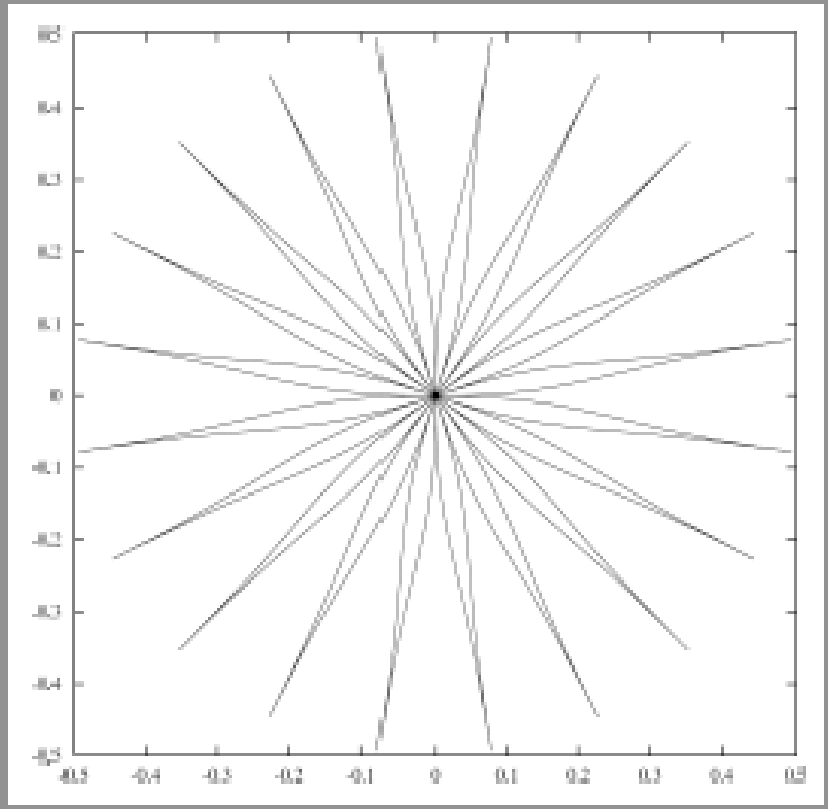


Concentric Rings

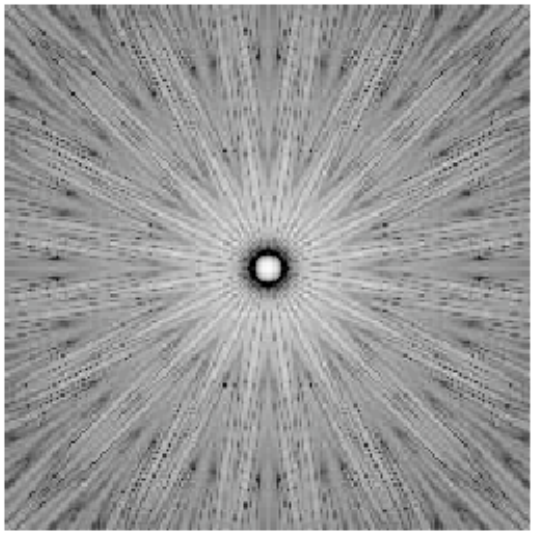


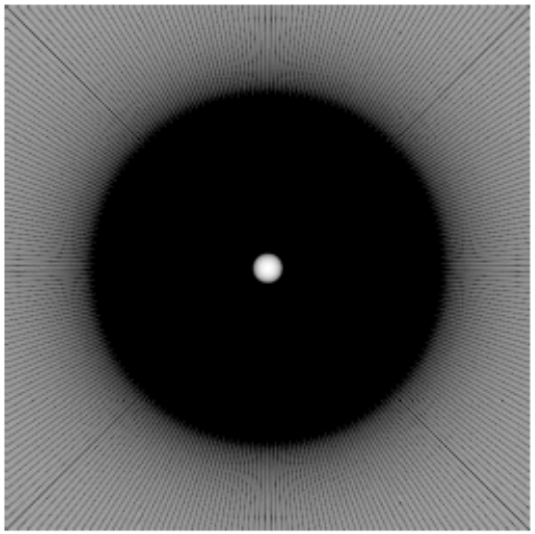


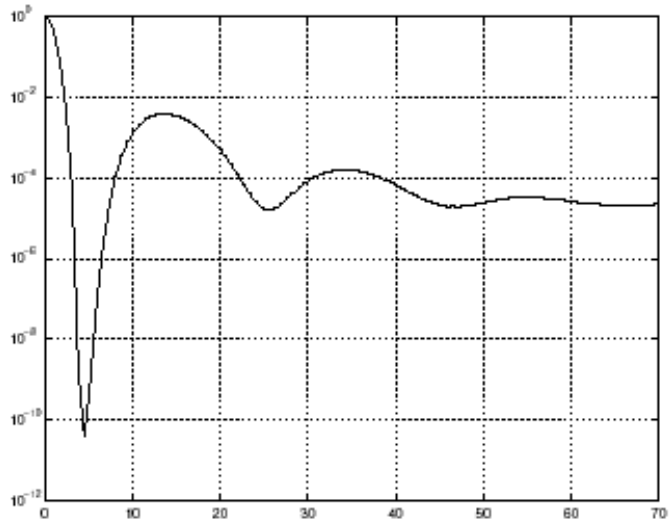
Starshaped Mask



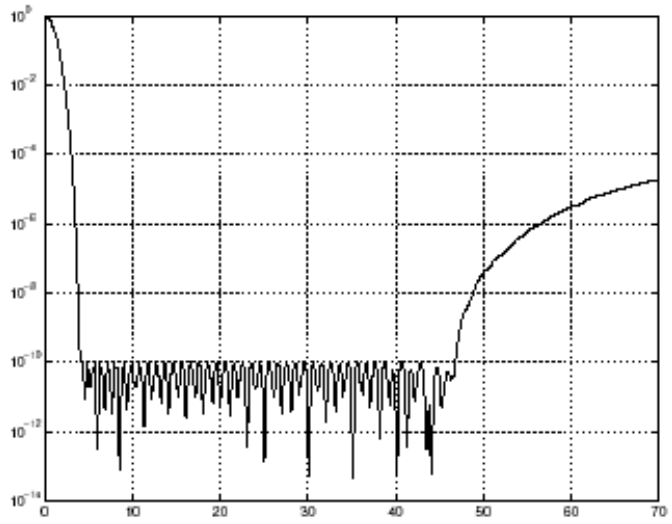
Starshaped mask





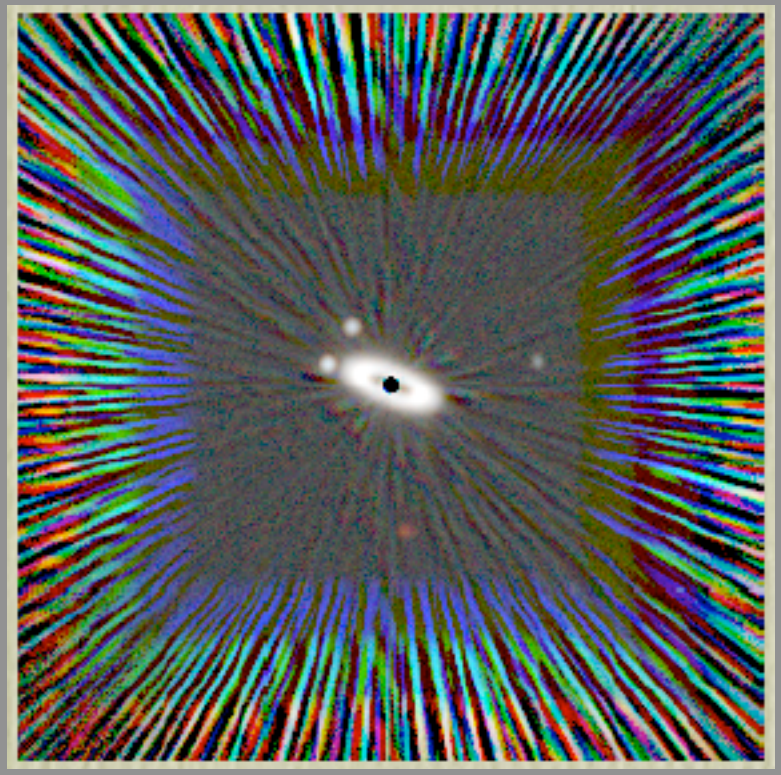


20-point star



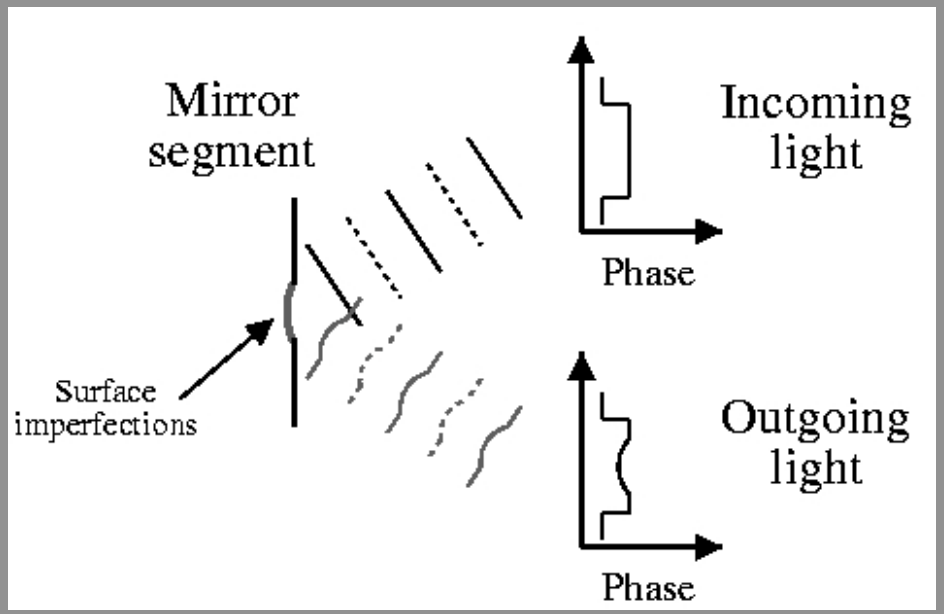
150-point star

Wavefront Sensing and Control

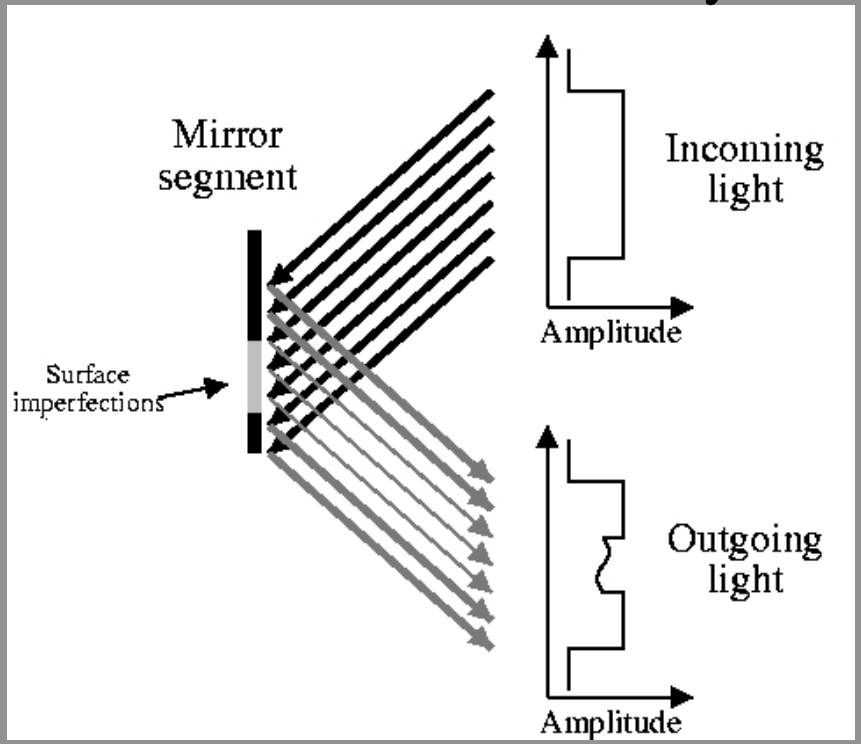


What is the biggest problem?

Surface Errors

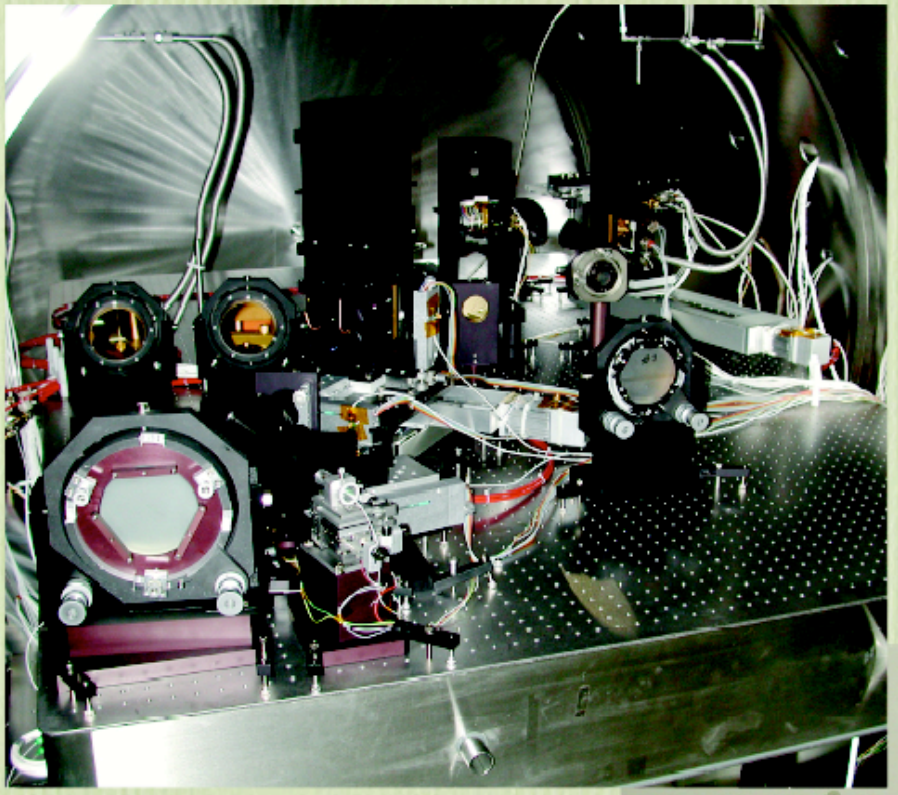


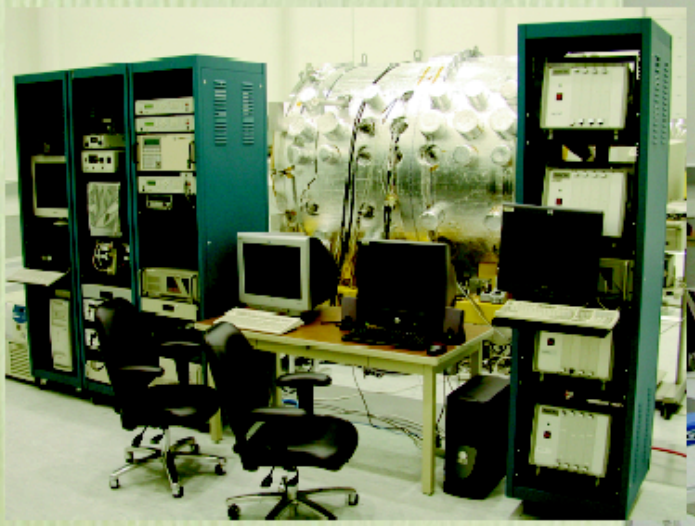
Variations in Reflectivity

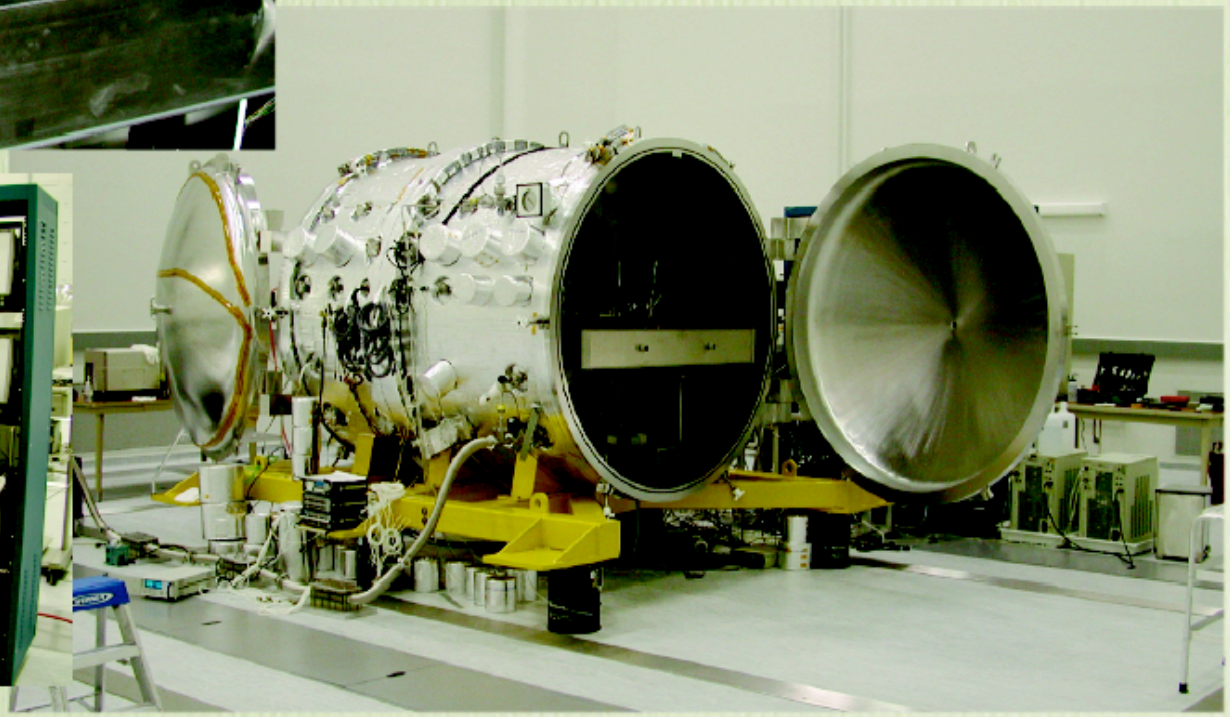


The HCIT laboratory

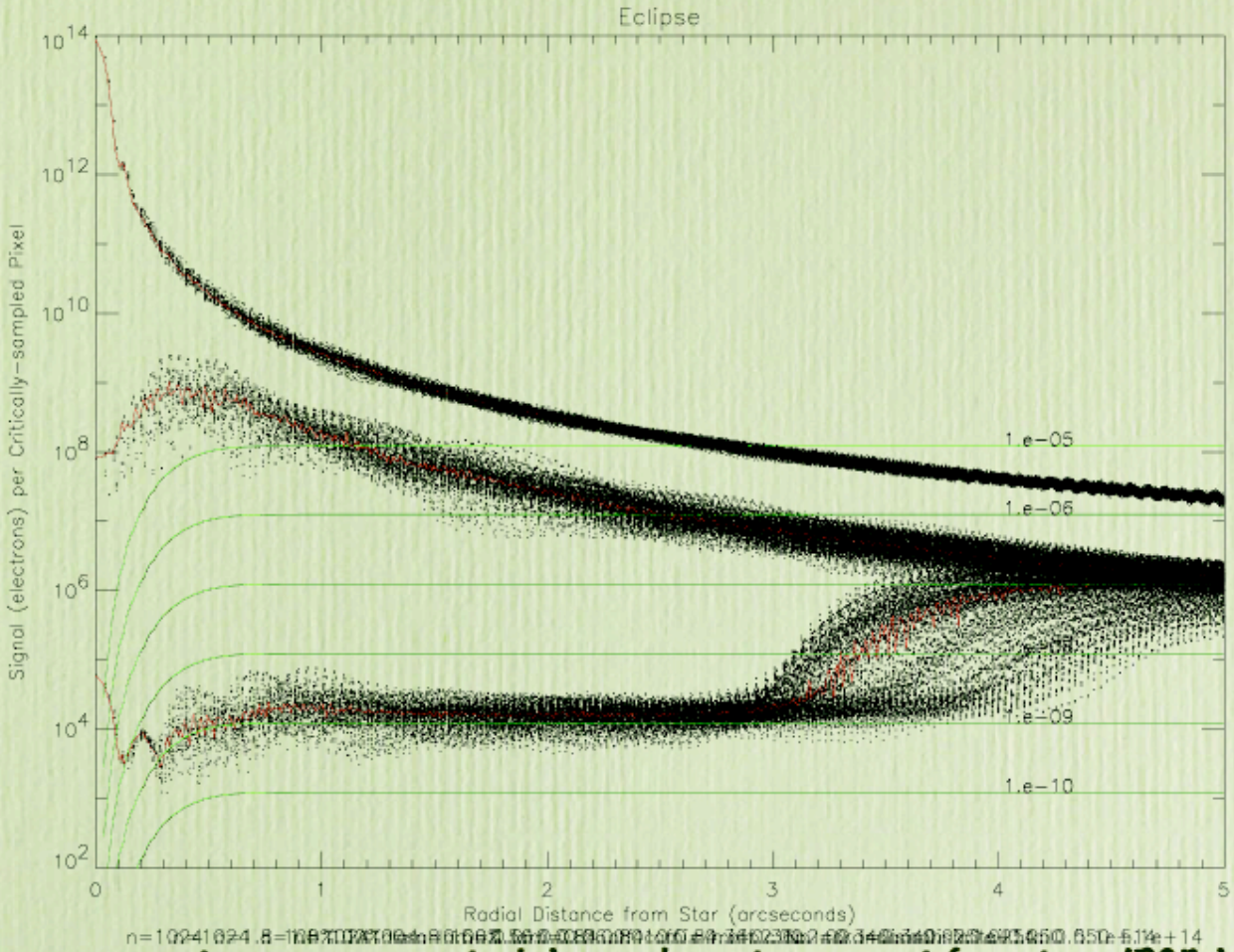
Initial testbed coronagraph configuration was assembled and tested in the ambient laboratory environment. Optical table now resides in a vibration-isolated and temperature-stabilized vacuum facility in JPL's Optical Interferometry Development Laboratory.





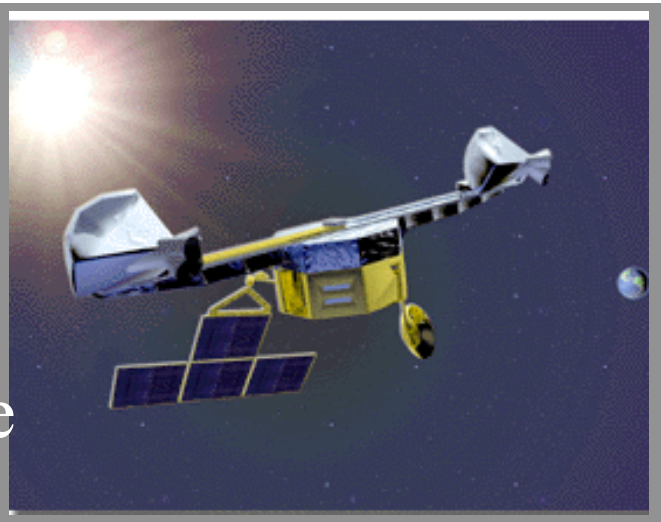


Eclipse Simulations



- Plotted (from top to bottom respectively) are the point spread functions (PSFs) of the Eclipse 1.8 meter telescope, coronagraph, and coronagraph with active wavefront correction.
- Instrument contrast is 10^{-9} with an inner working angle of 0.25 arcsec for broadband (20%) visible light.

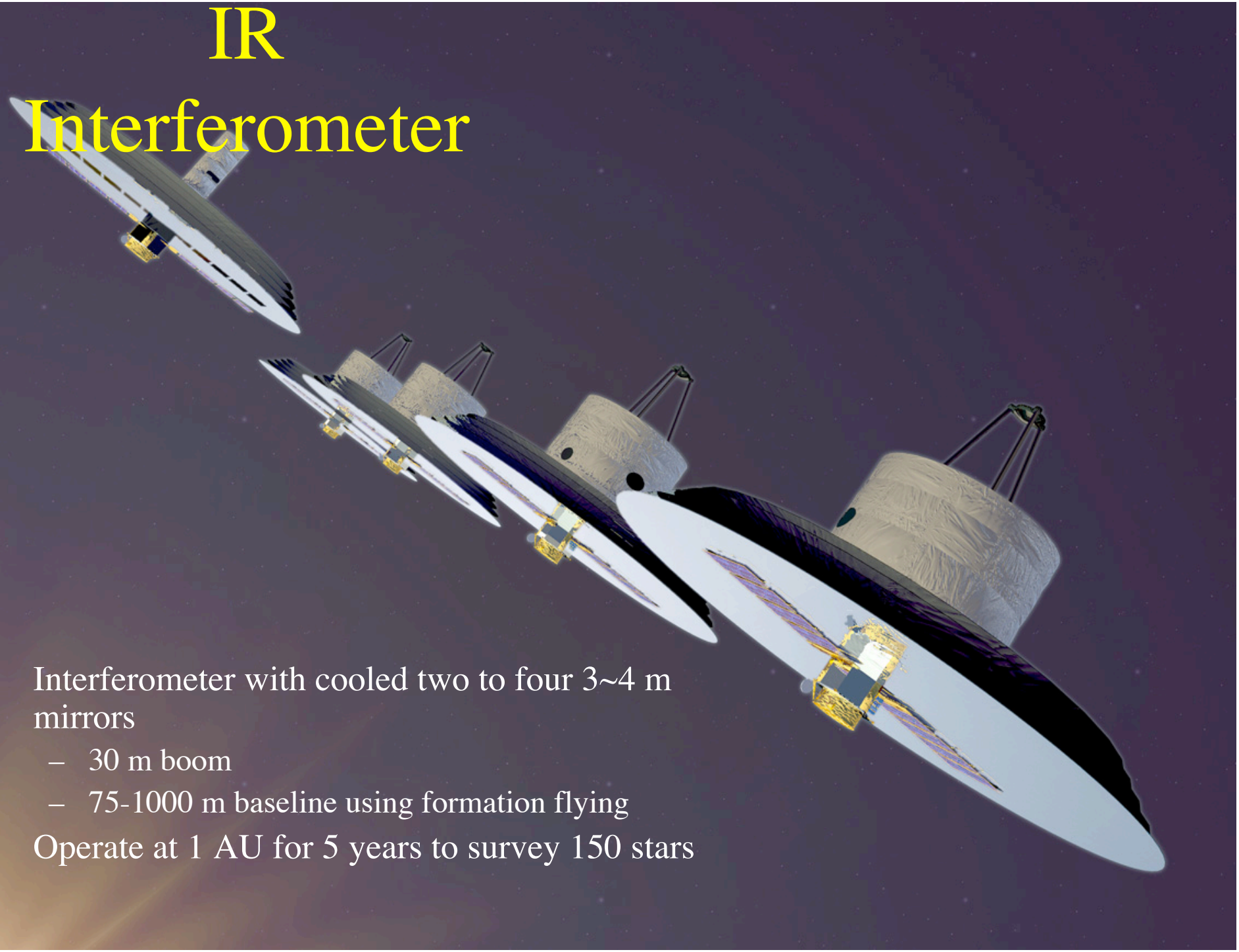
Interferometery



- Break link between diameter, baseline
  - Enables precision astrometry, high resolution imaging, starlight nulling

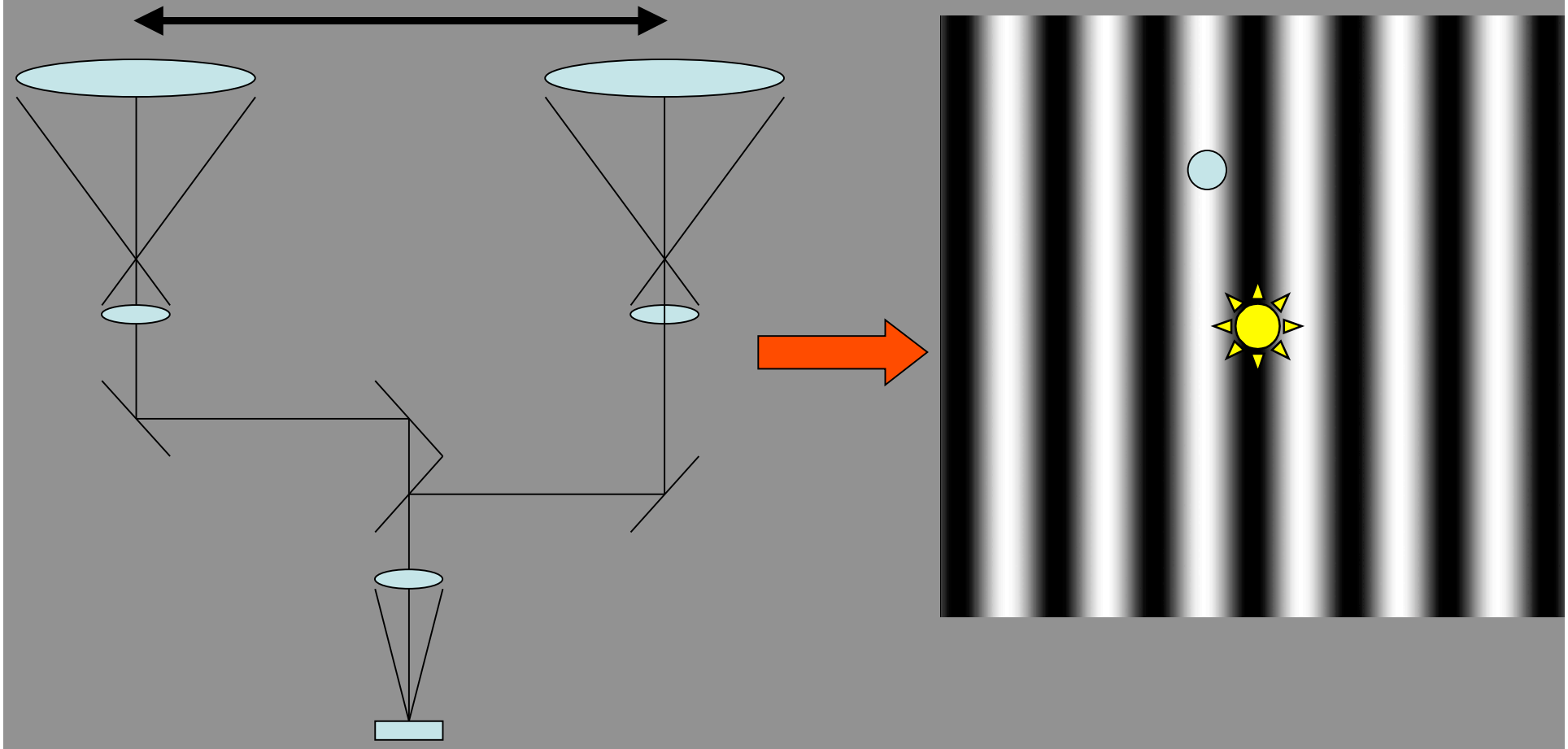
- Make astrometric census of planets
- Detect “Hot Jupiter’s”
- Detect exo-zodiacal dust clouds
- Image protostellar disks

IR Interferometer

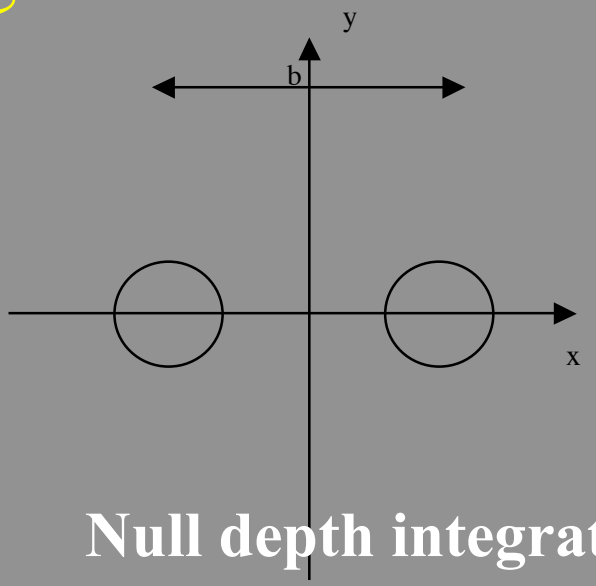


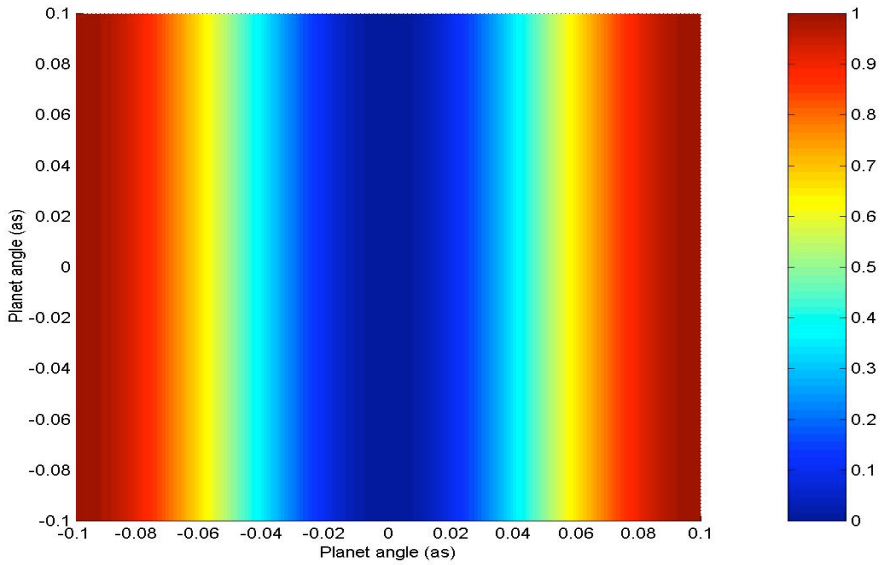
- Interferometer with cooled two to four 3~4 m mirrors
  - 30 m boom
  - 75-1000 m baseline using formation flying
- Operate at 1 AU for 5 years to survey 150 stars

Nulling Interferometry

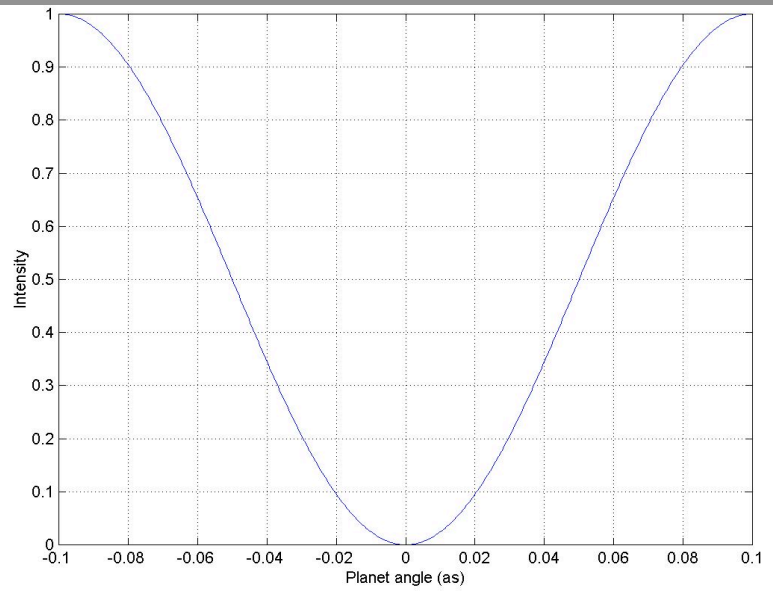


2-arm Nulling Interferometer



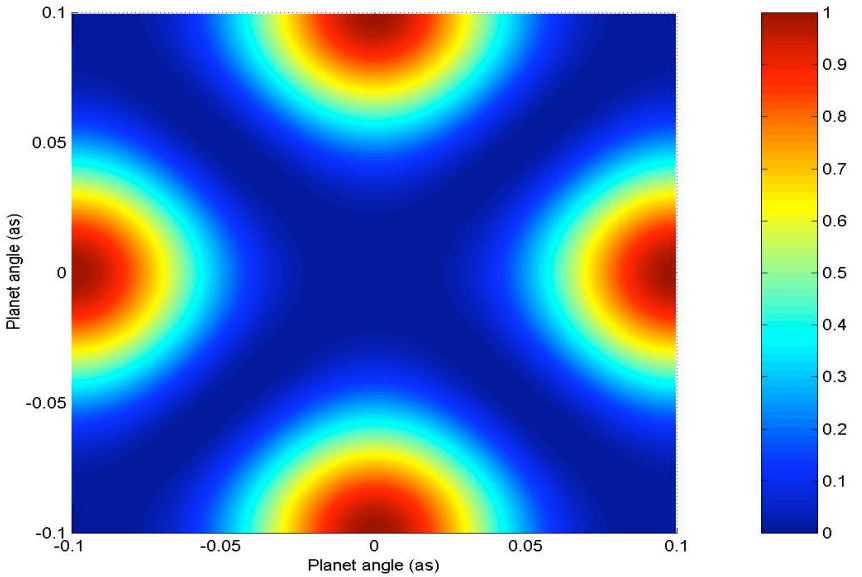


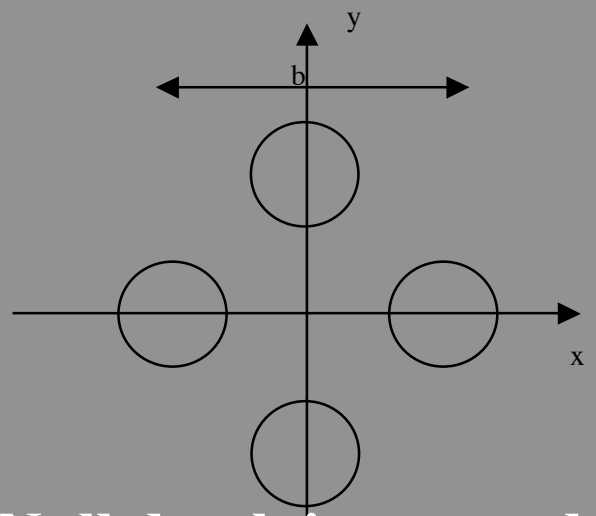
Null depth integrated over finite star diameter ~8×10^{-5}



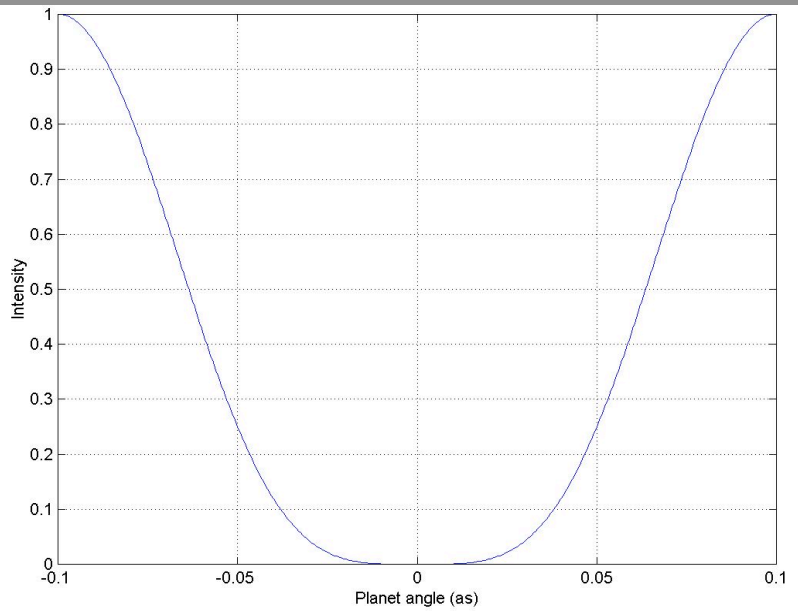
4-arm Nulling Interferometer

Intensity:

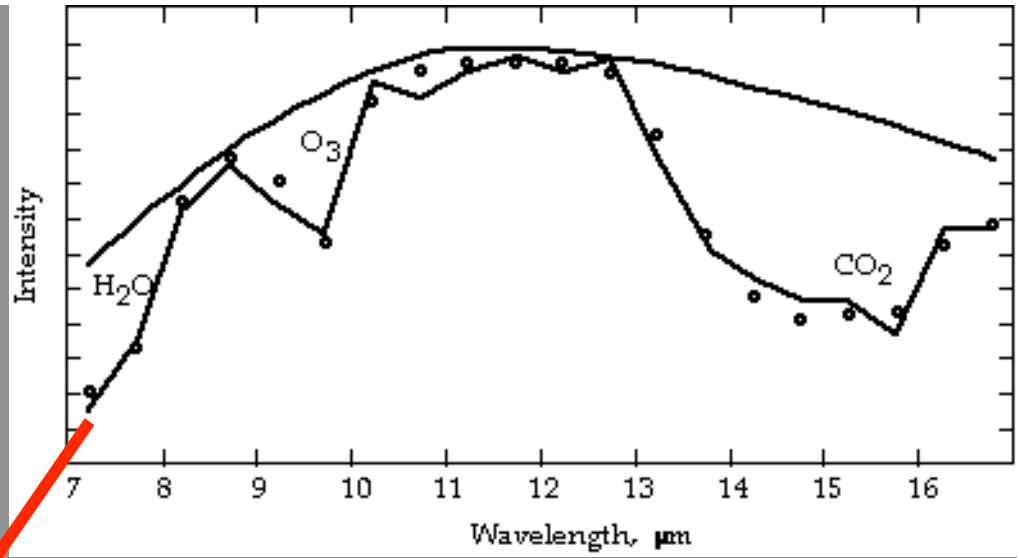


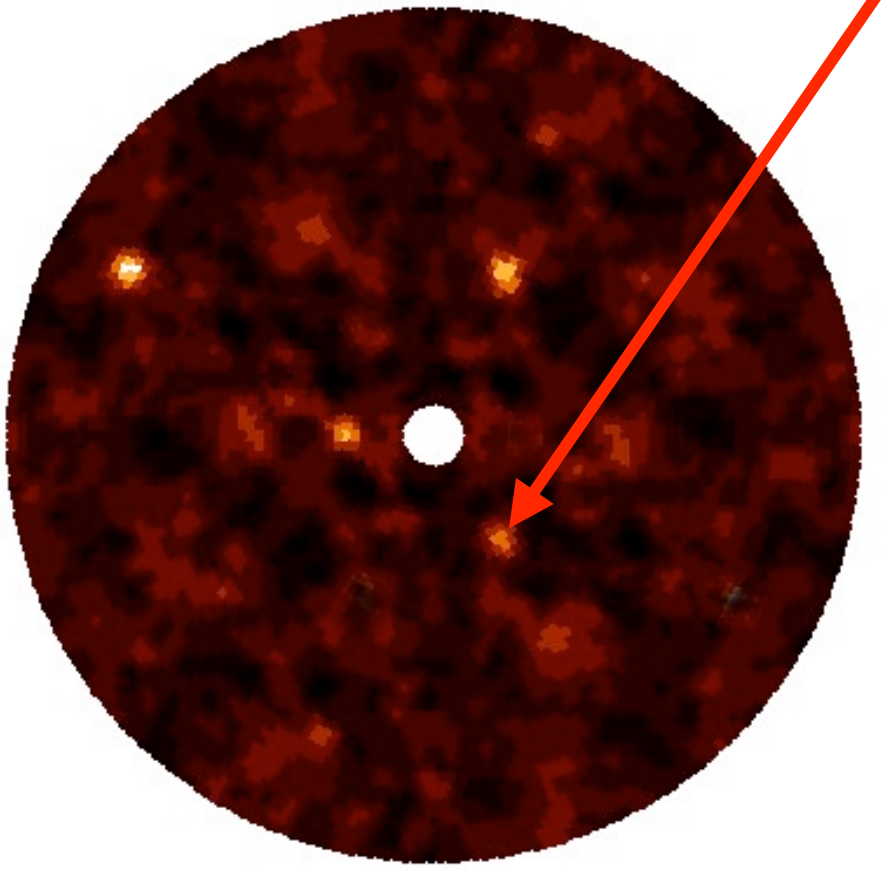


Null depth integrated over finite star diameter ~$6x10^{-10}$



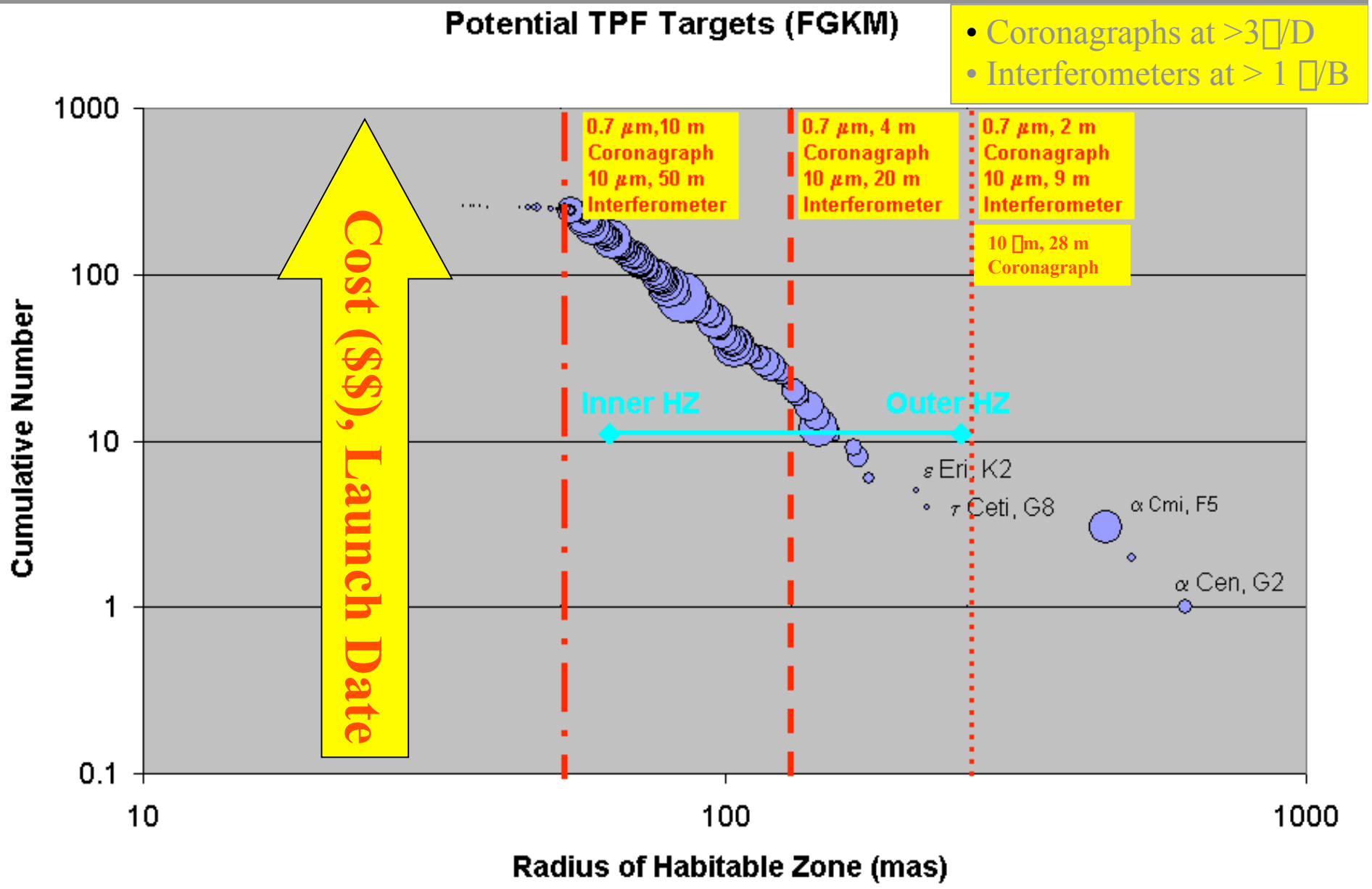
Interferometer Detects and Characterizes Planetary Systems





- TPF produces image of planetary system
  - Orbital location
  - Temperature and radius
- TPF produces spectrum to search for biomarkers
- 1-2 m telescopes to find Jupiters, nearest Earths
- 3-4 m telescopes for full TPF goals

The Angular Resolution Challenge



Conclusions

- Interferometry and Coronagraphy are two promising but difficult techniques
- They have the potential of yielding direct detections of Earth-like planets
- Planets can not only be detected but also characterized