CO_2 Freezer Testing

Presented by:

Malay Shah

malay.g.shah@nasa.gov

Jared Sass, Marty Grashik, Rene Formoso, Anne Meier, Jared Berg, Paul Hintze, Jon Bayliss, Rodolphe Carro, Arun Arora, Jonathon Gleeson

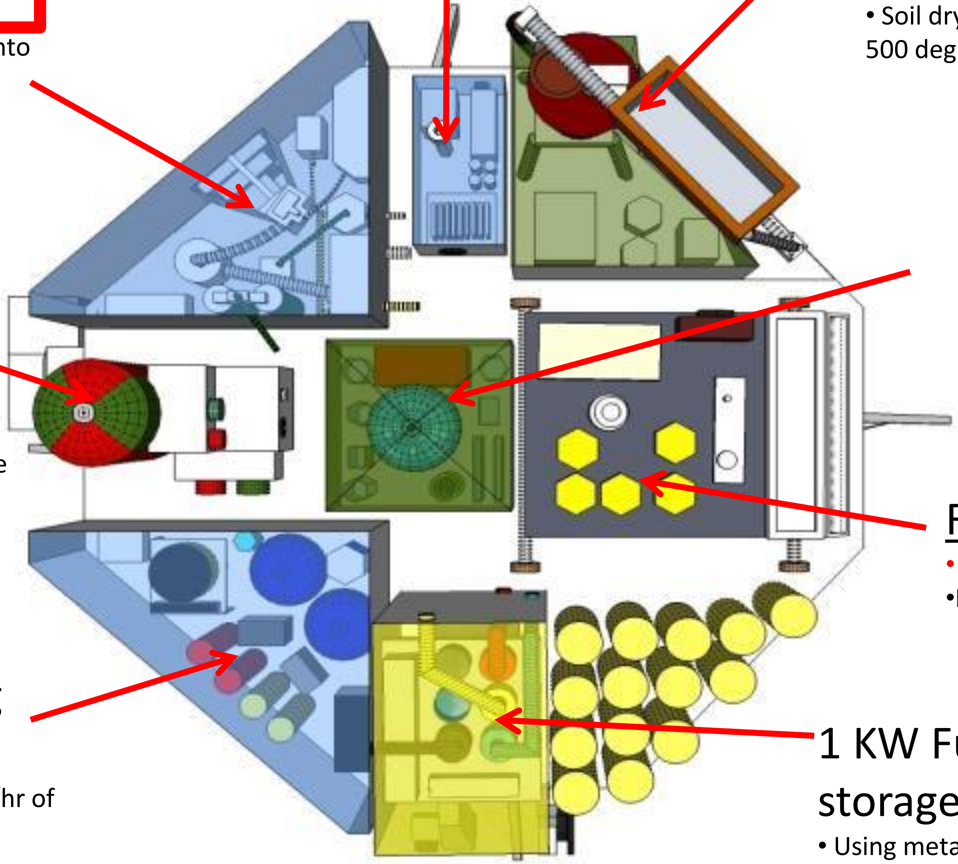
Background

Atmospheric Processing Module:
- CO_2 capture from simulated Mars atmosphere (KSC)
- Sabatier converts H_2 and CO_2 into Methane and water (KSC)

C&DH/PDU Module: (JSC)
- Central executive S/W
- Power distribution

Soil Processing Module:
- Soil Hopper handles 30 kg (KSC)
- Soil dryer uses CO_2 sweep gas and 500 deg C to extract water (JSC)

Liquefaction Module: (TBD)
- Common bulkhead tank for Methane and Oxygen liquid storage

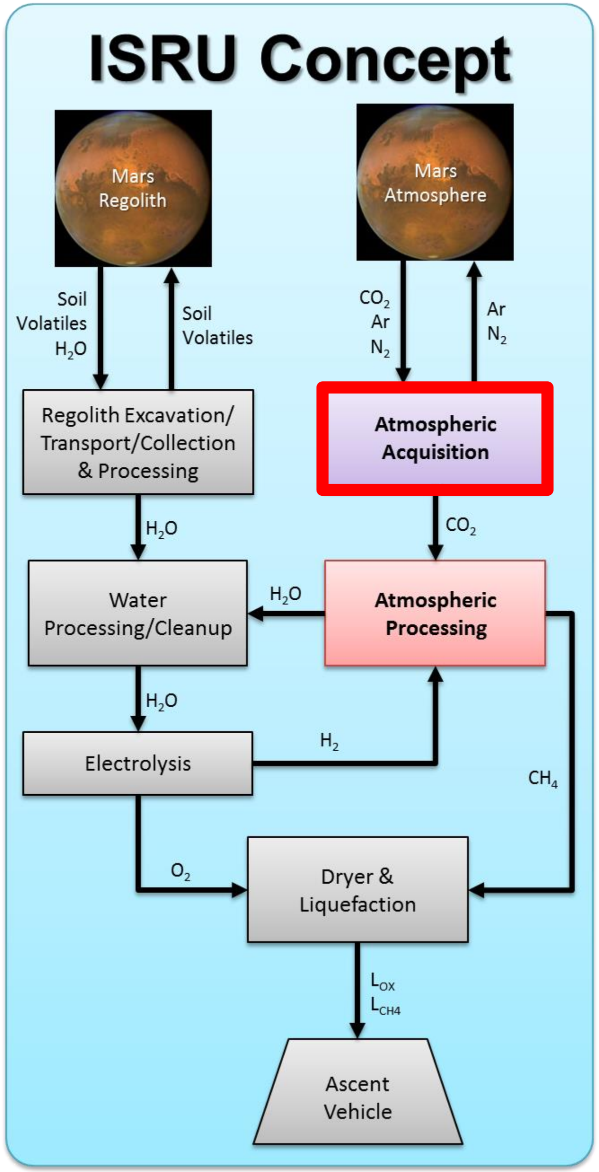


Water Cleanup Module: (KSC)
- Cleans water prior to electrolysis
- Provides clean water storage

RASSOR 2.0: (KSC)
- Excavator
- Provides feed to Soil Dryer

Water Processing Module: (JSC)
- Currently can process 520g/hr of water (max 694 g/hr)

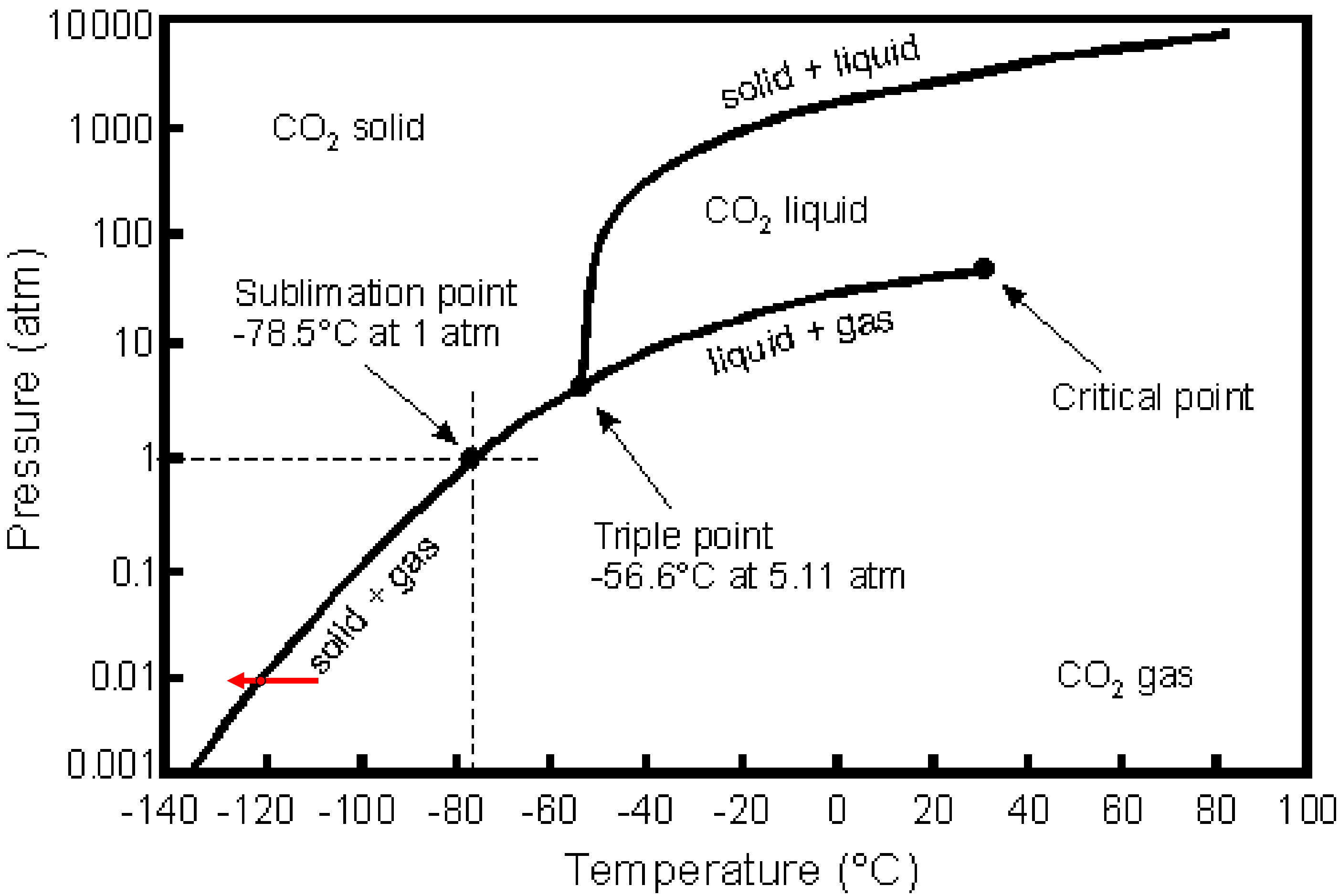
1 KW Fuel Cell and consumable storage (JSC & GRC)
- Using metal hydride for H storage due to available
- 1 KW No Flow Through FC (GRC)
- 10 KW main power FC not shown (JSC)



Concept

- Capture only CO_2 by freezing
  - Ar & N_2 pass through
- Sublimate and store for future use

- Freezing Conditions:
  - P = 7 Torr
  - T < 153 K (-120.15 ºC)



Pressure-Temperature phase diagram for CO_2.

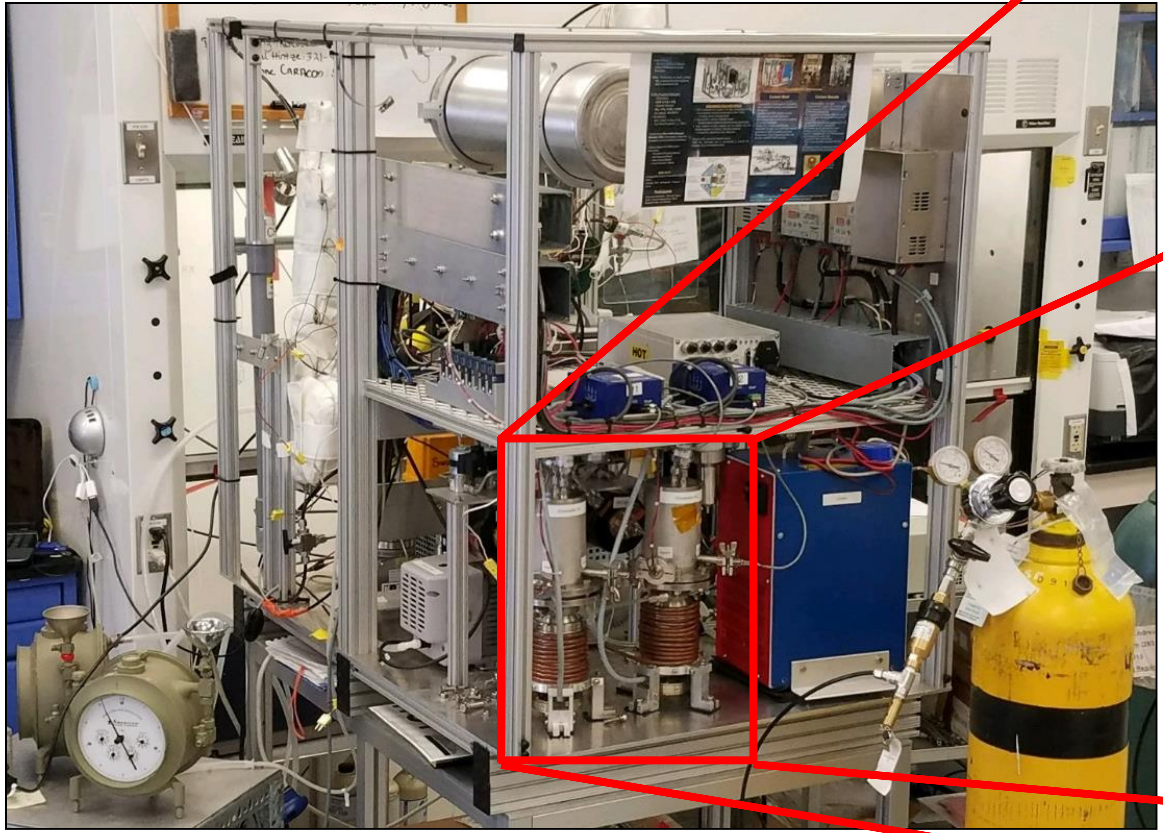
CO_2 Capture Requirement

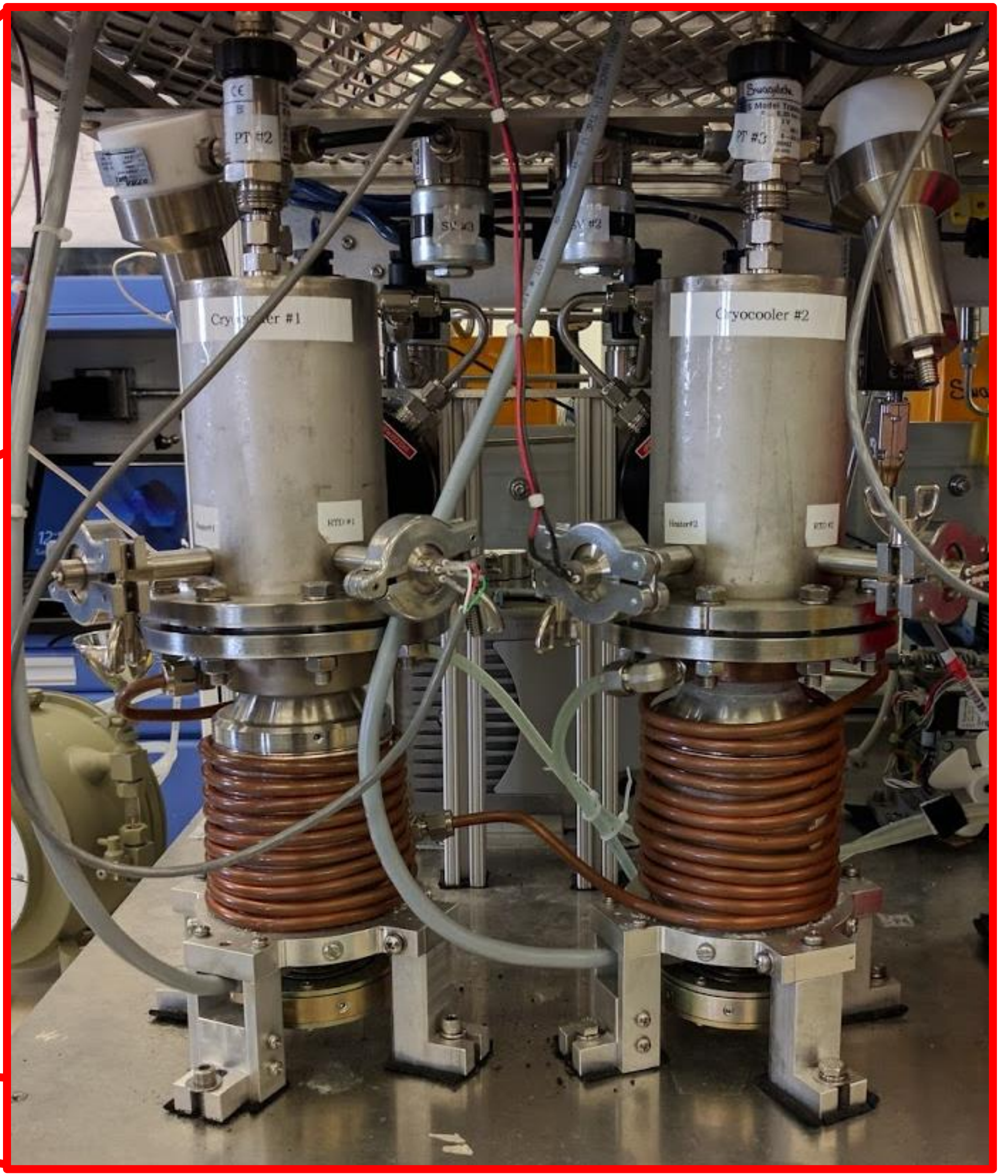
- CO_2 accumulation rate requirements based on fuel production
- Small Scale:
  - Total of 0.088 kg/hr required for CH_4 production
  - Cold heads running at optimal cycle time yielded around 0.054 kg/hr per cryocooler
  - Minimum 2 cryocoolers running in parallel
- Full Scale:
  - Targeting 1.1 kg/hr per cryocooler

Production Method	O_2 Production Rate (kg/hr)	%Conversion/ %Recycling	Required CO_2 Supply Rate (kg/hr)	Minimum # of Cryocoolers
O2 only, SOE	1.1	50 / 90	3.33	3
O2 only, SOE	1.1	50 / 0	6.1	6
Methane/Oxygen, Sabatier/Electrolysis	1.34	95 / 0	0.97	1

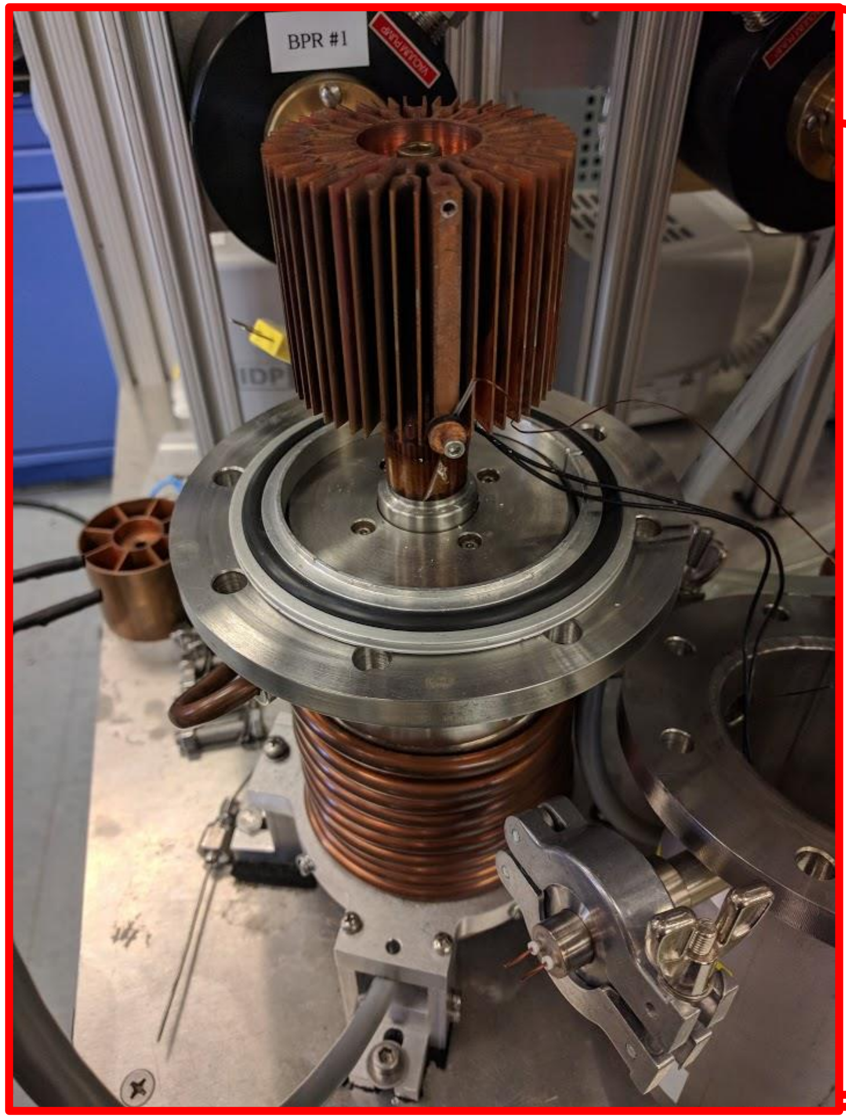
Concept – Small Scale

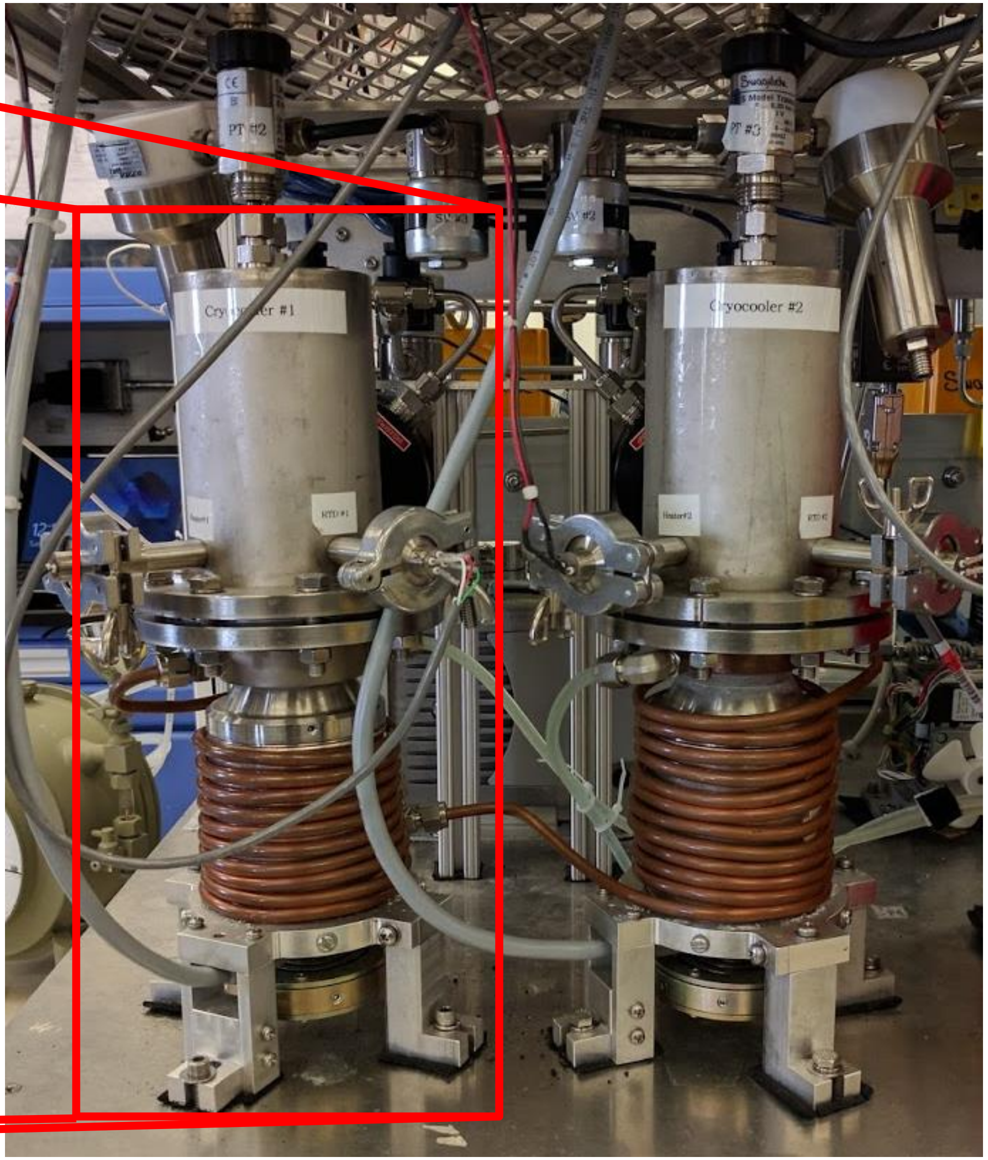
- Freezing accomplished by cryocoolers



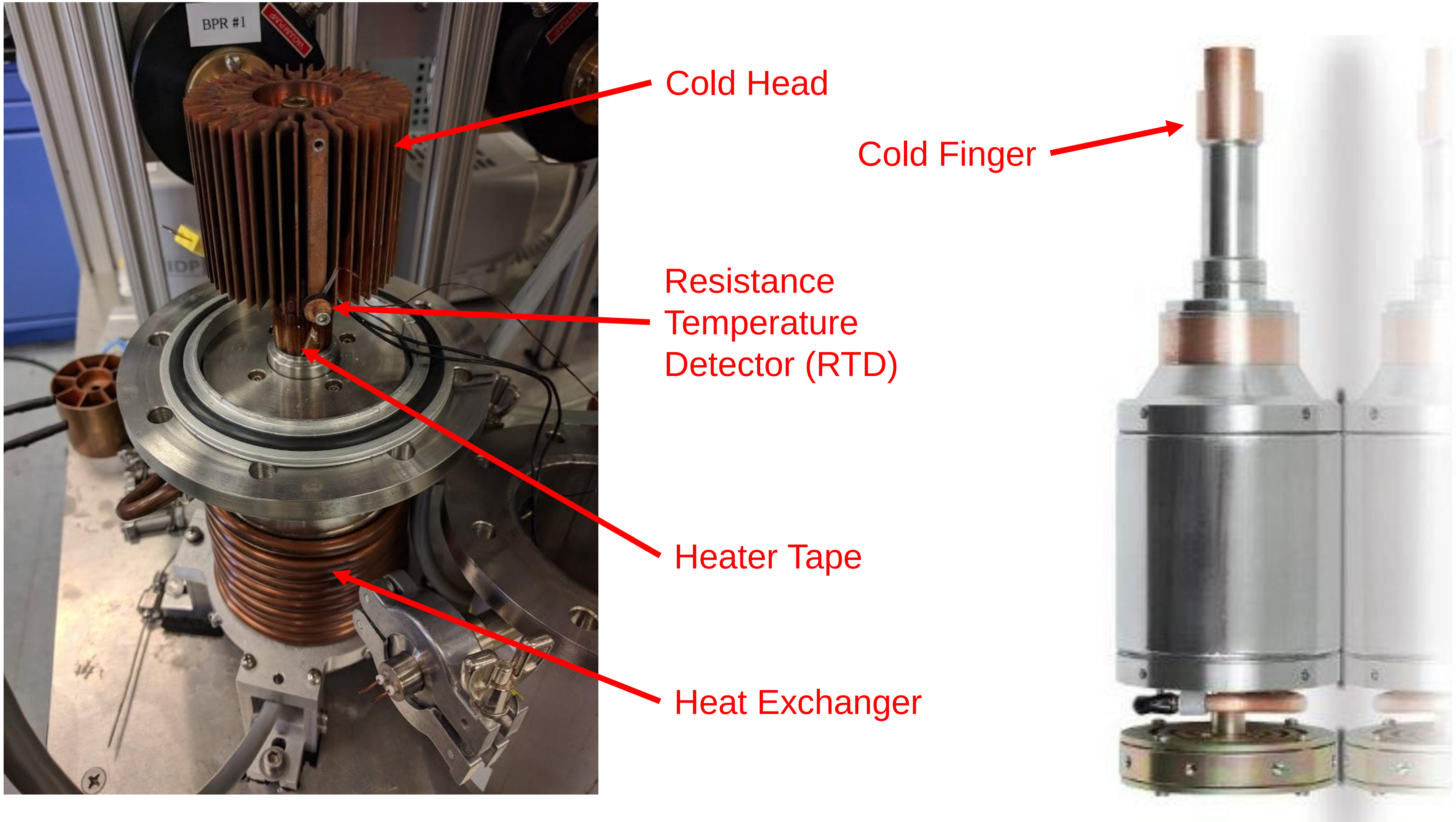


Concept – Small Scale





Concept – Small Scale



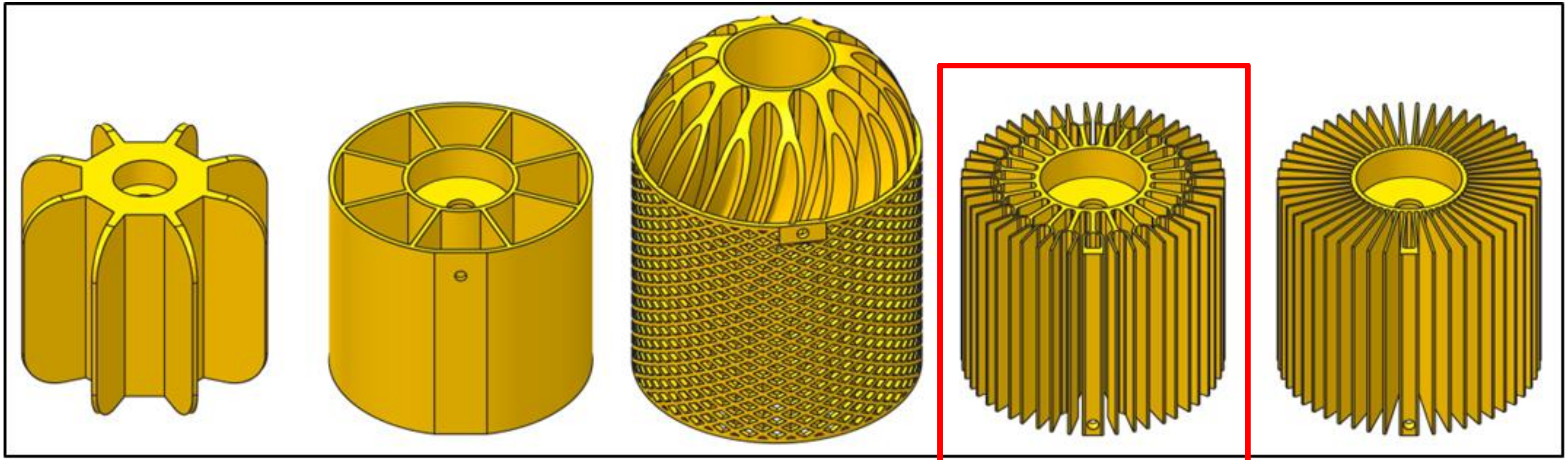
Concept – Small Scale

- Sunpower CryoTel GT cryocooler
  - ~37 W lift @ 150 K
  - 240 W input
  - External water cooling loop
  - Stirling cycle, helium working fluid
- Cold finger protrudes into freezing chamber
- Cold head mounted on cold finger with thermal grease, securing nut
- External chiller loop maintains 15ºC rejection temperature
- Can be set to specific power
- Forced 1.2 SLPM and 7 Torr via vacuum pump

Cold Head Design Iterations

Design	Starburst	Ferris Wheel	Swirl/Branching	Tuning Fork	Starburst v2.0
Volume Ratio	1.08	1.00	3.85	1.37	1.28
Area Ratio	0.48	1.00	2.56	2.00	2.47

Baseline



Starburst

Ferris Wheel

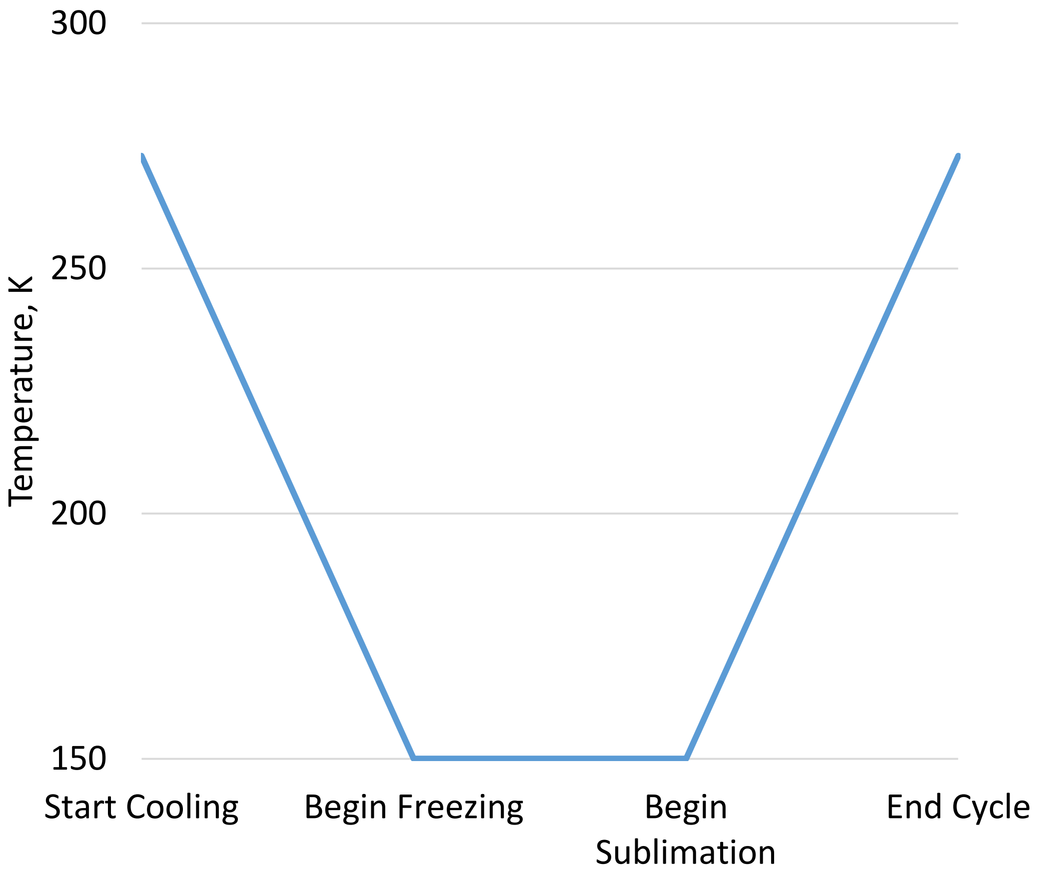
Swirl/Branching

3D printed at Marshall

Tuning Fork

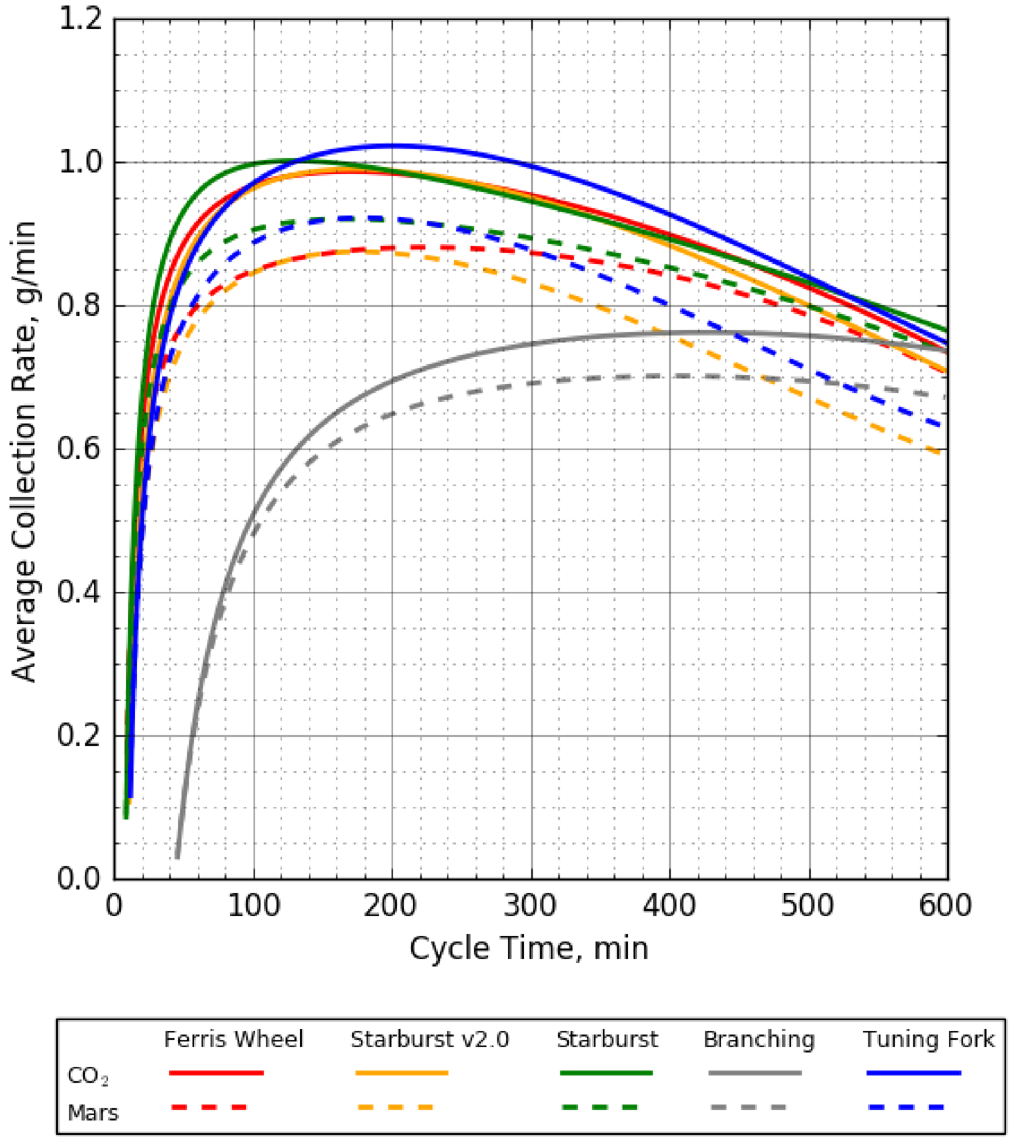
Starburst v2.0*

Cycle Schematic



- Temperature of system must be raised and lowered repeatedly
- Thermal mass of system determines time "lost" transitioning between operational temperatures

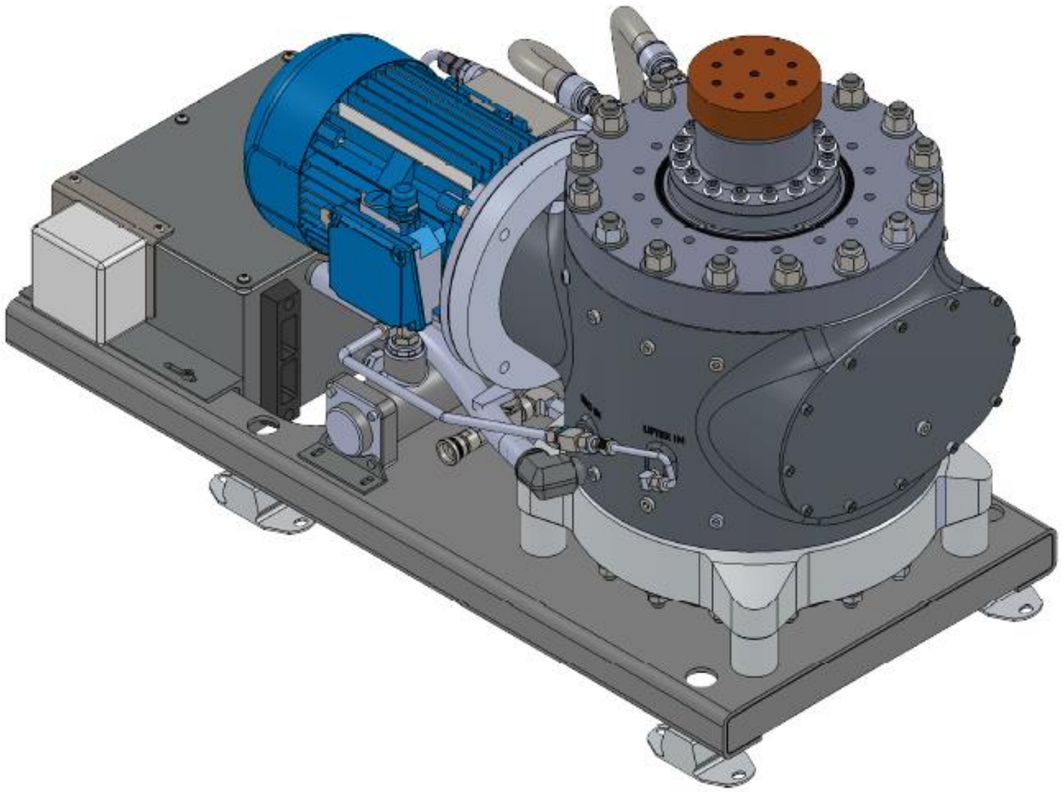
Cycle Duration Optimization



- Given collection rate degradation over time and fixed time “costs” of cooling and heating cold heads, what is the optimal cycle (cool + freezing) time that leads to the highest average collection rate?
- Design that sacrifices early performance never recovers from “deficit”
- Plateau region can allow trades for energy efficiency or reducing power on/off cycles
- Assumption: 1:1 ratio between collection and sublimation phase

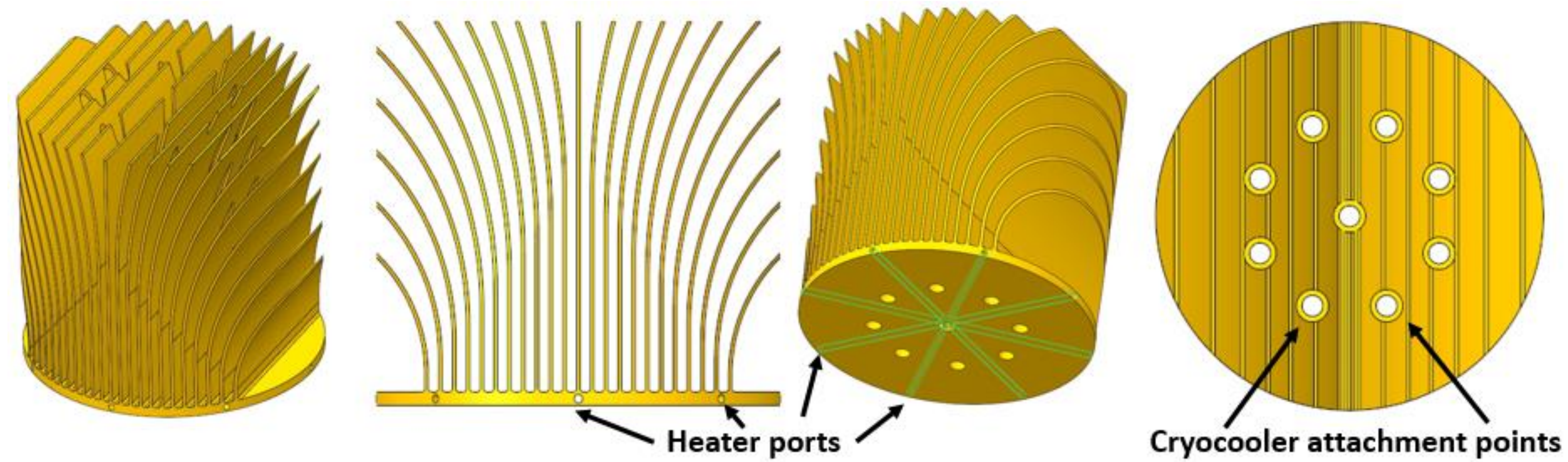
Concept – Full Scale

- AFCryo STC90 cryocooler
  - ~300-400 W lift @ 150 K
  - ~3000 W input
  - External water cooling loop
  - Stirling cycle, helium working fluid
- Cold plate protrudes into freezing chamber
- Cold head mounted on cold finger with thermal grease, securing nuts
- Cannot be set to specific power
  - On/Off only
- Will pull Mars gas from large chamber
  - Closer to actual operation

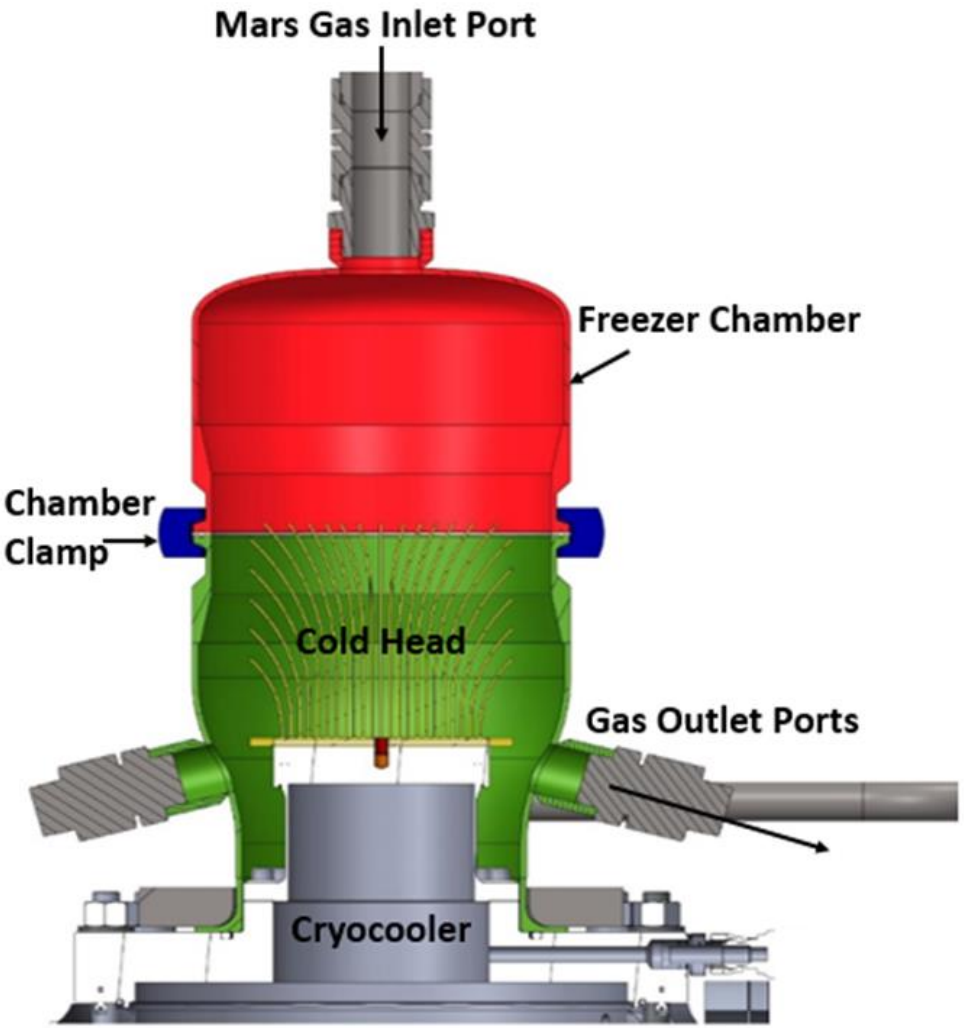


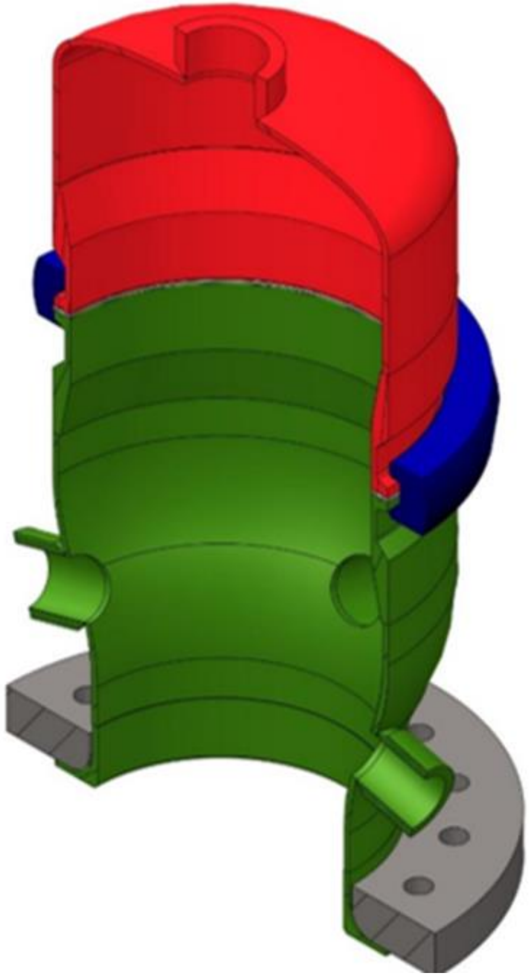
Concept – Full Scale

Similar Surface Area to Lift and Volume to Lift ratio as Tuning Fork



Concept – Full Scale





Current Status

- Open Questions:
  - How does optimization curve change when considering faster freezing phase compared to sublimation phase?
  - Will the current heating configuration ensure dry ice sublimates consistently over time?
  - How linear are the lift ratios from small-scale to full?
    - Must dial in cold head to maintain temperatures above freezing point of Ar/N_2
  - Does this method of operation allow non-condensing gases to be flushed away from cold head?
  - In multiple cryocooler configuration, can heat rejection be used effectively in sublimation phase?

Backup

Dry Ice Accumulation

Mid-experiment disassembly to get visual of growth pattern on cold head