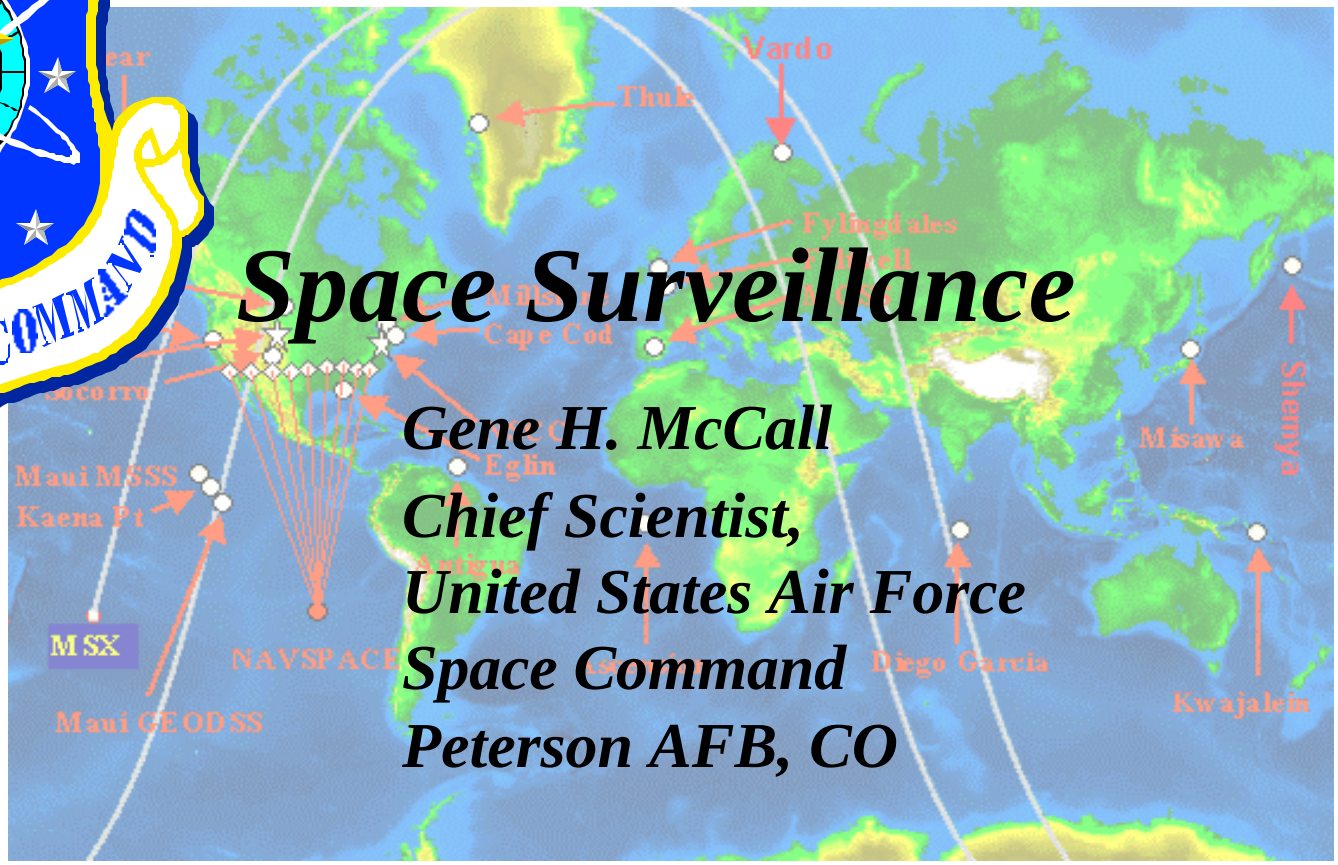
This Briefing Is Unclassified



Space Surveillance

Gene H. McCall
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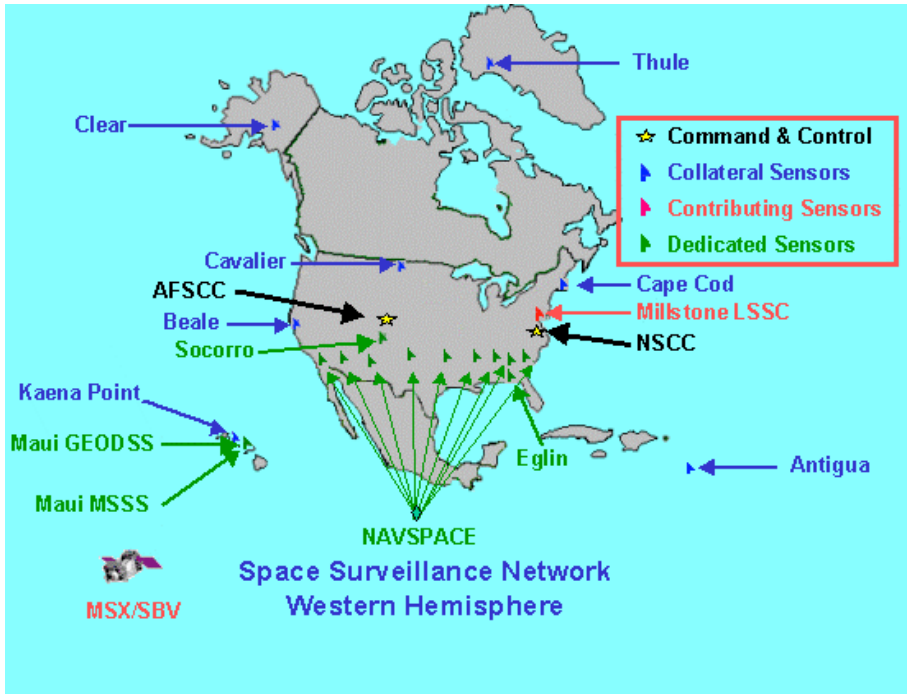
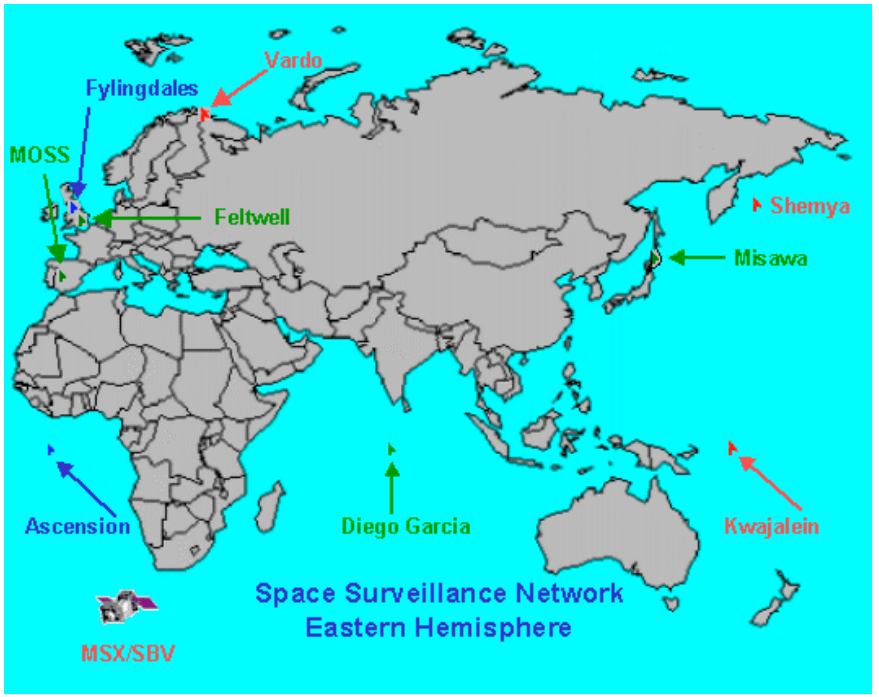
United States Air Force
Space Command
Peterson AFB, CO

Space Surveillance

- **Surveillance and cataloging of space objects is a high priority mission for Air Force Space Command.**
  - **Both civil and military applications**
  - **Collision warnings are an important output**
- **Includes cataloging and orbit predictions**
  - **Regularly published element sets**
- **Modern space conditions demand ever increasing accuracy of both measurement and prediction.**
- **Current standards are in need of revision**

SSN Sensors and C^2 Center Locations

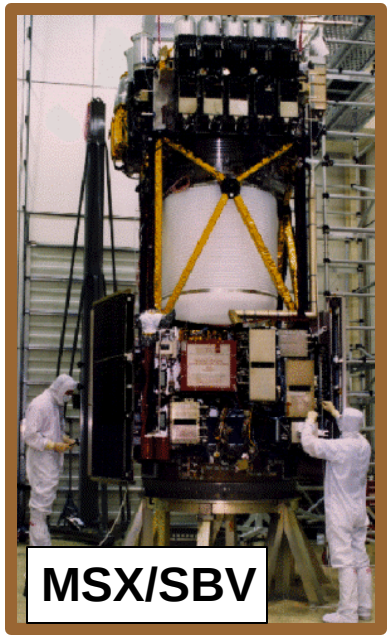


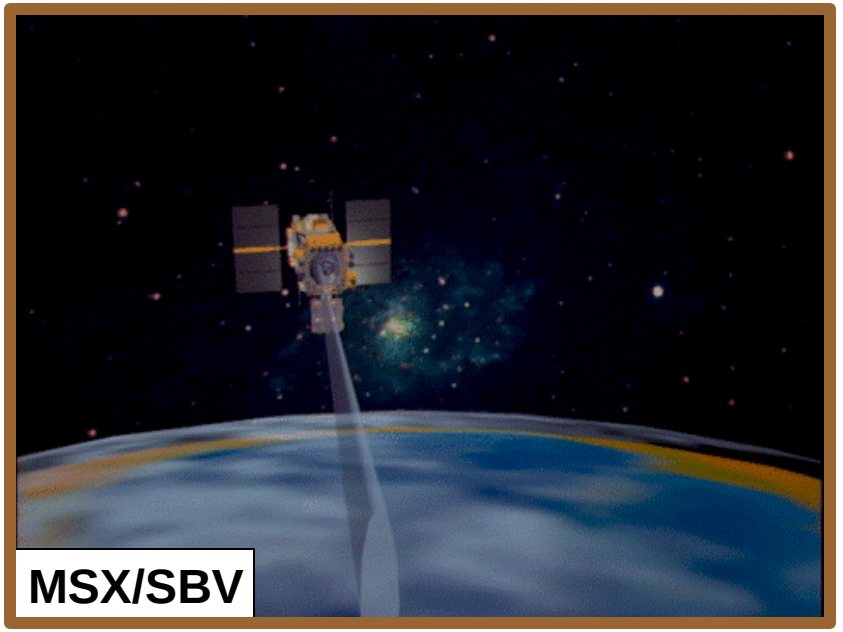


Sensors and Command and Control (C^2)

- **Three types of sensors that support the SSN**
  - **Dedicated. Space Surveillance is primary mission**
  - **Collateral. Space Surveillance is secondary or tertiary mission**
  - **Contributing. Non USSPACECOM sensors under contract to support space surveillance**
- **There are two major C^2 centers that manage the SSN**
  - **Air Force Space Control Center (AFSSC), in CMAS, CO**
    - **Primary C^2 center**
  - **Naval Space Control Center (NSCC), in Dahlgren, VA**
    - **Equivalent backup to the AFSSC**

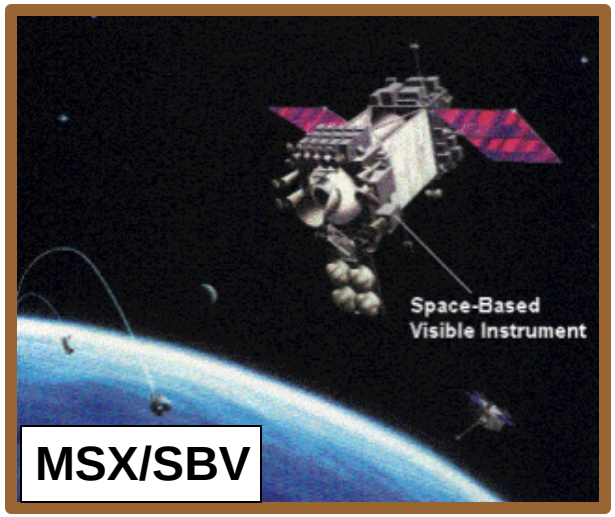
MSX/SBV Mission

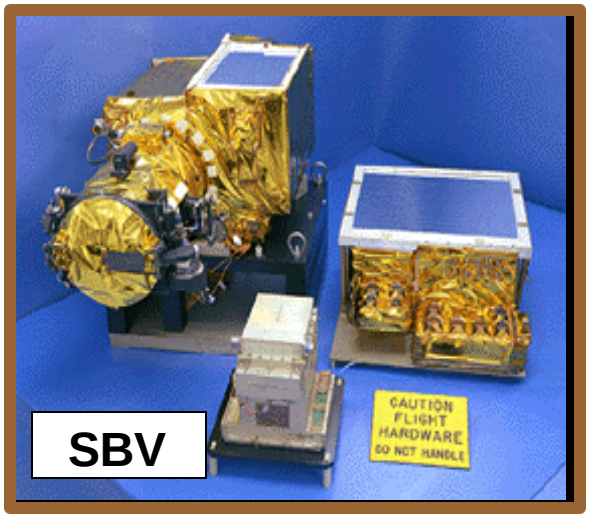




- **Primary Mission - Space Surveillance**
  - **Conduct space surveillance from space**
  - **Surveillance of entire geosynchronous belt**
  - **Assured access to objects of military interest**

MSX/SBV Description

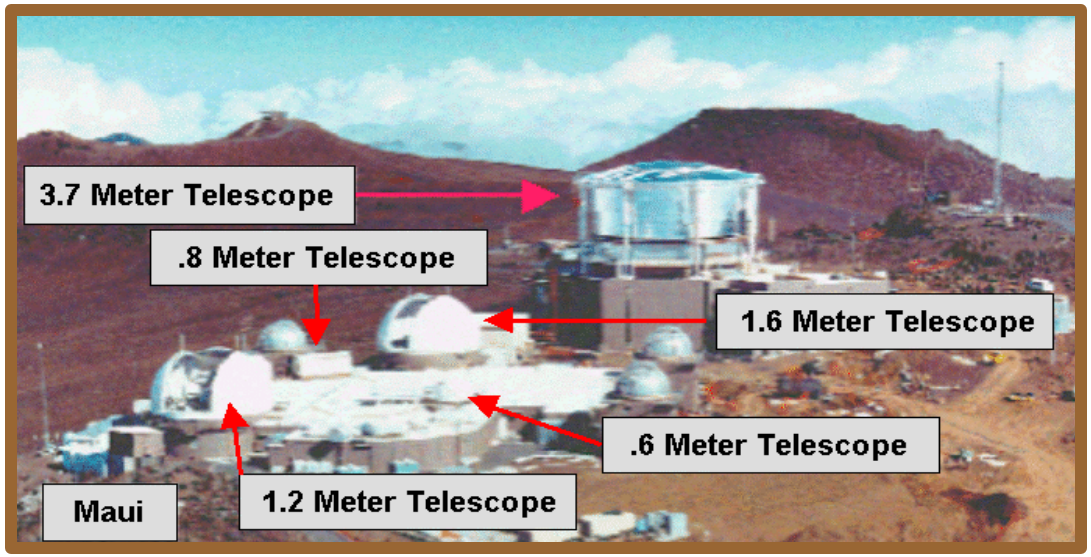




- **Strengths of space-based sensors**
  - **Access to all space**
  - **No weather outages**
  - **Reduced dependence on foreign-based sites**

- **Advanced Concept Technology Demonstration (ACTD)**
  - **Oct 1997 to Sep 00**
  - **Now making ~400 observations/day**
  - **Contributing sensor to Space Surveillance Network (SSN)**
  - **Significant impact on SSN Deep Space (DS) performance**

Maui(Haleakala) Description



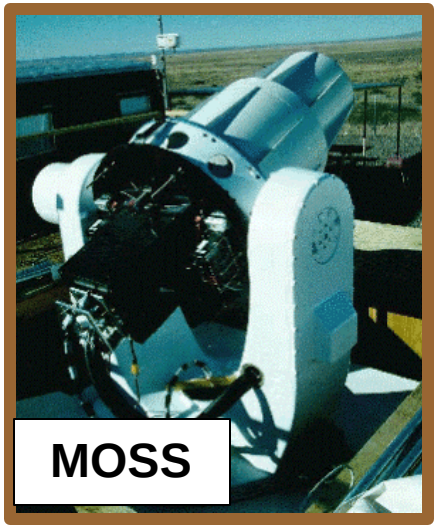
- **Located on Maui, Hawaii - Consists of the 3.7, 1.6, 1.2, .8 and .6 meter telescopes**
  - **Part of the Maui Space Surveillance Complex (MSSC) which includes Maui GEODSS**
  - **MSSS host and mission responsibilities to be transferred from AFSPC to Air Force Research Laboratory (AFRL), Oct 00**

3.7 Meter Mission and Description

- **Dedicated Electro-Optical (E-O) telescope with the following major features**
  - **Adaptive Optics Imaging System provides high resolution imaging and metric data on Near Earth (NE) objects**
  - **Longwave Infrared (LWIR) sensor provides LWIR images / temperature maps and metric data on NE objects**
  - **Radiometric/photometric sensor provides visible Midwave Infrared (MWIR), LWIR and signature/temperature data on NE/Deep Space (DS) objects**
  - **System supports Space Intelligence through high resolution E-O SOI data**

MOSS Description

- **MOSS is an Electro-Optical (E-O) surveillance system**
- **Located on Moron Air Base, Spain**
  - **Operational E-O prototype -- intended to be a gap filler**
  - **Operates in concert with GEODSS**
  - **Operations performed in 20’ X 8’ van**
- **Telescope has a nominal aperture of 22 inches and a focal length of 51 inches**
  - **Houses a 1024 X 1024 Massachusetts Institute of Technology/Lincoln Laboratory (MIT/LL) Charge Couple Device (CCD) focal plane array**

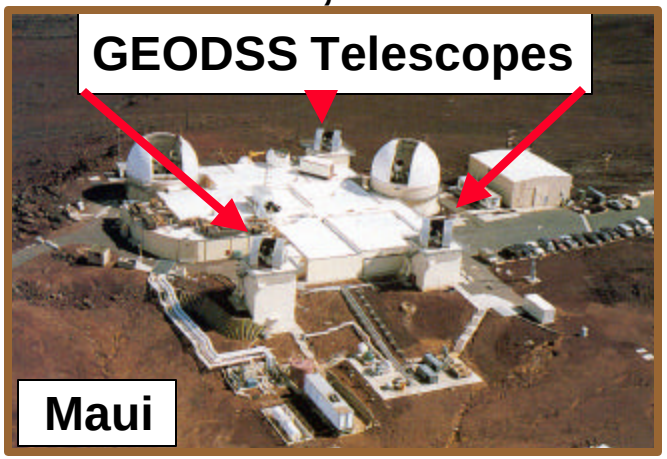


MOSS

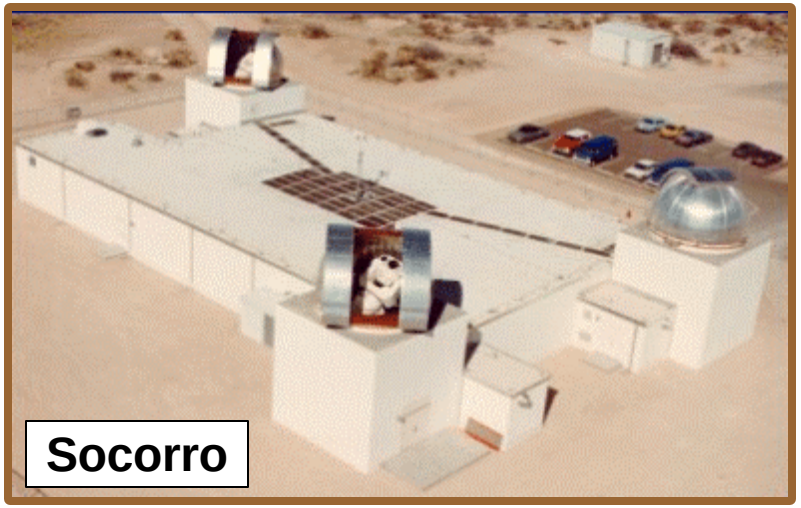
GEODSS Mission

Det 2, 18 SPSS

Det 3, 18 SPSS

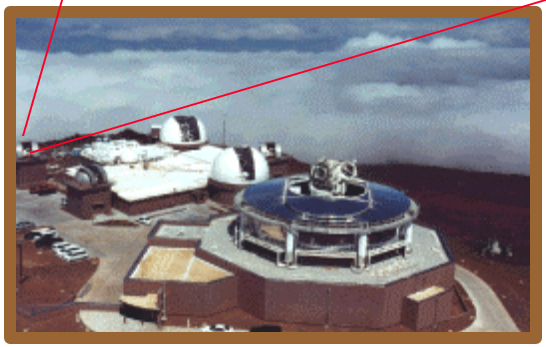


Det 1, 18 SPSS



- Primary: Space Surveillance
- Supports AFSPC as a dedicated Deep Space (DS) sensor
- GEODSS brings together the telescope, low-light-level television cameras, and computers -- three proven technologies

GEODSS Description



- Each site has three telescopes, two main and one auxiliary
  - Diego Garcia is exception with three mains
  - Maui will have 3 mains, Oct 00
  - Socorro will have 3 mains, Oct 01
- Main Telescopes have 40-inch aperture and 2^{o} field of view
- Auxiliary Telescopes have 15-inch aperture and 6^{o} FOV
- Operates at night
  - Cloud cover inhibits operation
    - Not a severe problem at Socorro or Diego Garcia

GLOBUS II Mission

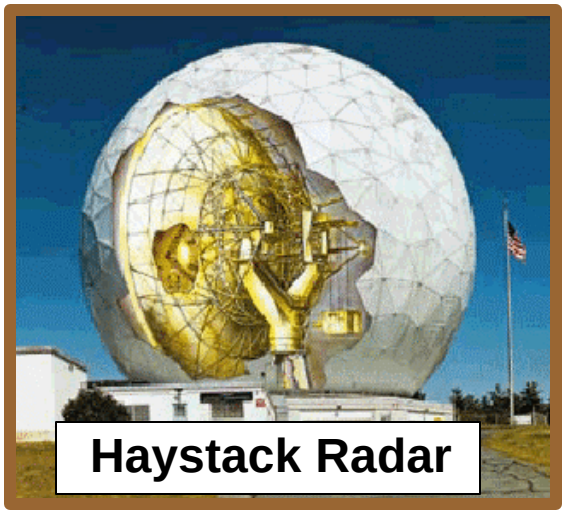
- **Primary: Space Surveillance**
- **GLOBUS II is expected to track 100 Deep Space (DS) objects per day**
  - **Expected to provide wideband Space Object Identification (SOI) imagery data on 3 DS objects per day**
  - **Numbers are based on studies, not actual data**

GLOBUS II Description

- **Globus II is a 27 meter mechanical tracker radar**
  - **Covers 0-360º in azimuth, 0-90º in elevation, and out to geostationary orbit in range**

LSSC Mission

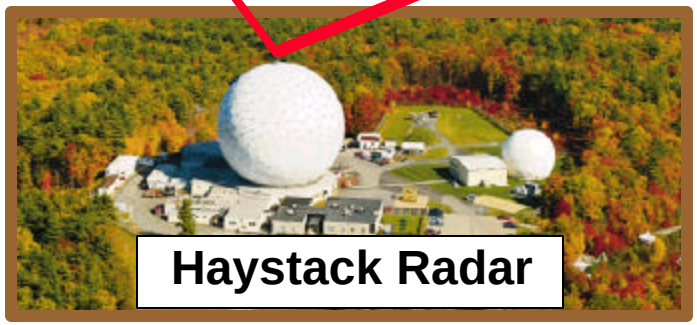

Haystack Aux


Haystack Radar


Millstone Hill Radar

- **Primary: Research and Development (R&D) of Space Surveillance techniques**
- **Secondary: Supports AFSPC as a contributing sensors**
  - **Millstone Hill Radar -- Near Earth (NE)/Deep Space (DS)**
  - **Haystack Radar -- NE/DS**
  - **Haystack Auxiliary (HAX) -- NE**

Haystack Radar Description



- Haystack is a mechanical tracker
- Only sensor in the SSN capable of imaging NE and DS objects
- Provides images for Mission Payload Assessment (MPA) and satellite status determination
  - High resolution in NE (25 cm)
  - All weather day/night capability
- Conducts measurements of space debris to sizes of 1 cm (NASA)
  - NASA debris campaign
- Provides unique support for satellite anomaly resolution

Millstone Hill Radar (MHR) Description

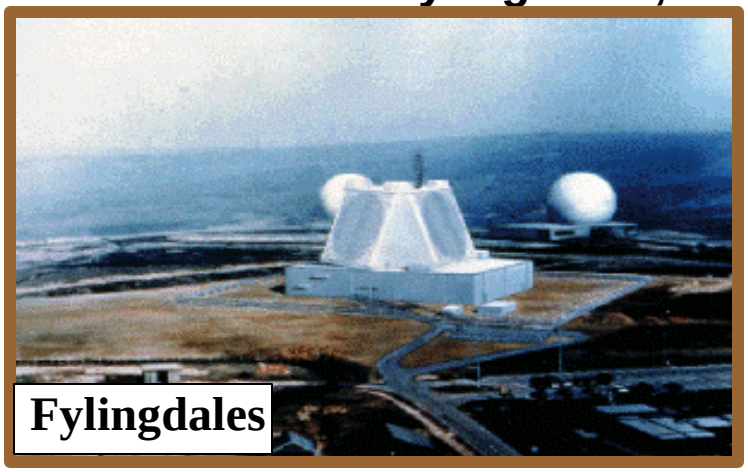
Millstone Hill Radar

- MHR is a mechanical tracker
- Built as a BMEWS prototype
  - First radar to track Sputnik 1957
- High power sensitive radar that routinely tracks DS satellites, rocket bodies and debris in the Geo belt
- High precision radar generates highly accurate orbital data
  - Provides Geo collision avoidance data to some commercial entities via Cooperative Research & Development Agreement (CRDA)

BMEWS Mission

Clear AFS, Alaska

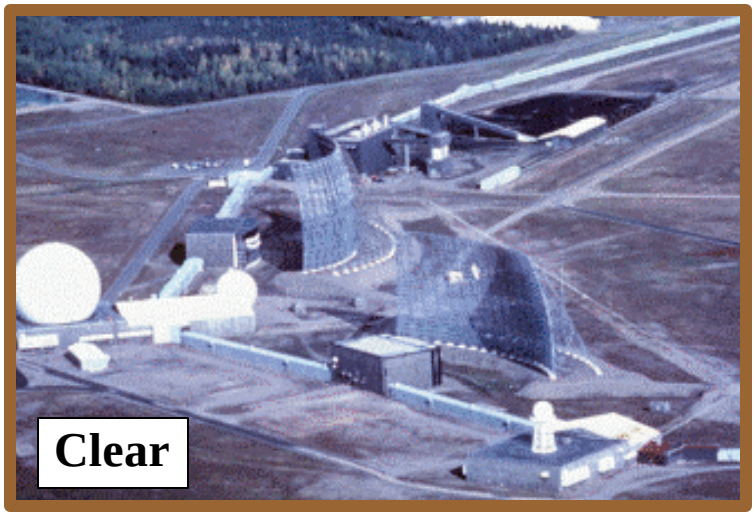
RAF Station Fylingdales, UK



Thule AB, Greenland

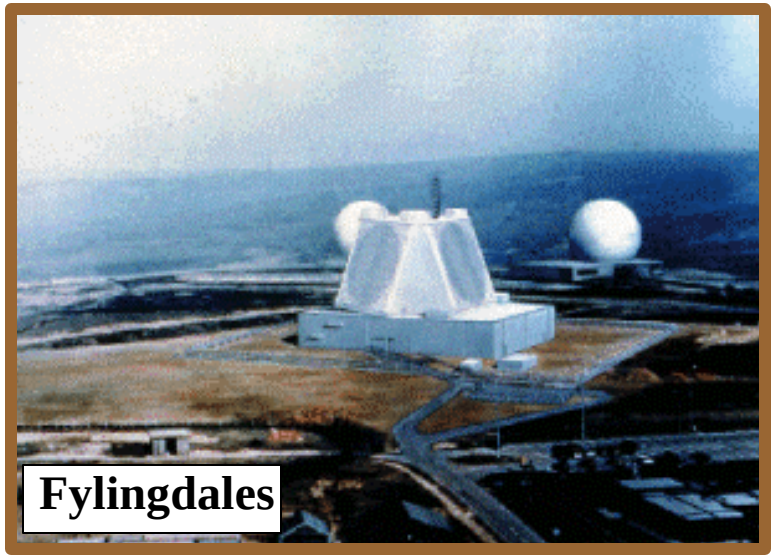
- **Primary: Missile Warning**
  - **Provides ballistic missile warning and attack assessment of a ballistic missile raid against CONUS, Alaska and Southern Canada**
- **Secondary: Space Surveillance**
  - **Supports SSN as collateral sensors**

Clear Mission



- **Primary Mission: Provide tactical warning and attack assessment of a ballistic missile attack against CONUS and southern Canada**
- **Secondary Mission: Support Space Surveillance as collateral mission**

Fylingdales Mission

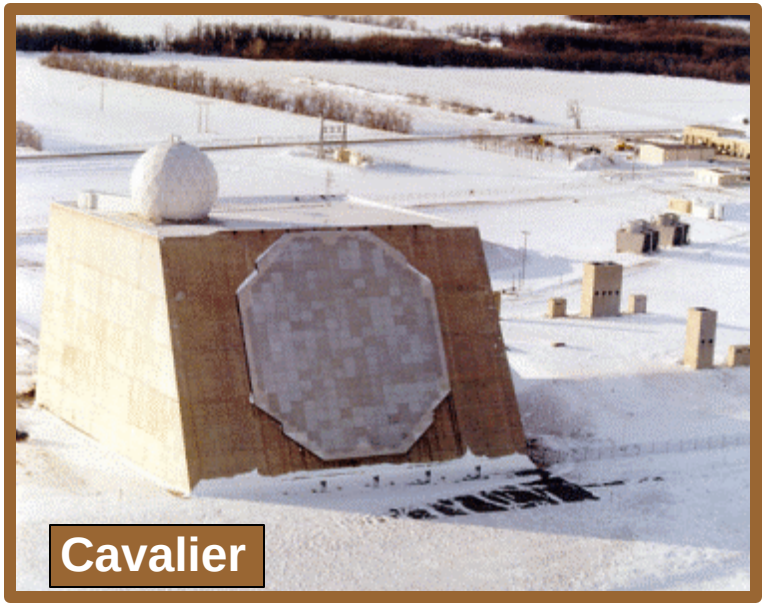


- **Primary Mission: Provides warning of an IRBM, MRBM, or SLBM against UK and Western Europe**
- **Secondary Mission: Provides warning of an ICBM/SLBM attack against CONUS**
- **Tertiary Mission: Space Surveillance as collateral mission**

Thule Mission

- **Primary Mission: Provides tactical warning and attack assessment of SLBM and ICBM attacks against CONUS and Canada**
- **Secondary Mission: Supports Space Surveillance as collateral mission**

Cavalier Mission

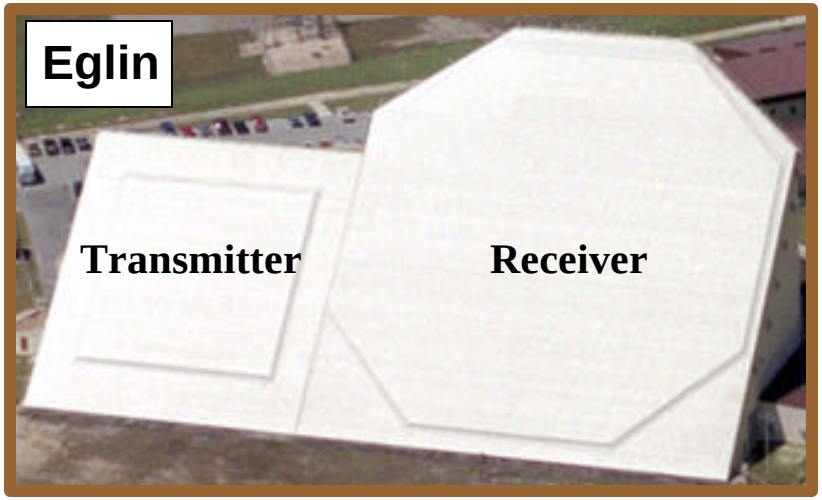


- **Primary: Missile Warning**
  - **Provides Warning and Attack Characterization of ICBM/SLBM attack against the CONUS and Southern Canada**
- **Secondary: Space Surveillance**
  - **Supports SSN as a collateral sensor**

Eglin Mission

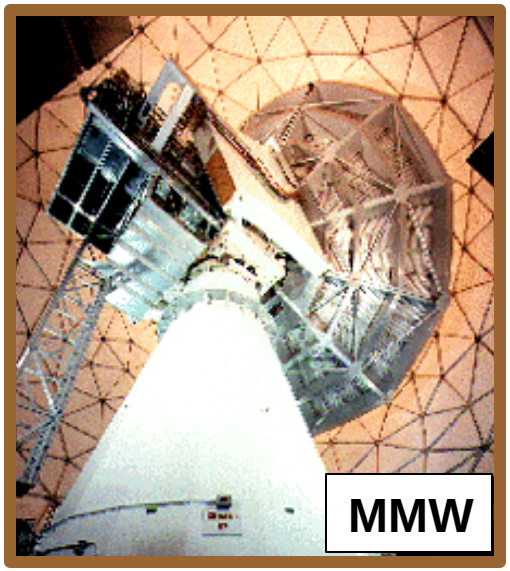
- **Primary Mission: Spacetrack as dedicated sensor**
  - **Tracks 4,257 NE and 357 DS objects per day per Jan 00 Space Surveillance Analysis Tool (SSPAT)**

Eglin Description



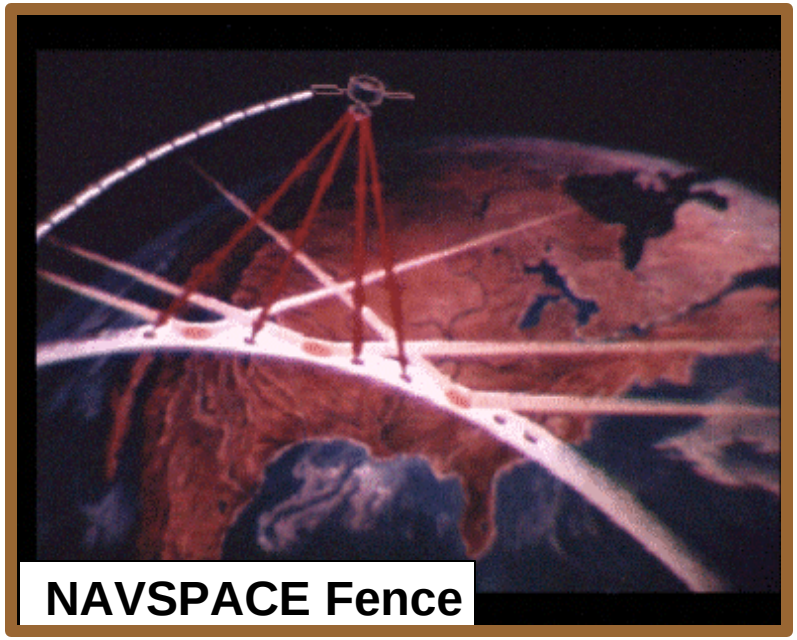
- **One of a kind phased array radar with a separate transmitter and receiver face**
  - **Covers 120^0 in azimuth and in excess of 22,000 NM in range**
  - **Has capability to track small objects**
  - **Only dedicated space surveillance phased array radar**

MMW Description



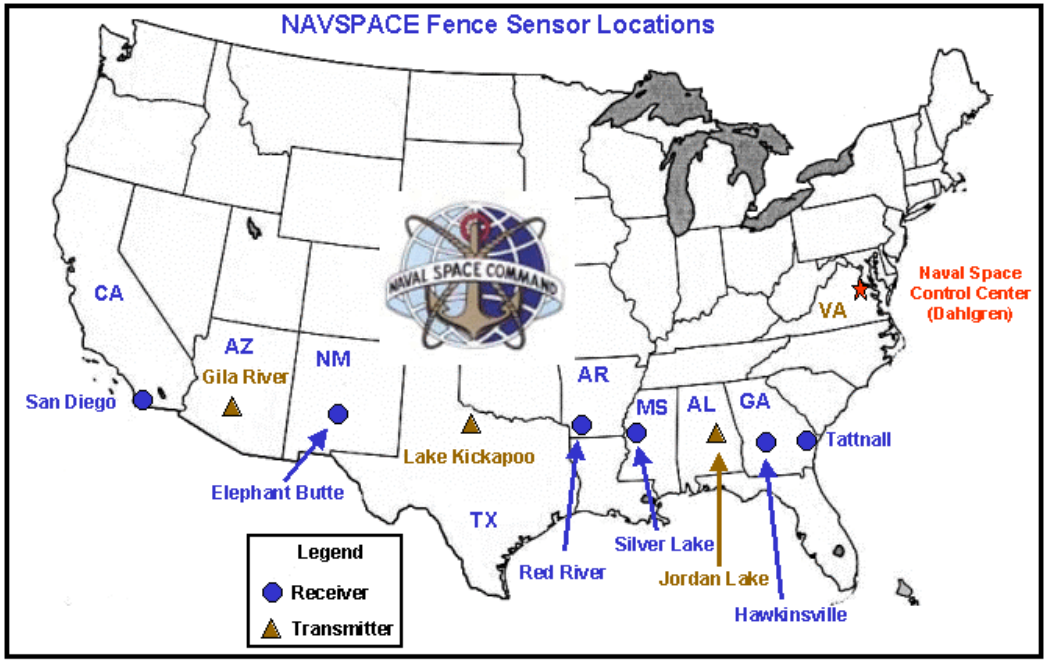
- MilliMeter Wave (MMW) Radar
  - Used exclusively for SOI collection
  - Highest Resolution Imaging radar in Space Surveillance Network (SSN)
    - 12-25 cm resolution
  - Missions supported
    - Imaging of new launches
    - Satellite anomaly resolution

NAVSPACE Fence Mission



- **Primary: Space Surveillance**
  - **Provides up to date satellite orbital elements to Fleet and Fleet Marine forces**
  - **Supports US Space Command as part of nation's worldwide Space Surveillance Network**

NAVSPACE Fence Description



- **Comprised of three transmitters and six receivers located along the 33rd parallel**
- **Transmits a continuous electronic fence straight up into space**
- **Relays unknown detections to Eglin Phased Array for further refined processing**

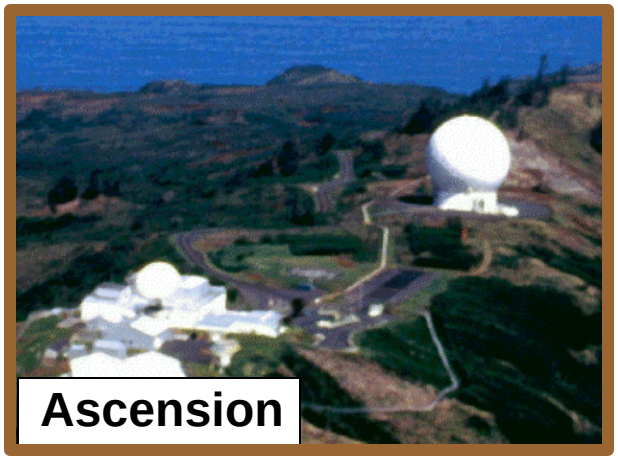
PAVE PAWS Description

6 SWS, Cape Cod AFS, MA

7 SWS, Beale AFB, CA

- **Both Beale and Cape Cod are dual face Solid State Phased Array Radars (SSPAR)**
  - **Both radars cover 240^0 in azimuth and in excess of 2,800 NM in range**
  - **At extreme range, both radars can detect objects the size of an automobile - smaller at closer ranges**

Range Radar Mission



- **Primary: Range Support**
  - **Supports test and evaluation of developmental and operational ICBMs, space launch vehicles and aeronautical development programs**
- **Secondary: Space Surveillance**
  - **Support of SSN as collateral Near Earth (NE) sensors**

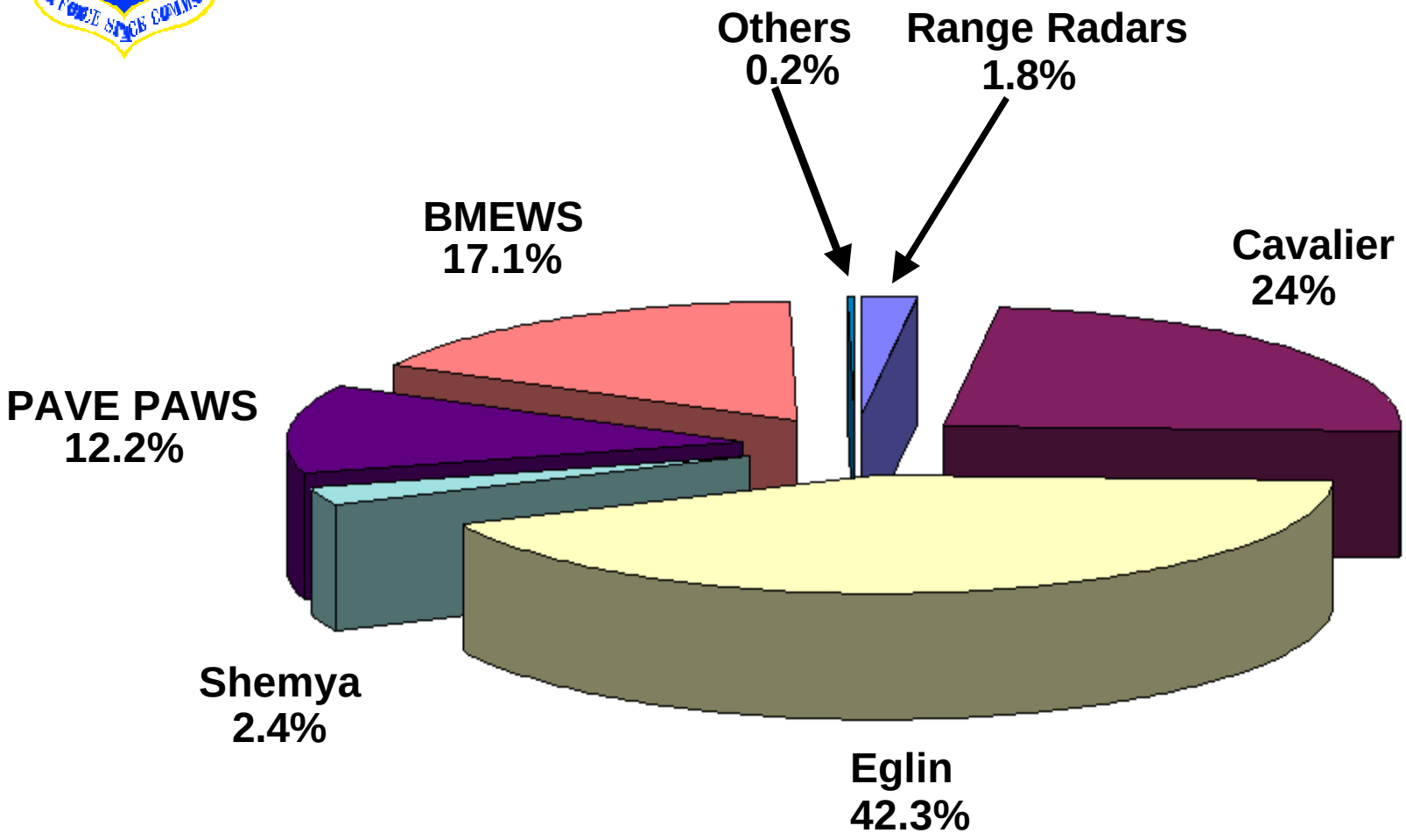
Shemya Mission

- **Primary: Intelligence**
  - **Supports Treaty Verification of Soviet ICBM & SLBMs**
- **Secondary: Space Surveillance**
  - **Supports SSN on limited basis**
  - **Highly valuable for tracking priority events**

Shemya Description

- **Located on Shemya Island, Alaska**
- **Cobra Dane is a single face Phased Array radar originally designed to monitor Soviet ICBM & SLBM tests**
- **Discontinued MW and Space Surveillance in 1994**
- **Recommissioned as a Space Surveillance asset in 1999**

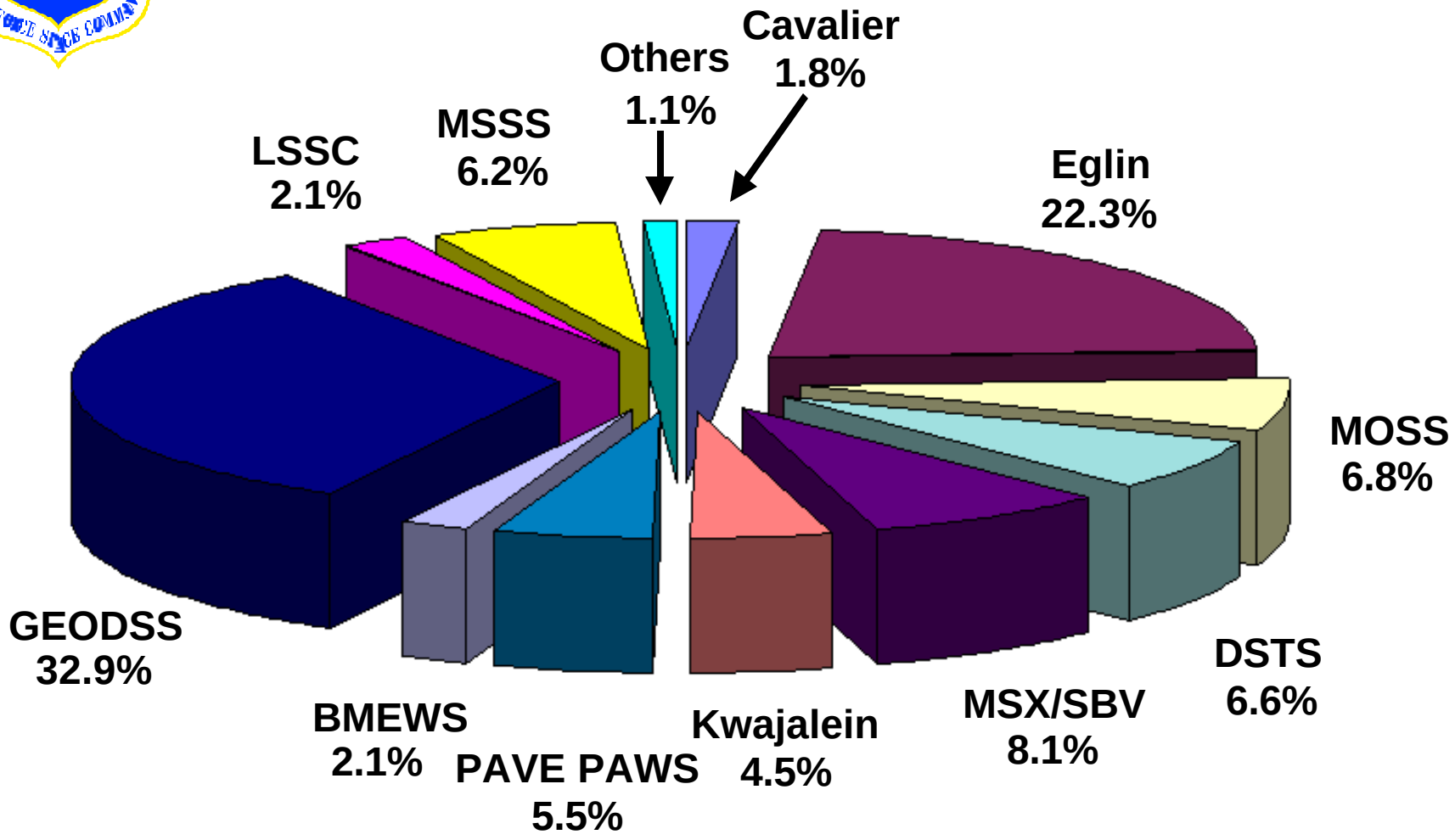
Near Earth Tracking Percentages



Note: Does not include NAVSPACE Detection Fence

Source: Jan 00 SSPAT data

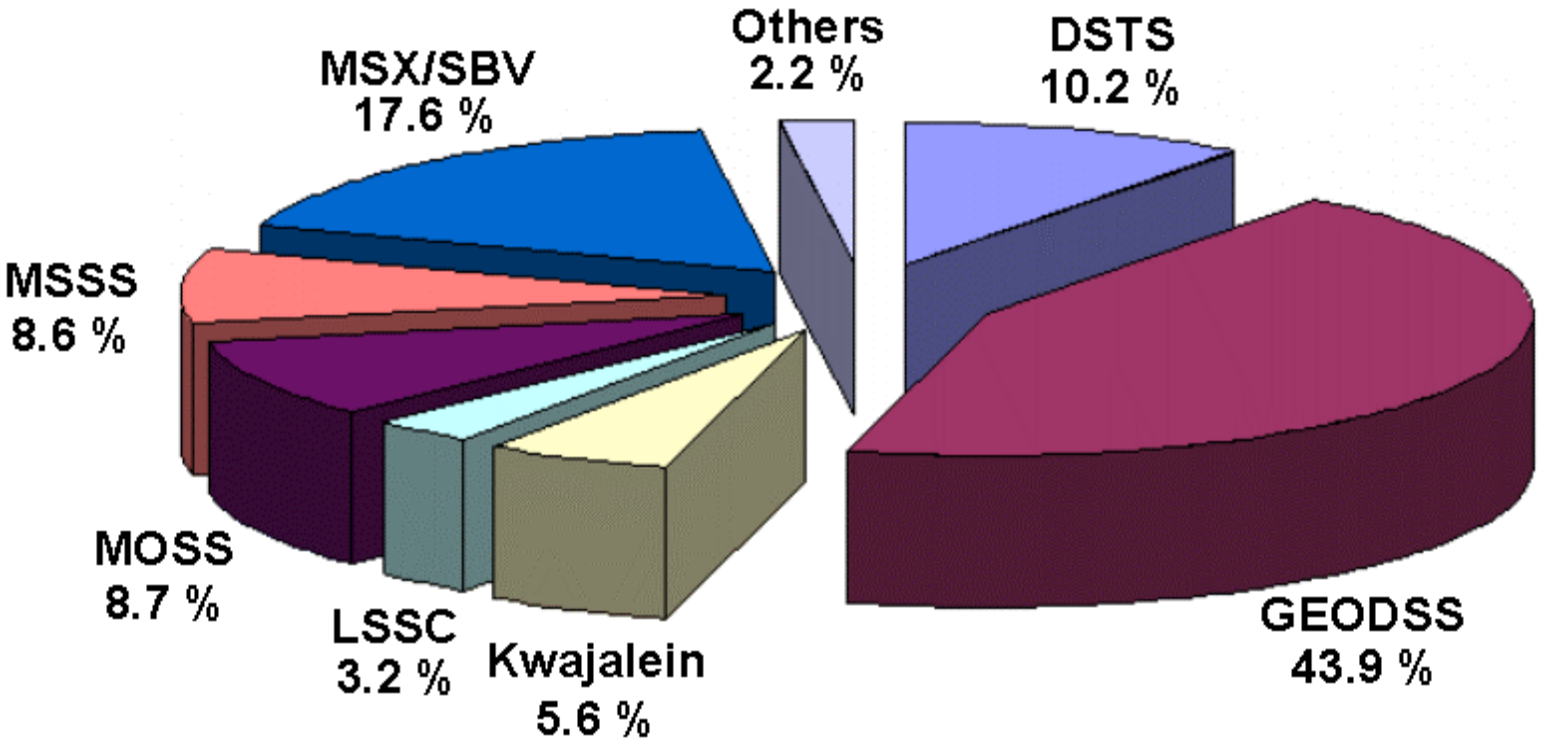
Deep Space Tracking Percentages



Note: Does not include NAVSPACE Detection Fence

Source: Jan 00 SSPAT data

Geosynchronous Tracking Percentages



Note: Does not include NAVSPACE Detection Fence

Source: Jan 00 SSPAT data

Current Catalog

Satellites - 2671

Space
Probes - 90

Debris - 6096

Total - 8927

Position estimates

- **Positions are calculated from a model of orbital motion.**
- **Orbital perturbations are included.**
  - **General perturbations**
    - **average atmosphere , 3-body, gravity models**
      - **J2 and J3 components of gravity model**
  - **Special perturbations**
    - **General + detailed atmosphere, better solar**
- **Element sets are generated to predict future motion**
  - **Include average motion and time derivatives**
  - **Production delay may be 3-4 days**
  - **Format based on 80 column IBM card**

Element sets and accuracy

- **Useful in calculating positions to ~1km accuracy**
- **Not all parameters are explicit**
  - **Major axis is calculated from other parameters**
    - **e.g. revs per day and eccentricity**
  - **Least squares analysis sometimes replaces physics**
  - **Parameters frequently derived from measurements on other satellites**
    - **Some quantities, such as atmosphere and solar effects are not directly measured**
      - **Results are based on analysis**
  - **Some sensors have systematic errors**

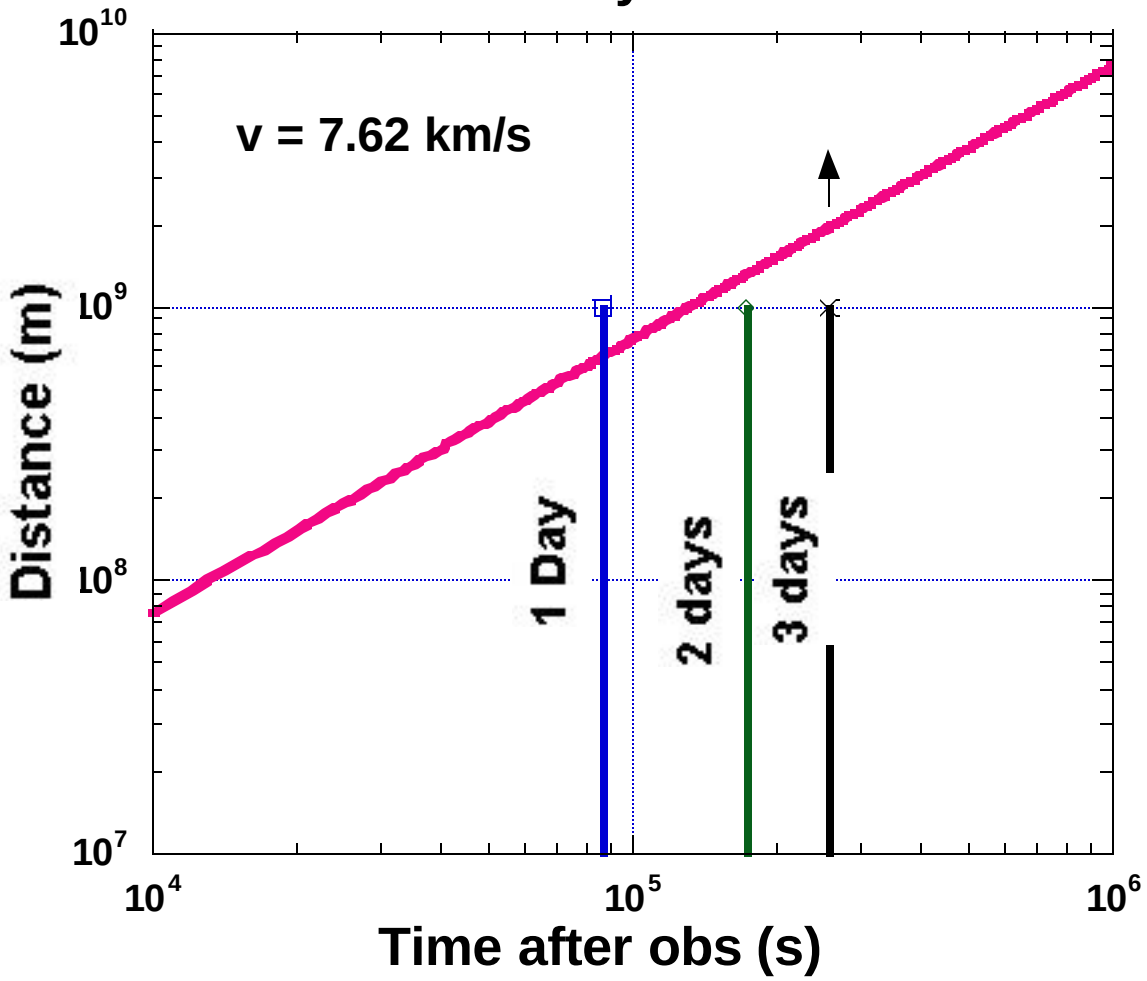
Calibration Satellites

- **Satellites with known mass, area, etc. are used to calibrate the system.**
- **Laser ranging is employed for satellites with corner cubes.**
- **Ajisai(EGP), Starlette, ERS-1, ERS-2, Topex/Poseidon**
  - **SLR measurements to cm accuracy**

Requirements for measurement accuracy

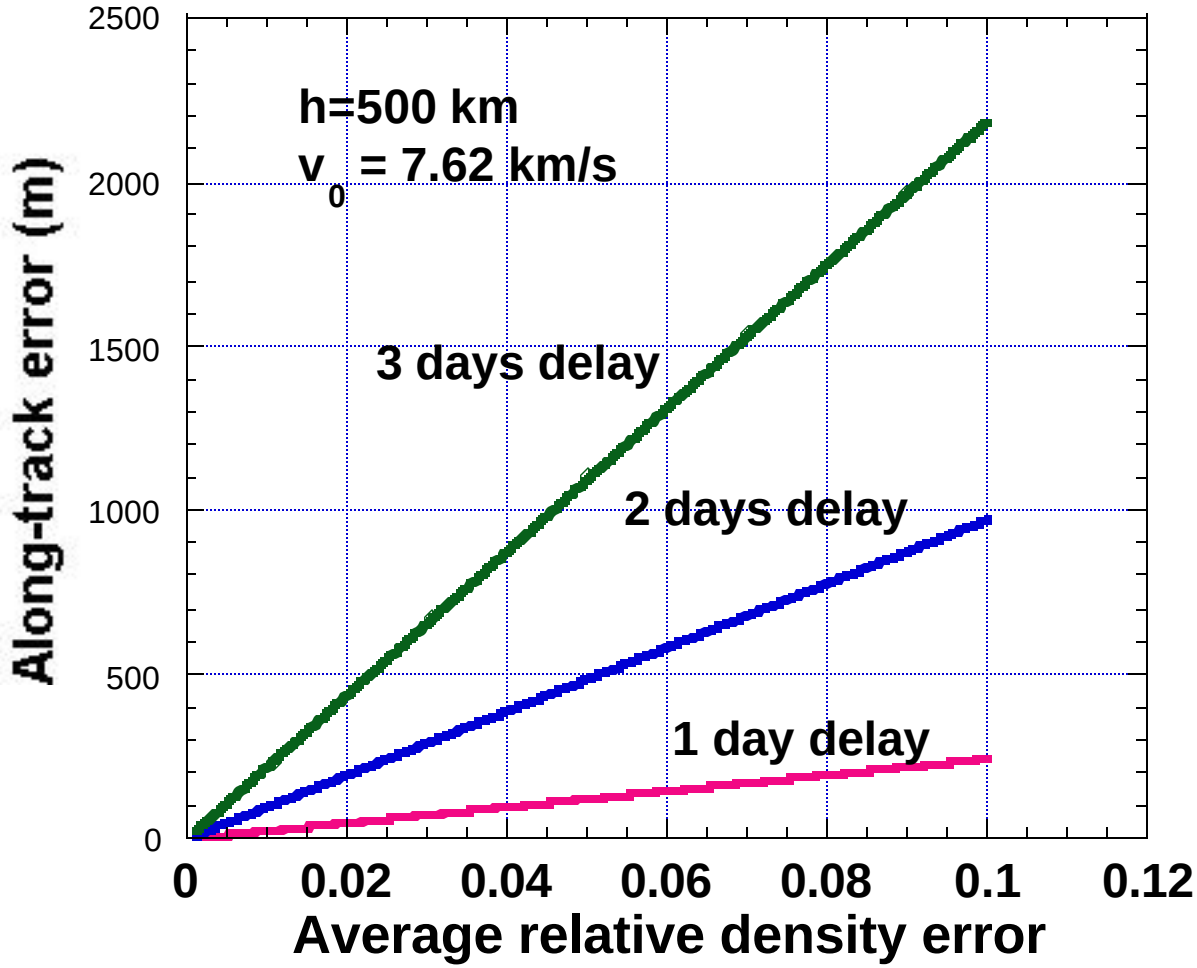
- **Consider quantities, such as velocity, based on radius measurement**
- **Derive required accuracy from simple orbital considerations**
- **Major errors are in sensors and in atmosphere**
- **Errors in calculated positions should be ~1 meter for future applications**

Distance travelled by a satellite at 500 km

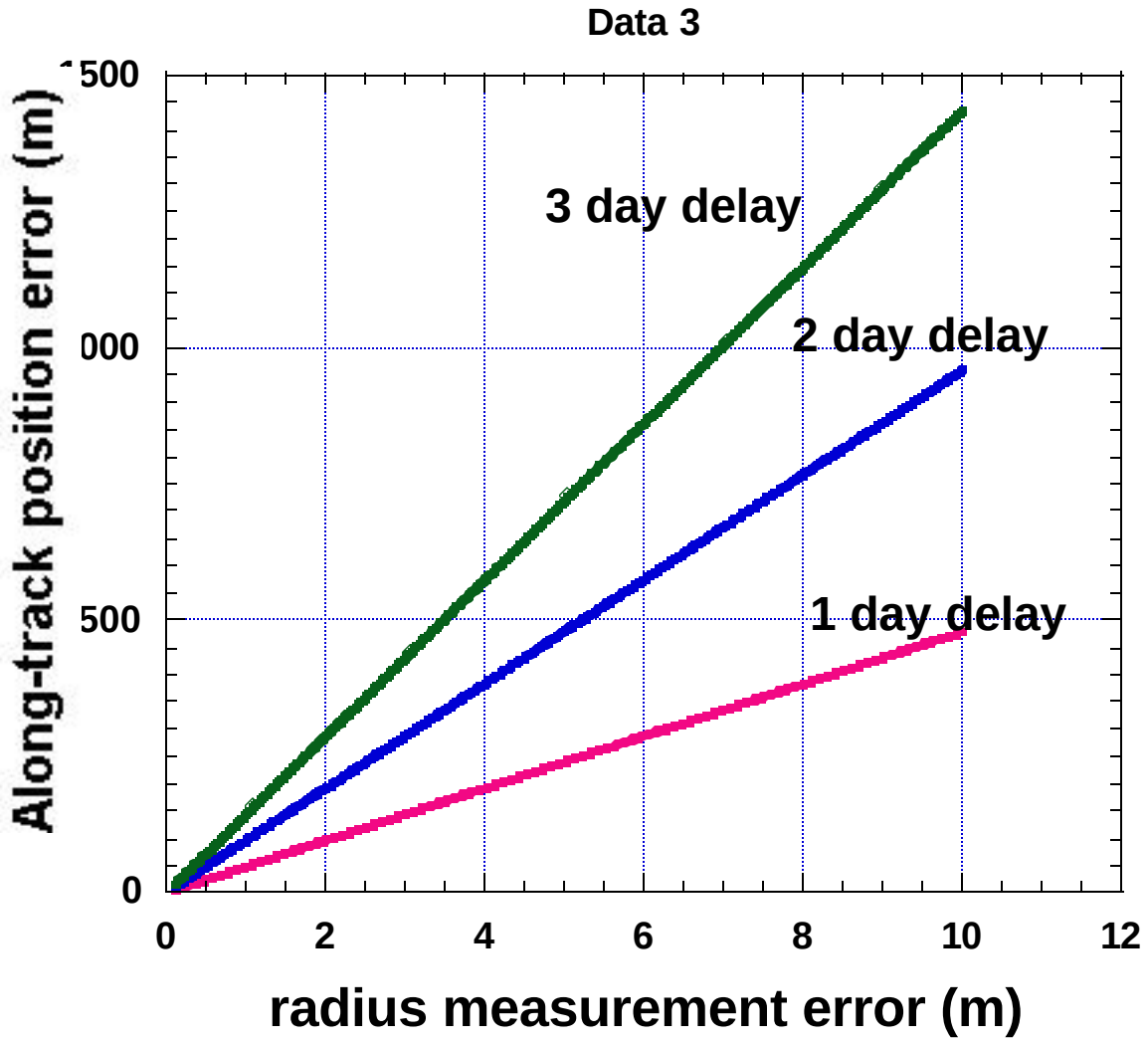


Air density contributes to error

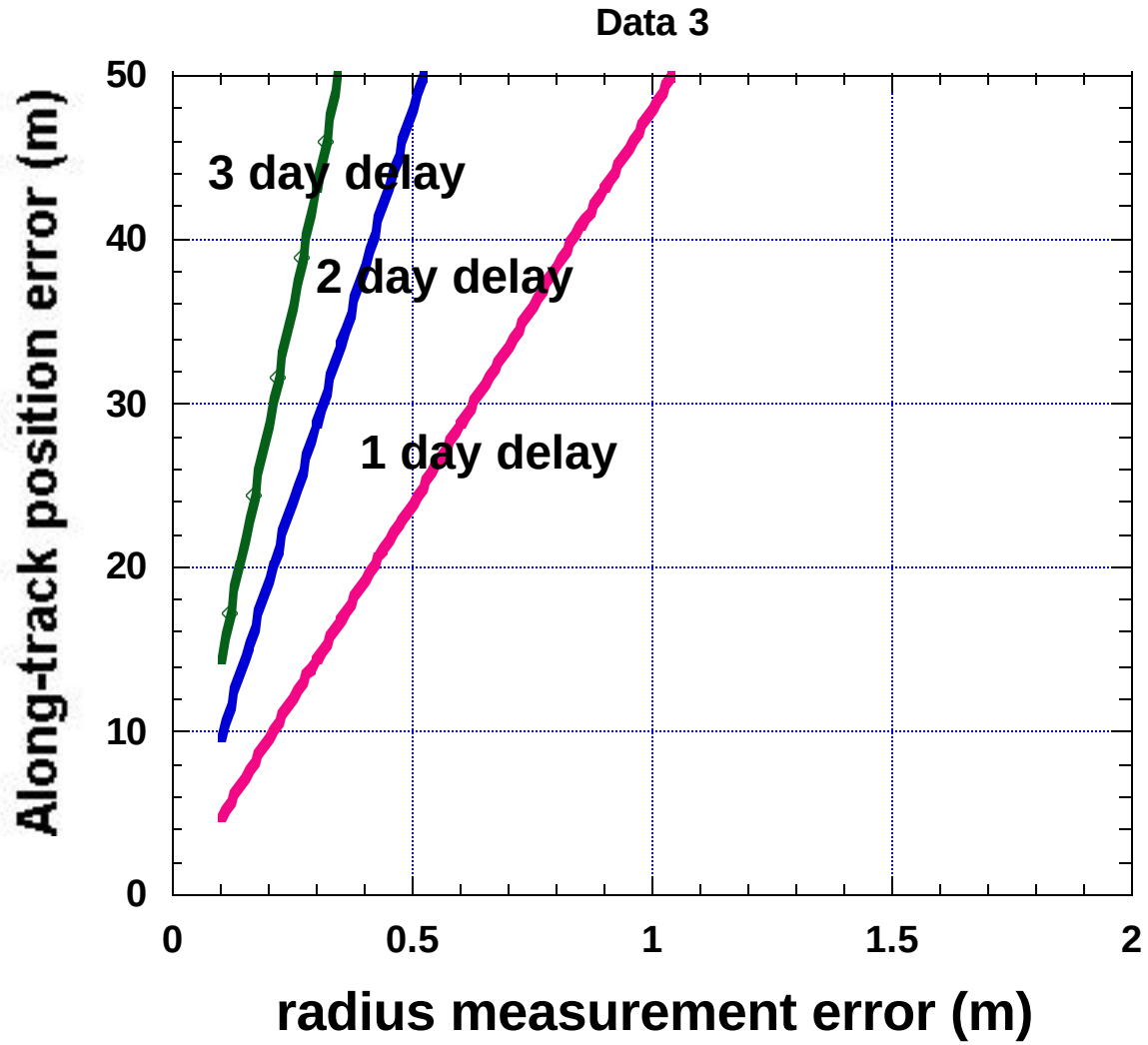
Position error as a function of density error



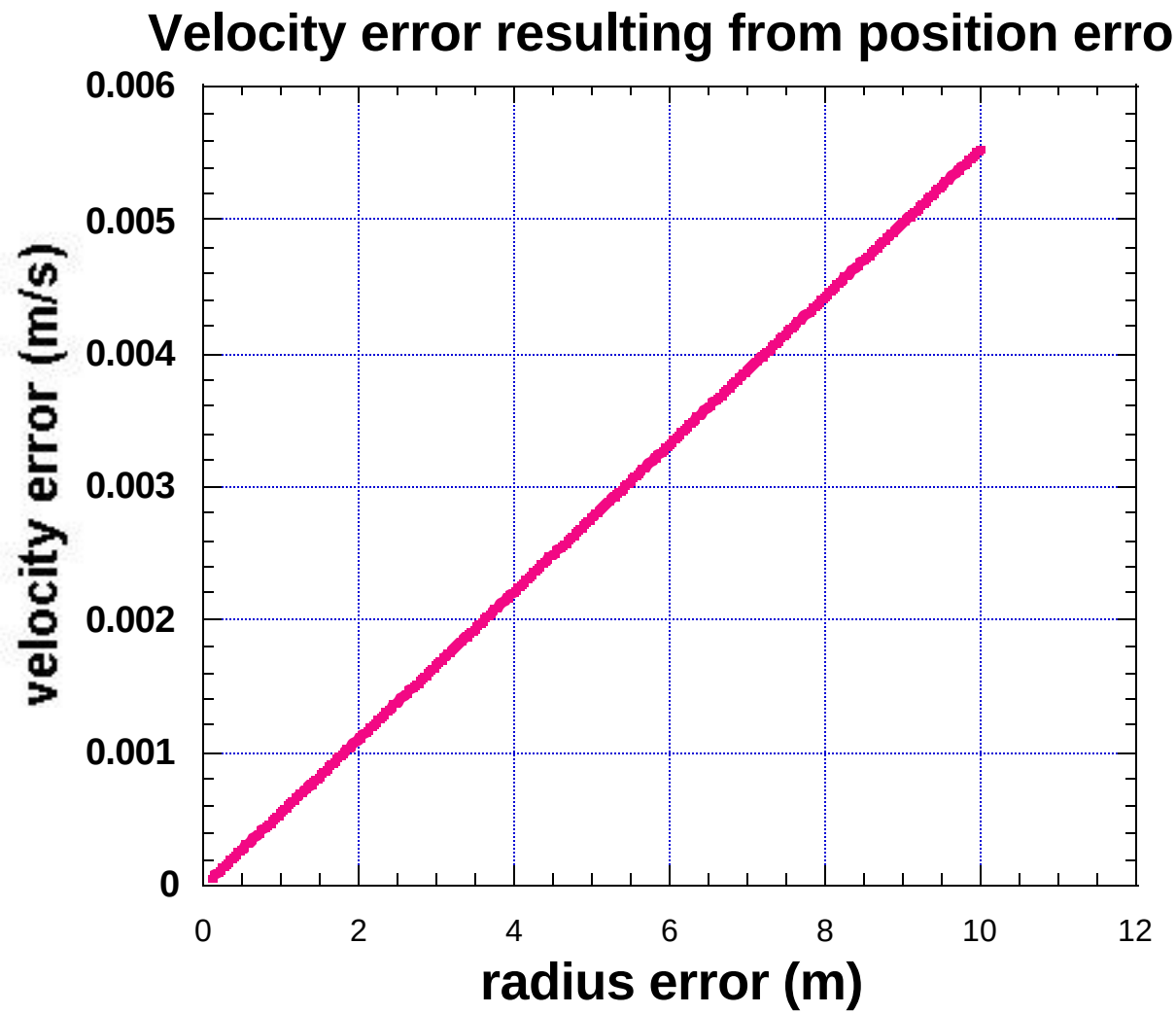
Position error after a given delay time



Error grows rapidly as a function of measurement error



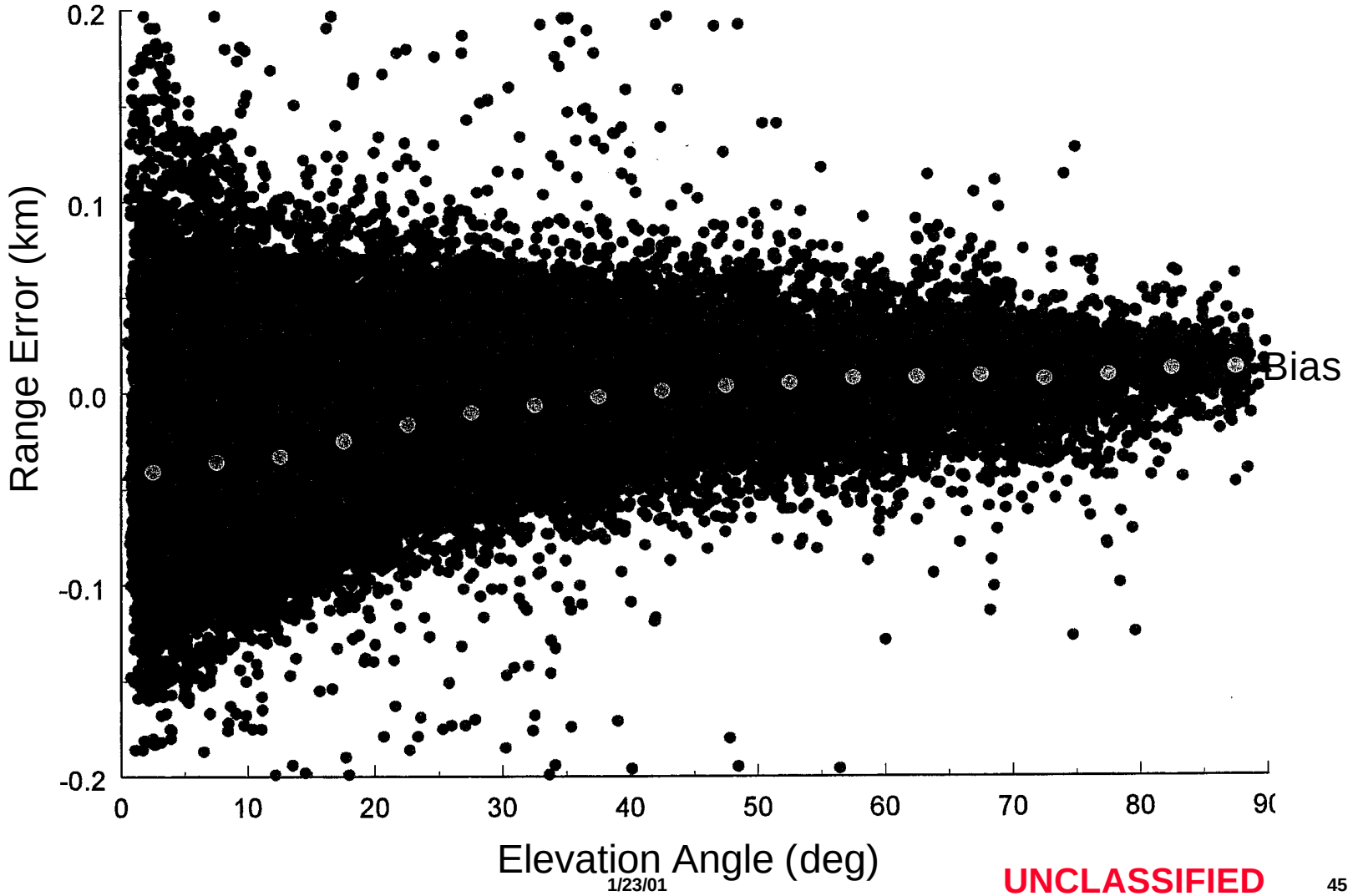
Error in range measurement is important



Some errors decrease with successive measurements

- **Element sets also include first and second derivatives of mean motion**
- **Drag coefficient is determined, but atmosphere is still an issue.**
- **How inaccurate are the initial measurements?**
  - **SLR range error is insignificant**
  - **Radar measurements may have significant error**
    - **Systematic range**
    - **Ionosphere and troposphere**
    - **Elevation**

Range residuals from Eglin Observations

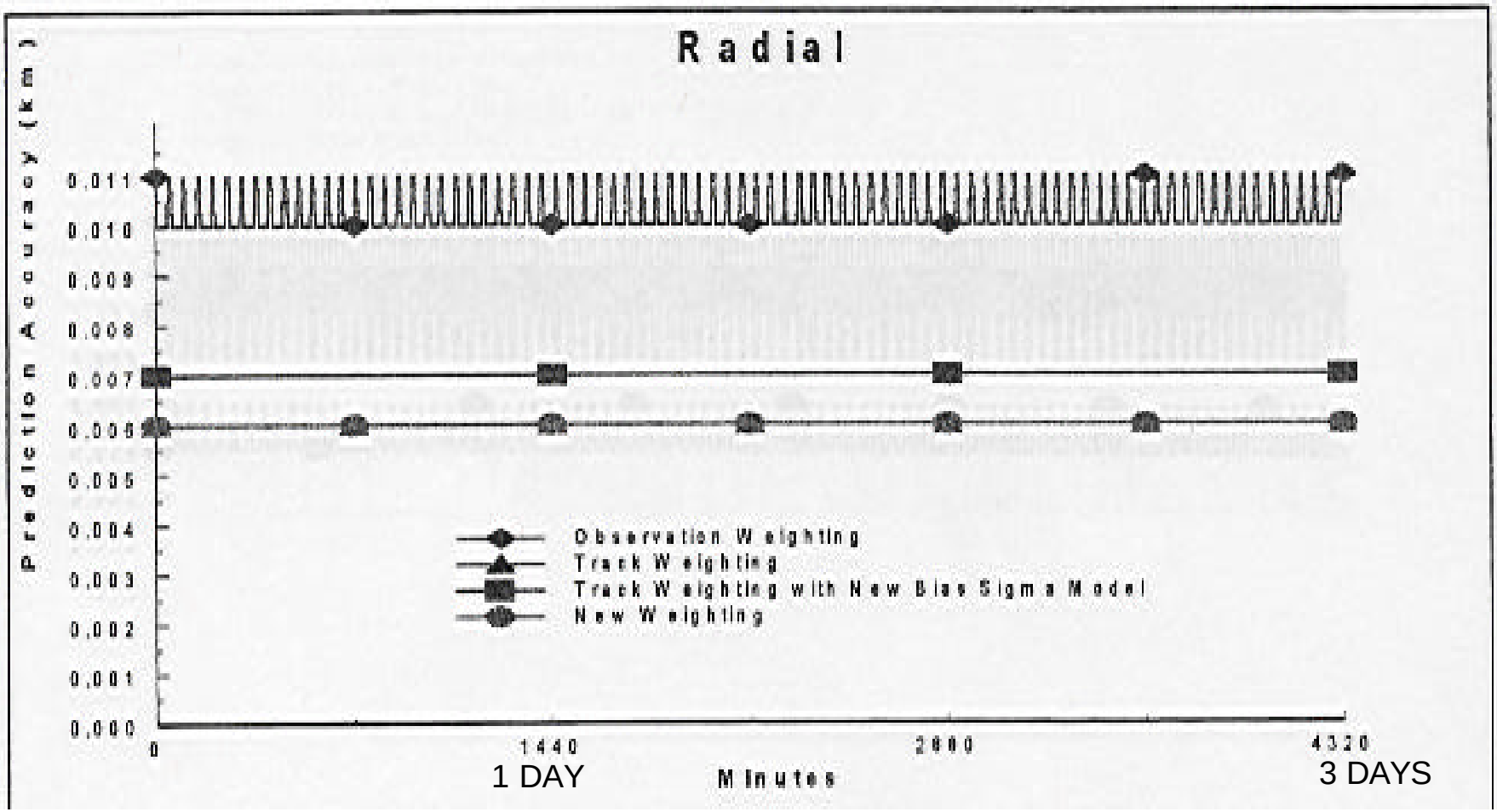


Special perturbation results

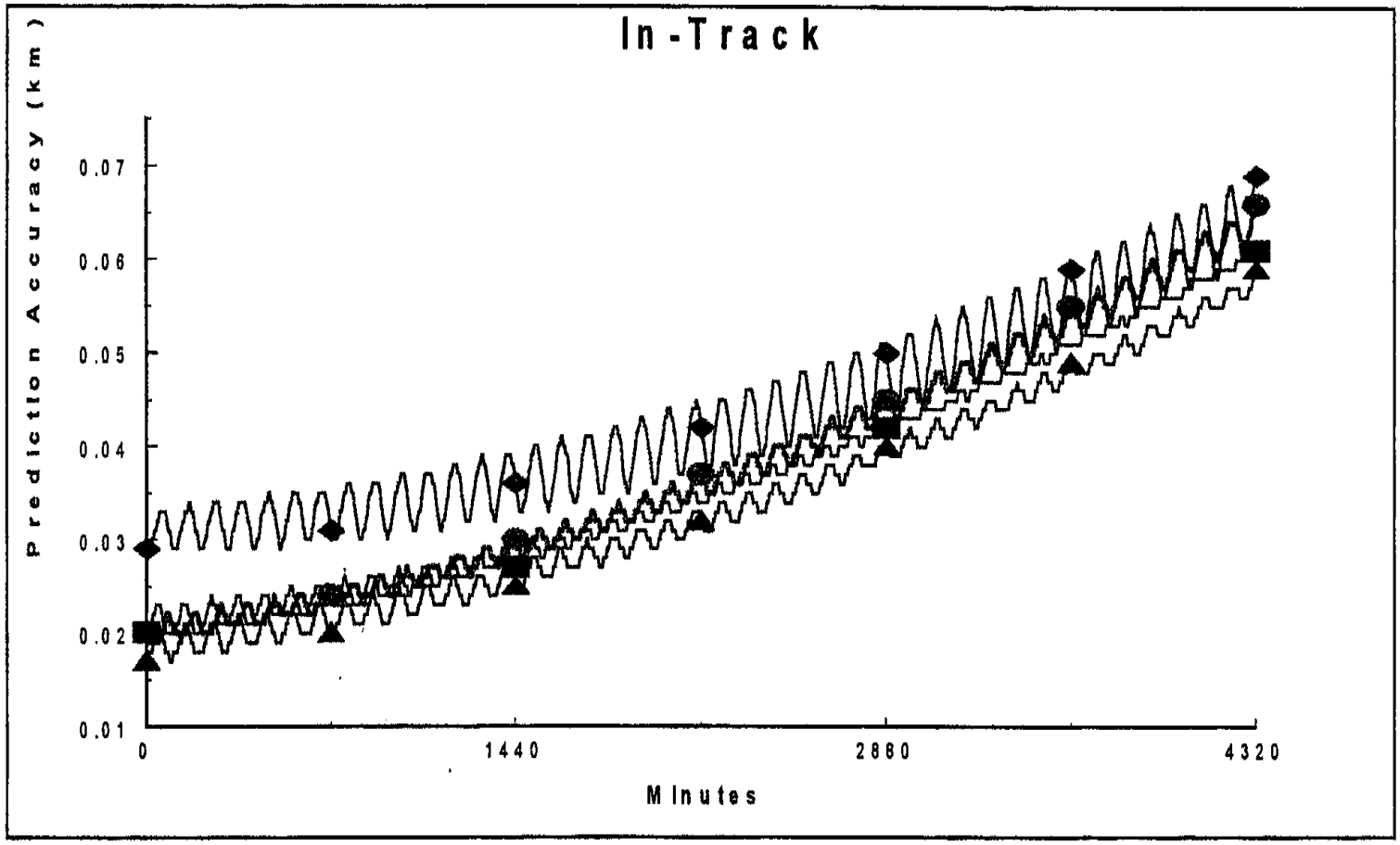
- **Calculate errors as a function of time**

New methods improve accuracy

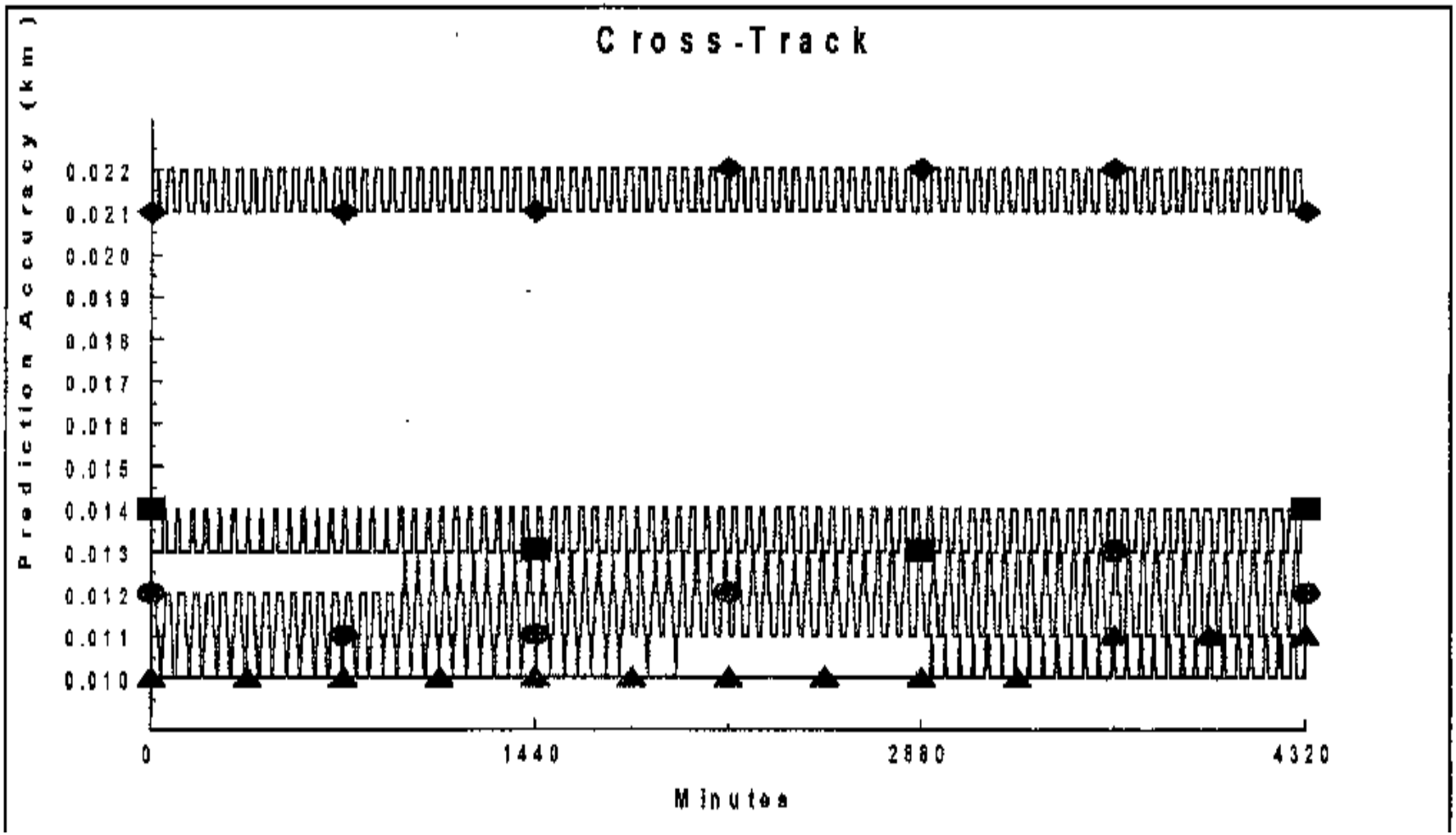
Starlette - Calibration Tasking



Improved, but not yet adequate



Crosstrack accuracy improved



observations

- **Improved calculational techniques have improved accuracy significantly.**
- **Accuracy is still inadequate for 21st century applications.**
  - **E.g. autonomous docking and servicing**
  - **Collision avoidance for robotic vehicles**
- **SLR measurements improve ranging accuracy**

Suggestions(personal, not official)

- **Add laser ranging measurements at selected sites**
  - **SLR sites are inexpensive**
  - **Enough real estate exists at many sites for two SLR systems.**
    - **Eglin**
    - **Clear**
    - **Thule**
    - **Socorro**
- **Increase element set update rate**
- **Set goal of 1 meter prediction accuracy at end of 24 hours.**

Conclusions

- **Improvements in orbit predictive capability since 1997 are striking.**
- **Work is ongoing**
- **Reentry point and time are still issues.**
- **Number of observations is adequate.**
- **Accuracy should be improved.**