Innovations Foresight

STAR WAVES

POWERED BY ALCOR SYSTEM

Astronomical wavefront analyzer

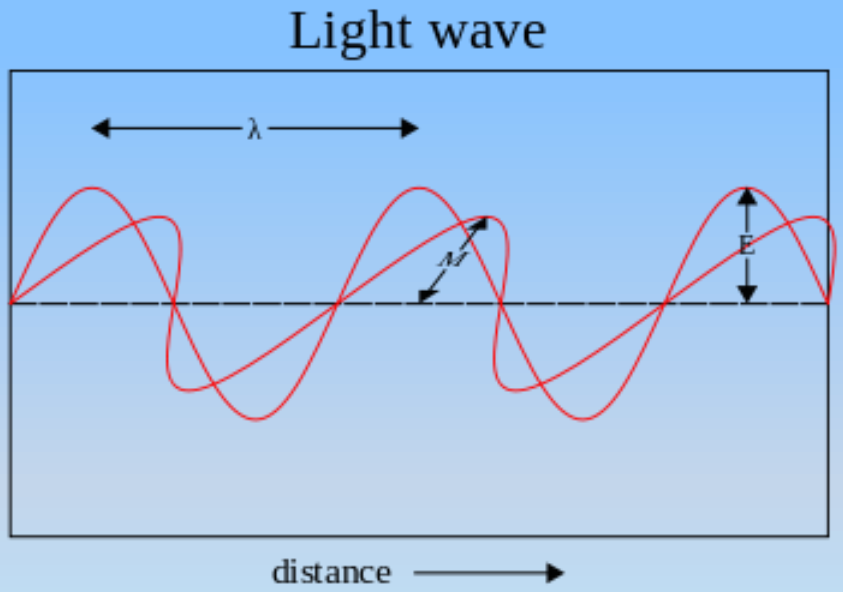
Northeast Astro-Imaging Conference 2015

Dr. Gaston Baudat

Innovations Foresight, LLC

The nature of light

By nature the light is a wave propagation phenomena.



λ = wave length

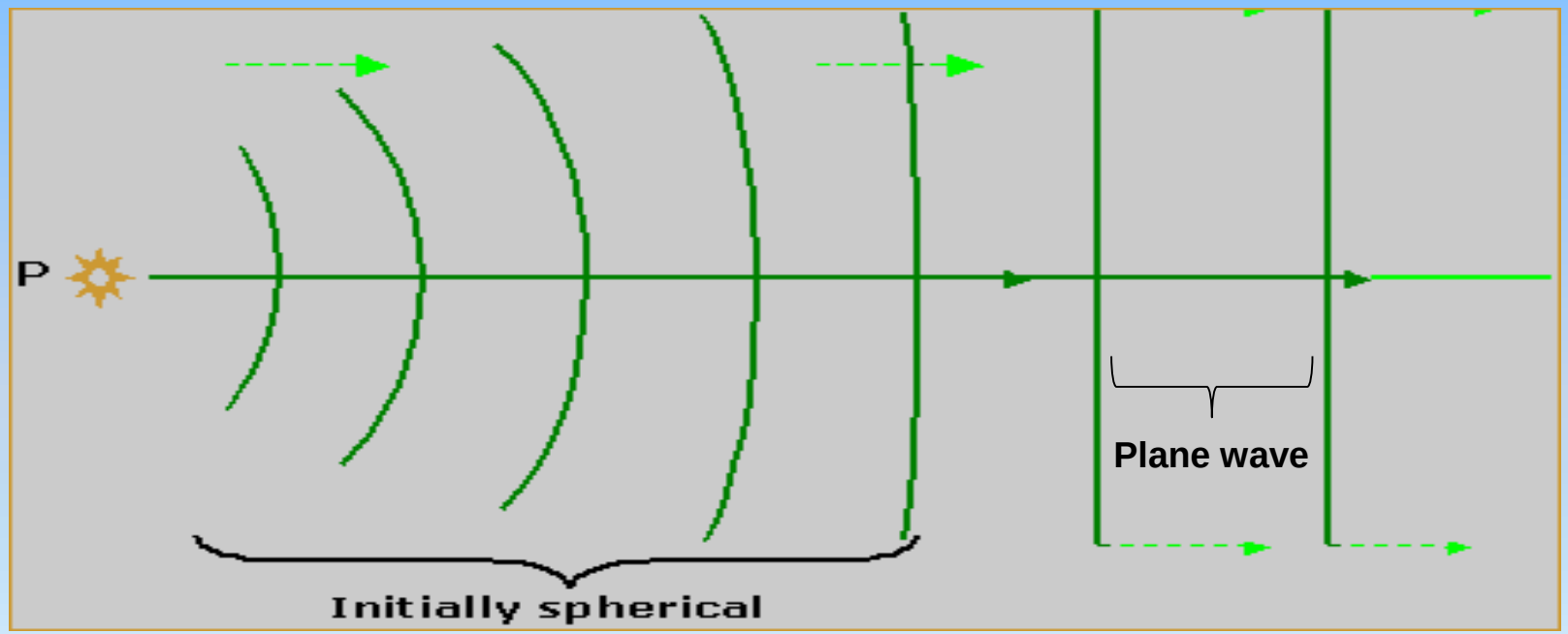
E = amplitude of electric field

M = amplitude of magnetic field

1. $\nabla \cdot \mathbf{D} = \rho_V$
2. $\nabla \cdot \mathbf{B} = 0$
3. $\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$
4. $\nabla \times \mathbf{H} = \frac{\partial \mathbf{D}}{\partial t} + \mathbf{J}$

Starlight and plane wave

A star is essentially a point source at the infinity (∞).
Therefore the starlight is a plane wave.



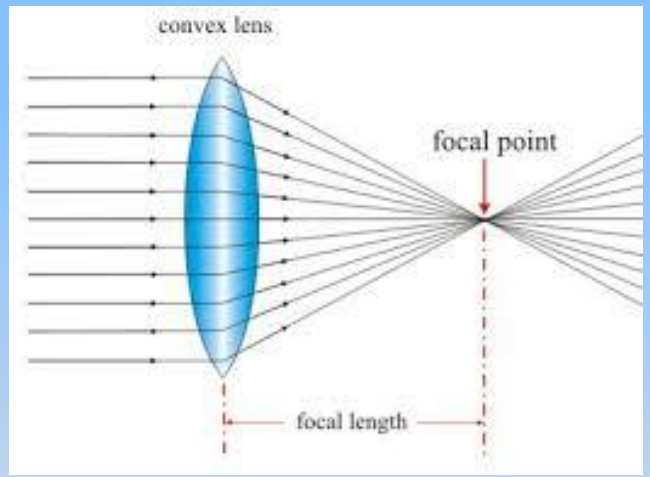
Geometric Optics

Innovations Foresight

STAR WAVES

POWERED BY ALCOR SYSTEM

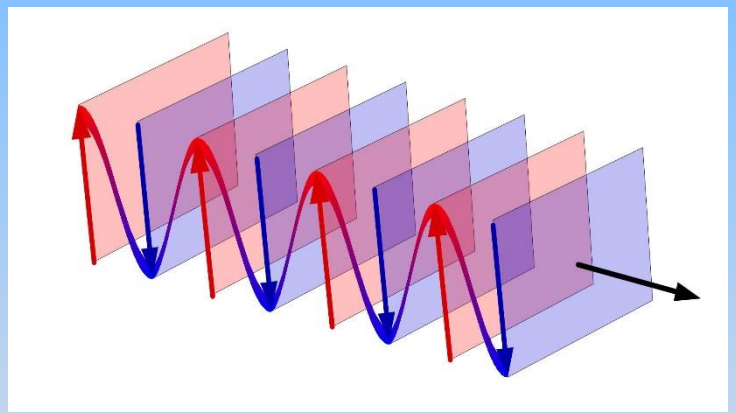
Geometrical optics (GO), or ray optics, describes light propagation in term of rays.

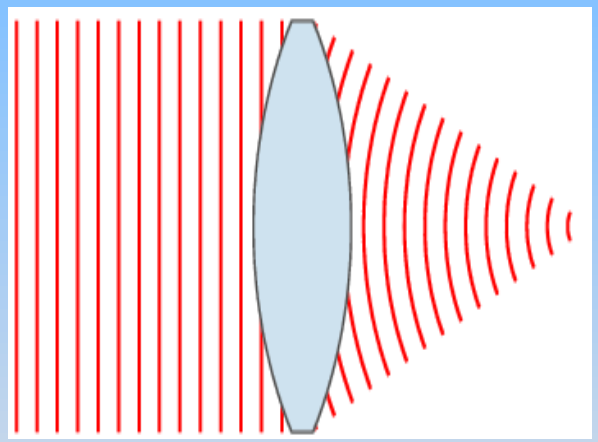


The ray in GO is an abstraction, leading to an useful, but limited approximation.
GO cannot account for diffraction, since phase information is not present.

Wave Optics

Wave optics (WO) treats light with explicit recognition of its wave nature.

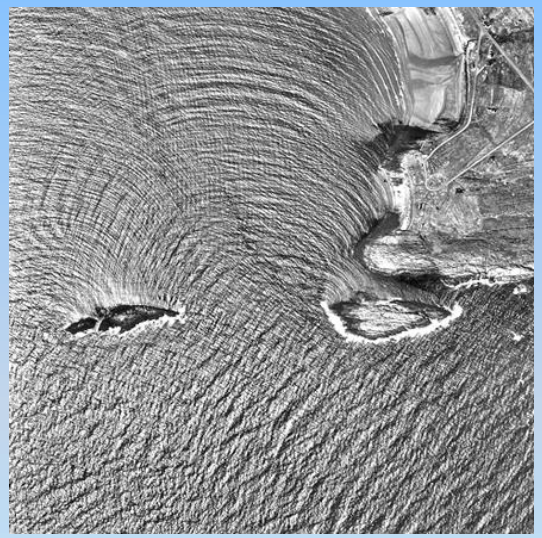




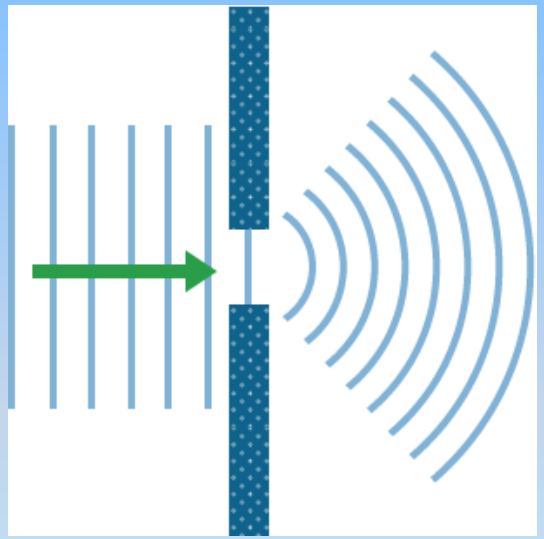
Phase information is present. WO can predicts and explains diffraction.

Diffraction

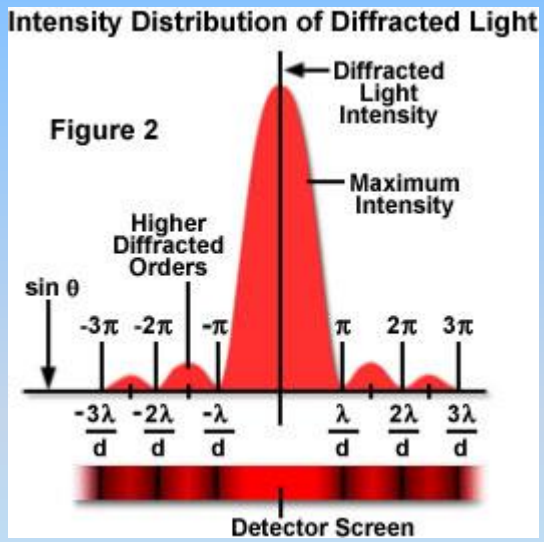
Diffraction occurs when a waves encounters an obstacle, such the aperture of a telescope.



Water diffraction



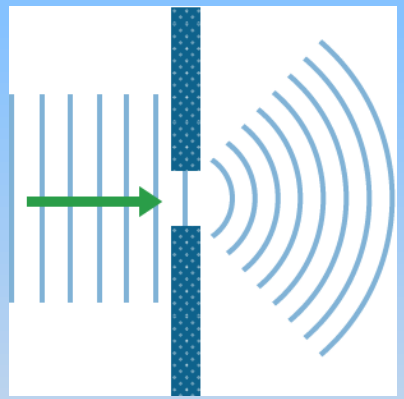
Light diffraction



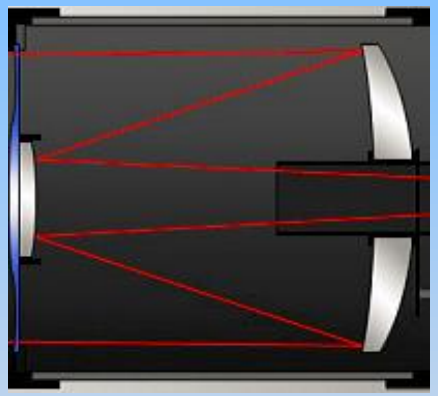
Diffraction pattern

Point Spread Function PSF

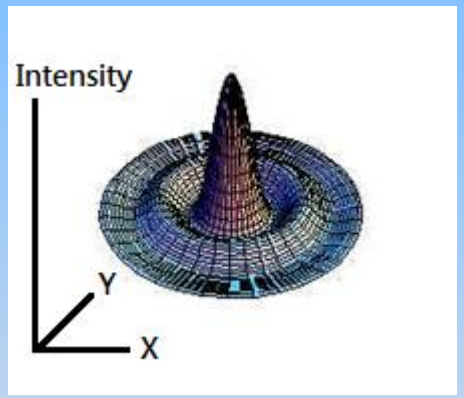
The **point spread function** (**PSF**) describes the response of an imaging system to a point source.



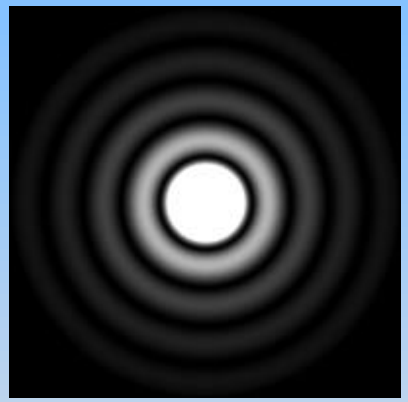
Plane wave diffraction



Telescope optics (imaging)



Diffraction limited PSF (light intensity)

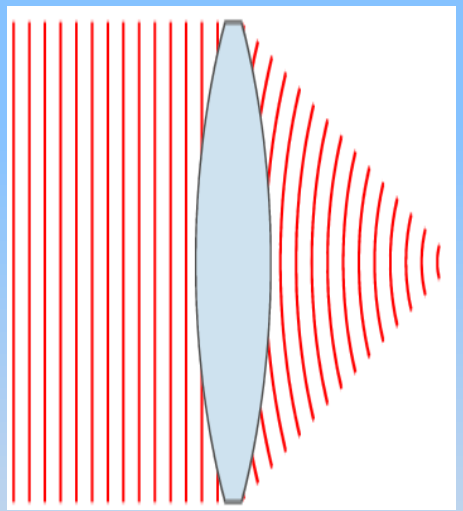


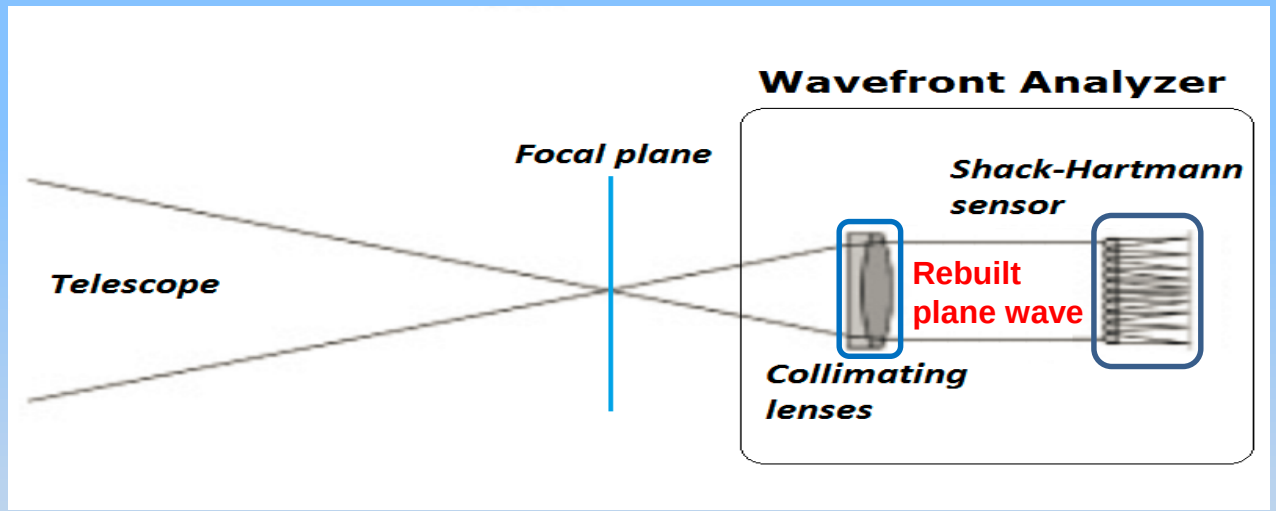
Diffraction limited image

When the point source is at the infinity (star) the PSF is the results of an plane wave diffracted by the scope aperture.

Wavefront Analyzer

Incoming/outgoing wavefronts fully characterize the system



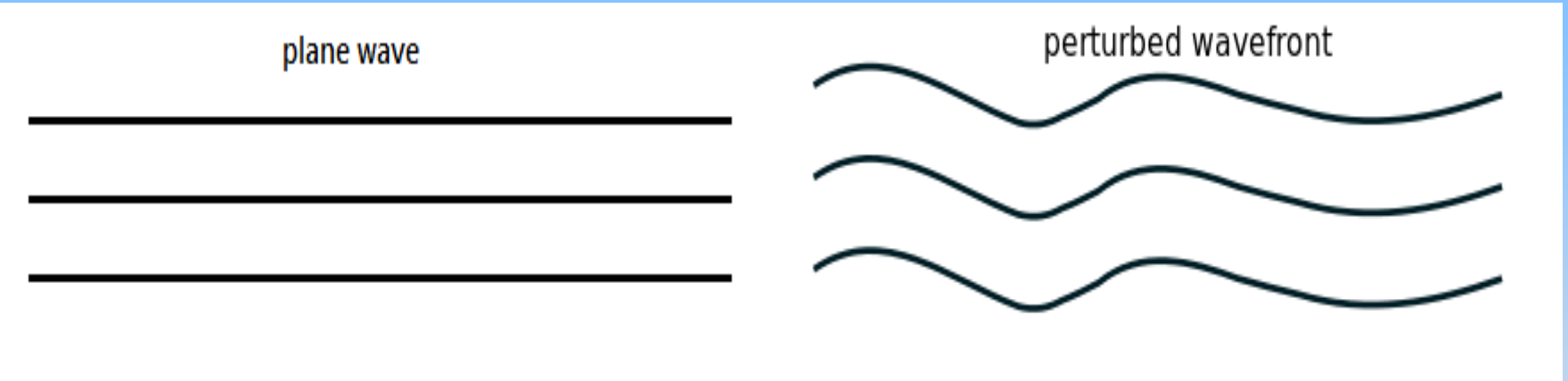


The analyzer is made of:

1. Collimator to rebuild the incoming plane wave from the PSF
2. Shack Hartmann sensor to analyze the rebuilt "plane wave"

Wavefront Analysis

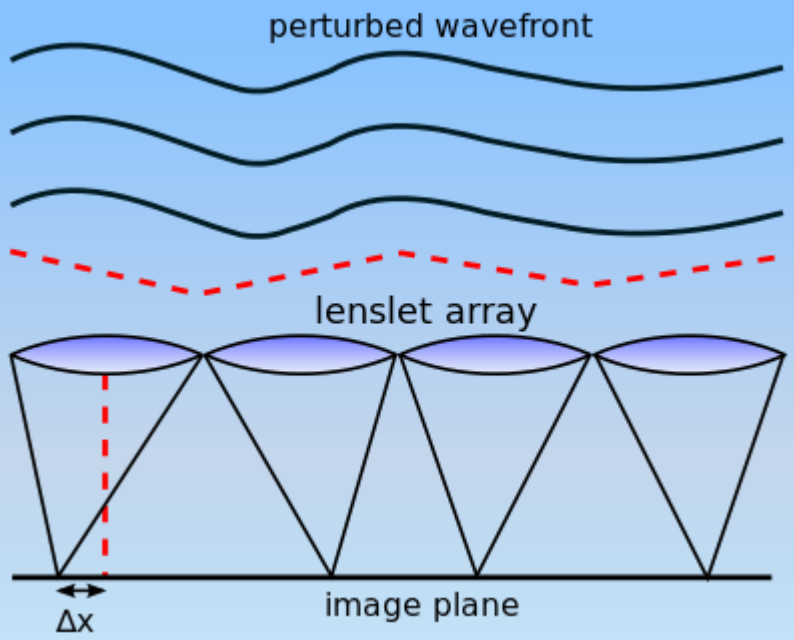
If the incoming wavefront is a plane wave indeed, so does the rebuilt one.

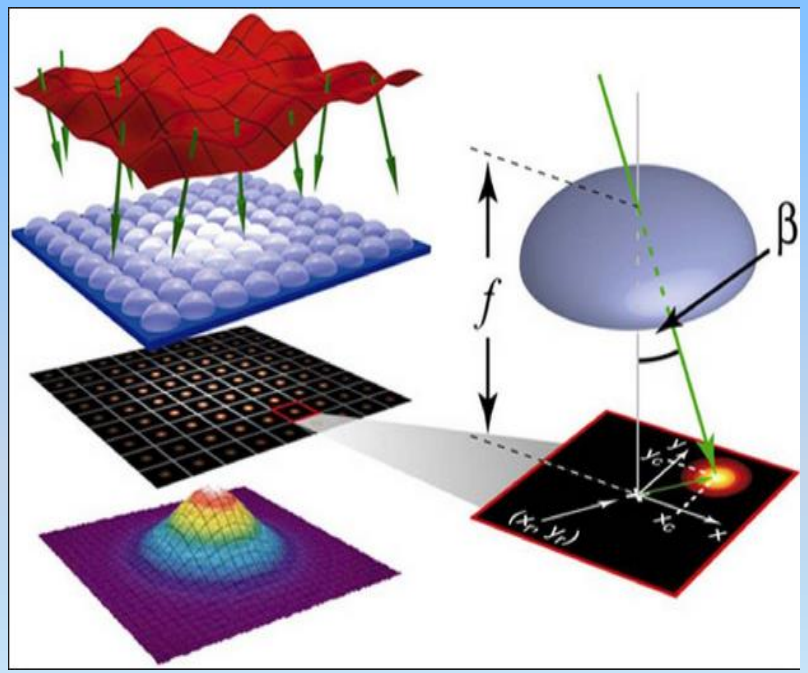


Any departure from a plane wave is the consequence of the telescope and optical train aberrations, typically coming from misalignments (collimation) and optical surface errors.

Shack Hartman Sensor

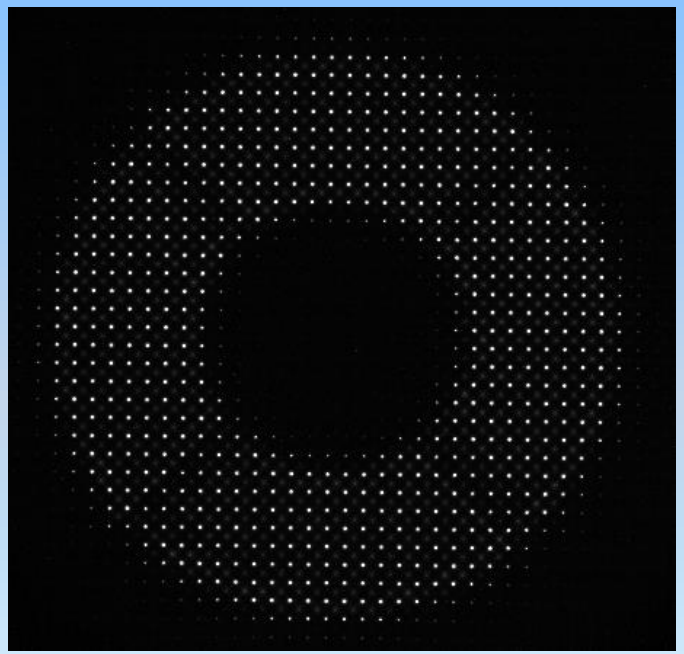
A Shack-Hartmann sensor uses a micro-lens array to analyze the wavefront



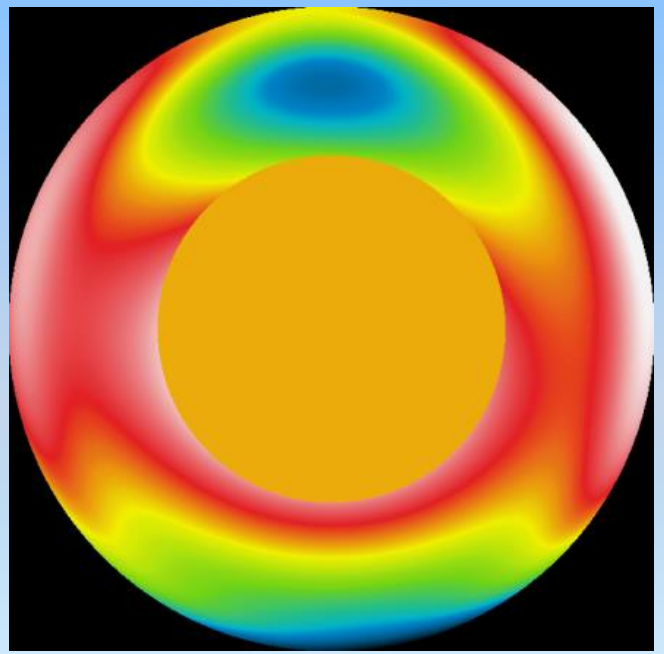


Wavefront Reconstruction

The star images from the micro-lens array are used for the reconstruction of the wavefront and its phase error (departure from a plane wave)



Micro-lens array raw image



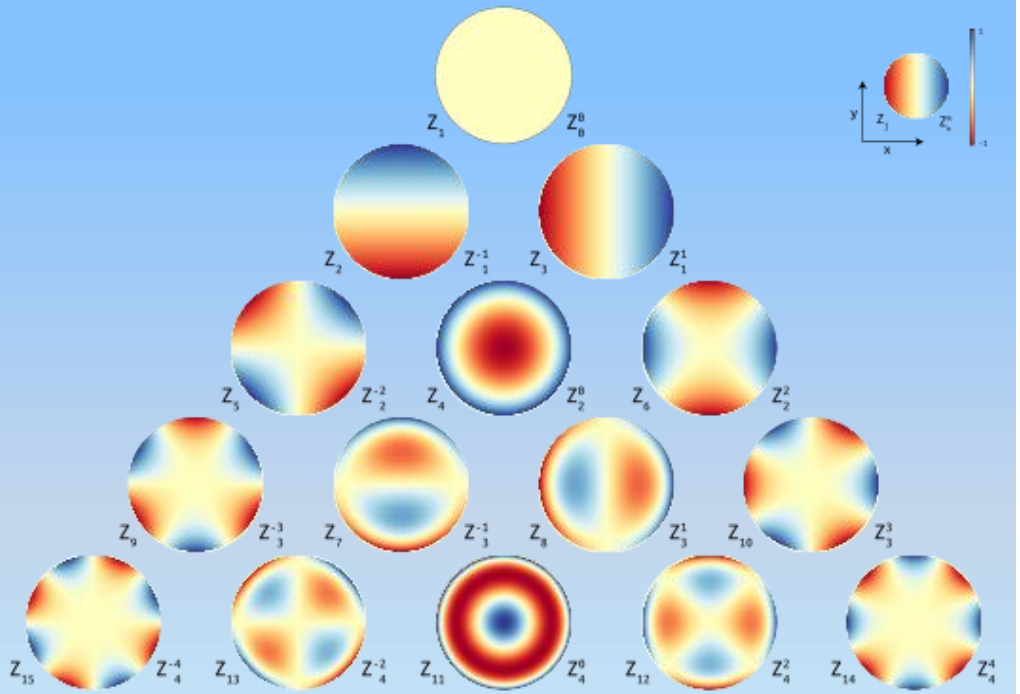
Wavefront phase error

Innovations Foresight

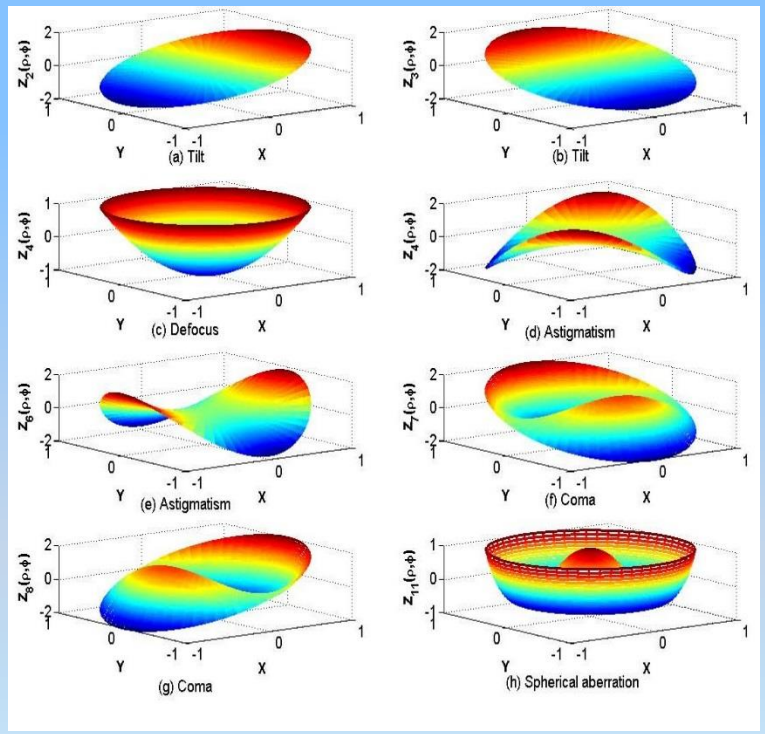
Aberration Analysis

STAR WAVES
POWERED BY ALCOR SYSTEM

The wavefront error is used to characterize the optical aberrations



Zernike's coefficients



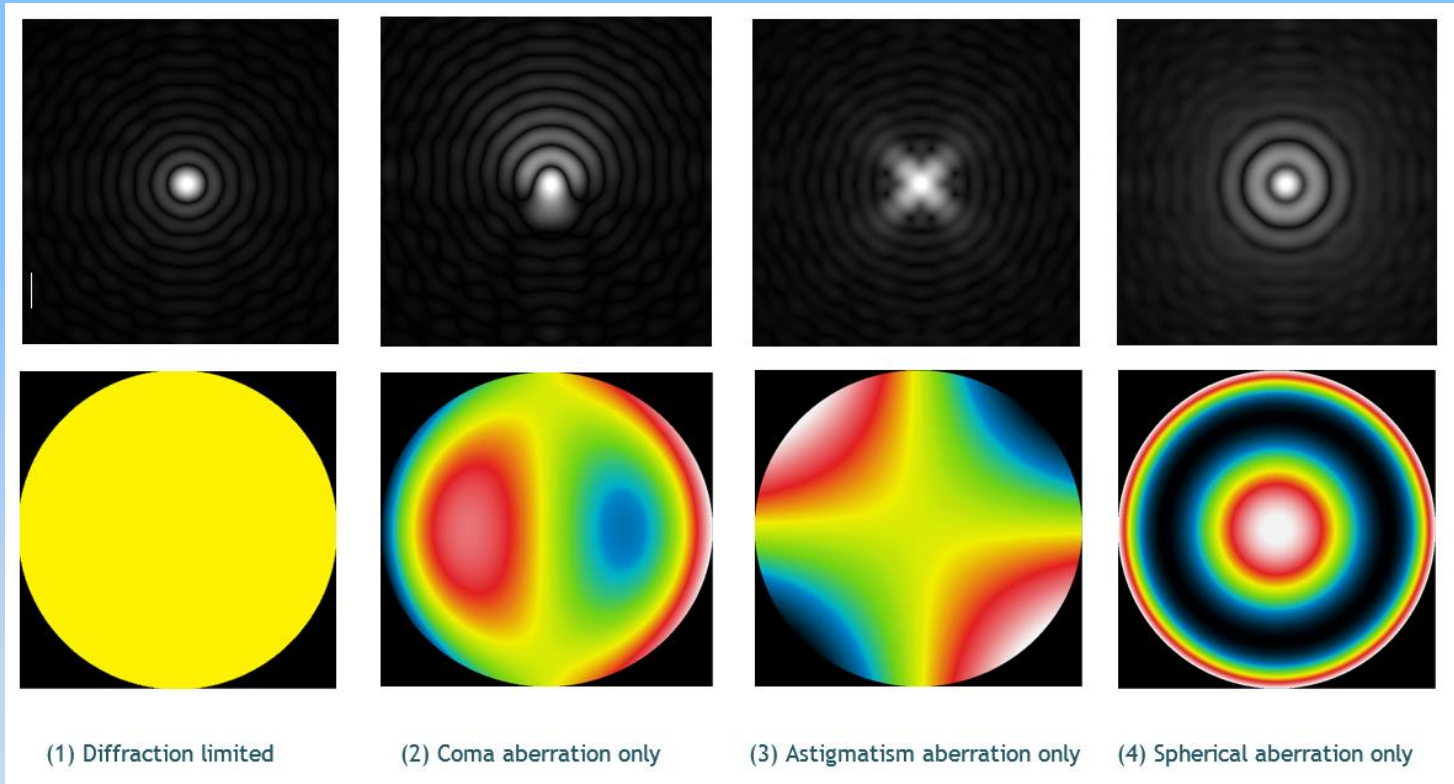
Related wavefront errors

Innovations Foresight

Common aberrations

STAR WAVES

POWERED BY ALCOR SYSTEM



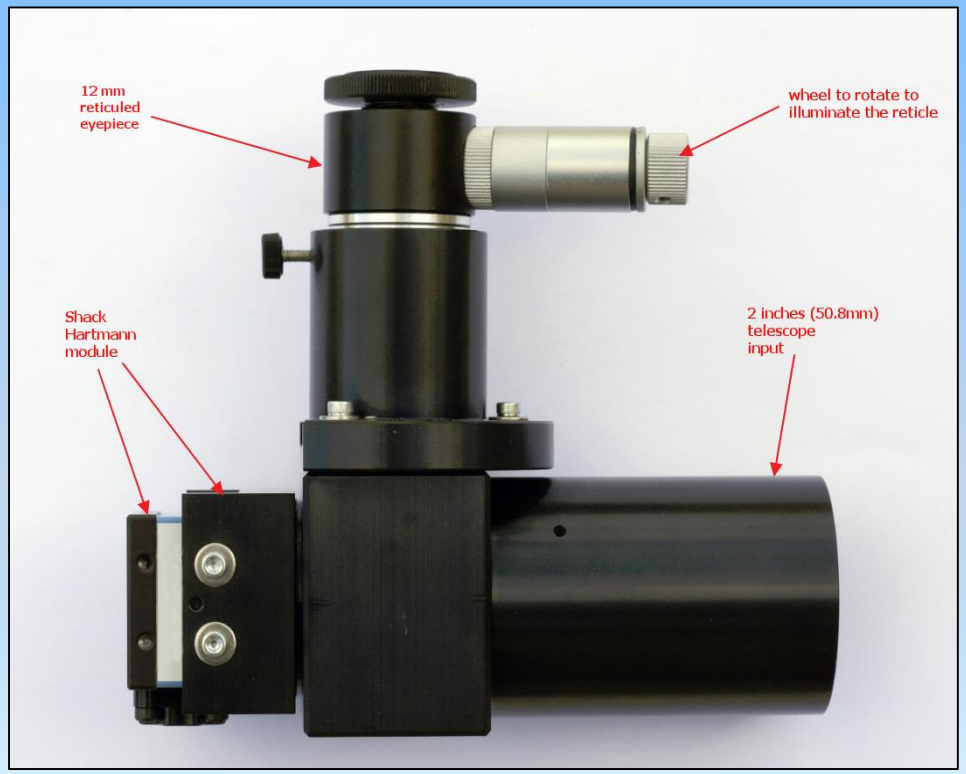
Many aberrations are challenging to detect with a simple "star test", specially under seeing limited conditions.

Innovations Foresight

Star Waves *Pro II* wavefront analyzer

POWERED BY ALCOR SYSTEM

STAR WAVES *Pro II* Shack-Hartmann astronomical wavefront analyzer set



Star Waves Wavefront Analysis

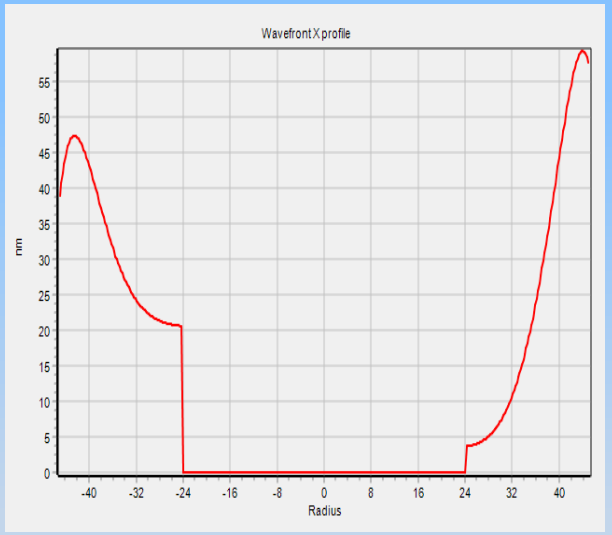
Innovations Foresight

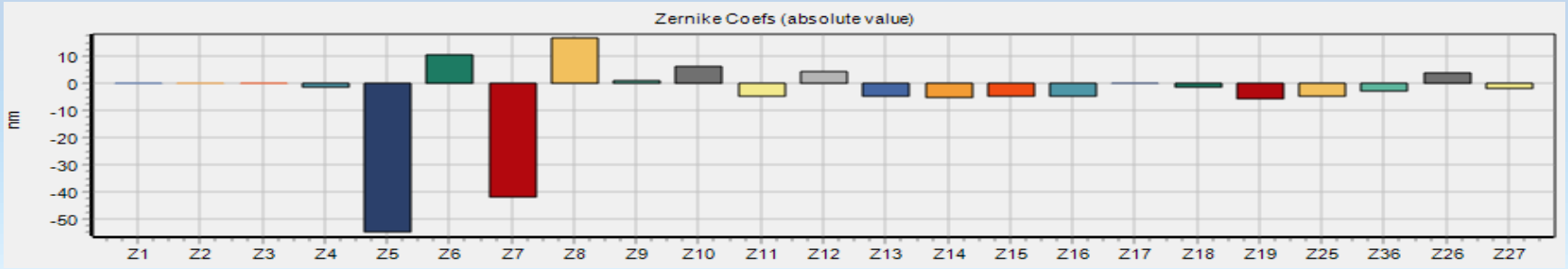
STAR WAVES

POWERED BY ALCOR SYSTEM

The STAR WAVES *Pro II* provides a quantitative aberration analysis

Zernike	nm
Z1 (Tilt X)	-1631.4 (set to zero)
Z2 (Tilt Y)	-1165.3 (set to zero)
Z3 (Defocus)	-836.1 (set to zero)
Z4 (Astigmatism +45°)	-1.3
Z5 (Astigmatism -45°)	-54.8
Z6 (Coma X)	10.6
Z7 (Coma Y)	-42.0
Z8 (3rd spherical)	16.6 [Z8 corrected]
Z9 (Trefoil X)	0.9
Z10 (Trefoil Y)	6.2
Z11 (5th astigmatism +/-45°)	-4.7
Z12 (5th astigmatism 0-90°)	4.3
Z13 (Tetrafoil 1)	-4.8
Z14 (Tetrafoil 2)	-5.5
Z15 (5th Trefoil x-axis)	-4.6
Z16 (5th Trefoil y-axis)	-4.8
Z17 (5th Coma x-axis)	-0.1
Z18 (5th Coma y-axis)	-1.7
Z19 (5th spherical)	-5.9
Z25 (7th spherical)	-5.0
Z36 (9th spherical)	-2.7
Z26 (Quadrafoil 1)	3.9
Z27 (Quadrafoil 2)	-1.8



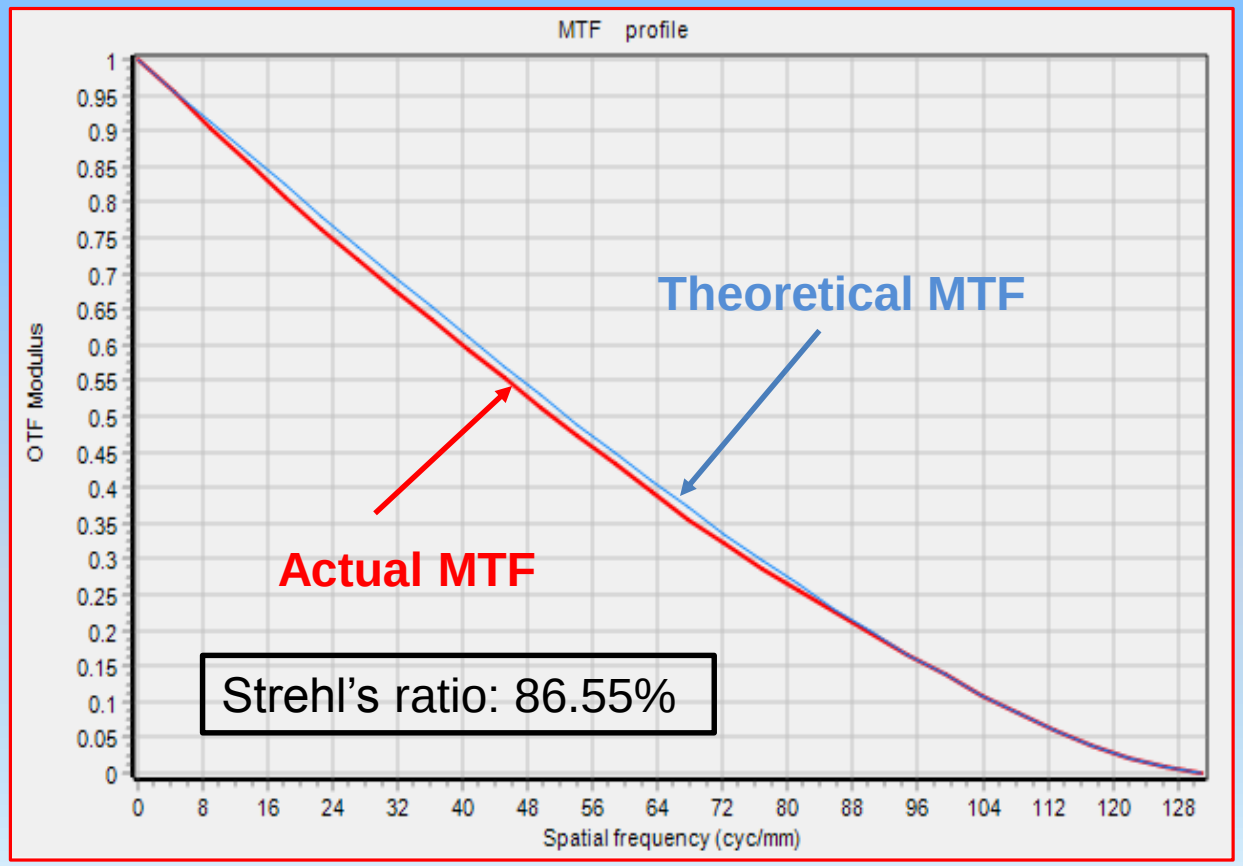


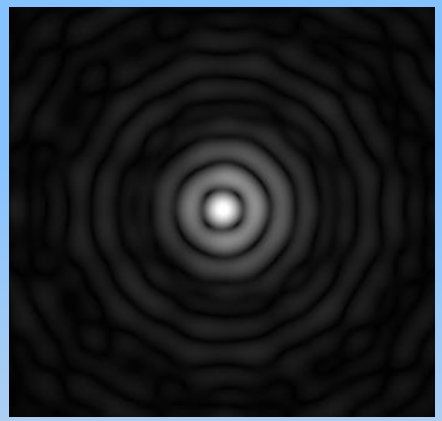
Ex: Scope Collimation

Innovations Foresight

STAR WAVES
POWERED BY ALCOR SYSTEM

10″ RCT collimated with a Star Waves *Pro II* analyzer





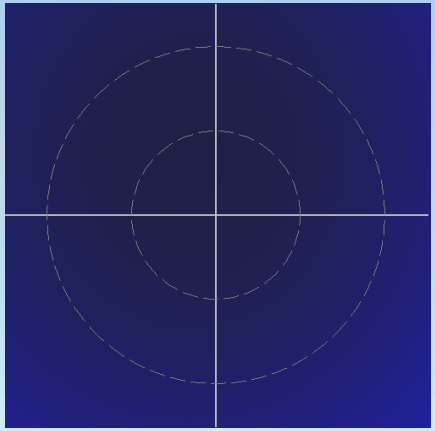
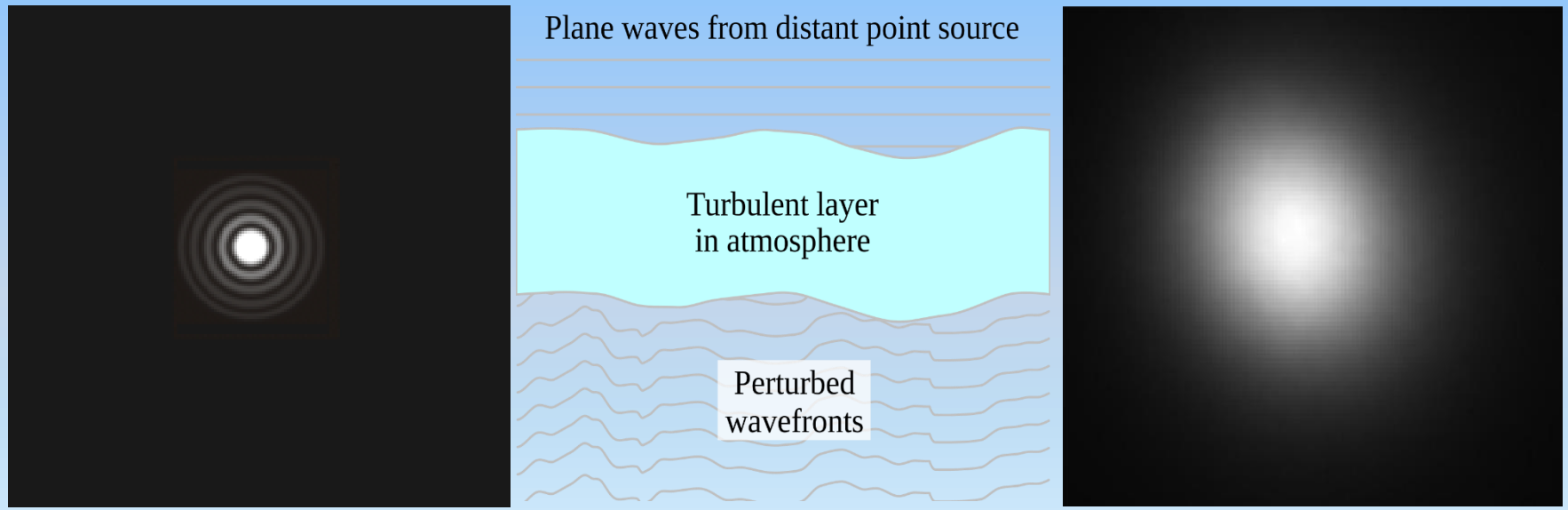


Image and seeing

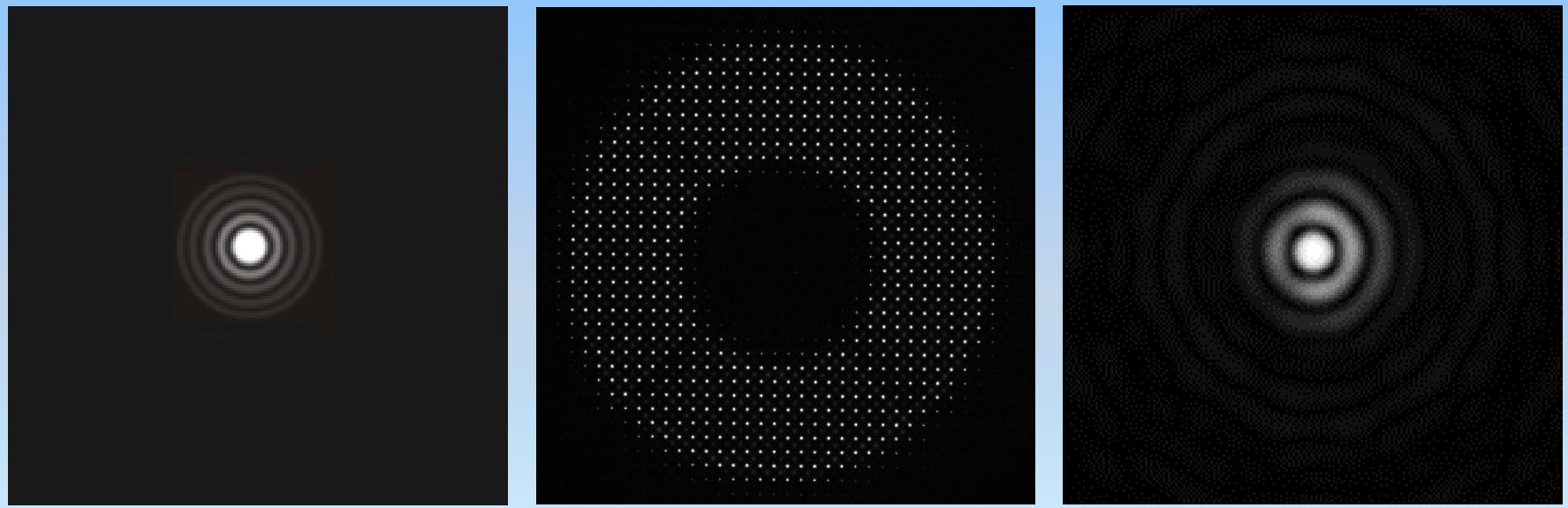
Long term (>10s) seeing permanently spreads the PSF



Wavefront and seeing

The starlight long term average wavefront is an plane wave!

Each micro-lens is diffraction limited

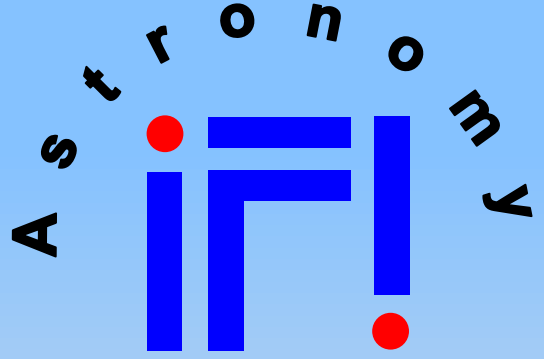


Innovations Foresight

Thank you!

STAR WAVES

POWERED BY ALCOR SYSTEM



Innovations Foresight, LLC

Clear skies!