SBIR Phase I for Contract No. NNX16CM17P

“Ultra-Stable Zero-CTE HoneySiC™ and H2CMN Mirror Support Structures”

Contract Brief

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Background & Technology Gaps

- **NASA Strategic Plan 2014, New Worlds, New Horizons, seeks cost-effective, high performance advanced space telescopes for Astrophysics and Earth Science**
- **2015 NASA Technology Roadmap (TA 8: Science Instruments, Observatories and Sensor Systems, part 8.2 Observatories) sub-goal for structures:**
  - The ability of the structure to hold mirrors in a stable, strain-free state under the influence of anticipated dynamic and thermal stimuli
  - For extra-large apertures, a method to create the aperture via deployment, assembly, or formation flying
- **NASA MSFC, GSFC and JPL interested in Ultra-Stable Mirror Support Structures for Exoplanet Missions**
  - Telescopes with apertures of 4-meters or larger and using an internal coronagraph require a telescope wavefront stability that is on the order of 10 pico-meters RMS per 10 minute
  - IR/FIR missions requiring 8-meter or larger diameter mirrors with cryogenic deformations <100 nm RMS

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Technical Solution: HoneySiC

- **HoneySiC™: Fantom's innovative, additively manufactured, ceramic matrix composites**
  - HoneySiC - T300 carbon fiber reinforced SiC CMC
  - HoneySiC - H^2CMN – hybrid hierarchical ceramic matrix nanocomposite with CNTs
- **Program effort addresses the need for stable, strain-free, precision optical structures under the influence of dynamic and thermal stimuli, specifically whiffle plates, delta frames and backplane**
- **Traceable to the needs of Cosmic Origins for UVOIR, Exo and FIR telescopes**
- **Maturation of this technology will allow NASA and Fantom to develop a method to create large aperture optical support structures and assemblies via deployment, assembly or active control**
- **HoneySiC additive manufacturing process significantly minimizes cost and schedule associated with post-production fabrication steps (machining, polishing, metrology).**

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HoneySiC Features

- **Rapid Prototyping -** Extremely rapid additive manufacturing process with all assets under a single roof.
  - Large complex mirrors/structures could be produced in a matter of weeks.
  - Web thickness < 1mm, core geometries (pocket depth, pocket size) easily tailored.
  - Minimizes machining, recurring/non-recurring costs; cost is 100X < beryllium.
- **Ultra-low areal cost -** Cost of raw materials ~\$38K/m^2 for unpolished HoneySiC, which already meets NASA's goal of \$100K/m^2 -> ~100X reduction in mirror cost based on current cost of \$4-\$6 million/m^2.
- **Ultra-low areal density**
  - Facesheets density same as beryllium; sandwich constructions are a fraction of Be density.
  - Void space in cells of honeycomb enables maximum lightweighting and stiffness.
  - 95% lightweighting w.r.t. bulk silicon carbide.
  - Areal density of first panel made: 5.86 kg/m^2.
  - Estimated weight and areal density of a 255-mm mirror: 0.35 kg and 6.8 kg/m^2, respectively.
  - Estimated mass of 305-mm optical bench with inserts: 0.94 kg.
- **Extreme dimensional stability -** CTE of HoneySiC can be tailored to match SiC or reduced to be near-zero with a variation of only 0.42 ppb/°C/°C from -200°C to 0°C in testing at Southern Research Institute.
- **Carbon fiber reinforced SiC structure**
  - Thermal conductivity "supercharged" by addition of CNT
  - No coefficient of moisture expansion (CME)
  - Low Z for nuclear survivability
  - Electrically conductive for dissipating static charge build-up
  - ~2X higher fracture toughness than pure SiC, estimated ~4.6 MPa-$m^{0.5}$
- **Nuclear and Space Survivable -** Precursor carbon-carbon honeycomb is flying on >100 space crafts.

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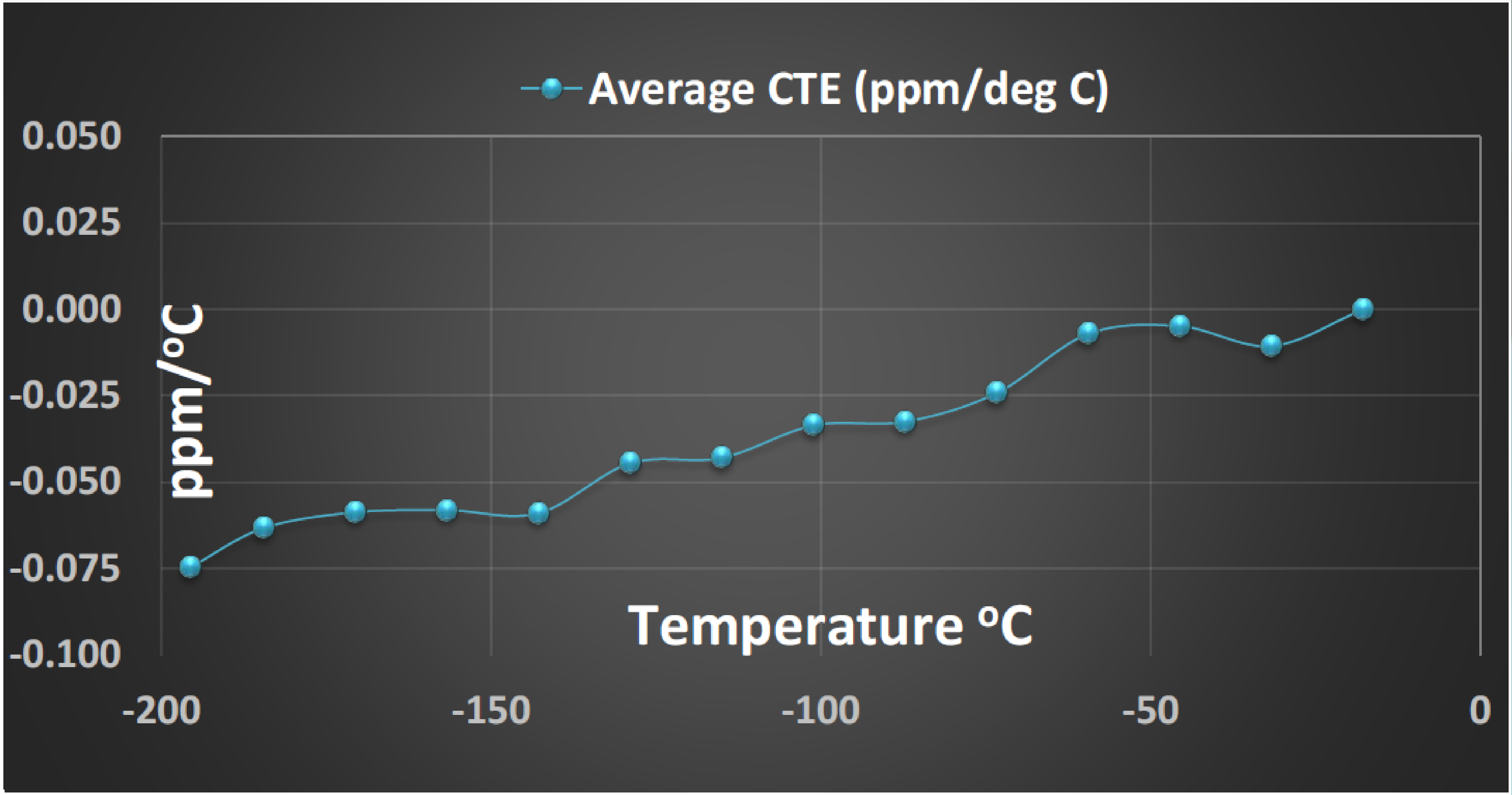
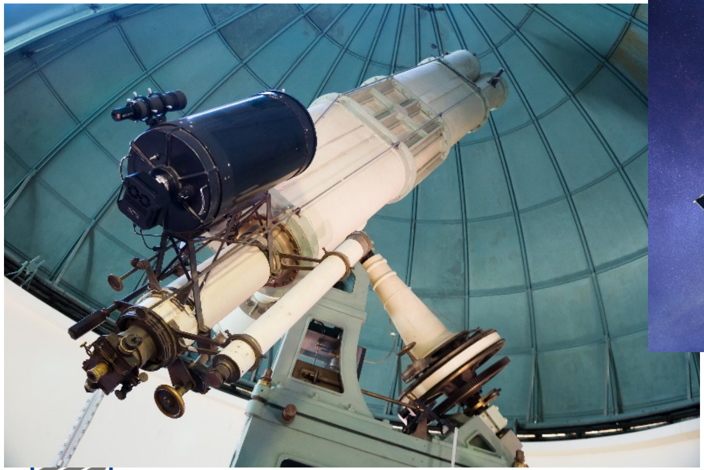
Ultra low CTE Material

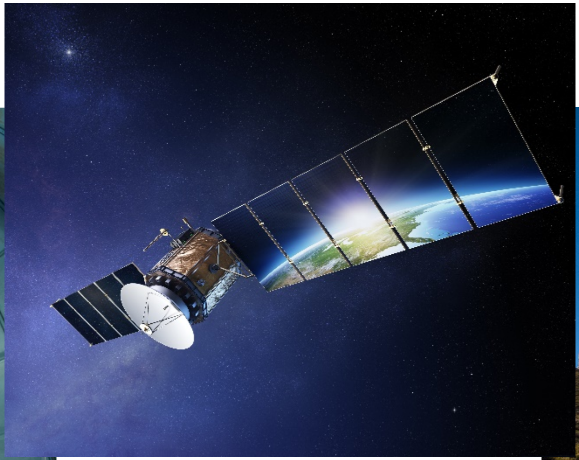


Average instantaneous CTE for T300HoneySiC. The slope of the curve over the temperature range is only 0.42 ppb/°C/°C!

Proposed Phase I Effort

- Collaborate with NASA MSFC, GSFC, JPL and Northrop Grumman Aerospace Systems (NGAS) to design prototype whiffle plates or delta plates to be made in Phase II using HoneySiC or H^2CMN materials.
- Evaluate HoneySiC and H^2CMN mechanical properties and coefficient of thermal expansion
- Prepare a material property test matrix to be executed in Phase II





Summary of Tasks

- **Task 1: Kick-off and Requirements Review**
  - Telecon with Ron Eng (NASA), Dr. Bill Fischer (Fantom), Lauren Bolton (Fantom), Professor Mehrdad Nejhad (UH), Brian Baldauf (Northrop Grumman)
- **Task 2: Reporting**
  - Interim report
  - Final report
- **Task 3: HoneySiC™ and H^2CMN Coupon Definition**
  - Identify geometry for material characterization coupons
- **Task 4: Coupon Preparation**
  - UH will produce T300 and H^2CMN coupons
- **Task 5: Measurements**
  - UH to perform basic mechanical measurements in-house
  - CTE measurements at SoRI and NGAS
- **Task 6: Phase II Plan**
  - Preliminary design effort and review for whiffle plate, delta plate, backplane or tube structure to be produced in Phase II

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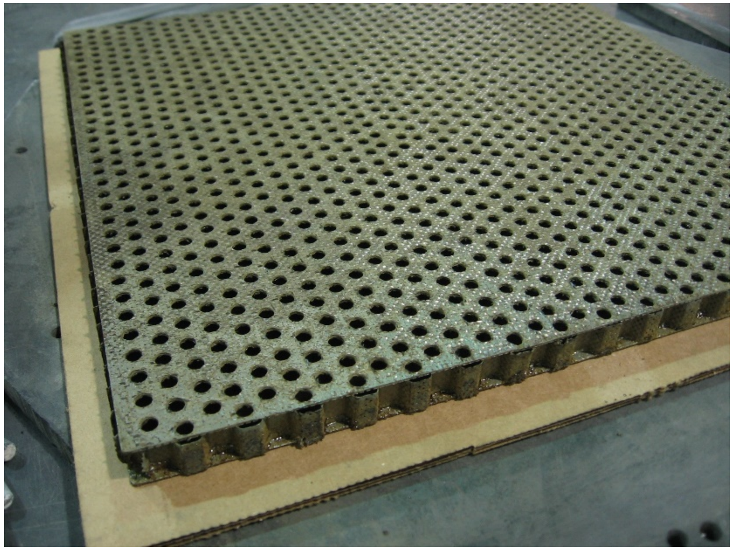
Program Status

- **HoneySiC™ and HoneySiC H^2CMN Coupon Definition**
  - HoneySiC and HoneySiC H^2CMN will undergo mechanical and CTE testing
    - Mechanical testing: strength, strain/deflection, stiffness and toughness
    - CTE testing: -200°C to +25°C
- **Coupon Preparation**
  - HoneySiC and HoneySiC H^2CMN coupons are in fabrication
  - CNT growth complete
  - Pre-pregging and PIP in process
- **Measurements**
  - UH to perform basic mechanical measurements (underway)
  - CTE measurements at SoRI in early November
- **Phase II Plan**
  - Preliminary design effort and review for Phase II prototype in process



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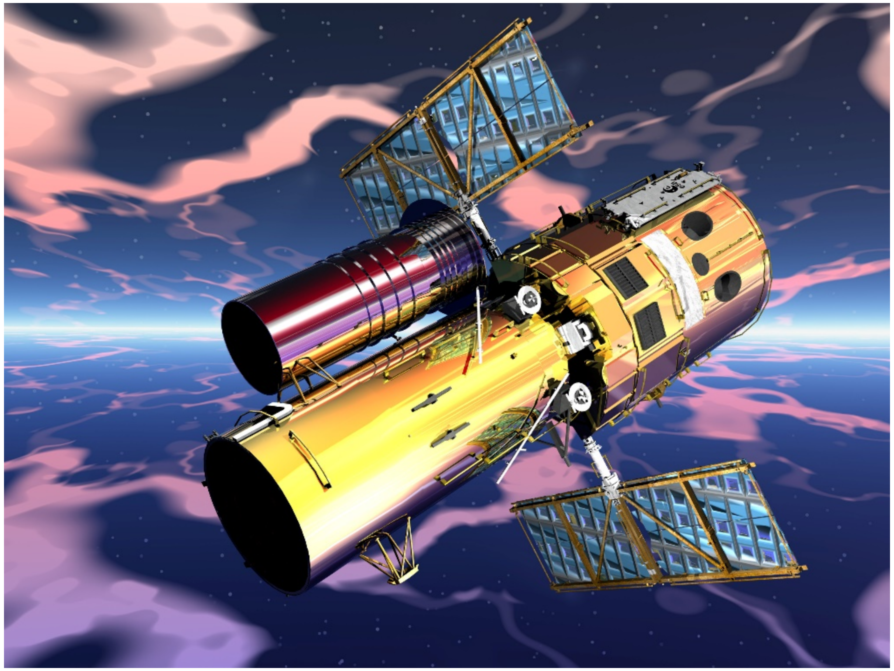
Outcomes of Phase I Effort

- **Produce T300 and H^2CMN coupons for material characterization**
- **Basic mechanical and CTE data acquisition**
- **Phase II material property characterization test matrix**
- **Preliminary HoneySiC™ whiffle plate, delta plate, backplane or tube structure design**



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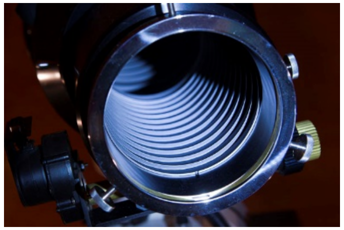
Proposed Phase II Effort

- **Complete a full suite of material property measurements**
  - Measurements will be used to take the Phase I Preliminary Design Review to a Critical Design Review and decision to start prototype production
- **Begin production of whiffle plate, delta plate, backplane or tube structure prototypes**
- **Continue to develop 3D Printing capability**
  - Processing will remove any inherent layering issues that can reduce the variability that can be found in many traditional 3D printing processes
  - Process also removes any potential layering issues in finished composites
  - Will further reduce lead time and cost



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NASA Applications

- **NASA sees potential for HoneySiC™ as an affordable technology for large observatories and future astrophysics missions[5] for:**
  - The Formative Era, answering such questions as “What are exoplanets like?”
    - Characterizing planet forming disks and planetary atmospheres with the LUVOIR Surveyor.
    - Searching for life using the LUVOIR Surveyor to obtain full-disk images and spectra of pale blue dots.
    - Making longitudinal maps and detecting seasonal variations on exoEarths.
    - Searching for signs of habitability and evidence of biological activity on exoEarths.
  - The Visionary ERA, searching for life using an ExoEarth Mapper to produce resolved maps and spectra of “New Earth”, confirming surface water and identifying possible life.

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