Lecture 11
Cryocoolers (Part II)

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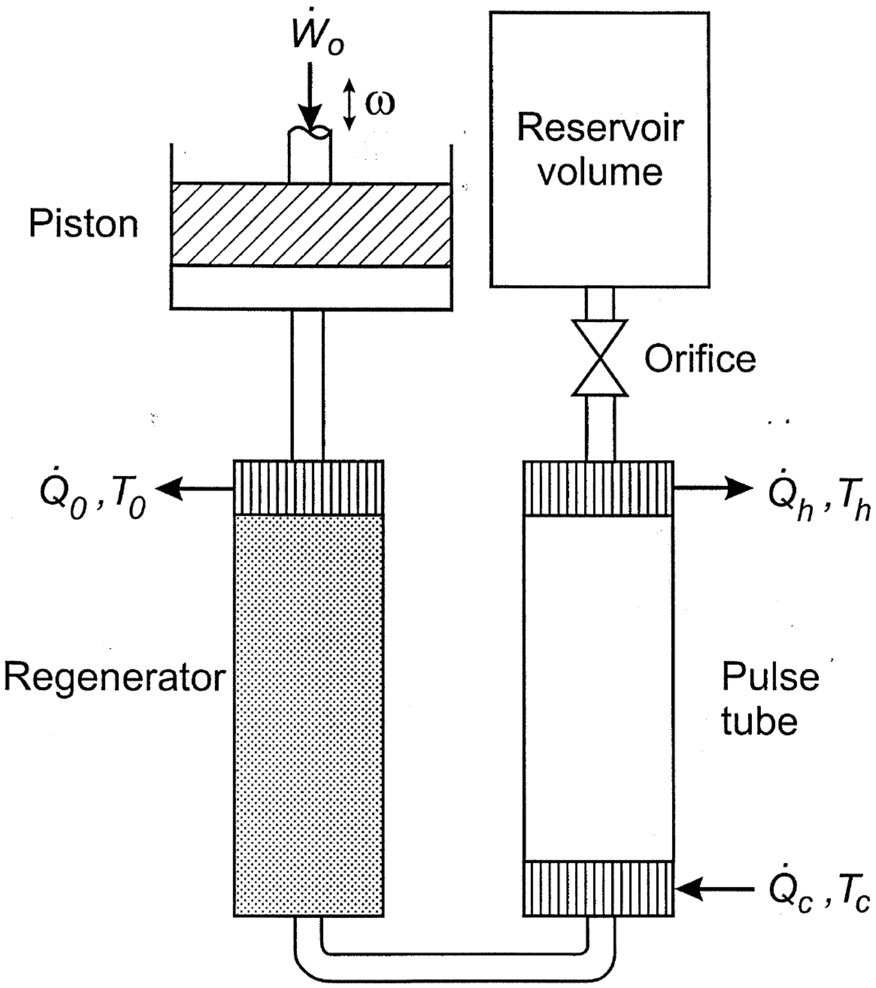
Goals

- Discuss Pulse Tube Cryocoolers

Displacers & Pulse Tube Cryocoolers

- GM and Stirling cycle cryocoolers using oscillating flows at 1 – 100 Hz
- The cold displacer plays an important role in these devices
  - Separate the heating and cooling effects of the cycle by placing the motion of the gas in proper phase with the pressure oscillations
  - Little pressure difference across the displacer but a large temperature difference
- However the cold displacer leads to a number of problems
  - Moving cold part leads to reliability problems and increased vibration at cold end
  - Axial heat conduction through the displacer leads to cycle inefficiencies
- What if we could eliminate the displacer ?

Pulse Tube Cryocoolers



- The gas in the pulse tube in effect replaces the displacer
- The pulse tube must be large enough so that the gas in cold end never reaches the warm end and gas in cold end never reaches the warm end
  - Thus gas in the middle of tube never leaves the tube and acts as an thermal insulator
  - Turbulence & mixing must be minimized
  - From this simple design there are many variations of pulse tube cryocoolers

Advantages of Pulse Tube Cryocoolers

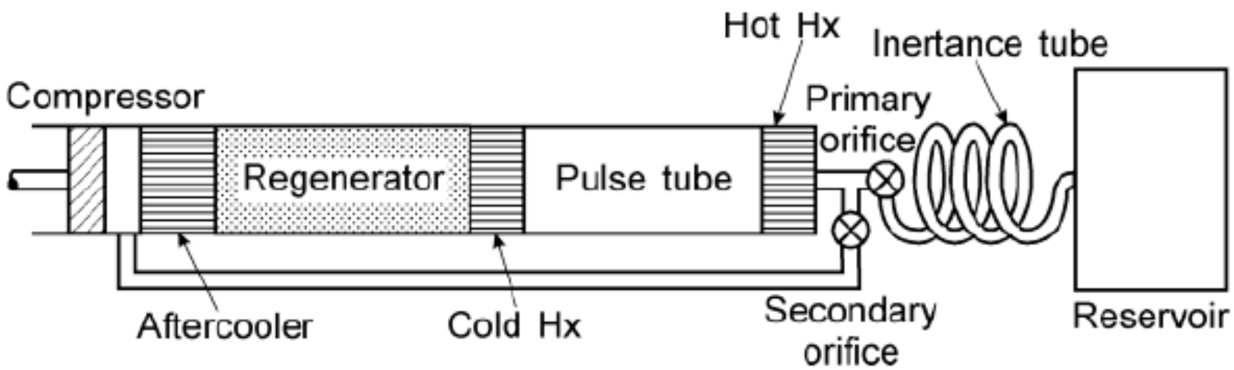
- High reliability (fewer cold moving parts)
- Lower cost
- Low vibration
- Higher efficiency
- Ability to work at all temperature levels
- Can be "space qualified"
- These advantages and the fact that there is still much to learn about pulse tubes make this a very active area of research
  - Roughly 10% of all the papers at the 2009 Cryogenic Engineering Conference dealt with pulse tube cryocoolers
- Commercial versions of pulse tube cryocoolers are available

Losses in Pulse Tube Cryocoolers

- Regenerator inefficiency (generally the largest single loss)
- Losses within the pulse tube itself
  - Heat transfer between gas and tube wall
  - Mixing of warm and cold gas segments
  - Circulation of gas within the pulse tube due to oscillating pressures (acoustic streaming)

Types of Pulse Tube Cryocoolers

- Double Inlet
  - Roughly 10% of the flow is bypassed around the regenerator and used to pressurize the reservoir
  - Reduces losses in the regenerator
  - Increases overall efficiency particularly at higher frequency operations
  - Presence of inertance tube (also used on other styles of PT cryocoolers) helps put the flow and pressure oscillations into a phase relationship that optimizes efficiency



Thermoacoustic Drivers

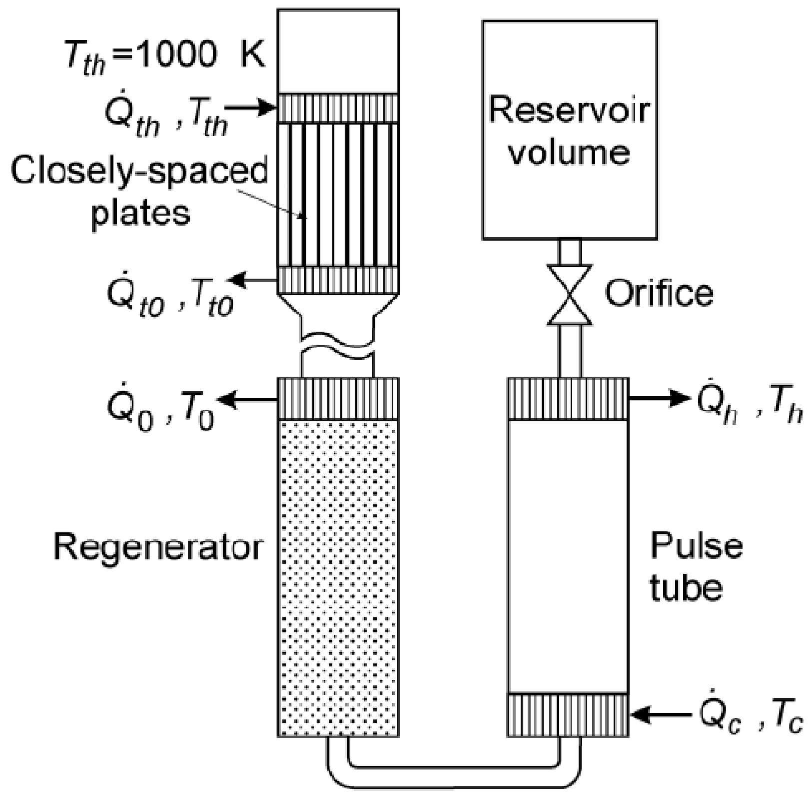


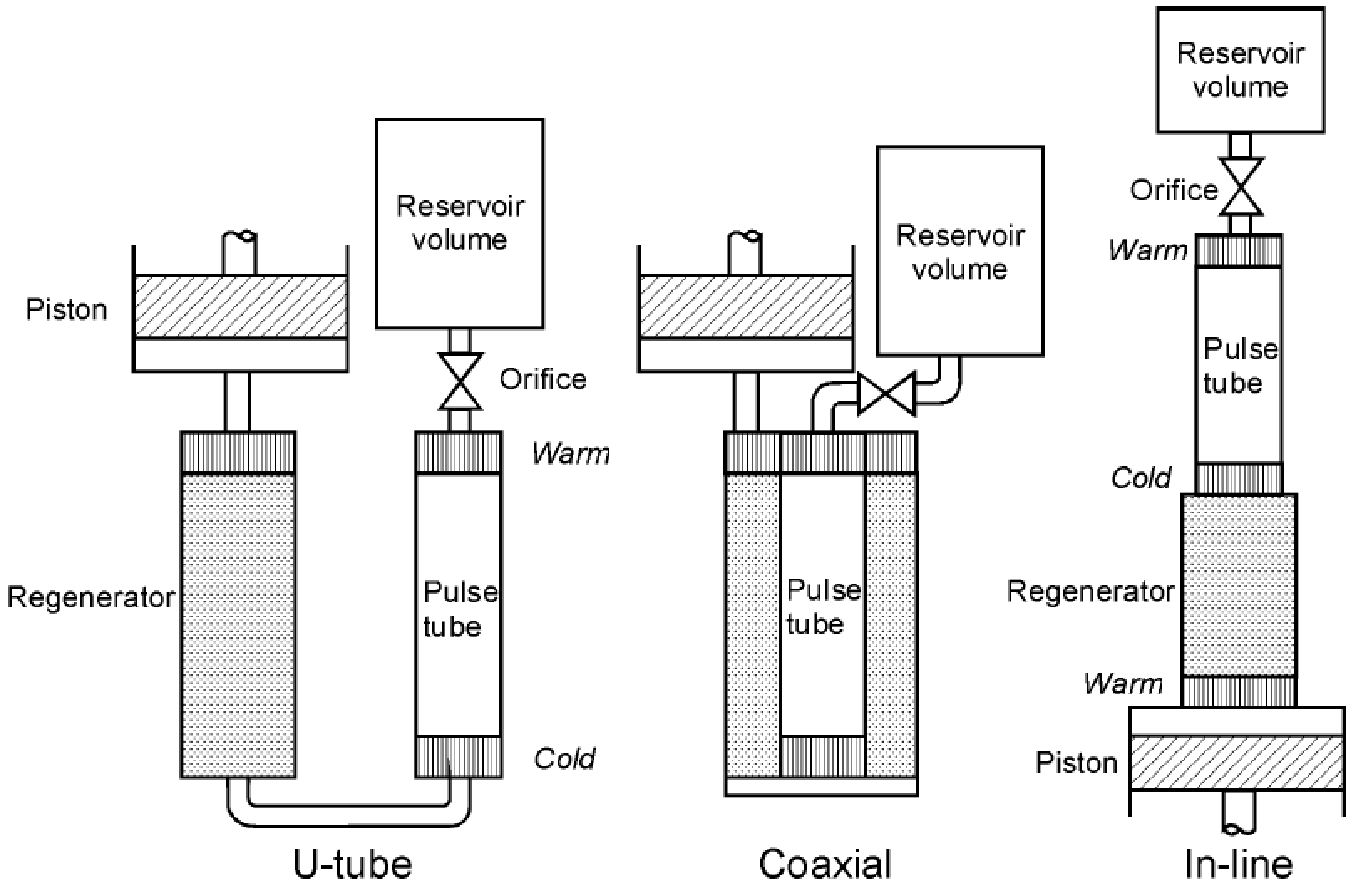
Figure 5. Schematic of ThermoAcoustically Driven Orifice Pulse Tube Refrigerator (TADOPTR)

Can result in cryocoolers with no moving parts

Generally only used in very large scale systems

R. Radebaugh – NIST

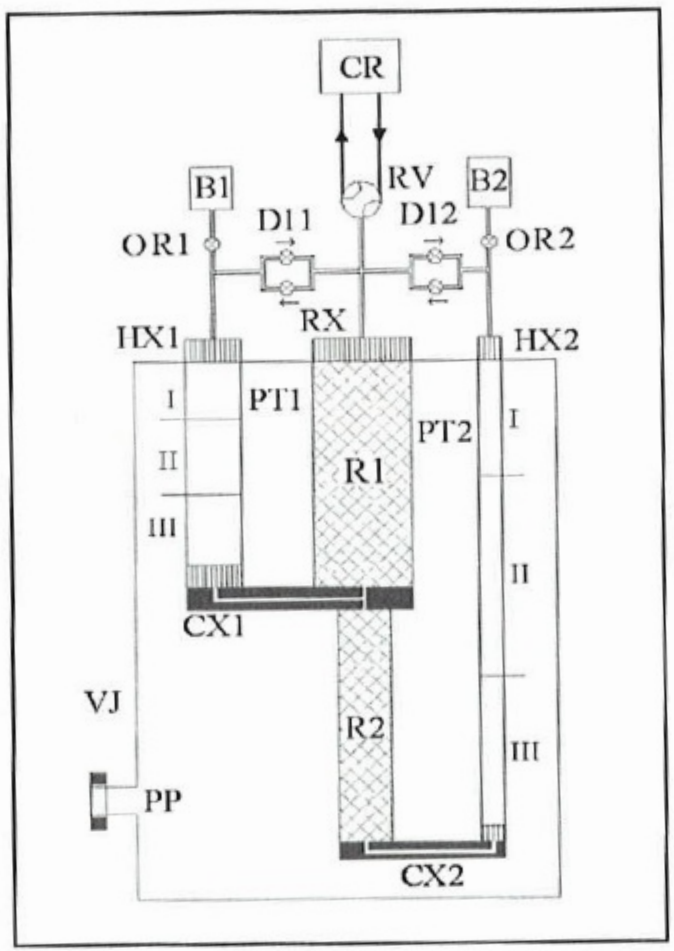
Different Geometries of Pulse Tube Cryocoolers



Frequently used to separate compressor vibration from the cold head

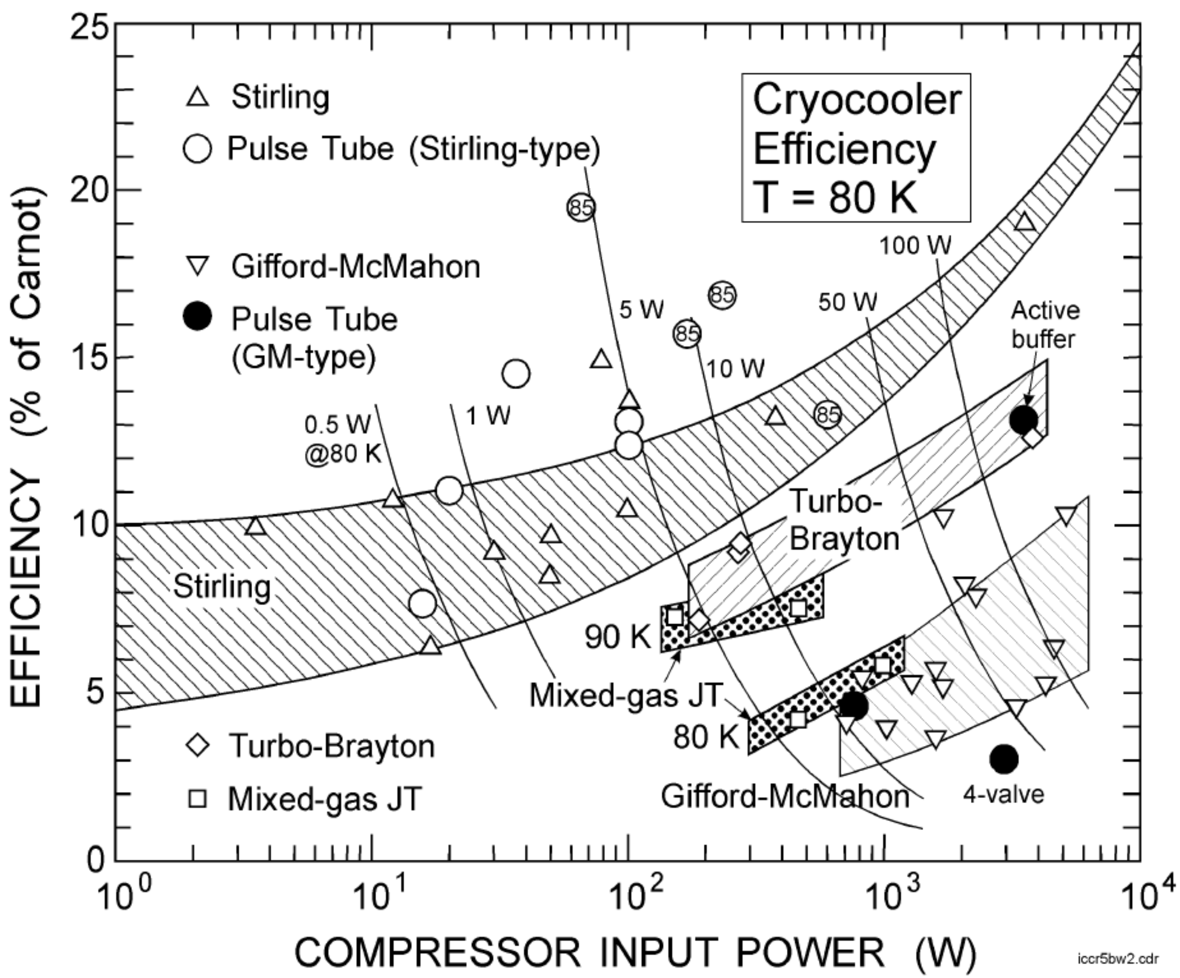
From R. Radebaugh NIST

Multistage Cryocoolers Are Also Common



From Kasthurirengen et al
Proc. ICEC 22 (2009)

Pulse Tube and other Cryocooler % Carnot at 80 K



From
R. Radebaugh
NIST

Pulse Tube Cryocooler
Commercially Available Examples

- CryoMech PT810
  - 14 W @ 20 K
  - 80 W @ 80 K

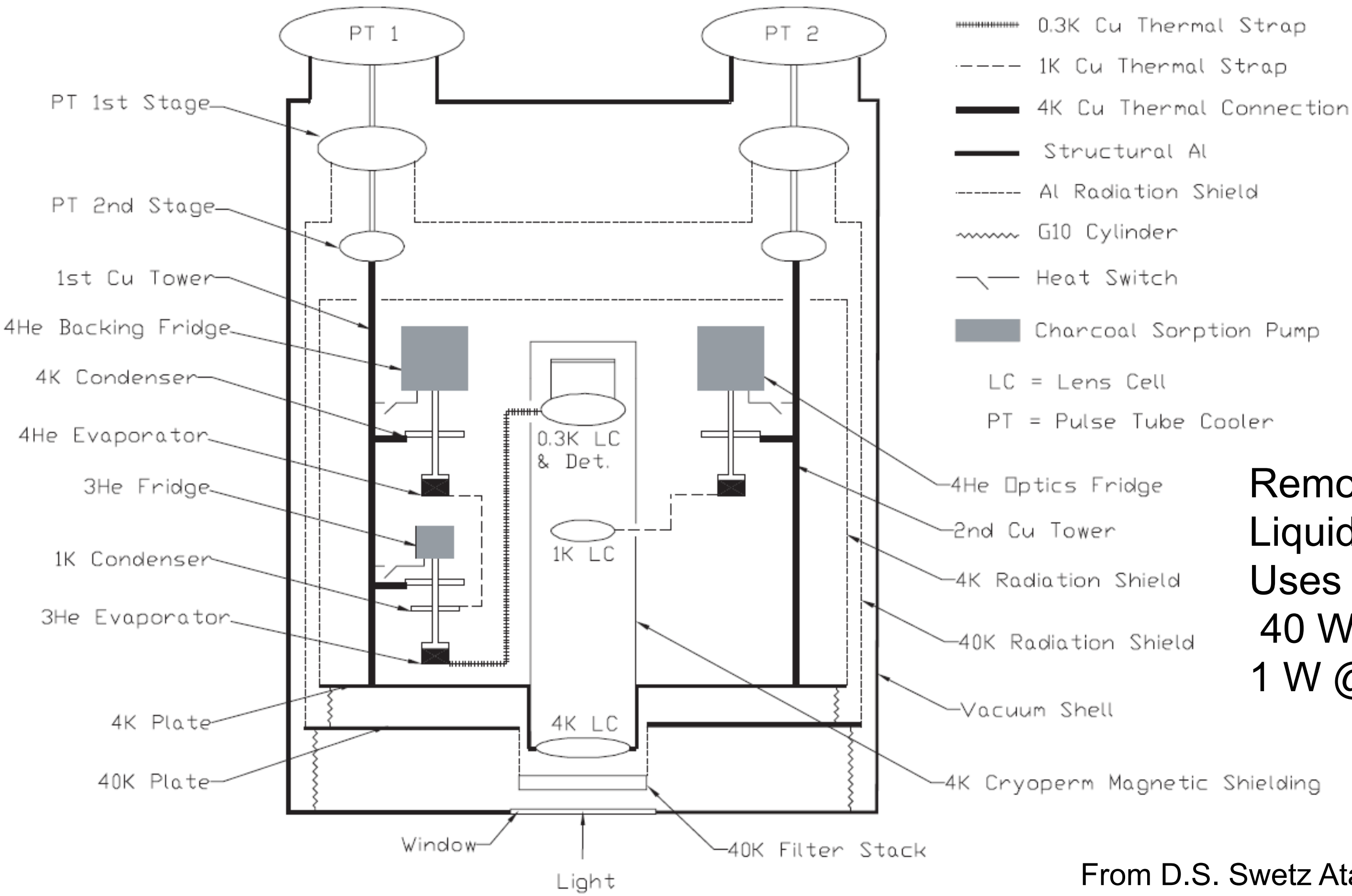
- CryoMech PT415
  - 40 W @ 45 K
  - 1.5 W @4.2 K

Pulse Tube Cryocooler Commercially Available Examples

- SHI Cryogenics SRP-062B
  - 30 W @ 65 K
  - 0.5 W @ 4.2 K
  - 6.5 kW power input

- Sierra Lobo
  - 4 W @ 65 K
  - 4 W @ 20 K
  - Can be used for Zero Boil Off Propellant Storage

Example of PT Use
Atacama Cosmology Telescope



Remote site
Liquid cryogens a problem
Uses 2 PT from Cryomech
40 W @ 45 K
1 W @ 4.5 K

From D.S. Swetz Atacama Cosmology Telescope PhD dissertation U. Penn 2009

Example of PT use
LNG production using a TADOPTR

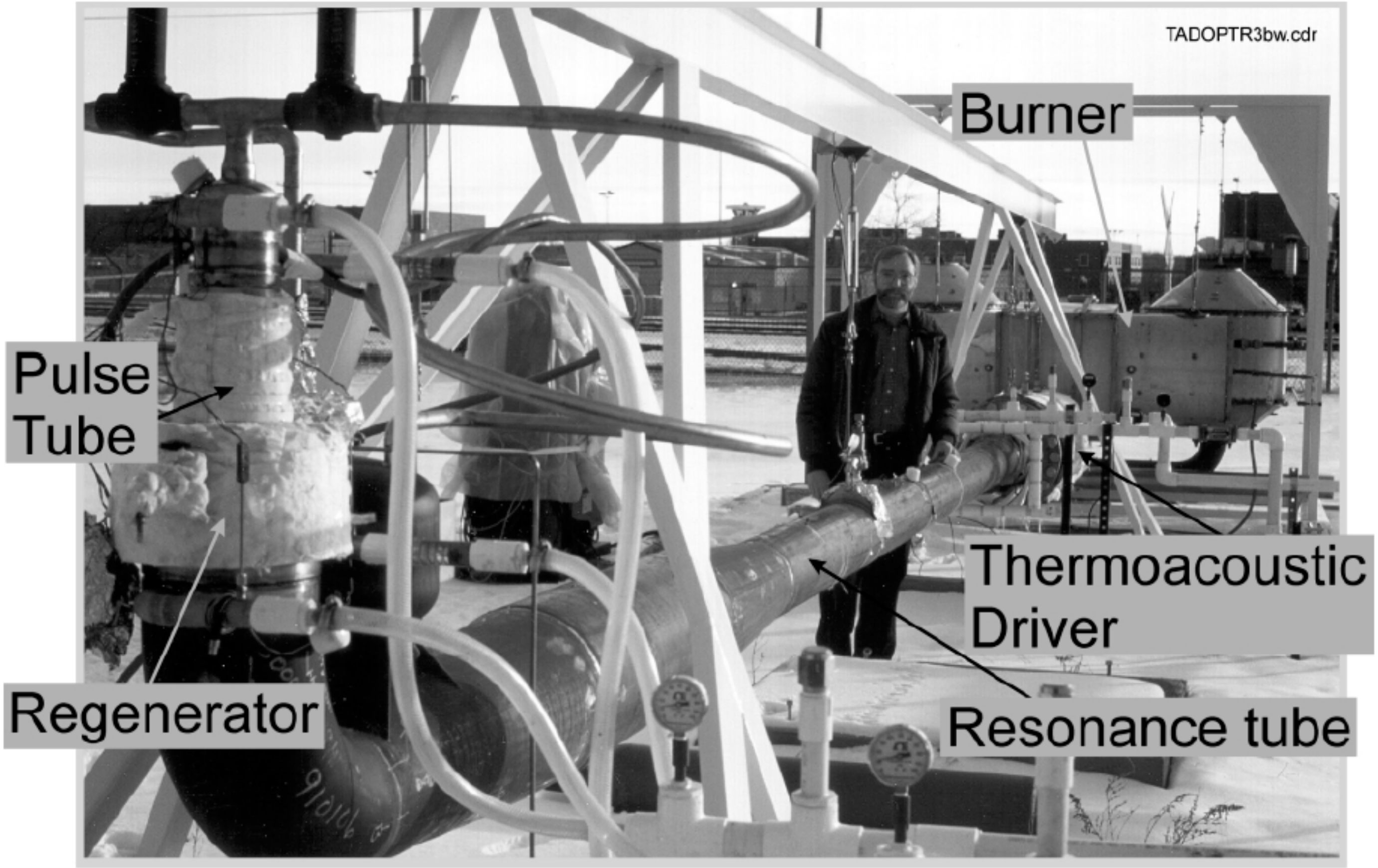


Figure 12. TADOPTR natural gas liquefier (600 L/day, 2.0 kW at 120 K)

No moving parts
burns 1/3 of natural gas stream
to liquefy the rest

From
R. Radebaugh
NIST

Space Applications

19 W @ 90 K
222 W input power

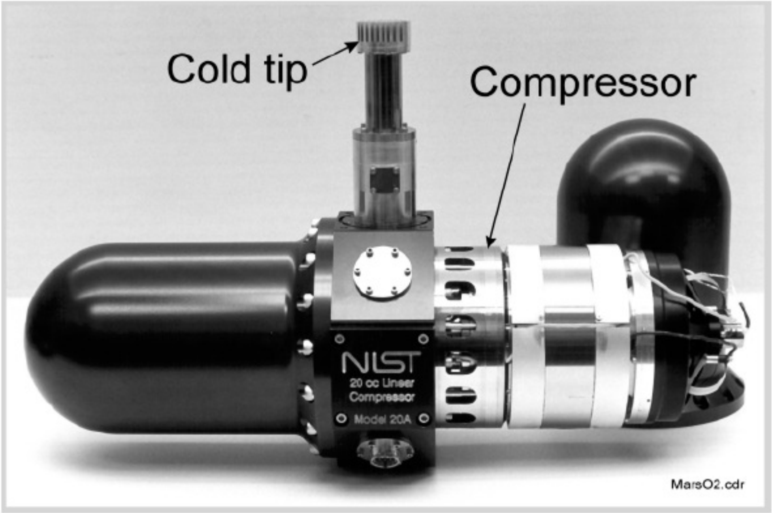


Figure 10. Pulse tube refrigerator for studies of liquefying oxygen on Mars (580 mm total length)

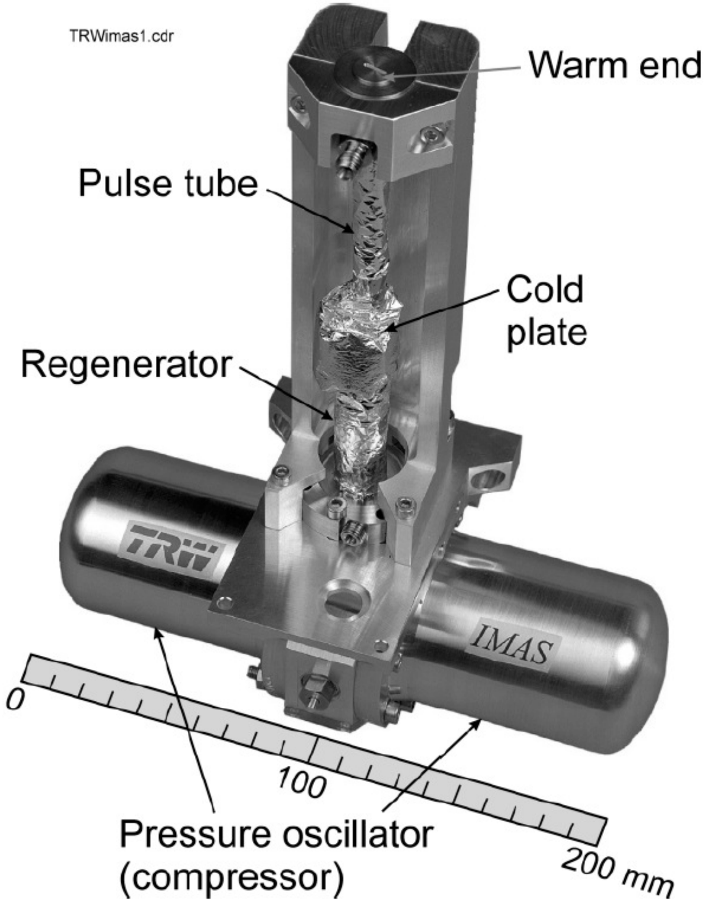
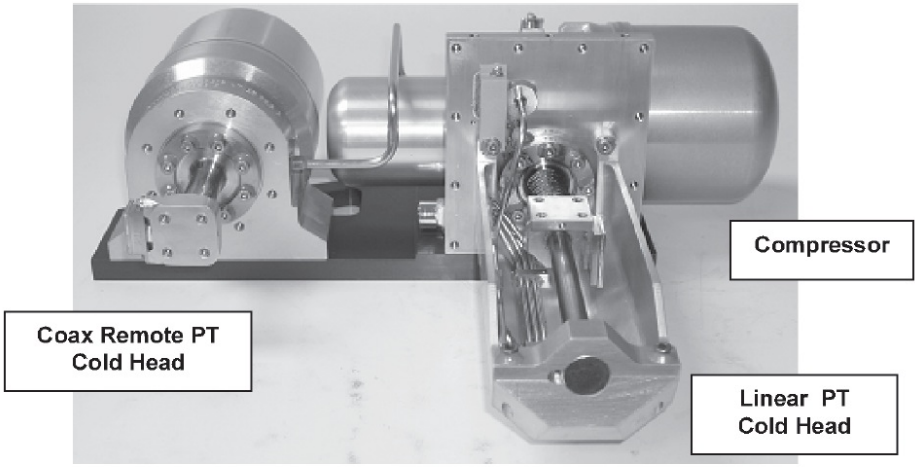


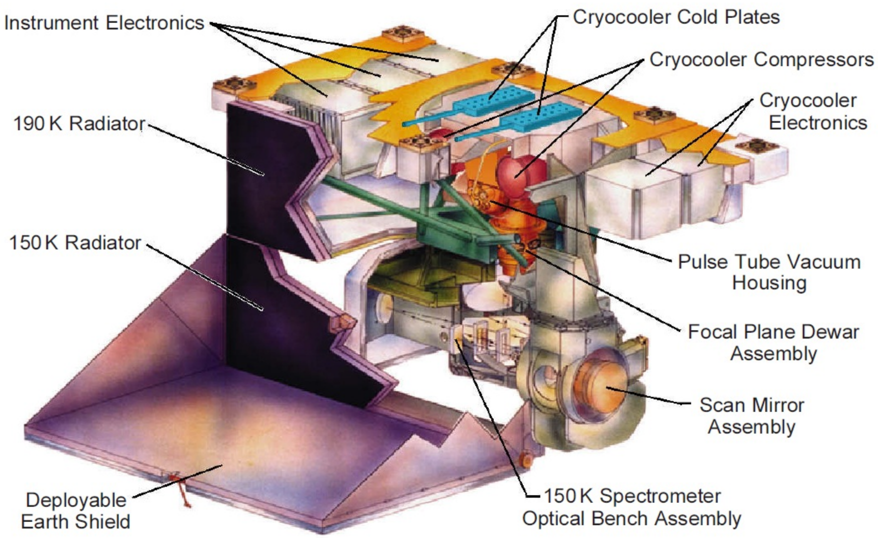
Figure 11. Pulse tube refrigerator for Integrated Multispectral Atmospheric Sounder (space appl.)

Both figures From R. Radebaugh
Proc. Instit. of Refrig.

0.5 W @ 55 K

Space Applications





2.3 W @ 53 K and 8 W @ 183 K
Designed for sensor cooling on NASA GOES-R Satellite

0.5 W @ 58 K
Atmospheric Infrared Sounder
On orbit for the last 6 years

Colbert et al.
Cryocoolers 15 (2009)

Ross et al.
Cryocoolers 15 (2009)

Summary

- Pulse tube cryocoolers have a number of advantages and are being applied in many different technical areas.
- Their potential for low vibration and high reliability make them particularly attractive to space applications
- They are a very active area of cryogenic research

- Some additional online resources for pulse tubes and other types of cryocoolers are:

http://www.cryocooler.org/ Contains online proceedings of the International Cryocooler Conferences

http://www.elsevier.com/wps/find/journaldescription.cws_home/30407/description#description Online link to the journal *Cryogenics* which includes proceedings of the Space cryogenics Workshops