Light-Filtering Ring and Novel Telescope: Super Eyes for Deep Space

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Abstract: Exploring the universe has been a dream of mankind since ancient times, and observation with a telescope is among the most economical way. However, using current large telescopes is far away from being "economical", and their observation capabilities are limited. In this regard, this article puts forward a new principle of telescope, designs a sophisticated light combing system - Light-filtering Ring, and conceives a new type of telescope - Light-filtering Telescope. Compared with current telescopes, Light-filtering Telescope has amazing observation ability and smaller size, which makes it naturally suitable for detecting dim cosmic targets in deep space. Once successfully used, it will greatly expand the horizons of astronomical observation and save tens of billions of dollars in the field.

One Sentence Summary: This article proposes a new type of telescope more powerful in observation capacity and smaller in size than existing telescopes, which is expected to reverse the trend of expensive large-scale astronomical telescopes.

Main Text:

0 Introduction

Since the invention of Galileo Telescope (1609) (*1*), the astronomical instrument has undergone more than 400 years of development. It has evolved from refraction types to reflection ones, from optical types to radio ones, from single-aperture types to synthetic-aperture ones (*2*), etc. However, with limited magnification, traditional telescopes only observe a very narrow part of the vast universe. At the same time, lights can travel for thousands of years, and seems to shuttle through the entire universe. The infinite nature of light propagation and the limited observation capability of telescopes together arise a great pity, that is, we can obviously receive lights from the distant world but cannot distinguish most of them.

The telescope's observation capability is related to its angle magnification. The angle magnification of a telescope (hereinafter referred to as "magnification") is approximately the ratio of the focal length of objective lens to that of eyepiece. Based on that, the magnification can be increased infinitely theoretically by increasing the focal length of objective lens or reducing that of eyepiece. To reserve room for observer’s eyeball, the current minimum eyepiece focal length of **4** mm is difficult to break through. Therefore, improving magnification of telescope mainly depends on the focal length of objective lens. However, increasing the focal length of objective lens will enlarge the length and aperture of telescope body, leading to practical problems in terms of technology, economy and utilization. The technology problem is the difficulty of manufacturing (*3*) and maintenance of large lenses or mirrors. The economy problem is that manufacturing large telescopes consumes a lot of materials and takes up a large geographic space. The problem of utilization is the difficulty of handling, installation, usage and maintenance of large telescopes. Therefore, the size of astronomical telescopes remains limited. The aperture of optical astronomical telescopes is generally between **3** and **10** meters (*4*). Radio telescopes are often larger than optical ones. As of 2020, the world's largest radio telescope is FAST from China with an aperture of **500** meters.

Here comes the question: In addition to increasing the focal length and aperture of objective lens, is there any better way to enlarge the magnification of telescopes? Through continuous exploration, this article finally finds a satisfactory answer. With the help of the imaging idea different from focusing, this paper proposes a new light processing system and telescope model. The magnification of traditional telescopes has a linear relationship with telescope size, while the magnification of the new telescope proposed in this paper exhibits a super-exponential growth pattern with the system size. Taking a simple form of two light-filtering rings as an example, the magnification of the new telescope already exceeds **10,000** times, which shows a huge advantage over traditional telescopes. What's more, the new telescope may keep tiny in size due to its relationship above with magnification. Intuitively, the discovery will greatly expand the observing horizons and cut large budgets for the astronomy field.

1 New principle for telescopes: from focusing to filtering

As mentioned in the introduction, the key to the telescope magnification is objective lens (*1*). Objective lens function as "moving" distant objects closer to the observer's eyes through the refraction and focus of lights, which may be called the first-order angle magnification. However, it has two apparent limitations: Firstly, the angle magnification of objective lens is still a small value, leading to image smaller than the object; Secondly, the angle magnification is sensitive to distance. As the distance of the object increases, the imaging angle will rapidly shrink. The two limitations result from the use of concentric light focusing for imaging. In the presence of interfering lights, focusing is a necessary process for imaging. However, if interfering lights are eliminated by an appropriate light-filtering process, then a small amount of target lights is able to form a clear image. imaging from a small hole is a vivid example of this principle. In this context, can we achieve the effect of "moving" object closer through the principle of light-filtering? Obviously, if we only collect lights that are parallel to the optical axis(target lights) and block lights from other directions (interfering lights), no matter how far the object is, we can see it as if it's right in front of us (Figure 1). Based on this idea, we explore light-filtering systems in the following section.

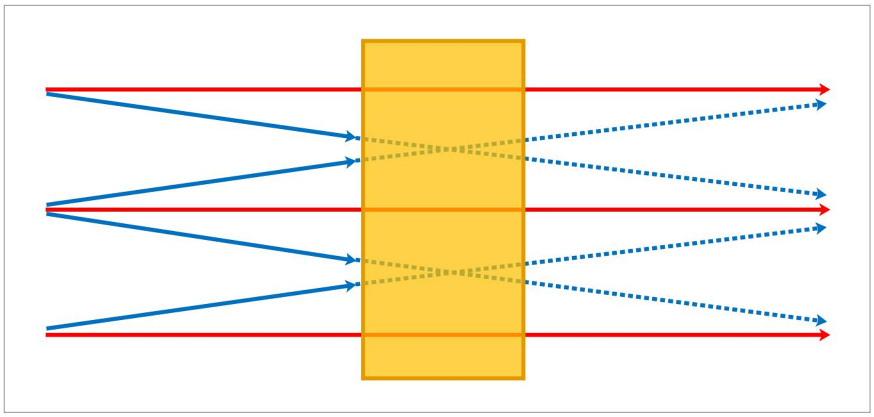

Fig. 1. The basic process of light-filtering. After a proper light processing system (yellow rectangle in the middle of the figure), target lights (red lights) pass through normally, and interfering lights (blue lights) are eliminated.

2 Design of light-filtering systems: from Straw Model to Light-filtering Ring Model

2.1 Straw Model

In order to obtain target lights and eliminate interfering lights, a natural method is to use parallel small tubes for light-filtering, which could be called "Straw Model". In an ideal state, receiving a single light through a small straw can well eliminate interfering lights, forming an image of the same size as the observed object and creating telescope effect.

In order to ensure that each straw allows only one light to pass through, the diameter of the straws is required to be small enough (but not too small). Referring to the existing research (*5*), the aperture of a hole that can best form an image turns out be about 0.35 mm. It is not easy to make a straw with such a small aperture. In addition, in order to eliminate interfering lights, the straw needs to be long and straight (in case target lights will be blocked too). However, it is difficult for slender materials to maintain a linear form. Used for light-filtering, the straw could not bend arbitrarily as an optical fiber does (*6*).

In addition to the difficulties in the straw producing and shape maintenance process, the bigger problem of Straw Model may be the light-filtering effect. On one hand, as long as the length of the straw is a finite value, there will always be a certain amount of interfering lights; on the other hand, there are gaps between straws. In order to minimize gaps, the (round) straws need to be arranged in the form of regular hexagons. Nevertheless, compared with the straw aperture, the gap area is not negligible. Therefore, the imaging effect of Straw Model will be very poor.

In order to further lessen the gap, a regular hexagonal straw can be used like honeycomb, fly eye and micro lens (*7*), which completely wipes out the gap. However, straw walls also have thickness. Compared with the aperture, the thickness of straw walls is not negligible either. All in all, regardless of the design, Straw Model doesn't work.

2.2 Plane Mirror Model

Considering the failure of Straw Model, it isn't feasible to directly filter lights. Is it possible to change lights first and then filter them? In detail, we first amplify the angle between target lights and interfering lights or the distance between spots of the two kind of lights on a certain plane (hereafter referred to as "spot distance"), and then eliminate the interfering lights that has become more obvious.

Based on the above idea, we design the second light-filtering system - Plane Mirror Model, which includes two sub-models: Bi-plane Mirror Model (Figure 2-A) and Multi-plane

Mirror Model (Figure 2-B). In fact, Plane Mirror Model has been widely used in scanning systems and image stabilization systems (*8*), where it aims only to adjust the propagation angle of all light as a whole, rather than filter lights. In Plane Mirror Model of Figure 2, the angle between light A(target light) and light B(interfering light) remains the same (for the same step of reflections, such as A_1 and B_1), but the spot distance between the two lights on the plane mirrors increases at a constant speed(In Figure 2, $|A_2B_2|-|A_1B_1|=|A_3B_3|-|A_2B_2|$). As long as the plane mirror is long enough (for Bi-plane Mirror Model) or the mirror number is big enough (for Multi-plane Mirror Model), the spot distance between light A and B on the plane mirrors can be expanded to a large extent, so that the two lights can be separated. The problem is that the spot distance expansion speed is very low due to its linear relationship with the length or number of the plane mirror. In order to eliminate light B with a small initial spot distance to light A, a lot of plane mirrors and geographic space are needed, which is uneconomical.

In short, Plane Mirror Model also fails. However, this model provides a basic mode for light-filtering system with repeated light reflection.

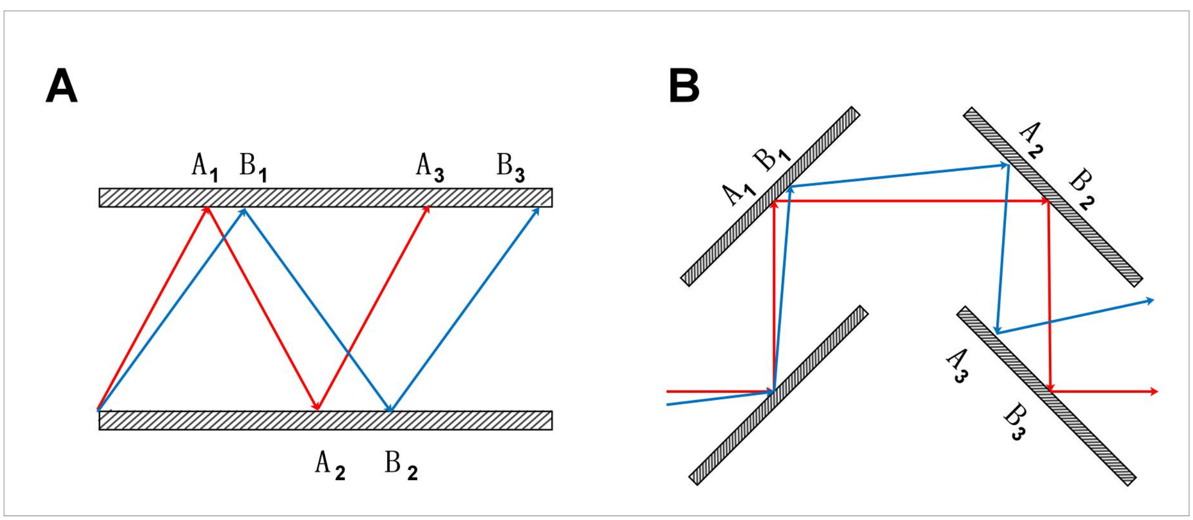

Fig. 2. Plane mirror model. (**A**) Bi-plane Mirror Model. The model consists of 2 mirrors. Red light is target light, while blue light is interfering light. (**B**) Multi-plane Mirror Model. The model consists of 4 or more mirrors.

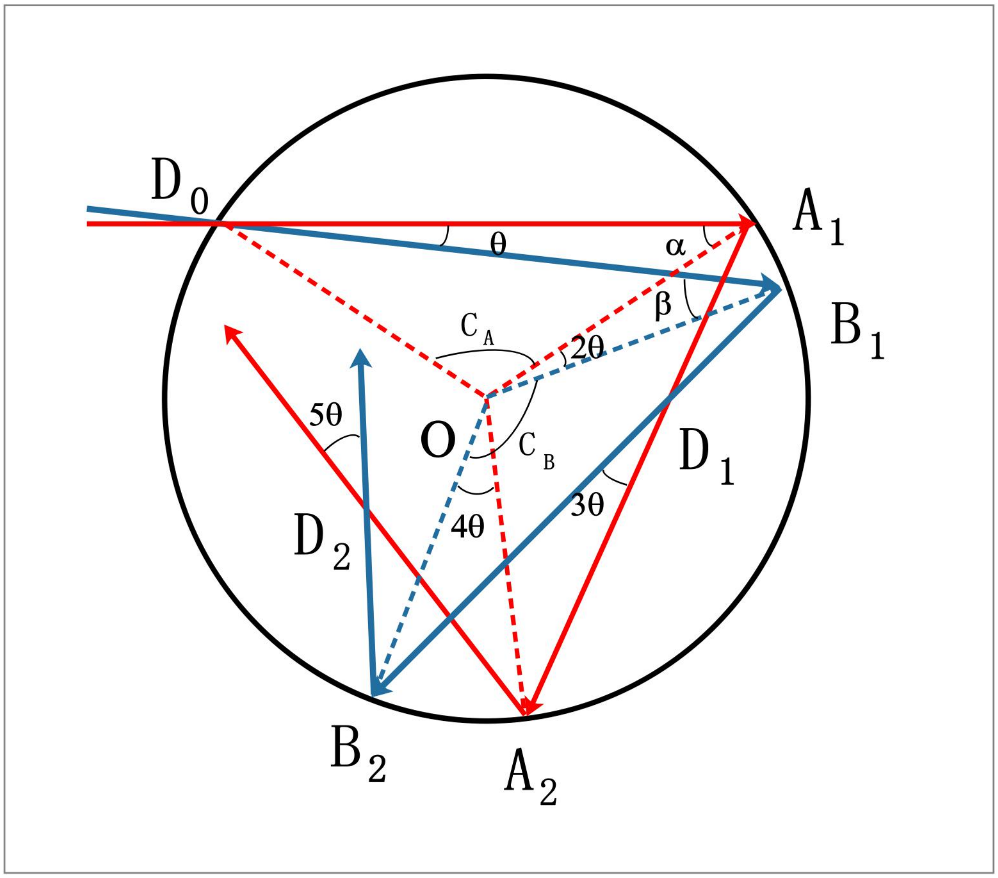

Fig. 3. Circular Cavity Model.

2.3 Circular Cavity Model

Considering the uneconomical problem of Plane Mirror Model, and inspired by the mode of repeated reflection, we replace plane mirrors with a circular cavity (as shown in Figure 3) as the light reflector. In Figure 3, for the moment, the light entrance and the light exit are assumed to merge to be a single point - $\boldsymbol{D_0}$.

For a single incident light (or rather, a collection of red directed solid lines within the cavity), each reflection expands the angle between light A and B, as well as the light spot distance. Compared with Plane Mirror Model, Circular Cavity Model can theoretically produce an infinite number of reflections, so as to obtain a large enough angle and spot distance increment. According to Figure 3, the evolution mechanism of the angle and related central angle is as follows:

$$\begin{aligned} \Delta\angle D_i &= 2\theta = 2(\alpha - \beta) \\ \Delta\angle O_i &= 2\theta = 2(\alpha - \beta) \end{aligned} \tag{1}$$

Among them, $\angle D_i$ is the angle between A_iA_{i+1} and B_iB_{i+1}. $\angle O_i$ is the central angle corresponding to A_i and B_i. θ is the initial angle between light A and B when they enter the cavity. α is the angle between the chord and the diameter corresponding to point A (referred to as the “reflection angle of A”). Similarly, β is the reflection angle of B. α and β are calculated as follows:

$$\begin{aligned} \alpha &= \arccos(x_A / d) \\ \beta &= \arccos(x_B / d) \end{aligned} \tag{2}$$

x_A and x_B are respectively the length of the string corresponding to light A and that to light B(e.g. $x_A = |D_0A_1|$, $x_B = |D_0B_1|$ in Figure 3). d is the diameter of the cavity.

According to equation (1) and (2), Circular Cavity Model already functions well in the light-filtering process for a single target light, and the angle increment value caused by each reflection is fixed.

When filtering a group of parallel target lights, Circular Cavity Model needs to be supplemented with a lens (hereafter called "refractor"). According to equations (1) and (2), in order to prevent the angle between two lights from growing, the chord length of the two lights in the cavity must be the same (Specifically, $x_A = x_B$). For this reason, we need a lens to distort the parallel lights so that they share a common chord length in the cavity. According to the uniqueness of light path, since the target lights are designed to have the same chord length, the interfering lights are destined to have different chord length from the target lights. In order to restore the parallel relationship between the target lights, we call for another refractor for outgoing lights from the cavity, which is same as that for the incident light (according to the reversibility of optical path). In the above process, the refractors placed outside the cavity are not ordinary focusing lenses. According to the law of intersecting strings, it can be proved that the refractors have no focus. In addition, for the purpose of filtering parallel lights, the entrance and exit of the cavity in Figure 3 should be an arc, rather than a point.

Supposing n_A and n_B are the number of reflections of light A and B in the cavity. The light path can be designed to ensure $n_A = n_B$ and make them large enough. The preconditions for $n_A = n_B$ are as follows: Firstly, both the angle between lights and the overall cross section of them are assumed to be very small initially (recorded as "strict interfering situation"); Secondly, the size of the entrance and exit is many times larger than that of cross section of lights. When light A pass through the entrance, light B in its neighborhood does too. The reason why n_A and n_B can be made large to an extent is that the arc length of adjacent reflection points (such as A_1 and A_2) (called "moving arc length") is much larger than the arc length of the light entrance and exit (called "entrance and exit arc length"), so the lights path can be well designed to make the lights spot skip the entrance and exit multiple times, thereby increasing the number of reflections. In a word, in order to ensure an excellent filtering ability, we need to make sure that: the light cross-section size << entrance and exit arc length << moving arc length. In a cavity of a given size, moving arc length has an upper limit, and what we can adjust flexibly are the entrance and exit arc length and the light cross-section size. In order to compress light cross-section size, we can learn from the laser beam expander (*1*). Finally, Circular Cavity Model includes three components: cavity, refractor, and beam expander.

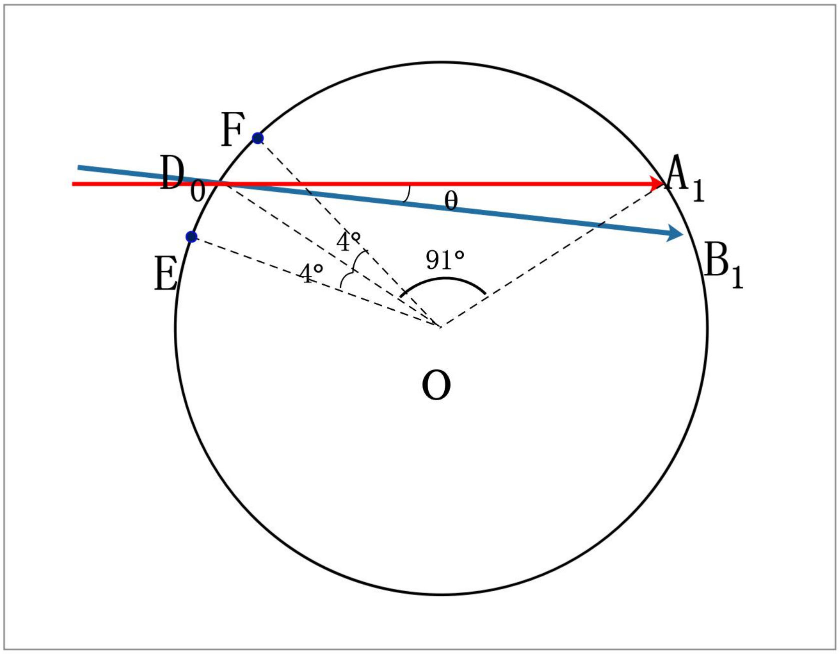

Fig. 4. An example of Circular Cavity Model.

We take Figure 4 as an example to illustrate the light-filtering performance of the cavity. Assuming that the entrance and exit of the cavity are arcs $\overset{\frown}{EF}$, the light enters the cavity from the middle of $\overset{\frown}{EF}$, the center angle of the chord corresponding to light A is ($\boldsymbol{C_A = 91°}$), the corresponding central angle of the entrance and exit arc is $\boldsymbol{4° \times 2}$, and the initial angle between light A and B is θ (in the strict interfering situation, the angle is very small). In this example, light A and B will exit the cavity after $\mathbf{87}$ reflections in the cavity. Since each reflection increases the angle between light A and B by $\boldsymbol{2\theta}$, the angle increases by $\boldsymbol{174\theta}$ after $\mathbf{87}$ reflections (that is, the angle of the outgoing lights becomes $\boldsymbol{175\theta}$). In other words, a single cavity already reaches the level of a primary astronomical telescope.

Since it's impossible to make the entrance and exit size and the cross section of the lights infinitesimal, no matter how the chord lengths(x_A and x_B) are designed, the number of light reflection in a cavity is limited. In order to improve the light-filtering capacity, we may consider taking multiple cavities in series. However, the series connection of cavities takes up lots of space and makes it hard to control the incident angle of lights in each cavity. Therefore, Circular Cavity Model needs an upgrade.

2.4 Light-filtering Ring Model

Given the drawback of multiple cavities connected in series, a more reasonable multi-circular cavity system is required. Naturally, if multiple cavities are nested around the same center (called "Light-filtering Ring Model"), they will not cause a great increase in space occupation. However, that is a question whether Light-filtering Ring Model works well.

Taking Light-filtering Ring Model with two cavities(Figure 5) as an example, it filters lights as follows: At the beginning, lights pass though the two cavities and start the reflection process in the inner cavity, and then they escaped to the outer cavity. After that, a second reflection process is carried out in the ring composed of the outer cavity and the surface of the inner cavity (called "light-filtering ring"). It's easy to find that the reflection process in the light-filtering ring is homogeneous with that in a single cavity, and they have similar light-filtering effects. What interests us most is the overall effect of Light-filtering Ring Model as a whole, which we illustrate in the following paragraphs.

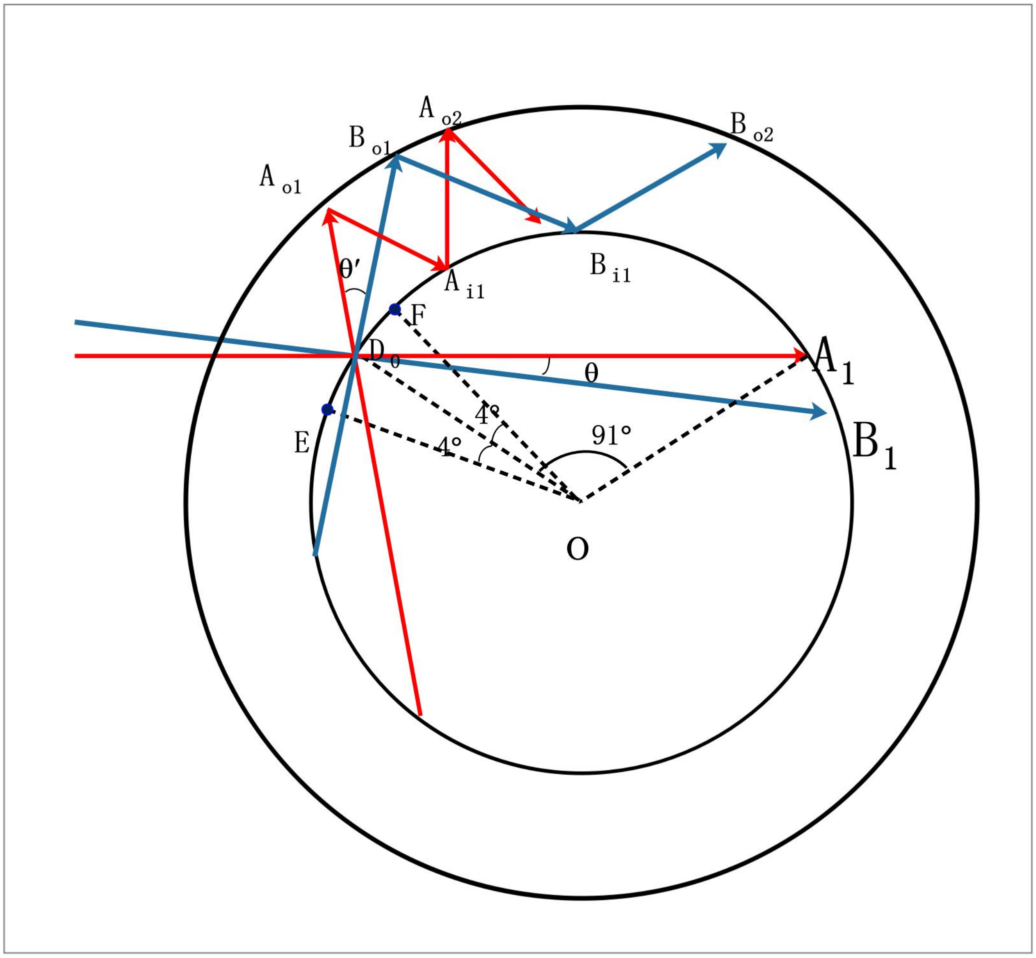

Fig. 5. Basic Light-filtering Ring Model example.

Take the model in Figure 5 as an example to illustrate the light-filtering performance of the light-filtering ring. When the lights transmitted from the inner cavity to the light-filtering ring, the angle between light A and B is $\theta' = 175\theta$.

Assuming $|A_{o1}D_0| = |D_0O|$ (called "Assumption 1"), the diameter corresponding to point A rotates by $22.25°$ after each reflection in the light-filtering ring (the central angle corresponding to A is $C'_A = 22.25°$, that is, the central angle corresponding to adjacent reflection points, $\angle A_{o1}OA_{i1}$ for example). Without loss of generality, it can be considered that light A is emitted after its diameter roughly rotates by $360°$ (especially when the number of rings increases, this assumption becomes more and more reasonable considering "angle loss of ring transformation" described below). Then, in the light-filtering ring, the number of light reflections is approximately $\left[\frac{360}{22.25}\right]=16$ times, and each time of reflection increases the angle between the target light (light A) and the interfering light (light B) by one central angle difference ($\angle A_{o1}OD_0 - \angle B_{o1}OD_0 = C'_B - C'_A$). Given the Assumption 1, $C'_B - C'_A \approx \theta'/2$. Under this condition, the angle between light A and B in the light-filtering ring is approximately enlarged by $16\times\theta'/2 = 8\theta'$, that is, the angle after the light exits from the light-filtering ring is $9\theta'$, where $\theta' = 175\theta$. Therefore, for the entire light-filtering ring system, the light-filtering capacity (magnification) is approximately $175\times 9 = 1575$, which is already comparable to that of a traditional astronomical telescope. In fact, it can be proved that in Figure 5, no matter how long $|A_{o1}D_0|$ is, the magnification of the angle between light A and B in the light-filtering ring remains between 8.47 and 13.57 (called "Law 1", see the supplementary materials for the proof process). Therefore, the magnification of the light-filtering ring has such excellent properties as being large, stable and space-independent. In other words, with $|A_{o1}D_0|$ fixed, no matter how long $|D_0O|$ is, the magnification of the angle between light A and B in the light-filtering ring keeps stable between 8.47 and 13.57 (called "Corollary 1"). Therefore, when more rings are added to the model, the magnification of each ring won't be weakened, which is one of the keys to the continuous magnification increase of Light-filtering Ring Model.

For Light-filtering Ring Model with more than 1 ring, when lights move from the inner light-filtering ring to the outer one, center angle(e.g. $\angle A_{o1}OD_0$ in Figure 5) and reflection angle(e.g. $\angle OA_{o1}D_0$ in Figure 5) of light will be reduced to a certain extent (referred to as "angle loss of ring transformation"). At the same time, the number of reflection increases, so that the overall angle-amplification capability of the outer ring will not decrease significantly compared to the inner one. In fact, as the reflection angle decreases, the magnification of the light-filtering ring increases (called "Law 2", see the supplementary materials for the proof process). Combining Law 1 and Law 2, the Light-filtering Ring Model has a magnification growth mode that exceeds the exponential explosion. The total magnification equation of Light-filtering Ring Model with "1 cavity + n rings" turns out to be $M = cr_0^n \times g(n)$, where M means the overall magnification, c represents the magnification of the innermost cavity, and r_0 is the magnification of the innermost ring. In Figure 5, $c = 175$; $r_0 \sim [8.47, 13.57]$; $g(n)$ is the adjustment coefficient, generated from the angle loss of the ring transformation and the reduction of the relative length of lights in light-filtering rings. $g(n)$ is no less than 1, and is the increasing function of n. Accordingly, we can continuously increase magnification by adding rings. Based on the example in Figure 5, with 1 more ring, even if the adjustment coefficient is ignored, the magnification has exceeded $[175 \times 8.47^2] = 12{,}554$. This shows the great advantage of Light-filtering Ring Model over traditional telescopes.

Although the angle loss of ring transformation poses no threat to the light-filtering ability, it's necessary to stop lights of the light-filtering ring from returning back to its inner cavity due to its small reflection angle. In view of this, the model needs to meet the following requirements: Firstly, the relative width of the ring (the ratio of the absolute width to the radius of the inner cavity of the ring) needs be large enough; Secondly the reflection angle of lights in the innermost cavity should not be too small. Thus, it's possible that he number of rings in a single light-filtering ring system cannot increase infinitely (called "structural constraints"). Under structural constraints, the overall magnification of the system can be further increased in the following ways: Firstly, light-filtering rings are connected in series (series system has the magnification growth mode similar to nested system), or; Secondly, the reflection angle in the light-filtering ring needs to be adjusted. Finally, the number of rings and magnification of Light-filtering Ring Model can theoretically increase infinitely.

So far, the discussed light-filtering ring is a 2D model, which can only deal with 2D interfering lights. In the 3D space, the light-filtering ring is a cylinder (Figure 5 is just a section). In such a light-filtering ring system, lights move not only on the planes where section circles are located (called "light-filtering process 1"), but also on the planes perpendicular to them and containing the light propagation route (called "light-filtering process 2"). Therefore, strictly speaking, light-filtering ring actually processes 3D interfering lights. However, the light-filtering process 2 is similar to that of Bi-plane Mirror Model. According to the previous analysis, the light-filtering ability of Plane Mirror Model can be ignored, so the cylindrical model of the light-filtering ring is still a 2D model.

In order to deal with 3D interfering lights, 3D light-filtering ring system is needed. Obviously, the 3D light-filtering ring is equivalent to two 2D light-filtering rings that are perpendicular to each other. Considering the deformation of rings caused by gravity, both light-filtering rings should be placed horizontally on the ground (like two tires lying on the ground). Therefore, in order to filter 3D interfering lights, two horizontally-placed light-filtering rings need to be connected by an optical rotator, such as Faraday Rotator.

3 Light-filtering Telescope: farther, smaller but darker

After obtaining the above Light-filtering Ring Model, what else we need to form a telescope(called "Light-filtering Telescope") is simply a common eyepiece(as shown in Figure 6).

Compared with traditional telescopes, the biggest advantage of Light-filtering Telescope lies in its larger magnification (farther) and smaller size (smaller). For Light-filtering Telescope, magnification increases super-exponentially with the addition of rings. At the same time, the reflection number increases linearly, making small the energy loss of the reflection process. This is a very important condition for processing weak target lights. Because the lights section is extremely small, Light-filtering Telescope can be designed to be very small (especially considering the role of the beam expander). Of course, Light-filtering Telescope also has some obvious shortcomings, such as lower brightness.

Compared to traditional focusing telescopes, Light-filtering Telescopes have lower brightness (darker). Despite of that, its resolution may not be lower than that of traditional telescopes. Traditional telescopes enhance the imaging of target lights by focusing, while Light-filtering Telescope weakens interfering lights to image by filtering. As the number of light-filtering ring grows, the brightness gradually decreases to an equilibrium - the brightness of pure target lights. Referring to pinhole imaging, few pure target lights are enough for imaging. In order to improve the brightness of target lights, the following measures may help: Firstly, referring to the synthetic-aperture radio telescope (*4*), imaging synthesis of multiple Light-filtering Telescopes; Secondly, replacing all lenses of the above Light-filtering Telescope with reflective systems. For example, the principle of Cassegrain Telescope can be used to manufacture beam expanders and refractors.

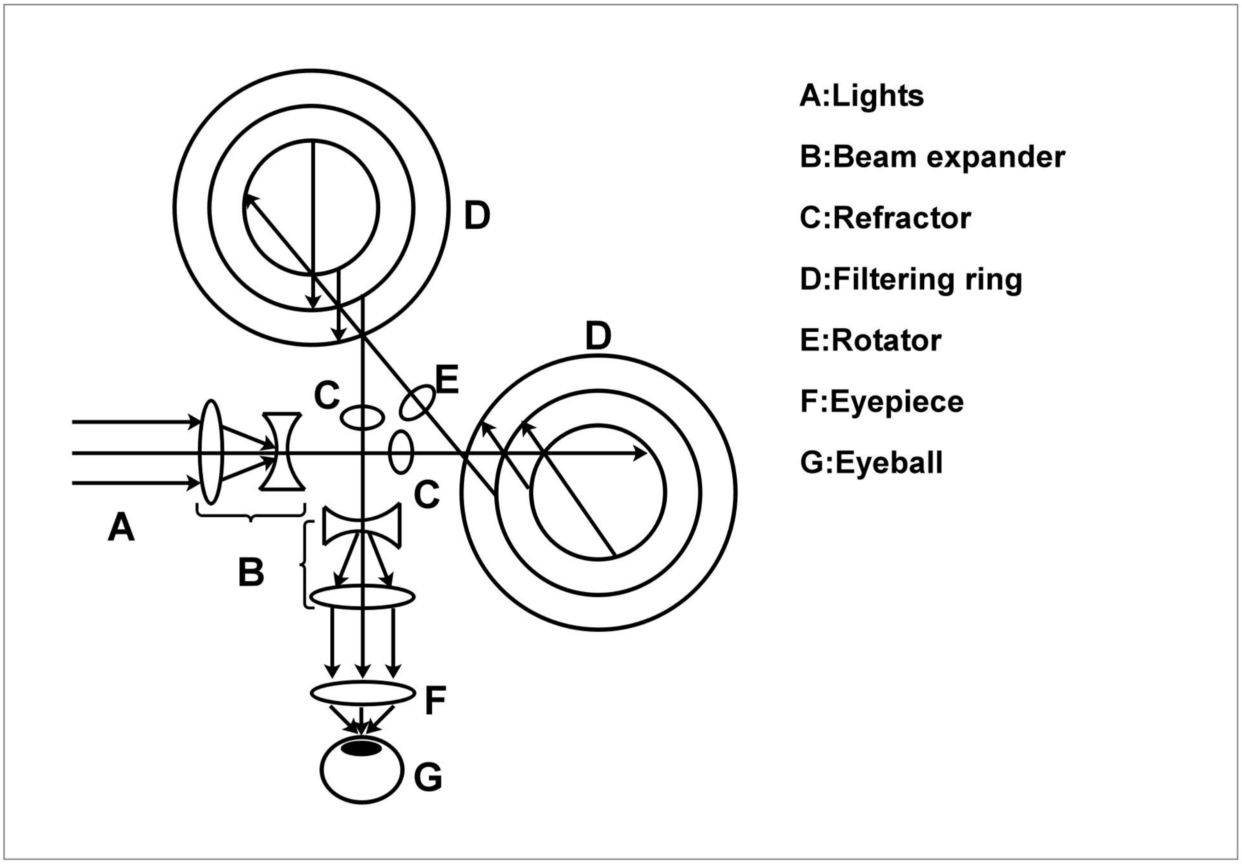

Fig. 6. The structure of Light-filtering Telescope.

4 Conclusion and discussion

This article briefly reviews the development history of telescopes, analyzes the shortcomings of traditional telescopes, proposes new telescope principle and models, and finally forms a novel telescope. Compared with traditional telescopes, the new telescope has obvious advantages of much more powerful observation capacity and smaller size, but it also has the disadvantage of darker vision. It is worth noting that the magnification of the new telescope shows a super exponential growth mode with its size, which leaves a broad space for further large-scale improvement of the magnification. When the distance of the observed object increases to a certain extent, the brightness of traditional telescopes will drop to the level of Light-filtering Telescope. Thus the brightness problem should not be emphasized. In fact, the two types of telescopes are complementary: For close objects, traditional telescopes perform better; For distant objects such as galaxies in deep cosmic space, Light-filtering Telescopes will be irreplaceable and play the role of super eyes without doubt.

5 Material and Methods

The influence of light length and reflection angle on the magnification of light-filtering ring

Parameters. The radius of the inner cavity($|D_0O|$ in Figure 7) is set to be 1, the length of light A ($|D_0A_{o1}|$ in Figure 7) and the length of light B ($|D_0B_{o1}|$ in Figure 7) are respectively x_A and x_B, (on the outer surface of the inner circle) the reflection angles of light A and light B are respectively α' and β' ($\beta' = \alpha' + \theta'$), the corresponding central angles of light A and light B are respectively C'_A and C'_B, the radius of outer cavity is r_2, the number of reflections is q, the total angle increment is Δ_c after the reflection process within light-filtering ring is completed, and the magnification of light-filtering ring is M_r. Among them, only the following 4 parameters are initial parameters (need to be given manually): the inner cavity radius($|D_0O|$), x_A, α' and θ', while the other parameters are function values of these 4 ones. Important parameters have been shown in Figure 7.

Assumptions. Firstly, no matter how small the reflection angle is, the light will not be reflected back into the inner circular cavity; Secondly, the number of reflections of the two lights in the light-filtering ring is roughly estimated as the ratio of 360 to the central angle C'_A (the estimation error is not significant, and it decreases as the ring number increases).

Results. With the 4 initial parameters, we calculates the magnification of Light-filtering ring M_r (equation (9)) as well as its relevant parameters from C'_A to Δ_c (equation (3)~(8)).

$$C_A^{'} = \arctan(\frac{x_A \sin\alpha'}{x_A \cos\alpha'+1}) \times \frac{180}{\pi} \tag{3}$$

$$C_B^{'} = \arctan(\frac{x_B \sin\beta'}{x_B \cos\beta'+1}) \times \frac{180}{\pi} \tag{4}$$

$$r_2 = \sqrt{(x_A \cos\alpha'+1)^2 + (x_A \sin\alpha')^2} \tag{5}$$

$$\begin{aligned} x_B &= \sqrt{\cos\beta'^2 + r_2^2 - 1} - \cos\beta' \\ &= \sqrt{\cos(\alpha'+\theta')^2 + (x_A \cos\alpha'+1)^2 + (x_A \sin\alpha')^2 - 1} - \cos(\alpha'+\theta') \end{aligned} \tag{6}$$

$$q = \frac{360}{C_A^{'}} \tag{7}$$

$$\Delta_c = q \times (C_B^{'} - C_A^{'}) \tag{8}$$

$$M_r = \frac{\Delta_c}{\theta'} + 1 \tag{9}$$

Conclusions. Based on the calculation results above, two laws come into being as follows:

Law 1: Assuming values of α' and θ' are fixed at $44.5°$ and $0.0001°$ respectively, as x_A changes in the real number domain, the magnification M_r remains within a range, or rather $M_r \sim [8.47, 13.57]$. As x_A approaches 0, M_r goes up to 13.57; When x_A increases to infinity, M_r goes down to 9 (rather than 8.47, which is just a special value when $x_A = 10$).

Law 2: Keeping other conditions unchanged, when α' is reduced to $\frac{1}{k}$ of its original value, the magnification M_r will roughly increase by k times.

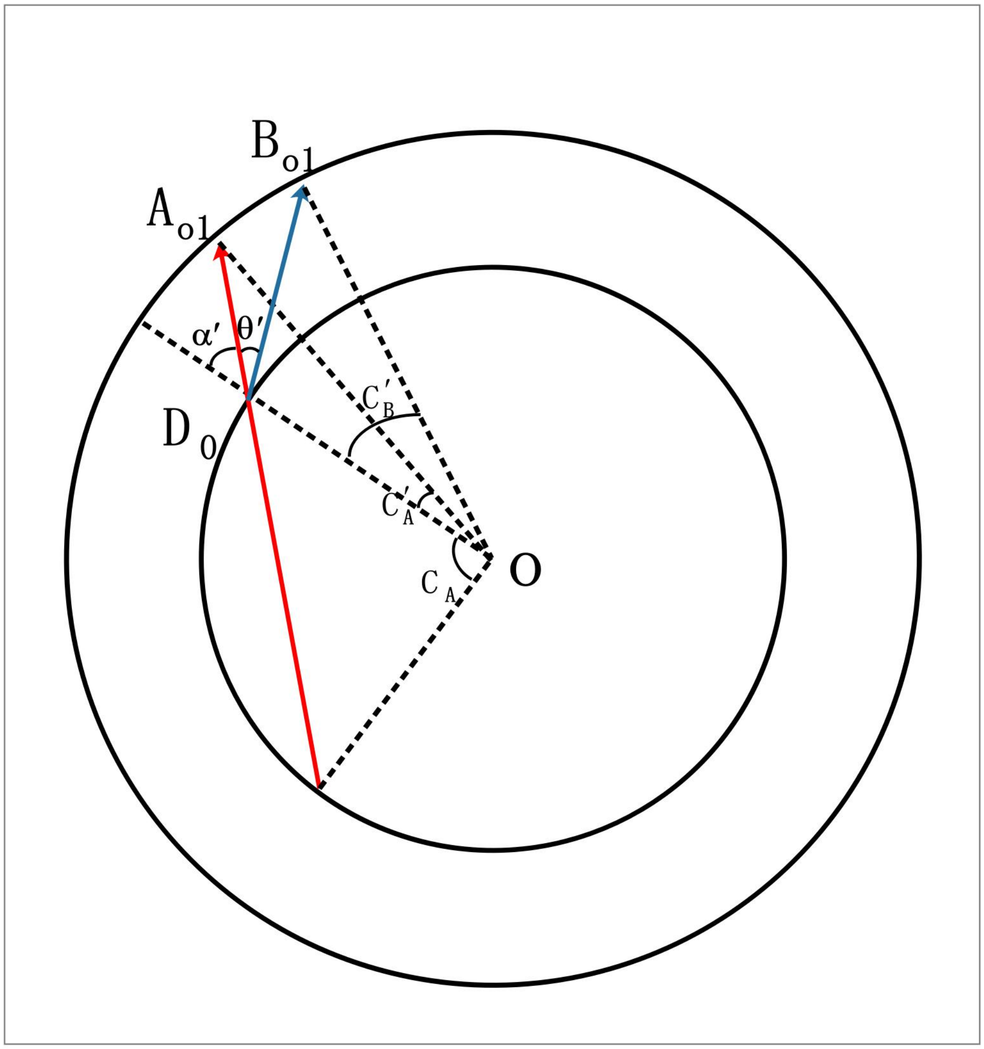

Fig. 7. The magnification of the light-filtering ring under ordinary circumstances

By setting the **4** initial parameters - the inner cavity radius($|D_0O|$), x_A, α' and θ', the number of reflections and the angle increment after each reflection can be calculated, which helps with calculating the magnification of the light-filtering ring.

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Supplementary Materials:

None

Figures and tables:

All figures are placed in the main text close to its citation and there is no table in the paper.

Figures

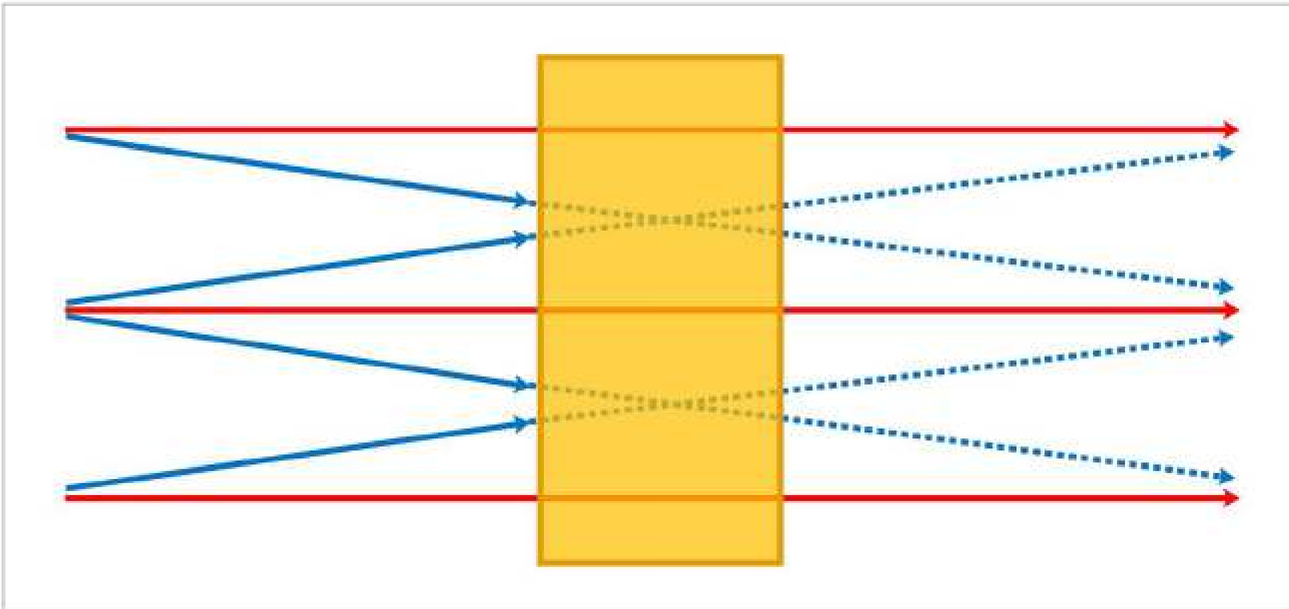

Figure 1

The basic process of light-filtering. After a proper light processing system (yellow rectangle in the middle of the figure), target lights (red lights) pass through normally, and interfering lights (blue lights) are eliminated.

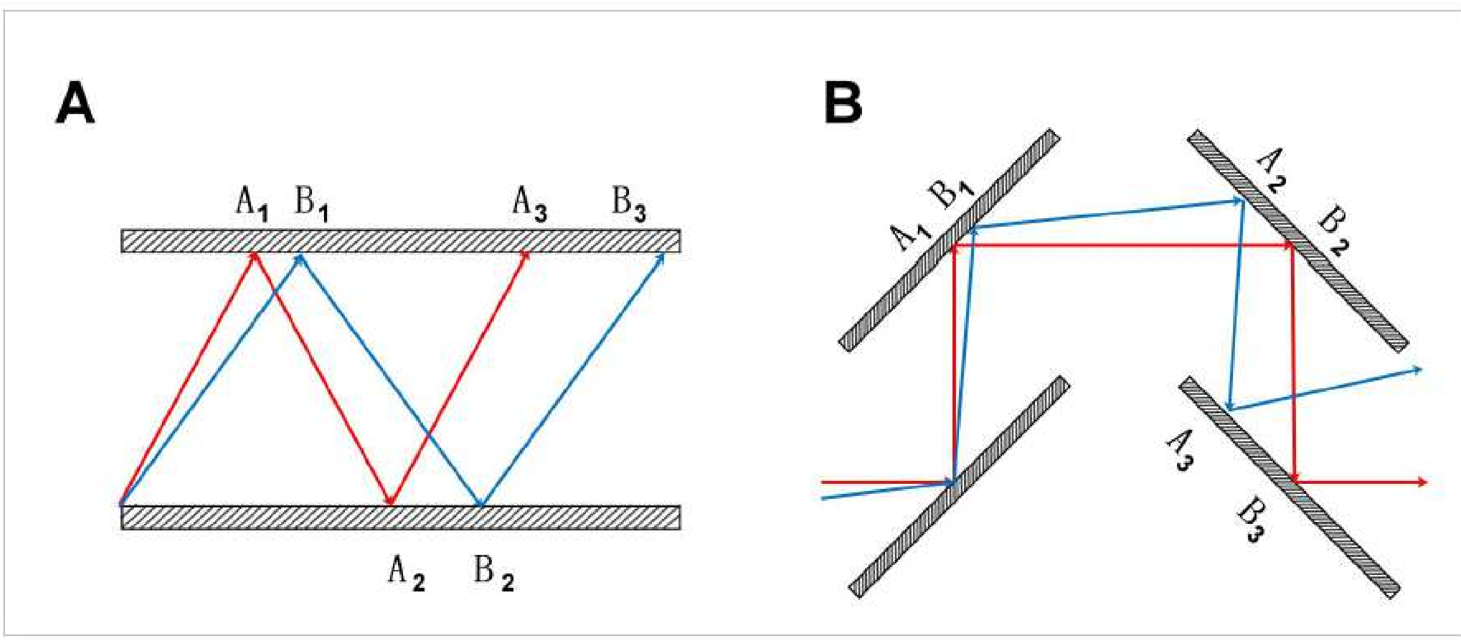

Figure 2

Plane mirror model. (A) Bi-plane Mirror Model. The model consists of 2 mirrors. Red light is target light, while blue light is interfering light. (B) Multi-plane Mirror Model. The model consists of 4 or more mirrors.

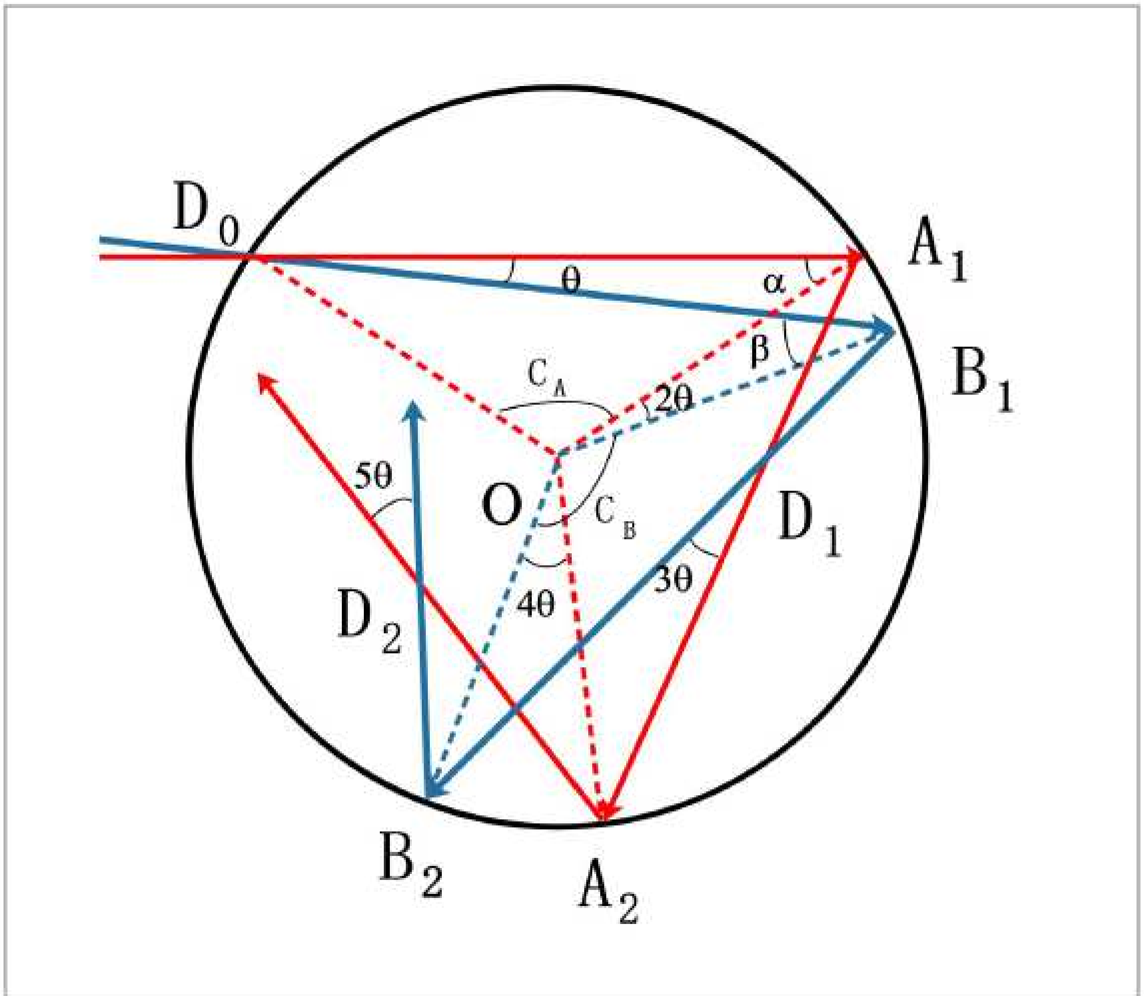

Figure 3

Circular Cavity Model.

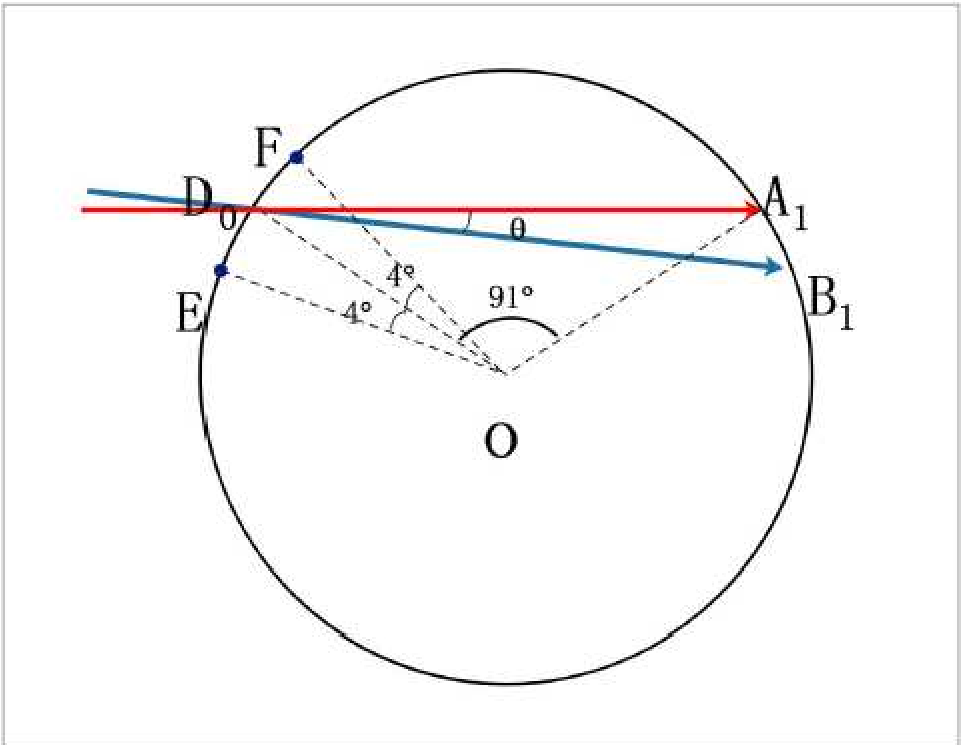

Figure 4

An example of Circular Cavity Model.

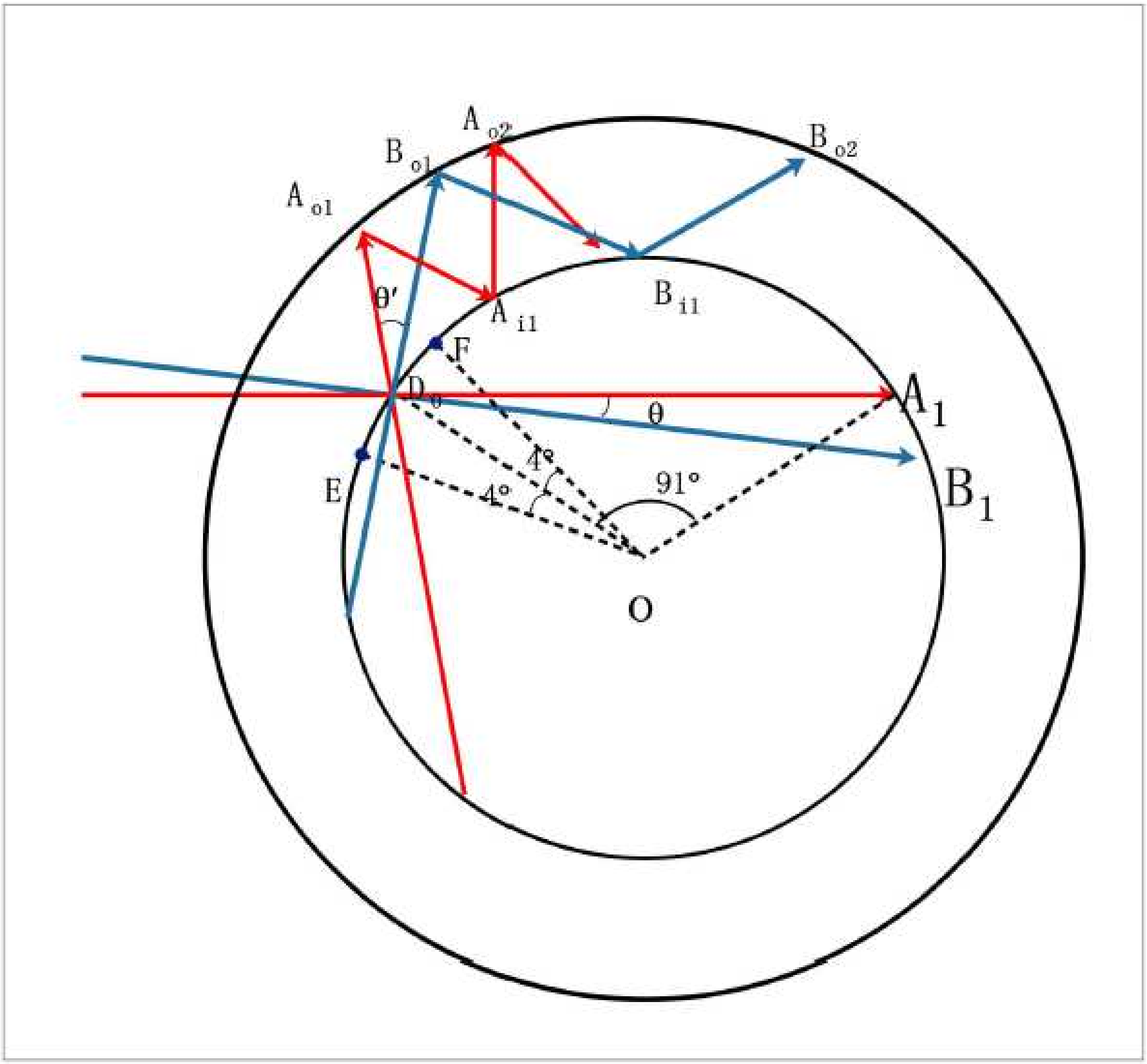

Figure 5

Basic Light-filtering Ring Model example.

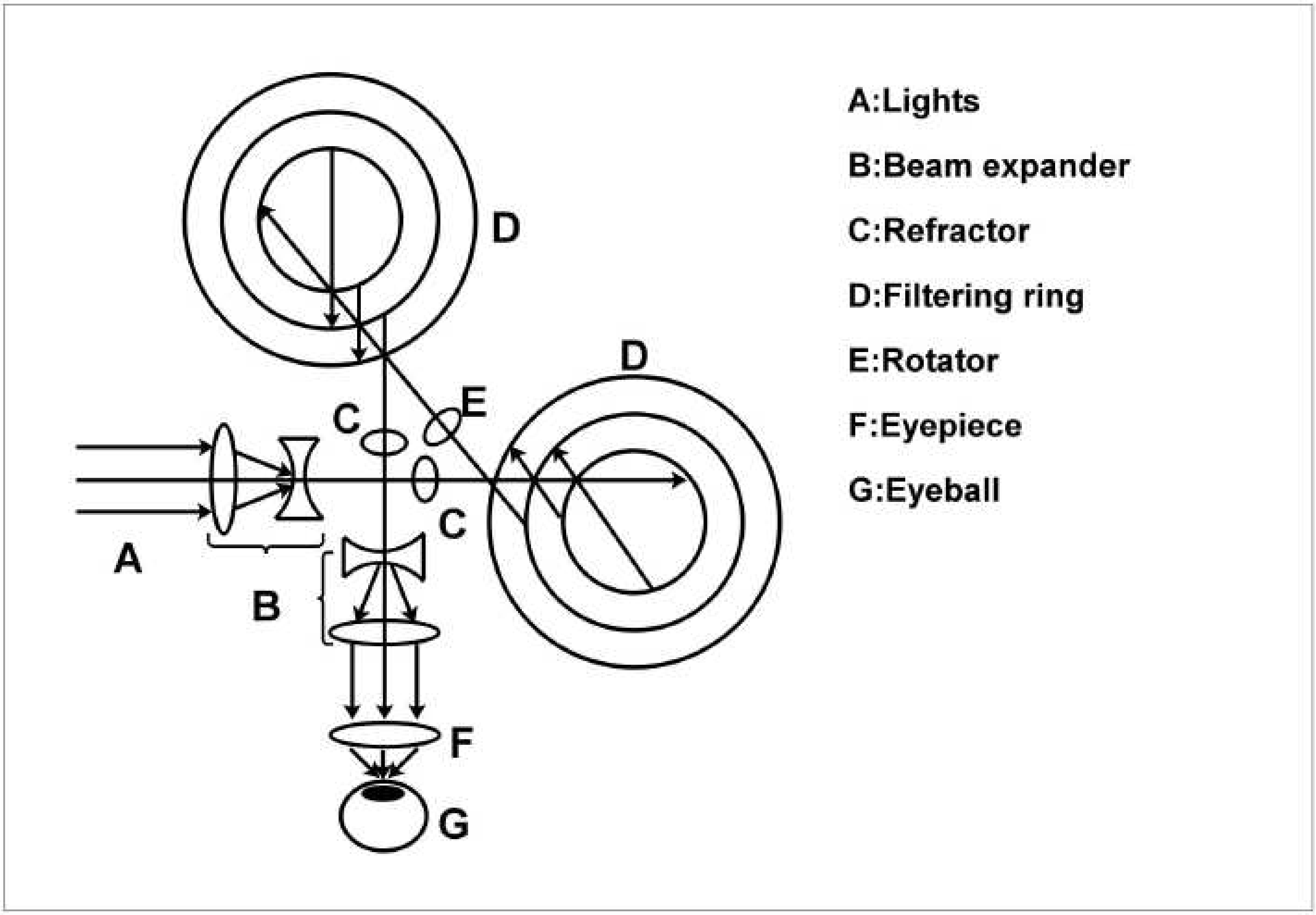

Figure 6

The structure of Light-filtering Telescope.

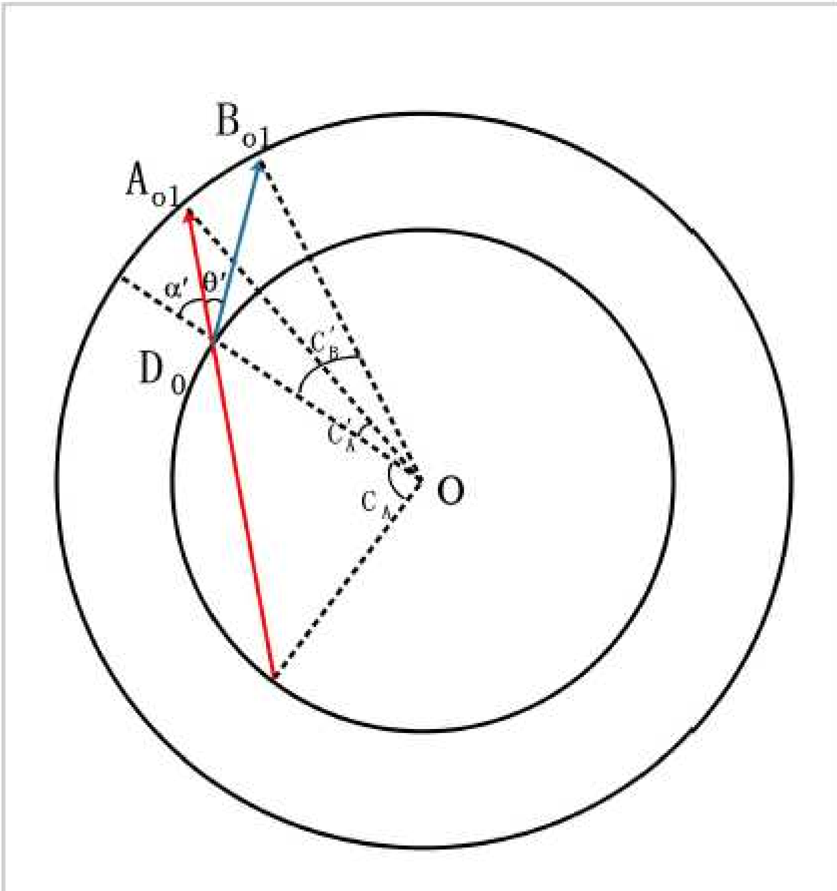

Figure 7

The magnification of the light-filtering ring under ordinary circumstances