Thermosolar Power Plants

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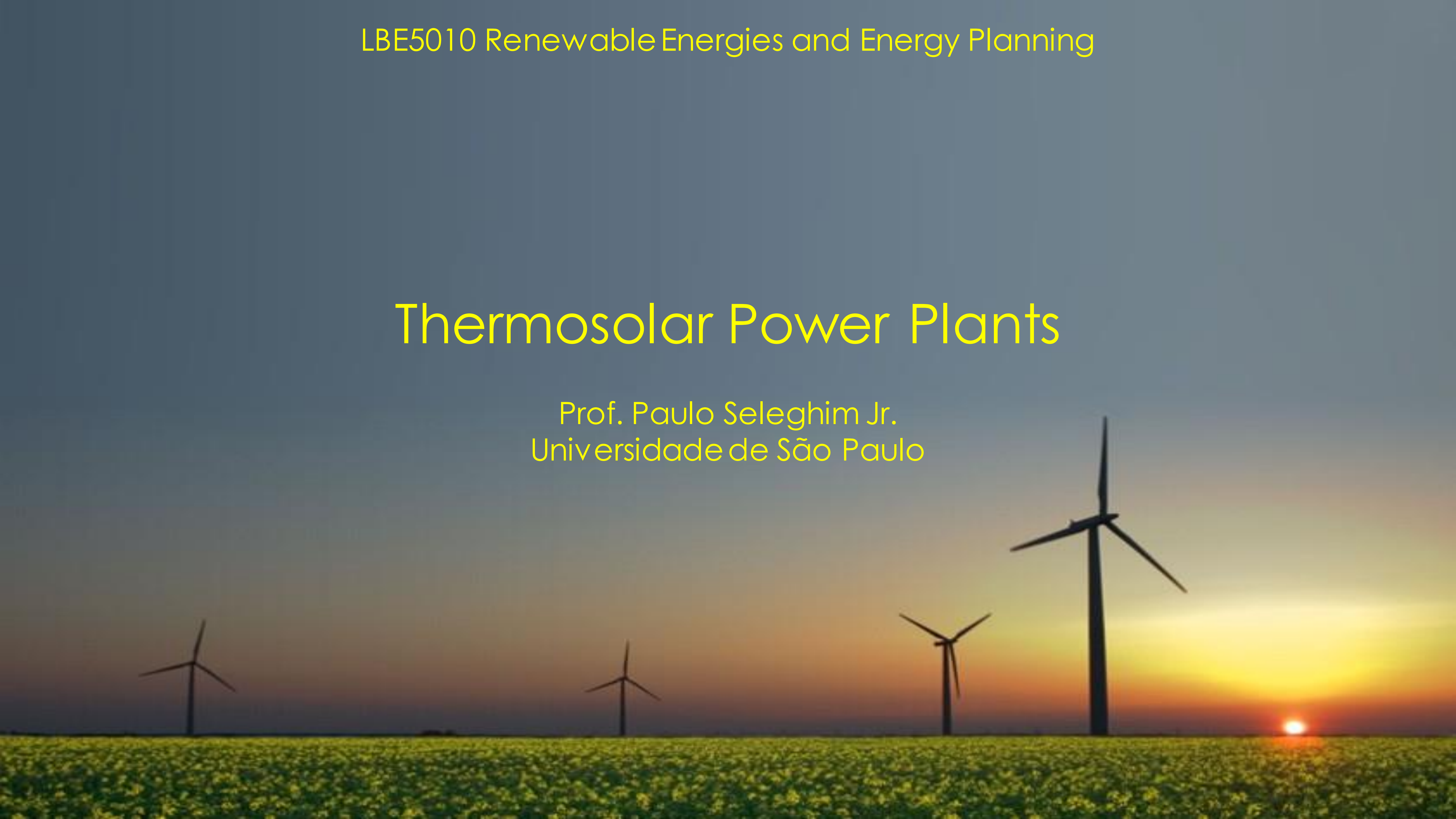
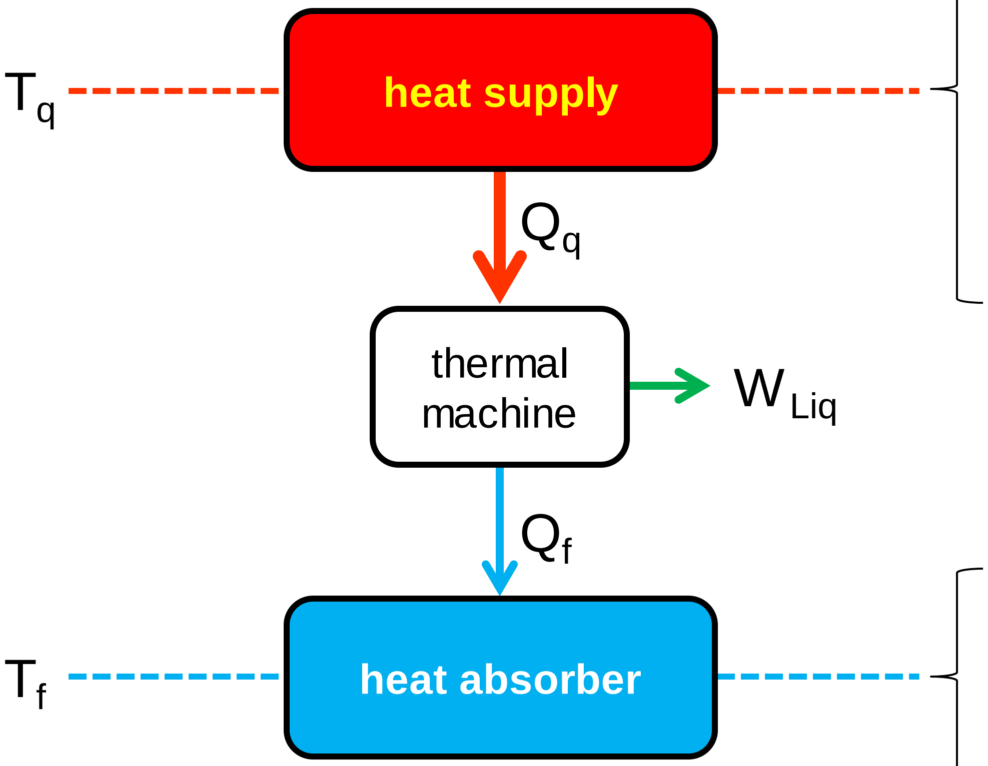


Conversion of thermal energy to mechanical energy (work)



combustion reaction:
coal, oil, gas or biomass

nuclear reaction:
nuclear fission or fusion

solar thermal:
concentrators, heating plates, etc.

Invariably the environment:
cooling towers (atmosphere)
body of water (river, lake, sea, etc.)

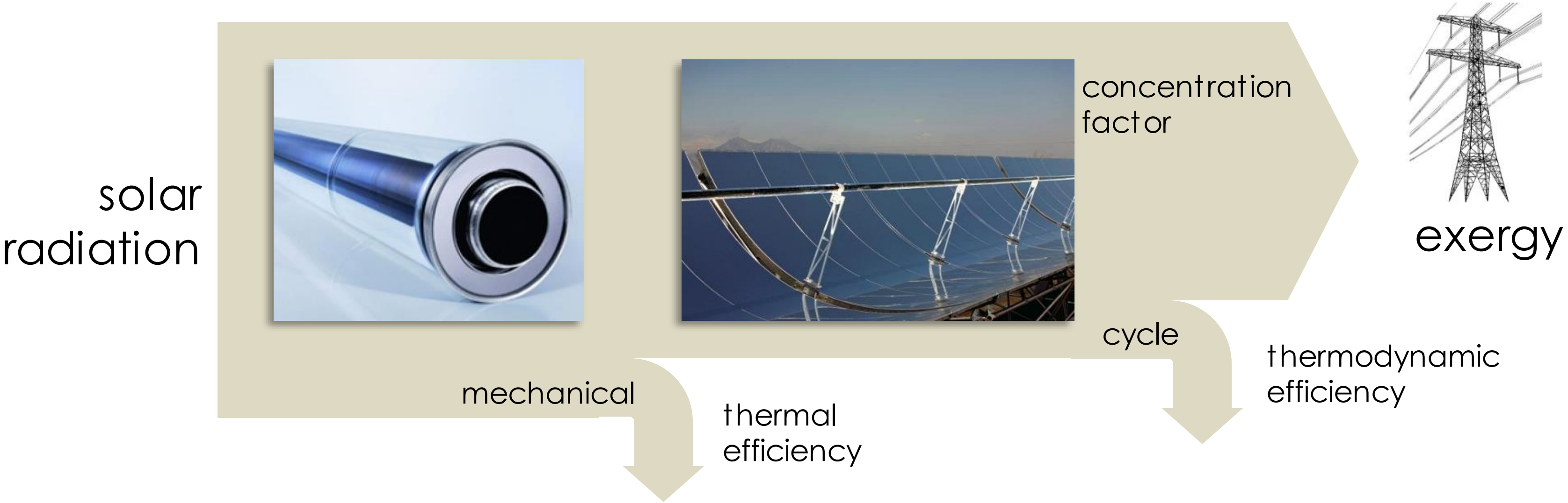
Conceptual design of a Thermosolar power plant …

Celestial Mechanics…

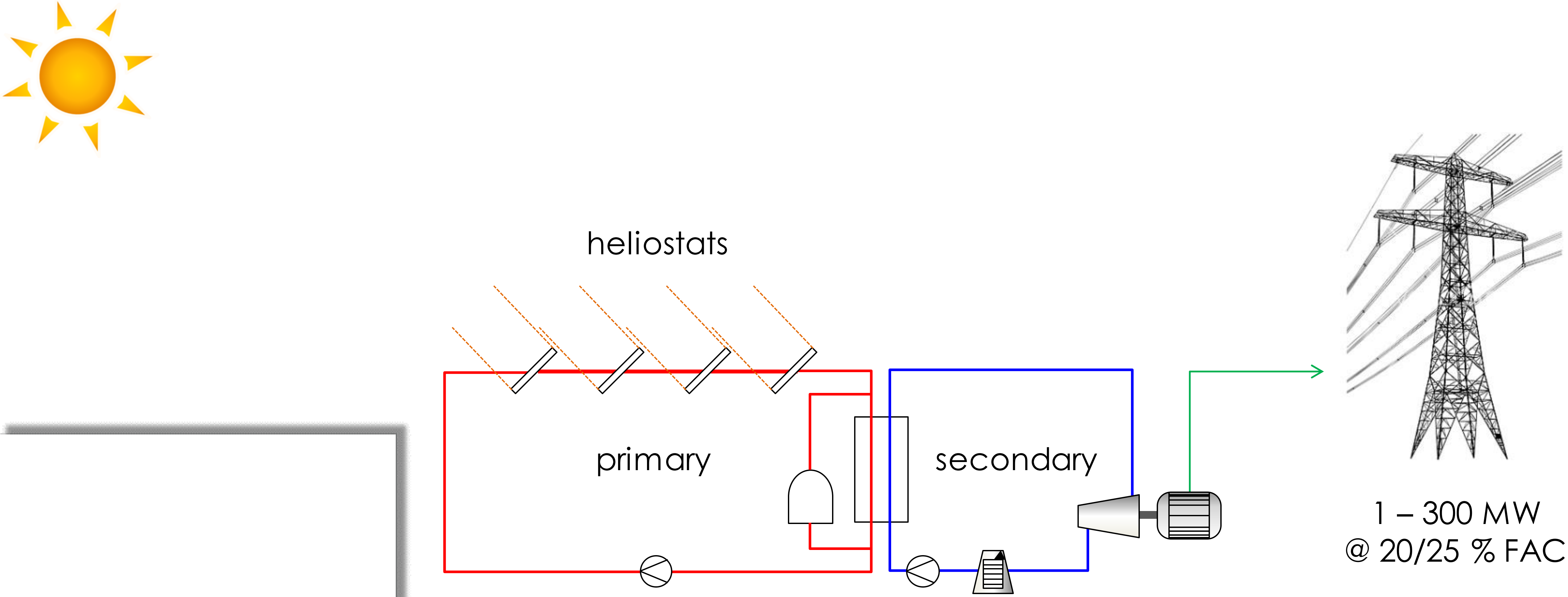
THERMOSOLAR POWER PLANT

Main subsystems:

1) Collectors / concentrators of solar energy (primary)
   - ✓ Fixed panels
   - ✓ Heliostats
2) Thermal energy storage to assure dispatchability
3) Thermodynamic conversion cycle (secondary)



THERMOSOLAR POWER PLANT



Thermosolar Power Plants:

PRINCIPAL ASPECTS OF A THERMOSOLAR POWER PLANT

Collector / concentrator geometry

1) Solar tower + heliostats
2) Liner collators (Fresnel)
3) Parabolic trough
4) Parabolic disk + Stirling

Andalusia, Spain

Seville, Spain.

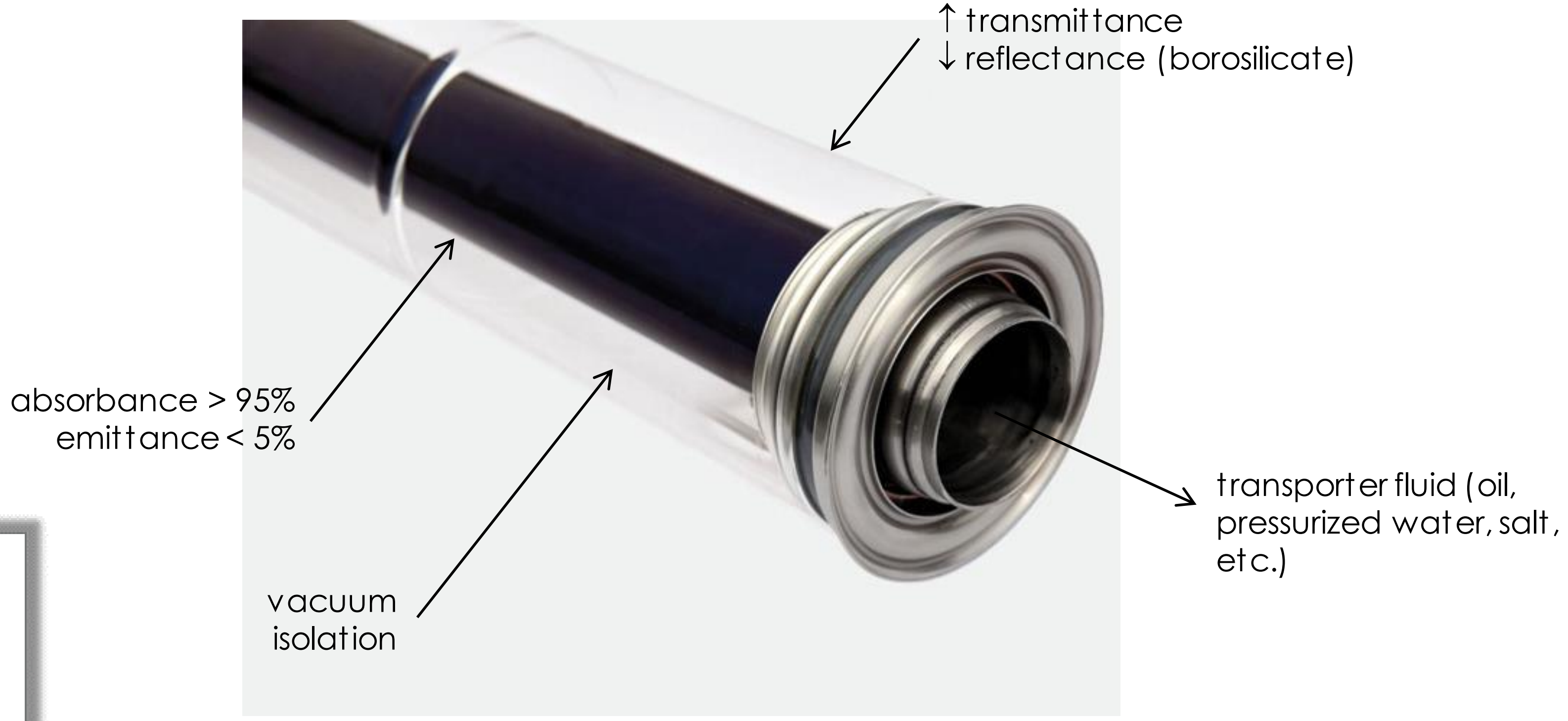
Murcia, Spain.


Stirling engine

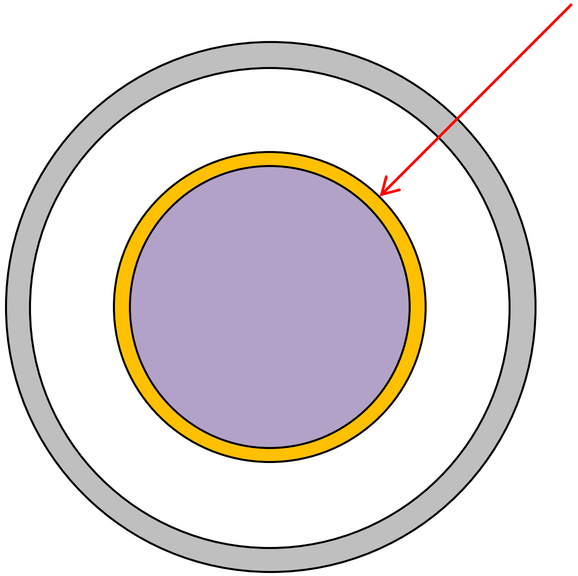
PRINCIPAL ASPECTS OF A THERMOSOLAR POWER PLANT

Collector / concentrator geometry

The collector receives energy from the concentrators and transfers it to the thermodynamic cycle working fluid



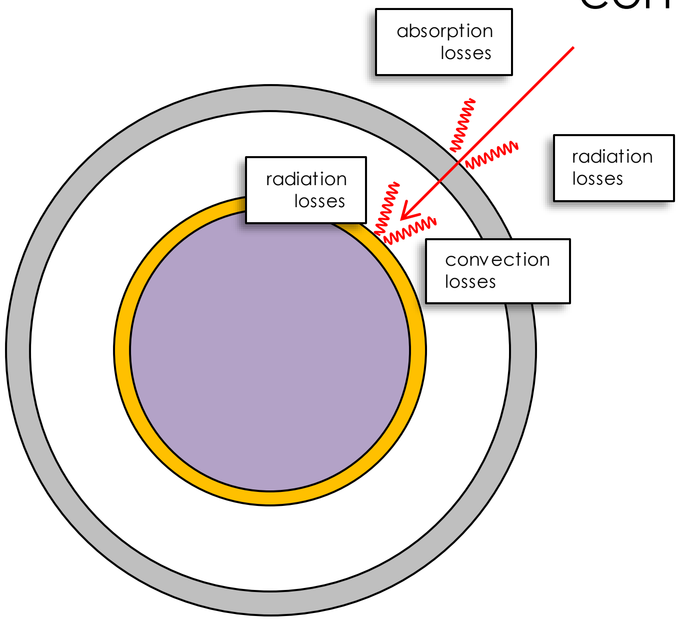
RECEPTOR / ABSORBER THERMAL ANALYSIS



Total solar energy flux (W/m^2) multiplied by the concentration factor due to the effect of collectors, lenses, etc.

RECEPTOR / ABSORBER THERMAL ANALYSIS

$f_{con} \cdot G_0$



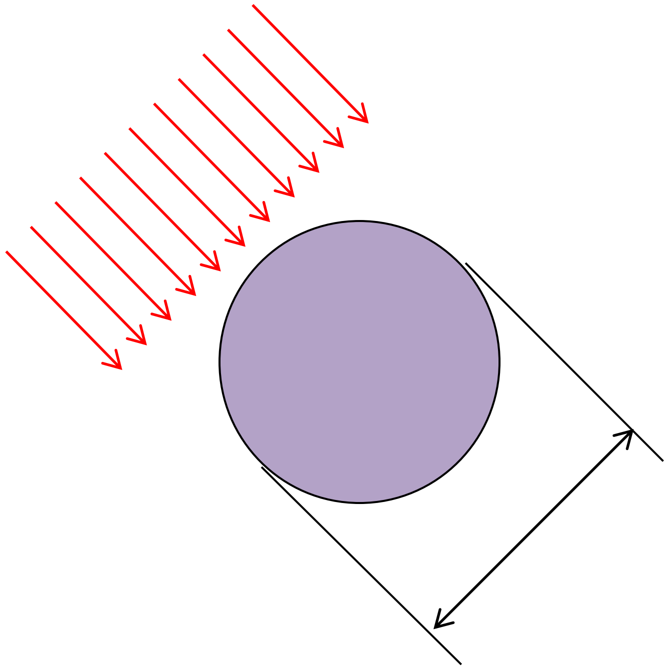
- glass reflectance ≈ 6,5%
- glass absorbance ≈ 1,8%
- tube reflectance ≈ 6,3%
- tube emittance ≈ 4,4%
- thermal losses ≈ 1,0%

- total losses ≈ 20%

$$G = \eta_{loss} \cdot f_{con} \cdot G_0$$

- G: Net solar energy flux that effectively arrives at the absorption / transportation fluid
- η_{loss}: effectivity (thermal losses)
- f_{con}: concentration factor
- G_0: mean solar incidence

RECEPTOR / ABSORBER THERMAL ANALYSIS



$$G = \eta_{loss} \cdot f_{con} \cdot G_0$$

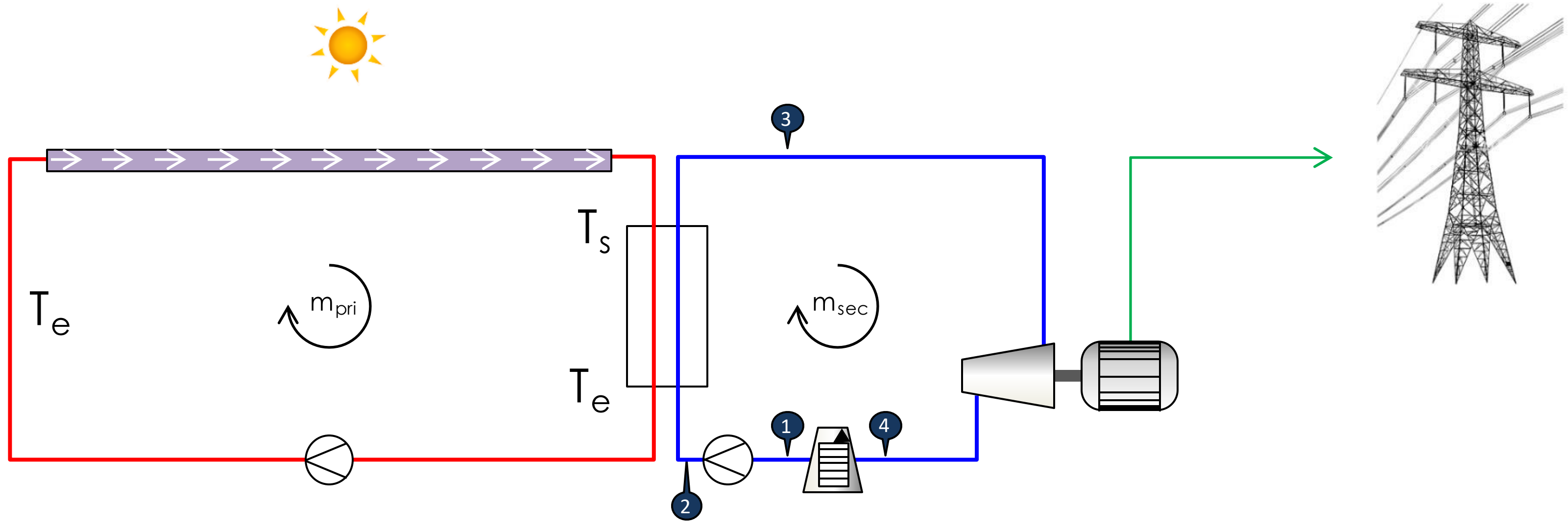
$$Q = D \cdot L \cdot G$$

net solar energy flux

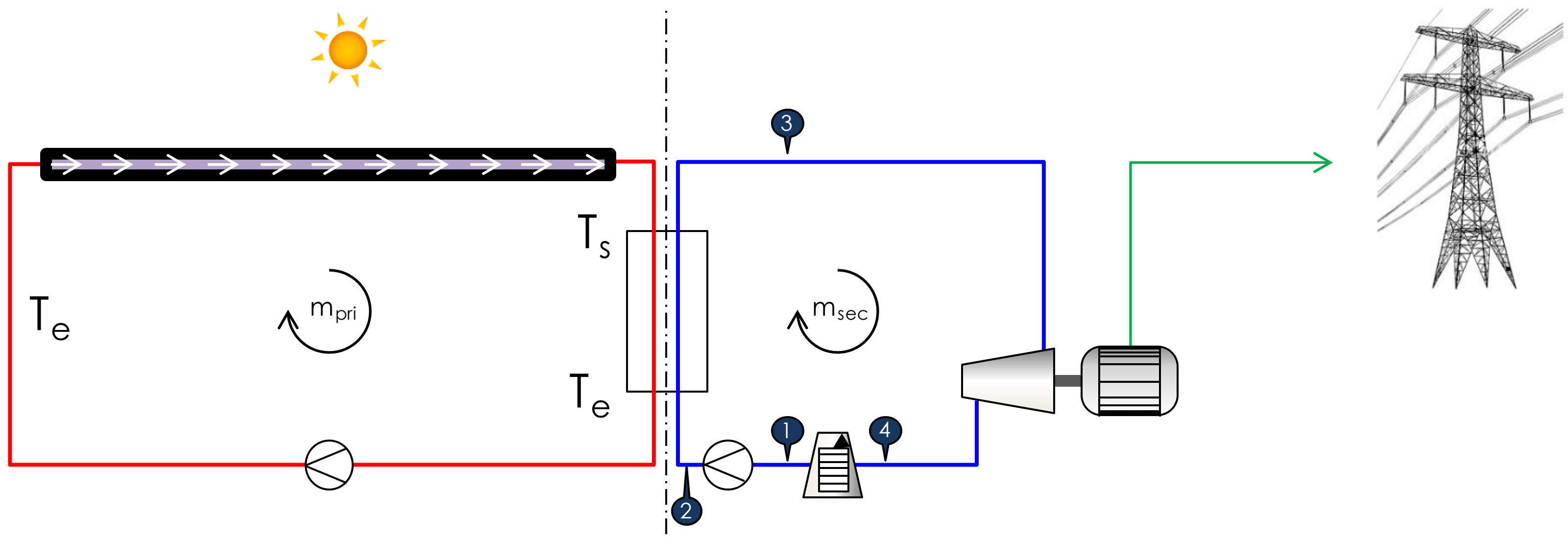
effective absorption area

heating power delivered to the transportation fluid

RECEPTOR / ABSORBER THERMAL ANALYSIS



RECEPTOR / ABSORBER THERMAL ANALYSIS



$$Q = m_{pri} \cdot C_P \cdot (T_s - T_e)$$

$$T_s = T_e + \frac{Q}{m_{pri} \cdot C_P}$$

$$T_s = T_e + \frac{DL}{m_{pri} \cdot C_P} \cdot \eta_{perd} f_{con} E_0$$

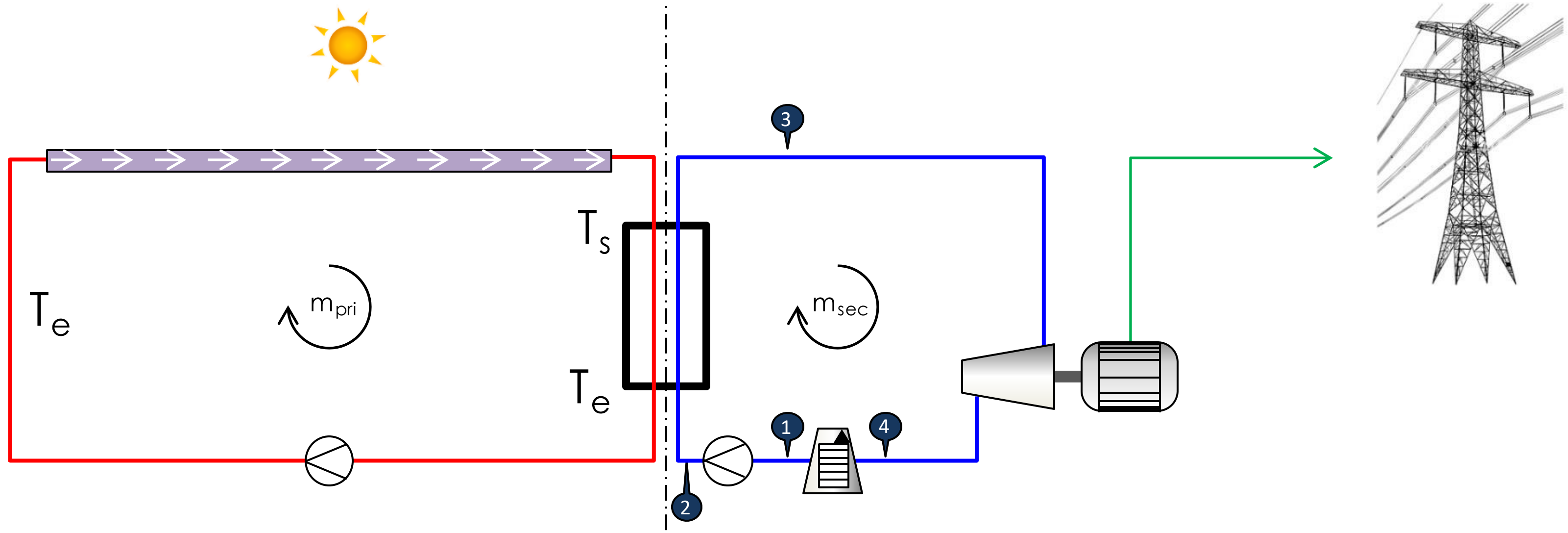
The efficiency of the thermodynamic cycle is maximized by increasing T_s which implies in augmenting f_{con}

collectors:

Linear	Tower	Disk+Stirling
$f_{con} < 50$	$f_{con} < 1000$	$f_{con} < 3000$

aeroelastic stability (Tower, Disk+Stirling)

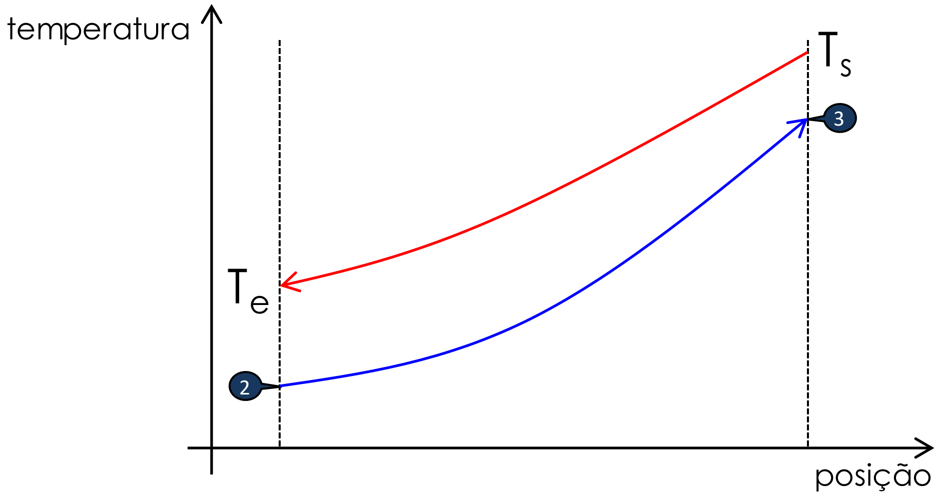
RECEPTOR / ABSORBER THERMAL ANALYSIS



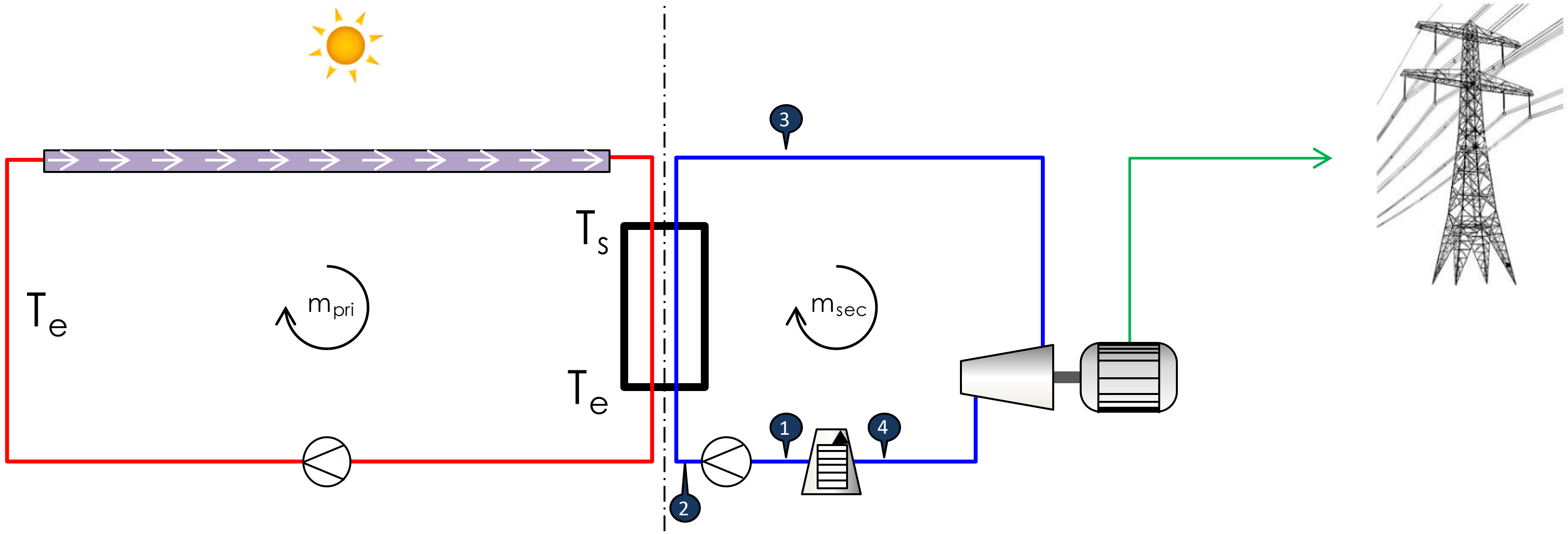
$$Q = m_{pri} C_{P,pri} \cdot (T_s - T_e)$$

$$Q = m_{sec} C_{P,sec} \cdot (T_3 - T_2)$$

$$\frac{T_3 - T_2}{T_s - T_e} = \frac{m_{sec} C_{P,sec}}{m_{pri} C_{P,pri}}$$

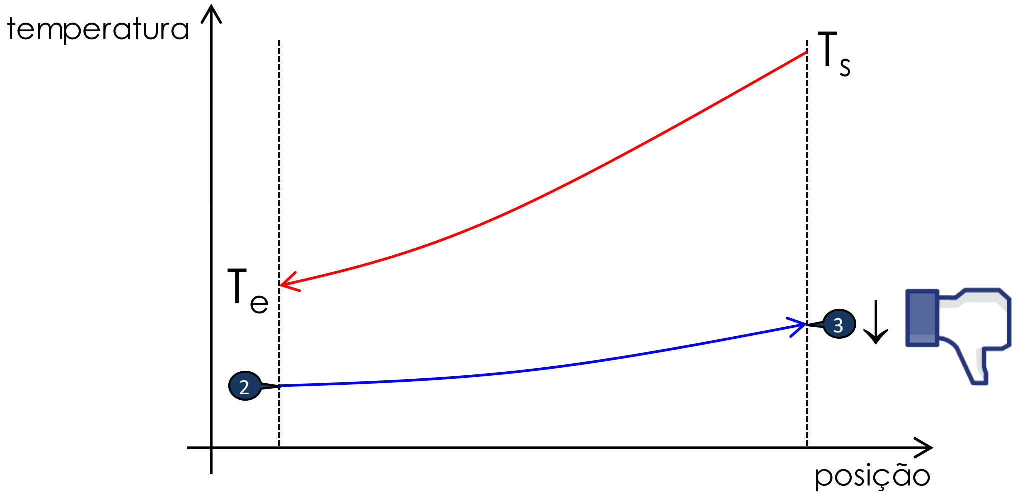


RECEPTOR / ABSORBER THERMAL ANALYSIS



$$m_{sec} C_{P,sec} >> m_{pri} C_{P,pri}$$

$$(T_3 - T_2) \rightarrow 0$$



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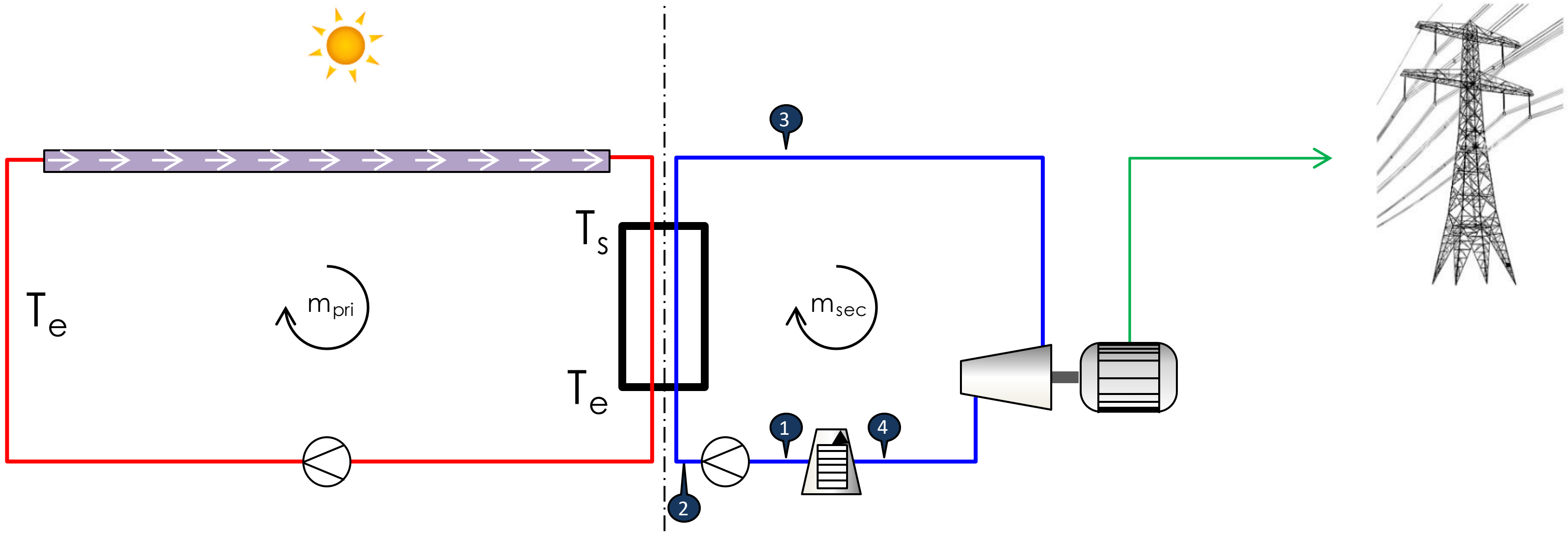
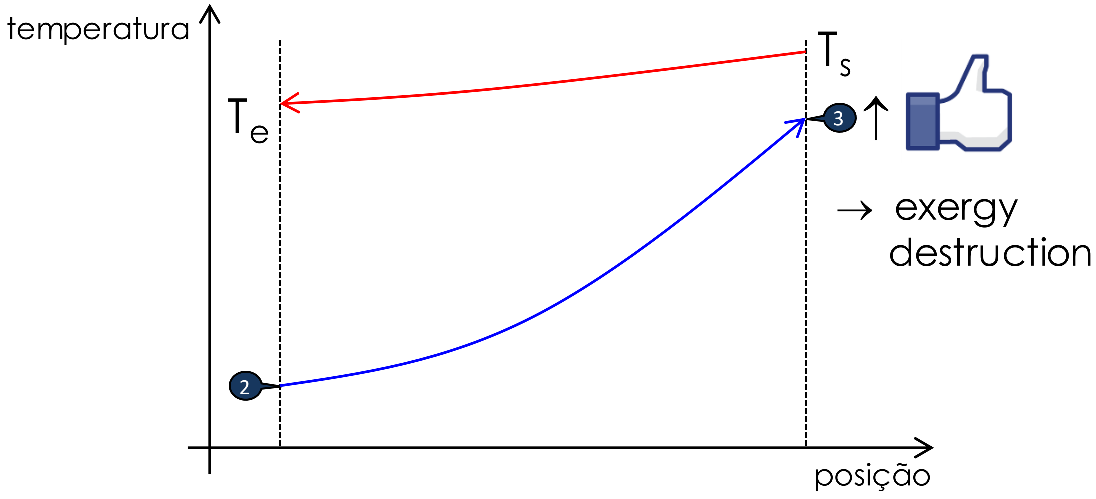




$$m_{pri}C_{P,pri} >> m_{sec}C_{P,sec}$$

$$(T_s - T_e) \rightarrow 0$$

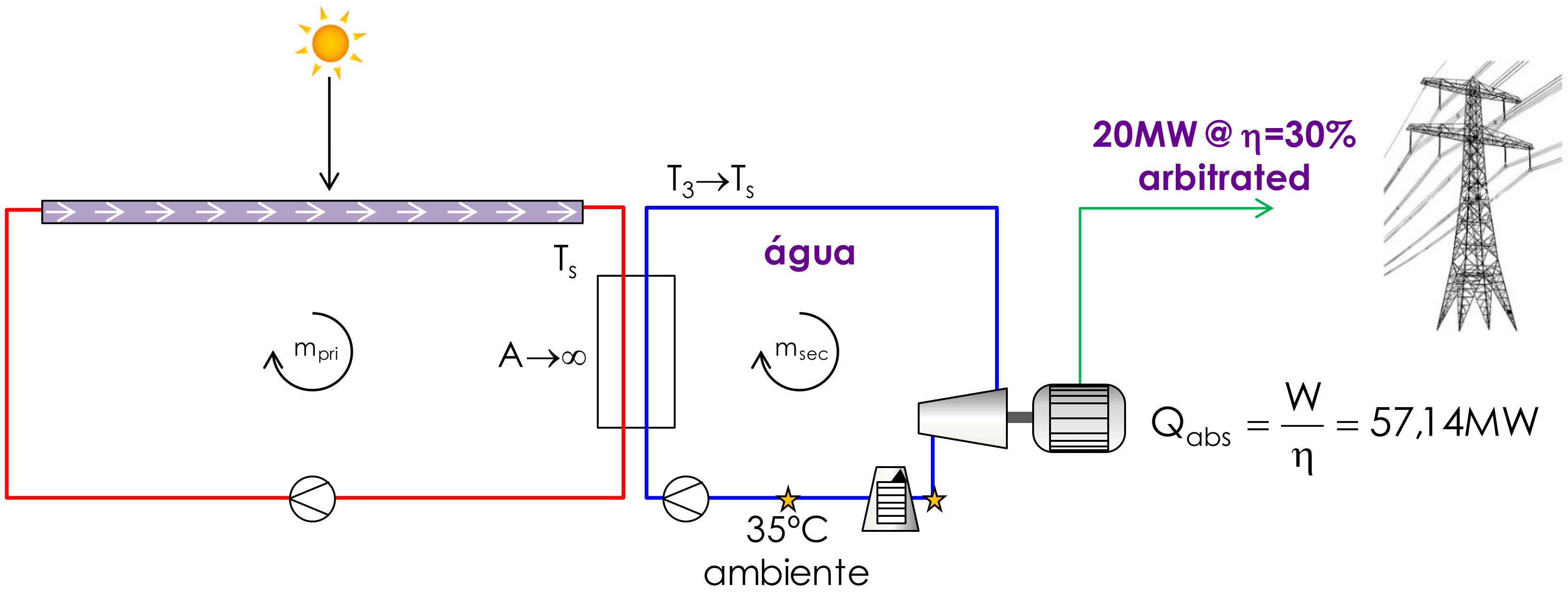
oil, liquid salt, etc.

Obs.: Área $\rightarrow \infty \Rightarrow T_3 \rightarrow T_s$

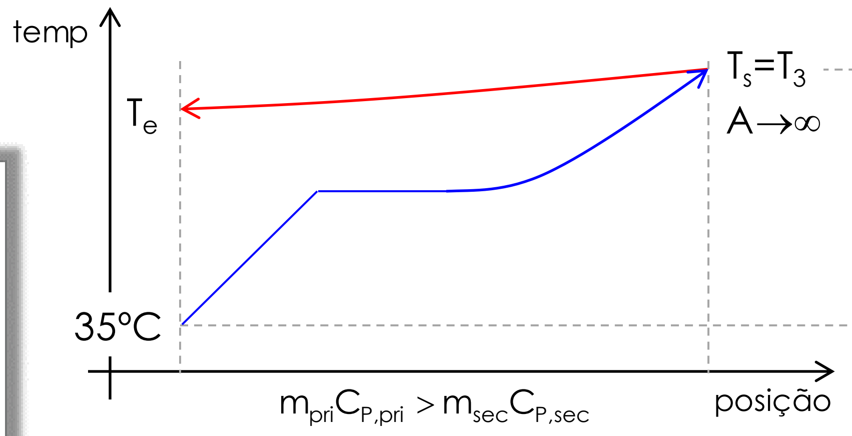
Conceptual design of a Thermosolar power plant …

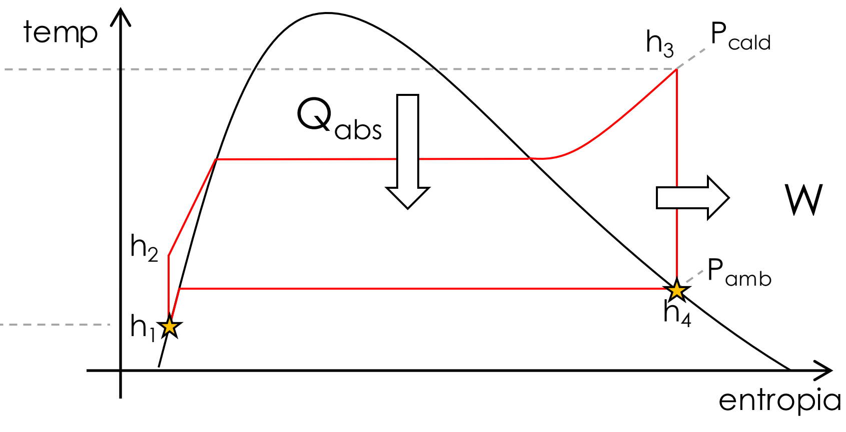
CONCEPTUAL DESIGN OF A THERMOSOLAR POWER PLANT…

Sizing the collectors / arbitrated performance

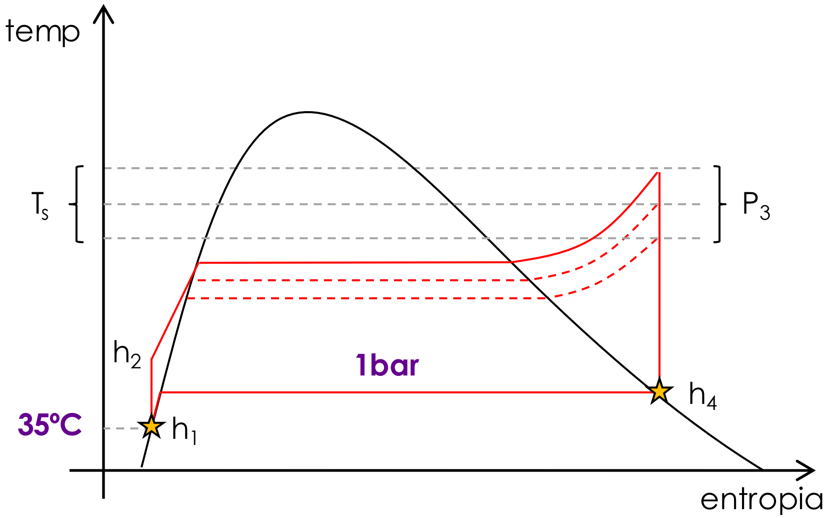


$$Q_{abs} = \frac{W}{\eta} = 57{,}14\text{MW}$$



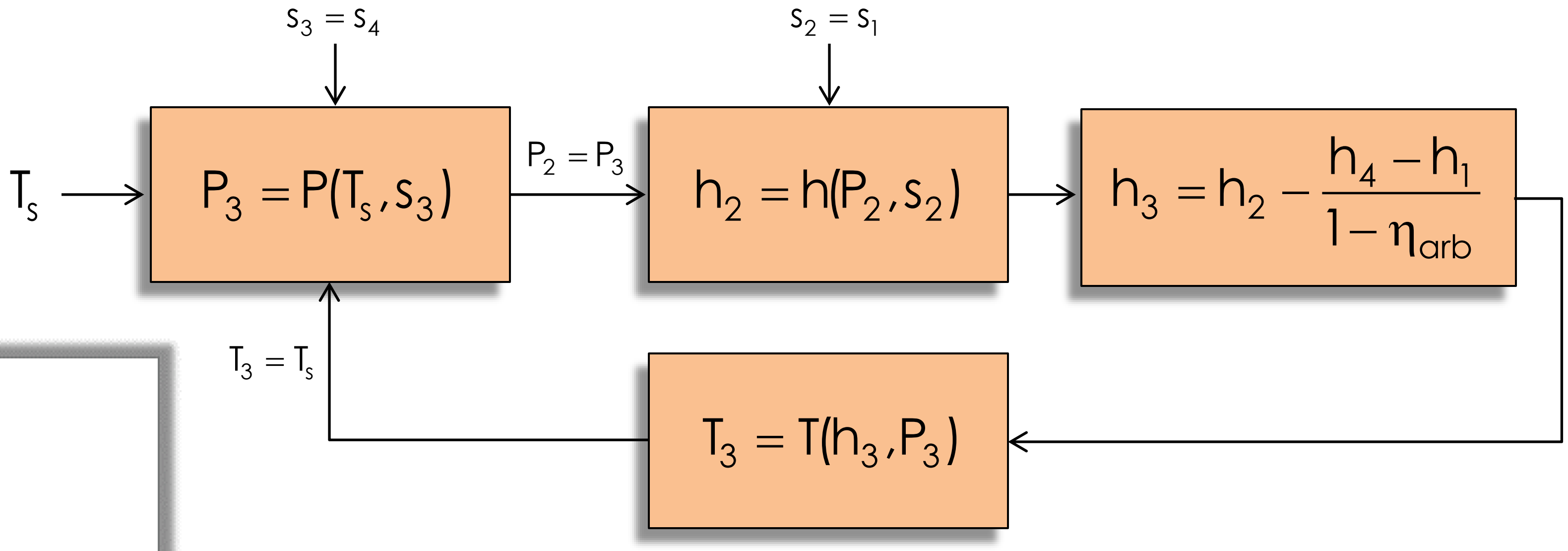


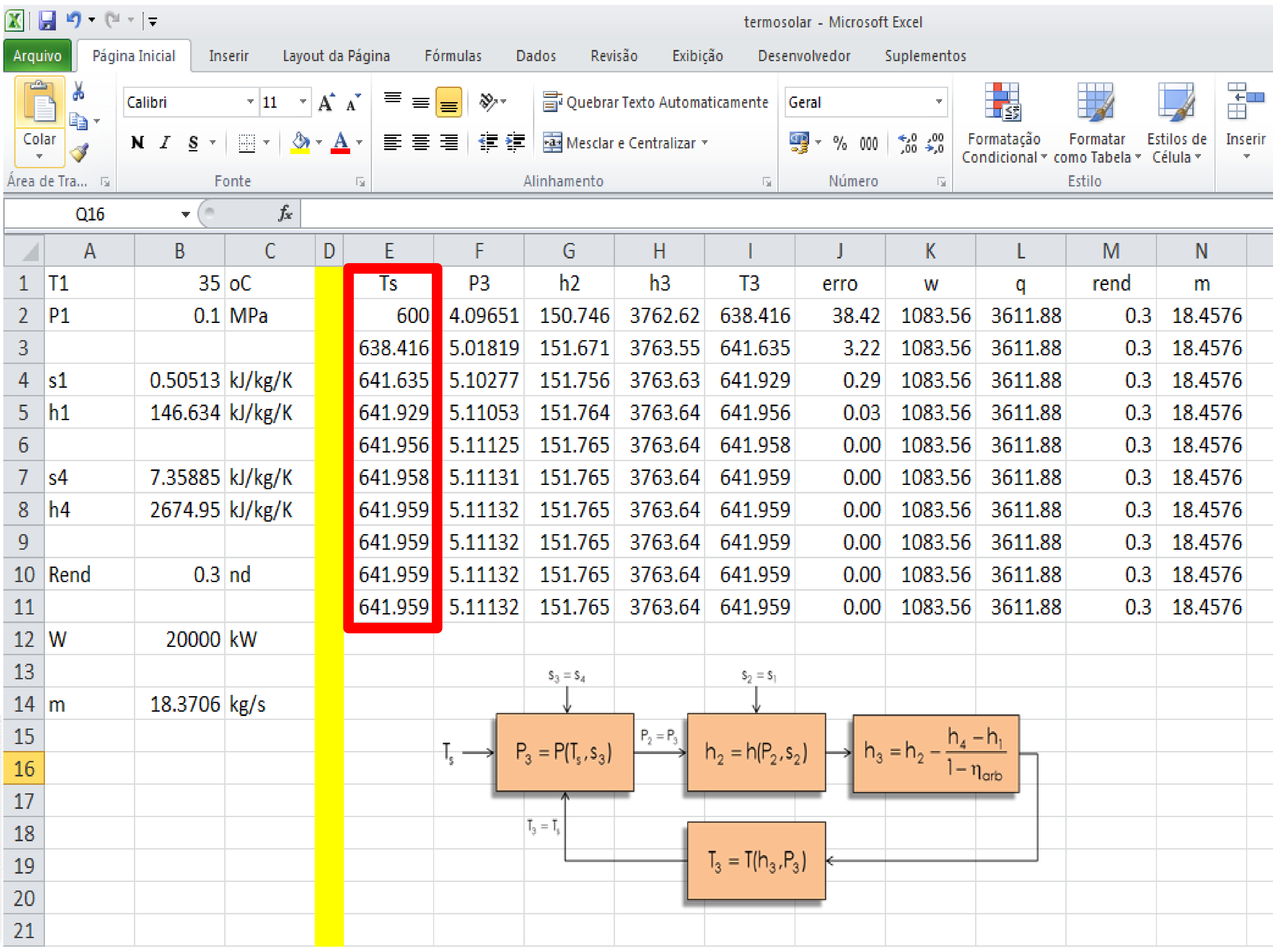
CONCEPTUAL DESIGN OF A THERMOSOLAR POWER PLANT...



$$\eta = \frac{W}{Q_{abs}} = \frac{(h_3 - h_4) - (h_2 - h_1)}{h_3 - h_2} = \eta_{arb}$$

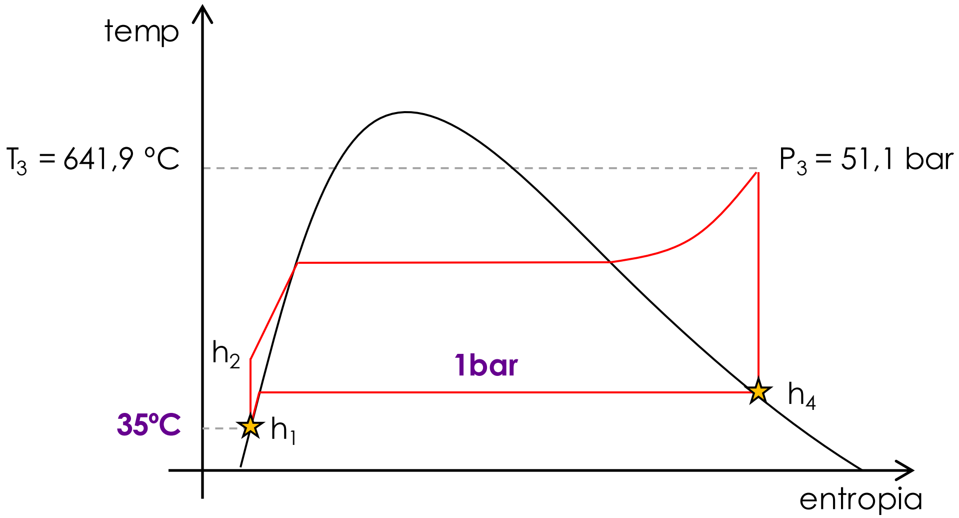
$$h_3 = h_2 - \frac{h_4 - h_1}{1 - \eta_{arb}}$$





	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	T1	35	oC		Ts	P3	h2	h3	T3	erro	w	q	rend	m
2	P1	0.1	MPa		600	4.09651	150.746	3762.62	638.416	38.42	1083.56	3611.88	0.3	18.4576
3					638.416	5.01819	151.671	3763.55	641.635	3.22	1083.56	3611.88	0.3	18.4576
4	s1	0.50513	kJ/kg/K		641.635	5.10277	151.756	3763.63	641.929	0.29	1083.56	3611.88	0.3	18.4576
5	h1	146.634	kJ/kg/K		641.929	5.11053	151.764	3763.64	641.956	0.03	1083.56	3611.88	0.3	18.4576
6					641.956	5.11125	151.765	3763.64	641.958	0.00	1083.56	3611.88	0.3	18.4576
7	s4	7.35885	kJ/kg/K		641.958	5.11131	151.765	3763.64	641.959	0.00	1083.56	3611.88	0.3	18.4576
8	h4	2674.95	kJ/kg/K		641.959	5.11132	151.765	3763.64	641.959	0.00	1083.56	3611.88	0.3	18.4576
9					641.959	5.11132	151.765	3763.64	641.959	0.00	1083.56	3611.88	0.3	18.4576
10	Rend	0.3	nd		641.959	5.11132	151.765	3763.64	641.959	0.00	1083.56	3611.88	0.3	18.4576
11					641.959	5.11132	151.765	3763.64	641.959	0.00	1083.56	3611.88	0.3	18.4576
12	W	20000	kW											
13														
14	m	18.3706	kg/s											

CONCEPTUAL DESIGN OF A THERMOSOLAR POWER PLANT…



$$\eta = \frac{W}{Q_{abs}} = \frac{h_3 - h_4}{h_3 - h_2} = \eta_{arb}$$

$$T_s = 641{,}95\,^{\circ}C$$

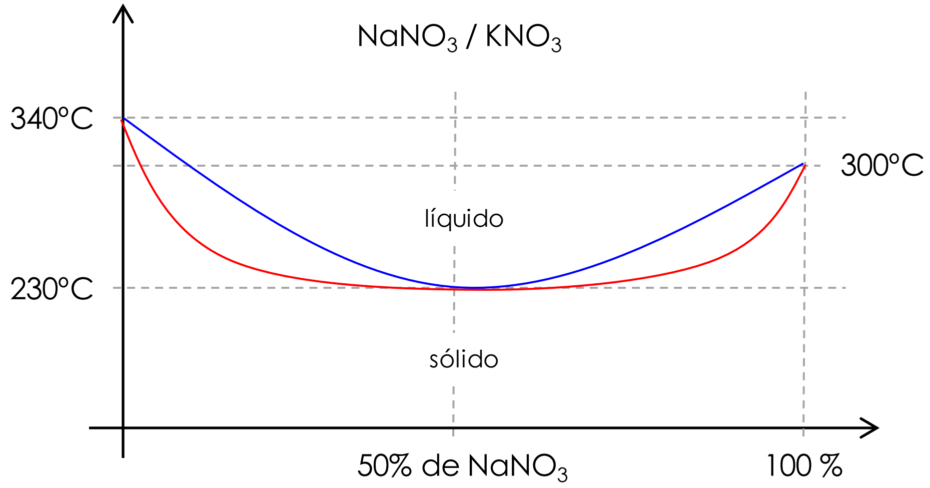
Due to the very high temperature it is necessary to work with liquid salt

$$m_{sec} = \frac{W}{(h_3 - h_4) - (h_2 - h_1)}$$

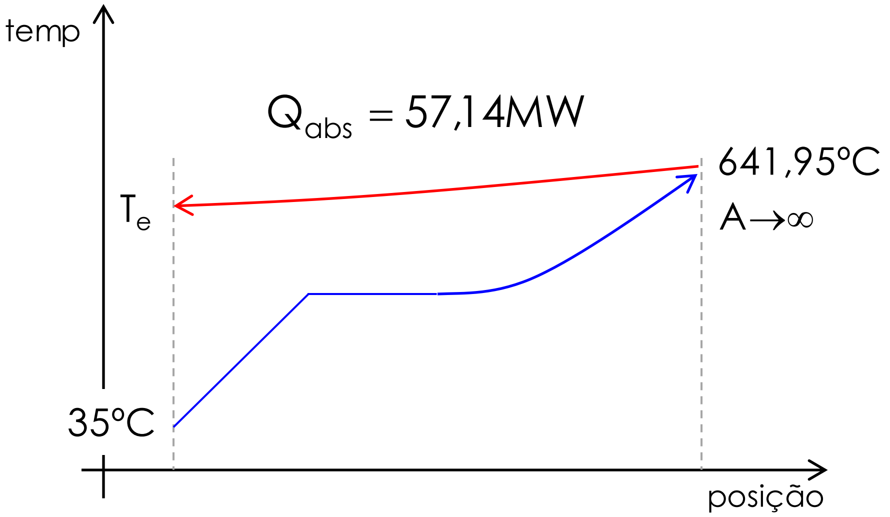
$$m_{sec} = 18{,}46 kg/s$$

⇩

$$T_2 > T_{fusão}$$



CONCEPTUAL DESIGN OF A THERMOSOLAR POWER PLANT…

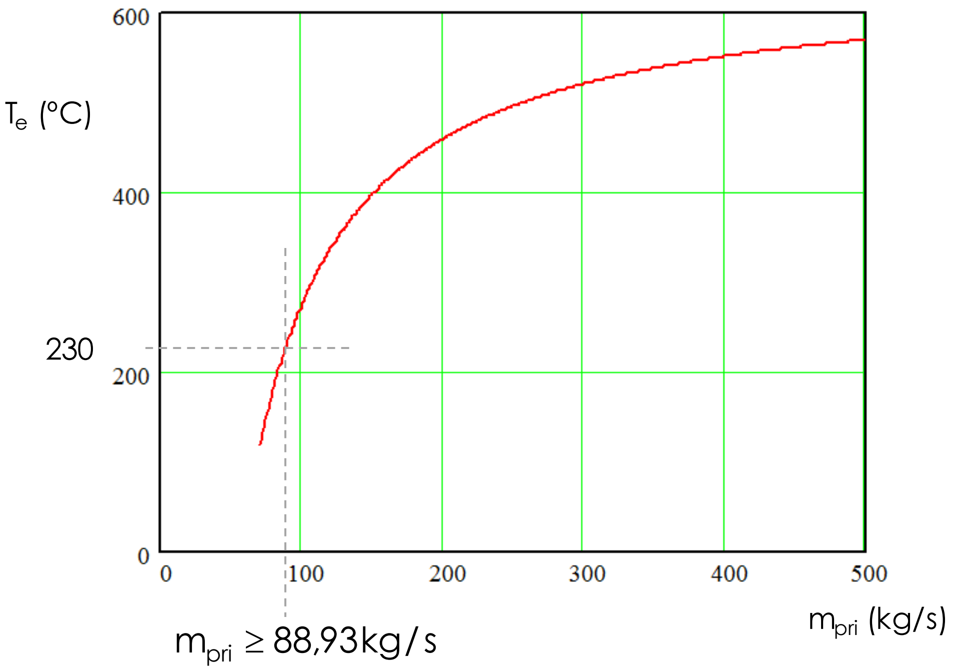


$$Q_{abs} = m_{pri} C_{P,pri} \cdot (T_s - T_e)$$

$$T_e = T_s - \frac{Q_{abs}}{m_{pri} C_{P,pri}}$$

$$C_{sal} = 1{,}56\,kJ/kg/K$$

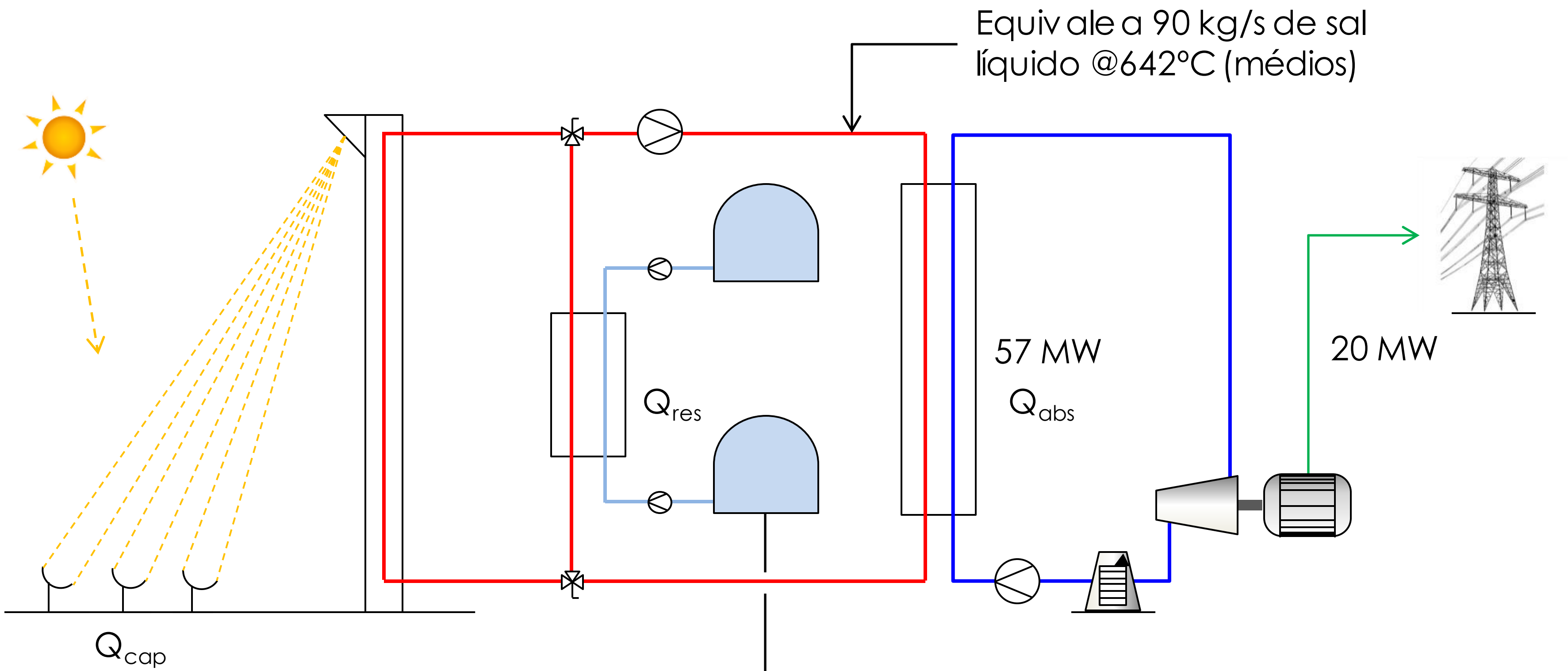
50% $NaNO_3$
50% KNO_3



Obs.: it is necessary to specify an "unfreezing" system for the salt in case of shut down…

Obs.: it is necessary to specify a thermal storage system capable of compensating variations of sun's absorbed energy so as to maintain a constant heat supply to the secondary during the nights…

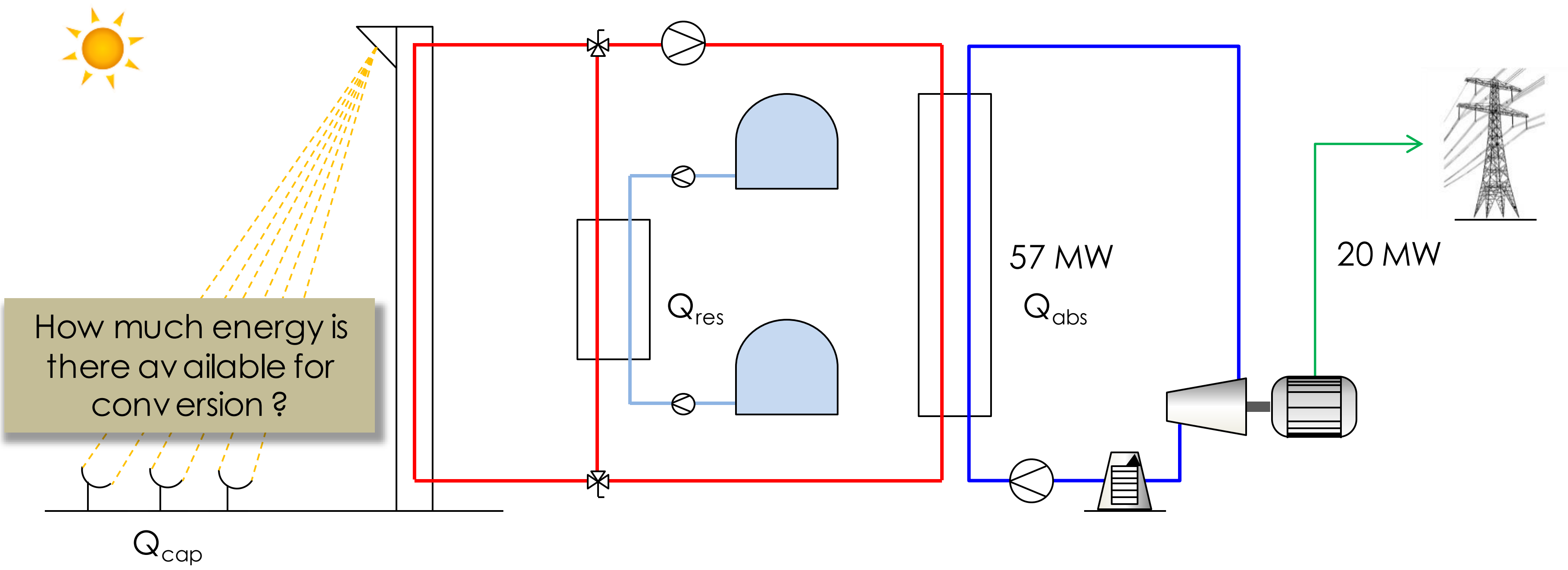
CONCEPTUAL DESIGN OF A THERMOSOLAR POWER PLANT…



Varies with the latitude and the position of the earth with respect to the sun

The thermal storage system also compensates for deterministic annual and daily variations, as well as for random variations due to the presence of clouds, dust, etc.

CONCEPTUAL DESIGN OF A THERMOSOLAR POWER PLANT…

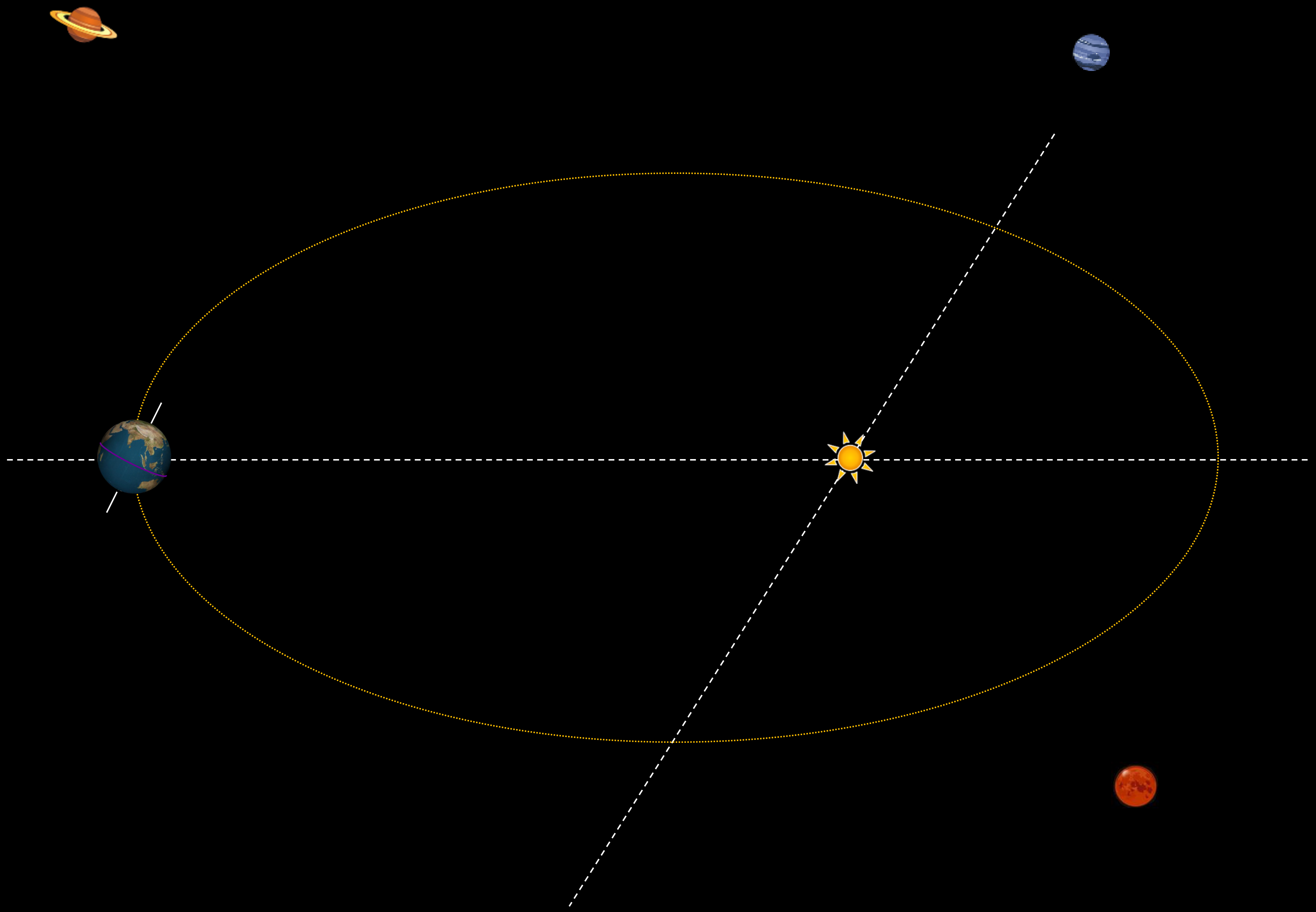


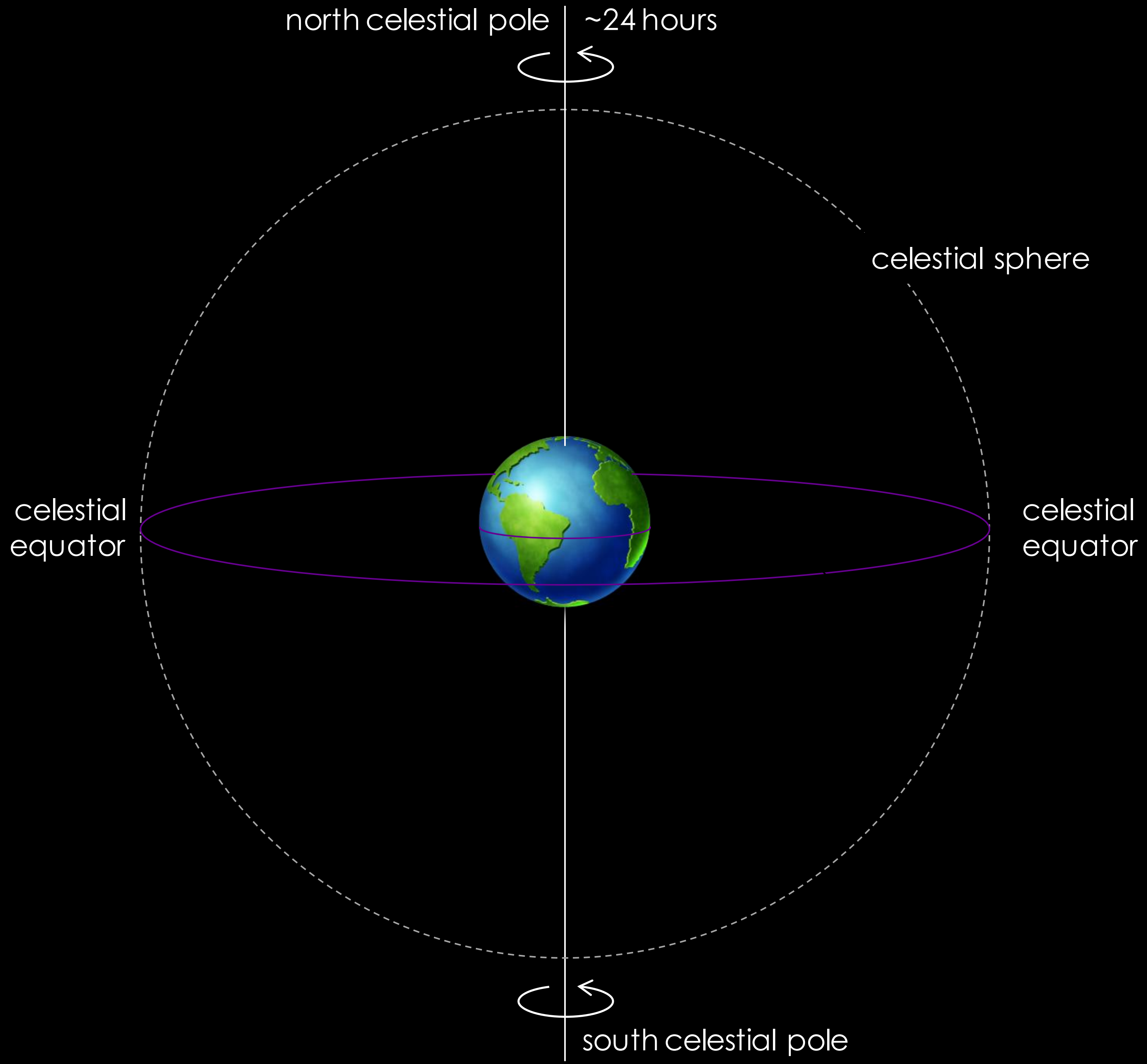
Average solar energy (W/m²) collected at earth's surface by a 2D collector placed at latitude ϕ, disregarding the presence of clouds and other random losses.

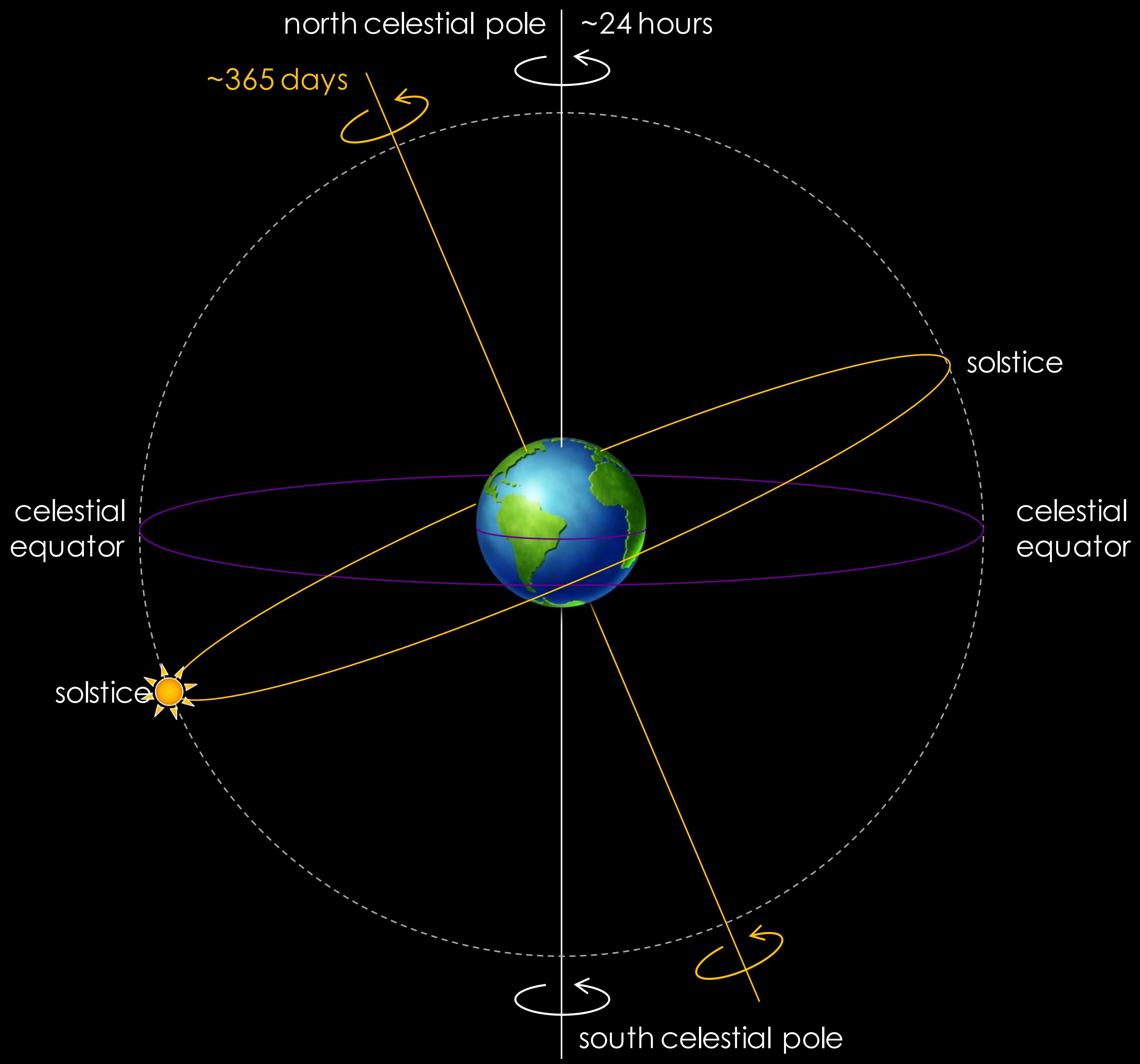
$$\overline{Q}_{cap}(\phi) \cong \frac{1}{365 \cdot 12} \int_{day} \int_{hour} \text{(solar energy)} \, d\varphi \, dn$$

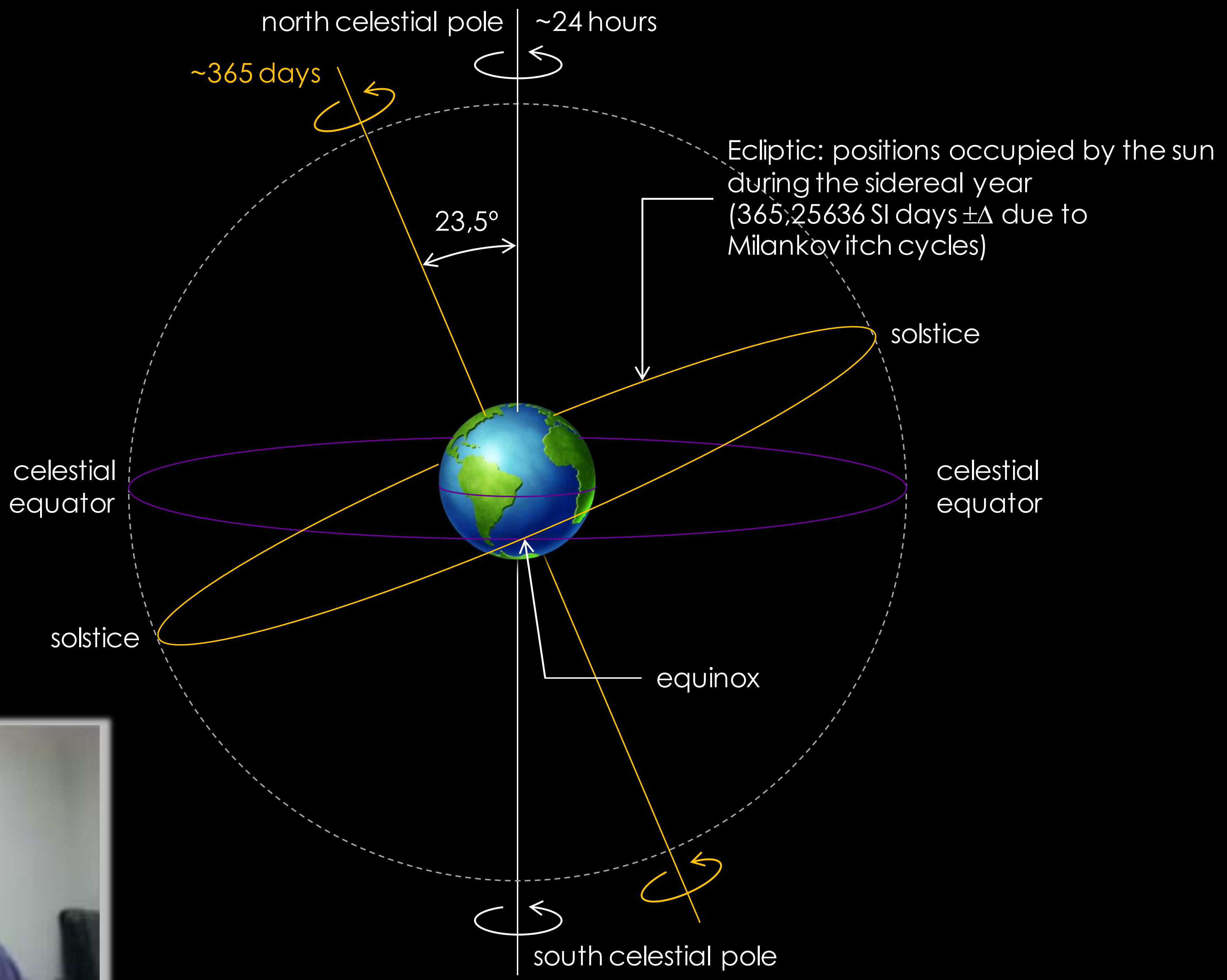
Celestial mechanics: calculating the motions of celestial objects.

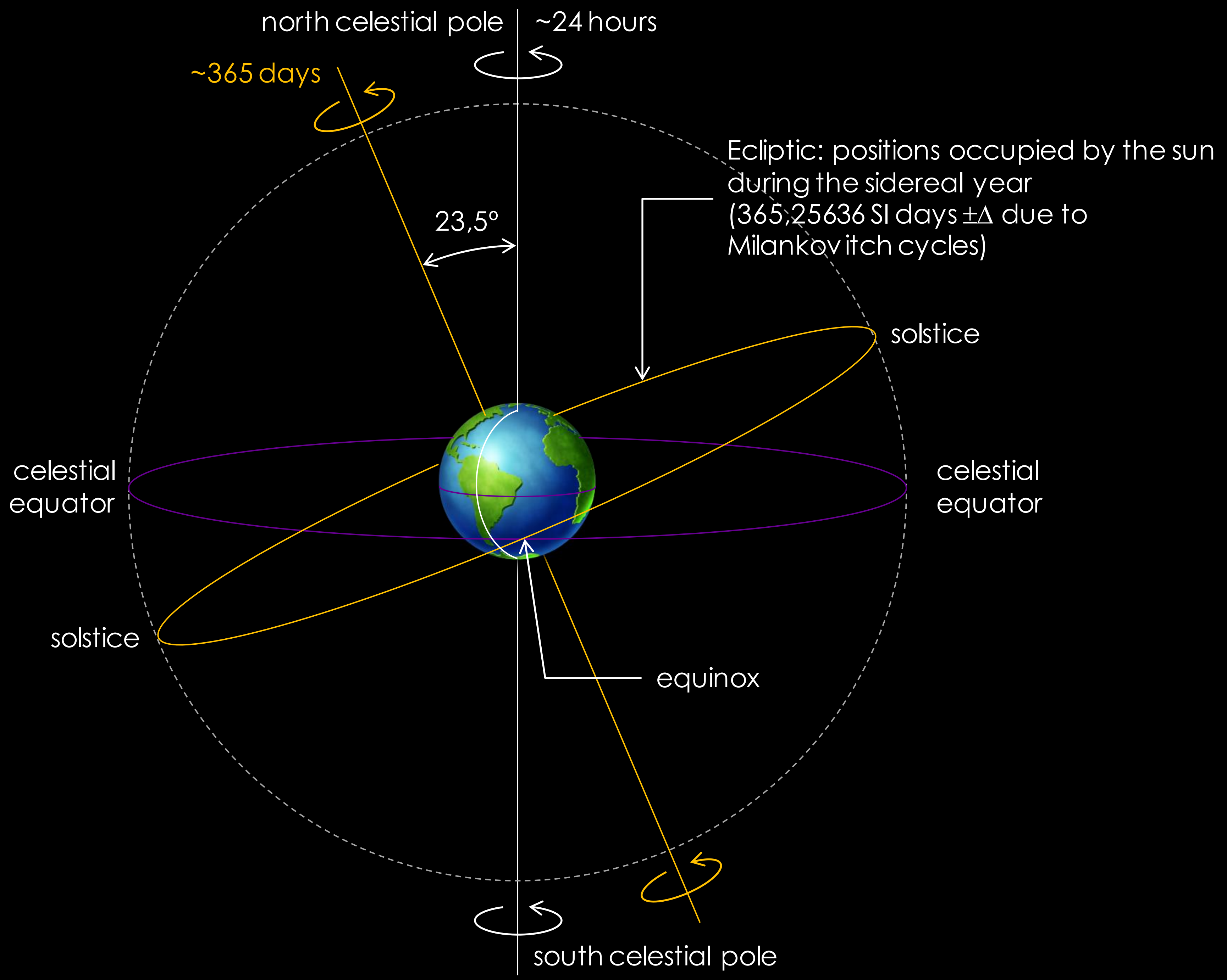
Tracking the sun…




north celestial pole
~24 hours
celestial sphere
celestial
equator
celestial
equator
south celestial pole


north celestial pole
~24 hours
~365 days
solstice
celestial equator
celestial equator
solstice
south celestial pole


north celestial pole
~24 hours
~365 days
23,5°
Ecliptic: positions occupied by the sun during the sidereal year (365,25636 SI days ±Δ due to Milankovitch cycles)
solstice
celestial equator
celestial equator
solstice
equinox
south celestial pole


north celestial pole
~24 hours
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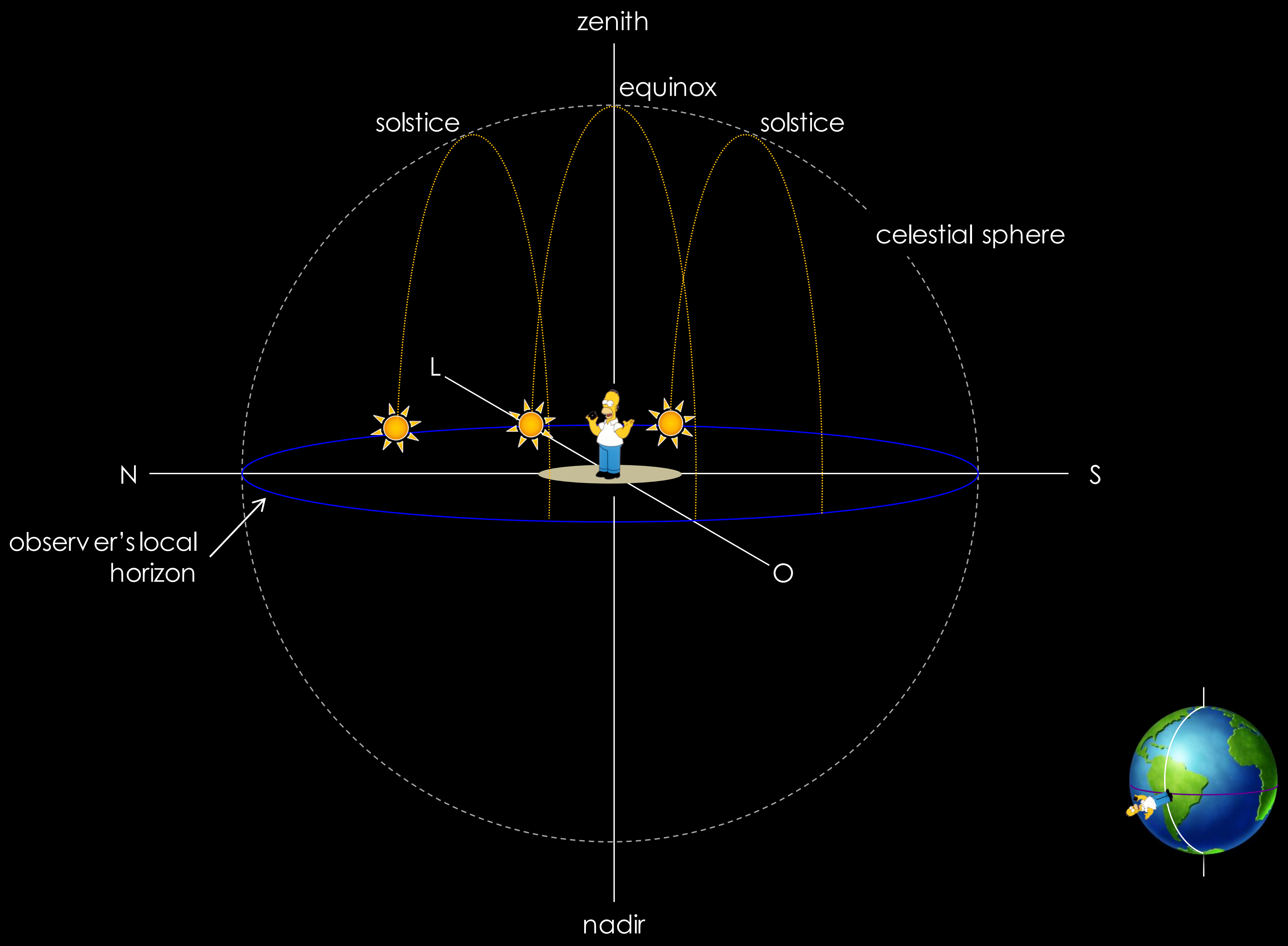
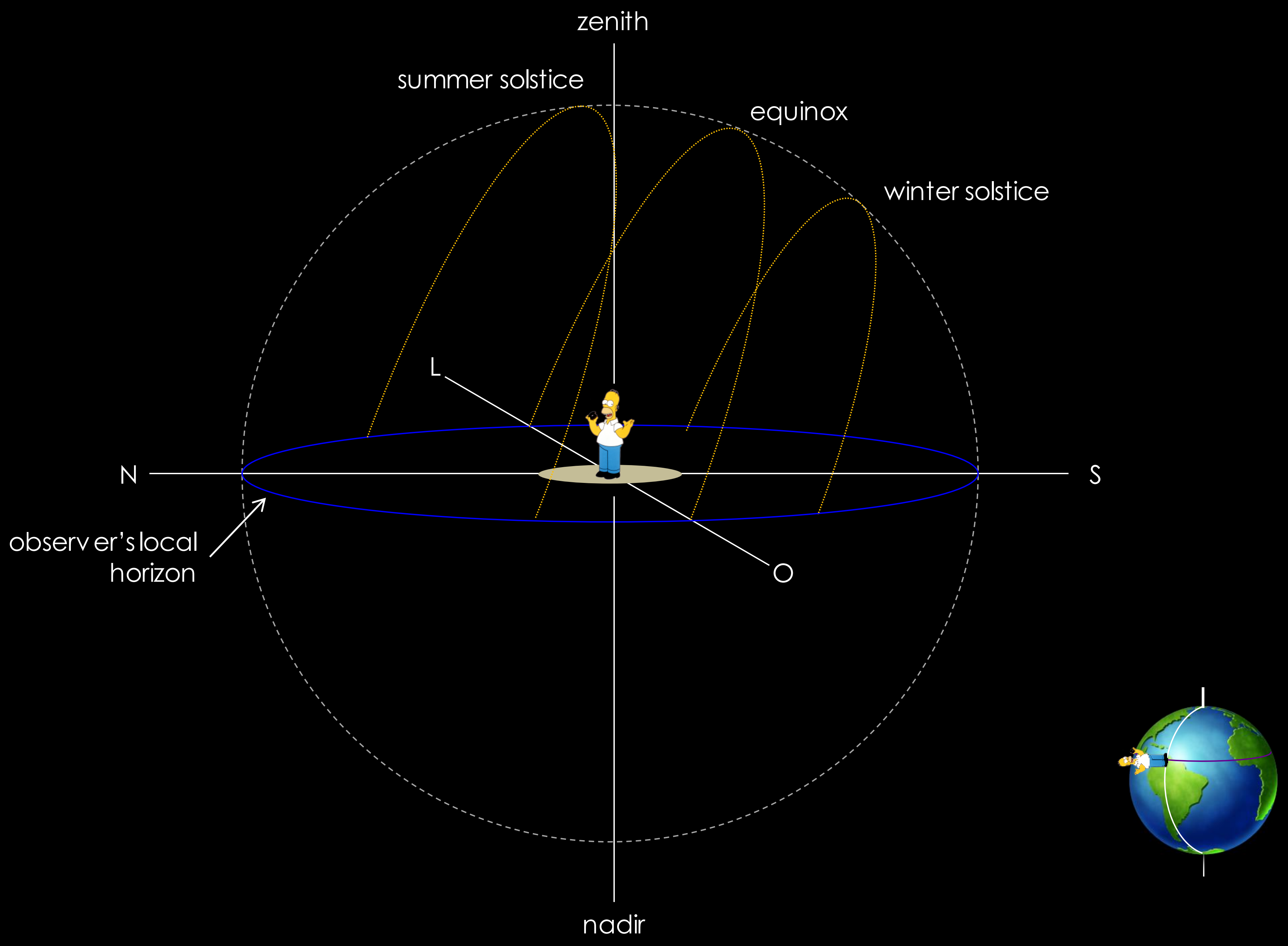
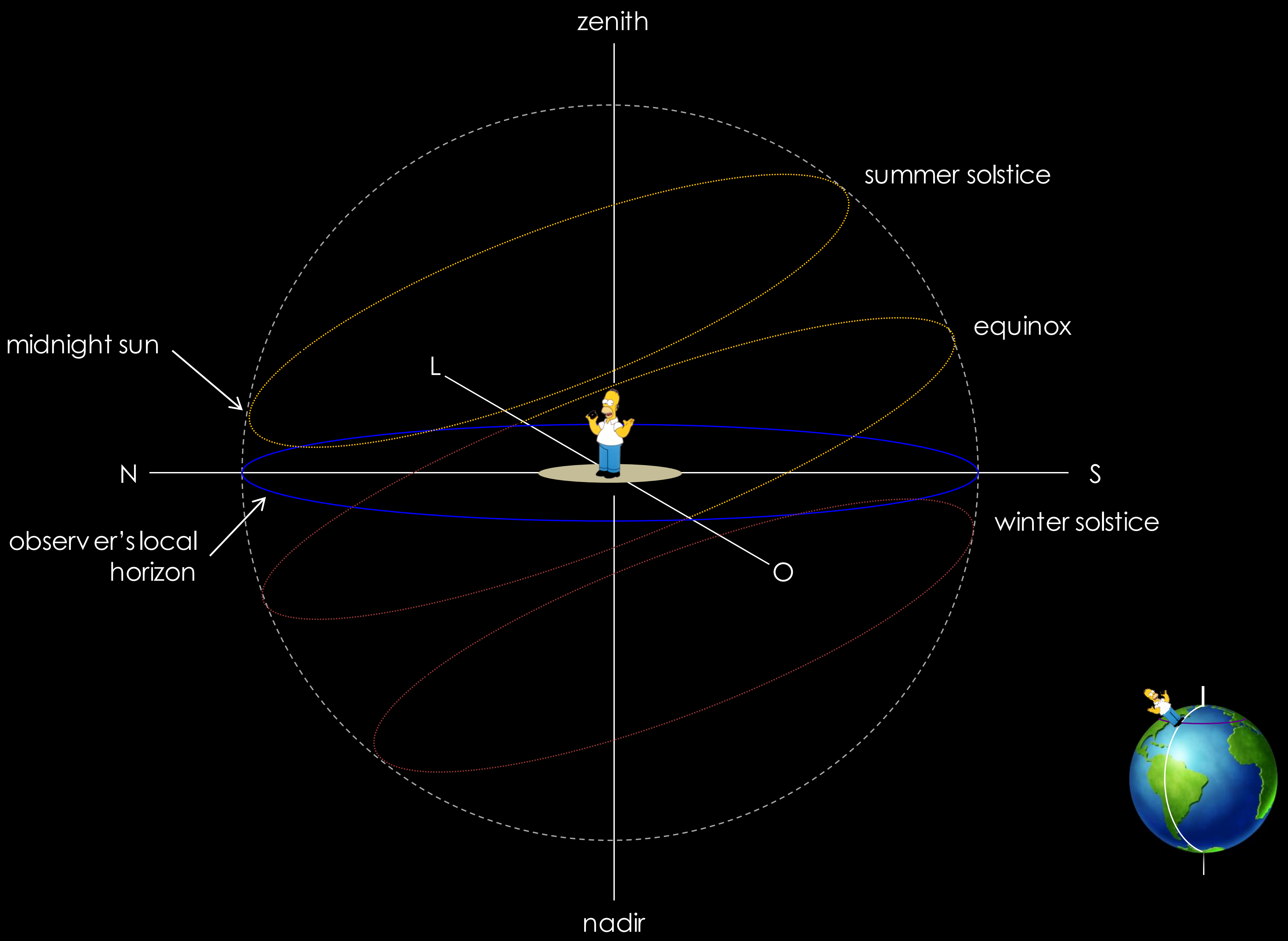
solstice
celestial equator
celestial equator
solstice
equinox
south celestial pole

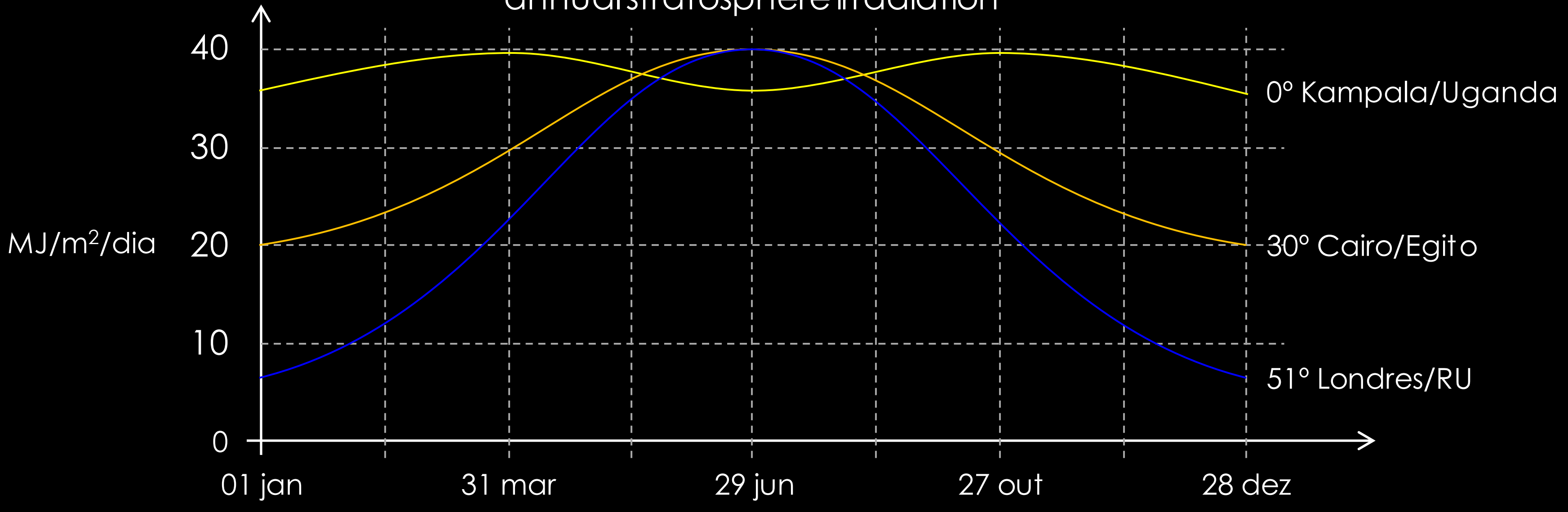
"A missionary of the Middle Ages tells that he had found the point where the sky and the Earth touch…"
Camille Flammarion's 1888 L'atmosphère: météorologie populaire

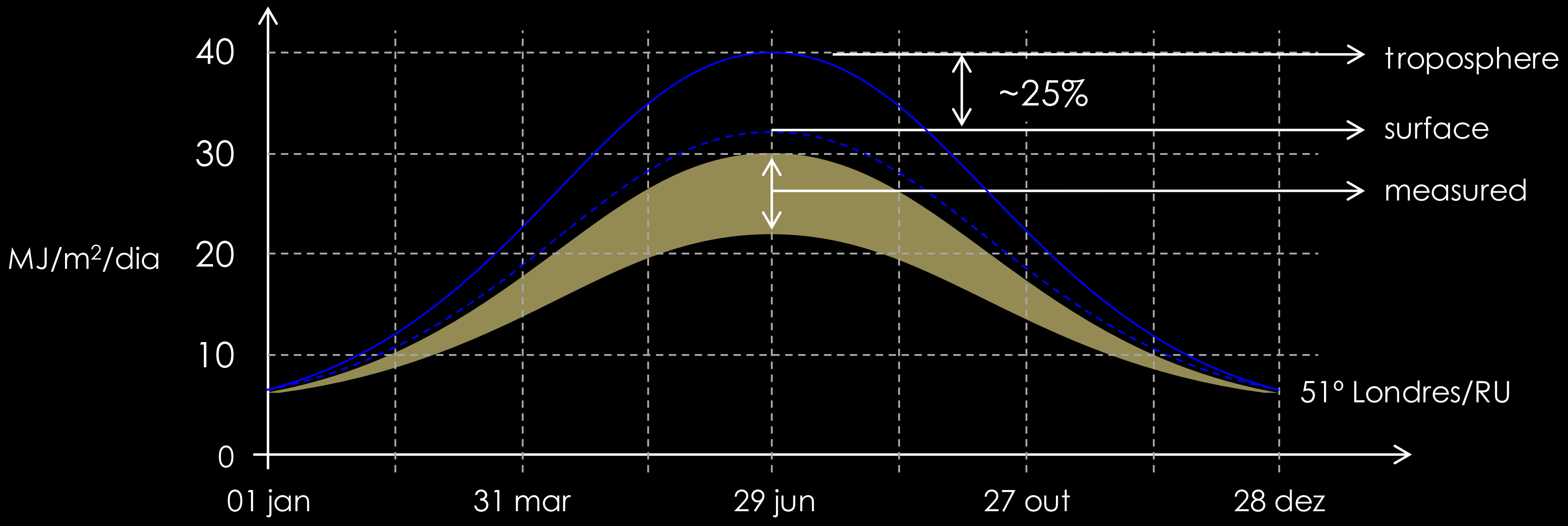

zenith
equinox
solstice
solstice
celestial sphere
L
N
S
O
observ er's local
horizon
nadir

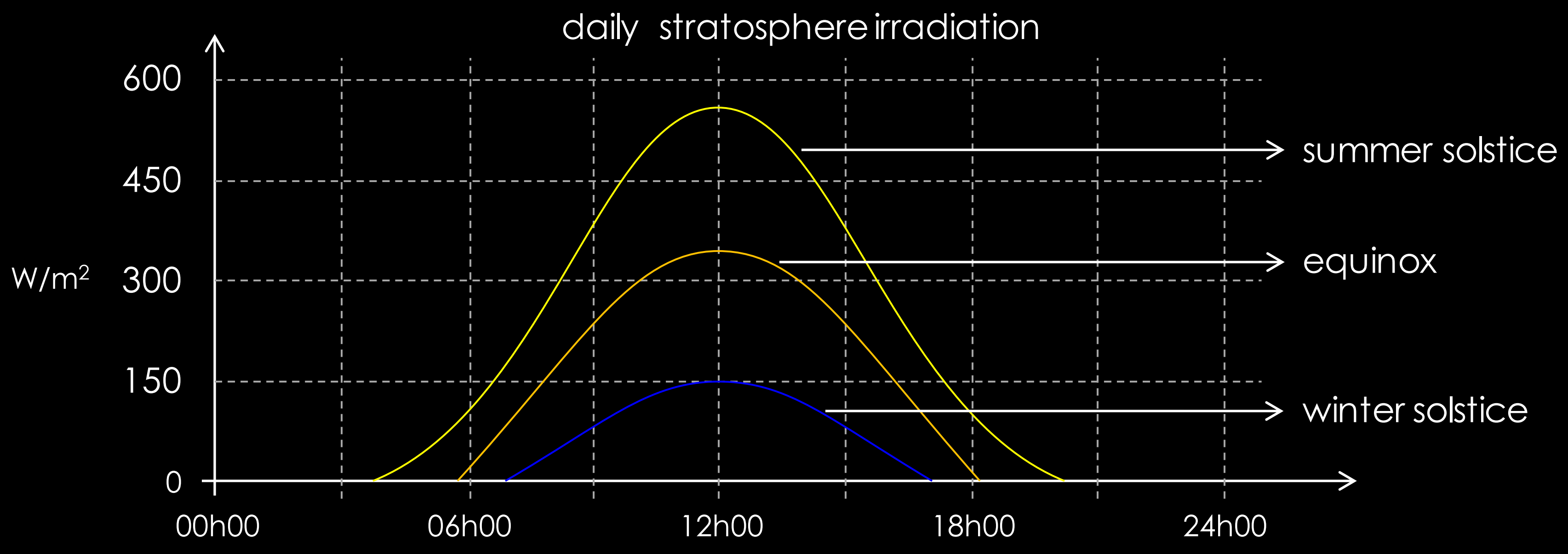

zenith
summer solstice
equinox
winter solstice
L
N
S
O
observ er's local
horizon
nadir


zenith
summer solstice
equinox
midnight sun
L
N
S
winter solstice
observ er's local
horizon
O
nadir

annual stratosphere irradiation







Incident solar energy main influencing factors...

day of the year
- Distance from the sun (earth's orbit eccentricity)
- Sun's position on the eclitic (solstice / equinox)

hour of the day
- incidence angle
- atmospheric absorption

- Random (clouds, aerosols, polutition, etc.) – capacity factor

Definitions and working formulae...

Observer's and sun's equatorial coordinates

Sun's horizontal coordinates / observer = (0,0)

Solar versor (direction of the line joining the sun and the observer)

Calculus of the solar versor in function of the observer's position (latitude and longitude) and the date; hour of the day (hour angle) + day of the year (declination)

Calculus of the solar maximum incident irradiation on a point of earth's surface in function of the date…

Definitions and working formulae...

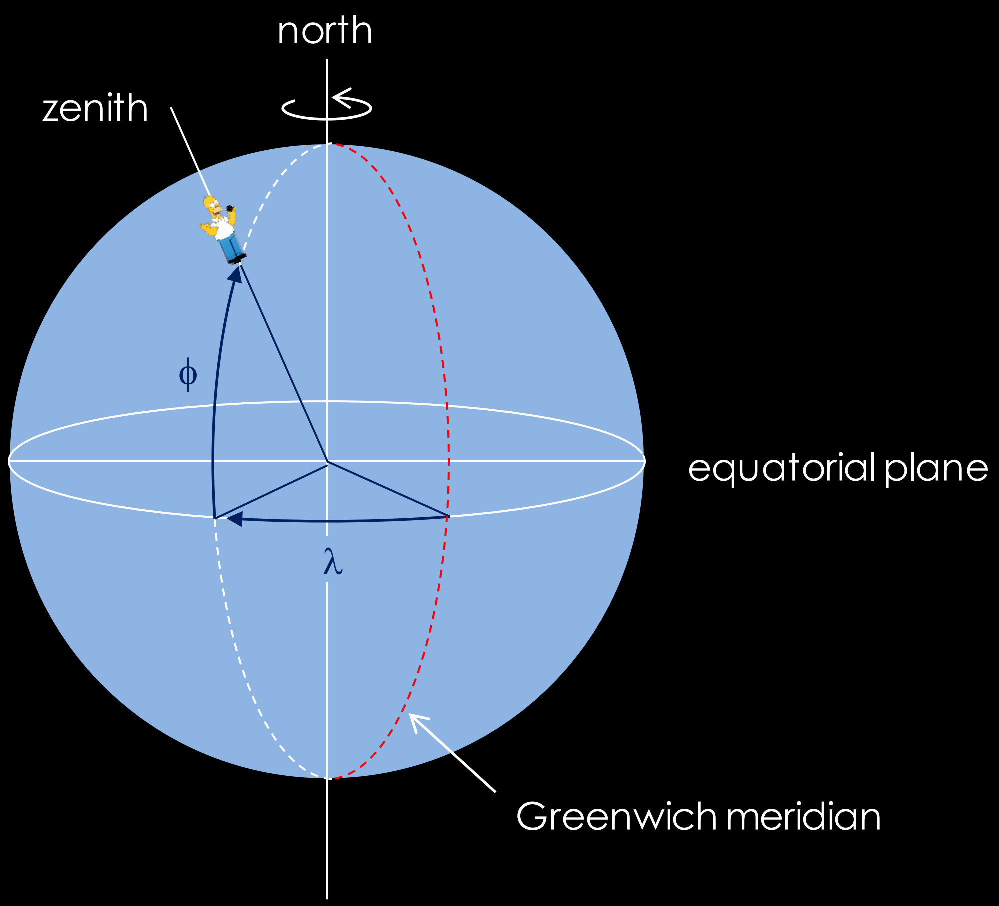
OBSERVER'S **EQUATORIAL** COORDINATES

ϕ = latitude

λ = longitude

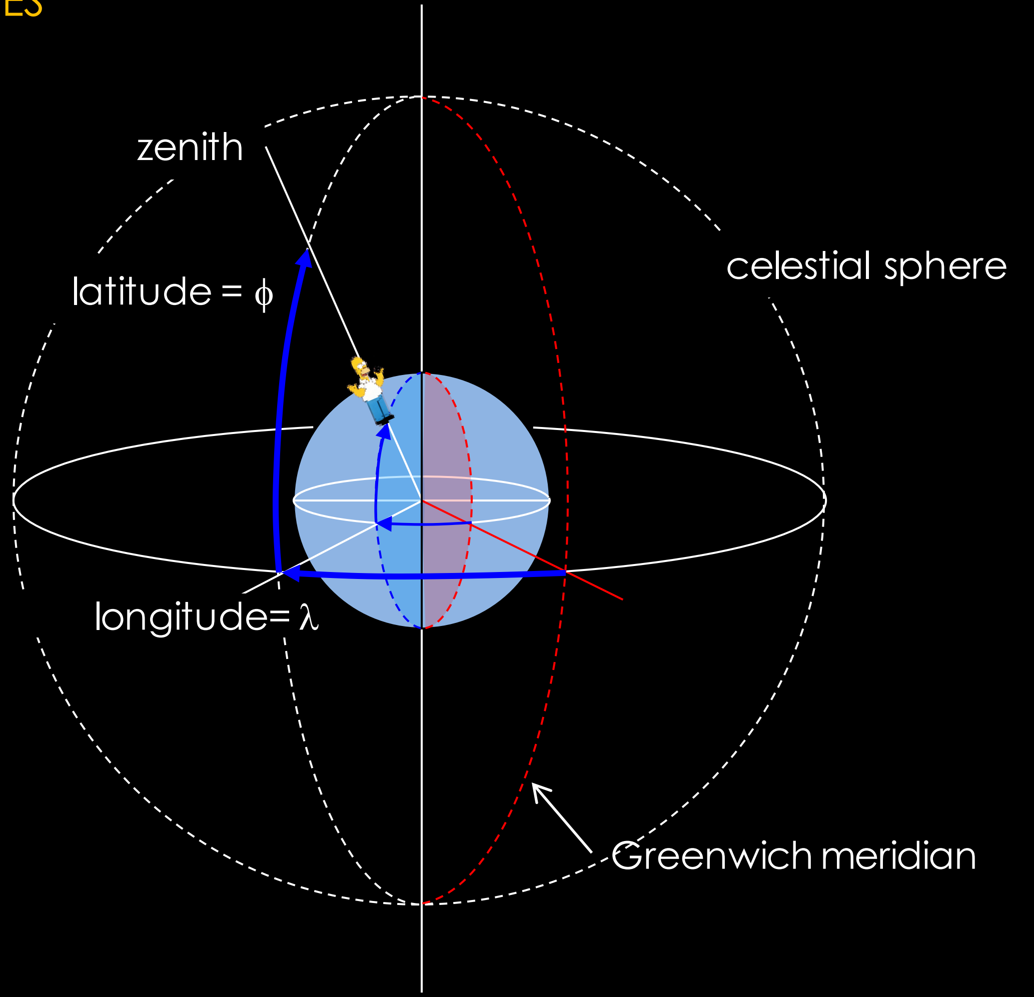
Greenwich ≡ 0°

Greenwich ≡ 12h00



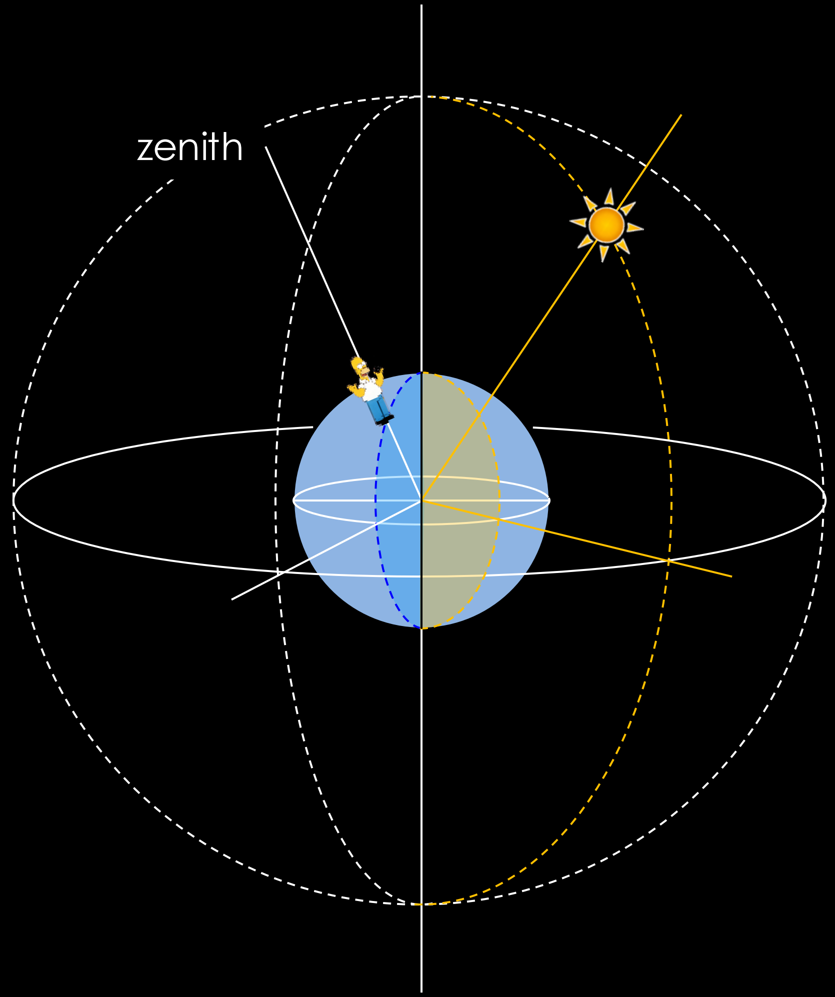
Definitions and working formulae...

OBSERVER'S **EQUATORIAL** COORDINATES



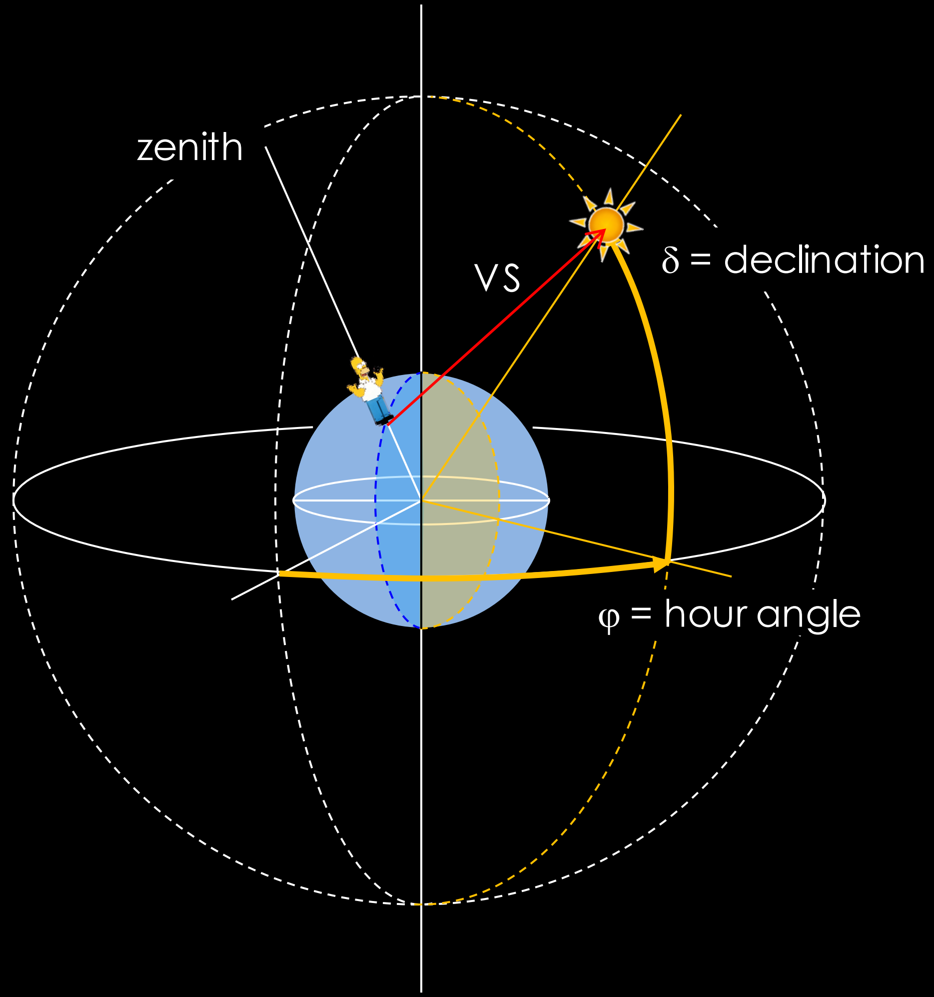
Definitions and working formulae...

SUN'S **EQUATORIAL** COORDINATES



Definitions and working formulae...

SUN'S **EQUATORIAL** COORDINATES



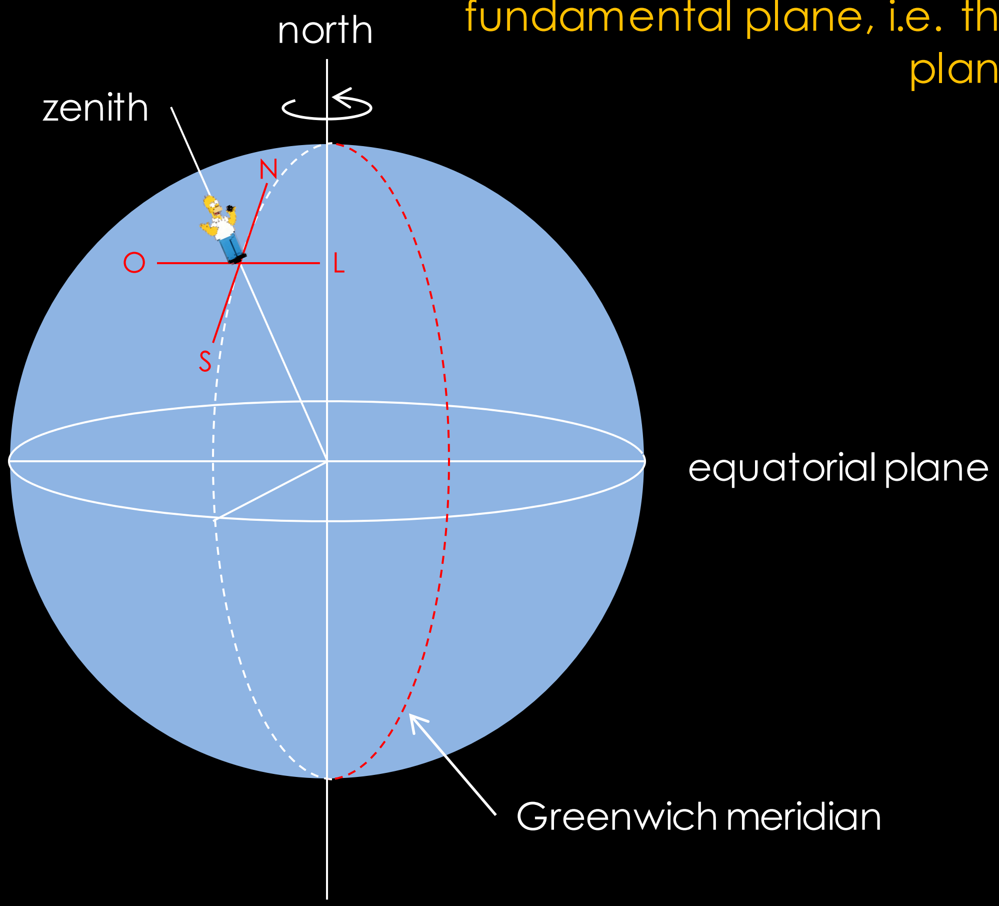
Obs.: depends on the day of the year

Obs.: depends on the hour of the day (local hour; 12h00 → φ = 0)

Definitions and working formulae...

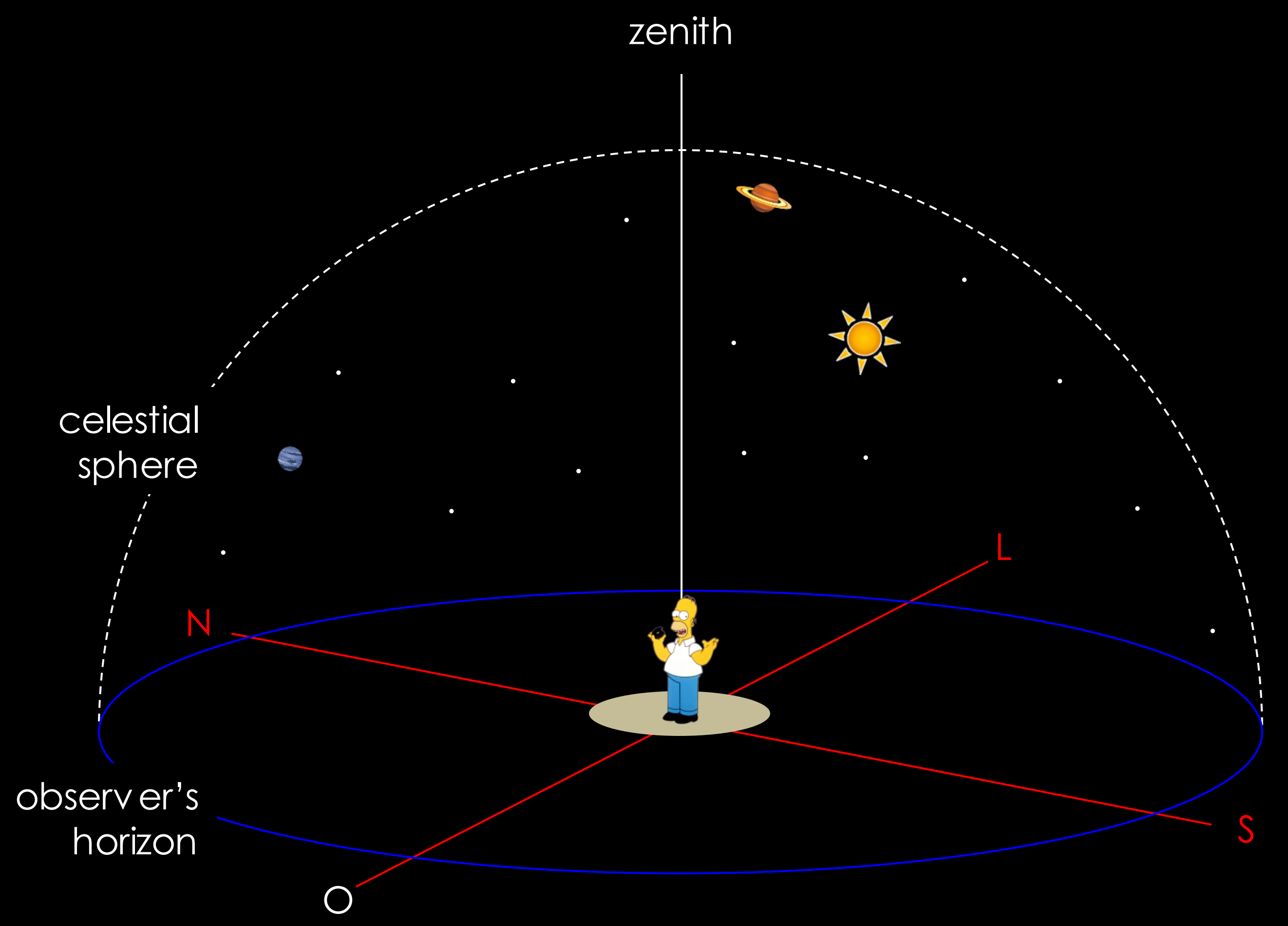
SUN'S **HORIZONTAL** COORDINATES

Utilizes the observer's local horizon as the fundamental plane, i.e. the plane that divides the planet in two hemispheres...



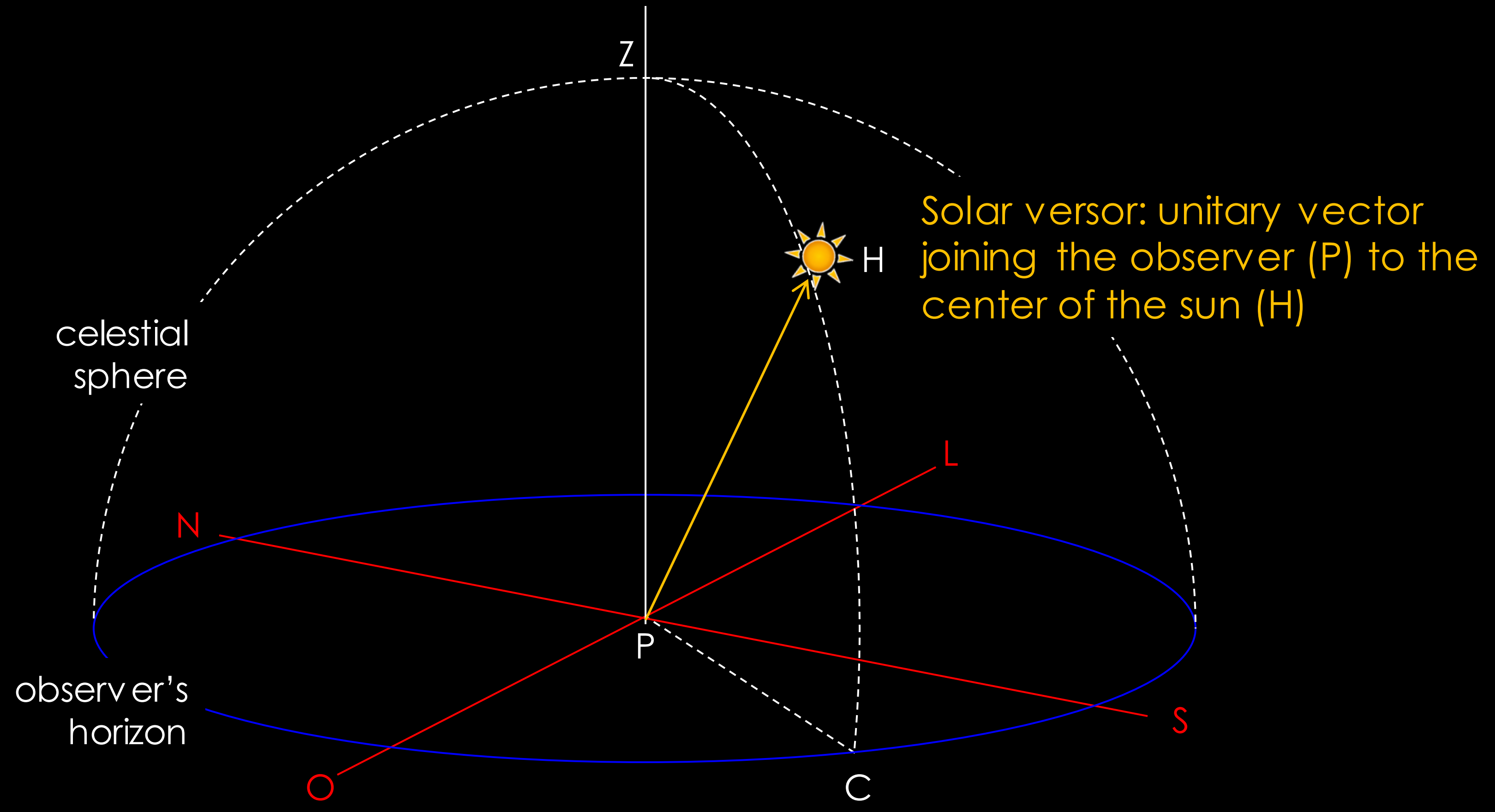
Definitions and working formulae...

SUN'S **HORIZONTAL** COORDINATES



Definitions and working formulae...

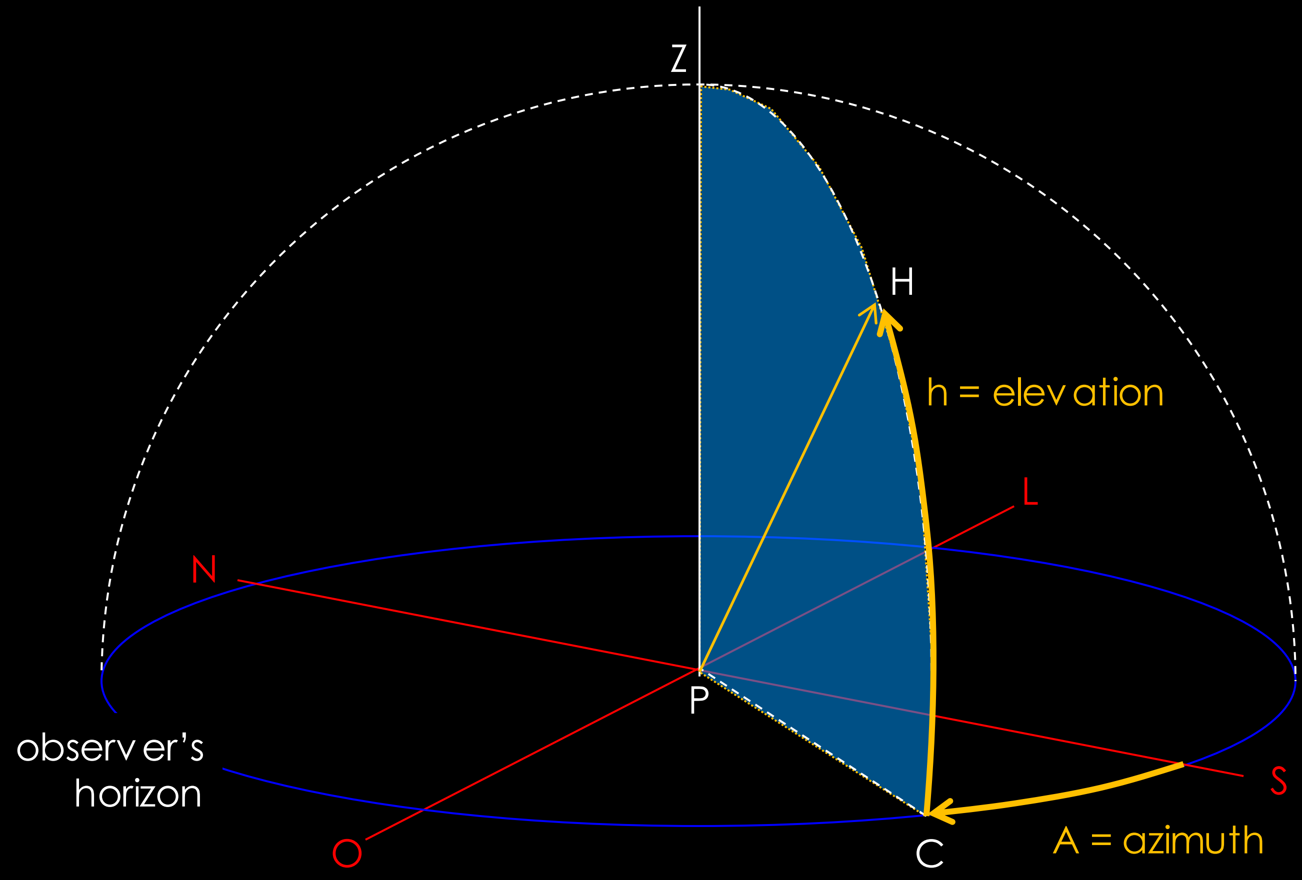
SUN'S **HORIZONTAL** COORDINATES



Definitions and working formulae...

SUN'S **HORIZONTAL** COORDINATES

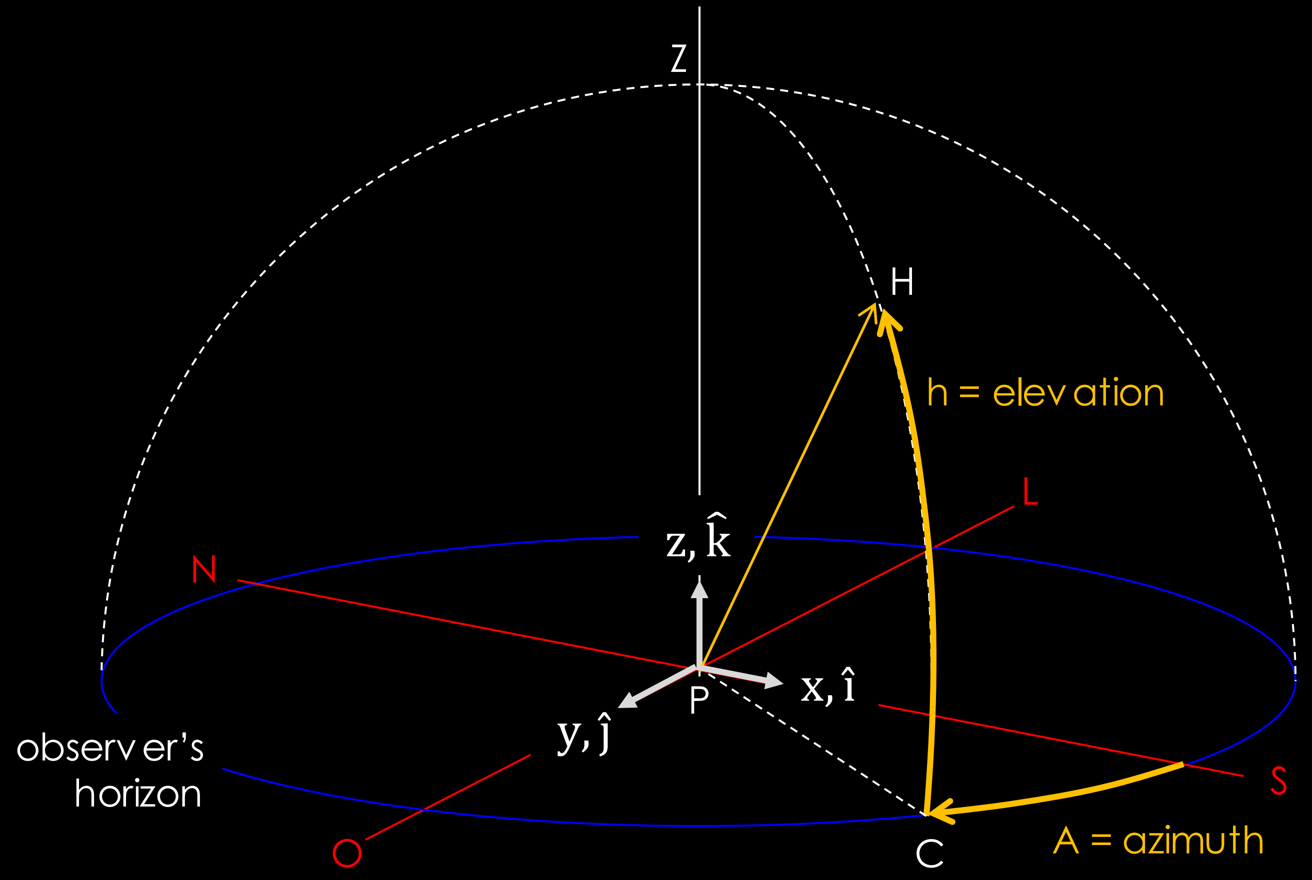
The elevation and azimuth depend on the observer's position (latitude and longitude) and vary in time due to earth rotation



Definitions and working formulae...

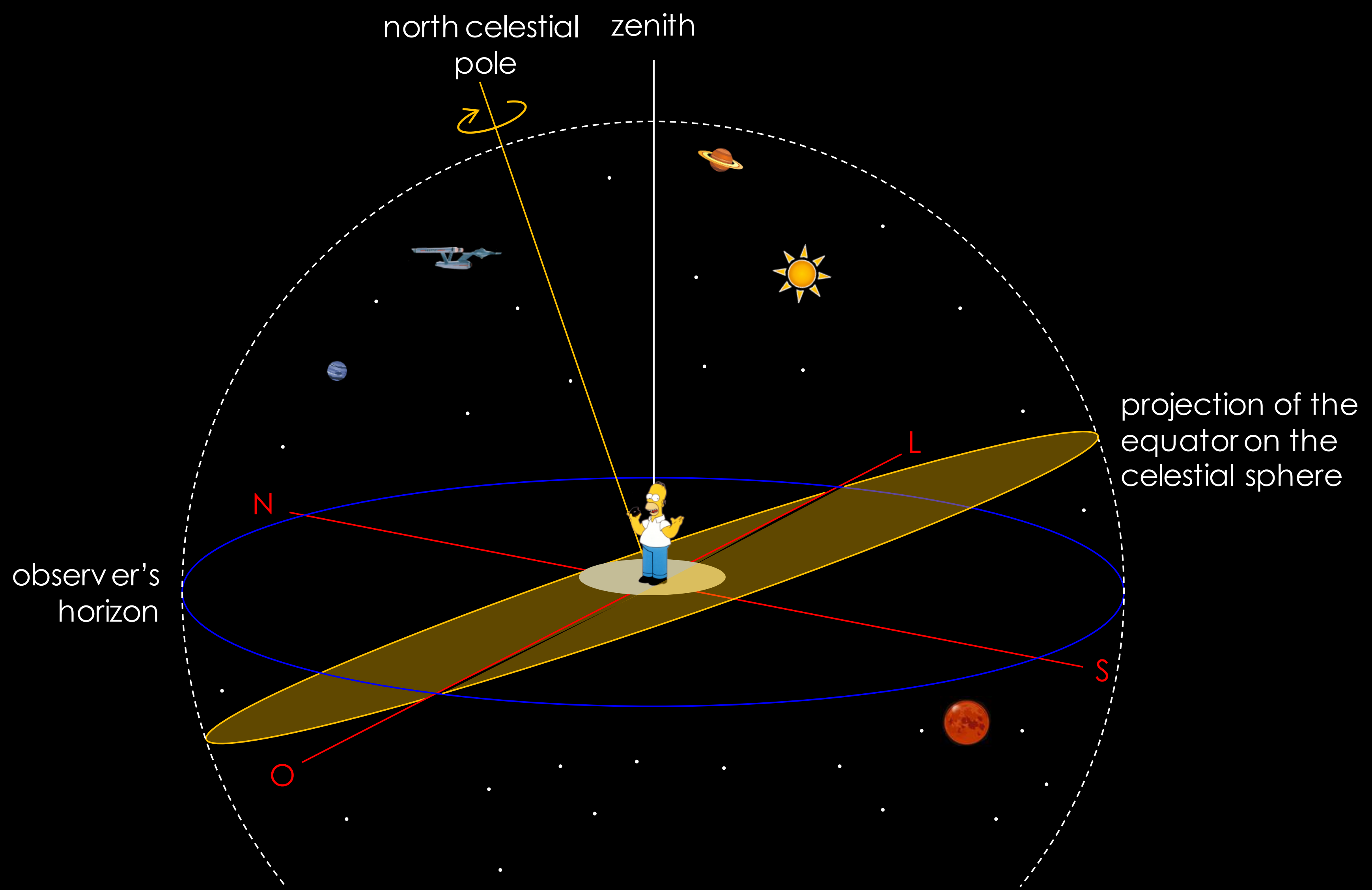
SUN'S **HORIZONTAL** COORDINATES

$$VS = \cos h \cos A\, \hat{\imath} + \cos h \sin A\, \hat{\jmath} + \sin h\, \hat{k}$$



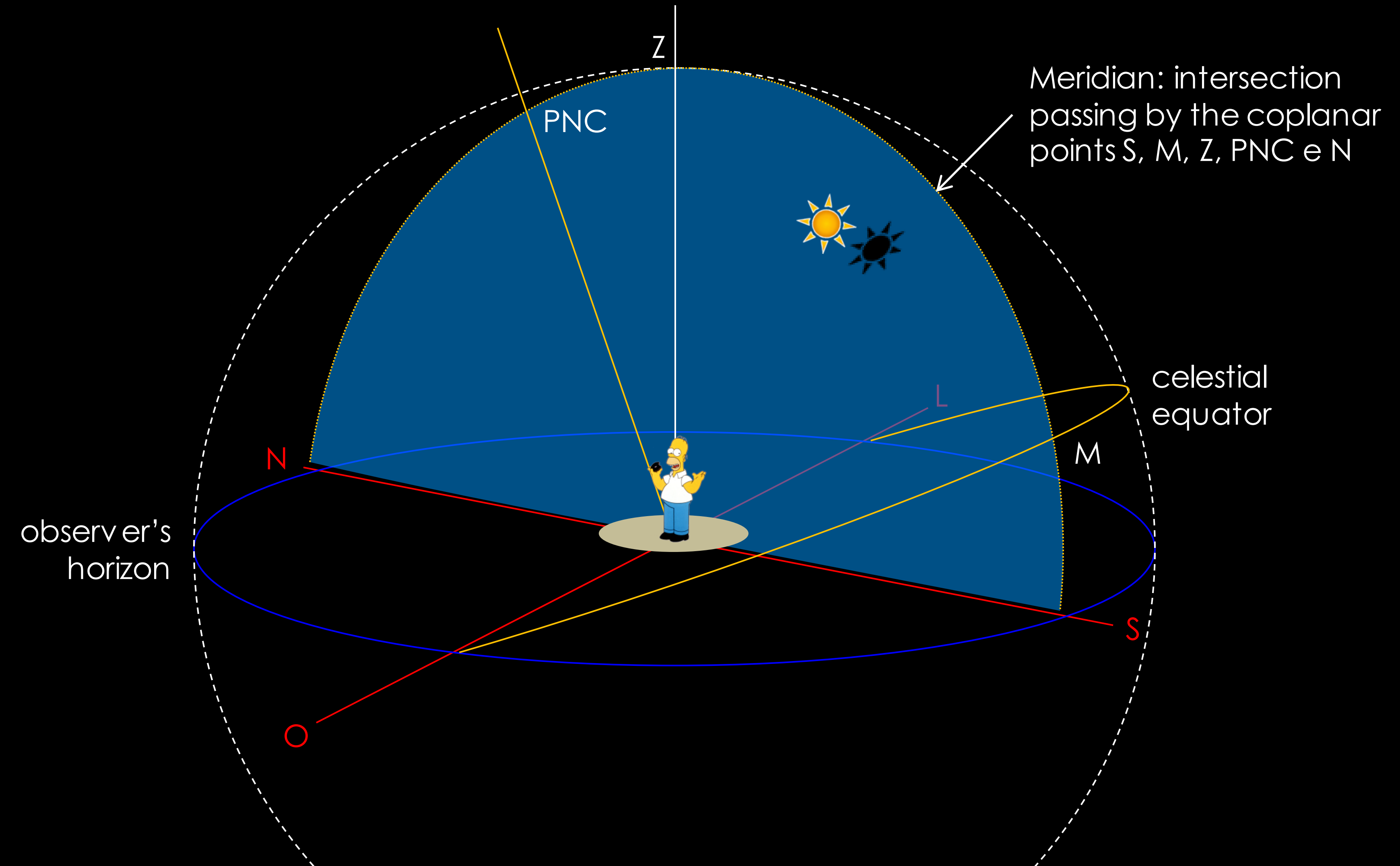
Definitions and working formulae...

SUN'S **HORIZONTAL** COORDINATES



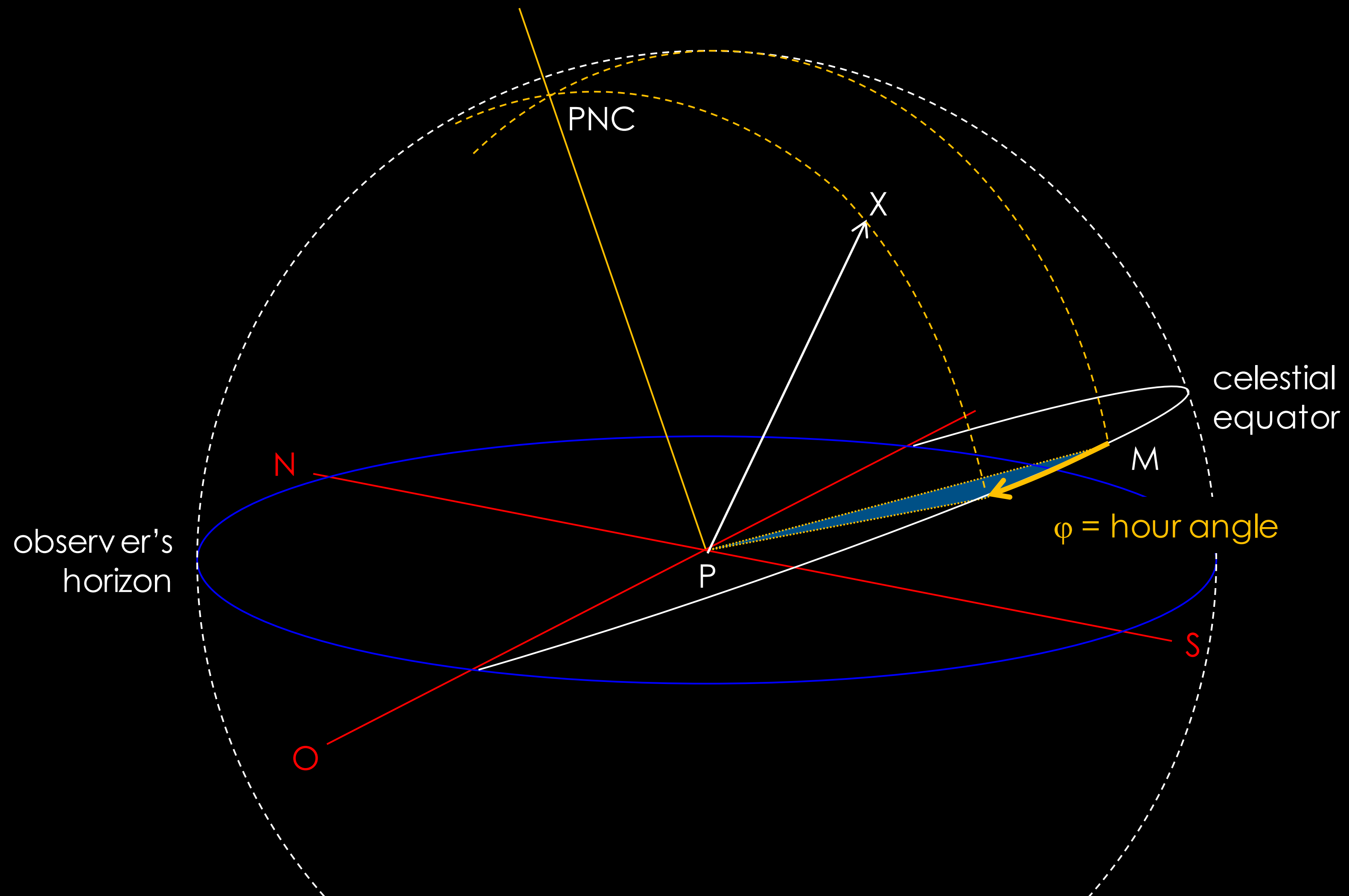
Definitions and working formulae...

SUN'S **HORIZONTAL** COORDINATES



Definitions and working formulae...

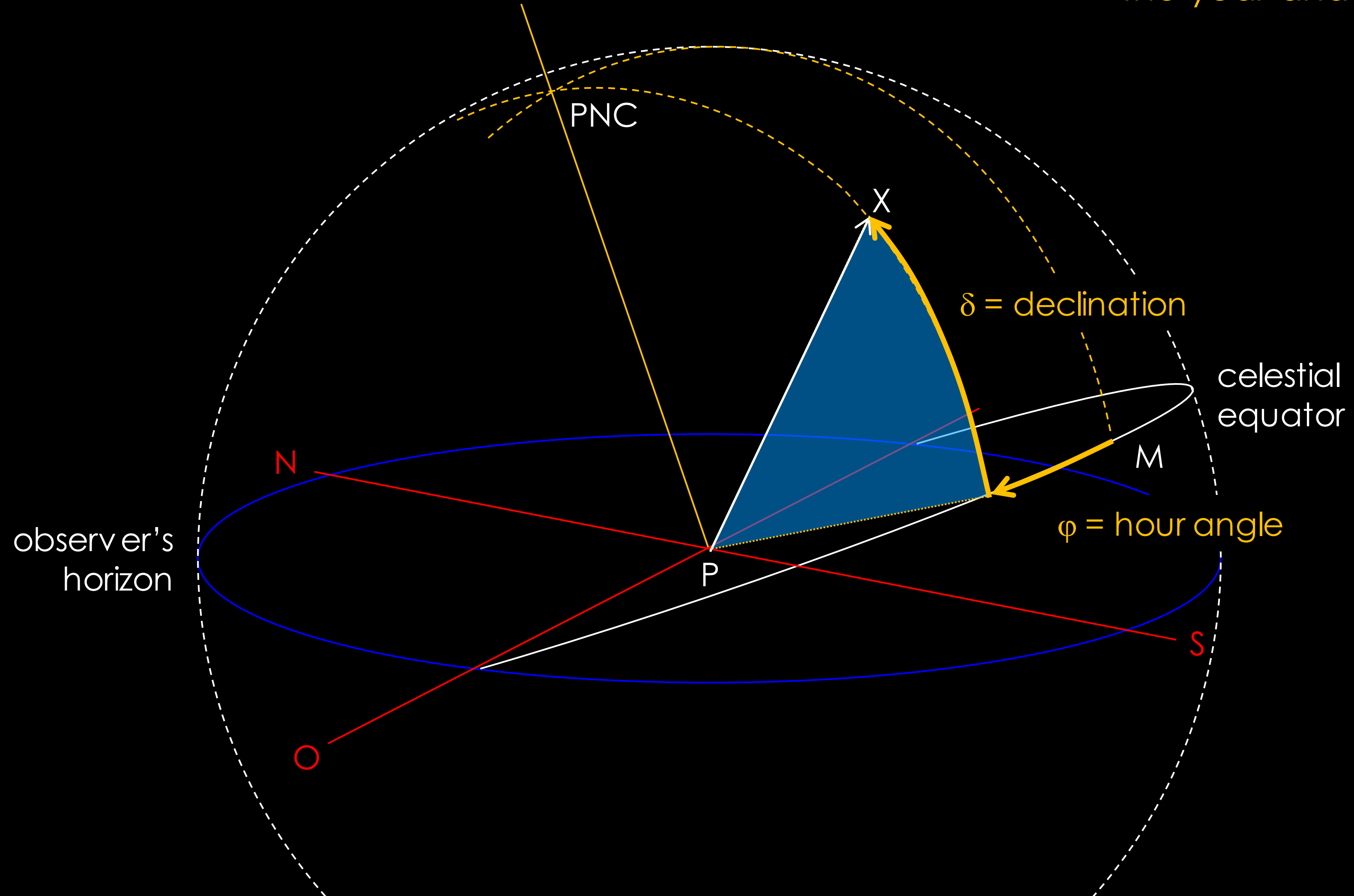
SUN'S **HORIZONTAL** COORDINATES



Definitions and working formulae...

SUN'S **HORIZONTAL** COORDINATES

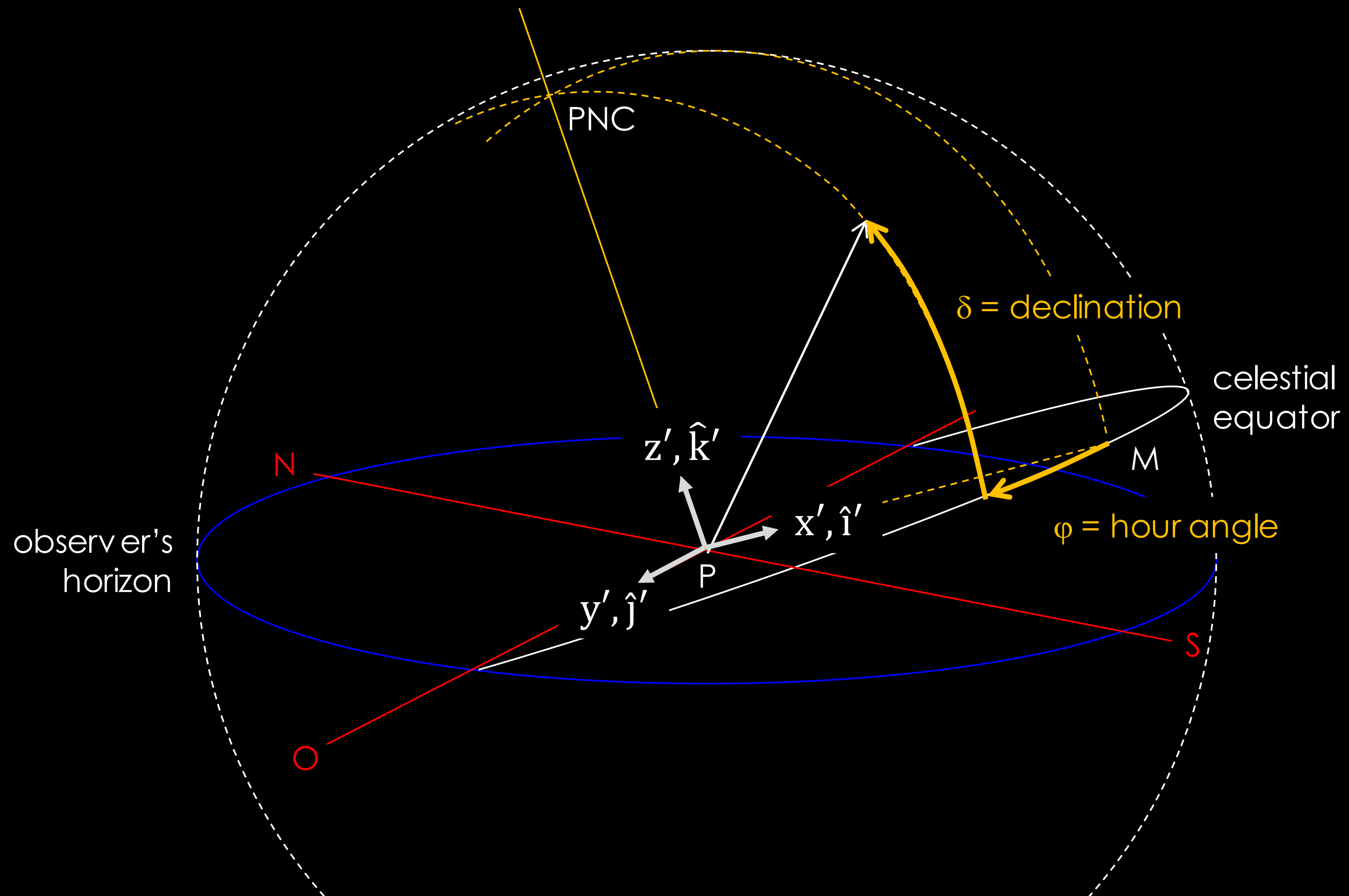
The hour angle and the declination are independent of the observer's position and can be easily determined in function of the day of the year and the hour of the day



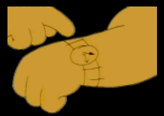
Definitions and working formulae...

SUN'S **HORIZONTAL** COORDINATES

$$VS = \cos\delta \cos\omega\, \hat{\imath}' + \cos\delta \sin\omega\, \hat{\jmath}' + \sin\delta\, \hat{k}'$$



Definitions and working formulae...



ϕ = latitude

λ = longitude

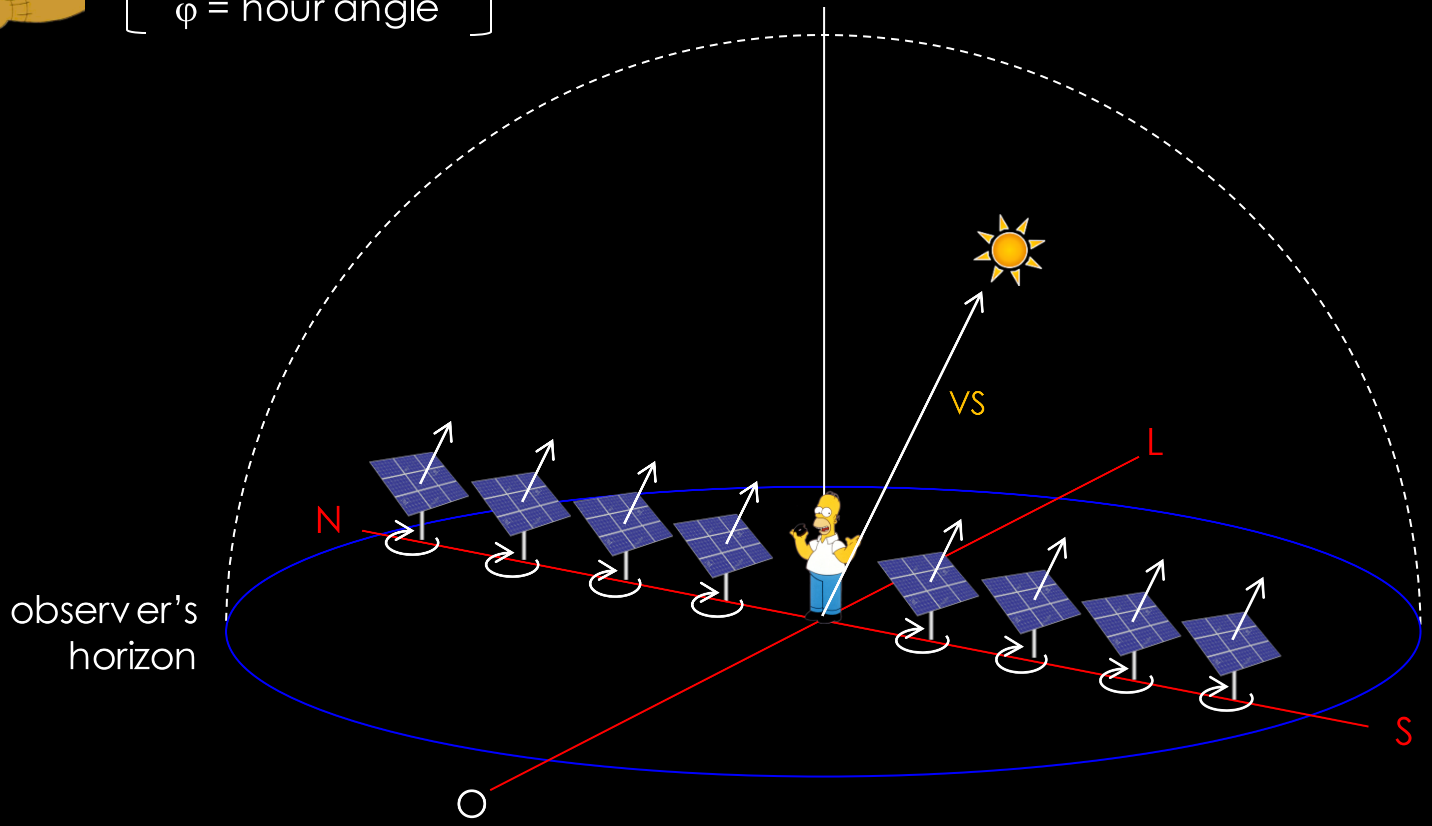
δ = declination

φ = hour angle

h = elevation

A = azimuth

$$\mathrm{VS} = \cos h \cos A\,\hat{\imath} + \cos h \sin A\,\hat{\jmath} + \sin h\,\hat{k}$$



Definitions and working formulae...

EQUATORIAL COORDINATES

Observer: longitude (λ) and latitude (ϕ)

Sun: hour angle (φ) and declination (δ)

HORIZONTAL COORDINATES

Observer: (0,0)

Sun: Azimuth (A) and elevation (h)

Definitions and working formulae...

Calculus of the solar declination (δ):

$\delta \equiv 0$ @ equinoxes

$\delta \equiv \pm 23{,}45°$ @ solstices

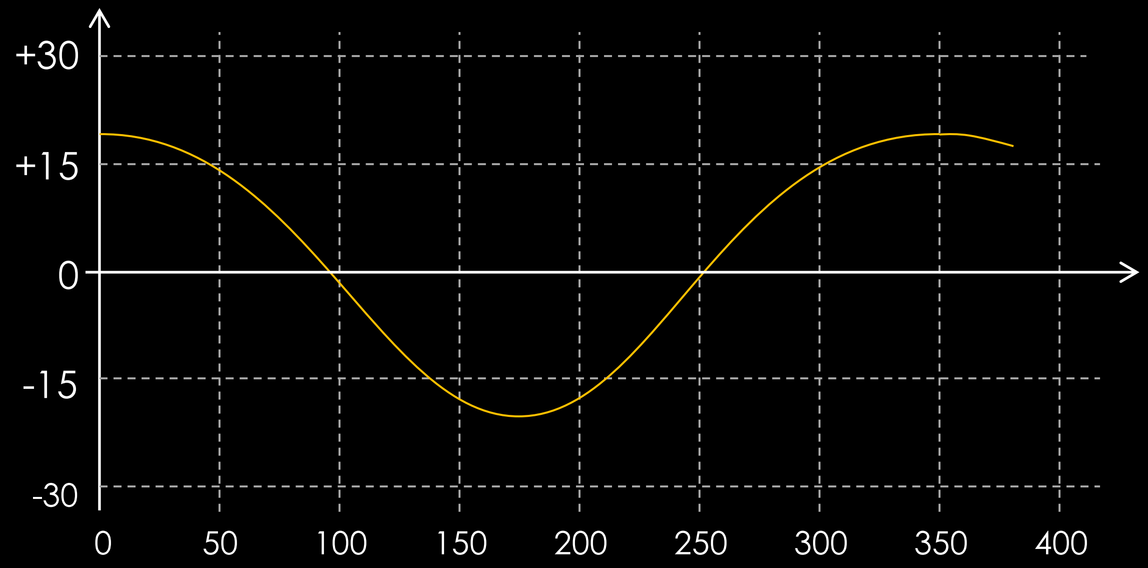
$\delta = (-23{,}45° \ldots + 23{,}45)$

convention: $\delta > 0$ when the north pole approaches the sun

Mês	D → n
janeiro	D
fevereiro	31+D
março	59+D
abril	90+D
maio	120+D
junho	151+D
julho	181+D
agosto	212+D
setembro	243+D
outubro	273+D
novembro	304+D
dezembro	334+D

Julian day (1° de Jan, n = 1)

$$\delta \approx -23{,}45° \cdot \cos\left[2\pi \cdot \frac{(n-172)}{365}\right]$$



Definitions and working formulae...

Definition of the day of the year and of the hour of the day

$$n = 1,2 \cdots 365 \qquad \varphi = -90°, -89°, \cdots + 90°$$

Calculus of the solar elevation (h):

$$\sin(h) = \sin(\phi)\sin(\delta) + \cos(\phi)\cos(\delta)\cos(\varphi)$$

Calculus of the solar azimuth (A):

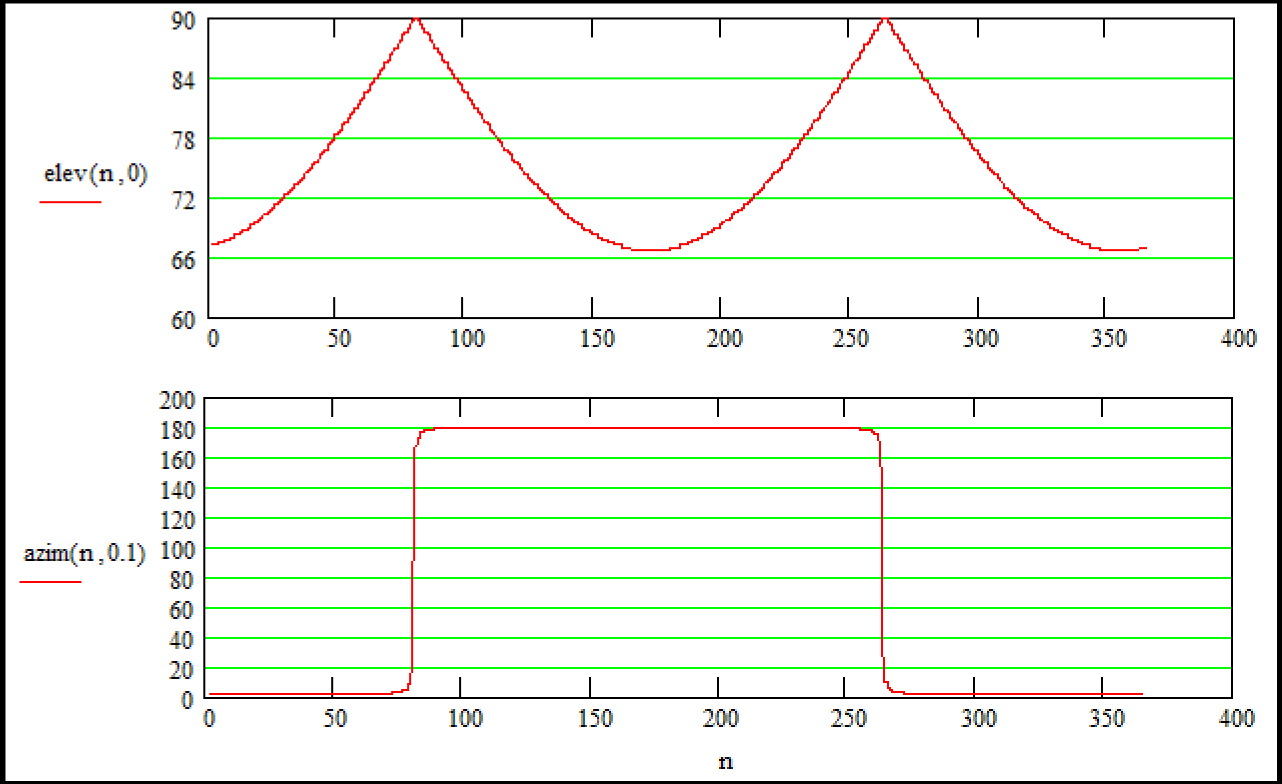
$$\cos(A) = \frac{\sin(\phi)\sin(h) - \sin(\delta)}{\cos(\phi)\cos(h)}$$

Definition of the solar vector (VS):

$$VS = \cos(h)\cos(A)\,\hat{\imath} + \cos(h)\sin(A)\,\hat{\jmath} + \sin(h)\,\hat{k}$$

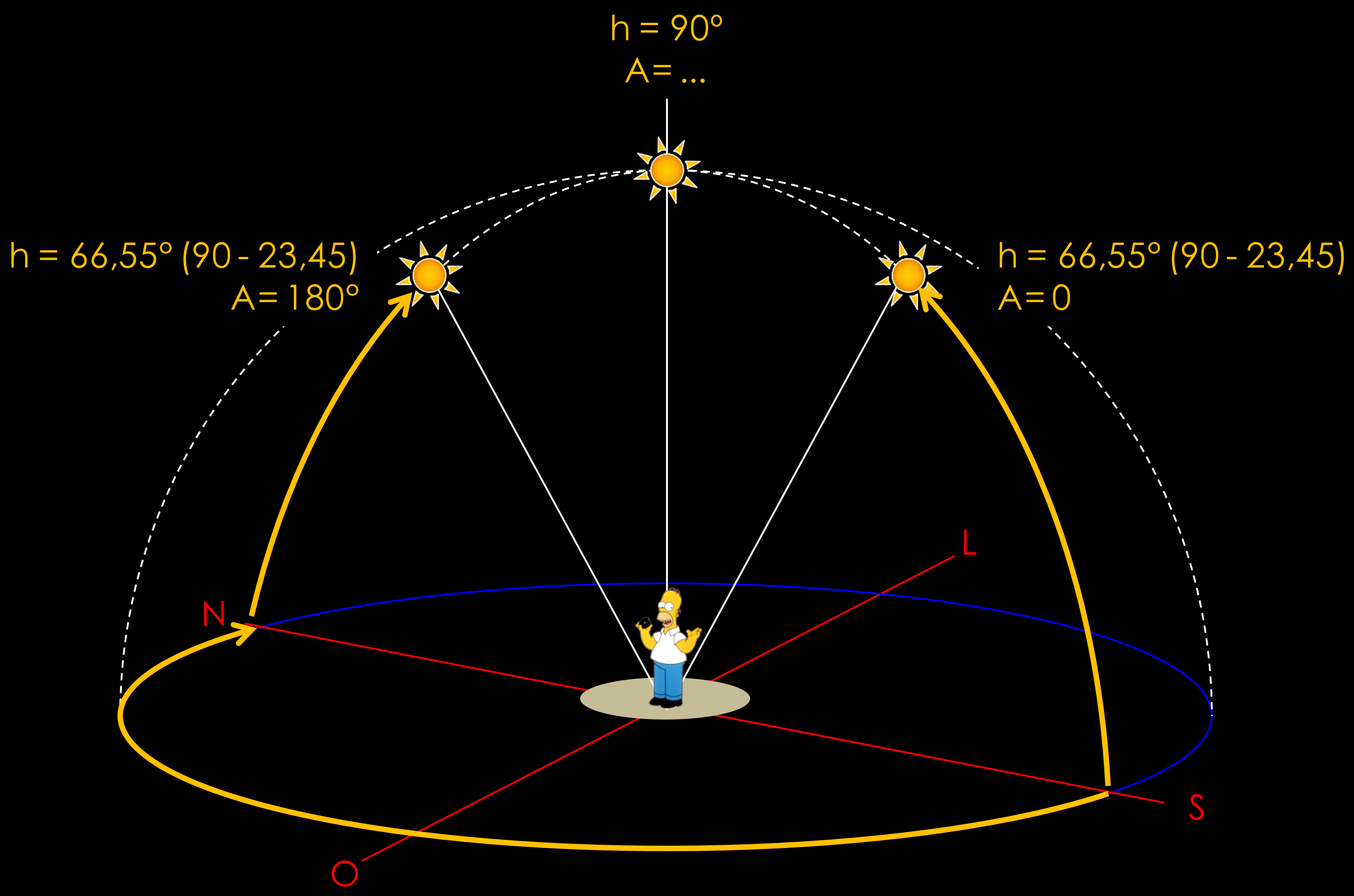
Definitions and working formulae...

Sun's elevation at noon in Singapura (1°17'N = 1,2833°)



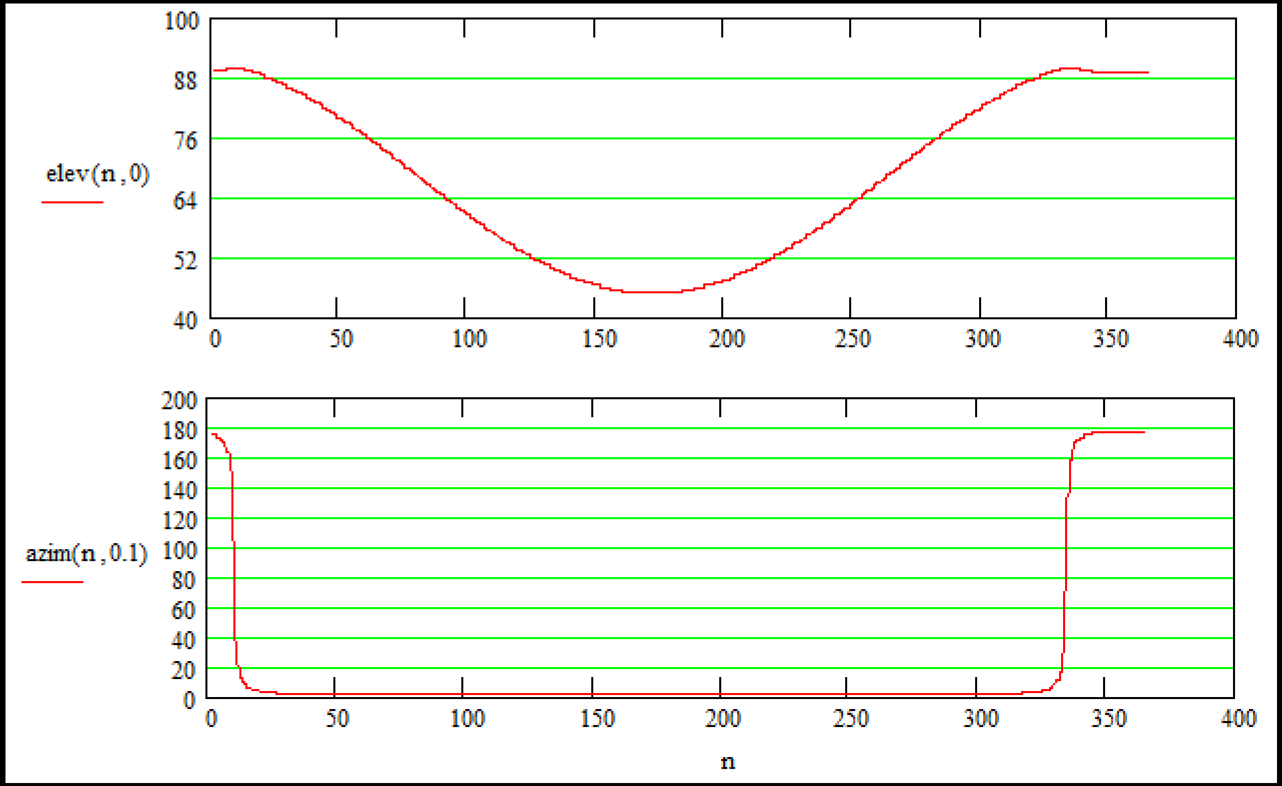
Definitions and working formulae...

Sun's elevation at noon in Singapura (1°17'N = 1,2833°)



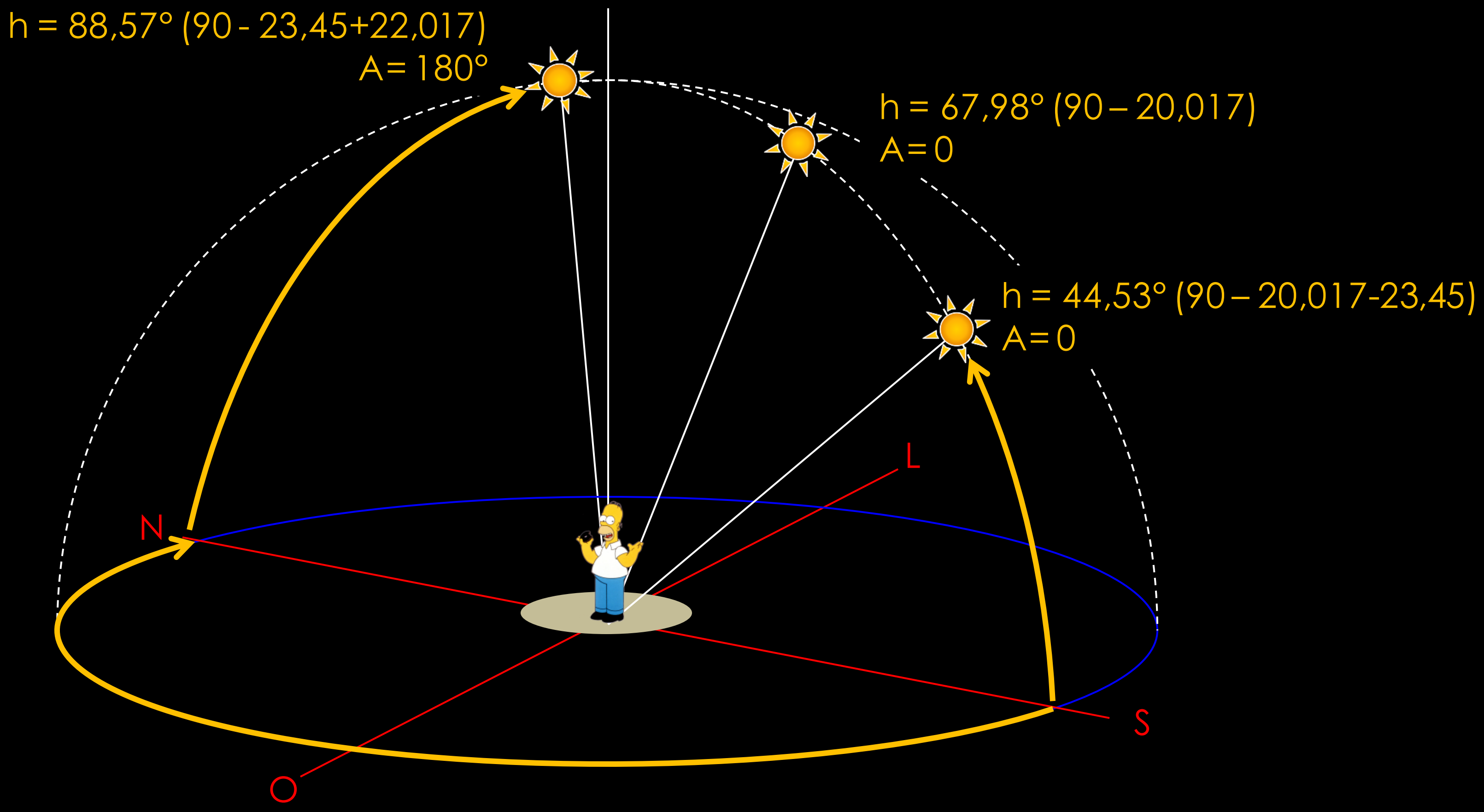
Definitions and working formulae...

Sun’s elevation at noon in São Carlos (22°01”S = - 22,017°)



Definitions and working formulae...

Sun's elevation at noon in São Carlos (22°01''S = - 22,017°)

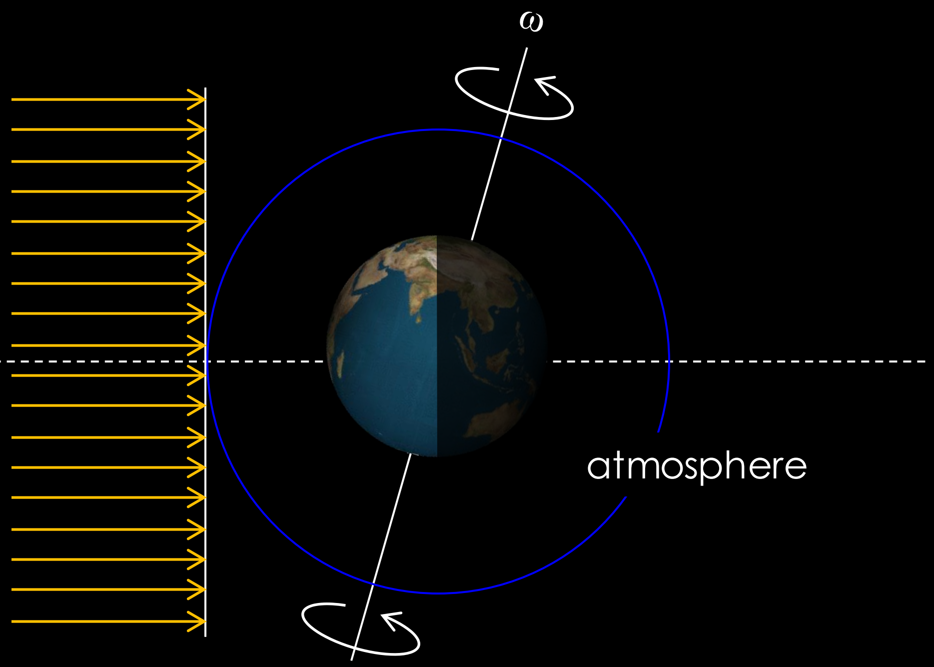


Solar energy losses in the propagation to earth's surface

How to calculate the maximum intensity of the solar irradiation at the surface in function of the hour of the day and taking into account the latitude and day of the year ?

solar constant

$$I_{SC} = 1367 \frac{W}{m^2}$$



Optical path between the collector and the sun's entry point at the atmosphere's frontier: latitude, declination and hour of the day

Solar energy losses in the propagation to earth's surface

Empirical model

$$I_{sup} \cong I_{SC} \cdot 0{,}7^{AM^{0{,}678}}$$

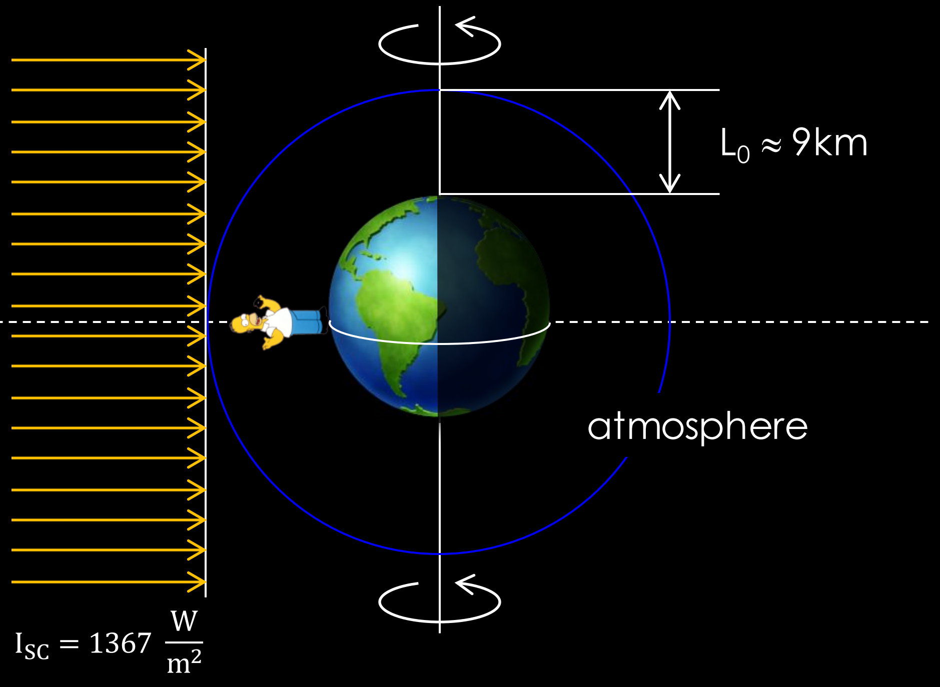
Accounts the atmospheric absorption in an azimuthal optical path… (approximately 10% of diffuse irradiation, etc.)

Air mass coefficient:

$$AM = \frac{\text{optical path}}{\text{minimum optical path}} = \frac{L_0}{L_0}$$

Different models: plane, spherical, etc.

Declination: $\delta = 0$
Latitude: $\phi = 0$



$$I_{sup} \cong 0{,}7 \cdot I_{SC}$$

Maximum solar irradiation at 12h00 on the surface

Solar energy losses in the propagation to earth's surface

Empirical model

$$I_{sup} \cong I_{SC} \cdot 0{,}7^{AM^{0,678}}$$

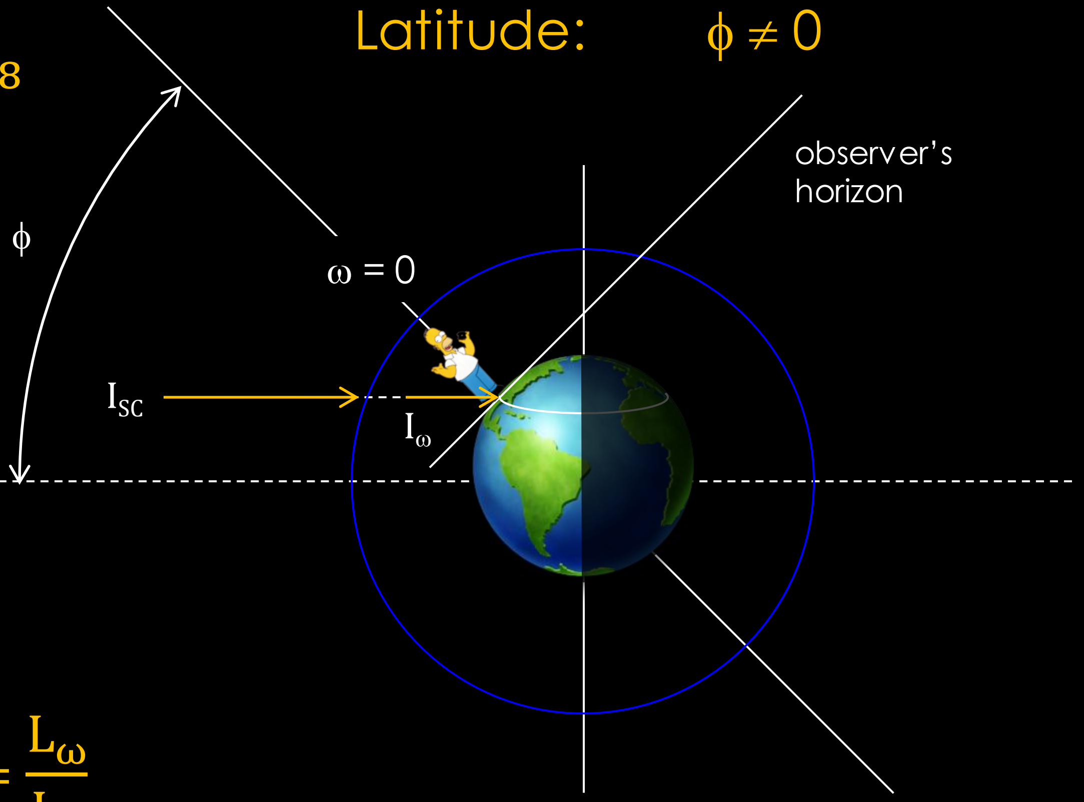
Accounts the atmospheric absorption in an azimuthal optical path… (approximately 10% of diffuse irradiation, etc.)

Air mass coefficient:

$$AM = \frac{\text{caminho óptico}}{\text{mínimo caminho óptico}} = \frac{L_\omega}{L_0}$$

Different models: plane, spherical, etc.

Declination: $\delta = 0$
Latitude: $\phi \neq 0$



Solar energy losses in the propagation to earth's surface

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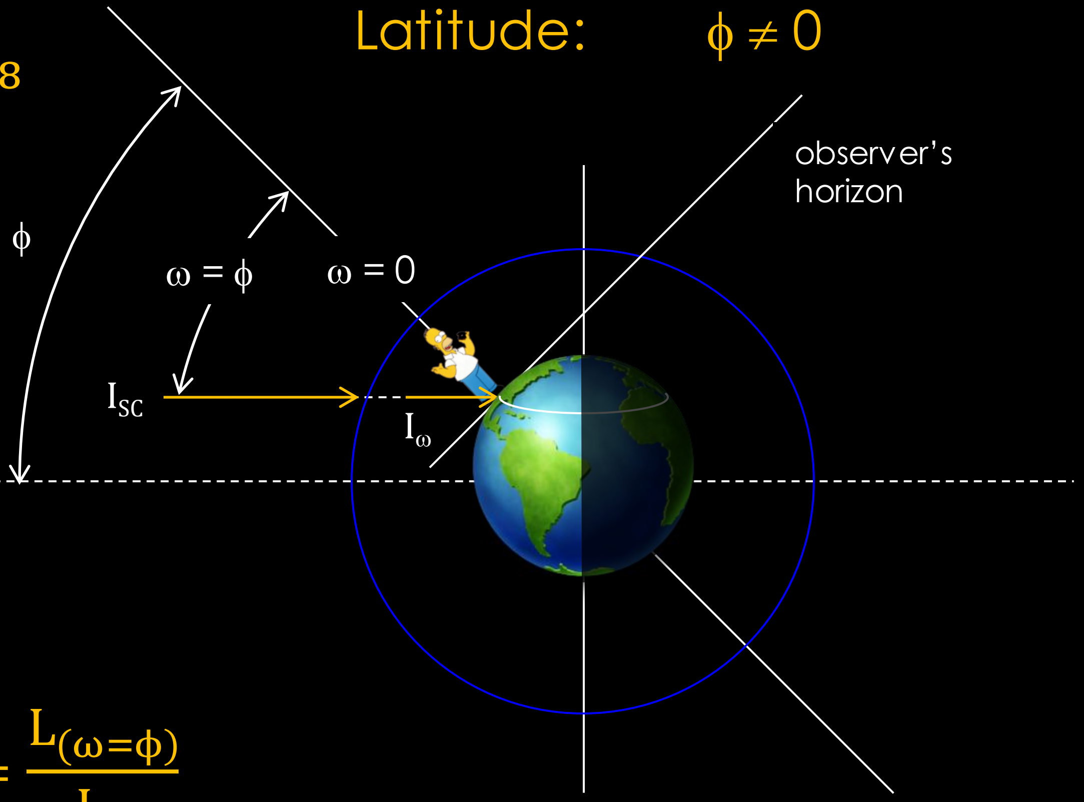


Air mass coefficient:

$$AM = \frac{\text{caminho óptico}}{\text{mínimo caminho óptico}} = \frac{L_{(\omega=\phi)}}{L_0}$$

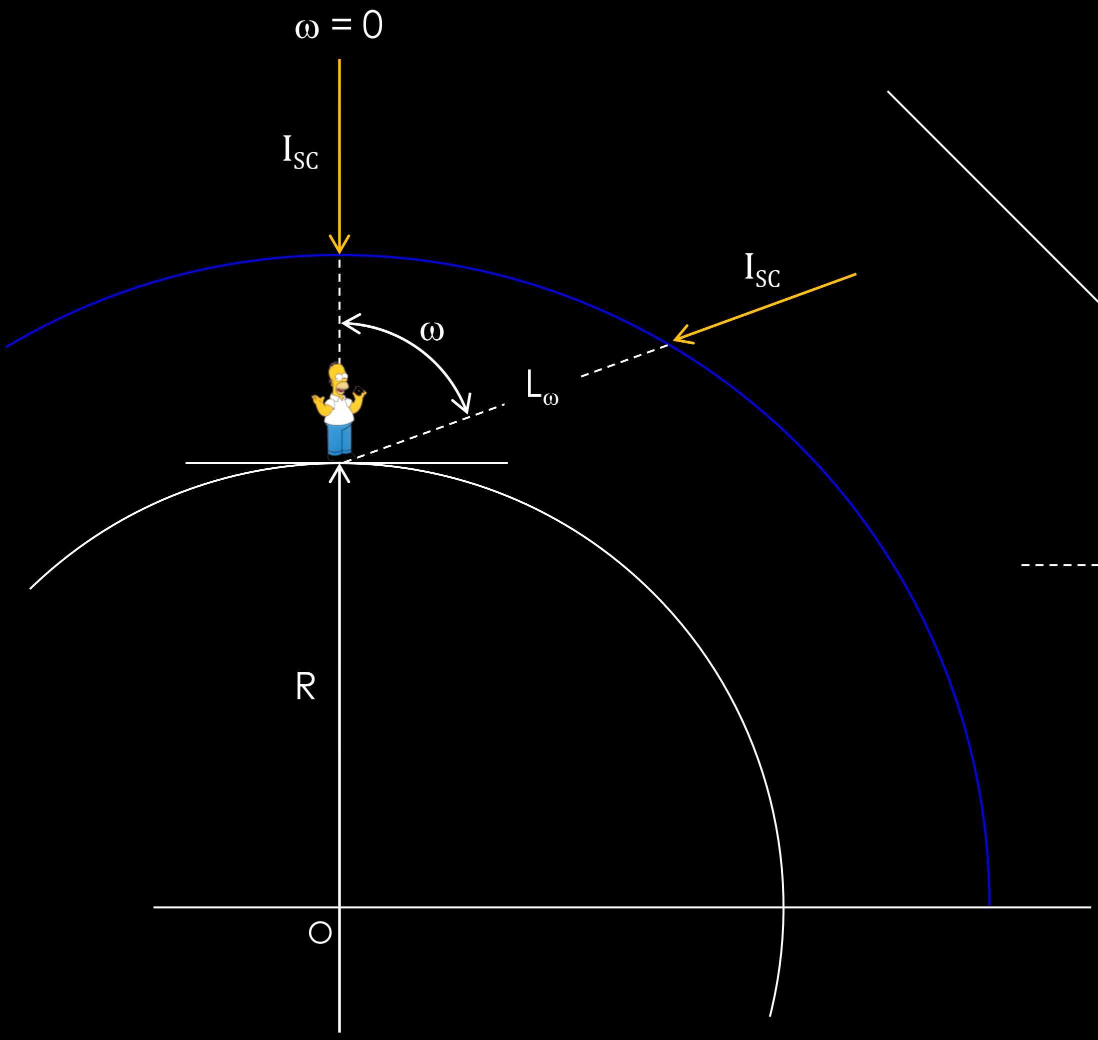
Spherical model:

$$AM(\omega,R) \cong \sqrt{\left(\frac{R}{L_0}\cos\omega\right)^2 + 2\frac{R}{L_0} + 1} - \frac{R}{L_0}\cos\omega$$

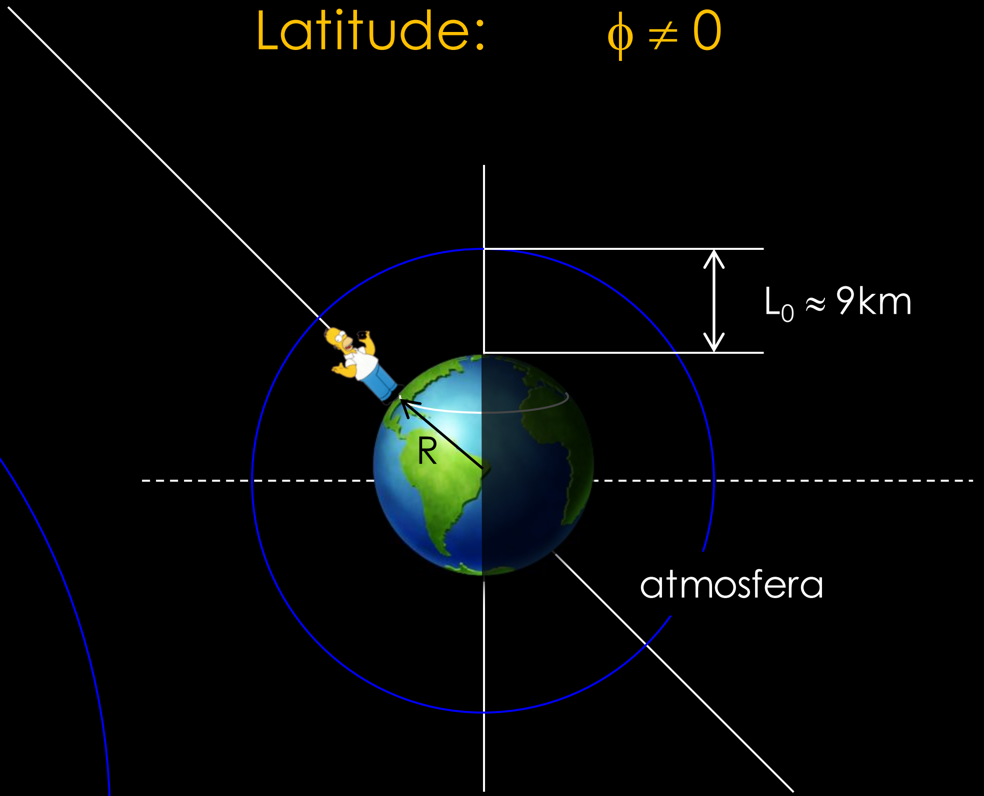
$$I_{sup} \cong I_{SC} \cdot 0{,}7^{AM(\phi,R)^{0{,}678}}$$

Maximum solar irradiation at 12h00 on the surface

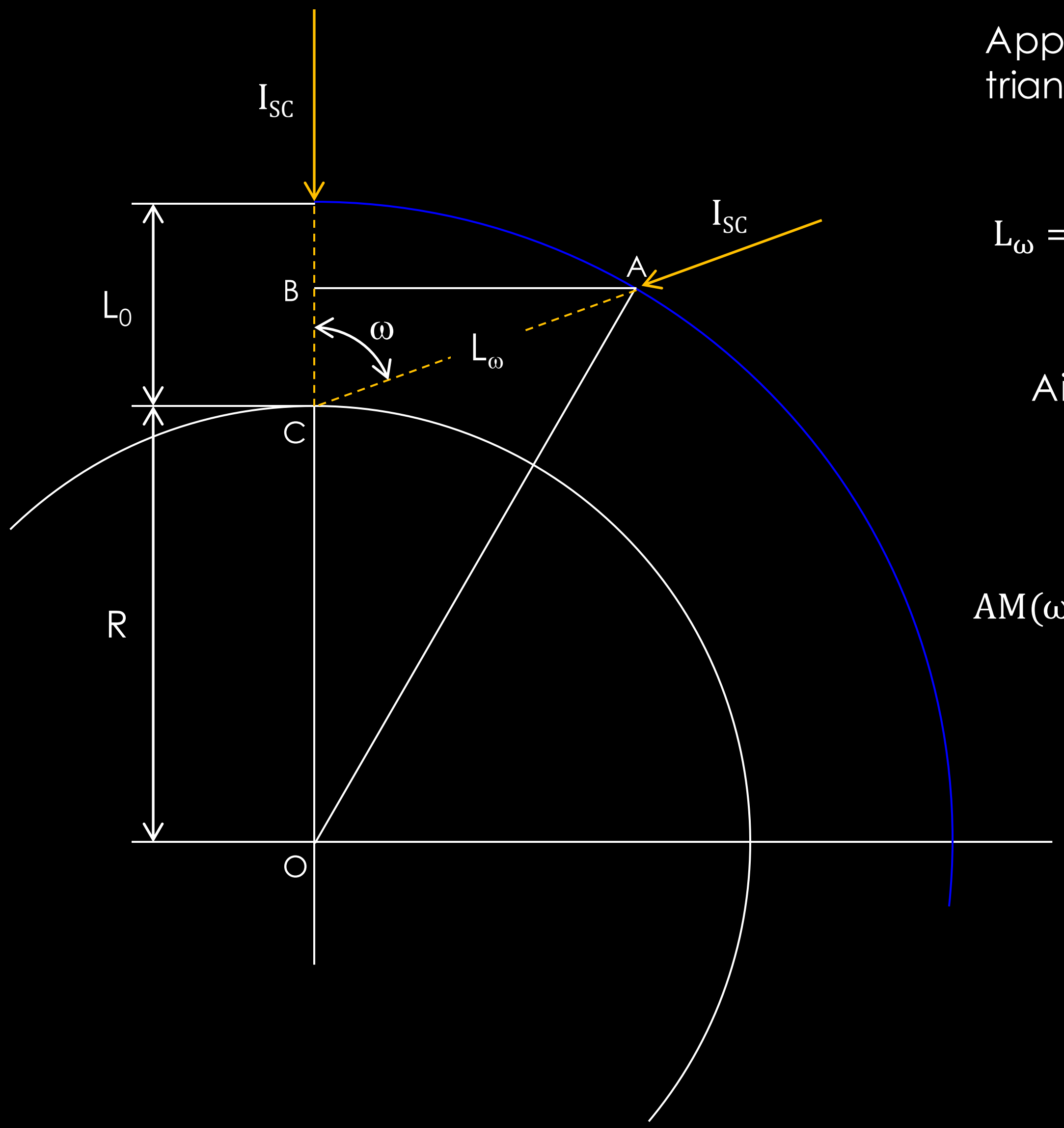
Solar energy losses in the propagation to earth's surface



Declination: $\delta = 0$
Latitude: $\phi \neq 0$



Solar energy losses in the propagation to earth's surface



Applying Pitagoiras theorem to triangles ABC and ABO...

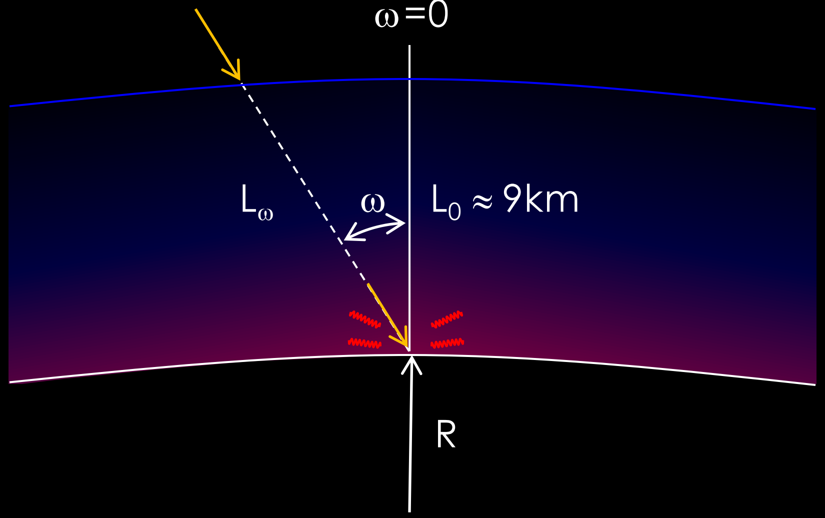
$$L_\omega = \sqrt{(R\cos\omega)^2 + 2RL_0 + (L_0)^2} - R\cos\omega$$

Air mass coefficient: $AM = \frac{L_\omega}{L_0}$

$$AM(\omega) \cong \sqrt{\left(\frac{R}{L_0}\cos\omega\right)^2 + 2\frac{R}{L_0} + 1} - \frac{R}{L_0}\cos\omega$$

Solar energy losses in the propagation to earth's surface

Earth is spherical and considering the atmosphere's density variation with respect to the altitude…

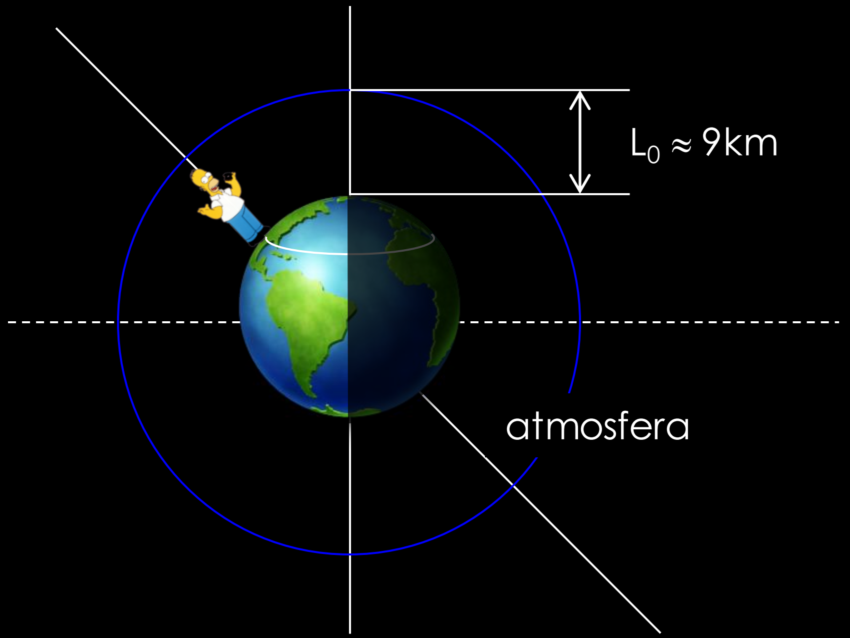


Kasten and Young' Model (1989):

$$AM \cong \frac{1}{\cos\omega + 0{,}50572 \cdot (96{,}07995 - \omega)^{-1{,}6364}}$$

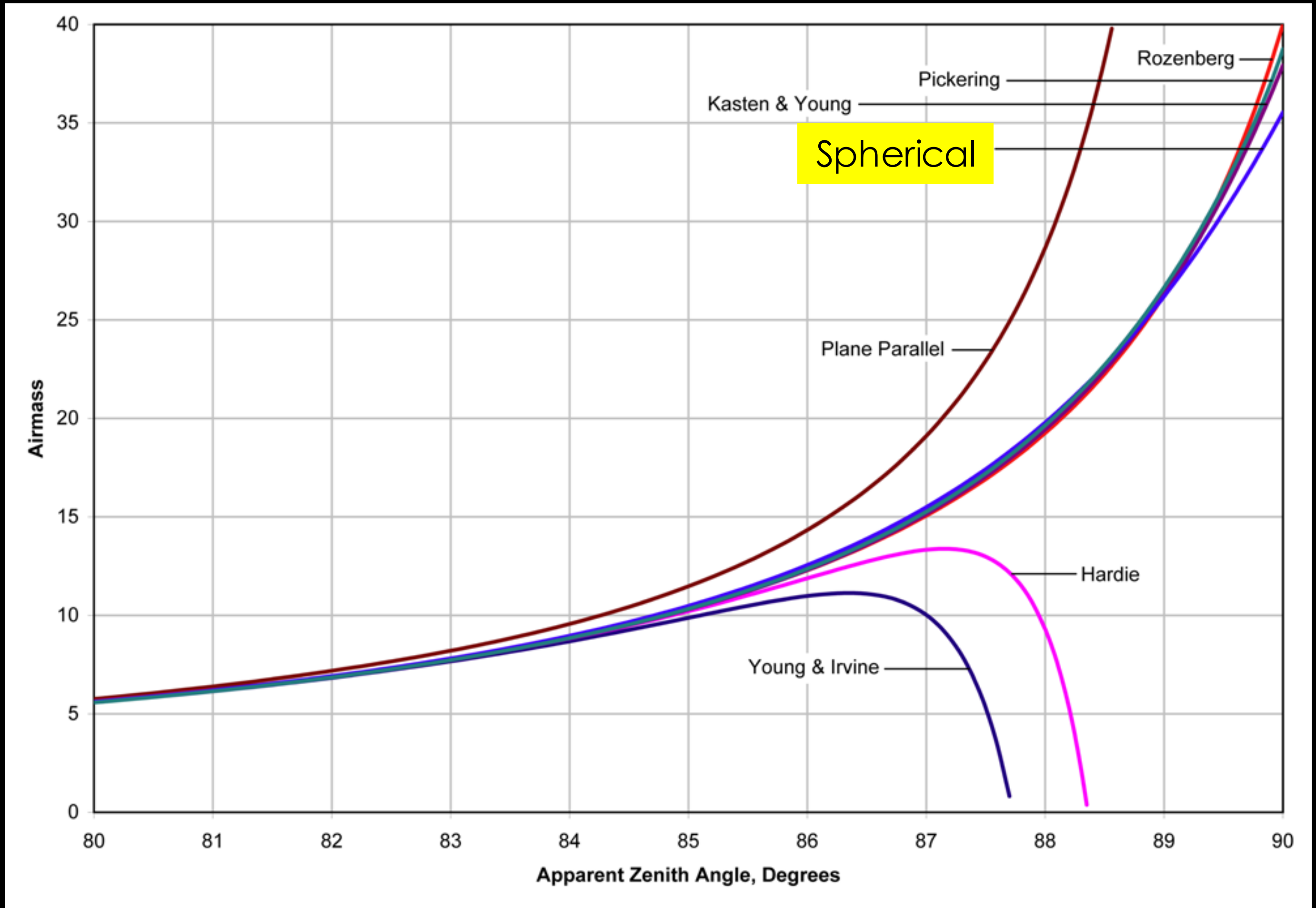
Declination: $\delta = 0$

Latitude: $\phi \neq 0$



$$I_{sup} \cong I_{SC} \cdot 0{,}7^{AM^{0{,}678}}$$

Solar energy losses in the propagation to earth's surface



"Airmass Formulae Plots" by Jeff Conrad

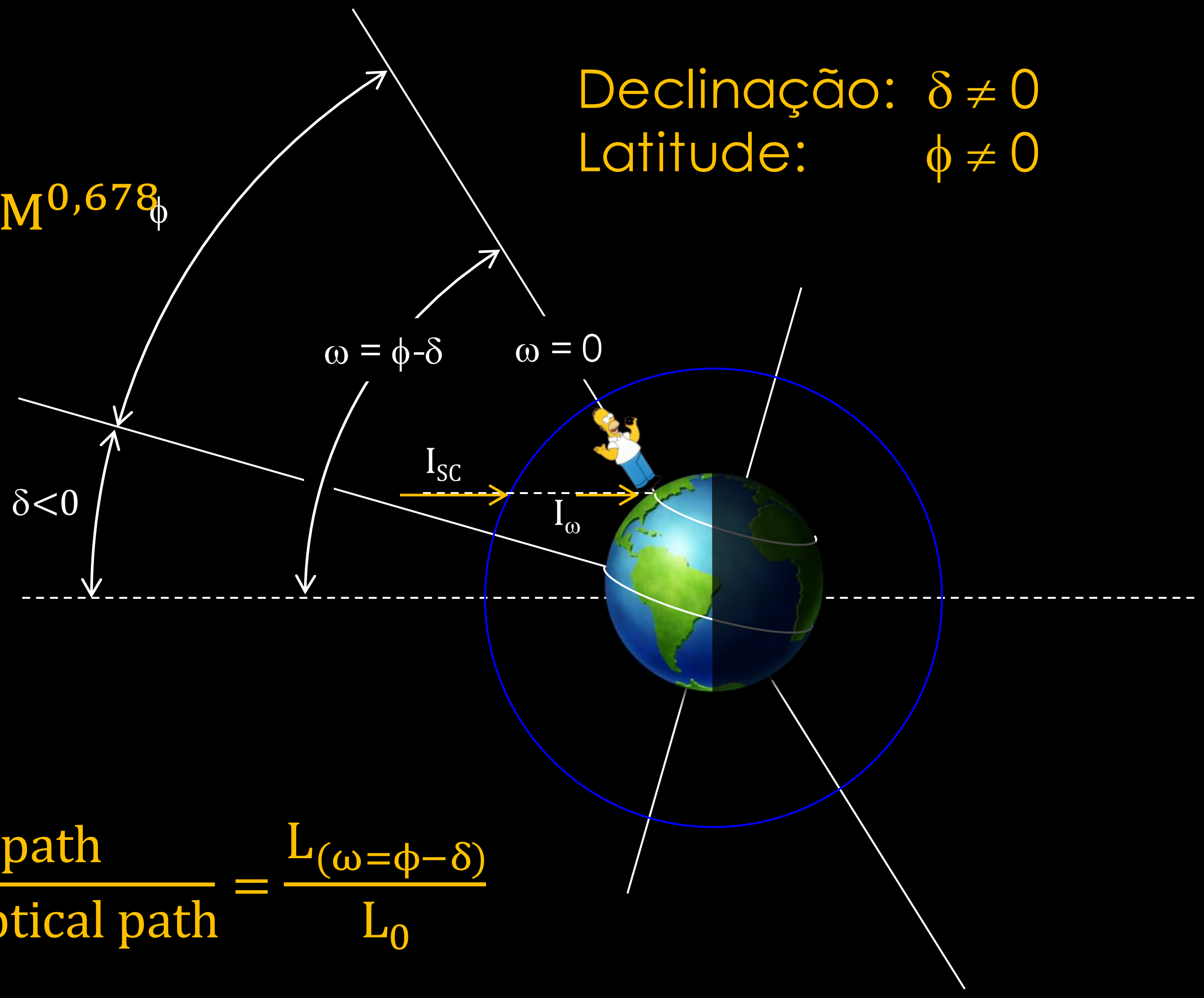
Solar energy losses in the propagation to earth's surface

Empirical model

$$I_{sup} \cong I_{SC} \cdot 0{,}7^{AM^{0{,}678}}$$

Declinação: $\delta \neq 0$
Latitude: $\phi \neq 0$

convention: $\delta > 0$ when the south pole approaches the sun



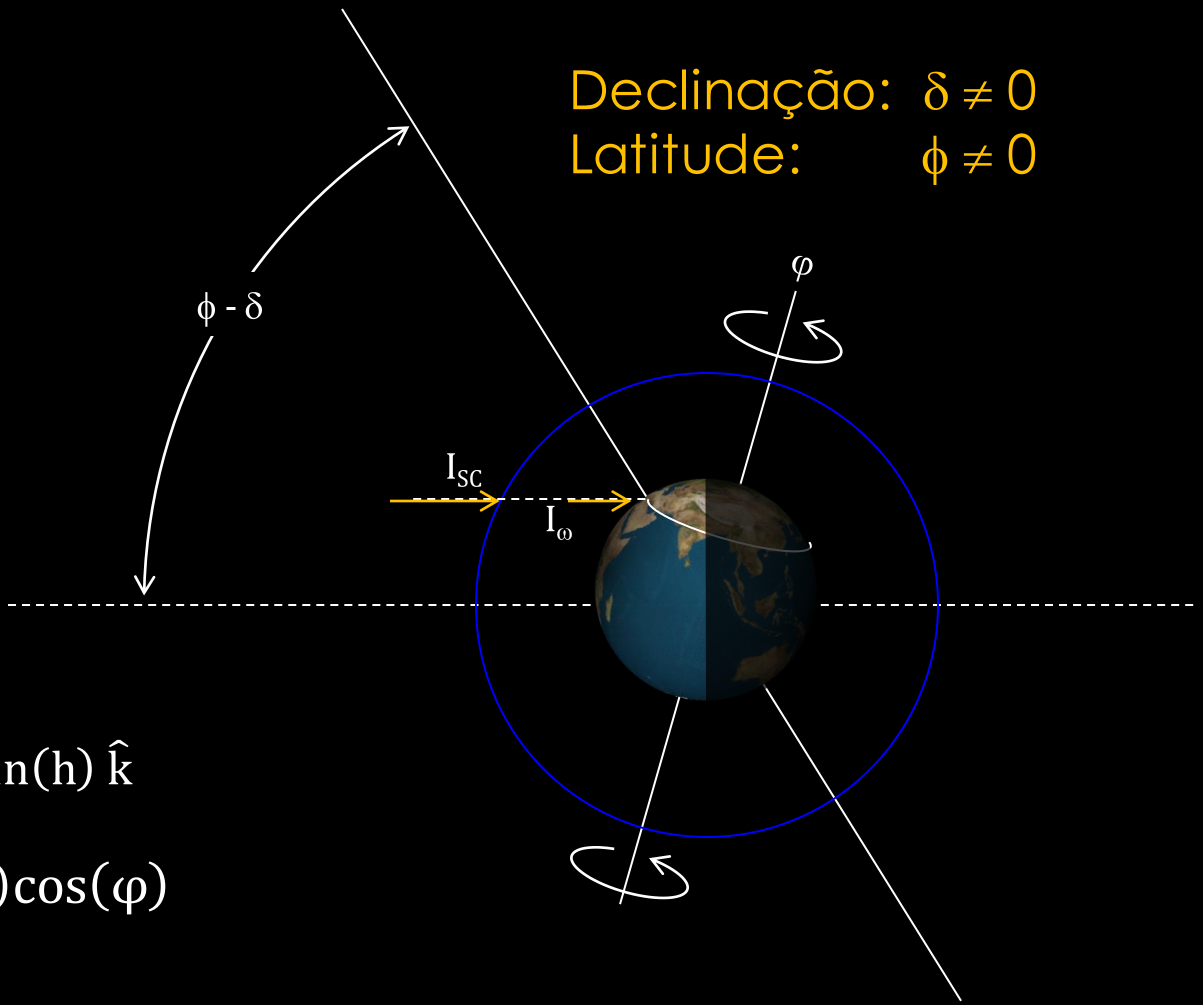
Air mass coefficient:

$$AM = \frac{\text{optical path}}{\text{minimum optical path}} = \frac{L_{(\omega=\phi-\delta)}}{L_0}$$

$$AM(\phi - \delta, R) \cong \sqrt{\left(\frac{R}{L_0}\cos(\phi - \delta)\right)^2 + 2\frac{R}{L_0} + 1} - \frac{R}{L_0}\cos(\phi - \delta)$$

Solar energy losses in the propagation to earth's surface

Declinação: $\delta \neq 0$
Latitude: $\phi \neq 0$

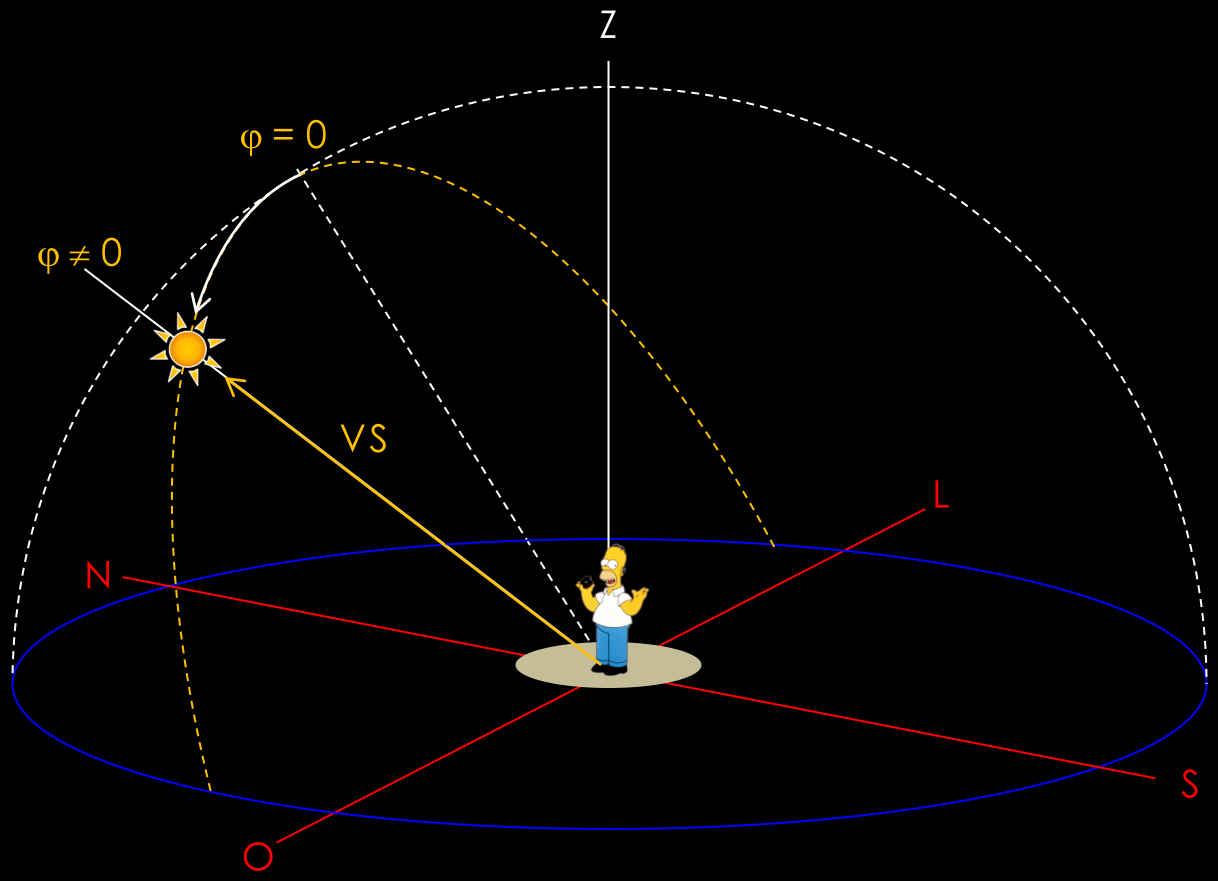


$$VS = \cos(h)\cos(A)\,\hat{\imath} + \cos(h)\sin(A)\,\hat{\jmath} + \sin(h)\,\hat{k}$$

$$\sin(h) = \sin(\phi)\sin(\delta) + \cos(\phi)\cos(\delta)\cos(\varphi)$$

$$VS = \cos(h)\cos(A)\,\hat{\imath} + \cos(h)\sin(A)\,\hat{\jmath} + \sin(h)\,\hat{k}$$

$$\sin(h) = \sin(\phi)\sin(\delta) + \cos(\phi)\cos(\delta)\cos(\varphi)$$



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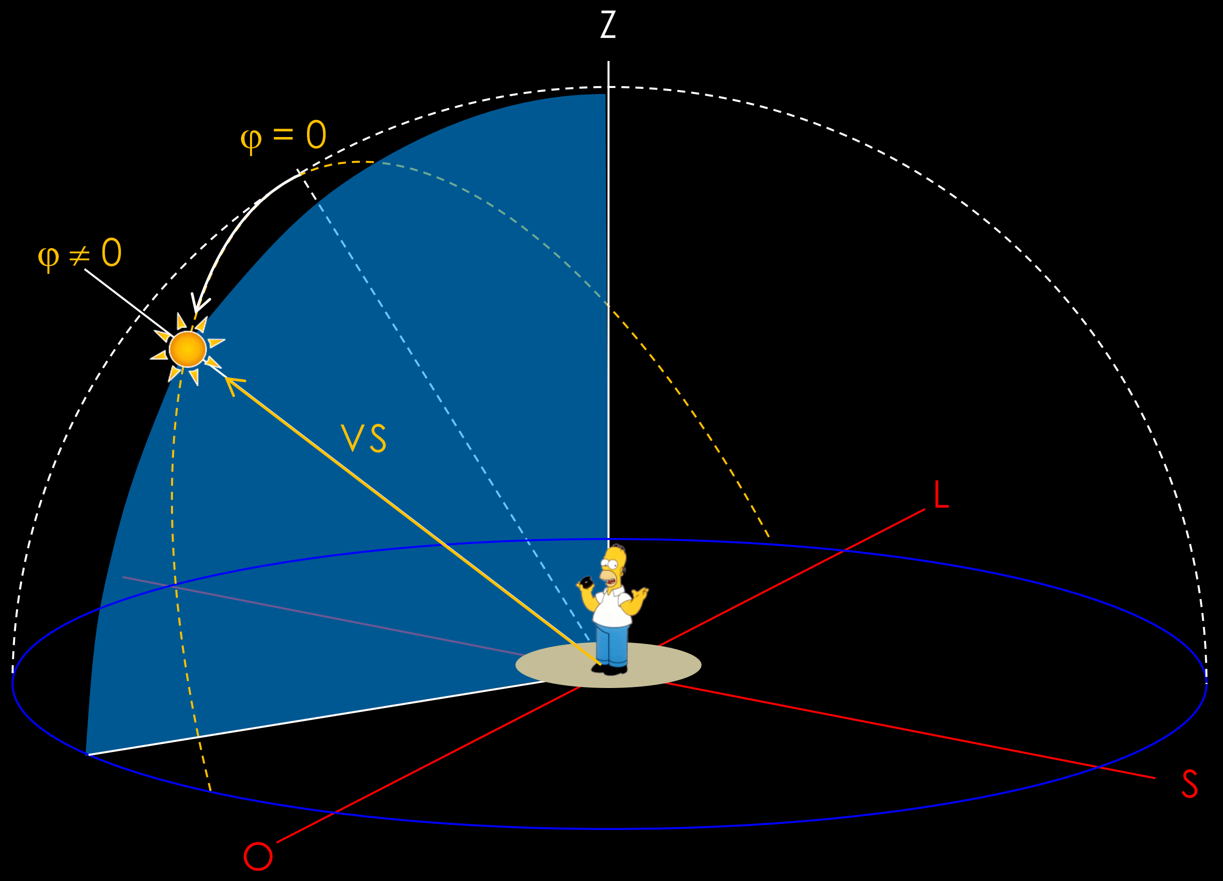

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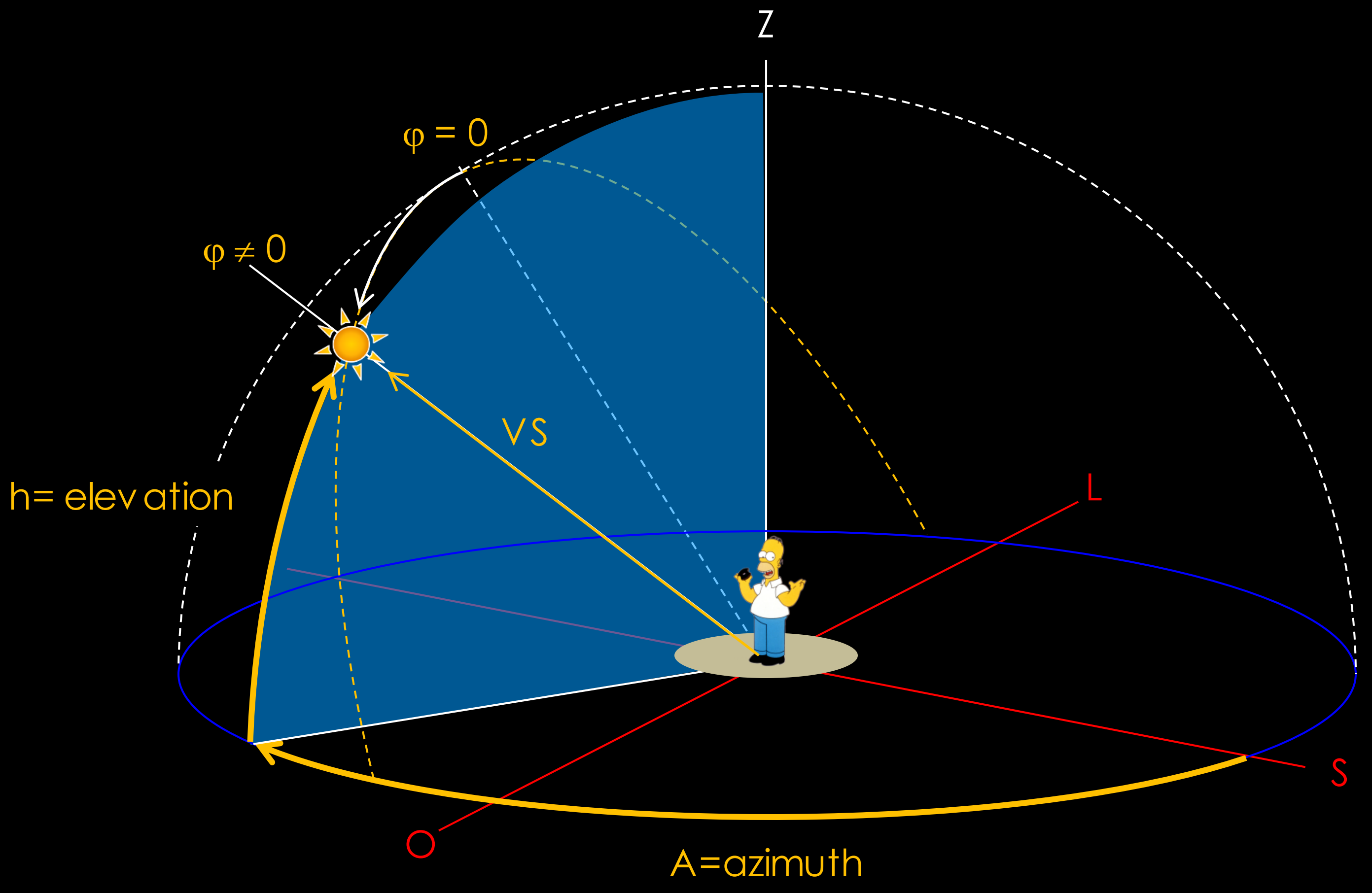

$$VS = \cos(h)\cos(A)\,\hat{\imath} + \cos(h)\sin(A)\,\hat{\jmath} + \sin(h)\,\hat{k}$$

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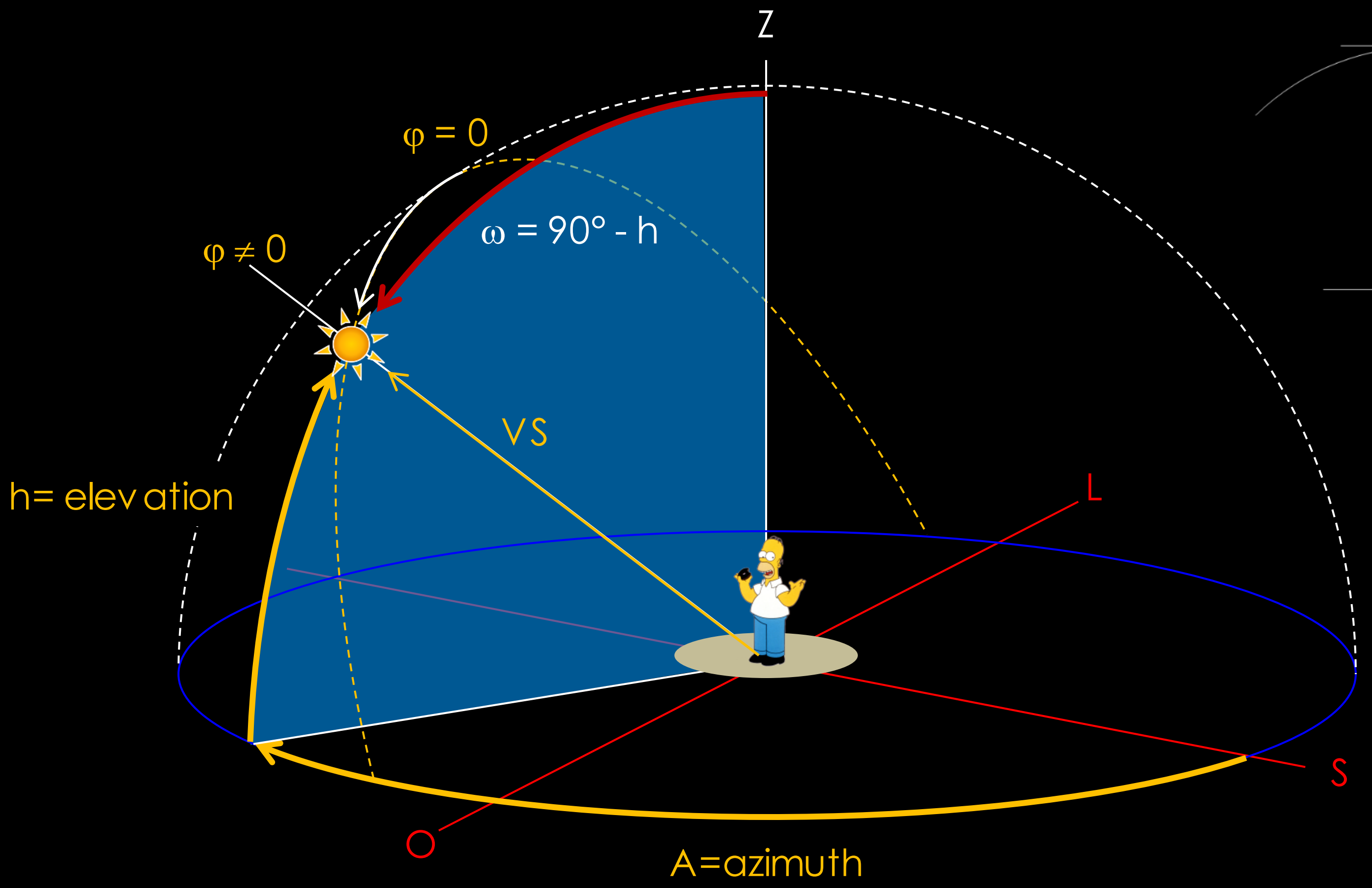
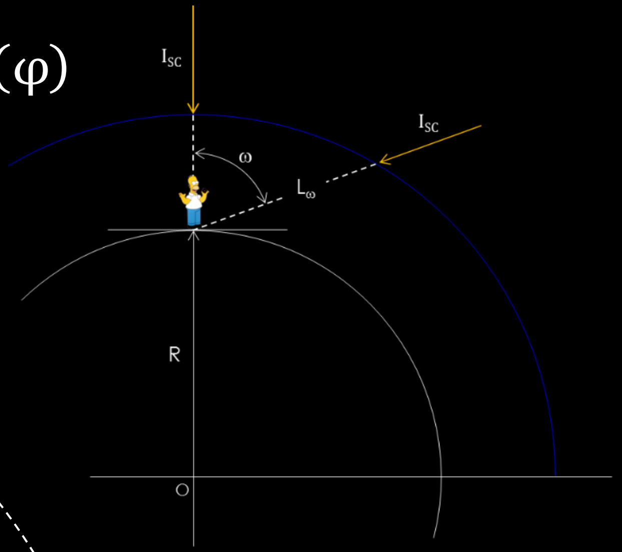




Definitions and working formulae...

$$I_{sup} \cong I_{SC} \cdot 0{,}7^{AM^{0{,}678}}$$

$$AM(90° - h, R) \cong \sqrt{\left(\frac{R}{L_0}\cos(90° - h)\right)^2 + 2\frac{R}{L_0} + 1} - \frac{R}{L_0}\cos(90° - h)$$

$$\sin(h) = \sin(\phi)\sin(\delta) + \cos(\phi)\cos(\delta)\cos(\varphi)$$

$$\varphi = 0 \rightarrow \qquad \sin(h) = \sin(\phi)\sin(\delta) + \cos(\phi)\cos(\delta)$$

$$\sin(h) = \cos(\phi - \delta)$$

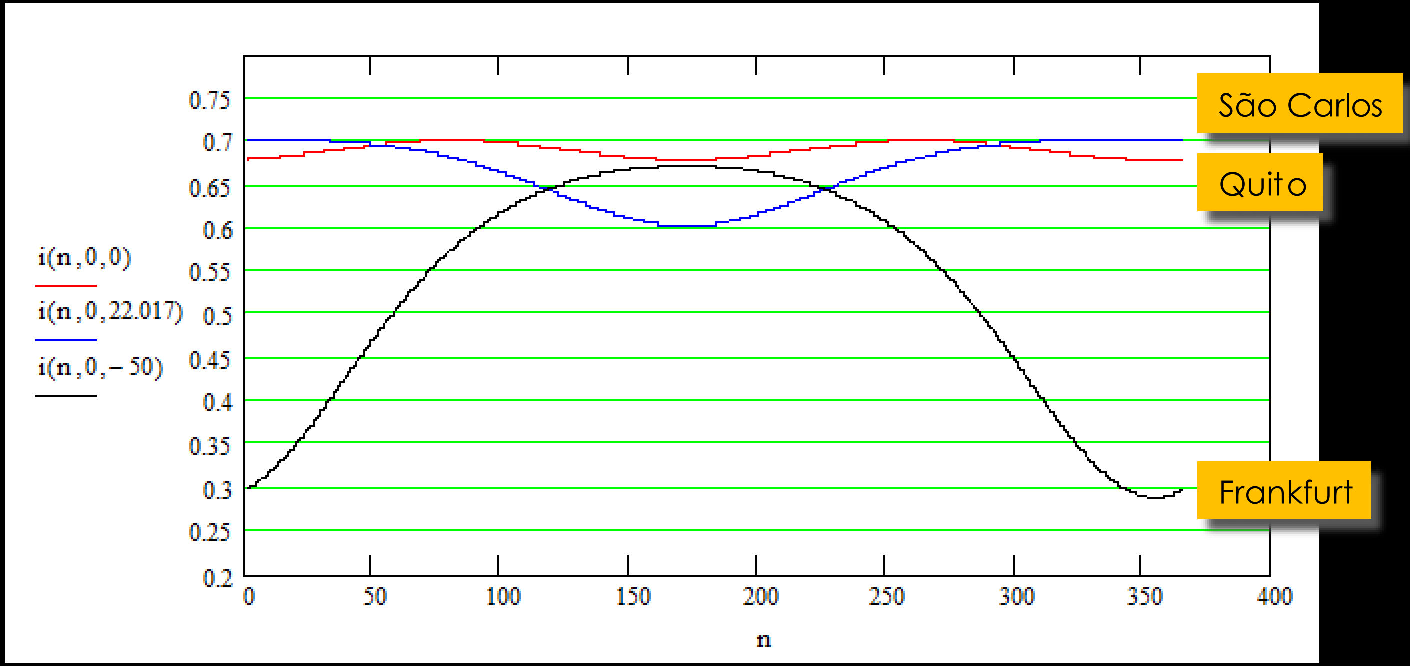
$$\cos(90° - h) = \cos(\phi - \delta)$$

$$h = 90° - (\phi - \delta)$$

$$\varphi = 0 \rightarrow \qquad AM(\phi - \delta, R) \cong \sqrt{\left(\frac{R}{L_0}\cos(\phi - \delta)\right)^2 + 2\frac{R}{L_0} + 1} - \frac{R}{L_0}\cos(\phi - \delta)$$

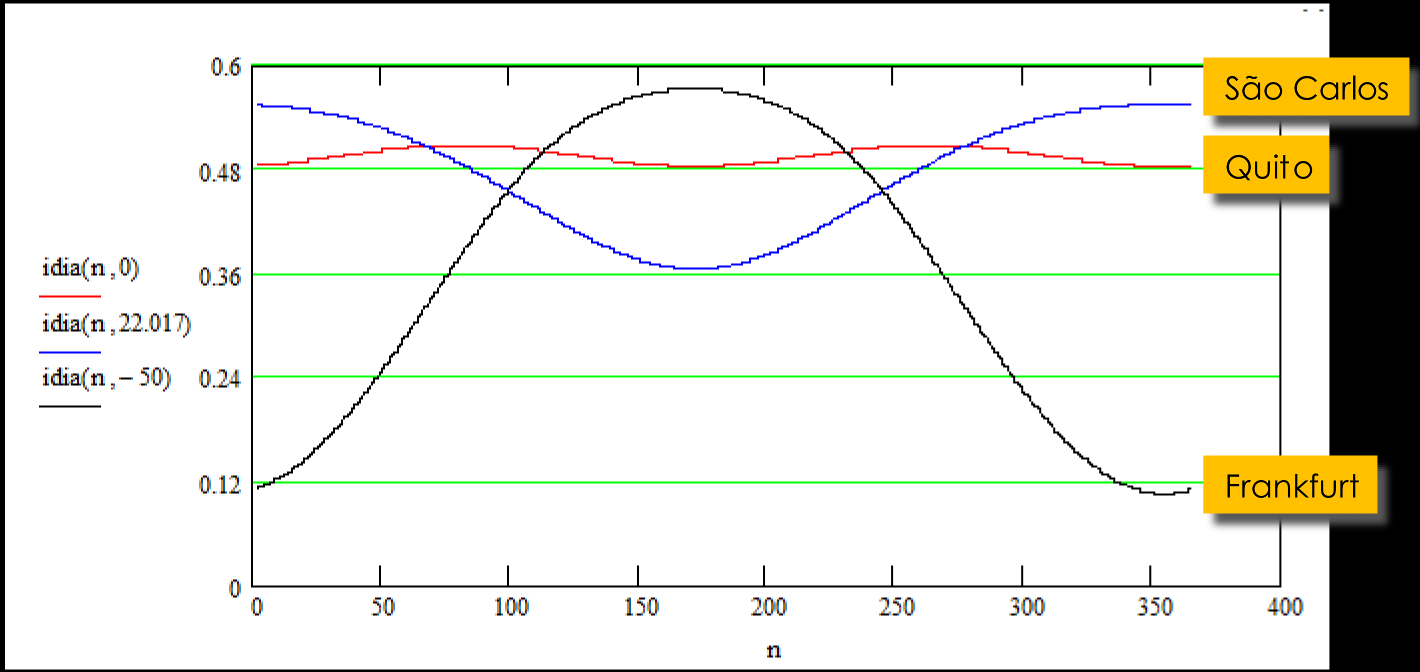
Definitions and working formulae...

Solar irradiation at noon (I_{sup}/I_{SC})



Definitions and working formulae...

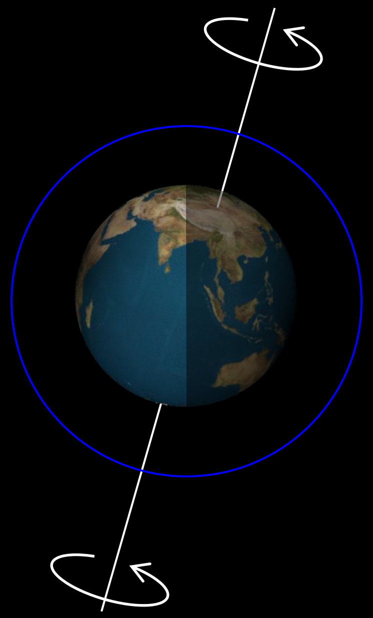
Daily average solar irradiation ($\hat{I}_{sup}/I_{SC}$)

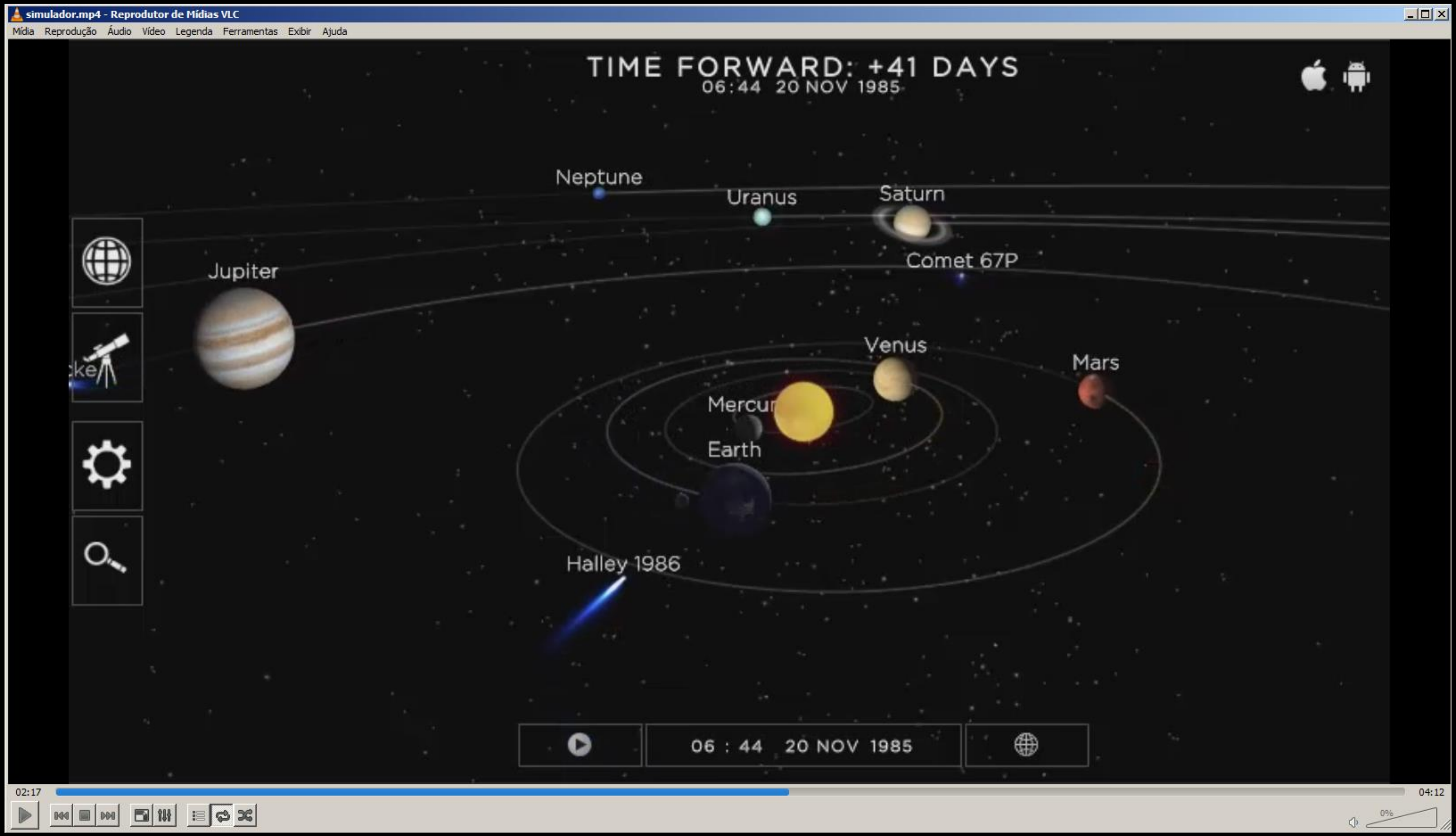


Alemanha: 36 GW (instalada)
Brazil: 25 MW (instalada)

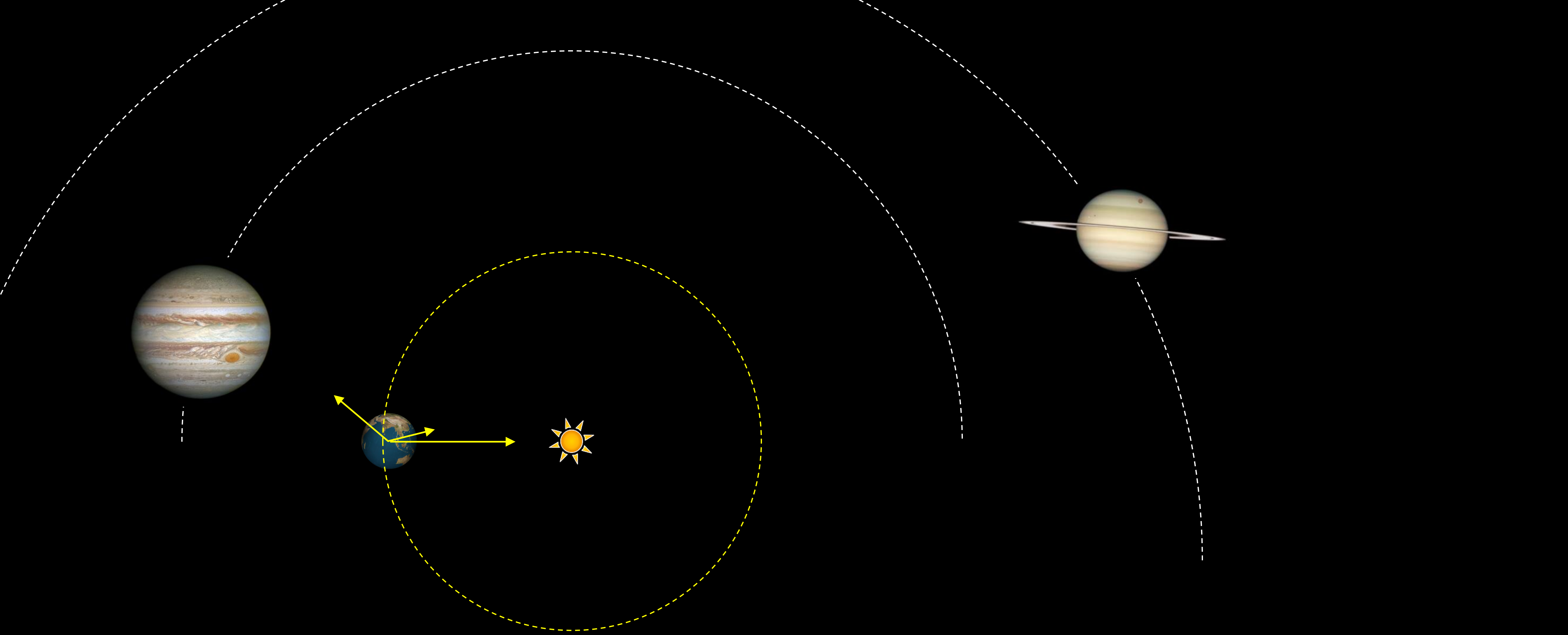
Other orbital cycles and their influence on the climate...

THE EARTH IS NOT MOVING AROUND THE SUN !





Milankovitch theory describes the collective effects of changes in the Earth's movements upon its climate, named after Serbian geophysicist and astronomer Milutin Milanković, who in the 1920s had theorized that variations in eccentricity, axial tilt, and precession of the Earth's orbit determined climatic patterns on Earth through orbital forcing. (http://www.solarsystemscope.com)



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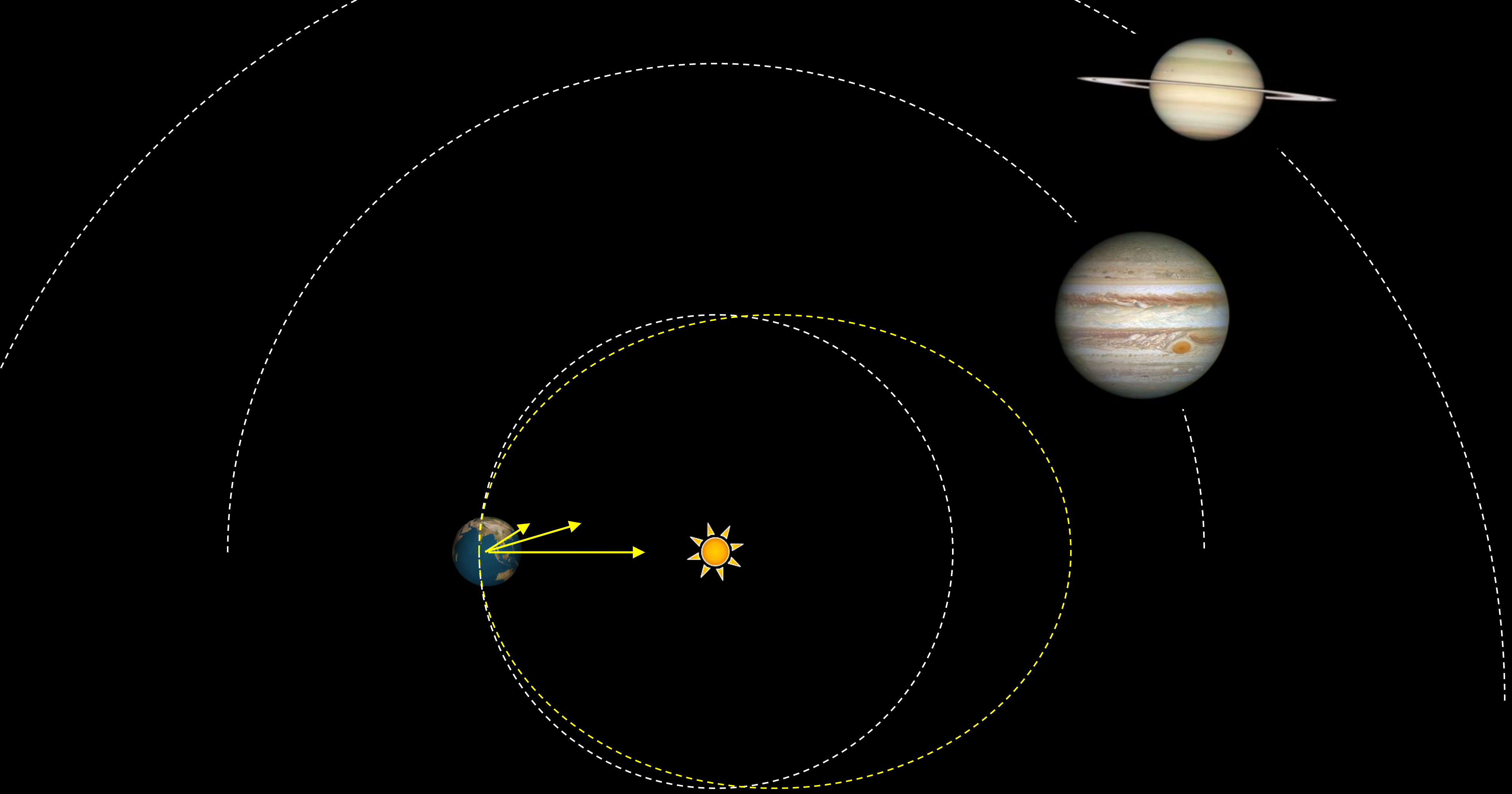

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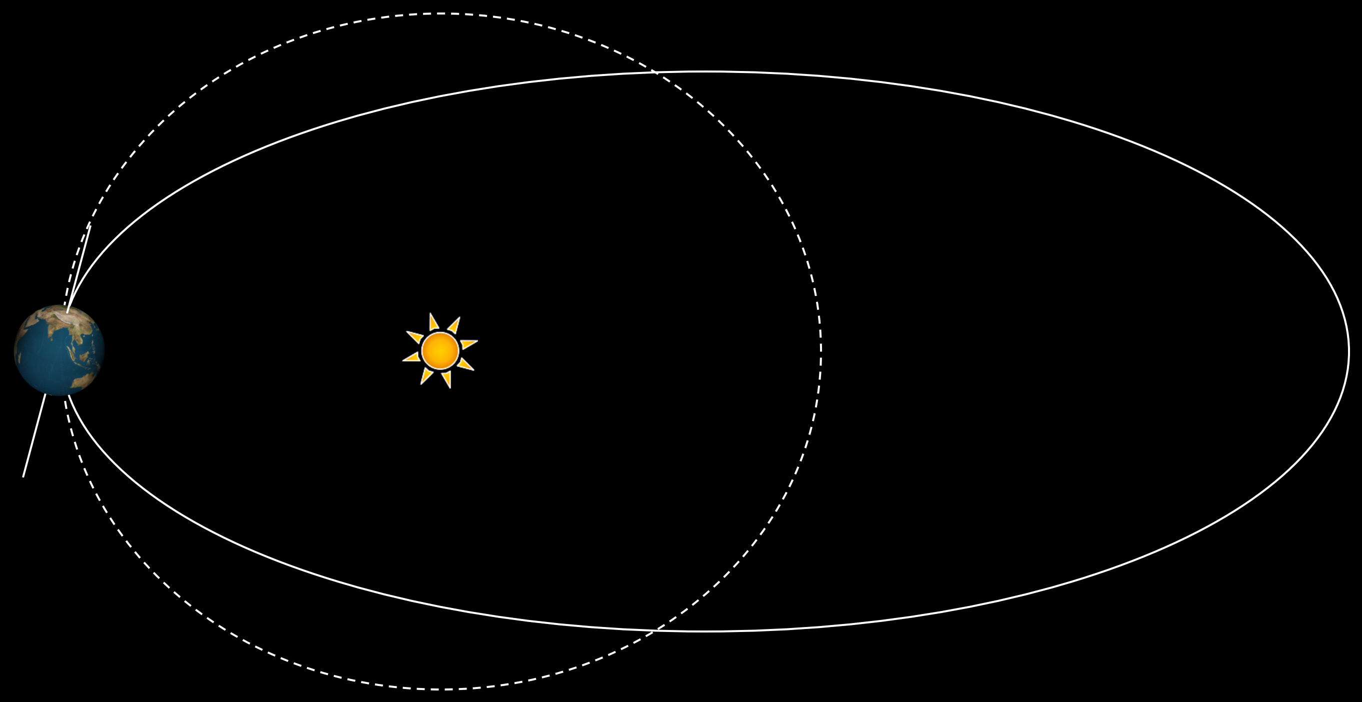
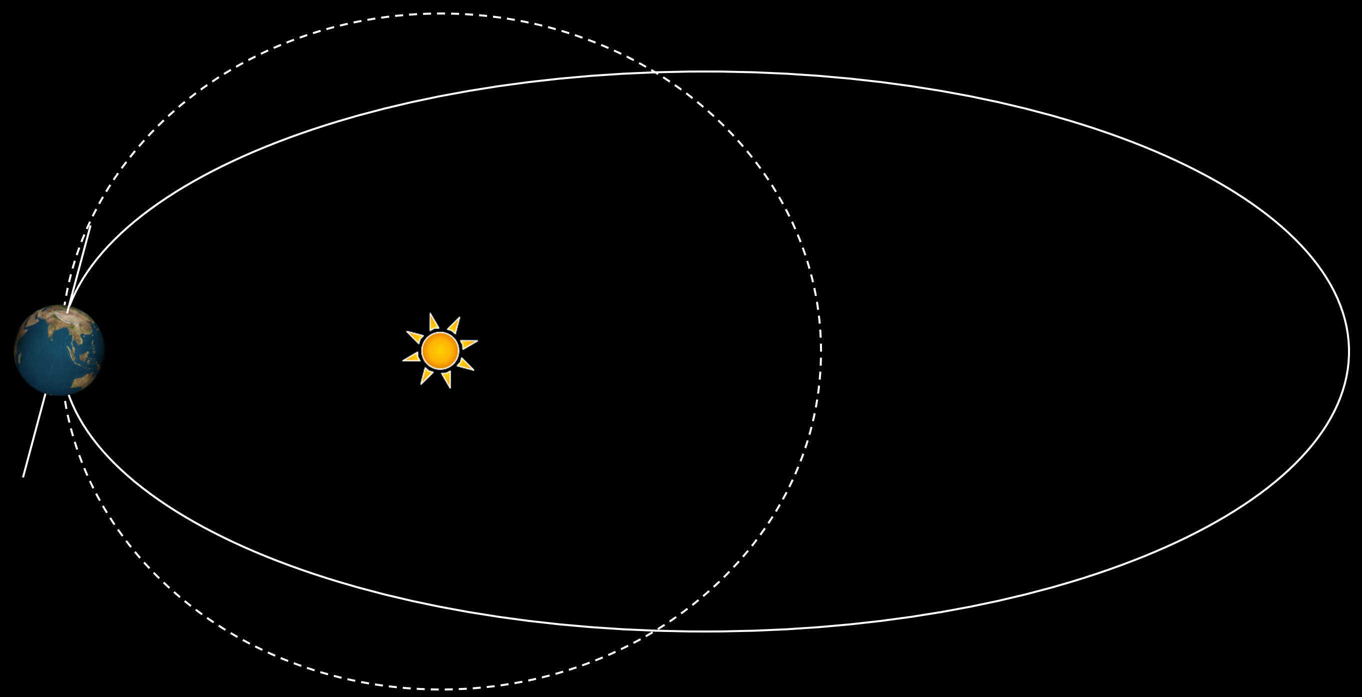
Orbital eccentricity...



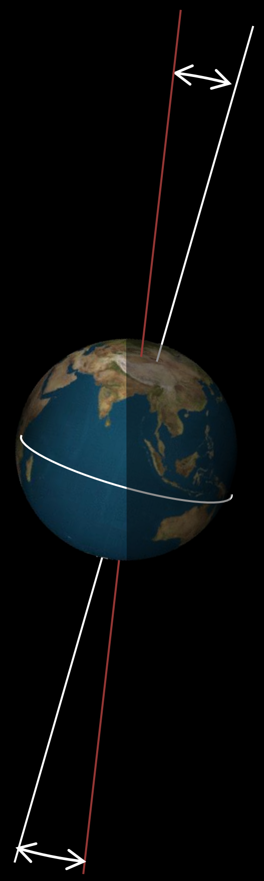
Period: 413 thousand years (±0.012)

Orbital eccentricity...



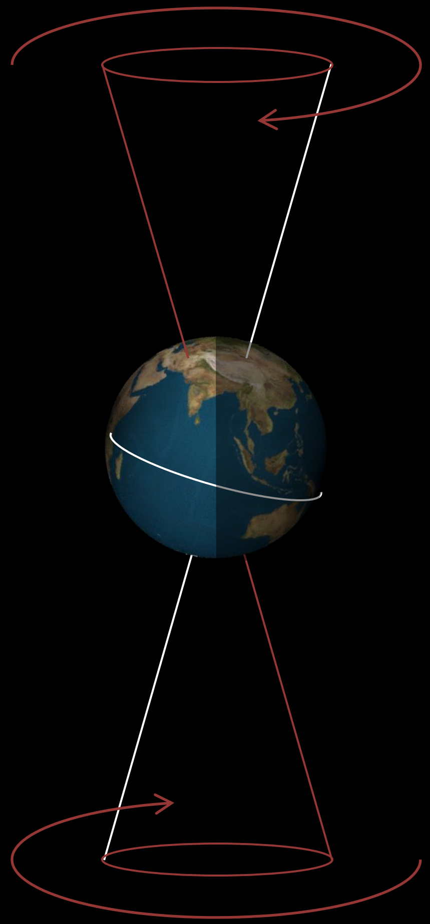
Period: 413 thousand years (±0.012)

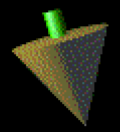
Earth's rotation axis obliquity



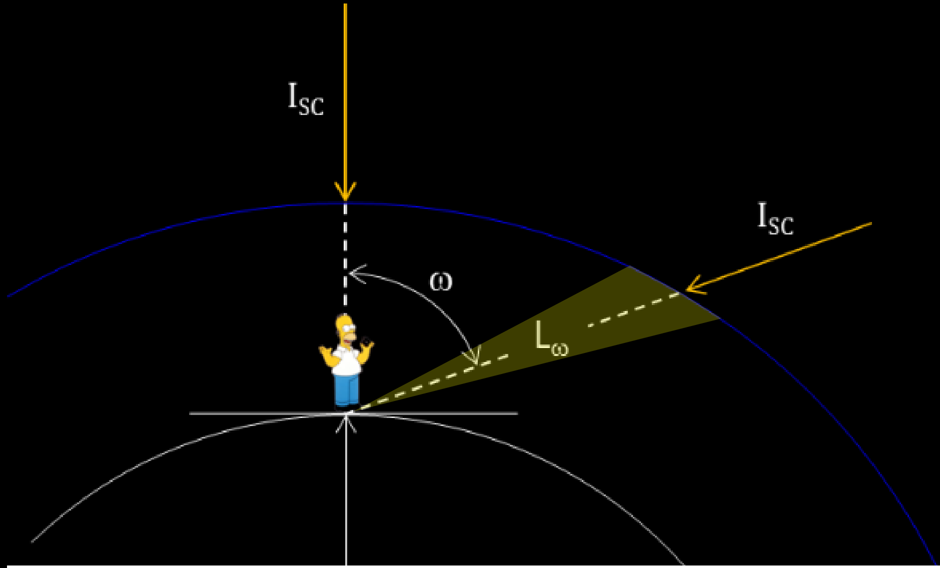
Period: 41 thousand years (22.1° - 24.5°)

Earth's rotation axis precession

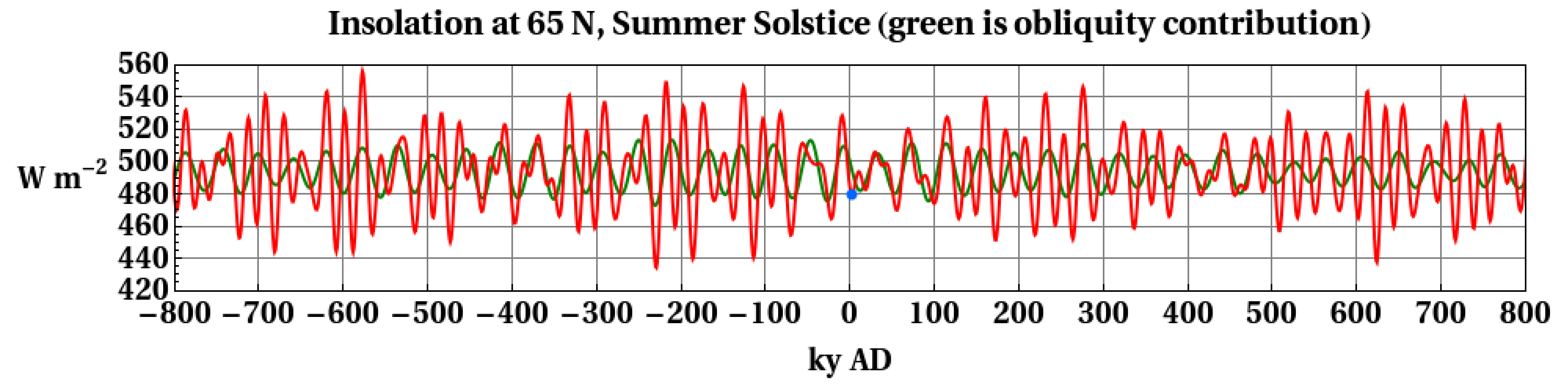


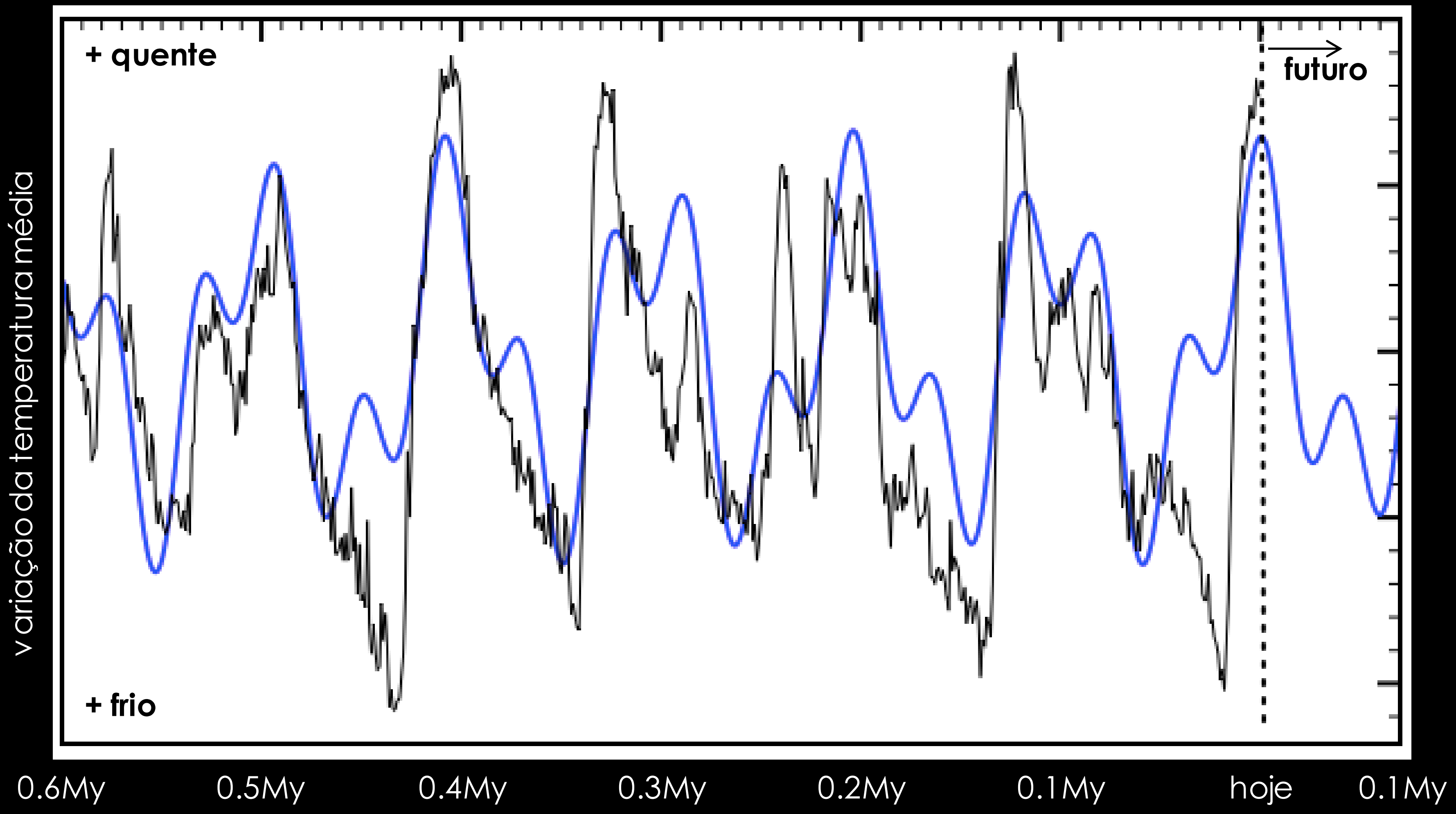


Period: 26 thousand years (360°)



A quantidade de energia solar que incide sobre a atmosfera varia, assim como a quantidade que efetivamente chega na superfície terrestre…



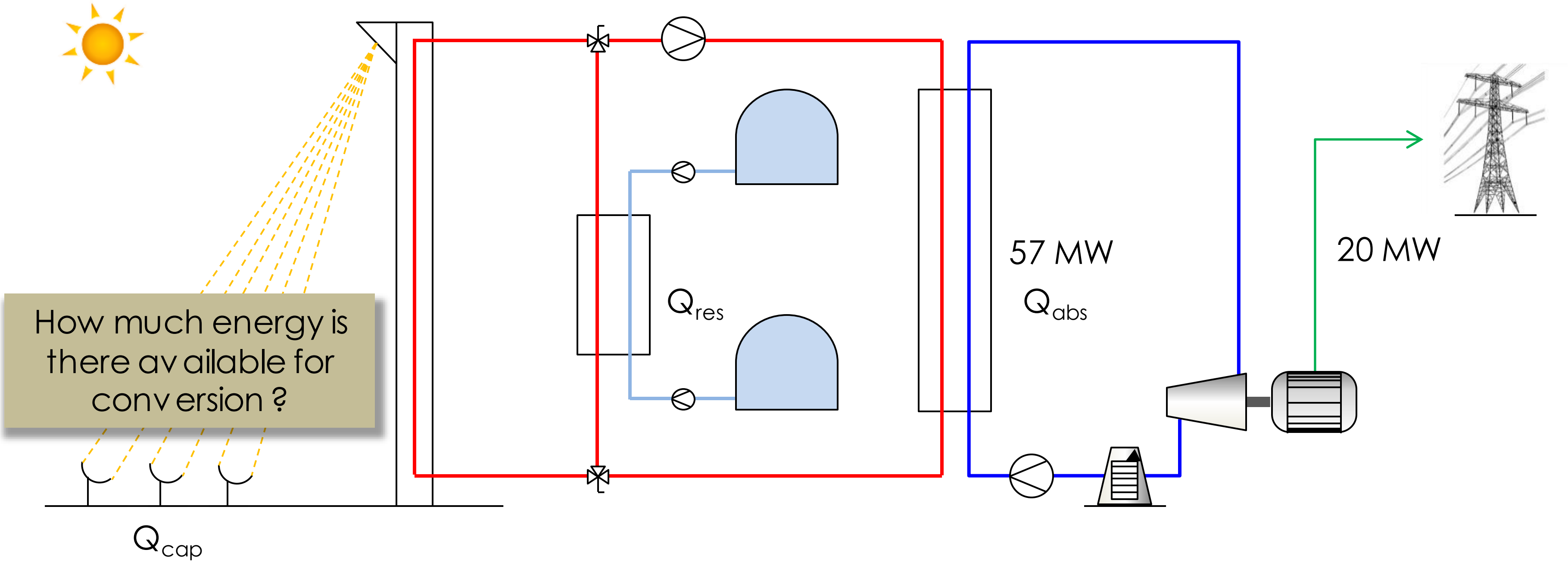


According to Physicist Clive Best we may already be past the optimum temperature of the Holocene Interglacial and be sliding back towards the next ice age. Clive has fitted the harmonics of combined Earth orbit cycles to a high resolution temperature record derived from carbonate microfossils from 57 ocean drilling sites. A combination of the 100,000 year eccentricity cycle and 41,000 year obliquity cycle provides an excellent fit to the ocean microfossil temperature record. Since Earth's orbital cycles are known with precision, this can be used to forecast what comes next.

Back to the power plant's design……

CONCEPTUAL DESIGN OF A THERMOSOLAR POWER PLANT…

$$I_{SC} = 1367\ \frac{W}{m^2}$$



Average solar energy (W/m²) collected at earth's surface by a 2D collector placed at latitude ϕ, disregarding the presence of clouds and other random losses.

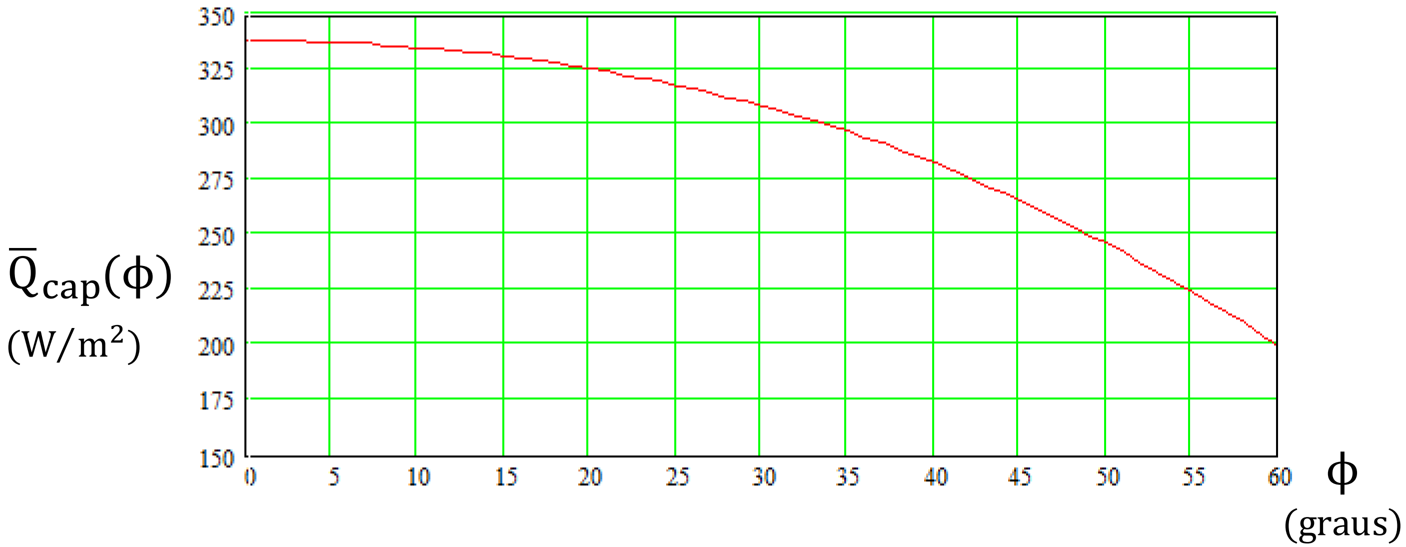
$$\sin(h) = \sin(\phi)\sin(\delta) + \cos(\phi)\cos(\delta)\cos(\varphi)$$

$$\overline{Q}_{cap}(\phi) \cong \frac{12}{24} \cdot \frac{I_{SC}}{365 \cdot 180} \int_{n=1}^{365} \int_{\varphi=-90°}^{\varphi=+90°} 0{,}7^{AM(h)^{0,678}}\, d\varphi\, dn$$

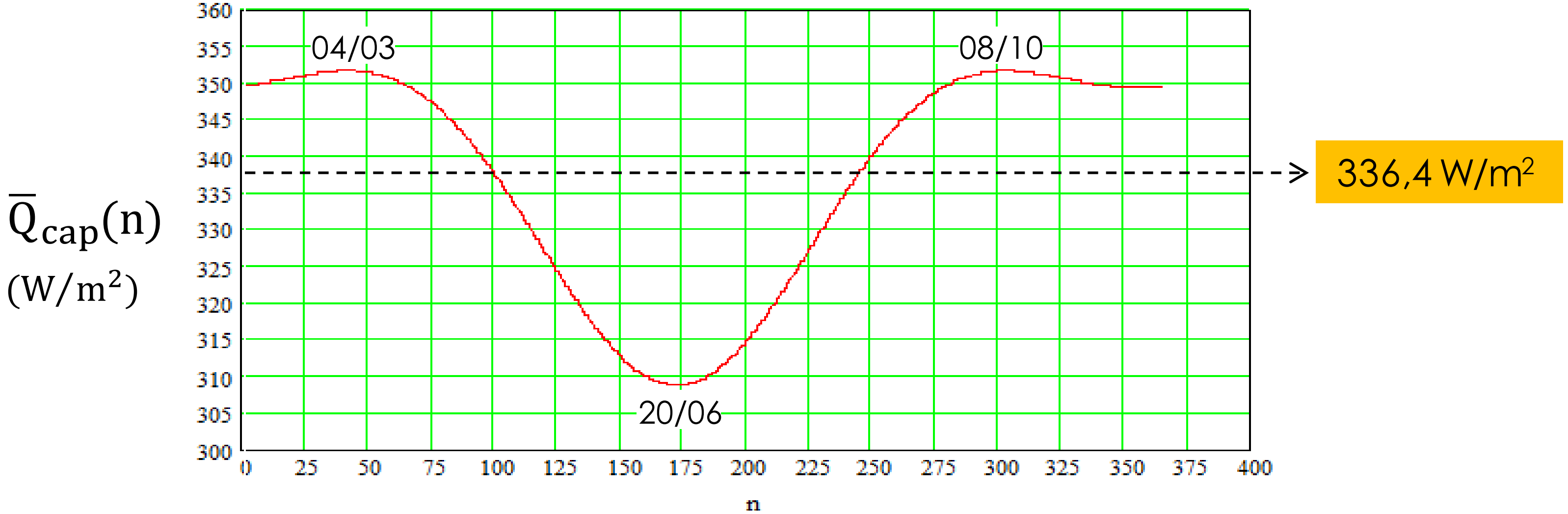
day of year

hour of day

CONCEPTUAL DESIGN OF A THERMOSOLAR POWER PLANT...

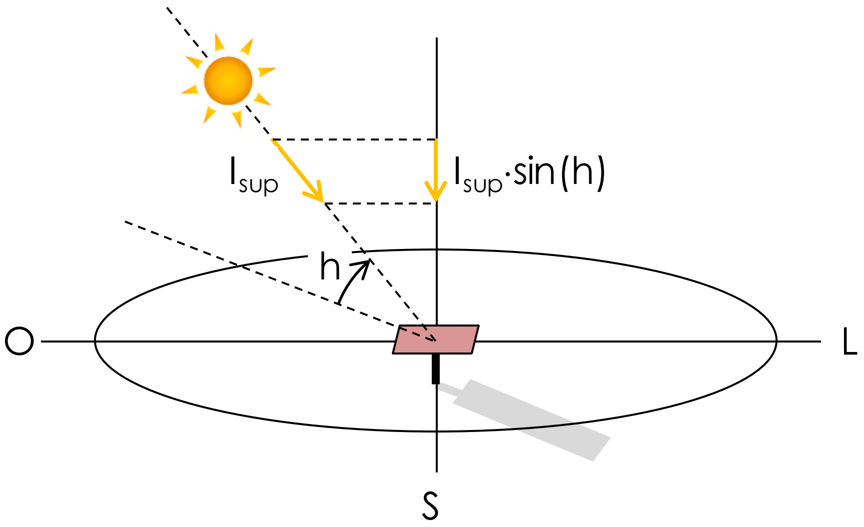


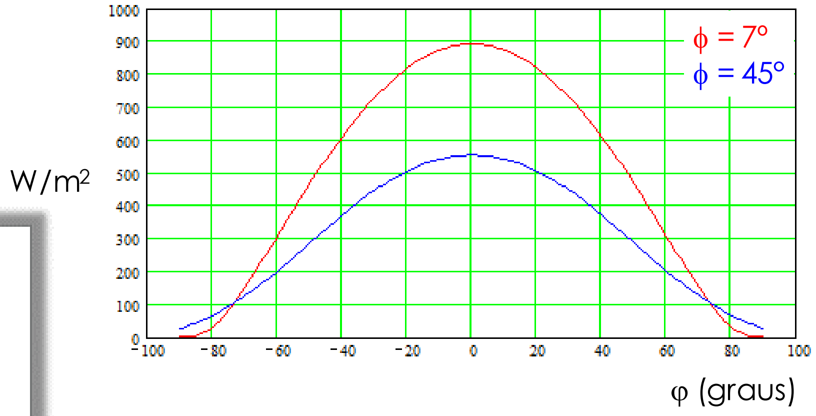
ϕ = –7° (Chapada do Araripe / Piauí)



FIXED × HELIOSTATIC (2D) SOLAR COLLECTORS...

$$\overline{Q}_{cap}(\varphi,\phi) \cong \frac{I_{SC}}{365}\int_{n=1}^{365} 0{,}7^{AM(h)^{0{,}678}} \cdot \sin(h)\,dn$$

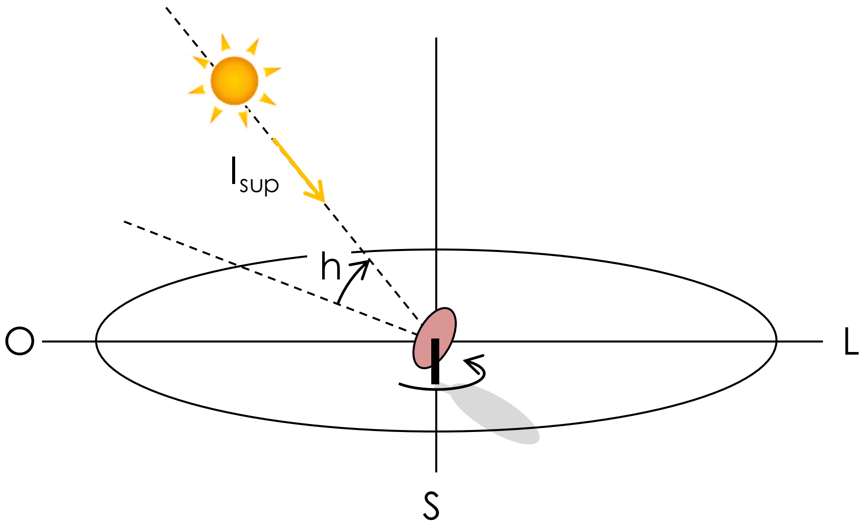


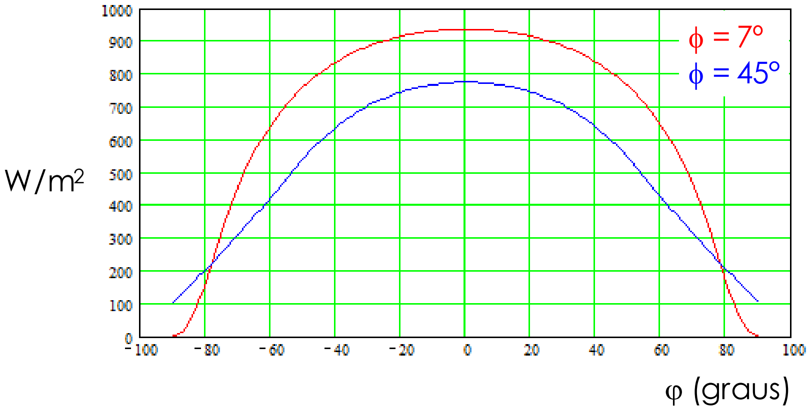


$\overline{Q}_{7^\circ} = 492\,W/m^2$

$\overline{Q}_{45^\circ} = 314\,W/m^2$

$$\overline{Q}_{cap}(\varphi,\phi) \cong \frac{I_{SC}}{365}\int_{n=1}^{365} 0{,}7^{AM(h)^{0{,}678}}\,dn$$



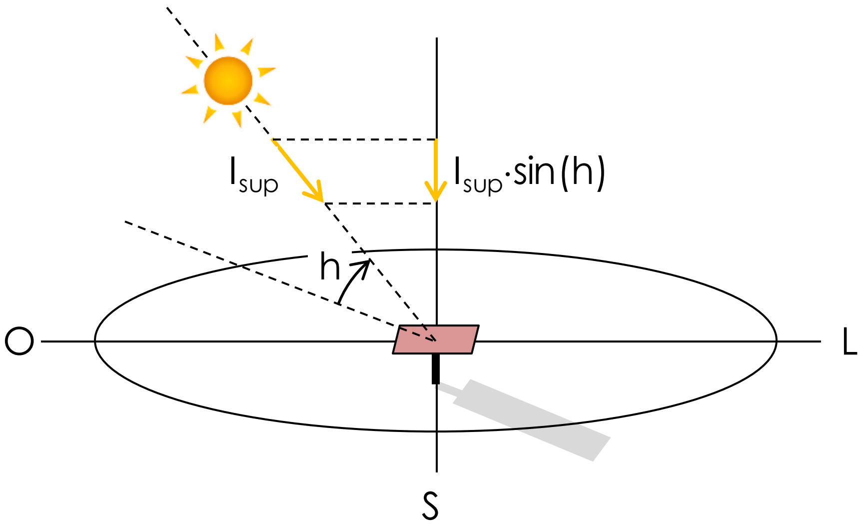


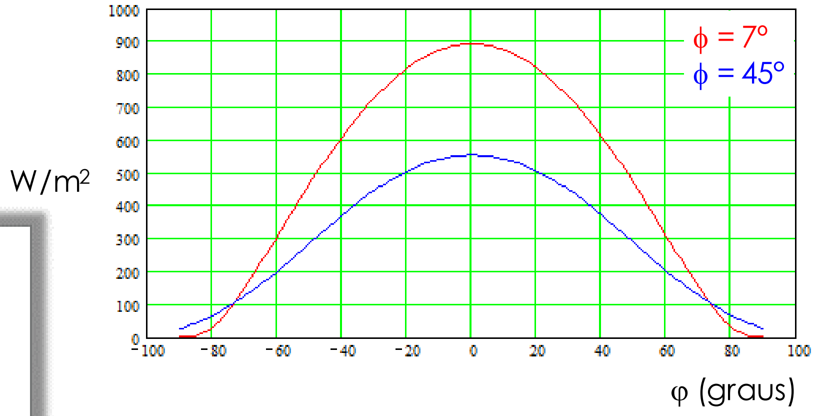
$\overline{Q}_{7^\circ} = 672\,W/m^2\ (+36\%)$

$\overline{Q}_{45^\circ} = 530\,W/m^2\ (+67\%)$

FIXED × HELIOSTATIC (2D) SOLAR COLLECTORS...

$$\bar{Q}_{cap}(\varphi,\phi) \cong \frac{I_{SC}}{365}\int_{n=1}^{365} 0,7^{AM(h)^{0,678}} \cdot \sin(h)\, dn$$





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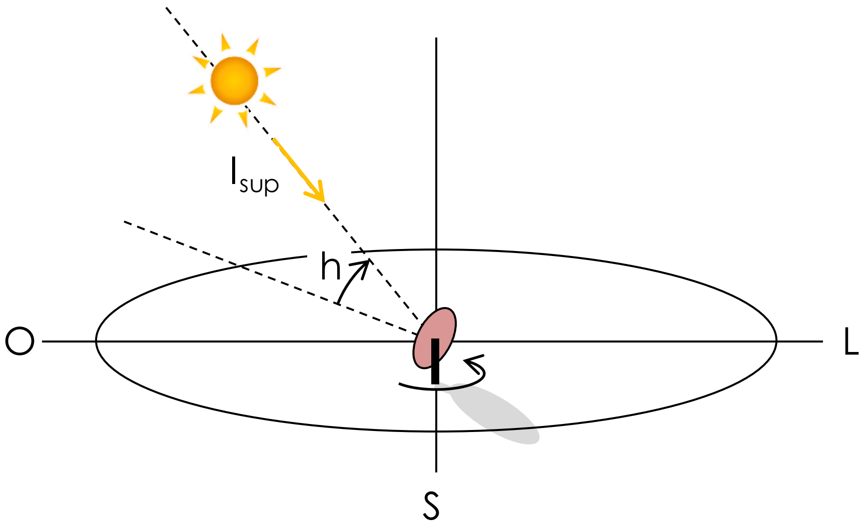

$$\bar{Q}_{7^\circ} = 672\ W/m^2\ (+36\%)$$

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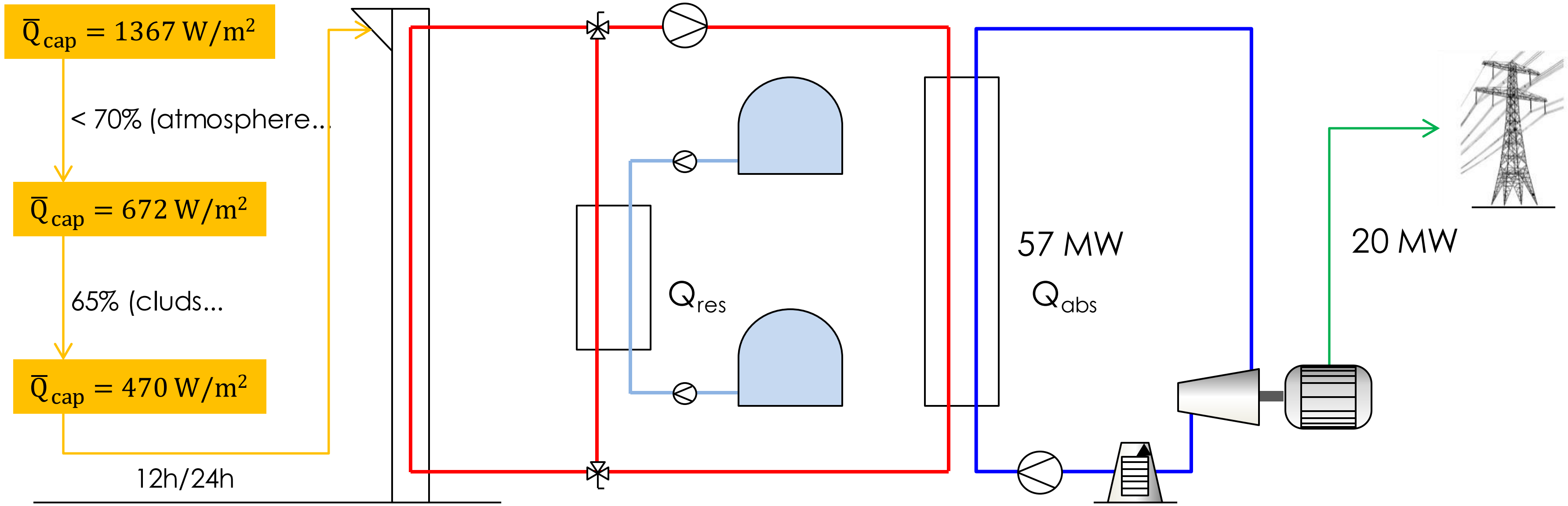
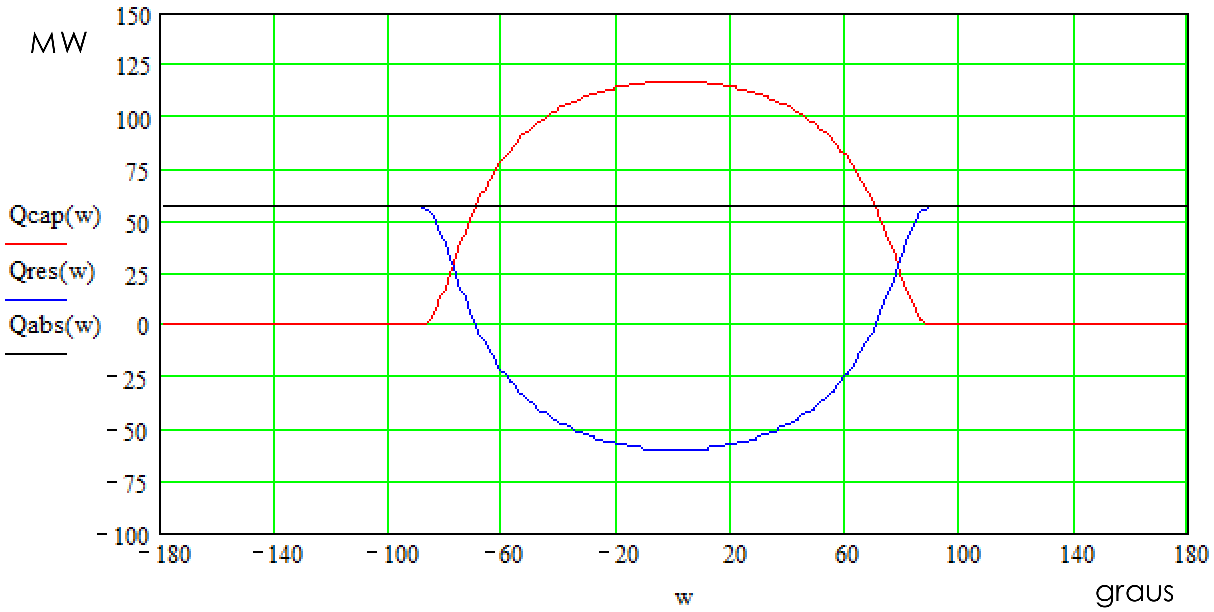
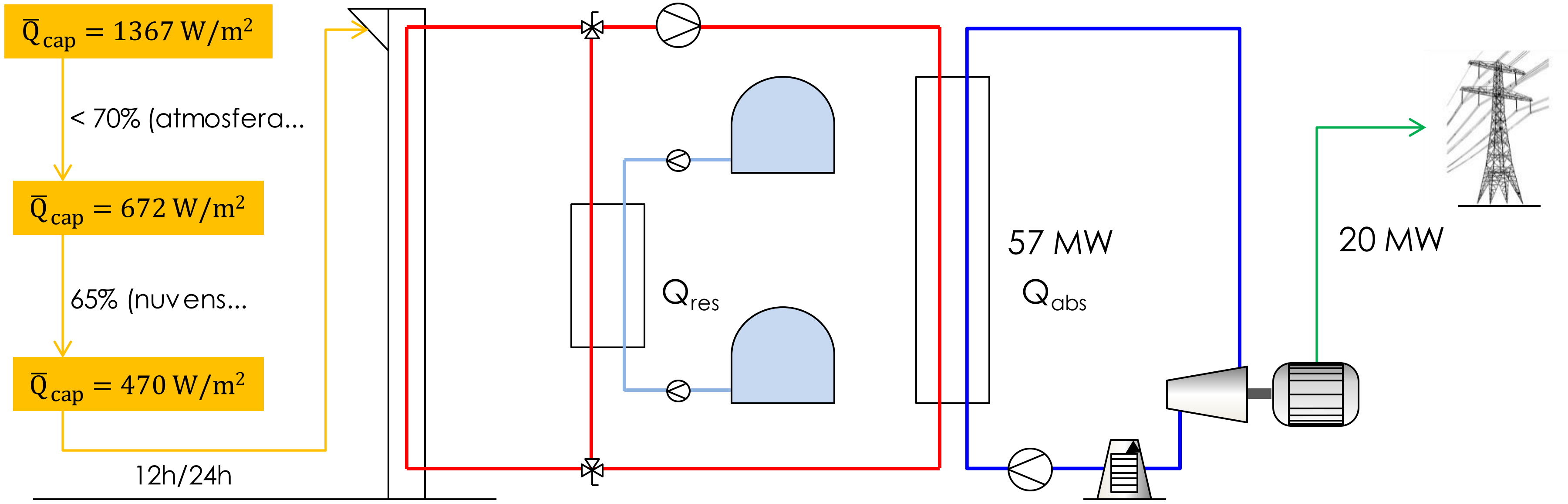
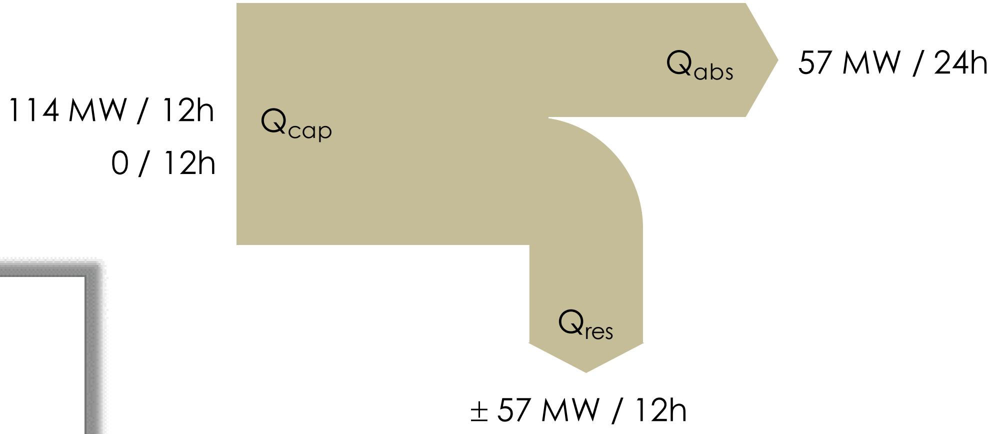


$\bar{Q}_{cap} = 1367\ W/m^2$
< 70% (atmosphere...
$\bar{Q}_{cap} = 672\ W/m^2$
65% (cluds...
$\bar{Q}_{cap} = 470\ W/m^2$
12h/24h
Q_{res}
57 MW
Q_{abs}
20 MW



MW
150
125
100
75
50
25
0
- 25
- 50
- 75
- 100
Qcap(w)
Qres(w)
Qabs(w)
- 180
- 140
- 100
- 60
- 20
20
60
100
140
180
w
graus





$$\bar{Q}_{cap} \cdot \text{Área} = 114\ \text{MW}$$

$$\text{Área} = \frac{114\ \text{MW}}{470 \cdot 10^{-6} \text{MW/m}^2}$$

$$\text{Área} \approx 25\ \text{ha} = 500\text{m} \times 500\text{m}$$

~2× + sistema de armazenagem

PS20 em Sanlucar la Mayor, Spain
20MW nominal / 1255 heliostatos ×120 m^2
5,5MW produção média anual

Getting notifications when PSELEGHIM goes live...