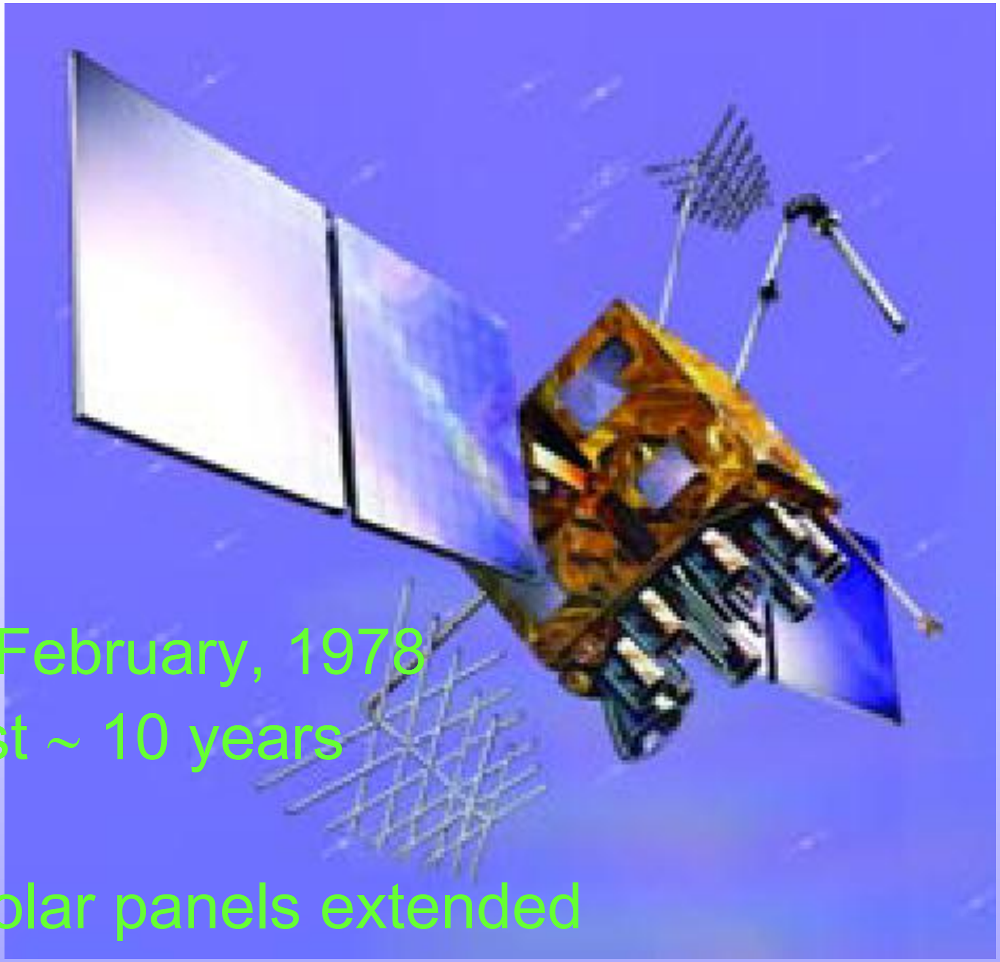
Global Positioning System
GPS

GPS permits land, sea and airborne users to determine their three dimensional position anywhere in the world very precisely and accurately

http://www.aero.org/education/primers/gps/howgpsworks.html
http://www.aero.org/education/primers/gps/GPS-Primer.pdf
http://www.unistrong.com/English/aboutgps/index.htm
http://www.eftaylor.com/pub/projecta.pdf

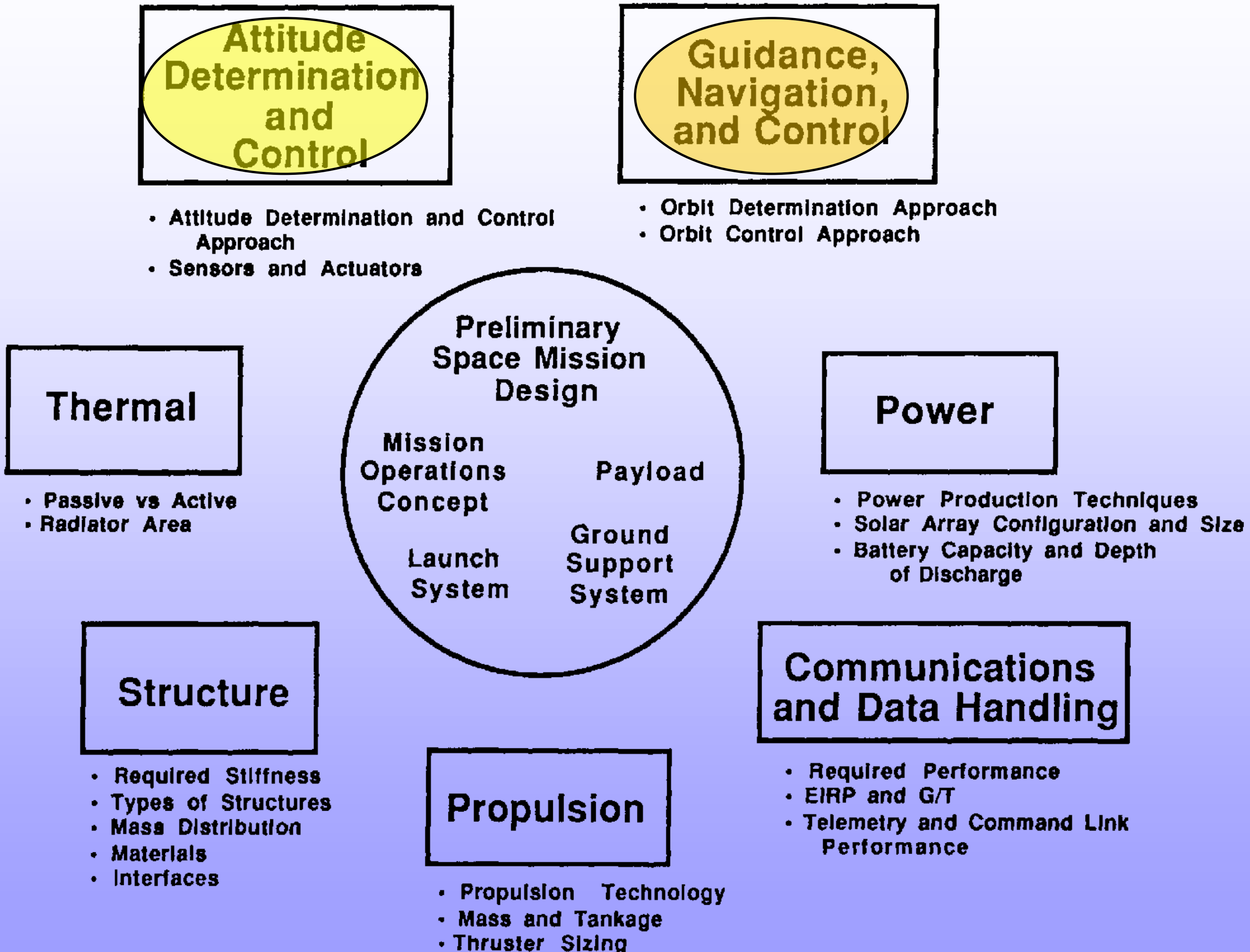
Characteristics

- a satellite-based navigation system
- developed and operated by the U.S. Department of Defence (DoD)



- First GPS satellite launched in February, 1978
- Each satellite is expected to last ~ 10 years
- Mass ~ 2,000 pounds (910 kg)
- Dimensions ~ 17 feet (5.2 m) solar panels extended
- Transmitter power ≤ 50 watts
- Each satellite transmits two signals, L1 (civilian, 1575.42 MHz) and L2

SOTTO-SISTEMI



Working Principle 1/4

- a network of 24 orbiting satellites at eleven thousand nautical miles in space (h=20100 km), at an inclination of 55 degrees and in six different orbital paths
- satellites are constantly moving, making two complete orbits around the Earth in just less than 24 hours
- user segment consists of receivers, processors and antennas

Working Principle 2/4

GPS receiver acquires the signal, measures the interval between transmission and receipt of the signal to determine the distance between the receiver and the satellite

The receiver has to calculated these data for at least 3 satellites, to determine its location on the Earth's surface (triangulation):

-the distance to one satellite narrows down the receiver's position to some place on an imaginary sphere

-the distance to a second satellite narrows the position down to the intersection of two spheres

-the exact position of a third satellite narrows the possibilities down to two points of intersection

The exact position is usually known because one of the points is usually not on the surface of the Earth

A fourth satellite position can be used to find the one single location without any doubt

Working Principle 3/4

Distance from the receiver to the satellite is measured by timing how long it takes for a signal sent from the satellite to arrive at the receiver

Both the satellite and the receiver simultaneously generate the same pseudo random code

The time delay before both codes will synchronise, multiplied by the speed of light gives the distance

Doppler Effect

The pseudo random code is a very complicated code that looks like random electrical noise:

-it makes sure that the receiver doesn't accidentally sync up to some other signal

-It guarantees that the receiver doesn't accidentally pick up another satellite's signal (each satellite has its own unique pseudo random code)

Information 1/2

Every satellite also transmits almanac and ephemeris data:

The almanac data is general information on the location and the health of each satellite in the constellation, which can be received from any satellite

Ephemeris data is the precise satellite positioning information that is used by the GPS receiver to compute its position

Timing: satellites have atomic clocks that can make precise time measurements (GPS receivers don't). To correct this, a fourth satellite distance measurement is made, providing perfect timing or atomic accuracy clock measurements

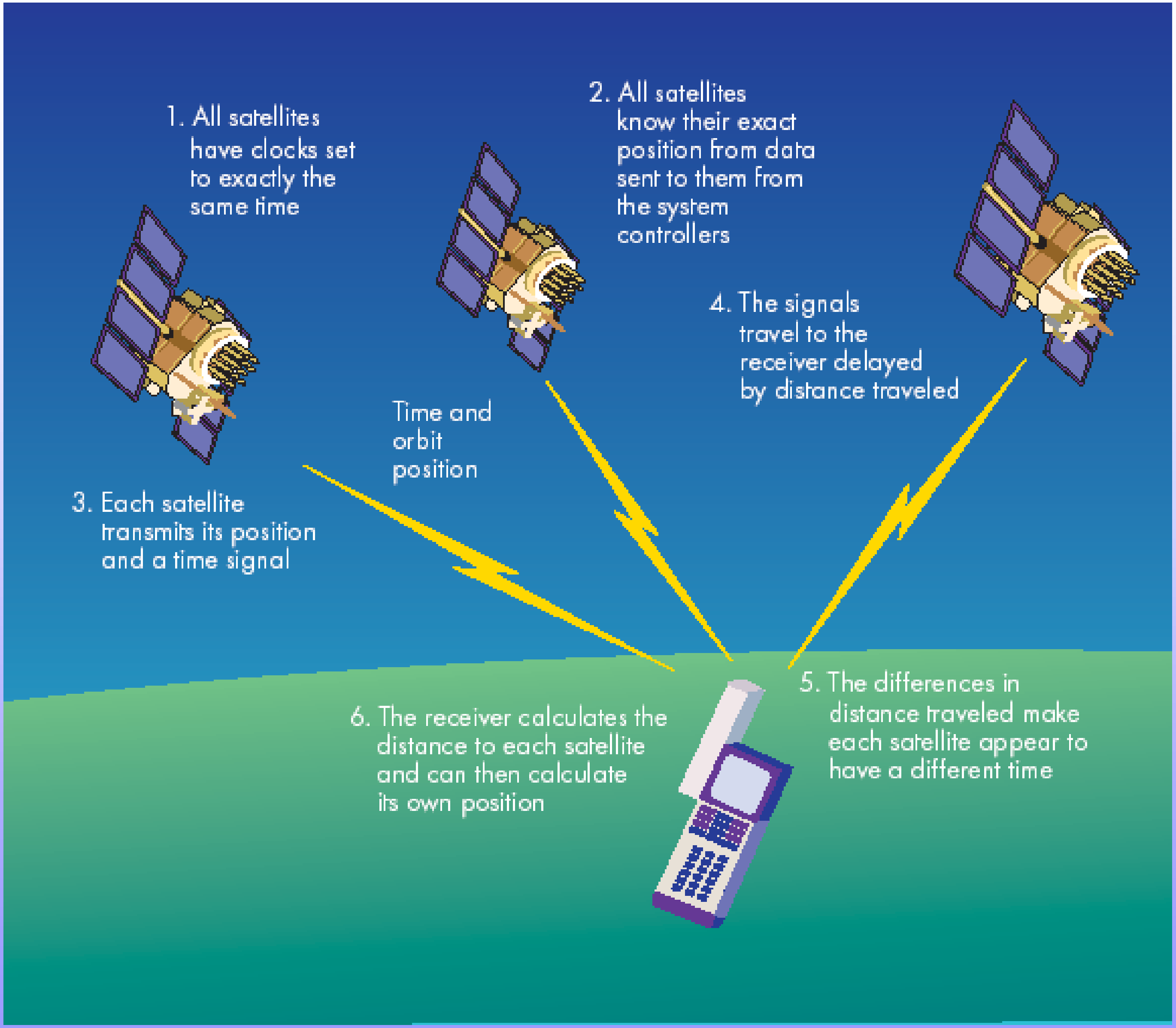
Information 2/2

Department of Defence constantly monitors the GPS satellites:

a master control station in Colorado Springs and five monitor stations and three ground antennas located throughout the world

1. monitor stations send the information they collect from each of the satellites back to the master control station computing extremely precise satellite orbits
2. information is formatted into updated navigation messages for each satellite
3. updated information is transmitted to each satellite via ground antennas, which also transmit and receive satellite control and monitoring signals

Working Principle 4/4



Errors

Multipath errors (< 15 feet ~ 4.5 m)

Internal clock errors

Triangulation

Propagation delay due to atmospheric effects (slowing down of the GPS signal as it passes through Earth's ionosphere)

$$u = \frac{c}{\sqrt{1 - e^2 n_e / \pi m_e \nu^2}}$$

$\Downarrow$

Accuracy: 60 ÷ 225 feet (~ 18 ÷ 68 m)

Solution

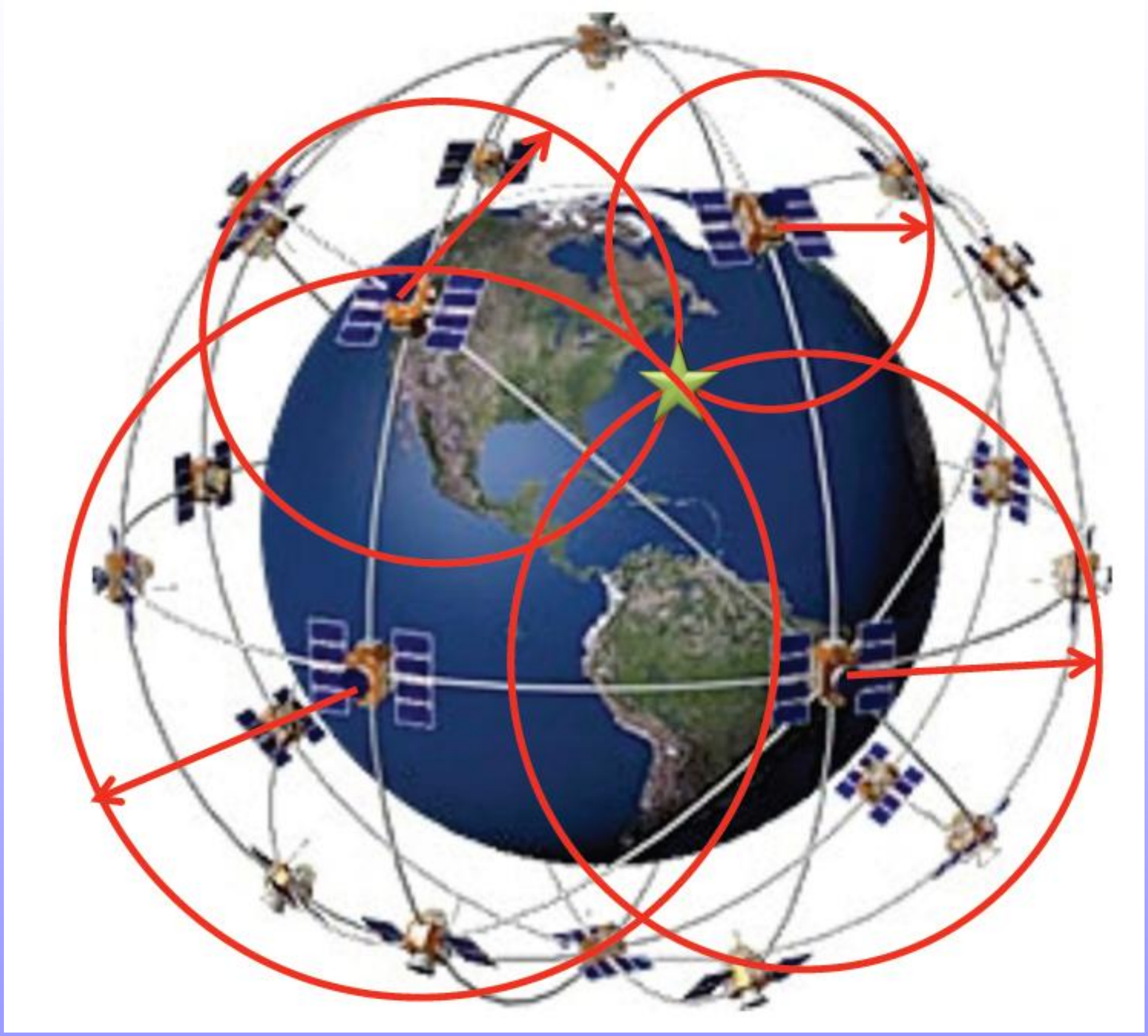
Dual GPS (DGPS)

Accuracy: 3 ÷ 15 feet (~ 1 ÷ 5 m)

U.S. Coast Guard, U.S. Army Corps of Engineers + foreign government departments transmit DGPS corrections (from L2 channel) through marine beacon stations

These beacons operate in the 283.5 - 325.0 kHz frequency range and are free of charge

Relatività



Con 0.86 ns di errore, la precisione può essere di ~30 cm (in teoria)

Relatività ristretta

- Osservatori in moto relativo uno rispetto all'altro misurano intervalli di tempo e lunghezze diverse
- Il tempo si dilata, quindi un orologio appare andare più piano, lo spazio si contrae (i satelliti GPS sono in moto…!)
- Un orologio in movimento va più piano di un orologio in quiete: $v_{sat} = 3.8$ km/s

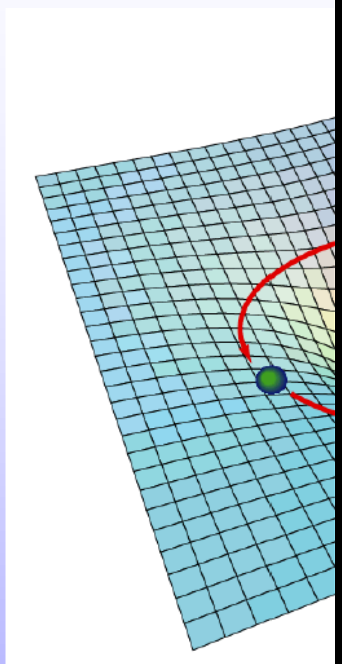
$$\gamma = \frac{1}{\sqrt{1 - v^2/c^2}} = 1{,}0000000000834$$

A 100 km/h
1,00000000000000428

- Alla velocità della luce 2.2 km!

Relatività generale

- Un campo gravitazionale curva lo spazio-tempo



Relatività: risultato

- Gli orologi dei satelliti vanno volutamente ad una velocità diversa (quindi non sono uguali a quelli a Terra)
- I clock nominali a Terra vanno a 10.23000000000 MHz
- Quelli sui satelliti: 10.22999999954326 MHz
- Vi sono ancora alcuni effetti PERIODICI legati all'orbita non circolare dei satelliti, e al cosiddetto effetto Sagnac (legato alla rotazione della Terra) che sono corretti sul ricevitore perché dipendono dalla posizione relativa fra ricevitore e satelliti nonché dalla latitudine…