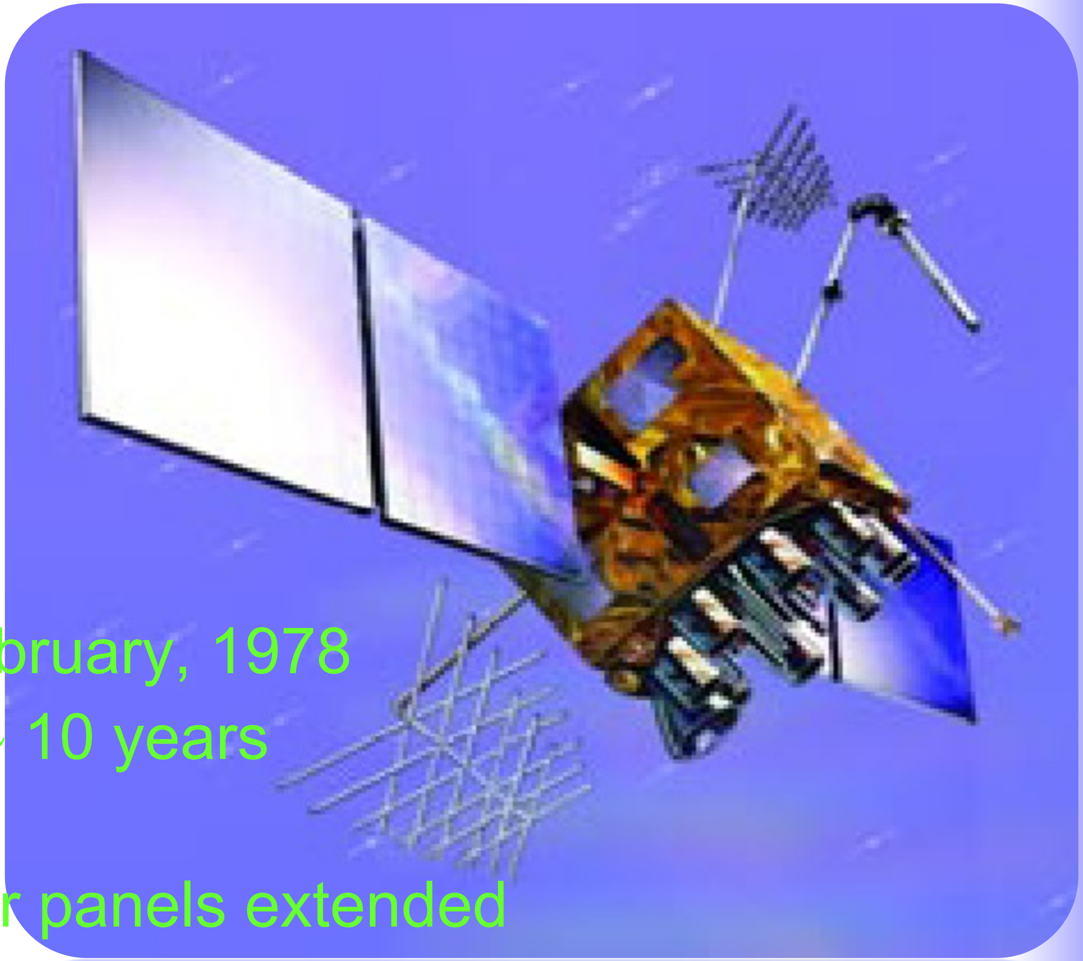
Global Positioning System

GPS & Galileo

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

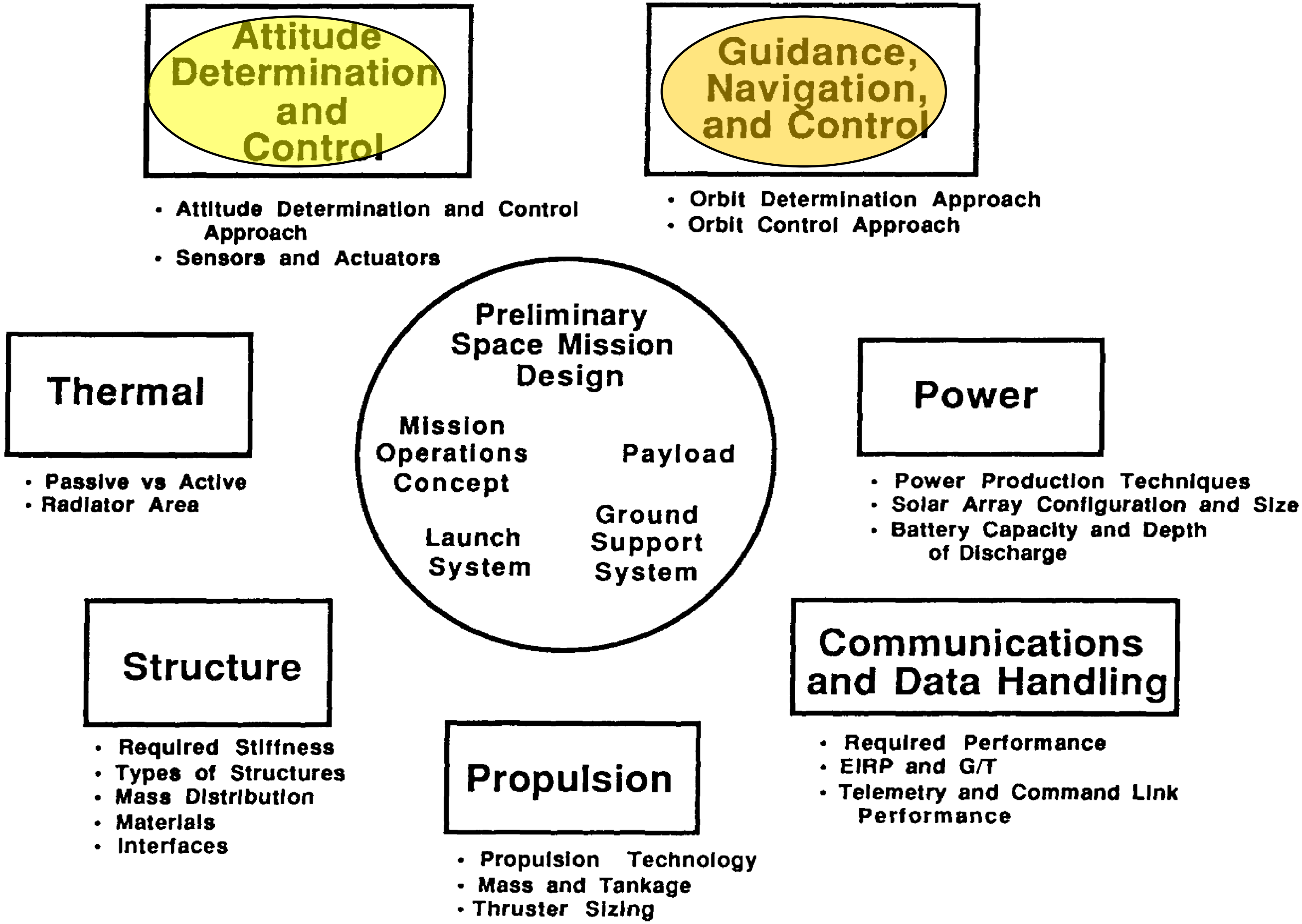
Mass ~ 2,000 pounds (910 kg)

Dimensions ~ 17 feet (5.2 m) solar panels extended

Transmitter power ≤ 50 watts

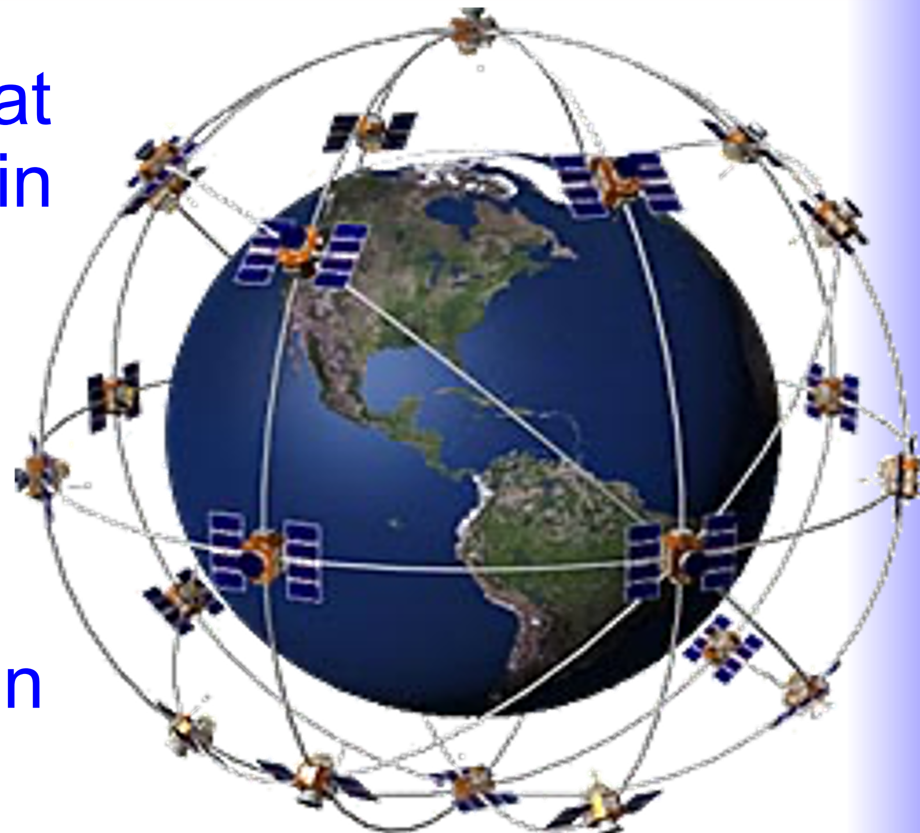
Each satellite transmits two signals, L1 (civilian, 1575.42 MHz) and L2

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:

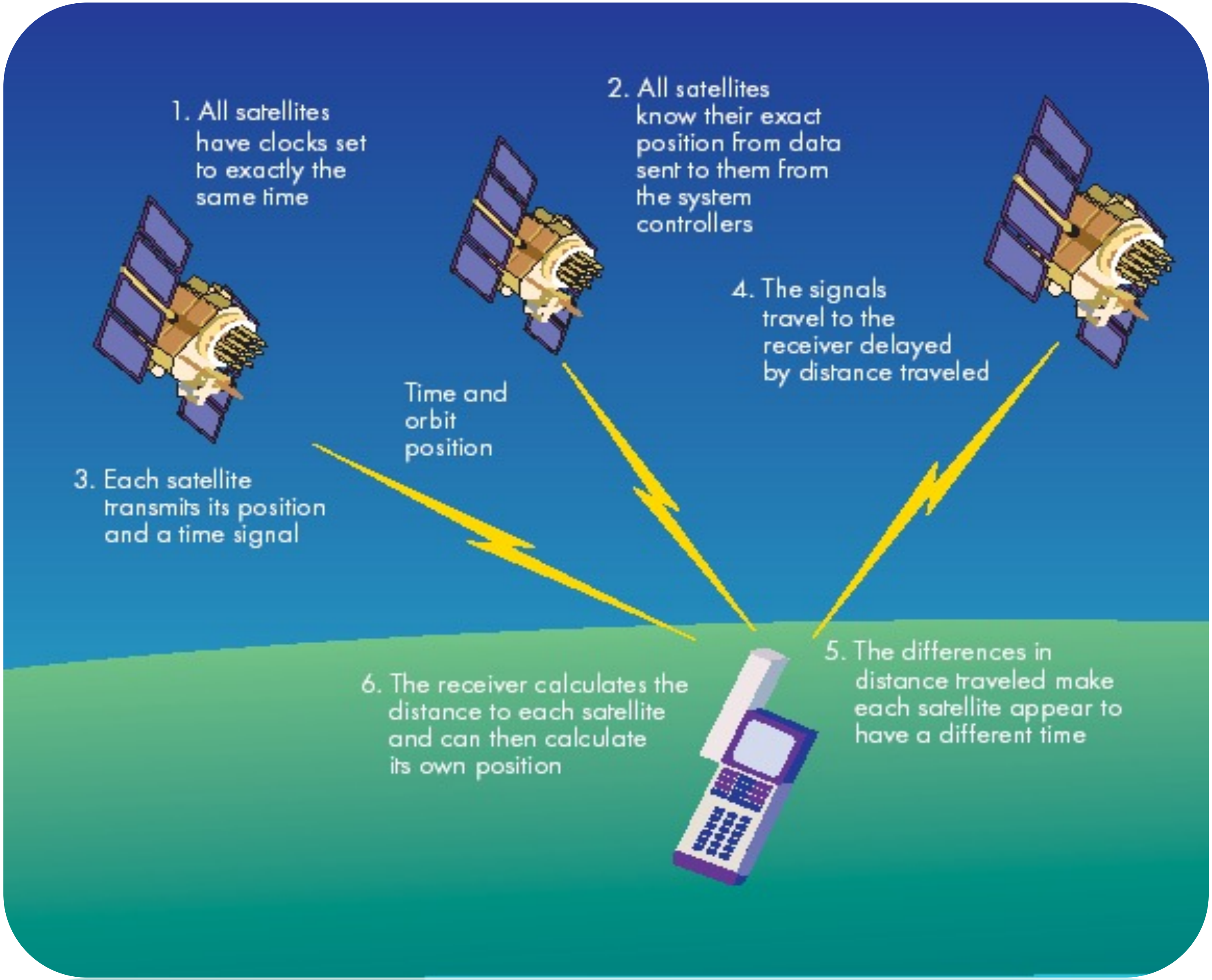
a master control station in Colorado Springs and five monitor stations and three ground antennas located throughout the world

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

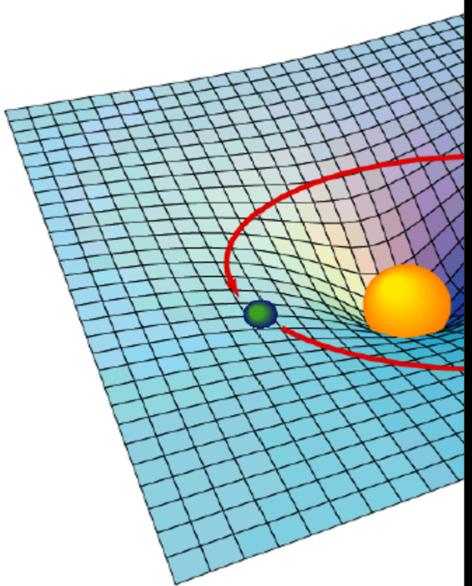
$$\gamma = \frac{1}{\sqrt{1 - v^2/c^2}} = 1{,}0000000000834$$

A 100 km/h
1,00000000000000428

- In un giorno 7 μs (orologi GPS in ritardo…)
- Alla velocità della luce: 2.2 km!

Relatività generale

- Un campo gravitazionale curva lo spazio-tempo



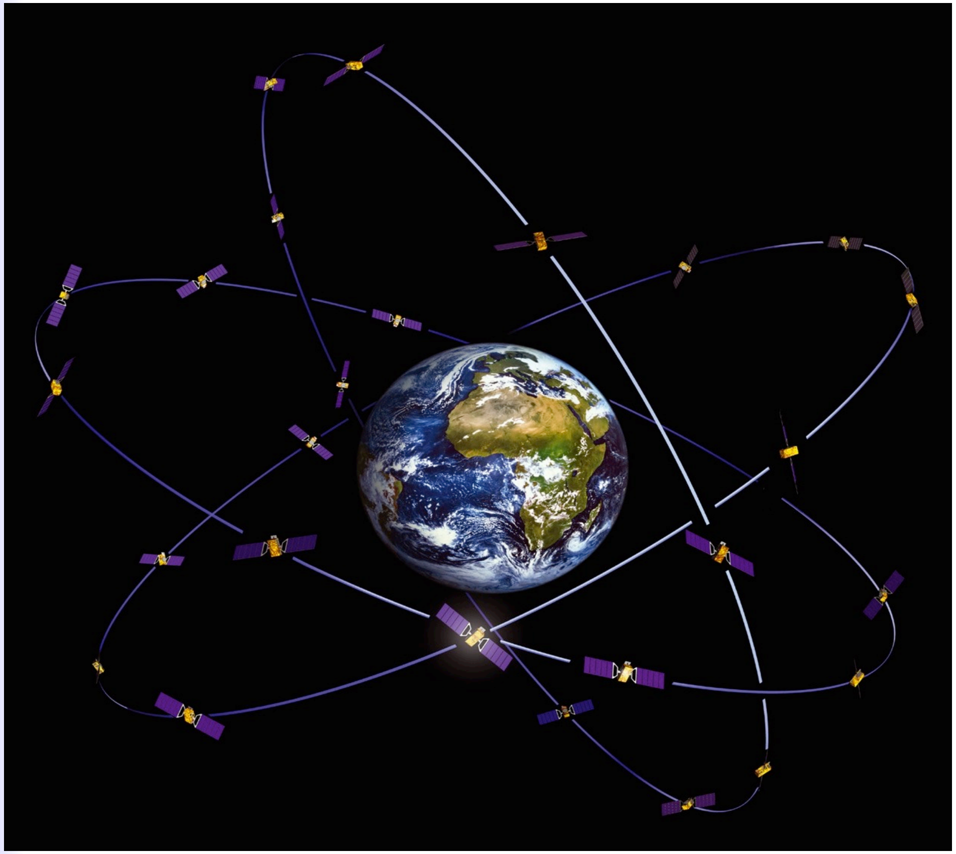
orologi GPS in anticipo…

TOT = (45-7) μs

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…

GALILEO



The Galileo programme is Europe's initiative for a state-of-the-art global satellite navigation system, providing a highly accurate, guaranteed global positioning service under civilian control.

Initial services: 2016
Fully operational: 2020

The fully deployed system will consist of **30** satellites, at 23 222 km altitude, 3 orbital planes at 56^{o} inclination, and the associated ground infrastructure. Galileo will be inter-operable with GPS and GLONASS, the 2 other global satellite navigation systems.

Galileo 2020

- 2016: 18 Galileo satellites in orbit and working transmitting navigation signals as fully operational members of Europe's satnav constellation
- 2017: With 18 satellites now in orbit, Galileo began initial services on 15 December 2016, the first step towards full operations. Additional four satellites, were launched together on 13th December 2017, by a customised Ariane 5
- 2018: On 24 July 2018, Galileo satellites (codenamed Samuel, Anna, Ellen and Patrick) lifted-off from the European Space Port of Kourou, aboard Ariane 5 ES flight VA244
- A further eight Galileo 'Batch 3' satellites were ordered on June 2017, to supplement the 26 built so far
- The full system of 30 satellites plus spares is expected to be in place by 2020

Galileo 2019

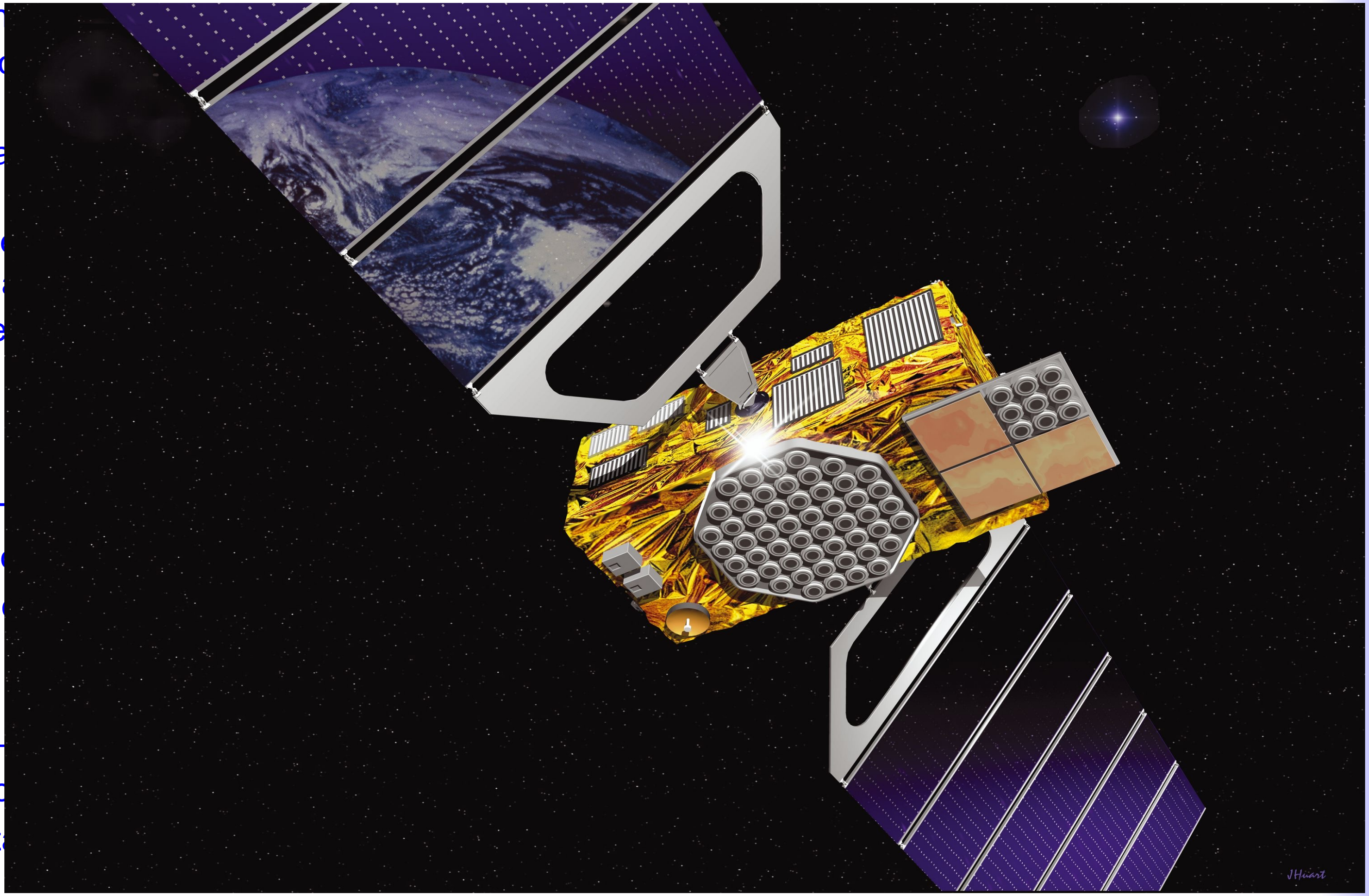
Galileo set to growth with global system upgrade

- Having completed all necessary qualification testing, ESA has received the green light to upgrade the global infrastructure running Europe’s Galileo satellite navigation system. The resulting migration, which started in February 2019, will incorporate new elements into the world-spanning system and boost the robustness of Galileo services delivered from the 26 satellites in orbit.

Galileo Satellites

Each 700 kg Galileo satellite contains all the equipment needed to perform its assigned navigation and timing tasks over the course of its 12-year design life:

- L-band antenna – Transmits the n
- Search and Rescue antenna – Pic forward to local rescue services
- C-band antenna – Receives signa integrity data)
- 2 S-band antennas – Part of the t signals to measure the satellite's
- Infrared Earth sensors and visible
- Laser retroreflector – to measure a year)
- Space radiators
- Passive hydrogen maser clock – hydrogen atom to measure time t
- Rubidium clock – A smaller atomi hours.
- Clock monitoring and control unit
- Navigation signal generator unit –
- Gyroscopes – Measure the rotatio
- Reaction wheels – Control the rot Sun



- Magnetotorquers – Modifies the speed of rotation of the reaction wheels by introducing a magnetism-based torque
- Power conditioning and distribution unit
- Onboard computer

Galileo Clocks

- Galileo's timing needs to be accurate to the scale of nanoseconds
- Combine inputs from several satellites simultaneously and the receiver's place in the world is pinpointed: Galileo's aim is to deliver accuracy in the metre range once the full system is completed
- Highly accurate atomic clocks rely on switches between energy states of an atom's electron shell, induced by light, laser or maser energy – if you force atoms to jump from one particular energy state to another, it will radiate an associated microwave signal at an extremely stable frequency
- The passive hydrogen maser clock is the master clock on board each satellite. It is an atomic clock which uses the ultra stable 1.4 GHz transition in a hydrogen atom to measure time to within 0.45 nanoseconds over 12 hours
- A rubidium clock will be used as a second, technologically [illegible] s accurate to within 1.8 nanoseconds over 12 hours. Prototy [illegible] ESA's GIOVE missions