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THZ ASTROPHYSICS FROM DOME A

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Abstract. The THz spectral region includes a number of important transitions which allow us to trace the evolution of the interstellar medium. Because of the opacity of the atmosphere in this spectral range, the best sites for ground-based THz observations are on the Antarctic Plateau; of these sites, Dome A is expected to be the best. THz survey science can be carried out with small telescopes, easing logistical constraints. By deploying a submillimetre-wave tipper/telescope to Dome A, we have trialled several technologies for such an instrument, and we are able to test whether the site quality is sufficient for THz surveys.

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1 THz Astrophysics

The THz region of the electromagnetic spectrum is crucial to our understanding of the evolution of the interstellar medium (ISM). The fine-structure line of ionized carbon (CII, 1.9 THz, 158 μm) is the dominant cooling line of the ISM in the Milky Way and traces cold neutral gas. The NII fine-structure line (1.46 THz, 205 μm) traces the warm ionised medium, and is also emitted from hotter HII regions. This allows it to serve as a tracer of massive star formation throughout the galaxy. At lower frequencies (0.81 THz, 370 μm), the fine-structure line of atomic carbon and high-J rotational line of CO (CO 7–6) are both found towards molecular clouds. The atomic carbon is expected to trace the interface of molecular and atomic material, while CO is found throughout the cloud.

Large-scale surveys of these tracers will enable us to:

1. Trace the evolution of the ISM from ionised to atomic to molecular gas;
2. Estimate the Galactic star formation rate;
3. Use the Milky Way as a template to compare to observations of CII and NII towards other galaxies.

These projects require the ability to make large maps in THz transitions. However, because these science goals are largely concerned with structures on the scale of giant molecular clouds (GMCs), only $\sim$arcminute resolution is required, implying a telescope aperture of order 1 m.

1.1 THz Astrophysics from Antarctica

Because the most stringent limiting factor on THz observations is the Earth's atmospheric opacity, the best place for a THz observatory is above most or all of the atmosphere, either airborne (*e.g.* SOFIA, balloons) or in space (*e.g.* Herschel). However, such facilities have drawbacks: They are expensive, have long development cycles, and stringent size and weight limits. Often, there is a strict limit on the available observing time, which makes it difficult to carry out large surveys. Ground-based instrumentation suffers few of these problems, exchanging them for the problem of the atmosphere. The instruments are cheaper and faster to build, and access to the observatory allows them to be maintained, repaired and upgraded as necessary.

Because of the very cold ambient temperatures of the Antarctic winter ($\sim$200 K), the absolute humidity is very low (although the relative humidity is of order 100%, since the atmospheric boundary layer is in phase equilibrium with the snow surface). On the high Antarctic plateau, the high altitude also reduces the pressure broadening of atmospheric absorption lines and the amount of dry air opacity (although the much higher sites in the Atacama desert have an advantage in these factors). Thus, the atmosphere above the Antarctic plateau is more transparent to THz radiation from space than any other observatory site on

Earth. Indeed, ground-based observations of the 1.46 THz NII line have been obtained from the South Pole Station during the best winter weather (Oberst *et al.* 2006).

The difficulty of constructing instruments for Antarctica falls somewhere on the spectrum between the space-based and temperate-site ground-based cases: the instruments must be winterised and may be remotely operated, making them a bit more expensive and time-consuming to design and build. In addition, logistical constraints in Antarctica tend to limit the size of instruments: a 10-metre submm-wave telescope is operating at the South Pole, but at sites such as Dome C and Dome A, telescopes apertures are unlikely to exceed a few metres for the next few years.

In carrying out the large-scale surveys we envisage, the instruments can be designed purely to execute the survey observations, rather than as common-user instruments, and apertures of order 1 m are acceptable. Thus, the science priorities identified above are well suited to the constraints inherent in Antarctica.

1.2 Dome A

As the highest point of the East Antarctic Ice Sheet (4093 m, with a pressure altitude ~4600 m), Dome A is an obvious candidate as a site for a THz observatory. It is the coldest and hence driest of the current astronomical sites in Antarctica, though it may not be the coldest and driest spot on the continent (*e.g.* Saunders *et al.* 2009). As such, it should have significant THz transparency, and it also benefits from the presence of scientific infrastructure. Expansion of the Dome A infrastructure is planned, and the future station there will greatly enhance support for all kinds of astronomical instrumentation.

In addition, a number of possible astronomical constraints on Dome A have no effect on its potential as a THz site: the thickness and turbulence of the boundary layer are not particularly important, while the frequency of aurora and distribution of optical sky brightness are entirely irrelevant.

1.3 Opacity Requirements

The scientific objectives outlined above require significant areas (10–20 square degrees) to be surveyed with ~arcminute resolution in CII and NII fine-structure lines, requiring about 50 days of time per 10 square degrees per transition. In order to detect CII, the atmosphere above Dome A must have precipitable water vapour (pwv) significantly less than 100 μm, while NII observations are possible with pwv of order 100 μm.

2 preHEAT

PreHEAT (Kulesa *et al.* 2008) is a small (0.2 m aperture) submm-wave tipper/telescope deployed to Dome A. It is mounted on PLATO (Ashley *et al.* 2009;

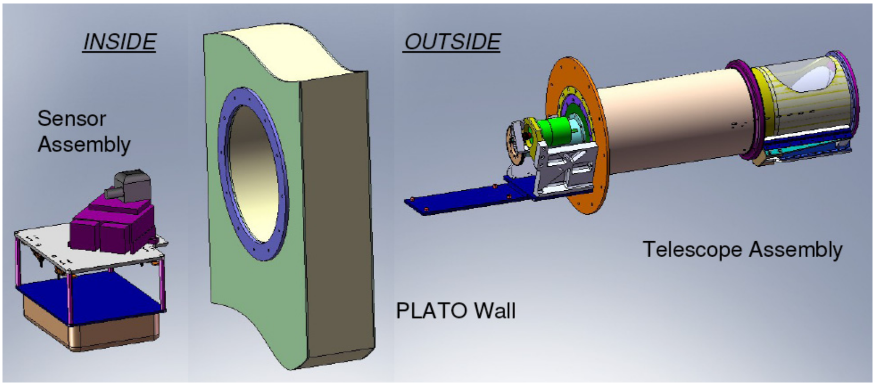

Fig. 1. Design of preHEAT, showing mounting through PLATO wall.

Yang *et al.* 2009), which provides logistical, as well as mechanical, support. Its design goals are:

1. To measure the pwv statistics of the site, and hence assess whether the site quality is sufficient for THz observations;

2. To trial several technologies for remote THz observatories on the Antarctic Plateau, laying foundations for larger instruments;

3. To carry out galactic surveys in the $J=6$–5 rotational transition of isotopically-substituted ^{13}CO.

2.1 preHEAT Design

The design of preHEAT prioritises simplicity and robustness for remote operation at Dome A. It only rotates in elevation, allowing skydip measurements of opacity, and mapping by earth rotation. The submm-wave detector system consists of a Schottky mixer operating at ambient temperature, with a direct FFT spectrometer backend. PreHEAT follows the PLATO instrument model: Power and communications infrastructure are supplied by PLATO, while the instrument operates automatically.

2.2 preHEAT Operation

PreHEAT was deployed to Dome A in the Austral Summer 2007/8, and operated continuously until the shutdown of PLATO in August 2008. The 660 GHz (450 μm) opacity of the atmosphere above Dome A was measured regularly, and converted to an estimate of the pwv, using the *am* model (Paine 2004). This model may then be used to estimate the atmospheric opacity over the whole THz range.

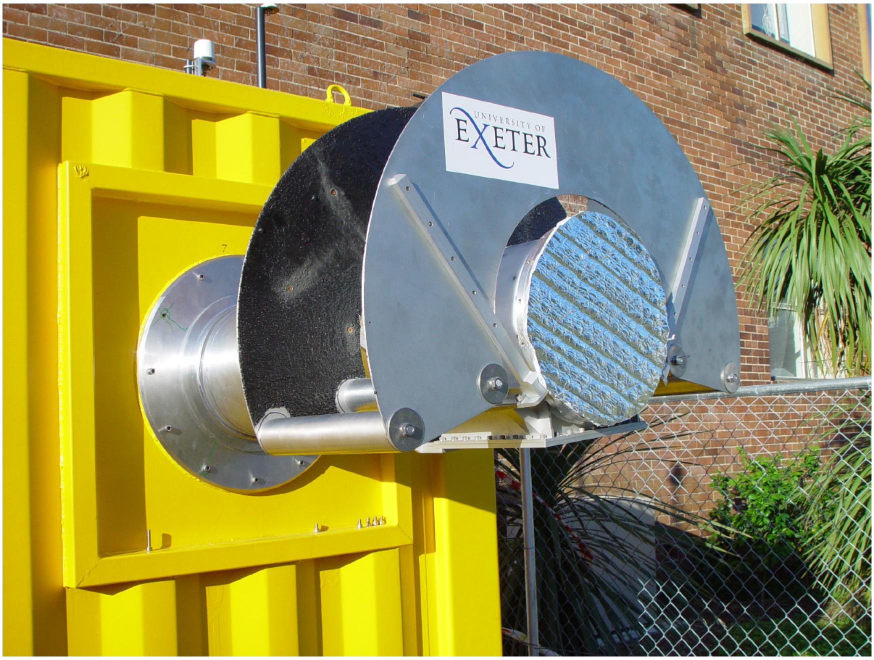

Fig. 2. preHEAT mounted on PLATO during pre-deployment testing.

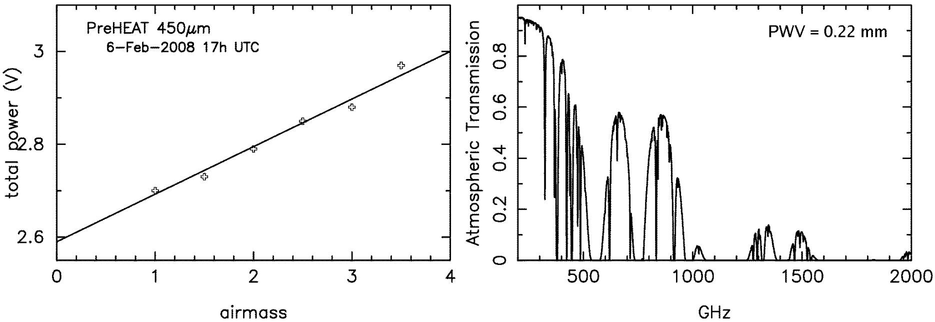

Fig. 3. *Left*: a sample skydip at 660 GHz, measured in late Austral Summer; *Right*: the atmospheric transmission spectrum estimated from the same skydip.

3 Future Instrumentation

3.1 HEAT

HEAT, the High Elevation Antarctic Telescope, is designed to address the science priorities listed above, building on both the success of preHEAT and the lessons learned during preHEAT operations. HEAT retains the one-axis design, and will also rely on PLATO for infrastructure, but will field multiple receivers to cover the various THz transitions. HEAT will also use Schottky mixers, with an option to cool them to decrease receiver noise.

There is further potential to upgrade HEAT (reHEAT), using cryogenic SIS and HEB mixers, whose better noise characteristics will enable a more extensive mapping programme.

3.2 FIRI Pathfinder

FIRI is a proposed far-IR space interferometer (Helmich & Ivison 2009). A pathfinder instrument has been suggested, which would act as a technology testbed and science demonstrator. Dome A is a possible site for such an instrument, most likely operating at a wavelength of 200 μm, where Dome A has significant transparency. An interferometer requires stability as much as transparency, however, and the stability of the THz sky above Dome A is not yet quantified.

4 Conclusions

The THz spectral range contains several important transitions, and ground-based exploitation of the THz will enable us to answer important questions about the evolution of the ISM. While some temperate sites can be used for THz observations, only Antarctic sites allow routine access to the THz spectrum in winter. Of the currently-exploited sites on the Antarctic Plateau, Dome A is the highest and coldest, and hence the driest. It is therefore the leading candidate site for THz surveys of the ISM. By operating preHEAT at Dome A for over 200 days in 2008, we have validated designs and technologies for a THz survey instrument (HEAT), and we are able to estimate the amount of time available at Dome A for such surveys.

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