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FINAL TECHNICAL REPORT

NASA Grant NSG-7324

"^{3}He BOLOMETER SYSTEMS"

Funded

October 1, 1978 through October 31, 1982

Principal Investigator: Prof. James R. Houck

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ABSTRACT

During the tenure of this grant a ^3He cryostat was constructed to cool a germanium bolometer for use as an infrared detector at submillimeter wavelengths. The system had better sensitivity than any other then existing system for these wavelengths; however, it was clear that the system could be greatly improved if better optical coupling could be achieved between the bolometer and the incoming photon stream. Considerable effort was expended to improve this coupling. However, even our best results fell short of an ideal system by a factor of nearly 5 in coupling efficiency.

CRYOSTAT

The cryostat built in this program used an adsorption pump to reduce the vapor pressure over a small bath of ^3He. A summary of the system's characteristics is presented in the Table 1.

Table 1 - Cryostat Performance

Liquid N_2 hold time	12 hours
Liquid ^4He hold time	14 hours
Pumped ^3He hold time	15 hours
Operating temperature	0.37°K
Heat load into the ^3He	13 μW
Thermal conductivity of heat switch	45 mW/°K
Volume of ^3He pumping system	120 cm^3
Amount of ^3He used in dewar	1 liter STP
Volume of ^4He bath	0.87 liters
Volume of liquid N_2 bath	0.80 liters

The ^3He system consists of three basic parts, a charcoal-filled adsorption pump, a ^4He cooled condenser and a small liquid ^3He chamber. In operation the system is first cooled to about 2K using conventional ^4He techniques. The adsorption pump is heated, forcing the ^3He gas out of the charcoal and into the condenser. The gas then condenses and runs by gravity feed into the ^3He chamber. The adsorption pump was then activated by closing a heat switch between it and the ^4He bath. The ^3He was thus pumped back into the charcoal, resulting in a cooling of the remaining liquid. The system had ^3He hold-time of 15 hours and could be recycled in about 20 minutes. It is an ideal system for conducting tests at temperatures between ~0.3 and 0.4K. A schematic view of the system is shown in Figure 1.

THE BOLOMETER

The bolometer was constructed from doped germanium supplied by A. J. Seivers of the Cornell Physics Department. Only very recently has better material been produced using transmutation-doping. The electrical leads to the bolometer chip were soldered on using gallium/indium solder. The leads themselves were fine brass wires. The bolometer chip was epoxied onto the sapphire receiver chip. The sapphire was coated with a semitransparent coating of Nicrome to improve its absorption properties. The electrical properties of the bolometer are shown in the table. A schematic view of the bolometer and its optical system are shown in Figures 2 and 3. Table 2 lists its physical properties.

Table 2

Heat Capacity of Bolometer Elements

Element	Volume	Heat Capacity	0.43°K Heat Capac
Sapphire chip	0.476x0.476x0.127 cm^3	$3.80 \times 10^{-7}\ T^3$ J/°K	8.39×10^{-11} J/°K
Ge thermistor	0.40x0.30x0.10 cm^3	$3.5 \times 10^{-6}\ T^3$ J/°K	3.22×10^{-11} J/°K
Epoxy	1.6×10^{-5} cm^3	$7.00 \times 10^{-4}\ T^3$ J/°K	8.60×10^{-10} J/°K
Indium solder	1.6×10^{-5} cm^3	$1.47 \times 10^{-4}\ T^3$ J/°K	1.81×10^{-10} J/°K
Brass wires	3.24×10^{-6} cm^3	1.36×10^{-4} T J/°K	2.02×10^{-10} J/°K
NiCr film	1.7×10^{-7} cm^3	1.50×10^{-3} T J/°K	1.10z10^{-10} J/°K

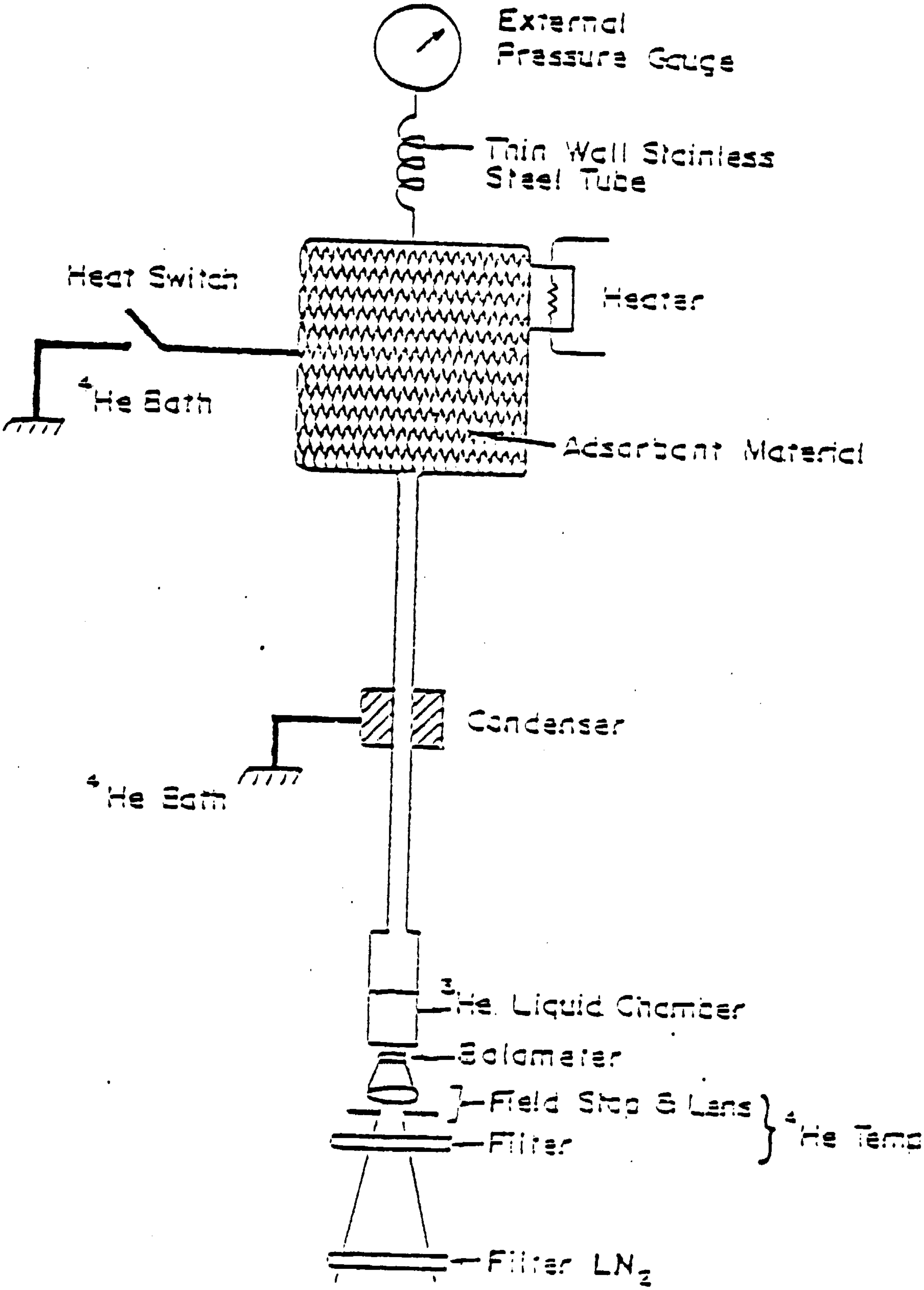
External
Pressure Gauge
Thin Wall Stainless
Steel Tube
Heat Switch
Heater
^{4}He Bath
Adsorbent Material
Condenser
^{4}He Bath
^{3}He Liquid Chamber
Bolometer
Field Stop & Lens
Filter
^{4}He Temp
Filter LN_2

Figure 1

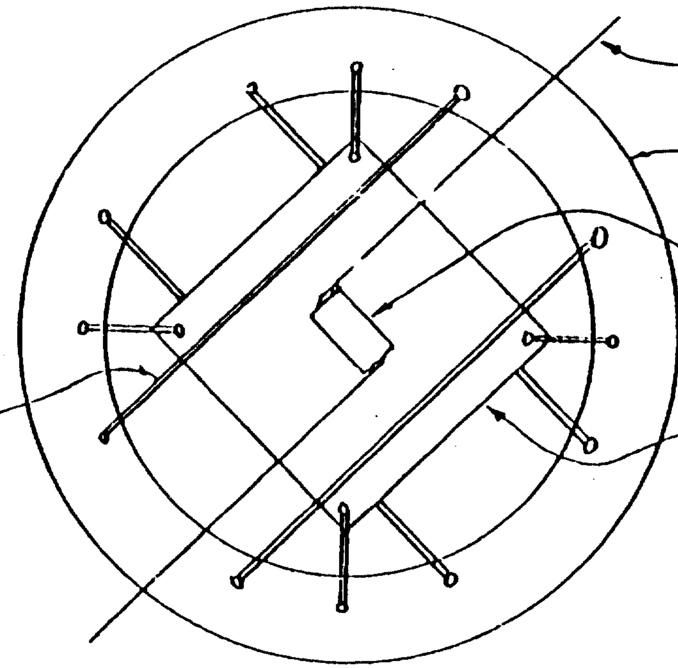

Figure 2 - Composite bolometer used in the ^{3}He dewar.

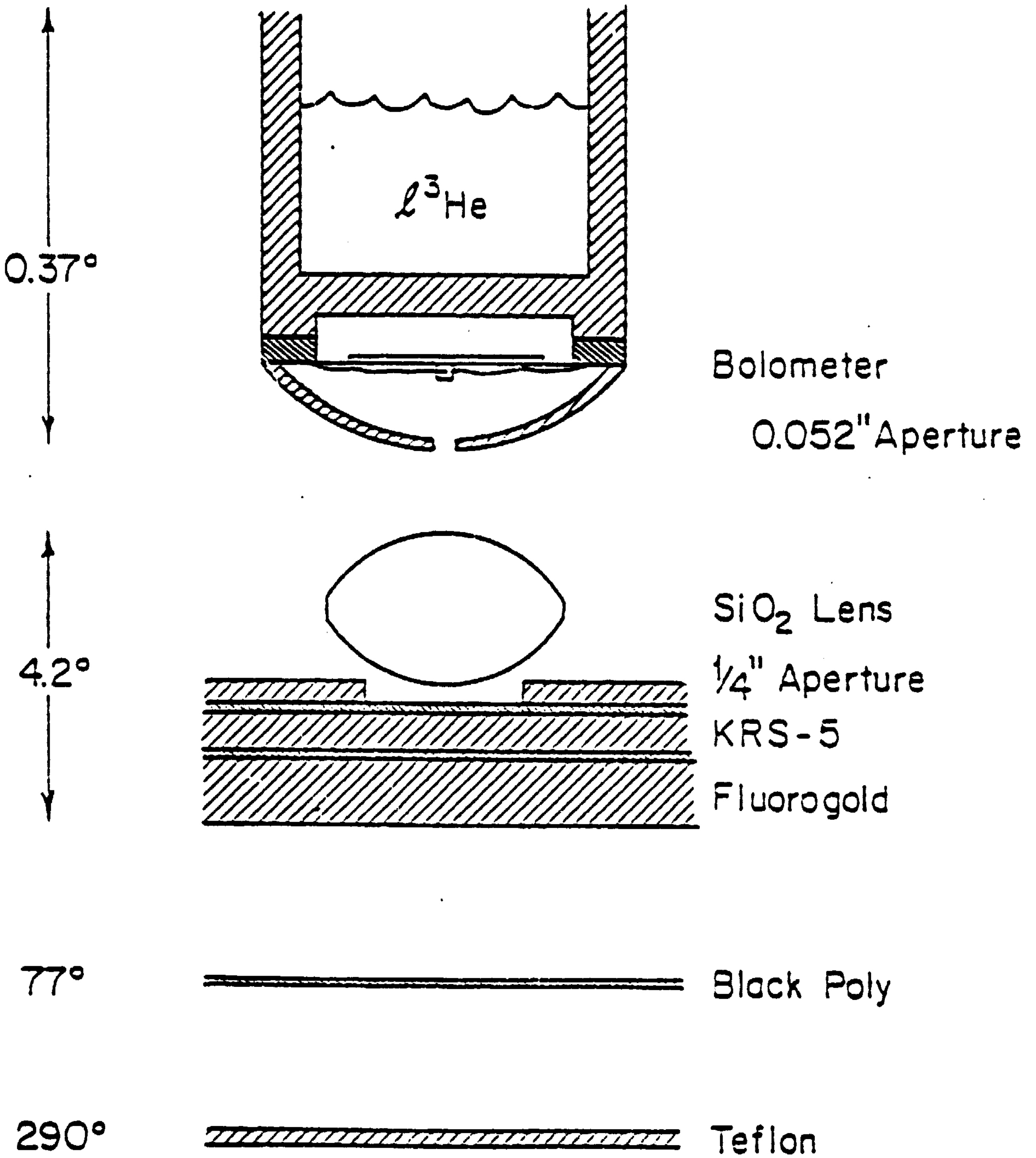
0.37°
ℓ^3He
Bolometer
0.052" Aperture
4.2°
SiO_2 Lens
1/4" Aperture
KRS-5
Fluorogold
77°
Black Poly
290°
Teflon

Figure 3

OPTICAL COUPLING

One of the main difficulties of a system of this type is to efficiently couple the radiation to the bolometer. Our first experiments used a quartz field lens to image the exit pupil to the source onto the entrance aperture of the bolometer cavity. In an effort to improve the coupling, a Winston cone was tested. Although superior- to-simple filed lenses, it did not perform better than our best field lens.

ELECTRONICS

Microphonics is one of the continual problems with many bolometer systems. This is because of the relatively small voltage responsivities of these devices. In a system used for routine observations all sorts of measures can be taken to reduce microphonic noise. Unfortunately, these procedures are not feasible in a system intended primarily for testing since they, in general, make rapid assembly and disassembly more difficult. We therefore equipped the system with an internal JFET preamplifier to reduce both the number and lengths of wires coming out of the dewar with low-level signals. The electrical noise sources are listed in Table 3. Table 4 gives a summary of the bolometer's performance.

Table 3

Dewar Noise at 10 Hz, Measured at the Bolometer

Background power noise	5.2 nV/$\sqrt{Hz}$
Thermal fluctuation noise	5.0 nV/$\sqrt{Hz}$
Bolometer Johnson noise	5.6 nV/$\sqrt{Hz}$
Load resistor Johnson noise	3.2 nV/$\sqrt{Hz}$
Excess current noise	4.9 nV/$\sqrt{Hz}$
Preamp voltage noise	4.1 nV/$\sqrt{Hz}$
Preamp current noise	5.4 nV/$\sqrt{Hz}$

Table 4

Measured Bolometer Electrical Performance

Time constant C/C_e = 13.9 msec

Heat capacity C = 1.50 x 10^{-9} J/°k

Effective thermal conductivity G_e = 1.08 x 10^{-7} W/°K

Thermal conductivity G = 0.91 x 10^{-7} W/°K

Operating temperature T_b = 0.43°K

Load resistor R_L = 36.5 MΩ

CONCLUSIONS

We have developed a high-sensitivity ^{3}He cooled system for submillimeter astronomy. However, thre are still large gains to be had by improving the coupling to the bolometer chip. This system was tested in the field on the Palomar 5-meter telescope and achieved a sensitvity of 5.8 Jy/(Hz)$^{1/2}$. The electrical NEP of the bolometer was considerably better an 10^{-15}W/(Hz)$^{1/2}$.