Pixel Mechanics

Disk Design and Prototypes

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ATLAS Pixel Disk Mechanics

5 Disks each end of pixel detector (672 total pixel modules)
- 3 Large disks each end
  - Inner active radius 12.6 cm
  - Outer active radius 18.6 cm
  - 12 sectors of 6 modules each
- 2 Small disks each end
  - Inner active radius 10.5 cm
  - Outer active radius 16.5 cm
  - 10 sectors of 6 modules each

Assembly precision:	~25 microns
Radiation length:	< 0.6% per layer for structure
Heat generated:	~400 Watts/disk
Operating temperature:	< -6 degrees C

Disk Sector Structural Requirements

(All tolerances are one sigma unless noted. Tolerances of modules are with respect to module center. Fifty micron radial pixel resolution assumed.)

a) construction tolerances including static deflection due to gravity after sector supported as in disk ring

- i) module placement tolerances:
  - azimuth: 15 microns
  - radial: 50 microns
  - z: disk 1: 60 microns,
    - disks 2 - 5: 80 microns
  - rotation about axis perpendicular to module: 0.34 mrad
  - rotation about long axis of module: 3.6 mrad
  - rotation about axis across module: 1.0 mrad
  - planarity of module (i.e. no twists): +/-10 microns (not 1 sigma)
- ii) tolerances on post construction knowledge of module locations
  - azimuth: 5 microns
  - radial: 25 microns
  - z: disk 1: 30 microns,
    - disks 2 - 5: 40 microns
  - rotation about axis perpendicular to module: 0.17 mrad
  - rotation about axis along z axis of module: 3.6 mrad
  - rotation about axis across module: 1.0 mrad
  - planarity of module (i.e. no twists): +/-10 microns (not 1 sigma)

b) The tolerances on module movement due to the combined effects of distortions from coolant flow, power on, cooldown and CME are:

- azimuth: 5 microns
- radial: 25 microns
- z: disk 1: 30 microns,
  - disks 2 - 5: 40 microns
- rotation about axis perpendicular to module: 0.17 mrad
- rotation about axis along z axis of module: 3.6 mrad
- rotation about axis across module: 1.0 mrad
- planarity of module (i.e. no twists): +/-10 microns (not 1 sigma)

c) Tolerances on stability and vibration modes: Motion due to vibration of the sector is restricted to less than one half the tolerances given above under a) ii). At present we do not have enough information about the vibration spectrum in the experimental cavern to calculate vibration amplitudes of a given design. In lieu of this information we set a limit that the frequency of the fundamental vibration mode of a stave must be greater than 100 Hz.

LBNL Pixel Disk Design

Based on Carbon-Carbon as the structural material
- An all carbon material using carbon fiber fabric
- CTE -1 ppm/degC
- Modulus ~160 Gpa
- Thermal conductivity xy: 150 W/mK, z: 30 W/mK
- Radiation length 23 cm
- Nonhygroscopic
- Radiation hard

Low CTE Design to match silicon, control distortion during cooldown

Modular Design for risk reduction, precision and assembly
- Pixel Module -> Sector -> Disk

Desire to use same module design for disks and barrels

Layout of disks leads naturally to sector structure of thin facings with coolant tube between. Have prototyped 3 sector designs:

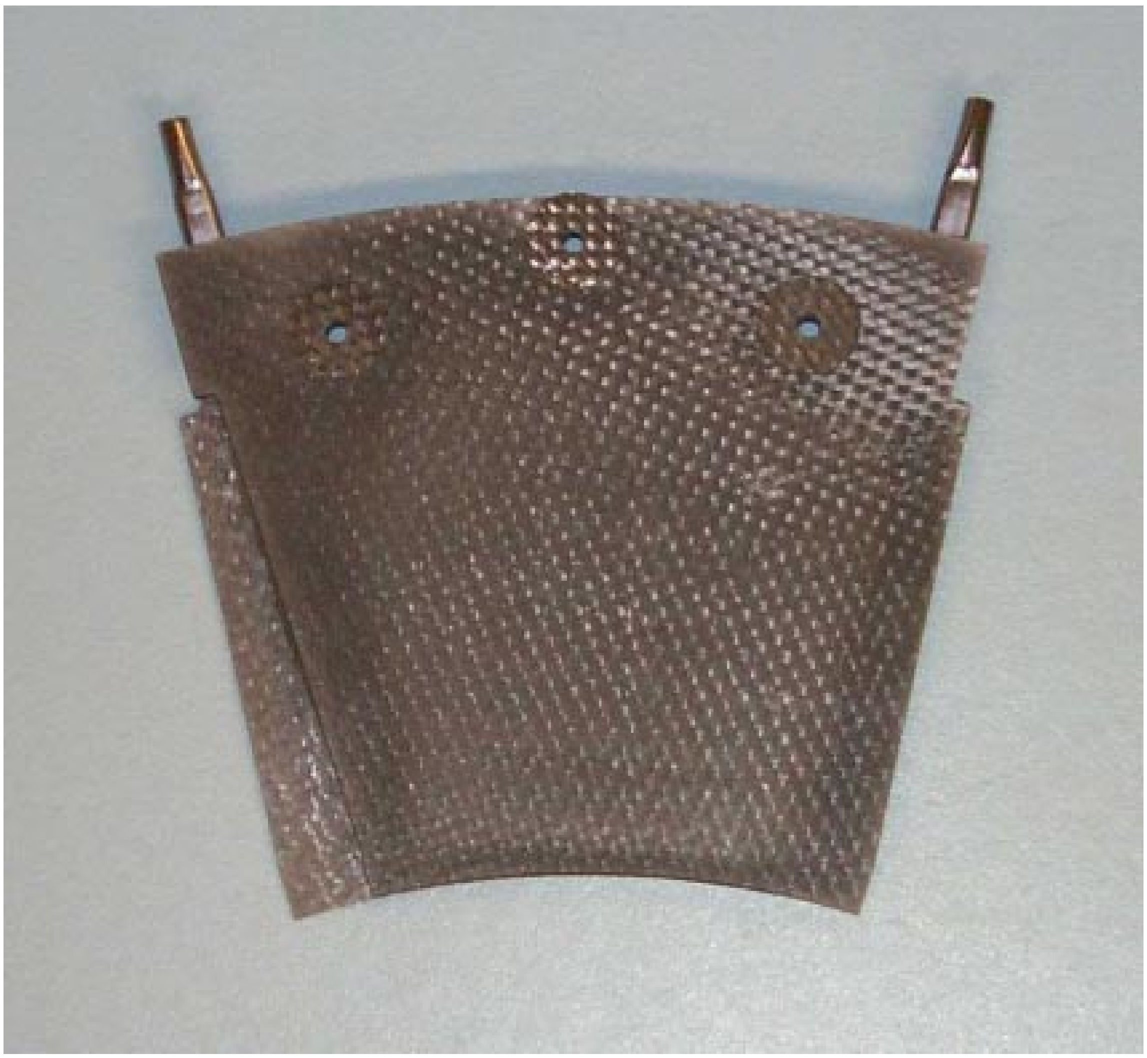
All carbon:	carbon-carbon facings, fuzzy glassy carbon coolant tube (ESLI, San Diego), 9 prototypes
Al Tube	carbon-carbon facings, aluminum coolant tube, 4 prototypes
C-C tube	carbon-carbon facings, sealed carbon-carbon coolant tube (Hytec, Inc.), first prototype being tested

ESLI Sector Prototype Number 9

ESLI sector number 9 from ESLI, San Diego is shown below. This sector has a flattened glassy carbon tube versus a round tube as on previous sectors from ESLI. The tube was flattened to improve heat transfer from the facings into the tube. This sector, as were previous ESLI sectors, is all carbon.

Tube: Glassy carbon 0.25 mm wall thickness
Facings: Carbon-carbon facings 0.46 mm thick
Fill: No fill
Radiation Length: 0.57% in active region
Thickness: 5.08 mm, 4.96 to 5.18 mm

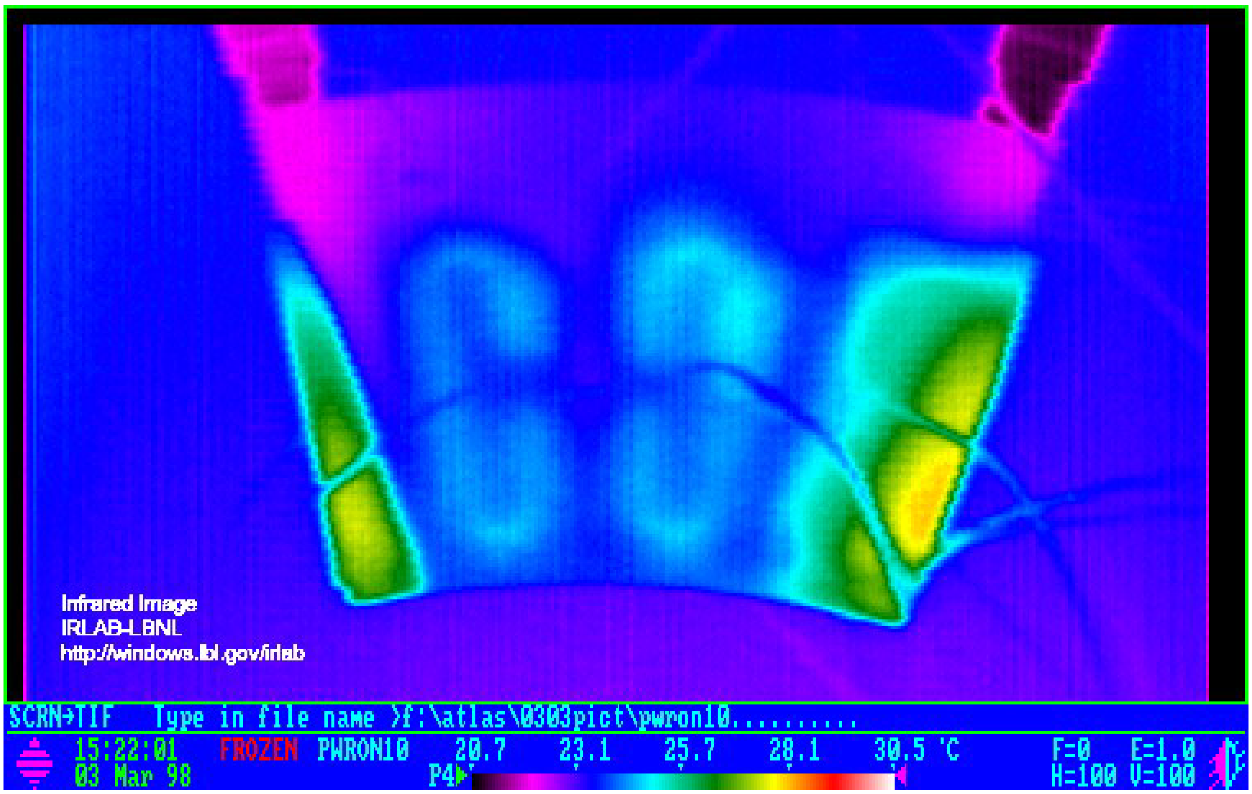
Have installed 300 micron thick silicon dummy modules with CGL7018 adhesive.



Thermal Test of ESLI Sector Number 9

Below is an infrared image of ESLI sector 9 with the nominal (36 Watts) heat load from dummy silicon modules. In general the temperatures of the dummy silicon modules vary from 4 to 8.5 degrees C above the coolant inlet temperature. For an assigned coolant inlet temperature of -15 degrees C the temperatures of all silicon would be below the required -6 degrees C. The sector meets thermal requirements.

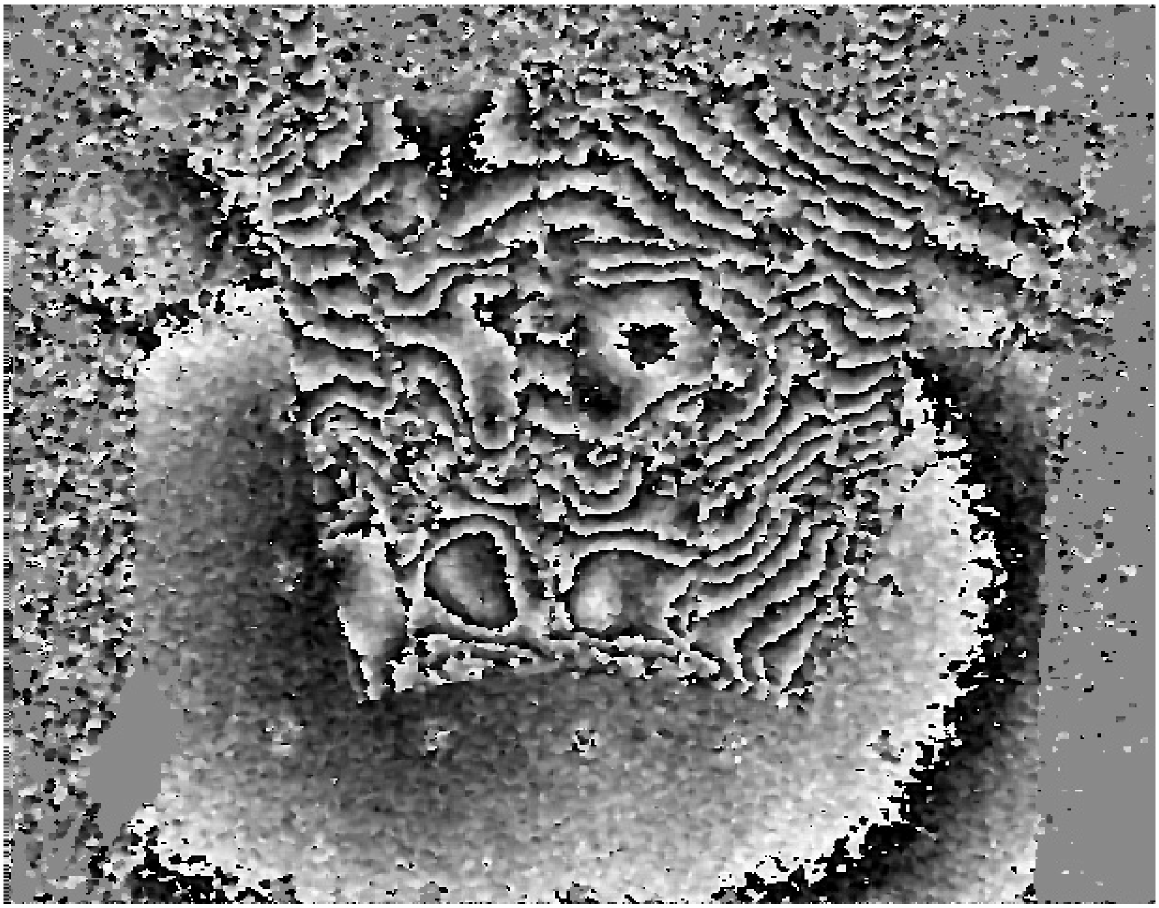
The coolant fluid was water. The ambient temperature was approximately 23.5 degrees C. The sector is the trapezoidal shaped object in the infrared images.



Power 36 Watts, coolant flow 10 cc/s, inlet temperature 20.0° C

TV Holography Test of ESLI Sector 8

ESLI sector 8 with silicon has been tested for distortion due to temperature change. ESLI sector 8 has 0.43 mm thick carbon-carbon facings and a fuzzy glassy carbon coolant tube. This sector has no fiber fill. Dummy silicon modules have been attached with CGL7018 adhesive.



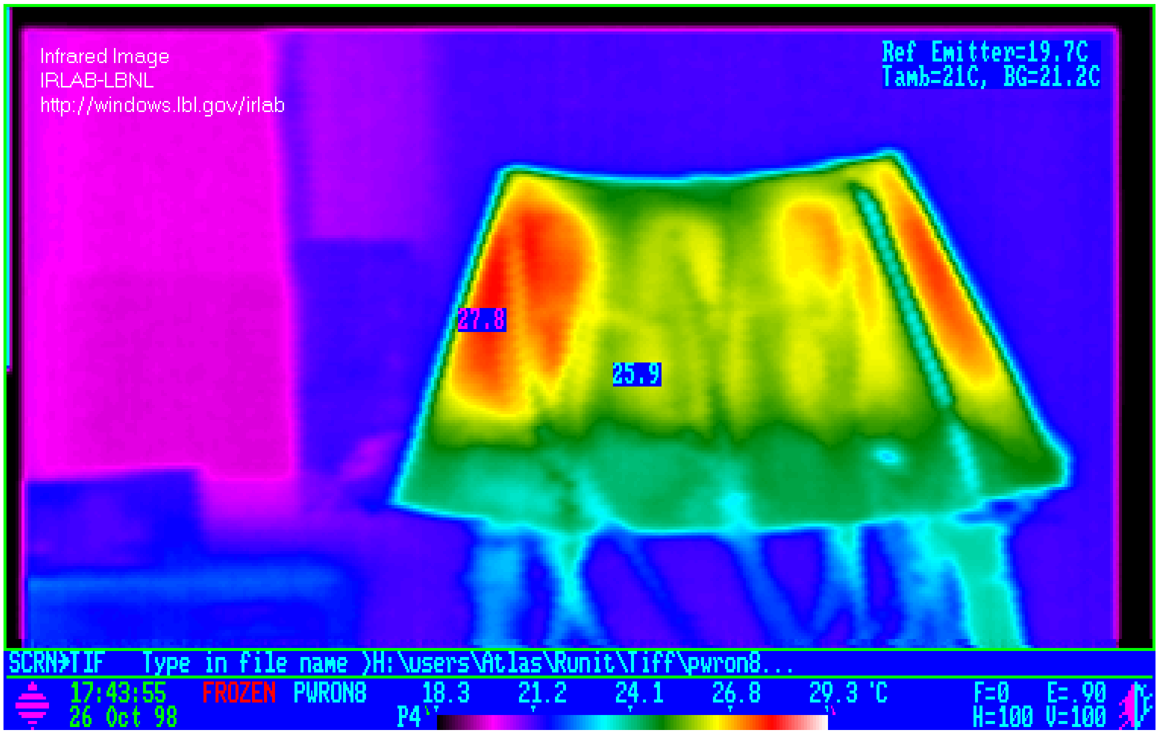
Above phase map from TVH shows distortions resulting from an 8 degree C temperature increase starting at 4.3 degrees C. Distortions along the right edge amount to 4.8 microns or 0.6 microns per degree C. Some of this distortion may be attributable to twisting of the support bar. There was no power or coolant flow. Power on distortion was approximately 1.6 microns.

Radiation Test of Aluminum Tube Sector Number 3

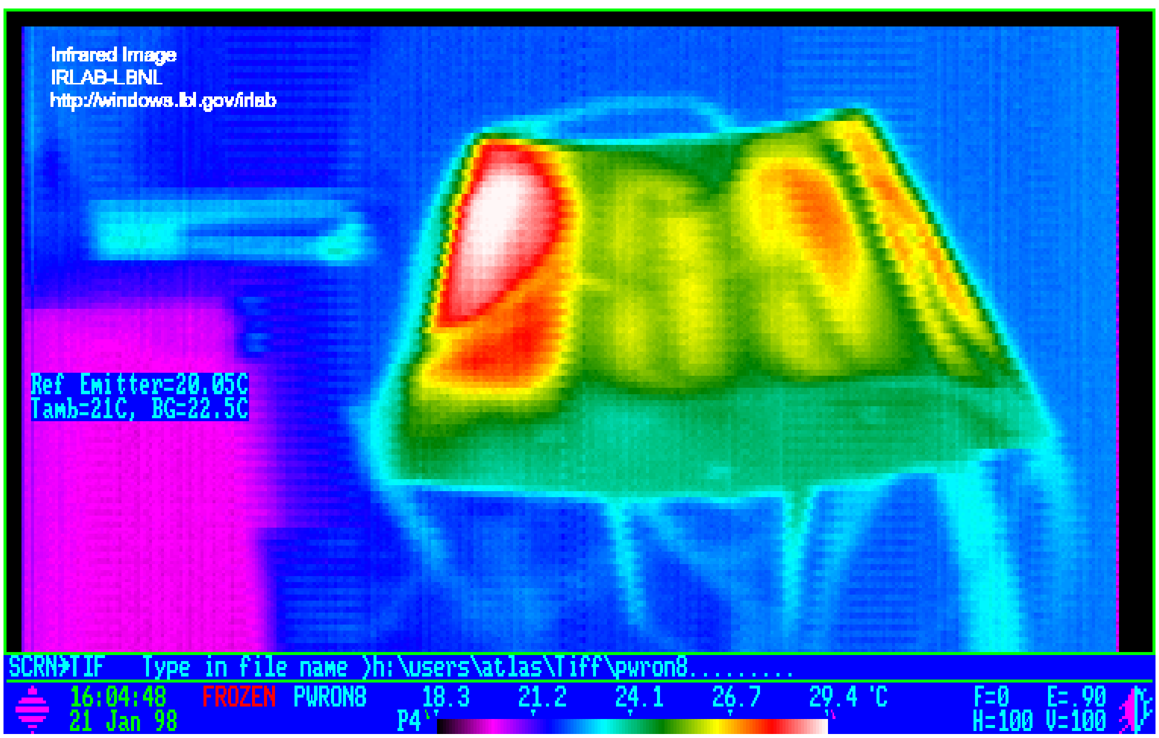
Aluminum Tube Sector 3 was irradiated with a Co60 source to approximately 22.3 Mrads during a period of approximately two months. Infrared images were taken of Aluminum Tube Sector 3 before and after the irradiation. These images are presented below. In general the temperatures of the dummy silicon modules after irradiation are within 1 degree C of the temperatures before irradiation for similar power and coolant flow conditions. The sector meets thermal requirements after irradiation.

Tube: Aluminum 0.20 mm wall thickness
Facings: Carbon-carbon facings 0.50 mm thick
Fill: Reticulated vitreous carbon foam of 0.05 g/cc density
Silicon: 300 micron thick, module size
Facing to Silicon adhesive: CGL7018
Radiation Length: 0.85% in active region
Thickness: 3.11 mm, 3.09 to 3.13 mm

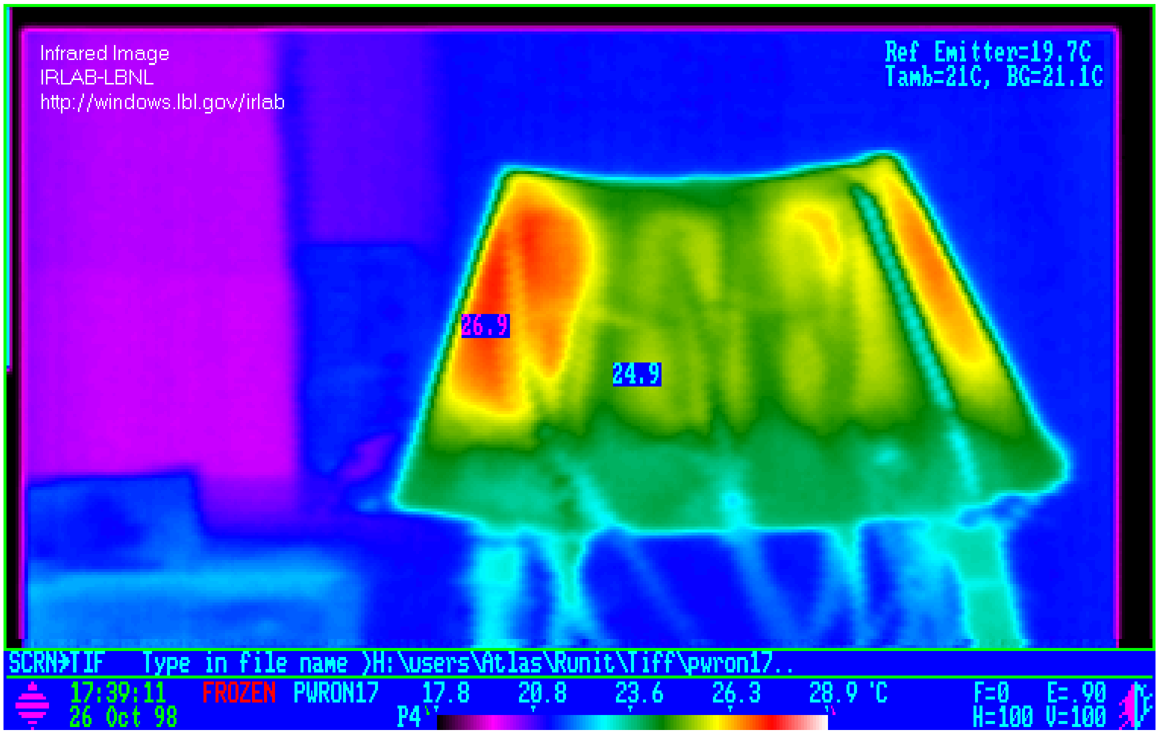
The coolant fluid was water. The ambient temperature was approximately 21 degrees C. The sector is the trapezoidal shaped object in the infrared images.



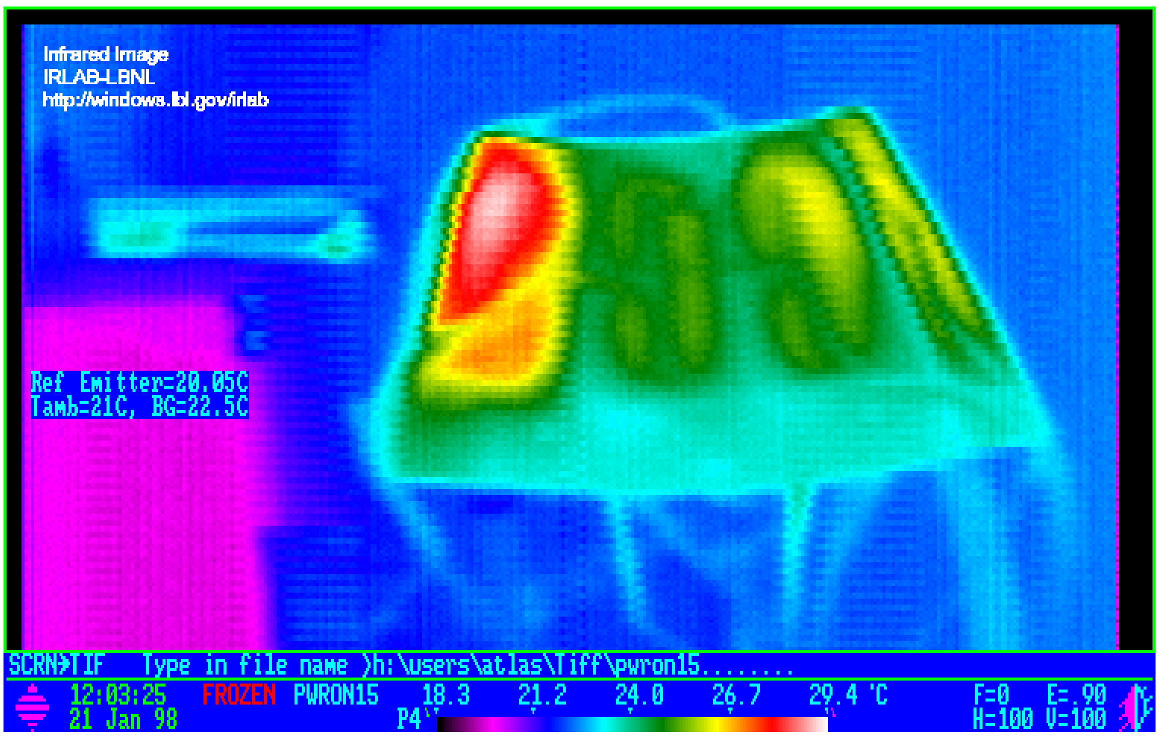
Before irradiation, 36 Watts, coolant flow 8 cc/s, inlet temperature 23.0° C



After irradiation, 36 Watts, coolant flow 8 cc/s, inlet temperature 22.7° C

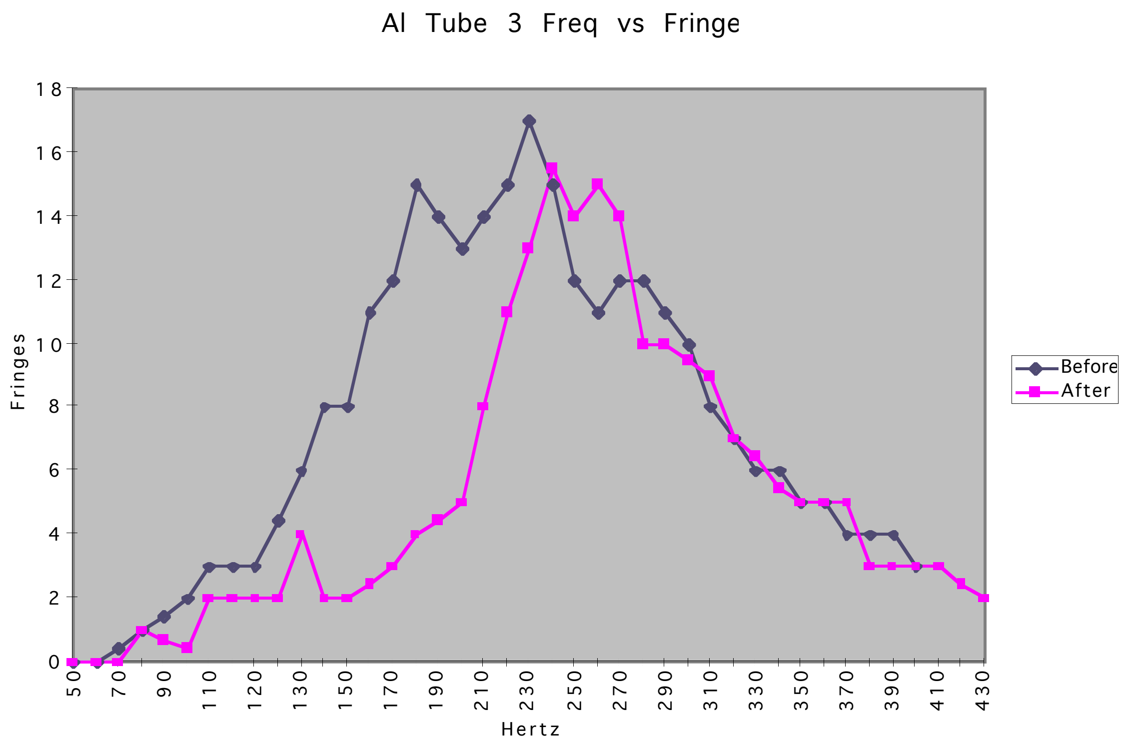


Before irradiation, 36 Watts, coolant flow 17 cc/s, inlet temperature 23.1° C



After irradiation, 36 Watts, coolant flow 15 cc/s, inlet temperature 22.7° C

Aluminum tube sector 3 was tested for vibration frequencies after irradiation using TVH and an acoustic speaker to drive the sector. A similar test was performed before irradiation. The fundamental mode before irradiation was approximately 220 Hz; after irradiation the fundamental mode was approximately 230 Hz. Care must be taken in using the term fundamental frquency as in this case there are a spectrum a response frequencies from 100 Hz to 400 Hz.



Aluminum tube sector 3 was also tested for vibration frquencies using a PZT shaker and TV Holography by Hytec, Inc. The fundamental frequency, a cantilever mode, was found to be approximately 170 Hz using this technique.

Distortion as a function of temperature change was also measured for Aluminum tube sector 3 before and after irradiation. Before irradiation the out-of-plane distortion of aluminum tube sector 3 was approximately 2.0 microns per degree centigrade. The out-of-plane distortion was approximately the same after irradiation.

Conclusion: In general the performance of aluminum tube sector 3 after irradiation is quantitatively the same as before irradiation.

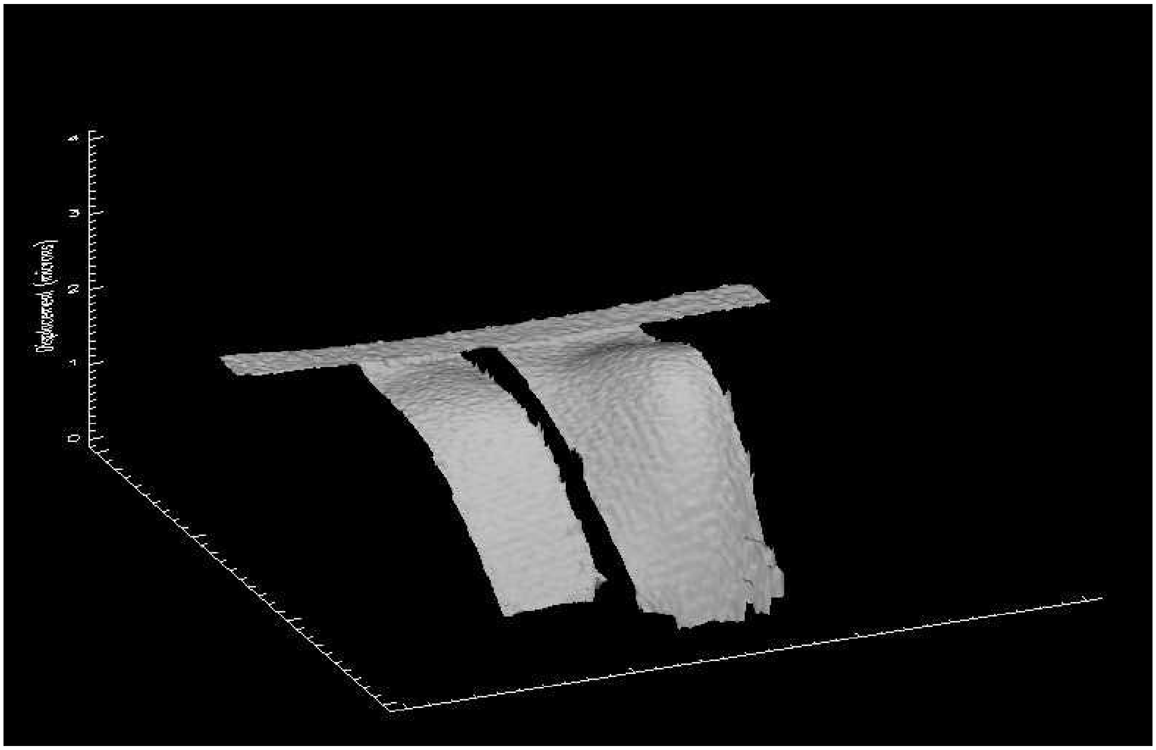
Distortion Tests of Sector Mockups with TV Holography

The purpose of the Aluminum Tube sector mockup tests is to determine the composition of the structure panel for aluminum tube sector 4. Aluminum tube sector 4 is a reduced mass version of aluminum tube sector 3. The first aluminum tube sector 4 showed distortions of approximately 3 microns per degree C at room temperature and approximately 8 microns per degree C at 5 degrees C. These distortions are excessive.

The mockups consist of two small panels that are sandwiches of carbon foam, carbon-carbon facings and silicon. Distortion due temperature changes are measured by TVH. One mockup panel is approximately the size of a single module and has silicon on one side only. The second panel is one and a half times as wide as the first and has silicon on both sides offset by half a module width as in a sector.

An initial mockup with the same construction (as given below) as the original aluminum tube sector 4 was tested and analyzed by Hytec, Inc.

Foam: Reticulated vitreous carbon foam of 0.05 g/cc density
Facings: Carbon-carbon facings 0.3 mm thick
Foam to Facings achesive: 3M VHB F-9460PC Transfer Tape
Silicon: 300 micron thick, module size
Facing to Silicon adhesive: CGL7018



Initial mockup. The above reconstructed image from TVH shows distortions of approximately 1.5 microns for a temperature change of +0.52 degrees C at 21.5 degrees C.

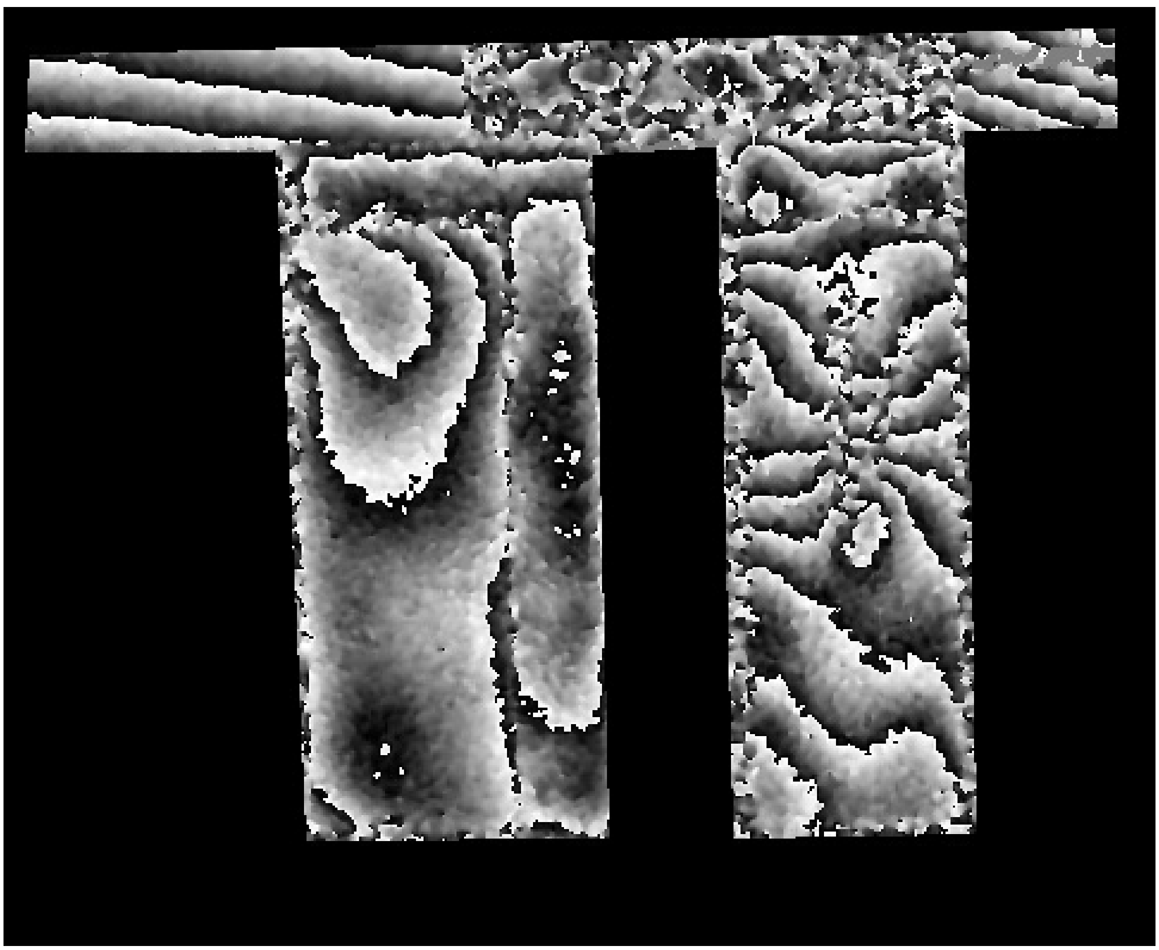
Conclusions from the TVH test and a finite element analysis by Bill Miller of this initial mockup are:

1) The foam core to facing adhesive has too low a shear modulus.
2) Stiffer foam core might help.
3) The facing to silicon adhesive may be too stiff (CGL7018)

Two additional mockups with the differing parameters were constructed by LBNL and tested by Hytec with TV holography. Some TVH results from mockup 3 are shown below.

Mockup 3:

- Foam: Reticulated vitreous carbon foam of 0.10 g/cc density
- Facings: Carbon-carbon facings 0.3 mm thick
- Foam to Facings achesive: Bryte Tech. Cyanate Ester EO11899
- Silicon: 300 micron thick, module size
- Facing to Silicon adhesive: CGL7018



Mockup 3. The above image from TVH shows distortion of the wide panel of approximately 0.9 microns for a temperature change of -13.4 degrees C.

Reticulated Vitreous Carbon foam compression tests:

Foam	Density	Compression modulus		Ultimate Strength	
		x-y	z	x-y	z
RVC	0.05 g/cc	30 N/mm^2	28 N/mm^2	0.3 N/mm^2	0.4 N/mm^2
RVC	0.11 g/cc	69 N/mm^2	15 N/mm^2	0.8 N/mm^2	0.6 N/mm^2
RVC/CVD	0.11 g/cc	159 N/mm^2	123 N/mm^2	1.4 N/mm^2	0.9 N/mm^2

Note: RVC foam is friable. The CVD treatment seems to have reduced this but does not eliminate it. Ultrasonic baths seem to clean the CVD foam. More studies are needed.

The shear modulus of the Bryte Technology cyanate ester sheet adhesive (EO11899) was measured to be greater than 650 N/mm^2.

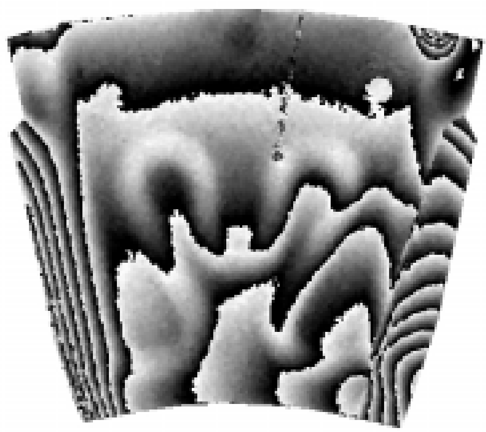
Reconstruction of Aluminum Tube Sector 4

Based on the TVH mockup results and the compression testing of the RVC foam, aluminum tube sector 4 has been rebuilt using the Bryte Technology cyanate ester adhesive and the RVC CVD foam. Aluminum tube sector 4 has 0.3 mm thick carbon-carbon facings. Its radiation length in the active region is 0.52%.

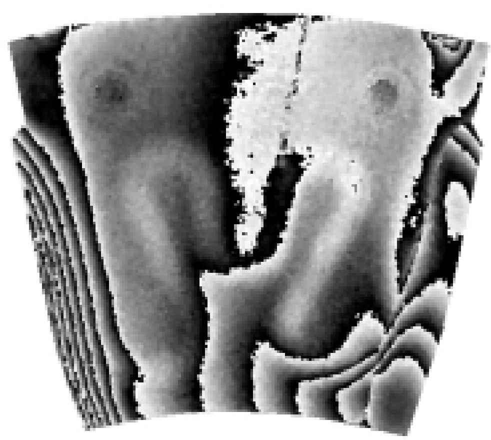
Aluminum tube sector 4 has been tested for vibration frequencies using a PZT shaker and TV Holography by Hytec, Inc. The fundamental frequency, a cantilever mode, was found to be approximately 259 Hz using this technique.

Distortion vs Temperature of rebuilt Aluminum Tube Sector 4.

The below TVH images show distortions for passive temperature change of rebuilt aluminum tube sector 4 without dummy silicon modules.



Distortions for a temperature change of -2.3 degrees C starting at 20.4 degrees C. The distortion of the sector body is 1.25 microns or 0.5 microns per degree C. The distortions of the overhangs are an additional 1.3 and 2.4 microns.



Distortions for a temperature change of -1.5 degrees C starting at 8.0 degrees C. The distortion of the sector body is 1.25 microns or 0.8 microns per degree C. The distortions of the overhangs are an additional 1.6 and 1.1 microns.

Conclusion: The temperature change distortions of the rebuilt sector are reduced from the original sector. Total front face distortion is 1.0 microns per degree at 20 degrees C and 2.0 microns per degree C at 8.0 degrees C. This is acceptable, however overhang distortions should be reduced.

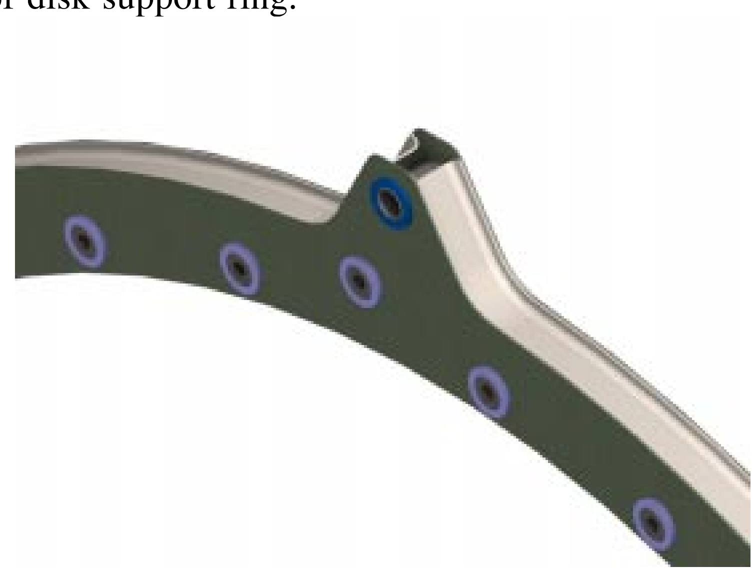
Summary of Sector Progress

ESLI sector:	Stiffness acceptable with 0.43 mm faces Thermal performance of sector 9 acceptable Quality control, dimensions? Probably radiation hard Reduction of radiation length from 0.57% ? Baseline choice
Al Tube sector:	Stiffness marginally acceptable with 0.30 mm faces Thermal performance good Quality control, dimensions good Survives 22.3 MRads Reduction of radiation length from 0.52% ? Aluminum-carbon corrosion ? Backup
C-C tube sectors:	Very stiff with 0.5 mm faces Thermal performance unknown at present Quality control, dimensions probably good Radiation hard ? Radiation length ? Testing of sealed tube ? Backup

Prototype Support Ring for Pixel Disk

A design for the prototype pixel disk support ring has been done by Hytec. Inc. The prototype will be fabricated by Hytec and ESLI in the next few months. The support ring will be used in the fabrication of a complete disk with 12 sectors fabricated by ESLI.

Overview of disk support ring.



Closeup of disk support ring showing mounting points.