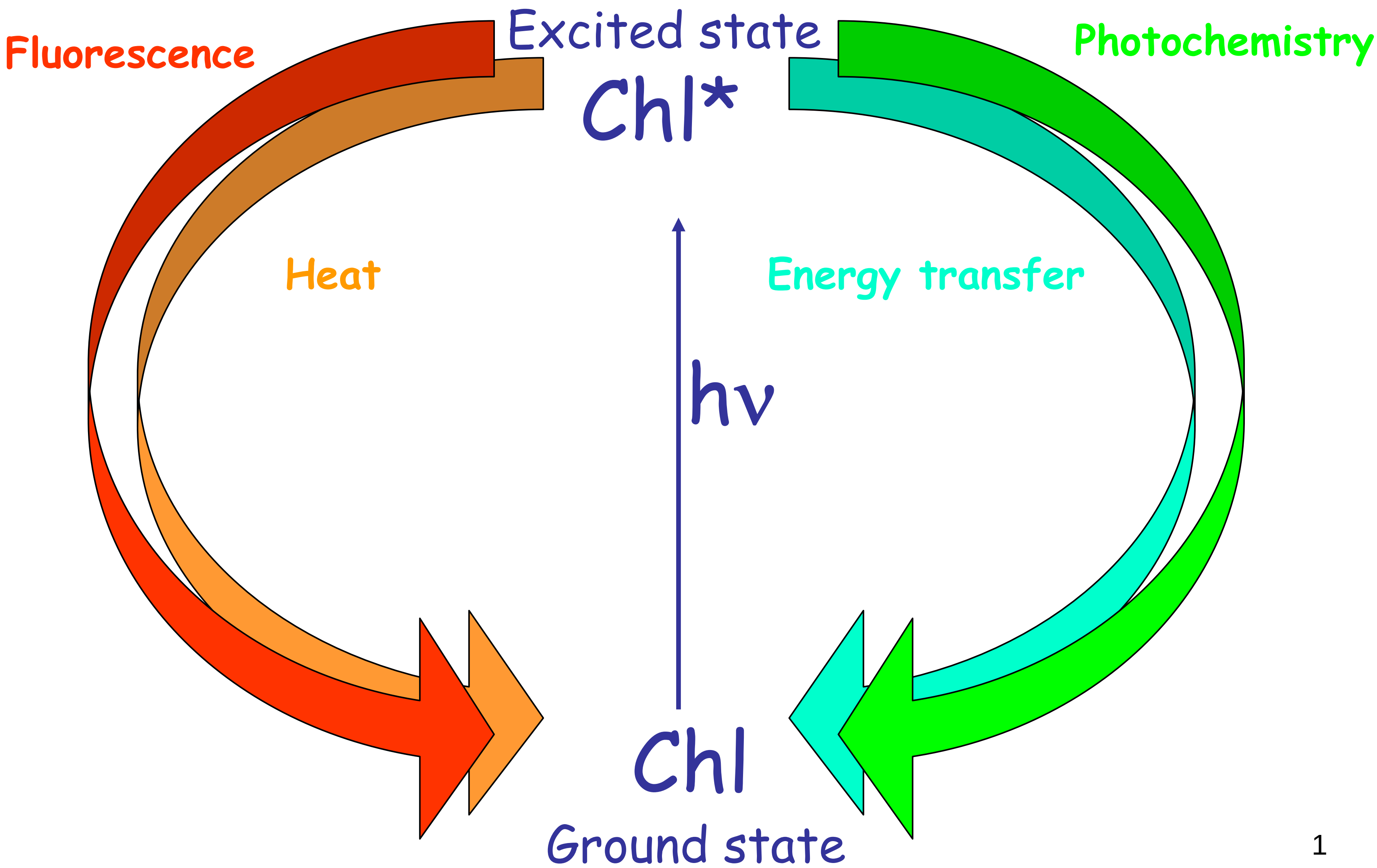
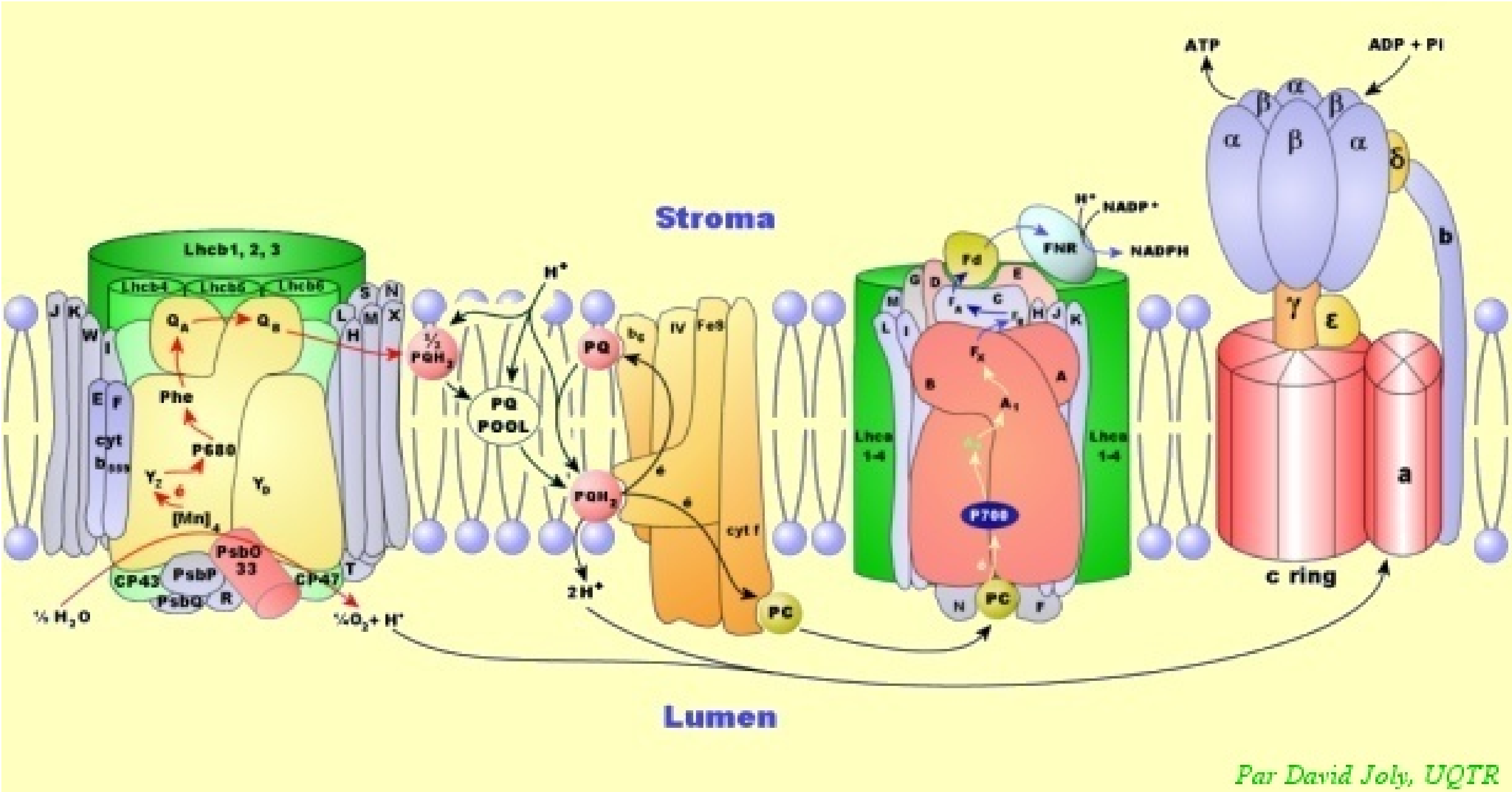
# De-excitation of Chlorophyll



# Quenching of Fluorescence

## Photochemical Quenching




# Photochemical Quenching via:

Linear electron transfer to NADP+

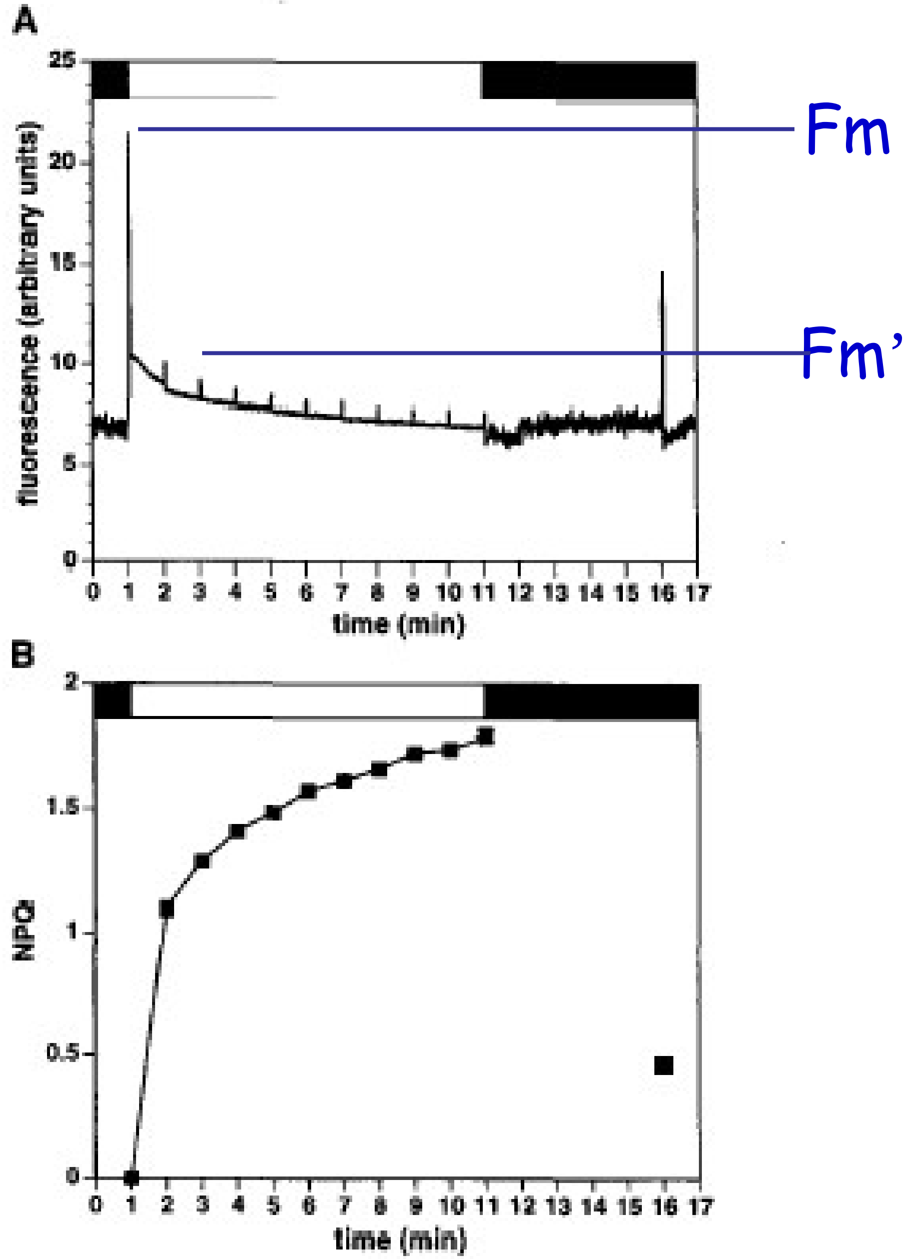
Mehler reaction (water-water cycle, pseudo-cyclic electron transfer)

# Quenching of Fluorescence

Photochemical Quenching

Non-Photochemical Quenching: NPQ

# Measurements of NPQ in Chlamydomonas




$$\frac{Fm - Fm'}{Fm'}$$

# Decrease of Chl Fluorescence Results from:

State transition

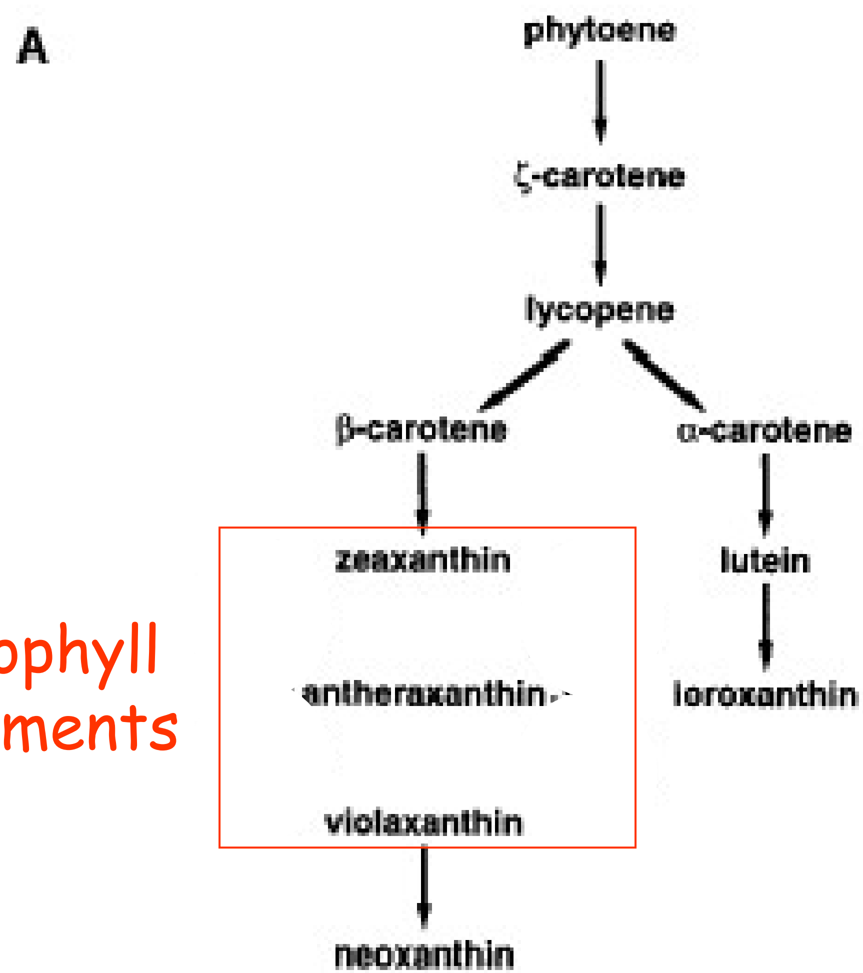
Photoinhibition ($q_I$)

# NPQ ($q_E$)

$\Delta pH^+$ is required for NPQ

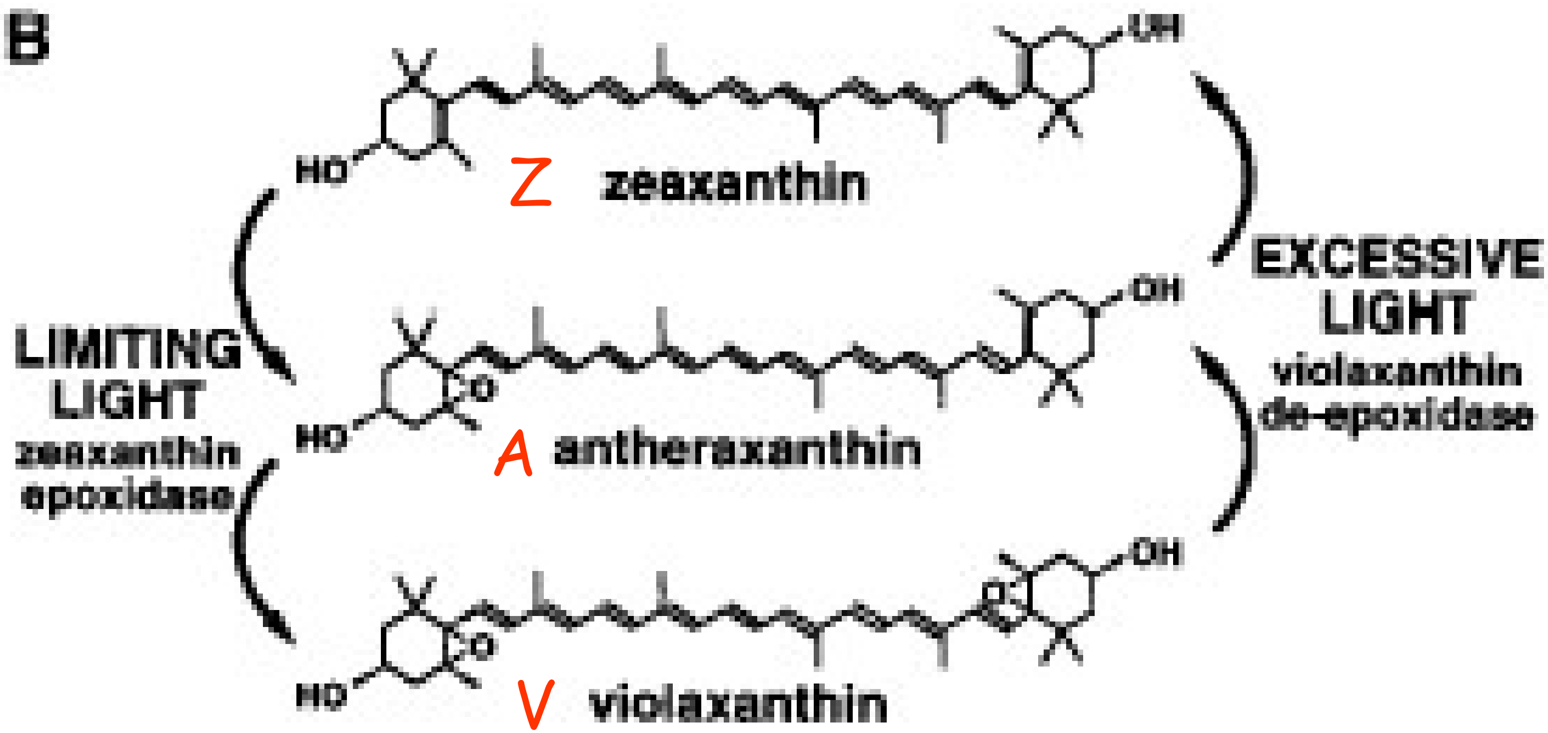
Specific Carotenoids are involved in NPQ

# Biosynthesis of Carotenoids

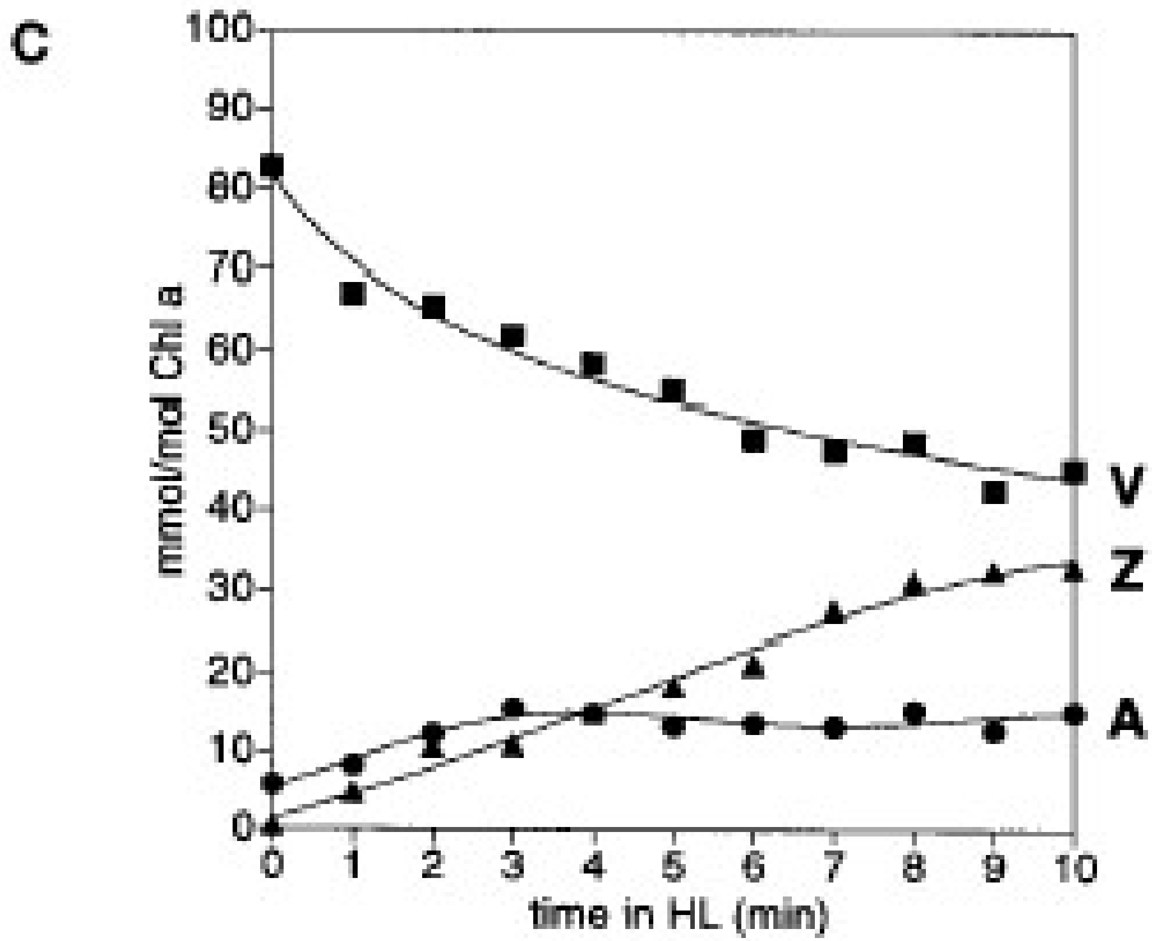



Xanthophyll cycle pigments

# Xanthophyll Cycle Pigments



# Analysis of Xanthophyll Cycle Pigments in Chlamy following High Light Treatment



# Analysis of Xanthophyll Cycle Pigments in Chlamy following High Light Treatment

**Table 1.** HPLC Analysis of the Xanthophyll Cycle Pigments in Wild-Type Chlamydomonas Cells under Different Growth Conditions[a]

| | | mmol/mol Chlorophyll *a* | | | | |
|---|---|---|---|---|---|---|
| Growth Medium | Incident PFD | V | A | Z | V + A + Z | (A + Z)/(V + A + Z) |
| TAP | 5 | 118 | 4 | 0 | 122 | 0.03 |
| TAP | 50 | 175 | 8 | 3 | 186 | 0.06 |
| TAP | 300 | 127 | 51 | 109 | 287 | 0.56 |
| HS | 50 | 123 | 3 | 0 | 126 | 0.02 |
| HS | 350 | 148 | 46 | 83 | 277 | 0.47 |

[a]Cells of an $Arg^{+}$ control strain wt, derived from CC-425, were grown at the indicated PFD ($\mu$mol photons $m^{-2}$ $sec^{-1}$) for 9 days. Cells were grown photoheterotrophically on agar medium containing acetate as a carbon source (TAP) or photoautotrophically on minimal medium lacking acetate (HS). Values are the averages of duplicate determinations. V, violaxanthin; A, antheraxanthin; Z, zeaxanthin.

The Plant Cell, Vol. 9, 1369–1380, August 1997 © 1997 American Society of Plant Physiologists

## Chlamydomonas Xanthophyll Cycle Mutants Identified by Video Imaging of Chlorophyll Fluorescence Quenching

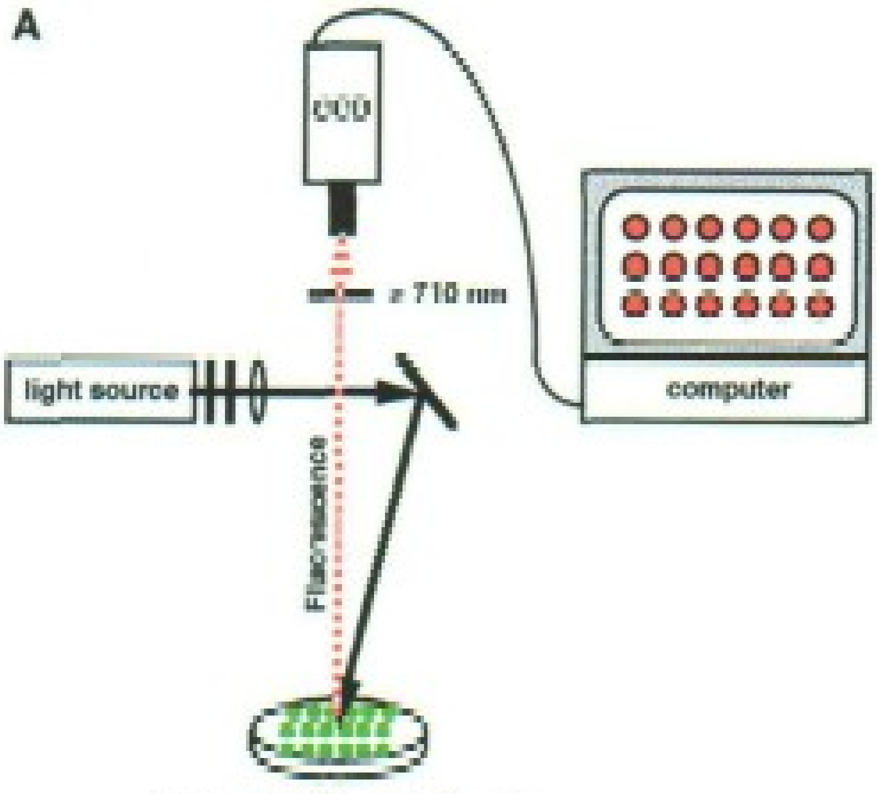
Krishna K. Niyogi,[1] Olle Björkman, and Arthur R. Grossman

The Plant Cell, Vol. 10, 1121–1134, July 1998, www.plantcell.org © 1998 American Society of Plant Physiologists

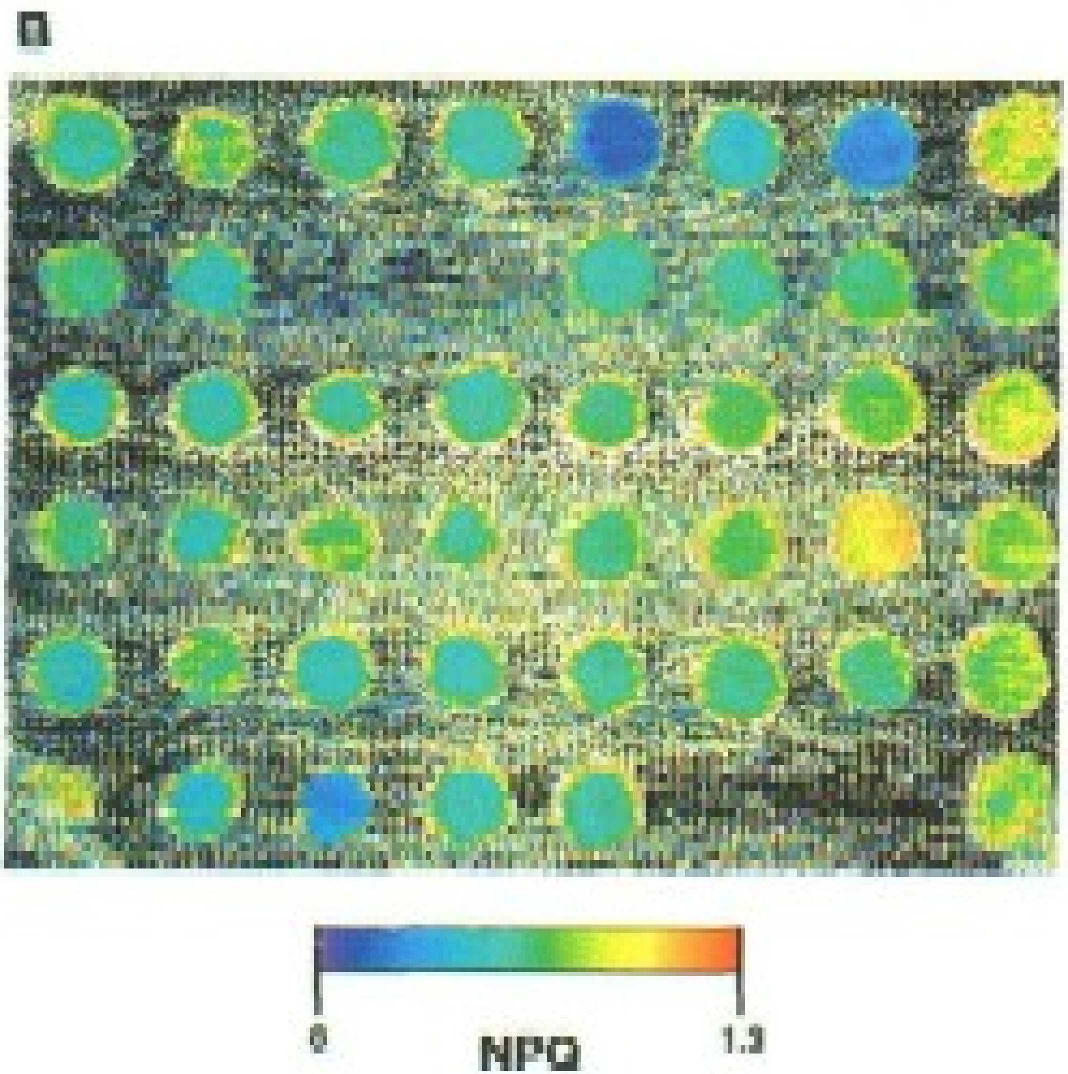
## Arabidopsis Mutants Define a Central Role for the Xanthophyll Cycle in the Regulation of Photosynthetic Energy Conversion

Krishna K. Niyogi,[1] Arthur R. Grossman, and Olle Björkman

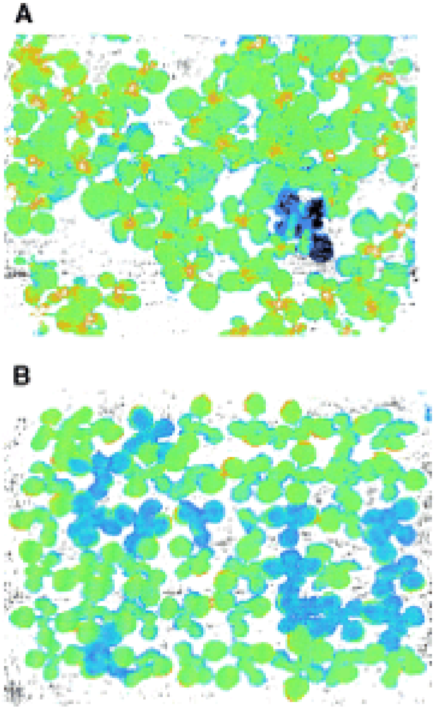
# Screening for NPQ Mutants



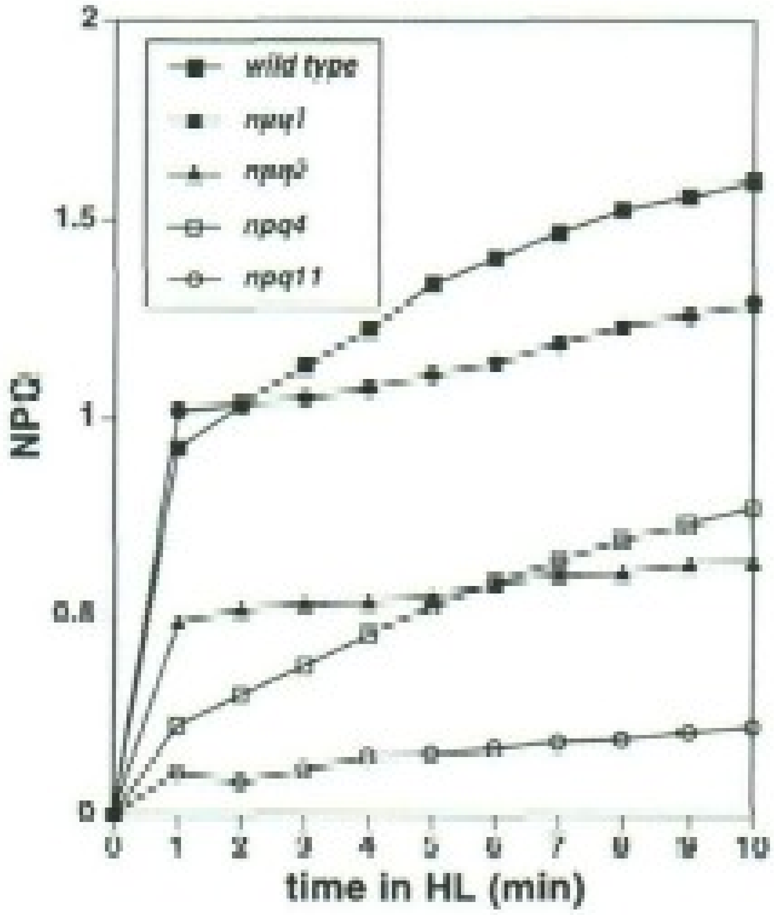
# Chlamydomonas NPQ mutants



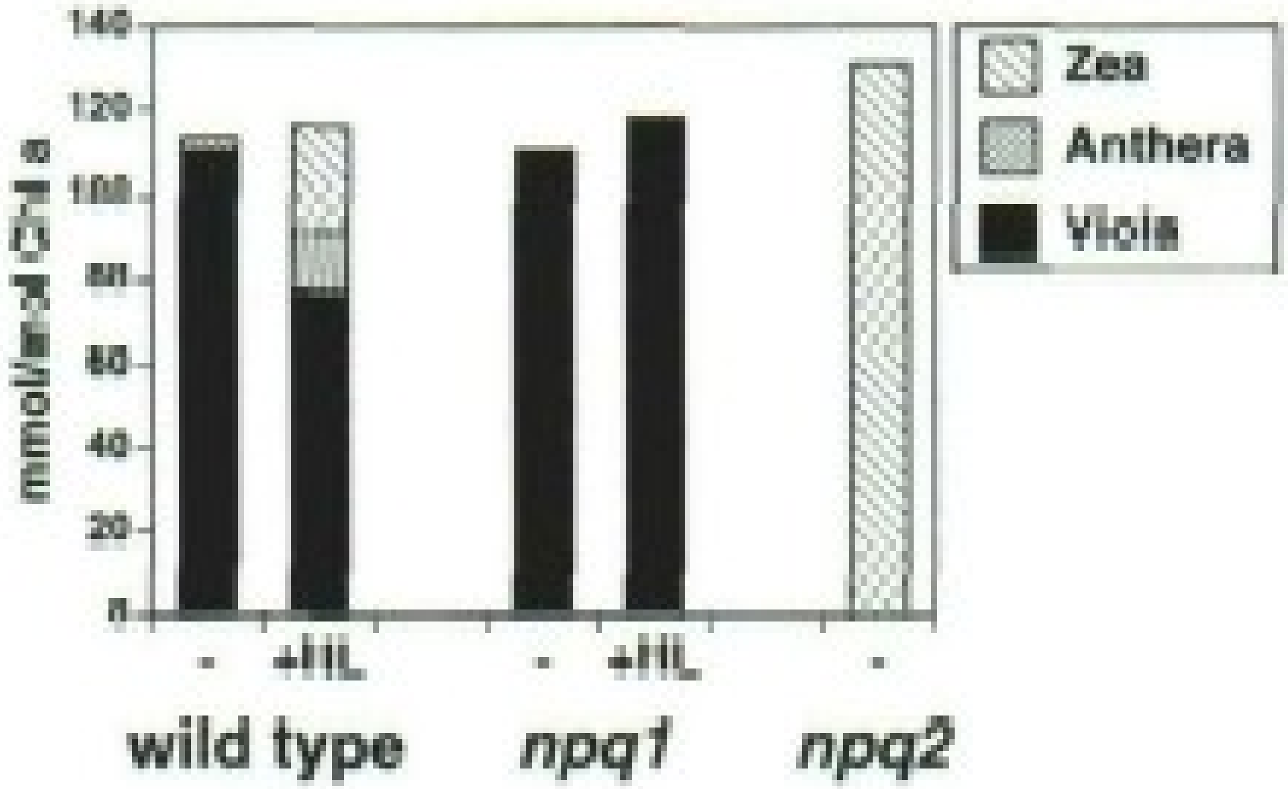
# Arabidopsis NPQ mutants



# NPQ in Wild Type and Mutants

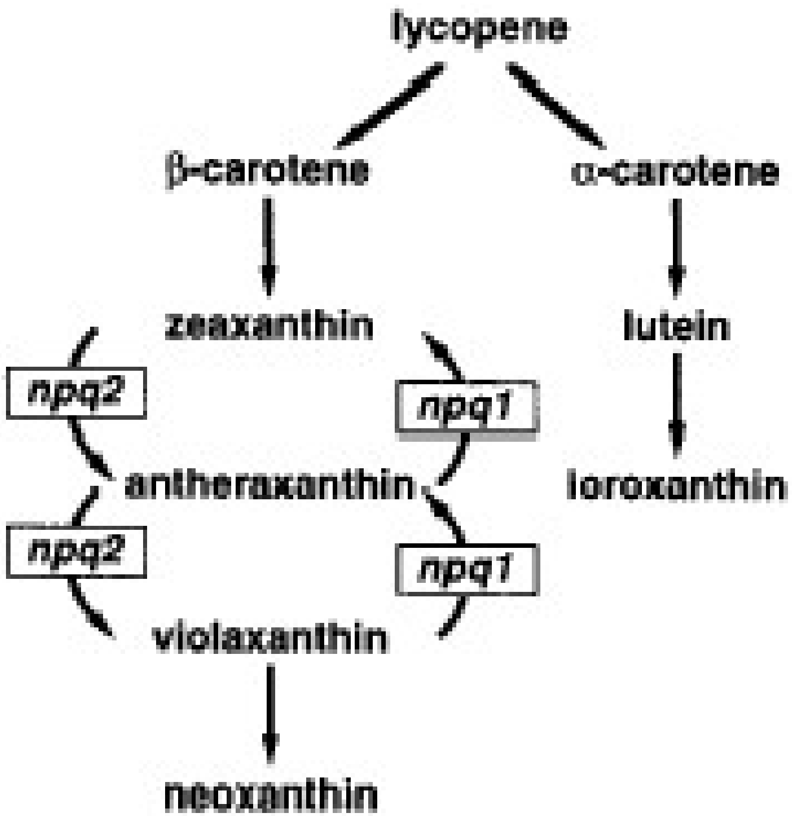


# Composition of Xanthophyll Cycle Pigments in WT and Mutants following High Light treatment

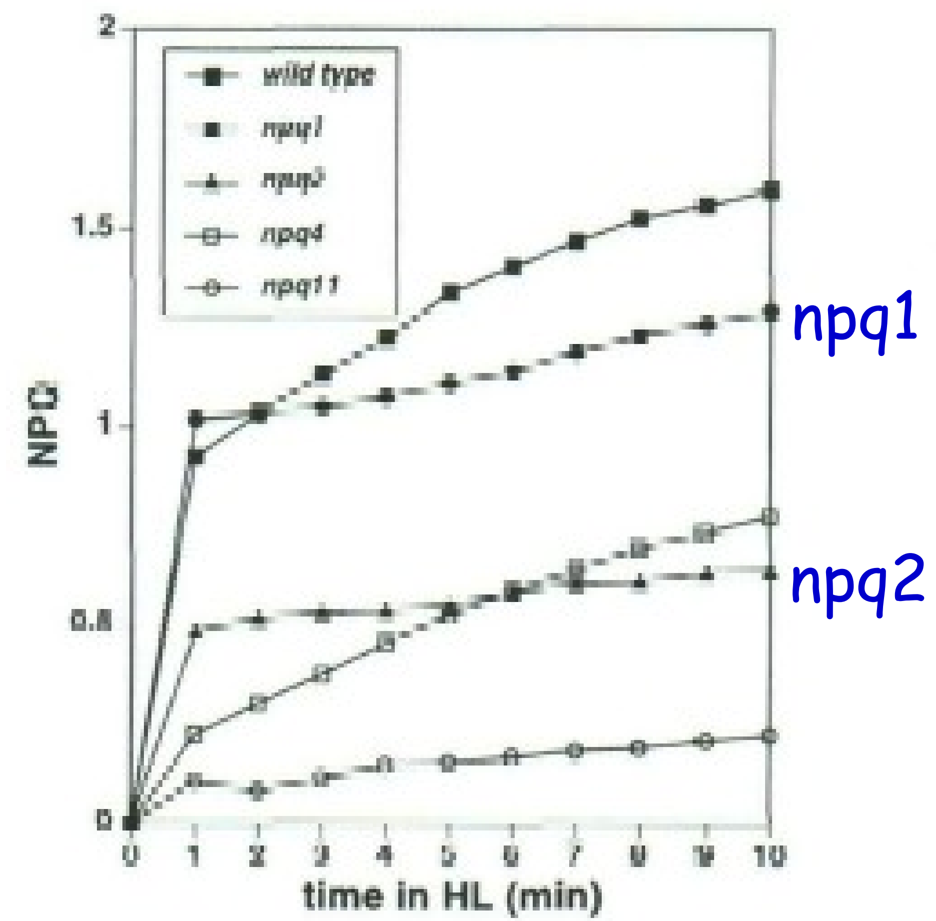


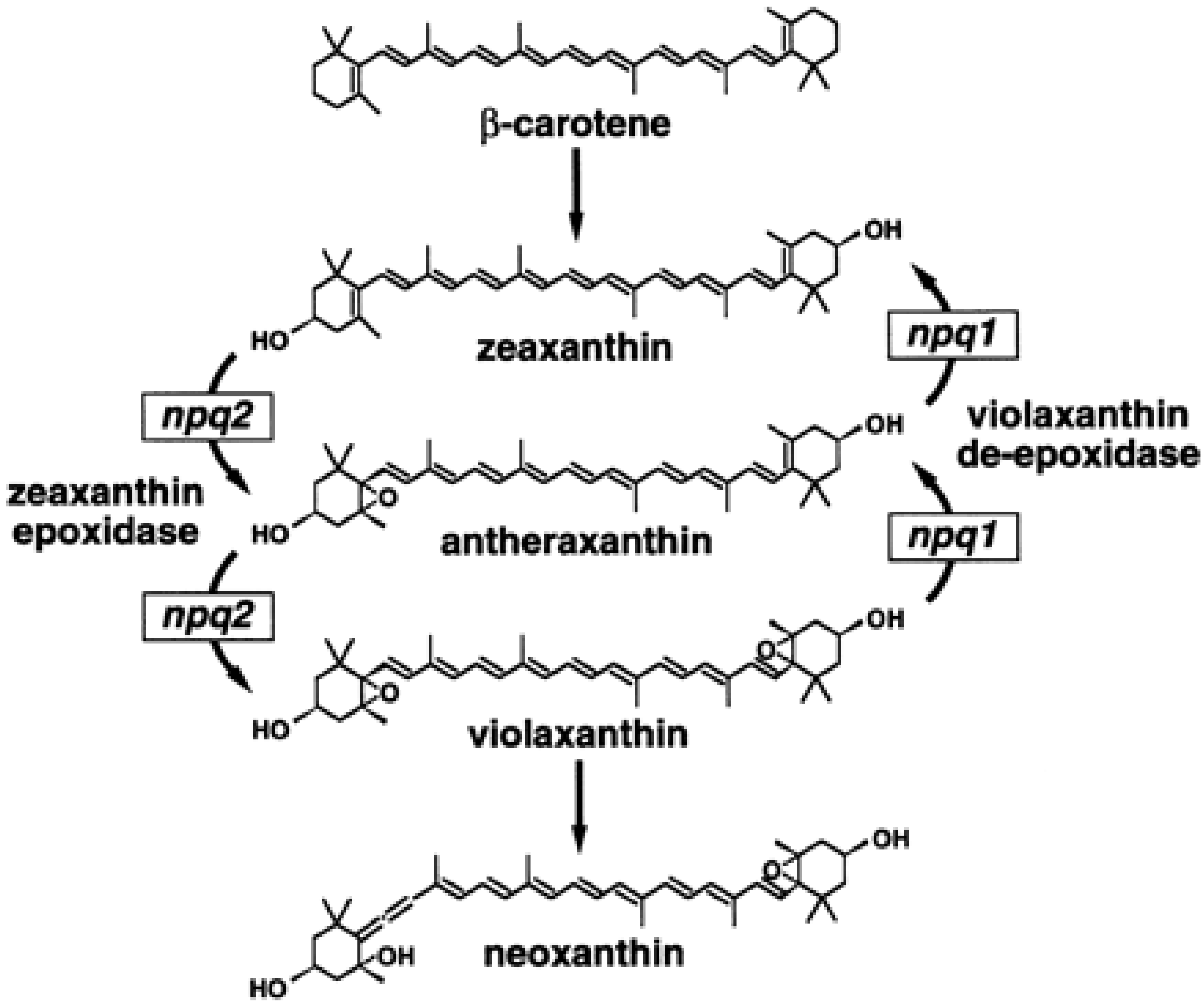
npq1 is impaired in violaxanthin de-epoxidase (VDE)

npq2 is impaired in zeaxanthin epoxidase

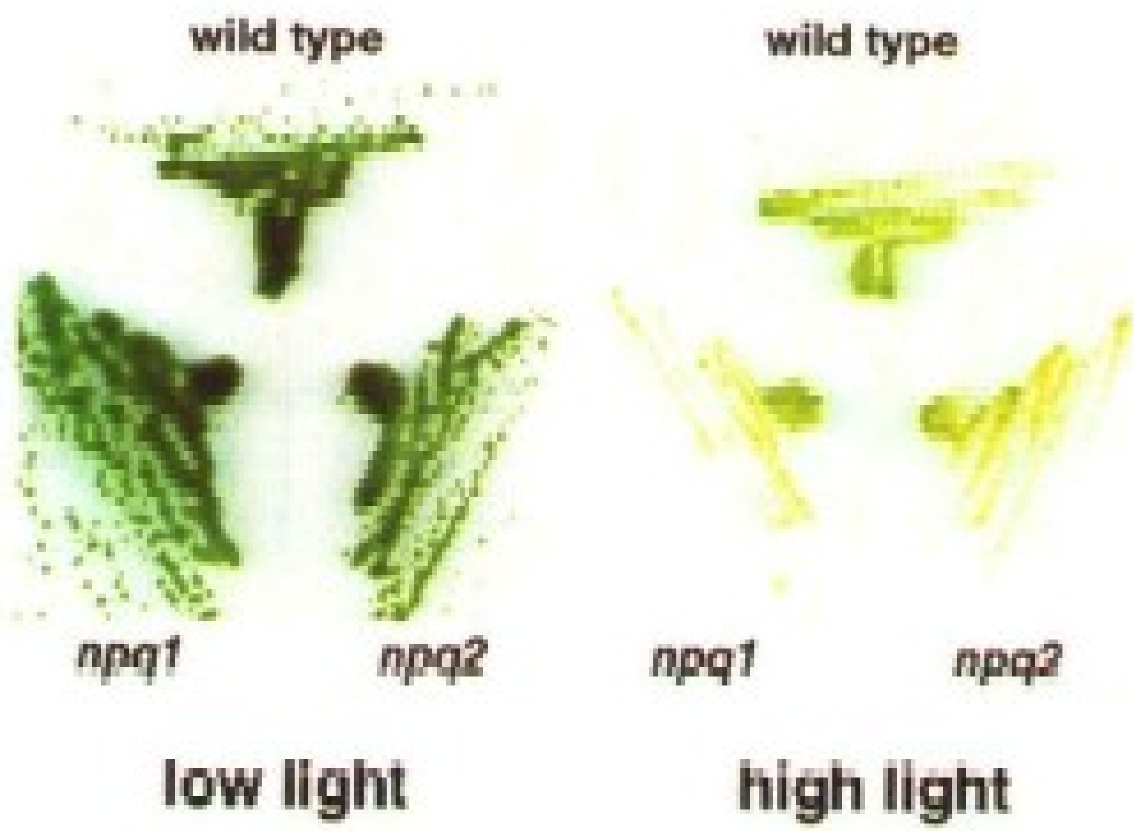


# NPQ in Wild Type and Mutants

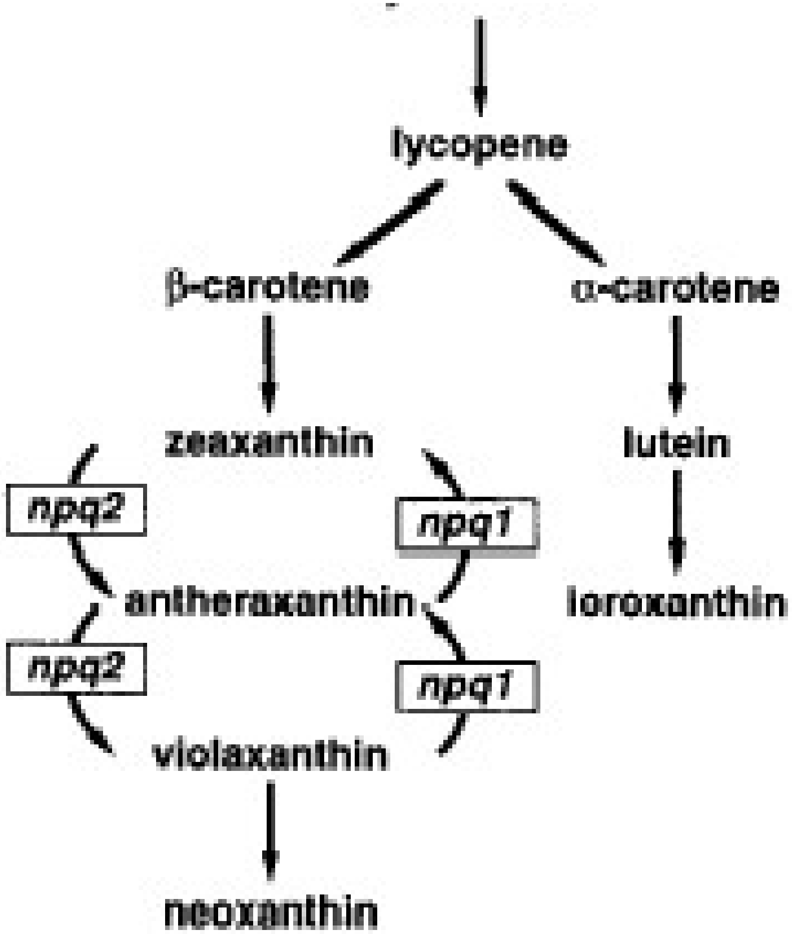



β-carotene
OH
HO
zeaxanthin
npq1
npq2
violaxanthin
de-epoxidase
OH
O
zeaxanthin
epoxidase
HO
antheraxanthin
npq1
npq2
OH
O
O
HO
violaxanthin
OH
O
OH
HO
neoxanthin

# Growth during High Light Illumination of WT and NPQ Mutants



# Double mutants impaired in npq1 and biosynthesis of lutein/loroxanthin are High Light Sensitive



# Xanthophyll cycle pigments in wild-type and npq4 leaves

| | | mmol per mol chlorophyll *a* | | | | |
|---|---|---|---|---|---|---|
| | | V | A | Z | V + A + Z | (A + Z)/(V + A + Z) |
| Wild type | before HL | 53 ± 8 | 16 ± 2 | 13 ± 1 | 82 ± 9 | 0.36 ± 0.03 |
| | after HL | 18 ± 1 | 8 ± 1 | 43 ± 9 | 70 ± 10 | 0.73 ± 0.03 |
| *npq4-1* | before HL | 54 ± 2 | 12 ± 1 | 6 ± 1 | 73 ± 2 | 0.26 ± 0.02 |
| | after HL | 17 ± 1 | 8 ± 1 | 43 ± 5 | 68 ± 6 | 0.75 ± 0.02 |

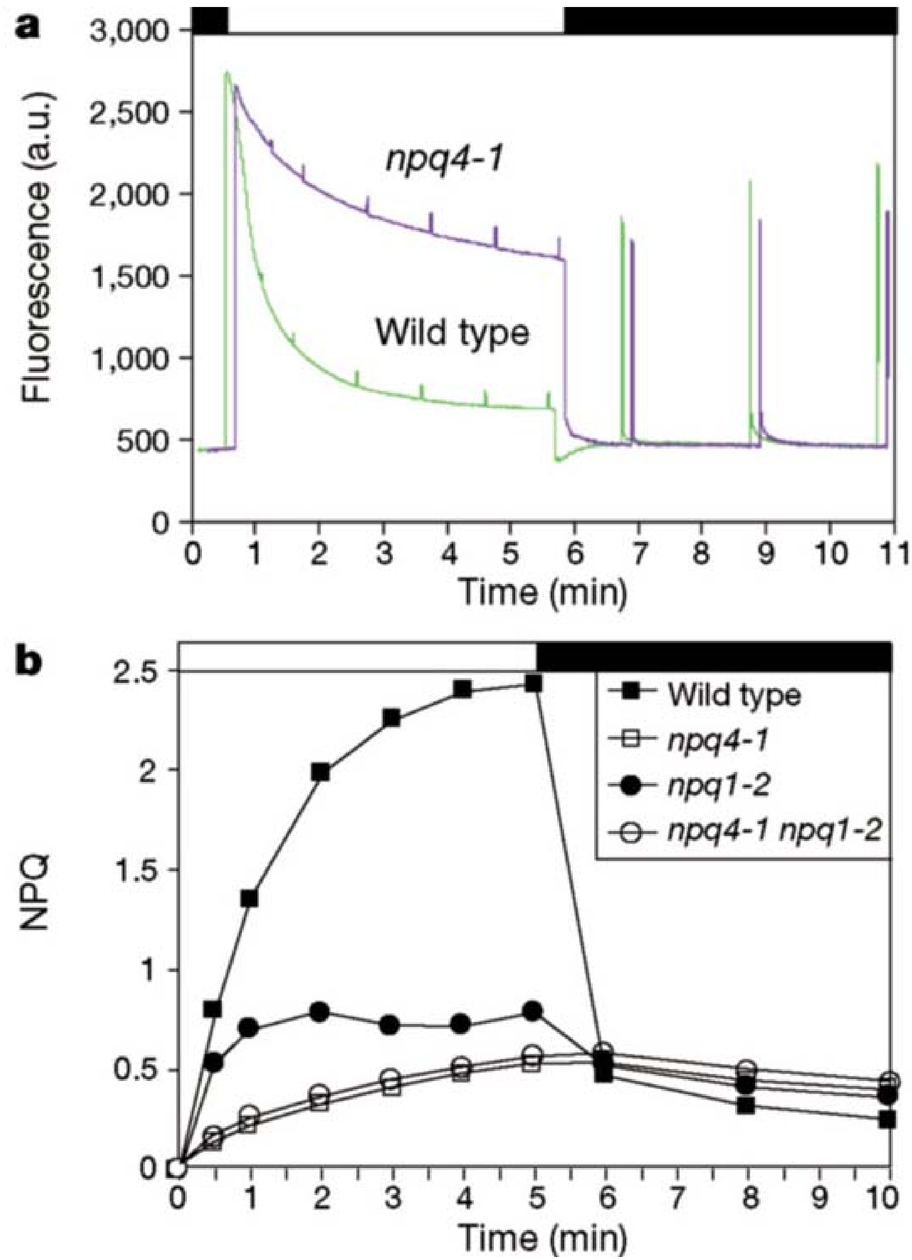
Pigment composition of leaves was measured by high-performance liquid chromatography either before or after exposure to high light (HL, 640 μmol photons $m^{-2}$ $sec^{-1}$) for 30 min. Values are means ± s.e. ($n = 4$).

# A pigment-binding protein essential for regulation of photosynthetic light harvesting

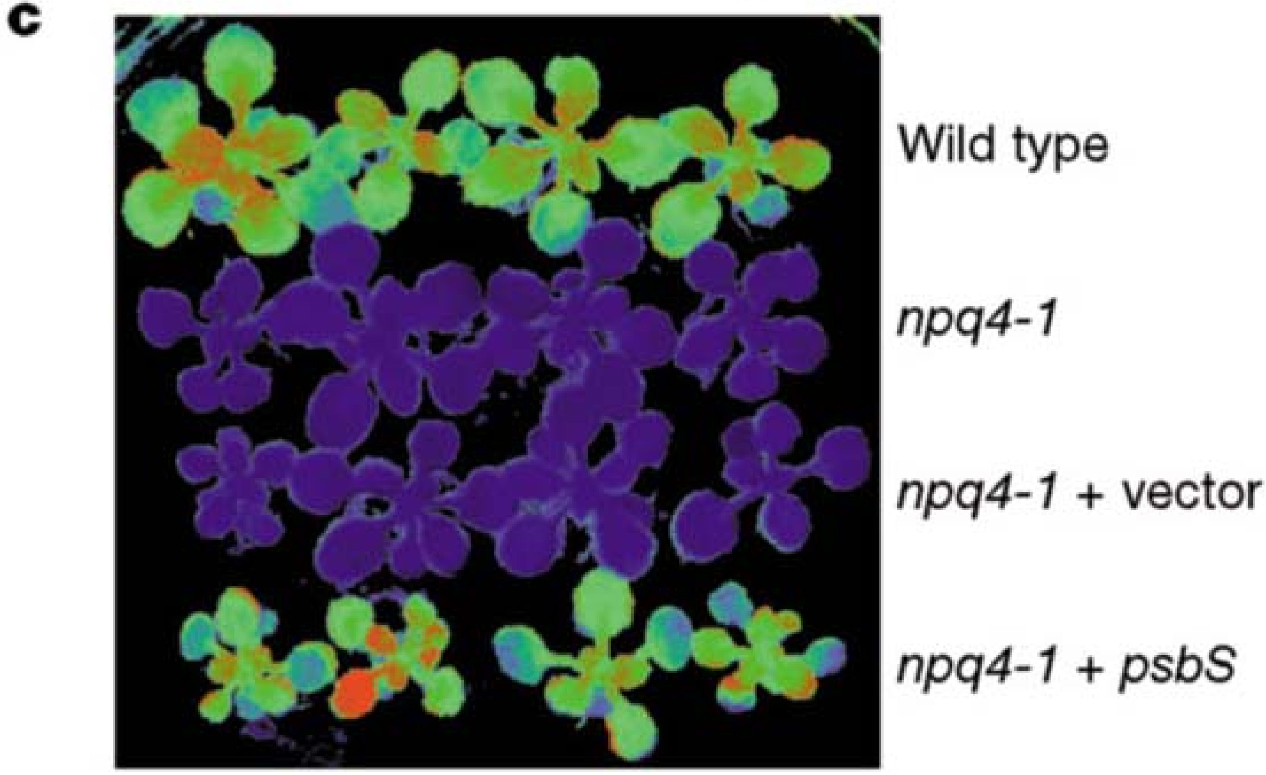
Xiao-Ping Li*, Olle Björkman†, Connie Shih†, Arthur R. Grossman†, Magnus Rosenquist‡§, Stefan Jansson‡ & Krishna K. Niyogi*

NATURE | VOL 403 | 27 JANUARY 2000 | www.nature.com

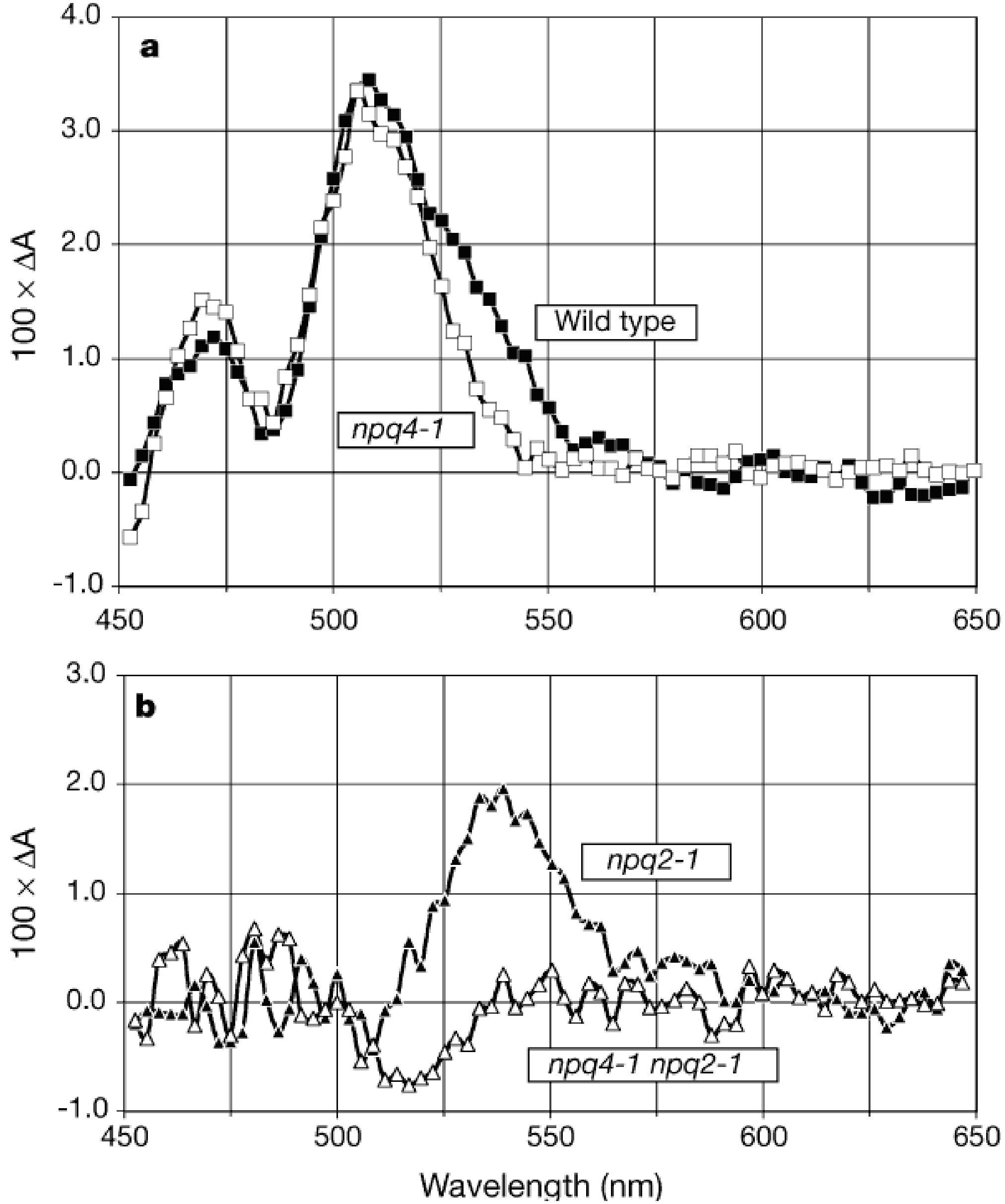
# Mutant npq4 exhibits abnormal NPQ



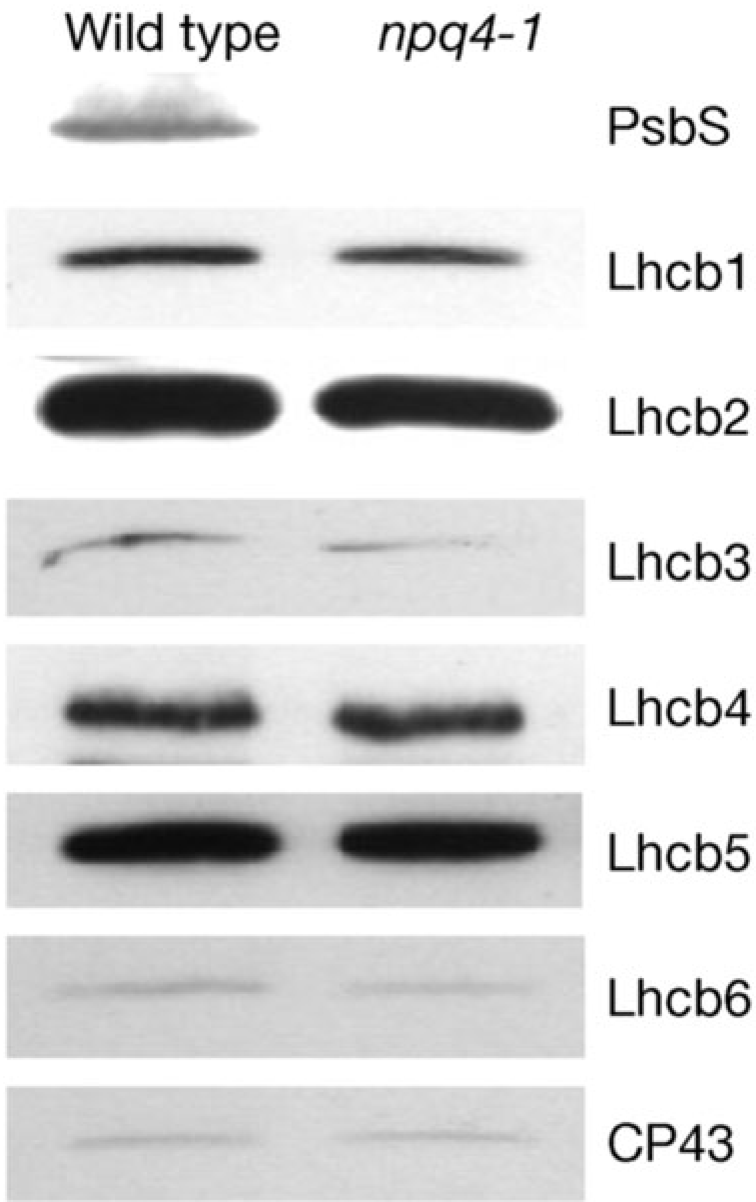
# Mutant npq4 is complemented by PsbS



# Mutant npq4 does not exhibit the typical spectral changes observed in the wild type upon high light illumination



# Content of LHC protein in wild type and mutant npq4



# Photosynthetic parameters of wild type and npq4 leaves

| Parameter | Wild type | *npq4-1* |
| --- | --- | --- |
| $\Phi(O_2)$ | 0.0818 ± 0.0024 (*n* = 5) | 0.0812 ± 0.0033 (*n* = 5) |
| $P_{max}$ | 18.15 ± 1.06 (*n* = 5) | 18.87 ± 0.92 (*n* = 5) |
| $F_v/F_m$ | 0.837 ± 0.003 (*n* = 8) | 0.836 ± 0.004 (*n* = 8) |

$\Phi(O_2)$, apparent quantum yield of $O_2$ evolution ($O_2$ evolved per incident photon); $P_{max}$, maximum rate of $O_2$ evolution (μmol $O_2$ $m^{-2}$ $sec^{-1}$); $F_v/F_m$, maximum quantum yield of photosystem II electron transport. Values are means ± s.e.

PsbS in specifically involved in NPQ and not in light harvesting

PsbS is required for the conformational change essential for NPQ