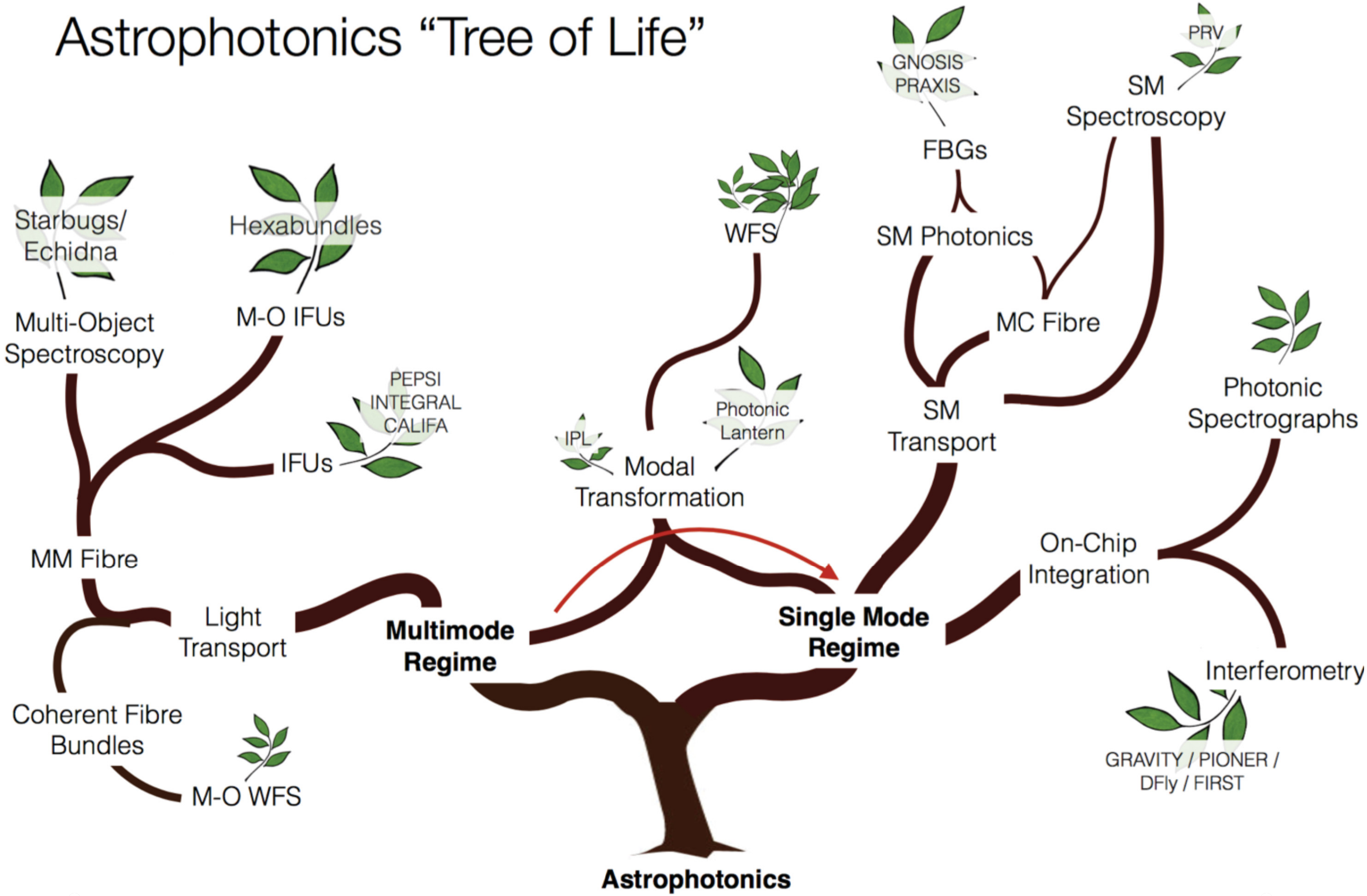
Photonic Reformatting

Robert J. Harris (ZAH, LSW)

In this talk

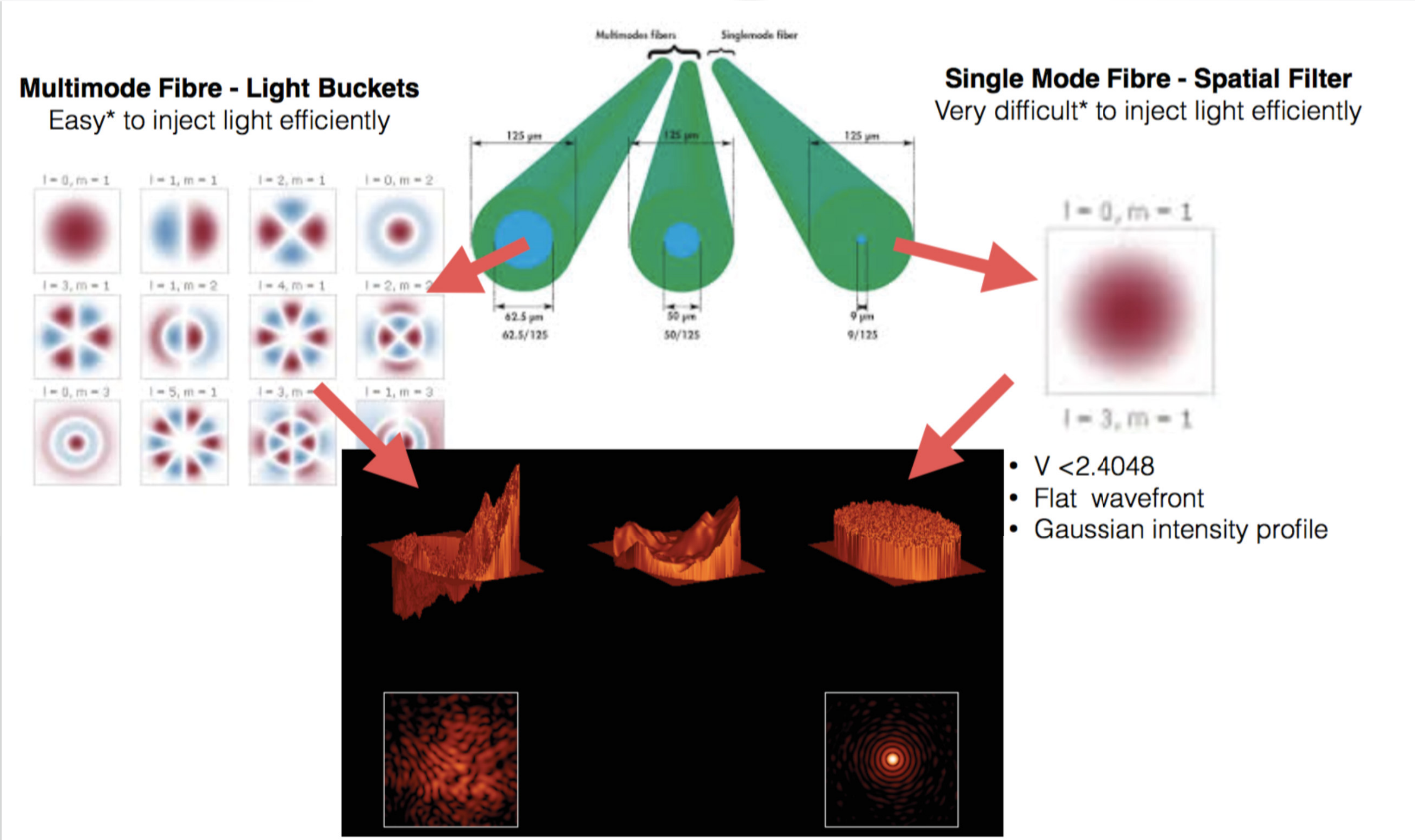
- *An overview of astrophotonics*
- *Single mode vs multi mode*
- *What is Photonic Reformatting*
- *Why it theoretically works*
- *How it practically works*
- *Further work on it*
- *Wavefront sensing using it*
- *Conclusions*

Astrophotonics "Tree of Life"



Taken from Nick Cvetojevic

The regimes

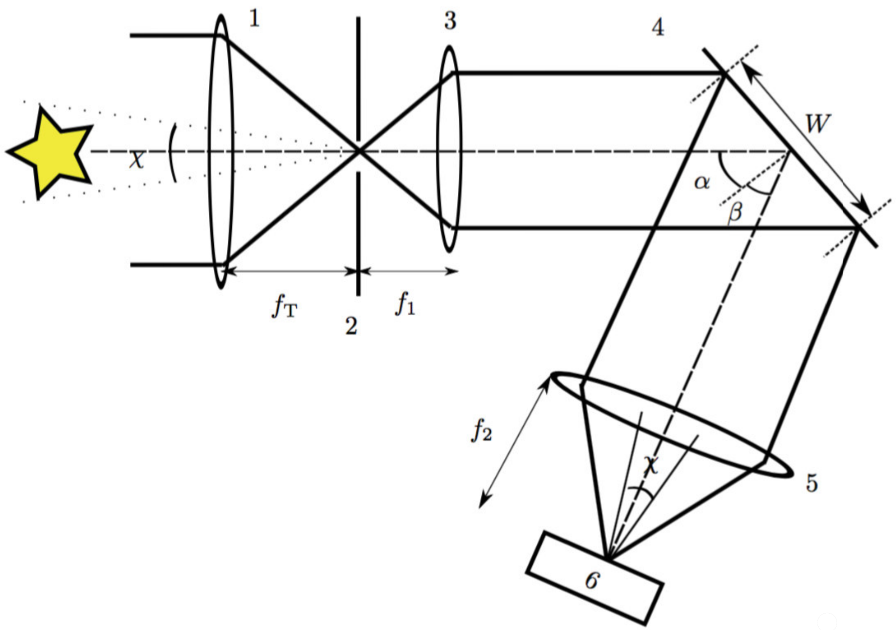


Taken from Nick Cvetojevic

Why is this important?

- For a given grating, the spectral resolving power is dependent on wavelength and 1/ telescope diameter and seeing
- Tradeoffs mean costs go up as your telescope gets bigger

$$R = \frac{m\rho\lambda W}{\chi D_{\mathrm{T}}}.$$



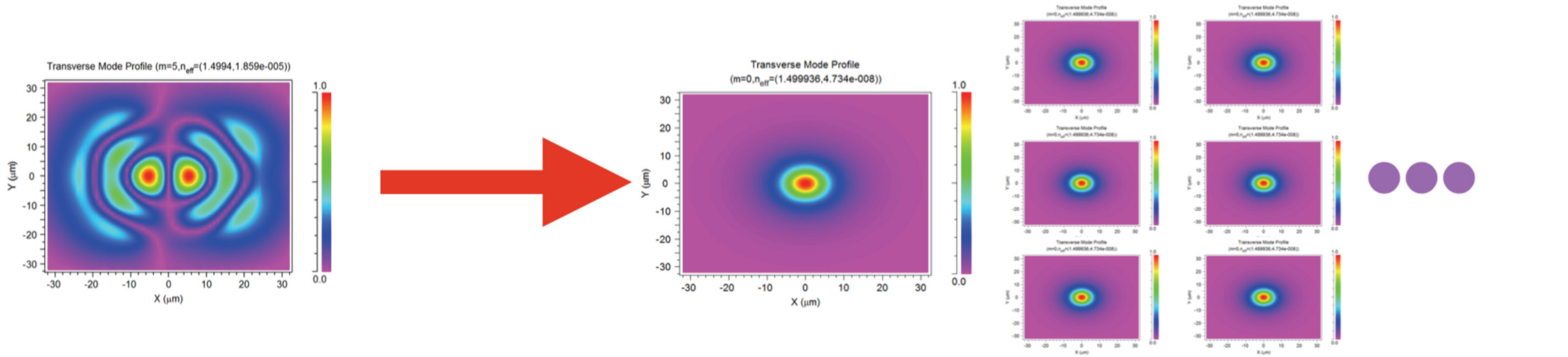
- Can imagine modally

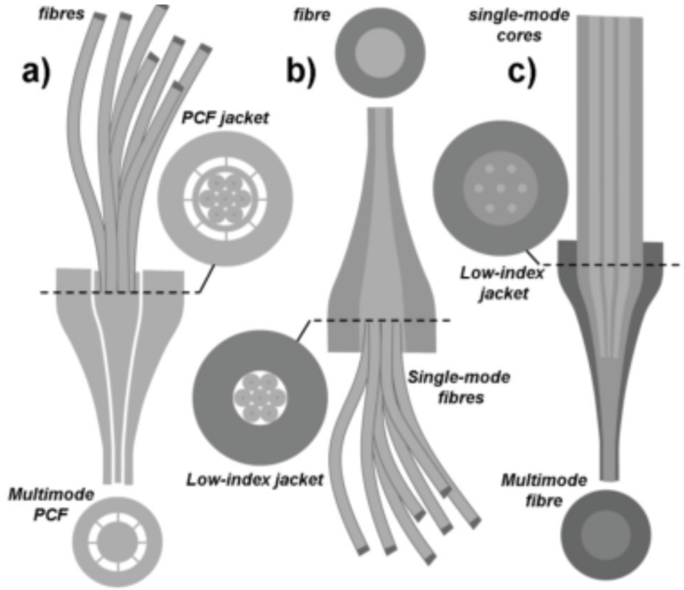
$$M = \left(\frac{\pi\chi D_{\mathrm{T}}}{4\lambda}\right)^2.$$

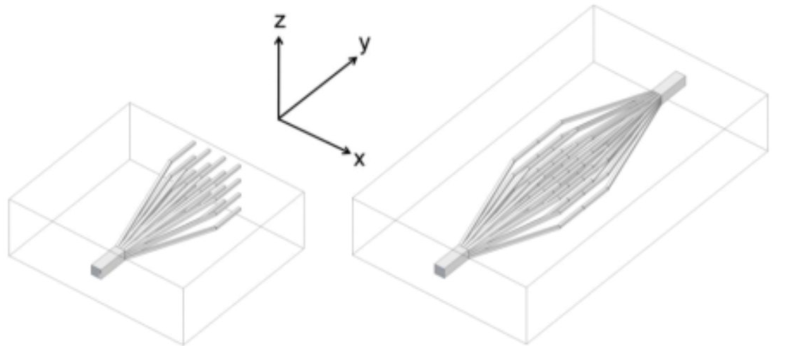
-

The photonic lantern

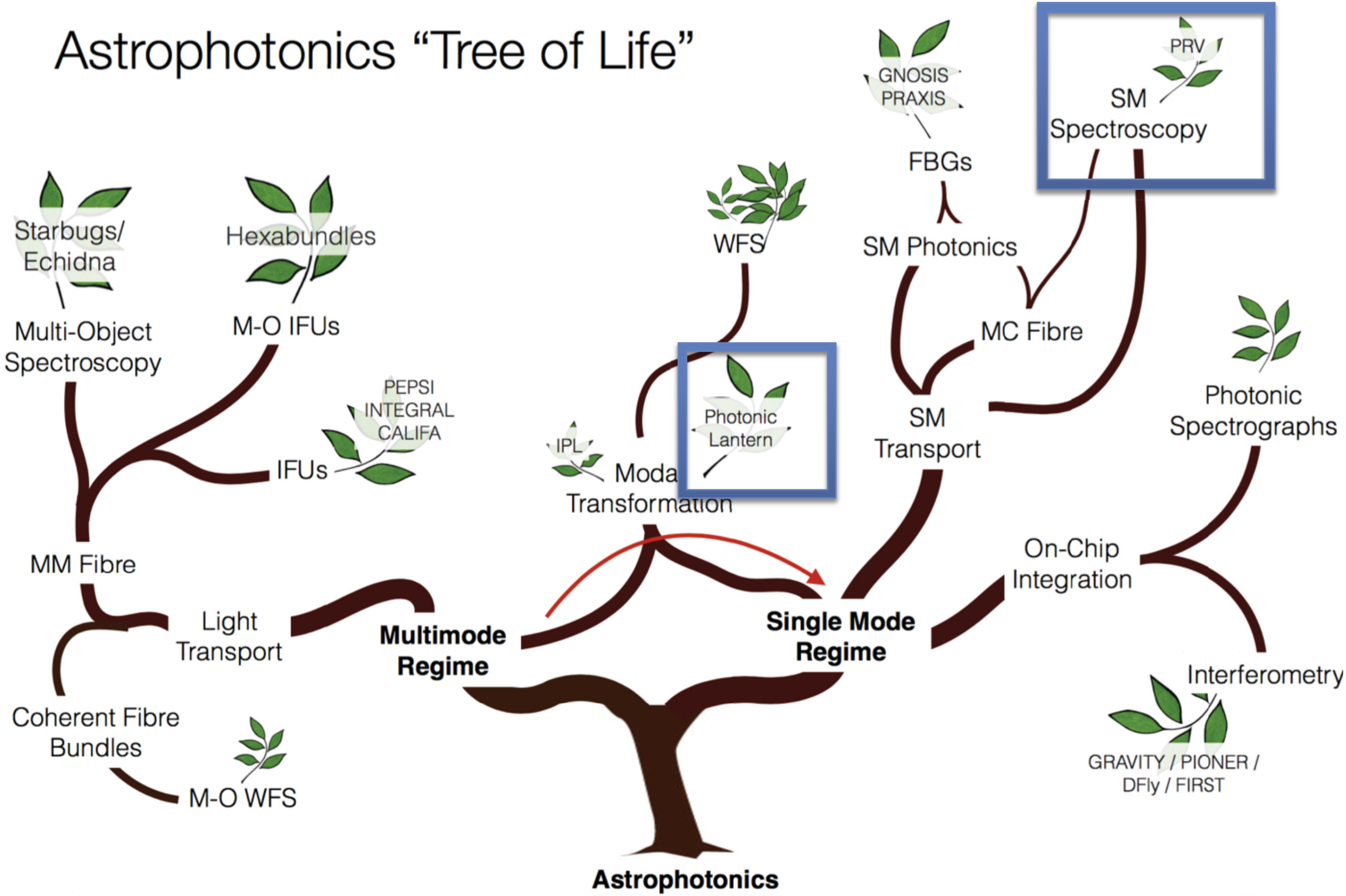
- Solves the problem, with a catch….







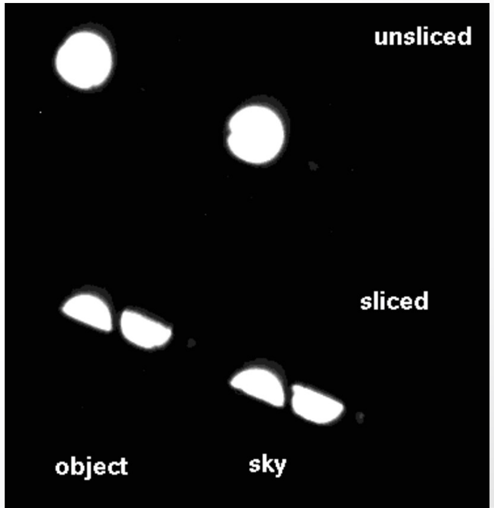
Astrophotonics "Tree of Life"



Reformatting, Image slicing

- As telescopes increase in size, resolution decreases
- So need a bigger grating, but that costs
- So keep the grating size and decrease the slit width
- But as you decrease slit width you lose light
- In astronomy image slicers are frequently used to retain resolution and throughput
- Conventionally these are bulk optics (prism or mirrors)
- We can do this photonically

$$R = \frac{m\rho\lambda W}{\chi D_{\mathrm{T}}}.$$



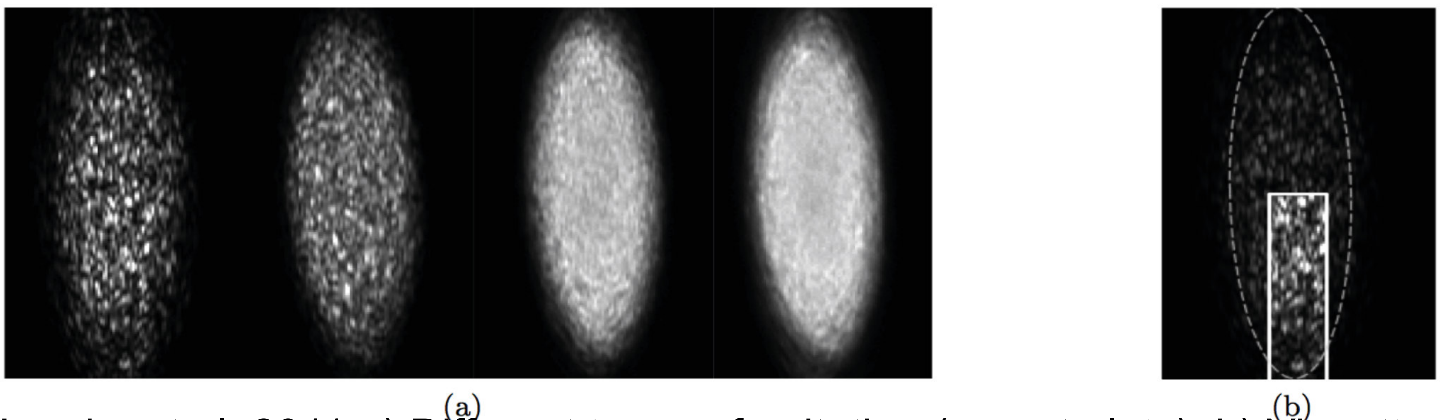
Problems : Modal noise

Modal noise is due to the interaction of the modes in the fibre and vignetting in the spectrograph.

Results in a barycentre shift in the measured wavelength.

Using single modes could eliminate this.

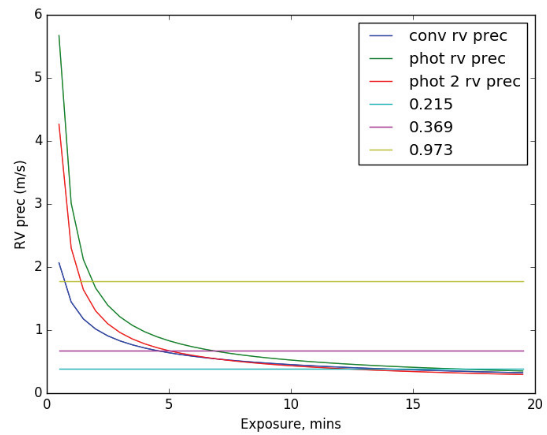
But where is modal noise actually a problem?



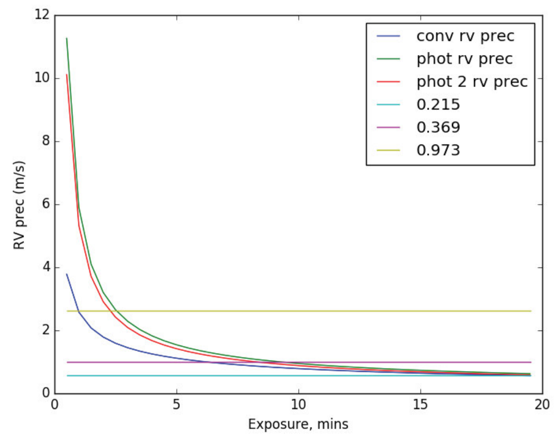
Lemke et al. 2011 a) Different types of agitation (none to lots), b) Vignetted image

Where is modal noise a problem?

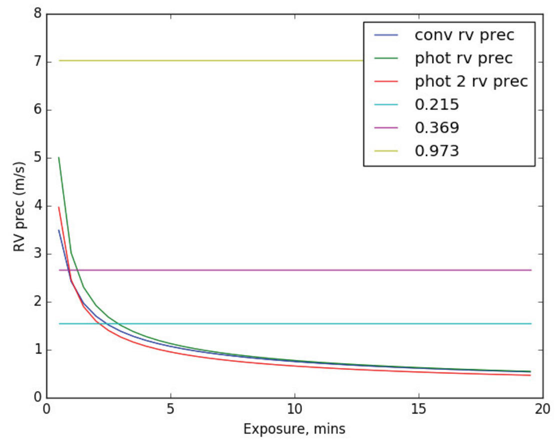
- Can be modelled theoretically.
- Harps – modal noise not a problem
- Carmenes – modal noise could be a problem
- GIANO – severely limited by modal noise
- Take away message : Fewer modes, more problems.



HARPS

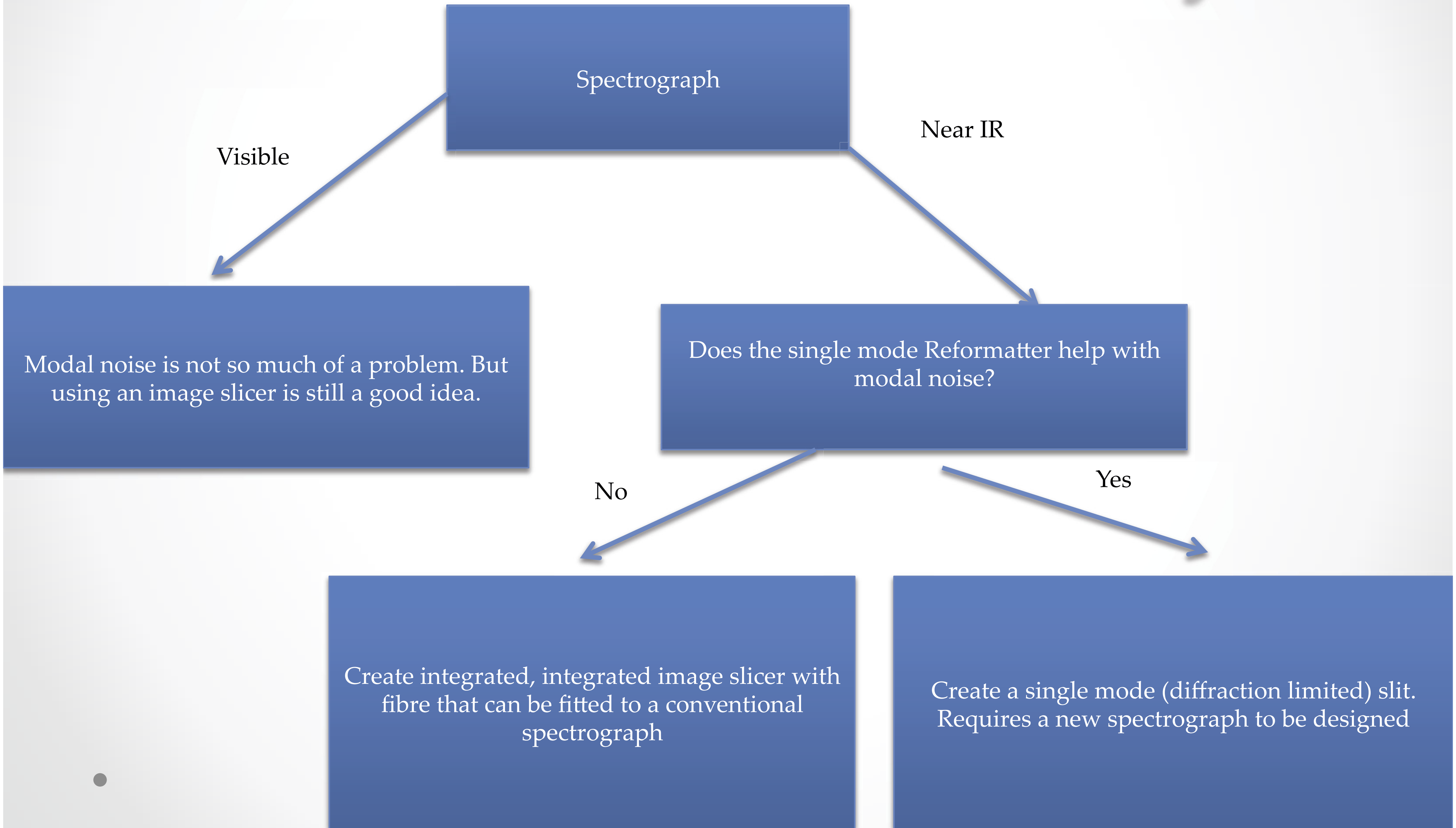


CARMENES

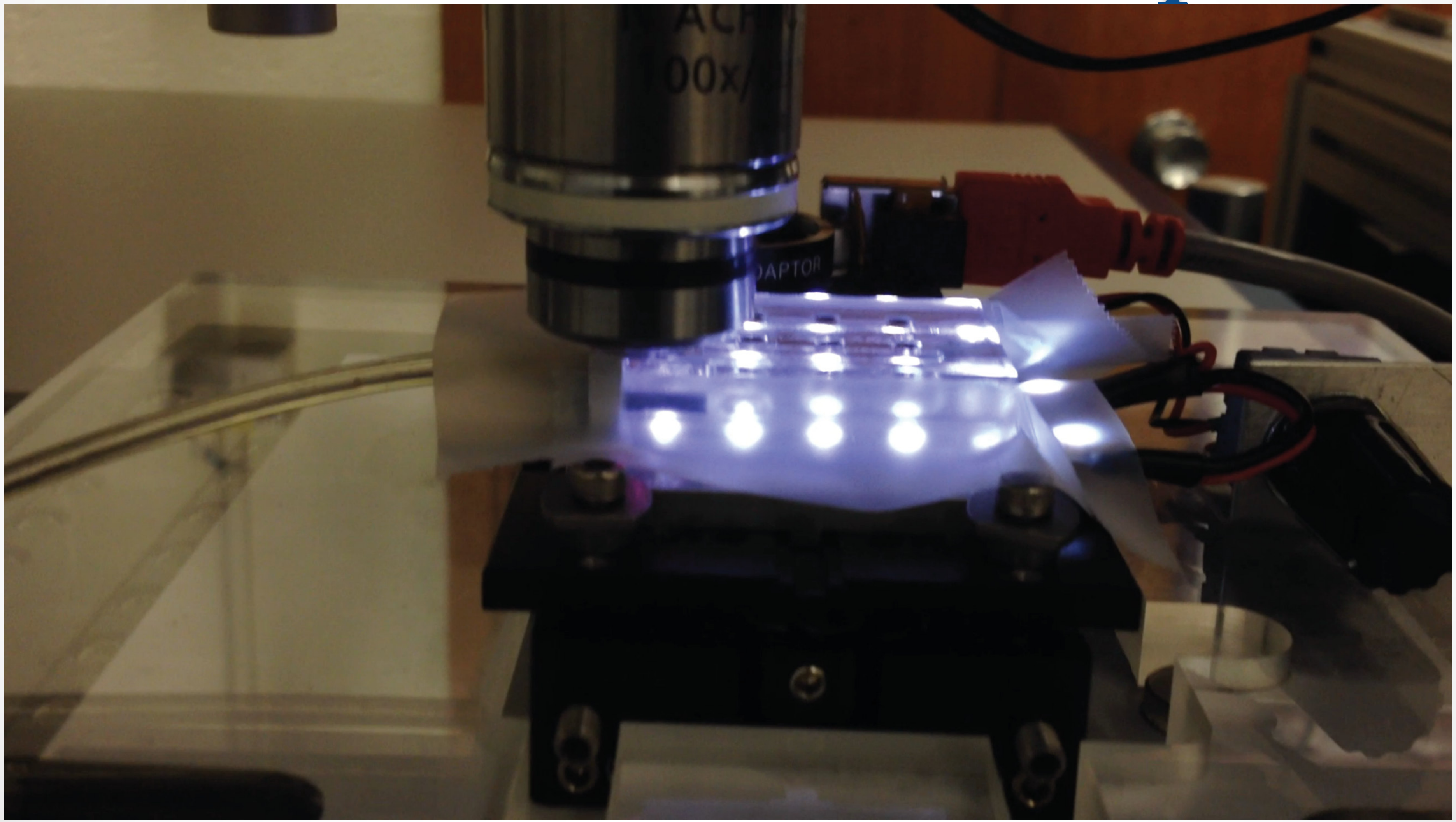


GIANO

Theoretical summary



Ultrafast Laser Inscription

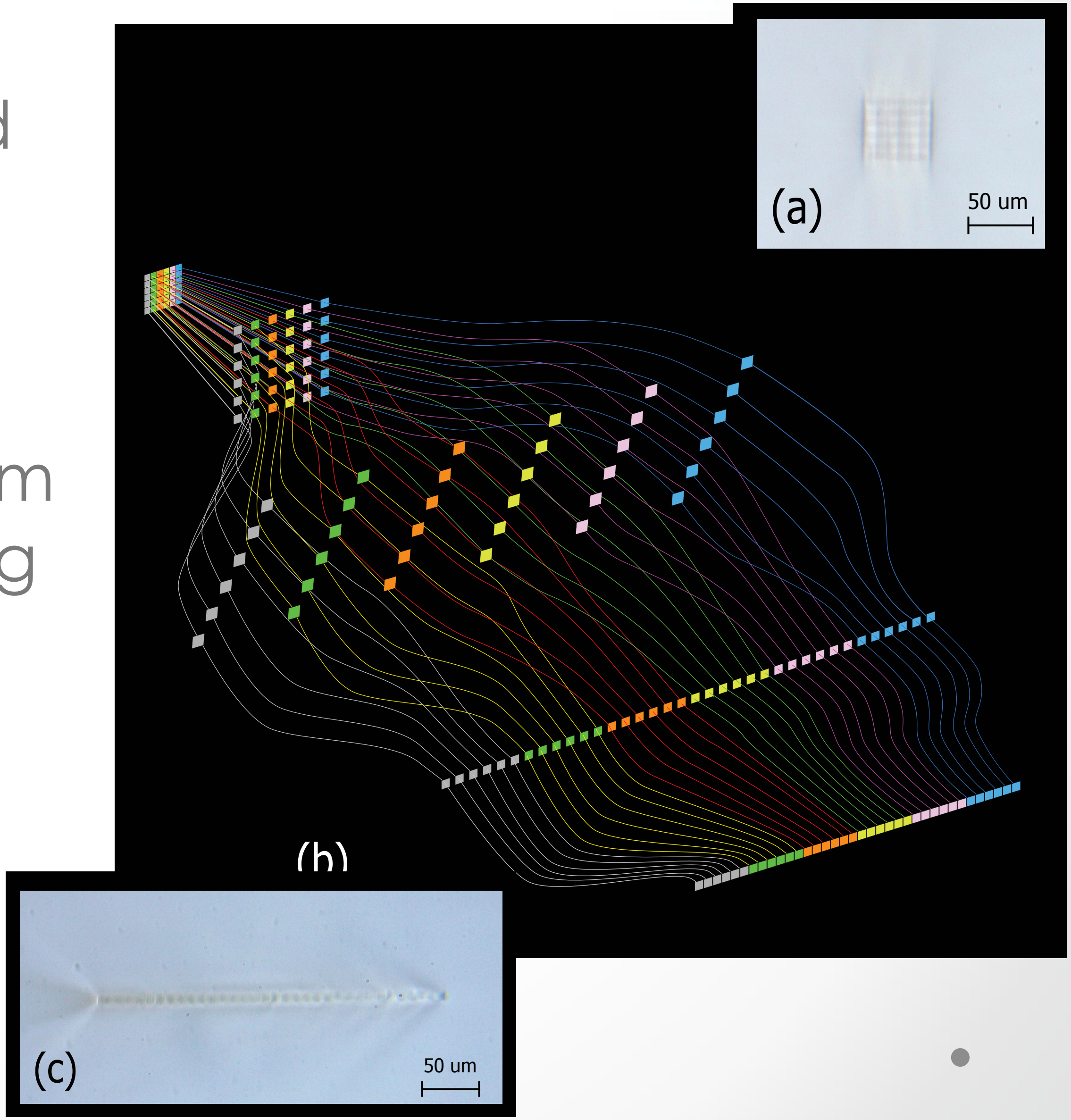


Credit : Izabela Spaleniak

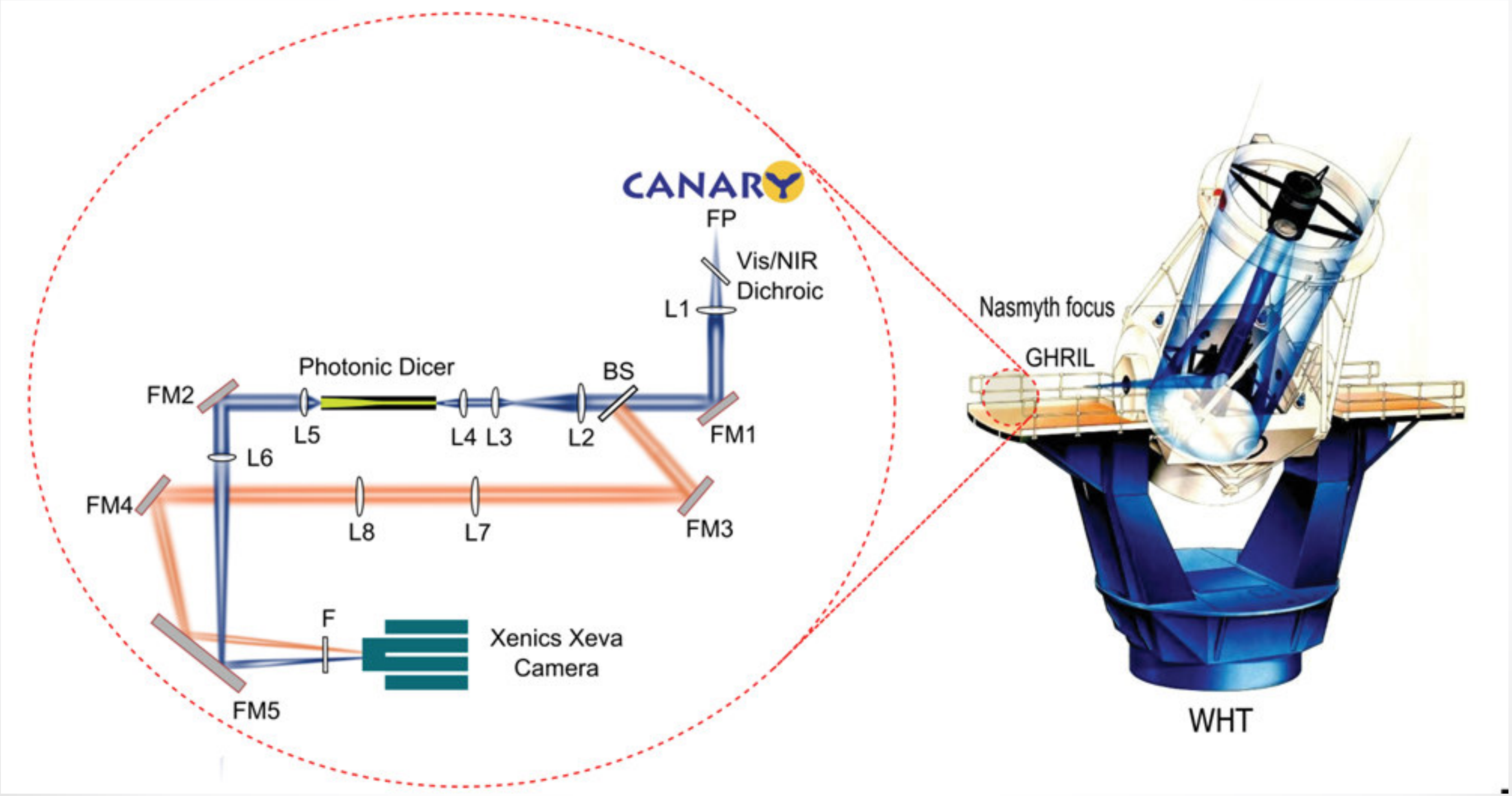
The Photonic Dicer

- A ULI block developed with Robert Thomson's group at Heriot-Watt

- It reformats the PSF from the telescope to a long slit (image slicer)

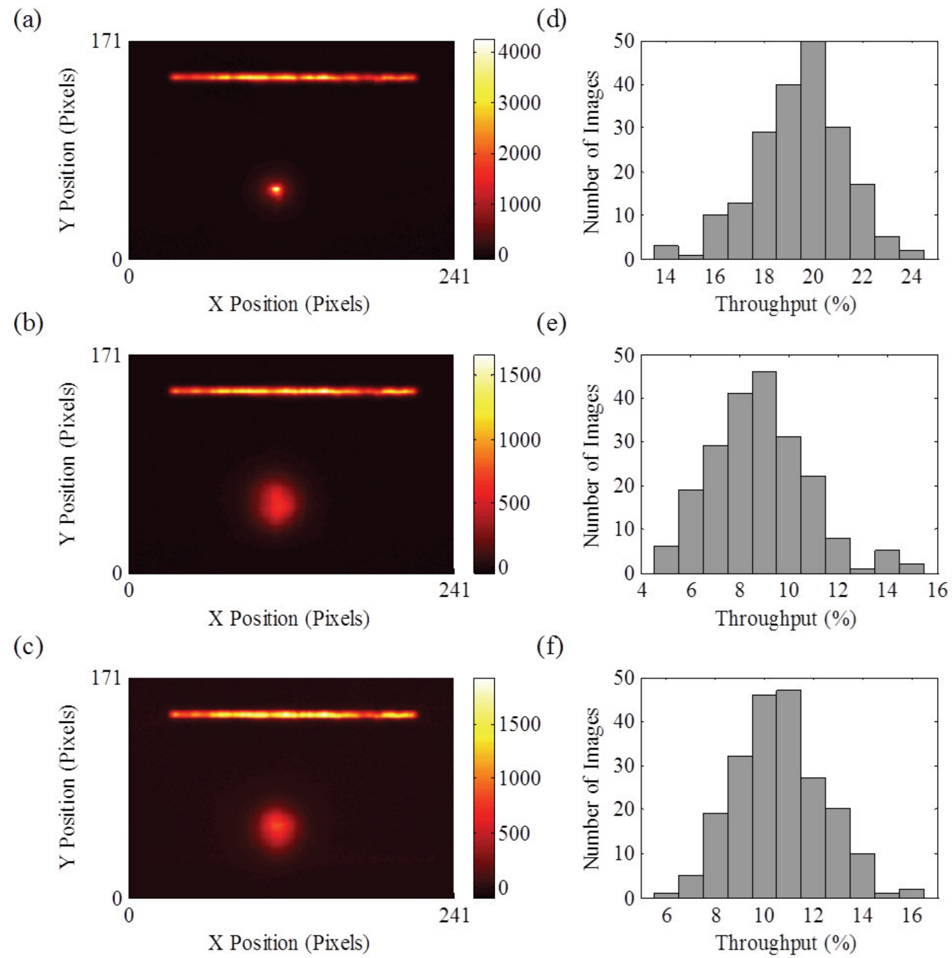


How to test it



Results

- Around 20% of the light from the star through (~55% goes through the chip).
- Slit wasn't perfectly straight.
- Mode field diameter (FWHM of slit varied)
- Overall pretty happy for a first attempt



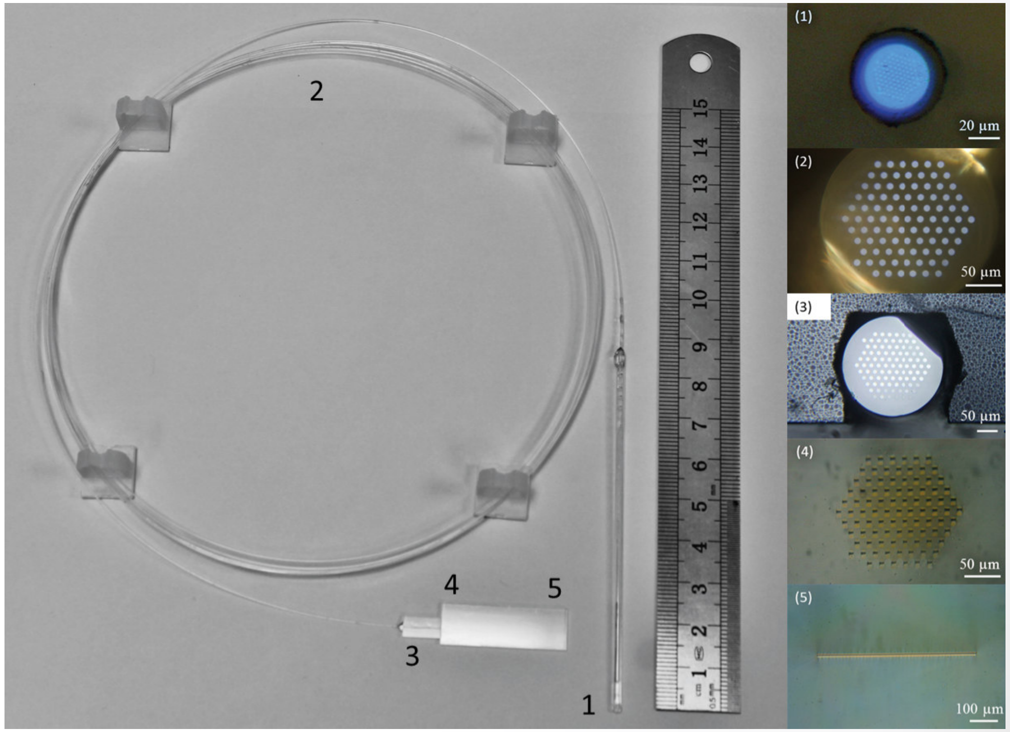
The Hybrid reformatter

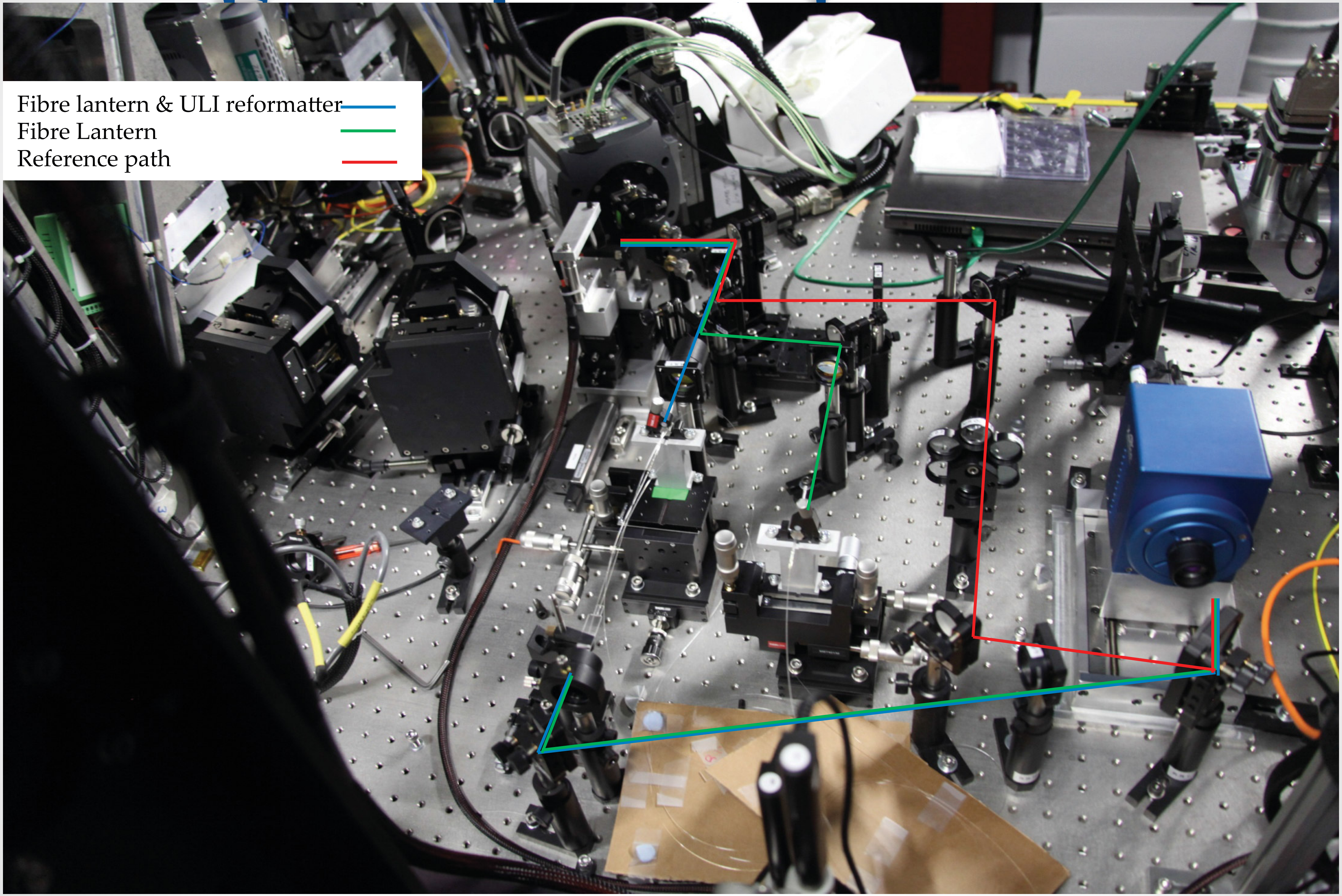
To improve throughput and flexibility we developed the Hybrid reformatter

A photonic lantern leading to a 92 core multicore fibre with a ULI block to reformat.

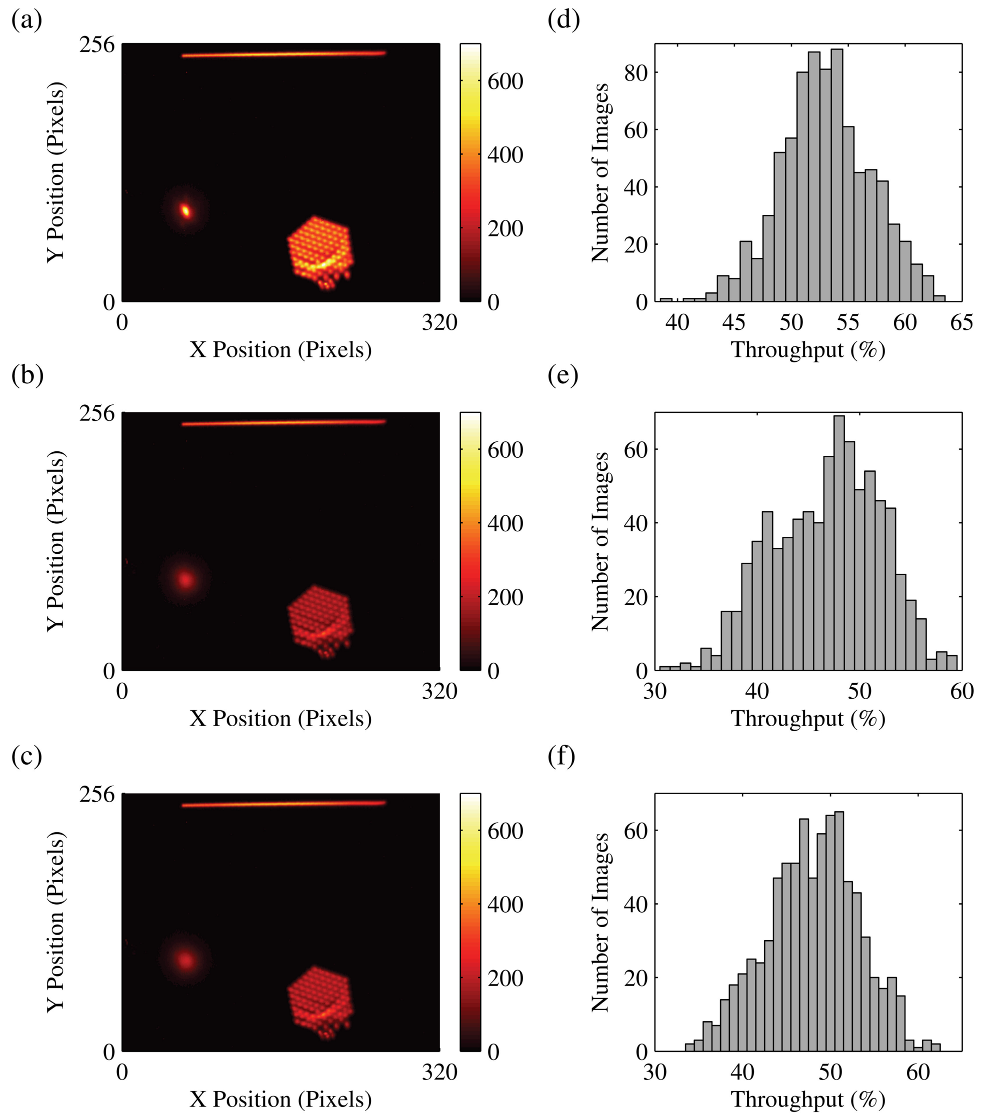
Developed with Herriot-Watt and Bath Universities

Tested with CANARY October 2014

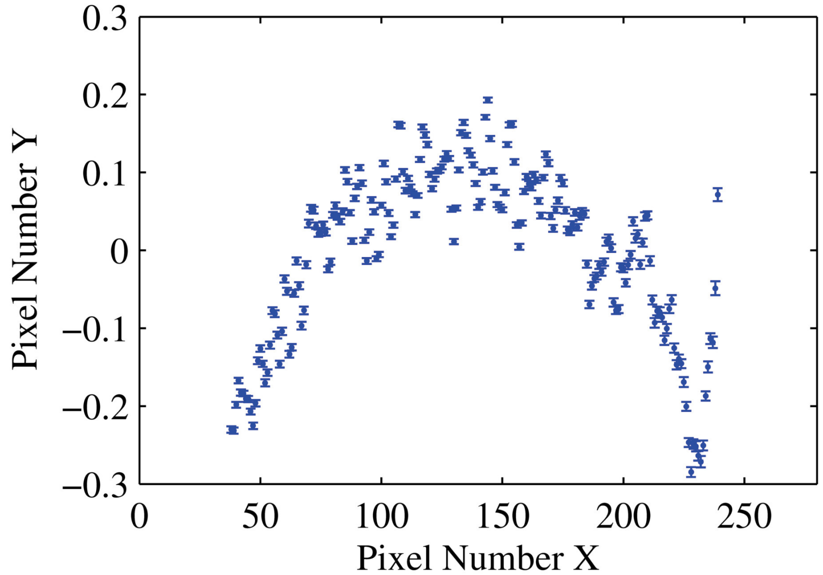



Fibre lantern & ULI reformatter
Fibre Lantern
Reference path

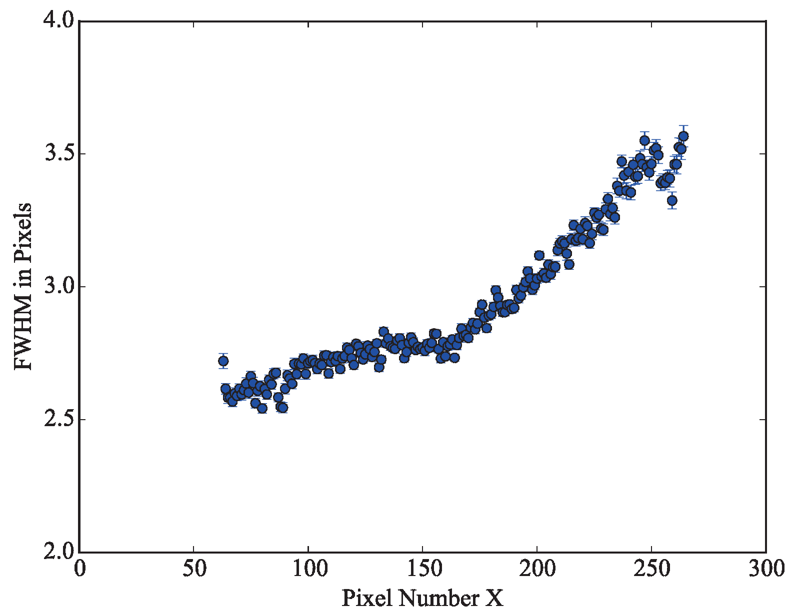
Results



(a)
(b)
(c)
256
0
320
Y Position (Pixels)
X Position (Pixels)
600
400
200
0
(d)
(e)
(f)
Number of Images
Throughput (%)
80
60
40
20
0
40
45
50
55
60
65
30

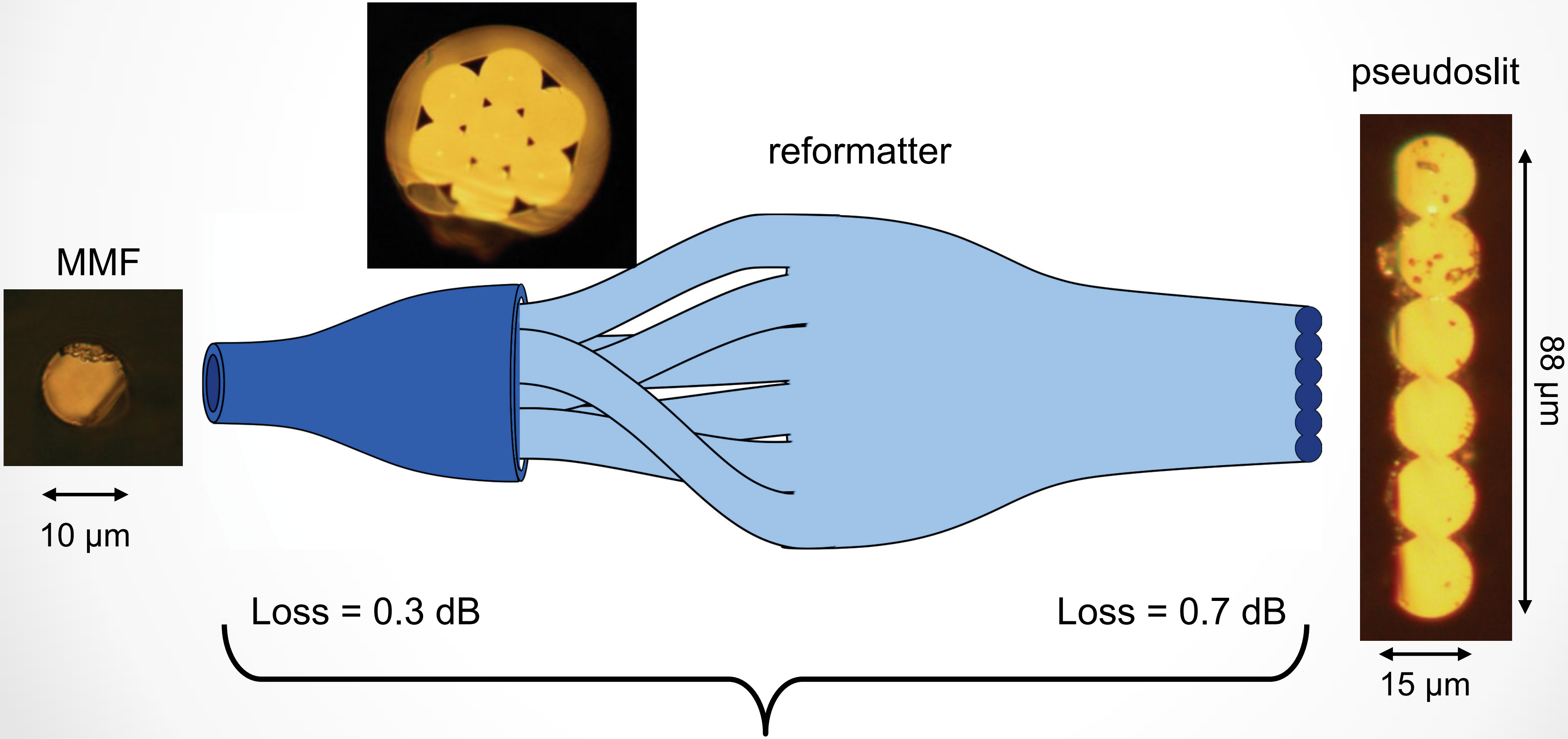


0.3
0.2
0.1
0
−0.1
−0.2
−0.3
Pixel Number Y
0
50
100
150
200
250
Pixel Number X



4.0
3.5
3.0
2.5
2.0
FWHM in Pixels
0
50
100
150
200
250
300
Pixel Number X

Others are also working on this

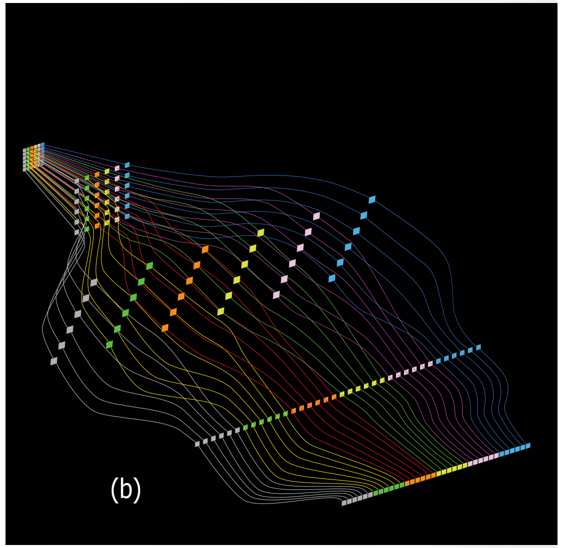


Stephanos Yerolatsitis (Bath)

Optimisation for Instrumentation

- So the devices work, but ideally we want to optimise them
- Optimise manufacture
- AR coat
- They need to be more rugged and rhobust
- We should optimise the input (AO)
- Optimise design (here)
- Test with spectrograph (here)

Theoretical optimisation



Courtesy of Theodoros Anagnos

Testing at the Waltz

A follow on from a survey 1999-2011 at 60cm CAT telescope, Lick observatory

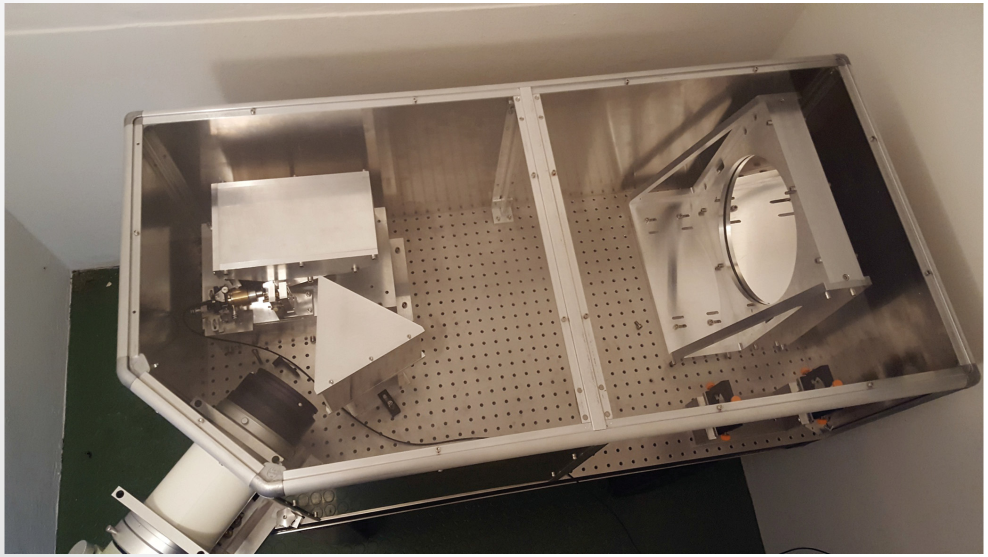
F/18 Reflector, D = 72cm
Plate scale: 15.03 “/mm
used at Nasmyth focus

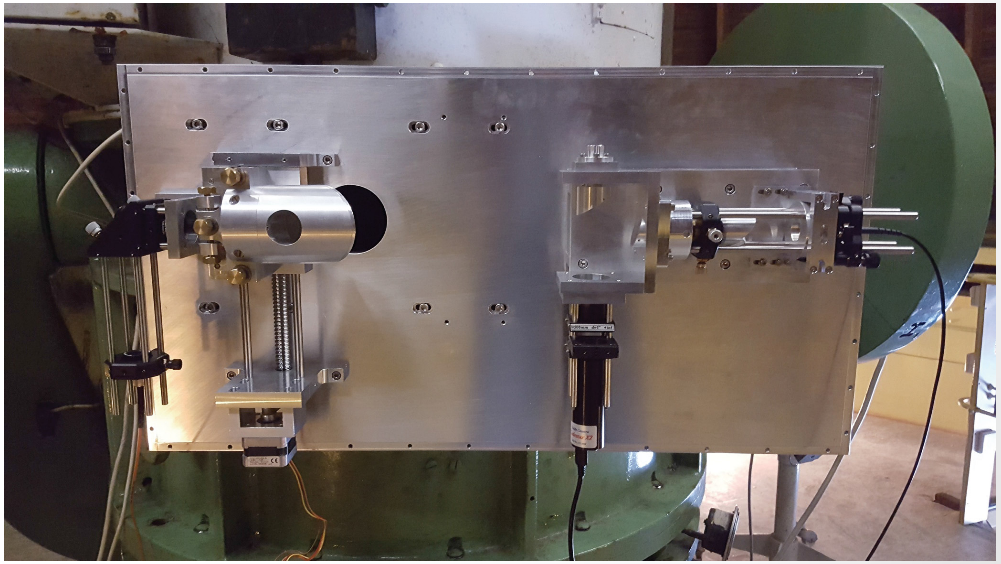
Courtesy : M Tala

R (λ/Δλ)	~ 60 000
Wavelength coverage	450 – 800 nm
Aperture on sky	2.5 arcsec
Fiber-feed	Rectangular fiber, 25 x 100 μm size
Collimator	Parabolic mirror off-axis F = 900mm, D = 300mm
Echelle grating	31.6 grooves/mm 63.5° blaze angle
Cross-dispersion prism	Schott F2 glass, 60° Apex
Camera	Apochromatic lens F = 530 mm, D = 106 mm
Detector	Andor iKon-L 936 2k x 2k, 13.5 μm per pixel
Average spectral sampling	2.6 pix

Modifications to the Waltz

- The Waltz spectrograph is nearing completion
- It still needs to be modified to allow testing





New method - 3D Lithography

During my PhD we had discussions about 3d printing reformatters

But at the time the technology didn't seem sufficiently developed.

I saw Lindenmann et al. 2012. All about photonic wirebonding

When done correctly, very low loss waveguides

This could be great for reformatting devices.

Fig. 7. Two-step writing strategy for PWB fabrication. The inner volume is exposed first by writing spiral lines. In a second step, an outer shell is added by writing lines parallel to the contour of the PWB for smoothening the surface.

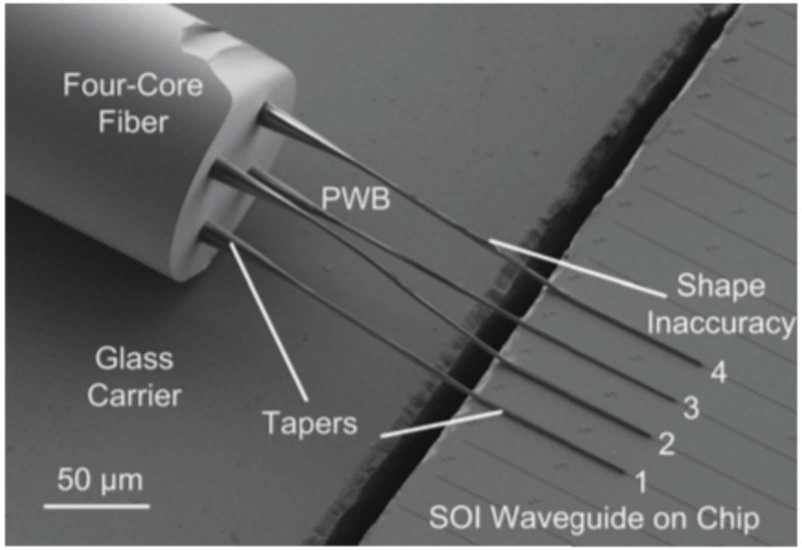
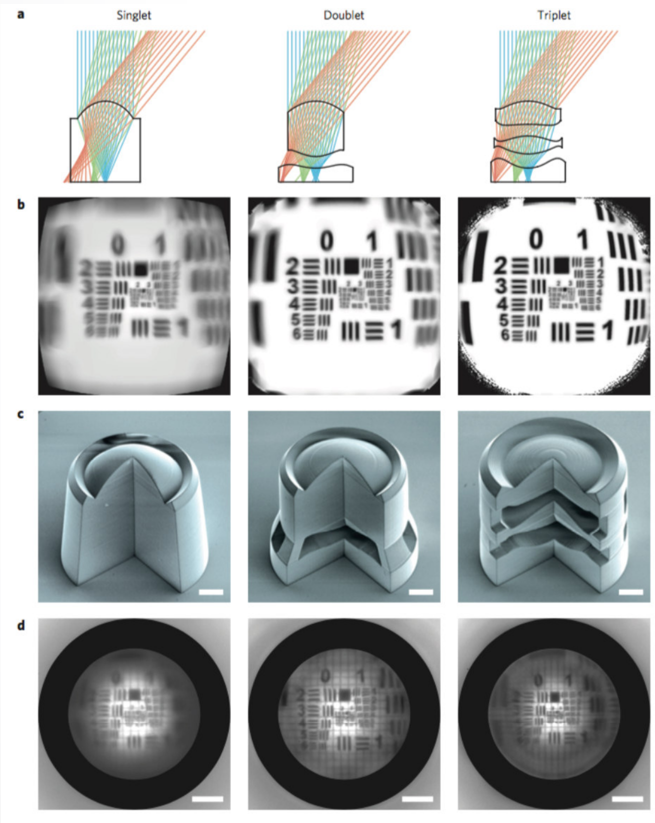
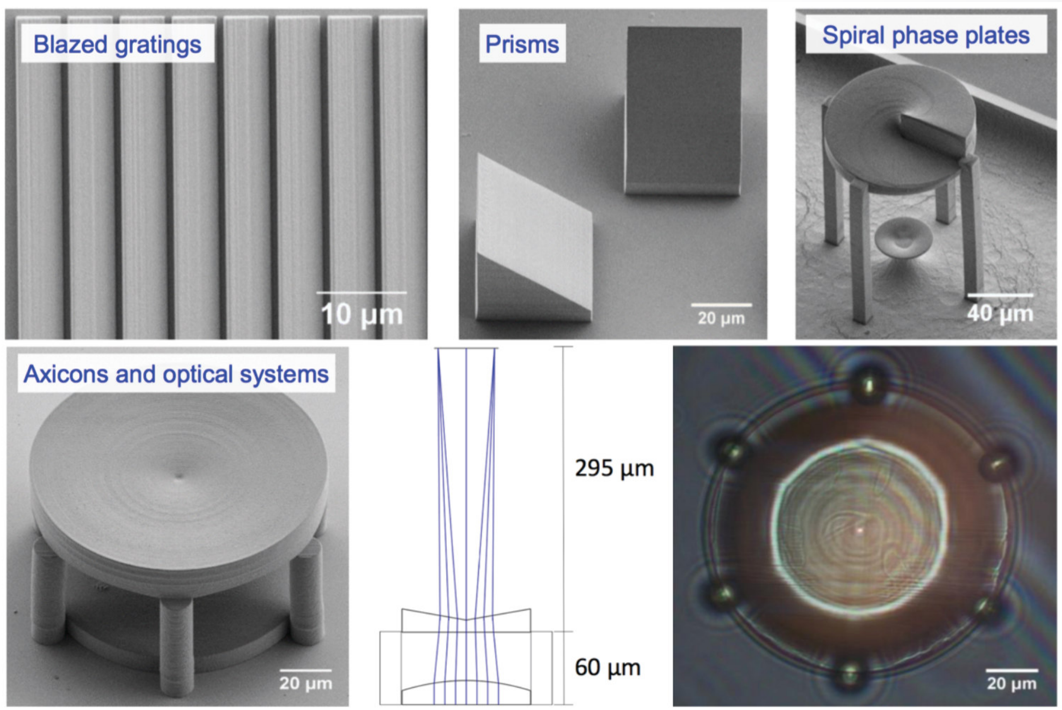


Fig. 8. Fabricated sample: Photonic wire bonds (PWB) connect the individual cores of a four-core fiber to different on-chip SOI waveguides. The PWB are up-tapered both on the MCF and on the SOI WG side to match the mode diameter to that of the fiber core and of the SOI WG, respectively. The PWB consist of a negative-tone photo-resist. At PWB 4, shape imperfections can be seen.

An aside : Other devices

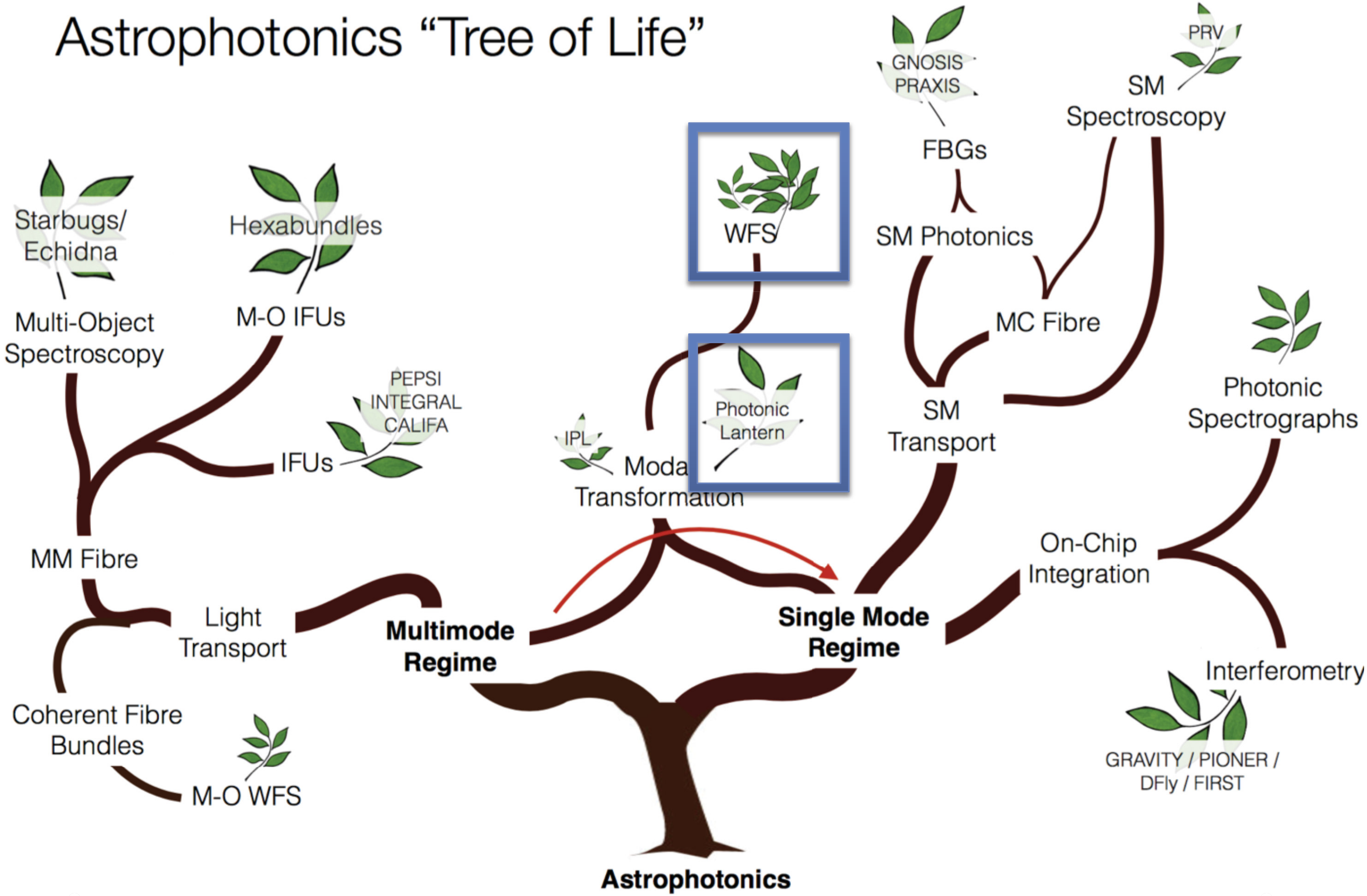
- There are other devices that can be made by 3d printing.





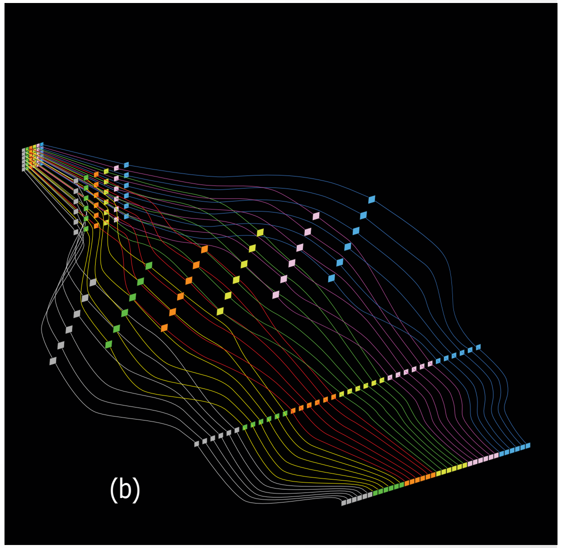
Examples from Stuttgart & KIT

Astrophotonics “Tree of Life”



Wavefront sensing?

- Could the reformatter be used for wavefront sensing?



Initial Tests

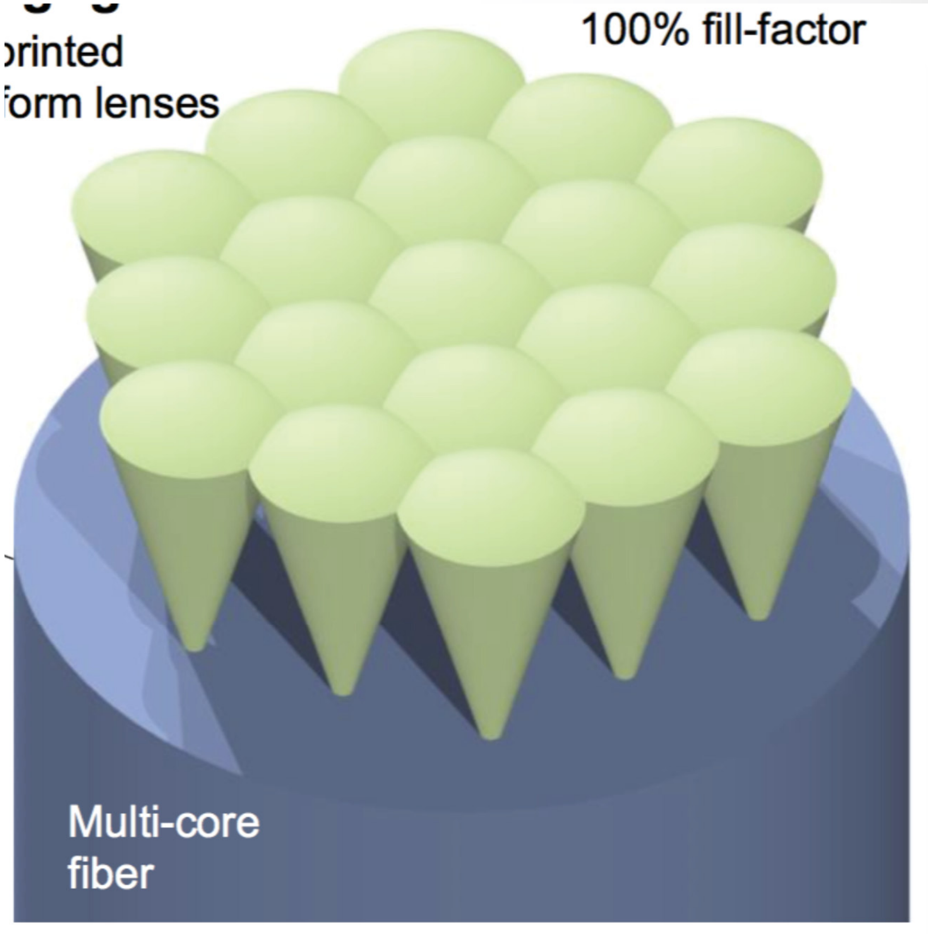
- Done by Mark Corrigan in Durham.
- Showed a very complex relationship.
- We think it may be possible, but requires a lot of redesign.

Low order LBT

- At SPIE 2016 I was approached by Notre-Dame
- They are developing Ilocator, a single mode spectrograph for LBT
- Due to vibrations in the system, they got around 20% light. Want more.
- Use a low order wavefront sensor to compensate (again Mark).

Alternative options?

- Use a more conventional approach?
- Use a multicore fibre to sense tip and tilt
- Low fill factor
- Design and manufacture a microlens array on top of a multicore fibre



Philipp Dietrich

Testing in Durham

- Similar system to CANARY experiment
- Allow tip-tilt and PSF aberrations to be sensed
- I was there for two and a half weeks setting the system up
- Currently Mark is taking more data
- More to come…

Conclusions

- Photonic reformatting is useful in certain situations
- The technology is now available, but needs to be matured
- Initial devices have been developed and tested
- Hopefully the next generation will be optimised

- The technology can also be used for wavefront sensing
- Or you can try doing it with 3d printed microlenses

- Still lots and lots to do!