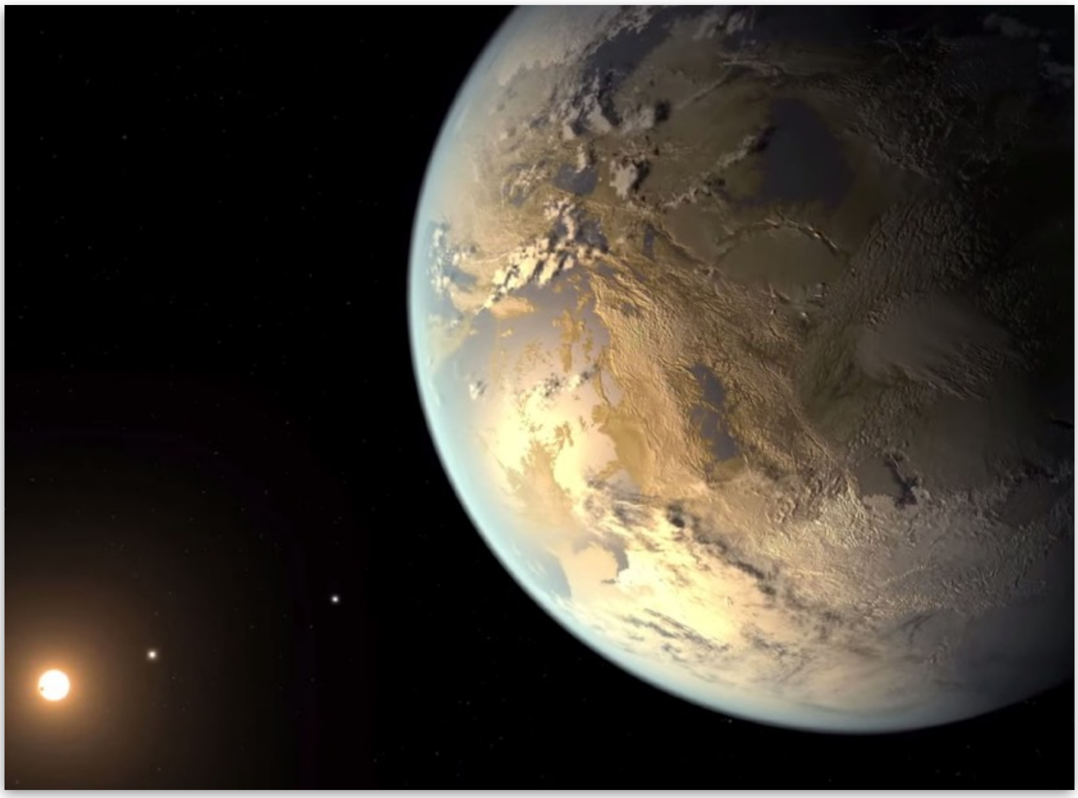
HOMEWORK



DELIVER BY 23:00 OF APRIL 24TH, 2020

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(NOTES: 1. FOR THE DOCUMENT FILENAME PLEASE USE THE FOLLOWING NOTATION: ***APPELLIDO_NOMBRE.PDF***

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Exercise I

1) The Sun radiates light with the luminosity $L_{\odot}=3.828 \times 10^{26}$ W. Let's compute the average temperature on the surfaces of the planets in the Solar System. For this you need to consider the following:

   a) Find an expression for the flux (L/Area) absorbed by the planet disk ($\pi \mathbf{R}^2$) at the average distance **D** of the planet from the Sun. However, consider that some fraction of the incident light will be reflected back into space, something that is called albedo (**a** = reflected light/incident light) and depends on the surface composition. The albedo values for the planets in our Solar system and Pluto are listed in the table below; use them for your calculations.

   b) Now consider that, in the equilibrium state, the planet absorbs the same amount of energy per second (in Watts) as it radiates per second back into space across the planet surface ($4\pi \mathbf{R}^2$), again in Watts. Assume that the planet redistributes the absorbed energy instantaneously across its entire surface and is homogeneously "warm" as it radiates. This allows you to simply use Stefan-Boltzmann's Law ($L = \text{Surface} \times \sigma T^4$) to compute the radiated luminosity of the planet. Find the expression for the equilibrium temperature.

   c) Compute the average surface temperatures and compare them to the measured average surface temperatures summarized in the table. Discuss possible reasons for the differences.

Solar System Data

Planet	Albedo	Distance [10^6 km]	Min/Max Surf. Temp [°C]
Mercury	0.106	57.9	–173/427
Venus	0.650	108.2	464
Earth	0.367	149.6	–88/58
Mars	0.150	227.9	–153/20
Jupiter	0.520	778.6	–110
Saturn	0.470	1433.5	–140
Uranus	0.510	2872.5	–195
Neptune	0.410	4495.1	–200
Pluto	0.300	5906.4	–225

2) Let's talk about the general planetary greenhouse effect.

a) How does it work? What is required? Discuss with as much detail as you deem necessary.

b) Where do you find the greenhouse effect operating in the Solar System?

3) With the Kepler spacecraft now switched off and TESS scanning the sky for new exoplanet candidates we have a good sample to explore exoplanet systems. Go to [NASA Exoplanet Archive]() and download the catalog of confirmed exoplanet parameters.

a) Construct your own Hertzsprung-Russell diagram for all stars with confirmed exoplanets.

b) Now color the star symbols in the HR diagram according to the orbit semi-major axis distance of their exoplanet. What systematics do you see in the plot? Why?

c) Determine now the exoplanets in the habitable zone of their host star. What is the overall fraction of exoplanets in the habitable zone in the entire dataset? Mark these stars in the HR diagram. Discuss what you observe.

d) Compute your own Earth Similarity Index (ESI) from the parameters available in the NASA Exoplanet Archive. Explain where you would like to send your next interstellar spaceship.

e) Plot the orbital period of planets vs. planet size and discuss the distribution of exoplanet data and the limits of this diagram.

4) BONUS QUESTION: As we discussed in the lecture, the stellar masses are not randomly distributed, but follow a mass function that astronomers refer to as the initial mass function. The number density of stars of a given mass can be written as $dN/dM = c\, M^{-2.35}$.
Because the central temperatures of stars with stellar masses $m \lesssim 0.1\, M_\odot$ are too low to ignite hydrogen fusion and stars with masses $m \gtrsim 100\, M_\odot$ are unstable against their own radiation pressure, the IMF is typically evaluated in the mass range between 0.1 and 100 $M_\odot$.

a) Compute what fraction of stars is at sub-solar masses ($0.1 - 1\, M_\odot$) and in the super-solar mass range ($1 - 100\, M_\odot$), and do the same for the stellar masses and luminosities, assuming $L \propto M^{3.5}$.

b) Given your knowledge about the equilibrium temperature from exercise I, discuss at what stellar masses you would find most of the "habitable zone real estate" (i.e. area of the habitable zone).