A new instrument to measure atmospheric refraction at any azimuth and elevation

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Outline

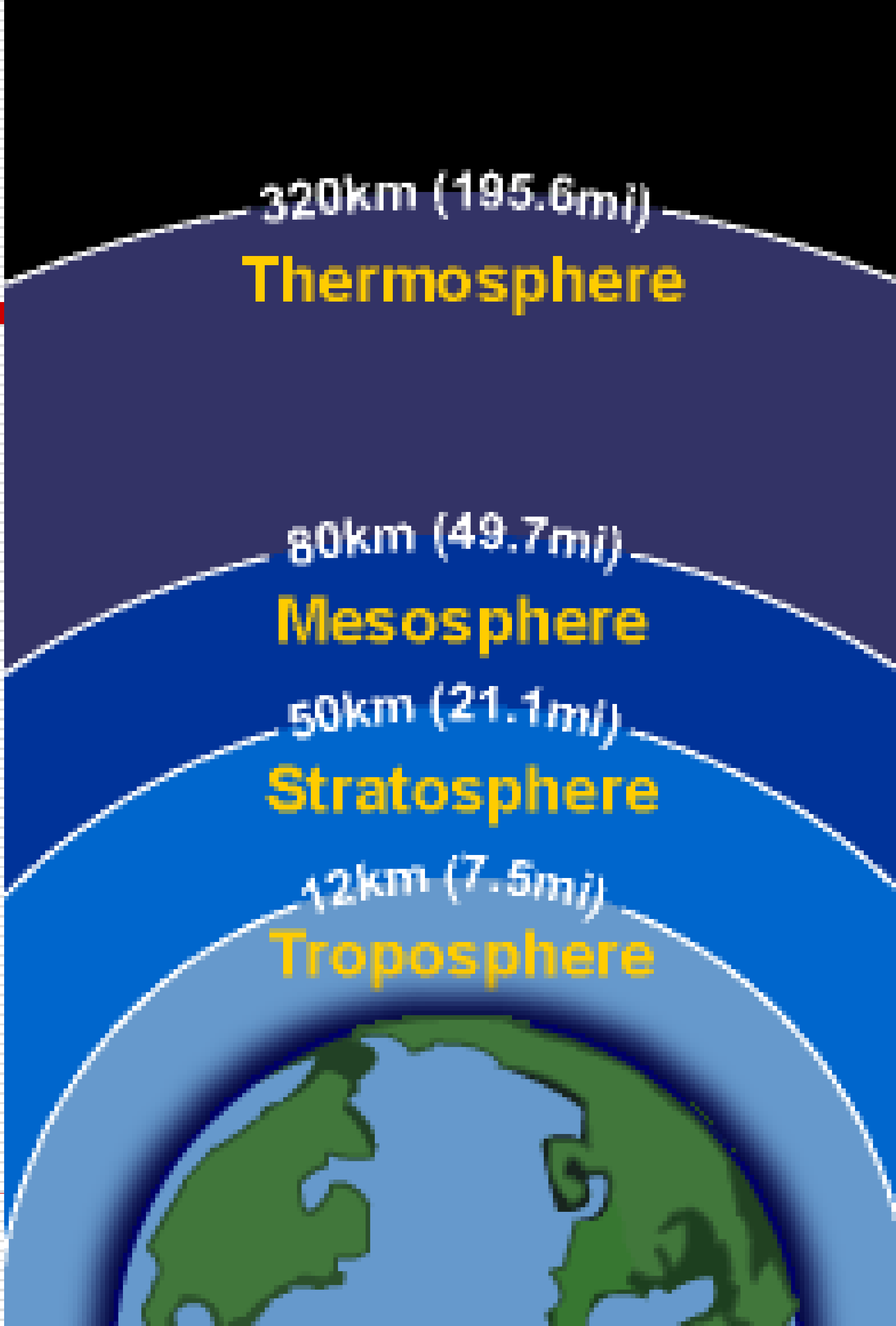
- Background
- Principle
- Prototype
- Next step

1. Background

- Atmosphere: a layer of gases surrounding our Earth, which is retained by Earth's gravity.

1. Background

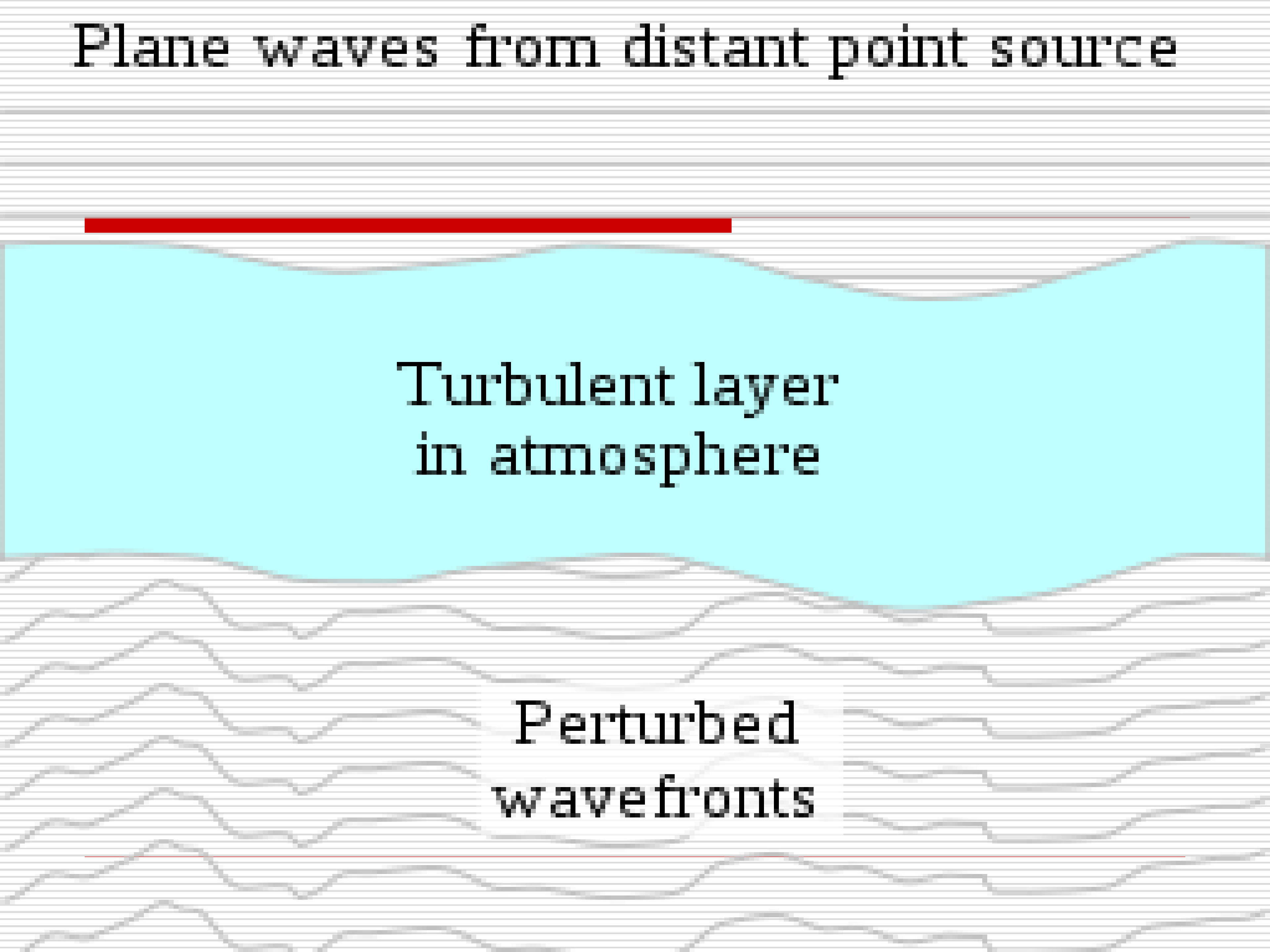
- Different layers of atmosphere.



1. Background

- Two main effects of atmosphere on astronomical observation:

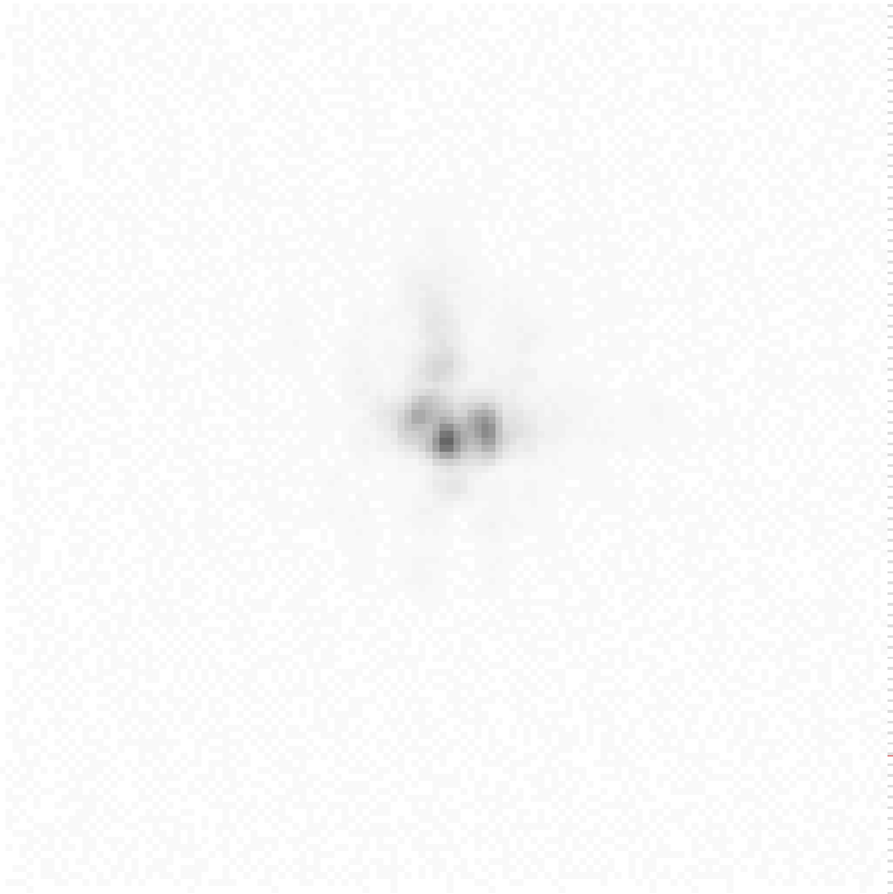
1) **Astronomical seeing**: refers to the blurring and twinkling of stars caused by turbulent atmosphere. It makes a star from a point to a blurred blob.



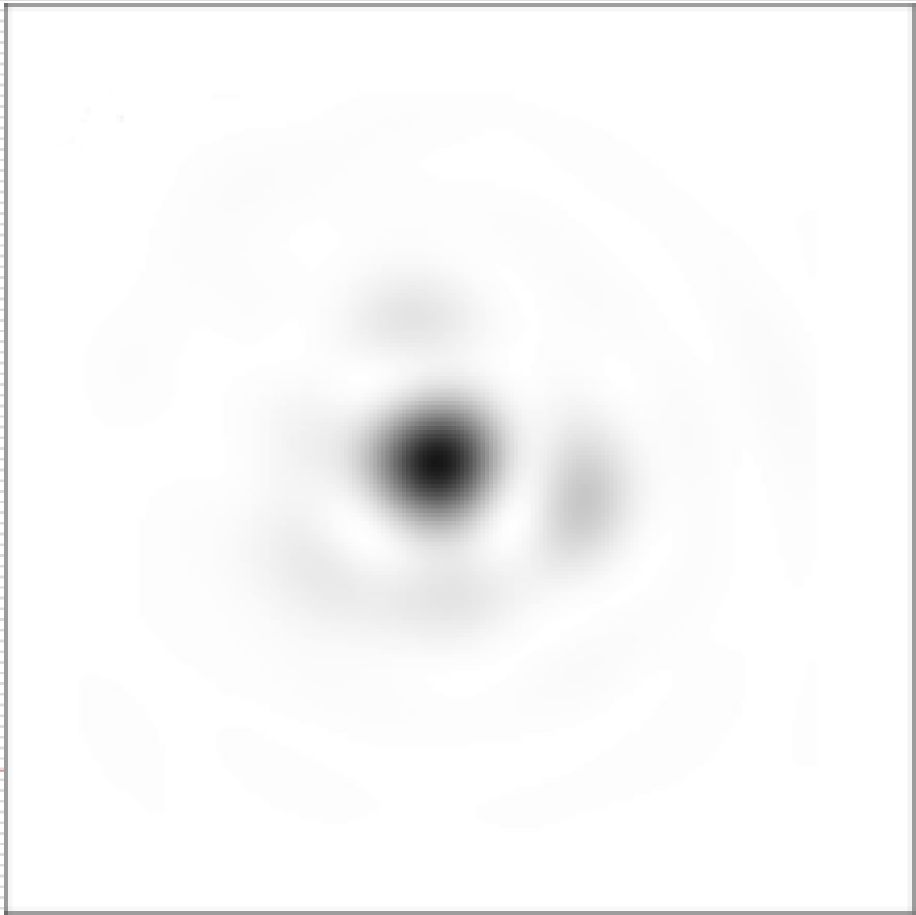
Plane waves from distant point source
Turbulent layer in atmosphere
Perturbed wavefronts

1)Astronomical seeing

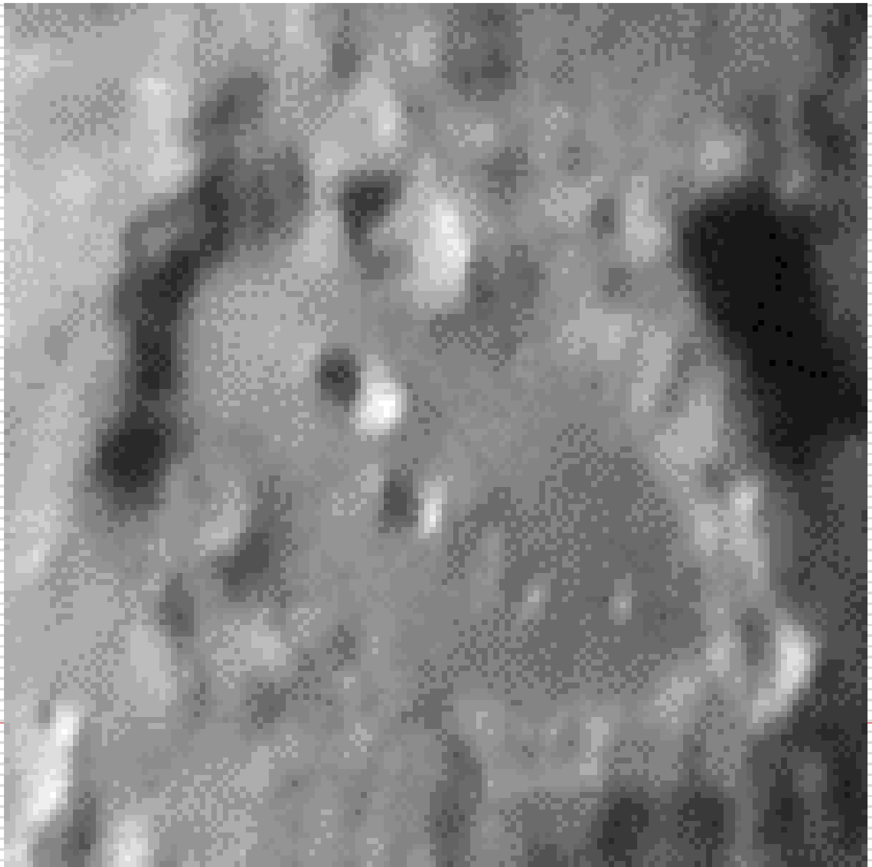
Images of short exposure



Final image after long exposure



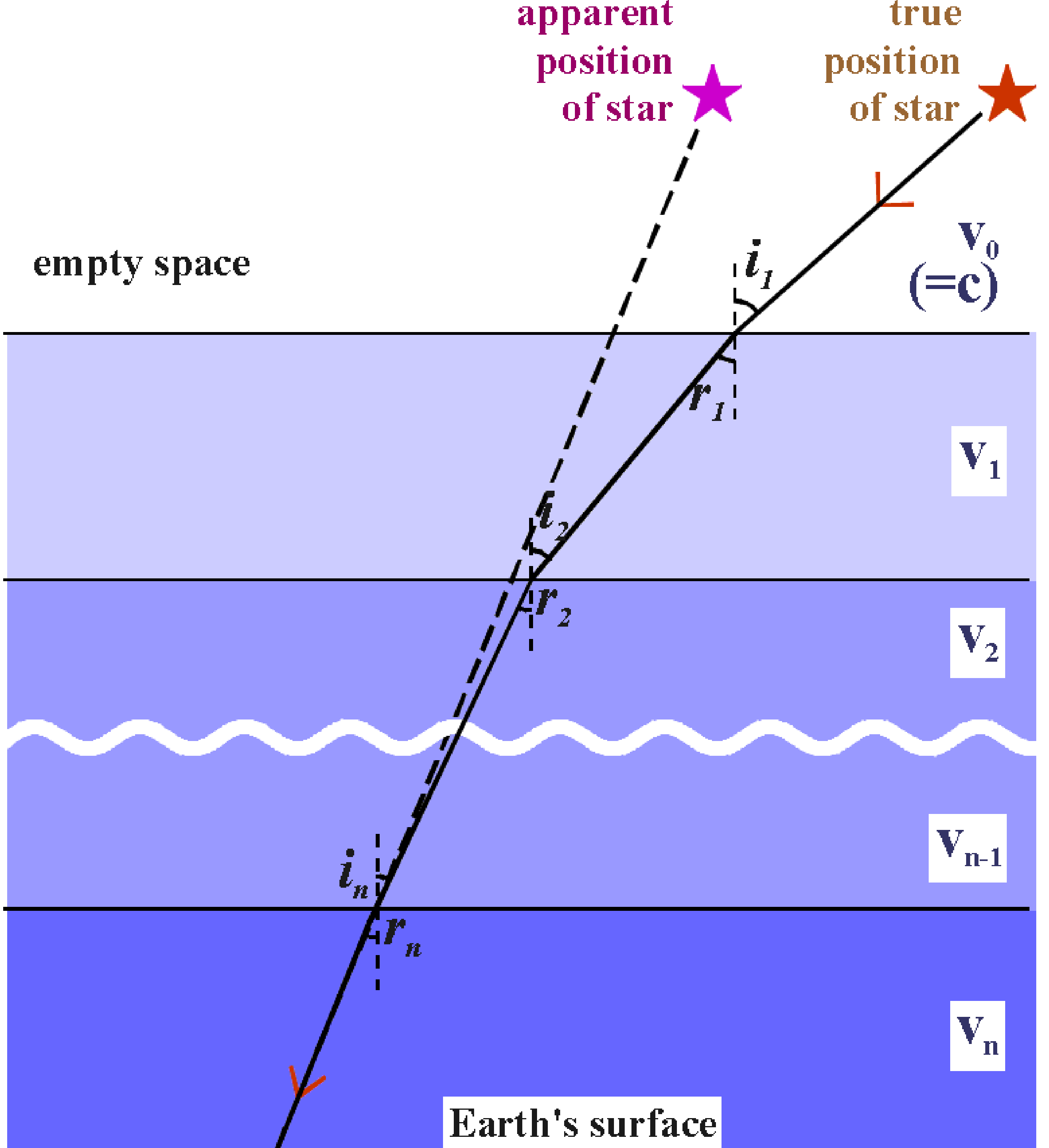
An animated image of the Moon’s surface showing the effects of Earth's turbulent atmosphere on the view.

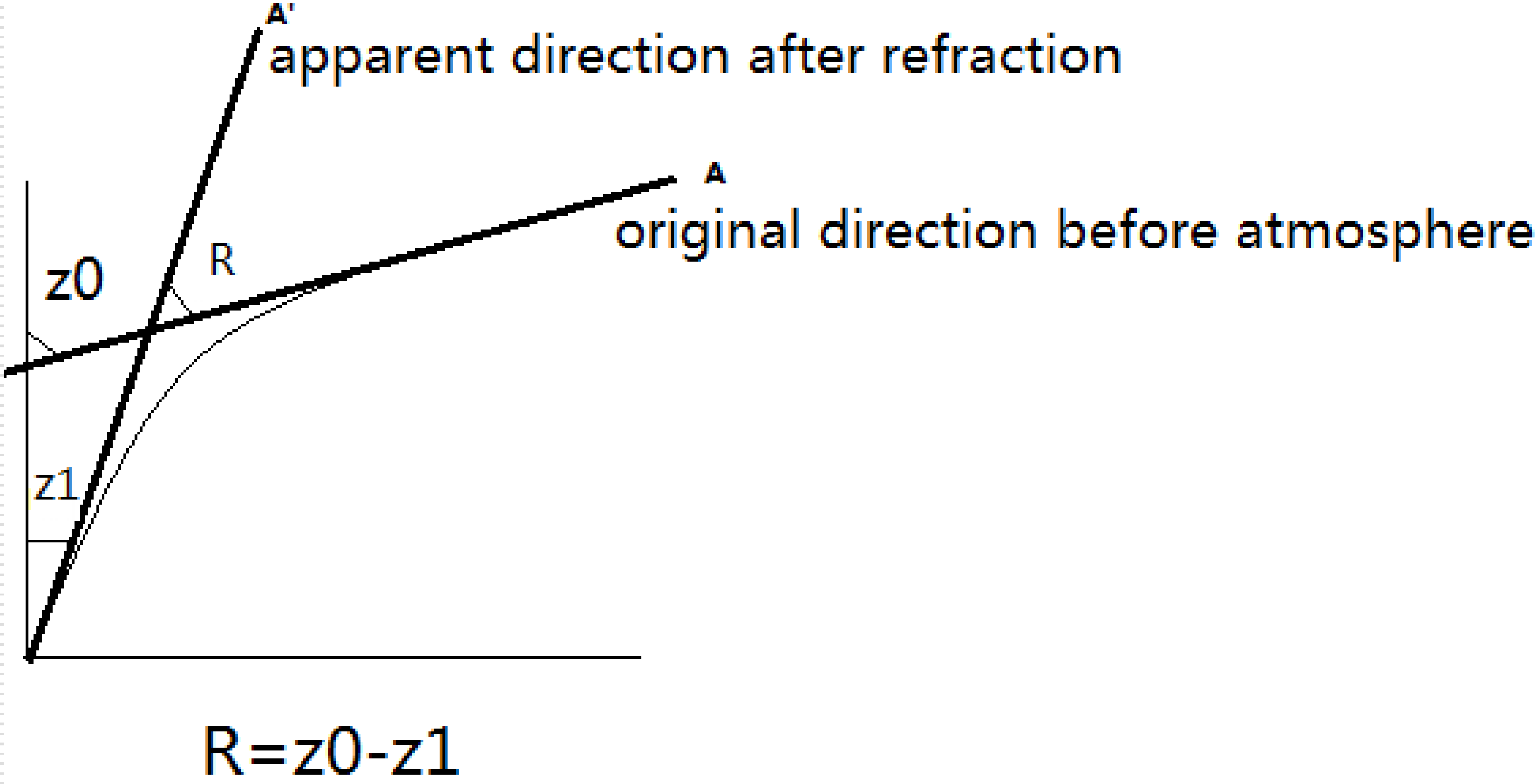


1. Background

- Another main effect of atmosphere on astronomy:

2) Astronomical refraction (AR): the deviation of light from a straight line as it passes through the atmosphere due to the variation in air density as a function of altitude (the lower, the bigger).


apparent
position
of star
true
position
of star
empty space
i_1
V_0
(=c)
r_1
V_1
i_2
r_2
V_2
V_{n-1}
i_n
r_n
V_n
Earth's surface

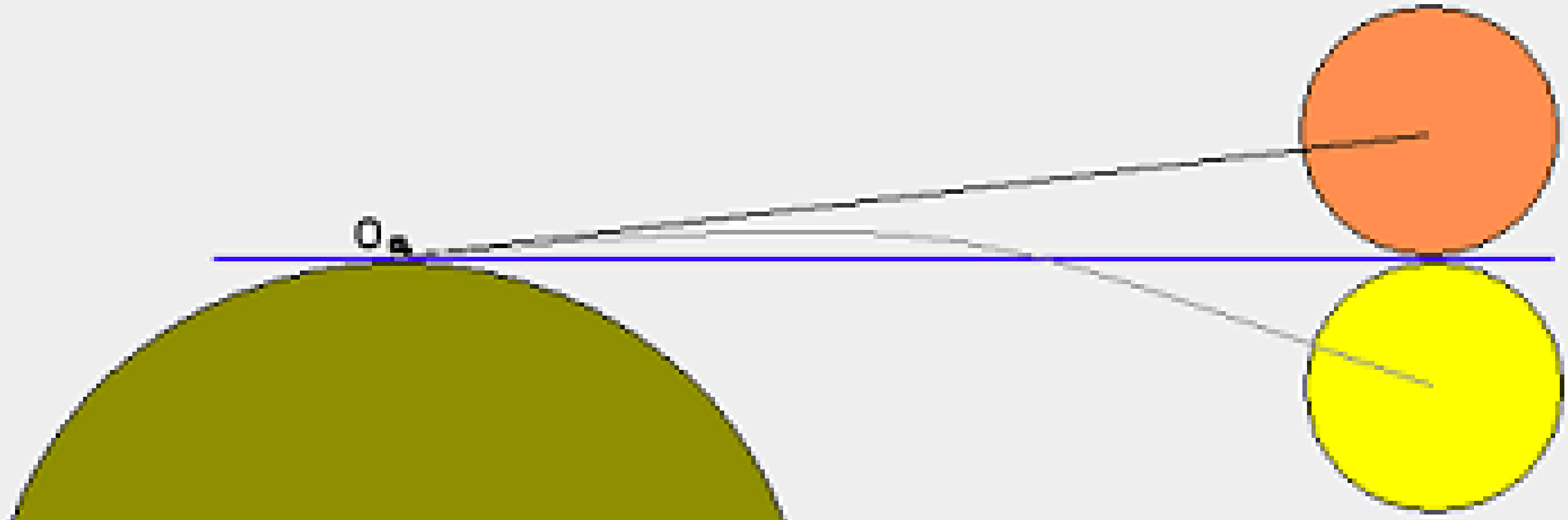


Formula to calculate AR (at a site of north latitude 45 deg, sea level, T=0℃, P=1013.25mb).

$$R = 60''.29 \tan z_0 - 0''.06688 \tan^3 z_0$$

2) Astronomical refraction

When we see the Sun is rising from the horizon, actually it is about 30 arc-minutes under the horizon! Because the AR along horizon is about 30 arcminutes.



1. Backgroundc

- Ground-based observation is always influenced by AR.
- One of the key tasks of ground-based astrometry is to correct AR to get real directions of stars.
- The formula is only valid for zenith distance smaller than 70 degree.

1. Background

- Besides the elevation, AR is quite related with many other factors, such as temperature, pressure, humidity, wind, nearby orographic (mountain, sea, flatland).

$$R(T,P) = R_0 \times \frac{P(\text{mb})}{1013.25} \times \frac{273.15}{273.15 + T(^\circ\text{C})}$$

- The refraction will be quite different at different locations; even at the same location, the refraction of different directions are not exactly the same. Especially at larger zenith distance.

1. Background

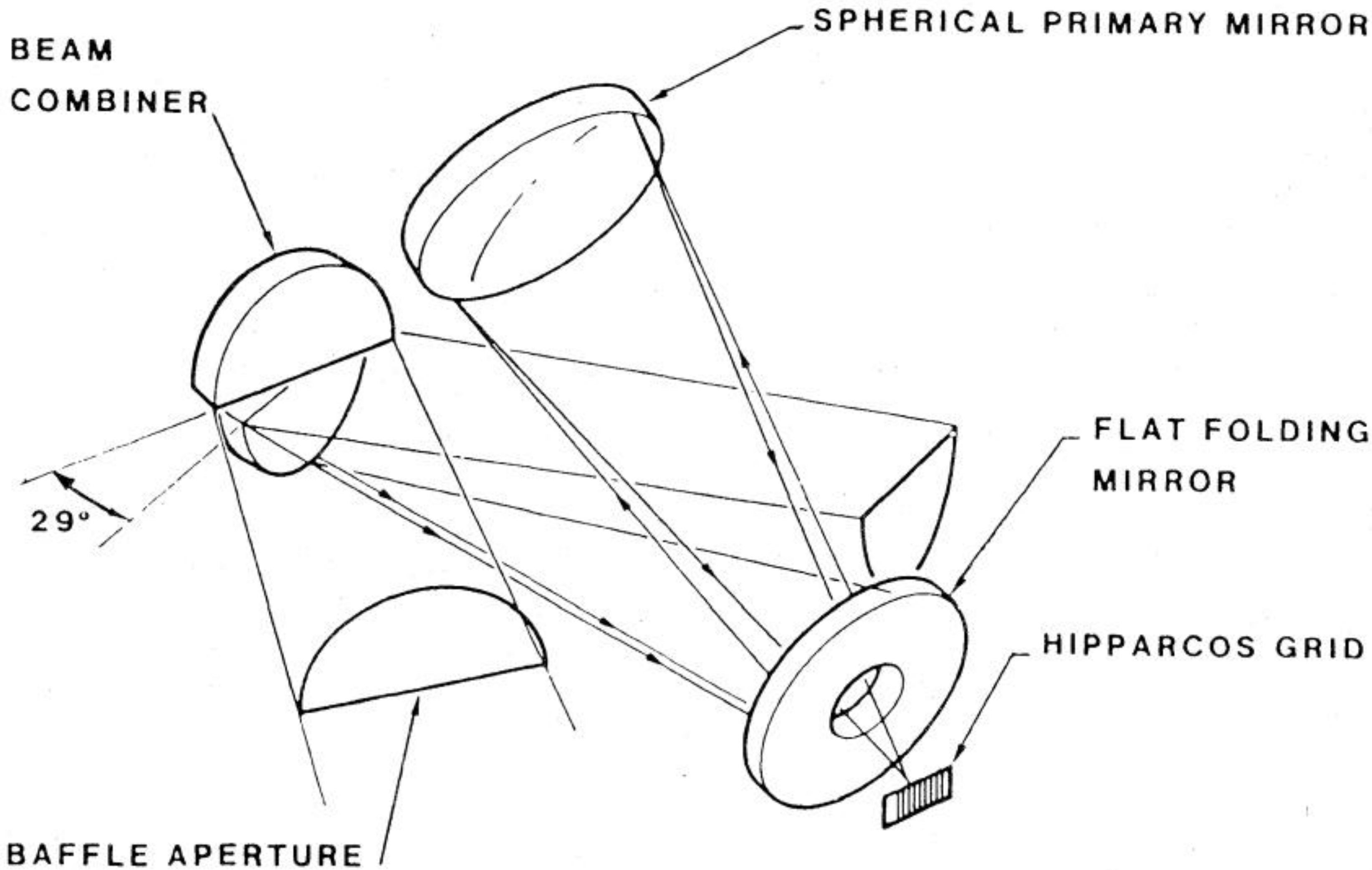
- It is difficult to build a global precisely refraction model. That’s why atmospheric refraction model created by Pulkovo Observatory have been used for more than 150 years.
- Astronomical observations to low elevation directions have to be avoided, even it is needed in some cases.
- Special instruments have been used to measure AR (meridian circle and astrolabe), but they can only measure AR for few zenith and elevation, and since the deflection of tube of telescope and AR have similar behavior, it is very hard to separate them precisely.

1. Background

- AR not only influence on optical observation, but also on radio observation. Better model of AR will be useful to both observations.
- Real time measurement of AR at any zenith and elevation is necessary to build a suitable model for one site and its data can be used to analysis variation of atmosphere.

2. Principle

- The only way to correct AR is to measure it precisely and easily.
- But how?
- The idea of the new instrument came from the optical design of HIPPARCOS satellite.



Configuration of the telescope of the HIPPARCOS satellite

2. Principle

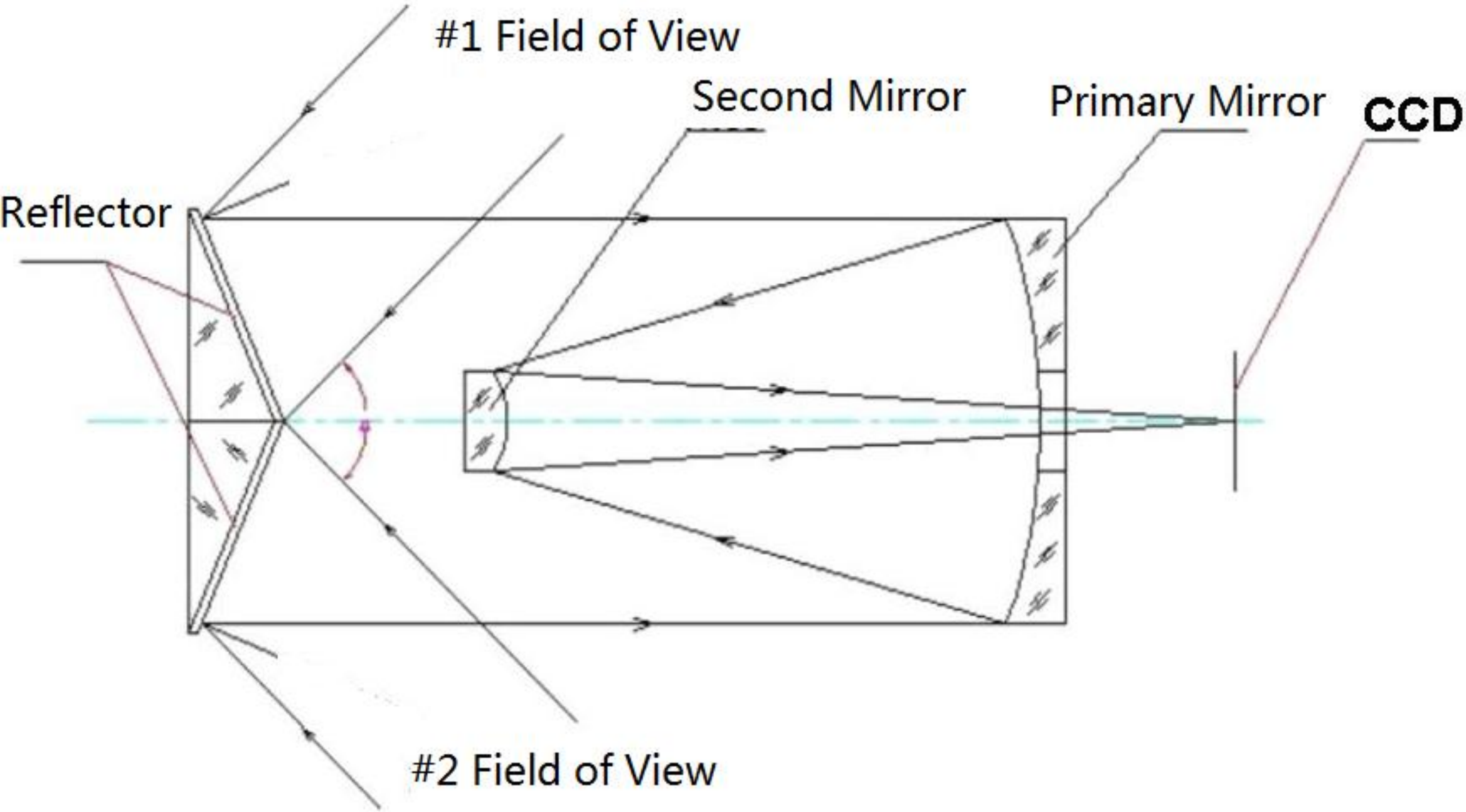
- Stars from two fields of view are imaged with the same optical system and detector, parallax of one star in one field can be determined with the reference stars of aother field.
- Such optical design can not be used on ground because AR is hard to be modelled very precisely.

2. Principle:

Two items that lead to new instrument.

- Now we have good catalogues like HIPPARCOS, TYCHO-2 and UCAC4, such optical design can be used to measure AR inversely!
- The formula of AR is very precise for small zenith distance.

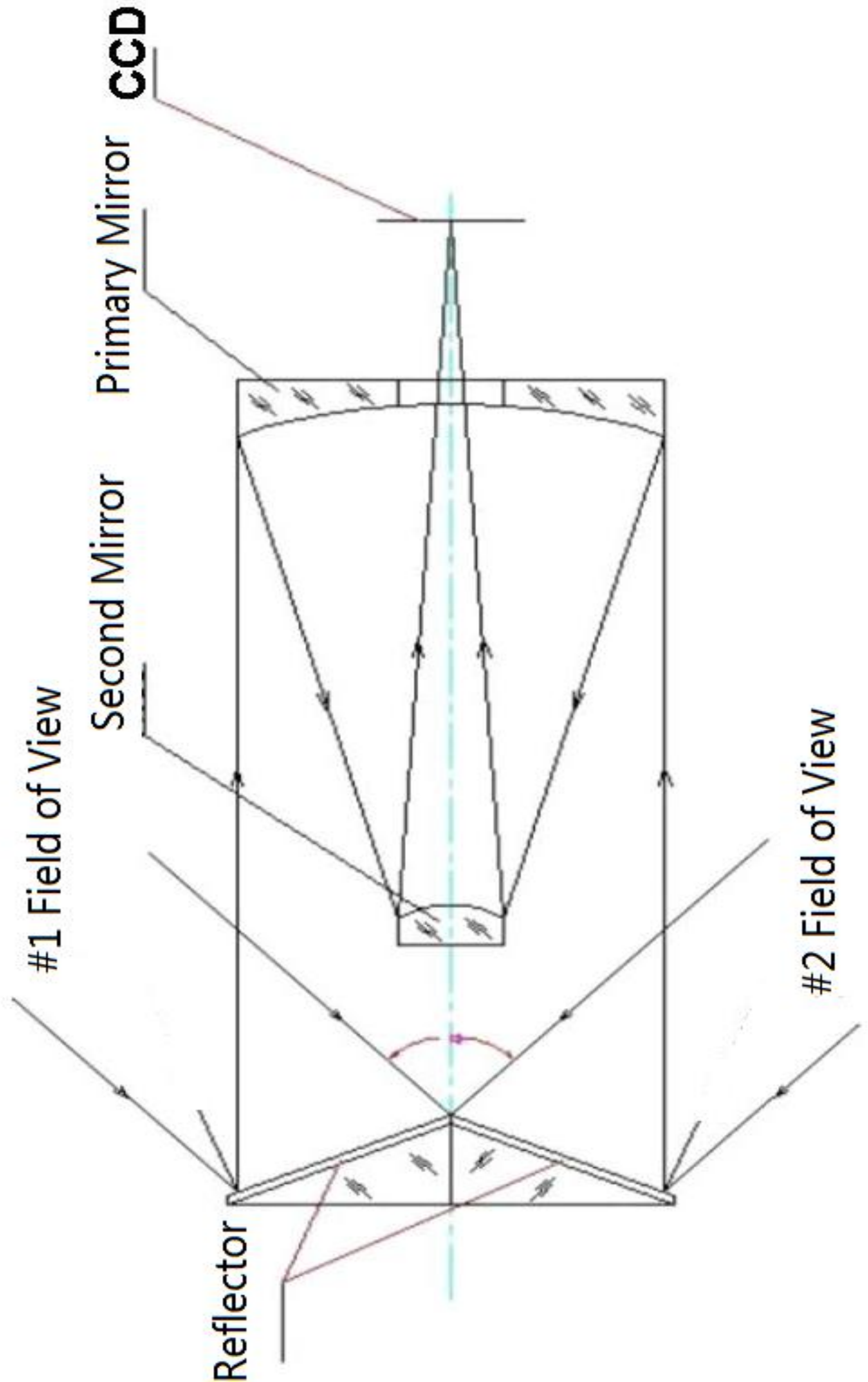
2. Principle:

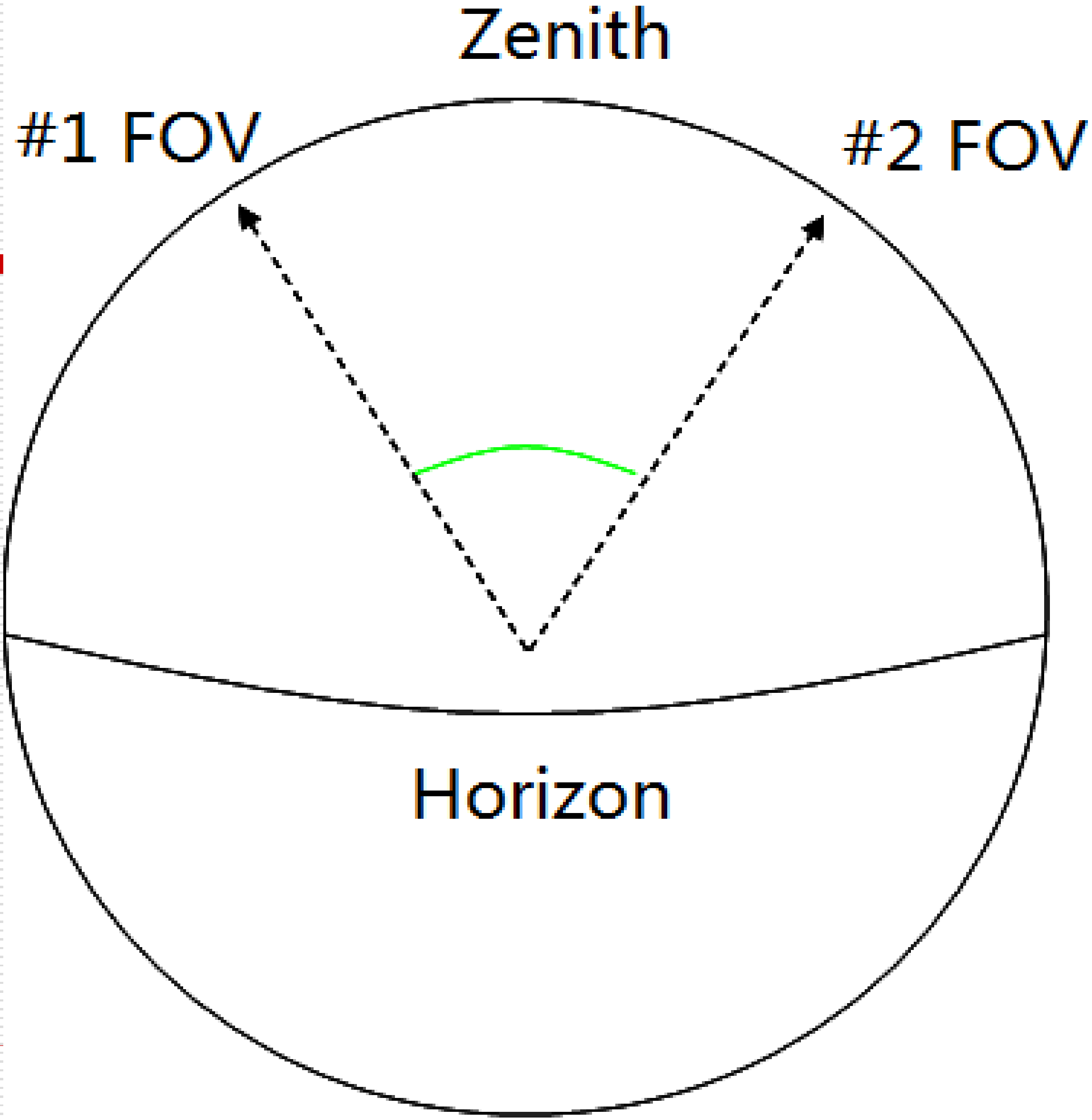

#1 Field of View
Second Mirror
Primary Mirror
CCD
Reflector
#2 Field of View

2. Principle:

Observing procedure

Step 1: Let two FOVs point to upper sky to make both FOVs near the zenith (~30 deg).



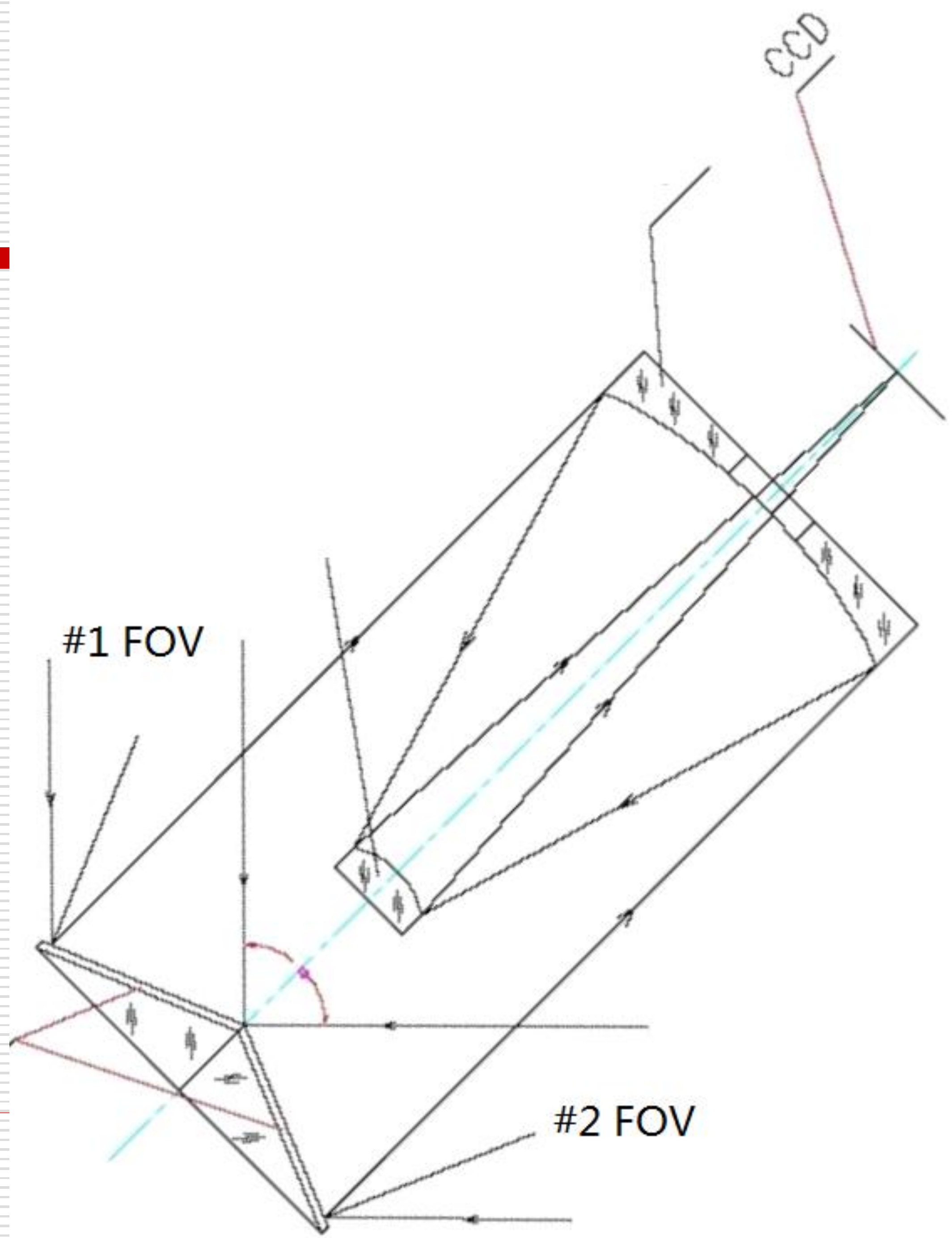

Zenith
#1 FOV
#2 FOV
Horizon

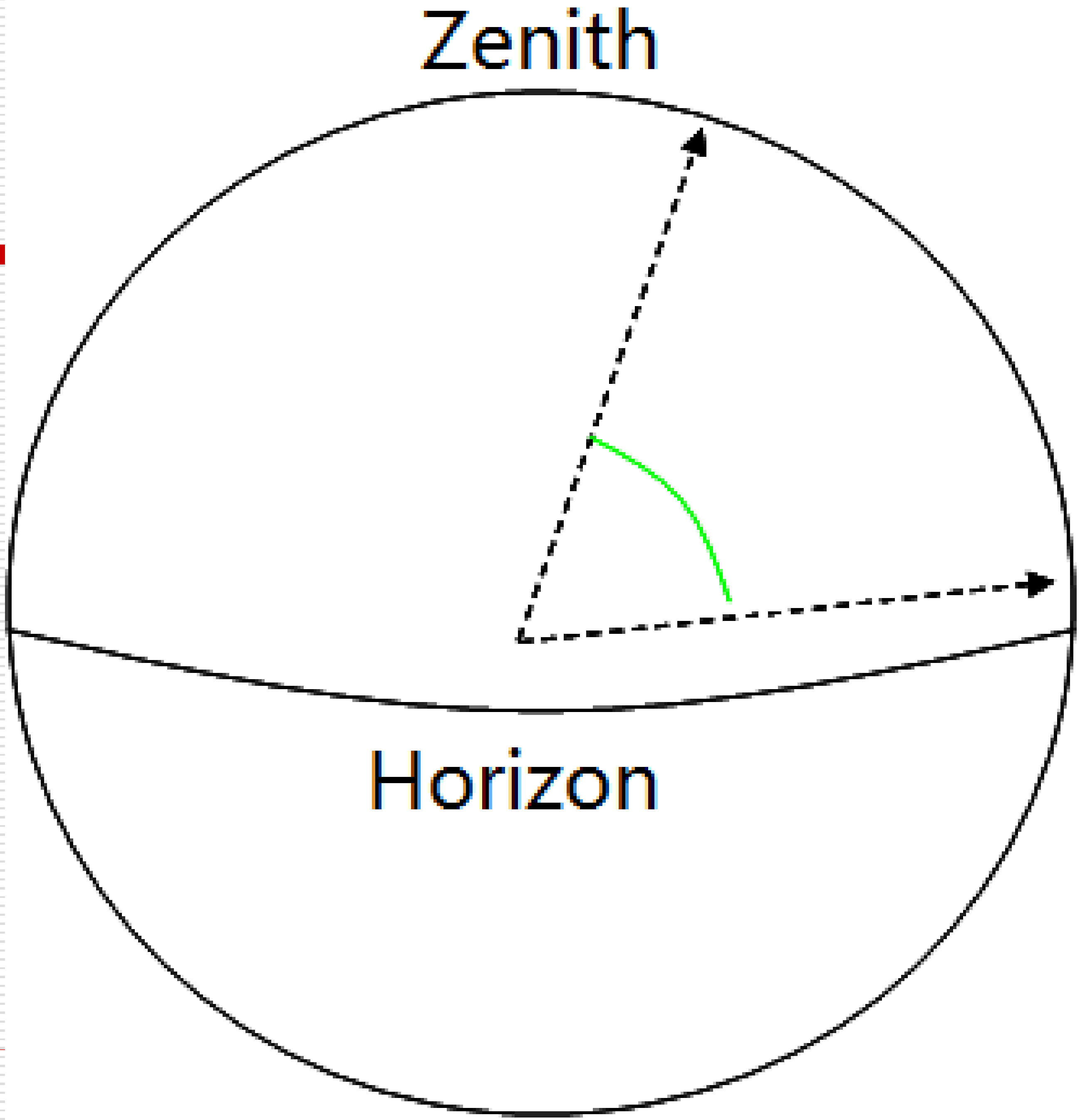
2. Principle:

- Since the formula of AR near the zenith is accurate enough (0".1), use the formula to calculate AR,
- Using star catalogue to calculate centers of the two FOVs.
- Calculate the angle between two mirrors of the Reflector from above two steps.

2. Principle:

Step 2: Let one FOV point to high elevation, another FOV point to low elevation.



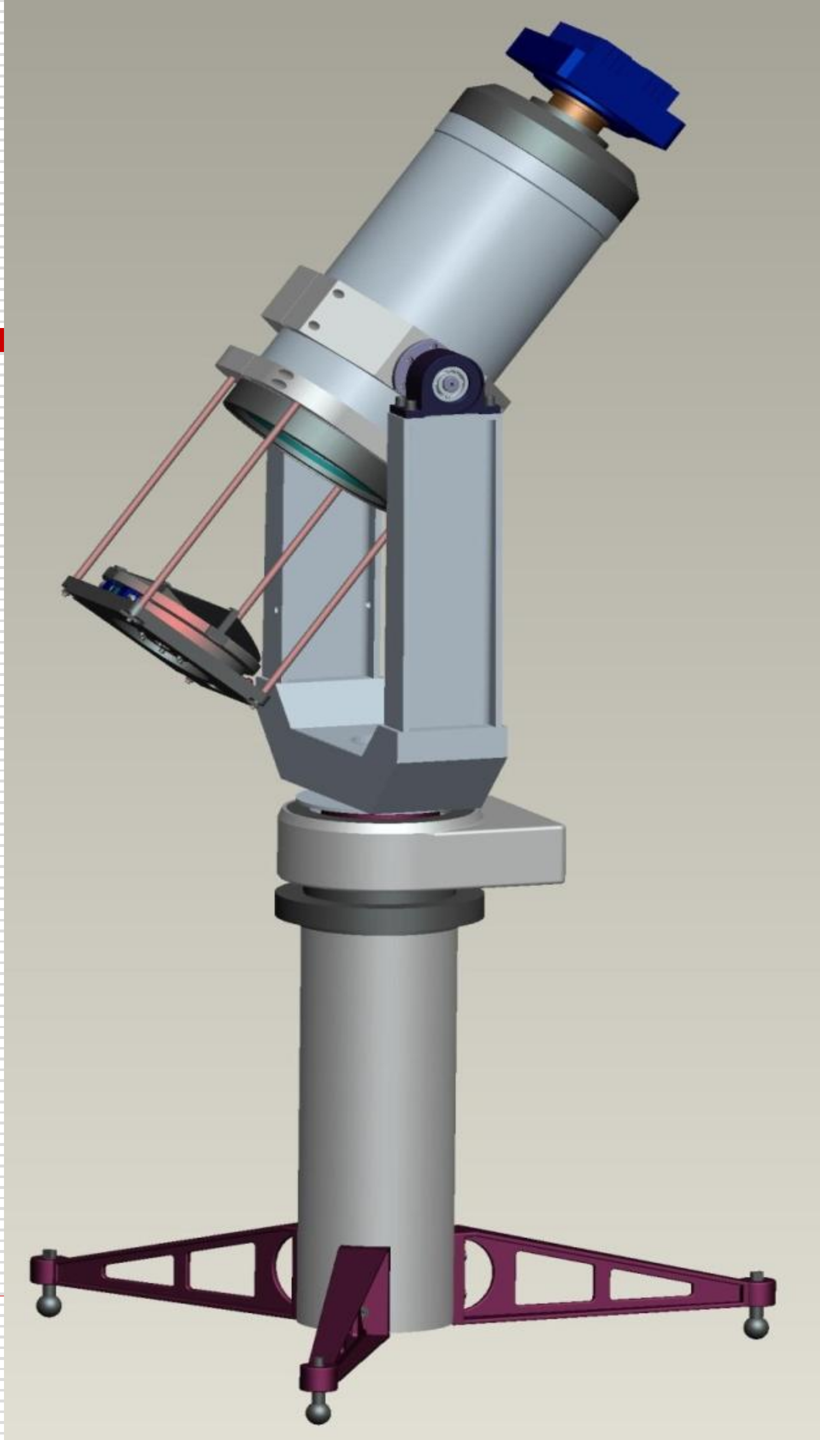

Zenith
Horizon

2. Principle

- Since the formula of AR near the zenith is accurate enough (0".1), use the formula to calculate AR of center of #1 FOV,
- Using star catalogue to calculate centers of the two FOVs (after all astrometric corrections).
- Using the angle between two mirrors of the Reflector and above results, calculate AR of center of #2 FOV.

3. Prototype

Concept design of the new instrument.



3. Prototype

- Reflector with two mirrors

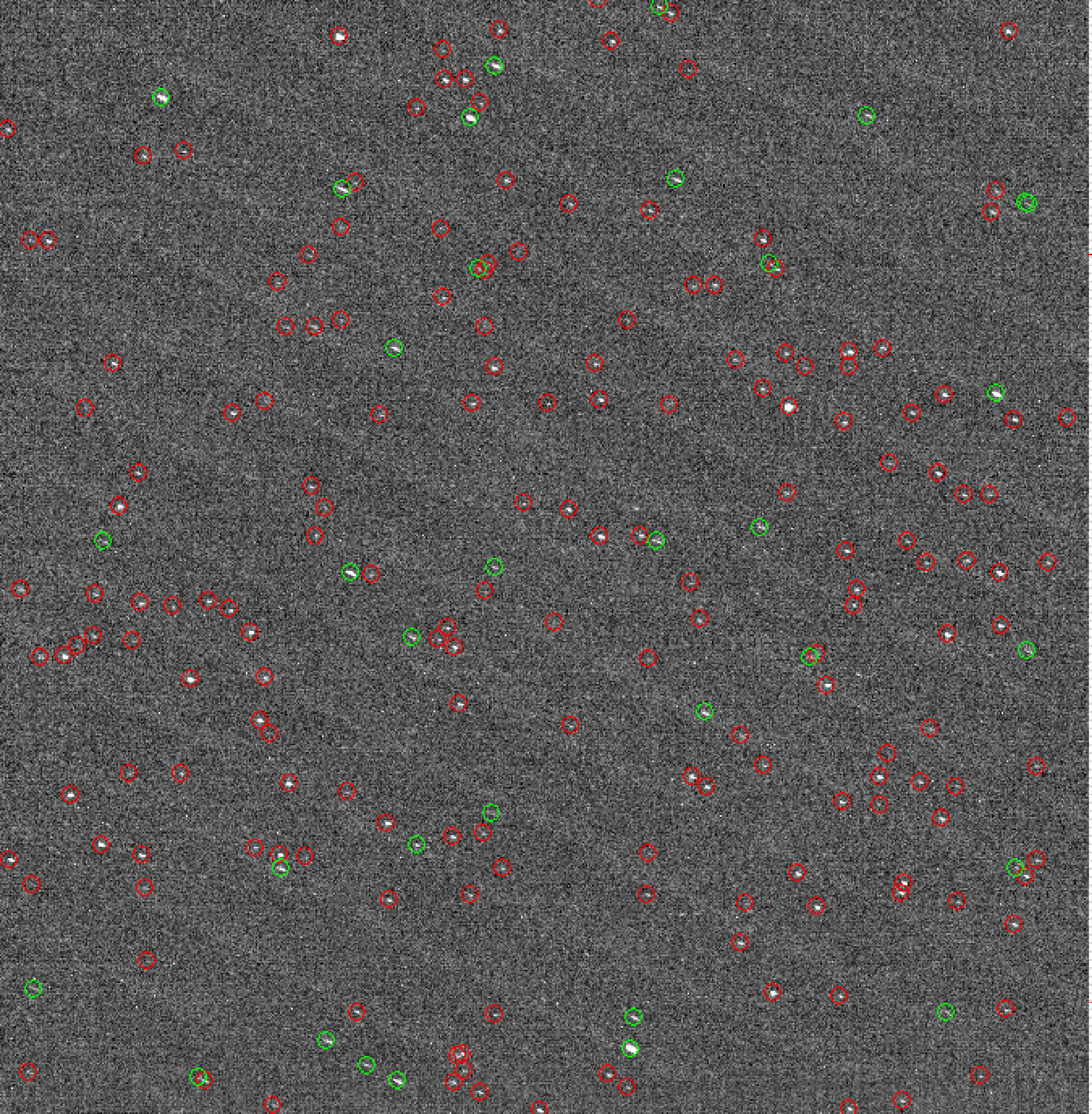
3. Prototype

Parameters:

- Diameter: 20cm
- Focal length: 2m
- FOV: 1° ×1°
- CCD: U9000
  APOGEE, 3K*3K
  12um*12um
- Pixel size: 2.5″

3. Prototype

Test observation was carried in Jiang-Nan-Tian-Chi station of SHAO in 2013.



Red stars:

From FOV of high elavation.

Green stars:

From FOV of low elevation.

3. Prototype

Measured values of the angle between two mirrors of the Reflector according to each observation.

No.	Angle between two mirrors of the Reflector
1	59.4645161°
2	59.4646490°
3	59.4646991°
4	59.4644882°
5	59.4646314°
6	59.4646355°
7	59.4645056°
8	59.4645428°
9	59.4646241°
10	59.4646586°
11	59.4648003°
12	59.4648016°
13	59.4647446°
14	59.4646272°
15	59.4646842°
Average	**59.4646413° ±0.09″**

3. Prototype

Measured AR of different zenith distances

No.	zenith dist	Nobs	Measured AR (″)	AR_Pulkov	Delta-AR
1	49.4019566°	15	57.63±0.14	57.68″	-0.05″
2	63.9007239°	15	100.28±0.10	100.60″	-0.32″
3	69.0029459°	15	127.06±0.13	128.04″	-0.98″
4	74.0948008°	12	169.90±0.16	171.46″	-1.56″
5	78.8301660°	9	240.23±0.27	244.11″	-3.88″

3. Prototype

Remarks:

- No systematic errors from hardware exist since relative measurement is carried out, especially the deflection of the tube.
- AR of any zenith and elevation can be measured, even direction under the horizon, only of stars from that direction can be observed.
- Simple and light instrument is enough, which can be moved to anywhere if needed.

4. Next step

Improvements needed to be done later (I):

- Limited by the aperture and focal length of the prototype, the ability of gathering light is inadequate, bigger telescope is needed to get sufficient stars in lower elevation.
- Considering the extinction of atmosphere, asymmetric mirrors of the Reflector are necessary to get similar number of stars for FOVs of both high and lower elevation.
- Filter is needed to get precise AR results.

4. Next step

Improvements needed to do later (II):

- Meteorological recording instrument is needed to get accurate record of temperature, humidity and barometric pressure, which are necessary to build AR model, and for future study on the basis of long-tern measurement.
- Automatic control is needed to measure AR easily. Here automatic means the whole procedure of observation program, control of telescope and CCD, image processing and data reduction et al., can be done by computer automatically.

4. Next step

- A small and automatic AR measuring machine is under developed now.
- Those who need such instrument is welcome to contact us.

Thanks!