UV measurements: The Basics

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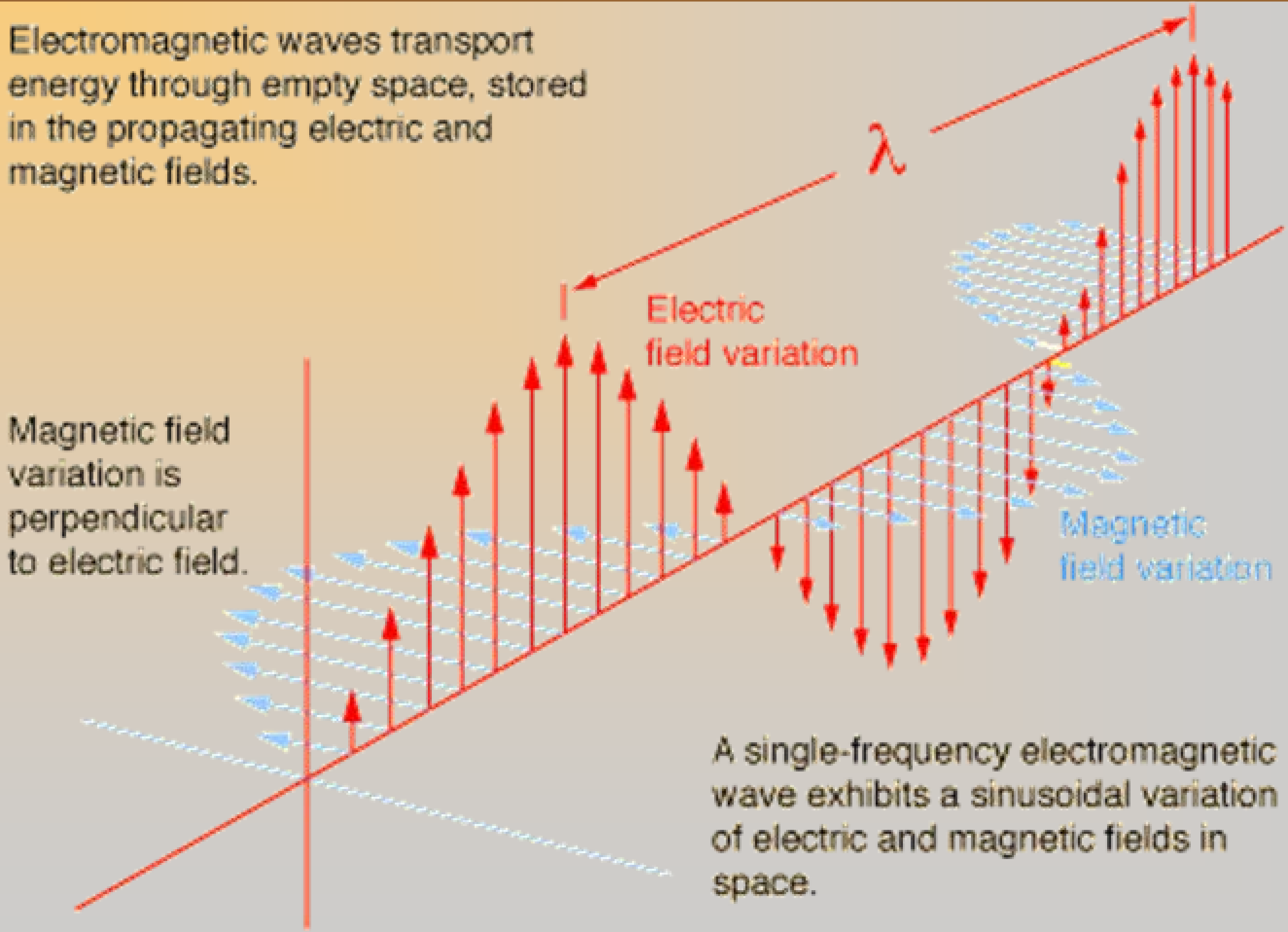
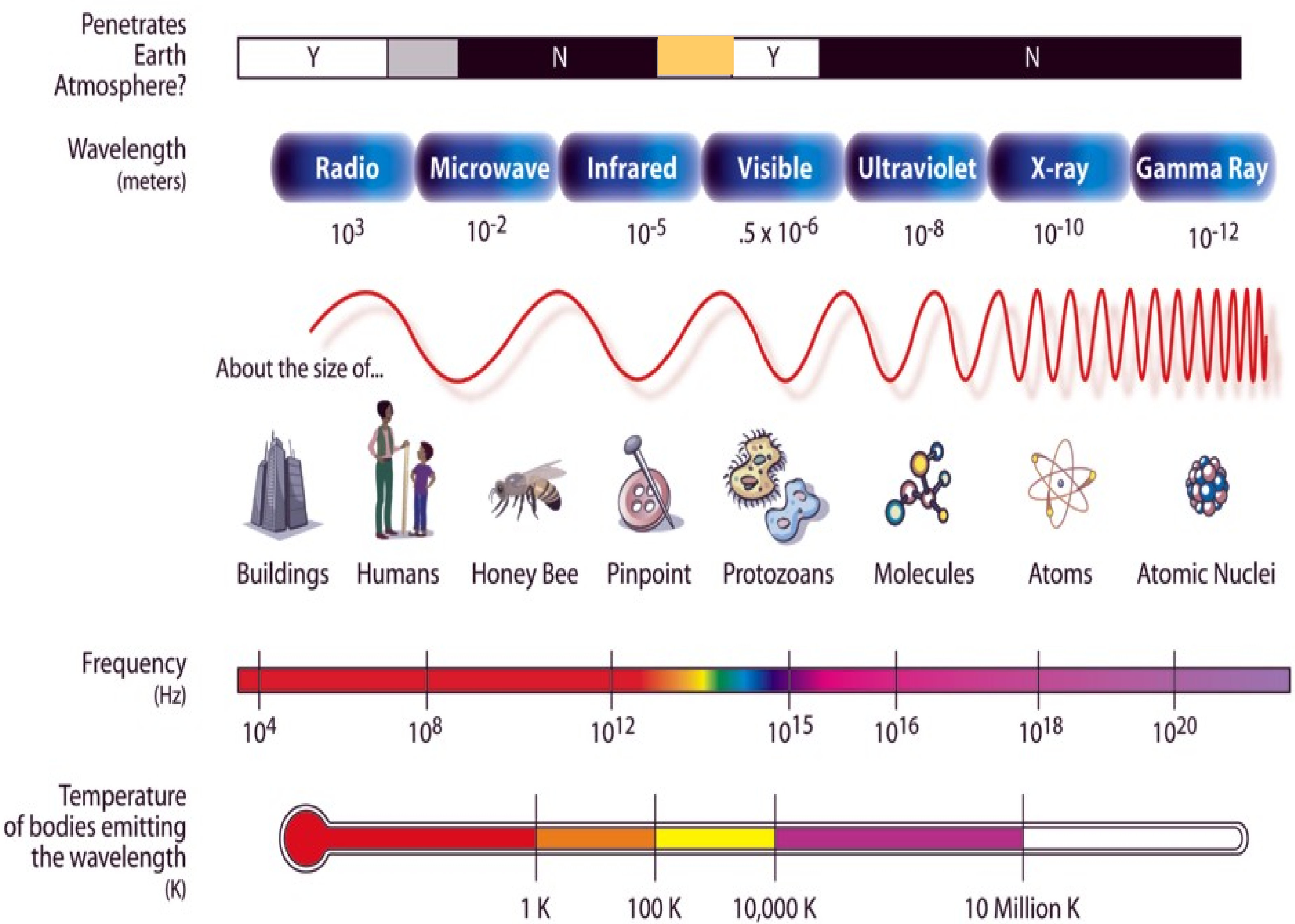
Electromagnetic Waves



THE ELECTROMAGNETIC SPECTRUM



Courtesy of NASA

Definitions of UV

Near UV

- UVA 315 – 400 nm (CIE) Blacklight
- UVB 280 – 315 nm
- UVC 200 - 280 nm Germicidal

- Far / Vacuum 10 – 200 nm (FUV, VUV)
- Extreme, Deep UV 1 – 31 nm

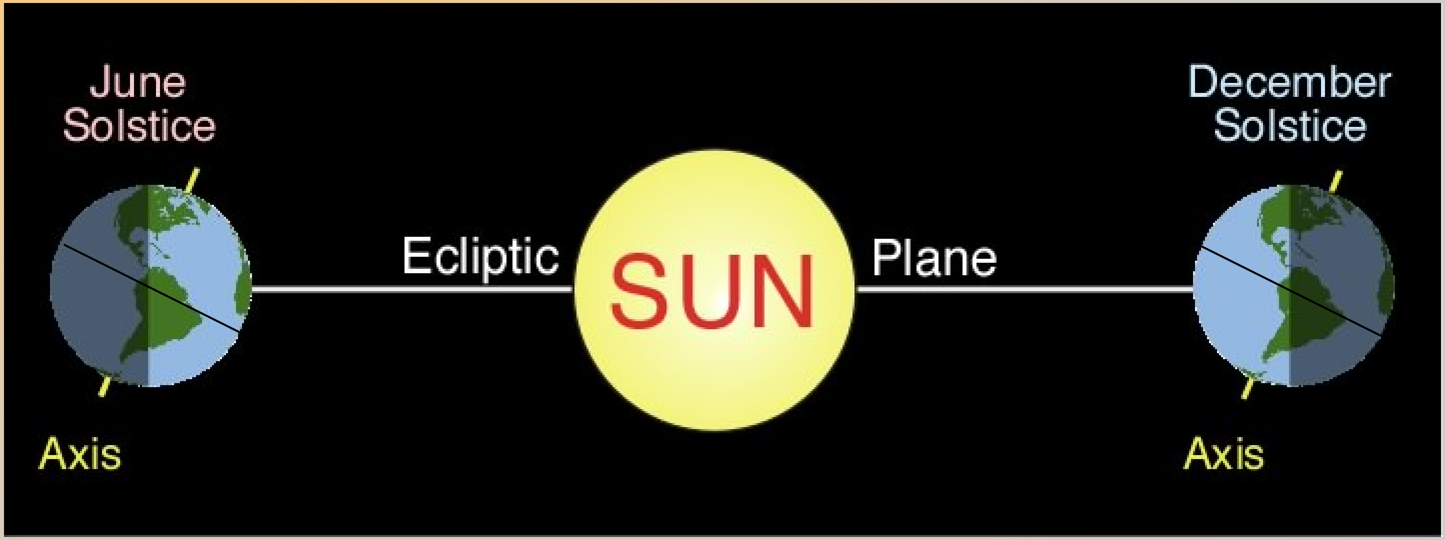
Solar UV

- The sun is the natural source of UV radiation to which we are all exposed.
- It is unlikely that you would be exposed to other sources of UV in daily life, unless you so choose (eg sunbed)
- Measuring solar UV is a challenge for many reasons

Changing solar zenith angle

- APPARENTLY:
- The sun rises, reaches a high point, and sets each day.
- Sunrise is latest, the high point lowest and sunset earliest in winter.
- Sunrise is earliest, the high point highest and sunset latest in summer.
- How early /late /high /low depends on latitude.

Astronomical Factors



Analemma – a picture of the sun taken at the same time each day.

N-S change in solar declination gives length of pattern.

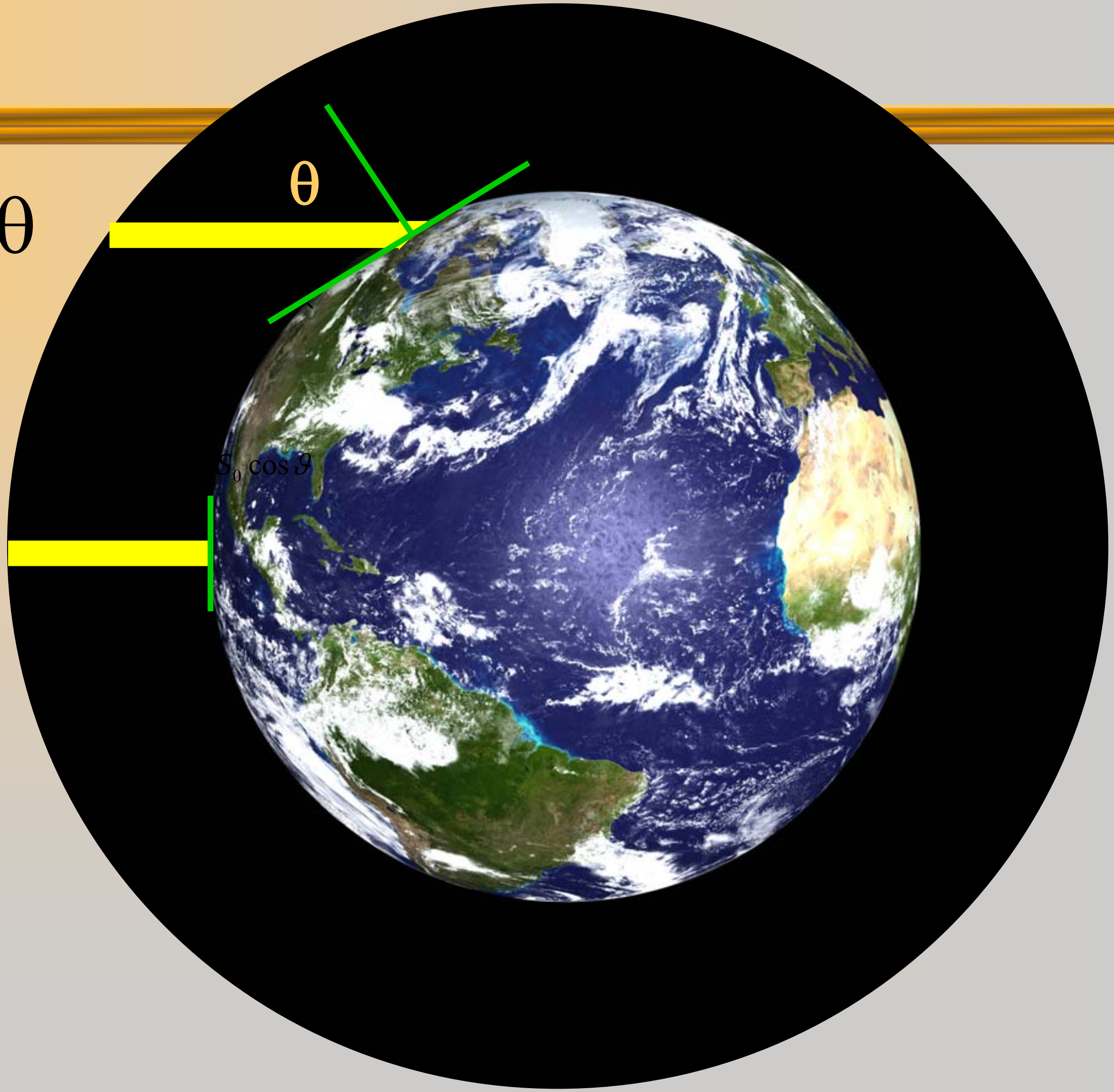
Difference of clock – solar time gives width of pattern.

Uneven loops due to elliptical orbit of sun.

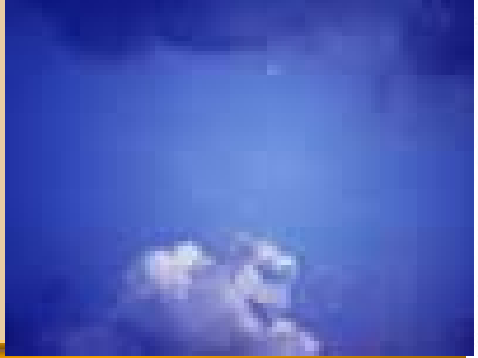
Effects of SZA

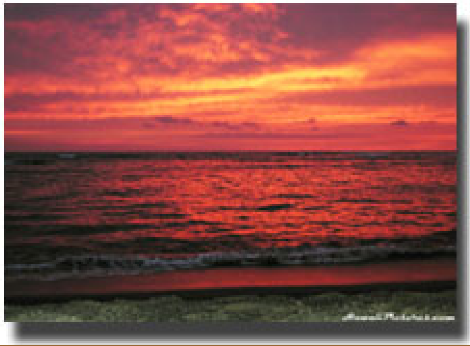
$$S = S_0 \cos \theta$$

Plus, the radiation has to travel a longer pathlength through the atmosphere, leading to more attenuation due to absorption and scattering.



Scattering



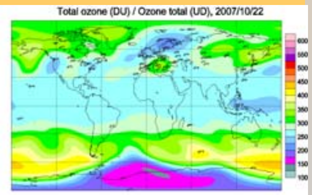


- Total solar radiation = Direct + Diffuse
- Diffuse radiation has been scattered out of the direct beam.
- Rayleigh scattering $\alpha\ \lambda^{-4}$ (½ ↓ and ½ ↑)
- Radiation at 300 nm is scattered ~3 times more than radiation at 400 nm
- Thus, as wavelength decreases more radiation is lost to back scattering, and more reaches the surface as diffuse. The direct beam is diminished.

Sun photographed in the UV, 300-400nm

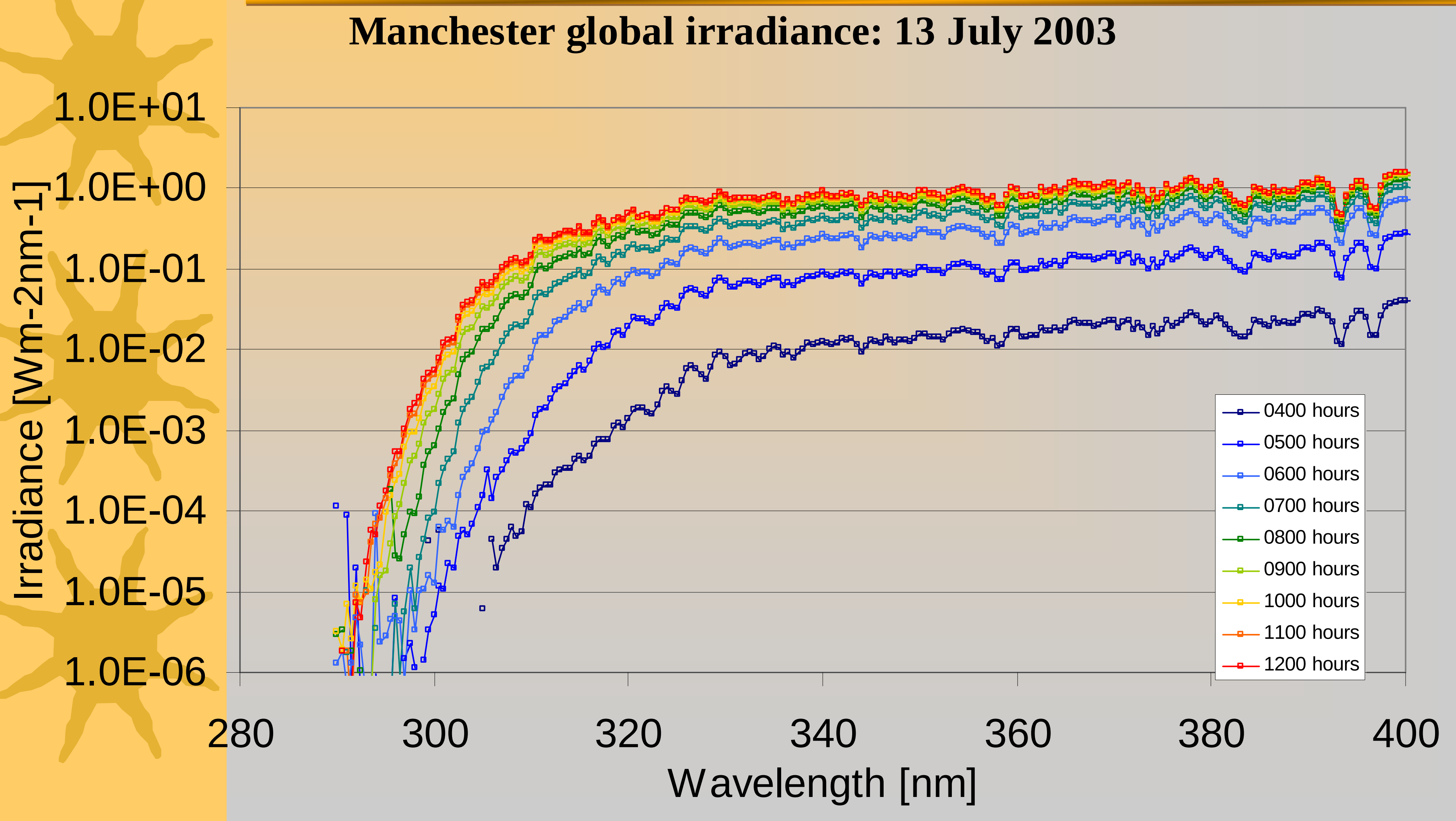
Sun photographed in the visible, 400-700nm

Other attenuators



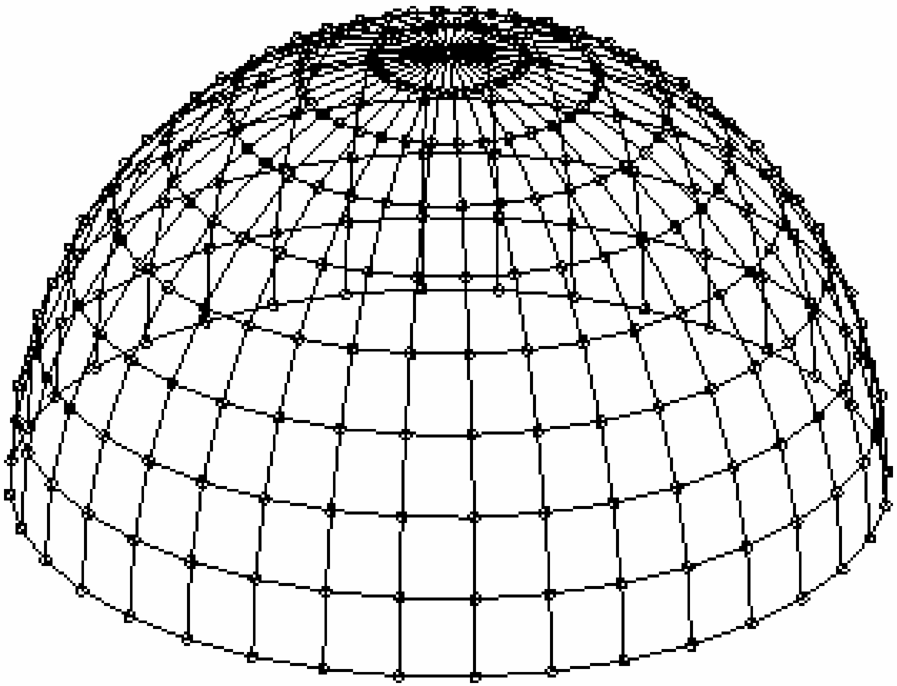
- Aerosol, natural and man made. May have selective absorption, but mainly Mie scattering (forward).
- Cloud. Acts as a neutral density filter but can have some spectral effects. Transient, variable and difficult to define.
- Ozone, a strong absorber in the UV. Prevents UVC and much of UVB from reaching the surface. Day to day variability and seasonal cycles.

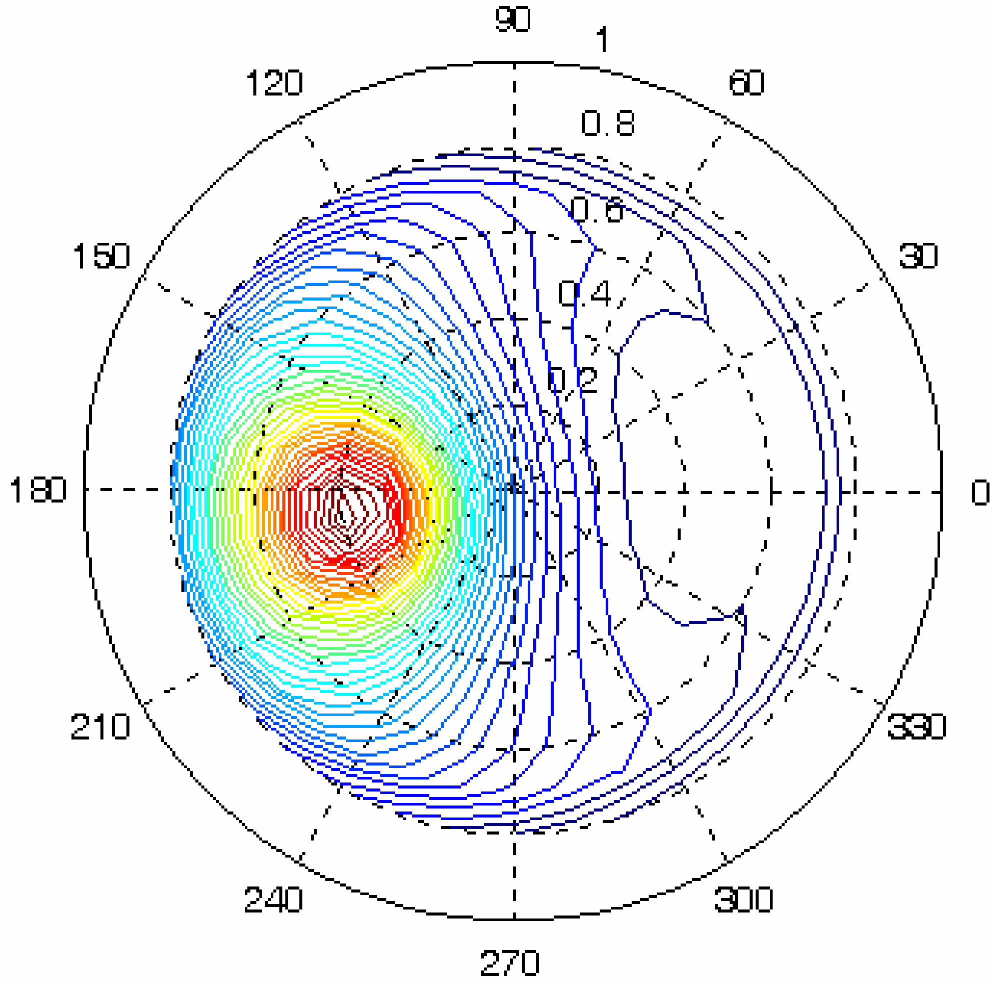
Solar spectrum at the surface



Radiance distribution

- i.e where in the sky the radiation is coming from – this changes as well!




90
1
120
60
0.8
0.6
150
30
0.4
0.2
180
0
210
330
240
300
270

Radiance distribution

- It differs with wavelength
- It changes with SZA (and azimuth) - direct:diffuse is greatest at solar noon, and by sunset virtually all the short wavelength radiation is diffuse.
- Also changed by cloud and aerosol.
- Can be important when comparing measurements, and for some applications.

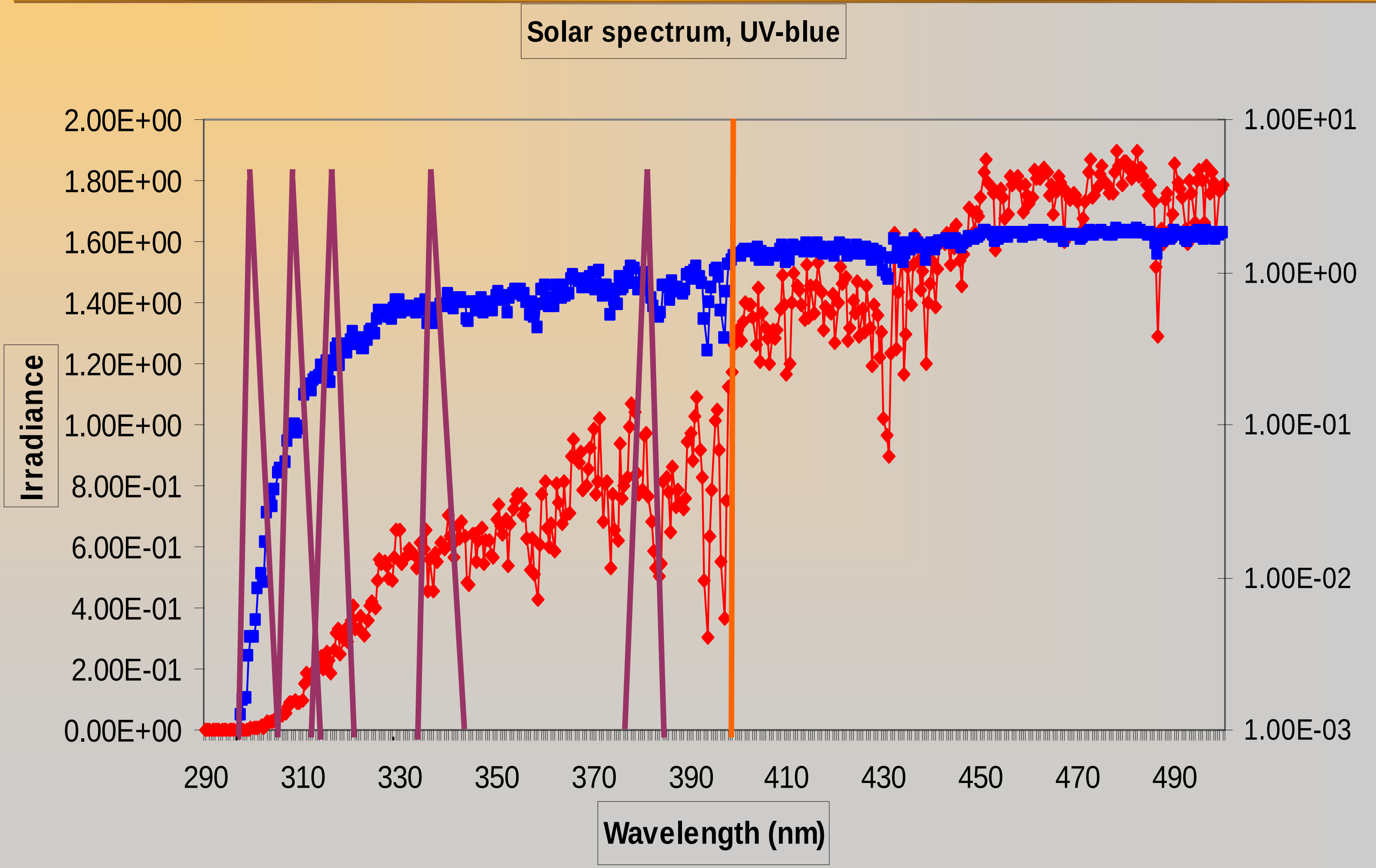
How do we measure solar UV?

- Depends what you want to know (why you are doing the measurement), and the practicalities of the measurement situation.

The basic options

- Spectroradiometer
- Broadband radiometer
- Dosimeter
- Multiband radiometer (hybrid of spectroradiometer and broadband radiometer)

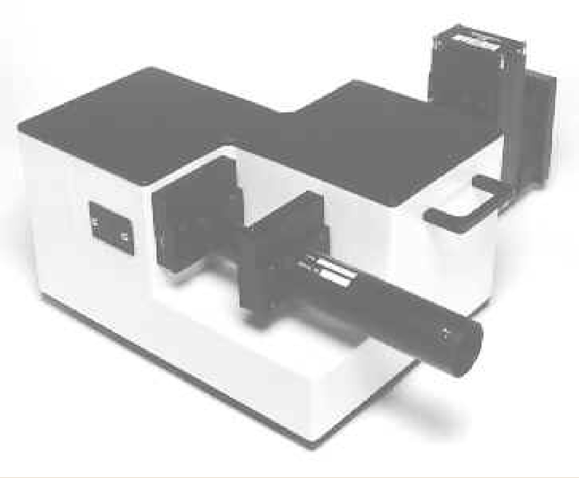
The options illustrated



Spectroradiometer

- Separates radiation into component wavelengths, measures each. Double monochromator recommended for UV
- Scanning (PMT detector) – slow
- OR diode array – fast, but beware stray light at short wavelengths, also need several integration times to cover UV
- ADVANTAGE – multi-purpose spectral data

Spectroradiometer



Needs power, computer control, (usually) temperature stabilisation, (usually) remote input optics

Broadband radiometers

- A single measurement representing the waveband covered by the instrument spectral response function.
- For solar UV this is most commonly the erythemal action spectrum (or approximation)
- $V = k \int E_\lambda A_\lambda \, d\lambda$

Pros and cons

- Small, robust, no moving parts, simple
- How close is response spectrum to desired action spectrum?
- $V = k\int E_\lambda A_\lambda \, d\lambda$ but E_λ not a constant spectral shape – errors unless calibration adjusted for SZA (and O_3).

Multi filter radiometers

- Operation similar to a broadband radiometer
- Larger unit measuring several narrow wavebands (typically 10nm) by using a collection of filters/detectors within one unit
- Rapid, coarse spectrum

Multifilter radiometer and solarimeter at UMIST

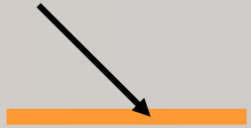
Dosimeters

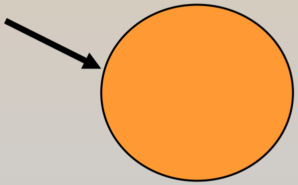
- Measure the total dose received
- Small (eg badge)
- Can involve significant post-analysis
- Most common approximate erythemal action spectrum (polysulphone film, viospor)
- Others based directly on biological effects eg DNA damage, vitamin D synthesis

Common feature

- Input optics / field of view

$$E(\lambda)=\int_0^{2\pi}\int_0^{\pi/2} L(\lambda,\theta,\phi)\cos\theta\sin\theta\, d\theta\, d\phi$$





$$F(\lambda)=\int_0^{2\pi}\int_{-\pi/2}^{\pi/2} L(\lambda,\theta,\phi)\sin\theta\, d\theta\, d\phi$$

Instruments and input optics

- Broadband and multifilter instruments have the input optics as an integral part of the instrument. Generally measure irradiance (E), either global, or diffuse if a shade ring / disc is employed.
- Spectroradiometers frequently use a fibre optic to connect input optics to detector, giving more flexibility to change input optics

More on input optics

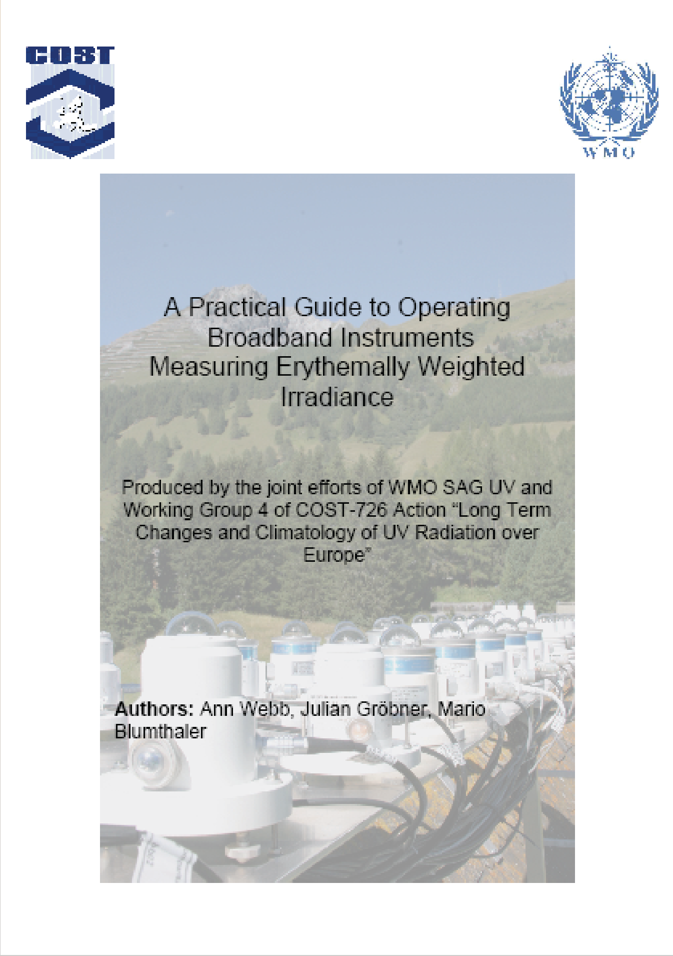
- Imperfect cosine response can be corrected for (at least partially) if the actual angular response is known.
- Field of view can be restricted (eg some dosimeters). Relevance depends on application
- Direct solar beam measurements can be made with narrow FOV (eg 1-3^{o}) and a sun tracker, as can radiance measurements.

Site selection

- Unobstructed view over half hemisphere (ideally). At least free of shadow.
- Map horizon and calculate loss
- Beware reflective surfaces
- Consider access, health and safety
- Security, power

Maintenance

- Check and clean input optics
- Change dessicant (if used)
- Check time on logging system
- Check levelling
- Check sun siting / shade ring
- See COST/WMO guide for broadband instruments



All instruments require calibration

Standard of spectral irradiance

↓

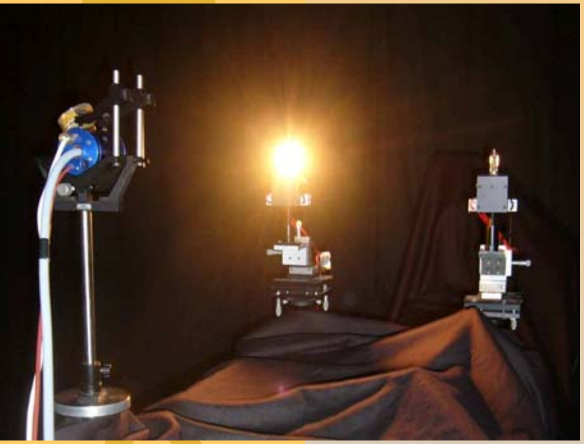
Spectroradiometer

↓

Broadband / multi-filter / dosimeter (sun as source) cf. spectroradiometer

↓

Same type calibration or intercomparison
(eg broadband – broadband, sun as source)



Summary – the sun (terrestrial view)

- Moving source
- Not constant (intensity or spectrally)
- Secondary source (diffuse)
- Radiance distribution changes
- Transient, short time scale, unpredictable changes superimposed on predictable cycles and (?) longer term trends that can be location specific.

Summary – solar UV measurement

- Spectroradiometer – very versatile data, but large instrument requiring power and associated computer, slow, needs a lot of attention. (Diode arrays smaller and faster) With careful operation has the lowest uncertainty.
- Broadband radiometer – smaller, more robust, still needs logger/power. Less versatile but (in principle) easier to use. Considerable effort needed for good data.

Summary – solar UV measurement

- Multifilter radiometer – some spectral information gives a degree of versatility. Operational advantages of BBR, but similar disadvantages are multiplied.
- Dosimeter – restricted information, but with small size, no power and no logger can be used where other instruments would be impossible. Biodosimeters give biological action spectrum exactly.