# Using R for photobiological calculations

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https://www.r4photobiology.info/

## 1. Introduction

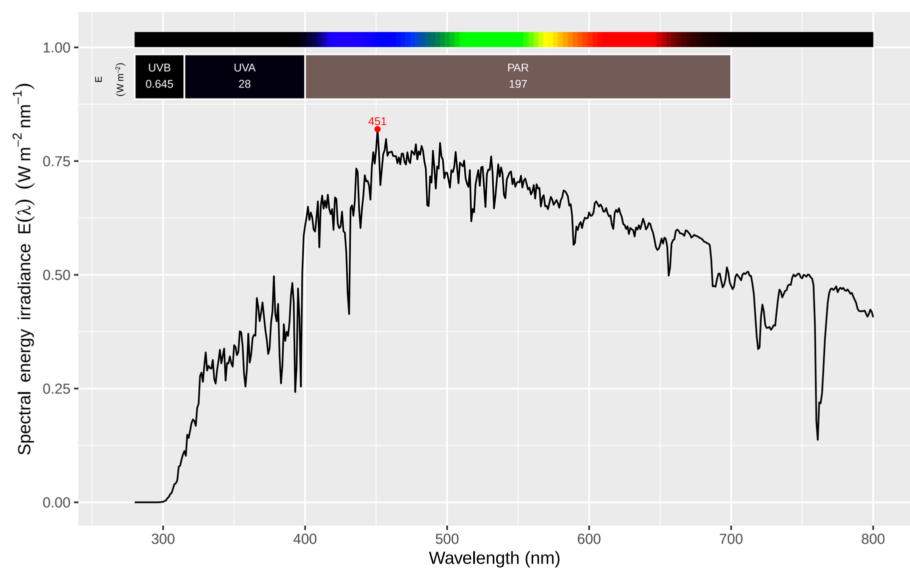
- Here I showcase my R packages for photobiology.
- In the examples I also use data included in them.
- Several of the packages contain only data.
- Most of the packages are published in the CRAN repository, open-source and regularly updated.

| Repository | Package | Type | Contents |
|---|---|---|---|
| CRAN | photobiology | funs + classes | functions, class definitions and methods |
| CRAN | photobiologyInOut | functions | data import/export |
| CRAN | photobiologyWavebands | definitions | quantification of radiation |
| CRAN | ggspectra | methods | plotting of spectral data |
| CRAN | photobiologySun | data | solar and daylight |
| CRAN | photobiologyLamps | data | emission by light bulbs |
| CRAN | photobiologyLEDs | data | emission by LEDs |
| CRAN | photobiologyFilters | data | transmission of filters |
| CRAN | photobiologySensors | data | response of sensors |
| Bitbucket | photobiologyReflectors | data | reflection by materials |
| CRAN | photobiologyPlants | funs + data | plants' responses |
| Bitbucket | rOmniDriver | driver API | Ocean Optics spectrometers |
| Bitbucket | ooacquire | data acquistion | Ocean Optics spectrometers |

## 2. Plotting spectra

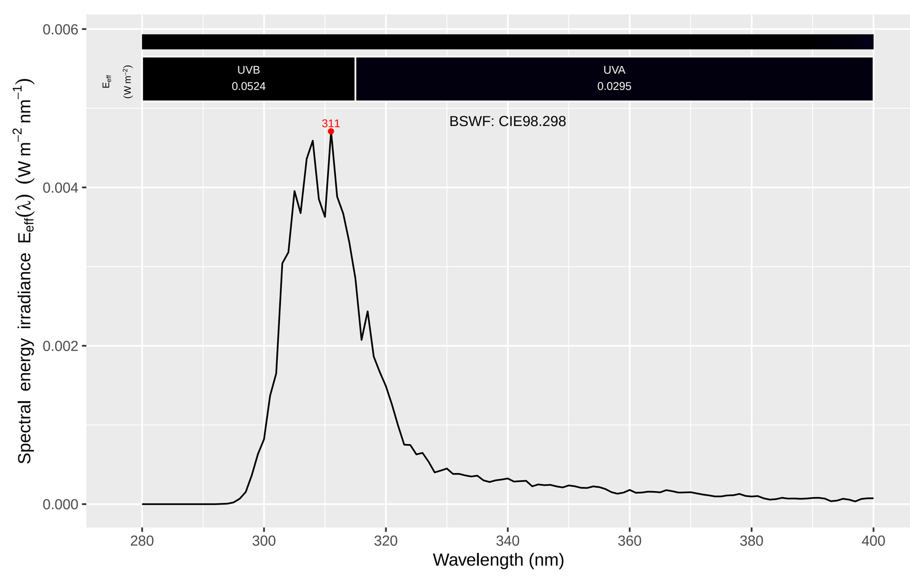
Units used when data is stored are consistent, and saved as metadata allowing their propagation to plot axis-labels and annotations.

```
autoplot(sun.spct)
```



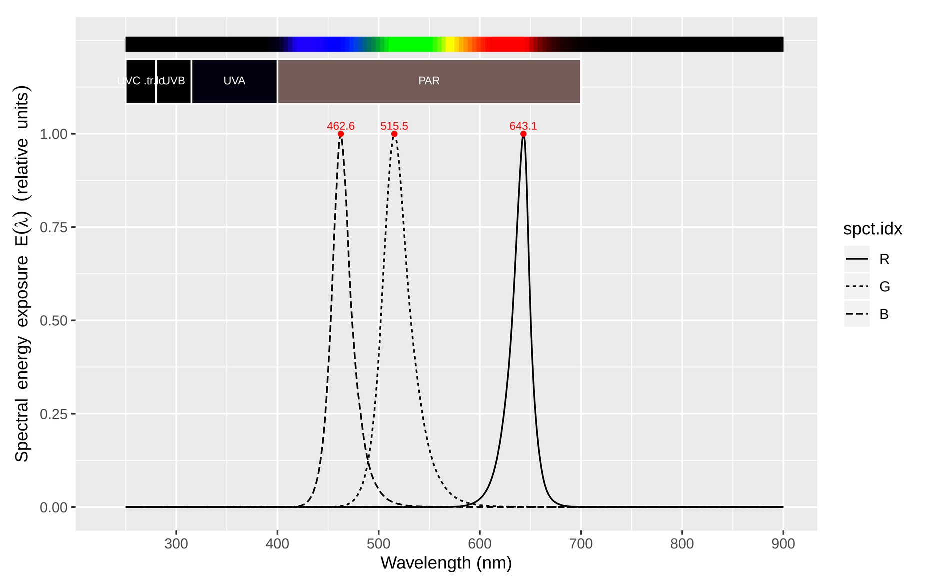

We convolute a radiation spectrum by multiplication with a weighting function.

```
autoplot(sun.spct * CIE())
```



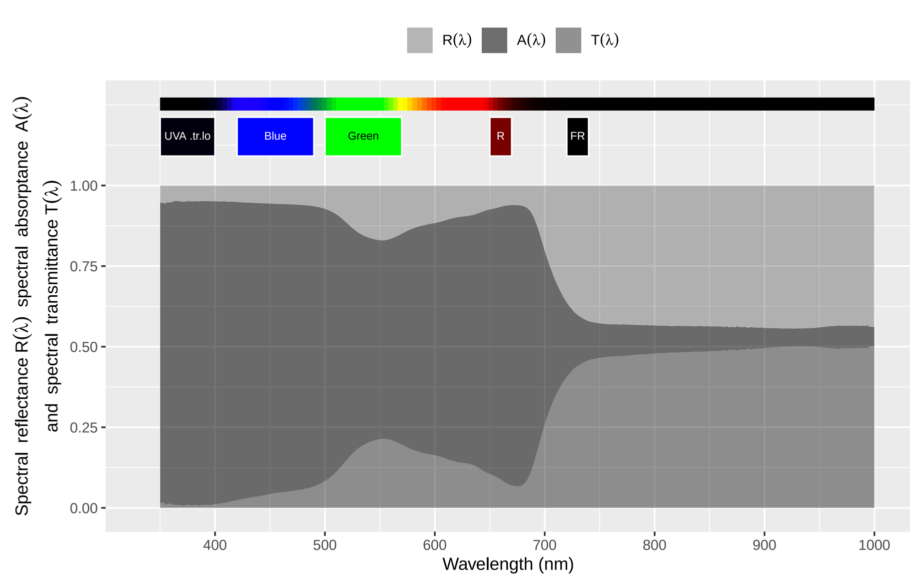

Normalized spectral photon irradiance for the three channels of a LED array.

```
my.leds <- leds.mspct[c("NHXRGB090_R", "NHXRGB090_G", "NHXRGB090_B")]
names(my.leds) <- c("R", "G", "B")
autoplot(normalize(my.leds))
```




Spectral transmittance and reflectance for a leaf, with annotations corresponding to wavebands of interest in plant biology.

```
autoplot(Solidago_altissima.mspct$lower_adax, w.band = Plant_bands()) +
  theme(legend.position = "top")
```




## 3. Irradiance

In this section we show examples of the calculation of energy and photon (quantum) irradiance, both weighted and unweighted, and for the whole spectrum or individual regions.

```
e_irrad(sun.spct)

##    Total
## 269.1249
## attr(,"time.unit")
## [1] "second"
## attr(,"radiation.unit")
## [1] "energy irradiance total"
```

```
e_irrad(sun.spct, CIE())

##  CIE98.298.tr.lo
##       0.08181583
## attr(,"time.unit")
## [1] "second"
## attr(,"radiation.unit")
## [1] "energy irradiance total"
```

```
e_irrad(sun.spct, VIS_bands())

##  Purple.ISO    Blue.ISO   Green.ISO  Yellow.ISO  Orange.ISO     Red.ISO
##    47.75529    37.55207    49.26860    13.67971    12.00432    79.38159
## attr(,"time.unit")
## [1] "second"
## attr(,"radiation.unit")
## [1] "energy irradiance total"
```

In the packages, S.I. units without 'multipliers' are used for radiation quantities. In this case we multiply the returned value, which is expressed in $\mathrm{mol\,m^{-2}\,s^{-1}}$, by $10^6$ to obtain the more familiar units $\mathrm{\mu mol\,m^{-2}\,s^{-1}}$.

```
q_irrad(sun.spct, PAR()) * 1e6

##      PAR
## 894.1352
## attr(,"time.unit")
## [1] "second"
## attr(,"radiation.unit")
## [1] "photon irradiance total"
```

## 4. Fluence

```
fluence(sun.spct, exposure.time = duration(12, "minutes"))

##    Total
## 193769.9
## attr(,"radiation.unit")
## [1] "energy fluence (J m-2)"
## attr(,"exposure.duration")
## [1] "720s (~12 minutes)"
```

## 5. Ratios

Photon ratios can be calculated for any pair of arbitrary regions of the spectrum. Here we use predefined wavebands, but the user can easily define new ones as needed.

```
q_ratio(sun.spct, UVB(), PAR())

##  UVB.ISO: PAR(q:q)
##        0.001873724
## attr(,"radiation.unit")
## [1] "q:q ratio"
```

Light source spectra can be convoluted with transmittance spectra as a simple multiplication operation. Interpolation is automatic when the wavelength values are not matched between the two spectra.

```
q_ratio(sun.spct * polyester.spct, UVB(), PAR())

##  UVB.ISO: PAR(q:q)
##       5.142362e-05
## attr(,"radiation.unit")
## [1] "q:q ratio"
```

For R:FR ratio a convenience function is available.

```
R_FR(sun.spct)

##  Red.Smith10: FarRed.Smith10(q:q)
##                          1.266704
## attr(,"radiation.unit")
## [1] "q:q ratio"
```

Photon : energy ratios are also easily calculated. As the result is in $\mathrm{mol\,J^{-1}}$ we multiply it by $10^6$ to obtain $\mathrm{\mu mol\,J^{-1}}$.

```
qe_ratio(sun.spct, list(Blue(), Red())) * 1e6

## q:e( Blue.ISO)  q:e( Red.ISO)
##       3.968591       5.682783
## attr(,"radiation.unit")
## [1] "q:e ratio"
```

## 6. Collections of spectra

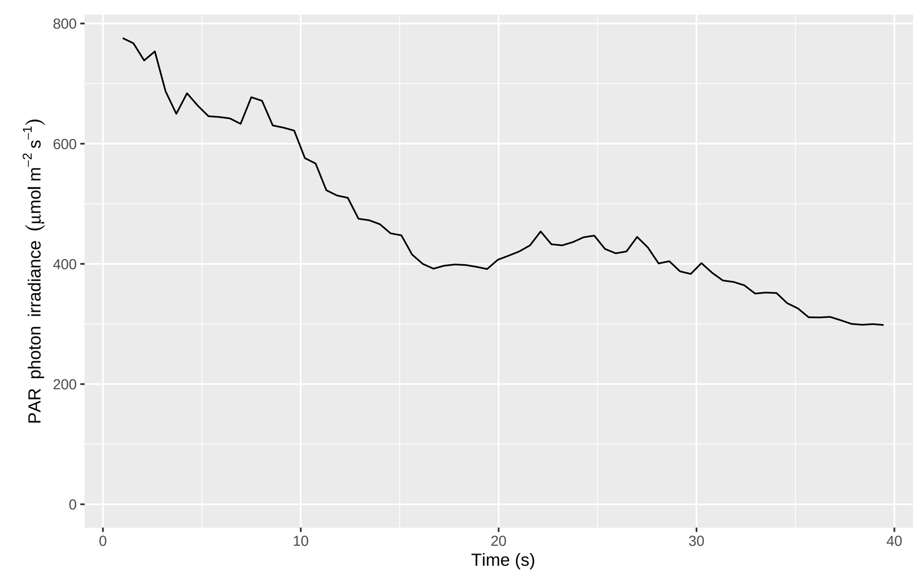
Collections of spectra, can be used to store groups of related spectra. Here we compare some Schott filters.

```
my.filters <- filters.mspct[intersect(schott_filters, uv_filters)]
summ.tb <- transmittance(my.filters, UV_bands())
# shorten column names
colnames(summ.tb) <- gsub("transmittance", "Tfr", colnames(summ.tb))
summ.tb

## # A tibble: 8 x 4
##   spct.idx       Tfr_UVC.ISO.tr.lo Tfr_UVB.ISO Tfr_UVA.ISO
##   <fct>                      <dbl>       <dbl>       <dbl>
## 1 Schott_UG1            NA               0.153       0.659
## 2 Schott_UG5             0.540           0.957       0.924
## 3 Schott_UG11            0.150           0.851       0.694
## 4 Schott_N_WG280         0.0742          0.795       0.986
## 5 Schott_N_WG295         0.00266         0.529       0.978
## 6 Schott_N_WG305         0.0000290       0.305       0.961
## 7 Schott_N_WG320         0.0000100       0.0533      0.887
## 8 Schott_UG2A            NA               0.0472      0.660
```

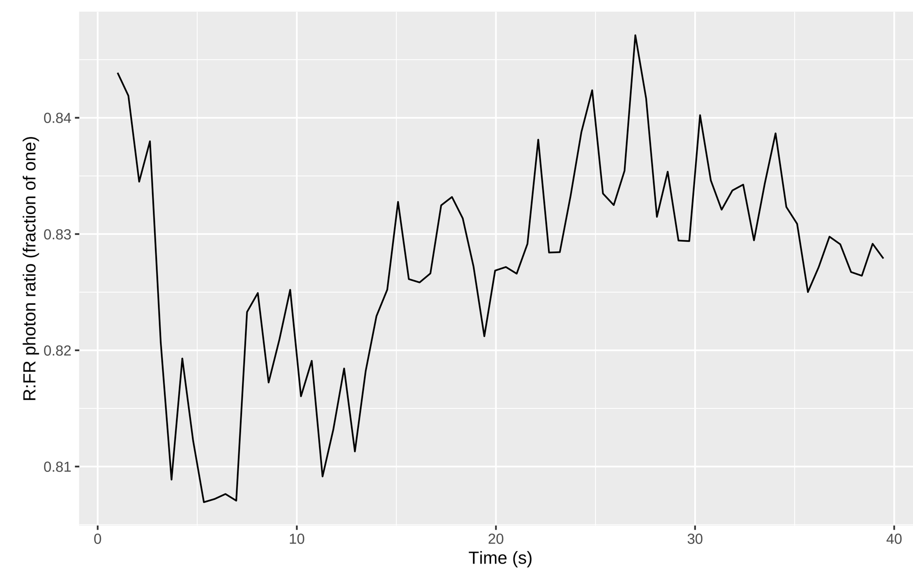
Collections of spectra can be also used to store time series of spectral measurements. We next use a time series of spectra measured with an array spectrometer in April in Helsinki, under silver birch trees. In this we use R package ggplot2 for plotting the summaries against time.

```
ppfd.df <- q_irrad(gap.mspct, PAR())
ppfd.df$time <- seq(from = 1, by = attr(gap.mspct, "time.step"),
                    length.out = nrow(ppfd.df))
ggplot(ppfd.df, aes(time, q_irrad_PAR * 1e6)) +
  geom_line() + ylim(0, NA) +
  labs(x = "Time (s)",
       y = expression(PAR~~photon~~irradiance~~(mu*mol~m^{-2}~s^{-1})) )
```




The time course of red:far-red photon ratio for the same time series of spectra.

```
R_FR.df <- q_ratio(gap.mspct, Red("Smith10"), Far_red("Smith10"))
names(R_FR.df)[2] <- "R_FR"
R_FR.df$time <- seq(from = 1, by = attr(gap.mspct, "time.step"),
                    length.out = nrow(R_FR.df))
ggplot(R_FR.df, aes(time, R_FR)) +
  geom_line() +
  labs(x = "Time (s)",
       y = "R:FR photon ratio (fraction of one)")
```




## 7. Photoreceptors

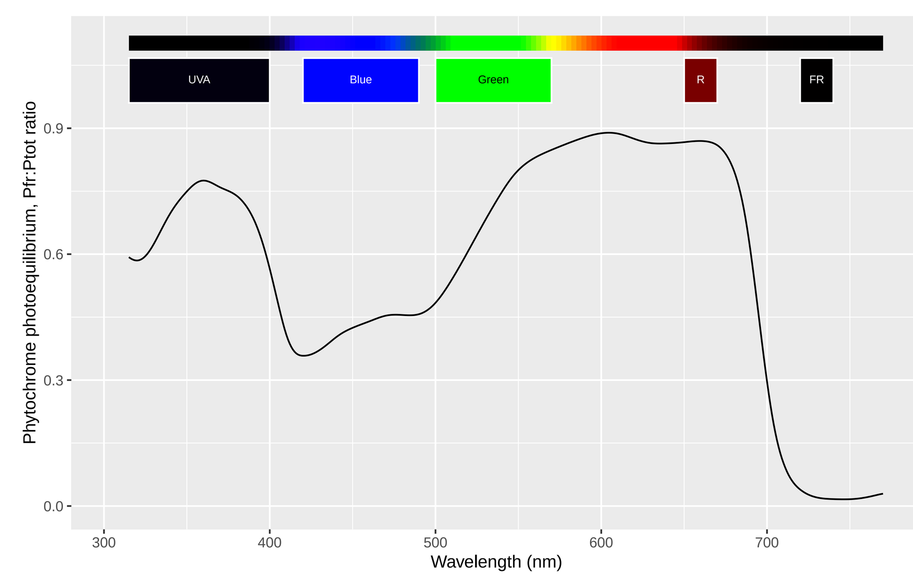
Phytochrome photoequilibrium from spectral data.

```
Pfr_Ptot(sun.spct)

## [1] 0.68341
```

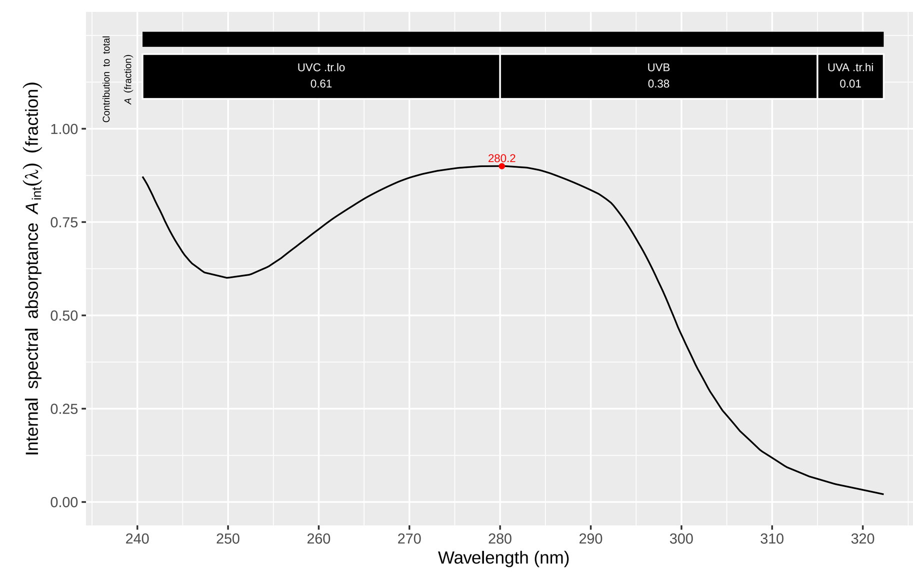
Plot of Pfr:Ptot as a function of wavelength (nm) of monochromatic light.

```
autoplot(Pfr_Ptot(315:770), norm = NULL, unit.out = "photon",
         w.band = Plant_bands(),
         annotations = c("colour.guide", "labels", "boxes")) +
  labs(y = "Phytochrome photoequilibrium, Pfr:Ptot ratio")
```




The absorptance spectrum of uvr8.

```
autoplot(UVR8s.mspct[[1]], plot.qty = "absorptance")
```




## https://www.r4photobiology.info/

More information is available at https://www.r4photobiology.info/ where installation instructions, documentation and announcements of updates are published. Each package includes one or more user guides and help pages containing additional examples and explanations.

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