# Comparing a Mass Spectrometer, a Total Pressure Sensor and Quartz Crystal Microbalances as an Environmental Sensor in Space

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PHYSICAL SCIENCES INC.

# MID-COURSE SPACE EXPERIMENT (MSX)

- MSX Planning Stage Began In The Mid ‘70s
- Objectives:
  - Collect data with 1st Generation Space Object Remote Sensors
  - Collect data of Realistic Backgrounds, including contamination effects
  - Collect Statistically Significant Target Data in Actual backgrounds
  - Integrate, Validate, And Transfer Key Technology To Future Systems
- Launch at VAFB: April 24, 1996
- Currently in relatively good health after 8 years in orbit

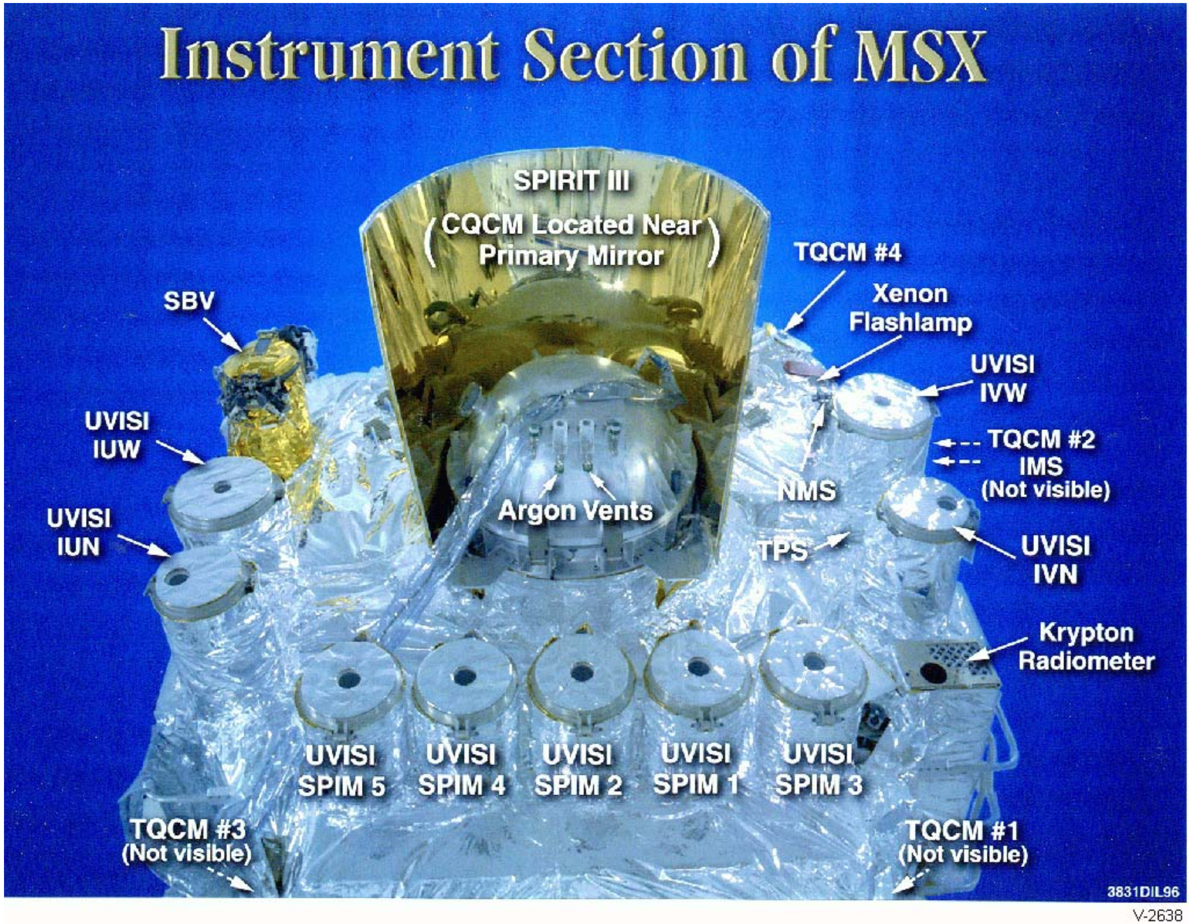
# Objectives: Contamination Instruments

•Measure the (short-term and long-term) effects of molecular and particle contamination on MSX and transfer these technologies to next mission.

•Provide contamination status during the MSX mission, including resolution of anomalies.

•Assess the effectiveness of the ground contamination control plan for future missions.

•Develop a validated contamination effects model for future missions.

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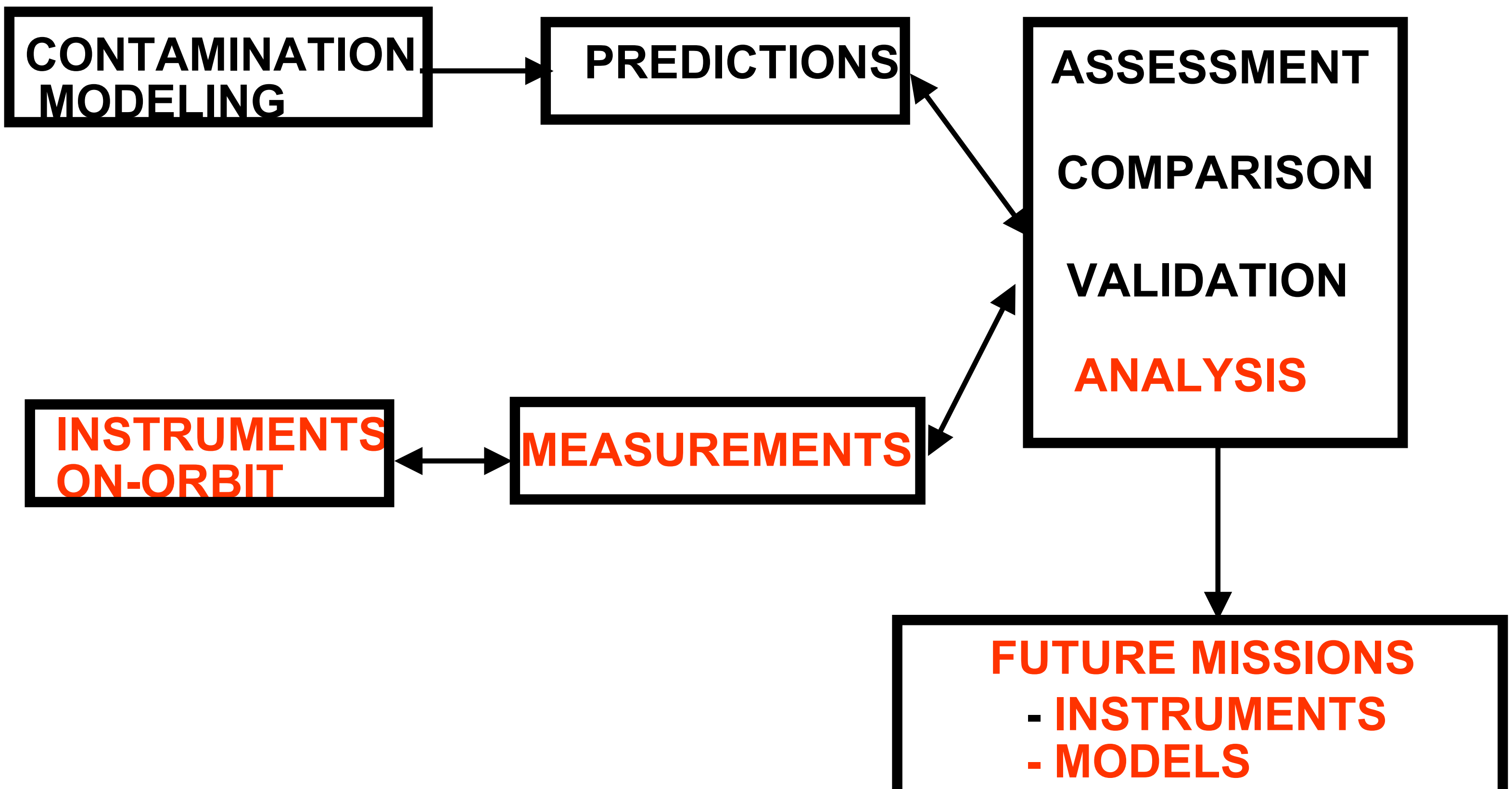
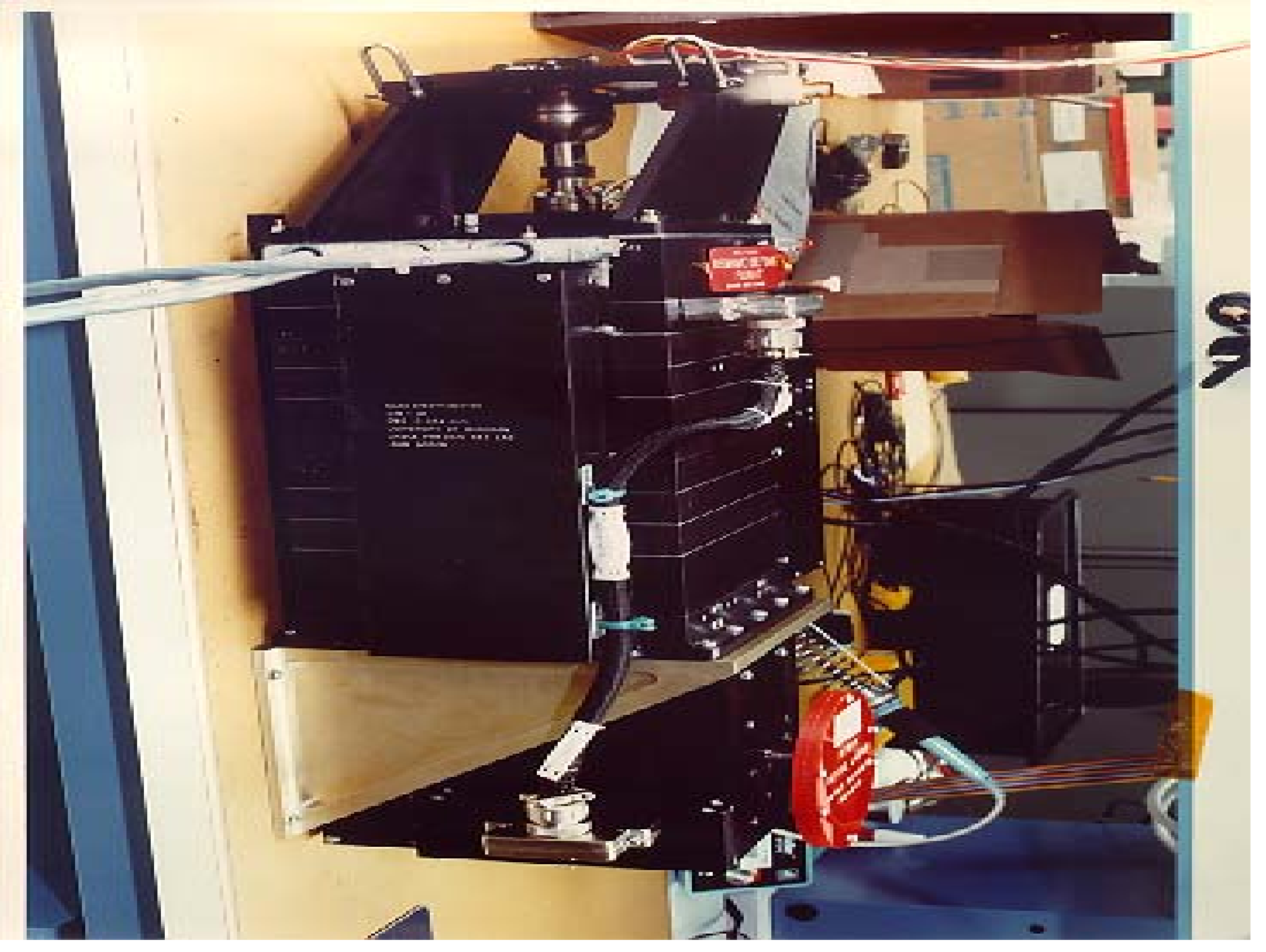
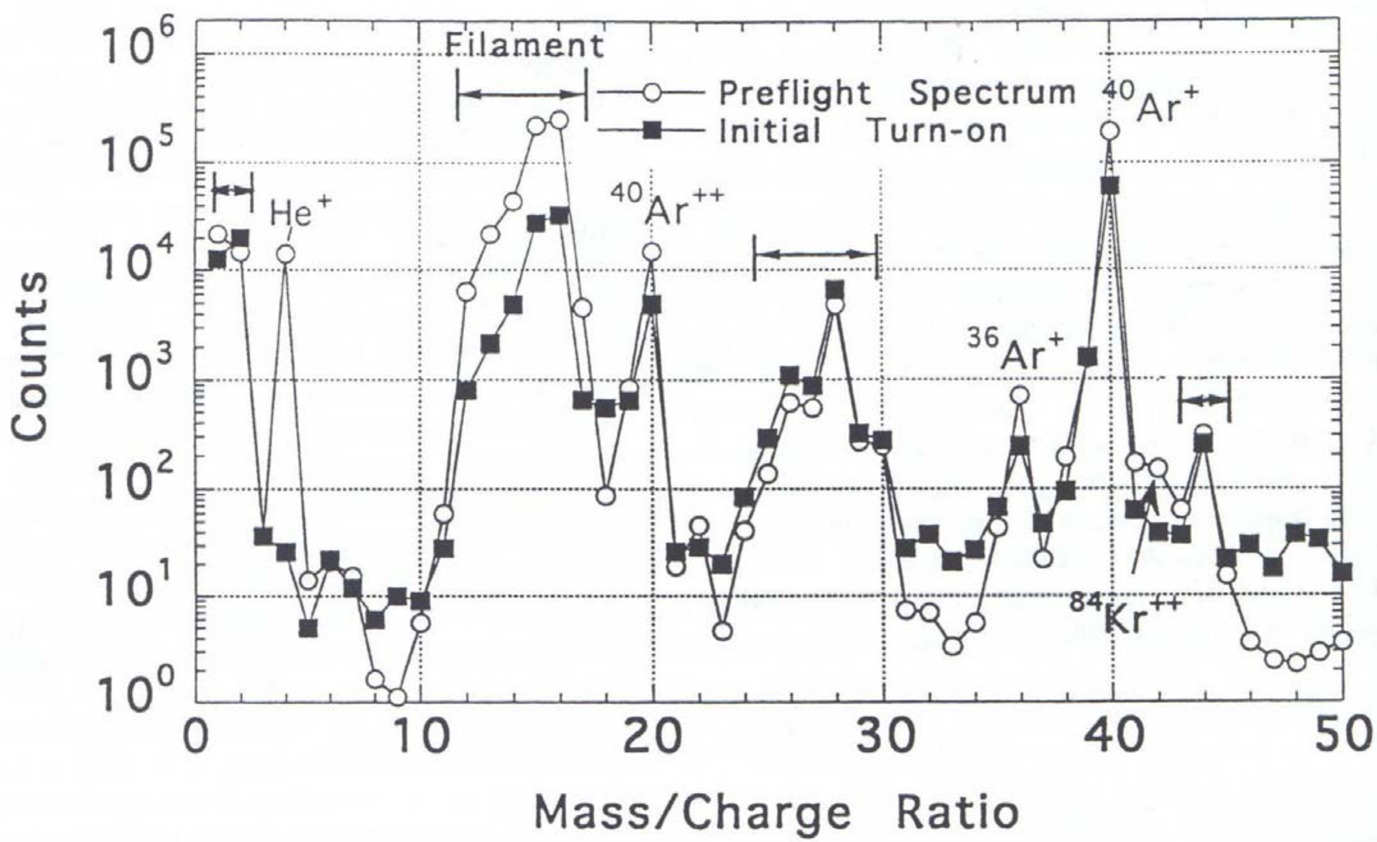
# CONTAMINATION OVERALL APPROACH:



# Neutral Mass Spectrometer (NMS)

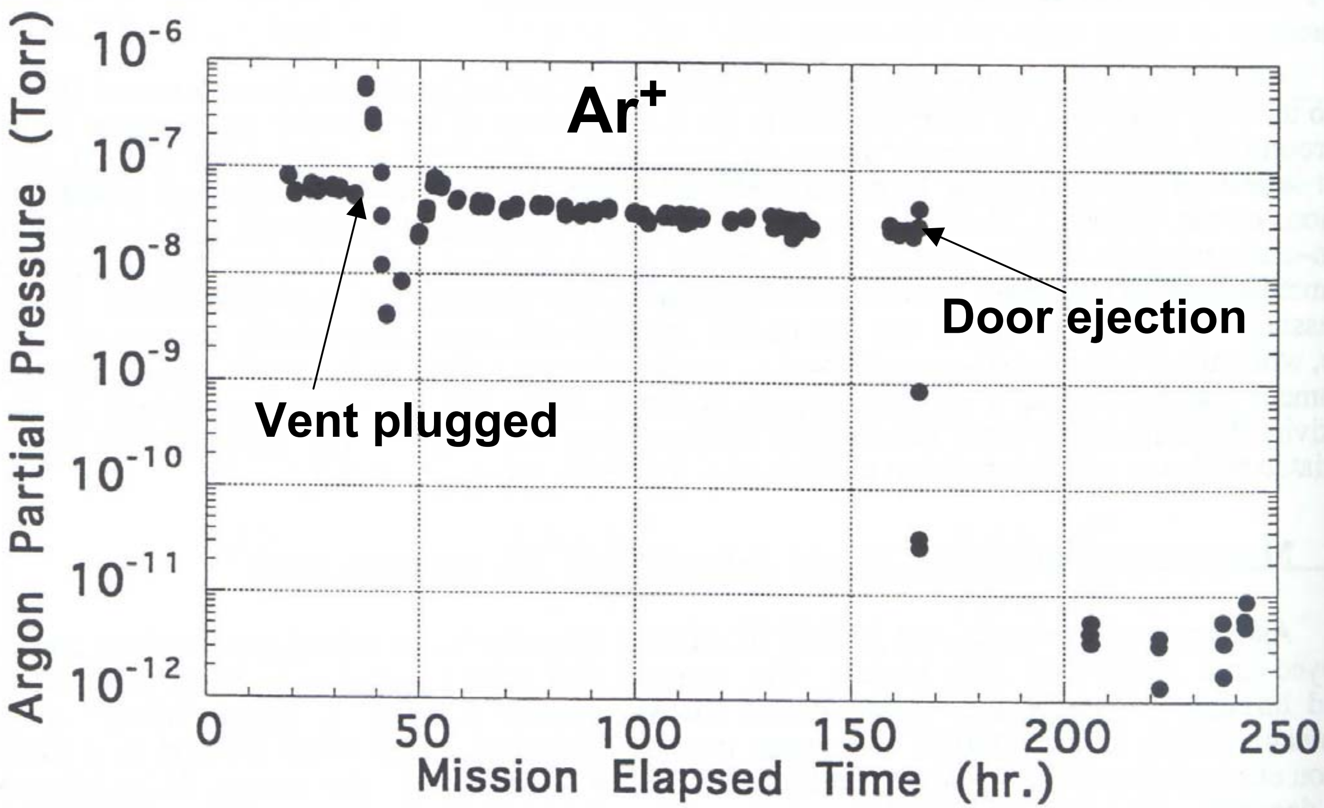


# Neutral Mass Spectrometer



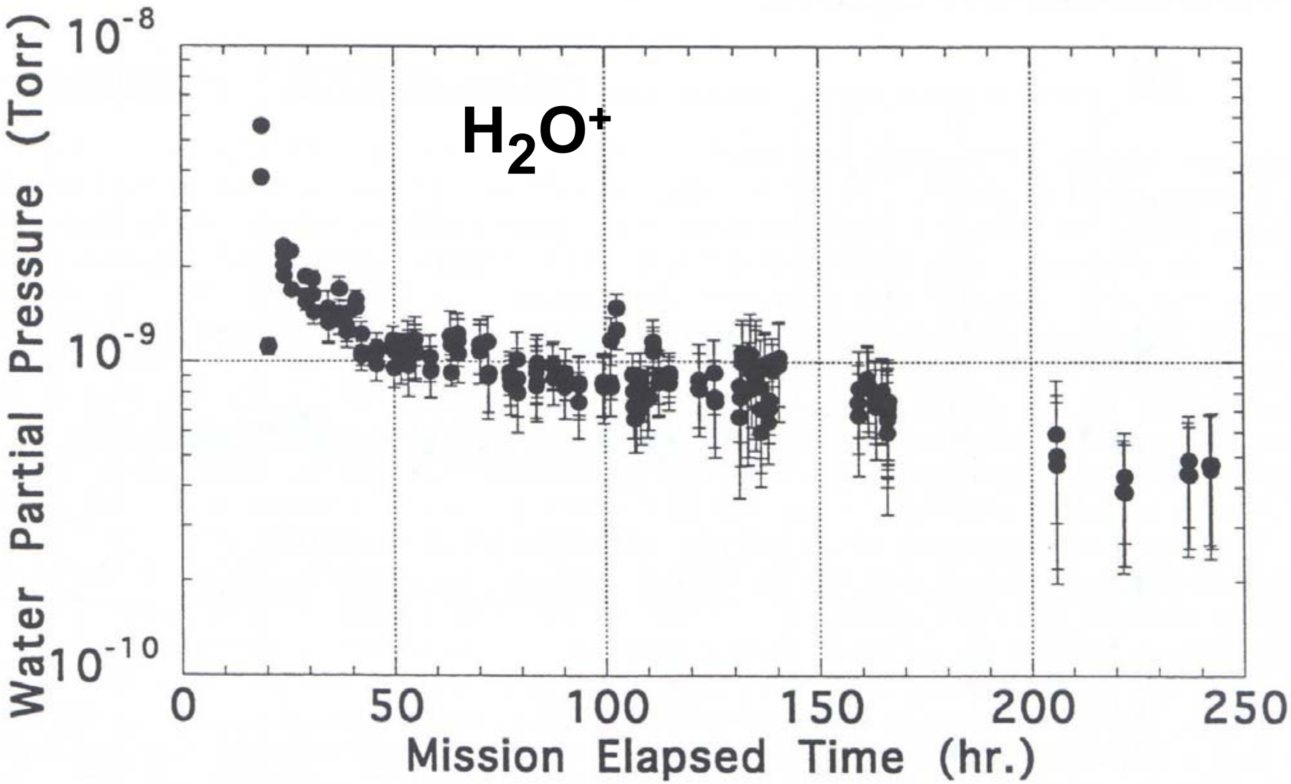

Comparison of spectra obtained initially on-orbit with the last ground measurement. Prior to its cover deployment after launch, the NMS contained a mixture of He, Ar, Kr, and Xe.

# Neutral Mass Spectrometer



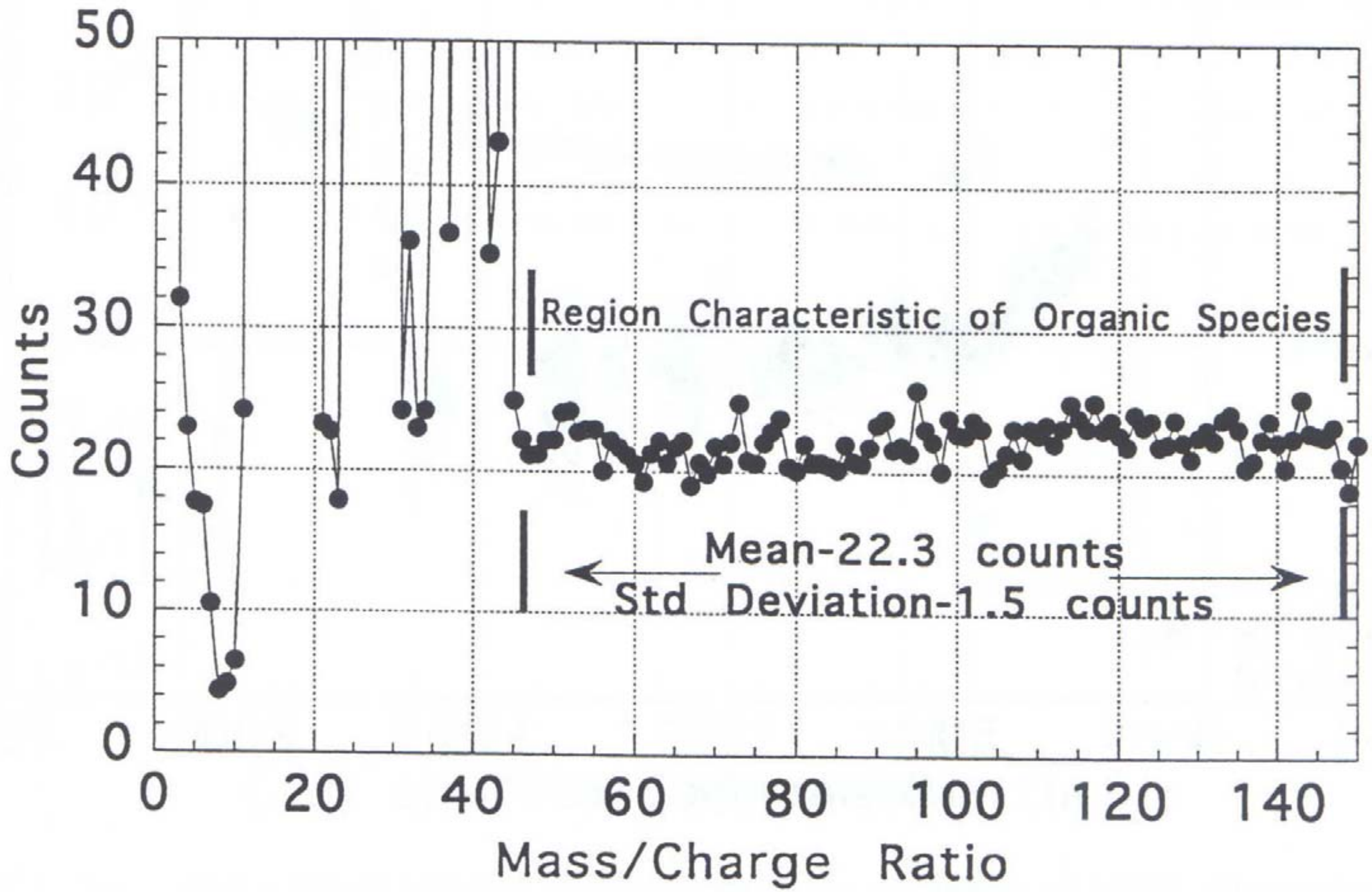

Argon partial pressure at NMS location as a function of MET. The source of the argon was venting from the solid argon cryogen in the SPIRIT III aperture door.

# Neutral Mass Spectrometer



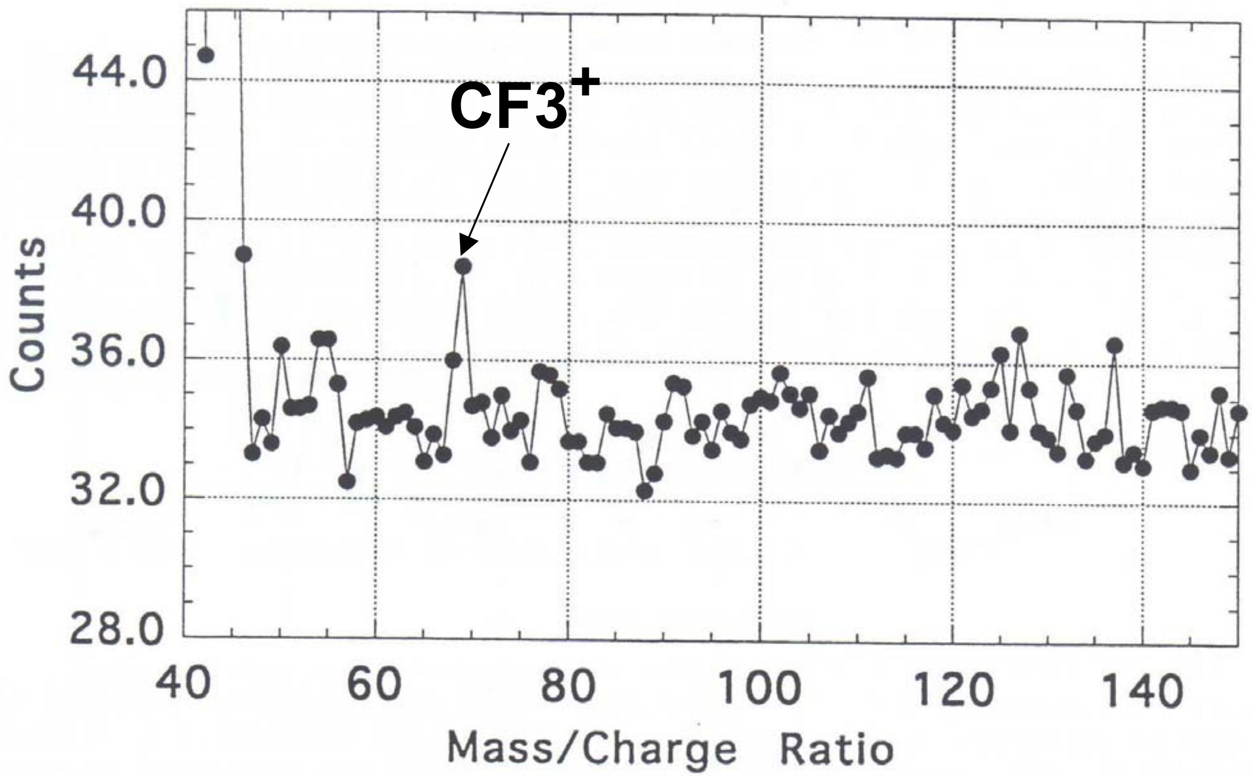

Water vapor partial pressure at NMS location as a function of MET. The error bars shown reflect uncertainties in the instrument background corrections.

# Neutral Mass Spectrometer



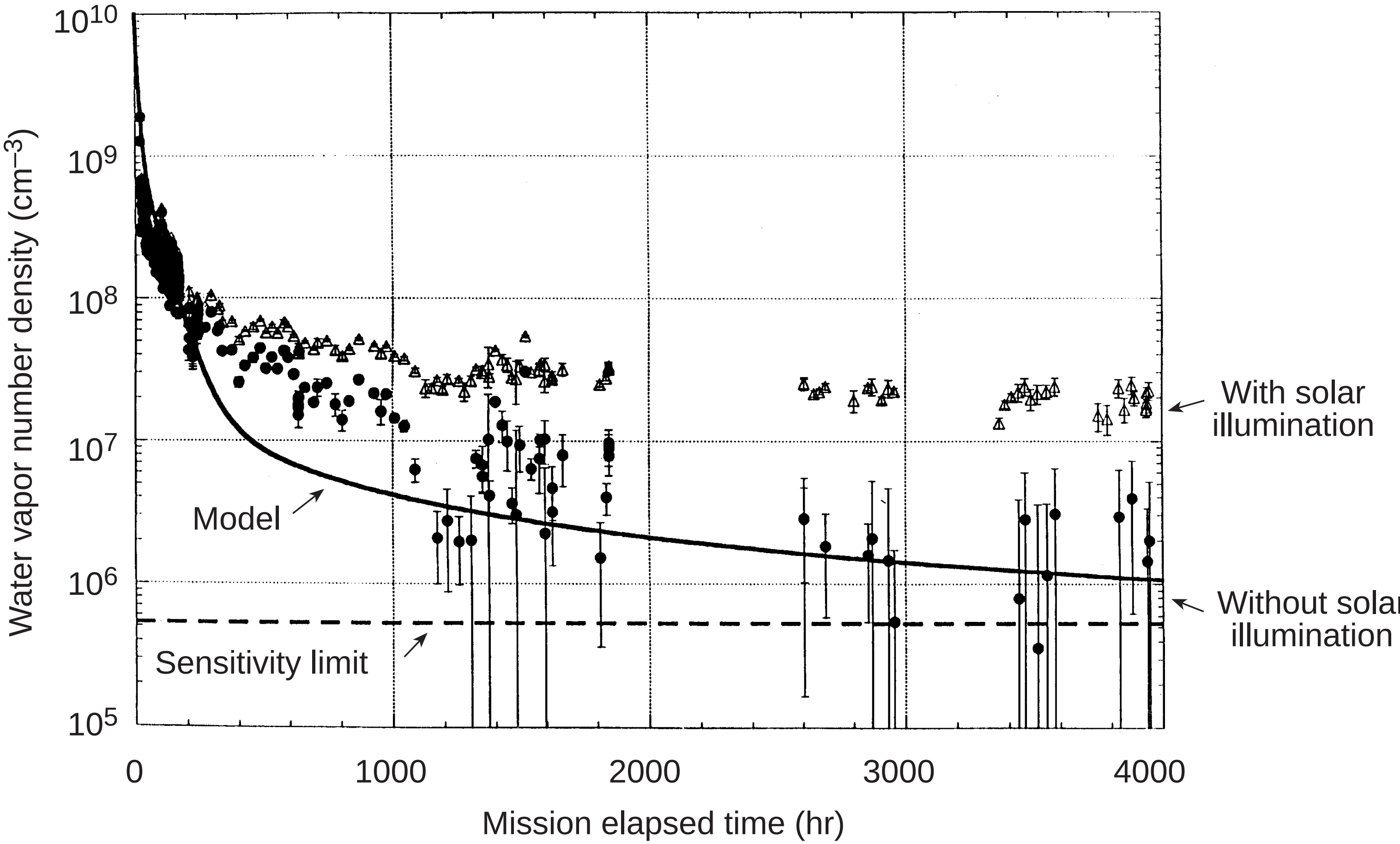

Mass spectrum obtained early in mission showing region of organic species (46-150 m/z); displayed spectrum is average of 12 individual spectral scans.

# Neutral Mass Spectrometer



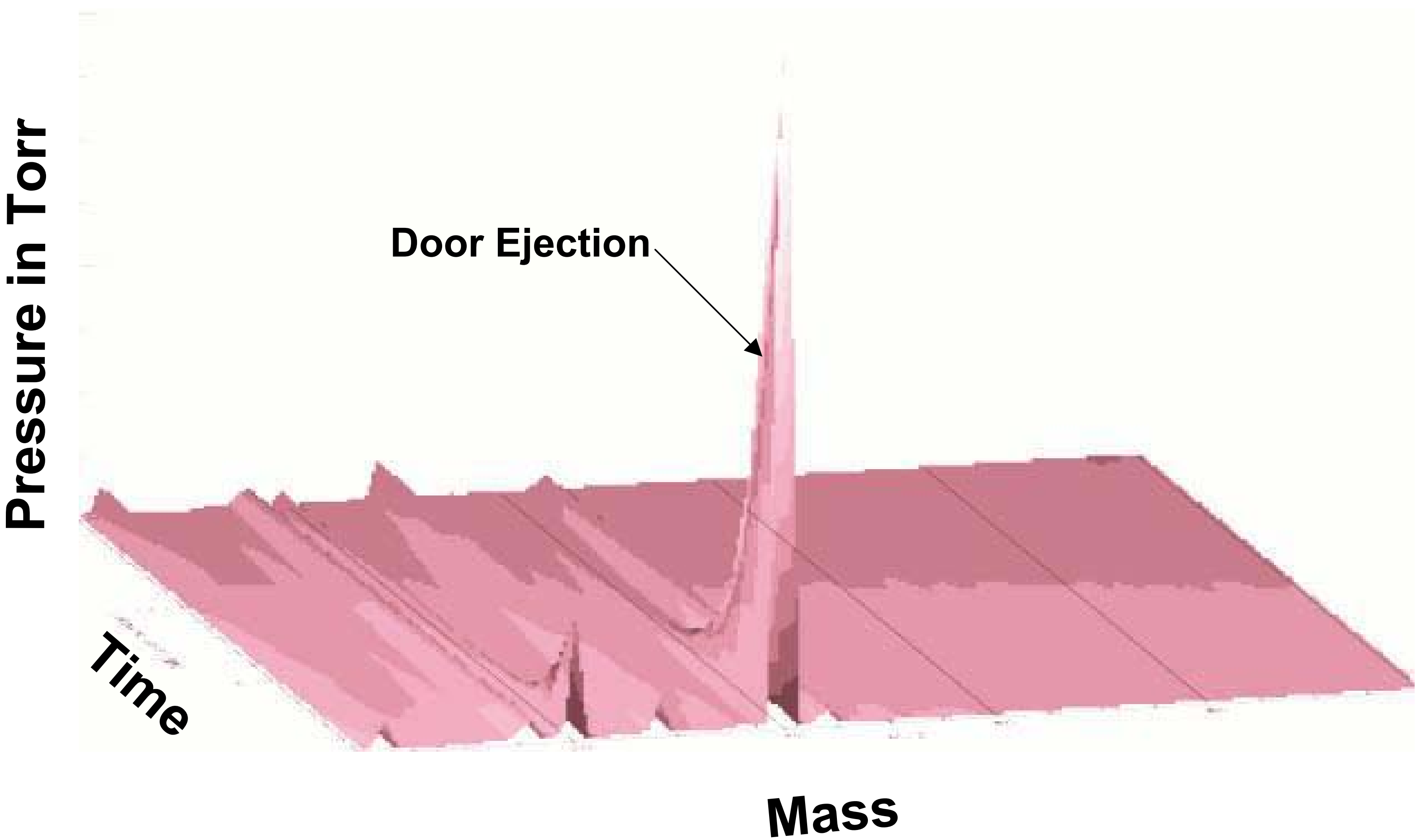

Mass spectrum obtained during Solar Bakeout Experiment; spectrum is the average of 47 individual spectral scans.

# Neutral Mass Spectrometer




**Water vapor densities measured by NMS, showing large variations with each DCE. Note agreement of model for no solar illumination case.**

# Neutral Mass Spectrometer



# NMS Summary

- NMS argon temporal behavior similar to TPS results, i.e. $t^{-1.0}$ decay.
- Water vapor temporal behavior similar to TPS, $t^{-0.8}$ at MET>45 h.
- Organic species (m/z>46) below detection limit of $2 \times 10^5$/cc at turn-on
  - Detected m/z=69 (possible $CF_3$ fragment ion) during Solar Bakeout Experiment.
- Measured inorganic species at m/z=19,23, 35, 37, 39 and 40 after NMS door deployed but not before, indicating F, Na, Cl, K and Ca (or MgO).
  - Possible inorganic debris from ceramic during NMS cover opening.

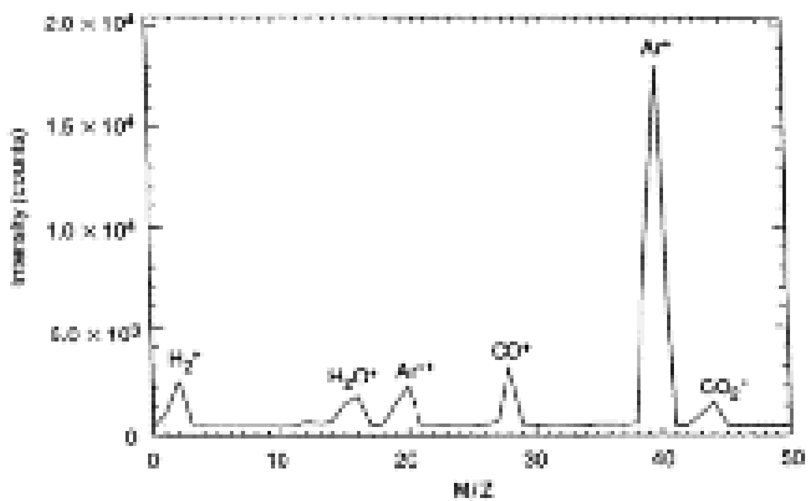
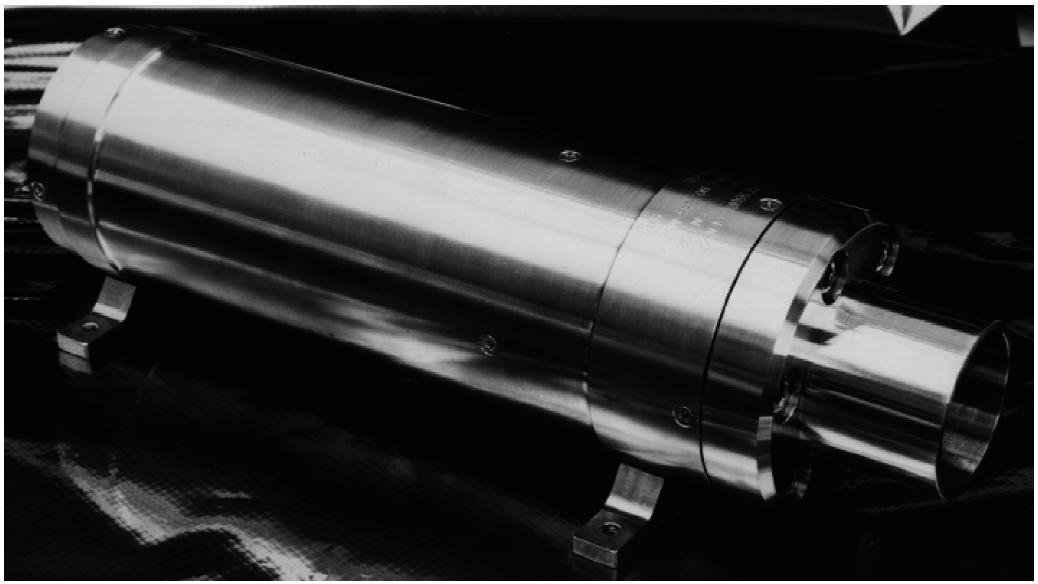



Figure 2. Early operations mass spectrum of the atmosphere above MSX, showing a large presence of argon.

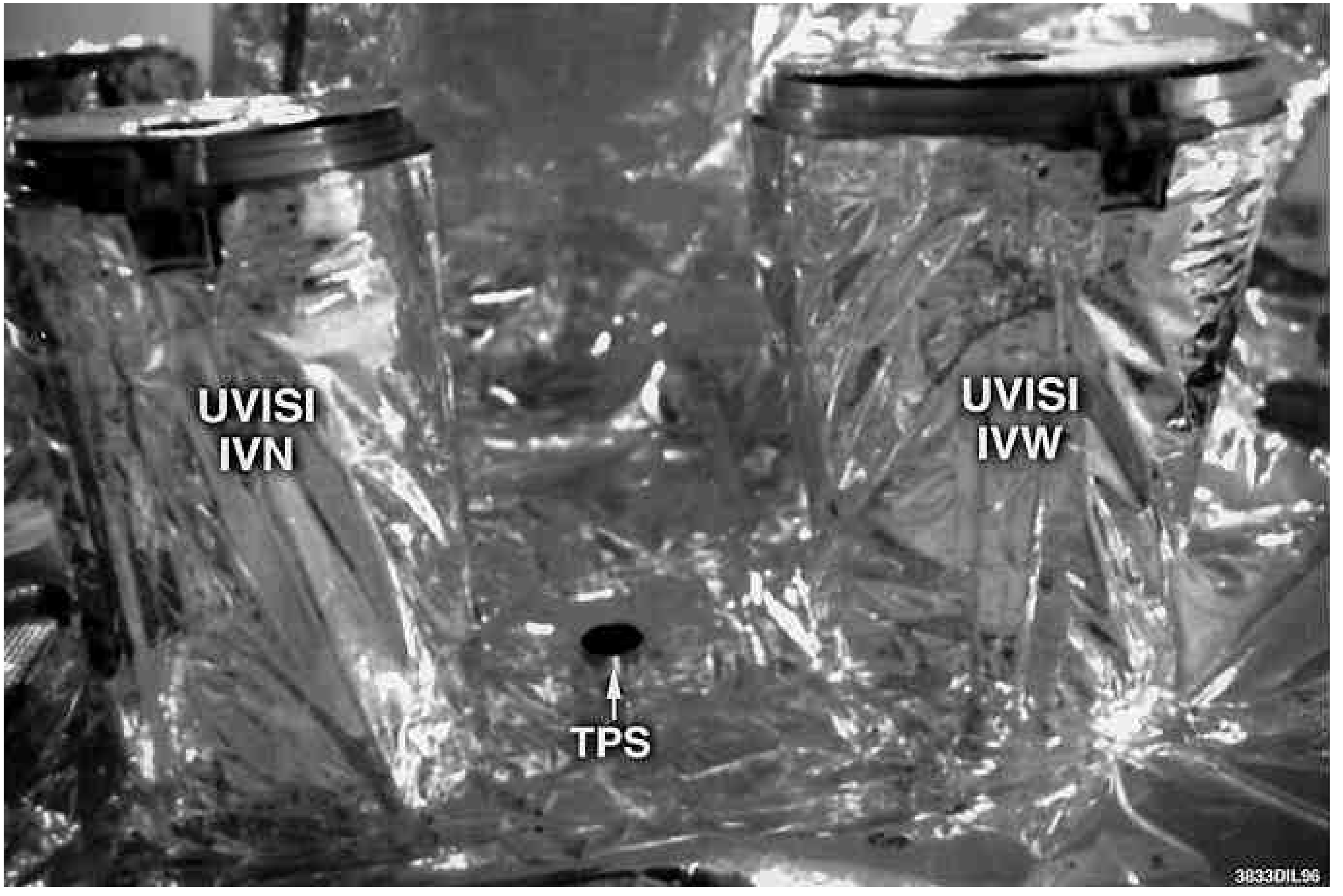
# Total Pressure Sensor (TPS)



- Cold Cathode Gauge
  - Penning type
- Measures Total Gas Pressure
  - 1 (0.2) Hz Sample Rate
  - 0 - 5 Volt Output
  - 8 bit digitization
  - 4 Watts Power / 8 Pounds
  - Size: 4”x 4” x 11”

- Performance
  - $10^{-5}$ to $10^{-10}$ Torr
- Calibrated by NIST
  - He, Ar, $N_2$, $H_2O$

# +Z Face of the MSX Instrument




- **The +Z face of the MSX instrument section illustrating the location of the TPS between the sunshades of the IVN and IVW imagers and in front of the Spirit 3 sunshade**

# Total Pressure Sensor

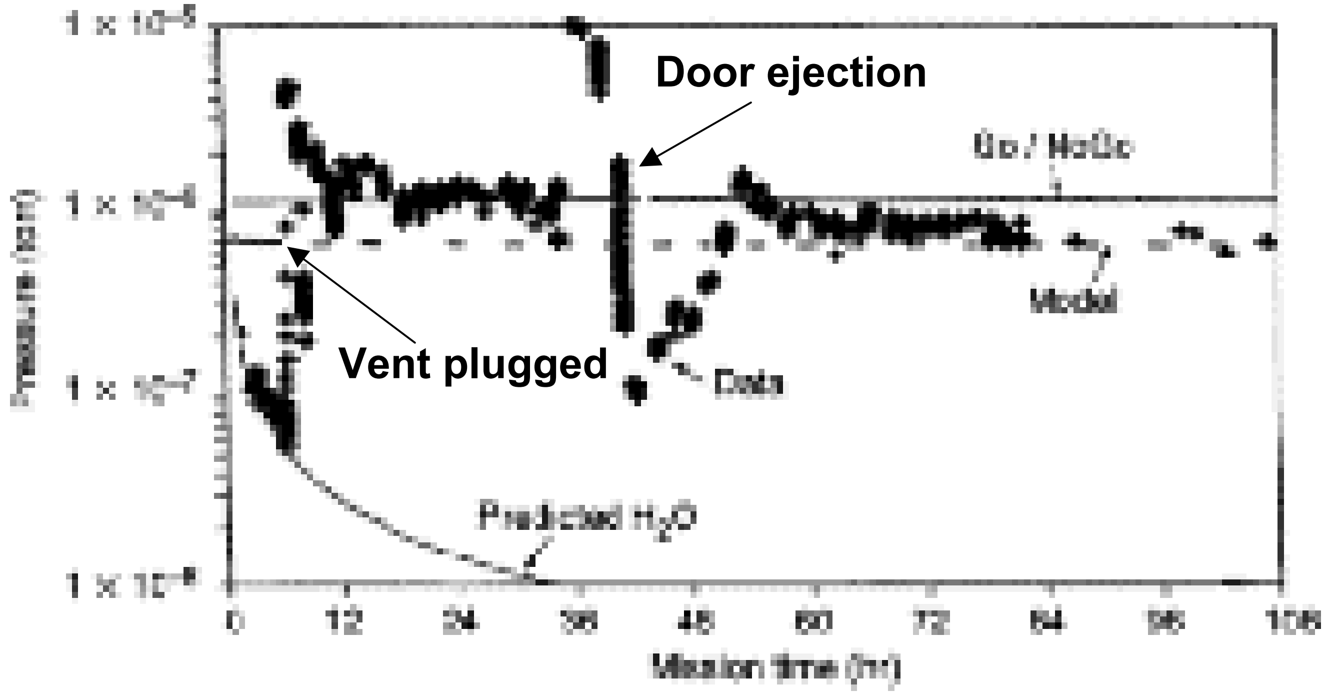
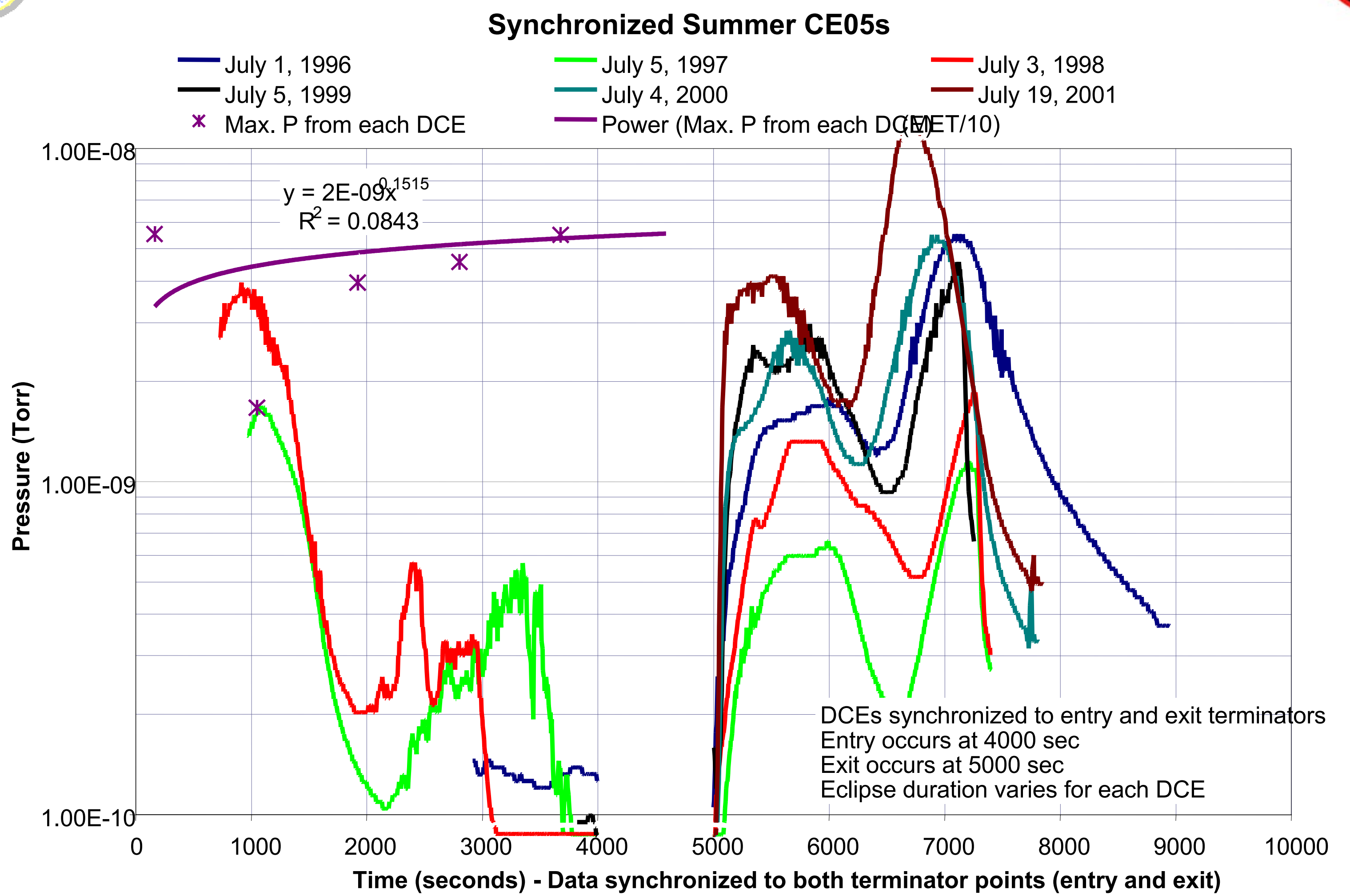
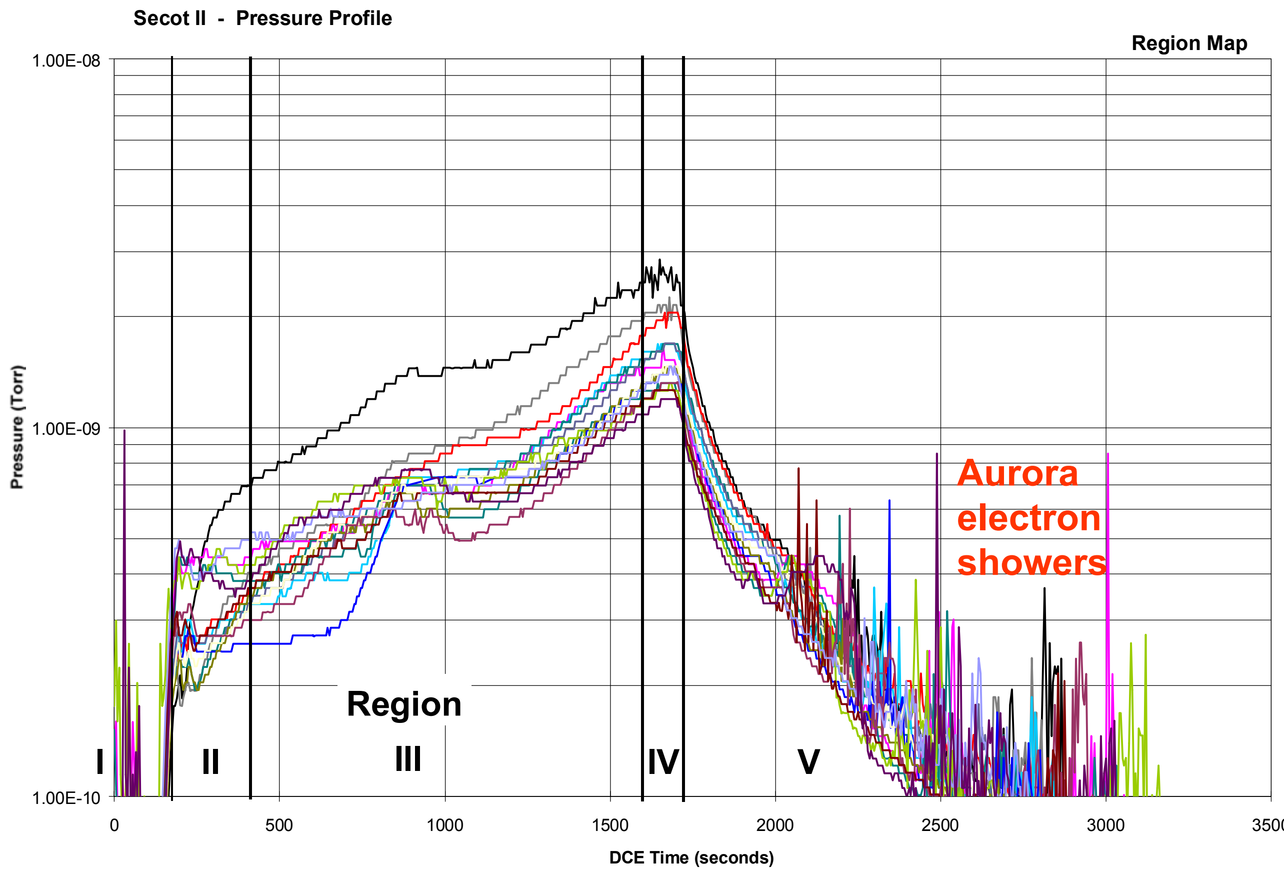



Figure 1. Early operations chart for the total pressure sensor.

# Synchronized Summer CE05S

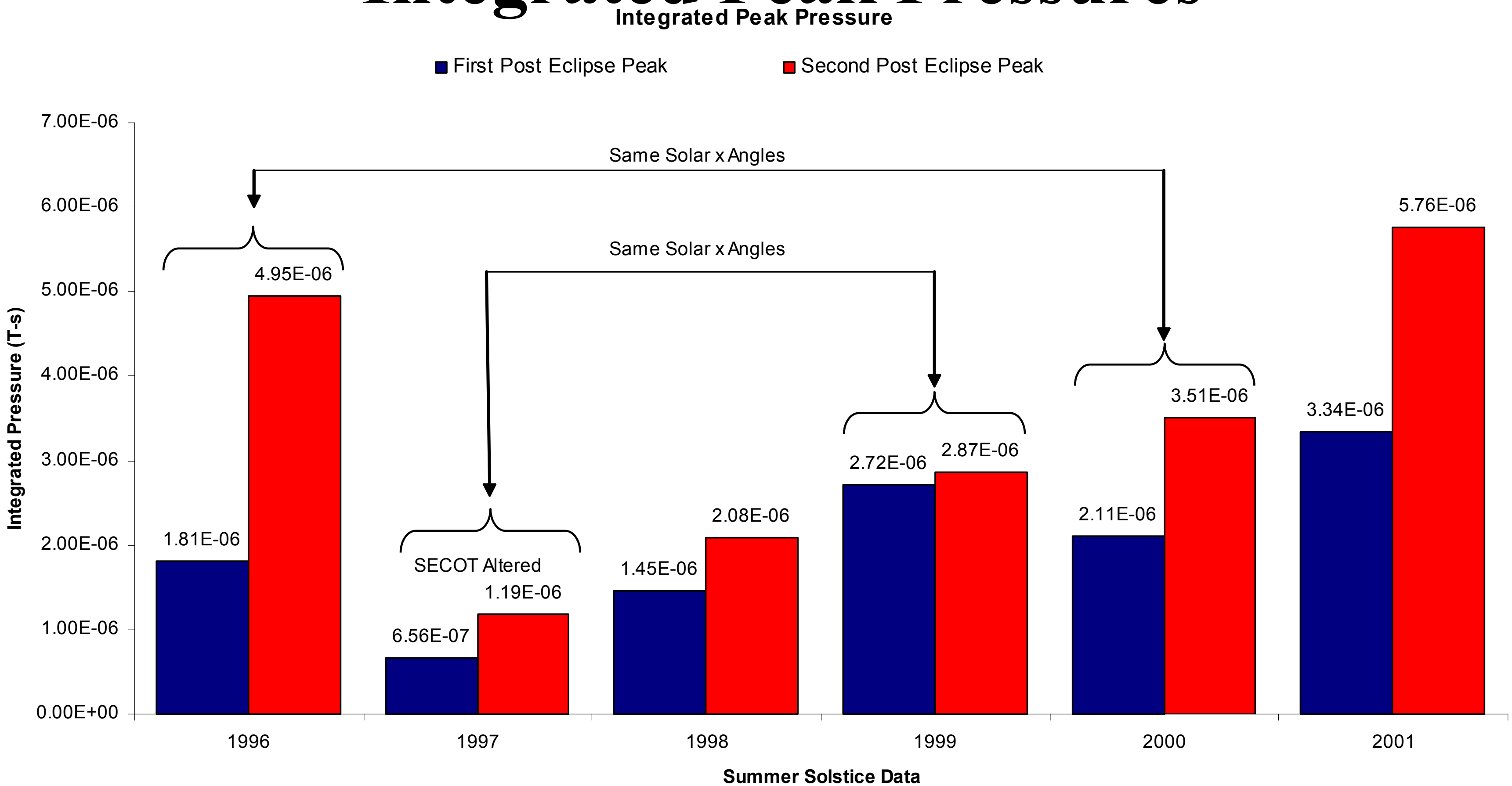



**Profile accurately maps illumination and shadow of MLI over several years**




**Total Pressure Measurements show fine structure over several days**

# Synchronized Orbital Effects Experiments Integrated Peak Pressures




**Integrated water flux in 2001 is 6x flux in 1997, slightly increasing over several years**

# TPS Summary

- Significant reservoirs of water are contained in the thermal blankets.  The deep reservoirs appear undiminished after 7+ years of operation
  - depleted by solar illumination, not time on orbit

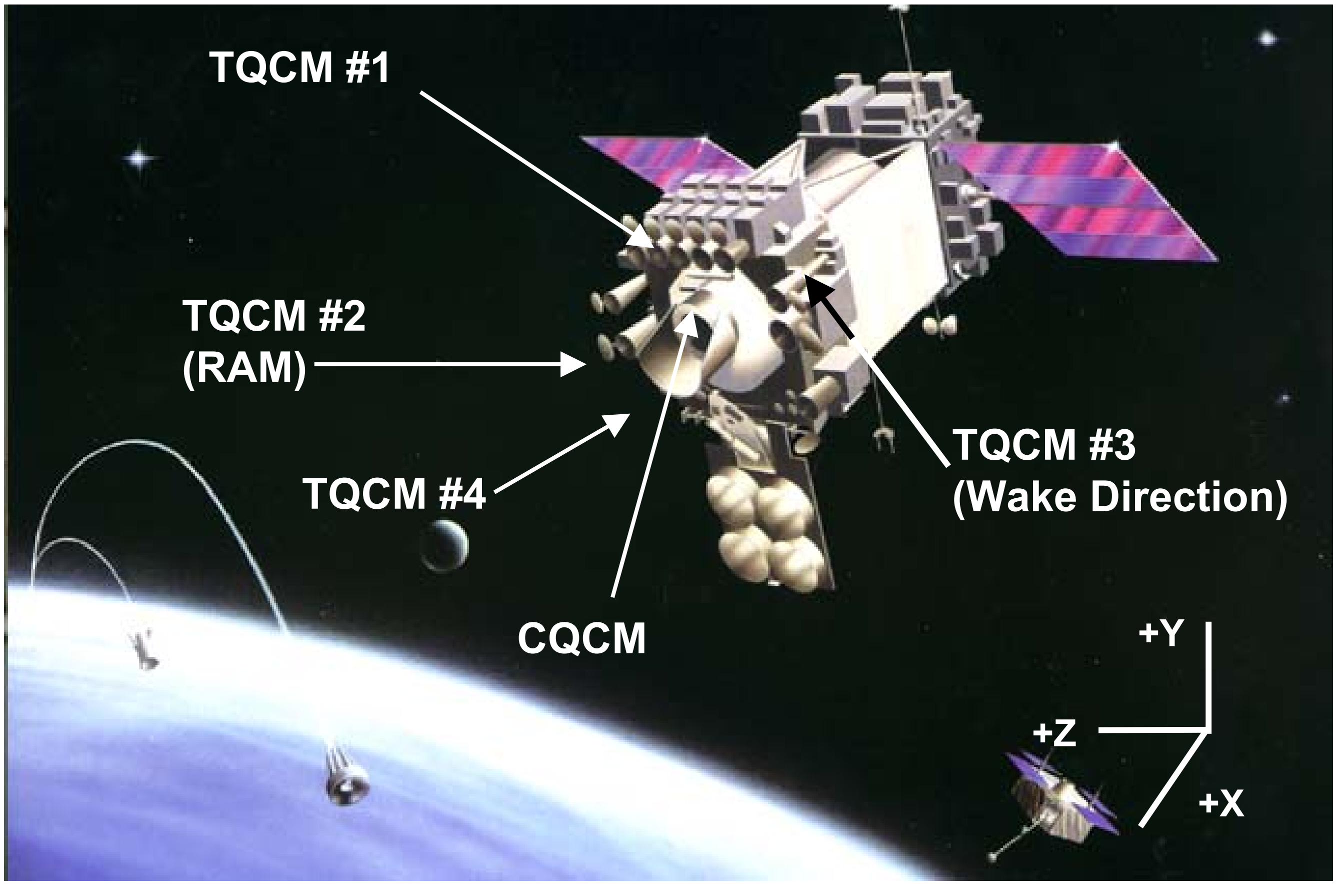
- Solar illumination will drive the water from the top most layers of insulation
  - magnitude related to incidence angle

- Water will continually redistribute within each blanket.  The lower levels replenishing the outermost levels.

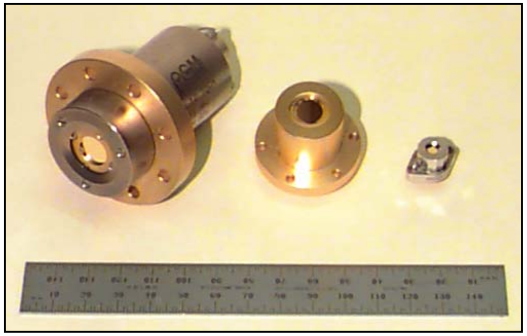
- The replenishment rate varies and depends upon the intensity and duration of the solar exposure

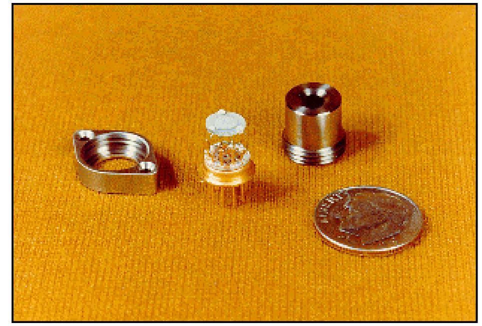
- The magnitude of the solar induced pressure is directly related to incidence angle, and shadowing of surfaces in a sensors field-of-view

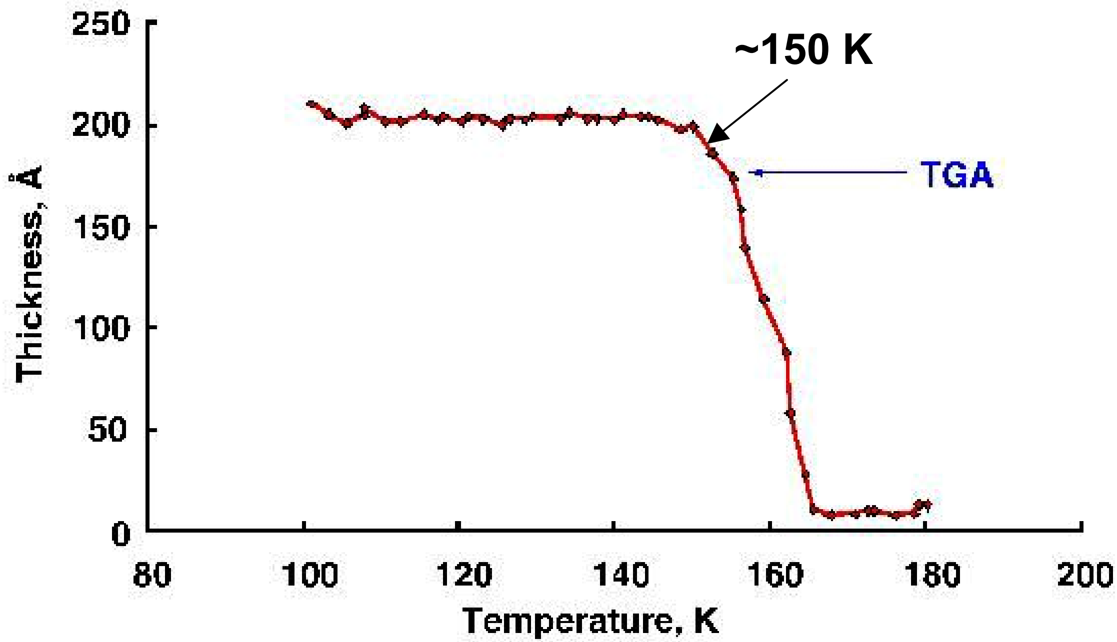
# Quartz Crystal Microbalances (QCM's) and their location in the Spacecraft



# Quartz Crystal Microbalances

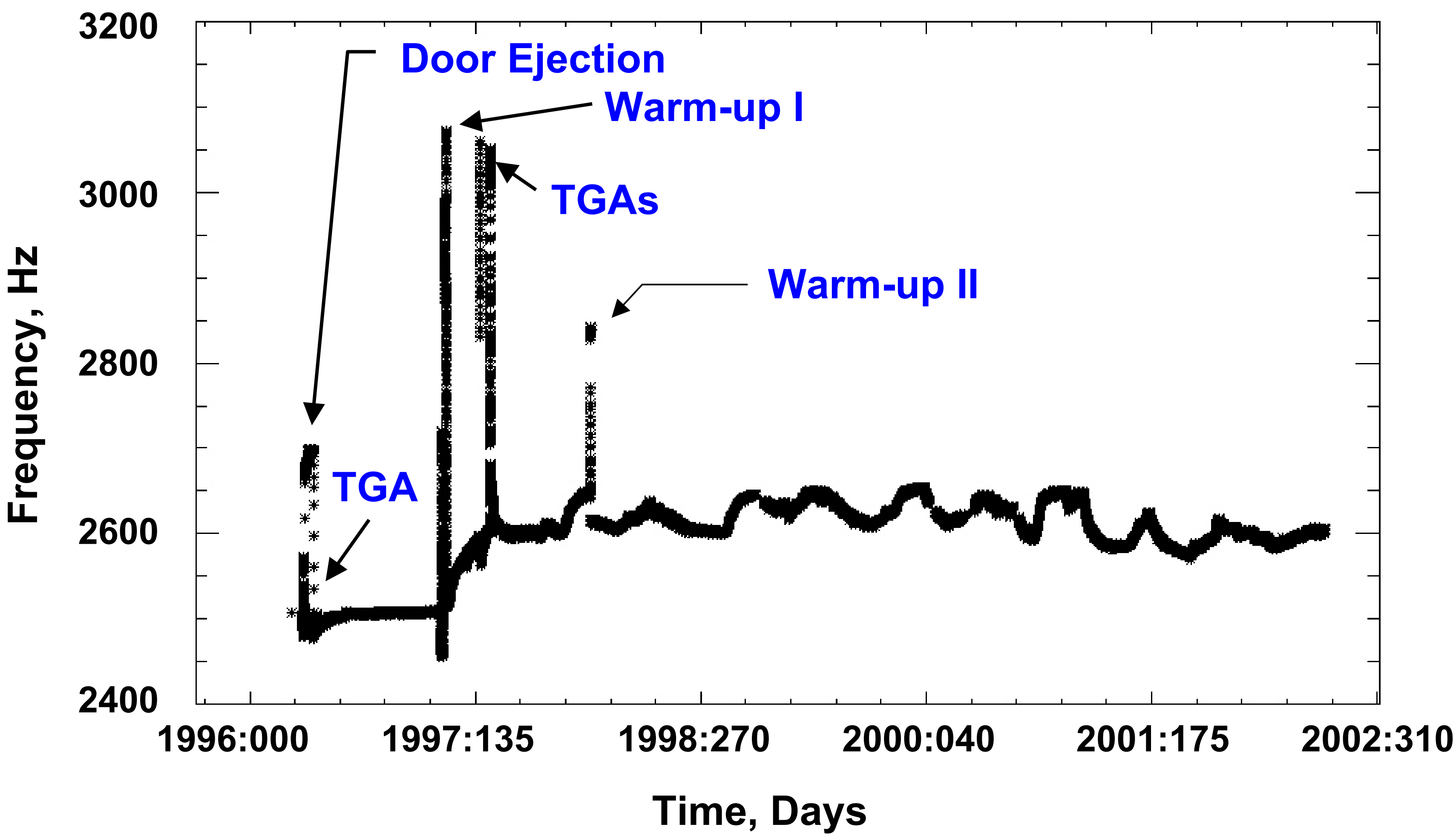


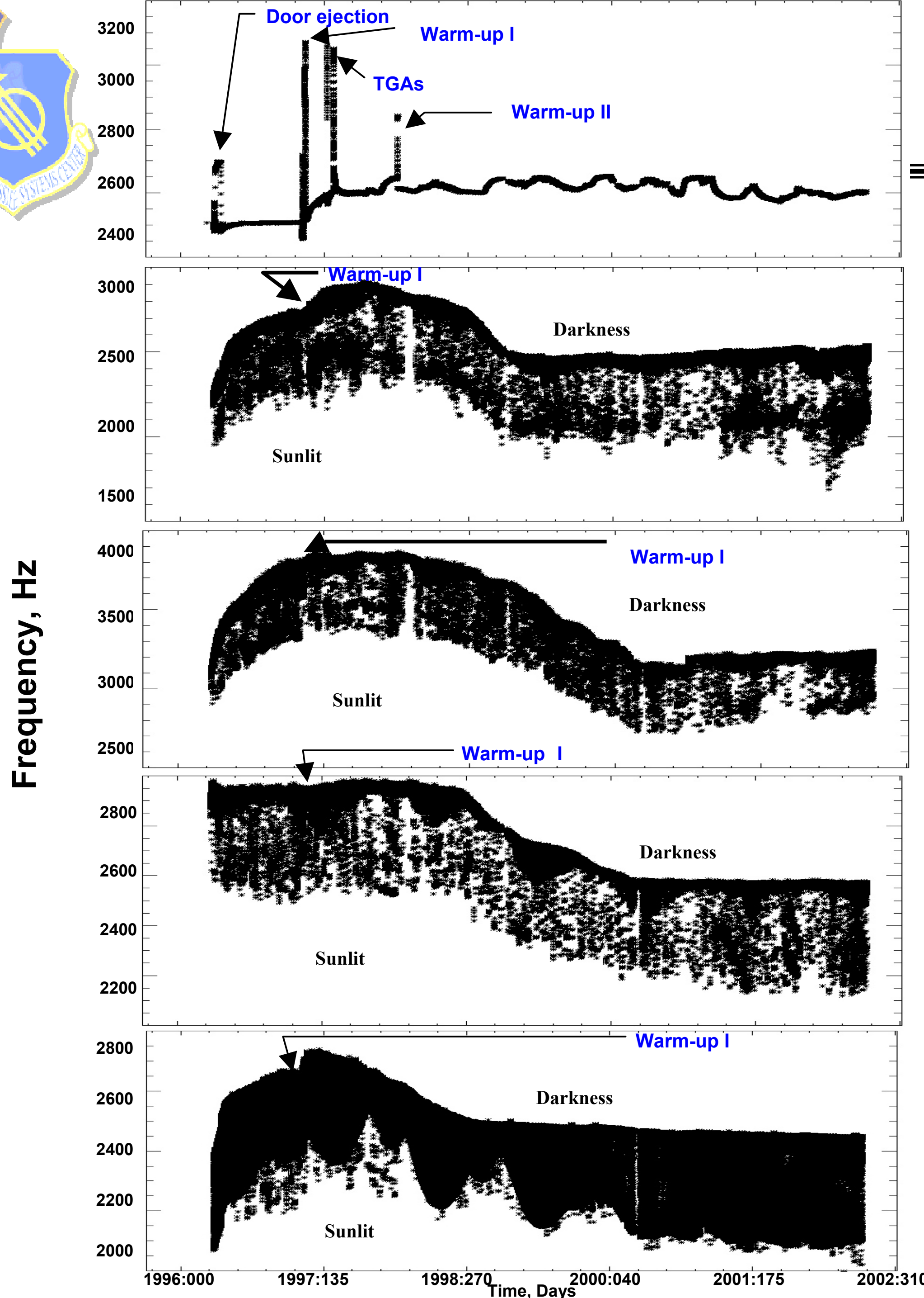





**TGA of the CQCM inside IR telescope showing that film deposit was water vapor**

# CQCM Frequency vs. Time(Located inside SPIRIT III Telescope) as of July 13, 2002





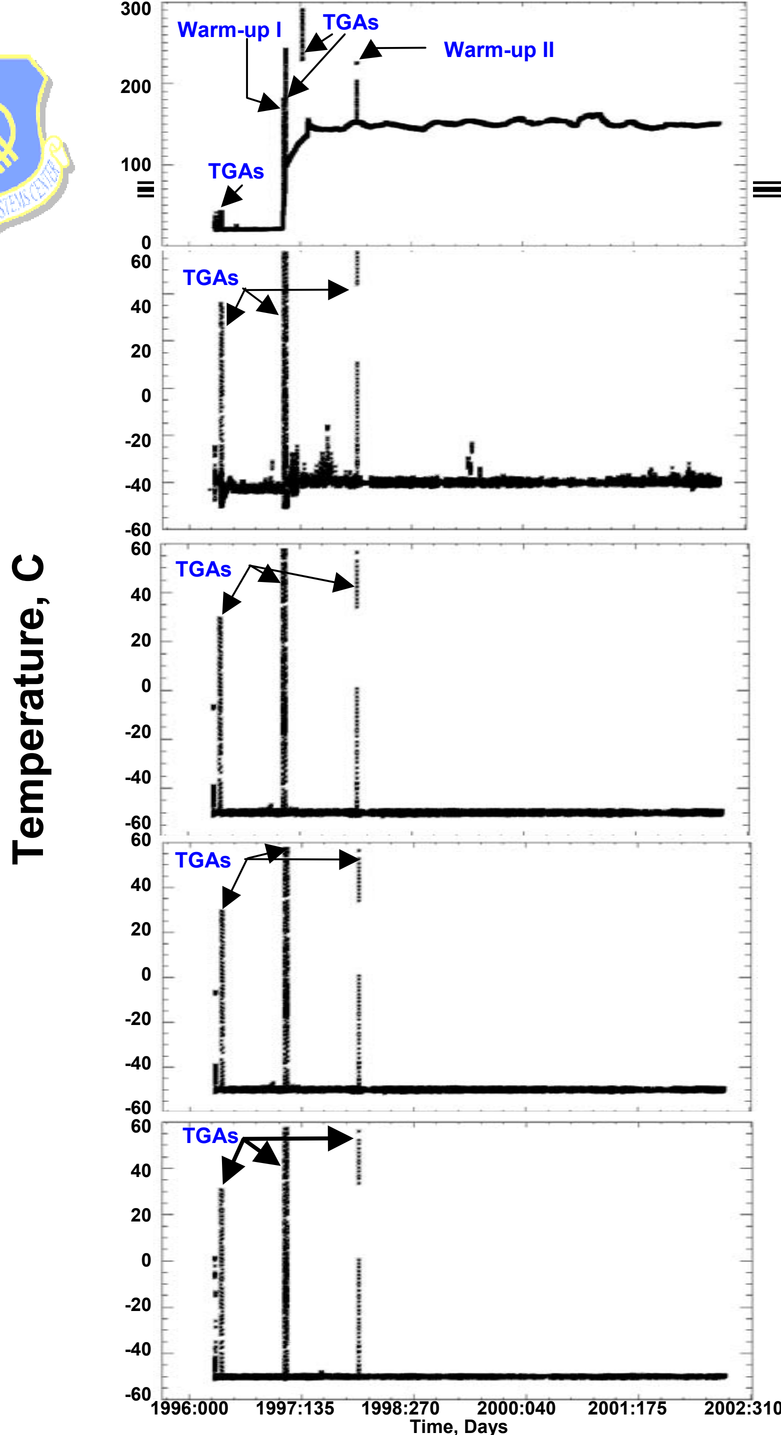

# CQCM

# TQCM #1

# TQCM #2

# TQCM #3

# TQCM #4




CQCM, K

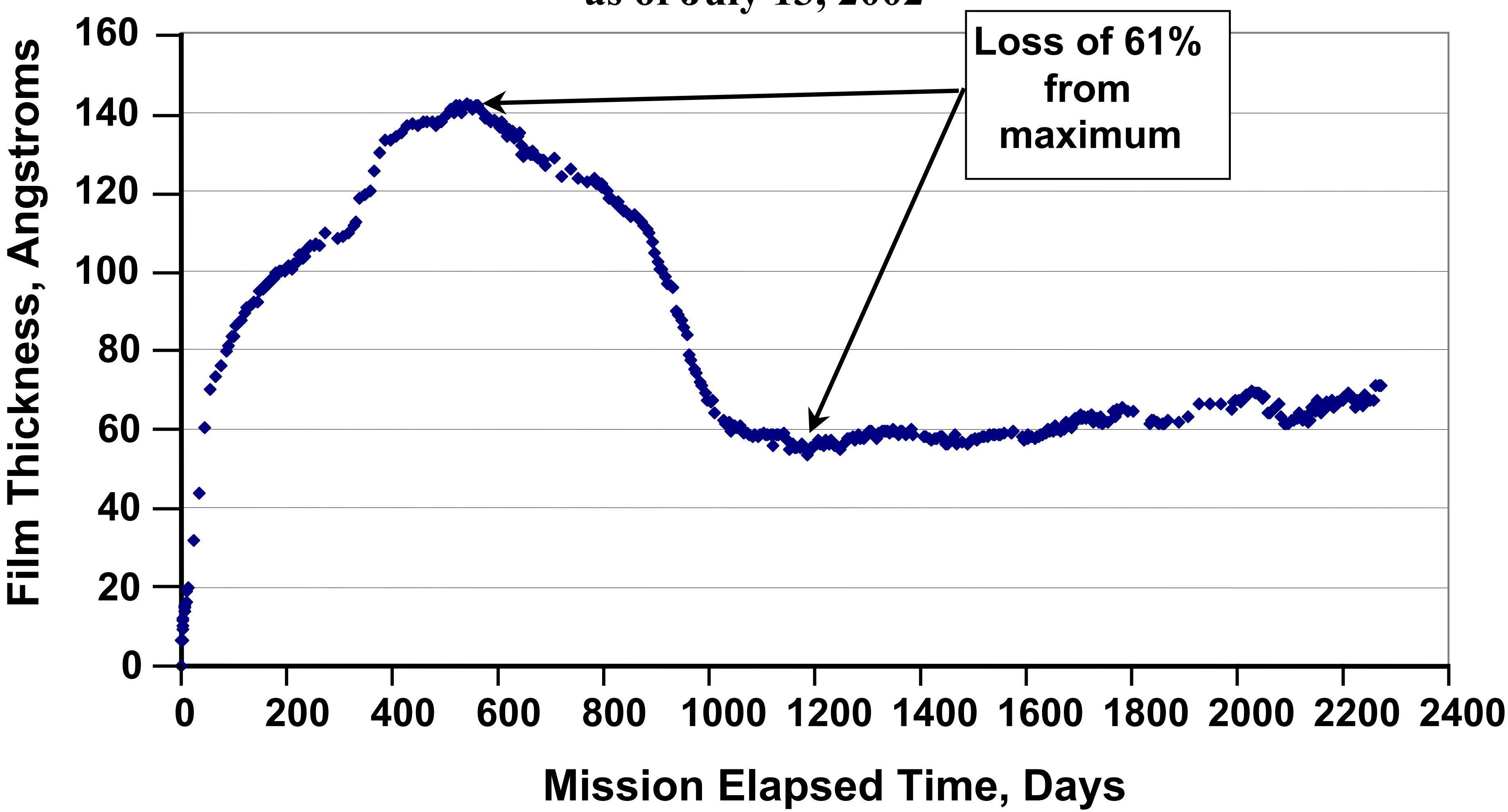
TQCM #1, C

TQCM #2, C

TQCM #3, C

TQCM #4, C

## TQCM #1 Film Thickness vs Time as of July 13, 2002



# Early Operations Analysis - CQCM

- Comparison of contaminant deposition rate on primary mirror pre/post door opening – inside S-3 versus space
  - determined $O_2$ to be the specie condensed prior to door opening
  - determined that 72 angstroms of contaminant condensed on S-3 mirror during argon-cooled door ejection. Species were identified as mainly argon with some oxygen during TGAs
- From CQCM $\Delta$F (and $\Delta$t), changes in mirror BRDF and mirror reflectance were determined as a function of thickness

# Calculated Average Contaminant Erosion Rates from TQCMs

| TQCM # | Erosion Rate Angstroms/day |
|---|---|
| 1 | 0.164 |
| 2 | 0.166 |
| 3 | 0.150 |
| 4 | 0.080 |

# Environmental Workbench Atomic Oxygen Predictions at 904 km during 1999

| Direction | O atoms/$cm^2$-sec |
|---|---|
| Ram direction (QCM #2) | $8.9 \times 10^{9}$ |
| Top, bottom,sides (QCM #1, 4) | $3.2 \times 10^{8}$ |
| Wake (QCM #3) | $6 \times 10^{-18}$ |

# For QCM #2

## (Ram Direction)

**Dividing the recession rate of**

**$0.17 \times 10^{-8}$ cm/day**

**by the calculated**

**$8.88 \times 10^{9}$ O atoms/$cm^2$-sec**

**gives a reaction rate of approximately $2 \times 10^{-24}$ $cm^3$/ O atom which is typical for highly reactive materials**

# QCM Summary

- After 8 years in orbit, all 5 of the MSX QCMs are still operational and are providing useful data
- CQCM data was invaluable in determining the health of the SPIRIT 3 primary mirror during a 10-month cryo-period
- TQCMs having view factors of solar panels received the largest deposition levels
- TQCM “solar effects” are appreciable and have to be accounted for in the data analysis
- Cause of erosion rates (frequency decreases) experienced by the TQCMs may be AO related

# Overall Summary

## Comparison of NMS, TPS & QCM Results

- How did these MSX contamination instruments function?
  - QCM's proved benefit to satellite sensor development, early operations and throughout the MSX mission
  - TPS proved valuable as an early orbit decision aid, easily deduced either Ar or water vapor sensor
  - NMS provided early identification of neutral species but later detected only He and residual water

**Conclusion:**

**The best performing instruments are the TPS and QCM's. They are small. rugged, reliable and also the least expensive and easiest to operate.**

# Suggestions for Future Space Missions

- Include TPS and QCM's in payload as environmental monitors. They:
  - reduce unnecessary cost and schedule impact during ground T&E
    - assist in cleaning, refurbishment decisions, accident evaluation
  - reduce impact on spacecraft data systems
    - have low power and telemetry requirements (<10 W total power, about 2 bytes/sec TM, CQCM <5 mW dissipation)
  - relate ground performance to on-orbit performance
  - have extensive flight heritage
- TPS and QCM's are the most cost effective instruments for contamination monitoring
- Use mass spectrometer only for special purpose

  e.g. ID of rocks, atmospheric constituents of planets & moons