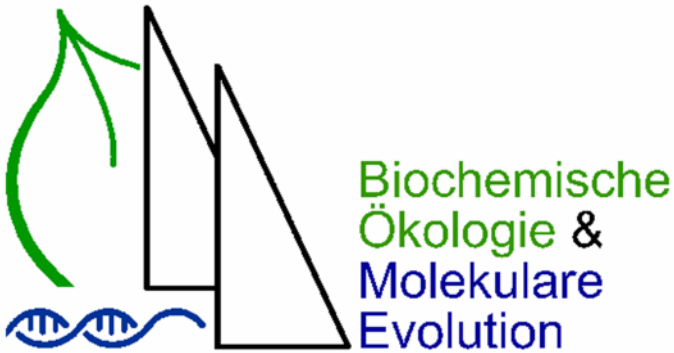
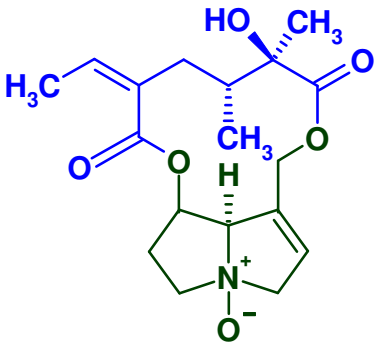
Vorkommen und Verbreitung von Pyrrolizidinalkaloiden in Pflanzen



Dietrich Ober

Botanisches Institut und Botanischer Garten
Universität Kiel

The Model System: Pyrrolizidine Alkaloids (PAs)



necic acid

necine base

senecionine *N*-oxide

- **ester alkaloids**, constitutively produced
- in most cases **toxic** (to vertebrates and insects)
- part of fascinating **interactions** between plants and specialized insects

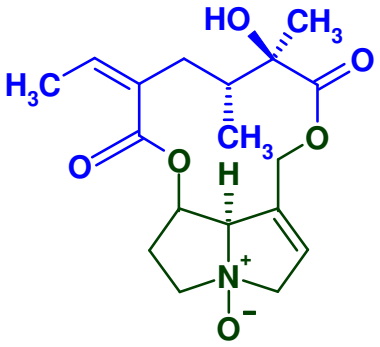
Our motivation:

- **understanding the function and evolution of**
  - **PA biosynthesis in plants**
  - **of specific adaptations to PAs by insects**

Tyria jacobaeae at the Kiel fjord

© *Dietrich Ober*

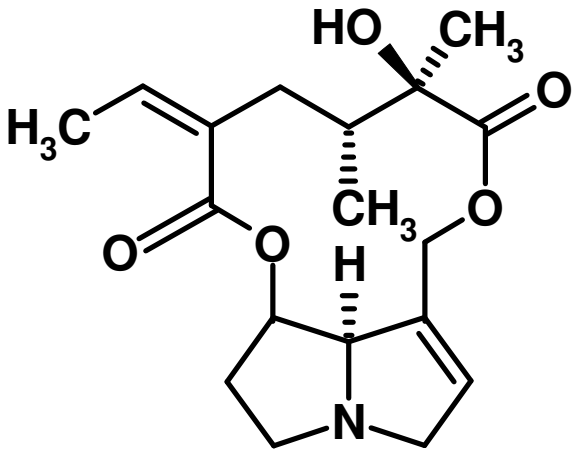
Insects with specific adaptations to PA-containing plants



	Alkaloid accumulation in the insect	Warning coloration of the insect	Alkaloid-based pheromones	PA-dependent morphology	PA-dep. behaviour
Beetles (Coleoptera) larvae of certain leaf bettles	×	×			
Grasshoppers (Orthoptera) e.g. West-african *Zonocerus*	×	×			
Aphids certain species	×				
Lepidoptera various moths and butterflies	×	×	×	×	×

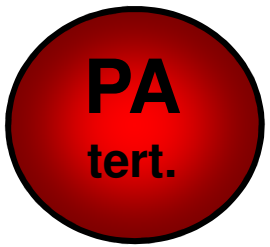
Toxic principle of pyrrolizidine alkaloids

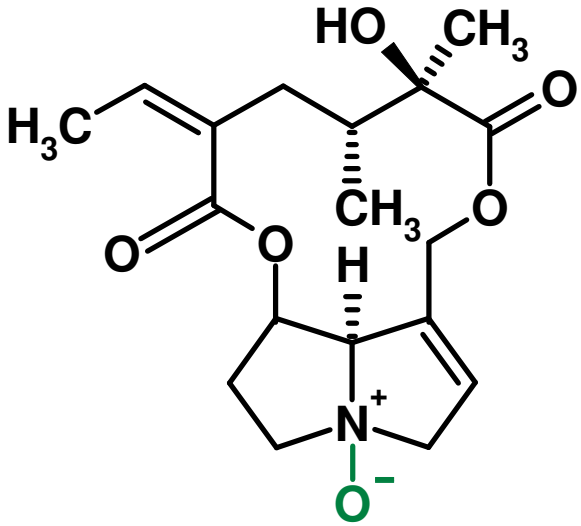
The two faces of pyrrolizidine alkaloids



tertiary PA

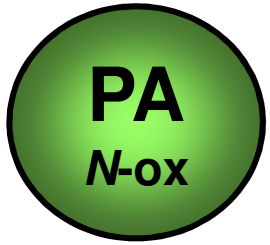
- lipophilic
- toxic after bioactivation





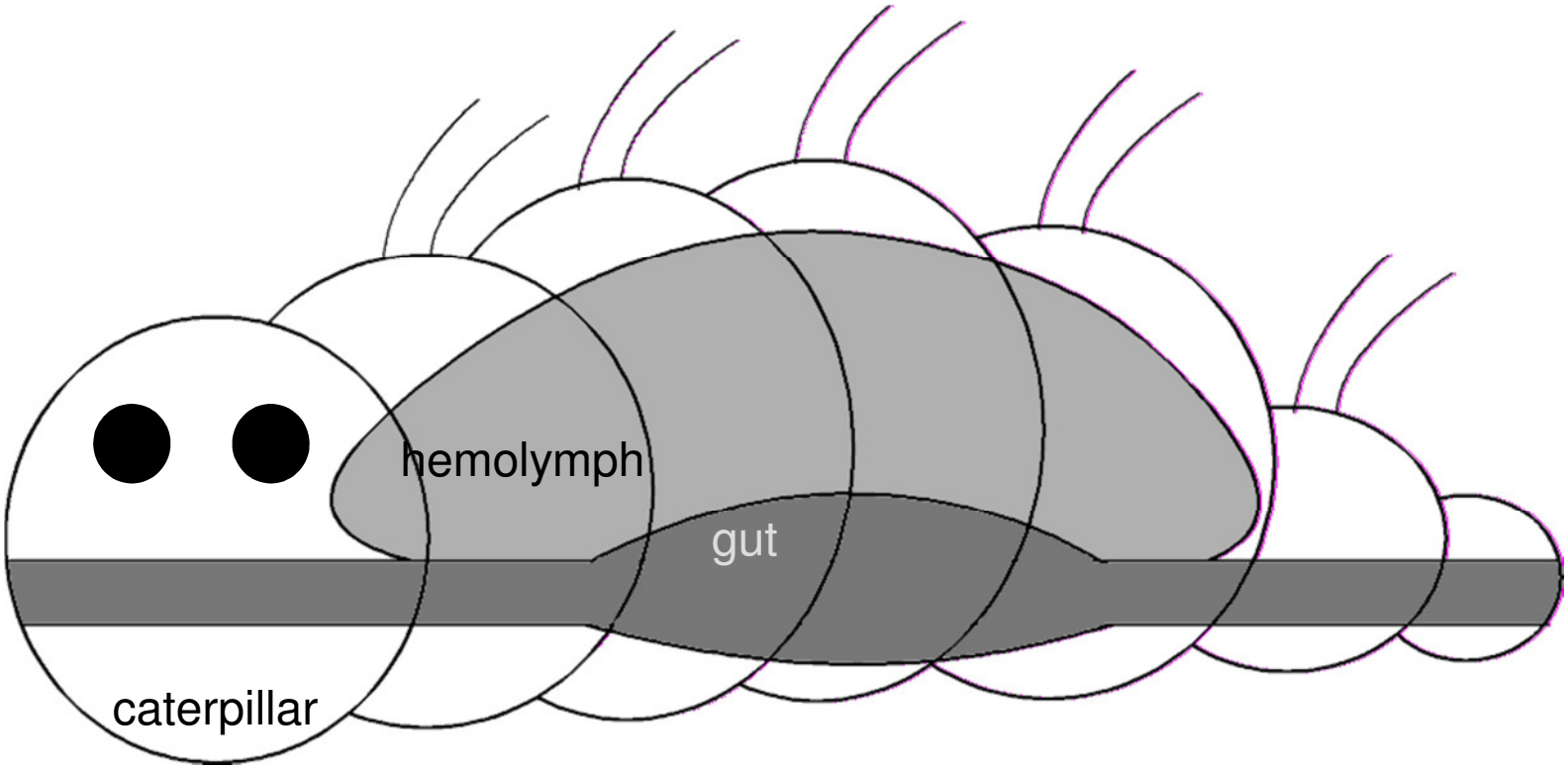
PA *N*-oxide

- hydrophilic
- nontoxic



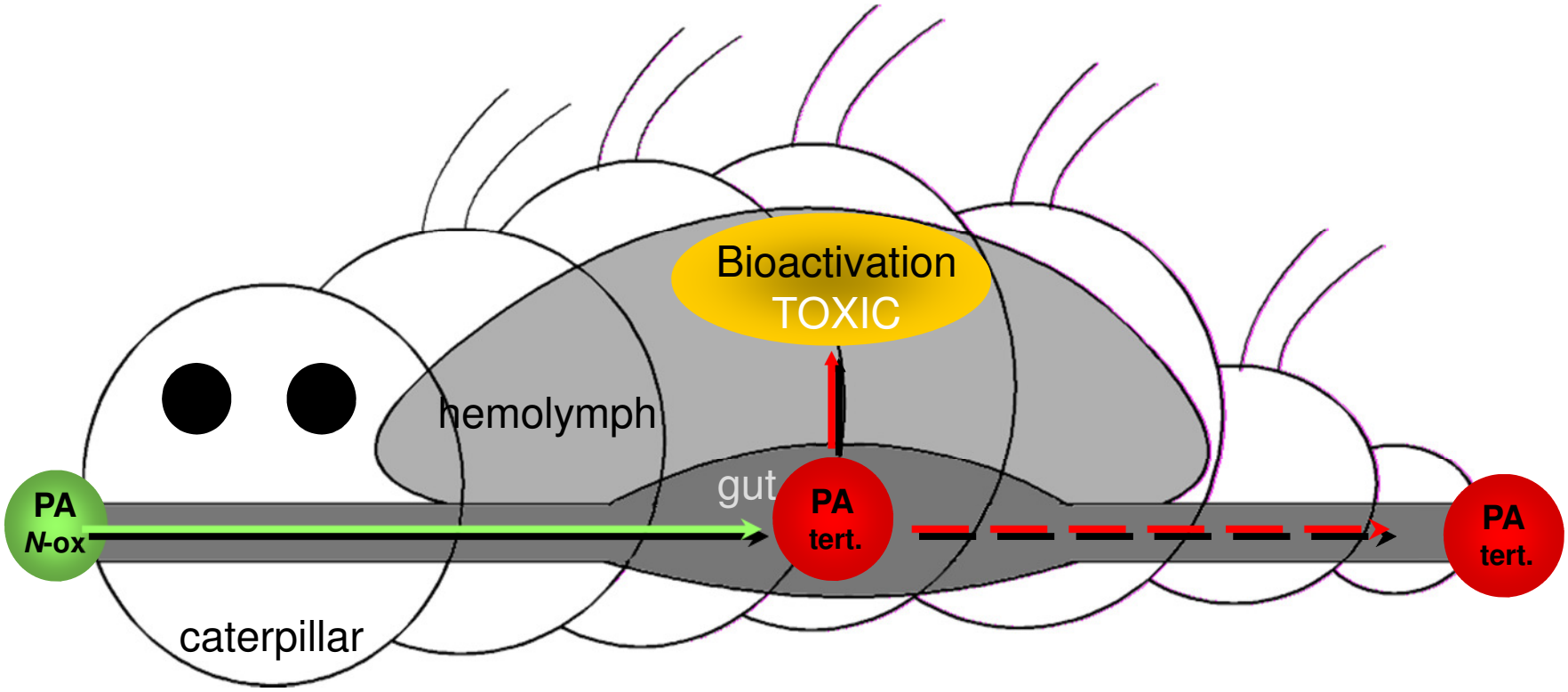
Toxic principle of pyrrolizidine alkaloids

in a **nonadapted** herbivor



Toxic principle of pyrrolizidine alkaloids

in a **nonadapted** herbivor



- unspecific reduction
- partial excretion
- passive resorption ⇨ bioactivation by cyt.P450s in hemolymph

Sequestration of toxic pyrrolizidine alkaloids

Orthoptera
(order of grasshoppers, locusts, and crickets)

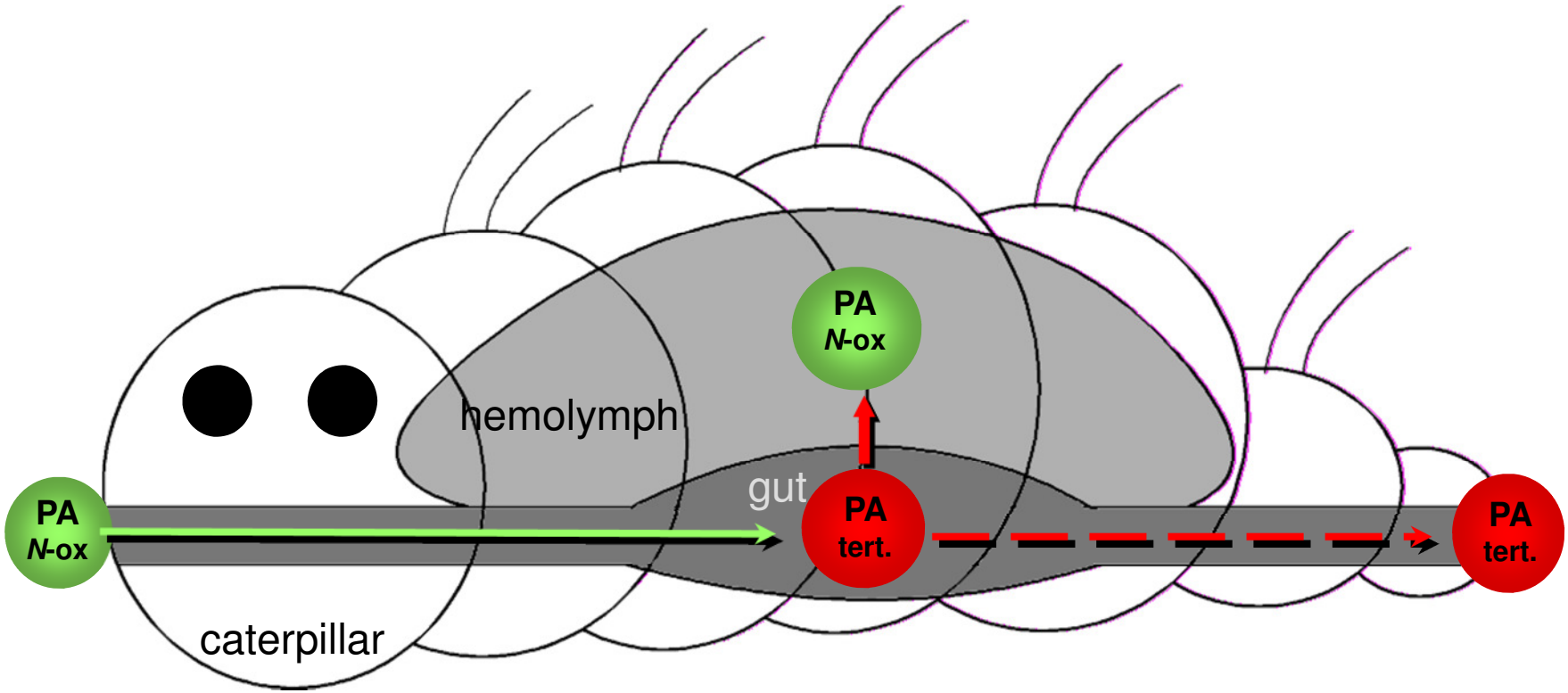
genus: *Zonocerus*
e. g. *Zonocerus variegatus*

Lepidoptera
(order of butterflies and moths)

family: Arctiidae (certain moths)
e. g. *Tyria jacobaeae*

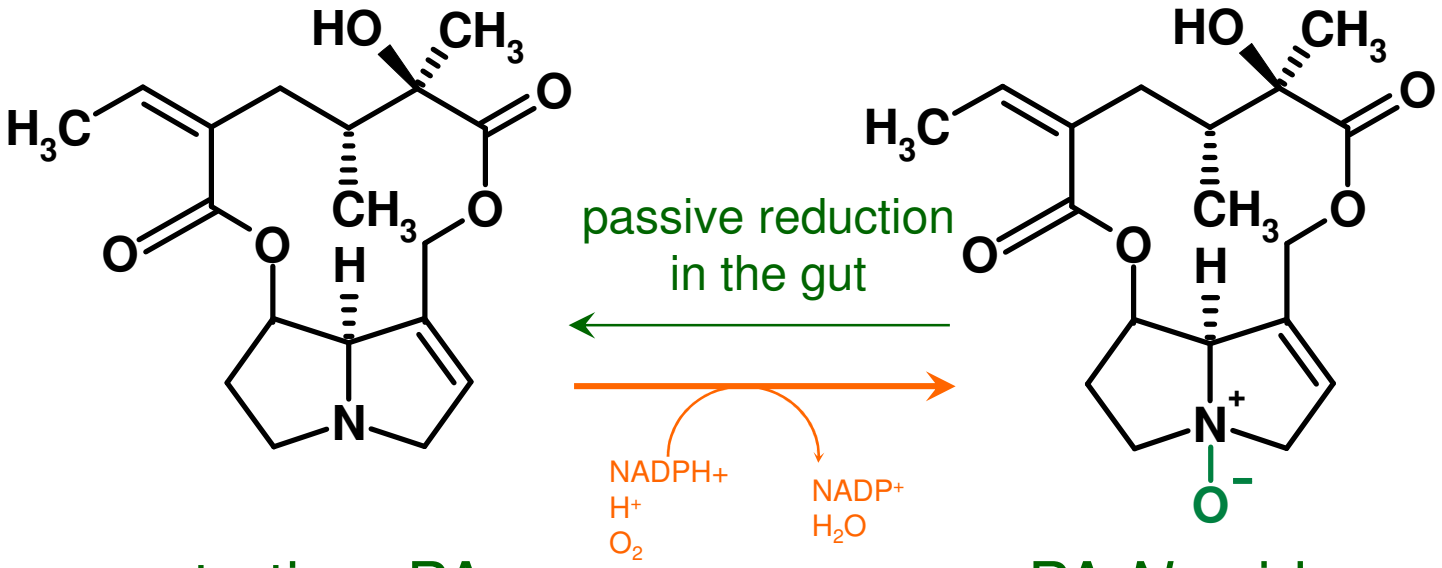
family: Nymphalidae (butterflies)

Sequestration of toxic pyrrolizidine alkaloids in an **adapted** herbivor



Sequestration of toxic pyrrolizidine alkaloids in an **adapted** herbivor

The two faces of pyrrolizidine alkaloids



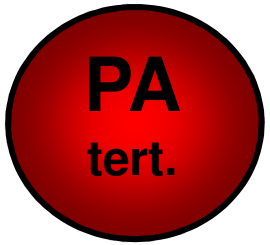
tertiary PA

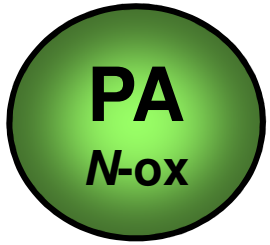
senecionine *N*-oxygenase

PA *N*-oxide

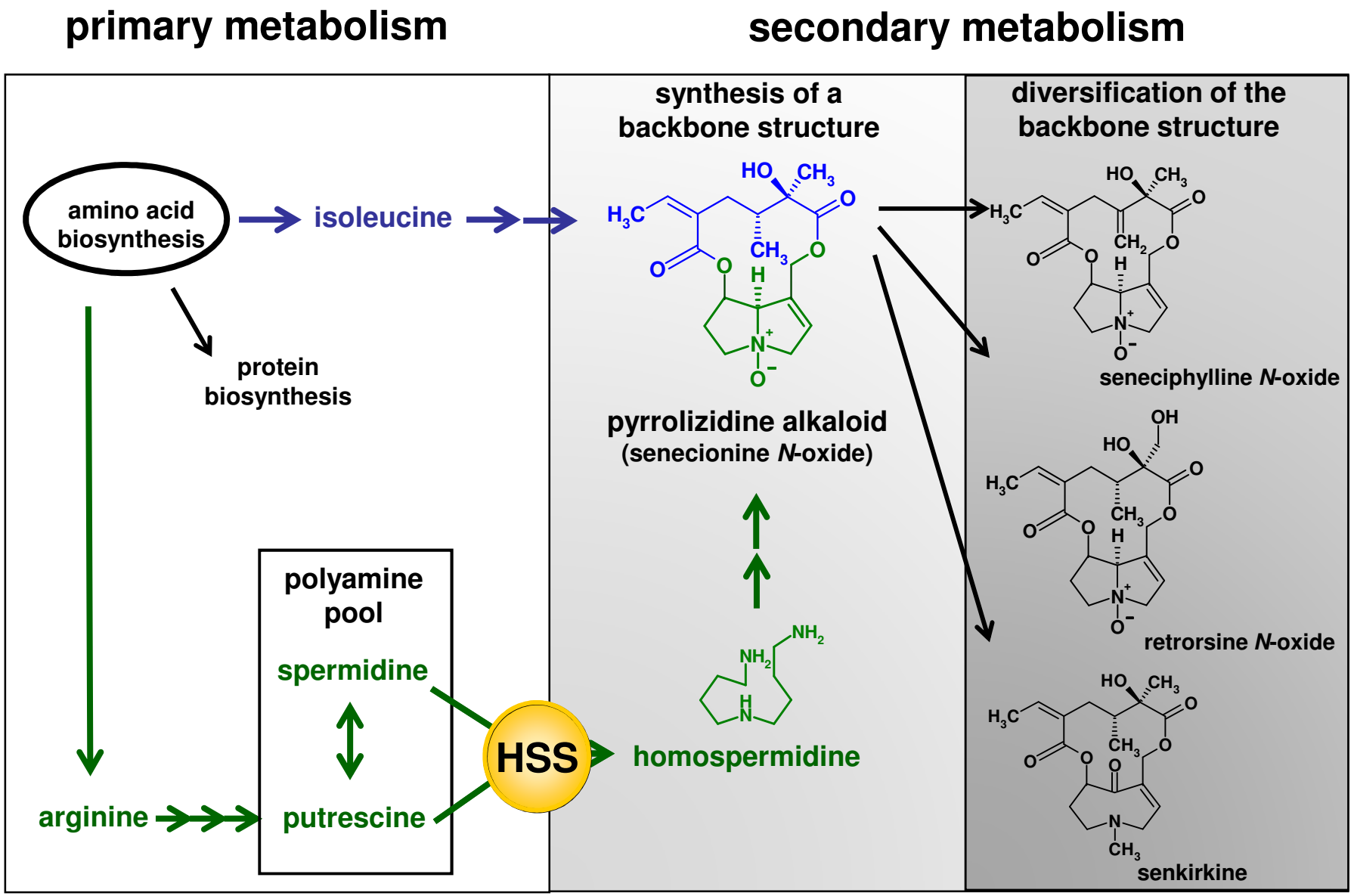
- lipophilic
- toxic after bioactivation

- hydrophilic
- nontoxic



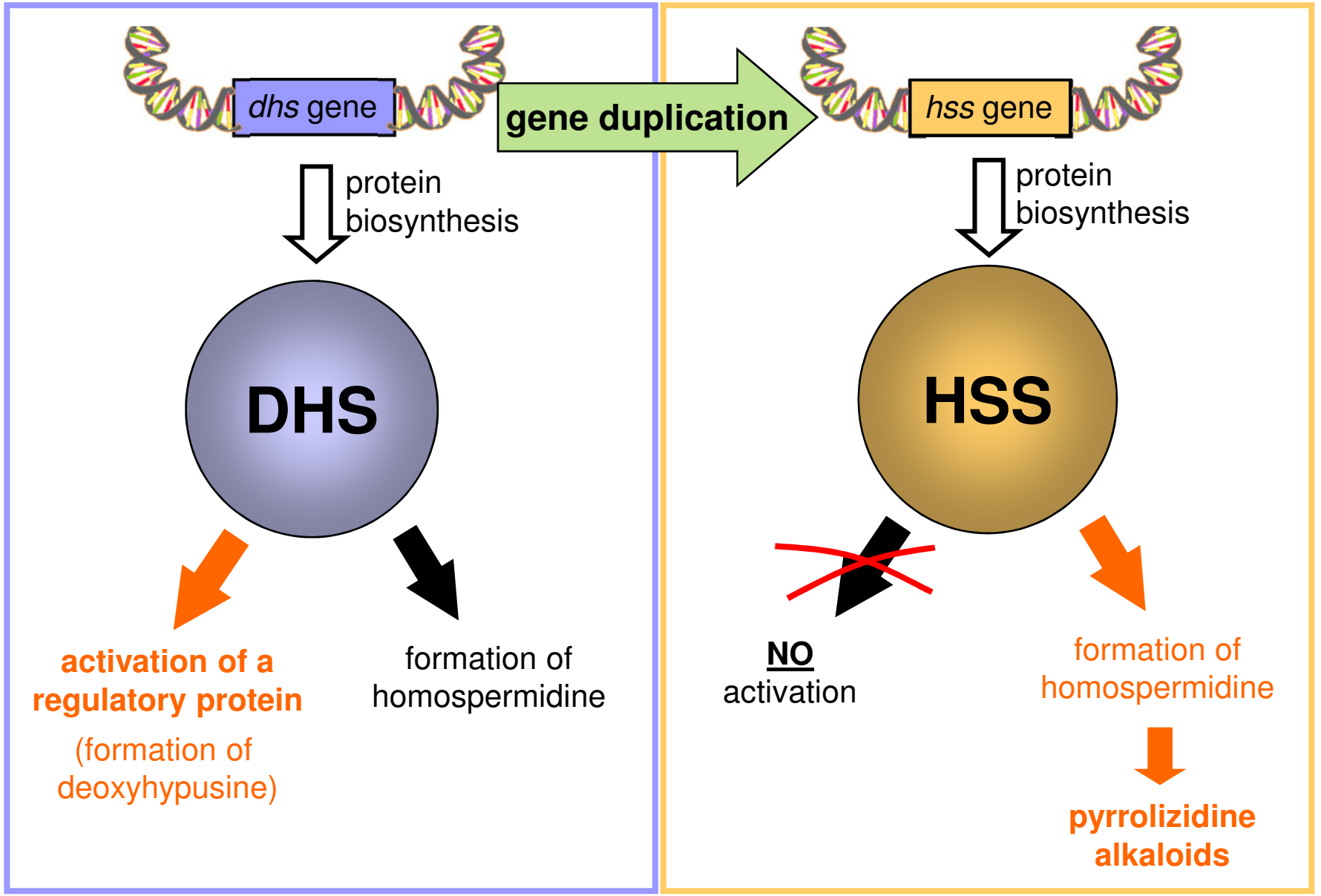


Biosynthesis



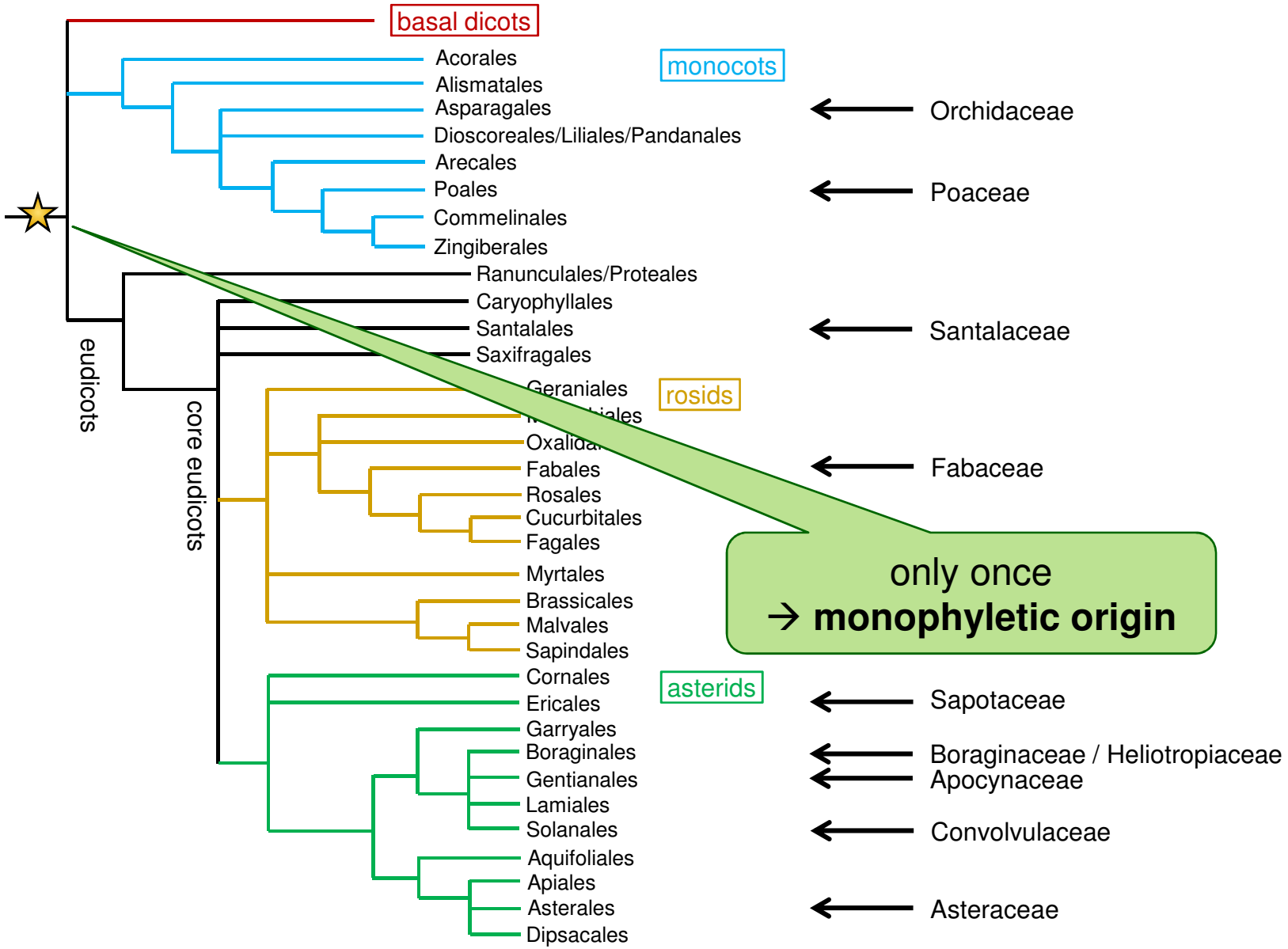
Ober & Hartmann (2000) Plant Mol Biol

Evolution of homospermidine synthase by gene duplication



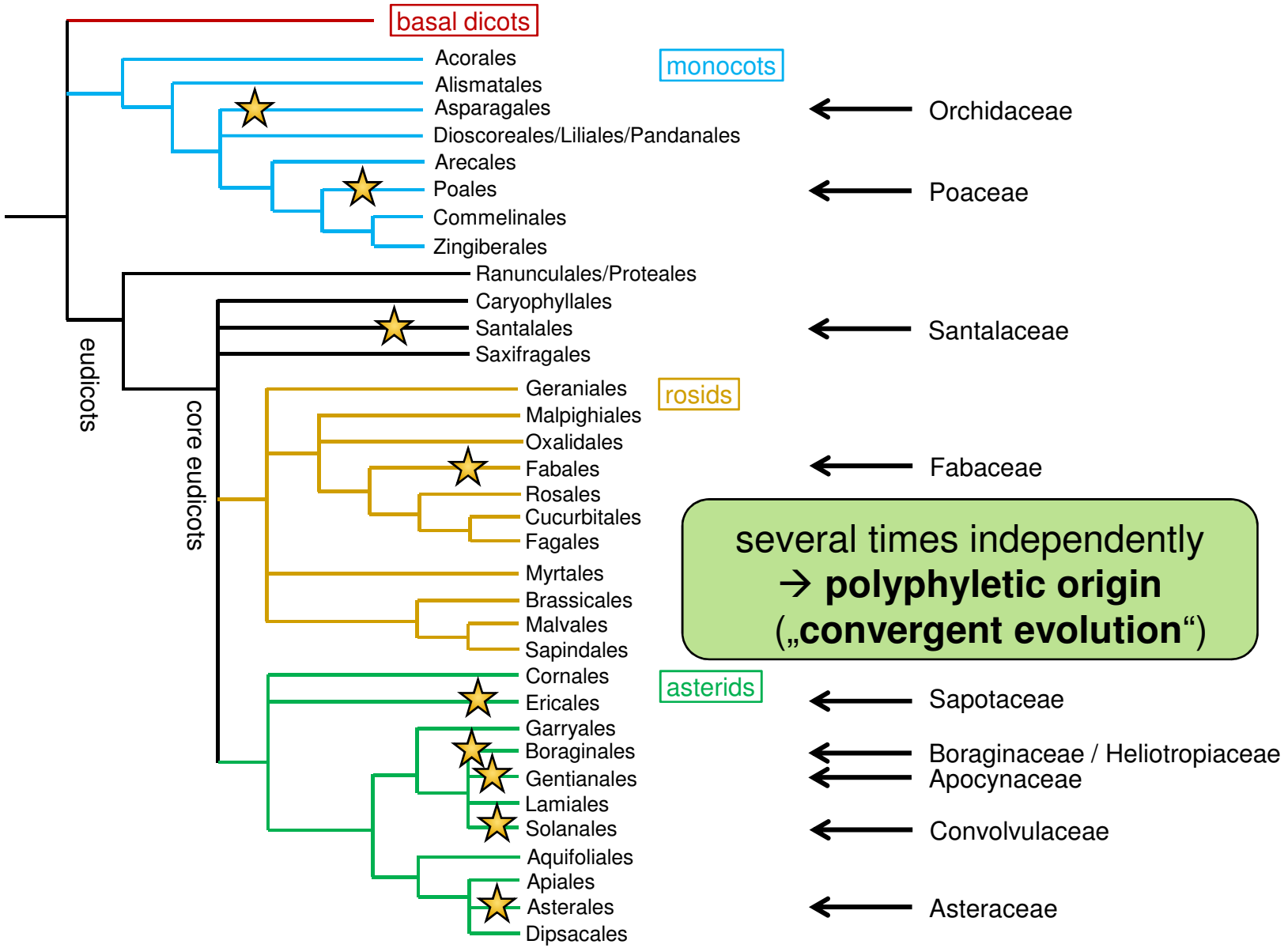
Ober et al. (2003) JBC

Occurrence of pyrrolizidine alkaloids



modified from Angiosperm Phylogeny Group III (2009)

Occurrence of pyrrolizidine alkaloids



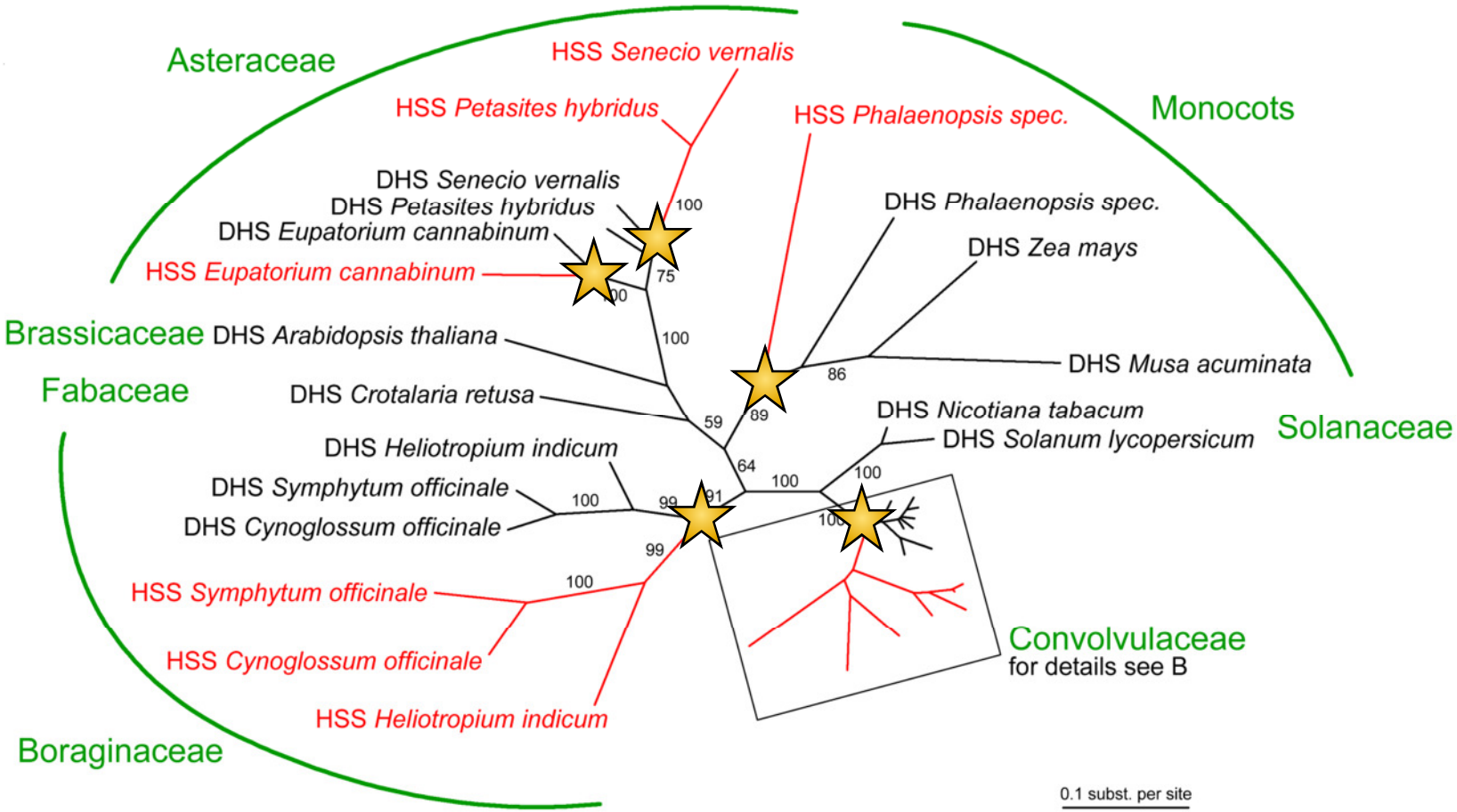
modified from Angiosperm Phylogeny Group III (2009)

Phylogenetic tree of DHS- and HSS-coding cDNA sequences

HSS coding cDNA

DHS coding cDNA

Maximum Likelihood Tree
Bootstrap proportions: 1000 replicates



Kaltenegger et al. (2013) Plant Cell

Tissue-specific expression of HSS

***Phalaenopsis* (orchid)**

→flower buds

→root tips

***Heliotropium* (Heliotropiaceae, Boraginales)**

→leaf epidermis

***Symphytum* (Boraginaceae, Boraginales)**

→root: only endodermis

***Cynoglossum* (Boraginaceae, Boraginales)**

→root: endodermis and pericycle

***Eupatorium* (Asteraceae)**

→cortex cells in the root

***Senecio* (Asteraceae)**

→group of cells in the root

→ HSS expression is highly specific

→ HSS highly variable between different plant lineages

Tissue-specific expression of HSS

C | A | U KIEL Biochemical Ecology and Molecular Evolution

Analysis of HSS-Evolution within the Convolvulaceae

Morning Glory Family

- belongs to the order Solanales
- approximately 1600-1700 species

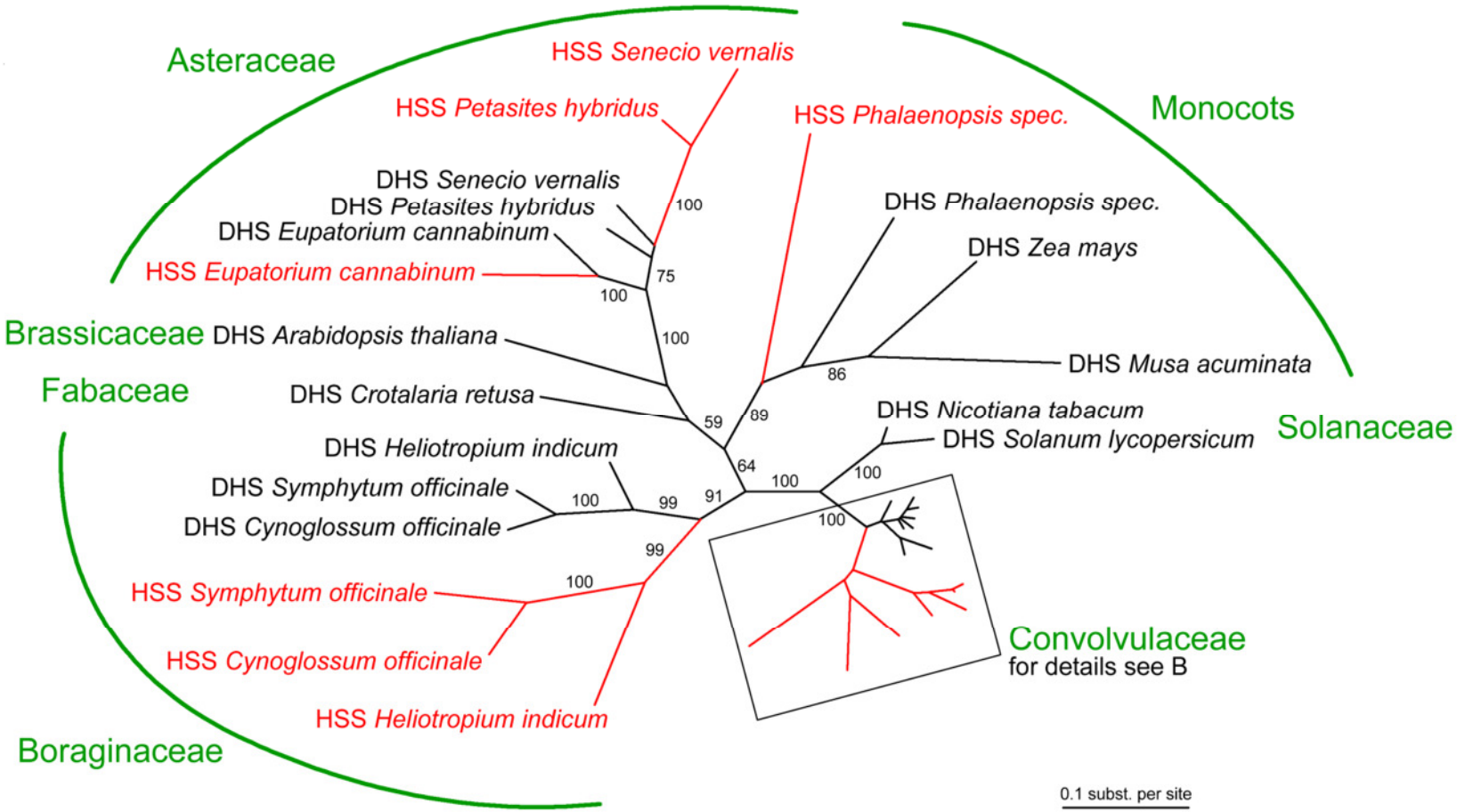
- PAs have been detected
  → only in individual unrelated species
  → of quite diverse chemical structures

Phylogenetic tree of DHS- and HSS-coding cDNA sequences

HSS coding cDNA

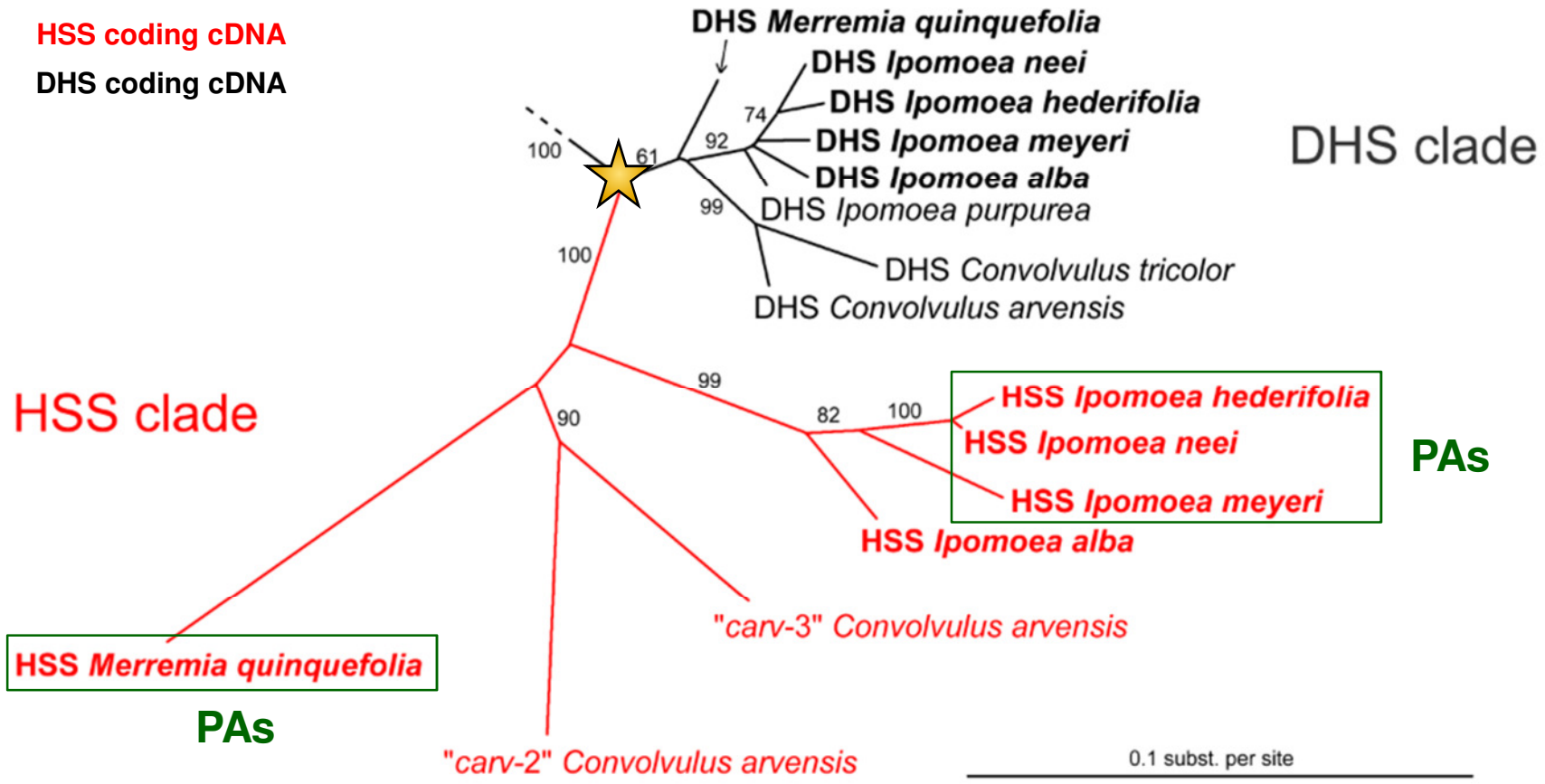
DHS coding cDNA

Maximum Likelihood Tree
Bootstrap proportions: 1000 replicates



Kaltenegger et al. (2013) Plant Cell

Analysis of HSS-Evolution within the Convolvulaceae



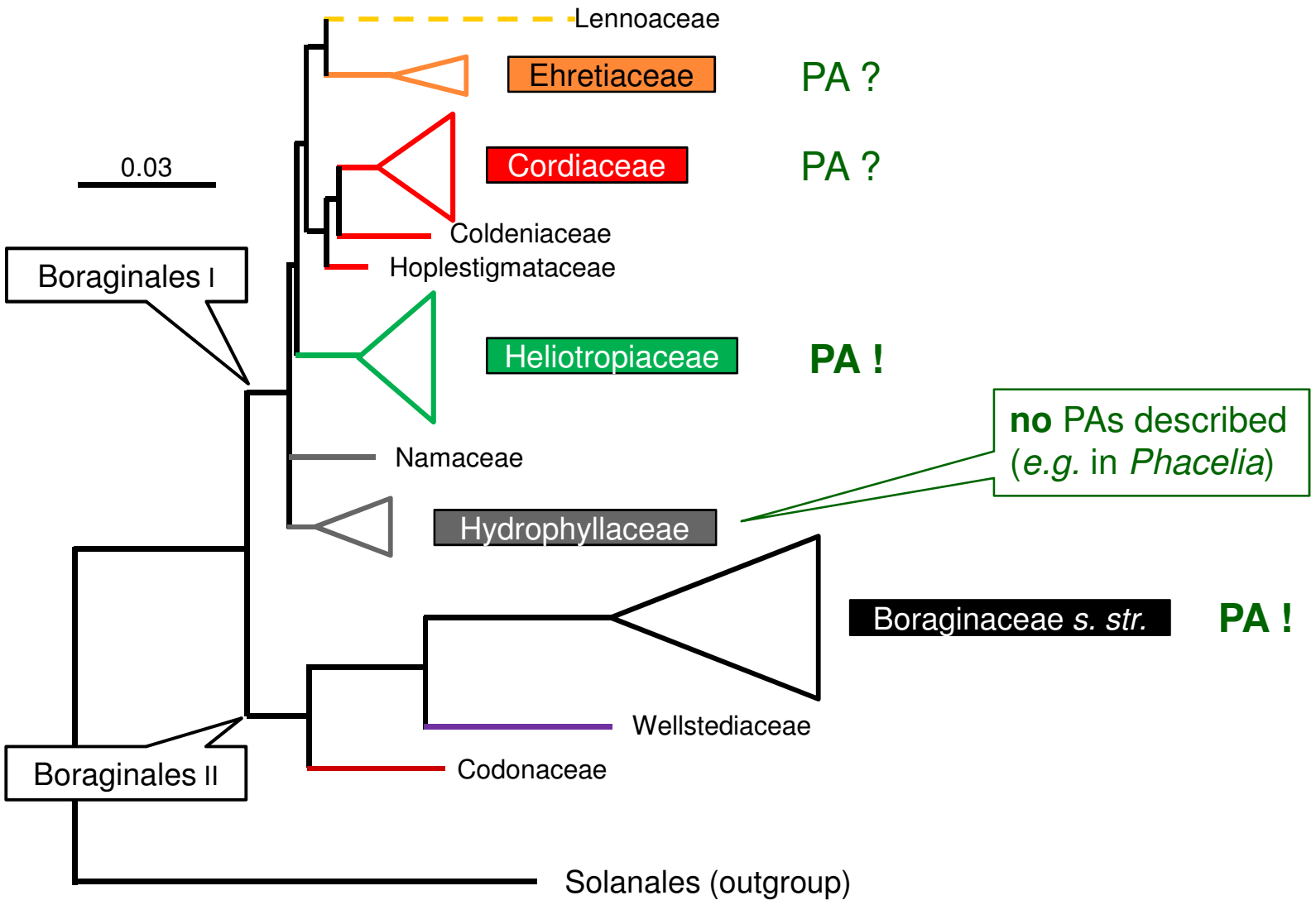
- only **one gene duplication** event within the Convolvulaceae lineage
- **pseudogenization** and **gene loss** of the HSS-related gene copy in several PA-free species

Kaltenegger et al. (2013) Plant Cell

Phylogeny of the Boraginales

Phylogeny based on four chloroplast sequences

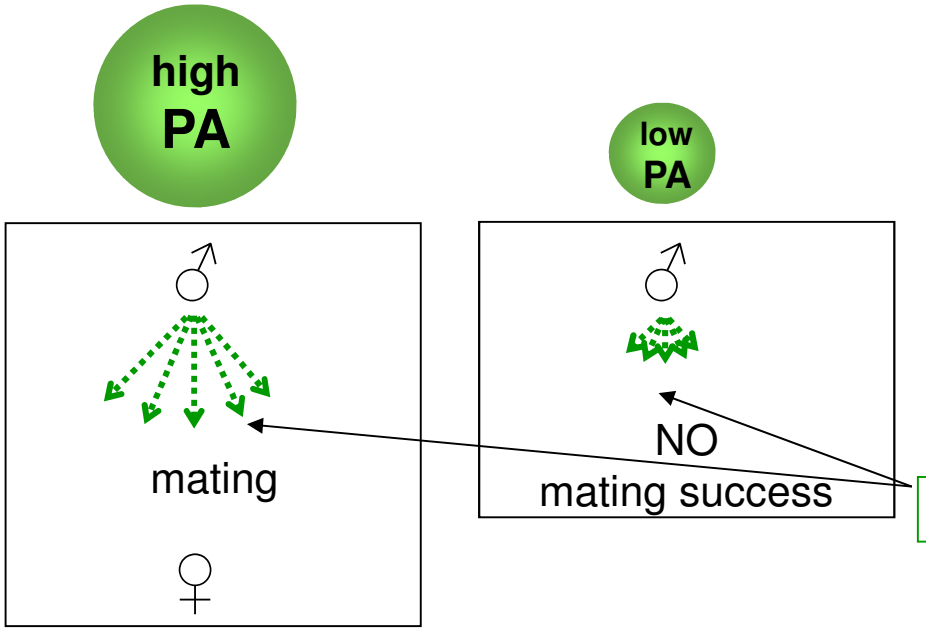
modified from Weigend et al. (2013) Cladistics



PA biosynthesis within Fabaceae

- **PA occurrence** is described for the two closely related genera of *Crotalaria* and *Lotononis*
- **PAs** are used by **specialized insects** like *Utetheisa ornatrix*

→ search for a PA-specific HSS was not successfull



PAs are transferred → **from the male to the female** → **to the next generation**

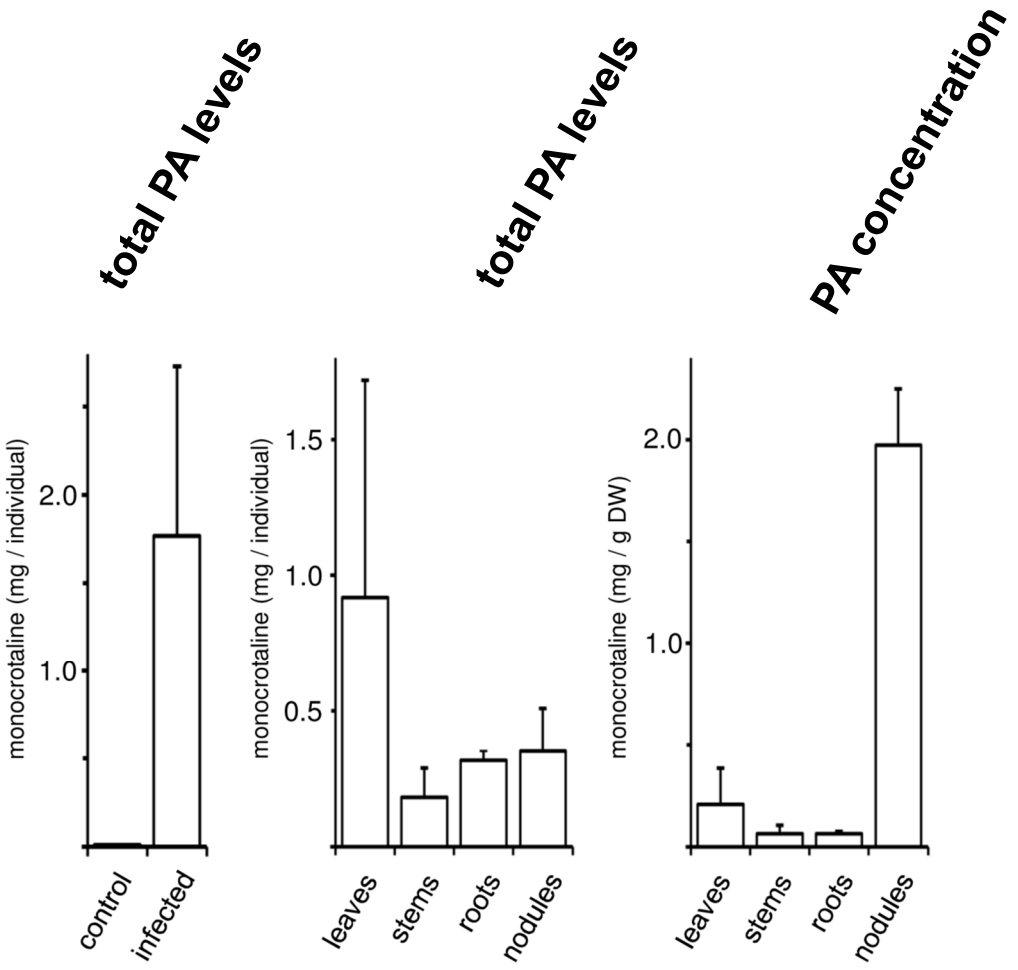
fitness advantage by plant-derived toxins

Eisner & Meinwald (1984-2000)

PA biosynthesis within Fabaceae

Comparison of nodulated and non-nodulated *C. spectabilis*

→ PA content



C. spectabilis
40 days after infection

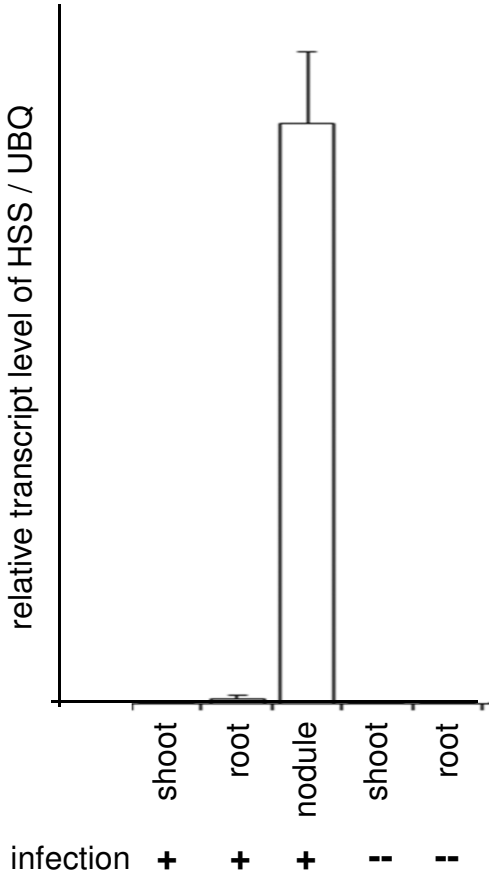
→ data suggest the nodules to be the site of PA biosynthesis

Irmer et al. (2015) PNAS

PA biosynthesis within Fabaceae

Comparison of nodulated and non-nodulated *C. spectabilis*

→ HSS expression



C. spectabilis
40 days after infection

→ HSS is expressed exclusively in the nodules

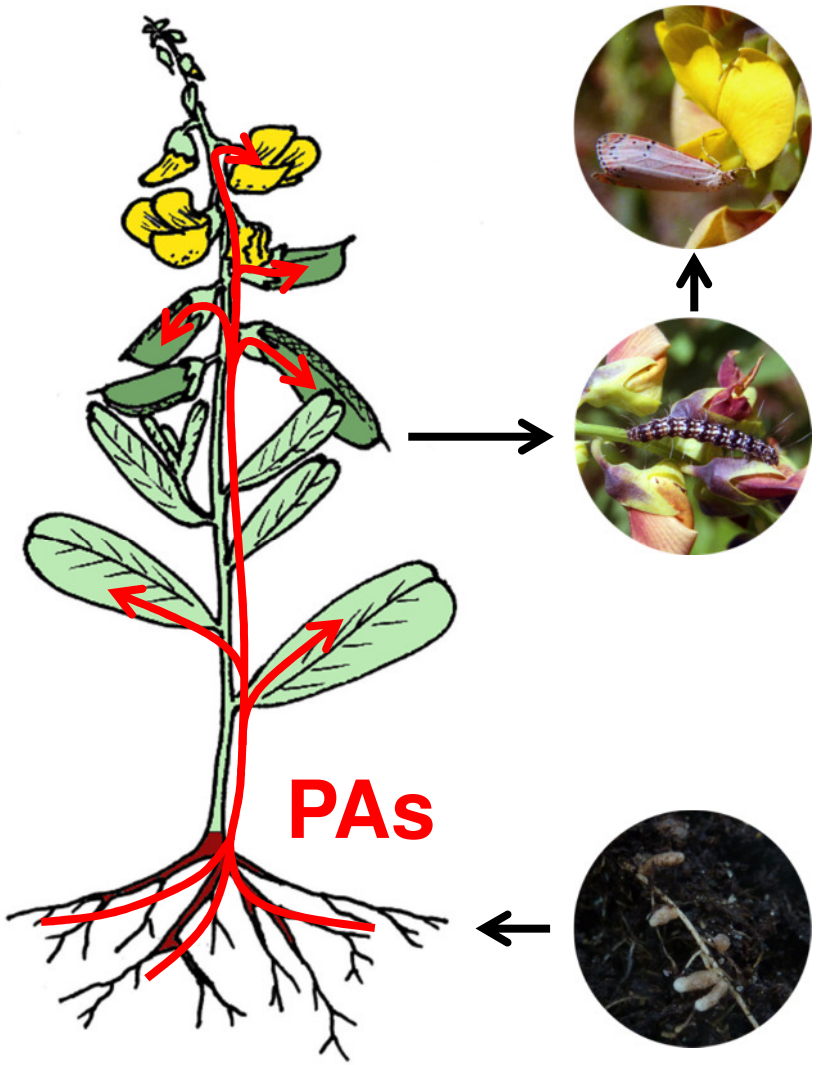
Irmer et al. (2015) PNAS

PA biosynthesis within Fabaceae

in *Crotalaria*

→ **PAs are a link between**

- **symbiotic bacteria**
- **plant**
- **specialized insect**



Thank you !

DFG DAAD

Max-Planck Institut für Evolutionsbiologie, Plön

CAU Christian-Albrechts-Universität zu Kiel

GEOMAR Helmholtz-Zentrum für Ozeanforschung Kiel

IMPRS Evolutionary Biology

ÖAW Österreichische Akademie der Wissenschaften

zeller