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Performance test of a small-scale prototype of Fresnel optics for cosmic ray observation

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Abstract. For optical detection of cosmic ray, the optics should have a wide-field system. And the system doesn't need a severe angular resolution like an astronomical telescope, so we can use a refracting optics which mechanical assembly may be looser than a reflecting optics. As a refracting optics, Fresnel lenses provide large-aperture and wide-field systems with drastically reduced mass and photon absorption. Such an optical system is adopted as the basic design of EUSO. Now we are developing a small-scale prototype of Fresnel optics, to establish a large-aperture, wide-field refracting optics. This optics has two plastic Fresnel lenses, which are $40cm$ diameter. These are cut on spherical substrates and have grooves in both sides. We report two results of optical tests. One is the result of focusing test using visible lasers. The other is the observation result of Čerenkov light of Air Shower and backscatter light of ultraviolet laser.

1 Introduction

In recent years, the optical observation of a high energy cosmic ray is briskly performed, like imaging atmospheric Čerenkov telescopes (IACTs) for VHE gamma rays and air fluoresce detectors for EHE cosmic rays. Their optical systems use the reflecting telescope. Since their view is narrow, they can observe only specific point sources, or they must arrange many telescopes in order to secure a large view. Then, to conquer these problems, we are developing the wide-field telescope. On the other hand, the severe angular resolution like an astronomical telescope is not required for the optical system for cosmic ray observation. And a refraction optics has little influence of aberration on the mechanical assembly accuracy compared with a reflecting optics. So we have decided to develop the refraction optics.

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2 small-scale prototype

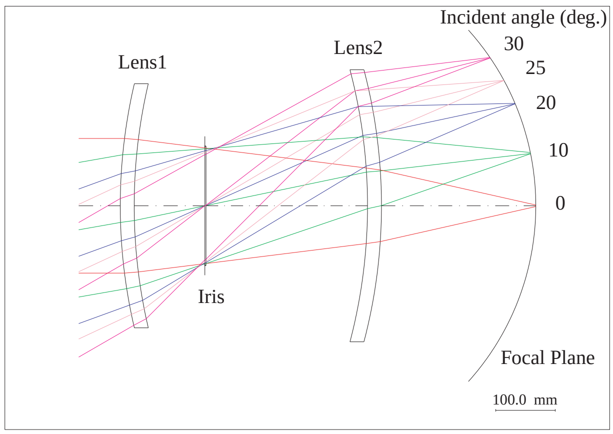

Fig. 1. Fresnel lens system design.

We are developing a small-scale prototype of Fresnel optics, to establish a large-aperture, wide-field refracting optics. A Fresnel lens is relatively light weight and little absorption of photon, even if the caliber is large. Our Fresnel lens system shown in a figure 1 consists of two double-sided Fresnel lenses (D.J.Lamb, 1998) which are cut on spherical substrates. By using this system, the aberration can be small in a wide field of view. Such an optical system is adopted as the basic design of EUSO.

As a first prototype, we made the 40cm diameter telescope shown in a figure 2. (H.Miyasaka, 2001)

Fig. 2. $40cm$ Diameter Telescope.

3 Testing of Prototype Optics

To investigate whether the created optical system functions as a design, two kinds of tests were performed. First, the focusing test was performed using visible laser. Next, the telescope was installed in the Akeno Observatory in Yamanashi Prefecture, Japan ($900m\ a.s.l.$, $138.5°$ N, $35.78°$ E). And we observed the Čerenkov light which a cosmic ray air shower actually emits and scattered light of ultraviolet laser.

3.1 Focusing Test

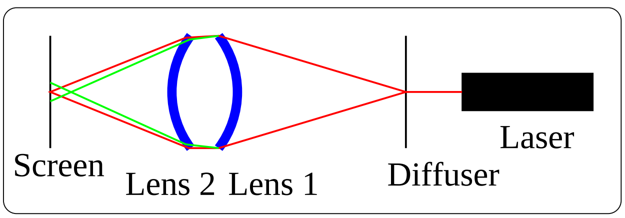

Fig. 3. Configuration of Focusing Test. A diffused laser light is focused on a screen.

Figure 3 shows the configuration of focusing test. A diffused green ($543.5nm$) or red ($632.8nm$) laser light is focused on a screen by Fresnel optics. The distance of lenses and the screen was changed and the relation between a focal length and spot size was measured. (Figure 4) The result of this test was almost obtained as a design.

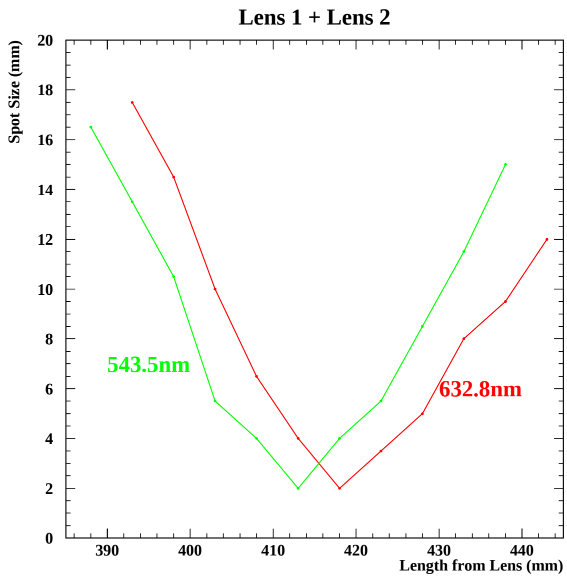

Fig. 4. Spot Size vs. the Focal Length.

3.2 Observation at the Akeno Observatory

3.2.1 Observation of Atmospheric Čerenkov Lights

For evaluation of an overall system, we installed the telescope in the Akeno observatory and observed the atmospheric Čerenkov lights which air showers emited.

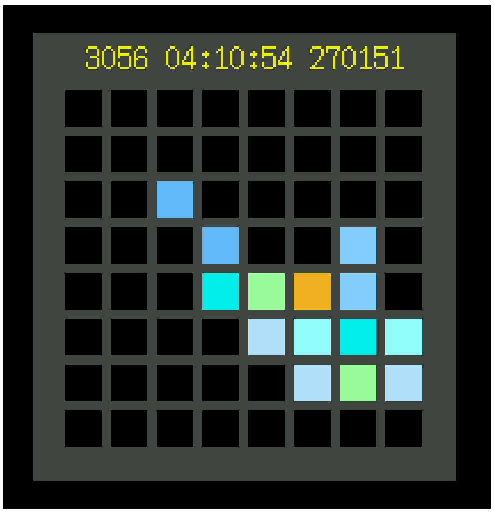

Fig. 5. an Typical Atmospheric Čerenkov Event.

An typical image of Atmospheric Čerenkov Event is shown in a figure 5. In this figure, one pixel size corresponds to about $0.2°\square$, and the field of view of one PMT, Hamamatsu H7546, corresponds to about $1.8°\square$. A distribution of the sum of ADC value, SumADC, which depends to the energy of a primary cosmic ray is shown in a figure 6. Due to the small lenses and slightly high electrical threshold, the threshold energy is considered to be several hundred TeV.

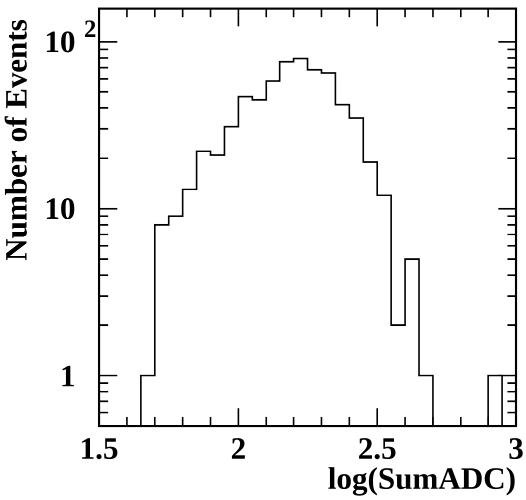

Fig. 6. a distribution of SumADC.

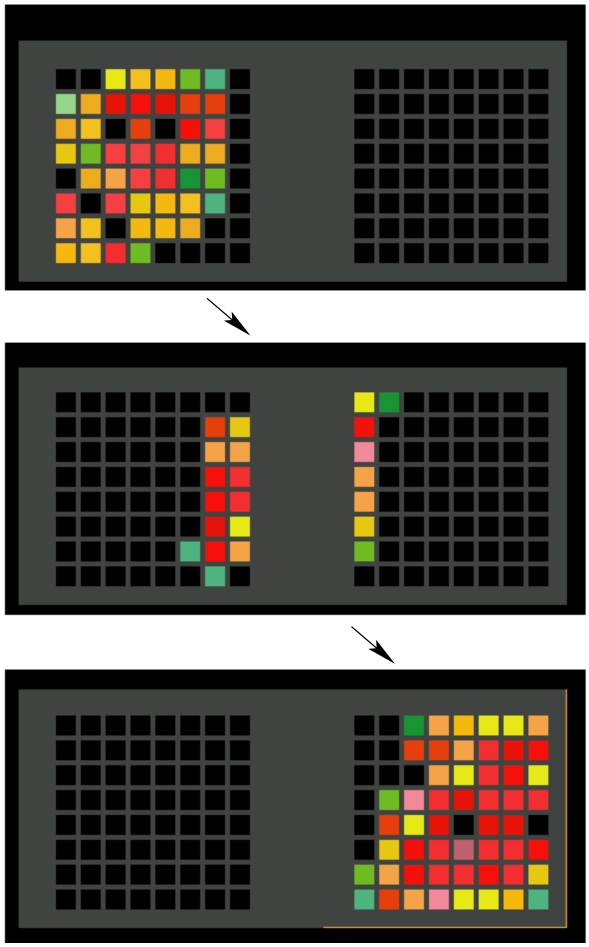

Fig. 7. Laser Event. The image of laser is moving to the right as it goes to the lower figure from the upper figure.

3.2.2 Observation of Ultraviolet Lasers

Observation of the scattered light of ultraviolet laser was also performed. This ultraviolet laser is an Nd:YAG laser with alt-azimuth shooting system. This system is installed in an astro-dome in the place about $20m$ away from our telescope. The wavelength of the third harmonic of Nd:YAG laser is $355nm$. This wavelength is the same as the wavelength region of atmospheric Čerenkov light or air fluorescence light, it is suitable for investigating the characteristic of our system.

The azimuthal scaned laser shooted about $25m$ above our telescope. Figure 7 shows the event display of laser events. It turns out that the image of laser moves to the right as it goes to a lower figure from the upper figure. Moreover, in the middle figure, the image of laser is straddling two PMTs.

4 Summary

We have developed a small-scale prototype of wide-field Fresnel optics. We made a $40cm$ diameter telescope with two double-sided Fresnel lenses which are cut on spherical substrates. The focusing test showed that the relation of the focal length and spot size is almost same as what we designed. We could also obtain expected result, which is the image of the atmospheric Čerenkov light and the scattered light of laser at the Akeno observatory.

Thus, since the first prototype of the optical system using the Fresnel lens showed the performance as a design, we have begun development of the telescope of several meters diameter as a following step. The lens with which a diameter becomes several meters cannot be created one piece. So the optical system must consist many divided lens materials. Therefore, we are beginning to develop the non-axial lens materials.

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References

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