Optical Interferometry
Motivation and History

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On Tides, Organ Pipes, and Soap Bubbles

- Tides at Batsha (1684)
- Newton’s *Principia* (1688)
- Thomas Young (1773-1829) and uncle Brocklesby
- General Law of interference
- Two slit experiment (1802)
Armand Hippolyte Fizeau (1819-1896)

- 1845 Fizeau and Foucault describe fringes in dispersed light
Fizeau Suggests
Stellar Interferometry 1867

PRIX BORDIN.

QUESTION PROPOSÉE EN 1865 POUR 1867.

(Commissaires : MM. Duhamel, Pouillet, Regnault, Bertrand,
Edmond Becquerel, Fizeau rapporteur.)

Rapport sur le Concours de l'année 1867.

« Le prix sera décerné au savant qui aura exécuté ou proposé une expérience
décisive permettant de trancher définitivement la question déjà plusieurs fois
étudiée de la direction des vibrations de l'éther dans les rayons polarisés. »

Il existe en effet pour la plupart des phénomènes d'interférence, tels que
les franges d’Yung, celles des miroirs de Fresnel et celles qui donnent lieu
décision des étoiles d'après Arago, une relation remarquable et
nécessaire entre la dimension des franges et celle de la source lumineuse,
en sorte que des franges d'une ténuité extrême ne peuvent prendre naissance
que lorsque la source de lumière n'a plus que des dimensions angulaires
presque insensibles ; d'où, pour le dire en passant, il est peut-être permis
d'espérer qu'en s'appuyant sur ce principe et en formant par exemple, au
moyen de deux larges fentes très-écartées, des franges d'interférence au foyer
des grands instruments destinés à observer les étoiles, il deviendra possible
d'obtenir quelques données nouvelles sur les diamètres angulaires de ces
astres.
Edouard Stephan (1837-1923)

- 1874 E. Stephan uses the Foucault refractor at the Marseilles Observatory to observe most stars down to 4th magnitude.
  - 65 cm aperture separation.
  - All stars produce distinct fringes.
  - Concludes stars must have diameters much smaller than 0.158 arcseconds.
Foucault Refractor
Albert A. Michelson (1852-1931)

- 1878. Measures speed of light 200 times more accurately than previous measurements.
- 1880. Invents *Interferential Refractometer* in Berlin while on leave from Naval Academy.
- 1887. Michelson-Morley experiment.
- 1890. Describes mathematical basis of stellar interferometry
  
  ...and proposes an approach to long-baseline optical interferometry
Moons of Jupiter (1891)

Interferometric mask used on the 12-inch refractor at Lick Observatory to measur the angular diameters of the Jovian satellites. The rod adjacent to the telescop tube is turned by the observer, which in turn rotates a lever connecting the tw slits immediately exterior to the pictured objective shroud. Photograph courtes University of California at Santa Cruz Library.

With this apparatus the satellites of Jupiter were measure ith results as given in the following table:—

<p>| No. of | TABLE I |       |       |       | Seeing. |</p>
<table>
<thead>
<tr>
<th>Satellites</th>
<th>I.</th>
<th>II.</th>
<th>III.</th>
<th>IV.</th>
</tr>
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<tr>
<td>August 2</td>
<td>1.29</td>
<td>1.29</td>
<td>1.88</td>
<td>1.68</td>
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<tr>
<td>August 3</td>
<td>1.29</td>
<td>—</td>
<td>1.59</td>
<td>1.68</td>
</tr>
<tr>
<td>August 6</td>
<td>1.30</td>
<td>1.21</td>
<td>1.69</td>
<td>1.56</td>
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<tr>
<td>August 7</td>
<td>1.30</td>
<td>1.18</td>
<td>1.77</td>
<td>1.71</td>
</tr>
<tr>
<td>Mean...</td>
<td>1.29</td>
<td>1.19</td>
<td>1.73</td>
<td>1.66</td>
</tr>
</tbody>
</table>
Other Applications in 19th Century

- First use of interferometry to measure binary stars (1895)

- 1896 M. Hamy performs aperture masking measurements at the Observatoire de Paris, repeating work by Michelson
Timeline of Interferometry to 1938

E. Stephan
Obs. de Marseille
65 cm
4th magnitude

A. A. Michelson
Lick Observatory
12 inch Refractor
Moons of Jupiter

K. Schwarzschild
Munich Observatory
10 inch Telescope
13 Binary Stars

M. Hamy
Obs. Paris
Grand Coude
Moons of Jupiter & Vesta

Anderson and Merrill
100 inch Telescope
Binary Stars

Michelson and Peacock
Mnt Wilson Obs
Stellar Diameters

1870 1880 1890 1900 1910 1920 1930 1940 1950 1960 1970
30 years goes by...

- Michelson’s measurements of the Moons of Jupiter was a feasibility test. Why didn’t he follow it up?
- Work had been planned with the 32-inch at Lick, but Michelson left for Europe.
- He never followed up with the observations at Lick
- Perhaps there was no point. Stars were obviously too small to measure with single telescopes
- ...stellar interferometry was only a footnote in Michelson’s extremely productive career
- Depression in Chicago in 1890s (little money)
- World War I
1914 Russell proposes two classes of red stars

1919 Michelson funded to measure diameters

Much confusion over predicted sizes of stars

25 ft rotatable interferometer proposed to George Elliot Hale
Michelson’s 20 ft Interferometer

Continuation of work left off in 1891, based on an idea published in 1890

Fig. 1.—Diagram of optical path of interferometer pencils. $M_1, M_2, M_3, M_4$, mirrors; $a$, 100-inch paraboloid; $b$, convex mirror; $c$, coudé flat; $d$, focus.

Stellar diameter estimated at baseline where fringes vanish
Fig. 3.—From F. G. Pease, Notebook 1, sheet 42; approximate date 14 July 1920 (Hale Observatories, copy in Michelson Museum). Crude drawings of the optical wedge used to equalise path length. Note the superimposed sketch illustrating how the night assistant must be perched to move the mirrors on the beam. This situation was necessary because the mirrors, at first, were not continuously adjustable.

Fig. 2.—Diagram of 20-foot interferometer beam. \(M_1, M_2, M_3, M_4\), mirrors; \(B, B\), 10-inch channels; \(C\), steel plate; \(E, E\), screws to move outer mirrors; \(F\), motor drive for screws; \(D\), Cassegrain cage.
Was Michelson Influenced by Fizeau?

- Yes
- No
...Work Continues in the 1920s and 30s

- Observations of Betelgeuse and other stars in 1921
- A small number of other targets observed in the 1920s
- Francis Pease plans a more ambitious instrument
- Michelson dies in 1931
50 ft Interferometer (1931-1938)
Light Paths in the 50 ft Interferometer

Abb. 8. Diagram of light path in 50 foot interferometer.
Ground-level at the 50 ft

Abb. 7. The 50 foot interferometer showing pedestal, mirror cell and worm sector.
F.G. Pease (1881-1938)

- Designed and built by F.G. Pease (1931).
- Probably subject to numerous problems
  - 38 cm mirrors produced speckled images
  - Increased fringe motion at longer baselines
  - Excessive vibrations
  - Polarization mismatch between arms
- Produced results of questionable value
  - Accuracies estimated at 10 - 20%
- Observations ceased in 1938
- ...at the limits of technology
Timeline of Optical Interferometry to 1970

- Radio astronomy born in 1932
- World War II creates a generation of radar engineers

Radio interferometry developed in 1950s
Earth-rotation aperture synthesis developed 1960
A New Type of Stellar Interferometer (1956)

- Diameter of Sirius estimated from experiments at Jodrell Bank, UK (1956).
Intensity Interferometer (1963-1976)

- Manchester University and Sydney University build the *Intensity Interferometer* at Narrabri, NSW, Australia (starting 1961)
  - Initially under the guidance of Twiss
  - Hanbury Brown established as Professor at Sydney University

![Diagram of the interferometer layout at Narrabri Observatory]

*Fig. 7. The general layout of the interferometer at Narrabri Observatory.*
Intensity Interferometer (1963-1976)

- Measures 32 stars to a limiting magnitude of B=+2.5, spectral types O-A inclusive, and accuracies of 1 or 2%.
- Measures orbit of Spica (α Vir)
Robert Hanbury Brown
Interest in Optical Interferometry in the 1960s

- 1967 Woods Hole Summer Study on *Synthetic Aperture Optics* - Advisory Committee to the Air Force Systems Command
  - Closure phase proposed by Rogstad for optical arrays
  - D. Currie and the University of Maryland (1967)
  - H.A. Gebbie, R.Q. Twiss, W.J. Tango and the Monteporzio Interferometer
  - Goodman proposes aperture masking imaging with closure phase information
- E.S. Kulagin, Pulkovo Observatory, measures Capella 1970
Interferometry in the Early 1970s

- Speckle interferometry invented 1970
- Lunar occultation measurements ongoing
- 10 micron heterodyne demonstrated by J. Gay at the Observatoire de Paris 1972.
- “Amplitude Interferometer” (aperture masking) by Currie et al. June-December 1972
- First long-baseline observations at 10 microns by Johnson et al. (1974) at MacMath Solar Observatory using the planet Mercury
  - Observations in late July and Early August 1974
A New Frontier is Opened up in 1974
Work by PRL was conducted at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

http://olbin.jpl.nasa.gov/