The Application of Interferometry to Magnetic Resonance Imaging

BASP Frontiers 2011.09.07

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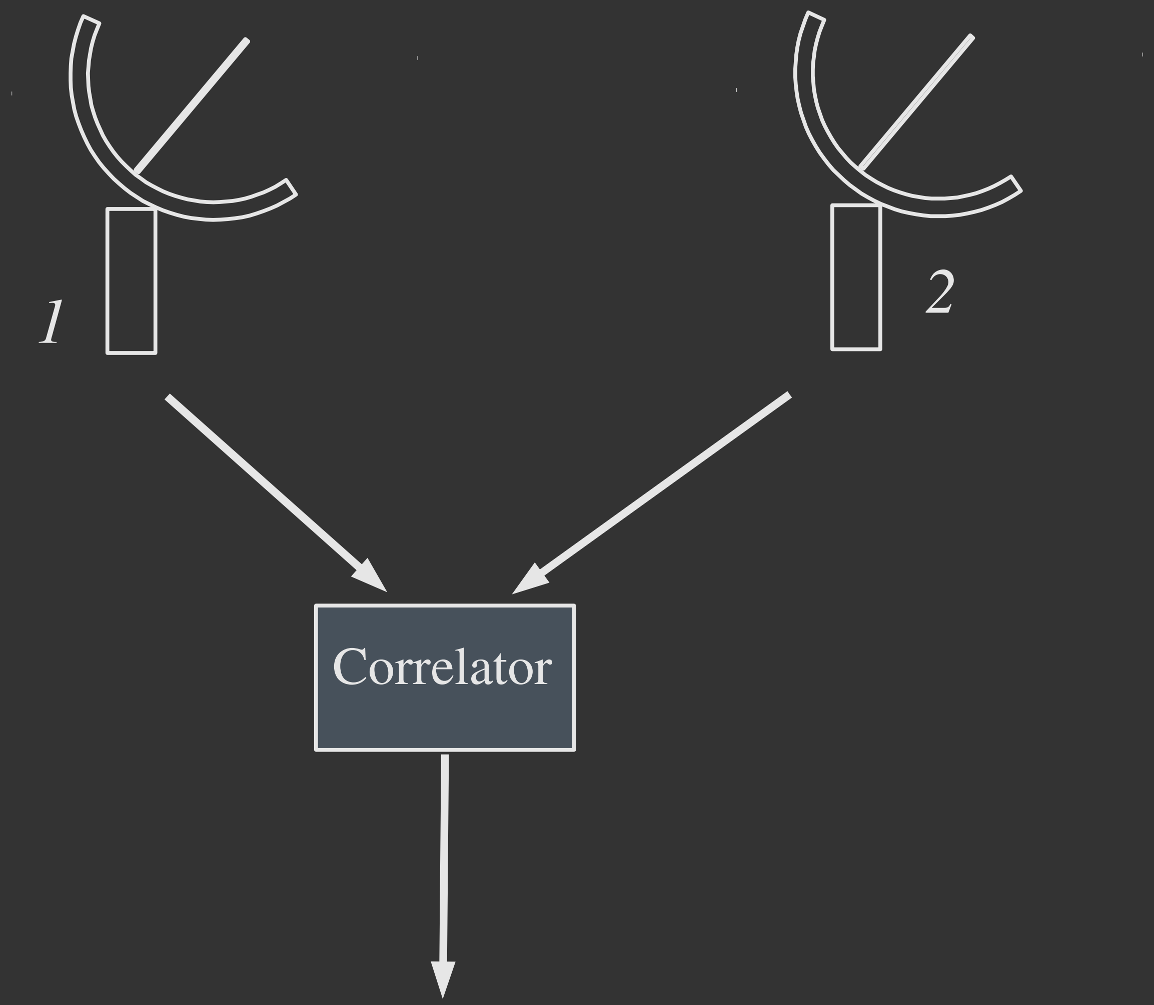
Introduction

- Interferometry is a powerful imaging technique
  - Radio Astronomy
  - Satellite Geography
  - Optical Coherence Tomograpy (OCT)
- Application of interferometry to MR
  - enhanced resolution
  - reduction in scan time
- Results for 1-D and 2-D (+time) MR Spectroscopic Imaging

Interferometry in Radio Astronomy



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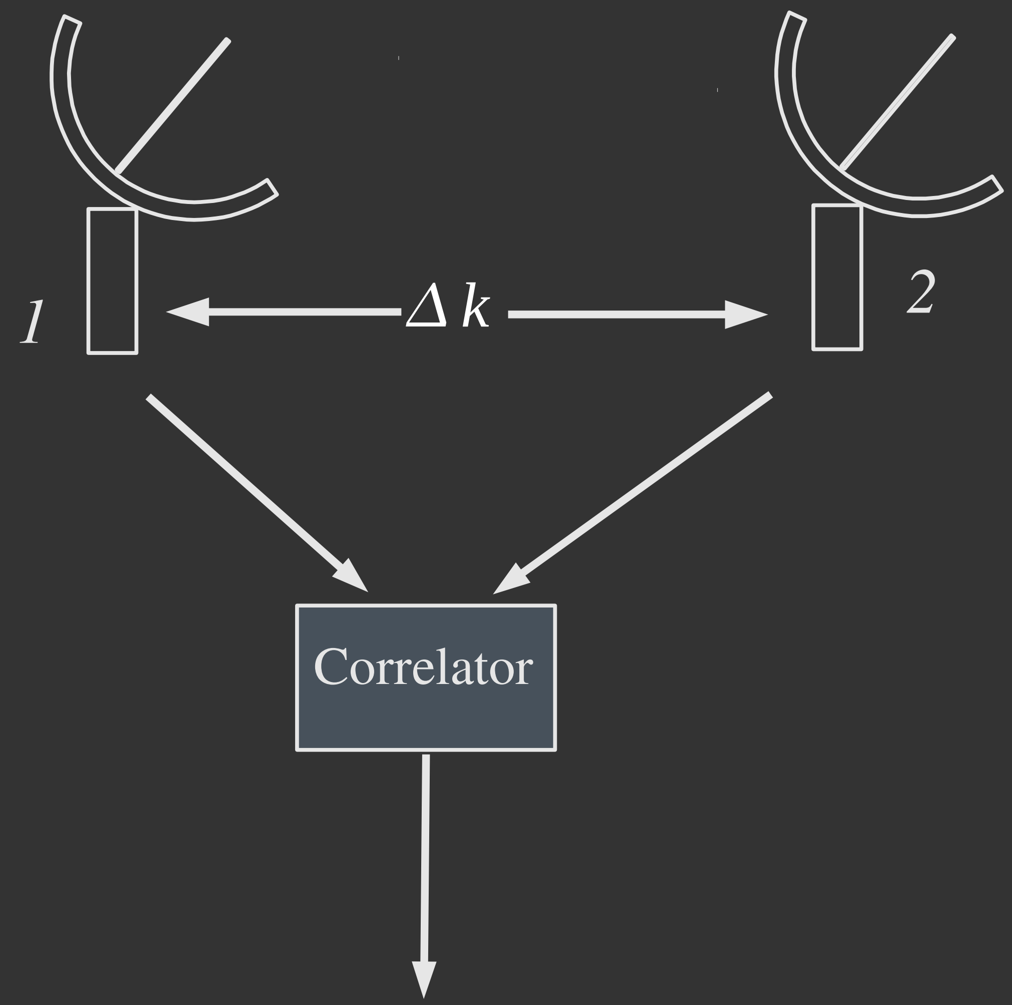
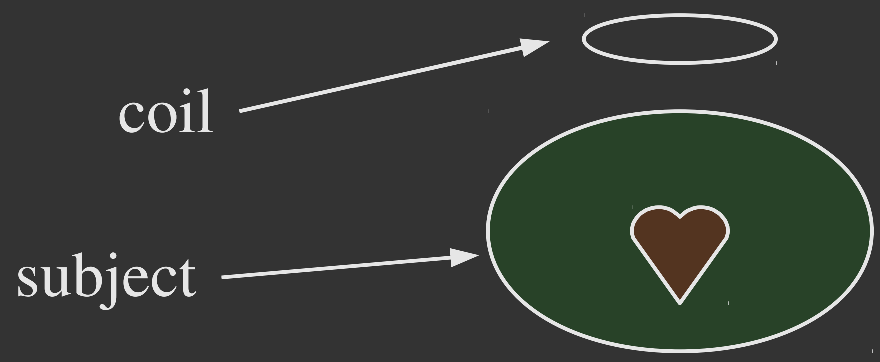


Interferometry to MR



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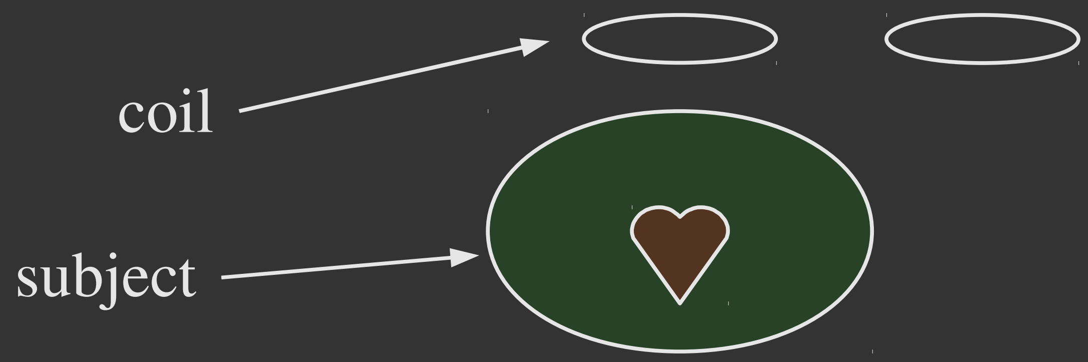

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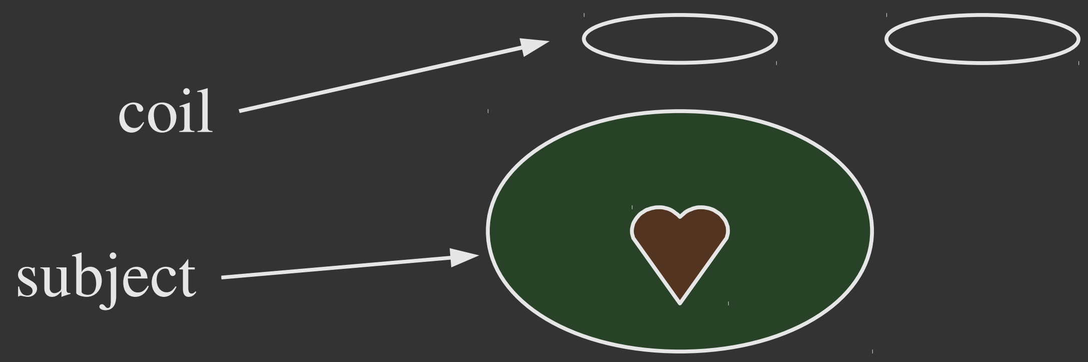

- Direct application: Coils need to be $3x10^8$ m apart

Ernst RR. Nuclear Magnetic Resonance Fourier Transform Spectroscopy (Nobel Lecture). Angewandte Chemie International Edition in English. 1992;31(7):805-823.

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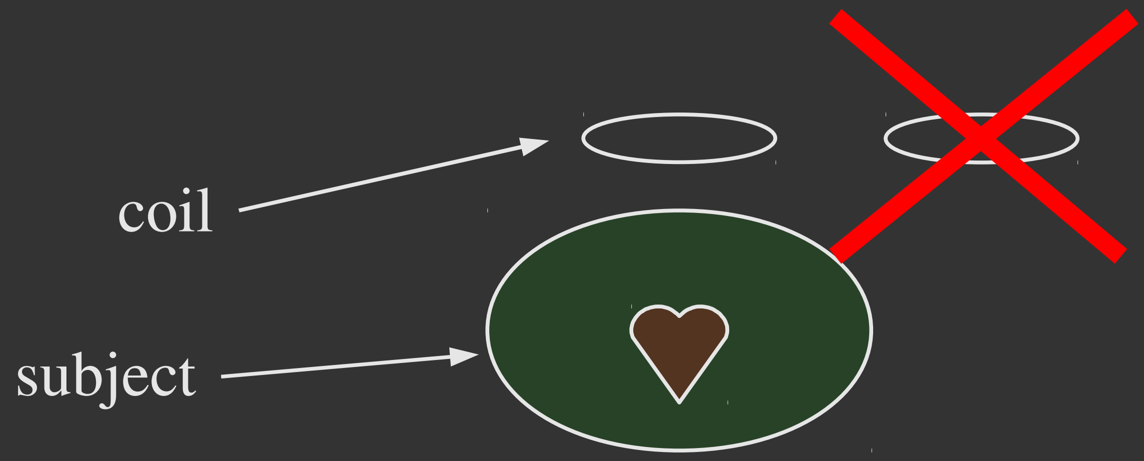

- Direct application: Coils need to be $3x10^8$ m apart
- Correlate signals from a single coil

Ernst RR. Nuclear Magnetic Resonance Fourier Transform Spectroscopy (Nobel Lecture). Angewandte Chemie International Edition in English. 1992;31(7):805-823.

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$$|s(r,f)|^2 \underset{FT}{\Leftrightarrow} \Gamma(\Delta k,\tau) \qquad \Delta k = k_1 - k_2$$

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- For *N* positions of *k*, there are at most *N(N-1)* positions of Δk

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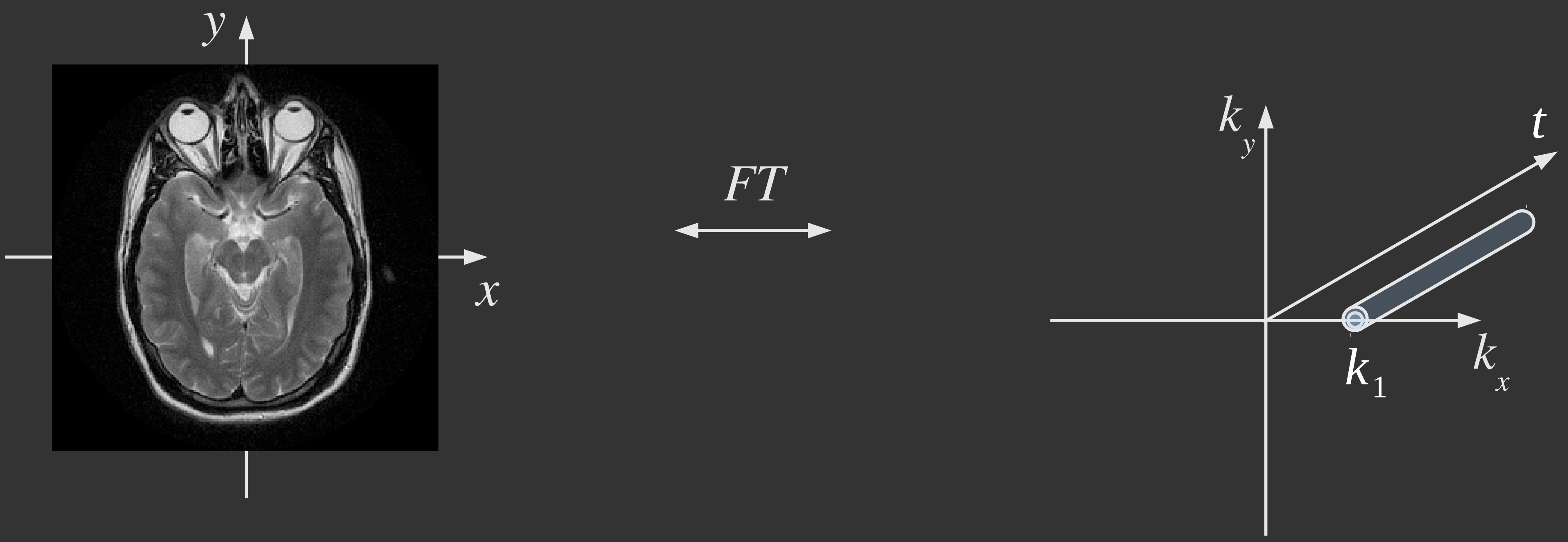
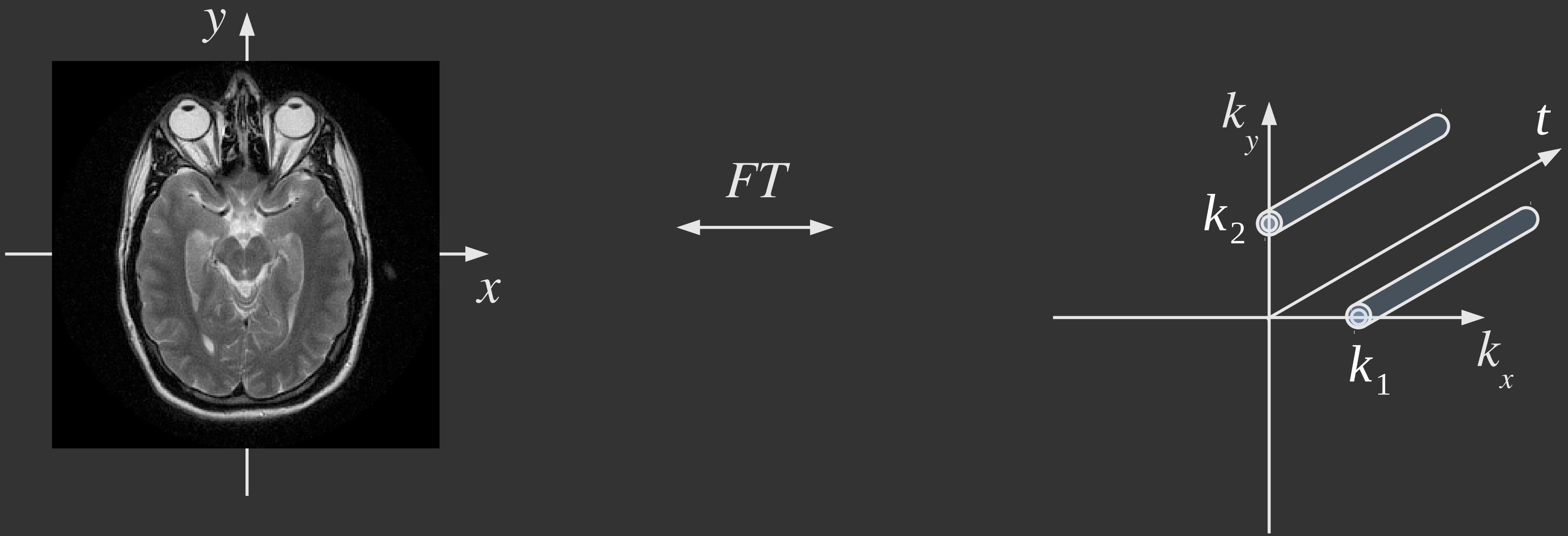
MR Interferometry



MR Interferometry



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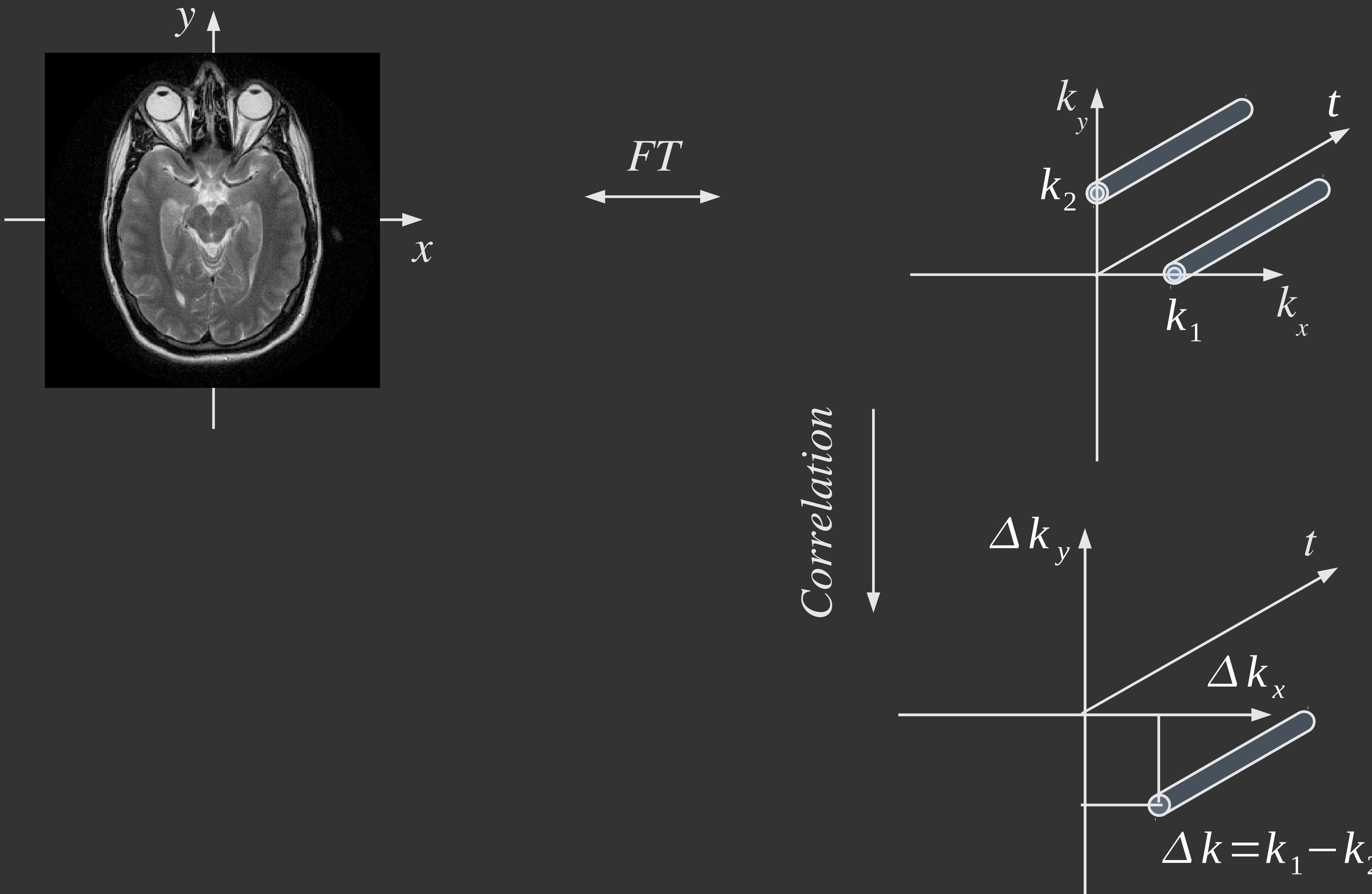

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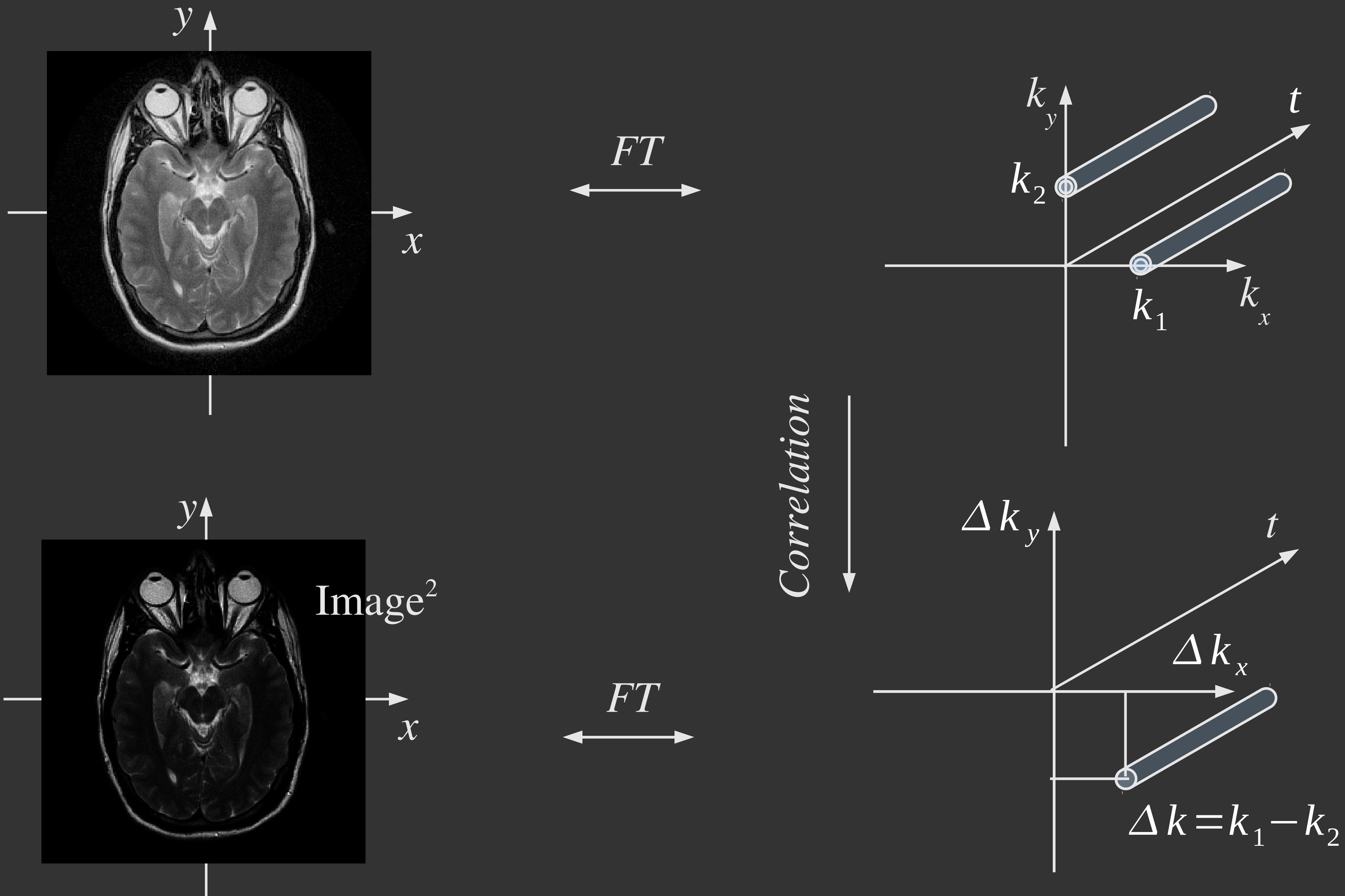
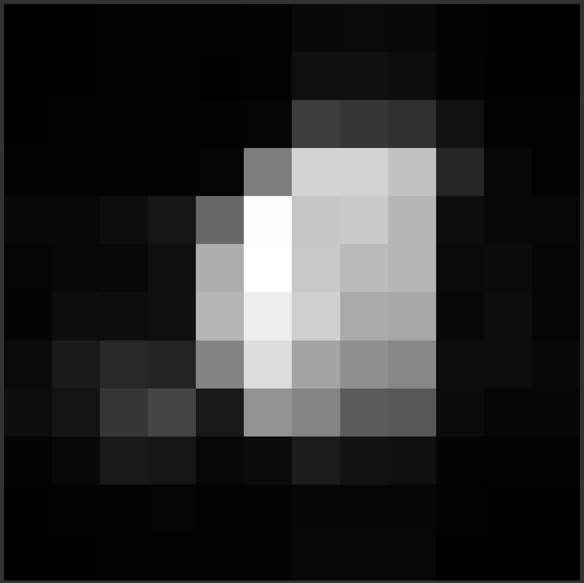


Proof of Concept

12x12x2080 Spectroscopic Image

$$\sum_f |s(\vec{r},f)|$$

Standard



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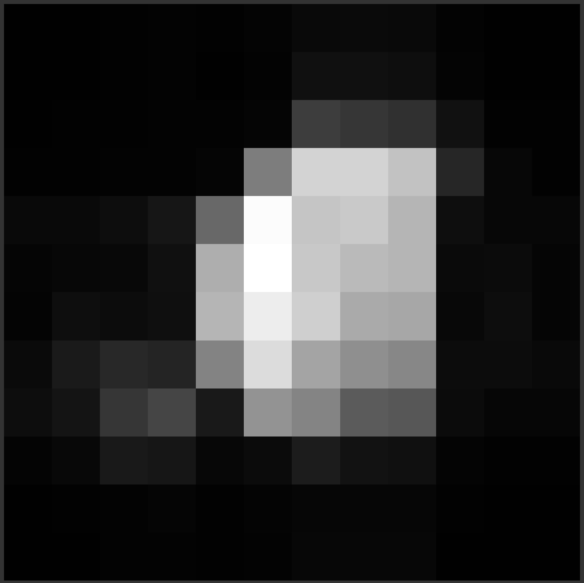
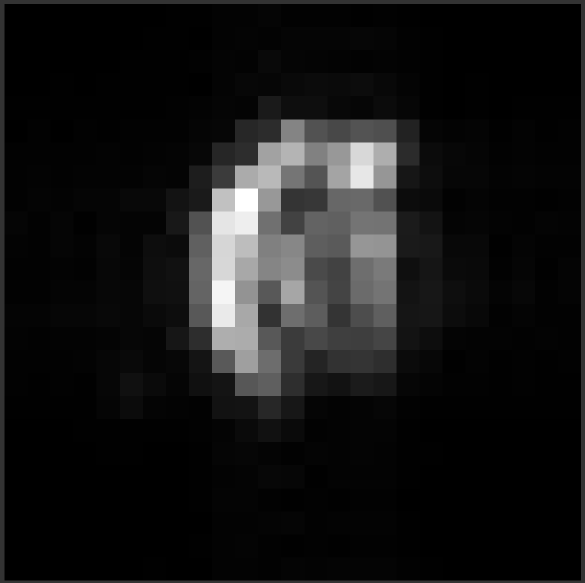


$$\sum_f |s(\vec{r},f)|^2$$



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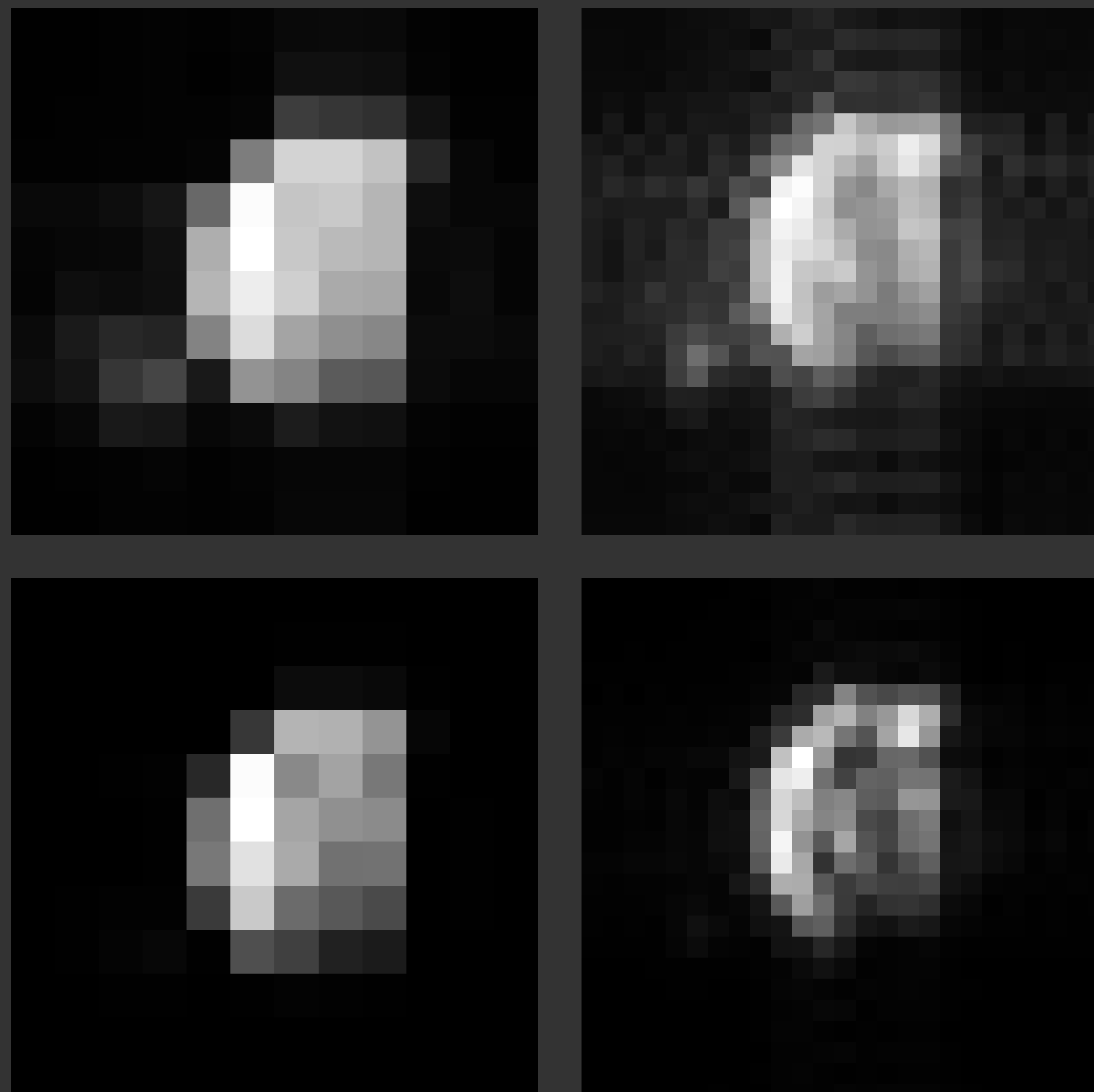

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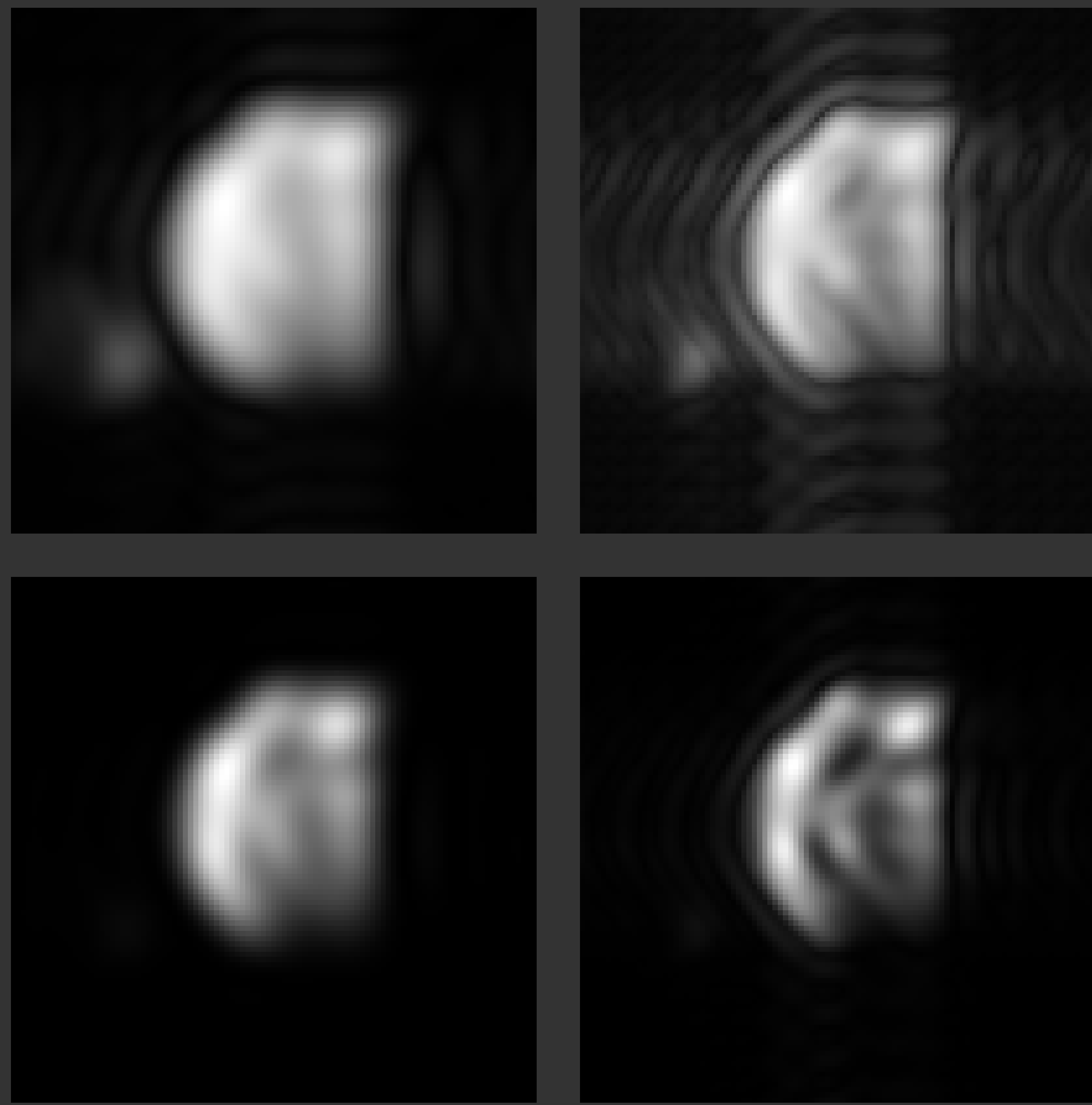

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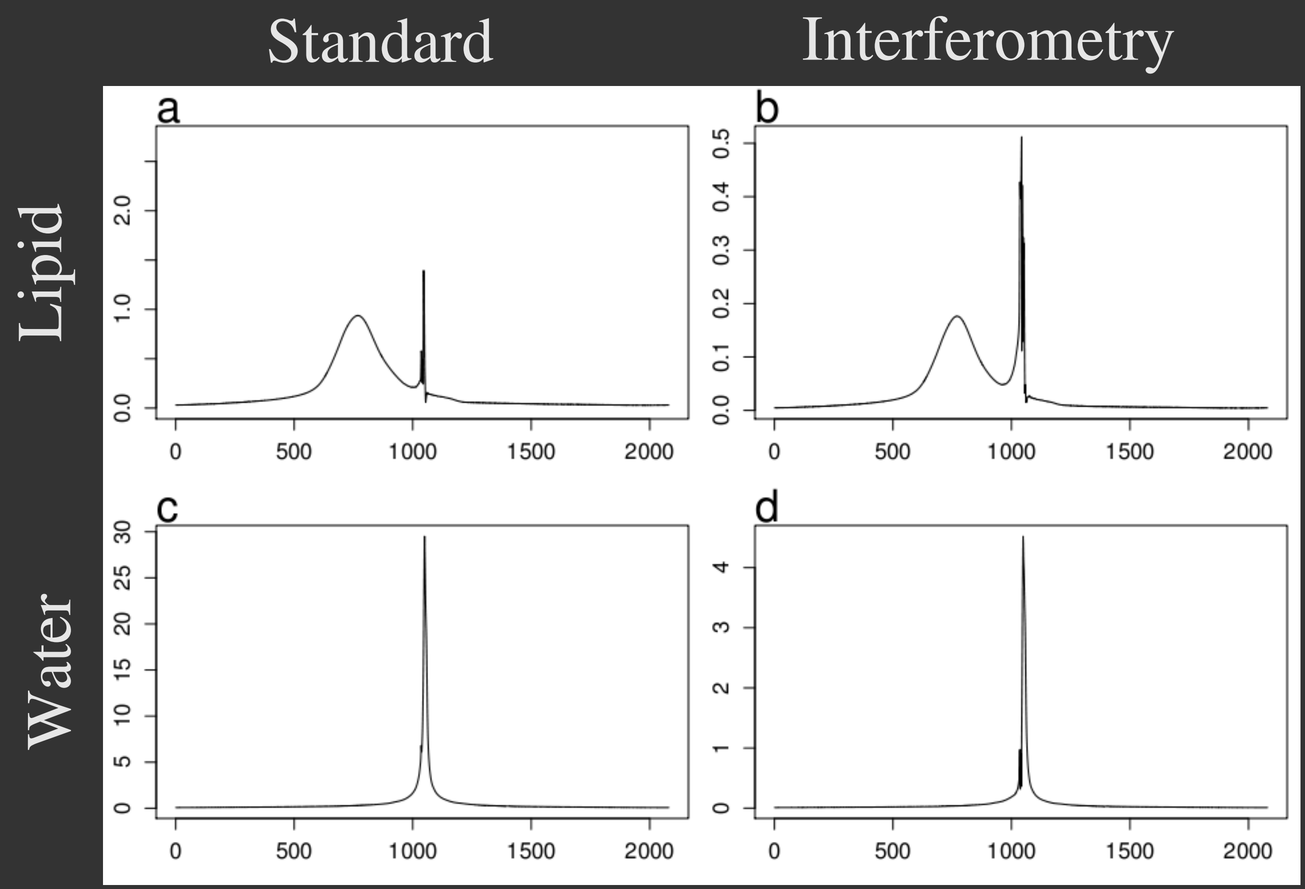

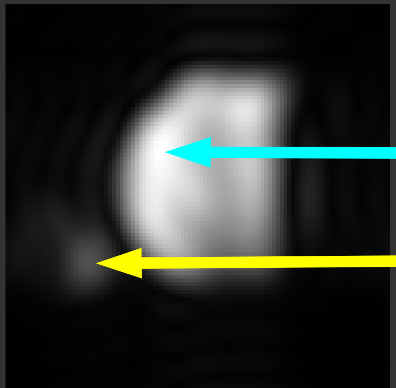

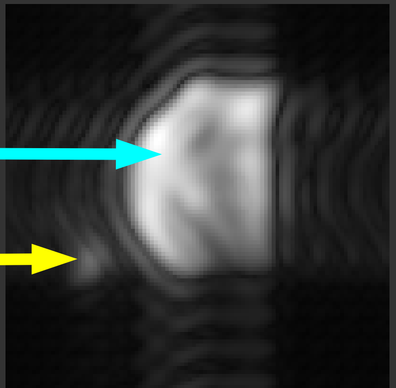

Complication: Coherence

- Voxels will confound with other voxels that oscillate at the same frequency

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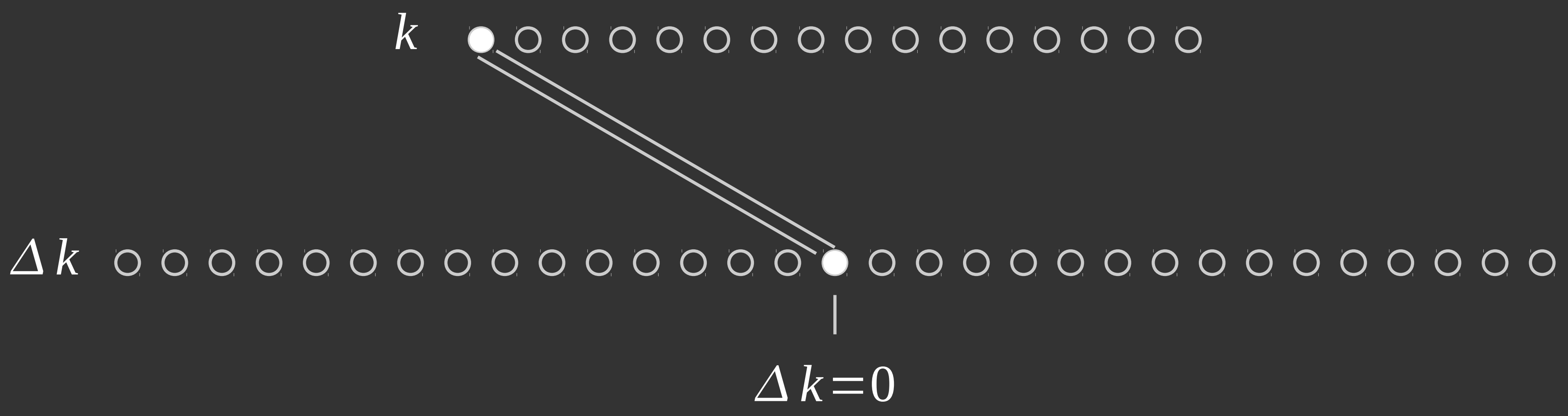
- A gradient during readout will avoid coherence for a 1-D image

1-D Incoherent Image

- Subset of k-space locations will fully map new domain



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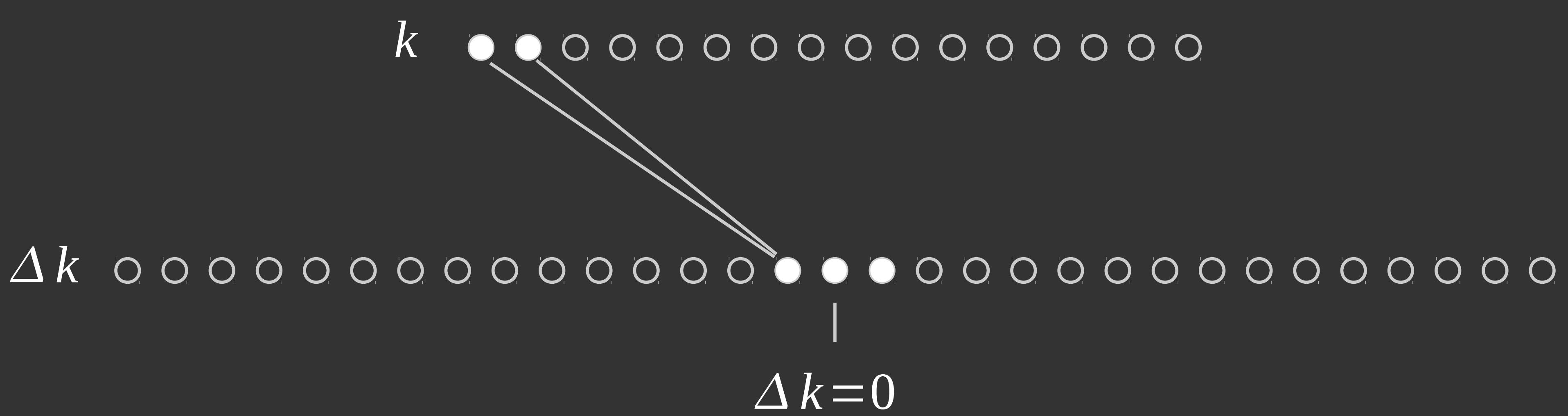

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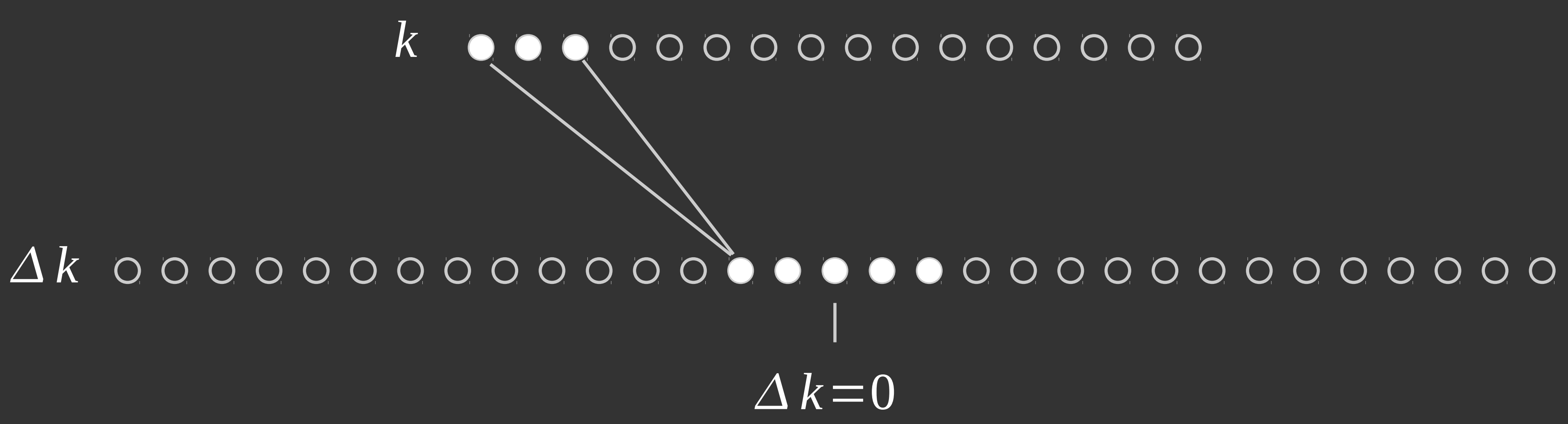

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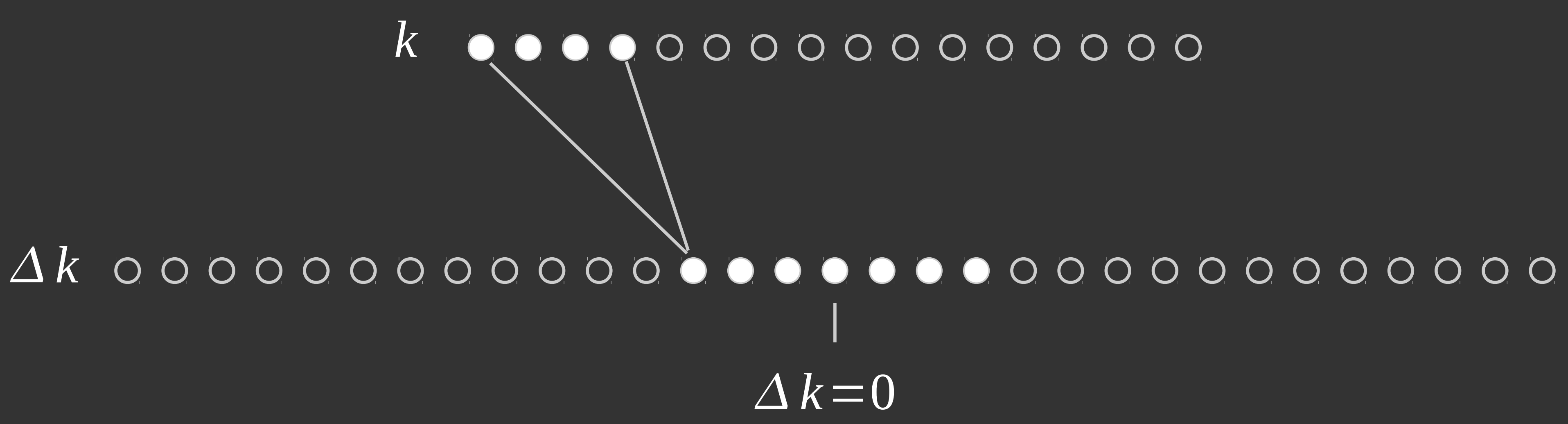

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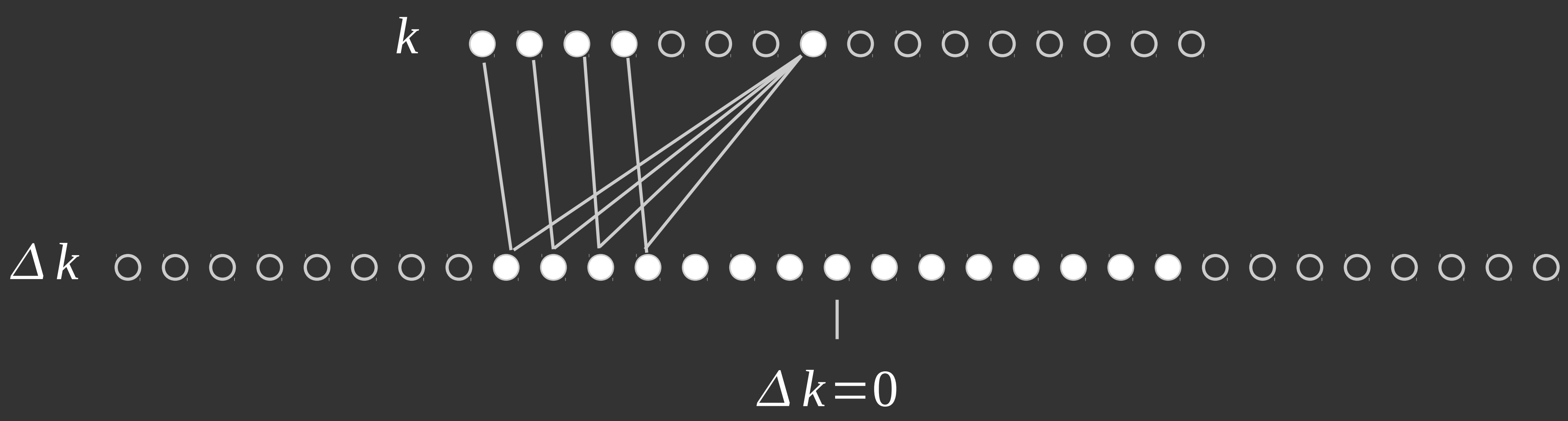

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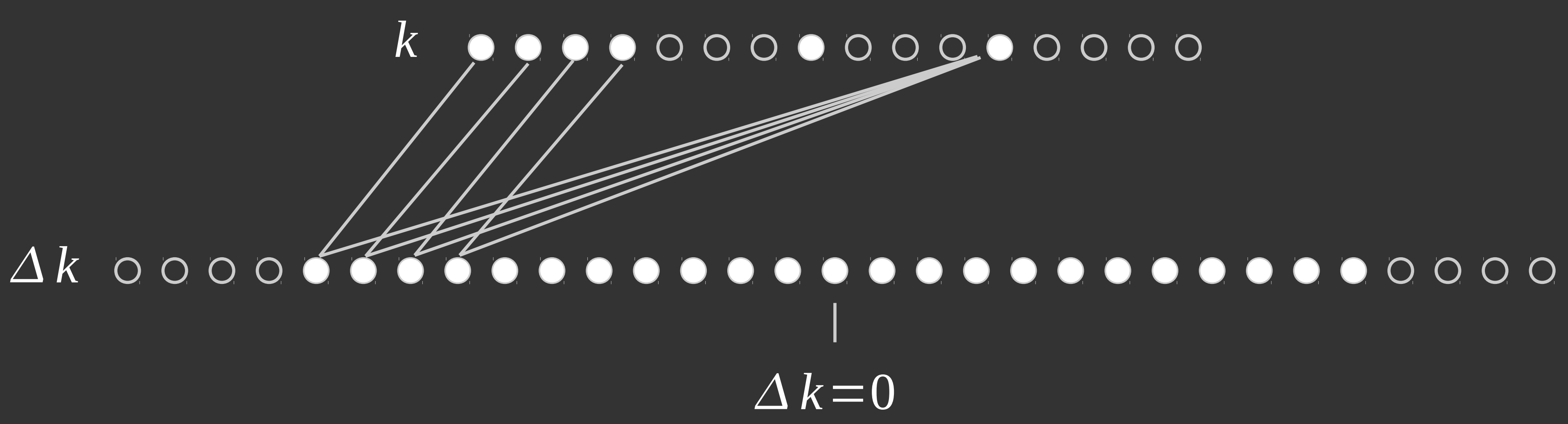

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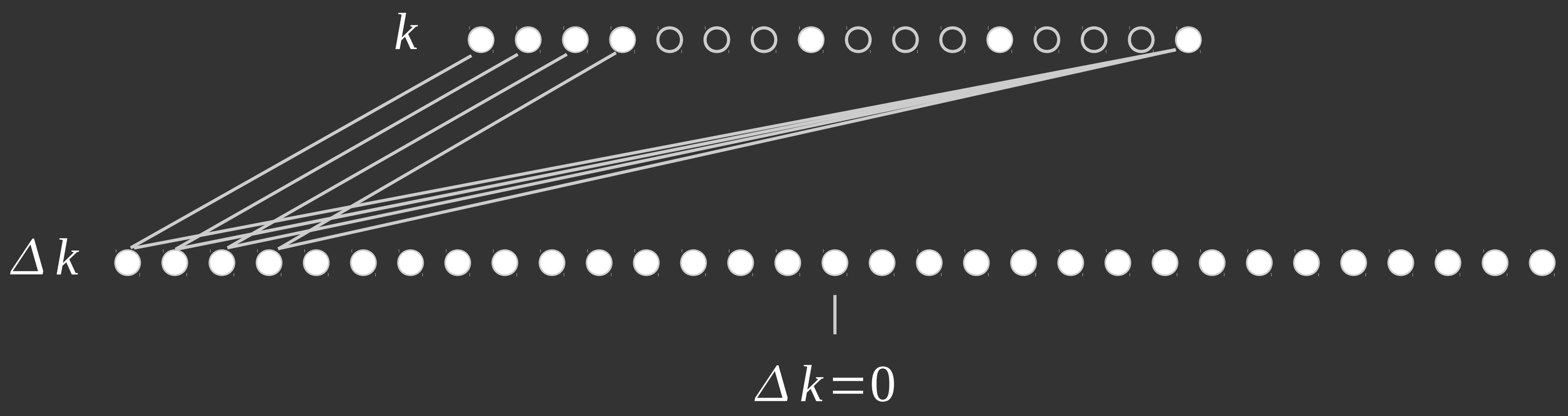
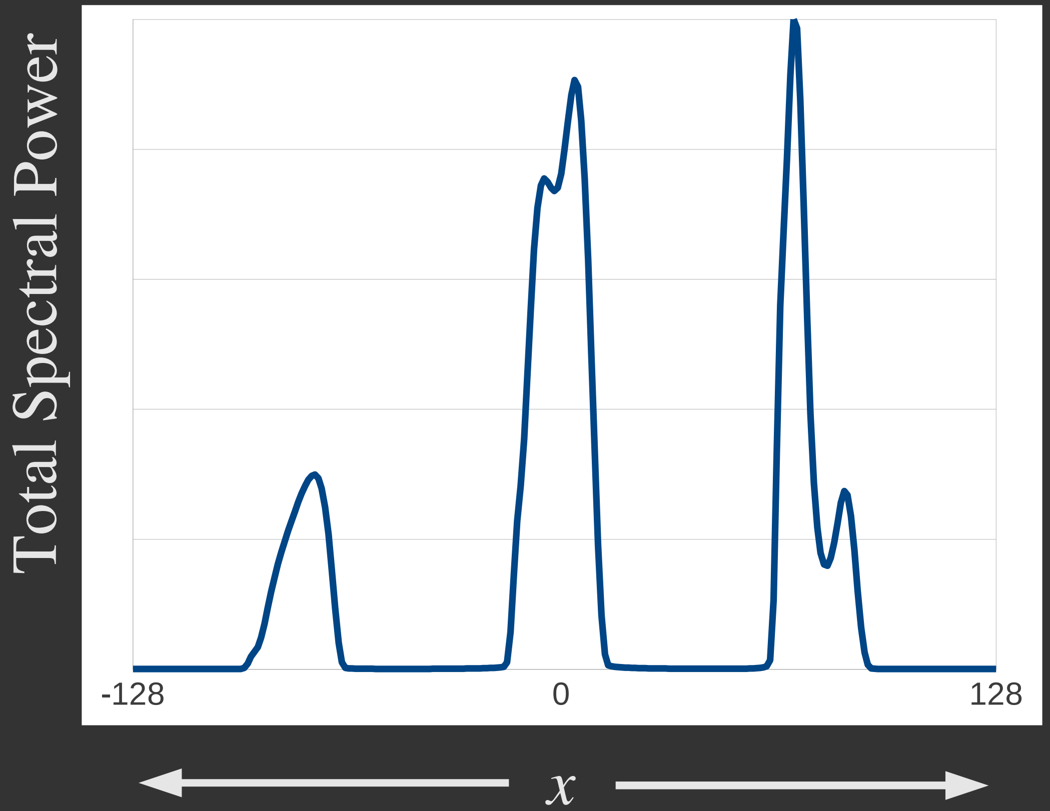


1-D Spectroscopic Imaging

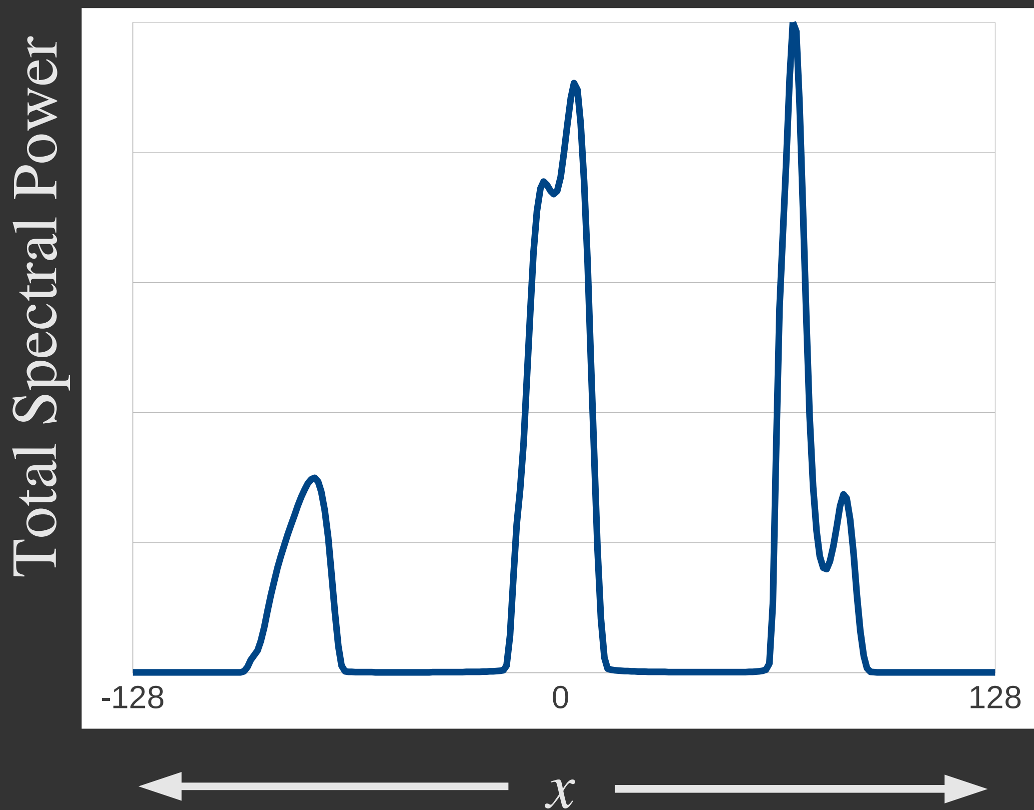


Standard

(257 phase encodes)

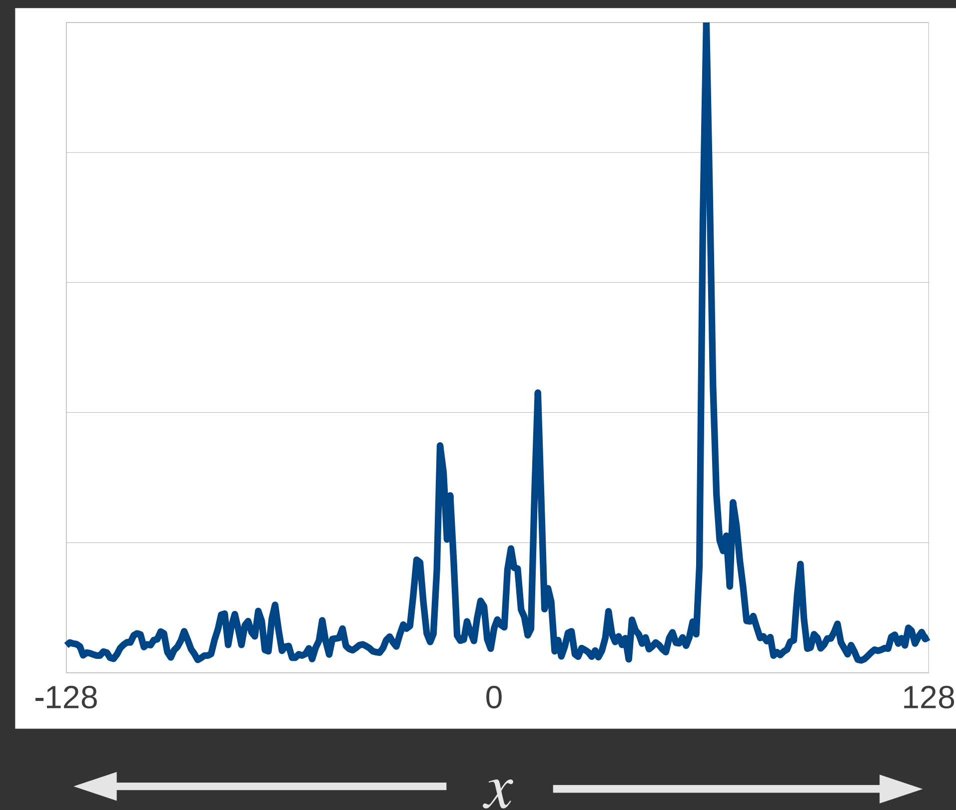
1-D Spectroscopic Imaging

Coherent (no readout gradient)



Standard

(257 phase encodes)



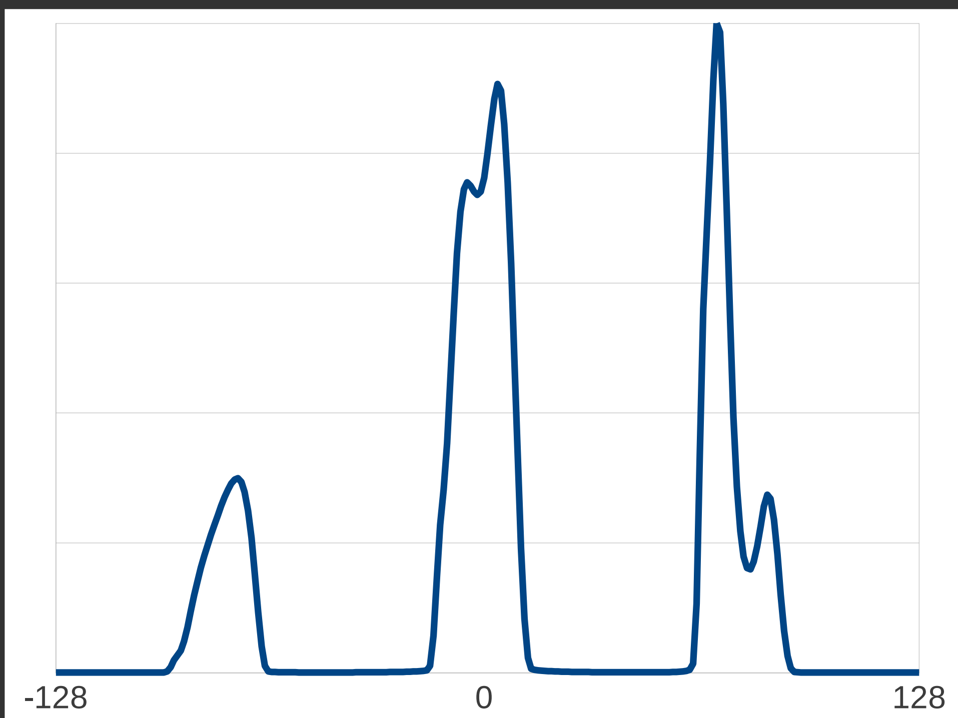
Interferometry

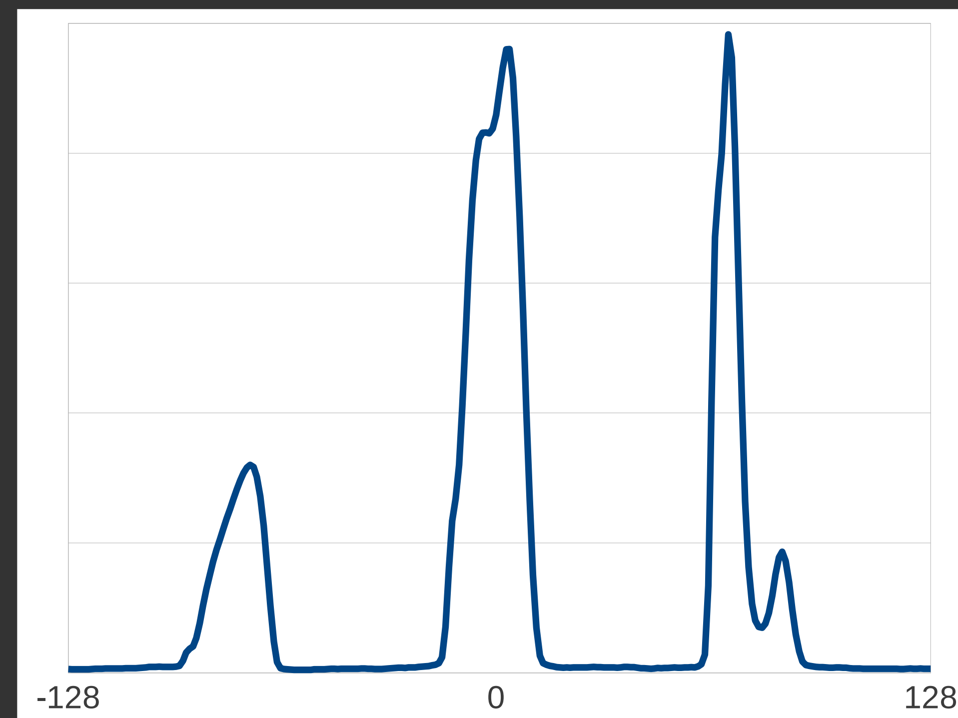
(39 phase encodes)

1-D Spectroscopic Imaging

Incoherent (readout gradient)

Total Spectral Power





x x

Standard

(257 phase encodes)

Interferometry

(39 phase encodes)

$R = 6.6 \approx \sqrt{N}/2.5$

2-D Interferometry

- Using a gradient in the *x*-direction, we would like to assemble

$$\Gamma(\Delta k_x, \Delta k_y, \tau)$$

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- Using a gradient in the *x*-direction, we would like to assemble

$$\Gamma(\Delta k_x, \xcancel{\Delta k_y}, \tau)$$

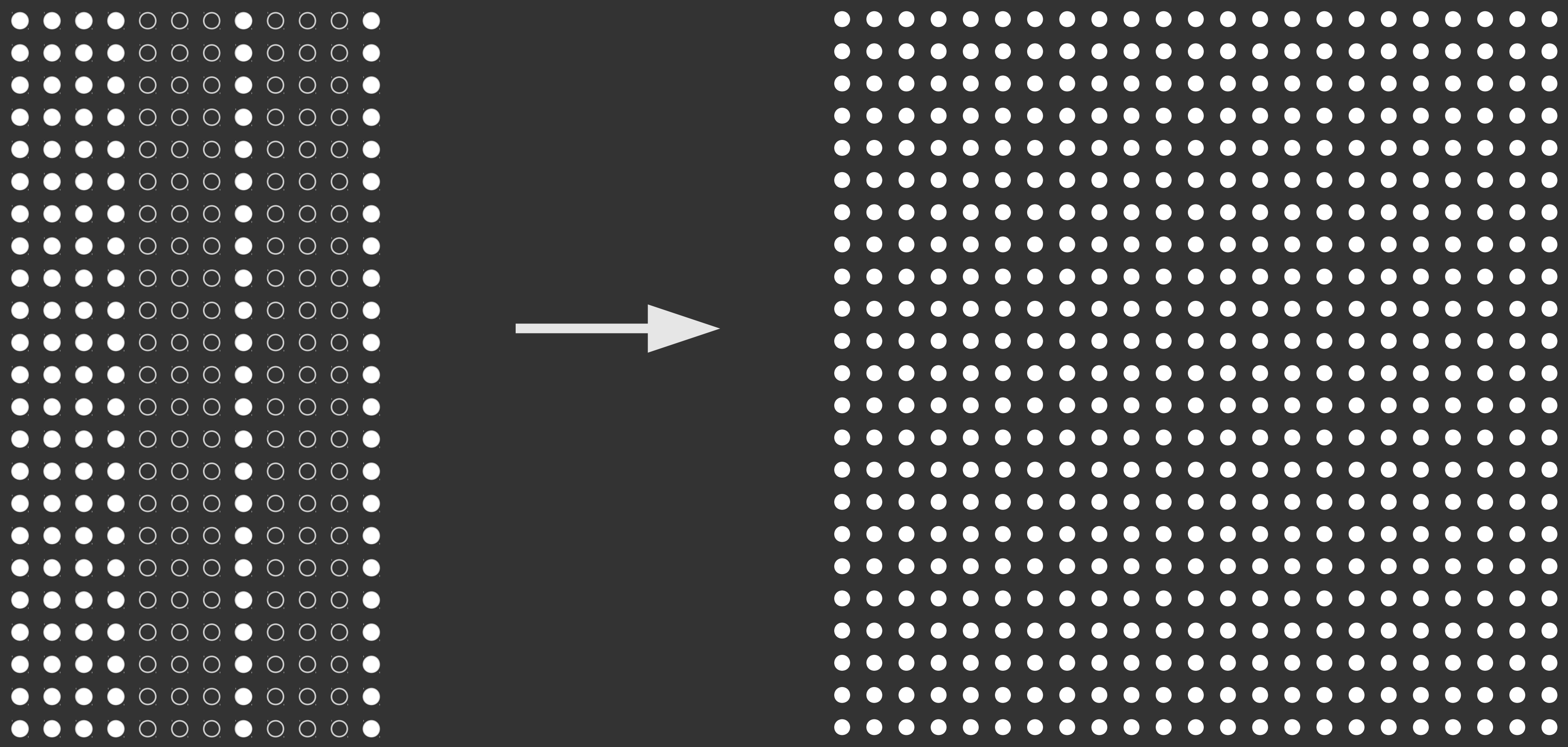
- Because of coherence in the *y*-direction
- The *y*-direction must be fully mapped

$$\Gamma(\Delta k_x, k_{y1}, k_{y2}, \tau) \underset{FT}{\Leftrightarrow} s(r_x, r_{y1}, f)\, s^*(r_x, r_{y2}, f)$$

- Results in a separable, but non-linear system

2-D MRSI

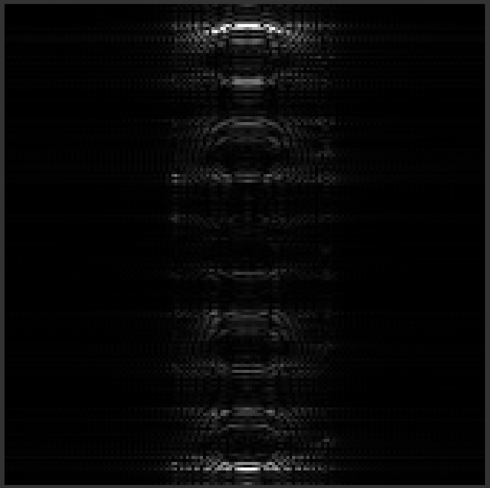
- The *y*-direction must be fully sampled, but the *x*-direction may still benefit



2-D Simulated MRSI

Typical

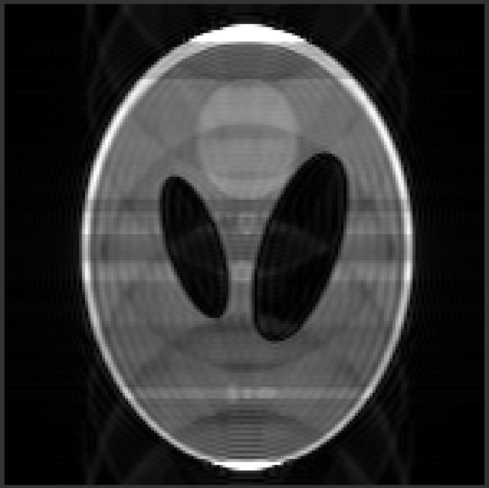
Coherent



R = 6.7

2-D Simulated MRSI

Typical



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2-D Simulated MRSI

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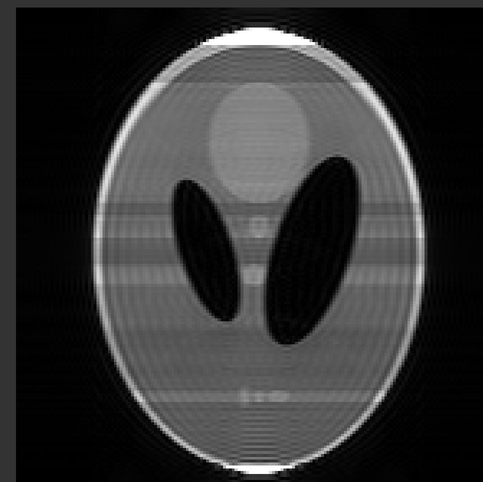
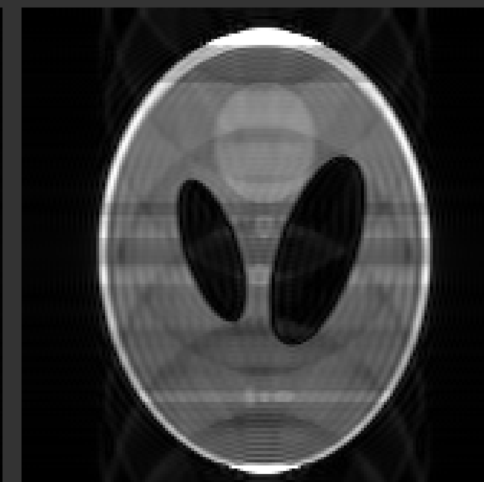


R = 4.9



R = 6.7

2-D Simulated MRSI


Typical


R = 2

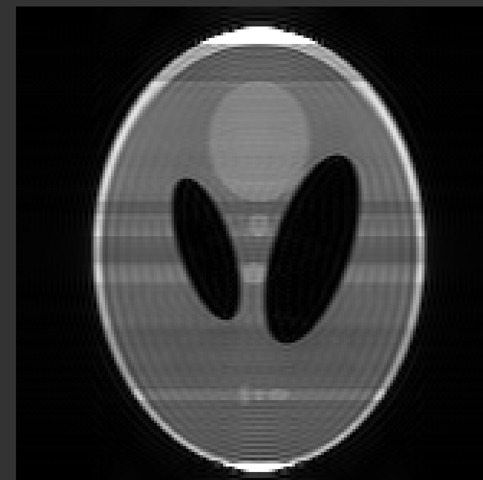

R = 4.9


R = 6.7

2-D Simulated MRSI

Typical

R = 2



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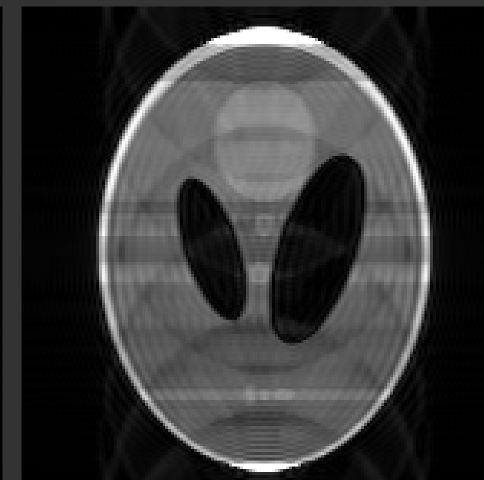

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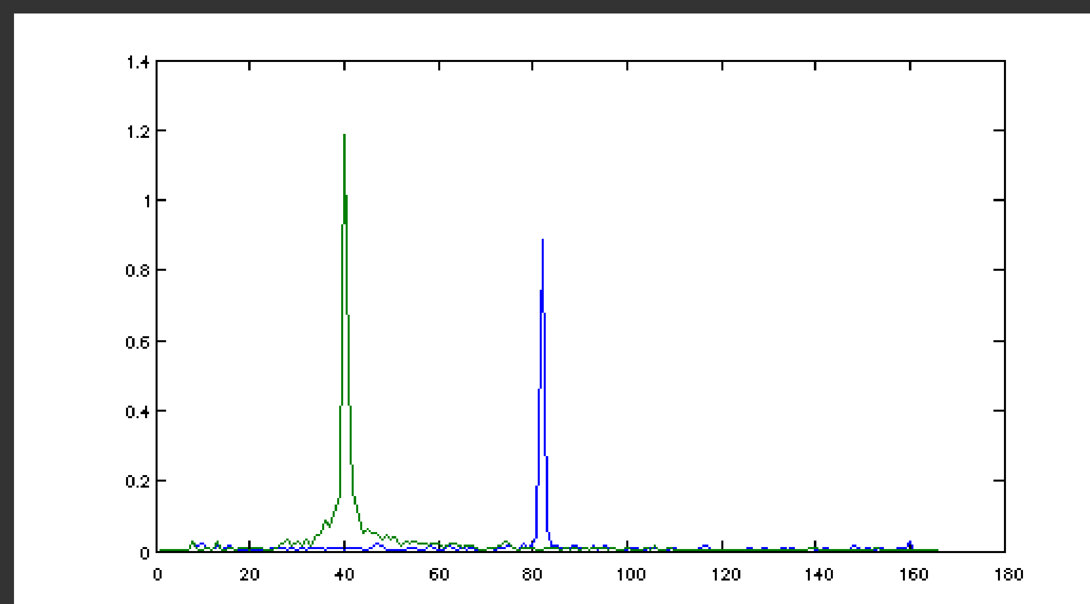

Conclusions

- Applied interferometry to MR
- Direct application to spectroscopic MR imaging
- 1-D MRSI improved by a factor of $\approx\sqrt{N}/2.5$
- Benefits are larger with more data
- Drive new acquisition methods for MR imaging

Acknowledgements

- Craig Meyer
- NIH R01HL079110
- NIH 5T32HL007284-33