

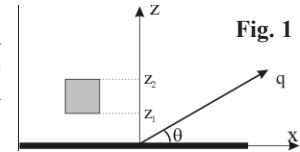
## On the Observation of (Remote) Anisotropy due to Macroscopic Restrictions

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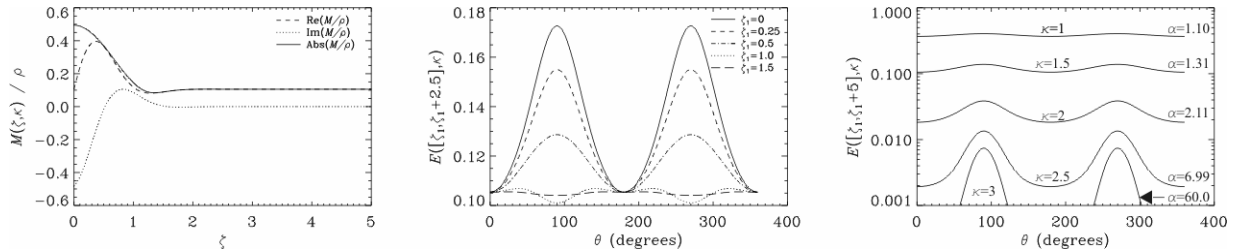
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**Introduction:** Diffusing molecules in the proximity of restrictions are known to cause the 'edge enhancement' effect in NMR imaging [1]. In diffusion-weighted (DW) scans the edge enhancement effect is more pronounced and gives rise to an observable level of anisotropy when the DW acquisition is repeated with the diffusion gradients oriented along different directions. This anisotropy can be exploited to estimate the orientation normal to the nearby boundary [2]. In this work, using a simple geometry of a single infinite plane, we demonstrate that when the voxel is situated sufficiently close to a boundary, the diffusion signal is anisotropic even if the voxel itself contains no structure. The expected behavior is verified experimentally on samples of parallel planes and hollow cylinders. The method can be utilized to infer information from various tissues with macroscopic boundaries such as the cerebral cortex and the colon wall.

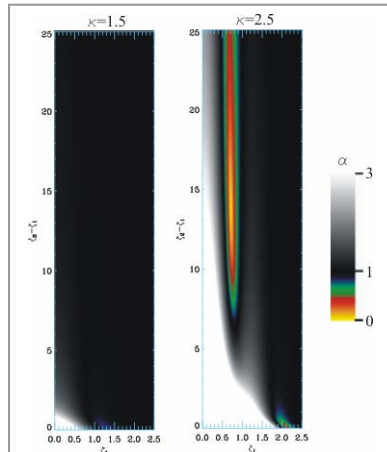
**Simulations:** We consider the geometry on the right, where the gray box depicts a representative voxel near the infinite plane. Starting from the propagator obtained using the method of images, we calculated the magnetization density and the total signal expected from the voxel. In our simulations we employ the following variables:



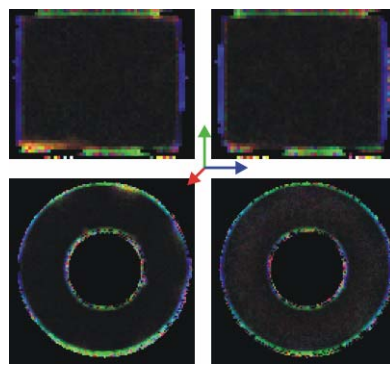
$$u = \sqrt{\lambda D_0 \Delta} \quad , \quad \zeta = \frac{z}{u} \quad , \quad \text{and} \quad \kappa = \pi q u$$



**Fig. 2** The magnetization density profiles as a function of the distance from the infinite plane located at  $\zeta=0$  with  $\kappa=1.5$ ,  $u=0.04$  (left panel). The signal attenuation values as a function of the angle between the infinite plane and the gradient direction ( $\theta$ ) where the length of the voxel along the  $z$ -direction ( $\zeta_2-\zeta_1$  value) was taken to be 2.5 (middle panel). The signal attenuation values as a function of  $\theta$  for various levels of diffusion weighting ( $\kappa$  varied between 1 and 3), with  $\zeta_1=0$  and  $\zeta_2-\zeta_1=5$ . Here  $\alpha=E(\theta=90^\circ)/E(\theta=0^\circ)$  is a measure of anisotropy (right panel).



**Fig. 3** Note that in the middle panel of Fig. 2, phase cancellations are responsible for  $E(\theta=90^\circ)$  to be even smaller than the free diffusion attenuation,  $E(\theta=0^\circ)$ , resulting in  $\alpha < 1$  i.e., the 'edge detractor' effect. The figure above depicts the  $\alpha$  values for a variety of  $\zeta_1$ ,  $\zeta_2-\zeta_1$  and  $\kappa$  values. It is clear that for smaller values of  $\kappa$  and  $\zeta_1$ ,  $\alpha > 1$ . In this regime, it is expected that the direction along which the signal is greatest is the surface normal.



**Fig. 4** Color orientation maps computed from the eigenvector of the diffusion tensor associated with the **smallest** eigenvalue hypothesized to yield the direction normal to the nearby boundary.

A cylindrical object with a rectangular void (top) was constructed in-house from Ultem 1000 (Boedeker Plastics Inc., Shiner, TX), whose susceptibility is similar to that of water. The resolution of the image was  $78 \times 312.5 \mu\text{m}^2$  in-plane; the slice thickness was 1.5mm. Clearly, the eigenvectors in the voxels near the edges are coherently oriented perpendicular to the surface. A hollow cylinder (bottom) was also constructed in-house from Ultem 1000. The resolution of the image was  $117 \times 117 \mu\text{m}^2$  in-plane, and the slice thickness was 1.5mm. The orientation map computed from the third eigenvalue of the tensor accurately revealed the normal vectors on concave as well as convex surfaces.

**Conclusion:** We have shown that the effect of macroscopic boundaries on the nearby diffusing nuclei may lead to diffusion anisotropy. Further, this anisotropy was shown to be within observable limits.

This different notion of anisotropy can be exploited to infer information regarding the structure of nearby walls. Because many structures in human body (most organs of the GI tract, lungs, blood vessels, etc.) possess macroscopic boundaries, the method may be useful in examining many organs and diseases.

**References:** [1] Hyslop & Lauterbur, J Magn Reson 1991;94:501-510.

[2] Özarlan, Nevo & Basser, Proc Intl Soc Mag Reson Med, 2007;15:1516.