UV4Plants

Bulletin
2018: 2

Reports on the Second Network Meeting

Outcomes from discussion sessions
Oral and poster presentations
Participation by gender and seniority

New section: *Meet a Member*
Using the Quick TUV Calculator
State of the art in UV LEDs

ISSN 2343-323X

Volume 2018, Issue 2

UV4Plants Bulletin

An open-access publication of the UV4Plants Association

December 2018

Front cover illustration: Participants in the Second UV4Plants Network meeting.
(Photo credit: T. M. Robson).

Back cover illustration: Spreading bellflower (*Campanula patula*) seen in UV-A radiation.
(Photo credit: P. J. Aphalo).

ISSN 2343-323X
DOI: 10.19232/uv4pb.2018.2.00

The UV4Plants Bulletin is published by the Organismal and Evolutionary Biology Research Programme, University of Helsinki
on behalf of the UV4Plants Association. `http://www.uv4plants.org/`

Typeset with LaTeX in Lucida Bright, Lucida Sans and Lucida Console DK using the KOMA-Script book class.
Edited with WinEdt.

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From the editors' desk

We have reached the end of 2018 and (once the frenzy of preparations for the festive season eases off) this is a good time for reflection on past achievements and to plan for the future. This also applies to us in *The International Association for Plant UV Research*. Digging deeper and deeper into the shady corners of the hard disc on my PC, I found that the name UV4Plants popped up for the first time in October 2014. Yes, we have been in existence for the past four years, and what started as an experiment is fast becoming something much more permanent (now don't jinx it, editor!). In those shady depths of my PC I came across a flurry of emails from four years ago, mostly on rules and objectives. Some of the proposed rules now seem rather draconic (how can we avoid a rogue UV-researcher capturing the UV4Plants assets (all of our €174.12, I believe) to go on a luxury cruise; or how can we avoid that a single dictatorially-minded researcher taking over the Association to dominate life on planet Earth)? Yet, some of the objectives are spot on, such as the objective "*To promote the advance of Plant UV Research by promoting sharing of knowledge and collaboration among academic and non-academic researchers*". Personally, I consider this the most important objective of UV4Plants. Only last week I visited, together with a Danish UV4Plants member, the laboratory of one of our Swedish members. While drafting papers, we reckoned we could achieve better science if we had some additional data on DNA-damage. A quick email to a German UV4Plants member, and within 24 hours we had a plan for collaboration. This is what the Association is all about!

In the past year, we had a wonderful opportunity to share knowledge and build networks at the great UV4Plants meeting in Bled, organised by Alenka Gaberščik, Mateja Germ and the singing members of their laboratory and university. In this Bulletin there is an excellent report by Louise Ryan and some of our other young researchers on the Bled meeting. From the photos accompanying the report you might assume that we just had a good time (I strenuously deny this!). In fact, for this issue Paul Barnes et al. drafted a detailed summary of the in-depth scientific debate on "the importance and relevance of current and future UV-research". The importance of this informal discussion paper is not to be underestimated since Paul, with several others, was instrumental in drafting the latest UNEP Environmental Effects Assessment Panel (EEAP) report. I have no doubt that the discussions in Bled filtered through to this important document.

An interesting aspect of community building is considered in this issue of the Bulletin by Robert Logan who discusses participation of early stage researchers and women in conferences. The dominance of senior male researchers among conference attendees can be a problem, and as a community it is good to be on the alert for a possible negative impact of gender and/or age imbalances.

Looking forward to 2019, there will be some excellent opportunities for further networking and knowledge sharing. On April 15–16 there will be a discussion-intensive UV4Plants workshop focussed on the interactive effects of UV- and climate change in Cork, Ireland (for details see the UV4Plants website, or contact Marcel Jansen). The small workshop will particularly focus on interacting effects, such as those of drought and UV, and CO_2 and UV, as well as on experimental approaches suitable for studies of interacting effects. On August 25–30 there will be a large photobiology conference in Barcelona jointly organized by the ESP and IUPB. This meeting covers all aspects of photobiology including plant photobiology, and photosensory biology and environmental photobiology sections (see UV4Plants website for updates).

As editors of UV4Plants we have recognised that the Bulletin can play a key role in bringing together our community of collaborating scientists. Therefore, we have instigated a new type of contribution named "**Meet-a-Member**". For those who love Christmas riddles, here is your challenge for the 2018 festive season: "What are the dangers associated with the use of tractors in plant UV research". Read "**Meet-a-Member**" in this issue, and I am sure you will laugh as loudly as I did! We hope to introduce two new members to the wider community in each issue of the bulletin. If you want to propose somebody (or yourself), please contact me.

Last but not least, in this issue we have a very instructive methodology paper on simulation of solar spectra by Pedro J. Aphalo. The described methodology enables creation of spectral data as a function of solar elevation and/or geographical location. This technology, together with the rapidly advancing technology/use of UV-emitting LEDs, might well underpin new series of experiments where we are mimicking solar light spectra more accurately than ever before.

Best wishes to you all,

Marcel A. K. Jansen (editor)

Cork, December 2018.

Letter from the President

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DOI: 10.19232/uv4pb.2018.2.02

Out with the old, in with the new

I very much hope everyone has enjoyed a wonderful Christmas break and I wish all readers a happy, healthy and successful 2019!

Inevitably at this time of year we look back over the previous 12 months and look forward to what is ahead. I think 2018 was a good year for UV4Plants, with the highlight being our memorable Network Meeting in Bled. One thing that stood out was the high quality of science presented, both in the posters and talks, which I feel emphasized the breadth, novelty and relevance of UV-B research. In addition, as in previous meetings, there was an exceptionally friendly and interactive environment, and a good number of new members, which bodes well for the future of our organization. And, last, but certainly not least, I remember the excellent hospitality from our Slovenian hosts, which made the meeting a very enjoyable experience.

Looking ahead, next year there will be two gatherings of particular interest to UV4Plants members. First, Marcel Jansen is organizing a workshop in University College Cork, Ireland in April. The focus is on interactions between UV-B and climate change variables such as temperature and water availability, which have major effects on plant growth and physiology. The discussions will range from the molecular to ecological levels with the aim of understanding the potential role of UV-B perception and response in plant acclimation and adaptation to climate change. This promises to be an excellent meeting and further information is available on the UV4Plants website (`https://cork2019.uv4plants.org`).

Second, there will be a large conference in Barcelona in late August jointly organized by the ESP and IUPB. This meeting, Light and Life, covers all aspects of photobiology and will have 6 sections, each with 10 symposia. Of particular relevance will be symposia in the Plant Photobiology, Photosensory Biology and Environmental Photobiology sections. These include: UV measurements, ozone and climate change (chair Laia Solà); Aquatic photobiology (chair Félix Figueroa), which will include talks on UV aspects in algae; Quality and security of crops and food (chair Janet Bornman); Blue and UV photoreceptors (chair John Christie) and Light and plant development (chair Carlos Ballaré), which will have several talks on UVR8; ROS signaling (chair Éva Hideg); and Effects of UV-B on plants (chaired by me), which will have presentations ranging from molecular to ecological to applied aspects. The meeting is unfortunately quite expensive, but there will be much to appeal to everyone interested in plant responses to UV-B and, indeed, plant photobiology in general. The meeting is still being organized so please watch out for further information on the UV4Plants website. I look forward to seeing many of our members in Barcelona!

Best wishes,

Gareth Jenkins, President UV4Plants.

Figure 2.1: Participants in the Second Network Meeting. Spring in Bled, 2018-04-17. Top photograph, in the visible- and bottom photograph in the UV-A regions of sunlight. Photo credits: Pedro J. Aphalo.

News

UV4Plants workshop "UV-B and Climate Change", Cork 2019

Subject: UV-B and Climate Change; impacts on plants and vegetation.
Location: University College Cork, Ireland
Dates: April 15-16, 2019
Organizer: Marcel A. K. Jansen
Format: A small, discussion-intensive workshop that will focus on the interactive effects of UV-B and climate change on plants.

Deadline for abstract submissions: 15 February 2019.

https://cork2019.uv4plants.org/

2019 ESP-IUPB World Congress "Light and Life Barcelona"

The 18th ESP Congress will be held jointly with the 17th International Congress of Photobiology on 25–30 August 2019 in Barcelona.

Not less than 60 symposia are programmed together with plenary and keynote lectures plus commercial exhibitions and other events and activities.

https://www.photobiology2019.org/

SEB Sevile 2019

SEB's Annual Meeting in Sevilla, Spain, 2–5 July 2019.

Deadline for abstract submissions: 15 March 2019.

https://www.sebiology.org/events/event/seb-seville-2019

Meet-a-Member: Wolfgang Bilger

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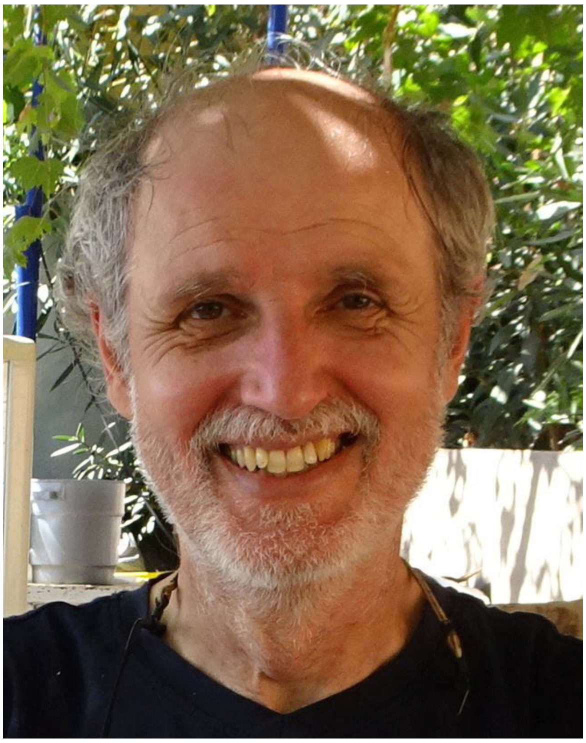
DOI: 10.19232/uv4pb.2018.2.21



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Why did you choose to work on plant UV-effects? In the 1990's I was working high light stress. A colleague in another department, Markus Veit, was interested in UV-dependent flavonoid biosynthesis. We started a collaboration, in which I initially contributed the assessment of UV-B-induced damage of PS II.

What is your research-specialisation? Acclimation of plants to high irradiance stress. We are using chlorophyll fluorescence to assess various reactions, among them epidermal UV transmittance or integrity of PS II.

Of which UV-related accomplishment are you most proud, and why? The development of the method to determine epidermal UV transmittance by a rapid chlorophyll fluorescence measurement (W. Bilger, M. Veit, L. Schreiber, and U. Schreiber (1997). Measurement of leaf epidermal transmittance of UV radiation by chlorophyll fluorescence. Physiol.Plant. 101:754-763). This method allows you to rapidly determine epidermal screening in the intact leaf, i.e. to see something which you otherwise could only assess by destroying the leaf. The method has given rise to commercially available apparatus such as the UV-A-PAM fluorometer or the Dualex (ForceA).

Can you tell a funny story relating to your work on UV-effects? The invention of the transmittance method was actually sparked by a seemingly unrelated question of a colleague, Lukas Schreiber. I had been thinking a lot about how to determine the irradiance reaching photosystem II in algae protected by a layer of stone (as in endolithic cyanobacteria) or by fungal hyphae (as in lichens). A similarly nagging unresolved question was how much of UV radiation was screened by epidermal flavonoids. Lukas Schreiber was investigating epiphyllic bacteria and used UV-induced DAPI fluorescence to quantify them. One day, he came in my office and asked why he was not able to see the red chlorophyll fluorescence below the blue DAPI fluorescence. This brought my thoughts finally on the right track and within five minutes I had the method in my mind. The rest was hard work to select the proper filter combinations and, especially, to select the proper reference with 100% epidermal transmittance.

Have you got any hints, tips or other advice to share? From my perspective it is of utmost importance to know the epidermal transmittance of your experimental plants before assessing any UV-B-induced effects. Unfortunately, this transmittance is not only determined by the UV irradiance the plant is exposed to but by a lot of other external and internal factors. Therefore, it can vary a lot in greenhouse grown plants.

What made you join UV4Plants? I enjoy very much exchanging views and ideas with other colleagues.

How would you like UV4Plants to develop in the future? I would prefer to keep it as familiar as it is now.

Who would you like to appear in a future "Meet-a-Member"? Åke Strid.

Editorial-board-reviewed article.
Published on-line on 2018-12-27.
Edited by: Pedro J. Aphalo.

Meet-a-Member: **Javier Martínez-Abaigar**

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Why did you choose to work on plant UV-effects? Since I was developing my PhD, I was abducted by mountain streams and plants inhabiting them, particularly bryophytes. This was due to two main reasons: the extremely dynamic nature of mountain streams, permanently changing (as the Greek philosopher Heraclitus already said in the 5th century BC), and the magic and tiny bryophyte universe under the microscope, plenty of diminutive and fascinating structures. After some years studying the limiting environmental factors for bryophyte life in such harsh ecosystems as mountain streams, we realized that solar radiation, and specifically UV, was surely key to understand the whole story. In Spain, stream bryophytes can live at even 2,000 m altitude, where summer UV levels are really high, and they frequently turn brown or black under these conditions. Surprisingly, they become bright green again from late autumn onwards. This apparent resurrection stimulated us to study the ecophysiological mechanisms underlying the apparent UV tolerance of bryophytes. We were lucky because, at that time, we could contact several very collaborative groups of physicists who introduced us to the basic concepts and instrumentation of this exciting world. After all, solar radiation is the force driving life on the planet and studying how it happens is addictive.

What is your research-specialisation? Now we are especially interested in two topics:

1. The effects of UV on bryophytes, an evolutionarily important plant lineage because they were the first “true” plants colonizing land from their algal aquatic ancestors, facing new challenges to plant life in the terrestrial environment, such

as high UV and low water availability.

2. Applied management aspects of UV which could allow us to influence the quality of grapes and wine, and the metabolite composition of mushrooms. (do not forget that grapevine is the most emblematic crop in my region, and mushrooms are also of strong commercial importance).

Nevertheless, we are always open to new topics and collaborations, particularly those including innovative ideas, underexplored approaches and collaborative projects.

Of which UV-related accomplishment are you most proud, and why? During the last years we are trying to understand to which extent molecular events related to UV are relevant under field conditions, applying also an evolutionary perspective. In 2018 we have published two papers that try to clear a path in this way. In the first one (Soriano et al., New Phytologist 217:151), carried out in collaboration with Prof. Gareth Jenkins, we have demonstrated that the action mechanism of the UV-B photoreceptor UVR8 is very old in evolution, being mostly common from bryophytes to higher plants. In the second one (Monforte et al., Functional Ecology 32:882), we propose that the two main bryophyte lineages (liverworts and mosses) use different accumulation strategies of UV-absorbing compounds to cope with UV radiation, which could have been important in the ecological segregation of both groups upon land colonization.

Apart from this, I am particularly proud of the collaborative experiments (and papers!) I have participated in, such as those developed within the Grapevine Ultraviolet Network.

Although I am happy with all these achievements, I hope that better things are still to come.

Can you tell a funny story relating to your work on UV-effects? We have a few of them. Recently, we designed a frame with UV lamps and assembled it on a tractor to irradiate grapes and analyze potential beneficial effects of supplemental UV on grapes quality. To ensure that every bunch received an adequate and homogeneous irradiation dose, the speed of the tractor had to be very low. The first lamp frame prototype we constructed finished its days crashed against a grapevine plant because the tractor was running so slowly that the driver fell asleep at the wheel. Fortunately, driver, tractor and plant uninjured.

Have you got any hints, tips or other advice to share? In the UV research context, it is crucial to be aware of the basic concepts and technical aspects, such as how to use lamps, filters and UV measurement instruments, and how to apply action spectra, calculation of UV doses, etc. A superb (and freely downloadable!) bibliographic source is available to learn everything about all these aspects and more: Aphalo et al. 2012, Beyond the visible: A handbook of best practice in plant UV photobiology (published under the auspice of COST Action FA0906, led by Prof. Marcel Jansen). This book should be the Bible for every UV researcher, both beginners and seniors, to avoid mistakes in the design and execution of experiments. In addition, to obtain good quality and adequately replicated results, and to use appropriate controls, are decisive aspects to build good and reliable UV science.

What made you join UV4Plants? It was an easy decision for me. I had previously been a participant in the COST Action FA0906 UV4Growth (UV-B radiation: a specific regulator of plant growth and food quality in a changing climate), where I found a UV community of scientists ready to share their science and friendship with everybody, something not easy to find in the scientific community. UV4Plants is the second part of UV4Growth and, in this case, second parts

Figure 5.1: Javier Martínez-Abaigar during his PhD, crossing the river Iregua (La Rioja) in spring, carrying pH-meter and other equipment.

are really good. If you need anything related to UV (technical advice, plant material, laboratories to develop short stays, support to young researchers, partners to apply for a project…) you will always find some kind guys in UV4Plants trying to solve your queries. Thus, I had no doubt to join this society and to recommend all my students to do so.

How would you like UV4Plants to develop in the future? UV4Plants is a solid scientific society with deep and strong roots, a web woven through many fruitful personal and scientific relationships. In some aspects, we are like a family, where the success of one is the success of everyone. Though, we can still improve. I think one of our challenges nowadays is to increase membership and thus critical mass, particularly from outside Europe (although not forgetting European countries where we currently have no or little presence). In addition, we surely can contribute more to the development of applied aspects of UV research which can be positive for the general society and/or the environment: functional foods, alternatives to chemical pesticides, etc. Innovative and collaborative research traditionally supported by UV4Plants should be greatly and continuously encouraged, particularly to help young researchers and researchers from developing countries.

Who would you like to appear in a future "Meet-a-Member"? Lars-Olof Björn, an eminent UV scholar from the very first steps of UV science and the first Honorary Member of UV4Plants. He combines the characteristics I have always admired in a scientist: professional expertise, humbleness, good mood and humour, and a collaborative attitude to help other people. All of us can learn a lot from his experience.

Editorial-board-reviewed article.
Published on-line on 2018-12-27.
Edited by: Pedro J. Aphalo.

■ Participants' report

A Summary from the 2nd UV4Plants Network Meeting at Bled, Slovenia

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DOI: 10.19232/uv4pb.2018.2.10

The 2nd network meeting of the International Association of Plant UV Research took place in the picturesque and touristic town of Bled in Slovenia. The conference was organized by UV4Plants and Prof. Alenka Gaberščik and her group of the University of Ljubljana. The meeting drew many researchers together from all across Europe, U.S.A and other continents to discuss and share ideas on recent advances in plant UV research. The two-and-a-half-day conference was divided into seven categories of research including molecular, biochemical and physiological aspects of UV-B responses, the interaction between UV-B and other factors, ecology and evolutionary aspects, and last but not the least application of knowledge. Altogether, there were 23 oral presentations and several posters discussing the latest ongoing research. In this article, we are summarizing some of the interesting oral and poster presentations, an enlightening discussion session, and an excursion to the beautiful Lake Cerknica and Rakov Škocjan area.

In the sessions on the molecular and biochemical aspects of UV-B response, we learned about how UVR8 inhibits stem elongation through regulation of PHYTOCHROME INTERACTING FACTORS (PIFs) and inhibition of auxin biosynthesis (K. Franklin). UVR8 monomerization, which is the immediate step after UV-B perception was studied at the level of the purified protein, plant extracts and whole plants, and included the study of the role of various tryptophans of UVR8 in UV-B mediated responses (L. A. Diaz-Ramos). Furthermore, the role of the E3 ubiquitin ligase ARIADNE 12 was discussed in long-term adaptation to UV-B (M.T. Hauser), and the role of vitamin B6 derivatives in plant acclimation to supplemental UV-B (G. Czégény). The biochemical aspect introduced interesting questions regarding the physiological function of UVR8 under ambient solar conditions. The crucial function of UVR8 is indicated by the presence of the gene across angiosperms and algal genomes (Å. Strid). Thus far, incomplete knowledge exists regarding the structure and function of UVR8 as studies have mainly been done on UVR8 produced in E. coli, and not in plants. In this context, experiments were done to show the difference between UVR8 protein produced in plant and bacteria (Å. Strid). As we progressed further in the sessions the studies were not limited to the UVR8 photoreceptor and UV-B waveband. In fact, the role of both UVR8 and Cryptochromes (blue/UV-A) photoreceptors were discussed in Arabidopsis plants, exposed to the short and long- term of UV-B,

Figure 6.1: A view of the alpine Lake Bled and serene Bled Island (Photo credit: N. Rai).

Figure 6.2: Image of Pletna boats on Lake Bled. These are traditional boats made only by the locals of Bled (Photo credit: L.M. Ryan).

UV-A and blue radiation (N. Rai).

This brought us to some interesting presentations related to the physiological aspect of plant-UV responses. UVR8-modulated physiological responses like phototropism (F. Vandenbussche) and sunlight acclimation (L. O. Morales) were reported, and the ecological importance of these responses was discussed. Additionally, the level of UV-transmittance and accumulation of UV-absorbing flavonoids in Okra was discussed in terms of diurnal solar UV fluctuations. This highlights the importance of natural plant abilities to UV-shield using specific compartments (S. Neugart). After this, we learned about how UV-B interacts with other factors. In today's changing climate, the modulation of UV-responses by drought and temperature is of high significance (M.A.K. Jansen). Continuing with drought and UV-B interactions, R. G. Guevera-González talked the audience through the importance of studying these interacting factors on the performance of *Capsicum annuum* L., the chili pepper. Interacting factors cause plant responses like phenolic and gene expression alterations. We also learnt that not only does water availability and UV radiation cause differing responses in different food crops, but also within a plant, like the differing uptake of various elements (M. Grašič).

On the ecological side of UV-B research, presentations covered studies on three distinct ecological settings and questions: the role of photodegradation and the interaction with other environmental factors as cooperative drivers of litter decomposition in drylands (P. W. Barnes); how the changes of the composition of different solar light wavelengths along latitudes day length and time of the year affect the understory seedling phenology (C. C. Bresford); how UV-B as an important factor drives alpine plants to adapt to harsh condition at high altitudes according to the research with *Saxifraga hostii* at two different altitudes in Julian Alps area (T. T. Sedej).

In the session concerning the evolutionary aspects of UV-B research, we learned that UV radiation pressure was an important evolutionary factor when aquatic organisms colonized land, together with water shortage (J. Martínez-Abaigar). An interesting talk by F. Peschek showed us different strategies for UV-B adaptation in non-UV-B screening green algae: UV-B-induced DNA damage was repaired by photoreactivation with greater efficiency compared to that in green macroalgae with UV-B screening capacity. In the third talk, a common garden experiment was reported on. The experiment conducted in New Zealand and Germany, with multiple species, was used to reveal the role of UV-B as a selecting factor in plant invasion (M. Hock).

In the knowledge application session, UV-B and UV-A were proposed as tools to improve plant quality in cucumber (M. Qian) and to improve phenolic profiles in peach fruit (M. Santin). We also gained knowledge about the effects of different climate screens and shade nets on the light quality and composition in controlled environments, and thus how big of an impact they can have on horticulture, and especially on crop performance (T. Kotilainen).

Apart from oral presentations, we had attendees sharing high quality works in the poster session. A separate room was designated for the poster session and throughout the conference. Poster presenters were given two-minute "flash-talks" to advertize their posters during the conference. A separate poster session was then held with refreshments where all attendees could discuss and ask questions about the posters they found interesting. This was a highly informative session held in an informal and enjoyable way. Each of the posters fitted well into one of the seven oral presentation sessions. Posters answered a wide range of interesting questions related with UV research: how UV-induced genes prompt long-term UV-B acclimation? How grapevine phenolic content responds to daily environmental changes?

Figure 6.3: The Church of St. Martin with the stunning snow-capped Julian Alps as a backdrop (Photo credit: N. Rai).

How are different cool-season turfgrasses affected by UV-B? What are of UV radiation and reduced rainfall on naturally growing *Erica scorpia*, a species of heath in the Mediterranean? What is the effect of altitude on the content of UV-B absorbing compounds in *Pinus* spp. pollen grains? How does the maternal effect of solar UV modify the response of *Vicia faba* to UV-B and blue light? And how does post-harvest UV-B exposure affect the metabolic content of peach fruit?

To summarize the conference and bring everyone's talks, questions, posters and discussions together, a large discussion session was conducted by M. Robson. All conference attendees were split into two breakout groups, depending on their specialized area of research. The discussion aim was to spark conversation and debate amongst the UV4Plants community about the future of plant-UV research, in terms of unsolved questions and knowledge gaps. The group notes were then categorized into practical and basic questions.

G. Jenkins and F. Vandenbussche led a group discussion specific to the molecular, biochemical and physiological responses of plants to UV. This group initiated their discussion by postulating possible novel areas of research in a "post-UVR8-discovery world", from unspecific multipurpose mechanisms and novel photoreceptors and crosstalk, to establishing specific roles for UVR8. The group also delved into the area of standardizing our UV-methodology as a community. Should there be uniformity in experimental procedures? Should there be standard guidelines and normalized result presentation?

The second group discussion was based on ecological research and plant production, led by P. Barnes and M. Jansen. The group ad-

Figure 6.4: First stop on the conference excursion, Prof. Alenka Gaberščik gives a detailed background to Lake Cerknica (Photo credit: Y. Yan).

dressed the questions: How will the changing climate affect plant UV exposure in a "post-ozone-depletion world"? How will plant UV-B responses interact with other environmental responses? A key issue brought forward, reflected throughout the conference, is the knowledge gap between plant-UV research and horticultural application. How do we make use of UV to enhance plant production, a commercial reality? How do we link our low PAR growth chamber experiments to high PAR natural environments? A research-horticulture interface would break boundaries between commercial producers and scientific information.

One topic that both groups covered was the upscaling of our experiments, so that the results reflect the natural world. Ultimately conference attendees agreed that we must enhance our scientific capabilities and understanding. We must scale experiments to allow for a reliable link not only within and between plants but across spatial and temporal scales, ecosystems and environments. This will allow us to capture a more detailed and comprehensive picture of how nature responds to and uses UV.

The ideas generated during the discussion session will also contribute to a perspective article in the special issue of *Photochemical and Photobiological Sciences* journal.

Apart from the scientific sessions and discussions, the conference also gave ample opportunities to socialize and network with fellow researchers during the long breaks between the sessions and the Gala dinner. During the Gala dinner, we got a chance to listen some of the traditional Slovenian music, which maintained a relaxed atmosphere throughout.

The conference successfully ended with an excursion to Lake Cerknica and Rakov Škocjan area. The intermittent lake Cerknica is a unique karst phenomenon characterized by inter-annual water level fluctuation. It dries up in summer and then floods for the rest of the year. This phenomenon is due to the special system of underground lakes interconnected with the system of a siphon. The time we visited in April, the lake was still full of water. We were astonished to learn about the hidden mechanisms, in the Lake Cerknica Museum, behind the appearing and disappearing lake that almost looks like magic. The Rakov Škocjan valley was a karst valley created by collapsing of the ceiling of a karst cave, we enjoyed a walk around the forest and a sightseeing of the remaining natural bridge of the karst cave.

In nature, we, as plant biologists, still never cease to be amazed and overcome with awe by all the beauty and secrets that nature has to offer.

Editorial-board-reviewed article.
Published on-line on 2018-12-27.
Edited by: Titta K. Kotilainen.

Figure 6.5: Conference attendees having fun on the way to the Museum of Lake Cerknica (Photo credit: Y. Yan).

Figure 6.6: Intermittent lake, Lake Cerknica, glistening in the Slovenian sun (Photo credit: L.M. Ryan).

Report on the discussions at Bled

Importance and direction of current and future plant-UV research

Barnes P.W.* , Jansen M.A.K.*, Jenkins G.I.*, Vandenbussche F.*, Brelsford C.C., Banas A.K., Bilger W., Castagna A., Festi D., Gaberščik A., Germ M., Golob A., Hauser M.-T., Llorens L., Martinez-Abaigar J., Morales L.O., Neugart S., Pieristè M., Rai N., Ryan L., Santin M., Seddon A.W.R., Stelzner J., Tavridou E., Łabuz J., Robson T.M.*

DOI: 10.19232/uv4pb.2018.2.11

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Background

During the 2nd Network Meeting of UV4Plants at Bled (14th–18th April, 2018) the delegates engaged in a group discussion of prescient questions concerning the future of in plant-UV

Table 7.1: Participants in group discussions at the UV4Plants 2nd Network Meeting in Bled on 17 April 2018 that form the basis of this document.

Molecular Biochemical Physiological: Gareth Jenkins, Filip Vandenbussche, Eleni Tavridou, Marie-Theres Hauser, Wolfgang Bilger, Andreas Albert, Pedro Aphalo, Aneta Bażant, Åke Strid, Katazyna Banas, Gyula Czegeny, Minjie Qian, Susanne Neugart, Yan Yan, Luis Morales, Kristof Csepregi, Marieke Trasser, Arnold Rácz, Andrew O'Hara, Aniko Matai, Neha Rai, Aranza Diaz Ramos, Éva Hideg, Piotr Zglobicki, Justyna Łabuz.
Ecological and Plant Production: Paul Barnes, Marcel Jansen, Marco Santin, Craig Brelsford, Knut Solhaug, Robert Logan, Daniela Festi, Twinkle Solanki, Thais Huarancca Reyes, Antonella Castagna, Maria Hock, Laura Llorens, Eva Rosenqvist, Claudia Rodriguez Hidalgo, Louise Ryan, Lars Olof Björn, Mara Pieriste, Alenka Gaberščik, Tjasa Jug, Mateja Germ, Alexandra Golob, Alistair Seddon, Titta Kotilainen, Javier Martinez-Abaigar, Lorenzo Guglielminetti, Jana Stelzner, Tadeja Trost Sedej, Frauke Pescheck.

research. The discussion group was tasked to identify the most valuable directions for plant UV research to take, and to create a coherent framework for how to move the field forward.

Here, the outcome of these discussions is summarised in sections that follow the composition of discussion groups as ideas taken from a molecular, biochemical and physiological perspective followed by those from an ecological and plant production perspective. In each case, first basic research questions are considered and then applications and methodological considerations are put forward. Finally, some common ground bringing the two perspectives together is discussed, with the aim of solving scaling problems and ways in which the UV4Plants network might be put to good use.

Research in Molecular Biology, Biochemistry and Physiology (discussion led by G. I. Jenkins and F. Vandenbussche)

What are the research priorities that will shape the focus of plant UV-research in a "post-UVR8-discovery research environment"?

1. Investigate signalling independent of UVR8: in three possible directions
   a) Unspecific non-photoreceptor mechanisms induced by UV-B radiation, e.g. via reactive oxygen species (ROS), damage, and class 3 peroxides, hormones such as jasmonic acid (JA) and abscisic acid (ABA) (Jenkins 2009; Vanhaelewyn et al. 2016).
   b) Via another unknown UV-B-specific photoreceptor: e.g. a response at very low fluence rate independent of UVR8; CRY3 (localised to the chloroplasts and mitochondria); retrograde signalling and UV-B response (Tilbrook et al. 2013; Yu et al. 2010).
   c) Distinguish between experiments in which UV-B exposure under controlled conditions is inducing responses and experiments in which uvr8 or other photoreceptor mutants are exposed to natural sunlight. The results of the UV4growth-consortium experiment growing uvr8 mutants across Europe and comparing their gene expression and biochemistry should give answers to this sort of question.

Figure 7.1: Discussions on plant UV research in molecular biology, biochemistry, and physiology led by G.I. Jenkins and F. Vandenbussche (Photo credit: T. M. Robson).

2. Roles/mechanism of UVR8? Spatially separated across on the plant (shoots and roots) and cells (cytosol, cell membranes and vacuoles).
   a) UVR8 could have a role in UV-A signalling because its absorption spectrum extends into the UV-A region and because solar spectrum has much higher irradiance of UV-A than UV-B, which potentially makes even a relatively small response in the UV-A region important. UV-A radiation also penetrates deeper into the leaf than UV-B radiation. How is this affected by hydroxycinnamic acids (HCA) and flavonoid (FLAV) contents? IS the mechanism of UVR* signalling the same in all tissues? What are the roles of cytosolic UVR8 (Bernula et al. 2017; Yin and Ulm 2017)?
   b) Regulation of gene expression by UVR8: What are the roles of those transcription factors recently reported to interact with UVR8? Are there more players in addition to HY5/HYH downstream of UVR8? Is there a complex associated with chromatin (Jenkins 2017; Yin and Ulm 2017)
3. Photoreceptor cross-talk

   We can draw an analogy between perception by plant photoreceptors and perception of light by the human eye: the sum is much more than the single parts. A more holistic approach is required, considering all photoreceptors acting together.
   a) How does HY5 integrate signals from multiple photoreceptors (Gangappa and Botto 2016)?
   b) What is the relative contribution of each different plant photoreceptor to COP1 binding/regulation when plants are exposed to the full spectrum of sunlight (Morales et al. 2012)

4. Upscaling to the natural environment to transfer knowledge beyond *Arabidopsis thaliana*

   This suggestion goes hand in hand with determining typical physiological combinations of UV-B radiation and other stresses (e.g. drought), which will differ on a species-specific basis (Hofmann et al. 2003; Robson et al. 2014). Ecologists and agronomists should give suggestions on which species to tackle with novel techniques such as CRISPR-Cas9 and fast sequencing methods. Options for broadening the species considered

   a) Using different Arabidopsis accessions; e.g. Cape Verde Islands (Cvi-0) accession from a UV-high environment (Botto 2003; Jansen and Biswas 2012).

   b) Finding alternative species to Arabidopsis: using new species (mutants/CRISPR; genome sequencing), note some species have more than one gene for UVR8; crop species potentially originating from the Mediterranean and cultivated over a large latitudinal gradient potentially offer high utility and intra-specific variability in UV response; the response of obligate shade species to UV-B may be very different to species from open-environments like Arabidopsis and will give a different perspective on shade responses (Ballaré and Pierik 2017).

   c) With respect to the CRISPR-Cas9 approach, it is imperative to follow up the state of legislation on CRISPR-generated plants. EU has not yet decided on the limitations; however the Swedish Board of Agriculture has given positive advice (for organisms that do not contain a transgene). It may be worthwhile for the UV4Plants network to look for partners in countries where a decision has already been made: e.g. in Argentina, CRISPR-generated plants are already allowed to be grown outdoors.

   In the end, all of this should lead to a greater number of specific model species/cultivars, well suited for UV-research. Such species preferably have not too many isoforms of enzymes/proteins of interest. For these developments to proceed, we need to define priorities.

   Collaboration between ecologists and molecular biologists is much needed and networks like UV4Plants should be exploited to ensure that this is no longer a problem. To illustrate the sort of approach that is envisaged, we need “molecular informed ecologists” and “ecologically informed molecular physiologists”.

5. For further consideration

   How do we avoid unnecessary overlap? How can we prevent work from being duplicated? How can we communicate effectively whilst prevent parasitizing among groups?

Where are the key areas we need to improve when applying this research to practical questions?

1. Can we better harmonise methodologies to make experiments comparable, and to scale between the lab and the field?

   Improving the uniformity of experimentation appears rather difficult considering the quantity of different experimental set-ups and interests. Field work and laboratory work does not always lend itself to the same techniques, e.g. (1) when harvested samples need to be frozen immediately, fresh-weight determination is not very practical; and (2) repeated recording of flavonoid accumulation in the same leaf by monitoring changes in optical properties, using for instance a Dualex, is difficult to compare with the results of biochemical analysis of a leaf harvested at a single point in time.

However, as the UV4Plants network, we could suggest some guidelines: e.g. on what units to state for specific analyses and measurements, and the best way of normalizing results (per weight/volume/surface area), and under which conditions to use each approach. Some progress has already been made (Aphalo et al. 2012; Neugart 2017), but up-to-date standardisation of molecular and genetic protocols in UV photobiology are absent. Standardizing procedures such as those to produce "dry mass" may be proposed. A protocol paper, like the Julkunen-Tiitto et al. (2014) review of biochemistry methodology that came out of UV4growth, or online guidelines on the UV4Plants website, could be helpful here.

2. Repair machinery and RNA

It is well known that UV-B damages DNA, and that the thymidine dimers can be repaired by photolyases. But what is the status on RNA? UV radiation can indeed damage RNA (Wurtmann and Wolin 2009), although damage to RNA appears to be less than to DNA (Kundu et al. 2004). Some data on RNA viruses in *Nicotiana* sp. are available. Studies from 1950-1970's on the TMV-RNA virus suggest that its UV-damaged RNA can be repaired by photoreactivation (Bawden and Kleczkowski 1959; Murphy and Gordon 1971). However, until now, true evidence for the mechanism of photorepair of TMV-RNA is missing (Wright and Murphy 1975).

UV-B induced crosslinking between ribosomal proteins and ribosomes has been shown in maize (Casati 2004), and RNA-crosslinking has been associated with UV-B radiation in peas (Brosché et al. 1999). In the light of new developments enhancing our knowledge of RNA editing (PPR proteins) and RNA breakdown, it may be prescient to revisit this area of research. UV-B radiation and heat stress do not seem to generate transcript profiles that hugely overlap in chaperones, suggesting that any UV-B damage to proteins may be very different from that during heat stress.

3. Within-plant light signalling

At the moment we do not know how the UV-B signal is propagated within plant tissue. This signal could be mediated through a transportable molecule, or by physical cell to cell contact. Associated with this problem, we often do not know how far light penetrates into plant tissues and thus directly, locally influences signalling. Some recently published data on light piping (mainly red light) in Arabidopsis seedlings (Gelderen et al. 2017), and reviews on (UV) plant tissue optics (Barnes et al. 2015) suggest this is a timely subject (Bailey-Serres et al., 2018). With respect to analysis, experimental methods based on microfibers have been developed in the previous century (Ålenius et al. 1995; Day et al. 1993; Liakoura et al. 2003), but were rarely used thereafter. It is said (Å. Strid personal communication) that Lund University had a device to measure the penetration of radiation into the leaf, but once it was deconstructed it could no longer be rebuilt!

In addition, a separate way to follow local light-regulated signals is by optogenetics (Kianianmomeni 2015). Here, a photoreceptor-based system is used to drive a visible/detectable output. There is also a suggestion that light sheet microscopy can be used (Lichtenberg et al. 2017).

Figure 7.2: Discussions on plant UV research in ecology and plant production science led by P.W. Barnes (Photo credit: T.M. Robson).

Ecological Research and Plant Production (discussion led by P. Barnes and M. A. K. Jansen)

What are the priorities that will shape the focus of basic plant UV-research in a "post-ozone-depletion world"?

1. How will solar UV-B radiation reaching the ground change in a post-ozone-depletion world?

   Solar UV irradiance will change compared to present in the "post-ozone-depletion world". However, there is considerable uncertainty concerning the direction of the change with both increases and decreases being forecast for different geographical areas depending on, amongst other things, patterns of local cloud cover, which cause spectrally differentiated change in irradiance, particularly with respect to UV-B and UV-A radiation and are strongly influenced by climate change. Thus, unlike "classical" stratospheric ozone-layer depletion of the 1980s, patterns of UV-change will be complex. Understanding of these patterns will be required to facilitate relevant plant UV-research (Bais et al. 2018; Bornman et al. 2015).

2. How will the UV-exposure of plants change and what are the implications?

   The UV exposure of plants in managed and unmanaged systems will also change as climate change shifts the geographical ranges of crops and wild plants. Climate-induced changes in plant phenology and modification of vegetation-land cover will determine UV penetration patterns through canopies. Depending on the situation and species, UV exposures could increase or decrease. Thus, future research needs to explore how both increases and decreases in UV radiation, at exposures and times of year relevant to projected future scenarios, influence plants and ecosystems (Bais et al. 2018). Information about how plants and ecosystems have responded to past changes in UV radiation at different points in Earth's history can also provide important insights here, but a better understanding how to reconstruct solar UV radiation based on proxy records, derived from UV-absorbing compounds in pollen, over geological time is first required ((Jardine et al. 2016) reviewed by (Bais et al. 2018)).

3. How do responses to UV radiation interact with responses to other environmental variables associated with climate change?

   Gaining an understanding of the interactions between UV-radiation and climate change variables (e.g., drought, temperature, carbon dioxide, and other abiotic factors) will be a major goal in the next decade. However, we need to be aware that climate change and UV-radiation both alter the environment in complex ways that are often specific to particular geographical regions (Bais et al. 2018; Bornman et al. 2015). Capturing these interactions and testing their consequences is a very broad and challenging aim, and distinctions need to be made across different organisational levels, including:

   a) Elucidating the interactions between climate change and UV-radiation, and how (1) these affect global meteorological phenomena, (2) co-exposure to these variables affects ecosystems, and (3) co-exposure can affect the physiology, biochemistry and/or molecular biology of individual plants.

   b) Assessing whether new experimental approaches are needed to explore how UV interacts with multiple environmental factors simultaneously.

4. Can we scale the knowledge of UV-responses gained under specific conditions across organisational and temporal scales, and make generalisations among organisms?

   Continuing from the previous point, the plant-UV research community has made major advances in linking molecular, genetic, physiological, biochemical, organismal, and ecosystem-approaches, yet, understanding across organisational and temporal scales is still in its infancy (Paul et al., 2012). Although there is evidence that some patterns are consistent across plant types, particular UV-responses can't yet confidently be attributed to specific functional traits, nor can particular taxonomic and geographic lineages be classified as susceptible or resistant to UV radiation.

   The increasing availability of non-GM mutants in key UV-response genes enables researchers to make advances in scaling across organisational scales (Li et al. 2018). In fact, it can be argued that the plant-UV research community is in a strong position to be a model community (i.e. an example for others) that can generate an integrated vision across multiple organisational levels.

   Our understanding of the relevant time-scales for UV-B responses is improving, but we still struggle to connect a UV-cue with the rate of response or acclimation. Recent research has shown that responses within the day are possible (Barnes et al. 2017) and yet responses over the course of a growing season can often also be interpreted with respect to the UV dose received – these two perspectives need to be reconciled. Much less is understood about the down-regulation of UV responses than about their stimulation and in particular what happens with respect to physiological UV protection at the end of the growing season is poorly understood. The presence of UV-absorbing compounds in senescent tissue and during the early stages of decomposition may continue to mediate the effect of sunlight on photodegradation and associated ecosystem processes. Further research encompassing a range of time periods is needed to reveal the temporal patterns in, and mechanisms that regulate, UV-absorbing compounds through the life and subsequent decomposition of plants, and to apply this knowledge to better model ecosystem processes.

5. Can we establish the role of UV-B photoreceptor-activated responses in an ecological context?

   While great progress has been made in understanding the mechanisms underlying the action of UV-B photoreceptor UVR8 and associated signalling pathways, many gaps remain in clarifying the importance of UVR8's role in ecological contexts and establishing how UV-B specific or more-generic plant UV-perception and response functions are. For instance, do these responses only imply UV-protection or is there a role associated with other seasonal changes such as drought, heat or high-light acclimation, or herbivores, pests and pathogens, coinciding with high UV-B radiation (Ballaré and Austin 2017; Paul et al. 2012)?

   We still need to establish the model of how plants respond to the full range of solar radiation that they receive, which contains different spectral compositions of light. These spectral regions are perceived by multiple photoreceptors which presumably interact allowing a coherent response to be produced. Describing this model will require a better understanding of cross-talk between different signalling pathways that operate following photoreceptor activation (Barnes et al. 2017). This information is needed to obtain a fuller understanding of the ecological function of the UV-B photoreceptor in plants of various growth forms and functional groups inhabiting different types of environments.

Practical Questions: Where can the application of UV research in plant production take us?

There remains understandable scepticism among growers concerning the horticultural applications of UV research. The plant UV-community has been preaching the usefulness of exposing plants in greenhouses and other indoor crops to UV-B for some time, but uptake among growers is very limited.

Research consistently finds that crop UV-exposure increases flavonoids and other desirable secondary metabolites that are considered by nutritionists to be beneficial for human consumers. Recently, the European Union has permitted the use of UV radiation to fortify Vitamin D in mushrooms (Taofiq et al. 2017). Likewise, post-harvest UV-exposure technology is promising in improving colouration and secondary metabolite content. Crop exposure to UV-B radiation can trigger plant defence compounds and responses, decreasing the need to use pesticides and reducing the impact of pests and diseases. These UV-B responses can be useful in crop production and include dwarfed architecture and increased branching, replacing the need for use of plant growth regulators for certain crops (Neugart and Schreiner 2018).

A number of practical and scientific steps need to be taken before we can know whether the use of UV in plant production can become a commercial reality. These include: detailed analysis of the regulatory aspects of crop UV-exposure, as well as health and safety considerations for workers. Greater interaction with legislators is also needed to ensure that rules for the safe use of UV radiation with crops and food are internationally-harmonised and fair. A comprehensive cost-benefit analysis is required.

As part of space-research, where plants need to be grown in either entirely artificial environments without the protection offered by the atmosphere or with respect to theoretical

Figure 7.3: Discussions on plant UV research in ecology and plant production science led by M.A.K. Jansen (Photo credit: T.M. Robson).

extra-terrestrial colonisation of other bodies, there is scope to consider plant responses to all UV-(and shorter)-wavelengths.

Practical Questions: How do we transition the knowledge we have from simple, short, controlled UV-experiments to understand highly-complex natural environments?

The key component of this question is the complexity of scaling between various organisational levels (from the molecule to ecosystem), which inherently requires scaling across spatial and temporal scales. Even though different approaches are available to combine –omics data, there is no reliable way to link this to the physiological change in UV-exposed plants. This point is made worse by the use of different UV-spectra, UV-doses, and exposure kinetics (Aphalo et al. 2012). It is widely acknowledged that we are still struggling to link organisational scales. For example, it is very difficult to extrapolate aspects of gene-regulation to ecologically-relevant scenarios, or to attribute changes in plants under natural conditions to a particular photoreceptor.

A specific gap in our understanding is how to develop the knowledge we have of plant UV-responses obtained using stable "low PAR" growth chambers, and make the transition to highly-dynamic, high-PAR outdoor environments (Coffey et al. 2017; Morales et al. 2012).

Challenges and possible solutions:

1. The UV4Plants network could play a role in facilitating large-scale experiments whereby UV-mutants are tested across multiple sites with different UV-regimes (latitudes and elevations). This sort of experiment could be a way to decrease void between organisational levels.

2. Imaginative meta-analysis could be a way to combine, contrast and connect disparate datasets referring to different organisational levels.

3. Techniques can be used or developed in remote sensing to assess plant and vegetation responses to UV radiation at the regional scale i.e., we can remotely-sense flavonoid levels in leaves in complex canopies (Gitelson and Solovchenko 2018). Recently, these techniques have been tested in Antarctica (Turner et al. 2018) and in the tropics (Asner and Martin 2016).

4. A greater quantitative understanding of how UV-driven processes, such as photodegradation, influence biogeochemistry and carbon storage/cycling at large spatial and temporal scales is desperately needed to understand important feedbacks in the climate system that involve UV radiation.

5. Significant gaps in knowledge still exist in understanding how UV mediates species interactions (e.g., plant-plant; plant-insect; plant-pathogen) and how these interactions will be influenced by climate change as plants encounter novel suites of interacting species as a result of species migrations, biodiversity loss and species invasions. Understanding how UV influences belowground processes and interactions with soil organisms is still minimal.

6. As the climate continues to change, does UV play any role in influencing species migrations (e.g., to higher elevations in mountains) and are invasive species more or less sensitive to UV than native species (Václavík et al. 2017).

Interdisciplinarity: What do we want from molecular biologists, physiologists and biochemists?

A key requirement is better knowledge of those regulatory processes that occur in a UV-exposed plant. There is a great demand for more non-GM mutants, disabled in key UV-responses, for testing under natural/outdoor conditions. Furthermore, there is a strong interest in having mutants in species other than Arabidopsis. While ecotypes of Arabidopsis exist, this species does not encompass the range of functions, adaptations, growth forms and physiology displayed by higher plants. Because of the strong site-specific evolutionary pressures that occur in nature, no single model plant species exists for ecological UV research. It would be best to focus on several plant species that represent the breadth of plant functional types (e.g., using Grime's CSR or other recent functional analyses of plants as selection criteria).

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Peer-reviewed article.
Published on-line on 2018-12-27.
Edited by: Pedro J. Aphalo.

■ Participants' report

Improving participation by early stage researchers and women in conference seminars

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DOI: 10.19232/uv4pb.2018.2.12

Introduction

Power hierarchies and gender biases are widespread and the science, technology, engineering, and mathematics (STEM) disciplines are not immune. Studies have repeatedly shown that double-blind reviews often lead to greater acceptance of publications by women, indicating biases against female authors (Knobloch-Westerwick et al. 2013; Roberts and Verhoef 2016). Across many STEM fields, women are less likely to be invited to give seminars (Schroeder et al. 2013), face greater levels of sexual harassment (Clancy et al. 2014), are interrupted more often during meetings (Kennedy and Camden 1984), and experience discrimination when their publications are reviewed by peers (Roberts and Verhoef 2016).

Although a growing body of literature has highlighted gender disparities in STEM, less research has been directed toward the role that academic hierarchies play in determining how individuals engage with one another professionally. For instance, students are less likely to participate in discussions at conferences and seminars oftentimes because they believe they do not have the expertise to speak up or feel that their contributions will not be taken as seriously as those of more senior researchers (pers. obs.). Identifying ways for early stage researchers to feel more confident and welcome to contribute to discussions is likely to lead to a more productive exchange of ideas at conferences and workshops that are designed to promote collaboration among researchers.

There has been a strong push in recent years to increase participation by underrepresented groups in STEM and academia generally. However, the mere presence of people from a group is insufficient if individuals are not able to contribute intellectually. If one of the goals of conferences is to teach and empower students and other early stage researchers, we should make efforts to ensure that everyone, including early stage researchers, is able to actively participate in a meaningful way. Recognizing barriers to inclusiveness during professional meetings is particularly important if we want to promote productive exchanges of ideas and equip students with the skills they need to succeed later on.

In order to determine how equally early stage researchers (ESRs) vs. faculty/principal investigators (PIs) and male vs. female researchers participate in conference discussions, I recorded the gender and career stage (ESR vs. PI) of each person asking a question following oral presentations at the Network Meeting of the International Association for Plant UV Research in Bled, Slovenia in April 2018. I report that there was a significant and large imbalance in the number of questions asked by certain groups and provide recommendations for improving participation at future meetings.

Methods

After each oral presentation, I recorded the gender and career stage of the presenter as well as the gender and career stage of each person asking a question during the discussion that followed. For confidentiality reasons, no identifying information was collected on anyone except career stage and gender. Students and post-doctoral fellows were classified as early stage researchers (ESRs) and researchers at later stages of their careers were classified as principal investigators (PIs). Because I did not know everyone's career stage at the start of the conference, several individuals were classified as "career stage unknown" during the first few talks. Since individual names were not recorded, it was impossible to retroactively assign career stages to these people so these "career stage unknowns" (7/100 questions) were removed from the analysis of career stage but still included for analyzing gender patterns. While this observational method runs the risk of misidentifying some individuals' genders, specifically asking people would have involved interaction in a way that would have likely affected people's behavior and lead to less informative results.

I used deviation as the metric used to the describe the difference between the number of questions asked by members of a given group and the number expected based on their representation in the audience of the room. Deviation was calculated as:

$$\Delta = N_{\text{group}} - P \times N_{\text{total}}$$

where N_{group} is the number of questions asked by members of that group, P is the proportion of the audience made up by that group, and N_{total} is the total number of questions asked during that session by everyone in the audience. A value of zero means that on average, that group asked a number of questions proportional to their representation in the room. A positive deviation means that a group spoke more than expected and a negative deviation means they spoke less. I calculated a deviation value for the four groups for each oral presentation at the meeting ($n = 21$). Finally, I conducted all analyses in R using base functions (t-tests and 2-way ANOVAs), using individual oral talks as the replicates. Since this study involved no subject interaction or intervention with regard to private information, Michigan State University's Human Research Protection Program determined that this work was not human subjects research (STUDY00001206).

Results

Who asks the questions

During the three-day meeting, 100 questions were asked following 21 talks. The average number of questions asked per talk was 4.7 (range 1--11) asked by 4.5 people (range 1--10). The gender and career stage of the presenter did not affect the number questions they received; male and female presenters and ESR and PI presenters received the same number of questions (gender $t = 1.5$, $p = 0.16$; career stage $t = 0.27$, $p = 0.79$).

There was however a large difference in who was asking the questions, with PIs and men asking more questions than would be expected based on their representation in the audience (Figure 8.1). However, the effect was purely additive with no significant interaction between career stage and gender (Table 8.2); male ESRs asked fewer questions than male PIs and female ESRs asked fewer questions than female PIs. Overall, the effect of career stage was considerably larger than that of gender (Figure 8.2, Table 8.1).

Despite making up only 45% of the audience, PIs asked 89% of the questions, twice as many questions as expected if everyone had participated equally (Table 8.1). ESRs on the other hand asked one fifth of the questions expected based on their representation in the room. Also of note, all but one presentation

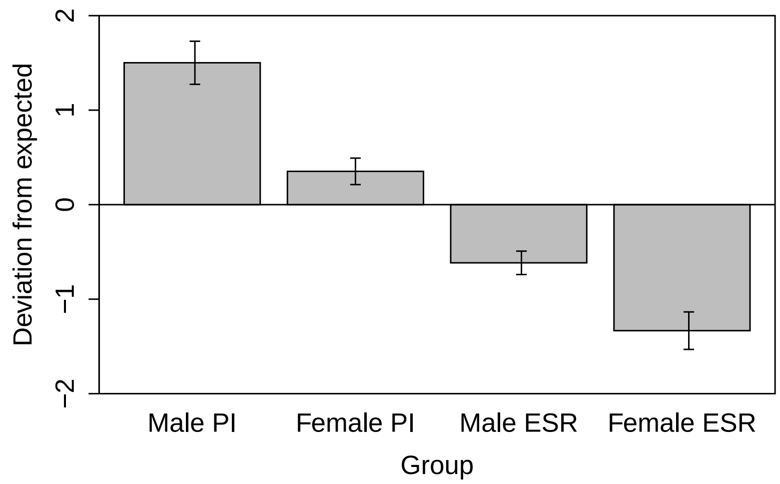

Figure 8.1: Deviations from expected number of questions asked by male and female PIs and early stage researchers. Positive values mean that group asked disproportionately more questions than would be expected based on their makeup in the audience and negative values mean they spoke less. All groups are significantly different from each other (Table 8.2). Bars represent ±1 S.E.

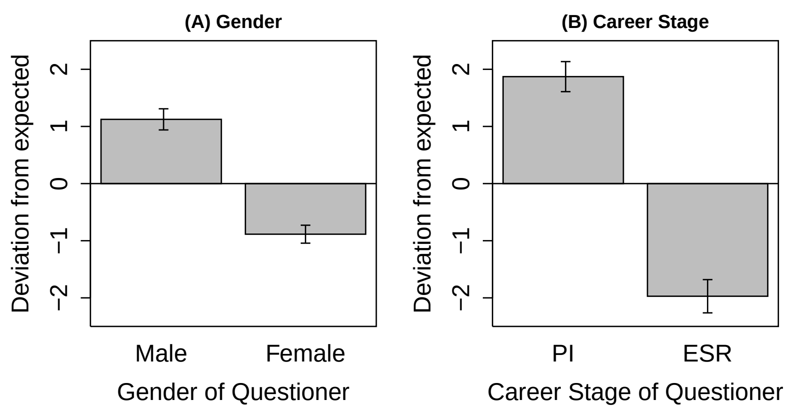

Figure 8.2: Deviation from expected number of questions asked based on the gender (A) and career stage (B) of the questioner (PI versus early stage researcher). Positive values mean that group asked disproportionately more questions than expected based on their makeup in the audience and negative values mean they spoke less. Bars represent ±1 S.E.

Table 8.1: Participation in discussions by members from different groups. Conference attendance numbers, number of questions asked by members of different groups, same number of questions expressed relative to that expected assuming equal participation, talks with at least one question by a member of the group, and talks where a member of the group asked the first question. The number of questions included in the career-stage descriptions is 93 (instead of 100) because I did not know the stage of seven questioners early in the conference and was only able to assign gender to them. The same is true for the last column indicating how many people asked the first question following talks (during one talk I didn't know the career stage of the first questioner so there are only 20 talks included for career-stage comparisons).

Group	attendance	number of questions	relative to expected	talks with a question by	talks with first question by
Male PI	27% (15/56)	61% (57/ 93)	2.3	95% (20/21)	40% (8/20)
Female PI	20% (11/56)	28% (26/ 93)	1.4	81% (17/21)	30% (6/20)
Male ESR	18% (10/56)	4% (4/ 93)	0.24	19% (4/21)	20% (4/20)
Female ESR	36% (20/56)	6% (6/ 93)	0.18	24% (5/21)	10% (2/20)
Male	46% (26/56)	66% (66/100)	1.4	100% (21/21)	62% (13/21)
Female	54% (30/56)	44% (44/100)	0.83	86% (18/21)	38% (8/21)
PI	45% (25/56)	89% (83/ 93)	2.0	95% (20/21)	70% (14/20)
ESR	55% (31/56)	11% (10/ 93)	0.20	38% (8/21)	30% (6/20)

Table 8.2: The effect of gender (male vs. female) and career stage (early stage researcher vs. principal investigator) on numbers of questions asked. Results of two-way Analysis of Variance testing the effect of gender and career stage of speakers on deviations from expectation of equal participation.

Source	d.f.	F	P-value
Gender	1	27.6	<0.001
Career stage	1	114.6	<0.001
Gender × C. stage	1	1.5	0.228
Residuals	80		

received a question from a PI (95%), whereas ESRs only asked questions after 38% (8/21) of the presentations (Table 8.1). PIs were also considerably more likely than ESRs to ask the first question ($X^2 = 5.2$, df = 1, $p = 0.02$).

While gender of the questioner did play a role, the effect was smaller than for career stage. Men made up 46% of conference attendees but asked 66% of the questions (Table 8.1). While every presentation received at least one question from a male researcher, female researchers asked a question following 86% (18/21) of presentations. Neither male nor female researchers were more likely to ask the first question ($X^2 = 2.0$, df = 1, $p = 0.16$).

Does it matter who asks the first question?

To determine whether people were more likely to speak when the first question was asked by a member of their group, I calculated the number of questions asked by women and ESRs when the first question was asked by another woman or ESR. Since the goal here was to determine whether the gender or career stage of the first questioner affects how likely other people from that group are to ask subsequent questions, I excluded the first question from the calculated deviations. The gender of the first person to ask a question had no effect on whether female researchers were more likely to ask follow-up questions (p = 0.21). However, when the first question was asked by an ESR, other ESRs asked follow-up questions somewhat more often ($p = 0.08$), suggesting a possible ”first question” effect based on career stage.

Discussion and recommendations

While there was a strong gender imbalance in how many questions were asked, the effect of career stage was much larger. Early stage researchers asked fewer questions, participated in fewer discussion sessions, and were considerably less likely to be the first ones to ask a question. While it might be expected that students are less likely to participate in discussions at conferences, the magnitude of the career stage effect was large. Male and female early stage researchers asked one quarter and one sixth of the questions they were expected to ask based on their attendance numbers. This shows that there are strong barriers preventing early stage researchers from fully participating in conference discussions.

I did not find a significant interaction between gender and career stage, as the effects were additive, leading to particular disenfranchisement of female students and post-docs. This is consistent with other studies that have also found that even among younger researchers, men ask more questions than women (Hinsley et al. 2017). Overall, while the magnitude of the effects were different, similar strategies may be used to encourage more equitable participation by both early stage and female researchers.

Although I only looked at two variables (gender and career stage), many identities may be relevant in determining how often an individual participates in a discussion, including race, ethnicity, nationality, native language, and field of study, among others. Especially for students at international meetings, whether an individual is a native speaker of the language used at the conference may play a large role in how confident they are in speaking up. While these may all have played a role, the relatively small sample size here as well as logistical constraints (being able to quickly classify people in real time) limited the scope of this study to just these two identity groupings.

One limitation of this study is that these data only reflect the total number of questions that were asked following oral presentations. As such, there is no way to know to what extent these imbalances were driven by decisions made by audience members (choosing whether to raise one’s hand or not) versus decisions made by the presenter and moderator (deciding who to call on), though both of these may likely have played a role. A survey of 600 academics in 20 countries found that women were more likely to report that they wouldn’t speak up because of internal factors (e.g. they couldn’t “work up the nerve” to ask a question or they felt intimidated by the speaker) (Carter et al. 2017). People also reported that speakers would call on people they know more often, suggesting that decisions other than those made by audience members may also play a role in the observed imbalance. Regardless of the specific mechanism, the disparities I report here highlight the fact that early career researchers and women have less access to presenters than do faculty and men.

Encouragingly, these results and previous observations suggest ways to build a more equal participation at conferences. Although PIs were more likely to ask the first question following a talk, early stage researchers tended to ask more questions when another student or post-doc asked the first question. This is consistent with previous findings, albeit most other studies have focused on gender imbalance rather than career stage imbalances. After observing the gender of questioners at almost 250 seminars, (Carter et al. 2017) found that when a female researcher is called on first, the gender imbalance of who asks questions disappears.

Similarly, a study that looked at who

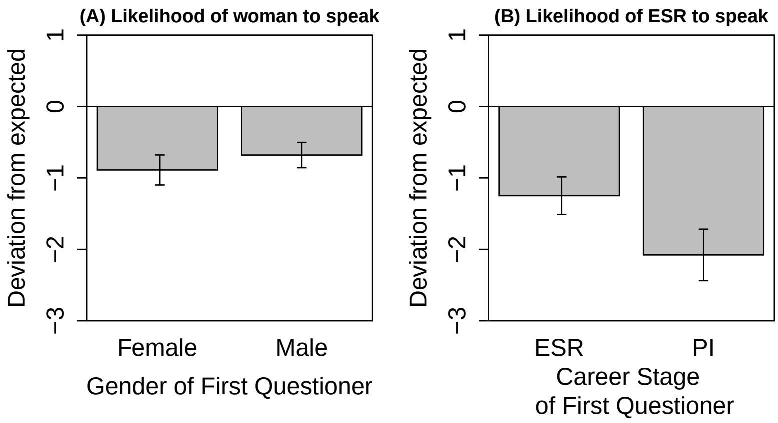

Figure 8.3: Likelihood of female researchers and early stage researchers to ask questions given the identity of the first questioner. (a) The likelihood of female researchers to ask a follow up question did not differ significantly based on the gender of the first person to ask a question (t = 1.3, p = 0.21). (b) The likelihood of ESRs to ask a follow up question was somewhat greater when the first question was asked by an ESR rather than a PI (t = 1.9, p = 0.08). Bars represent ±1 S.E.

was invited to give talks at a series of research conferences found that the number of female speakers at research symposia increases when women have leadership roles organizing the meetings (Sardelis and Drew 2016)). Although the effect here was driven by career stage and not by gender, these studies highlight that implementing simple structural changes (increasing leadership roles or implementing a rule about who may ask questions first) can have tangible effects on participation by individuals from groups that are traditionally excluded from the table, either because of bias by organizers or from internalized self-doubts. Developing structures to help amplify the voices and leadership responsibilities of individuals from disempowered groups can lead to more equitable participation and ultimately, a more productive exchange of ideas.

Based on observations from this meeting and suggestions from some of the studies cited above, I make several recommendations for improving participation at future meetings:

- Implement a rule that the first question following a talk must be asked by a student or post-doc. Similarly, moderators should make a point to call on female researchers first. Many departments have rules that faculty are only allowed to ask questions once several students have had an opportunity to speak and faculty feel this leads to an increase in participation by students (K. Jacobson, pers. comm.). This not only guarantees that more ESRs will be able to participate in discussions but also makes it more likely that others will ask more questions later on, further increasing participation.

- Designate early stage researchers as session chairs and moderators. Although students and post-docs made up 55% of conference attendees, none of the seven sessions was chaired by a student and only one was chaired by a post-doc. Since ESRs tend to be more likely to ask questions when another ESR “breaks the ice” with the first question, assigning students and post-docs to positions as session chairs will likely increase participation by other ESRs in discussions.

- Encourage more participation by early

stage researchers in oral presentations instead of only posters. While ESRs were very well represented in oral talks at the 2018 Network Meeting (they made up 55% of attendees and 52% of oral presenters), 73% of posters were presented by ESRs compared to only 27% by PIs. This shows that although students and post-docs are proportionally well represented as oral presenters, ESRs are more likely to request/be accepted for poster presentations and/or PIs are more likely to request/be accepted for oral presentations. Balancing the number of poster and oral presentations by ESRs and PIs could provide more opportunities for ESRs to present their work to the broader audiences of oral talks.

Diversity and inclusion efforts will only succeed if we recognize existing barriers to inclusion in academia and work to change existing structures to actively promote the success and participation of individuals who are not already at the table. While this is a long-term process that will include challenging individual biases and implementing changes to institutions, doing so will ultimately lead to more supportive, open, and productive research programs.

Acknowledgements

I would like to thank Dr. Bonnie McGill, Meredith Zettlemoyer, Ava Garrison, Mai Ha Vu, and Hung-Shao Cheng for their feedback on early drafts of this manuscript.

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Peer-reviewed article.
Published on-line on 2018-12-27.
Edited by: Titta K. Kotilainen.

Participants' report
UV-emitting LEDs: the future looks bright!

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DOI: 10.19232/uv4pb.2018.2.13

Several members of UV4Plants attended the "Joint International Conference on UV-LED Technologies and Applications" (ICULTA-2018) that took place in Berlin from April 22 through to 25. Indeed, UV-emitting LEDs are of considerable interest for plant UV-researchers, as well as for the horticultural industry. Rather than a talk-by-talk summary of the conference, this short report will give you an update on the state-of-the-art in UV-LED technology, and give an overview of key areas where advances can be expected in the next few years.

ICULTA-2018 was jointly organised by the "*International Ultraviolet Association*" (IUVA) and the German Research and Development consortium "Advanced UV for Life". IUVA (http://www.iuva.org) focuses on, and facilitates, scientific and technological issues that relate to the use of ultraviolet radiation. IUVA has some 500 members across 35 countries, and this includes many industry members. The "Advanced UV for Life" consortium (`https://www.advanced-uv.de`) aims to develop and market new products based on UV-emitting LEDs. This consortium brings together 35 industry members and 15 R&D members, from across Germany. For ICULTA-2018 some 260 participants were registered, and around 60% of these were industry based. As a result, the programme of ICULTA-2018 contained talks relating to all aspects of UV-LEDs, ranging from fundamental aspects of LED-design, LED-testing and LED-packaging, as well as device design, and product development. Product development was focussed on a number of distinct UV-LED applications, including disinfection technology, curing and printing, phototherapy, catalysis, communication and horticulture. While some of these UV-applications are very well established (e.g. disinfection of water, air or equipment, curing and phototherapy), others are much more pioneering (e.g. use of UV in horticulture).

The basic principle of UV LEDs (Figure 9.1) is the emission of radiation by a mixed crystal system made up of AlN, GaN and InN. The advantages of using UV-LEDs over traditional UV-sources are manifold. The LEDs are small and robust, produce little heat, can operate at low voltages, do not require toxic Hg, produce narrow emission peaks around a single wavelength, can be made to cover any wavelength in the UV spectrum, and output intensity can be electrically regulated. Emission spectra of UV LEDs of different compositions can be found in the brochure of (2018), freely available at https://www.advanced-uv.de/. One particular application that exploits the advantages of UV-LEDs is the development of a wearable device for phototherapy (e.g. used to treat psoriasis or eczema). Such light weight

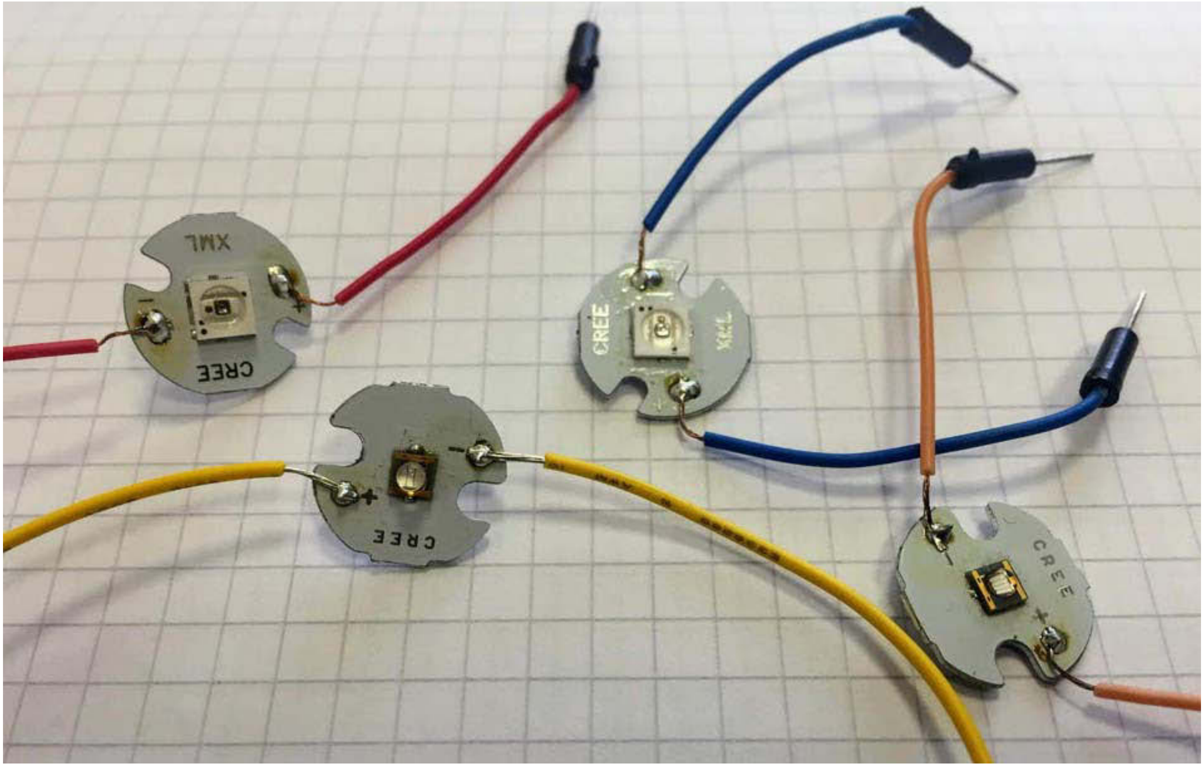

Figure 9.1: Typical UV-emitting LEDs. Photo: Dr. Alan Morrison, UCC, Ireland

devices do not require a high power connection and cooling arrangement, and the small size of individual LEDs mean that the device can follow the contours of the body-part that requires UV-phototherapy. The narrow bandwidth of UV-LEDs allows precision manipulation of chemical and biochemical processes (Figure 9.2), although a narrow bandwidth is not always an advantage. For example, polychromatic UV-C radiation may be more efficient for disinfection, presumably as both DNA and peptides are excited, creating a synergistic interaction.

The development of UV-A emitting LEDs is highly advanced, yet development of UV-B and UV-C emitting LEDs is more pioneering. Nevertheless, it became clear at the conference that UV-C and UV-B emitting LEDs can now be obtained from several different suppliers, and that it is possible to obtain a range of LEDs emitting different UV-B or UV-C wavelengths. For example, talks at ICULTA-2018 referred to 294, 298, 305, 310, 315, 320, and 325nm UV-LEDs. However, not all is well at this stage, as the efficiency and output of these LEDs is still very low. In this context Haitz's law is of interest as it states that every decade LED optical power increases 20-fold, while prices come down 10-fold. Although it is early day in UV-LED development, early trends are consistent with Haitz's law. At present, the light extraction efficiency of UV-LEDs is typically around 5% for UV-B and UV-C LEDs, although in some reported cases this was closer to 1-2%. In comparison, e.g. blue LEDs have an efficiency of 80% and higher.

Improving light extraction efficiency of UV-emitting LEDs is closely linked to temperature control. Thus, thermal management is a key consideration when developing devices equipped with UV-emitting LEDs. Another consideration is that, especially for applications in plant biology, exposure to humidity needs to be avoided. So, encapsulation of UV-emitting LEDs is another important topic, whereby the transmitting properties of poly-

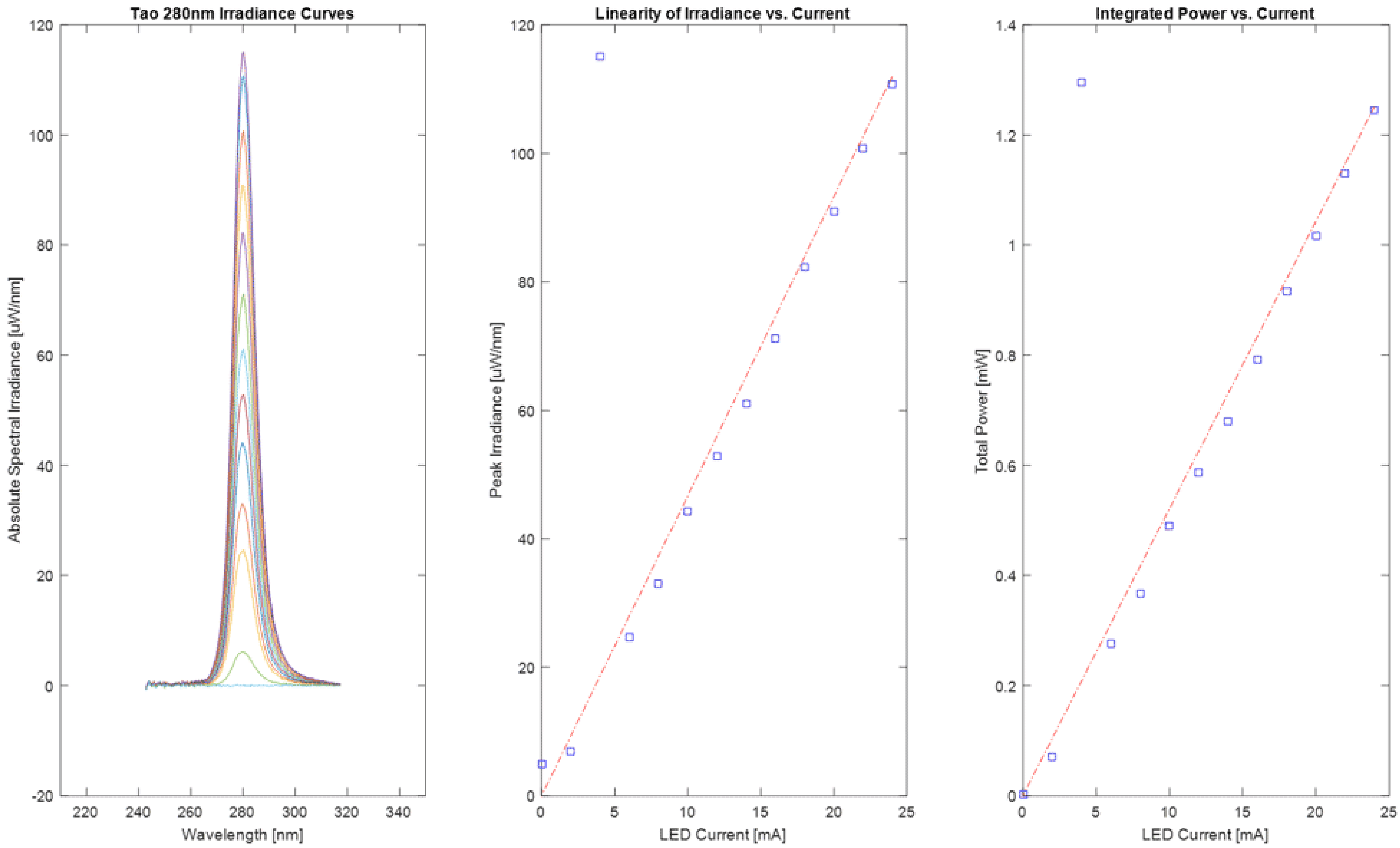

Figure 9.2: UV-B LED performance. Narrow output spectrum and excellent linear relationship between LED current and peak irradiance. Plots: Dr. Alan Morrison, UCC, Ireland

mers over the life-time of the LED are of particular interest. In this context, several speakers commented that replacement of traditional Hg-based UV sources by UV-LEDs will in many cases require the entire redesign of devices, and this applied specifically to well established devises such as disinfection devices currently relying on Hg-UV sources.

So, should we all dump our old UV-lamps and go for UV-emitting LEDs? The answer to this question might well be "yes, but not yet". UV-LED technology is rapidly advancing, but serious hurdles remain. To facilitate applications of UV-LEDs the emission spectrum, and optical output and spatial radiation pattern of LEDs should change as little as possible over the lifespan of the UV emitting LED. Life span is given as the L50, the time by which the LED emits just 50% of the initial intensity. Optical performance of some UV emitting LEDs can start decreasing after 100's of hours of operation in some cases, but in excess of 10.000 hours in other cases (the estimated L50 for a 310nm LED was around 20.000h). Another serious consideration is LED tolerances, as wavelength peaks can vary as much as ± 5nm. Clearly, not all UV-LEDs that emit nominally the same wavelength are equal, and there are high variances between the products of various manufacturers. Thirdly, cost is still prohibitive for the commercial use of UV-emitting LEDs in horticulture. However, at ICULTA-2018 presentations by Prof Marcel Jansen (Cork), Prof Annamaria Ranieri (Pisa) and Dr Melanie Wiesner-Reinhold (Grossbeeren, Berlin), all showed the potential benefits of UV-exposure of crops for both growers and consumers. Dr Wiesner-Reinhold reported how levels of metabolites are regulated in a number of crop species exposed to UV-radiation emitted by either 290nm or 307nm UV using a UV-B LED module developed by the Leibniz Ferdinand Braun Institute, Berlin, Germany. An advanced prototype was shown during the conference and is presented at https://www.fbh-berlin.com/prototype-engineering/prototypes. The clear impact of LED-emitted UV-radiation on the plants demonstrated that UV-LEDs are powerful enough to alter plant metabolism, and UV-LEDs are becoming a realistic perspective for plant biology researchers. The horticultural industry will need cheap, long-lived and reliable UV-emitting LEDS (which are not yet available), but conversely the horticultural industry can reduce LED costs by generating a large scale demand which results in production efficiencies of UV-B emitting LEDs. So, watch this space!

For those with an interest in UV-LEDs, the next IUVA world congress will take place in February 2019 in Sydney Australia (see www.iuva.org).

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Editorial-board-reviewed article.
Published on-line on 2018-12-27.
Edited by: Titta K. Kotilainen.

Methods

Exploring temporal and latitudinal variation in the solar spectrum at ground level with the TUV model

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DOI: 10.19232/uv4pb.2018.2.14

The simulation of solar spectra at ground level

Radiation transfer models use as input the extraterrestrial solar spectrum. The spectrum at ground level depends on atmospheric composition, path length through the atmosphere and the presence of clouds and/or aerosols. The path length is determined by the solar elevation above the horizon and the position of the observed with respect to ground level and the elevation of the ground above sea level. Atmospheric composition can vary most significantly with respect to water vapour and ozone "columns", but these data are not difficult to come by. In contrast, data on cloudiness expressed as cloud depth is difficult to obtain, mainly because it changes very rapidly. Consequently, for non-specialists the use of the TUV model is best restricted to simulations under clear sky conditions. In an earlier article in this Bulletin the model libRadtran (Emde et al. 2016) was introduced (Brelsford 2017). In the present article we will use the TUV model developed by Sasha Madronich, more specifically the web interface to this model called Quick TUV Calculator (`http://cprm.acom.ucar.edu/Models/TUV/Interactive_TUV/`).

The TUV model is a well known model of atmospheric chemistry that also simulates the solar spectrum within the atmosphere and at ground level using a radiation transfer approach. The model is written in FORTRAN and available for local use. When we need only to compute a few spectra with no special conditions, it is much easier to use the on-line interface provided by the National Centre of Atmospheric Research (NCAR) under the name of Quick TUV Calculator (`http://cprm.acom.ucar.edu/Models/TUV/Interactive_TUV/`) than to install the model programme.

The "quick" interface is menu/dialogue based and easy to use once one understands the different options and required input data. An annotated video captured during use of the Quick TUV calculator is included as supplementary material with permission of Sasha Madronich, creator of the TUV model.

The Quick TUV Calculator accepts as input either a solar zenith angle or geographic plus time coordinates. In the examples presented here I used zenith angles. The 'photobiology' package also includes functions for the calculation of the zenith and other angles for the sun position (see our previous article Aphalo 2016 and the R notebook in the supplemental files). The interface with the fields set to the values used for the simulations is shown in Figure 10.1.

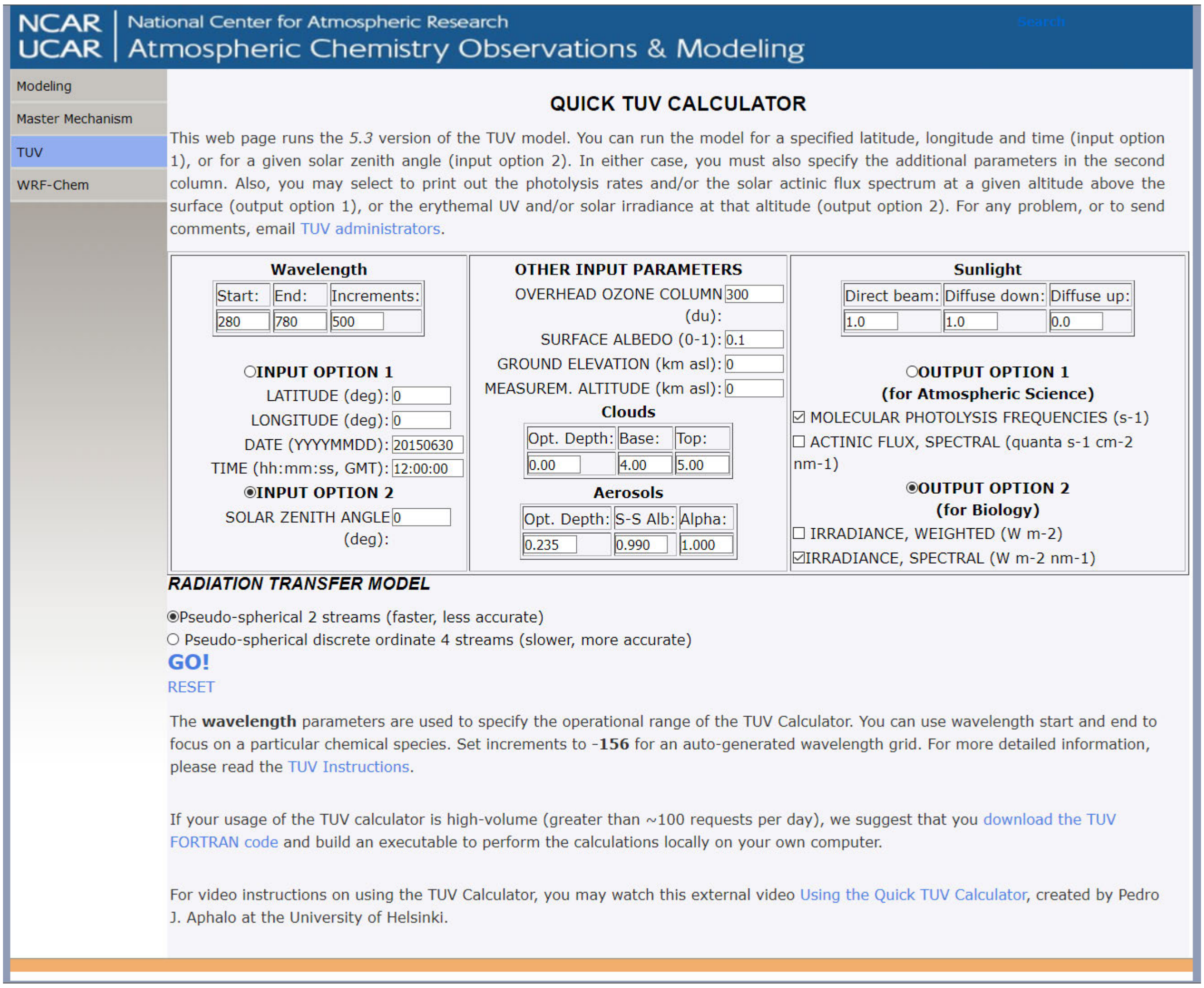


Figure 10.1: Quick TUV Calculator. User interface with settings as used to generate the data used for the examples shown in this article. To obtain the different spectra the value of the zenith angle was changed.

Using spectral data output by the Quick TUV Calculator

I will show how to import into R, compute summaries and plot the output from this model using the packages from the R for Photobiology suite. Package 'photobiologyInOut' was recently updated (versions >= 0.4.15) to support the import of spectral data from files returned by the *Quick TUV Calculator*. We will read solar spectra into R, plot and calculate summary quantities from them. The examples chosen will be useful as reference data also to those not interested in doing new simulations. When high quality spectral measurements are lacking, simulated spectra can be very useful for the interpretation of results from field experiments, the design of realistic treatments or the assessment of the relevance of results of past experiments to specific exposure conditions outdoors.

Two aspects of the use of the packages in the R for Photobiology suite have been described in previous articles published in this Bulletin: the calculation of summaries from spectra (Aphalo 2015) and computations related to the position of the sun (Aphalo 2016). Here we will make use, in addition to the functions previously described, of a function from package 'photobiologyInOut' that implements the import into R of the spectral data returned by the Quick TUV Calculator. We also use the plotting functions from package 'ggspectra'. Many functions in the packages earlier described now accept collections of spectra as arguments, which simplifies plotting or computations on multiple spectra. All the R packages used are available through public CRAN repository (https://cran.r-project.org/) and further information and on-line documentation can be found at the website https://www.r4photobiology.info/.

In the article itself we provide only partial examples of the R code, while fully reproducible source code and output is provided as supplementary material in the form of an R notebook readable with most web browsers. This R notebook includes the source code embedded which allows users to rebuild the HTML file and edit the source code as needed by opening the R notebook file in RStudio (https://www.rstudio.com/).

We start by loading the packages we will be using, and setting photon quantities as the default to use.

```
library(photobiology)
library(photobiologyWavebands)
library(photobiologyInOut)
library(photobiologySun)
library(dplyr)
library(ggplot2)
library(ggalt)
library(ggspectra)
library(knitr)

theme_set(theme_bw(13))
photon_as_default()
```

Importing spectral data

When running a simulation in the Quick TUV Calculator, the spectral data and/or summaries are returned as a simple web page. A web page is a text file, and can be saved from the web browser. Depending on the browser it may be possible to save the page as a text file without HTML header and footer and using `.txt` and file ending. In all cases it should be possible to save the output as an HTML file. In either case the files can be imported into R with function `read_qtuv_txt()` just by providing the file name as argument. As much metadata as possible is extracted from the file, while the HTML header is stripped if present before attempting the decoding of data and meta-data. If summaries are present in addition to the spectral data in the Quick TUV Calculator output, these are also discarded.

```
qtuv.spct <-
    read_qtuv_txt("tuv-zenith-00-03-300.html")
head(qtuv.spct, 4)

## Object: source_spct [4 x 7]
## Wavelength range 280.5 to 283.5 nm, step 1 nm
## Label: Quick TUV spectral simulation File: tuv-zenith-00-03-300.html
## Measured on 2015-06-30 UTC
## Time unit 1s
```



```
##
## # A tibble: 4 x 7
##   w.length s.e.irrad s.e.irrad.dir s.e.irrad.diff.~ s.e.irrad.diff.~ angle
## *    <dbl>     <dbl>         <dbl>            <dbl>            <dbl> <dbl>
## 1     280.  3.07e-15      1.76e-15         1.31e-15         3.07e-16     0
## 2     282.  1.17e-13      6.59e-14         5.14e-14         1.17e-14     0
## 3     282.  1.84e-12      1.01e-12         8.23e-13         1.84e-13     0
## 4     284.  9.92e-12      5.42e-12         4.51e-12         9.92e-13     0
## # ... with 1 more variable: date <dttm>
```

```
cat(comment(qtuv.spct))
```

```
##  SPECTRAL IRRADIANCE (W m-2 nm-1)
##  from file:  tuv-zenith-00-03-300.html  generated by Quick TUV on
##  2018-12-15 07:41:23 ozone column (DU) =
##  zenith angle (degrees) =  0
##  altitude (km)  =  0
##  observer elev. =  0
```

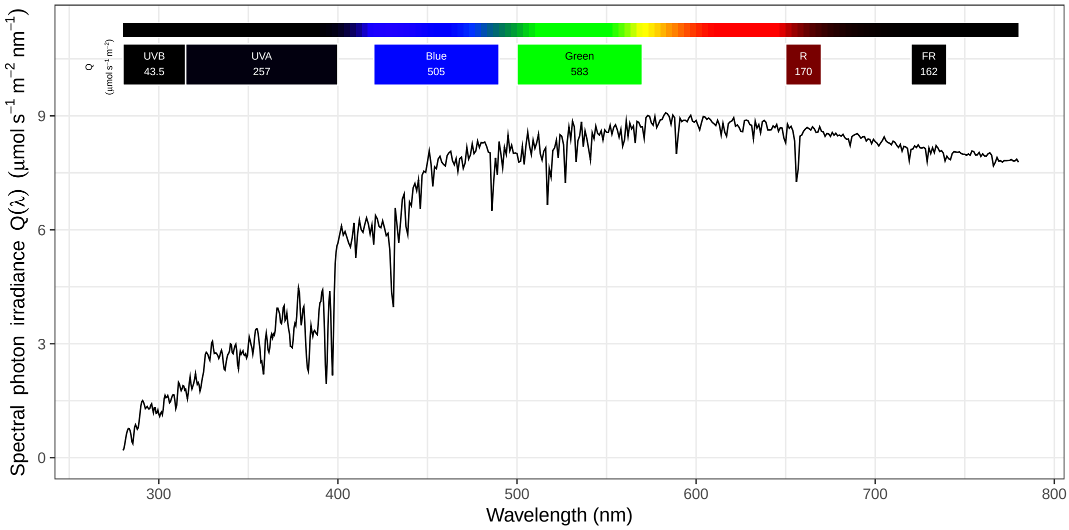
The example in the supplementary R notebook shows how to read multiple files into a collection of spectra using iteration. The result of running that code was saved to an R data file, which will be loaded below.

Plotting

In addition to simulations produced ad-hoc, existing measured spectra or standardized spectra can be useful as references and/or as examples. For example, it can be useful to compare the extraterrestrial solar spectrum and spectra at ground level. Package ‘photobiologySun’ provides spectral data for both of these types of spectra, with several measured and simulated sets of spectral data. We use these data only for the initial example but later rely on new simulations done with the Quick TUV Calculator. Although not shown here, package ‘photobiologySun’ also contains example data measured in the understorey of different forests.

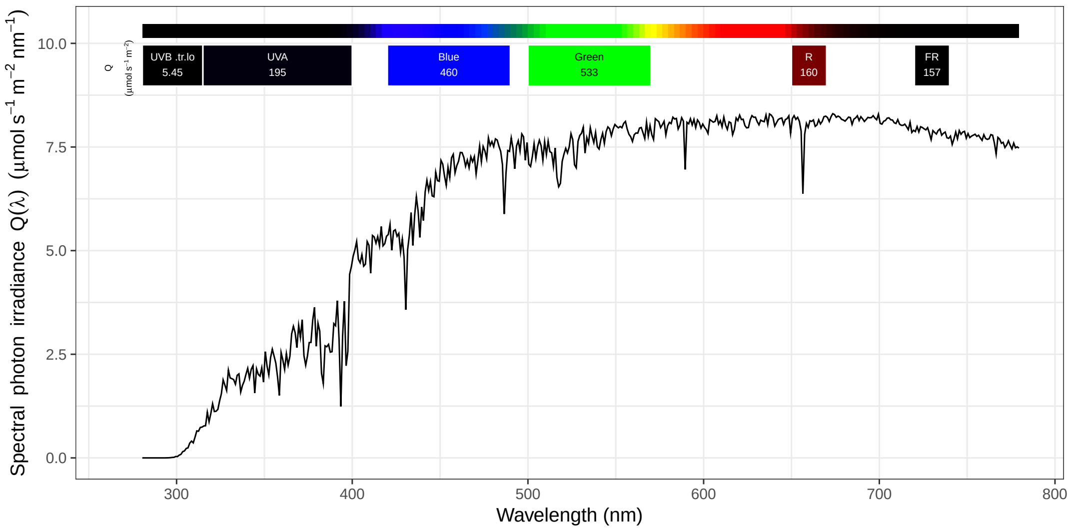
We here plot the extraterrestrial solar spectrum, which is an input to all radiation transfer models. The data used for this figure are from package ‘photobiologySun’.

```
sun_ET.spct <- sun_reference.mspct[["Gueymard.AM0"]]
plot(sun_ET.spct,
     range = c(250, 780), annotations = c("-", "peaks"),
     w.band = c(Plant_bands(), IR_bands())) +
  theme(legend.position = "top")
```



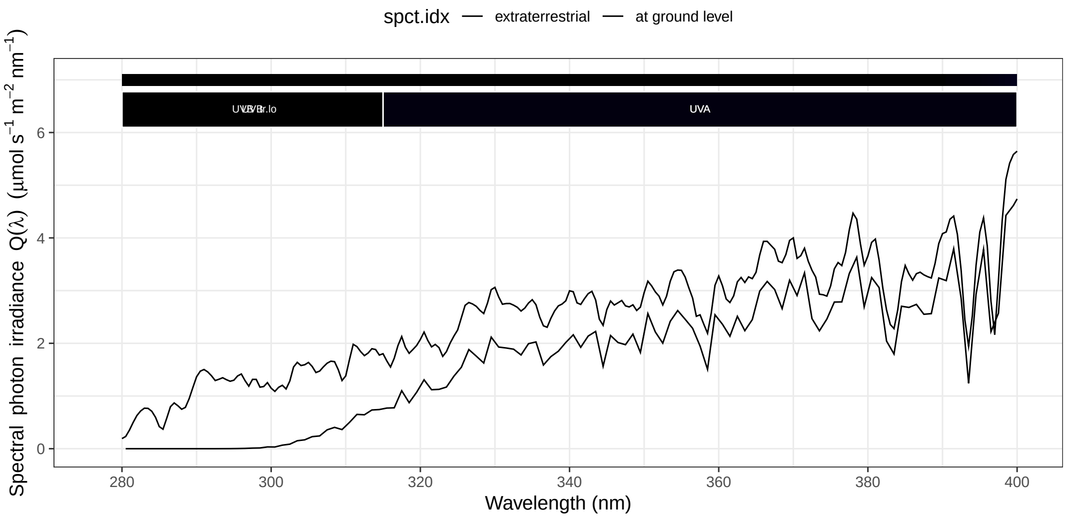
We can plot the simulated spectrum read above from the Quick TUV Calculator output in the previous section.

```
plot(qtuv.spct,
     range = c(250, 780),
     annotations = c("-", "peaks"),
     w.band = c(Plant_bands(), IR_bands())) +
  theme(legend.position = "top")
```



To highlight the effect of the atmosphere and solar elevation we can add to the plot the extraterrestrial spectrum, while also reducing the range of wavelengths plotted.

```
plot(source_mspct(list(extraterrestrial = sun_ET.spct, "at ground level" = qtuv.spct)),
     range = c(250, 400),
     annotations = c("-", "peaks"),
     w.band = c(Plant_bands(), IR_bands())) +
  theme(legend.position = "top")
```

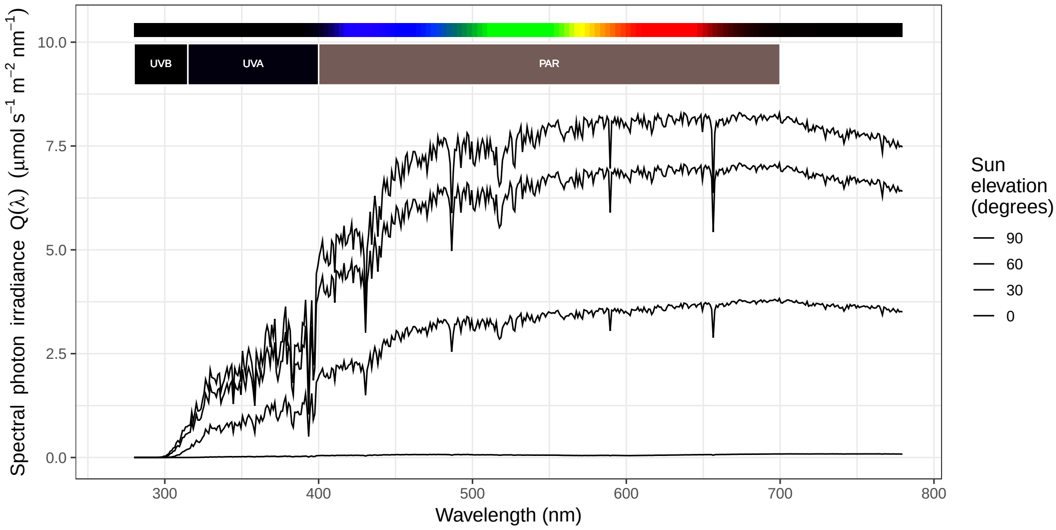
We can use models to simulate the solar spectrum at a specific geographical location and time point. We next load data for several spectra simulated with the Quick TUV Calculator and originally imported into R as demonstrated in the previous section and re-saved into an `.Rda` R data file (see the supplementary R Notebook for details).

```
load("QTUV-spectra.Rda")
length(sun_tuv.mspct)

## [1] 29
```

In the next figure we present spectral irradiance on a horizontal surface for the sun at different elevations above the horizon, assuming an ozone column of 300 DU (Dobson units). In the TUV model the zenith angle is used to describe solar elevation. The collection of spectra `sun_tuv.mspct` contains 29 spectra, and we use subscripting by name to select those we want to plot. To save typing we create two vectors with the names of the spectra we will use in different examples. We will use these vectors to select subsets of spectra from the collection of spectra.

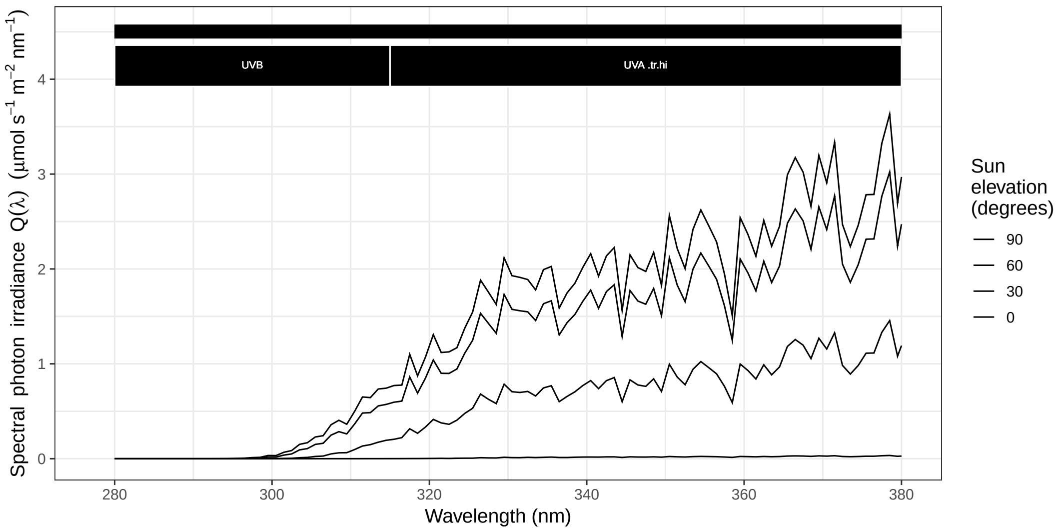
```
spectra7elevations <- c("tuv_zenith_00_O3_300",
                        "tuv_zenith_15_O3_300",
                        "tuv_zenith_30_O3_300",
                        "tuv_zenith_45_O3_300",
                        "tuv_zenith_60_O3_300",
                        "tuv_zenith_75_O3_300",
                        "tuv_zenith_90_O3_300")
the7elevations <- 90 - c(0, 15, 30, 45, 60, 75, 90)

spectra4elevations <- c("tuv_zenith_00_O3_300",
                        "tuv_zenith_30_O3_300",
                        "tuv_zenith_60_O3_300",
                        "tuv_zenith_90_O3_300")
the4elevations <- 90 - c(0, 30, 60, 90)
```

```
plot(sun_tuv.mspct[spectra4elevations],
     annotations = c("-", "peaks")) +
  scale_linetype(labels = the4elevations,
                 name = "Sun\nelevation\n(degrees)")
```



To obtain a detailed plot of the UV region we pass the desired range of wavelengths in nanometres `range = c(280, 380)`. Except for this the code below is the same as in the previous chunk.

```
plot(sun_tuv.mspct[spectra4elevations],
      range = c(280, 380),
     annotations = c("-", "peaks")) +
  scale_linetype(labels = the4elevations,
                 name = "Sun\nelevation\n(degrees)")
```

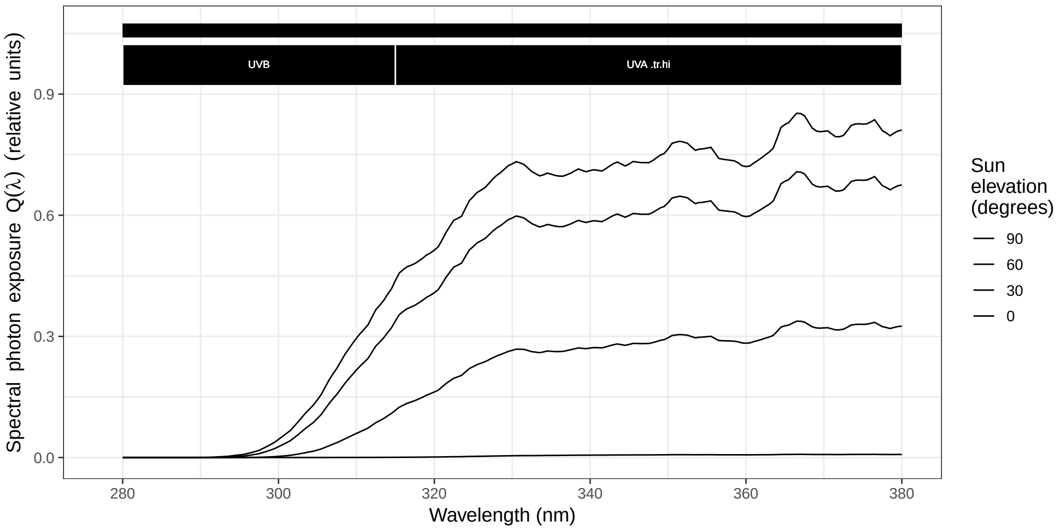


Although plotting the spectra as shown above illustrates the overall change in spectral composition, these plots are difficult to read. We will modify the previous figure expressing the irradiance at ground level as a fraction of the extraterrestrial one. There is a problem, though:

the spectra have different wavelength resolution, something that would lead to artifacts when ratios are computed. Consequently, we first smooth the spectra. We do this in separate steps for clarity.

```
tuv_smoothed.mspct <-
    msmsply(sun_tuv.mspct[spectra4elevations],
            smooth_spct, method = "supsmu")
extraterrestrial_smoothed.spct <-
    smooth_spct(sun_ET.spct,
                method = "supsmu")
sun_relative <-
    convolve_each(tuv_smoothed.mspct,
                  extraterrestrial_smoothed.spct,
                  oper = `/` )
sun_relative <-
    msmsply(sun_relative, setScaled, scaled = TRUE)
```

```
plot(sun_relative,
     range = c(280, 380),
     annotations = c("-", "peaks")) +
     scale_linetype(labels = the4elevations,
                    name = "Sun\nelevation\n(degrees)")
```



Computing summary quantities

Photon irradiance

```
irradiances.tb <-
    q_irrad(sun_tuv.mspct[spectra7elevations],
            w.band = list("UV-B" = UVB(), "UV-A" = UVA(), PAR = PAR()),
            scale.factor = 1e6)
```

```
irradiances.tb$elevation <- the7elevations

kable(irradiances.tb, digits = c(0, 2, 0, -1, 1))
```

spct.idx	UV-B	UV-A	PAR	elevation
tuv_zenith_00_O3_300	5.45	195	2220	90
tuv_zenith_15_O3_300	5.04	186	2130	75
tuv_zenith_30_O3_300	3.91	161	1880	60
tuv_zenith_45_O3_300	2.40	122	1480	45
tuv_zenith_60_O3_300	1.01	76	970	30
tuv_zenith_75_O3_300	0.19	31	420	15
tuv_zenith_90_O3_300	0.00	2	20	0

Biologically effective irradiance

```
be_irradiances.tb <-
    e_irrad(sun_tuv.mspct[spectra7elevations],
           w.band = list(GPAS = GEN_G(), PG = PG(), CIE98 = CIE()))

be_irradiances.tb$elevation <- the7elevations

kable(be_irradiances.tb, digits = 2)
```

spct.idx	GPAS	PG	CIE98	elevation
tuv_zenith_00_O3_300	0.45	1.67	0.30	90
tuv_zenith_15_O3_300	0.40	1.58	0.27	75
tuv_zenith_30_O3_300	0.29	1.31	0.20	60
tuv_zenith_45_O3_300	0.15	0.95	0.12	45
tuv_zenith_60_O3_300	0.05	0.55	0.05	30
tuv_zenith_75_O3_300	0.01	0.21	0.01	15
tuv_zenith_90_O3_300	0.00	0.01	0.00	0

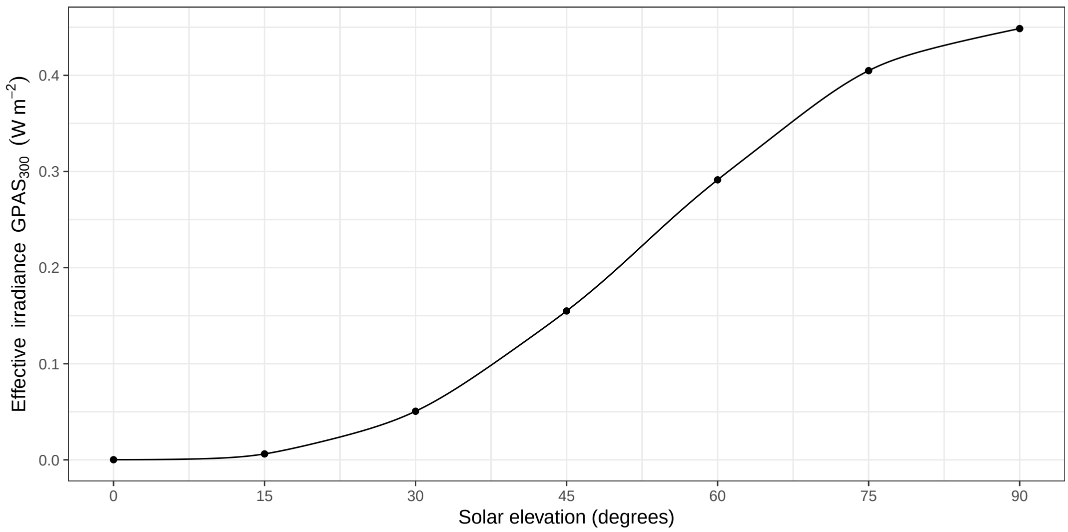
Or expressed as a fraction relative to the value for the sun at the zenith.

```
be_irradiances.tb %>%
  mutate(GPAS = GPAS / max(GPAS), PG = PG / max(PG), CIE98 = CIE98 / max(CIE98)) %>%
  kable(digits = 2)
```

spct.idx	GPAS	PG	CIE98	elevation
tuv_zenith_00_O3_300	1.00	1.00	1.00	90
tuv_zenith_15_O3_300	0.90	0.94	0.91	75
tuv_zenith_30_O3_300	0.65	0.79	0.69	60
tuv_zenith_45_O3_300	0.35	0.57	0.41	45
tuv_zenith_60_O3_300	0.11	0.33	0.17	30
tuv_zenith_75_O3_300	0.01	0.13	0.04	15
tuv_zenith_90_O3_300	0.00	0.01	0.00	0

We can also plot the values for one of the BSWFs, here GPAS.

```
ggplot(be_irradiances.tb, aes(x = elevation, y = GPAS)) +
    geom_point() +
    geom_xspline(spline_shape = -0.5) +
    scale_x_continuous(name = "Solar elevation (degrees)",
                       breaks = the7elevations) +
    scale_y_continuous(name =
        expression(Effective~~irradiance~~GPAS[300]~~(W~m^{-2})))
```

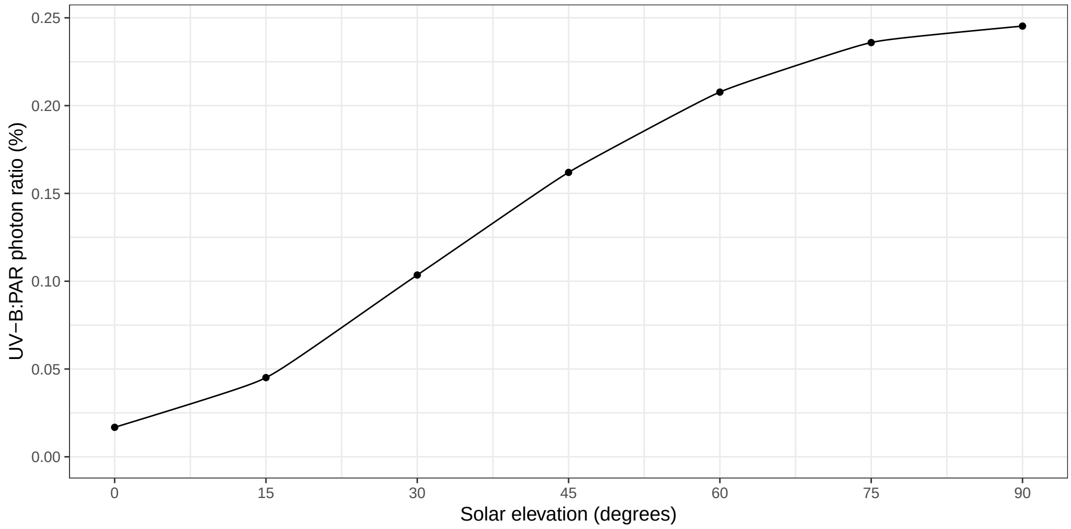


Photon ratio

```
uvb_par_ratio.tb <-
    q_ratio(sun_tuv.mspct[spectra7elevations],
           w.band.num = UVB(),
           w.band.denom = PAR())

head(uvb_par_ratio.tb)

## # A tibble: 6 x 2
##   spct.idx                `q_ratio_UVB.ISO:PAR(q:q)`
##   <fct>                                        <dbl>
## 1 tuv_zenith_00_03_300                       0.00245
## 2 tuv_zenith_15_03_300                       0.00236
## 3 tuv_zenith_30_03_300                       0.00208
## 4 tuv_zenith_45_03_300                       0.00162
## 5 tuv_zenith_60_03_300                       0.00104
## 6 tuv_zenith_75_03_300                       0.000451

uvb_par_ratio.tb$elevation <- the7elevations

names(uvb_par_ratio.tb)[2] <- "UV-B:PAR"
```



```
ggplot(uvb_par_ratio.tb,
       aes(x = elevation,
           y = `UV-B:PAR` * 100)) +
    geom_point() +
    geom_xspline() +
    scale_x_continuous(name = "Solar elevation (degrees)",
                       breaks = the7elevations) +
    scale_y_continuous(name = "UV-B:PAR photon ratio (%)", limits = c(0, NA))
```



Conclusions and caveats

Using the Quick TUV Calculator it is easy to obtain spectral data for clear-sky conditions. Including the effect of clouds is more difficult, as cloud depth data is rarely easily available. Having spectral data, as opposed to UVI or other summary data, allows the calculation of diverse derived quantities and summaries. Such calculations are best done using scripts to ensure reproducibility. The R packages in the R for photobiology suite aim at easing these computations while providing maximum flexibility. In the case of biologically effective exposures and irradiances, even for a single BSWF several alternative mathematical formulations are in use as well as different approaches to extrapolation. The defaults used in the 'photobiology' package differ from those used by the TUV model for the calculation of these values, which can result in apparent discrepancies. For example the formulation for GPAS in TUV is that of Micheletti which differs slightly from Green's formulation, but both of these differ quite much from Thimijan's formulation (see Aphalo et al. 2012, for details, equations and original references).

Supplementary material

File `QTUV-video.mp4`: An instructional video on how to use the Quick TUV web interface is provided to help new users. File `QTUV-notebook.html`: An R notebook with additional code examples and their output, viewable with a web browser. The embedded source code can be most easily accessed and edited using RStudio. File `QTUV-simulations.Rda`: Spectral data generated with Quick TUV Calculator, imported into R and re-saved as R objects.

The *R notebook* file contains worked out examples of reading into R several spectra downloaded from the Quick TUV site, plotting these spectra, their manipulation and the calculation of summary quantities. The HTML file contains brief text explanations, readable code listings and the rendered output. The actual source file used to produce the HTML file is embedded and can be extracted, modified and reused.

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Editorial-board-reviewed article.
Published on-line on 2018-12-27.
Edited by: Titta Kotilainen.

UV4Plants

Bulletin
2018: 2

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ISSN 2343-323X