

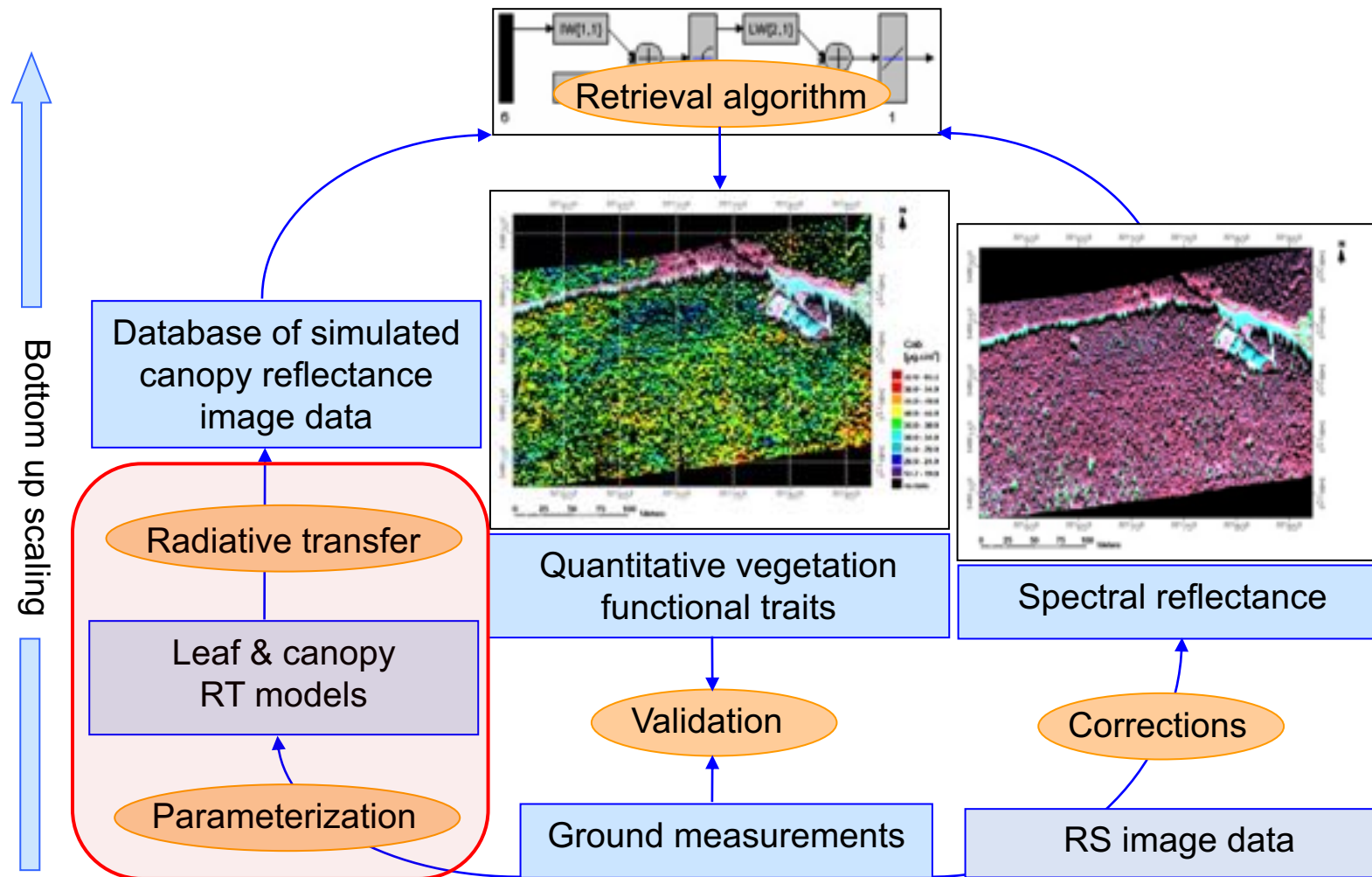
# Mapping of forest biochemical traits from space using 3D radiative transfer modelling: **Advances and challenges**

---

Zbyněk Malenovský<sup>1</sup>, Abdelaziz Kallel<sup>2</sup>, Tiangang Yin<sup>3</sup>, Yingjie Wang<sup>4</sup>, Omar Regaieg<sup>4</sup>, & Jean-Philippe Gastellu-Etchegorry<sup>4</sup>

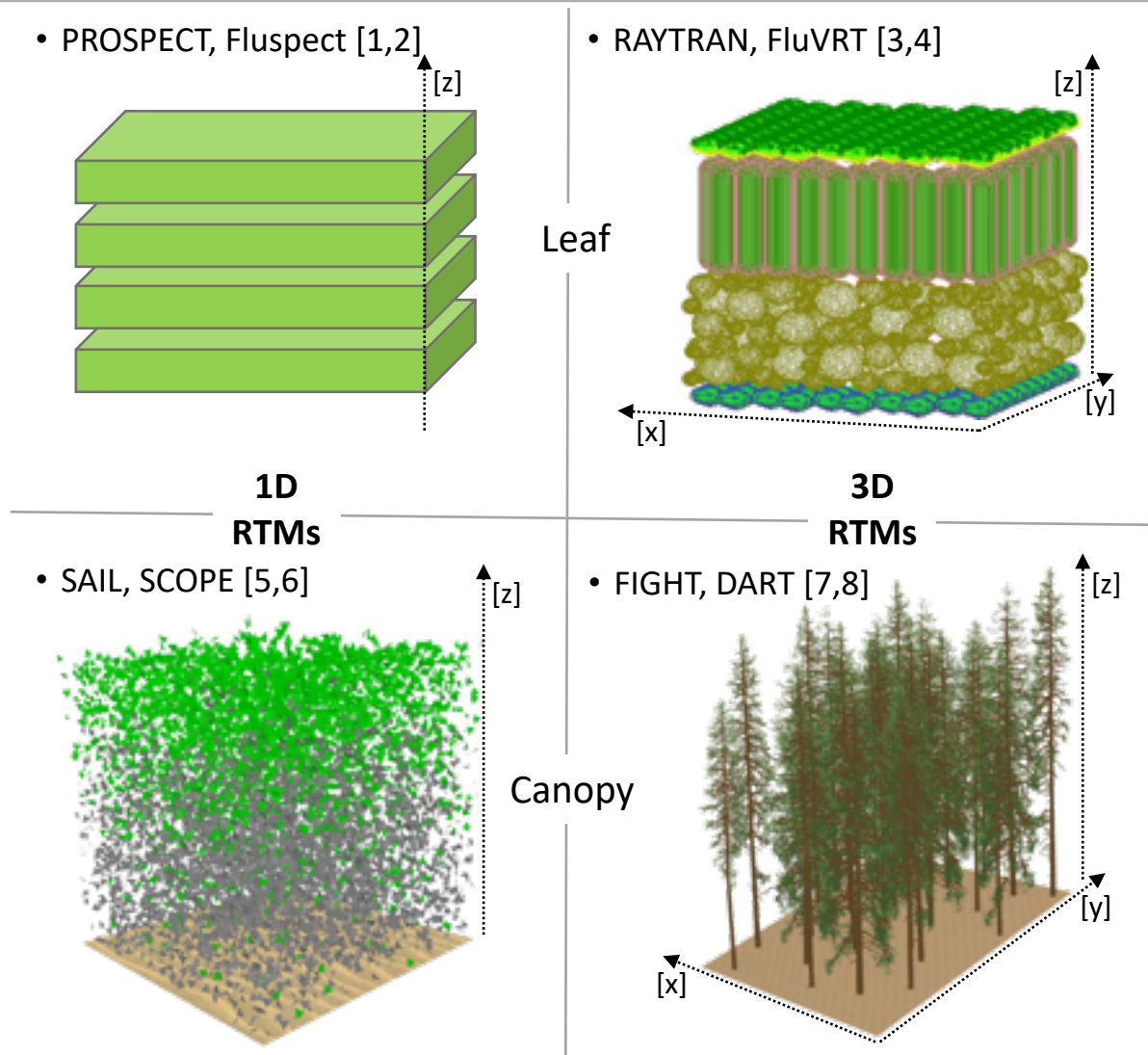
1. Department of Geography, University of Bonn, Germany
2. Centre de Recherche en Numérique de Sfax, Technopole de Sfax, Tunisia
3. Department of Land Surveying and Geo-Informatics, Hong Kong Polytechnic University, China
4. CESBIO - UPS, CNES, CNRS, IRD, INRAE, Université de Toulouse, France

# Hybrid physical data-driven retrieval of canopy traits from a spectral imagery



Malenovský et al., *Journal of Experimental Botany* (2009), <https://doi.org/10.1093/jxb/erp156>

# 1D vs. 3D leaf and canopy radiative transfer models

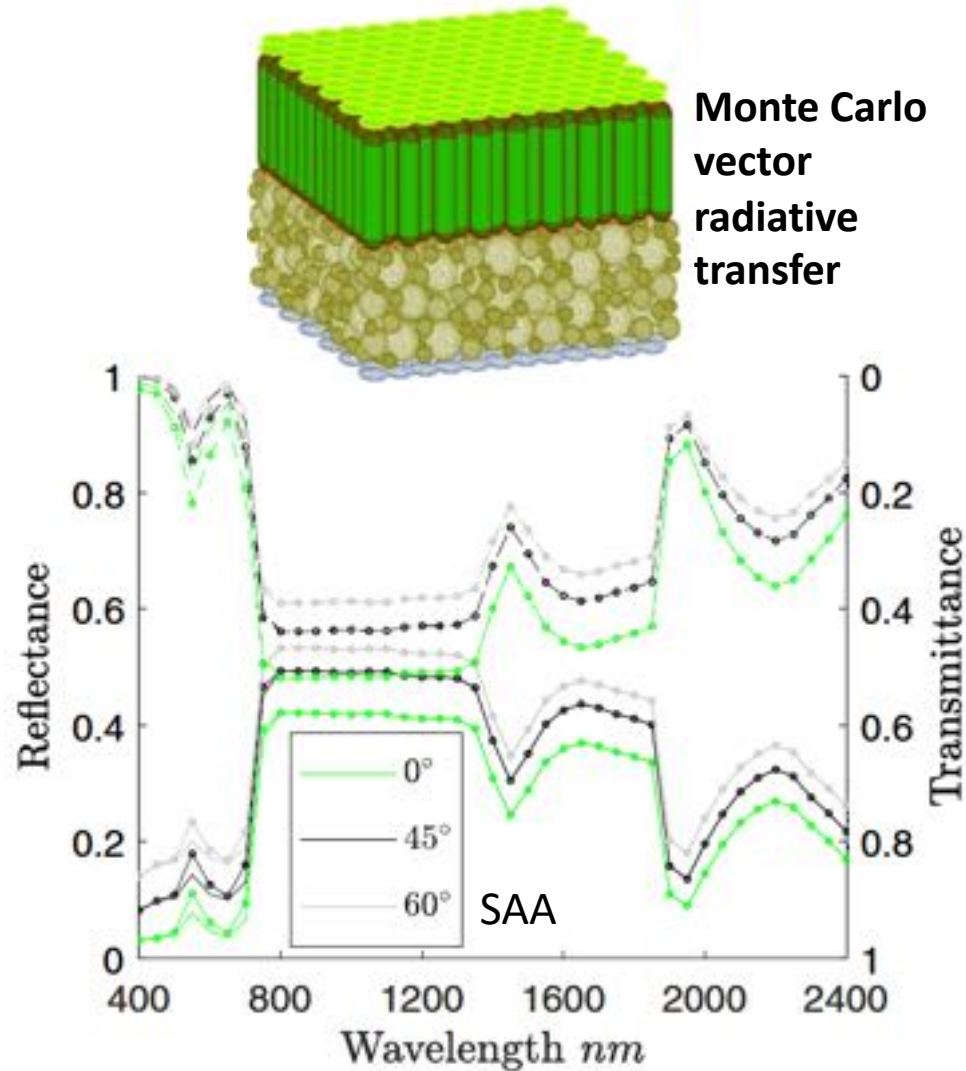


1. Féret et al., 2021
2. Vilfan et al., 2018
3. Govaerts & Verstrate, 1998
4. Kallel, 2018 & 2020
5. Verhoef, 1984
6. Van der Tol et al., 2009
7. North, 1996
8. Gastellu-Etchegorry et al., 2017

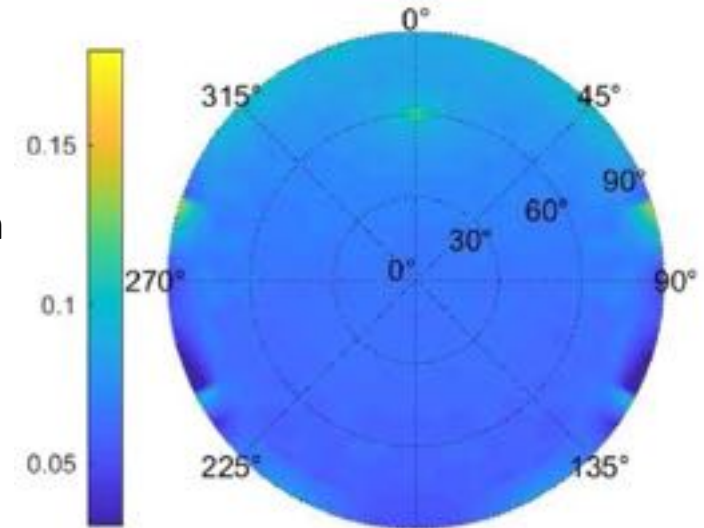
Malenovský et al.,  
*Surveys in Geophysics* (2019)  
<https://doi.org/10.1007/s10712-019-09534-y>

Porcar-Castel, Malenovský et al., *Nature Plants* (2021), <https://doi.org/10.1038/s41477-021-00980-4>

# 3D leaf radiative transfer – Impact of non-Lambertian leaf surface

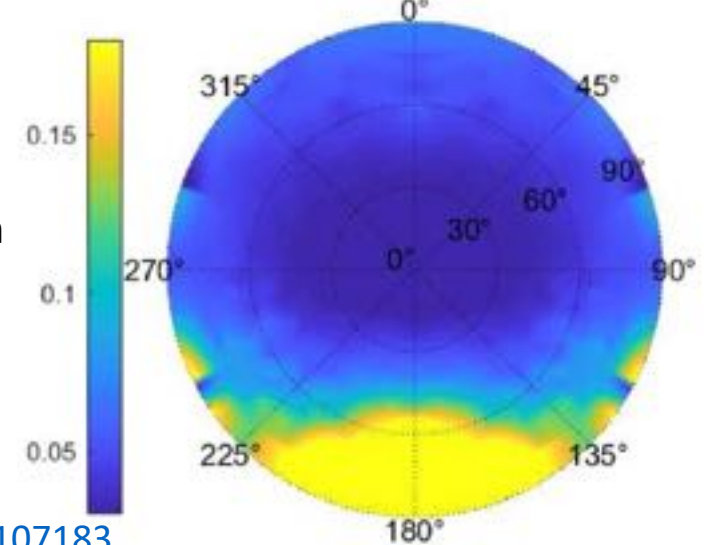


Canopy BRDF with **bi-Lambertian** scattering leaves



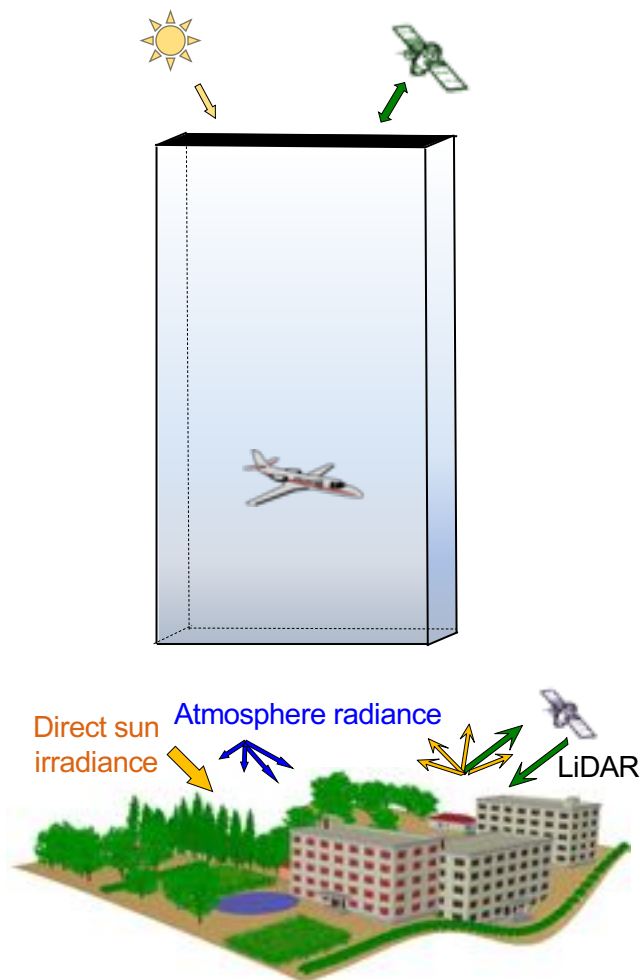
$\theta_s = 60^\circ$ , LAI = 3,  $\lambda = 650\text{ nm}$ , hotspot = 0.05 m, LAD~planophile

Canopy BRDF with **bidirectionally** scattering leaves

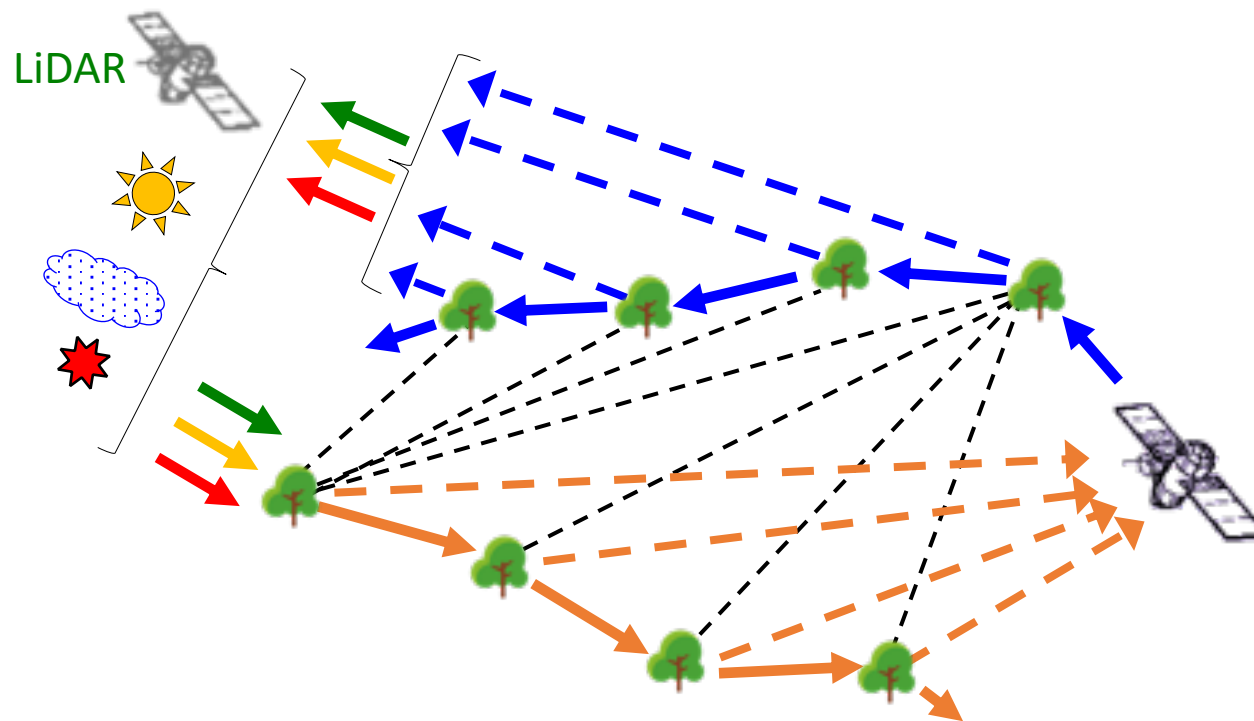


Kallel, *J. Quant. Spectr. & Rad. Trans.* (2020), <https://doi.org/10.1016/j.jqsrt.2020.107183>

# Bidirectional Monte Carlo vectorized path tracing (physical rendering)



- **Mitsuba 2** | ERADIATE: <https://www.eradiate.eu/>  
<https://rgl.epfl.ch/publications/NimierDavidVicini2019Mitsuba2>
- **LuxCoreRender** | DART-Lux: <https://dart.omp.eu>  
3D scene: **no voxels**, turbid/fluid volumes, facets with texture  
RT modelling: computation & RAM-usage reduced up to 100 times!



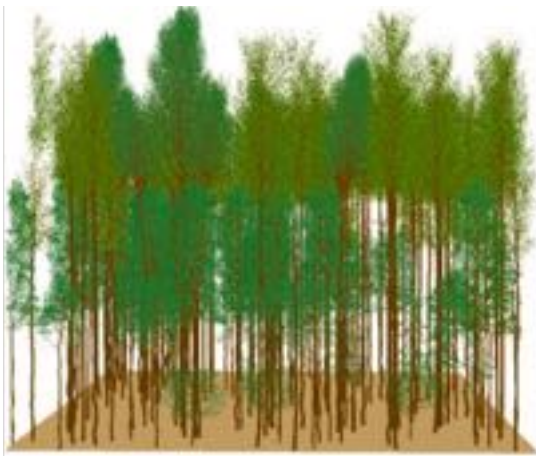
Wang et al., *Remote Sens. Environ.*, (2022)  
<https://doi.org/10.1016/j.rse.2022.112973>



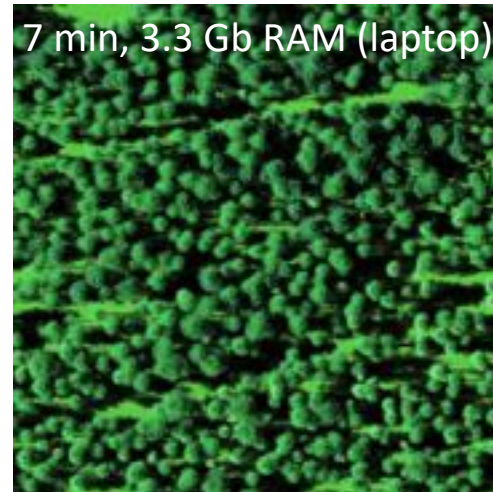
# DART-Lux simulated BRF of 3D forest stands in RAMI-V

3D forest representation

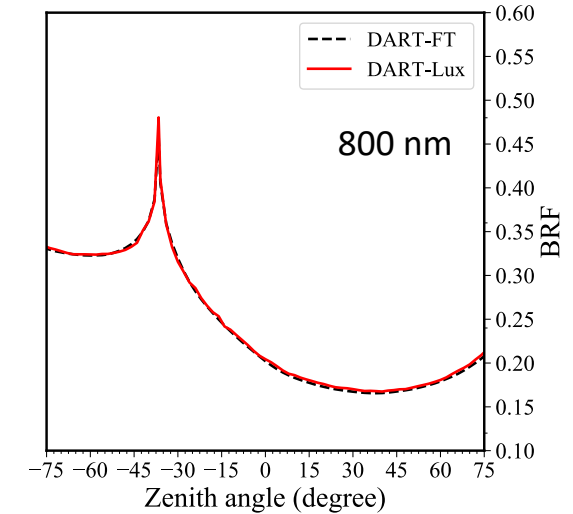
**Järvselja forest** – 1029 trees (465 birch, 196 alder, 185 aspen, 78 linden, 39 spruce, 46 ash, and maple)



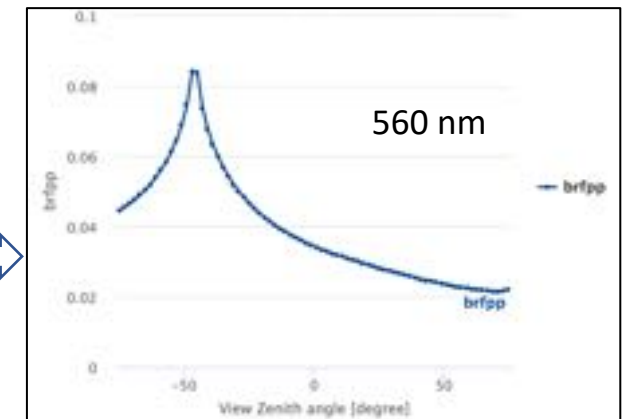
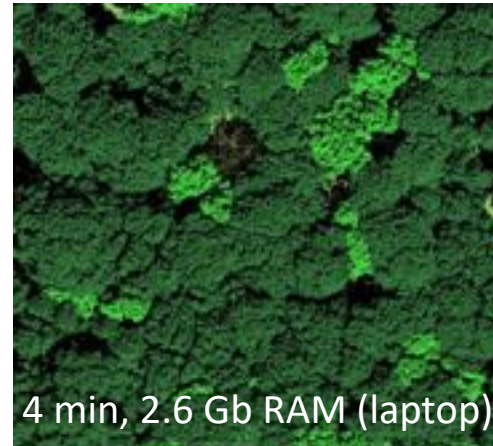
Nadir natural colour image



Solar principal plane BRF



**Wytham Woods** – 550 trees (362 sycamores, 51 ash, 33 hazel, 22 English oaks, 16 hawthorn, 2 maples, 34?, and 30†)

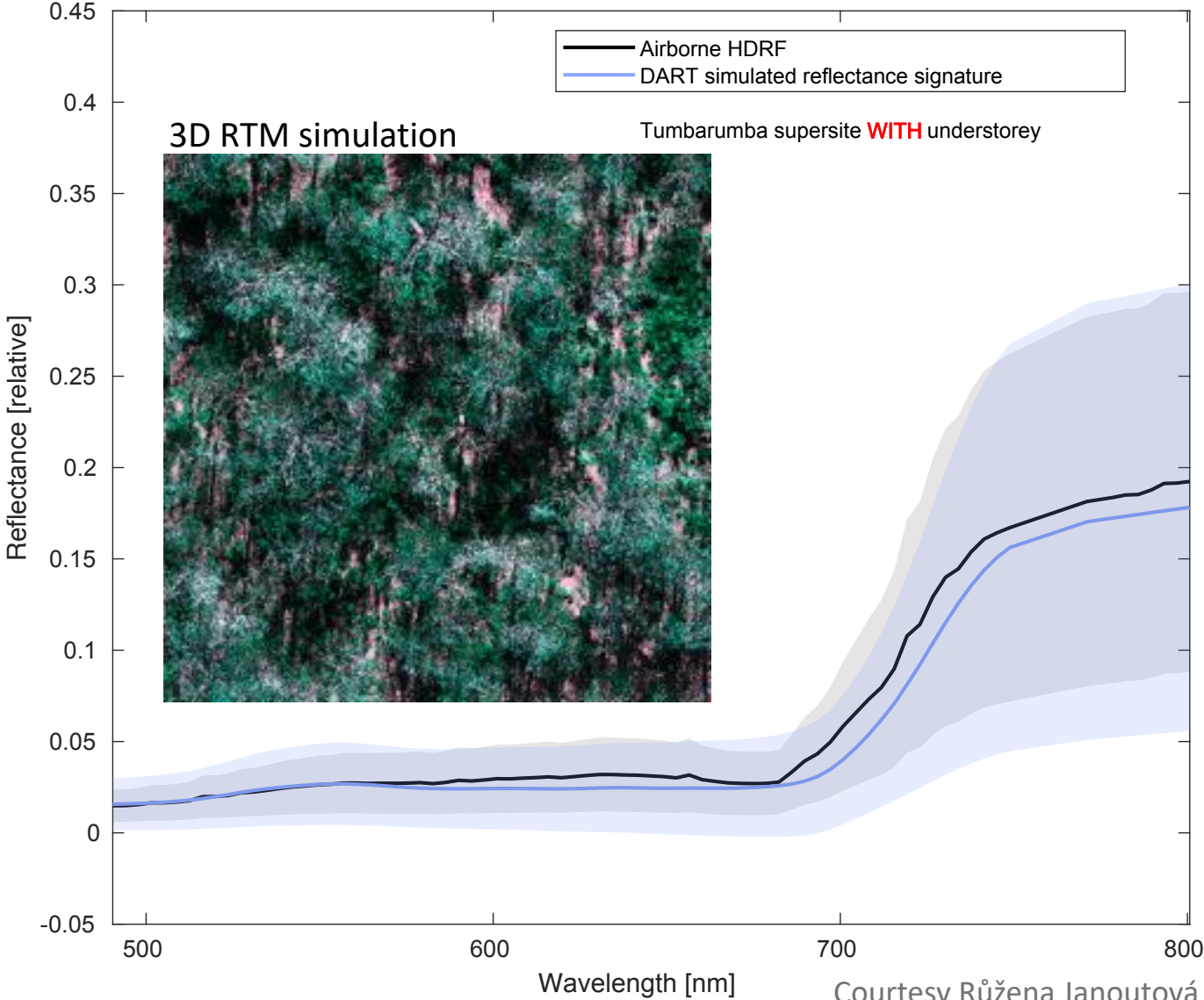
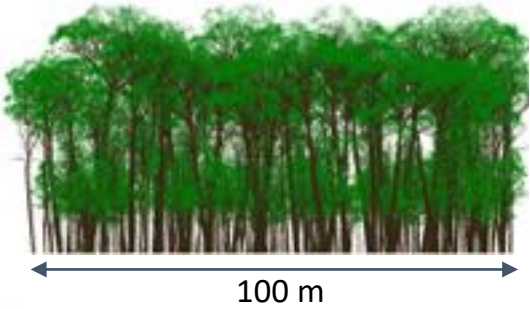
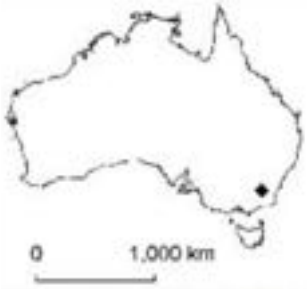


# 3D forest canopy radiative transfer – Impact of discrete canopy layers

## Tumbarumba

TERN forest monitoring supersite

Airborne (drone) acquisition



Courtesy Růžena Janoutová



# DART-Lux: Example of a high-resolution large scene simulation



Satellite image (Sept. 2018)



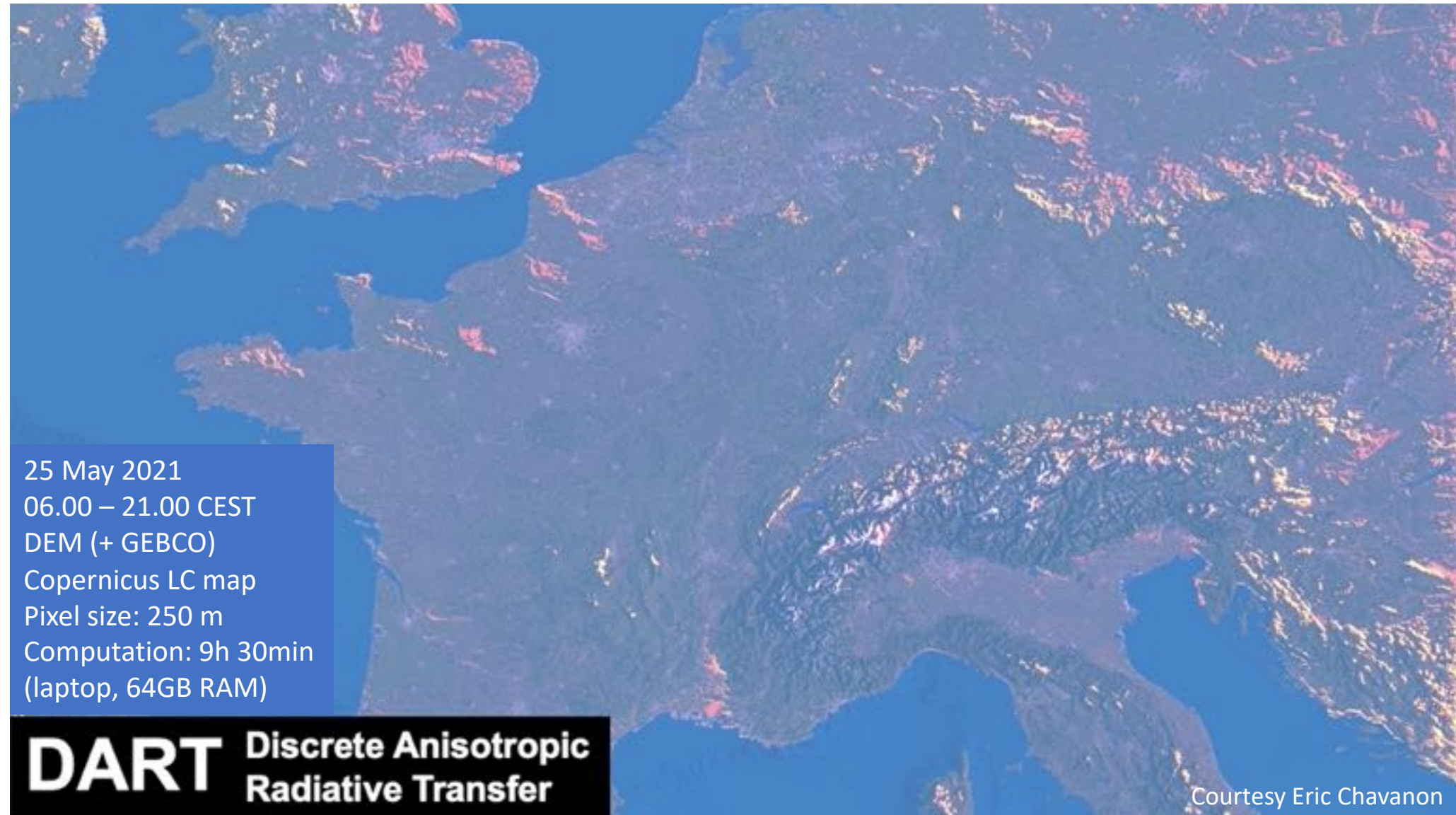
DART simulation

- Plantations & vineyards (Ripperdan, California), ESA project COPA2
- Exact 3D geometry of individual plants
- Spatial distribution based on high resolution satellite image

Courtesy Nicolas Lauret



# DART-Lux: Example of a diurnal simulation on a continental scale



# Challenges in 3D radiative transfer modelling of forests

## Leaf level

- Calibration of 3D leaf model optical parameters, e.g.:
  - refractive indices for leaf tissues,
  - specific absorption coefficients of leaf biochemical constituents.
- Library of species-specific 3D leaf representations (similar to spectral libraries).
- Validation of 3D leaf model simulations against multi-angular leaf optical measurements (leaf goniometer).

## Canopy level

- Database of 3D virtual forest architecture:
  - airborne laser scanning forest reconstruction,
  - process-based forest growth models.
- Multisensory parametrization of forest functional types, e.g.:
  - forest structure (e.g., canopy closure, height, LAI) & topography (DEM),
  - forest phenology driven biochemical parametrization.
- Hardware-GPU accelerated real-time path tracing.

*Questions?*

---

[zbynek.malenovsky@gmail.com](mailto:zbynek.malenovsky@gmail.com)

2<sup>nd</sup> Workshop on International Cooperation in Spaceborne Imaging Spectroscopy  
Frascati, Italy | 19 – 21 October 2022