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PLATO-R: a new concept for Antarctic science

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ABSTRACT

PLATO-R is an autonomous, robotic observatory that can be deployed anywhere on the Antarctic plateau by Twin Otter aircraft. It provides heat, data acquisition, communications, and up to 1 kW of electric power to support astronomical and other experiments throughout the year. PLATO-R was deployed in 2012 January to Ridge A, believed to be the site with the lowest precipitable water vapour (and hence the best atmospheric transmission at terahertz frequencies) on earth.[1–4] PLATO-R improves upon previous PLATO designs that were built into ten-foot shipping containers by being much smaller and lighter, allowing it to be field-deployable within 2–3 days by a crew of four.

Keywords: PLATO, PLATO-R, Ridge A, Antarctic astronomy, robotic observatory

1. INTRODUCTION

PLATO, formed from the words "PLATeau Observatory", is a platform developed by our group at the University of New South Wales for conducting remotely operated experiments on the Antarctic plateau. It shares some features with the US Automated Geophysical Observatories (AGOs) and is primarily distinguished by its greater electrical power capability—a kW or more, compared with ~ 60 W for the original AGOs.

The basic PLATO concept is built around two boxes, or modules: the Engine Module contains diesel engines, electrical generators, and 4000–6000 liters of Antarctic blend kerosene; the Instrument Module provides a warm environment for the control computers, DC power supplies, batteries, satellite communications, and the scientific experiments—although some of the experiments may be separated from the Instrument Module. The two modules are joined by an "umbilical" cable to distribute power and control signals; the modules are placed ~ 60 m apart to avoid water vapour from the diesel exhaust affecting the experiments.

In addition, eight 195 W solar panels provide power throughout the summer, allowing fuel to be saved for the winter.

The first PLATO[5–9] became operational at Dome A in 2008 January, and ran continuously for 204 days during that year.[10–12] Following a servicing mission in 2008/2009 conducted by the Polar Research Institute of China, PLATO operated without interruption for 1235 days, with no human on site apart from a few weeks during each of the yearly servicing missions. PLATO stopped on 2012 May 31, following many months of operation with much lower than usual temperatures in the Engine Module. The reasons for this are currently unknown.

The original PLATO weighed just over 8 tonnes. A scientific collaboration with Japan led us to develop a 4 tonne version, PLATO-F,[13] that was able to be lifted from the Shirase icebreaker to the traverse sleds by the helicopters that were available to the expedition. PLATO-F was deployed to Dome Fuji in late 2010. A very similar version, PLATO-A, was taken to Dome A in late 2011 to power the Chinese 0.5 m optical AST3 telescope.[14]

This article describes PLATO-R, our latest version, which at 1.5 tonnes is less than half the weight of PLATO-F. PLATO-R is able to be deployed using Twin Otter aircraft, and was successfully installed at Ridge A, 150 km from Dome A, in 2012 January. The "R" in PLATO-R stands for "Ridge".

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Figure 1: The central section of the PLATO-R Instrument Module being loaded into a Twin Otter by a forklift for the flight from the South Pole to Ridge A, 2012 January. The module has a few cm of clearance in width and depth. At Ridge A, the module was off-loaded by manually sliding it down a ramp. Black nylon webbing straps were riveted to the fibreglass module exterior to provide hand holds. On the right face of the Instrument Module there is visible one of two 150 mm diameter holes forming part of the heat exchanger system for cooling the module. The heat exchanger itself was removed for transport.

2. PLATO-R DESIGN

2.1 The design brief

PLATO-R was designed to run HEAT, a 0.6 m terahertz telescope with a detector cooled to 55K using a closed-cycle cooler. The average power draw for the experiment was 150 W, and the goal was to run it for one year between servicing missions. Being some 928 km from the nearest person (at the US Amundsen-Scott South Pole Station), PLATO-R has to be very reliable, and to incorporate redundant design elements to guard against single-point failures.

The most difficult design constraint to meet was that PLATO-R had to be deployable using a reasonable number of Twin-Otter flights from the South Pole. No heavy machinery is available at Ridge A to help with moving equipment. The size of the cargo door of the Twin-Otter set the maximum dimensions for the component parts (see Figure 1). PLATO-R also had to be able to be assembled and made operational by three people at a high altitude (4,035 m) field camp at ambient temperatures averaging $-40°$C over a period of 2–3 days. One thing in our favour is that the winds are very low, since Ridge A is close to the origin of the Antarctic katabatic wind flow.

2.2 Our solution

Much of the design of PLATO-R is in common with the other PLATOs, and can be found in the references. We used the same supervisor computer system, Iridium modem communications, and a Controller Area Network (CAN) bus connecting all the electrical sub-systems. The Engine Module was downsized to use two, rather than 5–6, Hatz 1B-30 diesel engines.

Eight solar panels arranged on the four vertical sides of a cube provide 1 kW of electrical power during bright sunshine. The panels are off-the-shelf monocrystaline solar panels designed for rooftop use. While each is nominally rated at 195 W,

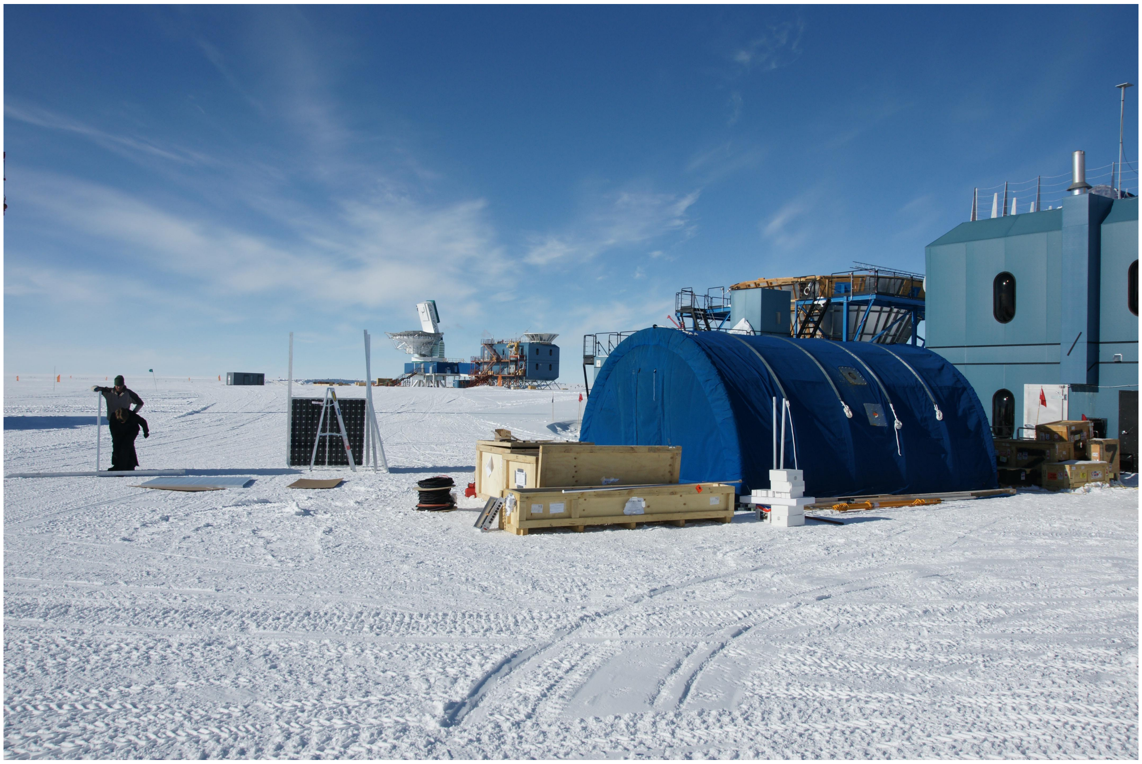

Figure 2: The Weatherhaven tent at the US Amundsen-Scott South Pole Station in which PLATO-R was assembled and tested prior to transport to Ridge A in 2012 January. The cube of solar panels is partially assembled to the right of center.

we achieve 230 W in Antarctica when the panel is mounted vertically; the difference is due to a combination of the lower temperatures improving the panel performance, and additional sunlight reflected from the snow. Each pair of panels is controlled by a separate maximum power-point tracker. The panels are arranged in a cube, to distribute power over the day, however, given sufficient battery capacity, it would be better to face all the panels north to maximize the total power available in a day.

The smaller size of PLATO-R compared to the earlier PLATOs, which were designed to the dimensions of two 10-foot shipping containers, meant that there was less room for thermal insulation. However, the smaller surface area or PLATO-R reduced the heat losses, so the net result was superior thermal performance. Thermal regulation remained one of the major issues, with a need to keep the batteries above $-25°$C, while using minimal power for heating. We provided resistive heaters for the batteries, and placed the batteries in a thermally insulated section within the Instrument Module, with provision for forced air circulation to move heat from the batteries to the main part of the Instrument Module.

It was also necessary to provide sufficient heat dissipation capacity to stop the Instrument Module from over-heating in summer. Furthermore, we wanted a completely sealed module to prevent the ingress of wind-blown snow. Our cooling solution was to use an external heat-exchanger through which air from within the Instrument Module could be blown.

Thermal regulation of the Engine Module mainly involves dissipating heat from the running engine, and was achieved by using a fan to expel air through a 150 mm diameter PVC pipe. A small pump was used to circulate fuel through channels in the alternators to keep the alternators cool, and to store heat in the fuel to help maintain the Engine Module temperature when the engines were off. Resistive heaters were provided at the bottom of the fuel tank, below each engine plate, and in the air intake for each engine. This allowed the Engine Module to be brought up to operating temperature under solar power, which is essential during the initial testing at the field camp, at the end of summer just before the sun is setting, and for restarting a cold engine during winter.

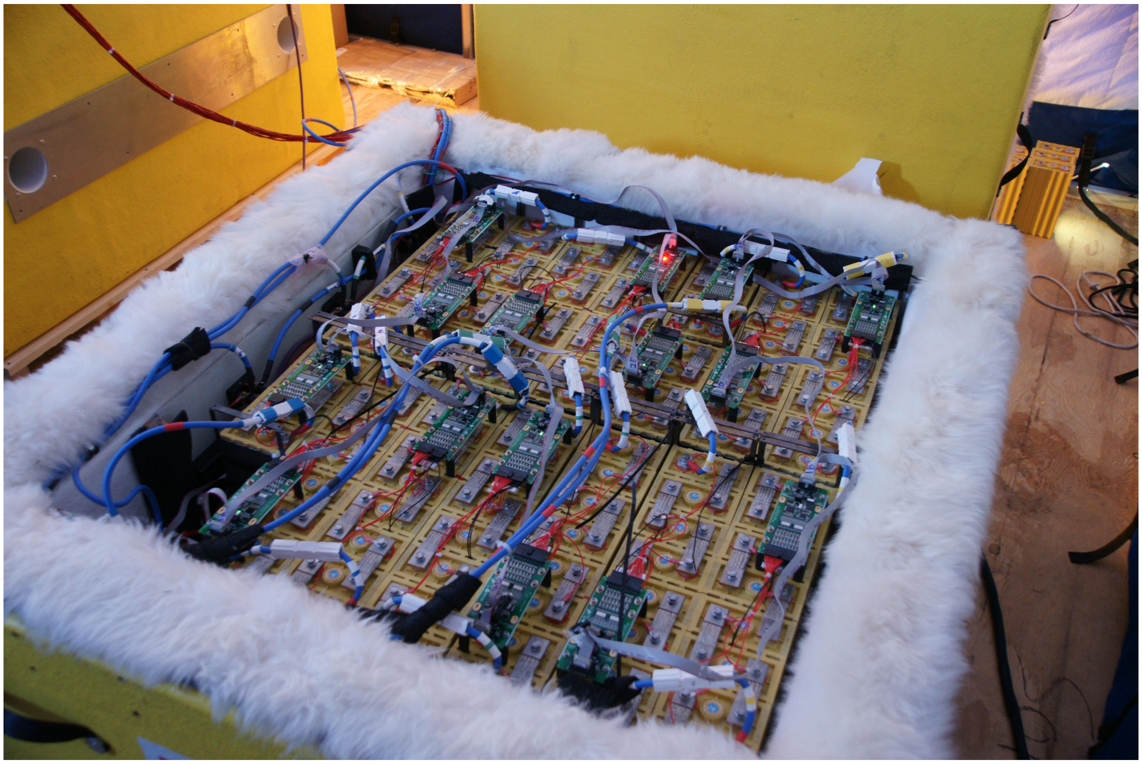

Figure 3: The 22 kWHr LiFePO4 battery pack in the base of the PLATO-R Instrument Module. Each block of 4 or 8 cells can be removed by disconnecting the white Anderson connectors. Each block has a battery management module that monitors the voltage of the cells, and can switch in 250 mA shunts to balance the pack. The batteries are isolated from the Antarctic ambient temperature by a 15 cm thickness of polyurethane foam. The New Zealand sheepskin around the edge of the battery box is design to make a seal with the module above, and effectively prevents the ingress of tiny wind-blown ice crystals known as "diamond dust".

Both the Instrument Module and the Engine Module were made in hinged sections (see Figures 4 and 5) for relatively easy access, and to allow disassembly for transport.

2.3 Batteries

PLATO-R contains 108 60 AH lithium iron phosphate (LiFePO4) cells (Figure 3), arranged in three parallel "strings" of 36 cells, producing a total storage capacity of 22 kWhr at 120 VDC. The battery pack weighs about 270 kg.

The large battery capacity increases the flexibility of operation of PLATO-R. E.g. it allows the engine duty-cycle to be set so that they are always run at their optimal load, thereby achieving maxmimum efficiency and eliminating wet-stacking. It also gives us a couple of days of leeway to attempt to remotely restart engines if something goes wrong.

The advantages of LiFePO4 cells for our application are excellent deep discharge capability, increased power density over lead-acid, and the ability to source and sink very large currents. The main disadvantages are a reduced lower temperature limit ($-25°$C, c.f. $-40°$C for lead-acid) and the need for a complex battery management system.

The strings are connected to the 120 VDC power bus through 150 A fast-blow fuses. The 36 cells in each string are divided into four packs of 8 cells, and one pack of 4 cells.

LiFePO4 cells need careful handling to avoid damage. They must be kept above about 3.0 V (else they can suffer loss of capacity), and they also must be kept below about 3.8 V (else they can out-gas and be irrevocably damaged). In practice, the cells are best kept between 3.1 and 3.5 V. The additional capacity gained by charging above 3.5 V is only a few percent, and the risk of over-charging is too great.

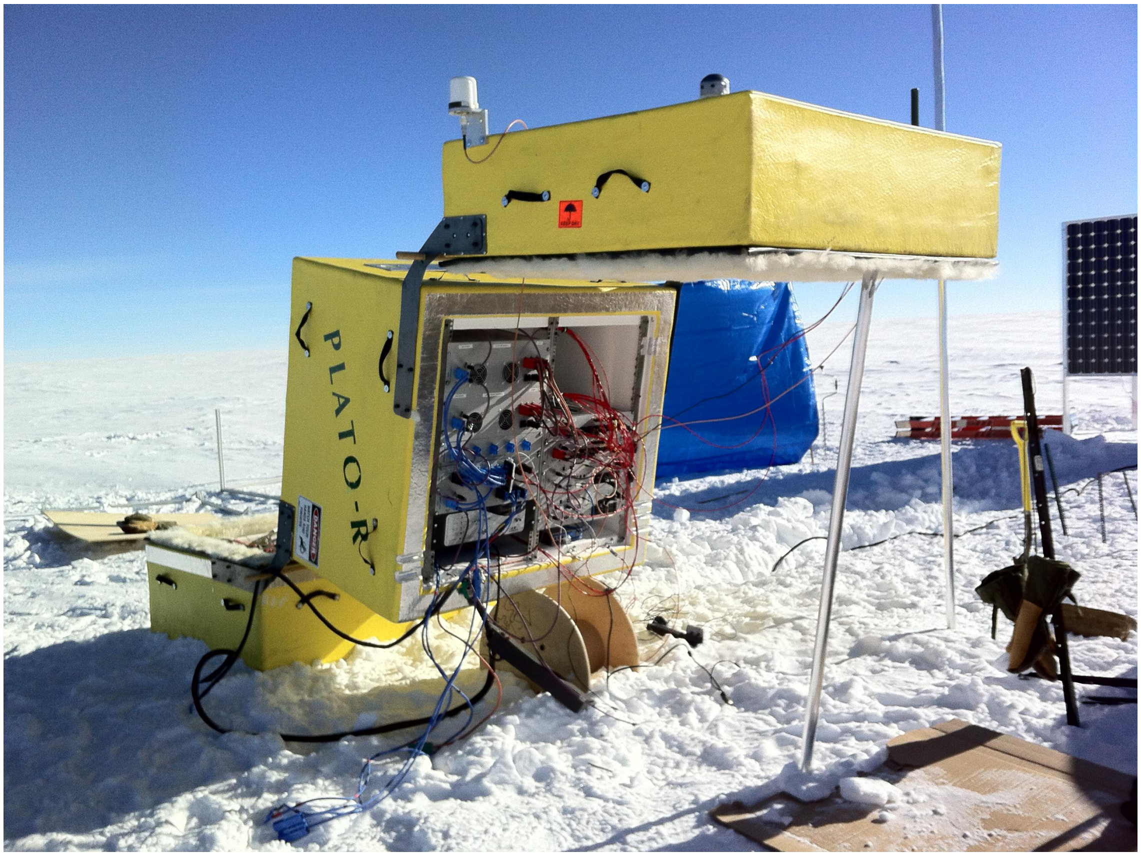

Figure 4: The PLATO-R Instrument Module at Ridge A, hinged open for easy access to the battery pack at left, the electronic racks in the center, and the lid containing the Iridium aerials and cameras. The thick black “umbilical” cable connects the Instrument Module with the Engine Module; it contains two 120 VDC copper wires, an earth wire, and a Controller Area Network cable. Solar panels are visible to the right. The tarpaulin to the right of center was used as a wind break during assembly.

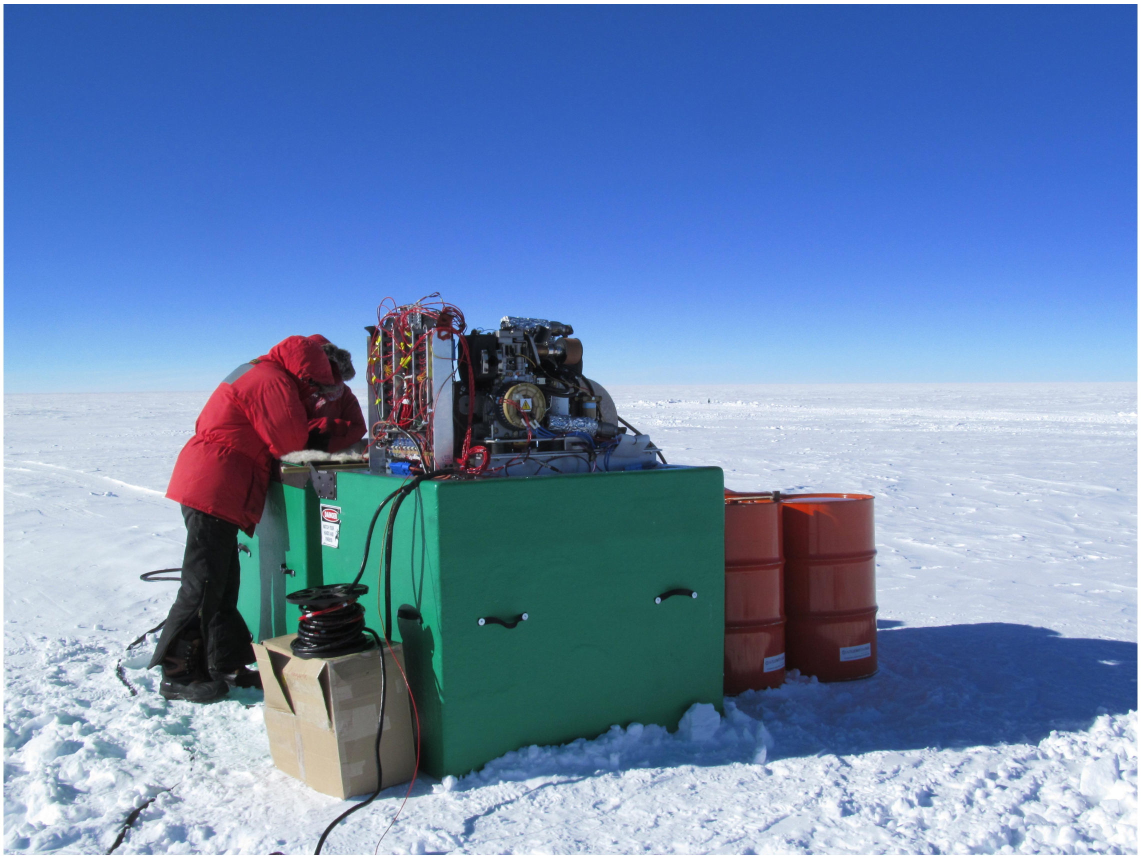

Figure 5: The PLATO-R Engine Module at Ridge A, with its lid unhinged to expose the diesel engines and control electronics. Beneath the engines is a bladder containing 800 liters of JP-8 fuel. Each of the two engines is on a separate plate for easy maintenance. The plate includes the engine control computer, Tritium WaveSculptor three-phase motor controller and DC regeneration unit, fuel pumps/filters, oil pumps/filters, and a 20 liter oil tank. The WaveSculptor is used to start the engine by driving the alternator from the 120 VDC bus, and, when the engine is running, the WaveSculptor sends a programmable amount of power from the alternator to the bus. Telemetry includes engine RPM, alternator current/voltage, cylinder head temperature, exhaust temperature, and alternator temperature.

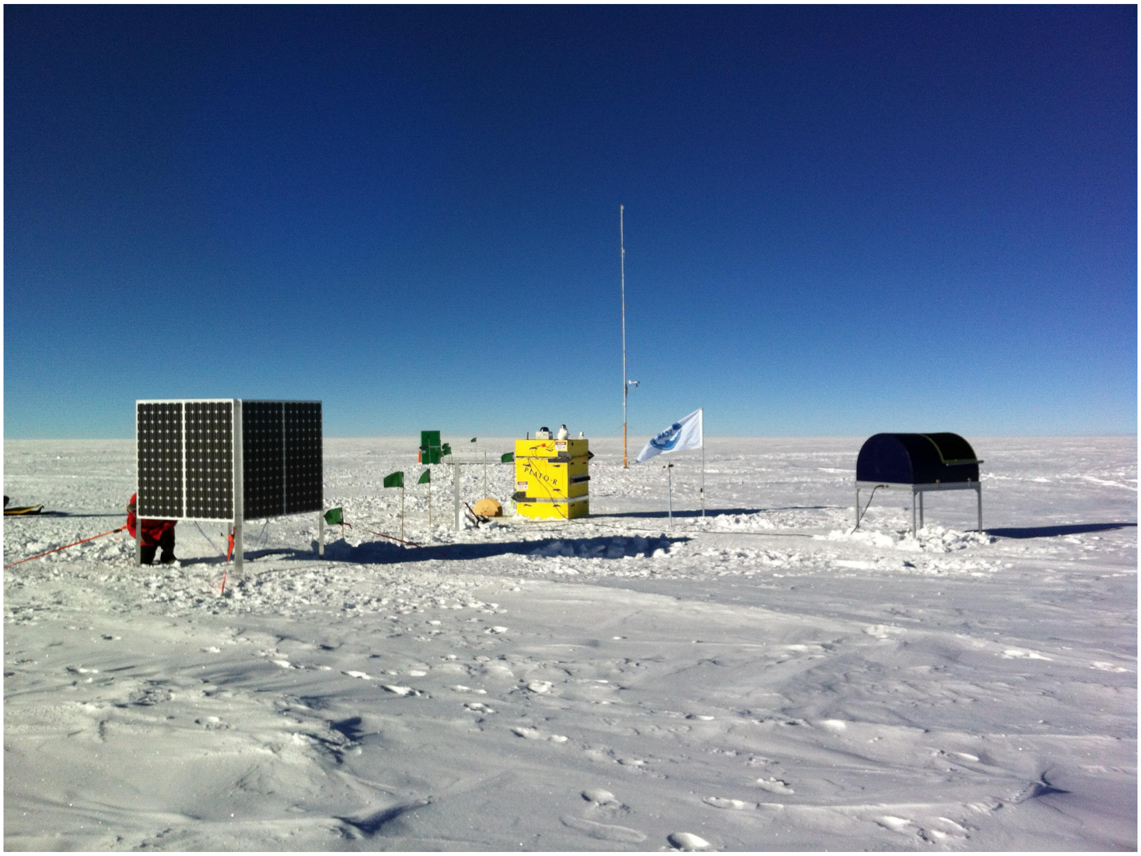

Figure 6: The PLATO-R observatory fully installed at Ridge A in 2012 January. The solar panel cube is at left, the Engine Module is barely visible, 60 m away in the background, the Instrument Module is near the centre, the HEAT telescope is the dark object to the right. The solar panels and telescope are on stilts to prevent wind-blown snow from accumulating. This is not an issue for the Engine Module and Instrument Module, provided that the snow drift is less than a meter or so. An all-sky camera, HRCAM3, is in the dome on the top of the Instrument Module. The pole in the center is a 15 m telescoping meteorological mast supported by four guy wires at about the 2 m level. The flag is that of SCAR, the Scientific Committee on Antarctic Research.

The battery pack must be maintained above around $-25°C$ to function. The pack can we warmed if necessary using resistive heaters beneath the batteries.

2.3.1 Battery management system

The battery management system (BMS) is made from components supplied by Tritium Pty. Ltd. and consists of three "BMS masters", one for each string of cells, and 15 "BMS nodes", one for each pack of 4 or 8 cells. The BMS nodes accurately measure the voltage of each cell (to an accuracy of 1 mV) and relay this information to the BMS masters, and thence via the PLATO-R CAN bus to the supervisor computers.

The nodes also contain shunt resistors that can bypass 250 mA of current around any cell. The nodes can be programmed to turn the shunts on/off at particular cell voltages on a per-master basis.

By judicious use of the 250 mA shunts, over a period of a day or so, it is possible to "balance" the cells in a pack, i.e., to equalize their voltage (which is a proxy for their state of charge).

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