Lecture 1 Introduction

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Class Goals

- Provide the basics of Cryogenic Engineering
  - Preparation for future work assignments or grad school
  - Cryogenic engineering utilizes many engineering disciplines & shows their applications
- Use real world examples
- Via the class project, provide insight into project management techniques
  - Nomenclature
  - Requirements, design choices, cost, schedule
  - Communication (oral & written)
- Be interesting
  - None of us started in this profession to be bored – cryogenics, I hope to show is an interesting application of engineering

Evaluation

- Design Project 70%
  - Requirements Definition & Project Organization 10%
  - Conceptual Design 20%
  - Final Design Oral presentation 15%
  - Final Design Written report 25%
- Final Exam 15%
- Problem Sets (Biweekly) 15%
- Note that exams will only cover what is presented in class

Resources

- Class slides and other information may be found on Indico Page

https://indico.esss.lu.se/category/22/

- Contact Information

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What is Cryogenics?

- Cryogenics is the science & engineering of phenomena that occur at

 T < 120 K

- Recall Kelvin scale: $^{o}C + 273$
  - Note it's K not ^{o}K

Why 120 K? The temperature below which "permanent gases" start to condense

Fluid	Normal Boiling Point (K)
Krypton	119.8
Methane	111.6
Oxygen	90.2
Argon	87.3
Nitrogen	77.4
Neon	27.1
Hydrogen	20.3
Helium	4.2

But still – Why do we care?

- Interesting & useful things happen at cryogenic temperatures
- Separation of air into constituent components for industrial use (oxygen, nitrogen, argon, krypton, neon)
- Liquefaction of gases allows transport at high densities and low pressure (LNG, oxygen, nitrogen, argon , hydrogen, helium)
- Superconductivity permits high field magnets (MRI, particle accelerators, basic research) and possibly electrical power applications (generators, motors, transmission lines). Superconductivity also permits powerful RF cavities for particle acceleration
- Exploration (rocket engines, cosmic background at 3 K)

Separation of air into constituent components for industrial use (oxygen, nitrogen, argon)

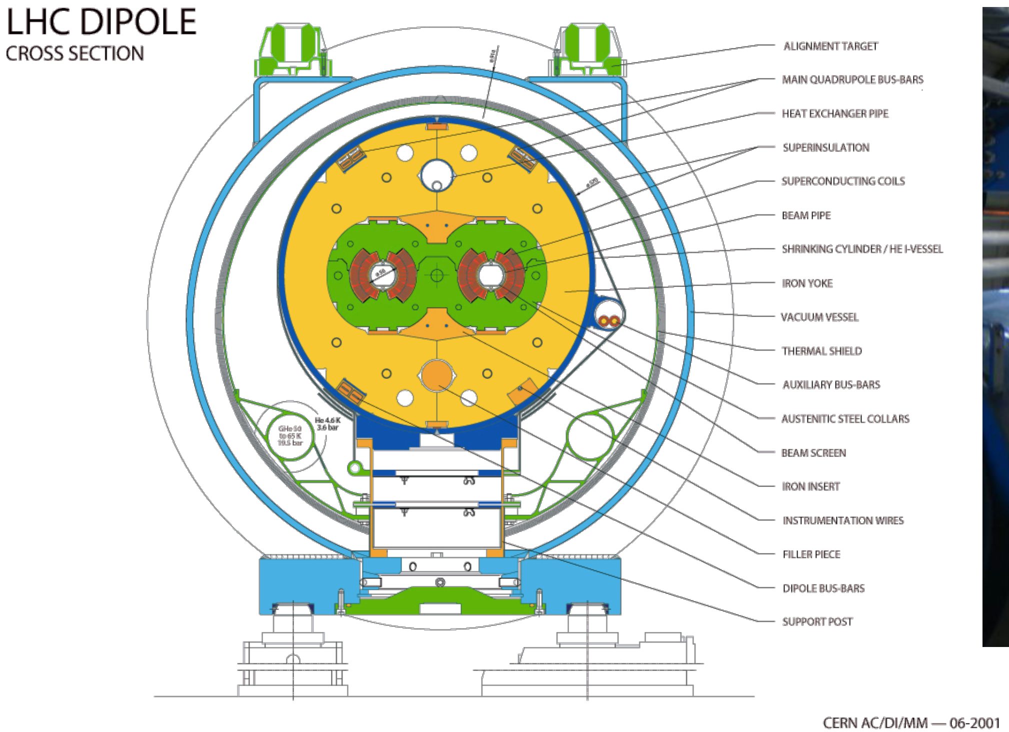
- Air separation by cryogenic distillation
- Up to 4500 t/day LOX

Liquefaction of gases allows transport at high densities and low pressure (LNG, oxygen, nitrogen, argon, hydrogen, helium)

130 000 m^3 LNG carrier with double hull

Superconductivity (enables high field magnets)

- Large Hadron Collider (CERN) 9 T magnets operating at 1.8 K (superfluid helium)

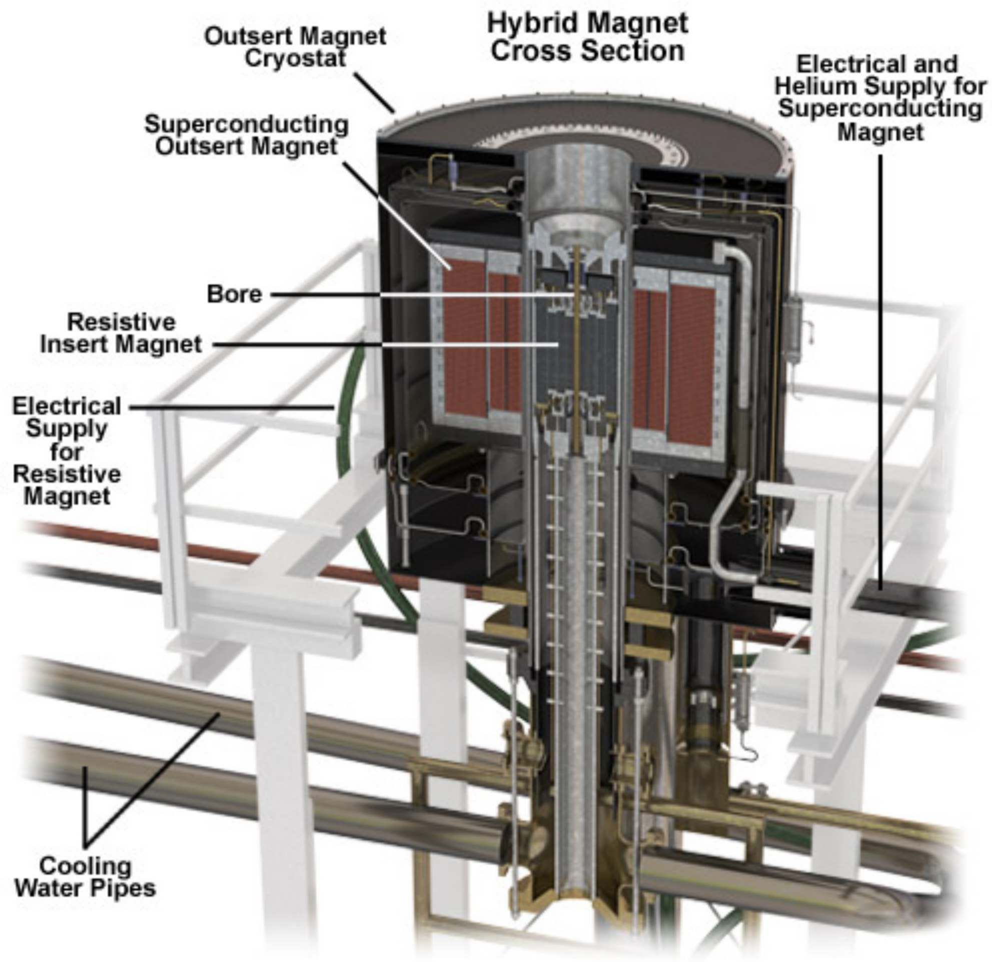


Superconductivity (enables high field magnets)

- Magnetic Resonance Imaging (MRI)
- Certainly the most common use of superconductivity
- Magnets operate in the 1 – 3 T range cooled to roughly 4 – 5 K
- Very low loss cryostats
  - Use of cryogenics is not obvious to staff or patients

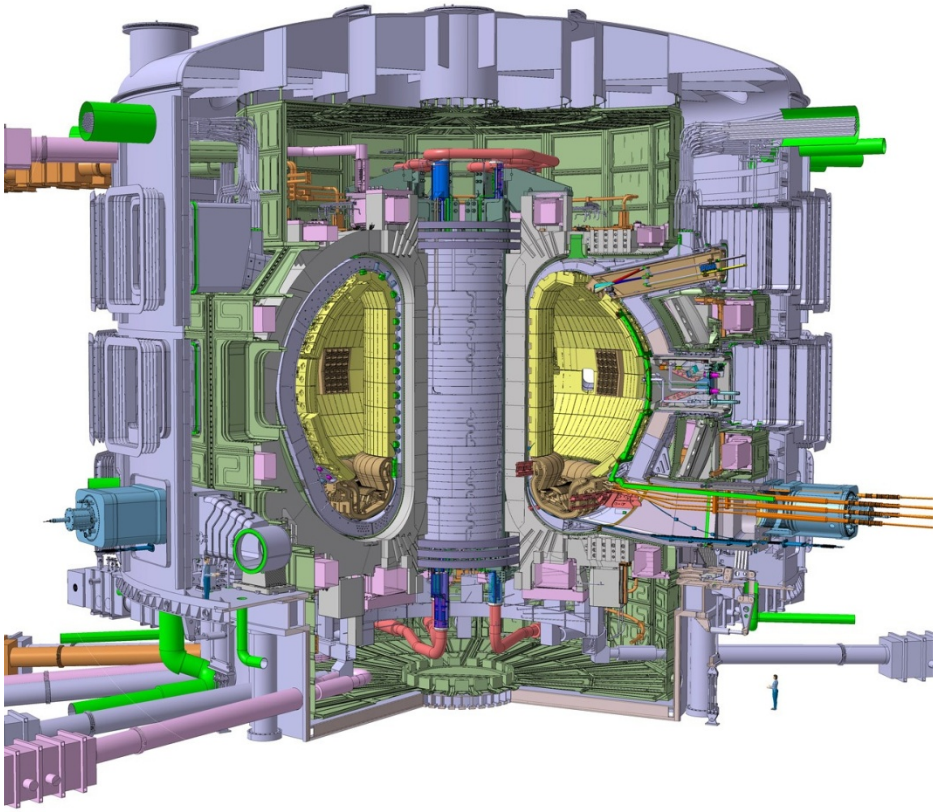
Superconductivity (enables high field magnets)

- Fundamental Research at High Fields
- This is the 45 T DC Hybrid magnet at the National High Magnetic Field Lab @ FSU
- The superconducting outset generates 11.5 T and is cooled to 1.8 K



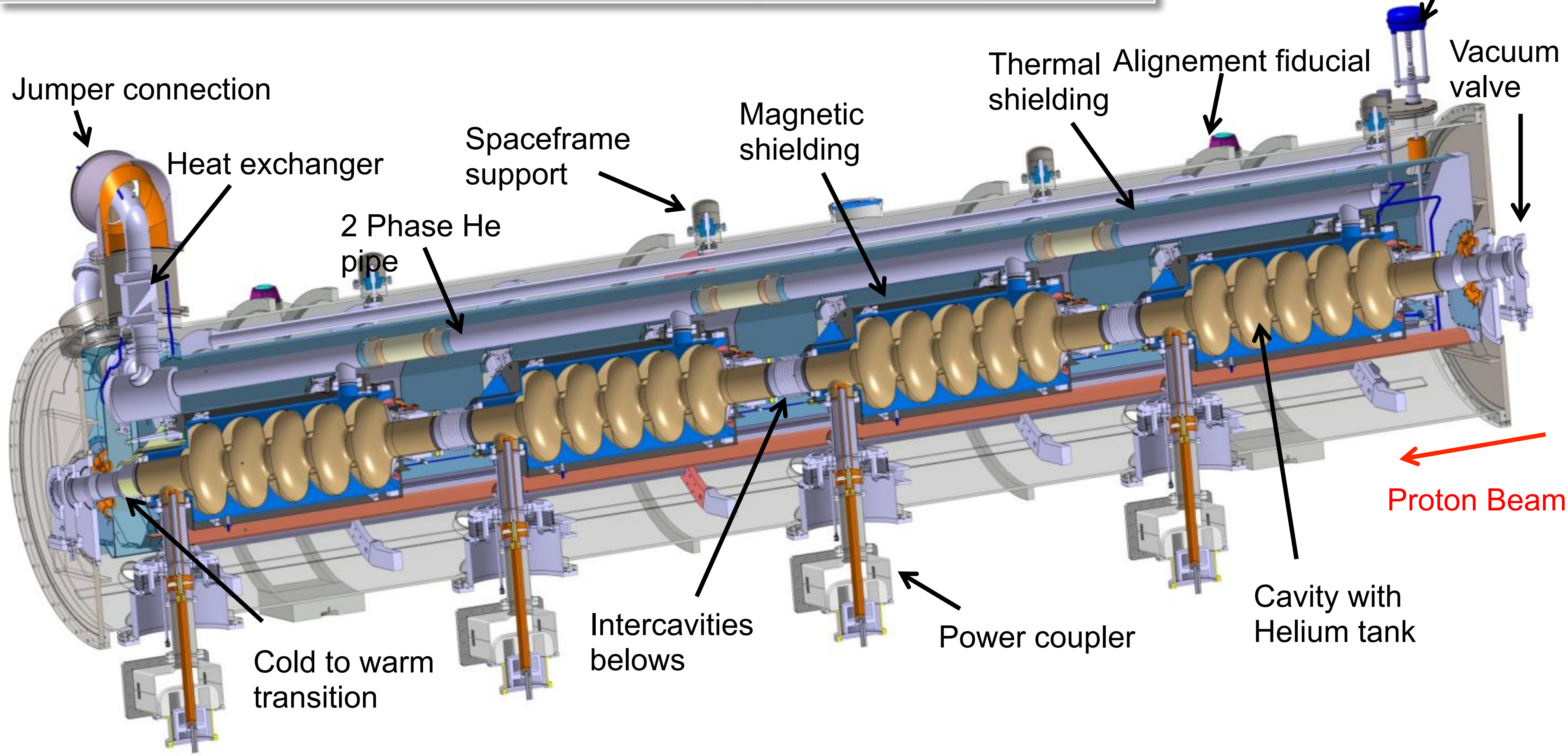
Superconductivity (enables high field magnets)

- ITER Fusion Reactor
  - Under design & construction in Cadarache, France
- 3 separate superconducting magnet systems
- 3 ~ 25 kW at 4.5 K helium refrigeration plants



Superconductivity allows powerful RF cavities for particle accelerators
ESS Elliptical Cavities & Cryomodule

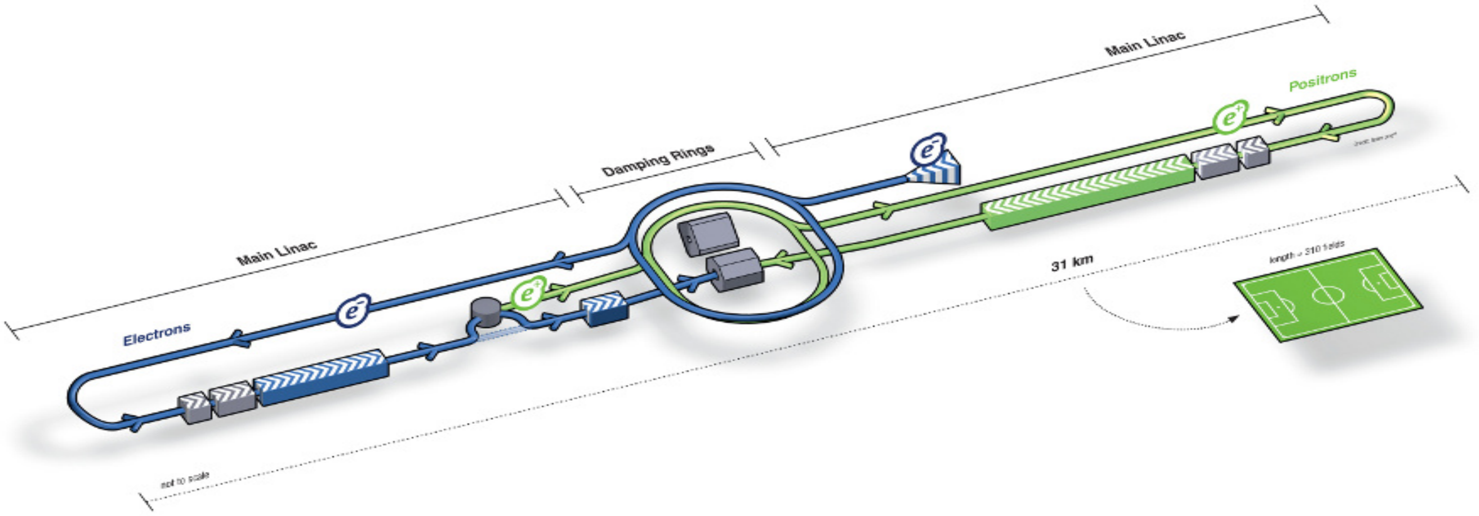
- Cavities operate @ 2 K
- Common design for medium (6 cells) and high beta (5 cells) cavities



Superconducting RF is Very Popular (In addition to ESS we have)

Name	Accelerator Type	Lab	T (K)	Refrigeration Capacity	Status
CEBAF	Electron Linac	JLab	2.0	4.2 kW @ 2.1 K	Operating
12 GeV Upgrade	Electron Linac	Jlab	2.0	4.2 kW @ 2.1 K	Under construction
JPARC	H^-	KEK			Operating
SNS	H^-	ORNL	2.0	2.4 kW @ 2.1 K	Operating
E Linac	Electron Linac	TRIUMF	2.0		Proposed
S-DALINAC	Electron Linac	TU Darmstadt	2.0	120 W @ 2.0 K	Operating
XFEL	Electron Linac	DESY	2.0	2.5 kW @ 2 K	Under construction
ATLAS	Heavy Ion Linac	ANL	4		Operating
LCLS II	Electron Linac	SLAC	2.0	8 kW @ 2 K	Under construction
ISAC - II	Heavy Ion	TRIUMF	4		Operating

International Linear Collider (most likely the upper limit of this approach)



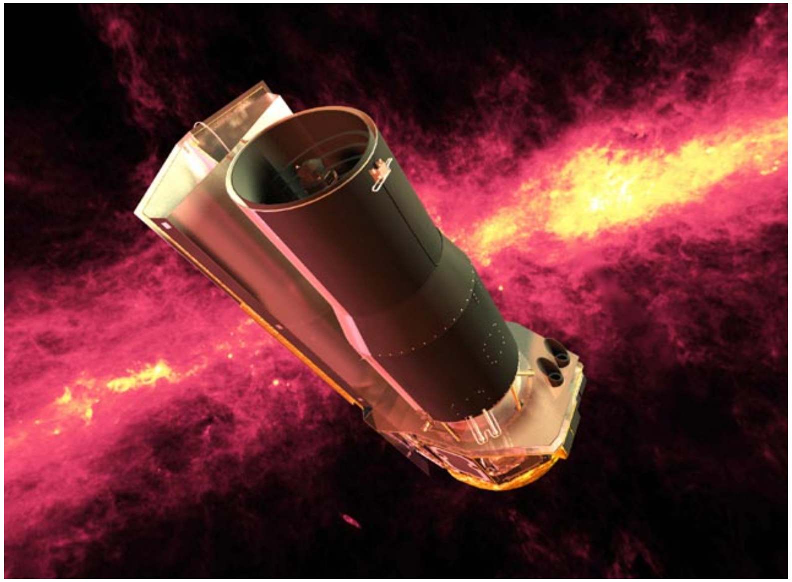
- e-/e+ linear collider (250 GeV on 250 GeV)
- ~ 2000 Cryomodules,
- ~ 16,000 SCRF cavities
- 2 K operation
- 10 x 20 kW (4.5 K eq) cryoplants
- TDR due in 2012

Exploration (rocket engines)

- Main Shuttle Engines use LH_2 and LOX
- Ariane 5 Cryogenic Main Stage

Cryogenics and IR Astronomy

- IR astronomy is an important window into understanding the universe
  - Allows observations of objects through dust clouds etc
  - Compliments other observing methods (radio, x-ray, gamma ray, UV, visual)
  - Measuring variations in the 3 K background gives information on the formation & evolution of the universe
- These are almost always space borne systems operating at temperatures of 2 K or less
- Examples:
  - IRAS, Spitzer, COBE, WMAP
  - Planck and Herschel (launched in 2009)



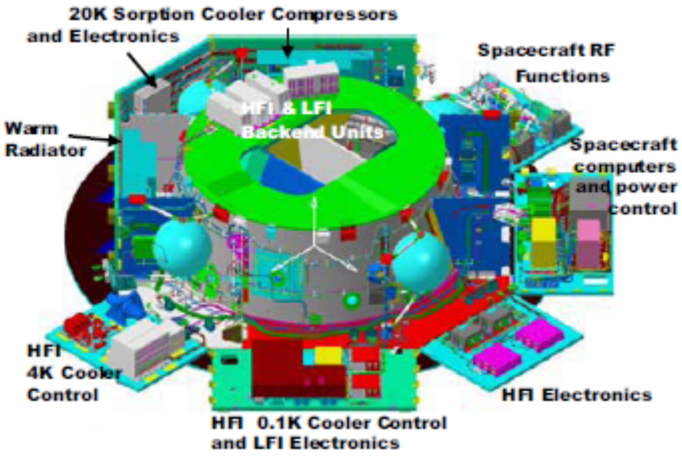
Spitzer Infrared Space telescope

(2003 -2009)

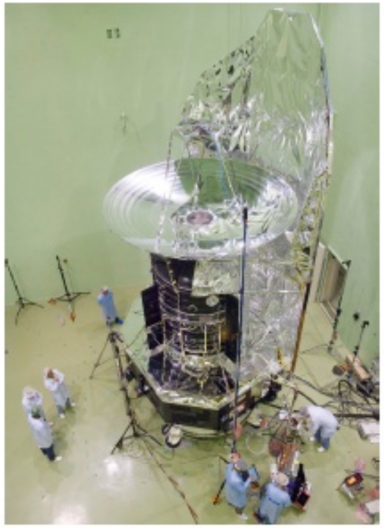
Cooled to 1.8 K via superfluid helium (360 L)

Planck & Herschel Missions (ESA)

- Planck
  - Surveys the structure of the cosmic background
  - Requires temperatures down to 100 mK
  - Uses only mechanical coolers
    - » Sorption (20 K), JT (4 K) and dilution refrigerator (100 mK)
    - » No tanked cryogens



- Herschel
  - IR observatory similar to Spitzer
  - Requires temperatures down to 300 mK
  - Contains 2360 L of He II (1.6K)
  - ^{3}He Sorption cooler provides 300 mK temperatures



Cryogenics is a major industry

- Firms with significant cryogenic activities include:
  - Air Products – 8 B$ in sales in 2009
  - Praxair – 9 B$ in sales in 2009
  - Linde – 11 B Euros in sales in 2009
  - Air Liquide – 12 B Euros in sales in 2009
  - Siemans – Significant MRI producer
  - General Electric – Significant MRI producer