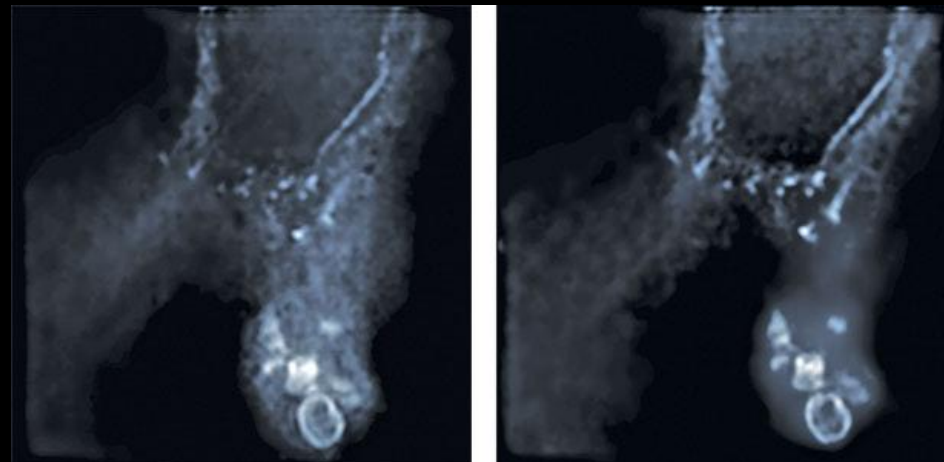
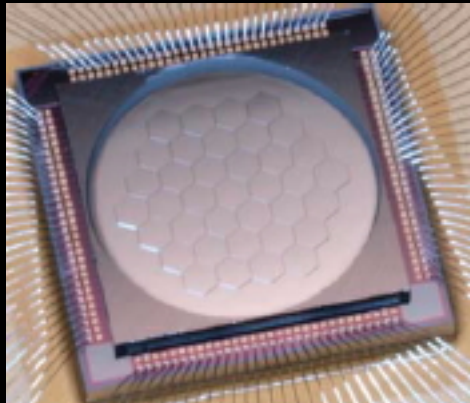


Adaptive Optics

Special Topic in Astrophysics

ASTRON 250 - Fall 2013



Homework

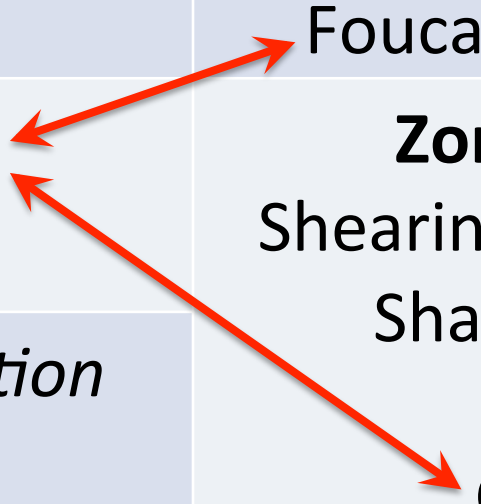
- Let's discuss your results!
- Strehl ratio? R_0 ? Time/wavelength dependence?
- Binary properties?
- Which methods did you use?

Wavefront sensing

- Objective: **characterize the wavefront** so as to know how to correct it
- In practice, one can determine:
 - The wavefront phase at each point
 - The wavefront local slope (piston irrelevant)
 - The wavefront local curvature (+slopes at edge)
 - The Zernike decomposition of the wavefront
- Or skip WF and **simply improve image quality**

An array of methods

Image plane techniques	Pupil plane techniques
Image sharpening (+trial-and-error)	Modal methods Centroid detection Foucault's knife edge
Phase diversity (+inversion)	Zonal methods Shearing interferometer Shack-Hartmann Pyramid Curvature
<i>Direct E-field detection</i>	



```
graph LR; A[Foucault's knife edge] --> B[Phase diversity (+inversion)]; C[Curvature] --> B;
```

Image plane techniques

- + **No new detector**: can use science camera!
- **Phase information lost** in detection
 - Generally an inverse problem
- Two basic options:
 - Compute one or several **image quality metric(s)**
 - **Compare images with known aberration added to the system** and perform inverse reconstruction (“phase diversity” – standard for focus)
- Need knowledge about object (can be resolved)

Pupil plane techniques

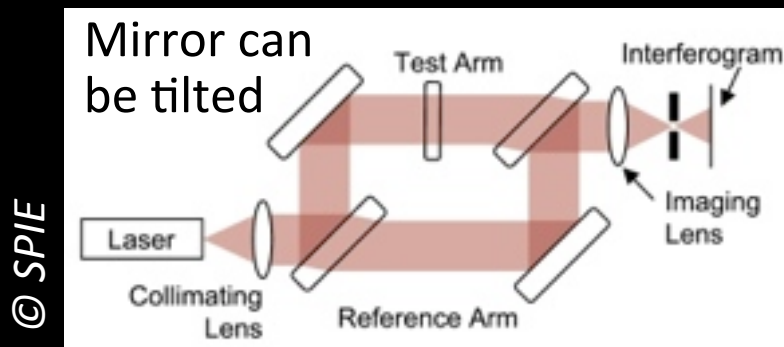
- + Phase information available
- Need a separate detector (non-common path!)
- Two basic options:
 - Find wavefront decomposition in Zernike modes
 - Measure local properties of wavefront

Modal wavefront sensing

- 1st order: Tip-tilt
 - Image centroiding with a quad-cell
- 2nd order: Focus
 - Foucault's knife edge
 - Response to introduced motion (*McLaughlin 1979*)
- Higher-order: much more complicated
 - Combine phase diversity with self-interference (*Lauterbach et al. 2006*)

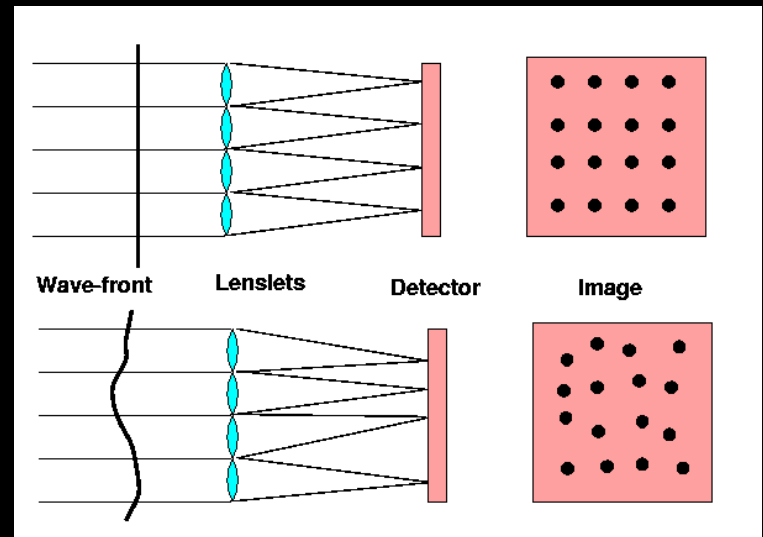
Zonal wavefront sensing (I)

- Shearing interferometer
 - Mach-Zender interferometer + introduced shear
- Recorded interference pattern directly yields a **map of the wavefront local slopes**
 - $I(s) = 1 - \cos(\varphi(x) - \varphi(x+s)) \approx 1 - \cos(s \, d\varphi/dx)$
- Works best for point sources



Zonal wavefront sensing (II)

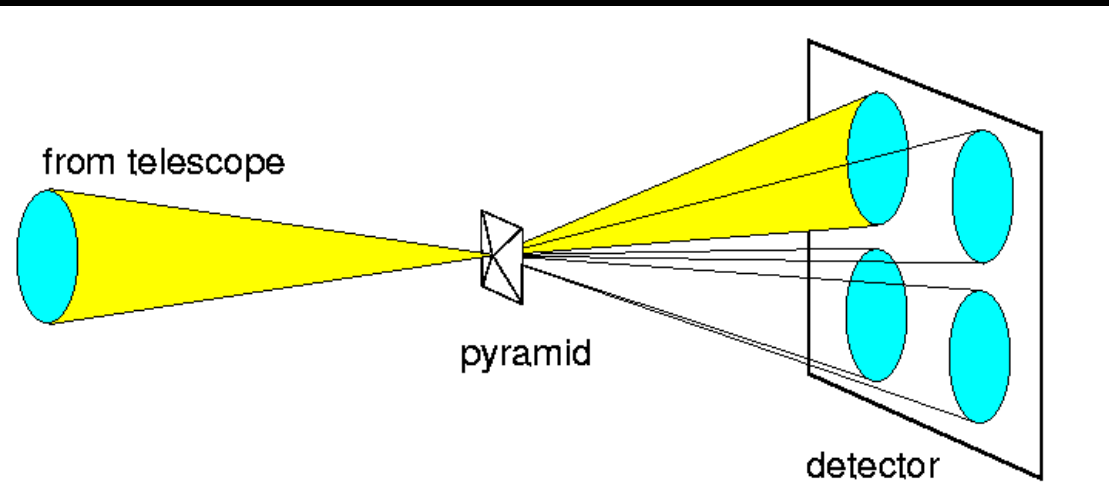
- Shack-Hartmann sensor
 - Split the pupil in subpupils and measure the local tip-tilt, i.e., the **local wavefront slope**
- Can work on resolved sources (only must be unresolved by a subpupil)
- Need to sample r_0



Credit: A. Tokovinin (CTIO)

Zonal wavefront sensing (III)

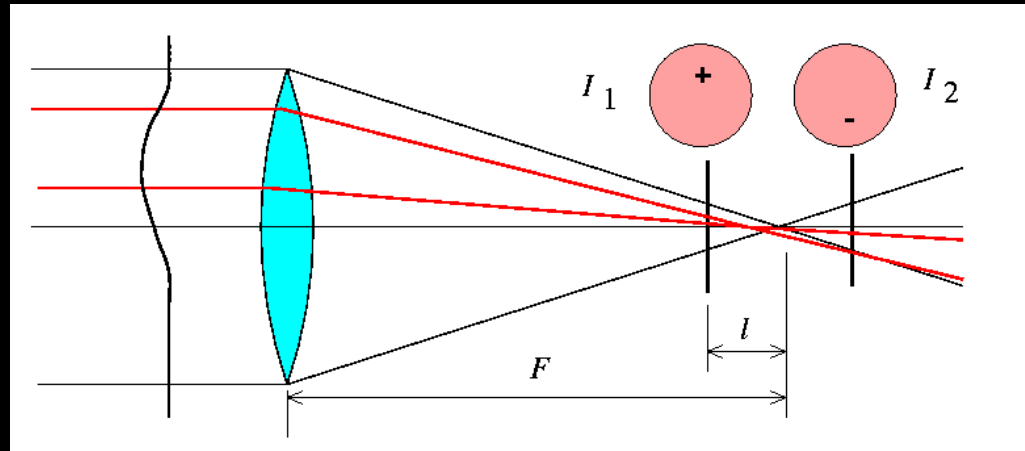
- **Pyramid sensor**: a cross-bread between a SH sensor and a knife edge sensor
- Yields a **wavefront slope estimate at each pixel** in the pupil plane detector (“subaperture”) – Oscillation mimics a (simple) resolved source



Credit: A. Tokovinin (CTIO)

Zonal wavefront sensing (IV)

- **Curvature sensor:** local focusing as a tracer of the wavefront 2nd derivatives
 - Probing high-order aberrations require large l , which reduces sensitivity (and increase diffraction effects)
 - Vary l depending on seeing, source properties and required correction



Credit: A. Tokovinin (CTIO)

There is no “ideal” WFS!

Sensing method		Strength
Image plane	Sharpening	Conceptually simple
	Phase diversity	Single detector/opt. path
Pupil plane: Modal		Direct measurement of most important modes (T/T, focus)
Pupil plane: Zonal	Shearing int.	No reference source needed
	S.-H.	Conceptually simple Sensitivity to larger aberrations
	Pyramid	Higher resolution than S.-H. Variable gain built-in
	Curvature	Simplicity for low-order

There is no “ideal” WFS!

Sensing method		Drawbacks/Limitations
Image plane	Sharpening	“blind”, slow
	Phase diversity	Difficult inversion problem, esp. if object is resolved
Pupil plane: Modal		Limited to low-order
Pupil plane: Zonal	Shearing int.	Requires narrow-band filtering
	S.-H.	Fixed discretization Complicated optics
	Pyramid	Continuous control required
	Curvature	Scaling to high-order difficult

Next week readings

- Deformable mirrors (wavefront correctors)
 - J. Kubby's book (§8)
- Additional reading (optional)
 - Tyson's book (§6)