UV-B radiation
An environmental stressor

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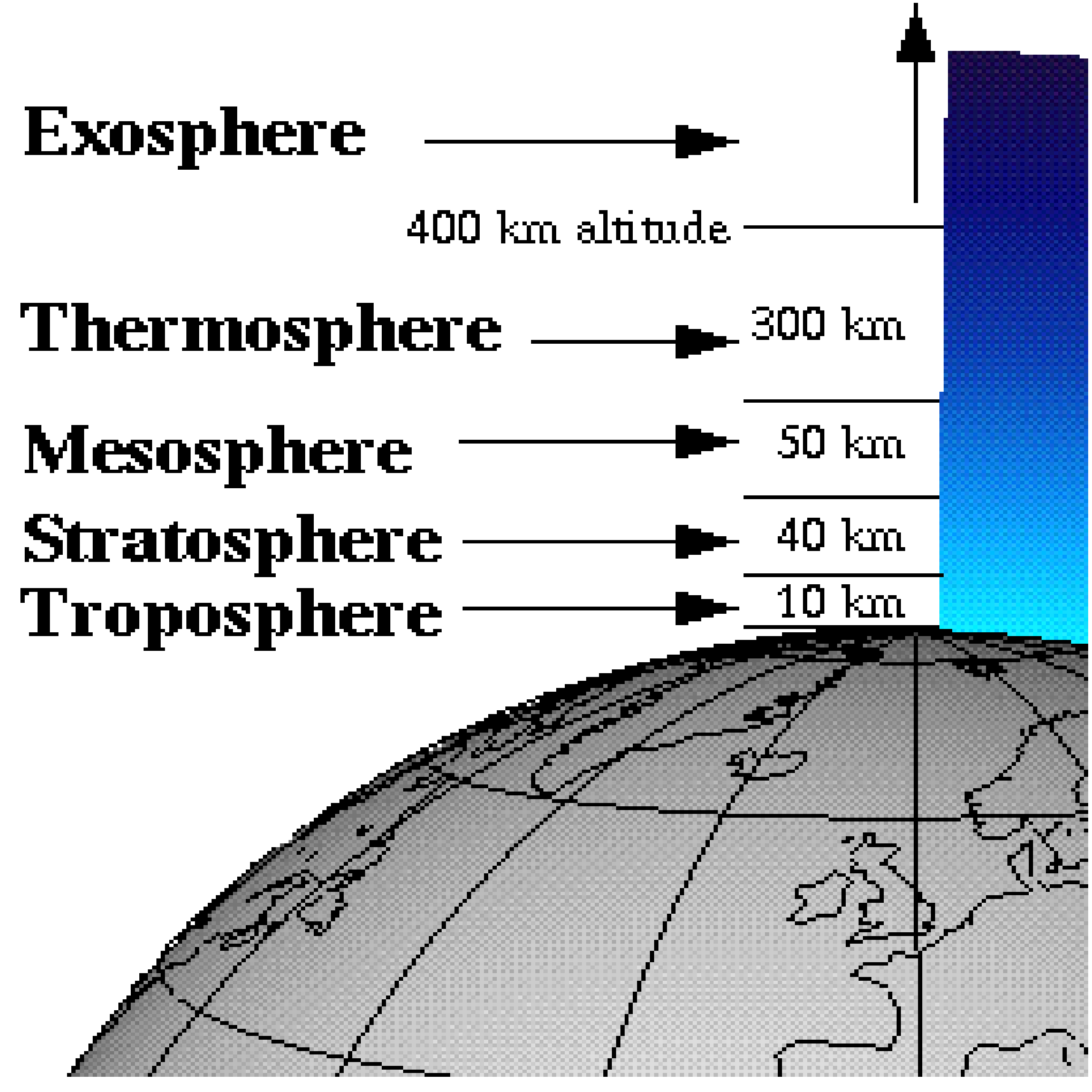
With the use of web-based materials of several authors:
Pitchaya Mungkornasawakul, Jelte Rozema, jednotlivé zdroje citovány přímo na obrázcích,
Web stránky“www.ciesin.org/docs/ 011-558/011-558.html,

Earth's Atmosphere



The ozone layer

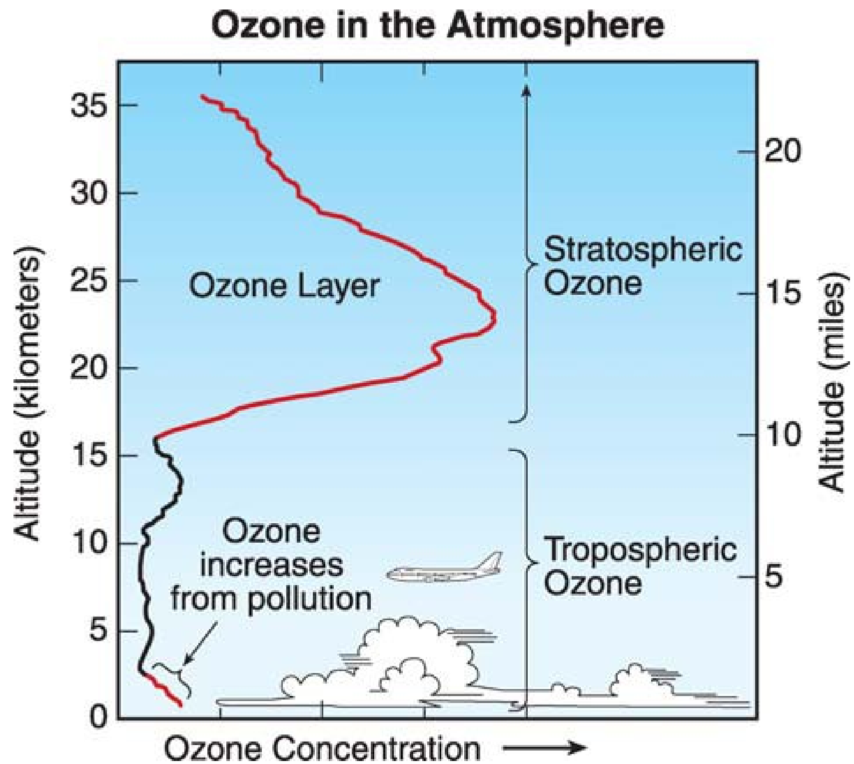
•Ozone is a triatomic form of oxygen (O_3) found in Tropospheric and Stratospheric zones of the Earth's atmosphere

•The ozone layer, situated in the stratosphere about 15 to 30 km above the earth's surface.

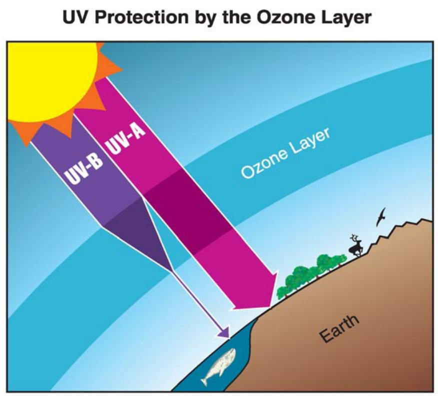
•Ozone protects living organisms by absorbing harmful ultraviolet radiation (UVB) from the sun.

•The ozone layer is being destroyed by CFCs and other substances.

• Ozone depletion progressing globally except in the tropical zone.

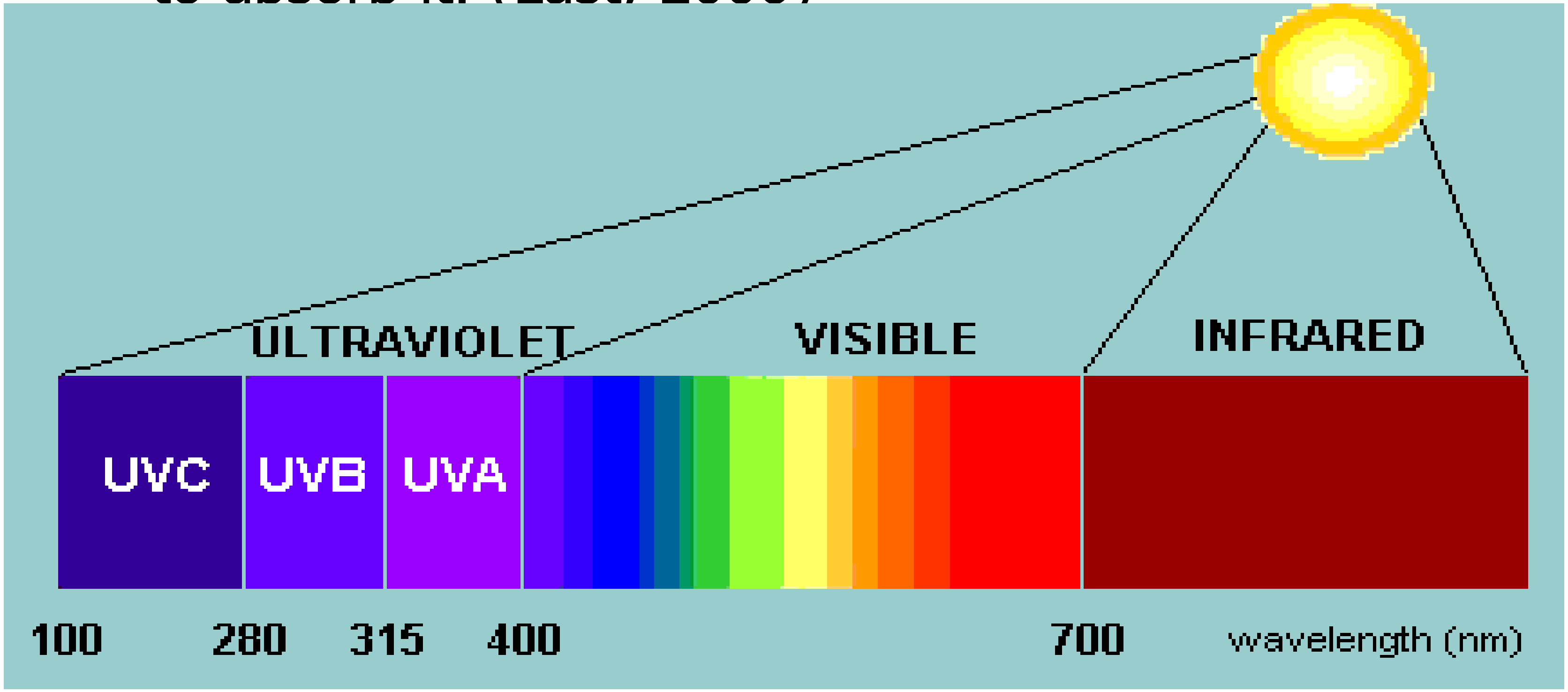


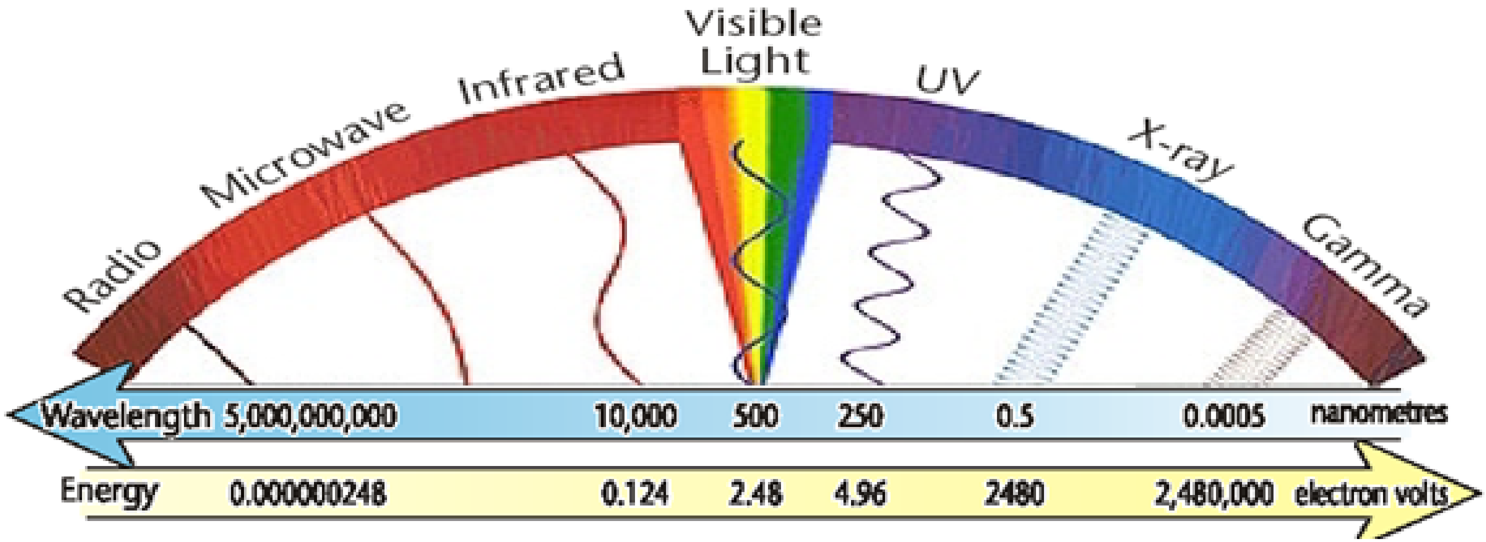
www.epcc.pref.osaka.jp/apec/ eng/earth/**ozone** layer_depletion/susumu.html



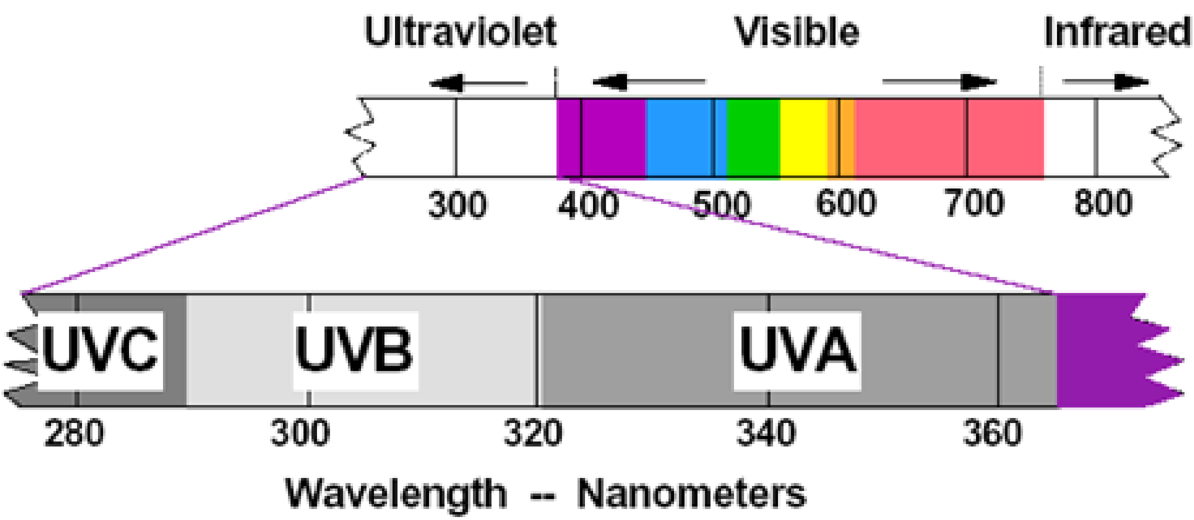
Radiation (UVR)

- **<u>Ultra-violet radiation (UVR)</u> 100 - 400 nm)**
- **<u>UV radiation includes</u> UV-A**, the least dangerous form of UV radiation, with a wavelength range between 315nm to 400nm, **UV-B** with a wavelength range between 280nm to 315nm, and **UV-C** which is the most dangerous between 100nm to 280nm. UV-C is unable to reach Earth's surface due to stratospheric ozone's ability to absorb it. (Last, 2006)





ULTRAVIOLET SPECTRUM



HISTORY

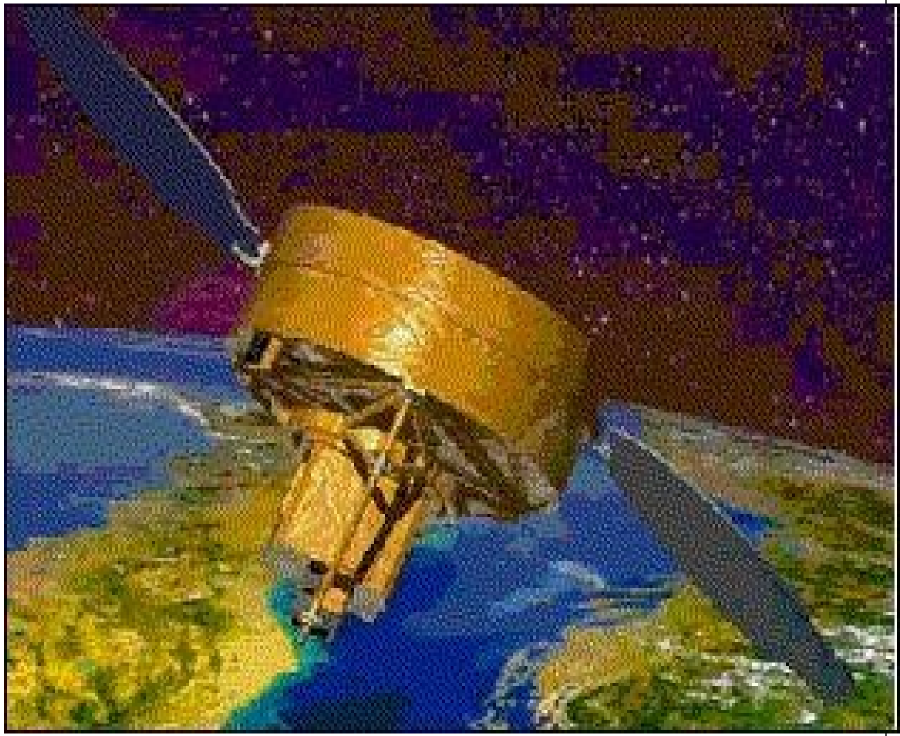
- In 1985, using satellites, balloons, and surface stations, a team of researchers had discovered a balding patch of ozone in the upper stratosphere, over Antarctica.

Team who discovered the hole 1985.
From left: Joe Farman, Brian Gardiner, and Jonathan Shanklin

British Atlantic Survey Research station, Holly Bay, Antarctic coast

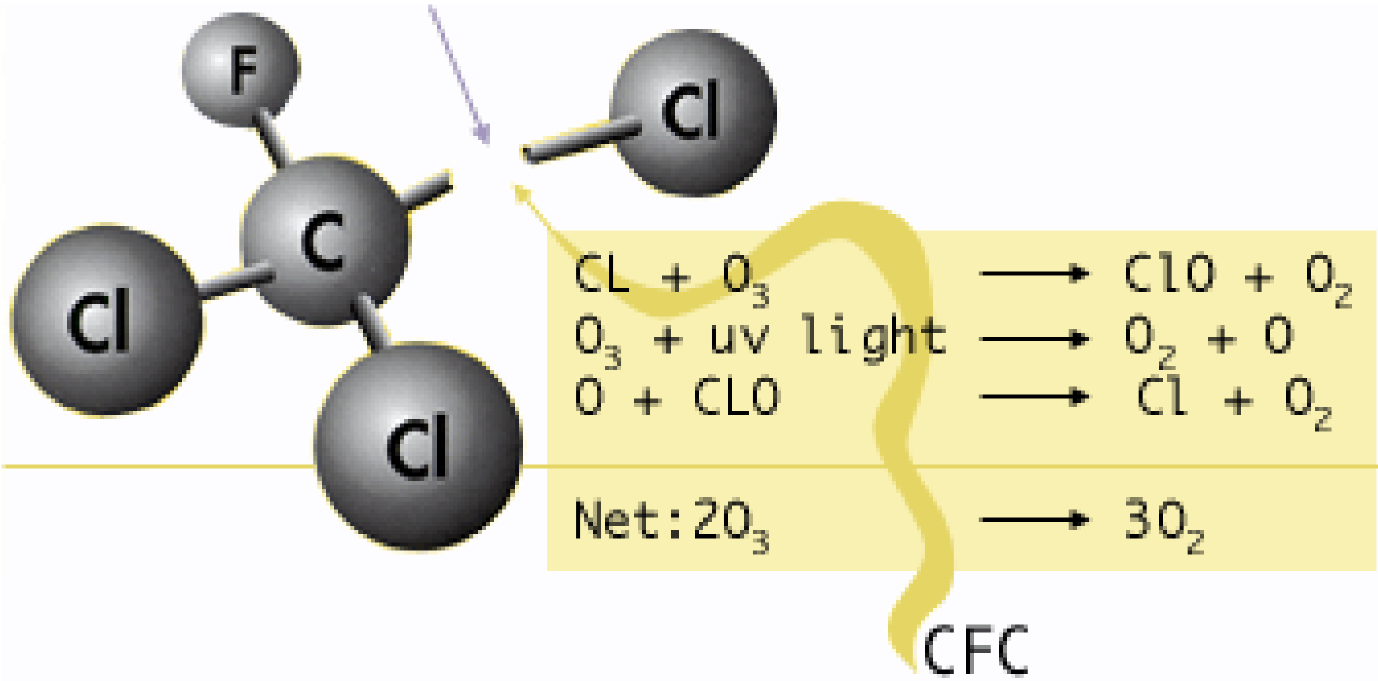
Total Ozone Mapping Spectrometer (TOMS)

- Used by NASA to measure ozone concentrations (1996).
- TOMS – a satellite-borne instrument
- TOMS launched in 1996 – makes 35 measurements every 8 seconds
- Levels of ozone are measured in Dobson units (DU), where 100 DU is equivalent to a 1 millimeter thick layer of pure ozone



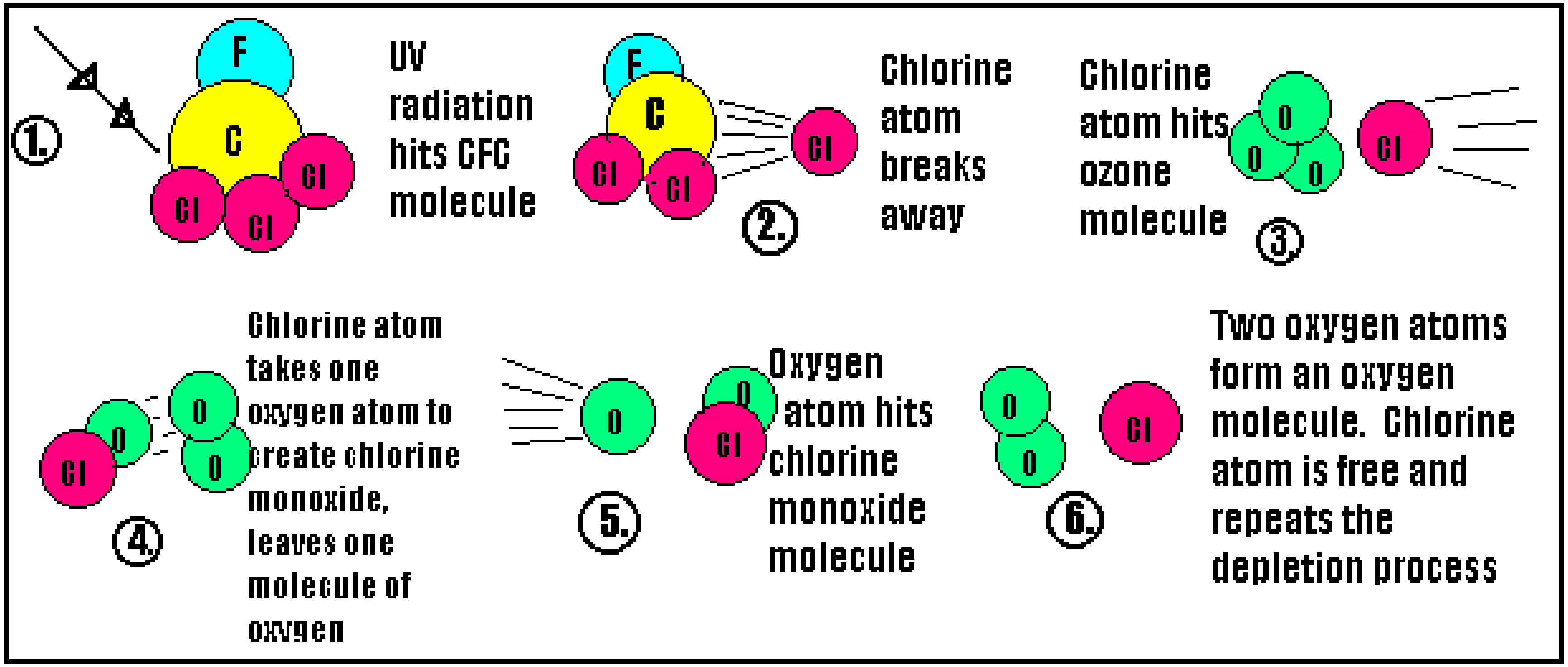
Artist's view of the QuikTOMS spacecraft (image credit: NASA)

2. Chemical mechanism

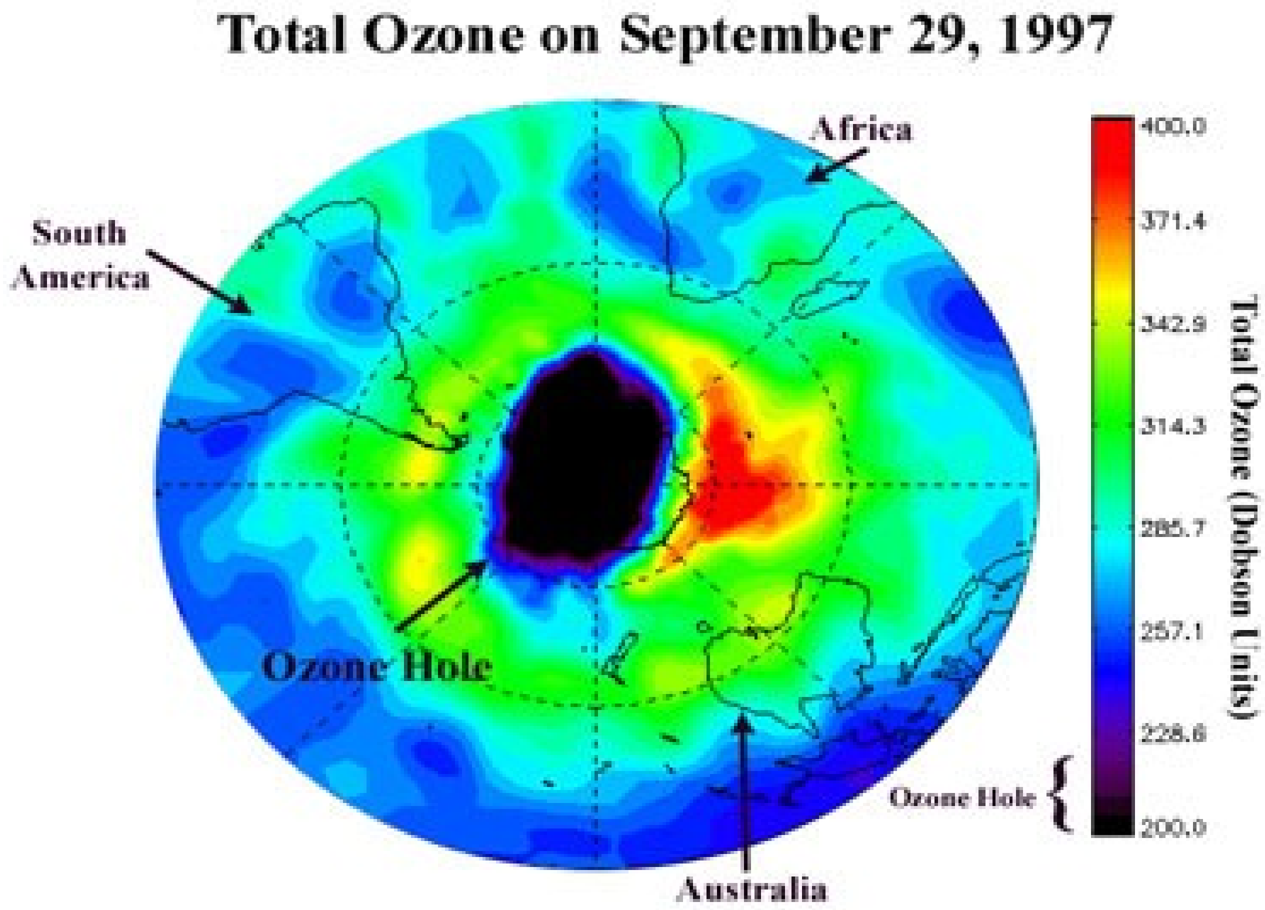


- Different chemicals are responsible for the destruction of the ozone layer
- Topping the list :
  - chlorofluorocarbons (CFC's)
  - man-made, non-toxic and inert in the troposphere
  - **In the stratosphere are photolysed, releasing reactive chlorine atoms that catalytically destroy ozone**

Destruction of ozone by chlorine

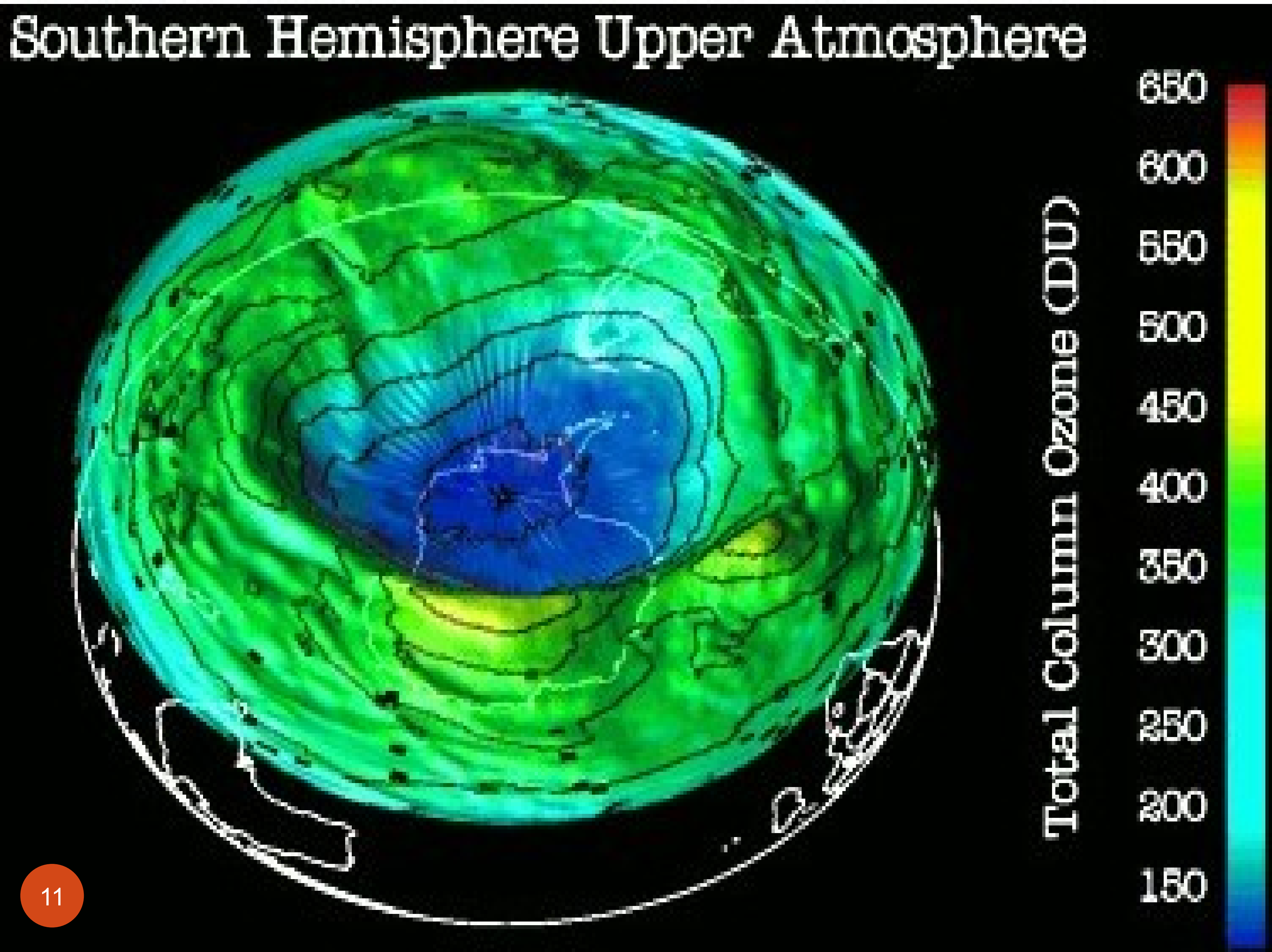


Molecular oxygen is broken down in the stratosphere by solar radiation to yield atomic oxygen, which then combines with molecular oxygen to produce ozone. The ozone is then destroyed by chlorine atoms.



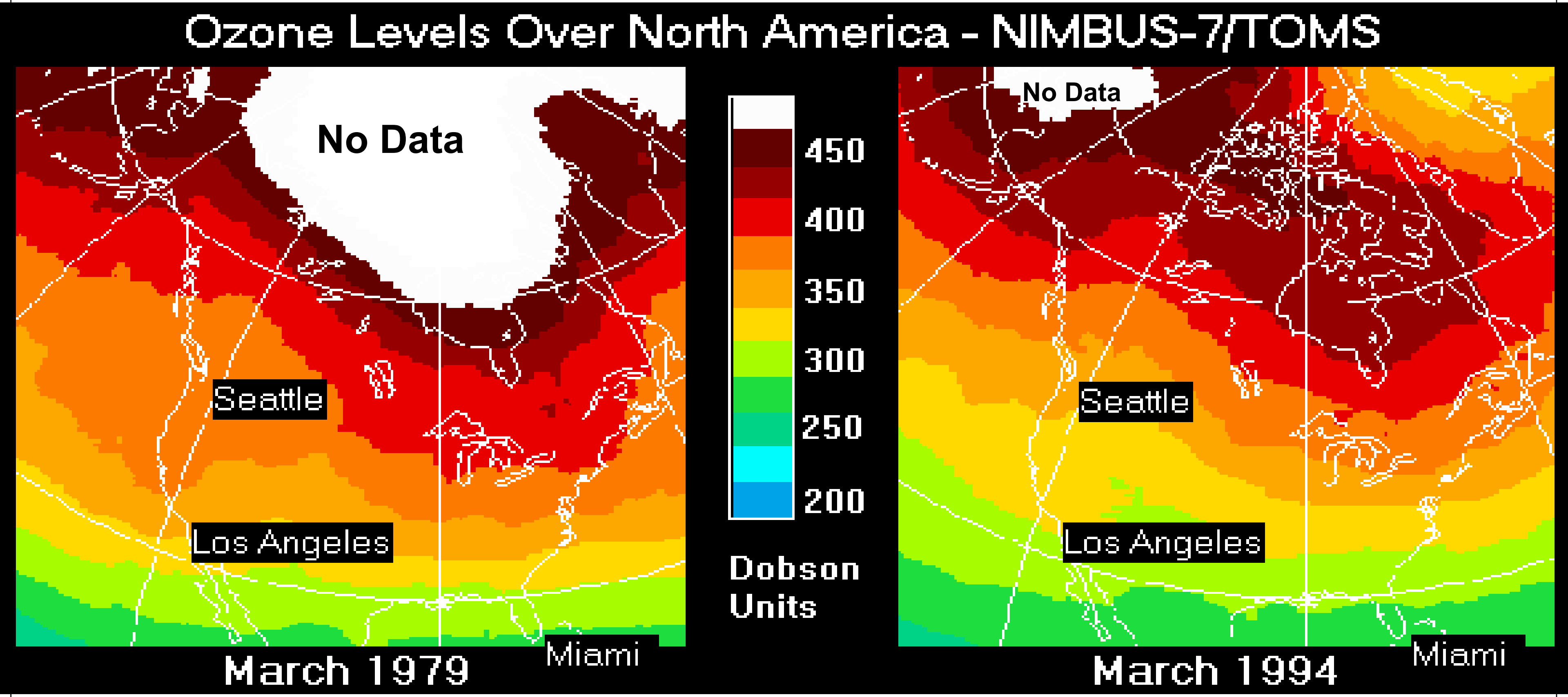
A combination of low temperatures and elevated chlorine and bromine concentrations are responsible for the destruction of ozone in the upper stratosphere thus forming a “hole”. (Kerr, 1987)

www.met.sjsu.edu/~cordero/ education/education.h



Southern Hemisphere Upper Atmosphere
Total Column Ozone (DU)
650
600
550
500
450
400
350
300
250
200
150

Ozone levels over North America (USEPA, March 1994)

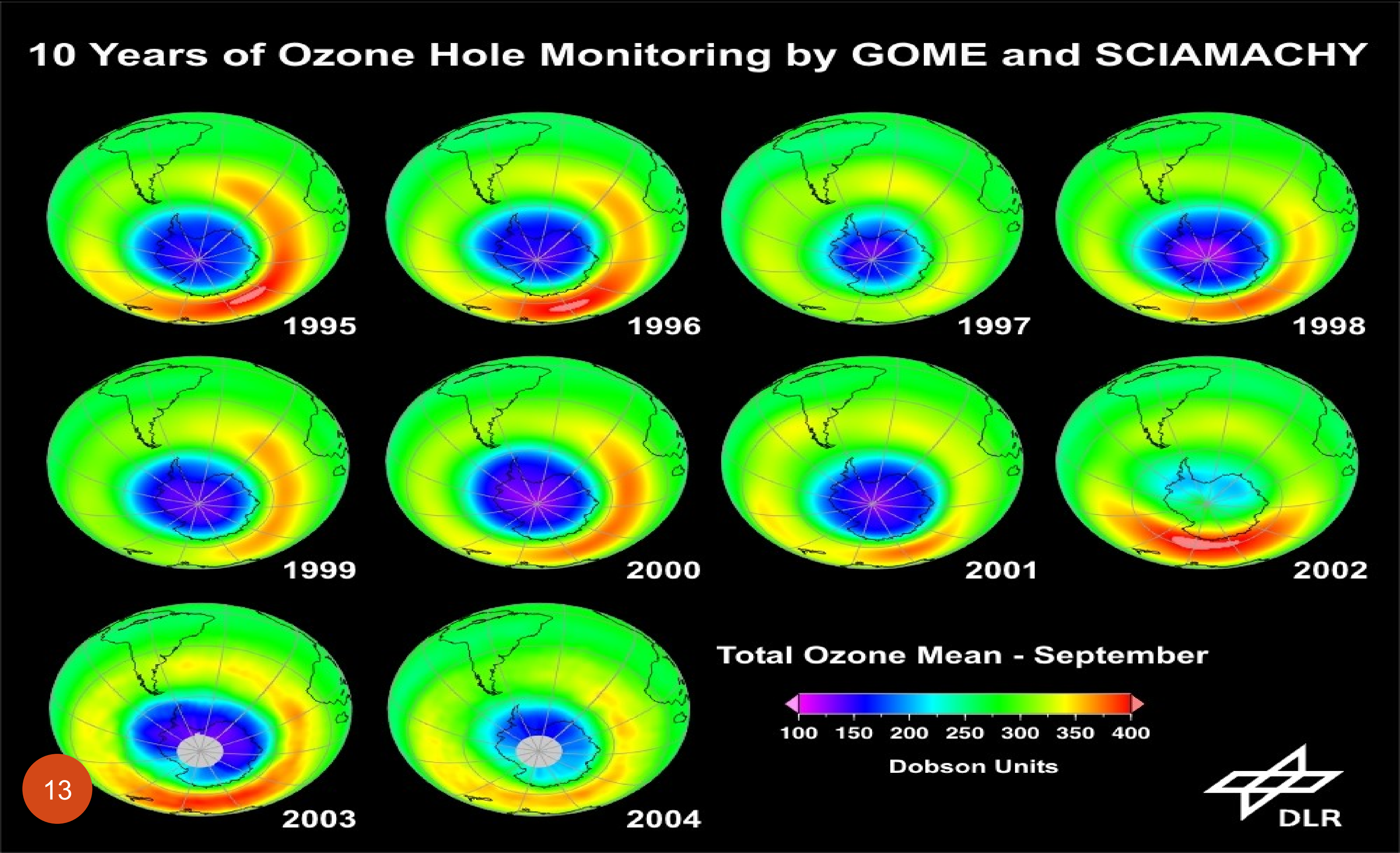


www.epa.gov/air/airtrends/ aqtrnd95/stratoz.html

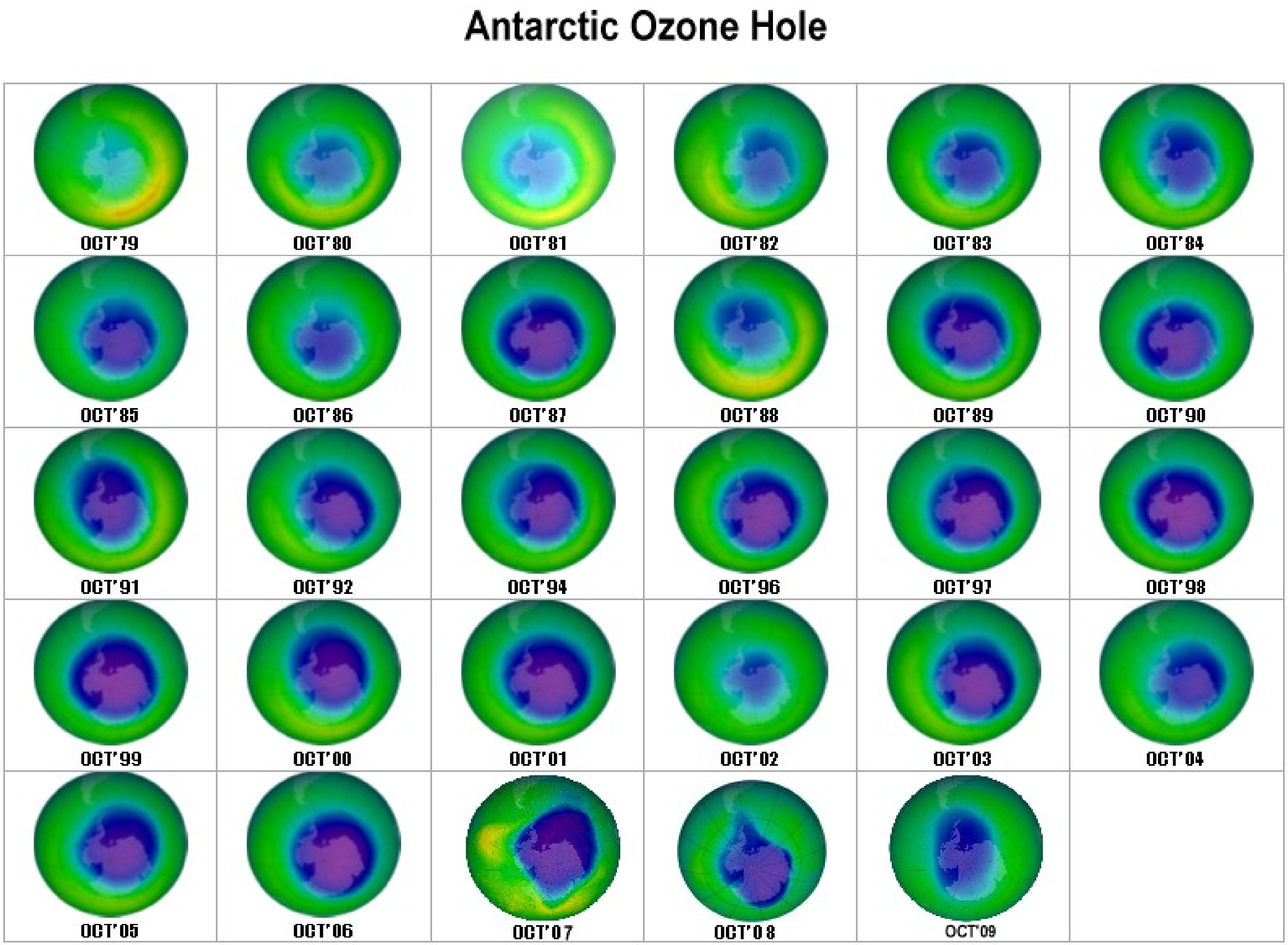
- Comparing the colors of the bands over a particular city, such as Seattle, shows lower ozone levels in 1994 than in 1979
- Over the U.S., stratospheric ozone levels are about 5 percent below normal in the summer and 10 percent below normal in the winter

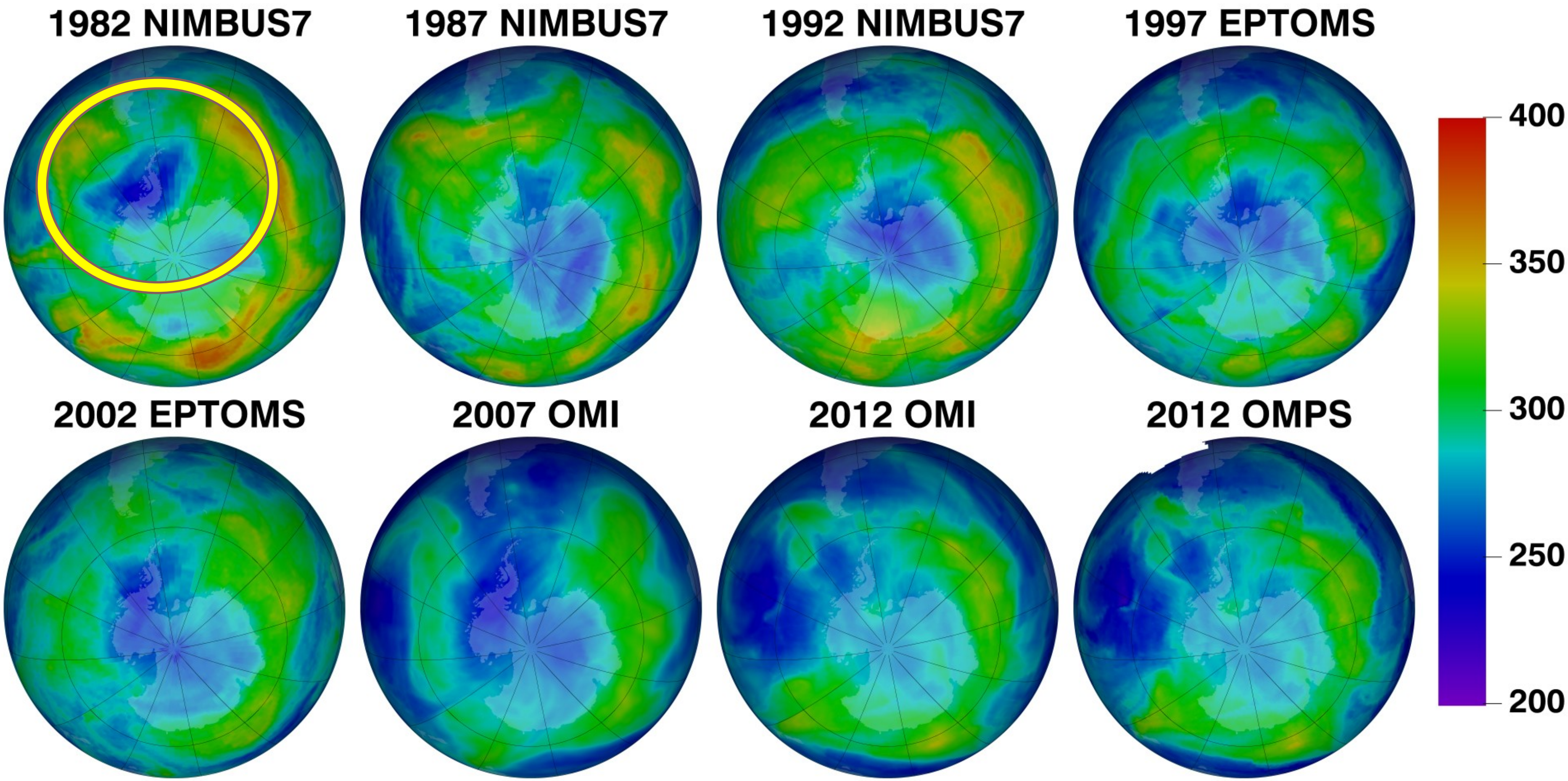
(U.S.E.P.A. 1994)

Images of Antarctica Taken Indicate A Slow Recovery



Antarctic Ozone Hole




1982 NIMBUS7
1987 NIMBUS7
1992 NIMBUS7
1997 EPTOMS
2002 EPTOMS
2007 OMI
2012 OMI
2012 OMPS
400
350
300
250
200

Effects of UV radiation on biological organisms

- **DNA damage** ……………………………. Maximum effect on small and single cell organisms
- **Impaired growth and photosynthesis** ...poor crop yields
- **Phytoplankton**: ………………………...Reduced uptake of CO_2

……………………………………………..mortality

……………………………………………..Impaired reproductive capacity

- **Nitrogen-fixing soil bacteria**…………. Reduced, damaged
- **Human health effects**:

Suppressed immune system……………..Enhanced susceptibility to infection

……………………………………………..Increase risk of Cancer

Dermatology (skin)……………………...Sunburn

…………………………………………….....Loss of skin elasticity (Premature aging)

…………………………………………… Photosensitivity

Neoplasia (cancer)……………………....Melanocytic (malignant melanoma)

……………………………………………....Squamous cell skin – cancer

……………………………………………Basal skin – cancer

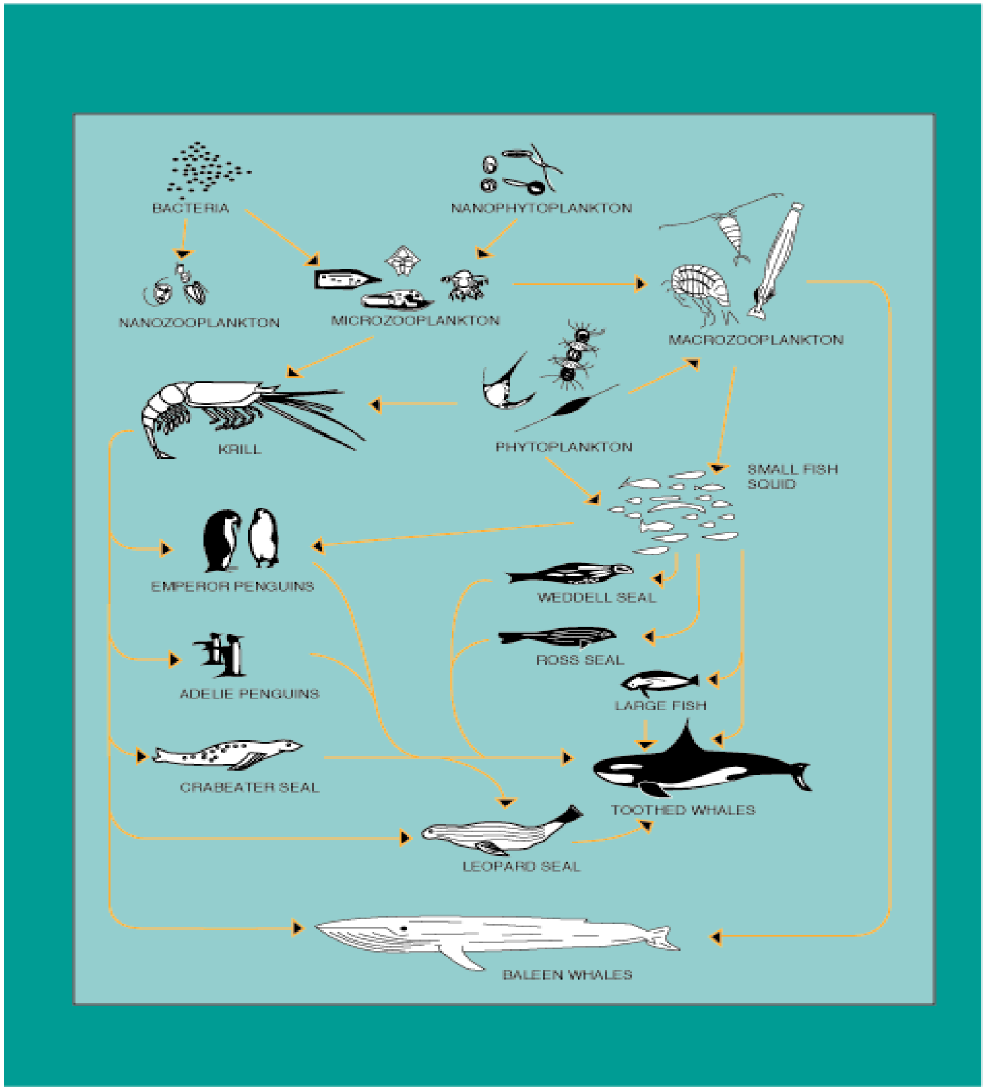
Still questionable if causes lip cancer or cancer of the salivary glands

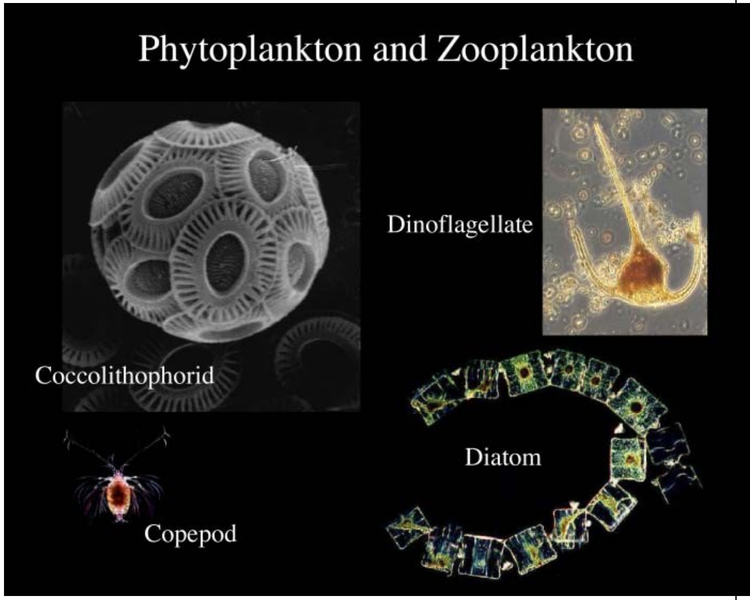
Oculur (Eye)……………………………...Cataract

……………………………………………...Pterygium

(last, 1993)

Aquatic Ecosystems



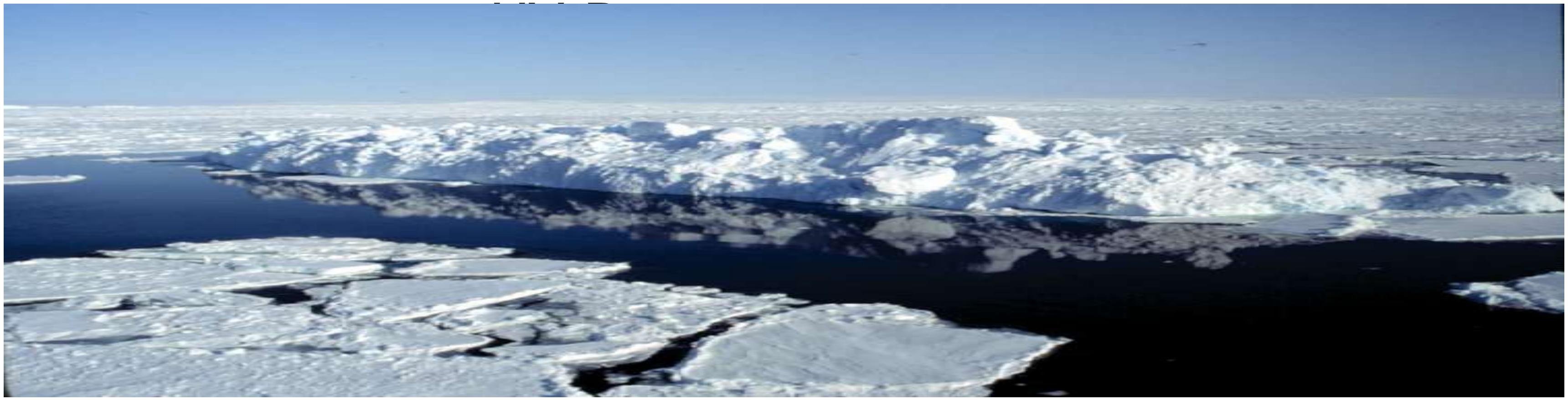


oceancolor.gsfc.nasa.gov/. ../phyto_zoo.jpg

Krill

www.ciesin.org/docs/ 011-558/011-558.html

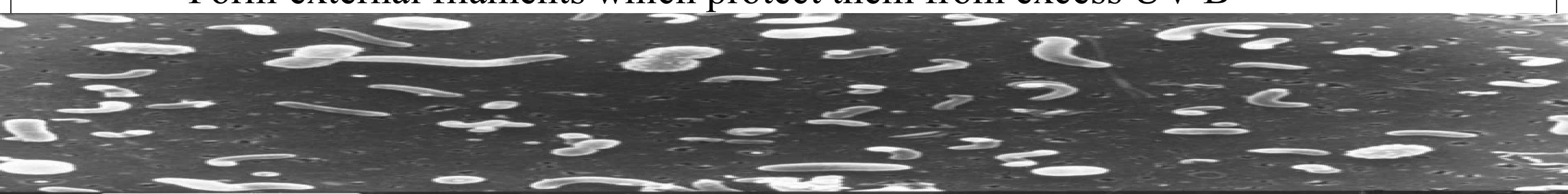
Phytoplankton



- Studies (1993) conducted in the Weddle Sea, Atlantica.
  - Evaluated effects of photosynthesis to UV exposure in the presence of vertical mixing, found:
    - photosynthesis by phytoplankton was strongly inhibited near the surface of the water
    - severe inhibition of photosynthesis

Bacterioplankton

- **Play critical role in aquatic system**
  - **Decomposers** - absorb dissolved organic carbon and recycle it back into the environment
  - **Primary producers** – found at the center of food web
- **Prone to UV-B stress**
  - Inhibits growth
  - Interferes with mechanisms for nitrogen fixation and carbon dioxide fixation
  - High mortality
- **Effects dependent on:**
  - Where found in the water column
  - Amount of exposure
  - Amount of protection when moving from one mixing layer to another
- **Adaptive Strategy:**
  - Pigmentation – absorb more than 90% of UV-B before it penetrates to the genetic material
  - Form external filaments which protect them from excess UV-B

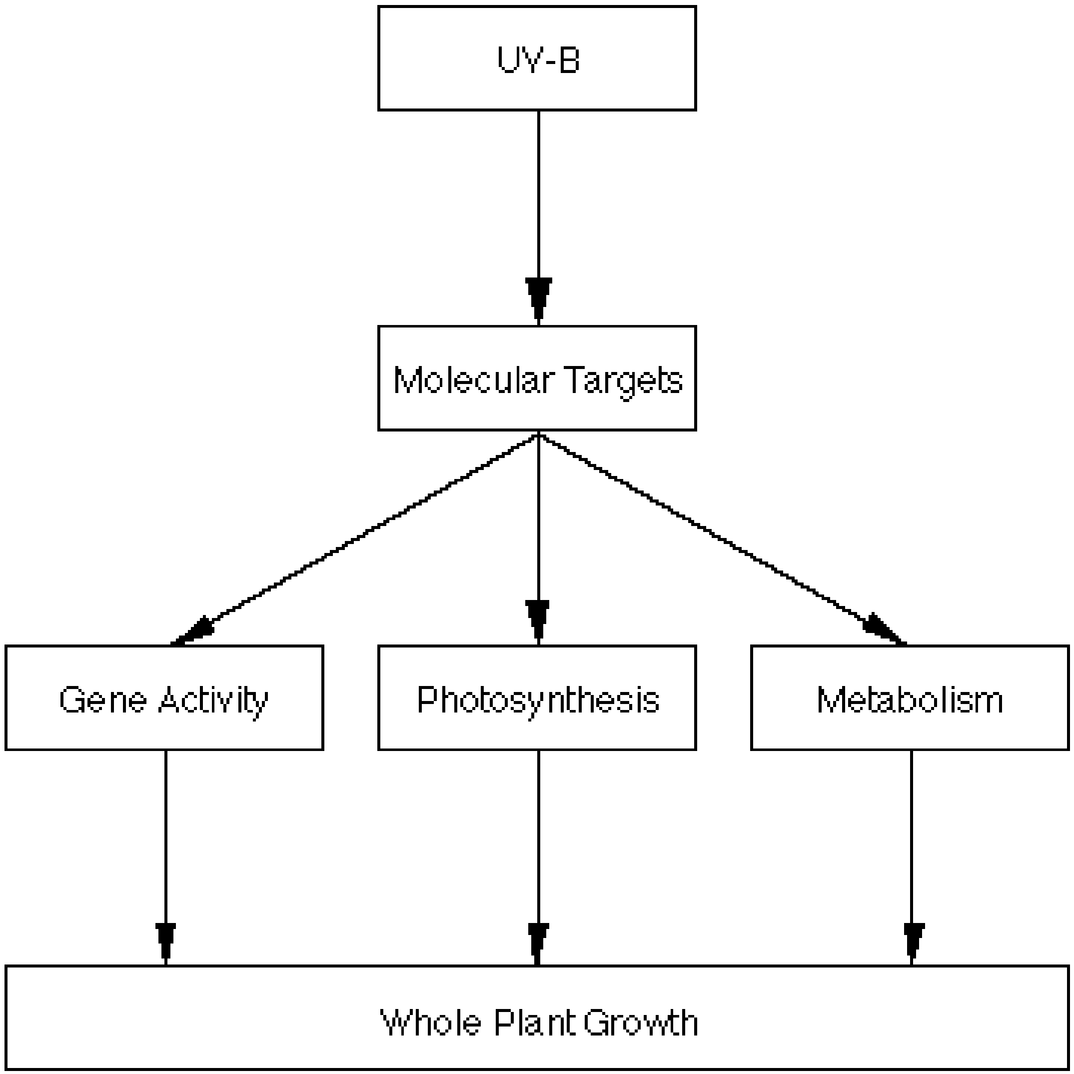


Macroalgae and Seagrass

- Have diverse habitats
  - Above tidal zones Some never exposed
- Have adapted to varying solar expos
  - Able to protect themselves from excessi using mechanisms of phototinhibition
    - mechanisms (electron transport) decrease photosynthesis during excessive radiation

Plants

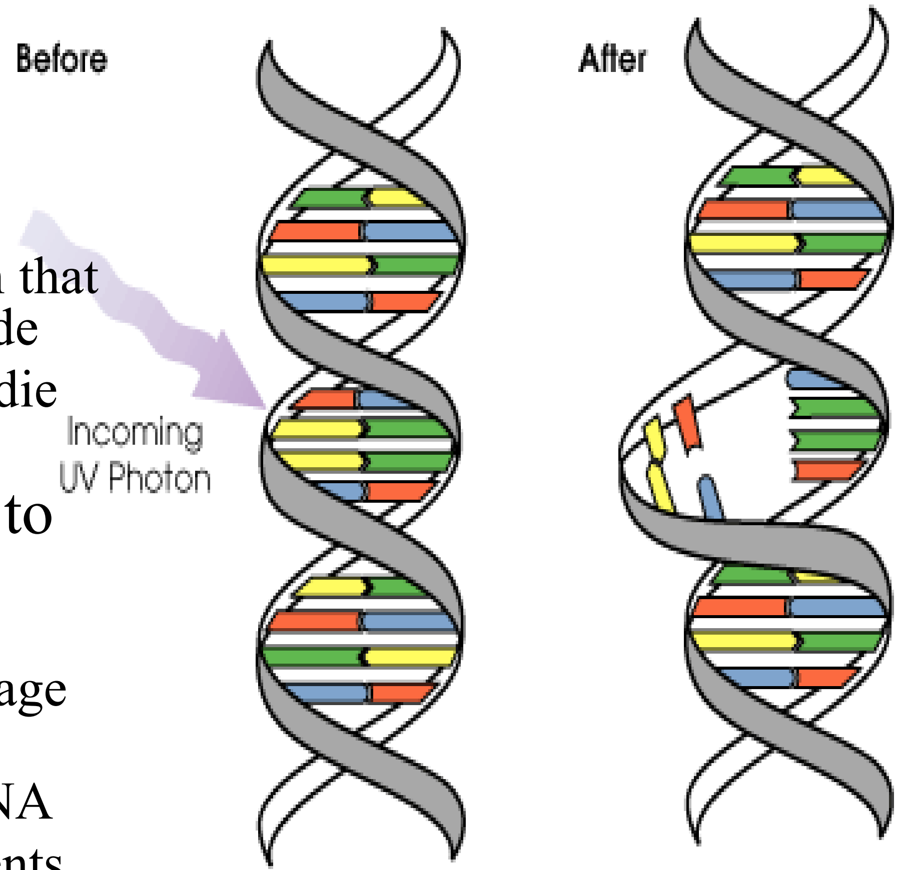
The influence of the UV-B radiation on plant process.



Environmental Effects of Ozone Depletion: 1994 Assessment

DNA & UV-B

- DNA absorbs UV-B radiation
- Changes shape in DNA
  - Changes in the DNA molecule mean that enzymes cannot “read” the DNA code
  - Results in mutated cells or the cells die
- Cells have developed the ability to repair DNA
  - A special enzyme arrives at the damage site
  - removes the damaged section of DNA
  - replaces it with the proper components
- This makes DNA somewhat resilient to damage by UV-B



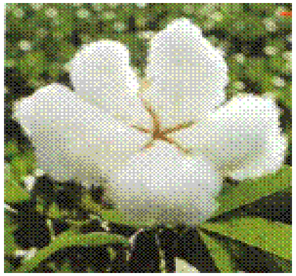
Higher Plants

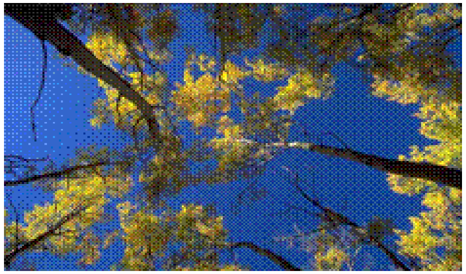
- Experiments were done to determine if increased UV-B is a threat to terrestrial vegetation:
  - Found
    - High UV-B exposure does induce some inhibition of photosynthesis

However….

- Studies found no significant effects on photosynthetic productivity

- Some researchers have concluded that ozone depletion and increase of UV-B not a direct threat to photosynthetic productivity of crops and natural vegetation (Allen, 1998)





Difficult to Unmask UV-B Effects

- Limitations in controlled and field studies include:
  - Large differences in temperature, precipitation, soil types from year to year and in different locations
  - UV-B radiation masked by other stresses of land plants such as drought
- Drought produces large reductions in photosynthesis and growth masking the effects of UV-B
- Water stressed plants produce a high concentration of leaf flavonoids (for pigmentation) providing greater UV-B protection

Environmental Effects of Ozone Depletion: 1994 Assessment

Flowering

- UV-B radiation can alter both the time of flowering as well as the number of flowers in certain species.
- Differences in timing of flowering may have important consequences for the availability of pollinators.
- The reproductive parts of plants, such as pollen and ovules are well shielded from solar UV-B radiation.

Can plants protect themselves against increased UV-B?

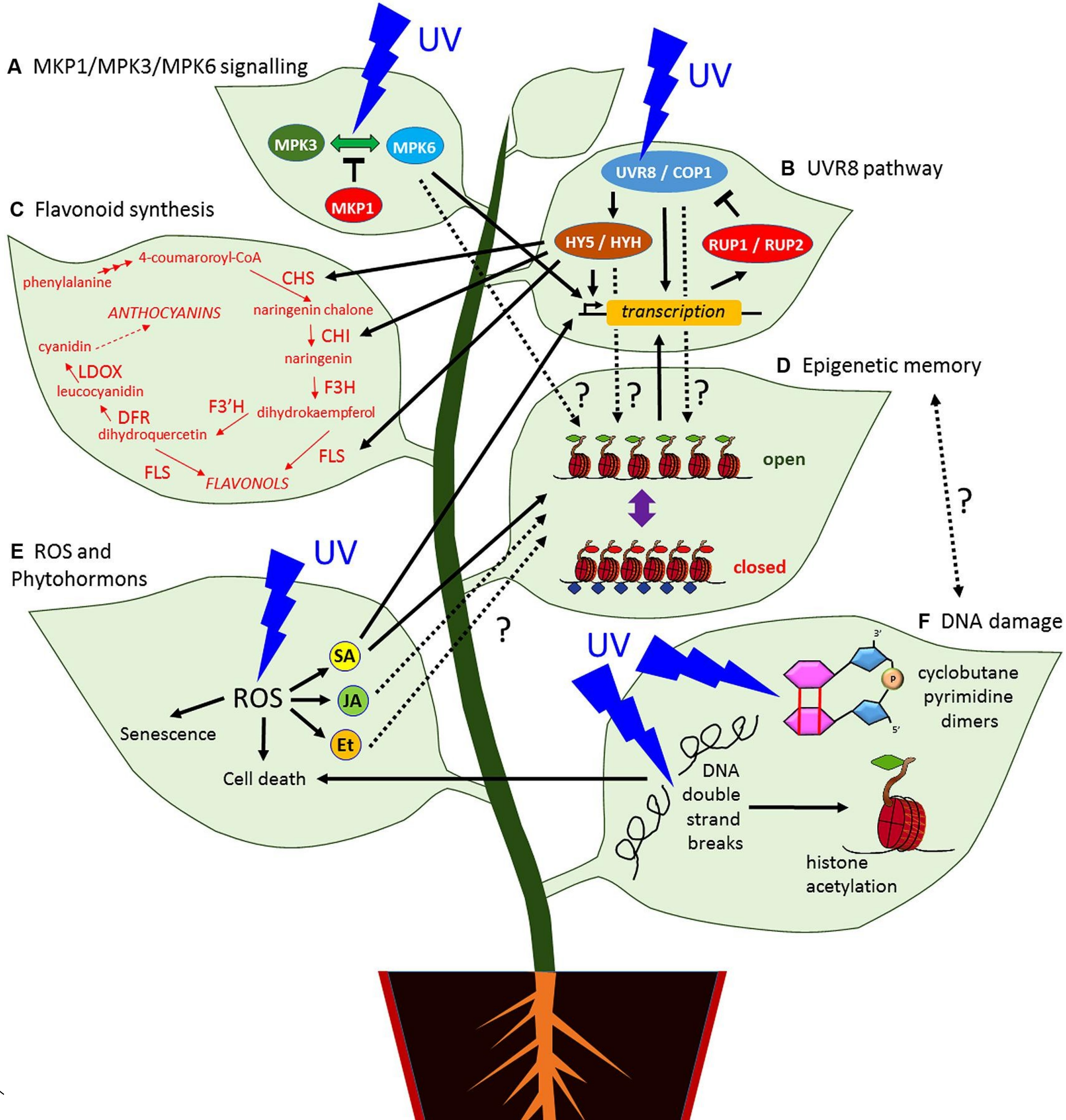
Plant adaptation:

- **Have UV shielding**
- **Only a small proportion of the UV-B radiation striking leaf penetrates into the inner tissues**
- **When exposed to increasing amounts of UV-B, many species of plants can increase the UV-absorbing pigments in their tissues**

Other adaptations include:

- **Increased thickness of leaves reducing the proportion of inner tissues exposed to UV-B radiation**
- **Have repair mechanisms in plants**
  - **includes repair systems for DNA damage**

Zdroj: www.unep.ch/**ozone/faq-env.shtml -**


UV
A MKP1/MPK3/MPK6 signalling
MPK3
MPK6
MKP1
UV
UVR8 / COP1
B UVR8 pathway
HY5 / HYH
RUP1 / RUP2
transcription
C Flavonoid synthesis
4-coumaroroyl-CoA
phenylalanine
CHS
ANTHOCYANINS
naringenin chalone
cyanidin
CHI
naringenin
LDOX
F3H
leucocyanidin
F3'H
dihydrokaempferol
DFR
dihydroquercetin
FLS
FLS
FLAVONOLS
D Epigenetic memory
?
?
?
open
closed
?
E ROS and Phytohormons
UV
SA
JA
Et
ROS
Senescence
Cell death
?
UV
F DNA damage
cyclobutane pyrimidine dimers
DNA double strand breaks
histone acetylation

Target Sites in Plants

- **Photosynthesis and Respiration**
- Photosynthesis is sensitive to increased UV-B effects on photosynthesis is not clear.
- Many studies
- The have demonstrated detrimental effects of UV-B radiation on photosynthesis under laboratory conditions in plants .

Target Sites in Plants

- At the whole-plant level, the effect of UV-B stress is usually perceived as a decrease in photosynthesis and growth.

- This is associated with alterations in carbon and nitrogen metabolism .

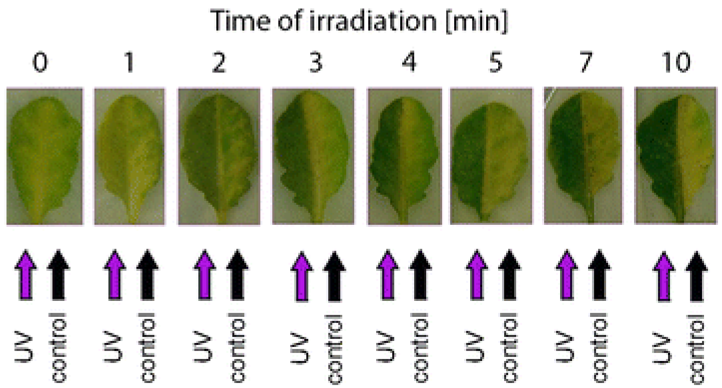
- Julkunen-Tiitto et al 2005.

- Lidon 2012.

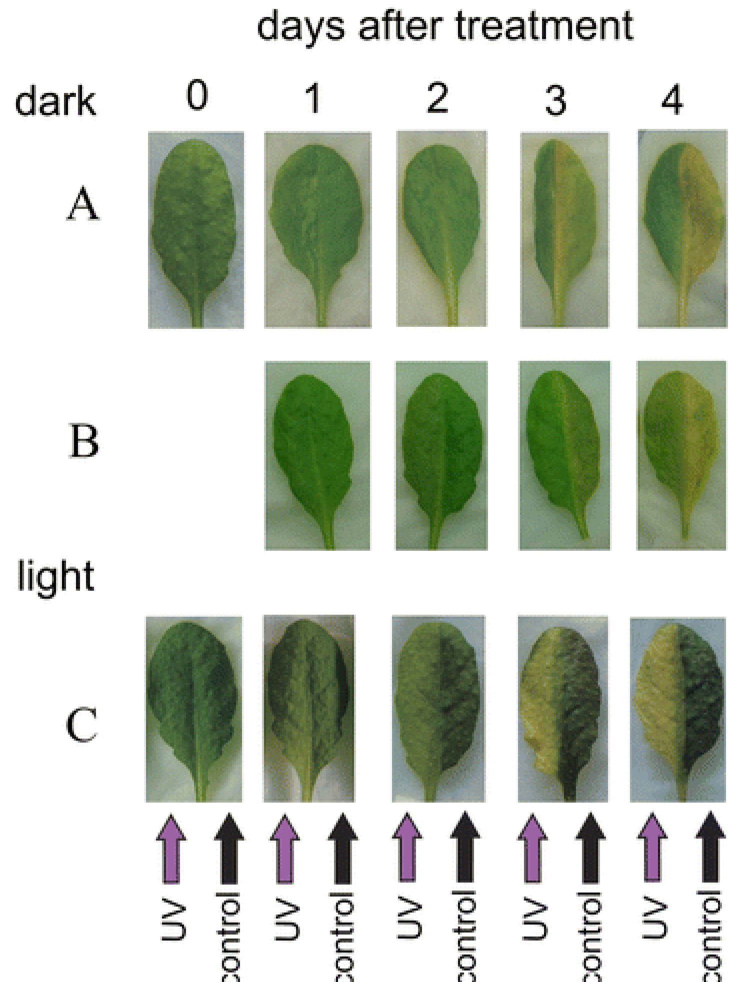
2015: The effect of UV-B on Arabidopsis leaves depends on light conditions after treatment

Olga Sztatelman, Joanna Grzyb, Halina Gabryś and Agnieszka Katarzyna Banaś

BMC Plant Biology 2015



- Photographs of the detached leaves of 6-week old *A. thaliana* with one half covered with black paper, and another half irradiated with UV-B (8 W·m^{-2}) for the indicated time and left in darkness for 4 days



A. thaliana leaves with one half covered with black paper, and another half irradiated with UV-B (8 W·m^{-2}) for 5 min and left in darkness (**a** and **b**) or under constant illumination (100 μmol·m^{-2}·s^{-1} of white light, **c**) for the indicated time. The leaves were taken from plants dark-adapted overnight (**a**), or from plants kept in a growth chamber for 2 h after the dawn (**b**and **c**)

Table 12.1 Relative sensitivities of some cultivated crops to enhanced UV-B radiation derived from biomass accumulation. This is only a notional classification for average behaviour of a given species because significant cultivar differences do exist. By and large, monocotyledons are less sensitive to UV-B than dicotyledons, but no obvious correlations with taxonomy or morphology are apparent

Sensitive to UV-B	Insensitive to UV-B
Soybean	Lucerne
Clover	Cabbage
Pea	Lettuce
Faba bean	Cotton
Cauliflower	Rice
Turnip	Wheat
Spinach	Maize
Cucumber	Tomato

(Based on various sources including Krupa and Kickert 1989; Rozema *et al*. 1997)

Fyziologie buňky

- Several sets of processes at both cellular and molecular levels which are critical to plant growth and reproductive development appear to be affected by absorption of UV-B radiation. Especially prominent are photosynthesis, signal transduction and nucleic acid metabolism.
- In general, UV-B radiation causes a net inhibition of photosynthesis in a wide range of plants (see Tevini 1993). From laboratory studies, this inhibition appears to arise from disruptions at a number of points in the photosynthetic cycle including disruption of PSII reaction centres (Strid *et al*. 1990), a decrease in Rubisco activity and damage to photosynthetic pigments (chlorophylls and carotenoids). Stomatal function, and thus leaf gas exchange, is also commonly impaired (Teramura 1983; Tevini and Teramura 1989).
- Alterations in plant growth induced by UV-B radiation have been partly attributed to changes in nucleic acid structure and function (Beggs *et al*. 1986; Tevini 1994). DNA absorbs strongly in the UV region and is thus especially prone to damage by UV-B radiation (Figure 12.17). The most common lesions are breaks in DNA chains, with a resultant production of thymine dimers. They in turn interfere with accurate base pairing, leading to a disruption of transcription and replication of DNA (Stapleton 1992). These disruptions amount to a mutagenic action for UV radiation in many organisms. Proteins and RNA can also absorb UV-B and are inactivated as a result, but this loss is of secondary importance due to their relative abundance compared with DNA (Stapleton 1992).
- Activation and photo-deactivation of important signal molecules, such as hormones and photoreceptors, may also compound effects of UV-B irradiation on plant growth and development. For example, cell extension in many plants is influenced by indole acetic acid (IAA) which absorbs in the UV-B region and is photo-oxidised to 3-methyleneoxindole, an inhibitor of hypocotyl growth when exogenously applied (Tevini and Teramura 1989). In contrast, irradiation with UV-B can induce enzyme activity in the shikimic acid pathway, which regulates the synthesis of a broad array of plant compounds ranging from flavonoids to lignin, all of which are important to plant function, including tolerance to UV-B radiation (Caldwell *et al*. 1989).

Rozmnožování rostlin

- Flowering, pollination and seed development are variously affected by UV-B irradiation. Flowering also appears to be disrupted by UV-B radiation with decreases in flower number and alteration in timing reported in the few species so far studied (Tevini and Teramura 1989). Such effects may have important consequences for natural plant populations which rely on the synchrony of flowering with the presence of appropriate insect pollinators.
- Although pollen appears resilient to UV-B radiation damage, owing to high levels of flavonoids in the anthers and pollen wall, germinating pollen tubes are highly sensitive to UV radiation and suffer from large decreases in growth rate. Such disruption can lead to lowered fertilisation success and decreases in seed yield (Tevini and Teramura 1989).

Ekologické vztahy

- Genetic variation in sensitivity to UV-B radiation has implications for plant competition and thus plant ecosystem dynamics and community structure, in both natural and managed ecosystems. Gold and Caldwell (1983), for example, showed that competition between seven agricultural crops and associated weeds was significantly altered under enhanced UV-B irradiation in the field, *Triticum aestivum* (bread wheat) being outcompeted by *Avena fatua* (wild oat) essentially through differences in the rates of biomass production. By contrast, wheat growth under enhanced UV-B was favoured when in competition with *Aegilops cylindrica* (goat grass). In the few studies considering the impact of UV-B irradiation on natural plant communities most notable is the work of Caldwell and colleagues (Caldwell *et al*. 1982) who found that arctic plant species are much more sensitive to UV-B, both in terms of growth and reproduction, than alpine species. Arctic species grow under a naturally low UV-B environment, whereas alpine species grow under a naturally high UV-B environment by virtue of higher altitude. Arctic plant com-munities could thus be altered to a greater extent than alpine communities by any substantial rise in natural UV-B.

- Field-grown plants are subject to variable environmental conditions during their life cycle. In their extremes such factors can lead to stresses such as water stress, mineral stress, temperature stress, disease and stresses due to anthropogenic pollution (ozone, acid rain). The interaction of UV-B irradiation stress with other environmental factors has been examined in only a few cases, essentially because of the difficulty of simulating elevated UV-B irradiation in the field. Of the environmental interactions studied water stress appears to influence plant responses induced by UV-B irradiation. In soybean, for example, a decrease in yield in sensitive cultivars under elevated UV-B irradiation was most apparent under well-watered conditions. Water deficit in combination with elevated UV-B irradiation did not reduce yield to a greater extent than water deficit alone (Tevini and Teramura 1989). Water stress may therefore mask UV-B responses of plants.
- Elevated CO_2 levels may also modify the response of sensitive plants to UV-B irradiation. In rice and wheat (but not in soybean) an increase in seed yield and biomass under elevated CO_2 was reversed under moderate levels of supplementary UV-B irradiation (Teramura *et al*. 1990).
- UV-B irradiation appears to exacerbate the impact of plant pathogens. In one of a limited number of published findings, UV-B intensifies adverse effects of *Cercospora beticola* (leaf spot) on sugar beet. Symptoms include greater loss of chlorophyll and dry mass under UV-B and leaf spot fungus than occurs with leaf spot fungus alone (Panagopoulos *et al*. 1992).
- Interactions between UV-B radiation and other environ-mental factors are obviously complex and their combined effects on plant responses cannot be predicted from single-factor experiments. Global changes in coming decades — such as elevated CO_2 and higher temperatures — will most likely be superimposed on a predicted increase in UV-B radiation. Consequently, studies of combined impacts of environmental factors and UV-B radiation will be necessary if plant breeders are to select crop varieties that are better adapted to cope with these stresses, and for ecologists to predict likely outcomes for natural ecosystems.

Ochranné mechanismy

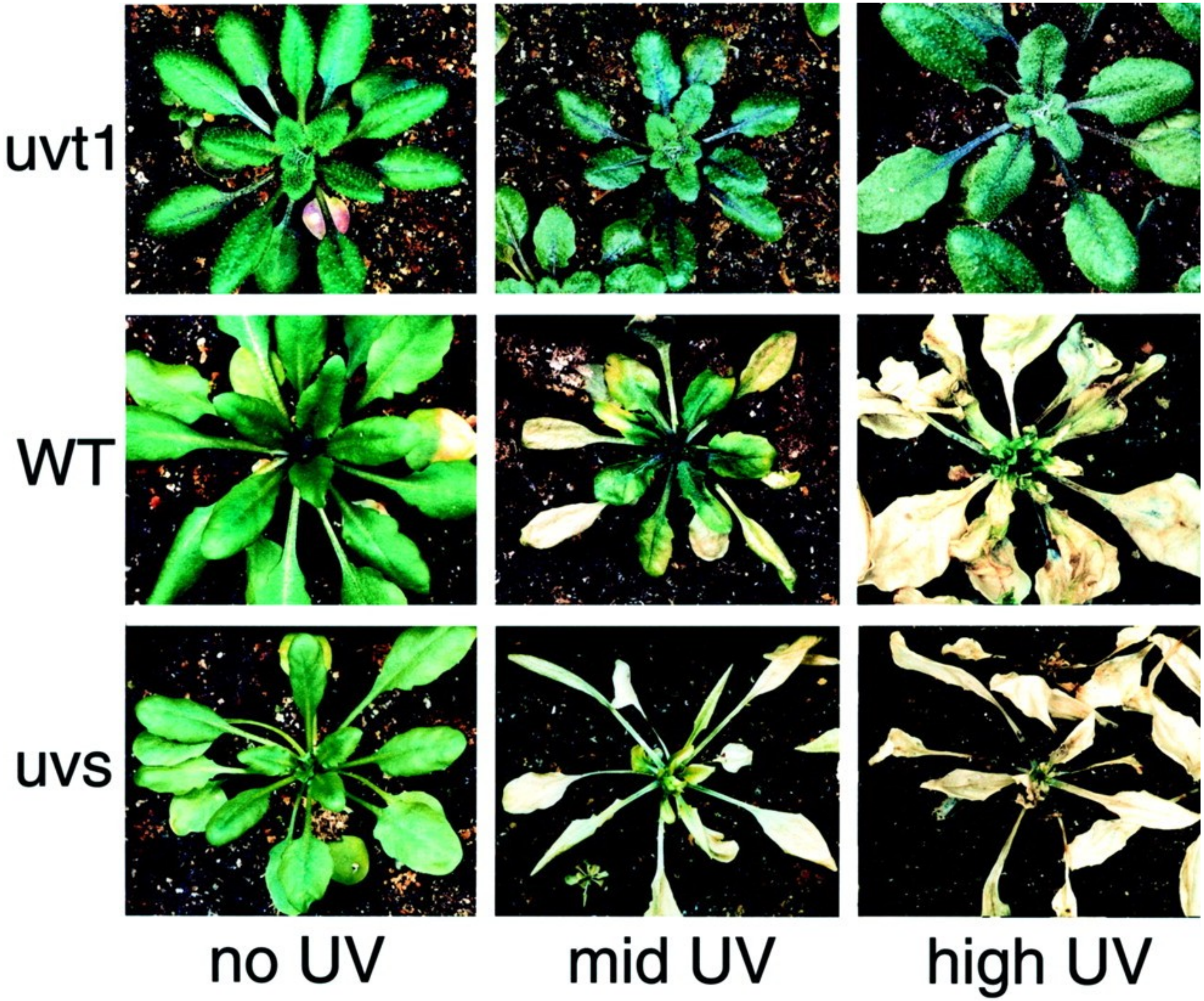
(působící proti dopadům UV-B stresu)

Ochranné mechanismy 1

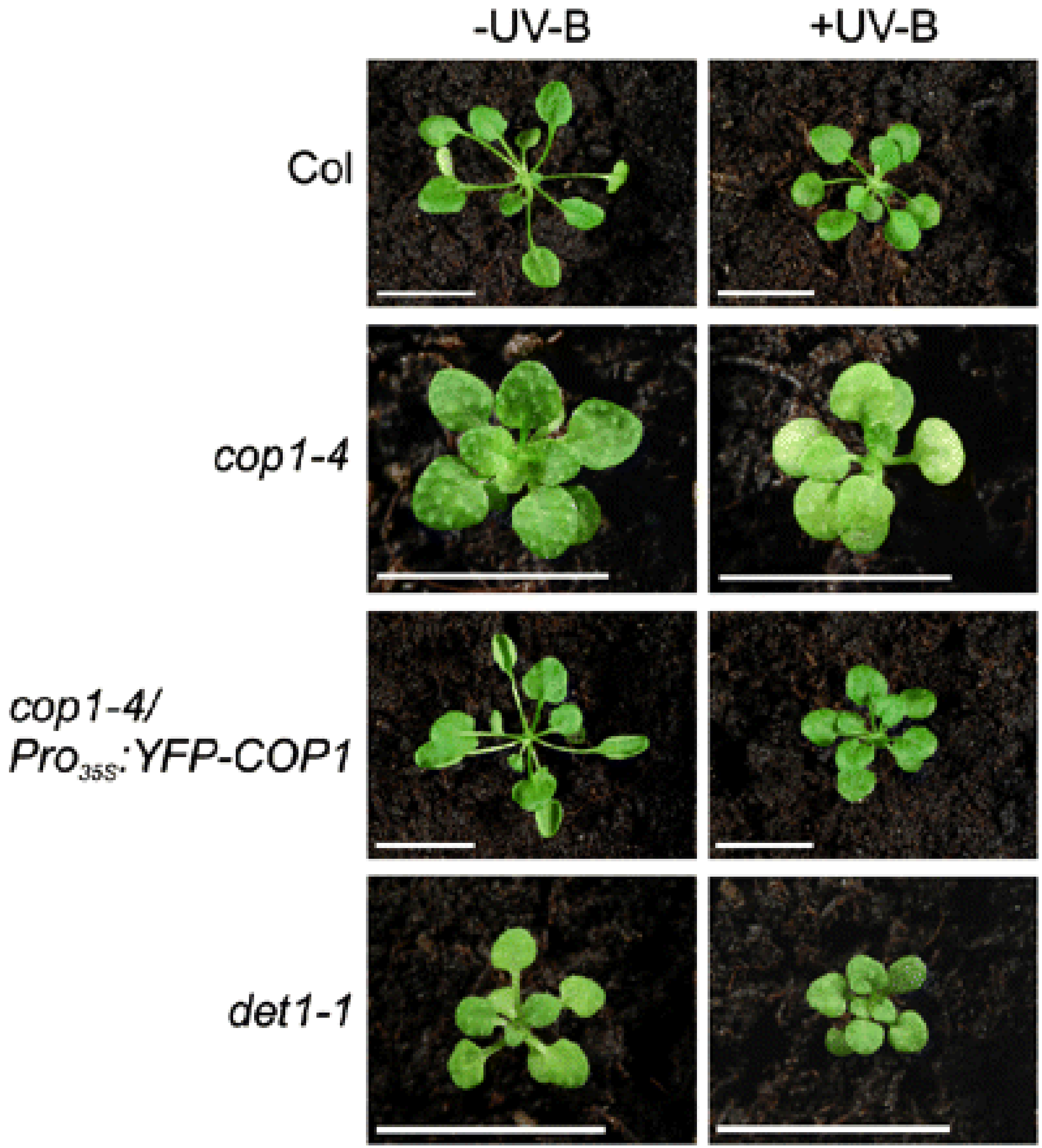
- Many organisms have evolved mechanisms to undo the molecular damage caused by UV radiation. Possibly the most adaptive are terrestrial plants that rely on full sunlight for photosynthesis. Protective mechanisms can be classified into two main classes: (1) those whereby UV damage is repaired or its effects negated or minimised, and (2) those whereby the amount of UV radiation actually reaching sensitive areas is reduced. While protective in nature, all of these mechanisms impose an energy cost on plants so adapted.
- Considering the first class of protective mechanism, organisms have developed three important repair processes for UV-induced DNA damage (Stapleton 1992): (1) photoreactivation, a light-induced enzymatic process which cleaves pyrimidine dimers formed by UV radiation — thus restoring proper base pairing; (2) excision repair of DNA, which involves the excision of UV photoproducts from DNA molecules (this mechanism requires no light energy and uses undamaged DNA templates as a guide); and (3) post-replication repair, where DNA lesions are bypassed during DNA replication and information from the sister duplex is later used to fill gaps.

Ochranné mechanismy 2

- Screening sensitive tissues from UV-B radiation is a secondary option available to plants either to avoid or at least minimise damage. Tissue screening may be achieved through structural modification of organs or by screening molecules which absorb UV radiation. Such features may be either static, as with leaf orientation or phototaxis, or dynamic, as in synthesis of screening molecules which absorb UV radiation in a highly selective way. Screening molecules commonly appear after exposure to UV radiation (Beggs *et al*. 1986) as secondary metabolites such as flavonoids. Substantial amounts of such pigments accumulate especially in the upper epidermis of leaves. Along with cuticular waxes and other cellular components, these substances attenuate incident UV radiation, and energy transmitted to underlying tissue is decreased by up to two orders of magnitude (Figure 12.19; Beggs *et al*. 1986). Flavonoid pigments are synthesised by leaves on many plants in direct response to UV radiation. Such photoprotective mechanisms can be likened to tanning responses in humans.



- An Arabidopsis Mutant Tolerant to Lethal Ultraviolet-B Levels Shows Constitutively Elevated Accumulation of Flavonoids and Other Phenolics



The Plant Cell **August 2006** vol. 18 no. 8 **1975-1990**

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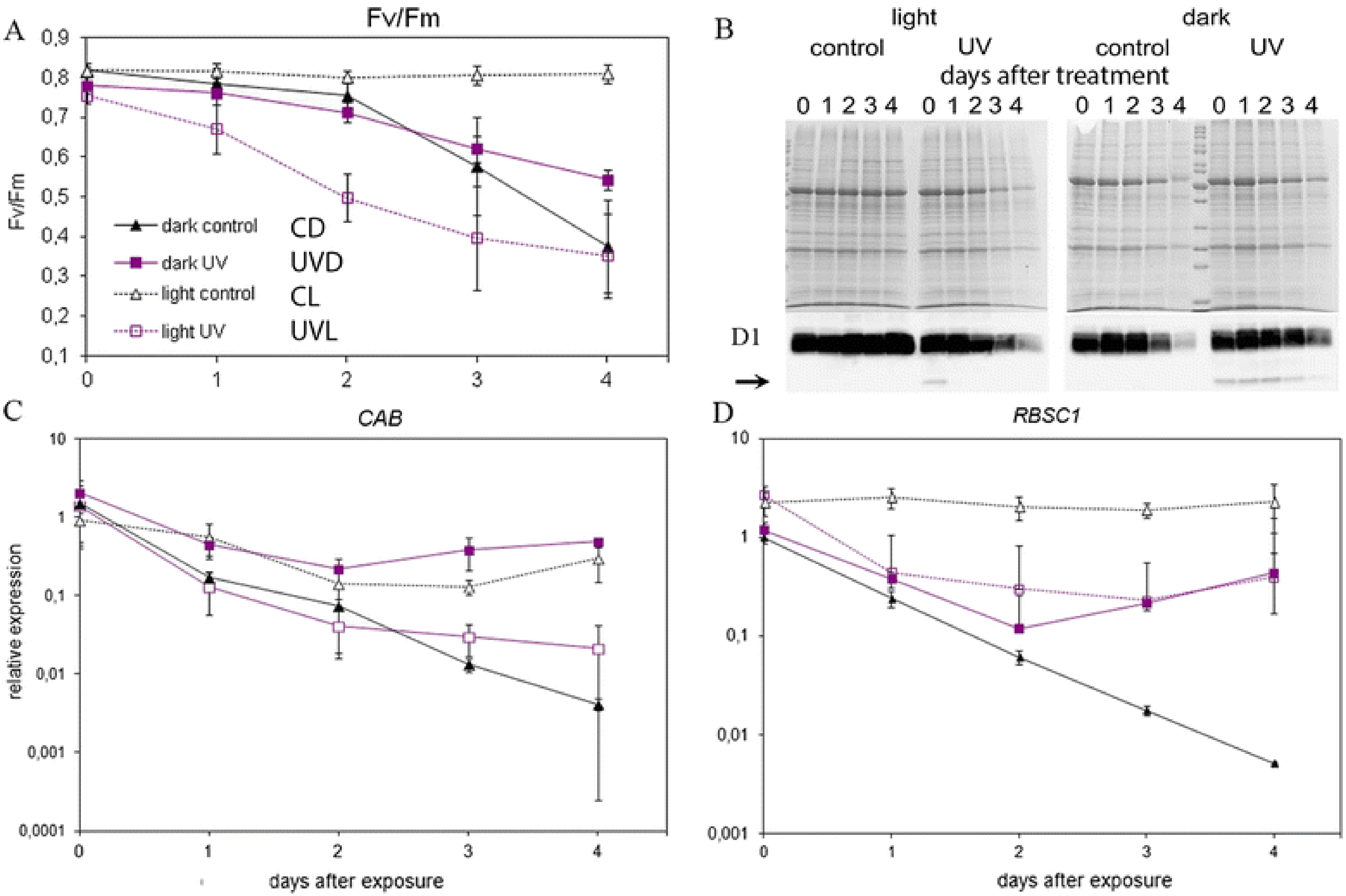
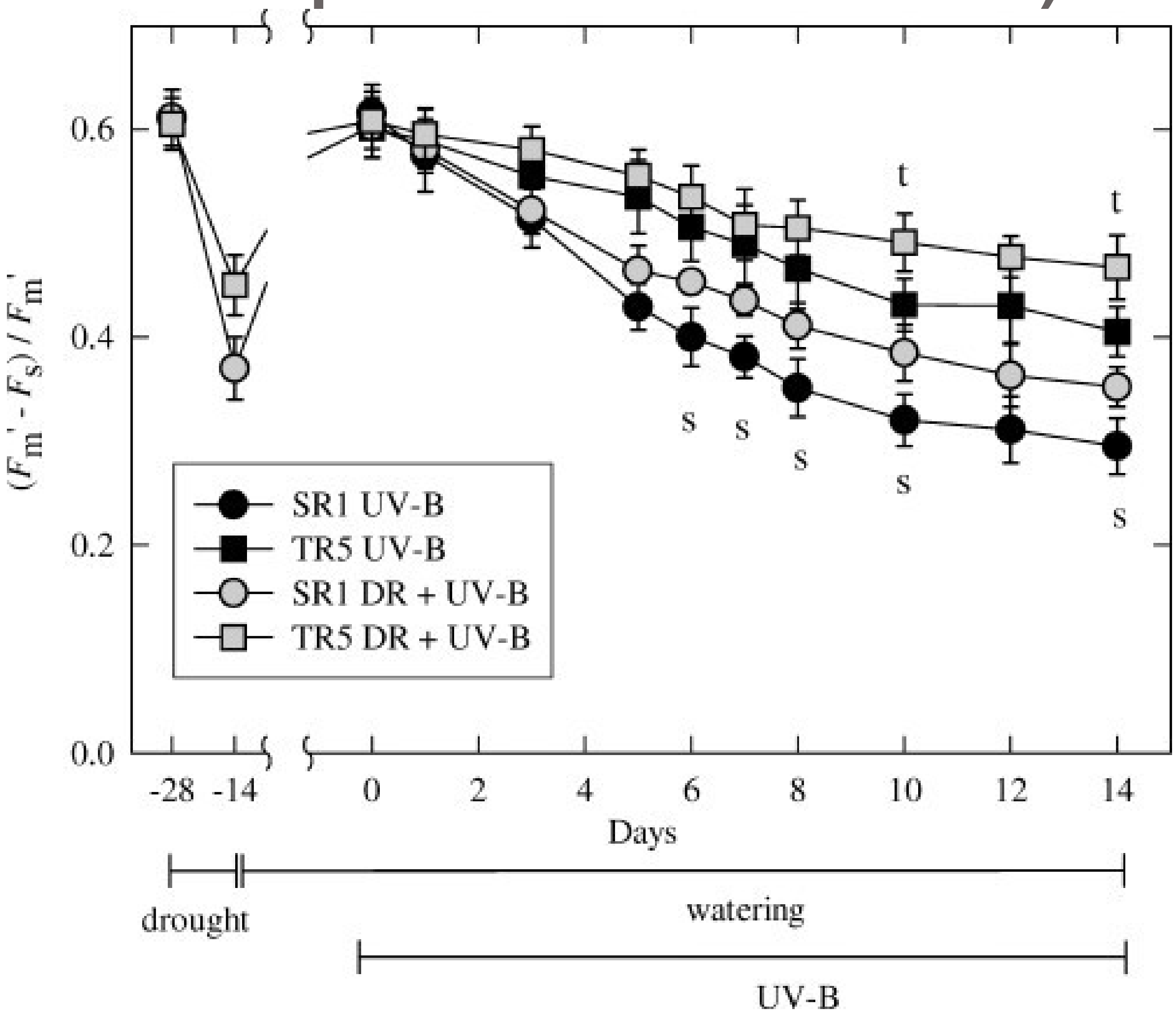
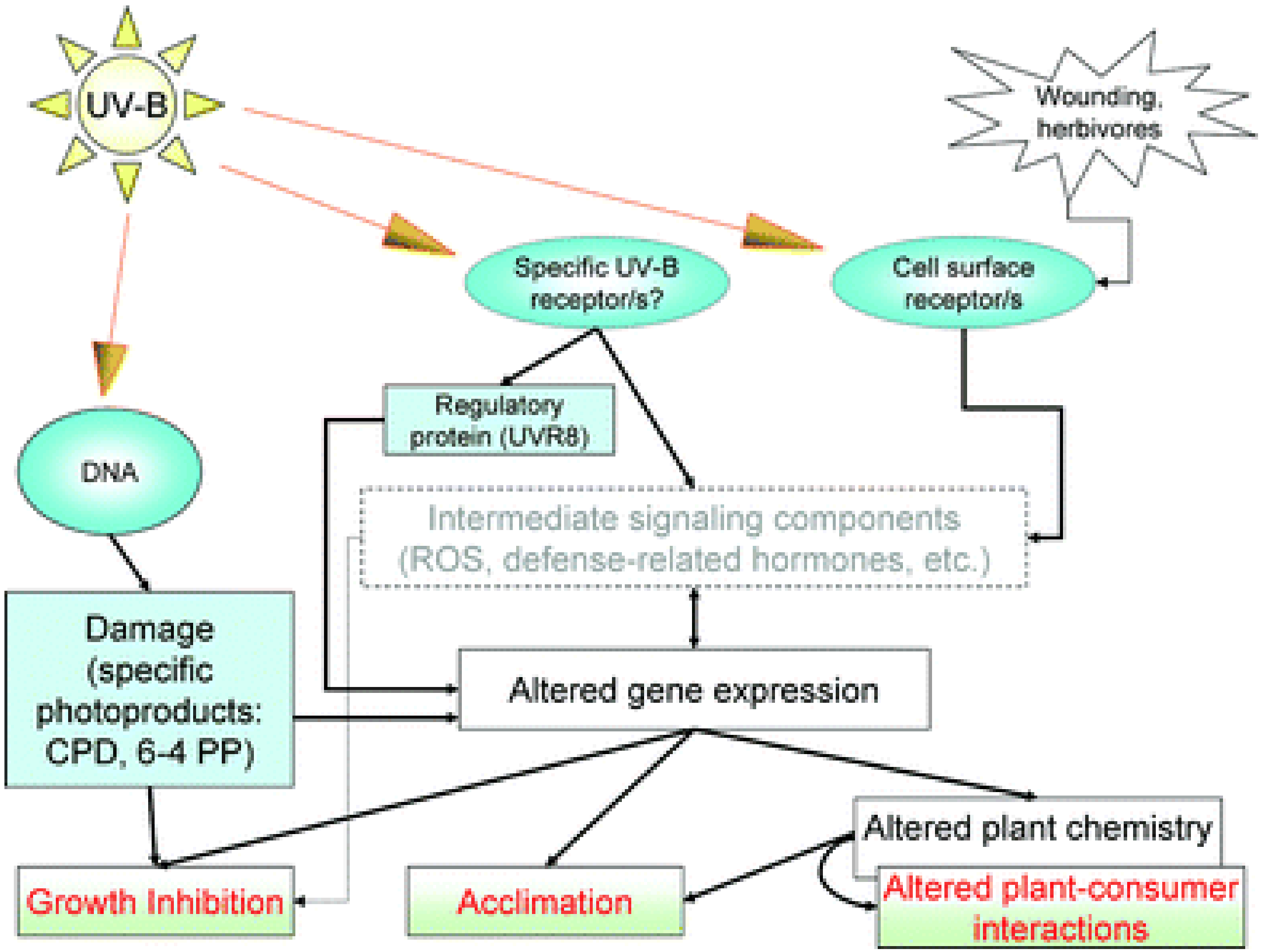
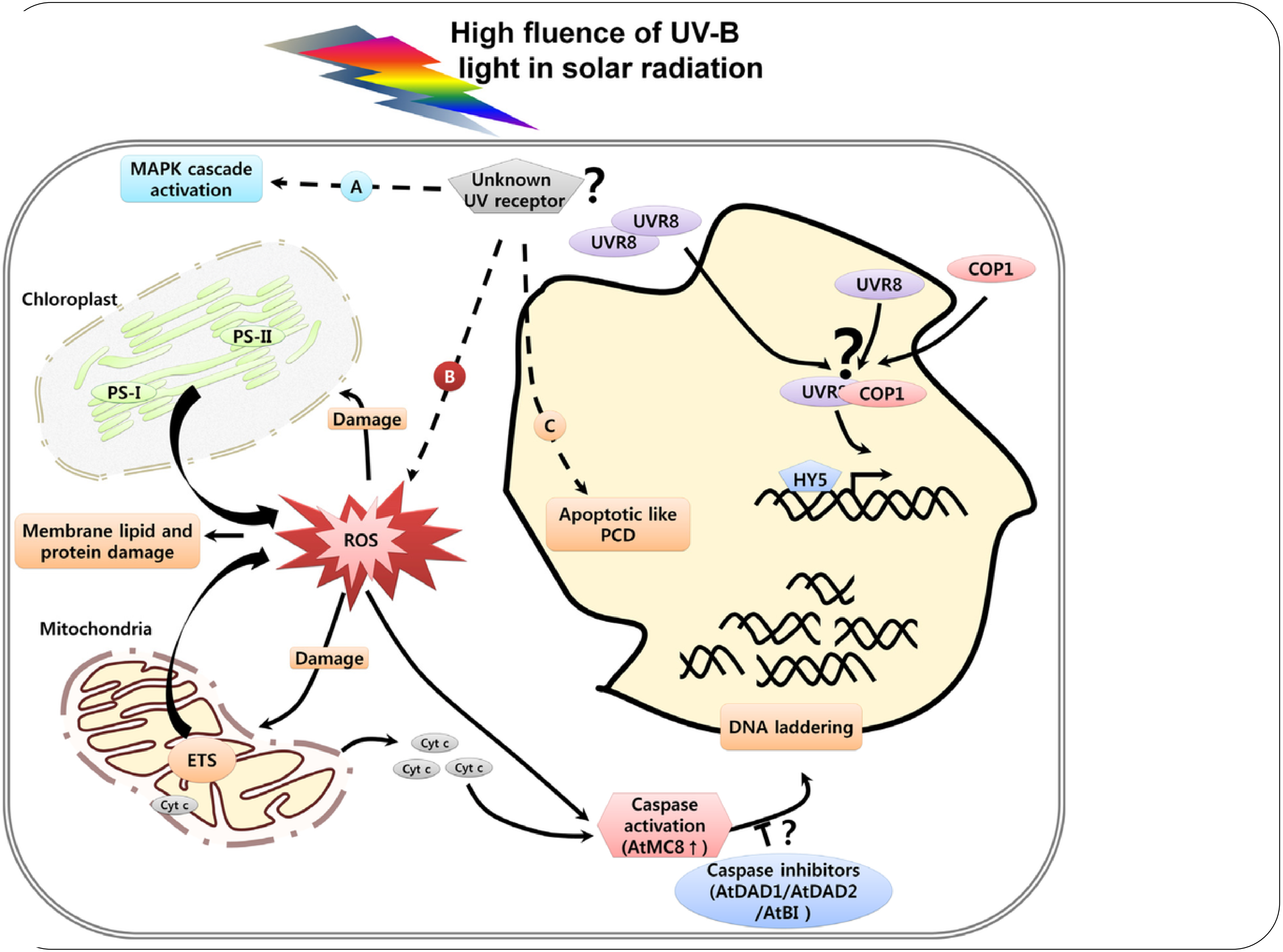
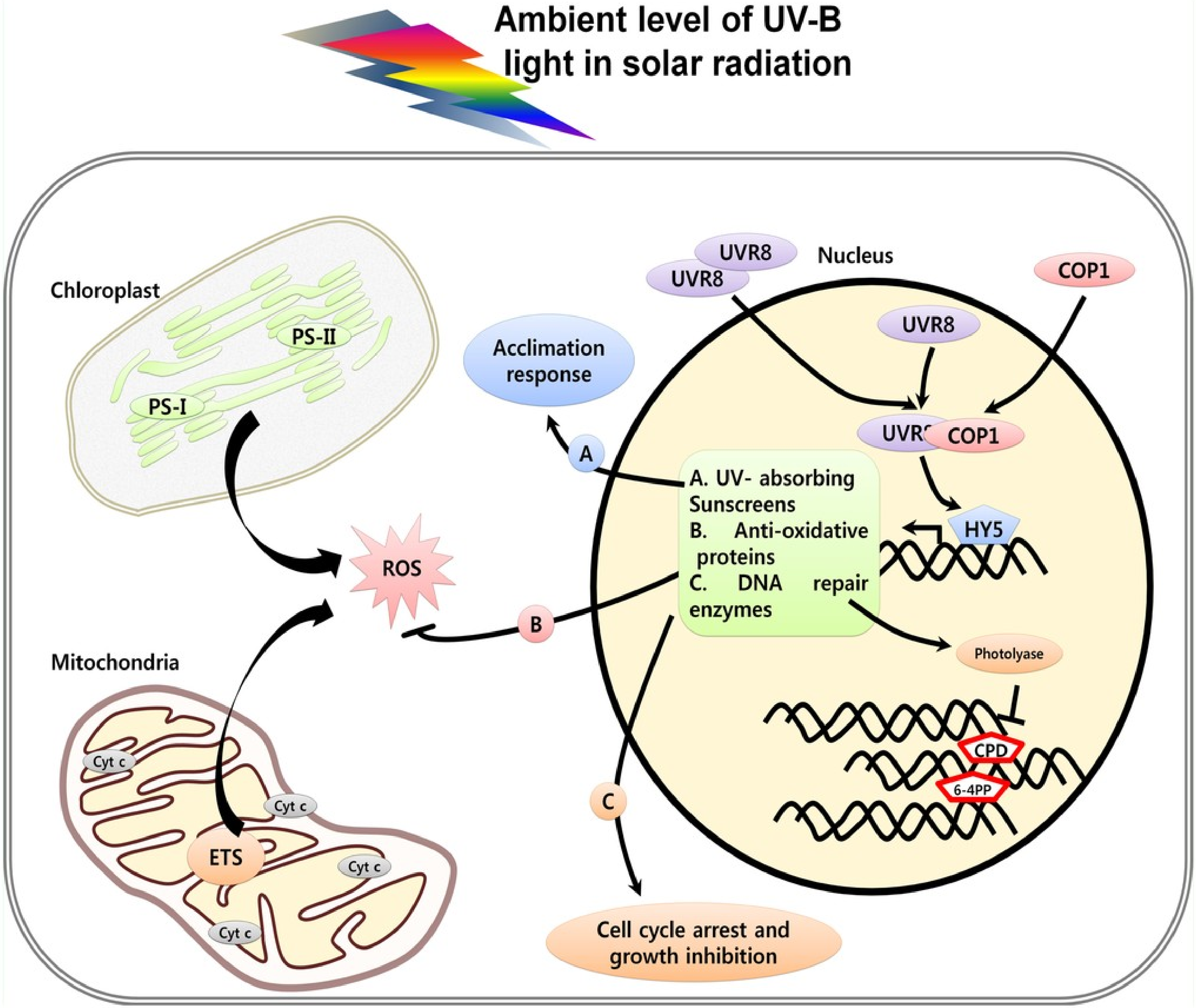


Fluorometrické metody (sucho plus UV-B stres)




UV-B
Wounding, herbivores
Specific UV-B receptor/s?
Cell surface receptor/s
Regulatory protein (UVR8)
DNA
Intermediate signaling components (ROS, defense-related hormones, etc.)
Damage (specific photoproducts: CPD, 6-4 PP)
Altered gene expression
Altered plant chemistry
Growth Inhibition
Acclimation
Altered plant-consumer interactions


High fluence of UV-B light in solar radiation
MAPK cascade activation
A
Unknown UV receptor
?
UVR8
UVR8
Chloroplast
PS-II
PS-I
B
Damage
C
COP1
UVR8
?
UVR8
COP1
HY5
Apoptotic like PCD
Membrane lipid and protein damage
ROS
Mitochondria
Damage
ETS
Cyt c
Cyt c
Cyt c
Cyt c
DNA laddering
Caspase activation (AtMC8↑)
?
Caspase inhibitors (AtDAD1/AtDAD2 /AtBI)



UV-Induced Cell Death in Plants
Ganesh M. Nawkar †, Punyakishore Maibam †, Jung Hoon Park, Vaidurya Pratap Sahi, Sang Yeol Lee * and Chang Ho Kang *

Metody studia dopadu UV radiace na rostliny v terénu


Abisko, Sweden

Abisko (Sweden)

- Among the traditional beliefs about alpine plant stress, the one that UV-radiation is destructive ranks very high, although there is no evidence in support of this. The epidermis of alpine plants contains UV-absorbing substances, in part the same that are used in suntan cream (e.g. flavonoids). Also chloroplasts are packed with protective pigments (e.g. carotenes). A comparison of the actual UV-B exposure of the leaf interior between arctic lowland, temperate and tropical mountains revealed no difference, although the surface exposure differs dramatically.
- To test the influence of UV-B radiation on all sorts of alpine plant characteristics, alpine plants have been experimentally exposed to natural and artificially reduced UV-B in situ, and no differences have been found (experiments with UV-transmissive and absorptive glass,

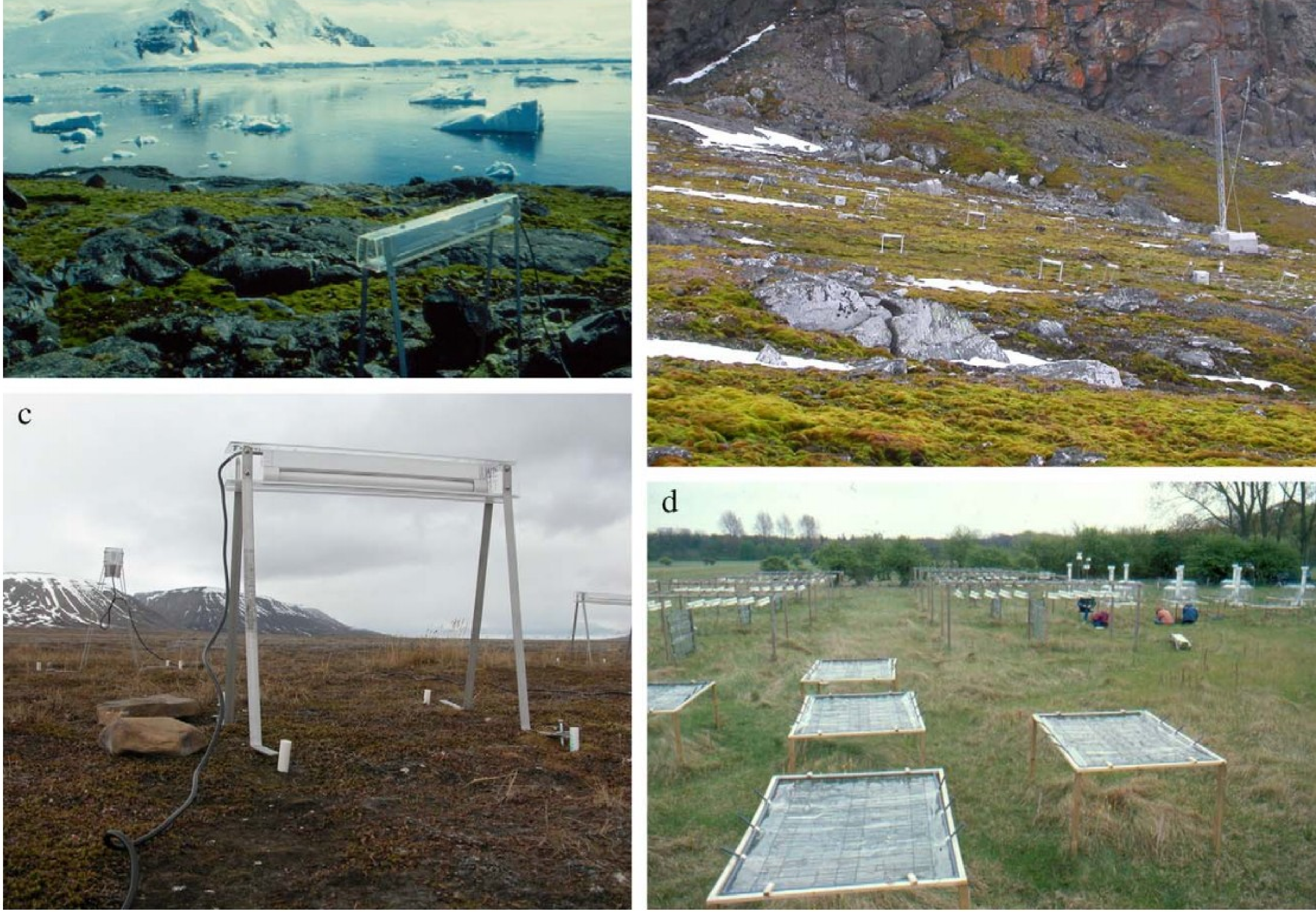


Fig. 2. a–d. UV-B supplementation set up with small UV lamp systems. (a) At the Antarctic: Leonie Island (Rozema et al., 2001a,b,c). (b) At Signy Island at a moss peat bank vegetation (Boelen et al., in press). (c) At the Arctic at the high arctic tundra of Adventdalen, Svalbard (Rozema et al., in press). (d) UV-B exclusion set up in a coastal dune grassland ecosystem (Rozema et al., 1999). The UV-B blocking or transmitting foil is supported by a frame and consists of overlying strips, transmitting precipitation to some extent. Ballaré et al. (2001), Searles et al. (2002) and Robson et al. (2003) use a similar UV-B exclusion set up in Tierra del Fuego terrestrial ecosystems, with perforated foil. Day et al. (1999, 2001) used vertical cylindric set-ups surrounding the antarctic hairgrass *Deschampsia antarctica*.

Dámy a pánové,
děkuji Vám za pozornost