**Photgraphic camera. How it works? Take a simple converging lens:**

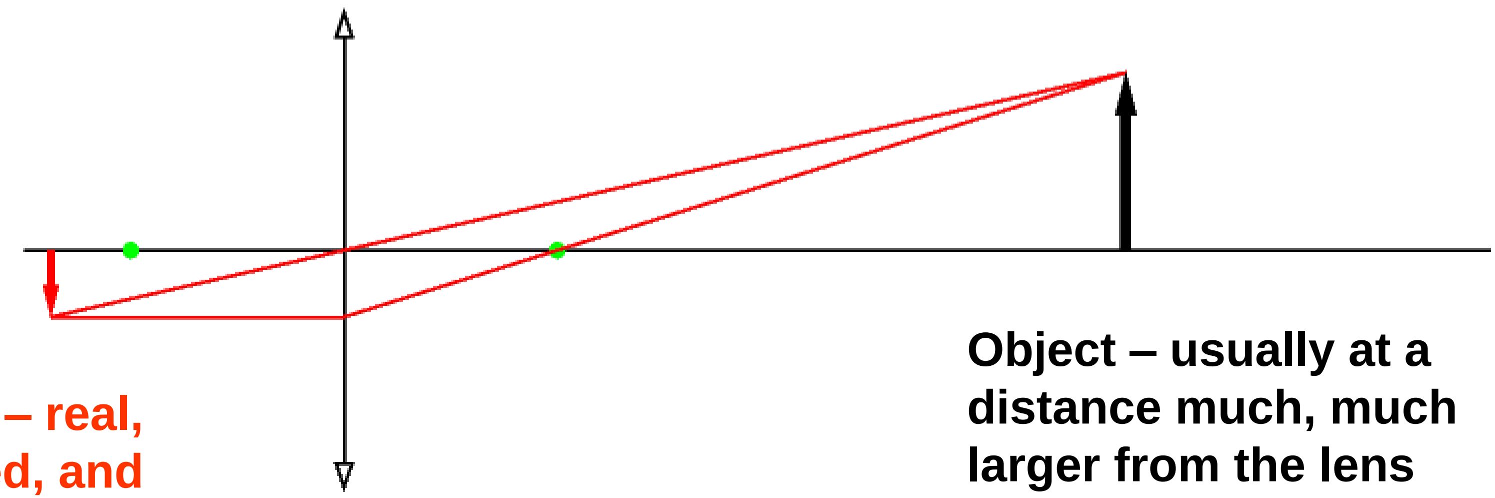
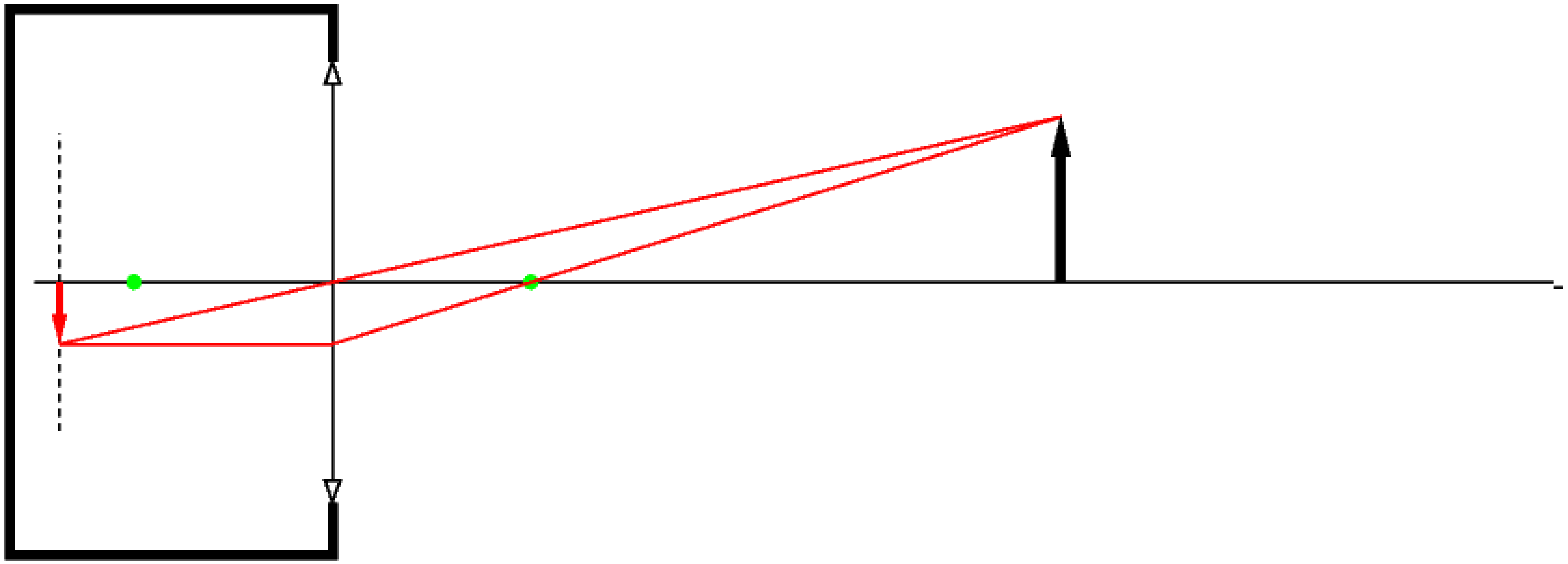


Image – real, inverted, and much smaller than the object

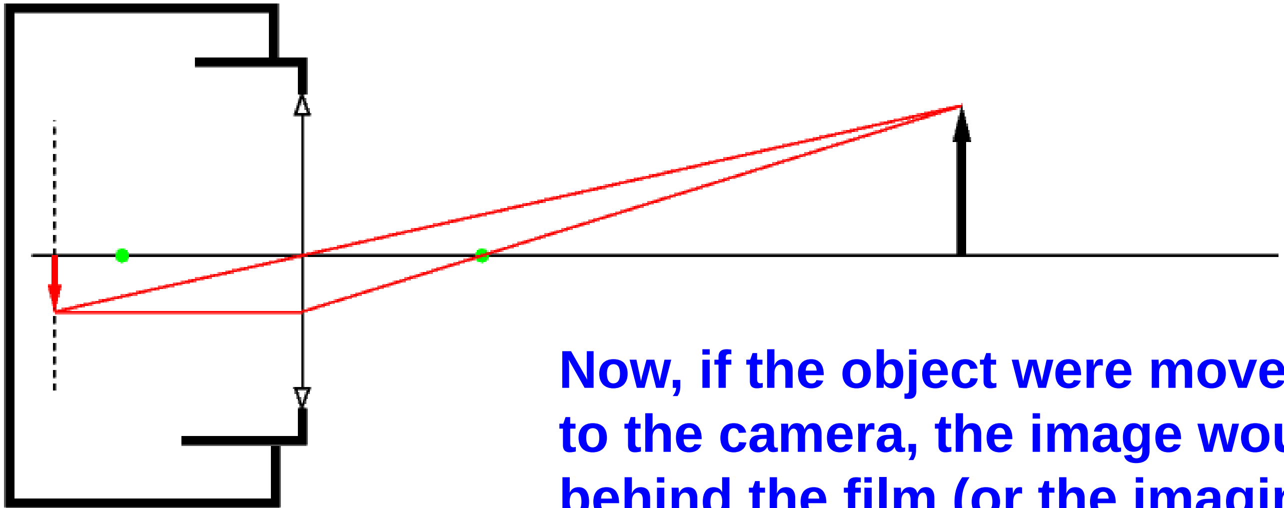
Lens

Object – usually at a distance much, much larger from the lens than its focal length

**To make a camera, we put the lens at the front side of a black box, and then we put a piece of photographic film, or a modern CCD image converter where the image forms. Such a camera really can take pictures!**

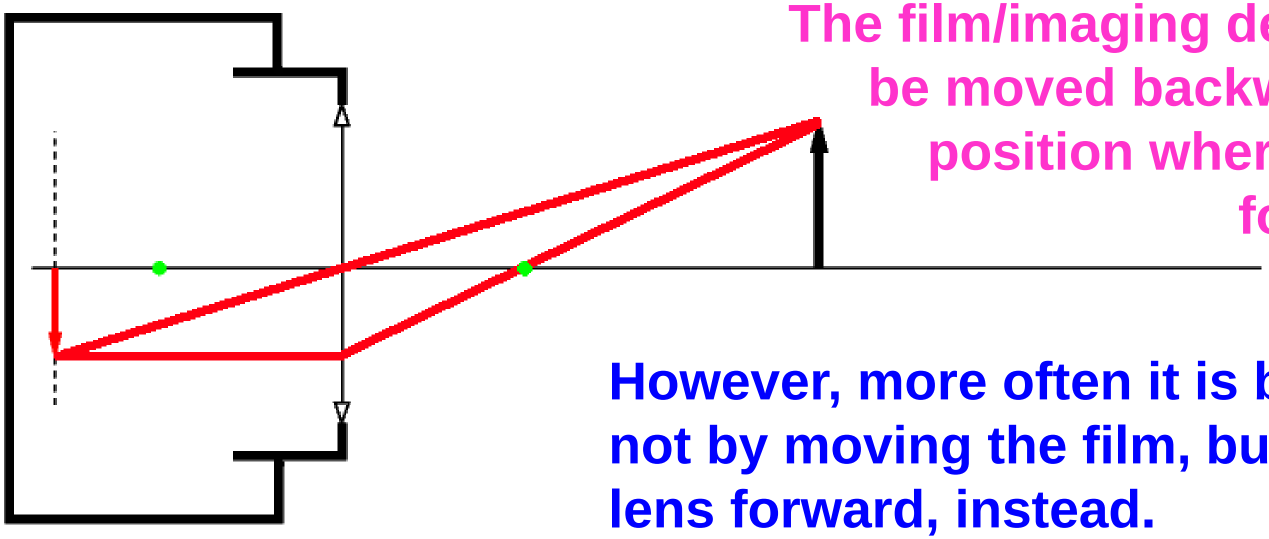


# “Focusing” a camera:



**Now, if the object were moved <u>closer</u> to the camera, the image would form <u>behind</u> the film (or the imaging device)**

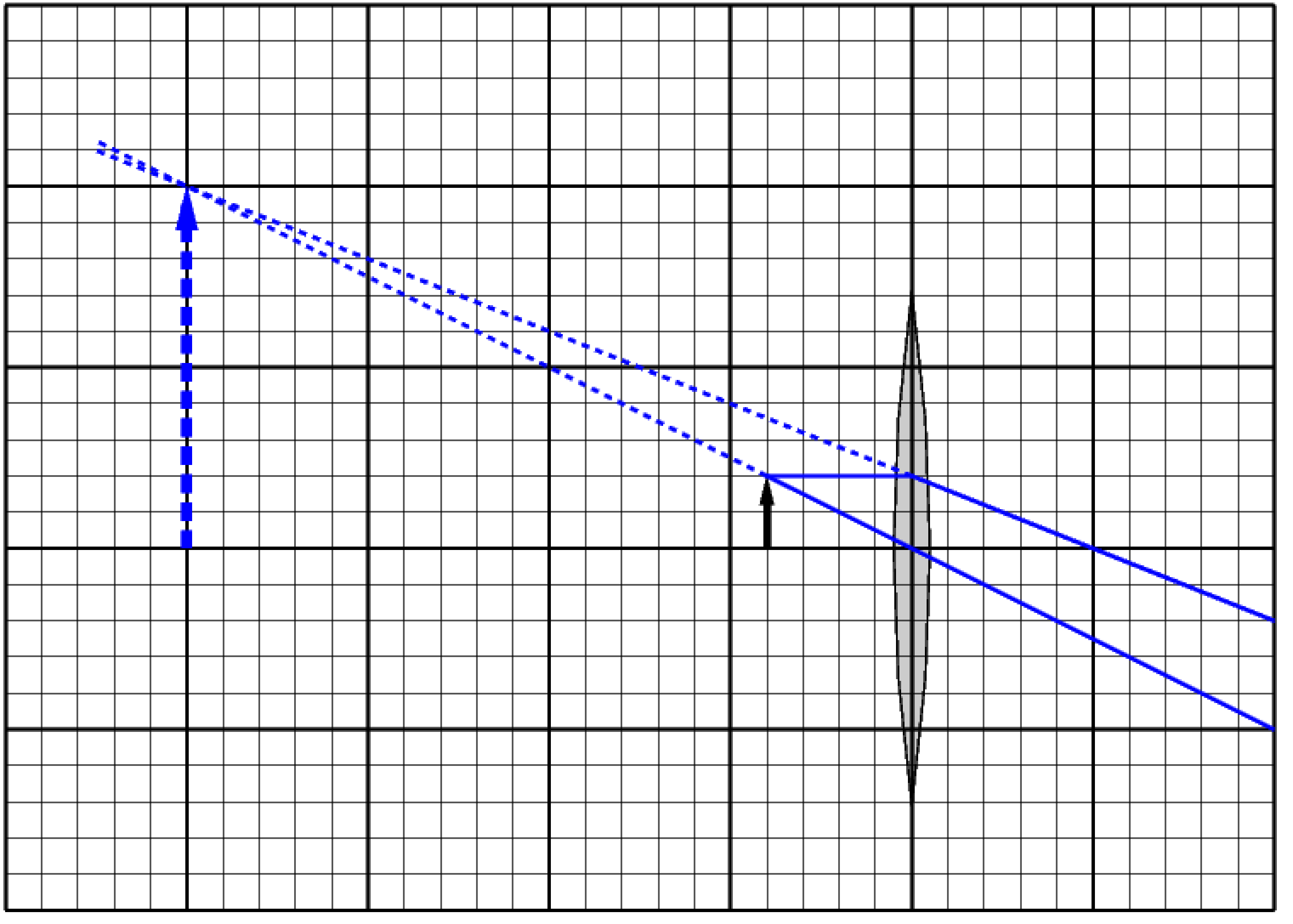
**The film/imaging device should be moved backwards, to the position where the image forms, right?**



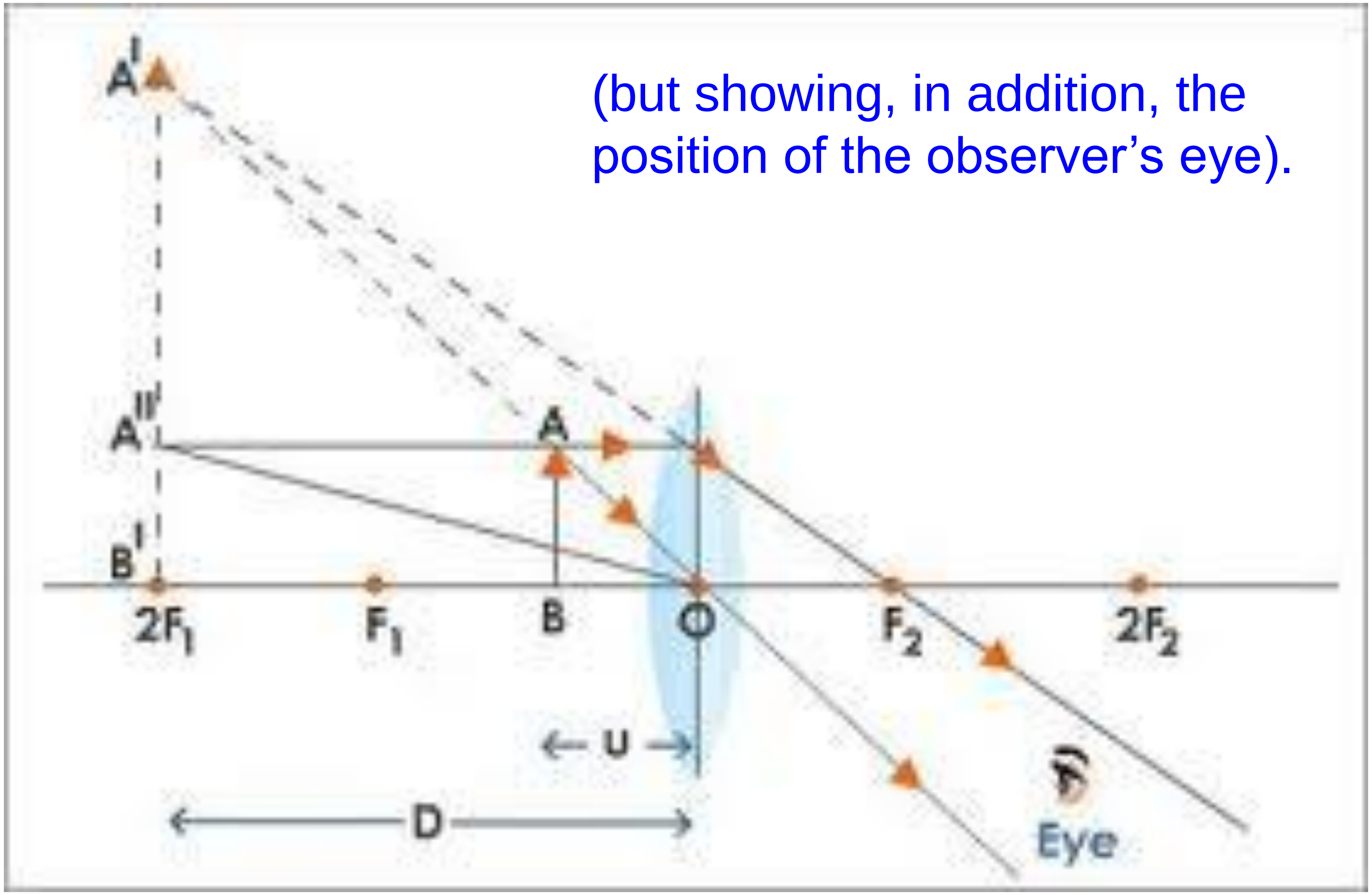
**However, more often it is being done not by moving the film, but moving the lens forward, instead.**

# Magnifying glass – the simplest of all optical devices

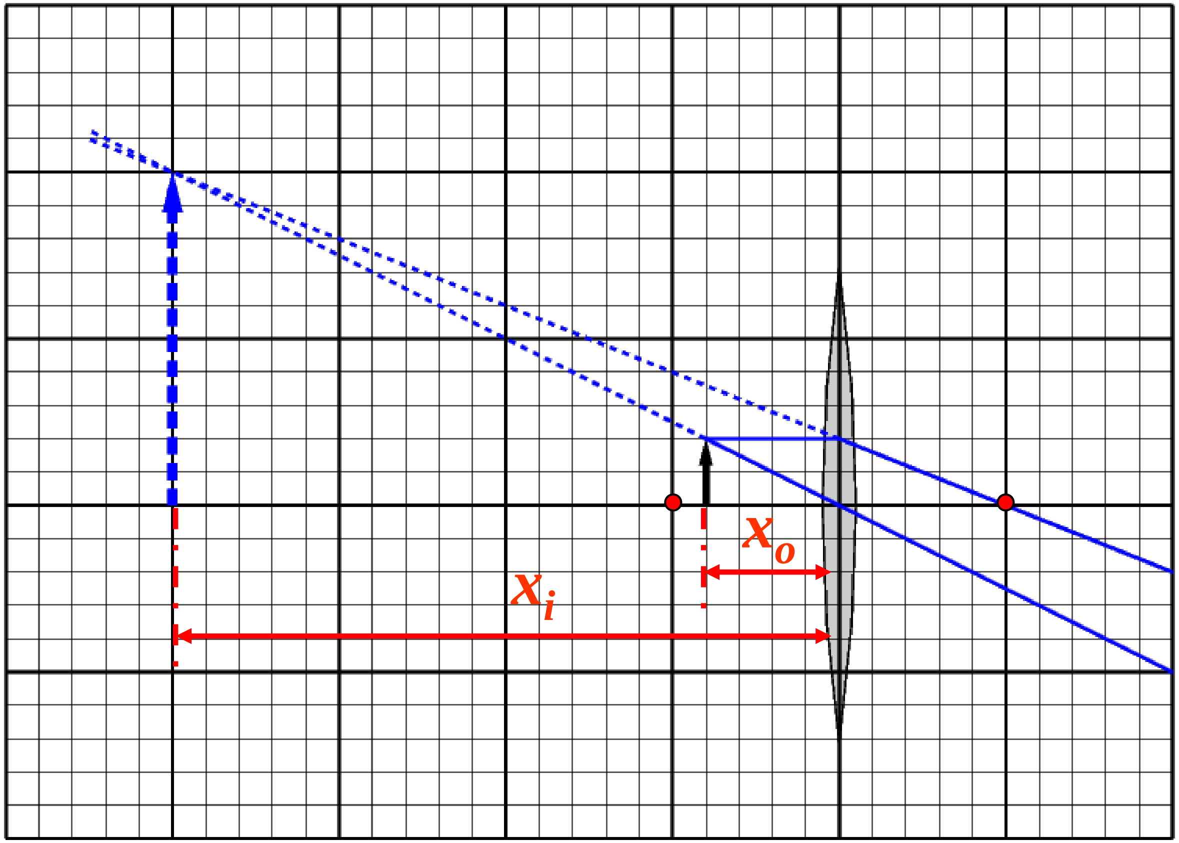
**The magnifying glass is just a single converging lens. We place the object somewhat closer than the focal distance,  and we We obserwe the virtual image by eye.**



Another graph depicting the same situation as in the preceding slide:




(but showing, in addition, the position of the observer's eye).



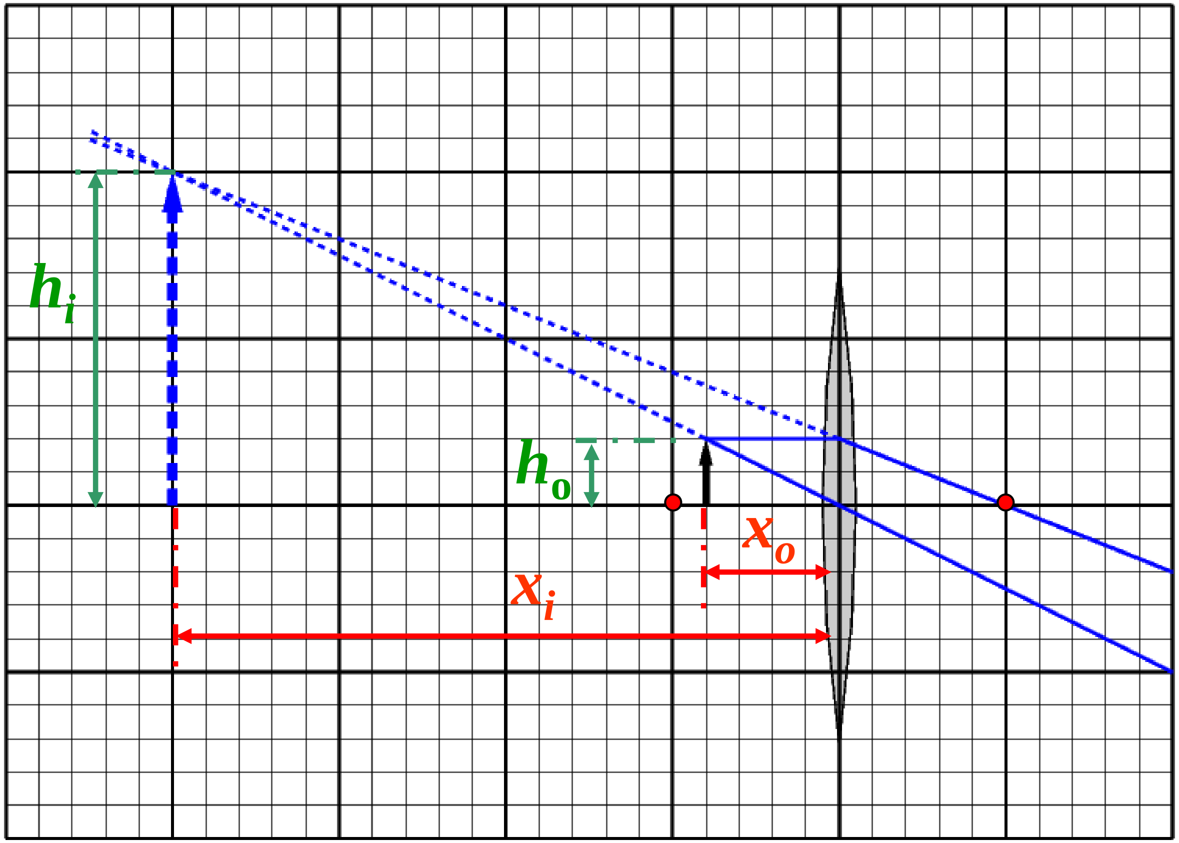

Our eye is right behind the lens.

We want the image to be at a distance of about 25 cm from the eye; this is the so-called “near point”, a distance at which we put small objects when we want to see them best,

So, $x_i$ is ≈ - 25 cm (minus, because the image is virtual);

$f$ is the focal length.

$$\frac{1}{x_o}+\frac{1}{x_i}=\frac{1}{f} \quad \text{so that} \quad \frac{1}{x_o}=\frac{1}{f}-\frac{1}{-25\,\text{cm}}=\frac{1}{f}+\frac{1}{25\,\text{cm}}$$




From the preceding slide :

$$\frac{1}{x_o} = \frac{1}{f} + \frac{1}{25\,\text{cm}}$$

$h_o$ is the object vertical size, $h_i$ - the image's vert. size.

"Magnifying Power" we define as $\text{MP} = \frac{h_i}{h_o}$; from the graph above it is clear that $\frac{h_i}{h_o} = \frac{|x_i|}{x_o} = \frac{25\,\text{cm}}{x_o}$

therefore $\text{MP} = \frac{25\,\text{cm}}{f} + \frac{25\,\text{cm}}{25\,\text{cm}} = \frac{25\,\text{cm}}{f} + 1$

Practical formula for magnifying power (MP) :

$$\text{MP} = \frac{25\,\text{cm}}{f\ [\text{in cm}]} + 1$$

## "Optical power": definition of a *dioptre*, or *diopter*:

A **dioptre**, or **diopter**, is a unit of measurement of the optical power of a lens or curved mirror, which is equal to the reciprocal of the focal length measured in metres (that is, 1/metres).

It is designated by the Greek symbol "$\boldsymbol{\delta}$":

$$\delta = \frac{1}{f\ \text{[in meters]}}$$

$$\text{Therefore, for a magnifying glass:}$$

$$\text{MP} = \frac{0.25\,\text{m}}{f\ \text{[in meters]}} + 1 = \frac{1}{4}\delta + 1$$

**Practical example: focal length of 5 cm corresponds to how many dioptres? What's the MP of such lens? (solve on the blackboard).**

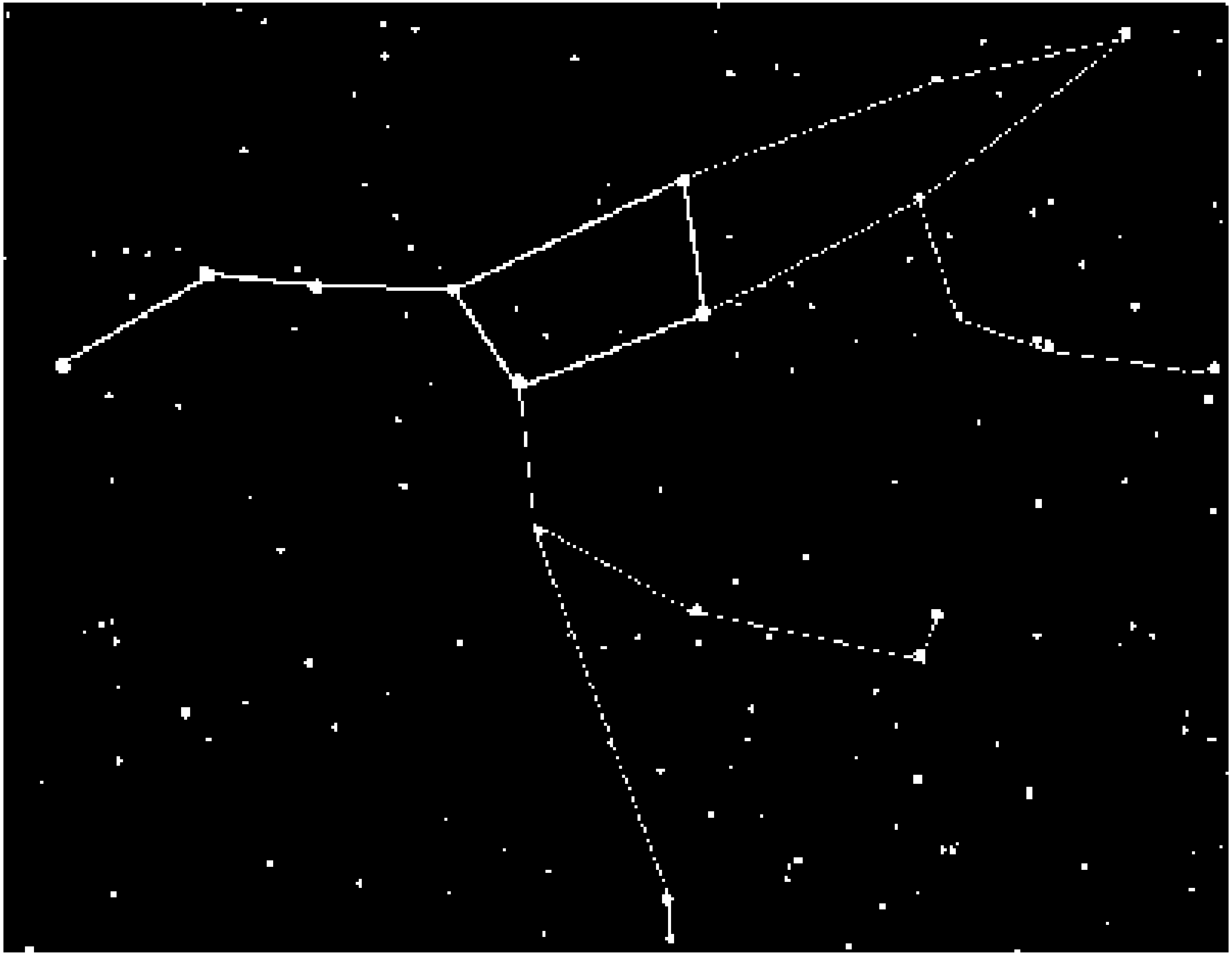
**<u>The importance of *angular magnification:*</u>**
Angular size (diameter), a.k.a. *aparent size*, or *visual angle* – explanation, and comparison with the *actual size* is given in this Wiki article.

**<u>To give you an idea</u>**:
Angular size of 1°: a nickel (5 cents) viewed from the distance of 3 feet;

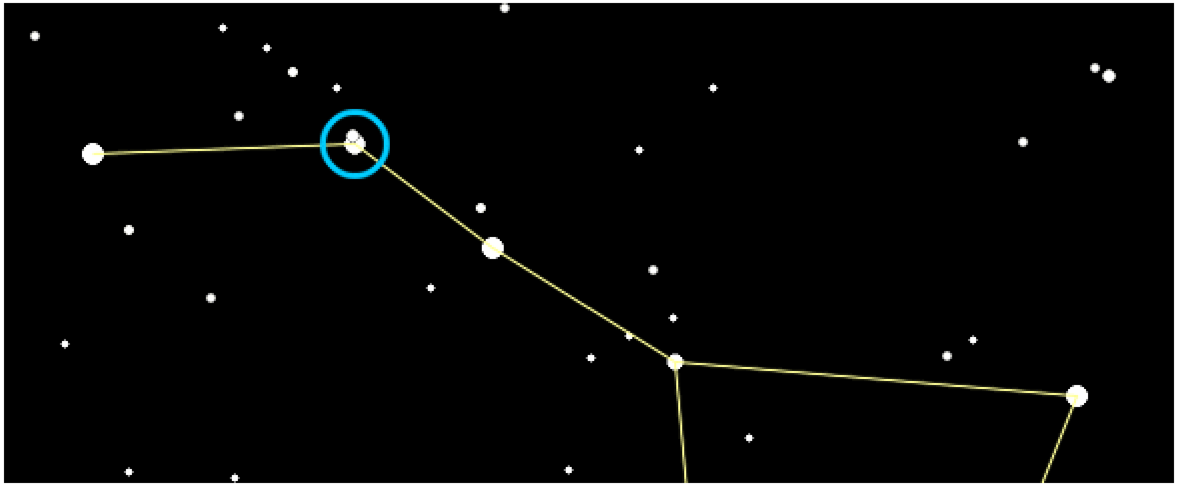
Angular size of 1 arc-minute: 0.01 inch object from the same distance;

Angular size of 1 arc-second: a dime viewed from the distance of 1 mile.

Everybody knows this constelation, right? This is *Ursa Major,* in Latin: “the larger female bear” (there is also a smaller one).

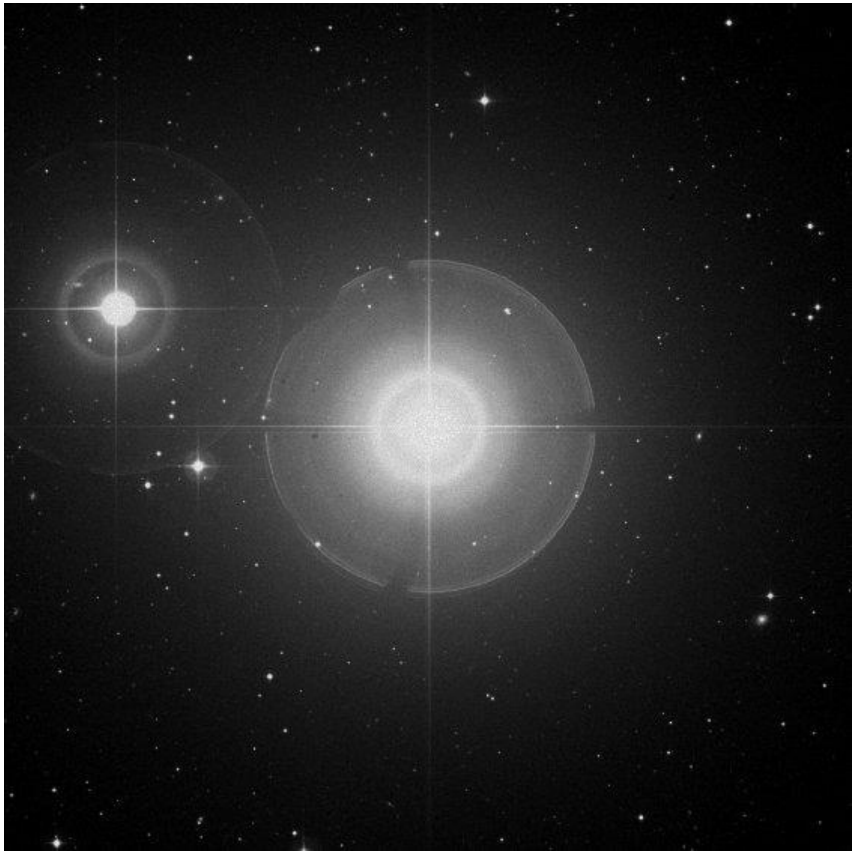


The highlighted seven stars form the “Big Dipper”



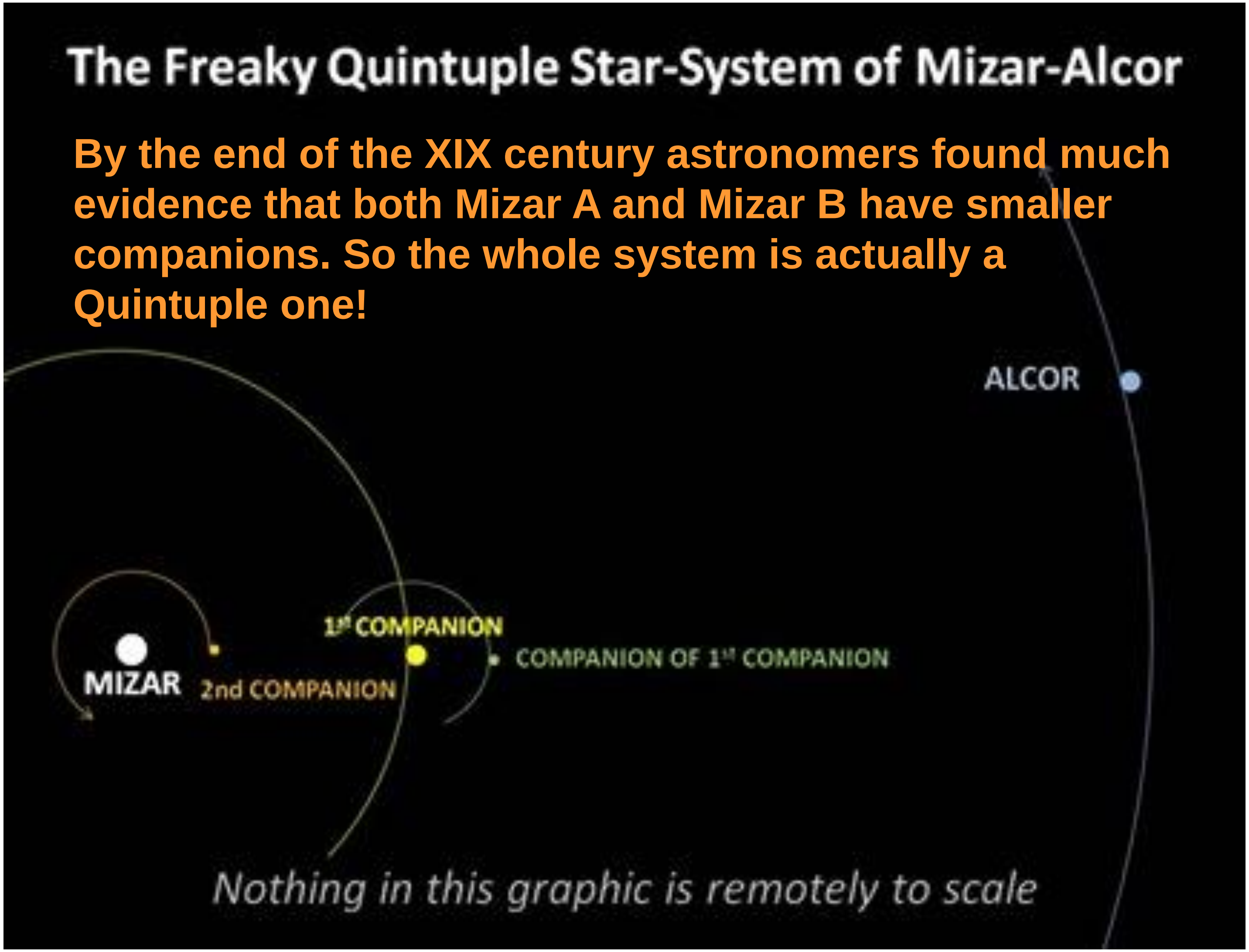
Seven stars in Big Dipper? No! Thousands of years ago it was known that the uppermost star in the group, called *Mizar,* has a companion, a somewhat dimmer star.

The smaller star was given a name of *Alcor* . The angular size of the Mizar-Alcor pair is about 12 minutes of arc. People with good eyes can see that it is a pair, not a single star. It was used as an "eye-test" by the ancient armies.

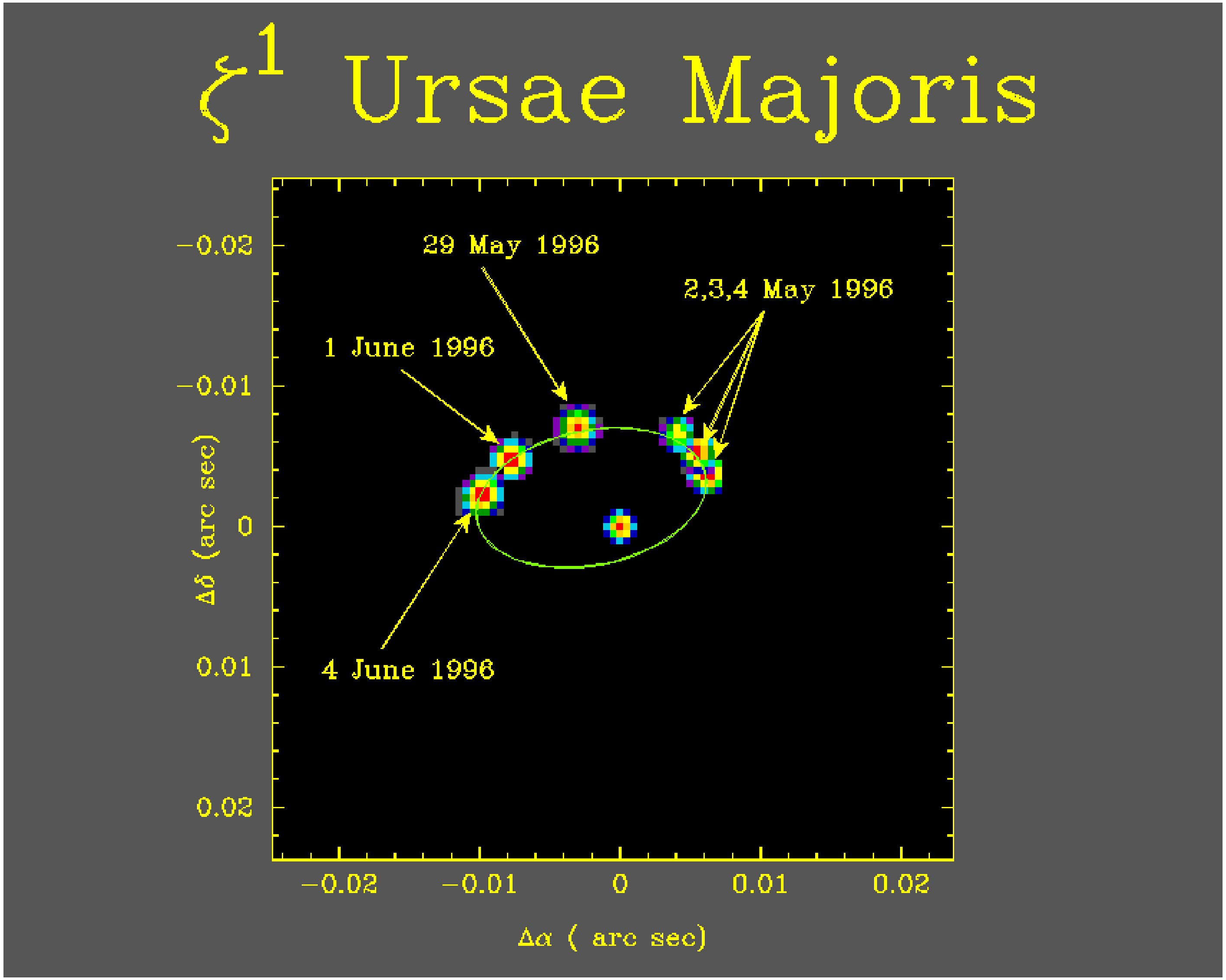


Using even a small telescope, one can clearly see that Mizar and Alcor form a binary star system. They orbit the common center of mass, one cycle last about 750,000 years.

Around the year 1650, shortly after Galileo built his first telescope, it was discovered that Mizar is not a single star, but a system of two! The angular size of the "Mizar A" and "Mizar B" system is only 14 seconds of arc, almost 60 times less then the Mizar-Alcor angular size.



However, the first direct observation of the Mizar A companion was made only in 1996, using an extremely powerful instrument that can “see” object of angular size as small as 0.001 second of arc!

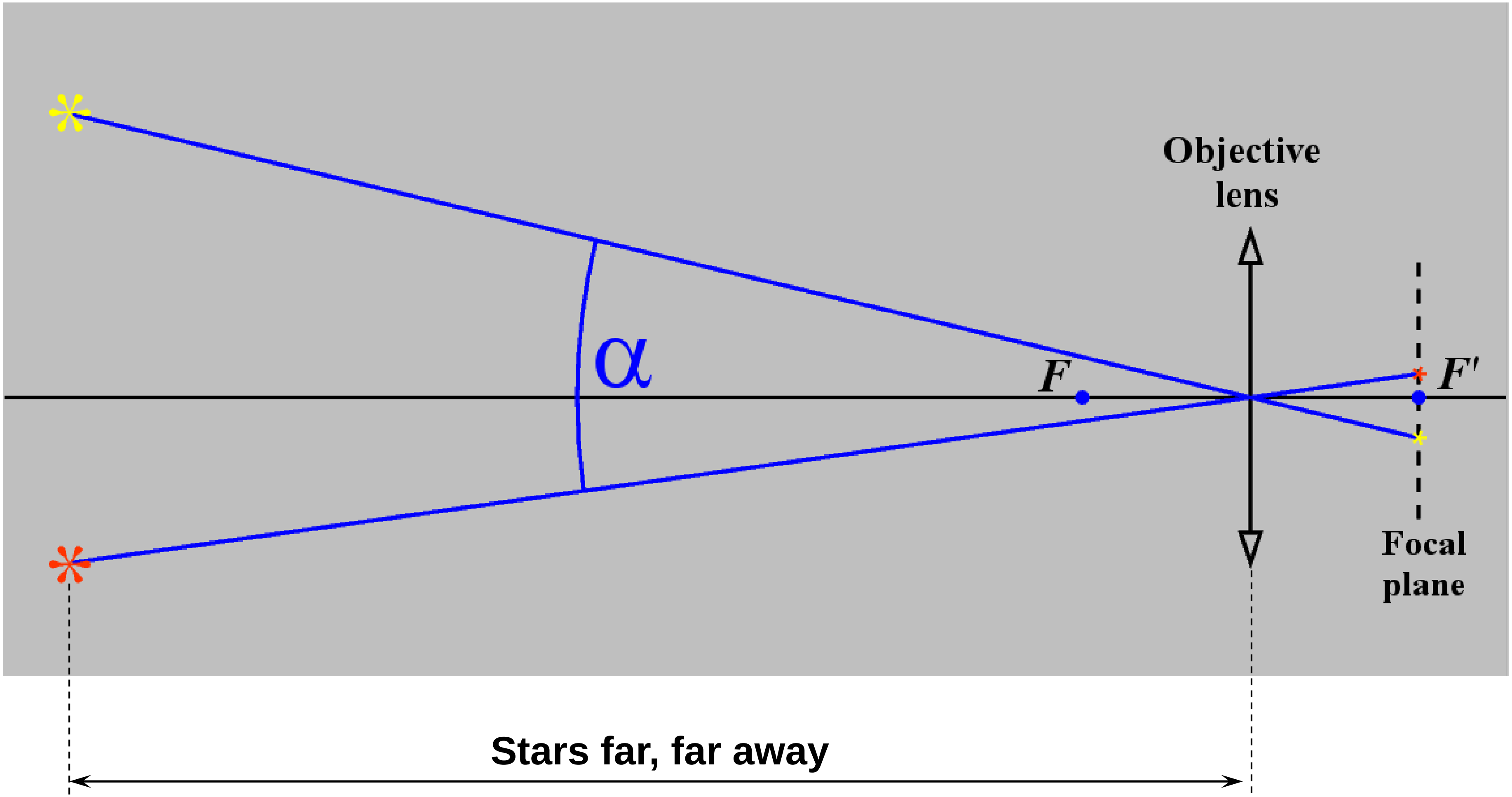


**The angular size of the Mizar-Alcor pir, 12 minutes of arc, is more or less the limit of human eyesight.**

**State-of-the-art instruments now can see objects with angular size as small as 0.001 second of arc – which corresponds to *angular magnification* of nearly one million!**

**The simplest optical instrument that magnifies the angular size of distant object is a *refracting telescope*, consisting of just two lenses. Historically, the first telescope used for astronomical observation was built by Galileo in 1609. It used a convex objective lens, and a diverging lens as the eyepiece. In 1611 Kepler invented another type that uses two convex lenses. The "Keplerian telescope" became far more popular than the "Gallilean" one, and is still widely used today – so we will discuss only the Kepler's design.**

Consider a pair of distant stars that together form an object of angular size $\alpha$. It is easy to construct the image of such object formed by a converging lens.



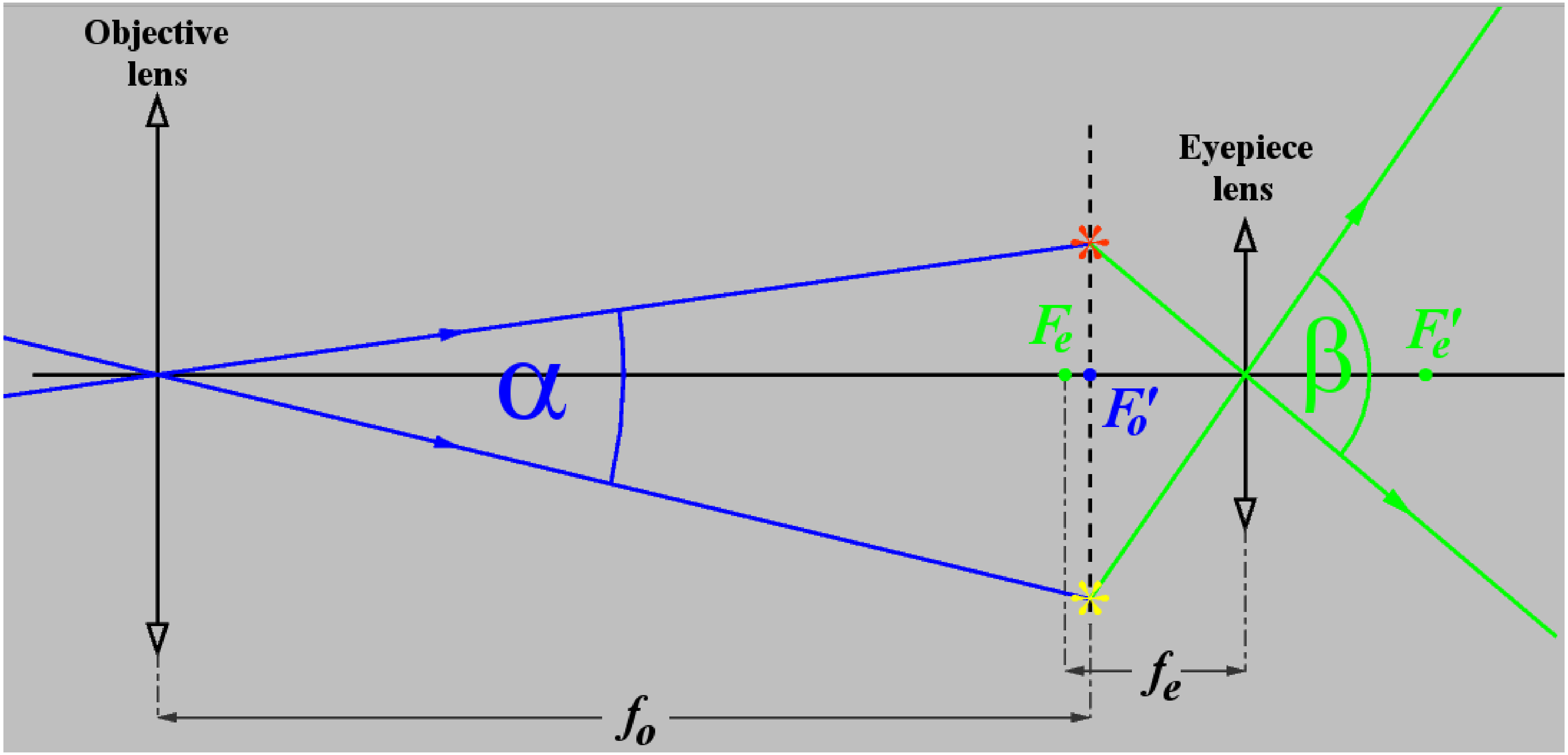

The rays from a very distant point object are nearly parallel, so that the image is a point located at the *focal plane.* The ray-tracing is very simple, it's enough to draw just a single ray for each star – the one passing through the lens center.

**The images formed on the focal plane are *real images.* Real images, as we know, can be viewed on a screen. But we will not use a screen – we want to get a <u>magnified</u> image! Therefore, we will use another lens, the *eyepiece,* which will act as a *magnifying glass.* Simple idea? Surely!**

**Now, let's think. It's quite clear that we want to get a magnification as big as possible. And how we use a magnifying glass to get the best possible magnification?**

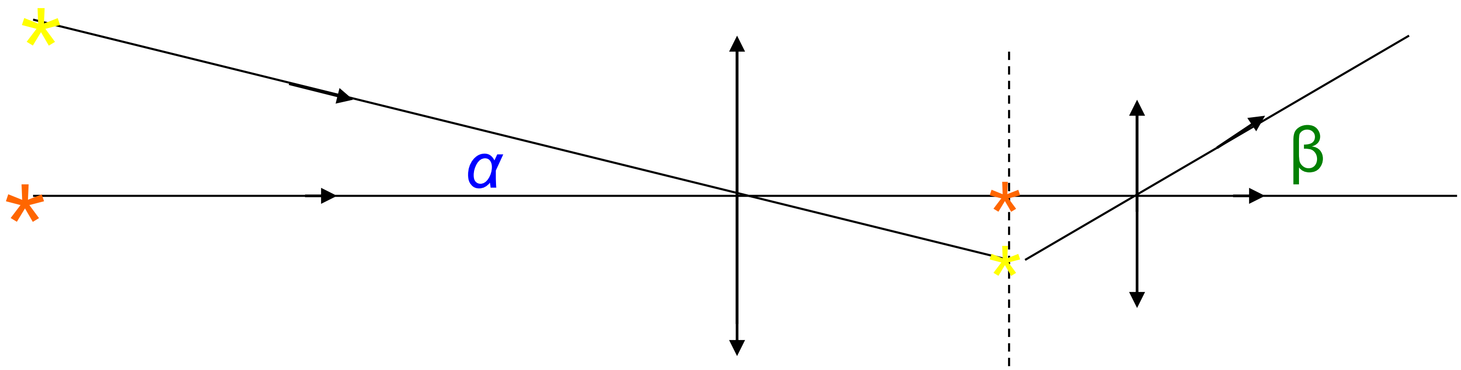
**Let's make a small break now, and let's switch for a moment to the "Java Lens Tutorial".**

Back to the slides. We have refreshed our memory with the "Java tutorial": One gets the best magnification by placing the object just behind the focal point of the magnifying glass (below, marked as $F_e$ ).




Our "objects" for the "magnifying glass" – i.e, the eyepiece lens – are the star images that formed on the focal plane of the objective. Again, we can use A simplified "single-ray ray-tracing procedure", to obtain the angular size β of the star pair image seen through the eyepiece lens.

**To find the angular magnification of a "Keplerian Telescope", we will use the same ray tracing scheme as in the preceding slide. However, in order to facilitate the calculation, we will place one of the stars exactly on the instrument's axis*:**

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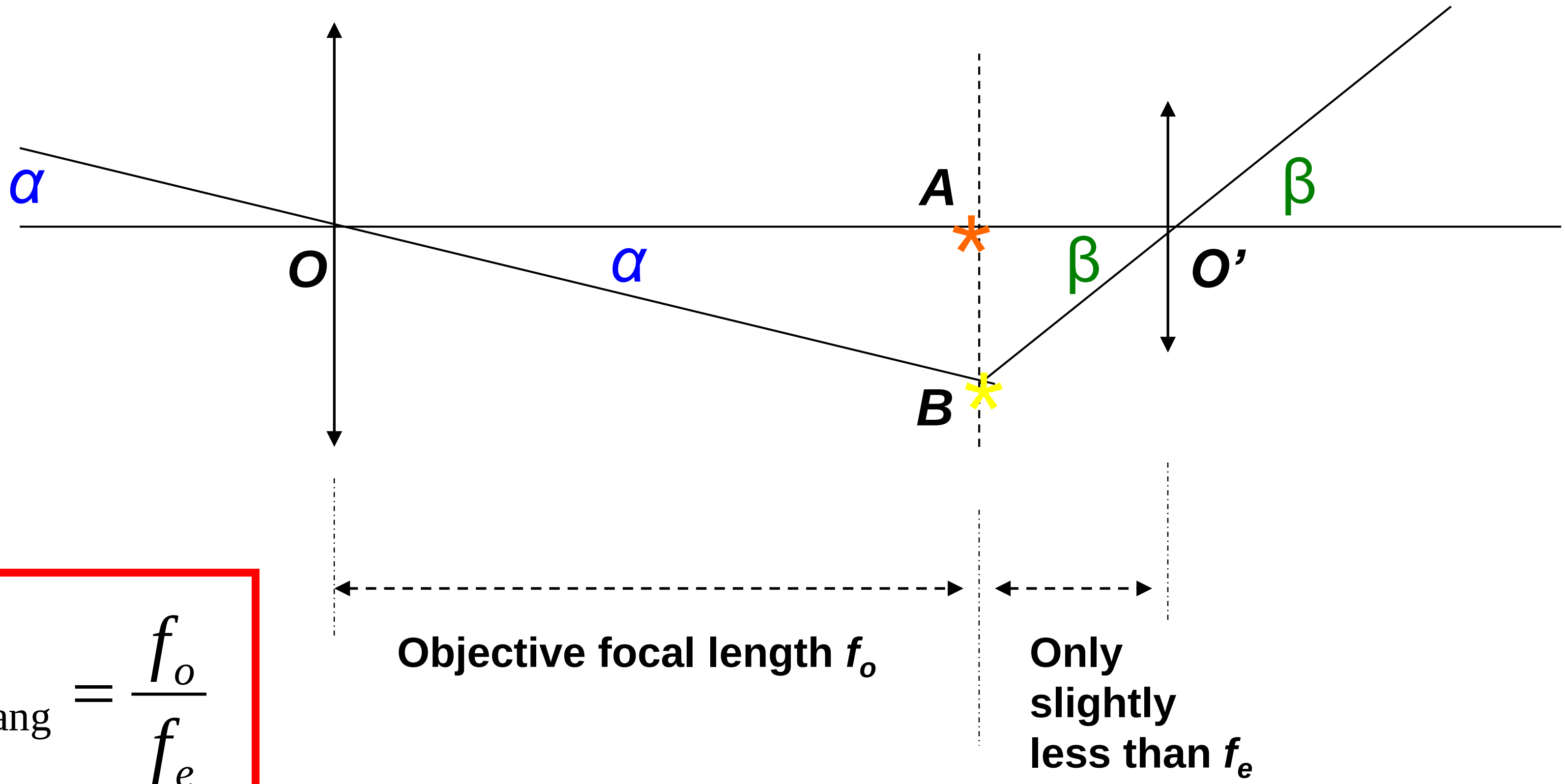
•One can always do that by aiming the telescope in such a way that one of the stars is exactly in the center of the vision field.

**Now, a tiny bit of trigonometry….**

**For small angles, the tangent is, to a very good approximation, equal to the angle.**

$$\alpha \approx \tan\alpha = \frac{AB}{AO} = \frac{AB}{f_o}; \quad \beta \approx \tan\beta = \frac{AB}{AO'} \approx \frac{AB}{f_e}$$

$$\text{Angular magnification } M_{\text{ang}} = \frac{\beta}{\alpha} \approx \frac{f_o \cdot AB}{f_e \cdot AB} = \frac{f_o}{f_e}$$




$$\boxed{M_{\text{ang}} = \frac{f_o}{f_e}}$$