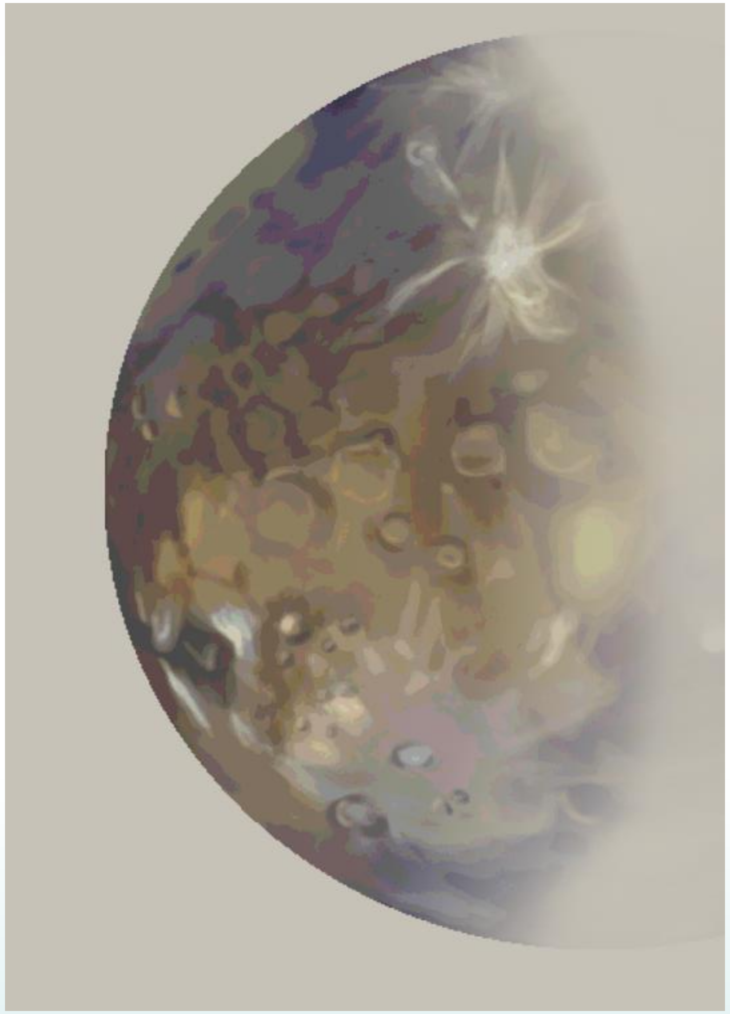

Passive Cooling for Mercury Lander Electronics

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Mercury

Can we make a mission to land and operate on the planet Mercury?

- Perihelion solar Intensity: 14,536 W/m^2
  - (**10.6** times higher than in Earth orbit intensity)
- Maximum surface temperature **427 C**
  - perihelion at subsolar point on the equator

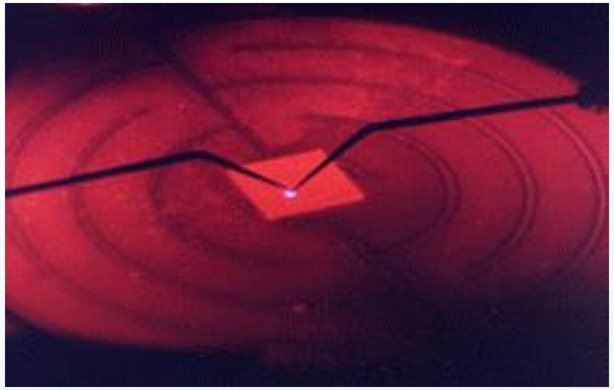
Our problem: learn to keep things cool, or learn to operate hot!

Mercury viewed from MESSENGER probe

Image Credit: NASA/Johns Hopkins University Applied Physics Laboratory/Carnegie Institution of Washington

Solution 1: high temperature electronics

- Electronics components exist that can operate at temperatures on the surface of Mercury (~427° C)
  - The approach is to use the semiconductor silicon carbide (SiC), instead of the silicon electronics used on terrestrial electronics
  - SiC electronics is now being developed at NASA Glenn for missions to the surface of Venus (450 C).



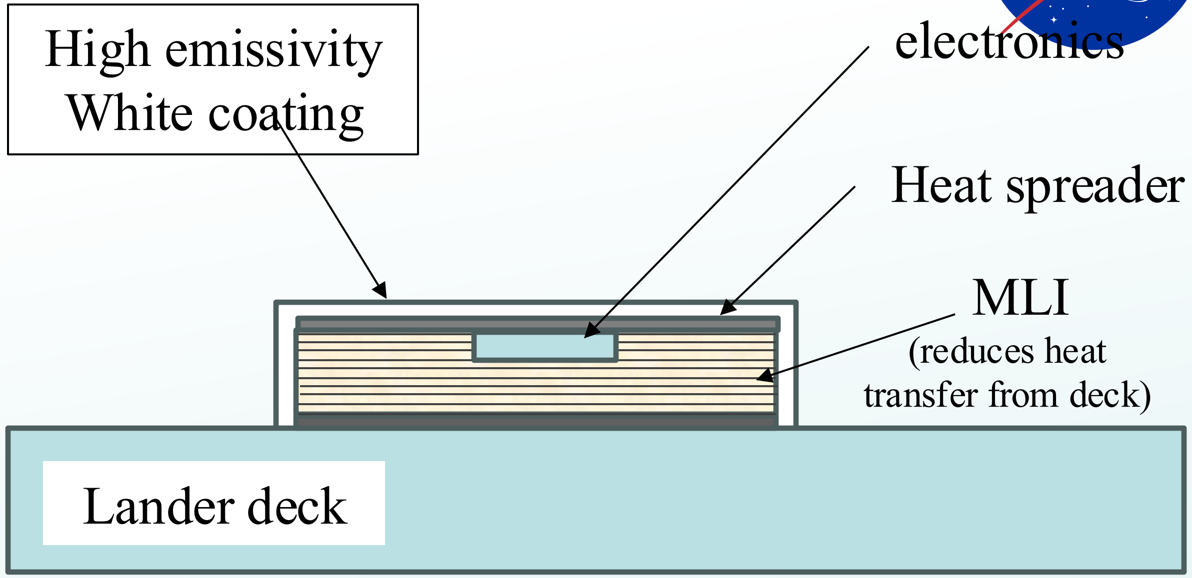
NASA Glenn Silicon Carbide LED operating at 650° C.

- But not all types of electronics can operate at Mercury temperature
  - We do not (yet) have SiC components with the capability of high-capacity microprocessors, or high-density memory chips

Need a thermal solution to operate silicon microelectronics at Mercury daytime temperatures

Passive Cooling for Mercury lander

- Objective: Keep memory chips (and possible other temperature sensitive electronics) below maximum operating temperature at solar noon



Thermal approach:
(1) minimize solar heat by low optical absorptivity
(2) Minimize IR heating from hot surface (and hot lander) by multi-layer insulation
(3) Maximize infrared emissivity (zero view factor to surface or lander

How low can we go?

High Emissivity White coatings

- **Radiator thermal white paint**

- Used operationally in space
  - **Z93 white thermal paint,** α = 0.15 , ε = 0.91
  - **YB-71 white thermal paint over Z93** (after space exposure) α = 0.11 , ε = 0.87

- Developmental
  - **AZW/LA-II thermal paint,** 0.33 mm thickness, α = 0.09±.02 , ε = 0.91 ±.02
  - **AZW/LA-II thermal paint,** 0.20 mm thickness*, α = 0.11 , ε = 0.91

*thinner paint used for improved adhesion

Can we do better?

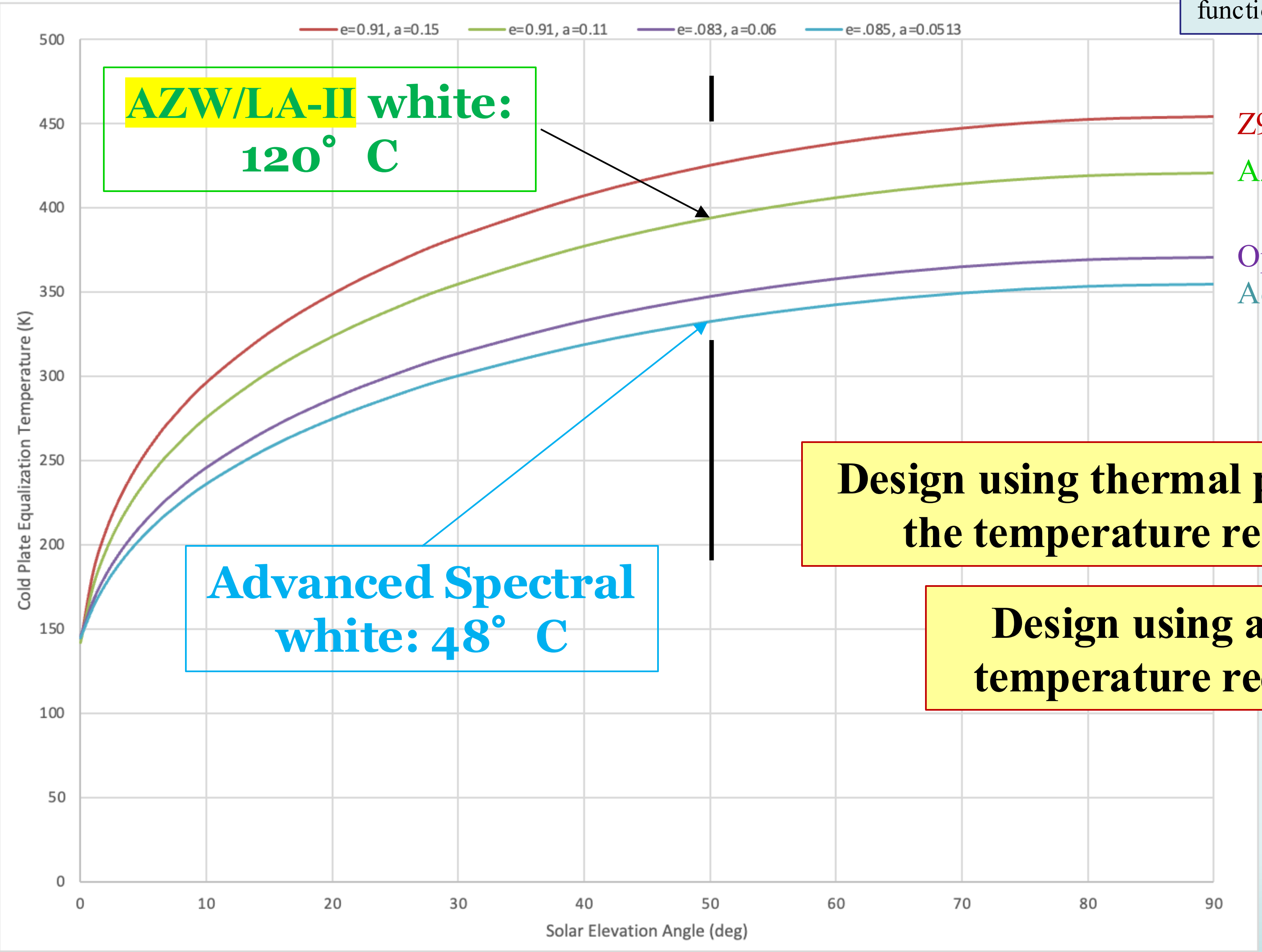
Advanced High emissivity White surfaces

- **Optical surface reflectors:**
    - absorptivity is for normal incidence
  - Helios second-surface mirror/silver backing $\alpha = 0.08$, $\varepsilon = 0.79$ (after solar exposure)
  - Excelitas (Qioptiq) CMX with UVS coating PS347 optical surface reflector, $\alpha = 0.06$, $\varepsilon = 0.83$
  - Thales Optical thermal reflector $\alpha = 0.08$

- **Advanced spectral white**
  - **Y_2O_3-based High emissivity white coating:**
  - **Developed for cryogenic fuel tanks**
  - **Emissivity measurements are for low temperature, not high**
  - $\alpha = 0.046 \pm 0.005$ (0.0413-0.0513), $\varepsilon = 0.85$ for the spray-on version
  - $\alpha = 0.012$, $\varepsilon = 0.85$ for the spectral white tile*
    - *(but not clear how this holds up to space exposure)

Calculated Equalization Temperature

Calculated equilibrium temperature at perihelion as a function of sun angle from horizontal



Z93 thermal paint

AZW-LA-II thermal paint

Optical surface reflector

Advanced spectral white

Design using thermal paint demonstrated in space meets the temperature requirements for SOI electronics

Design using advanced thermal coating meets the temperature requirements for all silicon electronics

Conclusions

- A passive thermal control solution was found for a surface mission to Mercury
- With existing space-qualified thermal coatings, we can keep the electronics temperature to levels compatible with silicon-on-insulator (SOI) electronics, even at solar noon when Mercury is closest to the sun
- With advanced thermal coatings, we can keep the electronics temperature to temperatures suitable for all electronics