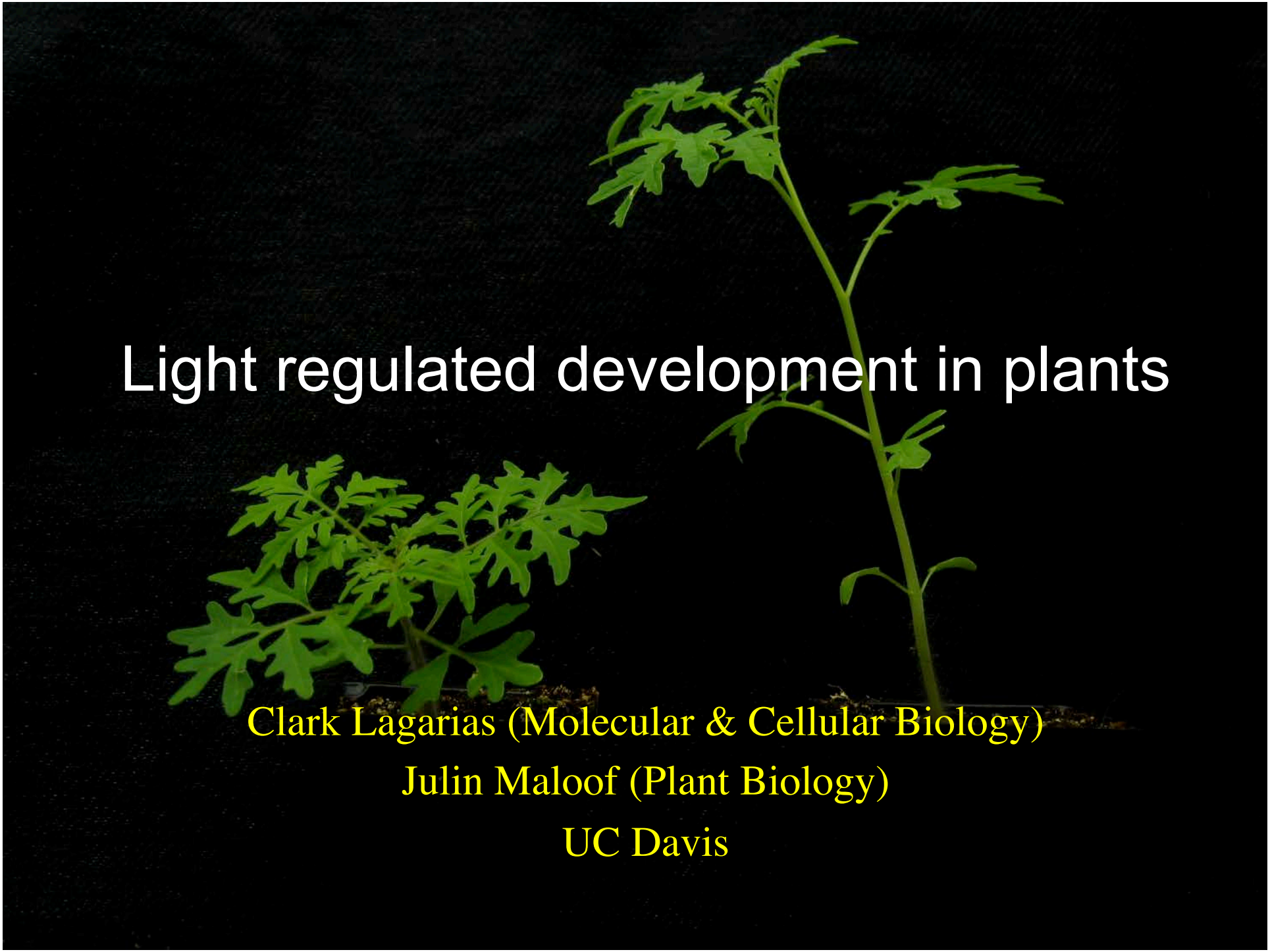


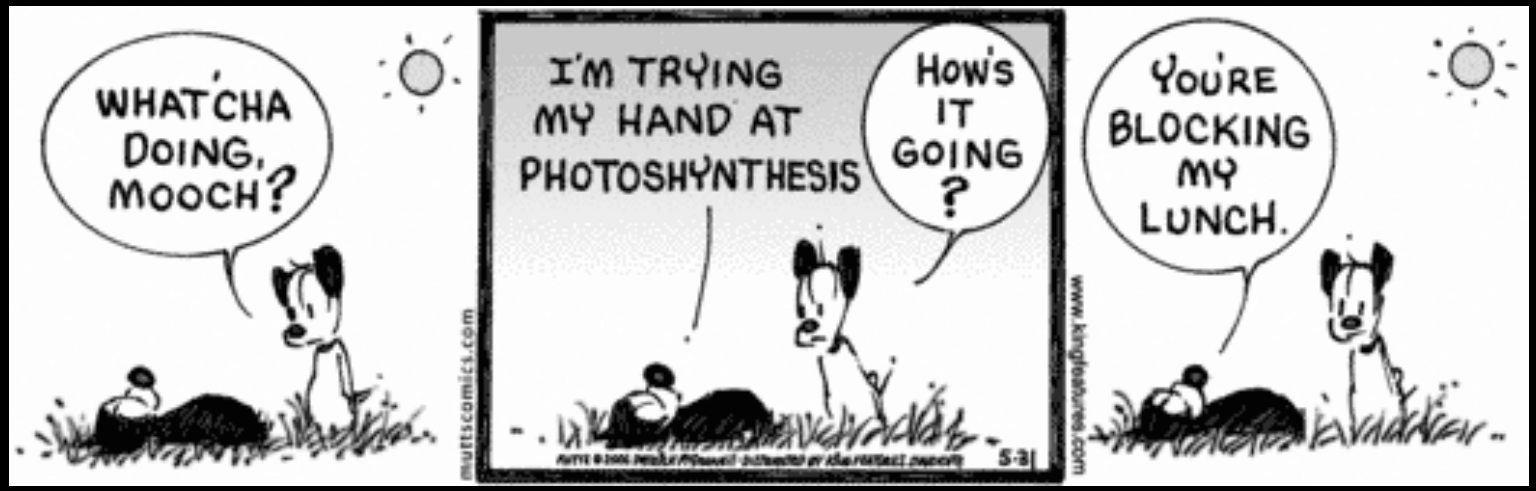
Light regulated development in plants

Clark Lagarias (Molecular & Cellular Biology)
Julin Maloof (Plant Biology)
UC Davis

Talk Outline

- Light control of Plant Development
- Photoreceptors
- Signaling Mechanisms

For plants: Light = Food



Animals can walk to better foraging

Plants must grow to better foraging

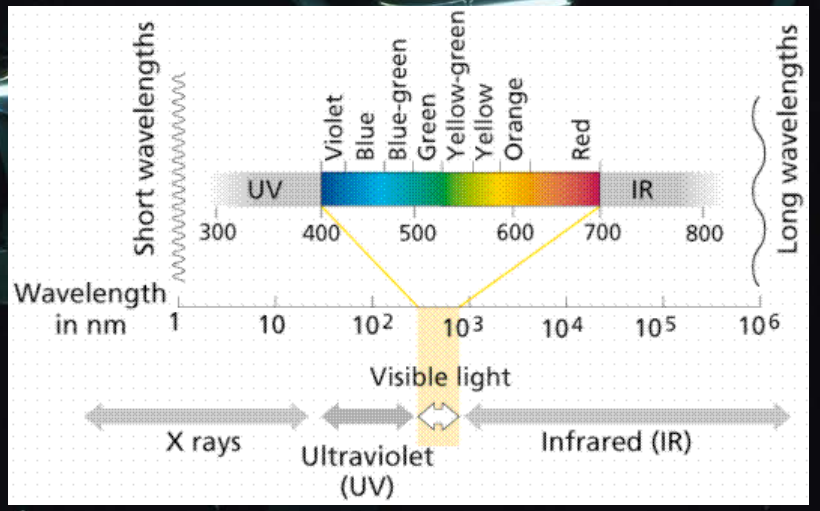
As a consequence, plant development is extensively regulated by the environment

Plants monitor many aspects of their light environment in real time

- Intensity
- Color (also known as “quality”)
- Direction
- Duration

Seed plants require light for the synthesis of chlorophyll
... and for photosynthesis.

Light regulates many aspects of development

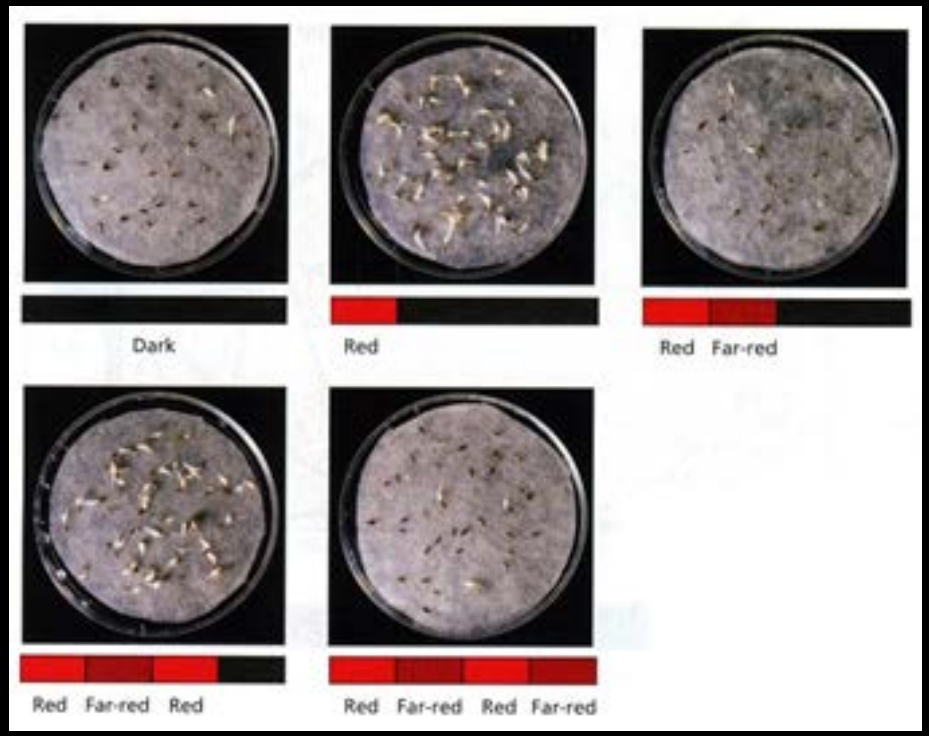


Action Spectroscopy: effectiveness of different wavelengths of light to support a biological response

Okazaki Large Spectrograph

Light regulates many aspects of development

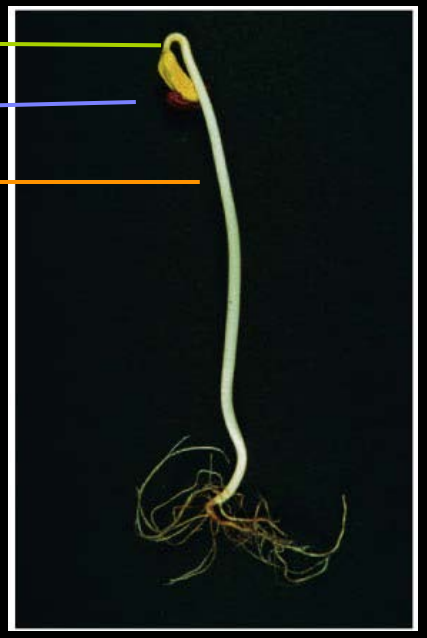
- Seed Germination
  - Light induces germination
    - Red (R) promotes germination
    - Far-red (FR) inhibits germination
    - Depends on seed size



Adapted from
Borthwick *et al*, 1952

Light regulates many aspects of development

- Seed Germination
- Seedling Emergence
  - Light is a cue for seedling emergence
  - In the dark seedlings show **etiolated** growth:
    - apical "hook"
    - unexpanded cotyledons
    - elongated hypocotyl
  - Light causes **de-etiolation**:
    - hypocotyl elongation is inhibited
    - the hook straightens
    - cotyledons expand and green



Taiz & Zeiger, Plant Physiology, Fourth Edition, Fig. 17.1 (2006)

Light regulates many aspects of development

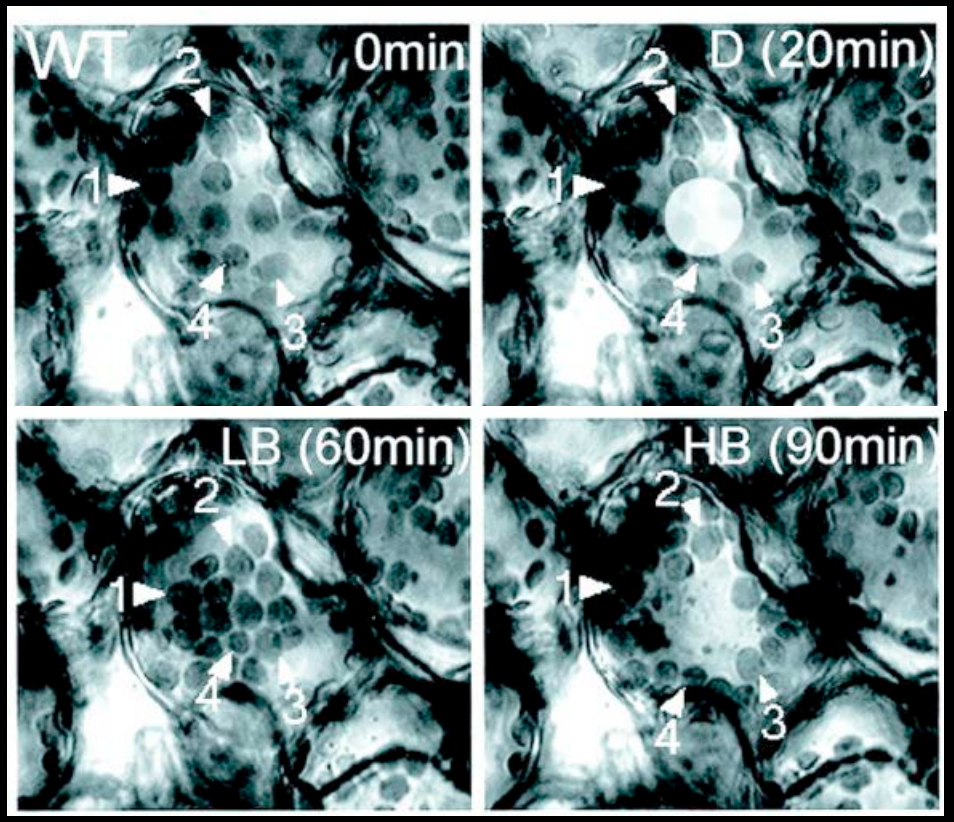
- Seed Germination
- Seedling Emergence
- Direction of growth (phototropism)

Courtesy of Takatoshi Kagawa
http://www.agbi.tsukuba.ac.jp/~k-lab/tropism/stem.html

Courtesy of Roger Hangarter: http://plantsinmotion.bio.indiana.edu

Light regulates many aspects of development

- Seed Germination
- Seedling Emergence
- Direction of growth (phototropism)
- Chloroplast arrangement within cells



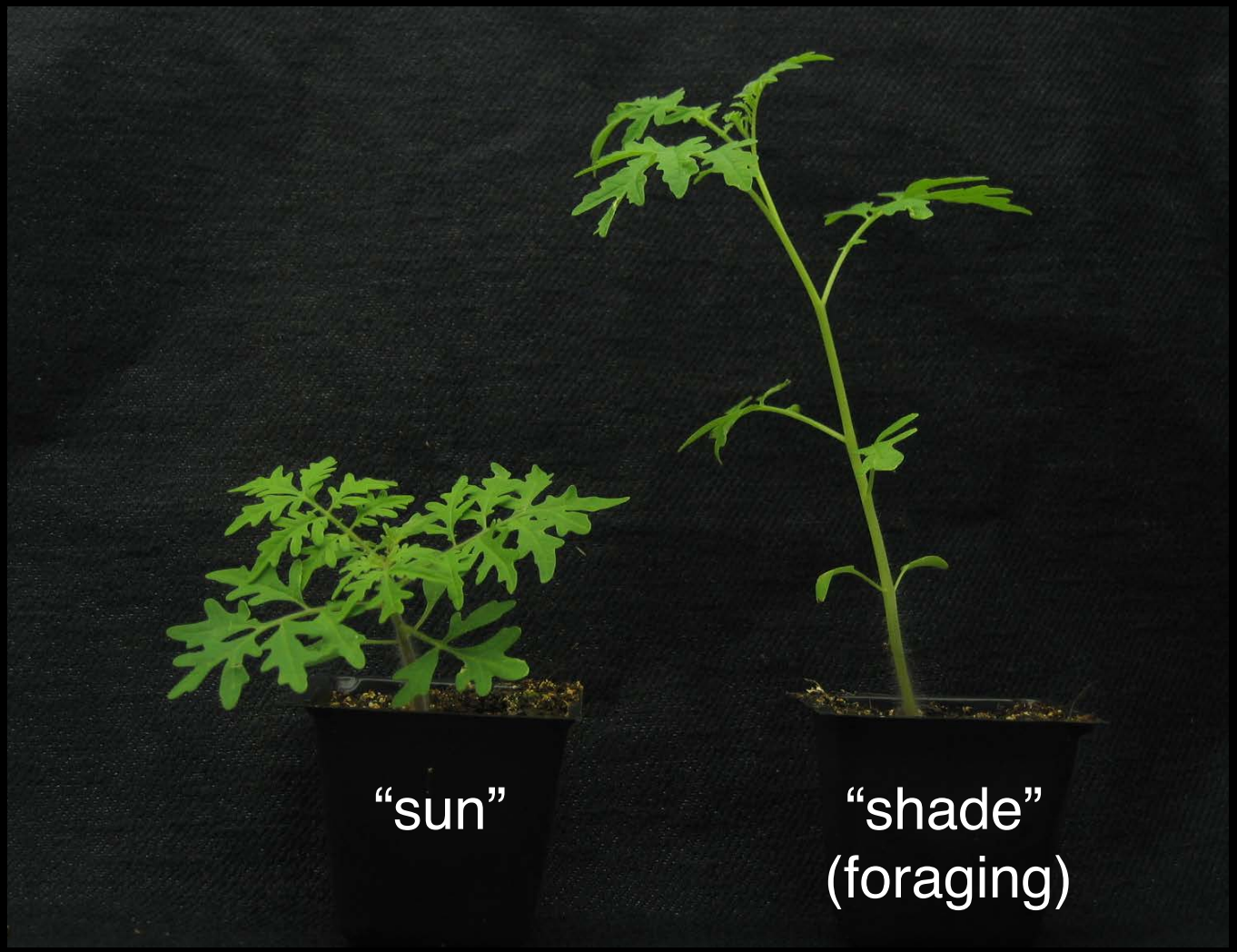
Sakai et al PNAS 2001

Light regulates many aspects of development

- Seed Germination
- Seedling Emergence
- Direction of growth (phototropism)
- Chloroplast arrangement
- Amount of growth
  - stem and petiole elongation
- Resource allocation
  - amount of carbon to leaves, roots, shoot, seed, fruit.
  - therefore affects extent of organ development
  - defense vs. growth paradigm

} Shade Avoidance

Light quality signals neighbor proximity (Shade avoidance)



Light regulates many aspects of development

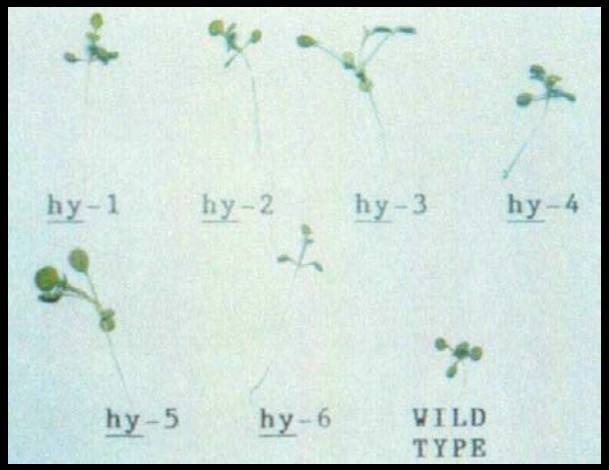
- Seed Germination
- Seedling Emergence
- Direction of growth (phototropism)
- Chloroplast arrangement
- Amount of growth
- Resource allocation
- Flowering time
  - Many plants use light to determine daylength and thereby seasonality
    - Long day plants are induced to flower when days are longer than a critical threshold
    - Short day plants are induced to flower when days are shorter than a critical threshold

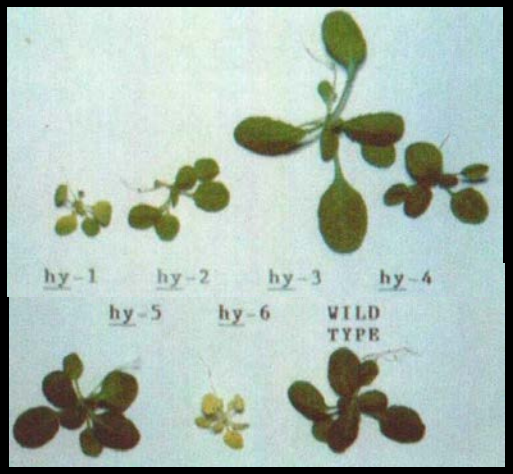
Take Home Message

Plant development is strongly affected by the light environment.

Genetic Screens for Light Signaling Mutants

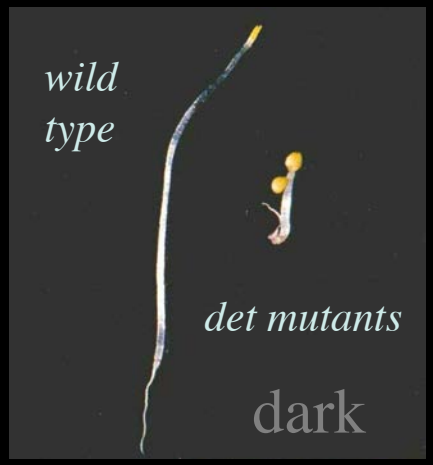
- *hy (elongated hypocotyl)* mutants have tall hypocotyls in the light

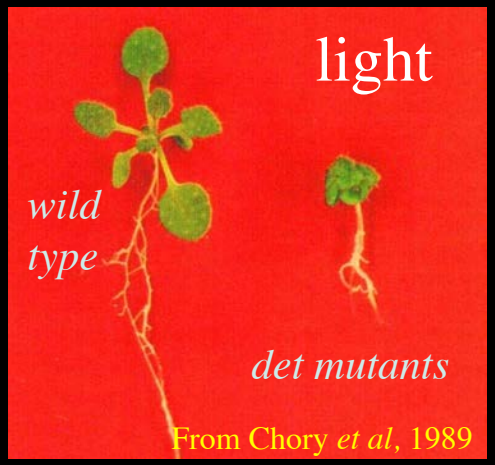




From Chory *et al*, 1989
Based on earlier work of Martin Koorneef

- *cop (constitutively photomorphogenic)* and *det (de-etiolated)* mutants are de-etiolated even in the dark.





From Chory *et al*, 1989

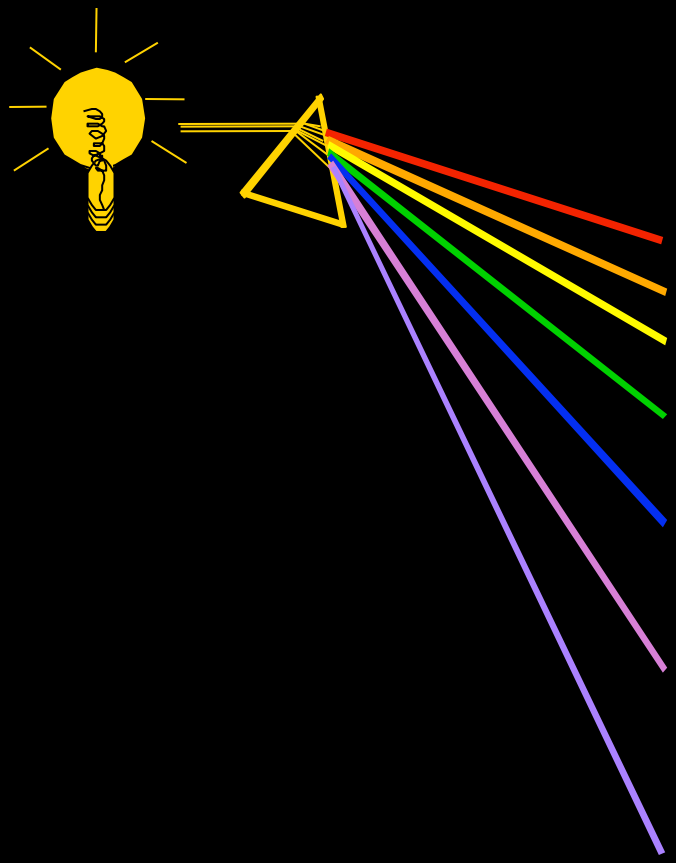
From Deng *et al*, 1991

Genetic Screens for Light Signaling Mutants

- *hy (elongated hypocotyl)* loci are mostly photoreceptor mutants
- HY1 & HY2 encode enzymes of phytochrome chromophore
- HY3 encodes phytochrome B
- HY4 encodes cryptochrome
- HY5 encodes MYB transcription factor (promotes light-reg'd genes)
- HY8 encodes phytochrome A

- *cop* and *det* mutants are repressors of photomorphogenesis.
- COP1 & DET1 regulate protein degradation in darkness
- Other COP/FUS loci are components of the proteosome
- DET2 involved in brassinosteroid metabolism (and growth regulation)
- DET3 involved in vacuolar H+-ATPase (and growth regulation)

Photomorphogenesis: Integration of light signal perception by multiple photoreceptors



PHYA/B/C

R/FR

CRY1/2/3

B/UV-A

PHOT1/2
ZTL/FKF1

UV-B

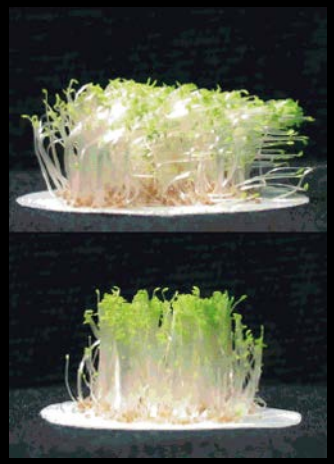
UVR8

Plant development
- seed germination
- de-etiolation
- floral induction
- senescence

Plant growth
- shade avoidance
- phototropism
- organelle movement

Flavin-based photosensors are widespread in plants and mediate blue light responses (PHOT/CRY/ZTL/FKF)

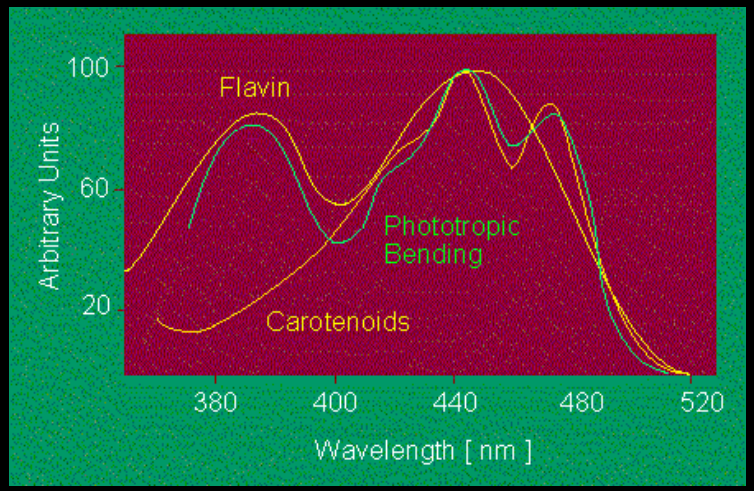
Phototropism in seedlings
(first described by Darwin)

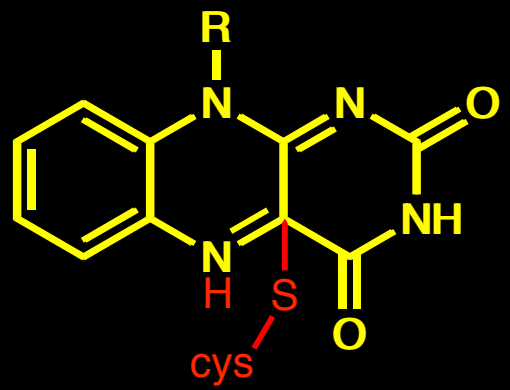


<- blue light

<- blue light
(no phototropin)

Col (WT) *cry2* *cry1*

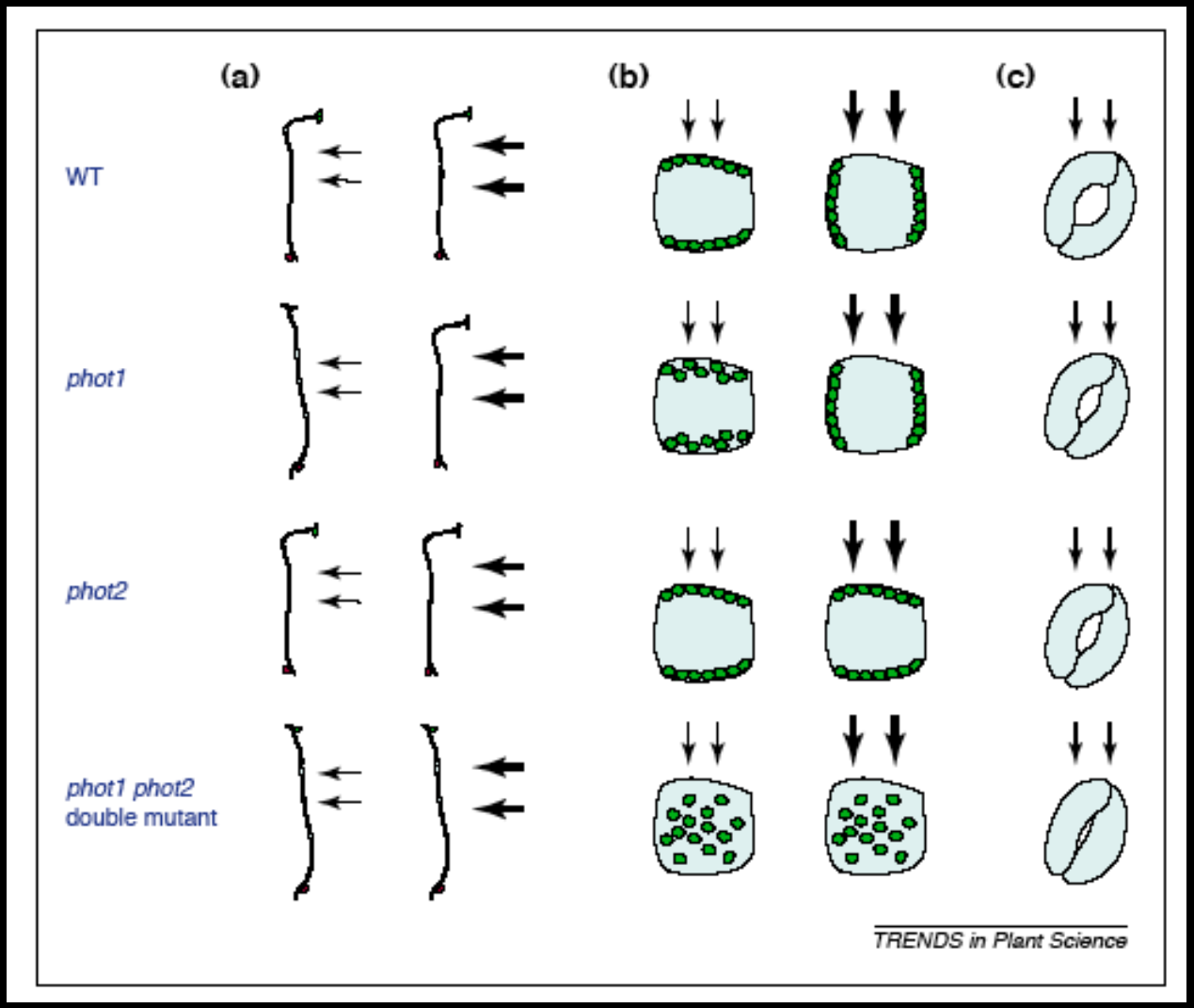




flavin chromophore

Cryptochromes & Seedling Growth

Phototropism, chloroplast movement & stomata opening are **all** mediated by phototropins, Phot1 and Phot2

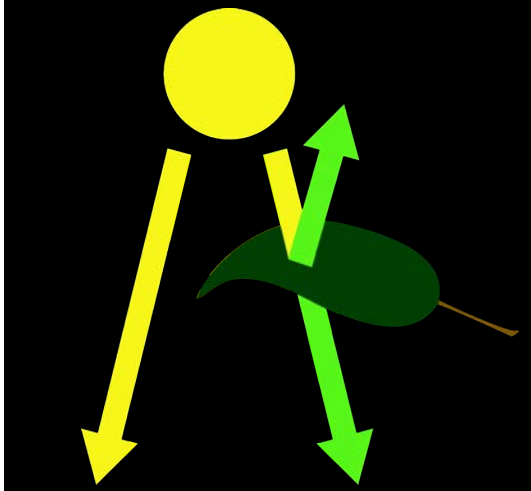


PHOT1 mediates the low fluence response

PHOT2 mediates the high fluence response

Briggs & Christie 2002 TIPS 7, 204-210

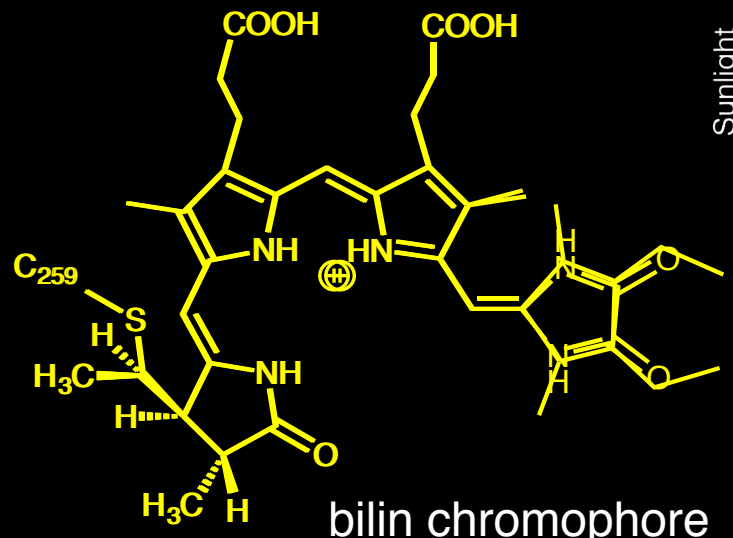
Bilin-based phytochromes detect shade by measuring the red/far-red ratio (PHY)



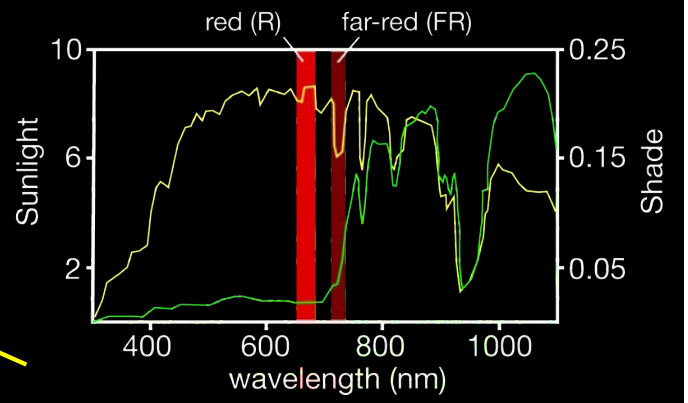
sun

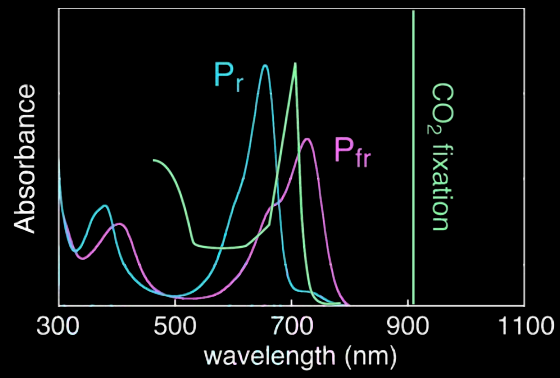
shade

$P_r \rightleftharpoons P_{fr}$ $P_r \rightleftharpoons P_{fr}$



bilin chromophore





R/FR ratio 1.1 0.9 0.8 0.5

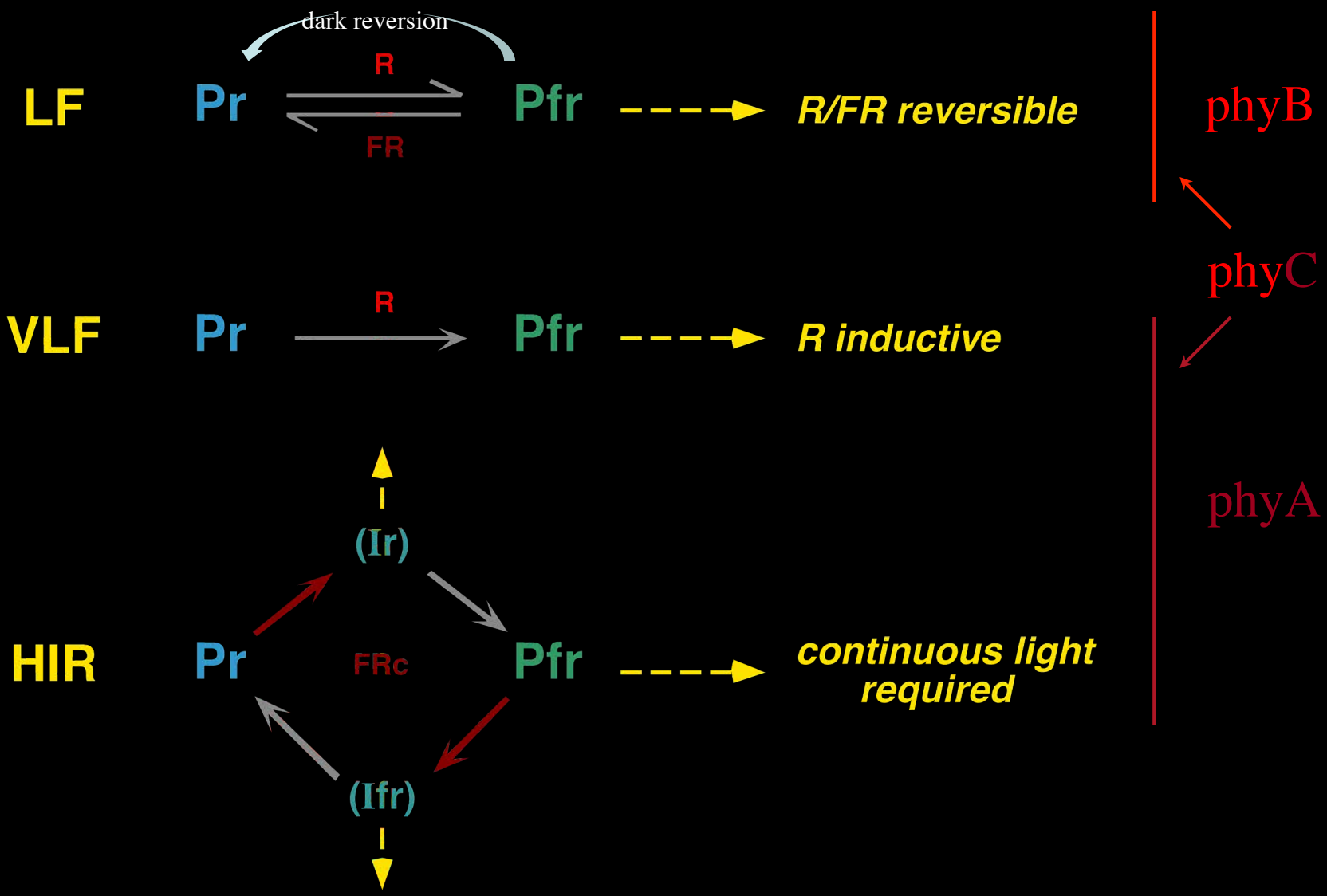
From Casal, ARPB 2013

Take Home Message

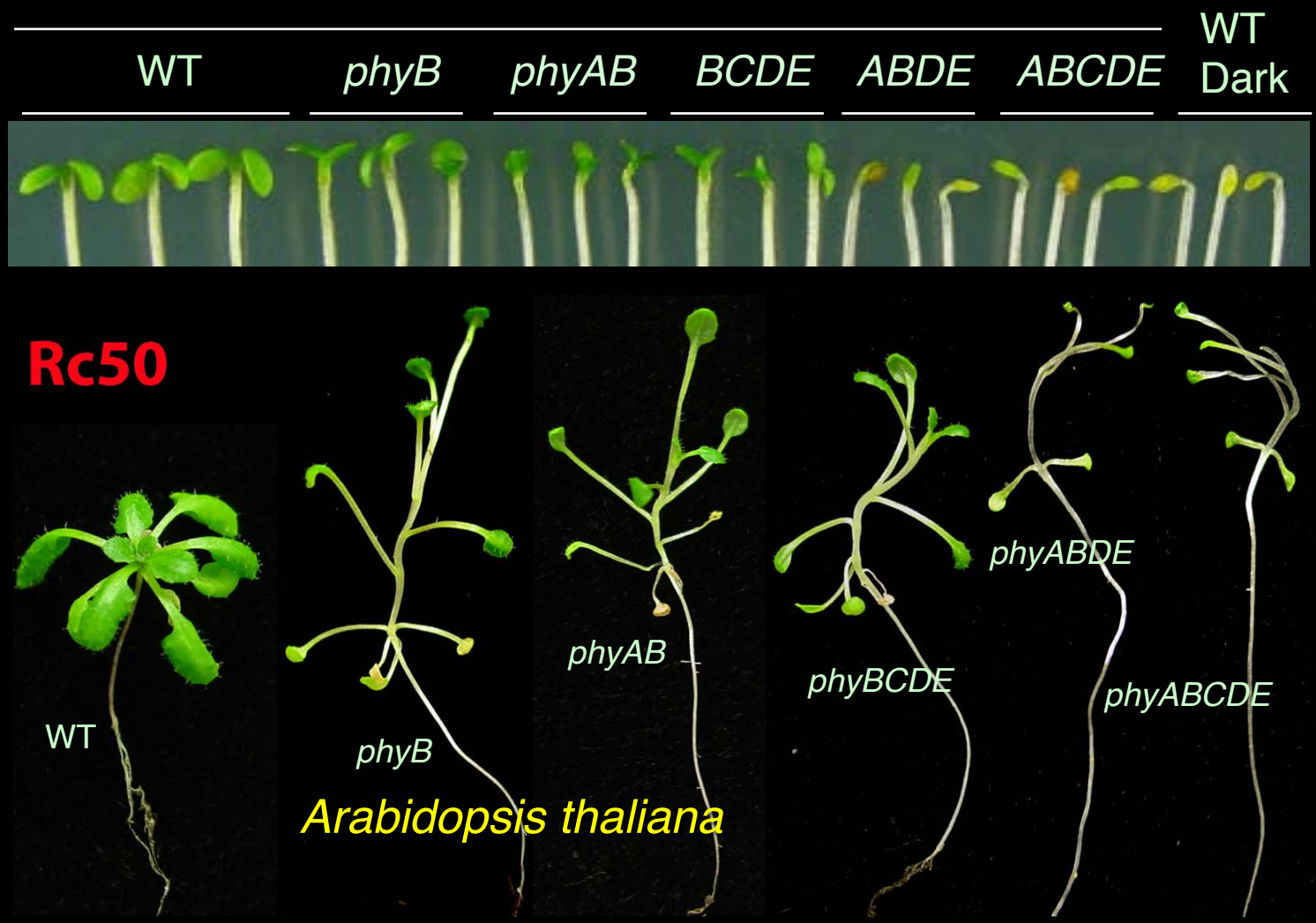
Plant development is strongly affected by the light environment.

In addition to the photosynthetic apparatus, plants possess a wide variety of flavin- and bilin-based photoreceptors that sense light color, intensity, direction and duration of exposure to regulate both growth and development.

Phytochrome Modes of Action



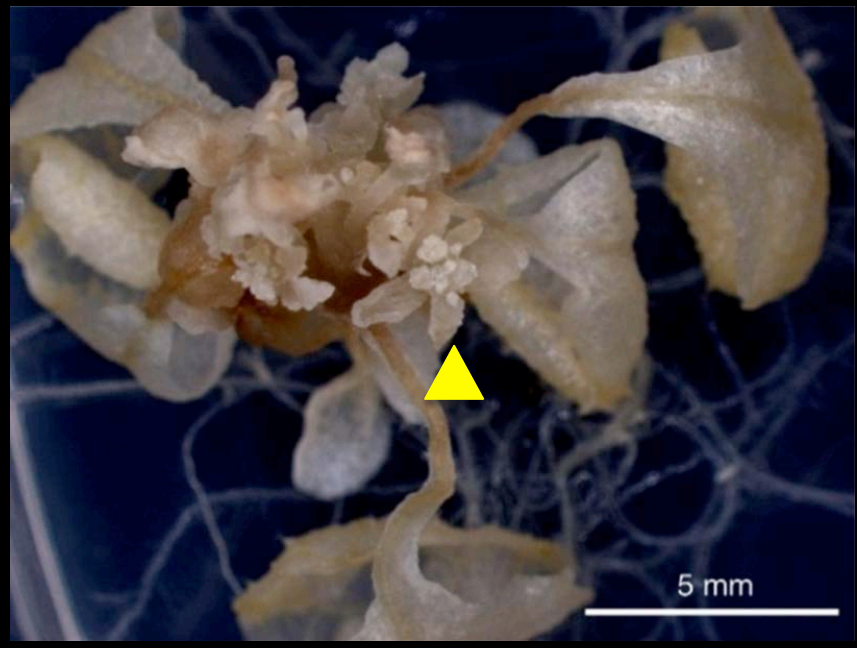
Although important, phytochromes are non-essential …



… but, plant growth and development is severely impaired.

Hu *et al*, 2013 PNAS

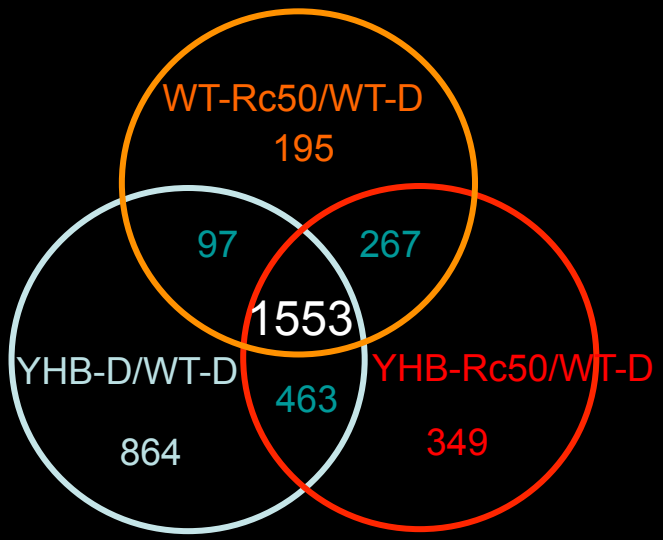
Arrested plant development in darkness is overcome by phytochrome activation.

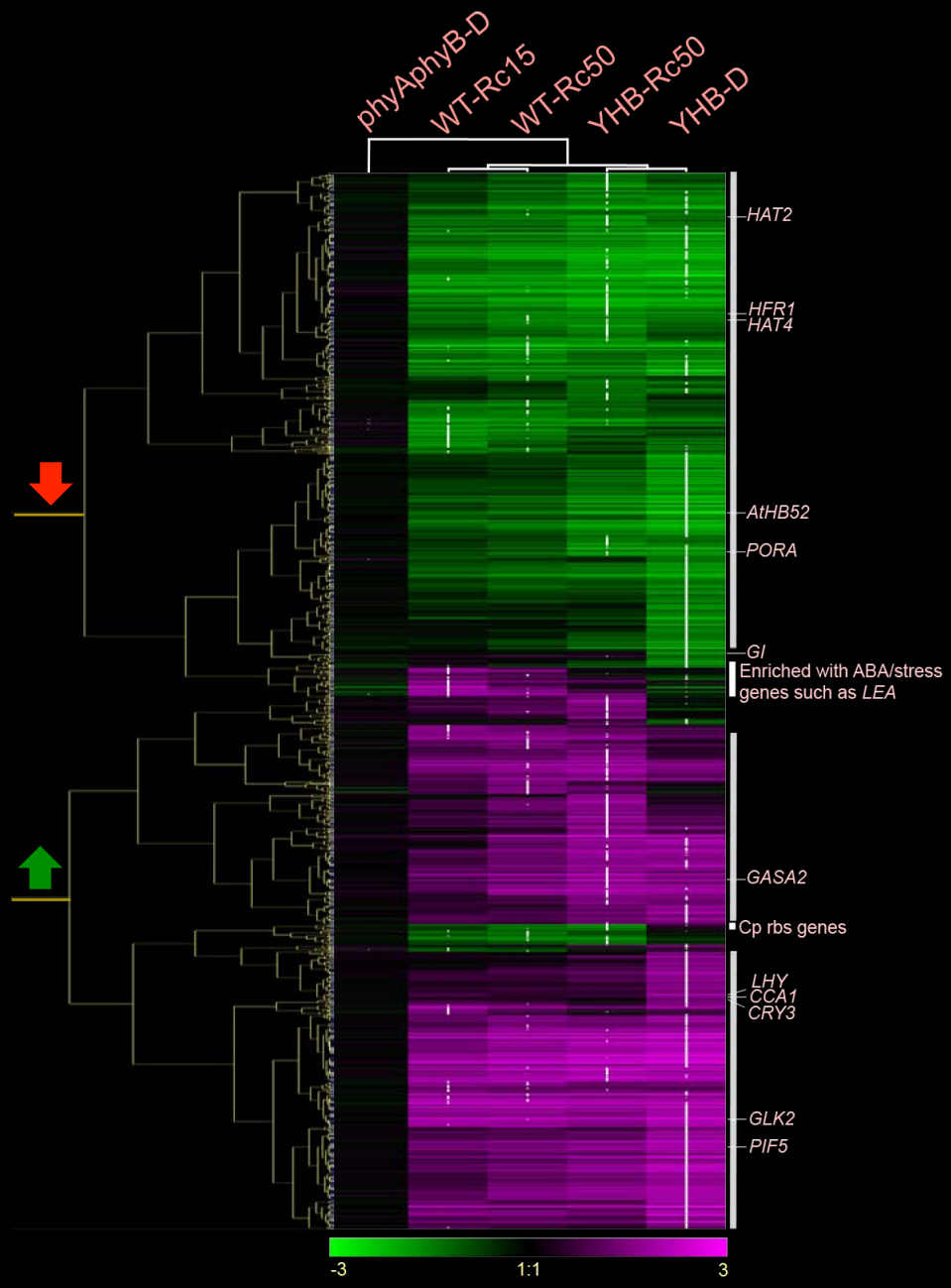


Constitutive phytochrome alleles permit plant development in the absence of light.

Su & Lagarias 2007 Plant Cell

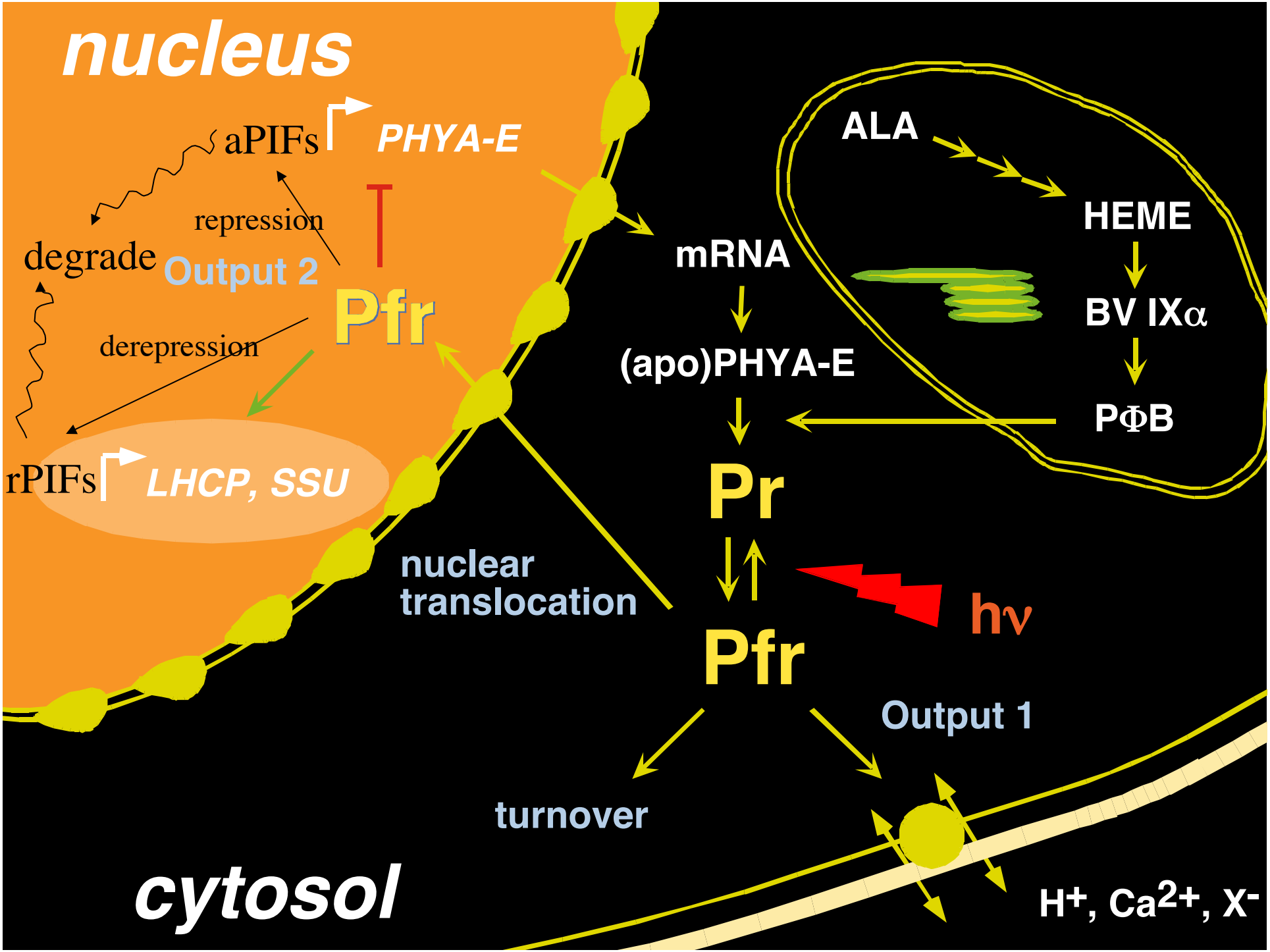
Phytochromes regulate >10% of the plant transcriptome...





… in a manner independent of photosynthesis.

Hu, Su & Lagarias, 2009 Mol. Plant


nucleus
aPIFs
PHYA-E
repression
degrade
Output 2
Pfr
derepression
rPIFs
LHCP, SSU
ALA
HEME
BV IXα
PΦB
mRNA
(apo)PHYA-E
Pr
nuclear
translocation
hν
Pfr
Output 1
turnover
cytosol
H+, Ca2+, X-

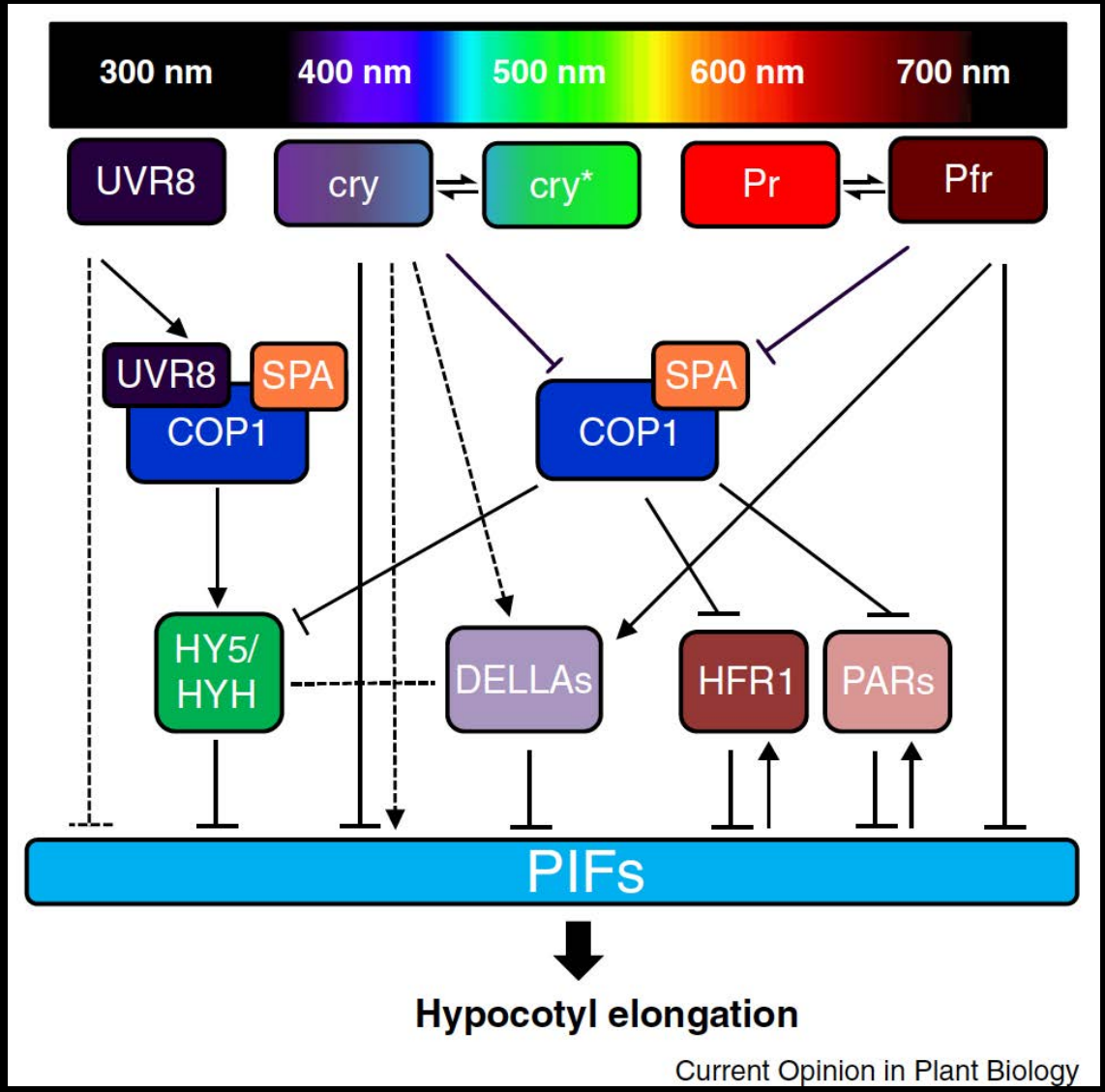
Some Take Home Messages

Plant development is strongly affected by the light environment.

In addition to the photosynthetic apparatus, plants possess a wide variety of flavin- and bilin-based photoreceptors that sense light color, intensity, direction and duration of exposure to regulate both growth and development.

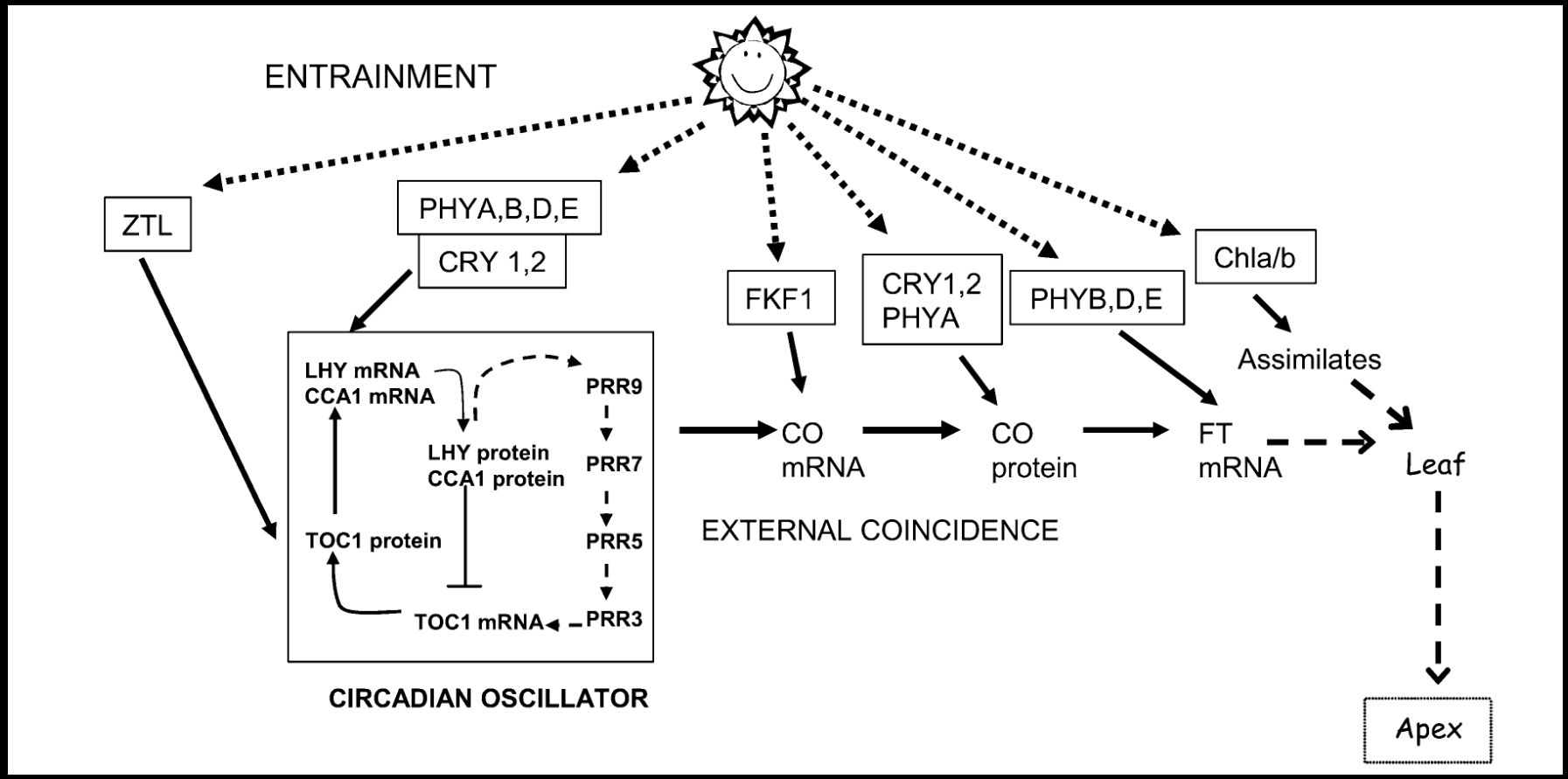
Such regulators are non-essential for survival in controlled light environments, but are essential for successful competition with other plants for survival in a fluctuating diurnal light environment.

Crosstalk between photoreceptors



Fraser *et al* 2016 Curr. Opin. Plant Biol.

Crosstalk between photoreceptors



Brian Thomas 2006 JXB

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Such regulators are non-essential for survival in controlled light environments, but are essential for successful competition with other plants for survival in a fluctuating diurnal light environment.

These photoreceptors have overlapping and distinct signaling pathways which regulate development in a wide variety of light environments.