Radar imaging with EISCAT3D

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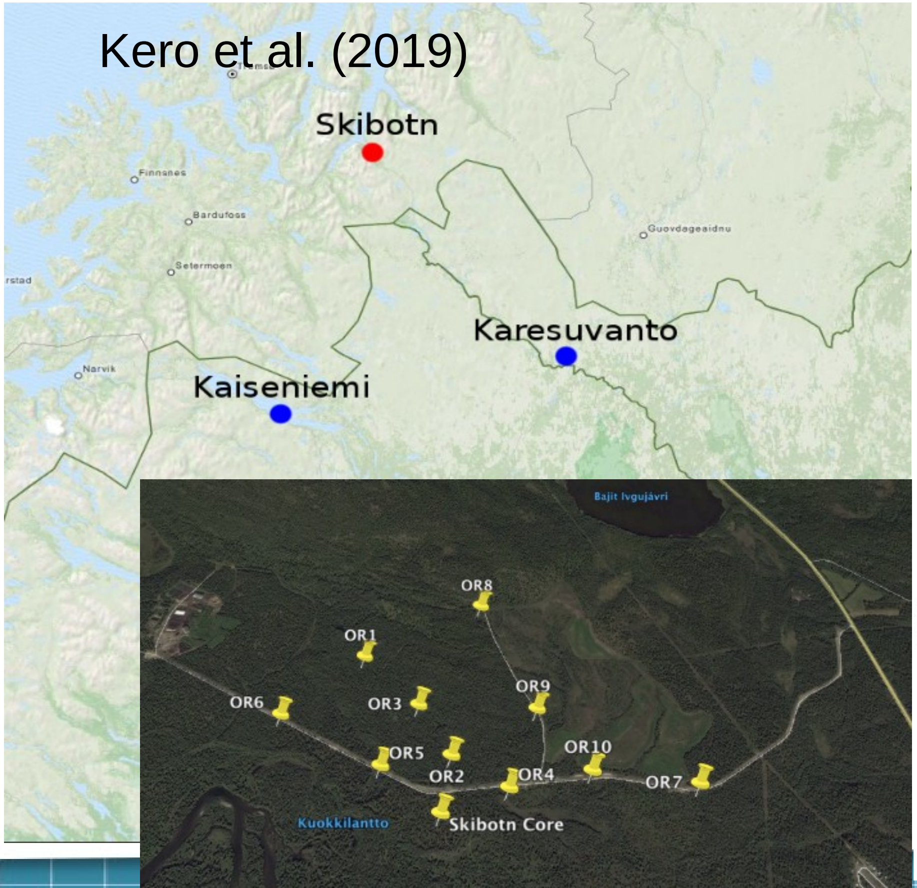
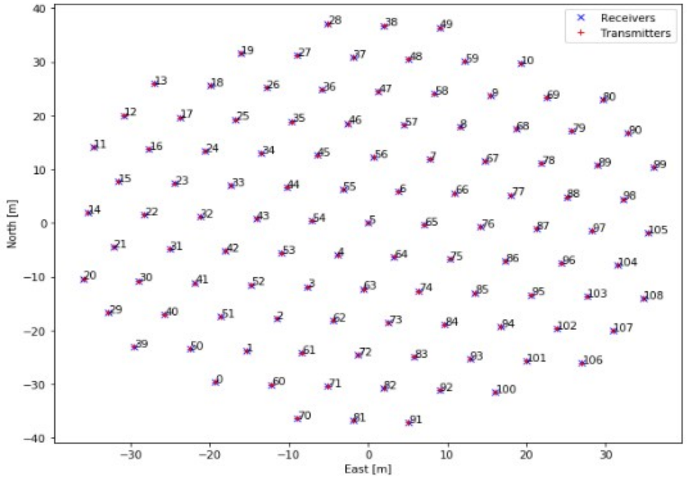
EISCAT 3D

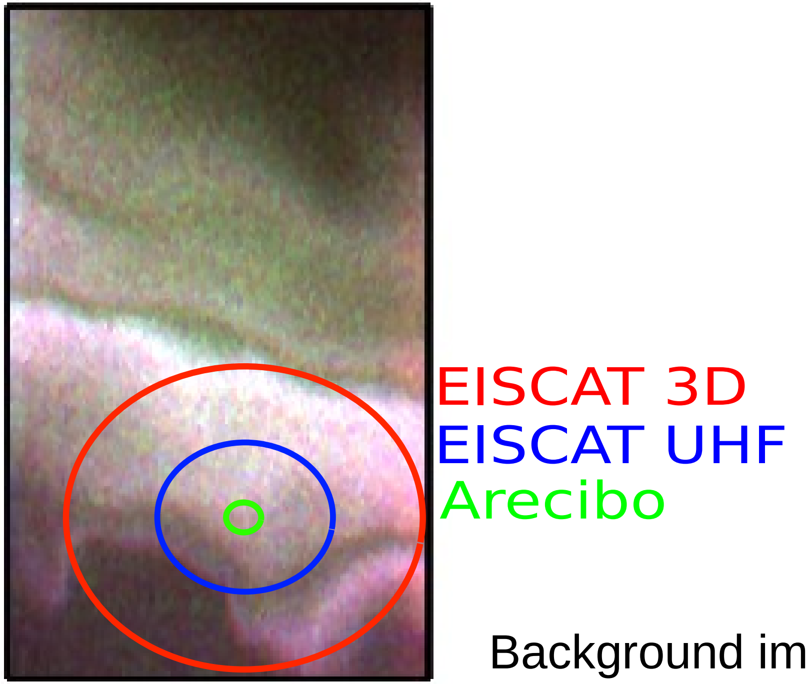


Kero et al. (2019)

- 91 antennas = 1 subarray
- 109 subarrays in the core + 10 outrigger subarrays



EISCAT 3D



Background image: Ashrafi (2007), courtesy D.K. Whiter

- Measurements are averaged over whole beam means that small features are blurred out.

Aperture synthesis radar imaging (ASRI)

- Aperture synthesis – use several antennas as one single antenna
- Imaging – obtaining spatial distribution perpendicular to range direction
- We pay a bit of the resolution in time to get resolution perpendicular to the beam

Source: evertiq.se

A measurement

$$\rho_{\mathrm{ADBE}} = \frac{P_{\mathrm{t}} G_{\mathrm{t}} G_{\mathrm{r}} \lambda^2 \sigma_{\mathrm{p}}}{(4\pi)^3 R_{\mathrm{t}}^2 R_{\mathrm{r}}^2} \mathrm{d}r \left(2R \tan \frac{\theta}{2} \right)^2 \sum_{q=1}^{Q} \frac{n_{\mathrm{e}}[q]}{Q} e^{2\pi i f \left(T_{\mathrm{AD}}^{q} - T_{\mathrm{HB}}^{q} \right)}.$$

- Transmit with core array, receive with every subarray
- Consider imaging of electron density
- Cross-correlation between receivers.
- Constant in front of sum

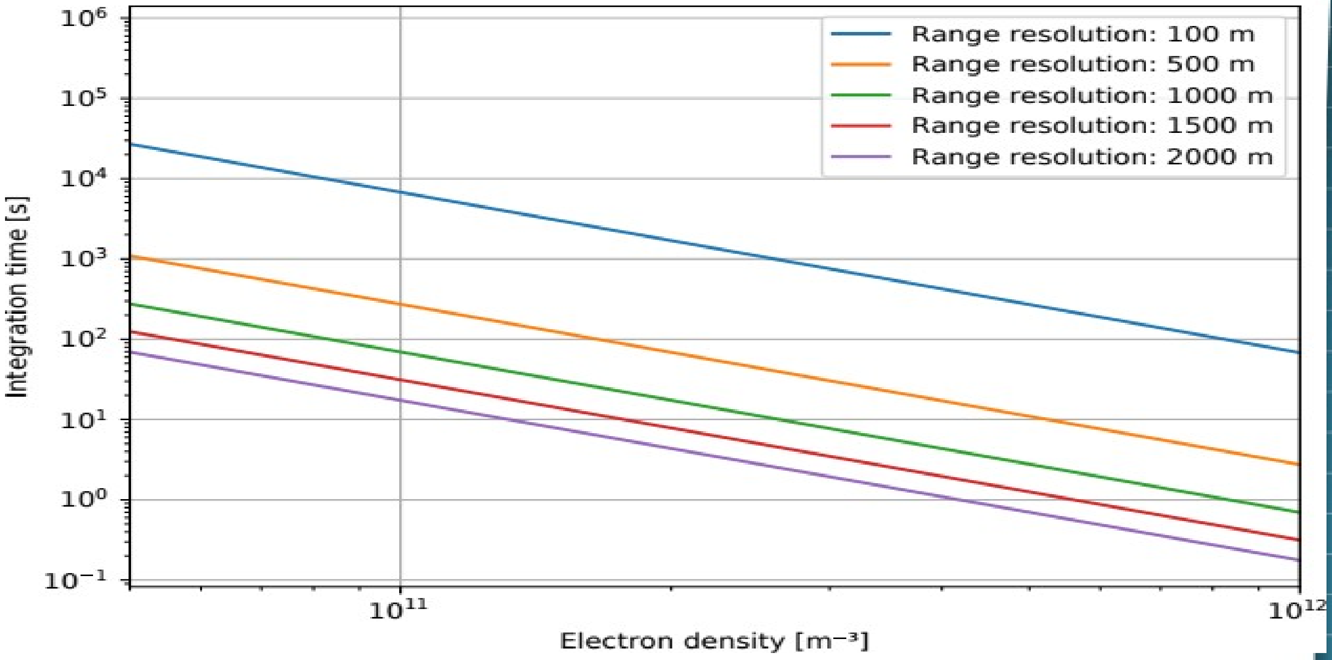
Time and range resolution (In E region)

Assumptions:

- Measurement error 5 %
- Te = 400 K
- Ti = 300 K
- Alternating code
- Pulse length 0.5 ms

Result:

- T ≈ 30 s, Δr ≈ 1 km



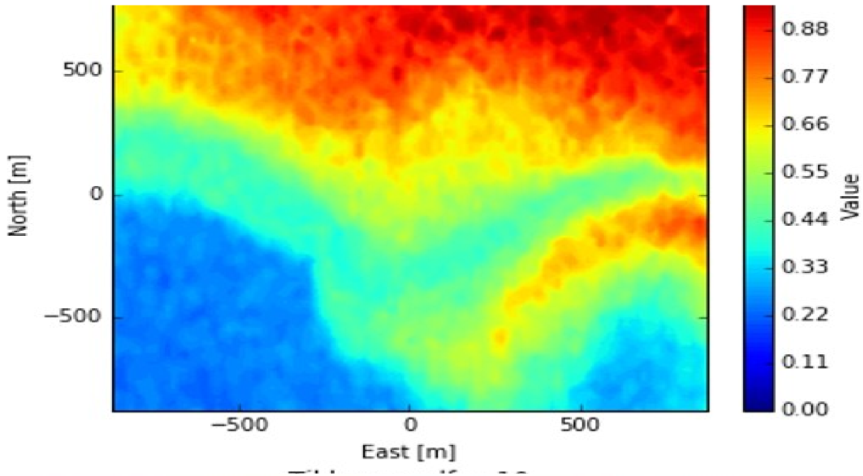
Imaging resolution

- Inverse problem

$$\begin{bmatrix} m_{\mathrm{AAAA}} \\ m_{\mathrm{AAAB}} \\ \vdots \\ m_{\mathrm{KKKK}} \end{bmatrix} = \frac{a}{M} \begin{bmatrix} e^{2\pi i f\left(T^1_{\mathrm{AA}} - T^1_{\mathrm{AA}}\right)} & e^{2\pi i f\left(T^2_{\mathrm{AA}} - T^2_{\mathrm{AA}}\right)} & \dots & e^{2\pi i f\left(T^M_{\mathrm{AA}} - T^M_{\mathrm{AA}}\right)} \\ e^{2\pi i f\left(T^1_{\mathrm{AA}} - T^1_{\mathrm{AB}}\right)} & e^{2\pi i f\left(T^2_{\mathrm{AA}} - T^2_{\mathrm{AB}}\right)} & \dots & e^{2\pi i f\left(T^M_{\mathrm{AA}} - T^M_{\mathrm{AB}}\right)} \\ \vdots & \vdots & \ddots & \vdots \\ e^{2\pi i f\left(T^1_{\mathrm{KK}} - T^1_{\mathrm{KK}}\right)} & e^{2\pi i f\left(T^2_{\mathrm{KK}} - T^2_{\mathrm{KK}}\right)} & \dots & e^{2\pi i f\left(T^M_{\mathrm{KK}} - T^M_{\mathrm{KK}}\right)} \end{bmatrix} \begin{bmatrix} n_e^1 \\ n_e^2 \\ \vdots \\ n_e^M \end{bmatrix} + \begin{bmatrix} \varepsilon_{AAAA} \\ \varepsilon_{AAAB} \\ \vdots \\ \varepsilon_{KKKK} \end{bmatrix}$$

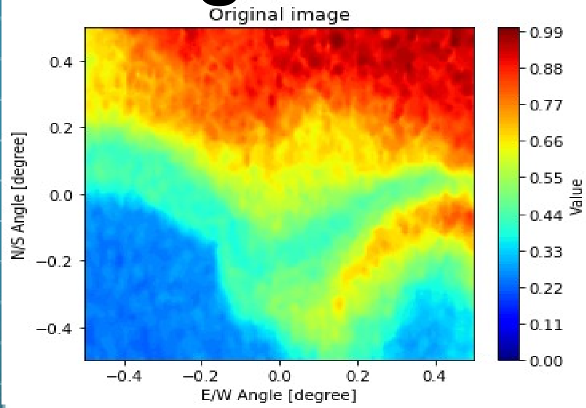
- In short: $|m\rangle = \mathbb{A}|x\rangle + |\varepsilon\rangle.$
- Simulated measurements of -->
- Want to recover |x> =
- Want uncertainty of recover

Assumed electron density distribution
At 100 km range

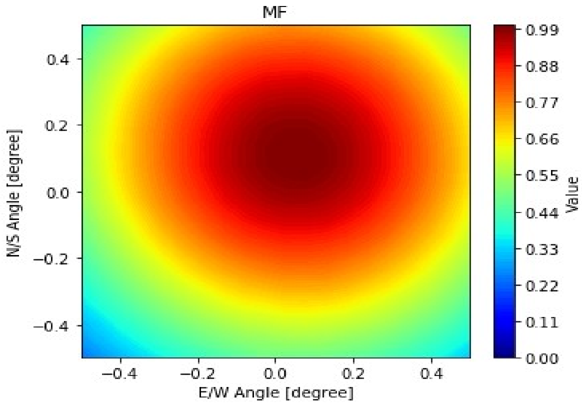


Methods for recovering the electron density distribution

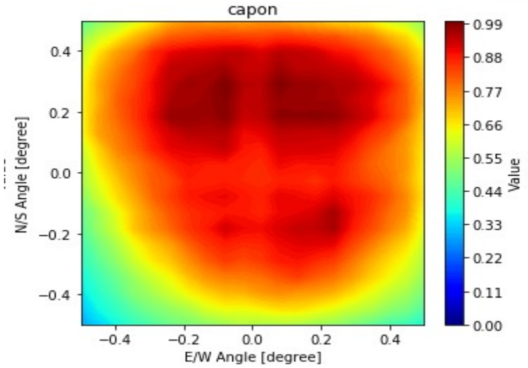
Original



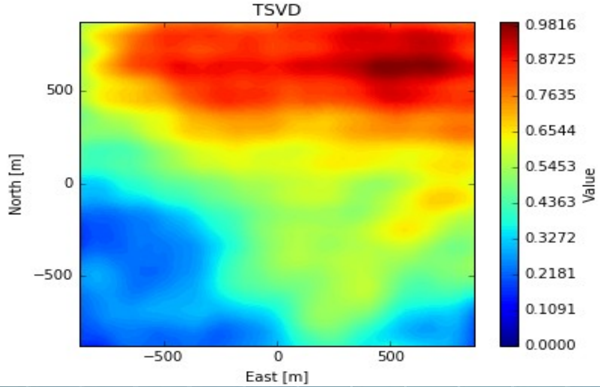
Matched filter



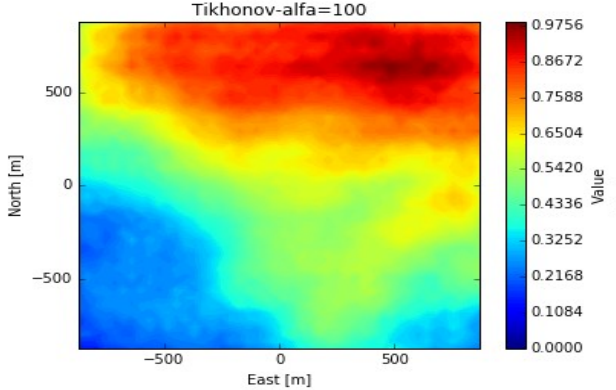
Capon



TSVD



Tikhonov

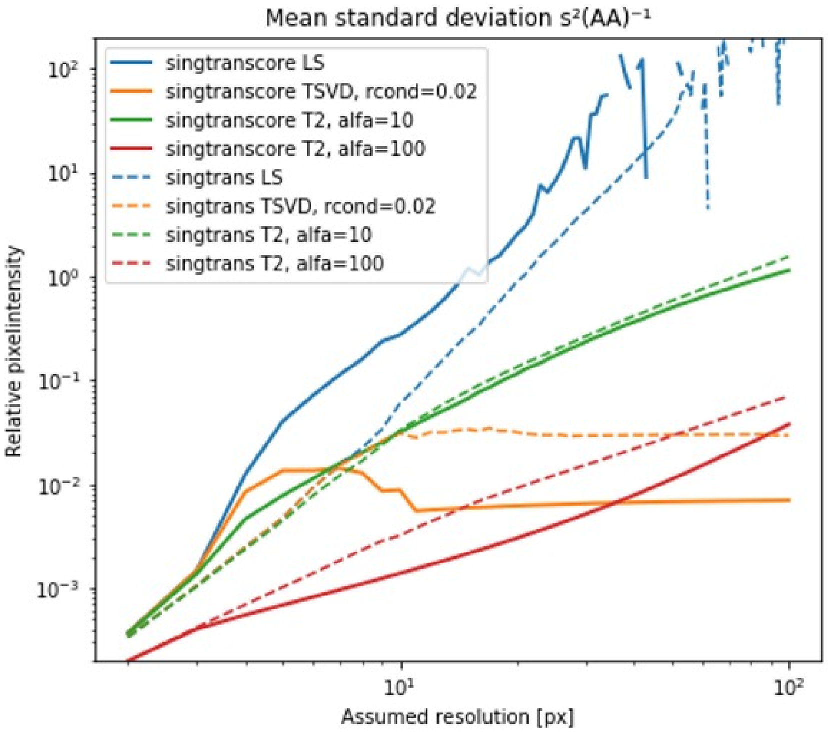


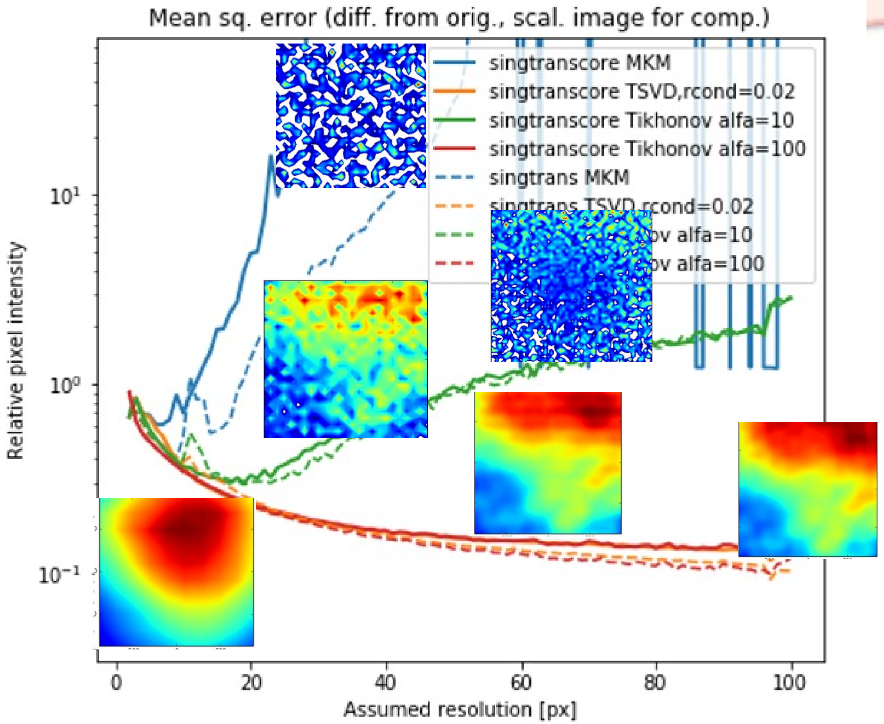
Imaging resolution

- Know how to recover
- Uncertainty?
- Resolution?

- Statistics
- Compare to original image

Imaging resolution





Watch out for different axes!

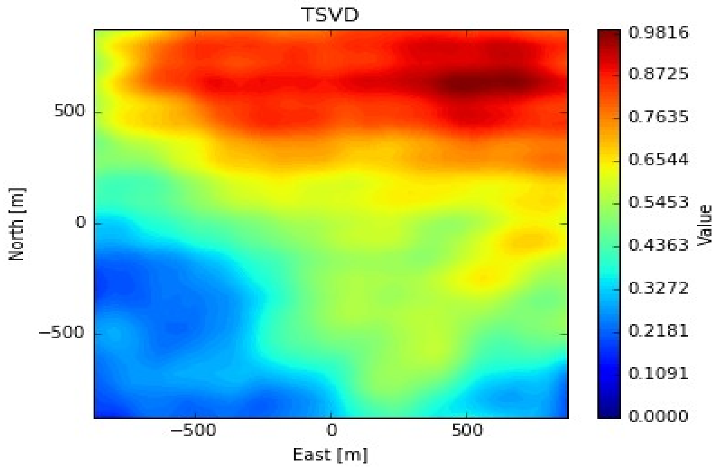
First conclusion

- Imaging of E region:
- Integration time ~30 s
- Range resolution ~1 km
- Imaging resolution ~100x100 m
- Uncertainty of image ~10 %

Next step: MIMO?

- Divide core into N transmitters
- Longer integration time
- More details

SIMO



MIMO