地上ガンマ線望遠鏡 CTA のための 高効率な集光装置の試作

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Cherenkov Telescope Array (CTA)



Cherenkov Telescope Array (CTA)



LST Status

1st Large-Sized Telescope under construction at Roque de los Muchachos Observatory, La Palma, Spain As of Feb 17, 2018 (~2400 m a.s.l)



- 1st LST is under construction for the CTA Northern Array at La Palma, Spain
- Camera, mirrors, and auxiliary systems are in the final development and testing phase
- LST First light is scheduled in 2018

The More Photons, the Lower Threshold & Higher Sensitivity



- Night-sky background is dominant for lower-energy gamma rays
- Larger mirror area or higher photodetector efficiency lowers the trigger energy threshold → higher sensitivity

Winston Cones

http://www.mpi-hd.mpg.de/hfm/HESS



- Cherenkov camera = Winston cones + Photomultiplier Tubes (PMTs) + Frontend Elec. + Back-end Elec.
- Hexagonal Winston cones cover the whole camera to maximize the collection efficiency and to reduce BG photons

ROBAST

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ROBAST	Hame	Download	Support & FAQ	Documentation -	Publications	

What is ROBAST?

ROOT-based simulator for ray tracing (ROBAST) is a non-sequential raytracing simulation library developed for wide use in optical simulations of gamma-ray and cosmic-ray telescopes. The library is written in C++ and fully utilizes the geometry library of the ROOT analysis framework.

In 2007 ROBAST was first developed to simulate the modified Baker-Nunn optical system of the Ashra experiment, which is composed of three aspherical lenses and apherical segmented mirrors as illustrated in Figure 1. In 2010 ROBAST was released as an open-source project to be more widely used in the coemic-ray and gamma-ray community. It is currently used by many sub projects of the Cherenkov Telescope Array and some other projects.

If you are already familiar with ROOT and C++, and if you are looking for a ray-tracing simulator suited for cosmic-ray telescopes, ROBAST is what you want. Even if you are a ROOT/C++ beginner, it is worth to try ROBAST and start learning ROOT and C++ right now.

Complex Telescope Geometry

Thanks to the ROOT geometry library and additional ROBAST classes, complex telescope geometry with a number of segmented mirrors and telescope masts can be built. Indeed, ROBAST is currently used for optics simulations of several telescope designs of the Cherenkov Telescope Array;

- Large-Sized Telescope (LST): A parabolic telescope comprising of 198 hexagonal segmented mirrors with spherical surfaces.
- Medium-Sized Telescope (MST): A Davies-Cotton system comprising of 88 hexagonal segmented mirrors with spherical surfaces.



Fig 1. ROBAST 3D model of the

Ashra optical system (modified

Baker-Nunn optical system)



- **ROOT-based simulator for ray tracing (ROBAST)** <u>https://robast.github.io</u>
- Developed for cosmic-ray and gamma-ray telescopes with use of the ROOT Geom library
- Open source <u>https://github.com/ROBAST/ROBAST</u>

Winston Cones



- Invented by Winston (1970) a.k.a. Compound Parabolic Concentrators (CPCs)
- In 2D space, Winston cones ideally work (100% for θ < cutoff, 0% for θ > cutoff)
- **.** Not ideal for PMT arrays

Bézier-Curve Profile



- Inclined parabola (conventional Winston cones) is not ideal for hexagonal pixels
- Use of a Bézier curve profile → higher collection efficiency & sharper cutoff

UV-Enhanced ESR



- 54 additional layers (Ta₂O₅ & SiO₂) on 3M Vikuiti Enhanced Specular Reflector (ESR, ~1000-layer polyester film)
- ~93% to almost 100% (w/ ~1% err.) in λ = 300–600 nm and θ = 20°–70°

PMT Characteristics

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- CTA LSTs and MSTs will use Hamamatsu R11920-100-20 and R12992-100-05
- Spherical matte-surface photocathode
- Positional and angular dependence must be taken into account in the design

Angular Distribution of Incident Photons



 Also need to consider the angular distribution of incident photons to maximize the collection efficiency

Prototype Production and Evaluation



Results (465 nm)



- Define **rel. anode sensitivity** (~ col. eff.) because col. eff. $Q = \frac{A_{LC}(\theta)}{A_{mask}} \times \frac{1}{3.7515 \times \cos \theta}$ cannot be defined due to the angular and positional dependencies
- Reaches 100% and higher in the most important angles

Measurement v.s. Simulation (465 nm)

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- ROBAST simulations
 - Rel. anode sensitivity
 - Collection efficiency
- Measured and simulated values are consistent within ~5% (points) for 465 nm
- Rel. anode sensitivity has a bump higher than 100% due to the angular dependence of the PMT sensitivity

365 nm and 310 nm

- Performance at 365 and 310 nm is worse than that of 465 nm presumably because lower reflectance (~93–100%) of UV-enhanced ESR
- Not very consistent with a simulation (PMT angular dependency is different?)
- **But still better by 5–10 points than Al coating cones**

Conclusion

- Developed new techniques to improve conventional Winston cones
 - ROBAST: New ROOT library for ray-tracing simulations
 - Use of Bézier-curve profile
 - UV-enhanced ESR (92–100% reflectance for 300–600 nm and 20– 70°)
 - Take into account the PMT characteristics in simulation and design
- Measured performance at 465, 365, and 310 nm
 - Rel. anode sensitivity of ~95% to ~105% for the most important angles
 - Better by 5–10 points than Al-coating cones