Project Hyaline

Tim Large, Neil Emerton, Daming Xu, John Lutian

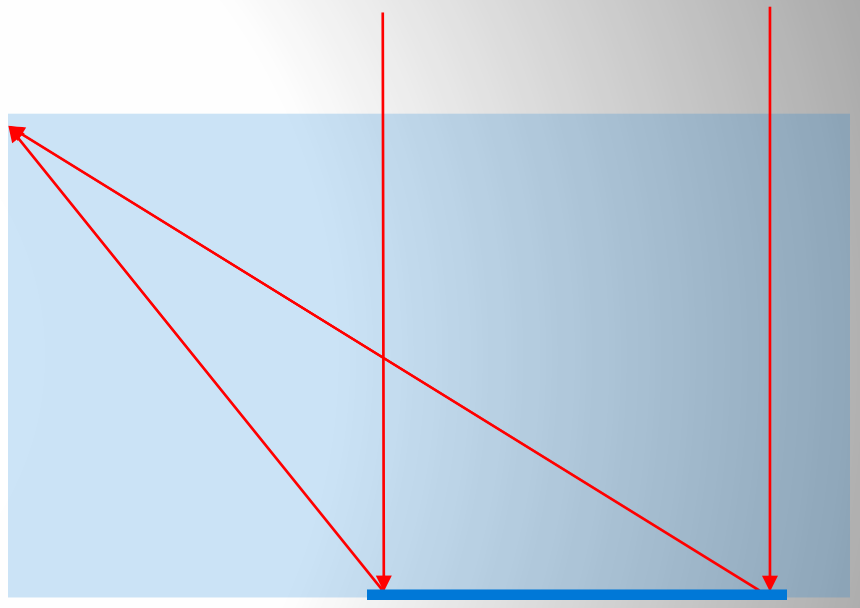
Microsoft Devices

Project Aim

- We aim to create a fully transparent, flat imaging device.
- This technology has applications in mixed reality displays, energy harvesting, and sensors, and forms the core of many futuristic display interactions.
- Application examples are shown left (Office Labs envisioning video).
- “Hyaline” means glass-like.

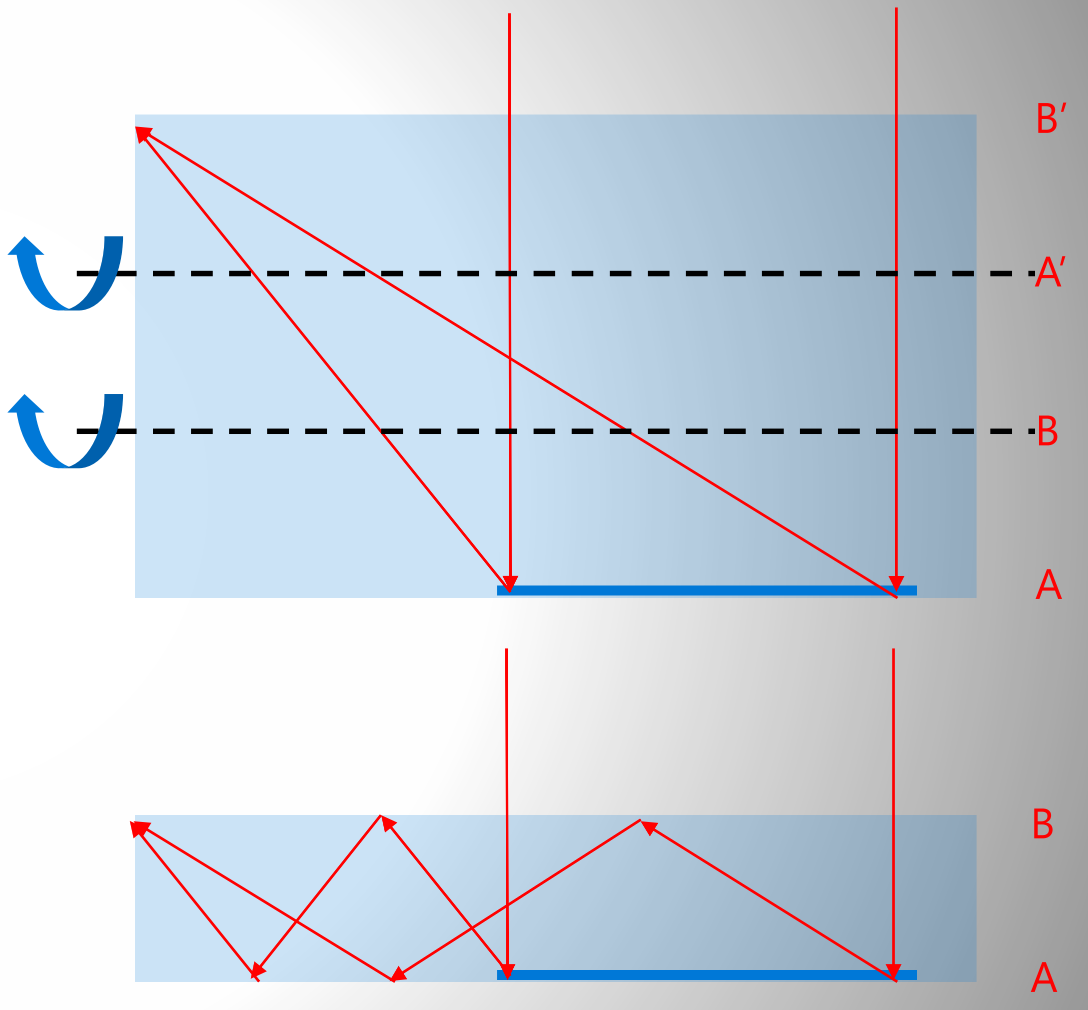
Making a flat imager

- The first step is to create a flat lens.
- This needs to create a focus at the edge of a plate or block.
- We use a reflective holographic optical element (HOE), shown right.



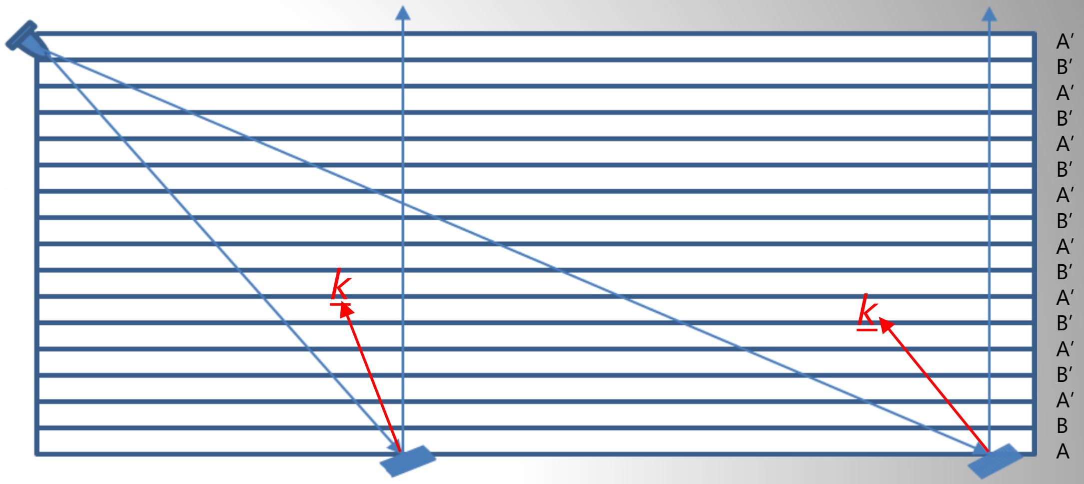
Folding the back focal length

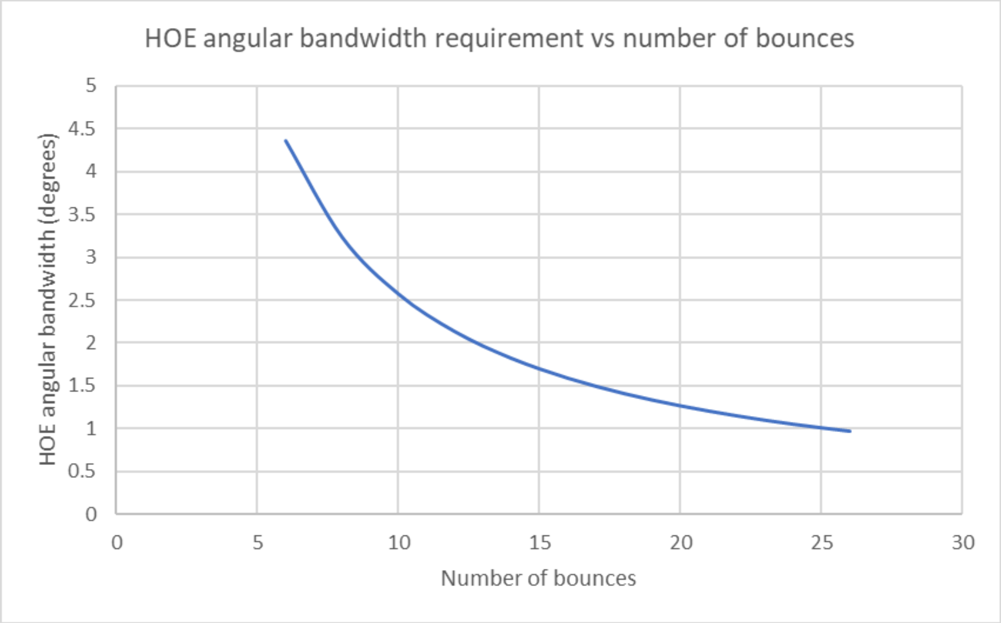
- We use total internal reflection to fold the back focal length of the HOE.
- Here a simple 2-fold is illustrated.
- In this sample case, the edge rays from the HOE don't hit the element twice, but for many folds, the rays intersect the HOE many times.
- Reflections of the real surfaces *A* and *B* are denoted *A′ B′*



Layout of a Holographic Flat Imager

- A thin flat plate contains the back focal length.
- The HOE is a structure whose grating vector, <u>*k*</u>, bisects the surface normal and the angle subtended by the source.
- Sometimes this type of HOE is called a "*rolling k grating*".
- The angular selectivity of the HOE determines the maximum number of bounces in the guide.

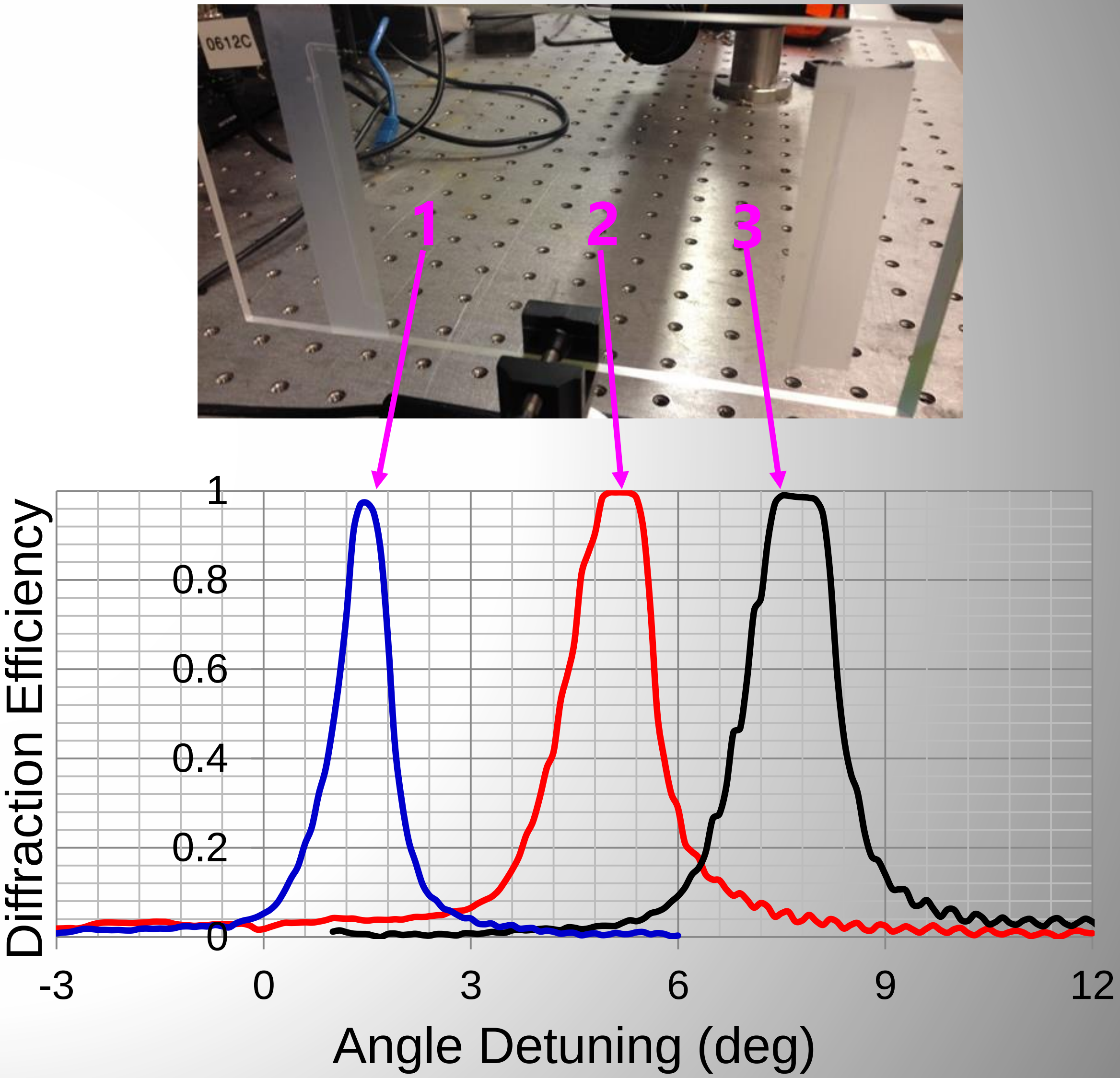




HOE bandwidth

- We constructed such a HOE on a 150x100 plate and measured the angle bandwidth to be 1.4 degrees.
- The coupling efficiency is >97%.
- Note the bandwidth is so narrow that the plate appears entirely transparent in broadband illumination.

Position	Peak DE	FWHM
#1	97.2%	0.8°
#2	99.7%	1.4°
#3	98.9%	1.4°



A modelled example

- This example was created in Zemax OpticStudio, using Kogelnik's equations for the HOE.
- The plate aspect ratio is 30:1
- A 15um thick layer of grating is assumed.
- Rays are colored by segment. All the rays exiting from the panel are the same color, showing that they all interacted with the internal surfaces the same number of times, regardless of position.
- The keystone effect results from the off-axis nature of the optics, but the image is continuous.

Input image

Output image

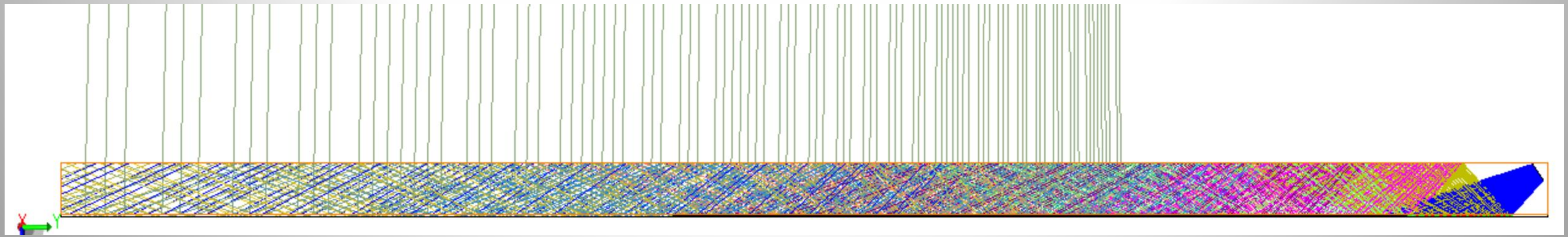
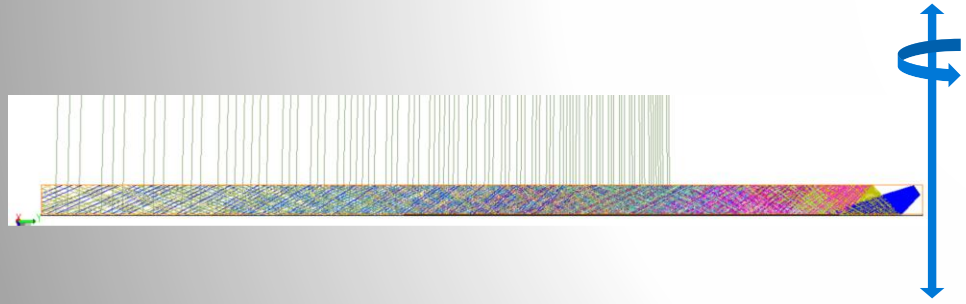
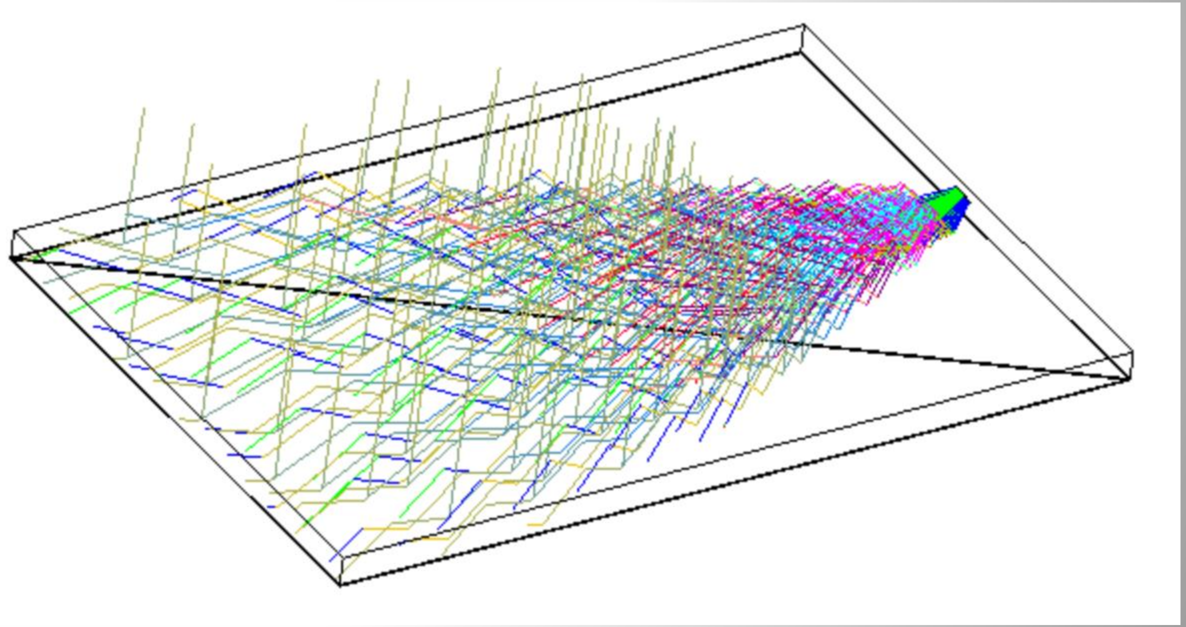


Figure of Revolution

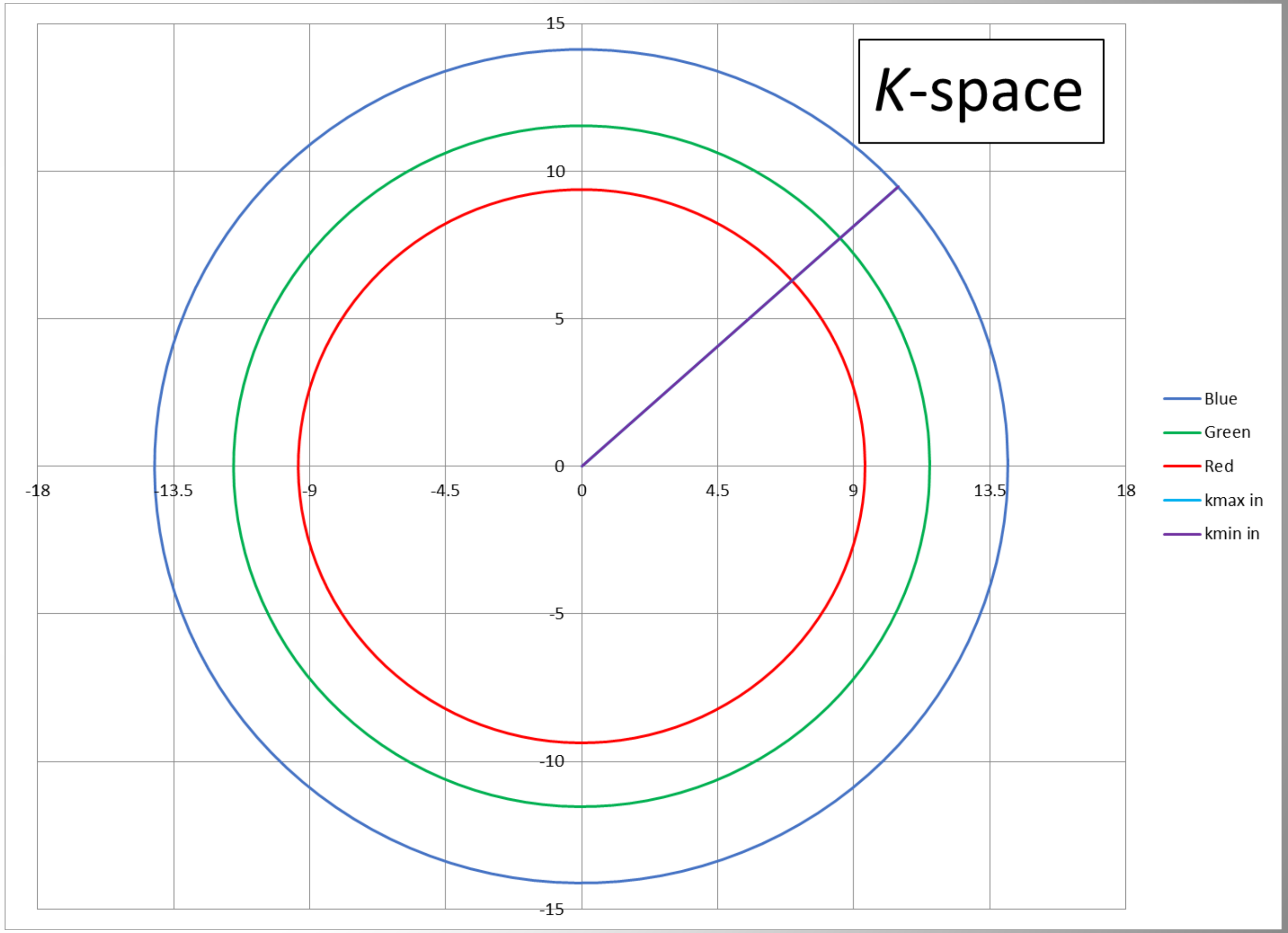
- The solution works in 3D as a figure of revolution about the focus.
- We can therefore figure out the key design limitations in 2D, and know that the solution will work in 3D.





K-Space

- The interactions of light with gratings can be represented as vector addition of grating and photon momentum.
- Photon momentum is $p=(h/2\pi).k$, where h is Planck's constant and k the wavenumber.
- The wavenumber is inversely proportional to the wavelength $k=2\pi/\lambda$.
- As the grating can only change the photon direction, not the energy, the allowed *k*- states form a circle.
- The available *k*-states for each wavelength in the system form concentric circles, with blue outside and red inside.



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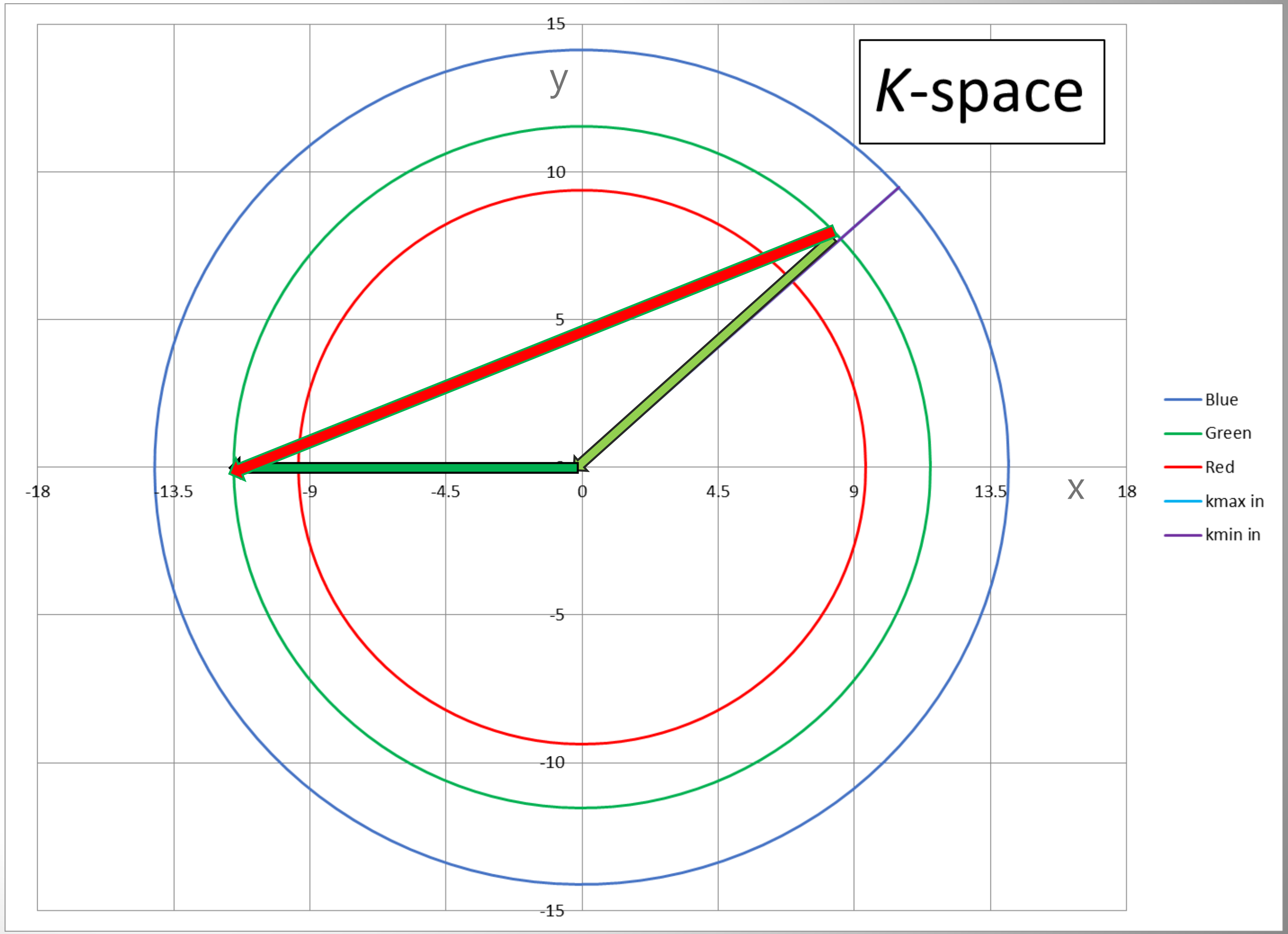
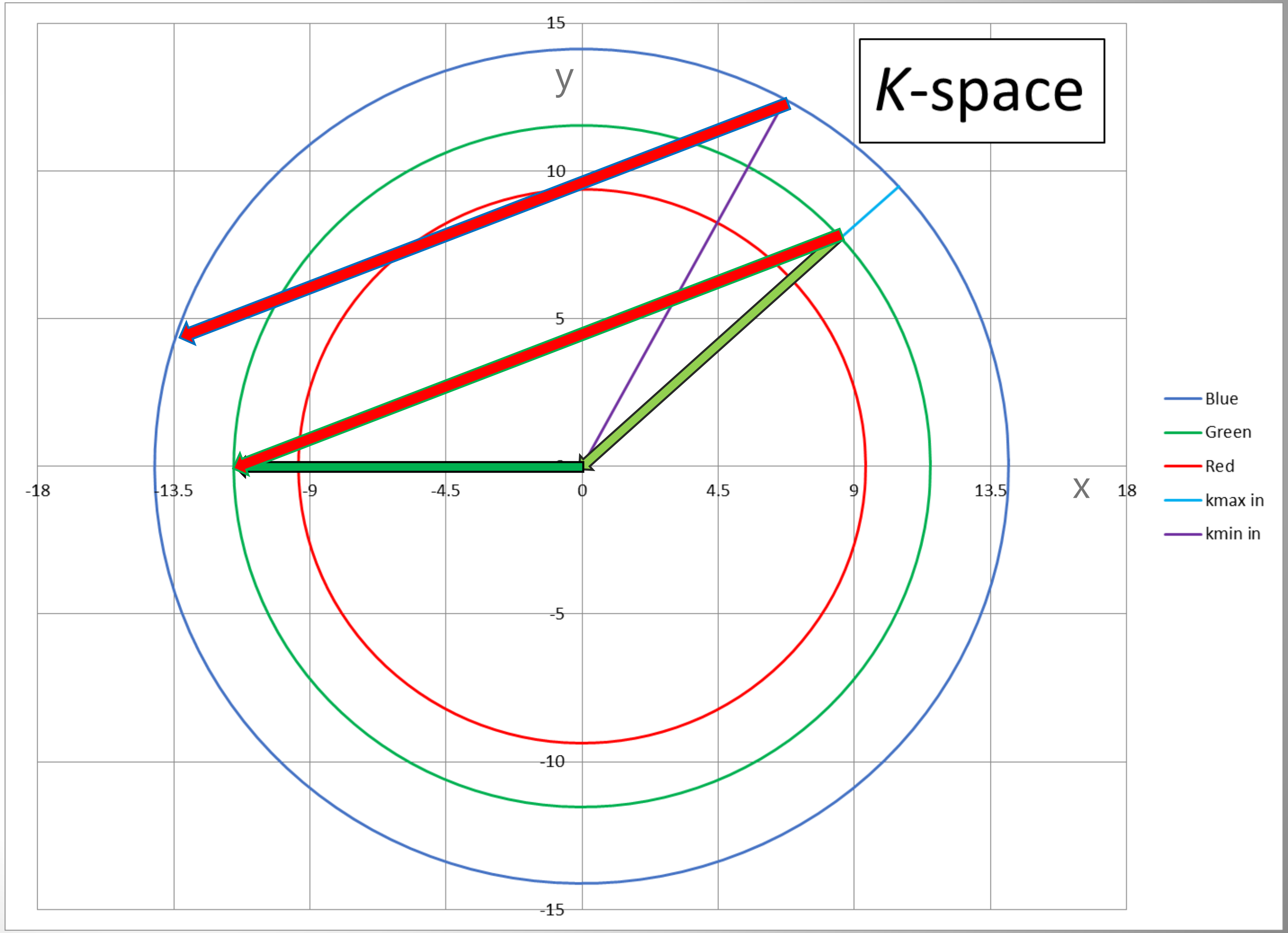
Using the K-Space Representation

- The steepest ray that can propagate is determined by the refractive index.
- For a PMMA plate, the TIR angle is 42 degrees.
- Rays outside this angle leave the guide.
- This steepest green input ray is shown by the light green arrow.
- In a system where the output is collimated, the output k vector is represented by the green arrow.
- The grating momentum is represented by the red arrow.
- The plane of the plate is the y-axis.



Using the K-Space Representation

- It can be observed that blue light from the input cone may also be coupled out by the green grating momentum vector.
- We can avoid this by limiting the maximum cone angle to 20 degrees (30 degrees external).



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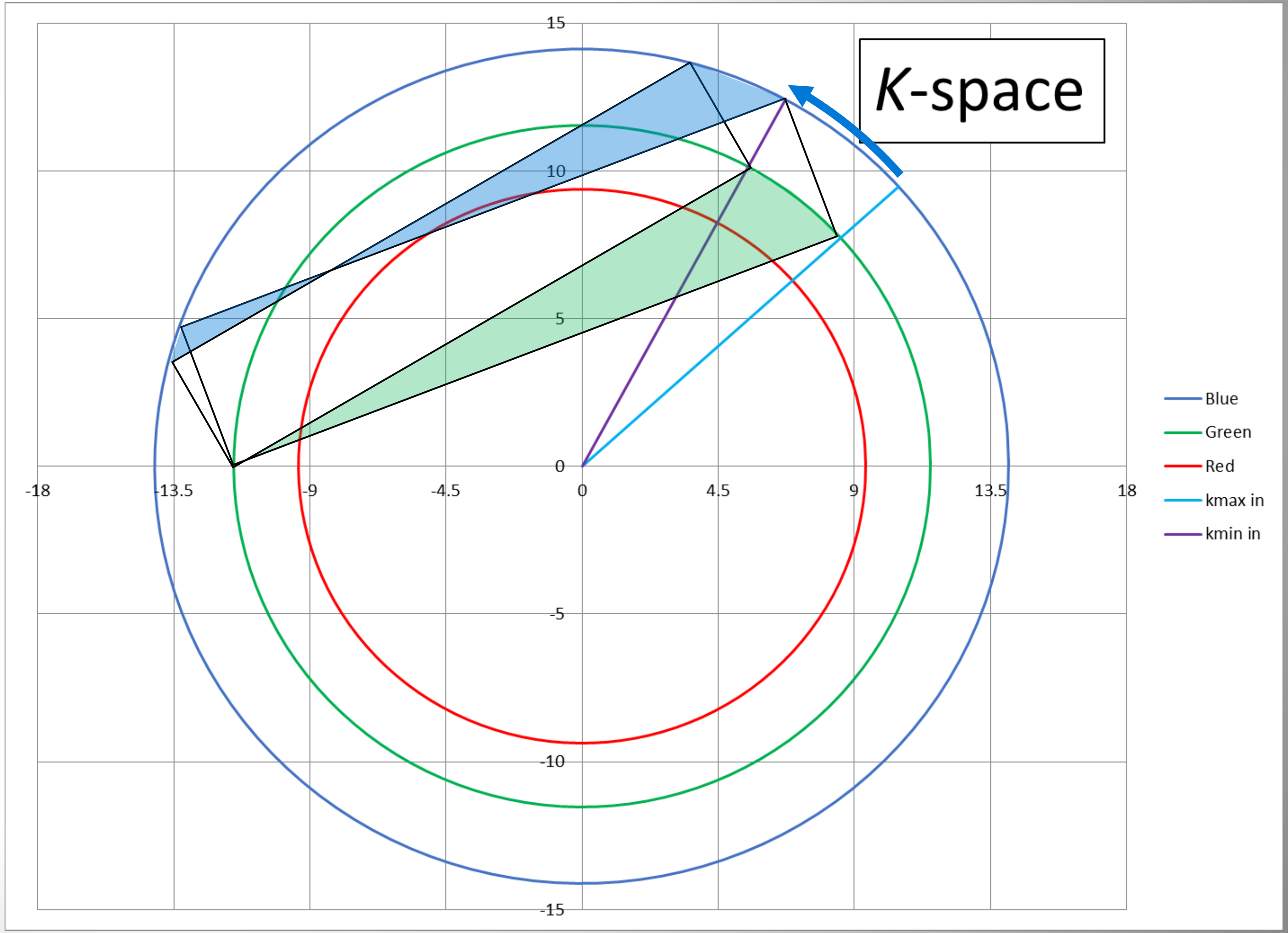
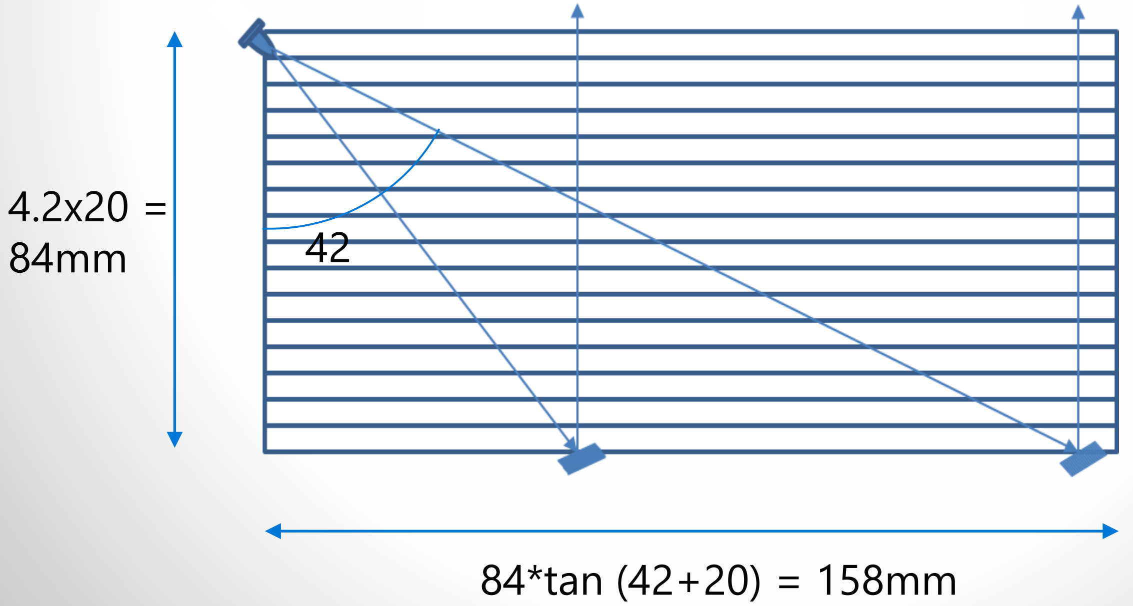
Using the K-Space Representation

- The incident angle at the HOE gets shallower as rays travel down the plate, as shown by the blue arc.
- For a green device, the range of k-vectors present in the HOE fall within the green triangle.
- The range of blue k-vectors that can interact with the green grating is shown by the blue bow-tie.
- There should be no blue input light within these k-spaces.
- The entrance condition limits the range of angles in the guide to 20 degrees, for a three- color guide.



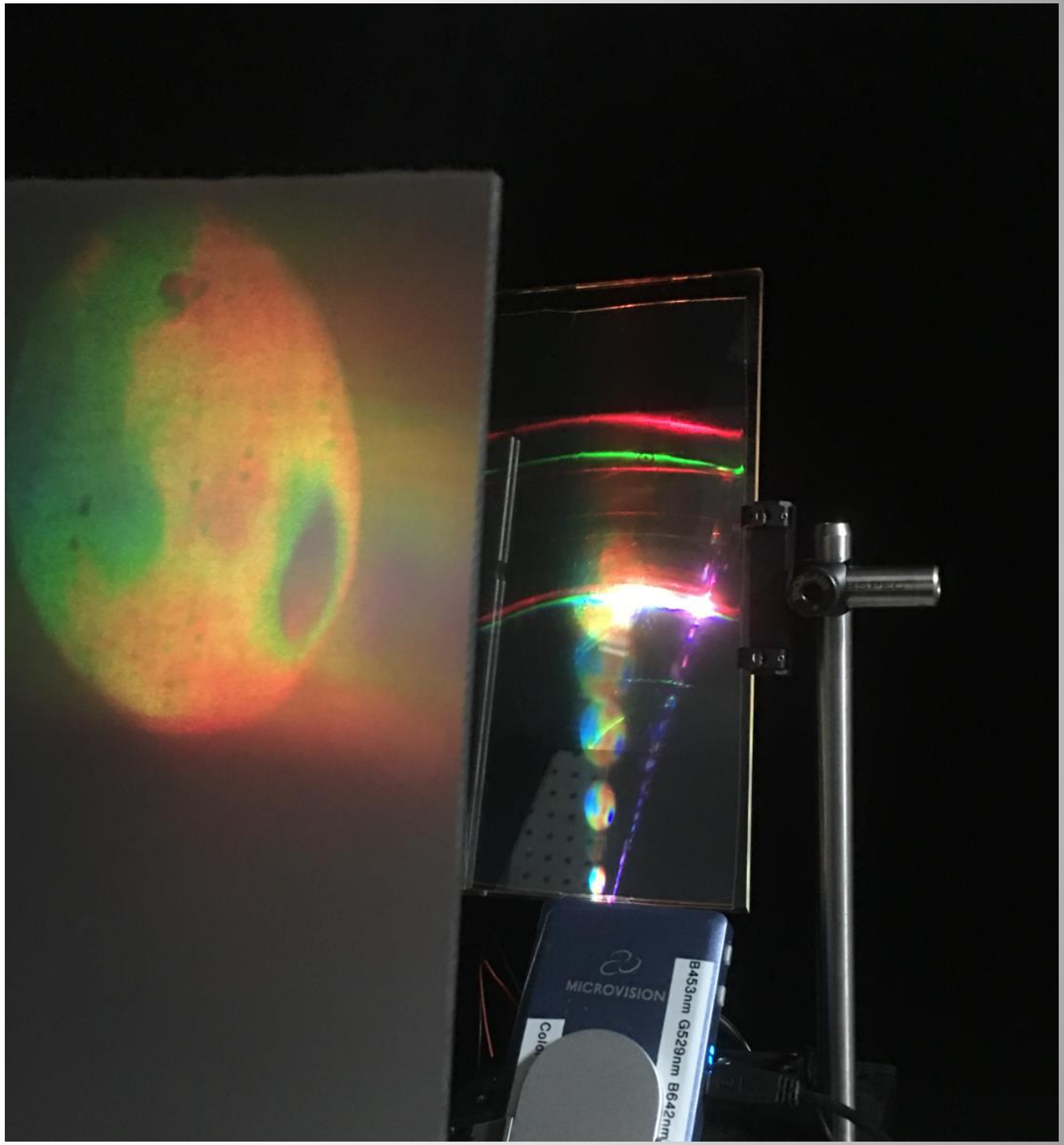
Putting the design together

- The angular bandwidth limits the number of bounces to ~20
- The requirement to separate R,G & B in k-space means the internal angle space filled is ~20 degrees, so the active area is just over half the total area.
- We constructed a demo 170mm long by 4.2mm thick, based on simple trigonometry.



Demo

- An false color image of a planet from a laser pico-projector is projected onto a screen, via a flat imager.
- The screen is 200mm from the plate.



Applications?

- Imaging from the display area, for detecting motion and objects outside the display. The sharp wavelength response and flat form means it could be in front of a display.
- Increasing the output power of laser projectors, without exceeding laser safety specifications.
- Telecentric or structured illumination.
- Compact virtual displays, such as lightweight glasses or car heads-up displays.
- Transparent displays.
- Flat lens systems.