The Sydney University Stellar Interferometer (SUSI)

John Davis
School of Physics
University of Sydney

Outline

- Background
  - What SUSI is and is not!
  - What SUSI is designed to do
- SUSI
  - The instrument
  - The problems faced by optical stellar interferometry
  - Solutions adopted/developed for SUSI
- Example SUSI observations & results

SUSI is not an imaging instrument!

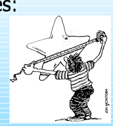
$$\gamma_{12}(\tau) = |\gamma_{12}(\tau)| \exp i\phi_{12}(\tau)$$

$$V_{12}(0) = |\gamma_{12}(0)|$$

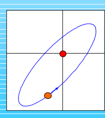
- Atmospheric turbulence introduces phase fluctuations - the phase of the interference fringes is corrupted
- It uses 2 apertures at a time (i.e. a single baseline) so phase closure and image reconstruction is not possible - SUSI measures "correlation" C = V^2

Some Programs for SUSI

- Measurement of the angular diameters of single stars leading to the determination of fundamental stellar properties:



  - Emergent fluxes
  - Effective Temperatures
  - Radii
  - Luminosities
- Measurement of orbits of close binary stars leading to:



  - Stellar Masses
  - Accurate distances
  - M, L & R for individual stars

SUSI from the air

Photo: D. McConnell

Baselines
$5 < b < 640$m

Aperture Diameter
14cm

Spectral Range
$440 < \lambda < 900$nm

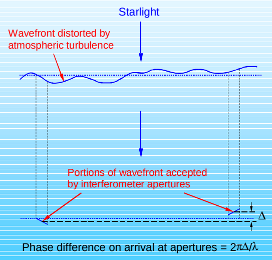
Resolution
75µas - 20mas

The Basic Problems to be Solved

I. Wavefront distortion due to atmospheric turbulence

The Effects of Atmospheric Turbulence

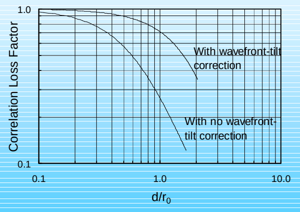
- Wavefront distortion in the form of:
  - Wavefront curvature
  - Wavefront tips and tilts
  - Phase fluctuations

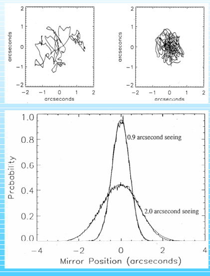


How SUSI overcomes Wavefront Distortion

- Wavefront curvature - small apertures ($< r_0$)
- Wavefront tilt - "tip-tilt" correction (first order adaptive optics)
- Phase fluctuations - rapid signal sampling and processing

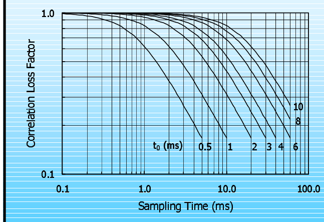
The Effect of Atmospherically Induced Wavefront Tilts

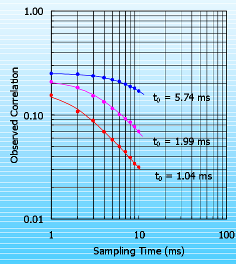




$$\theta_{FWHM} \approx \left(\frac{D}{r_0}\right)^{\frac{5}{6}} \frac{\lambda}{D}$$

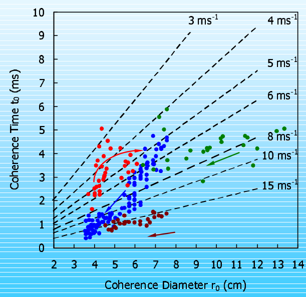
The Effect of the Atmospheric Coherence Time





SUSI Simultaneous Observations of Atmospheric Coherence Time and Coherence Diameter

$t_0 = 0.314 r_0 / V$



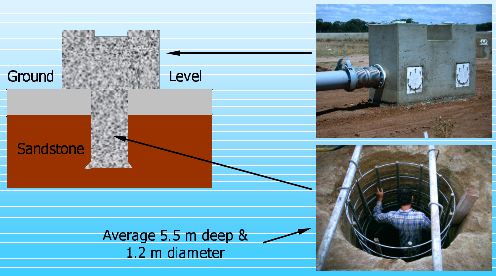
The Basic Problems to be Solved

I. Wavefront distortion due to atmospheric turbulence

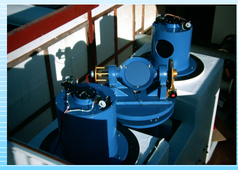
II. Need for extreme mechanical stability

Mechanical Stability

Example: Siderostat support pier



A SUSI Siderostat & Housing



Siderostat & Relay Mirrors

Siderostat Housing
with Roll-off Roof

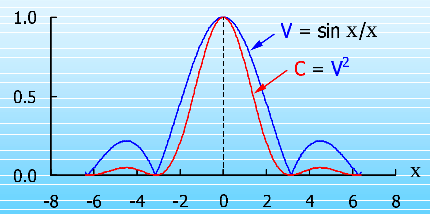
The Basic Problems to be Solved

I. Wavefront distortion due to atmospheric turbulence

II. Need for extreme mechanical stability

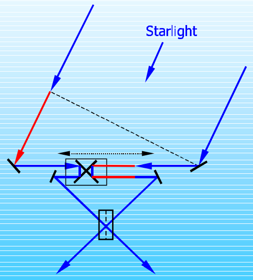
III. Need to match the optical paths

The Variation of V and C with OPD



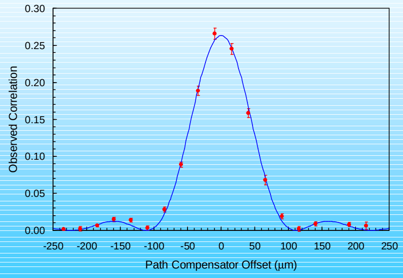
$x = \pi.\mathrm{OPD}.\Delta\lambda/\lambda_{mean}^2$

Optical Path Length Compensation

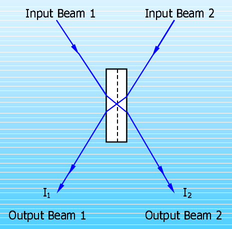


- The individual sections of the blue paths are all equal in the two arms
- The internal red path compensates the external red path

Delay Curve for Sirius



Beam Combination in SUSI



Photon counts n_1 and n_2 in sampling time t

$$n_1 \propto [1 + |\gamma_{12}(0)| \cos \phi]$$

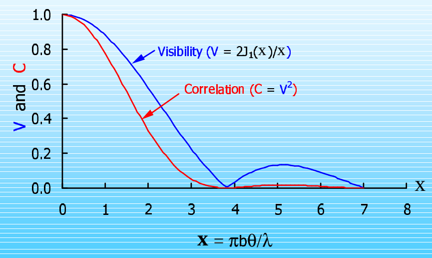
$$n_2 \propto [1 - |\gamma_{12}(0)| \cos \phi]$$

$$n_1 - n_2 \propto 2|\gamma| \cos \phi$$

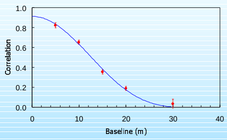
$$< (n_1 - n_2)^2 > \propto 4|\gamma|^2 < \cos^2 \phi >$$

$$< (n_1 - n_2)^2 > \propto 2|\gamma|^2$$

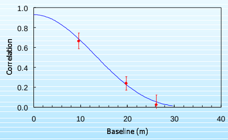
Interferometer Response to a Uniform Disk Source



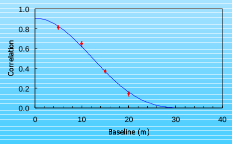
Observations of Delta Canis Majoris



SUSI (ε CMa as calibrator)



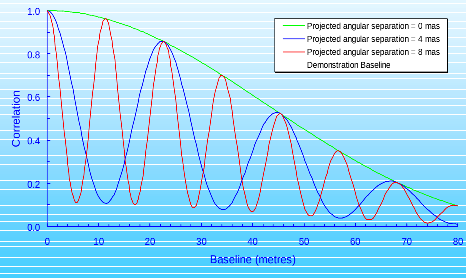
Stellar Intensity Interferometer



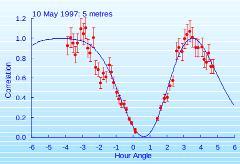
SUSI (η CMa as calibrator)

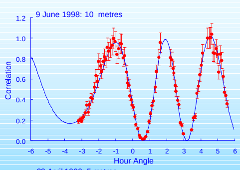
Instrument	Calibration Star	$\theta_{UD} \pm \sigma$ (mas)	σ%
NSII	n/a	3.29 ± 0.46	14
SUSI	ε CMa	3.474 ± 0.091	2.6
SUSI	η CMa	3.535 ± 0.090	2.5
SUSI Mean		3.505 ± 0.064	1.8

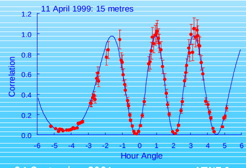
Response of an Interferometer to a Binary Star

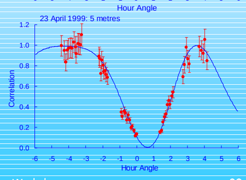


Examples of SUSI Observations of Beta Centauri

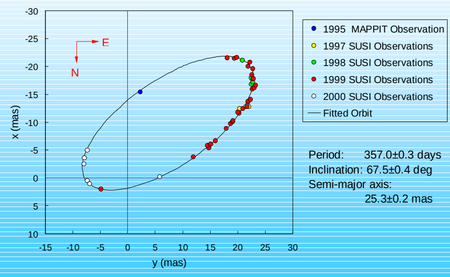








The Orbit of Beta Centauri determined from SUSI Observations



Period: 357.0±0.3 days
Inclination: 67.5±0.4 deg
Semi-major axis: 25.3±0.2 mas

The SUSI Programme

- Observing Programme
  - Single stars for Te, R and L
  - Spectroscopic binaries for M and d, as well as Te, R and L
  - Pulsating stars (e.g. Cepheids) for d
- Technical Programme
  - Installation and commissioning of “red” beam combination system

Ground-Based Long-Baseline Optical/IR Interferometers

Instrument Acronym	Institution	Location	Aperture Diameter (m)	Maximum Baseline (m)	Wavelength Range (μm)	Status
NSII	Sydney U.	Narrabri, Australia	2×6.8	188	0.44	C
SUSI (P'type)	Sydney U.	Sydney, Australia	2×0.10	11	0.4-0.5	C
Mark III	NRL/MIT/CfA	Mt. Wilson, USA	2×0.05	32	0.45-0.8	C
I2T	CERGA	Calern, France	2×0.26	144	Visible	C
GI2T	CERGA	Calern, France	2×1.5	65	Visible/IR	W
COAST	Cambridge U.	Cambridge, UK	5×0.4	100	Red/near IR	W
SUSI	Sydney U.	Narrabri, Australia	2×0.14	640	0.4-0.9	W
IOTA	CfA	Mt.Hopkins, USA	3×0.45	38	Visible/IR	W
ISI	UC Berkeley	Mt. Wilson, USA	2×1.65	70	10	W
NPOI	USNO/NRL	Anderson Mesa, USA	2×6.17	435	0.45-0.9	W
PTI	JPL/Caltech	Mt. Palomar, USA	2×0.4	110	2.2	W
CHARA	Georgia St. U.	Mt. Wilson, USA	6×1.0	350	0.45-2.4	UC
Keck	CARA	Mauna Kea, USA	2(4)×10(1.5)	165	2.2-10	UC
VLTI	ESO	Cerro Paranal, Chile	4(3)×8(1.8)	200	0.45-20	UC

KEY: C - Closed; W - Working; UC - Undergoing commissioning or under construction