Earth Science Applications of Space Based Geodesy

DES-7355

Tu-Th 9:40-11:05

Seminar Room in 3892 Central Ave. (Long building)

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Office Hours – Wed 14:00-16:00 or if I'm in my office.

http://www.ceri.memphis.edu/people/smalley/ESCI7355/ESCI_7355_Applications_of_Space_Based_Geodesy.html

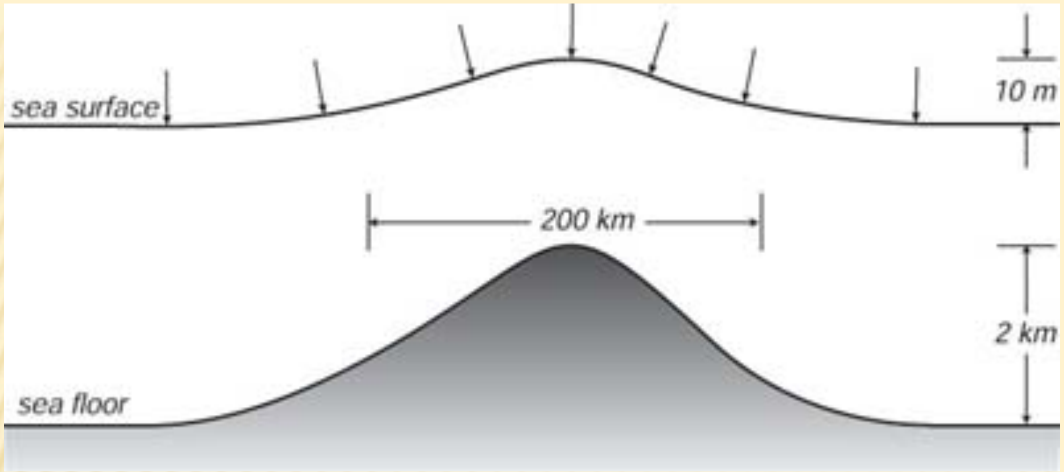
Class 4

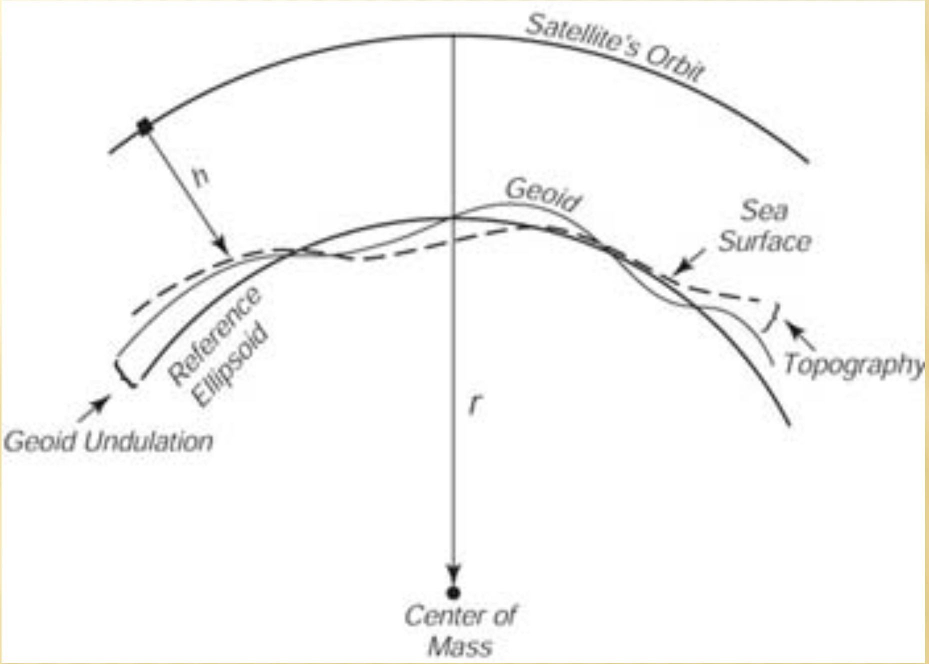
Go over homework

Go over big picture of homework

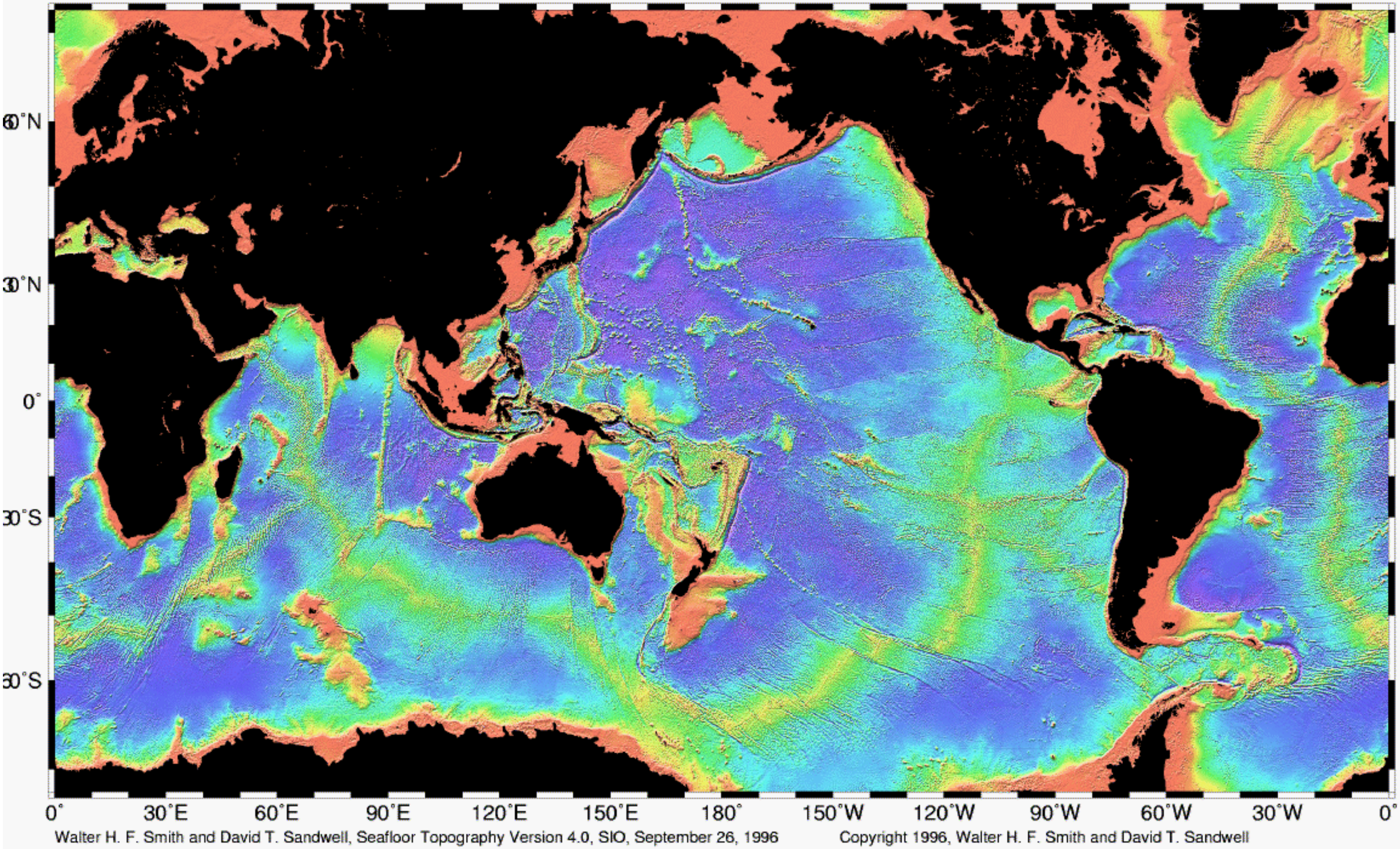
GPS stuff

Correlation (important for GPS) and Convolution (important for calculating correlation)



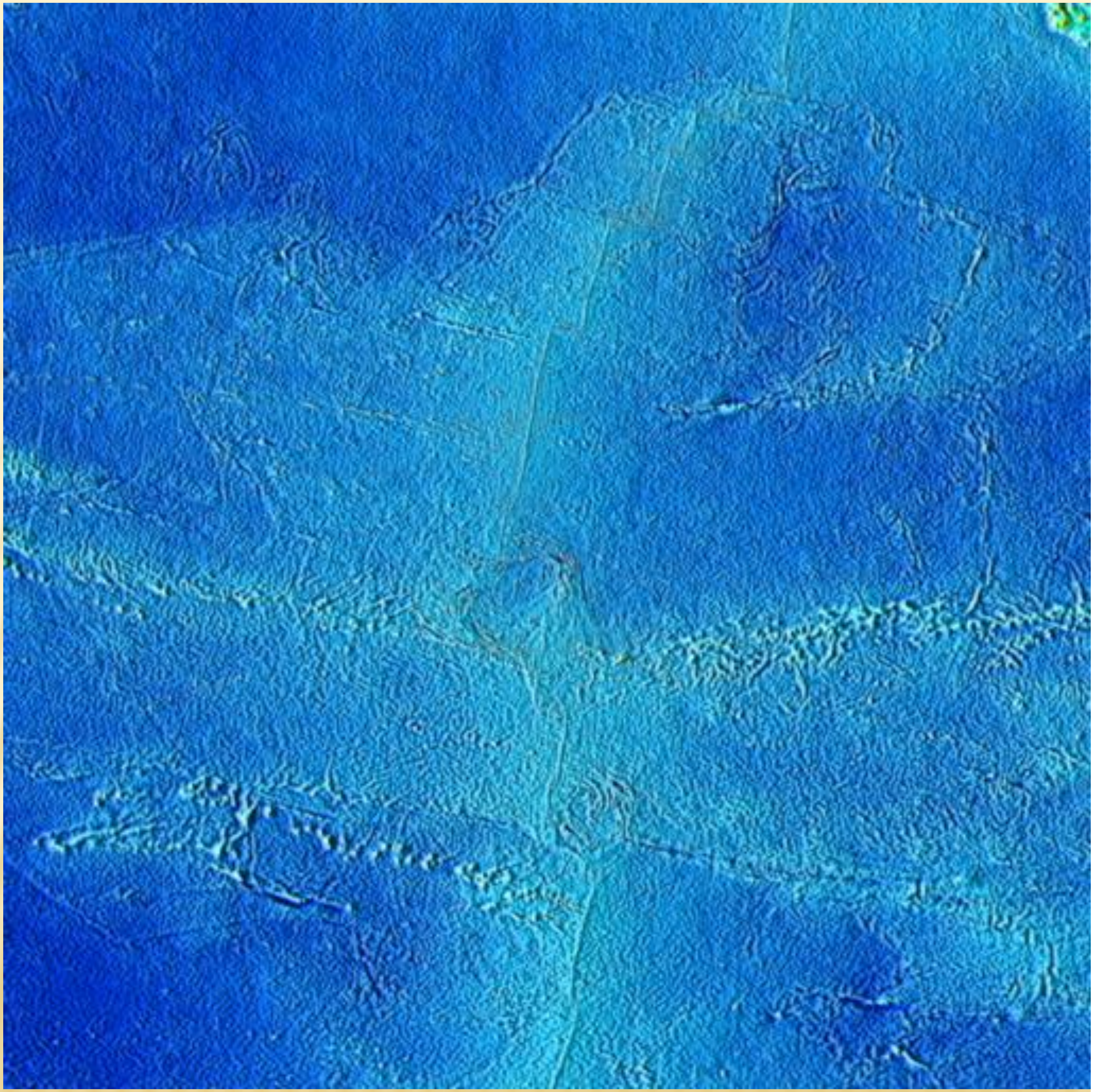


http://oceanworld.tamu.edu/resources/ocng_textbook/chapter03/chapter03_04.htm

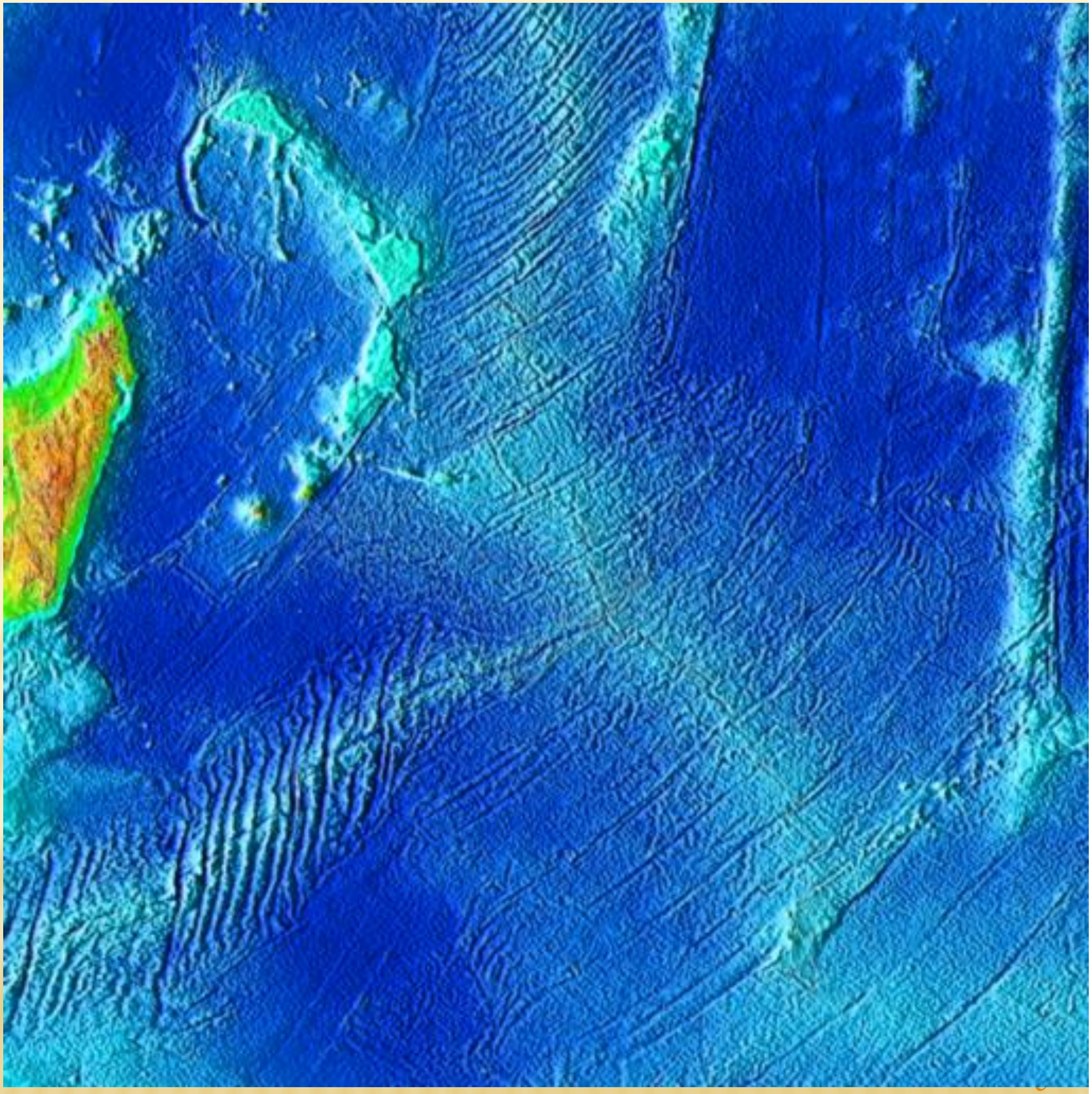


<u>Predicted</u> or <u>Estimated</u> topography from gravity (gravity is not topography, but they are related with some simple assumptions). Have to worry about things like isostatic compensation (EPR – fast spreading, hot and soft, is nearly isostatically compensated, so NO gravity signal – notice it is "fuzzy"). Can see dense structures (seamounts) completely buried in sediment! A 2000 m tall, 20 km diameter undersea volcano will produce a bump 2 m high and perhaps 40 km across (not visible to the naked eye!) Large scale, poorly understood density variations in the earth's crust, lithosphere and upper mantle cause 100 m undulations in the sea surface from the ellipsoid.

East Pacific Rise (EPR). Fast spreading ridge - hot. Topography isostatically compensated so "fuzzy", since "predicted" topography comes from gravity anomaly signal (gravity is NOT topography).



Indian Ocean. Lithosphere supports topography elastically rather than isostatically. Get gravity signal due to departure from isostacy.



In 1997, U.S. Secretary of Transportation Federico Pena stated, "Most people don't know what GPS is. Five years from now, Americans won't know how we lived without it." Today, Global Positioning System in included as part of in-vehicle navigation systems and cellular phones. It's taken a few more than five years but I know the rate of Global Positioning System use will continue to explode.

step 1: using satellite ranging

MULTI-SATELLITE RANGING

GPS is time of flight (range) system

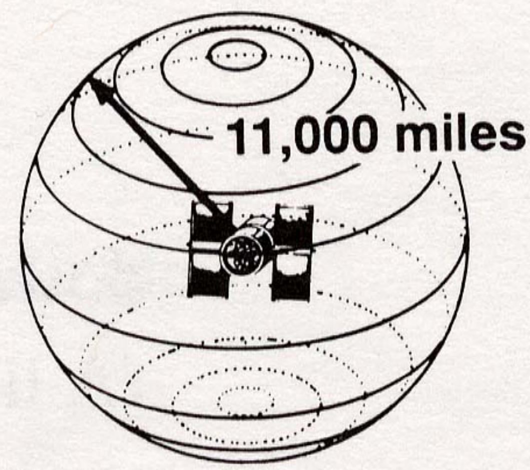
(like locating earthquakes with P waves only)

step 1: using satellite ranging

GPS is based on satellite ranging, i.e. distance from satellites
...satellites are precise reference points
...we determine our distance from them

we will assume for now we know exactly where satellite is and how far away from it we are...

if we are lost and we know
that we are 11,000 miles
from satellite A...
we are somewhere on a sphere
whose middle is satellite A
and diameter is 11,000 miles



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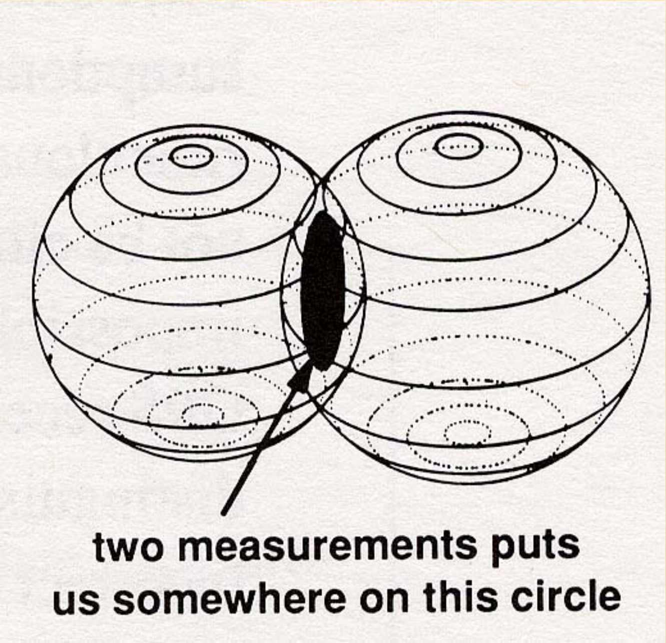
step 1: using satellite ranging

if we also know that we are
12,000 miles from satellite B
...we can narrow down where
we must be...
only place in universe is on
circle where two spheres intersect



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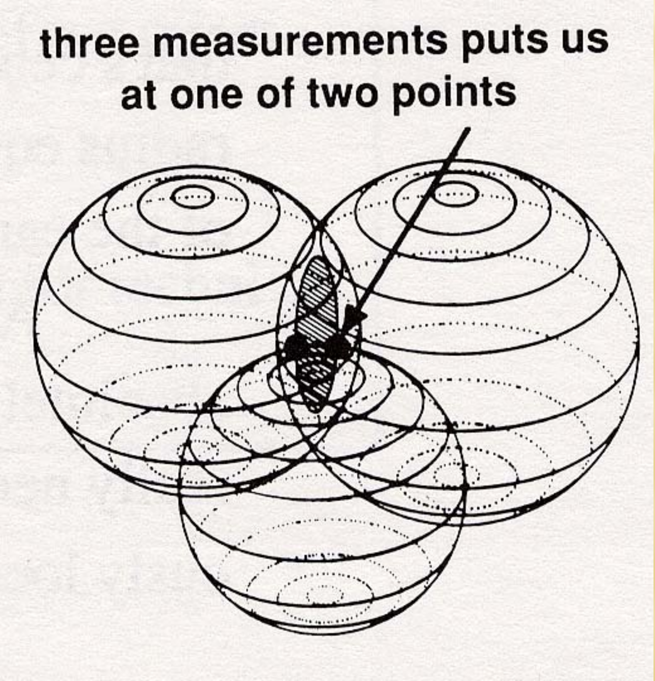
step 1: using satellite ranging

if we also know that we are
13,000 miles from satellite C
...our situation improves
immensely...
only place in universe is at
either of two points where
three spheres intersect



Which point is determined by "sanity" –

1 point obviously wrong.

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step 1: using satellite ranging

three can be enough to determine position…
one of the two points generally is not possible
(far off in space)

two can be enough if you know your elevation
…why?

one of the spheres can be replaced with Earth…
…center of Earth is "satellite position"

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step 1: using satellite ranging

generally four are necessary

....why this is a little later

And more is better

this is basic principle behind GPS...

...using satellites for trilaturation

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step 2: measuring distance from satellite

because GPS based on knowing distance from satellite

…we need to have a method for determing how far away the satellites are

use velocity x time = distance

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step 2: measuring distance from satellite

GPS system works by timing how long it takes a radio signal
to reach the receiver from a satellite…

…distance is calculated from that time…

radio waves travel at speed of light: 300×10^6 m/second

problem: need to know when GPS satellite started sending its radio message

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requires very good clocks that measure short times…
…electromagnetic waves move very quickly

step 3: getting perfect timing

use atomic clocks

step 3: getting perfect timing

atomic clocks

came into being during World War II

-physicists wanted to test Einstein's ideas about gravity and time

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step 3: getting perfect timing

atomic clocks

- previous clocks relied on pendulums

- early atomic clocks looked at vibrations of quartz crystal

...keep time to < 1/1000th second per day

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step 3: getting perfect timing

atomic clocks

- early atomic clocks looked at vibrations of quartz crystal

...keep time to < 1/1000th second per day

..not accurate enough to assess affect of gravity on time

...Einstein predicted that clock on Mt. Everest would run 30 millionths of a second faster than clock at sea level

...needed to look at oscillations of atoms

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step 3: getting perfect timing

atomic clocks

principle behind atomic clocks…

atoms absorb or emit electomagnetic energy in discrete amounts

corresponding to differences in energy between different configurations of the atoms

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step 3: getting perfect timing

atomic clocks

principle behind atomic clocks…

when atom goes from a higher energy state to lower one, it can emits an electromagnetic wave of characteristic frequency

…known as "resonant frequency"

these resonant frequencies are identical for every atom of a given type:

ex. - cesium 133 atoms: 9,192,631,770 hz

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step 3: getting perfect timing

atomic clocks

principle behind atomic clocks...

cesium can be used to create an extraordinarily precise clock

(can also use hydrogen and rubidium)

GPS satellite clocks are cesium and rubidium clocks

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step 3: getting perfect timing

electromagnetic energy travels at 300 x 10^6 m/second
...an error of 1/100th second leads to error of 3000 km.

how do we know that receiver and satellite are on same time?

satellites have atomic clocks (4 of them for redundancy)

...at $100,000 apiece, they are not in receivers!

receivers have "ordinary" clocks
(otherwise receivers would cost > $100K)

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step 3: getting perfect timing

…can get around this by having an "extra" measurement

…hence 4 satellites are necessary

three perfect time measurements will lead to unique, correct solution [(x,y,z) or (lat, lon, elevation)]

….four imperfect time measurements also will lead to correct solution [(x,y,z,δt) or (lat, lon, elevation,δt)]

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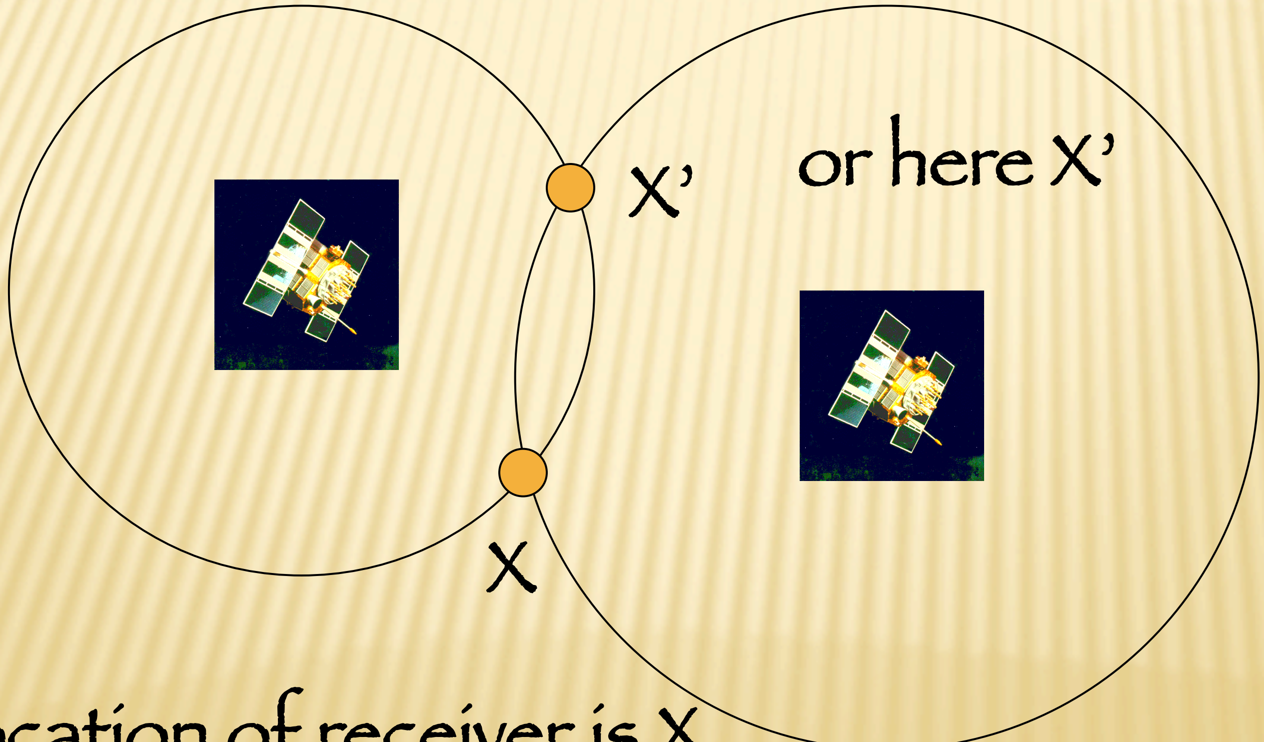
illustrate this in 2D…

instead of referring to satellite range in distance,
…we will use time units

two satellites: first at distance of 4 seconds
second at distance of 6 seconds

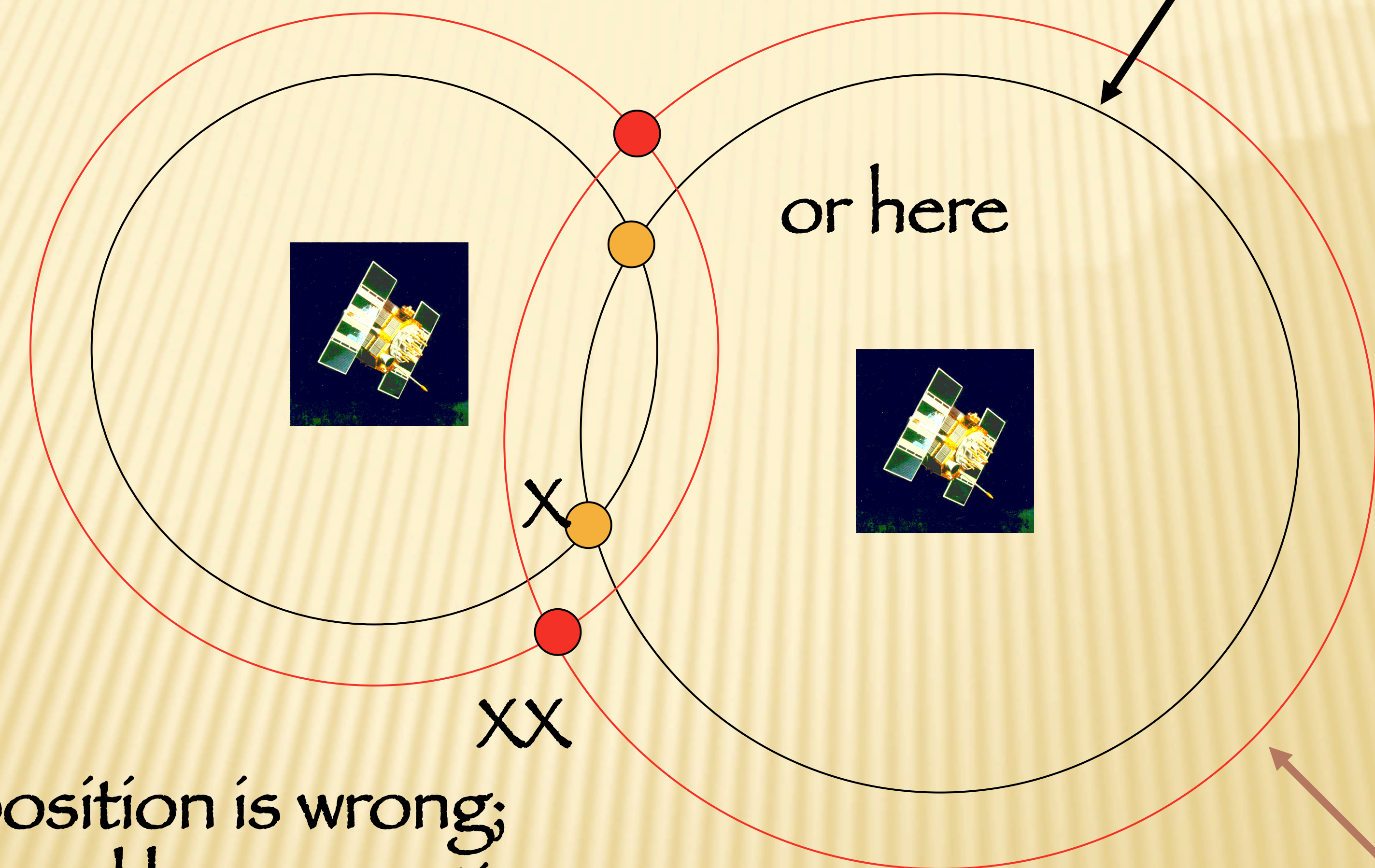


this is if clocks were correct…

what if they weren’t correct?

location of receiver is X

what if receiver wasn't perfect?
...receiver is off by 1 second



XX position is wrong; caused by wrong time measurements

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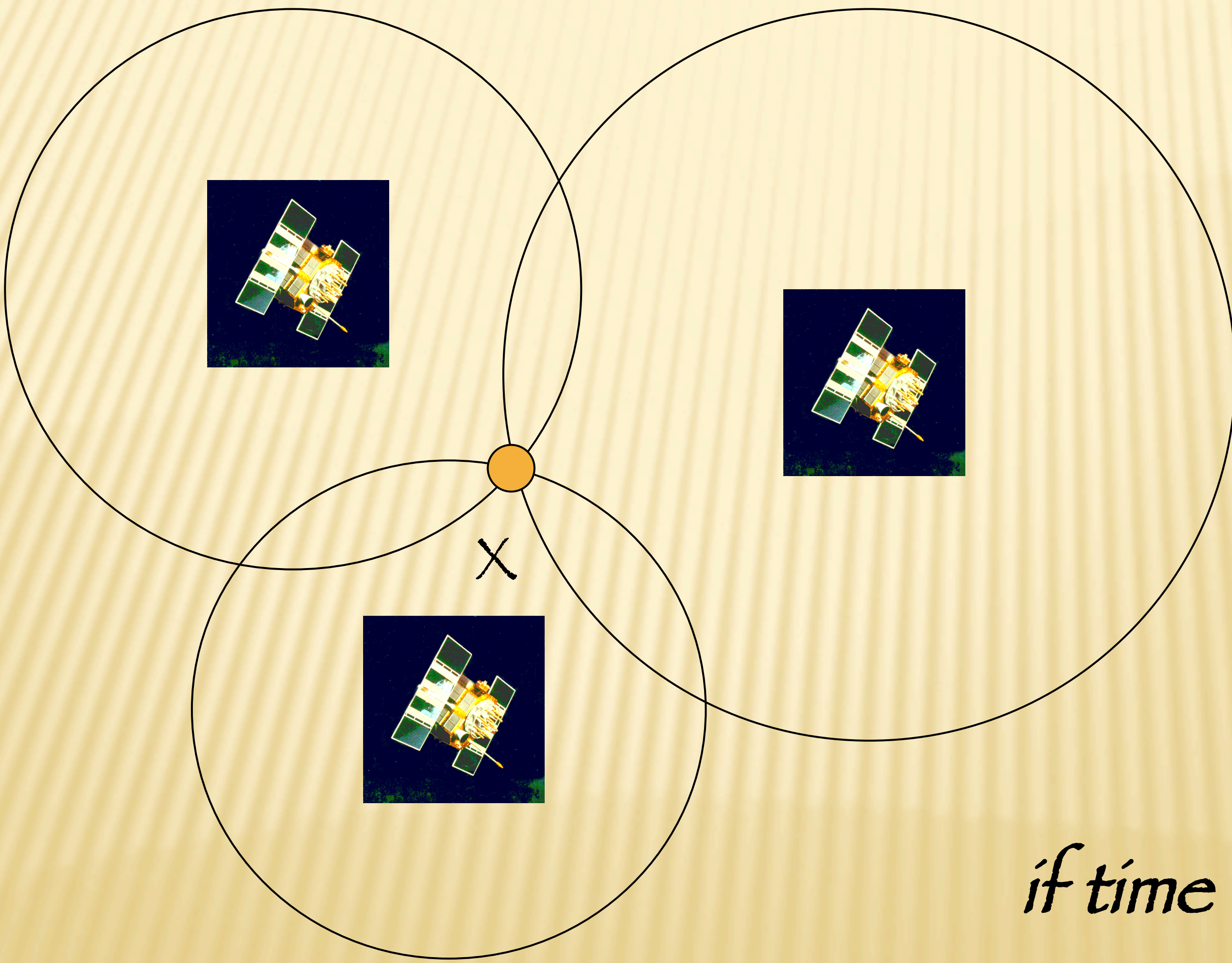
how do we know that it is wrong?

…measurement from third satellite (fourth in 3D)

Add a 3rd satellite at 3 seconds



Circles from all 3 intersect at X…

if time is correct

This also solves the uniqueness problem

if time is not correct…

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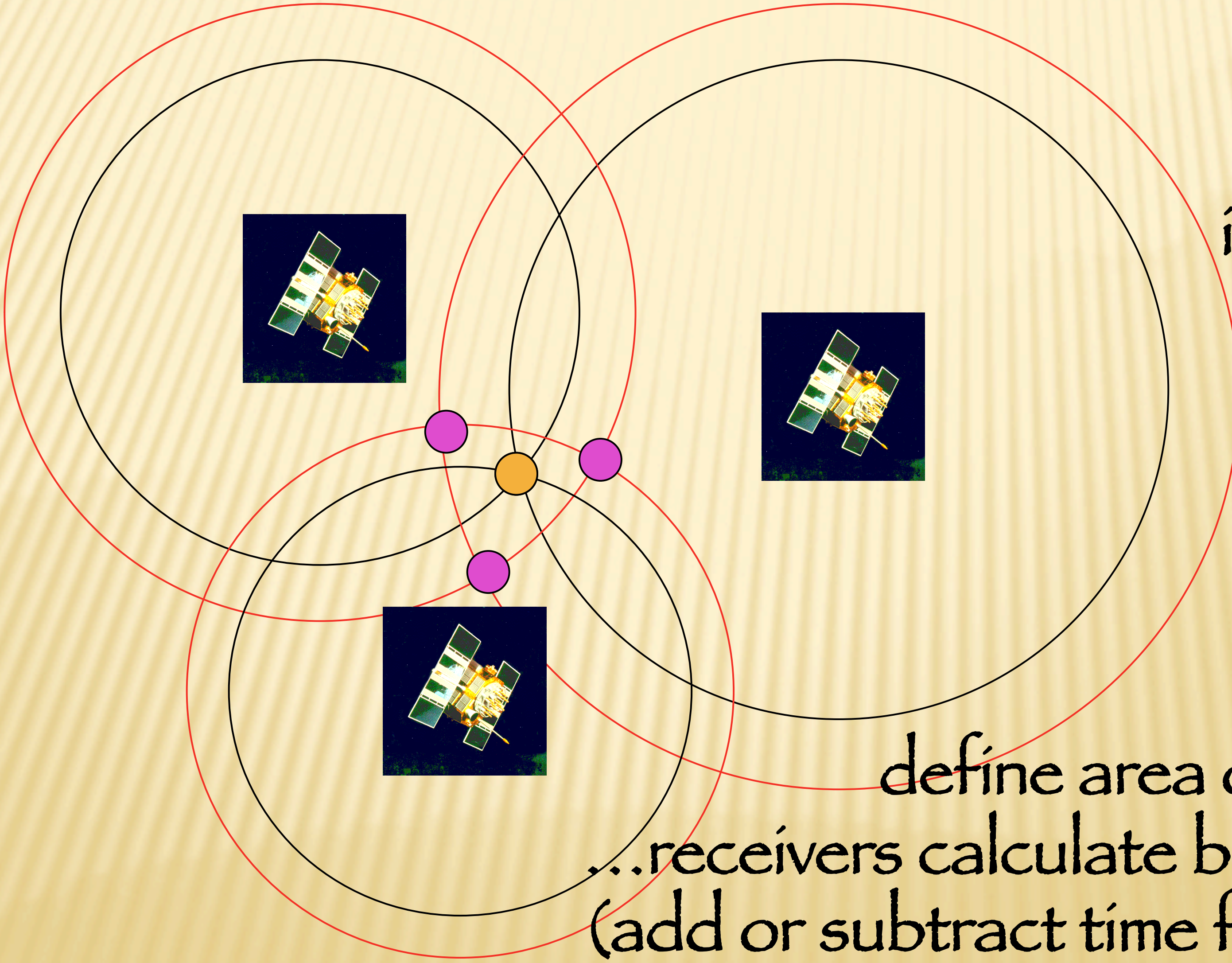
add our one second error to the third receiver…

…circle from 3rd SV does not intersect where other 2 do



purple dots are intersections of circles from2 SVs

define area of solutions

…receivers calculate best solution (add or subtract time from each SV)

Aside –

LORAN also transmits time synchronized, identifiable signals

therefore

One can locate oneself (in 2-D) using the same techniques as GPS using 3 or more LORAN signals

(they do not all have to be in the same "chain")