VIENNA UNIVERSITY OF TECHNOLOGY
DEPARTMENT OF GEODESY AND GEOINFORMATION
RESEARCH GROUPS PHOTOGRAMMETRY & REMOTE SENSING

EuroSDR Workshop on Multispectral LiDAR

Multispectral LiDAR basics

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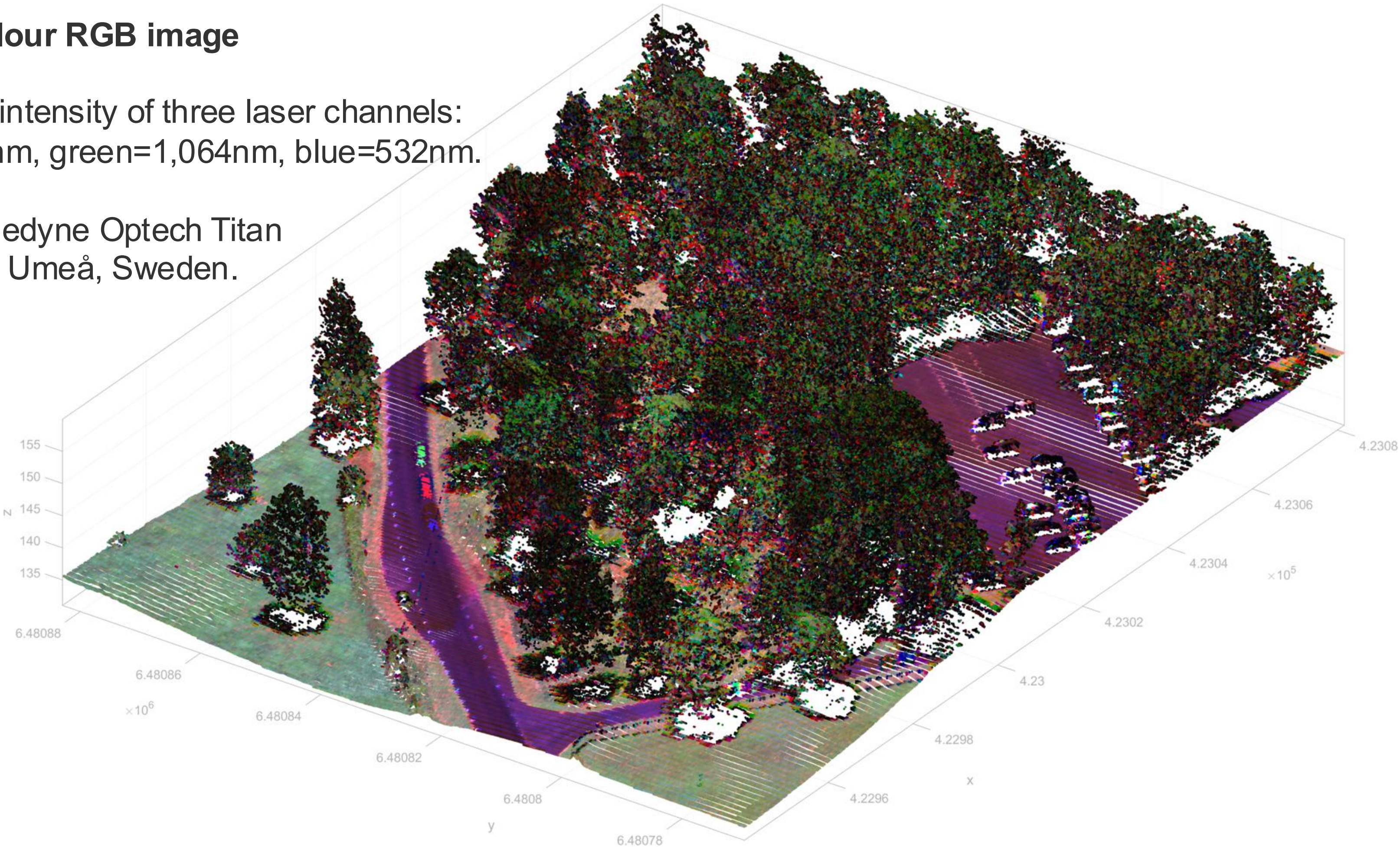
Application: 3D Visualization

Pseudocolour RGB image

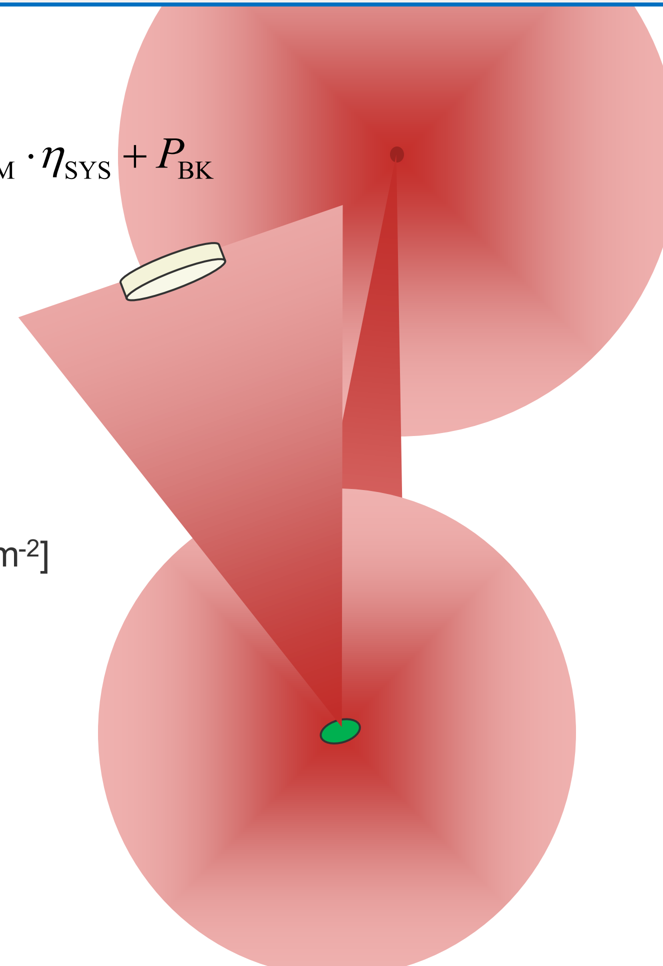
composed intensity of three laser channels:
red=1,550nm, green=1,064nm, blue=532nm.

Sensor: Teledyne Optech Titan
Data: SLU, Umeå, Sweden.



Laser-Radar equation

$$P_E = \frac{P_S}{4\pi R^2} \times \frac{4\pi}{\pi\,\gamma^2 / 4} \times A \cdot \rho \times \frac{1}{4\pi R^2} \times \frac{4\pi}{\Omega} \times \frac{\pi D^2}{4} \times \eta_{\mathrm{ATM}} \cdot \eta_{\mathrm{SYS}} + P_{\mathrm{BK}}$$



- Received power P_E [W]
- Transmitted power P_S [W]
- Equally distributed over entire sphere [m^{-2}]
- Beam opening angle (beam divergence) γ [],dB
- Target area A [m^2] with reflection coefficient ρ
- Backscattering equally distributed over entire sphere [m^{-2}]
- Backscattering within cone with opening angle Ω
- Size of receiver aperture D [m^2]
- Atmospheric and system loss factors η_{ATM}, η_{SYS} []
- Back ground radiation P_{BK}

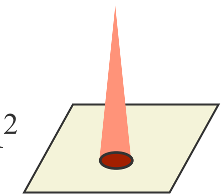
Influence of target size on received power

$$P_E = \frac{P_S D^2}{4\pi\gamma^2 \boxed{R^4}} \times \frac{4\pi A\rho}{\Omega} \times \eta_{\mathrm{ATM}}\eta_{\mathrm{SYS}} + P_{\mathrm{BK}}$$

- Influence of the size of the target on the received power
  - Extended target

    $A = R^2\gamma^2\pi/4$ $\quad P_E \propto 1/R^2$

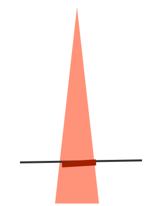
    example: terrain, streets, etc.



  - Linear target

    $A = R\gamma\, d$ $\quad P_E \propto 1/R^3$

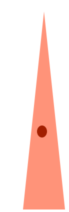
    example: powerline with diameter d



  - Small point target

    $A = \mathrm{const}$ $\quad P_E \propto 1/R^4$

    example: leaf

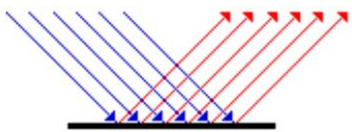


Backscattering cross section

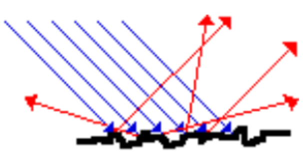
$$P_E = \frac{P_S D^2}{4\pi\gamma^2 R^4} \times \underbrace{\frac{4\pi A\rho}{\Omega}}_{\sigma} \times \eta_{ATM}\,\eta_{SYS} + P_{BK}$$

- Backscattering cross section σ [m²]: includes all object parameters
  - Isotrop (omnidirectional) → $\Omega=2\pi$ → $\sigma = 2\rho A$
  - Lambertian (half-sphere) → $\Omega=\pi$ → $\sigma = 4\rho A$ (orthogonal incidence angle)
  - General case:

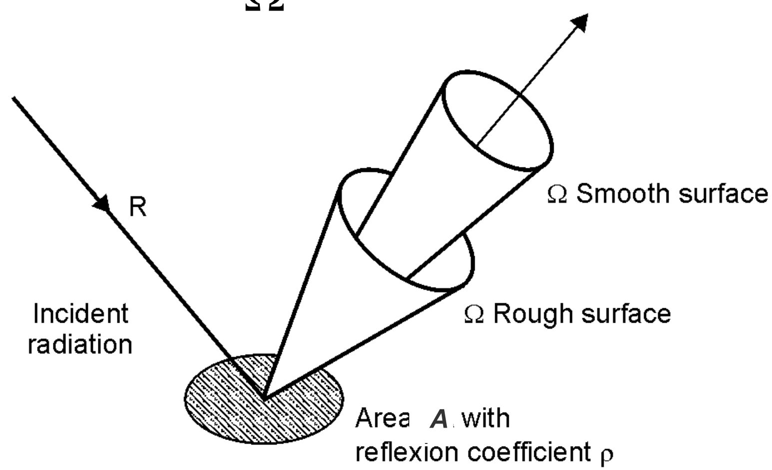
$$\sigma = \frac{4\pi}{\Omega}\rho\, A$$

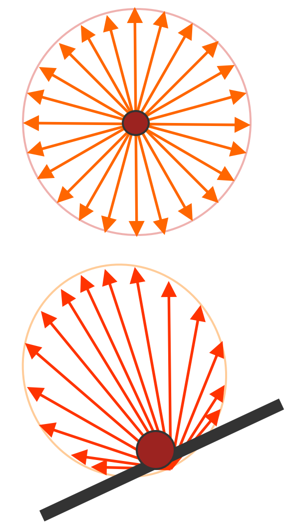


Specular reflexion



Diffuse reflextion



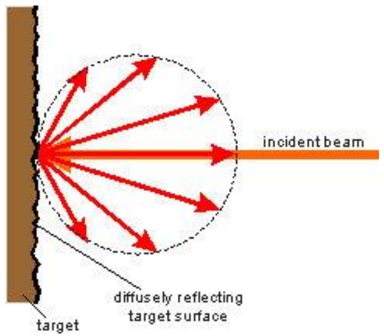


Diffuse reflectivity ρ

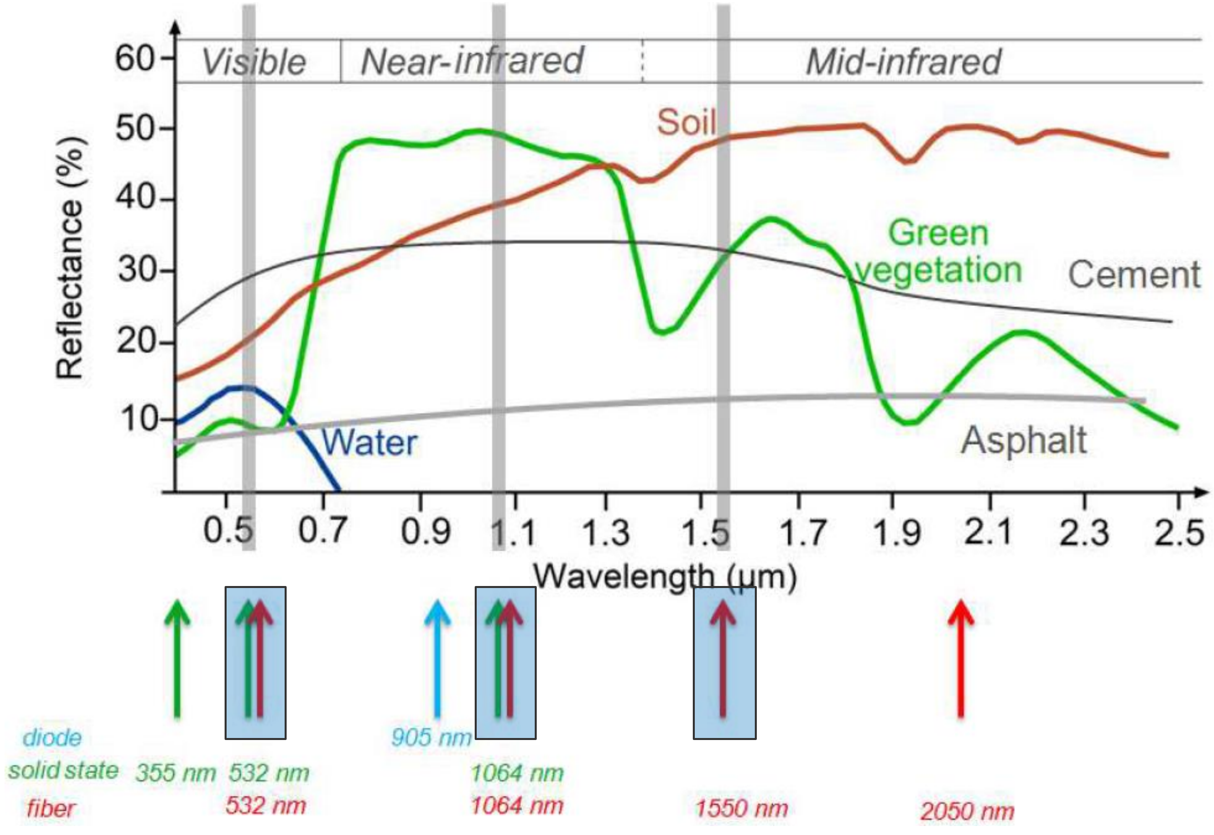
Reflection coefficient (reflectivity) ρ depends on **material** properties and **incidence angle**

Values for **λ=900 nm**, average for typical incidence angles

White paper	**up to 100%**
Dimension lumber (pine, clean, dry)	**94%**
Snow	**80-90%**
Beer foam	**88%**
White masonry	**85%**
Limestone, clay	**up to 75%**
Newspaper with print	**69%**
Tissue paper, two ply	**60%**
Deciduous trees	**typ. 60%**
Coniferous trees	**typ. 30%**
Carbonate sand (dry)	**57%**
Carbonate sand (wet)	**41%**
Beach sands, bare areas in dessert	**typ. 50%**
Rough wood pallet (clean)	**25%**
Concrete, smooth	**24%**
Asphalt with pebbles	**17%**
Lava	**8%**
Black neoprene	**5%**
Black rubber tire wall	**2%**



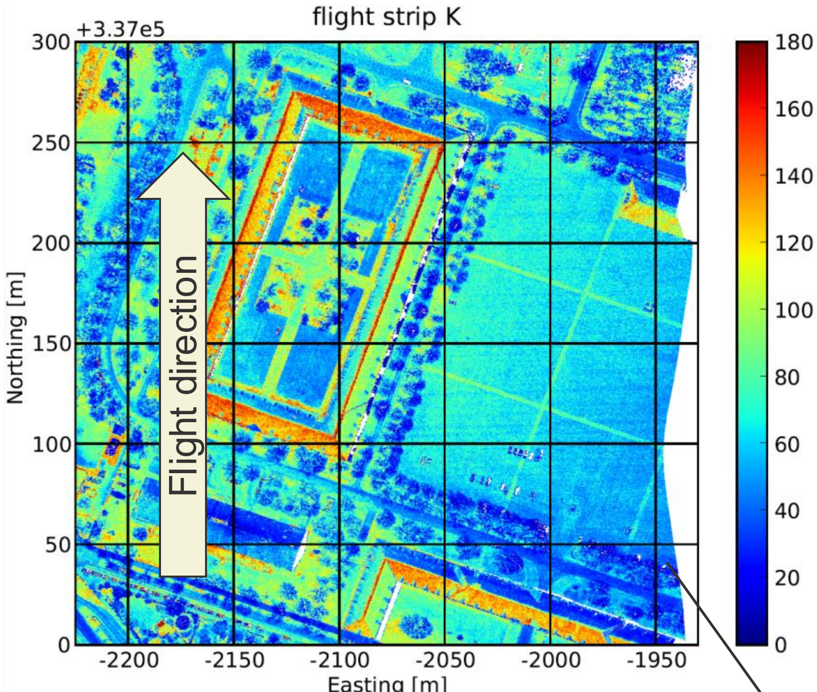
Reflectance depending on laser wavelength



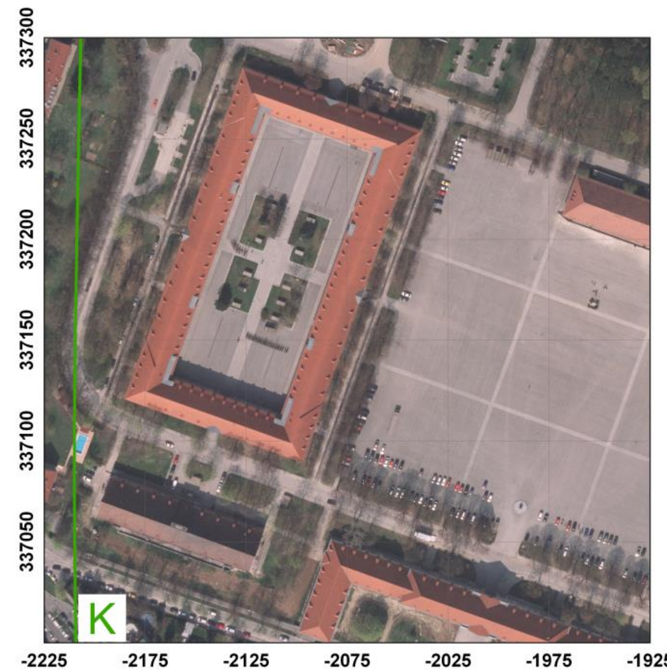
Source: Based on Pfennigbauer and Ullrich (2011), Bakula (2015)

Radiometric calibration: Motivation

Amplitude [DN]



Maria Theresia barracks, Vienna



Data: City of Vienna (MA41), Dec 2006

Amplitude drop towards strip boundary
→ larger ranges
→ larger incidence angle

Backscattering cross section, backscattering coefficient

Laser-Radar equation with BCS σ[m²]:

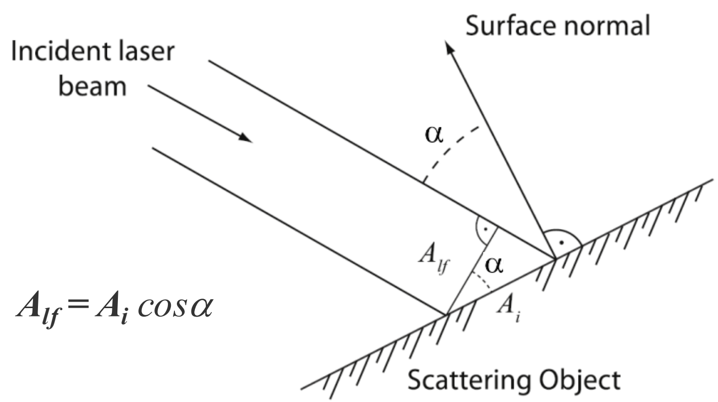
$$P_E = \frac{P_S D^2}{4\pi\beta^2 R^4} \times \sigma \times \eta_{ATM}\eta_{SYS} + P_{BK} \quad ^{*)}$$

Backscattering coefficient [dB]:

$$\gamma = \frac{\sigma}{A_{lf}} = \frac{\sigma}{A_i \cos\alpha} = \frac{4\sigma}{\pi\beta^2 R^2}$$

Laser-Radar equation with γ:

$$P_E = \frac{P_S D^2}{16 R^2} \times \gamma \times \eta_{ATM}\eta_{SYS} + P_{BK}$$



Beam cross section: $A_{lf} = A_i \cos\alpha$

*) β ... Beam divergence (in this context)

Radiometric Calibration

Source: Wagner et al, IAPRS XXX, 2004.

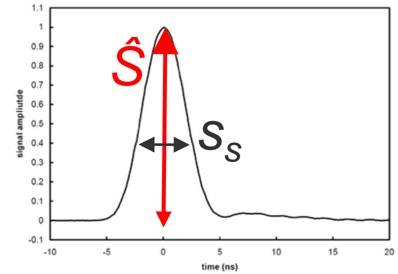
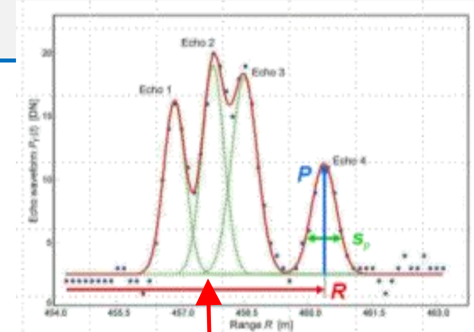


Figure 6. High-resolution sampled transmitter pulse of RIEGL LMS-Q560. Temporal resolution 50 ps, calculated from



Laser-Radar equation re-formulated:

$$P_E = \frac{P_S\, D_E^2}{16\, R_i^2} \eta_{atm} \eta_{sys}\, \gamma_i \;\rightarrow\; P_S \rightarrow \hat{S} s_s,\quad P_E \rightarrow \hat{P}_i s_{p,i} \;\rightarrow\; \gamma_i = \frac{16}{D_r^2\, \hat{S}\, s_s\, \eta_{sys}} \frac{R_i^2\, \hat{P}_i\, s_{p,i}}{\eta_{atm}}$$

$\frac{16}{D_r^2\, \hat{S}\, s_s\, \eta_{sys}} \rightarrow C_{cal}$

$$\eta_{atm} = 10^{-2 R_i a / 10000}$$

- P_E ... Received power [W]
- P_S ... Transmitted power [W]
- D_E ... Receiver aperture [m]
- R .... Range [m]
- η_{sys} ... Transmission factor (system)
- η_{atm} ... Transmission factor (atmosphere)
- γ_i ... Backscattering coefficient [$m^2 m^{-2}$]

- Ŝ ... Amplitude of system waveform [DN]
- s_s ... Std.dev. Of system waveform [ns]
- P_i ... Amplitude of i-th echo [DN]
- $s_{p,i}$ ... Std.dev. of i-th echo [ns]

a ... Atmosph. Dämpfungskoeff. [dB/km]

Derivation of calibration constant C_{cal}

Calibration areas (German: Kalibrierfläche, KF) with **known or measured** reflectivity (e.g. asphalt)

$$\tilde{\rho}_{KF} = \frac{\gamma_{KF,i}(\alpha_i)}{4 \cos\alpha_i} \Longrightarrow \gamma_{KF,i}(\alpha_i) = 4 \tilde{\rho}_{KF} \cos\alpha_i$$

Holds for Lambertian back scattering

$\gamma_{KF,i}$… Backscattering coefficient of i-th laser echo within KF [$m^2 m^{-2}$]

ρ_{KF}… Reflectivity of KF

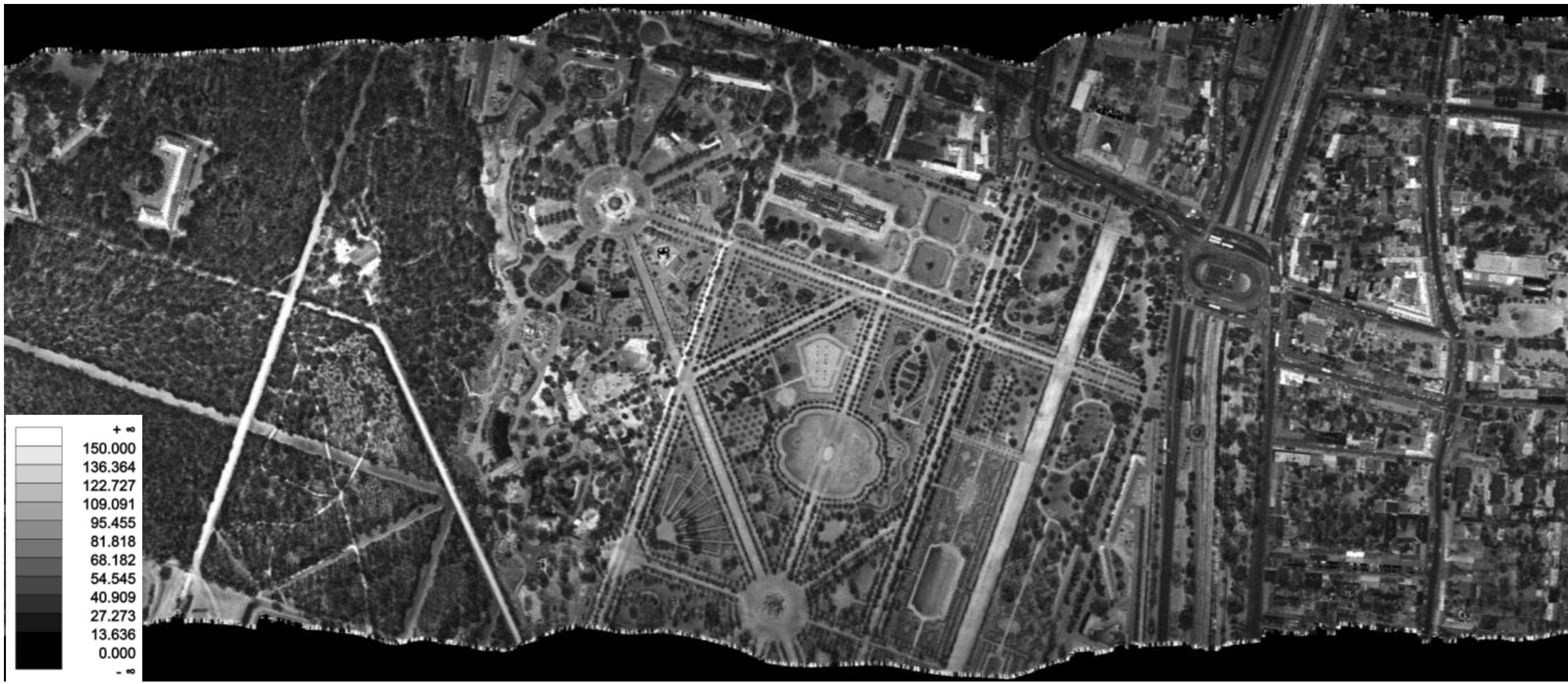
α_i … Incidence angle of i-th echo within KF

N_{KF}… Number of laser echoes within KF

Mean calibration constant C_{cal} [$m^{-2}s^{-1}$] (**valid for a certain laser channel**)

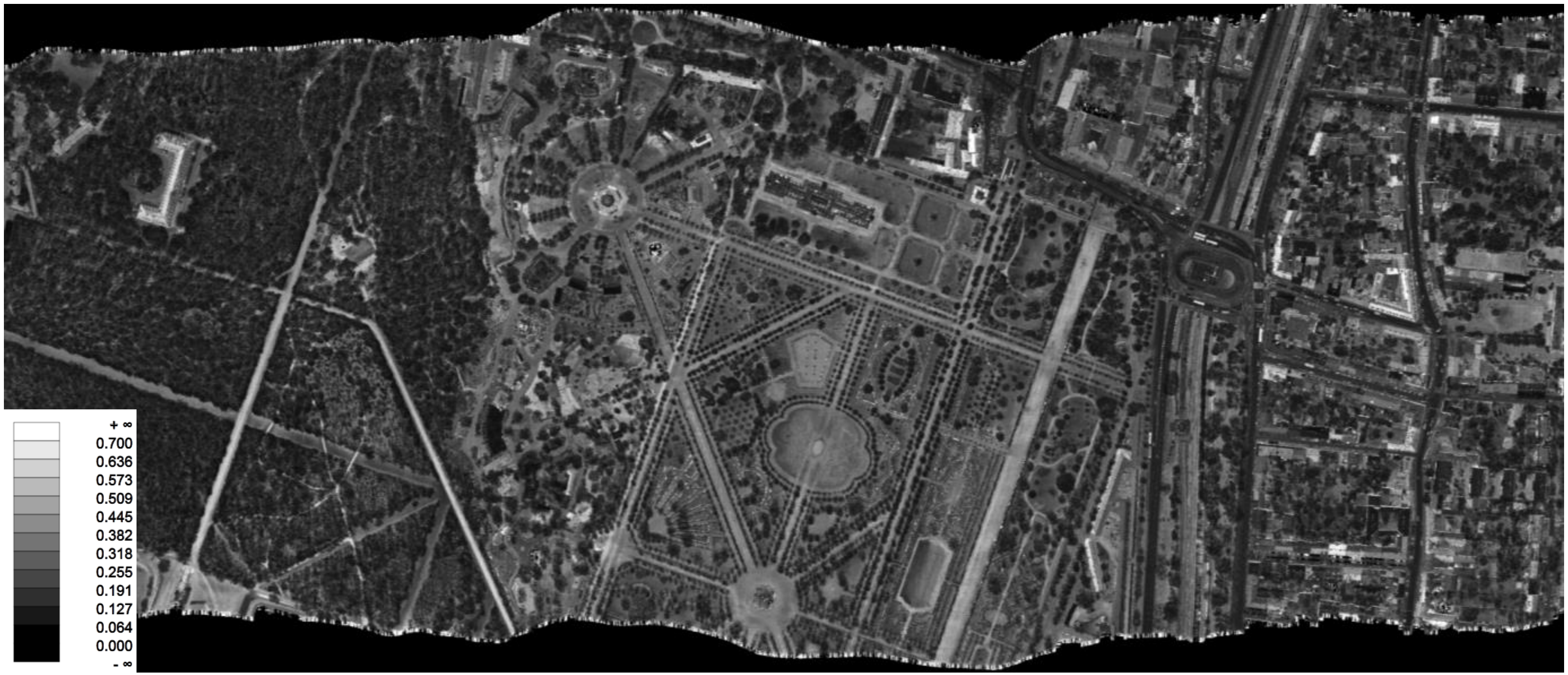
$$C_{cal} = \frac{1}{N_{KF}} \sum_{i=1}^{N_{KF}} \frac{10^{-2R_i a/10000}}{R_i^2 \hat{P}_i s_{p,i}} 4 \tilde{\rho}_{KF} \cos\alpha_i$$

Raw signal amplitude [DN]



Data: City of Vienna (MA41), Dec 2006

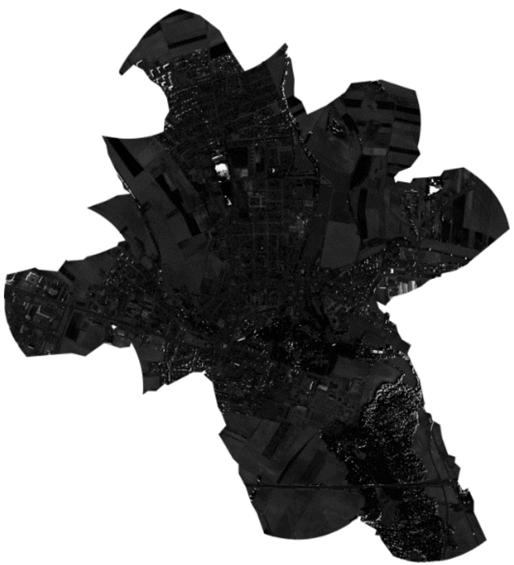
Diffuse reflectivity ρ



Data: City of Vienna (MA41), Dec 2006

Calibrated reflectance @ 532 nm, 1064 nm, and 1550 nm

λ=532 nm



532 nm

λ=1064 nm

1064 nm

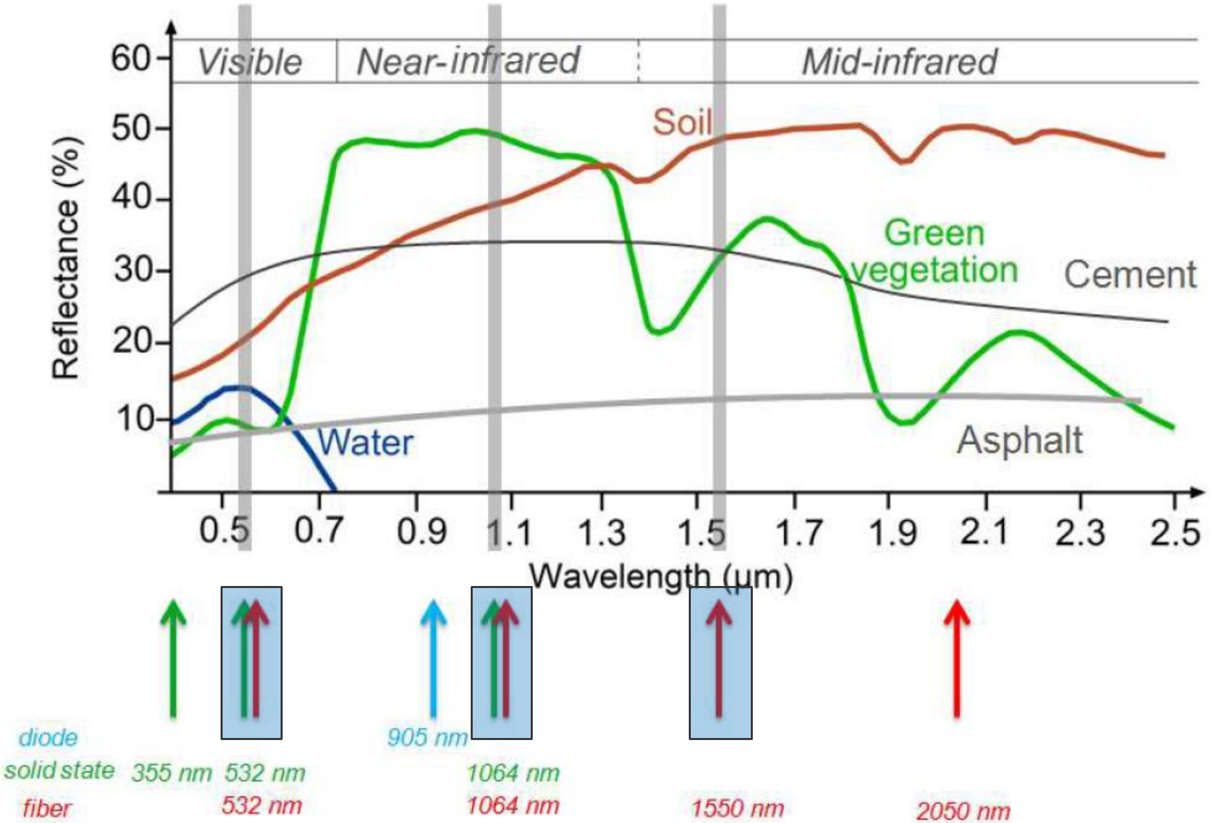
λ=1550 nm

1550nm

Calibrated multispectral image

Source: Briese et al, 2012

Reflectance depending on laser wavelength



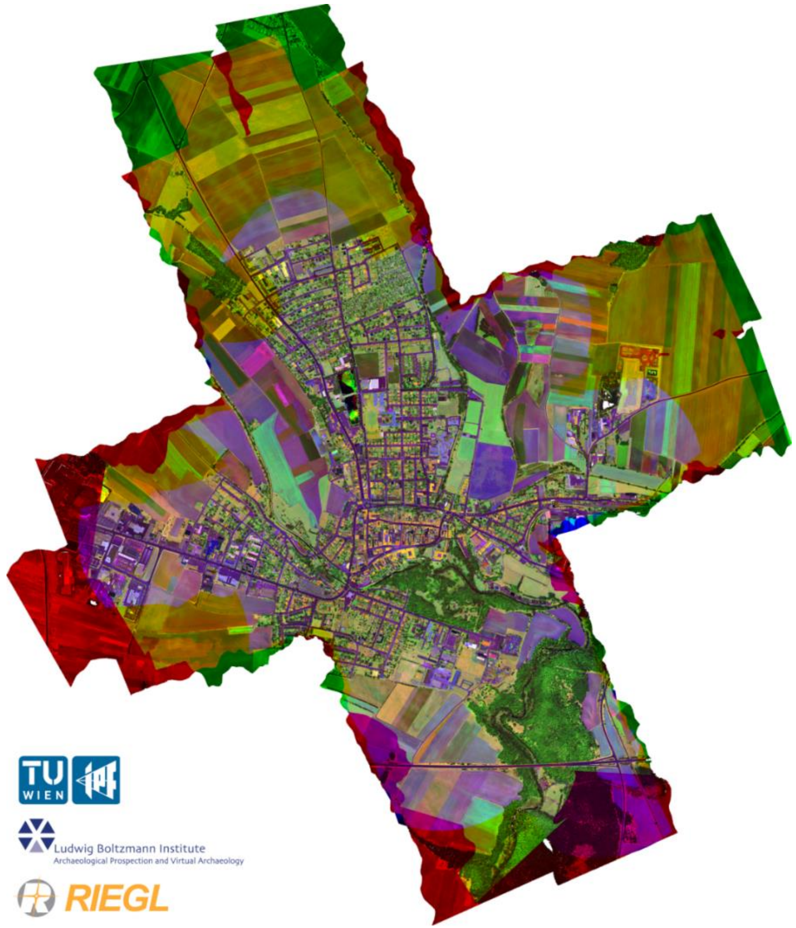
Source: Based on Pfennigbauer and Ullrich (2011), Bakula (2015)

Calibrated multispectral reflectance

RIEGL Q-680i 1550nm

Black to Red

Value	Color
BG	
0	
0.25	64, 0, 0
0.5	128, 0, 0
0.75	191, 0, 0
1.0	255, 0, 0



RIEGL VQ-580 1064nm

Black to Green

Value	Color
BG	
0	
0.25	0, 64, 0
0.5	0, 128, 0
0.75	0, 191, 0
1.0	0, 255, 0

RIEGL VQ-820-G 532nm

Black to Blue

Value	Color
BG	
0	
0.038	0, 0, 64
0.075	0, 0, 128
0.113	0, 0, 191
0.15	0, 0, 255

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FONDAZIONE BRUNO KESSLER
FUTURE BUILT ON KNOWLEDGE

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