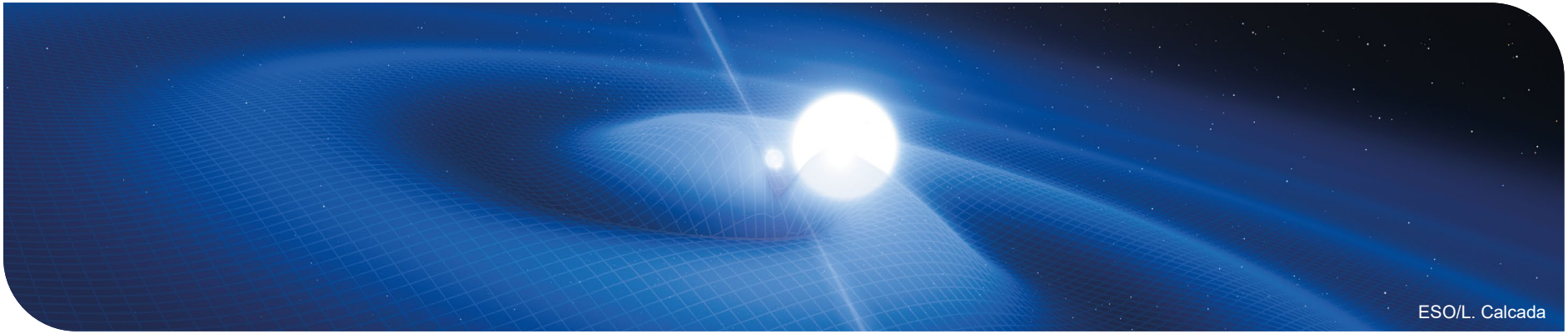
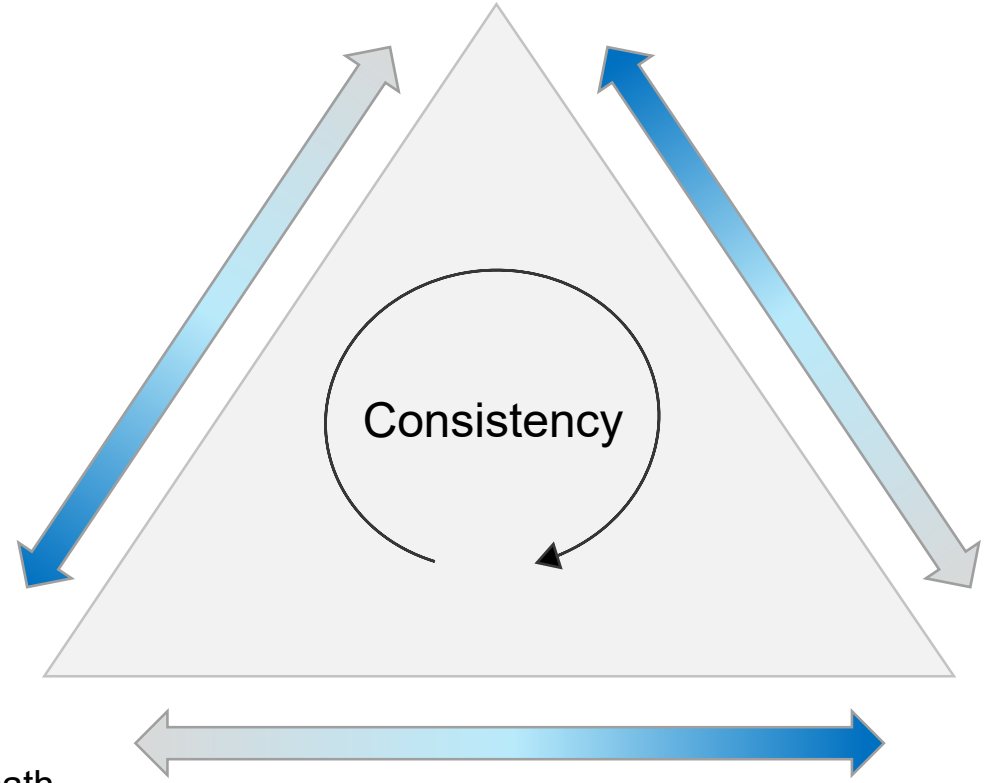
Part II on Update of STN modelling for the cryogenic payload of ET-LF



Suspension Thermal Noise (STN)

- ET Sensitivity curve



Thermal Design

- Heat extraction path
- Interfaces & Temperatures

Mechanical Design

- Materials
- Dimensions

Outline

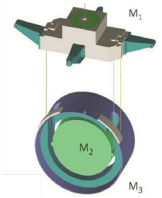
- Inconsistencies in current ET-LF Payload design
- Cooling concepts
- Impact of Test mass suspension design on STN
- Impact of Marionette suspenion design on STN
- Summary of updated Payload design parameters

Inconsistencies in Current ET-LF Payload Design

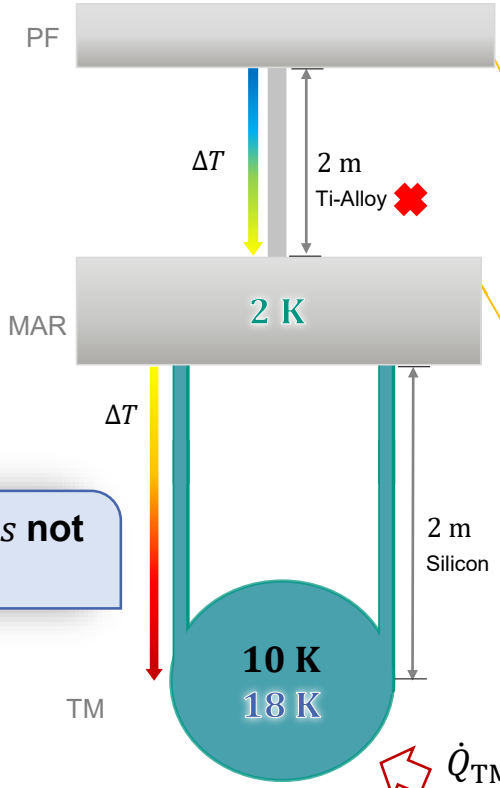
ET-LF Payload

	Marionetta	Recoil Mass	Mirror
Masses for ETDLF (kg)	422	211	211
Wire Diameter (mm)	3	3	3
Wire length (m)	2	2	2
Wire Material	Ti6Al4V	Silicon	Silicon
Loss Angle	10^{-5}	10^{-8}	10^{-8}
Temperature (K)	2	10	10

Source: ET Design Report (2011)



Interface temperatures and ΔTs not yet consistently implemented



Heatlink on PF

- Cooling interface on PF completely ineffective due to Ti-Alloy fiber [2]
- Consideration of ΔTs in fibers

How? $T_{\mathrm{MAR}} = 10\ \mathrm{K}$ with heatlink connection to heatsink?

- No! → Heatlink on MAR not possible due to STN, cooling interface muss be on PF [1]

Heatlink on MAR

$\dot{Q}_{\mathrm{TM,total}} = 0.1\ \mathrm{W}$

$\dot{Q}_{\mathrm{TM,total}} = 0.5\ \mathrm{W}$

Conservative value due to size and complexity of ET-LF cryostat

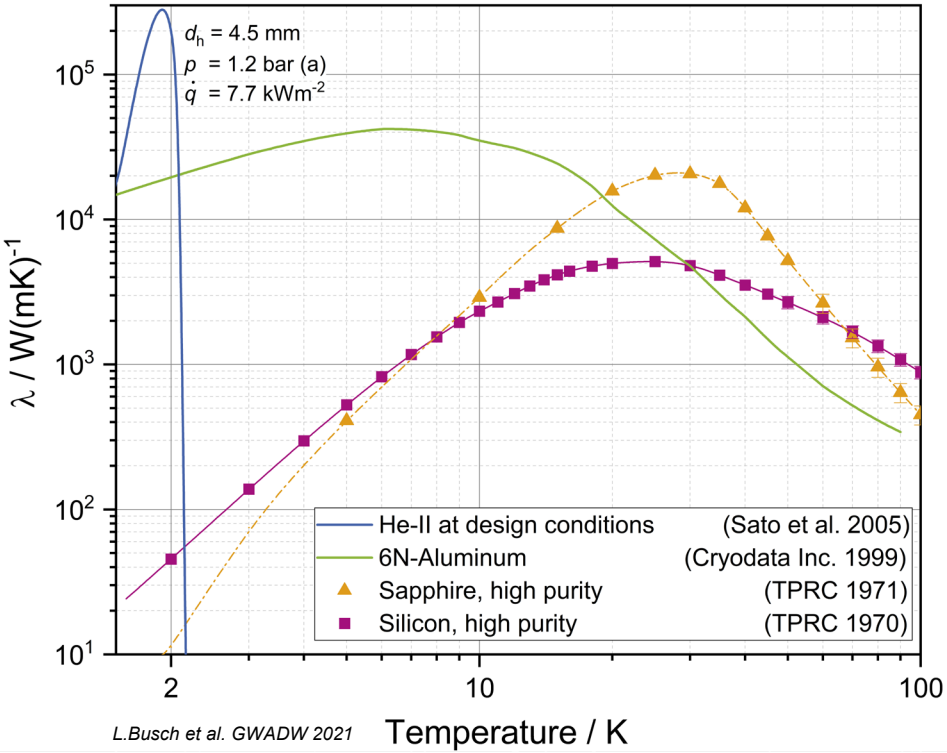
[1] P.Puppo (2022) - ET-D: FEA models for the ET Payload: status and preliminary results
[2] L.Busch (2022) - ET-D: Payload cooldown studies

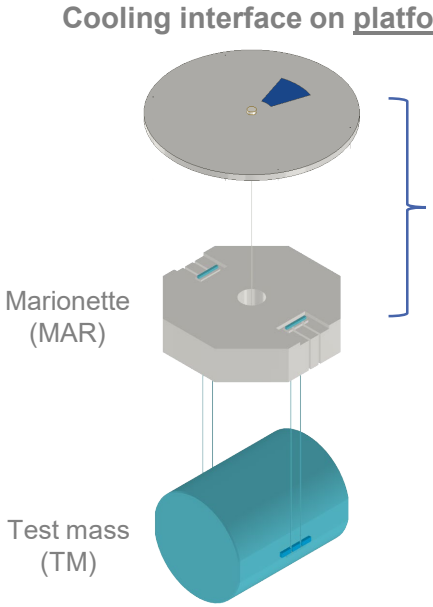
Conclusions I

- $\dot{Q}_{\mathrm{TM,total}} = 0.5\ \mathrm{W}$ as conservative value due to size and complexity of ET-LF cryostat
- T_{TM} defined from $\dot{Q}_{\mathrm{TM,total}}$ and T_{MAR}
- T_{MAR} dependant on cooling concept, $2\ \mathrm{K}$ not achievable via solid conduction cooling
- Cooling interface should be implemeted on the platform (PF) due to STN
- Heat extraction path for ET-LF payload to be described correctly

ET-LF payload cooling concepts

Thermal conductivity

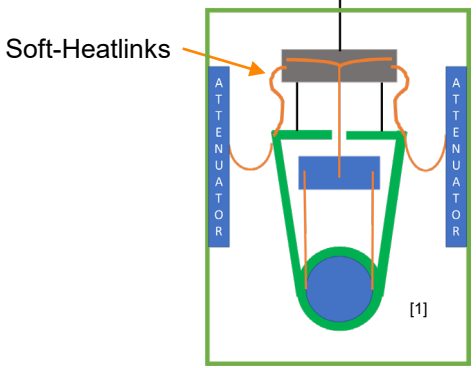


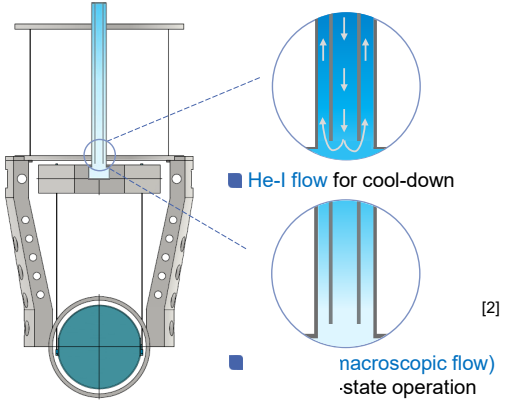


Thermal conductivity of Marionette suspension crucial for cooling!

ET-LF Payload Cooling concepts

- Detector cooling with PT cryocoolers
  - **Sapphire or silicon** marionette suspension fiber
  - Cooling interface: Soft-Heatlinks
  - $T_{\mathrm{MAR}} \approx 14 - 20\ \mathrm{K}$
  - R&D @ INFN Roma
- Detector cooling with superfluid He-II
  - **He-II-filled** marionette suspension tube
  - Cooling interface: He-supply capillaries
  - $T_{\mathrm{MAR}} \approx 2\ \mathrm{K}$
  - R&D @ Karlsruhe Instiute of Technology





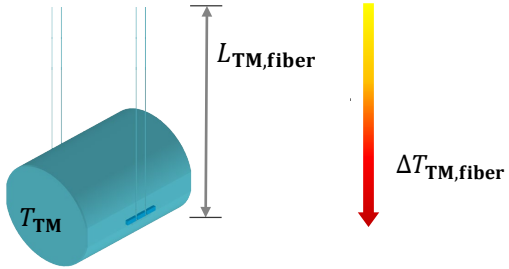
[1] P.Puppo (2022) - FEA models for the ET Payload: status and preliminary results
[2] X. Koroveshi (2022) - Feasibility of He-II suspensions based on thermal noise modelling

STN modelling

Impact of Test mass suspensions

Test mass suspension

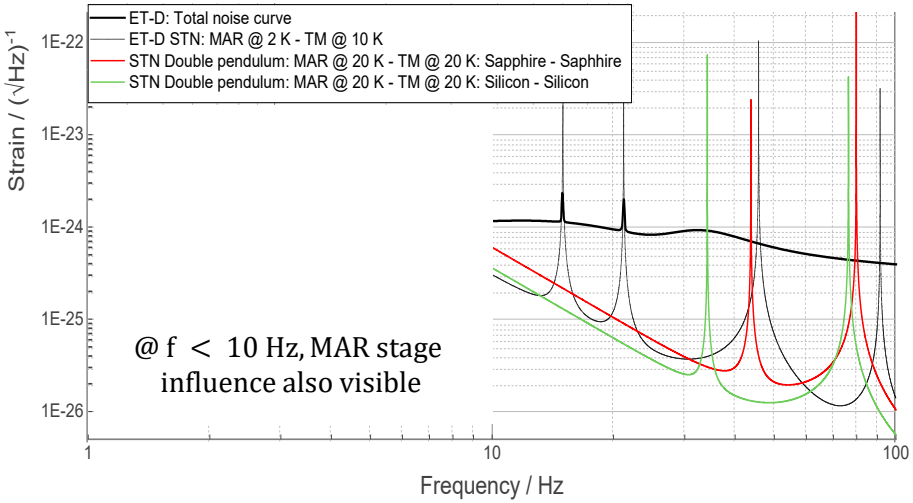
- Material choice: Sapphire or Silicon



$L_{\mathrm{TM,fiber}}$	$d_{\mathrm{TM,fiber}}$
STN @ LF : $L \uparrow$	Mechanical structure
Manifacture of fibers : $L \downarrow$	$(SF = 3)$: $d \uparrow$
$\Delta T_{\mathrm{TM,fiber}}$: $L \downarrow$	STN @ LF : $d \downarrow$
Reduced cryostat height : $L \downarrow$	Efficient heat extraction : $d \uparrow$

Possible parameters for mirror suspensions:

- ✓ $T_{\mathrm{TM}} = 14 - 20\ \mathrm{K} = f(\dot{Q}_{\mathrm{TM,total}}, \text{cooling concept})$
- ✓ $M_{\mathrm{TM}} = 211 - 220\ \mathrm{kg}$
- ✓ $L_{\mathrm{TM,fiber}} = 1.2\ \mathrm{m}$
- ✓ $d_{\mathrm{TM,fiber}} = 2.3 \text{ or } 3.0\ \mathrm{mm}$



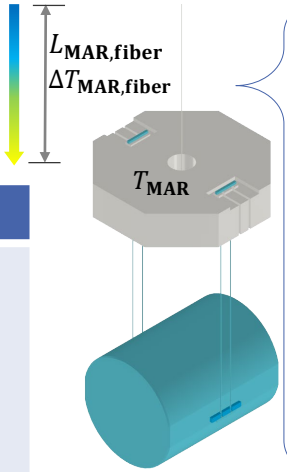
STN modelling

Impact of Marionette suspension

Marionette suspension

- Possible design based on **cooling concept**:
  - Sapphire or silicon fiber ($T_{\mathrm{MAR}} \approx 20$ K)
  - He-filled suspension tube ($T_{\mathrm{MAR}} \approx 2$ K)

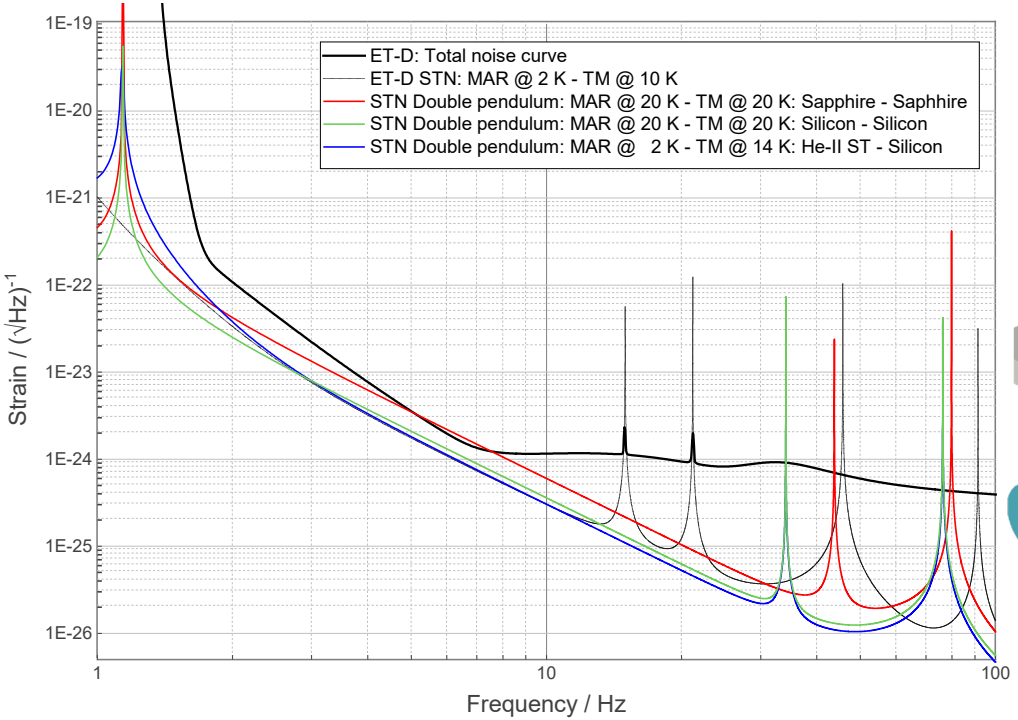
$L_{\mathrm{MAR,fiber}}$	$d_{\mathrm{MAR,fiber}}$
STN @ LF : $L \uparrow$	Mechanical structure
Manifacture of fibers : $L \downarrow$	$(SF = 3)$: $d \uparrow$
$\Delta T_{\mathrm{MAR,fiber}}$: $L \downarrow$	STN @ LF : $d \downarrow$
Reduced cryostat height : $L \downarrow$	Efficient heat extraction : $d \uparrow$

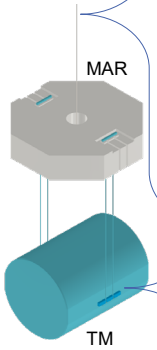


Sapphire or Silicon marionette fiber:
- ✓ T_{MAR} @ 20 K ($\Delta T_{\mathrm{fibers}}$ **to be implemented**)
- ✓ $M_{\mathrm{MAR}} = 100 - 110$ kg
- ✓ $L_{\mathrm{MAR,fiber}} = 1.0$ m
- ✓ $d_{\mathrm{MAR,fiber}} = 5.6$ or 7.0 mm

He-II-filled marionette suspension tube:
- ✓ T_{MAR} @ 2 K
- ✓ $M_{\mathrm{MAR}} = 100 - 110$ kg
- ✓ $L_{\mathrm{MAR,fiber}} = 1.0$ m
- ✓ $d_o = 8.3$ mm, $d_{\mathrm{i}} = 4.1$ mm, $s_o = 0.25$ mm

STN with updated ET-LF payload parameters





Possible ET-LF suspension design parameters

Concept: Sapphire or Silicon marionette fiber:

- ✓ T_{MAR} @ **20 K** ($\Delta T_{\mathrm{fibers}}$ **to be implemented**)
- ✓ $L_{\mathrm{MAR,fiber}} = \mathbf{1.0\ m}$
- ✓ $d_{\mathrm{MAR,fiber}} = \mathbf{5.6\ or\ 7.0\ mm}$
- ✓ $M_{\mathrm{MAR}} = \mathbf{100\ -110\ kg}$

Concept: He-II-filled marionette suspension tube:

- ✓ T_{MAR} @ **2 K**
- ✓ $L_{\mathrm{MAR,fiber}} = \mathbf{1.0\ m}$
- ✓ $d_{\mathrm{o}} = \mathbf{8.3\ mm}$, $d_{\mathrm{i}} = 4.1\ \mathrm{mm}$, $s_{\mathrm{o}} = 0.25\ \mathrm{mm}$
- ✓ $M_{\mathrm{MAR}} = \mathbf{100\ -110\ kg}$

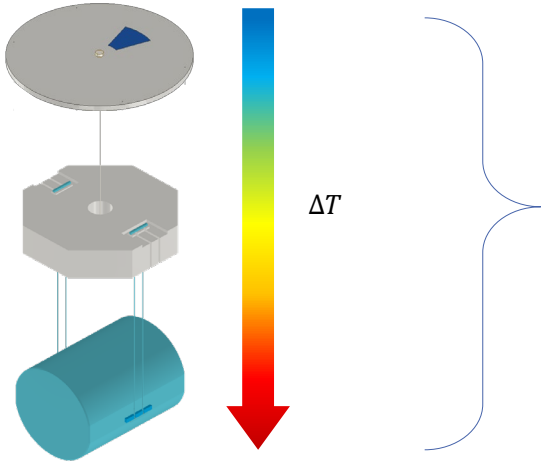
Mirror/Test mass suspensions:

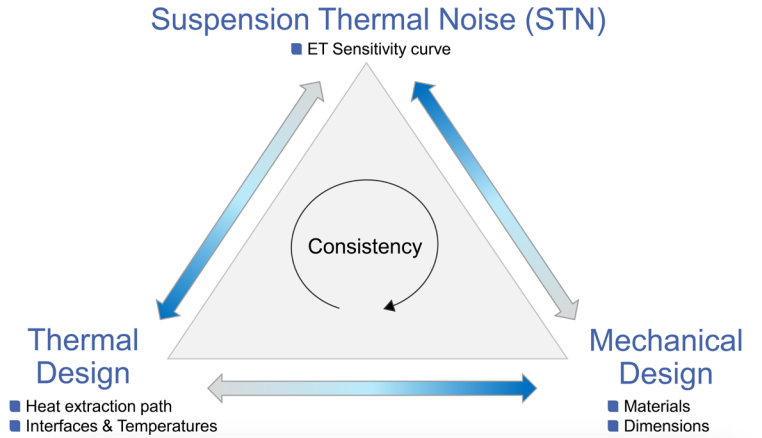
- ✓ Sapphire or silicon
- ✓ $T_{\mathrm{TM}} = \mathbf{14-20\ K} = f(\dot{Q}_{\mathrm{TM,total}}, \mathrm{cooling\ concept})$
- ✓ $L_{\mathrm{TM,fiber}} = \mathbf{1.2\ m}$
- ✓ $d_{\mathrm{TM,fiber}} = \mathbf{2.3\ or\ 3.0\ mm}$
- ✓ $M_{\mathrm{TM}} = 200-220\ \mathrm{kg}$

Conclusions & Outlook

- Two concepts for marionette suspension based on cooling concept
- One concept for mirror suspension

- Implementation of heat extraction path with corresponding temperatures in STN model essential:
  - Heat sink
    - $\Delta T_{\text{thermal links}}$
  - Platform
    - $\Delta T_{\text{MAR suspension}}$
  - Marionette
    - $\Delta T_{\text{TM suspension}}$
  - Mirror





- Implementation of conservative loss angles

To be updated in each design iteration

Thank you for your attention

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