

# **Professional Development Short Course On:**

## GPS Technology

### **Instructor:**

Thomas S. Logsdon

**ATI Course Schedule:**

<http://www.ATCourses.com/schedule.htm>

**ATI's GPS Technology:**

[http://www.aticourses.com/gps\\_technology.htm](http://www.aticourses.com/gps_technology.htm)

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## GPS SOLUTIONS ON EARTH AND IN SPACE

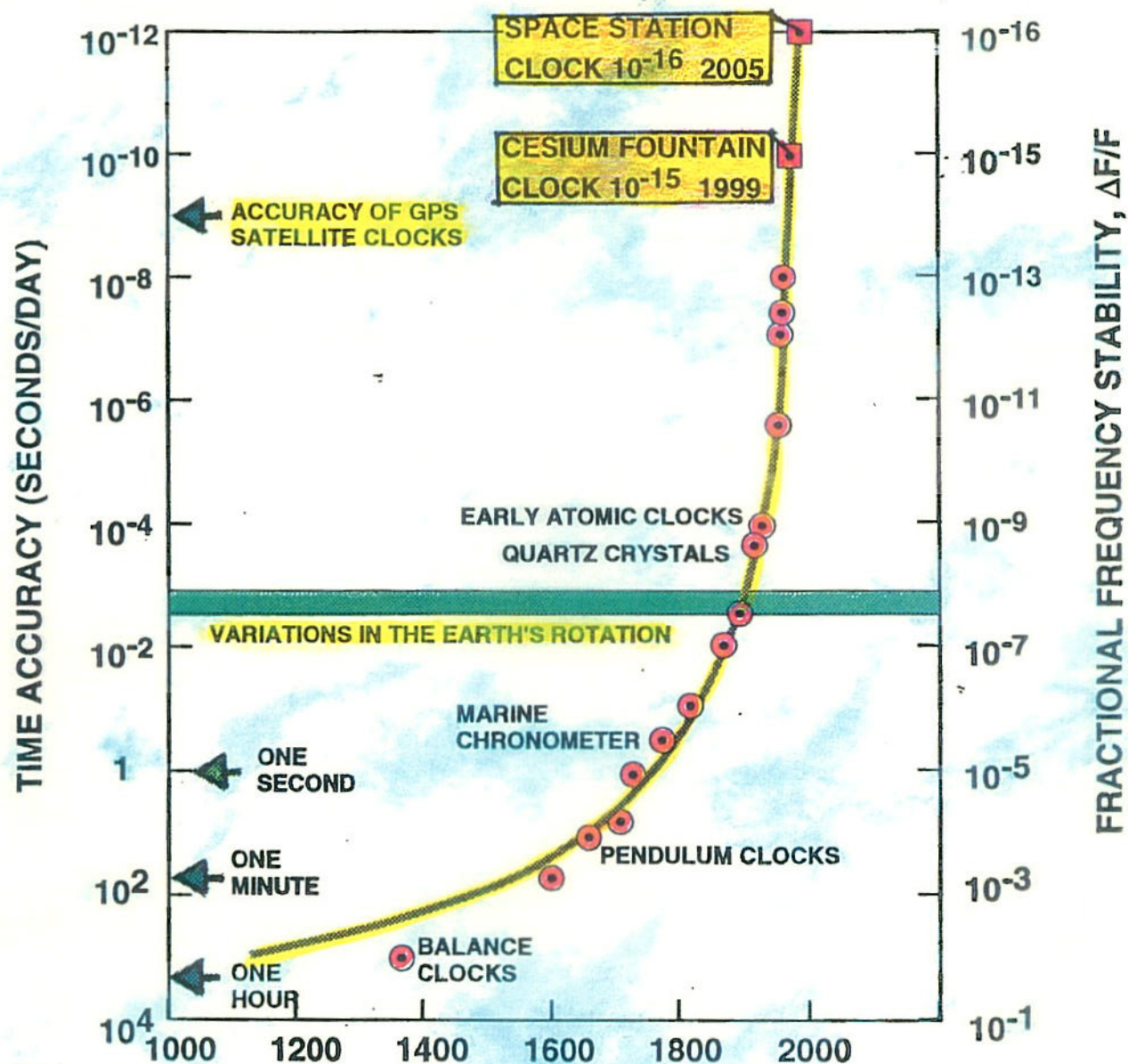
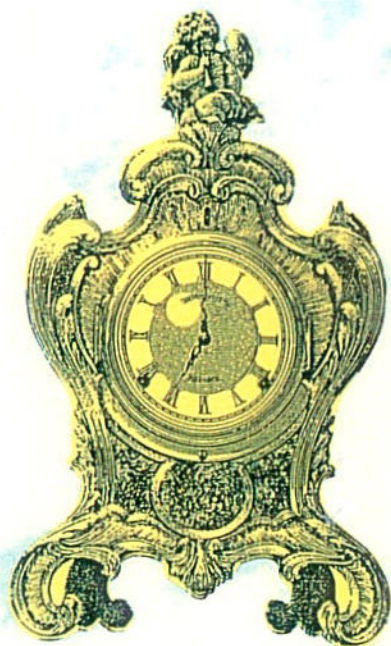
*"Excellent course!"* wrote one enthusiastic participant from Northrop Grumman in his evaluation. *"**Mr. Logsdon**, having participated in the development of the GPS is a great source of information."* Another student from Scitor Corporation was equally pleased, *"**Tom Logsdon** . . . is the most knowledgeable instructor I've ever had. What made the class even better was Tom's ever-pleasant demeanor."*

Since 1982 he has been teaching various short courses on the GPS and other related topics such as Orbital Mechanics. **Logsdon**, who first began working on the GPS in 1972, has taught and lectured in 31 different countries on every continent except Antarctica. He has written and published 29 technical books, including *The Global Positioning System* and *Understanding the Navstar*. He also writes under contract for *Encyclopedia Britannica*.

Over three or four days **Mr. Logsdon** uses 450 to 500 full-color visuals to explain what the GPS is, how it works, how it is being used, how clever researchers are accentuating its performance, and how you can design or purchase a GPS receiver specifically suited to your needs.

*"**Mr. Logsdon** presents complicated topics in an easy-to-follow method,"* one student from the Navy's NAVAIR organization noted. *"He covers both the technical and the practical aspects of GPS . . . very easy to listen to, very knowledgeable!"* Students truly enjoy the material and the playful stories from the industry --and each one receives a free receiver! Sample charts, a topic outline, and **Mr. Logsdon's** professional resume are included in the pages that follow.

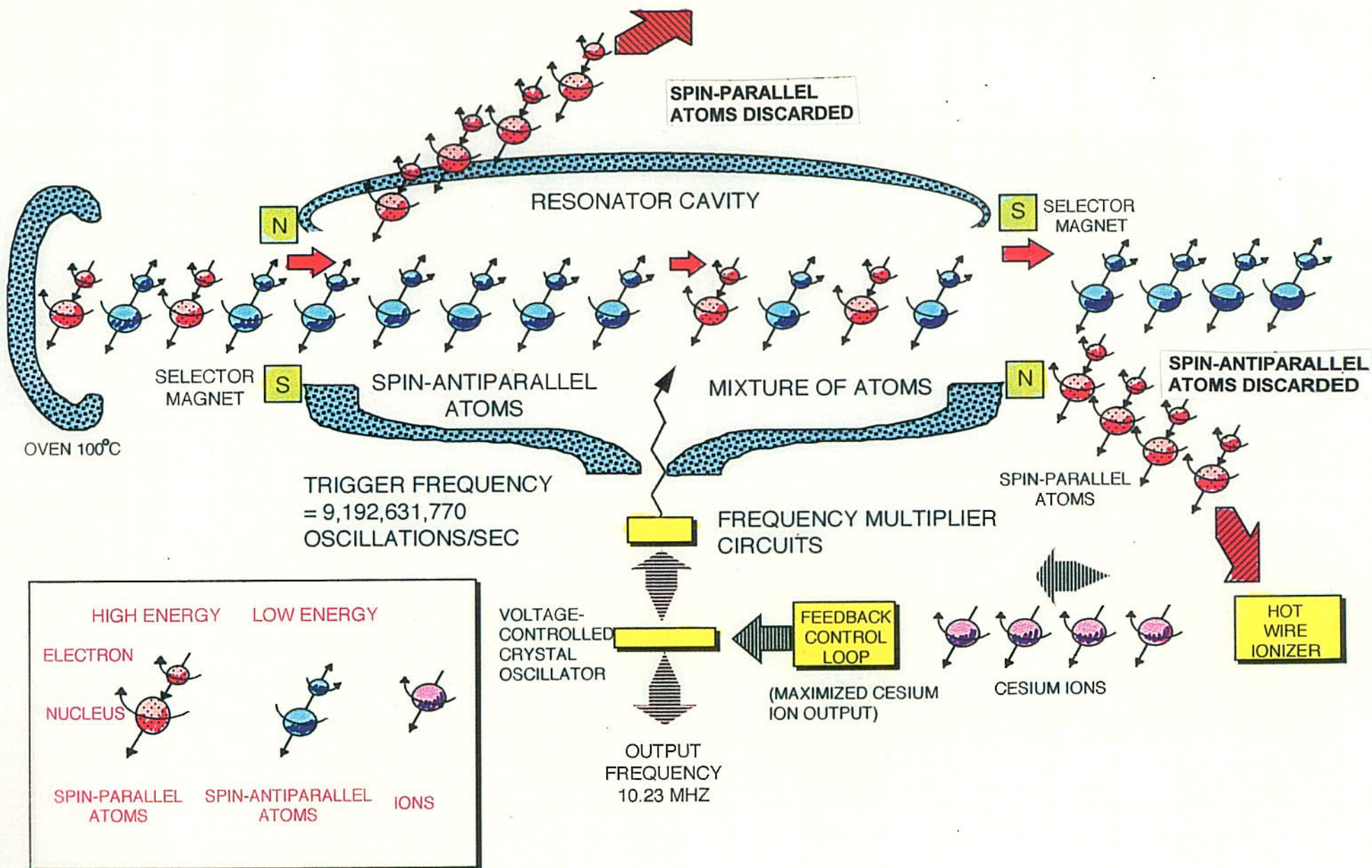
# ANTICIPATED ACCURACY IMPROVEMENT FOR ATOMIC CLOCKS



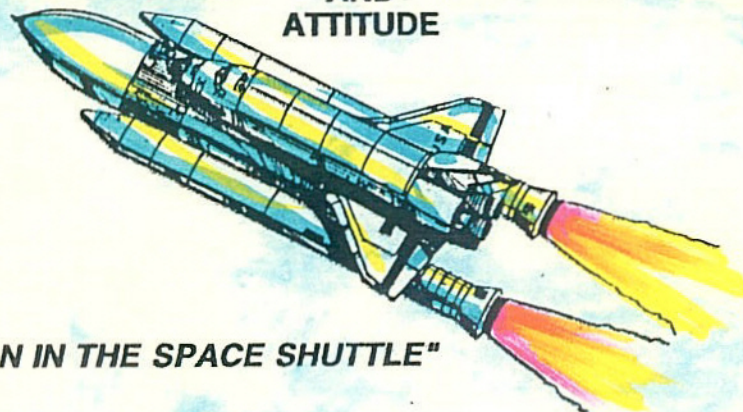
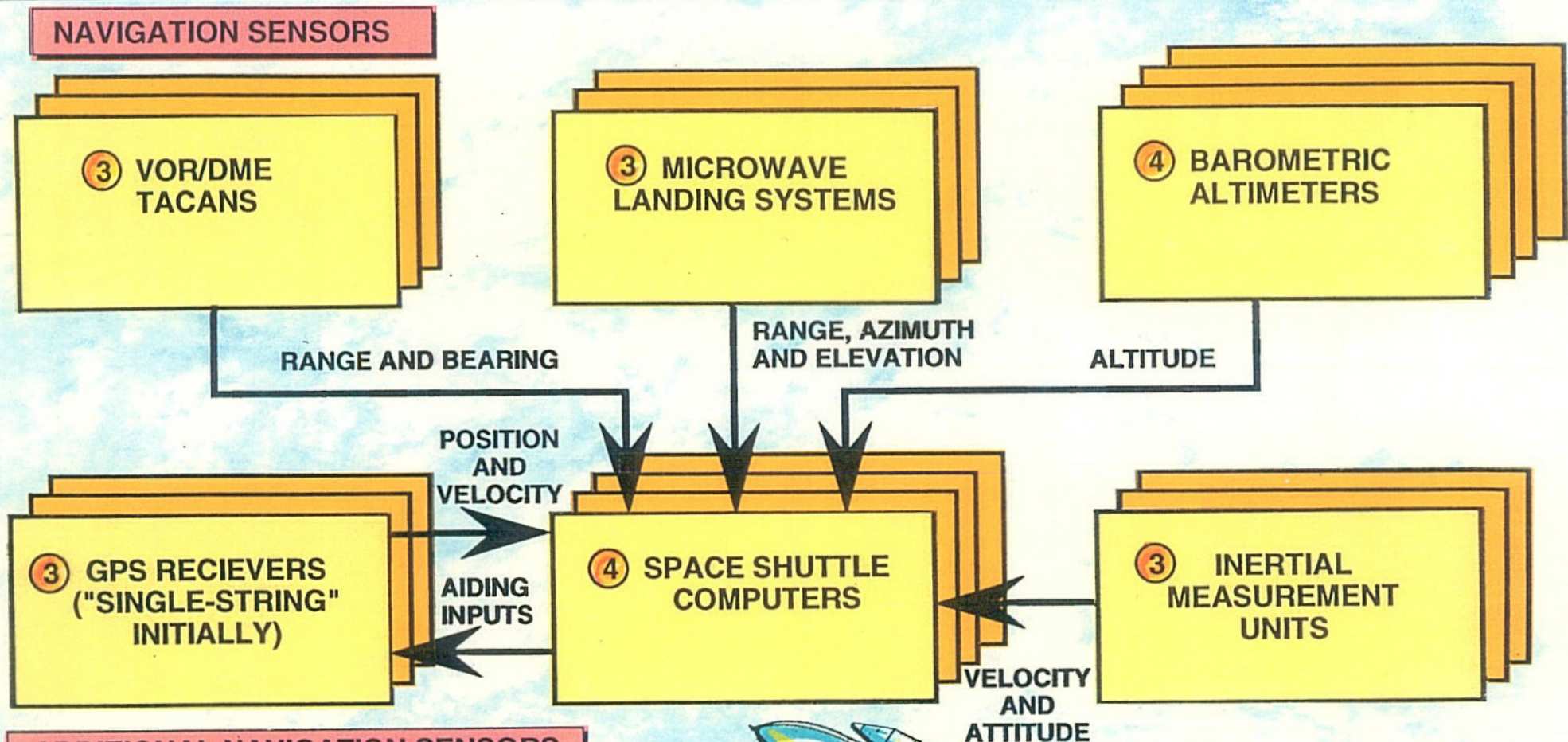
SOURCE: "ULTIMATE CLOCKS" W. WAYT GIBBS. SCIENTIFIC AMERICAN SEPTEMBER 2002

TL-01/18/03-22

# THE CESIUM ATOMIC CLOCKS CARRIED ONBOARD THE NAVSTAR SATELLITES

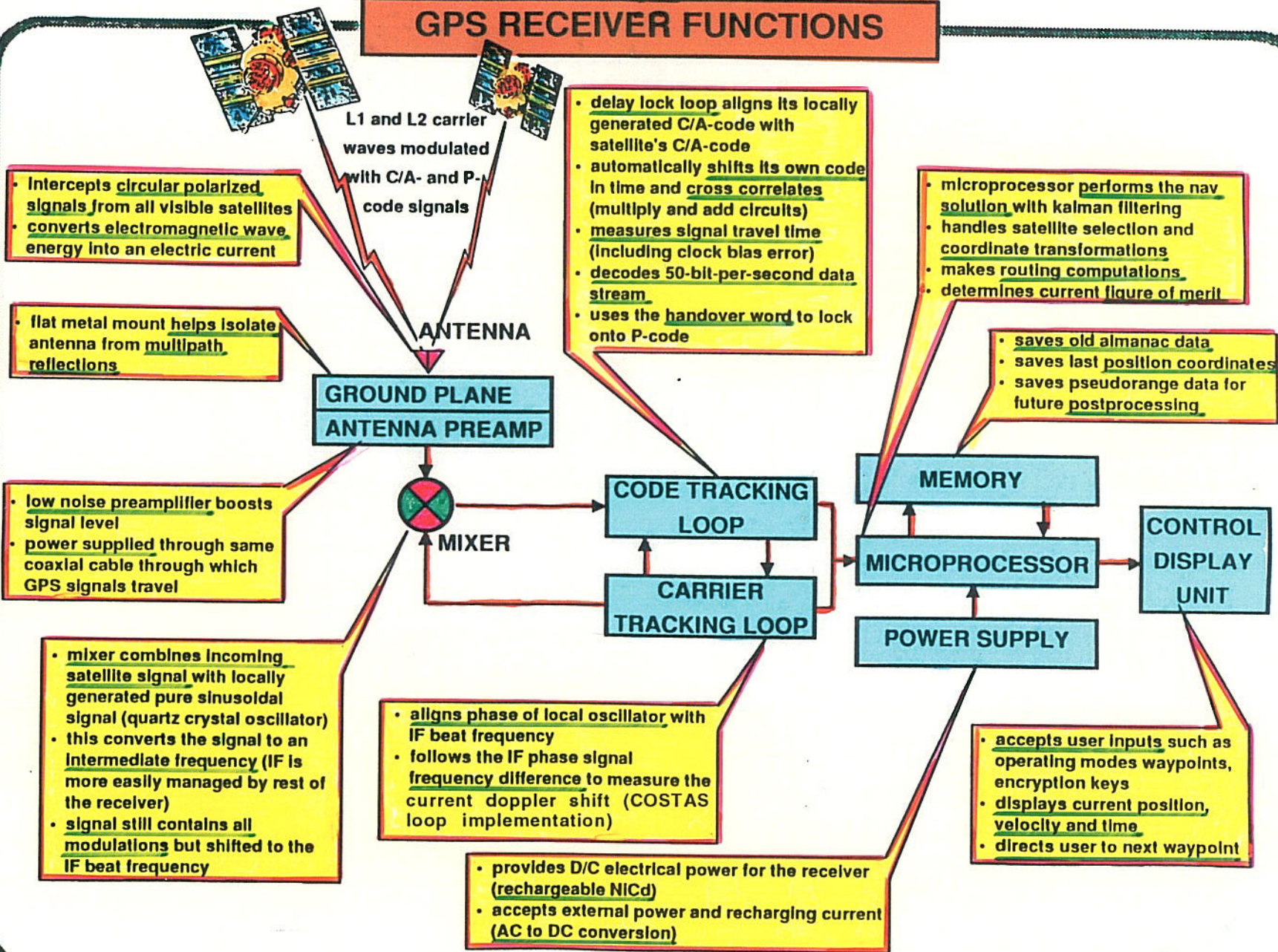


# SPACE SHUTTLE NAVIGATION WITH THE GPS

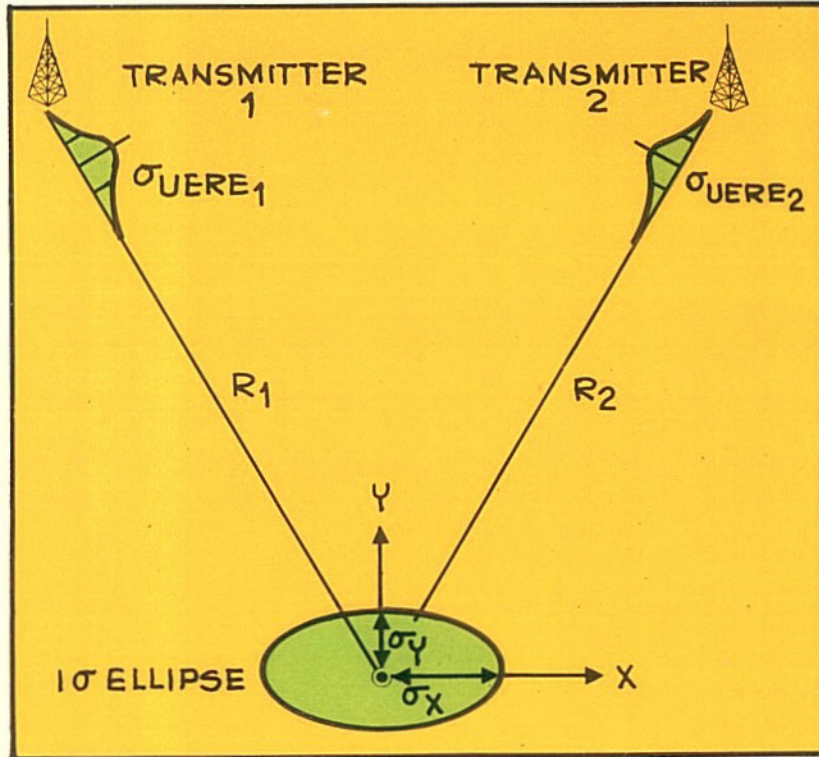


**"PARALLEL PROCESSING: GPS AUGMENTS TACAN IN THE SPACE SHUTTLE"**  
JOHN L. GOODMAN. GPS WORLD OCTOBER 2002

# GPS RECEIVER FUNCTIONS



# THE GDOP DERIVATION



IF THE STATISTICAL VARIATIONS IN THE RANGES  $R_1$  AND  $R_2$  EQUAL  $\sigma_{UERE1}$  AND  $\sigma_{UERE2}$ , HOW BIG ARE THE CORRESPONDING ERRORS IN THE USER'S POSITION COORDINATES  $U_X$  AND  $U_Y$  ?

WORKING FIRST WITH  $\sigma_X$ , WE HAVE

$$\sigma_X^2 = \frac{1}{n} \sum_{i=1}^n [\Delta X_i - \Delta X]^2$$

SUBSTITUTING  $\Delta X$  GIVES

$$\sigma_X^2 = \frac{1}{n} \sum_{i=1}^n \left[ \Delta X_i - \frac{\Delta R_1 - \Delta R_2}{2 \sin \theta} \right]^2$$

WHICH EQUALS

$$\sigma_X^2 = \frac{1}{n} \sum_{i=1}^n \left[ \Delta X_i - \frac{\sin \theta \Delta X_i + \cos \theta \Delta Y_i + U_{1i} + \sin \theta \Delta X_i - \cos \theta \Delta Y_i - U_{2i}}{2 \sin \theta} \right]^2$$

$$\sigma_X^2 = \frac{1}{n} \sum_{i=1}^n \left[ \frac{U_{2i} - U_{1i}}{2 \sin \theta} \right]^2 = \frac{1}{4 \sin^2 \theta} \left\{ \frac{1}{n} \sum_{i=1}^n U_{2i}^2 - \frac{2}{n} \sum_{i=1}^n U_{2i} U_{1i} + \frac{1}{n} \sum_{i=1}^n U_{1i}^2 \right\}$$

$$\sigma_X^2 = \frac{\sigma_{UERE2}^2 + \sigma_{UERE1}^2}{4 \sin^2 \theta}$$

IF WE ASSUME THAT THE STATISTICAL VARIATION ON EACH RANGE IS EQUAL, WE HAVE

$$\sigma_X = \frac{\sigma_{UERE}}{\sqrt{2} \sin \theta}$$

# NEW MODEL SMART BOMBS

## BOEING MK84 BOMB KIT

- ★ ACCURACY = 40 FEET
  - ★ WEIGHT = 2000 POUNDS
  - ★ COST = \$23,000
- TAIL-KIT ASSEMBLY  
ATTACHED TO CONVENTIONAL  
DUMB BOMB

## LOCKHEED CBU-87 BOMBLETS

- ★ ACCURACY = 85 FEET
  - ★ WEIGHT = 1000 POUNDS
  - ★ COST = \$24,000
- AREA-EFFECTS MUNITIONS  
THAT STRIKE ACROSS A WIDE  
TARGET

## RAYTHEON BLU-97 BOMBLETS

- ★ ACCURACY = 50 FEET
  - ★ WEIGHT = 1065 POUNDS
  - ★ COST = \$220,000
- UNPOWERED GLIDE BOMB  
WITH 15-MILE LOW-ALTITUDE  
RANGE

## TYPICAL WING PYLON CLUSTER



## BOEING BLU-109 PENETRATOR KIT

- ★ ACCURACY = 40 FEET
  - ★ WEIGHT = 2000 POUNDS
  - ★ COST = \$25,000
- SPECIFICALLY INTENDED FOR  
HARDENED TARGETS

## LOCKHEED CBU-97 MUNITIONS

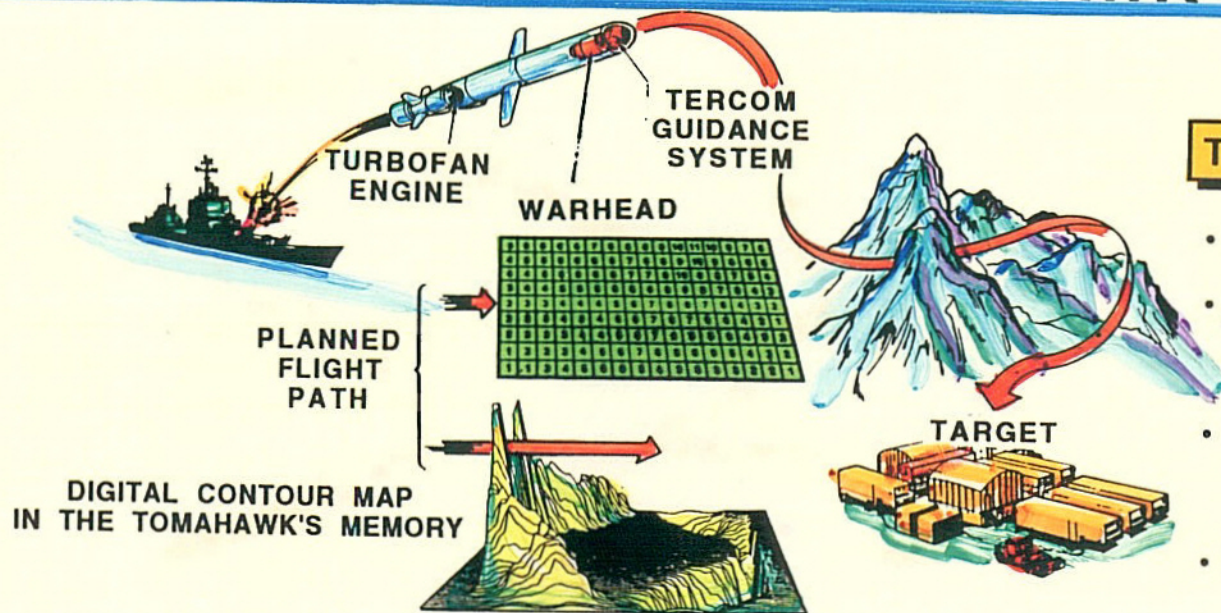
- ★ ACCURACY = 85 FEET
  - ★ WEIGHT = 1000 POUNDS
  - ★ COST = \$310,000
- AREA-EFFECTS MUNITIONS THAT  
STRIKE OVER A WIDE TARGET  
(INFRARED DETONATION)

## LOCKHEED AGM-158 WARHEAD

- ★ ACCURACY = 10 FEET
  - ★ WEIGHT = 2250 POUNDS
  - ★ COST = \$700,000
- USED INFARED TERMINAL  
SEEKER, A TURBOJET ENGINE,  
AND GPS JAMMING RESISTENCE

SOURCE: "SATELLITE-GUIDED MUNITIONS" MICHAEL PUTTRE, SCIENTIFIC AMERICAN. FEBRUARY 2003. TL-04/23/03-05

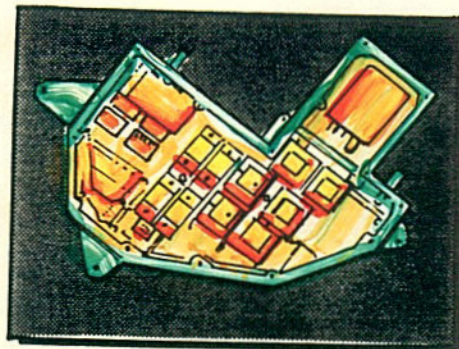
# GPS FOR TOMAHAWK UPGRADE



## THE TOMAHAWK CRUISE MISSILE

- SUBSONIC VELOCITY 1500-MILE RANGE
- SKIMS OVER THE GROUND AS LOW AS 100 FEET
- FOLLOWS A WINDING DEFENSIVE TRAJECTORY
- INERTIAL GUIDANCE PERIODICALLY UPDATED BY "TERRAIN MATCHING"

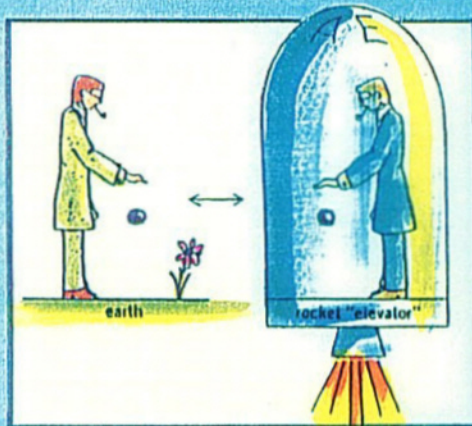
## GPS UPGRADES FOR THE TOMAHAWK



8 INCHES

- 2-CHANNEL NAVSTAR RECEIVER
- ADVANTAGES OF GPS INSTALLATION:
  - IMPROVED TARGETING
  - REDUCED MISSION PLANNING TIME
  - ENHANCED NAVIGATION ACCURACY

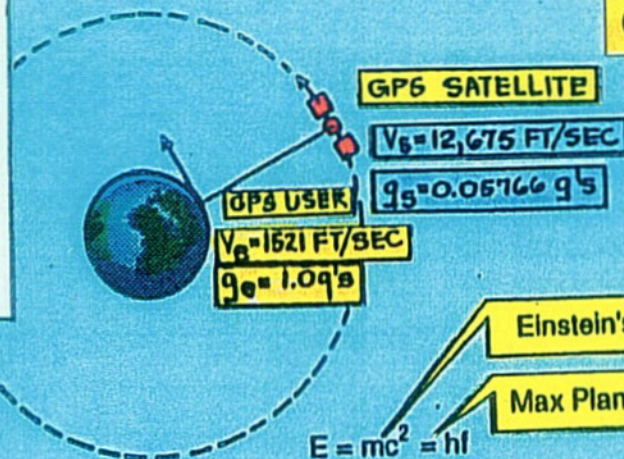
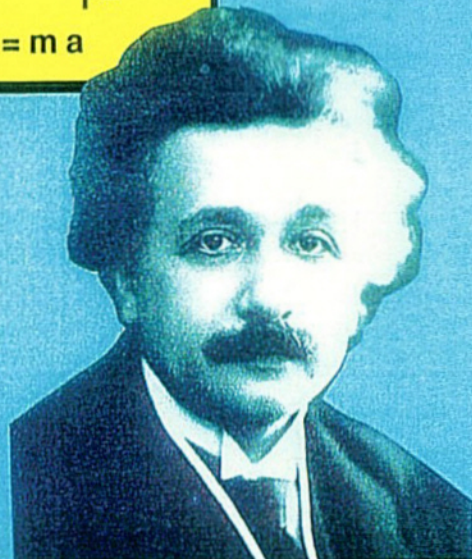
# SIMPLE MATHEMATICAL DERIVATION OF EINSTEIN'S GENERAL THEORY OF RELATIVITY



GRAVITATIONAL  
MASS AND  
INERTIAL MASS  
ARE THE SAME

$$F = \frac{GmM}{r^2}$$

$$F = ma$$



## GENERAL THEORY OF RELATIVITY

IF A PHOTON FALLS FREELY FROM THE GPS ALTITUDE TO THE SURFACE OF THE EARTH, IT MUST UNDERGO A CHANGE IN POTENTIAL ENERGY WHICH EQUALS THE INTEGRAL OF THE PRODUCT OF FORCE AND DISTANCE.

$$\Delta E_{\text{POT}} = \int_{r_s}^{r_e} F dr = \int_{r_s}^{r_e} \frac{mg_e r_e^2}{r^2} dr$$

$$\Delta E_{\text{POT}} = -mg_e r_e^2 \left[ \frac{1}{r_e} - \frac{1}{r_s} \right]$$

$$\Delta E_{\text{POT}} = -\frac{hf}{c^2} g_e r_e^2 \left[ \frac{1}{r_e} - \frac{1}{r_s} \right]$$

Einstein's Equation

Max Planck's Equation

$$E = mc^2 = hf$$

SO

$$m = hf/c^2$$

THE PHOTON'S TOTAL ENERGY MUST BE CONSERVED DURING THE FALL SO

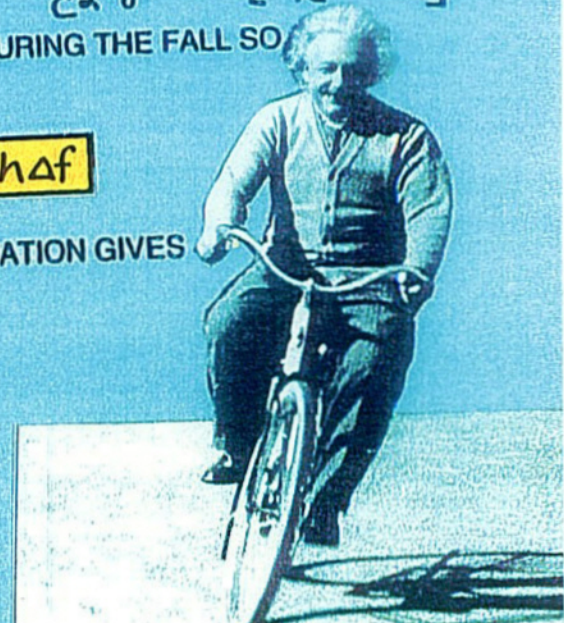
$$E_{\text{TOT}} = E_{\text{POT}} + hf = \text{constant}$$

$$0 = \Delta E_{\text{POT}} + h\Delta f$$

$$\Delta E_{\text{POT}} = -h\Delta f$$

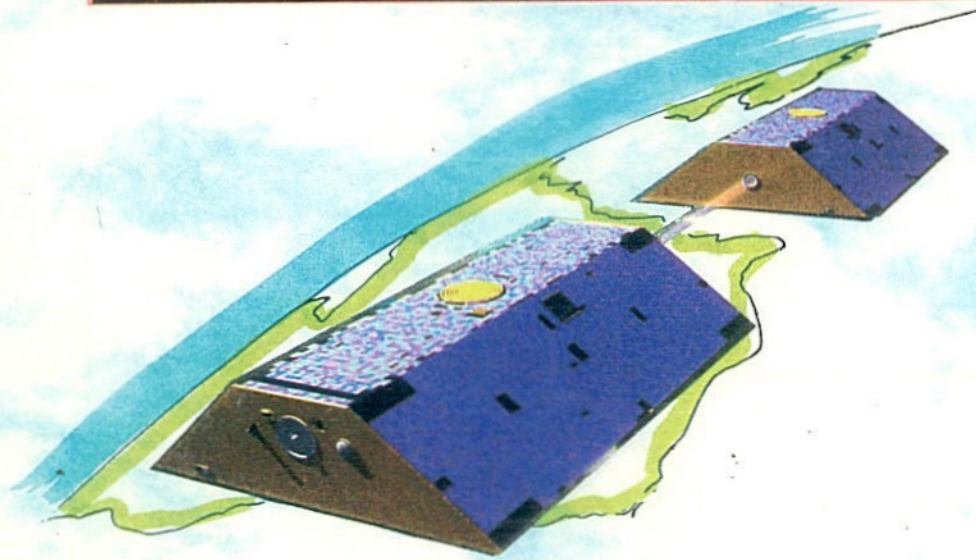
SUBSTITUTING THIS INTO THE POTENTIAL ENERGY EQUATION GIVES

$$\frac{\Delta f}{f} = \frac{g_e r_e}{c^2} \left[ 1 - \frac{r_e}{r_s} \right]$$



# TWO IDENTICAL GRACE SATELLITES FLYING IN FORMATION TO MAP THE EARTH'S INTERIOR

## THE TWIN GRACE SATELLITES



## FORMATION FLYING

- ★ TWO 950-POUND GERMAN-AMERICAN GRACE SATELLITES FLY IN "SINGLE-FILE" 200 MILES APART
- ★ THE 311-MILE ORBITS ARE INCLINED 89°
- ★ CONTINUOUS K-BAND AND KA-BAND RANGING MEASUREMENTS- ACCURATE TO 1/2500 OF AN INCH (10 MICRONS)

## MAPPING CAPABILITIES

- ★ GRACE CAN DETECT 200 MILE DISK OF MATERIAL 1/2 INCH THICK
- ★ 60 MAPPINGS OVER 5 YEARS

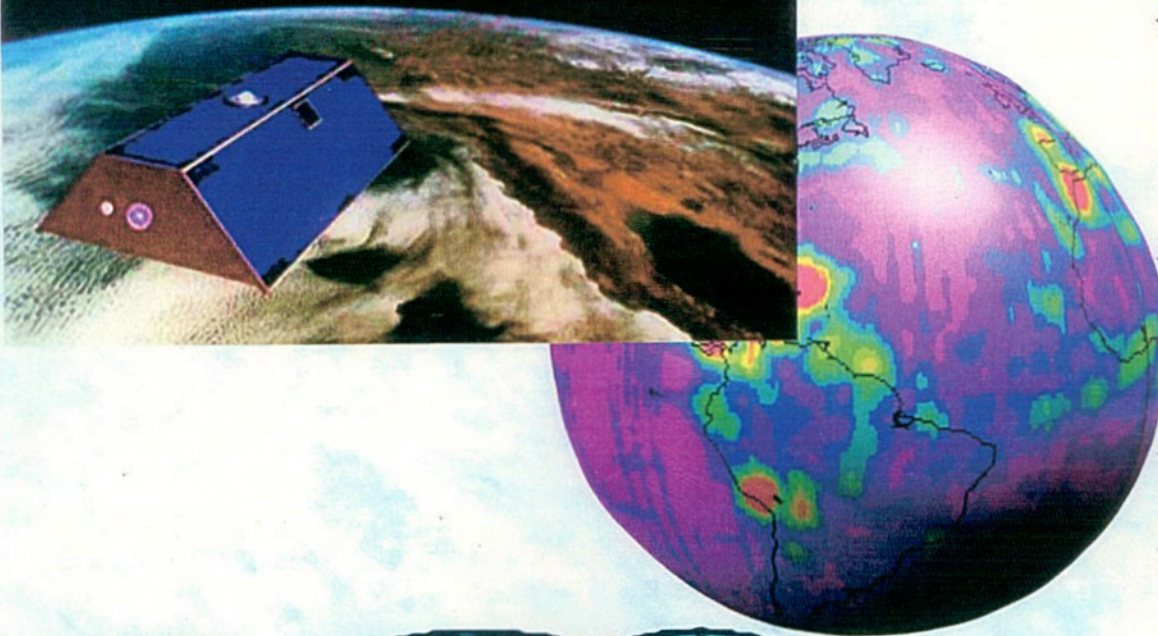
## ON-ORBIT MEASUREMENTS

- ★ "SPEED BUMPS" SPEED UP APPROACHING SATELLITE, THEN SLOW IT DOWN-THIS CHANGES THE RANGE!
- ★ ON BOARD GPS PINPOINTS THE SATELLITE LOCATIONS

**"ORBITING GRAVITY MAPPERS MIGHT SPOT OIL FIELDS"**  
FRANK MORRING, JR. AVIATION WEEK. MARCH 4, 2002.

# POSITIONING THE GRACE SATELLITE TO WITHIN TWO INCHES!

## Instrument of Grace GPS Augments Gravity Measurements



THE NET RESULT:  
DYNAMIC **3** -DIMENSIONAL ORBITAL  
POSITIONS ACCURATE TO WITHIN  
**2** TO **3** CENTIMETERS  
(ABOUT ONE INCH!)

### SATELLITE POSITIONING AND CROSSLINK RANGING

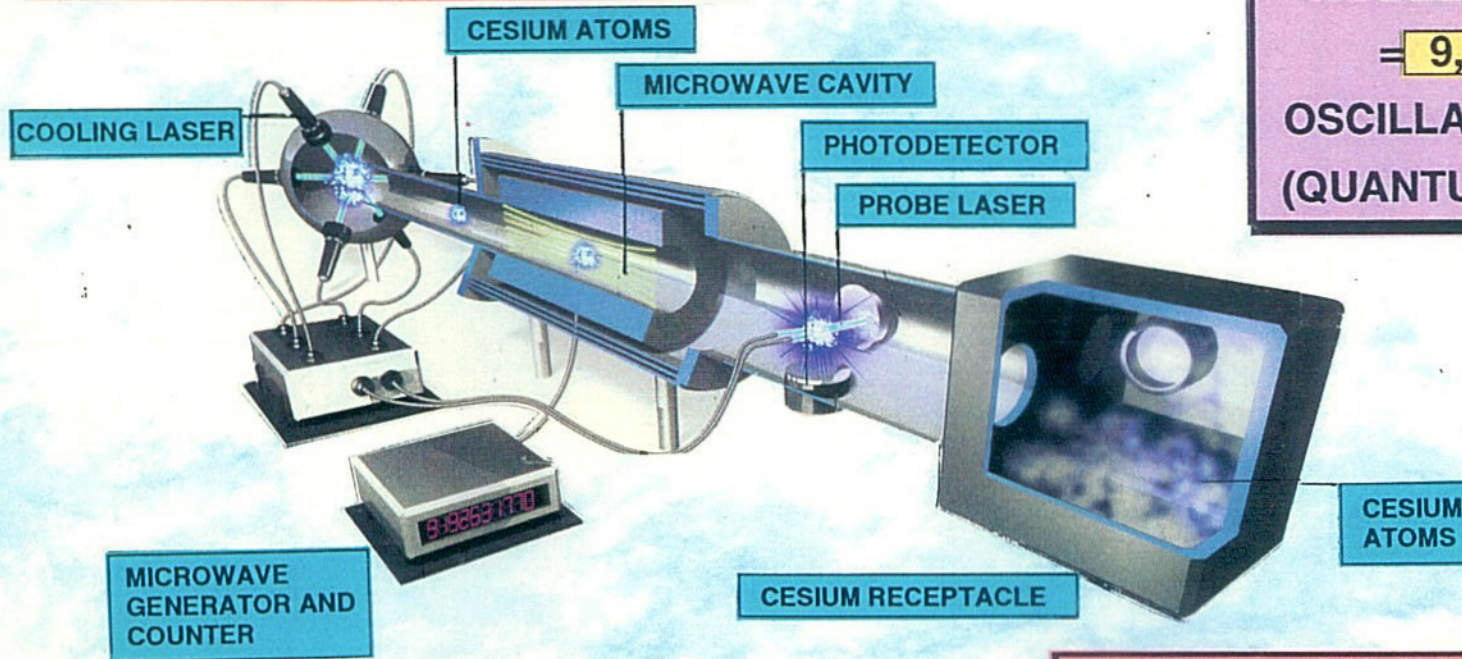
- ★ CROSSLINK RANGING SIGNALS AT **32.7 GHz** AND **24.5 GHz**  
(**1/3** AND **1/2**-INCH WAVELENGTHS, RESPECTIVELY)
- ★ THE CROSSLINK RANGING IS ACCURATE TO **10** MICRONS, **1/2500**-INCH  
(THE WIDTH OF A HUMAN BLOOD CELL)
- ★ STAR TRACKERS MEASURE THE SPACECRAFT ATTITUDES TO WITHIN **25** ARC-SECONDS  
(**0.0075** DEGREES)
- ★ SOLID-STATE ACCELEROMETERS MEASURE SPACECRAFT  
ACCELERATIONS TO WITHIN **10<sup>-11</sup> g's**
- ★ GPS AIDED ATOMIC CLOCKS MEASURE TIME TO WITHIN **150** PICOSECONDS  
(EFFECTIVE  $\Delta f/f = 2.4 \times 10^{-14}$ )

SOURCE: "INSTRUMENTS OF GRACE: GPS AUGMENTS GRAVITY MEASUREMENTS!!" CHARLES DUNN PLUS 19 COAUTHORS (17 OF THEM FROM JPL, 2 FROM THE UNIVERSITY OF TEXAS) GPS WORLD FEBRUARY 2003.

TL-04/23/03-03

# THE FRENCH PHARAO ATOMIC CLOCK IS HEADED FOR THE INTERNATIONAL SPACE STATION

## THE FRENCH PHARAO



TRIGGER FREQUENCY

= 9,192,631,770

OSCILLATIONS/SECOND  
(QUANTUM MECHANICS)

## CLOCK DESCRIPTION

- ★ CESIUM FOUNTAIN CLOCK IS DESIGNED TO BE OPERATED IN ZERO-g (SPACE STATION)
- ★ CESIUM ATOMS ARE SUPERCOOLED INTO GASEOUS BALLS BY LASERS
- ★ PROBE LASER ZAPS THE BALLS OF ATOMS TO MEASURE SPIN-STATE INVERSIONS

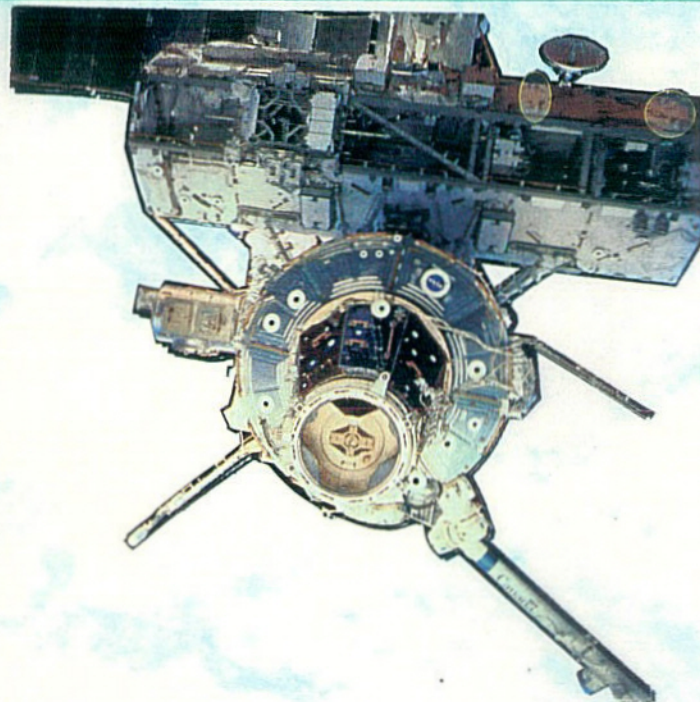
"HOW TIME WILL FLY" W. WAYT GIBBS  
SCIENTIFIC AMERICAN. SEPTEMBER 2002

## THE BENEFITS OF SPACE

- ★ LOW TEMPERATURES MINIMIZE THE RELATIVISTIC AND DOPPLER SHIFTS  
LONGER TRAVERSE=> MORE ACCURACY
- 6 -FOOT PATH ON EARTH =  
= 0.25 SECONDS
- IN SPACE 0.5 FT/SEC  
INJECTION USES 10 -SECOND TRAVERSE TIME

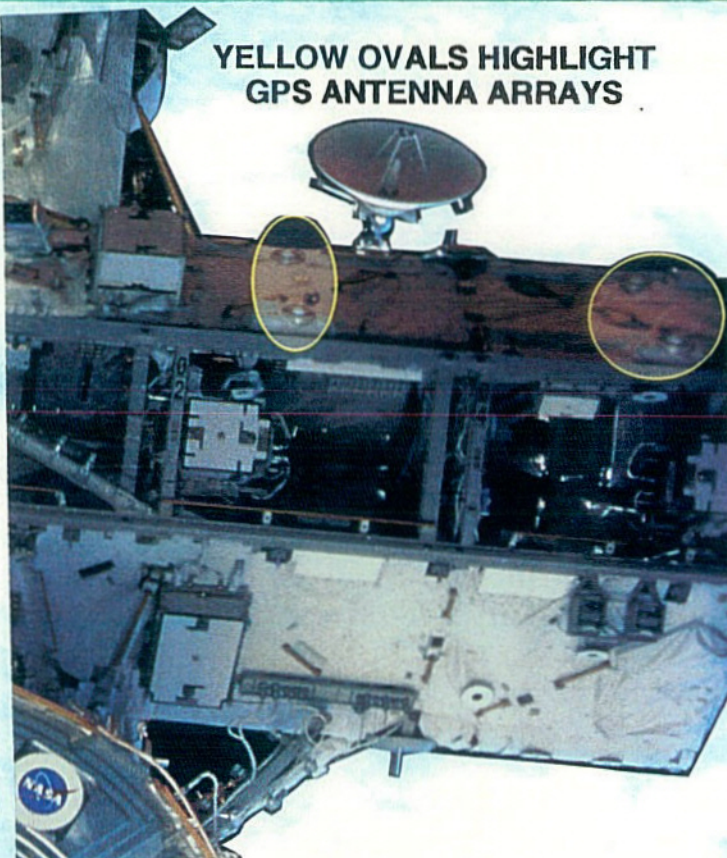
TL-01/18/03-07

# FLYING HIGH: GPS ON THE INTERNATIONAL SPACE STATION



YELLOW OVALS HIGHLIGHT  
GPS ANTENNA ARRAYS

FOUR **GPS**  
ANTENNAS  
ARRANGED IN A  
**5** BY **10** FOOT  
RECTANGLE



## PERFORMANCE REQUIREMENTS

ERROR	INTERNATIONAL SPACE STATION (3 $\sigma$ VALUES)	CREW RETURN VEHICLE (3 $\sigma$ VALUES)
POSITION	3000 FT	330 FT
ATTITUDE	0.50°	0.25°

## SPECIAL PROBLEMS

- ★ MULTIPATH AND 100-FOOT CABLING LENGTHS ON THE SPACE STATION CREATE SOLUTION AMBIGUITIES AND OTHER TECHNICAL PROBLEMS
- ★ **40**-MINUTE RISE AND SET TIMES FOR **GPS** SATELLITES RATHER THAN **6** TO **8** HOURS

"FLYING HIGH: GPS ON THE INTERNATIONAL SPACE STATION AND  
CREW RETURN VEHICLE. SUSAN F. GOMEZ. GPS WORLD. JUNE 2002.

TL-01/18/03-08

# EUROPE'S GALILEO IS SLATED TO JOIN THE GPS AND THE GLONASS

PARAMETER	AMERICAN GPS CONSTELLATION	RUSSIAN GLONASS	EUROPEAN GALILEO CONSTELLATION
NUMBER OF SATELLITES	24 TO 28	24 (ULTIMATE GOAL)	30 (CURRENT THINKING)
ORBITAL ALTITUDE	10,898 N.MI.	10,313 N.MI.	12,418 N.MI.
ORBITAL PERIOD	11 HRS. 28 MIN	11 HRS 15 MIN	13 HRS 55 MIN
NUMBER OF ORBIT PLANES	6	3	3
INCLINATION ANGLE	55°	64.8°	54°
DATE OF OPERATIONAL STATUS	1995	UNKNOWN	2008 (CURRENT THINKING)
L-BAND NAVIGATION FREQUENCIES	L <sub>1</sub> = 1575.42 MHZ L <sub>2</sub> = 1227.6 MHZ (OTHERS ARE IN THE WORKS)	12 DIFFERENT L-BAND FREQUENCIES	L <sub>1</sub> = 1575.42 MHZ

**"HOW GALILEO WILL IMPROVE POSITIONING PERFORMANCE".  
GERALD LACHPELLE, et. al GPS WORLD. SEPTEMBER 2002.**

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I suggest that you read through these course descriptions and then call me personally, Jim Jenkins, at (410) 531-6034, and I'll explain what we can do for you, what it will cost, and what you can expect in results and future capabilities.

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