Linnik microscope as an optical analog of holographic electron microscope and Doppler electron microscope.

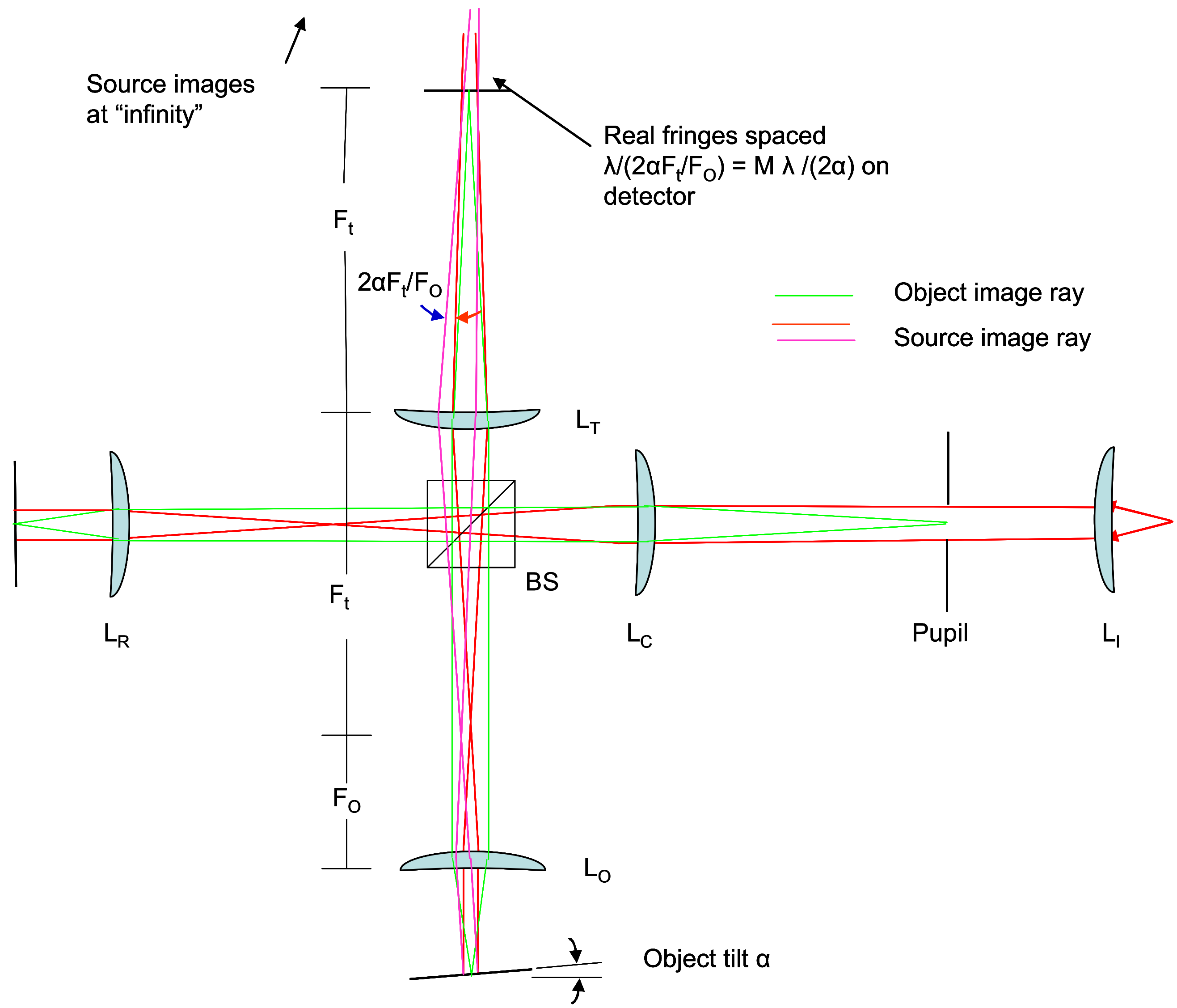

Figure 1 Point source ray diagram of Linnik Microscope

Figure 1 shows that, in the "standard" Linnik configuration, the source is collimated (imaged at negative infinity) by lens L_I. The pupil is in the front focal plane of converging lens L_C, so the combination of L_C and the objective lens L_O image the pupil onto the object. Since the illumination is essentially collimated at the pupil, it is also collimated at the image of the pupil on the object—hence there is a source image at infinity below the object. The reference lens L_R is identical to the objective L_O, so a similar description applies to the reference leg. The object is assumed to be reflective, and its localized tilt α is small enough to avoid vignetting by the microscope optics (combination of objective L_O and tube lens L_T). If we consider the reference leg imaged in the beamsplitter to the object space, this results in two virtual images of the source at negative infinity, separated by angle 2α. Thus we have “virtual fringes” on the object with spacing $\lambda/(2\alpha)$. These fringes are imaged, along with the object, onto the detector with magnification $M = F_T/F_O$.

If the source is an extended, spatially incoherent source, we can perhaps consider the pupil as an extended incoherent source as well. {Is this true? It is the argument given in Völkl, *et al*[1] page 63. But Verbeeck, *et al*[2] propagate the mutual coherence of the (relatively large) source disk to the condenser aperture, assume the aperture is small relative to the propagated mutual coherence function, and therefore the pupil is highly coherent. **Question 1:** Which makes sense in our case, and in the case of the imaging holographic microscope?}

We consider each image point (where “point” is an isoplanatic patch of the microscope objective, of size λ/(N.A.), N.A. being the numerical aperture of L_O) as a separate interferometer, with image intensity governed by path length difference between reference and object *at that point*. Since the source point images from object and reference are superimposed only on themselves at the image, light from neighboring, phase incoherent source points does not affect the local intensity, and the image has high contrast fringes, regardless of the size of the illumination pupil. This argument would seem valid whether the pupil is coherent or incoherent. The images from object and reference must be aligned within the resolution limit of the microscope, which is quite practical at optical wavelengths.

Question 2: Could this be done with the electron microscope? If so, it would eliminate the limitation imposed by the coherence area $l_s = \lambda/(2\beta)$ (Tonomura[3], p 18). Perhaps this alignment cannot be achieved in the electron microscope. The question is somewhat academic, BUT not entirely—we are proposing essentially the same thing, with a source image small relative to the object (the Doppler probe size) as opposed to flooding the entire object. Note that our Doppler probe typically will not need to be as small as the probe beam spot in the STEM.

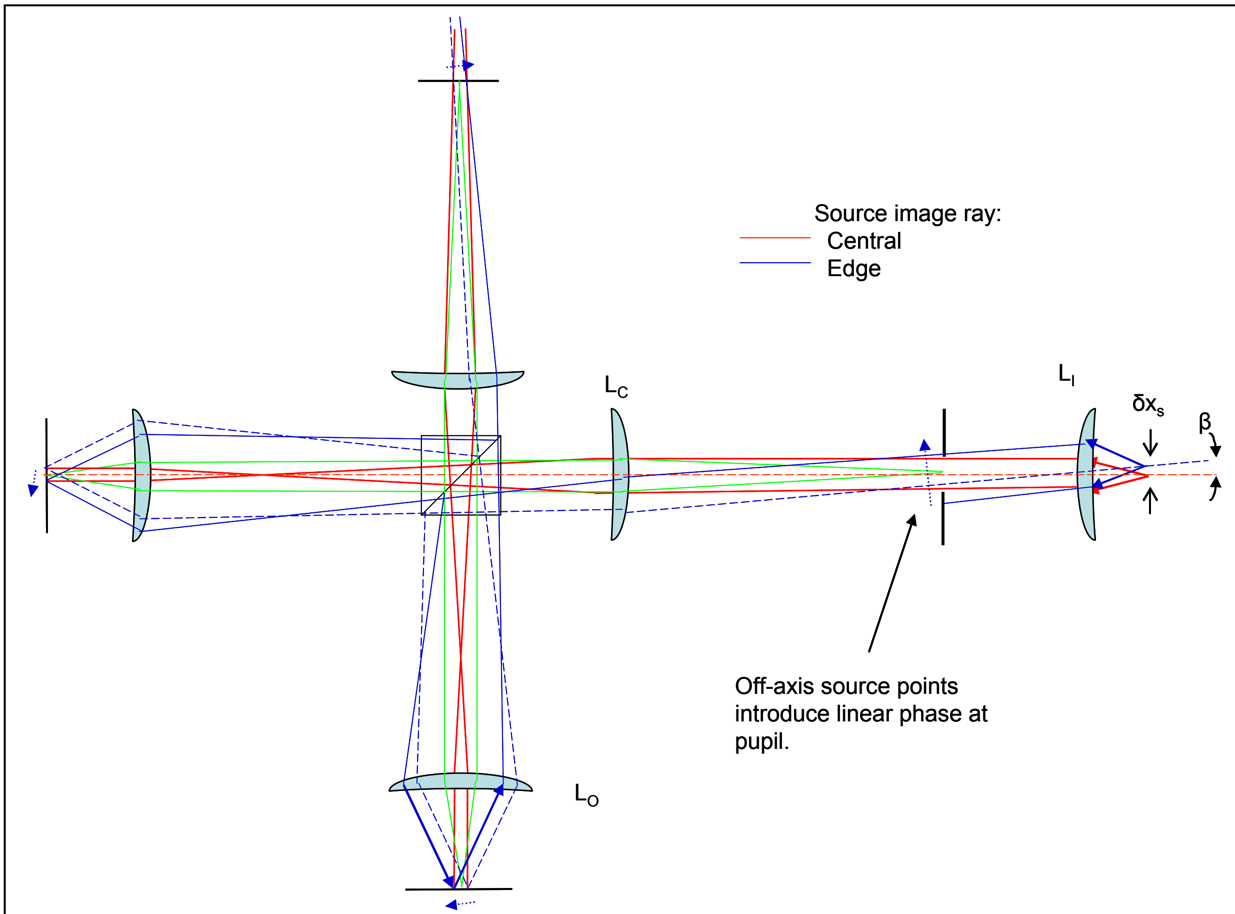

Figure 2. Ray diagram showing off-axis source point

Figure 2 shows that each off-axis source point contributes a plane wave at the pupil. Each of these plane waves is incoherent with all other plane waves from other source points, and has a linear phase related to the location of its particular source point. But, since the pupil images from the object and reference legs are imaged at the detector, the linear phases subtract out, and only the phase differences due to object shape remain. Again, high contrast fringes result. This argument is somehow equivalent to the above argument about imaging each point in the pupil separately, but I am not sure how. {This is how Mike Sinclair explains it}. Again, there is essentially no limitation on β, the angle subtended by the source. In our configuration, our source is a green LED about 1mm in diameter, and L_I is a 10X microscope objective of about 16mm focal length, so the half angle β=.031. At λ=0.5μ, we get a coherence length at the pupil of l_s=8μ. Our actual pupil is a few mm in diameter, clearly well above the coherence length (this presumably validates considering the pupil as an incoherent source).

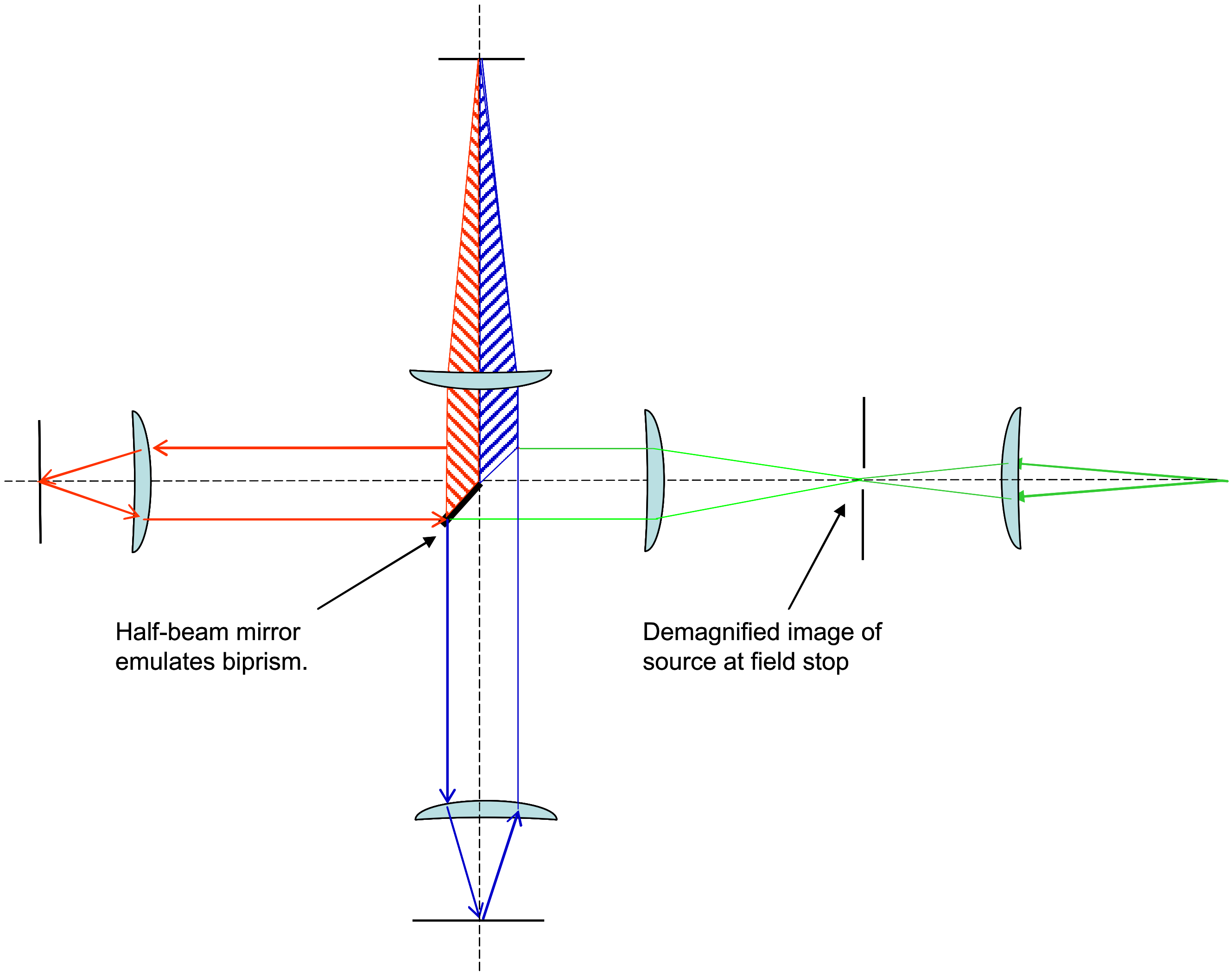

Figure 3

Figure 3 is a ray diagram of my proposed optical analog of the biprism interferometer. Using a half-mirror instead of a beamsplitter splits the beam spatially, instead of by amplitude, just like the electron biprism. In this diagram, the pupil is assumed small, to simulate the Doppler probe beam. The light passes twice through the "biprism"—this would require two electron biprisms, above and below the object as in Figure 4a. **Question 3:** is this a reasonable analog for the biprism based electron interferometer?

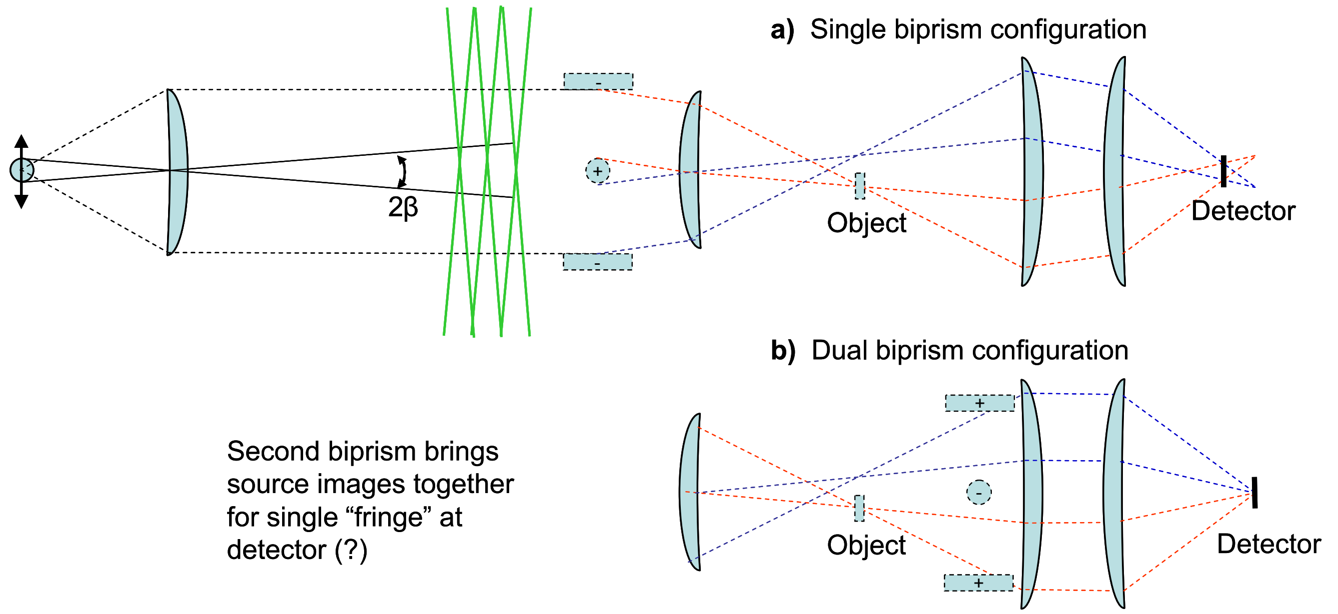

Figure 4

Figure 4 is a ray diagram of the electron microscope in "Doppler" mode. The second biprism will probably be essential to put all the energy onto the detector. See Figure 5 for implications of single biprism case. **Question 4:** Is this a reasonable configuration for Doppler? Can we in fact violate the $l_s = \lambda/(2\beta)$ criterion, since we are imaging the source onto the detector (in the two biprism configuration).

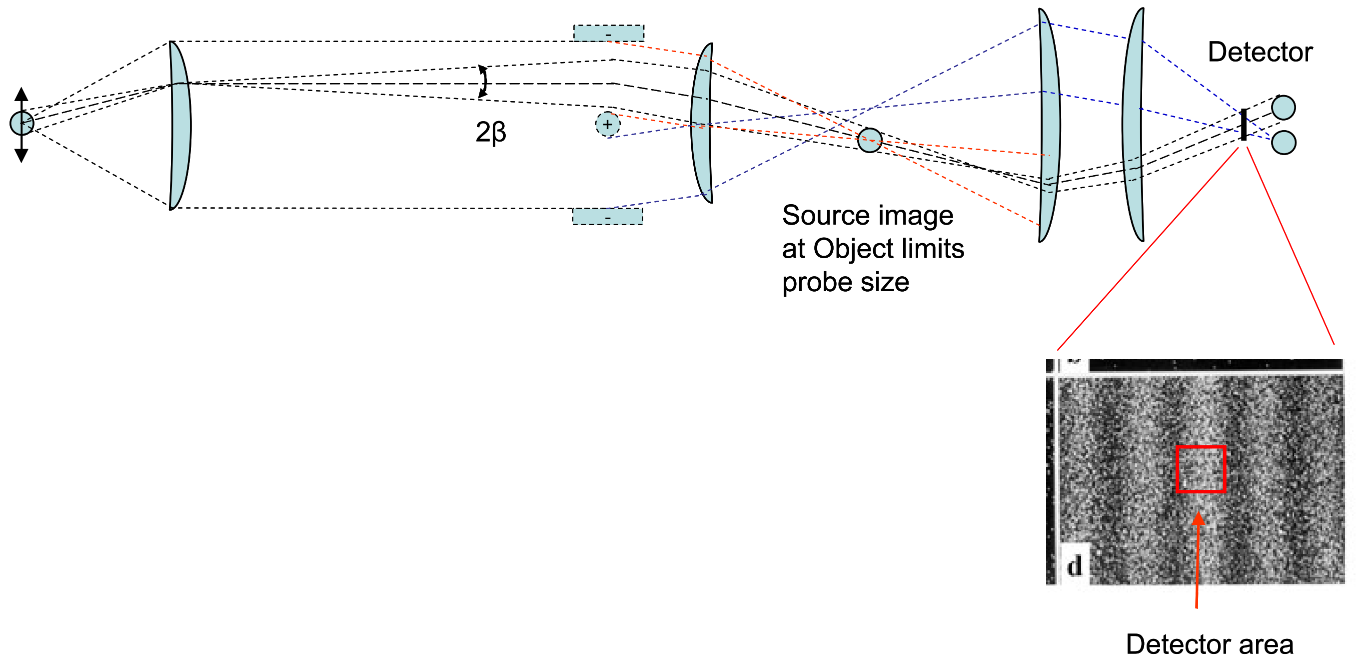

Figure 5

Figure 5 is a similar ray diagram, considering finite source size. **Question 5:** In this single biprism implementation, since the source images do not overlap, will we not get coherent fringes? I think we will get fringes, *if* the source satisfies the $l_s = \lambda/(2\beta)$ criterion. Also shown here is what happens if we don't have the second biprism—the two virtual sources, IF they are coherent, create a fringe pattern in the overlap space. Our detector must be small enough to capture a single fringe, thus wasting energy.

References

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[1] E. Völkl, L. Allard and D. Joy, *Introduction to Electron HolographyI,* Kluwer Academic/Plenum, New York, 1998.
[2] J. Verbeeck, D. vanDyck, H. Lichte, P. Potapov, and P. Schattschneider, "Plasmon holographic experiments: theoretical framework:, Ultramicroscopy 102 (2005), pp239-255.
[3] Tonomura, A., *Electron Holography*, Springer, Heidelberg, Germany, 1999.