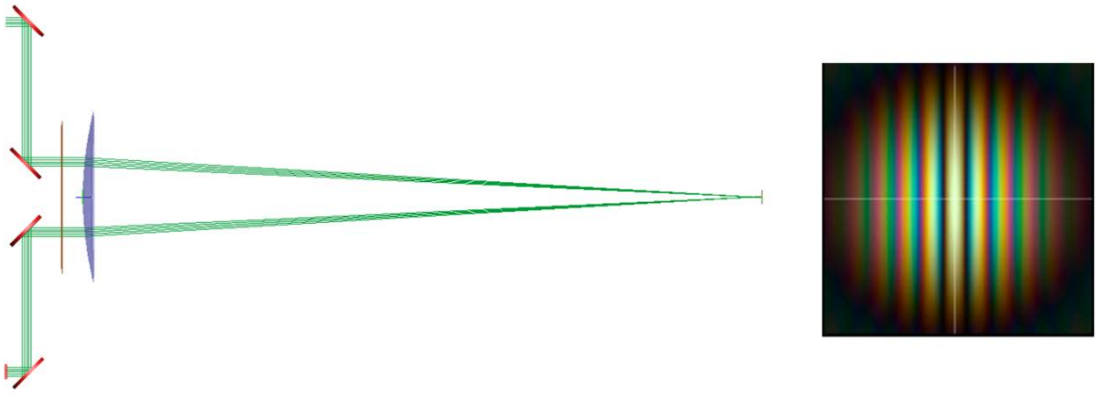
FRED Stellar Interferometer Application Note



Introduction

Astronomical interferometers are capable of taking high angular resolution measurements of stars and galaxies. One of the first astronomical interferometers created was proposed by Fizeau in 1868 and Michelson in 1890. The Michelson stellar interferometer successfully measured the diameter of Betelgeuse in 1920. Today, stellar interferometers are used in cutting-edge research such as exoplanet identification and incredibly high-resolution (4 milliarcseconds) images of stars. In this application note, a classic Michelson stellar interferometer will be designed and analyzed in FRED.

Stellar Interferometer Design

The geometry of the system is shown in Figure 1. The interferometer consists of four mirrors, a set of two pinholes, a positive lens, and a detector.

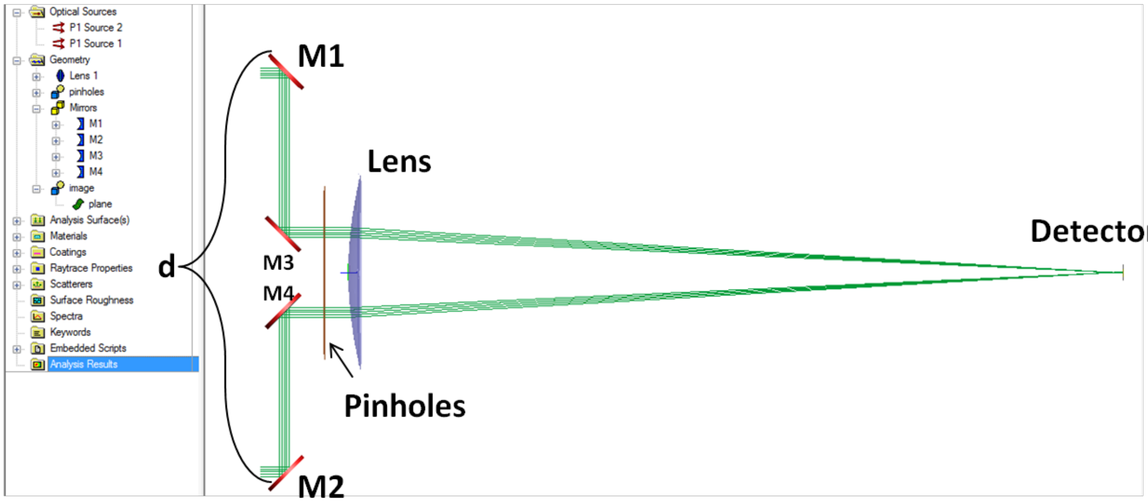


Figure 1. Geometry of Michelson stellar interferometer. Mirrors M1 and M2 are separated by a variable distance d. Another set of mirrors directs this light through a set of pinholes in an opaque mask. The pinholes and mask are part of a custom element with circular trimming. A plano-convex lens is placed behind the mask, and an absorbing plane with corresponding detector element is placed at the focal plane of the lens.

Consider the measurement of a star. The star is modeled as a polychromatic light source which illuminates the interferometer within a small range of angles corresponding to its angular diameter. Normally-incident starlight experiences no OPD between the two paths P1 and P2. However, light entering the interferometer at increasing angles experiences increasing OPD. Some examples of the resulting interference pattern on the detector are shown in Figure 2.

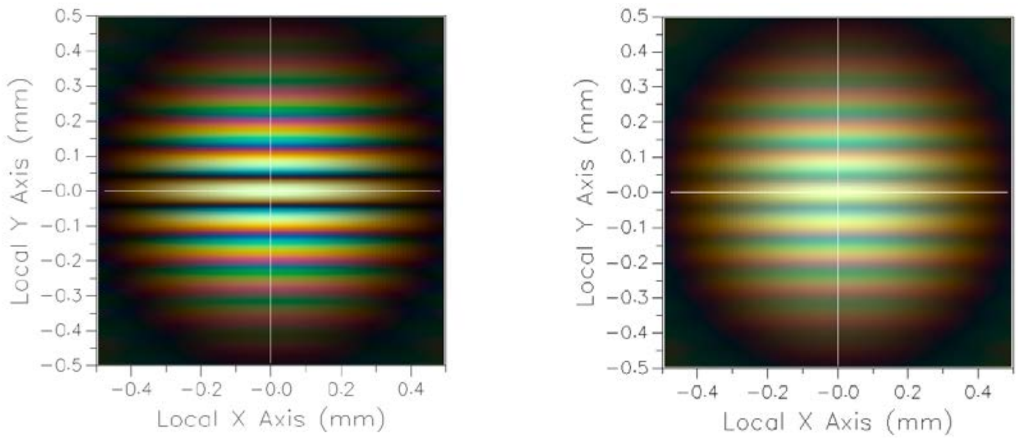
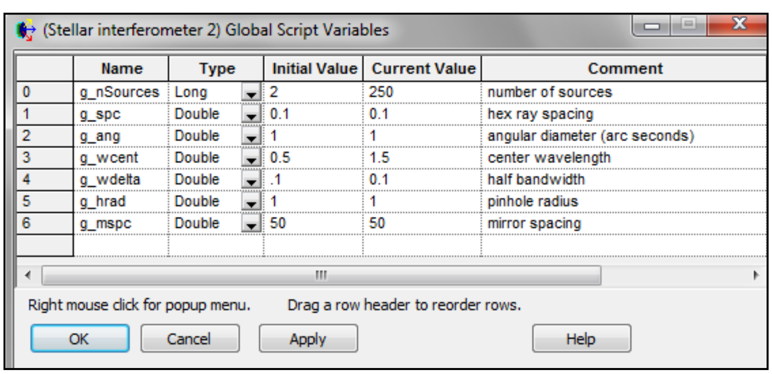


Figure 2. Left: White-light interference pattern on detector from a star with angular extent of 1 arcsecond, central wavelength of 0.55 µm and half-bandwidth of 0.1 µm. The interferometer has a pinhole radius of 1 mm and mirror separation of 50 mm. Right: Interference pattern of the same star with increased mirror separation of 100 mm. Visibility in this pattern is reduced.

Script with Global Variables

Fringe visibility is a function of source angular extent, spectral content, pinhole radius, and the distance d between the two outer mirrors (M1 and M2). In practice, mirror spacing is varied in order to obtain the desired unknown value: angular extent of the source. To observe the effect of each of these variables on the interference pattern, an embedded script with global variables can be written. These variables are shown in Figure 3. Global variables allow the user to make adjustments to a scripted FRED model without directly editing the script itself.


(Stellar interferometer 2) Global Script Variables

	Name	Type	Initial Value	Current Value	Comment
0	g_nSources	Long	2	250	number of sources
1	g_spc	Double	0.1	0.1	hex ray spacing
2	g_ang	Double	1	1	angular diameter (arc seconds)
3	g_wcent	Double	0.5	1.5	center wavelength
4	g_wdelta	Double	.1	0.1	half bandwidth
5	g_hrad	Double	1	1	pinhole radius
6	g_mspc	Double	50	50	mirror spacing

Figure 3. Global script variables for Michelson stellar interferometer.

An embedded script can be used to generate sources with the appropriate wavelength and angular subtense to represent the stellar object. One way to achieve this is by generating pairs of coherent plane wave sources: one source located just before M1 and the other located just before M2. Each source has an appropriate wavelength and relative power based on the spectrum of the source, and propagates in a random direction within the angular diameter provided. Once all sources are created, a coherent raytrace is performed. Irradiance or a Color Image in the detector plane can be computed and displayed. To simulate the operation of a Michelson stellar interferometer, an additional loop can be included in the script which scans mirror separation and calculates fringe visibility at each step. The first minima of fringe visibility will occur when $d=\lambda_0/(2\theta)$ where λ_0 is the central wavelength of the star and θ is its angular subtense in degrees.

References:

1. "Astromomical Interferometer." Wikipedia. September 16, 2015. Accessed December 15, 2015. https://en.wikipedia.org/wiki/Astronomical_interferometer.
2. "Michelson Stellar Interferometer." Wikipedia. June 15, 2014. Accessed December 15, 2015. https://en.wikipedia.org/wiki/Michelson_stellar_interferometer.
3. “Measurement of Stellar Diameters.” Brown, R. H. Annual Review of Astronomy and Astrophysics, vol. 6, p.13. 1968.

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