Overview L3

- Where does earth's energy come from?

  → Sun

- Follow the ~~money~~ energy!

  Sun → Earth → . . . .

- How come we don't burn up?

Example questions (2018 Summer School)

5) About 173,000 TW of radiant energy (power) reaches the earth from the sun. About 30% of this is reflected back to space. Meanwhile, geothermal energy supplies about 32 TW of power. By what factor is the power absorbed by the earth greater than the power available from geothermal energy?

(2 marks)

L3 →

* $\boxed{4.}$ 'Raw' energy = 2649 kJ

most relevant

Available for work = 0.2×2649 kJ = 529.8 kJ

$\approx 530 \times 10^3$ J

Needed to climb to height h : $mgh = 72\,kg \times 9.81\,m/s^2 \times h$

$\Rightarrow$ set mgh = available

$$\Rightarrow h = h_{max} = \frac{529.8 \times 10^3\,J}{72\,kg \times 9.81\,m/s^2}$$

$= 750\,m$

$\gg 328\,m$, so yes, can climb!

5. No! 'Converted' to thermal energy etc.

$\rightarrow$ 'heat up'.

$\rightarrow$ total energy is conserved

End L2.

L3

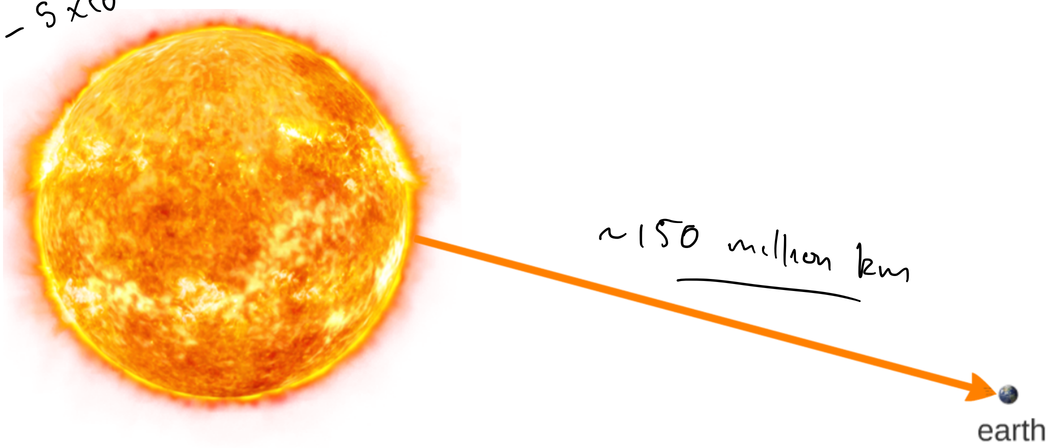
1.5 Planetary energy balance

L3 —

Energy is crucial for life on Earth. Human society uses various forms of energy to - hopefully - improve quality of living. We will look at patterns of human energy consumption soon; first, we ask the more basic question: *where does the energy we use come from in the first place?*

The simple answer is: **the Sun!** It *radiates* energy generated from nuclear fusion reactions. Only a small part of this reaches us, however!

$3-5 \times 10^{26}$ W



~150 million km

Figure 2: The Sun!

Let's do some calculations to look at this in more detail.

Consider the following questions:

1. What is the total radiant energy of the Sun?
2. How much reaches Earth?
3. How much of the energy is absorbed by the Earth?
4. What happens to the energy that is absorbed by the Earth?

We'll primarily focus on calculating the answers to the last three questions, taking the first for granted. We *may* look at a calculation of the answer to the first question in a tutorial lecture slot.

1.5.1 The radiant energy of the sun

Here we'll just state the facts.

Power $\approx 3-5 \times 10^{26}$ W at surface

eg $\boxed{3.8 \times 10^{26} \text{ W}}$

or 'Total Energy Flux' J/s →

1.5.2 How much reaches earth?

or 2...

Consider Figure 3. Some key features to note: the Earth is very far from the Sun, and the Earth is much smaller than the Sun! These account for the fact that only a small amount of the total energy of the Sun actually reaches us.

Flux: rate of transport.

J = Total Energy Flux : energy / time [=] W ie power.

j = Energy Flux (per area) : energy / time · area [=] W/A. (power per area)

Factors

affects:

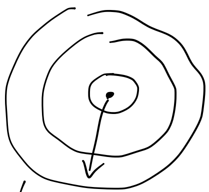
(1) Far away : } energy 'intensity' or 'density'

Total Flux = constant (steady rate of energy radiation)

&

$\frac{\text{Total}}{\text{Area}}$ = Flux × Area = constant

ie $(\downarrow) \times (\uparrow)$ = same



$A\uparrow$ $j\downarrow$,

$J = j \cdot A$ = const.

ie $\boxed{\text{'intensity' goes down}}$ since Area $\uparrow$

Surface area at radius R_{se} = 150×10^9 m

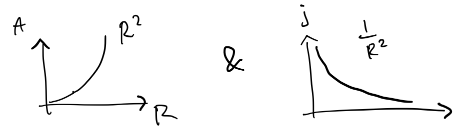
dist. sun to earth.

$= 4\pi R_{se}$

$\approx 2.83 \times 10^{23}$ m^2

Flux per area = $\frac{3.8 \times 10^{26} \text{ W}}{2.83 \times 10^{23} \text{ m}^2} \approx \boxed{1.34 \times 10^3 \text{ W/m}^2}$

Note: scale nonlinearly



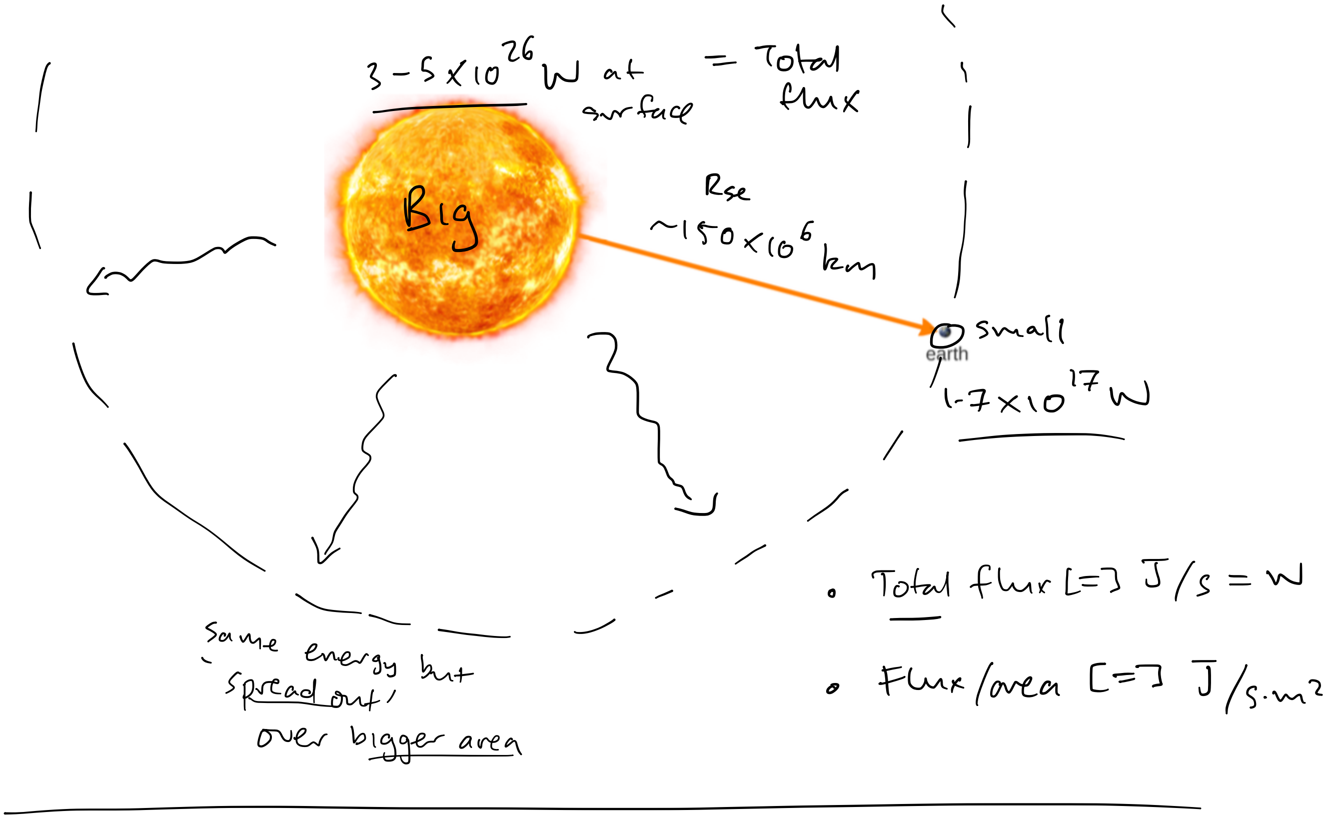
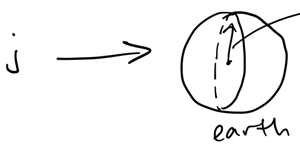


Figure 3: The Sun! Again...

(2.) Earth is small. ⇒ much of energy 'misses' earth.
Let use cross-sectional area for irradiated area



(could also use eg $\frac{1}{2} \times SA$ etc)

note $R_e \neq R_{se}$!

$$A_{cross} = \pi R_e^2, \quad R_e \approx 6.4 \times 10^6\,m \approx \boxed{1.29 \times 10^{14}\,m^2}$$

So: Total flux 'hitting' earth $= \left(\frac{\text{Flux}}{\text{Area}}\right)_{sun} \times (\text{Area})_{earth}$

$$\approx (1.34 \times 10^3\,W/\cancel{m^2}) \times (1.29 \times 10^{14}\,\cancel{m^2})$$

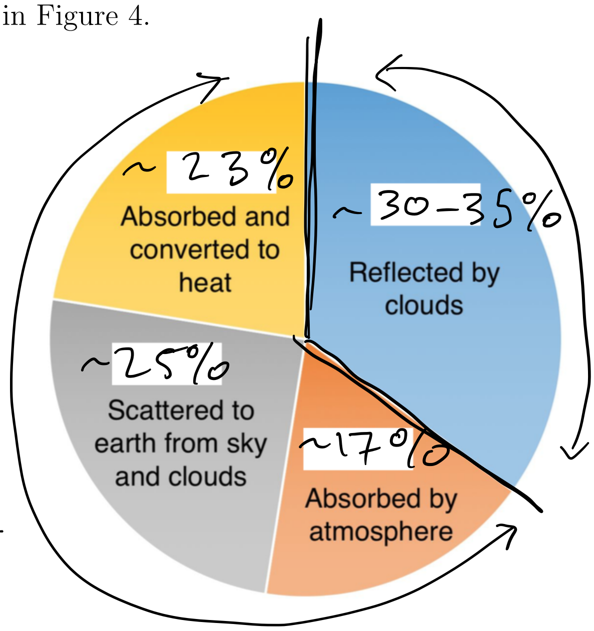
$$\approx 1.73 \times 10^{17}\,W = \boxed{173{,}000\,TW}$$

$(T = \times 10^{12})$

$\frac{1.73 \times 10^{17}}{4 \times 10^{26}} \approx 4 \times 10^{-10}$!

1.5.3 How much of the energy is absorbed by the Earth?

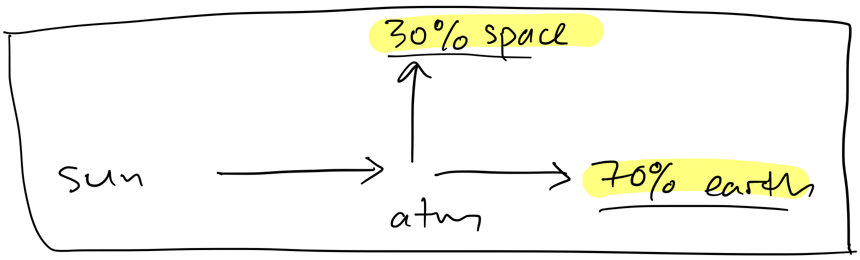
Even given that only a small fraction of the total energy output of the Sun reaches the Earth, *we also need to account for what happens to the energy that reaches the outer atmosphere*. In particular, **not all of this energy is absorbed on earth**. This is illustrated in Figure 4.



~ 30-35% reflected away

Figure 4: The relative distribution of the energy that reaches the Earth.

65-70% absorbed by earth in some way ie



(*)

1.5.4 What happens to the energy that is absorbed by the Earth?

Continuing to follow the energy, we now consider what happens to that absorbed by the Earth. This is illustrated in Figure 5.

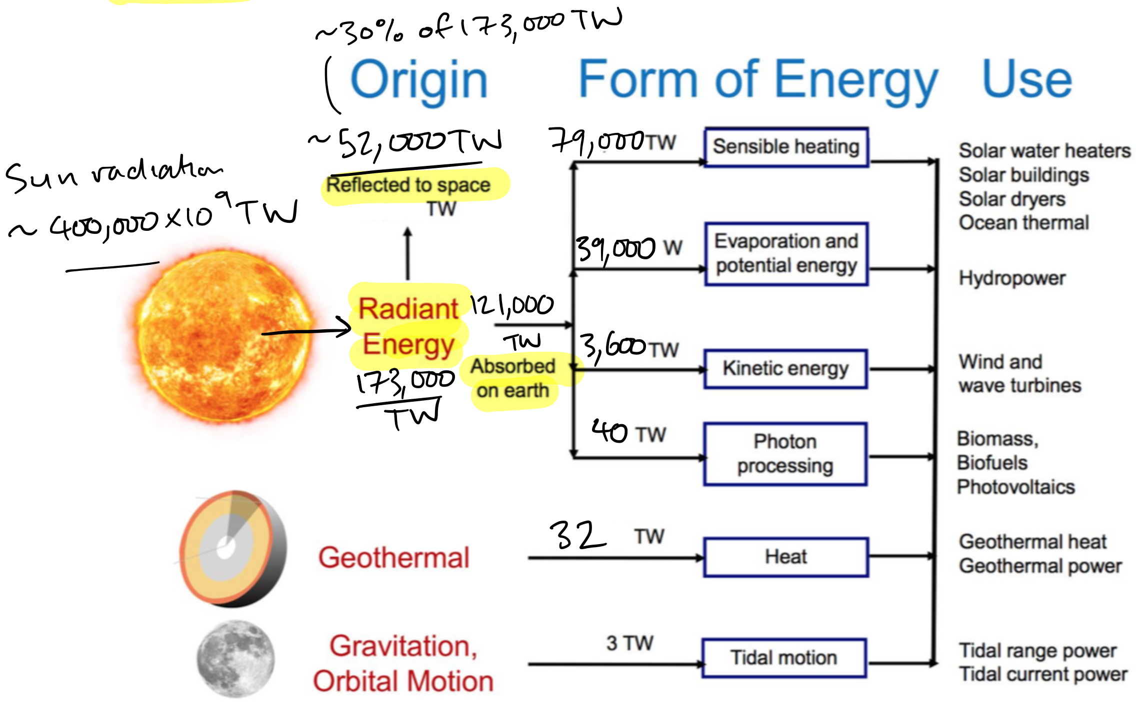


Figure 5: Planetary energy balance.

Note that radiant energy provides orders of magnitude more energy than geothermal or gravitational energy.

- Raw radiant energy from sun ~173,000 TW

  ↳ 70% available → ~ 120,400 TW available

- Energy from geothermal + gravitational

  ~35 TW

  ie sun provides ~ 3440 (available)

  x that of geo + grav.

Example Problems 4: Planetary energy balance

Most rel.

1. By what factor is the radiant energy provided by the Sun greater than that provided by geothermal and gravitational (tidal) energy combined?
2. In the next section we will estimate the human worldwide energy use per year as about 17 TW. Hence comment on the potential to use tidal motion (gravitational energy) as a renewable energy source.
3. Why could geothermal energy ultimately be considered a form of nuclear energy?
4. Geothermal energy appears useful for use in heat pumps. What does this have to do with refrigerators?

Answers

1. ✓ (~ 3440)

2. $\frac{\text{Usage}}{\text{Available}} \approx \frac{17\text{ TW}}{3\text{ TW}} \approx 6$

ie world usage ≈ 6 x that avail. from grav.

⇒ not feasible to provide all

3. Ultimate source is radioactive decay of potassium, thorium, uranium etc in earth's interior.

4. Heat pump = refrigerator run backwards!