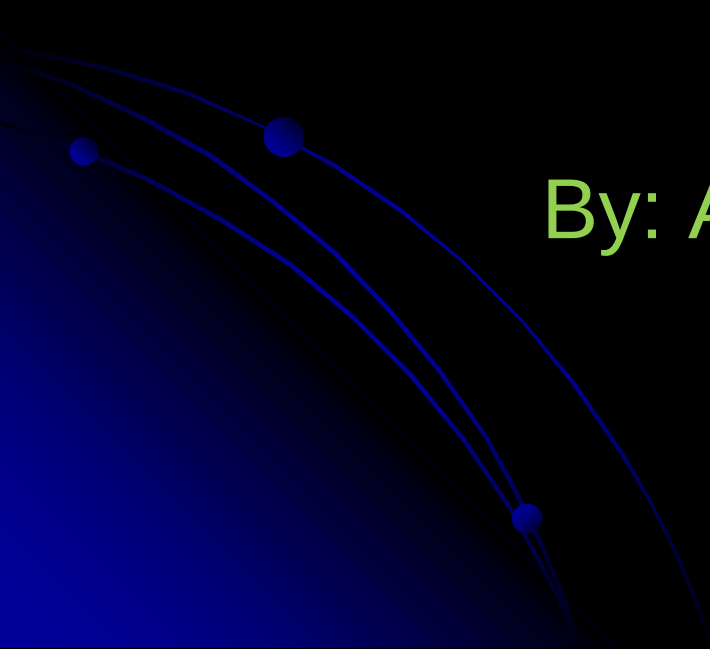


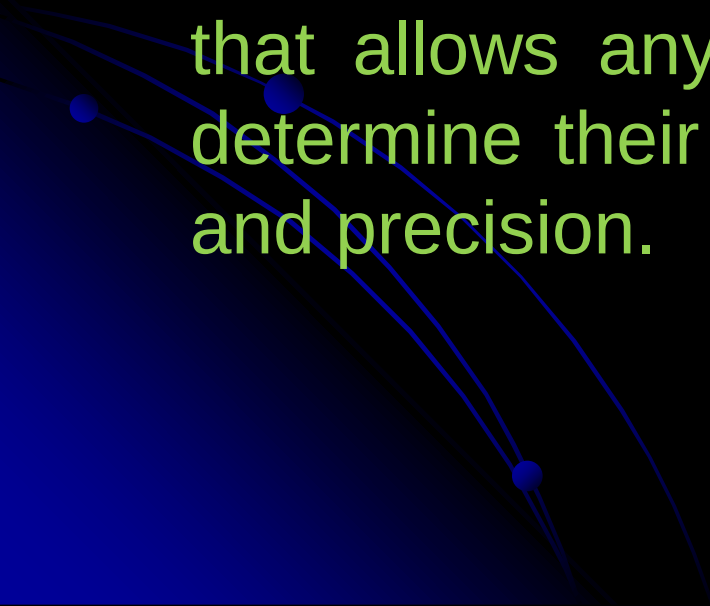
Ph.D. school of STMS

How does Global Positioning Systems (GPS) work?

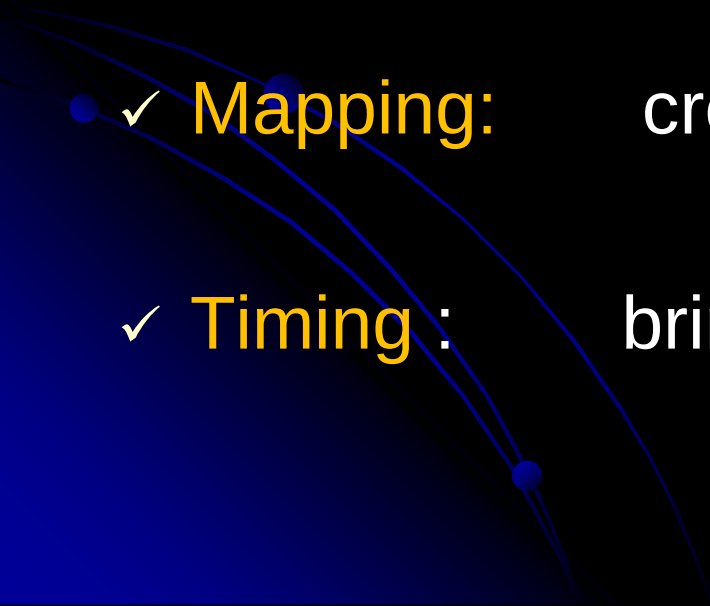
By: Alireza Torghabeh



What is GPS

- ✓ GPS stands for “Global Positioning System”. Initially developed for military purposes in the US in 1978.
 - ✓ GPS is a satellite-based radio navigation system that allows anyone anywhere on the planet to determine their 3D position with great accuracy and precision.
- 
- A decorative graphic in the bottom-left corner of the slide. It features several blue curved lines representing satellite orbits or signal paths, with small blue dots placed at various points along these curves.

Typical GPS Applications

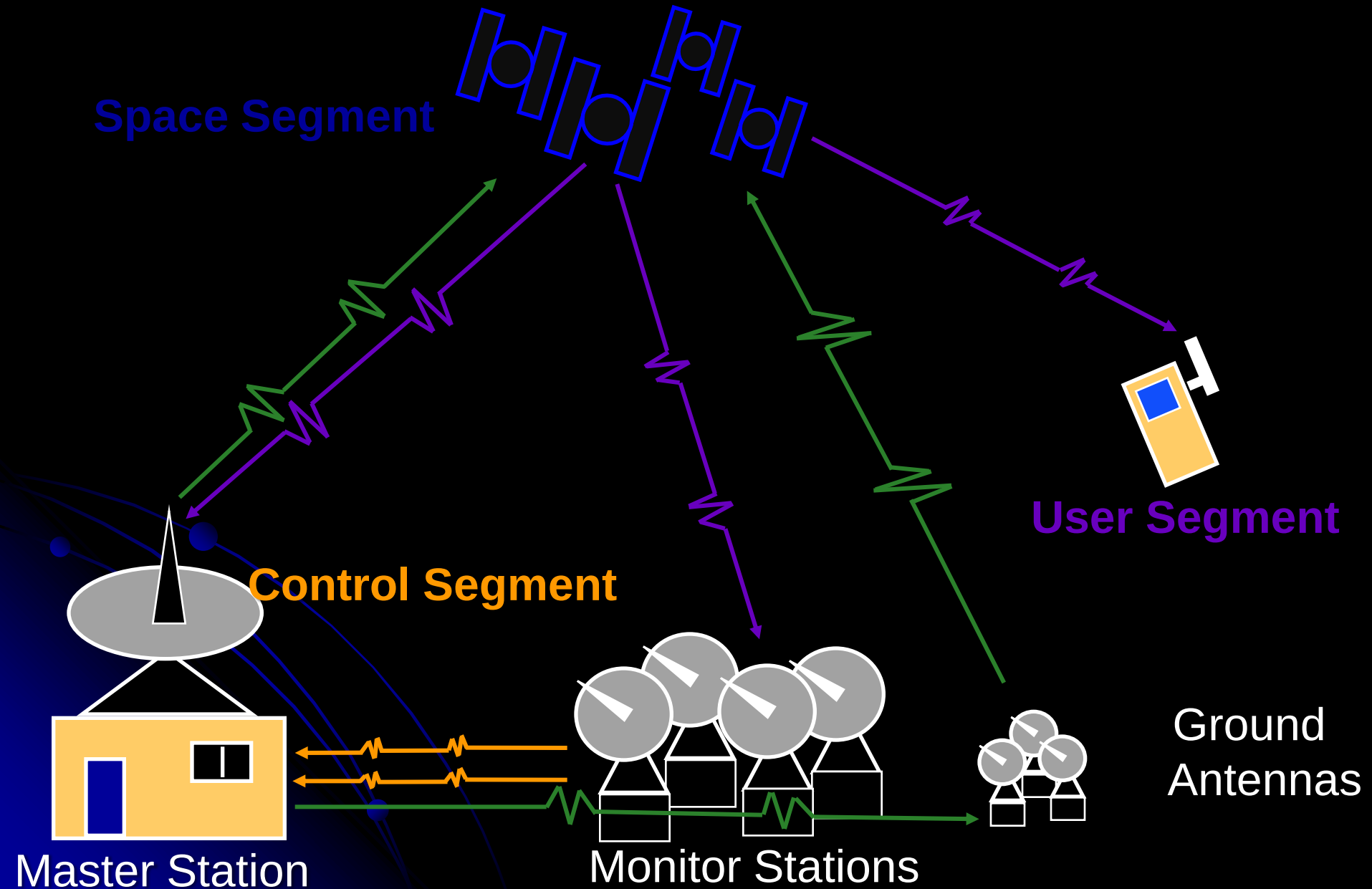
- ✓ **Location :** determining a basic position.
 - ✓ **Navigation:** getting from one location to another
 - ✓ **Tracking:** monitoring the movement of people
 - ✓ **Mapping:** creating maps of the world.
 - ✓ **Timing :** bringing precise timing to the world.
- 

GPS elements

There are 3 Segments to the GPS System:

- **Control Segment:** five ground stations located on earth.
- **Space Segment:** satellite constellation (24 active satellites in space).
- **User Segment:** GPS receiver units that receive satellite signals and determine receiver location from them.

Three Segments of the GPS

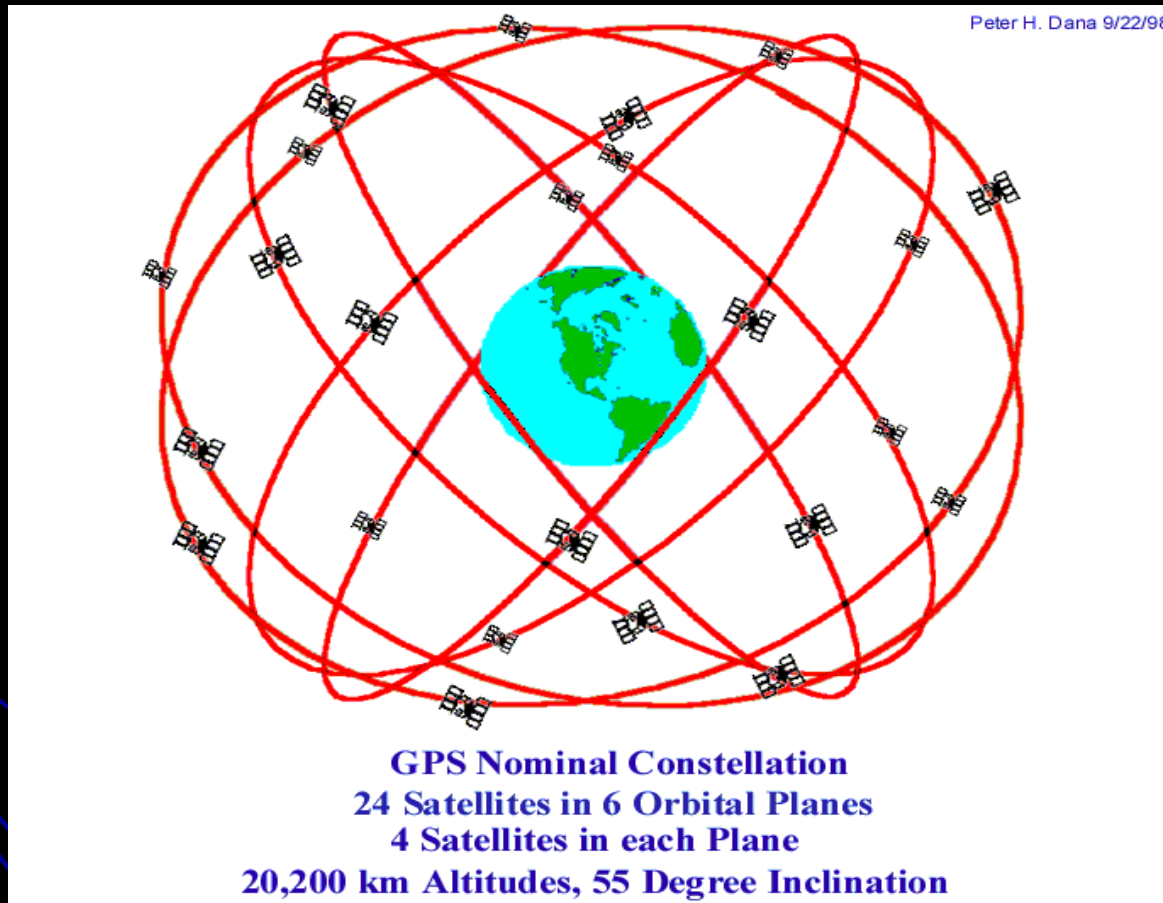


Space segment

- ✓ The nominal GPS Operational Constellation consists of 24 satellites that orbit the earth in 12 hours at approximately 20,200 km.
- ✓ There are six orbital planes (with nominally four satellites in each).
- ✓ Solar Powered and battery backup (in case of Solar Eclipse)



Space segment



Space segment (signal structure)

Each satellite transmits its own unique code

Two frequencies used

L1 Carrier 1575.42 MHz

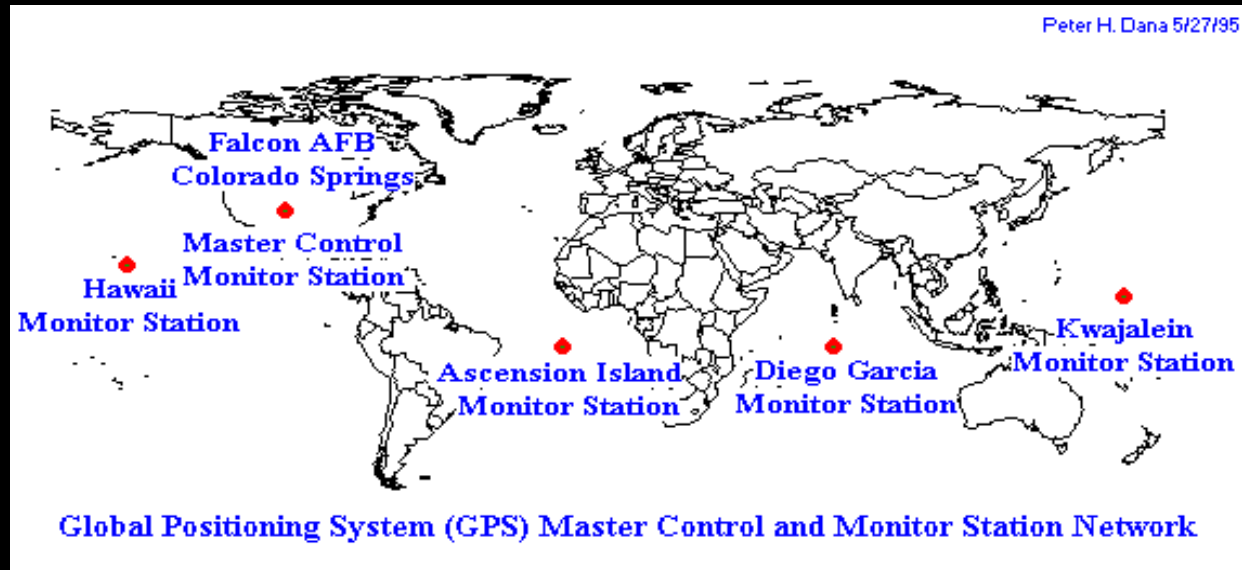
L2 Carrier 1227.60 MHz

Codes

CA (Coarse/Acquisition or Clear/Access) Code use
L1 (civilian code)

P (Y) Code use L1 & L2 (military code)

Control segment



There are 5 control stations that monitor the satellites.

Control stations enable information on Earth to be transmitted to the satellites.

Control stations continually track satellites, and update the positions of each satellite.

Without control stations the accuracy of the system would degrade in a matter of days.

Basic Functions of Monitor Stations

These stations are the eyes and ears of GPS, monitoring satellites as they pass overhead by measuring distances to them every 1.5 seconds

This data is then smoothed using ionospheric and meteorological information and sent to Master Control Station at Colorado Springs.

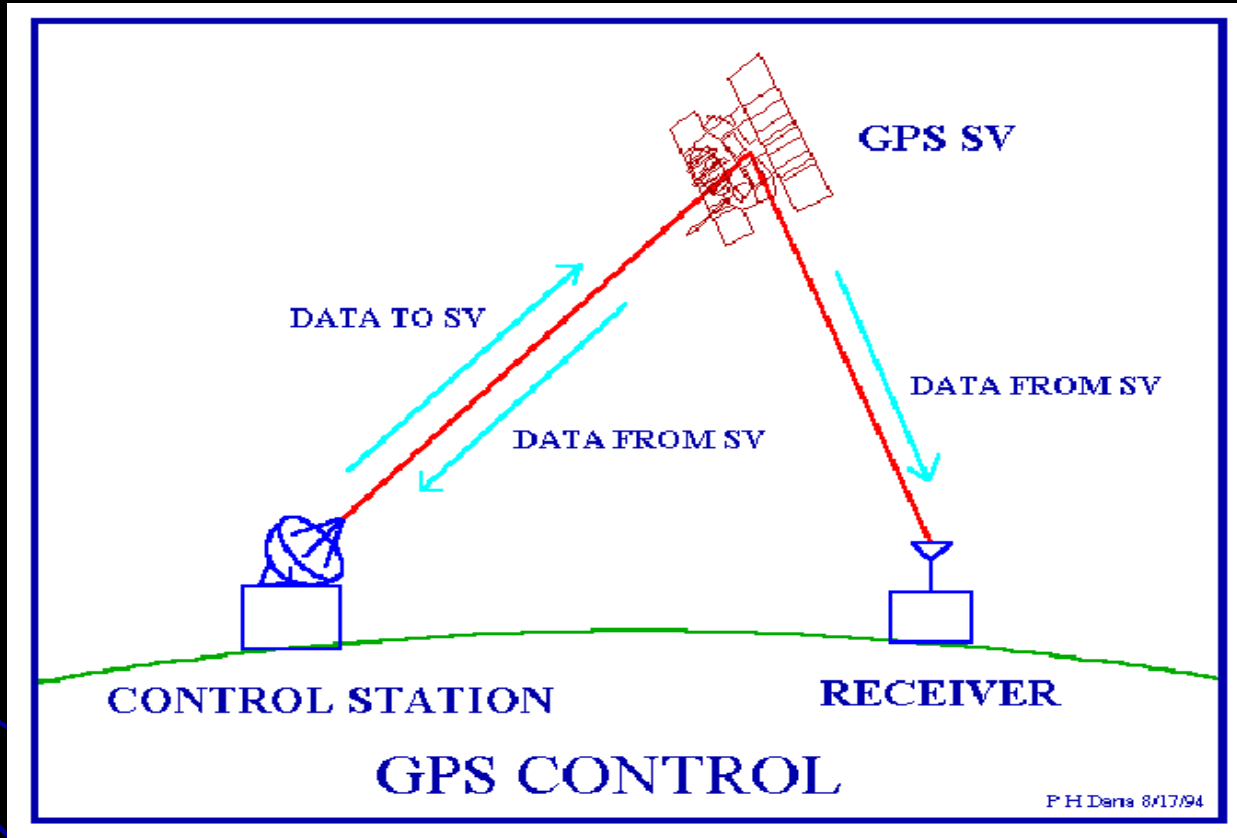
The ionospheric and meteorological data is needed to get more accurate delay measurements, which in turn improve location estimation.

Basic Functions of Monitor Stations

Master control station estimates parameters describing satellites' orbit and clock performance,. It also assesses health status of the satellites and determines if any re-positioning may be required.

This information is then returned to three uplink stations (collocated at the Ascension Island, Diego Garcia and Kwajalein monitor stations) which transmit the information to satellites.

Control segment



User segment

A GPS receiver will tell you the following

Distance traveled

Current speed (usable to over 900 MPH)

Average speed of travel

How long you've been traveling

Where you've been and how to retrace your path

Estimated time of arrival (ETA) when destination is known.

Keeps track of way points (imaginary markers)

GPS involves 5 Basic Steps

Trilateration

Intersection of spheres

Satellites Ranging

Determining distance from satellites

Timing

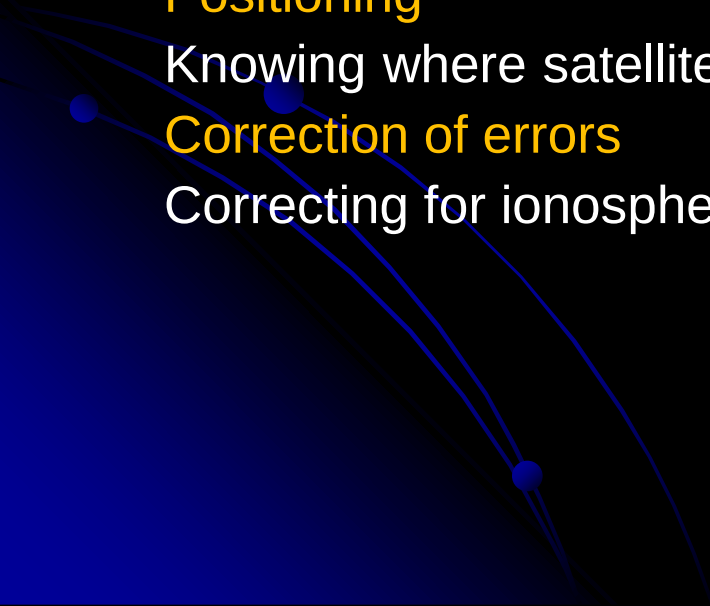
Why consistent, accurate clocks are required

Positioning

Knowing where satellites is in space

Correction of errors

Correcting for ionospheric and tropospheric delays



Measuring distance to satellite

At a particular time (let's say midnight), the satellite begins transmitting a long, digital pattern called a pseudo-random code (PRC).

The receiver begins running the same digital pattern also exactly at midnight.

- When the satellite's signal reaches the receiver, its transmission of the pattern will lag a bit behind the receiver's playing of the pattern.

Measuring distance to satellite

Distance to a satellite is determined by measuring how long a radio signal takes to reach us from that satellite.

To make the measurement we assume that both the satellite and our receiver are generating the same pseudo-random codes at exactly the same time.

By comparing how late the satellite's pseudo-random code appears compared to our receiver's code, we determine how long it took to reach us.

Multiply that travel time by the speed of light and you've got distance.

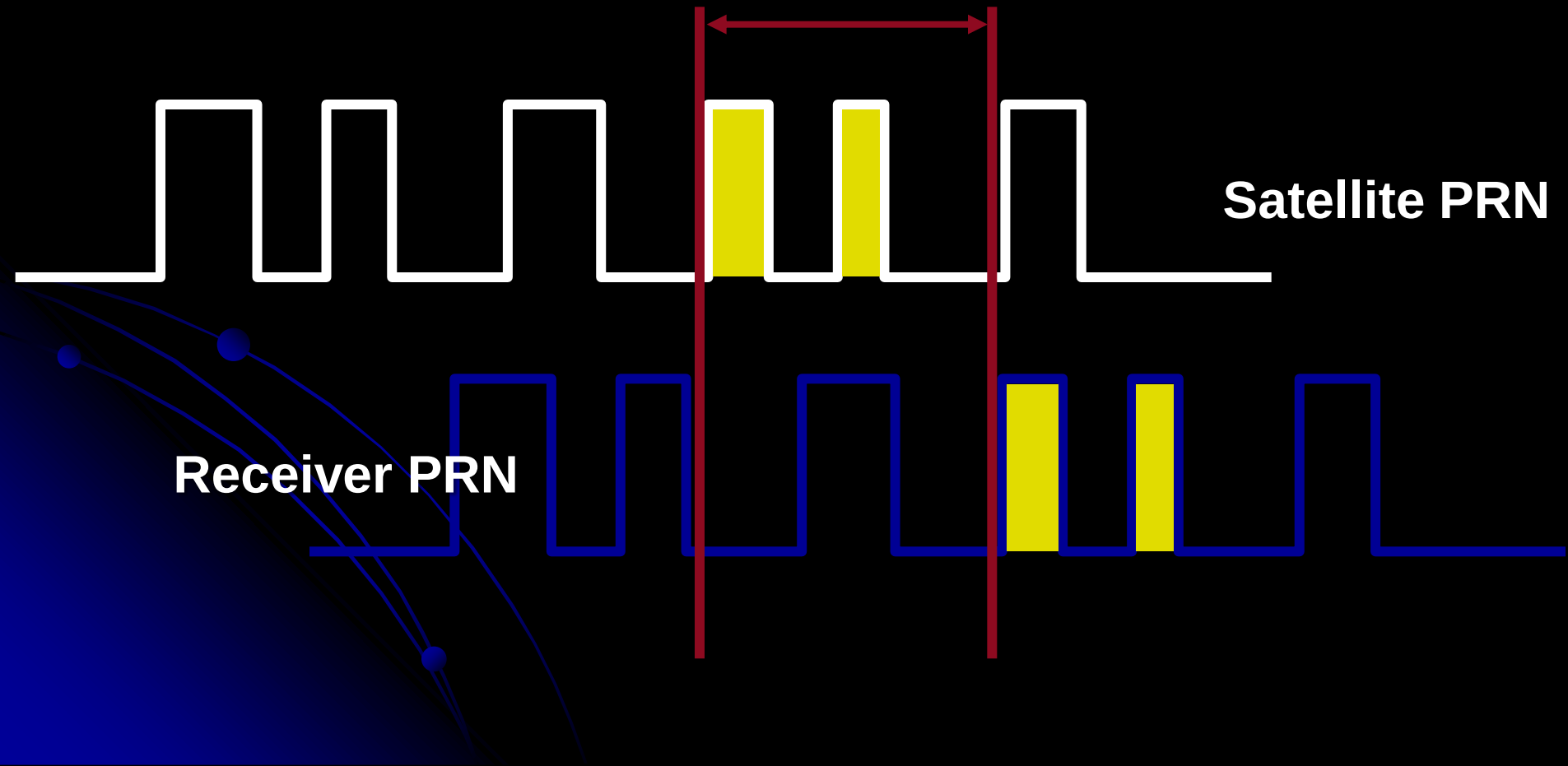
Pseudo Random Noise Code

range = time delay $\times$ speed of light

Time
Difference

Satellite PRN

Receiver PRN



Pseudo Random Noise Code

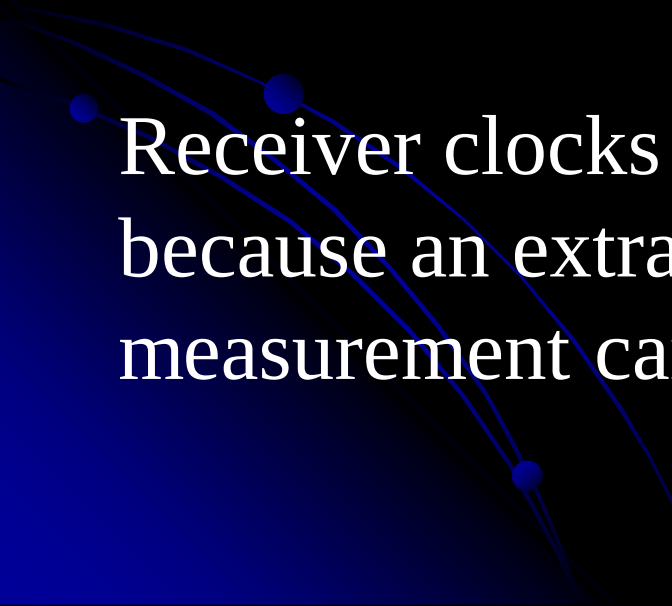
For example, here are the first 1000 numbers of the code
for satellite 1

```
00001000101001110000111001001000100001000101011000111101110010101101100111101011
00101100101001100111111011001111001001100110100011100010010001011000101101110000
00110110010001000101101000101001000000011111000110001011111011111100110111001011
01111000111111010100101000010101001110000110100111011000111101111100001111111111
01001001001001100111010101111100001000101101001111110000100110111100111000110110
10110110101000010110100101000101001000111001110001010010111010111010101000001011
01110011011001101000000000001110111011000110110101010110110001110001100110011111
01011111001110101010000011111100100101000000111010001111011010010110110000010010
01001100001101100001111011101110001101110110100111001000110101010000110110100101
1100101111111110110001110000001101110001100000010000000100000110101000101011110
11000111011010001100101011111001111010000000110111100110011101011110000011110110
01000100101011100000000100001010101001111101100111011011111100101111000100110101
```

Timing

Accurate timing is the key to measuring distance to satellites.

Satellites are accurate because they have four atomic clocks (\$100,000 each) on board.



Receiver clocks don't have to be too accurate because an extra satellite(4th) range measurement can remove errors.

Important Terminology

Satellite transmits Ephemeris and Almanac Data to GPS receivers.

Ephemeris data contains important information about status of satellite (healthy or unhealthy), current date and time. This part of signal is essential for determining a position.

- **Almanac data** tells GPS receiver where each GPS satellite should be at any time throughout day. Each satellite transmits almanac data showing orbital information for that satellite and for every other satellite in the system.

Location of satellites in the sky

Satellites are in relatively stable orbits and constantly monitored on the ground

All GPS receivers have an almanac programmed into their computers that tells them where in the sky each satellite is, moment by moment.

- Minor variations in their orbits are measured by the Department of Defense.

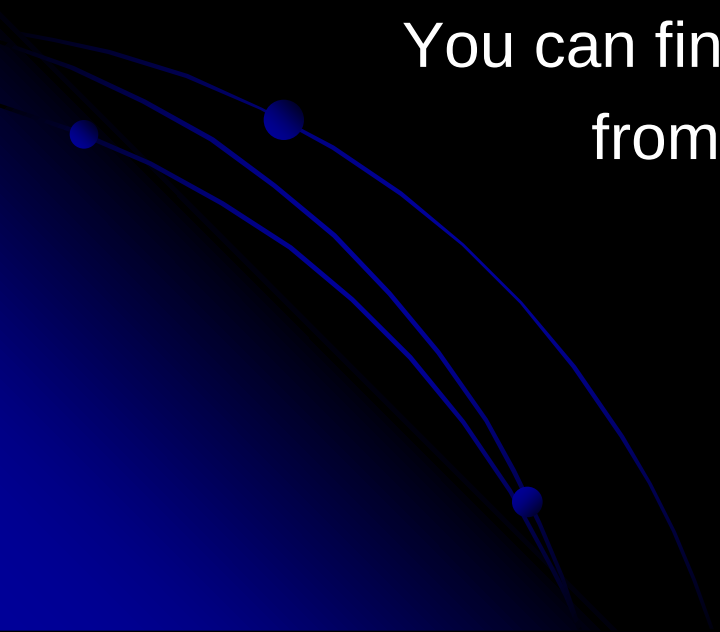
The error information is sent to the satellites, to be transmitted along with the timing signals.

How GPS works . Trilateration

How does the GPS know where you are?

GPS uses “Triangulation”

You can find any point if given distances
from 3 other points.



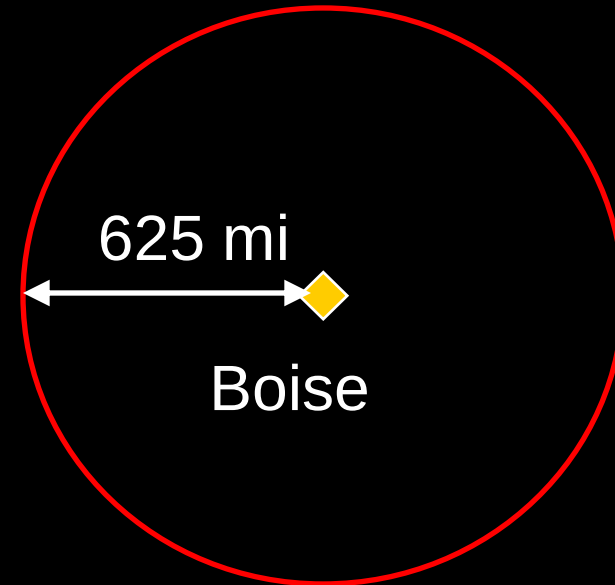
How GPS works . Trilateration

2-D Triangulation

Imagine you are somewhere in the United States and you are **TOTALLY** lost -- for whatever reason, you have absolutely no clue where you are.

You find a friendly local and ask, "Where am I?" He says, "You are 625 miles from Boise, Idaho."

This is a nice, hard fact, but it is not particularly useful by itself. You could be anywhere on a circle around Boise that has a radius of 625 miles, like shown here.



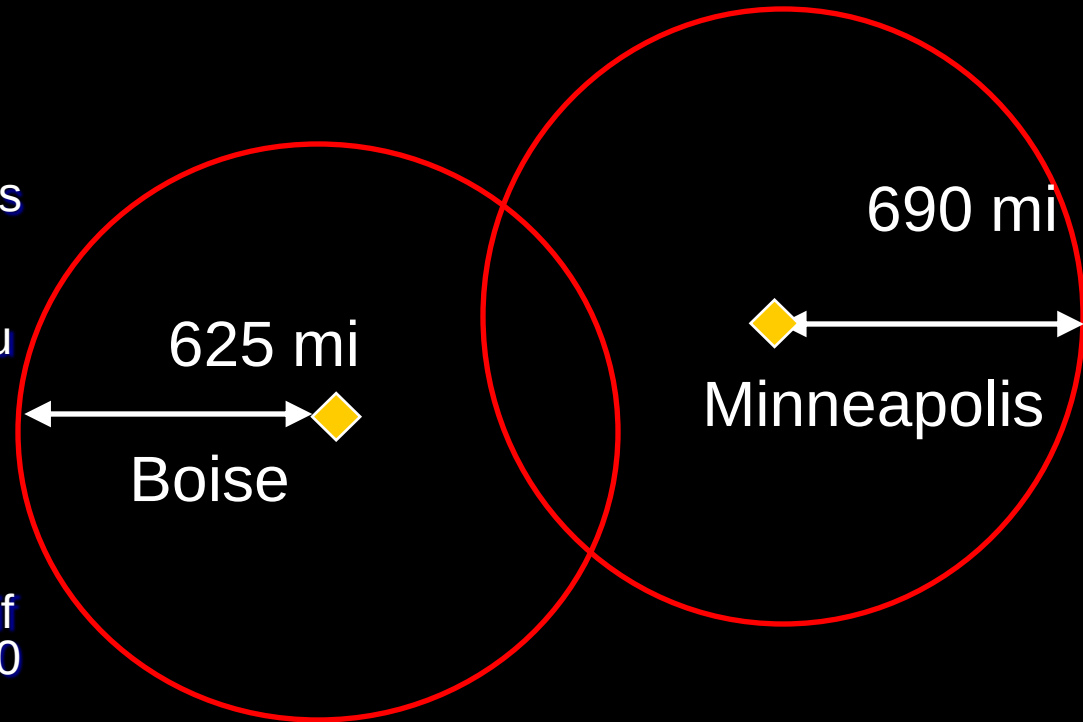
How GPS works . Trilateration

2-D Triangulation

You ask somebody else where you are, and she says, "You are 690 miles from Minneapolis, Minnesota."

Now you're getting somewhere. If you combine this information with the Boise information, you have two circles that intersect.

You now know that you must be at one of these two intersection points, if you are 625 miles from Boise and 690 miles from Minneapolis.

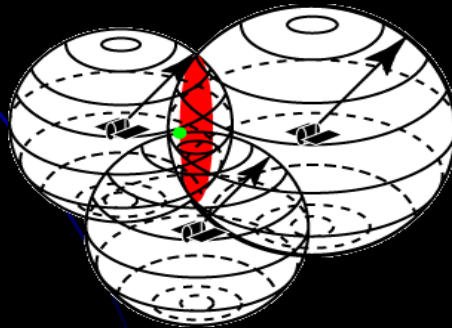
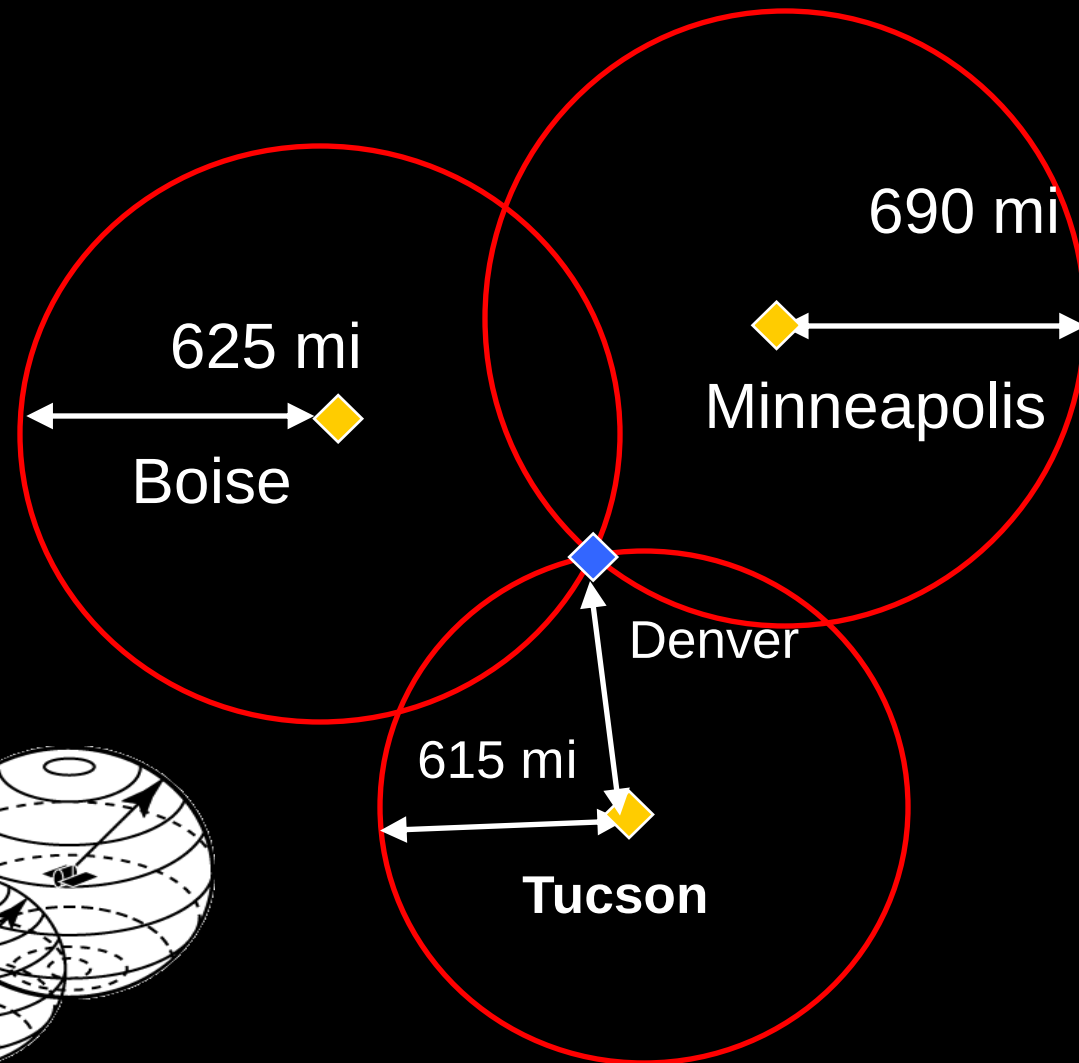


How GPS works . Trilateration

2-D Triangulation

If a third person tells you that you are 615 miles from Tucson, Arizona, you can eliminate one of the possibilities, because the third circle will only intersect with one of these points.

You now know exactly where you are in --Denver, Colorado. In 3-D Trilateration spheres are used instead of circles

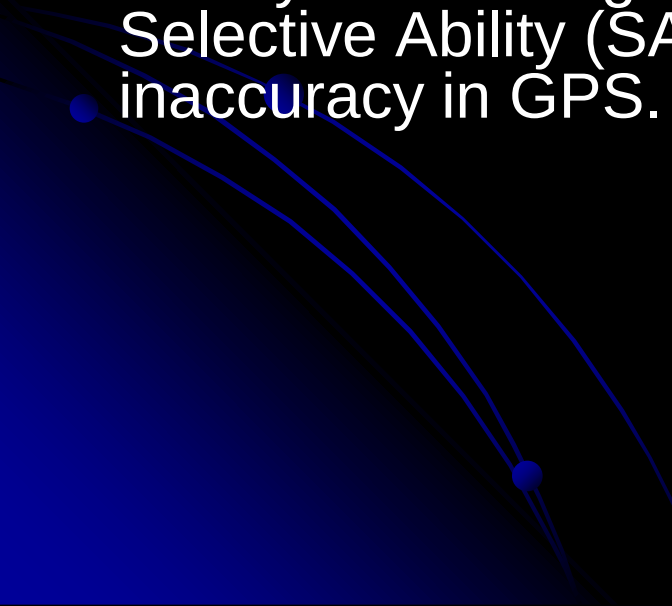


Types of errors

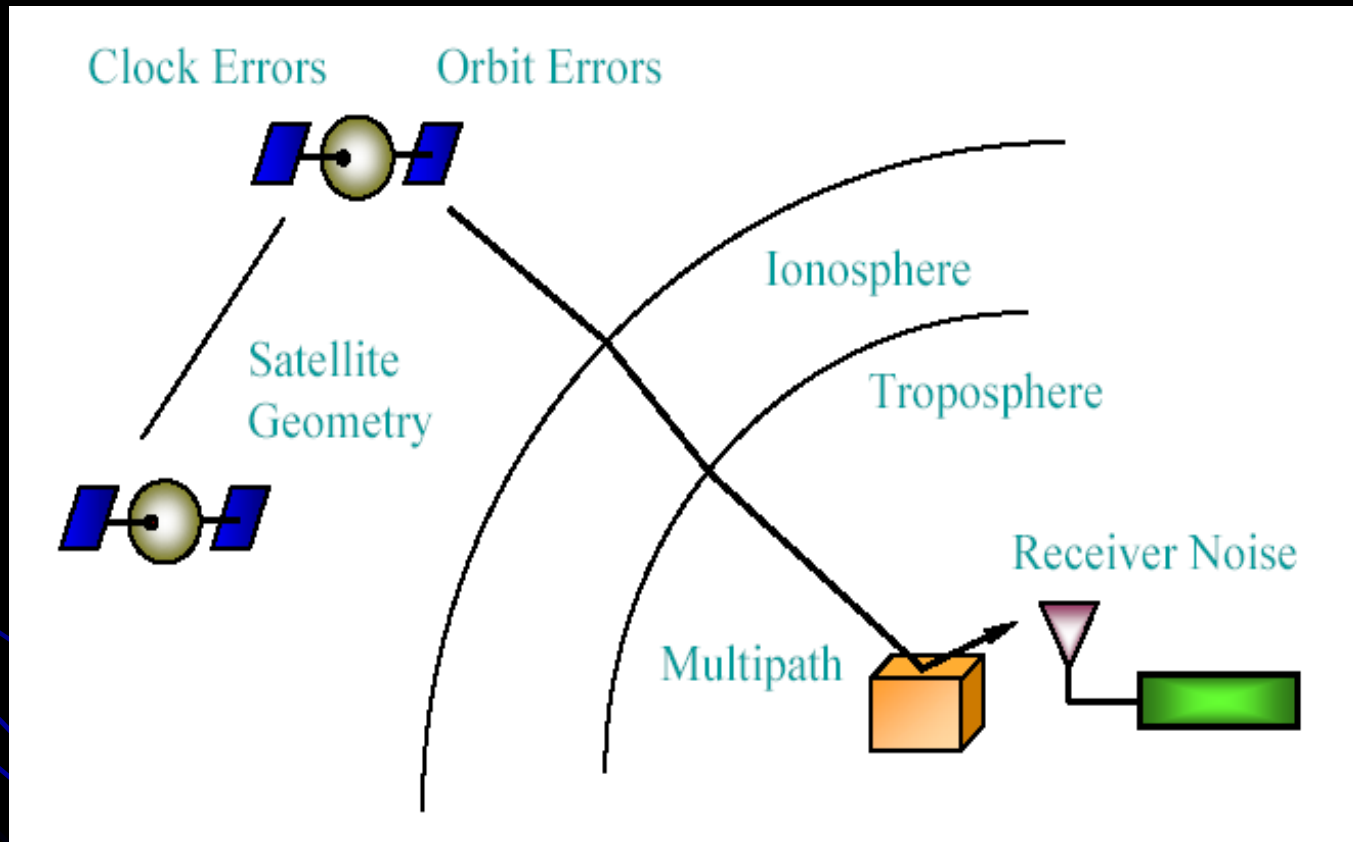
Errors can be categorized as intentional and unintentional.

Intentional errors: government can and does degrade accuracy of GPS measurements. This is done to prevent hostile forces from using GPS to full accuracy.

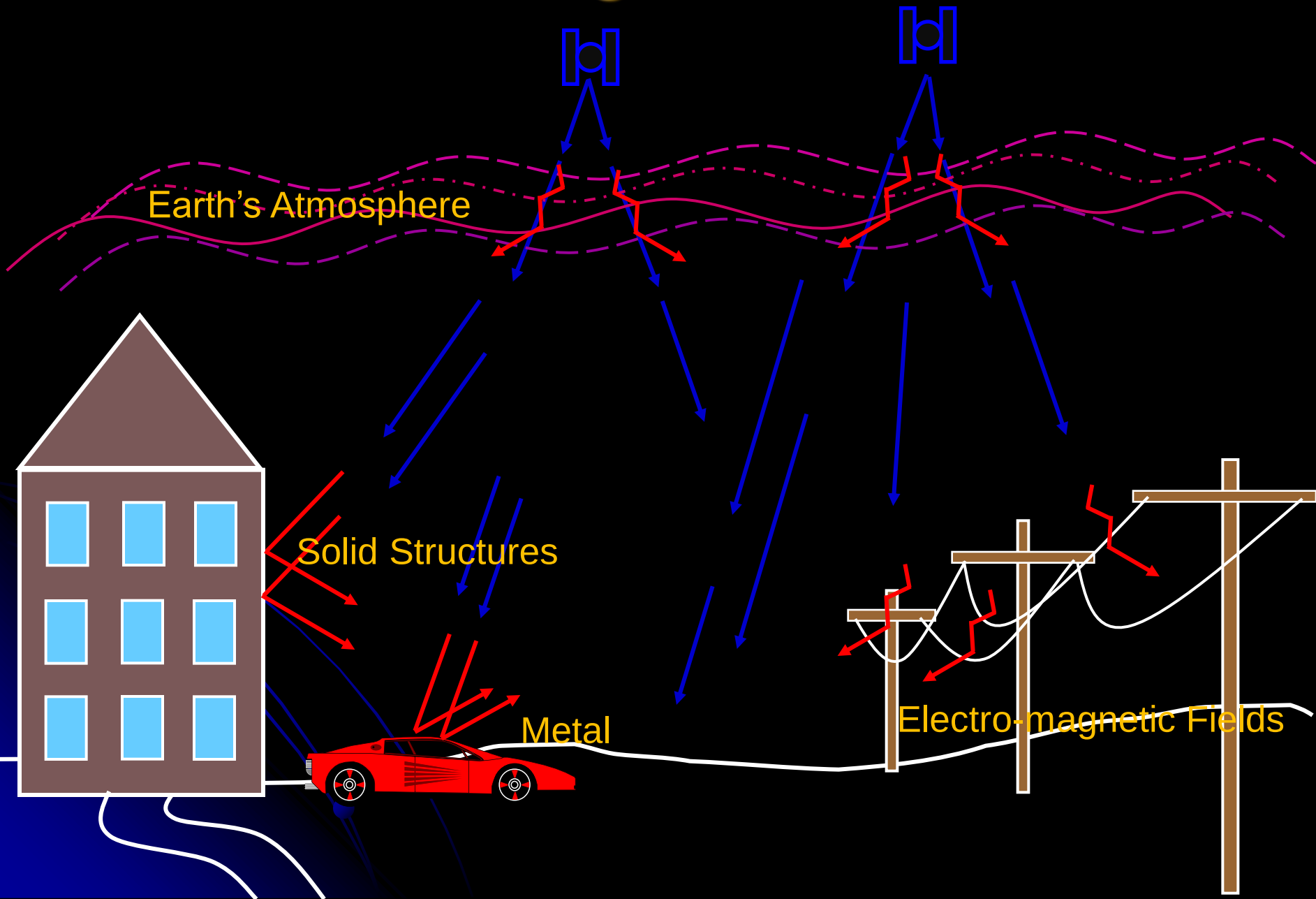
Policy of inserting inaccuracies in GPS signals is called Selective Ability (SA). SA was single biggest source of inaccuracy in GPS. SA was deactivated in 2000.



Sources of Unintentional Timing Errors



Sources of Signal Interference



Typical Errors

Typical Error in Meters (per satellite)	Source of Error
1.5	Satellite Clocks
2.5	Orbit Errors
5.0	Ionosphere
0.5	Troposphere
0.3	Receiver Noise
0.6	Multipath
30	SA

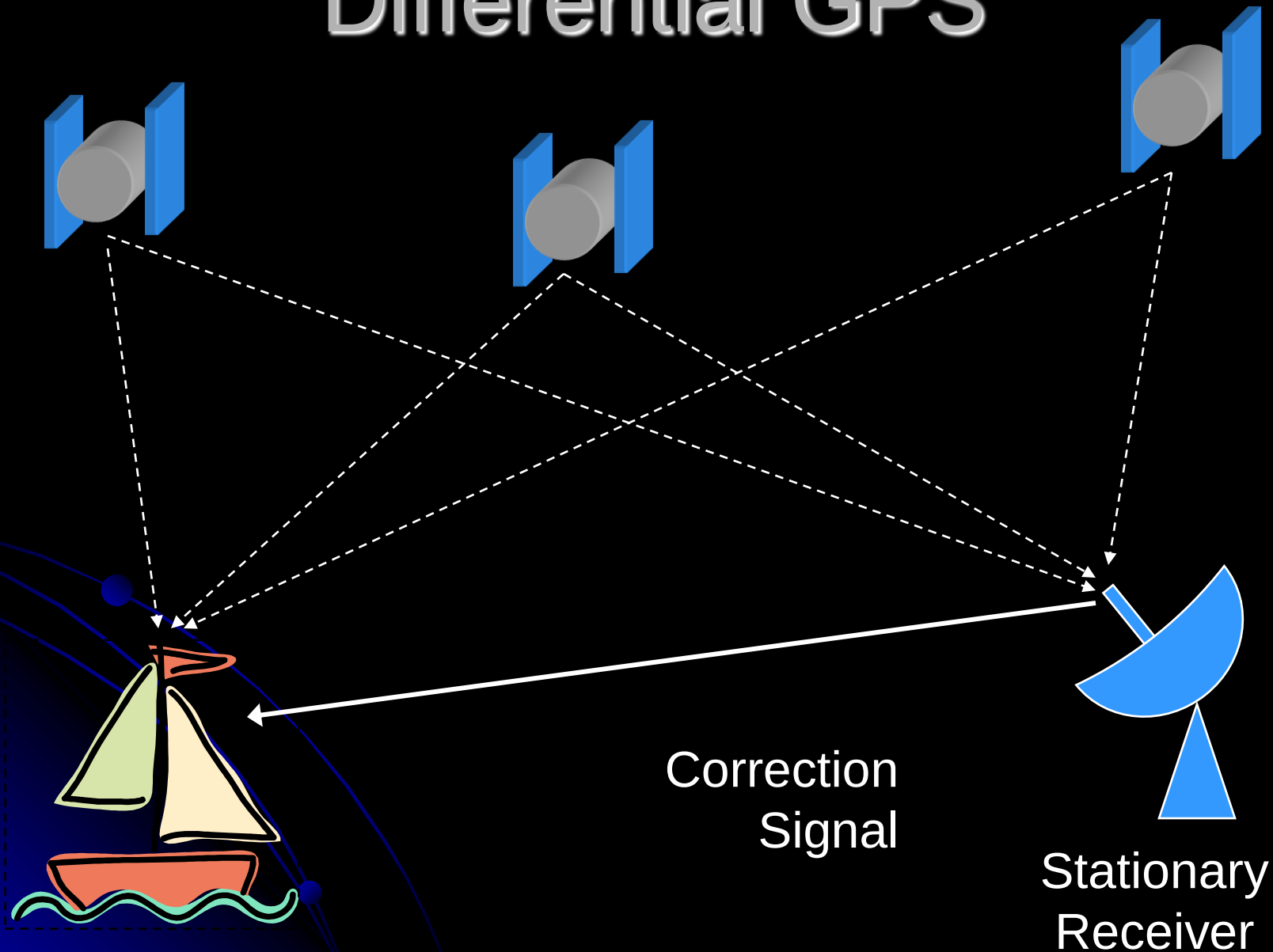
Differential GPS

Technique called **differential correction** can yield accuracies within 1-5 meters, or even better, with advanced equipment.

Differential correction requires a second GPS receiver, a base station, collecting data at a stationary position on a precisely known point.

- Because physical location of base station is known, a correction factor can be computed by comparing known location with GPS location determined by using satellites.

Differential GPS



Differential GPS Methods

Post-processing

Corrections performed after the data is collected
Special software required.

Real-time

Corrections are performed while the data is being collected

Need special equipment to receive the DGPS signal

Improved Offered by Differential GPS

With Differential	Uncorrected	Source
Mostly Removed	0-30 meters	Ionosphere
All Removed	0-30 meters	Troposphere
All Removed	0-10 meters	Signal Noise
All Removed	1-5 meters	Orbit Data
All Removed	0-1.5 meters	Clock Drift
Not Removed	0-1 meters	Multipath
Not Removed	~1 meter	Receiver Noise
All Removed	0-70 meters	SA

Dilution of Precision (DOP)

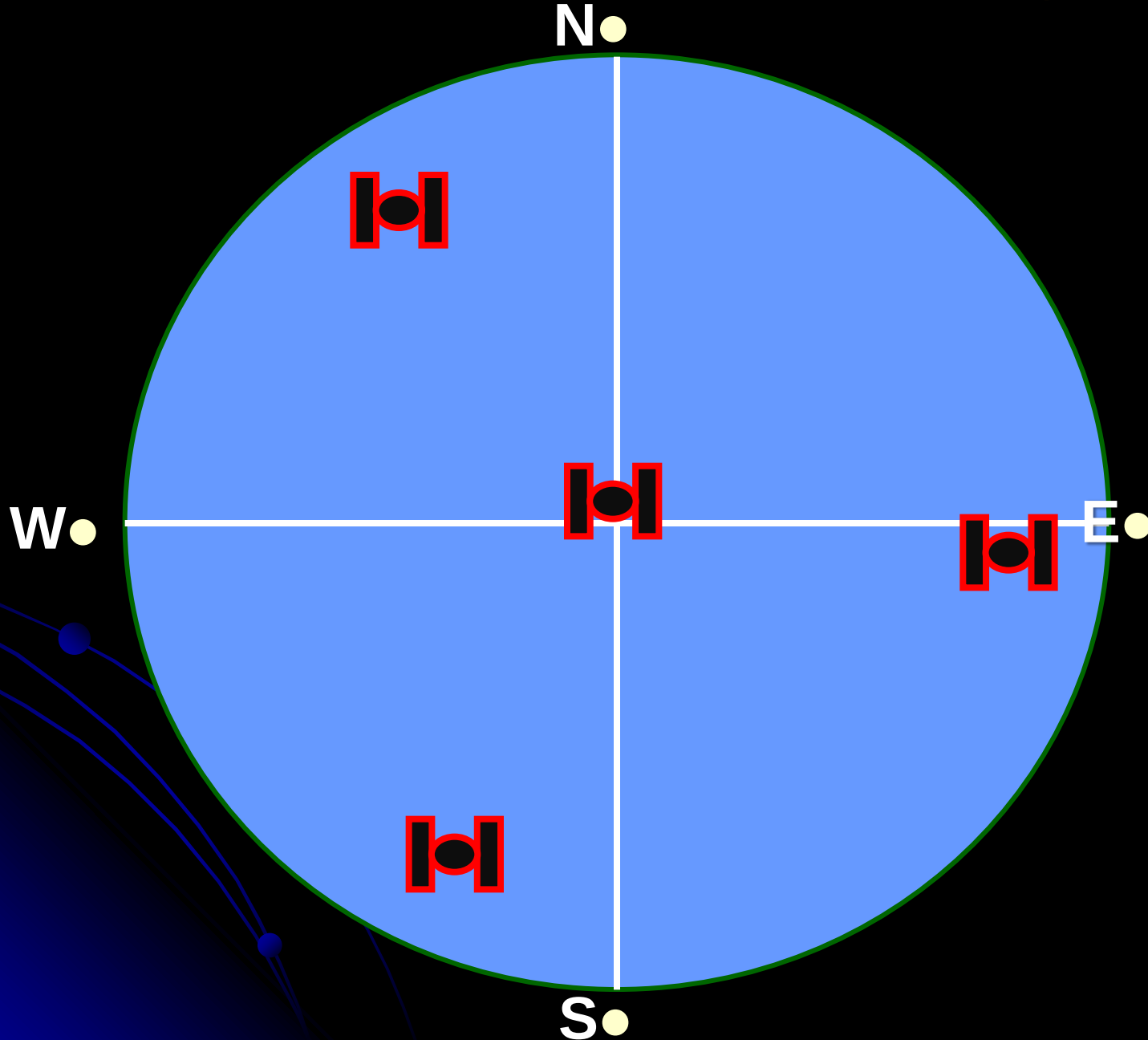
It's usually up to the GPS receiver to pick satellites which provide the best position triangulation.

More advanced GPS receivers can filter out poor DOP values.

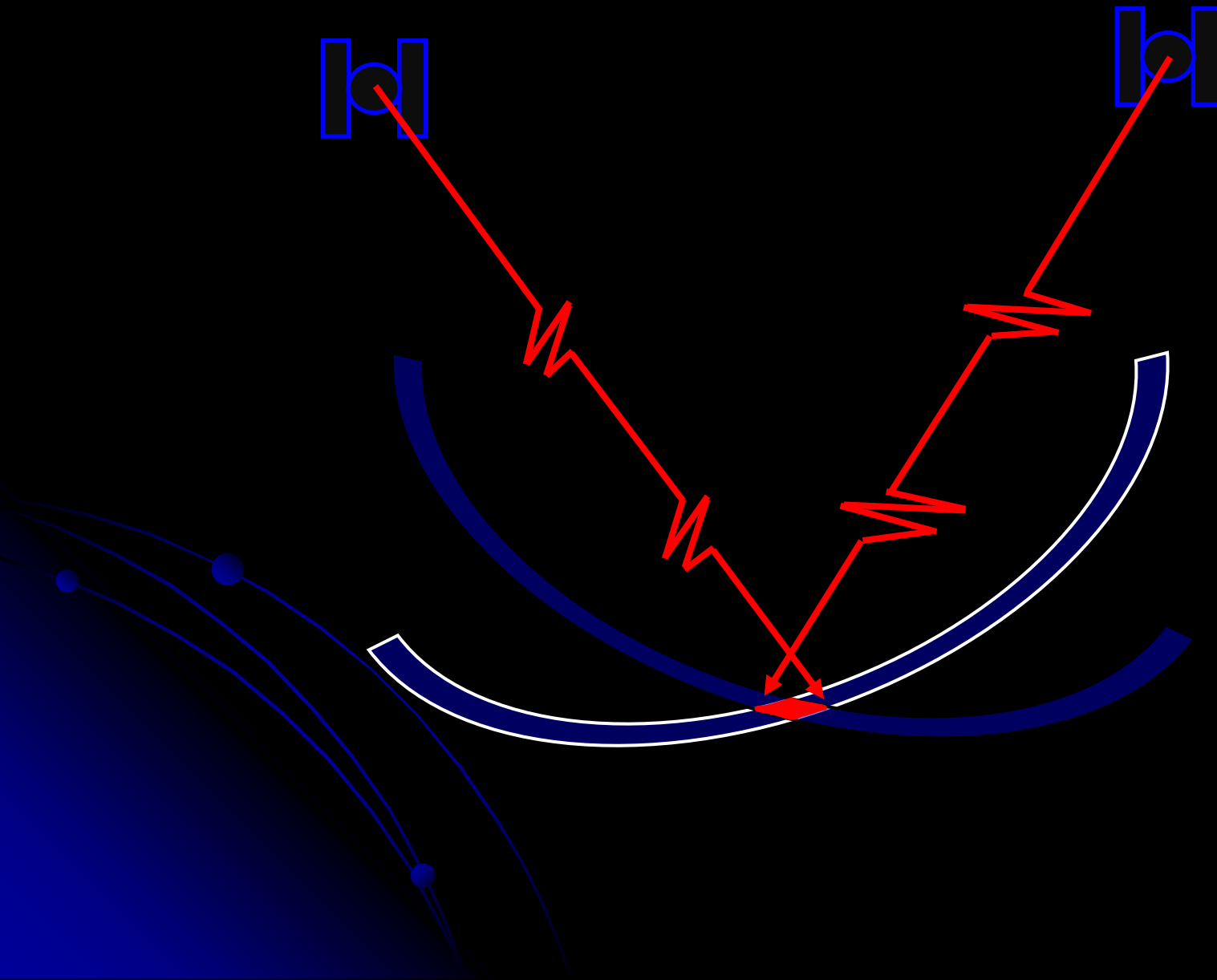
The more spread out the satellites are in the sky, the better the satellite geometry

The lower the PDOP (position dilution of precision) value, the better the geometric strength

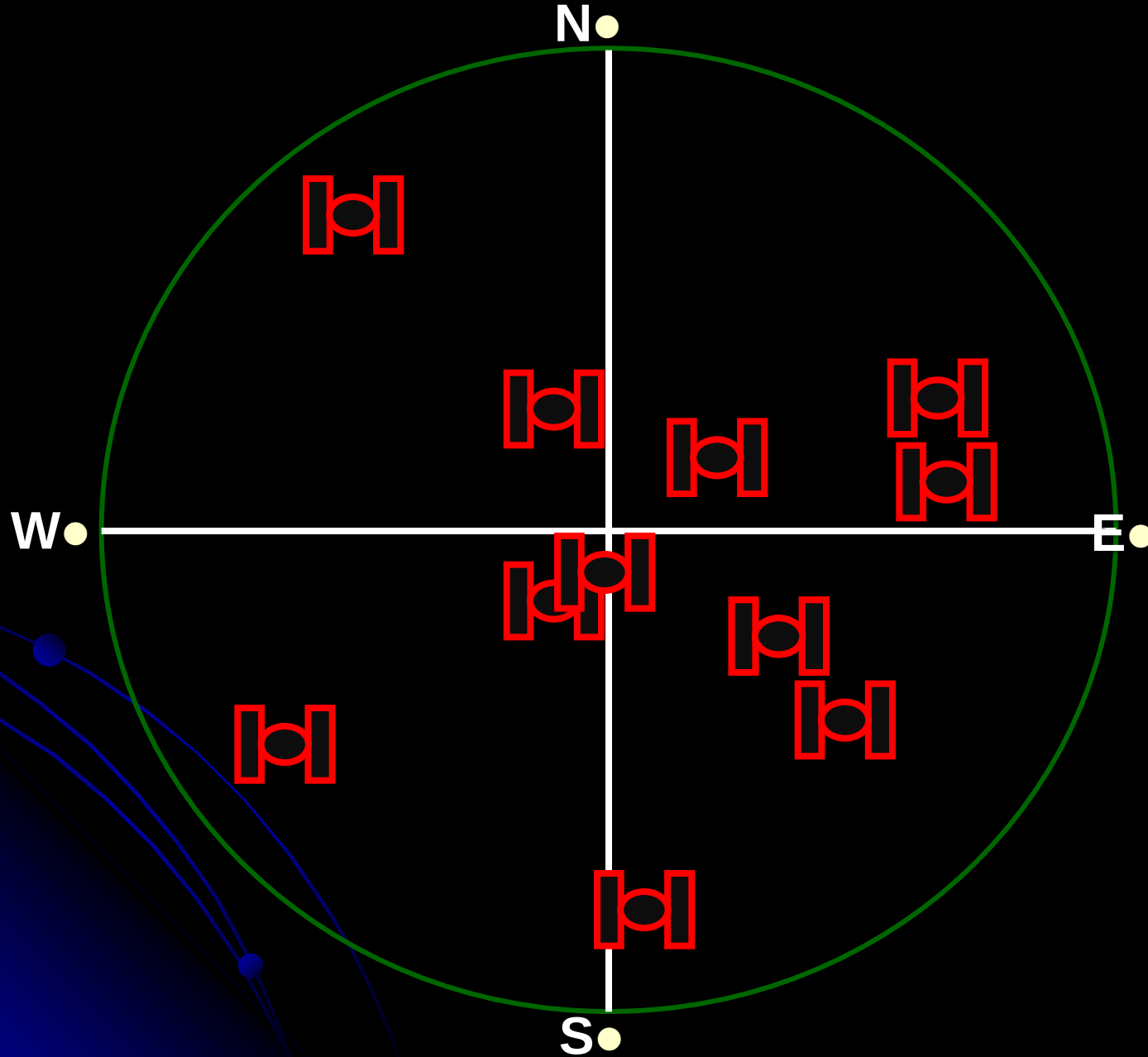
Ideal Satellite Geometry



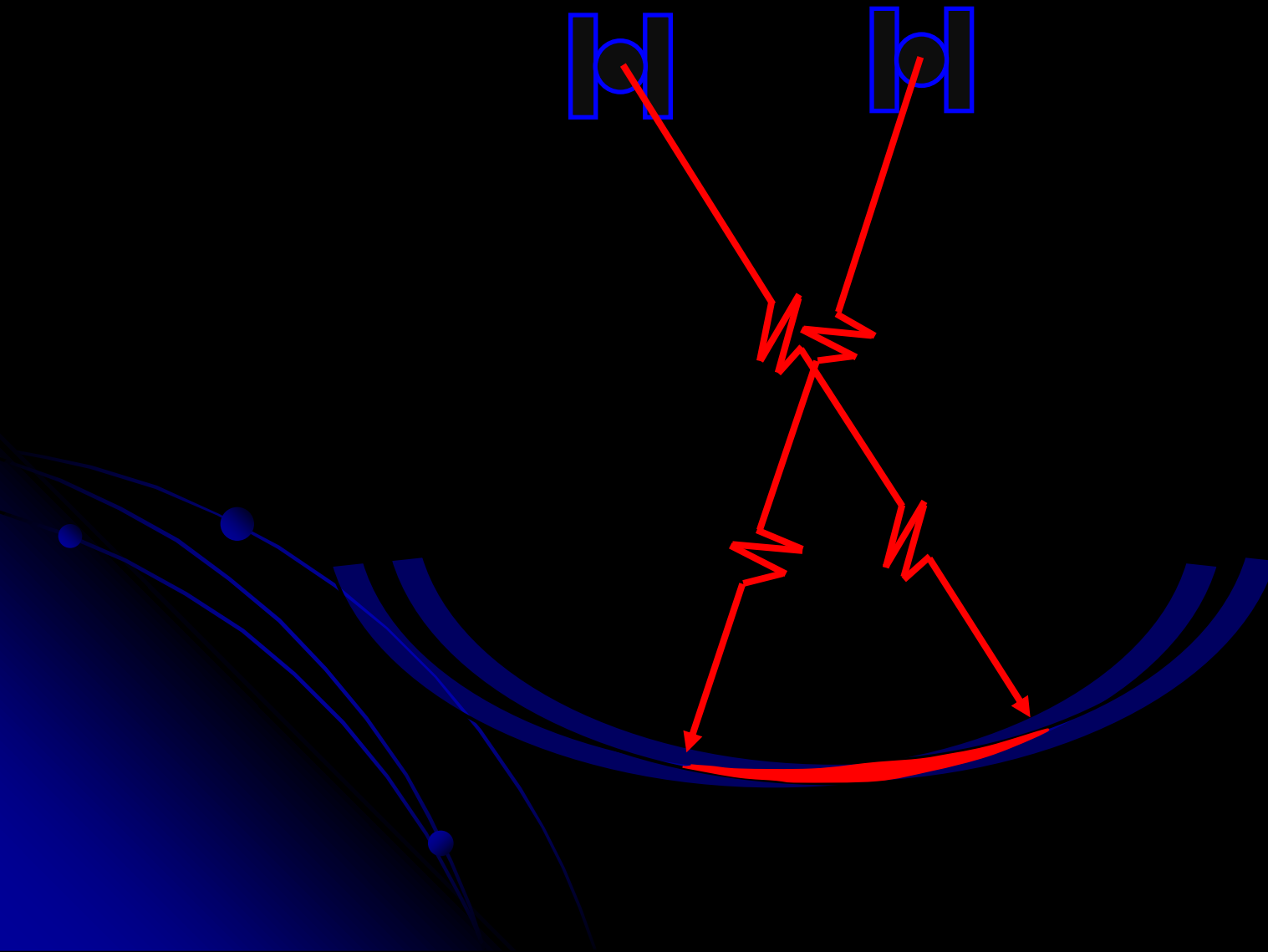
Good Satellite Geometry



Poor Satellite Geometry



Poor Satellite Geometry



Thanks for your kind attention

