MUPS Tank Pressure Anomaly

A scary story with a happy ending*

ITAR (International Traffic in Arms Regulations)
IANAL (I Am Not A Lawyer)

nature International weekly journal of science

Export-control laws worry academics

US researchers hope planned reforms will reduce the risk of prosecution.

Academics in the United States are hoping that pending legislation and a presidentially mandated review could provide long-sought relief from export laws they believe hamper international scientific cooperation and research.

The defence and aerospace industries have long struggled with the seemingly Byzantine nature of export-control regulations, as has NASA, which has sought exemptions to cover its work on the International Space Station. The recent sentencing of two US physicists to prison underscores how academics can also face penalties for failing to comply.

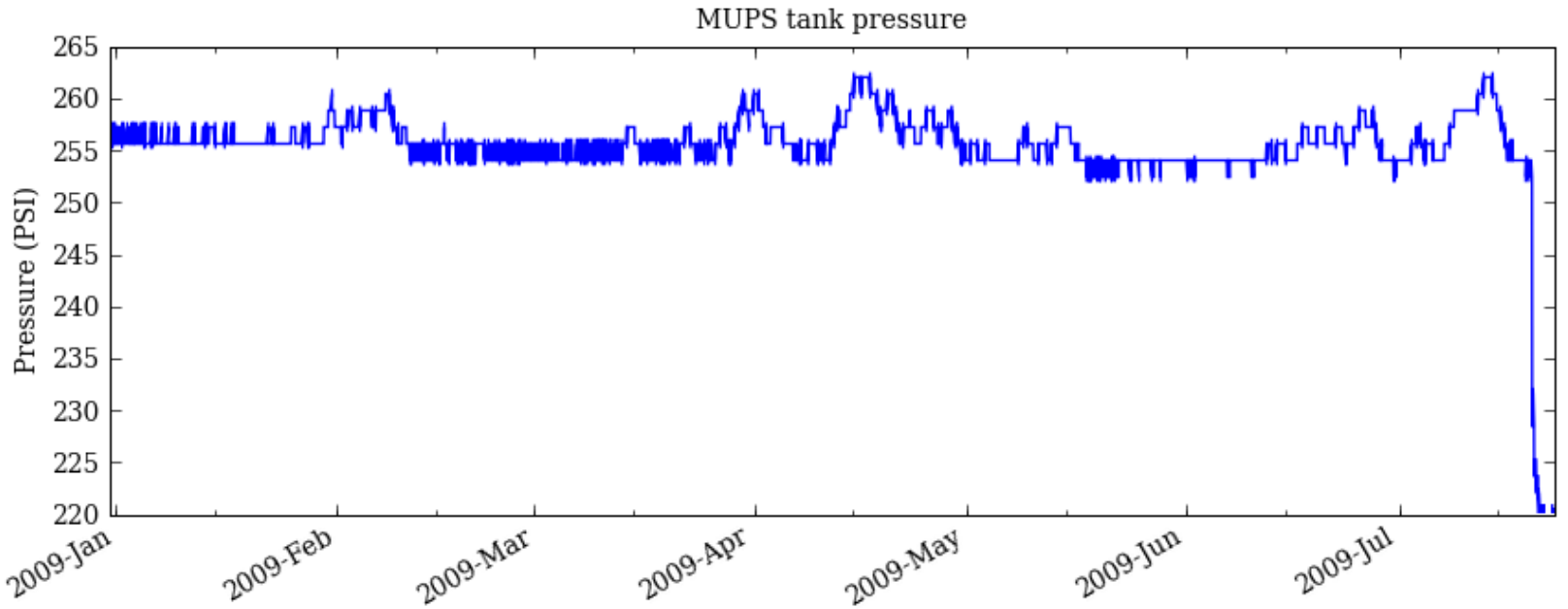
S. DOERING/VISUM/STILL PICTURES

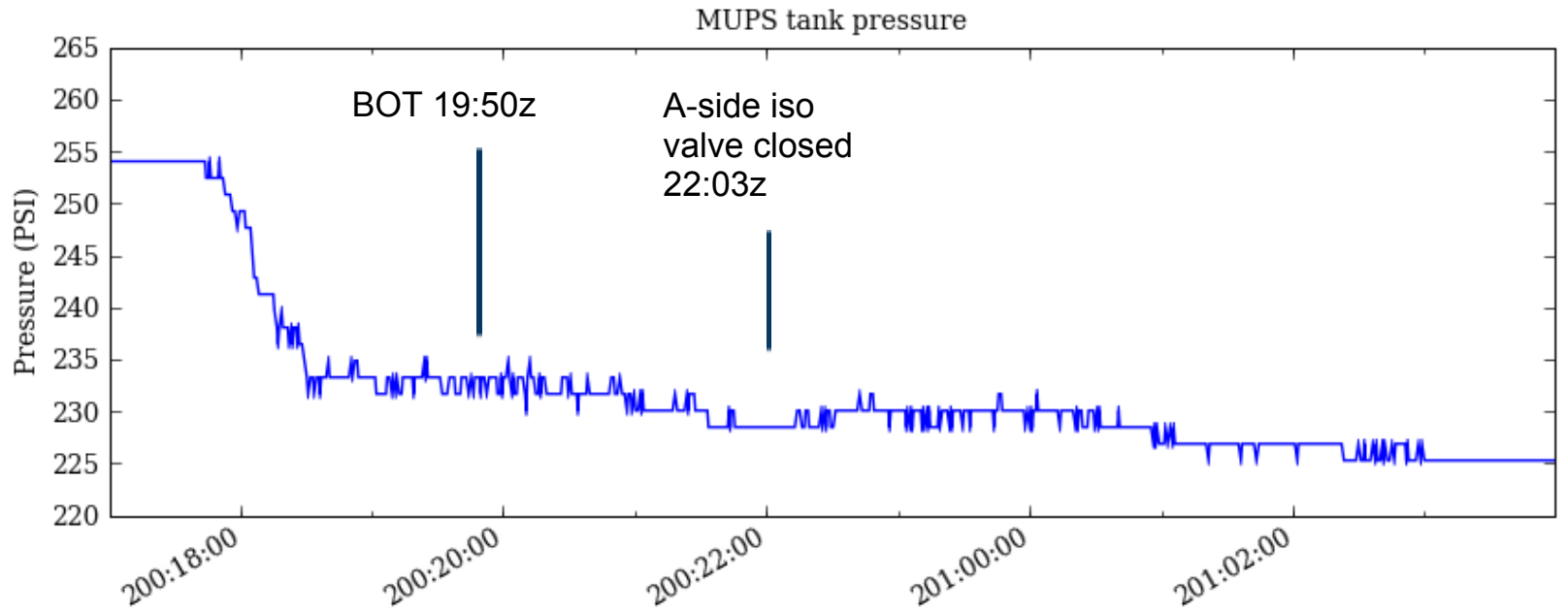
The Scary Bit in words

"On DOY 200 *[July 19]* during the 1950-2205 GMT pass, G_LIMMON reported the MUPS tank pressure at 233.2 psia, well below its yellow caution low of 250 psia. Upon further investigation, it was discovered that a few hours into the JUL2009A loads at 1750 GMT the tank pressure suddenly dropped ~21 psi over 45 minutes, from 255 psia to 234 psia. It stabilized until 2100 GMT and then began a slow drop to the last known value of 228.5 psia at 2205 GMT (end of track).

There were no significant changes in rates, momentum, or propulsion system temperatures. As a precautionary measure, the crews closed the MUPS bank-A isovalve at the end of the track by executing script P_ISO3 with inputs of C for Close and F for Forward."

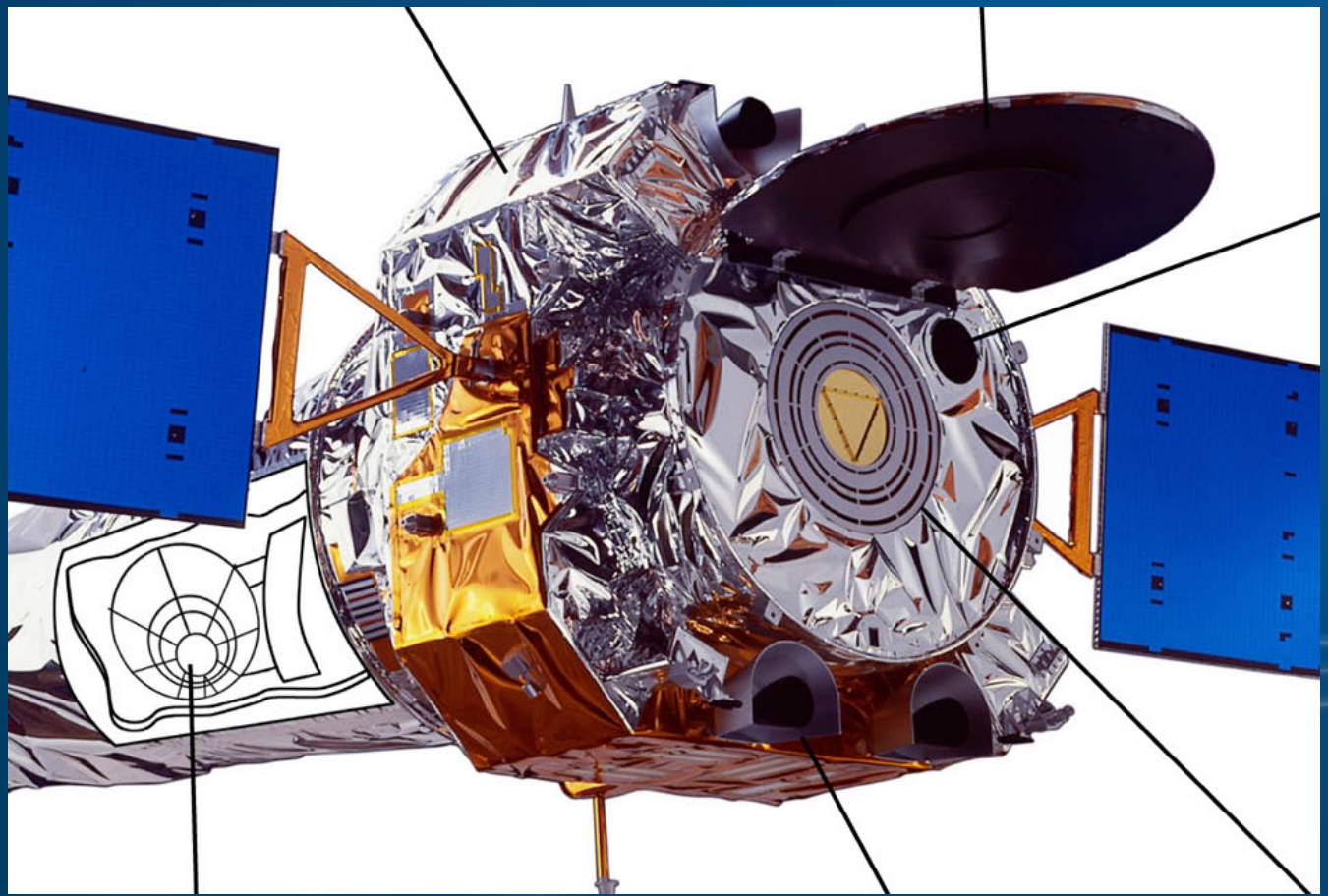
The Scary Bit in pictures



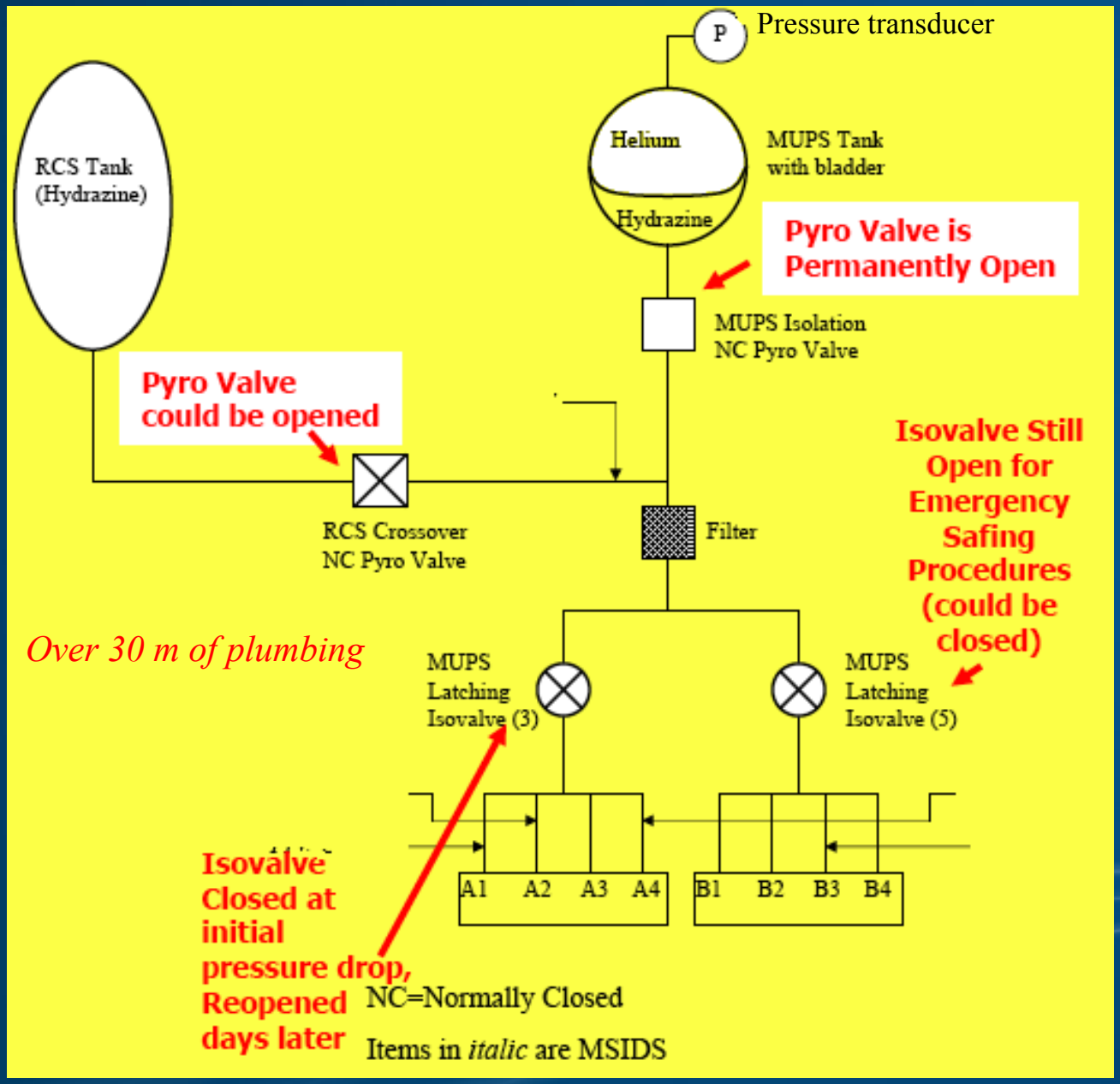


Momentum Unloading Propulsion System

- Maneuvers and external torques cause accumulation of momentum in Reaction Wheel Assemblies
- Momentum removed through a set of 4 MUPS thrusters that catalyze the hydrazine propellant



Momentum Unloading Propulsion System



Anomaly response (July 19 to August 27)

- Initial telecon and commanding to close A-side valve
- Instituted daily anomaly status telecon/report and used collaborative Wiki page to communicate results
- FOT engineering substantially focused on anomaly
- FOT operations crew went to 24 hr ops
- Worked to obtain every spare minute of DSN comm
- Obtained significant NGST engineering support (including a formerly "retired" propulsion expert)
- SOT and MSFC carried out science team analyses
- FOT/SOT MP and CDO handled schedule, user needs
- *No interruption of science observations* (but pitch restrictions and no momentum dumps)

The Mystery: leak or no leak?

Leak :-(

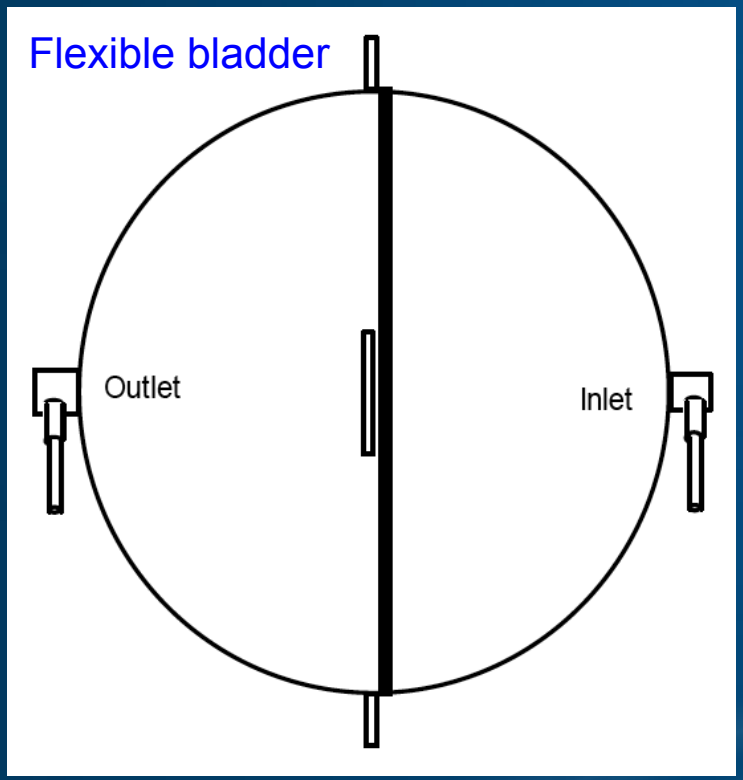
- Initial drop looks like a self-sealing propellant leak
- Observed self-sealing from ice build-up in prior tests
- Signature unlike any known pressure transducer failure, no credible mechanism
- Transducer vendor: it couldn't be the transducer

No Leak :-)

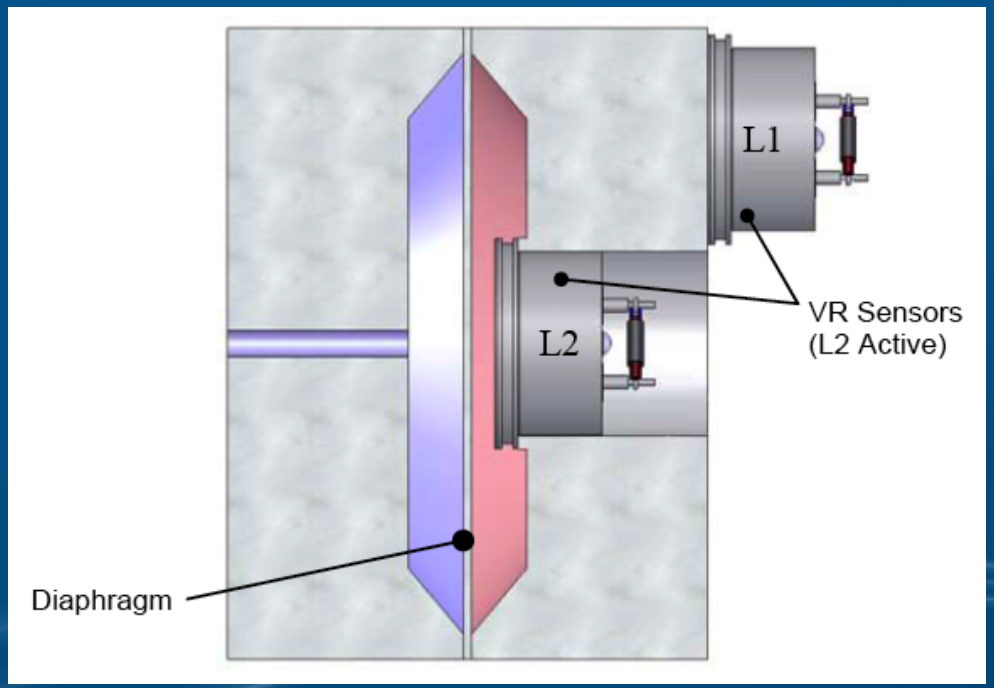
- *No temperature drop or disturbance torque*
- Extremely difficult to leak over 5 lbs of hydrazine in 45 minutes without either signature, but ...
  - "Constrained" leak might not generate torque
  - Leak location: tank or 5' of lines, maybe no nearby thermistor??
- Transducer noise signature changed
- Tank vendor: it couldn't be the tank

The Mystery: leak or no leak?

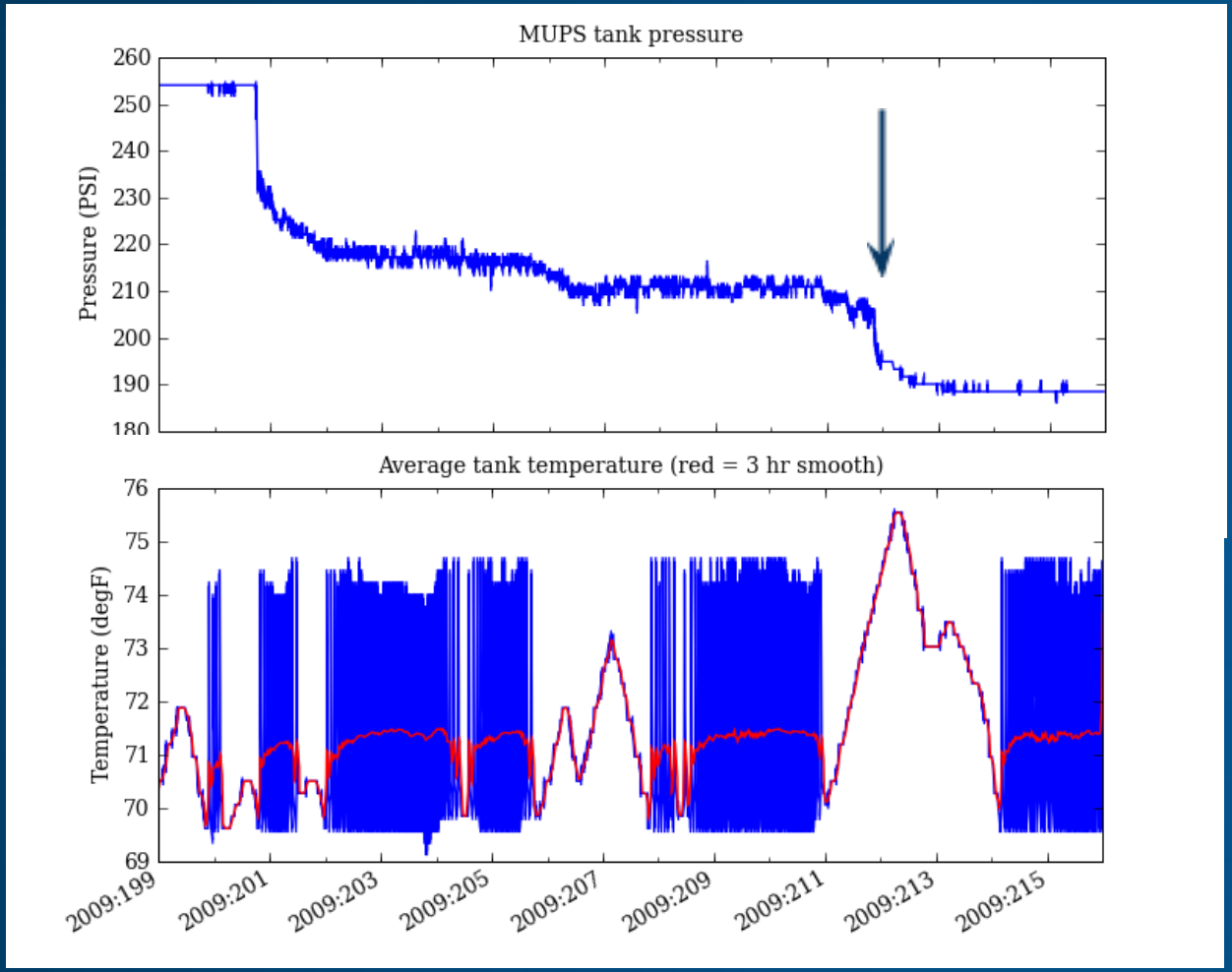
MUPS Tank
Hydrazine Helium



Variable reluctance
pressure transducer



Another bump in the night (zulu)



- Keep MUPS tank cool by restricting pitch > 130 degrees
- MP and observers feel the heat

Investigations: leak or no leak?

- A large volume of analysis strongly implicated a transducer failure but without a smoking gun

Engineering Analyses:

- Initial Indicated Leak Rates and Equivalent Orifice Sizes
- System Loading and Volume
- PressureAnomalyPropTemps_r7.pdf: Using line & panel temperatures to narrow down potential leak location
- MUPS_Tank_Pressure_Drop_RevD1.pdf: Summary Brief Rev D - Updated slides highlighted in yellow
- Thermal Cycling Analysis
- Rate of Tank Pressure Drop vs MFP Temperature
- Propellant Line Heater Cycling
- Inter-Compartmental Venting Diagrams: As designed, not necessarily as built
- MUPS Tank and Fill Panel Heater Cycling Analysis
- Plot of MUPS Tank Temperature and Pressure from 2009:100 to 2009:200
- MUPSThrusterUse
- ThrustVsPressure

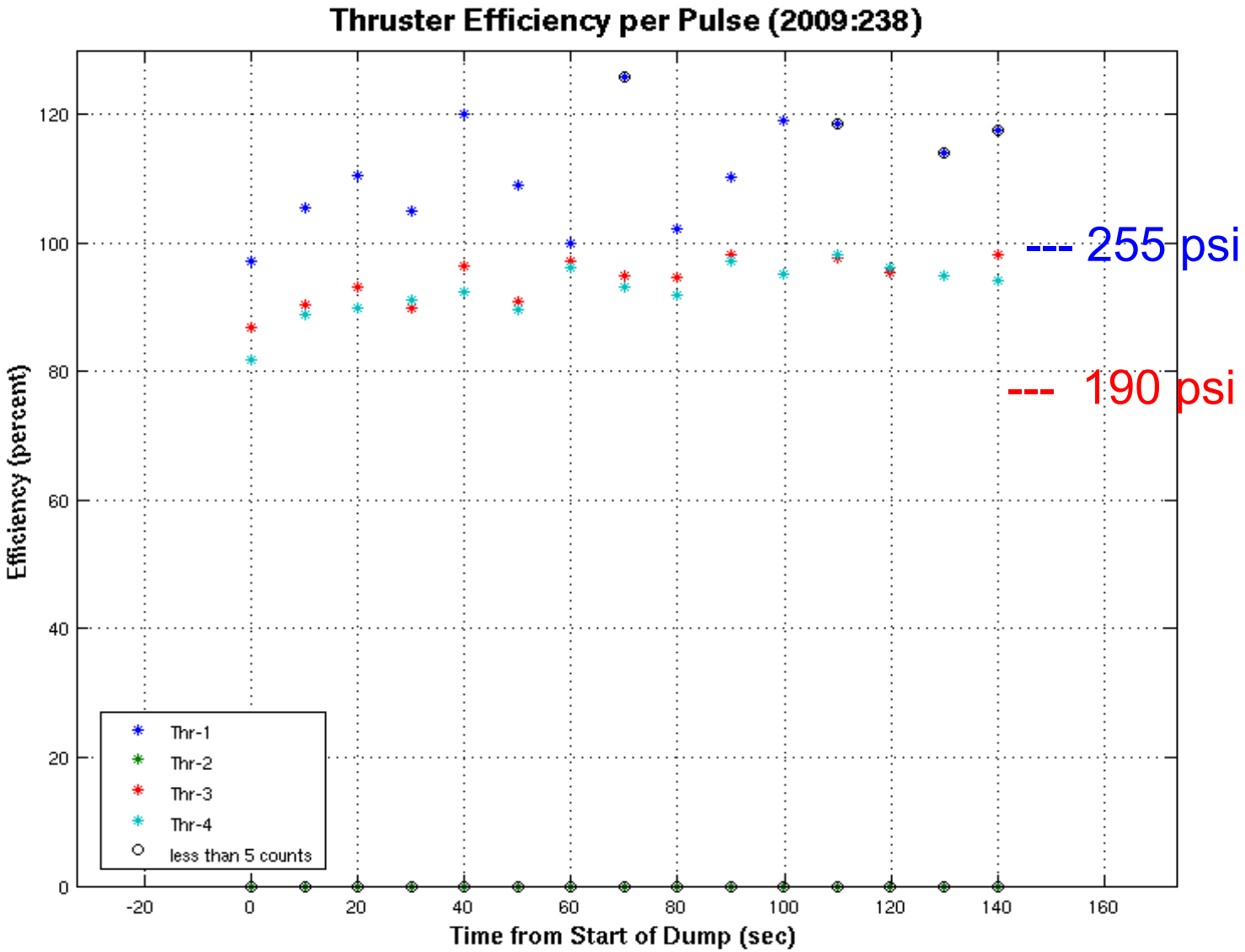
Science Team Analyses:

- MUPS pressure quicklook plots
- Telemetry auto-correlation analysis (aka toggles)
- FormatFourTelemetry: About 50 minutes of high-rate prop data collected in format 4 (approx 208:2140 - 2230)
- PressureIncrease: Investigation of possible pressure increase in post-anomaly data
- SputteringNoise: Analysis of sputtering as the cause of observed pressure telemetry noise
- SloshingNoise: Analysis of sloshing as the cause of observed pressure telemetry noise
- TankHeatCapacity: Measuring tank heat capacity as an indication of possible propellant loss
- ObserveVentedHydrazine: Discussion of feasibility and strategy for ground-based observation of vented propellant.
- HeaterPressureCorrelation: Correlation between heater cycling and pressure toggles near the toggle point.
- TempPressureCorrelation: Temperature and tank pressure correlation.

A definitive test: fire the thrusters

- Recognized early on that a MUPS unload would be sufficiently sensitive to determine if there was a leak
- Obvious risk in this test (e.g. open self-sealed leak)
- *BUT* not understanding anomaly had increasing risk
- Maintaining high-alert operations was not feasible
- On 24-August the FOT presented a very detailed analysis that the risk of a firing test was lower than the risk of doing nothing: *all stakeholders concurred* .
- On 26-August a 150 sec momentum dump was commanded

A definitive test: fire the thrusters



A happy ending*

- Firing test showed 95% efficiency: No leak!
- Operations back to normal effective immediately
- Many subsequent MUPS unloads confirm

Hold on a second ...

- Still no credible failure mechanism for transducer
- Coincidence?
  - EPHIN planning limit increased to 120F on 2-July
  - HETG limit switch anomaly on 7-July
  - MUPS tank pressure anomaly on 19-July
- EPHIN limit is now protecting *other* parts of Chandra
- Planning limit reduced to 117F on 27-August
- Looking very closely at other components, thermal trending, and cycle analysis