Towards a Cherenkov Telescope Ring

Project Overview and Update

Simon Lee 2020-11-03

Cherenkov Telescope Ring (CTR)

- An idea for a world-wide network of Imagin Air Cherenkov Telescopes
- Allows for instantaneous follow-up on transients
- Allows for continuous monitoring of sources over days
- Necessitates a telescope in Australia



VERITAS (\bigcirc), MAGIC (\blacksquare), CTA-South (\Box), H.E.S.S. (\blacktriangle)

Motivation: AGNs

- Science drivers:
 - Blazars: Source type, jet dynamics, energy budget...
 - Radio Galaxies: Inner-jet behaviour, small-scale structure
- Day- & year-scale γ -ray flux variations
- Research requires:
 - Time-dependent spectral energy distributions
 - Multi-wavelength lightcurves
- \rightarrow Requires continuous monitoring



Motivation: Transients

- Science drivers:
 - Neutrinos: Probing particle acceleration processes
 - Gravitational waves: Neutron star merger contribution to very-high-energy γ-ray flux
 - AGN flares
- Research requires:
 - Rapid & continuous followup
- \rightarrow Requires 24-hour availability



Australian site: Location

- An Australian site would be needed
- Which location?
- Weather conditions?
- Accessibility?
- Does altitude significantly affect performance ?



Australian site: Configuration

- How does the performance compare between:
 - A single MST
 - SSTs in an array of 2, 3, 4...
 - How widespread?
 - Multiple MSTs?



Project outline

- Investigate Australia telescope site possibilities with simulations
- Aiming to understand:
 - Significance of altitude
 - Performance difference between **telescope sizes**
 - Amount of improvement with **more telescopes**
 - Performance difference between geometric configuration

CORSIKA & sim-telarray



CORSIKA

sim-telarray

My current simulations

• Testing setups in Arkaroola at 1000m altitude



Simulation runs

- **Source gammas**: gamma rays originating from a specific point-source
- **Diffuse gammas**: gamma rays coming from random places in the camera's FOV
- **Diffuse protons**: proton coming from random places in the camera's FOV

- 7-telescope arrangement to investigate a variety of array setups
- Simulating both MST and SST arrays



• Single telescope centred in a smaller and a larger triangle



 1-telescope setup option to assess monoscopic performance











• 3-telescope arrangements of different sizes



• 3-telescope arrangements of different sizes



• 4-telescope arrangements of different sizes



• 4-telescope arrangements of different sizes



Simulation runs

Energy range	Particle type	Simulated particles	
0.01-0.5 TeV	source gamma-rays	30,000,000	
	diffuse protons	2,000,000,000	
	diffuse gamma-rays	38,000,000	
0.3-5 TeV	source gamma-rays	440,000	
	diffuse protons	120,000,000	
	diffuse gamma-rays	3,600,000	
3-50 TeV	source gamma-rays	170,000	
	diffuse protons	9,400,000	
	diffuse gamma-rays	1,100,000	
30-500 TeV	source gamma-rays	180,000	
	diffuse protons	5,900,000	
	diffuse gamma-rays.	500,000	

Analysis pipeline



Low-level processing

- Telescope simulations need to be calibrated and extracted
- Tools from *ctapipe* are used, the CTA lowlevel data processing pipeline framework prototype



An example gamma ray shower as seen by an SST

Extraction optimisation

- Extraction takes the waveform of a telescope camera pixels and outputs a charge value
- This charge estimates how many photon were incident on the pixel
- The extraction method used in ctapipe finds a peak and sums to the left and right of the peak



An example pixel signal with example shift and width parameters that are chosen for extraction

Extraction optimisation

- Optimising these parameters required simulating Cherenkov photon pulses with night sky background and electronic noise
- Extraction performance can be tested on many thousands of simulated pixel signals



An example simulated pixel signal

Extraction optimisation

 These "shift" and "width" values were optimised for both MST and SST



Extraction performance for different shift values for different numbers of incident photons

Cleaning

- Removes background pixels so the remaining image can be parameterised
- Cleaning method:
 - Choose all pixels above a threshold A with at least 3 neighbours
 - Add all pixels above a lower threshold B that arrived within a given time frame
 - Remove pixels with no neighbors



An example shower with postcleaning pixels highlighted

My script

- Uses tools from *ctapipe*
- Outputs to an .hdf5 files with tables for:
 - 'runs' simulation settings
 - 'array events' shower info (energy, direction, core position etc.)
 - 'telescope events' Hillas parameters, telescope info etc.

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https://github.com/simonleeADL/simtel_processing

My script

- Useful for mono an stereo configurations
- Can process:
 - Arbitrary number of telescopes
 - Arbitrary telescope types
- Outputs:
 - Hillas parameters
 - Event time gradient
 - Geometric direction reconstruction
 - Per-telescope impact distance...



Some of the Hillas Parameters used for reconstruction

High-level processing

- *aict-tools* is a collection of AI tool for gamma-ray astrophysics
- For this project it is used to apply Random Forests on diffuse gamma-ray and diffuse proton simulations to create and implement models for:
 - Energy
 - Direction
 - Gamma / hadron separation

Regression & classification

Regression

• Uses available parameters to estimate the value of a **continuous** variable for an input



Classification

• Uses available parameters to predict the **discrete** category of an input



Gamma/hadron separation

- A model is made to classify showers as being from gamma-rays or from hadrons
- The classifier is trained on diffuse gamma and diffuse proton data
- Assigns a score between 0 and 1 for relative "gamma-ness"



Direction reconstruction

- To reconstruct the direction of the source, the DISP analysis method is used
- The source is assumed to lie on the Hillas ellipse's major axis
- disp is the distance along this axis from the centre-ofgravity to the source position
- Regression is used



- The direction along the axis (the "sign",) needs to be determined
- Classification is used

Performance

- Telescope performance can be estimated using the reconstructed source gamma and diffuse proton events
- *pct-tools* is a collection of scripts to calculate and plot
 - Sensitivity
 - Angular resolution
 - Energy resolution
 - etc.

Angular resolution



Tighter distribution of reconstructed directions around source position \rightarrow better angular resultion

Stereo direction reconstruction

With more than one telescope, geometric direction reconstruction could be used



Angular resolution?



Sensitivity comparison?



Conclusion

- The **Cherenkov Telescope Ring** is an idea to have a worlwide network of IACTs
- Simulations have been made to compare performance of different array setups and telescope types for one altitude
- Performance calculations to be made soon
- Future simulations will compare with an altitude of 0m, compared to 1000m

Thankyou