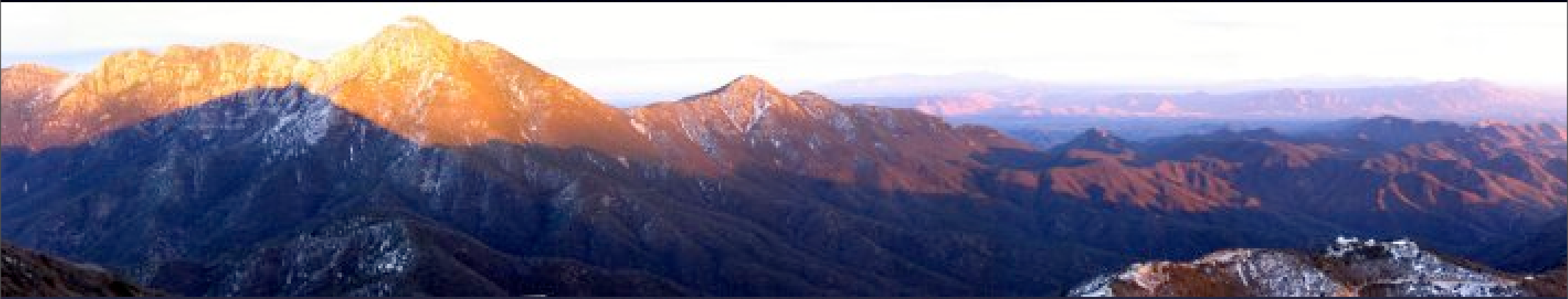


# Hunting for Extrasolar Planets using the MMT



**Matthew Kenworthy**

Steward Observatory, University of Arizona

Huachuca Astronomy Club, 21 November 2008

Are there other worlds  
in the Universe?



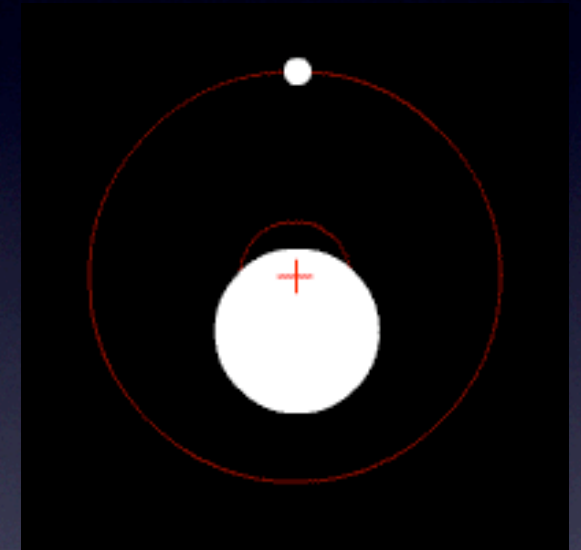
# The first ones found...



...in 1992, but around a PULSAR!

# Indirectly Detecting Planets

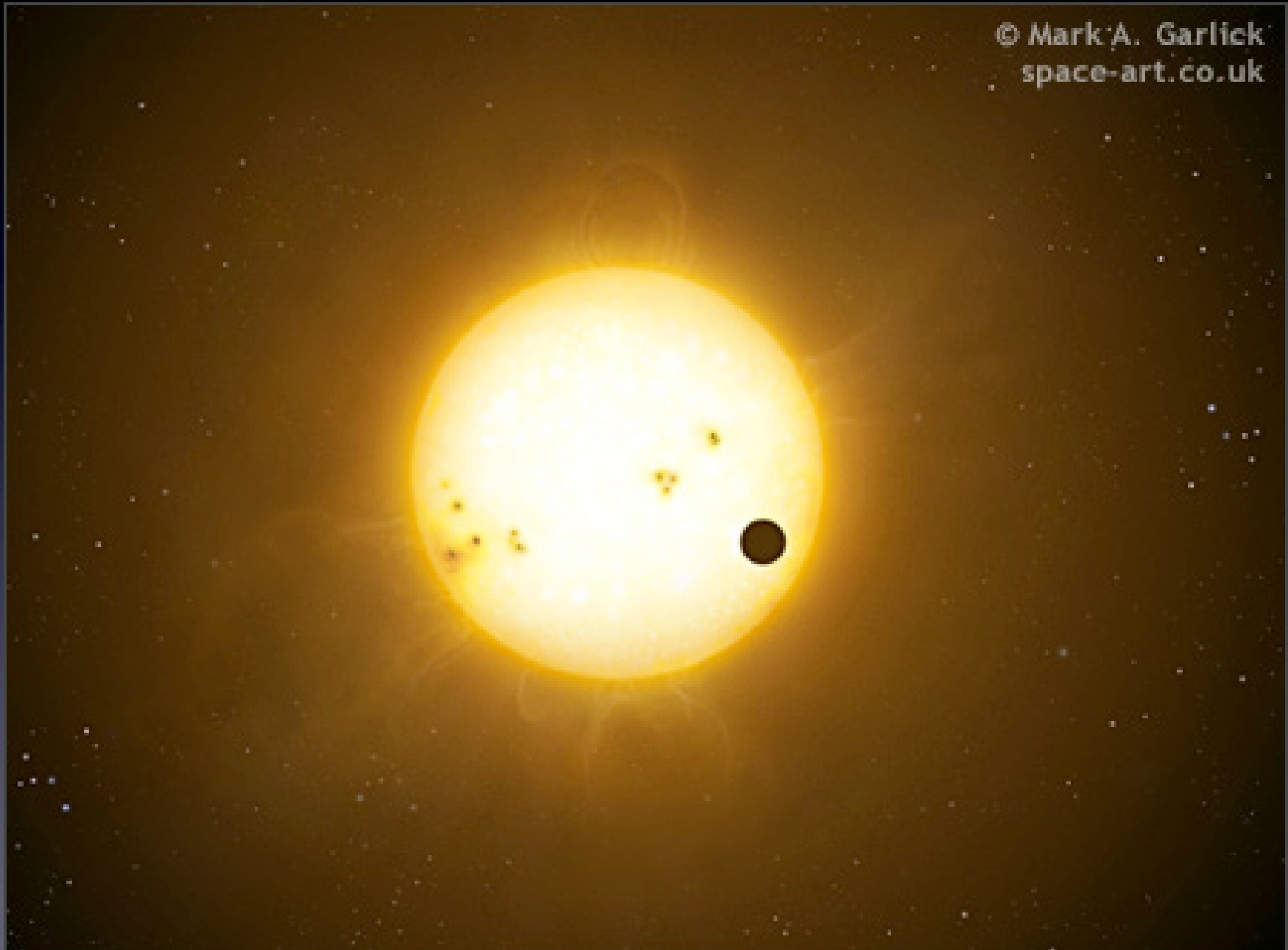
- ~300 planetary systems indirectly detected by radial velocity reflex motion
- CANNOT see the planet - only its influence on the parent star





# Transits

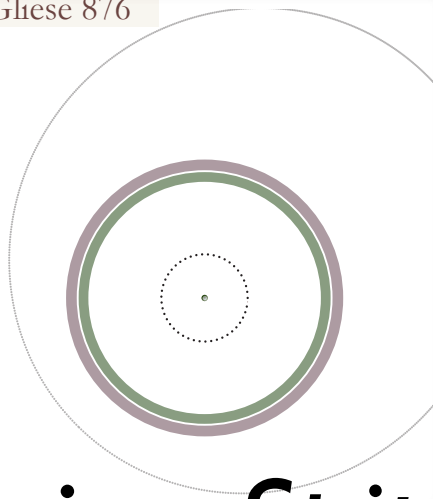
© Mark A. Garlick  
space-art.co.uk



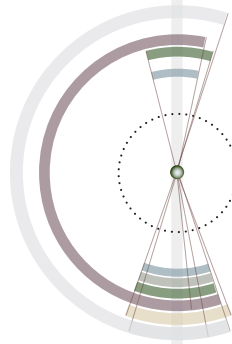
# Transits

- Primary transits give star/planet ratio
- Follow-up radial velocity confirms them
- Don't need big telescope for this!
- In space, CoRoT and Kepler

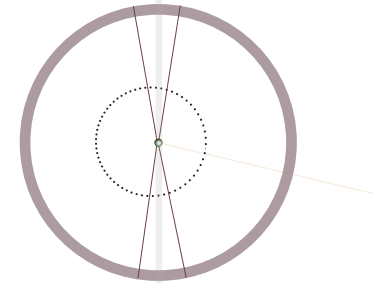
Gliese 876



HD 189733

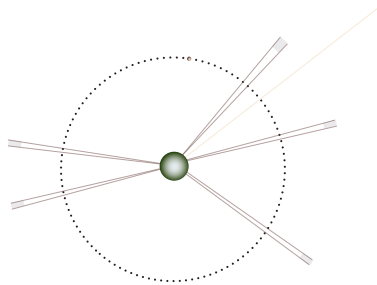


Gliese 436

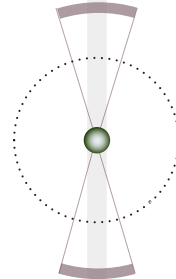


# Using *Spitzer* for Transit followup

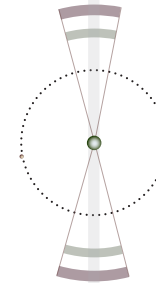
Ups And



HD 149026

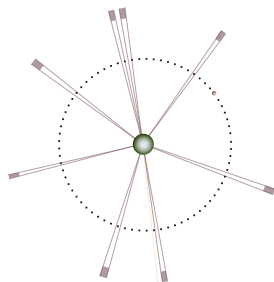


Tres-1

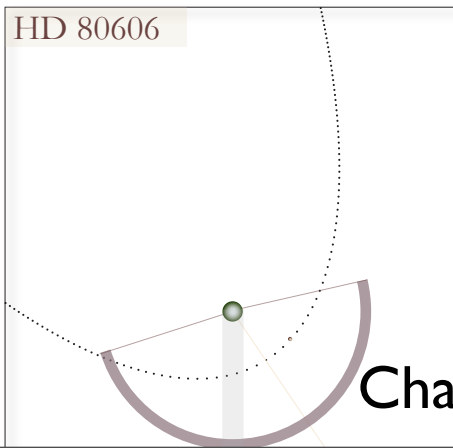


Lots of interesting systems!

HD 179949



HD 80606



HAT-P-2

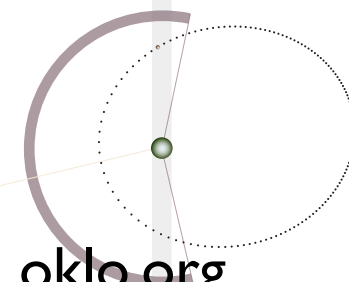


Chart from [oklo.org](http://oklo.org)



# Detecting Planets

- Radial Velocity technique leads the way!
- Transits are catching up though.....
- Others are microlensing, astrometry



# Why not Direct Imaging?

# Why not Direct Imaging?

- 20 years ago, astronomers assumed other planetary systems would be like ours



# Why not Direct Imaging?

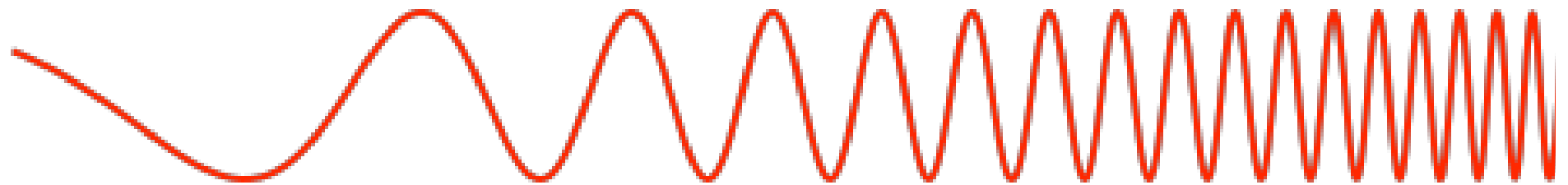
- 20 years ago, astronomers assumed other planetary systems would be like ours
- We assumed that direct imaging would see a planet first

# Why not Direct Imaging?

- 20 years ago, astronomers assumed other planetary systems would be like ours
- We assumed that direct imaging would see a planet first
- Because these extrasolar planet systems look **VERY DIFFERENT** compared to ours, Radial Velocity and Transits are detecting them first!

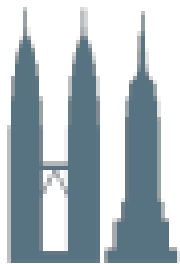


# How we see things



**Radio**

$10^3$



Buildings

**Microwave**

$10^{-2}$



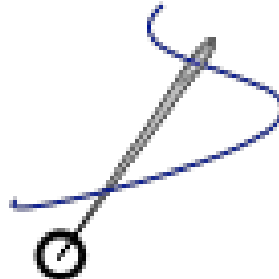
Humans

**Infrared**

$10^{-5}$



Butterflies



Needle Point

**Visible**

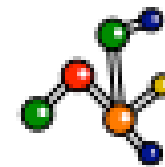
$0.5 \times 10^{-6}$



Protozoans

**Ultraviolet**

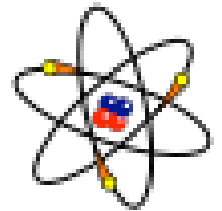
$10^{-8}$



Molecules

**X-ray**

$10^{-10}$



Atoms



A diagram illustrating light as a series of waves. It features a central yellow circular area representing a star, with several concentric black circles radiating outwards. The circles are filled with a yellow-to-white gradient, becoming lighter as they move away from the center. A black rectangular box is positioned around the star, with a white label 'Distant Star' above it. Another black rectangular box is positioned further out, intersecting several of the concentric circles. The overall image is set against a white background.

Distant Star

**Light as a series of waves**



A diagram illustrating light as a series of waves. On the left, a yellow star is shown with concentric circles representing light waves emanating from it. The waves are represented by black lines that curve away from the star. A black box highlights the star, with a line pointing to the text 'Distant Star'. Another black box highlights a specific distance between two troughs of the waves, with a line pointing to the text 'Distance between one trough and the next is the wavelength'.

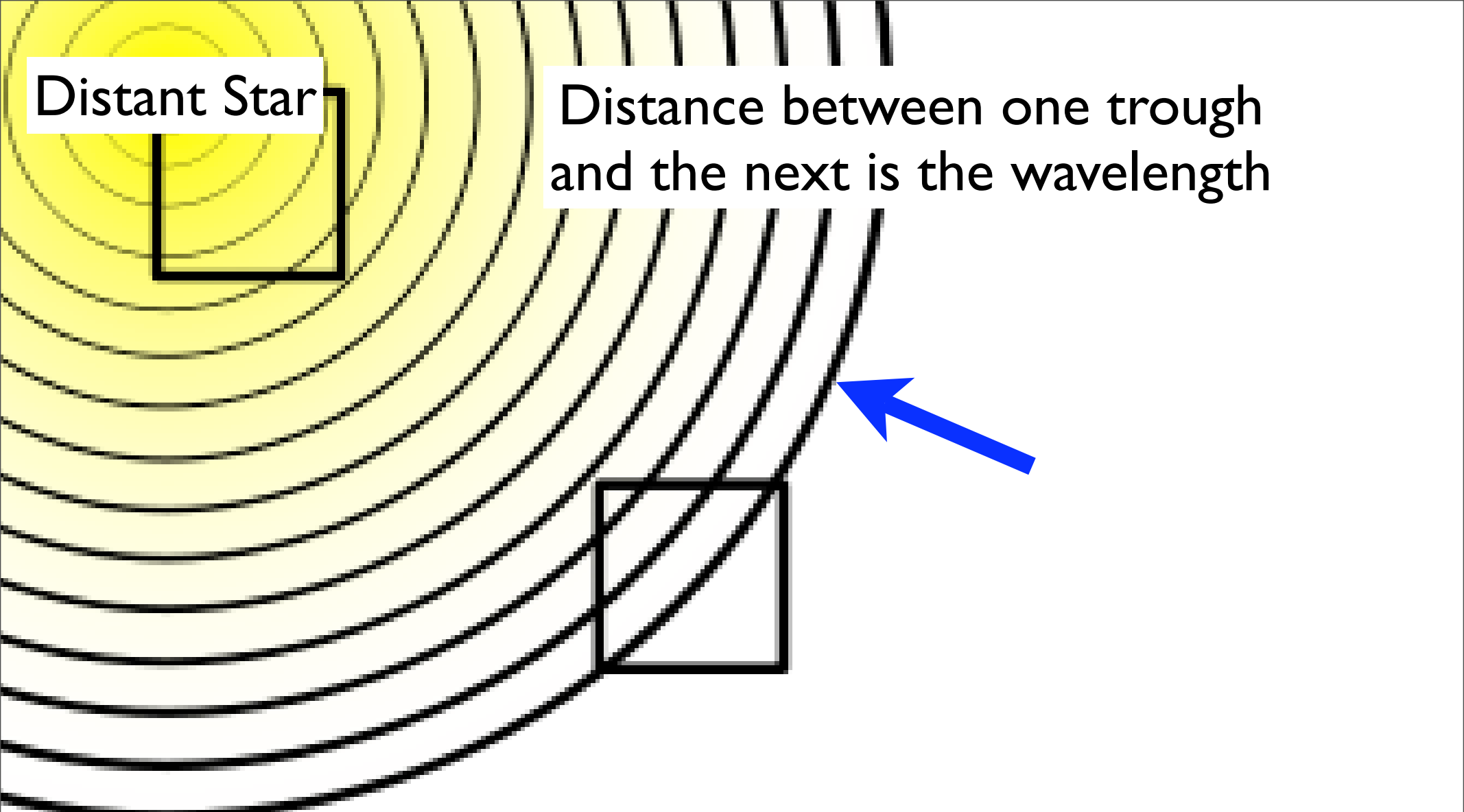
Distant Star

Distance between one trough and the next is the wavelength

# Light as a series of waves

Distant Star

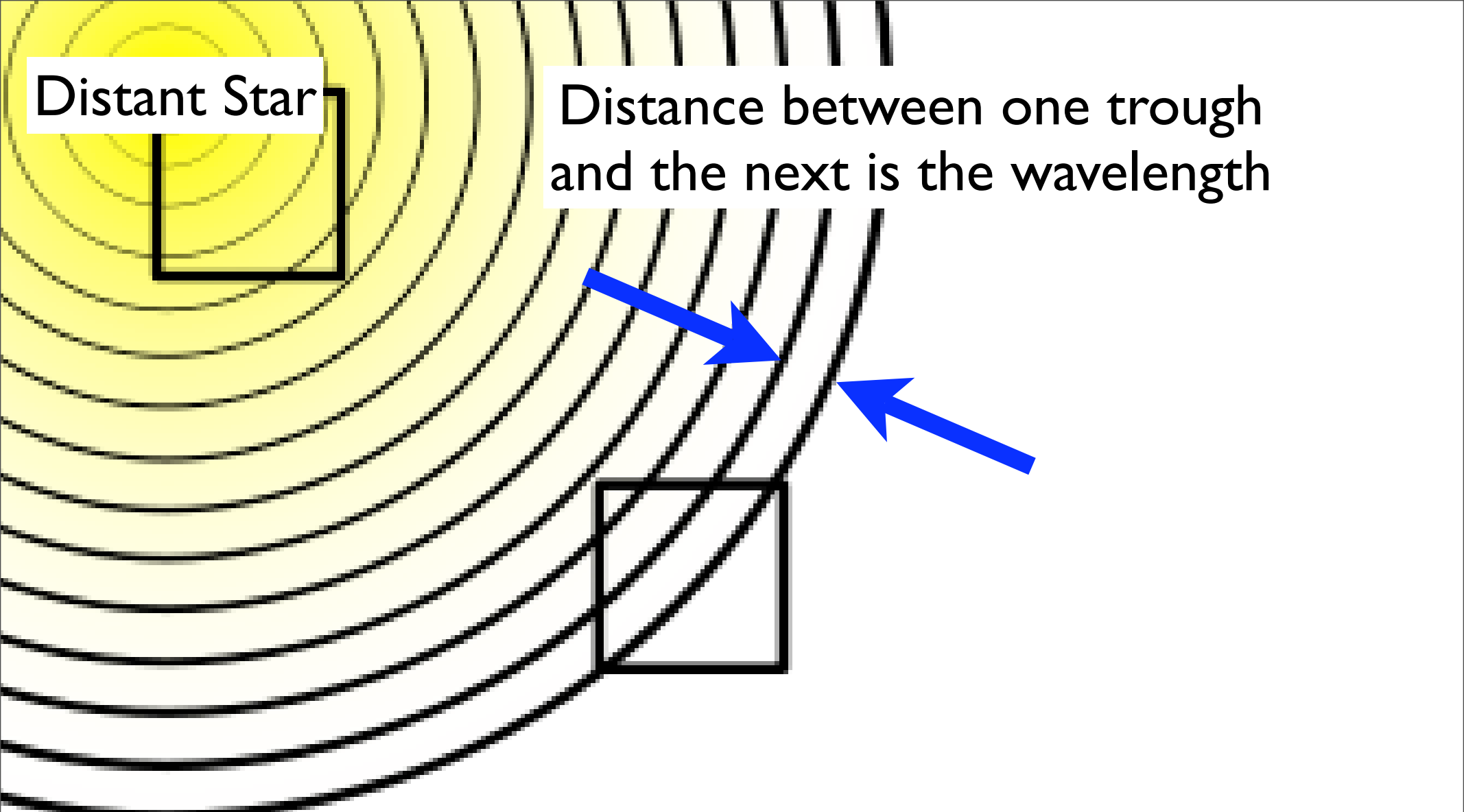
Distance between one trough and the next is the wavelength



Light as a series of waves

Distant Star

Distance between one trough and the next is the wavelength



Light as a series of waves





Distant Star

Distance between one trough and the next is the wavelength

Blue light is 0.4 millionths of a meter  
Red light is 0.8 millionths of a meter

# Light as a series of waves



Distant Star

Distance between one trough  
and the next is the wavelength

Blue light is 0.4  
Red light is 0.8

microns

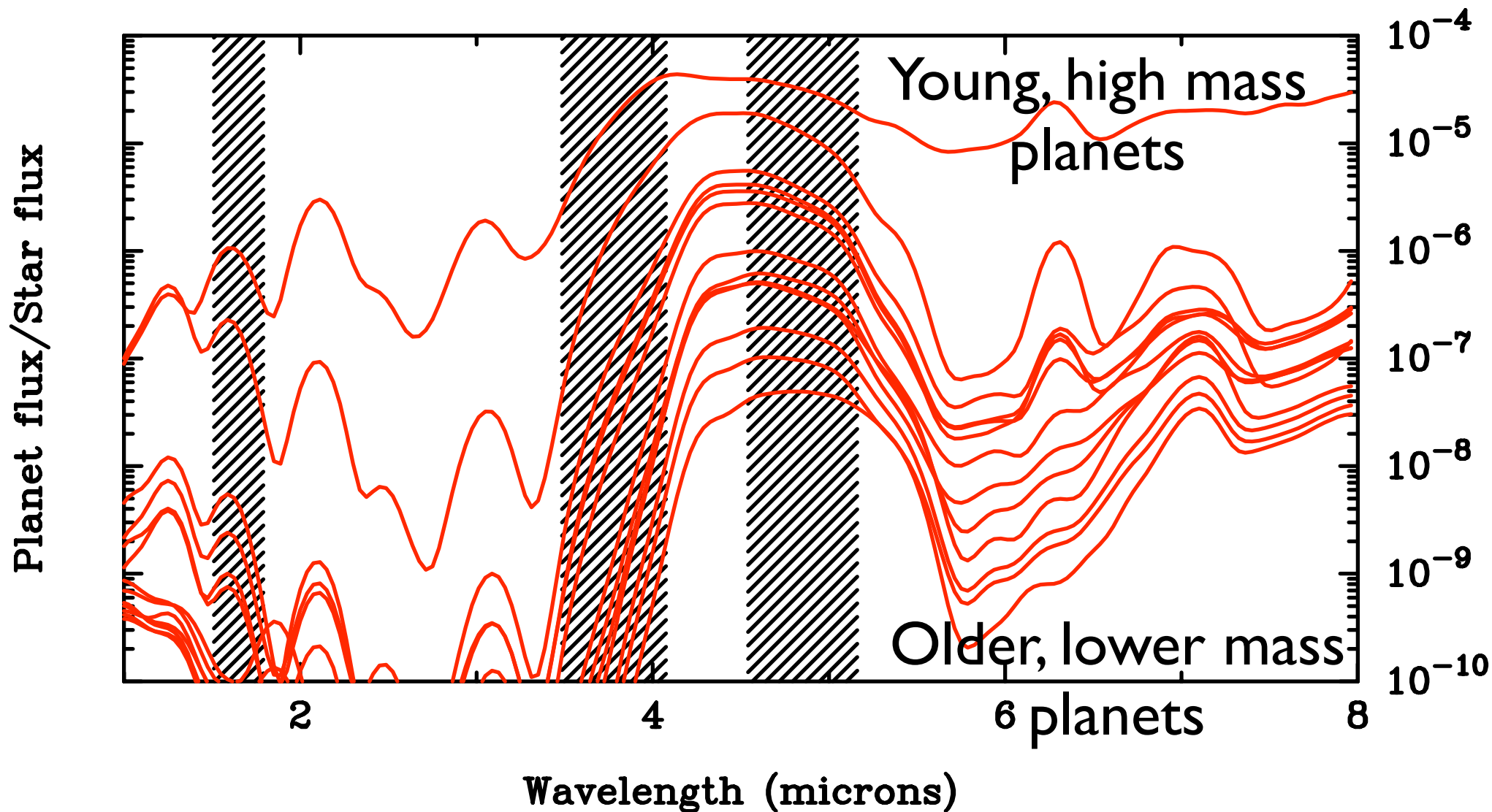
Light as a series of waves

# Where do planets glow?

H Band

L Band

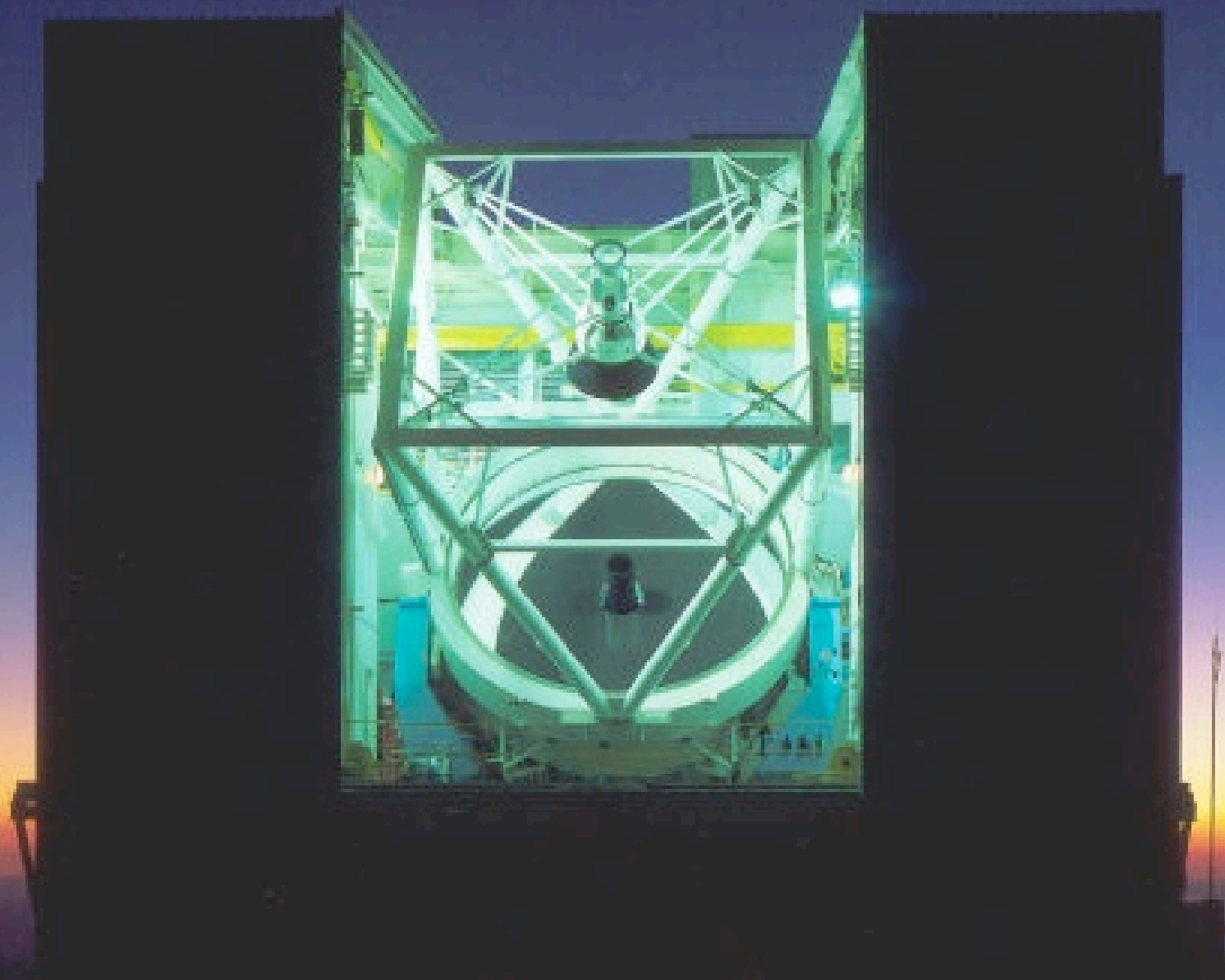
M Band



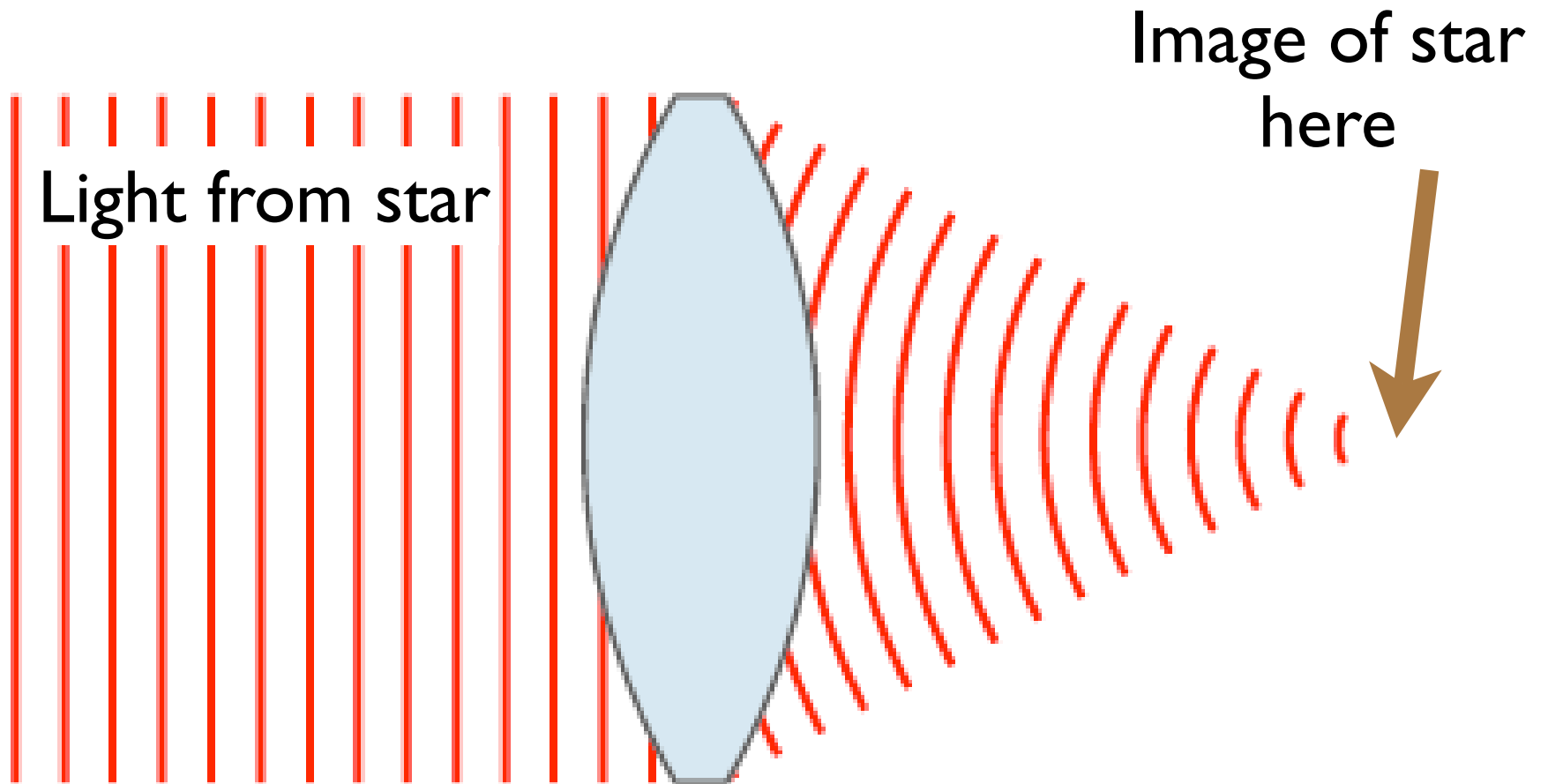
Adapted from Burrows, Sudarsky and Hubeny 2004



# MMTO 6.5m Telescope



# Focusing light

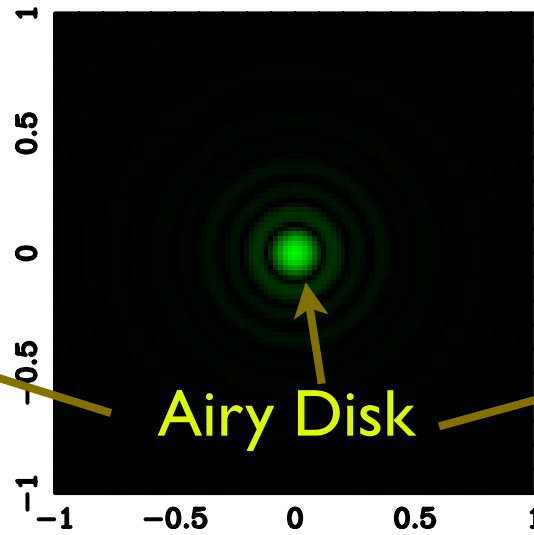
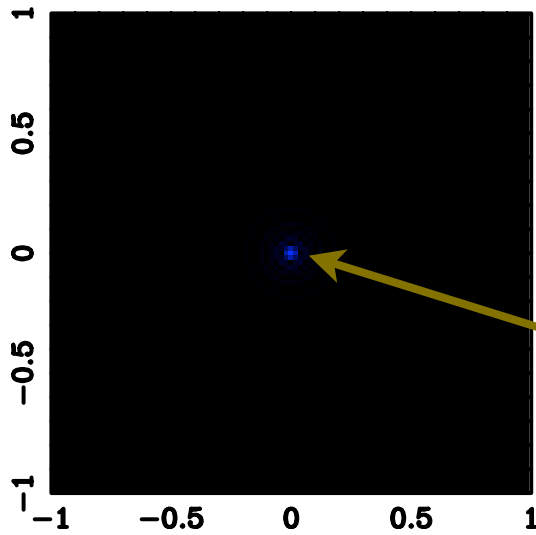


# Not-so-point sources

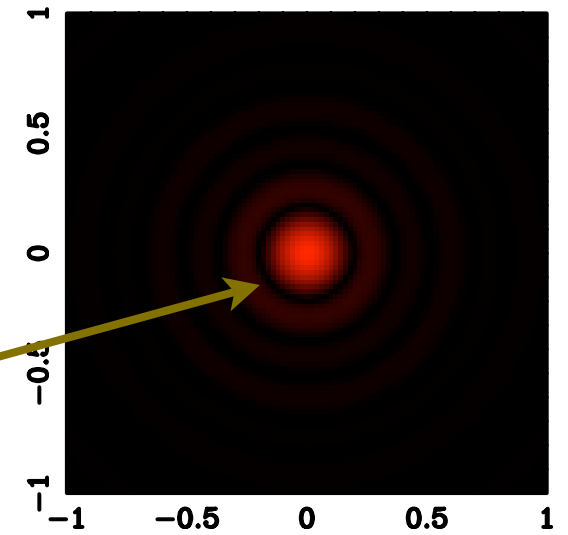
Blue Light

Green Light

Red light



Airy Disk



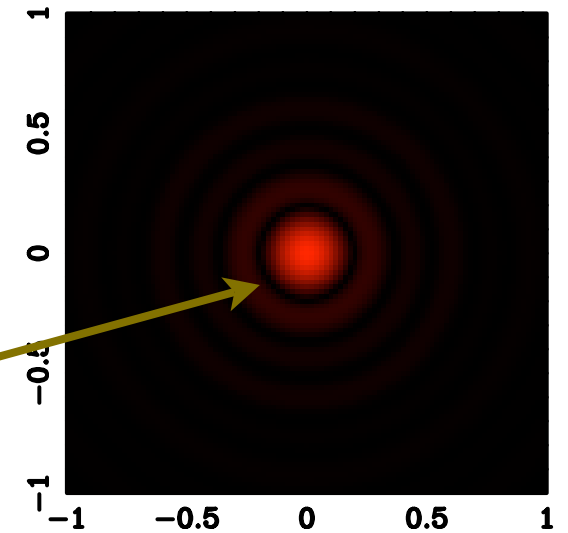
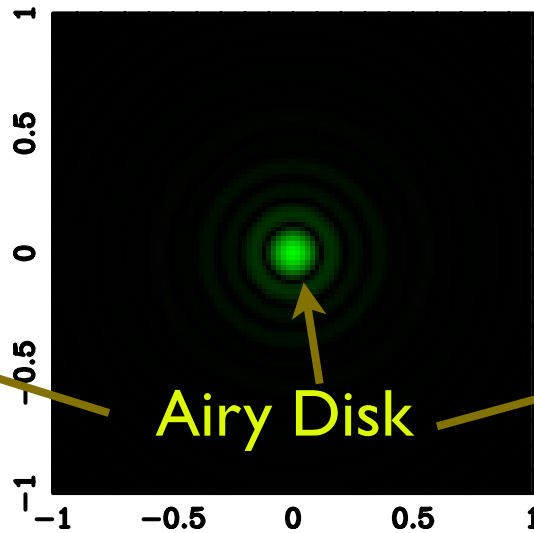
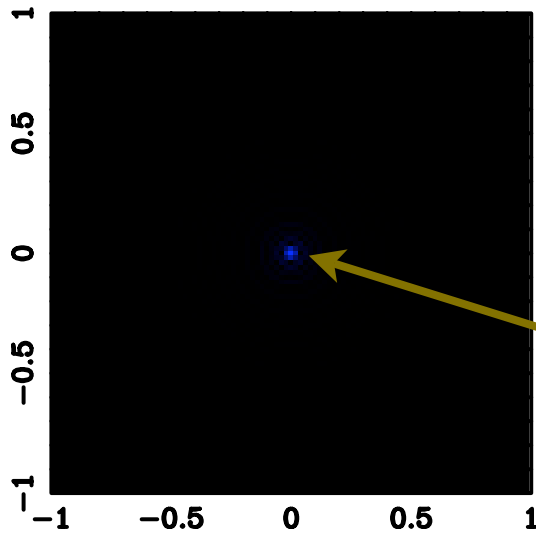


# Not-so-point sources

Blue Light

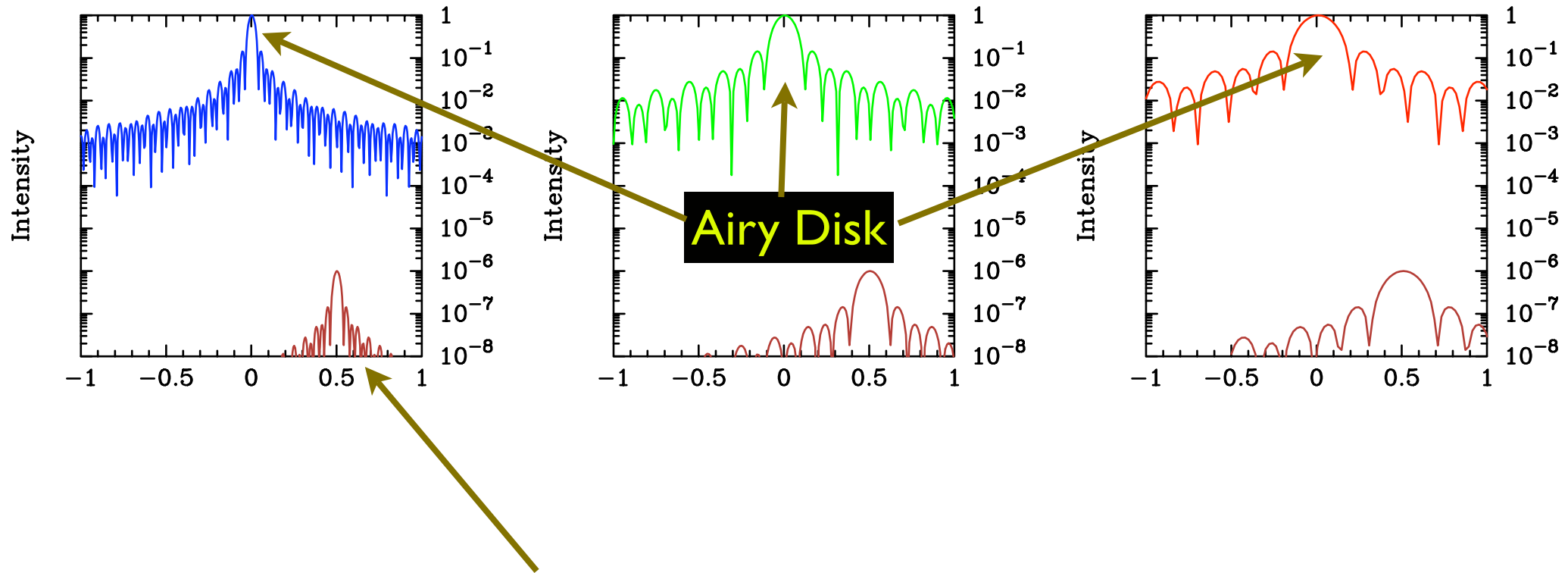
Green Light

Red light



**This is called  
DIFFRACTION LIMITED IMAGING**

# Not-so-point sources



Planet a million times fainter at 0.5 arcsec  
Corresponds to Jupiter around a star 30 light years away

Why are they not  
point images?

Diffraction





But wait! It gets tougher...



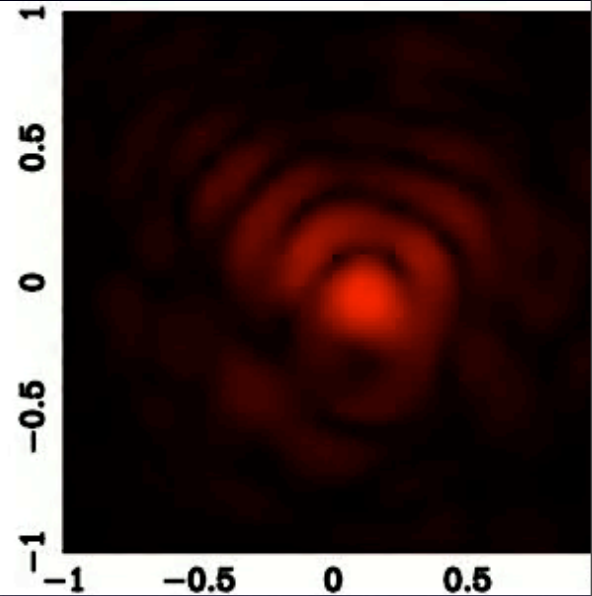
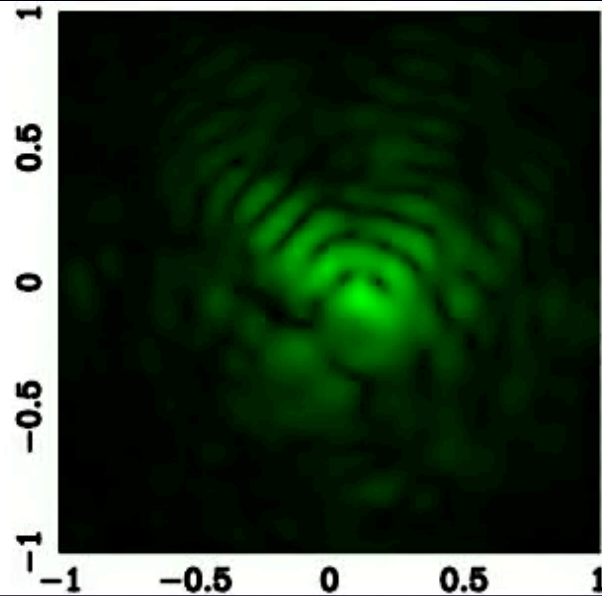
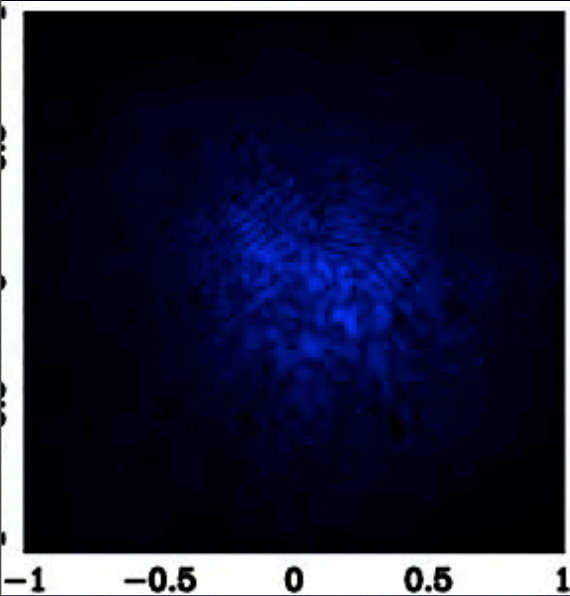
# But wait! It gets tougher...

- When we use telescopes on the ground, we rarely see diffraction limited images

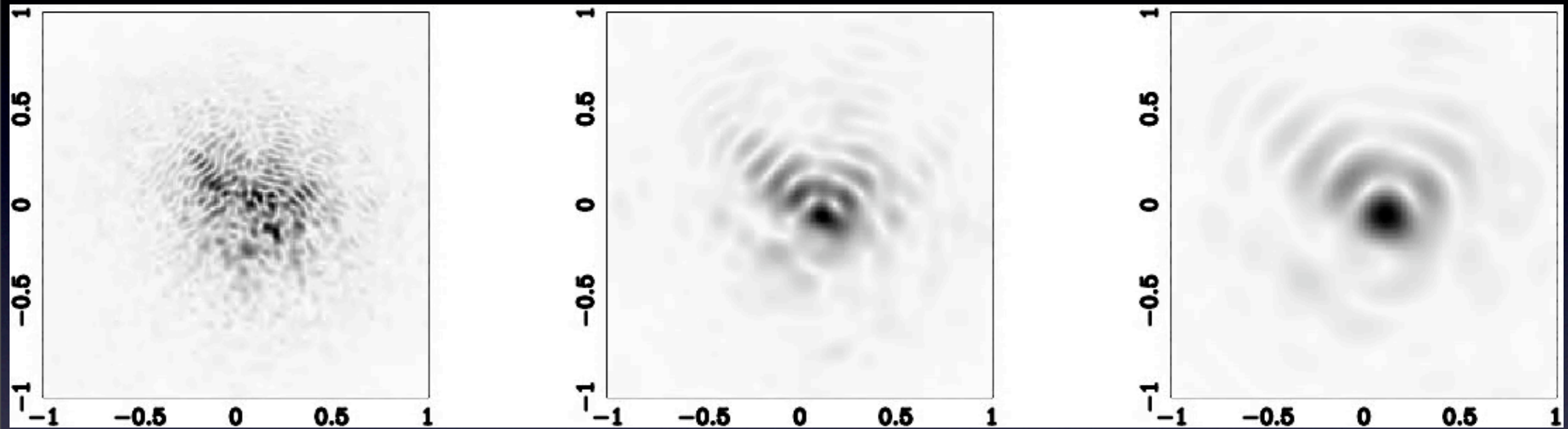




# Turbulent Atmosphere



# Turbulent Atmosphere



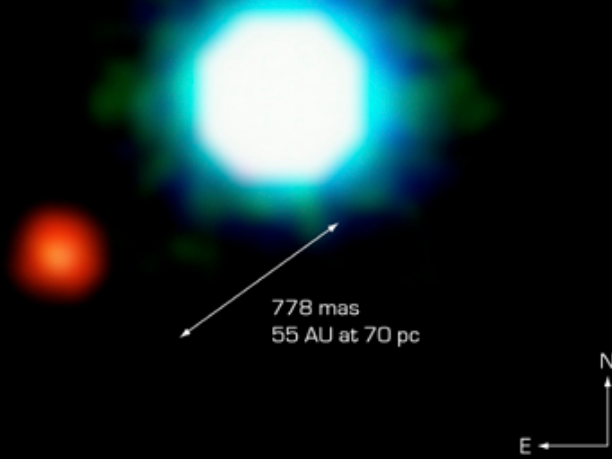


# What we'd *like* to see...

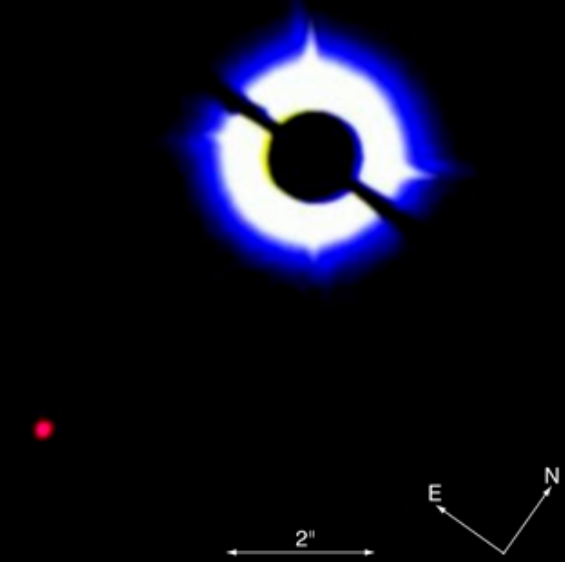


Credit: G.Bacon, NASA and ESA

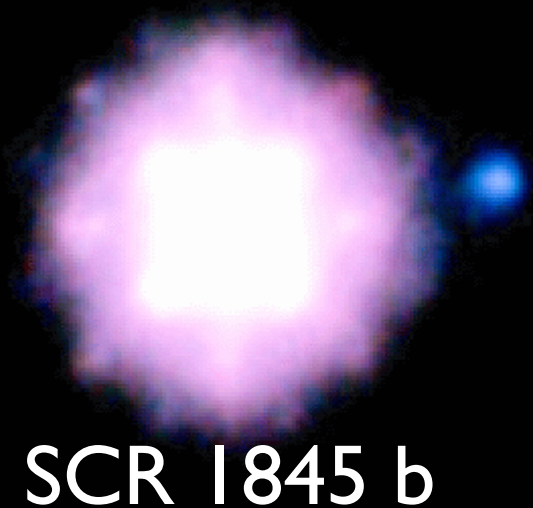
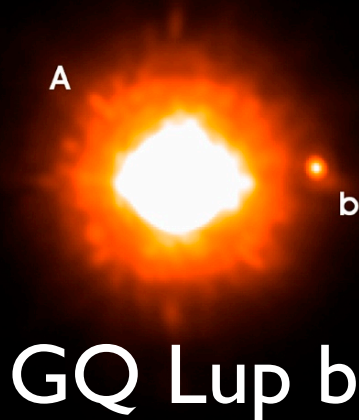
2M1207b  
Confirmed planetary mass  
companion to a Brown Dwarf



AB Pic b



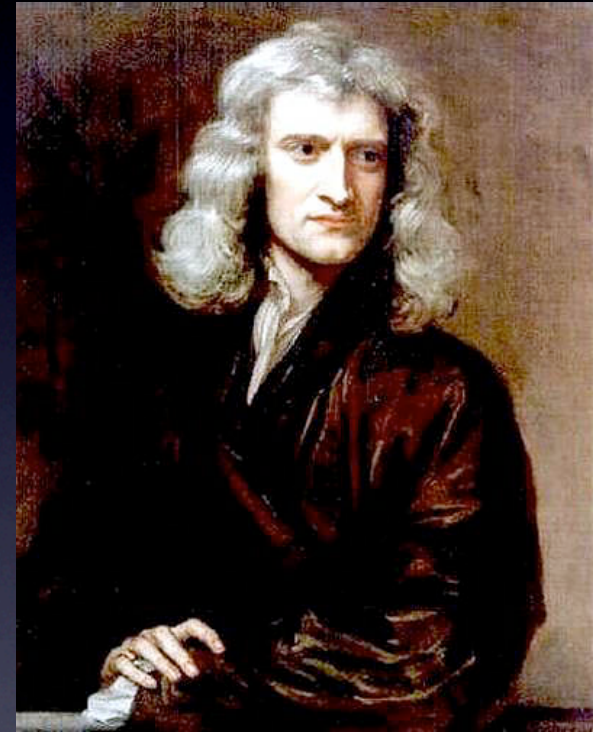
...but what we really see



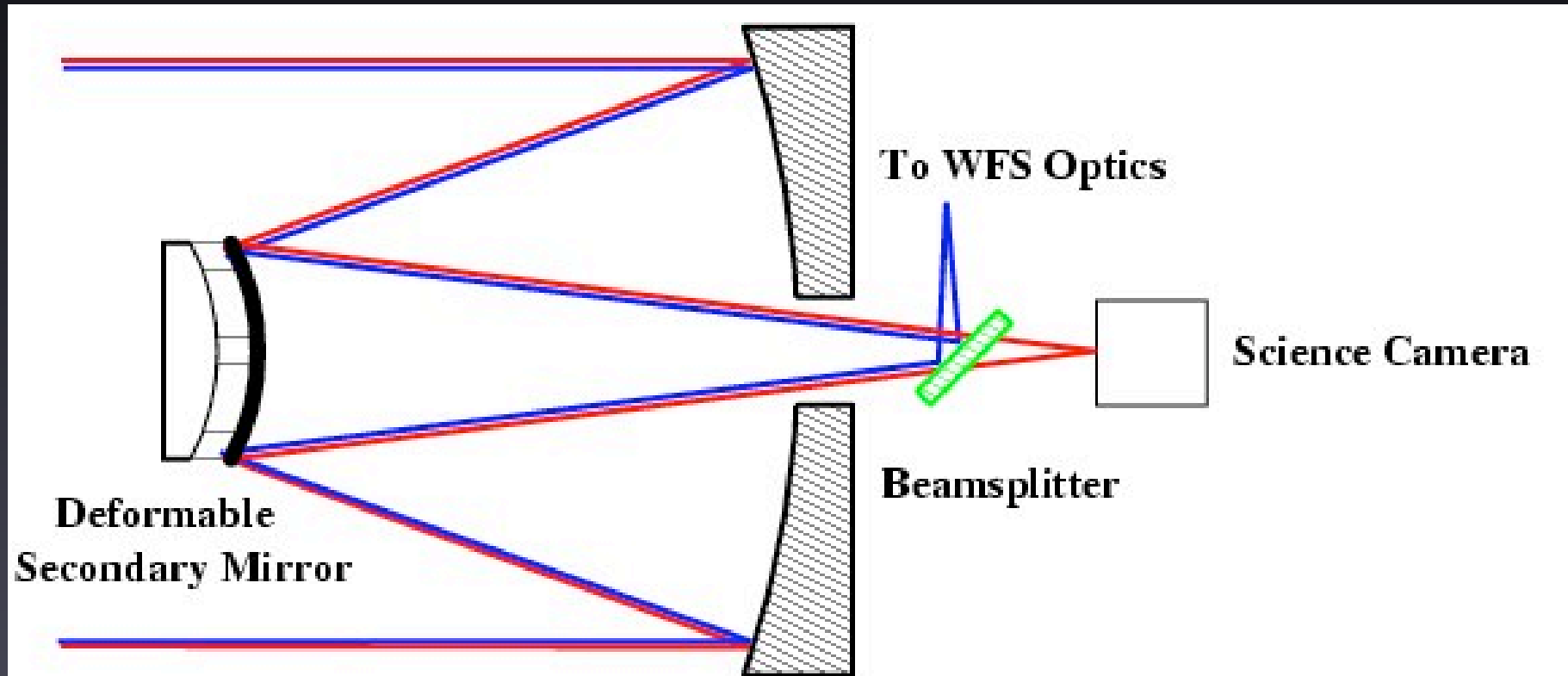


# ‘Seeing’ is the problem

“Telescopes ... cannot be so formed as to take away that confusion of the Rays which arises from the Tremors of the Atmosphere. The only Remedy is a most serene and quiet Air, such as may perhaps be found on the tops of the highest Mountains above the grosser Clouds.” (Isaac Newton, 1730)



# Remove the effects of the atmosphere with ADAPTIVE OPTICS!





# Deformable Secondary Mirror



**Great for thermal infrared**

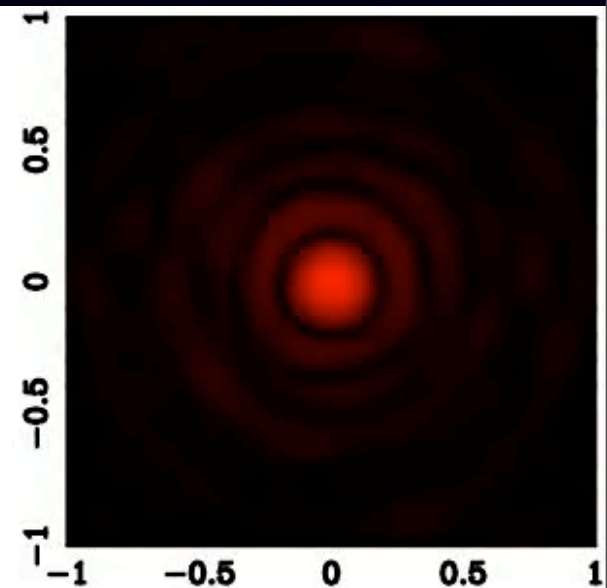
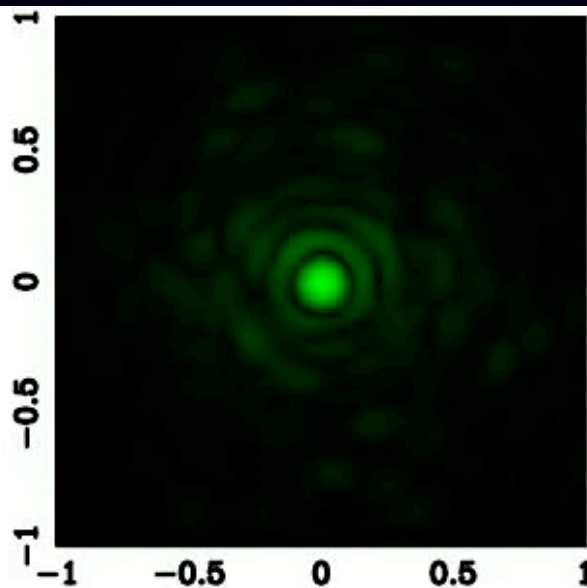
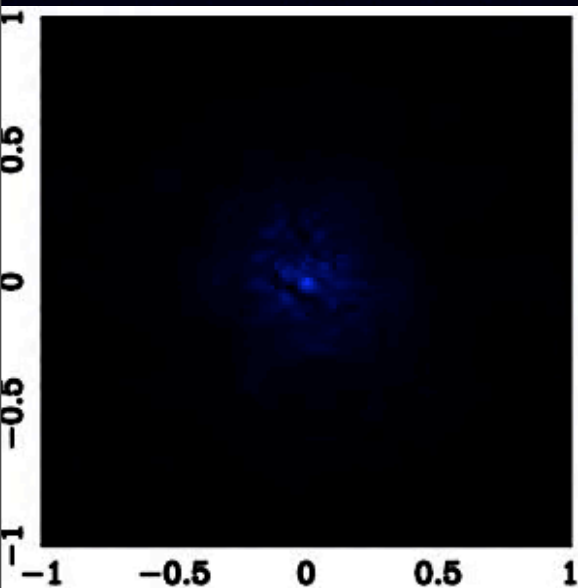
2mm thick by 640 mm diameter

336 voice coil actuators

Undersized pupil  
for IR observations  
(effective  $D=6.35\text{m}$ )

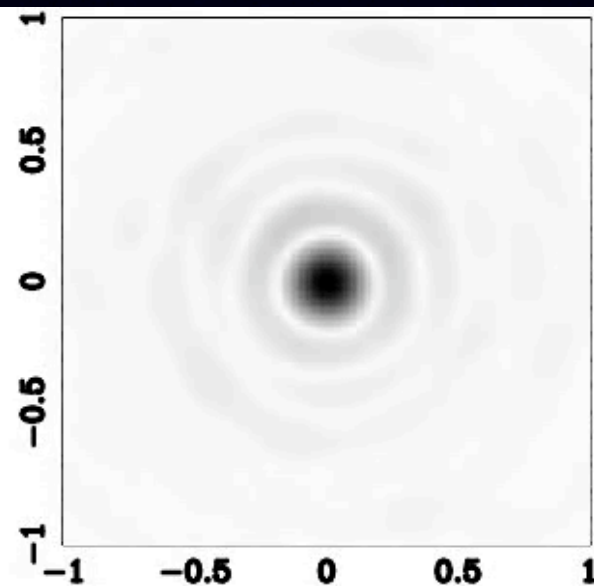
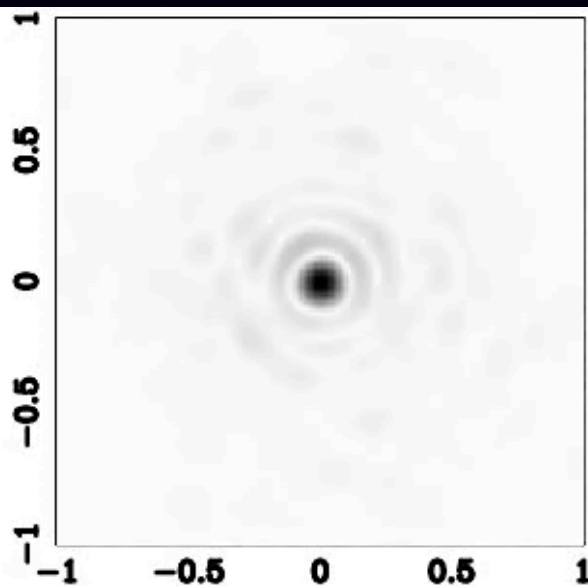
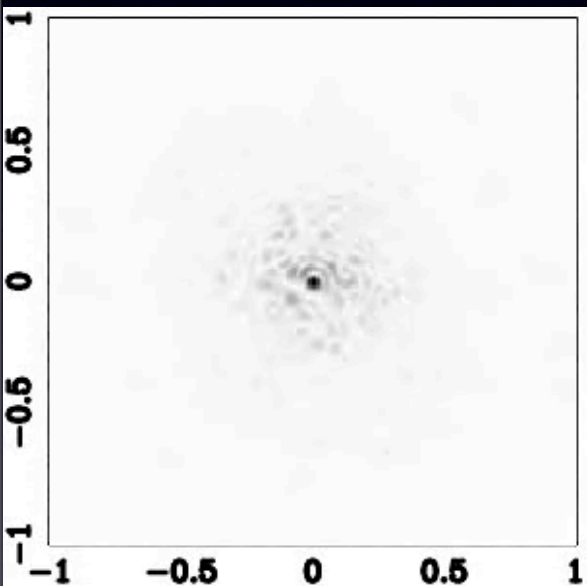
# AO correction

- the longer the wavelength,  
the more stable star's image

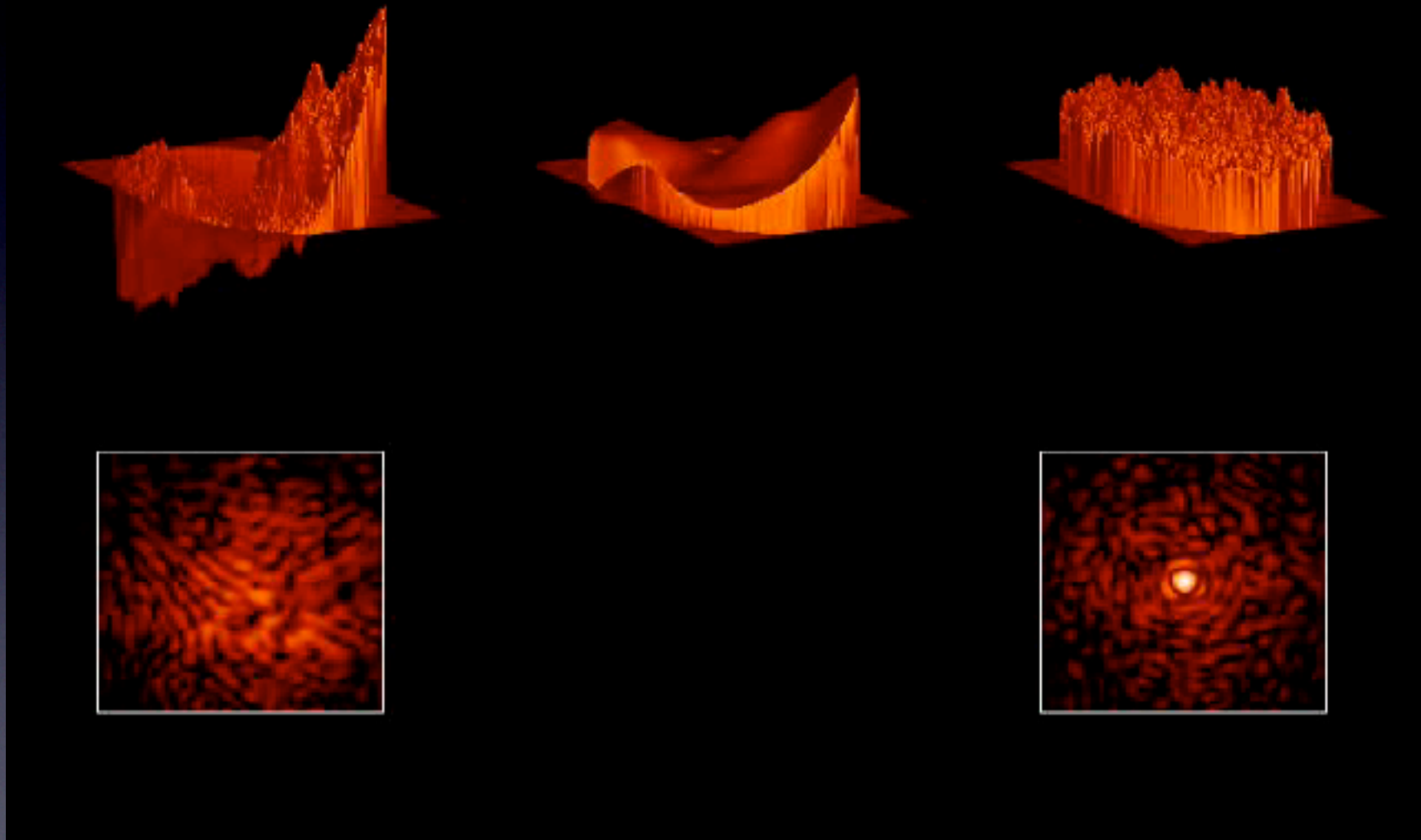


# AO correction

- the longer the wavelength, the more stable the PSF







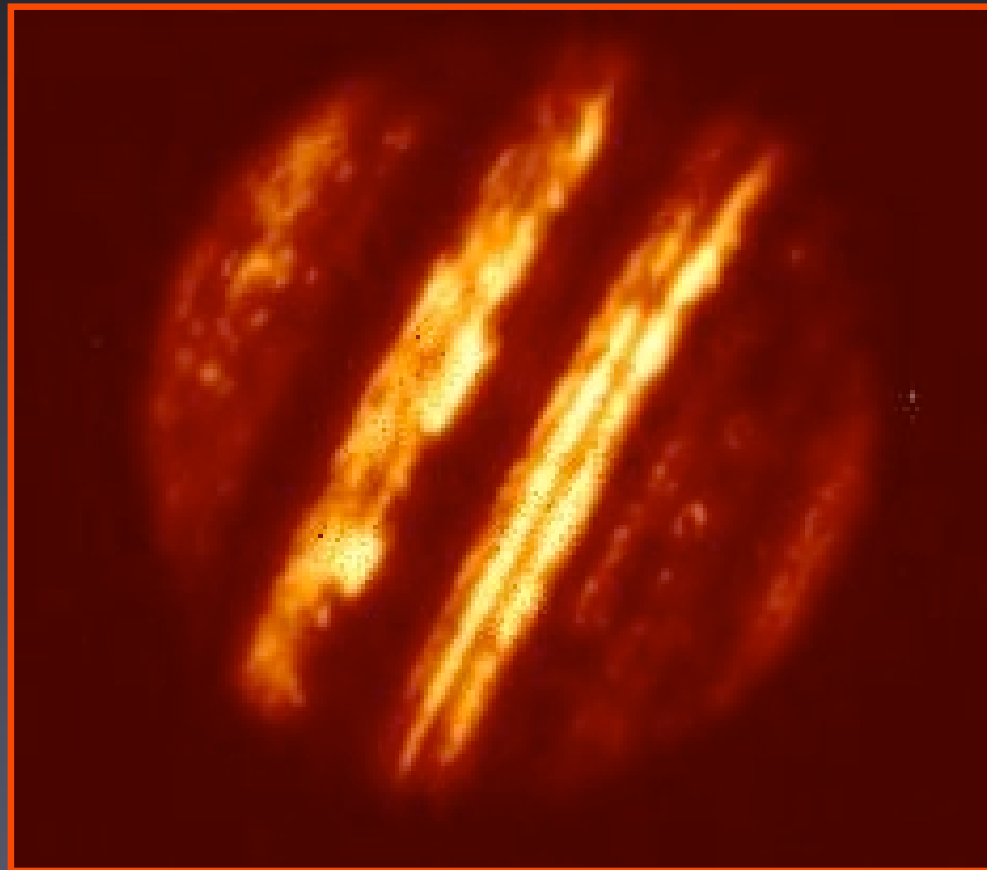
The Lyot Project <http://lyot.org/>



# Thermal Imaging with Clio

Built by Prof. Phil Hinz

- 3 to 5 micron imaging camera/coronagraph



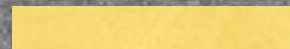
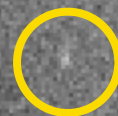
# Typical Clio Observation



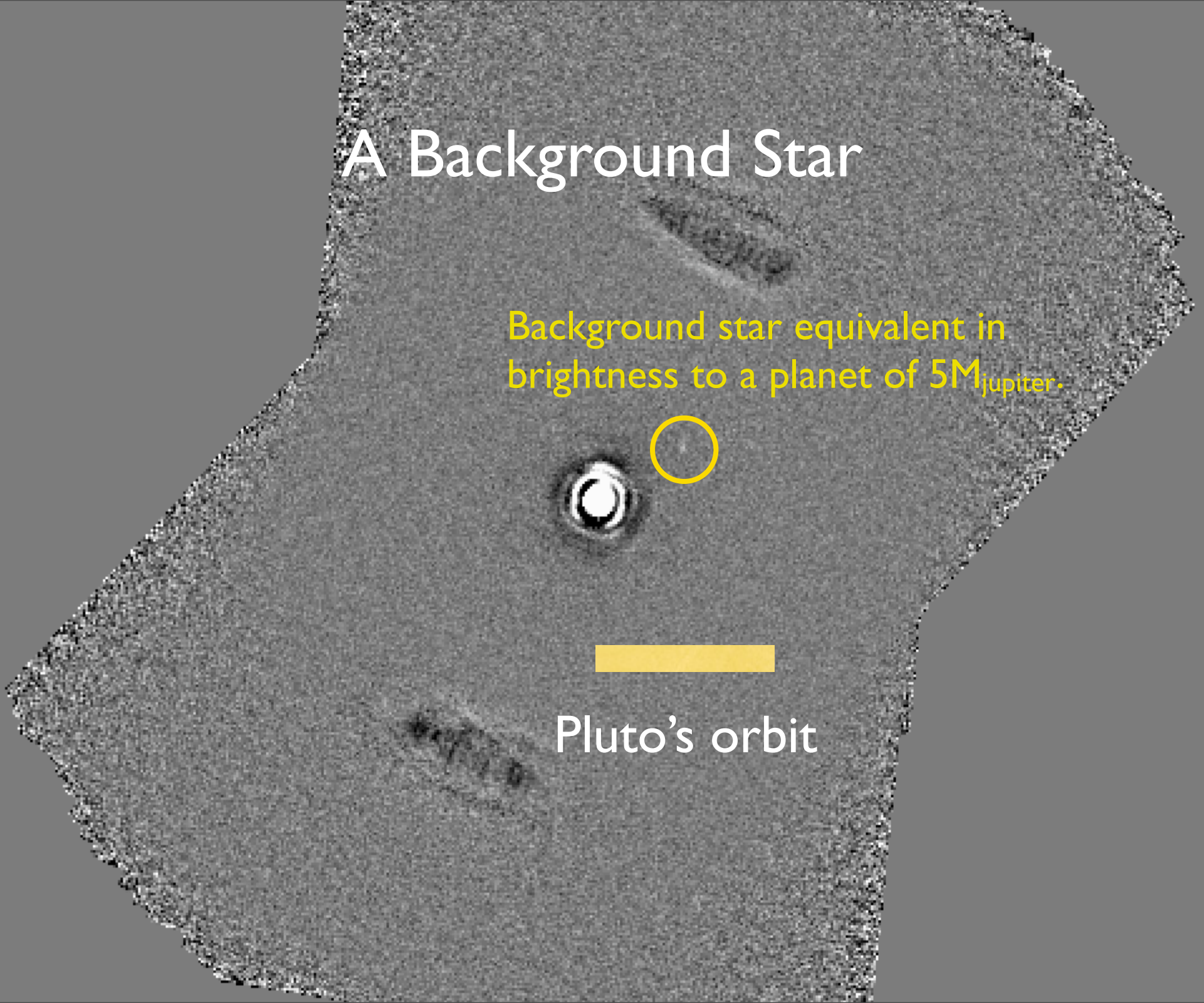
**Background star**

# A Background Star

Background star equivalent in  
brightness to a planet of  $5M_{\text{jupiter}}$ .

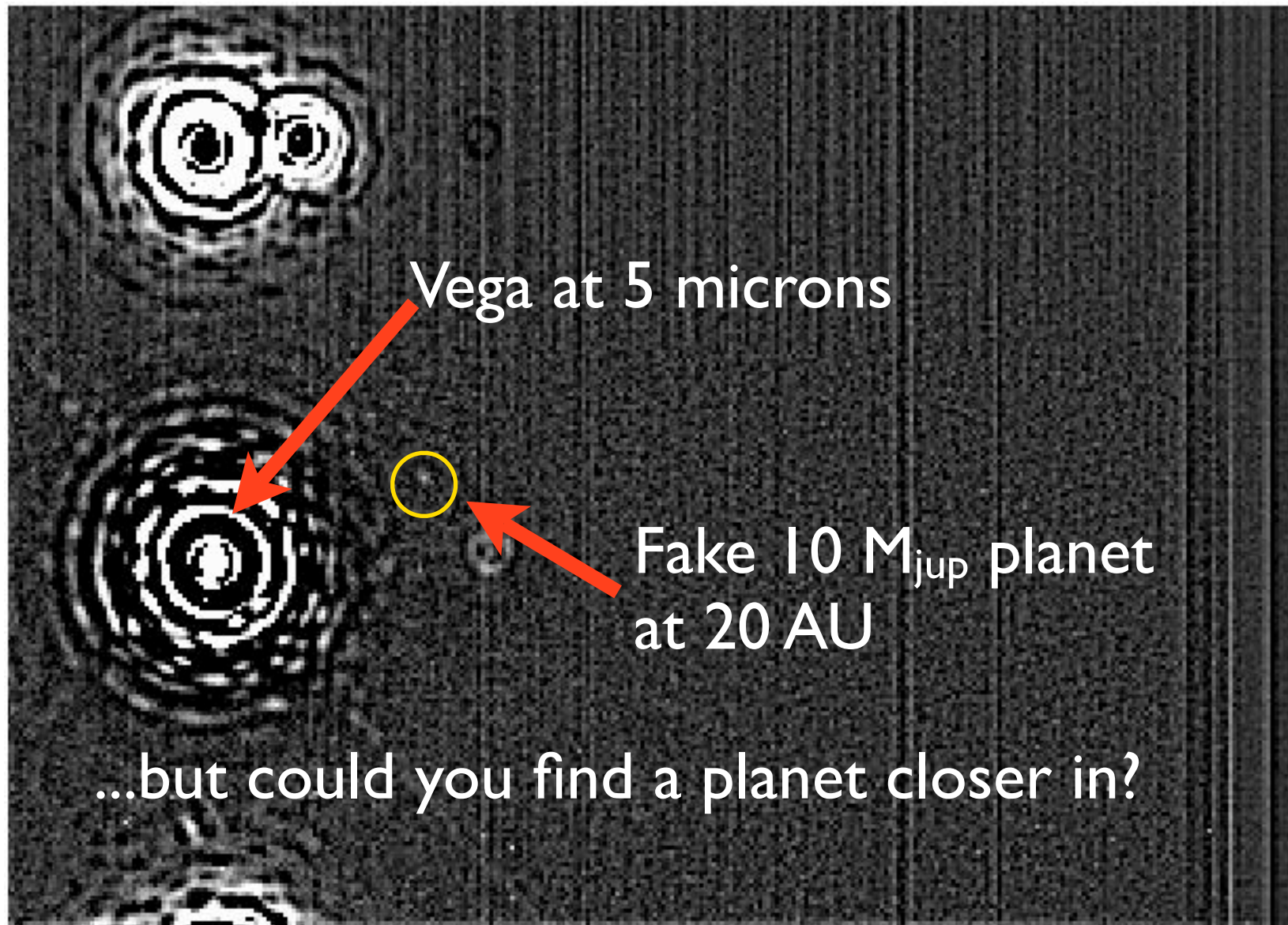


Pluto's orbit





# Diffraction Effects





# Why does Image Subtraction not work?

- Two images taken about 20 minutes apart are not identical
- Quasi-static 'speckles' are present in all images

But wait! It gets **even**  
tougher...



# Coronagraph

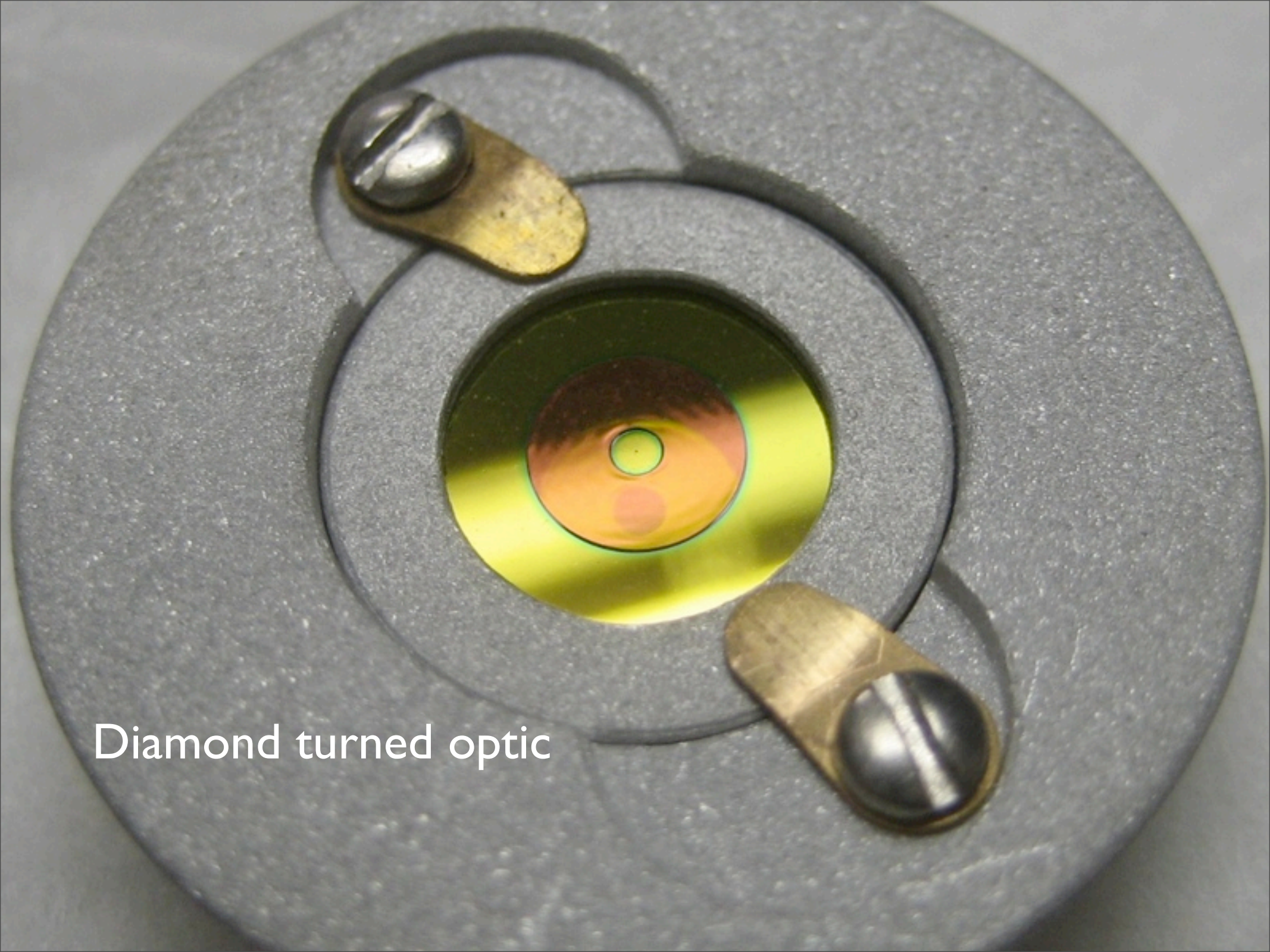
- 'Looking at the Sun's Corona'
- Invented by Bernard Lyot



# Coronagraphy

- “Cover the star with your thumb!”
- Removing diffraction from star whilst letting planet light through

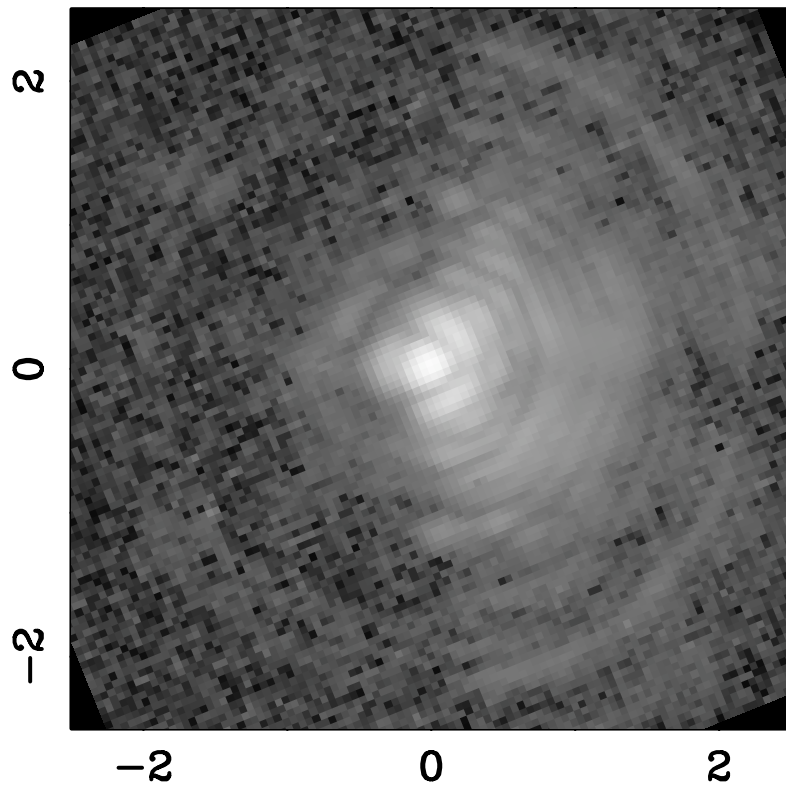




Diamond turned optic

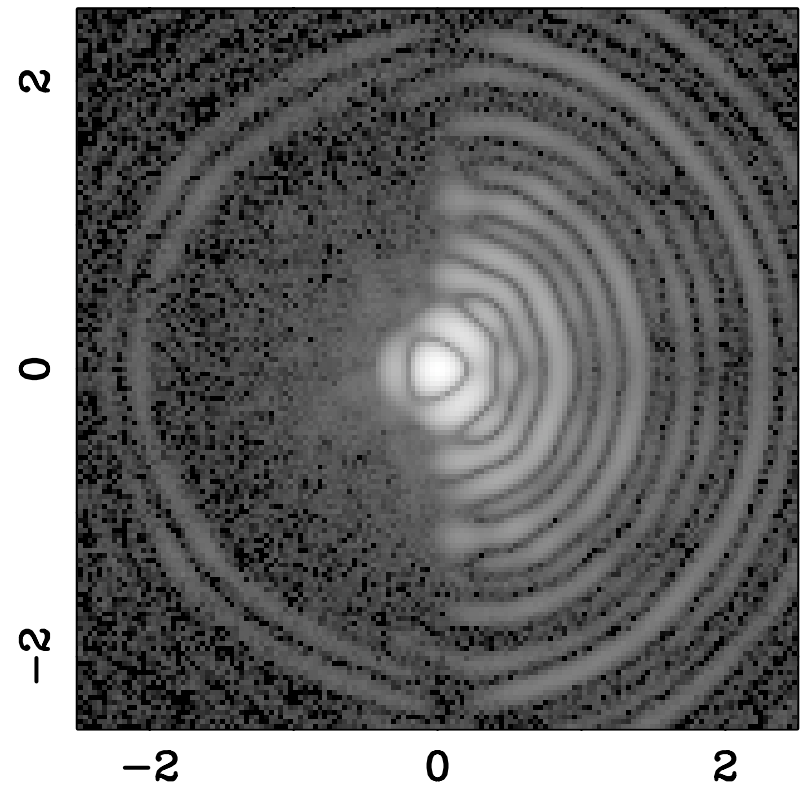
# It works...

Real Image with Phase Plate



Arcsec

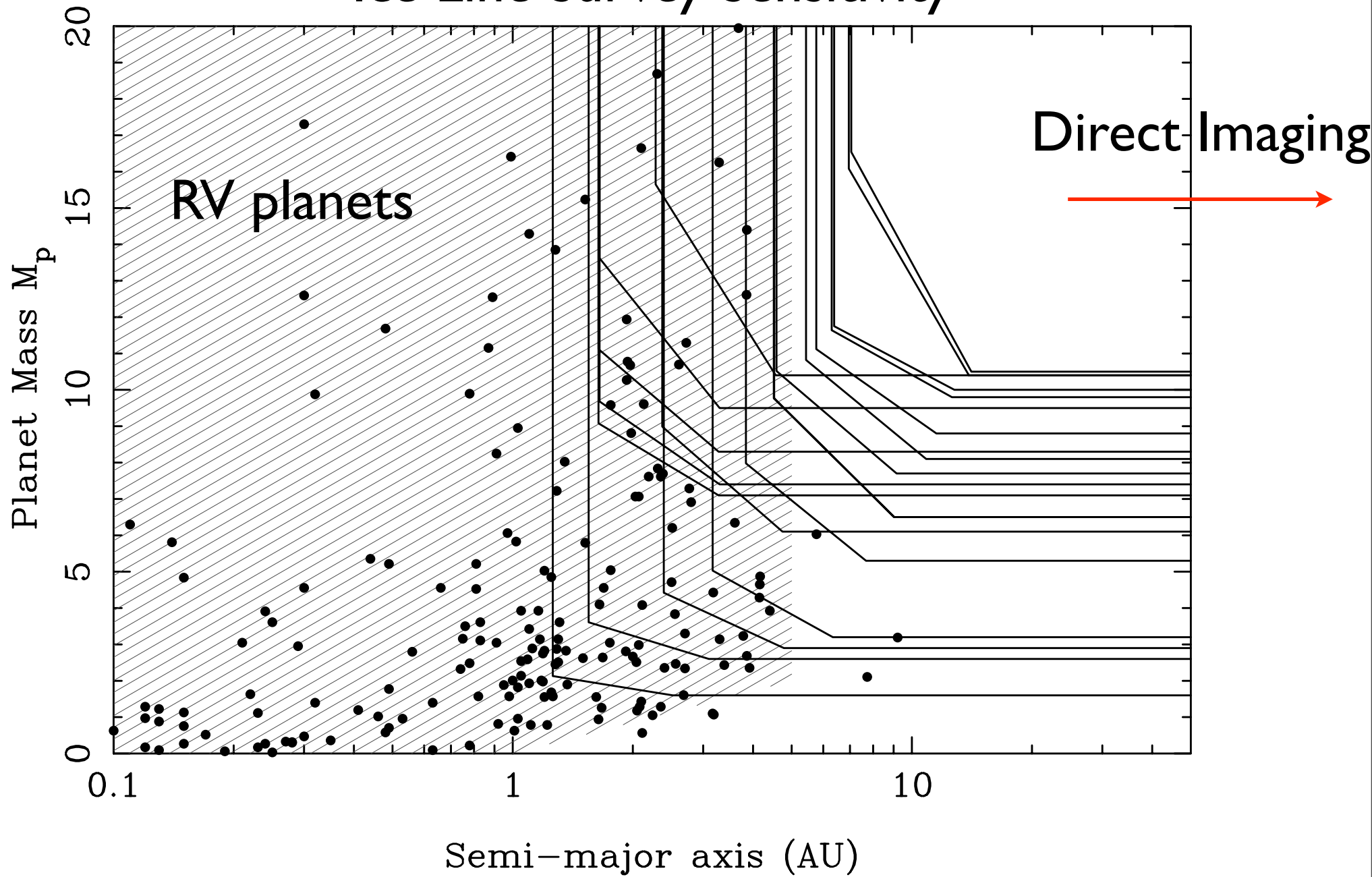
Modeled Image



Arcsec

April/May 2006

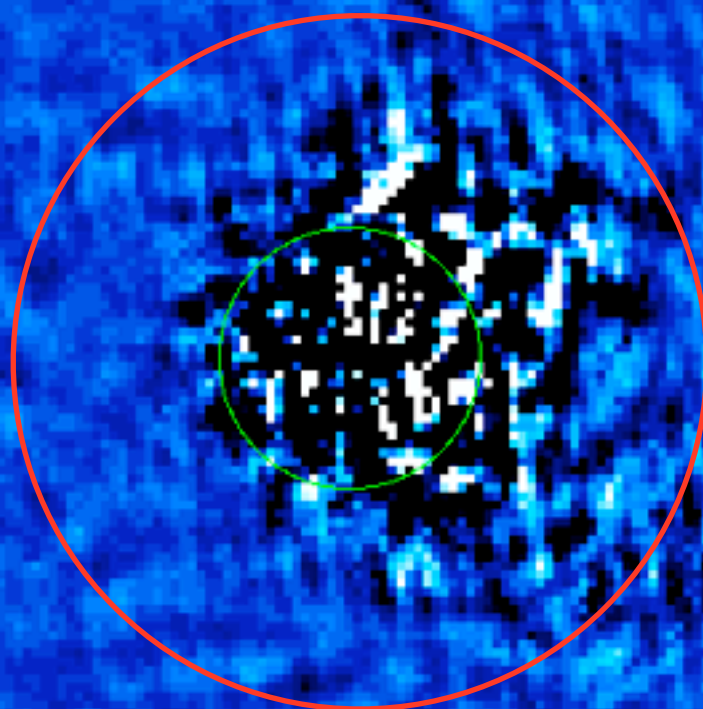
# Ice Line Survey Sensitivity



- **Play animation**



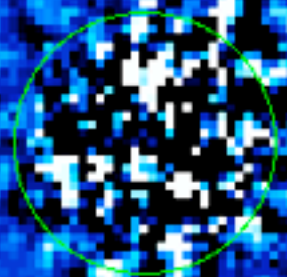
dM=11mag  
2.46 arcsec  
0.6 hours



Procyon B

20 40 60 80 100 120 140 160 180 200

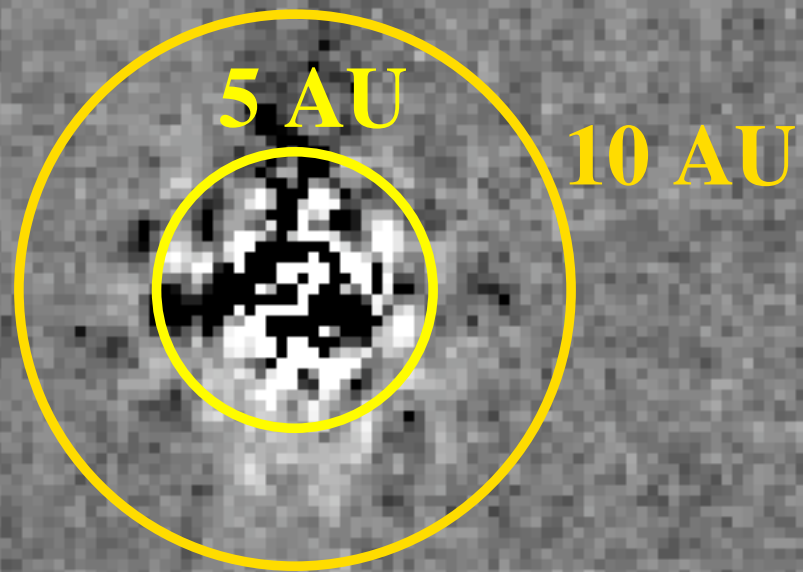
dM=11mag  
2.46 arcsec  
1.5 hours



Procyon B



Pi 3 Ori  
d=7pc  
1.5 Gyr



Mass limit:  $11M_{\text{jup}}$  in to 5 AU

# Conclusions

- Thermal imaging is sensitive enough (assuming models are close to reality...)
- No planets so far... but watch this space!
- 8 stars out of 25 observed, no planet candidates



# Fomalhaut

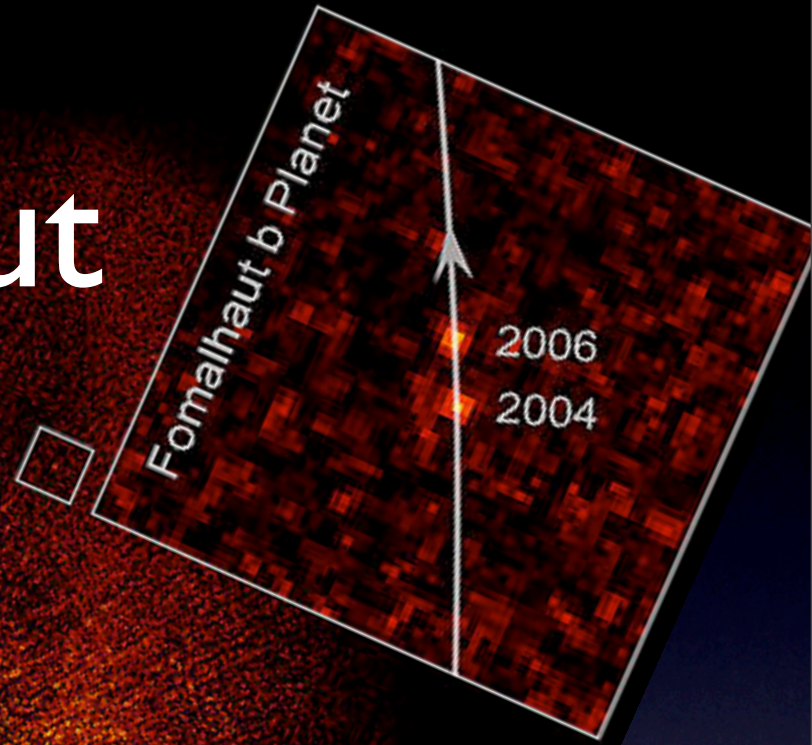
Dust Belt



Hubble Space Telescope in 2006



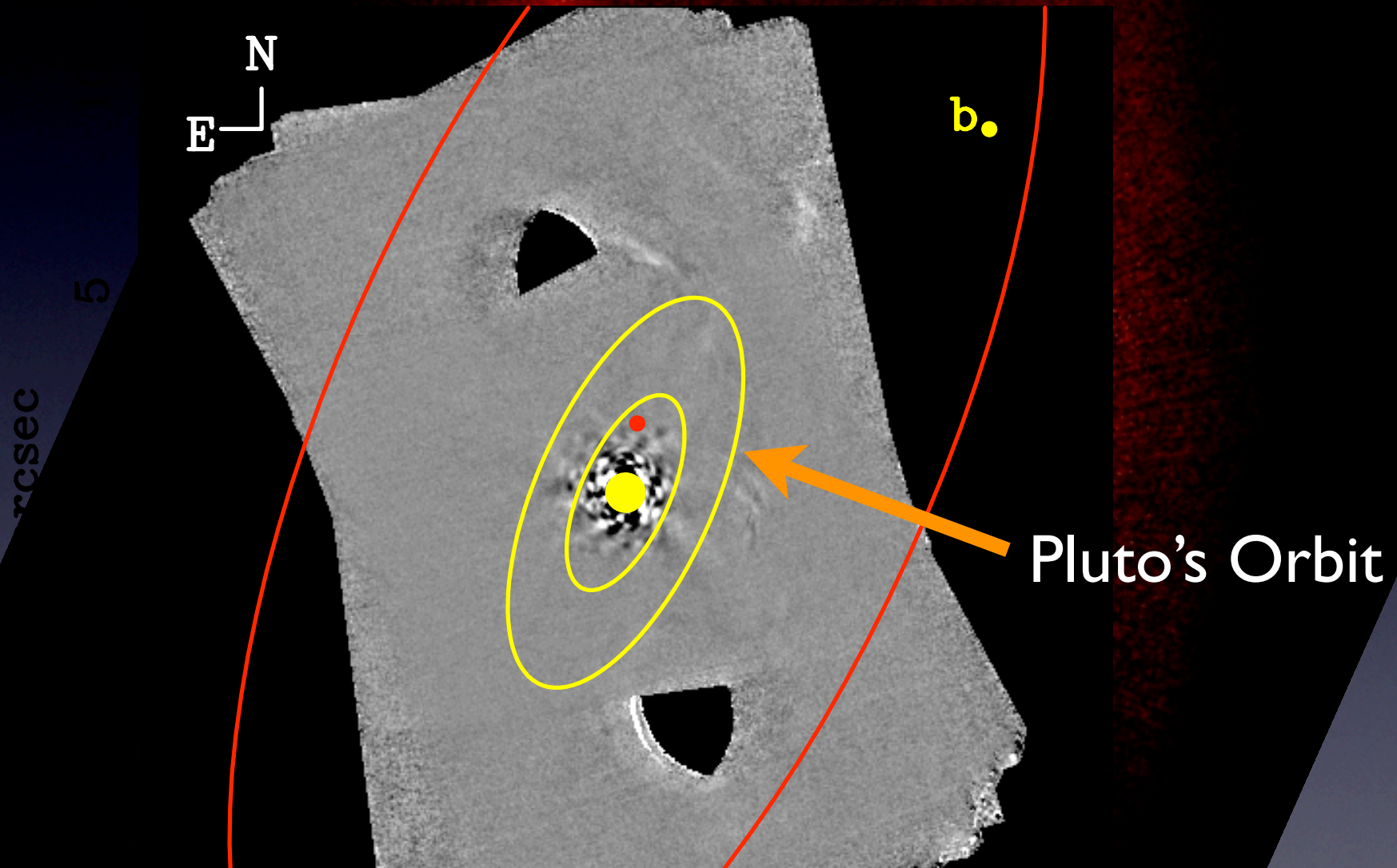
# Fomalhaut





Clio at MMT  
Dec 2006

# Fomalhaut



Nothing bigger than 2 Jupiter Masses

Gemini CH4S Oct. 17, 2007UT

# HR 8799



b

c

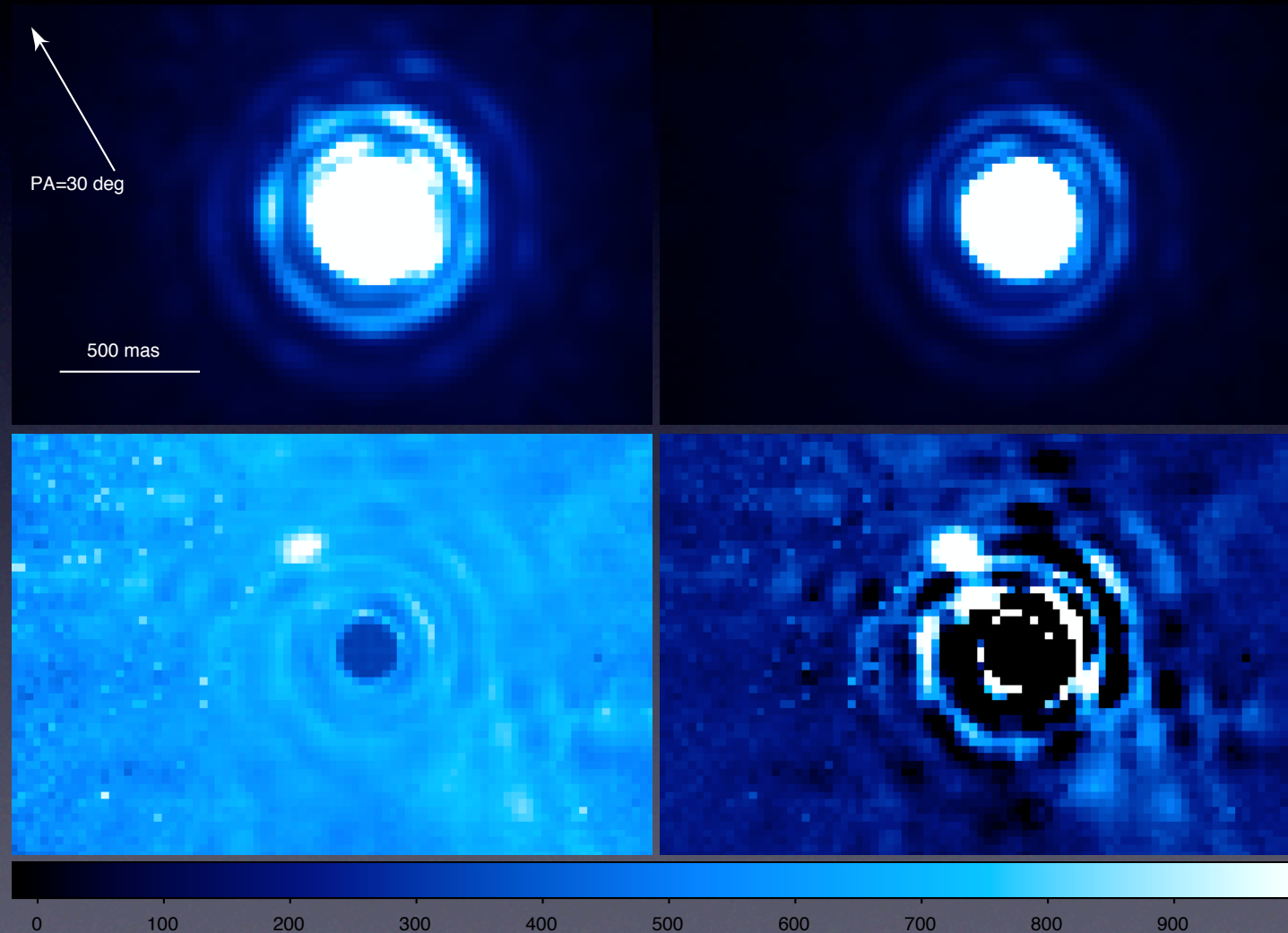


- Images with Clio tonight!

0.5''



# Beta Pic



**Fig. 1.**  $\beta$  Pic and HR 2435 recentered and saturated  $L'$  images (top left and top right, respectively) in data set A. Below are the divided (bottom

**Thanks for listening!**