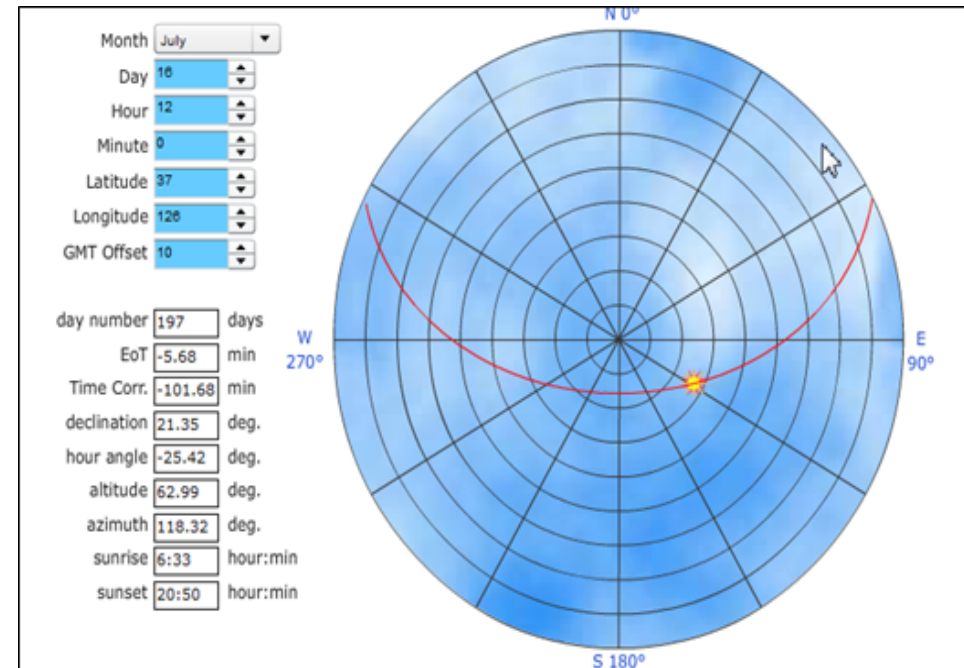


Chapter 7. Solar Resource

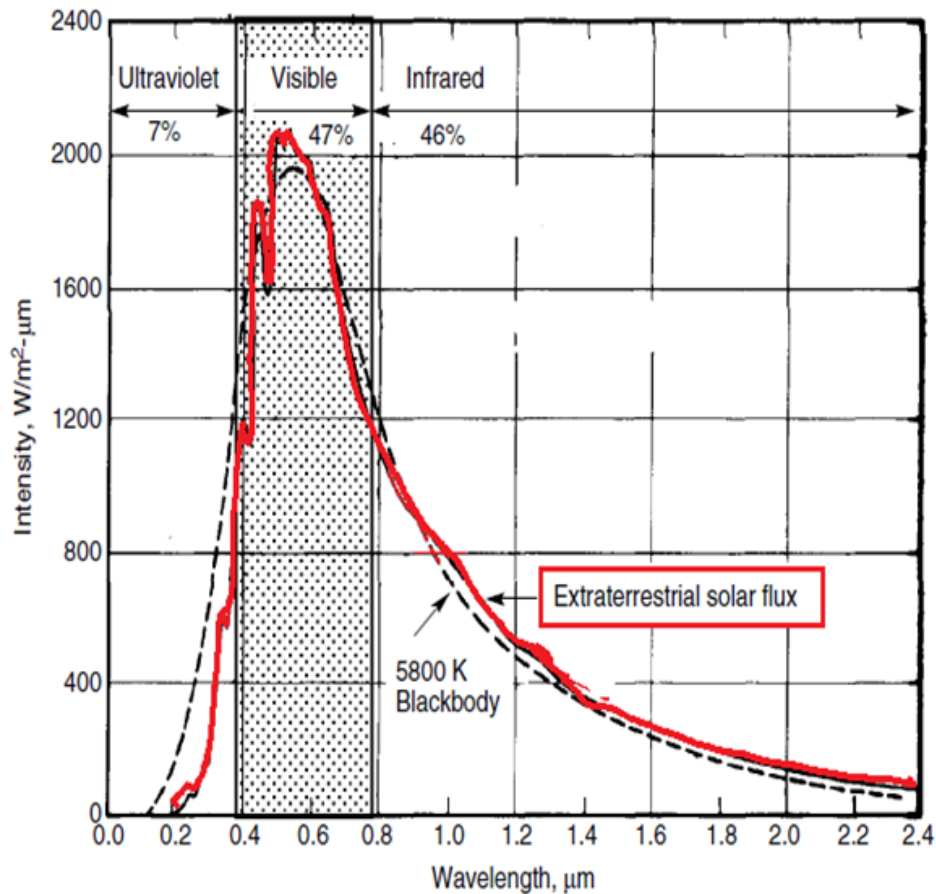


⌘ What do we have to know to design a solar system?

- ☒ How much sunlight is available?
- ☒ Where is the sun in the sky at any time of the day?
- ☒ Solar intensity ("Insolation" = Incident Solar Radiation)
- ☒ Average Daily Insolation
- ☒ Insolation on collector surfaces



Solar Spectrum



☒ Solar Spectrum (scaled to have the total area under the curve is 1.37 kW/m^2)

☒ UV 7%

☒ Visible Light 47 %

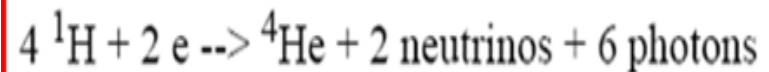
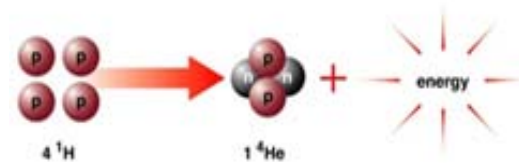
☒ IR 46%

☸ Sun

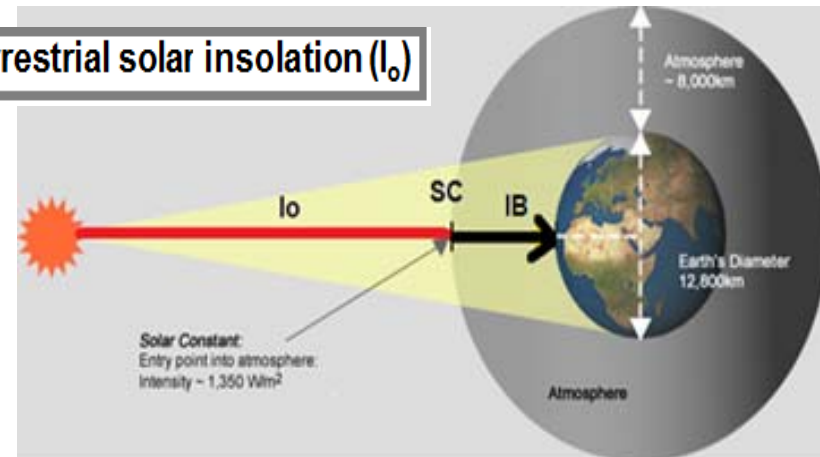
☒ 1.4 million kilometer diameter

☒ Thermonuclear furnace fusing hydrogen atoms into helium

☒ $3.8 \times 10^{20} \text{ MW}$ electromagnetic energy radiation into space



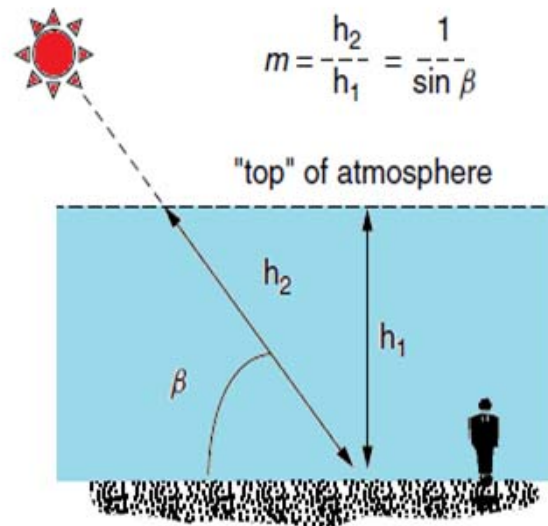
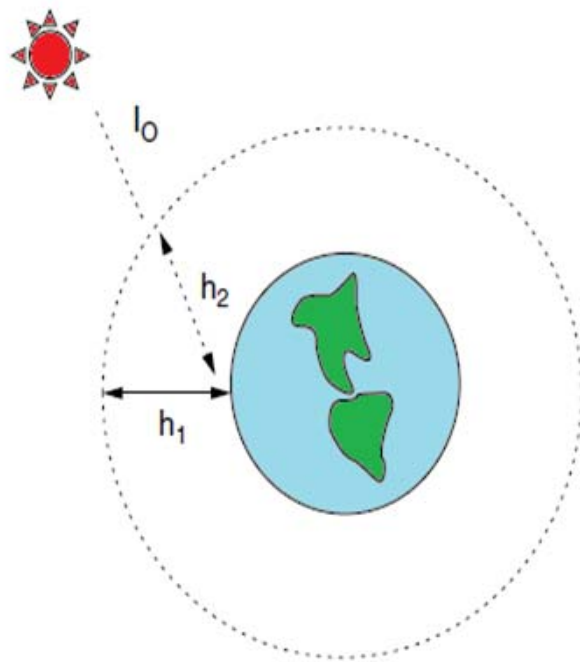
extraterrestrial solar insolation (I_0)



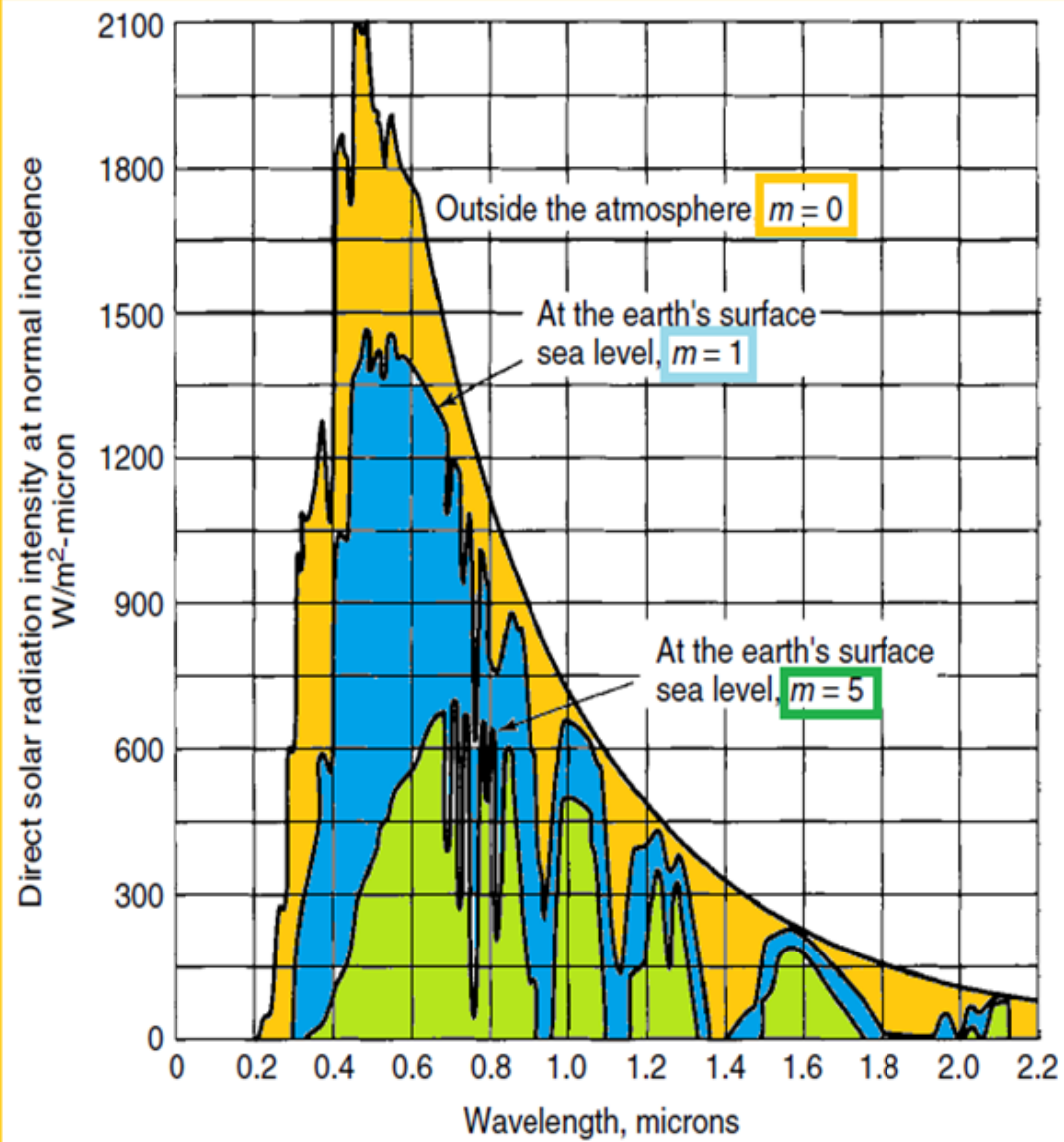
☒ **solar insolation** just outside the earth's atmosphere (~ 8000 km)
= "**Solar Constant**" = 1.37 kW/m^2

Solar Spectrum Shift by Air Mass Ratio (AM)

⌘ Length of path of sun's rays changes/shifts the solar spectrum

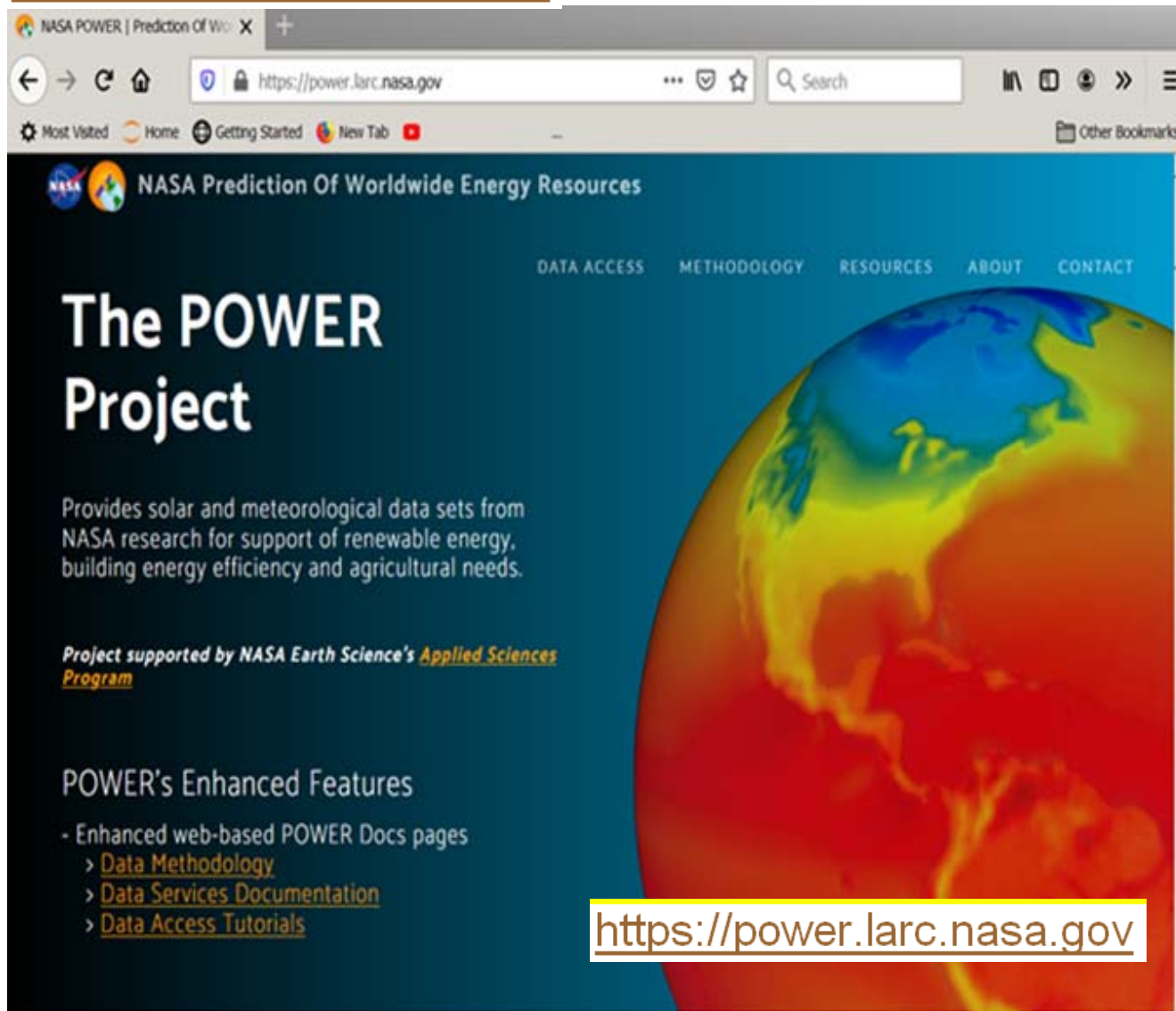


Solar Spectrum



More information on Solar Energy Resources

<https://power.larc.nasa.gov>

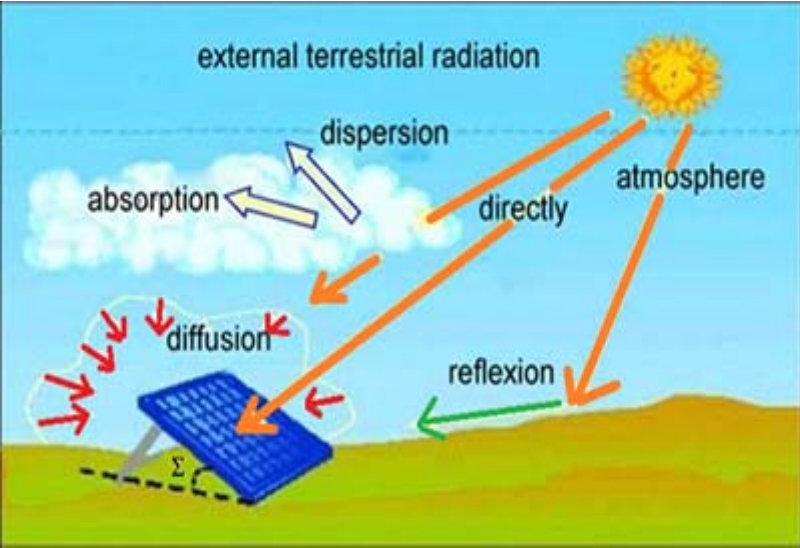


The screenshot shows a web browser window with the URL <https://power.larc.nasa.gov> in the address bar. The page title is "NASA POWER | Prediction Of Worldwide Energy Resources". The main heading is "The POWER Project". Below this, it states: "Provides solar and meteorological data sets from NASA research for support of renewable energy, building energy efficiency and agricultural needs." It also mentions: "Project supported by NASA Earth Science's [Applied Sciences Program](#)". Under the heading "POWER's Enhanced Features", there is a list of links: "Enhanced web-based POWER Docs pages", "> [Data Methodology](#)", "> [Data Services Documentation](#)", and "> [Data Access Tutorials](#)". The background of the page features a stylized Earth with a color gradient from blue to red, representing energy levels. A navigation menu at the top right includes links for "DATA ACCESS", "METHODOLOGY", "RESOURCES", "ABOUT", and "CONTACT".

<https://power.larc.nasa.gov>

Next Subjects

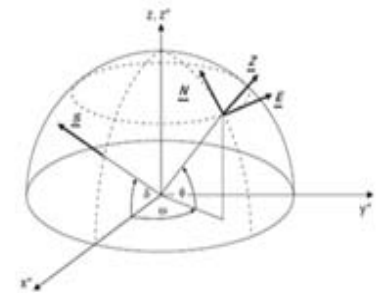
🌀 Our eventual goal of this study



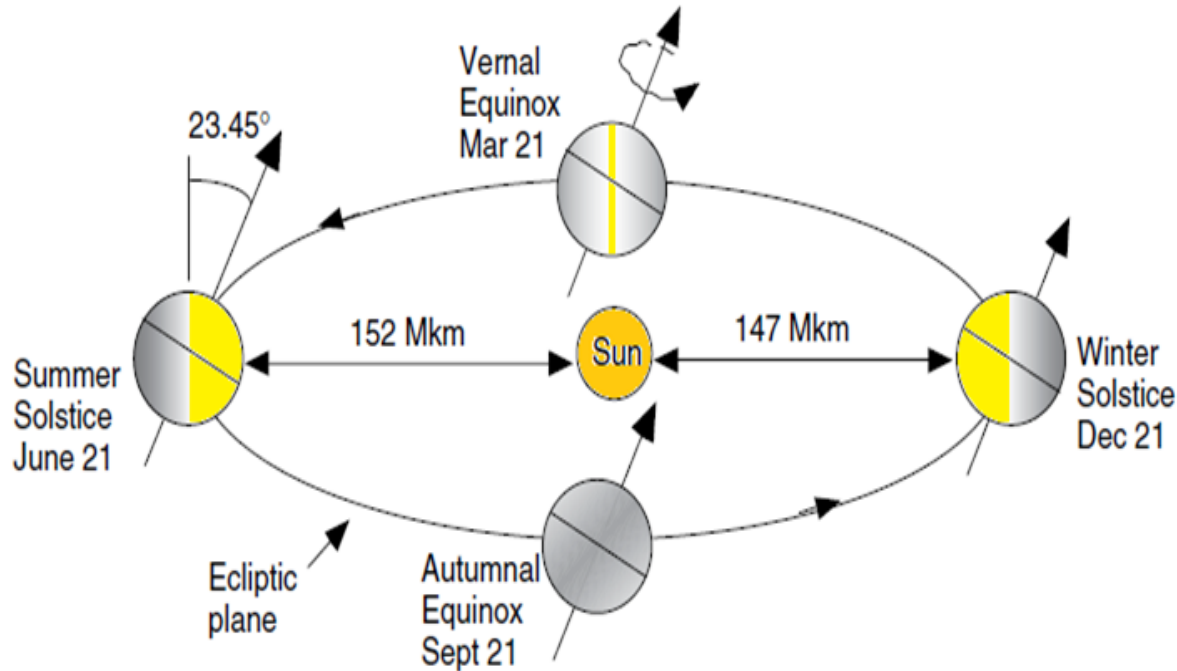
🌀 Basic knowledge we need

✂ The subjects

Notice



The Earth's Orbit



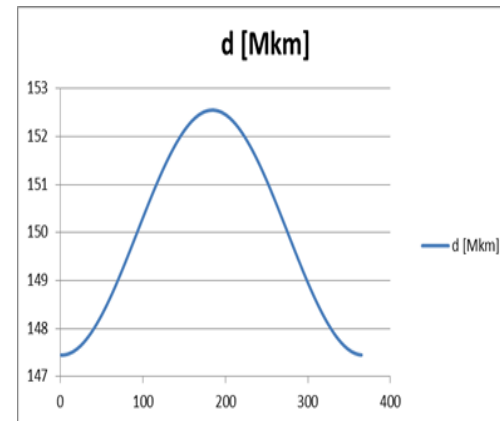
Distance between Sun and Earth on a given day

☒ n : day number (1: Jan 1, 365: Dec 31)

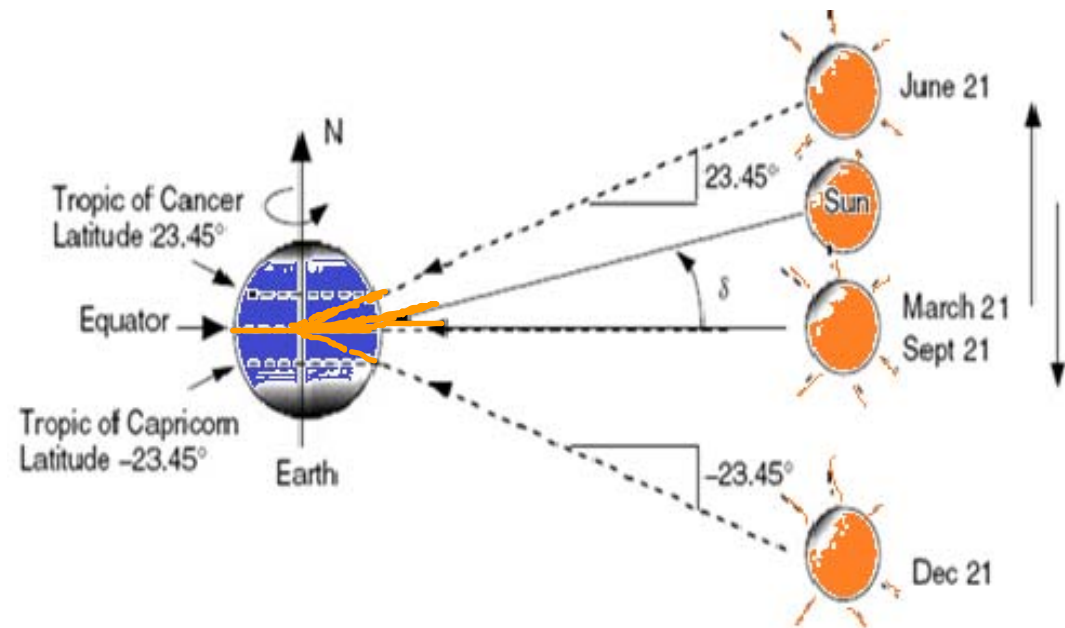
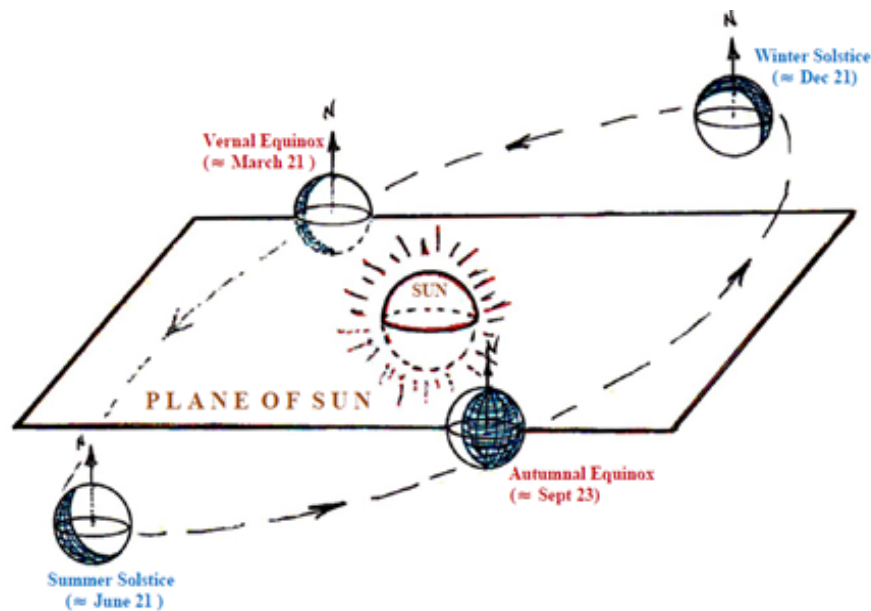
☒ Angle in **degrees**

$$d = 1.5 \times 10^8 \left\{ 1 + 0.017 \sin \left[\frac{360(n - 93)}{365} \right] \right\} \text{ km}$$

Day Numbers for the First Day of Each Month			
January	$n = 1$	July	$n = 182$
February	$n = 32$	August	$n = 213$
March	$n = 60$	September	$n = 244$
April	$n = 91$	October	$n = 274$
May	$n = 121$	November	$n = 305$
June	$n = 152$	December	$n = 335$



Earth's Orbit – Solar Declination



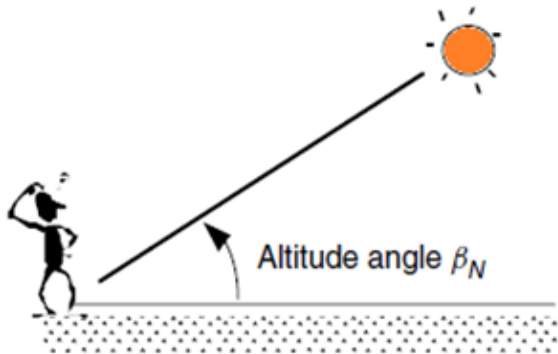
⌘ **Solar declination:** “angle between the sun's rays and the earth's equatorial plane, **or** the latitude at which the sun is directly overhead at midday.”

$$\delta = 23.45^\circ \sin \left[\frac{360}{365} (n - 81) \right]$$

Solar Declination δ for the 21st Day of Each Month (degrees)

Month:	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec
δ :	-20.1	-11.2	0.0	11.6	20.1	23.4	20.4	11.8	0.0	-11.8	-20.4	-23.4

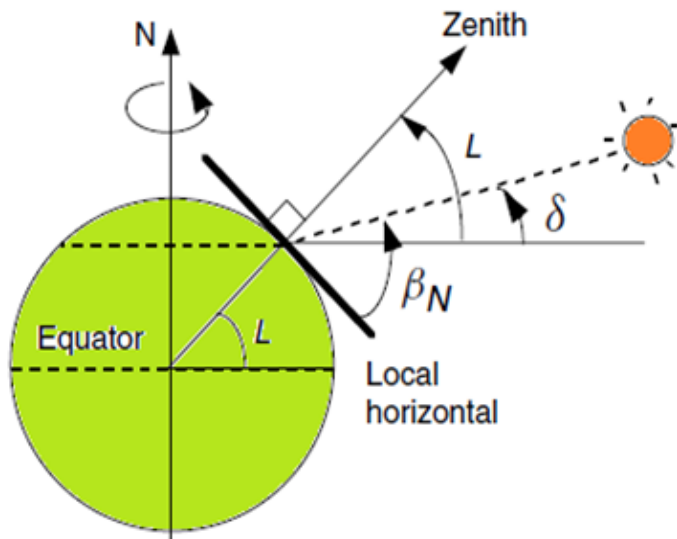
Altitude Angle of the Sun (at **Noon**) and Solar Declination



$$\delta = 23.45^\circ \sin \left[\frac{360}{365} (n - 81) \right]$$

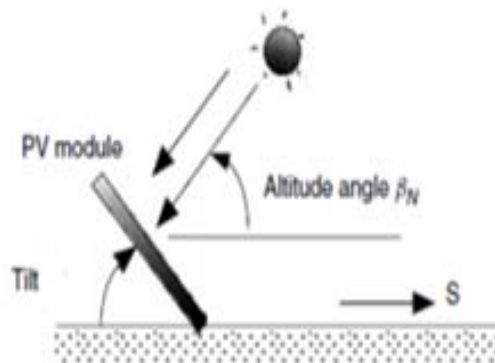
$$\beta_N = (90^\circ - L) + \delta$$

Noon



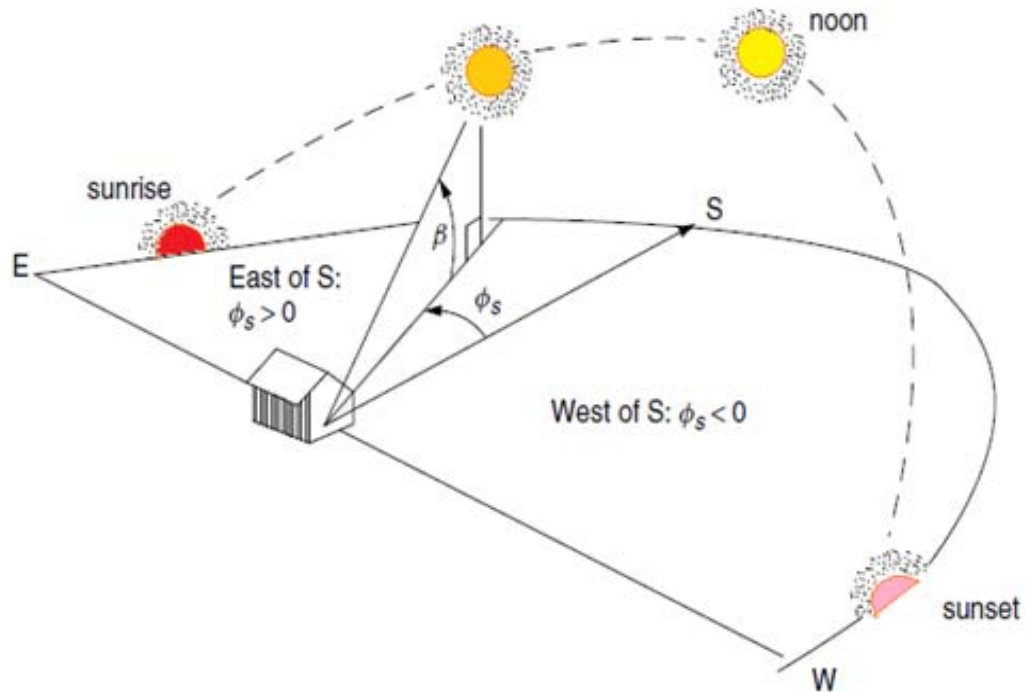
Example

- ⌘ Find the optimum tilt angle for a south-facing PV module in Tucson (Latitude 32.1°) at solar noon on March 1.



Day Numbers for the First Day of Each Month			
January	$n = 1$	July	$n = 182$
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March	$n = 60$	September	$n = 244$
April	$n = 91$	October	$n = 274$
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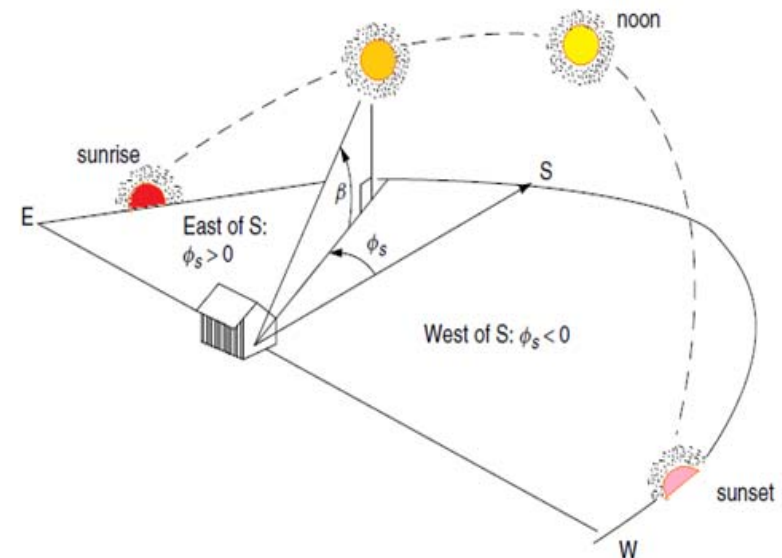
Sun Position at **Any Time** of Day



Sun Position at Any Time of Day: **EXAMPLE**

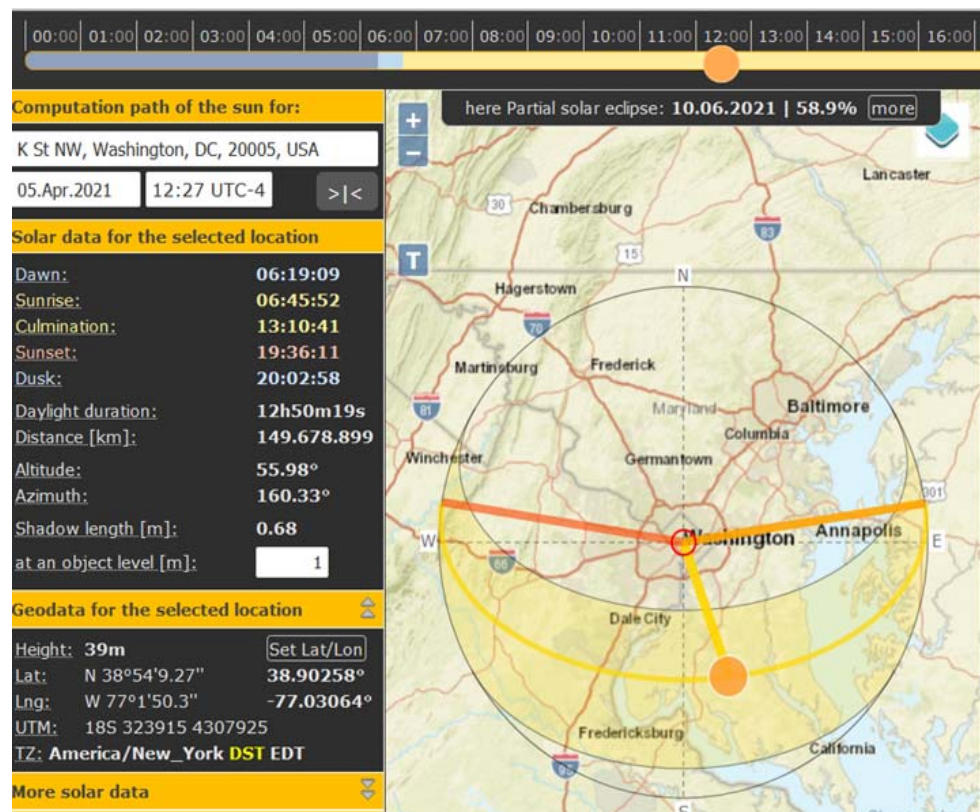
⌘ **Question:** Find the altitude angle (β) and azimuth angle (ϕ) for the sun at 3:00PM in Boulder, CO (Lat = 40°) on the summer solstice.

Day Numbers for the First Day of Each Month			
January	$n = 1$	July	$n = 182$
February	$n = 32$	August	$n = 213$
March	$n = 60$	September	$n = 244$
April	$n = 91$	October	$n = 274$
May	$n = 121$	November	$n = 305$
June	$n = 152$	December	$n = 335$



Sun Position Calculator – Web Site

<https://www.suncalc.org/>



More solar data

Mar Equinox:	20.03.2021 05:37 EDT
Jun Solstice:	20.06.2021 23:31 EDT
Sep Equinox:	22.09.2021 15:21 EDT
Dec Solstice:	21.12.2021 10:59 EST
Declination:	6.335°
RightAscension:	0h 59m 20.88s



<https://www.esrl.noaa.gov/gmd/grad/solcalc/>

City:	Deg:	Min:	Sec:	Time Zone	
Washington DC	Lat: North=+ South=-	38	53	0	Offset to UTC (MST=+7):
Click here for help finding your lat/long coordinates	Long: East=- West=+	77	2	0	Daylight Saving Time: Yes

Note: To manually enter latitude/longitude, select **Enter Lat/Long** -> from the City pulldown box, and enter the values in the text boxes to the right.

Month:	Day:	Year (e.g. 2000):	Time (hh:mm:ss)		
April	5	2021	12	: 27	: 53

AM PM 24hr

Calculate Solar Position

Equation of Time (minutes):	Solar Declination (degrees):	Solar Azimuth:	Solar Elevation:	cosine of solar zenith angle
-2.56	6.33	160.7	56.05	0.8295

Azimuth is measured in degrees clockwise from north.
Elevation is measured in degrees up from the horizon.
Az & El both report dark after [astronomical twilight](#).