Single-distance high-resolution in vivo imaging with propagation based X-ray phase contrast

Ralf Hofmann
Karlsruhe Institute of Technology – ANKA, Germany

Propagation based X-ray phase contrast microtomography is a promising venue to investigate vertebrate development in vivo and in 4D.
Here we discuss a computationally efficient approach to phase retrieval from a single-distance measurement of intensity using hard and highly coherent X-rays. Since lifecell imaging depends on a low dose per tomographic projection the signal-to-shot-noise ratio in retrieved phase maps ought to be made large by other means than high event rates in a micron-sized effective detector pixel. That is, at a given level of comparably high noise the signal (contrast) must increase without sacrificing resolution. For propagation distances z larger than those of the edge-enhancement regime contrast emerging from pure phase objects rises as z^(1/2) while shot-noise essentially does not depend on z. The large-z application of the conventional (Paganin) phase-retrieval algorithm, which truncates linear-in-phase-variation contrast-transfer (CTF) at linear order in z, however, increasingly ignores high-frequency information. We have observed that the all-order-in-z CTF, which yields algebraic phase retrieval in Fourier space, actually can be extended to the situation of rather non-linear phase variations by a mild and well justified local renormalisation of intensity contrast. This gives a signal-to-noise ratio in the phase maps which rises linearly in z. The situation is quite ubiquitous in condensed-matter and plasma physics resembling quasi-particle approaches to successful descriptions of interacting systems. The thus achieved retainment of high resolution in phase maps, retrieved from large-z intensity contrast, of course, relies on high spatial and temporal beam coherence.
In the talk, applications, imaging development in Xenopus laevis (African clawed frog) in vivo and ex vivo at micron resolution, are discussed which represent the presently achievable resolution limit at most 3rd generation synchrotrons using z ~ 1m. However, a worldwide ongoing wave of machine upgrades towards micron-range source sizes will soon enable values of z in the tens of meter. Resolution can then additionally be boosted by introducing slight beam divergences in terms of focussing optics. In passing, we mention conditions under which the application of algebraic reconstruction techniques is advantageous in reducing the number of measured projections and thus X-ray dose.