EYECAP FILTERS
HOW DANGEROUS ARE THEY?

Throughout the C19th, and well into the latter half of the C20th, eyepiece eyecap filters, either Sun or Moon filters, were commonly sold for use with telescope eyepieces. The eyecap was made from the same grade of brass as the eyepiece, and screwed over the eye end. This is probably the least safe place to locate a Sun filter whose purpose is to attenuate the blindingly brilliant solar rays to a comfortable viewing brightness.

The purpose of this article is not to assess infra-red leakage and consequential solar retinopathy caused by antique or vintage eyecap Sun filters. There are numerous papers covering the subject.

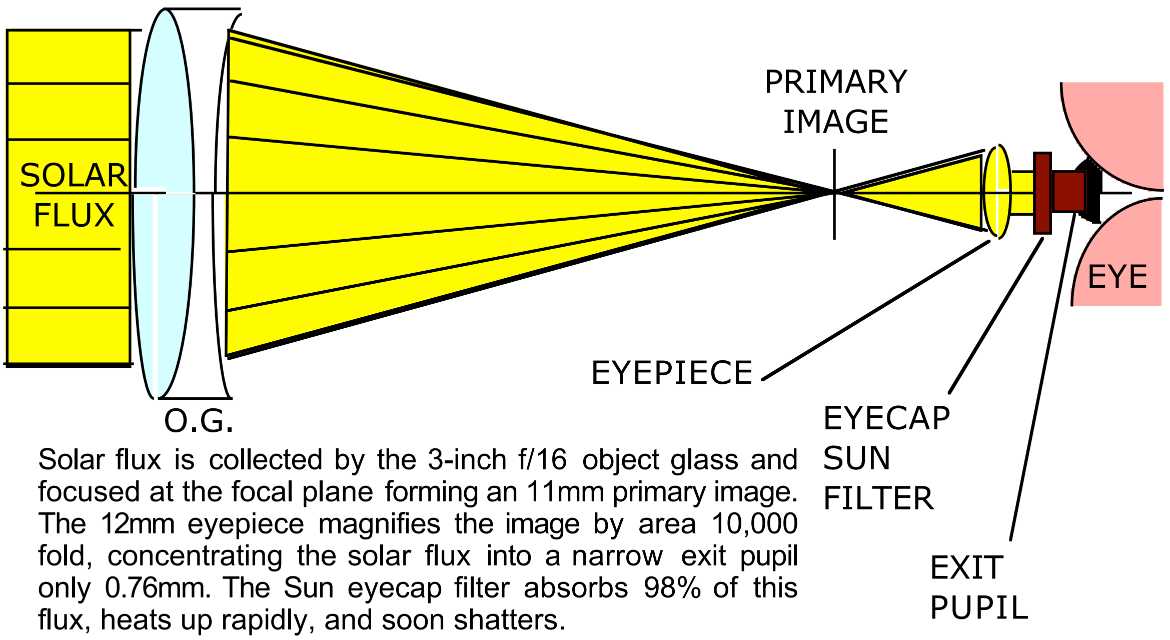
What I wanted to find out is just how dangerous eyecap Sun filters are. How much heat they are subjected to, how hot they get, and how long they last before shattering. As far as I am aware no one has conducted such an investigation.

The type of eyecap filter I have examined is that made from dyed in the mass crown glass, about 3/8-inch diameter by 1/24th inch thick, tightly spun into a brass cell.

Sun eyecap filter spun into brass cell.

Sun eyecap screwed onto a 12mm Huyghenian RAS eyepiece.

SOLAR FLUX SCHEMATIC



Solar flux is collected by the 3-inch f/16 object glass and focused at the focal plane forming an 11mm primary image. The 12mm eyepiece magnifies the image by area 10,000 fold, concentrating the solar flux into a narrow exit pupil only 0.76mm. The Sun eyecap filter absorbs 98% of this flux, heats up rapidly, and soon shatters.

The design leaves no room for expansion. Heating from the Sun's concentrated rays induces expansion and because there is no space for the filter glass to expand into, it becomes stressed, to the point where it shatters.

NATURE of the INVESTIGATION

I decided to perform a mathematical investigation to ascertain how long it would take for the filter glass to shatter, taking as a representative contemporary example; a 3-inch f/16 refractor, a x100 Huyghenian eyepiece, assuming it accepted the full height of the solar image, and a dyed in the mass filter with near IR transmittance of 2%, typical of Schott RG695.

THE CALCULATION

The calculation breaks down into the following:

Likely maximum solar flux at the observing site:
(Blackpool: lat. +54° @ sea level)

The air mass coefficient defines the direct optical path length through the Earth's atmosphere, expressed as a ratio relative to the path length vertically upwards, i.e. at the zenith. The air mass coefficient can be used to help characterise the solar spectrum after solar radiation has travelled through the atmosphere.

Modelling the atmosphere as a simple spherical shell provides a reasonable approximation:

$$AM = \sqrt{(r\cos z)^2 + 2r + 1} - r\cos z$$

where the radius of the Earth R_E = 6371 km, the effective height of the atmosphere y{atm} ≈ 9 km, and their ratio r = R_E / y{atm} ≈ 708. Solar Constant [9km] Io = 1353 W/m^2

Solar flux collected by the object glass.

Assuming clear sky equals the product of the area of the object glass to solar flux intensity.

$$I_{OG} = I_O \times \frac{\pi}{4} OG^2$$

Solar image size and flux at focal plane.

Neglecting optical system losses (negligible in refractor) equals product of objective flux and ratio OG/image area

$$I_i = I_{OG} \times \left(\frac{OG \times 110}{OG \times f/\#} \right)^2$$

Solar flux at the exit pupil.

Neglecting optical system losses (negligible in refractor) equals product of objective flux and square of magnification and exit pupil area

$$I_{ep} = I_{OG} \times M^2 \times \frac{\pi}{4} \left(\frac{OG}{M} \right)^2 = I_{OG} \times \frac{\pi}{4} (OG)^2$$

Heating of filter at exit pupil.

Rate of temperature rise above ambient equals ratio exit pupil flux/sensible heat of filter glass. Sensible heat is product of filter glass mass, temperature rise and the specific heat (κ=0.198)

$$\frac{Q}{t} = m \times \kappa \times \Delta T$$

Thermal conductivity of glass filter & brass cell.

Heat conduction through filter into brass cell.

Heat absorbed by the filter glass is conducted (albeit inefficiently) to the brass cell. The conductivity of brass is over 100 times that of crown glass. This has a substantive effect on how heat is conducted from the exit pupil area to the edge of the filter into the cell. I have neglected radiation through the filter glass because less than 2% of the exit pupil flux is transmitted.

Net rate of temperature rise above ambient equals rate less thermal conductive rate.

Expansion of filter due to heating including thermal conduction.

Heat absorbed by the filter glass less that conducted into the brass cell causes the filter glass to expand. The rate of increase in volume is the product of the net rate of temperature rise above ambient and the cubical (volumetric) expansion coefficient of the filter glass. The brass cell absorbs some of the heat and it too expands (slightly) exerting an inwards force on the filter glass. The combination of these forces induces a strain in the filter glass.

Force induced in filter due to expansion including thermal conduction.

The induced strain results in a load exerted inwards on the filter glass which in turn produces an outward force.

Time before mechanical failure including thermal conduction.

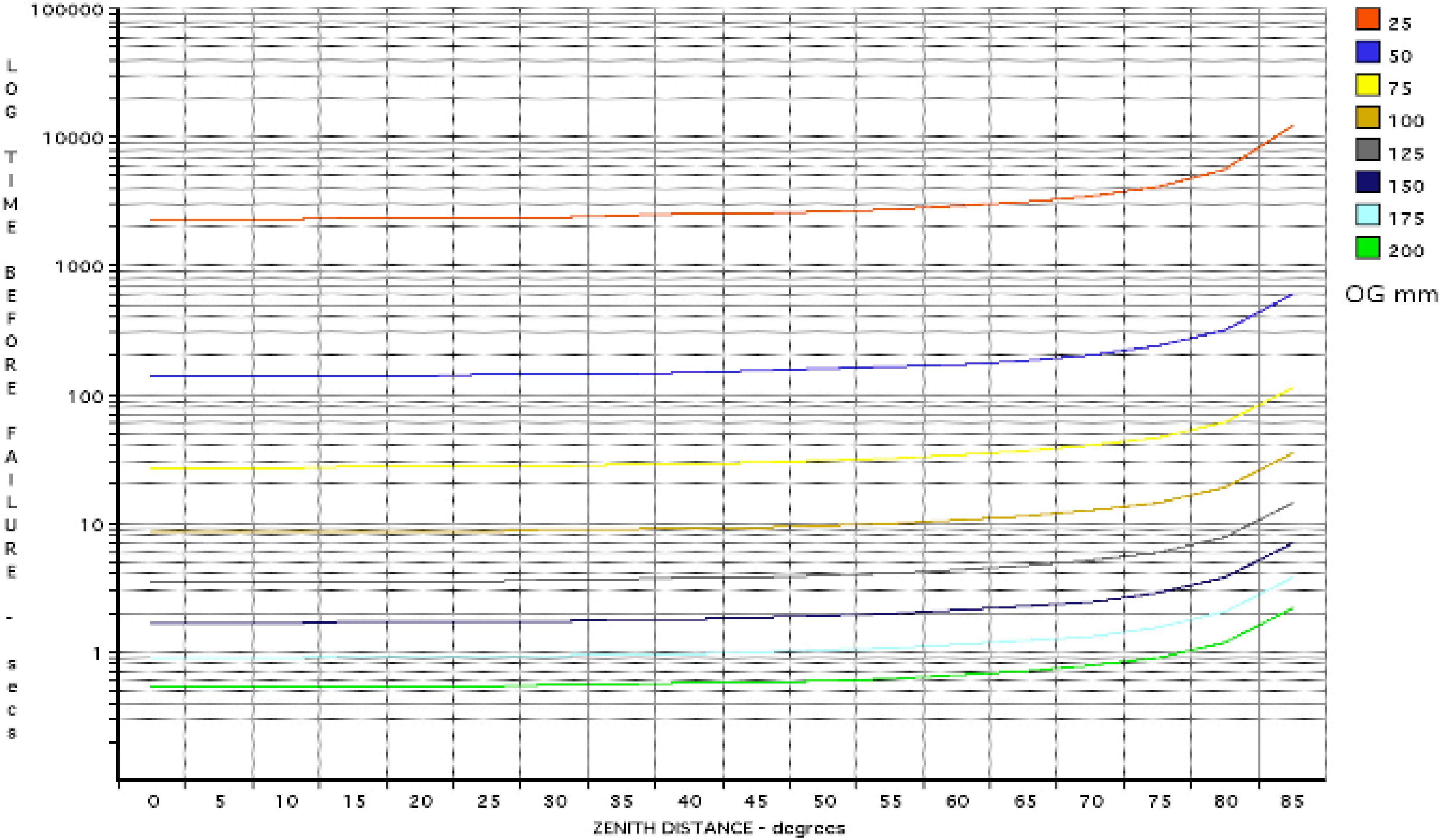
Because the filter glass continues getting hotter the outwards force increases until the ultimate compressive strength of the glass is exceeded, at which point the filter ruptures.

Temperature rise before mechanical failure including thermal conduction.

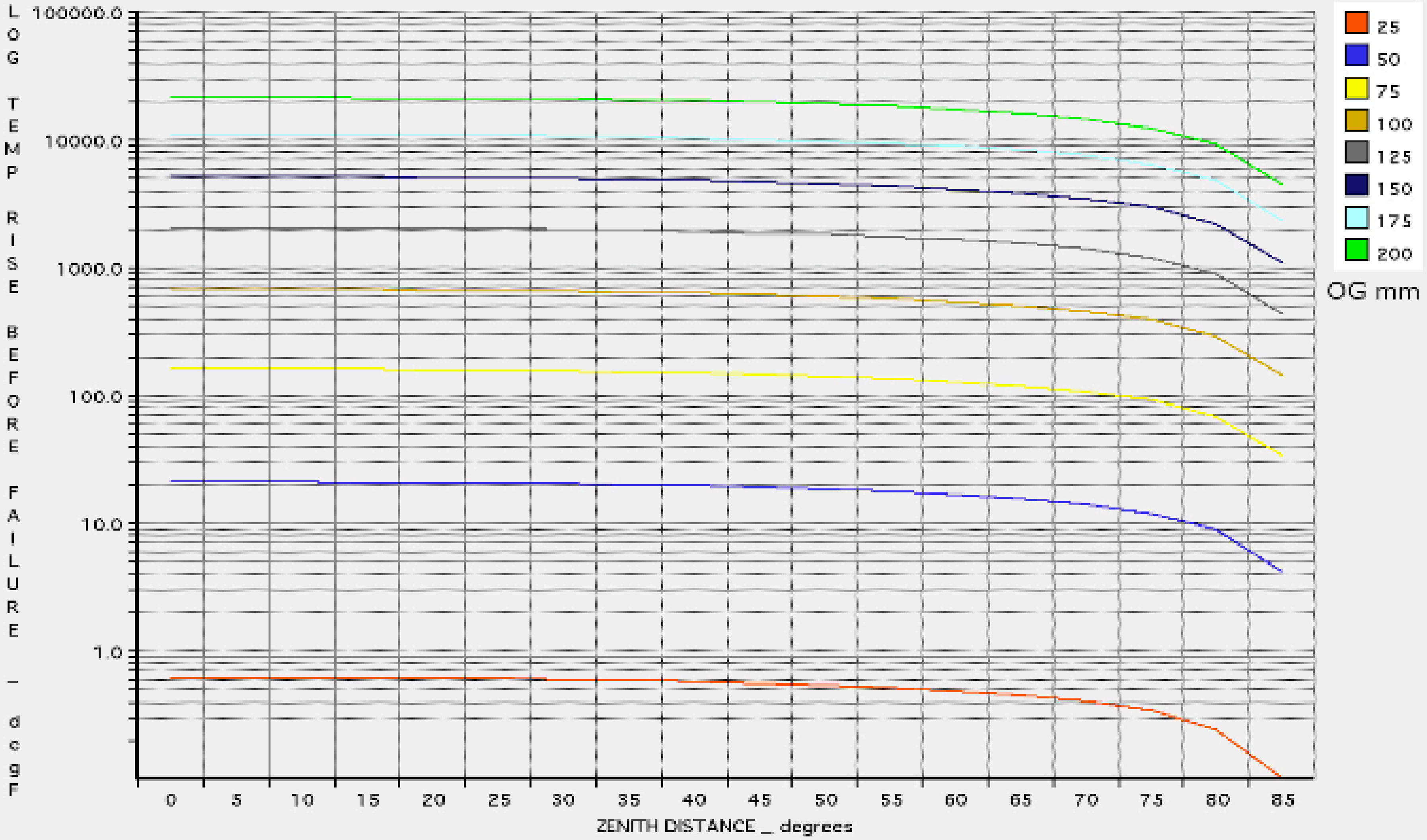
The total temperature rise above ambient is determined assuming the specific heat of the crown glass remains constant (κ=0.198). This is nearly so until the temperature increases above the phase transition (2192°F) at which glass melts and heat (latent) is used to produce the liquid phase change. I have calculated temperature rise before failure allowing for the effect of heat being concentrated in the exit pupil area (hot spot) and conducted to the rest of the filter glass (outer zone). Calculated temperaure rise greater than 2192°F indicated the glass melts at failure.

I have developed a spreadsheet model of the somewhat complex calculation, & plotted two graphs; time before failure against zenith distance & temperature rise above ambient before failure, against zenith distance:

SUN EYECAP FILTER - TIME BEFORE FAILURE



SUN EYECAP FILTER _ TEMP RISE BEFORE FAILURE



For the 3-inch refractor in question, the time before mechanical failure is only 27 secs after a temperature rise above ambient of 165ºF. Hence if the filter were at 70ºF ambient, at failure it would have risen to 235ºF.

Because the brass cell is spun tightly over the filter glass, the glass cannot actually expand sideways. In reality, with the heat concentrated on the centremost spot, the filter will bulge outwards producing radial fractures.

CONCLUSION

The calculation shows that from a north temperate latitude, at the summer solstice with the Sun on the meridian, in a clear sky, with the eyecap Sun filter screwed onto a 12mm Huyghenian eyepiece, on a 3-inch f/16 refractor (a telescope with which the filter was intended to be used), the filter glass rapidly heats up by 165ºF above ambient and cracks after only 27 seconds. The temperature increase is so rapid and so great that it actually causes the filter glass to rupture. The calculation in this respect is only approximate, as the fundamental mechanical properties of the glass change. In reality the filter would fail sooner. The filter cannot conduct heat into the brass cell rapidly enough to offset the rapid temperature rise because glass has very low thermal conductivity.

You really couldn’t arrive at a less safe arrangement, no sooner have you placed your eye at the eyepiece, accustomed yourself to the view, and focused the image, than the filter shatters.

How dangerous are eyecap Sun filters? About as dangerous as sticking a white hot needle in your eye. The question is, “Do you feel lucky?”

EPILOGUE

My findings reveal nothing new, only what *“everybody knows”*. Eyecap Sun filters are known to be hazardous. All my calculation shows is they can be more hazardous than one might imagine. It does however beg the question, *“If eyecap Sun filters shatter so readily on a small refracting telescope, how is it they were made for well over a century?”*

My initial calculation was based on a worst case scenario for England. If the Sun were at the zenith the time to failure would be sooner, but what if the Sun is low in the sky, say only 5º altitude? The solar flux, for a clear sky, is then 270 W/m^2. Repeat the calculation for a 2-inch f/12 refractor: Time before failure = 630 secs
Temp rise before failure: 4ºF (filter does not fail)

The heating effect on the filter is low enough for the glass to conduct the heat into the brass cell. Even after over 10 mins at such flux levels the filter wouldn’t fail. At the latitude of Blackpool, the time for observation from Sun altitude 5º to sunset is no more than quarter of an hour. The situation is not true at sunrise, and circumstances would soon become potentially hazardous. Within an hour solar flux will approximately double. However at sunset the atmosphere is likely to be hazy owing to aerosols and dust born aloft by thermals throughout the day. In these circumstances the eyecap Sun filter copes adequately, and as the Sun sets, the image becomes too dim to see. The issue then becomes one of potentially risky solar viewing having removed the filter!

At the time eyecap Sun filters were ubiquitous most astronomers would have used them with smaller refractors than generally used nowadays. Urban skies were also more heavily polluted. Apart from the then unknown effects of retinal scotoma caused by IR leakage, when used with a modest aperture late in the afternoon or early morning, the filter would not have failed. Unfortunately they do fail, rapidly, on a slightly larger refractor, and dangerously so. If you have such a filter amongst your accessories, please don’t be tempted to use it.