Bracewell nuller 'PSF'
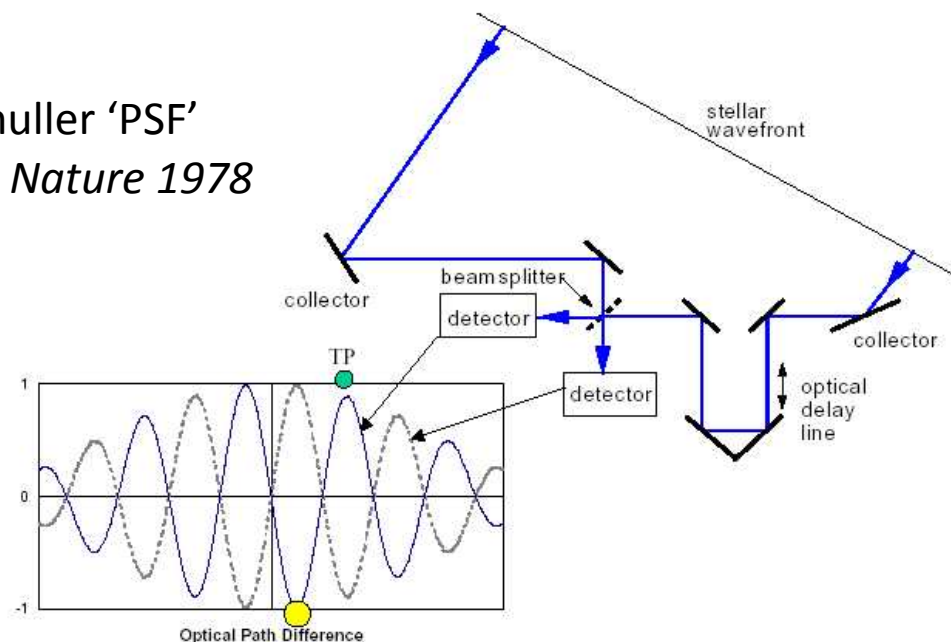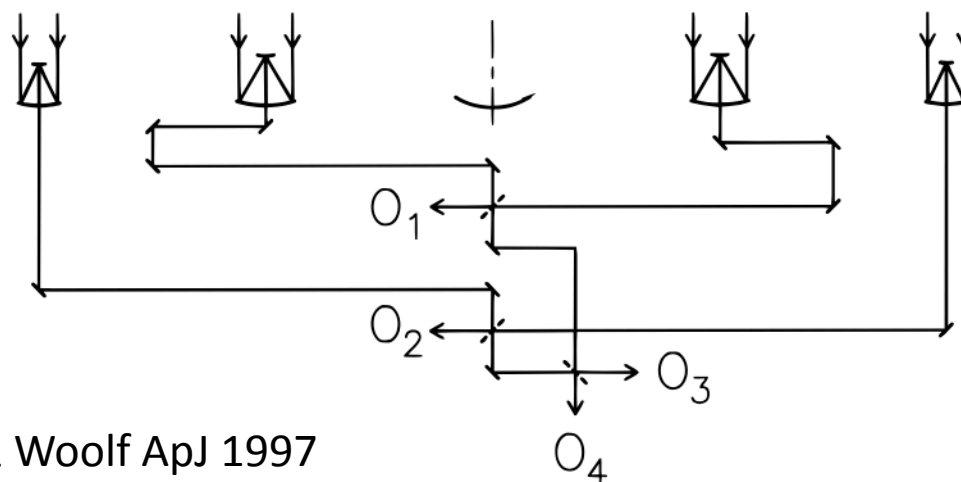(wikipedia) *Nature 1978*

374   ANGEL & WOOLF   Vol. 475


Angel & Woolf ApJ 1997

O_1 O_2 O_3 O_4

Fig. 1.—Schematic diagram of the four-element linear nulling interferometer. The fixed beam combining geometry is configured to give equal path lengths from all four telescopes. The inner and outer pairs are combined with beam splitters having equal transmitted and reflected intensities. The final combiner transmission is chosen to yield amplitudes in the ratio (inner pair/outer pair) = 0.504.

NRM is Interferometry

- Better resolution than traditional aperture

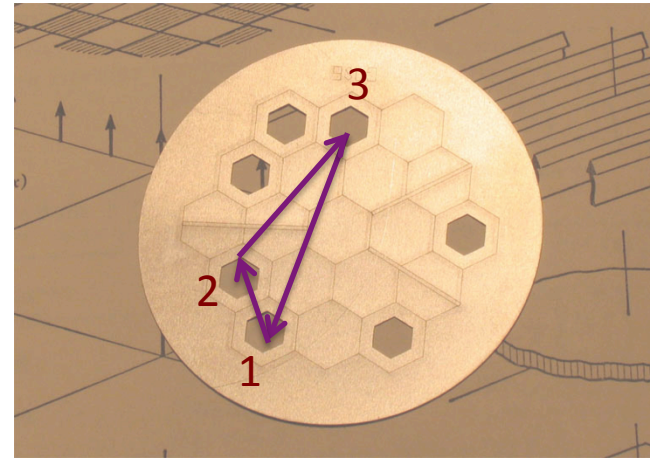- **Achieves high contrast at small inner-working angle**
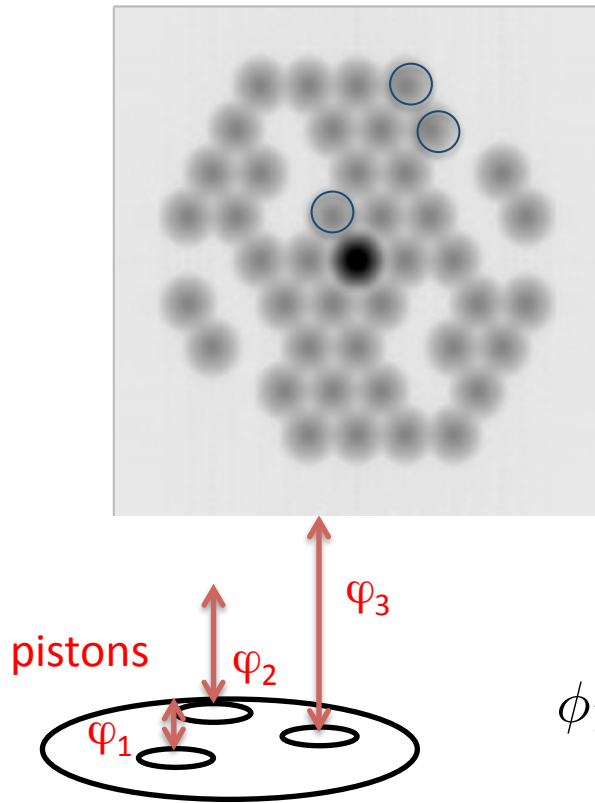
n holes → $\frac{n(n-1)}{2}$ baselines

7 holes – 21 baselines
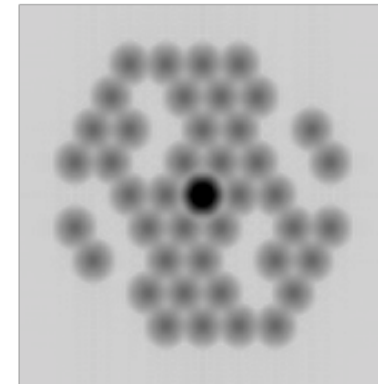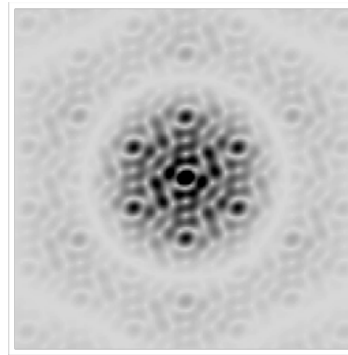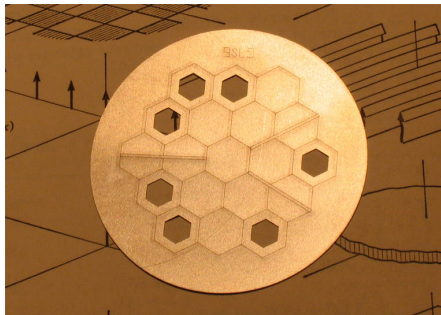
From AG

Closure Phase Measures Structure

$$\phi_{i,j} = \phi_j - \phi_i$$
$$\phi_{1,2} + \phi_{2,3} + \phi_{3,1} = 0$$

pistons

φ_1 φ_2 φ_3

Non-zero closure phases are a result of **structure** or **measurement errors**

Contrast ~ $1/\sigma_{CP}$

From AG

Apr 1998   Jun 1998   Sep 1998

50 mas (75 AU)

Tuthill et al. *Nature 398, 487–489, 1999*

Nov 2009 L'   Nov 2010 K'

100 mas

N

E
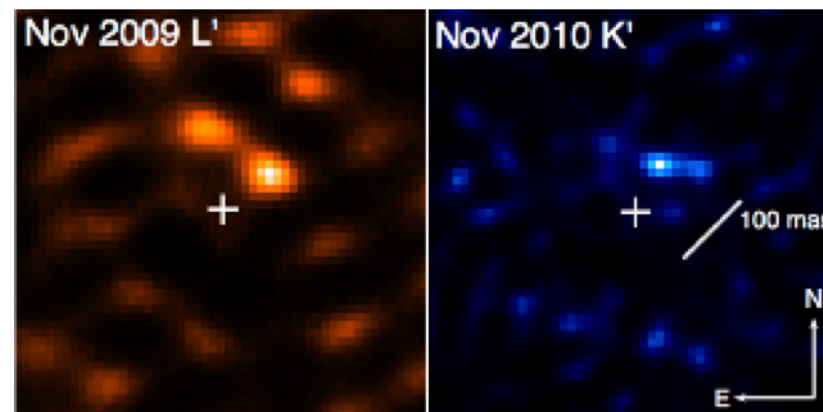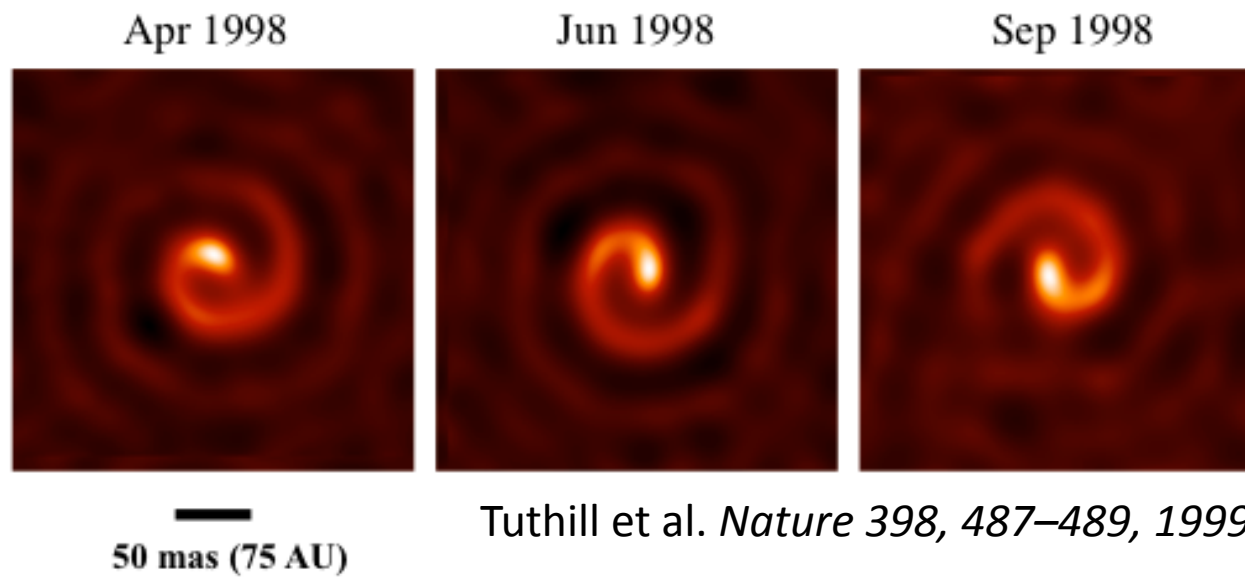
Kraus & Ireland ApJ , 745:5 (12pp), 2012 January 20

Pupil	Hex	2-ring	JWST	JWST NRM
Circ				

PSF 10,000:1 DR

$5\lambda/D$

PSF core 100:1 DR

$0.75\lambda/D$

Distance in Astronomical Units (AU)

Brightness Ratio Relative to Star

Sun

Rocky Planets

Jupiter

Saturn

Uranus

Neptune

Nulling Interferometers (mid−IR)

JWST Coronagraphs

Hubble Coronagraph

JWST NRM Parameter Space

Coronagraph +psf subtract

$10M_J$ 10MYr

$10M_J$ 100MYr

$1M_J$ 10MYr

Resolution Elements λ/D (3.5 μm, 6.5m telescope)

Angular Scale at Taurus (milli−arcseconds)