Solar_single_photon_source

June 7, 2019

1 Solar single photon source

- What photon rate ($\dot{N}$) do we see from solar irradiation?
- Is it possible to bandpass solar irradiation to such a degree to achieve similar specifications (i.e. $\dot{N} = 1$ MHz $\equiv 1$ photon/μs) to a single photon source?
- What is the best wavelength to do this at?

1.1 Theory

$$I = \frac{P}{A} \tag{1}$$

$$A = \frac{\pi d^2}{4} \tag{2}$$

$$P = \frac{E}{t} = \frac{Nhc}{\lambda t} = \frac{\dot{N}hc}{\lambda} \tag{3}$$

$$\therefore\ I = \frac{4\dot{N}hc}{\pi d^2 \lambda} \tag{4}$$

$$\therefore\ \dot{N} = \frac{I\pi d^2 \lambda}{4hc} \tag{5}$$

The solar irradiance spectrum is typically referred to as *Air Mass 1.5*, or *AM1.5*, which is available online (data taken from here).

$$\dot{N}(\lambda) = \frac{\pi d^2}{4hc} I(\lambda)\lambda \tag{6}$$

Taking the photon rate from within a given bandpass filter (centre wavelength λ_0, FWHM $\Delta\lambda$):

$$\dot{N}_{\Delta\lambda} = \frac{\pi d^2}{4hc} \int_{\lambda_0 - \frac{\Delta\lambda}{2}}^{\lambda_0 + \frac{\Delta\lambda}{2}} I(\lambda)\lambda \partial\lambda \tag{7}$$

Assuming that $I(\lambda) \approx$ const. over the range $\Delta\lambda$:

$$
\begin{aligned}
\dot{N} &= \frac{\pi d^2}{4hc} \int_{\lambda_0 - \frac{\Delta\lambda}{2}}^{\lambda_0 + \frac{\Delta\lambda}{2}} I(\lambda)\lambda \partial\lambda && (8) \\
&\approx \frac{I_0 \pi d^2}{4hc} \int_{\lambda_0 - \frac{\Delta\lambda}{2}}^{\lambda_0 + \frac{\Delta\lambda}{2}} \lambda \partial\lambda && (9) \\
&= \frac{I_0 \pi d^2}{4hc} \left[\frac{\lambda^2}{2} \right]_{\lambda_0 - \frac{\Delta\lambda}{2}}^{\lambda_0 + \frac{\Delta\lambda}{2}} && (10) \\
&\vdots && (11) \\
&= \frac{I_0 \lambda_0 \Delta\lambda \pi d^2}{4hc} && (12)
\end{aligned}
$$

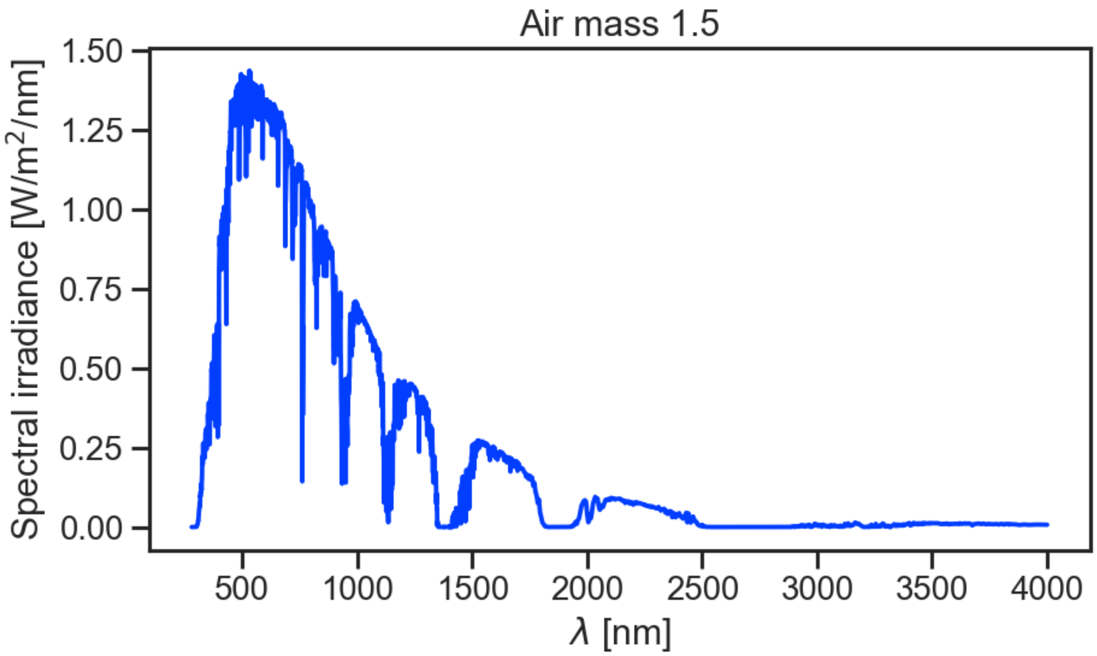
In [1]:
```
from numpy import *
from matplotlib.pyplot import *
from seaborn import *

set_palette('bright')
set_context('talk')
set_style('ticks')
```

In [2]:
```
rcParams['figure.figsize'] = [8,5]
rcParams['figure.dpi'] = 120
```

1.2 Import data

In [3]:
```
lambdas, _, _, solar_irradiance = genfromtxt(
    'ASTMG173.csv',
    delimiter=',', skip_header=2, unpack=True
)
```

In [4]:
```
plot(lambdas, solar_irradiance)

xlabel('$\lambda$ [nm]')
ylabel('Spectral irradiance [W/m$^2$/nm]')
title('Air mass 1.5')
tight_layout()
show()
```

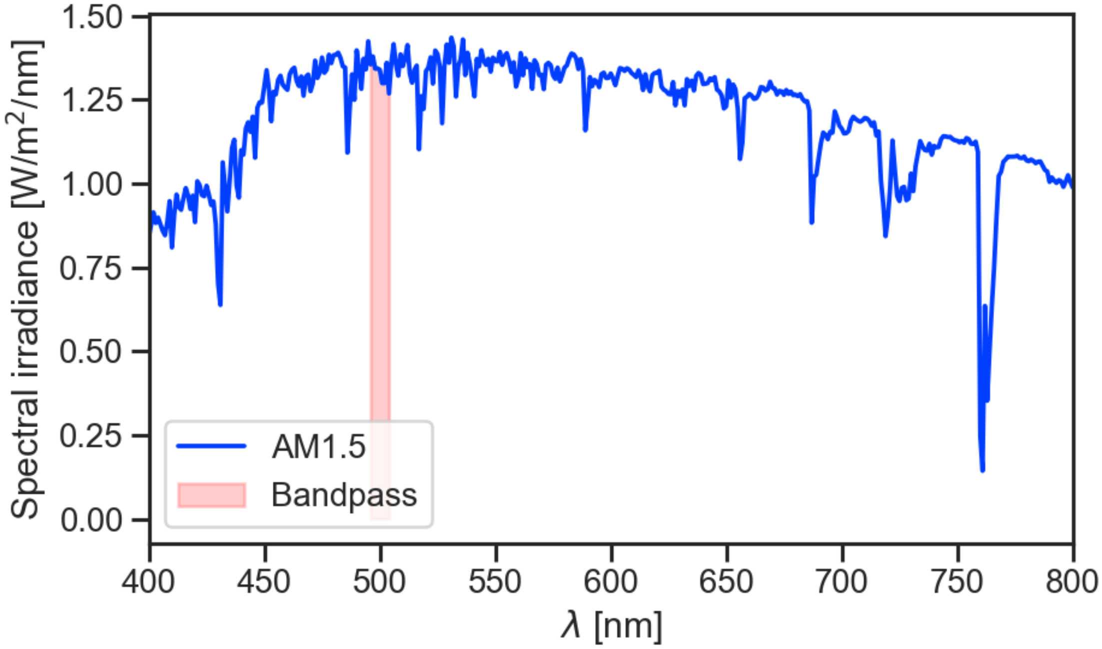


1.3 Spectral irradiance

In [5]:
```
h = 6.626e-34 # [J.s]
c = 3e8 # [m/s]
d = 1e-2 # [m]

# bandpass filter
lambda_0 = 500 # [nm] --- centre wavelength
delta_lambda = 10 # [nm] --- FWHM
```

In [6]:
```
# only data within our bandpass
bandpass = \
    (lambdas > (lambda_0 - delta_lambda/2)) \
    & (lambdas < (lambda_0 + delta_lambda/2))

plot(lambdas, solar_irradiance, label='AM1.5')
fill_between(
    x=lambdas[bandpass],
    y1=solar_irradiance[bandpass],
    color='r', alpha=0.2, label='Bandpass'
)

xlim(400,800)
legend()
xlabel('$\lambda$ [nm]')
ylabel('Spectral irradiance [W/m$^2$/nm]')
```

```
tight_layout()
show()
```



1.4 Solar photon rate

We want to know the overall solar spectral photon rate and the integrated rate within some spectral band.

$$\dot{N}(\lambda) = \frac{\pi d^2}{4hc} I(\lambda)\lambda \tag{13}$$

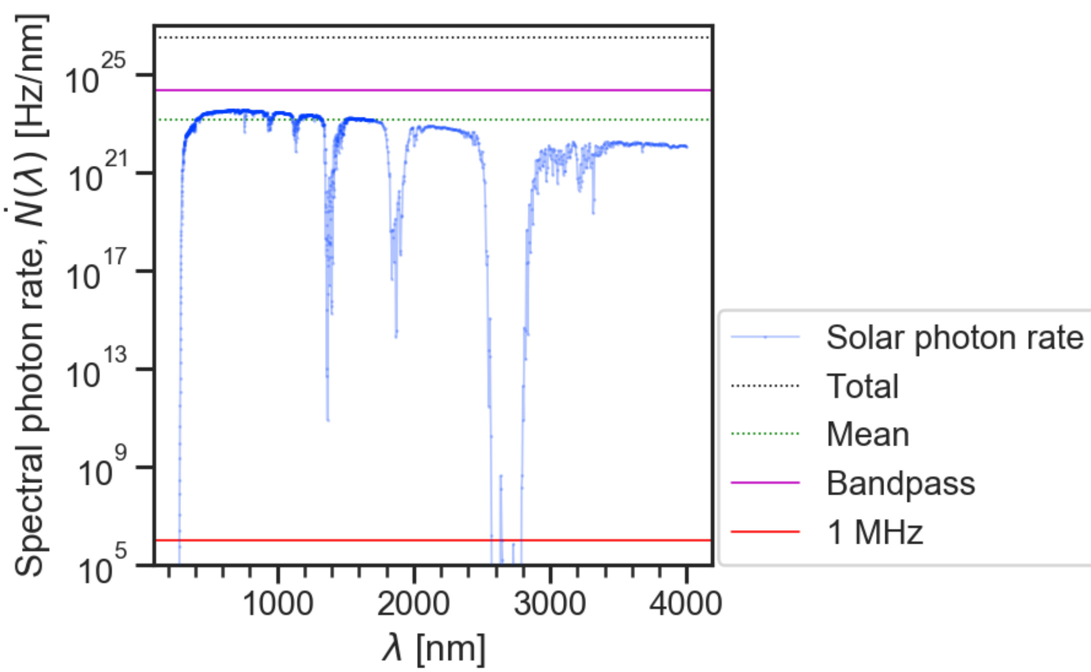
$$\dot{N}_{\Delta\lambda} = \frac{\pi d^2}{4hc} \int_{\lambda_0 - \frac{\Delta\lambda}{2}}^{\lambda_0 + \frac{\Delta\lambda}{2}} I(\lambda)\lambda\partial\lambda \tag{14}$$

In [7]:
```
solar_photon_rate = \
    ( (pi * d**2) / (4*h*c) ) \
    * (solar_irradiance * lambdas) # [Hz] vs wavelength

bandpass_photon_rate = trapz(
    solar_photon_rate[bandpass],
    lambdas[bandpass],
) # [Hz]

print('Photon rate: ~%.0e' % bandpass_photon_rate, 'Hz') # scientific notation
```

```
Photon rate: ~2e+24 Hz
```

1.5 Solar photon rate ($\dot{N}(\lambda)$)

```
In [8]: plot(lambdas, solar_photon_rate,
             '.-', lw=1, ms=1, alpha=0.3, zorder=4,
             label='Solar photon rate')

        axhline(trapz(solar_photon_rate, lambdas),
                lw=1, ls=':', color='k', label='Total')
        axhline(mean(solar_photon_rate),
                lw=1, ls=':', color='g', label='Mean')
        axhline(bandpass_photon_rate,
                lw=1, color='m', label='Bandpass')
        axhline(1e6,
                lw=1, color='r', label='1 MHz')

        yscale('log')
        minorticks_on()
        ylim(1e5,1e27)
        legend(loc=[1.01,0])
        xlabel('$\lambda$ [nm]')
        ylabel('Spectral photon rate, $\dot{N}(\lambda)$ [Hz/nm]')
        tight_layout()
        show()
```



1.6 Solar single photon source

It appears that there are two spectral bands where this could work --- DUV ($\lambda < 300$ nm) and IR ($\lambda \approx 2.6 \rightarrow 2.8\ \mu$m).

```
In [9]: ssps_lambdas_DUV = lambdas[
            (solar_photon_rate <= 1e6)
            & (lambdas < 300)
        ]

        ssps_lambdas_IR = lambdas[
            (solar_photon_rate <= 1e6)
            & (lambdas > 500)
        ]

        print('Potential solar single photon source (SSPS) ranges:')
        print(
            '\tDUV: <', ssps_lambdas_DUV[-1], 'nm'
        )
        print(
            '\tIR:',
            ssps_lambdas_IR[0]/1e3, '---', ssps_lambdas_IR[-1]/1e3, 'um'
        )
```

```
Potential solar single photon source (SSPS) ranges:
        DUV: < 284.0 nm
        IR: 2.575 --- 2.785 um
```

2 Conclusions

- What photon rate ($\dot{N}$) do we see from solar irradiation?

  Total: $\dot{N} \approx 10^{26}$, typical: $\frac{\dot{N}}{\lambda} \approx 10^{22}/\mathrm{nm}$

- Is it possible to bandpass solar irradiation to such a degree to achieve similar specifications (i.e. $\dot{N} = 1$ MHz $\equiv 1$ photon$/\mu$s) to a single photon source?

  Perhaps. Spectral bands exist where the atmosphere is extremely opaque to solar radiation. Questions remain as to the *purity* of these photons and their jitter (i.e. deterministic vs probabilistic sources).

- What is the best wavelength to do this at?

  $\lambda < 284$ nm. and $\lambda = 2.575 \rightarrow 2.785\ \mu$m.