24th International Young Physicists' Tournament

Team of Belarus

Iran Tehran
July 2011

Ministry of Education Republic of Belarus

Kayson Belarus

Belarusian team

Problem #17

“Vikings”

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Vikings

- According to a legend, Vikings were able to navigate in an ocean even during overcast (dull) weather using tourmaline crystals. Study how it is possible to navigate using a polarizing material. What is the accuracy of the method?

Stages

What is tourmaline crystal?

Polarization of light in the atmosphere

Method of navigation

- Experiment
- Accuracy

Part 1
What is a tourmaline crystal?

What is tourmaline?





Physical properties:

•**Polarizer** is a device that converts a beam of electromagnetic waves (light) of undefined or mixed polarization into a beam with well-defined polarization.)

tourmaline → **polarizer**

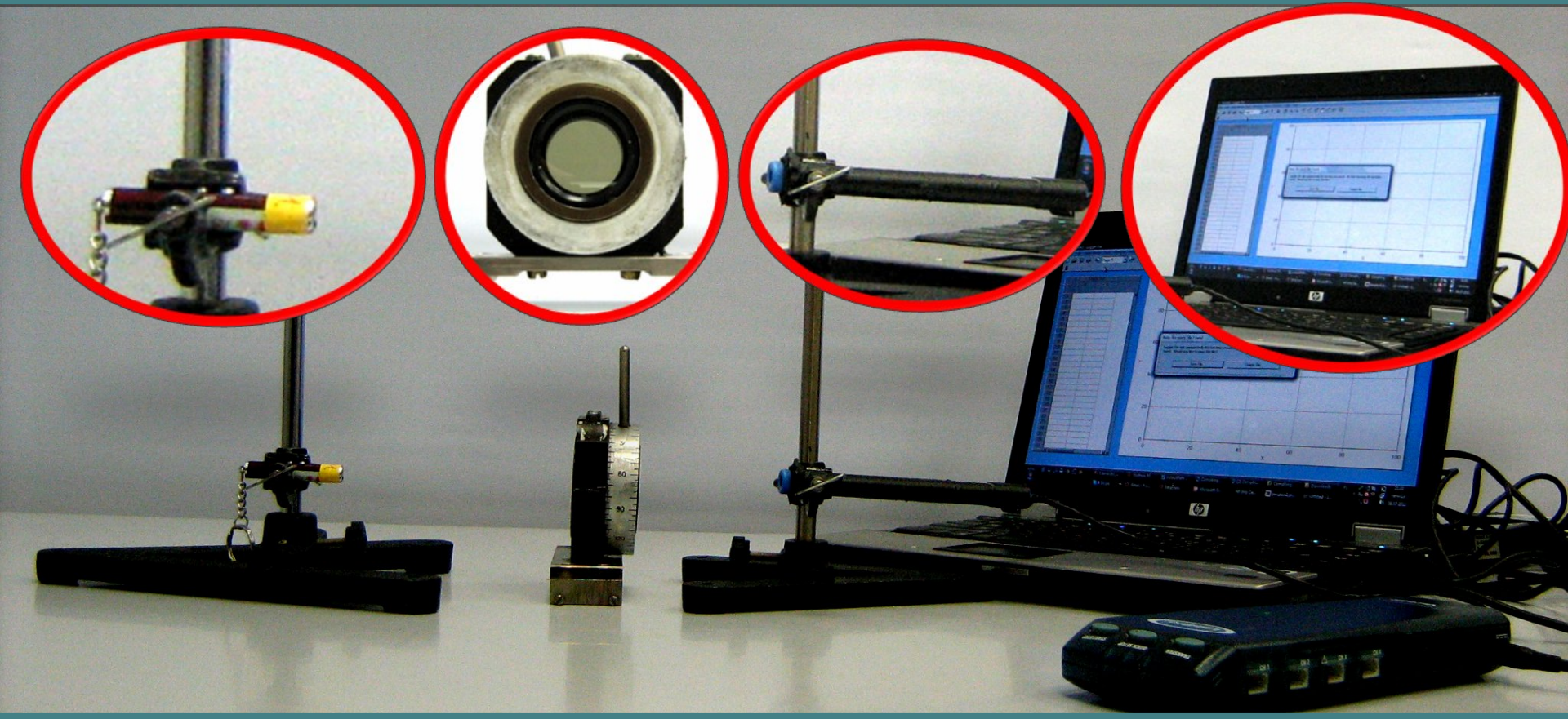
Tourmaline plate(experiment)

tourmaline

Polarizer

polarizer
↓

Experimental setup



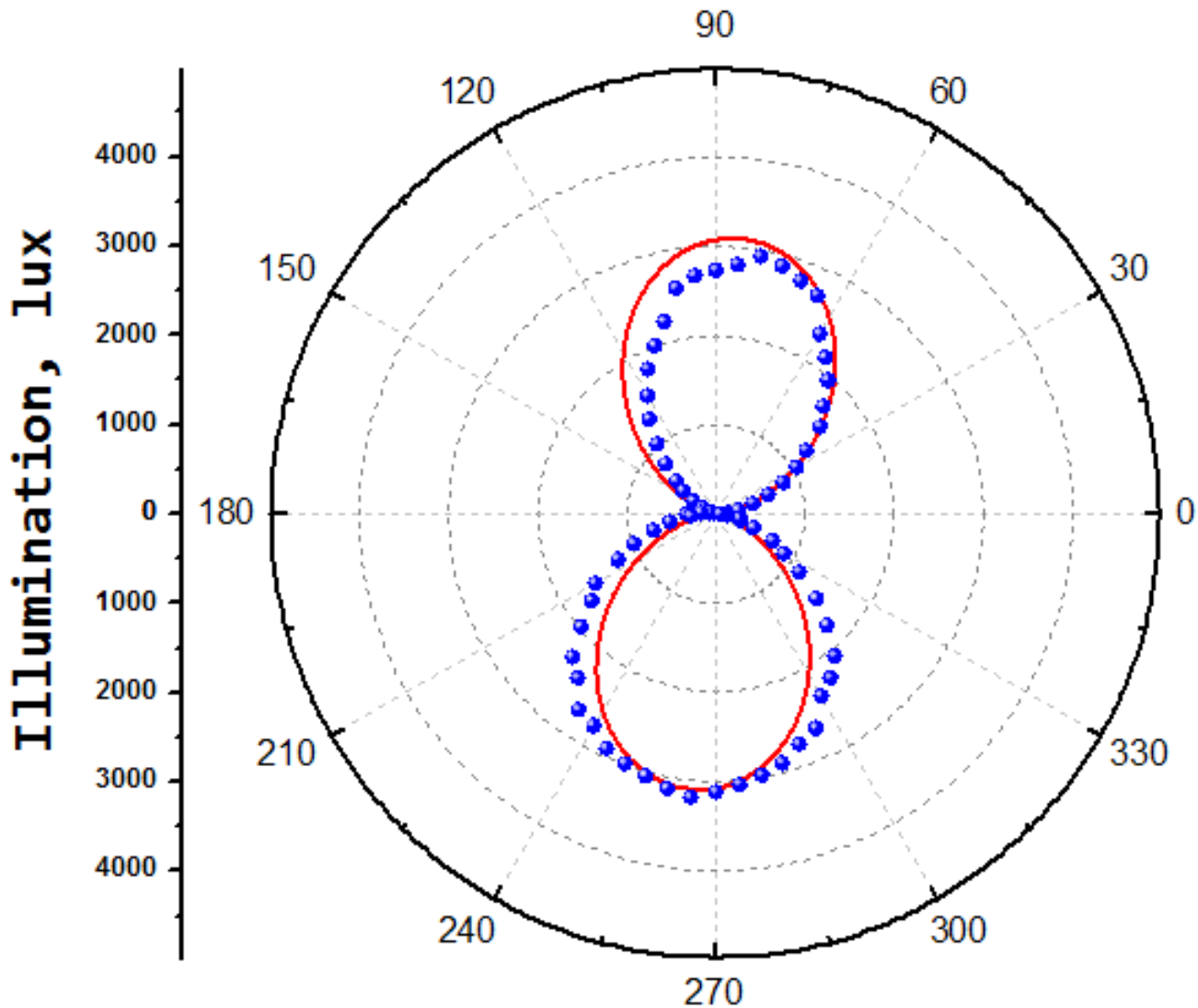
Laser pointer

Polarizer

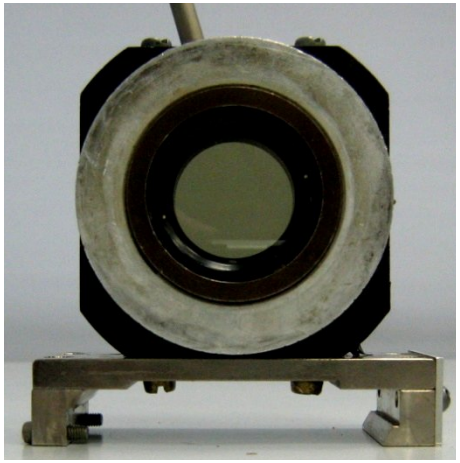
Sensor

Laptop

Illumination against angle



Polarizer



is theory

$I=A\cos^2\alpha$

is experiment

Part 2

Polarization of light in the atmosphere

Earth's atmosphere

Exosphere

Thermosphere

Mesosphere

Stratosphere

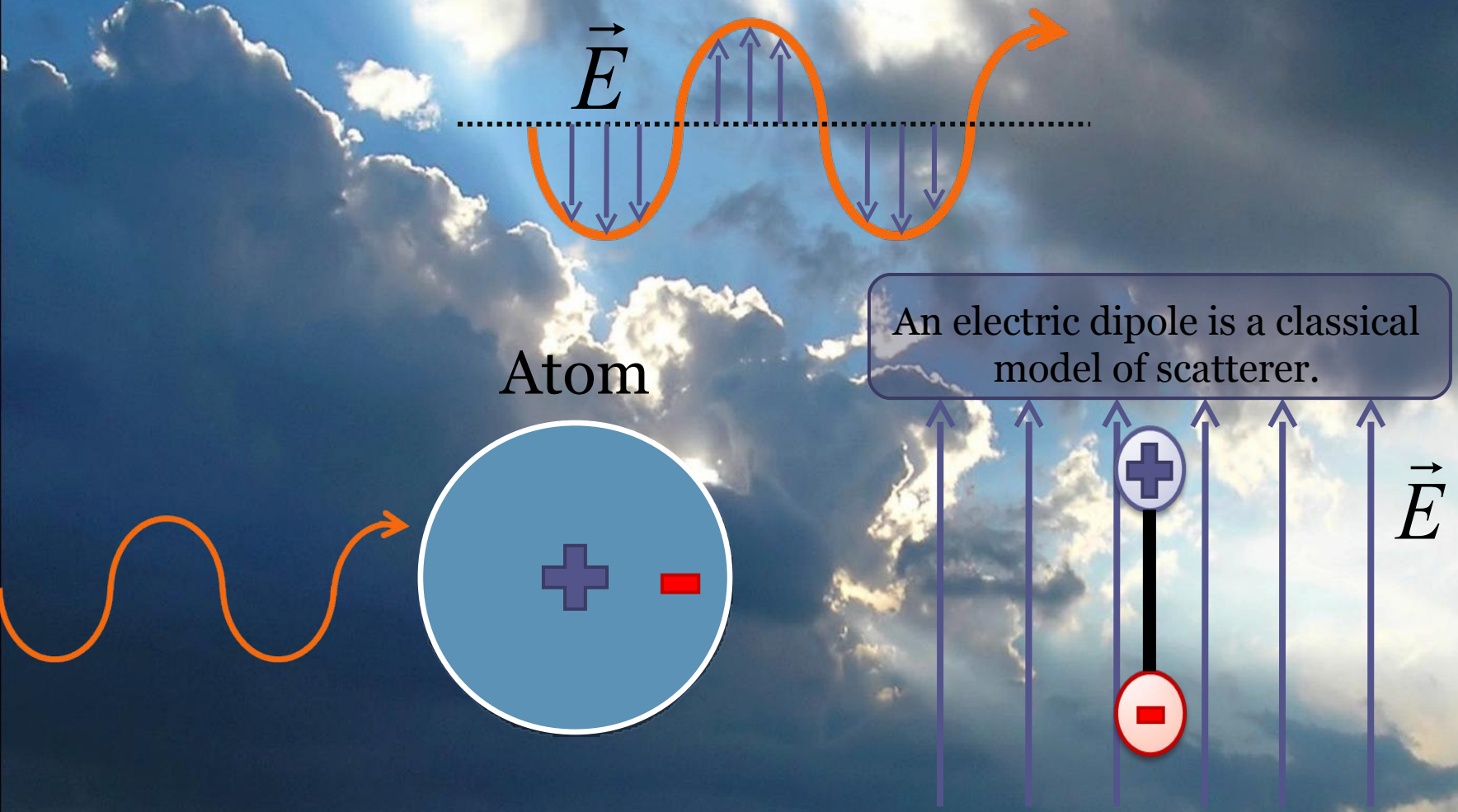
Troposphere

- Fluctuations of density

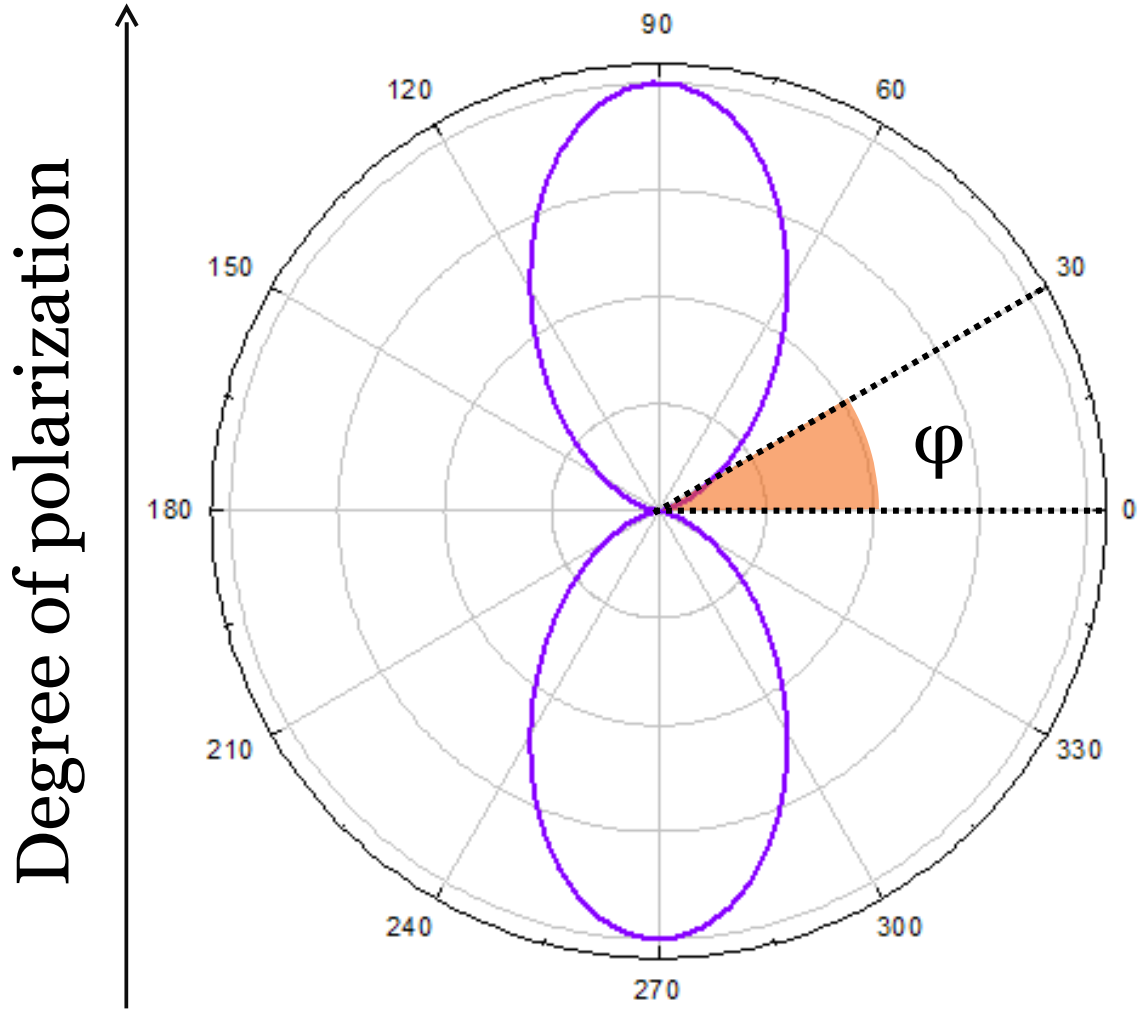
Size of fluctuations <0.03λ

Rayleigh scattering

Physical model of the Rayleigh scattering in the atmosphere



Polarized light

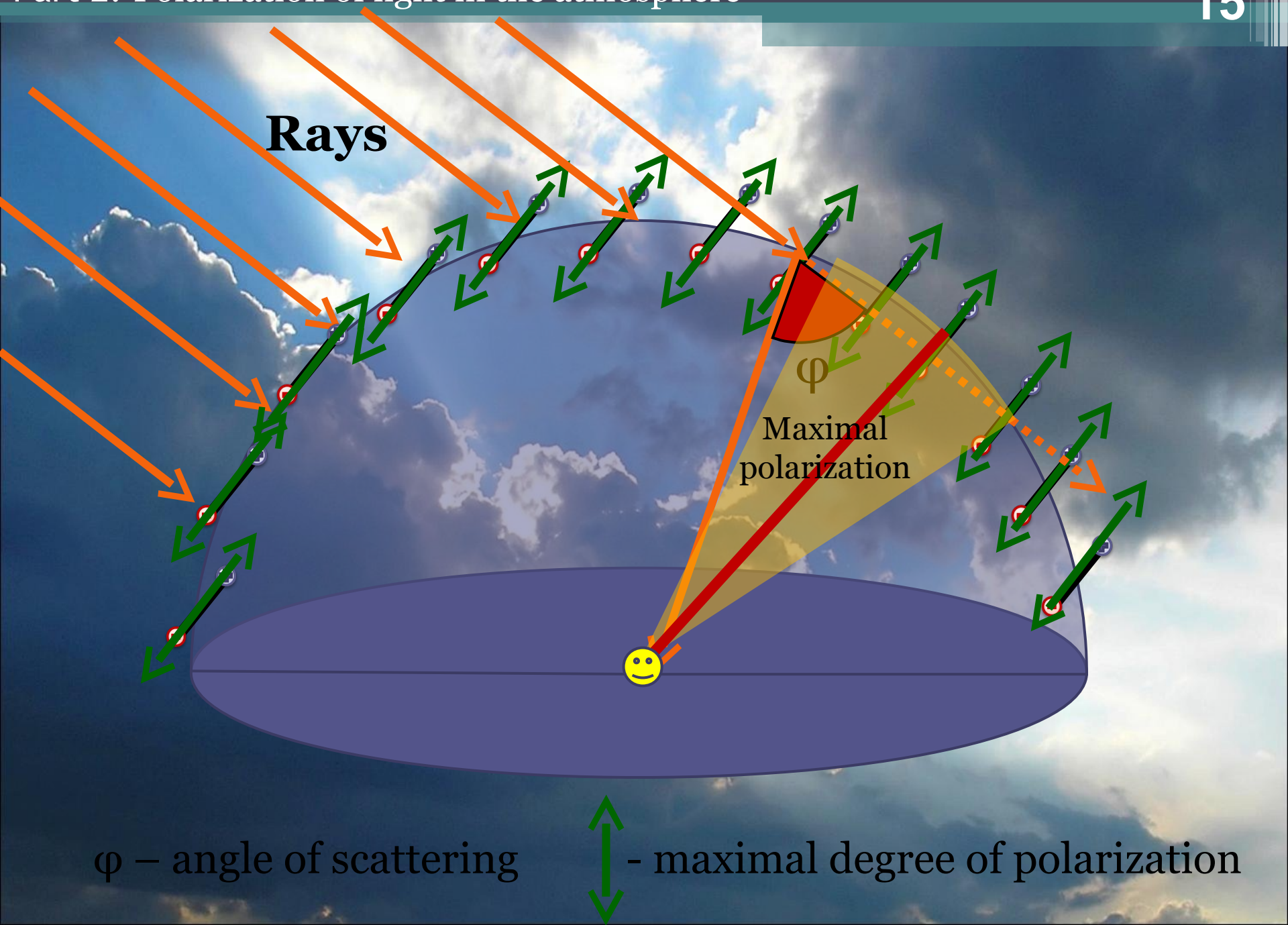


Volume with dipoles

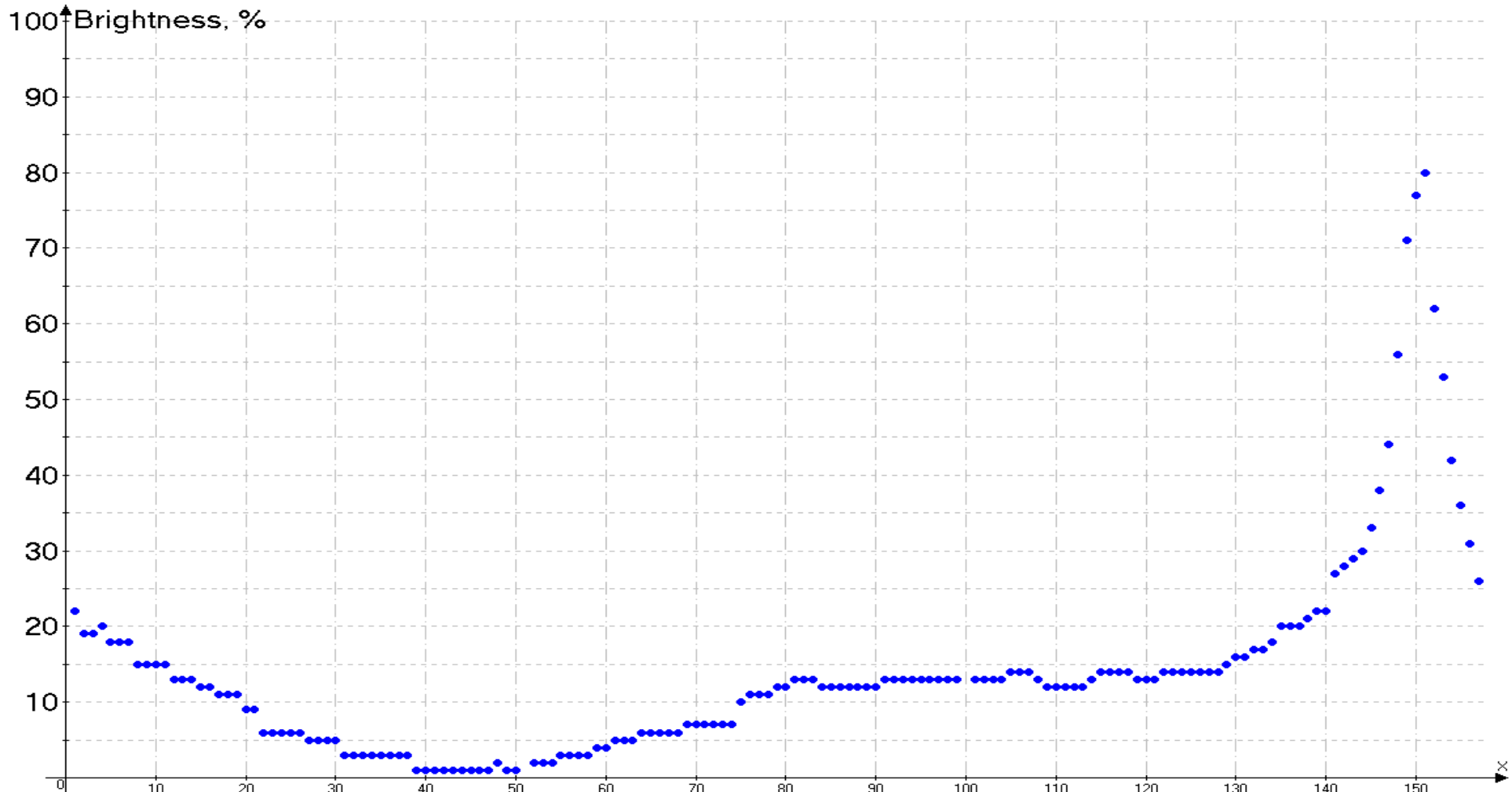
P is the degree of polarization

φ is the angle of scattering

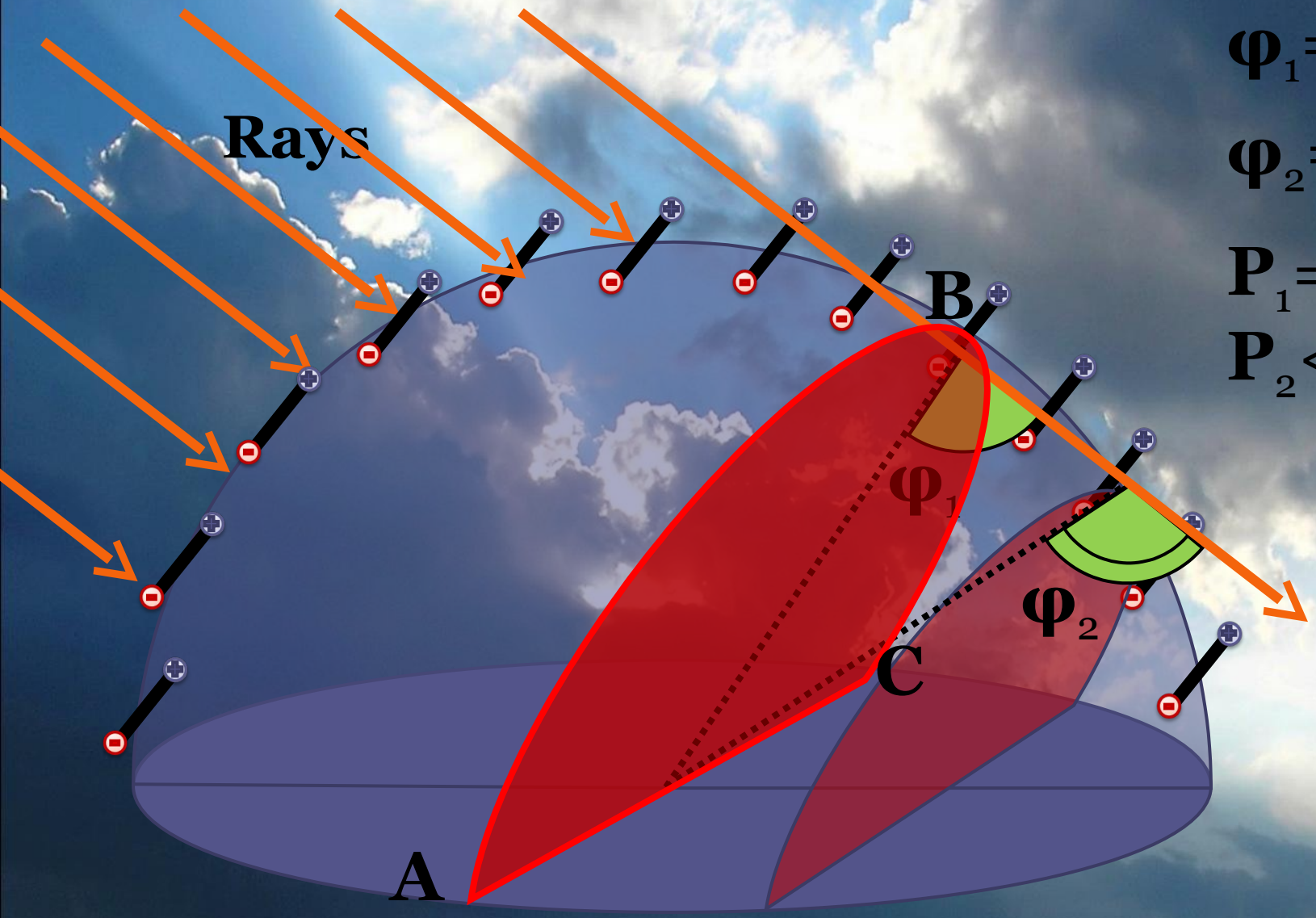
$$P = \frac{\sin^2 \varphi}{1 + \cos^2 \varphi}$$


Rays
φ
Maximal polarization
φ – angle of scattering
- maximal degree of polarization

Panoramic photo



Polarization direction



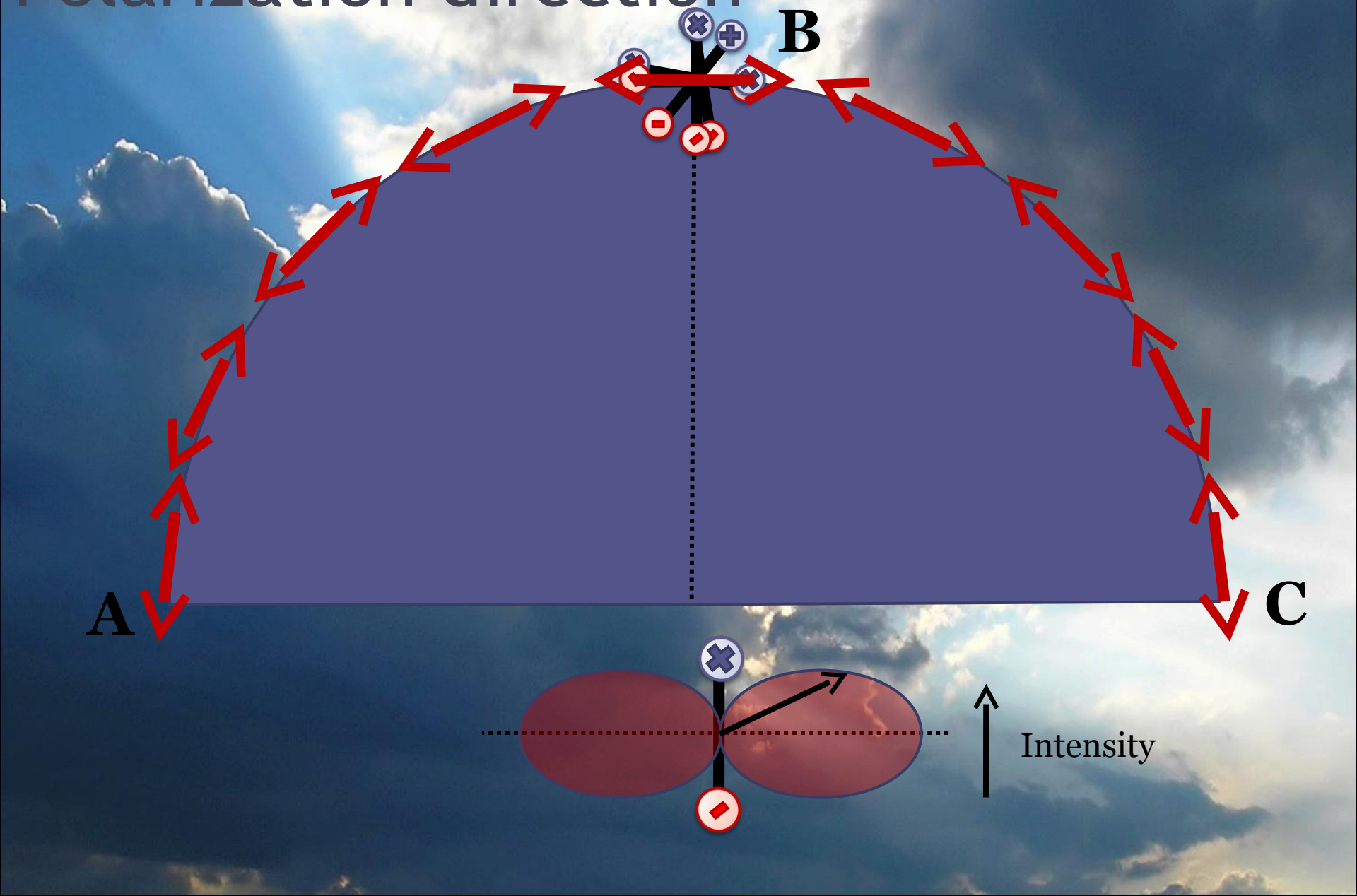
$\varphi_1 = 90^o$

$\varphi_2 \neq 90^o$

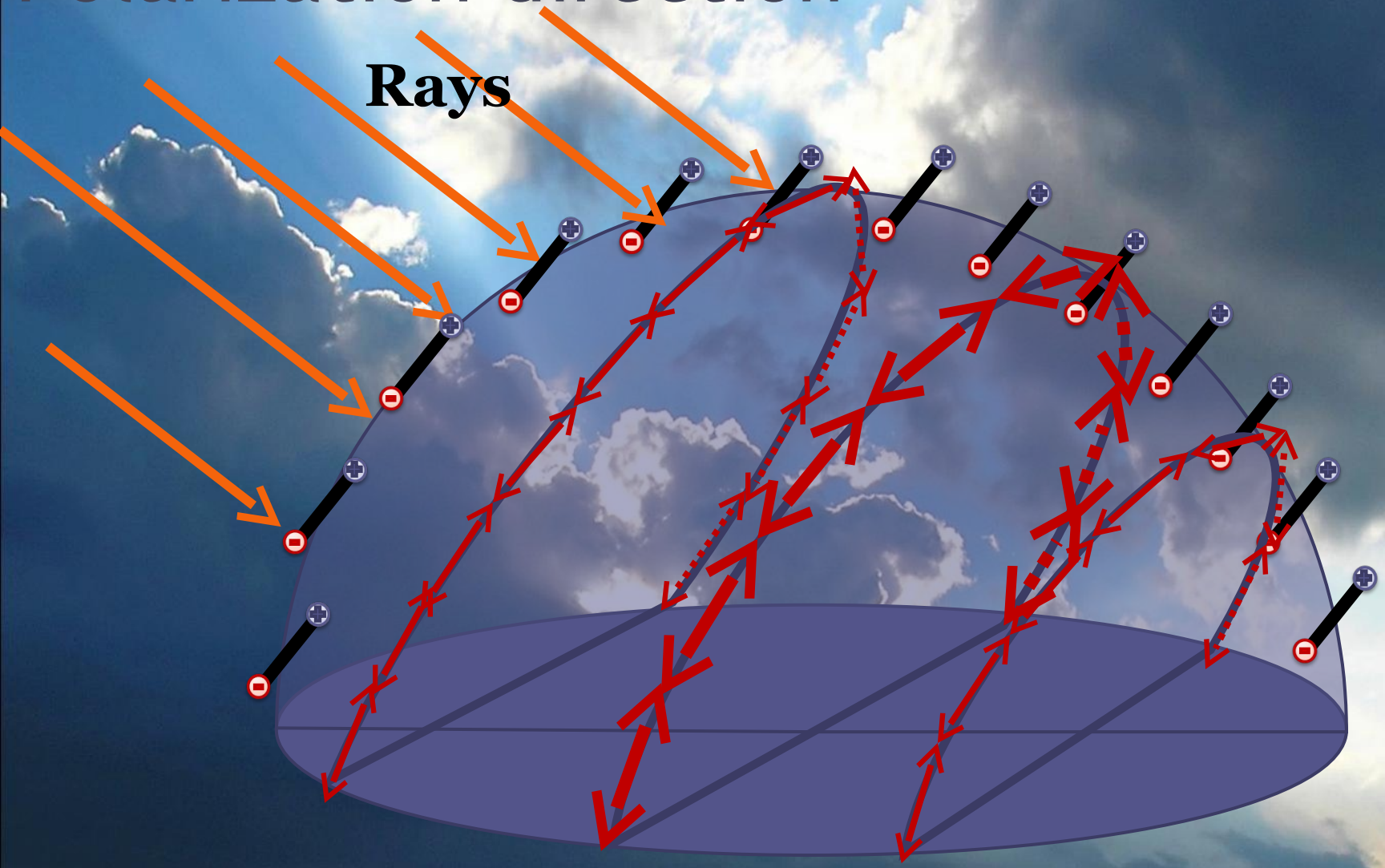
$P_1 = P_{max}$

$P_2 < P_{max}$

Polarization direction



Polarization direction



Part 3

Method of navigation

What we should do?

1. Find the location of the Sun

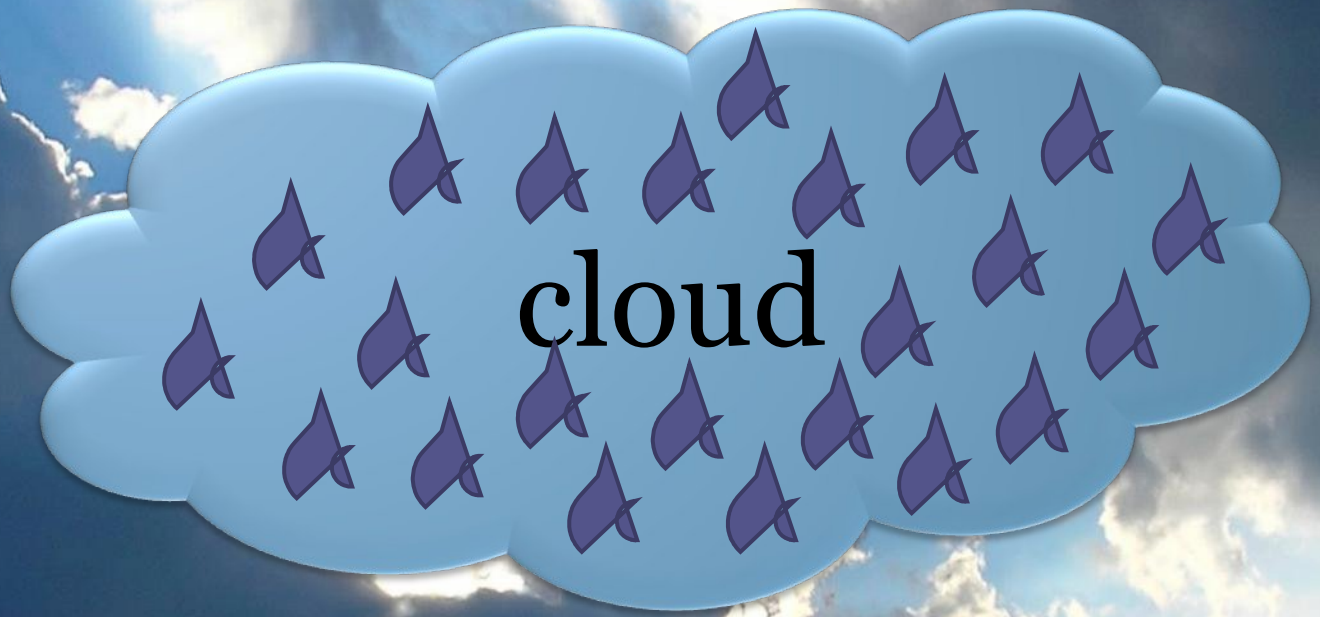
2. Find direction to the north, south, east and west

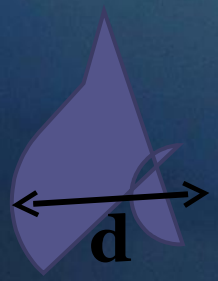
How can we find the location of the Sun?

1. Measurement of intensity (Vikings did not have sensors)

2. Polarization direction (You need only polarizer and eyes)

Where can we see polarized light?





d ≈1-10 micrometers

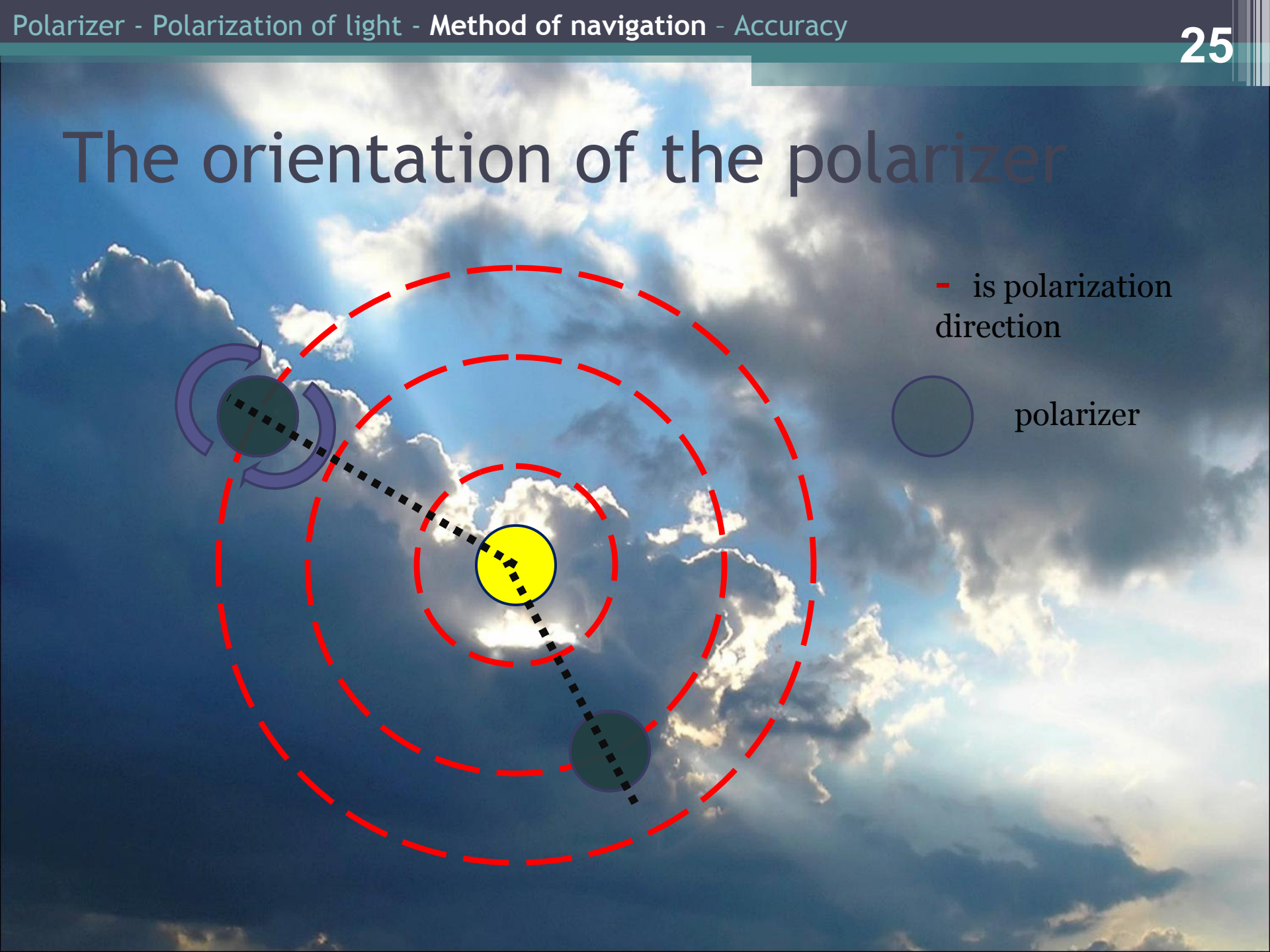
d>0.03 **λ**

~~**Rayleigh scattering**~~

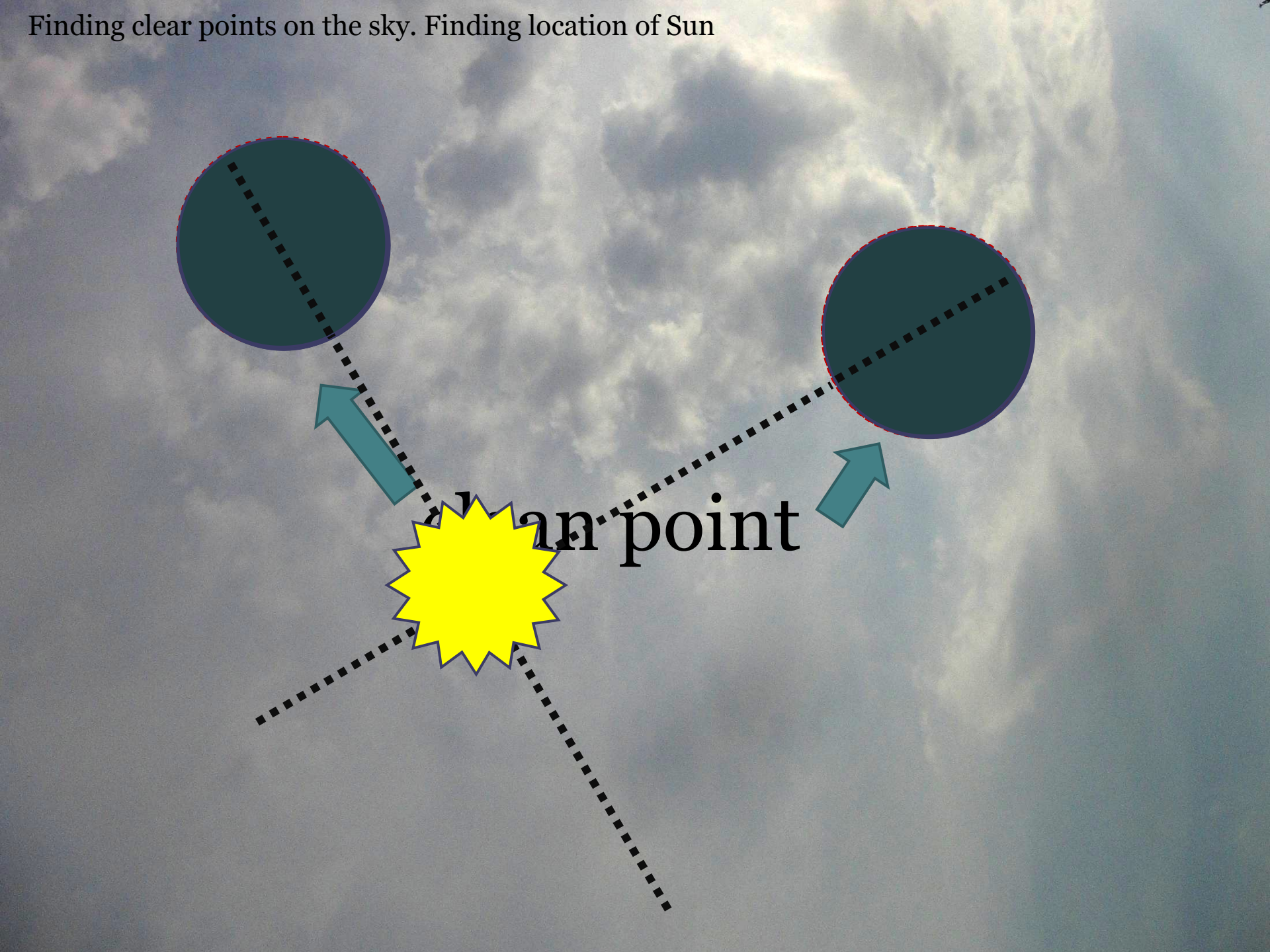
Unpolarized light

Cloudy weather

The orientation of the polarizer

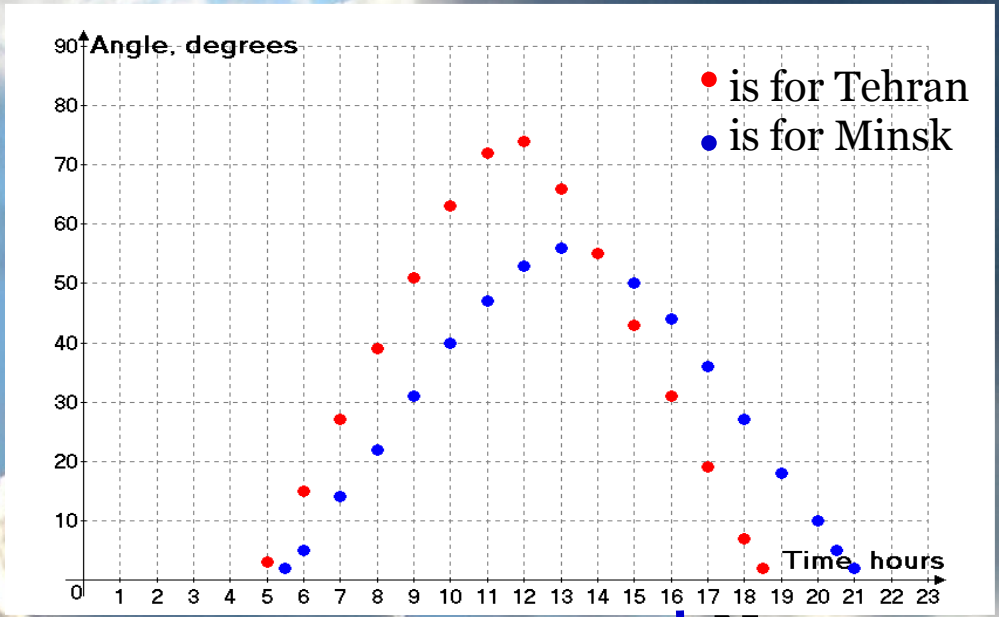


Finding clear points on the sky. Finding location of Sun

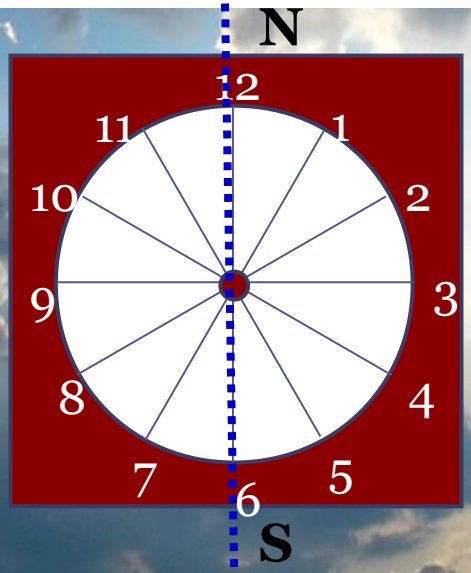


Finding sides of the world

- calendar

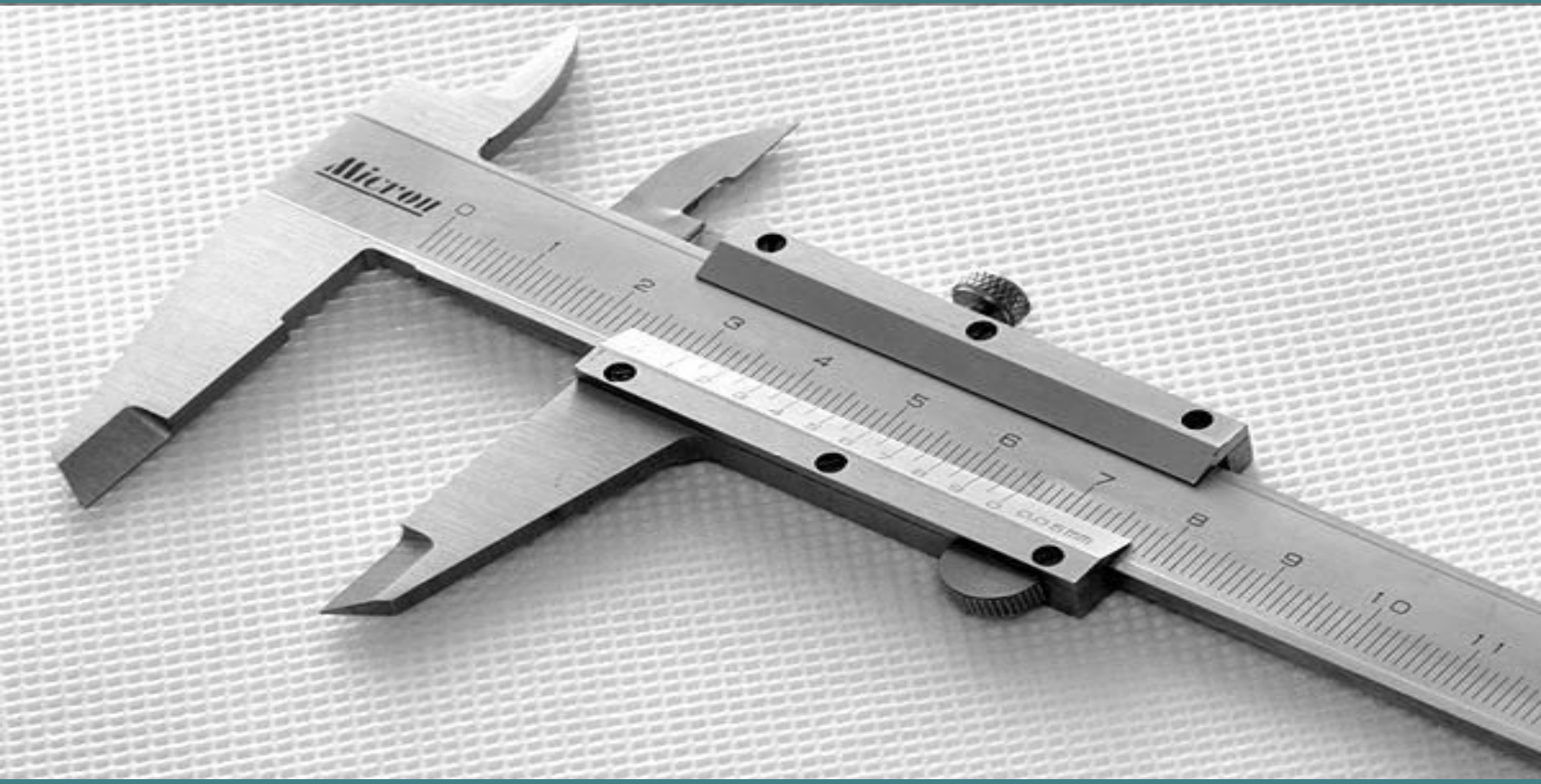


- sundial



Part 4

Accuracy



Where can we get the error?

Polarizer

- Unideal polarizer
- We can not accurately determine the time of complete darkening

±4°

Finding location of the Sun

- Connection of two perpendicular

± 10°

Finding direction on North

- Location of an artificial light source
- Error of the calendar
- Error of angle

± 3°

Conclusions

1. Vikings could navigate by polarized light.
2. Light is polarized by scattering on fluctuations of optical density in the Earth's atmosphere.
3. Rayleigh scattering is simple physical model for explanation polarized light.
4. There is a certain polarization direction in the sky (on a tangent to the circles, which are held symmetrically from the Sun)
5. Any other polarizer can be used instead of tourmaline
6. The greatest error appears in determining the position of the Sun

References

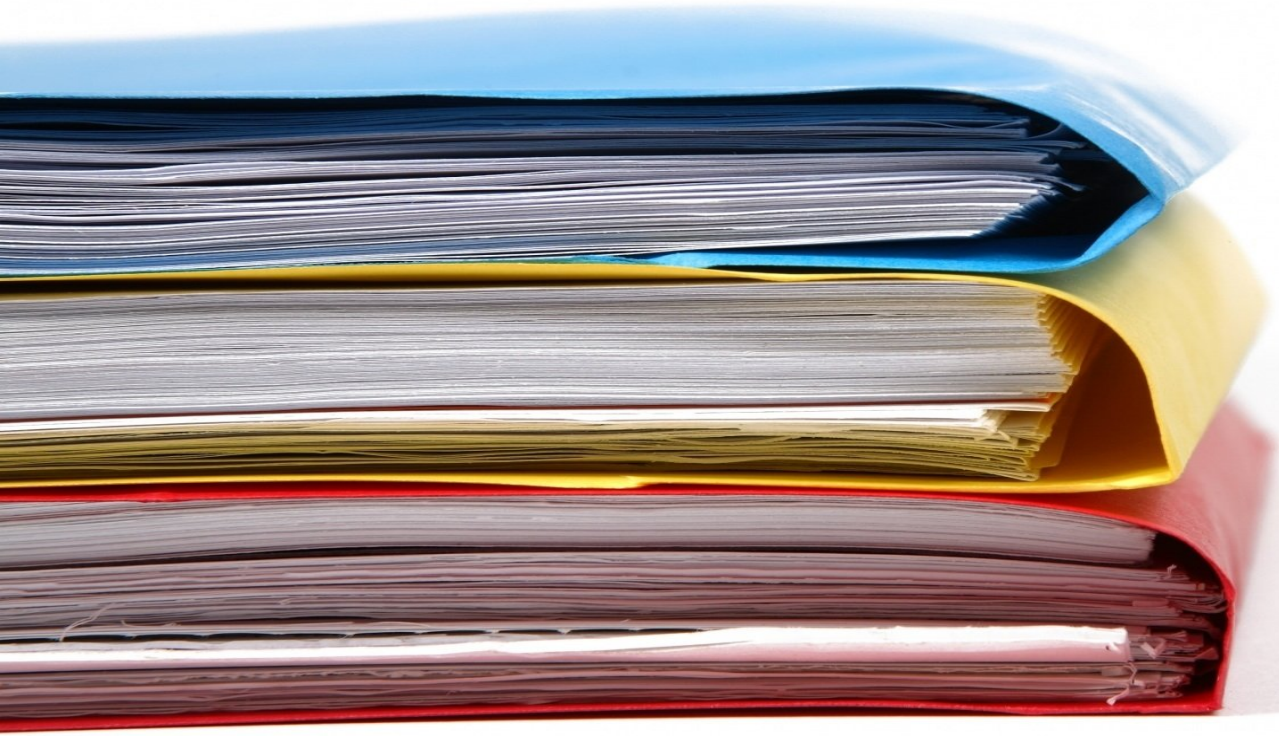
- Matveev, Optics (1989)
- Ramón Hegedüs, Susanne Åkesson, Rüdiger Wehner and Gábor Horváth. Could Vikings have navigated under foggy and cloudy conditions by skylight polarization? On the atmospheric optical prerequisites of polarimetric Viking navigation under foggy and cloudy skies. Proc. R. Soc. A 463, 1081-1095 (2007)

Thank you for attention!

Team is supported by

Kayson Belarus

Extra slides

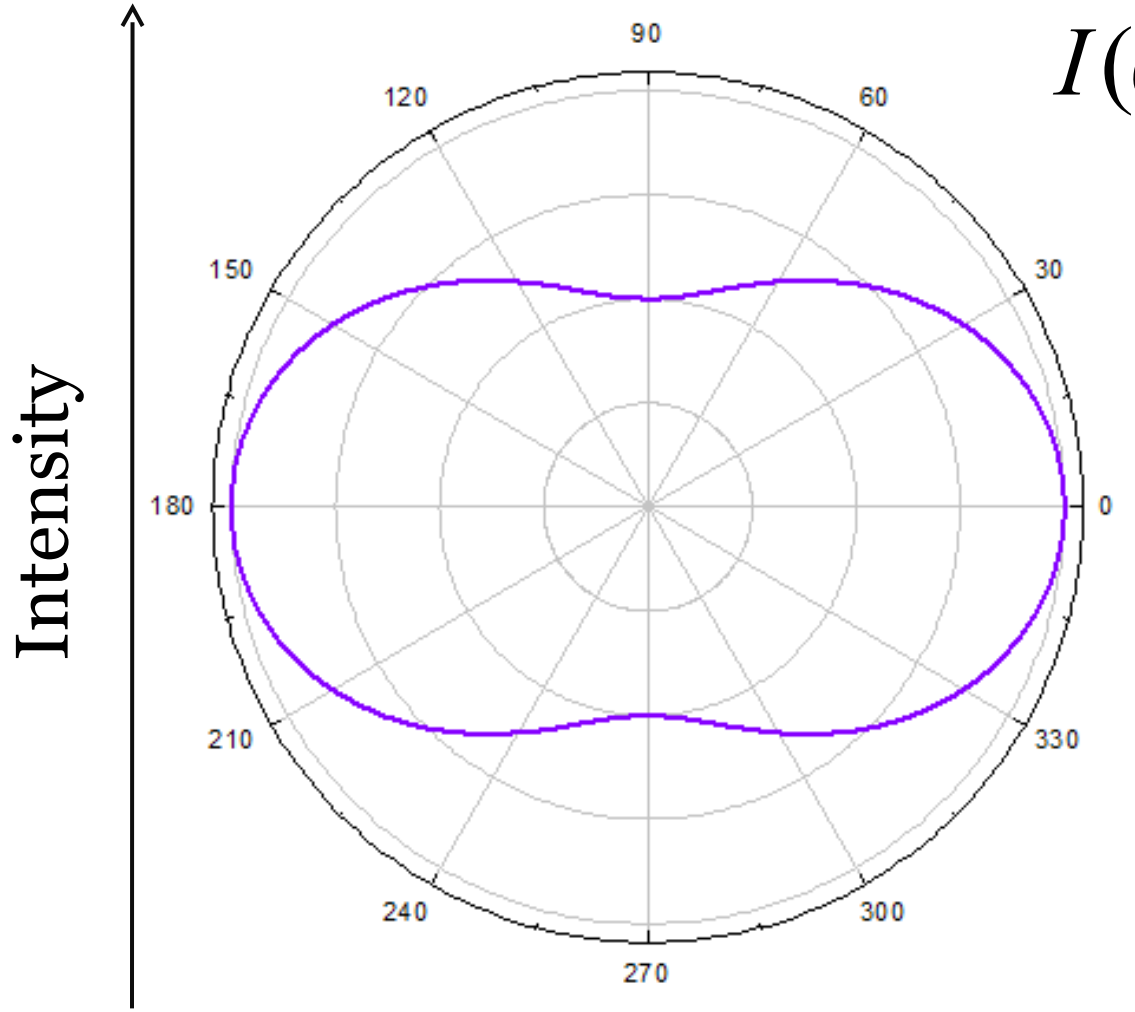


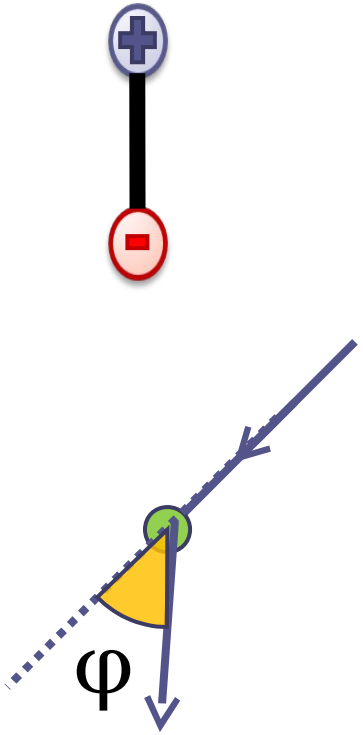
Results

1. We checked ability of navigation with help polarized light
2. We found the direction of polarization of light in the sky
3. We have found where we can take the measurement error for the chosen method of navigation

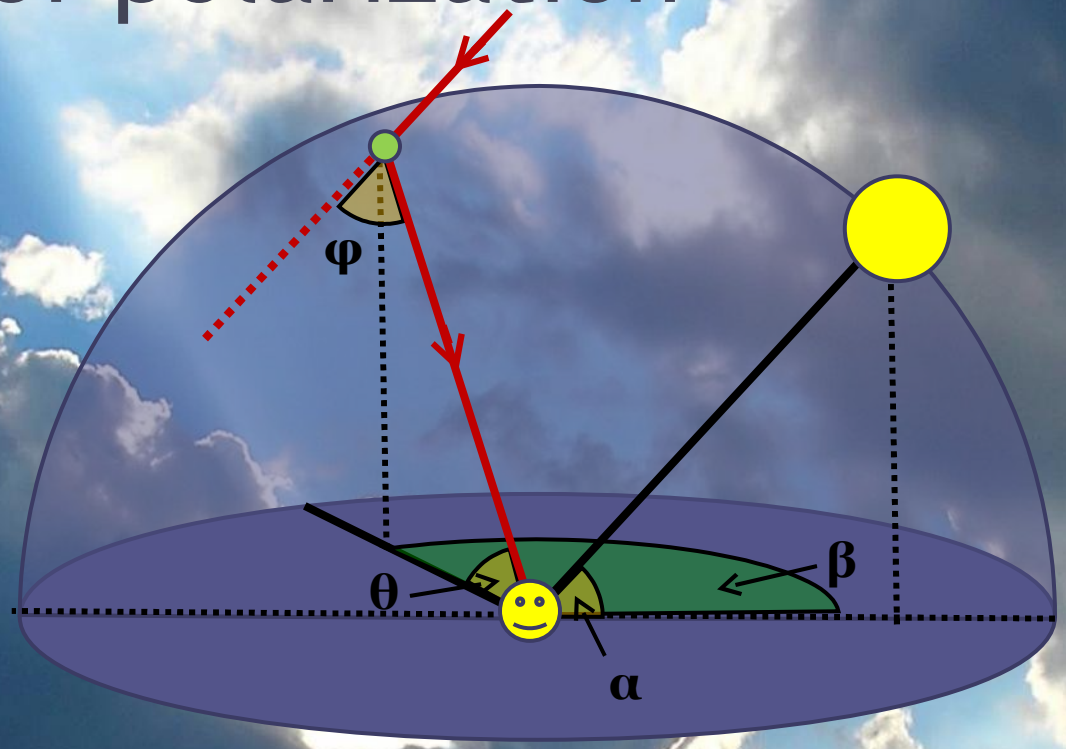
Reemission

$$I(\varphi) \sim A(1+\cos^2\varphi)$$





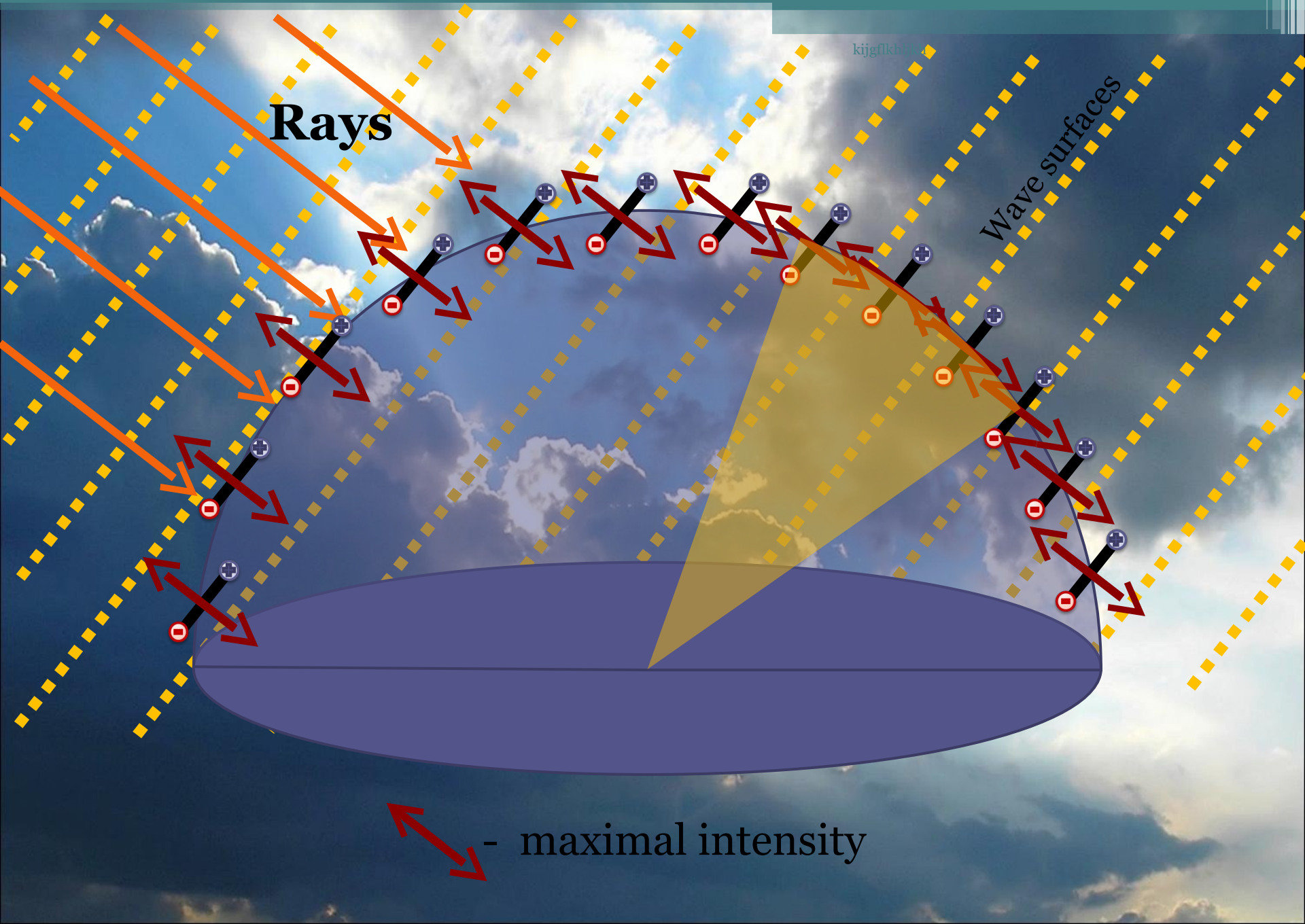
Degree of polarization



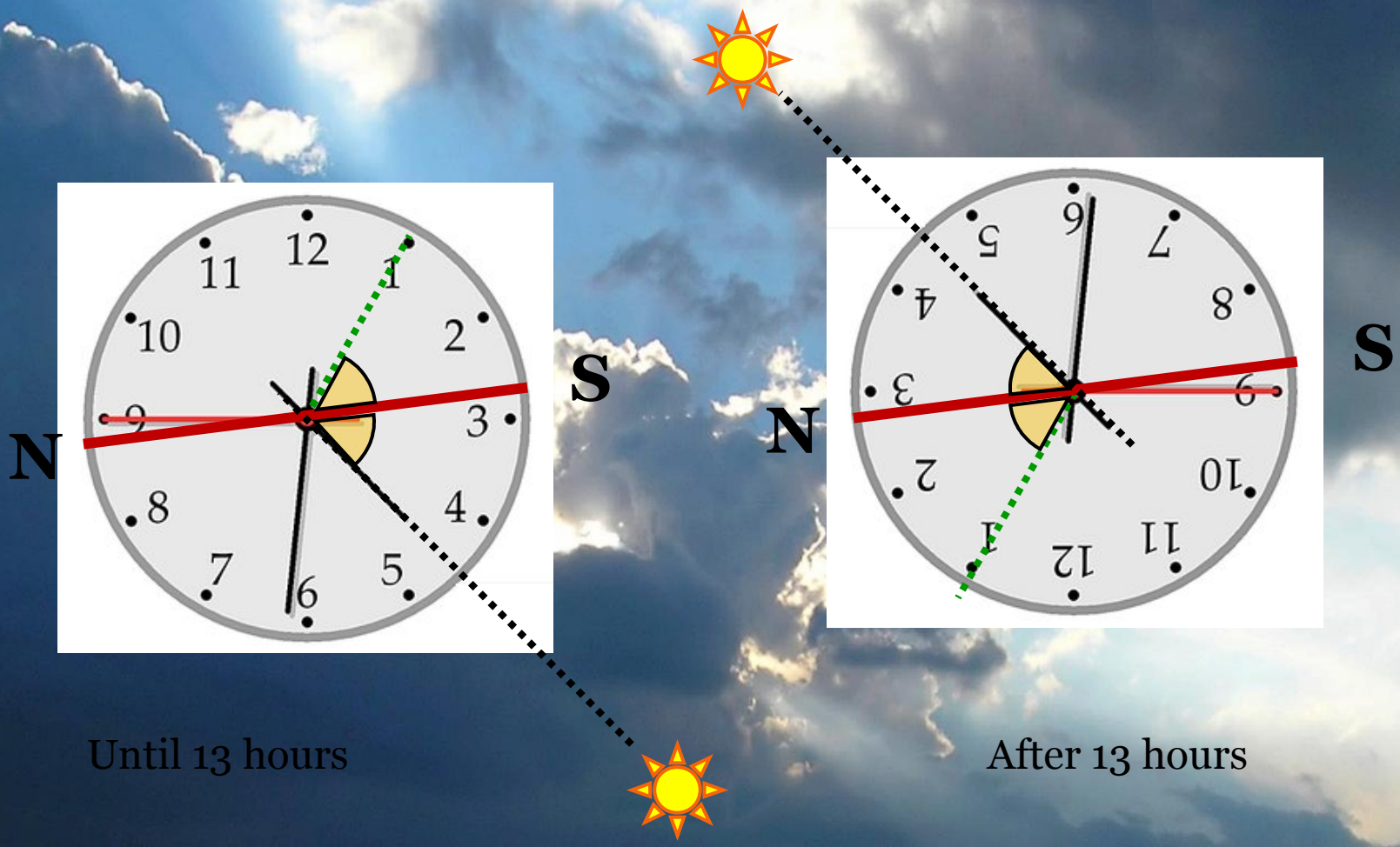
$$\cos\varphi = \frac{2 - \cos^2\theta - \cos^2\alpha + 2\cos\theta\,\cos\alpha\,\cos\beta}{2}$$

$$P = \frac{\sin^2\varphi}{1 + \cos^2\varphi}$$

$$I(\varphi) \sim A(1 + \cos^2\varphi)$$


Rays
Wave surfaces
- maximal intensity

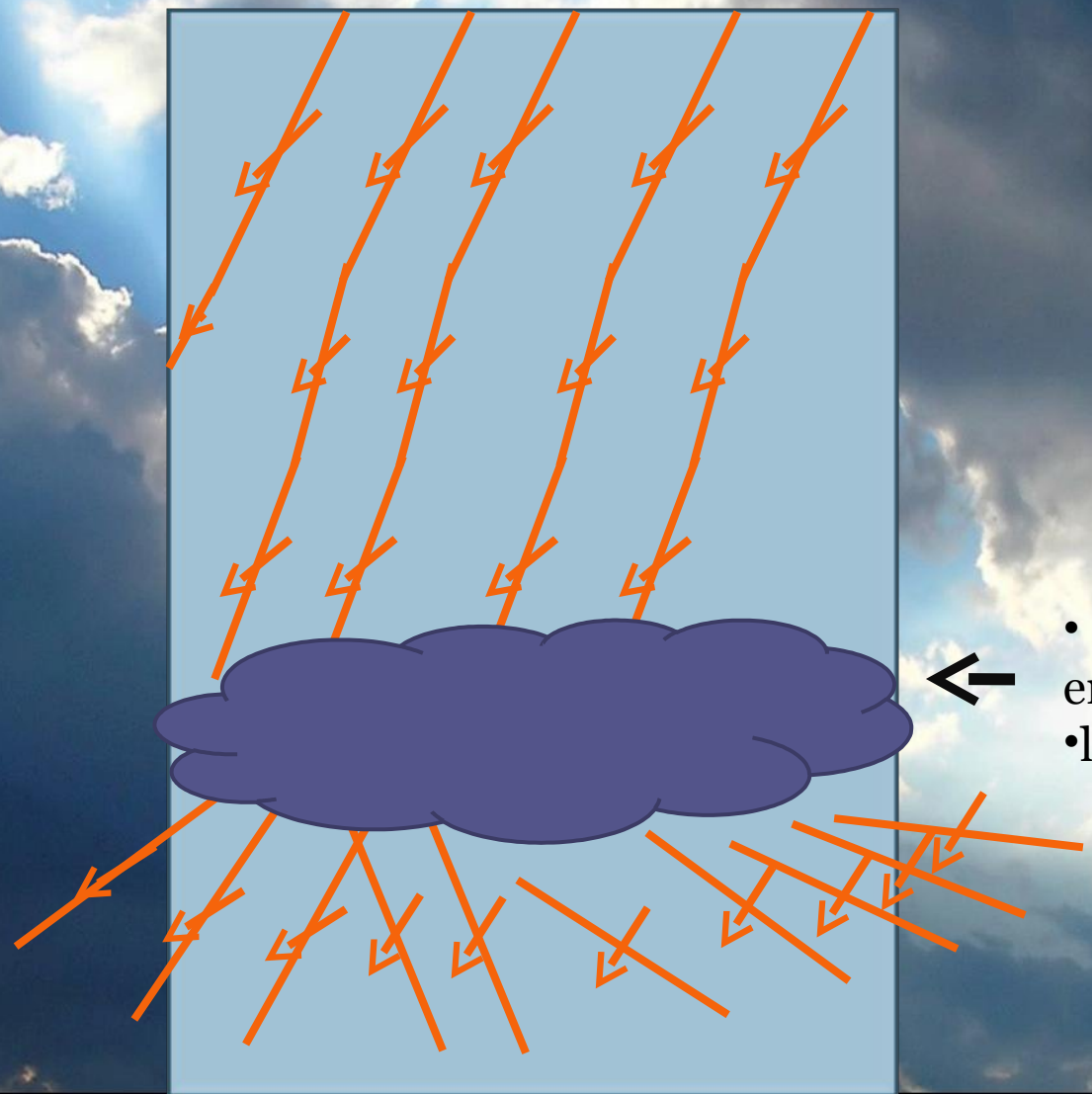
Finding the sides of the world using Sun and clock



Until 13 hours

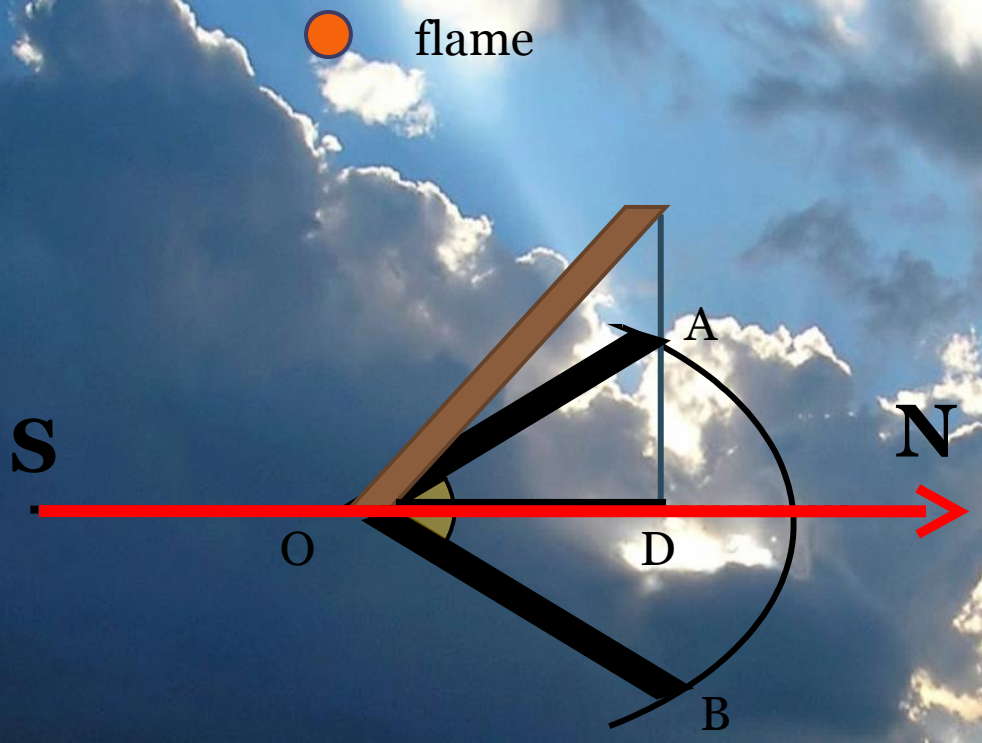
After 13 hours

Scattering on clouds

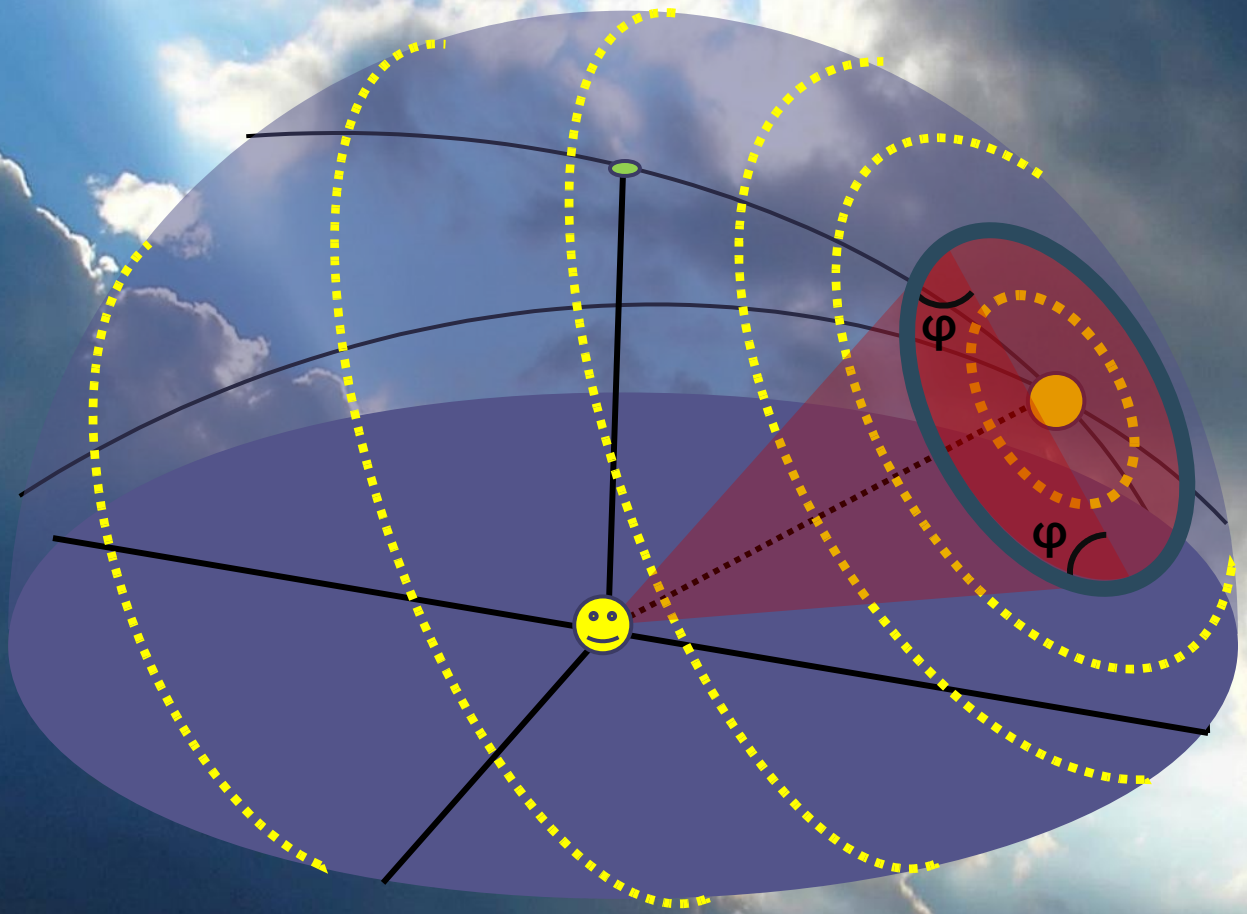


- dense environment
- large particles

Finding the sides of the world using the midday shadow



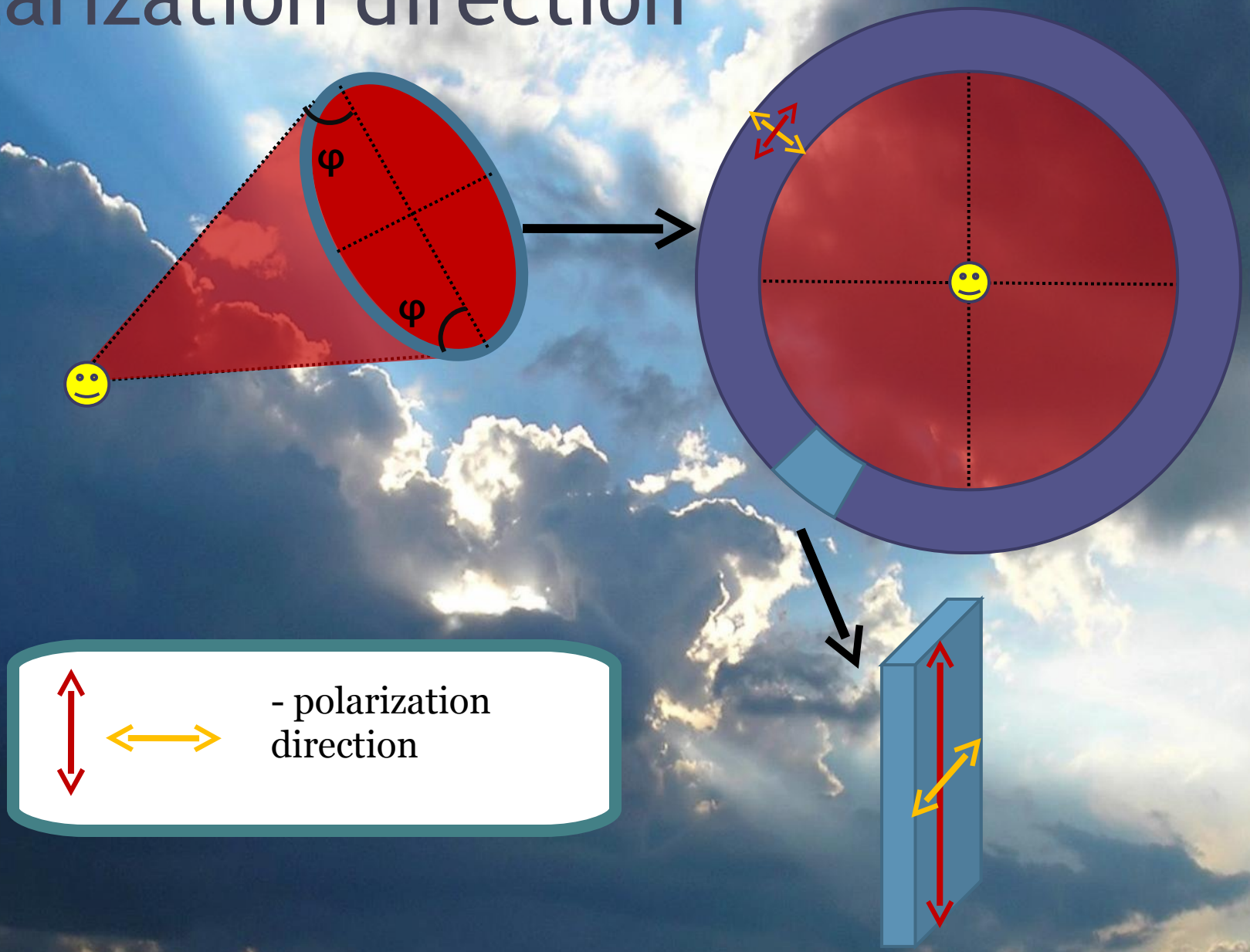
Polarization direction



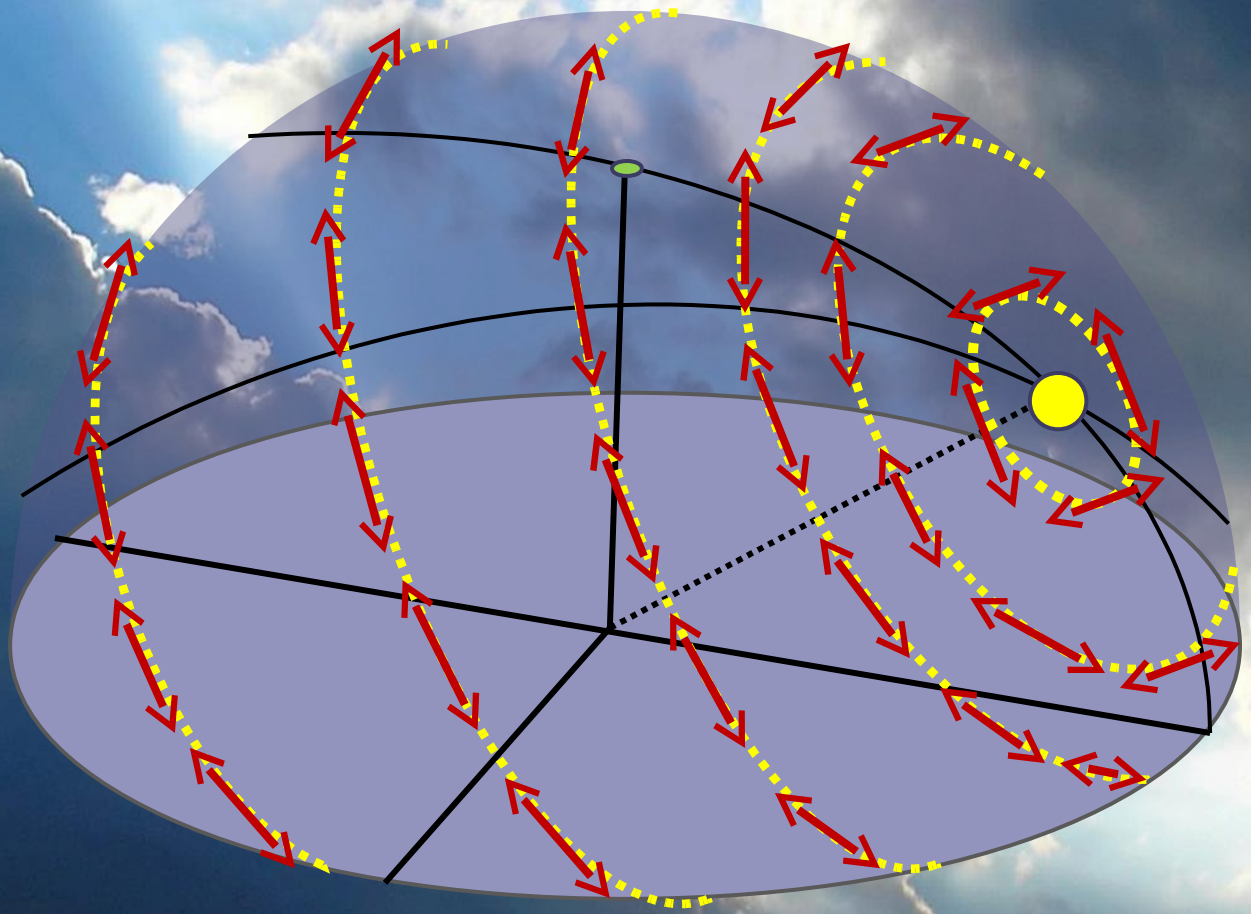
φ - angle of scattering

φ= constant for points in a circle

Polarization direction



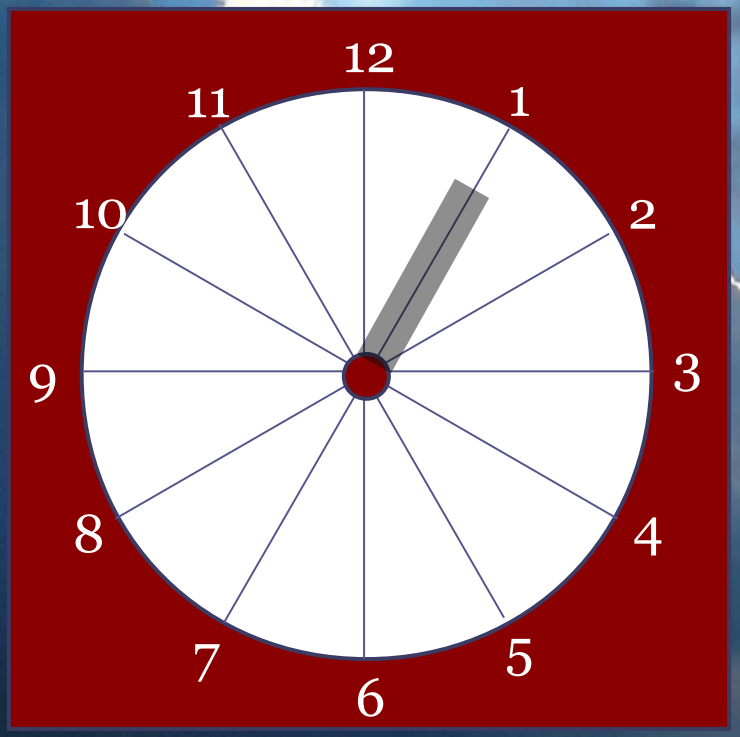
Polarization direction



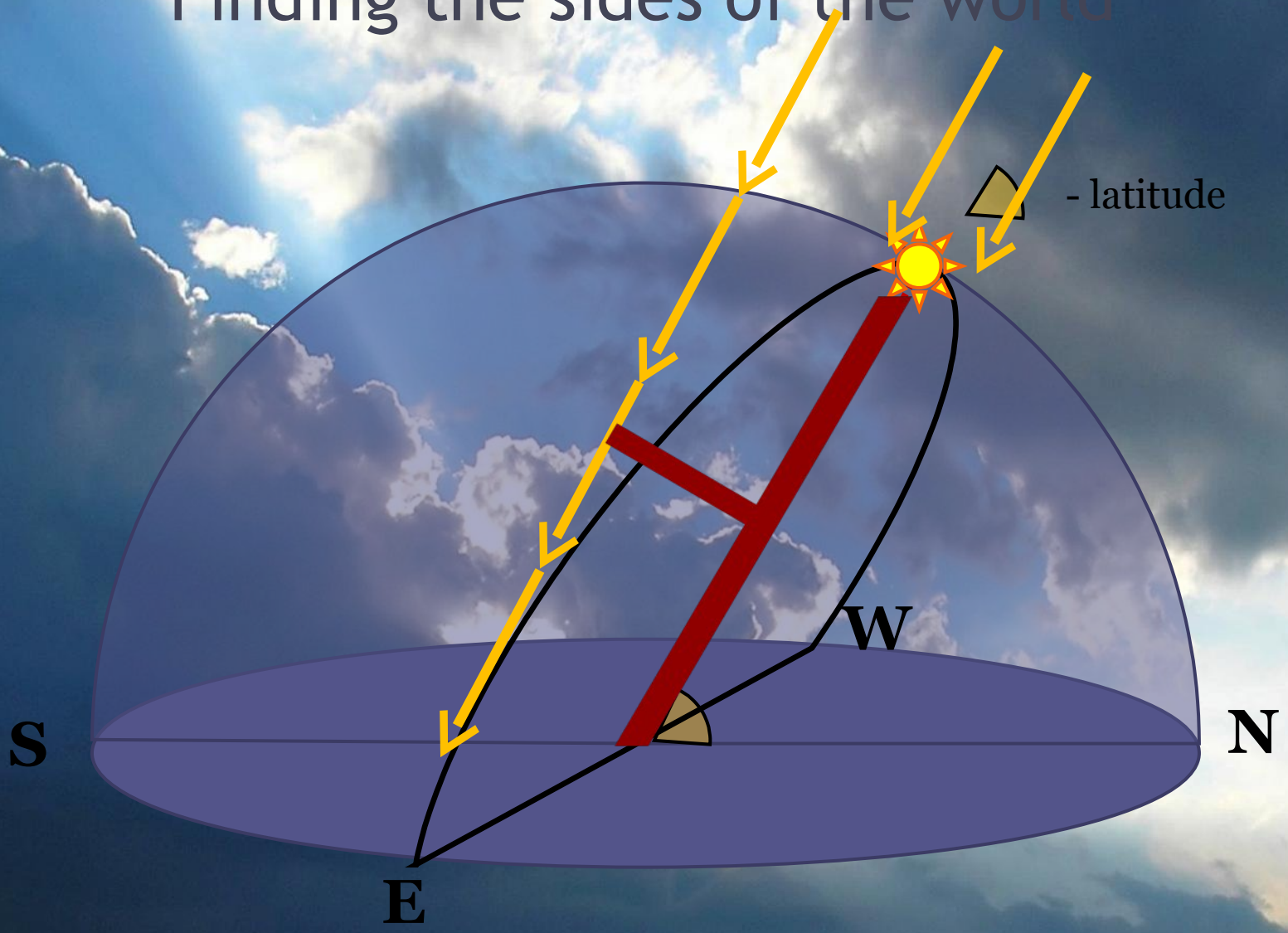
φ is angle of dispersion

φ= constant for points in a circle

Sundial



Finding the sides of the world



Sundial

α – angle of elevation