Advances in Thermal Technologies Using Pyrolytic Graphite Sheet

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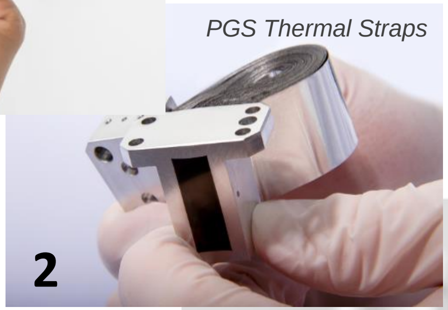
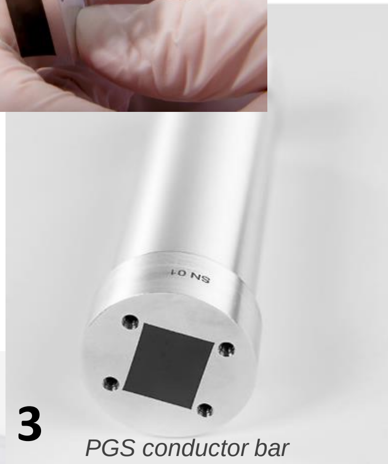
Outline

1. Introduction to PGS
2. PGS Thermal Straps
3. PGS-Embedded Conductor Bars
4. PGS-Embedded Cryocooler Brackets
5. PGS-Embedded Radiators
   a) Solid metallic
   b) Honeycomb
6. Conclusions

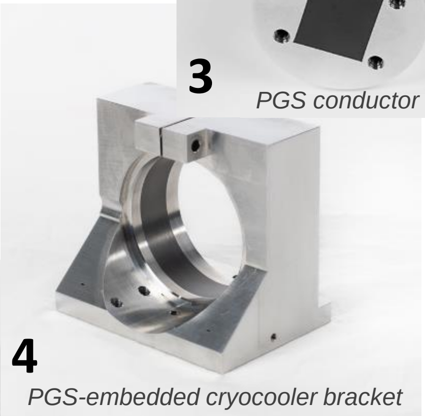
Intro to PGS



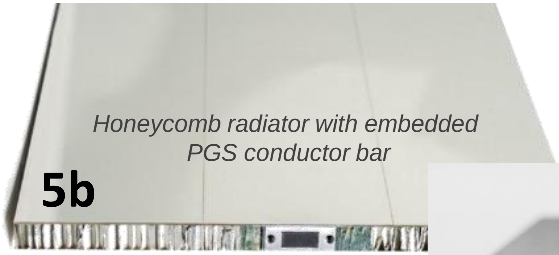
PGS Thermal Straps



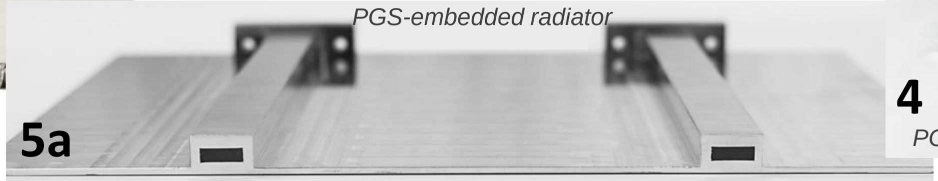
PGS conductor bar



PGS-embedded cryocooler bracket



Honeycomb radiator with embedded PGS conductor bar



PGS-embedded radiator

Introduction to PGS

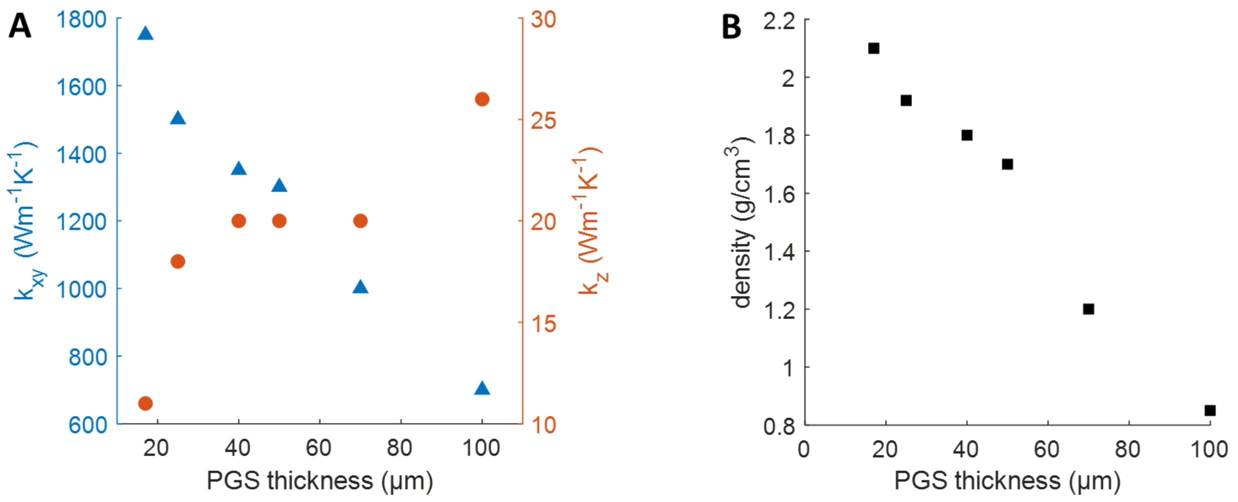
- PGS: Pyrolytic Graphite Sheet
  - "Created from a high temperature sintering process, heating a polymer film to its decomposition temperature in a vacuum and allowing it to carbonize then graphitize until ultimately left with a highly oriented graphite material." *(https://hpmsgraphite.com/pyrolyticgraphitesheet)*
  - Highly aligned graphite layers provide exceptionally high in-plane thermal conductivity

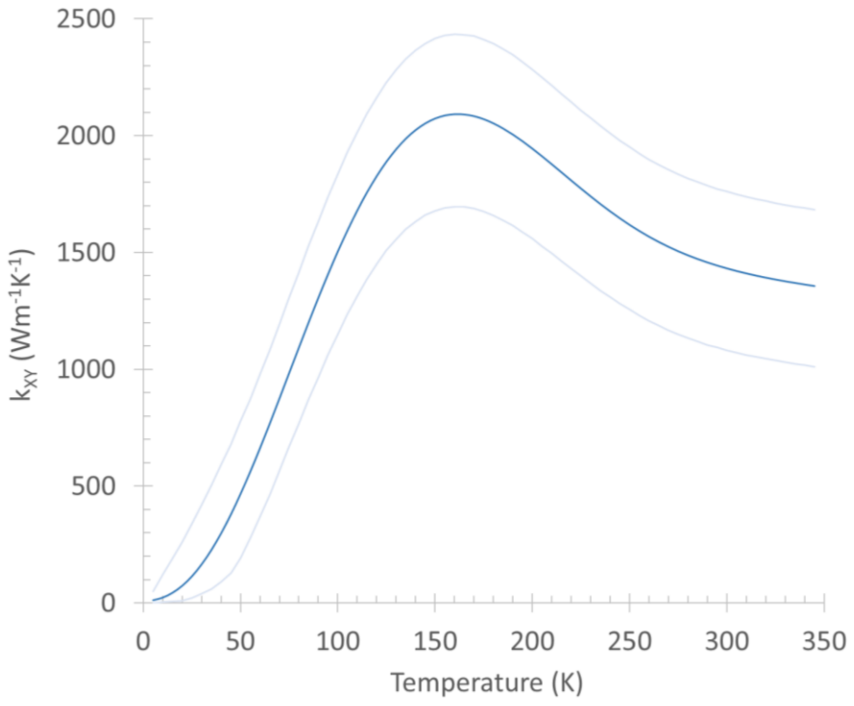
Property	Direction	Value at R.T.
Thermal Conductivity	XY	1500 $Wm^{-1}K^{-1}$
	Z	17 $Wm^{-1}K^{-1}$
Expansion Coefficient	XY	9.3×10^{-7} K^{-1}
	Z	3.2×10^{-5} K^{-1}
Specific Heat	-	0.85 $Jg^{-1}K^{-1}$
Density	-	1.92 g/cm^3

Exceptional thermal conductivity to density ratio (10 × that of aluminum 1100!) makes it ideal for passive thermal control in space

Introduction to PGS

- Properties dependent on sheet thickness
- Conductivity peaks around 160 K
- Durable *(see airplanes on previous slide)*
  - Manufacturer fatigue life = +20,000 cycles
  - Thermal strap cycled to nearly 300,000 cycles to deflections expected in space flight applications





Application temperature and sheet thickness are critical when designing with PGS

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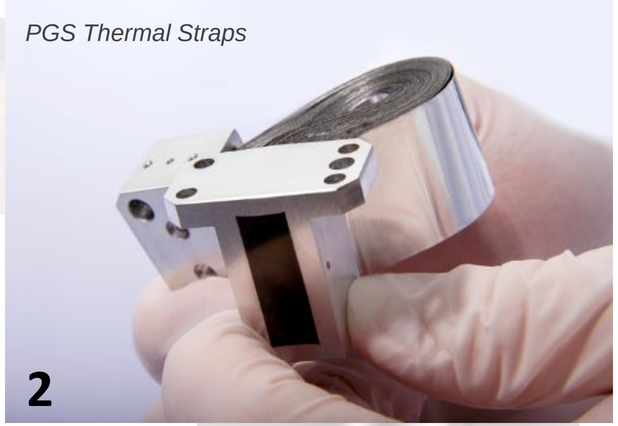
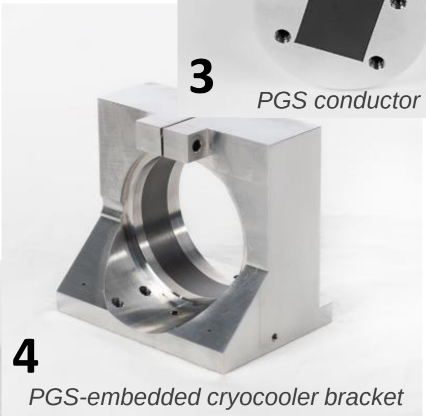
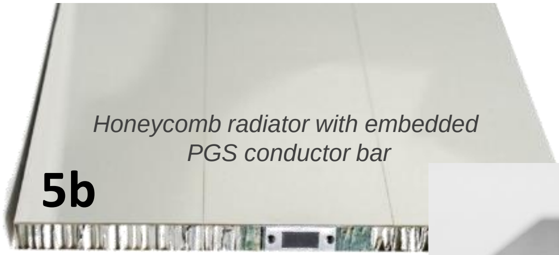
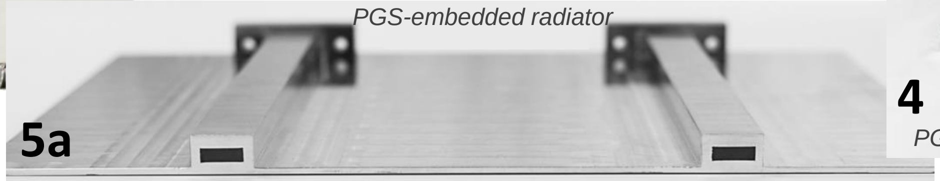








PGS Thermal Straps

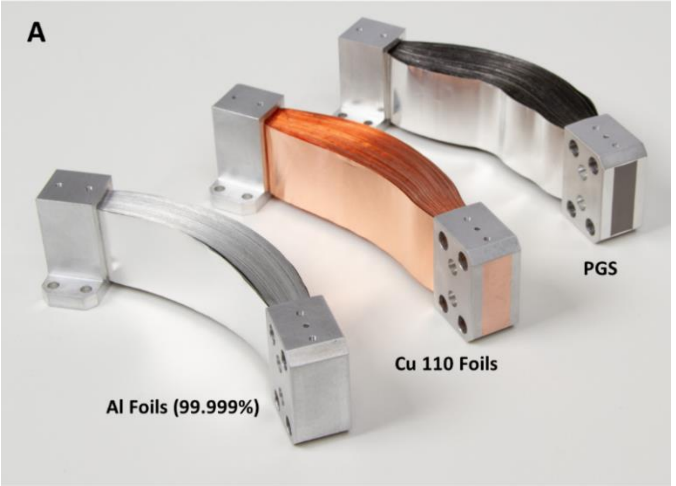
- SDL has been making thermal straps for space flight since the early 1990s
- SDL PGS thermal straps are TRL-9
  - TRL-6 in 2020 and over 150 custom designed space-bound PGS thermal straps have been delivered to date
- Majority of thermal straps that SDL delivers are now PGS
- Same proprietary swaging process means no adhesives, glues, or solder
  - Less contamination risk and higher thermal performance
- PGS thermal straps are superior to metallics in:
  - Thermal conductivity *(temperature dependent)*
  - Density
  - Flexibility
  - Vibration isolation

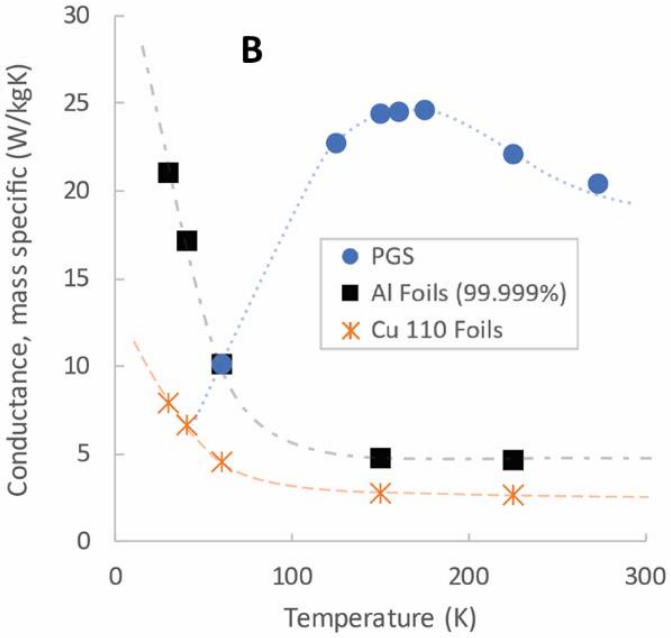
SDL PGS thermal straps result in less mass and higher thermal performance than metallic straps for applications above 80 K

PGS Thermal Straps

- High thermal conductivity + low density = superior mass-specific conductance
- Three times more flexible than aluminum foil strap of the same geometry
- Relatively short PGS strap (~2” of exposed PGS) reduced a random vibe input of 48 GRMS on one end to less than 1 GRMS on the other end
- For more information on PGS straps compared to metallics:
  - M Ralphs, M Sinfield, M Felt. “High performance thermal straps for a full range of application temperatures.” 21st Int. Cryocooler Conf, 2020

More flexible, more conductive, and better at isolating from vibration then metallic foil straps





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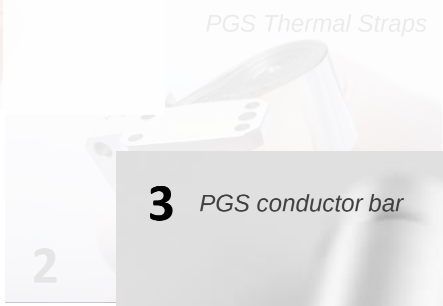
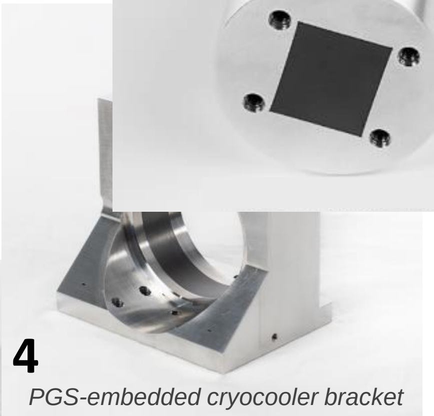
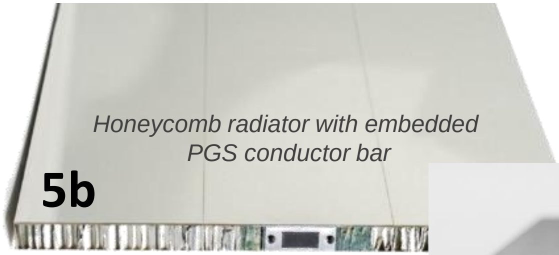
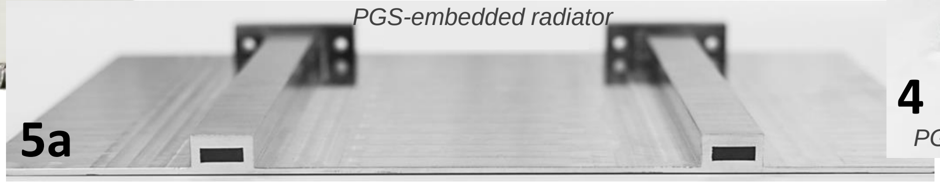
Intro to PGS


2 PGS Thermal Straps


3 PGS conductor bar

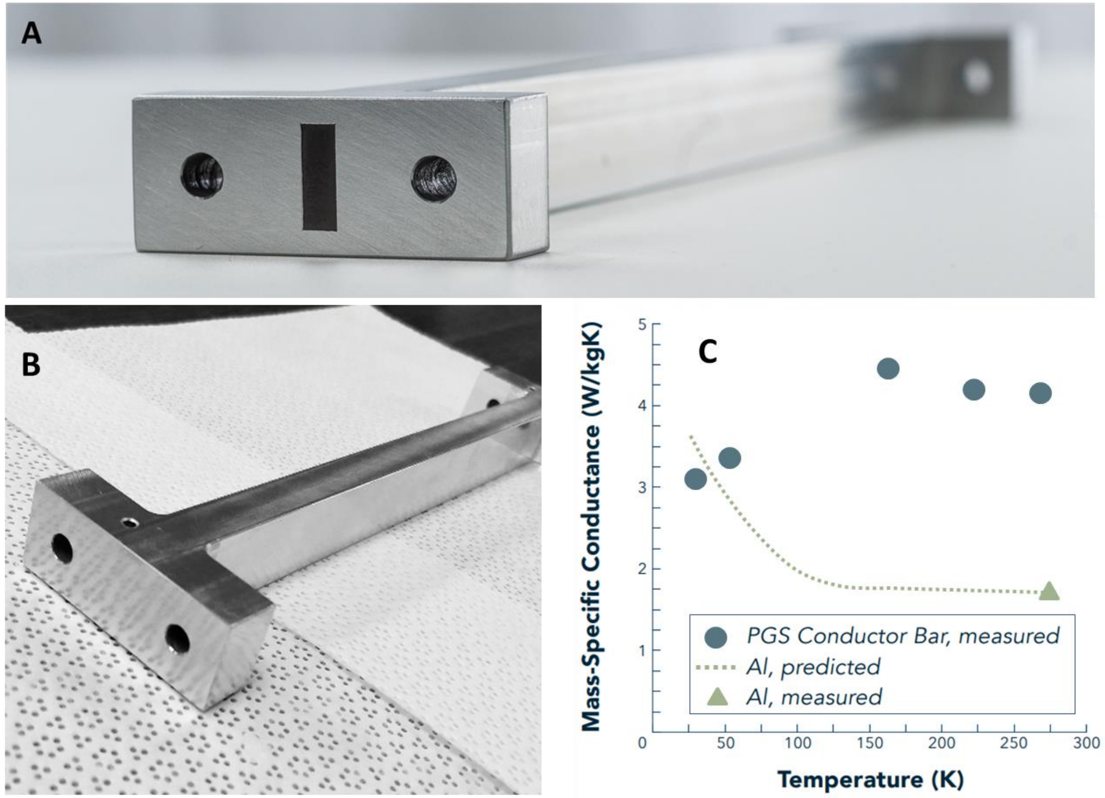

4 PGS-embedded cryocooler bracket


5b Honeycomb radiator with embedded PGS conductor bar


5a PGS-embedded radiator

PGS-Embedded Conductor Bars

- Conductor bars are used when heat needs to be conducted from point A to point B and the compliance of a thermal strap is not needed
- PGS-embedded conductor bars combine the strength of the housing material with the high thermal performance of PGS
- Housings have been made and tested using Al 1100-H112, Al 6061-T4, and 6063-T5
- Custom interfaces are added along the length to accommodate multiple connections, conducting heat to the cold sink from multiple components
- SDL PGS conductor bars are TRL-8



Combine strength of housing material with high conductivity of PGS for superior mass-specific conductance

PGS Embedded Conductor Bars

- Thermal straps commonly attach to the end of conductor bars to provide necessary compliance where needed in the system, adding an additional thermal joint
- PGS conductor bars and straps can be integrated into a single component to eliminate thermal joint and further improve performance

Combine bar and strap for even higher thermal performance and mass savings

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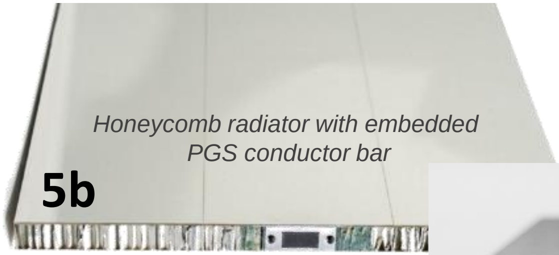
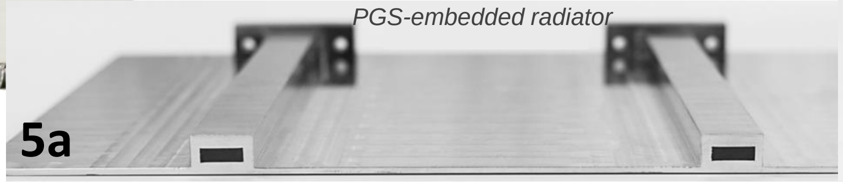
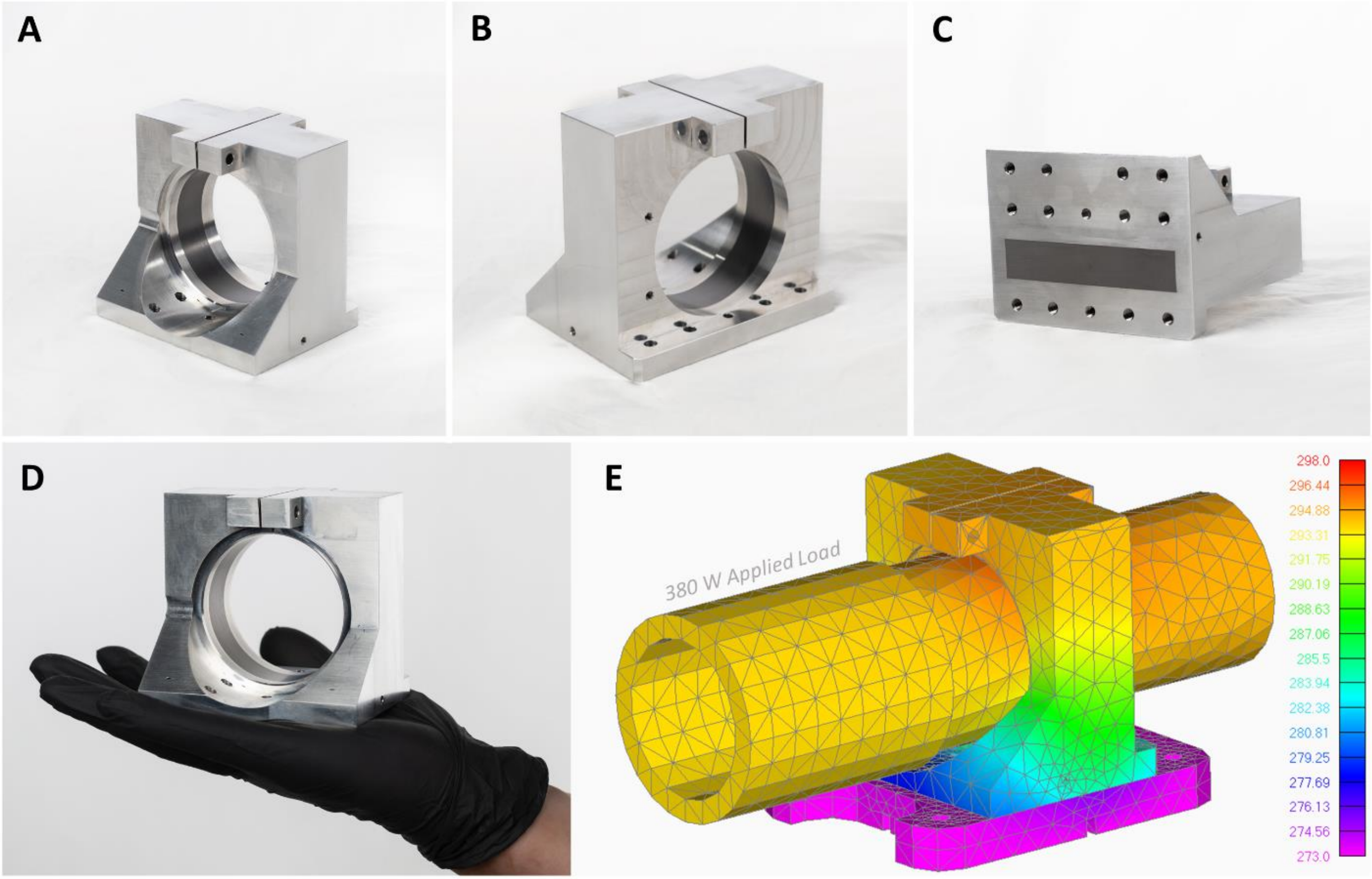




PGS-Embedded Cryocooler Brackets

- High power cryocoolers limited by how much waste heat can be disposed
- PGS-embedded cryocooler brackets provide 2-3x boost in conductance, enabling the use of more cooling capacity
- More than 17 W/K from cryocooler to cold plate (sink)
  - 23 K dT with 380 W load



2-3x thermal performance enables higher power cryocoolers and more cooling

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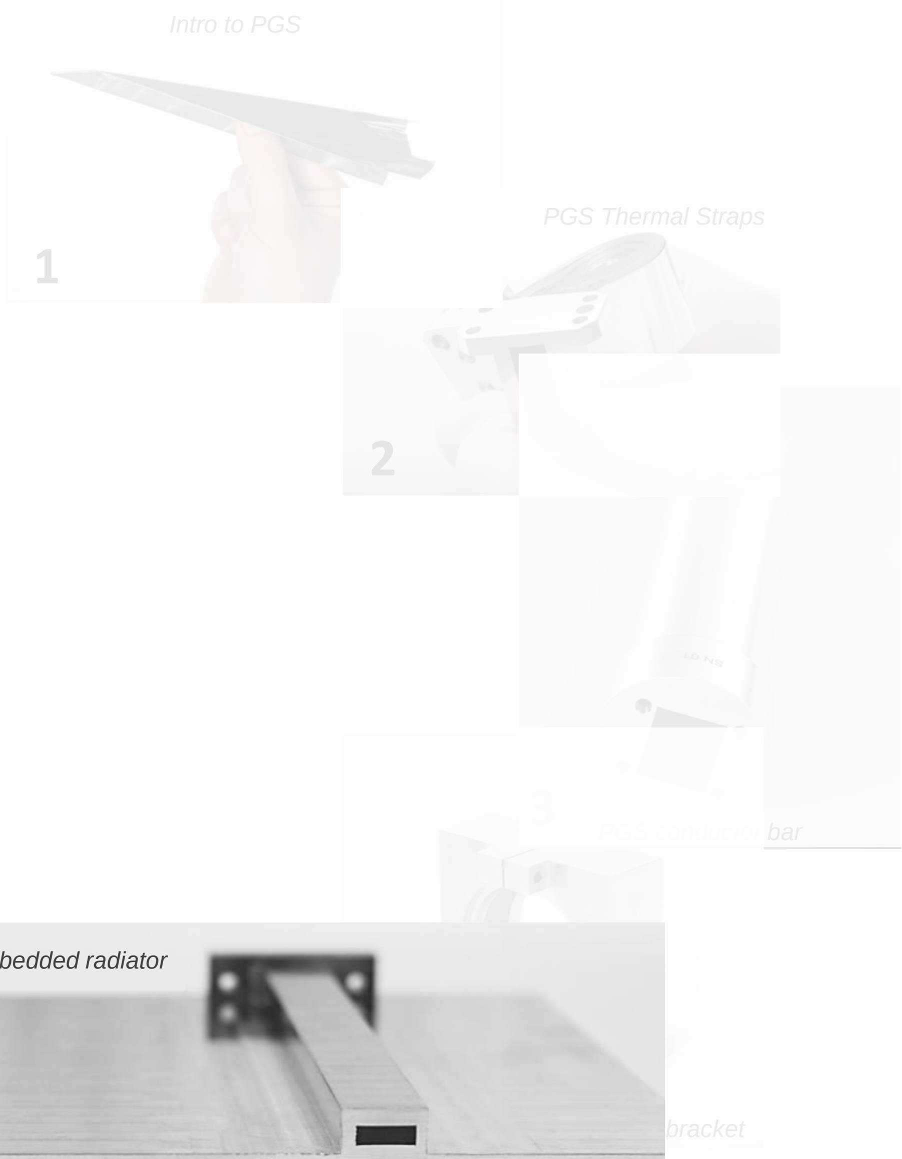
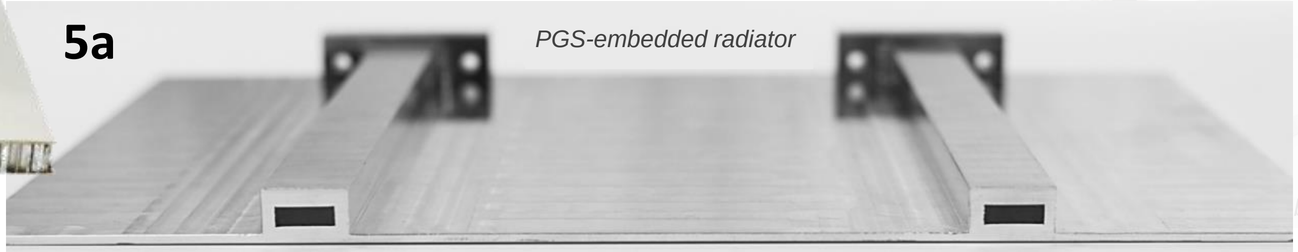


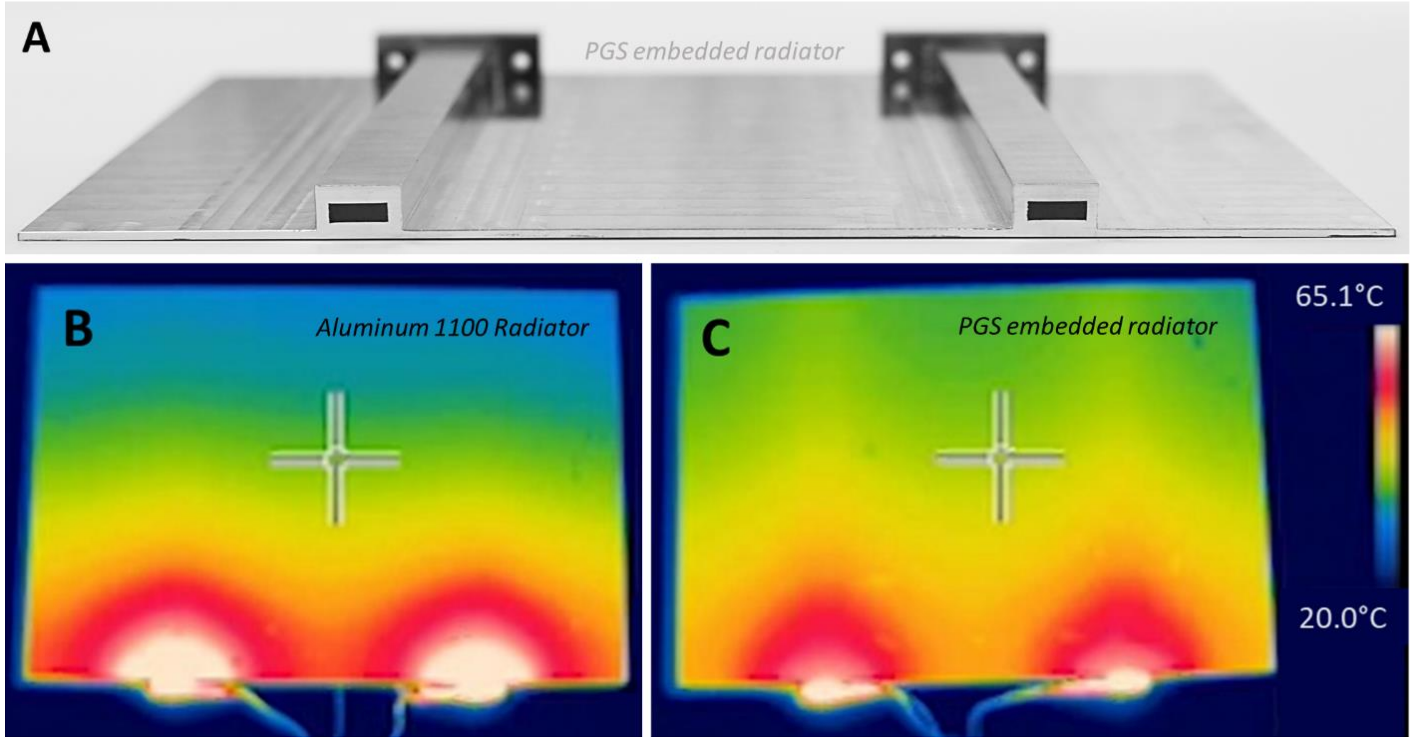
5b Honeycomb radiator with embedded PGS conductor bar



5a PGS-embedded radiator

PGS-Embedded Radiators

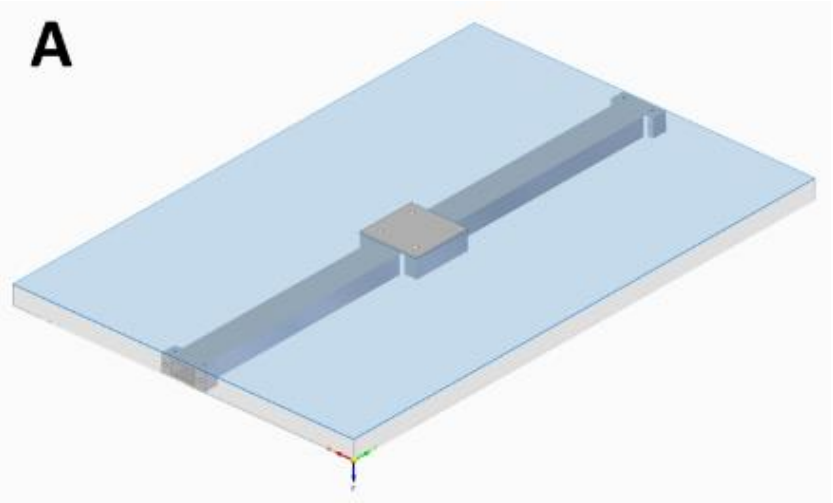
- Radiator efficiency is often limited by how well the heat can be spread
- Adding heat spreaders to a radiator is common to boost efficiency
- PGS-embedded radiators spread heat better than traditional methods
- Multiple thermal interfaces can be machined into spreader to accommodate multiple sources of heat to a single radiator

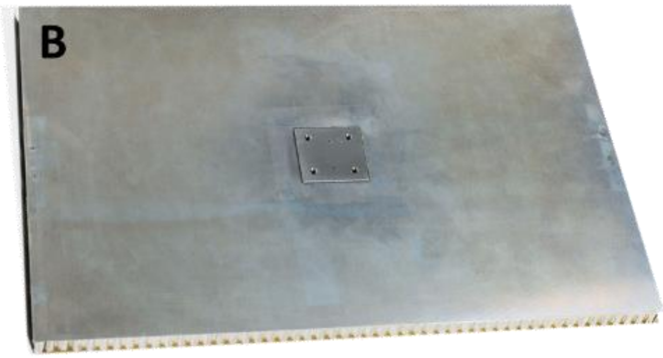


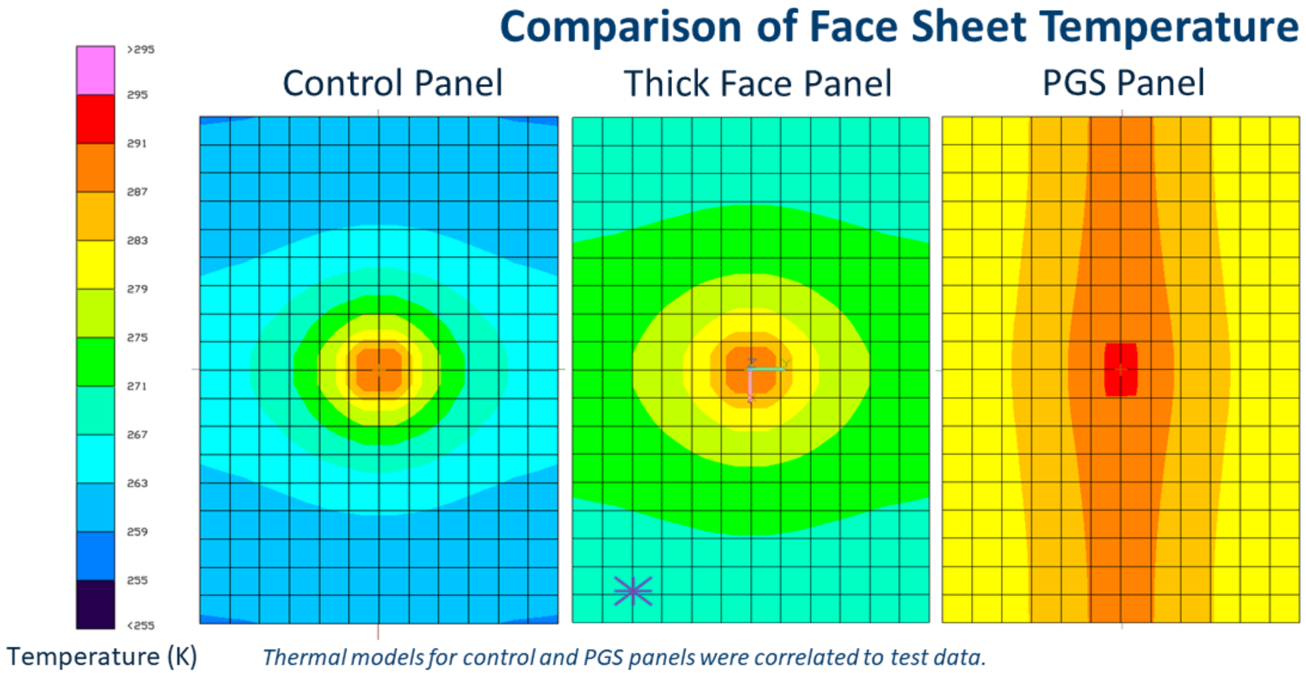
PGS boosts radiator efficiency, reducing mass and volume

PGS-Embedded Radiators

- PGS-embedded conductor bars are embedded in honeycomb radiators, similar to traditional spreaders
- TRL-6





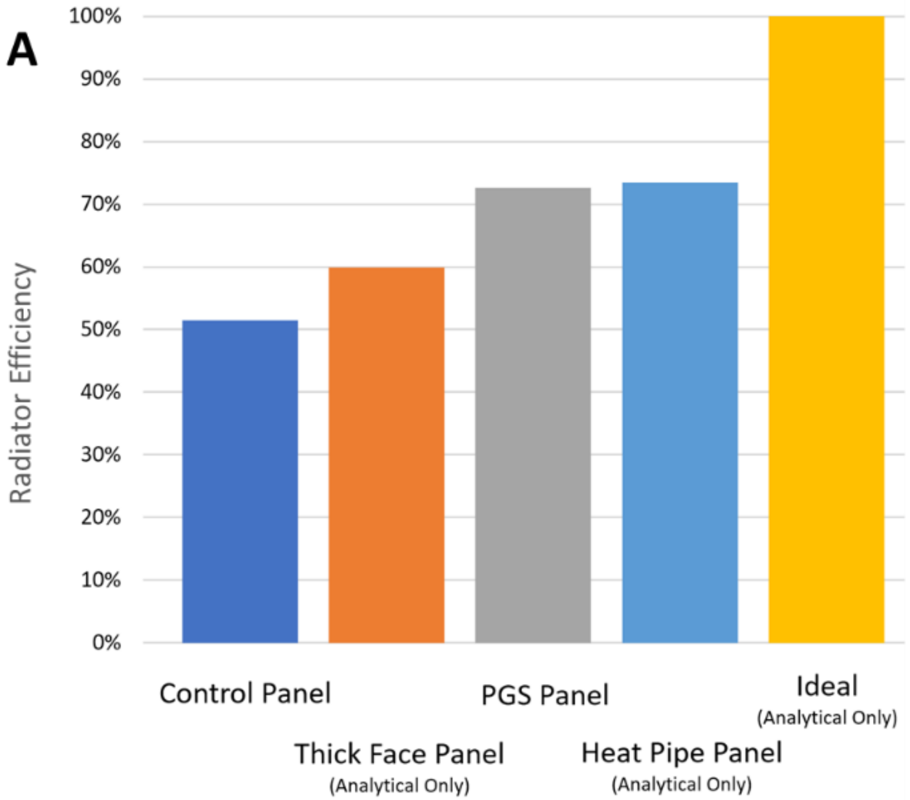


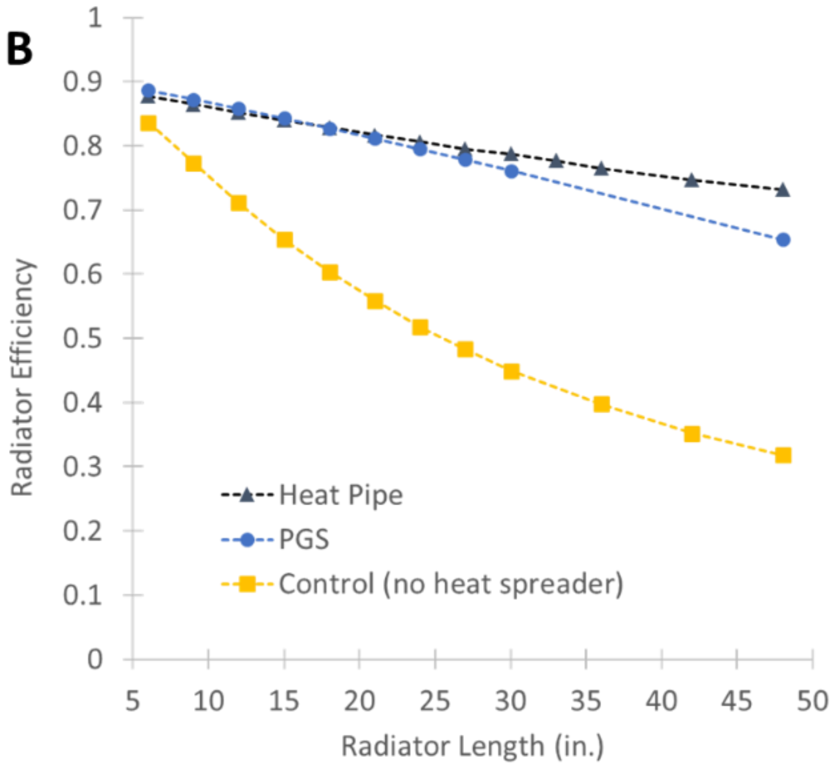
Thermal models for control and PGS panels were correlated to test data.

Smaller face sheet gradient = more heat dissipated to space

- Comparison of honeycomb radiator efficiencies
  - Comparing heat rejected to space against an ideal radiator (uniform temperature)

$$Q_{rejected} = A\,\varepsilon\,\sigma\left(\left(T_{panel}\right)^4 - \left(T_{target}\right)^4\right)$$





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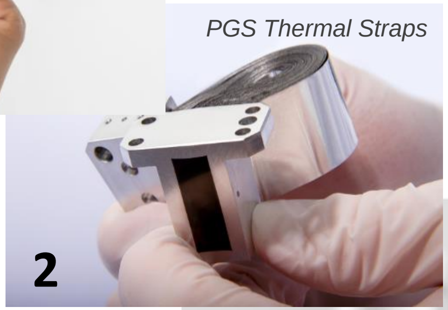

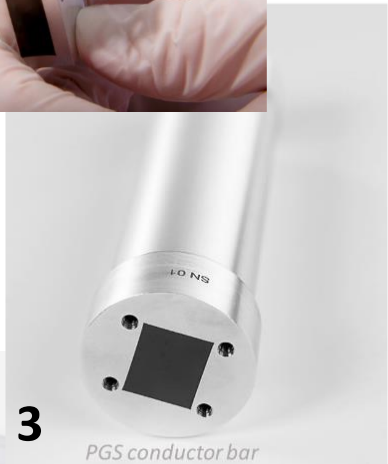

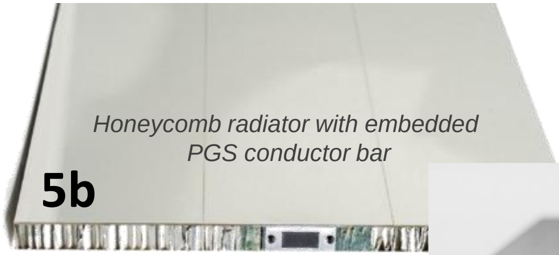

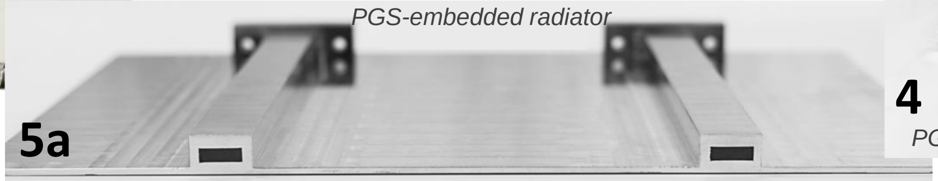

Conclusions

1. PGS has an exceptionally high conductivity-to-mass ratio
2. PGS straps, conductor bars, cryocooler brackets, and radiators all outperform their traditional passive thermal counterparts
3. PGS-embedded components save mass and enable higher power components

QUESTIONS?