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Atmospheric sensing for ground-based gamma-ray telescopes

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Abstract. The atmospheric Cherenkov telescope technique is unique in that the atmosphere is an integral part of the detector. A realistic goal for the next generation of telescopes is to make energy assignments and flux determinations to better than 10%. We discuss the requirements for atmospheric monitoring that will be necessary to achieve this and look forward to how these requirements can be implemented.

1 Introduction

The development of the next generation of atmospheric Cherenkov telescopes (typified by the HESS and VERITAS arrays (Hofmann, 2000; Krennich, 2000)) will significantly lower the energy threshold and increase the sensitivity of VHE gamma ray astronomy. However, to exploit the science returns from these facilities it will be necessary to make significant improvements in the determination of the measured energies and fluxes. In previous generations of VHE telescopes, energy and flux uncertainties — mainly due to uncontrolled systematics — have been in the region of 50%. The goal of the next generation must be to reduce these to $\sim 10\%$.

The calibration problem basically breaks down into two parts — the determination of all relevant parameters of the detector (detector calibration) and then feeding these into shower simulation codes to interpret the measured data. The extensive work on shower simulation over the last ten years or so (Mohanty et al., 1998; Konopelko et al., 1999) has resulted in a number of reliable and generally consistent codes being produced. The major limitation now is our ability to perform the required calibrations.

The atmospheric Cherenkov technique is unique in astronomy in that the atmosphere forms the detection medium. Thus, as well as having to calibrate the telescope (optics, detector package, electronics, etc), we also need to calibrate the atmosphere. This means that we need to know the (time-varying) atmospheric composition as a function of height. The remainder of this paper will discuss possible approaches to this problem.

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2 Measurement of atmospheric composition

Bernlöhr (2000) has made an extensive analysis of the effects of the variation of atmospheric composition on the development of gamma ray cascades. He concluded that the following atmospheric properties were significant

1. pressure and temperature profiles
2. ozone profiles
3. aerosol profiles
4. water vapour profiles.

Surprisingly, the ozone profile seems to be the least important of these.

There are a large number of possible approaches to determining these parameters. However, for our purposes, we will require any measurement technique to be capable of routine operation, to be affordable and to be tailored to our purpose.

2.1 Temperature and pressure profiles

The obvious and established method of of measuring atmospheric temperature and pressure profiles is by the use of radiosondes. These are commercially available at moderate cost. Options that are available include free-flying balloons which can provide profiles up to altitudes of ~ 30 km or tethered systems which can sample up to altitudes of 3 km. The tethered option can provide near continuous measurement through attachment of a number of sensors to the balloon or by continuously winching the balloon up and down. A further advantage of radiosondes is that most commercially available systems provide the water vapour profile as well.

The capital cost of a dedicated commercial free-flying system is ~ 100K euro with additional costs of ~ 150 euro per

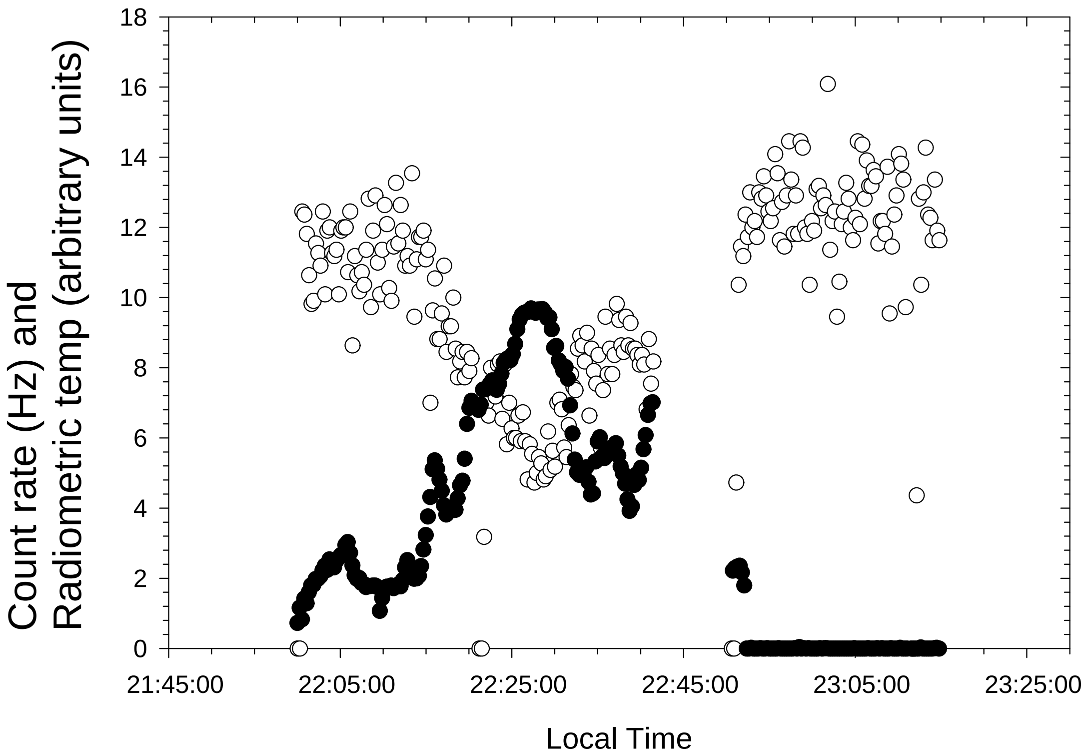

Fig. 1. Variation of count rate of the HEGRA array (open circles) and radiometric sky temperature (filled circles) with time for the night of 24th September 2000. The radimetric temperature is measured in arbitrary units. After about 23:00 the combination of sky conditions and zenith angle was such that the sky temperature dropped below the sensitivity limit of the radiometer.

launch. For a tethered system, the capital cost is ~ 50K euro and no ongoing costs.

2.2 Water vapour profiles

Water vapour profiles can be measured using radiosonde techniques (see above) and commercial systems will provide this as part of the package. The Durham group has had extensive experience of using commercial IR radiometers working in the $8-14\mu$m band to detect atmospheric water vapour (Buckley et al., 1999). This gives a measure of the integrated water vapour profile. We show in Figure 1 the variations of count rate and radiometric sky temperature for the HEGRA array at La Palma. The expected anti-correlation of radiometric temperature and count rate is shown by the data.

Cloud-sensing LIDAR systems working in the IR are available commercially. By recording the backscatter profile a mixture of the water vapour and aerosol profiles can be determined. Systems are available at moderate cost (~ 30K euros) and are reliable. Combining LIDAR techniques with IR radiometers to characterise better the atmosphere is a promising way forward.

Recently, there have been developments in the use of GPS techniques to measure the atmospheric water content (Davies and Watson, 1997, 1999). These use differential GPS receivers and look at differences in reception of signals from a number of satellites. This technique currently gives the integrated water vapour content in the atmosphere but it is hoped that devlopments of the technique will enable water vapour profiles to be available in the next few years. It is difficult to quantify the possible costs at this stage but a figure of ~ 75K euro might be reasonable.

2.3 Aerosol profiles

Aerosol profiles can be obtained from commercial cloud-sensing LIDAR systems working in the red/IR bands (see above). However, the aerosol profile needs separating from the water vapour profile, probably by the use of a LIDAR system in conjunction with another water detection method.

2.4 Ozone profiles

There are two possible approaches to measuring the ozone profile. The first involves the use of radiosondes, where ozone detectors are available as an option on commercial packages. To add an ozone monitoring capablity (for the bottom 3 km of the atmosphere) to a tethered facility costs around 25K euro. To add this capability to a free-flying facility (which will provide ozone monitoring up to 30 km) icreases the capital expenditure by about 15K euro and costs about 500 euro per flight.

The other approach to measuring the ozone profile is through a UV/multiwavelength LIDAR system. This has conventionally been thought to be a very expensive solution. However, we should bear in mind that the essential elements of a UV LIDAR system are a UV laser, a large steerable optical receiver and a fast optical detector package with a digitization and recording facility. This is just an ACT with the addition of a bore-sighted UV laser (which are commercially available at modest cost). However, we will probably find that our electronics packages are too fast for this purpose — typically we will want to record returns over timescales of $\sim 100\mu$s.

3 Conclusions

This brief survey has shown that the technology is available to characterise the atmosphere to a level which may meet the goal of energy and flux determinations to $\sim 10\%$ from the next generation of ACTs. Much of the required instrumentation is available commercially or could be used with small adaptions. In view of the importance of atmospheric sensing for the science returns from these telescopes, it is recommended that a multi-strand approach is taken to these determinations and one technique alone is not relied on.

The use of ACTs themselves as the basis for a multiwavelength LIDAR system opens up possibilities for the future. It is suggested that this requirement should be fed into the design of future telescope systems and detector packages.

The ability to fully characterise the atmospheric composition (and particularly the water vapour content) may provide a means of extending the duty cycle of ACTs. Under conditions of thin high cloud, ACTs still respond to incident showers, but at a reduced counting rate and elevated energy threshold. By using the measured atmospheric composition to fully simulate and so interpret these events, and hence to separate gamma rays from cosmic rays would enable such data to be used. Such an approach may have particular application to multi-wavelength campaigns.

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