Light!
Glorious Atmospheric Phenomena

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Outline

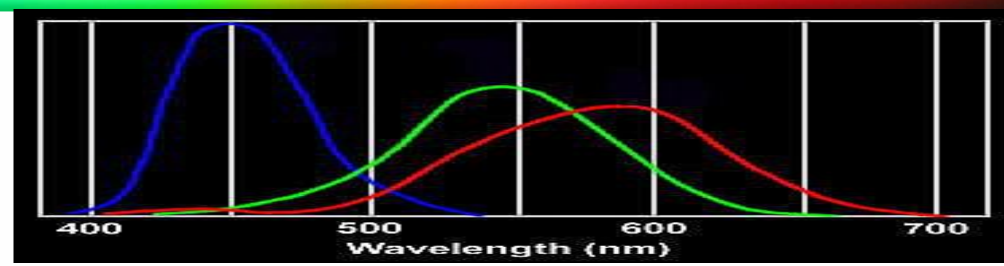
- Blue sky
- Shadows: clouds, mountains, …
- Water: droplets of various size
- Ice crystals
- Curved light paths
- Colours in the night

Blue sky

Our eyes:

- Intensities – adaptive
- Sensitive to differences
- Colours – if bright enough

eye sensitivity (cones)



No sense for:

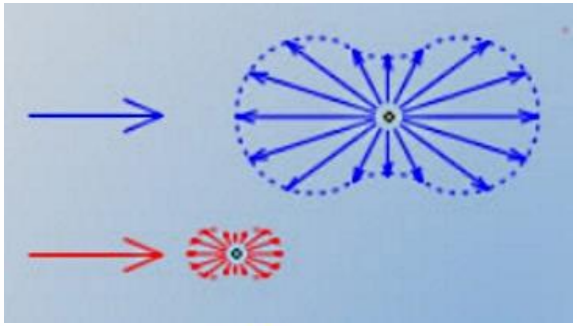
- Polarization

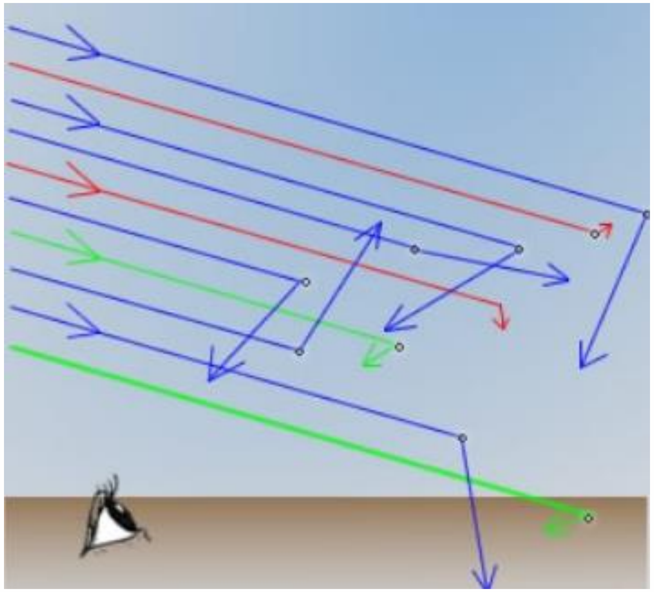
Blue sky

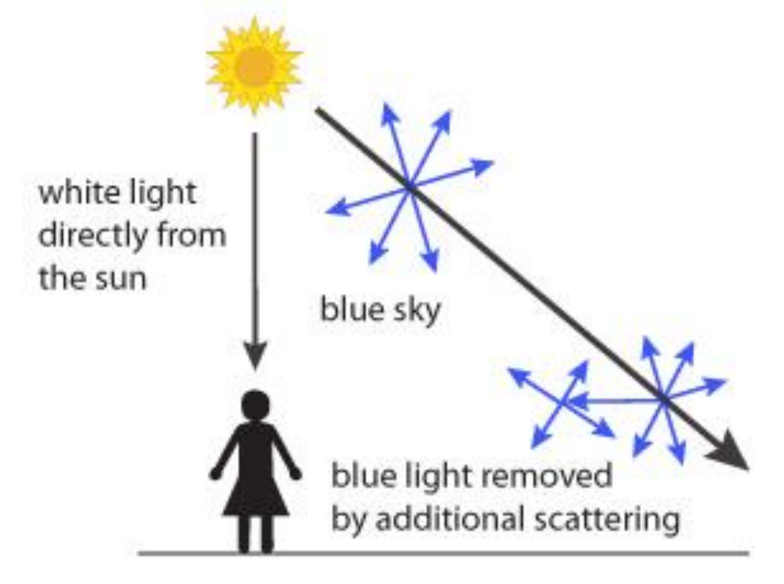
Scattered light

molecules (smaller than wavelength)

$\sim 1/\lambda^4$







pale blue near horizon

Blue sky

Scattered light

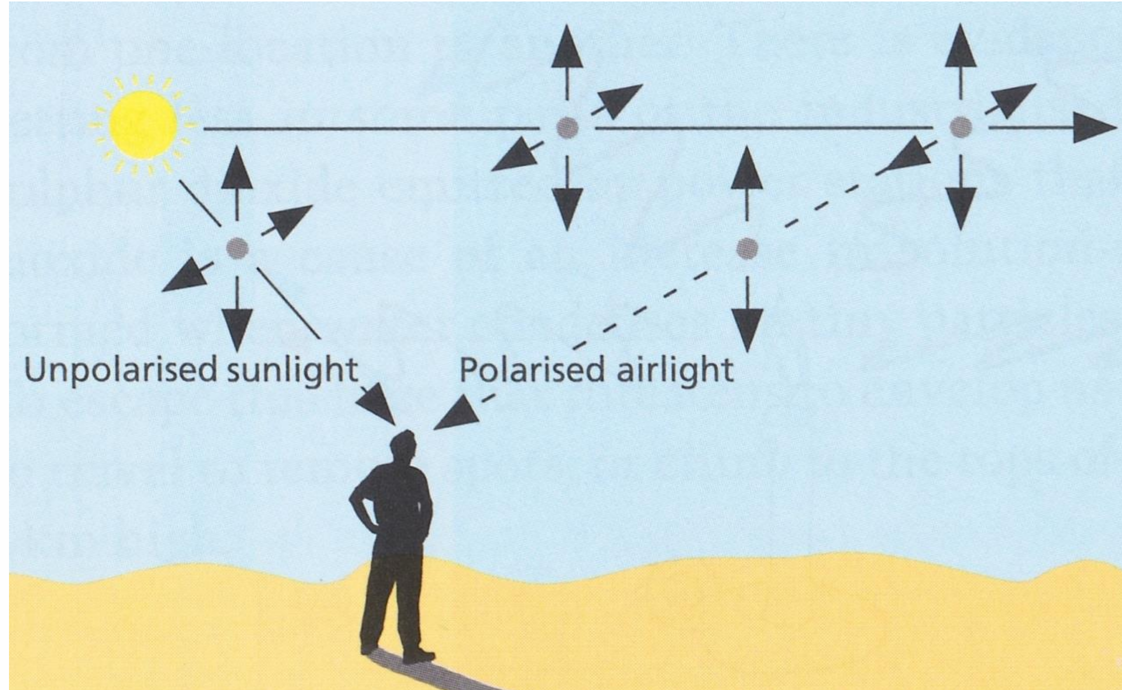
molecules (smaller than wavelength)

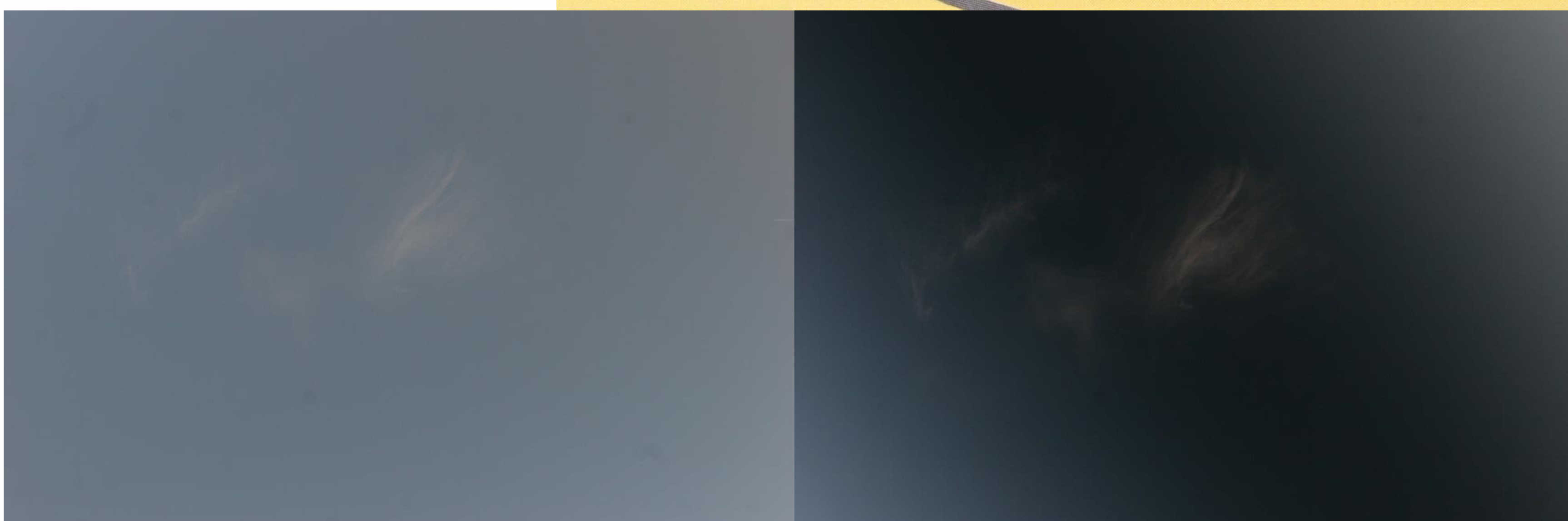
$\sim 1/\lambda^4$

Night sky also blue
(here scattered moonlight)
limit: sensitivity level of the cones

Blue sky

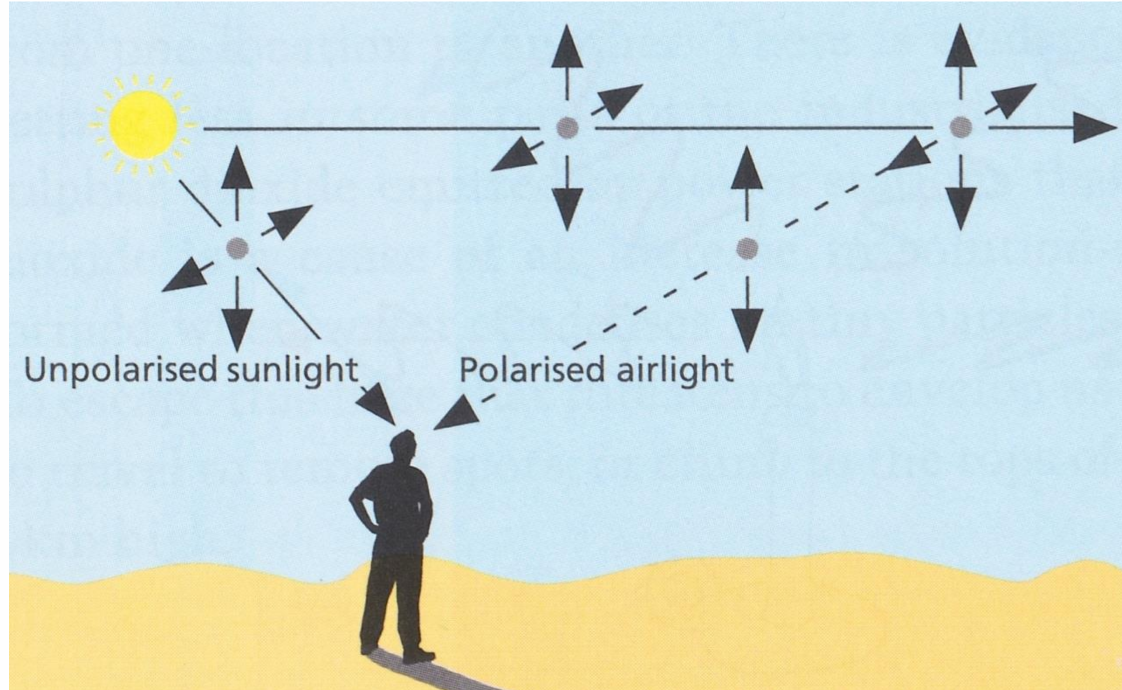
Polarization of skylight

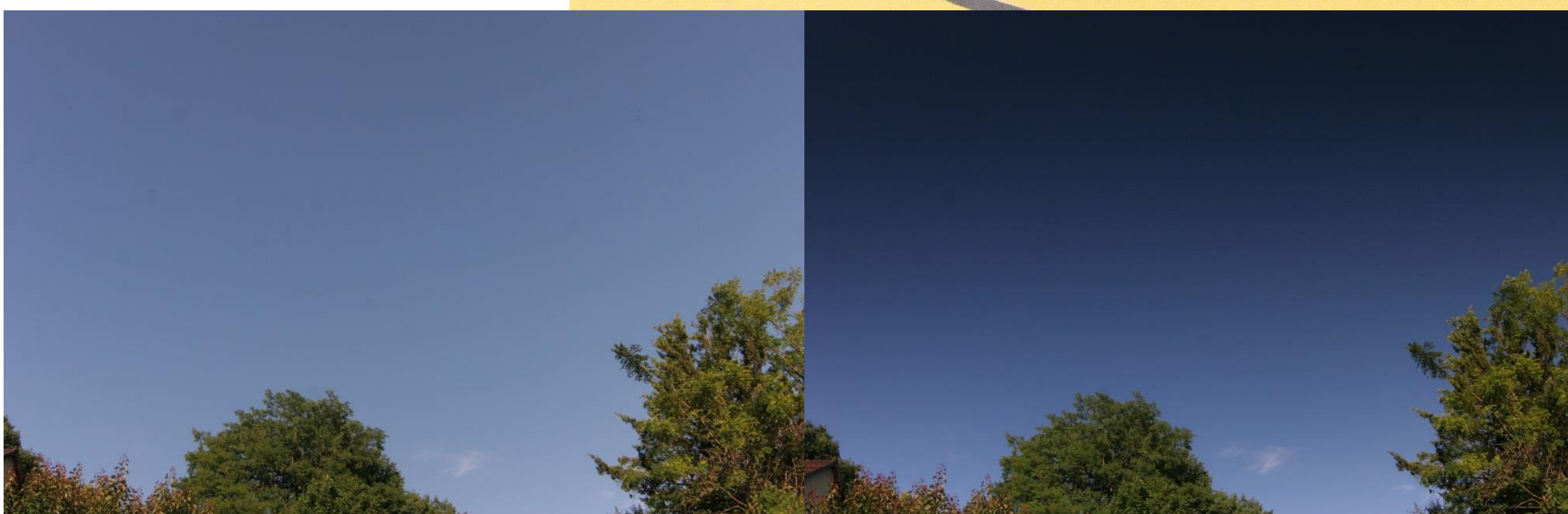




Blue sky

Polarization of skylight



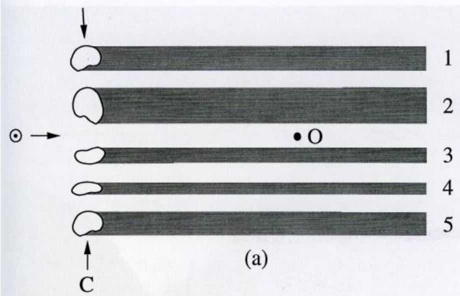


Shadows

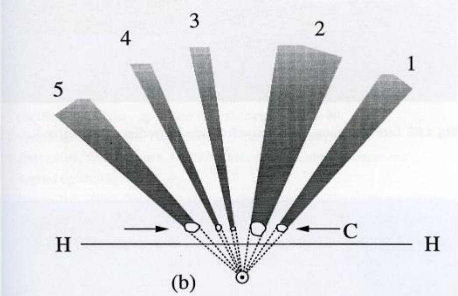
(Relative) darkness behind objects

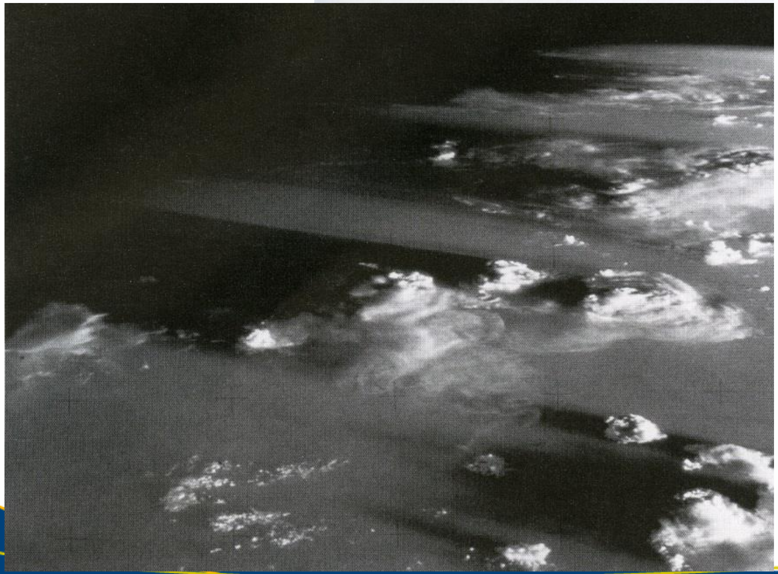
sunlight – parallel light

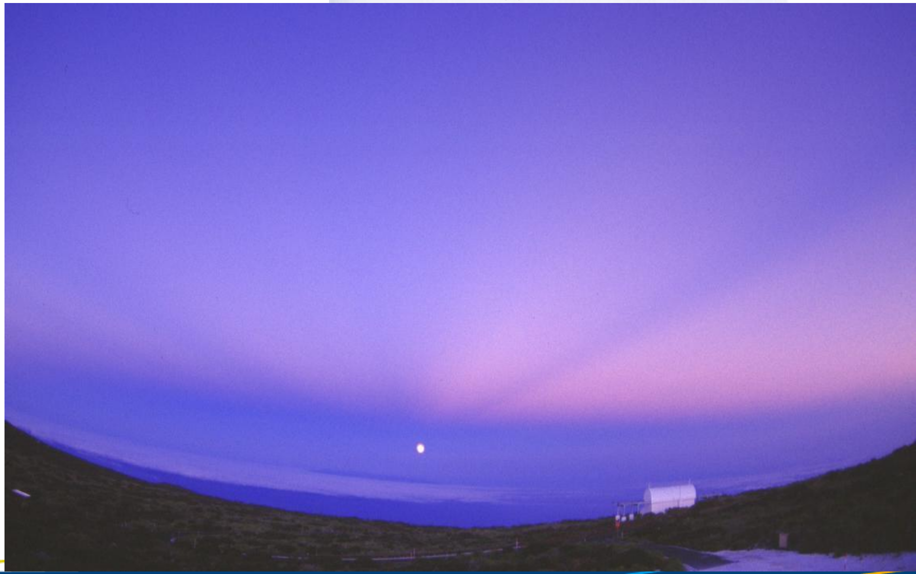
view from top



from observer O

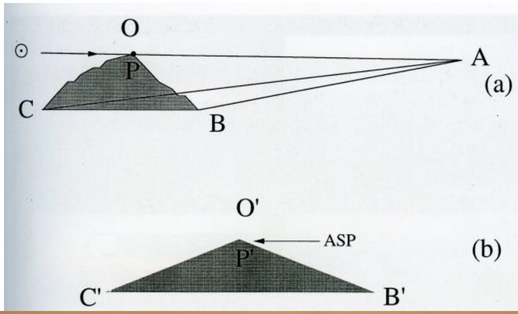






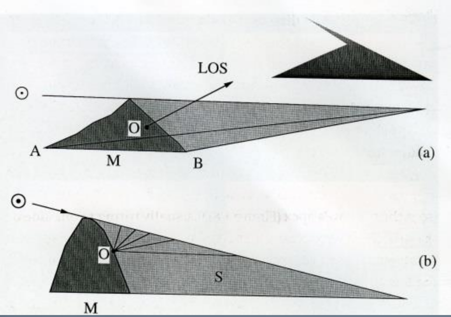
Shadows

Mountain shadows



symmetric

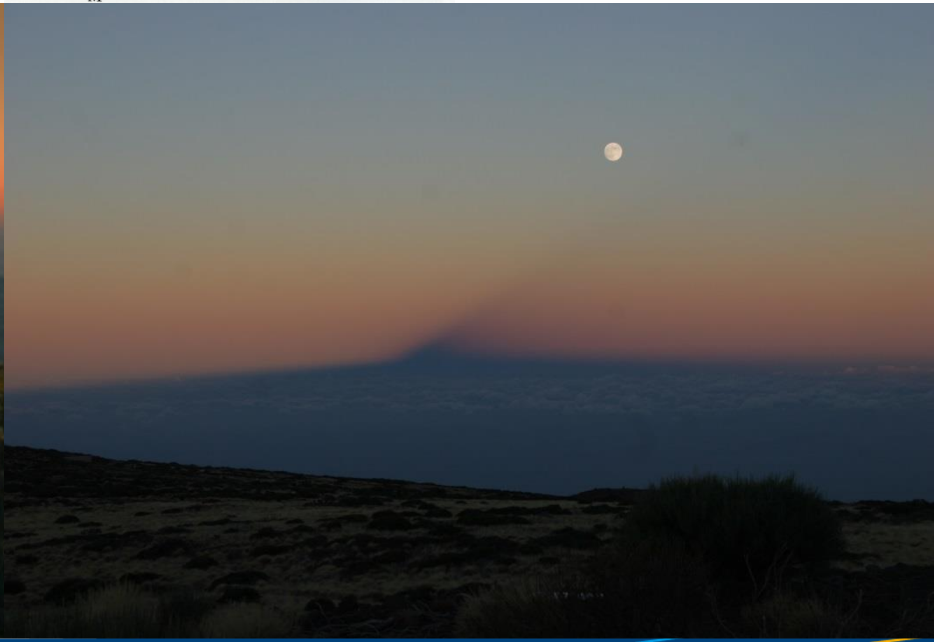
Wendelstein (C.Hinz)



observer at O

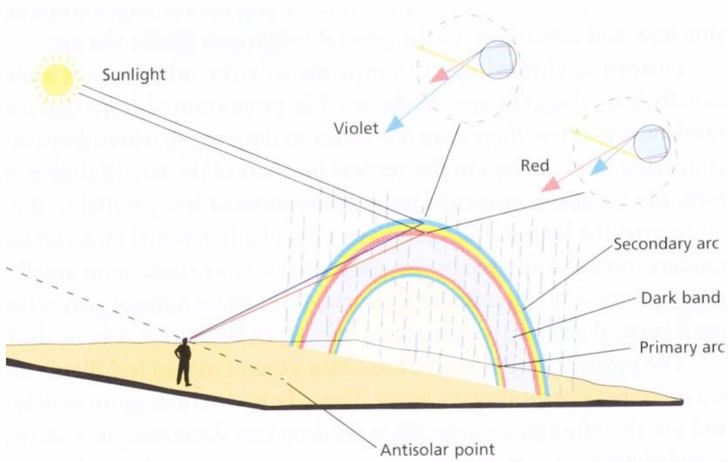
„shadow spike“

Teide, with ~full moon



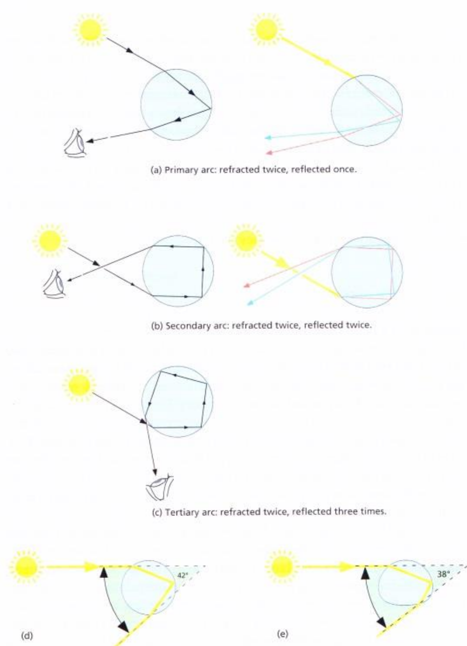
Rainbow

Water droplets
+ sunlight
= rainbow



primary arc:
radius 42°
refracted 2x, reflected 1x

secondary arc:
radius 51°
refracted 2x, reflected 2x



Alexander's dark band

effects of drop size + shape?

Rainbow

Water droplets

+ sunlight

= rainbow

primary arc:

radius 42°

refracted 2x, reflected 1x

in water…

but different in sea water

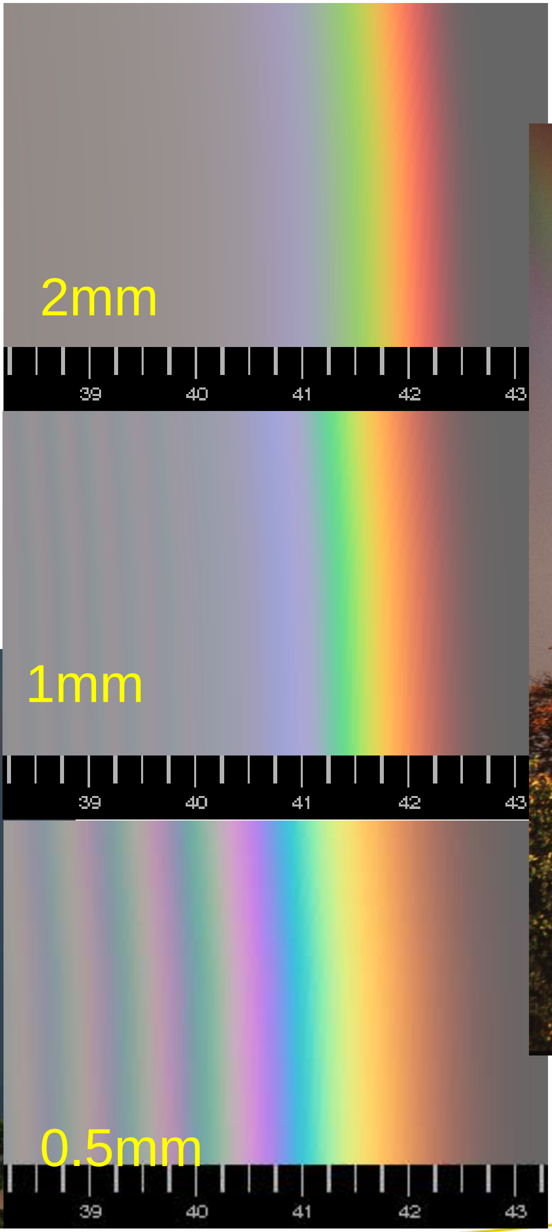
(higher refractive index)

Lynch & Livingston 2001, p. 118

Rainbow

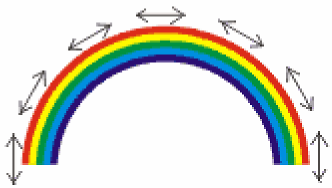
Drop size

interference
around the reflection
inside the drop



Rainbow

Reflection inside the drop causes linear polarization



linear polarizer: vertical

-45°

Rainbow

Drop shape
not spherical

flattened
(turbulence)

split rainbows

Rainbow

Additional reflection
e.g. on water surfaces

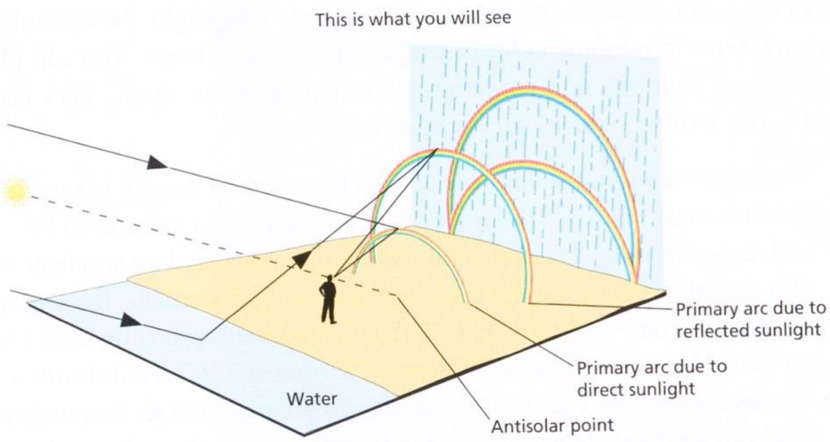


photo: T.Wassmuth

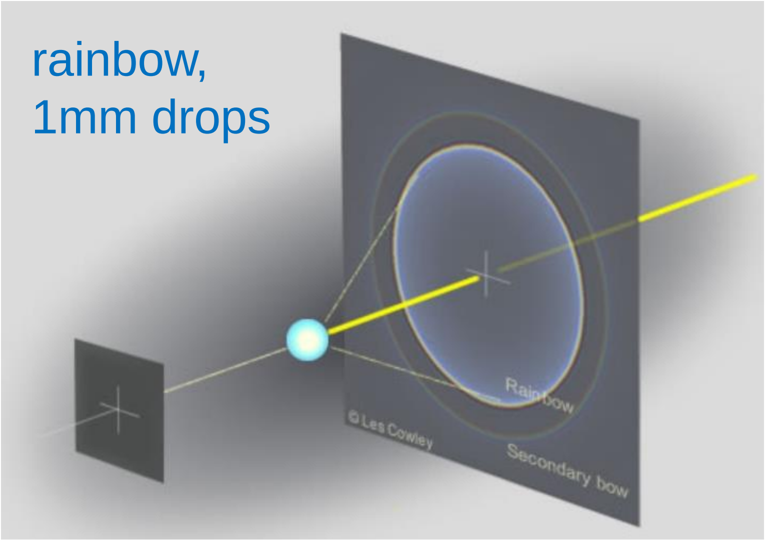
Fogbow

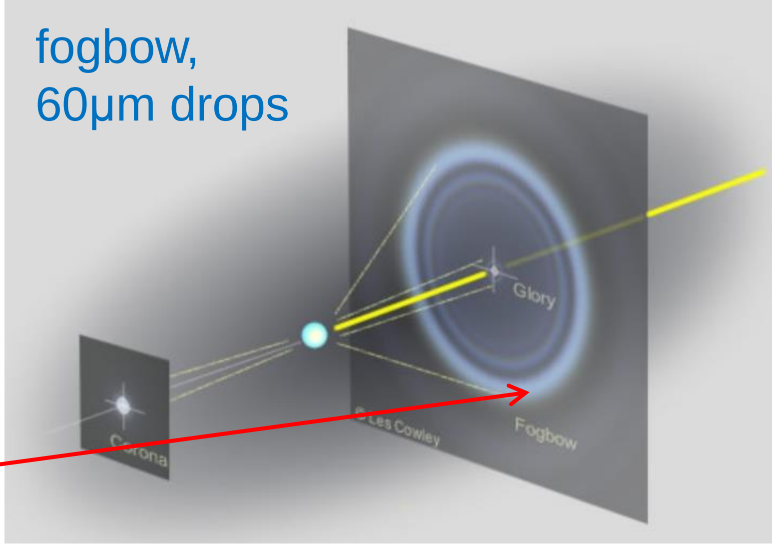
Drop size in fog
much smaller

refraction angle
differences small
white bow

additional effects occur
towards the light source and opposite

1. the fogbow





Fogbow

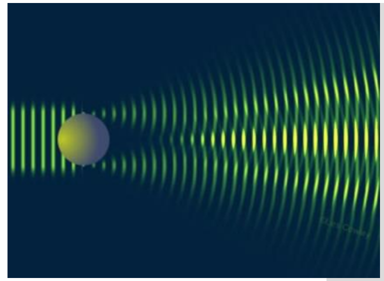
Drop size in fog
much smaller

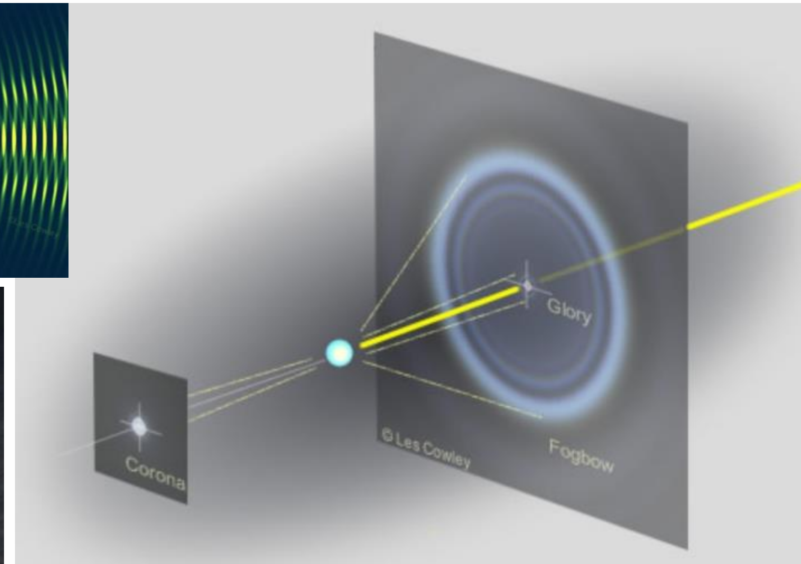
refraction angle
differences small
white bow

(best seen when close to
upper fog/cloud limit)

Corona

Tiny drops in clouds cause: diffraction

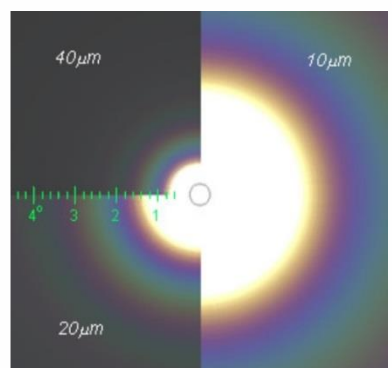


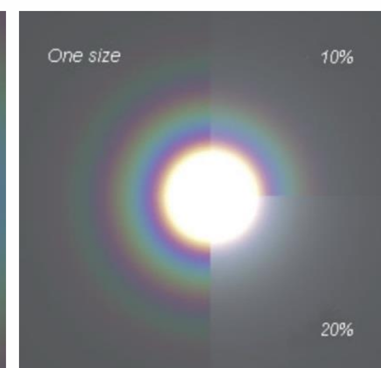


view towards light source

depends on size and wavelength

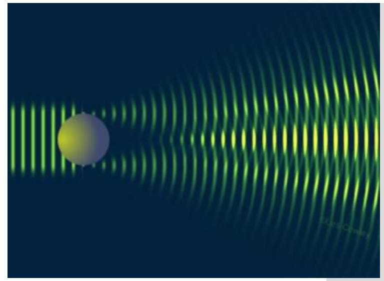
circular if all drops same size

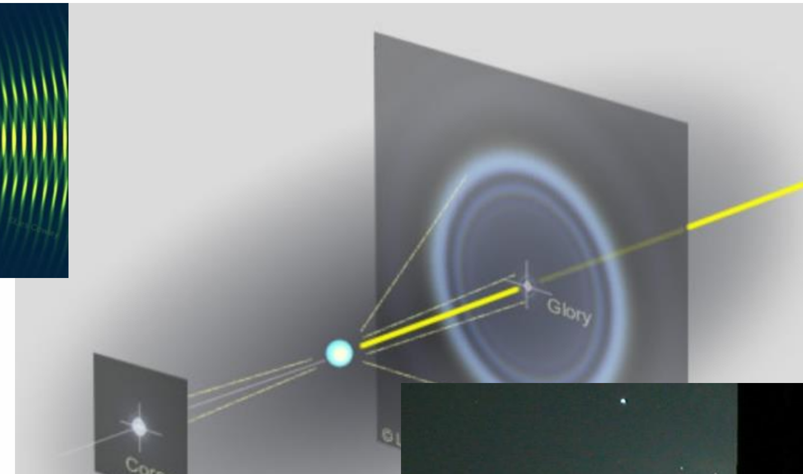




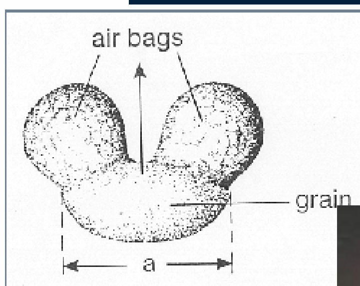
Corona

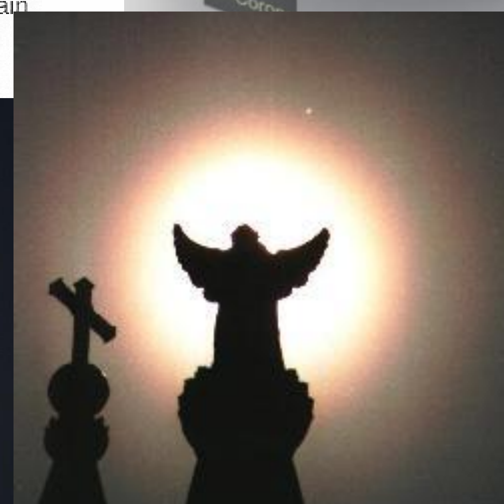
Pollen in the air
cause diffraction



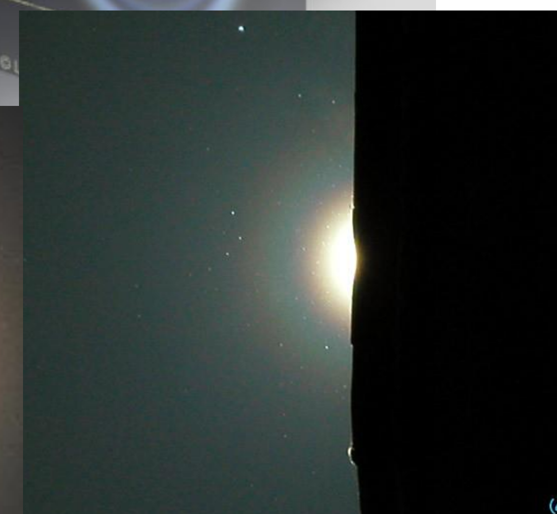


pollen spherical
or other geometry





pine pollen



birch tree pollen

B.Kühne

Iridescence

Tiny drops in clouds

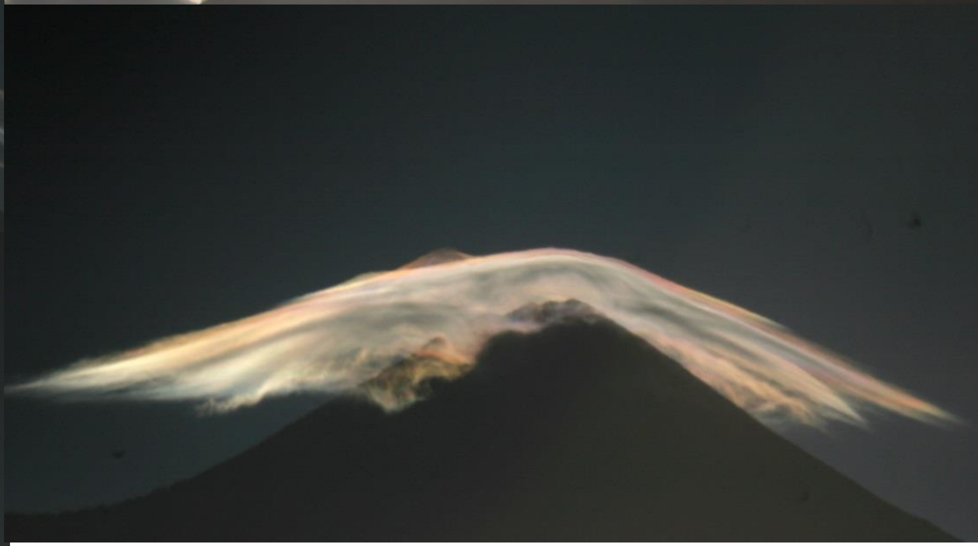
drop size varies from

one cloud to next = repeated corona

C.Hinz

Iridescence

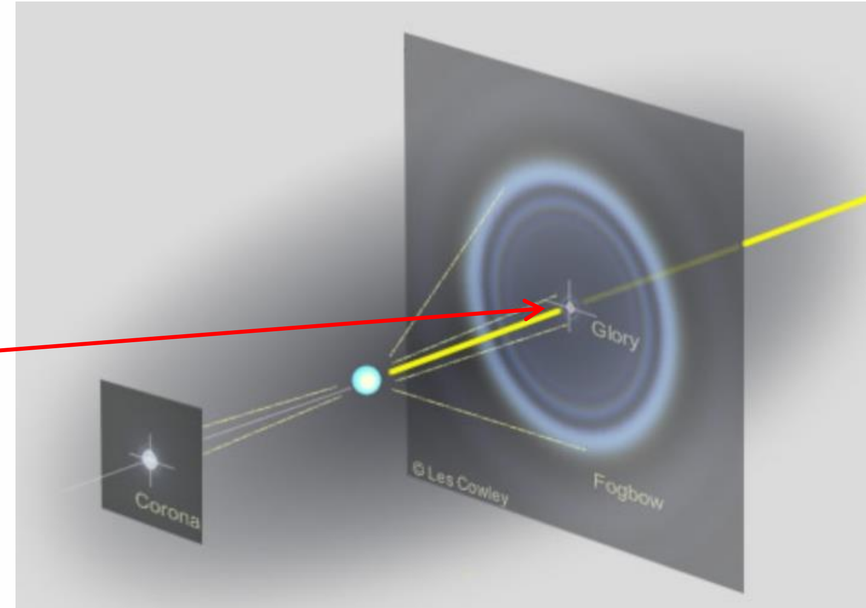
Orographic cloud + iridescence



shape + colour varying within mins.

Glory

Opposite to the light source:



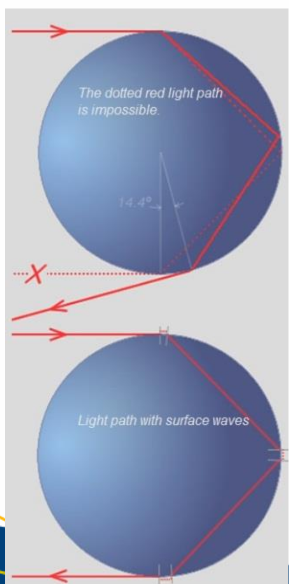
shadow + reflected light

(often together with a fogbow)

theory not yet complete:

bright center strongly polarized, 180° angle

at least 1 internal reflection



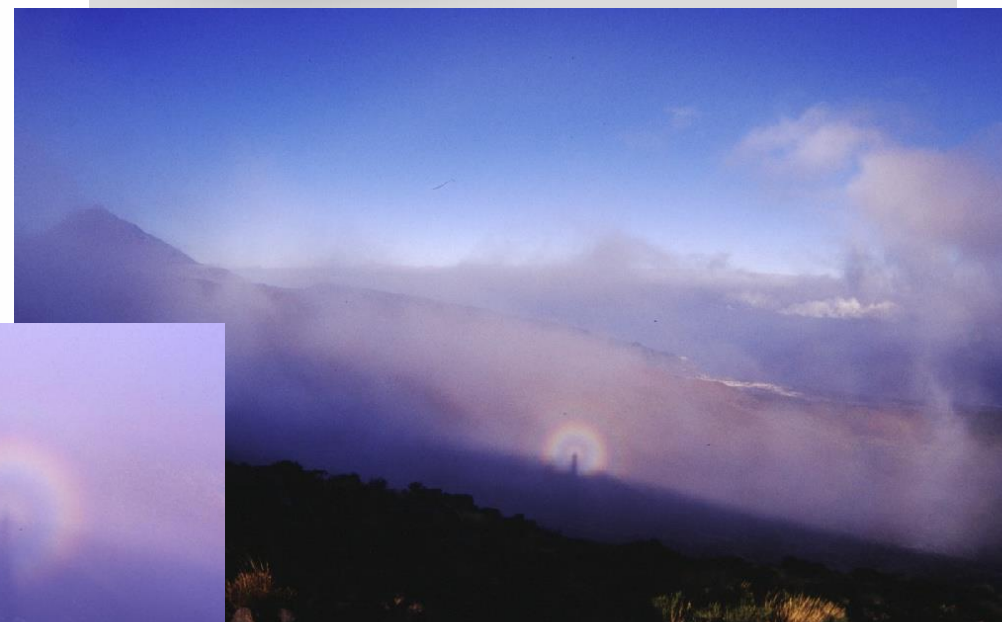
possible path 14° away

assuming surface waves

decay rapidly

needed for ~1µm

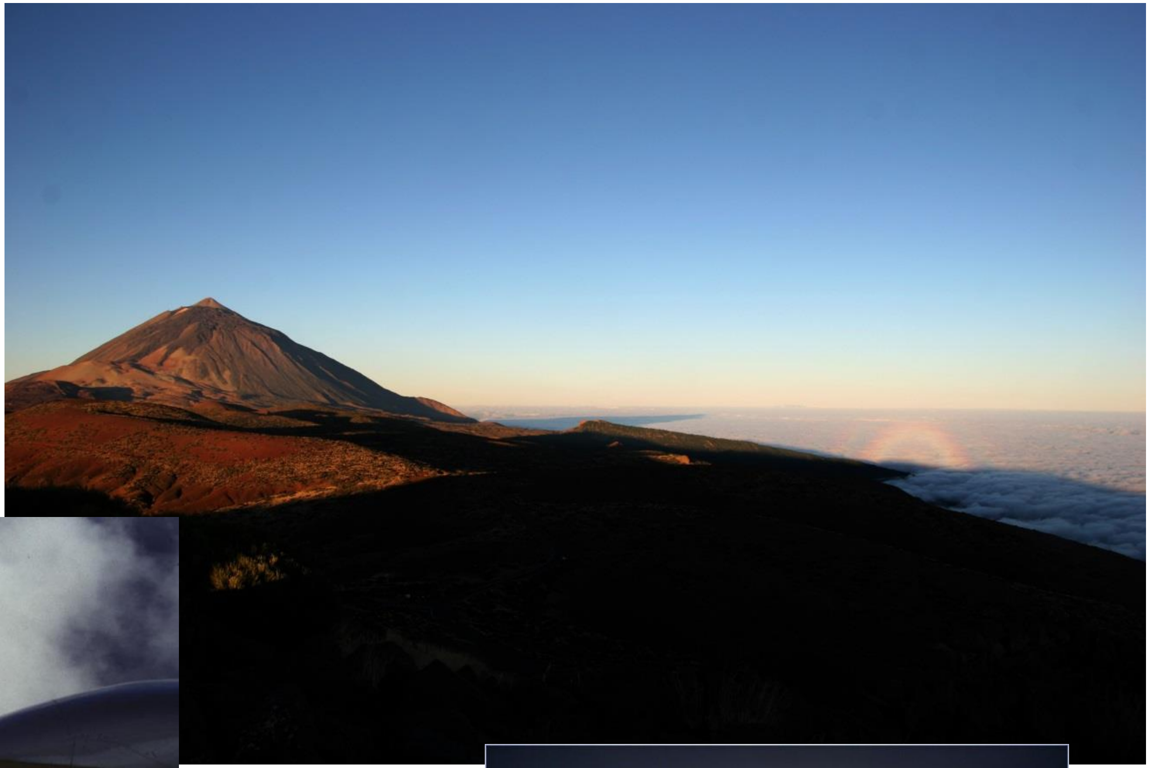
(2 wavelengths)



Glory

Known from mountains and from airplanes

centered at the observer



car headlights: fogbow, glory

(J. Hackmann)

Haloes

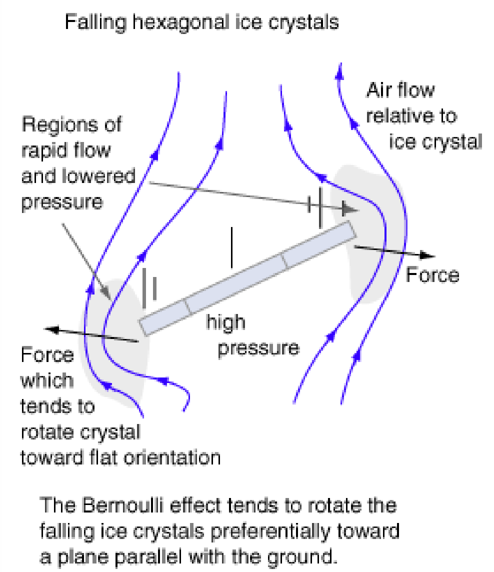
formed in cirrus clouds

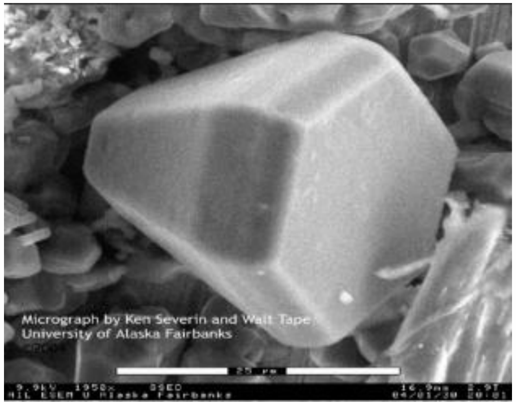
water ice crystals

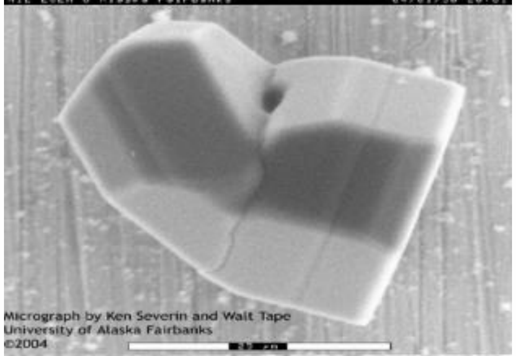
most frequent: 22° ring

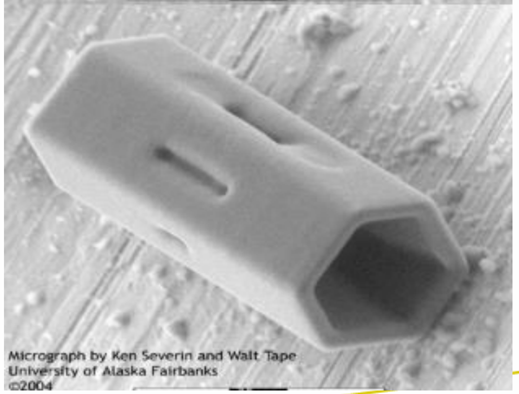
ice columns, turning while falling

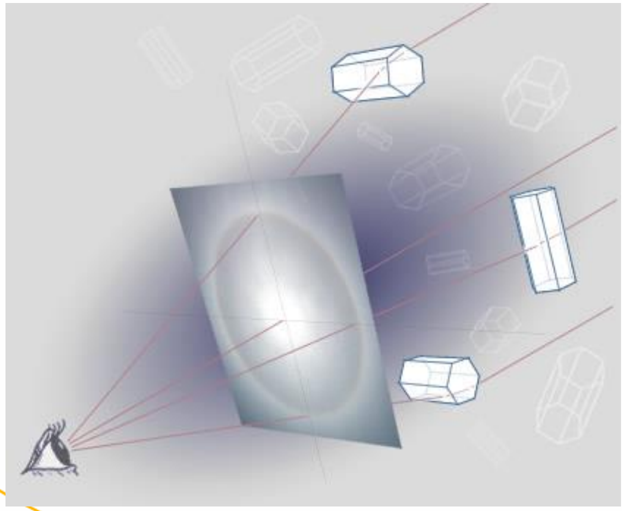
samples collected Severin & Tape, Univ. of Alaska









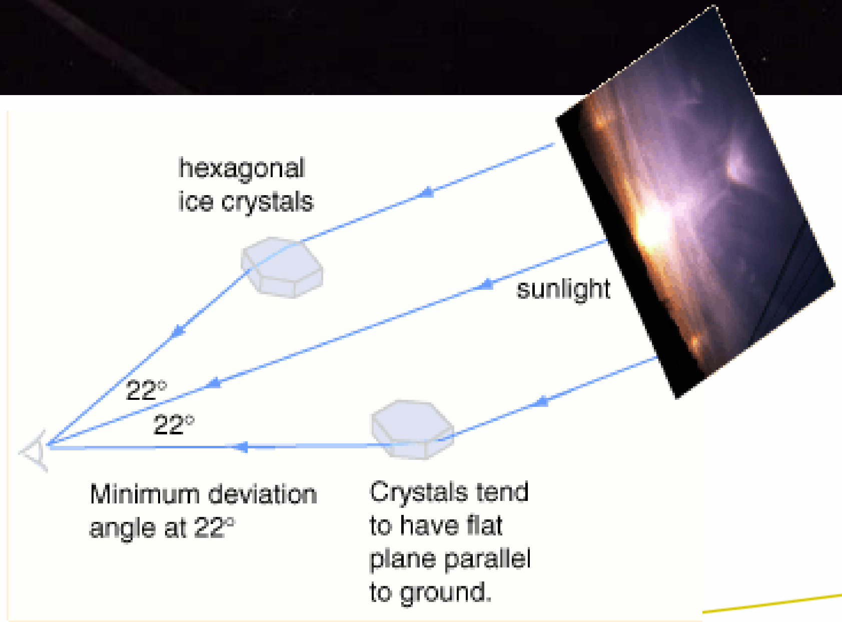


Haloes

most common types:

22° ring

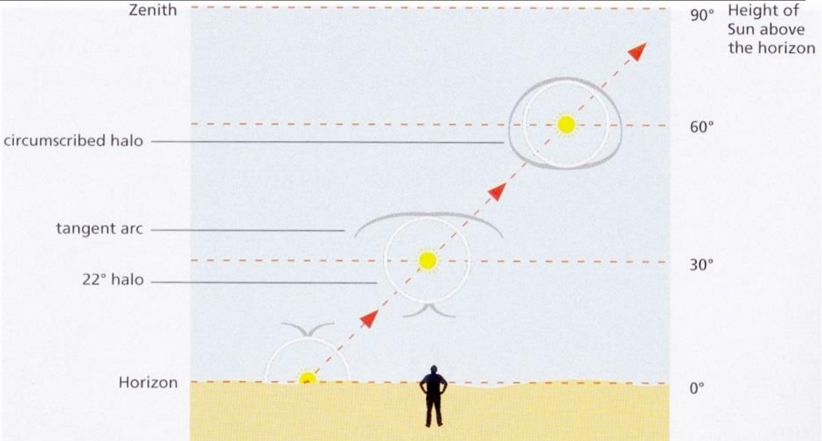
parhelia



Haloes

most common types:

circumscribed halo



shape may vary with Sun elevation

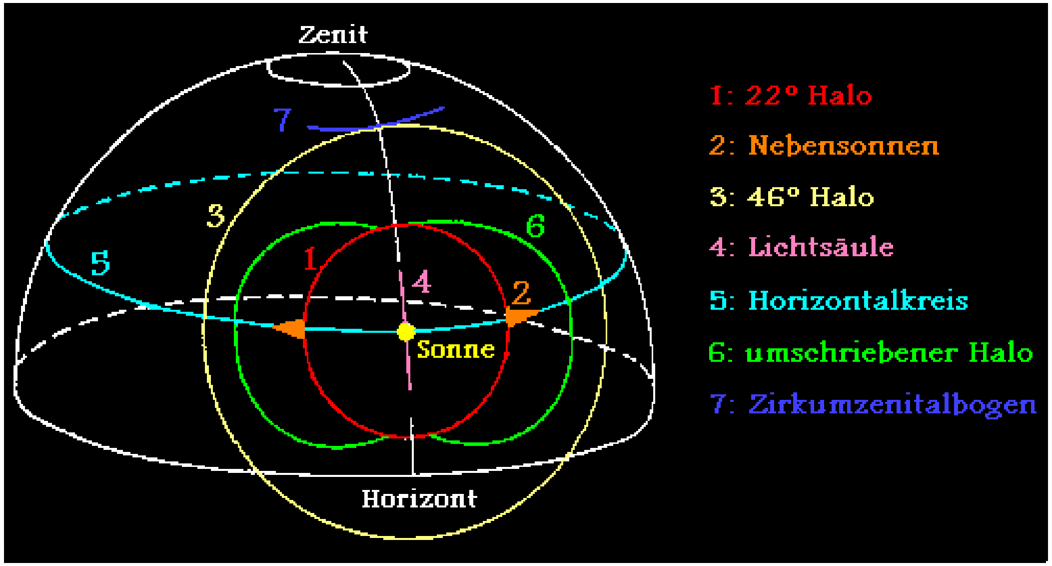
Haloes

most common types:

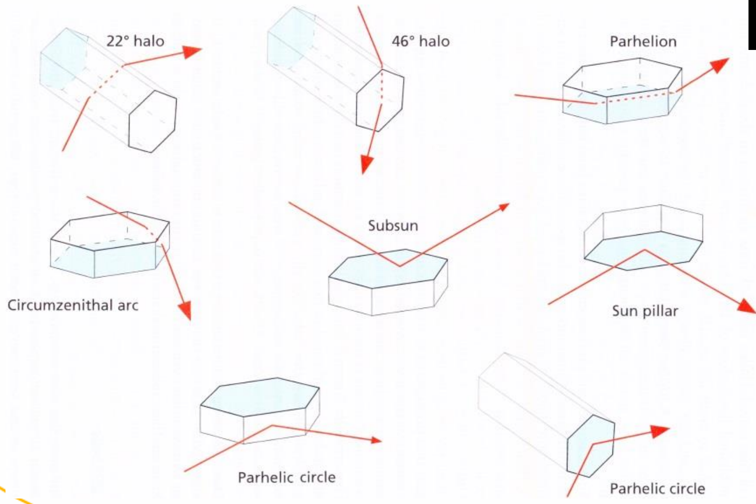
light paths in crystals

reflections (no colours)

refraction (colours)



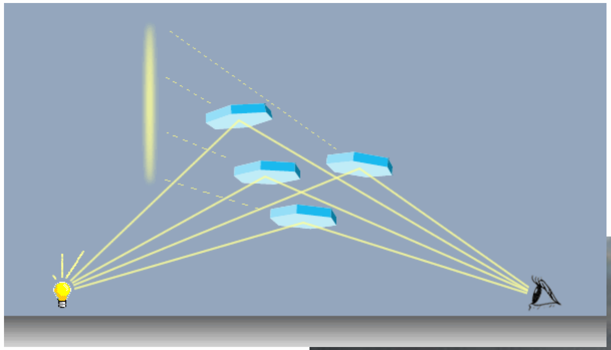
often shown scheme of haloes



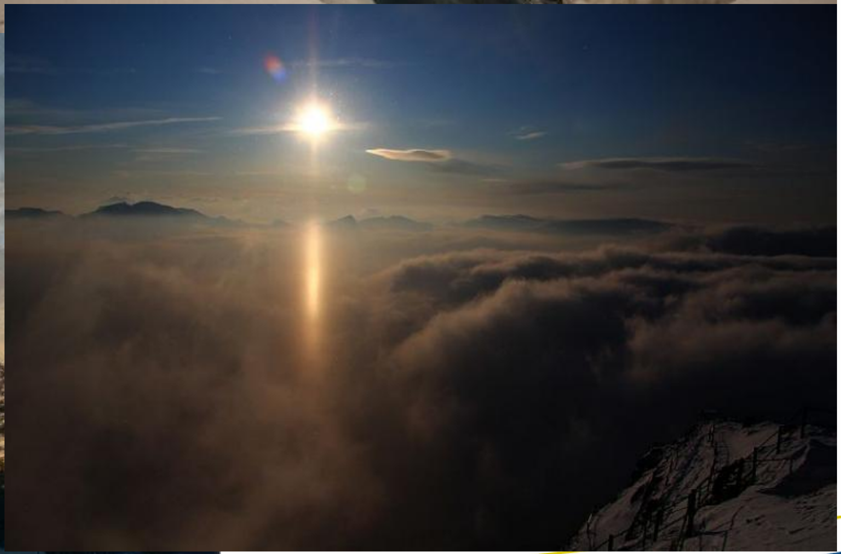
Haloes

some more examples

pillars (above or/and below)



lower pillar
often from
airplanes,
mountain tops



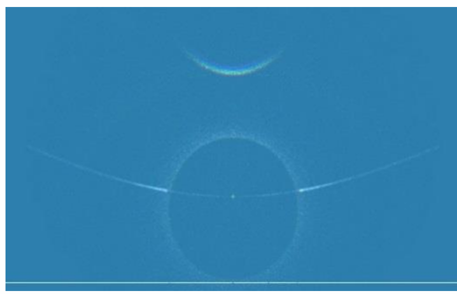
Haloes

surprising colours:

refraction

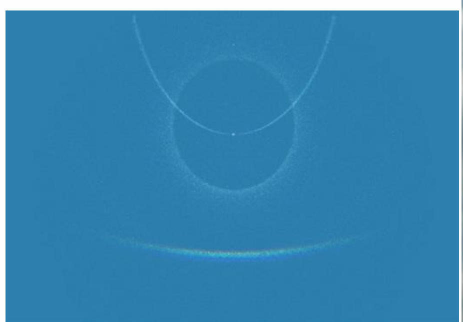
at top base

and one side



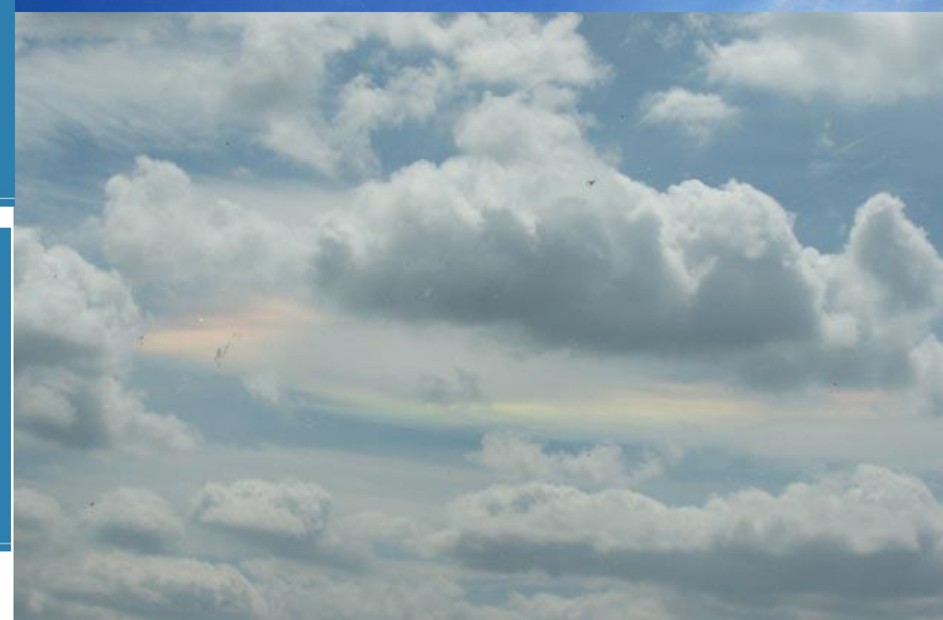
sun h<58°

circumzenithal arc



sun h>58°

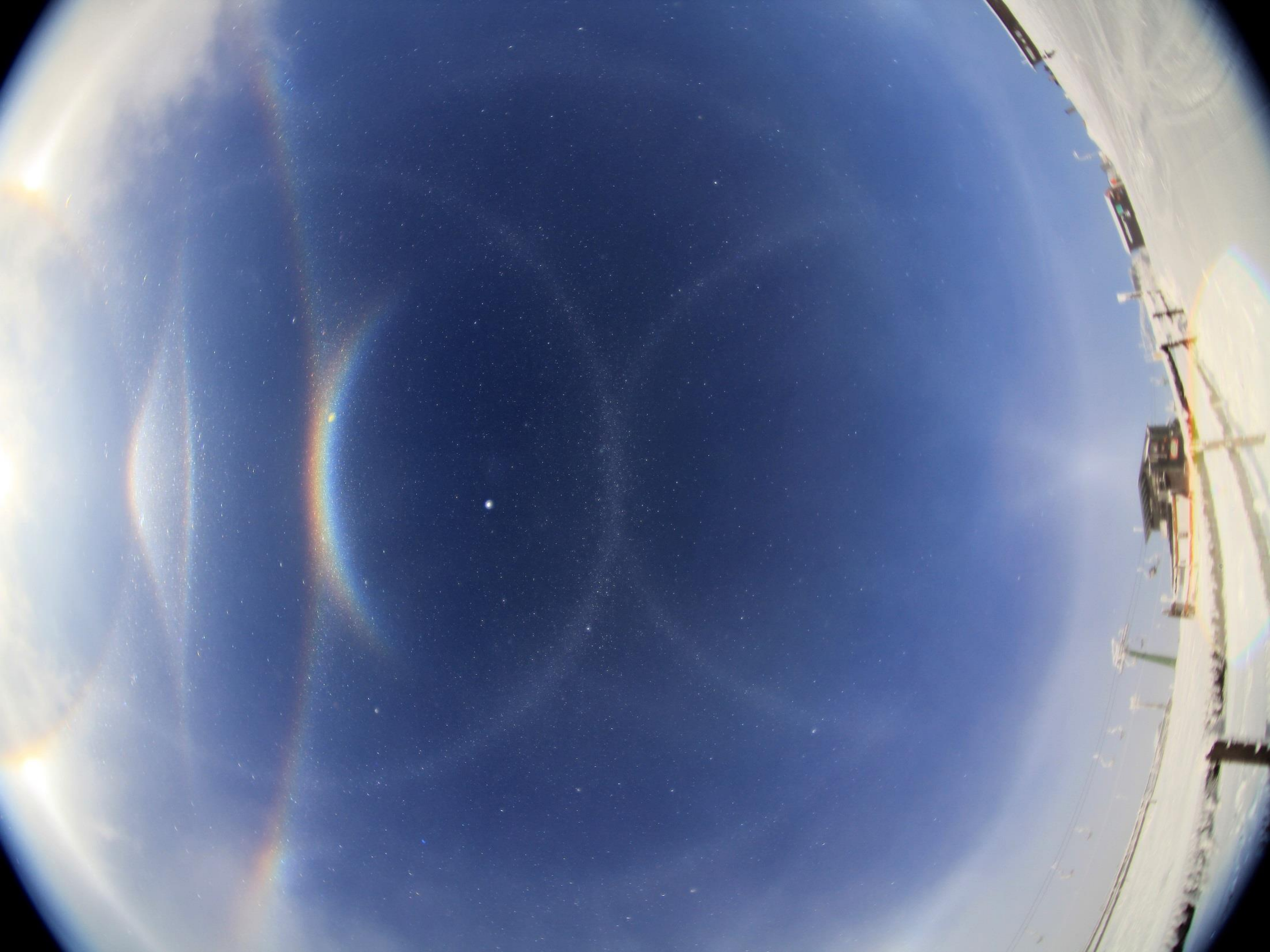
circumhorizon arc



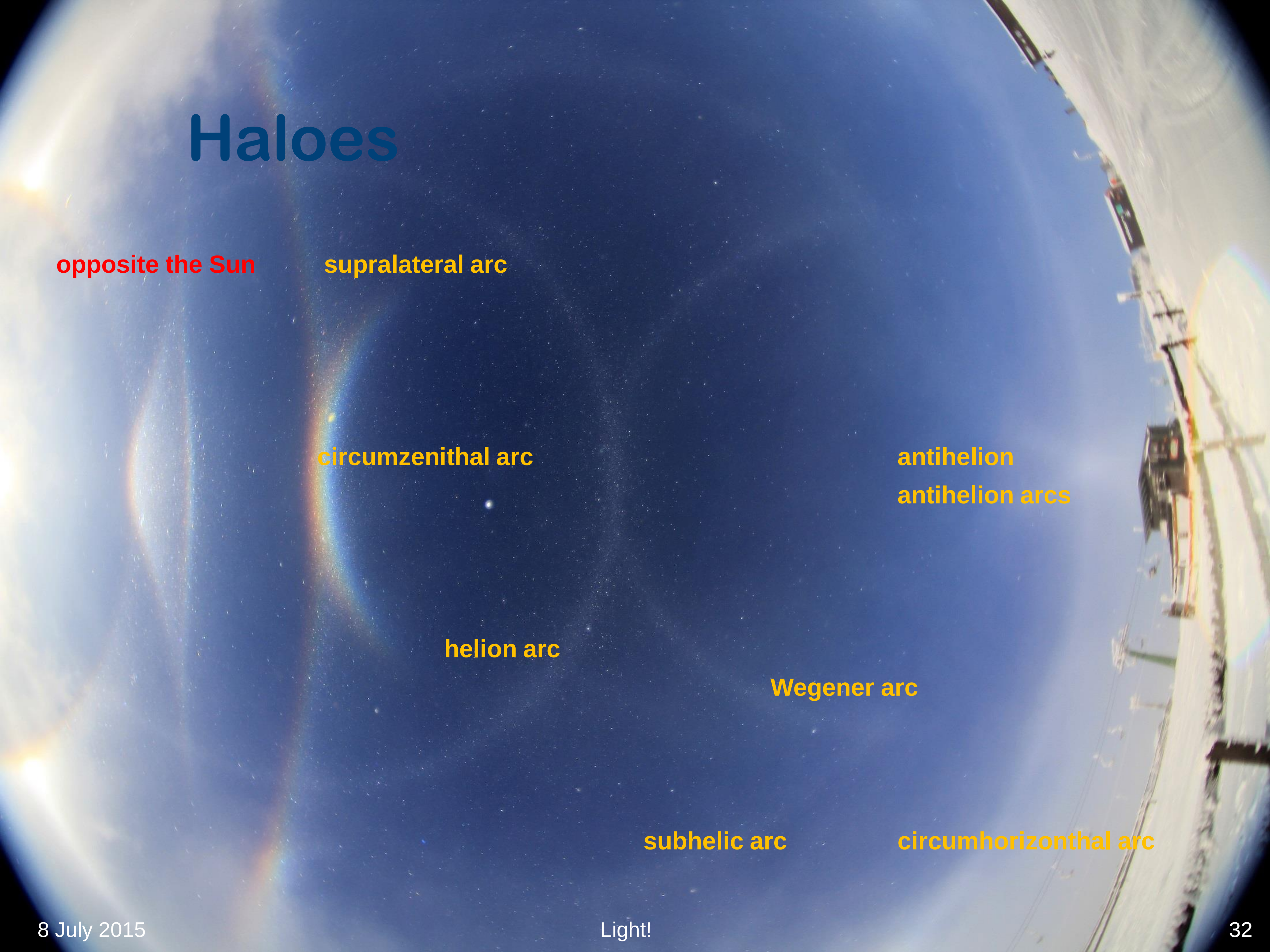
Haloes

complex haloes

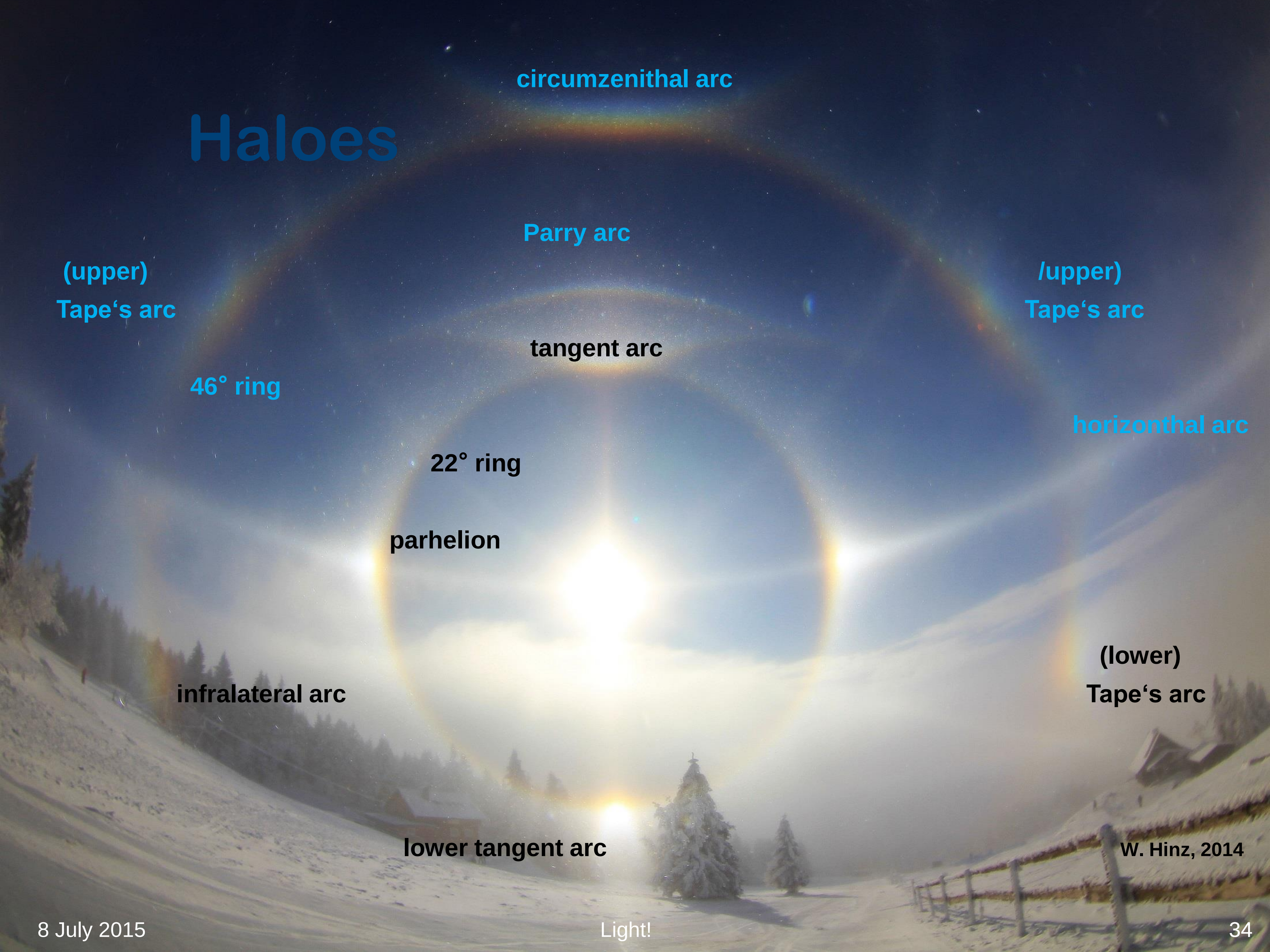
many halo types
various crystals
 (plates, columns,
 pyramids)



Haloes


opposite the Sun
supralateral arc
circumzenithal arc
antihelion
antihelion arcs
helion arc
Wegener arc
subhelic arc
circumhorizonthal arc

Haloes

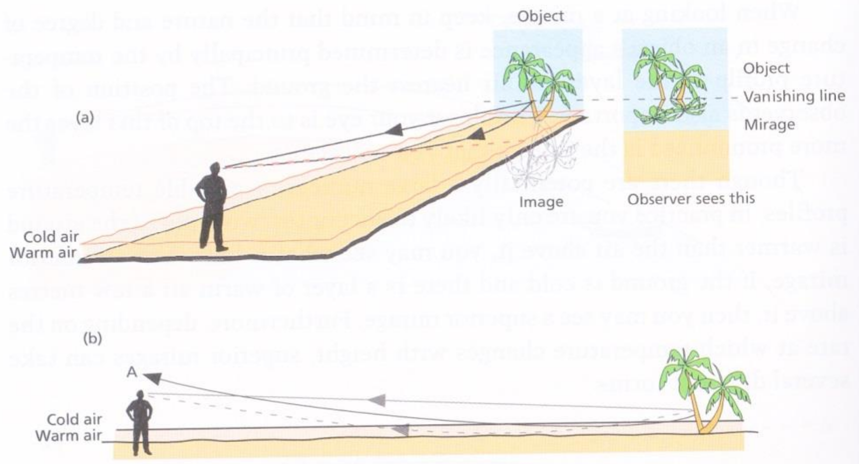

circumzenithal arc
Parry arc
(upper)
Tape‘s arc
/upper)
Tape‘s arc
tangent arc
46° ring
horizonthal arc
22° ring
parhelion
(lower)
Tape‘s arc
infralateral arc
lower tangent arc
W. Hinz, 2014

Curved light paths

refraction near surface

inferior image

warm ground layer

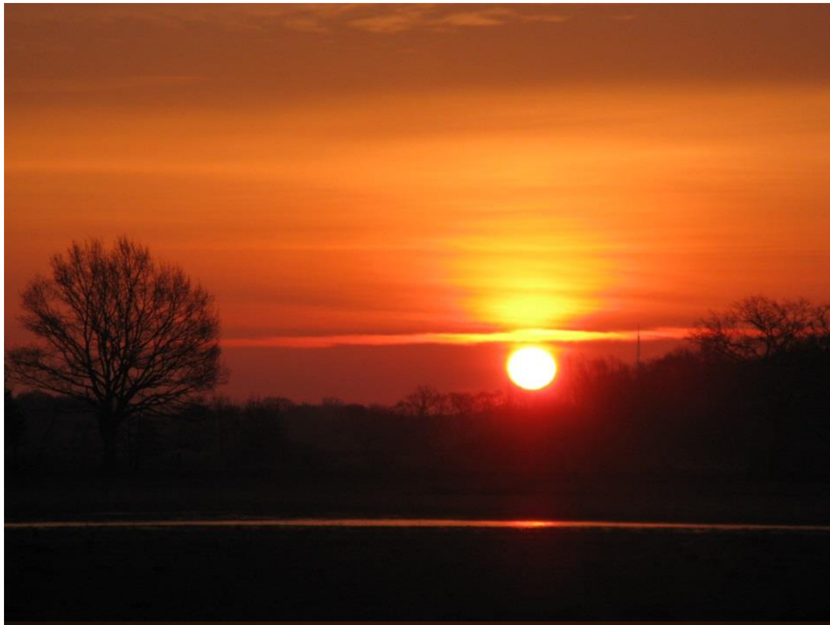


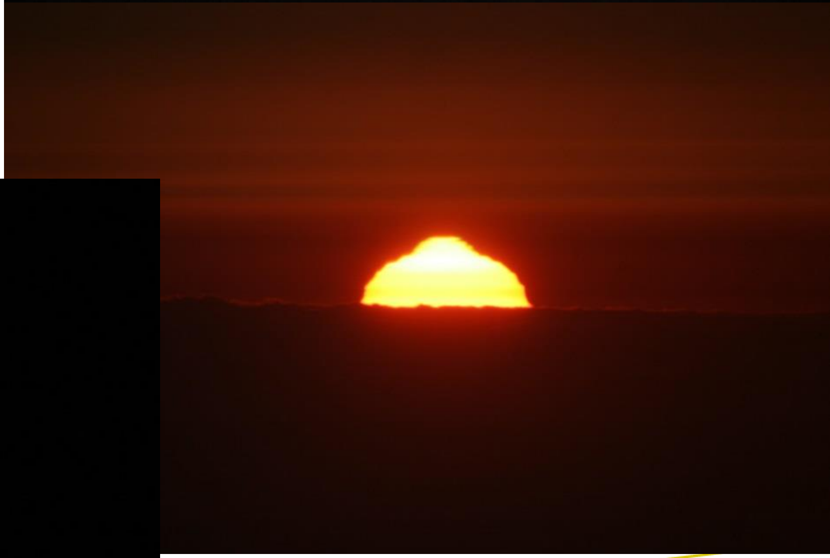
Near horizon

long light path through atmosphere

mainly red remains in the direct beam

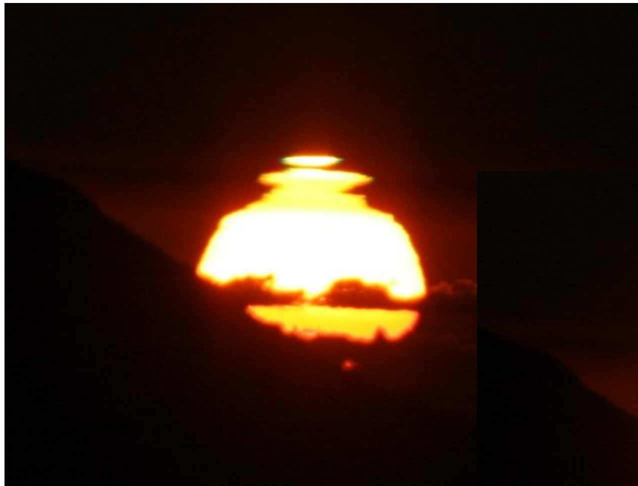
differences in refraction cause distortions

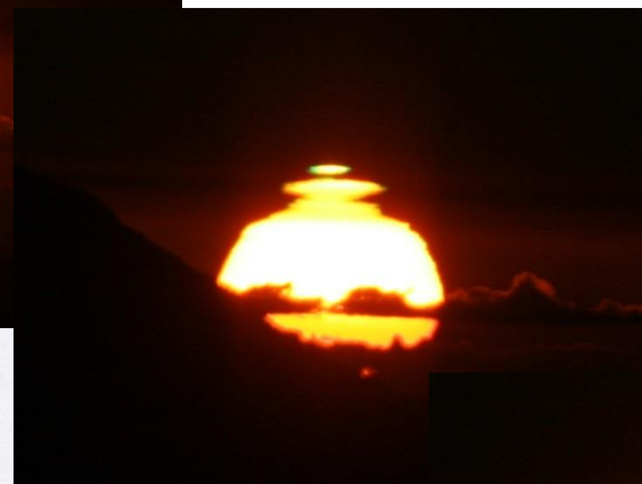


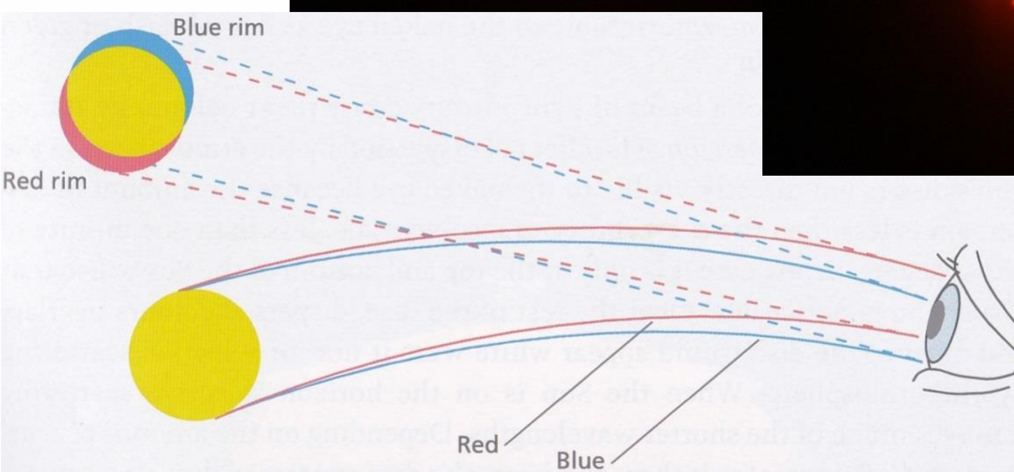


Green flash

differential refraction



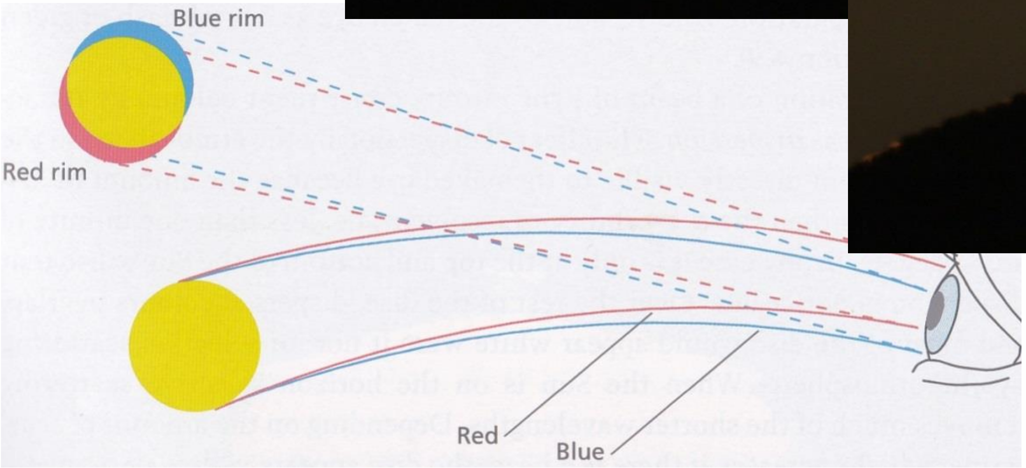




Green flash

differential refraction

blue at mountain rim

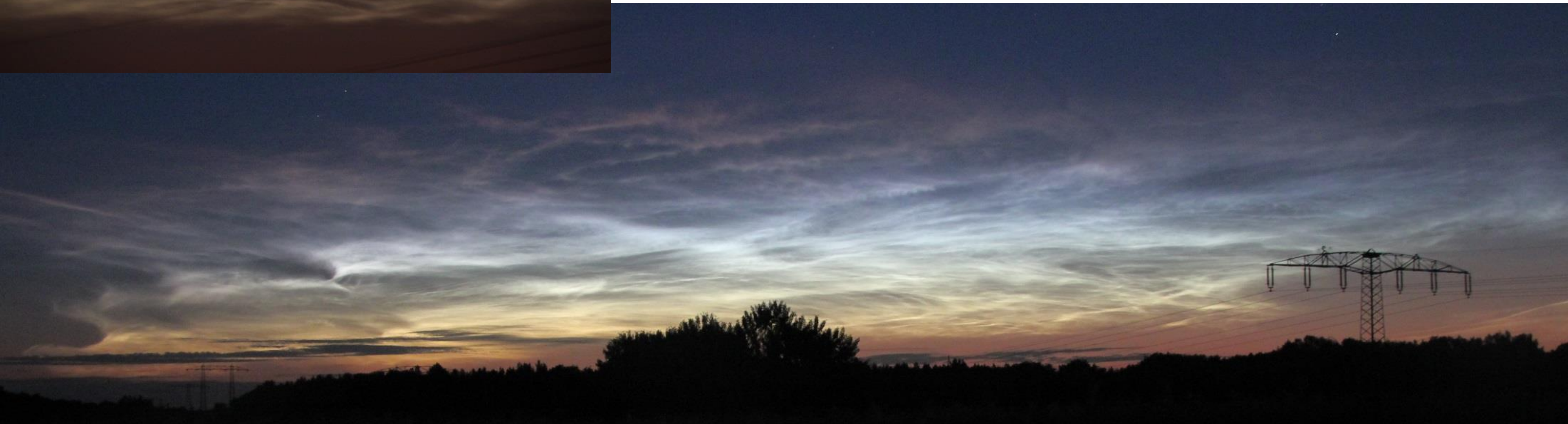


Night sky

Noctilucent clouds (NLC)

at mesopause level (83km)

sunlit while dark on ground



Night sky colours

aurorae: usually along the auroral oval
occasionally further south

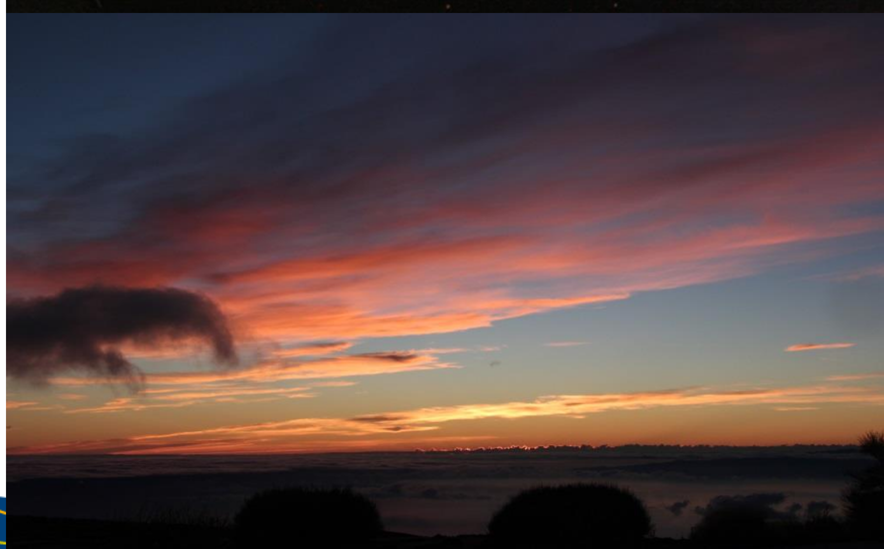
2013 Oct 31, C. Hinz (Wendelstein)

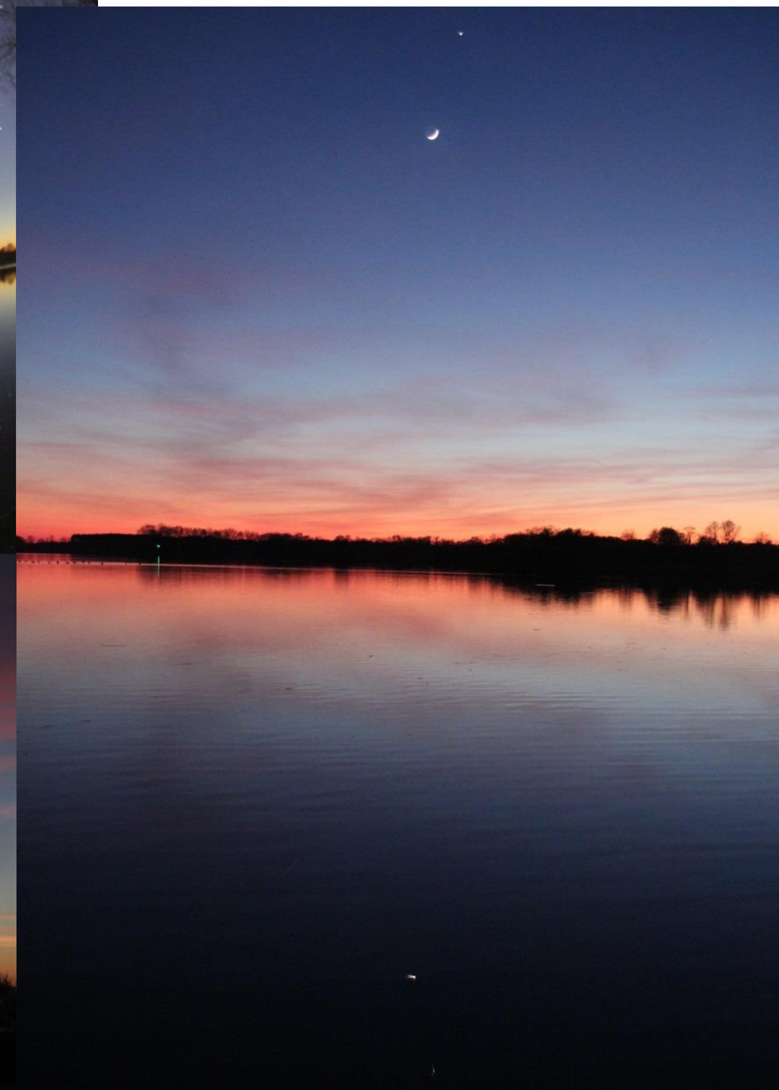
2015 Mar 17, U. Freitag (Lübeck)

Night sky colours

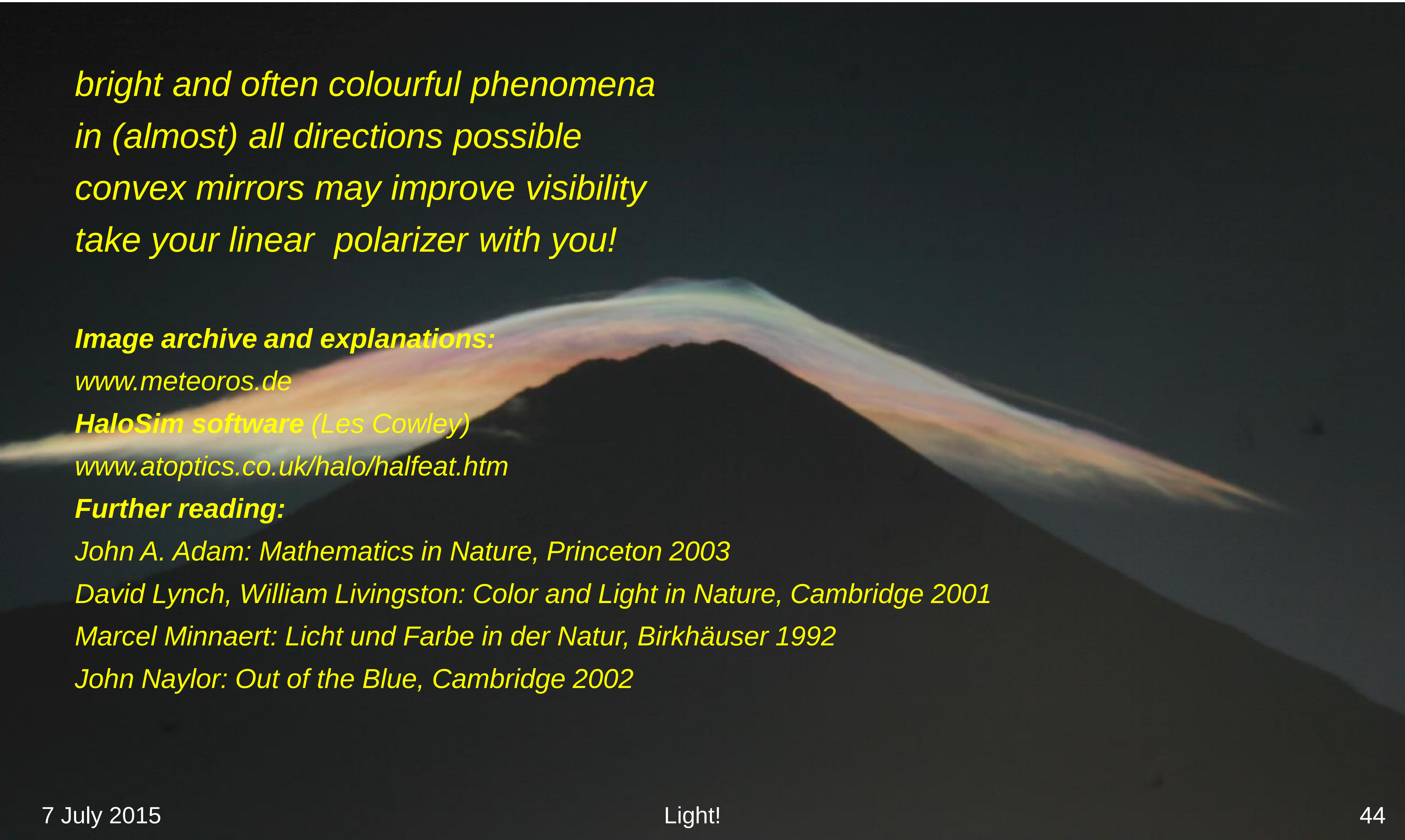
Night sky colours

Night sky colours





Summary



bright and often colourful phenomena

in (almost) all directions possible

convex mirrors may improve visibility

take your linear polarizer with you!

Image archive and explanations:

www.meteoros.de

HaloSim software *(Les Cowley)*

www.atoptics.co.uk/halo/halfeat.htm

Further reading:

John A. Adam: Mathematics in Nature, Princeton 2003

David Lynch, William Livingston: Color and Light in Nature, Cambridge 2001

Marcel Minnaert: Licht und Farbe in der Natur, Birkhäuser 1992

John Naylor: Out of the Blue, Cambridge 2002