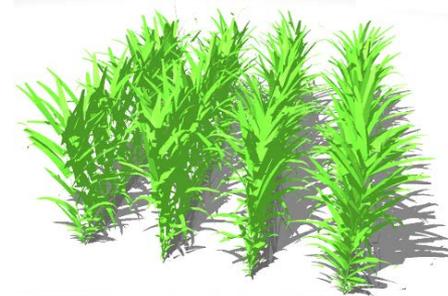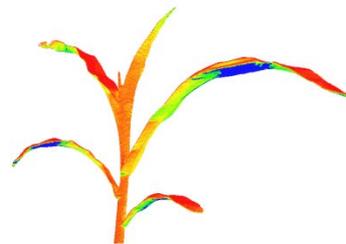# Image workflows for high throughput phenotyping platforms

Simon Artzet, Nicolas Brichet, Llorenc Cabrera, Tsu-Wei Chen, Jerome Chopard, Michael Mielewczik , Christian Fournier, Christophe Pradal
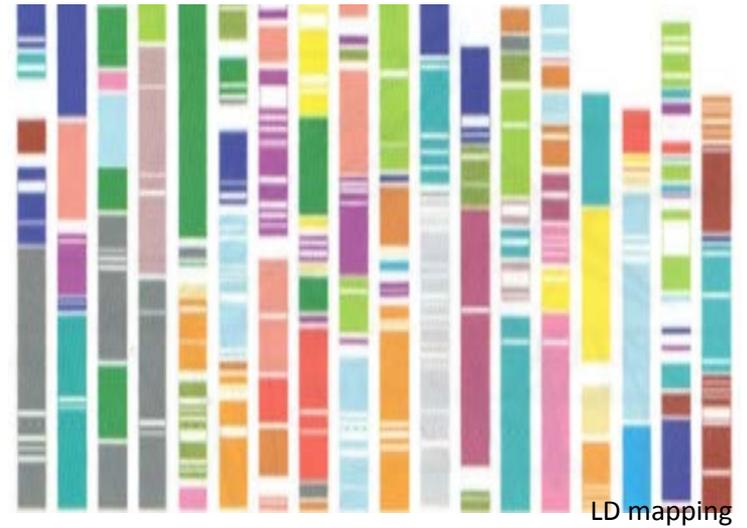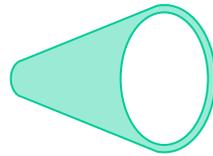
Phenotyping bottleneck

Phenomics   Genomics

High Throughput Phenotyping
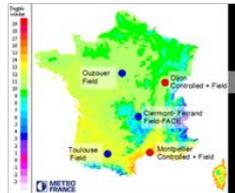
International development

Phenome infrastructure

Montpellier Plant Phenotyping Plateforms

The Plant Accelerator , Adelaide, AUSTRALIA

Pioneer platform, Des Moines, USA

Phenome infrastructure

PHENOPSIS, Montpellier

M₃P

PHENOARCH, Montpellier, FRANCE

Phenoarch

Imaging unit
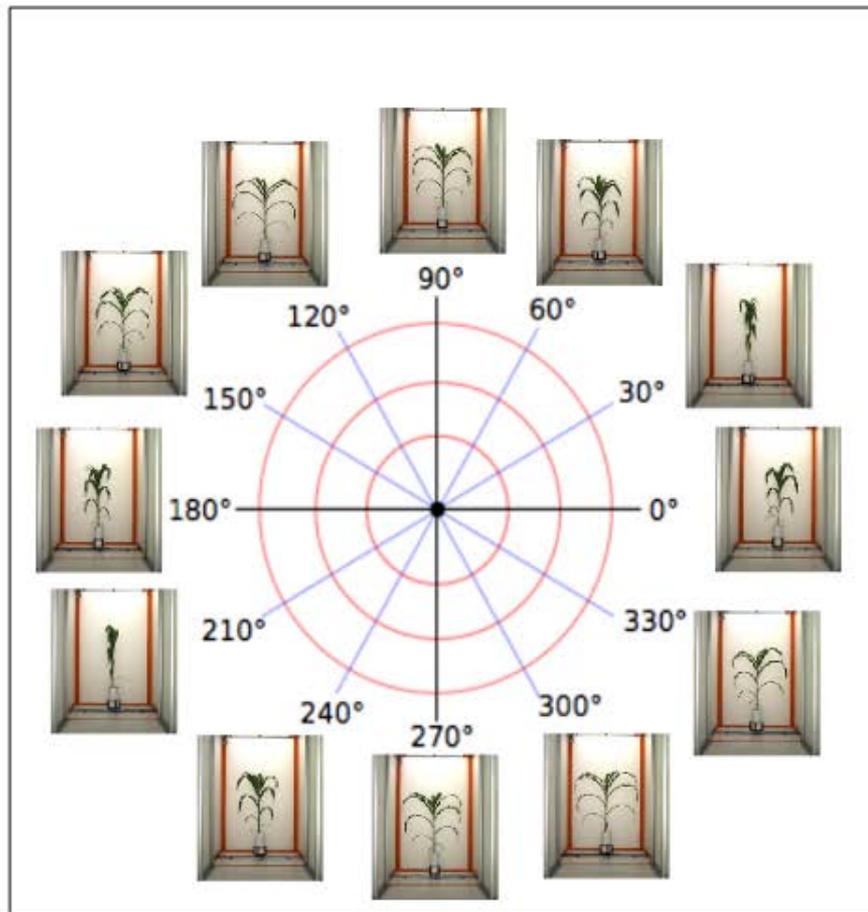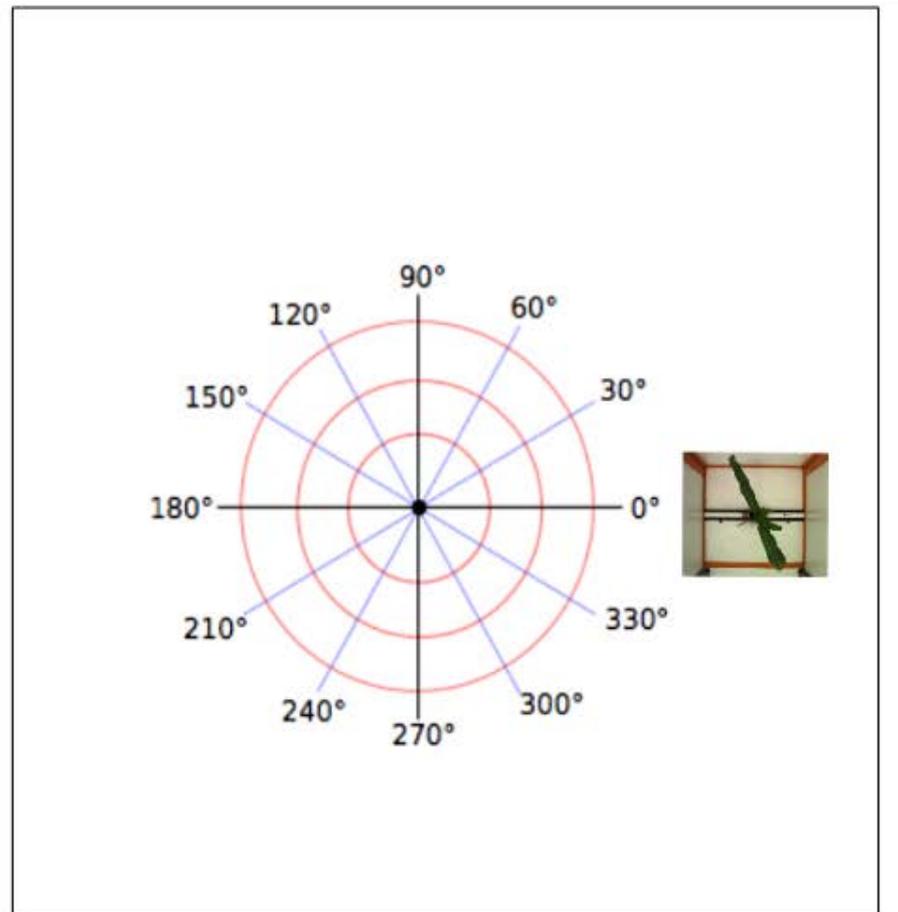

Conveyor belts

Watering stations

Multiview imaging

Side Camera

Top Camera

Monitoring of plant development

Typical experiment:

- 1680 plants

- 40 time point per plant

- 13 views per plant per time point

- ~50 Go per time point
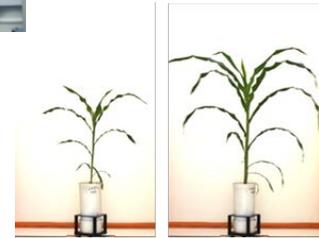
Software development

Infraphenogrid

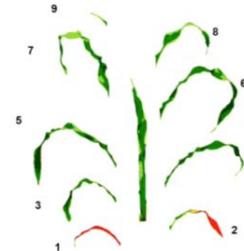- Scientific workflow for reproducible analysis and efficient computing on the grid
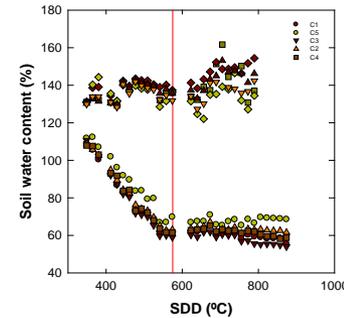
Phenomenal

- Algorithm and Library for automated (high throughput) image analysis in plant phenotyping

Phenoarch

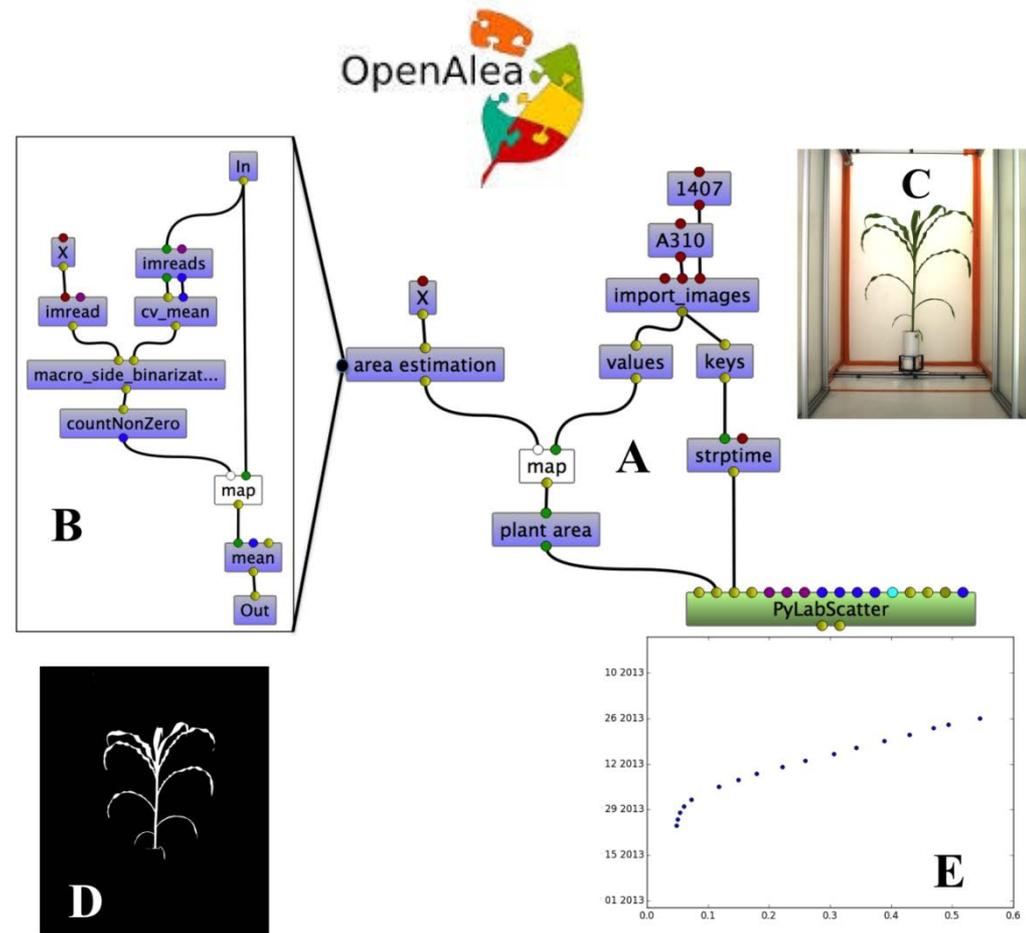- Runnable workflow collection of applications for PhenoArch platform

Infraphenogrid: workflows

OpenAlea / python based

Python Scientific libraries
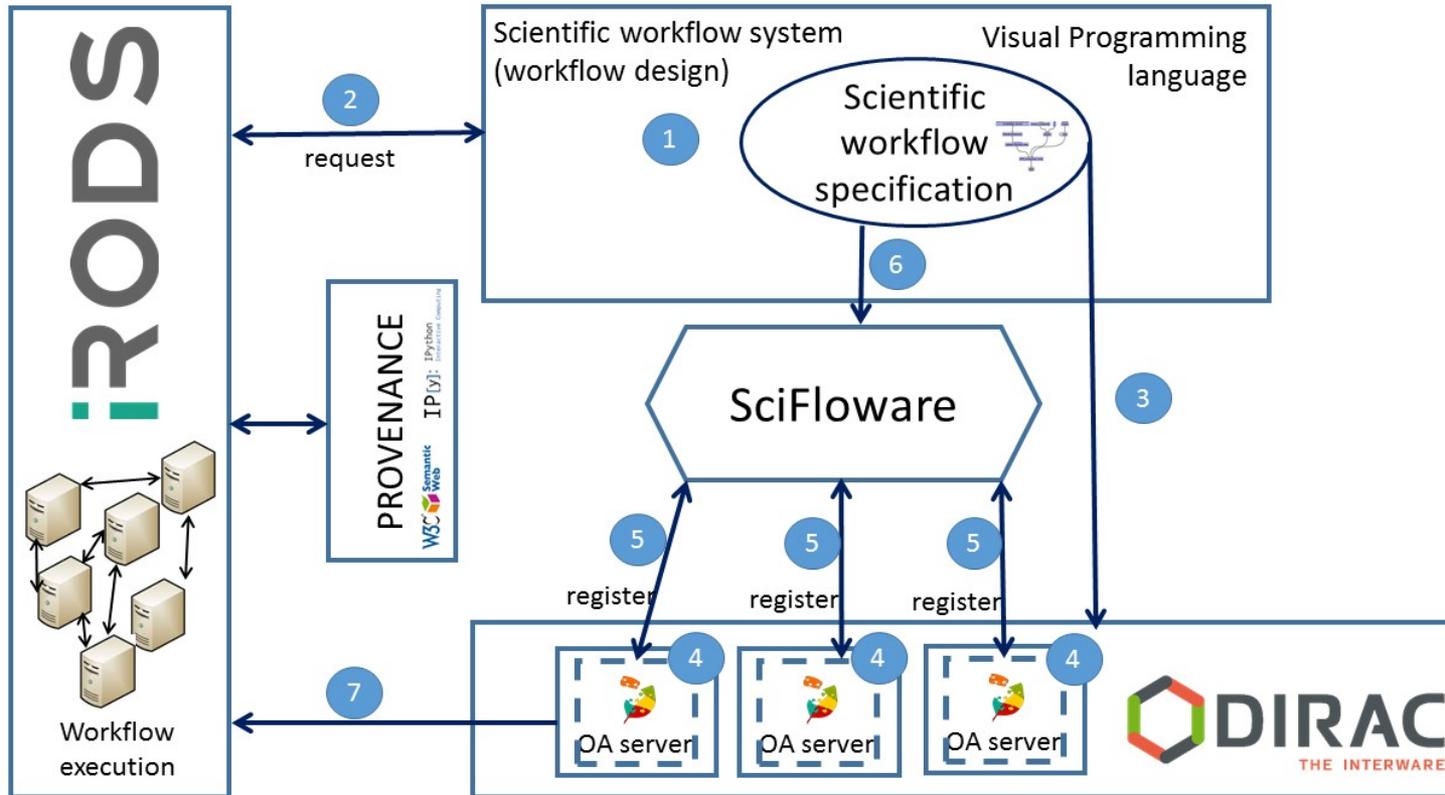**(OpenCV, scikit image, scikit learn, …)**

OpenAlea Models (light distribution, plant structural models)

Reproducibility & automated provenance recording

Pradal C, Artzet S, Chopard J, Dupuis D, Fournier C, et al. (2016) InfraPhenoGrid: A scientific workfow infrastructure for plant phenomics on the Grid. Future Generation Computer Systems (in press).
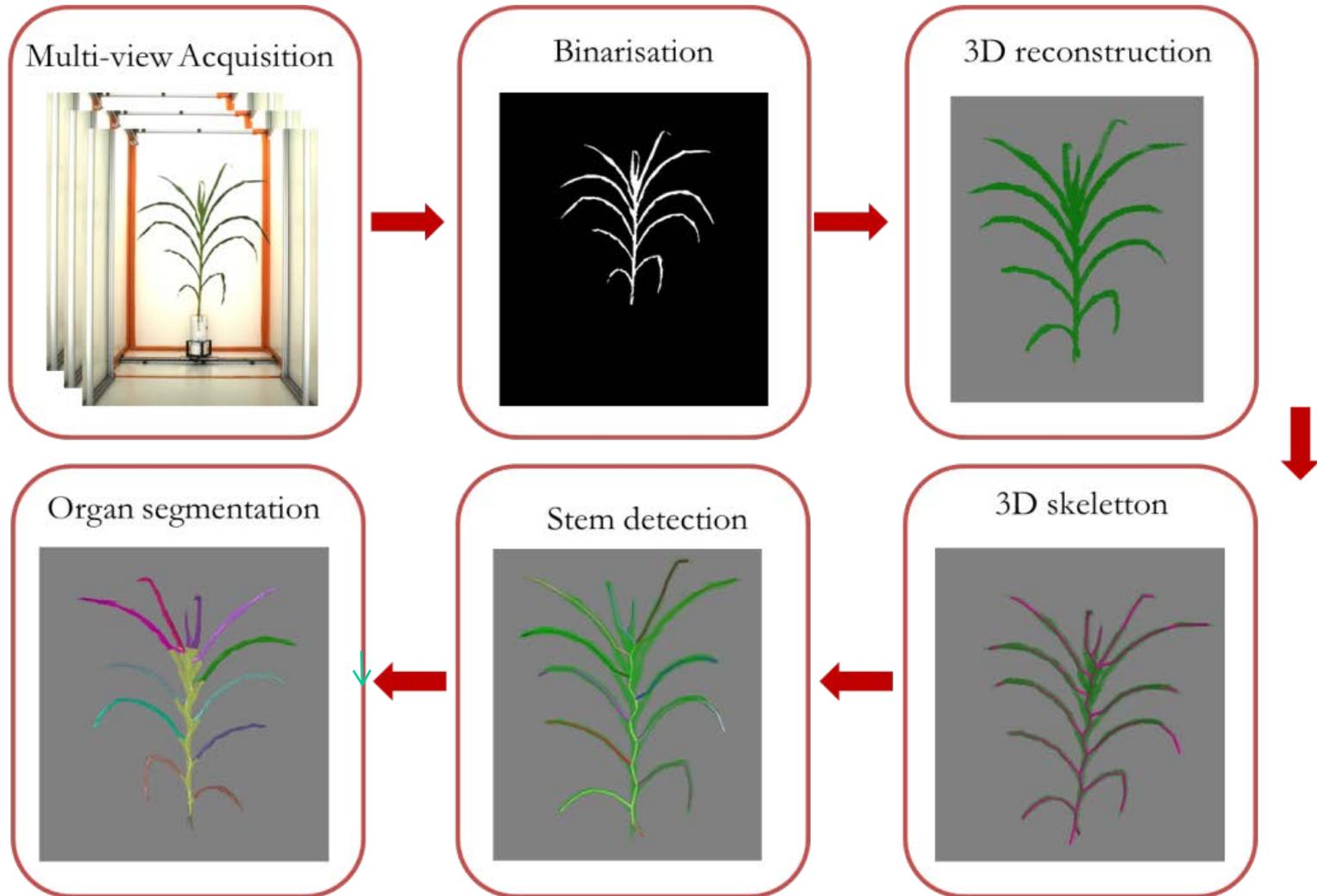
Infraphenogrid: infrastructure

Pradal C, Artzet S, Chopard J, Dupuis D, Fournier C, et al. (2016) InfraPhenoGrid: A scientific workfow infrastructure for plant phenomics on the Grid. Future Generation Computer Systems (in press).

Phenomenal

Multi-view Acquisition → Binarisation → 3D reconstruction → 3D skeletton → Stem detection → Organ segmentation

Artzet et al. (unpublished)

Phenomenal: binarization

Algorithms :
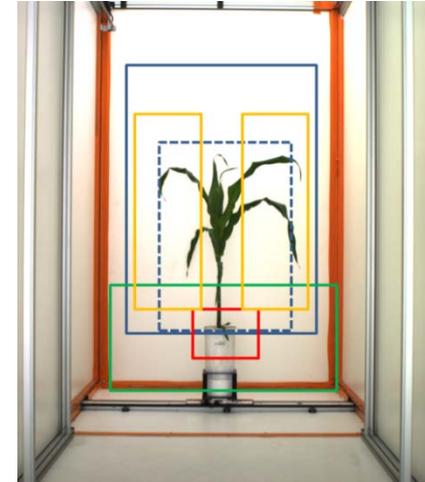
- Mask / multiple ROI segmentation

- 'Mean shift'

- Threshold HSV

    Hue Saturation Value

- Adaptive Threshold :

    Mean :

    T(x,y) = Mean of the blockSize * blockSize
        neighborhood of (x, y)

    Gaussian :

    T(x,y) = Weighted sum (cross-correlation with a
        Gaussian window) of the blockSize *
        blockSize neighborhood of (x, y)
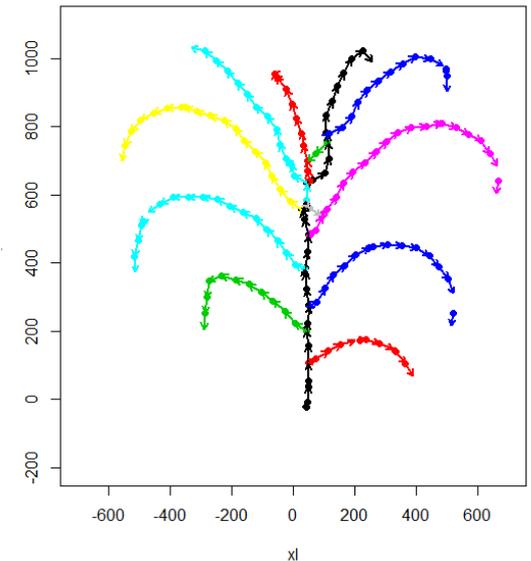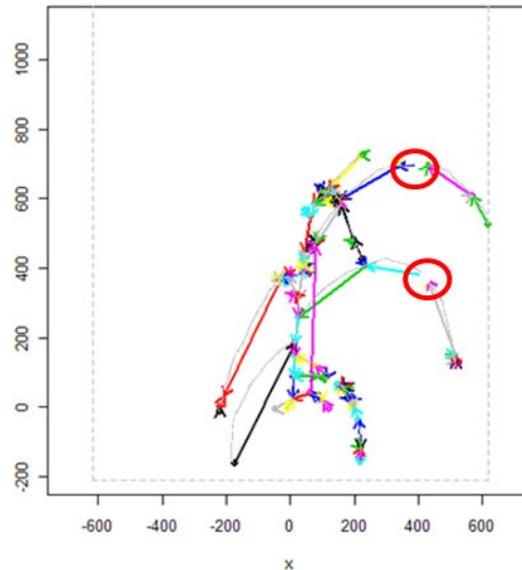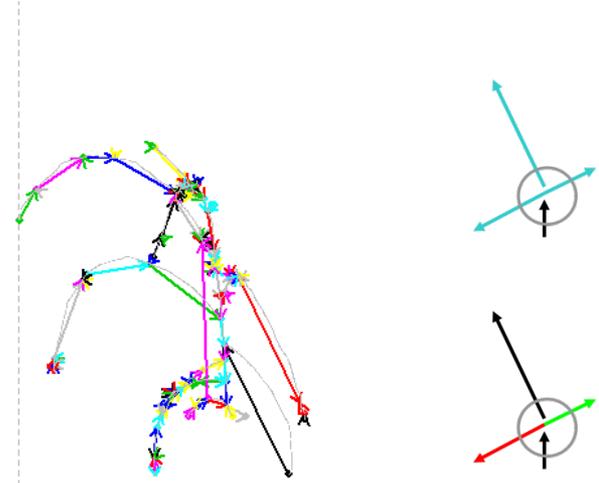
Phenomenal: 2D Segmentation

2D Skeleton :

- Erode / Dilate
- Thinning

Graph transform

Polyline analysis
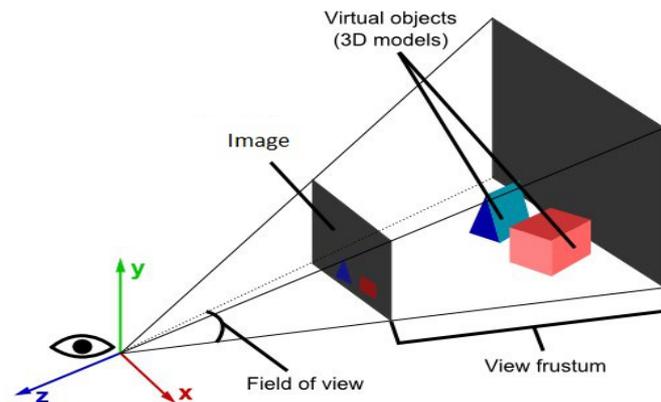
- Mean leaf angle
- traversal

Gap detection

- .

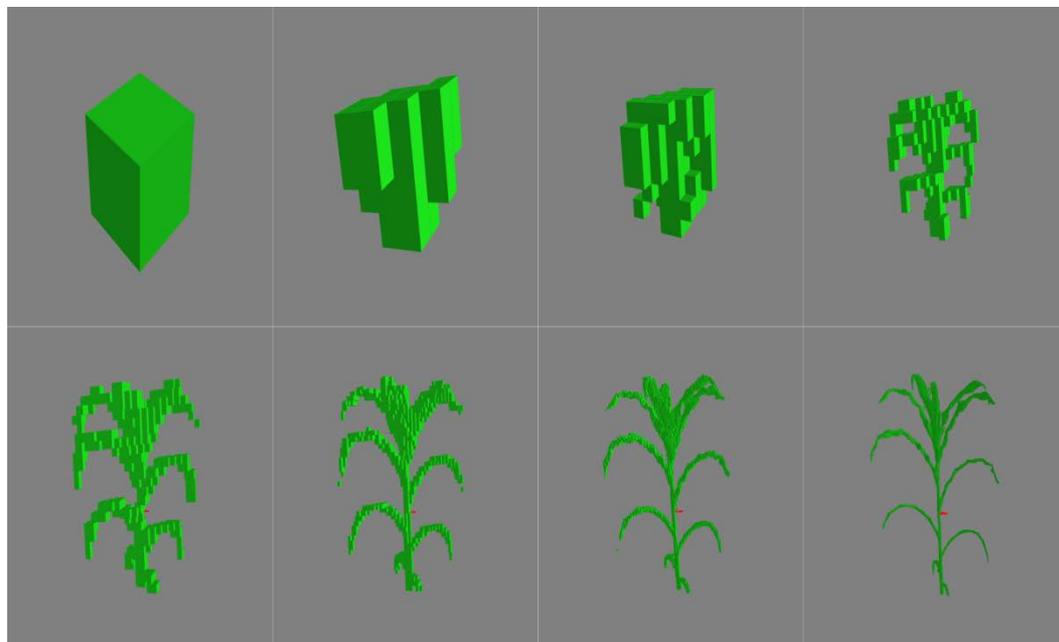# Camera Calibration & multiview reconstruction

Calibration of the camera

- OpenCV chessboard detection + fiting of moving pinhole camera along a rotation axis
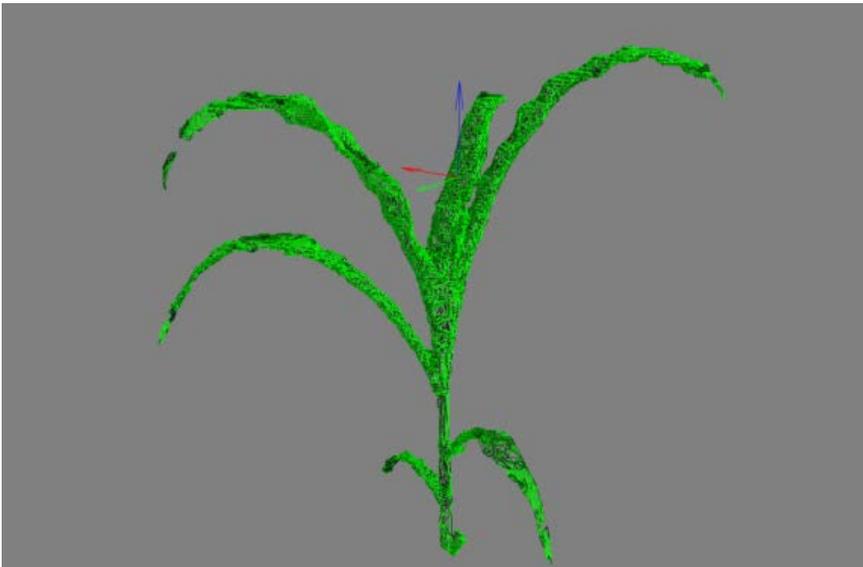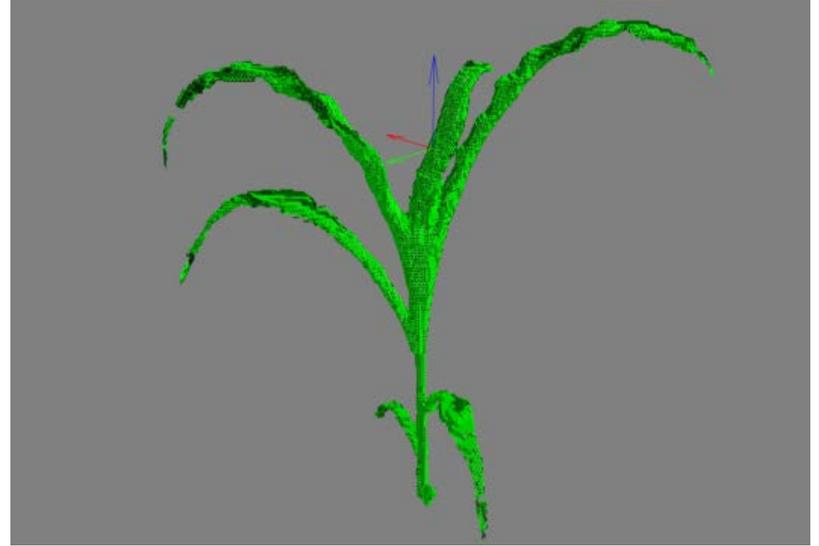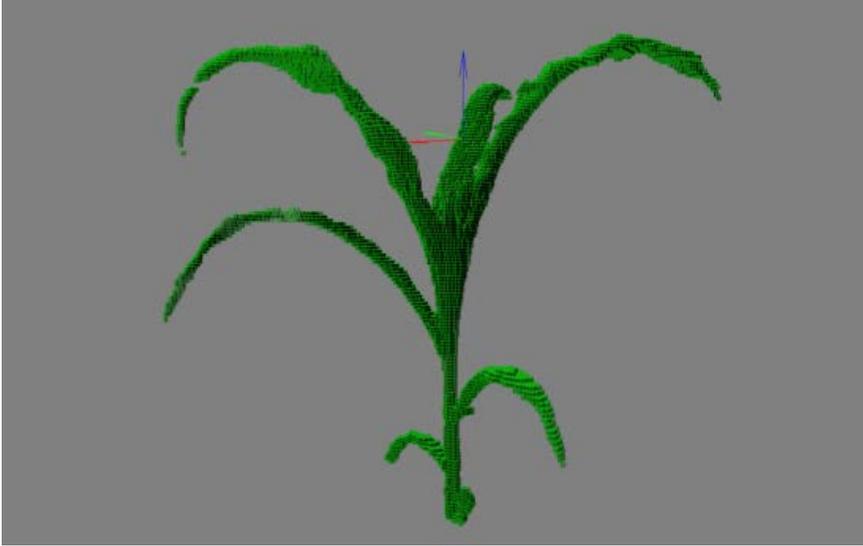
- Projection function

Iterative space carving for 3D reconstruction

- Defines a voxel of the size of the scene.

- Iterative octree subdivision

- Keep voxel projected on segmented object

Surface reconstruction & Mesh decimation

3D Skeleton

3D thinning

A 3D 6-subiteration thinning algorithm for extracting medial lines of Kalman Palagyi and Attila Kuba

Space colonization

Implementation of Xu et al. 07 method for main branching system (space colonisation clustering)

Longest shortest path

voxel cloud graph shortest path transform (networkx) + interative simplification with planar intersection along longest paths
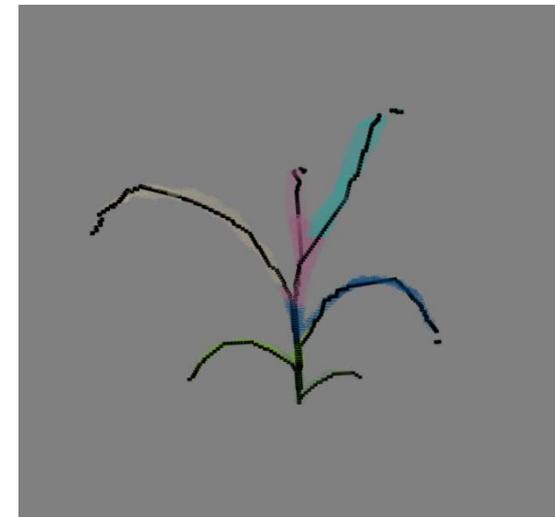
3D Segmentation + data extraction

Stem detection

Longest path

Planar intersection along longest
path + analysis of radius + pic
detection

Leaf detection

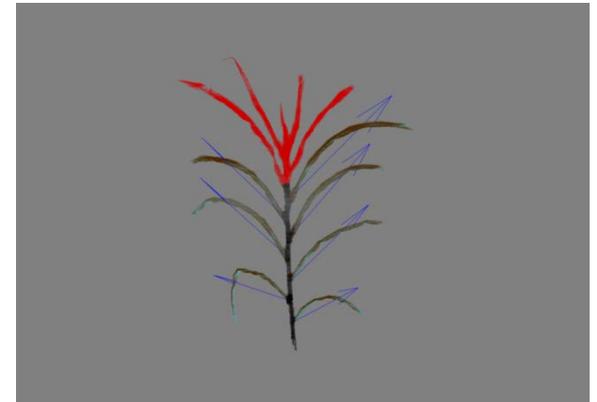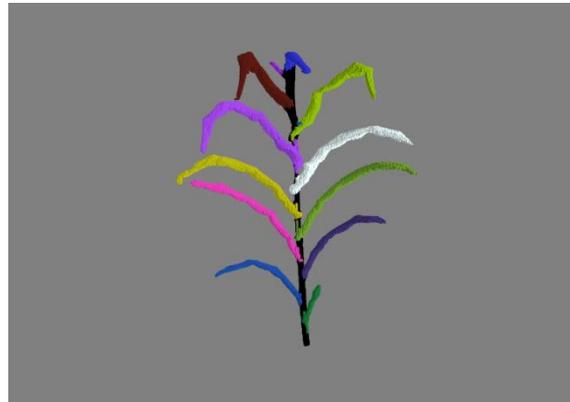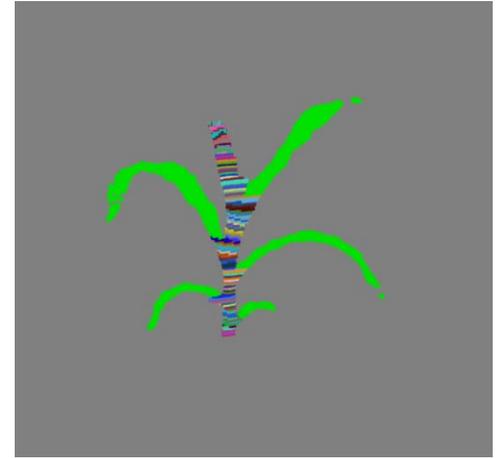Stem removal + path labelling among
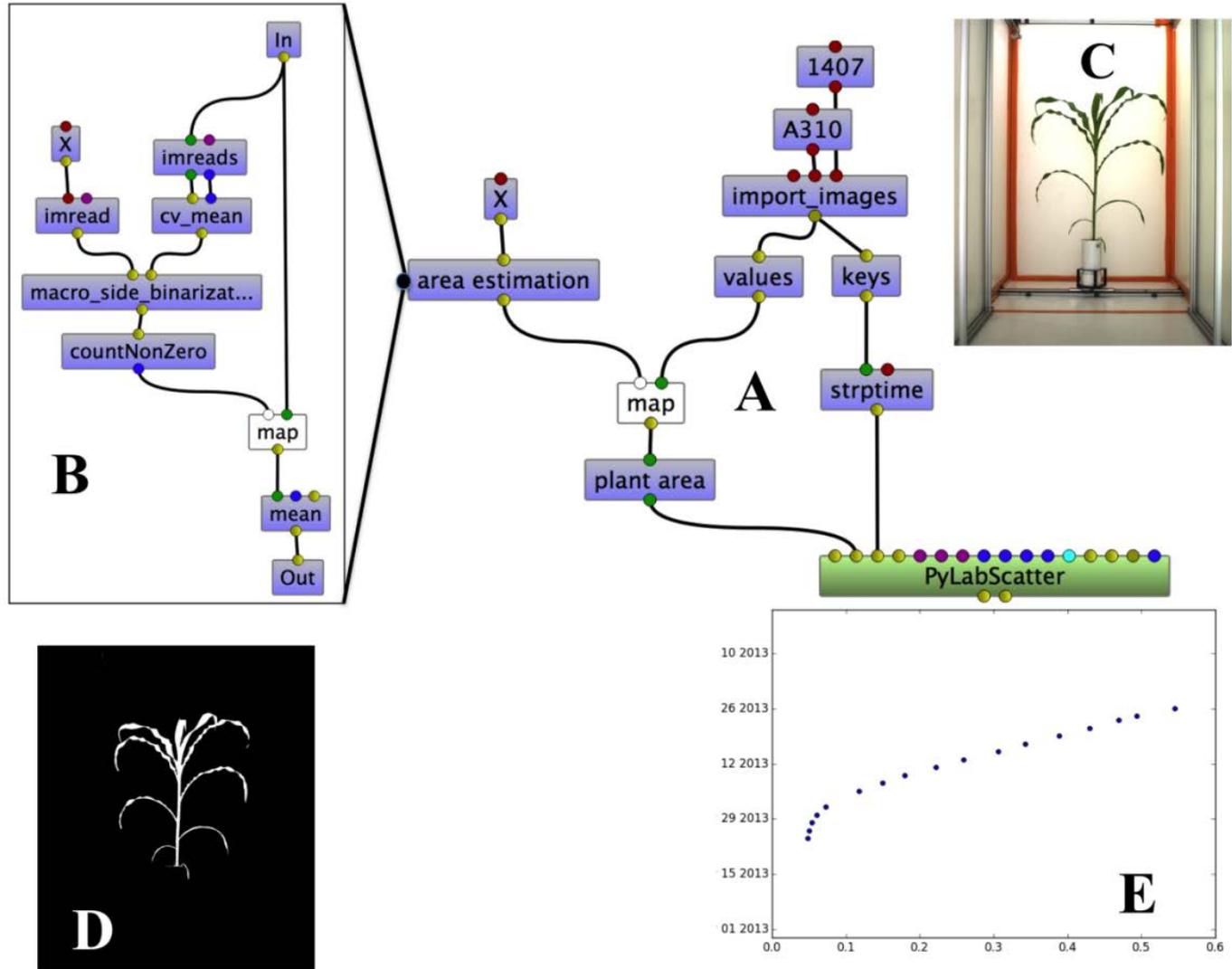connex voxels

Data extraction

Path lengths

Radius along path

Path polylines

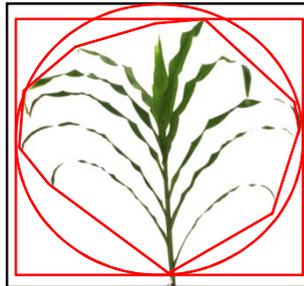Azimuth...

Applications: Phenoarch

Whole Plant growth analysis
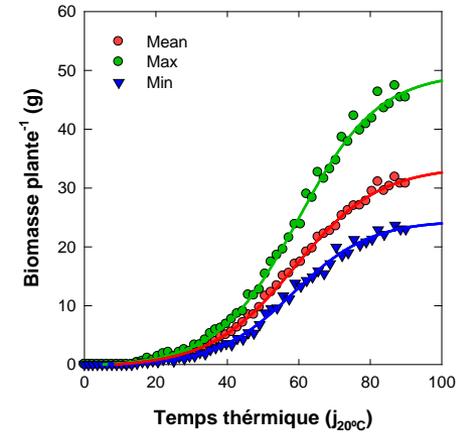

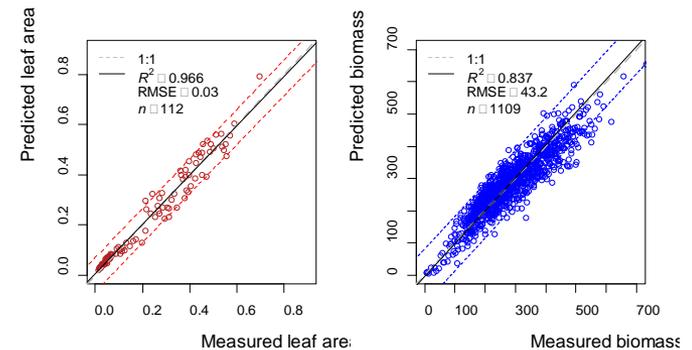**RGB image** **Green pixel separation** **Image descriptors**

Combination of 0°, 90° and Top view:
Projected Leaf Area, Convex Hull Area, Minimum Enclosing Circle, Minimum Enclosing Rectangle, etc…

Multiple Linear Regression with Measured Plant Biomass and leaf area

Estimation of Plant Growth over time

Biomasse plante^{-1} (g)

- Mean
- Max
- Min

Temps thermique (j$_{20°C}$)

Predicted leaf area

1:1
R^2 □ 0.966
RMSE □ 0.03
n □ 112

Measured leaf area

Predicted biomass

1:1
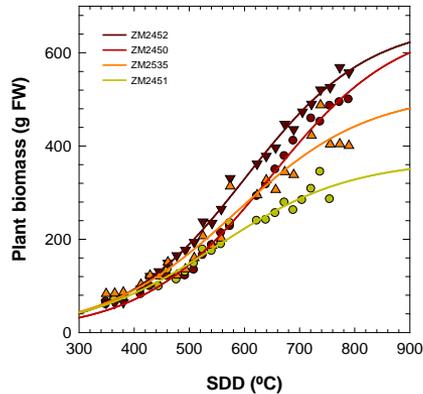R^2 □ 0.837
RMSE □ 43.2
n □ 1109
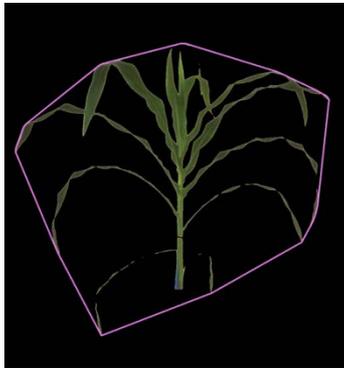
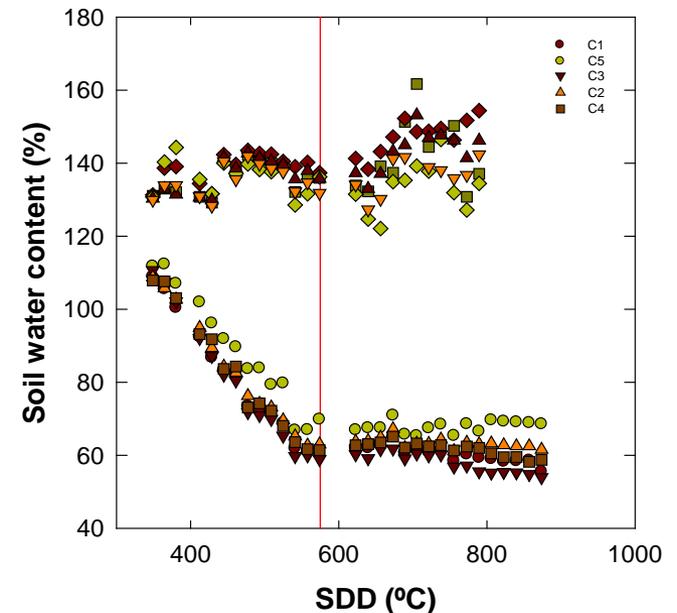Measured biomass

Control of irrigation

Weigth plants + pots
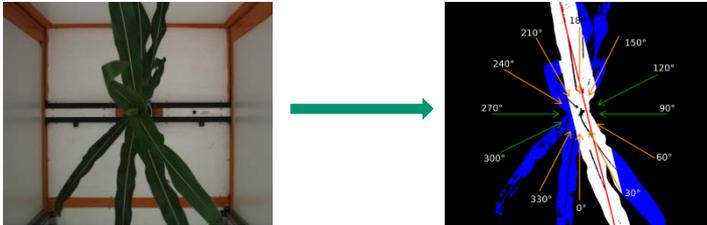

Irrigate for constant SWC
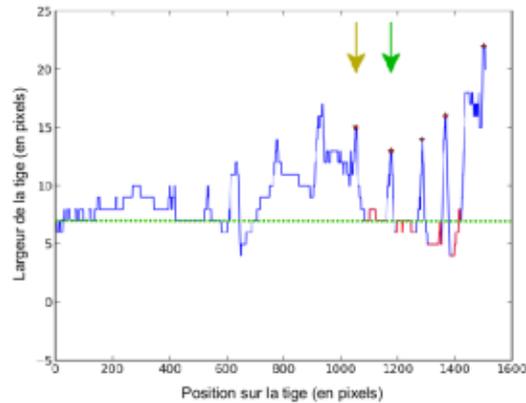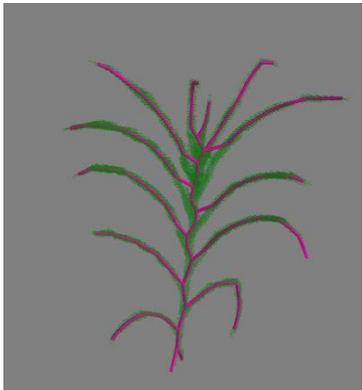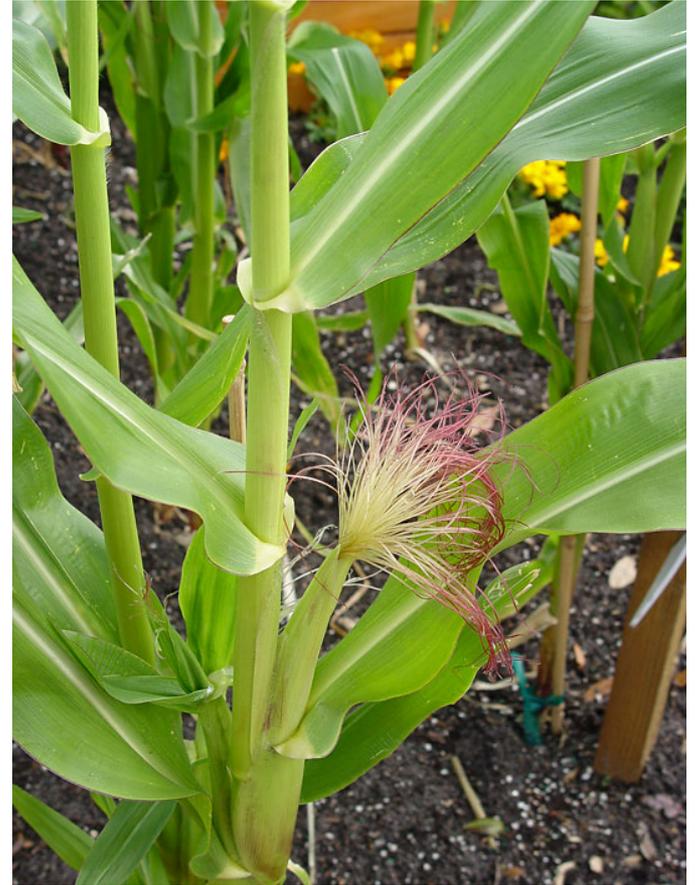

Estimate biomass

Predicting ear position for triggering ear measurements with moving camera

Top view image analysis

Find best side images using top

Stem diameter analysis along longest skeleton path

Simulation of the greenhouse and ist ligth environment

PHENOARCH Expts

Plant Images

Binarization

3D-Reconstruction

Experiment: ZB14
Genotypes: 330 maize lines
Number of repetition: 5
Treatment: non
Row distance: 40 cm
Plant distance 20 cm

R1 R2 R3 R4 R5

■ genotype A ■ genotype B

Leaf area and biomass

RATP light model

Sinoquet *et al*., 2001

3D virtual canopy

Canopy light interception
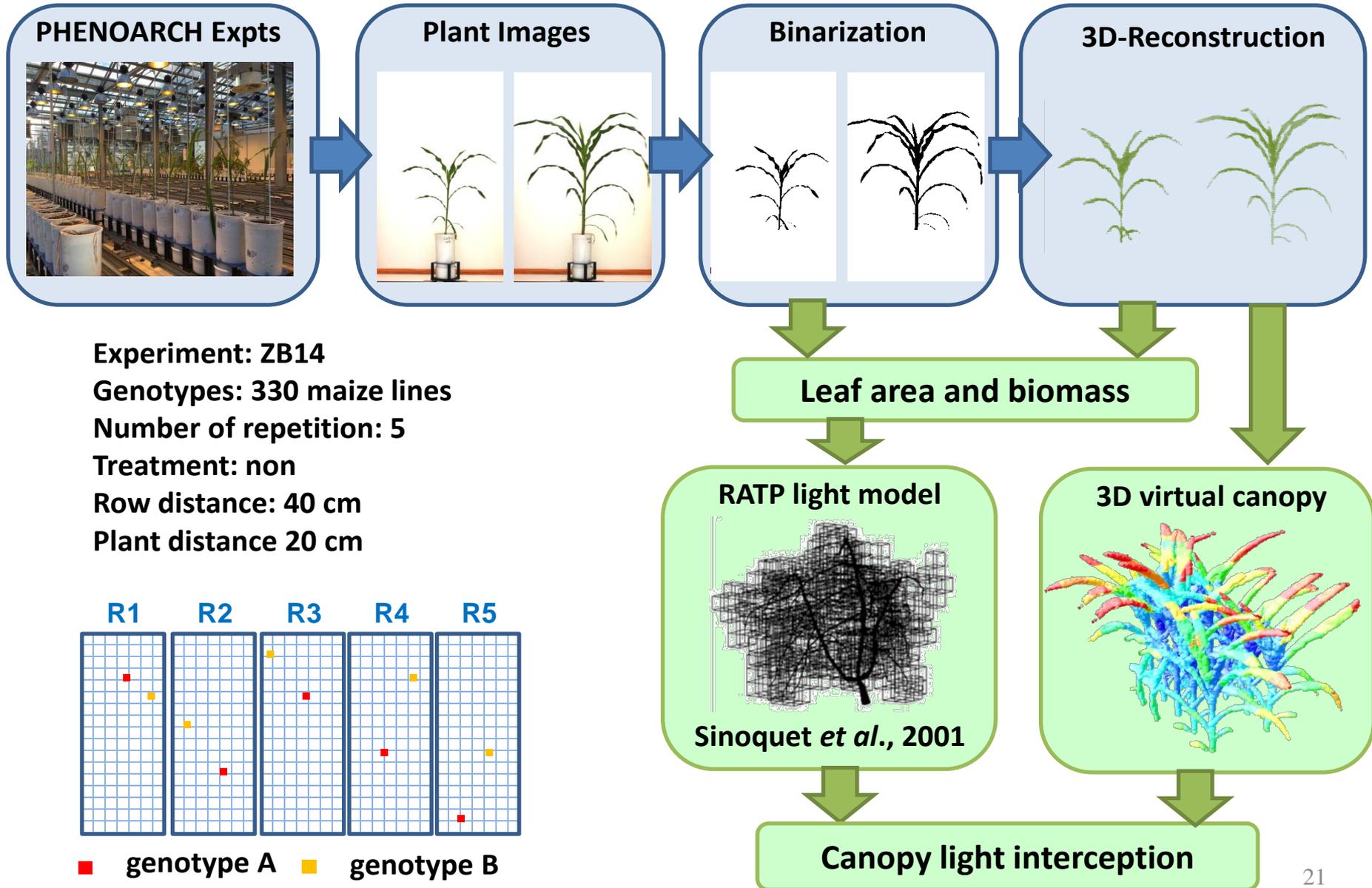
Retrieving light interception for individuals
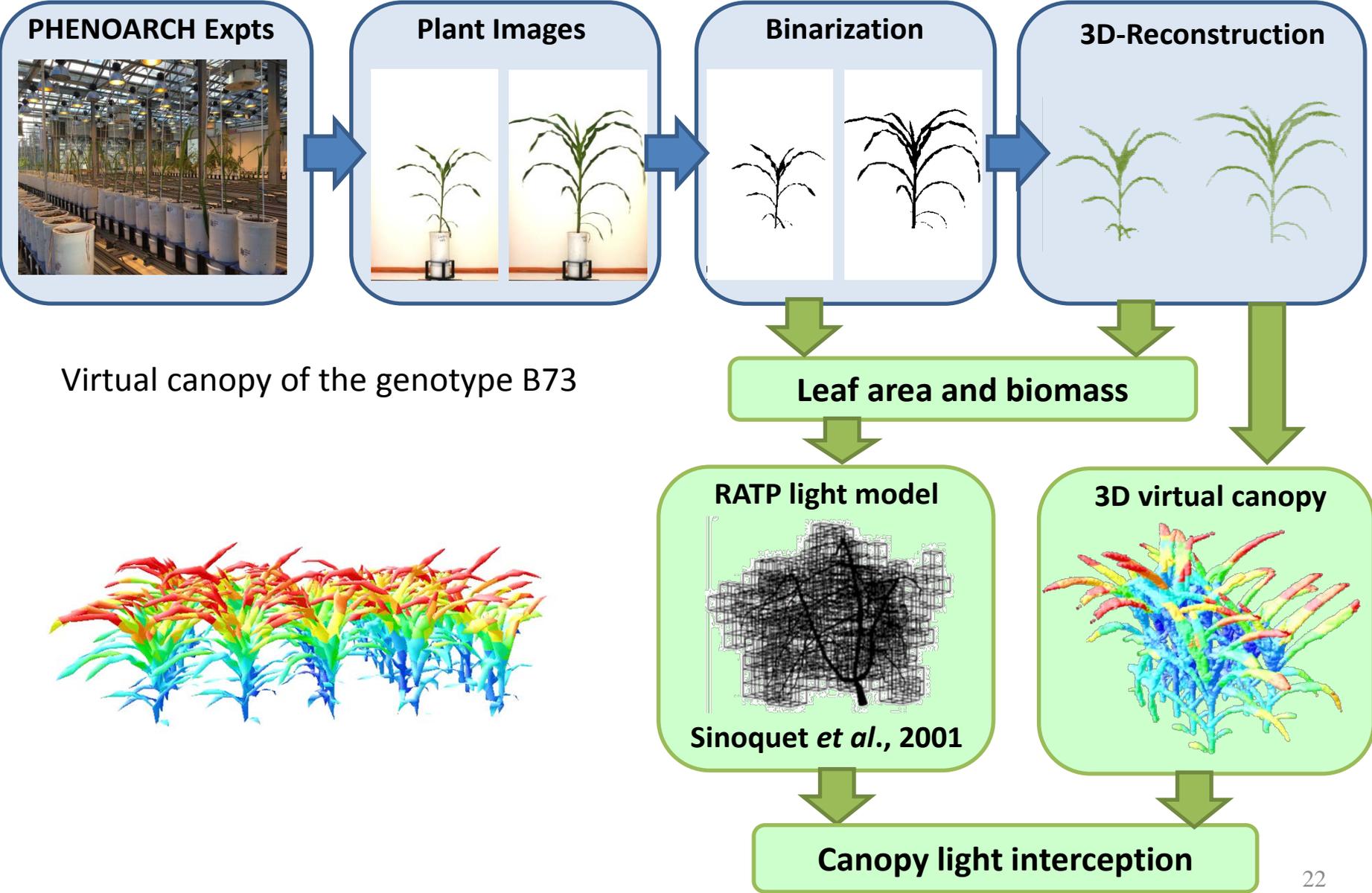
Virtual canopy of the genotype B73
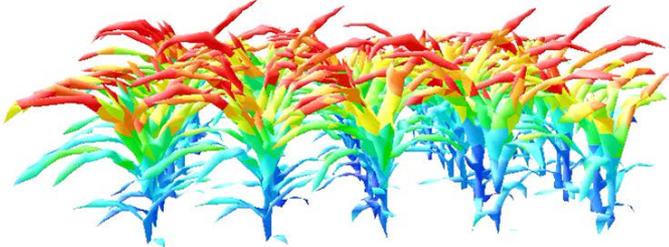
Radiation interception efficiency

PHENOARCH Expts → **Plant Images** → **Binarization** → **3D-Reconstruction**

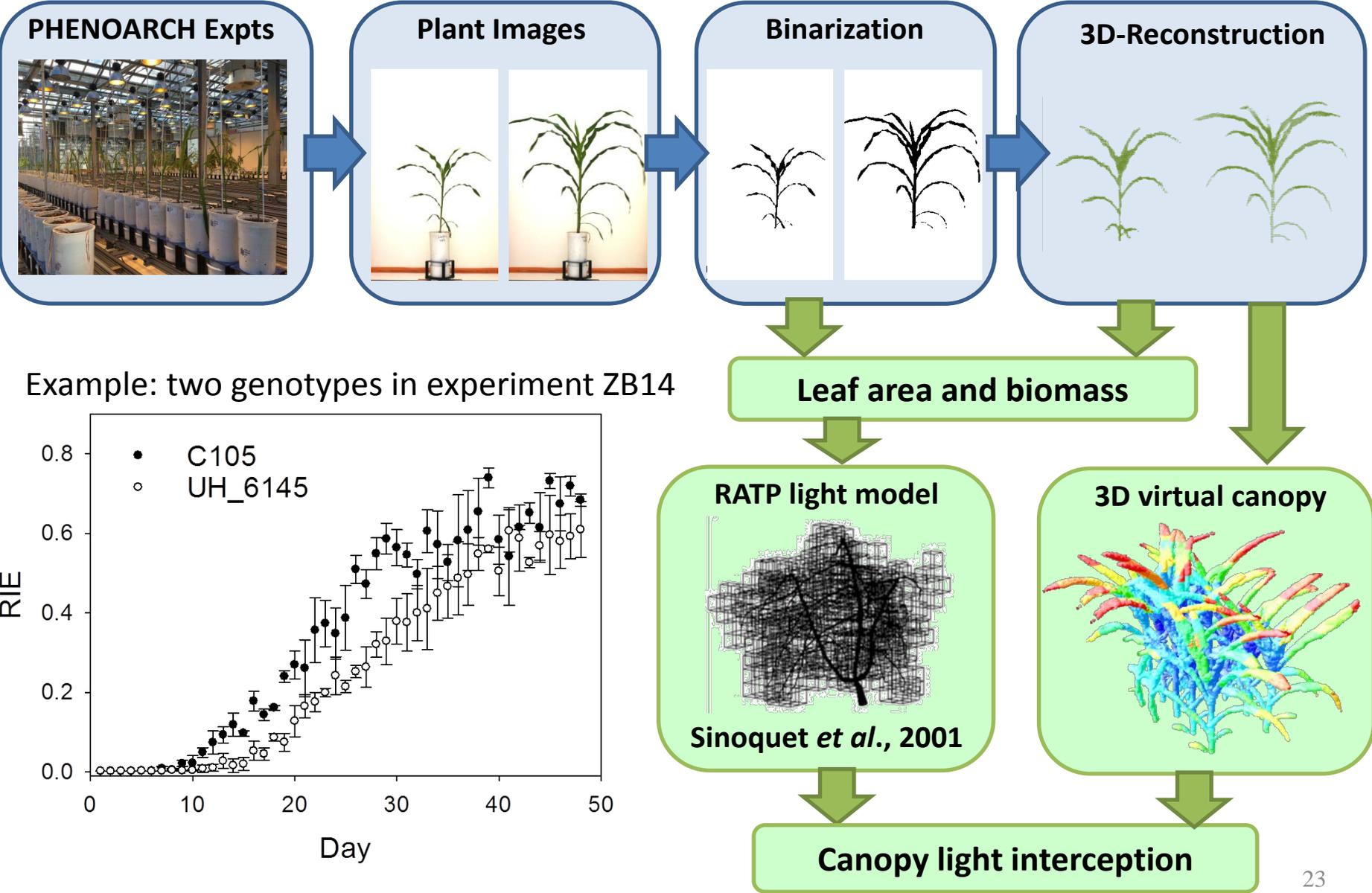**Leaf area and biomass**

RATP light model

Sinoquet *et al.*, 2001

3D virtual canopy

Canopy light interception

Example: two genotypes in experiment ZB14

- ● C105
- ○ UH_6145

RIE vs Day

Traits & QTL detection

Analyzed by Aude Coupel-Ledru and Santiago Alvarez-Prado
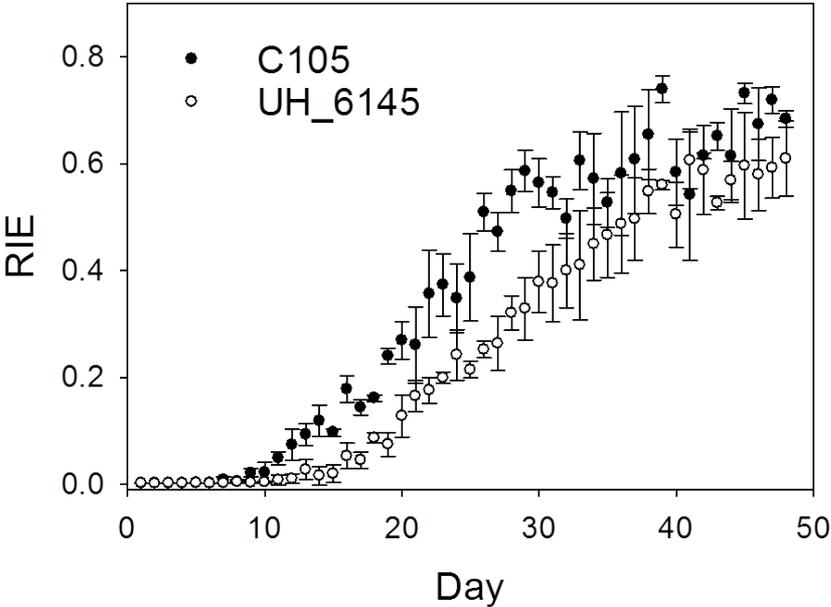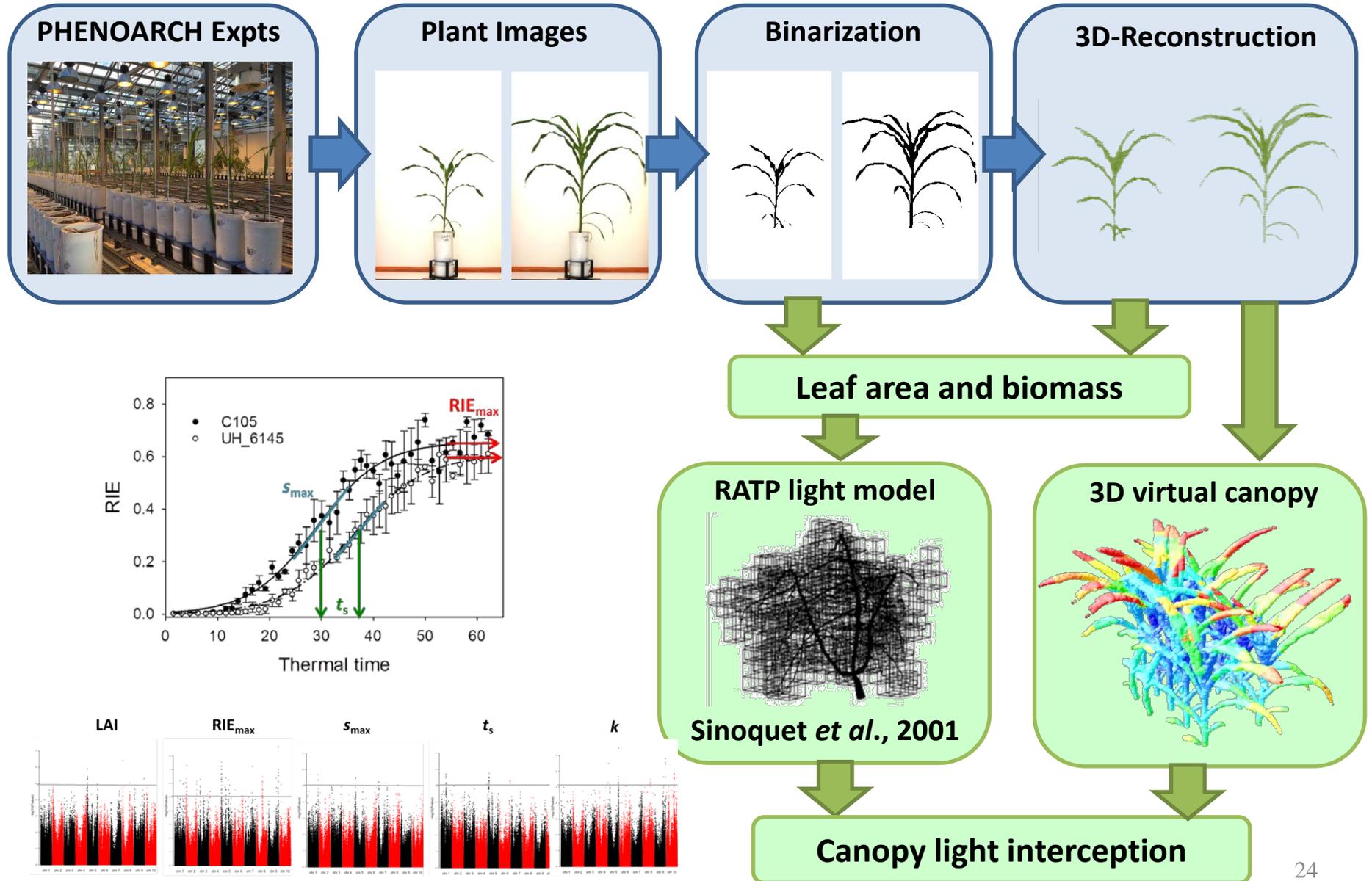
Radiation use efficiency: biomass + light

PHENOARCH Expts → **Plant Images** → **Binarization** → **3D-Reconstruction**

Leaf area and biomass

RATP light model
Sinoquet *et al.*, 2001

Reconstructed 3D Canopy
Cabrera-Bosquet et al.

Single plant light Interception

Biomass (g FW plant⁻¹) vs I_{PPFD} (mol plant⁻¹)

1:1
R^2 ⊓ 0.72
RUE aut
RUE win/sp

$RUEaut = 8.7\ g\ FW\ mol^{-1}$
$RUEwin/sp = 8.6\ g\ FW\ mol^{-1}$
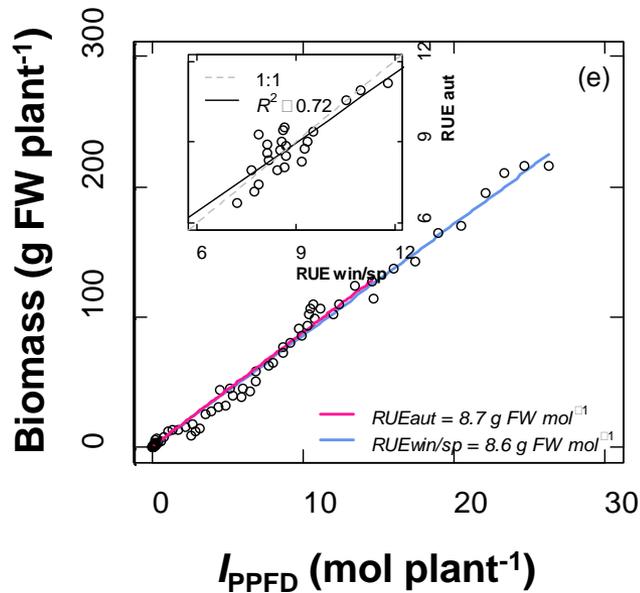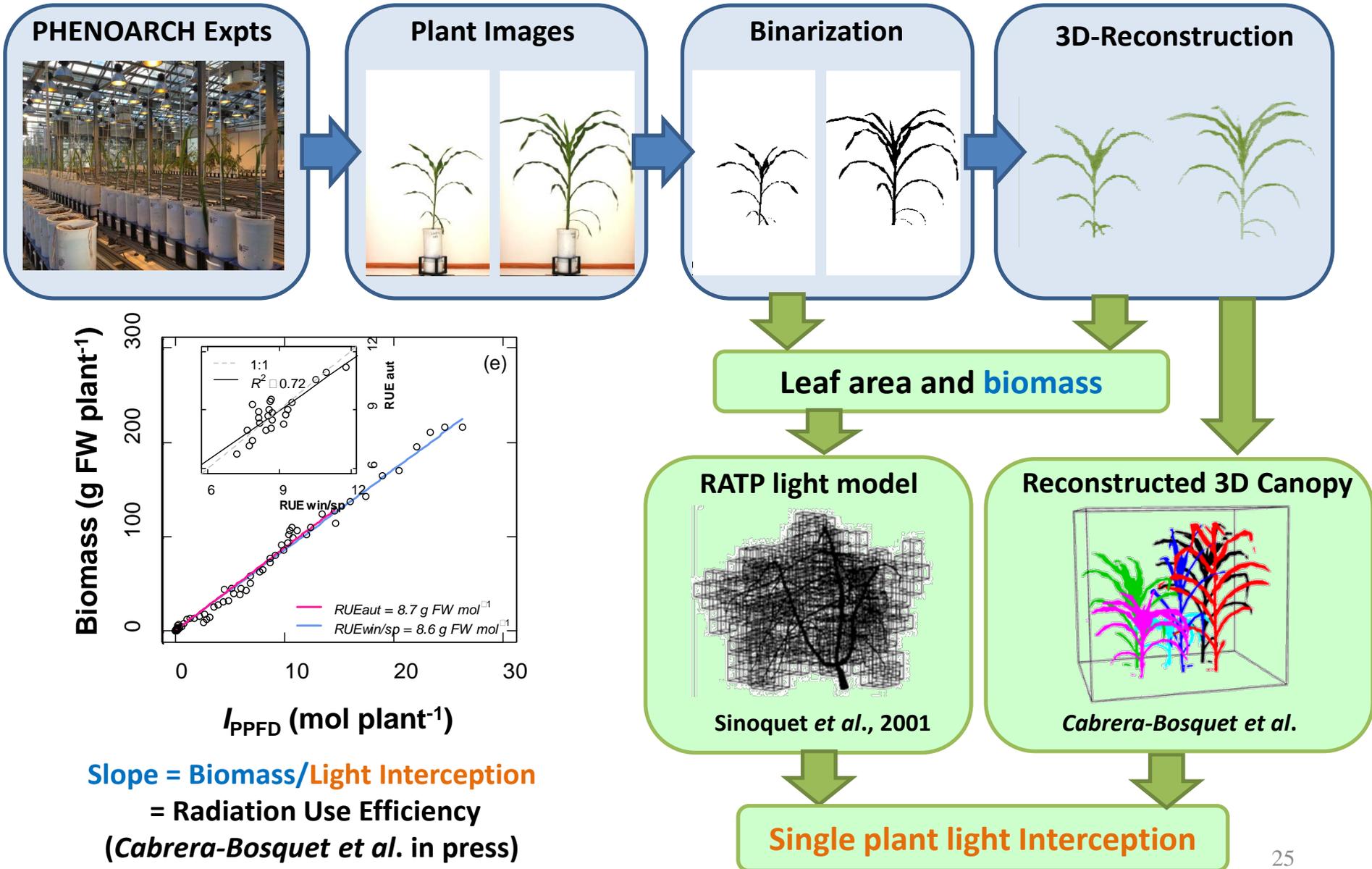
Slope = Biomass/Light Interception
= Radiation Use Efficiency
(*Cabrera-Bosquet et al.* in press)

25

3D Plant development & model fitting (ongoing)

| Plant Images | Binarization | 3D-Reconstruction | segmentation |
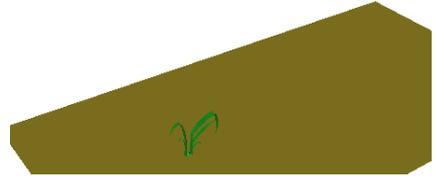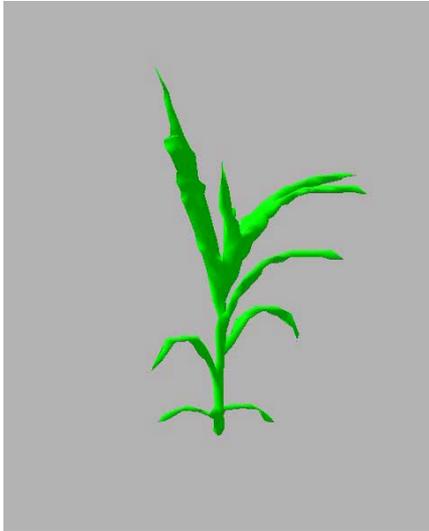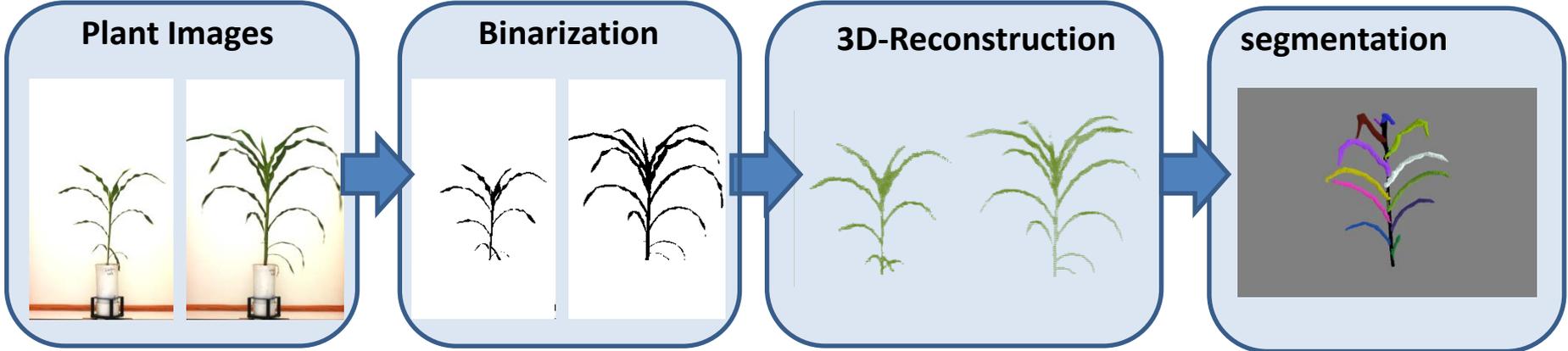
Summary

Fully Integrated & Automated image workflows

OpenAlea Plateform

Phenomenal library

Phenoarch application

InfraphenoGrid infrastructure

Control

Biomass & irrigation

Ear detection

Analysis

Radiation interception & Radiation use efficiencies

Whole Plant development

Ongoing : organ development