From projections to small-angle scattering : Artifacts induced by polychromatic cone-beams

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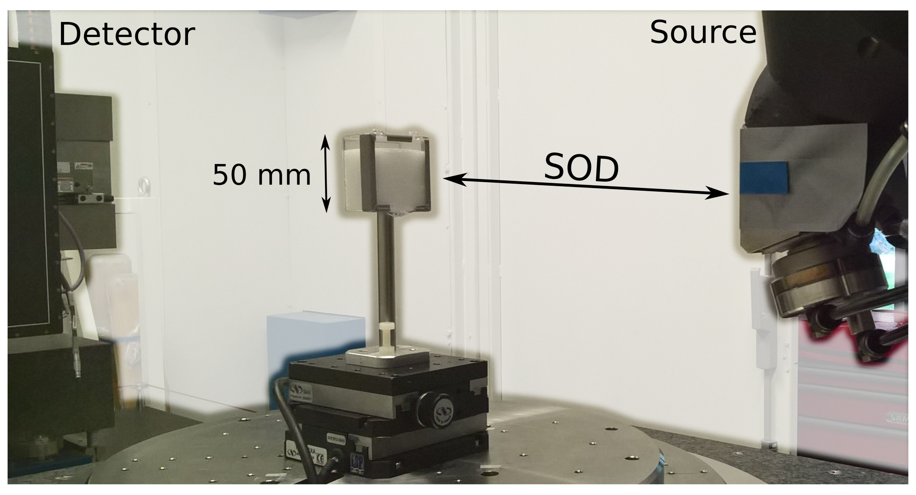
Context and objectives

- **Small-angle scattering** (SAS - X-ray, neutron) is a technique for the investigation of the structure of disordered materials at the 1nm – 100nm scale. It delivers, in Fourier space, the two-point correlations of the electron density within the material.
- For isotropic materials, the SAS pattern *I(q)* depends on the norm *q* of the wave-vector only, and the covariance function *γ(r)* depends on the norm *r* of the lag-vector only.

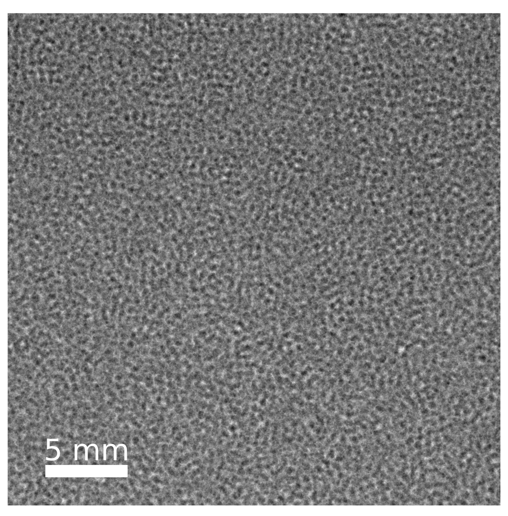
$$I(q) \propto \int_0^{+\infty} 4\pi r^2 \,\mathrm{sinc}(qr)\, \gamma(r)\, \mathrm{d}r$$

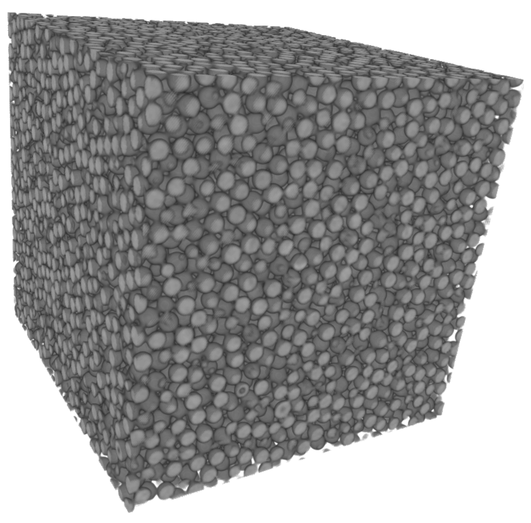
  - The sample preparation is kept to a minimum.
  - The 3d structural information [*γ(r)*] is limited, but quantitative: volume fraction, specific surface area, particle-size distribution…
  - Applications from biology [1] to geomaterials [2-3].
- A technique was proposed to simulate the SAS pattern of a material from **a single X-ray radiography** [4], which:
  - bridges the length scales explored by SAS and by microtomography,
  - opens the door to time-resolved, quantitative experiments,
  - was successfully used in various applications [3, 5, 6].
- However, it is mathematically correct (and fully validated) for parallel beams only. In order to **extend this technique to cone-beam geometries**, our goal in this project is to quantify the distortions induced by non paraxial rays.

Materials and Methods



- Polystyrene beads were placed in a plastic container. Projections were acquired on a laboratory tomograph (RX Solutions) under various source-to-object distance (SOD) and a long source-to-detector distance.
- For reference, a full tomography scan was also acquired (voxel-size 30µm).



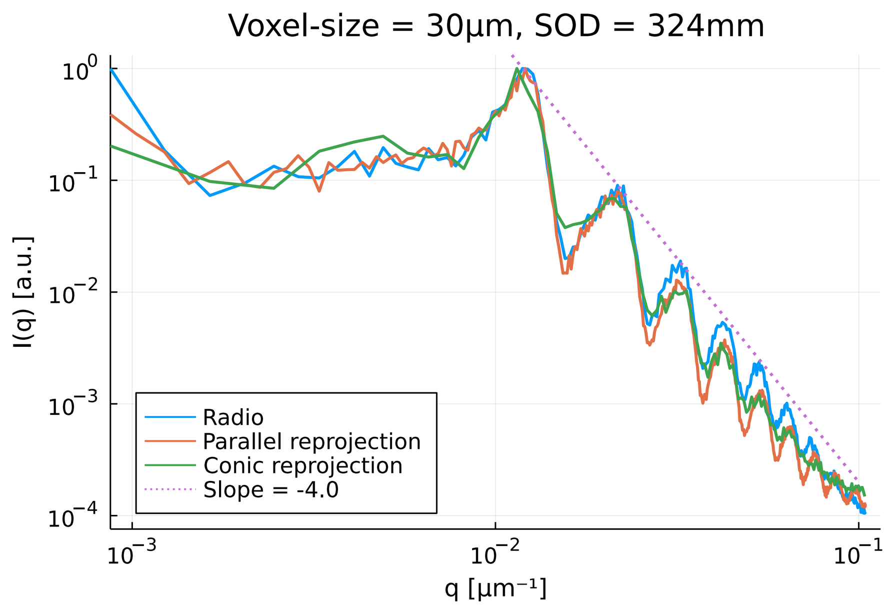


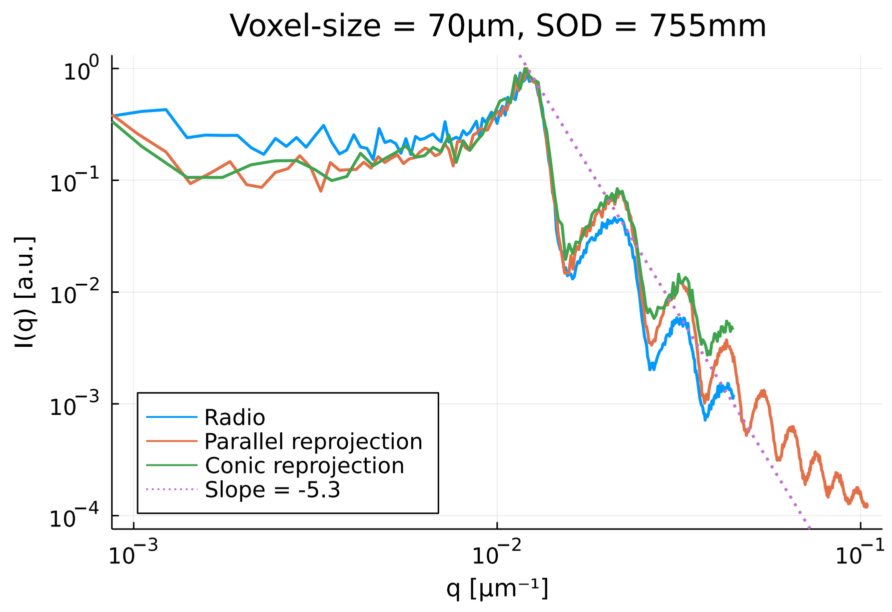
- The SAS spectra were computed from the projections *P* (log of radios) at each SOD.

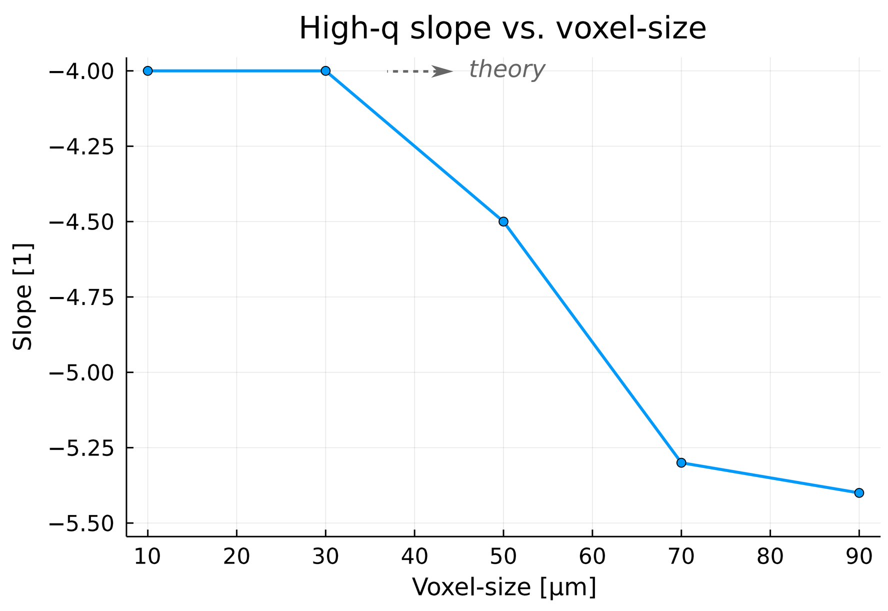
$$I(q_x, q_y, q_z = 0) = \left|\hat{P}(q_x, q_y)\right|^2$$

- The SAS spectra were also computed from the **parallel reprojection** and **conic reprojection** of the 3D reconstructed + thresholded volume. Both reprojections are monochromatic.

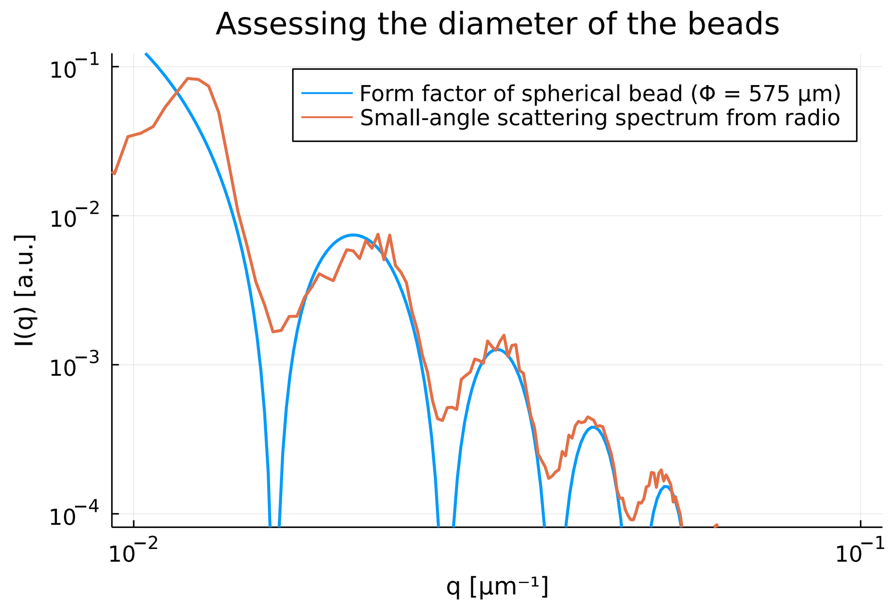
Results



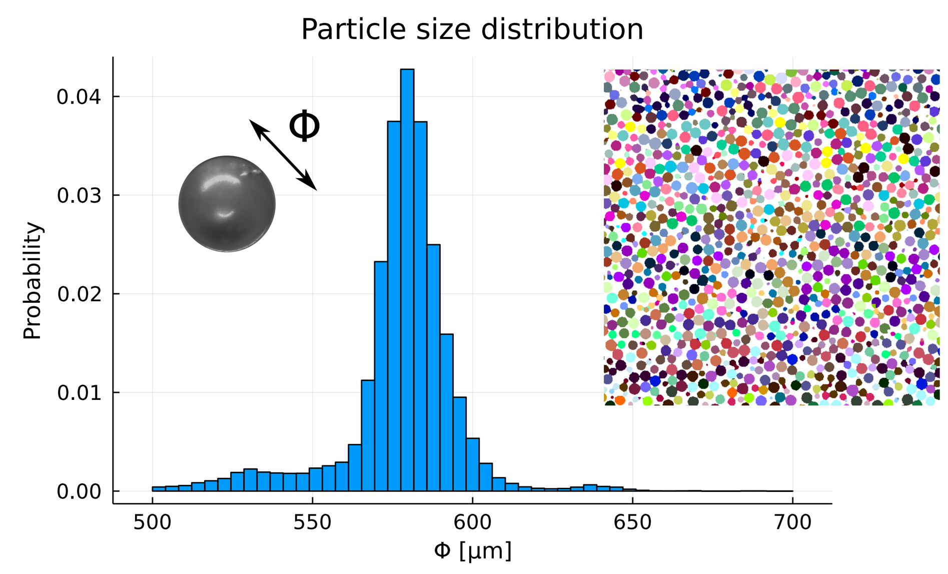


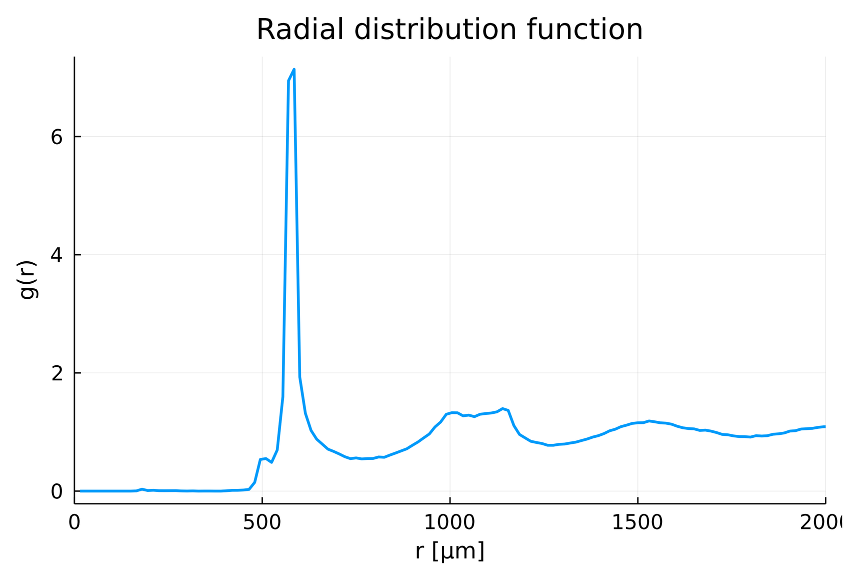


- Maximizing the source-to-object distance minimizes the distortions induced by the conic geometry. Our results therefore suggest that there is at least one more source of distortions.
- Comparison of **radio** and **conic reprojection** shows that beam-hardening cannot be neglected.
- Despite these distortions, the proposed method is **quantitative**. We were able to measure the average radius of the spherical beads from one single radio.



- The resulting value was confirmed by a more costly analysis of the 3D reconstructed volume (PSD + RDF [8]).





Perspectives

- New experimental setup, with a more controlled sample (dimensions, …)
- Quantification of other descriptors: volume fraction, specific surface area …
- Analytical model of geometric, noise-induced and beam-hardening distortions → deconvolution
- Extension to N > 2 phases: vary source kV and/or use photon-counting, dual energy, XC-Thor sensor from DirectConversion
- “Sub-pixel” accuracy?

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