



Technology Conference 2011



HARVESTING THE ELECTROMAGNETIC SPECTRUM

From Communications to Renewables

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(Anglesea Bg, Room AG2.08, 12:10:12:45)



To harvest = To reap, to gather

THIS TALK

Big Ideas for a Small Planet!



- Describe **What are electromagnetic waves?**
 - Frequency, wavelength and speed of a wave
- Introduce **Electromagnetic Spectrum:**
 - what is it and why is this important?
- Present **Communication Systems** on earth & beyond
 - How waves provide a service to the world and make (lots of) money
- Present **Remote Sensing and Understanding the Universe**
 - Help our lives and harvesting scientific knowledge
- Present **Renewable Energy and Fighting Global Warming**
 - Can electromagnetics help save the world?
- **How e.m waves are used to improve our Health?**

A beautiful mind



MAXWELL

$$\begin{aligned}\nabla \cdot \mathbf{E} &= \frac{\rho}{\epsilon_0} \\ \nabla \cdot \mathbf{B} &= 0 \\ \nabla \times \mathbf{E} &= -\frac{\partial \mathbf{B}}{\partial t} \\ \nabla \times \mathbf{B} &= \mu_0 \mathbf{J} + \mu_0 \epsilon_0 \frac{\partial \mathbf{E}}{\partial t}\end{aligned}$$

Solve eqs \rightarrow

em waves travel at a speed \mathbf{c}

$$c = \frac{1}{\sqrt{\mu_0 \epsilon_0}}$$

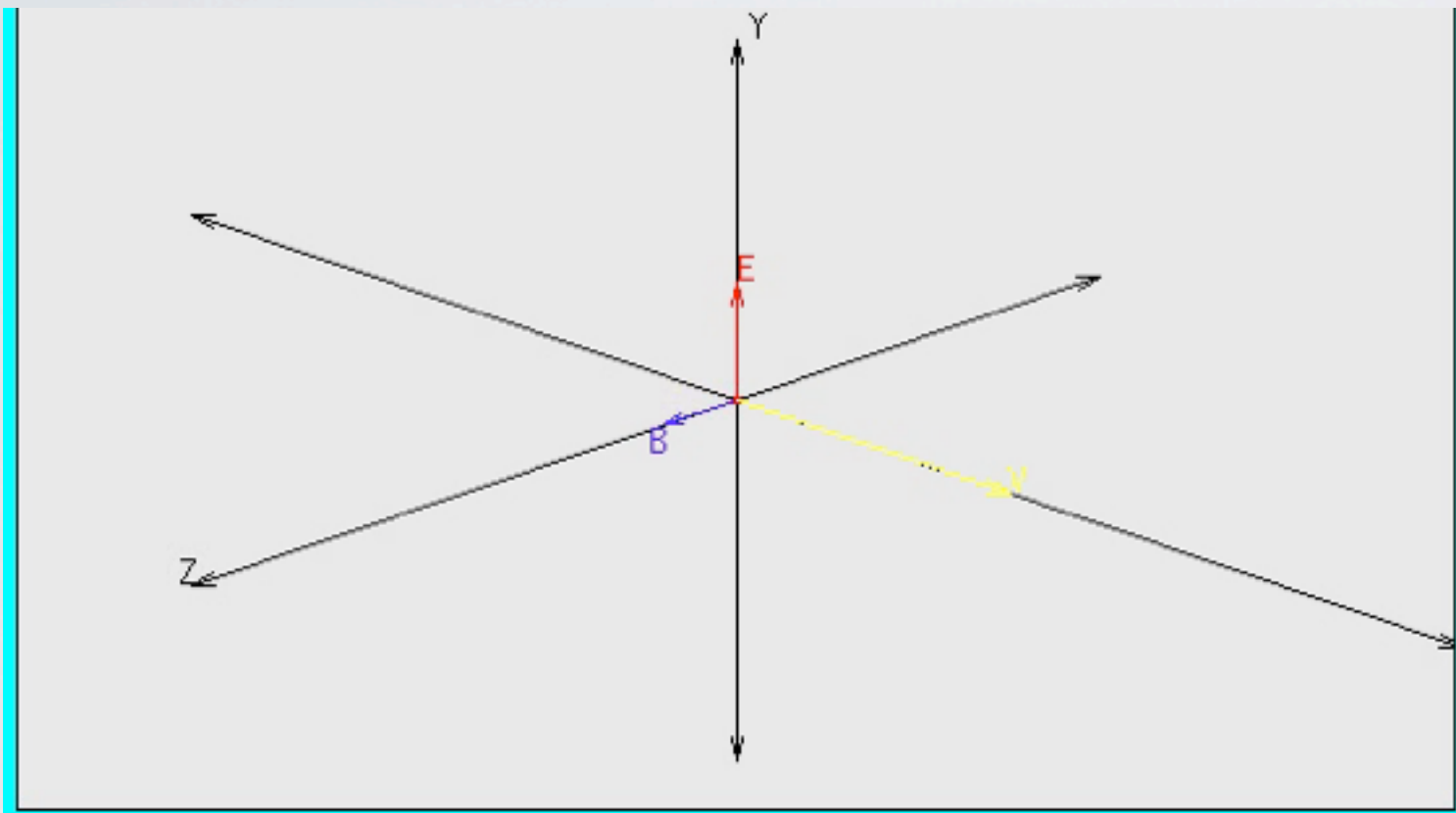
$\mathbf{c} = 299\,792\,458 \text{ m/s}$
 \mathbf{c} is the speed of **light!!!**

Maxwell Equations (beautiful!!!!)

- **James Clerk Maxwell** (13 June 1831 – 5 November 1879) was a Scottish theoretical physicist and mathematician. His most important achievement was formulating classical electromagnetic theory. This united all previously unrelated observations, experiments and equations of electricity, magnetism and even optics into a consistent theory. His set of equations—Maxwell's equations—demonstrated that electricity (\mathbf{E}), magnetism (\mathbf{B}) are manifestations of the same phenomenon, the **electromagnetic field**.
- One set of remarkable solutions to these equations takes the form of traveling sinusoidal plane waves, with the directions of the electric and magnetic fields being perpendicular to one another and the direction of travel. The two fields are in phase, traveling at the speed of light = First derivation from first principles of the **speed of light!!!!** This strongly indicated that **light is an electromagnetic wave!!!!** Later proven/verified by experiment.
- Great scientist who has unified electric and magnetic phenomena into **one single coherent framework** (like Newton, Einstein for example).
- Two fundamental constants (permittivity and permeability) used to predict the value of another fundamental constant, c , the speed of light!!!!

ELECTROMAGNETIC WAVES

e.m. wave generation

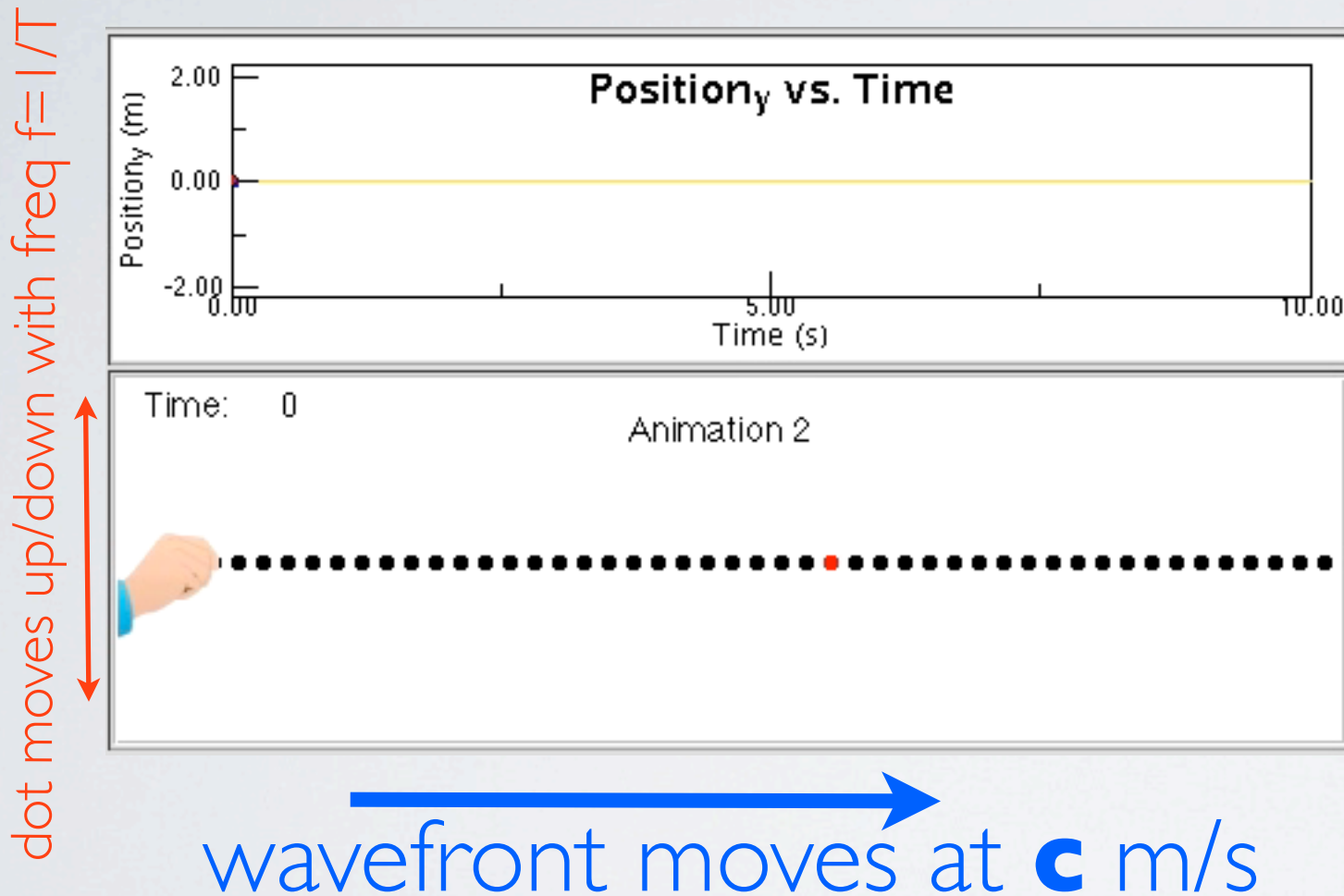


Accelerated charges (e.g. electrons) produce electromagnetic waves

electric charge moves up and down repetitively every **T** seconds or equivalently with frequency (in **Hertz**):

$$f = \frac{1}{T}$$

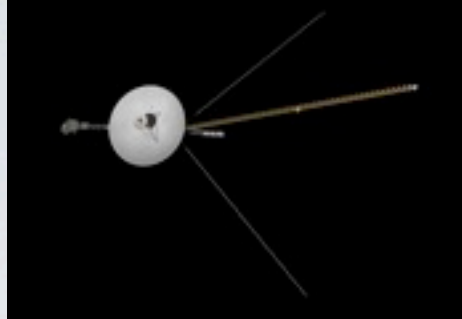
FREQUENCY & WAVELENGTH



The wave propagates at c
The wave repeats in space with a spatial length called the wavelength λ (meters)

At a fixed location (e.g. red dot), the wave beats with a repetition time T (seconds)

For all waves: $c = f\lambda \Leftrightarrow c = \lambda / T$



Voyager 1 spaceprobe some 17 billion miles = 180 AU away!!

EM WAVES GO ON FOREVER!!!

- **Power: Inverse square law in empty space = free space loss'**

$$P_r = P_t \times \frac{1}{4\pi d^2} (\times \text{opacity})$$

Diagram illustrating the inverse square law equation: $P_r = P_t \times \frac{1}{4\pi d^2} (\times \text{opacity})$. Arrows point from the labels to the corresponding parts of the equation: 'received' points to P_r , 'transmitted' points to P_t , 'distance' points to d , and 'medium' points to 'opacity'.



- em waves go on forever through empty space but they get smaller (=free space loss)!!

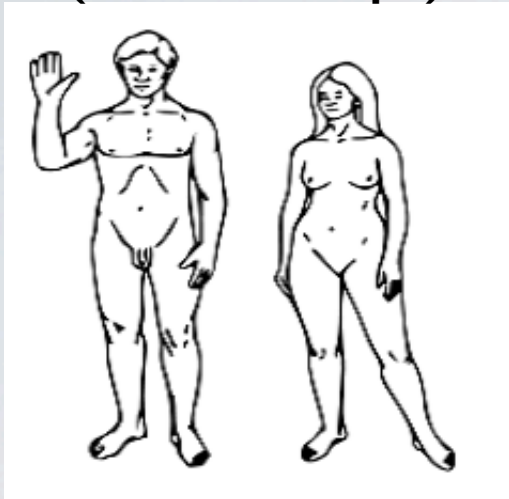
Big Antennas required to receive signals from (very) distant objects.

=> we can see far but we need big antennas = **astronomy** (later)
but first earth applications

WAVES FOR EARTHLY COMMS

Homo Sapiens

(Pioneer II Plaque)



- (Latin: "wise man" or "knowing man")
- Hominidae family (the great apes).
- Highly developed brain capable of abstract **reasoning, language, and introspection.**
- Erect body carriage that frees their upper limbs for manipulating objects, has allowed humans to make far greater use of tools than any other species.

The sharing/passing of information is central to the success of homo sapiens.

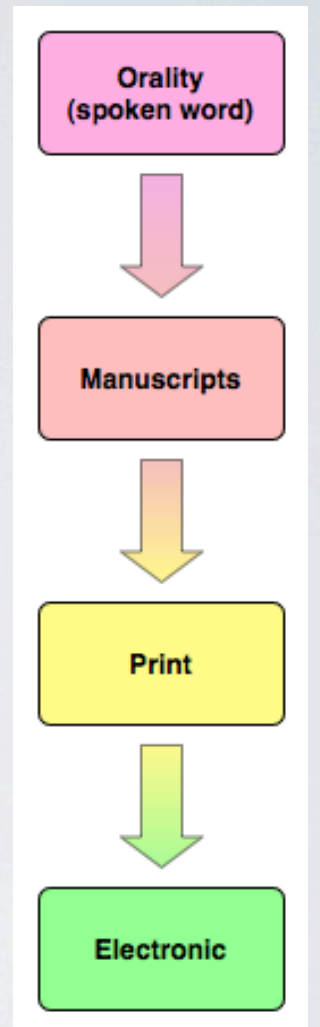
Communication through time

- Storage systems (hard disks, SSD, data centres)
- CDs, tapes etc

Communication through space (WAVES)

- Internet
 - Terrestrial cable, fiber optics
 - Radio Communications

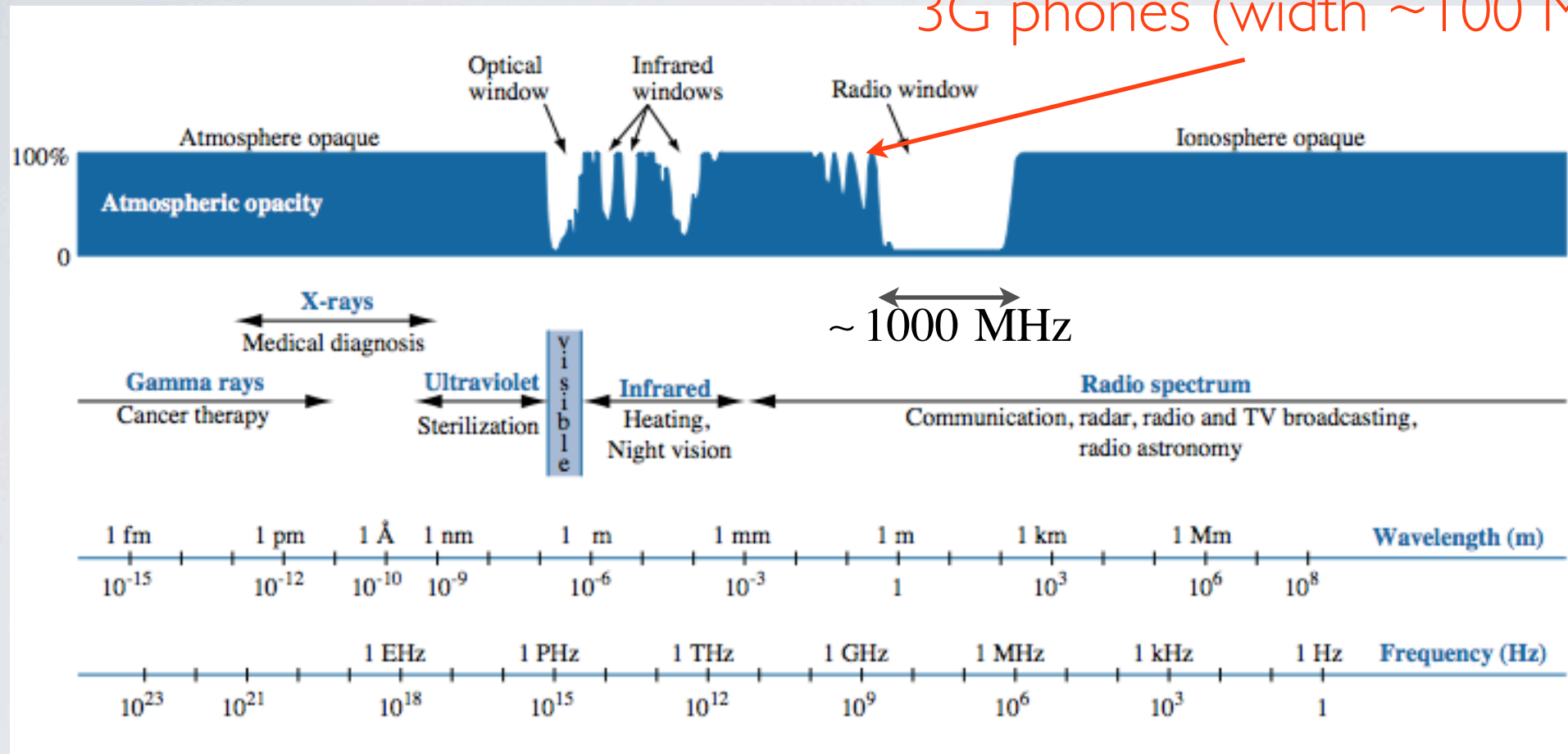
There is money to be made but how much???



Global Village was a term probably first coined by Marshall McLuhan and Quentin Fiore in the 1967 book *The Medium is the Message*

E.M SPECTRUM ON EARTH

3G phones (width ~ 100 MHz @ 2 GHz)



Total **finite** available radio spectrum is 1 GHz wide = 1000 MHz = 10x3G **not much really!!!**

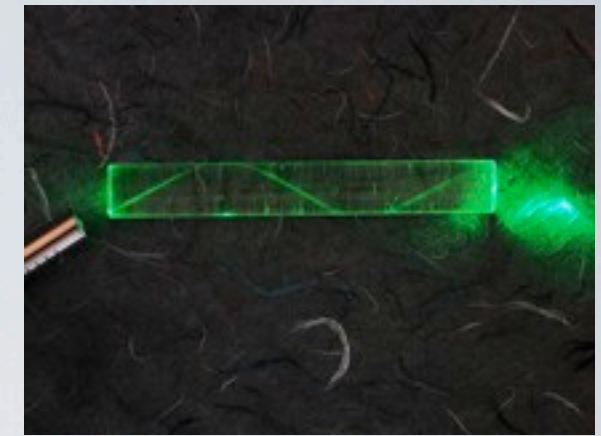
Test the atmosphere opacity (**Radio propagation**)

1/ Send known e.m. waves through the atmosphere

2/ Receive the e.m. wave

Compare the sent and receive waves to infer characteristics of the atmosphere (on top of free space loss)

FIBRE OPTICS

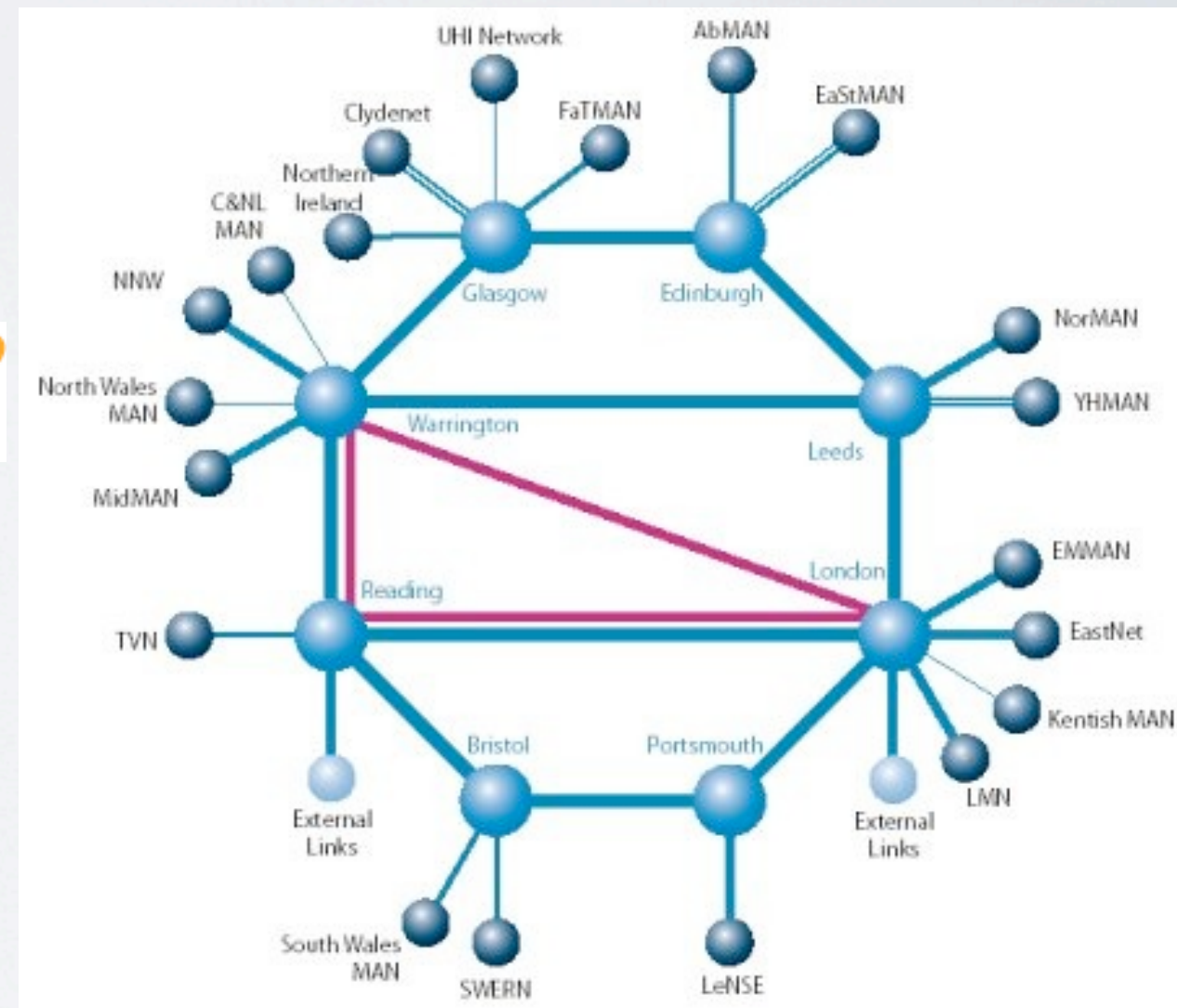
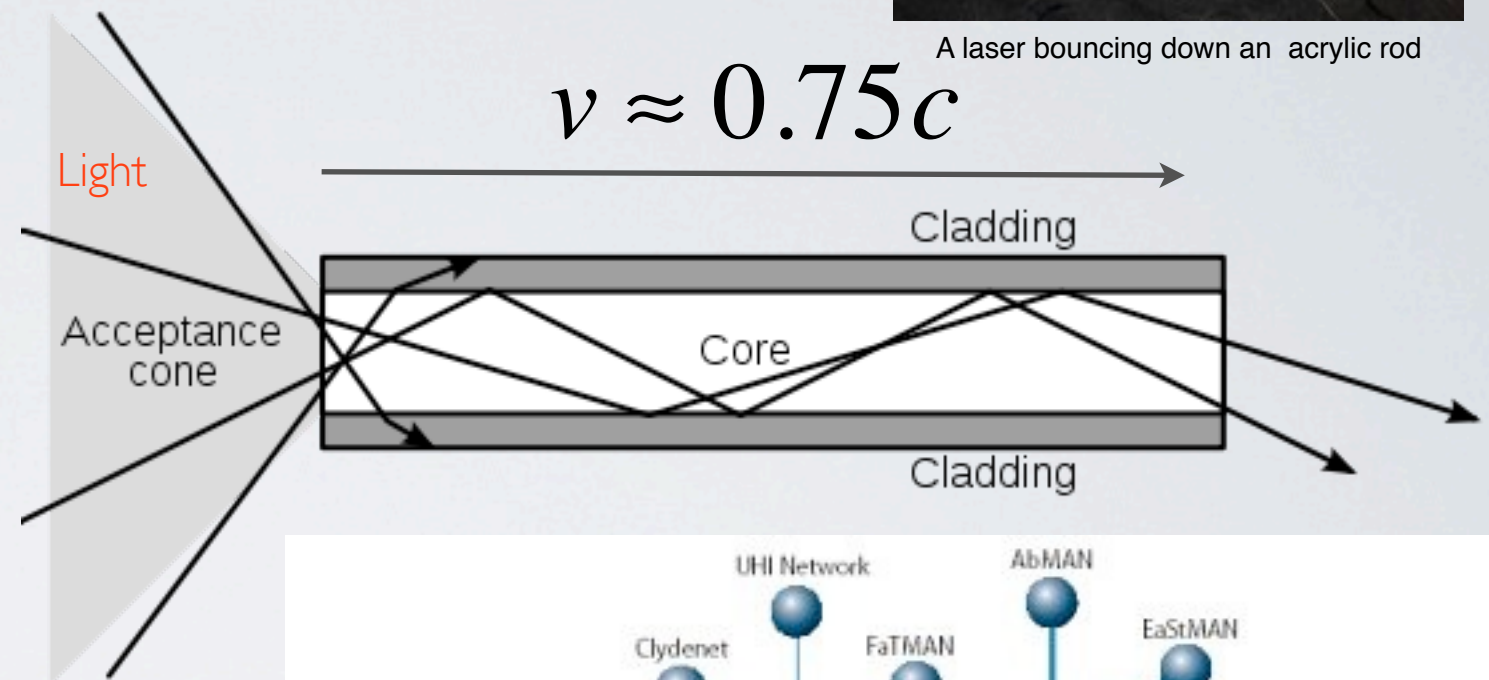


A laser bouncing down an acrylic rod

- Key Technology for the **Internet Backbone**

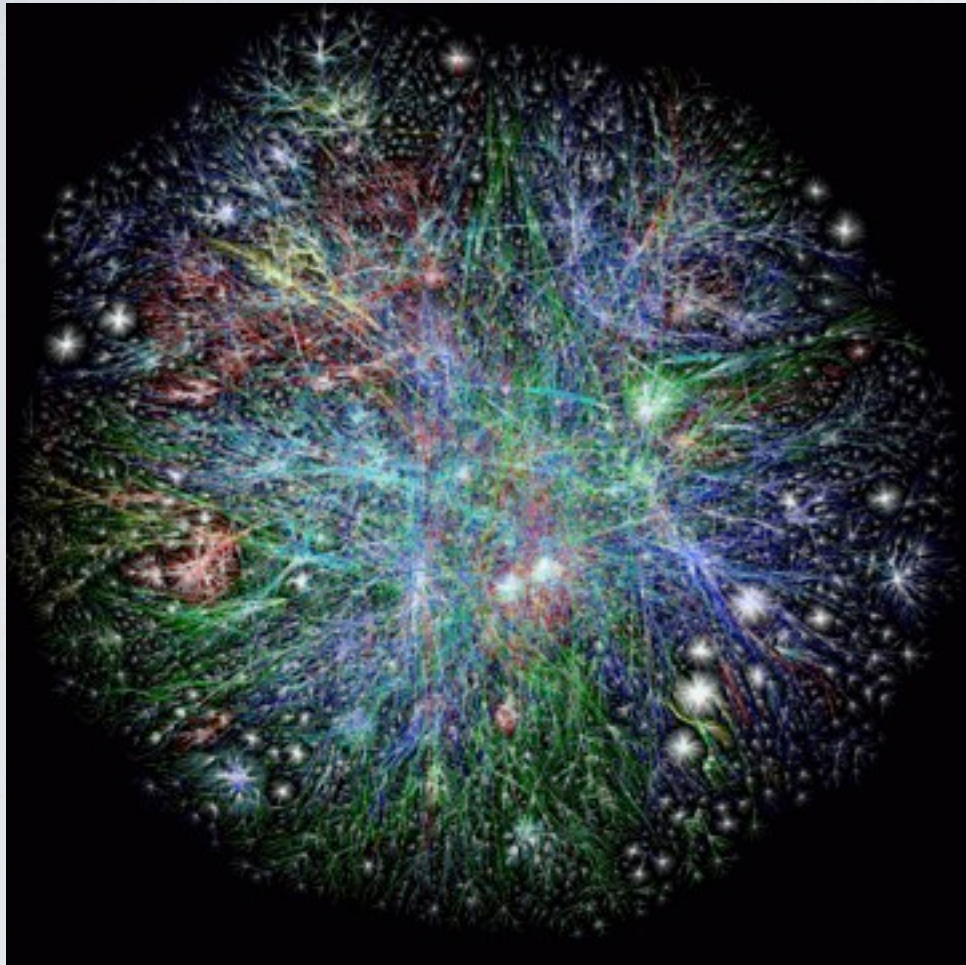


Roughly 1 fibre ~ 10 Gbps
(500 20 Mbps internet connections)
Lay 100 fibers ~ 1000 Gbps
(~ 50000 connections)



THE STRUCTURE OF INTERNET

map of the internet



fiber optics under sea cables (internet backbone)



Role of IP protocol: find the route for data packets from source to destination

Example: Cost TAT-14 Atlantic cable

Cost: ~£1 billion

Bit Rate: 640 Gbps (~32k IP conn.)

Running cost ~ £300m/yr?

Total length 15428 km

THE PRICE OF SPECTRUM

- UK 3G License Auction: **£22.5 bn**
 = £22,500,000,000 for **100 MHz**
 of bandwidth to 5 operators
 => **£400/UK head (in 2000)**
~£600/head today!!

UK Tax receipts £390 bn
 so 3G represents **6% of UK govnt total revenue**

Total price of UK radio spectrum
£22.5b * 10 ~ £225b

UK=0.16% of total world land area
 so
 Total Price of World Radio Spectrum is worth
 ~£140,625 billion
 about twice the total GDP of the earth...

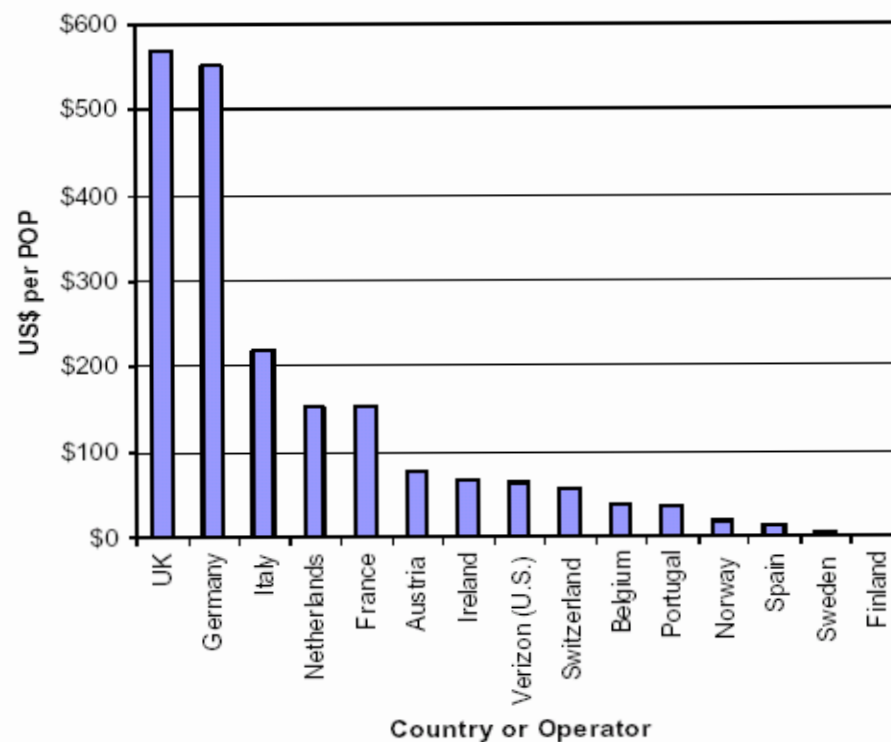
<http://news.bbc.co.uk/1/hi/business/727831.stm>

Exhibit 1.11

(Yr 2000)

COST OF 3G FREQUENCY PER POP

Country or Operator	Spectrum Cost / POP
UK	\$570
Germany	\$551
Italy	\$218
Netherlands	\$153
France	\$152
Austria	\$77
Ireland	\$65
Verizon (U.S.)	\$63
Switzerland	\$55
Belgium	\$39
Portugal	\$36
Norway	\$18
Spain	\$12
Sweden	\$5
Finland	\$0



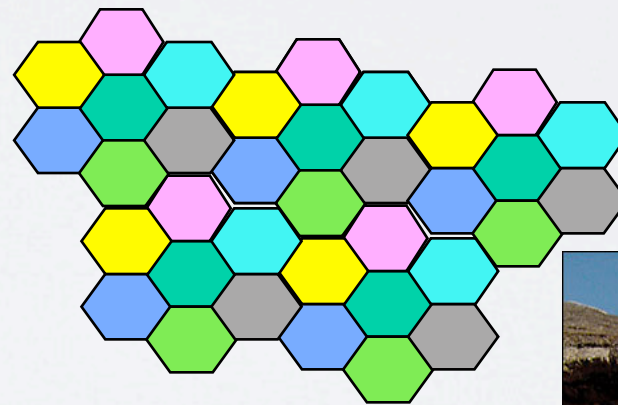
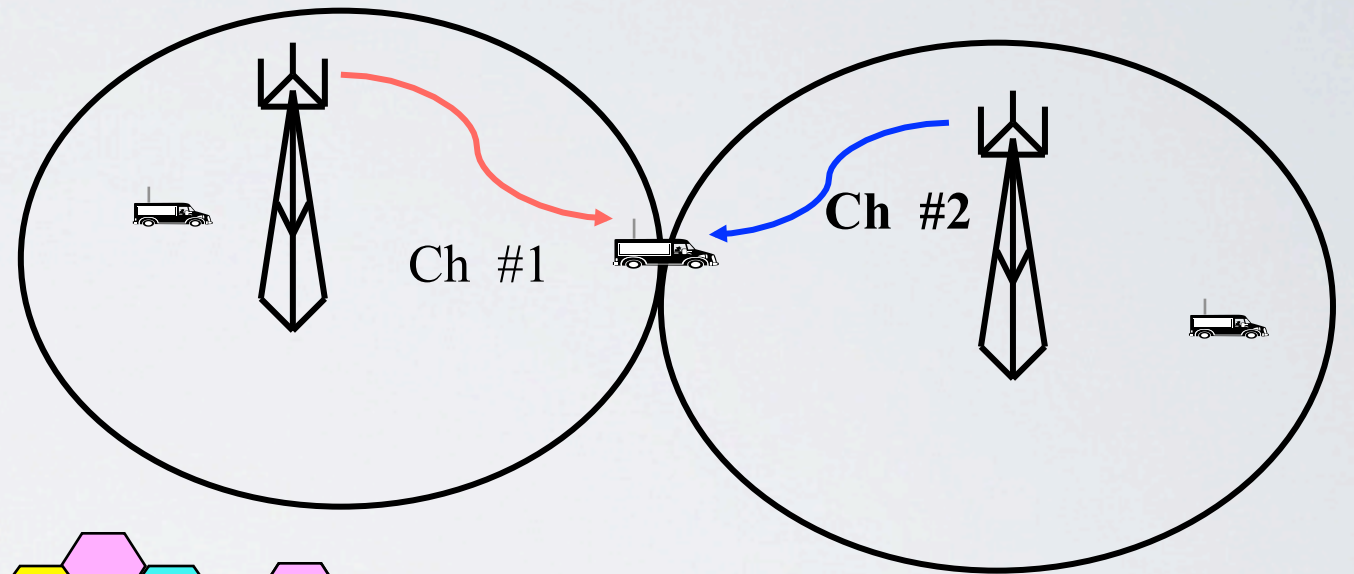
HUMBLE BEGINNINGS BUT COMMON NOW

Communication Systems Engineering

1928



2G/3G Cellular Networks



Tessellation to cover large areas



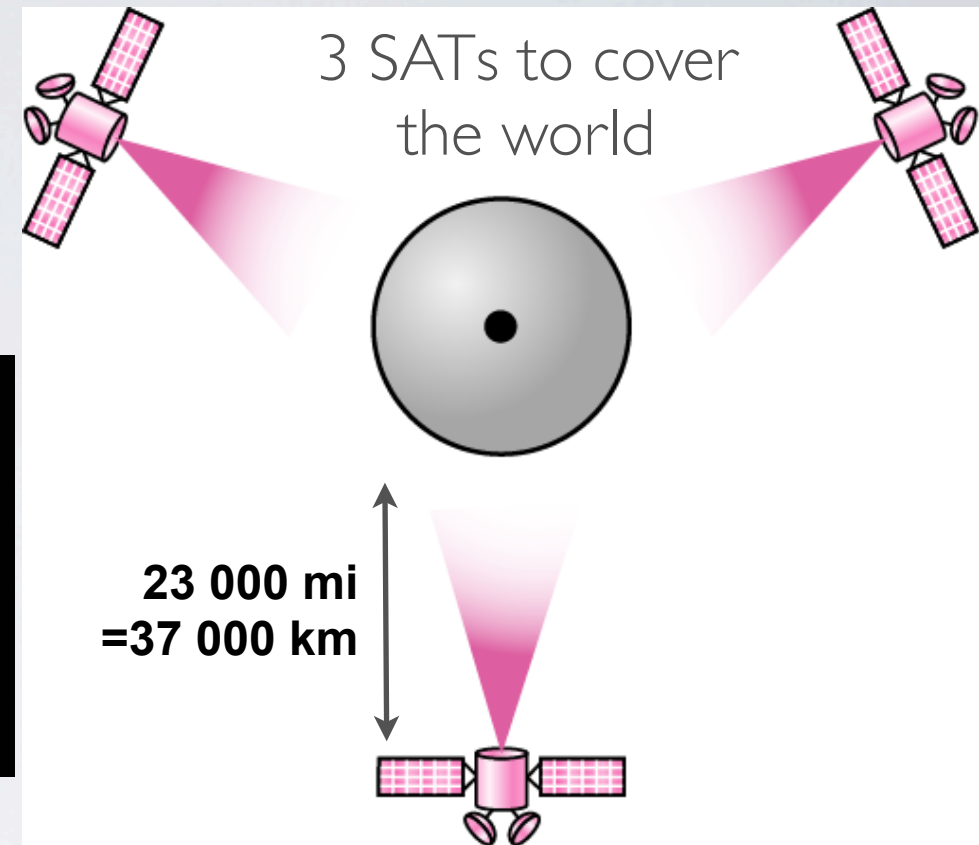
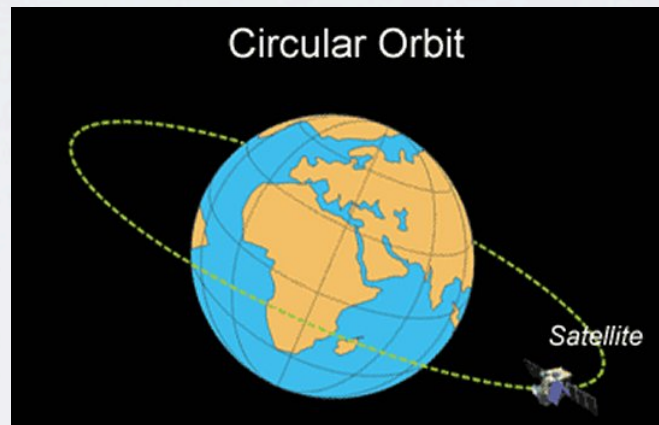
$$f \approx \frac{c}{2d} \approx 150 \text{ MHz} \quad \lambda \approx 0.5 \text{ m}$$

Antenna size

GEOSTATIONARY SATELLITE



1945
Arthur C. Clarke
 (SF writer, futurist)

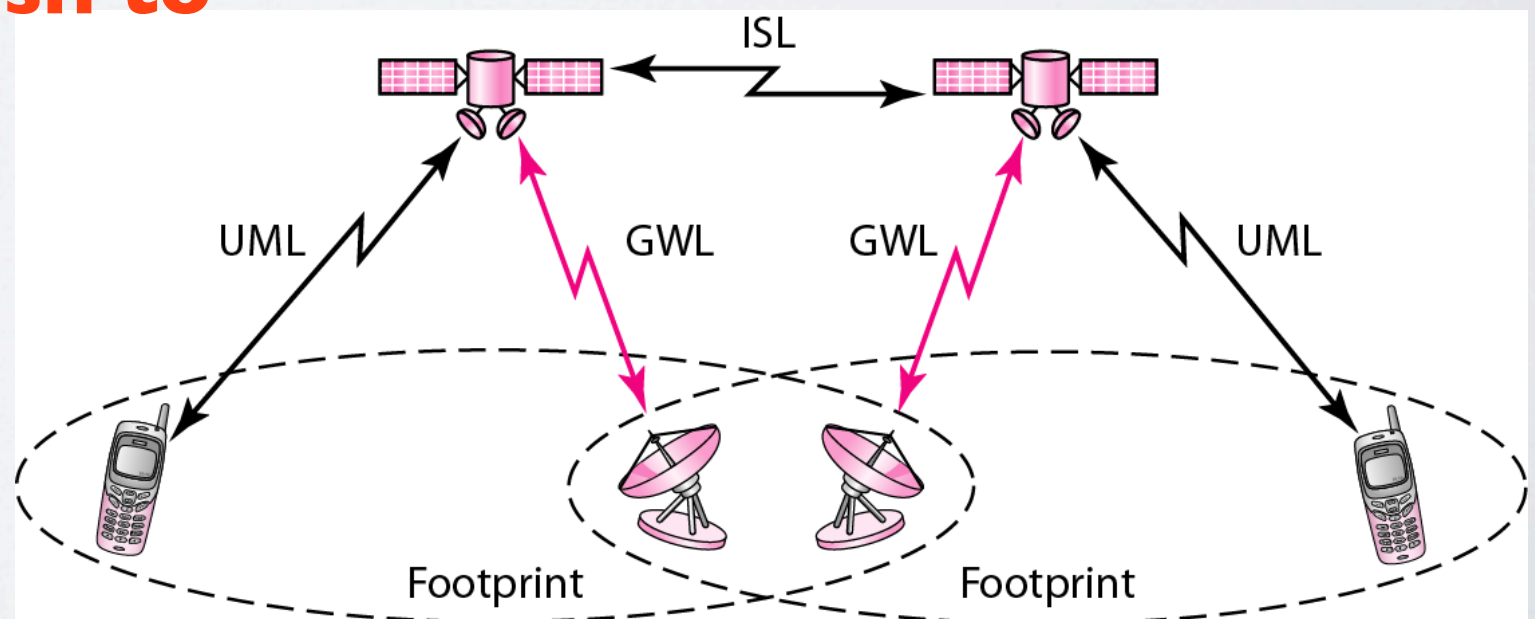


GEO= Fixed Antenna/dish to point to satellite

GEO: £22000/kg



£28000/kg

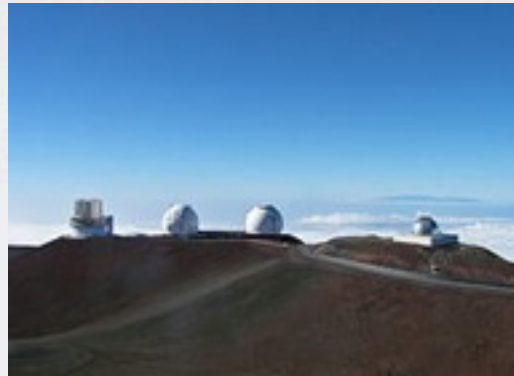


UNDERSTANDING THE UNIVERSE

Hubble Space Telescope



Mount Mauna Kea, Hawaii



Stellar nursery

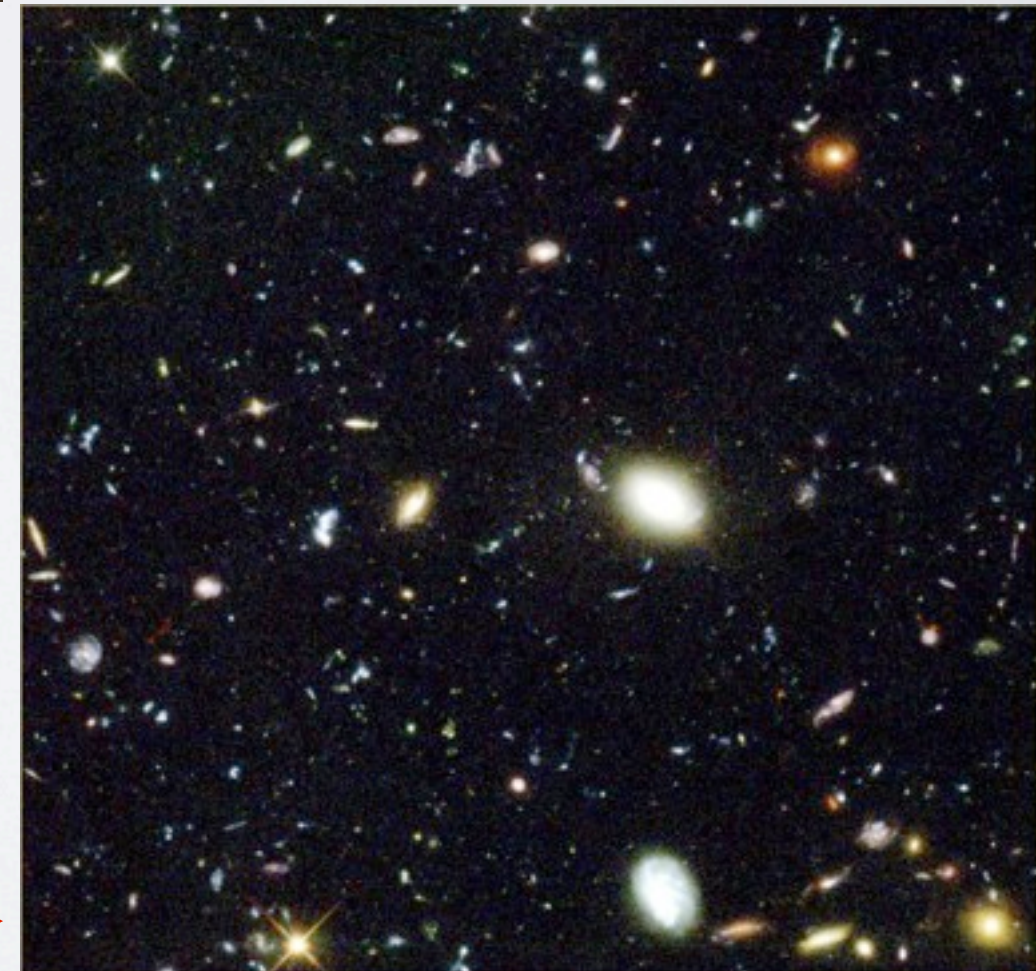


- **Optical telescope**

(visible light, 400 to 700 nm)

- Limited by turbulent atmosphere and clouds/pollution-> altitude is good!
- **Hubble Space Telescope** (1991-now)
 - Look at planetary nebulae
 - Galaxies
 - Deep universe

Hubble Deep Field 13 billion yr old!!! →

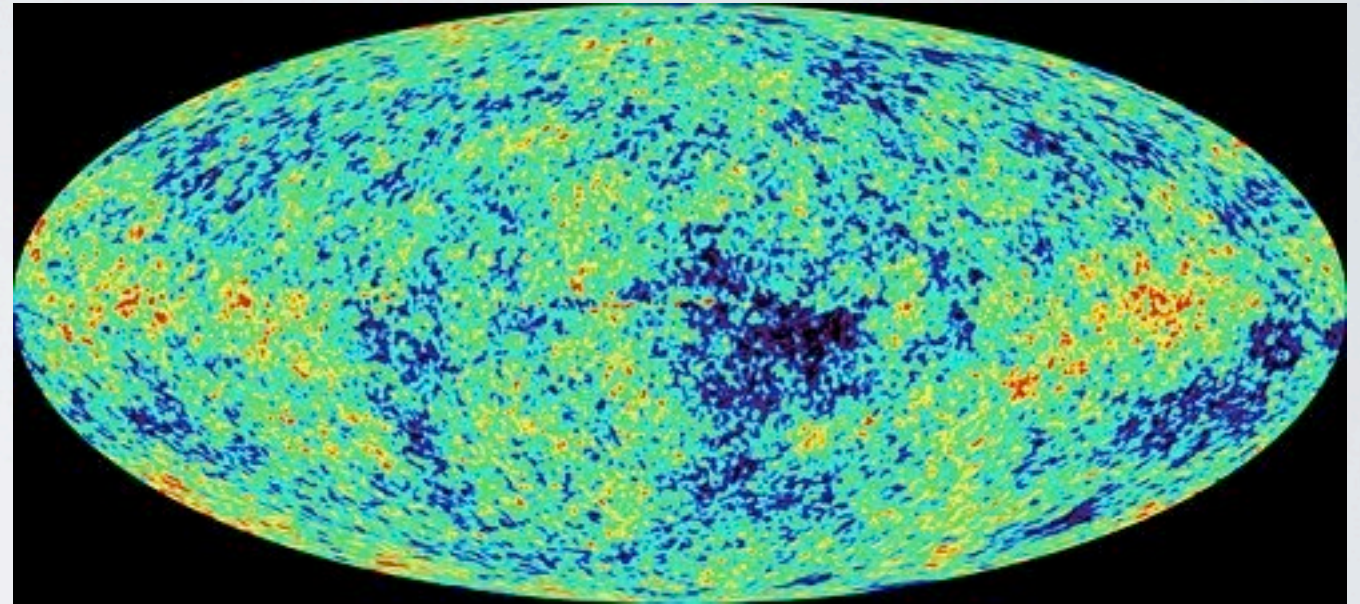




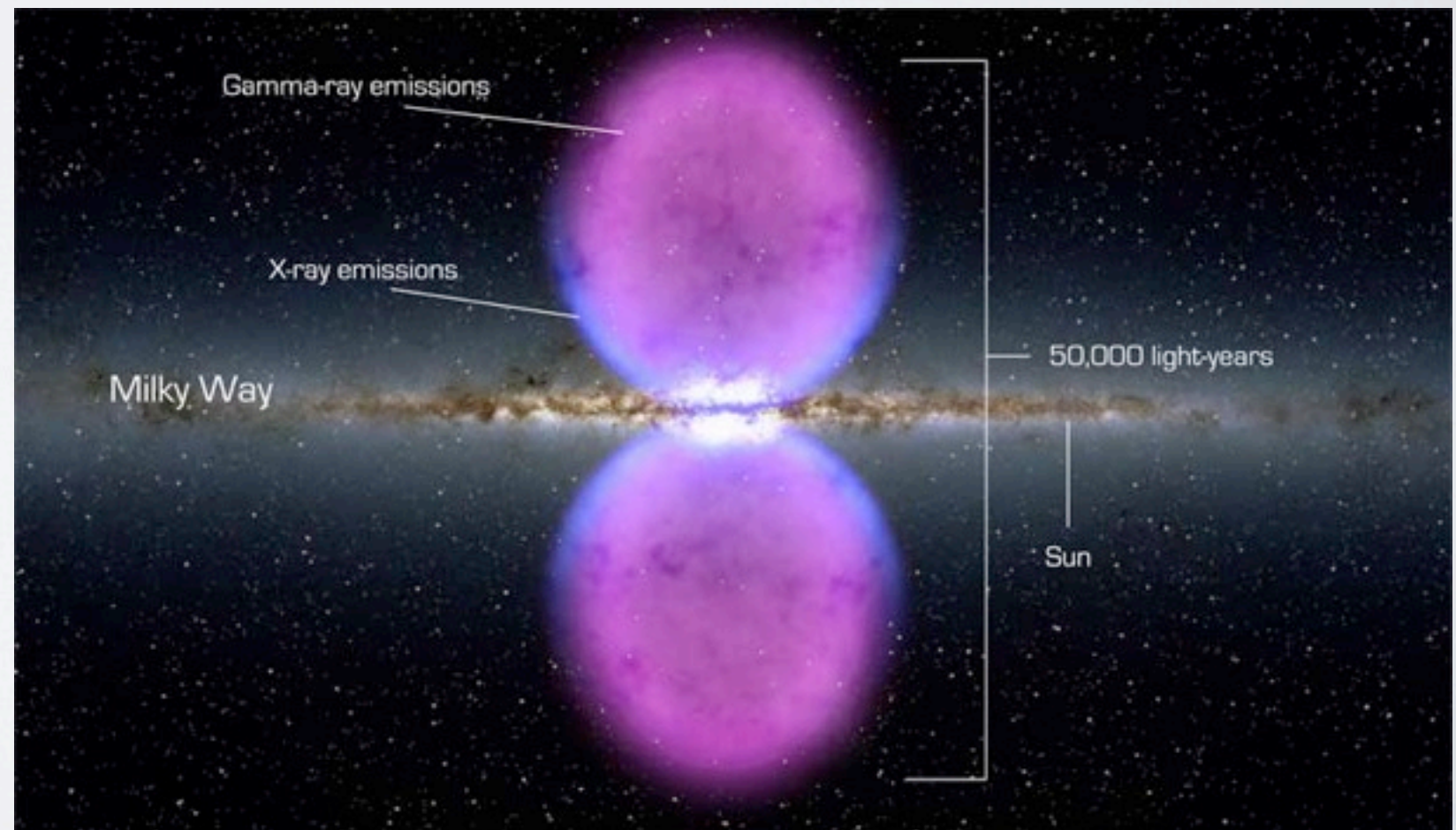
Two engineers, Penzias and Wilson discovered in 1964 the cosmic microwave background.

ASTRONOMY

Cosmic background radiation from WMAP (~380,000 years old)



- **Radio** (wave frequency) **astronomy** has been used to verify the bigbang theory (Earth & Space)
- **Gamma ray astronomy** used to detect gamma ray bursts proving existence of black holes and supernovas





FIND E.T!!!!



- Search for **E**xtra **T**errestrial **I**ntelligence
- **Allen Telescope Array (ATA)** in California - 43 dishes
- Radio communications receiver steerable phased array
 - 1 to 11 GHz

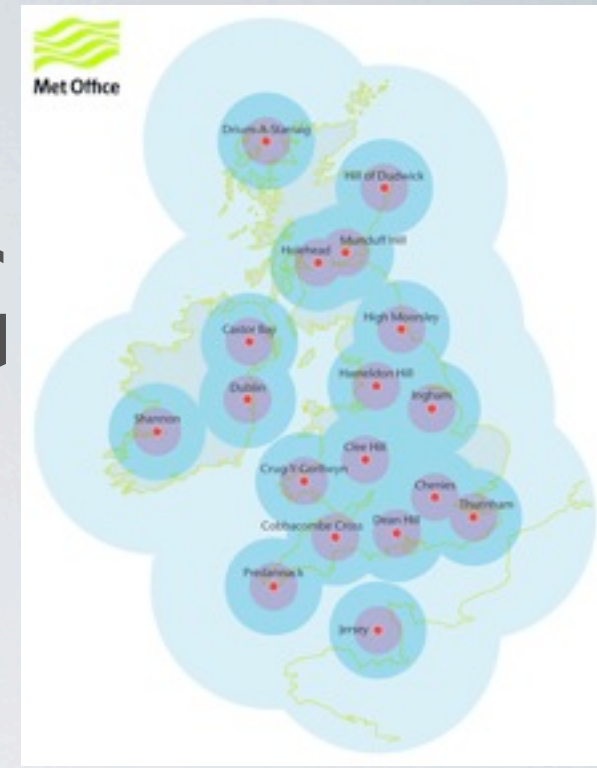


**Aricebo Radio Telescope
(Puerto Rico, 310 m reflector)**





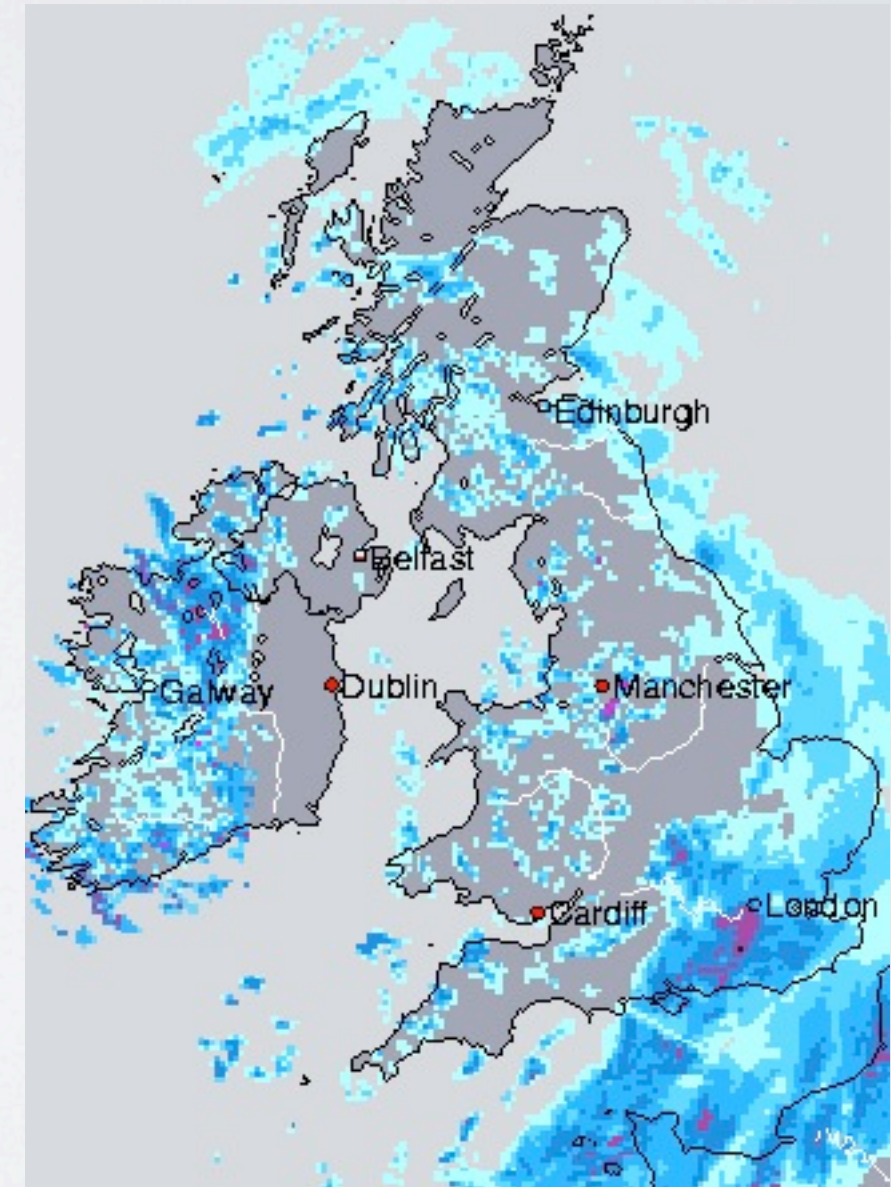
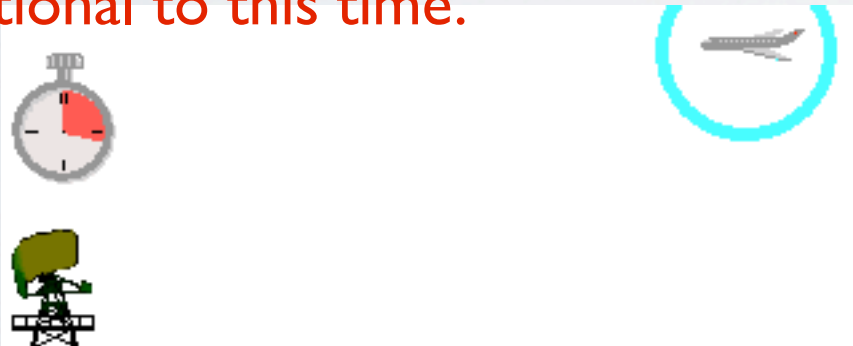
Weather radar



REMOTE-SENSING

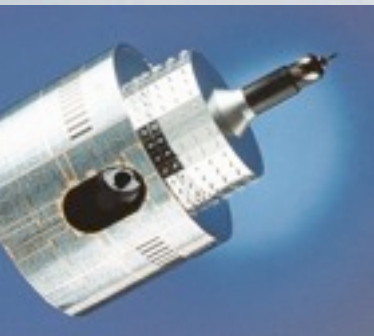
- **Radar** is an object-detection system which uses e.m. waves (radio waves) to determine the range, altitude, direction, or speed of both moving and fixed objects
 - Military and security applications
 - Air & Marine Traffic Management
 - Weather Rain/cloud/storm chasing Radar

Round-trip time for the radar pulse to get to the target and return is measured. The distance is proportional to this time.



Doppler Effect Siren Example

Measuring frequency allows to determine speed of target (Police speed radar)

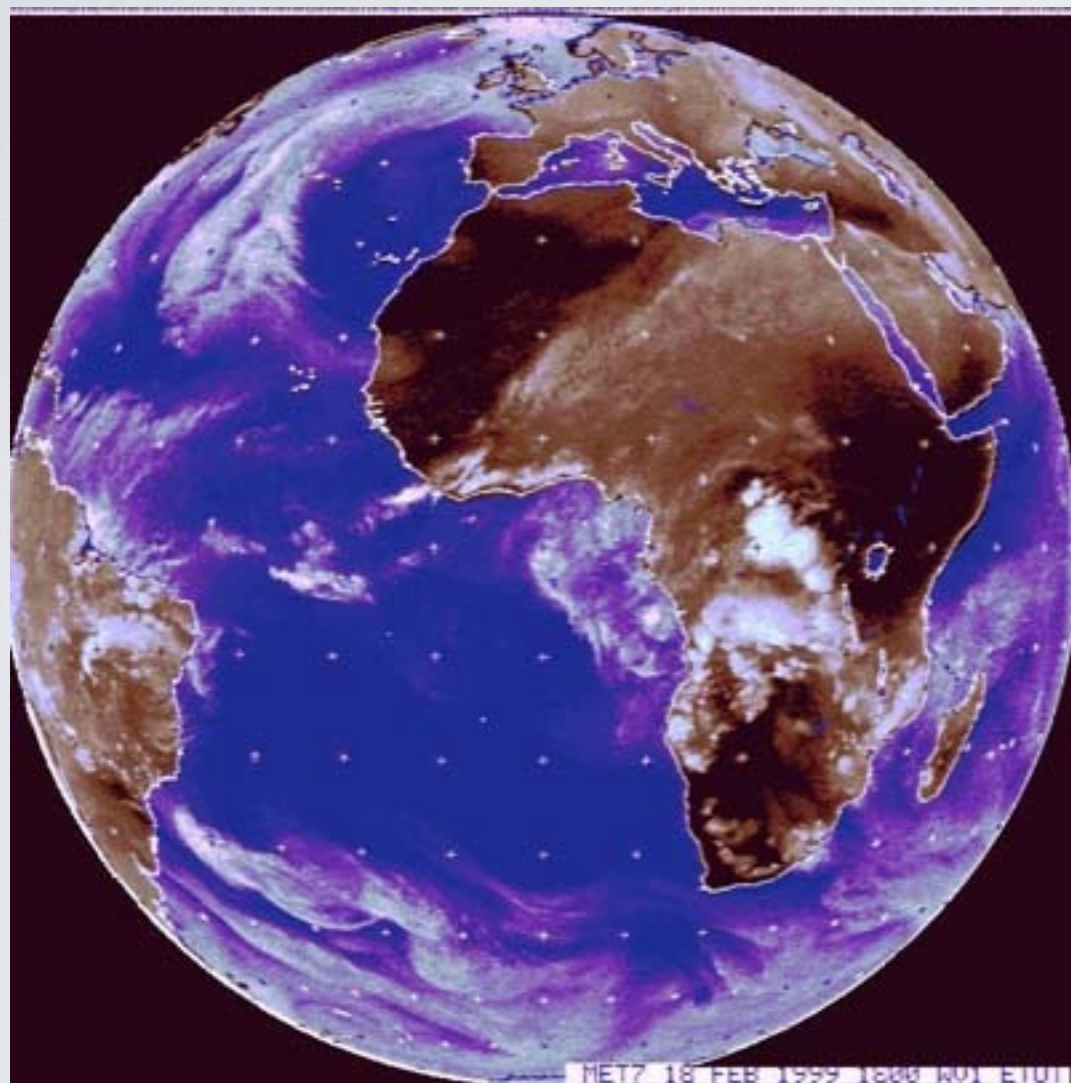


Meteosat

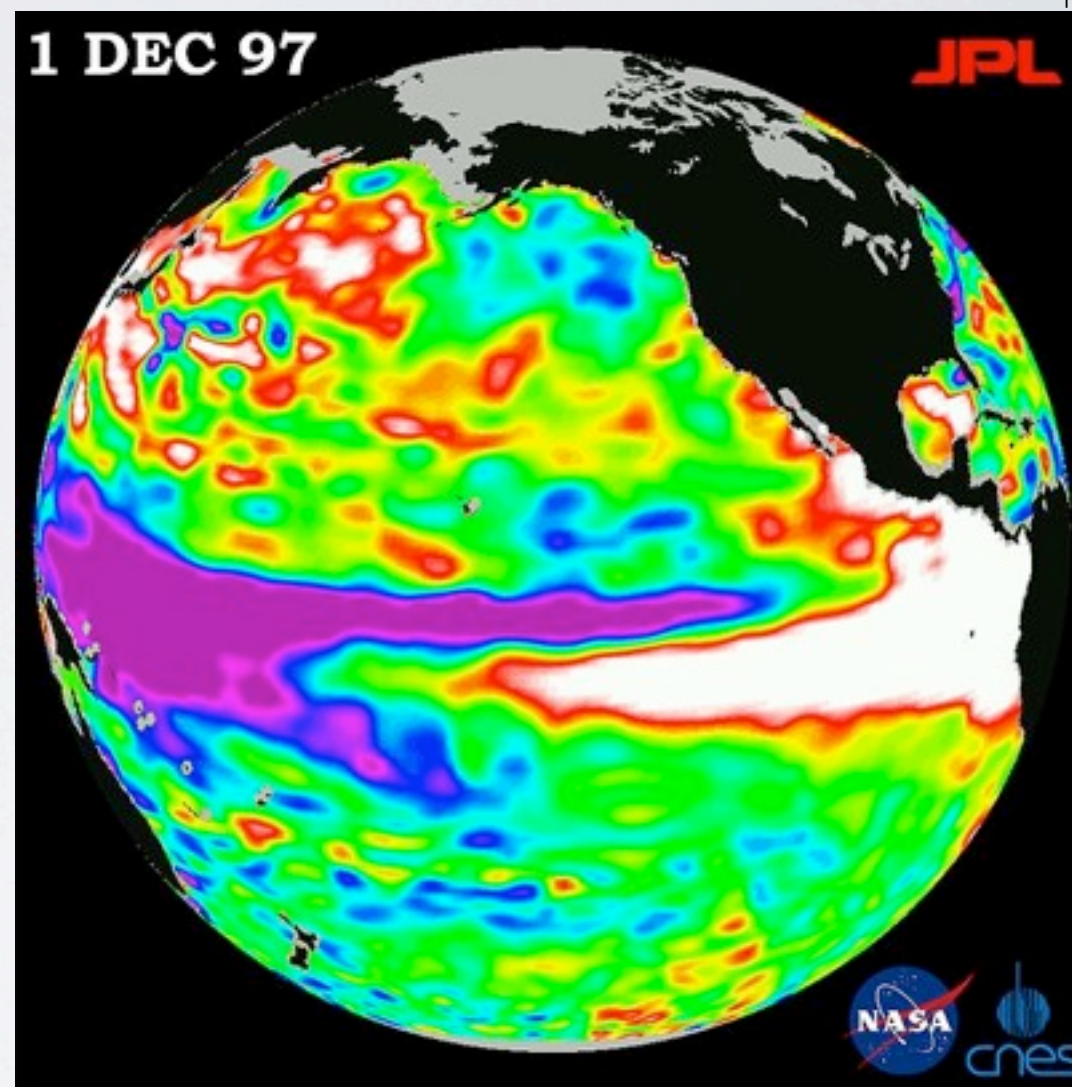
WEATHER AND EARTH OBSERVATION



Topex/Poseidon



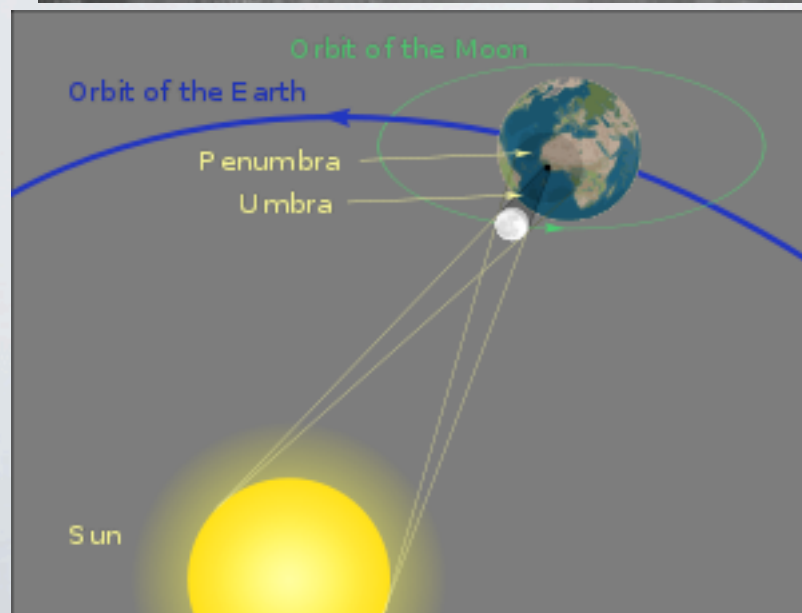
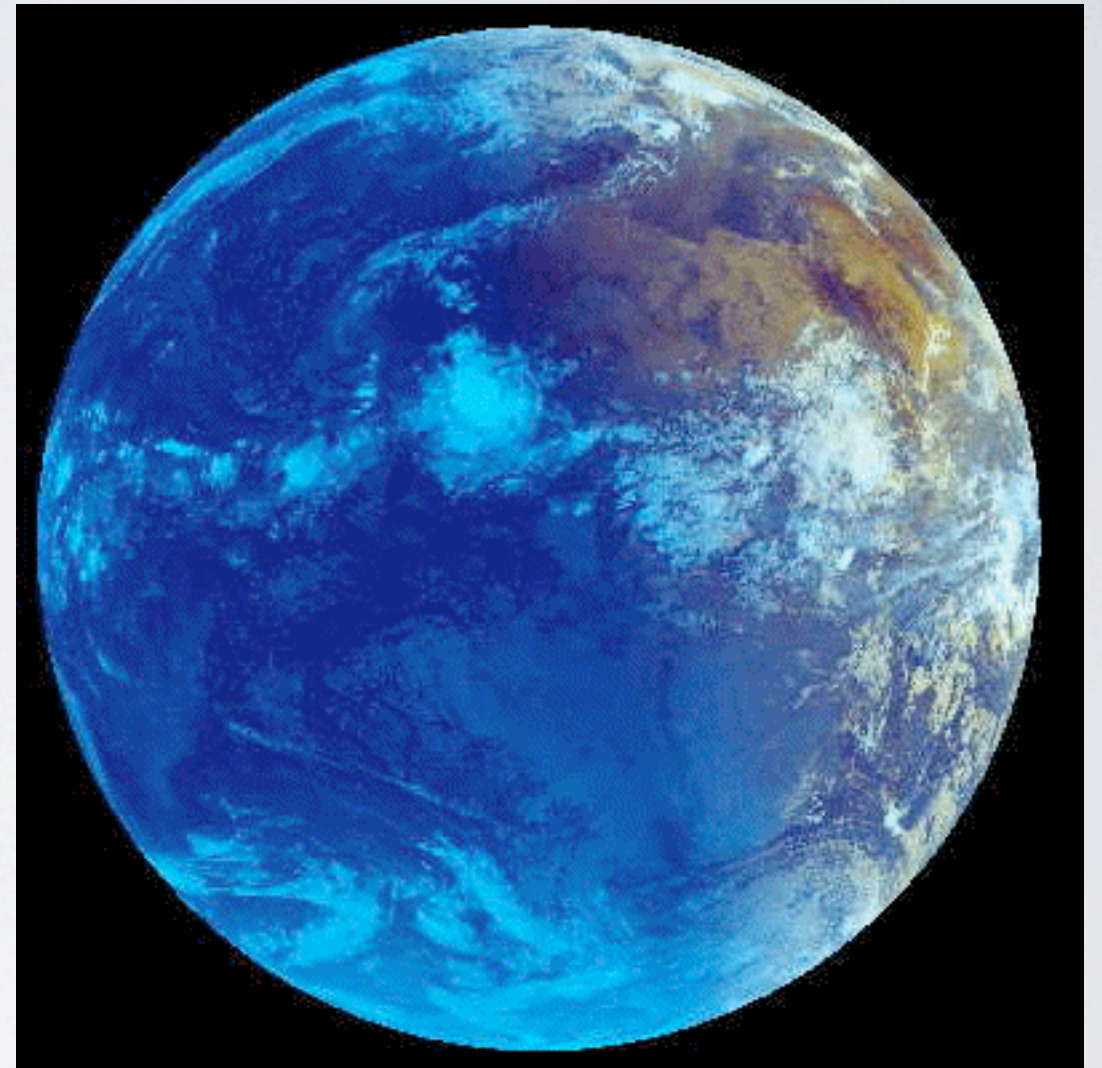
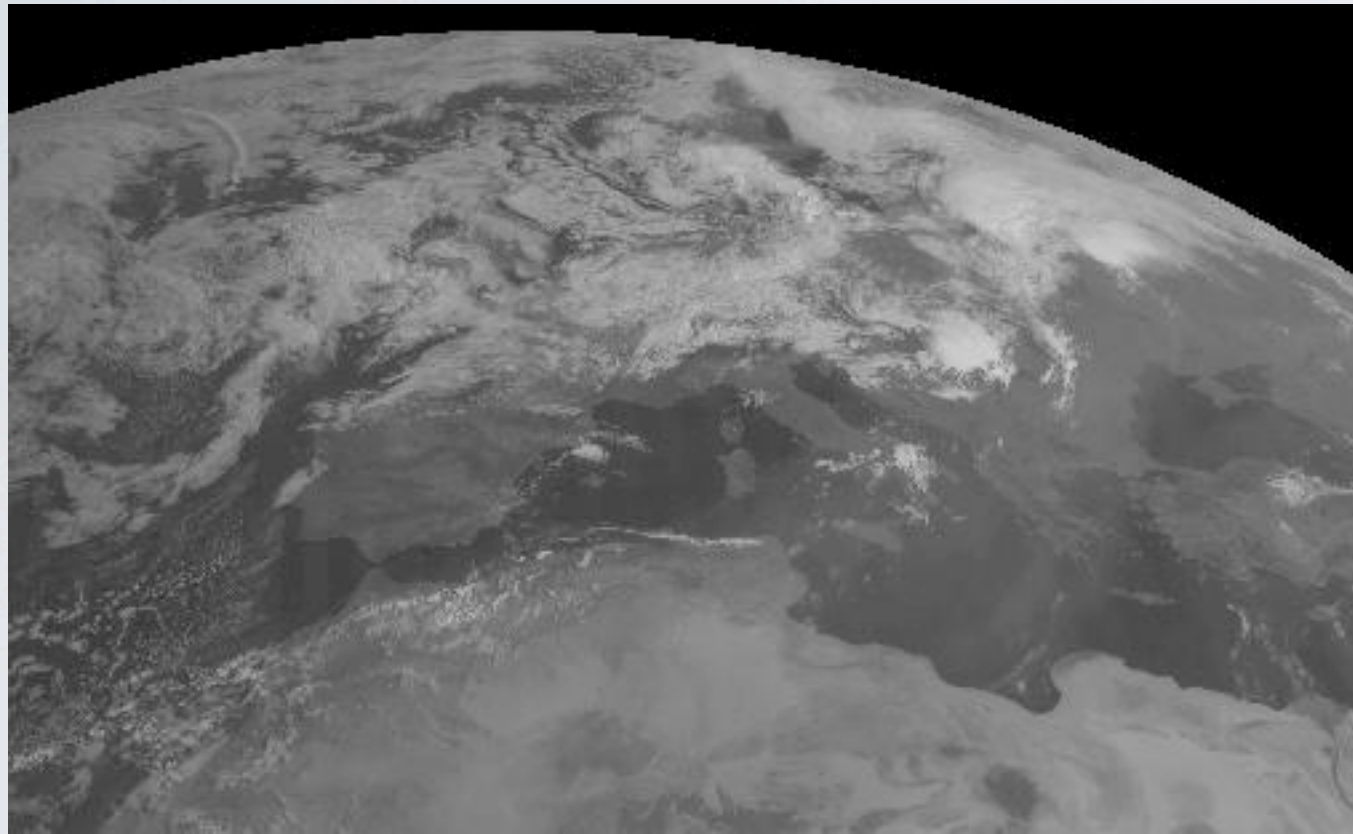
Meteosat (Eumetsat)
3 GEO satellites
3 wavelength:s Visible, IR and water vapour
(6 micrometers)



Topex Poseidon- Ocean topography (3 cm)
LEO Satellite (5 and 13 GHz)- 1330 km orbit
Observation of El Nino (wet in south america, dry in indonesia/australia)

SOLAR ECLIPSE (METEOSAT)

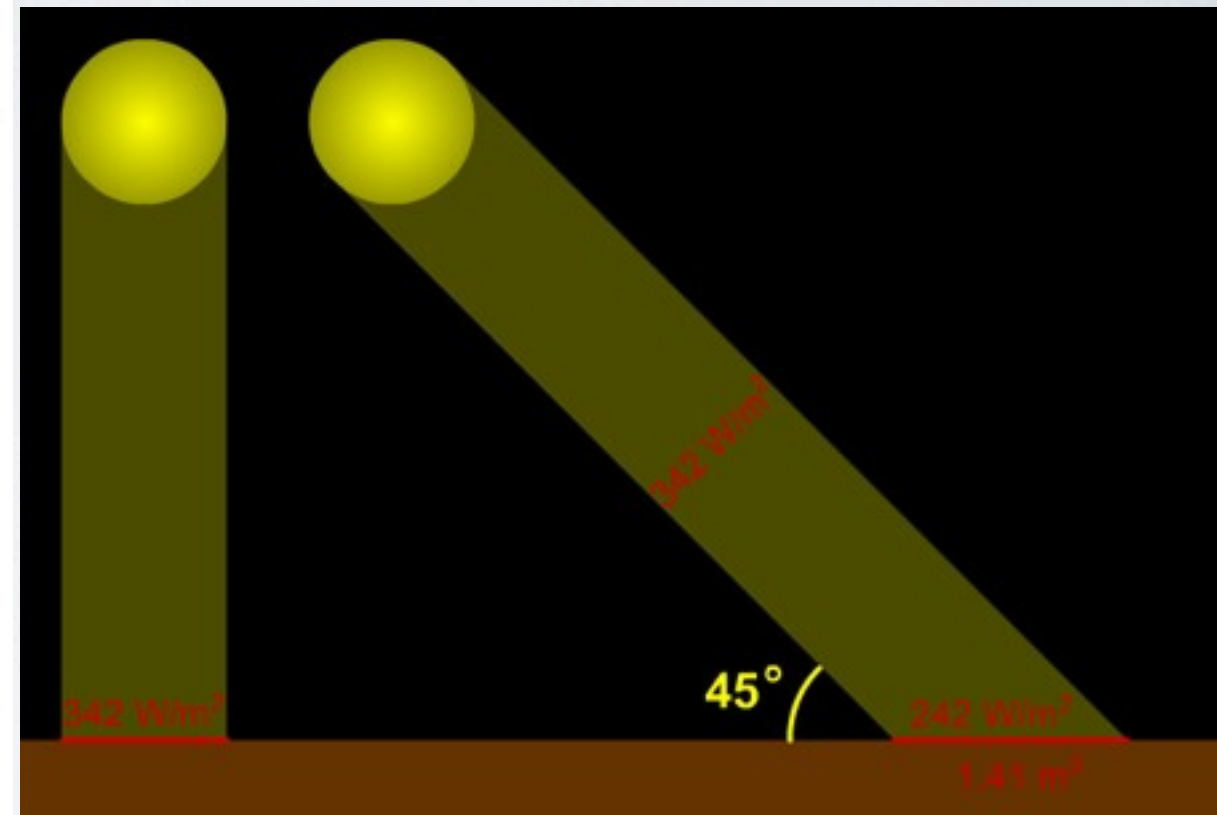
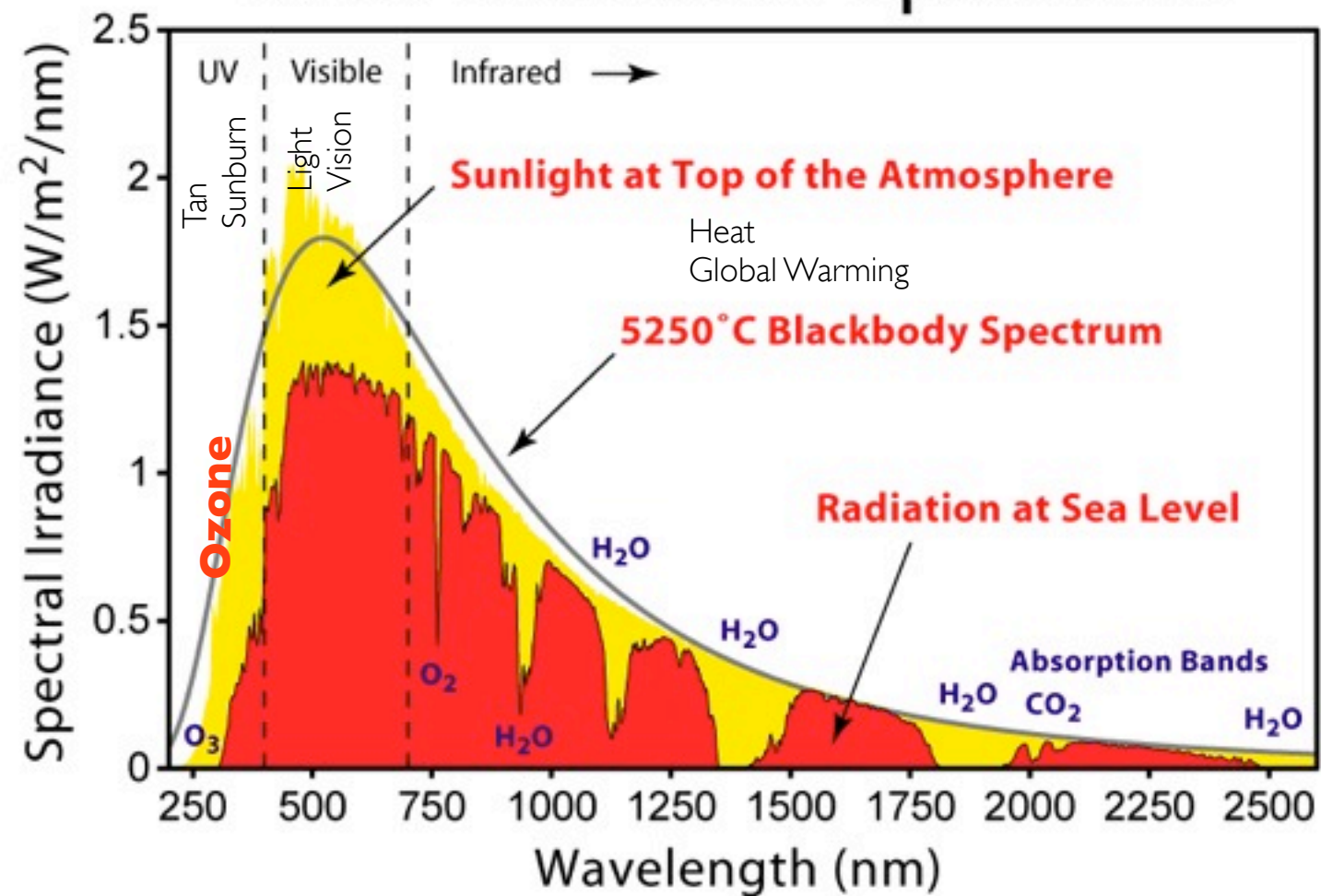
- 11 August 1999



HARVESTING SUN LIGHT

$1300\text{W}/\text{m}^2$ (top of atmosphere)

Solar Radiation Spectrum

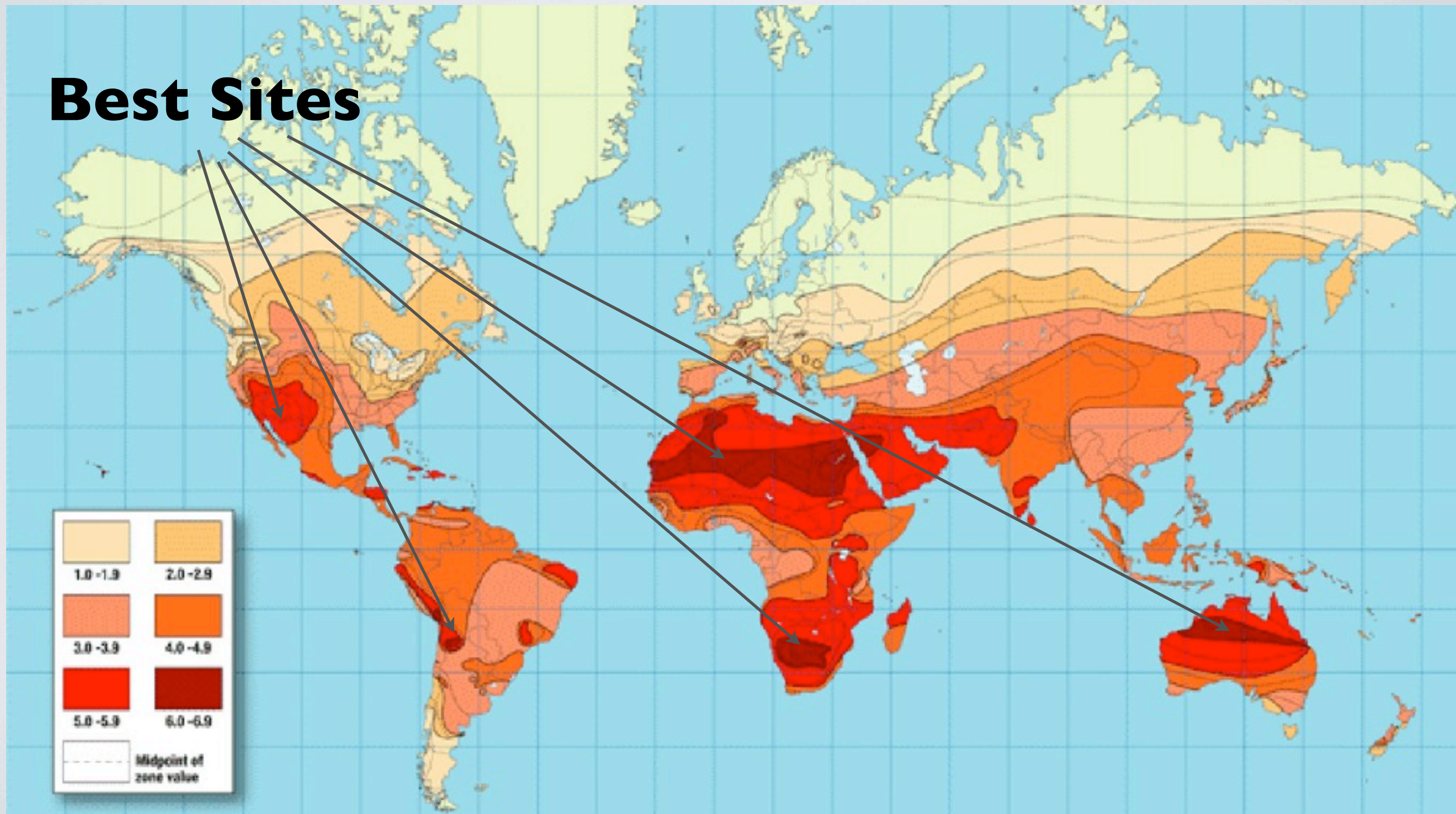


Kettle (2000W)
so we'd need $3*3\text{m}$ area to boil water

SOLAR RADIATION

Energy: UK 10p/kWh

Best Sites



SOLAR FARMS



- Largest: **SEGS (Solar Energy Generating Systems)**

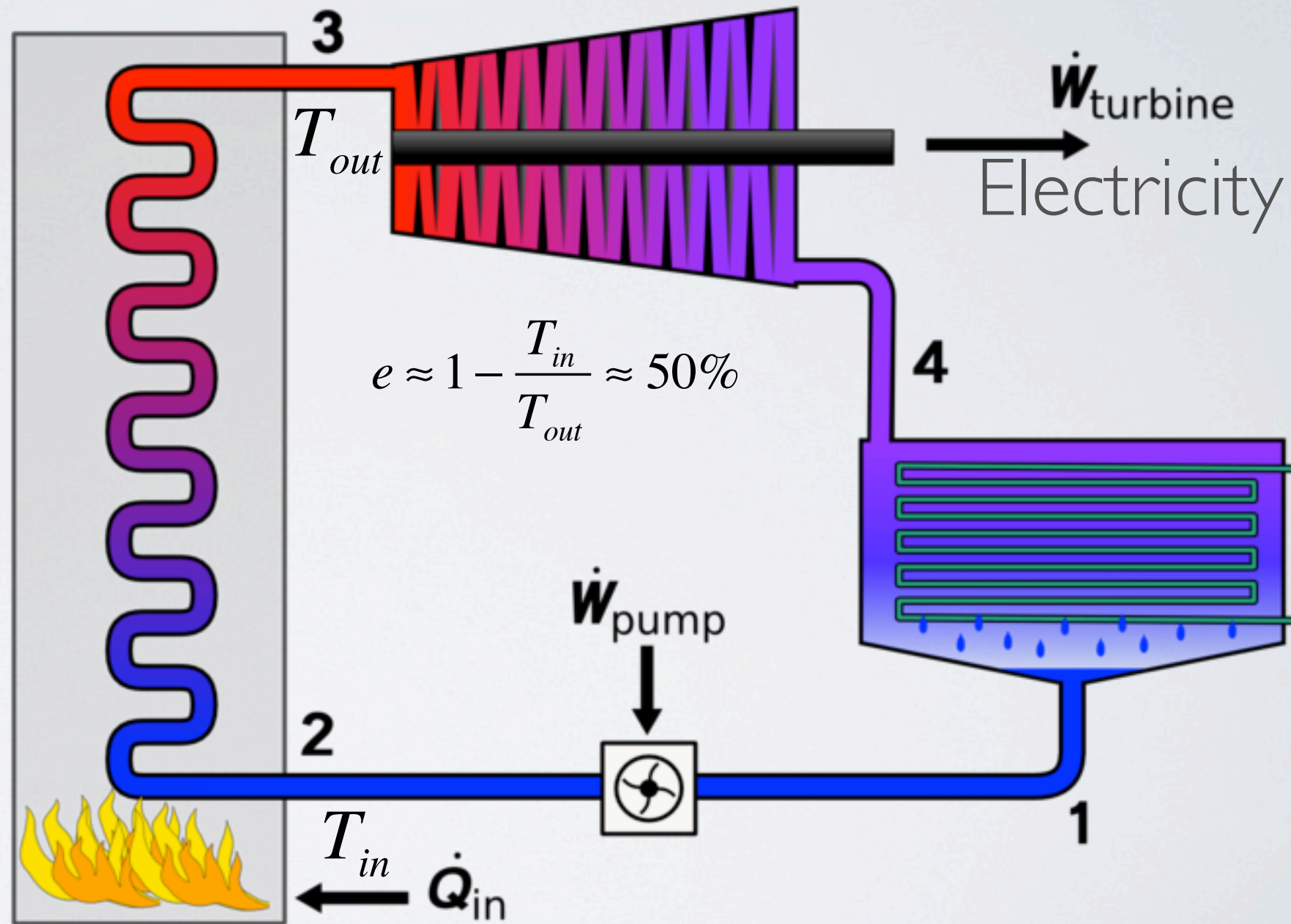
- 9 solar farms in Mojave's desert (California, USA)
- 354 MW Capacity (Support city with 71 000 people)
- 1 million mirrors, cover 1 600 acres ($2.5 \times 2.5 \text{ km} = 6.5 \text{ km}^2$). Lined up the mirrors would extend for 230 mi (370 km).



- Not a solution for the UK!!! But where?

RANKING ENGINE TO GENERATE ELECTRICITY

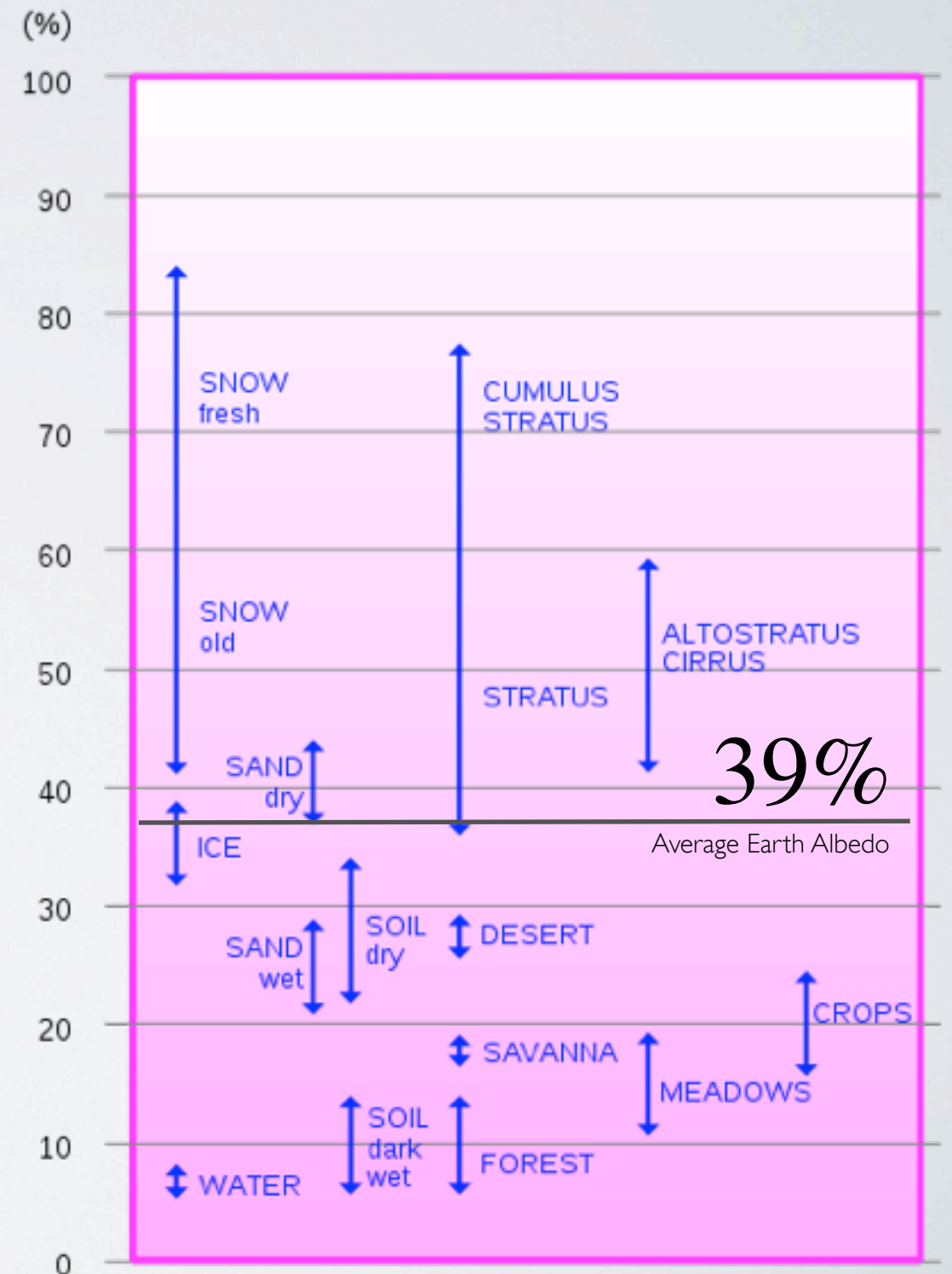
- Process 1-2:** working fluid is pumped from low to high pressure
- **Process 2-3:** The high pressure liquid enters a boiler where it is heated at constant pressure by an external heat source to become a dry saturated vapour.
- **Process 3-4:** The dry saturated vapor expands through a turbine generating power. This decreases the temperature and pressure of the vapor, and some condensation may occur.
- **Process 4-1:** The wet vapour then enters a condenser where it is condensed at a constant pressure to become a liquid again.

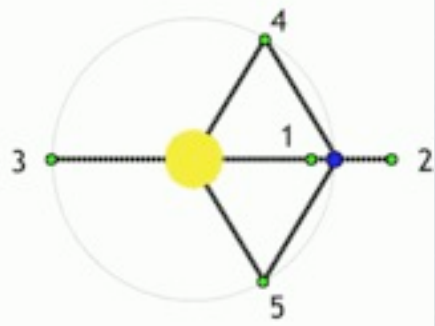


Sun light

SOLAR RADIATION MANAGEMENT

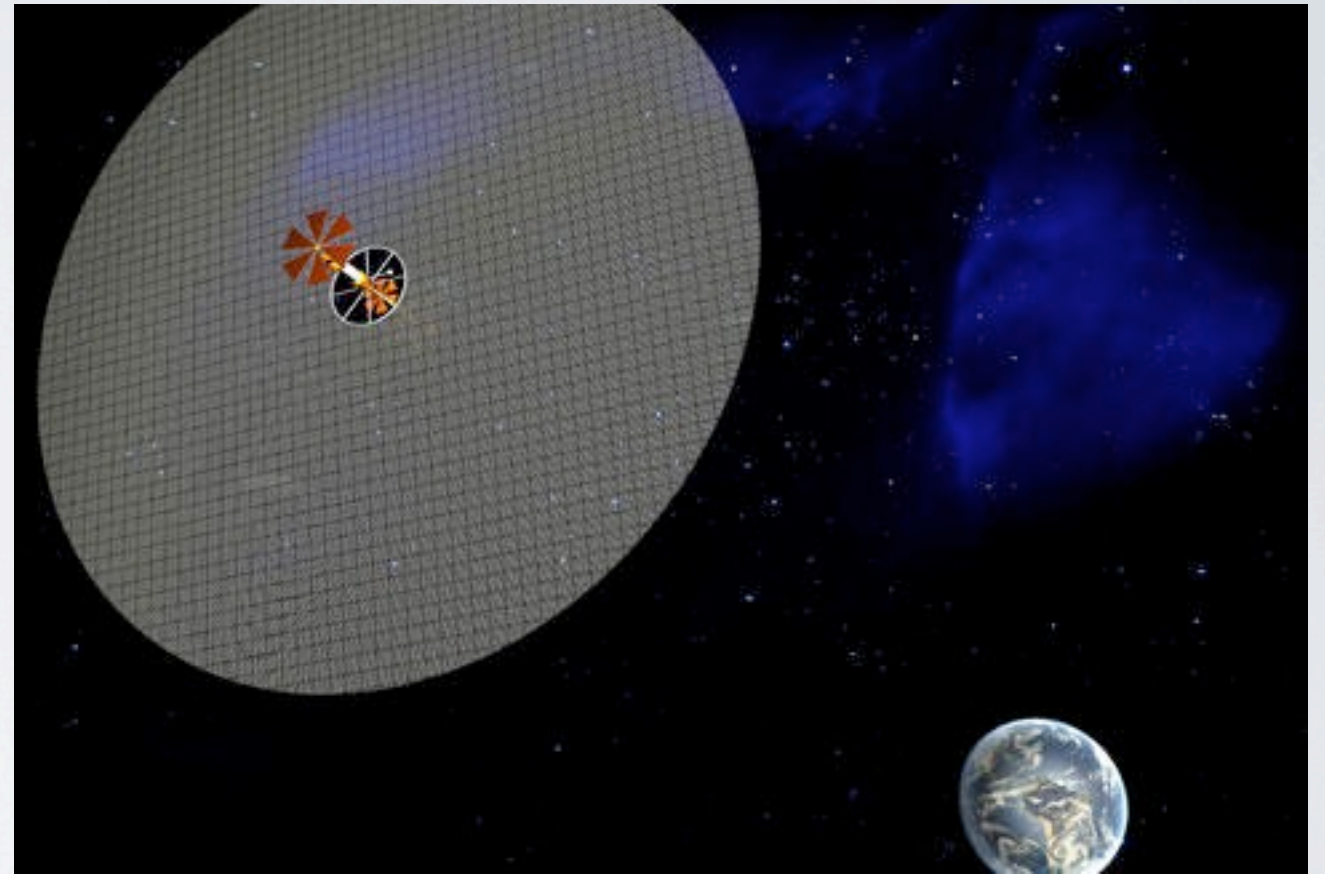
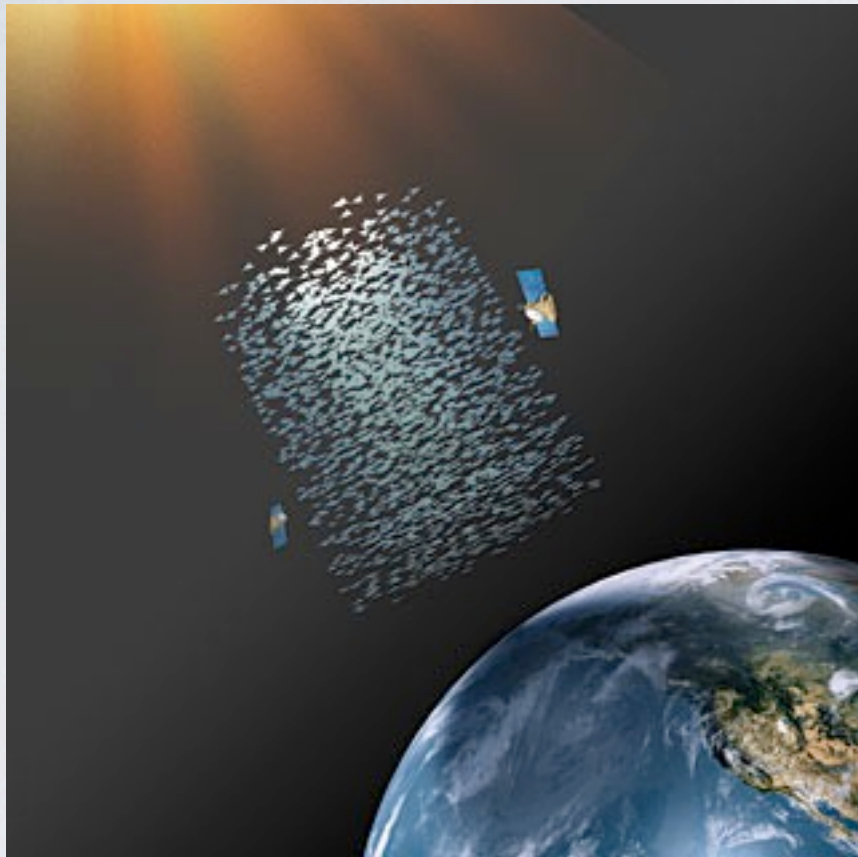
- **Geoengineering** that seeks to reflect sunlight to reduce global warming
- **Albedo**: Amount of e.m. energy reflected back to space
- Reflective Sheets covering 260mi*260mi=67000 square mile (170000 square km) would reduce world's energy by **1.74W/m²** (**Global warming** due to CO2 represents **3.7W/m²**)





The five Lagrangian points (marked in green) at two objects orbiting each other (here a yellow sun and blue earth)

SPACE MIRRORS

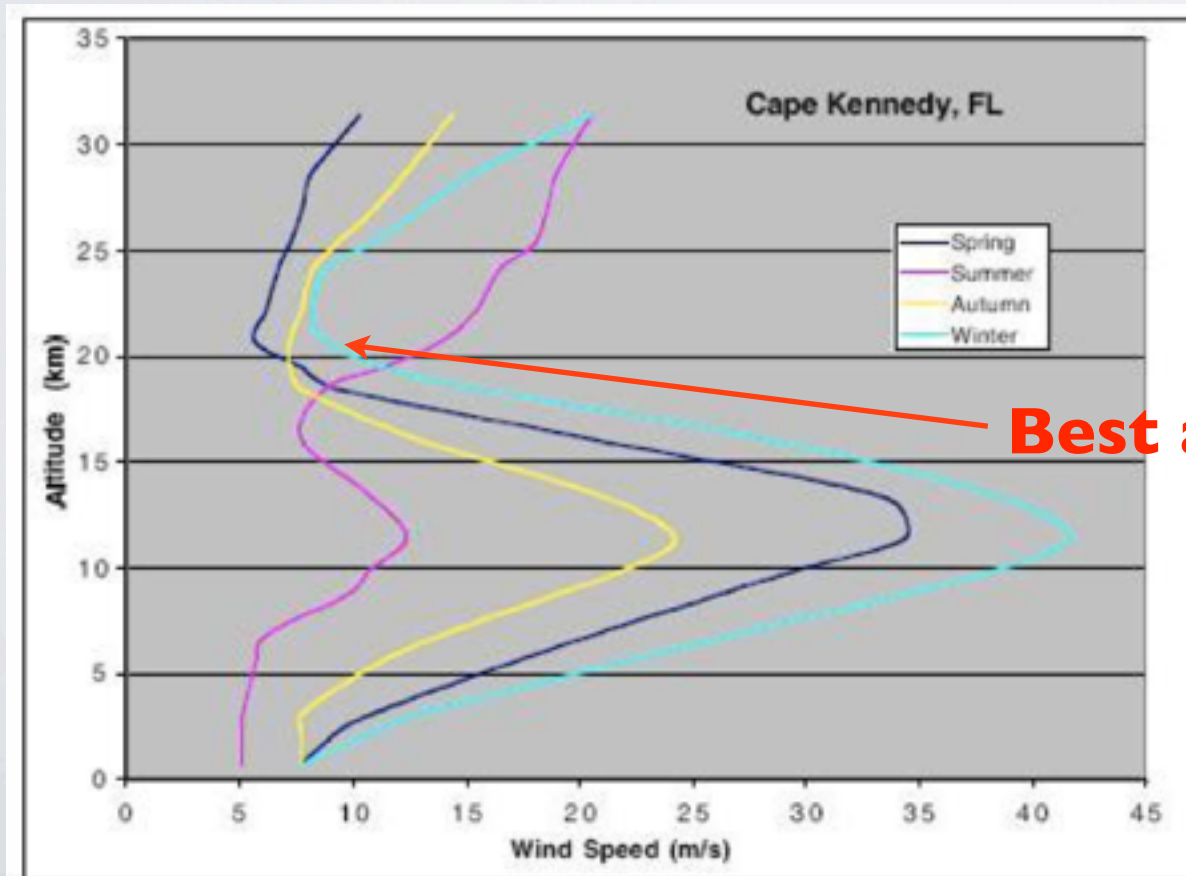
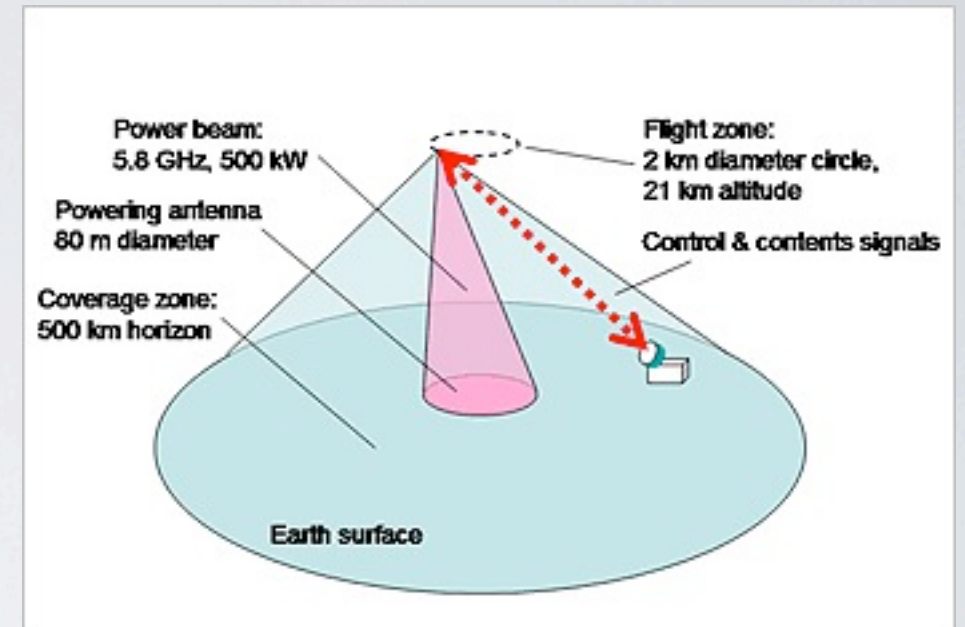


- 6 trillion small disks at the Sun-Earth L1 Lagrangian point, 1.5 million kilometers above Earth. Each disk is proposed to have a 0.6 meter diameter and a thickness of about 5 microns. The weight of such a sunshade would be about a gram, adding up to a total weight of almost 20 million tonnes. Such a **group of small sunshades that blocks 2% of the sunlight**, reflecting it off into space, would be enough to halt global warming.
- The problems are (i) the price (ii) materials
http://en.wikipedia.org/wiki/Space_sunshade

SAVING LIVES

• High Altitude Platforms (HAPs)

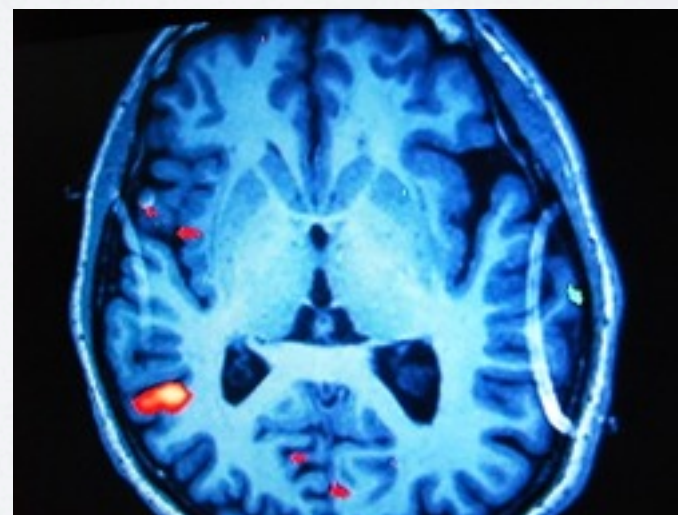
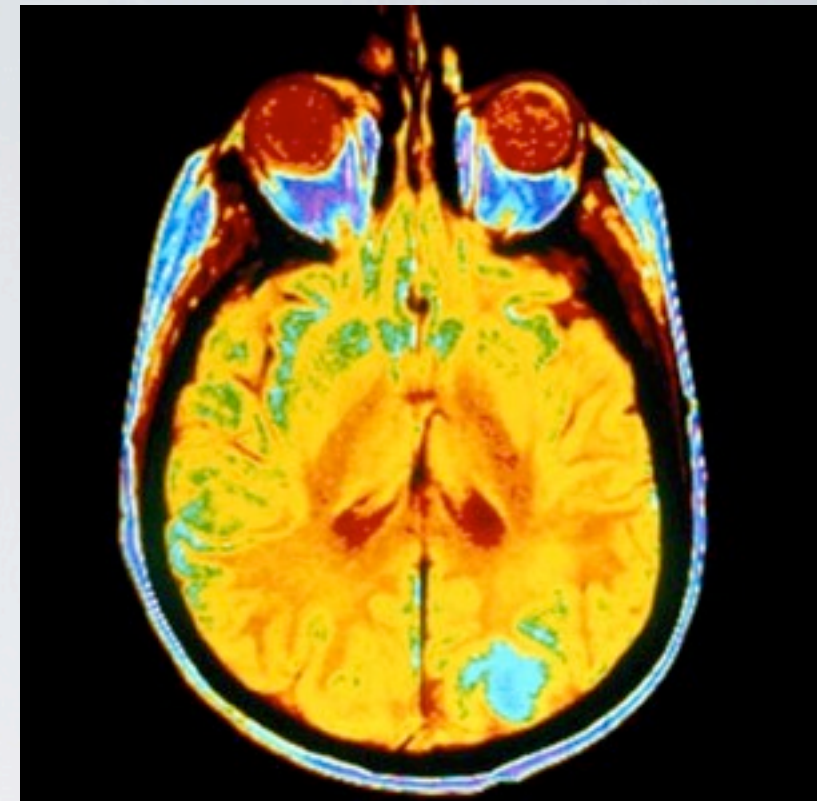
- For disaster areas (tsunamis, earthquake, floods..)
 - Communications
 - Monitoring
 - Surveillance and military
- Special events (Olympic games)



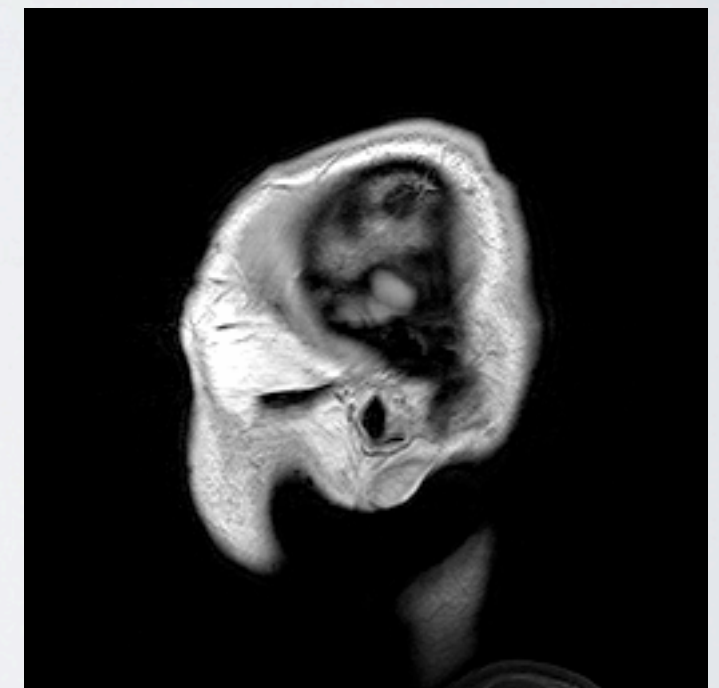


X-RAYS

- **X-radiation** (composed of **X-rays**) is a form of em radiation.
- Einstein $E = hf = hc / \lambda$
- **Dangerous radiation** (protection using lead sheets).
- Discovered by **Röntgen (1895)**
- X-rays have a wavelength in the range of 0.01 to 10 nanometers corresponding to frequencies in the range 30 petahertz to 30 exahertz (3×10^{16} Hz to 3×10^{19} Hz)
- 2010: **5 billion medical imaging studies** were done worldwide.
- **Computed axial tomography** (CAT or CT scan)
- Digital Processing is used to generate a 3D image of the inside of an object from a large series of two-dimensional X-ray images taken around a single axis of rotation.



mapping the regions of the brain



CONCLUSIONS

- **Electromagnetic waves**
- **Harvesting spectrum for Communications**
 - Cellular & Satellite Communications
 - Fibre Communications (Internet backbone)
- **Harvesting Sunlight Energy**
 - Solar Farms
 - PV Cells
- **Fighting Global Warming**
 - Earth & Space Mirrors
- **Harvesting Information from the Universe**
 - Visible Light, Gamma Ray and Radio Astronomy
- **Remote Sensing & Saving Lives**
 - Radar, HAPs, X-ray and other scanning technologies

THANK YOU!