Cryocoolers for Space

Mid and Far Infrared Astronomy for Future Space Missions

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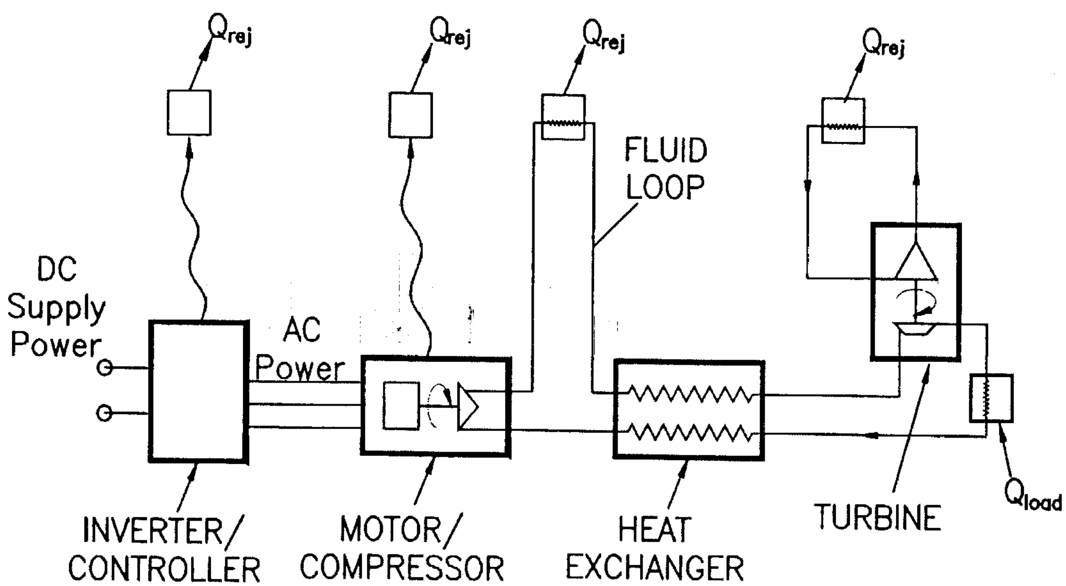
US Cryocoolers for 4 to 6 Kelvin

- Turbo-Brayton
  - Under development at Creare
- Two-stage Sorption Joule-Thomson (J-T)
  - Under development at JPL
- Stirling/J-T Hybrid
  - Under development at Ball
- Two-stage J-T with Rotary Vane Compressor
  - Under development at Ball
- Stored Cryogen
  - Solid hydrogen plus liquid helium
  - Multi-stage radiators plus liquid helium

Turbo Brayton Cryocooler - Features

System Elements

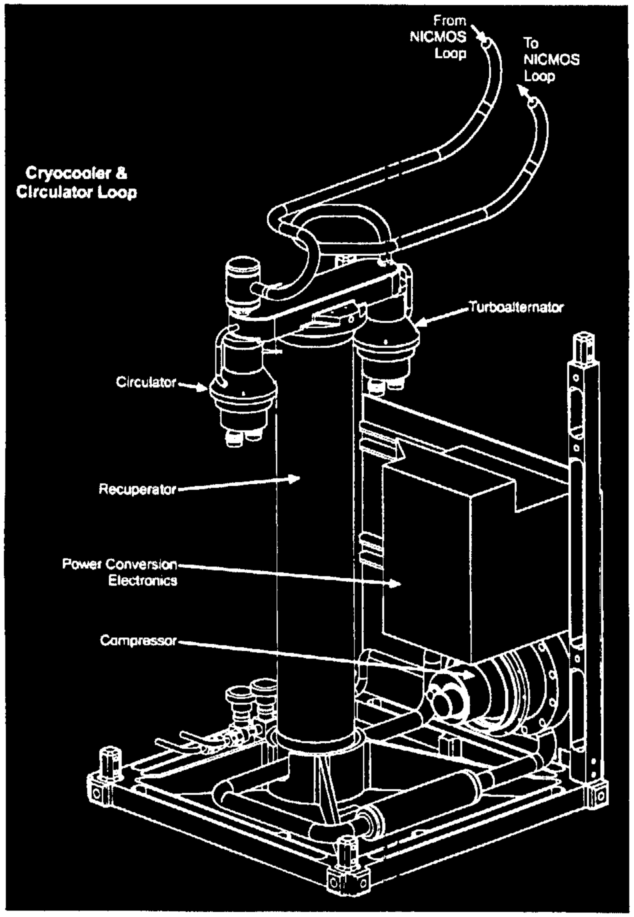
- **DC/AC conversion for motor drive**
- **Turbomachines for compression and expansion**
- **High performance recuperative heat exchangers**
- **Heat, $Q_{(re)}$, conveyed to radiator(s) by conduction and gas (fluid loop)**



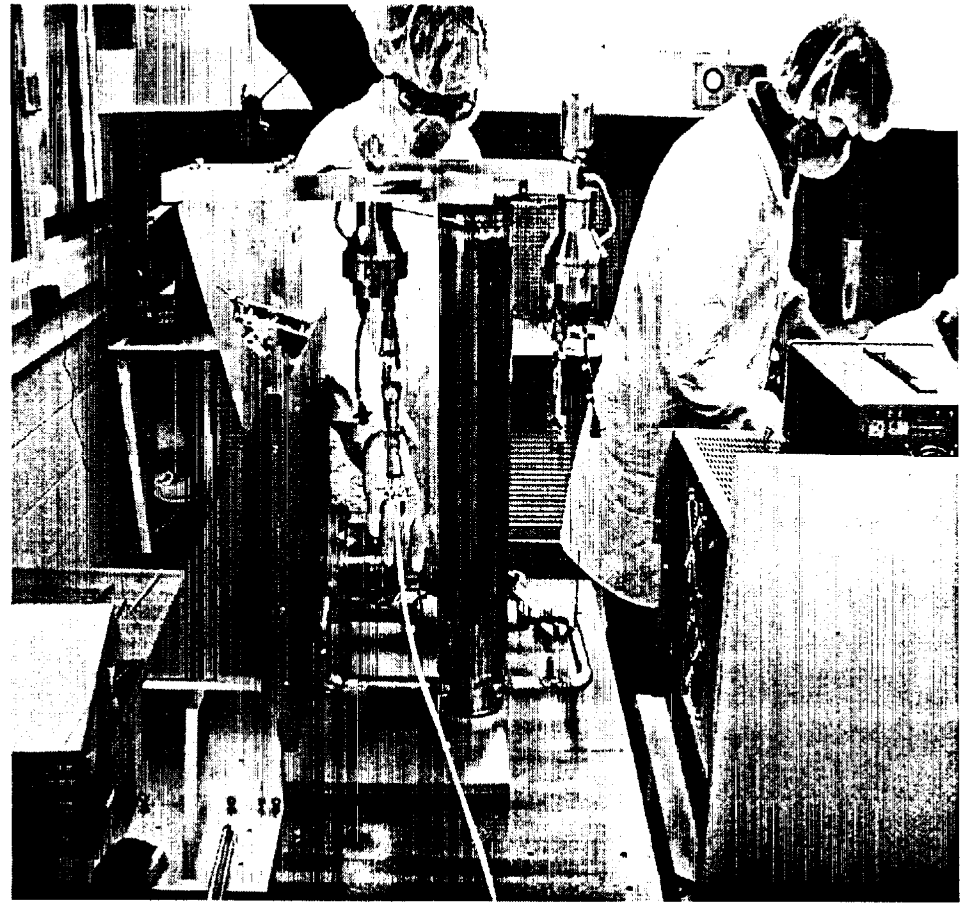
Features

- **Hermetic, single gas, closed loop**
- **Low mass, high speed turbomachines produce essentially no vibration**
  - No linear motion mass
  - Continuous, steady gas flow
- **Self acting gas bearings support shaft**
- **All metal - no contaminants**
- **Component based system**
  - Fluid tubes between components
  - Readily adaptable to multiple loads
  - Simple cold plate thermal interfaces
- **Simple electronics and controls**
  - Cooling controlled by compressor speed
  - No vibration compensation required
- **Space qualified 70 Kelvin cryocooler**
  - HST Orbital System Test on STS-95, October, 1998

HST/NICMOS 75 Kelvin Cryocooler



- Single stage TurboBrayton Cryocooler with cryogenic circulator

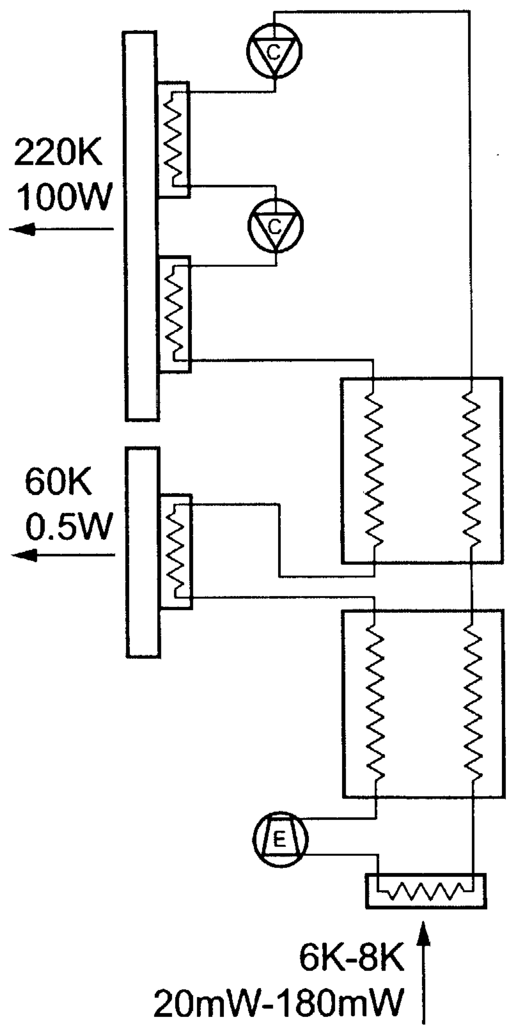


- Flight cryocooler components during initial mechanical spin tests

Turbo-Brayton Cryocooler - NGST Design

- **Turbo-Brayton cryocooler design presented herein is based on the GSFC Yardstick NGST design**
- **Nominally 100 W input power**
- **Mid-IR detector cooling at 6.5 Kelvin**
- **Heat rejection by radiators**
  - 1.7 m^2 split radiator for NGST Yardstick design presented here
- **Essentially no vibration tolerance**

Turbo-Brayton Cooler - NGST System Schematic



- Two compressors in series
  - 50 W each, rejected at 220 K
  - 1 m^2 radiator at about 220 K
  - Will use existing gas-bearing centrifugal design
- Intermediate-stage radiator
  - Approximately 0.5 W, 60 Kelvin radiator
- Two recuperators in series
  - Warm recuperator parasitic heat load rejected at 60 K
  - Baseline existing slotted plate design for both recuperators
- Single expansion turbine
  - Produces refrigeration at 6 to 8 Kelvin
  - Up to 100 mW at 6 Kelvin capacity

Turbo-Brayton Cooler - Technology Status

- **Flight heritage from HOST (STS-95)**
  - Design approach, materials, and assembly methods established during HST/NICMOS Cryocooler qualification
- **Compressor**
  - Operating temperature and power levels have been demonstrated
  - Performance optimization required for NGST flow rate
- **Turbine**
  - Bearings demonstrated at 12 Kelvin
  - Demonstration for 6 K operation in year 2000
- **Recuperator**
  - Slotted plate (NICMOS) design is baseline
  - New recuperator developments aimed at improved efficiency and packaging of recuperators

Turbo-Brayton Cooler - Development Plan

- **Proof of Principle System Demonstration in 2000**
  - Component designs tested
    - **Low power compressor modified for helium (approximately 50 W)**
    - **Turboalternator modified for helium gas and 6 Kelvin operation**
    - **HST/NICMOS slotted plate recuperative heat exchanger**
  - Establish component performance characteristics
    - **Compressor efficiency**
    - **Heat exchanger effectiveness down to 6 Kelvin**
    - **Turboalternator efficiency**
- **Integrate improvements into breadboard by 2002**
  - Refine turbine design to improve cycle efficiency
    - **Reduced rotor size**
    - **Hybrid bearing support**
  - Higher performance recuperators

Turbo-Brayton Cooler - Summary

- **Turbo-Brayton Technology for NGST**
  - 100 W input power, 40 kg mass, approximately 100 mW at 6 K
  - Radiator size of 1.7 m^2
- **Development Schedule**
  - Proof of Principle demonstration in 2000
  - Breadboard cooler demonstration and begin life test in 2002
  - Flight qualification of cooler in 2004
- **Interfacing and integration issues should be addressed as part of payload design since components can be integrated separately**
  - Components are connected by stainless steel tubing over large distances
    - Bellows can be added to allow flexibility between components

Two-stage Sorption J-T Cryocooler

- **NASA/Jet Propulsion Laboratory (JPL) has designed a two-stage J-T cryocooler**
  - **Hydrogen first-stage based on sorption J-T cryocooler for Planck**
    - Pre-cooling of hydrogen provided by radiator
  - **Helium second-stage provides 10 mW of cooling at 6 Kelvin**
    - Second-stage uses carbon adsorption compressor cooled to 18 Kelvin by the first-stage

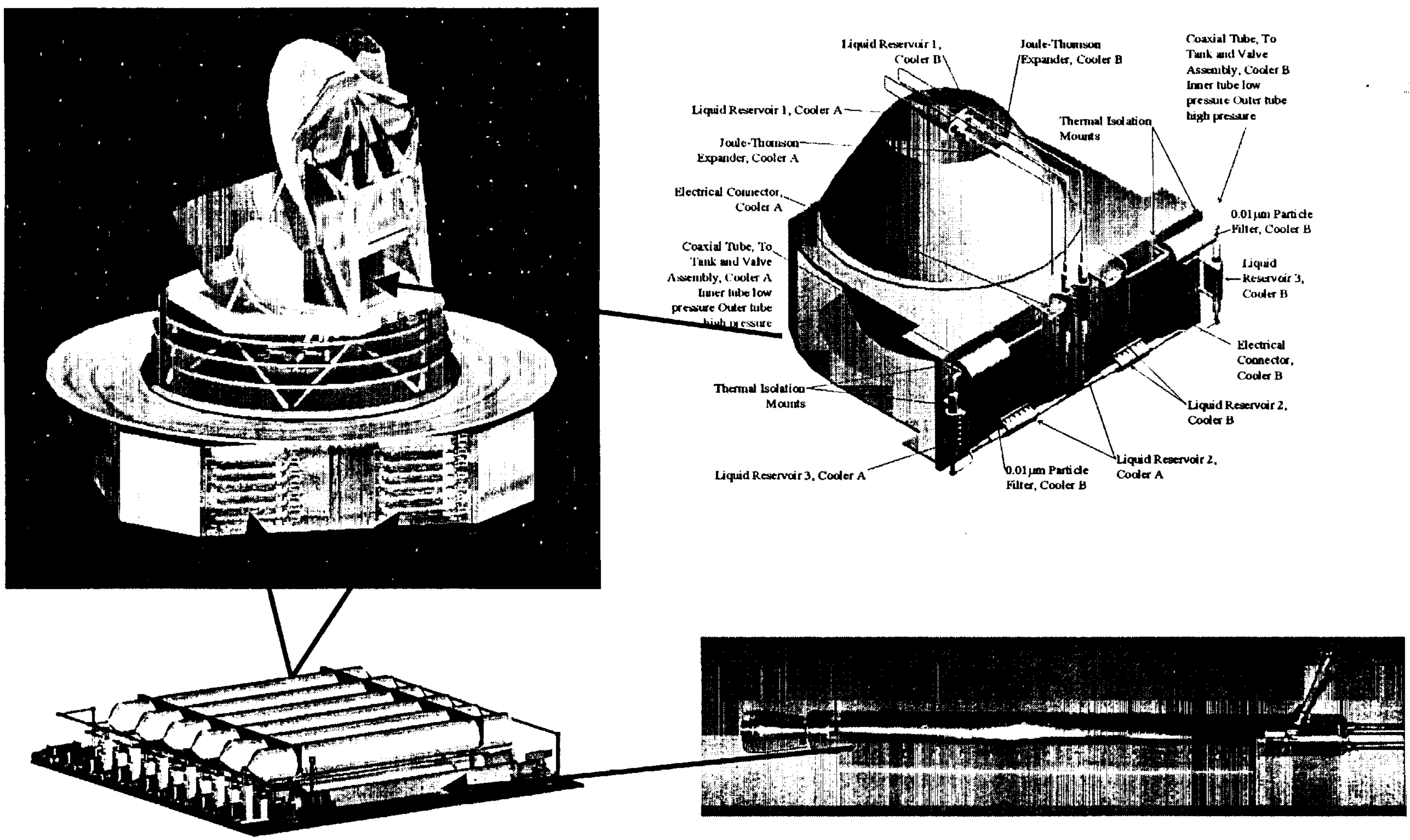
Planck Will Make The Definitive Measurement of The Cosmic Microwave Background

- Planck Is the European Space Agency's Third Mid-Sized Mission (M3)
  - Planck Will Launch With FIRST In 2007
- Two Instruments Image Full Sky Between 30 and 857 GHz In Nine Spectral Bands
  - High Frequency Instrument (HFI) Bolometric Array at 0.1 K
  - Low Frequency Instrument (LFI) HEMT Radiometer at 20 K
- Complete Cooling Chain Includes
  - Passive Cooling To less than 50 K Using V-Groove Radiators
  - Sorption Coolers (Two For Full Redundancy) To 20 K and 18 K
  - RAL Mechanical J-T Cooler To 4.5 K
  - Benoit-Style Open-Cycle Dilution Cooler to 1.6 K and 0.1 K

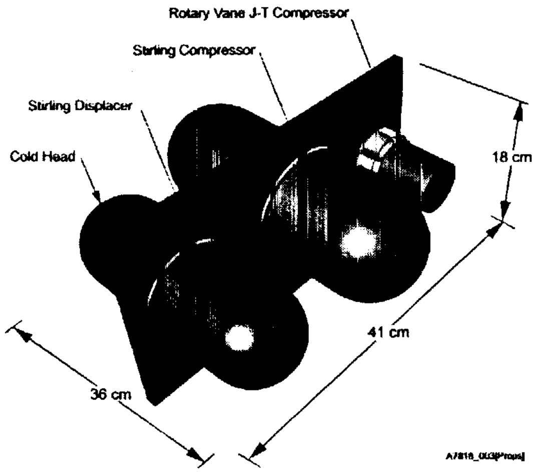
Two Vibration-Free Sorption Coolers Will Fly on the Planck Mission

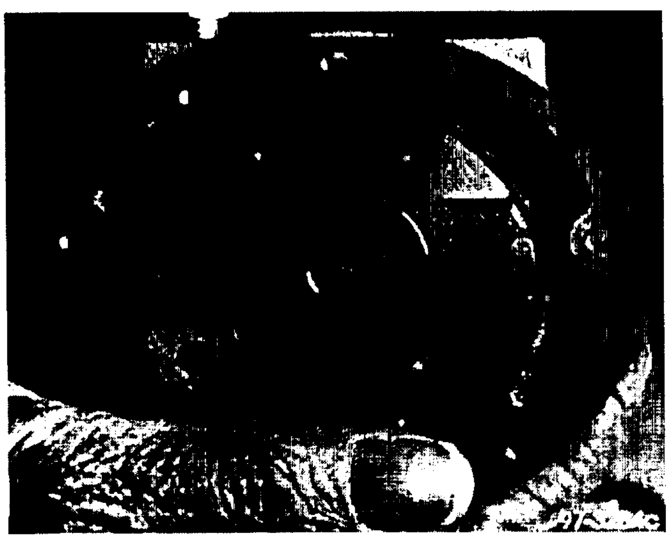
- The fully redundant cooler design will provide approximately 230 MW cooling at 18 K for HFI and approximately 1.45 W cooling at 20 K for LFI
- Mission life requirement is 18 months on orbit
  - 2.5 years minimum with ground testing
- Input power of less than 550 W including electronics
  - Heat rejected at 270 K radiator on spacecraft bus
- Each cooler will mass less than 50 kg including electronics and support structures
- Cooler now in development at NASA's Jet Propulsion Laboratory
  - Flight electronics and software will be developed by ISN in Grenoble, France
  - Qualification Model Cooler delivered January 2003 will fly as redundant spare
  - Flight Model Cooler delivered March 2004

Planck 18K/20K Sorption Cryocoolers



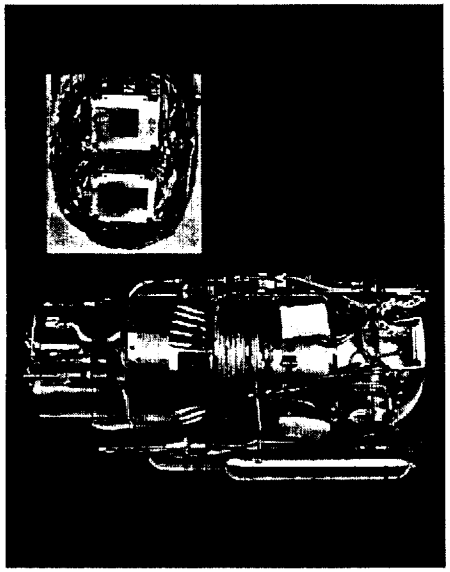
Stirling/J-T Cryocooler - Introduction

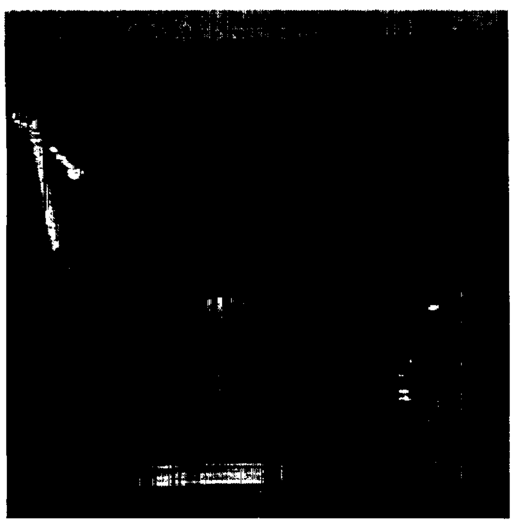




- Stirling/J-T hybrid system under development to provide 250 mW cooling at 10 K
  - Can be scaled to provide 10 mW at 6.5 Kelvin for NGST
- Three-stage Stirling cryocooler based on existing 35/60 Kelvin three-stage cooler
  - New cold finger will provide 15 Kelvin pre-cooling for J-T stage
- Currently developing rotary vane compressor for helium J-T loop

Ball Development of J-T Cryocoolers





- Initial development focused on three-stage J-T systems
- COOLLAR program began in 1985 - developed:
  - compressors
  - non-plugging J-T Valves
  - heat exchangers
  - contamination control systems
- COOLLAR cryocooler flight demonstrated
  - flew on STS-85 in August 1997
  - demonstrated performance of oil-lubricated compressor, non-plugging J-T valves, heat exchangers, and contamination control system
  - all mission objectives met - 300 hours of continuous operation

Stirling/J-T Cryocooler - Status

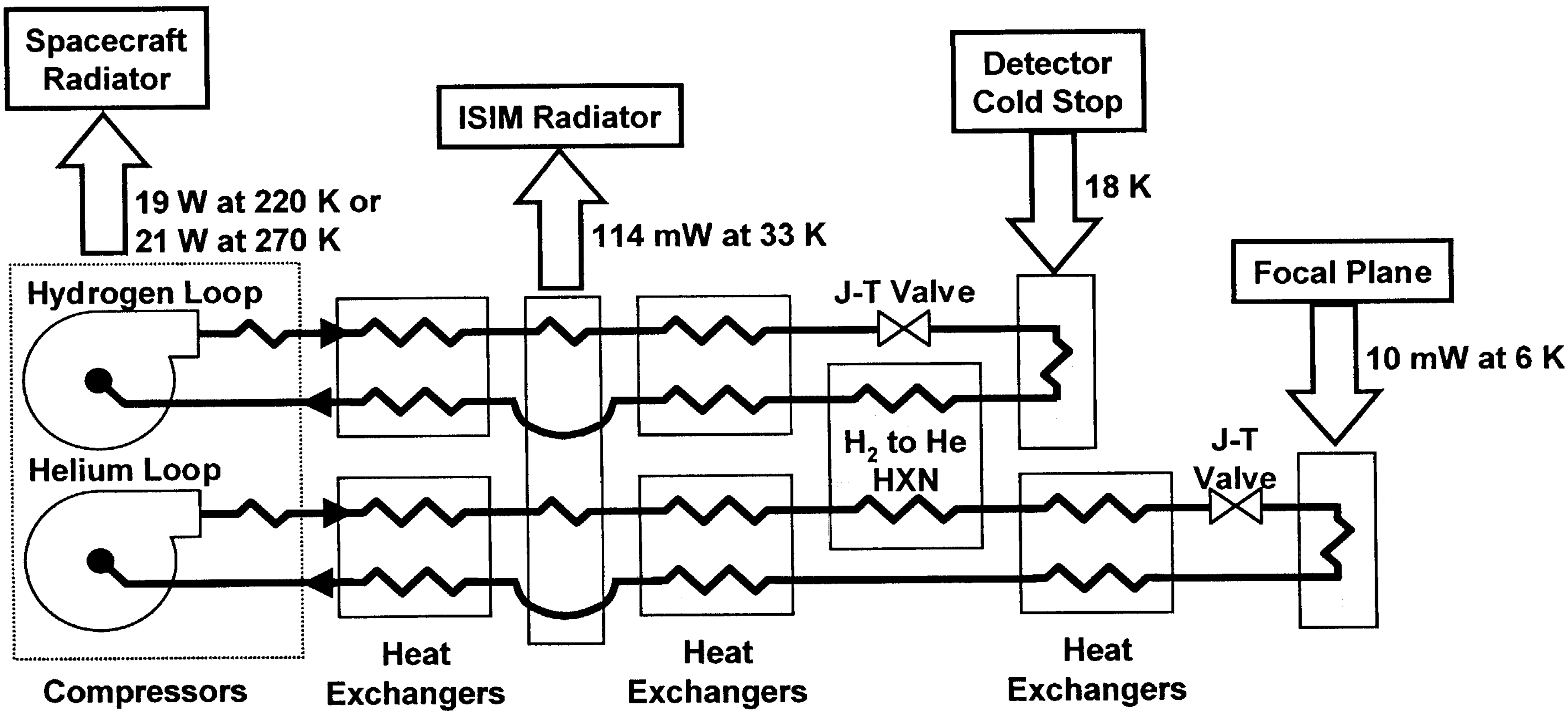
- **Began development of rotary vane compressor in 1996**
  - Based on highly reliable commercial compressor
  - Small, lightweight, no valves
  - Vane wear rate testing shows 10 year life in dry helium

- **Currently developing helium J-T loop**
  - Stirling/J-T hybrid system to provide 250 mW cooling at 10 K
  - Fabrication of J-T loop underway

Ball Two-Stage J-T Cooler - Introduction

- Two-stage hydrogen & helium Joule-Thomson Cryocooler
- Long life rotary vane compressor for each stage
  - Reduced vibration from Stirling cycle linear cooler
- Flight proven J-T cold head technologies
  - Compact, simple tube in tube heat exchanger design, demonstrated on COOLLAR
  - J-T Valves with in line filter - clog resistant, etched “button” valves from COOLLAR
- Electronics
  - Simple brushless DC motor controller
- Low input power system design with use of mid-stage radiator

Hydrogen/Helium Two-Stage J-T Cryocooler



H_2/He J-T Cryocooler - Characteristics

Feature	Benefit
Rotary vane compressors	Simple, valve-less design with long life, no linear motion
Compressors, warm radiator located at/near S/C bus	Minimizes jitter impact, allows optimum NGST passive thermal performance
No moving parts in cold head	No vibration source at detector interface
High efficiency	Minimizes input power, radiator size
Design based on heritage at Ball	Minimizes risk

H_2/He J-T Cryocooler - Performance

Item	NGST Requirement (Goals)	Performance
Focal Plane Temperature	6-8 K	6.5 K w/^{4}He 6 K w/^{3}He
Focal Plane Load	10 mW	10 mW
Cold Shield Temperature	15-20 K	18 K
Vibration Induced Jitter	< 15 nrads LOS disturbance	< 6 nrads if passively isolated, 19 nrads if hard-mounted
NGST ISIM Radiator Sink	<200 mW at 33 K	114 mW at 33 K
Input Power	<100 W at 220 K goal	19 W at 220 K, or 21 W at 270 K
Mass (including Electronics)	Minimize as a goal	12 kg

H_2/He J-T Cryocooler - Summary

- Highly Leveraged, Low Risk Design
  - AFRL 10 K development of long life rotary vane helium compressor
    - Easy scaling (80% of 10 K) to low pressure hydrogen
  - COOLLAR development of cold head technologies
- Inherently High Efficiency
  - Very low input power < 20 W with electronics
- Inherently High Reliability
  -
- Minimal System Impacts
  - Minimal power usage at either 220 K or 270 K
  - Flexible location of compressor
  - No moving parts in cold head
  - Very low induced vibration