Mobile Computing

Lecture 8: The Global Positioning System

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Location Representation

Different ways to express location info

- **Absolute:** position within a global reference frame. E.g. (long., lat.)
- **Relative:** based on arbitrary coordinate systems and reference frame.
  I.e. four meters to the north west.
- **Symbolic:**
  I.e. office 212, second floor.

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GPS

Ubiquitous positioning system

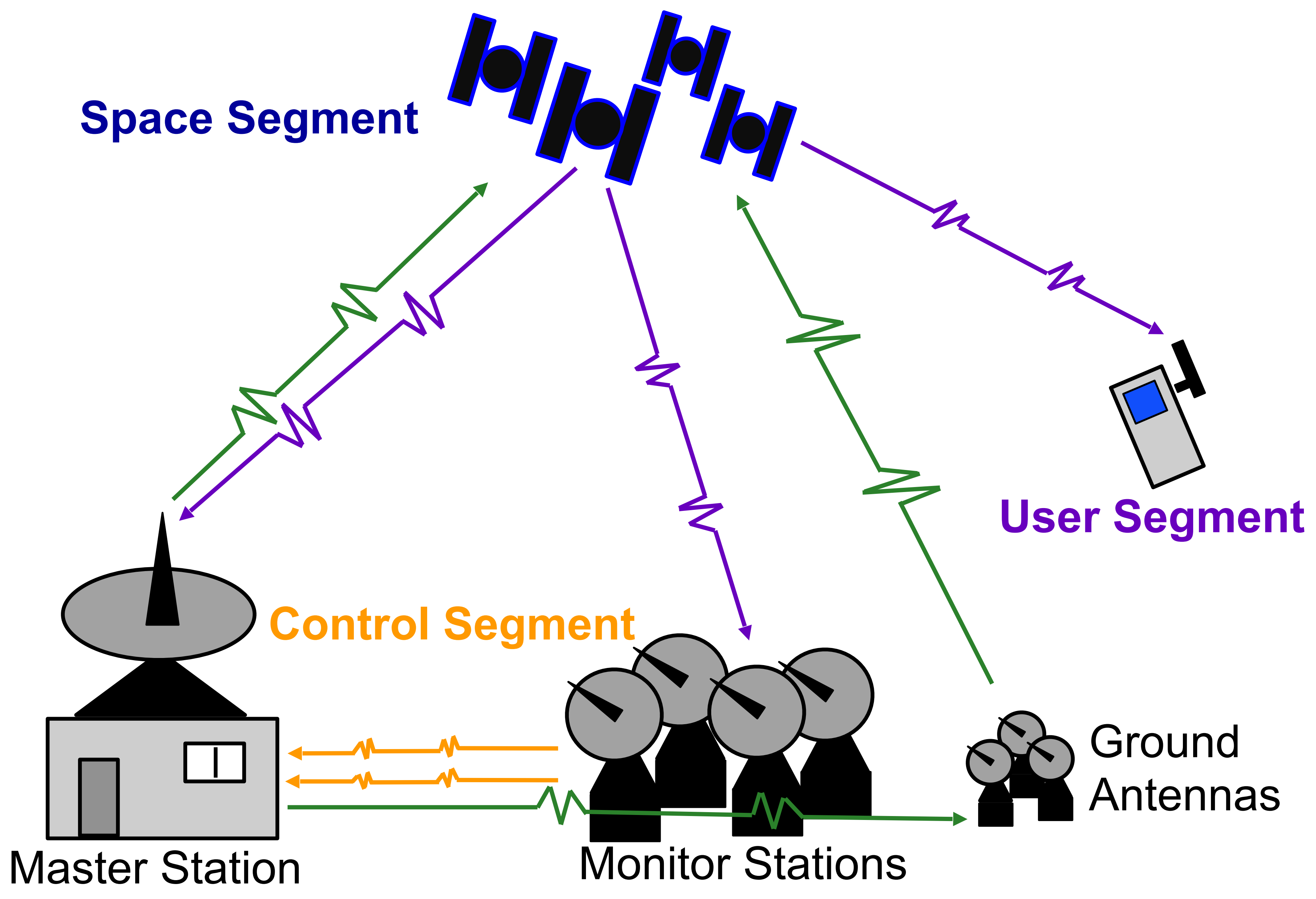
Created by US military - but also available for civilians

GPS : accuracy within 10m for 90% of all measurements

- Accuracy: 10 m (how close the readings to the ground truth ?)
- Precision: 90% (how consistent are the readings?)

GPS

The Global Positioning System consists of three segments

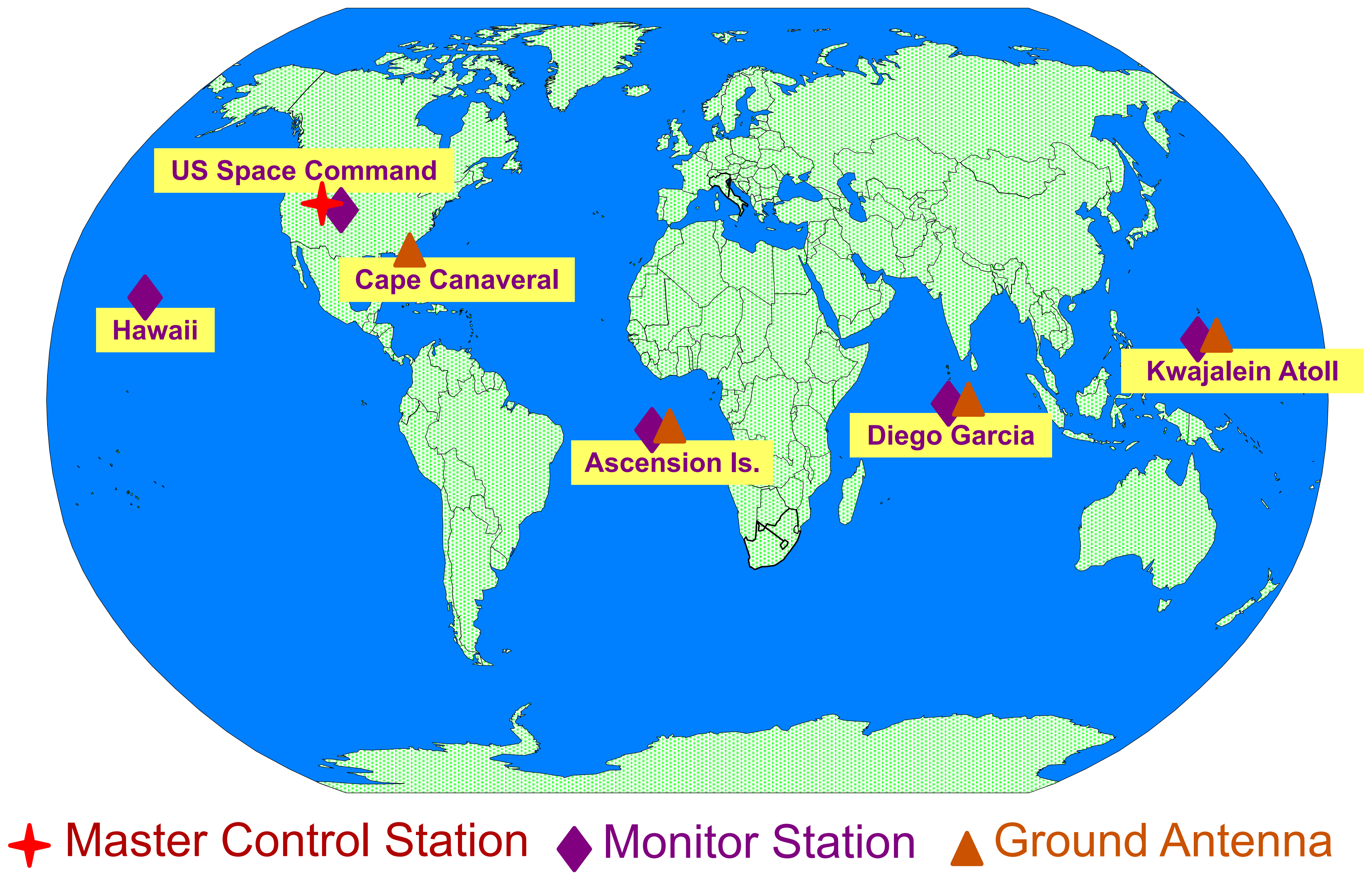


GPS : Control Segment

Control Segment consists of

- **Master Control Station (MCS)**: located at the US Air Force Space Command Center in Colorado. Responsible for satellite control and overall system operation.
- **Monitor Stations :** receive GPS satellite transmissions and relay this information to the MCS.
- **Ground Antennas**: used to uplink data to GPS satellites. Those are remotely controlled by MCS to transmit data and commands

GPS : Control Segment



GPS : Control Segment

MCS regular send the following data (via Ground Antennas) to all GPS satellites

- Clock correction factors to ensure all satellites operate at the same precise time - GPS time
- Atmospheric data to help correct distortion of GPS satellite signals passing ionosphere.
- ***Almanac:*** *which is a log of all GPS satellites positions and health.*

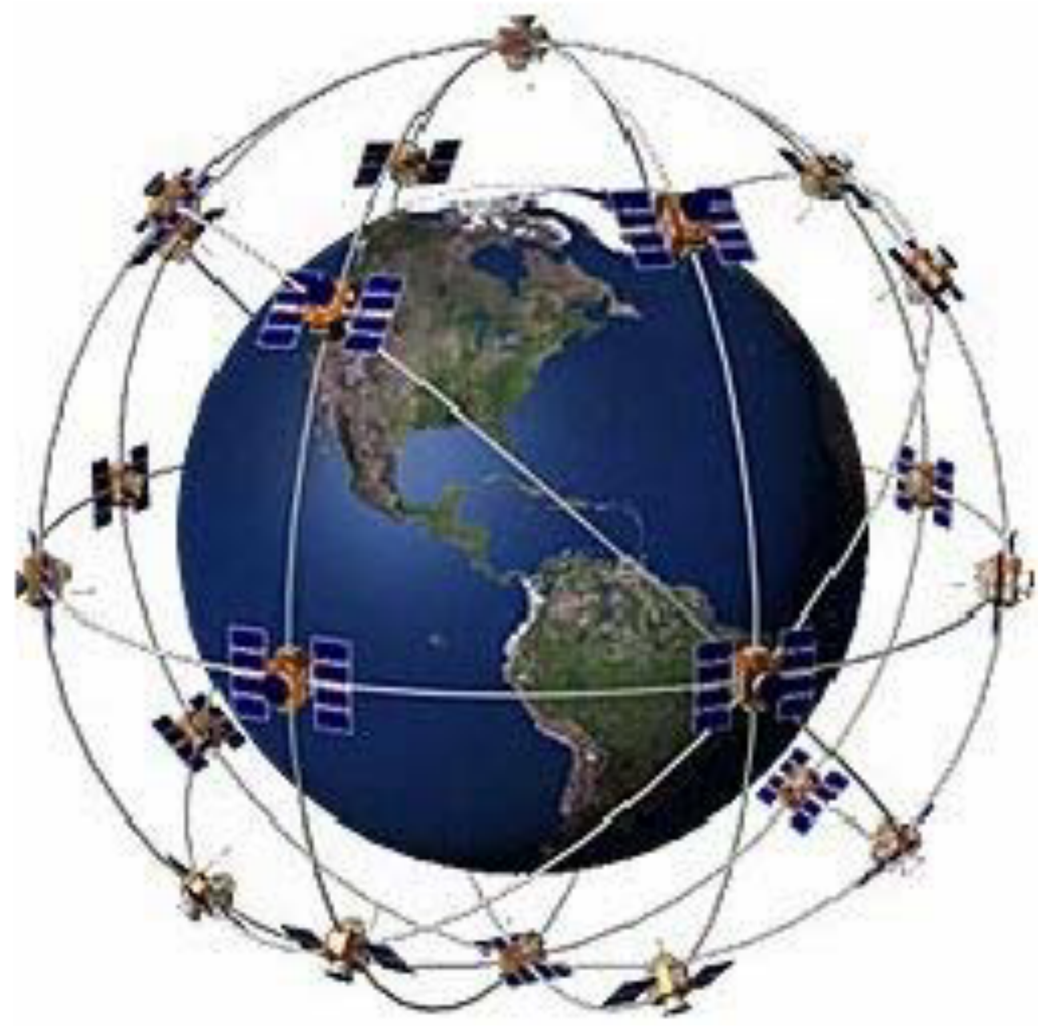
GPS : Control Segment

Almanac:

- *It is like a schedule that allows GPS receiver to chose the best satellite signals to use to determine position.*
- *Automatically downloaded by from satellites whenever a receiver collects a GPS signal.*

GPS : Space Segment

- GPS space segment consists of 24 active and 5 spare satellites.
- GPS satellites are circling the earth in 6 orbital planes.
- Each satellite completes one earth orbit every twelve hours.
- Satellites designed life time is approximately 10 years.
- Satellites equipped with Atomic Clocks.



User Segment

GPS receiver device with the users.

Receives signals from GPS satellites and use it to calculate the user’s location.

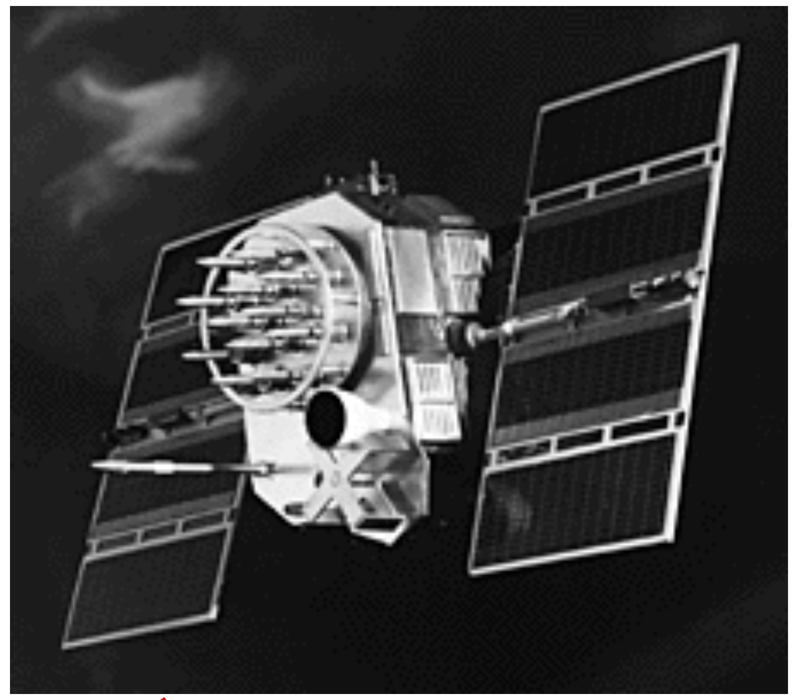
Different applications:

- Military
- Navigation
- Surveying
- GIS
- Robot and vehicle guidance.

How Does GPS Positioning Work ?

Distance measurement based on Time

distance = time * velocity



Radio waves travel at the speed of light. If GPS signal leaves satellite at time "T"…

T

…and is picked up by the receiver at time "T + 3."

T + 3

Then distance between satellite and receiver = "3 * times the speed of light"

How to compute the travel time ?

The travel time estimate must be very accurate.

1 microsecond time error = 300 m distance error

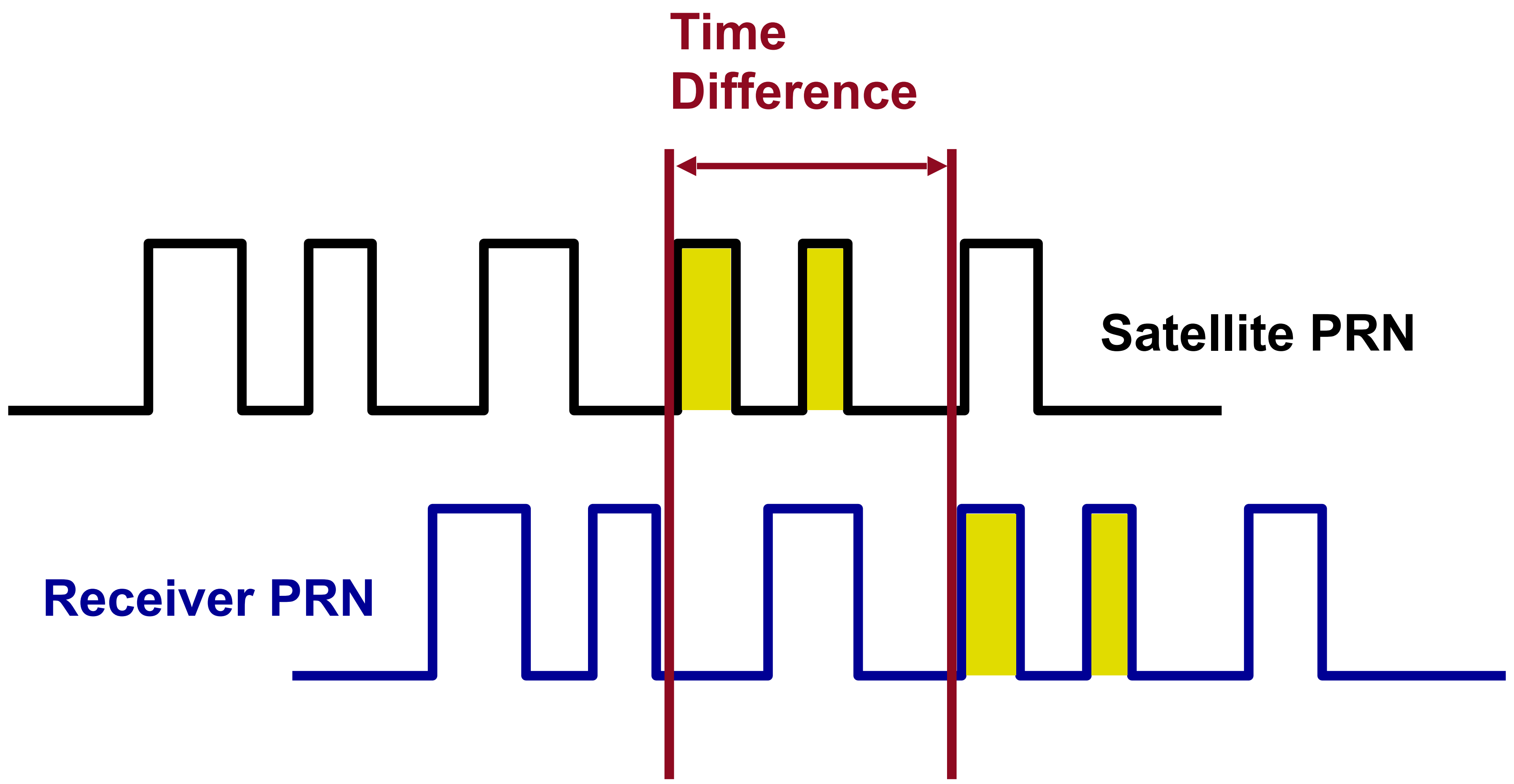
Therefore, precise time synchronization is critical for GPS operation.

GPS satellites are equipped with Atomic clocks which are maintained for accuracy by MCS.

But it is not possible to have high precision atomic clocks in GPS receivers.

How to compute the travel time ?

GPS receiver receives Pseudo Random Noise Code from GPS satellite

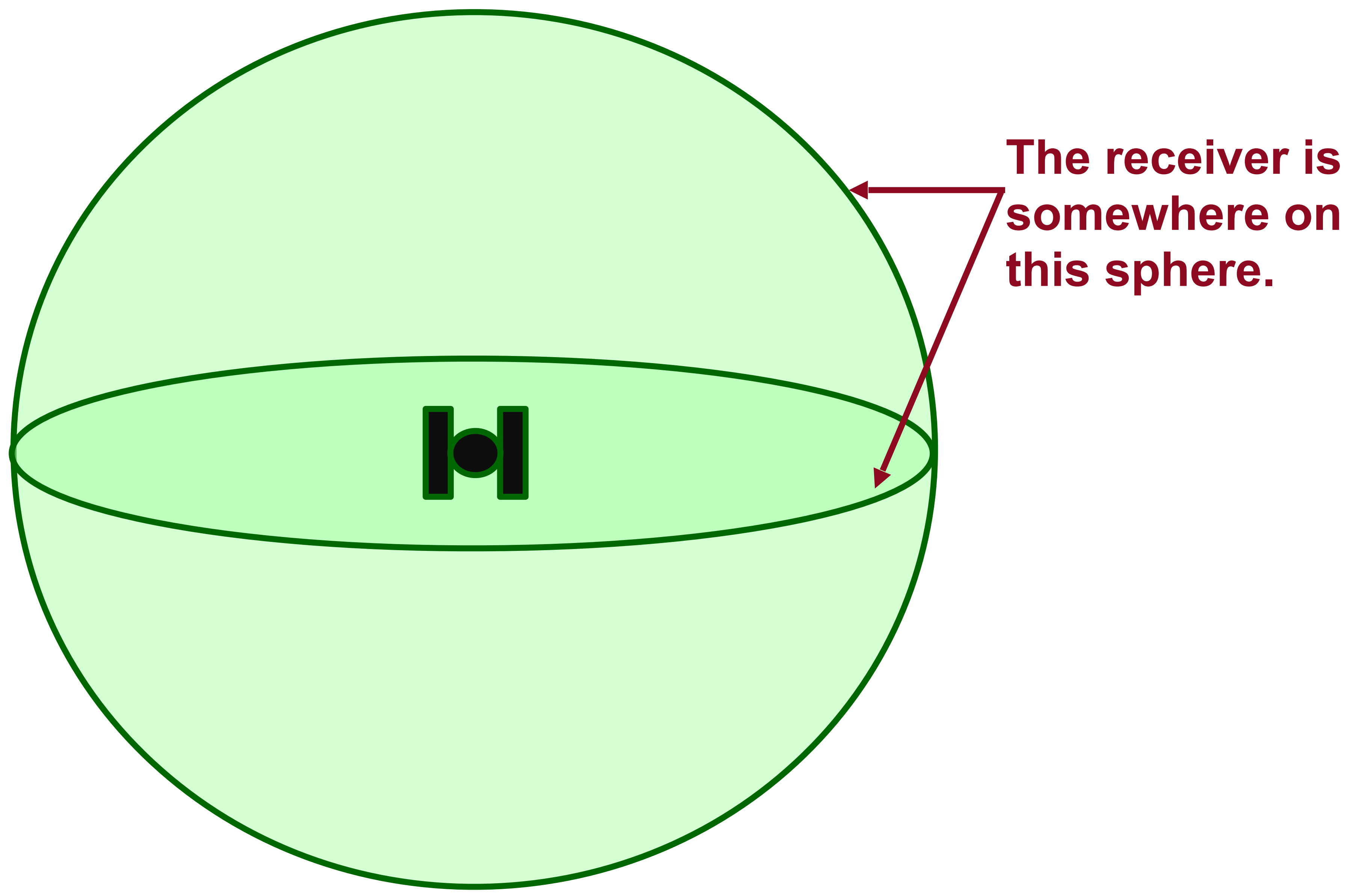


GPS receiver receives Pseudo Random Noise Code from GPS satellite .

It also generates its own copy of the Satellite’s PRN , then compare the two signals to find the shift. The amount of shift corresponds to travel time.

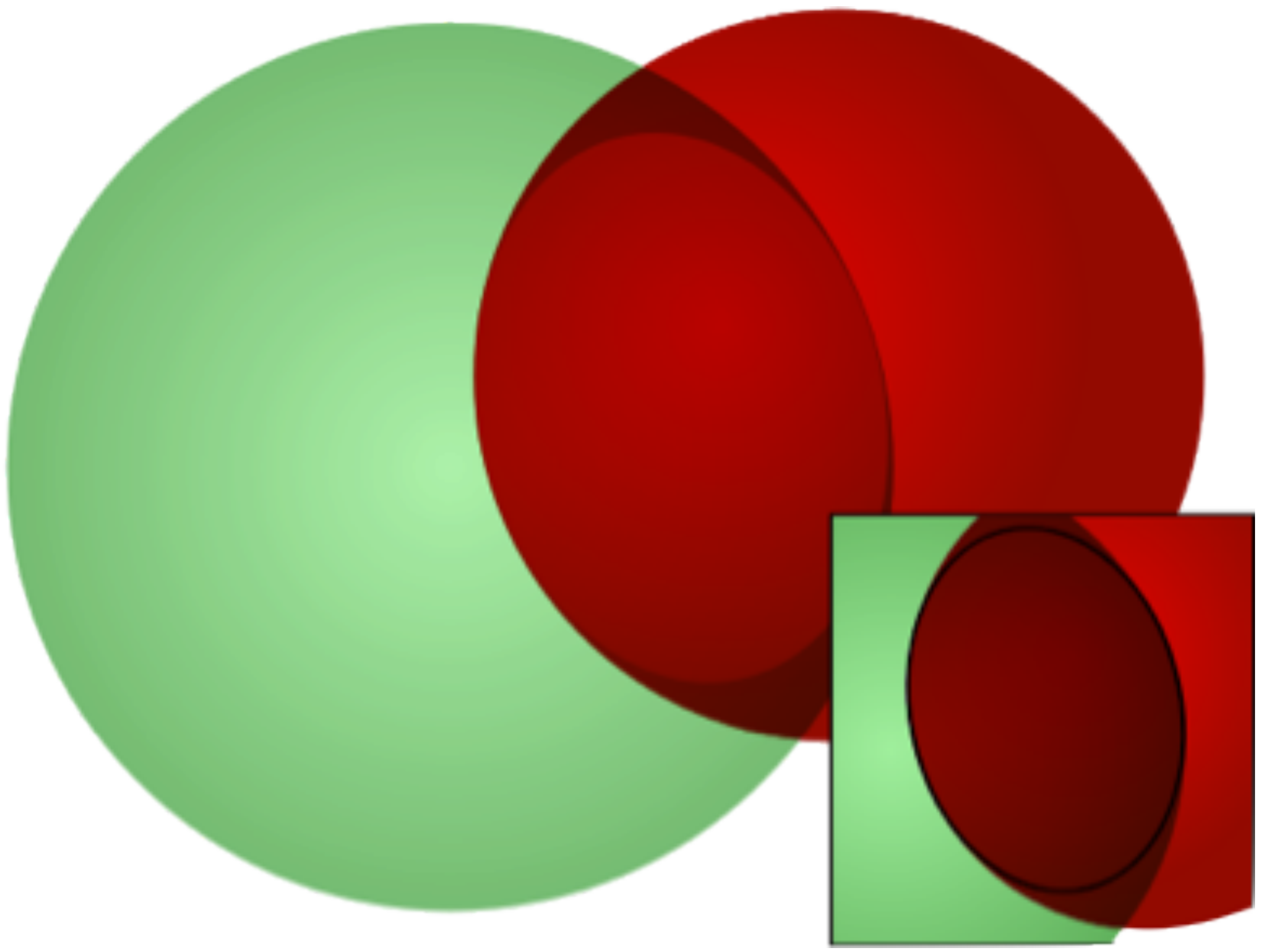
GPS Trilateration

Signal From One Satellite



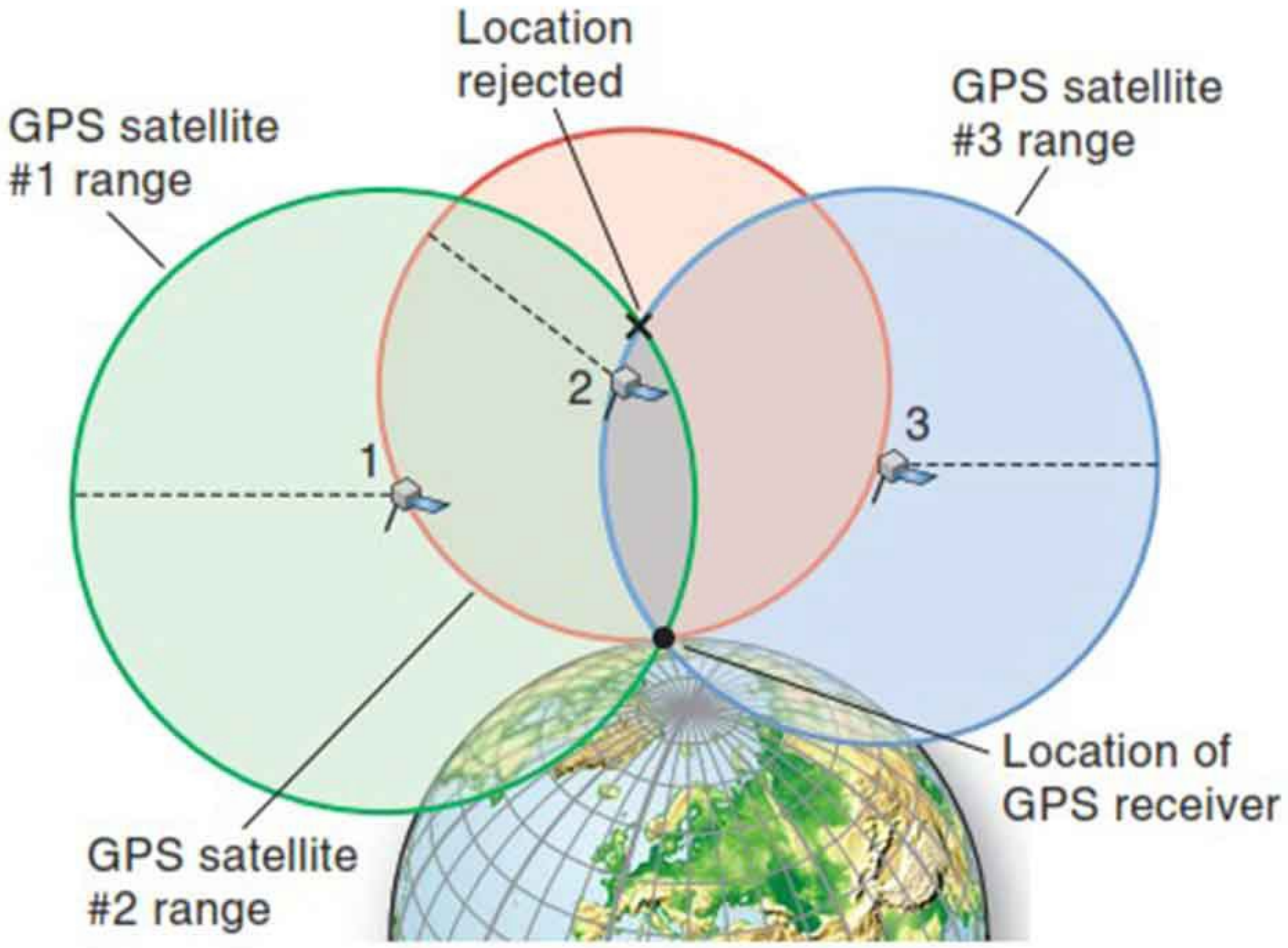
GPS Trilateration

Signal From Two Satellites



GPS Trilateration

Theoretically, at least three satellites needed to find 2D location



Watch

https://www.youtube.com/watch?v=QK1lDsinMwk

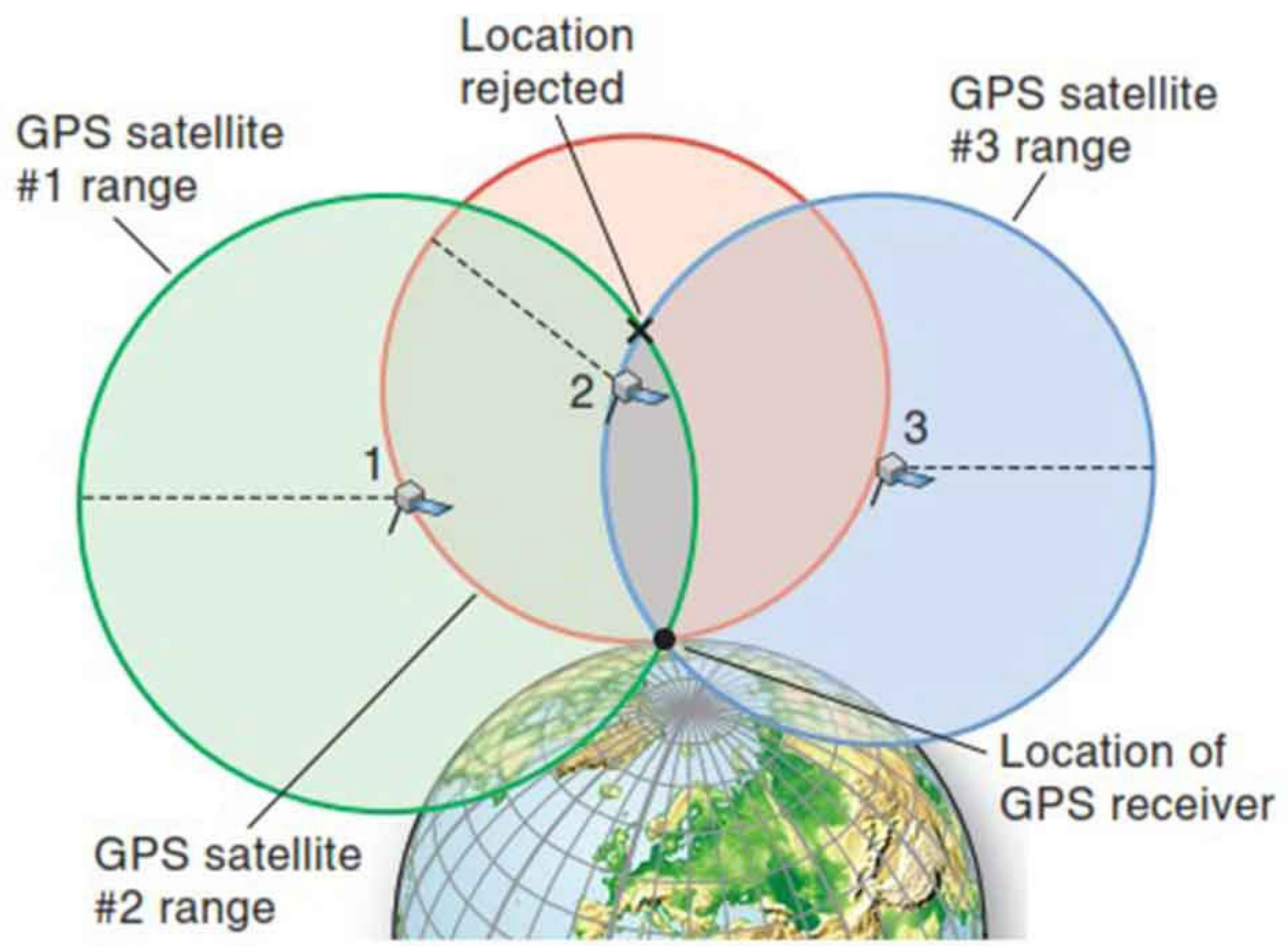
GPS Trilateration

Due to time-synchronization errors

In practice, signal from a fourth satellite is needed.

•Used to solve for clock error

•Also useful for finding the altitude value.



GPS and The Relativity

Time Dilation: *slowing in time in according to the theory of relativity.*

GPS and The Relativity

Time Dilation:

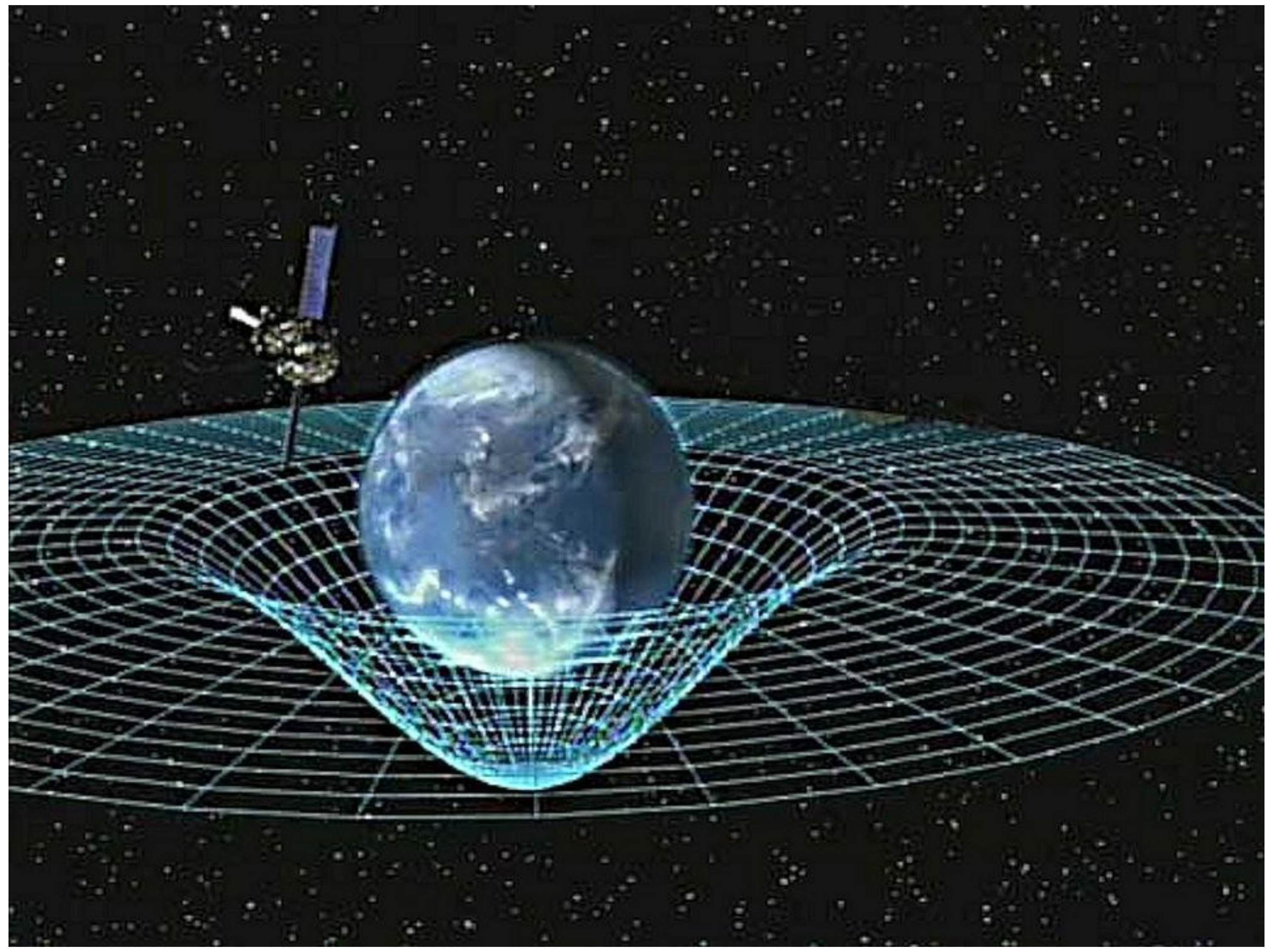
Theory of special relativity : clocks slow down as determined by an observer who is in relative motion with respect to clock.

Because satellites are constantly moving relative to observers on Earth, time appears to us to be slower there. ***Therefore clocks in GPS satellite will fall behind clocks on Earth by 7 microseconds per day.***

GPS and The Relativity

Time Dilation:

Theory of general relativity : clocks closer to a massive object will seem to tick more slowly than clocks located further away.



Clocks located on satellite are further from the Earth gravity than clocks located on Earth. ***Therefore clocks in GPS satellite will be 45 microseconds ahead than identical clocks on Earth, per day.***

GPS and The Relativity

Engineers who designed GPS accounted for the theory of relativity effects by designing GPS satellites on-board clocks to tick at a slower frequency than ground reference clocks.

Once they are in orbit, their clocks would appear to tick at the same correct rate as reference atomic clocks on the ground.

Read more: http://www.astronomy.ohio-state.edu/~pogge/Ast162/Unit5/gps.html

GPS and The Relativity

Putting together, clocks on GPS satellite seem to be ticking faster than identical clocks on earth by 38 microseconds per day.

why 38 ? (38 = 45-7)

If this effect not taken into account, GPS error would accumulate by 10 KM per day.

GPS Selective Availability (S/A)

Since GPS was originally developed for military purposes, Before May 2000 the USA government added time-varying obfuscations to civilian GPS signal in order to reduce positioning accuracy.

Authorized groups such as US military and allies could still access a second highly accurate GPS signal.

In May 2000, US government reduced selective availability intentional error to zero meters

- differential-GPS could compensate for that source of error.
- It possible that Pentagon activates S/A again at anytime.

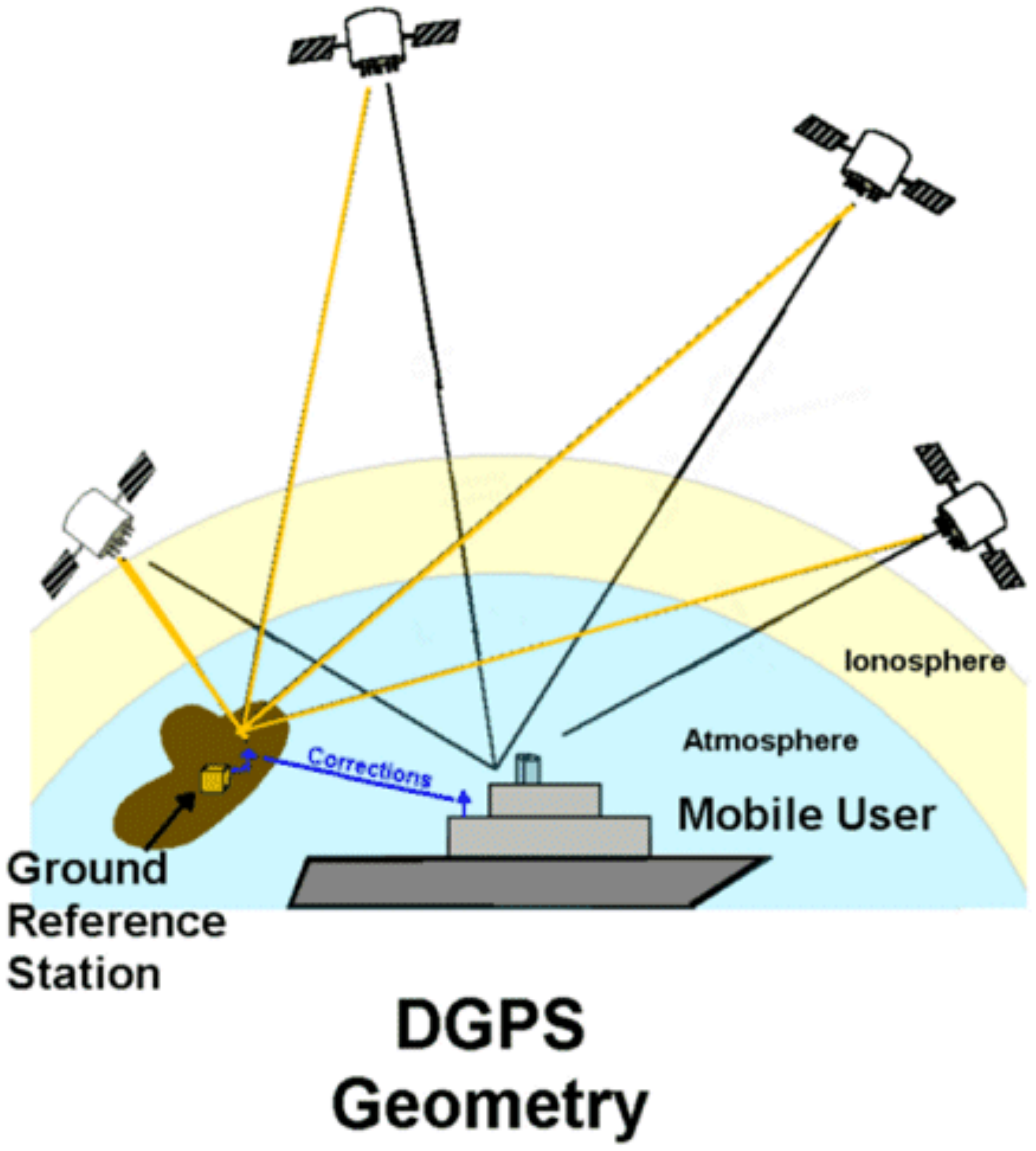
Differential GPS (DGPS)

A method for improving accuracy of receiver by adding a local reference station to augment information available from satellites.

Reference nation with known location will measure errors and send corrections to users in “local” area.

Corrections are not universal, but will be useful over significant area.

DGPS accuracy can be 1-3 centimeters.



GPS Clock Synchronization Applications

Time synchronization is the second prominent application for GPS

Computers clocks suffer from clock drift due to manufacturing issues, change in temperature, and quartz crystal aging.

Clock drift

- Consider two clocks that are synchronized at the beginning of the year. One of them consistently requires an extra 0.04 milliseconds to increment itself by a second.
- ***By the end of the year, the two clocks will differ by more than 20 minutes.***

GPS Clock Synchronization Applications

Accurate timing is very important in many applications.

Application such as financial "stock" market transactions and distributed database (e.g. Google Spanner [1]) rely on GPS and atomic clocks for time synchronization.

[1] https://static.googleusercontent.com/media/research.google.com/en//archive/spanner-osdi2012.pdf