

Investigation of Shuttle and Orion Reentry Temperature Anomalies

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SPACECRAFT ANOMALIES AND FAILURES WORKSHOP
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Introduction

NESC asked to determine cause of anomalous temperatures witnessed during Orion EFT-I and Shuttle reentries

Anecdotal evidence of similar anomalies on other spacecraft

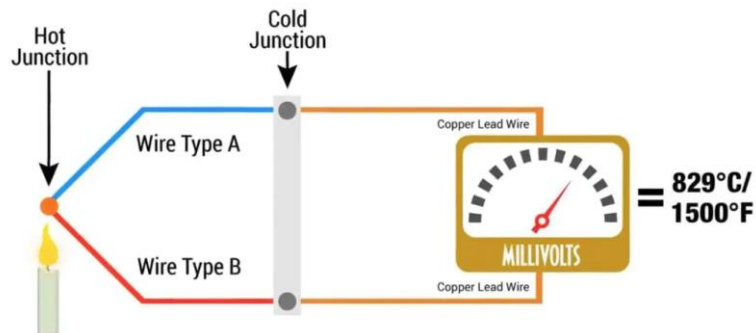
Thermocouples (TCs) measure temperatures on heat shield during reentry to:

- Characterize heating environment
- Evaluate heat shield performance
- Identify boundary layer transition between laminar and turbulent flow

Future missions need reliable reentry temperature data



Infrared Image of STS-131 Reentry

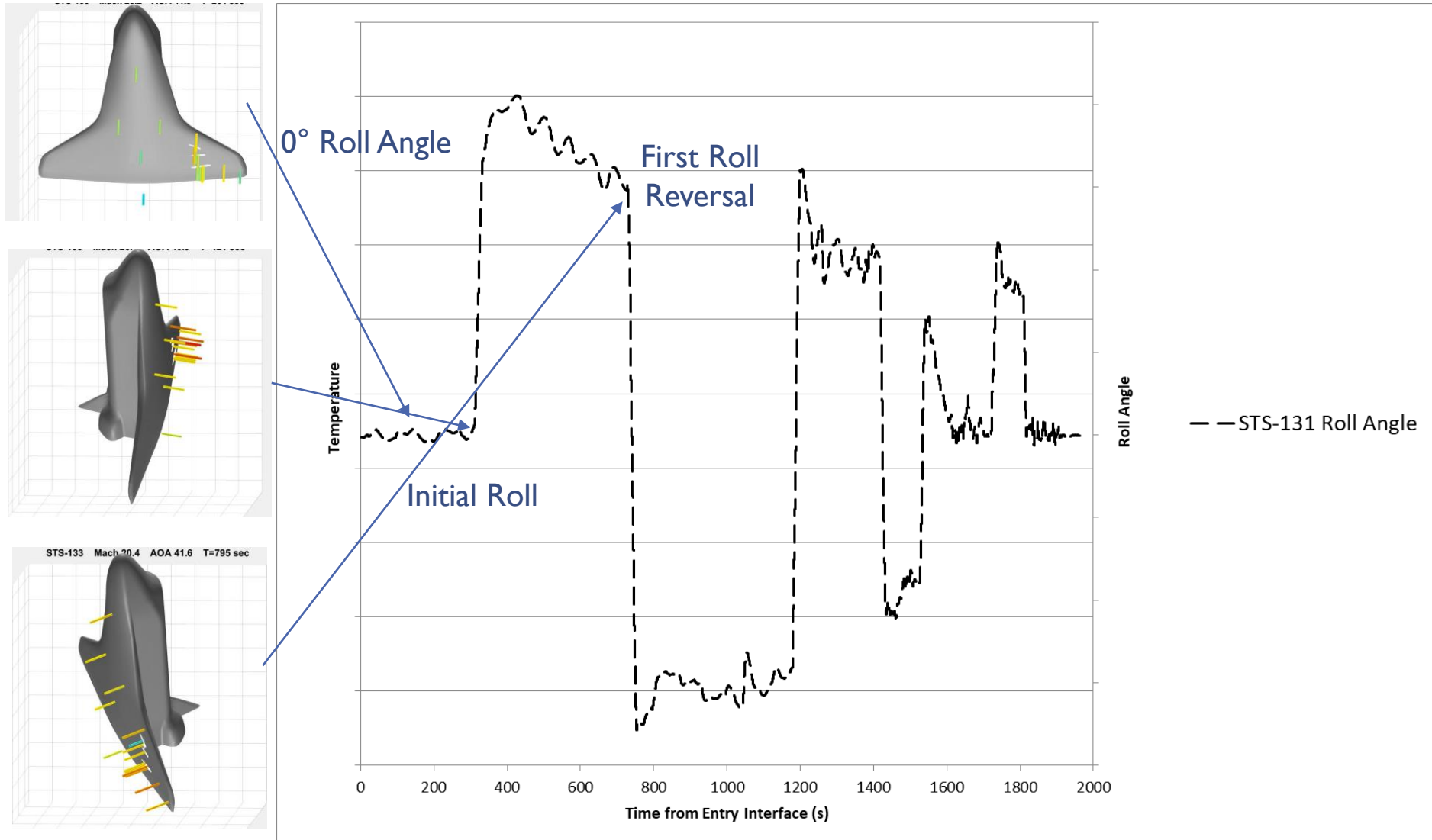


TC Circuit

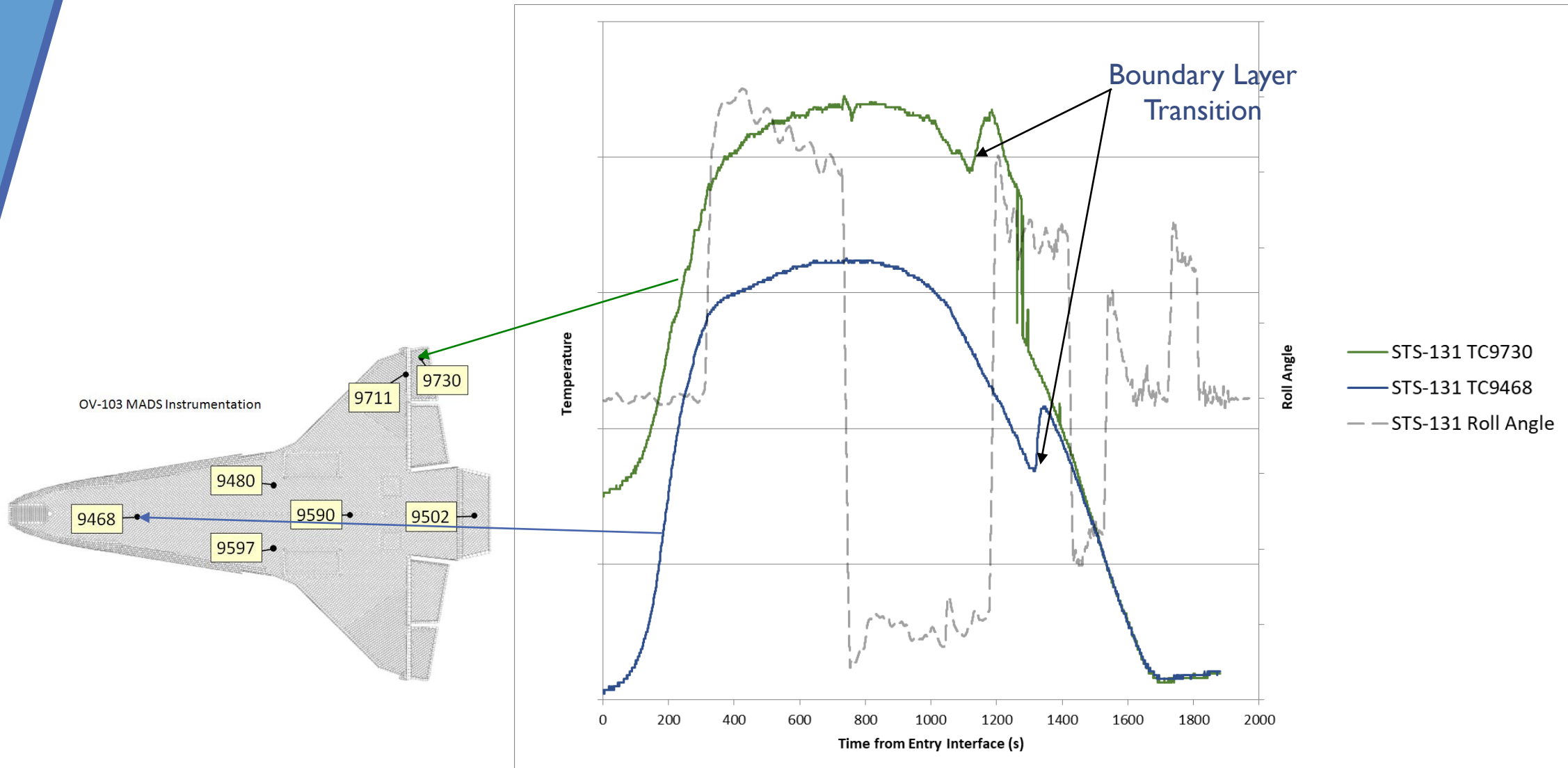


EFT-I Reentry View from Side Window

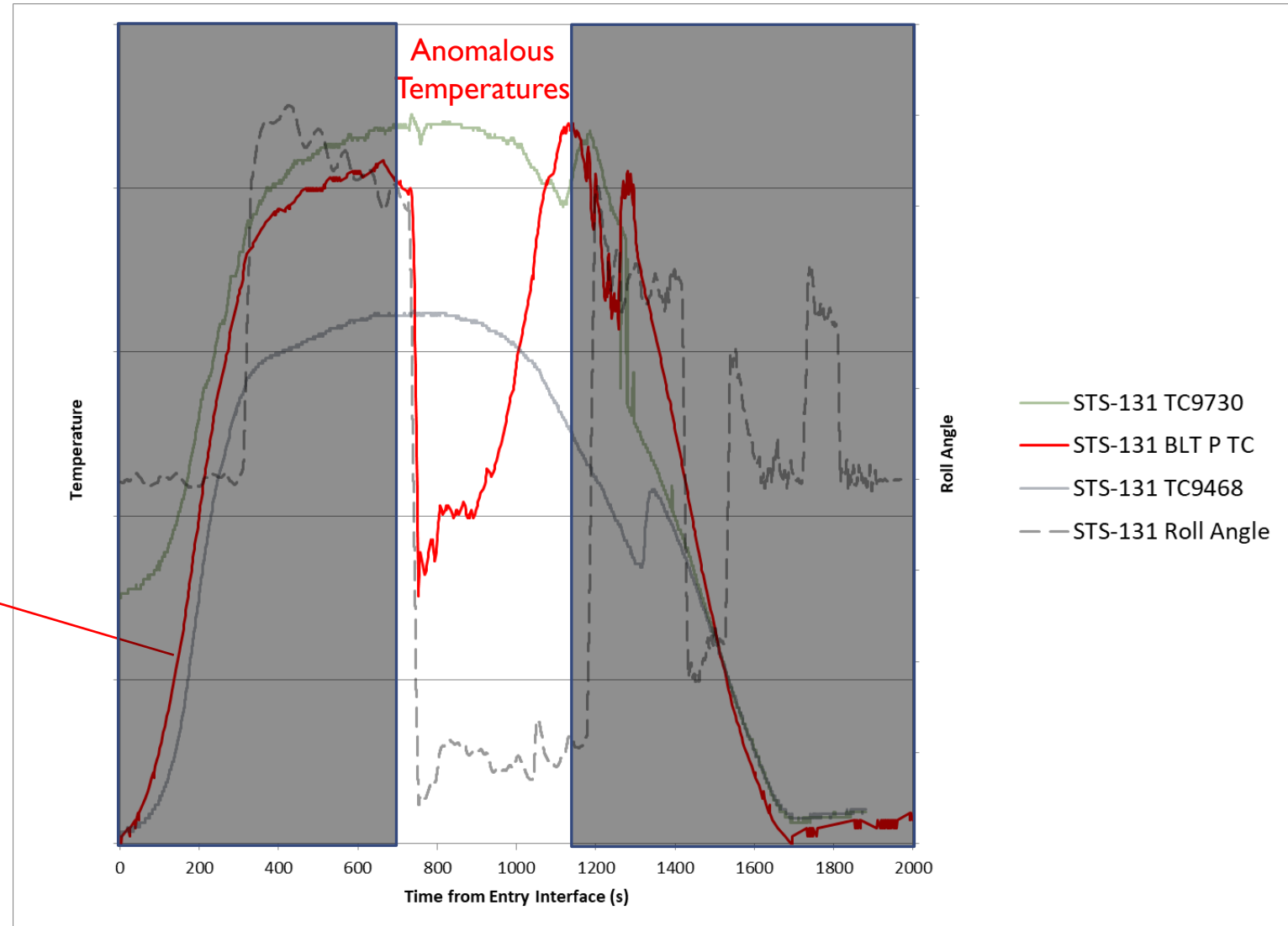
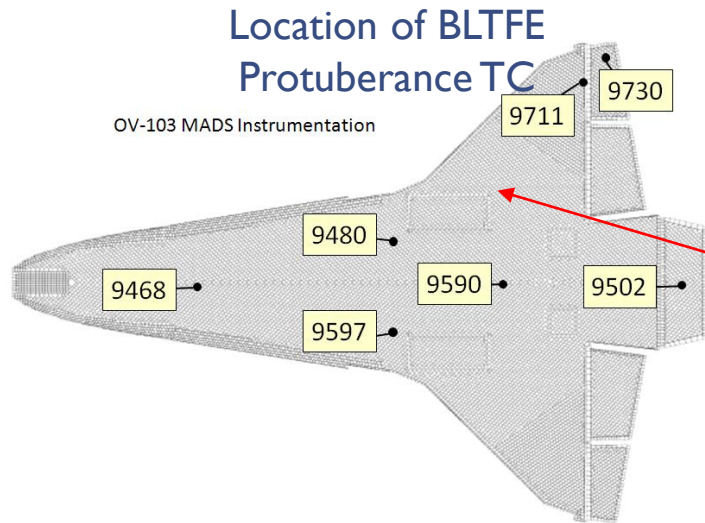
Shuttle Entry Roll Maneuvers



Nominal Entry Temperatures

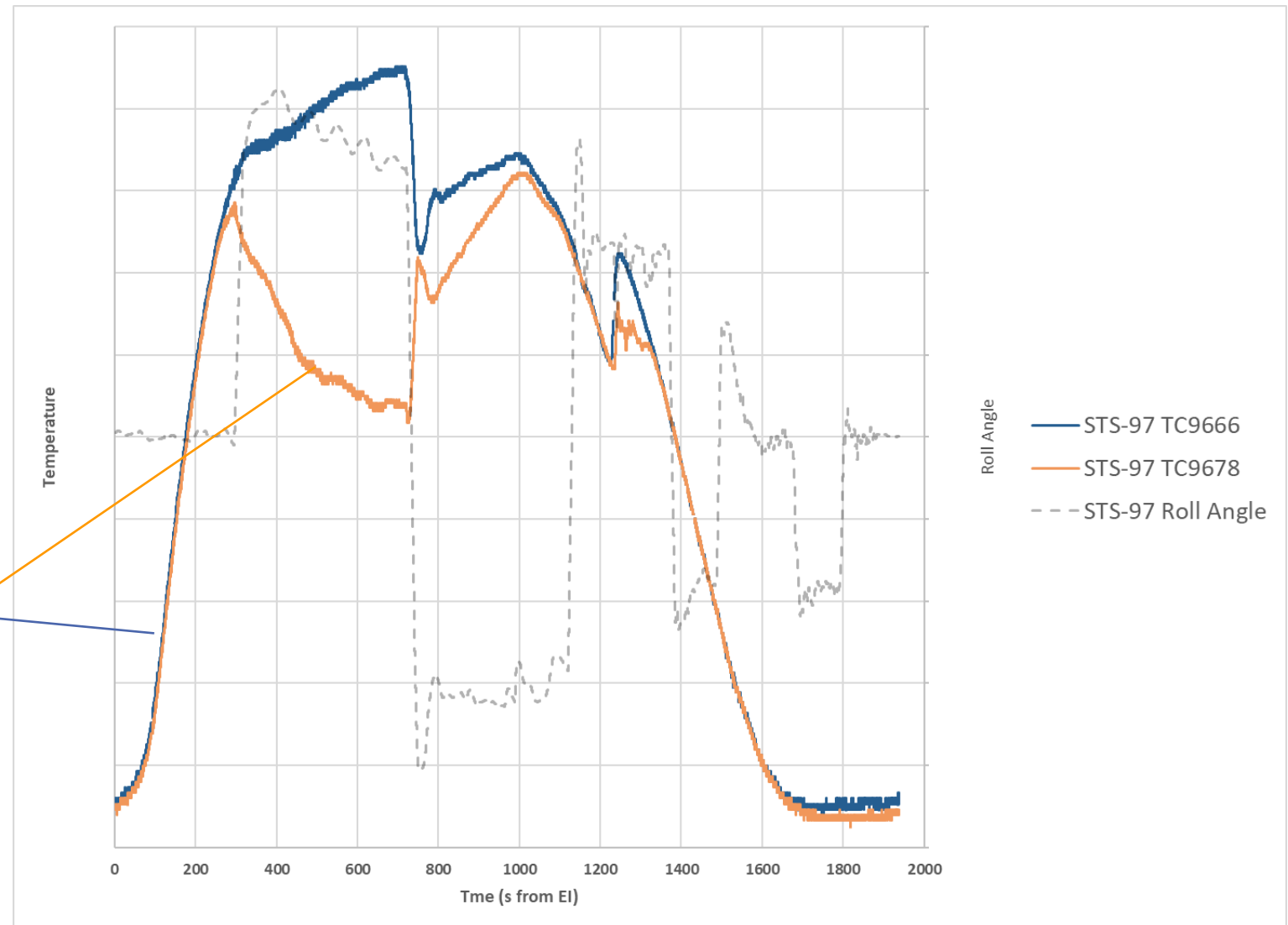
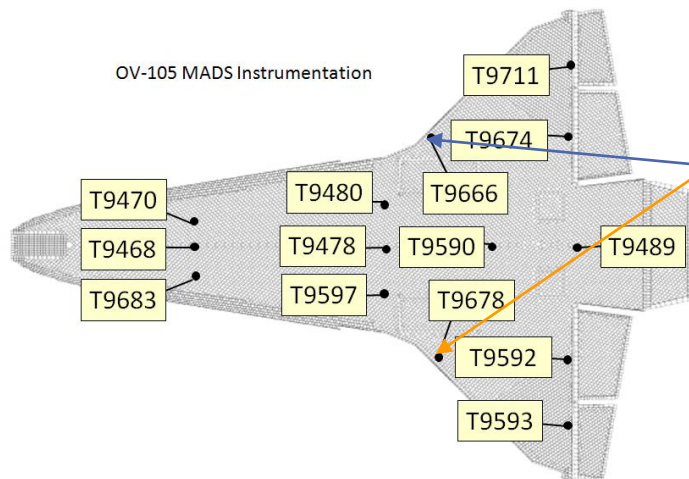


Anomalous Entry Temperatures



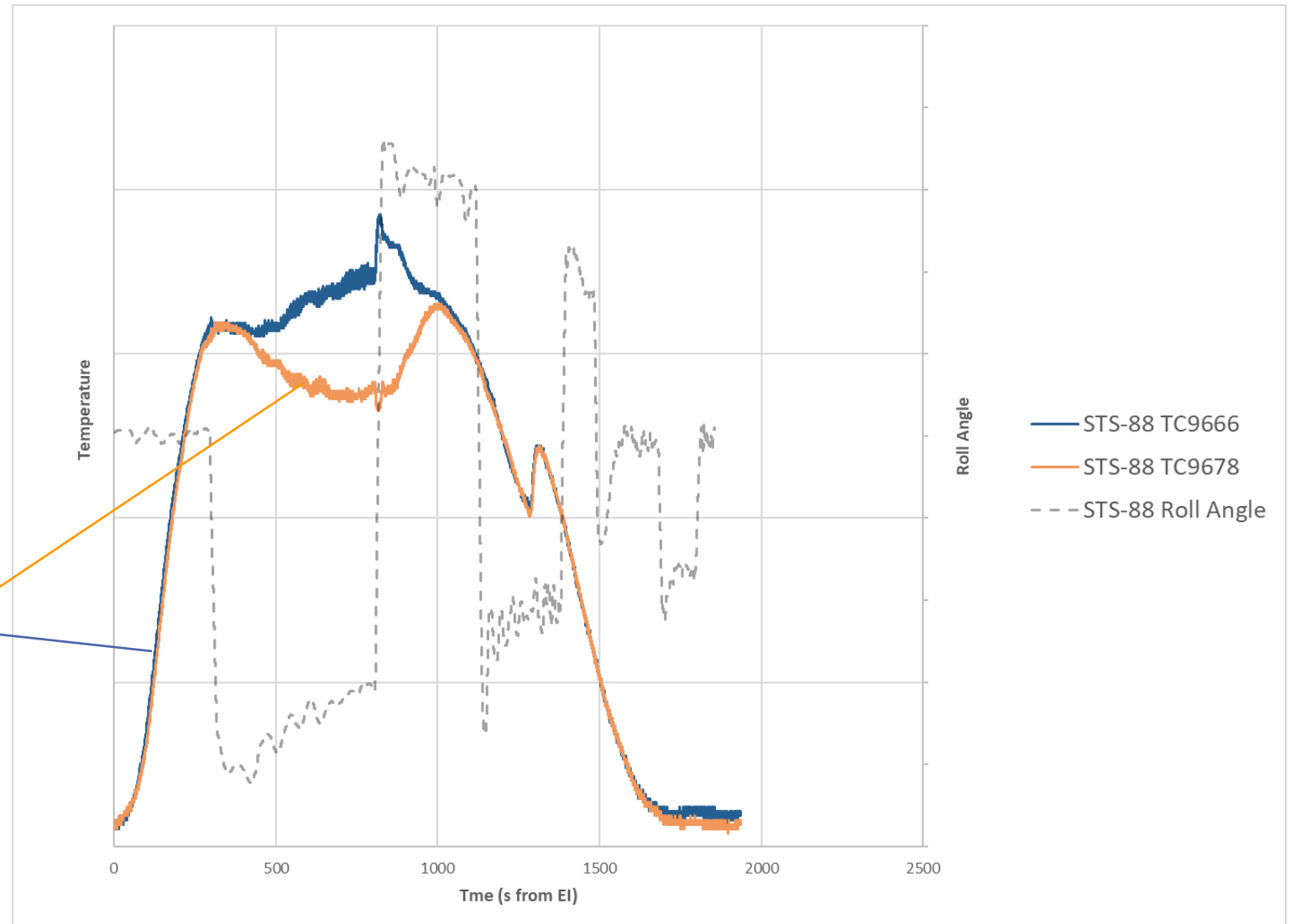
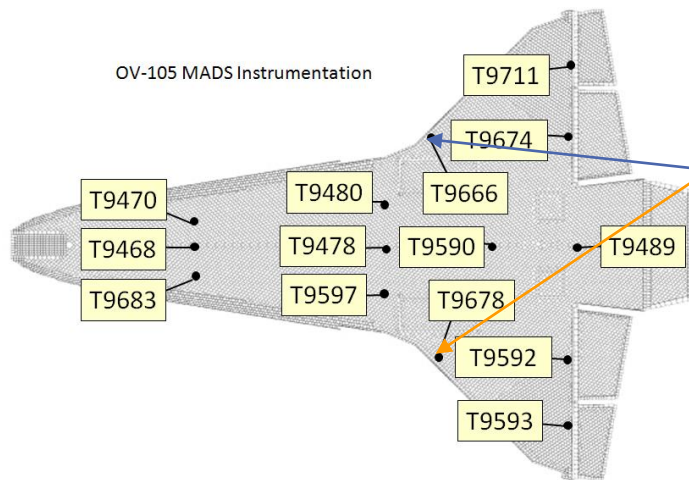
Varies by Installation Location

TCs 9666 and 9678 on STS-97



Varies by Roll Order and Trajectory

TCs 9666 and 9678 on STS-88



Shuttle Anomaly Characteristics

Rapid apparent temperature increase or decrease coincident with first roll reversal

Anomalies identified on several Shuttle missions, but not all

Missions with comparable entry trajectories tend to have comparable anomaly signatures

Anomalies occurred on several different TCs, but not all

Occurred near peak entry heating around Mach 23-7, ~400-1200 seconds after entry interface (EI), ~76-46 km altitude

Temperatures return to expected after ~1200 after EI

Possible Causes

Thermodynamic Effects (TCs Reflect Actual Temperature)

- No mechanism identified that would produce temperatures or rates of change observed

Electromagnetic Interference (EMI)

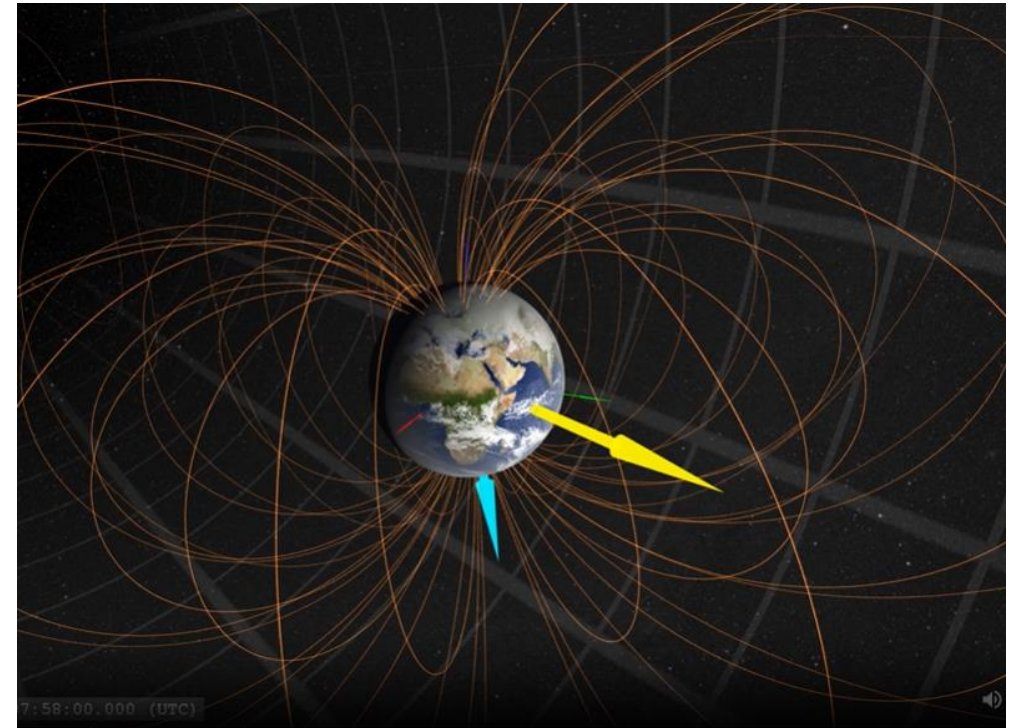
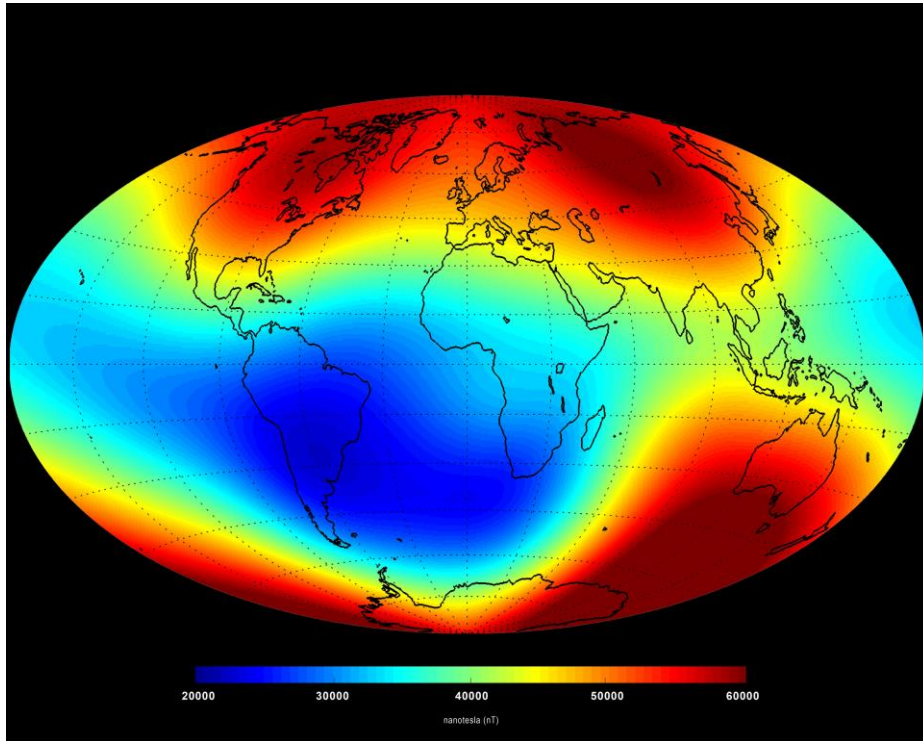
- EMI would produce high frequency noise – not consistent with observed anomalies without rectification
- No explanation for roll/attitude dependence

TC Open Circuit or Shorts

- Failures in circuits never found
- Repeatability and consistent return to normal hard to explain

Interaction with the Earth's Magnetic Field

Earth's Magnetic Field

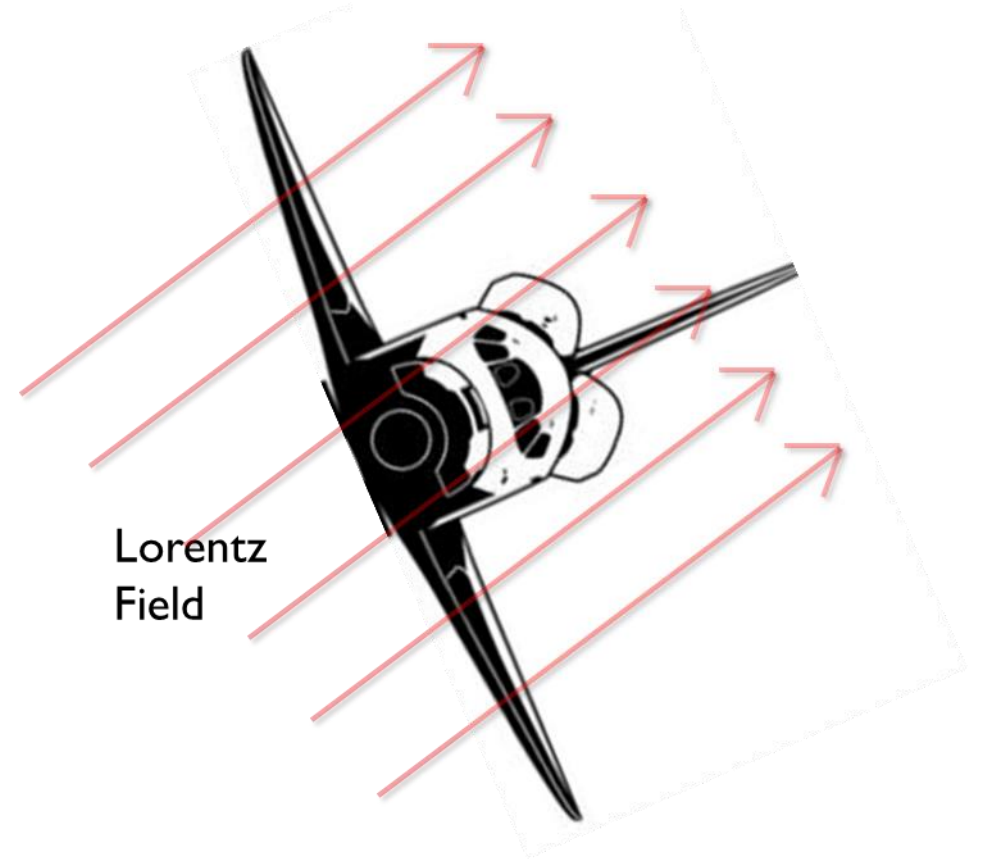
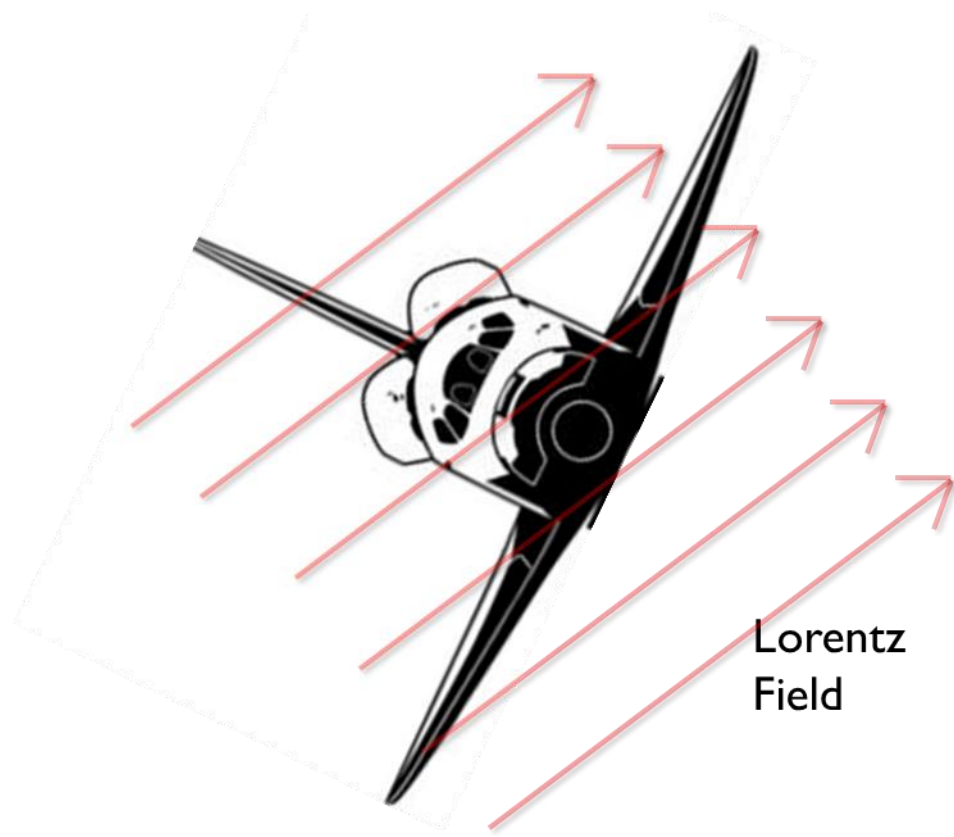


Varies with time and location

Faraday's Law: electromotive force (voltage) produced when conductor moves through a magnetic field

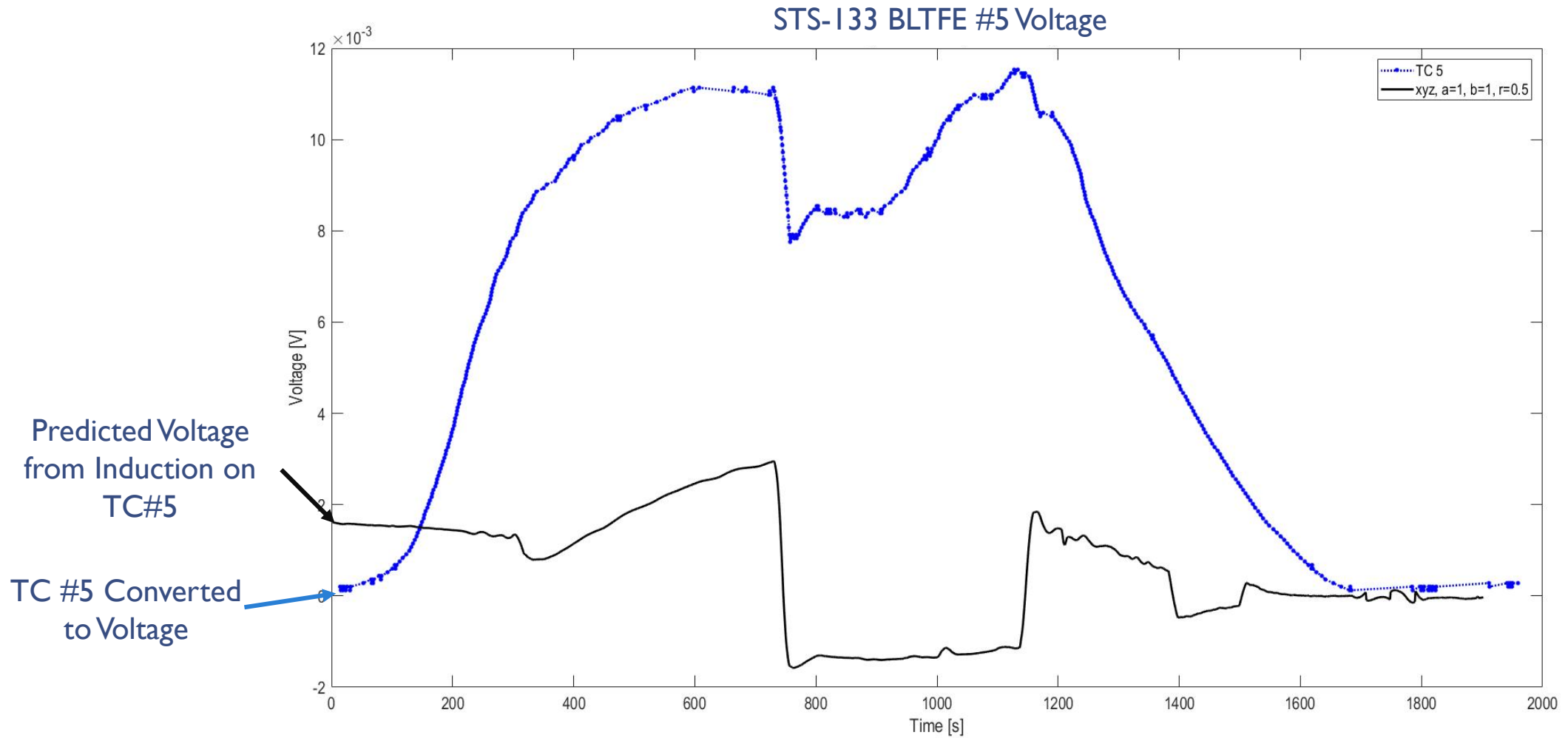
Earth's magnetic field is weak, but Shuttle velocity is high

Travel Through Earth's Magnetic Field

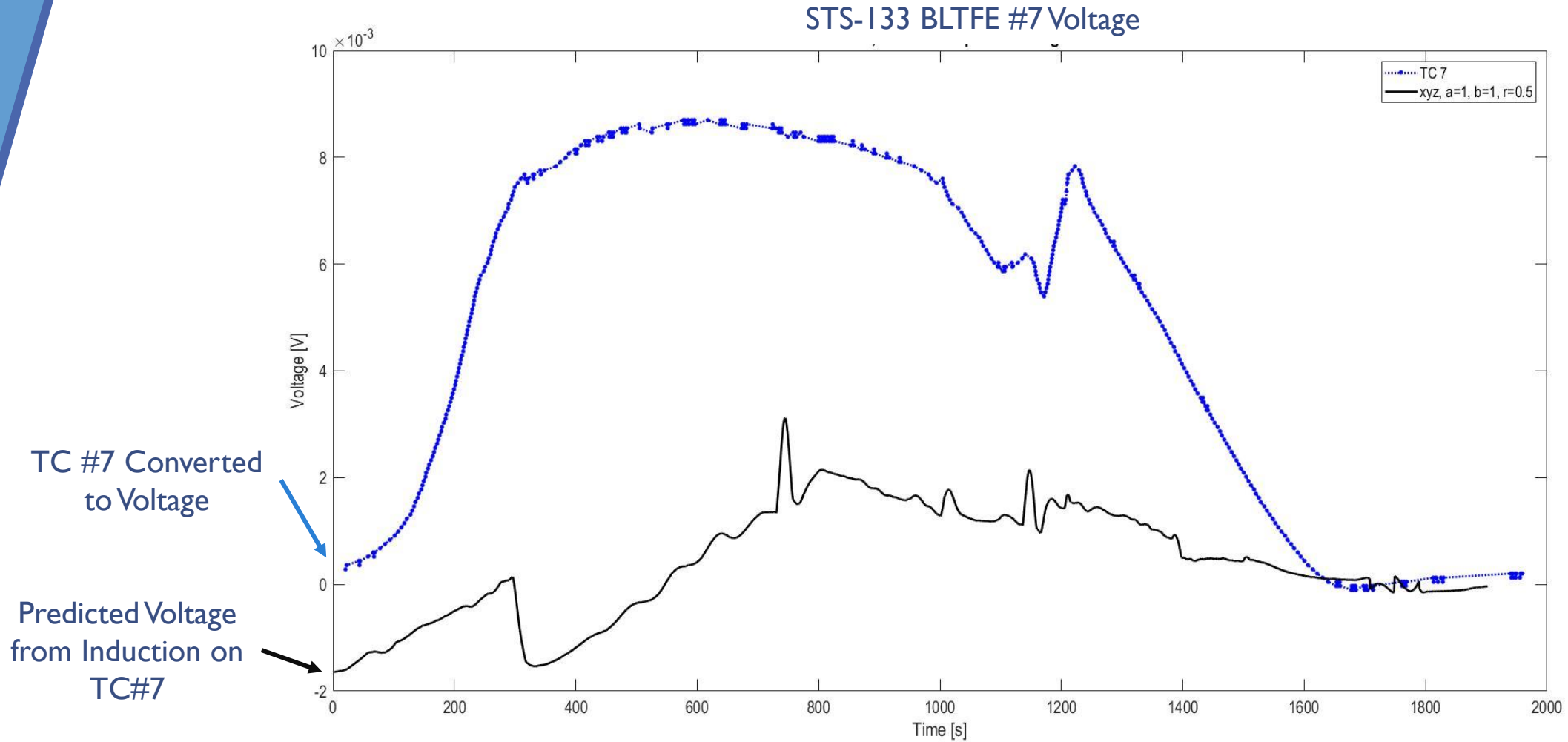


Orbiter's Attitude in Relation to Lines of Magnetism
Changes with Roll Angle and Direction of Travel

Earth's Magnetic Field Induction Analysis

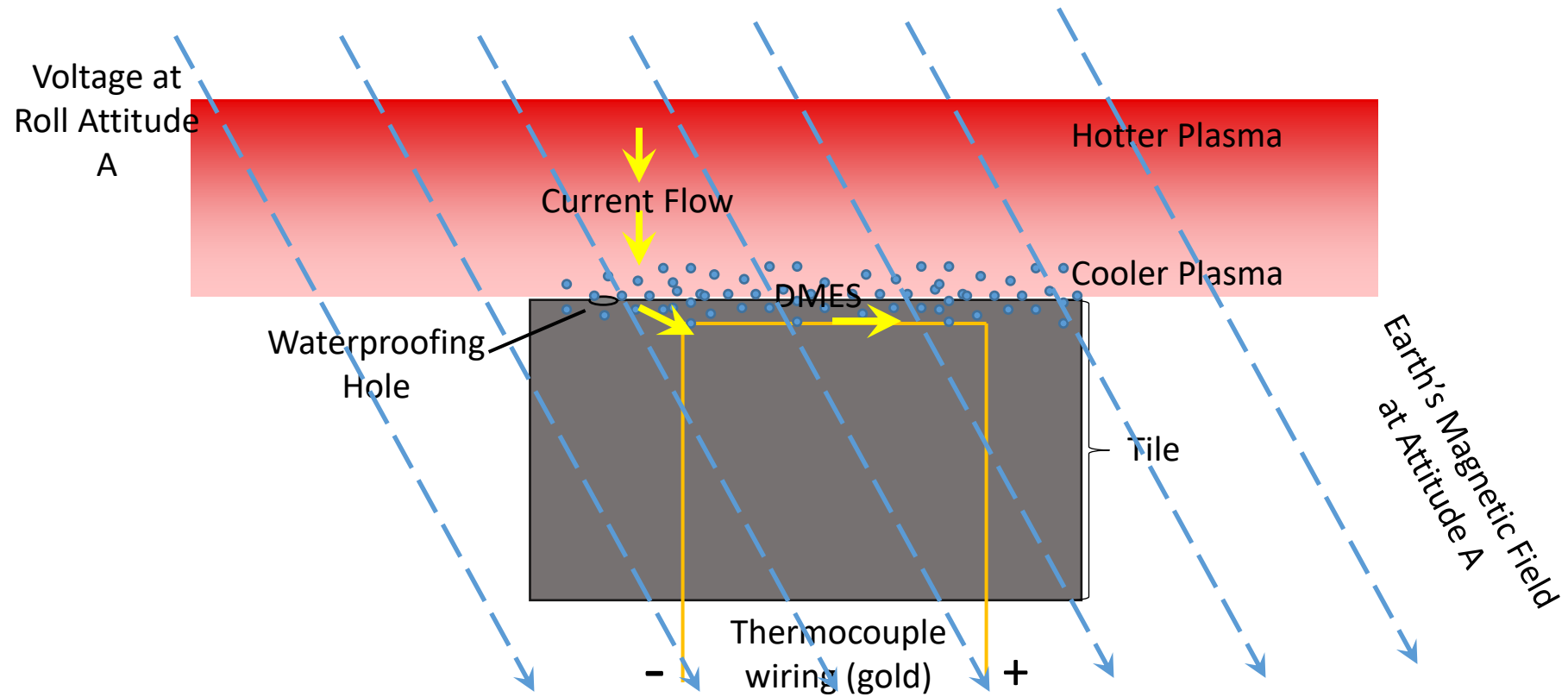


Earth's Magnetic Field Induction Analysis



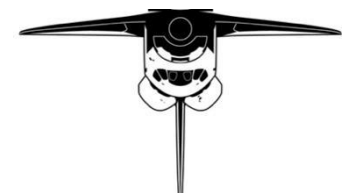
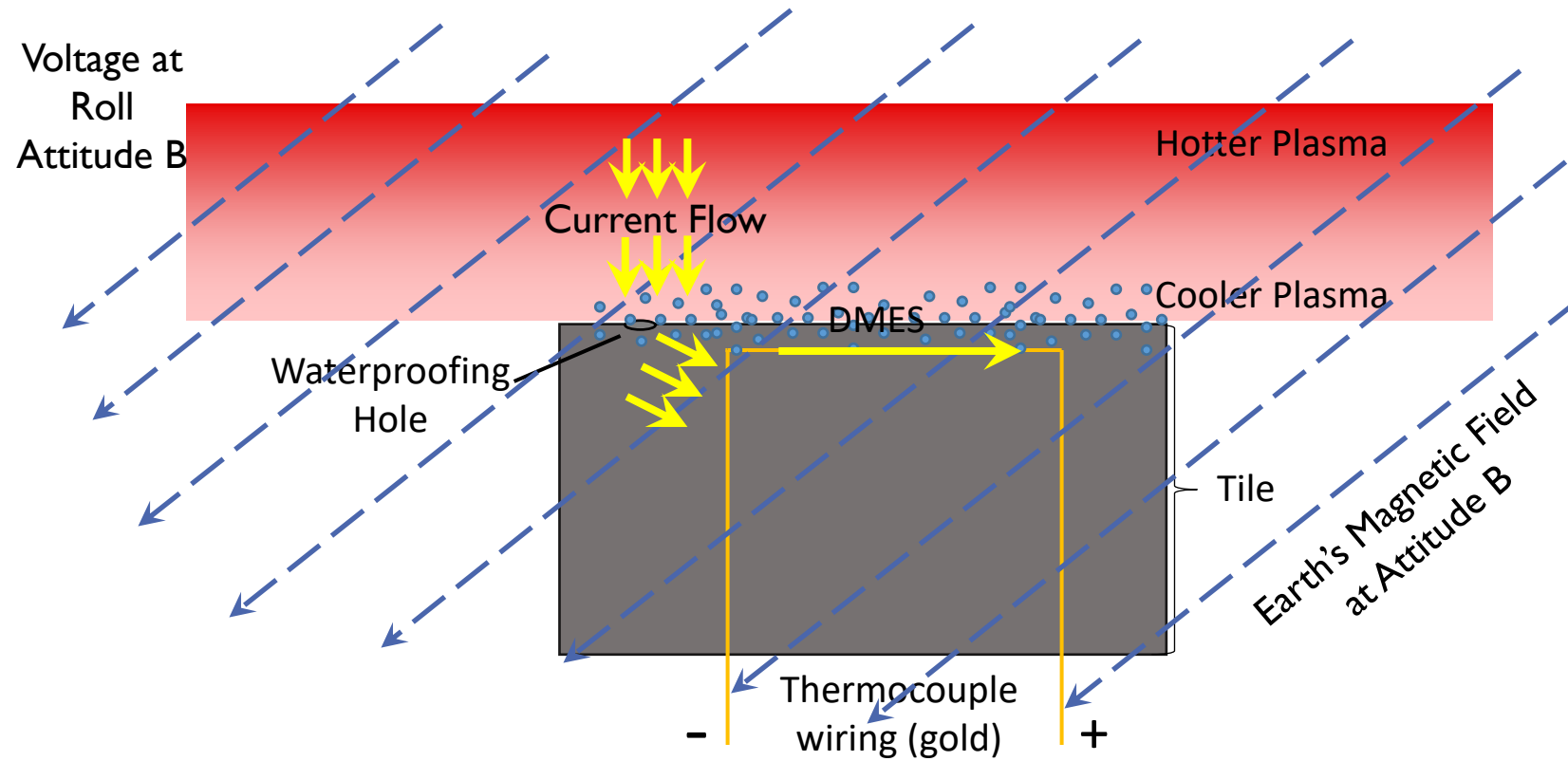
Alternative Explanation

Lorentz Field Acting on Conductive Plasma



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EFT-I Anomaly

Temperature anomalies also on the Orion heat shield TCs for EFT-I entry

Temperature oscillations corresponding to small crew module roll oscillations

Like the Shuttle anomaly, probable cause was introduction of direct current

Mechanism driven by turbulent flow over TCs

Electrical path provided by products from heat shield ablation

TC alignment relative to flow important

Anomaly increased and decreased as vehicle oscillation brought TC in and out of turbulent regions

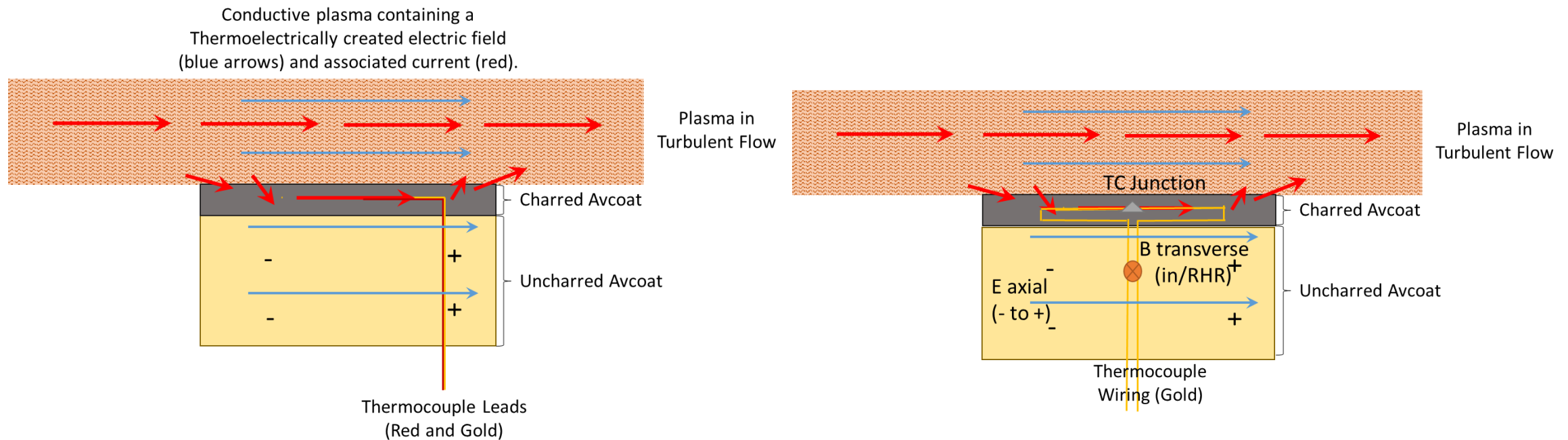


Mitigation Suggestions

Align TC perpendicular to plasma flow

Electrically insulate wires as much as possible

Orient the TC loop into an “L” or “T” to cancel out anomaly



Questions?

