GPS Current Status & Future Enhancements

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Marc A. Weiss, Ph.D.
Time and Frequency Division
National Institute of
Standards and Technology

OVERVIEW

- **GPS Current Status**
- **GPS Future**
- **GPS-Galileo Interoperability**
- **Failure Modes**
- **Summary – Conclusions**

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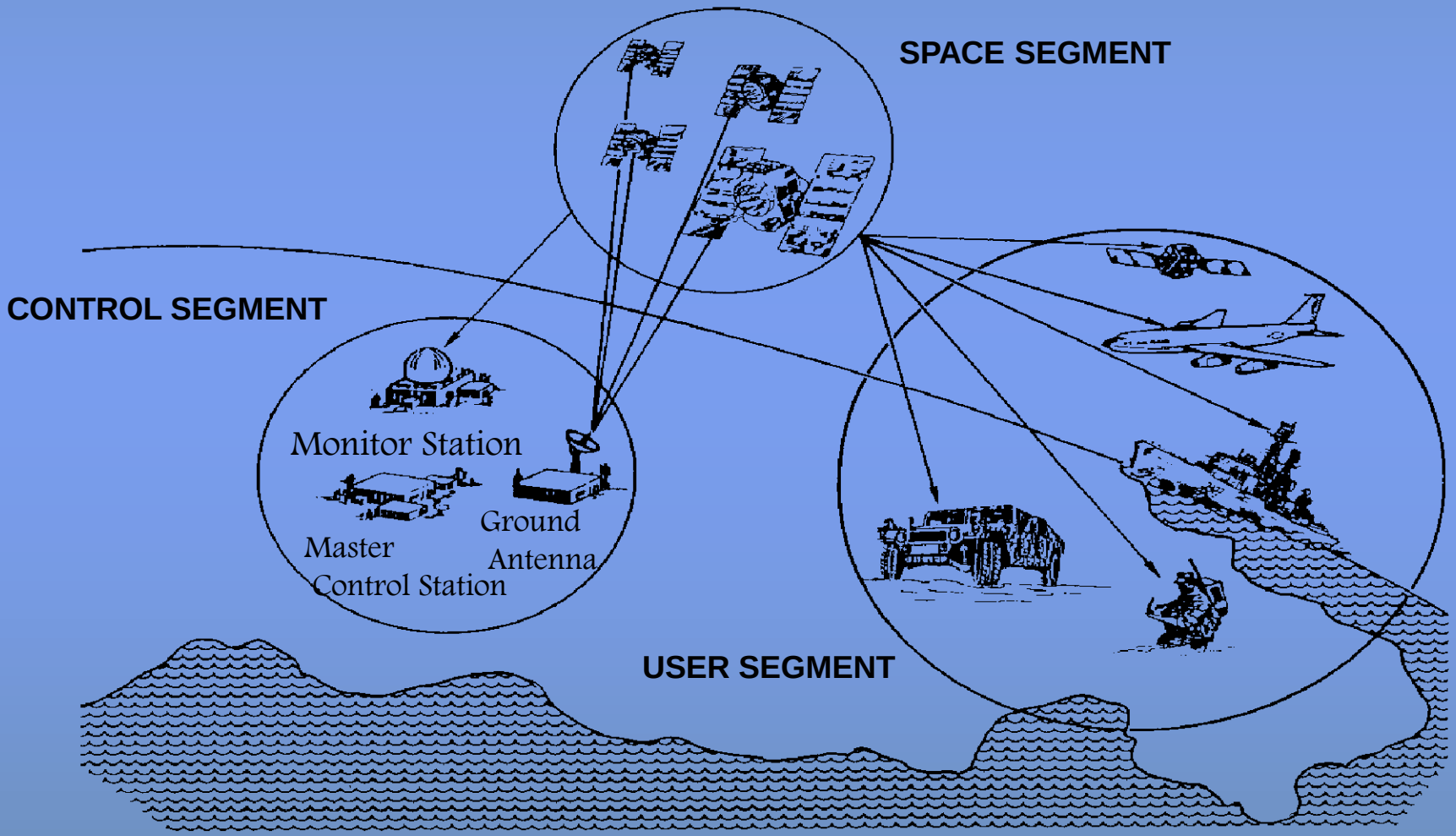
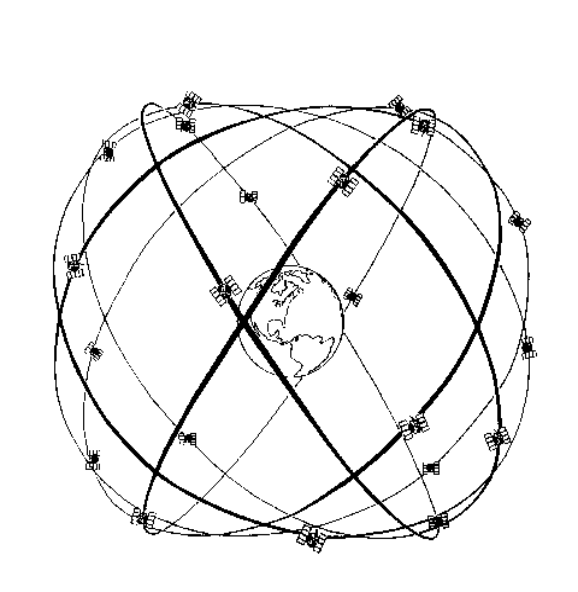
GPS System Configuration - Three Major Segments



Space Segment

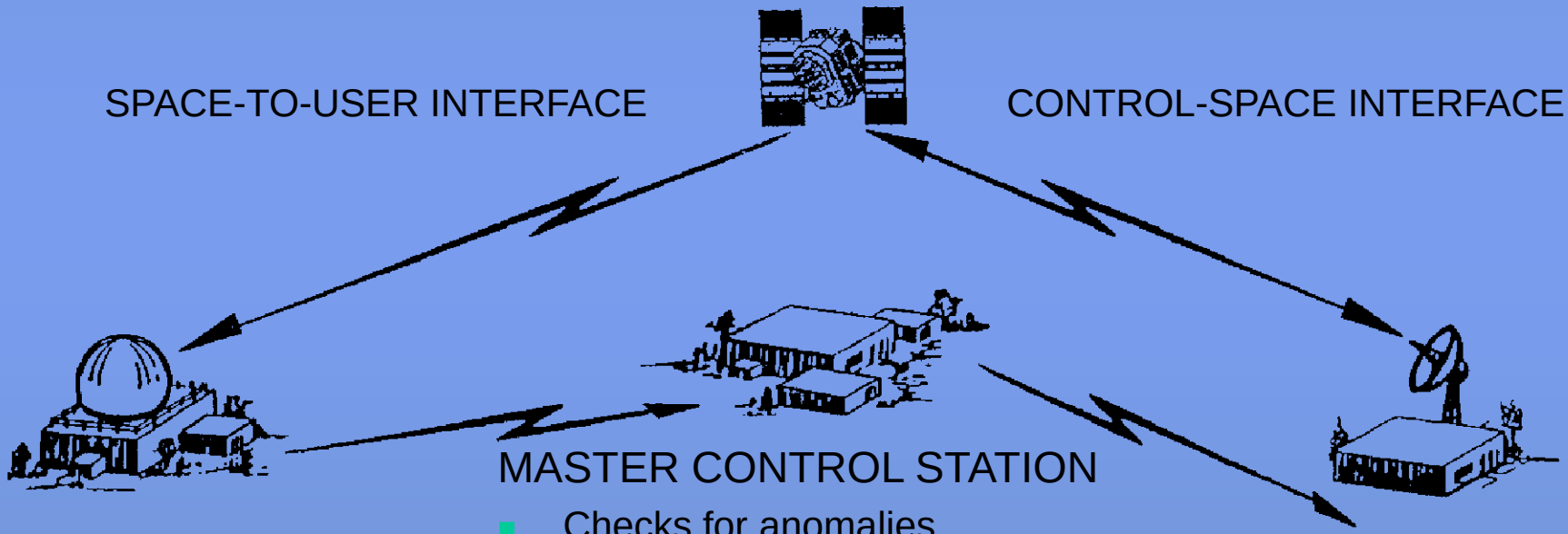


- Nominal 24 satellite constellation
  - Semi-synchronous, circular orbits (~20,200 km/10,900 nautical miles altitude)
  - Repeating ground tracks (11 hours 58 minutes)
  - Six orbital planes, inclined at 55 degrees, four vehicles per plane
  - ➢ *designed for global coverage (at least 4 sats in view)*
- Redundant cesium and/or rubidium clocks on board each satellite
- In recent years there have been two to three replenishment launches per year

Control Segment

SPACE VEHICLE (SV)

Broadcasts the SIS PRN codes, L-band carriers, and 50 Hz navigation message stored in memory



MONITOR STATION

- Sends raw observations to MCS

MASTER CONTROL STATION

- Checks for anomalies
- Computes SIS portion of URE
- Generates new orbit and clock predictions
- Builds new upload and sends to GA

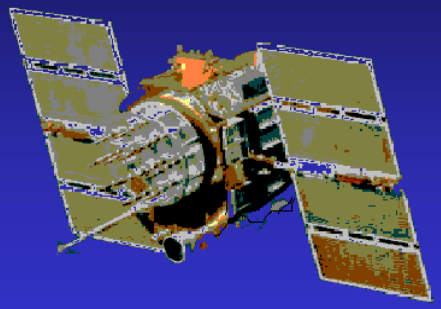
GROUND ANTENNA

- Sends new upload to SV

Control Segment – Monitor Stations

- Existing GPS Monitor Stations
  - Hawaii, Ascension Island, Diego Garcia, Kwajalein, and Colorado Springs

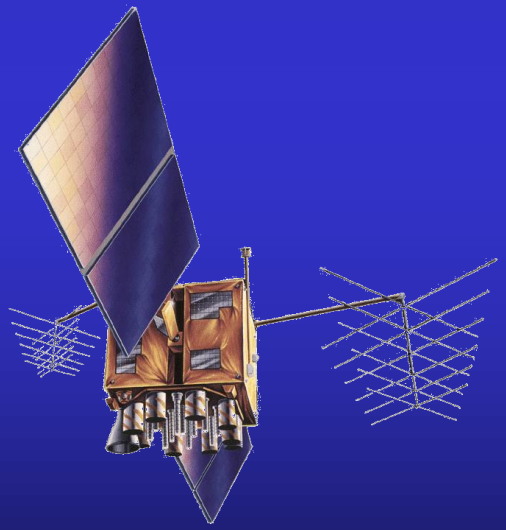
Current GPS Constellation Status



Block II/IIA
Built by Boeing Aerospace
Launched 1989 - 1997

- Currently 28 satellites operational
  - 14 Block IIA
  - 12 Block IIR
  - 2 Block IIR-M
- Next Block IIR-M launch scheduled for 14 November 2006 Today!

- Age Summary
  - All satellites have greatly exceeded original design lifetime
  - 12 satellites are more than 10 years old
  - Several are “single string”

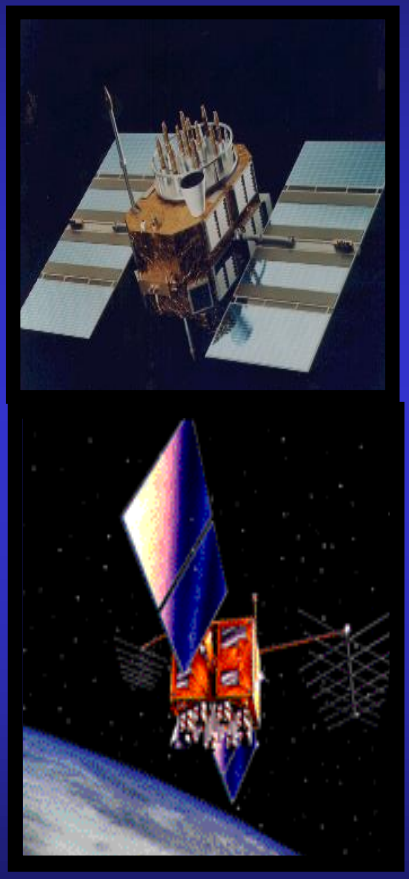


Block IIR/IIR-M
Built by Lockheed Martin
Launched 1997 - 2007

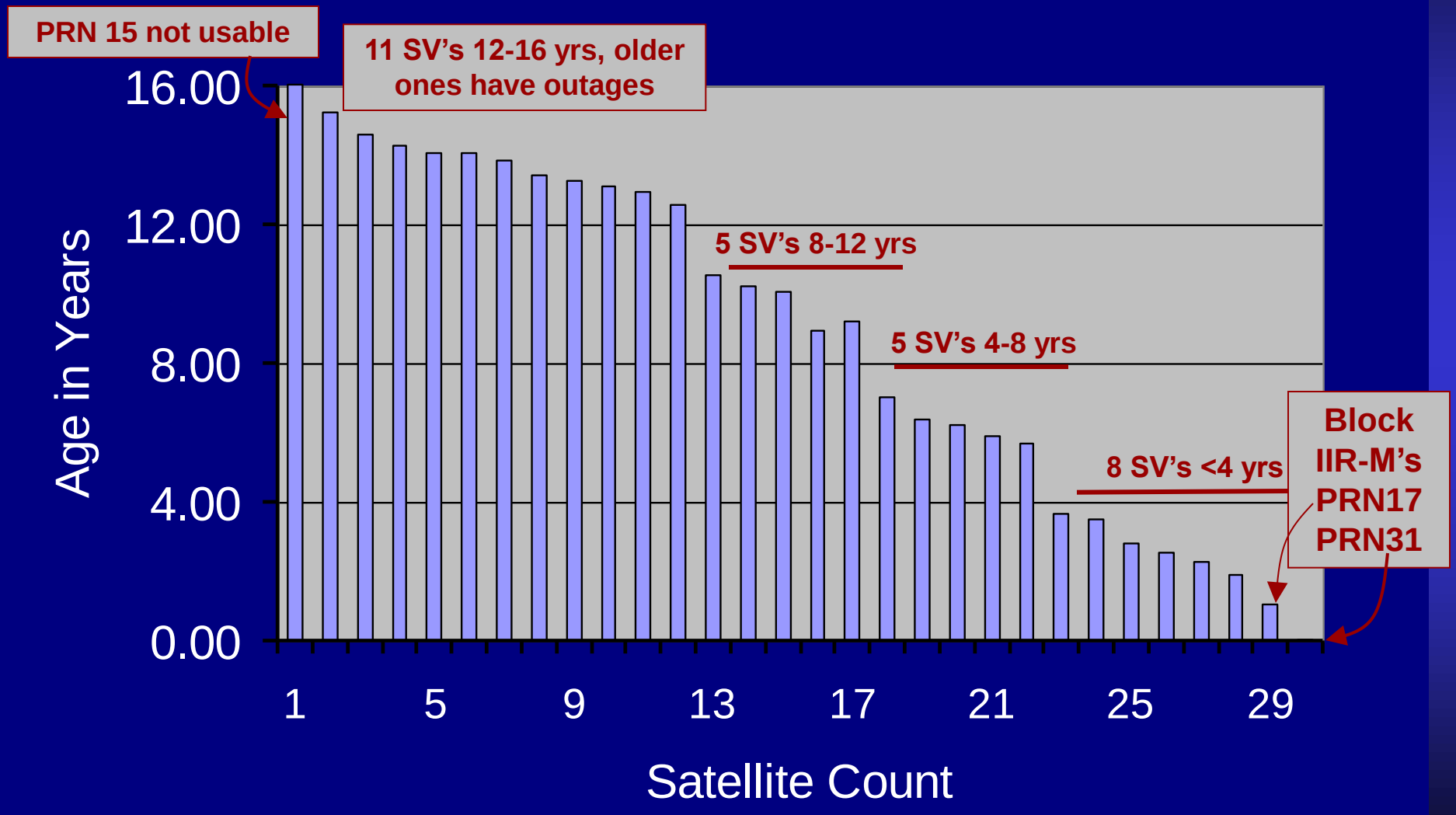
GPS Constellation Status

28 Operating Satellites
(to ensure 24)

- **14 Block IIA satellites operational**
- **12 Block IIR satellites operational**
  - **Modernizing up to 8 Block IIR satellites**
- **2 Block IIR-M in orbit**
  - **PRN 17 launched Sep 2005**
  - **PRN 31 launched Sep 2006**
- **3rd IIR-M launch currently scheduled Nov 2006**
- **Continuously assessing constellation health to determine launch need**
- **Global GPS civil service performance commitment met continuously since Dec 93**



Age of GPS Satellites as of 13Oct-2006



SPS Performance

source: GPS SPS Performance Standard, Department of Defense, Oct 2001

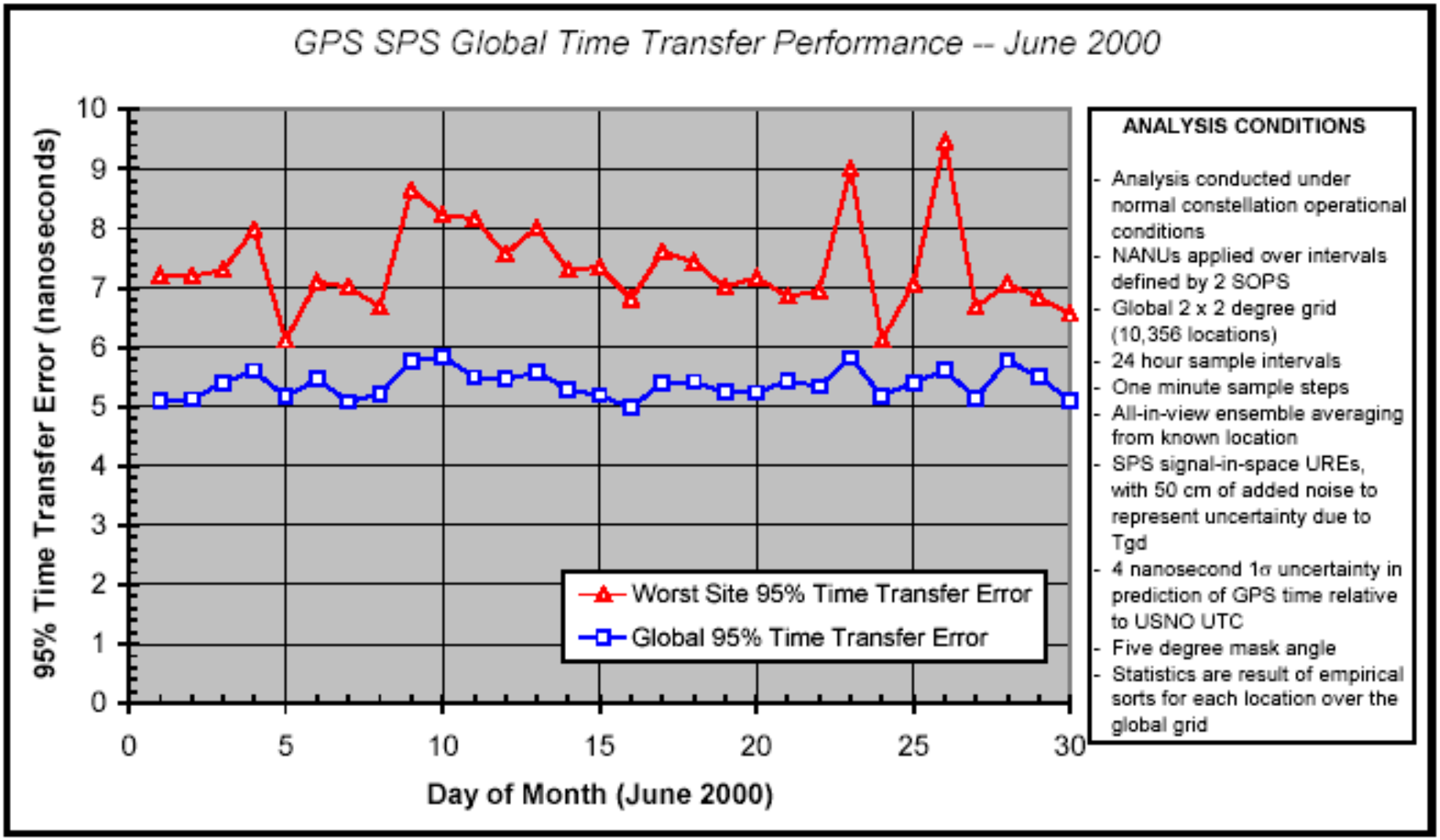
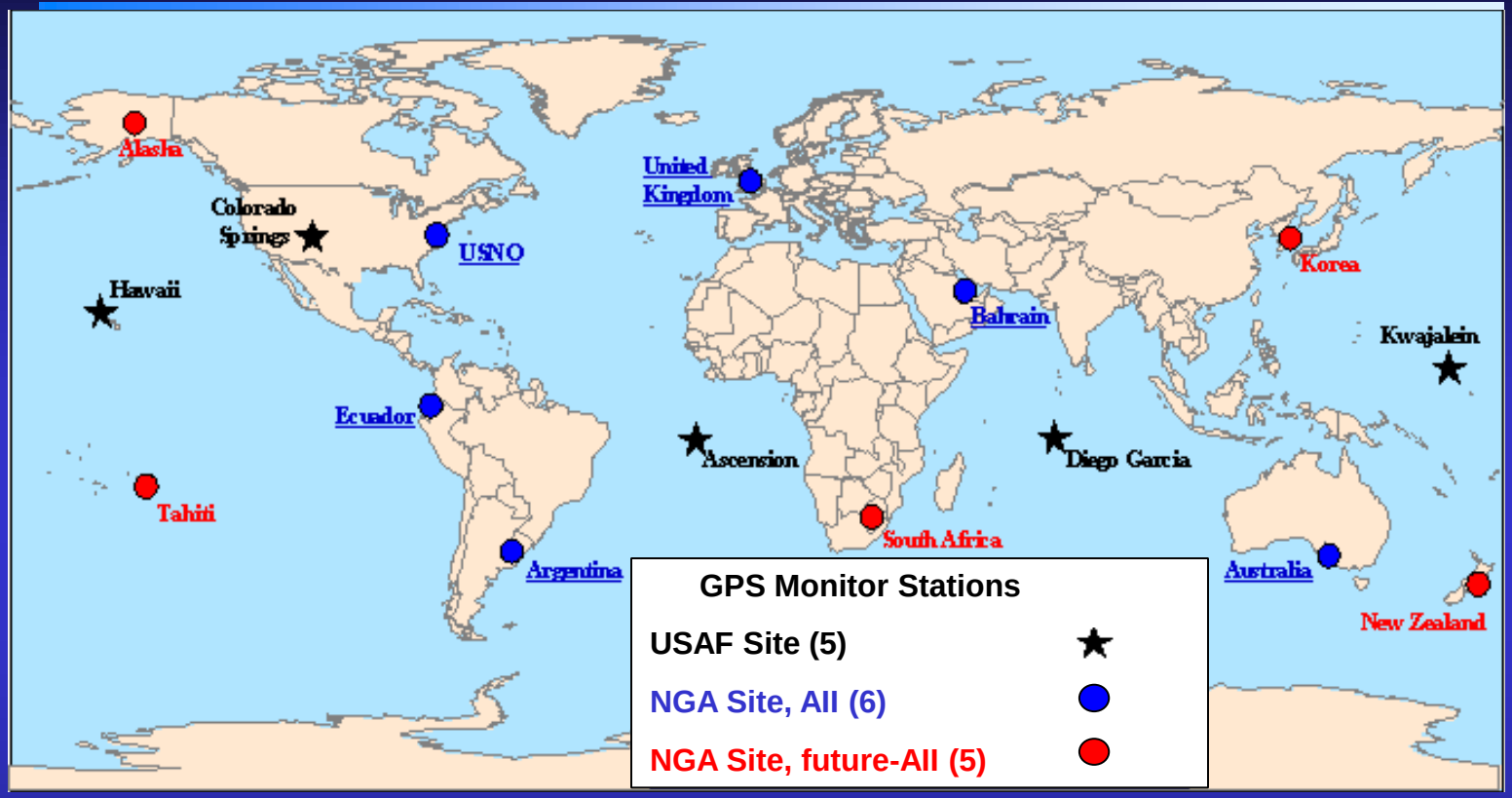


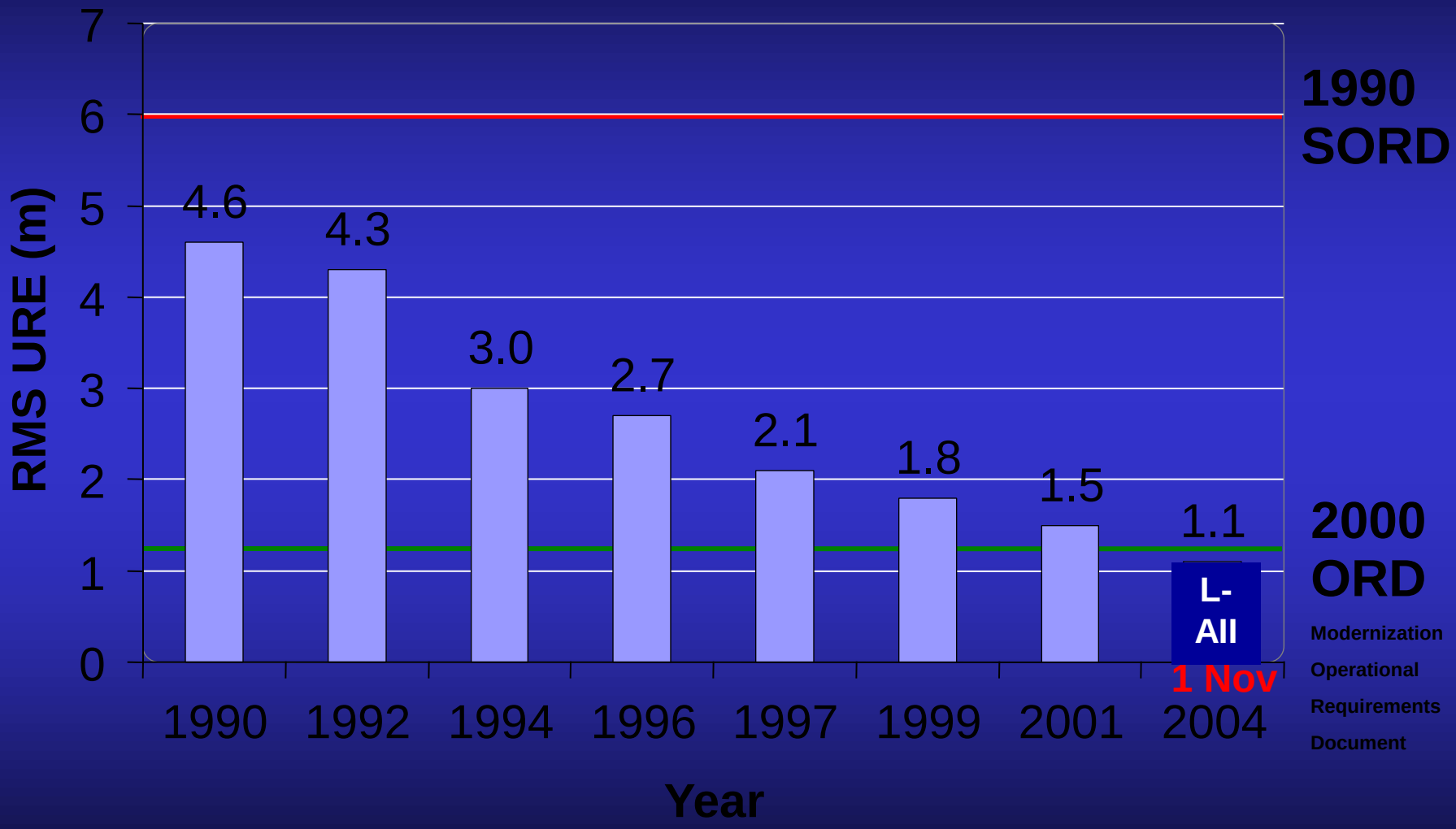
Figure A-5-10. Typical Example of GPS SPS SIS Time Transfer Performance – June 2000

Legacy Accuracy Improvement Initiative (L-AII)



- USAF working with National Geospatial-Intelligence Agency (NGA) to incorporate NGA ground stations into GPS network
  - Reduce range error and improve accuracy
  - Initially six NGA sites will be added
  - By 2006, 5 more NGA sites will be added to L-AII

URE Performance History

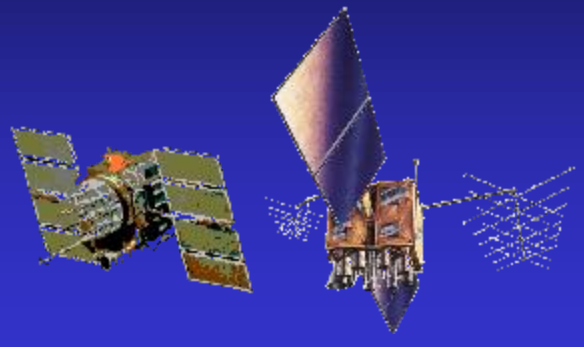


OVERVIEW

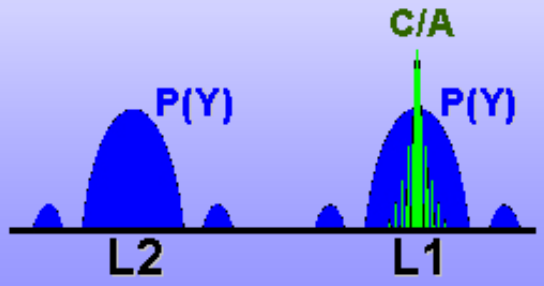
- GPS Current Status
- GPS Future
  - Modernization
  - New Signals
  - New Monitor Stations & Ground Antennas
  - GPS III
- GPS-Galileo Interoperability
- Failure Modes
- Summary – Conclusions

GPS Modernization Plan

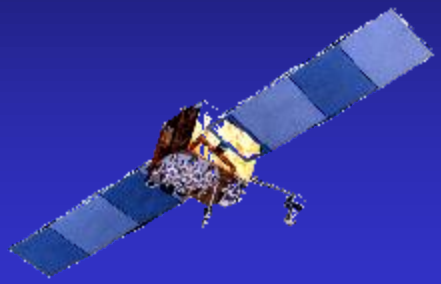
Block IIA/IIR



IIA / IIR: Basic GPS
- C/A civil signal (L1C/A)
- Std Service, 16-24m SEP
- Precise Service, 16m SEP
  - L1 & L2 P(Y) nav

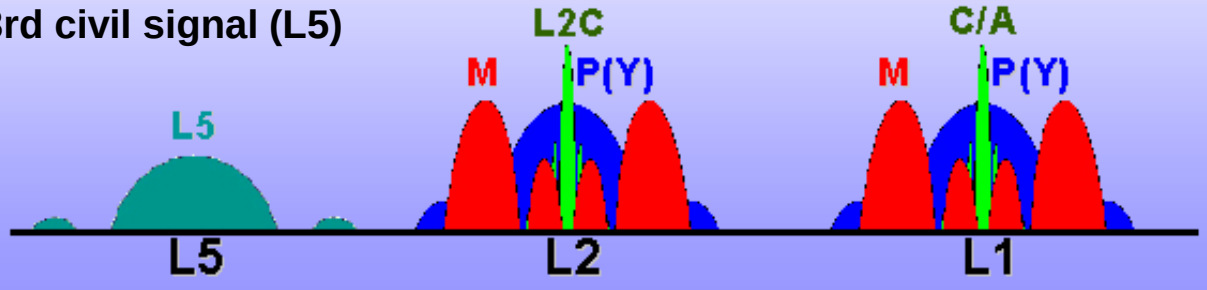


Block IIR-M, IIF

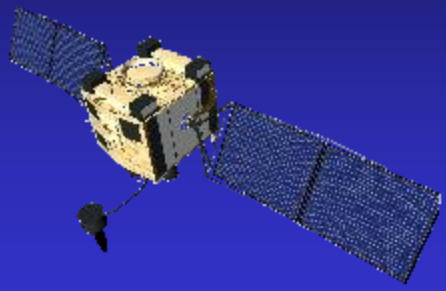


IIR-M: IIA/IIR capabilities &
- 2nd civil signal (L2C)
- New military code
- Flex A/J power (+7dB)

IIF: IIR-M capability plus
- 3rd civil signal (L5)



Block III



III: IIF capabilities &
- Improved civil signal (L1C)
- Increased accuracy (4.8-1.2m)
- Evaluating integrity improvements
- Navigation surety
  - Increased A/J power (+20 dB)

Monitoring Civil Signals

- Current C/A code monitored indirectly
  - Needed to lock on P-code at monitor stations
  - Depends on common hardware in SV
    - Clock
    - Some electronics
- Has been prioritized by PNT-ExCom
  - Planned to come on line in 2009

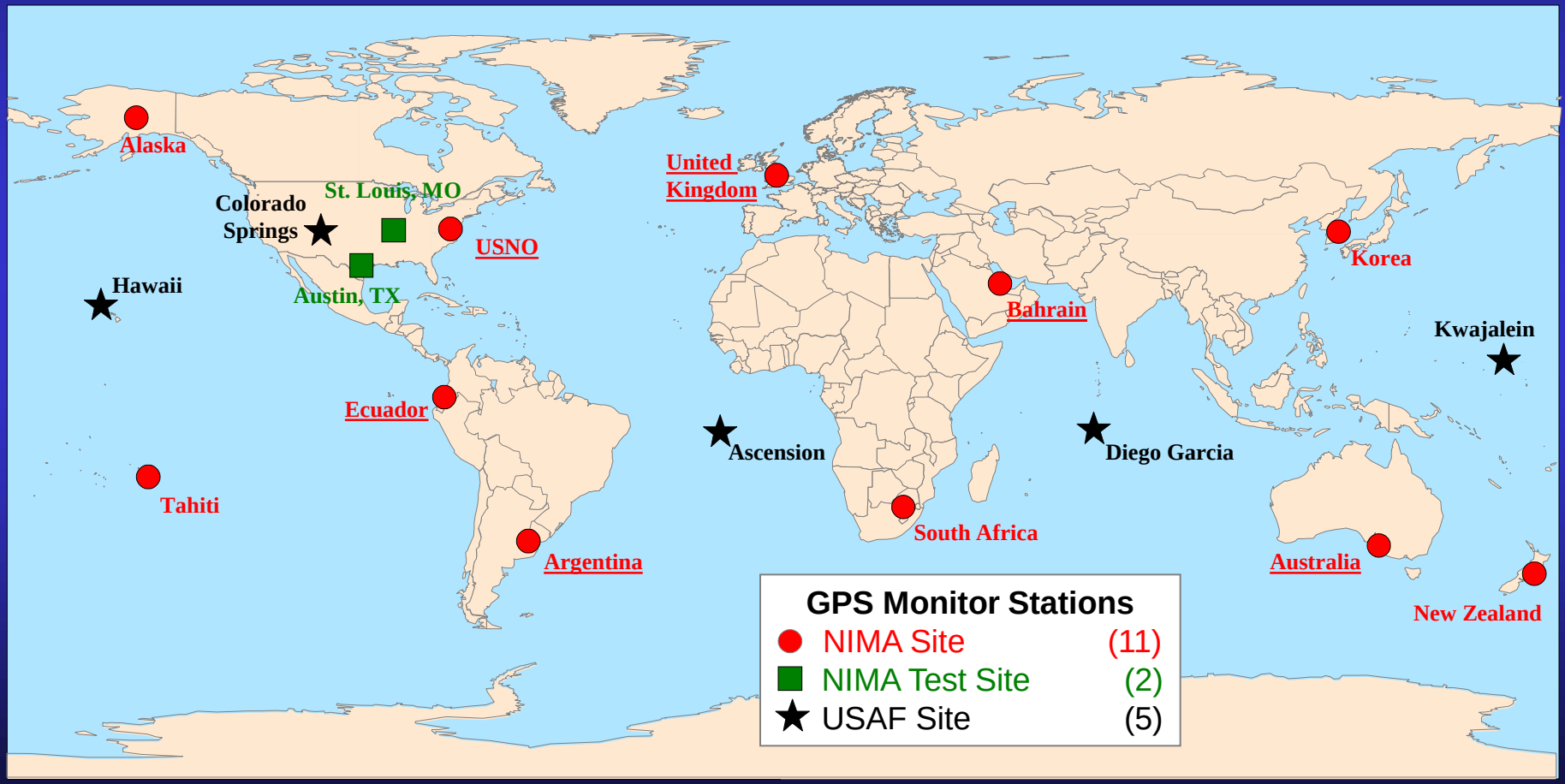
Ground Control Modernization

- **Replace existing Master Control Station mainframe computer with a distributed architecture**
- **Build fully mission capable Alternate Master Control Station (AMCS)**
- **Add IIF command and control functionality**
- **Legacy Accuracy Improvement Initiative**
  - Additional information from National Geospatial-Intelligence Agency sites decreases "Age of Data", thus increasing accuracy in GPS satellite orbital position and clock data

GPS Future Monitor Station Network

- Six stations added to existing five in 2005
  - UK, Australia, Bahrain,Argentina, Equador, USNO
- Additional five to be added in ~ 2007

Developing GPS Monitor Station Network



GPS Modernization Schedule

Activity	Implementation Date
SA set to zero	May 2000
GPS IIR-M Enhancements - New L2 Civil (L2C) Signal - M-code on L1 & L2	Launches: September 2005, September, November 2006, …
GPS IIF Enhancements - New L2 Civil (L2C) Signal - M-code on L1 & L2 - L5	1st launch currently scheduled for 2008
GPS III Enhancements - New L2 Civil (L2C) Signal - M-code on L1 & L2 with greater power - L5 - Future Capabilities	1st launch ~ 2012
OCS Enhancements	On-going

GPS III

- Concept Definition completed in 2005
- Development contract to be awarded summer 2007
- GPS-III (2013 ? -): New features are being considered to increase reliability and accuracy
  - Faster time to alert or correct failures
  - More accuracy
  - More availability
  - Increased signal strength

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Galileo / GPS Time Offset (GGTO) ICD

- Scope:
  - The purpose of the Galileo / GPS Time Offset (GGTO) ICD is to provide a starting point for developing a detailed ICD that will allow precise estimation of the GGTO and inclusion of the offset between GPS and Galileo system time in each system's navigation message
- Goal:
  - An objective of three nanoseconds (one meter) accuracy for the GGTO message has been accepted

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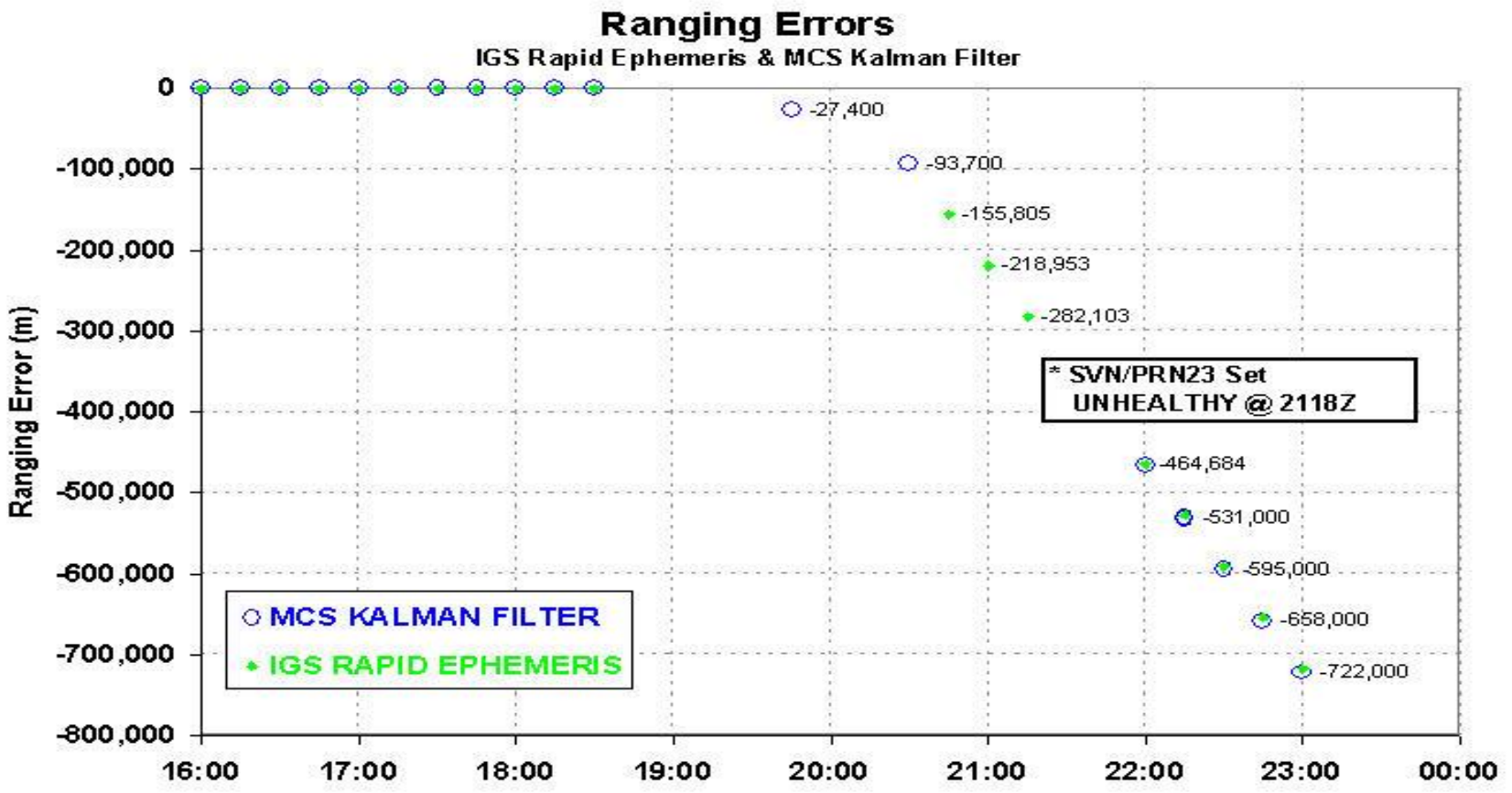
Failure Modes

- Satellite failure modes can produce signals with large errors
  - Receiver Autonomous Integrity Monitoring (RAIM) should compare all satellite signals and discard errors
  - System design should compare GPS-based clock to local signals
- Receiver problems
  - Satellites set unhealthy should not be used
  - Firmware errors and wrong interpretations of specs
    - Ionosphere/troposphere models
    - Leap seconds
- Jamming: intentional and unintentional

PRN/SVN 23 Anomaly: Jan 1, 2004

Due to failed atomic frequency standard



Plot Courtesy of Boeing

Non-Standard Code Problems

- “The SV will transmit intentionally ‘incorrect’ versions of the C/A and the P(Y) codes where needed to protect the users from receiving and utilizing anomalous NAV signals as a result of malfunction …”-ICD200
- 18March97 PRN 5 jumped forward 2 hours, 20 minutes and remained in standard code.
- Several wireless base station transmitters failed in the U.S.

GPS is Vulnerable to Jamming

- GPS signals can be easily jammed
- Incident of a synthesizer accidentally jamming aircraft
  - Transmitter accidentally left on near New York, two weeks Dec 1997 – Jan 1998
  - Jammed aircraft within 300 km
- Most telecom receivers can go into holdover for at least a week with few ill effects

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Summary

- **Civil GPS service continues to exceed performance standards**
- **GPS Modernization is underway**
  - **IIR-M launch with L2C and M-code**
  - **Enhancements will continue through GPS III**
- **US and EU cooperation has made great progress at ensuring compatibility and interoperability between GPS and Galileo**
  - **GPS/Galileo Timing Offset ICD**

Meeting the interoperability challenge will entail simultaneous cooperation and competition over a sustained period of time

Conclusions

- Global GPS civil service performance commitment met continuously since Dec 93
- Future:
  - GPS: new signals, more accuracy, yet backward compatible, more integrity information
  - New/other systems: GLONASS, Galileo, QZSS
- GPS failure modes: they exist **and** there are precautions
- Resources are available