Solar_single_photon_source

June 6, 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$/\mu$s) 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).

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

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

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

$$\dot{N} = \frac{\pi d^2}{4hc}\int_{\lambda_0-\frac{\Delta\lambda}{2}}^{\lambda_0+\frac{\Delta\lambda}{2}} I(\lambda)\lambda\partial\lambda \tag{8}$$

$$\approx \frac{I_0\pi d^2}{4hc}\int_{\lambda_0-\frac{\Delta\lambda}{2}}^{\lambda_0+\frac{\Delta\lambda}{2}} \lambda\partial\lambda \tag{9}$$

$$= \frac{I_0\pi d^2}{4hc}\left[\frac{\lambda^2}{2}\right]_{\lambda_0-\frac{\Delta\lambda}{2}}^{\lambda_0+\frac{\Delta\lambda}{2}} \tag{10}$$

$$\vdots \tag{11}$$

$$= \frac{I_0\lambda_0\Delta\lambda\pi d^2}{4hc} \tag{12}$$

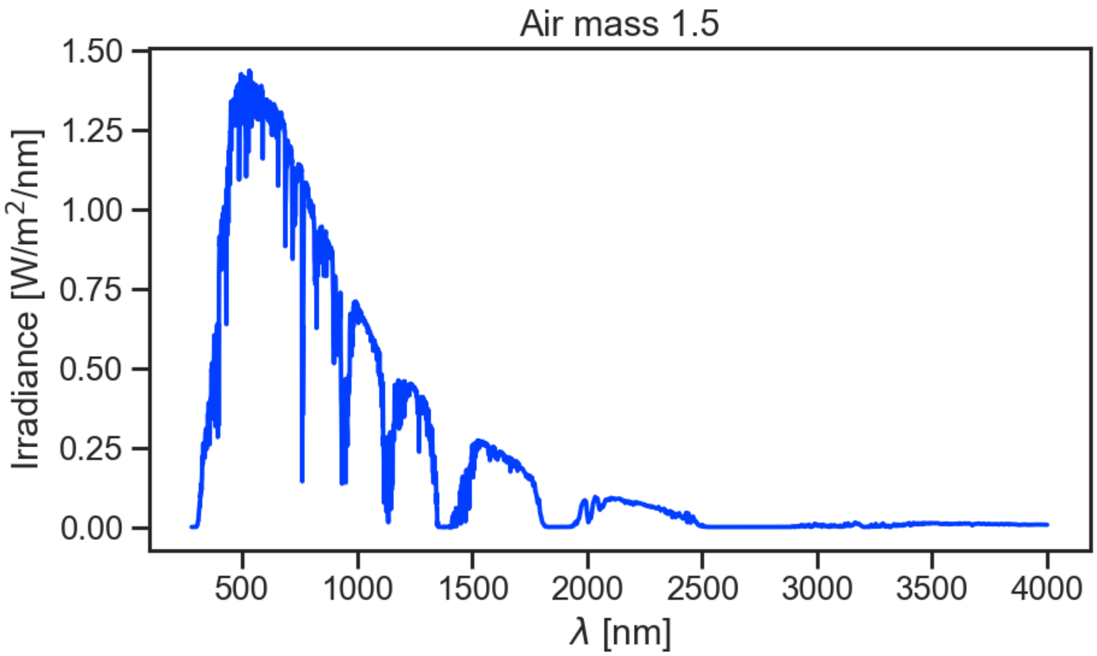
In [1]:
```
from numpy import *
from matplotlib.pyplot import *
from seaborn import *

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=
```

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

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

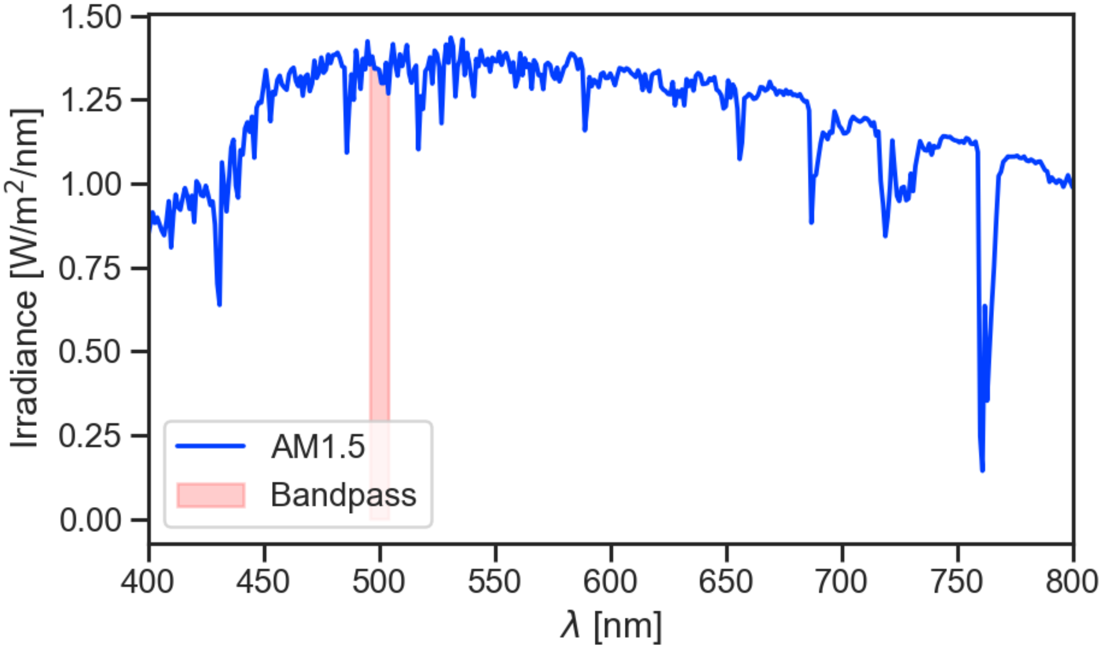


1.3 Solar photon rate

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

lambda_0 = 500e-9 # [m]
delta_lambda = 10e-9 # [m]
```

In [6]:
```
# only data within our bandpass
mask = \
    (lambdas > 1e9*(lambda_0 - delta_lambda/2)) \
    & (lambdas < 1e9*(lambda_0 + delta_lambda/2))

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

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

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



$$\dot{N} = \frac{\pi d^2}{4hc} \int_{\lambda_0 - \frac{\Delta\lambda}{2}}^{\lambda_0 + \frac{\Delta\lambda}{2}} I(\lambda)\lambda\partial\lambda \tag{13}$$

```
In [7]: lambda_range = linspace(
            lambda_0 - delta_lambda/2,
            lambda_0 + delta_lambda/2,
            100
        ) # [m]

        intensity_range = interp(
            1e9*lambda_range, # [nm]
            lambdas, # [nm]
            solar_irradiance, # [W/m^2/nm]
        ) # [W/m^2/nm]

        photon_rate = sum(
            ( (pi * d**2) / (4*h*c) )
            * (intensity_range * lambda_range)
        ) # [Hz]

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

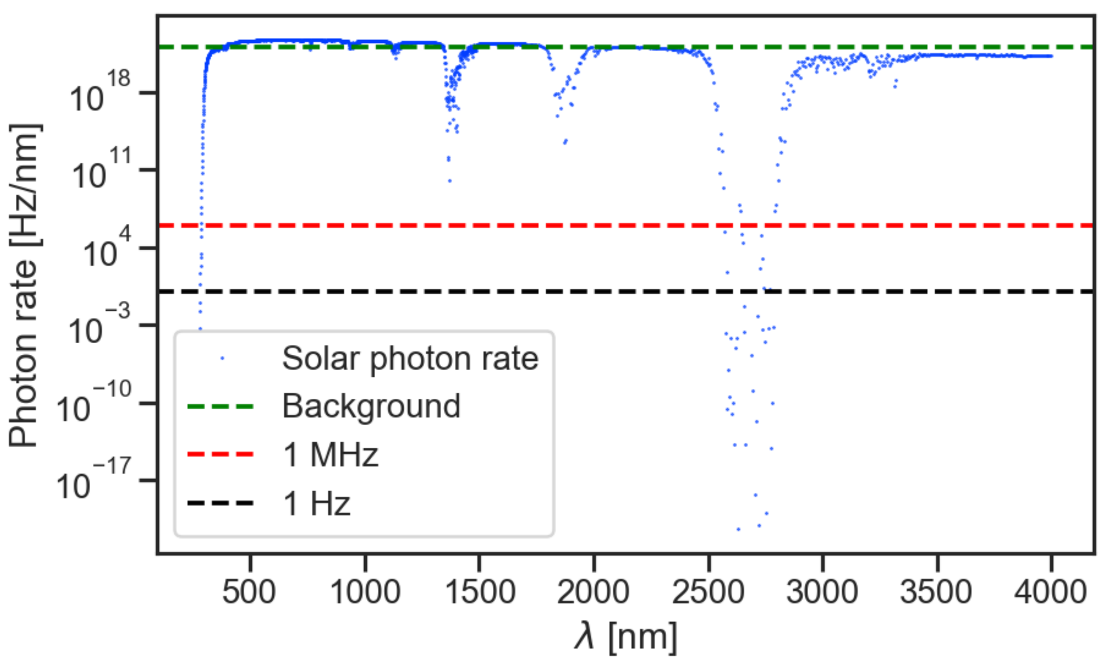
```
Photon rate: ~4e+15 Hz
```

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

$$\dot{N} = \frac{\pi d^2}{4hc} I(\lambda)\lambda \tag{14}$$

In [8]:
```
solar_photon_rate = ( (pi * d**2) / (4*h*c) ) * solar_irradiance * lambdas
```

In [9]:
```
plot(lambdas, solar_photon_rate, '.', ms=1, label='Solar photon rate')
axhline(1e22, ls='--', color='g', label='Background')
axhline(1e6, ls='--', color='r', label='1 MHz')
axhline(1, ls='--', color='k',  label='1 Hz')

yscale('log')
legend()
xlabel('$\lambda$ [nm]')
ylabel('Photon rate [Hz/nm]')
# title('Solar photon rate')
tight_layout()
show()
```



1.5 Solar single photon source

In [ ]:
```
# pick d_min
# pick delta_lambda_min
# minimise photon_rate with lambda_0 (bound > 0?)
```