particular, Tseng et.al. obtained values of up to 520 Poise for the mean shear viscosity of the intranuclear region in Swiss 3T3 fibroblasts, while the values of the diffusion coefficient obtained by particle tracking match ours very well (of the order of 10^{-3} $\mu m^2/s$ and below). Interestingly, evidence was found for elastic behavior in nuclei at time scales below 1 s, which is currently not covered by our current instrument. Taken together, these results and ours indicate that the transport in live cells is far from being fully understood. We believe our dispersion relation analysis may provide a complementary approach for studying this phenomenon label-free, over broad spatial and temporal scales.

5. Summary and discussion

In sum, we developed an approach to study the intracellular transport that is based on measuring the dispersion curves, $\Gamma(q)$, from quantitative phase imaging. On average the mass transport in a live cell is diffusive at small scales (1 μm and below) and deterministic at large scales (several microns). Our experiments show that continuous or completely transparent systems can be studied successfully by this method, in a label-free manner. Biologically, this result is quite reasonable: mass transport at large scales cannot be accomplished effectively by diffusion alone, as it is too slow; thus, it requires energy consumption. For example, neurons are a particular cell type that must accomplish transport over very large distances. Our results showing that the dendritic transport is largely directed strongly supports this idea.

It is worth noting that DPS can be equally used with other quantitative phase imaging techniques, such as these described recently in Refs [30–32]. The temporal limitations of studying subcellular transport are due to the acquisition rate; currently SLIM acquire 2.3 frames/s. However, this is not a limitation of principle and higher acquisition rates can be reached by using, for example, faster camera and spatial light modulation.

Acknowledgments

This research was supported by National Science Foundation (CBET 08-46660 CAREER, CBET-1040462 MRI) and Grainger Foundation (G. Popescu). L. J. Millet was supported by the NIH HD007333 Developmental Psychobiology and Neurobiology Training Grant. AJL acknowledges support from NSF-DMR-0907212. G. P. acknowledges stimulating discussions with Tommy Angelini.