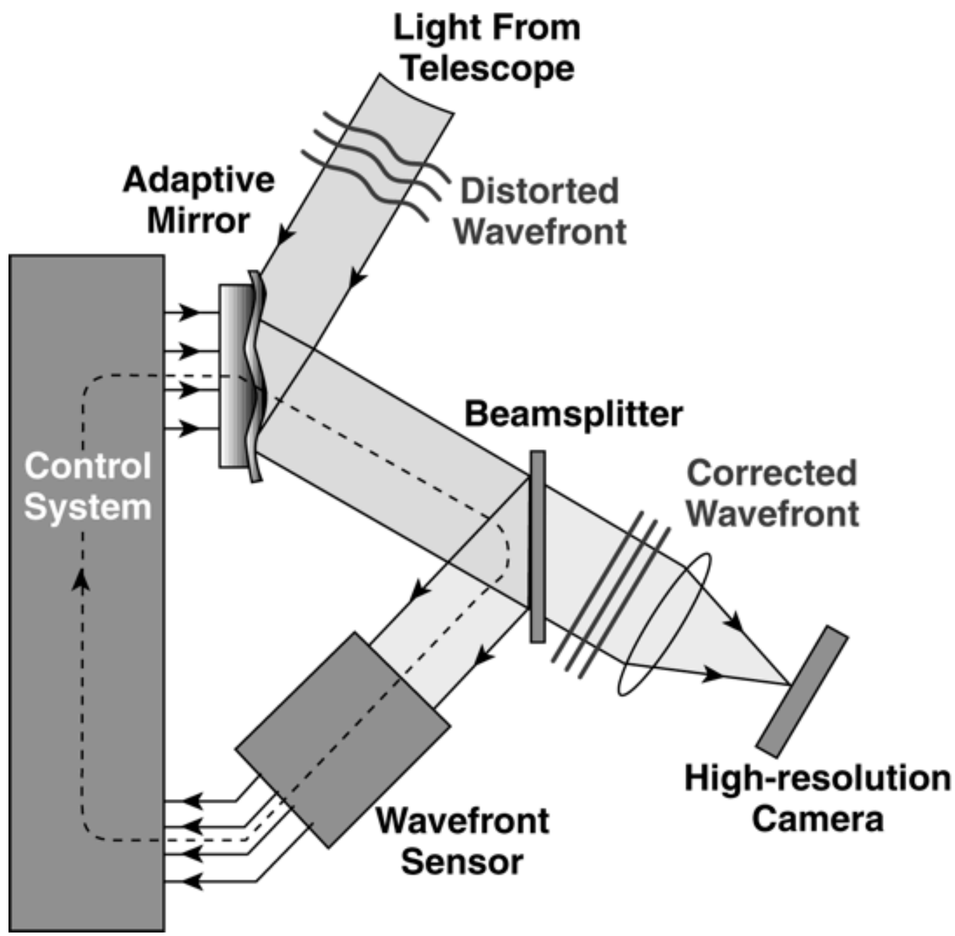
Schematic of adaptive optics system

Feedback loop: next cycle corrects the (small) errors of the last cycle



e.g. SHACK-HARTMANN WAVEFRONT SENSOR or PYRAMID WAVEFRONT SENSOR

Part II - PSF theory

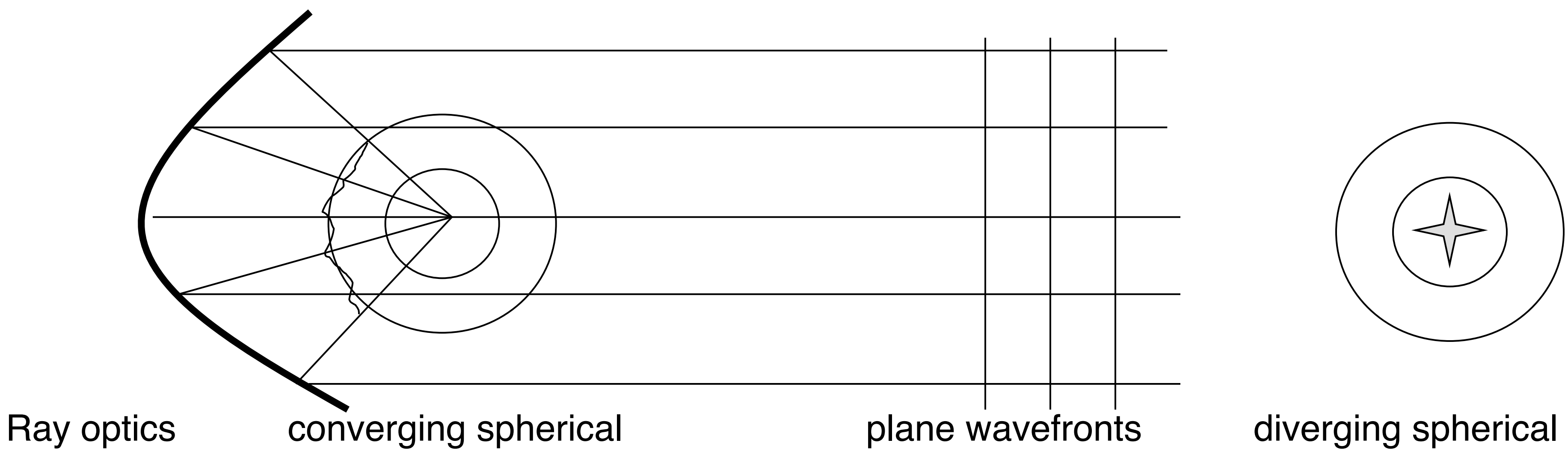
Optical Path Difference
This is the deviation of the wavefront from 'perfect'… when talking of an image being formed by a converging wavefront,

THE DEVIATION OF THE WAVEFRONT FROM THE
PERFECT SPHERICAL CONVERGING WAVE

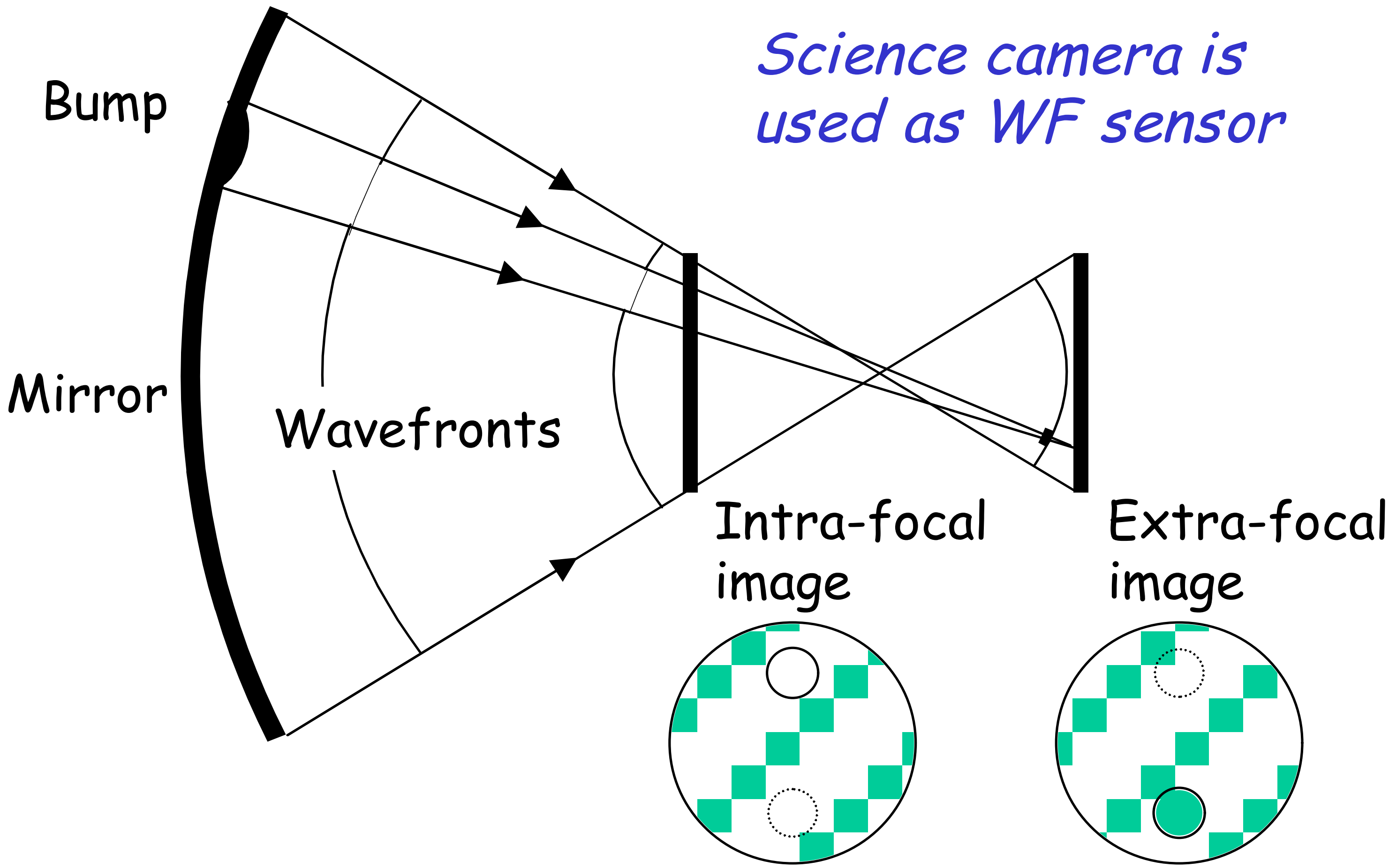
is the optical path difference.

In a collimated beam such as an interferometer, the deviation of a wavefront from the perfect, flat wavefront is the OPD.

OPD(x,y) is a real function in 'pupil space', dimensions of LENGTH usually
At wavelength it is expressed in RADIANS of PHASE: $\phi(x,y) = (2\pi / \lambda)\mathrm{OPD}(x,y)$



Unfocussed images measure the mirrors



S. Basinger

Phase aberrations in cycles per diameter

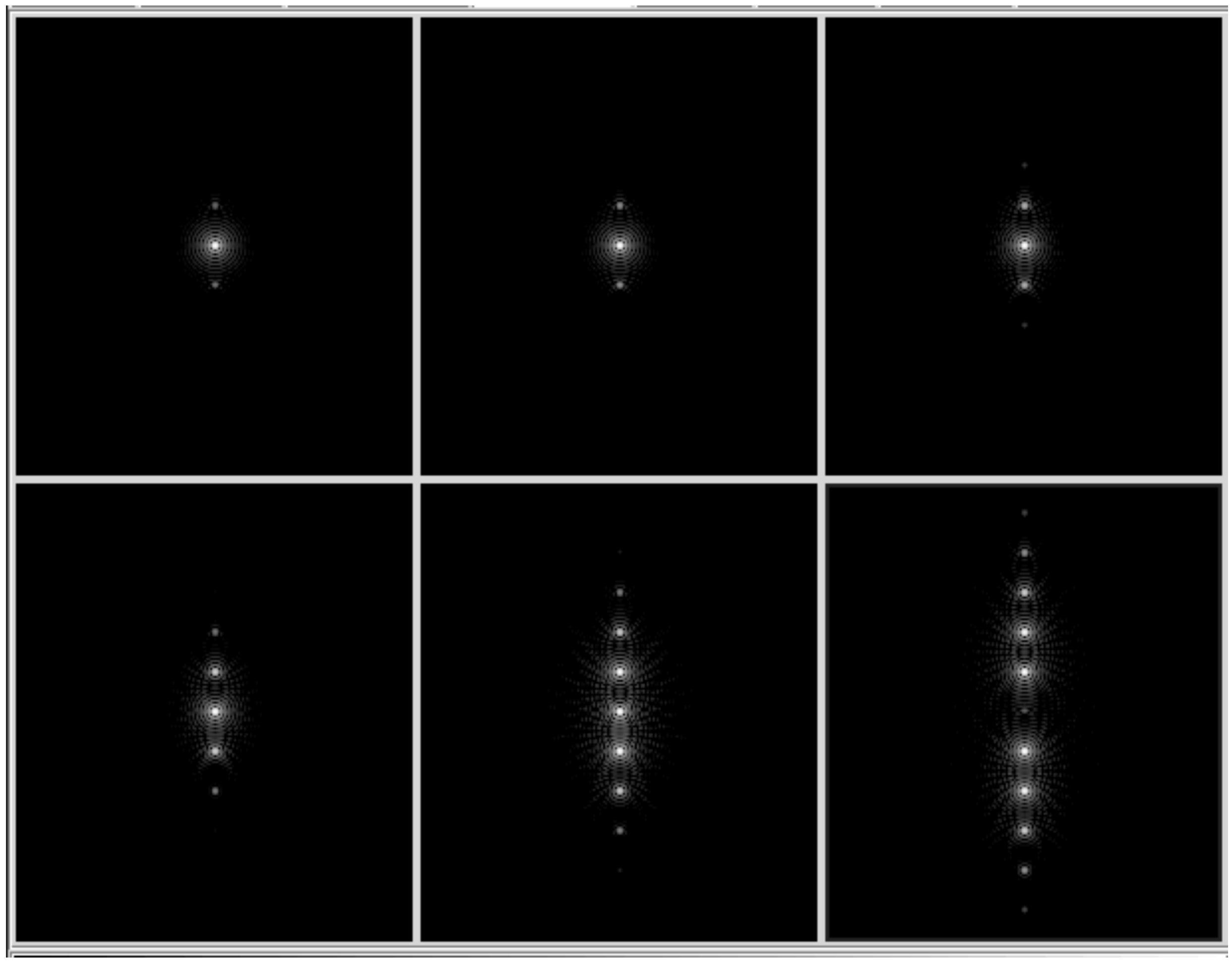
Think Fourier

Sine wave aberration is a pair of delta functions in its 'Fourier transform domain'

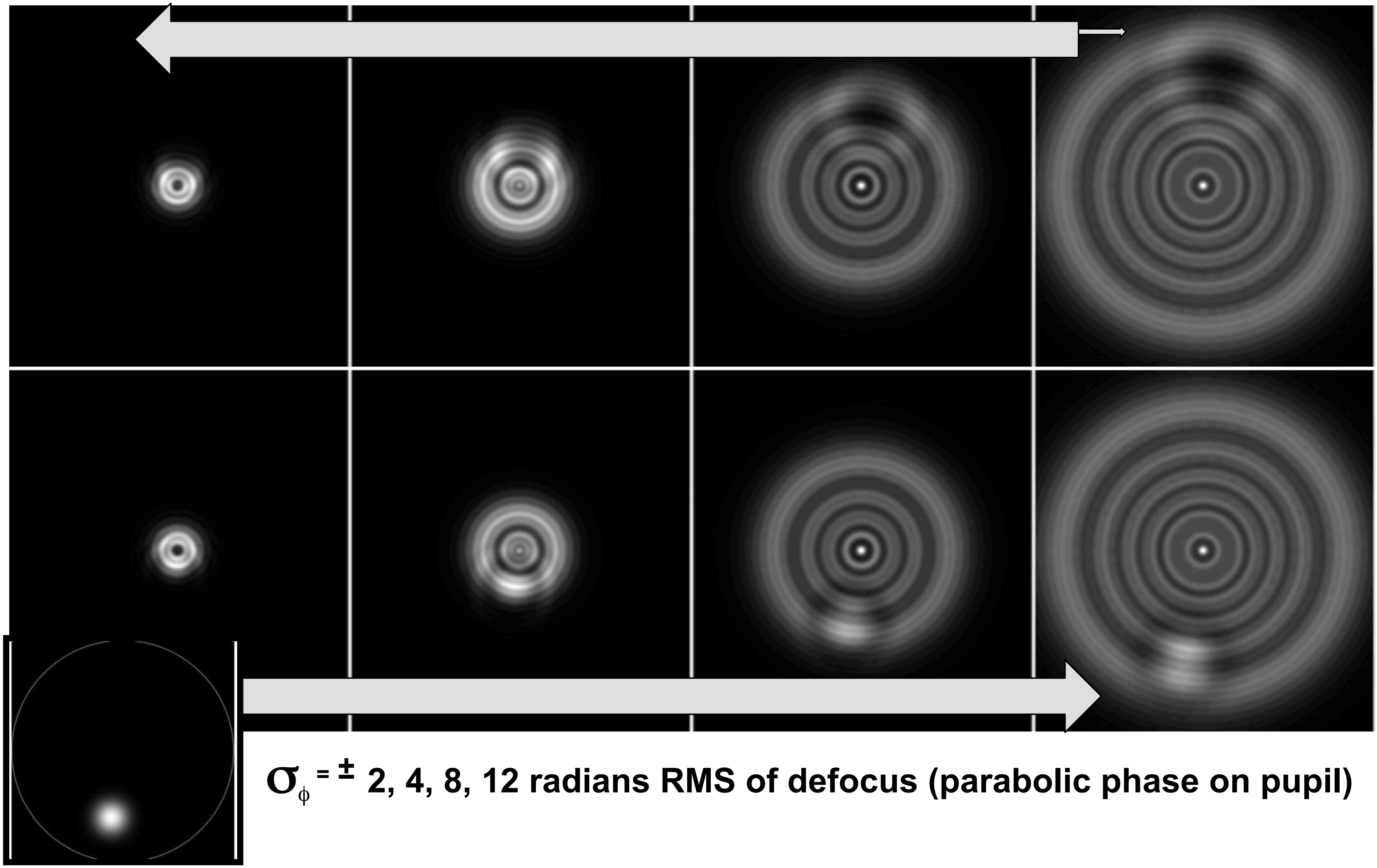
At small amplitudes this corresponds to pair of bright spots in the PSF: pupil: $\exp(i\phi) \sim 1 + i\phi$ image: $\delta(0)$ + FT(sine)

As size of aberration increases, $\exp(i\phi)$ expansion gets higher order terms. Quadratic terms produce spots at twice the separation...

$\sigma_\phi^2 = 0.01$ $\sigma_\phi^2 = 0.03$ $\sigma_\phi^2 = 0.10$

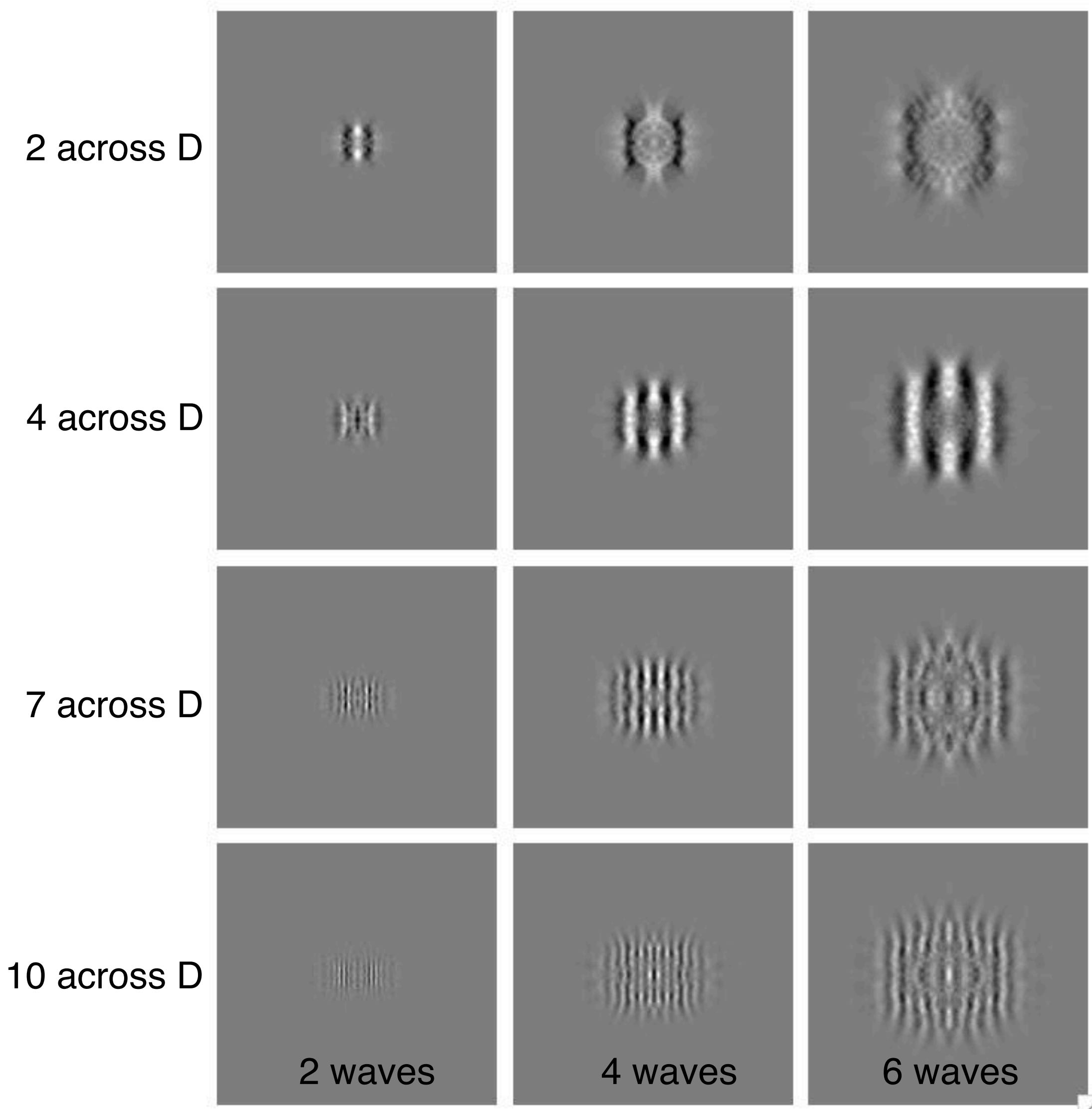


$\sigma_\phi^2 = 0.30$ $\sigma_\phi^2 = 1.0$ $\sigma_\phi^2 = 3.0$



$\sigma_\phi = \pm$ **2, 4, 8, 12 radians RMS of defocus (parabolic phase on pupil)**

Choosing the amount of defocus



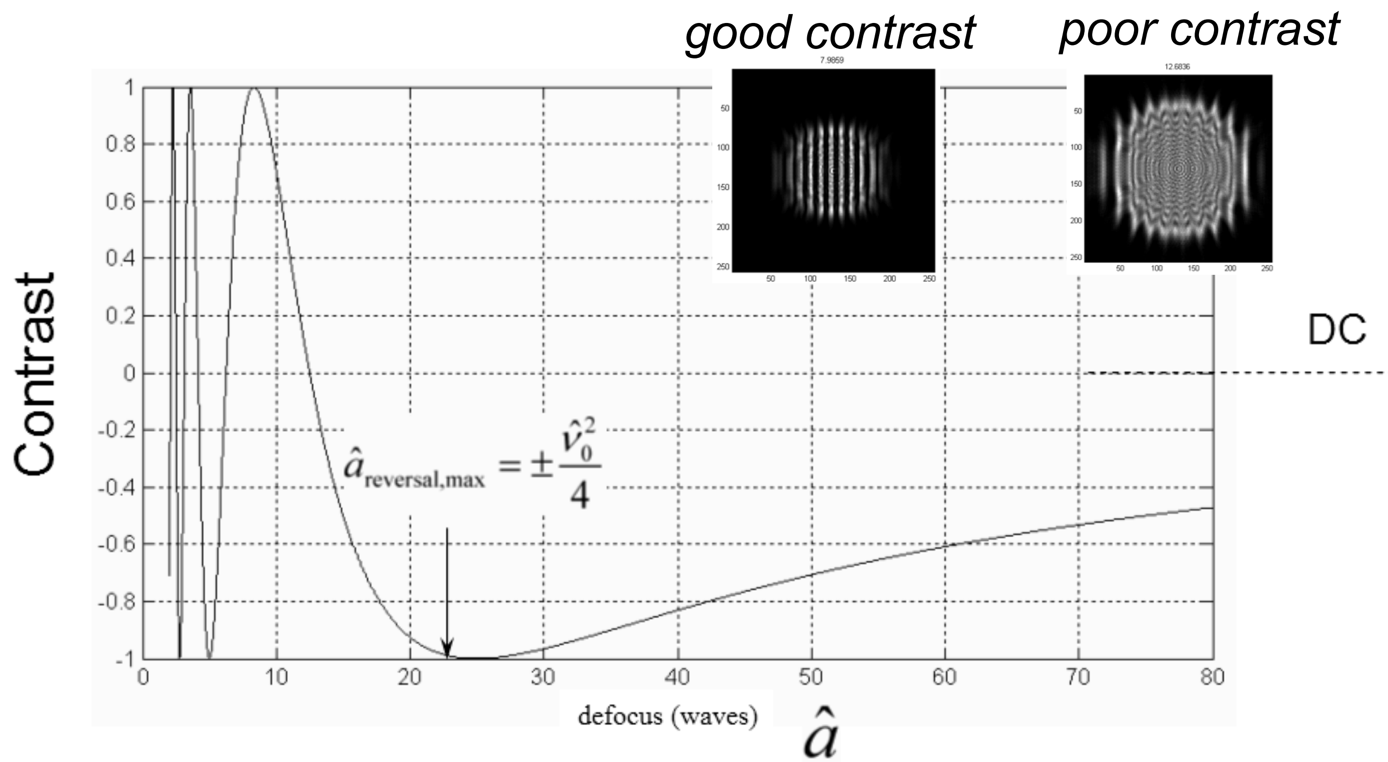
Numerical experiment

Place a sinusoidal phase aberration over the pupil and try three different amounts of defocus.

pre-focus image
-
rotated post-focus image
=
signal

What is the best defocus to use?

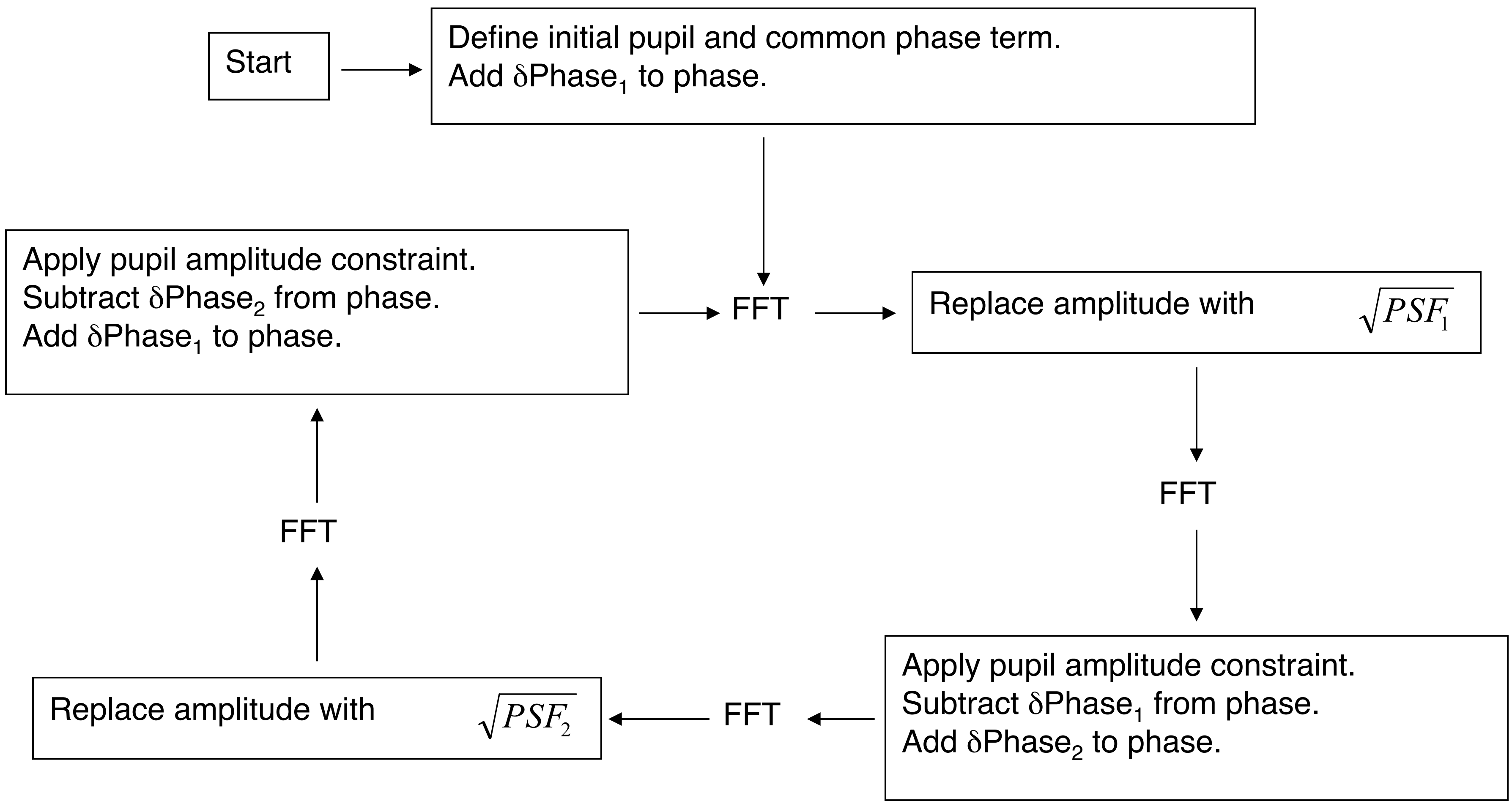
Signal strength for given spatial frequency of aberration (number of ripples across mirror) is periodic in 1/defocus



B. Dean, C. Bowers, “Diversity Selection for Phase-Diverse-Phase-Retrieval,” JOSA, 20(8), 2003, pp. 1490-1504

Missel Algorithm

Goal: Derive high-resolution exit pupil amplitude and phase maps



Pupil amp constraint: Enforce amplitude, zero outside pupil, or free everywhere

Misell-Gerchberg-Saxton (MGS) algorithm

MGS in this case - a mapping from one guess at the phase, $f_1(x)$, to a better estimate, $f_2(x)$, using a known pupil function and image data I(k)

- Assume a pupil function A(x) and a first-guess phase $\mathbf{f_1(x)}$
- Calculate $a(k) = F[(A(x) \exp\{i\, f_1(x)\}] = b(k) \exp\{i\, g(k)\}$ *(b is real)*
- Use measured data for intensity I(k) - replace b(k) with sqrt(I(k))
- Now we have $\mathrm{sqrt}(I(k)) \exp\{i\, g(k)\}$
- Back-transform it - we write this as $C(x) \exp\{i\, f_2(x)\}$
- This gives us our revised estimate of the phase, $\mathbf{f_2(x)}$

- Now write the pupil field using known pupil A instead of C: $A(x) \exp\{i\, f_2(x)\}$
- And do the same operations to get the next estimate, $\mathbf{f_3(x)}$, for the phase

Keep going till you are happy. It WILL converge but not necessarily to the right phase -
- Incorrect A(x)
- Improperly reduced data I(k) (CR, flats, photon noise, real pixel response,…)
- Difference between FFT samples and physical pixels, *etc.*

Misell, D. L. 1972, J. Phys. D, 6, L6
Gerchberg, R. H. & Saxton, H. O. 1972, Optik, 35(2), 237