

A vibrant rainbow arches across a clear blue sky, its colors transitioning from red at the top to violet at the bottom. The rainbow appears to connect the ground to the sky, acting as a natural bridge. Below the rainbow, a mountain range stretches across the horizon. In the foreground, a green field is visible, and a small white church with a green roof stands on the right side of the image. The overall scene is peaceful and scenic.

LIKE A BRIDGE TO THE SKY

*La fisica degli
arcobaleni*

Everybody knows that....



Raindrops act like prisms and diffract light.

Different wavelengths are differently refracted when they cross over the boundary from one medium to another (air $\rightarrow$ water $\rightarrow$ air)

The result is a rainbow.

Simple questions and curiosities

- *Where is the sun when we look at a rainbow?*

Rainbow @ Rome observatory



©Luca Zappacosta

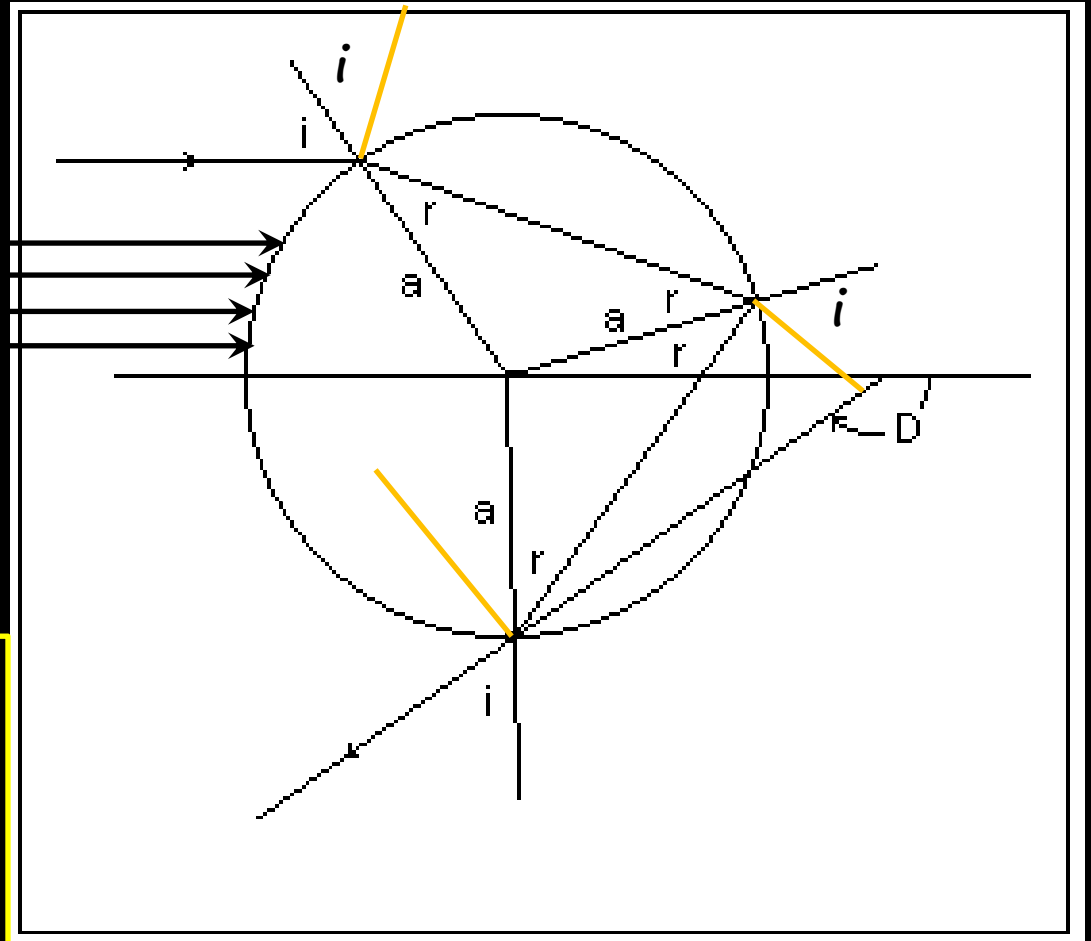
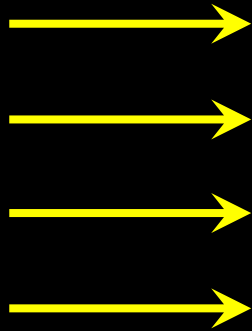
Where is the sun?

Simple questions and curiosities

- Where is the sun when we look at a rainbow?
- When and where can we see a rainbow?
- If each raindrop creates a rainbow, why do I see a single large rainbow?
- How big is a rainbow?
- What's the color sequence in a rainbow?
- Is there any difference between the sky brightness inside and outside the rainbow?
- How many rainbows can I see simultaneously? 2? 3? 10?
- If another rainbow is there, what's its color sequence?
- Is the rainbow light polarized?

Raindrop and sunlight: refraction and reflection

For a spherical
raindrop



Snell law

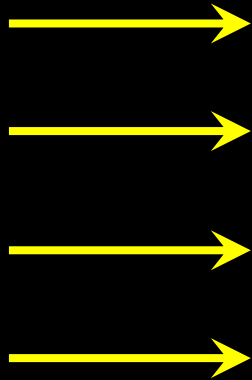
$$n_{\text{air}} \sin i = n_{\text{water}} \sin r$$

$$n(\text{air}) = 1.003$$

$$n(\text{water}) \sim 1.333$$

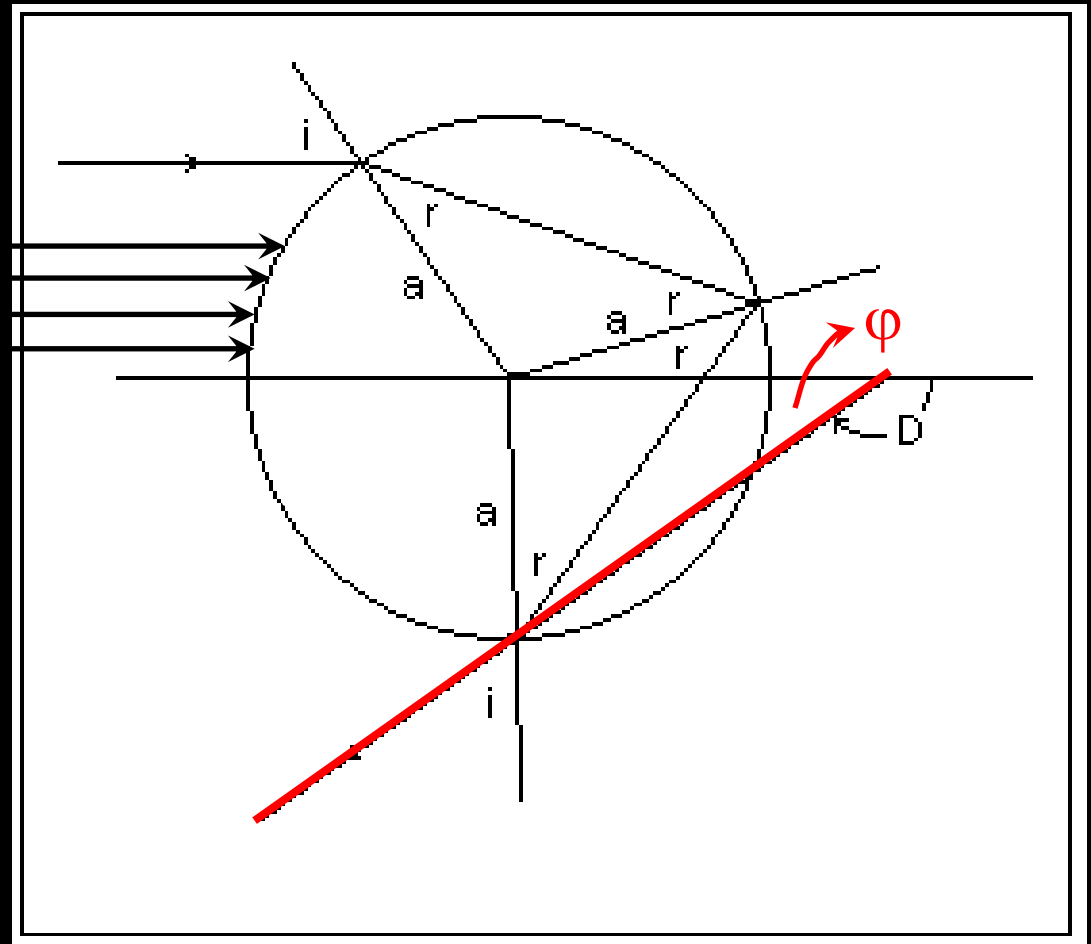
Deviation angle: ϕ

For a spherical
raindrop



$$\sin i = n \sin r$$

$$\phi = 4r - 2i$$

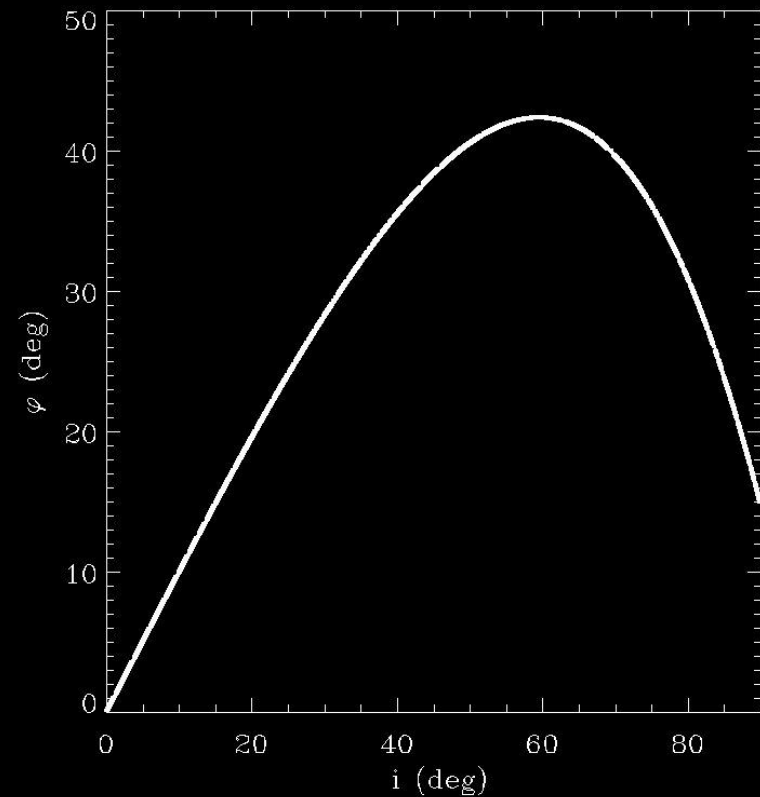
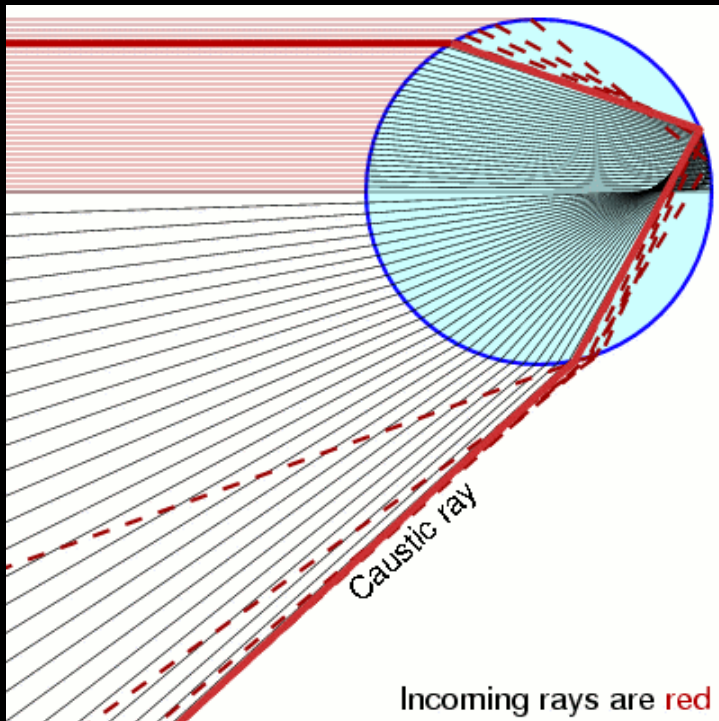


ϕ does not depend from the raindrop radius.

For $n = 1.336$

$\phi_{\max} = 41.6$;

$i = 60$, $r = 40.4$ deg



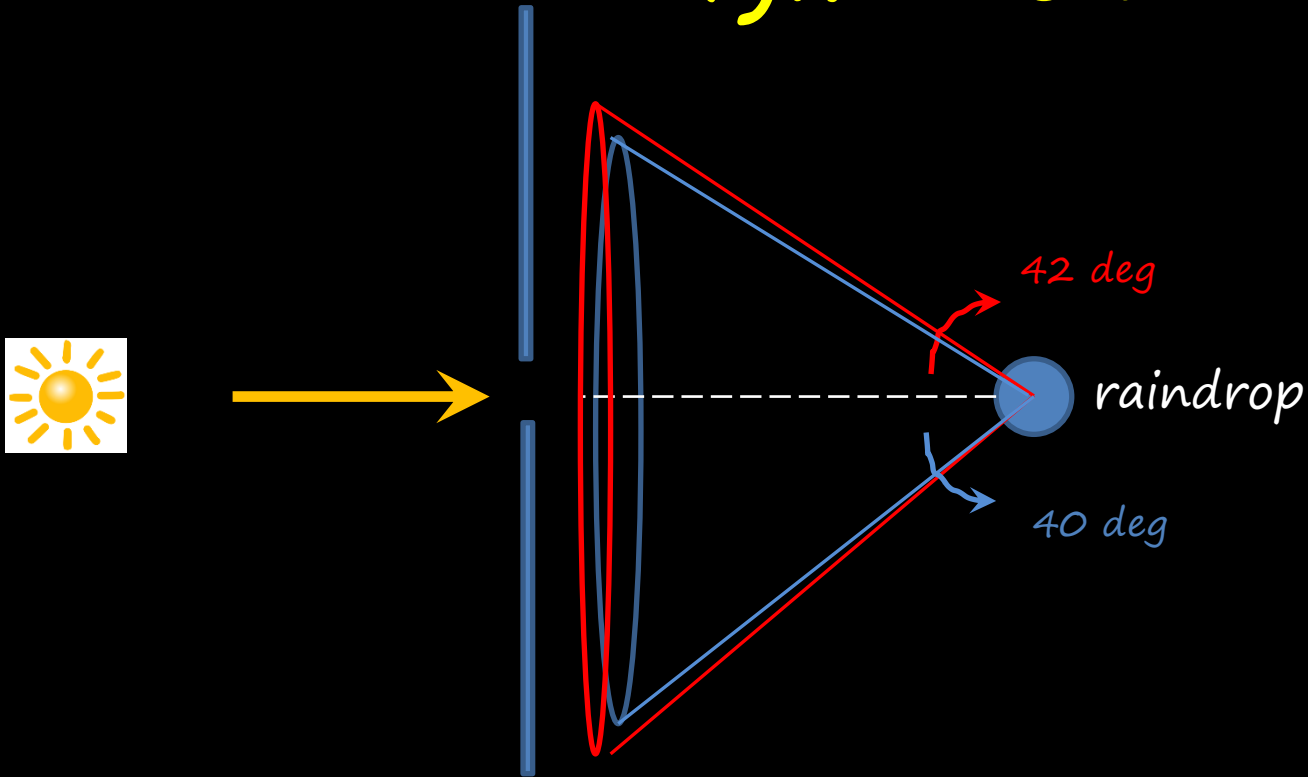
For red light : $n = 1.331$

For blue/violet light: $n = 1.343$

For red light $\phi_{\max} = 42.4$ deg

For blue light $\phi_{\max} = 40.6$ deg

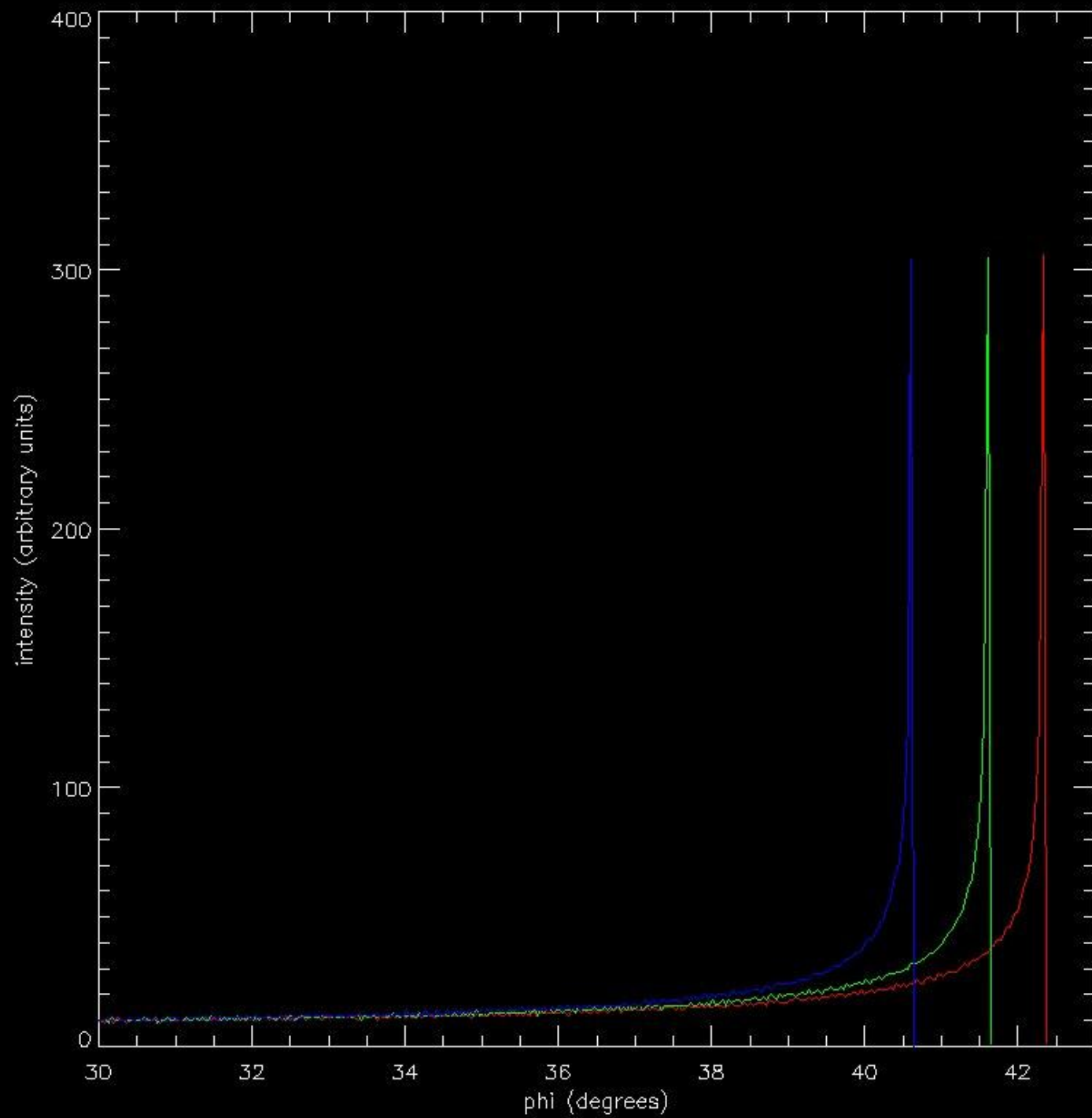
Light cone



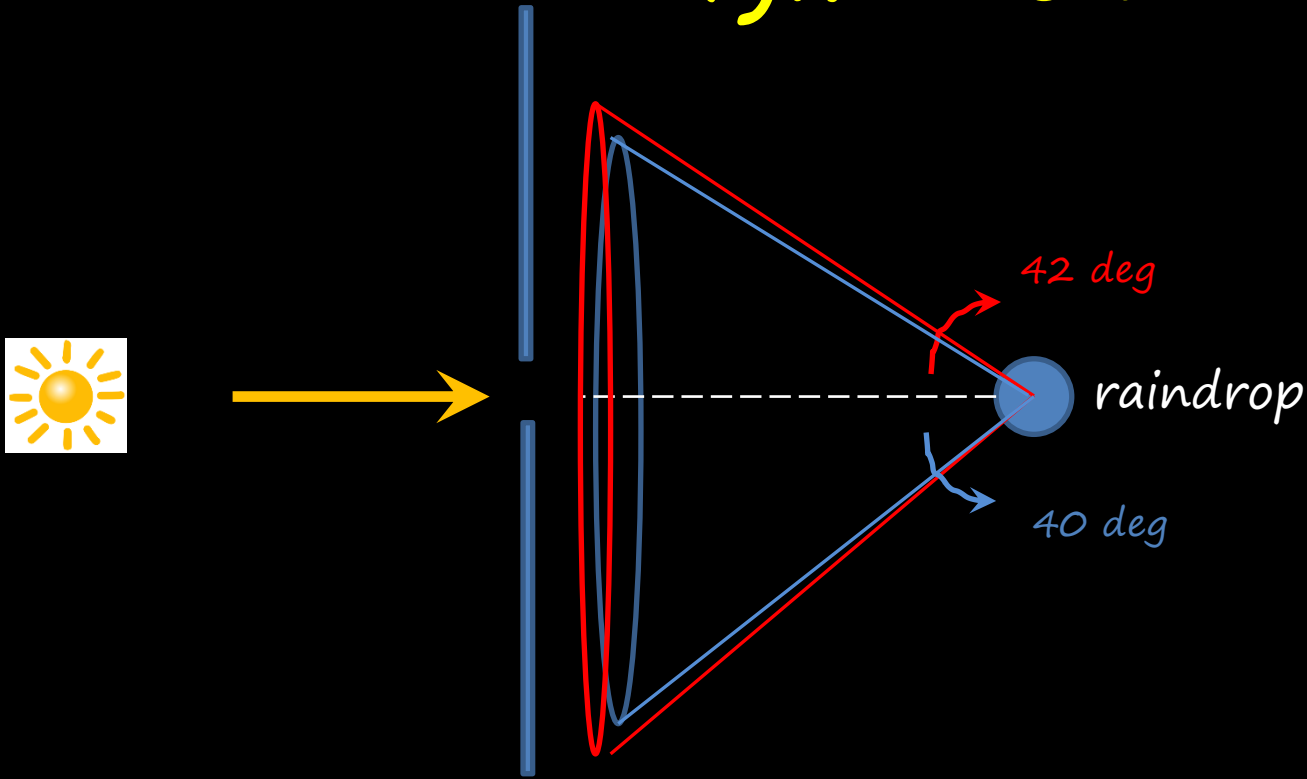
$\varphi > 42^\circ$: DARK!!!

$\varphi < 40^\circ$: WHITE LIGHT

$\varphi @ 42^\circ$: RED LIGHT



Light cone



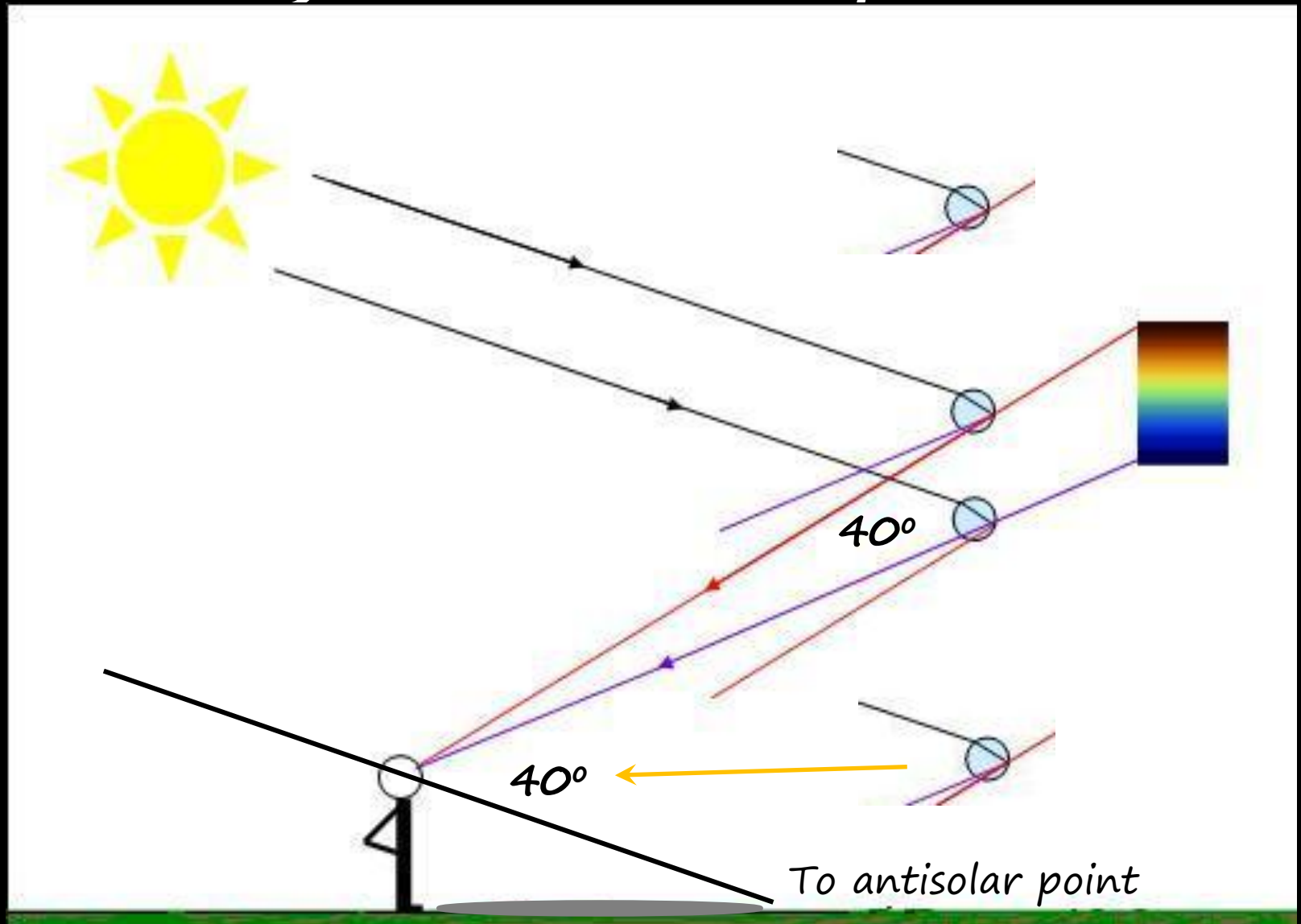
$\varphi > 42^\circ$: DARK!!!

$\varphi < 40^\circ$: WHITE LIGHT

$\varphi @ 42^\circ$: RED LIGHT

$\varphi @ 40^\circ$: BLUE LIGHT

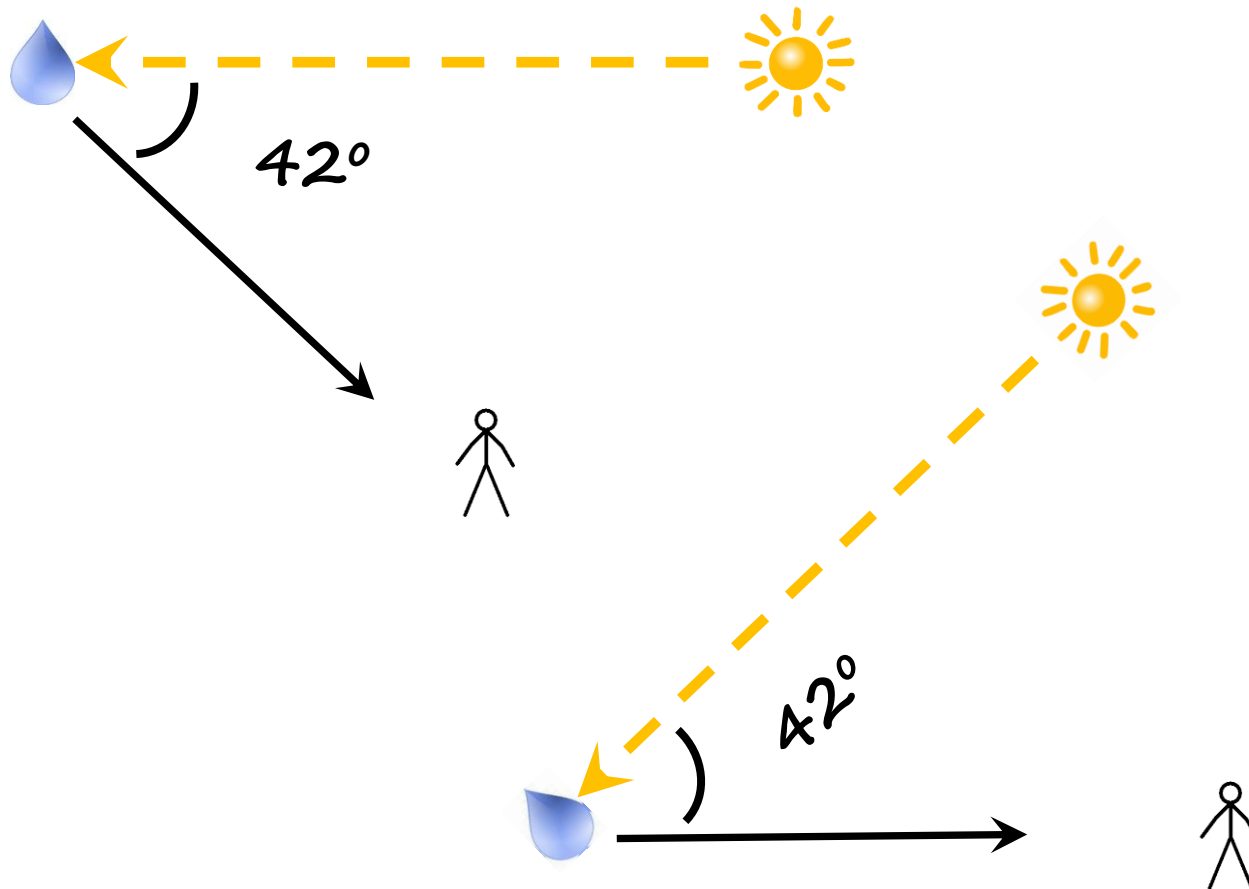
Myriads of droplets





Everybody has his own personal rainbow!

Sun inclination to see a rainbow



At ground level the highest sun inclination to see a rainbow is 42 deg

Circular rainbows

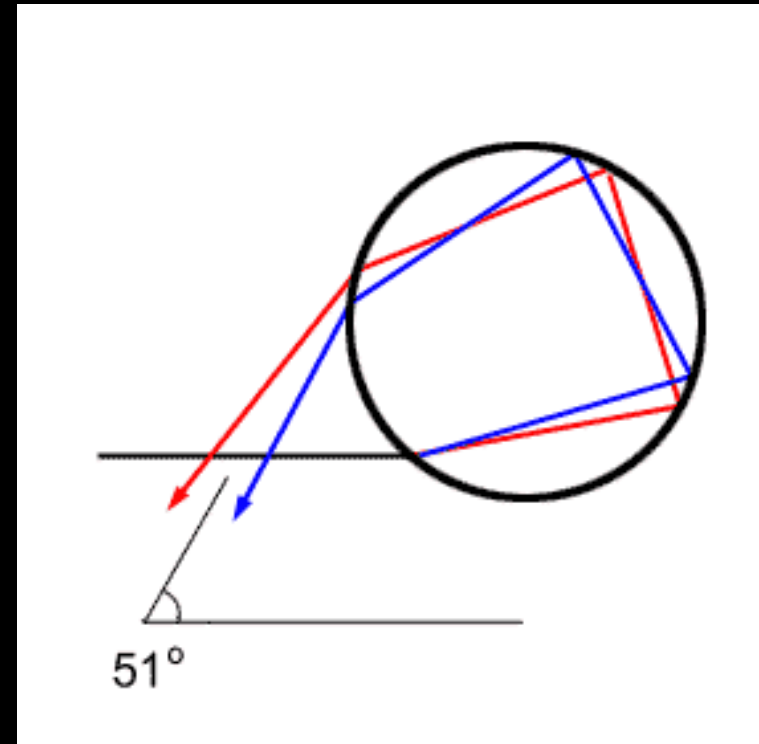
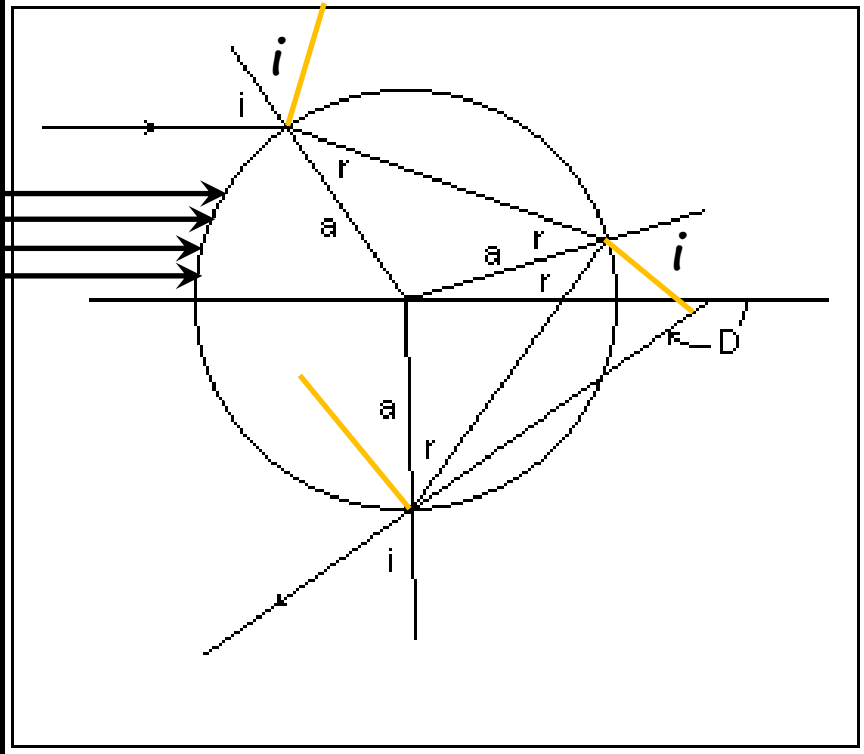




herald edens



Secondary rainbow



$$\phi = \pi - 6r + 2i$$

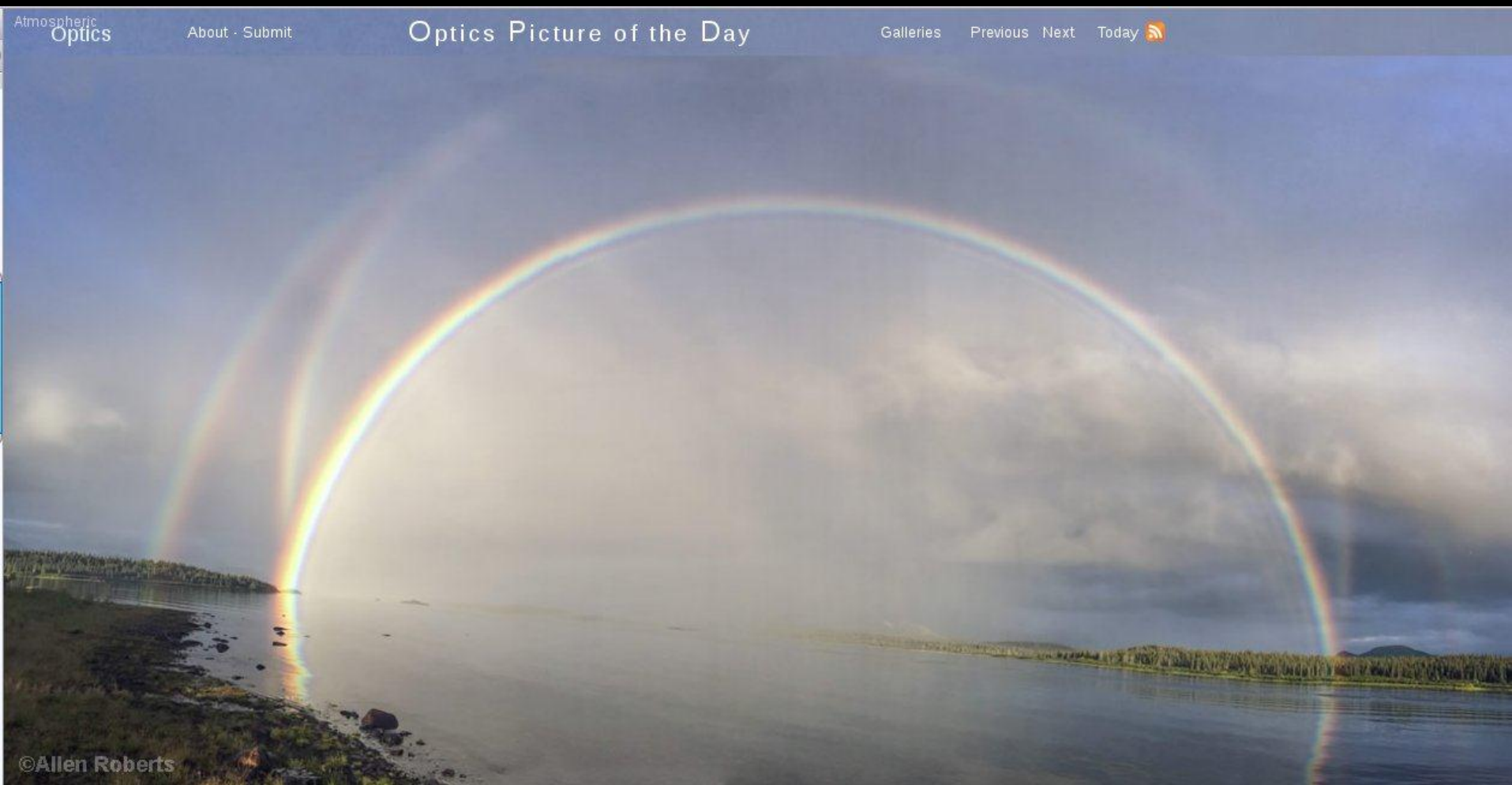
$$\phi_{\min} = 51 \text{ deg}$$

Secondary rainbow

Alexander dark band

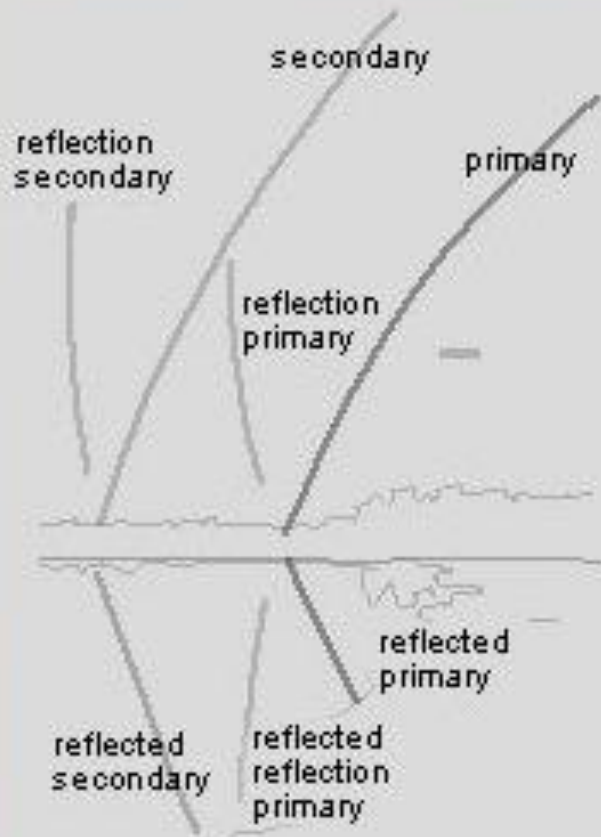


Reflection bows

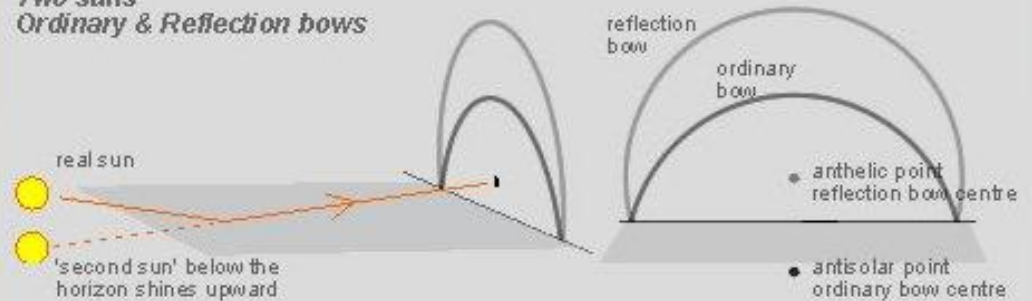


Reflection and reflected bows:

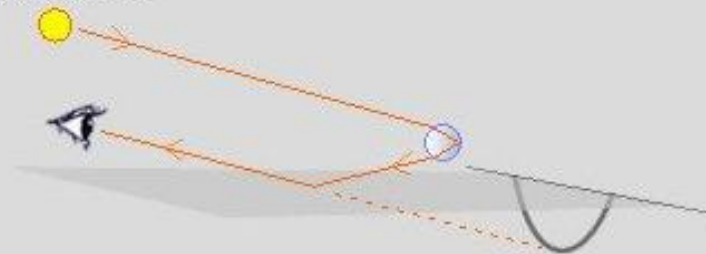
the combination of two effects



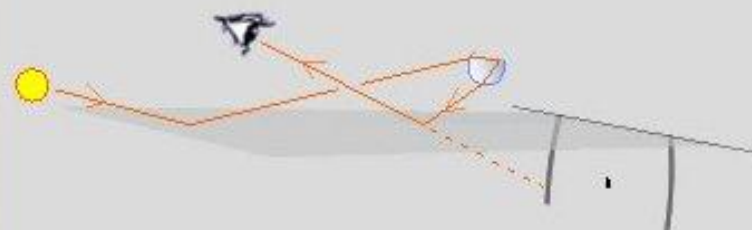
*Two suns
Ordinary & Reflection bows*



Reflected bow



Reflected - reflection bow





Inverted colors??????



Only the secondary rainbow, low on the horizon!!!! Sun is higher than 42 deg but lower than 51 deg.

At sunset only red light: red bows



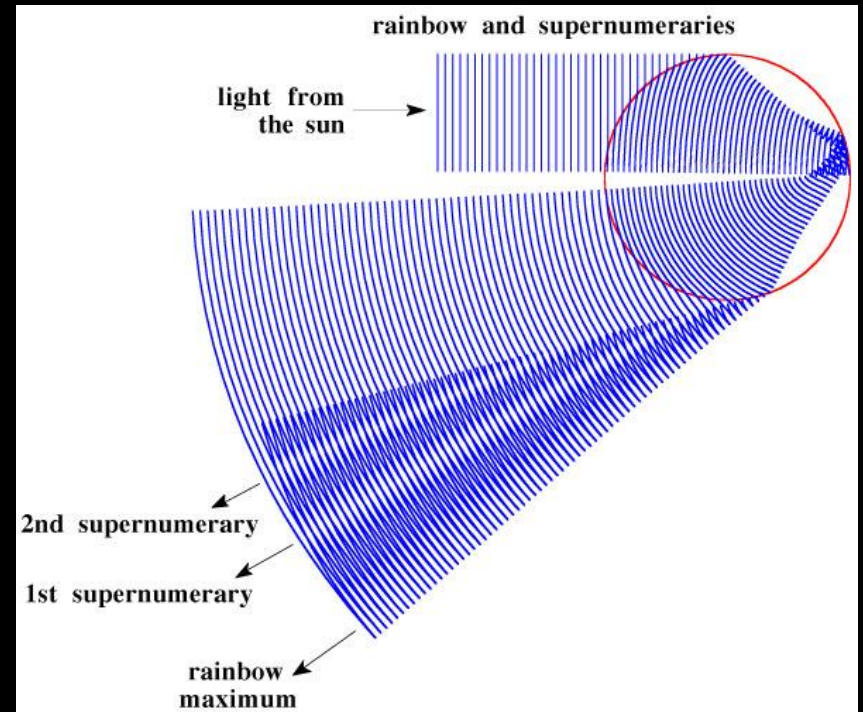
Moonbow



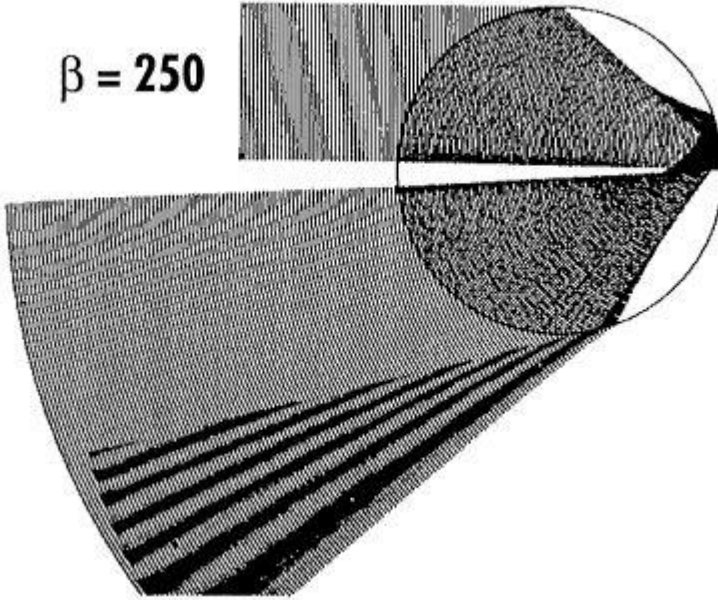
Supernumerary bows

Drop size $\sim 1\text{mm}-2\text{ mm}$

When drop size $< 0.5\text{ mm}$
interference becomes important



$$\beta = 250$$

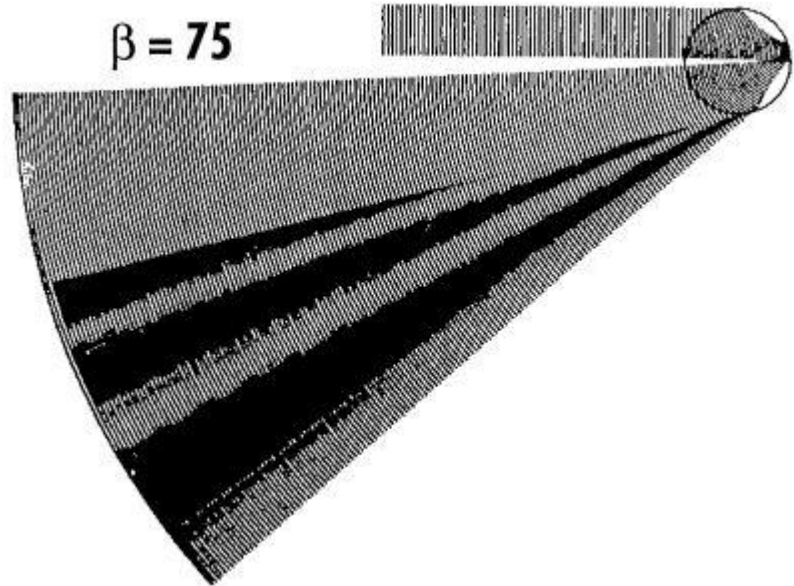


The number and the size of supernumeries depends on the drop size

$$\beta = 2\pi a / \lambda$$

(a = drop size)

$$\beta = 75$$



Fogbow

For very small droplets ($\sim 30\text{ }\mu\text{m}$) like in fog, the bow light is white



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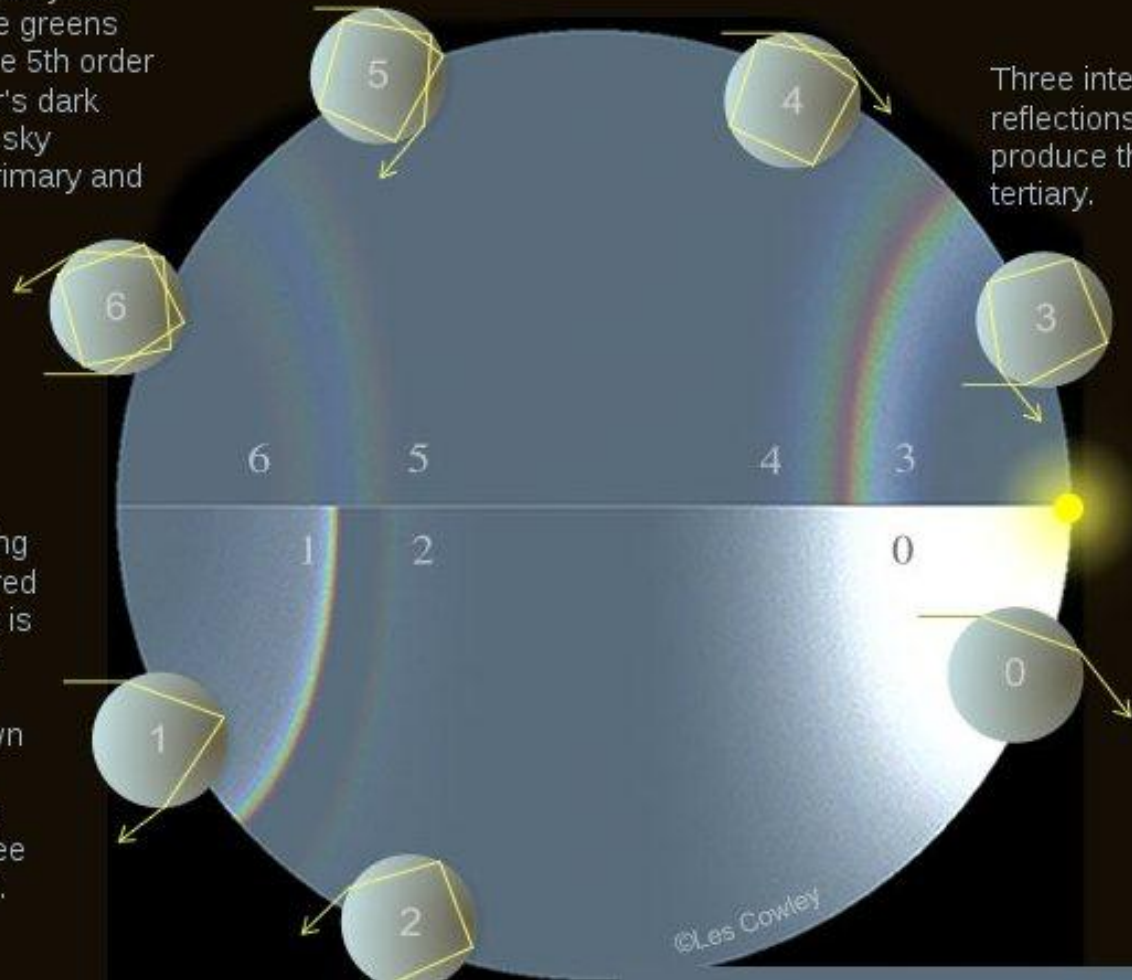
0th, 3rd, 4th 5th ... orders

5th and 6th order bows overlap the primary and secondary. The greens and blues of the 5th order lie in Alexander's dark band, the dark sky between the primary and secondary.

Three internal reflections produce the tertiary.

This Bowsim ray tracing is an all sky view centred on the zenith. The sun is on the horizon at right.

The upper half is shown 20X brighter and is filtered to remove rays reflected less than three times inside raindrops.

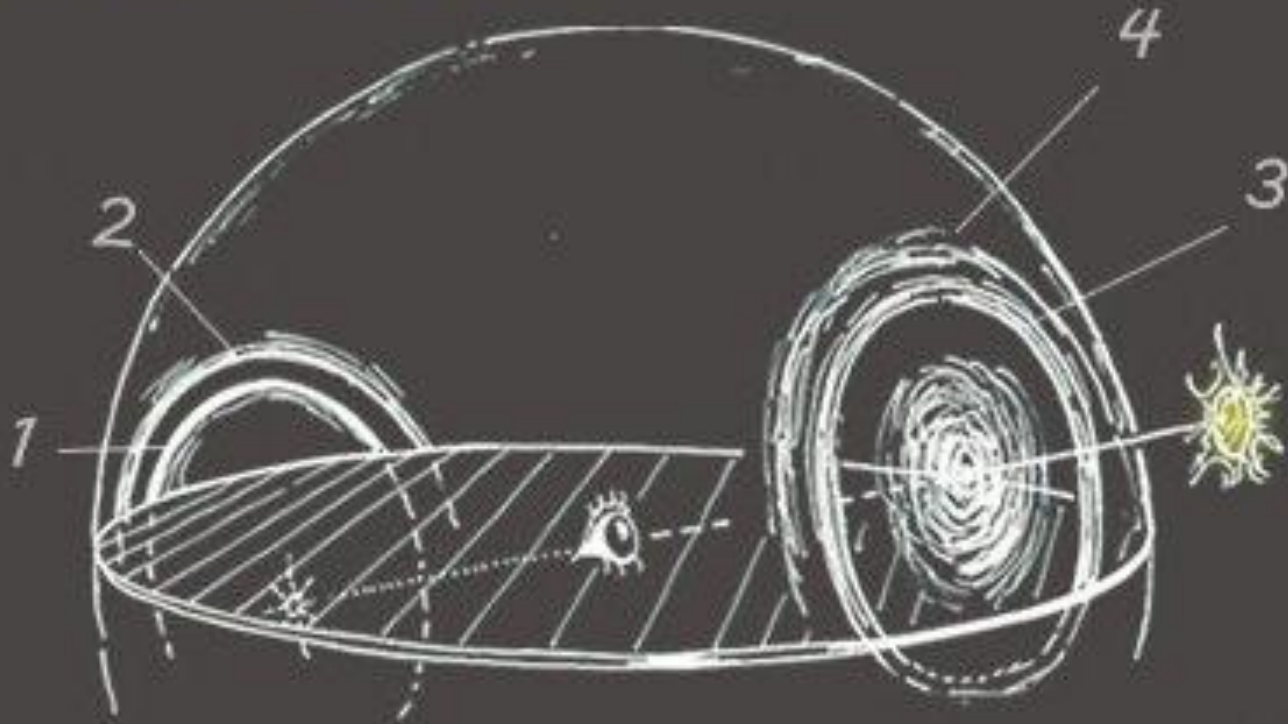


Zero order glow



3rd and 4th orders

The 3rd and 4th orders are faint, broad and close to the sun.



3rd and 4th orders





3rd and 4th
order rainbows



5th and 6th orders



5th order



Adjusting contrast and luminosity...



5th order

3rd September 2009

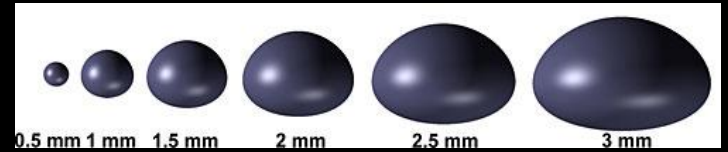


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Non-spherical droplets: twinned rainbows



Rainbow polarization

$$\theta_{\text{Brewster}} \sim 37^\circ$$

Rainbow light is 96% linearly polarized



Not a rainbow

- *Many optical phenomena look like rainbows but are not rainbows*

Circum-zenital halo



Circum-horizontal arc



Glory



©2006 Vincent Lowe

Light pillars

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Sun halo

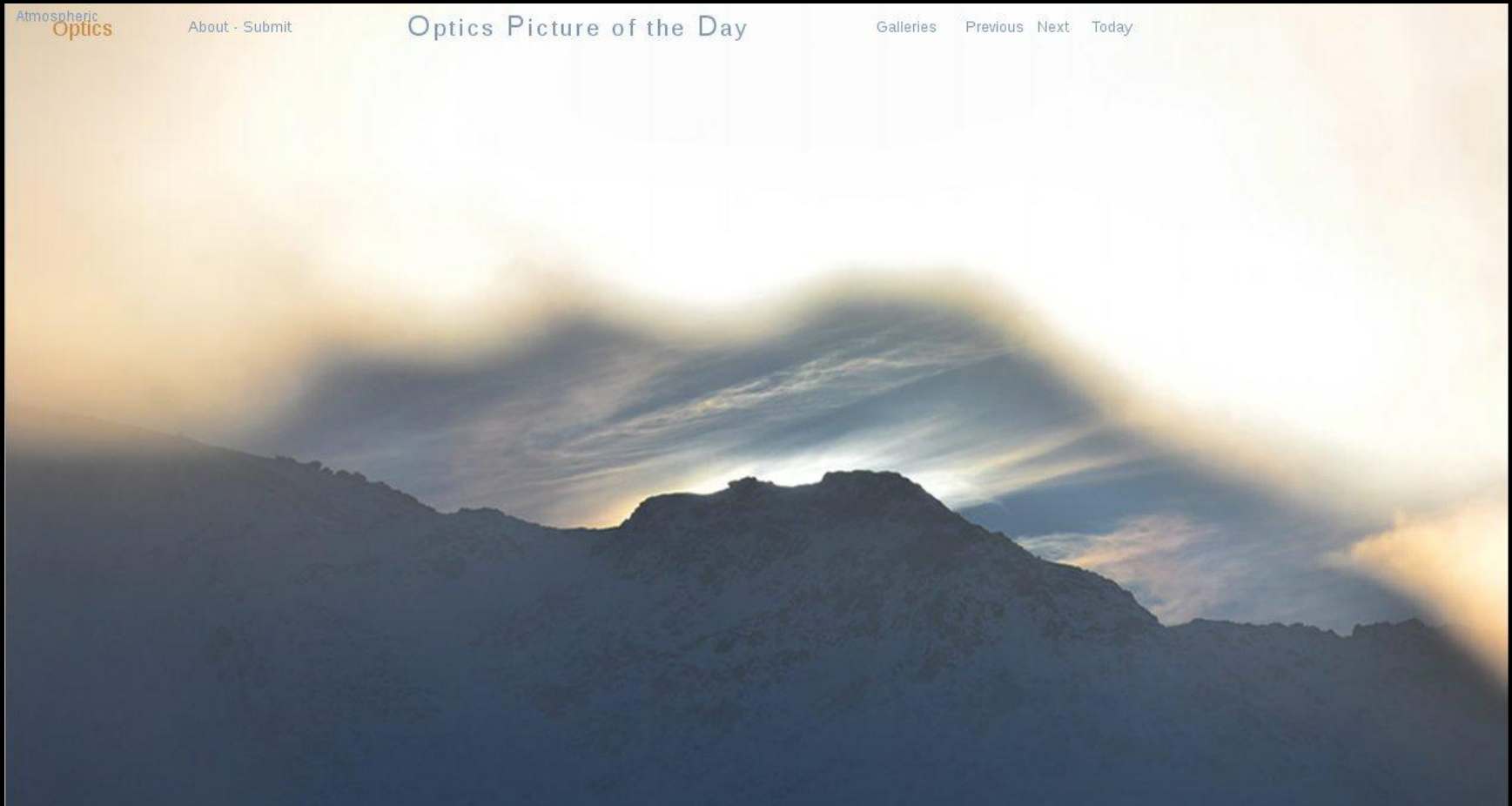


sundogs



Other optical effects

Mountain shadow



Mountain shadow



Mirage



Mirage

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Yacht on Waterfall Sea

At the breakwater's left the sea pours downwards, a waterfall into some bottomless pit. The falls stretch even to the horizon. To their right the sea is lower and tilted.

A small yacht sails innocent of nearing doom. It is grabbed. Its hull is bent down to match the plummeting waters. Rigging and sail rip, stretch sideways and upwards.

A scene captured by Sandy Robertson at Alderney (Channel Islands) Breakwater, an immense 200ft long structure jutting east.

