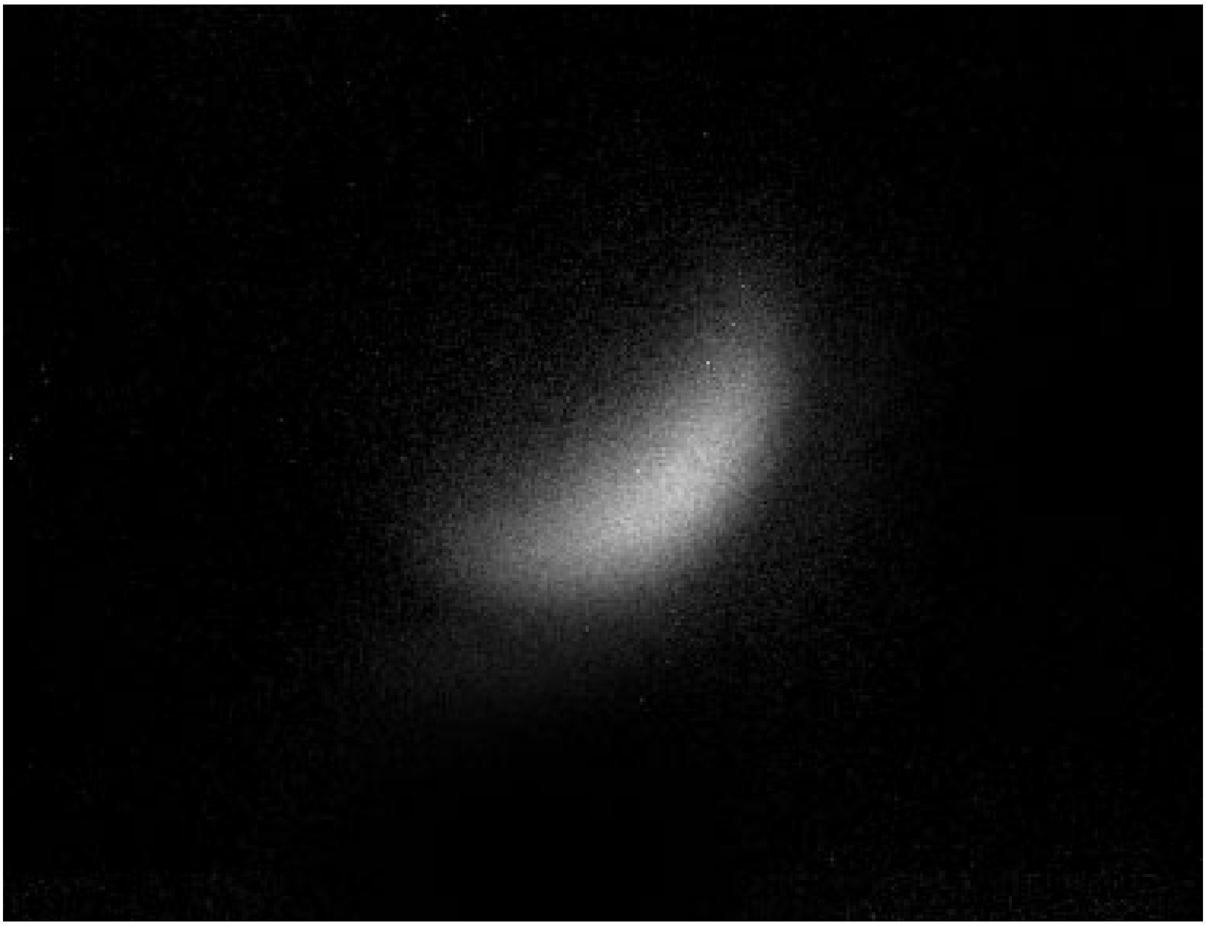
ATM Project ZPPT:
Venus in my 4 m Zoneplate Planetary Telescope

by Peter C. Slansky, Munich June 26th 2007

(translated into english [puh...] by the author)



I: General Idea

An astronomical telescope is a device for enlarging observation of sky objects. Therefore the light must be focused. All “normal telescopes” use two different optical principles (or a combination of both): refraction by lenses or reflection by mirrors.
But there is a third way to change the direction of a light wave: diffraction. This phenomenon takes allways place when waves move. It reduces the resolving power of our “normal” telescopes. “Diffraction limited” – that doesn’t sound nice. So refraction and reflection are astronomers friends, diffraction is the freak, who is allways at the party without invitation.

My general idea was to turn the tables, to make friends with diffraction.

Could I build a telescope without lenses or mirrors, only with diffractive elements?

Next thought: A pinhole camera uses diffraction as well. With pinhole cameras I had experimented already for a long time. Because the hole has to be so small for a shrp image a pinhole camera can be used only with long exposure times in a bright scenery. Normlaly we do not have bright sceneries in astronomy so often. Sun is an exception. So I built a pinhole telescope of 2.3 m length to photograph the Venus transit on June 8th 2004 (ATM project LHG[1]). For the sun eclipse on March 23rd 2006, I built a special panoramic pinhole camera from a cockies box[2] that I took with me to turkey.

In early 2007 I rembered an exotic optical device I had heard about during my studies of photoengineering: the “zoneplate”. Zoneplates are diffractive optical elements, which are used in holography or X-ray optics. In the meantime even some “normal” photo “lenses” use diffractive elements for the correction of chromatic aberations.

The simplest zoneplate can be formed by an arrangement of alternately transparent and opaque concentrical rings which diffract the light waves. If the diameter is proportional to the square root of the order of the zone, the incoming plane wave is focussed to a focal point, similar to the effect of a lens. But there the similarity ends: A zoneplate behaves like a convex *and* a concave lens at the same time!

With every additional zone, with every additional order, the image size and the image sharpness increases. But let’s question, which sky objects could be onbserved and recorded by an ATM zoneplate telescope.

Concerning surface brightness the brightest sky object after the sun is Venus. There should be good observing conditions for Venus from spring to early summer 2007. These considerations took me to the main idea of my ATM project “ZPPT”:

Can I observe and photograph the crescent of Venus with a self made <u>Z</u>one<u>P</u>late <u>P</u>lanetary <u>T</u>elescope?

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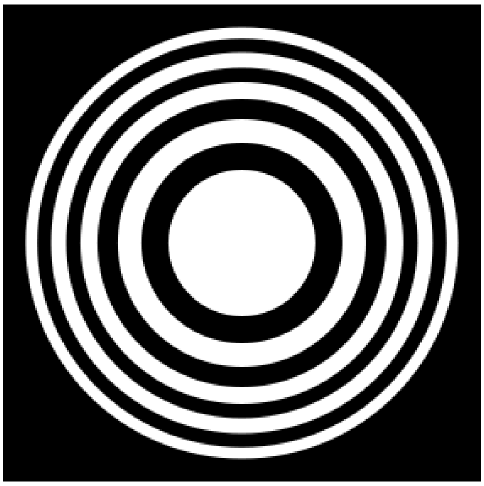
[1] www.lrz-muenchen.de/~slansky/bereiche/astronomie/planeten/venus/bericht_lochblenden-heliograph01.html

[2] www.lrz-muenchen.de/~slansky/bereiche/astronomie/sonne/sonnenfinsternis/sofi_06/panorama_lochblendenkamera_01.html

II: Optical Basics

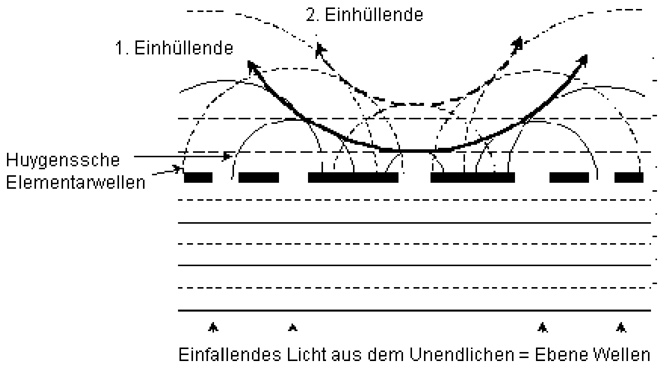


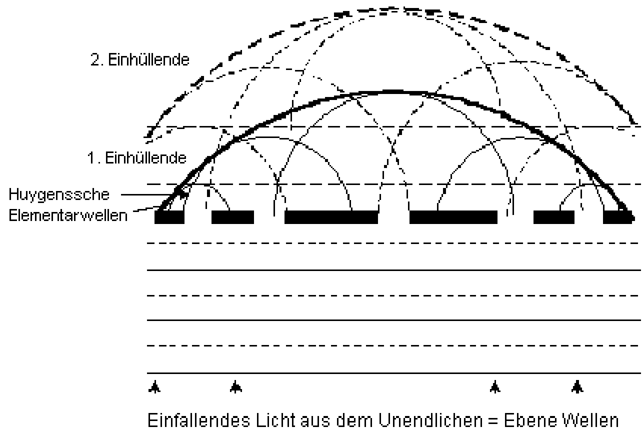
This is a simple zoneplate with 9 orders. The simplest zoneplate is the pinhole camera: the pinhole is the first order. Every additional ring around the center hole forms an additional order. On every ring aperture the light waves are diffracted: at the transitions from transparent to opaque as well as at the transitions from opaque to transparent. For light waves incoming from infinity the diameters of the rings are calculated by:

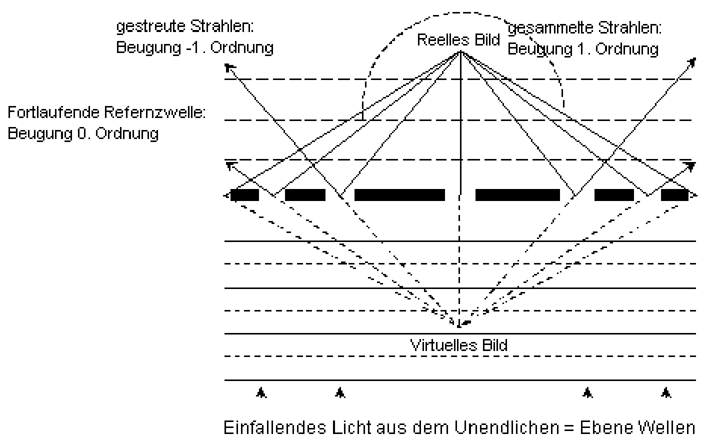
$$d_n = 2\sqrt{n\lambda f}$$

In this formula n is the order, λ the wavelenght of light and f the focal lenght. This formula also shows that order means order: transitions from transparent to opaque as well as at the transitions from opaque to transparent. In other words: the inverted image of the original zoneplate has exactly the same optical effect!

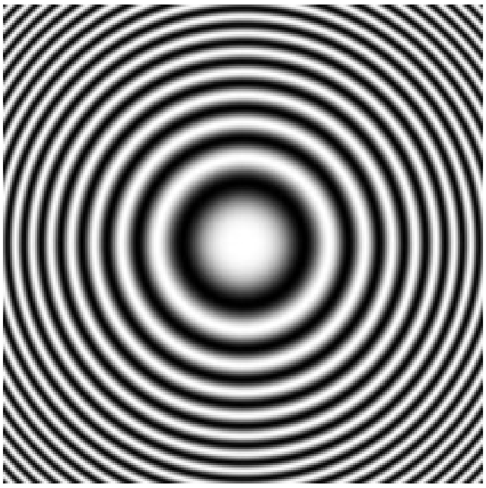
On first sight this is as ridiculous as the fact, that a zoneplate has a certain focal length, positive *and* negative at the same time! So, a zoneplate works like a concav *and* a convex lens at the same time!







There's a way to improve the optical quality of a zoneplate: the use of soft transitions in transparency between the rings instead of purely opaque or purely transparent rings. This shall be done by a cosinus modulation:



Such a cosinus zoneplate (sometimes called "holographic lens") has only one focal length, compared to the simple zoneplate from the pages before. The cosinus zoneplate has a better resolving power and a better light efficiency. Obviously for a telescope a cosinus zoneplate is first choice.

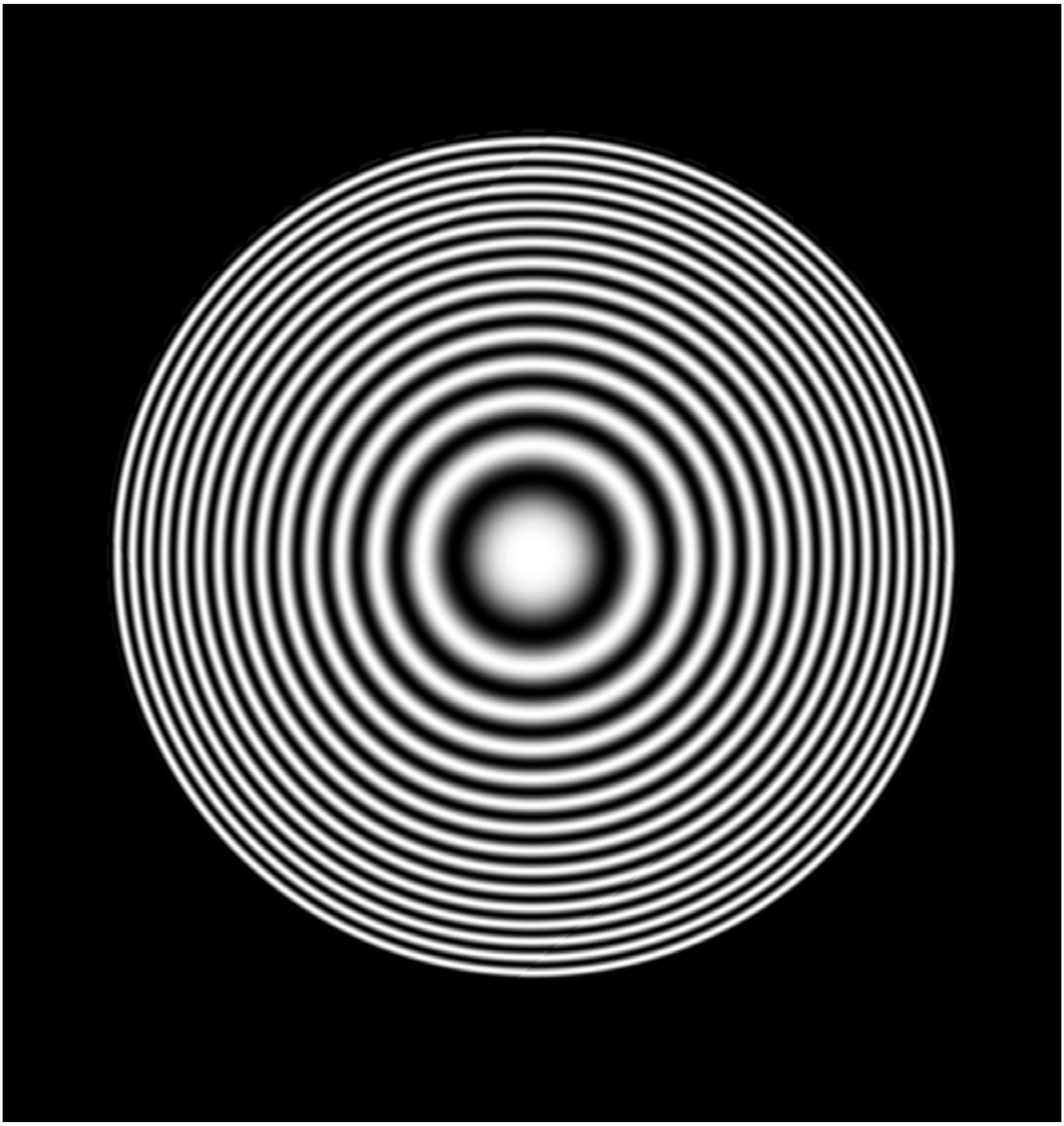
III: Optical Design

Remember? My main challenge was to resolve the crescent shape of Venus. In the time of the narrow crescent Venus has a diameter of 45 to 60 arcseconds. But which resolving criterium should be used? Dawes? Rayleigh? Modulation Transfer Function? First approach was that Venus' crescent can be resolved, if the resolving power is about three times better than the vritual diameter. This means, the resolving power of my ZPPT should be better than 15".

Unfortunately I did not find any formula for the resolving power of a cosinus zoneplate in literature. So I relied on my practical experiences with my ATM project LHG where I managed to resolve the Venus transit before the sun with a pinhole telesope. The virtual diameter of Venus during the transit had been 60". 2.3 m focal length had been enough for a proper resolution. And with a zoneplate resolution increases with the number of orders.

I decided to use my monochrome CCD-Kamera ATIK 1 HS II at the ZPPT with a green filter, mounted in a flip mirror for finding and for visual observation.

The making of a cosinus zoneplate with defined diameters of the orders is a little bit tricky. In the internet I found a png file. After some image processing I had the pattern for a cosinus zoneplate with 29 orders:



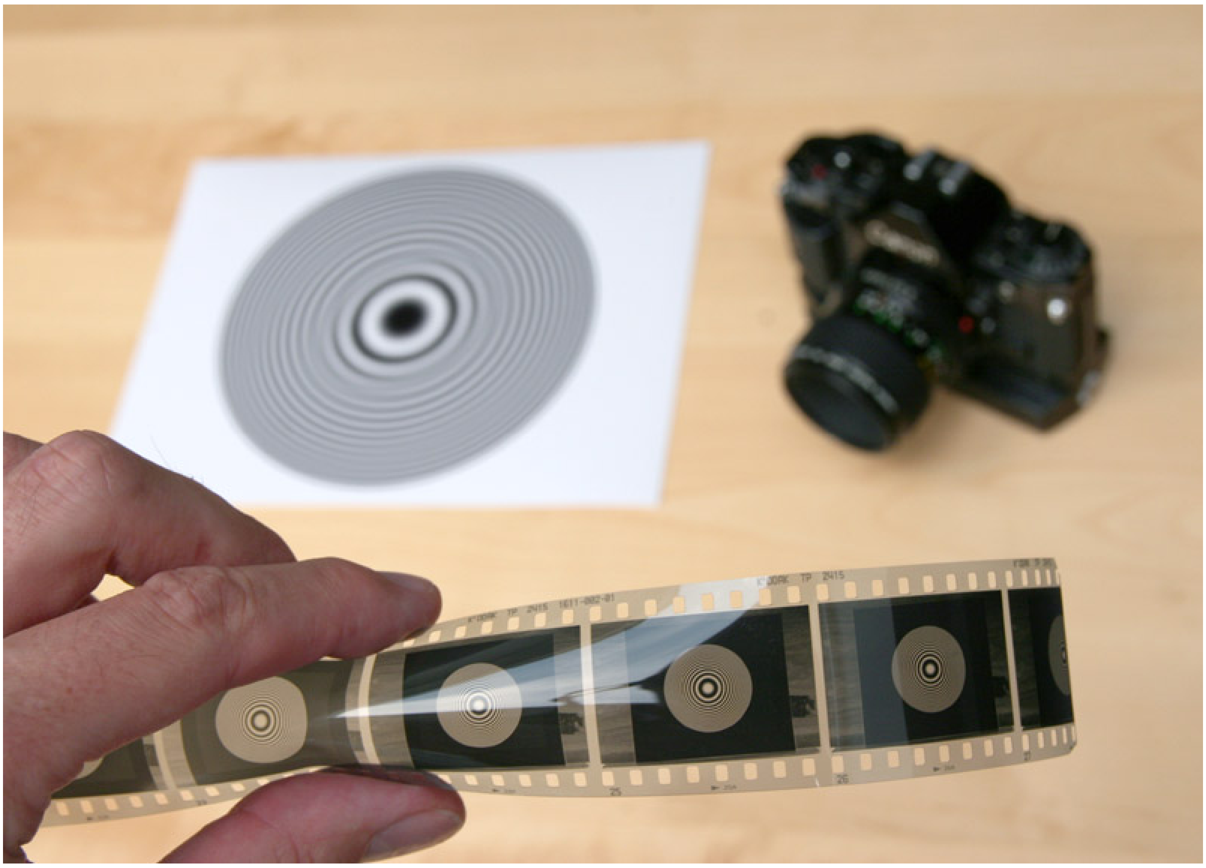
Download: www.lrz-muenchen.de/~slansky/bereiche/astronomie/aufnahmetechniken/bilder/zonenplatte_31.jpg

Instead of 2.3 m focal length of my LHG I choose 4 m focal length for the ZPPT, because I could get a 4 m tube from hard paper. The wavelenght I assumed with 540 nm (green). Then I calculated with 29 orders:

$$r_n = \sqrt{n\lambda f}$$

As the result the outmost ring, the 29th order, had to have a diameter of 15,8 mm.

IV: The Making of the Zoneplate



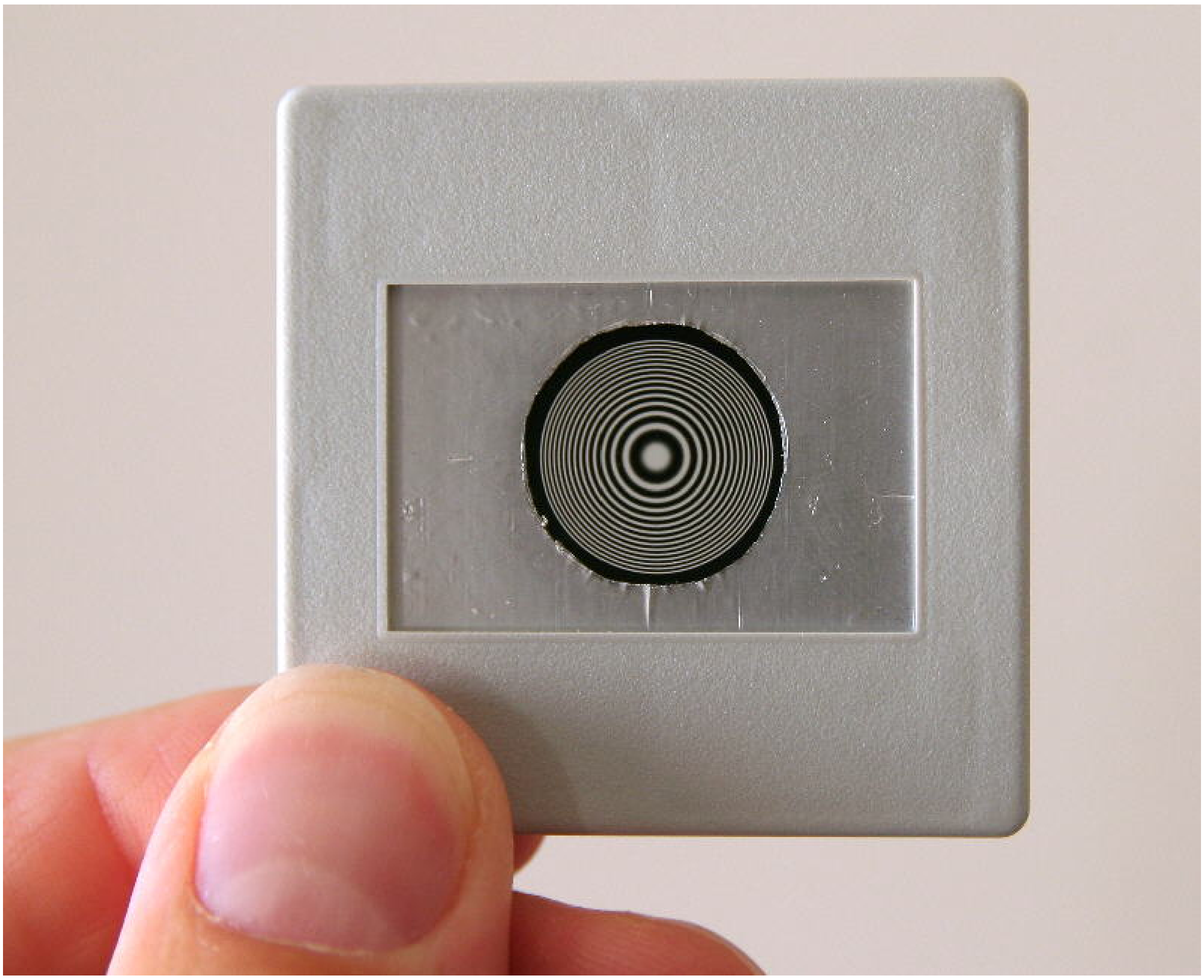
The making of a zoneplate is done best by classical photographical reproduction. First one has to make a negative print of the later zoneplate 10 to 20 times bigger than calculated. This negative print is scaled down to the exact size by photographical reproduction on high resolving black and white negative film. First choice is good old Technical Pan (if You still have some remains).

Object distance can be calculated by the formula:

$$B/G = f/a$$

B means image size, that is the diameter of the 29th ring on the film, G is the object size, that is the diameter of the 29th ring on the negative print, f is the focal length of the photograpic lens (in my case 50 mm) and a is the object distance. With my negative print I came to 607 mm object distance.

For a proper reproduction of the transitions between the black and white - later: transparent and opaque - zones the Technical Pan film has to be developed to a gamma of 1. After some tryout I developed 5 minutes in Neofin-Doku 1+20 with a 3-second shaking rythm plus additional 3 minutes in Dokumol 1+15 with a 30-second shaking rythm.



The result is my cosinus zoneplate mounted in a glasless 135 slide frame. The inner part has an additional aperture of aluminum foil. The slide frame is later to be set into a corresponding front hood of the telescope tube.

V: The Making of the Tube

One of our technicians gave me a 4 m long hard paper tube, a left over from the background of a studio film set.

The bulky tube made a strong suggestion for the observation place: I decided to build the telescope completely in the facilities of the university where I am teaching as a professor, the University of Television and Film Munich[3], and to make the observations from the university garden.

First the 5 mm strong hard paper tube was blackened inside with dispersion paint. From the outside it was painted with transparent acryl paint to make it water resistant and to improve stability. But with 4 m length the tube tended to bend too much, so I supported it with a 2 m long L-shaped wooden frame.

[3] Maybe You have heard about – or You have seen – the film "The Lives of Others", the diploma film of our alumni Fliorian Henckel von Donnersmark, who won an Academy Award for it 2007.

ATM Project ZPPT: Venus with a 4m Zoneplate Planetary Telescope

On the left image below You can see the hard paper tube with the wooden support, both connected with nylon cable clamps. The front hood for the zoneplate is missing yet. On the right You see the back end with the attatched flip mirror with an 40 mm ploessl and the ATIK 1 HS II.

Technical Data ZPPT:

Optical system	Cosinus zoneplate with 29 orders
Aperture	15,8 mm
Focal length (= tube length)	4 m
Outer tube diameter	117 mm
Tube material	5 mm hard paper, wooden support
Weight OTA	approx. 6.0 kg
Building time	April 2007 to June 2007
Overall costs	35.- €

VI: First Light and Second Light

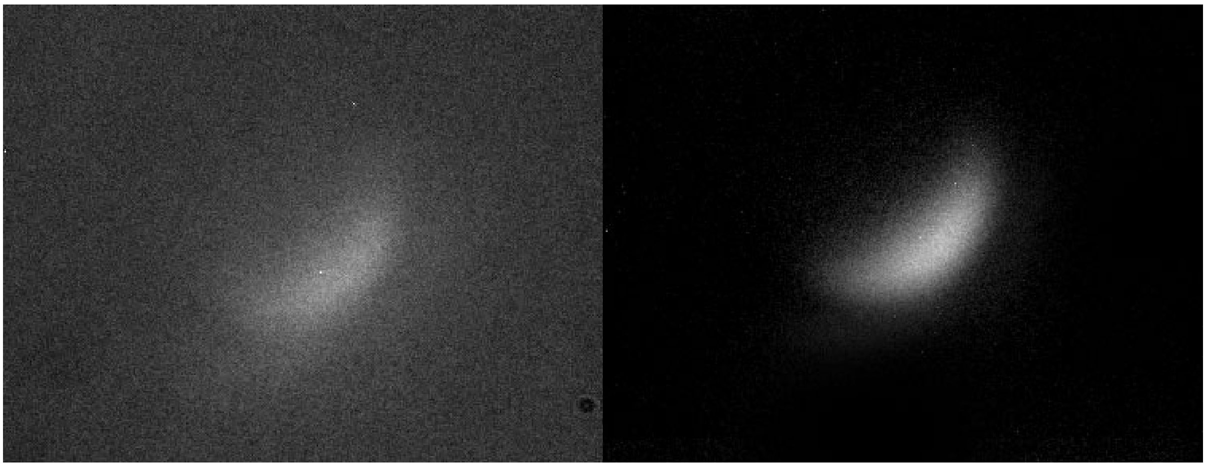
After weeks of clouds skies over southern Germany had become clear on Sunday evening July 15th 2007. But it was allready late. At that time Venus was only 12° above horizon by sunset. I built up my ZPPT on my Lichtenknecker M 100 B mounting in the university garden.

Photo: Ulrich Oberlaender

Shortly before sunset I had an exciting view. A small green banana had appeared in my 40 mm ploessl: VENUS! At that time Venus had a virtual diameter of 40", phase 0.238. In the garden a student film time celebrated the end of their film shooting. So I asked the producer of our feature film department, Mr. Hans-Joachim Koeglmeier, to my telescope. He confirmed my observation. Then I flipped to the CCD camera. But fate was against an all too easy breakthrough in amateur astronomy and optics: before I managed to center Venus onto the tiny chip of the ATIK, the planet had vanished behind the trees opposite of the street. Bad luck!

Now time ran out: Venus sank deeper and deeper every evening and the weather announced a change to cloudy again. So I had to try it again next day. On July 16th 2007 I set uo the ZPPT again. After nearly 20 minutes searching – it's not so easy to find Venus with a 4 m tube at 100x – the little green banana appeared again, a nearly familiar look by then. This time our technician, Mr. Ulrich Oberlaender, was my witness.

From 21:11 to 21:30 MESZ I could record a video sequence at 8 seconds exposure time for a single frame. After summing up the 14 sharpest frames I only did contrast correction and moderat sharpening.



raw image processed image from 14 raw images

Venus could be seen clearly in the ocular and could also be seen on the raw CCD images; the ZPPT experiment was a full success!

I don't know if any amateur on the world had observed Venus with a zoneplate telescope before. If so, please send me a note: slansky (a t) hff-muc.de.

After the Venus experiment I ask myself what could be next with the zoneplate telescope. One could try sunspots if there were bigger ones. One could try to improve resolving power significantly by a zoneplate with much more orders. I already have a pattern - but time, time, time...

To be continued (maybe...)

Peter C. Slansky, Munich June 26th 2007

For further information (in german language, yet...) please refer to my website: www.peter-slansky.de

www.lrz-muenchen.de/~slansky/bereiche/astronomie/aufnahmetechniken/aufnahmetechniken09a.html

Epilog

At the 28th Planet and Comet Observation Conference from May 29th to June 2nd 2008 in Violau, Germany, I presented the ZPPT project and gave a demonstration. For this I had to get the 4 m tube (together with the mounting and all the accessories of course) into my Porsche. But my beloved 22 years old 944 did – once again - not dissapoint me...

Photo: Georg Dittié