Webinaire de l'Académie d'agriculture de France :
Les hormones végétales, progrès récents et perspectives, un hommage à Jean Guern
Lundi 7 décembre 2020

Interactions entre la voie hormonale des cytokinines et de peptides de signalisation

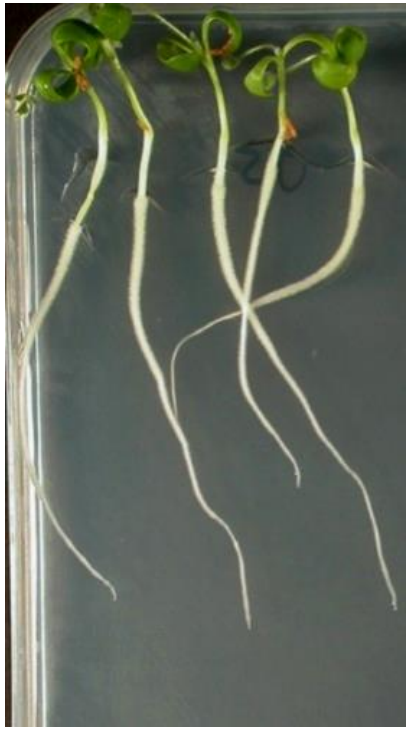
Florian FRUGIER

IPS2 Institute of Plant Sciences Paris - Saclay

université PARIS-SACLAY

cnrs

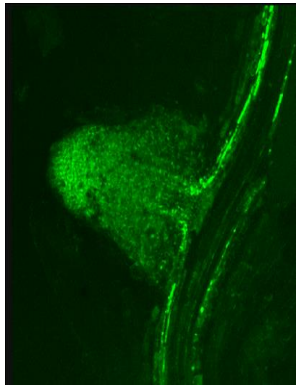
Developmental plasticity of root system adaptation to the environment

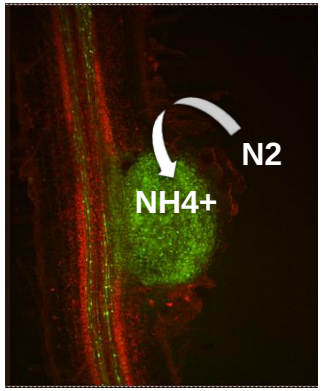


Nutrient-poor medium

Nutrient-rich medium

The legume root system





Lateral roots

Nutrients availability

Nodules

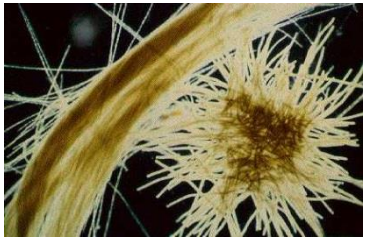
Symbiotic Rhizobia
Nitrogen starvation

Medicago truncatula

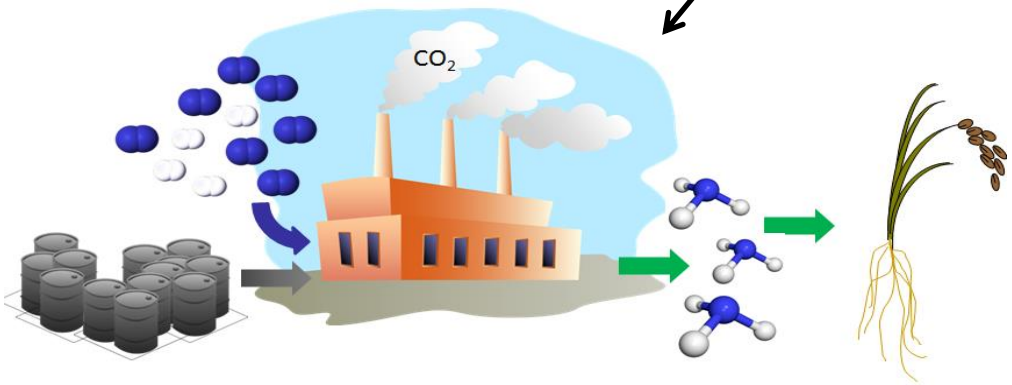
Nitrogen fixation

Source	Quantité de N-fixé
N-fixation biologique (systèmes terrestres)	90-140 T/an
N-fixation biologique (systèmes marins)	30-300 T/an
N-fixation industrielle	80 T/an

Rhizobium, nitrogen fixing soil bacteria Interacting with legumes in root nodules



Trichodesmium, cyanobactaria

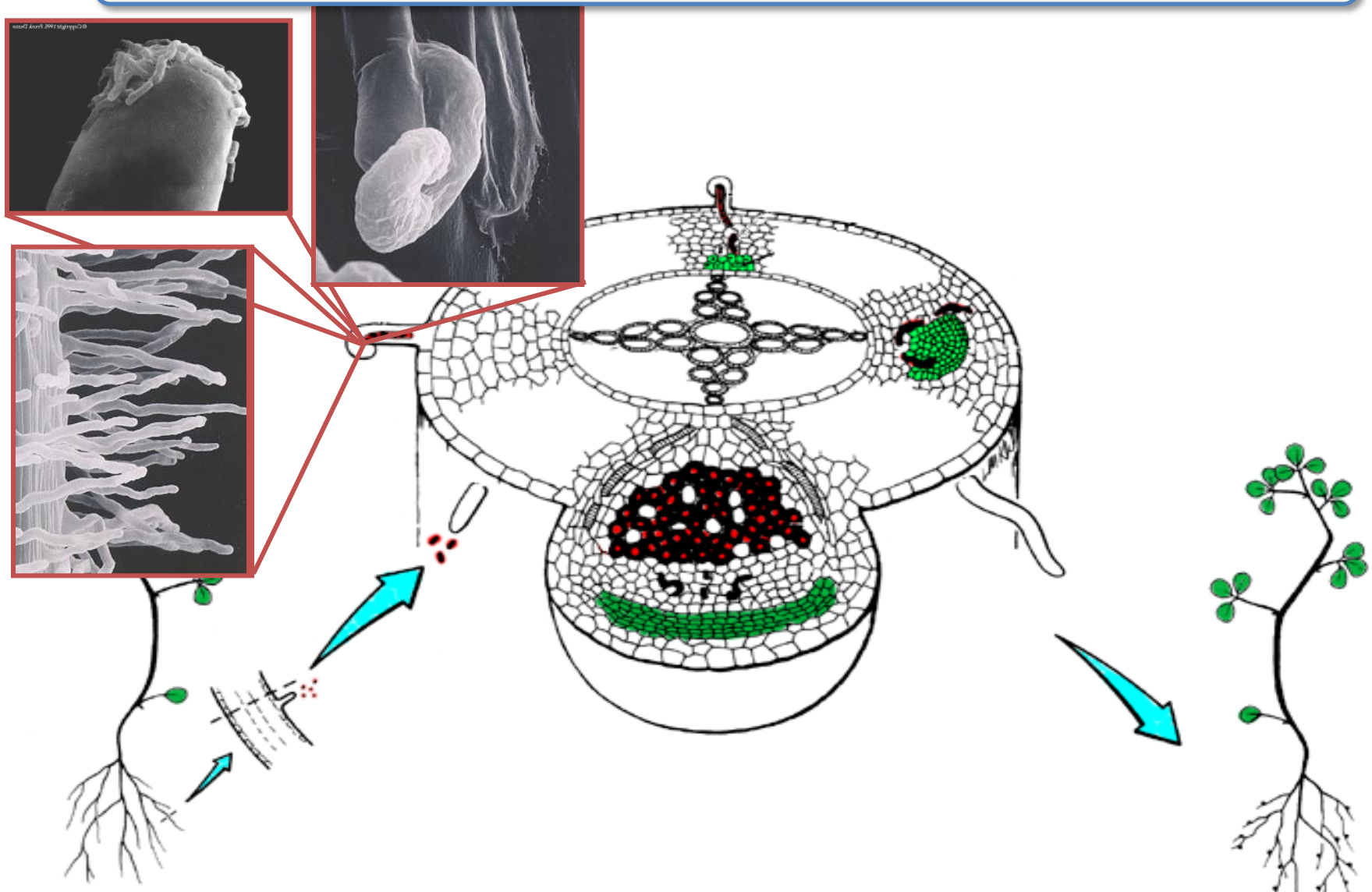


Gaz

Nitrogen fertilizers

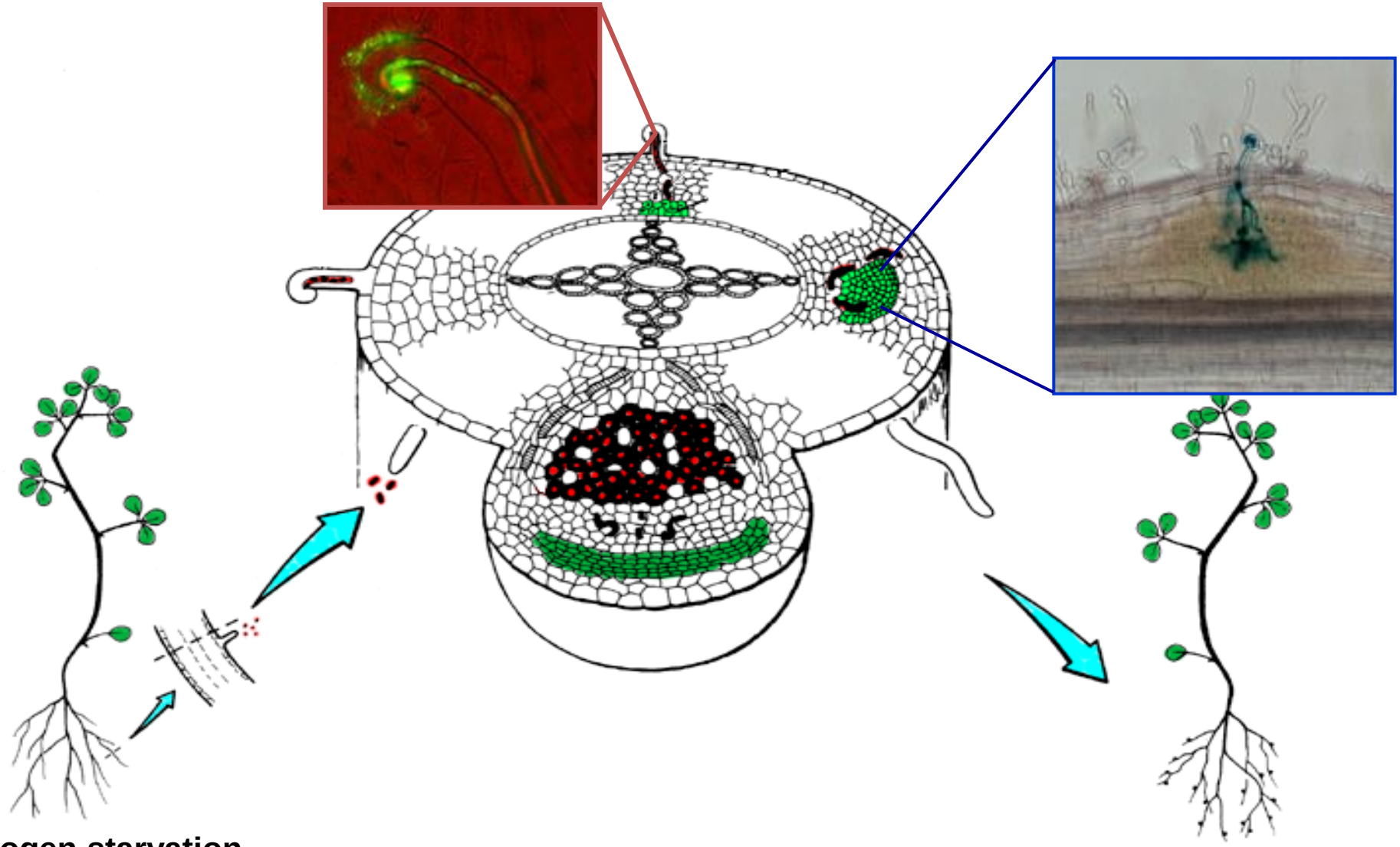
Food and feed

Symbiotic nodulation: a plant microbe interaction



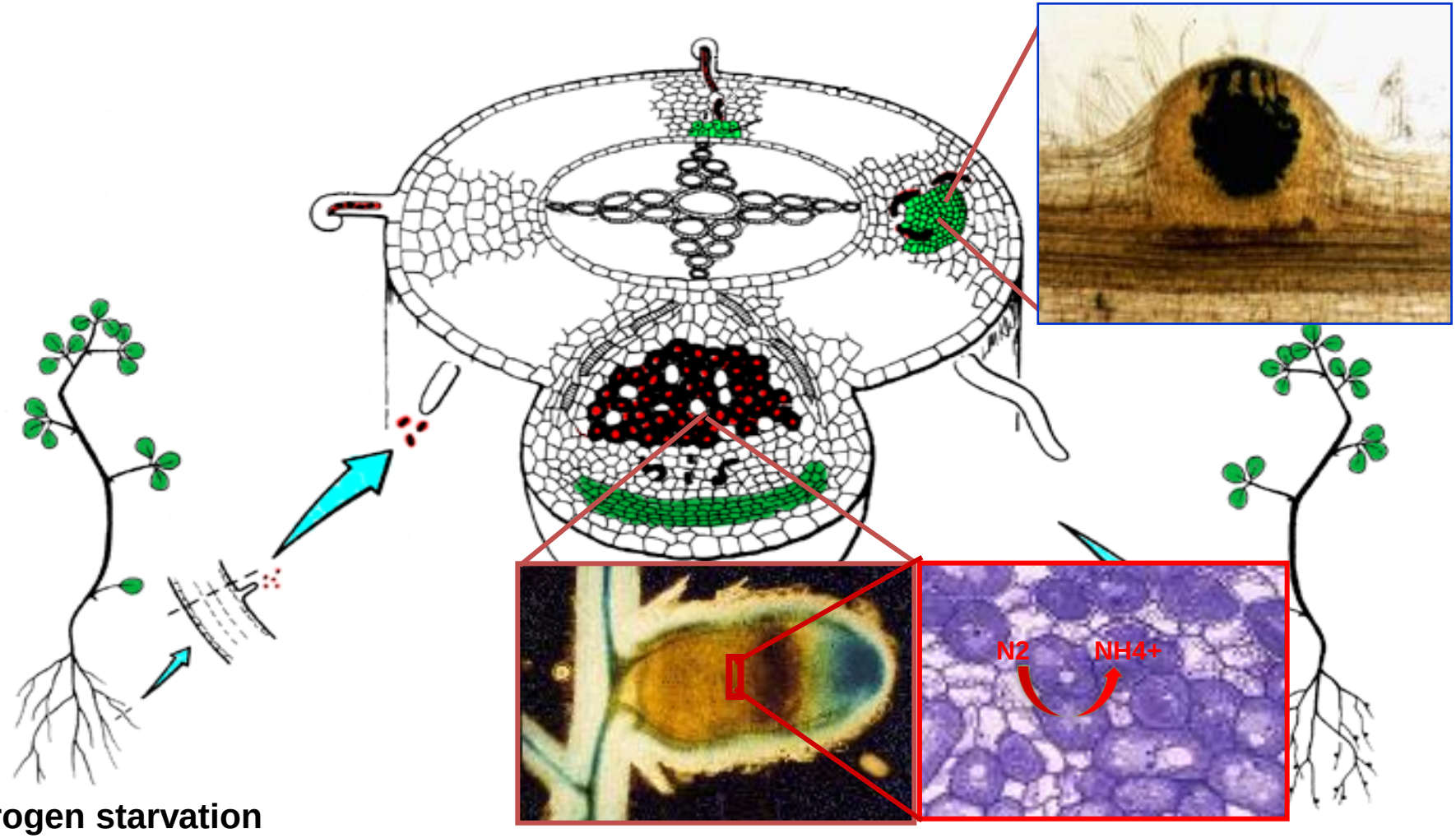
Nitrogen starvation

Symbiotic nodulation: an infection and a developmental process



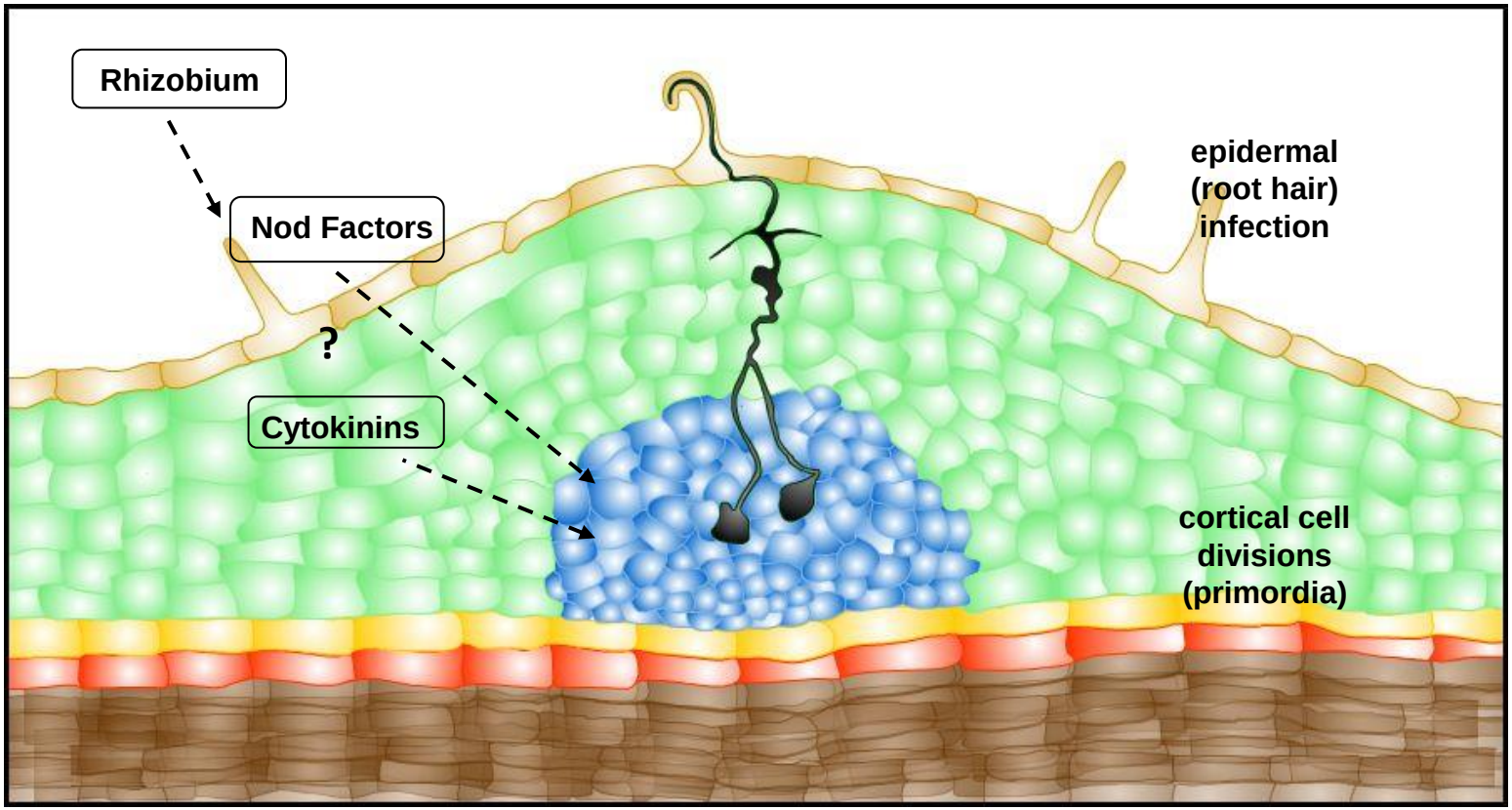
Nitrogen starvation

Symbiotic nodulation: a metabolic process

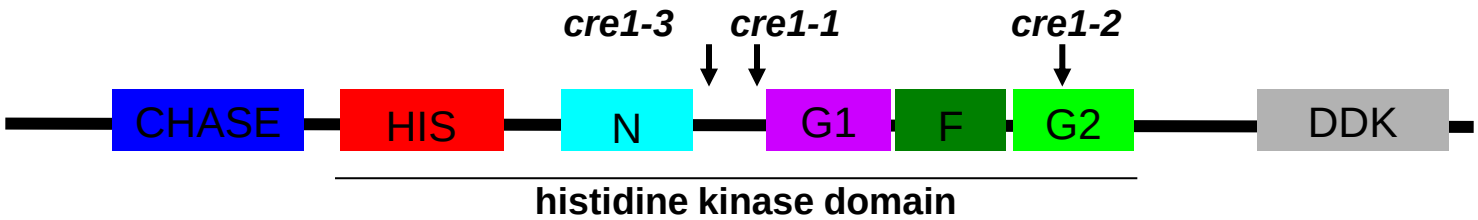


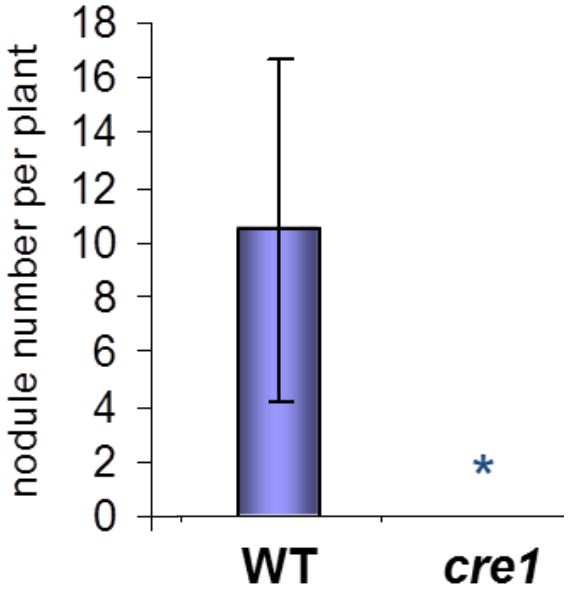
Nitrogen starvation

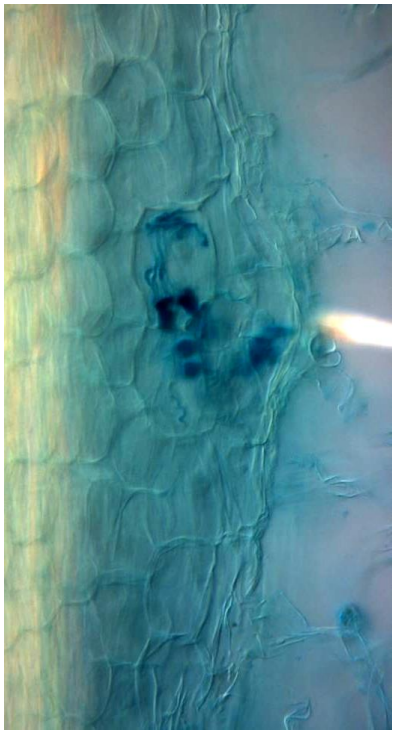
Initiation of symbiotic nodulation: a cross-talk between bacterial and plant signals



Nodule initiation is blocked in mutants affecting the CRE1 cytokinin receptor





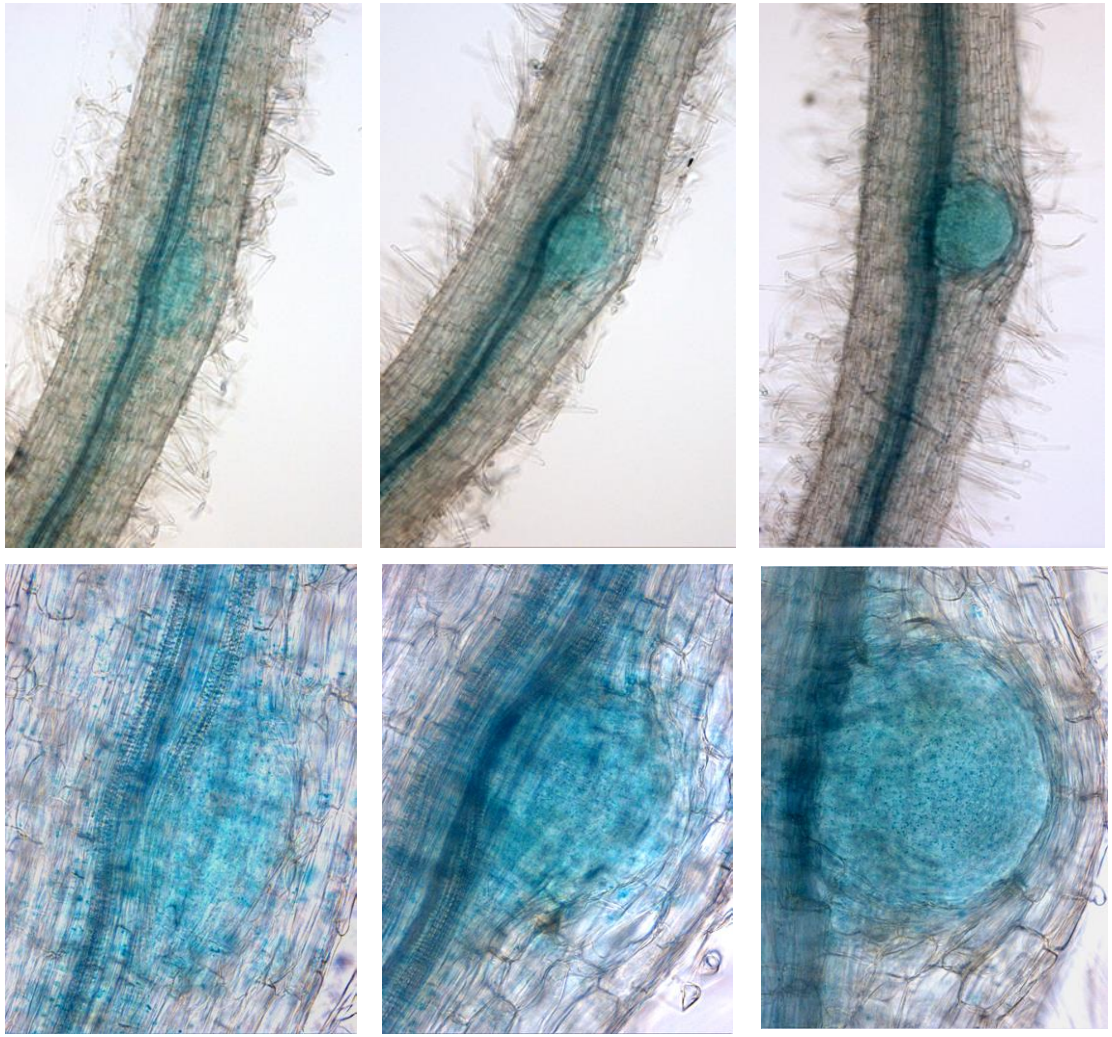


cre1

Gonzalez-Rizzo et al., 2006; Plet et al., 2011

The cytokinin response is activated in nodule primordia

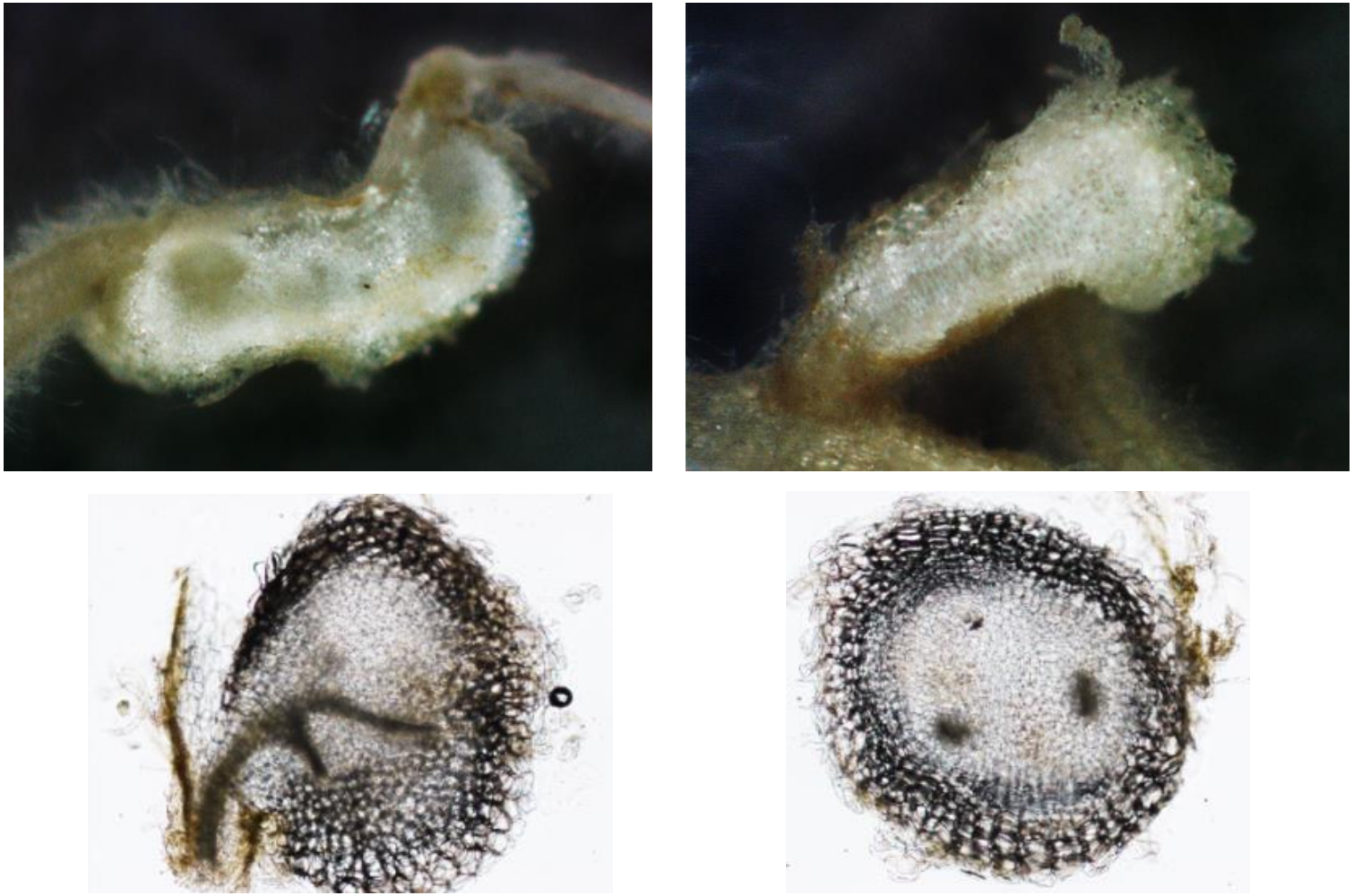
pMtRR4:GUS



Plet et al., 2011

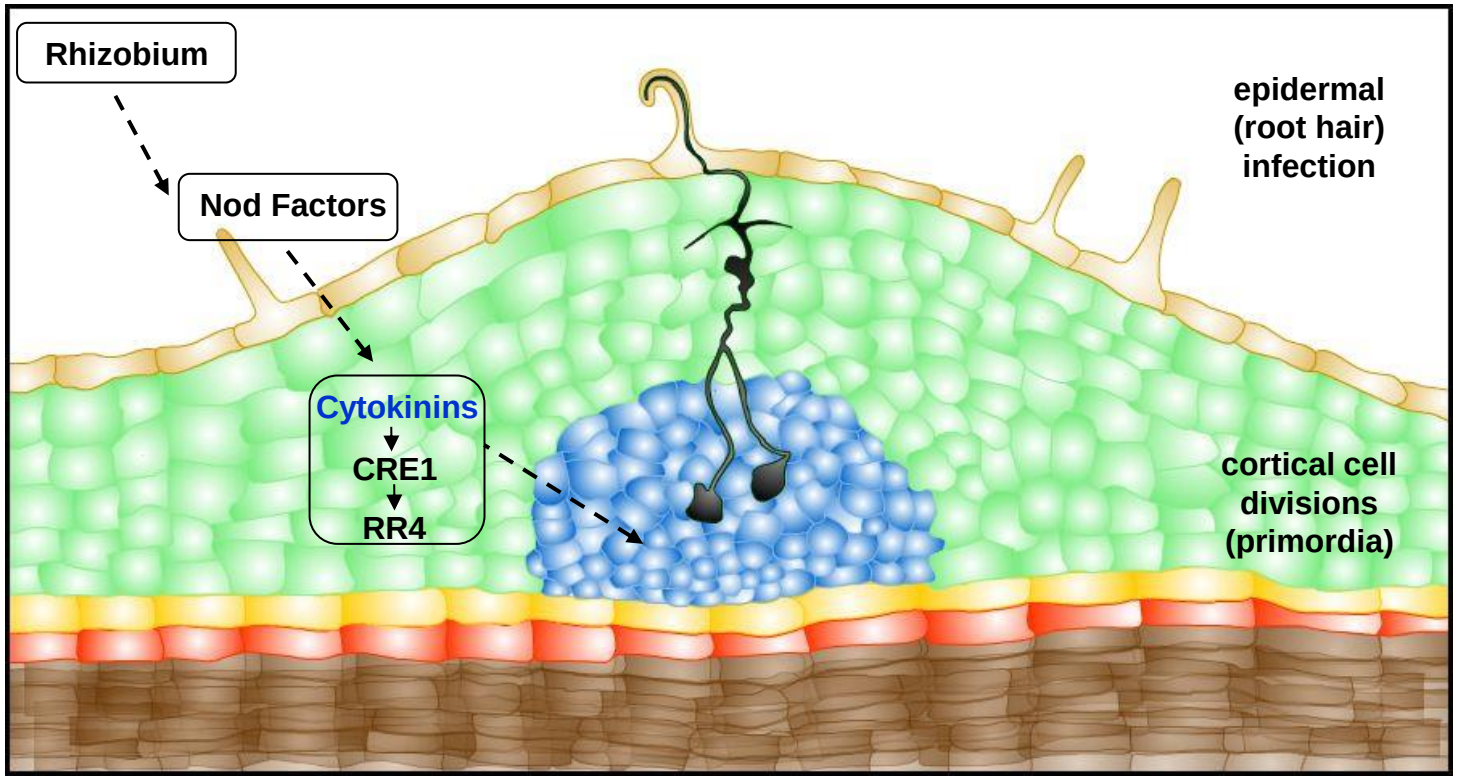
Constitutive activation of the cytokinin/CRE1 pathway: spontaneous nodulation in the absence of rhizobium

pMtCRE1-CRE1gof



Unpublished results

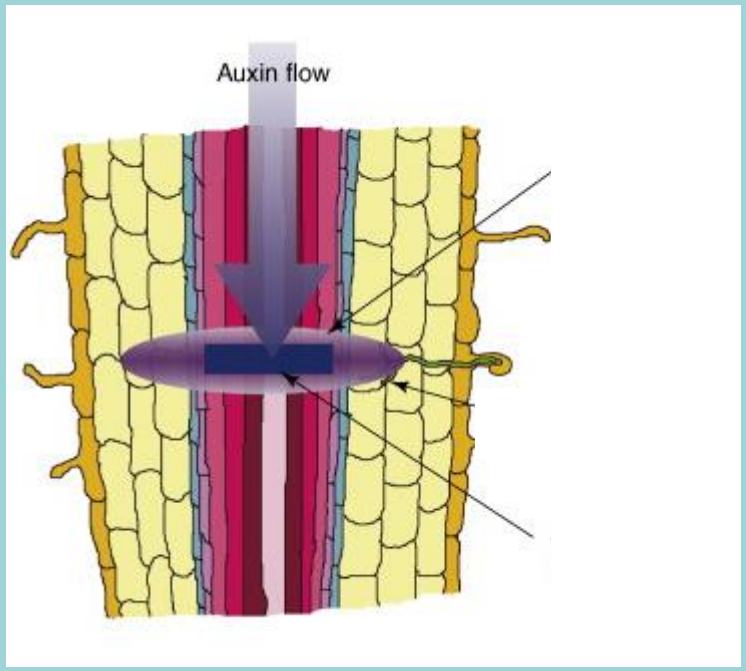
Cytokinins are necessary and sufficient to induce nodule organogenesis



Gonzalez-Rizzo et al., 2006, Plant Cell; Plet et al., 2011, Plant J.

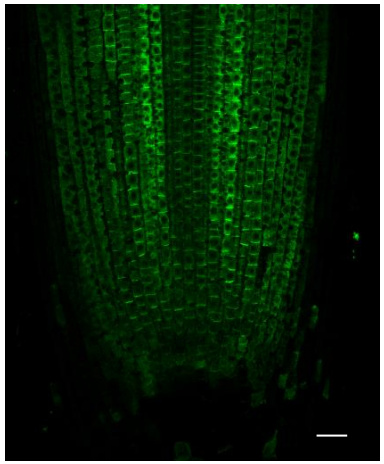
The rhizobium-induced regulation of polar auxin transport relies on the cytokinin/CRE1 pathway

Measure of polar auxin transport in root tips

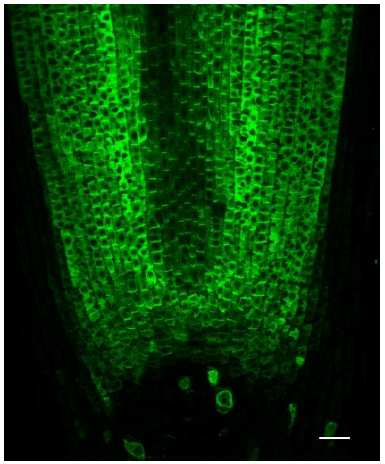


Auxin carriers (PINs) immunolocalisation in root tips

WT



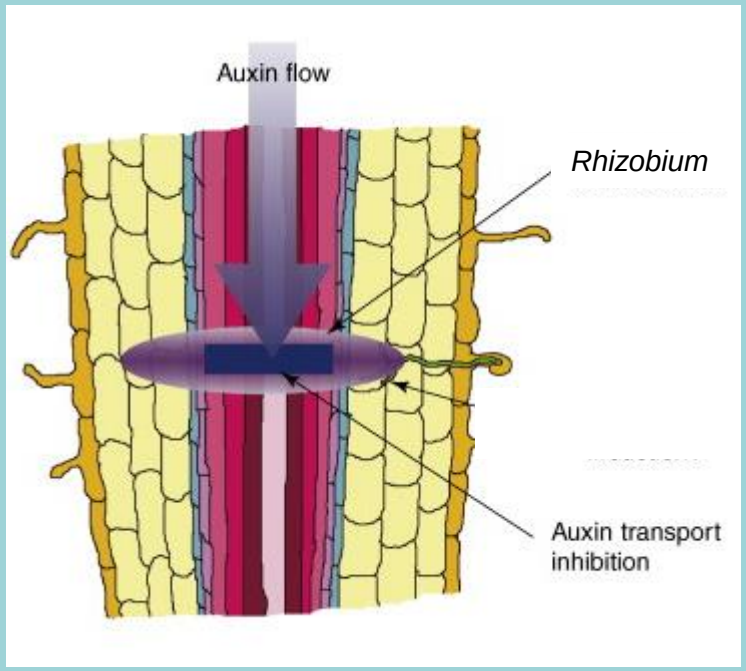
cre1



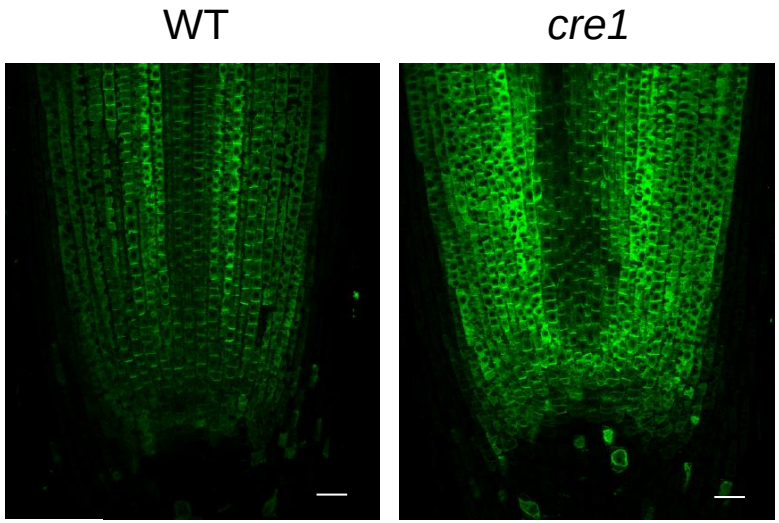
Plet et al., 2011

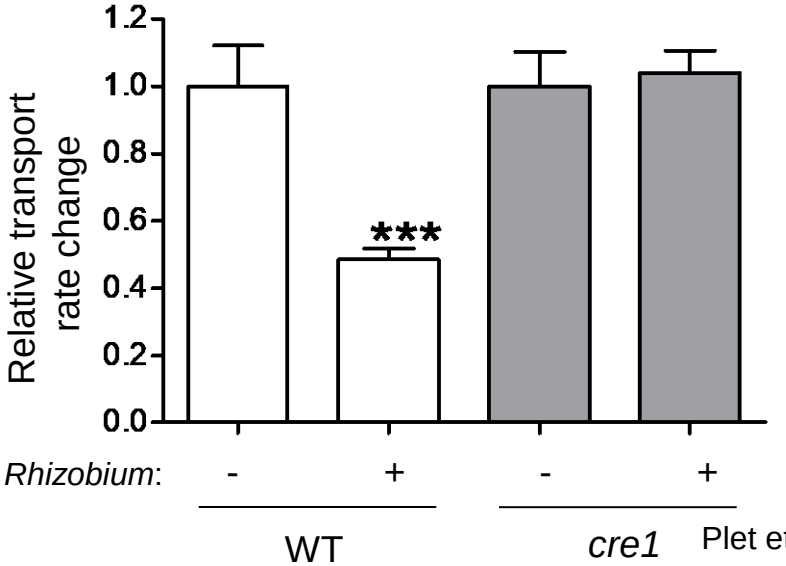
The rhizobium-induced regulation of polar auxin transport relies on the cytokinin/CRE1 pathway

Measure of polar auxin transport in root tips



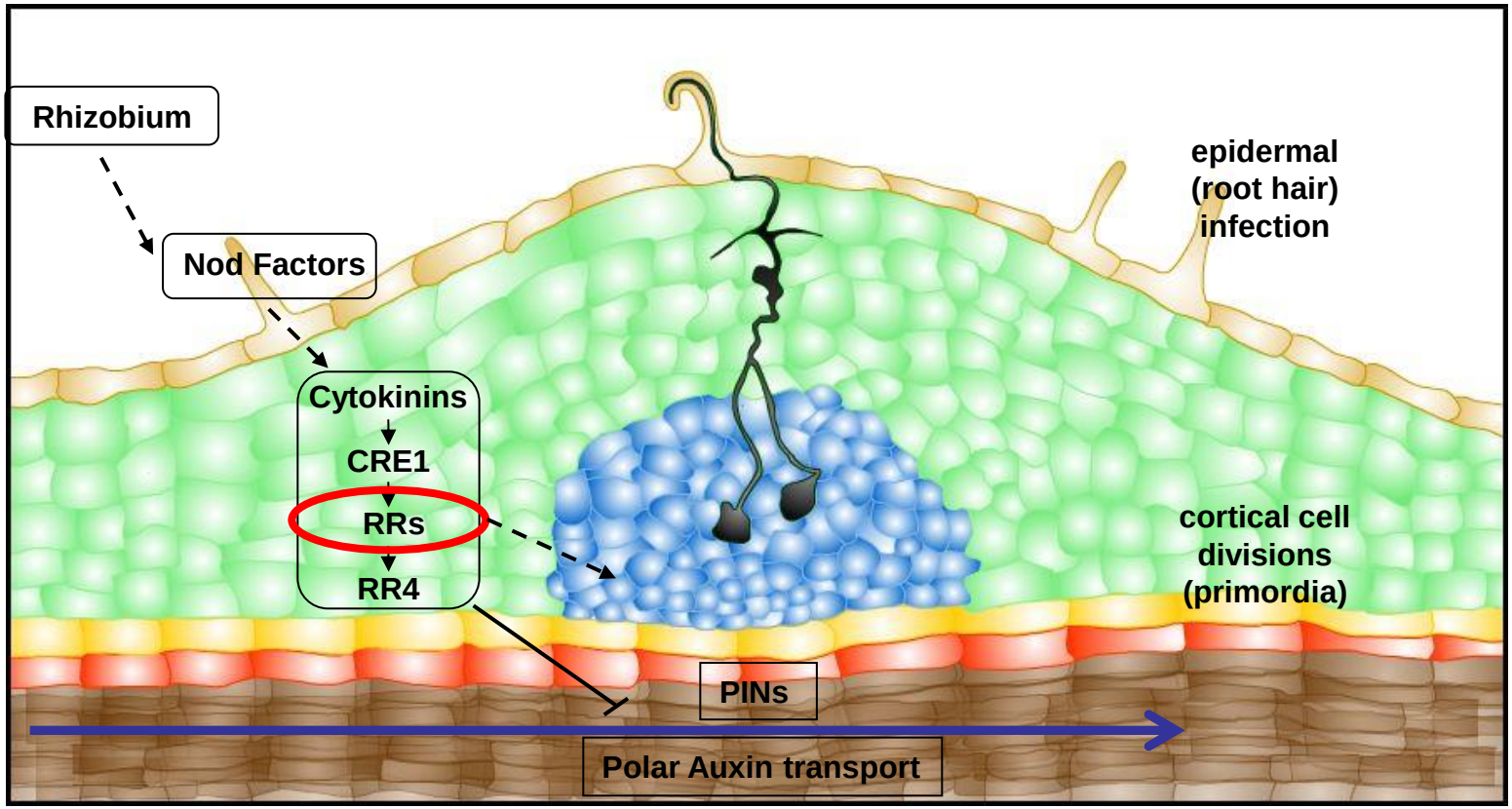
Auxin carriers (PINs) immunolocalisation in root tips





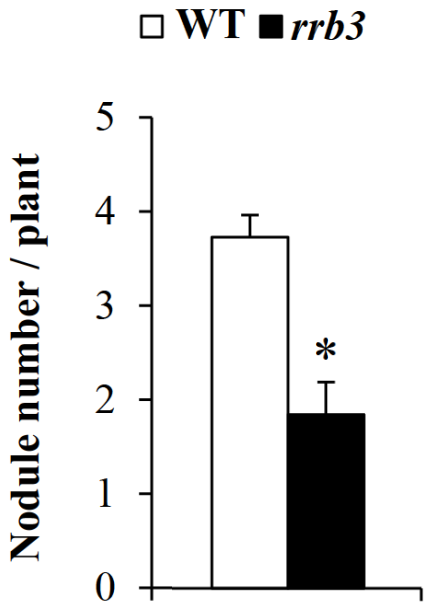
Plet et al., 2011

Cross-talk between Nod factors, cytokinins and auxin during nodule initiation



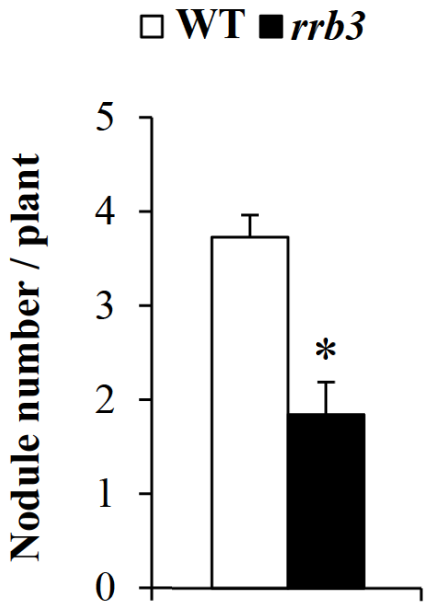
Gonzalez-Rizzo et al., 2006, Plant Cell; Plet et al., 2011, Plant J; Ng et al., 2015, Plant Cell

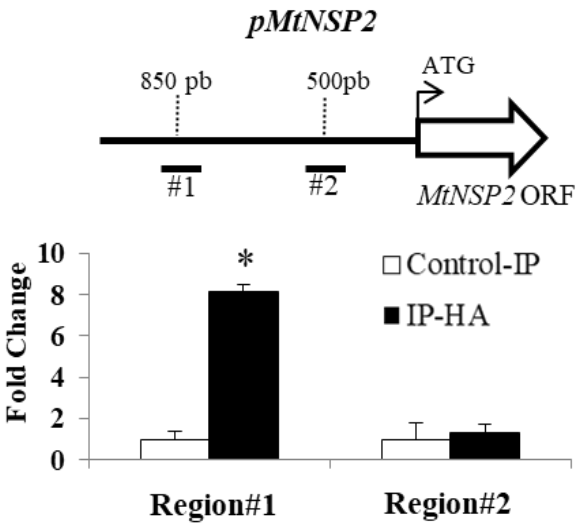
The MtRRB3 cytokinin signaling transcription factor promotes nodulation by regulating the NSP2 early nodulation gene



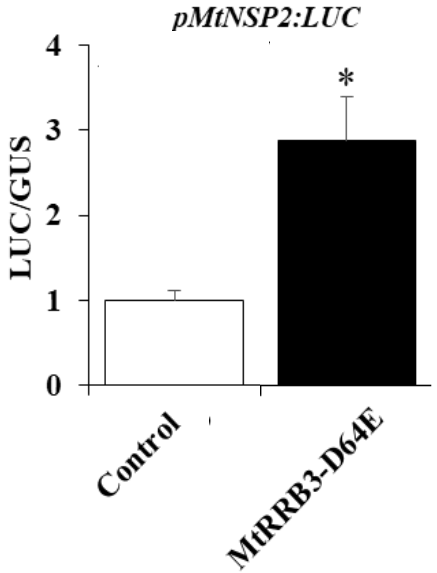
Tan et al., 2020

The MtRRB3 cytokinin signaling transcription factor promotes nodulation by regulating the NSP2 early nodulation gene





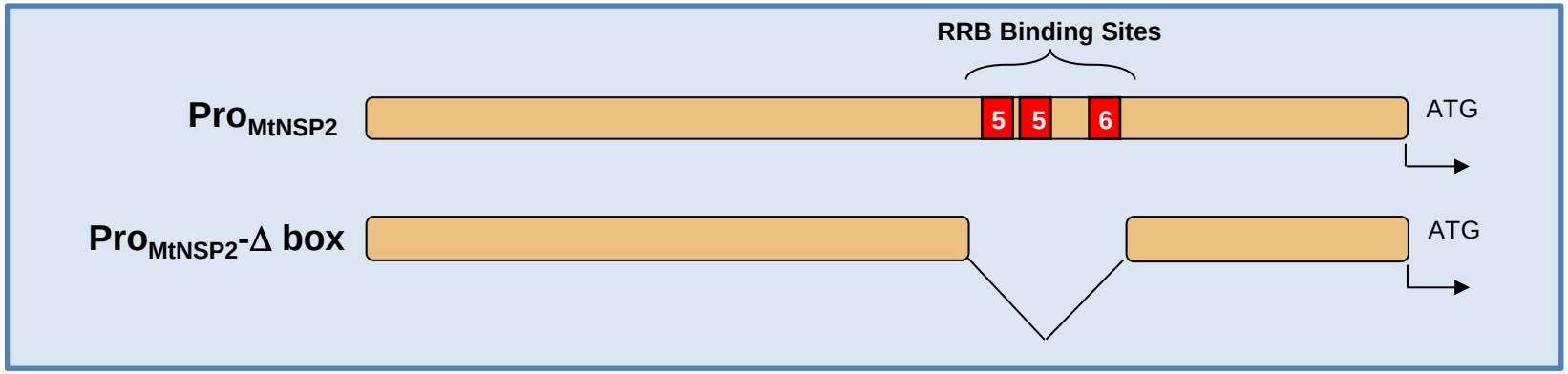
ChIP qPCR

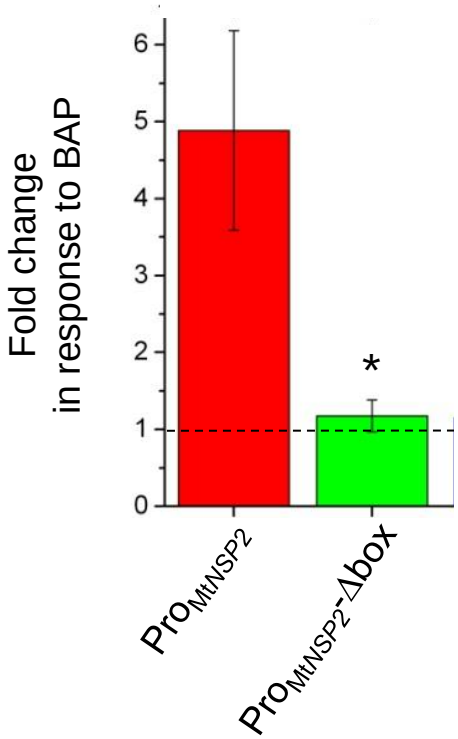


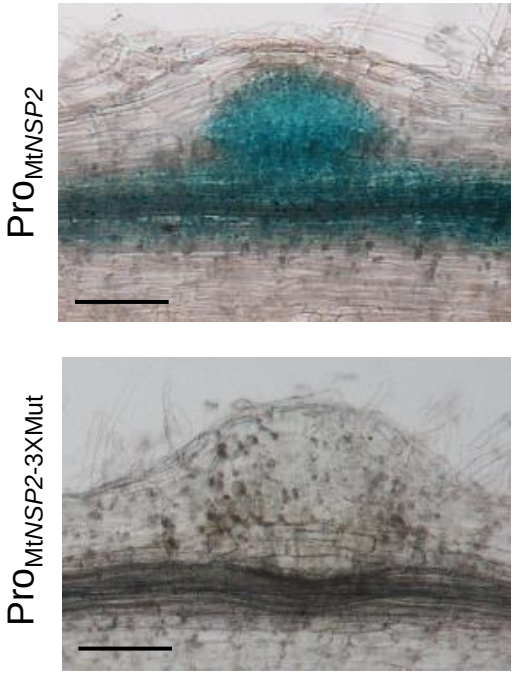
Transactivation

Tan et al., 2020

RRB binding sites in the promoter of the early nodulation gene NSP2 are required for cytokinin and symbiotic responses

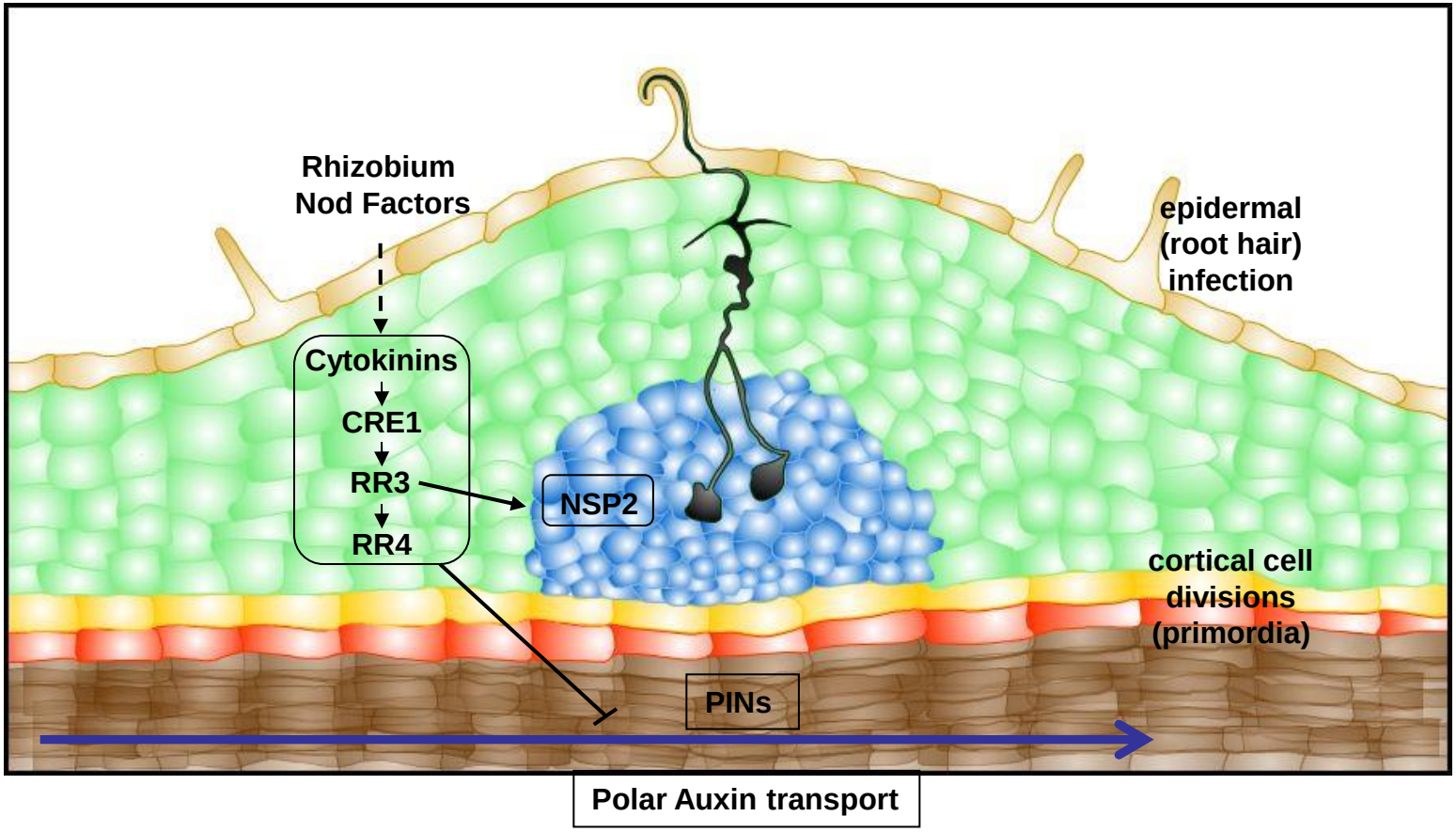






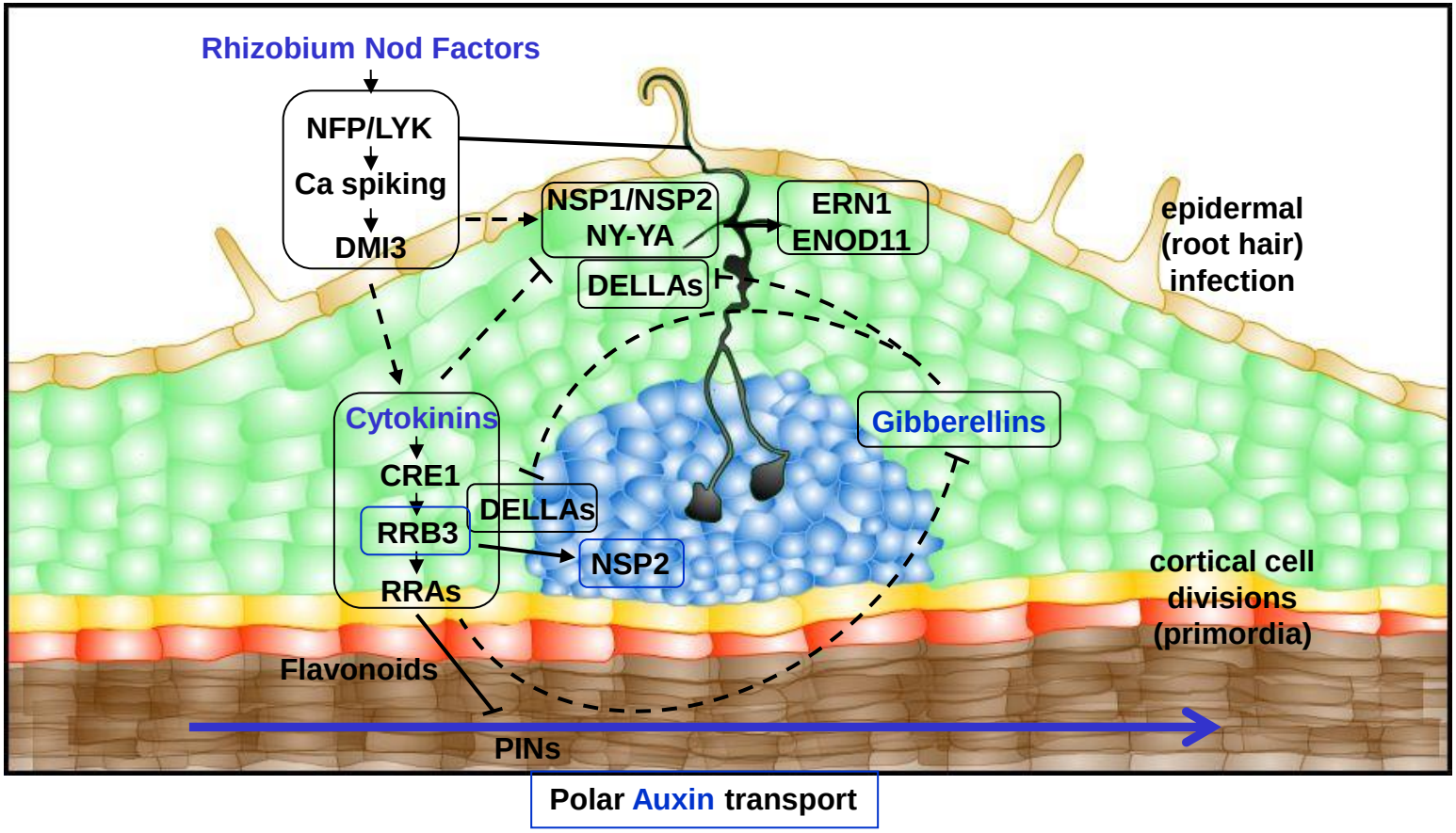
Ariel et al., 2012

Cytokinin signaling pathway recruited to induce nodule organogenesis



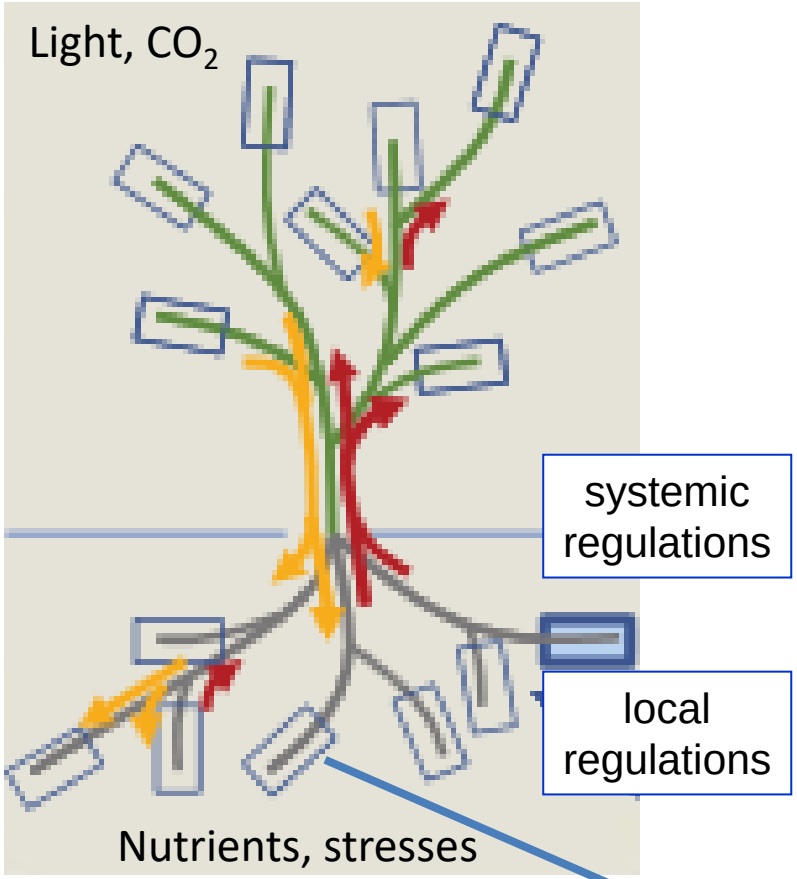
Gonzalez-Rizzo et al., 2006, Plant Cell; Plet et al., 2011, Plant J.; Ariel et al., 2012, Plant Cell
Ng et al., 2015, Plant Cell; Tan et al., 2020, Plant Phys.

Local regulatory pathways acting in symbiotic nodule initiation



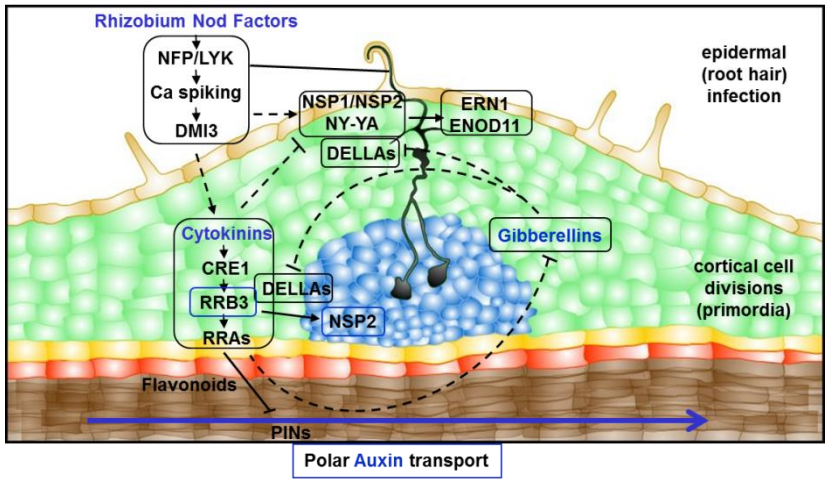
Gonzalez-Rizzo et al., 2006, Plant Cell; Plet et al., 2011, Plant J.; Ariel et al., 2012, Plant Cell
Ng et al., 2015, Plant Cell; Tan et al., Plant Phys.;
Fonouni-Farde et al., 2016, Nat. Commun.; Trends Plant Sci.; and 2017, Plant Physiol.;
Tan et al., 2020, Plant Physiol.

Integration of local and systemic regulations



De Kroon et al., 2009

?



The *cra2* mutant: compact root architecture and low nodulation

WT

cra2

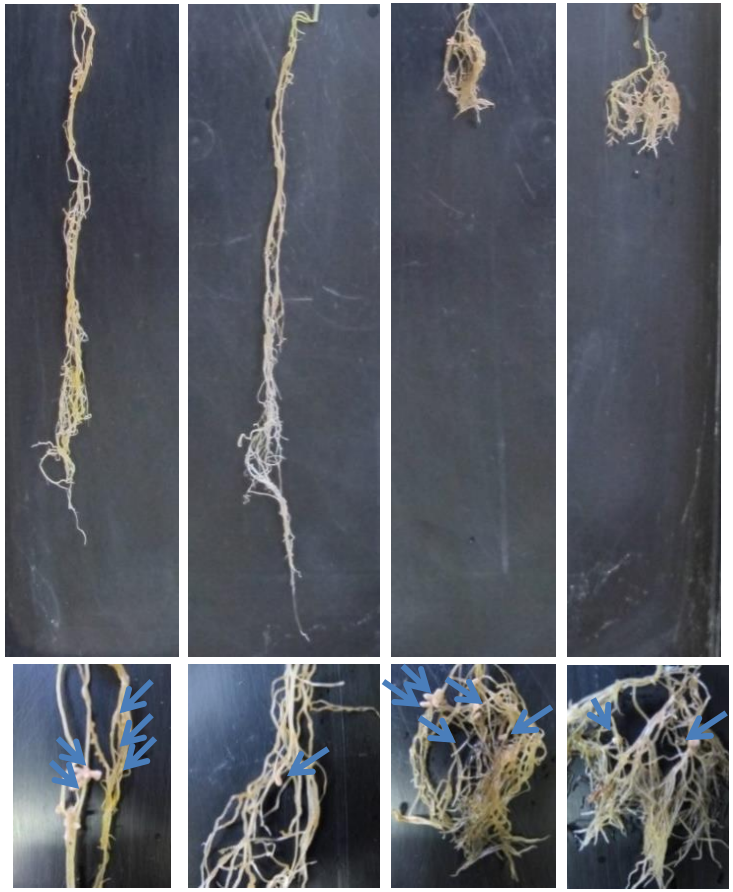
Huault et al., 2014; Laffont et al., 2019

A systemic function of CRA2 to regulate nodulation from shoots

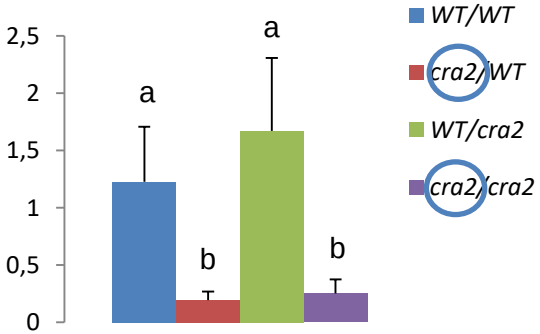
WT ***cra2***

Grafting experiments

WT / WT **cra2-1 / WT** **WT / cra2-1** **cra2-1/ cra2-1**



Number of nodules

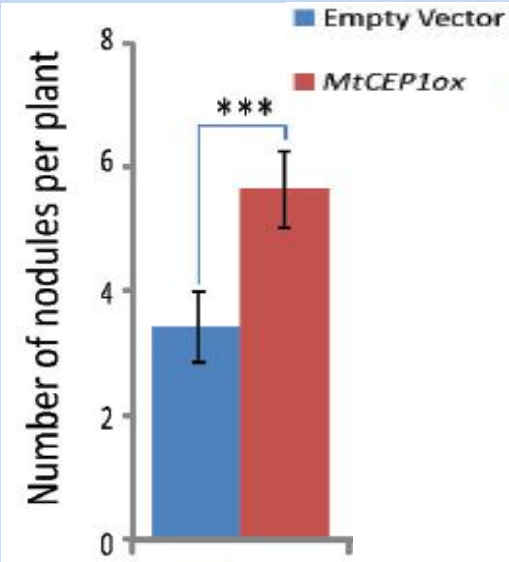


Huault et al., 2014; Laffont et al., 2019

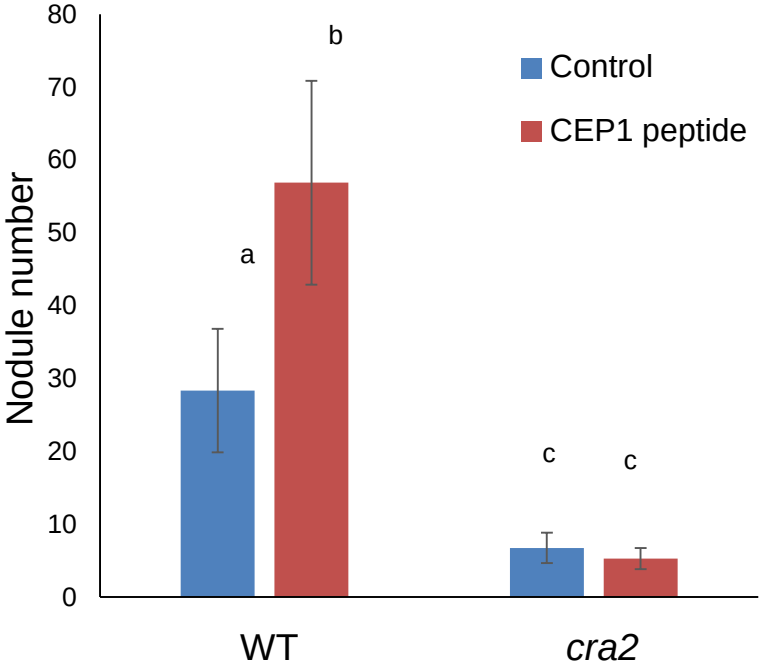
The CEP1 signaling peptide requires the CRA2 receptor to promote nodulation

control

+ CEP1 peptide

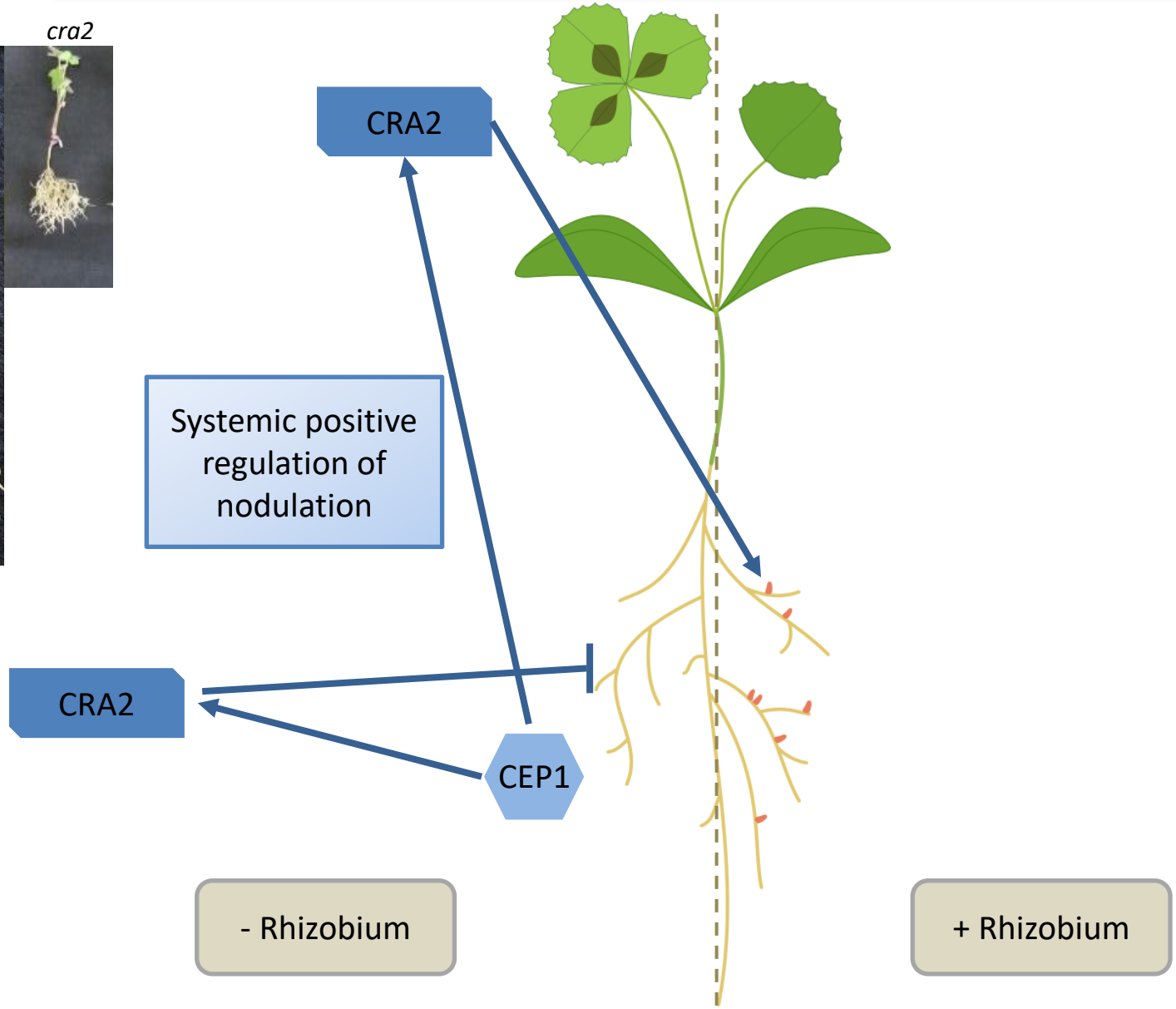


Imin et al., 2013



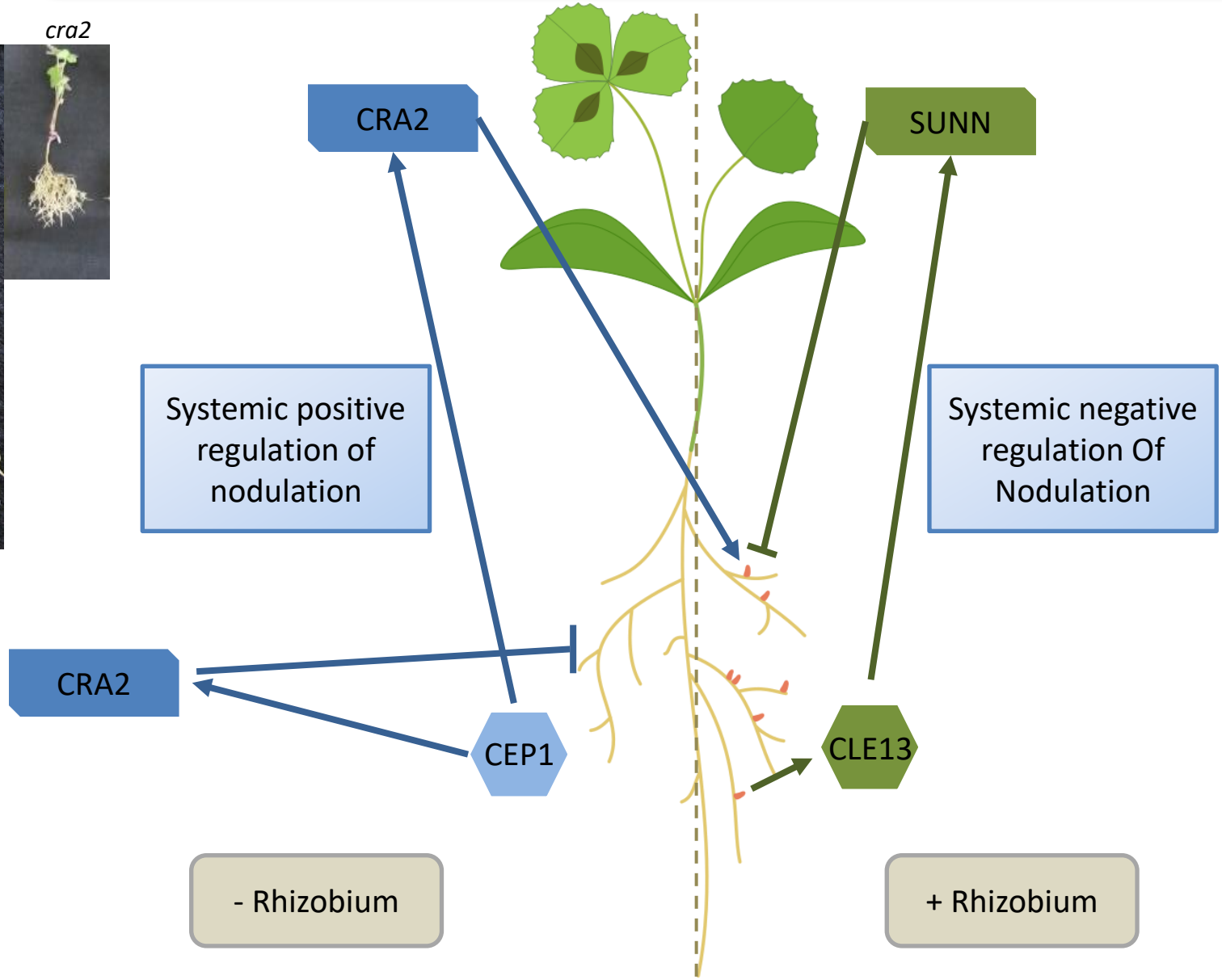
Mohd-Radzman et al., 2016; Laffont et al., 2019

Systemic pathways regulating lateral root and nodule formation are mediated by different signaling peptides



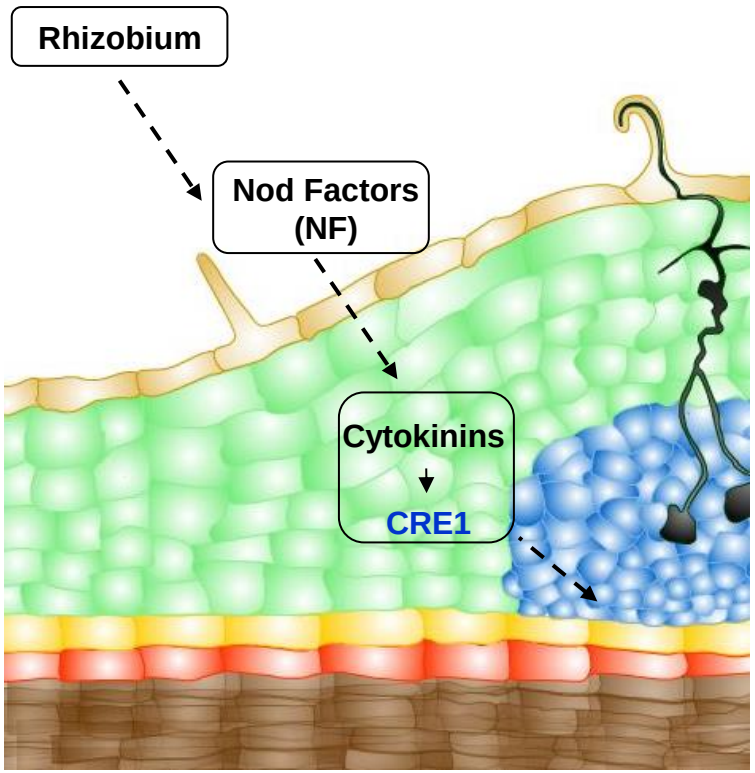
Imin et al., 2013
Huault et al., 2014
Mohd-Radzman et al., 2016

Systemic pathways regulating lateral root and nodule formation are mediated by different signaling peptides

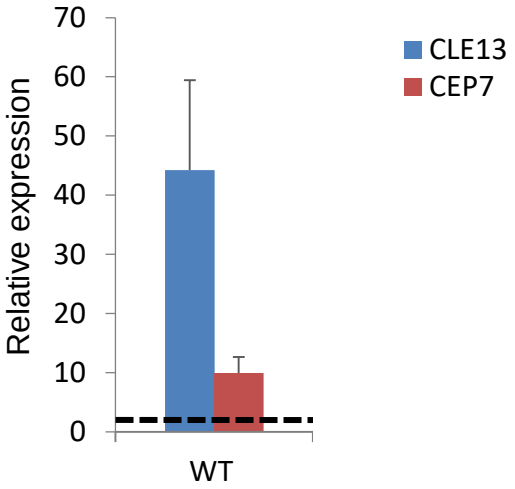


Mortier et al., 2012

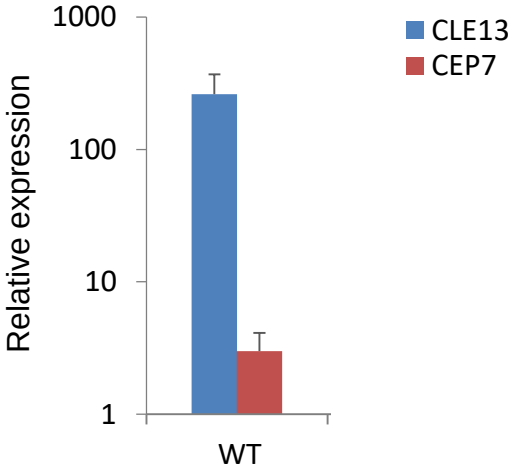
The symbiotic regulation of the production of MtCEP7 peptides relies on the CRE1 cytokinin receptor



NF

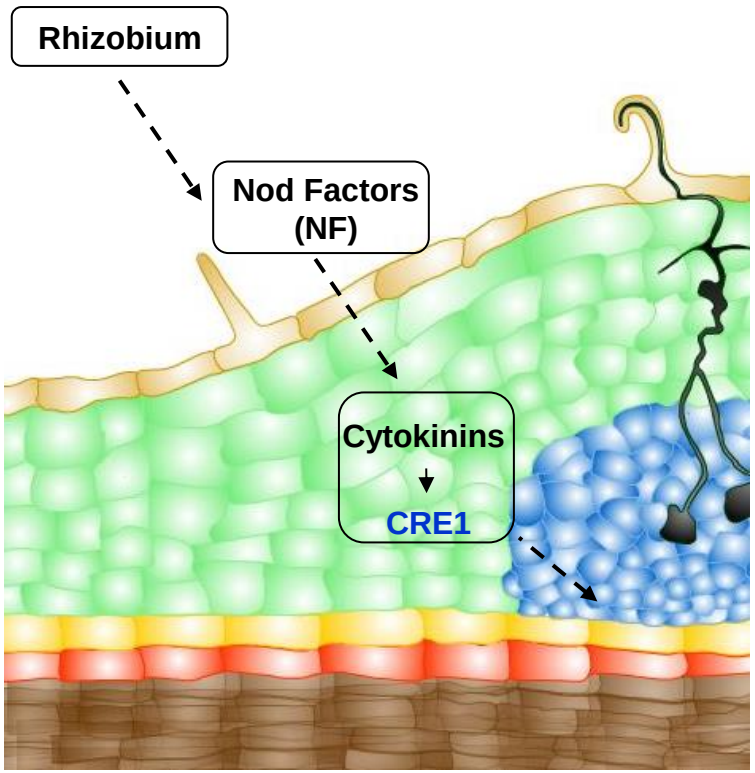


cytokinin

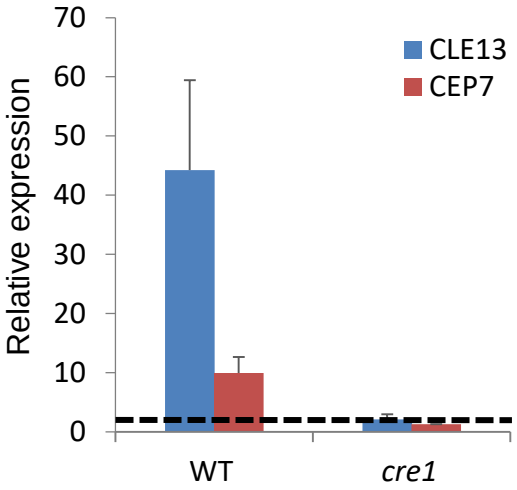


Laffont et al., 2020

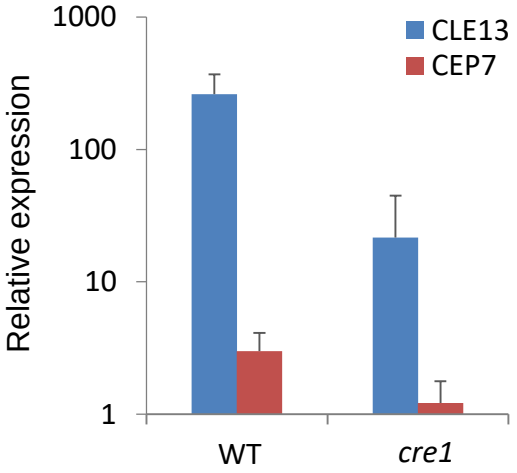
The symbiotic regulation of the production of MtCEP7 peptides relies on the CRE1 cytokinin receptor



NF

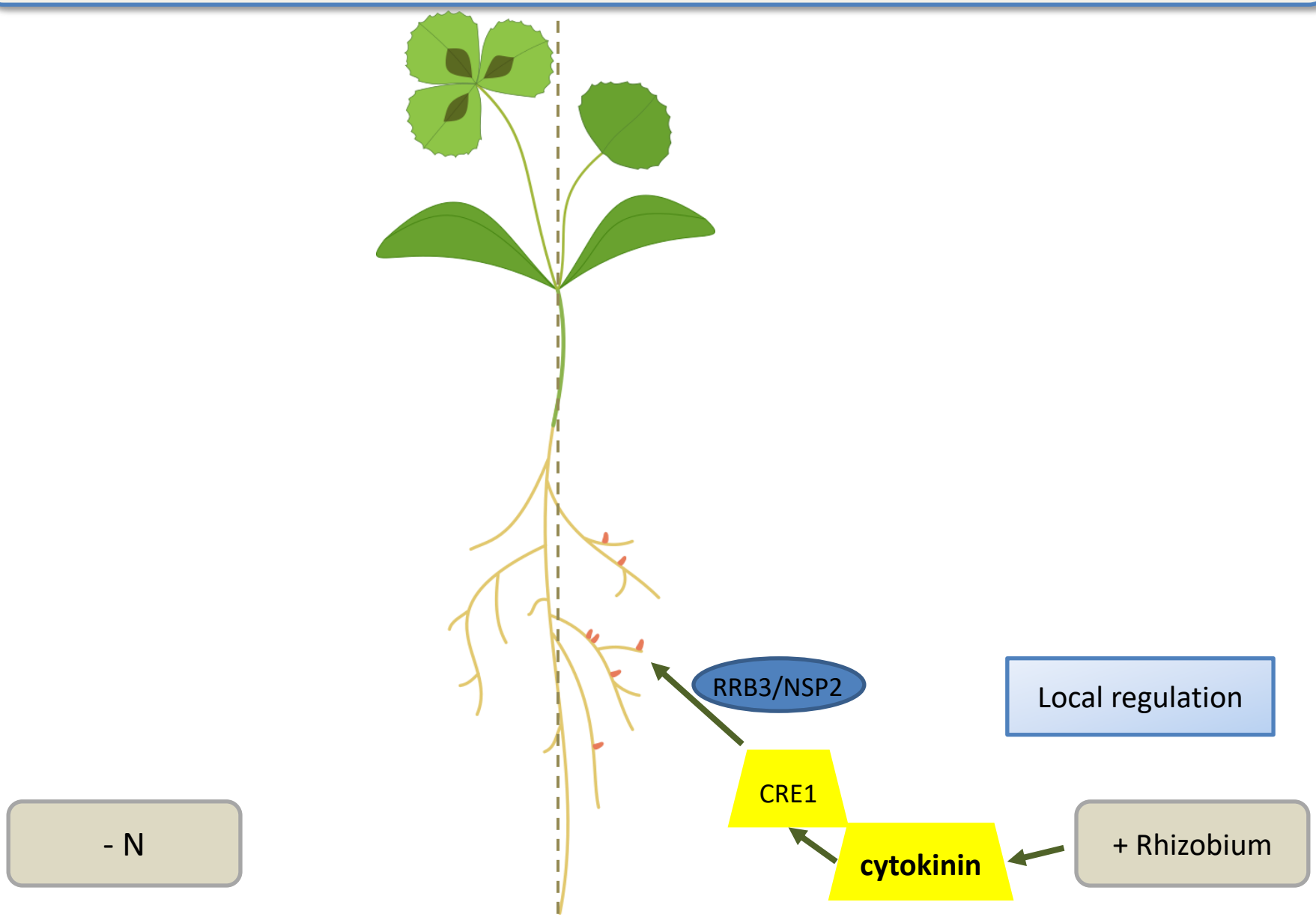


cytokinin

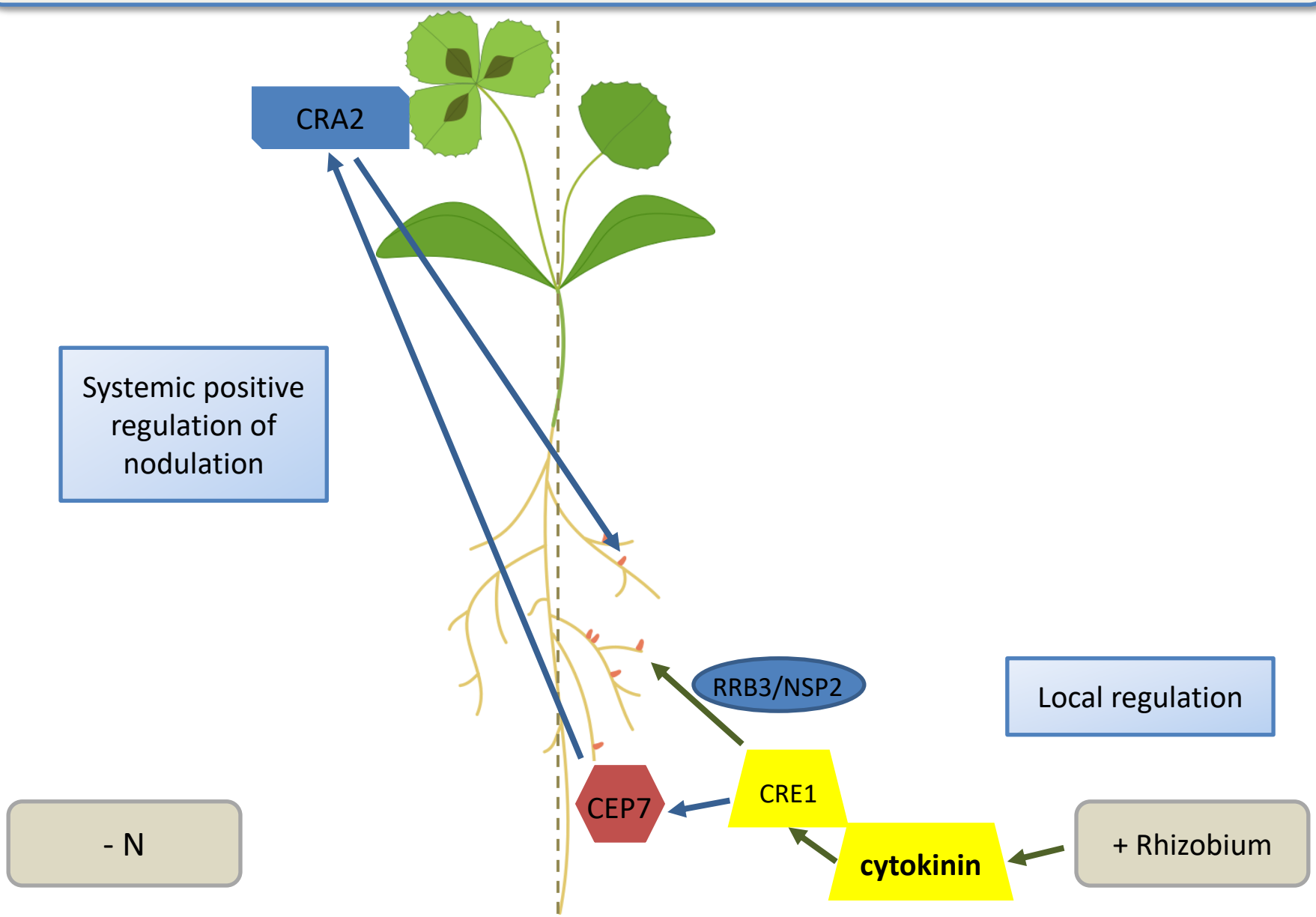


Laffont et al., 2020

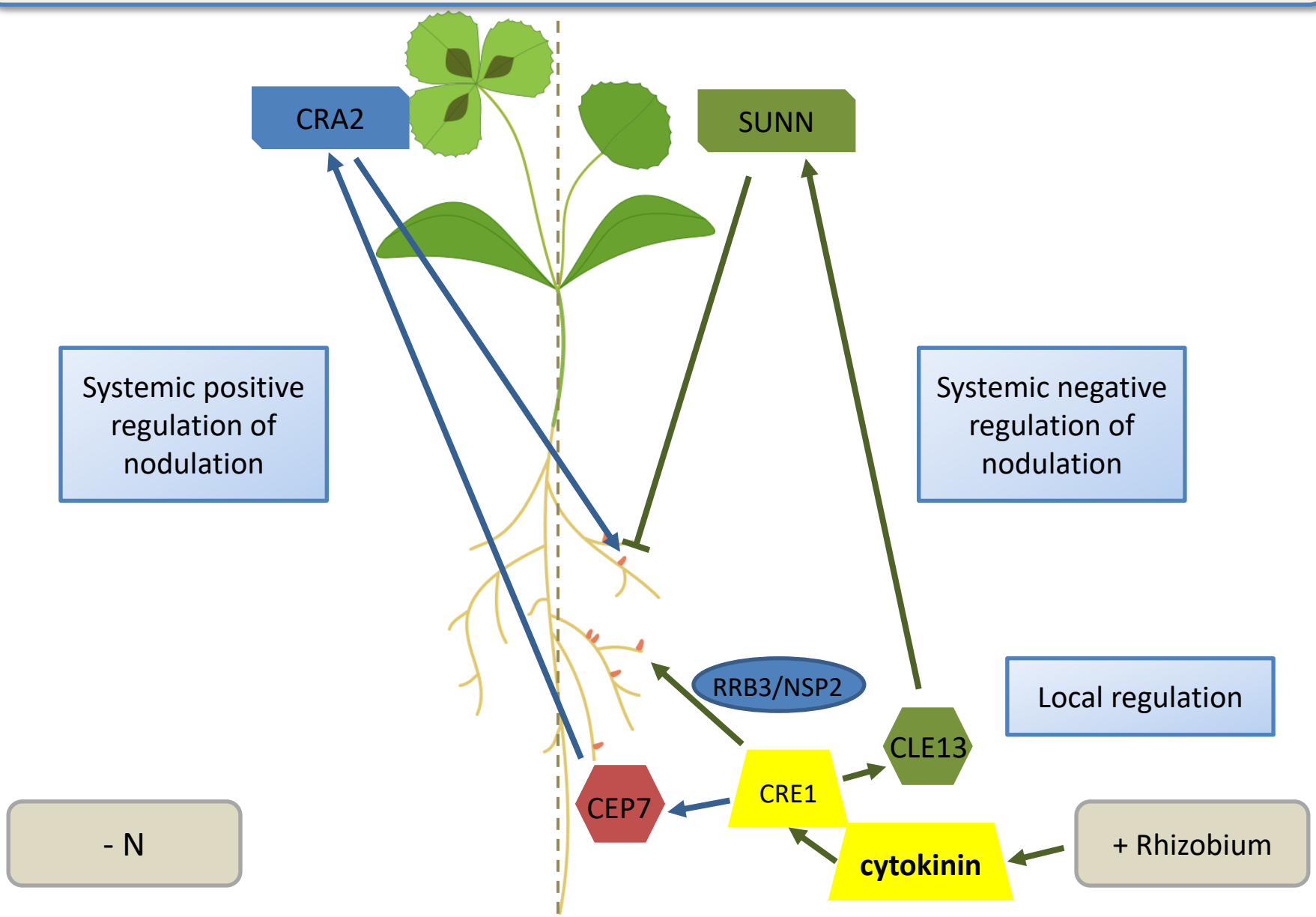
Symbiotic nodulation is tightly controlled by the integration of cytokinin-dependent systemic and local regulatory pathways



Symbiotic nodulation is tightly controlled by the integration of cytokinin-dependent systemic and local regulatory pathways



Symbiotic nodulation is tightly controlled by the integration of cytokinin-dependent systemic and local regulatory pathways



Acknowledgements

Silvina Gonzalez-Rizzo
Julie Plet
Federico Ariel
Marianne Brault-Herdandez
Stéphane Boivin
Sovanna Tan
Camille Fonouni-Farde
Emeline Huault
Pierre Gautrat
Carole Laffont
Anouck Diet
Mathias Brault
Florian Frugier

IPS2 Institute of Plant Sciences Paris - Saclay

Peptides:
Nijat Imin, Michael Djordjevic;
Canberra University, Australia

Sofie Goormachtig;
VIB-Ghent, Belgium

Mutants:
Virginie Bourion, Gérard Duc;
INRA-Dijon, France

Kiran Mysore, Jiangqi Wen;
Noble Foundation, USA

Peter Kalo, Gabriella Endre,
Hungary

AGENCE NATIONALE DE LA RECHERCHE ANR
SPS SCIENCES PLANTES SACLAY
université PARIS-SACLAY
Université de Paris
cnrs