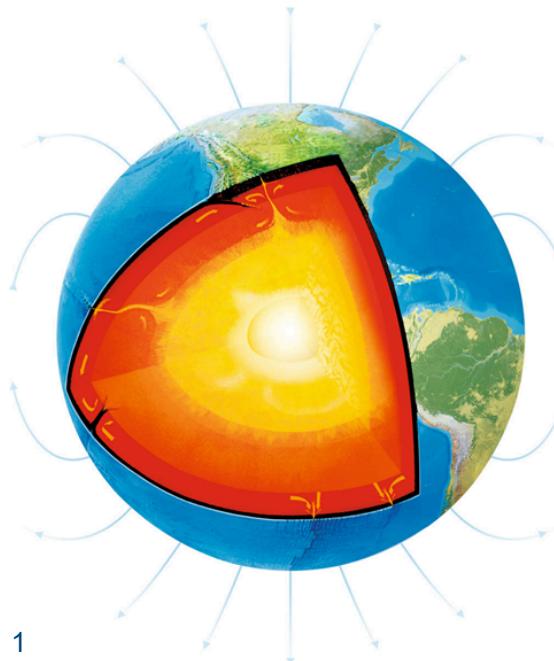


Einführung in die Geophysik

Teil 10: Induktive Elektromagnetik, Georadar

2. BSc Geophysik und Geoinformatik (BGIP)



Thomas Günther
(thomas.guenther@geophysik.tu-freiberg.de)

Previously on AnGy

1. ~~Gravimetric (1.5)~~
2. ~~Geomagnetik (2.5)~~
3. ~~Geelektrik+Inversion (3)~~
4. Induktive Elektromagnetik (4.5)
5. Georadar (0.5)
6. Seismik (3)

Termine Praktikum

jeweils Freitags, 08-09:30 Uhr

- 13.06. Auswertung Geoelektrik (+Mag+Grav)
- 20.06. Versuch Georadar + EM38
- 27.06. Versuch Refraktions-Seismik
- 04.07. Auswertung EM + Seismik
- 11.07. Zusammenfassung

Induktive Elektromagnetik

- Elektromagnetische Größen: H/B , E/D , μ , ϵ , σ
- 4 Maxwell-Gleichungen (dB-E, dD-H, div B, div D)
- quasistationäre Näherung j (σ wichtiger als ϵ)
- 2-Spulen-Verfahren
- Controlled-Source Elektromagnetik (CSEM)

Gleichungen und Methoden (TD)

$$\nabla \times \mathbf{H} = \frac{\partial \mathbf{D}}{\partial t} + \mathbf{j} \quad \nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

Vorgänge/Felder	$\nabla \times \mathbf{H}$	$\nabla \times \mathbf{E}$	Methoden
Stationär	$\mathbf{j} = \sigma \mathbf{E}$	0	Geoelektrik
Diffusiv	$\mathbf{j} = \sigma \mathbf{E}$	$-\partial \mathbf{B} / \partial t$	Induktion
Wellenvorgänge	$\partial \mathbf{D} / \partial t$	$-\partial \mathbf{B} / \partial t$	Georadar

Telegrafengleichung: $\nabla \times \nabla \times \mathbf{E} + \mu \epsilon \partial^2 \mathbf{E} / \partial t^2 + \sigma \mu \partial \mathbf{E} / \partial t = 0$

Gleichungen und Methoden (FD)

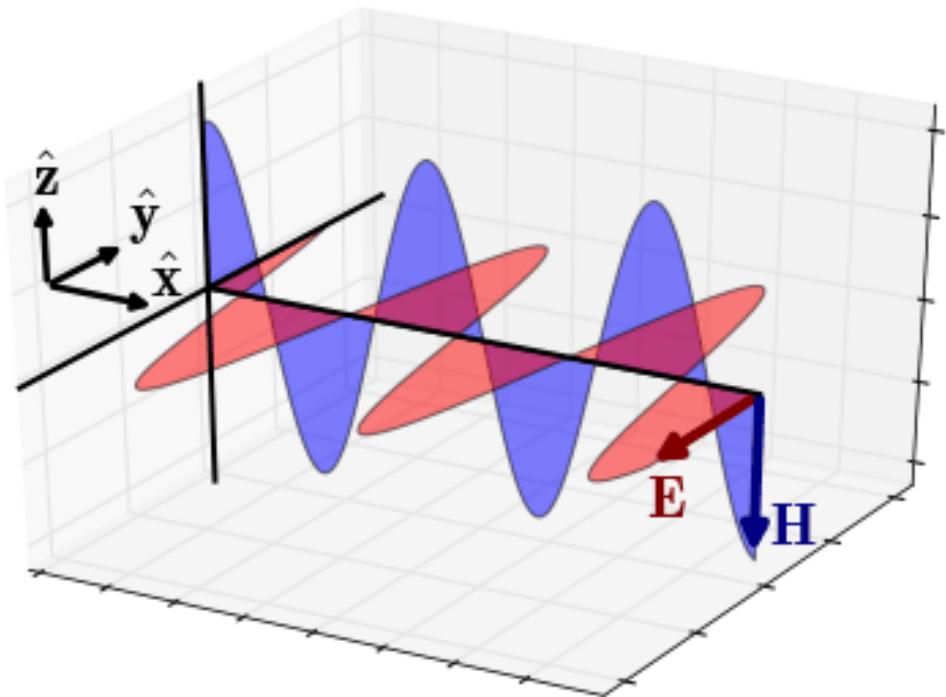
Harmonischer Ansatz

$$E = E_0 e^{i\omega t} \Rightarrow \partial \mathbf{E} / \partial t = i\omega \mathbf{E} \quad \partial^2 \mathbf{E} / \partial t^2 = -\omega^2 \mathbf{E}$$

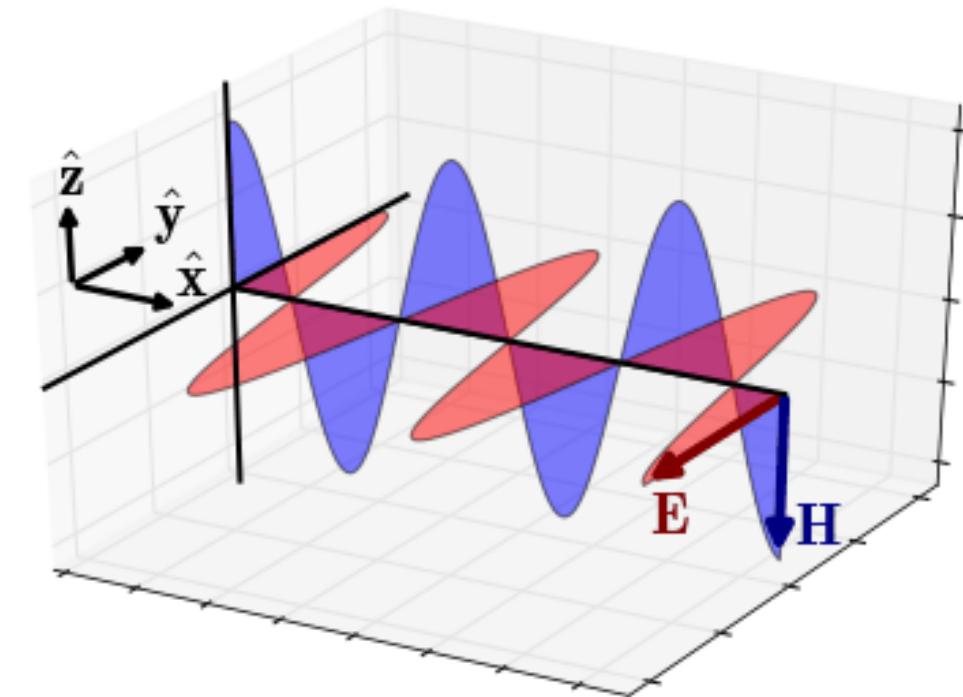
Vorgänge/Felder	$\nabla \times \mathbf{H}$	$\nabla \times \mathbf{E}$	Methoden
Stationär	$\mathbf{j} = \sigma \mathbf{E}$	0	Geoelektrik
Diffusiv	$\mathbf{j} = \sigma \mathbf{E}$	$-i\mu \mathbf{B}$	Induktion
Wellenvorgänge	$i\epsilon \mathbf{E}$	$-i\mu \mathbf{B}$	Georadar

$$\nabla \times \nabla \times \mathbf{E} - \mu\epsilon\omega^2 \mathbf{E} + i\sigma\mu\omega \mathbf{E} = 0$$

Induktiv

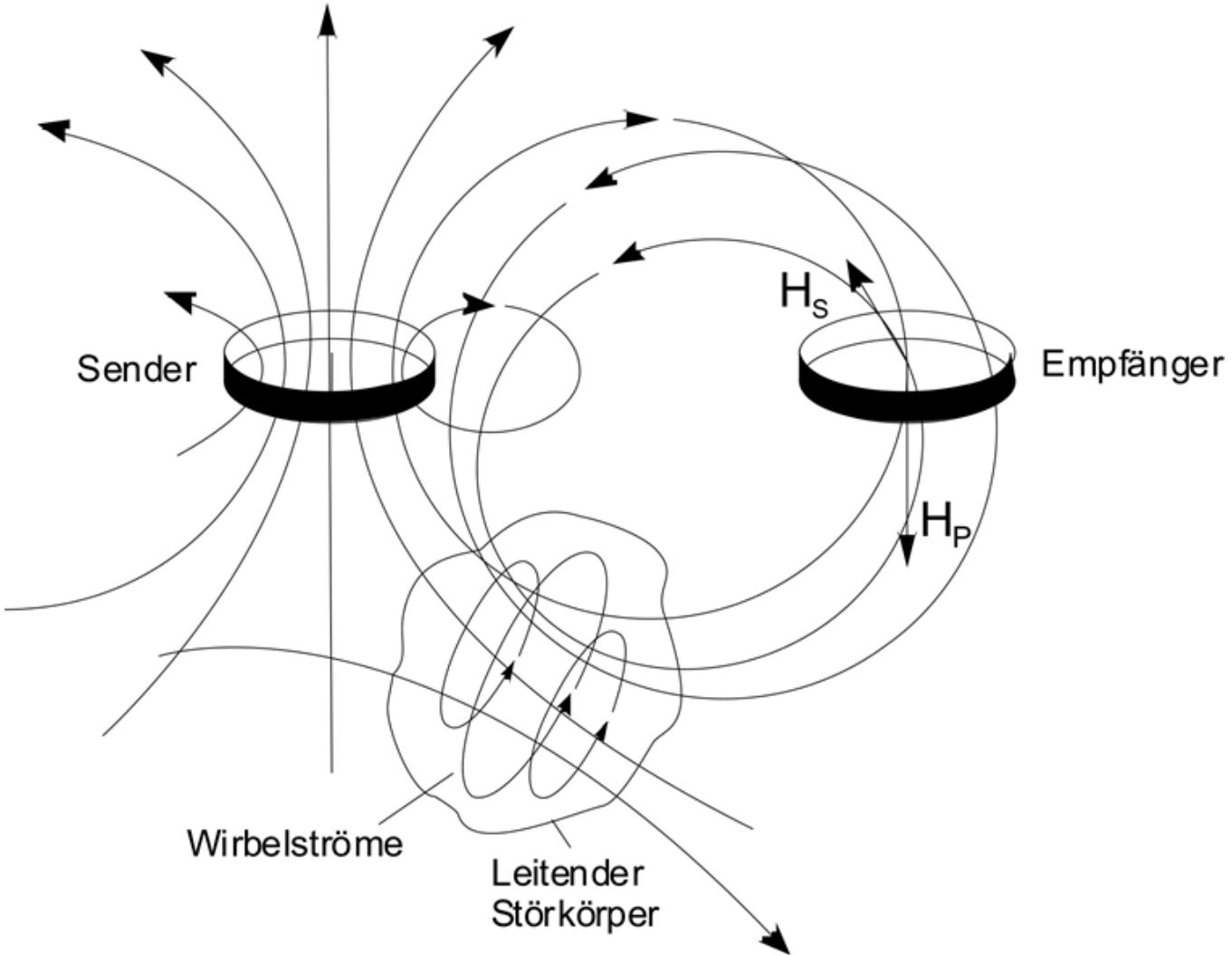


Induktiv

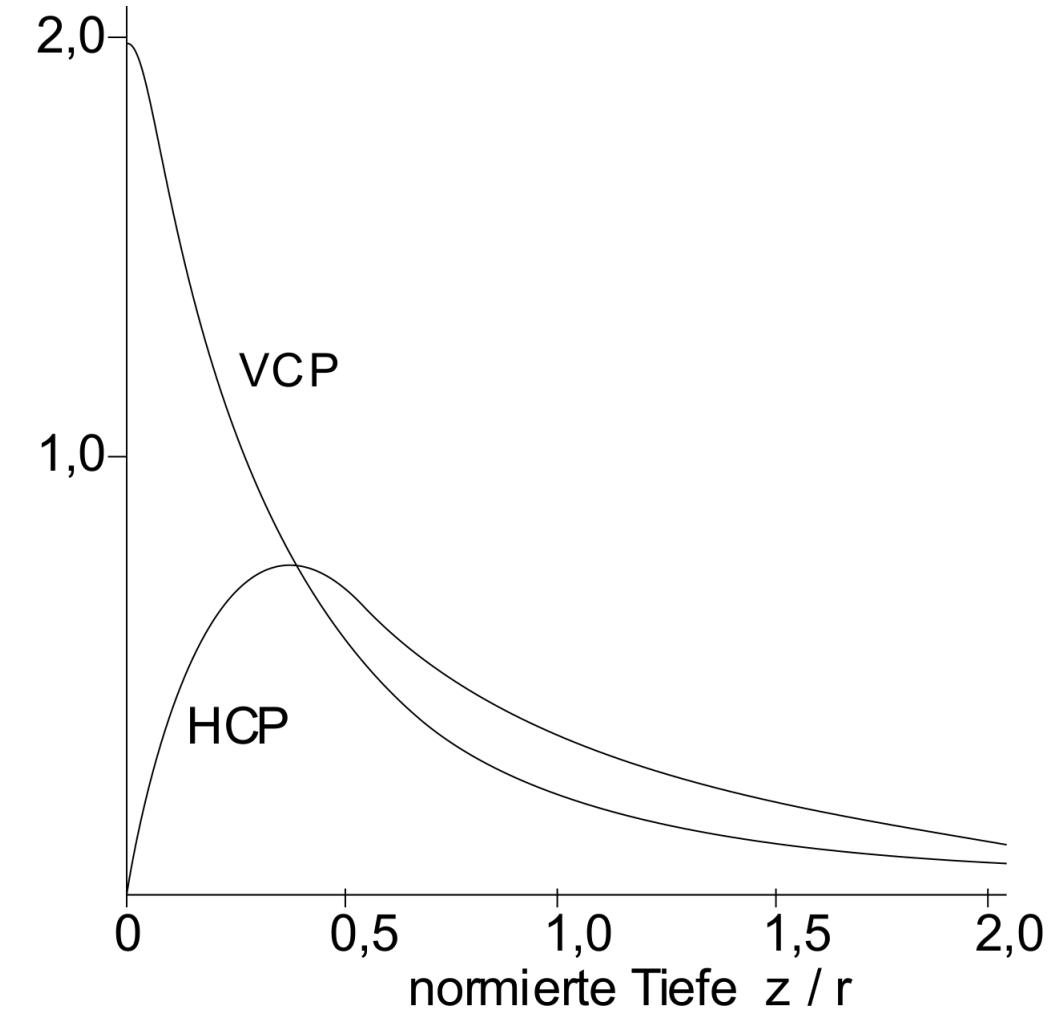


Welle

2-Spulen-Methode (EMI)



$$\text{Skintiefe: } d = 503 \sqrt{\rho/f}$$

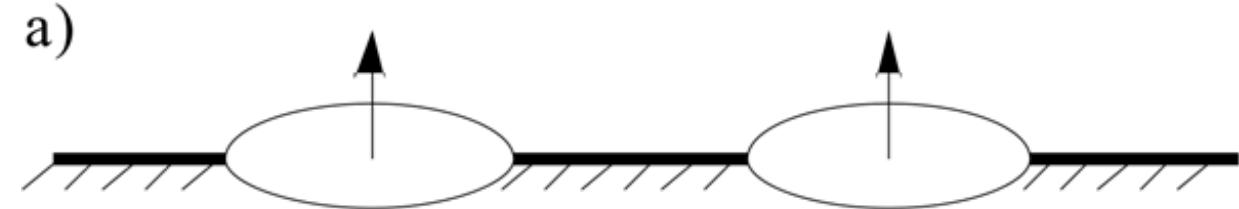


Skintiefe

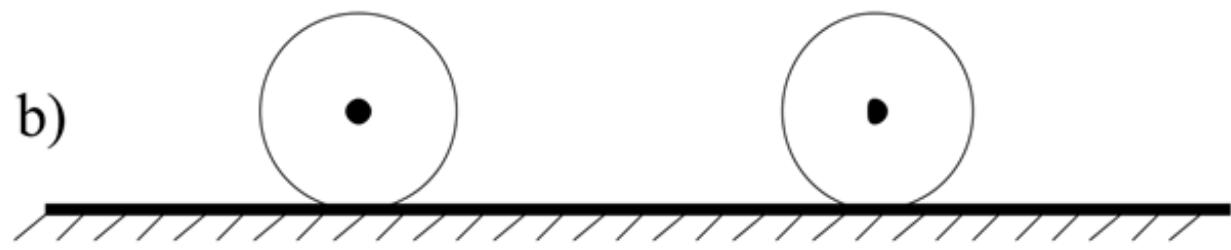
Type	σ	μ_r	ϵ_r	δ (1Hz)	δ (1kHz)	δ (1MHz)	δ (1GHz)
Air	0 S/m	1	1	∞	∞	∞	∞
Sea Water	3.3 S/m	1	80	277 m	8.76 m	0.277 m	0.015 m
Igneous	10^{-4} S/m	1	5	50,300 m	1,590 m	121 m	119 m
Sedimentary (dry)	10^{-3} S/m	1	4	15,900 m	500 m	18 m	11 m
Sedimentary (wet)	10^{-2} S/m	1	25	5,000 m	160 m	5.4 m	2.6 m
Sulphide Skarn	10^2 S/m	1	5	50 m	1.6 m	0.05 m	0.002 m
Magnetite Skarn	10^2 S/m	2	5	36 m	1.1 m	0.04 m	0.001 m

Spulenanordnungen

Sender



Empfänger

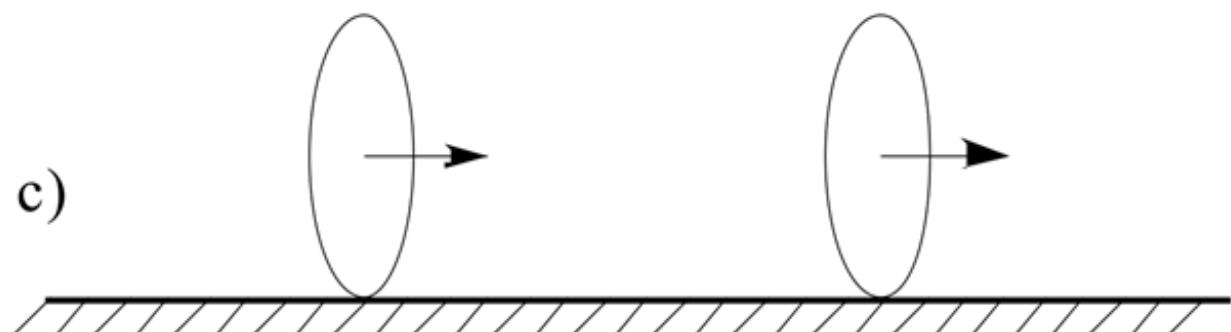


Spulenachsen

Vertikal,
parallel

Spulenebenen

Horizontal,
koplanar (HCP)



Horizontal,
parallel

Vertikal,
koplanar (VCP)

Horizontal,
koaxial

Vertikal
parallel (VCA)

Geräte

FDEM - Geräte



CMD-Mini Explorer 6L

six-depth probe
with depth ranges 0.3 / 0.15 m, 0.5 / 0.25 m, 0.8 / 0.4 m, 1.1 / 0.5 m, 1.6 / 0.8 m,
2.3 / 1.1 m for high resolution mapping and section imaging.



EM34

f=640Hz-6.4kHz, d=10-40m



d = 10..20..50..100..200m

Apex Maxmin I+10

10 frequencies:
110 Hz – 56 kHz
Pen. Depth ~100m



CMD - 4/6 single-depth probe
with variable depth range 6.0 / 3.0 m or
9.0 / 4.5 m for similar purposes like CMD-4
with significantly enhanced survey depth.

GCM: ground-conductivity meter

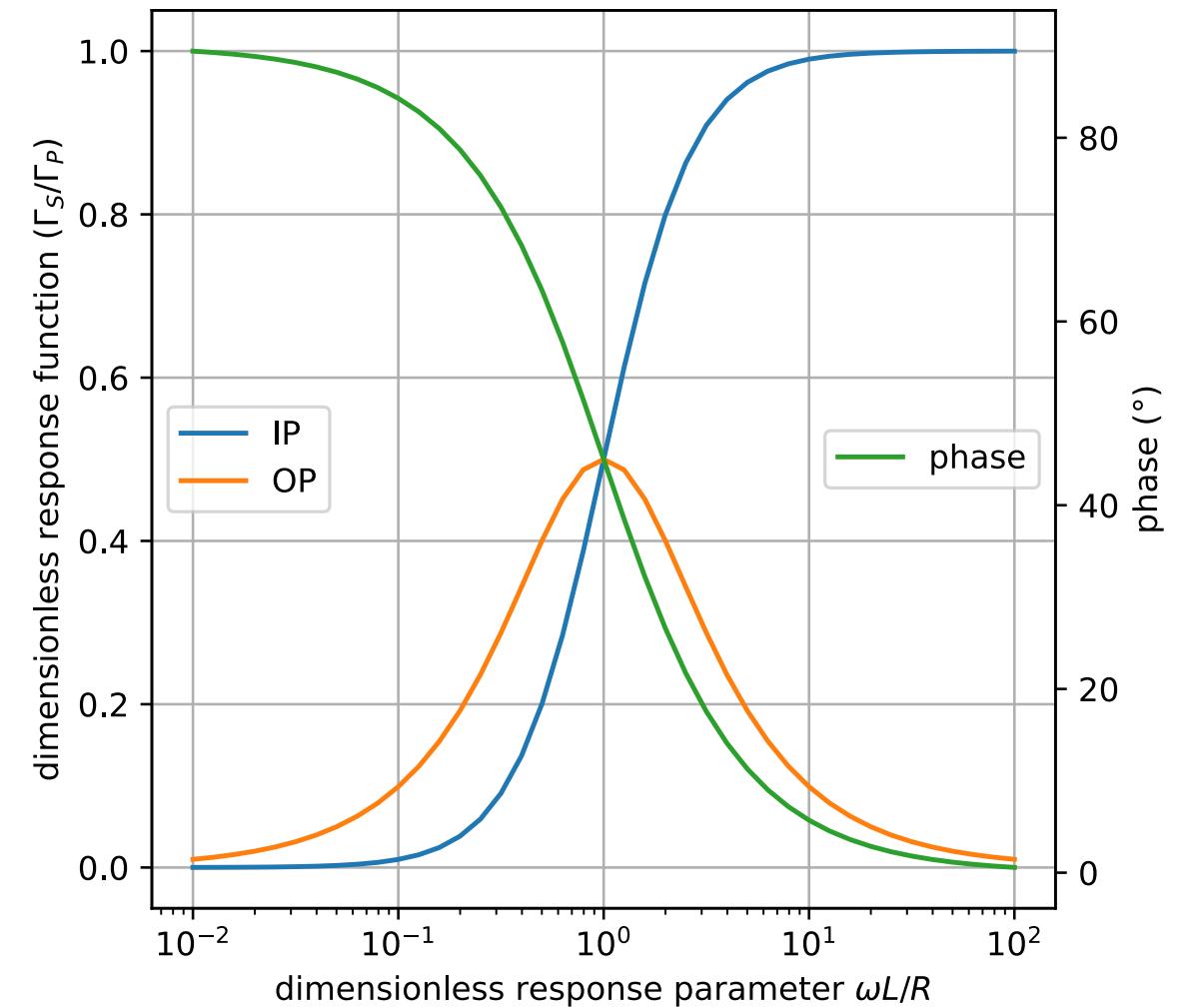
Geophysica Brno

Response function

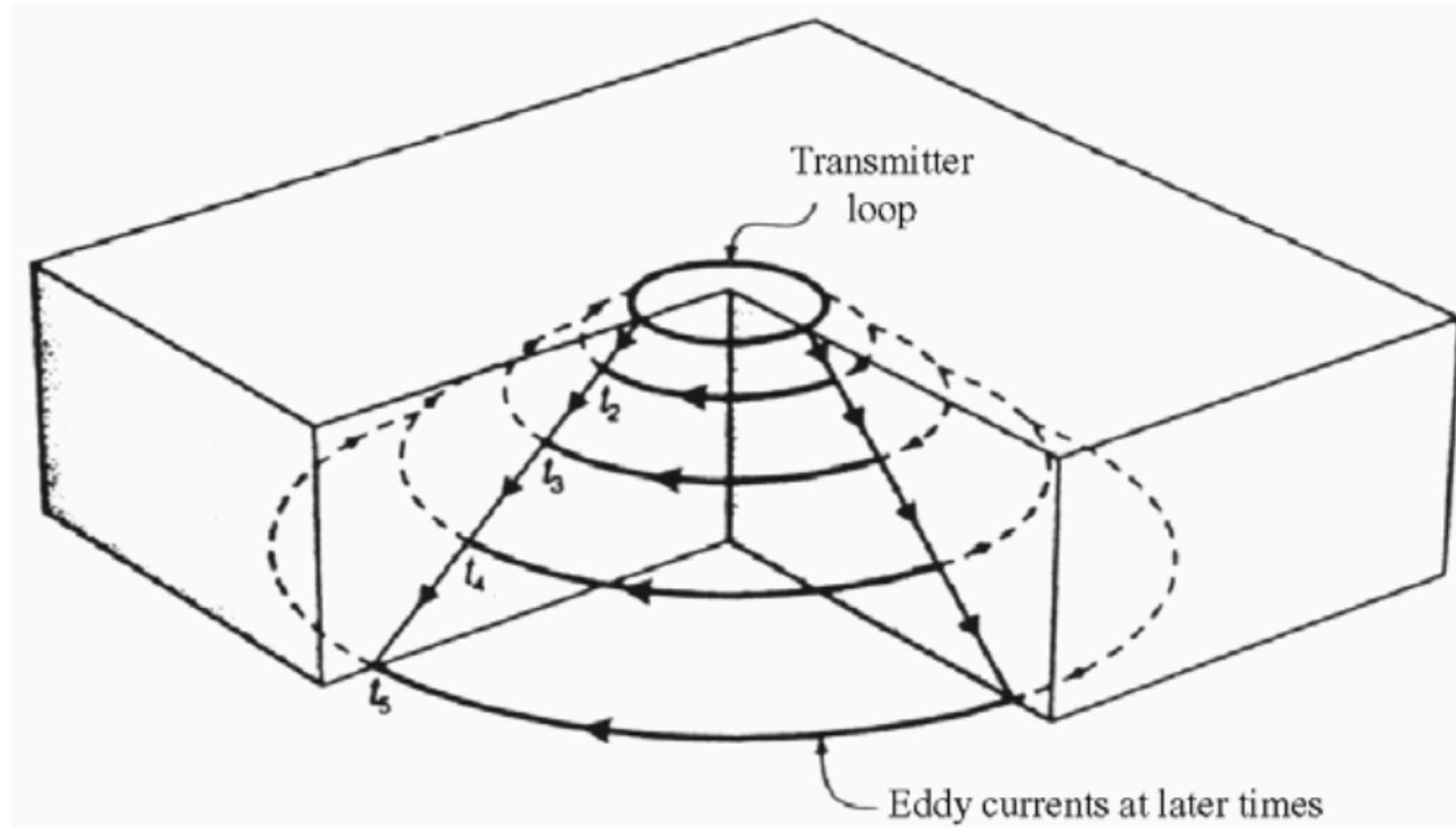
$$\frac{\Gamma_S}{\Gamma_P} = \kappa \frac{i\omega L/R}{1 + i\omega L/R}$$

$\omega \rightarrow 0$ secondary OP signal
(resistive limit)

$\omega \rightarrow \infty$ secondary IP signal
(inductive limit)

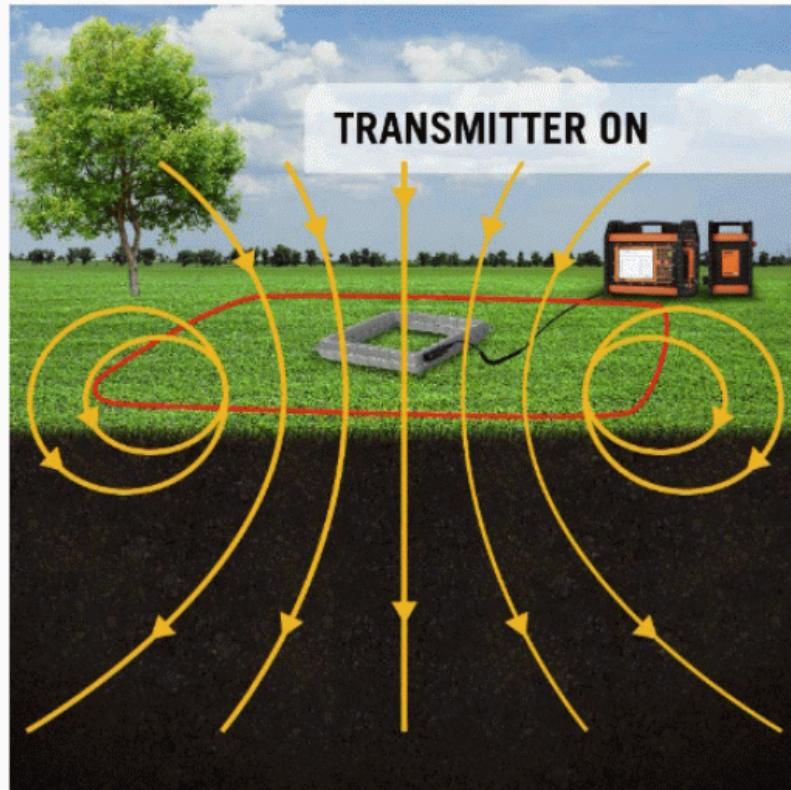


Transient-Elektromagnetik (TEM)

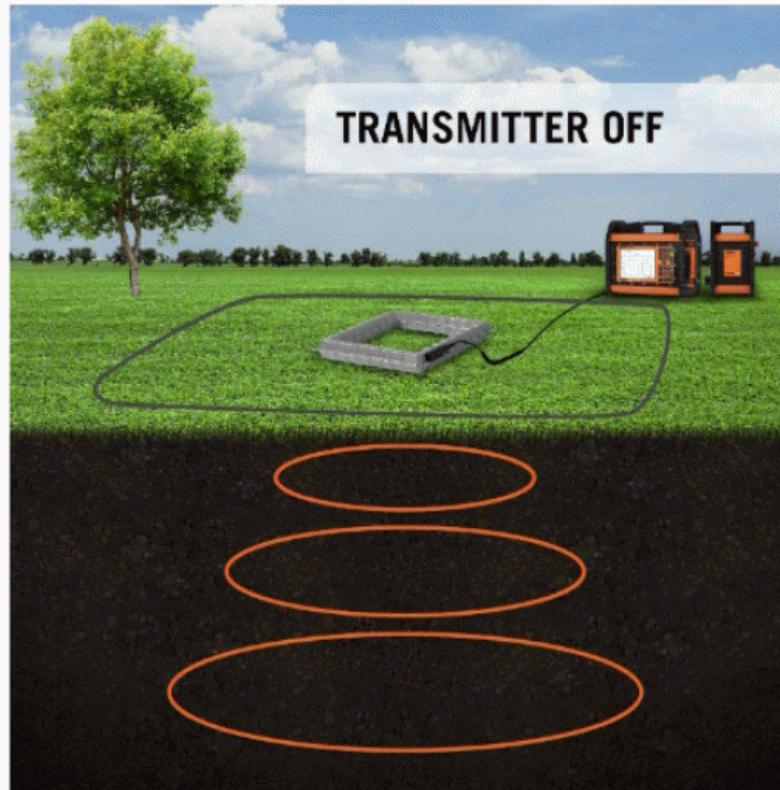


- große Kreisspule
- Abschalten des Stroms
- Spiegelstromsystem
- Zerfall mit Zeit

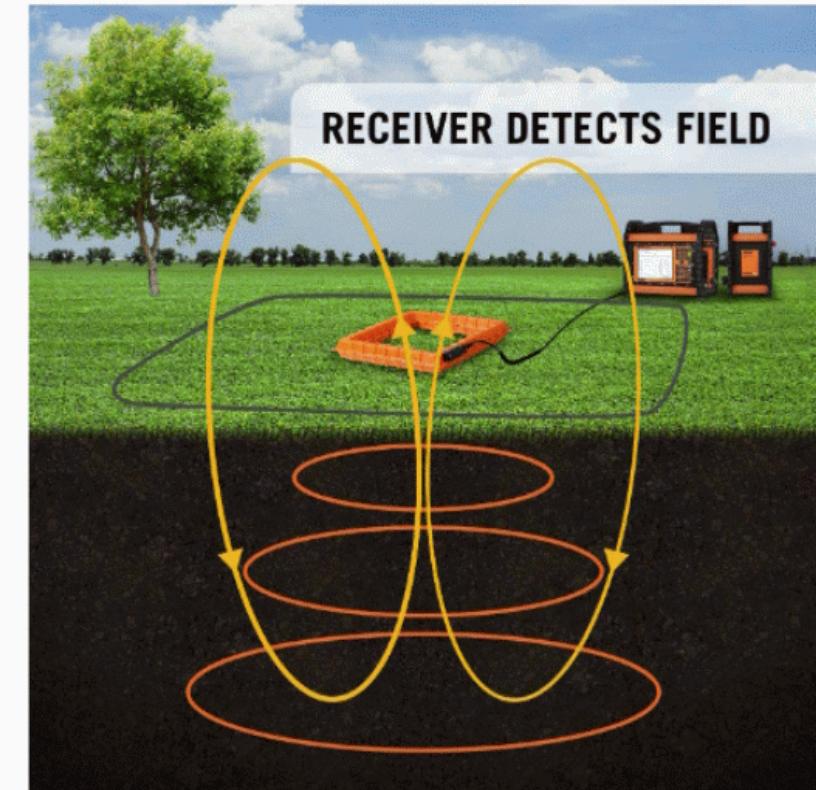
TEM am Boden (WalkTEM)



Current flowing through TX Loop (red) create a magnetic field (yellow)



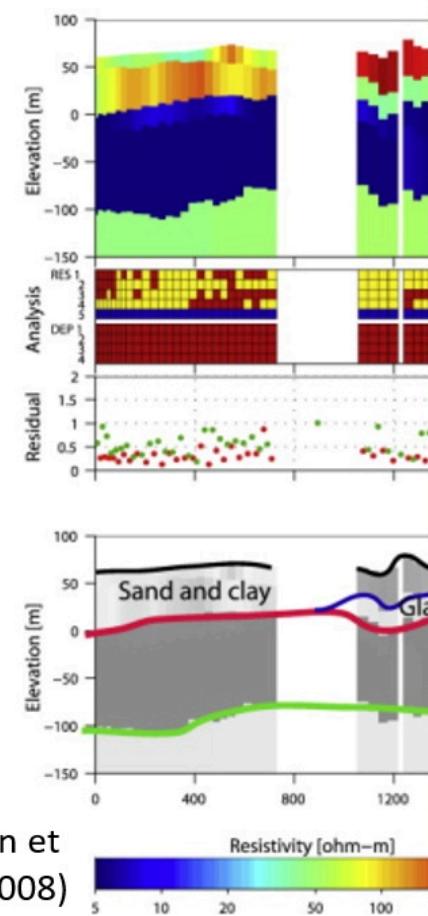
The collapsing magnetic field creates electrical currents in the ground (orange)



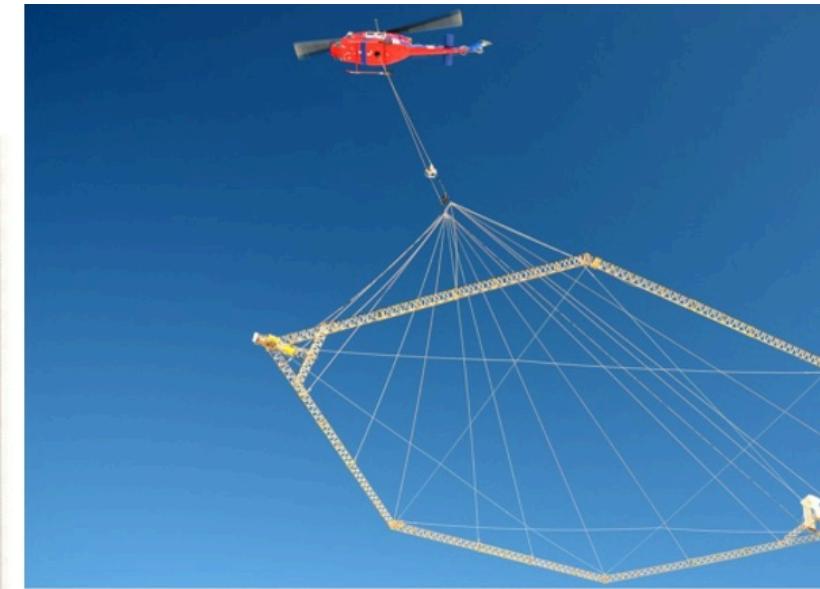
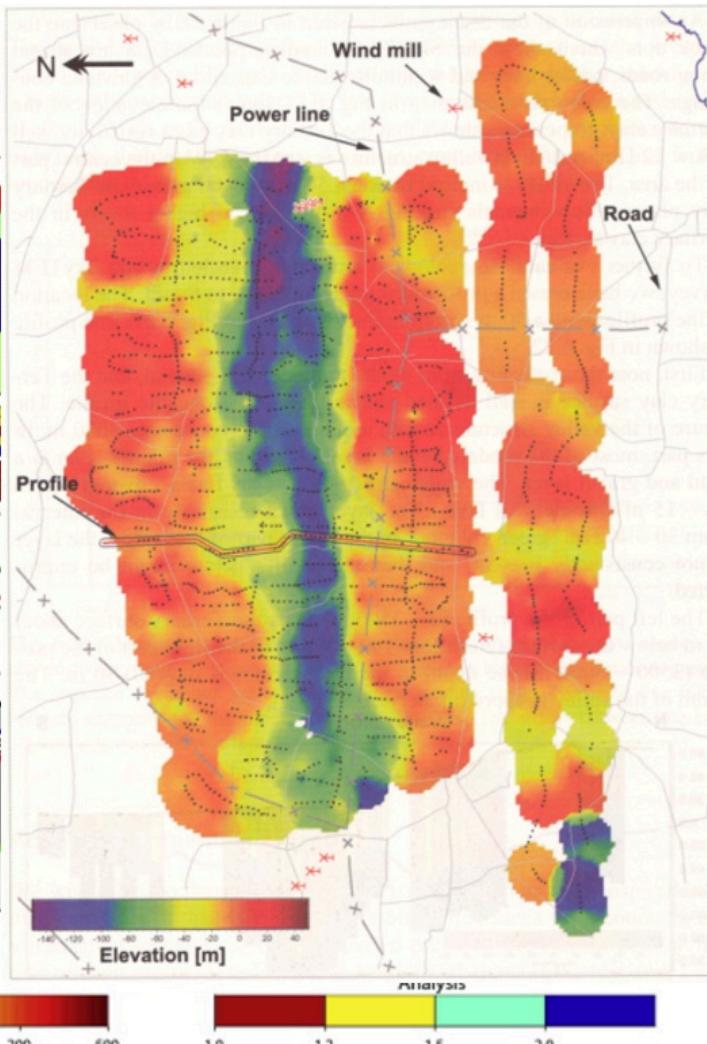
Ground currents create a secondary magnetic field (yellow) recorded by the RX coil (centre)

Airborne TEM (SkyTEM)

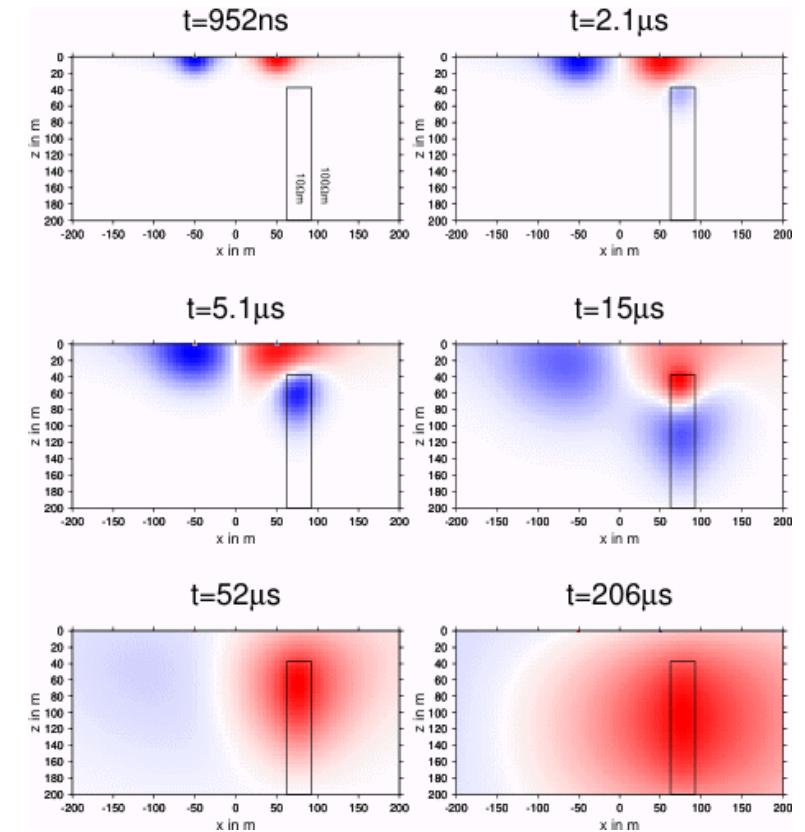
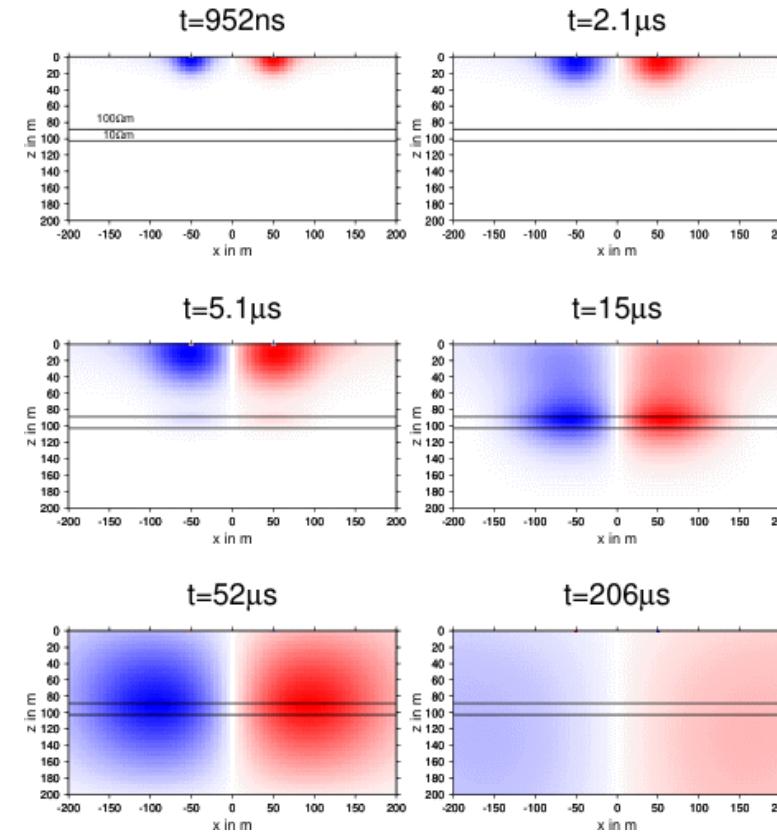
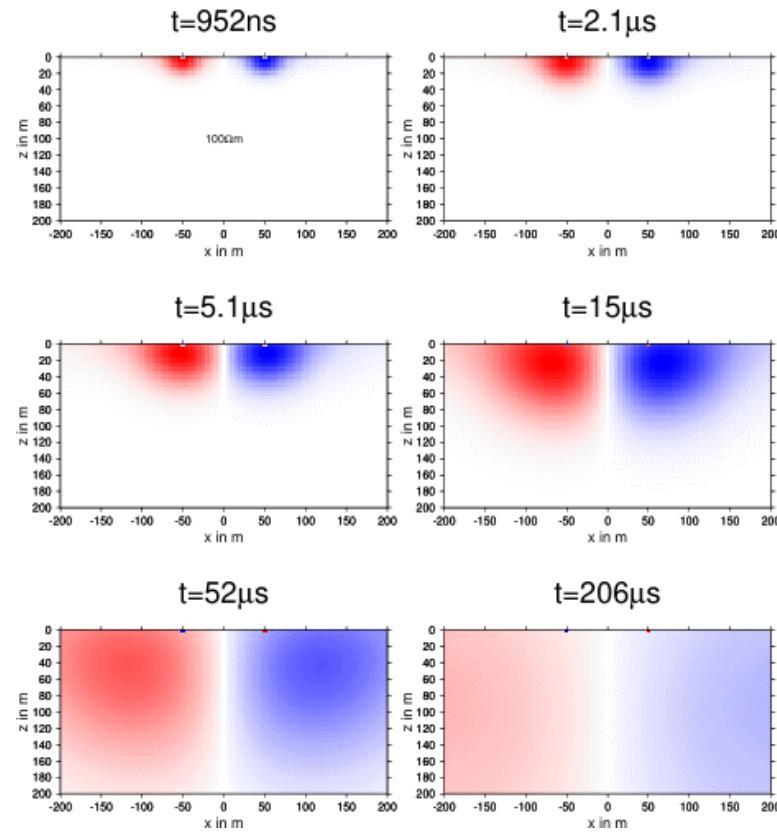
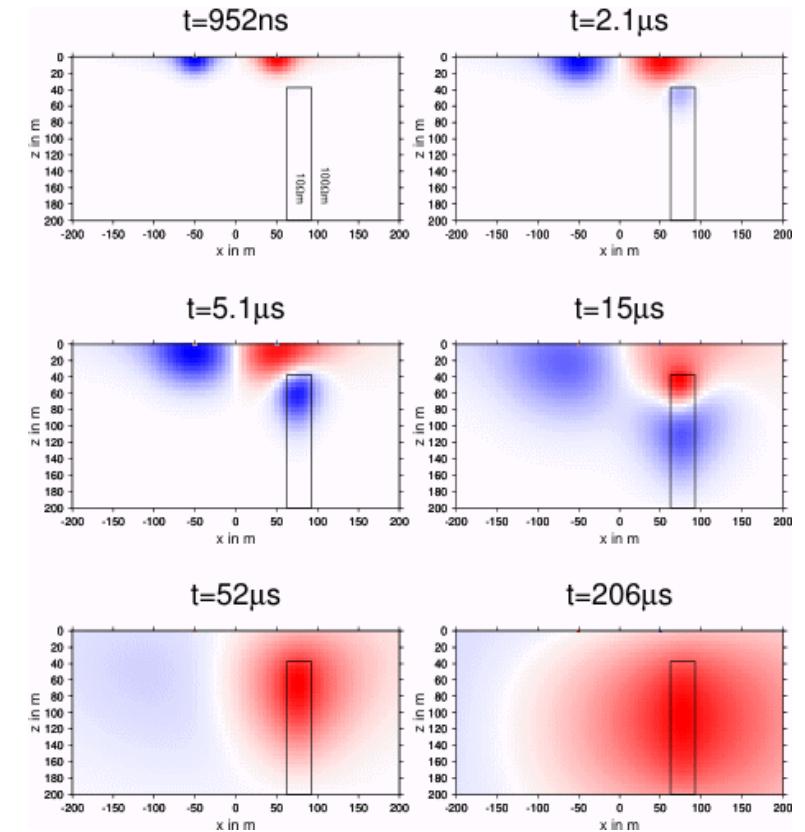
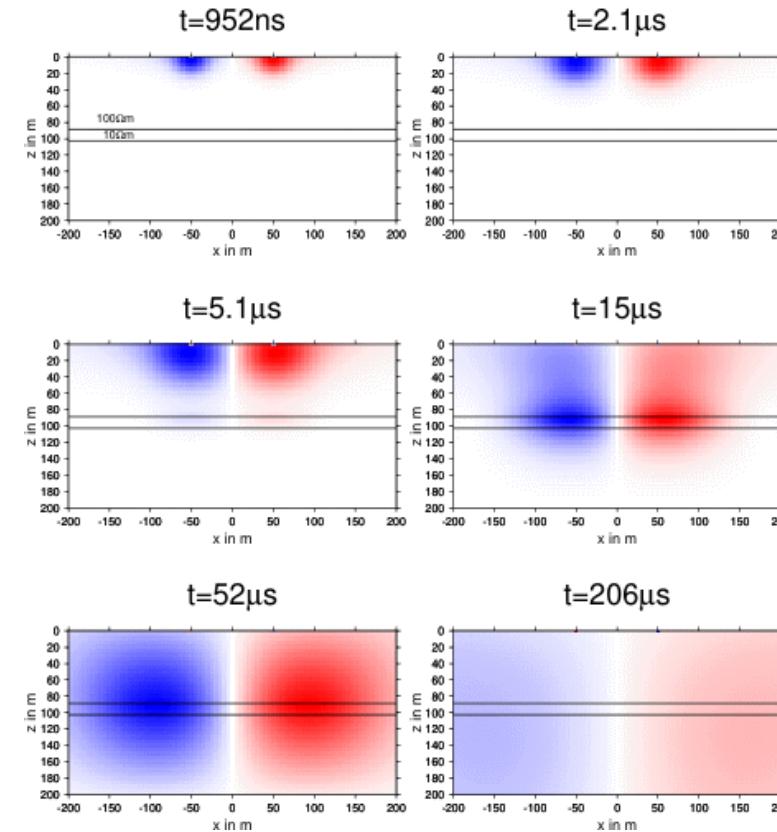
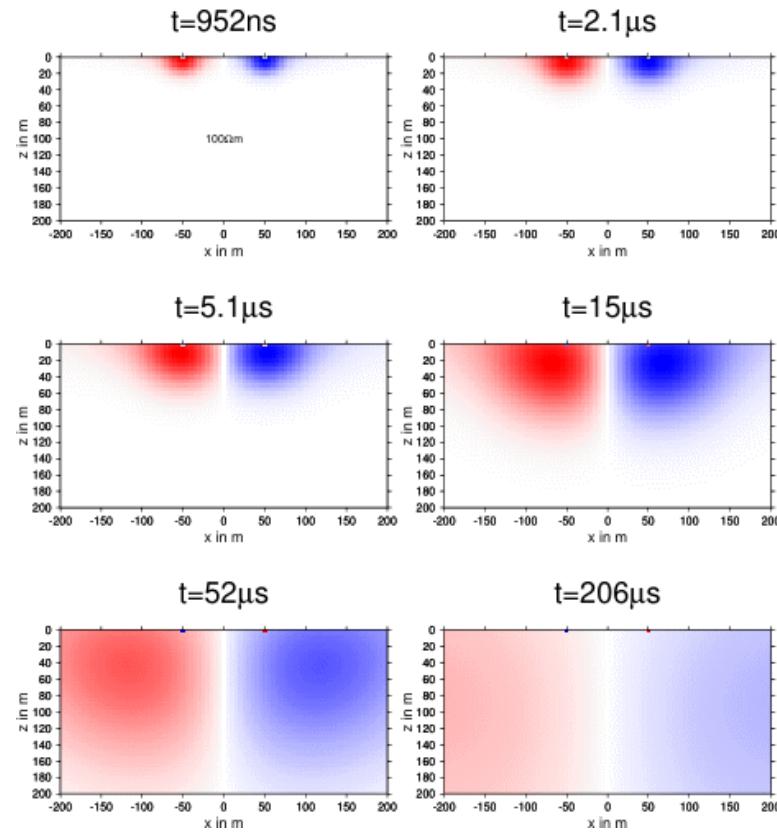
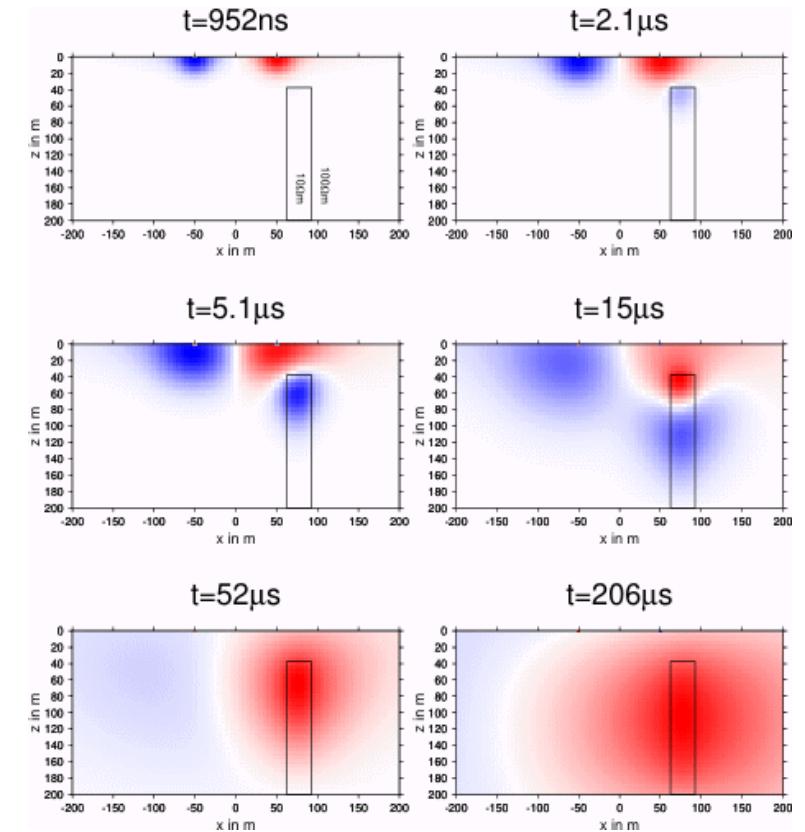
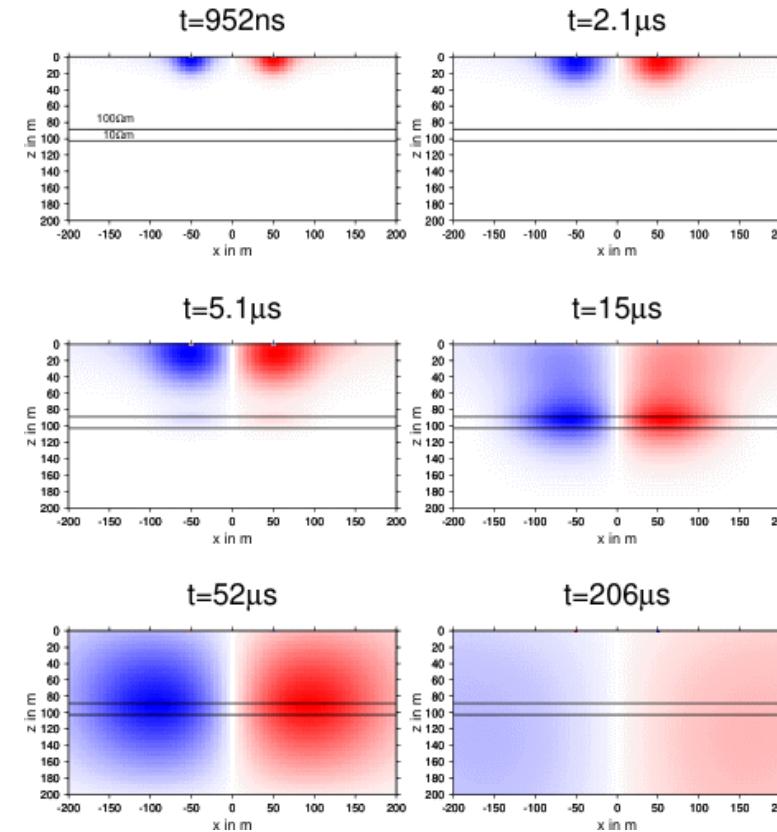
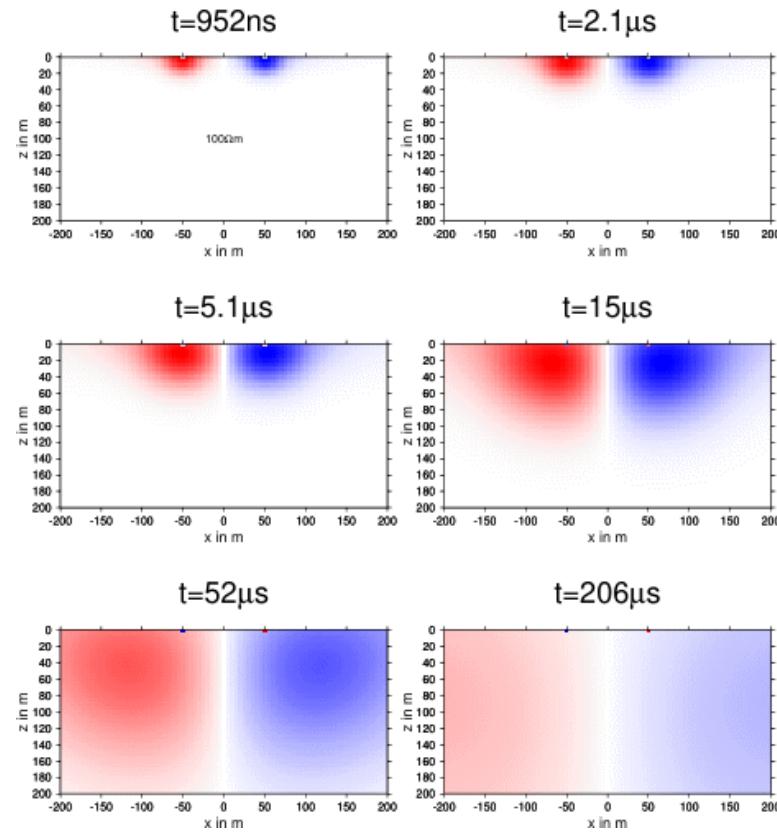
skyTEM



Auken et
al. (2008)

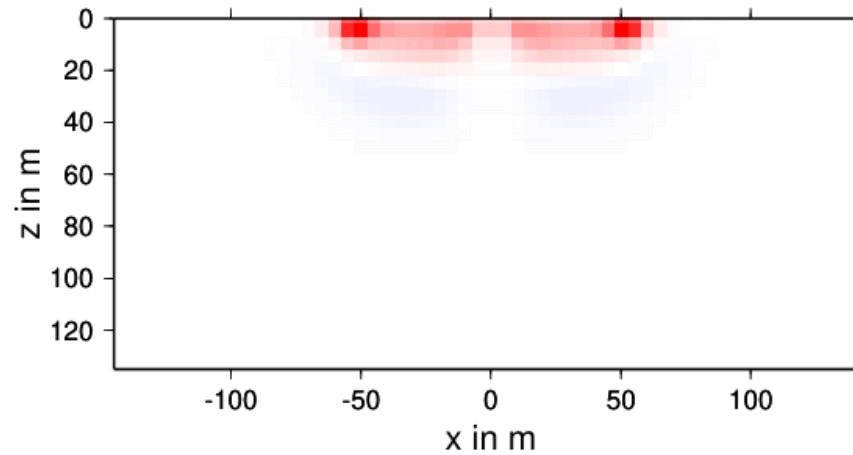


TEM Stromdichte-Verteilung

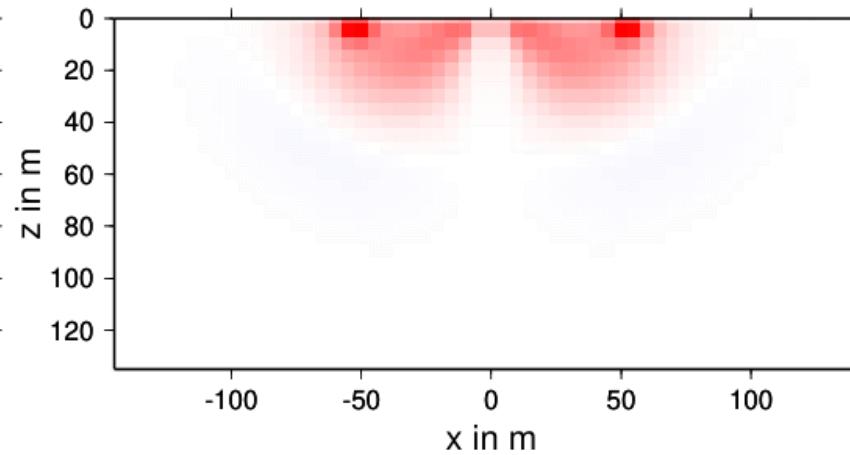


TEM Sensitivität

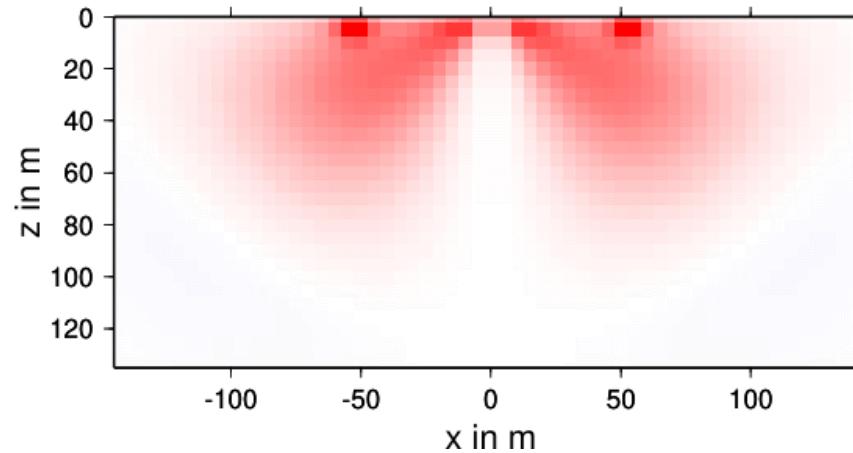
$t=5.1\mu s$



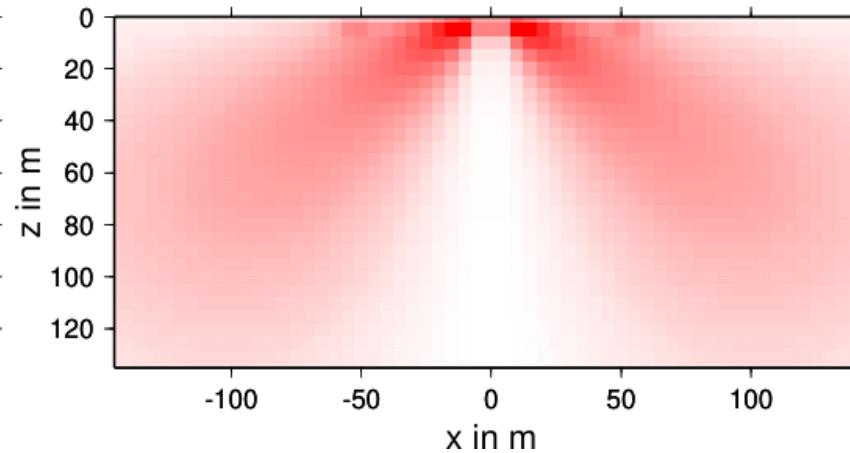
$t=15\mu s$



$t=52\mu s$



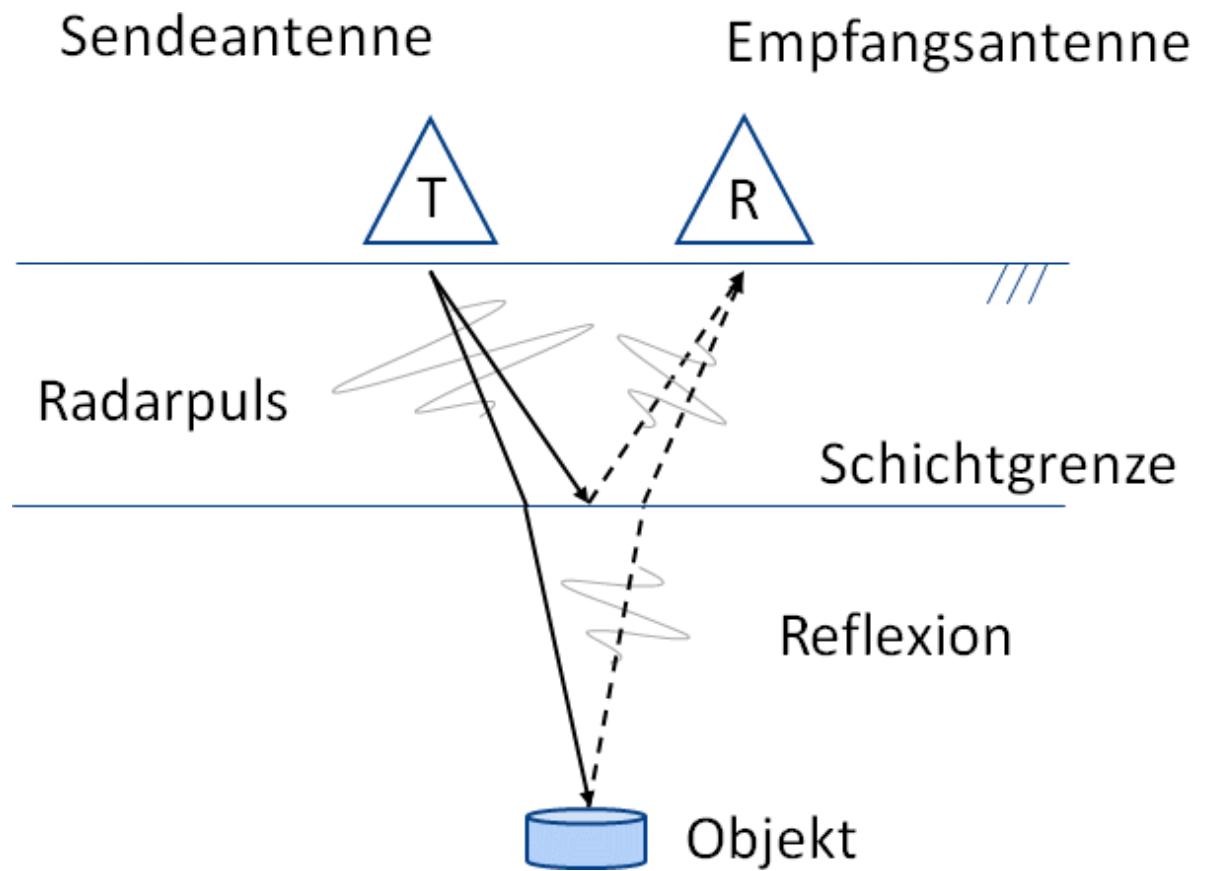
$t=206\mu s$



Georadar

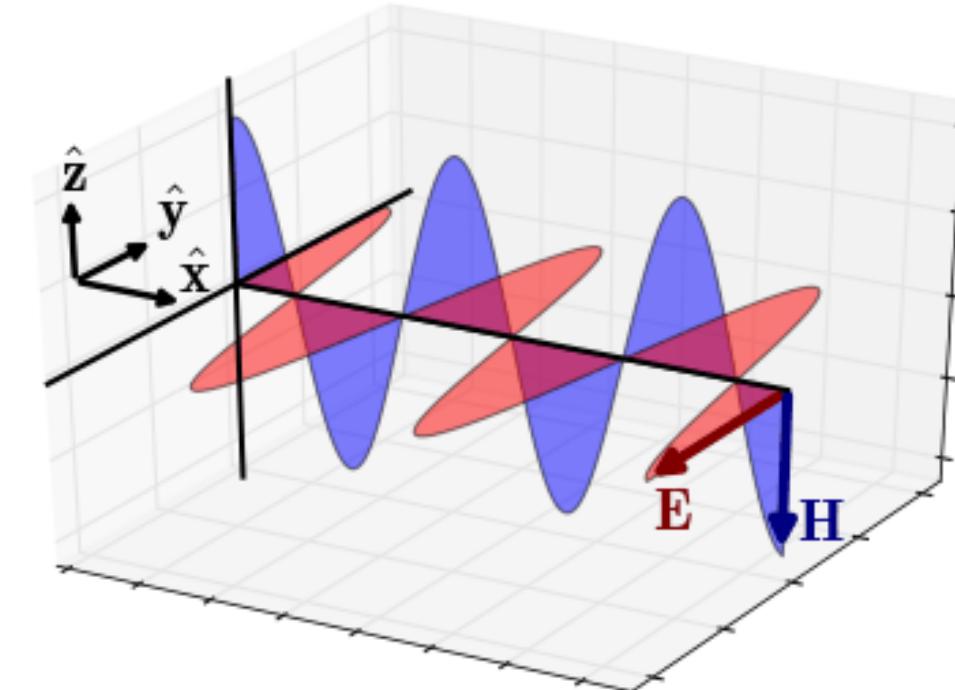
Ground-Penetrating radar (GPR)

- EM-Wellenverfahren
- ϵ spielt eine Rolle
- hochfrequent (50 mHz-5 GHz)
- Wellenlänge $\lambda = f/c$ cm-m
- Reflektion bei ϵ oder σ Kontrast



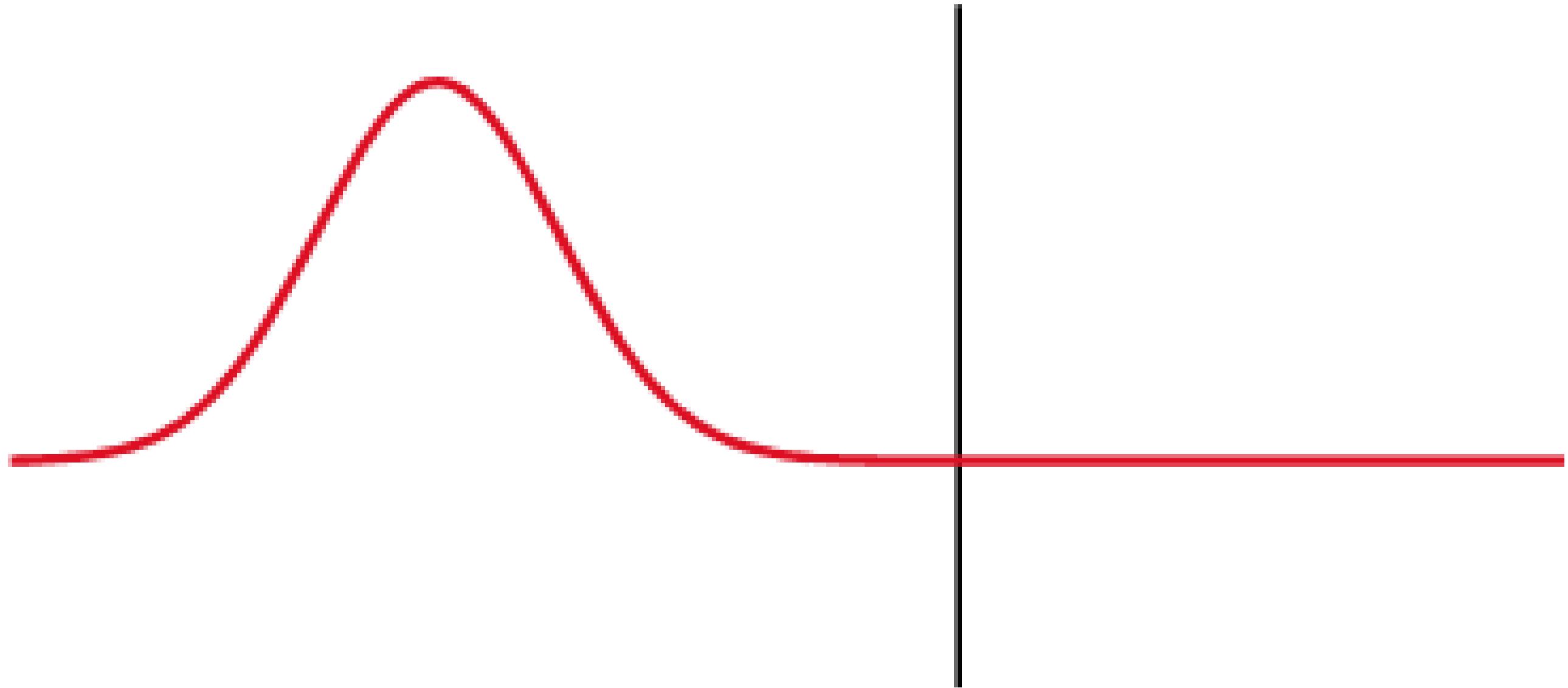
Elektromagnetische Wellen

- dD/dt dominiert \mathbf{j}
- Wellenausbreitung
- Felder senkrecht zu Ausbreitung
- B und E phasenverschoben
- in der Erde sehr schnell gedämpft

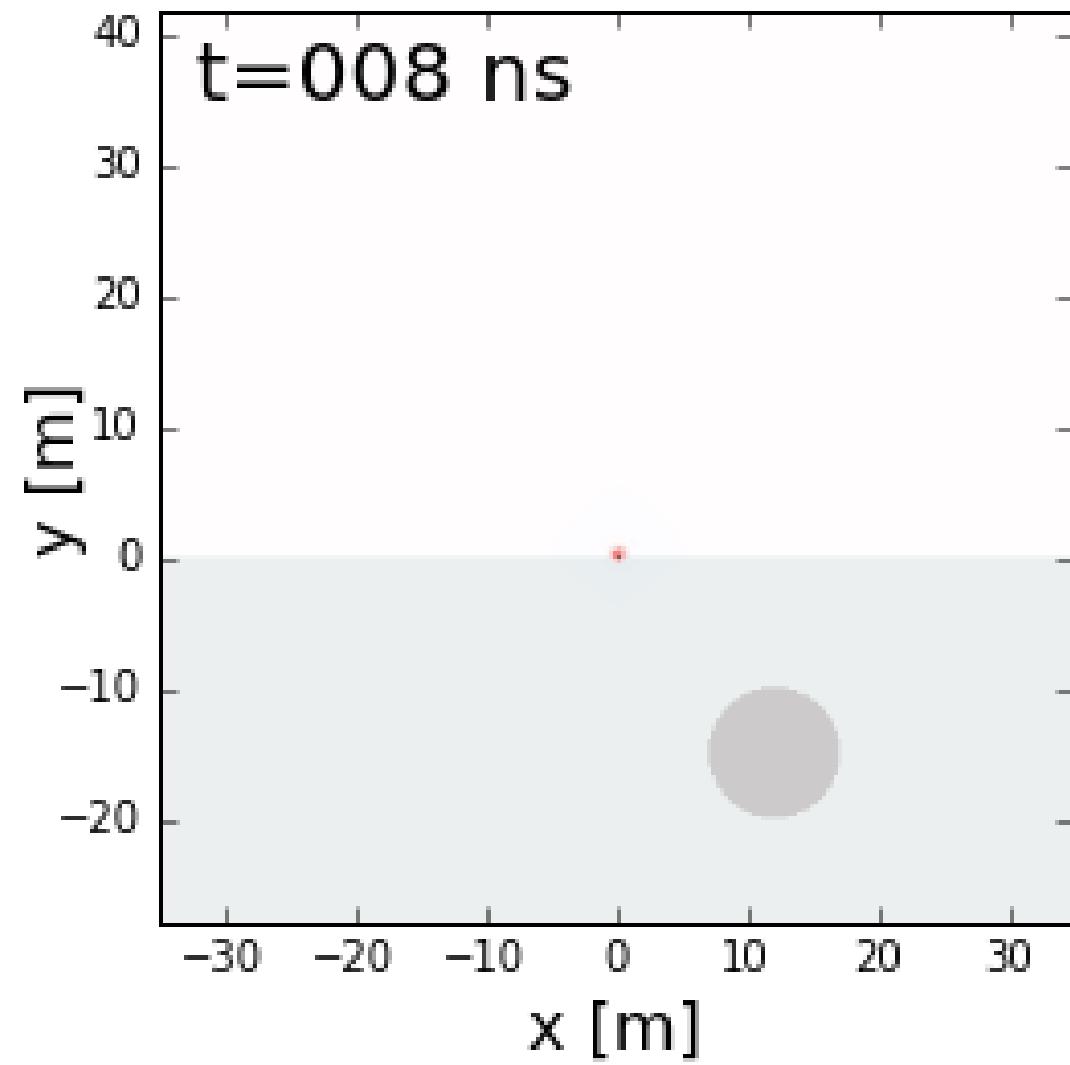
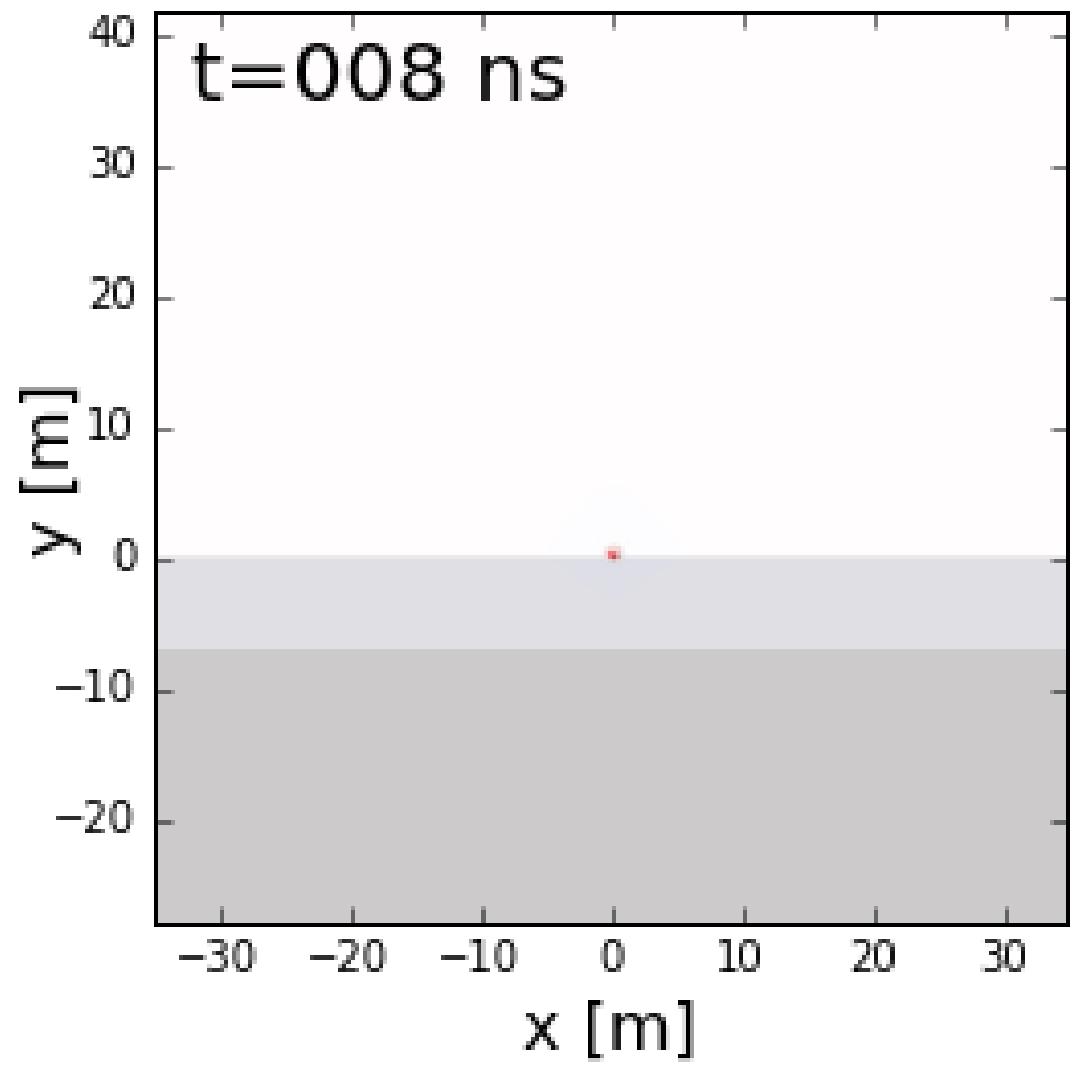


GPR-Wellenausbreitung

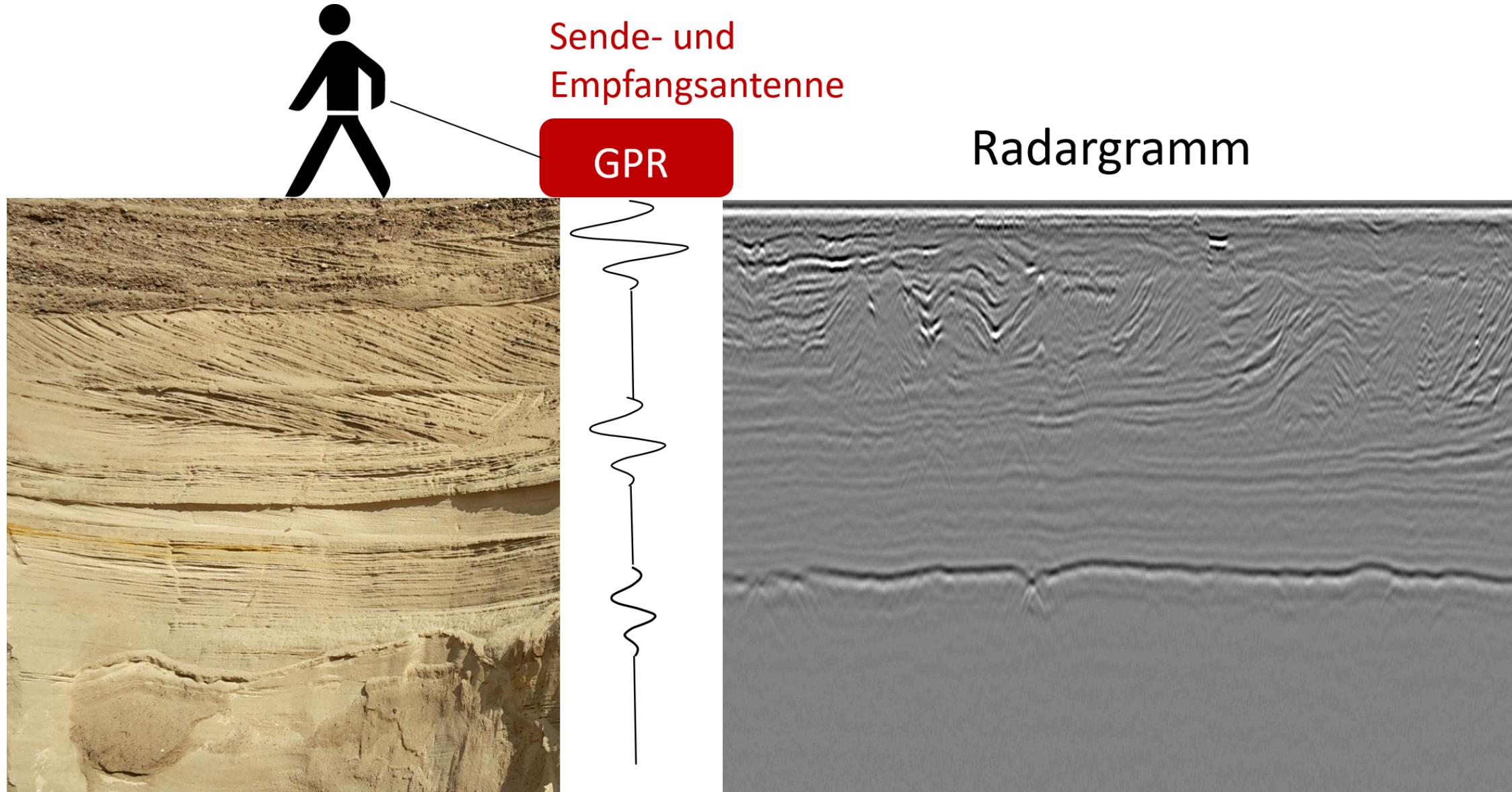
Reflektion & Transmission



Reflektionsmuster



GPR-Messung



GPR-Ausbreitungsparameter

Material	Relative Permittivity	Conductivity (mS/m)	Average Velocity (m/ns)
Air	1	0	0.3
Fresh Water	80	0.5	0.033
Sea Water	80	3000	0.01
Ice	3-4	0.01	0.16
Dry Sand	3-5	0.01	0.15
Saturated Sand	20-30	0.1-1	0.06
Limestone	4-8	0.5-2	0.12
Shales	5-15	1-100	0.09
Silts	5-30	1-100	0.07
Clays	5-40	2-1000	0.06
Granite	4-6	0.01-1	0.13

3D-GPR Kilmore (Ireland)

