

Como detectar planetas derivando

Matemáticas en acción
Santander. 2009

Sumario

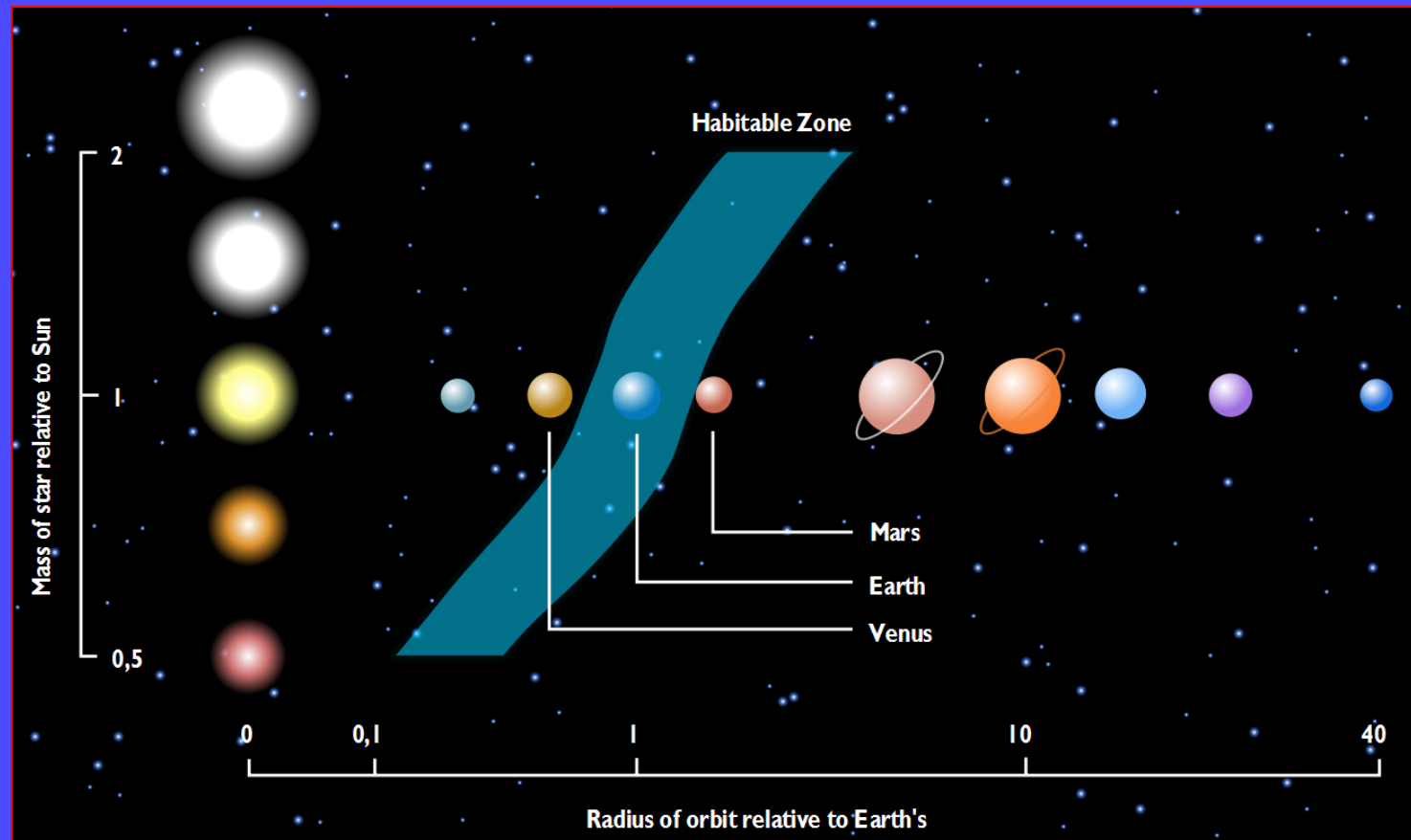
- o Búsqueda de planetas
- o Diferentes técnicas de detección
- o Coronografo de diferenciación óptica
- o Nuestro instrumento

OBJETIVOS

- Detección de planetas extrasolares.
(Primero planetas gigantes, ahora similares a la tierra)
- Evidencia de actividad biológica.
- Identificar planetas habitables en otros sistemas estelares.

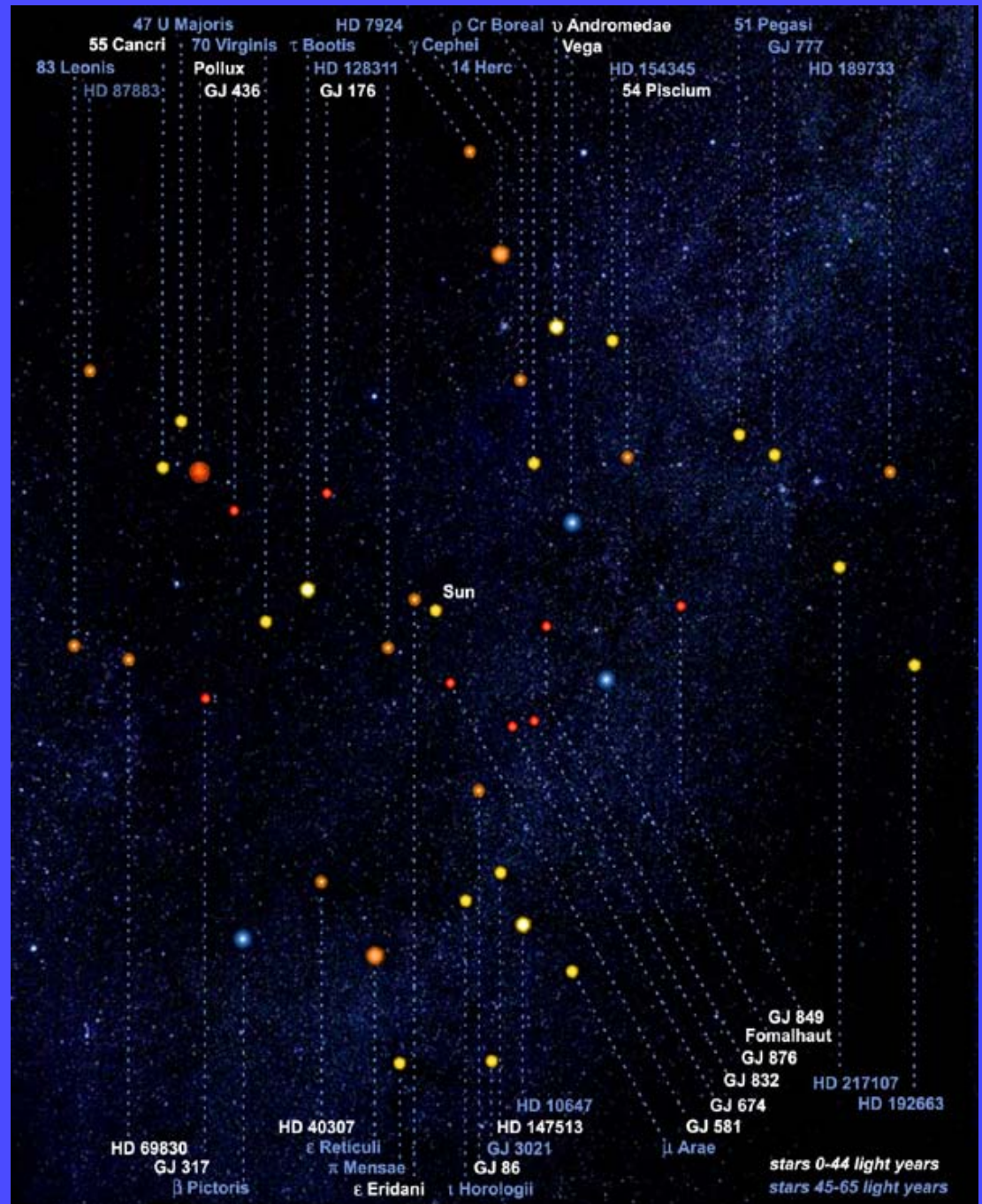


Zona Habitable



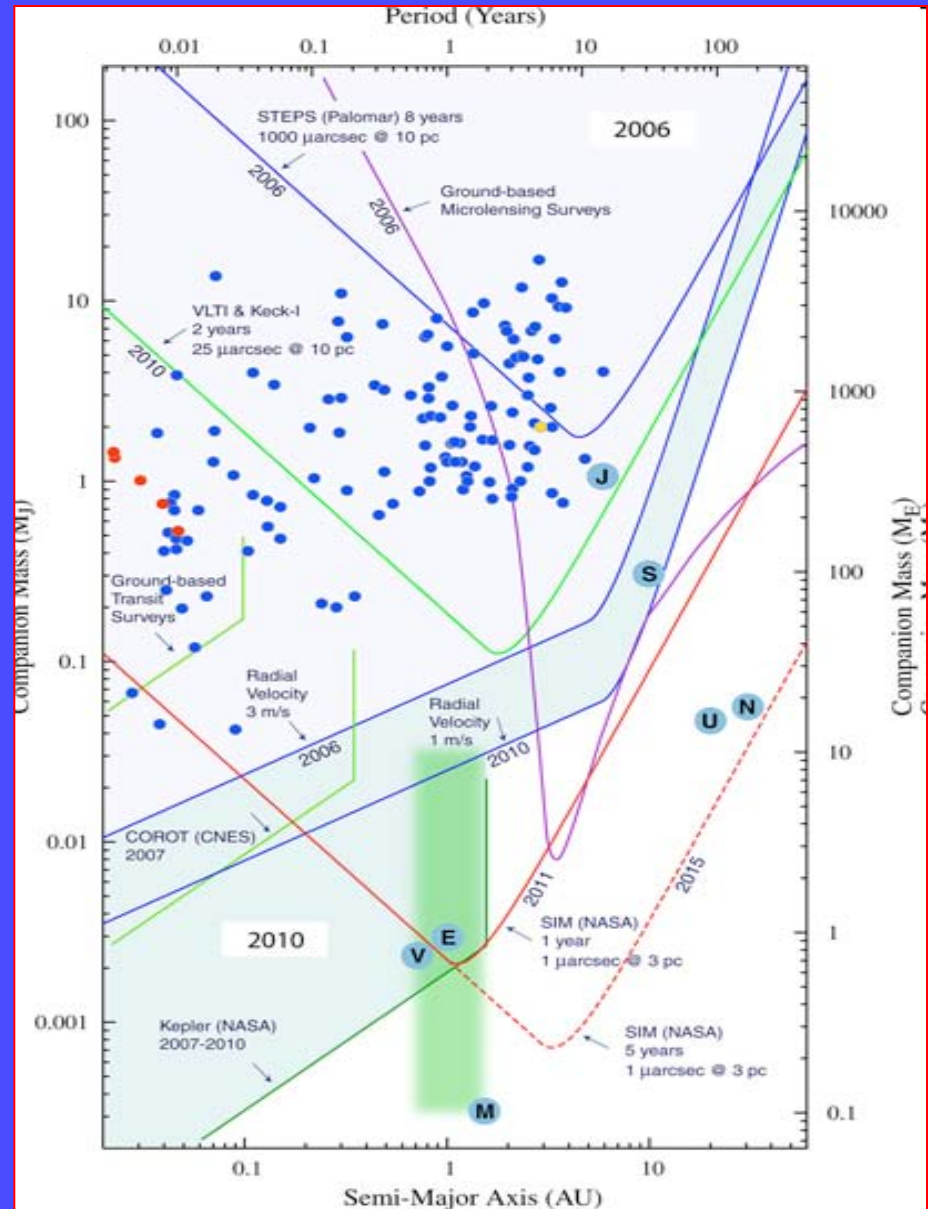
Planetas detectados

Schematic view of the central stars of all known planetary Systems within 65 light years (20 parsecs).



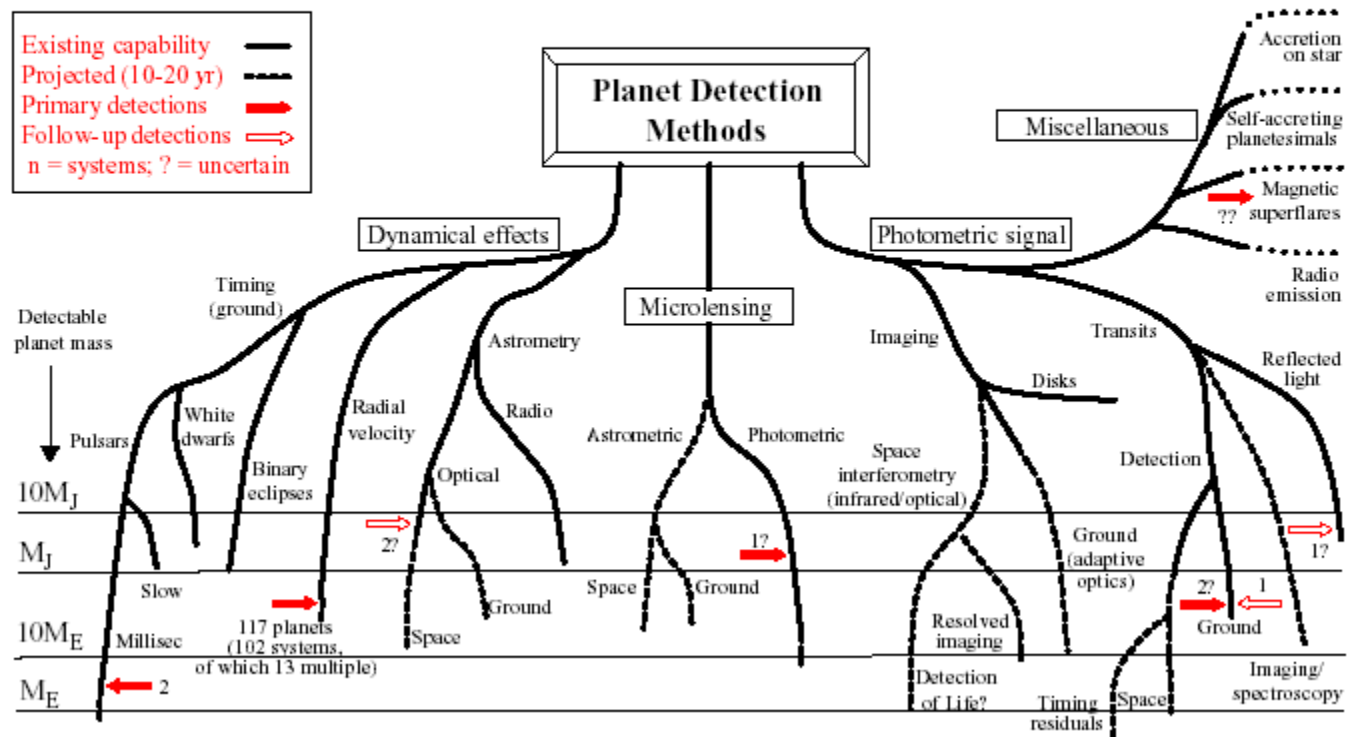
Detectados

En la actualidad hay 400
exoplanetas detectados,
pero en zonas no habitables

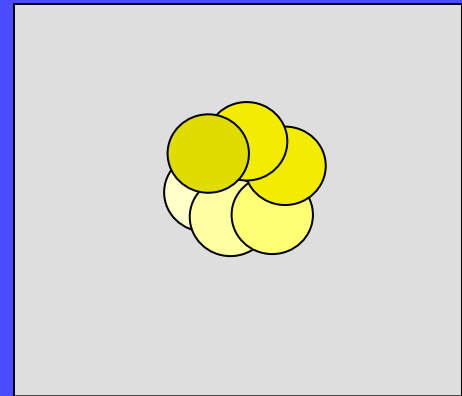
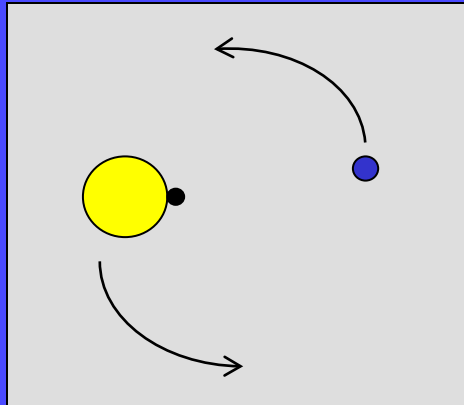
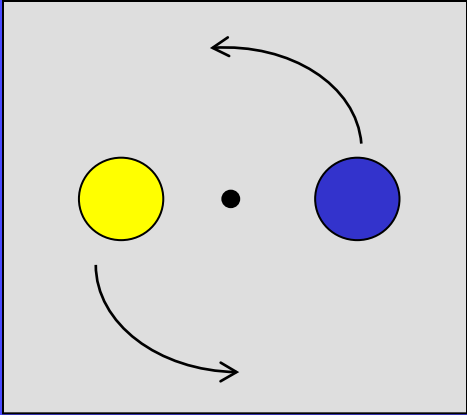


Planet Detection Methods

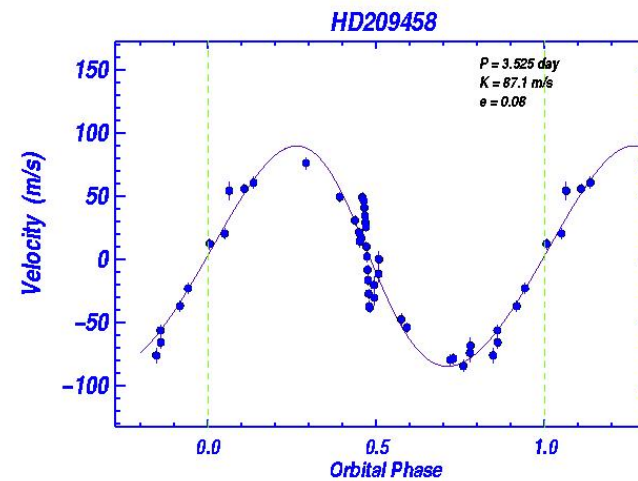
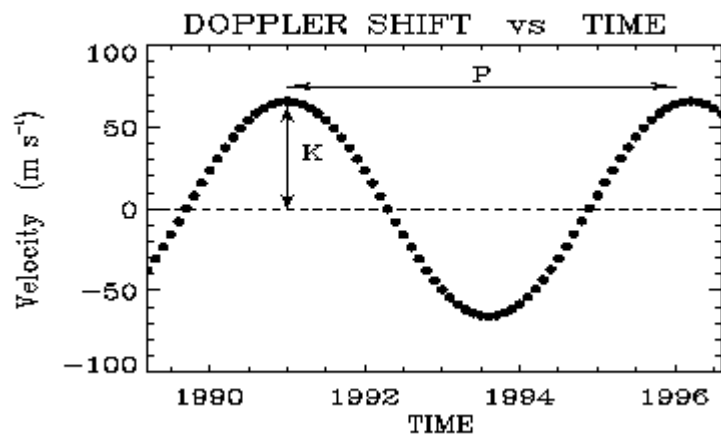
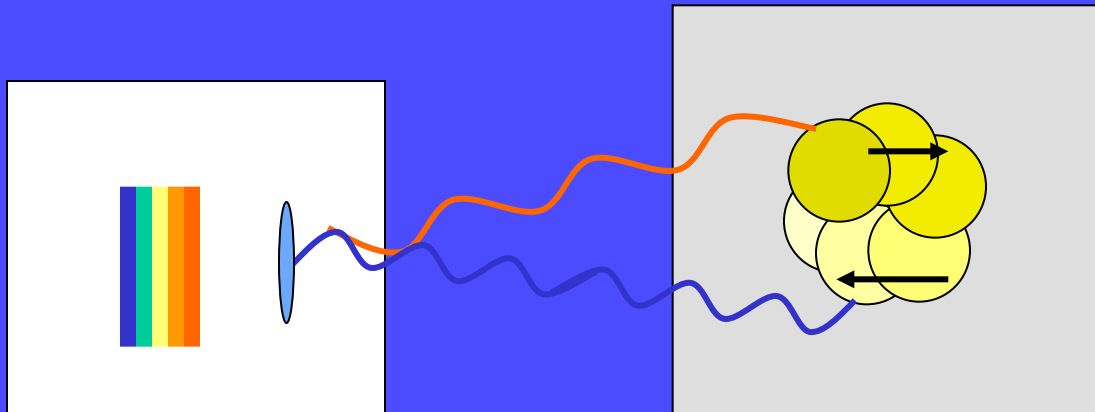
Michael Perryman, Rep. Prog. Phys., 2000, 63, 1209 (updated September 2003)



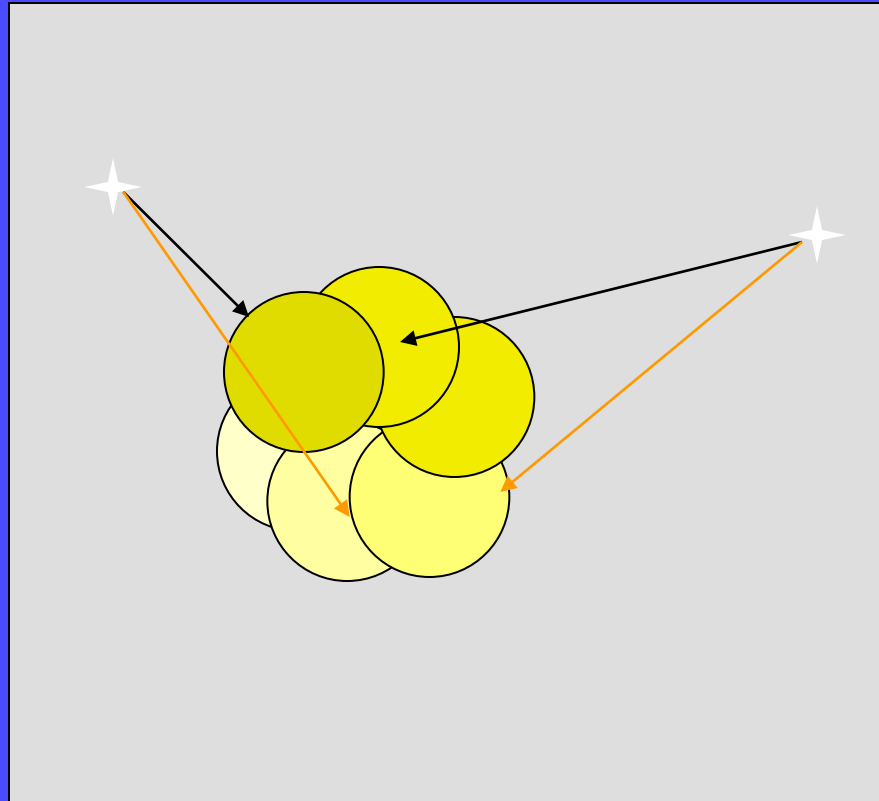
Detección de exoplanetas



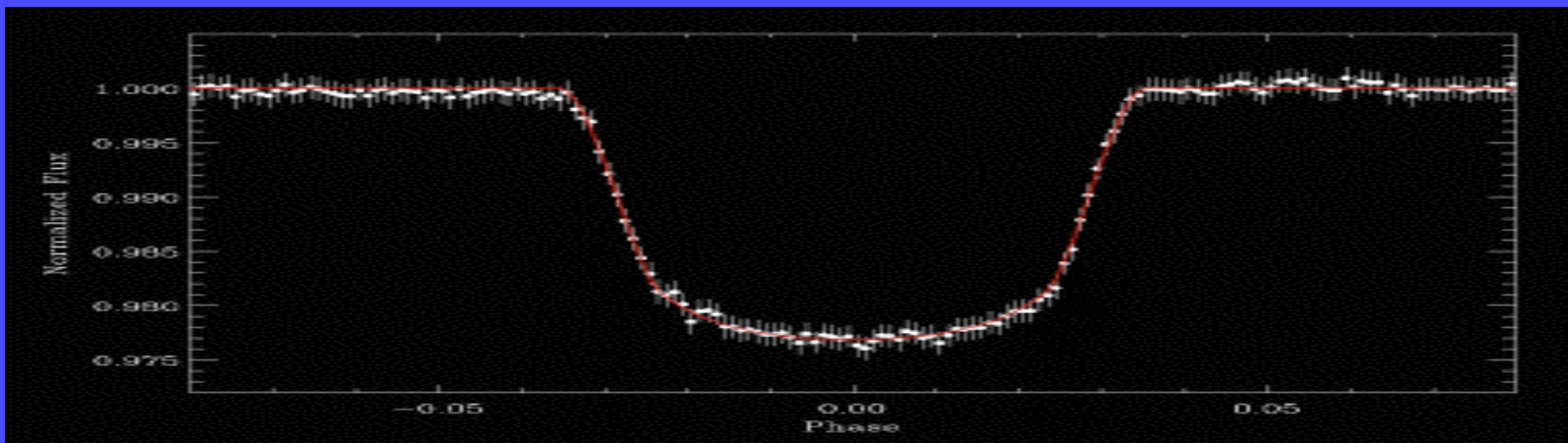
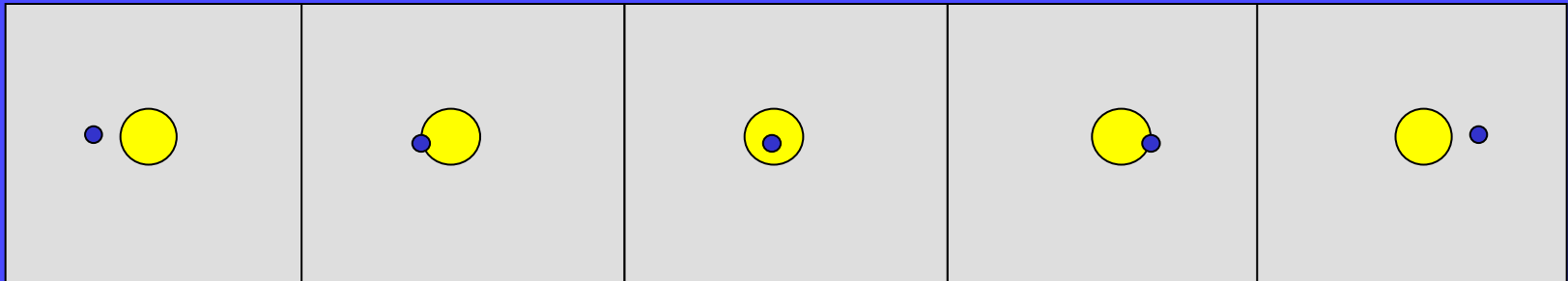
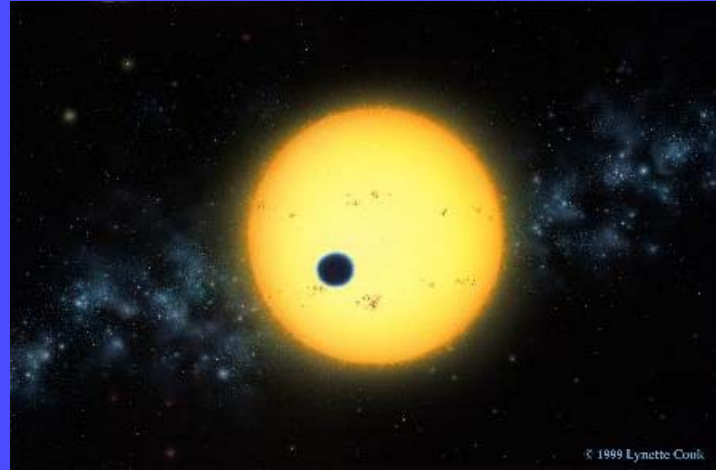
Velocimetría Radial



Astrometría



Fotometría de tránsito



Microlensing

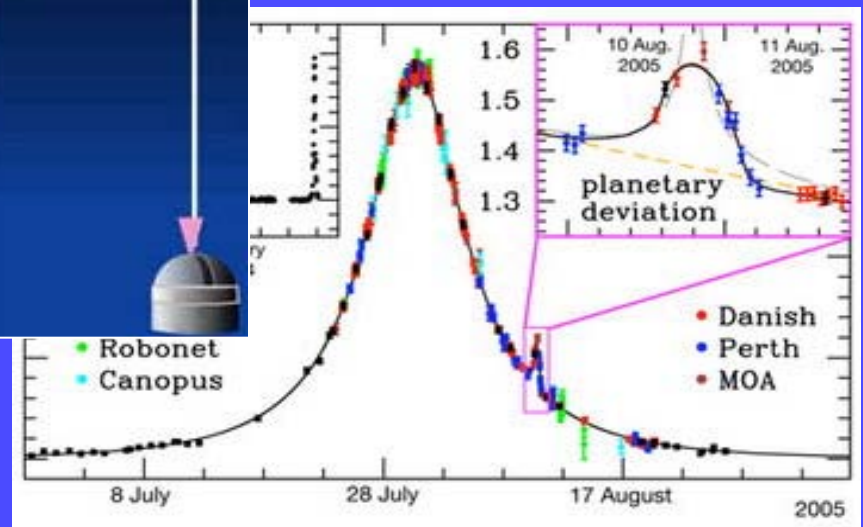
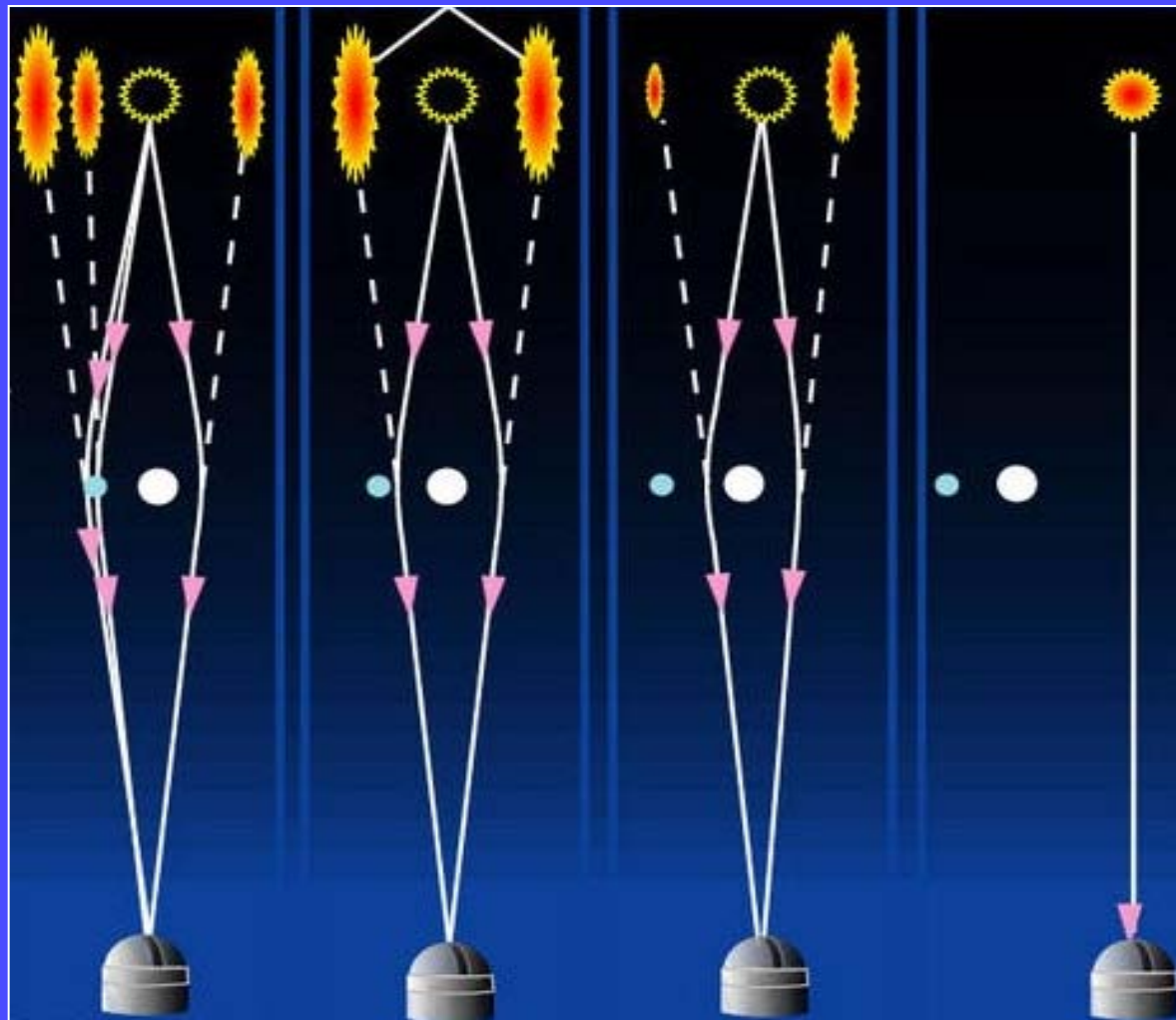
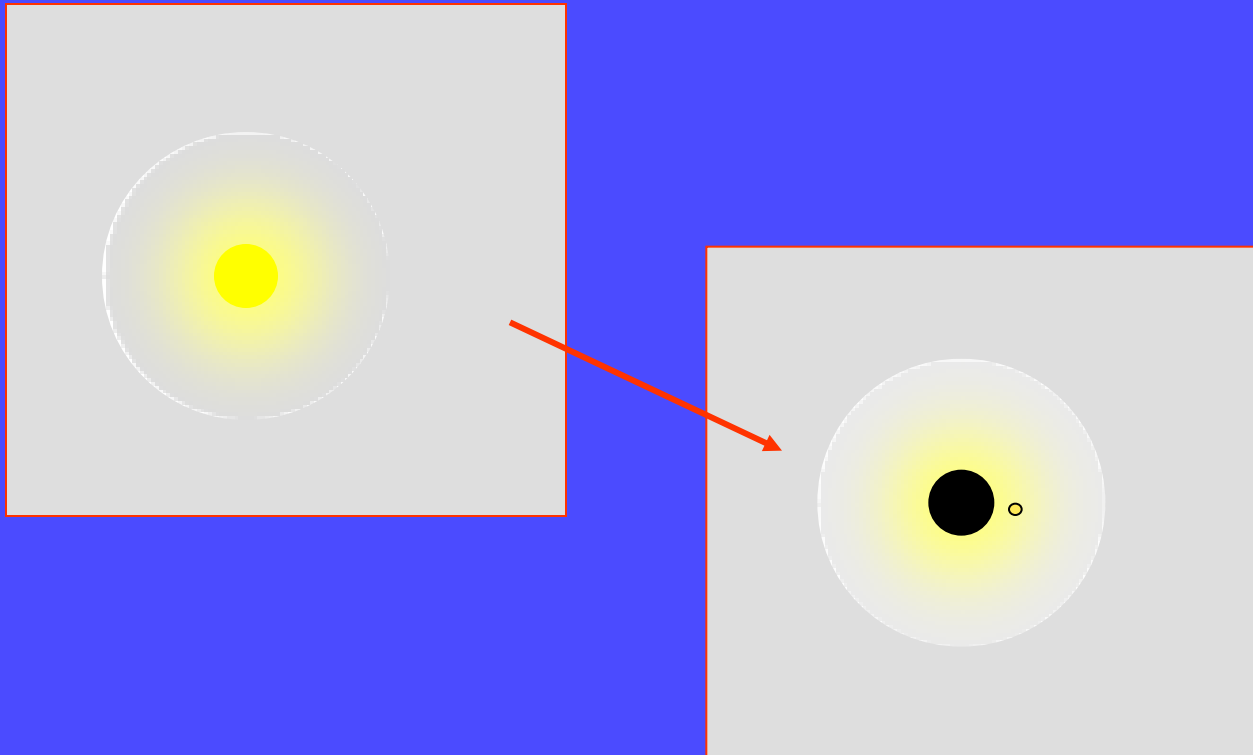


Imagen directa



Búsqueda de agua

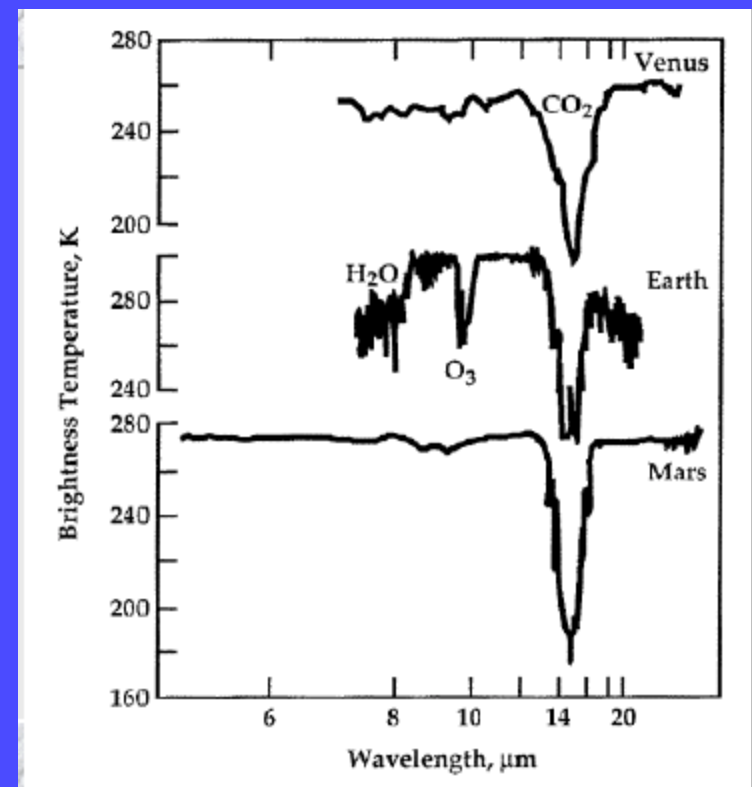
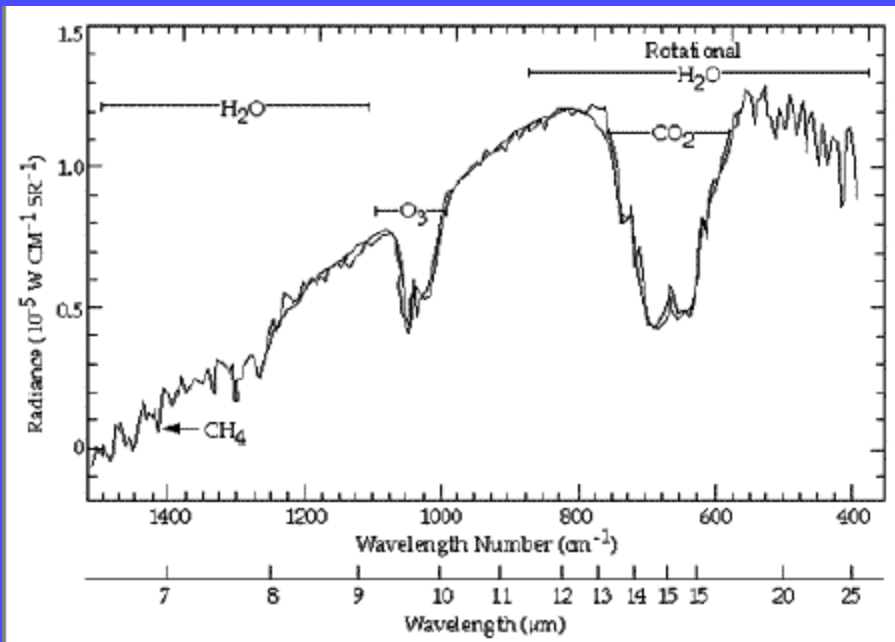
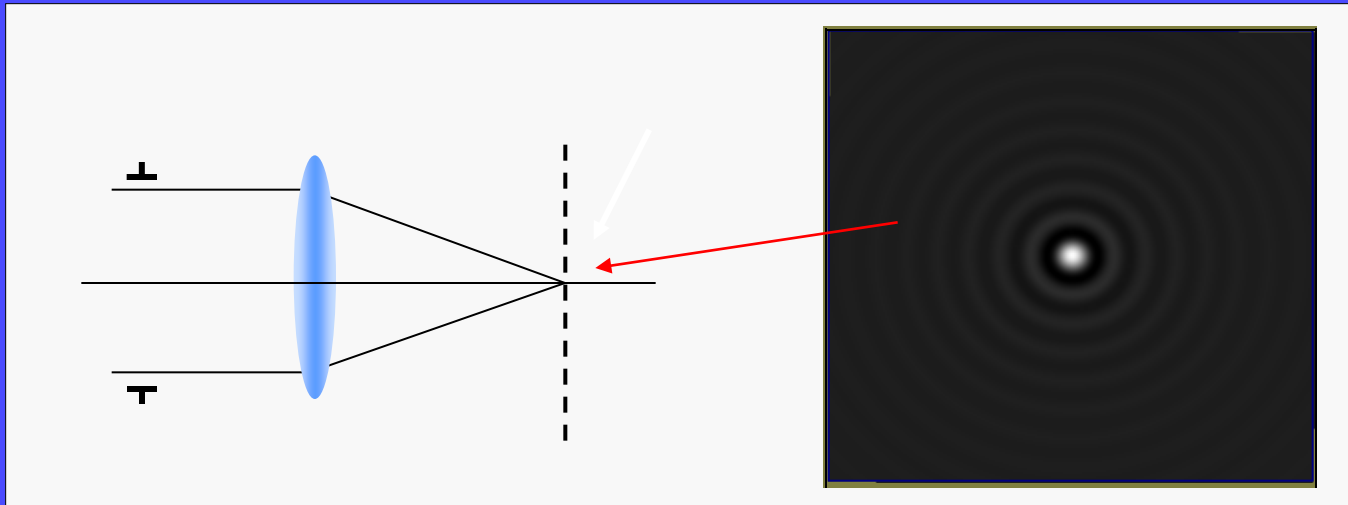
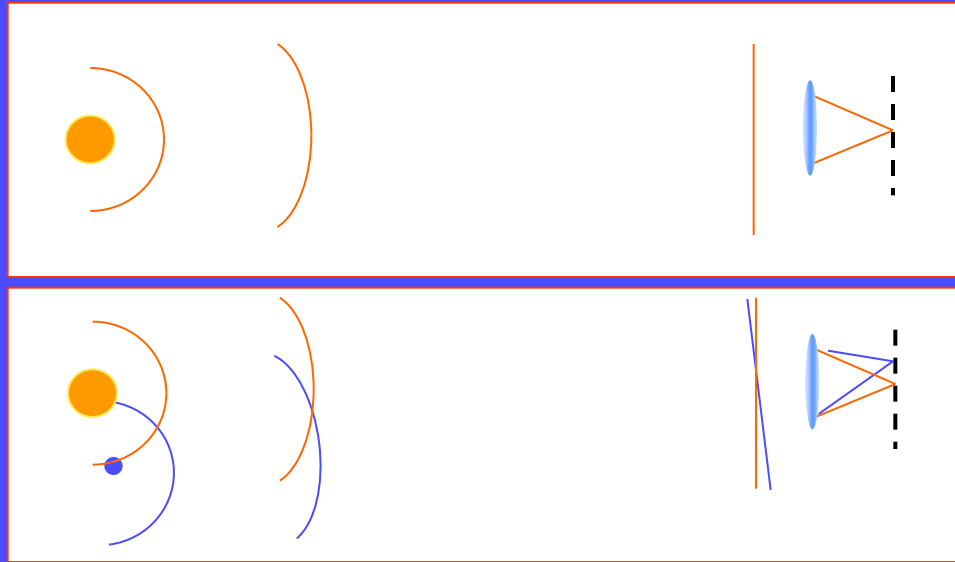
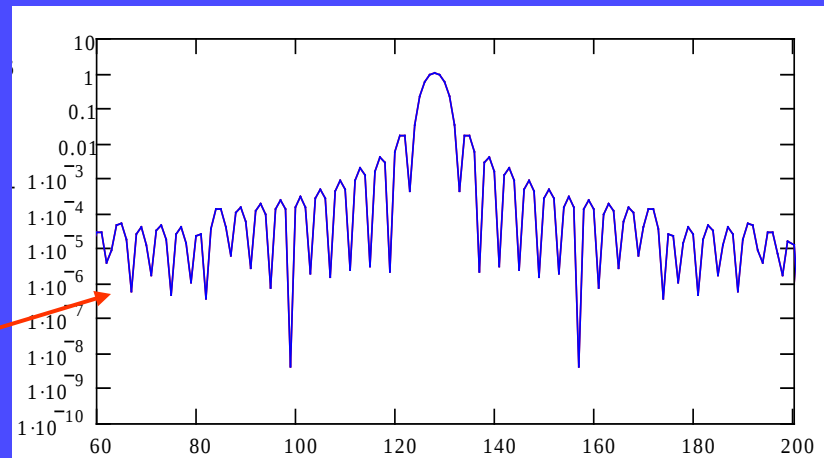
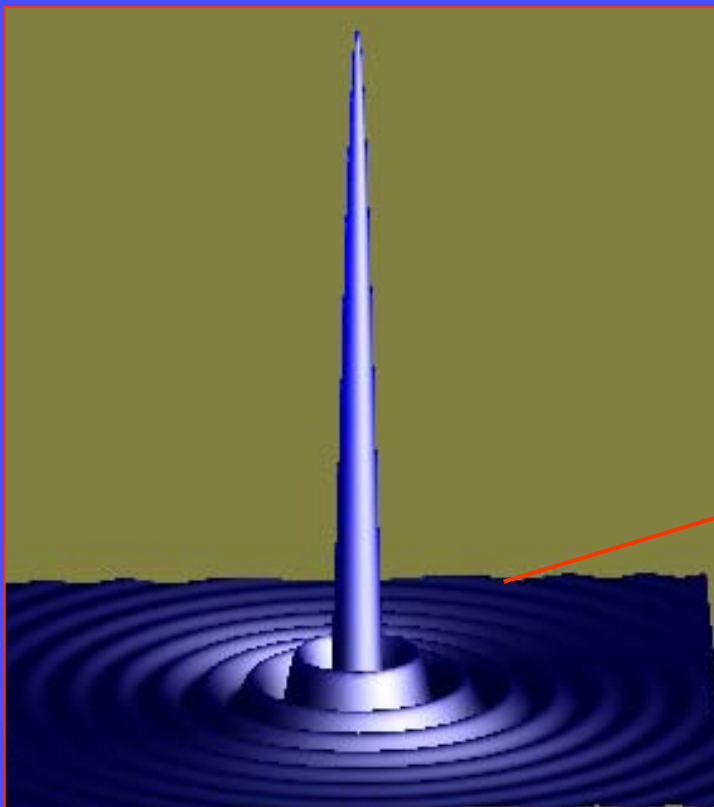
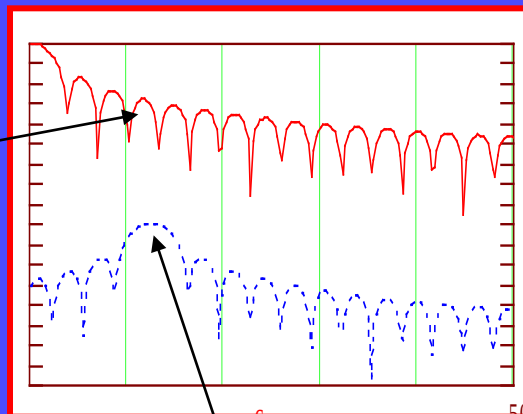


Imagen de un punto: PSF





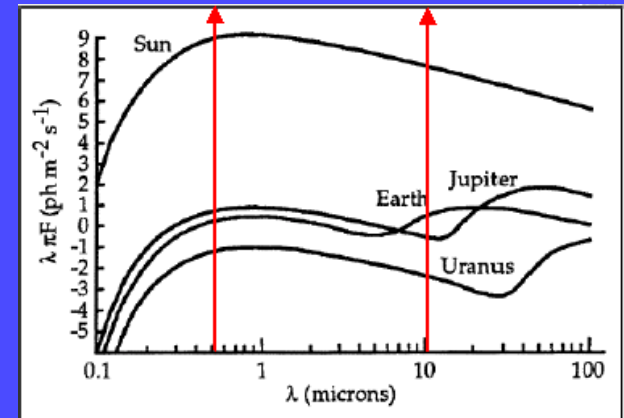
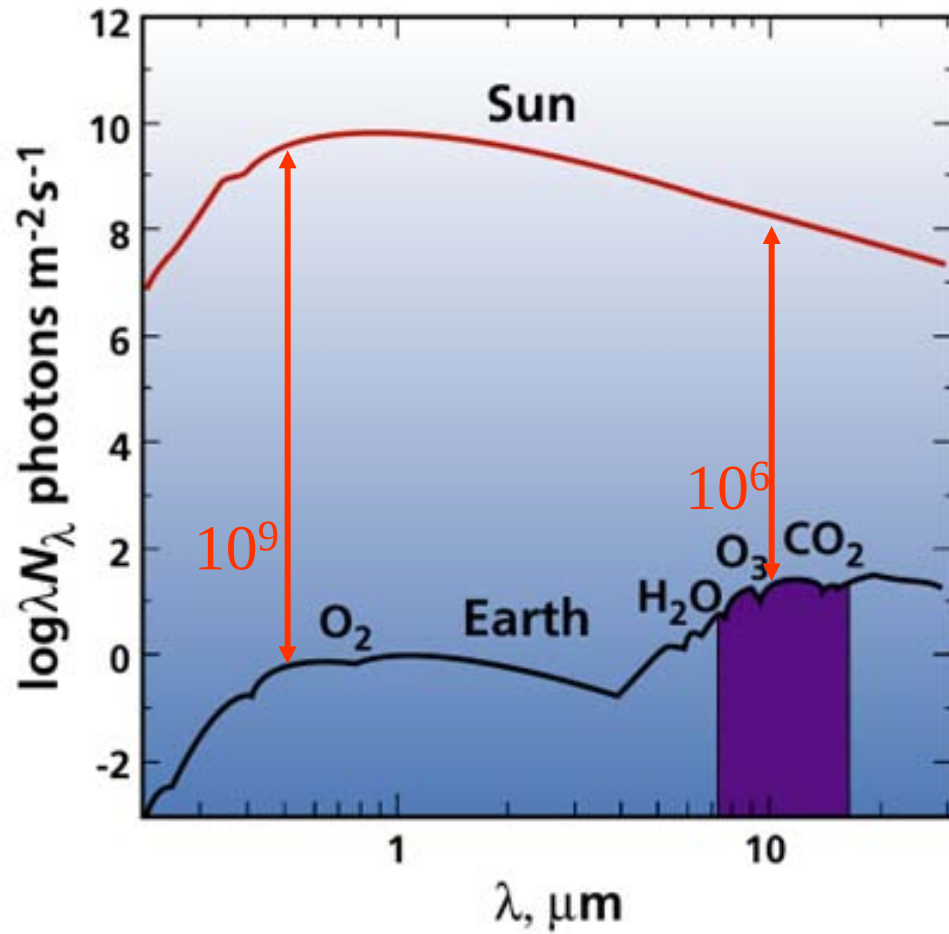
Estrella



Planeta

$$I_{\text{Estrella}} = 10^9 I_{\text{Planeta}}$$

Relación de intensidades



"Interferometric" coronagraphs

Achromatic Interferometric Coronagraph	AIC
Common Path AIC	CPAIC
Visible Nulling Coronagraph, X & Y shear, 4 th order	VNC
Pupil Swapping Coronagraph	PSC

Pupil Apodization

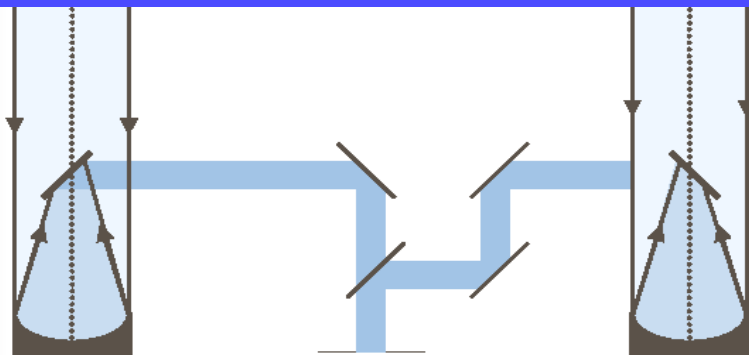
Conventional Pupil Apodization/ Shaped pupil	CPA
Achromatic Pupil Phase Apodization	PPA
Phase Induced Amplitude Apodization Coronagraph	PIAAC
Phase Induced Zonal Zernike Apodization	PIZZA

Improvement on the Lyot concept

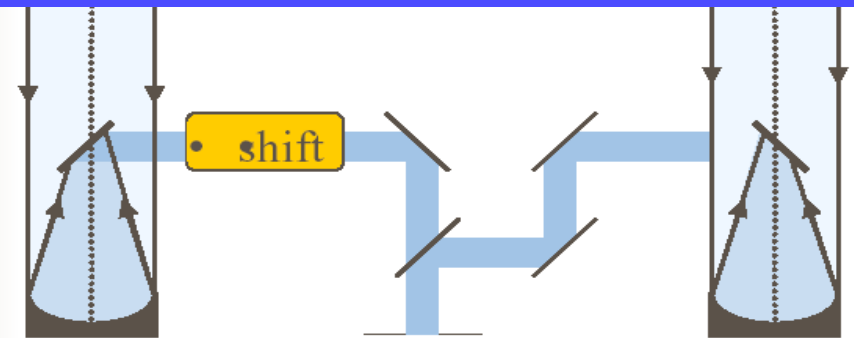
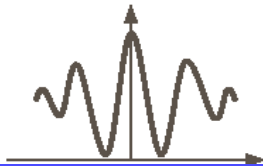
Apodized Pupil Lyot Coronagraph	APLC
Multistep APLC	APLC1, APLC2, APLC3...
Band Limited, 4 th order	BL4
Band Limited, 8 th order	BL8
Phase mask	PM
4 quadrant	4QPM
Achromatic Phase Knife Coronagraph	APKC
Optical Vortex Coronagraph, topological charge m	OVCm
Angular Groove Phase Mask Coronagraph	AGPMC
Optical Differentiation Coronagraph	ODC

(External Occulter)

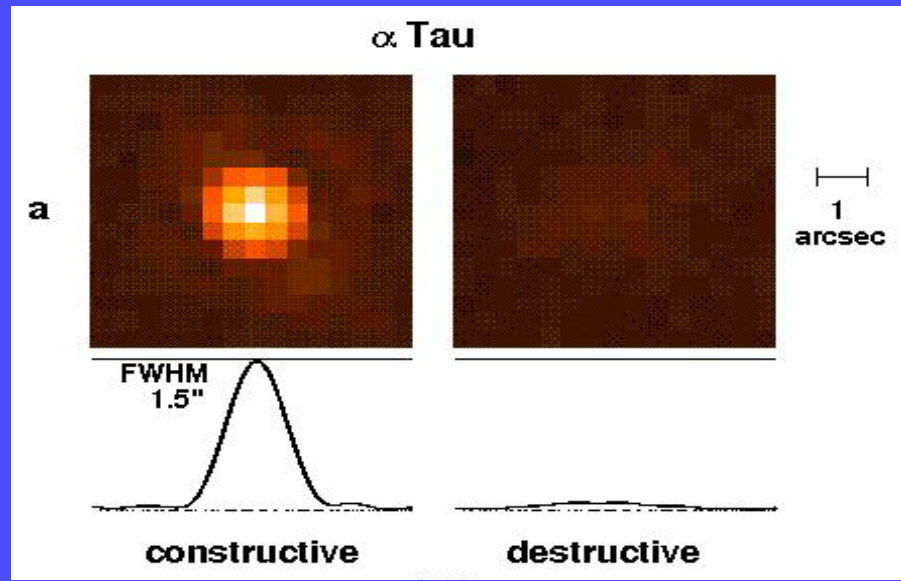
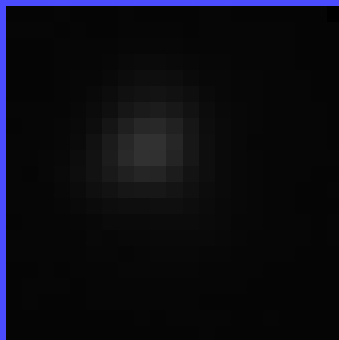
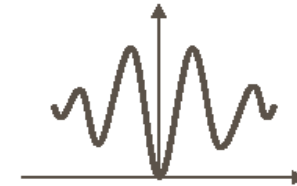
Interferómetro de nulo



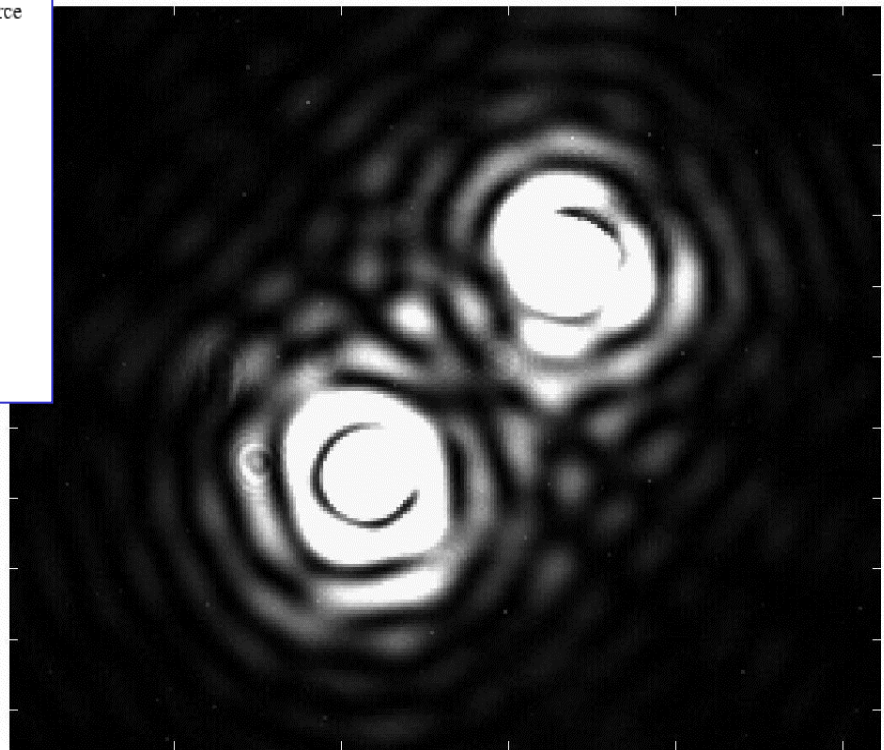
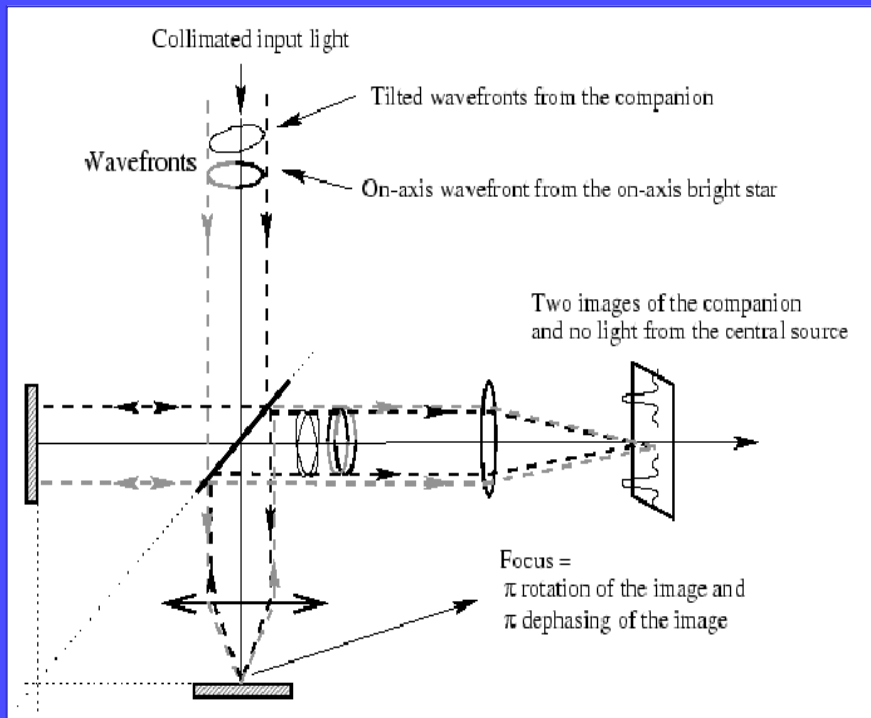
Constructive



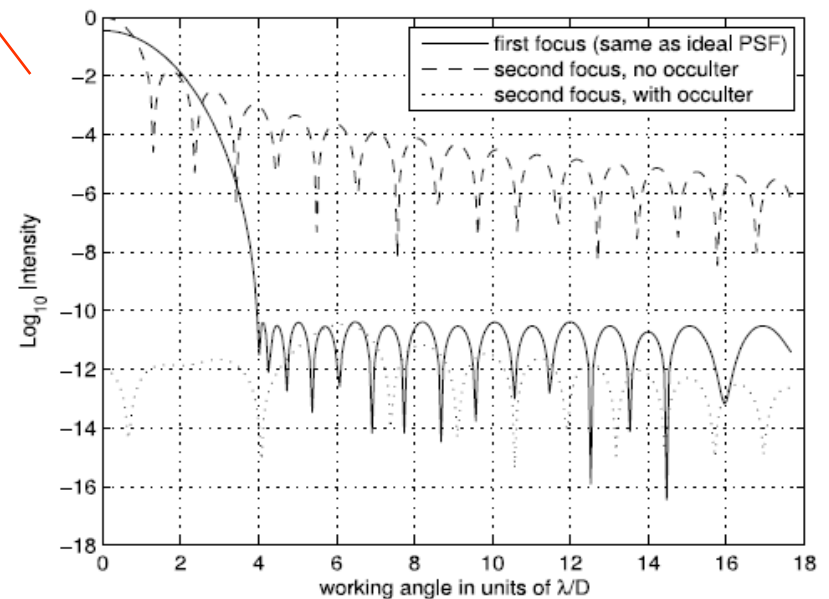
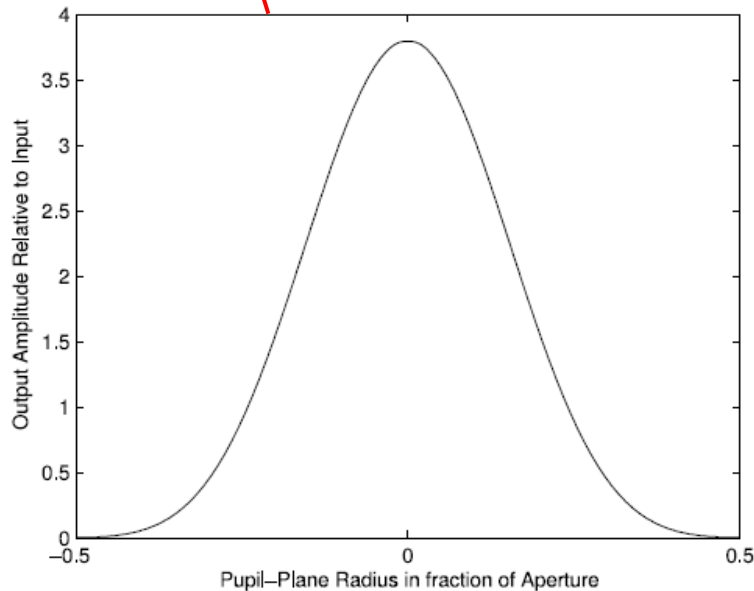
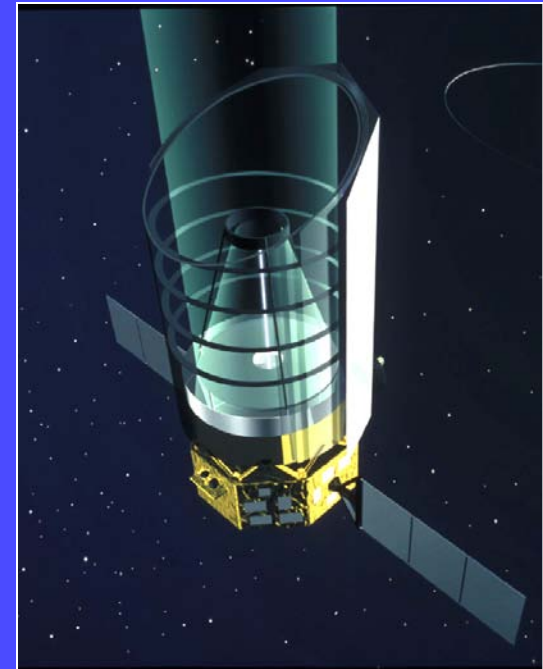
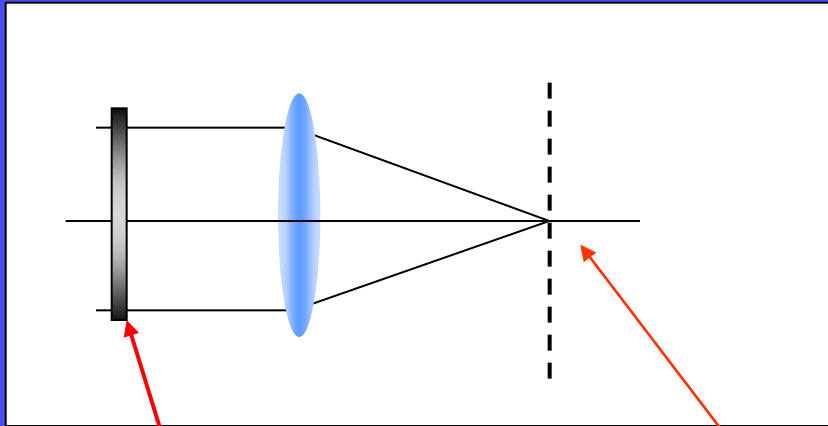
Destructive



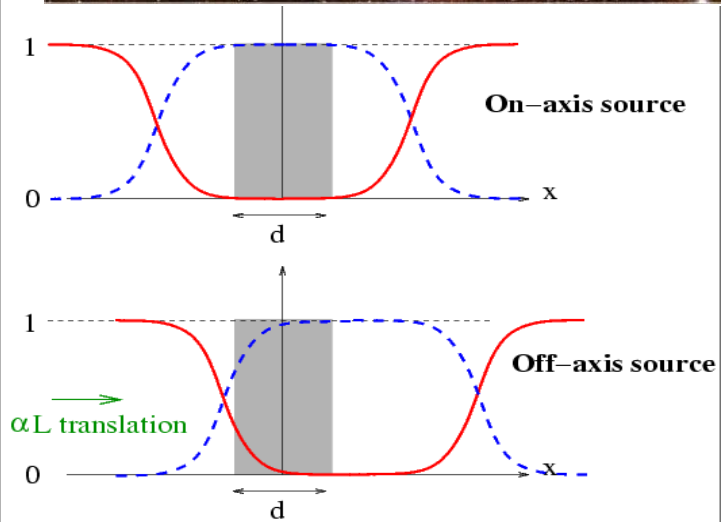
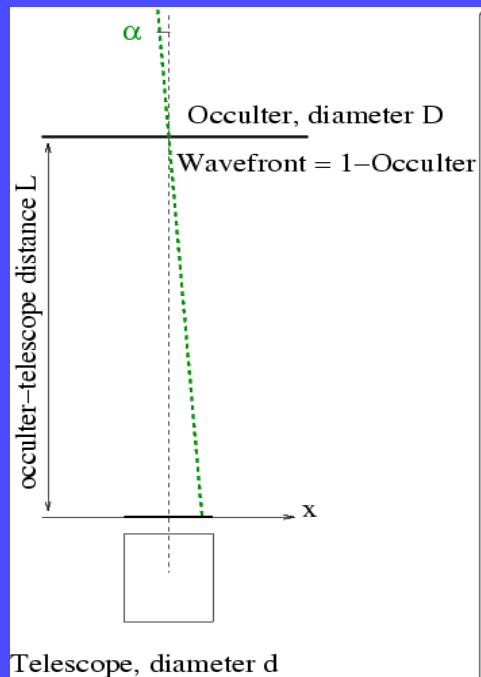
Interfero-coronografo



Apodizadores de pupila



Ocultador externo

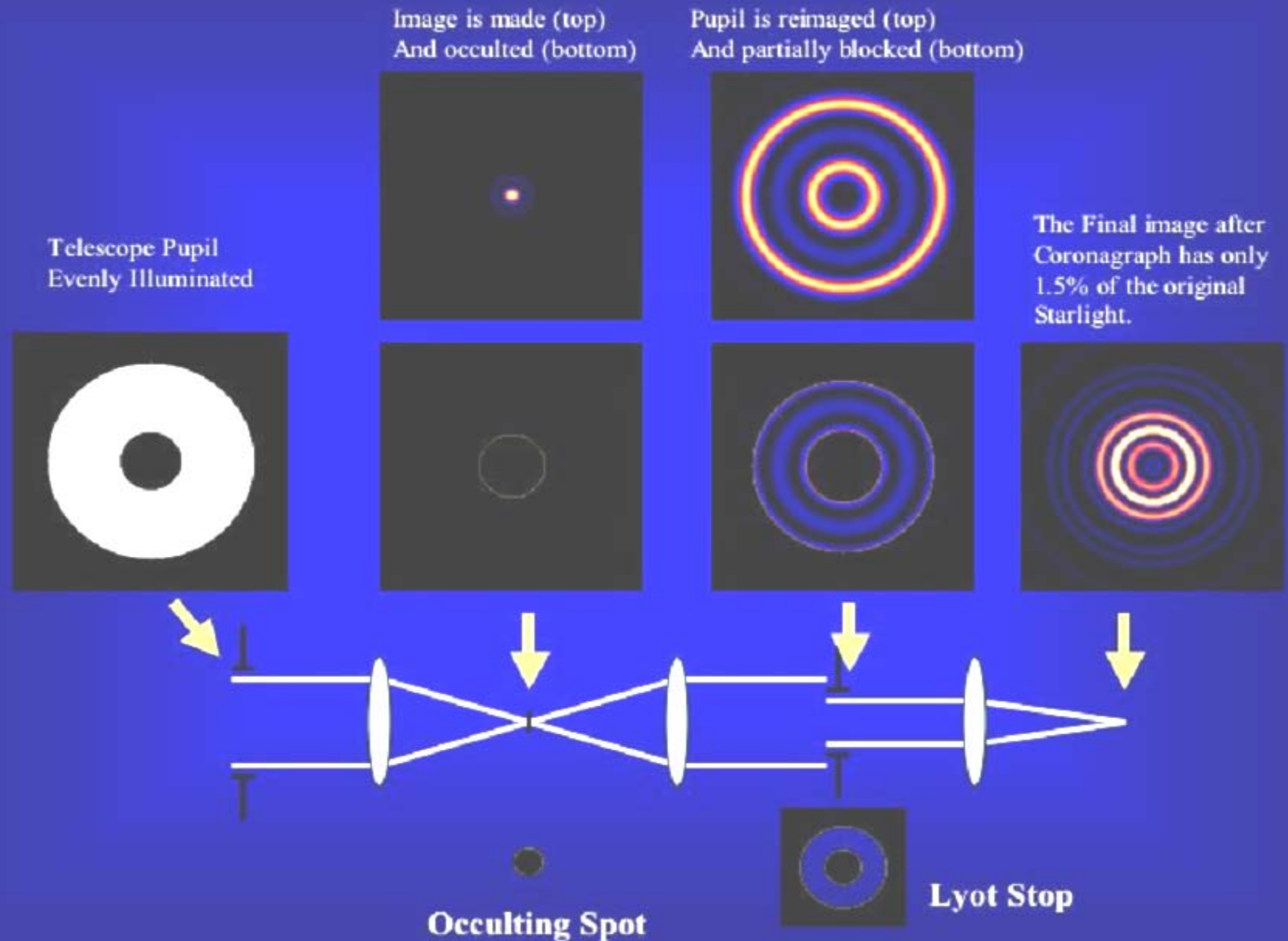


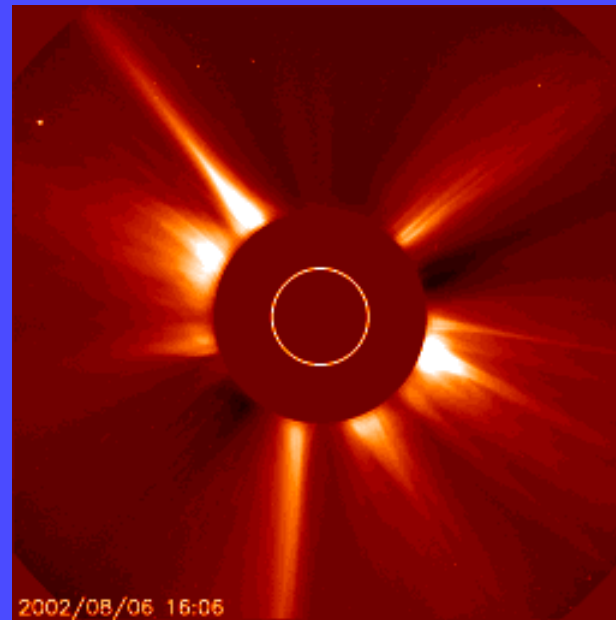
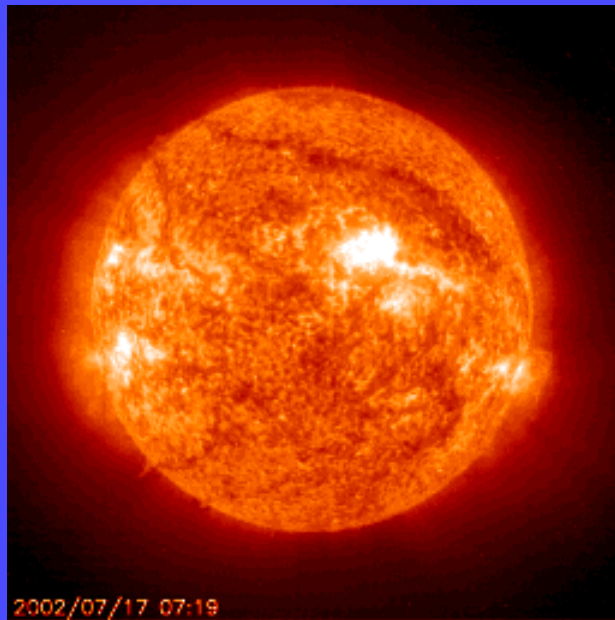
Coronografo



Bernard Lyot, 1939, at Pic du Midi
French Astronomer
Inventor of the Coronagraph

Coronografo



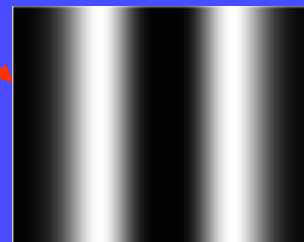
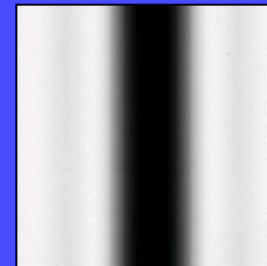
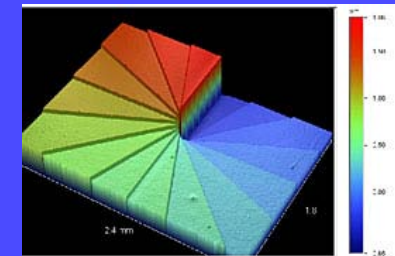
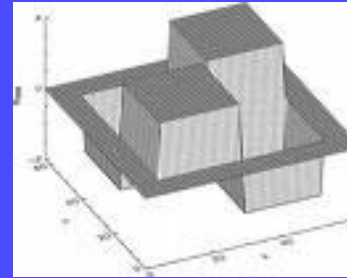


Phase-quadrant

Optical Vortex Coronagraph,

Band Limited, 4th, 8th order

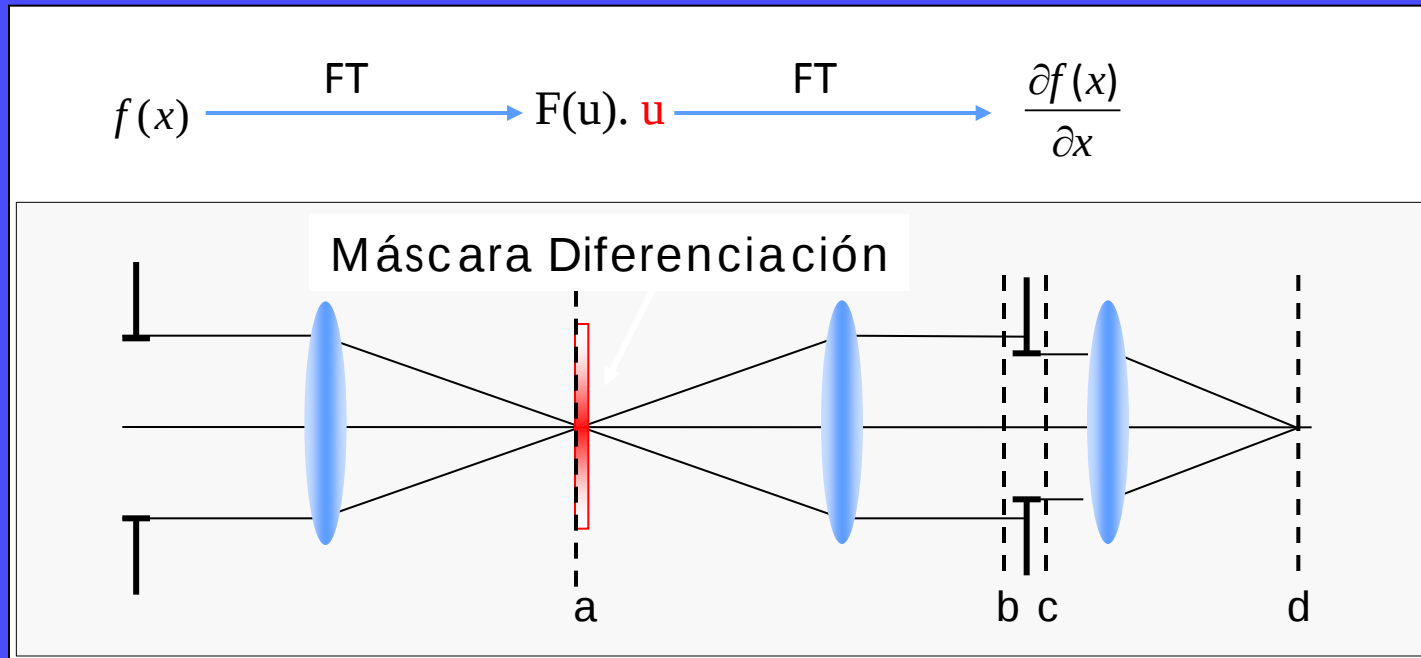
**Optical Differentiation
Coronagraph**

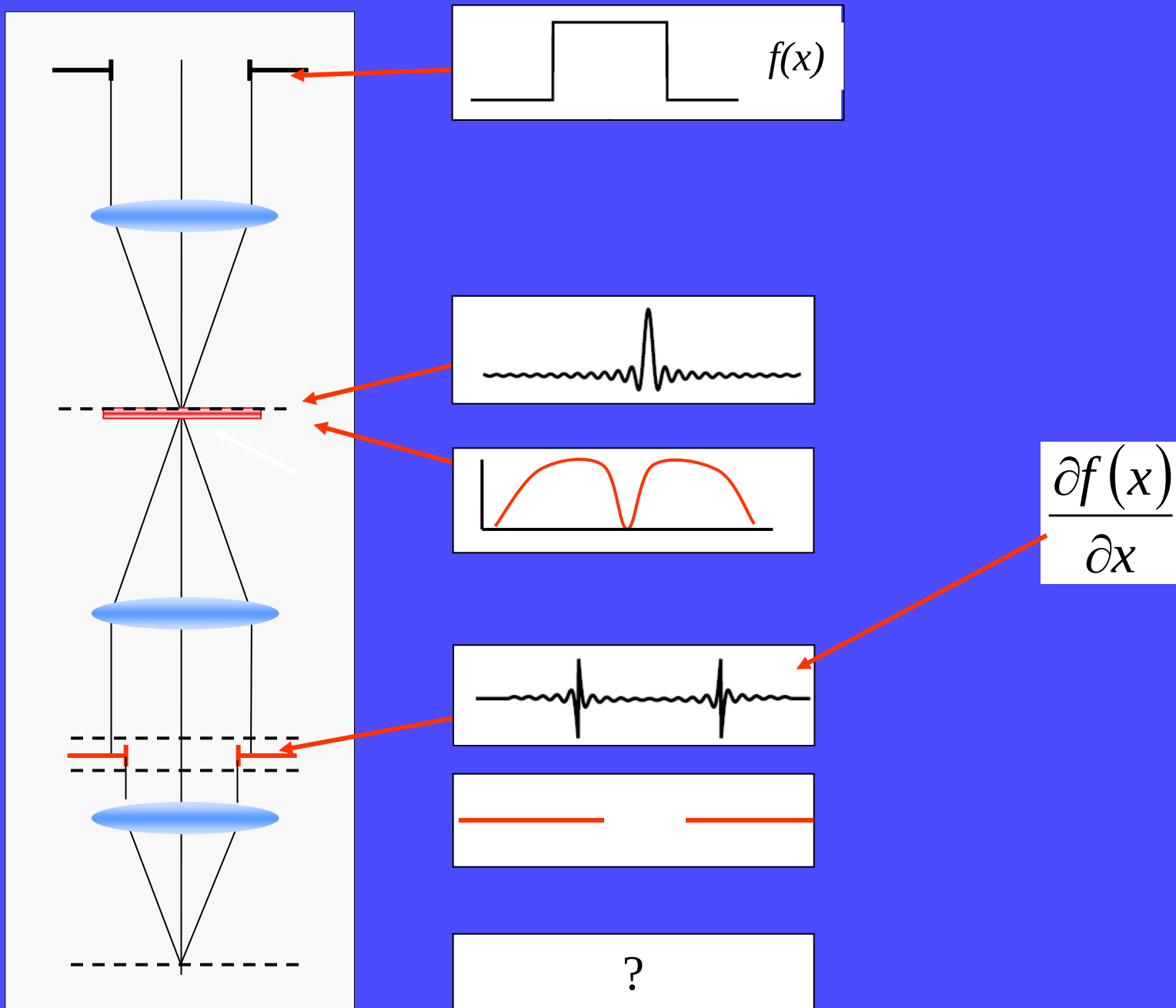


Diferenciación y Transformada de Fourier

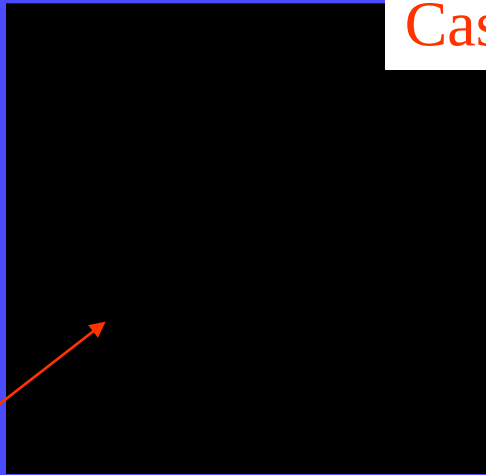
$$f(x) = \int_{-\infty}^{\infty} F(u) \cdot e^{2\pi i u x} du$$

$$\frac{df(x)}{dx} = \int_{-\infty}^{\infty} (2\pi i u) F(u) e^{2\pi i u x} du$$





Caso ideal

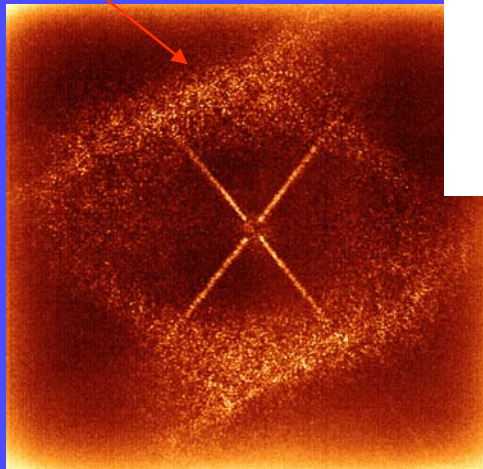


?

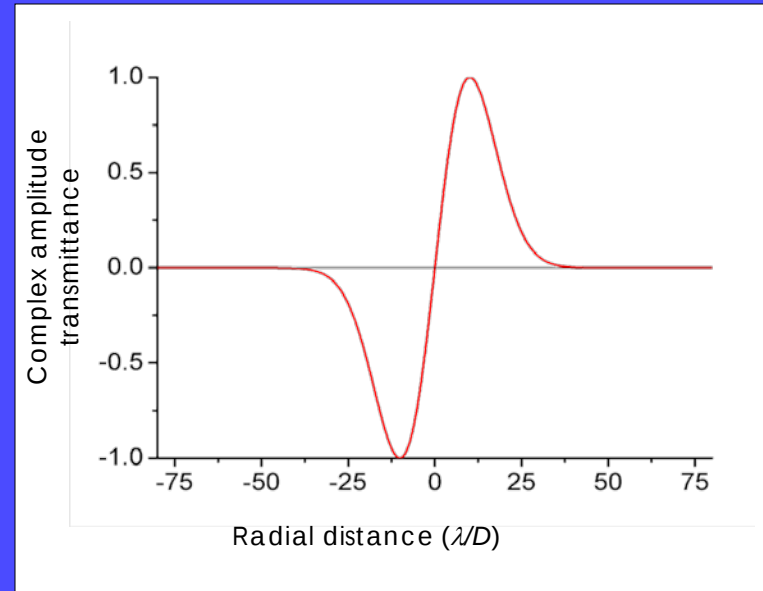
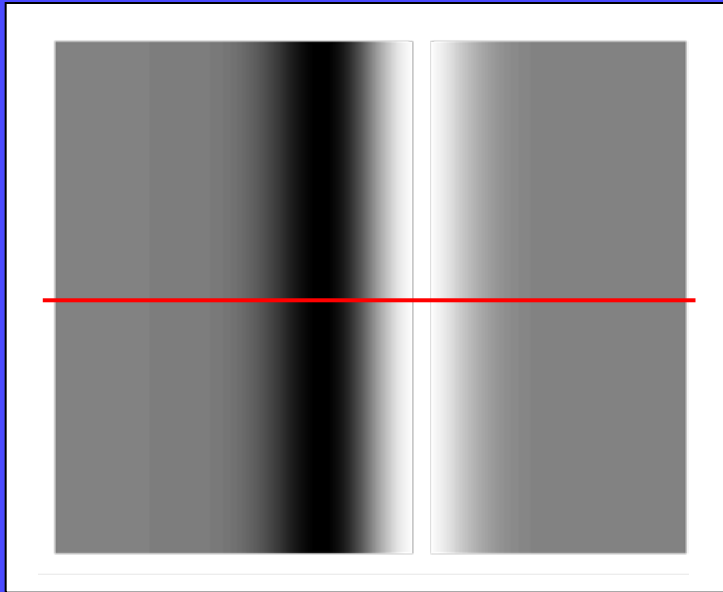
Caso real:

Imperfecciones instrumento

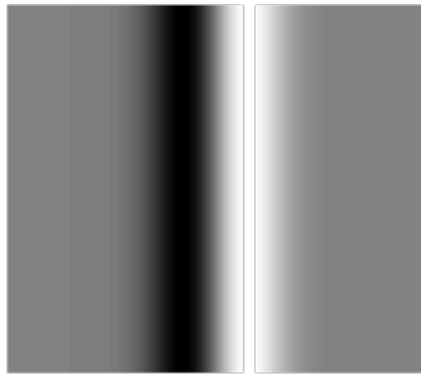
Imperfecciones mascara



Mascaras de Diferenciación



$$2\pi ui$$



$$(2\pi u)^2$$



$$(2\pi)^2 \cdot (u^2 + v^2)$$



Inciso sobre Funciones de Hermite

$$H_n(x) = (-1)^n e^{x^2} \frac{d}{dx^n} e^{-x^2}$$

Polinomios de Hermite

$$M_n(x, v) = \frac{1}{\sqrt{n! 2^n \sqrt{\pi}}} \exp\left(-\frac{x^2}{2v}\right) H_n(x)$$

Funciones de Hermite

$$\text{FT}\left[M_n(x, v)\right](u) = \sqrt{2\pi v} (2v-1)^{n/2} i^n M_n\left(\frac{2\pi v}{\sqrt{2v-1}} u, \frac{v}{2v-1}\right)$$

Funciones propias
para la TF

$$MC_2(x, v) = M_2(x, v) + \frac{1}{\sqrt{2}} M_0(x, v) = \frac{1}{\sqrt{2! 2^2 \sqrt{\pi}}} \exp\left(-\frac{x^2}{2v}\right) [H_2(x) + 2H_0(x)]$$

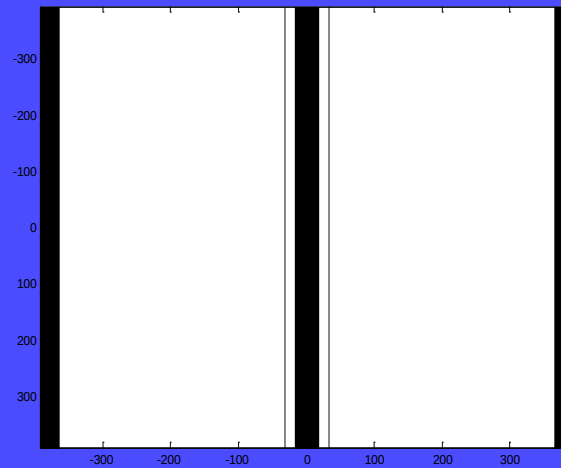
Mascara Derivada Segunda como comb. lineal de Funciones de Hermite

Diferentes procedimientos de binarización

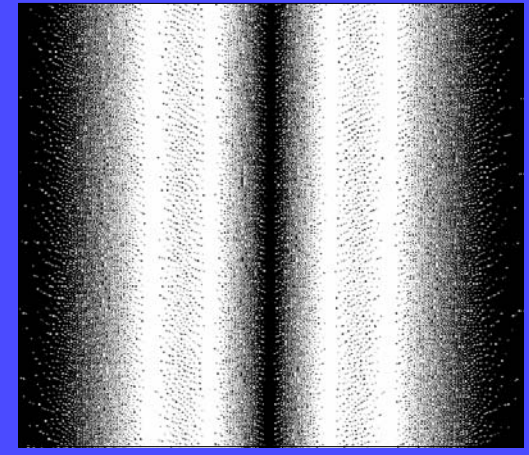
Notch



IFTA

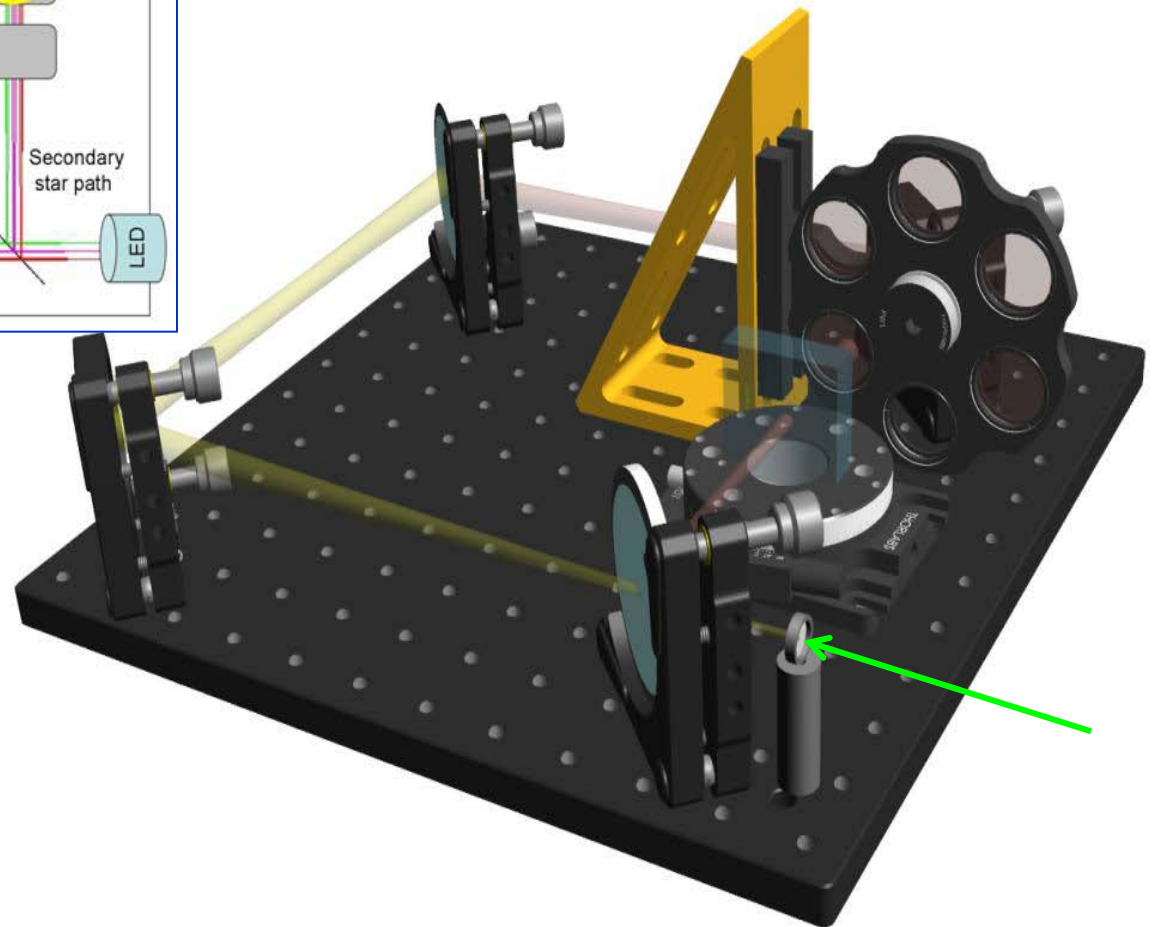
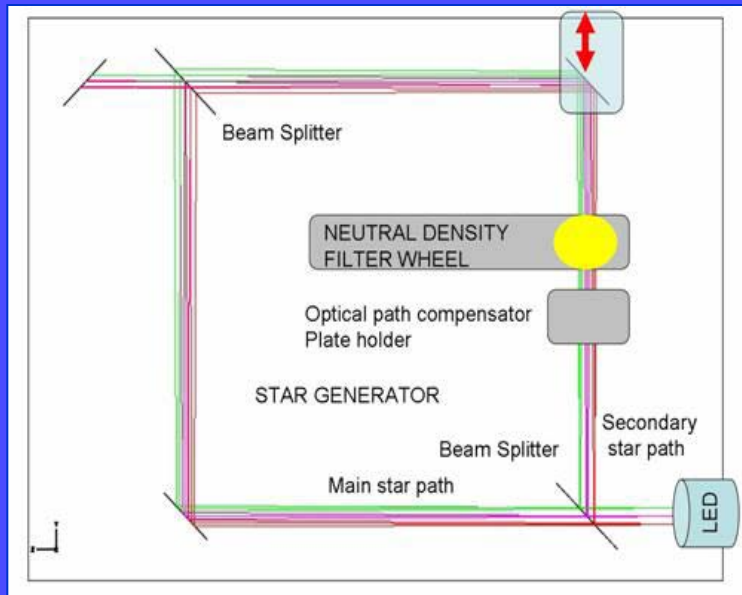


Error dispersion

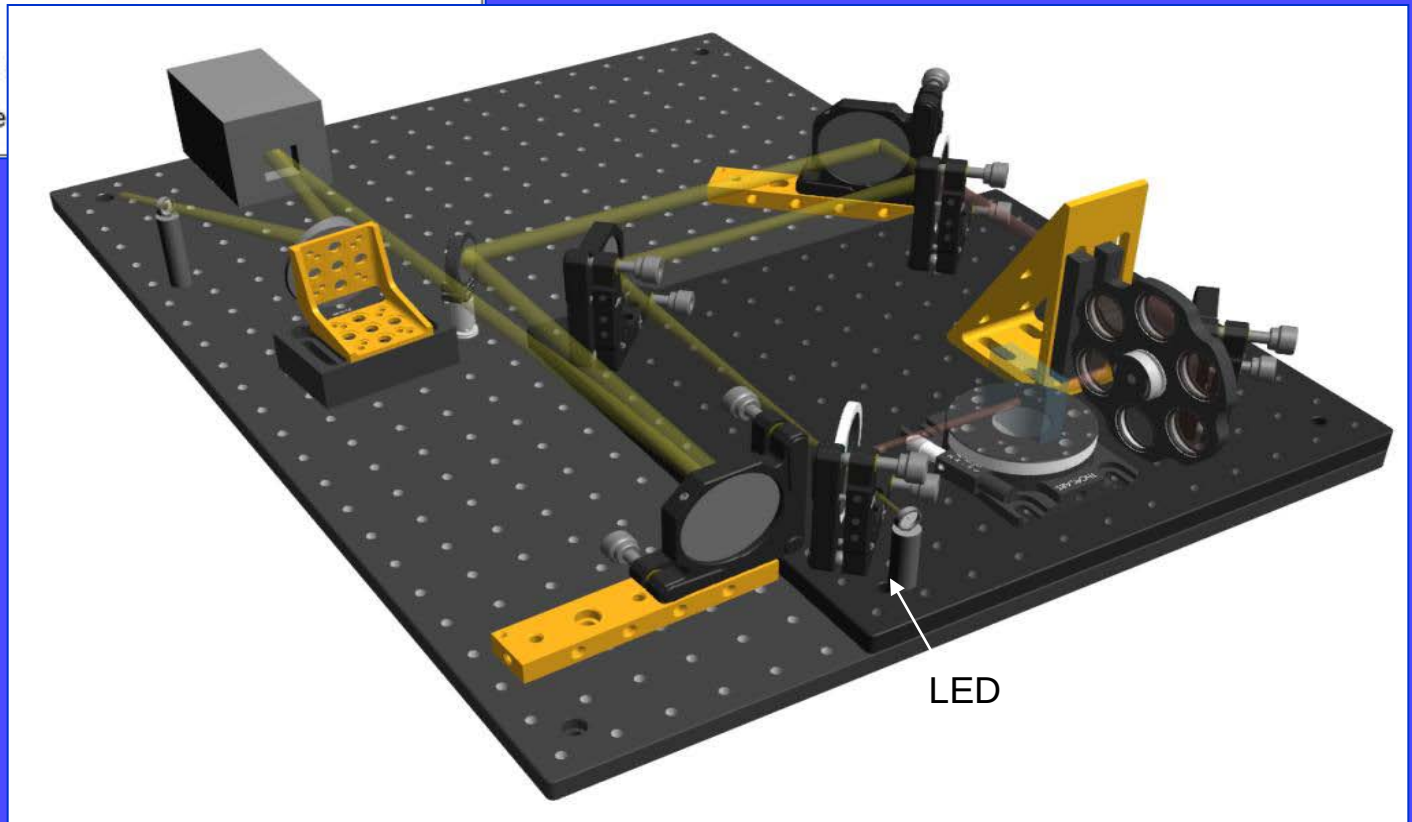
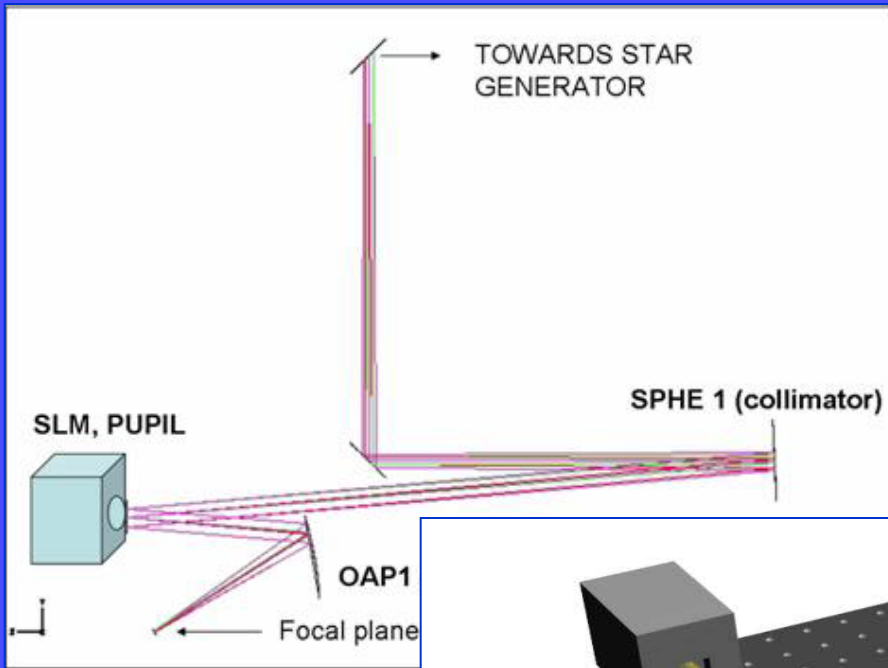


Pup3D

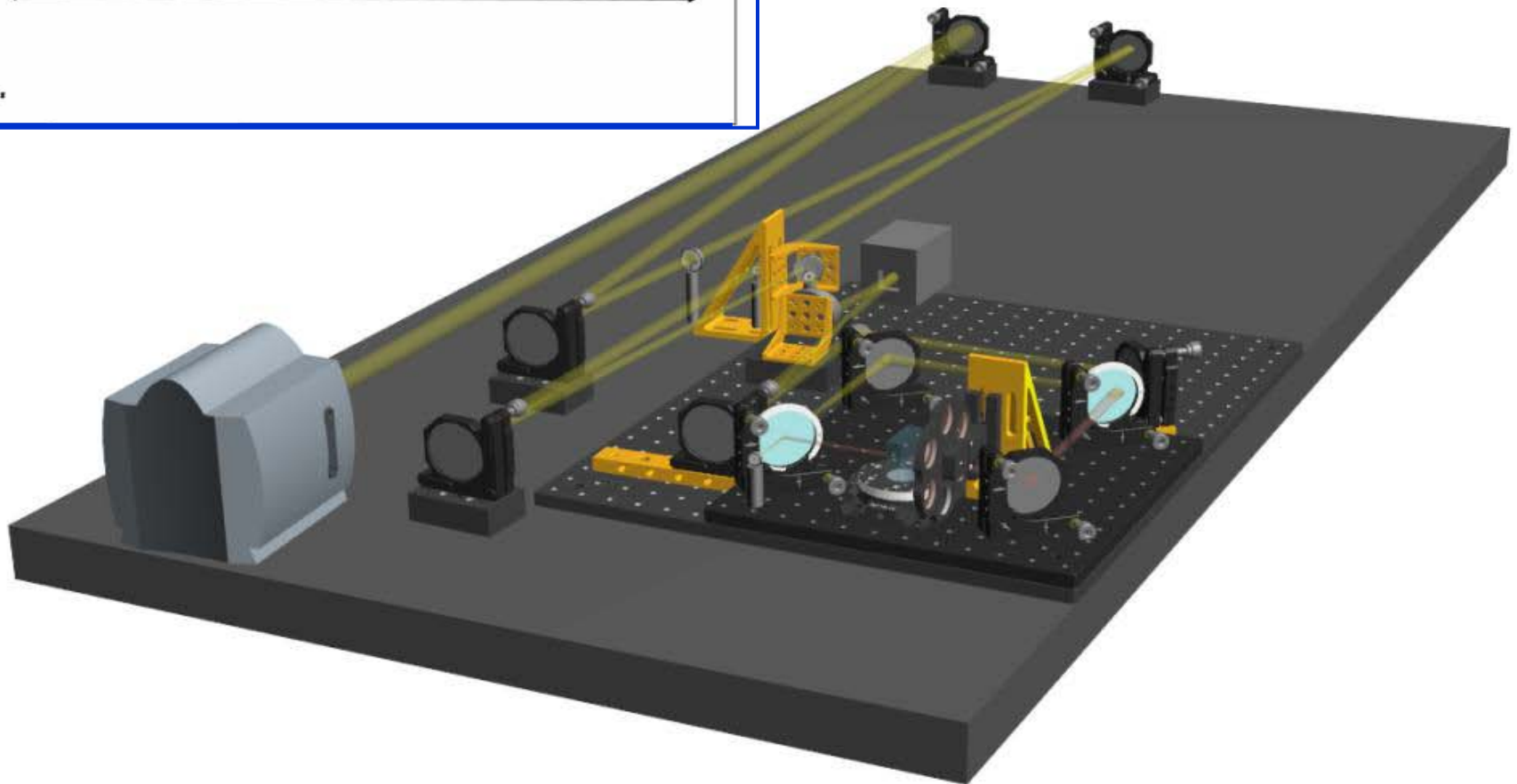
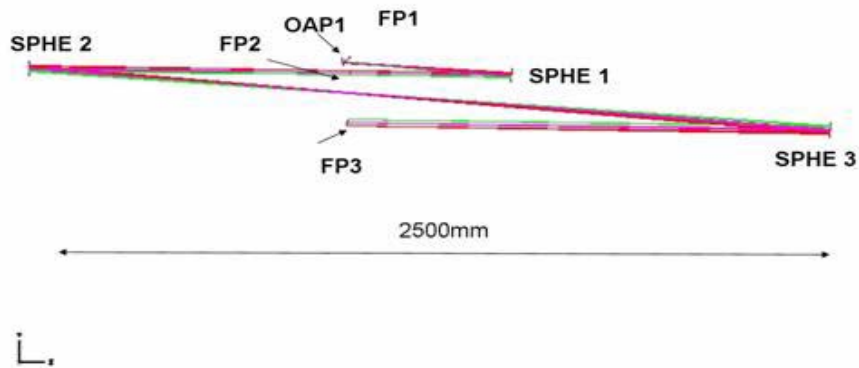
Simulador Estrella-Planeta



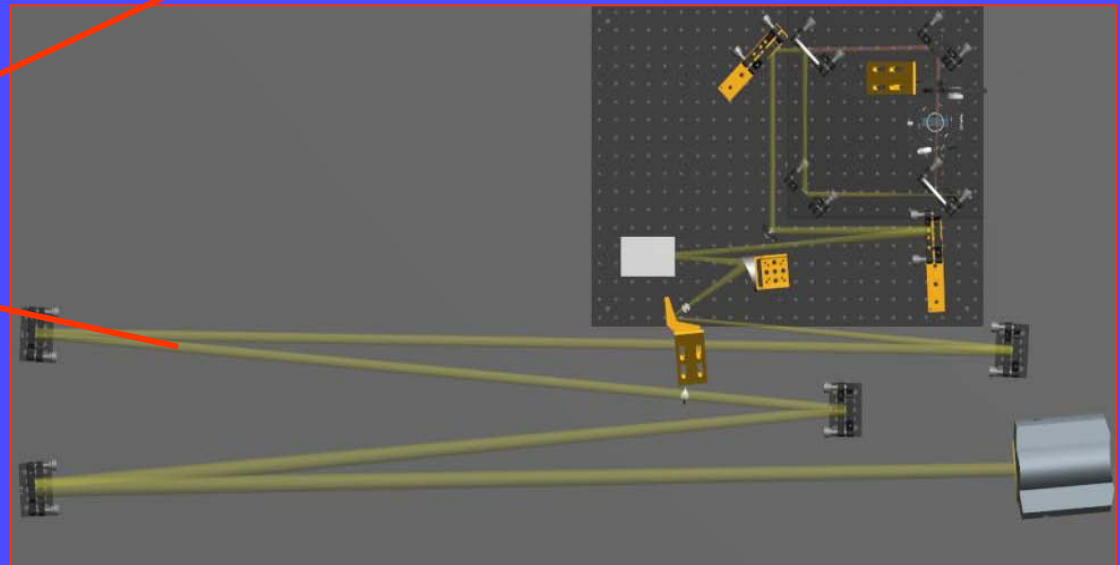
Simulador Telescopio CaHa



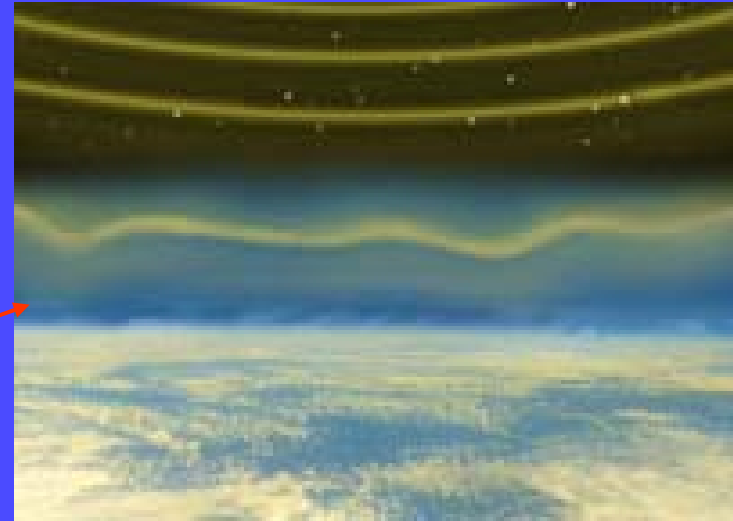
Simulador + Coronógrafo



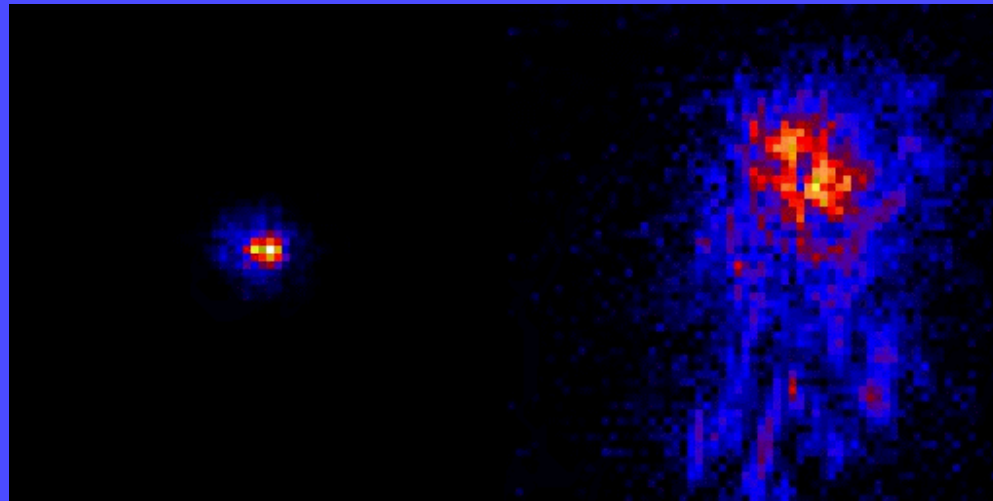
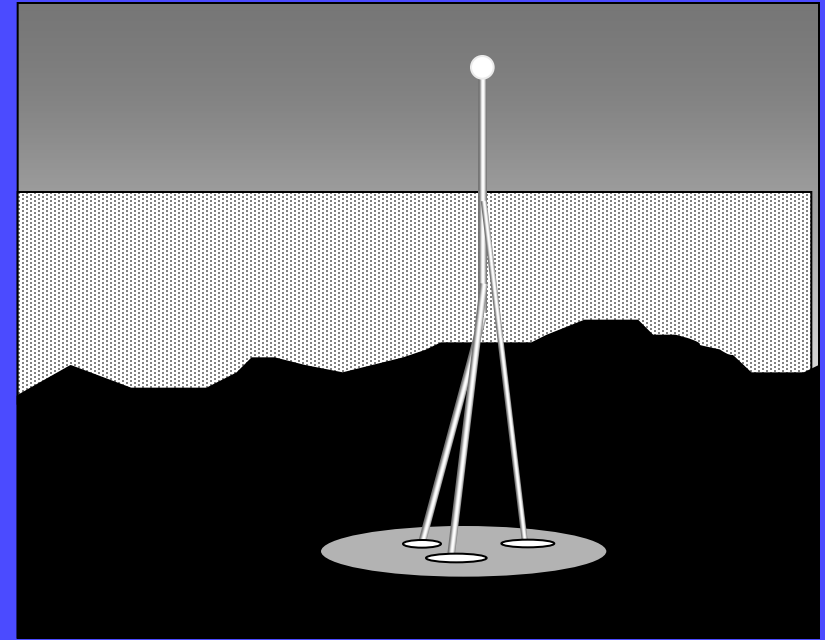
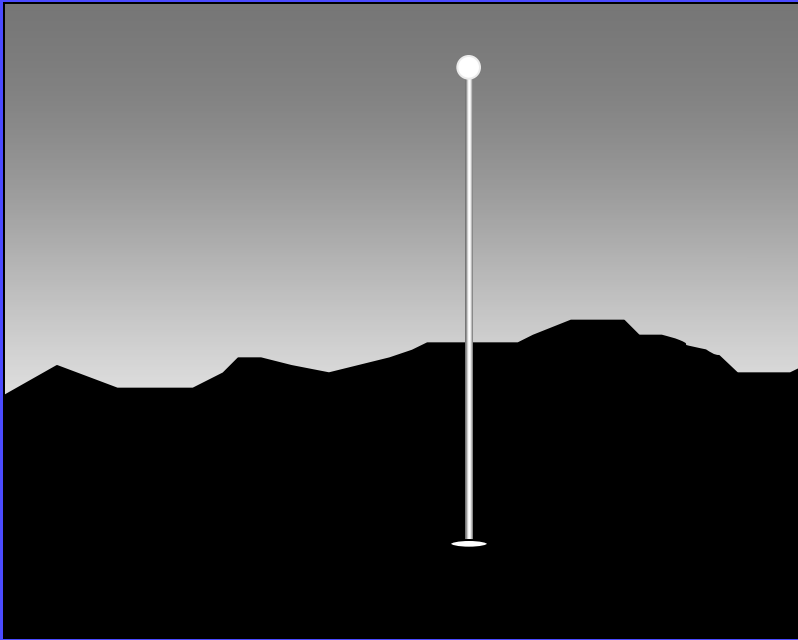
Telescopio Calar Alto



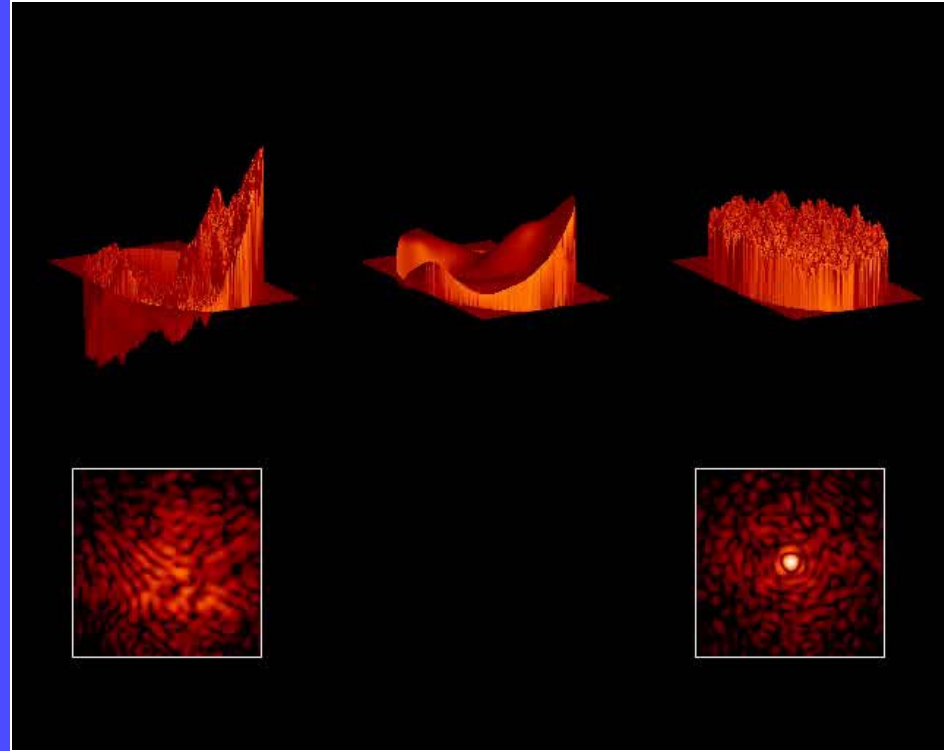
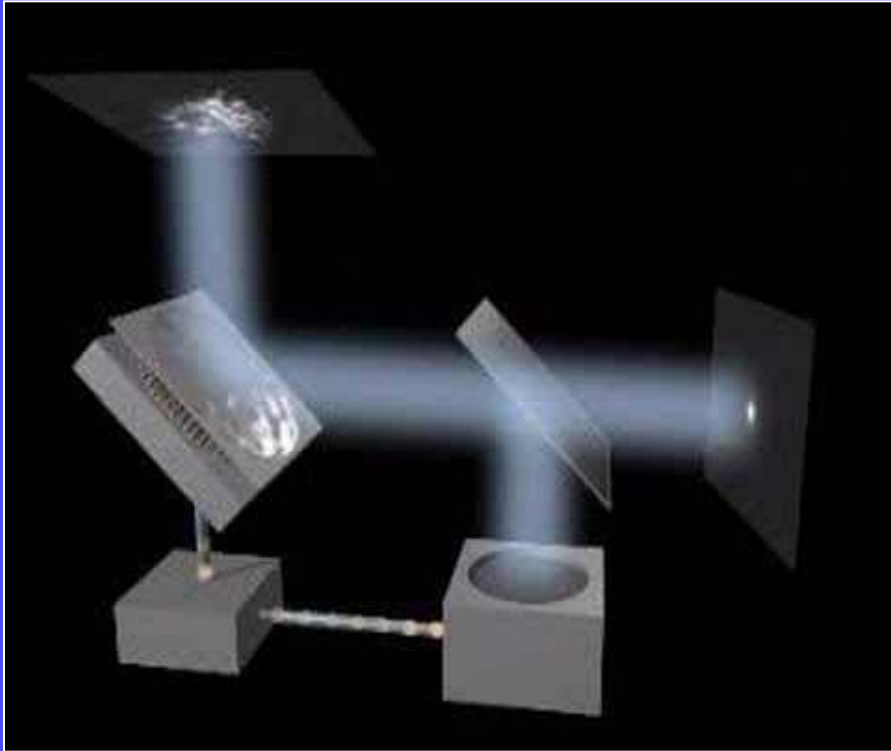
Efecto de la atmosfera



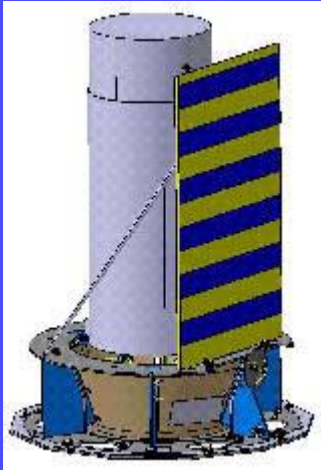
Efecto de la atmosfera



Solución en tierra

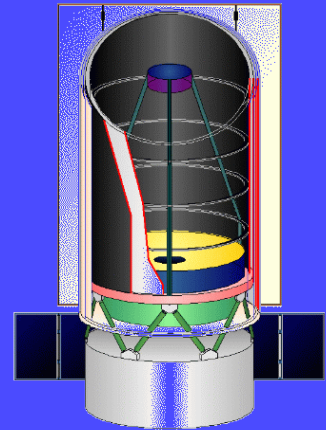


Solución en el espacio



SEE-COAST: The Super-Earth Explorer. ESA

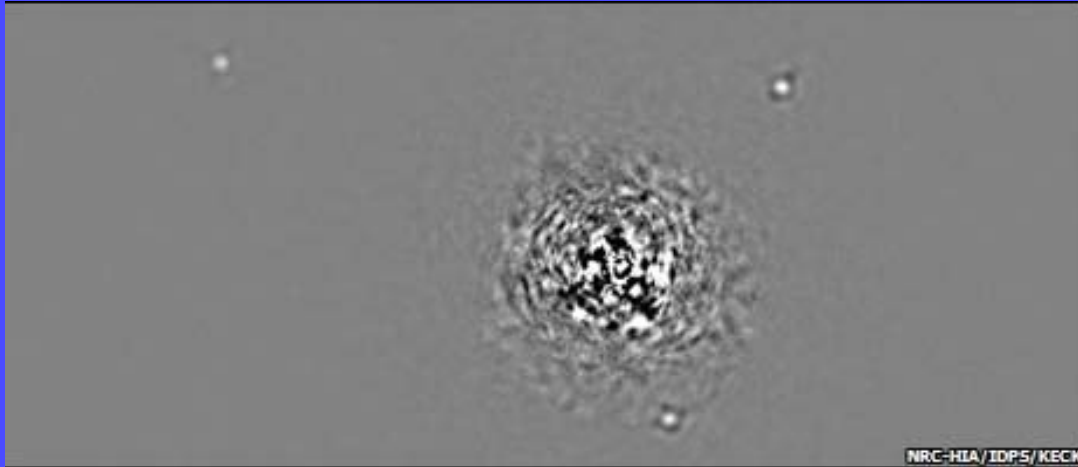
(Sp)ace (I)nfrared Telescope for
(C)osmology and (A)strophysics



Terrestrial Planet Finder Coronagraph. NASA



HR 8799



HR 8799 es una estrella en la constelación de Pegaso de magnitud +5,96 que se encuentra a 129 años luz del Sistema Solar. En 2008 se anunció el descubrimiento de tres planetas en su órbita, siendo el primer sistema planetario múltiple del que se ha obtenido una imagen directa.

Nombre	Masa	Separación proyectada	Periodo orbital	Radio
HR 8799 d	$10 \pm 3 M_J$	24 UA	36.500 días	$1,2 \pm 0,1 R_J$
HR 8799 c	$10 \pm 3 M_J$	38 UA	69.000 días	$1,2 \pm 0,1 R_J$
HR 8799 b	$7 (-2/+4) M_J$	68 UA	170.000 días	$1,1 \pm 0,1 R_J$