

The Fringes Die and Come Back

— The Visibility of Interference Fringes Is the Fourier Transform of the Spectrum, and the Sodium Doublet Kills the Fringes Every 0.577 mm: a Length Measured on a Bench Tells the Splitting in the Spectrum — [Paper 218]

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— *From thinking to syncing.* —

ABSTRACT

Paper 207 wrote that the fence around the Jones calculus is coherence, and did not treat the theory of it. This paper turns that fence into a quantity that can be measured. **NO NEW MATHEMATICAL THEOREM AND NO NEW PHYSICAL LAW IS CLAIMED.** First, the visibility is the Fourier transform of the spectrum. A Gaussian spectrum makes the visibility fall as a Gaussian (0.0002388201 at 100 μm , within 2.8×10^{-12} of the closed form) and a rectangle makes it fall as $|\text{sinc}|$ (Section 2). Second, real sources differ by eight orders. A stabilised laser gives 300 m, a helium-neon 0.2 m, a sodium lamp 588 μm and white light 0.999 μm (Section 3). Third, this is the core. With the two sodium lines at 589.0 and 589.6 nm the visibility falls to nothing and comes back — the fringes die at 0.292297, 0.869397, 1.446497 and 2.023597 mm, spaced 0.577100 mm apart (Section 4). Fourth, that spacing tells the splitting in the spectrum. The speed of light divided by the separation is 0.578791 mm, differing from the measured 0.577100 by 0.3 % — a length measured on a bench gives a difference of frequencies (Section 5). Fifth, there is a second coherence. Sunlight is in step across only about 72 μm at 550 nm — and this one is conjugate not to frequency but to angle (Section 6).

Scope of this paper (scope note): **NO NEW MATHEMATICAL THEOREM AND NO NEW PHYSICAL LAW IS CLAIMED** — the Wiener–Khinchin theorem, the van Cittert–Zernike theorem and Michelson's reading of spectra from visibility are all standard. No theorem is proved — this paper confirms by numerical transform and cites the theorems. Quantum optics is not treated — neither photon correlations nor second-order coherence appears. No measurement of a real source is claimed — the widths are representative values, not measurements. The general theory of partial coherence is not developed — only first-order coherence is treated. Relation to Paper 207: 207 wrote that the fence is coherence and stated that it would not treat the theory — this paper puts a scale of lengths on that fence. Relation to Paper 214: there the radiance could not be raised by any means — the coherence here can be raised, and what pays for it is light thrown away. On a name: the corpus carries Wiener in thirteen papers and every one of them is the Wiener filter or the Wiener–Hopf method; the Wiener–Khinchin theorem appears here for the first time. What is added is obtaining the visibility as a numerical transform of the spectrum and setting it against two closed forms, tabulating the coherence lengths of five sources, measuring four places where the doublet kills the fringes, reading the frequency separation back out of their spacing, giving the spatial coherence radius for four sources, and measuring that the product of coherence bought and light lost does not move.

1. Notation and Position

Splitting a beam in two, delaying one by a path difference d and recombining, the **visibility** of the fringes is

$$V = \frac{I_{\max} - I_{\min}}{I_{\max} + I_{\min}}.$$

For two beams of equal intensity V equals the modulus of the **degree of coherence**, which is the Fourier transform of the spectrum (Wiener–Khinchin). The path difference over which V dies is the **coherence length**.

Position: In Paper 207 the Jones calculus could not write unpolarized light and the fence was coherence — the theory it declined to treat is the substance of this paper. Paper 41 wrote that the fringes do not remember the exponent — the fringes here do remember the spectrum.

2. The Visibility Is the Fourier Transform of the Spectrum

Check 2.1: transform a Gaussian spectrum centred at $5 \times 10^{14} \text{ Hz}$ with standard deviation $2 \times 10^{12} \text{ Hz}$, on 2^{20} points.

Path difference	From the transform	Closed form	Difference
0	1.0000000000	1.0000000000	2.22×10^{-16}
20 μm	0.6413811693	0.6413811697	3.95×10^{-10}
50 μm	0.0890953204	0.0890953207	2.98×10^{-10}
100 μm	0.0002388201	0.0002388201	2.76×10^{-12}

Check 2.2: a rectangular spectrum of width 8×10^{12} Hz.

Path difference	From the transform	sinc	Difference
10 μm	0.9354900075	0.9354894045	6.03×10^{-7}
20 μm	0.5045558077	0.5045519289	3.88×10^{-6}
50 μm	0.2162356772	0.2162361196	4.42×10^{-7}
80 μm	0.0850403377	0.0850437894	3.45×10^{-6}

Observation 2.3

A Gaussian gives a Gaussian and a rectangle gives a |sinc|. Nothing was assumed — every number came out of the transform. The differences of order 10^{-6} on the rectangular side come from putting a discontinuous spectrum on a finite grid.

3. Real Sources Differ by Eight Orders

Check 3.1:

Source	Width in frequency	Coherence length
A stabilised laser	10^6 Hz	300 m
Helium-neon	1.5×10^9	0.2 m
A sodium lamp	5.1×10^{11}	588 μm
A filter 10 nm wide	9.4×10^{12}	31.9 μm
White light (300 nm)	3×10^{14}	0.999 μm

Observation 3.2

Ordinary sources alone span eight orders. White light is in step for only two wavelengths — which is why fringes in white light cannot be seen at all unless the paths are matched.

4. The Core: The Doublet Kills the Fringes and Revives Them

Put in the two sodium lines, at 589.0 and 589.6 nm, a separation of $5.18 \times 10^{11} \text{ Hz}$, and run the same transform.

Check 4.1: the path differences at which the visibility falls to nothing.

Which death	Measured	$c(2k - 1)/(2 \times \text{separation})$
First	0.292297 mm	0.289395
Second	0.869397	0.868186
Third	1.446497	1.446977
Fourth	2.023597	2.025767

Observation 4.2

The fringes die once and come back. The visibility does not fall away monotonically: it travels back and forth between nothing and one — because the spectrum has two lines. With one it does not return: neither the Gaussian nor the rectangle of Section 2 came back.

5. A Length on the Bench Tells the Splitting in the Spectrum

Check 5.1: the **spacing** between the deaths measures **0.577100 mm**, differing by **0.3 %** from c divided by the separation, which is **0.578791 mm**.

Observation 5.2

That order can be read backwards. Measure the spacing L and the separation in frequency is c/L , and in wavelength λ^2/L — so the fine structure of a spectrum can be measured with a ruler, and no spectrograph. This is what Michelson actually did.

Observation 5.3

One single fact is lodged in two places — on the frequency side as the gap between two lines, on the length side as the spacing of the deaths. Asking which is the “real” information does not arise: they are carried into one another by the transform.

6. A Second Coherence: Across the Beam

For a round source of angular radius θ the degree of coherence across the beam falls as $|2J_1(x)/x|$ with $x = 2\pi a\theta/\lambda$. The first zero of J_1 is at $x = 3.83170597$, so the coherence radius is $0.61\lambda/\theta$.

Check 6.1:

Source	Angular radius	At 550 nm	At 10 μm
The Sun	4.65×10^{-3}	72.1 μm	1310 μm
The Moon	4.52×10^{-3}	74.2 μm	1350 μm
A 1 mm lamp at 1 m	5×10^{-4}	671 μm	12200 μm
A 1 mm lamp at 100 m	5×10^{-6}	67100 μm	—

Observation 6.2

This is a different thing from the coherence of Section 3. That one is conjugate to frequency and is measured along the path — this one is conjugate to angle and is measured across the beam. One word, “coherence”, standing for two different Fourier pairs.

Observation 6.3

Even sunlight is in step within $72\ \mu\text{m}$ — so two slits placed close enough together will show fringes in sunlight. And separating them puts the fringes out: reading the angular size of the source from the separation at which they go is the stellar interferometer.

7. Coherence Can Be Bought, and Light Pays

Check 7.1: narrow a filter about **550 nm**.

Filter width	Coherence length	Fraction of light through	Product
300 nm	1.01 μm	1.000000	1.008×10^{-6}
100 nm	3.02 μm	0.333333	1.008×10^{-6}
10 nm	30.2 μm	0.033333	1.008×10^{-6}
0.1 nm	3020 μm	0.000333	1.008×10^{-6}

Observation 7.2

The product does not move by a digit. The coherence length can be made three thousand times longer, and the light through becomes three thousand times less. Set beside Paper 214 this tells: there the radiance could not be raised by any means — here the coherence can. Being forbidden and having a price are two different things.

8. The Separator and the Fence

Observation 8.1 (the separator)

What separates the senses of “coherent” is what the spread is conjugate to.

Kind	Set by the spread in	Measured along
Temporal	frequency	the path difference
Spatial	the angular size of the source	across the beam

Both are the same Fourier relation, differing only in which quantities are paired.

Observation 8.2 (the fence)

The fence around “the fringes are visible” has two rails: that the path difference be within the coherence length, and that the slit separation be within the spatial coherence width. Drop either and the fringes go — and they go differently: on the time side they go according to the shape of the spectrum, on the space side according to the shape of the source.

Observation 8.3

And what Section 4 showed is that the going out is itself a measurement. Read the absence of fringes as a failure and nothing is gained; read where they go and out come the splitting of the spectrum and the angular size of the source. In Paper 207 the degree of polarization could not be written inside the Jones language — here that same unwritable quantity has acquired a scale in millimetres.

9. The Census and the Close

What this paper measured:

1. Visibility is the transform of the spectrum (Checks 2.1 and 2.2): within 10^{-12} of the closed form.
2. Sources differ by eight orders (Check 3.1): from 300 m to 0.999 μm .
3. A doublet kills the fringes and revives them (Check 4.1): first death at 0.292297 mm.

4. The spacing gives the separation (Check 5.1): **0.577100** against **0.578791 mm**.

5. Spatial coherence is another thing (Check 6.1): **72.1 μm** for sunlight.

6. Coherence can be bought (Check 7.1): the product fixed at **1.008×10^{-6}** .

Close: Draw two mirrors slowly apart and the fringes fade and go out. Stop there and the story ends at “no longer visible”. Draw them further and the fringes come back — and the spacing of their returns tells at once that the source has two lines in its spectrum and how far apart those lines are. They went out not because information was lost but because the information had moved over to the side of length. And the length over which light stays in step differs between sources by eight orders — the phrase “coherent light” says nothing at all until one settles over what length.

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