LATR Update
March Meeting
March 10, 2021
Brad Benson, Pato Gallardo, Don Mitchell, Matt Hollister
Outline

- Introduction
- Lens design in optics tubes (Pato)
- Cryostat design (Don)
  - Cryogenics and Fast Cooldown (Brad, Matt)
- Next steps and group feedback
  - Optics tube concept and layout
  - Readout mapping
LATR optics tubes design overview

Designing 85x optics tubes for the CD and TMA

Camera layout:
- 3 Silicon lenses
- Alumina wedge for IR blocking and tilt correction

Lens prescription:
- CD: Biconic lenses (for astigmatism)
- TMA: Aspheric lenses (radially symmetric aberrations)
LATR optics tubes design status

- We have built cameras individually optimized, work in progress to group designs to minimize complexity.
- Code to generate TMA grouped camera designs is yielding results (using aspheric lenses), need to fine tune parameters to give a left-right symmetric design.
- Code to generate CD grouped cameras need some development, we have demonstrated ability of optimizing individually, however the groups and minimum number of biconics need to be explored some more.
  - How many biconic lenses?
  - Clockings
LATR optics tubes design challenges

Fabrication complexity:

- Silica wedges have a (per tube) clocking, CD and TMA have unique per-tube clockings and wedge tilt
- Biconic lenses also have a specific per tube clocking

Design complexity:

- The CD with biconic lenses seems more complex to design than the TMA tubes, as there are more degrees of freedom
  - What is the minimum number of biconic lenses that yield a good design?
  - Will the 5 groups work in the CD?
- Drawing creation and specification for all tubes. Interfacing with our CAD experts, also Zemax Optics Builder has tools for this.
LATR optics tubes design next steps

Next steps:

Define camera groups of designs

1. CD: needs some exploration (~month)
2. TMA: close to have a working system

Integrate filters into the Zemax design

Opto-mechanical integration, check for clearances and lens clamping

Drawing creation

System evaluation
LATR Mechanical Design of the Receiver

Don Mitchell
Fermilab
March 10, 2021
Conceptual Model

<10,000 Lbs (4536 kg)
Optics Layout – Preliminary Design from P. Gallardo (85 Tubes)

Here are a few numbers from the center tube model with aspheres:

L1 active diameter: 180mm (though, for optical throughput the more the better)
L2, L3 active diameter: 170mm
FP diameter: 130mm
Stop diameter: 80mm

Positions measured from the focus (here the distance is measured from the facing side of the lens):

L1: 5.08E+01 mm
L2: 2.89E+02 mm
Lyot: 3.74E+02 mm
L3: 5.30E+02 mm
FP: 6.41E+02 mm
Optics Tube Layout

UHMW Front Window (3/16”)

50K Alumina Filter

Lyot Stop, 1k

1K Lens1

4K Absorbing Baffle

4K Lens3

4K Lens2

4K-1K Carbon Fiber Standoff

Heat Sink, 100mk

Focal Plane, 100mk

300-150K Zote Filters (10x ⅛” stack)
Overall concept seems reasonable, but some details still to consider / explore / get-feedback:

- **Magnetic shielding req:**
  - Concept is for 1K A4K shield going back from L1, and Nb spitoon around. Need specs from flowdown.

- **SSA SQUID location:**
  - Do we want SSAs at 1K plate near detectors? Is there room on 1K plate? How would connection to focal plane look?

- **Radial space:**
  - This looks plausible, but once we add all the details for flanges, interfaces, lens mount, and clearances, will it really fit?

- **Detector Module pre-Install?**
  - Plan is for detector modules to be installed in-situ in the cryostat.
Conceptual Model: Heat Shields

109 mm (Front Plate to Lens 1)
Proposed Assembly Plan: Installation Proposal

Fixed assembly fixture for the construction of the cold-mass
Proposed Assembly Plan: Add Insulation around Coldmass

Wrap MLI around cold-mass layers

Slide vessel over cold-mass and connect to cold-mass supports
Readout Ports

20 Ports:
- 24, 100 micro-D pin connectors per port
- 480 Circuit Boards
Receiver Support

F10151659.sim1_A: Mechanical Analysis of Support Frame Result
Subcase - Static Loads 40deg, Static Step 1
Displacement - Nodal, Magnitude
Min: 0.000, Max: 0.781, Units = mm
Deformation: Displacement - Nodal Magnitude
Animation Frame 1 of 8
LATR Cryostat Mechanical Design Future Work

• Iterate design of the support structure
• Modal analysis
• Engineer:
  – Supports for cold-mass
  – Cooldown calculations
  – Vessel calcs per ASME B&PV code
  – Iterate on the heat shield designs – assembly issues
• Engage others to integrate the design with other systems
  – Cryogenic
  – Vacuum
  – Optics
• ...
Numbers based on scaling from the DSR design to reflect the updated baseline design (major changes being the elimination of the 80-K filters and the move to 85 smaller optics tubes)

Cooling capacity figures assume 2 x PT420 coolers on the main instrument and a BlueFors SD400 dilution refrigerator cooling the 1-K and 100-mK stages.

- I.e., assumes PT420 on SD400 is not used to cool main cryostat

No account is being made for temperature gradients between the cryostat stages and the coolers, so the “useable” capacity is going to be lower.

- E.g., above 40K stage numbers assume components are heat sunk at 50K, but need to ensure gradient requirements are also met

<table>
<thead>
<tr>
<th>Stage</th>
<th>Support</th>
<th>Radiative</th>
<th>Optical</th>
<th>Readout</th>
<th>Total</th>
<th>Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>40 K</td>
<td>10 W</td>
<td>16 W</td>
<td>75 W</td>
<td>30 W</td>
<td>131 W</td>
<td>120 W</td>
</tr>
<tr>
<td>4 K</td>
<td>860 mW</td>
<td>10 mW</td>
<td>14 mW</td>
<td>1.53 W</td>
<td>2.54 W</td>
<td>4 W</td>
</tr>
<tr>
<td>1 K</td>
<td>5 mW</td>
<td>0.1 mW</td>
<td>6.46 mW</td>
<td>0.87 mW</td>
<td>12.4 mW</td>
<td>25 mW</td>
</tr>
<tr>
<td>100 mK</td>
<td>69 μW</td>
<td>0.1 μW</td>
<td>0.5 μW</td>
<td>74 μW</td>
<td>144 μW</td>
<td>400 μW</td>
</tr>
</tbody>
</table>

Cooling capacity figures assume 2 x PT420 coolers on the main instrument and a BlueFors SD400 dilution refrigerator cooling the 1-K and 100-mK stages.
Fast Cooldown System

Large cryogenic mass of instruments will require a method to cool more rapidly than the on board cryocoolers alone.

Room temperature compressor circulates helium through a counterflow heat exchanger, with further cooling provided by one or more single stage cryocoolers.

Cold fluid line connected to internal cryostat structures, removing heat from the distributed network.

Similar systems implemented on large particle physics experiments (SuperCDMS, CUORE…).
Cooldown Estimates

Mass estimates based on conceptual model, materials other than the primary are neglected.

<table>
<thead>
<tr>
<th>Stage</th>
<th>Mass / kg</th>
<th>Primary Material</th>
<th>Heat Capacity (300 K to 40 K)</th>
<th>Heat Capacity (40 K to 4 K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>40 K</td>
<td>260</td>
<td>Aluminum</td>
<td>44 MJ</td>
<td>n/a</td>
</tr>
<tr>
<td>4 K</td>
<td>500</td>
<td>Aluminum</td>
<td>85 MJ</td>
<td>115 kJ</td>
</tr>
<tr>
<td>1 K</td>
<td>500</td>
<td>Aluminum</td>
<td>85 MJ</td>
<td>115 kJ</td>
</tr>
<tr>
<td>100 mK</td>
<td>450</td>
<td>Copper</td>
<td>36 MJ</td>
<td>87 kJ</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Total time 300 K to 40 K</th>
<th>Total time 40 K to 4 K</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 days</td>
<td>2 days</td>
</tr>
</tbody>
</table>

Assuming lumped heat capacities cooled by a 10 g/s fluid flow for 300 K to 40 K, followed by cooling by 2 x PT420 coolers (4 K stage) or 1 x PT420 (1 K and 100 mK stages).
Cryogenic Further Work

• Refine thermal budgets at each stage, including budgets for temperature gradients across structures and between structures and coolers

• Dynamic thermal analysis for cool down, and refinement of the fast cooldown system design
Next Steps for LATR

- **Lens design for optics tubes**
  - Develop working design for full 85-tubes for both TMA and CD designs, including sensible grouping for design

- **LATR cryostat design**
  - Adding detail generally working from vacuum window to back, next big steps are setting on concepts for:
    - Optics tube mechanical design concept
    - Stage mounts and FEA
    - Readout wiring and heat sinking is going to be very complex

- **Cyogenics**
  - Develop more realistic and detailed thermal model to better estimate heat load and gradients across stages
  - Develop requirements for any fast cooldown system
# LAT - Optical Elements and Requirements

<table>
<thead>
<tr>
<th></th>
<th>Temp.</th>
<th>Baseline</th>
<th>AR coating</th>
<th>Alternatives</th>
<th>Count per LAT Tube</th>
<th>Key requirements (roughly ordered in challenge)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vacuum Window</td>
<td>300K</td>
<td>UHMW</td>
<td>x-teflon</td>
<td>HDPE, HMPE</td>
<td>1</td>
<td>Scattering, absorption, reflection, mechanical robustness</td>
</tr>
<tr>
<td>Warm IR-Blockers</td>
<td>300K-50K</td>
<td>Zotefoam</td>
<td>-</td>
<td>Thin film metal</td>
<td>10 or 8 layers, ⅛&quot; each</td>
<td>Scattering, absorption, reflection, thermal cycle robustness</td>
</tr>
<tr>
<td>Mid-IR Filter</td>
<td>50K-40K</td>
<td>Alumina</td>
<td>Plastic, epoxy, spray, laser</td>
<td>HDPE</td>
<td>1 (6-mm thick)</td>
<td>Scattering, absorption, reflection, thermal cycle robustness</td>
</tr>
<tr>
<td>Lenses</td>
<td>4K, 1K, 1K</td>
<td>Silicon</td>
<td>Metamaterial</td>
<td>HDPE, Alumina</td>
<td>3</td>
<td>Reflection, absorption (freq dep), thermal performance, robustness</td>
</tr>
<tr>
<td>Cold Stop and Baffling Elements</td>
<td>4K-1K</td>
<td>Plastic Absorber</td>
<td>-</td>
<td>Carbon Loaded Foam</td>
<td>~5</td>
<td>Absorption, thermal performance</td>
</tr>
<tr>
<td>Cold-IR Filter</td>
<td>1K</td>
<td>None</td>
<td>-</td>
<td>Nylon</td>
<td>-</td>
<td>Scattering, in-band transmission, submm rejection, reflection</td>
</tr>
<tr>
<td>Edge Filter (at Lyot)</td>
<td>1K</td>
<td>Metal Mesh Low Pass Edge</td>
<td>-</td>
<td>Nylon</td>
<td>1</td>
<td>Scattering, in-band transmission, above-band rejection, reflection</td>
</tr>
<tr>
<td>[ Coupling Elements to Detectors ]</td>
<td>100mK</td>
<td>Feedhorns, etc.</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Edge taper, polarization fidelity</td>
</tr>
</tbody>
</table>
Baseline Filter Config

- Vacuum Window (300K, UHMW):
  - 3/16” thick (4.76-mm)
- Warm IR-blockers (300K-50K, Zotefoam):
  - Foam stack of 10 filters, 5x 0.34” = 1.70” thick (43.2-mm)
- Mid IR filter (50K-40K, Alumina):
  - 6-mm thick
- Lenses (3x lenses: 4K, 1K, 1K; Silicon)
  - 1-m long tube: maximum 4-mm thermal contraction
- Cold Stop & Baffling Elements (4K-1K, carbon-loaded plastic)
- Edge Filter (1K, Metal Mesh LPF):
  - ⅛” thick (3-mm)
SPT-3G IR Filtering

- Filtering config similar to BA, except with a 3rd 4K lens and LPF at Lyot stop (see https://arxiv.org/abs/1809.00032)

- SPT-3G first stage head runs at 30 K, indicates <=5-10 W of power coming through window.

- Alumina IR filter runs at 40-K with <=0.5K gradient across filter.

Credit: BICEP collab
Window Loading and Zotefoam IR Filters

- For SPT4, we should experiment with other types of Zotefoam with smaller cell size.
- Loss in CMB bands is expected to be scattering dominated, when cell size approaches wavelength. Scattering ~ (\(\lambda/d\))^6.
- Scattering loss might not be negligible at 1mm for HD-30, e.g., for PPA-30 (0.3-mm cell size) CSO measurements by Kooi (1998) suggests 4% loss at 300 GHz from 1” thick zotefoam.
- LD-24 (perhaps MP-24) appear to be an acceptable IR filter replacement with smaller cell size:

<table>
<thead>
<tr>
<th>Cell size (mm)</th>
<th>Typ.</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>HD-30</td>
<td>0.4</td>
<td>0.25</td>
<td>0.7</td>
</tr>
<tr>
<td>LD-24</td>
<td>0.3</td>
<td>0.15</td>
<td>0.4</td>
</tr>
<tr>
<td>MP-24</td>
<td>0.2</td>
<td>0.1</td>
<td>0.3</td>
</tr>
</tbody>
</table>

Credit: BICEP collab
Follow lens mount scheme from Thorton et al. 2008
(https://act.princeton.edu/sites/act/files/halpern_spie_7020_70201r.pdf)
Spacing between top of front plate to front of first 4K lens

- Vacuum window: 3/16” thick UHMW (not included in total)
- Front Plate: 1.5” thick + 0.6” deflection
- Zotefoam filter stack: 1.70” thick
- 300-50K space: 0.25”
- 50K filter: 0.25” thick (6-mm)
- 50-4K space: 0.25”
- 4K optics tube contraction: 0.16” (4-mm)
- Total distance (top of front plate to top of first 4K lens: 4.71” (=2.1” + 1.7” + 0.75” + 0.16”)

LAT: Window to 4K Lens spacing
Coldmass Layout
Conceptual Model
Conceptual Model: 1k Shield Connection to 4k Shield