Calculating the Solar Radiation Intensity on Planets

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Objective

- To determine the amount of solar radiation intensity that planets receive from a sun using known constants and publicly available data
- To develop an application that can calculate solar radiation intensity that planets receive within our solar system and in other star systems

Background

- **Radiation**: energy that takes the form of heat, light, or sound that either comes in waves or particles
  - **Ionizing Radiation**
  - **Non-ionizing Radiation**
- **Electromagnetic spectrum:** range of frequencies used for comparison and measurement
- **Solar radiation:** a subset of electromagnetic radiation emitted from the Sun, providing energy
- **Solar irradiance:** refers to the power density an object receives from the Sun
- **Galactic Cosmic Radiation (GCR):** an outcome of stellar explosions outside of the solar system
- **Atmospheres:** can absorb UV light and reduce the amount of radiation entering the planet
- **The Orbital Plane:** all the planets have their own orbit around the sun allowing them to line up, forming a flat disk

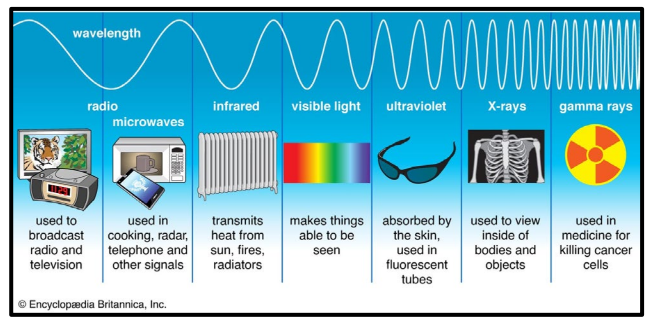

Figure 1: Types of Electromagnetic Radiation

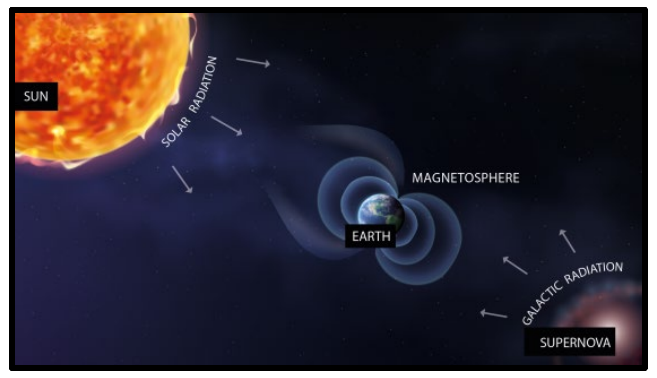

Figure 2: Visual of the Sun's radiation towards Earth

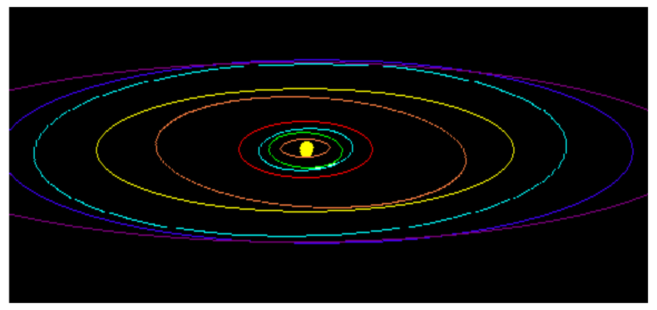

Figure 3: Planet orbital paths in the solar system

Solar Radiation Intensity Equation

Solar Radiation Equation:

- Equation was presented by Christina Honsberg and Stuart Bowden

$$H_0 = \frac{R_{sun}^2}{D^2} H_{sun}$$

H_0 : solar radiation intensity; units: $Watt/meter^2$

R_{sun} : radius of the sun ($695 * 10^6$ $meters$)

D : distance the planet is from the sun; units: $meters$

H_{sun} : sun's surface power density ($64 * 10^6$ $Watt/meter^2$)

- H_{sun} is based on the **Stefan-Boltzmann's blackbody equation:**

$$E = \sigma * T^4$$

E : the radiant heat emitted; units: $Area\ per\ unit\ time$

σ : the Stefan-Boltzmann constant ($5.6703 * 10^4$ $Watt/meter^2 \times Kelvin^4$)

T^4: the absolute temperature of the radiator; units: $Kelvin$

Data

- Dr. Dominic Ford, data scientist at the Institute of Astronomy in Cambridge, created a searchable catalog of astronomical events spanning from 1950 to 2300, including orbital distances
- The application incorporates orbital distance data for all planets in the Solar System, except Earth
- Data used in this application ranges from January 1, 2024, to December 31, 2026

```
Date(0 UT),Distance to Earth (au),Distance to Sun (au)
1/1/24,2.42382,1.48066
1/2/24,2.42077,1.47939
1/3/24,2.41769,1.47811
1/4/24,2.41459,1.47685
1/5/24,2.41146,1.47558
1/6/24,2.40831,1.47432
1/7/24,2.40513,1.47306
1/8/24,2.40193,1.47181
1/9/24,2.39871,1.47056
1/10/24,2.39546,1.46931
1/11/24,2.39218,1.46806
1/12/24,2.38889,1.46682
1/13/24,2.38557,1.46559
1/14/24,2.38223,1.46436
```

Figure 4: Data sample for Mars in CSV format

The Process & Model

1. For each planet, daily orbital data was gathered
2. Data was parsed and converted to standard units (e.g., astronomical units to meters)
   - $1\ au = 1.496 \times 10^{11}\ meters$
3. Distance to Sun was specifically used for the solar radiation intensity equation
4. Solar radiation intensity per second was calculated depending on distance to Sun on each day

$$H_0 = \frac{R_{sun}^2}{D^2} H_{sun}$$

```python
def calculateSolarIntensity(distance):
    #constants
    radiusSun = 695e6
    radiantSolarIntensity = 64e6

    #chaning distance from string to float
    distanceFloat = float(distance)

    #changing distance units from au to meters
    distanceInMeters =  distanceFloat * 1.496e11

    #calculating the solar intensity
    solarIntensity = (((radiusSun**2)/(distanceInMeters)**2) * radiantSolarIntensity)
```

Figure 5: Solar radiation intensity equation in Python

- The application does not consider external factors such as atmospheres, GCRs, etc.

Results

- **Solar Radiation Intensity Minimum and Maximum:**
  - Mercury is the closest to the sun
  - Neptune is furthest from the sun

Planet	Date	Distance to Sun (au)	Solar Radiation Intensity (W/m^2)	Orbital Period (days)
Mercury	01-01-24	0.3479	11412.41	88
	12-31-24	0.4203	7819.30	
Neptune	01-01-24	29.9038	1.54	59800
	12-31-24	029.8944	1.55	

- **Solar Radiation Comparison**
  - Application calculations compared to Honsberg and Bowden's calculations

Planet	Average Distance to Sun Calculated by Application (au)	Average Solar Radiation Calculated by Application (W/m^2)	Average Solar Radiation Calculated by Honsberg and Bowden (W/m^2)
Mercury	0.395	9419.63	9116.4
Venus	0.723	2619.31	2611.0
Mars	1.530	655.40	588.6
Jupiter	5.030	54.61	50.5
Saturn	9.685	14.73	15.04
Uranus	19.584	3.60	3.72
Neptune	29.899	1.55	1.51

- **Exoplanet application of equation:**
  - Implementation assumes Kepler-186 has the same surface power density of the Sun
  - Kepler-186f orbits an M-dwarf star named Kepler-186
  - The solar radiation intensity estimated for Kepler-186f is 1668.19 W/m^2
  - This solar radiation intensity is comparable to Earth's, which is approximately 1366 W/m^2

$$H_0 = \frac{R_{Kepler-186}^2}{D^2} H_{sun}$$

$$H_0 = \frac{(328417600)^2}{(6.4327 \times 10^{10})^2}(64 \times 10^6)$$

$$H_0 = 1668.19\frac{W}{m^2}$$

Limitations

- The solar irradiance equation does not consider the effects of GCRs, atmospheres, solar events, etc.
- Data acquired for distances were also calculated and are approximations by Dr. Ford

Future Work

- The application can be extended to make predictions for other star systems
- Extend the model to include various external factors such as GCRs, atmospheres, higher accuracy orbital routes
- Determine how different cosmic events impact the solar irradiance of planets within the solar system

Conclusions

- Solar irradiance can be estimated using the solar radiation intensity equation
- An application to compute solar radiation intensity was implemented using Python and solar irradiance was calculated for all planets in the solar system between 2024-2026
- The application can be extended to estimate the solar radiation intensity for exoplanets

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