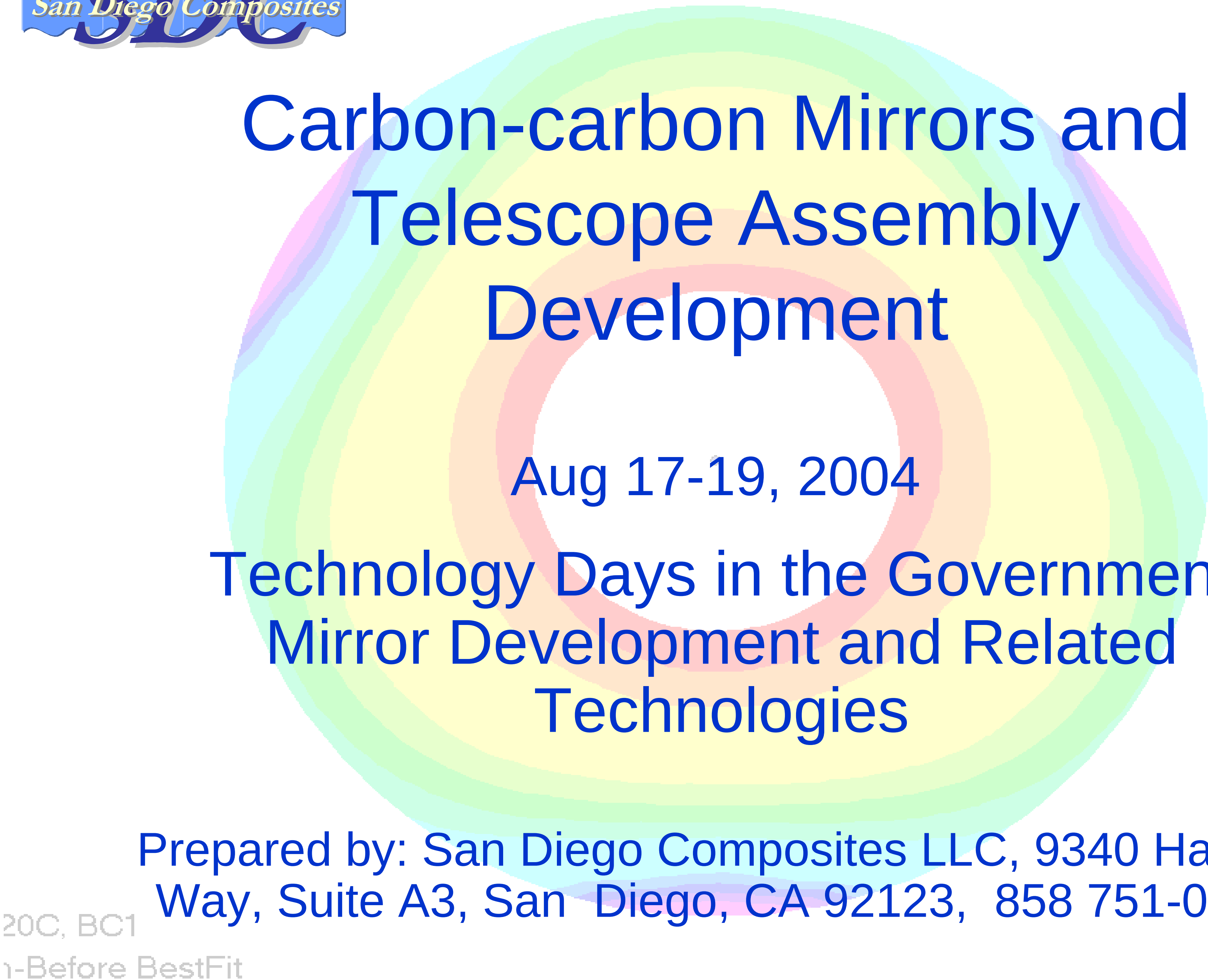
Carbon-carbon Mirrors and Telescope Assembly Development



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Technology Days in the Government Mirror Development and Related Technologies

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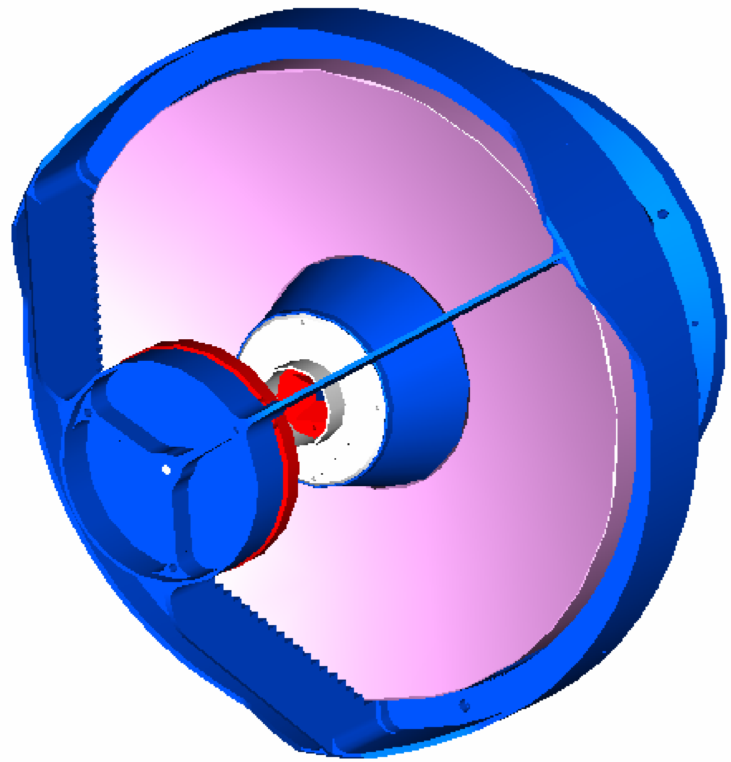
SBIR Programs

- Phase I
  - Analytically verified validity of C-C approach to replace beryllium Primary Mirror (1/20/03-7/20/03)
- Phase II
  - Objective: Development of carbon-carbon telescope assembly conceptual design and mirror fabrication processing (5/5/2004-5/4/2006)
- Phase III
  - Objective: Detailed design verification of telescope assembly/mirrors and housing fabrication process development (7/15/2004-7/14/2006, projected start date)



Four Mirror Anastigmat Telescope Assembly

Beryllium to Carbon-carbon Comparison

Property	Comparison
Thermo-mechanical behavior	Beryllium is isotropic (athermalization is inherent); C-C is anisotropic, can be tailored using different fibers and or laminate architectures to achieve athermalization
Material stiffness	Beryllium has exceptional specific stiffness; C-C has very good specific stiffness properties (lower density), but must use structural construction to achieve lower weight compared to Be
Material strength	Beryllium has moderate strength, can integrate fasteners into metal; C-C has good strength in-plane, but has low transverse shear strength, must trade off mechanical fasteners versus other joining approaches
Design issues	Can machine geometrically complex details into Be; can machine C-C, but prefer to keep shapes simple with no sharp corners (do not want to machine fibers in-plane)

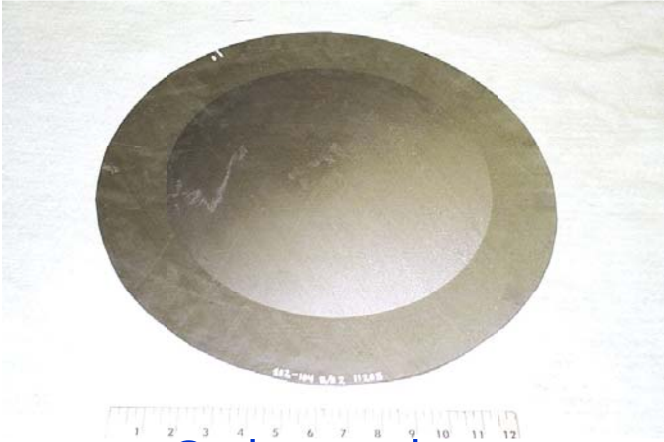
C-C Mirror Technical Approach

Materials Technology	Advantages
• Carbon-carbon substrate	• Insensitive to moisture, long term temporal stability[1], low density, low atomic number
• Carbon-carbon honeycomb	• High specific shear stiffness, insensitive to moisture
• Glass and or C coating	• Seals carbon-carbon dust
• SiOx mirror surface coating	• Low cost, thick coatings, uniform thickness
• Magneto-rheological Finishing	• Reduces possibility for print through (zero normal pressure), rapid process developed for machining glass

[1] Long term and thermal instability of carbon-carbon composite, W. Sokolowski, K. Brown, Tim O'Donnell and S. Jacobs, Jet Propulsion Laboratory, Cal Tech.,

Phase II Mirror Plans

- C-C team:
  - Allcomp, SMJ Carbon, AFRL
  - Ultracor, Inc.
- Pyrogenics, Inc. selected for carbon CVI
- SiOx Glass
  - San Diego Composites LLC
- University of Arizona Optical Science Center
  - Metrology/Materials Processing



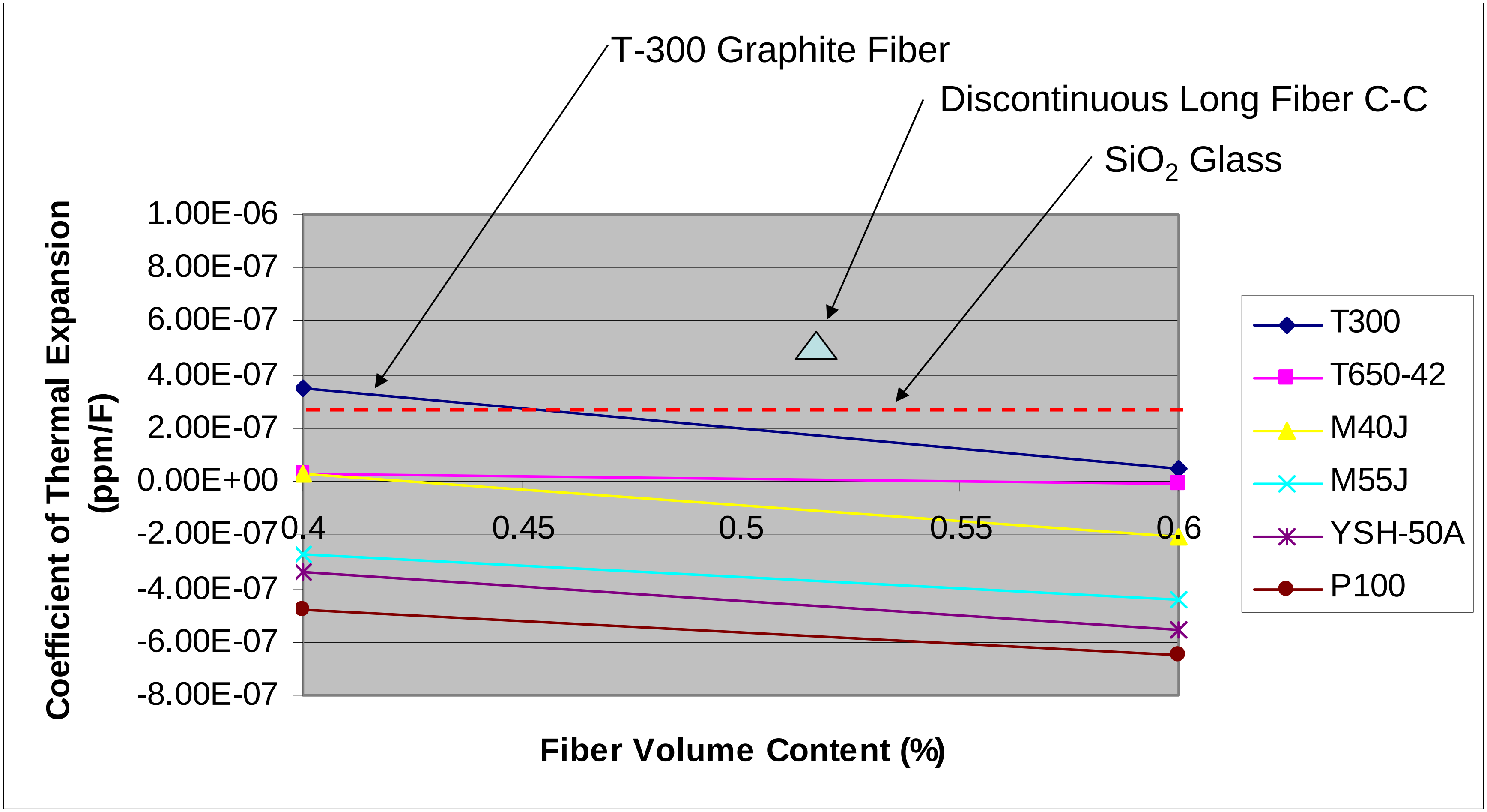
Carbon-carbon Plate (Allcomp)

Carbon-carbon honeycomb core (Ultracor Corp.)

Phase II Mirror Plans (Continued)

- Building block approach planned
  - Coupon tests – materials characterization (e.g., CTE, hysterisis, virtual leakage, nuclear)
  - Coating studies (glass coating and chemical vapor infiltration (CVI))
  - Subscale (meniscus) test articles at various curvatures – natural frequency, damping, and thermal temporal stability
  - Prototype test articles – structural and optical performance
- Design verification – athermal telescope demonstration
- Detailed manufacturing plans and cost models development

Key Mirror Requirement – CTE Matching of C-C and Glass



Key Telescope Requirements

- Telescope optical performance is determined by the shape and alignment of the optics
- Deformation of the optical surfaces or structure degrades optical performance
- Both material properties and design configuration determine the ability of the telescope to resist deformation
- Possible sources of deformation:
  - Gravity (ground testing)
  - Dynamics (vibration in flight)
  - Temperature (temperature change in flight)
  - Temporal (dimensional instability)
  - Mounting stresses

Telescope Design for Manufacturing and Assembly

DFMA Process

Understand → Brainstorm → Evaluate → Implement

- Key production techniques are:
  - Diamond turning of optical surfaces
  - “Bolt-together” assembly
- Single point diamond turning produces the required tolerances
- Bolt together assembly requires:
  - Mounting surfaces referenced to optical surfaces
  - Axi-symmetric shapes much easier to produce and assemble
  - Mounting surfaces must be very flat and co-planar to avoid distortion of optics during assembly

Summary

- A material system comprised of carbon-carbon and glass was selected in Phase I for precision mirror application
  - Carbon-carbon found to provide substantial weight, nuclear, contamination, cost and schedule benefits
- Phase II and Phase III to develop and integrate mirrors and telescope assembly (2004-2006)
- Phase II and III team in place
- Requirements for mirrors and telescope assembly defined
- Design concept for telescope assembly in development
- Primary mirror design concept developed in Phase I
  - Weight was found to be proportional to density to the 1.3 power and elastic modulus to the 0.3 power
- Building block approach planned for Phase II carbon-carbon mirror development