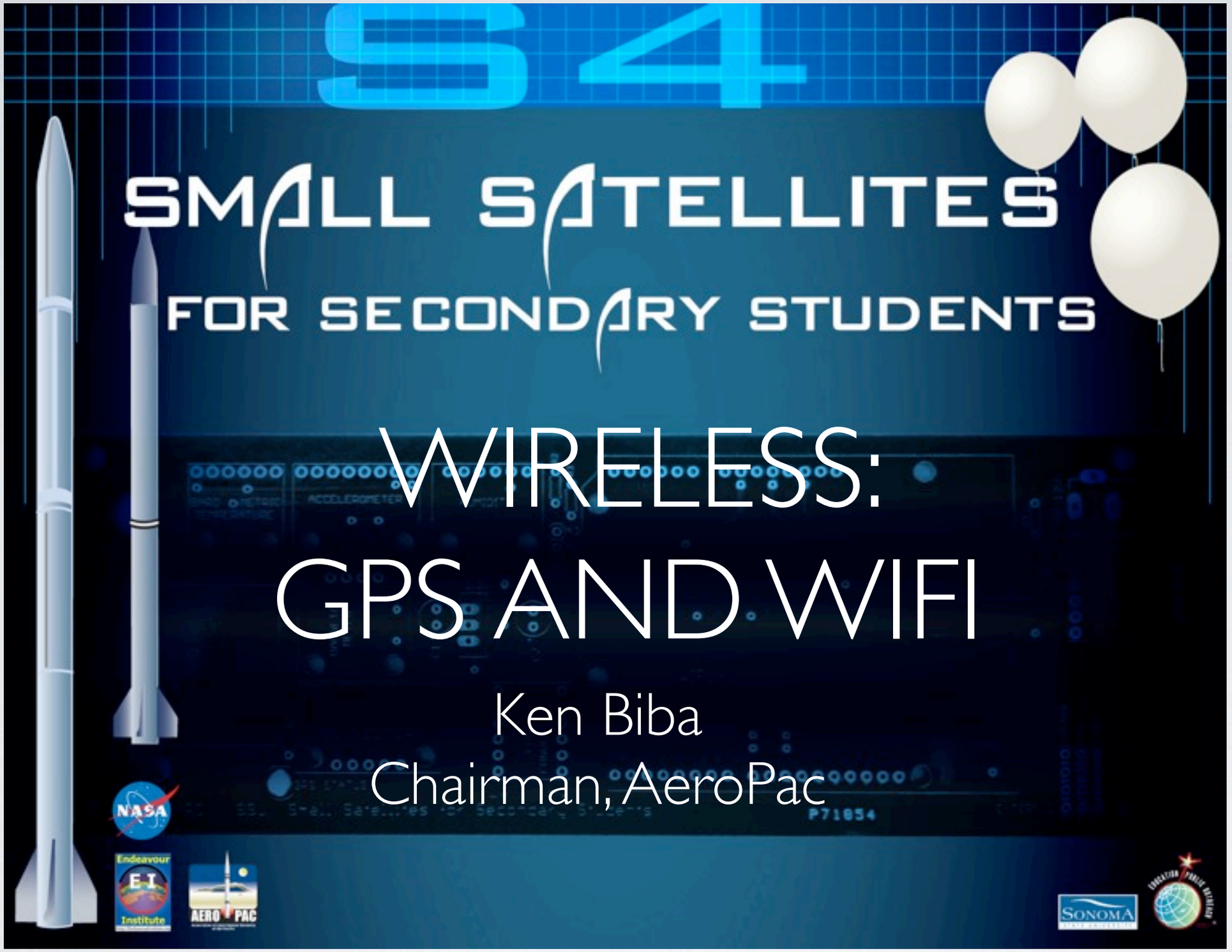
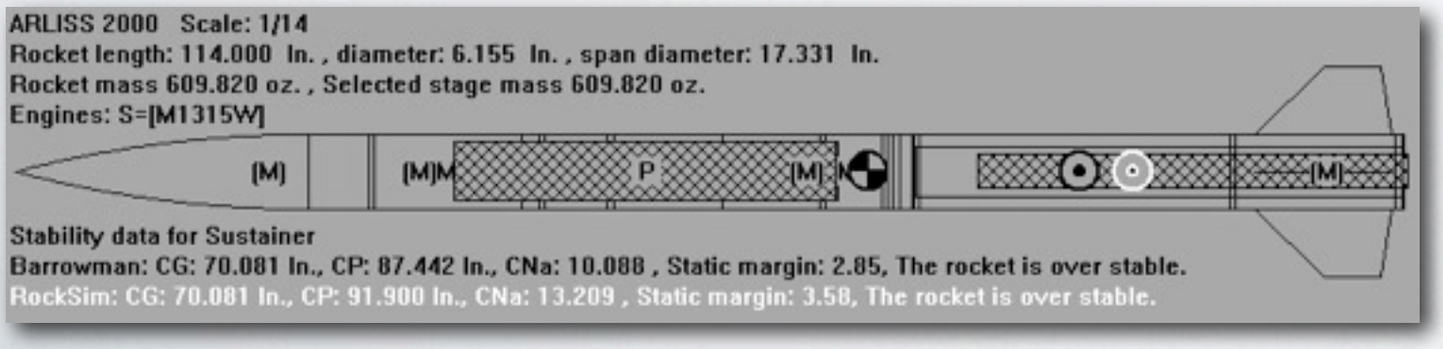
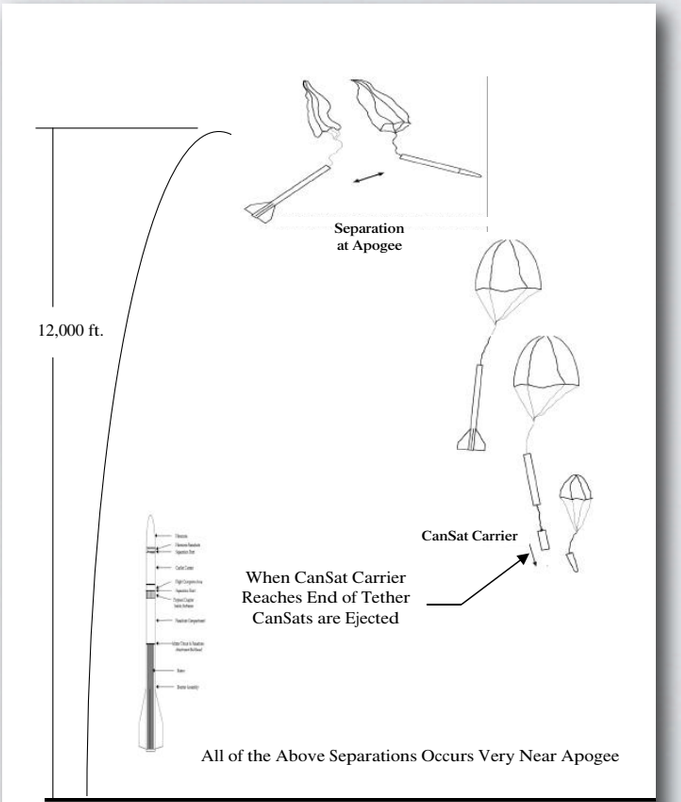

S4
SMALL SATELLITES
FOR SECONDARY STUDENTS
WIRELESS:
GPS AND WIFI
Ken Biba
Chairman, AeroPac
NASA
Endeavour
EI
Institute
AERO PAC
SONOMA

AEROPAC AND ARLISS

- We are amateurs - all of us have day jobs and none of us are paid
  - But experienced amateurs - about $2x10^6$ collective Nsec
- We fly as part of a California educational non-profit corporation
  - AeroPac - Association of Experimental Rocketry of the Pacific
  - 25 years of amateur rocketry in the Black Rock Desert - 70+ organized launches
  - High focus on education
- Reliability and reusability - the core experience of ARLISS
  - 14 year joint project of AeroPac and Japan's University Space Engineering Consortium - founded by Dr. Bob Twigss, UNISEC and AeroPac
    - AeroPac amateurs build and fly standardized airframes, students build autonomous satellite payloads
    - 1500 students, 25 countries, 500+ launches, alumni with 12 sats in orbit and one mission to Venus
- 1 kg science autonomous robot CubeSat/CanSat payloads to 3.5 km AGL (M motors)
- Inexpensive - $450/flight
- High degree of airframe reliability and reusability (99.8% success)
- 7 out of 8 members of the team are fliers -150+ collective flights
- Most ARLISS airframes have 20+ flights useful life, not unusual to have 3 flights/ day





CanSat ARLISS Rocket Launch Profile

Jim Green, Becky Green, Ken Biba, David Raimondi, Erik Ebert, Casey Barker - Tom Rouse, Steve Wigfield not shown, Karl Bauman

AGENDA

- Finding your position: Global Positioning Satellites
  - Gives 2/3D position, velocity and time with high accuracy
- Telemetry: WiFi - Wireless Fidelity Communications
  - Gives high performance wireless communications over surprisingly long distances

STRUCTURE OF GPS

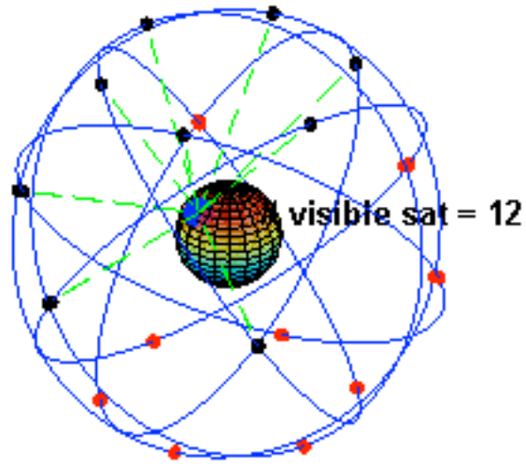
Space Segment

32 Satellites

12000 mile orbits

Cesium atomic clocks

Continuously broadcasting time



User Segment

Smartphones

Cars

Boats

Airplanes

Rockets

Control Segment

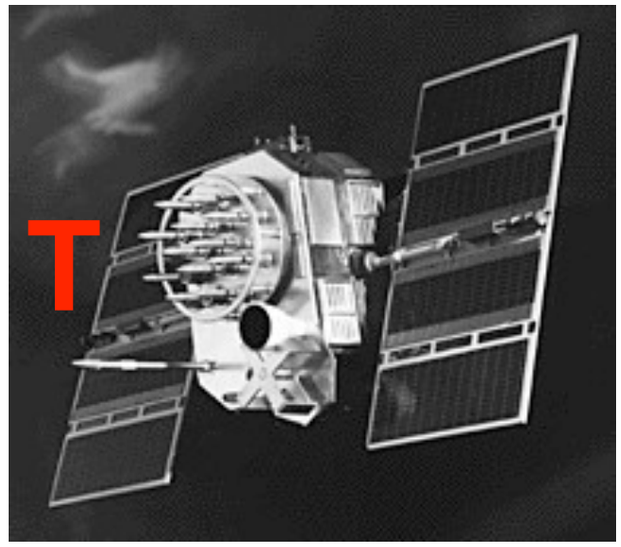
Master Station

Monitor Stations

Ground Antennas

POSITION IS BASED ON TIME

Signal leaves satellite at time “T”



T + 3

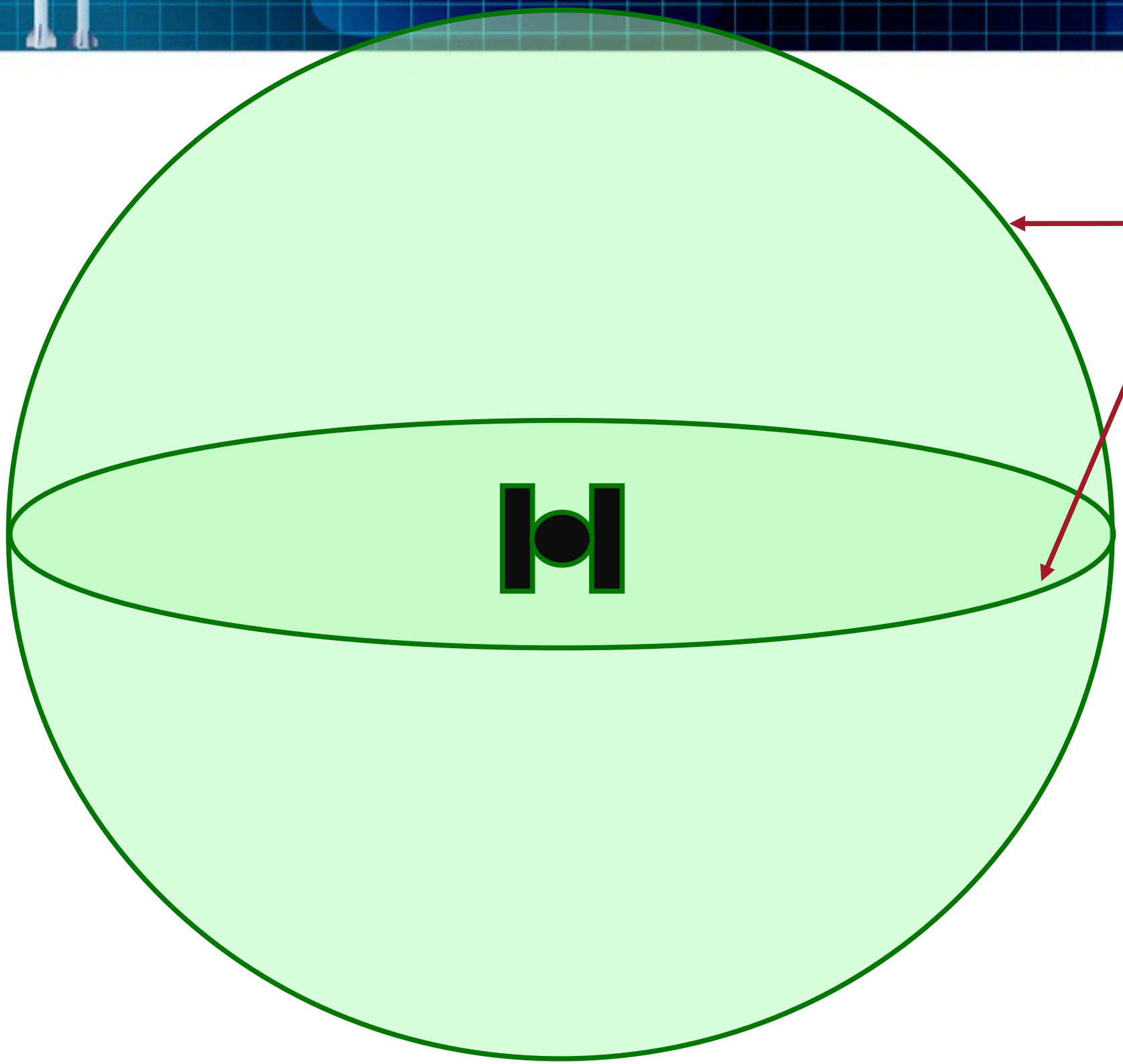
Signal is picked up by the receiver at time “T + 3”

Distance between satellite and receiver = “3 x the speed of light”

THE MAGIC OF GPS

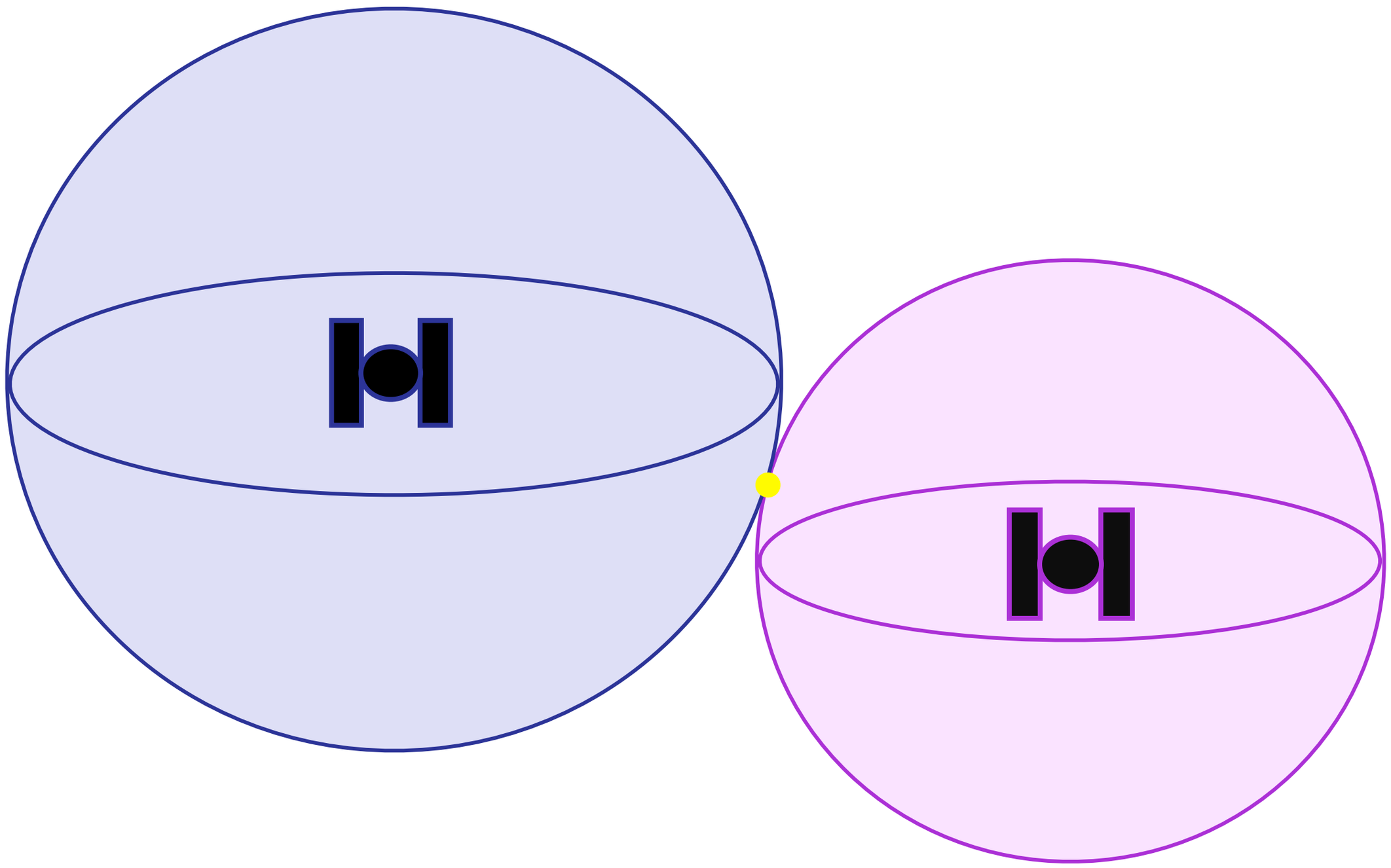
- We know four things
- An ephemeris of the location in space AND time of each of the constellation of positioning satellites (either bootstrapped from the satellites or sideloaded from the cellular network - for smartphones)
- Spherical geometry
- The speed of light
- The time for radio waves to reach our location from each of several of these satellites as measured by a GPS receiver in the field - hence we know the distance to each satellite to the receiver
- Magic of GPS receiver firmware algorithms solving the spherical geometry problem yield:
  - The position of receiver with high accuracy - <~10m
  - Sequential position fixes yield velocity and heading

SIGNAL FROM ONE SATELLITE

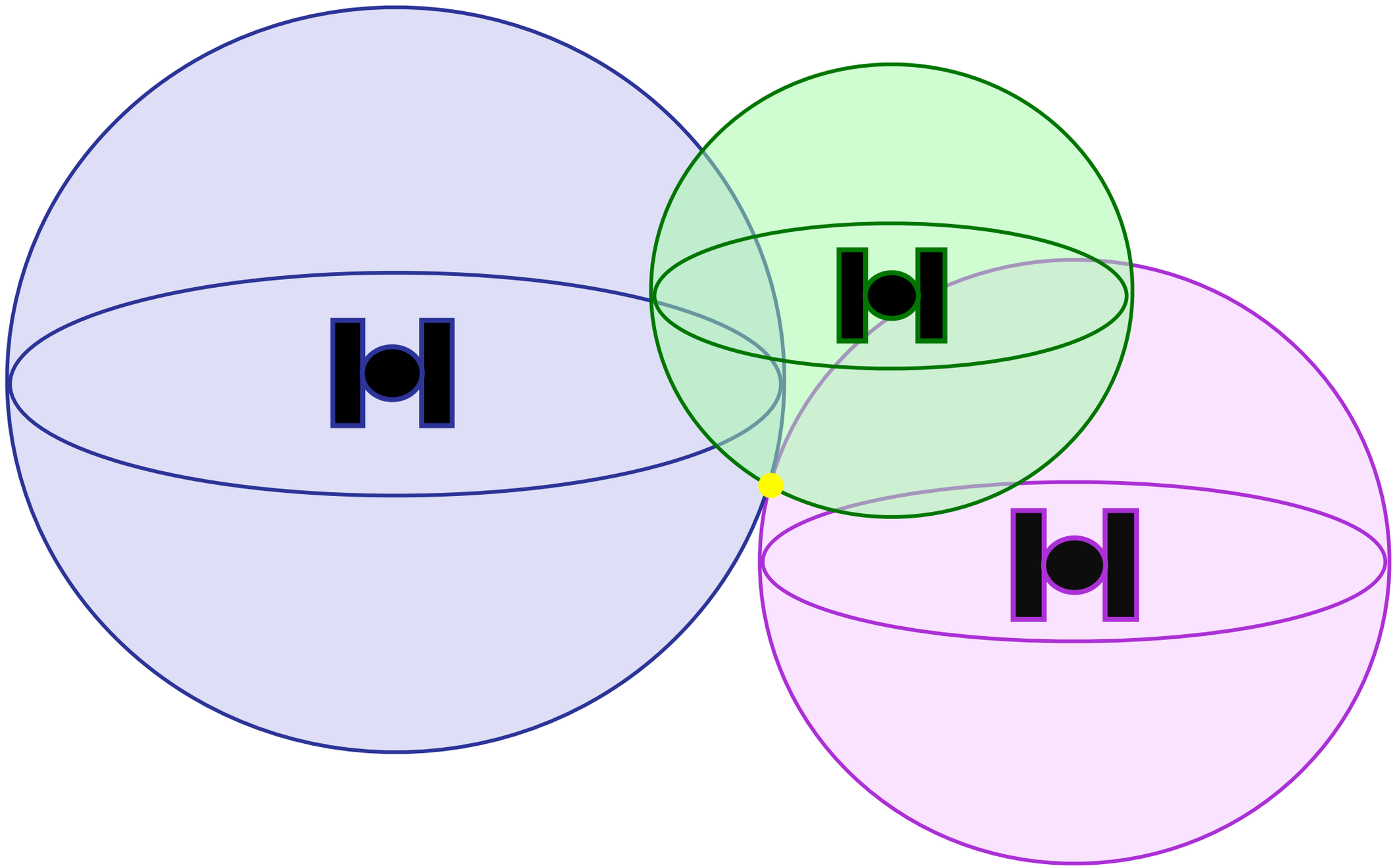


The receiver is somewhere on this sphere.

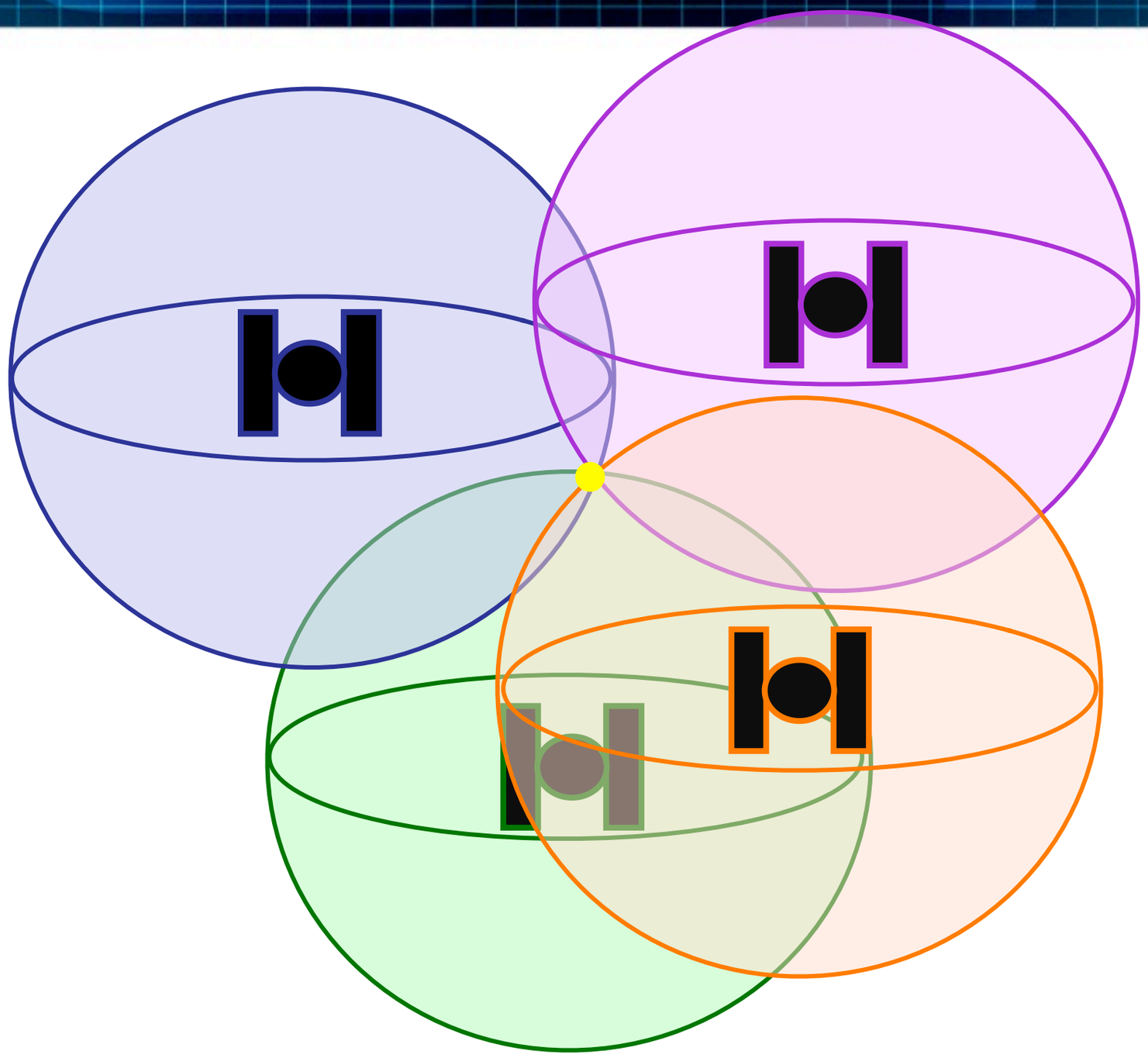
SIGNALS FROM TWO SATELLITES



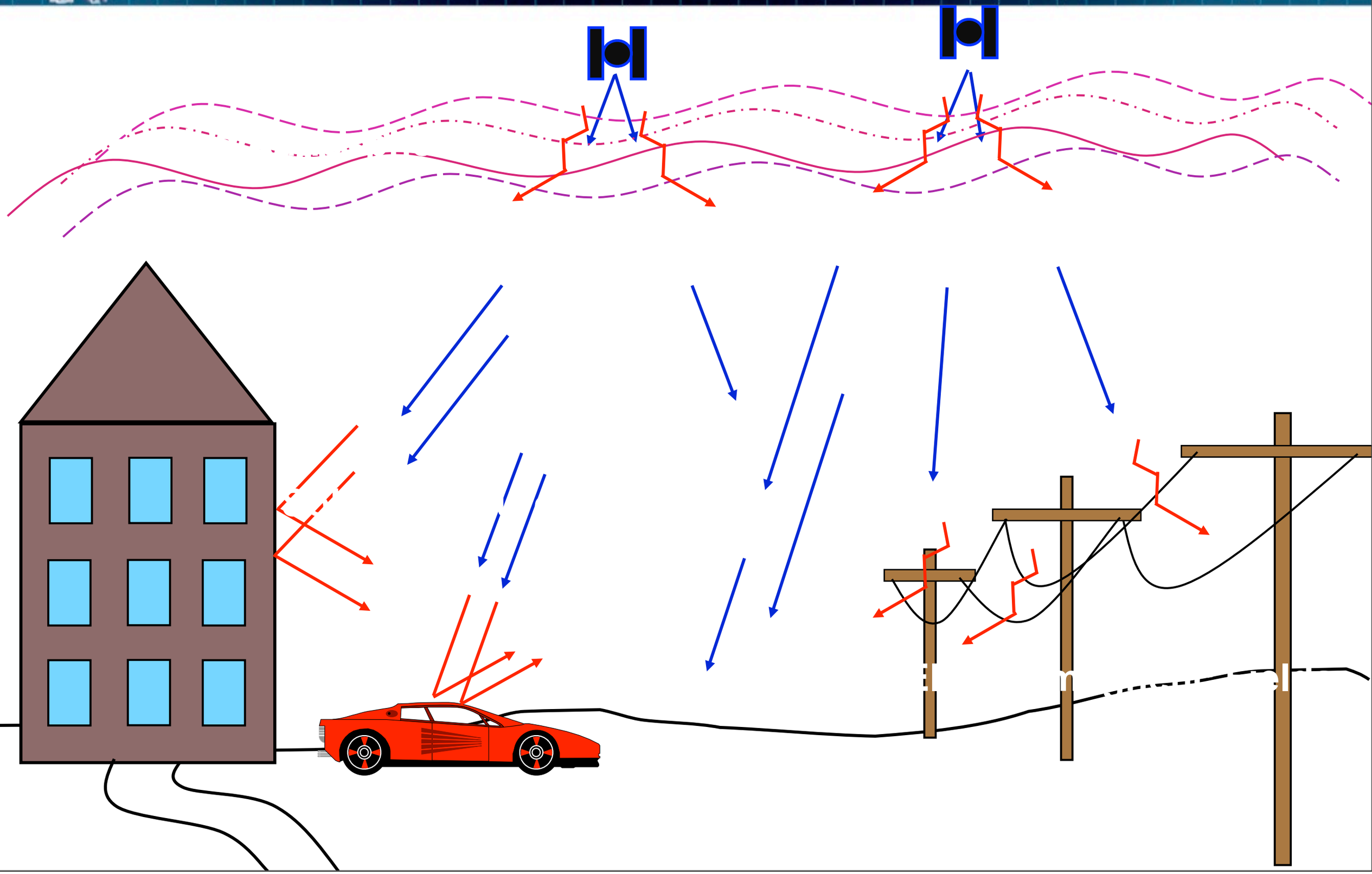
THREE SATELLITES (2D POSITIONING)



THREE DIMENSIONAL (3D) POSITIONING



SOURCES OF GPS IMPERFECTION



SOURCES OF GPS ERROR

Standard Positioning Service (SPS): Civilian Users

Source	Amount of Error
Satellite clocks:	1.5 to 3.6 meters
Orbital errors:	< 1 meter
Ionosphere:	5.0 to 7.0 meters
Troposphere:	0.5 to 0.7 meters
Receiver noise:	0.3 to 1.5 meters
Multipath:	0.6 to 1.2 meters

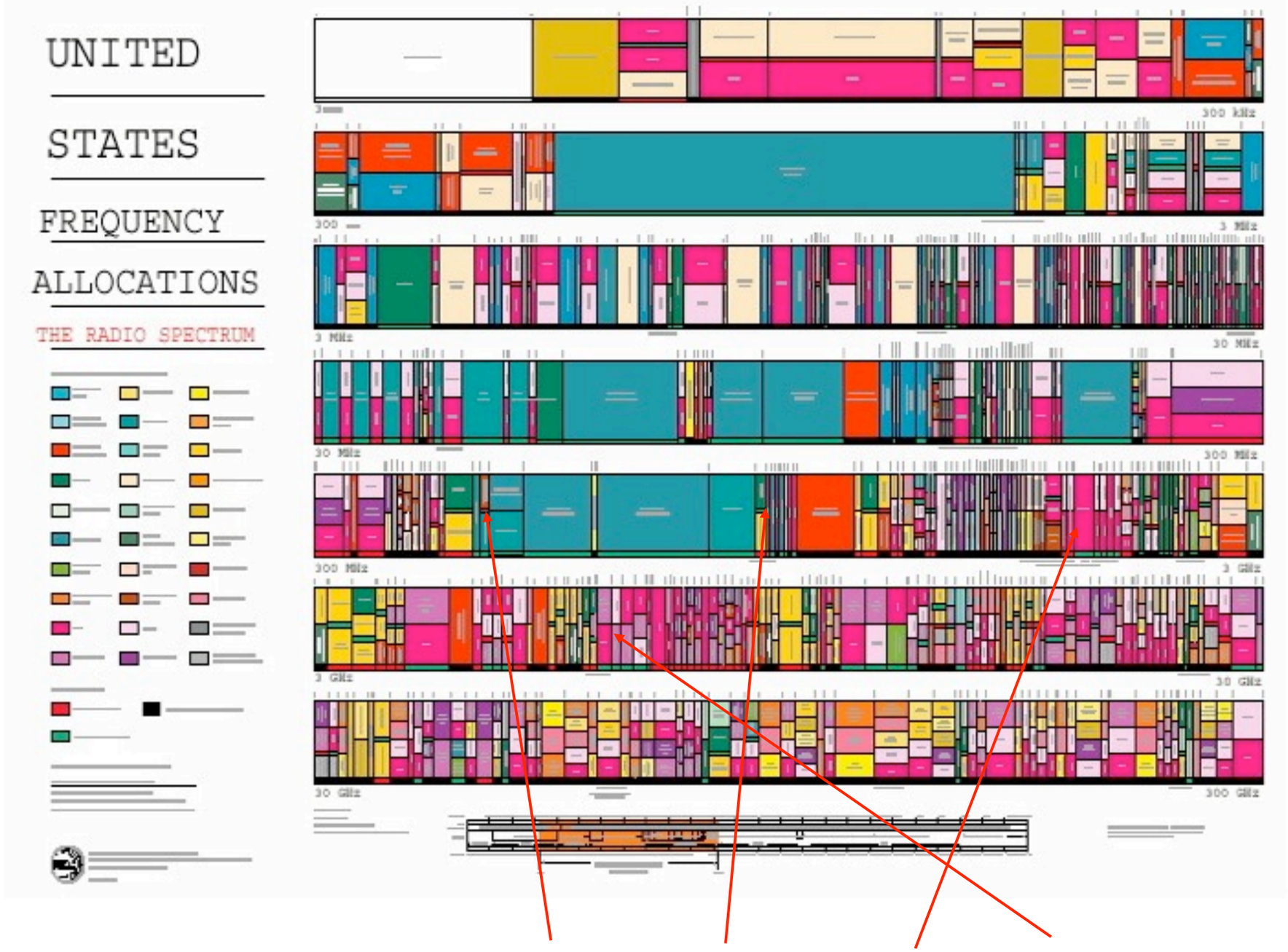
GPS FOR MORTALS

- Not all chipsets are alike
  - We are using the wonderful uBlox 6 chipset that knows how to track in 3D with high motion dynamics of the receiver
- Not all antennas are alike
  - We are using the Sarantel quadrafilar helical antenna that has builtin amplifiers, no polarization bias and high gain
- Chipset does the hard work
  - Generates 1 Hz serial data stream of lat/lon/altitude
  - Can actually be set to give 4 Hz updates
  - Works well pointed out the side of a rocket - even while with modest spin (will cover both ascent and descent)
  - Will stop reporting at velocities > 500 m/s and diminished accuracy > 50 km

WIFI: OPEN WIRELESS COMMUNICATIONS

- WiFi is abbreviation for Wireless Fidelity - an industrial interoperability certification program for communications radios implementing IEEE standard 802.11
  - Using shared, public radio spectrum harmonized worldwide
  - WiFi Alliance is industry group that does certification (my partner Phil Belanger started it)
- Designed as a "wireless Ethernet" - creating small local area networks of desktop computers for small business and residences - the 50m network of 10 stations
- Exceeded all expectations of scale
  - Included in all modern smartphones, tablets and laptops
  - ~50% of all Internet data traffic originates/terminates on WiFi
  - Soon to be in cameras, light bulb, sensors - the "Internet of Things"
  - Networks as small as a 1-2 stations to networks of 30-50,000 (sports stadiums)
  - Networks as close as a few feet to as distant as 100 km
  - Data transfer speeds of a few Kb/s to streaming video at 10s of Mb/s

FCC Doomed WiFi to Radio Bands that Nobody Wanted



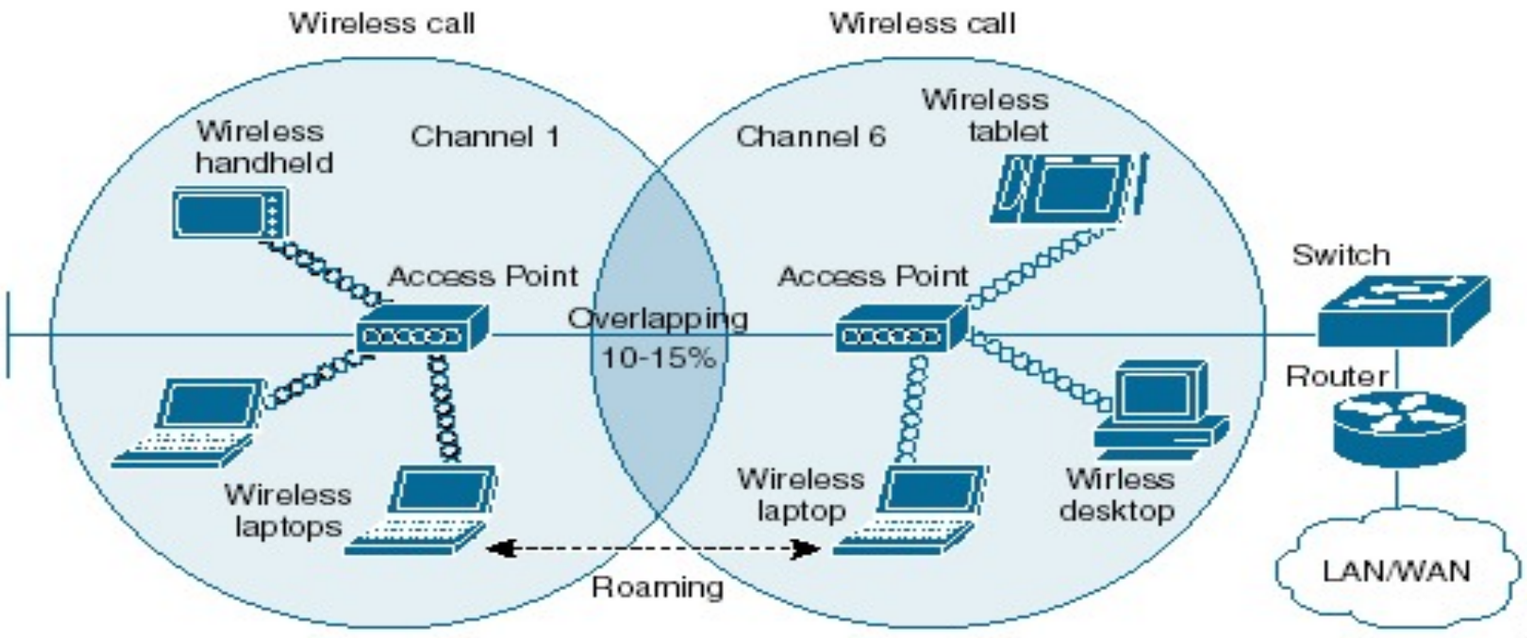
The ISM bands most commonly used are at 433, 915, 2400, 5000 MHz.

SALVATION THROUGH SUFFERING

- Public radio bands were filled with industrial meat cookers, microwave ovens, wireless telephones ... and endless list of incumbent users that WiFi needed to coexist with
  - And not just coexist but deliver a useful service
- WiFi - by necessity - created a communications system that is free, robust, reliable and efficient even when the underlying radio environment is ... chaotic
- The success is that most users don't know (nor appreciate) how WiFi delivers ... in the vast majority of cases it just works
- But the robust structure of WiFi yields a remarkably robust and extensible system
  - That scales in distance, number of stations, traffic load

ACCESS POINT BASED TOPOLOGY

- The user WiFi Station normally communicates through an Access Point
- An Access Point provides the radio coverage and the connection to the backbone network
  - A smartphone AP can be 10s of feet in diameter
  - An enterprise AP can 100m in diameter
  - An extreme outdoor AP can be 50km+ in diameter
- Access points can be connected to extend coverage as micro cellular topology



PROTOCOLS - A COMPLETE SYSTEM

Arduino

Arduino Program

TCP - Reliable Data Streams

End to End Reliable, Flow Controlled Byte Streams

IP - Unreliable Datagrams

End to End Unreliable Datagram Packets

WiFi Media Access Control - Shared Datagrams

Radios - Modulating Microwaves

WiFi Chipset

WiFi

WiFi Access Point Datagram Bridging Media Access Control

Radios - Modulating Microwaves

Modulating Wire

Access Point

Ethernet

Server Program

TCP - Reliable Data Streams

IP - Unreliable Datagrams

Ethernet Media Access Control - Shared Datagrams

Modulating Wire

Ethernet Chipset

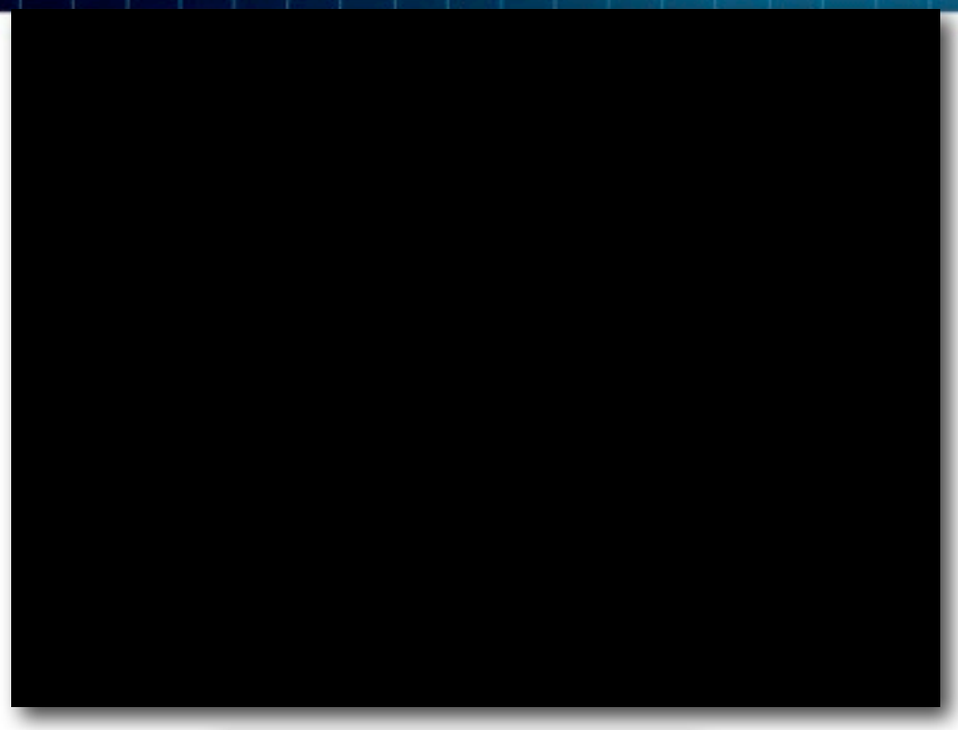
Windows /Mac OS X

WHAT WE DO

- We are using WiFi as a long distance telemetry system
- We pick the small integrated station to support the payload
- We pick a good high power access point for the ground station
  - 600 mW - 10x typical residential access point
- We pick a good high gain antenna on the ground station
  - 9 dBi - 8x typical residential access point
  - 60 degree FOV
- Voila!
  - Range to about 10k' LOS
  - With upgrades can extend range to 300k'

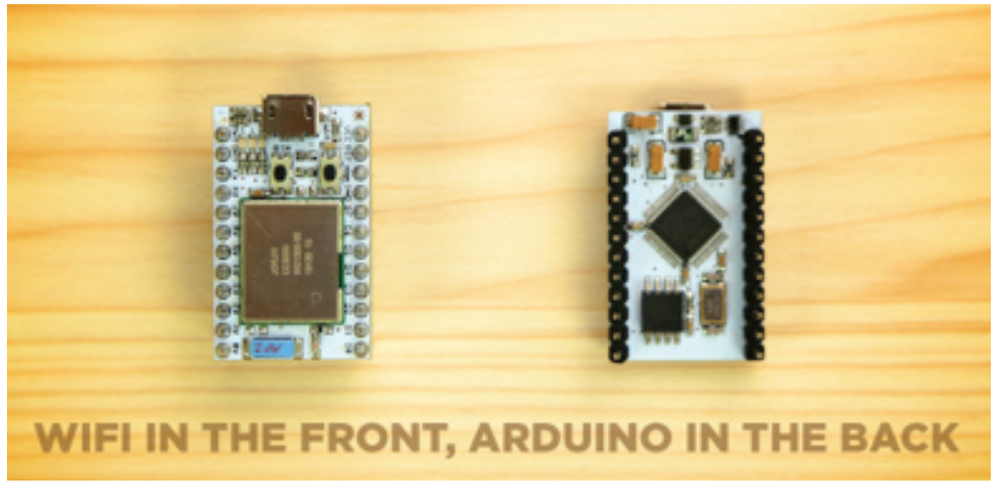
VIRTUAL CLASSROOM

- Real-time telemetry via AeroPac's Virtual Classroom
  - (idea courtesy of Bob Twiggs of CubeSat/CanSat fame)
  - Ku band Internet backhaul
  - 4 km^2 WiFi hotspot
  - Video streaming
  - Telemetry gateway
- 70 cm HAM band APRS beacons
  - Sustainer and booster
  - Improved ground station with 18 dB omni circular polarized satellite antenna with LNA
- WiFi in the Sky
  - Superset of what we are doing here
  - Can take WiFi telemetry to 100 km via tracking dish
- Local tracking at launch site
  - Google Earth track and map
- Live Web cast
  - Launch video
  - GPS tracking



WHAT THE FUTURE HOLDS

- Moore's Law Continues
  - Smaller, faster, cheaper, longer range, less power draw
  - Spark Core (10/2013 ship)
    - Integrates Arduino and WiFi on single package
- New versions of WiFi will further extend range and performance
  - 802.11n (2x)
  - 802.11ac (10x)
- Machine2Machine (telemetry and control) next major area of WiFi penetration
  - Exactly what we are doing here



www.aeropac.org