Photonic dicer – Simulation & Optimisation

Credit: Zac Posen dress

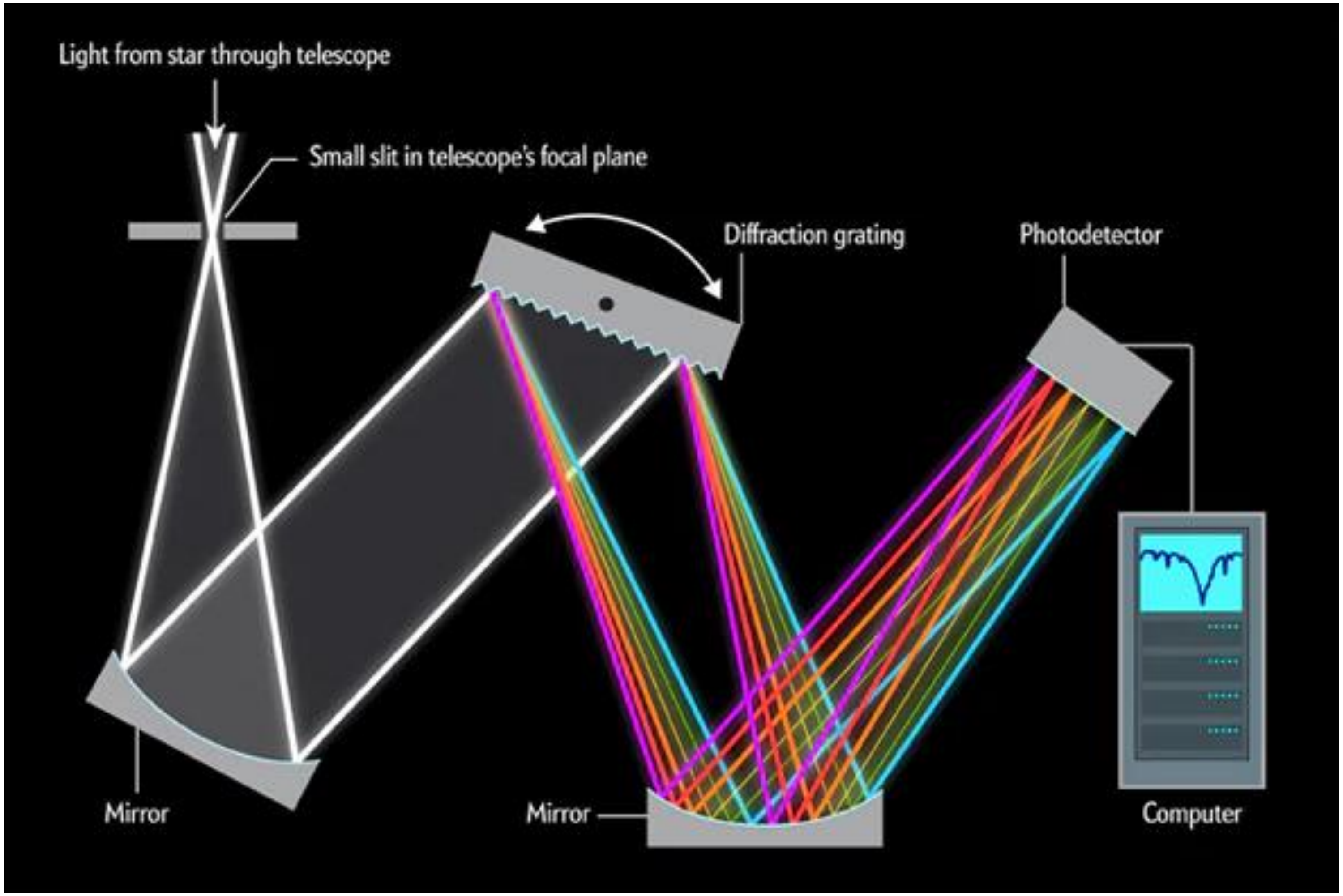
Theodoros Anagnos, Heidelberg

Haus der Astronomie, 2017

In this talk

- Basic spectrograph configuration
- What is astrophotonics and fundamentals
- The Photonic Dicer:
  - Modelling - Simulations - Optimisation
- Conclusions

Example of a spectrograph



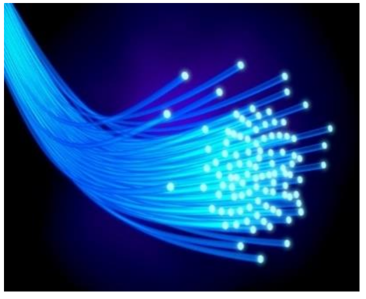
Credit: Zac www.scientificamerican.com

Resolving power – throughput relation

$$R = \frac{\lambda}{\Delta\lambda} = \frac{m\rho\lambda W}{\chi D_T}$$

- For fixed resolving power R and seeing limited slit width χ, collimated beam W must get larger as telescope D_T does
- Major costs for larger grating and parts
- Fragile
- Solution photonics!

What is Astrophotonics?


Credit: http://www.ictxwavemedia.net/

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Credit: http://deepastronomy.com/

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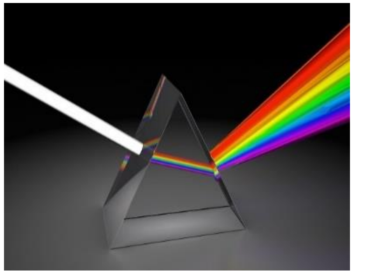
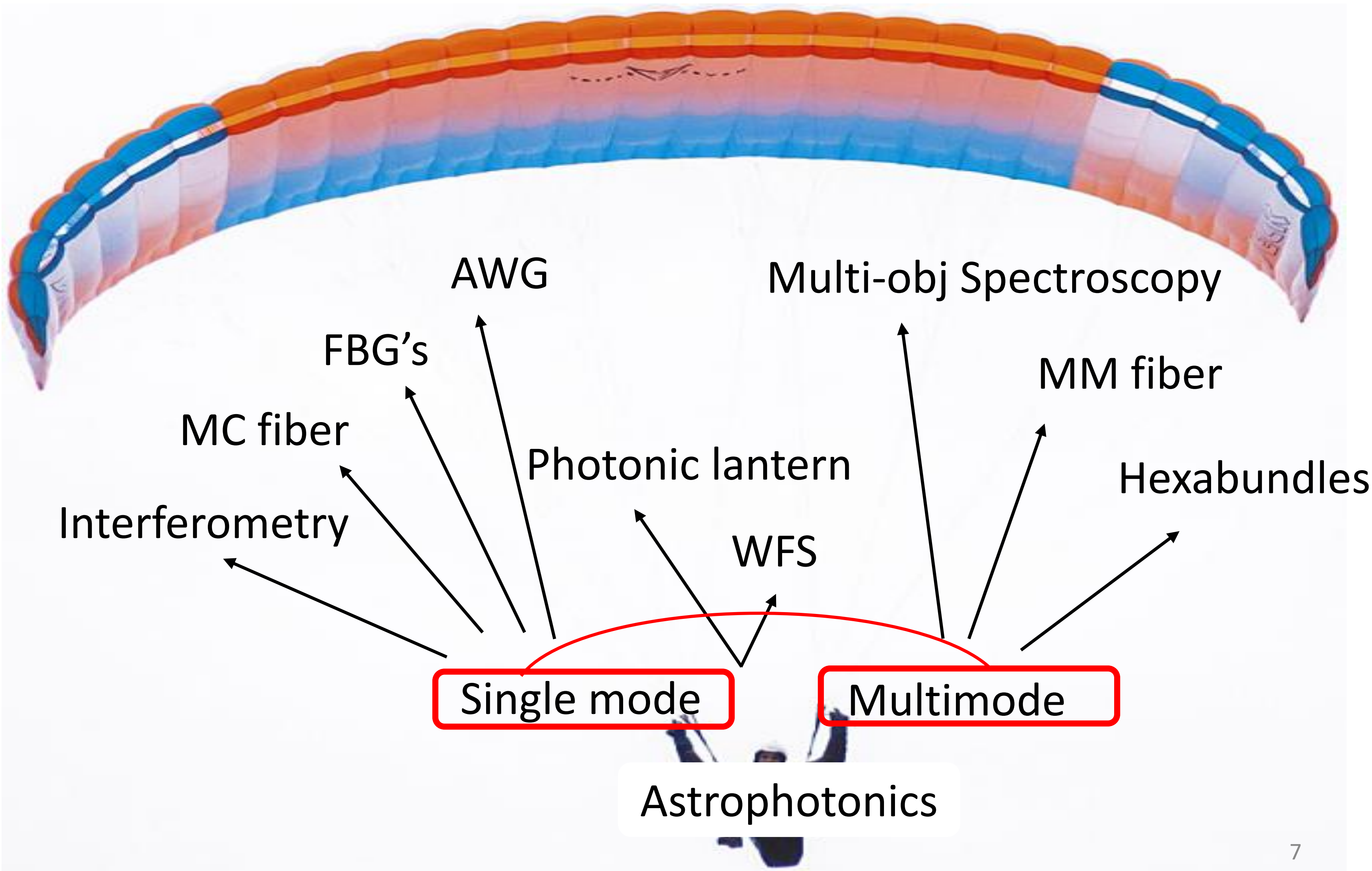

Credit: http://www.azooptics.com/

Photonics + Astronomical instrumentation = Astrophotonics

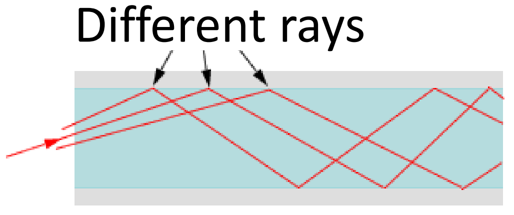
Fundamentals of Astrophotonics

Single mode – multimode connection

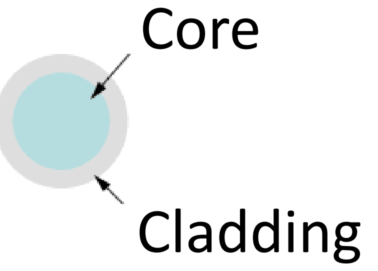


Single mode vs Multimode

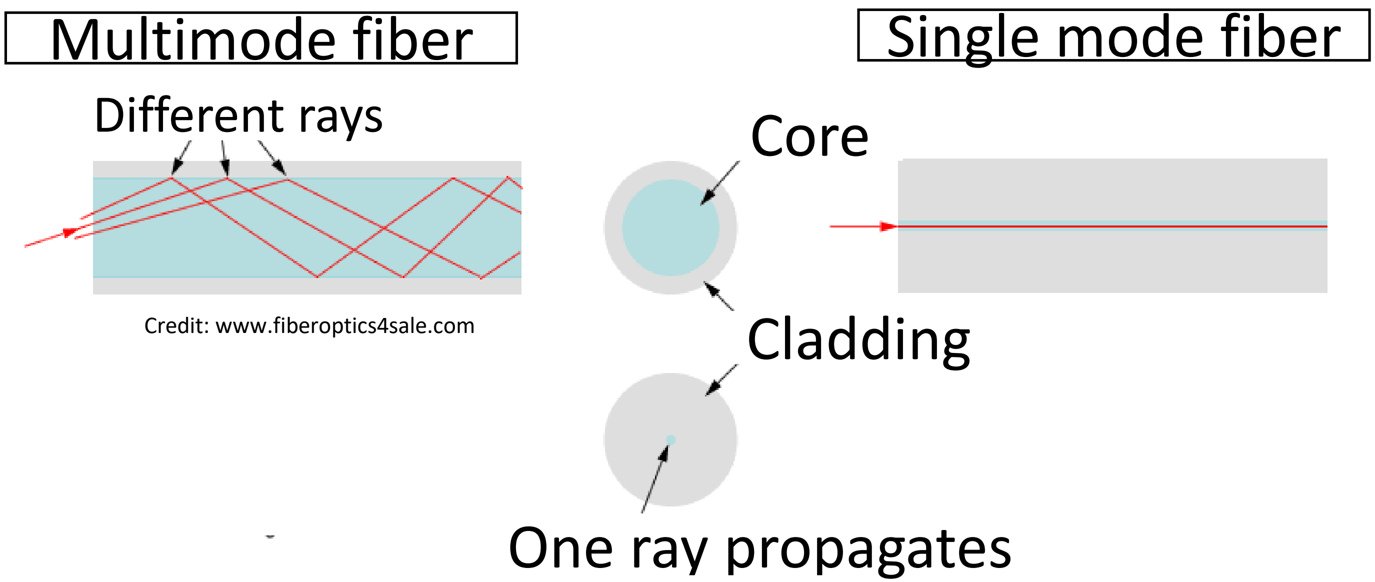
Multimode fiber



Credit: www.fiberoptics4sale.com



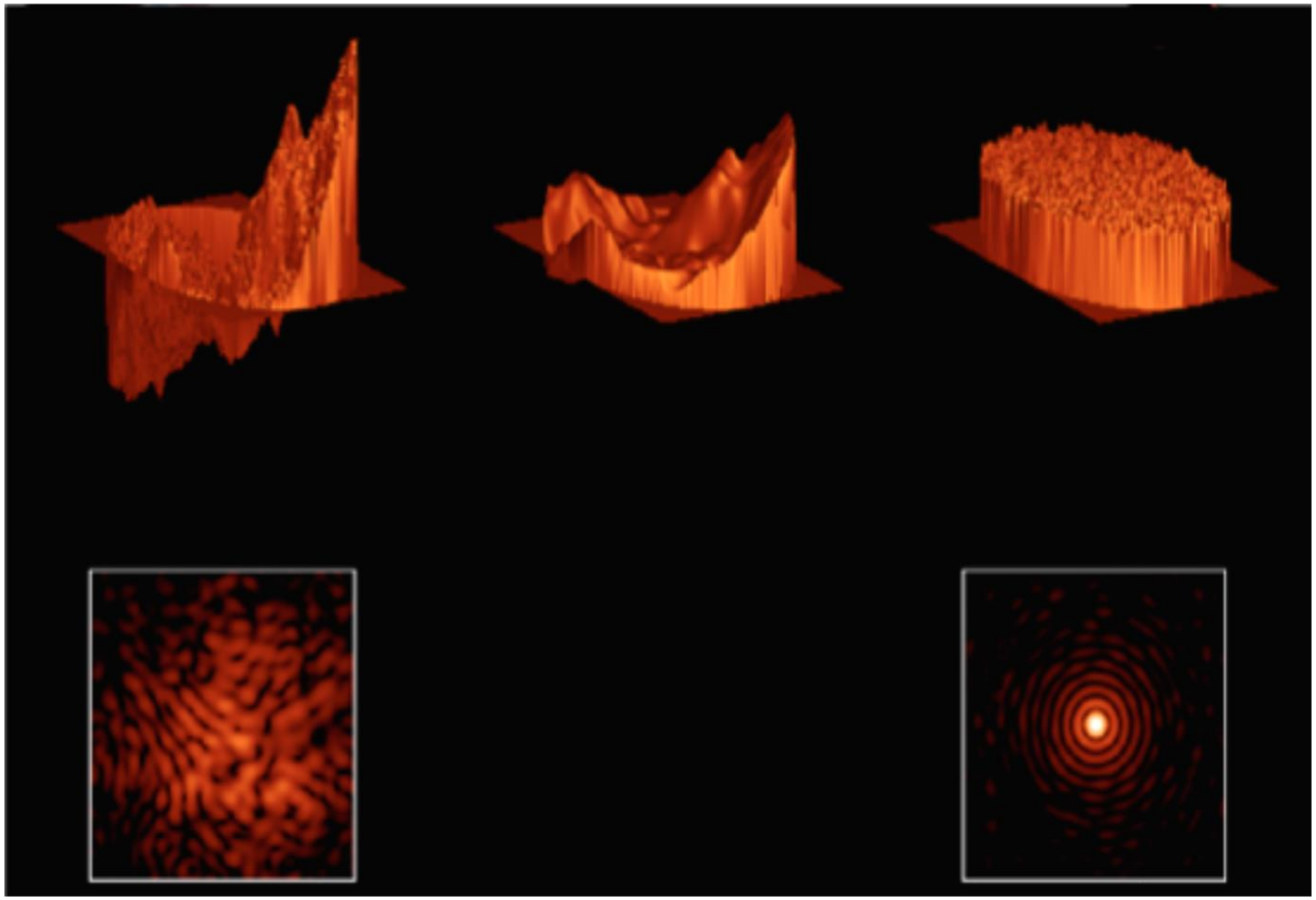
Single mode vs Multimode



Credit: www.fiberoptics4sale.com

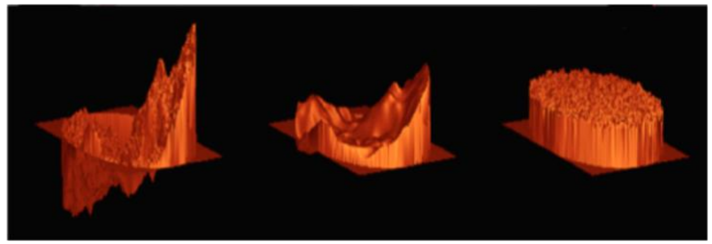
Single mode vs Multimode

Credit: J. P. Lloyd



Single mode vs Multimode – wave model

Credit: J. P. Lloyd

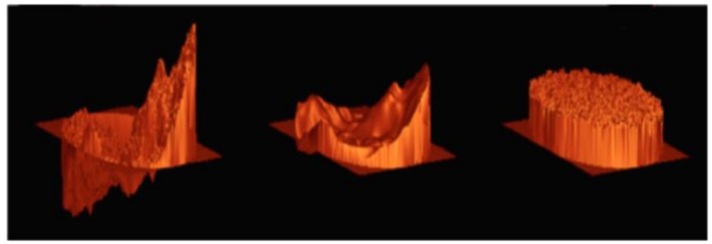


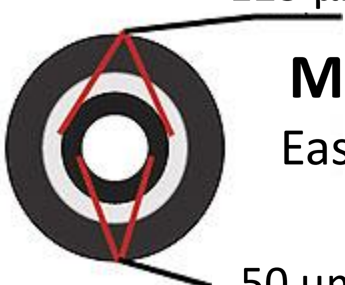
Multimode fiber

Easy coupling of light efficiently

Single mode vs Multimode – wave model

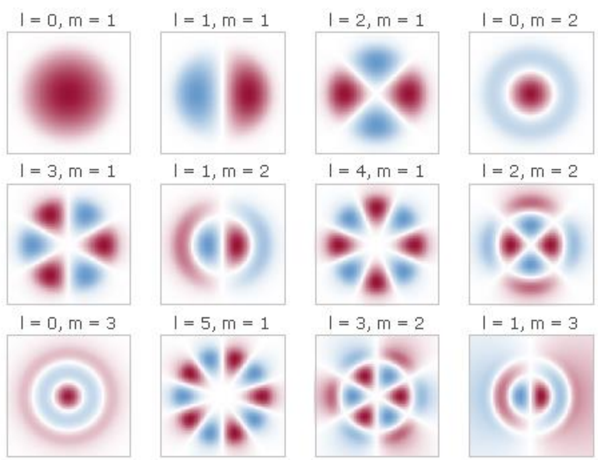
Credit: J. P. Lloyd





Multimode fiber

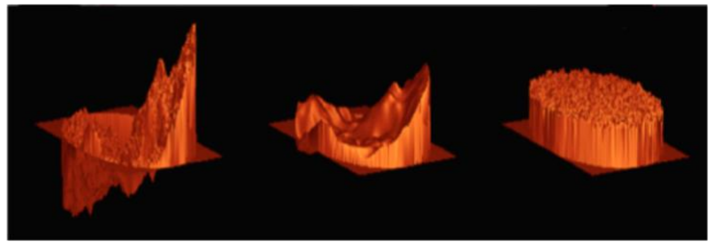
Easy coupling of light efficiently



Credit: http://www.multicominc.com

Single mode vs Multimode – wave model

Credit: J. P. Lloyd



125 µm

50 µm

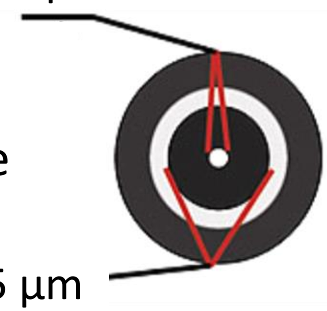
Multimode fiber

Easy coupling of light efficiently

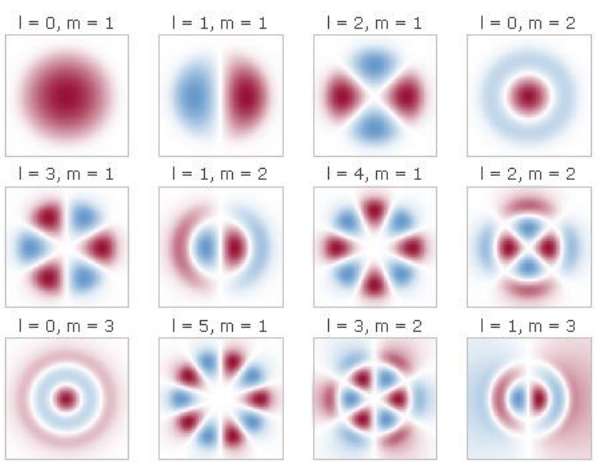
Single mode fiber

Very difficult to couple light efficiently

9 µm



125 µm



Credit: http://www.multicominc.com

Single mode vs Multimode – wave model

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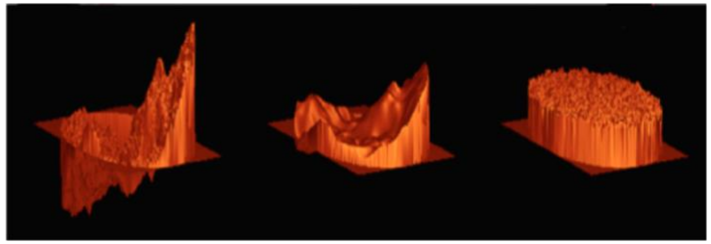

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Multimode fiber

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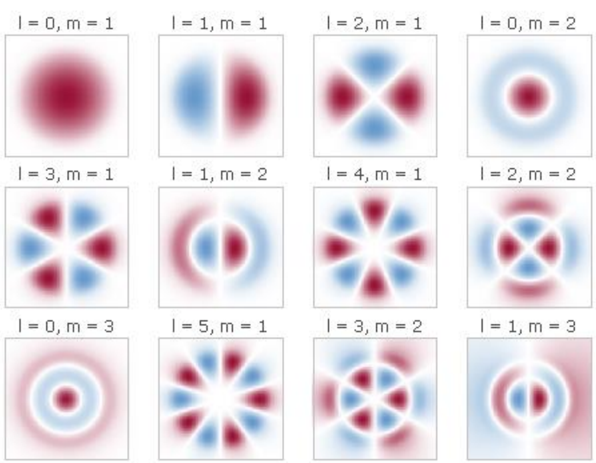
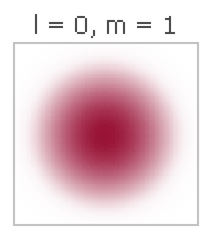
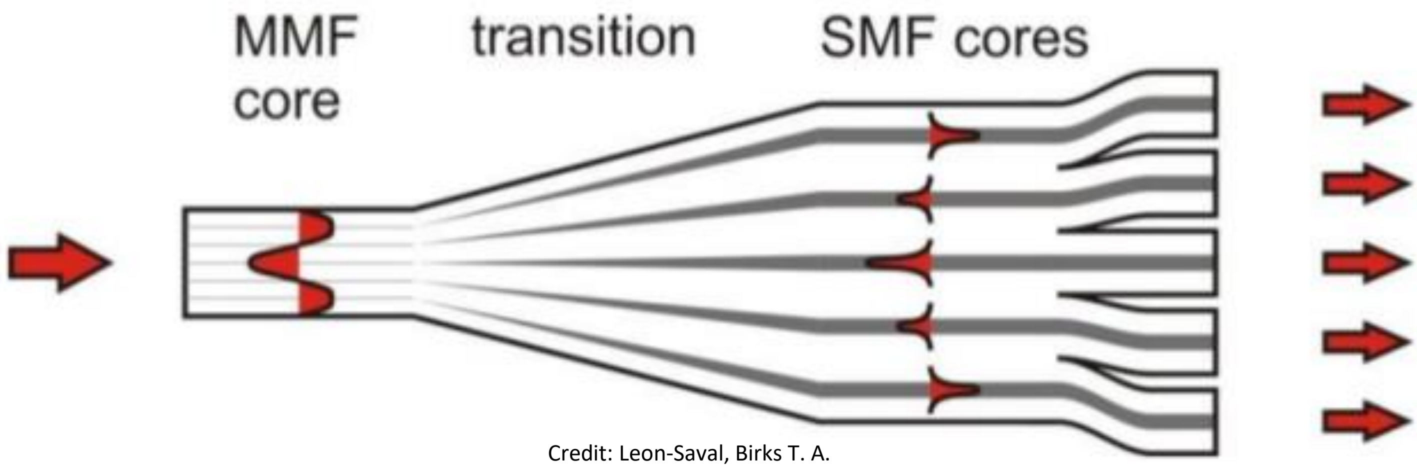




- Gaussian intensity profile
- Wavefront flat
- Stable PSF, only amplitude variations

Credit: http://www.multicominc.com

The Photonic Lantern



Credit: Leon-Saval, Birks T. A.

- Low loss conversion between one large core – several smaller cores
- If transition is gradual - long enough- low loss
- Device is reciprocal, if the number of modes remain the same
- Low demand in AO performance system

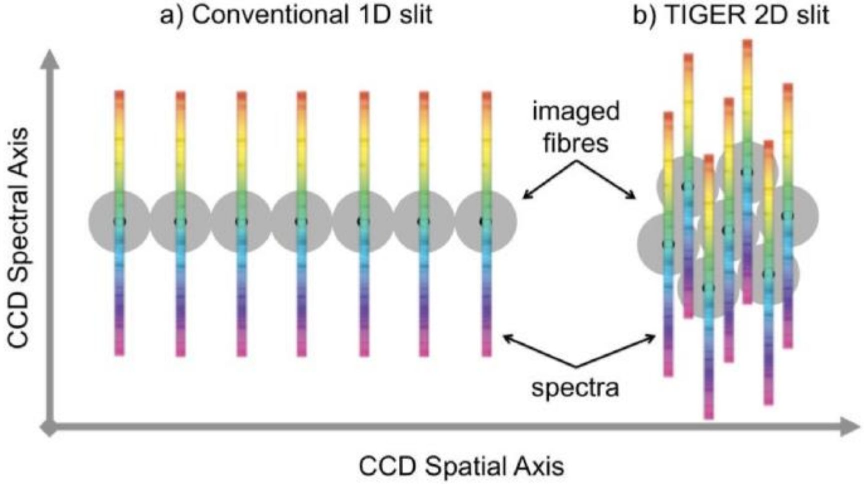
Operating in the Single Mode regime

<u>Why?</u>

- Elimination of modal noise in spectrograph
- More precise calibration of measurements
- Exploiting advantages of photonics working in SM

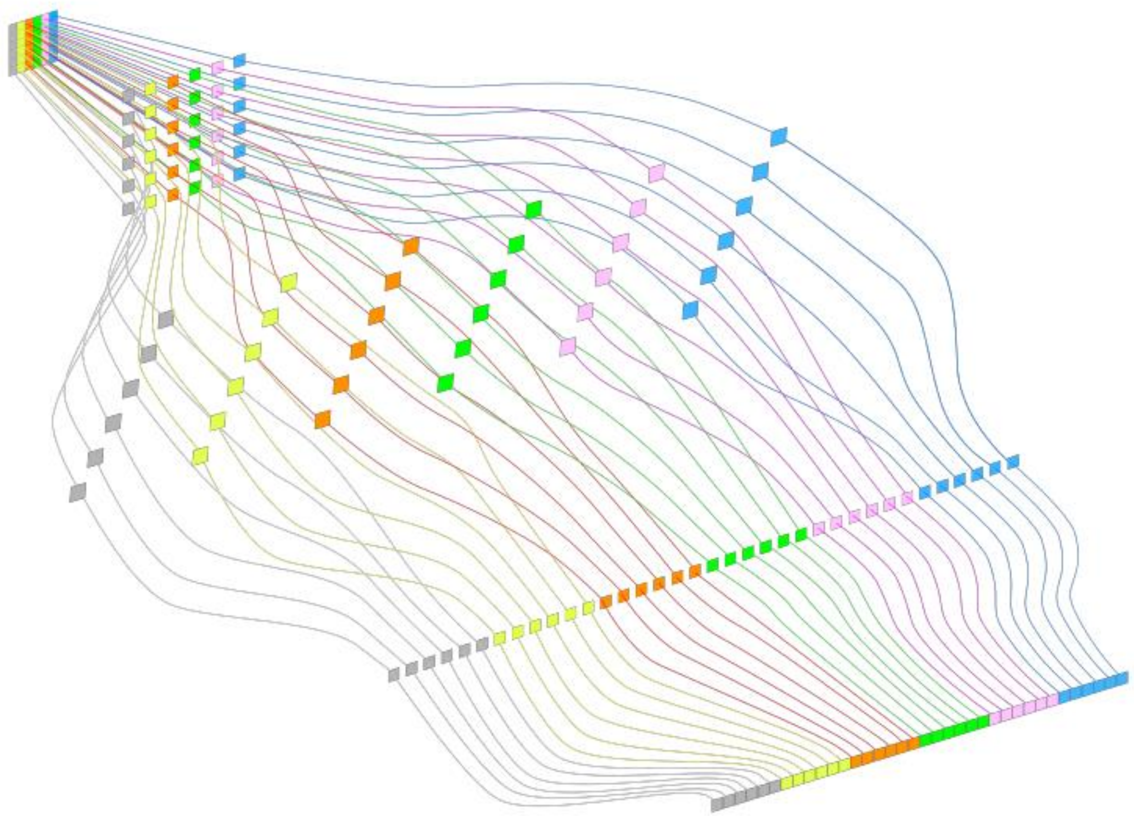
<u>Examples:</u>

Astrophotonic reformatters, multicore fibers, SM fibers!



Credit: Bland-Hawthorn et al. 2010

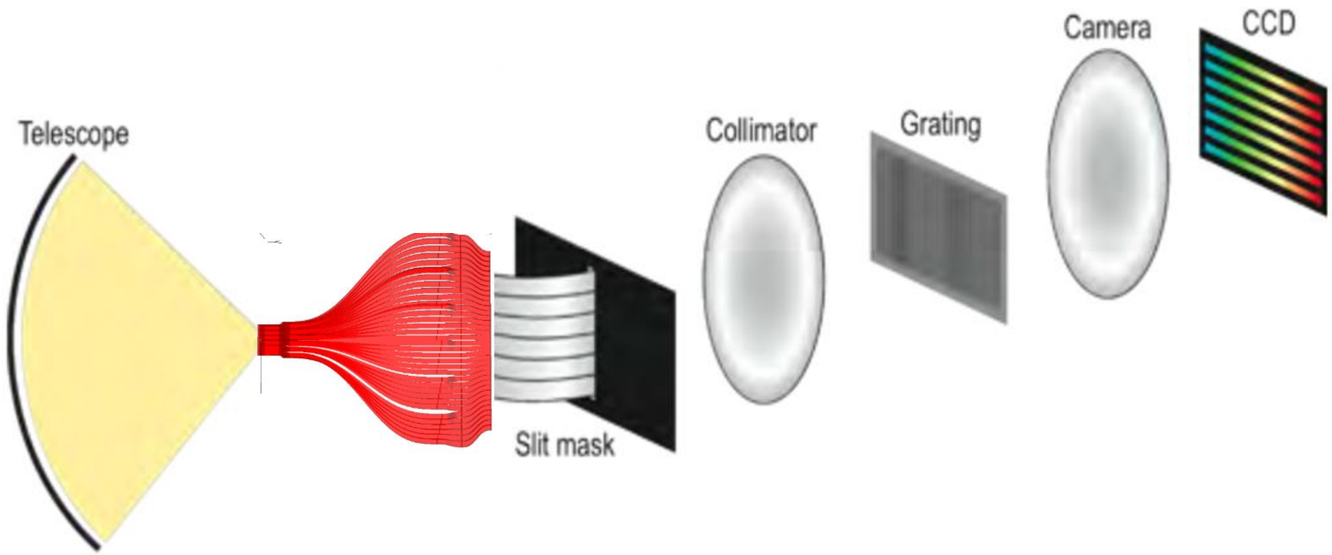
The Photonic Dicer - an astrophotonic reformatter



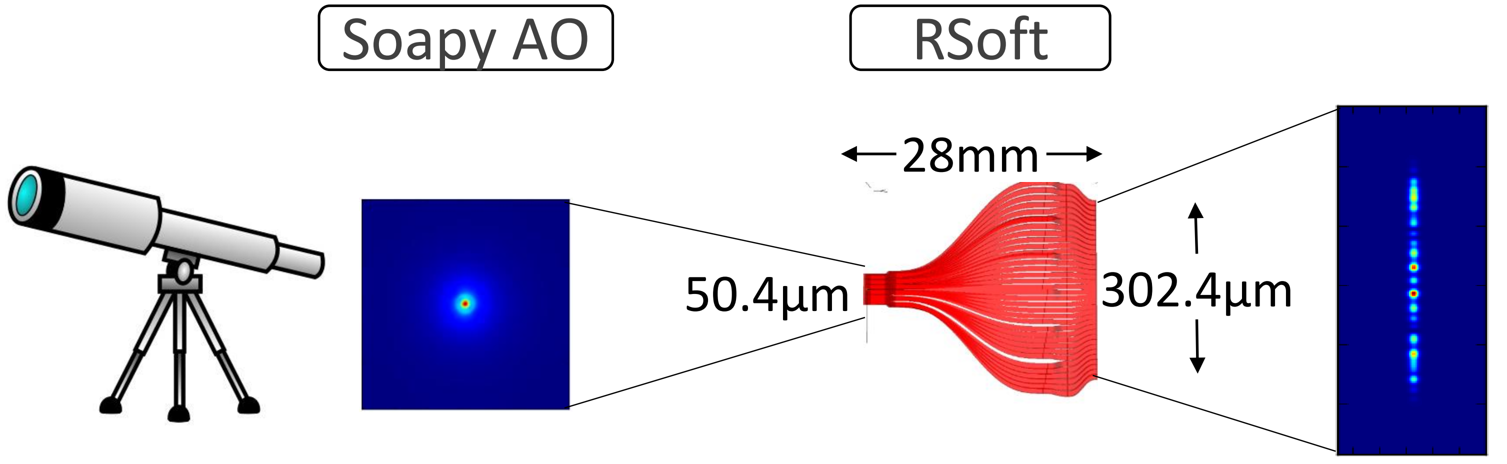
Credit: Harris R.J., MacLachlan D.G. et all. 2015

Modelling & results

The Photonic Dicer with spectrographs



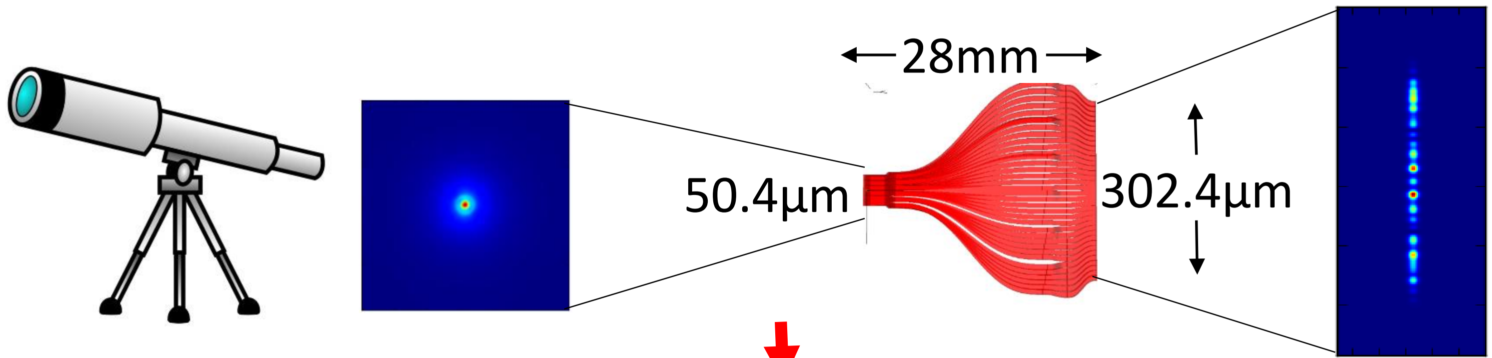
Simulations Layout



Simulations Layout

Soapy AO

RSoft



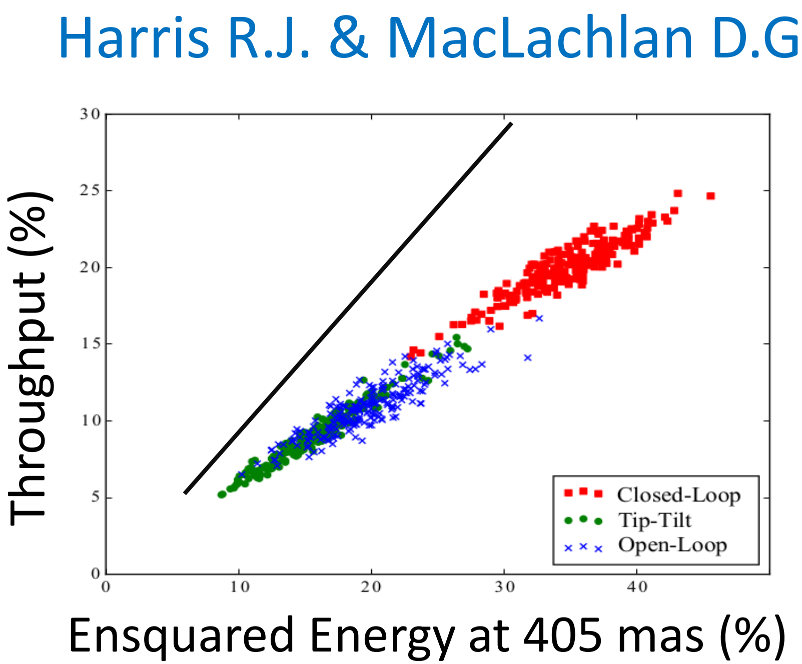
Dicer optimisation

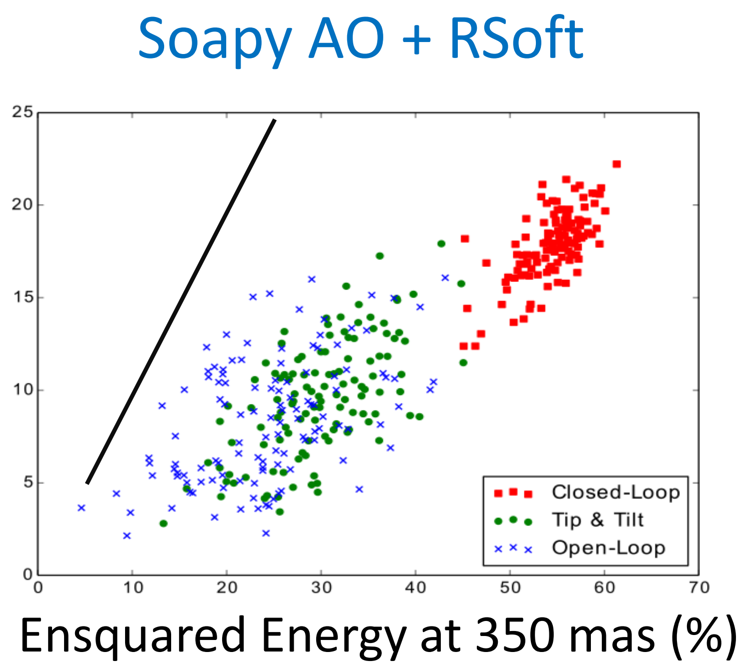
Waveguides shape

Better entrance design to couple modes

Planes position

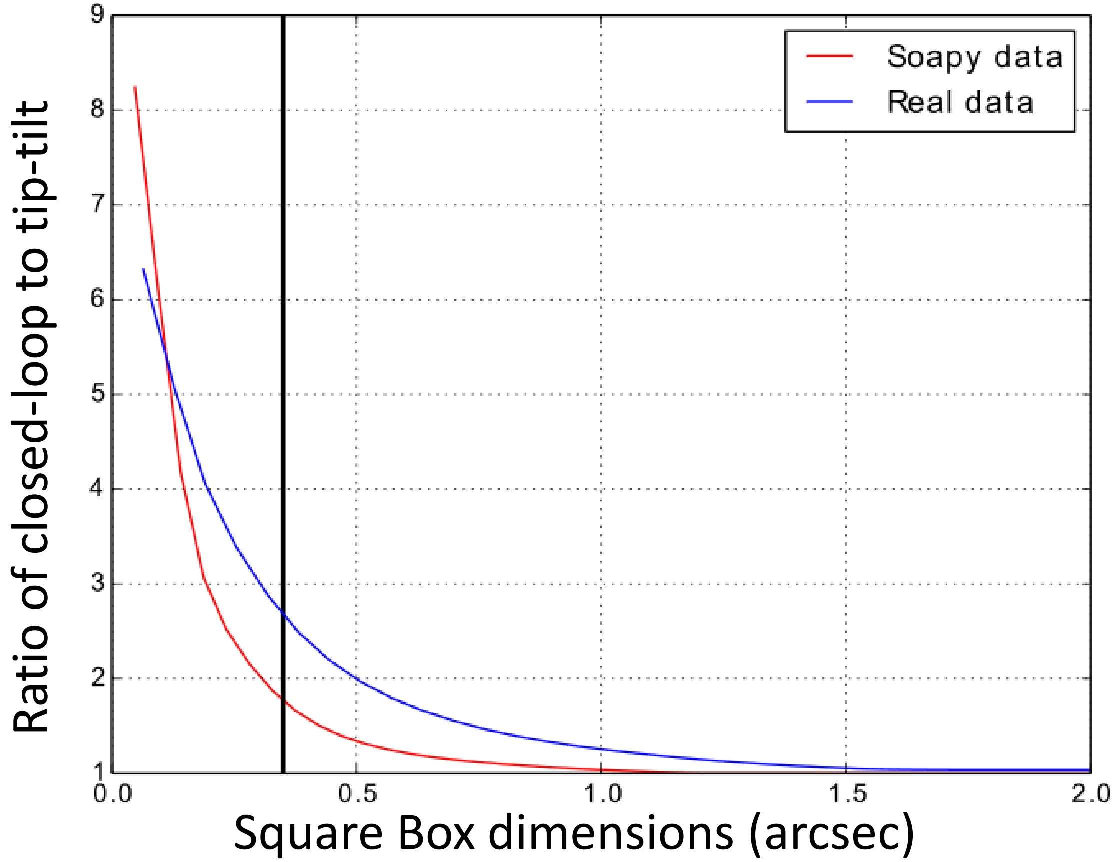
Preliminary Results - Throughput





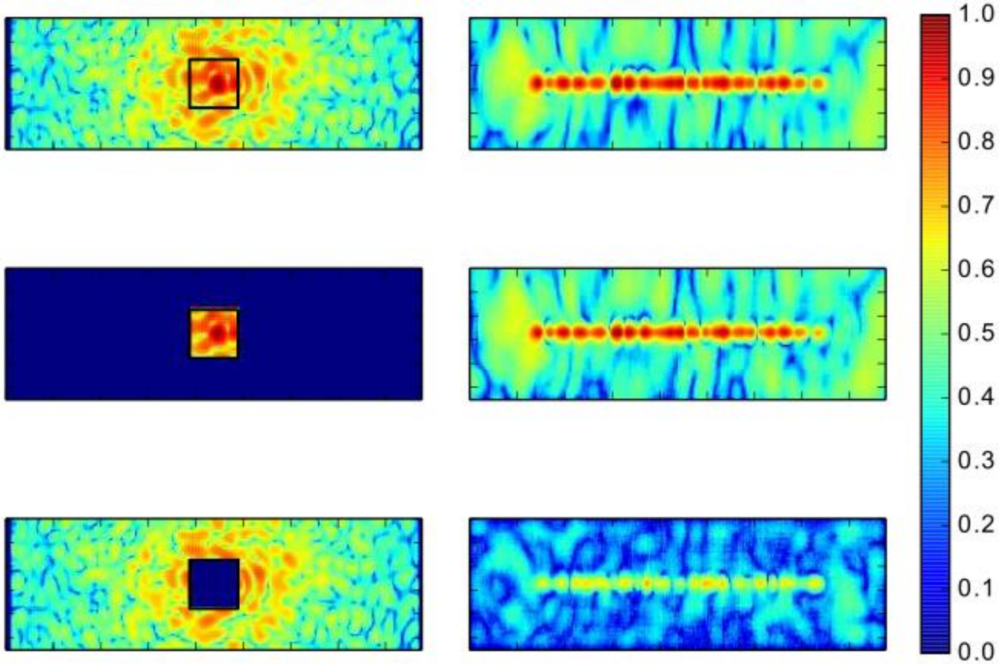
	On-sky	Soapy + Rsoft
Closed-Loop (%)	19.5 ± 2	17.8 ± 3
Open-Loop (%)	10.5 ± 2	8.4 ± 3
Tip & Tilt (%)	9 ± 2	9.6 ± 3

Preliminary Results – AO performance



AO performances not matched!

The Photonic Dicer – coupling of evanescent field



EE - Throughput

(1) 57.08% - 22.6%

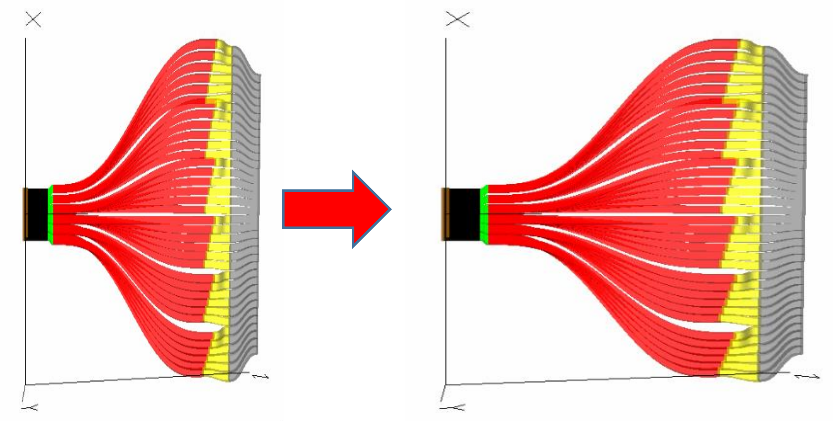
(2) 57.08% - 38.16%

(3) 42.91% - 1.9%

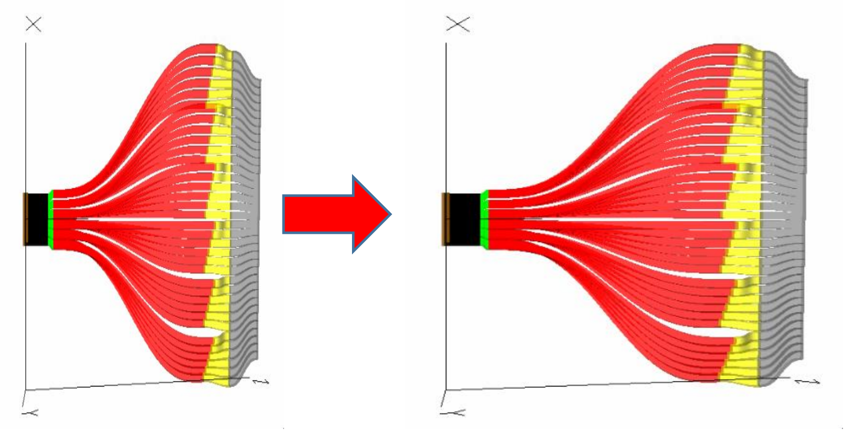
EE 2 x T 2 + EE 3 x T 3 = T 1

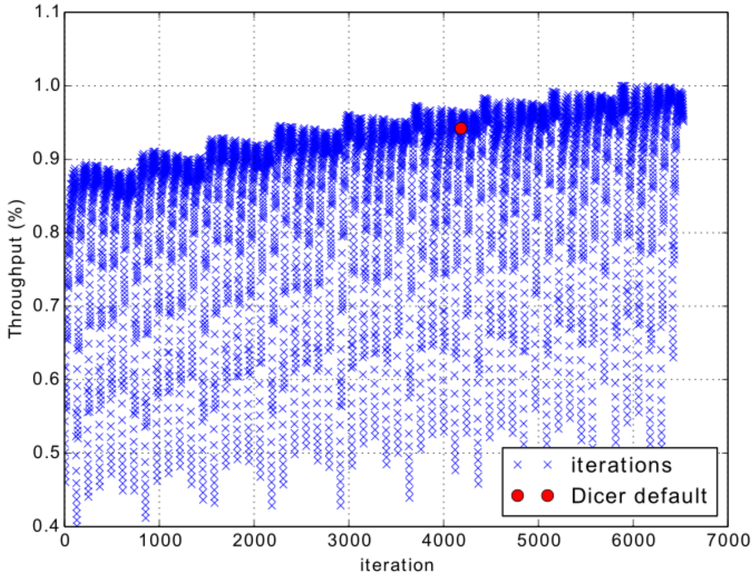
57.08% x 38.16 + 42.91% x 1.9% = 22.6%

Photonic Dicer Optimisation - transition planes



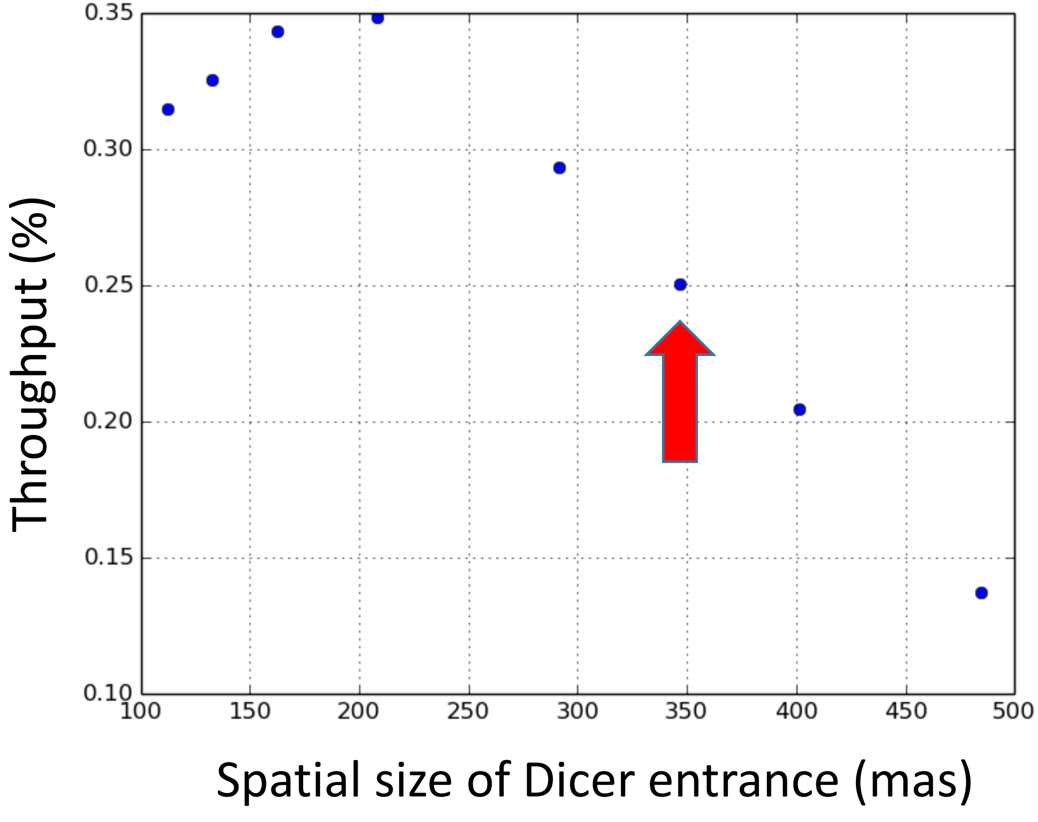
Photonic Dicer Optimisation - transition planes



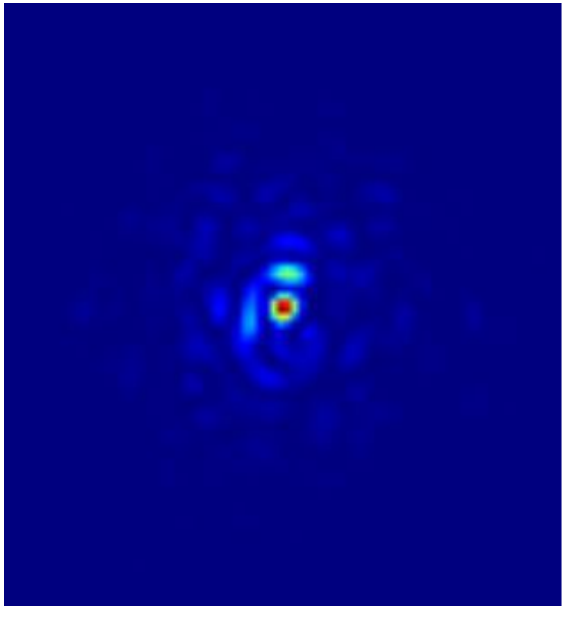


Geometric re-arrangement of planes improve throughput by 6.4%

Photonic Dicer Optimisation - magnification



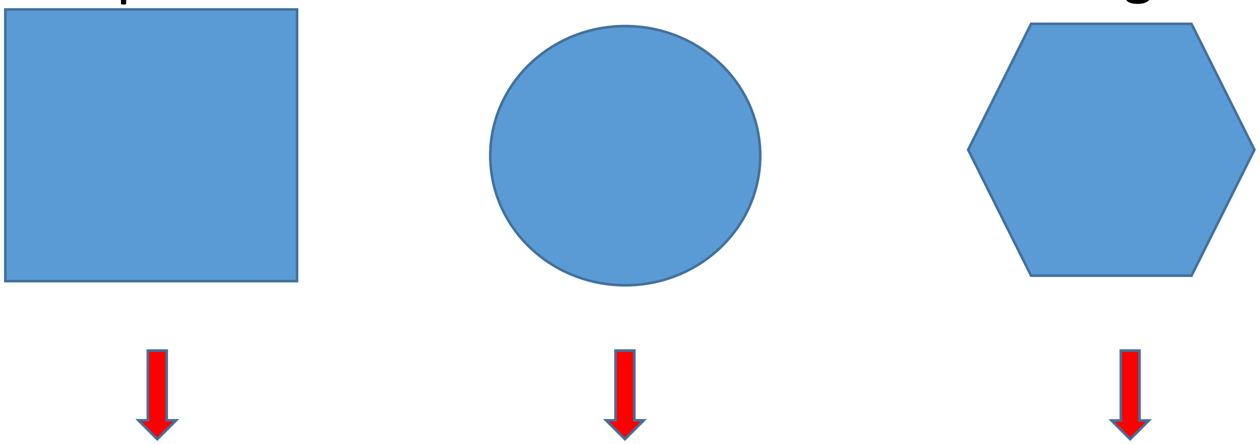
Input field (I)



Photonic Dicer Optimisation- Geometry of fibers

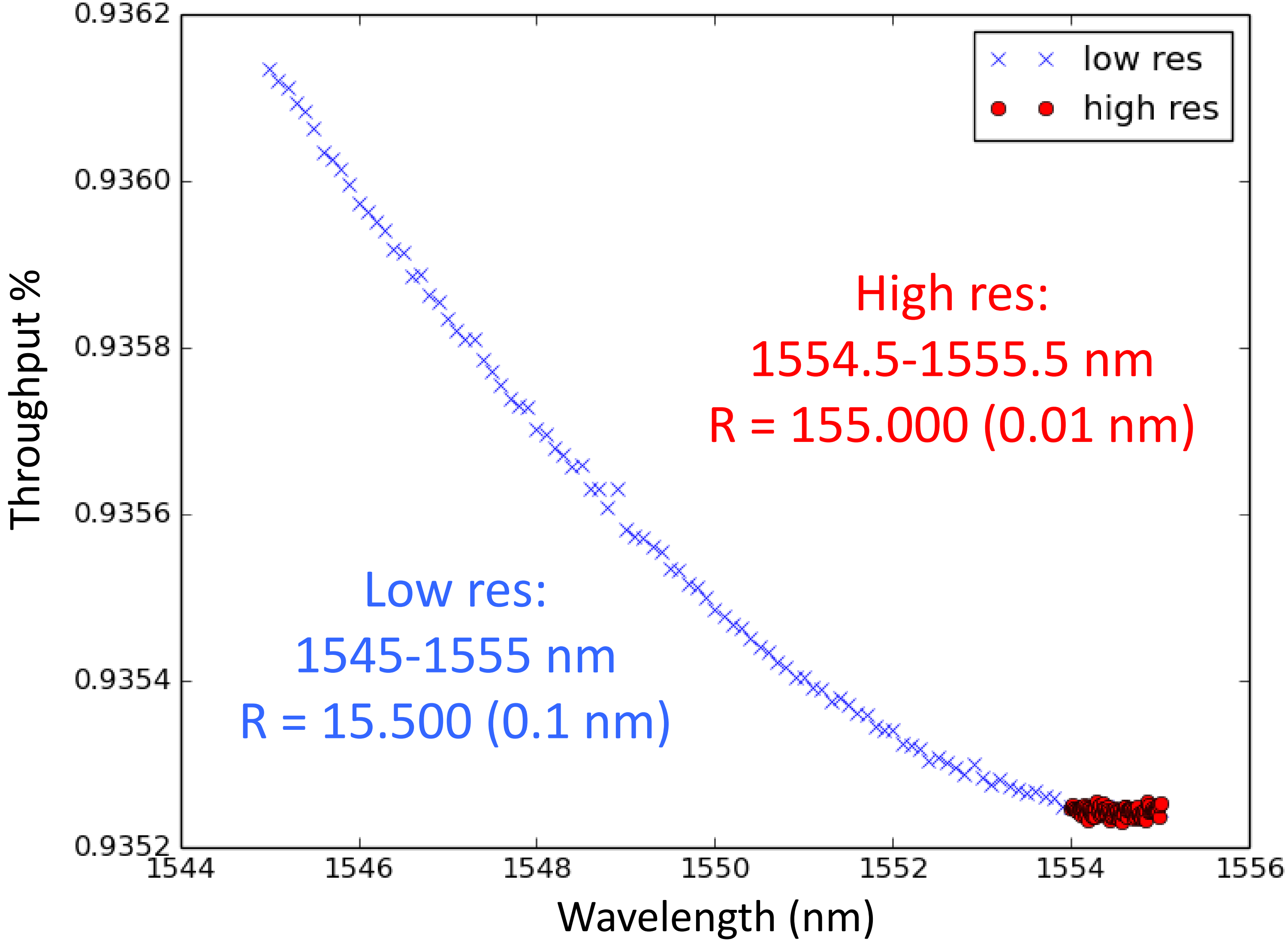
Throughput

Square | Circle | Hexagonal



94.69% | 96.45% | 93.61%

The Photonic Dicer - modal noise free



Conclusions

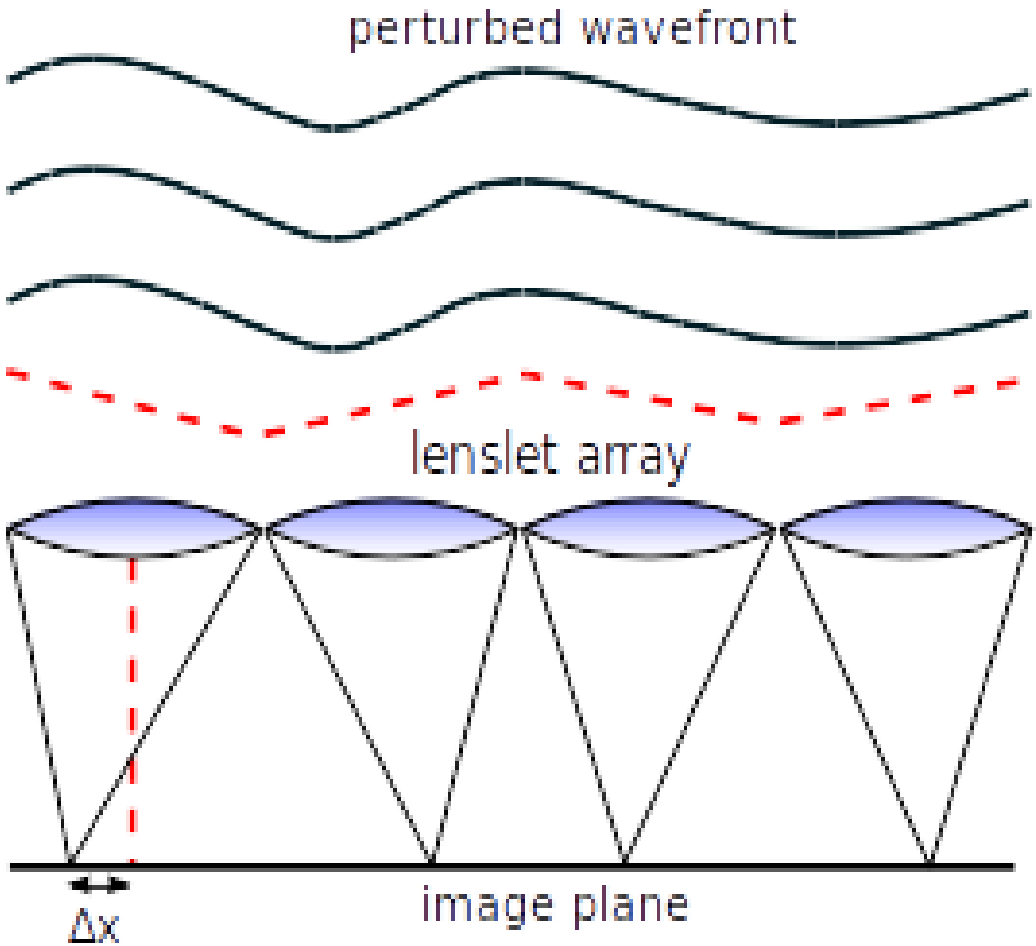
- We theoretically test Photonic Dicer
- Preliminary results were strange, but we found an explanation
- We have further optimised using the knowledge
- Soapy and RSoft are powerful tools for modelling astrophotonic devices, useful for future tests

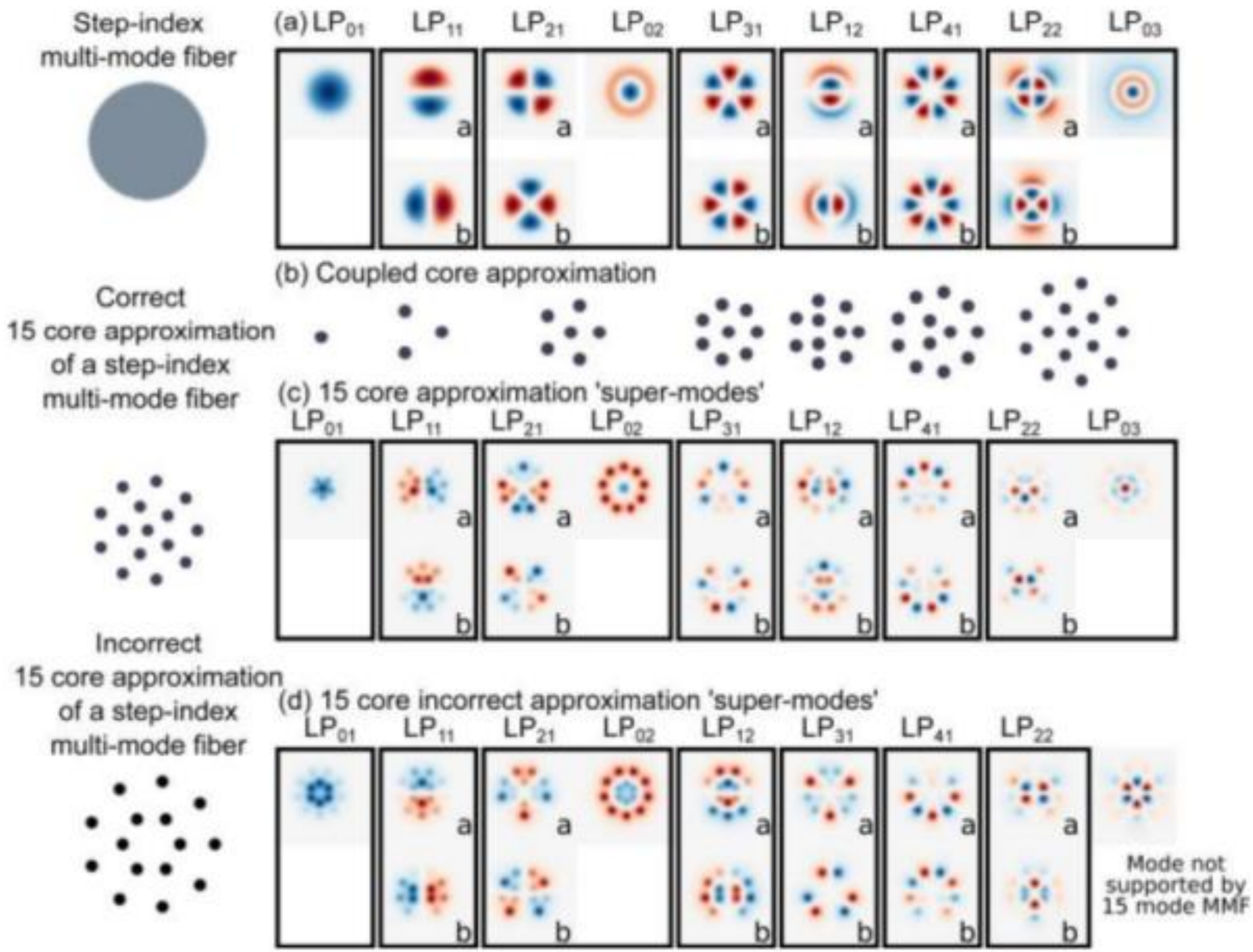
Resolving power – throughput relation

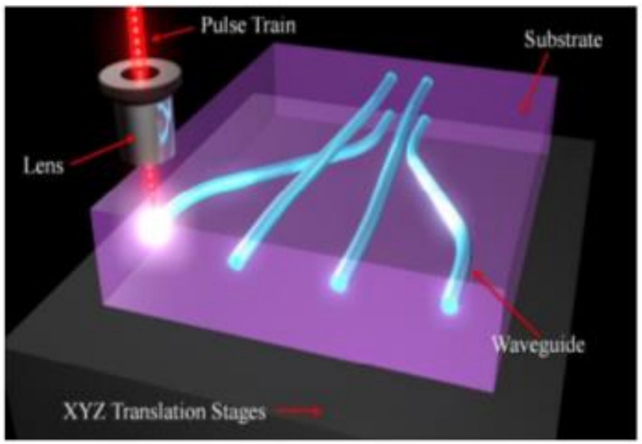
$$R = \frac{\lambda}{\Delta\lambda} = \frac{m\rho\lambda W}{\chi D_T}$$

λ = central wavelength of observation
$\Delta\lambda$ = smallest distinguished wavelength difference

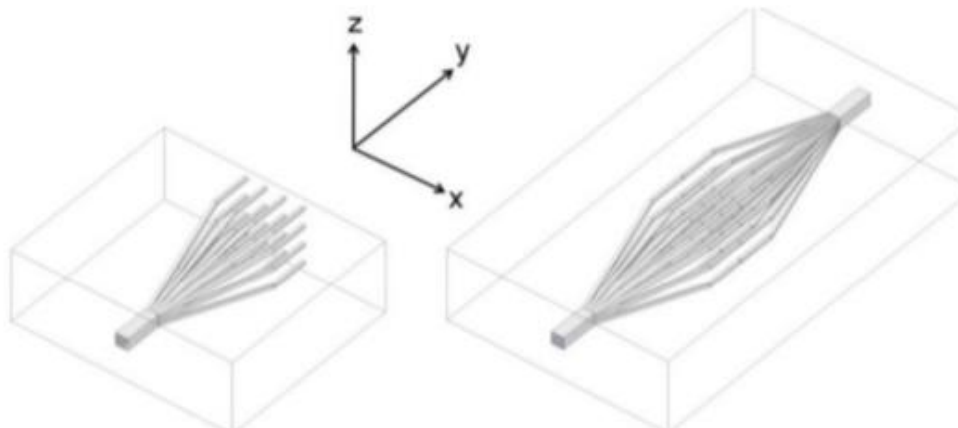
m = diffraction order
ρ = grating ruling density (mm −1)
W = length of grating illuminated
χ = seeing
D_T = diameter of telescope


perturbed wavefront
lenslet array
image plane
Δx


Step-index multi-mode fiber
(a) LP01 LP11 LP21 LP02 LP31 LP12 LP41 LP22 LP03
a
b
Correct 15 core approximation of a step-index multi-mode fiber
(b) Coupled core approximation
(c) 15 core approximation 'super-modes'
LP01 LP11 LP21 LP02 LP31 LP12 LP41 LP22 LP03
Incorrect 15 core approximation of a step-index multi-mode fiber
(d) 15 core incorrect approximation 'super-modes'
LP01 LP11 LP21 LP02 LP12 LP31 LP41 LP22
Mode not supported by 15 mode MMF


Pulse Train
Substrate
Lens
Waveguide
XYZ Translation Stages

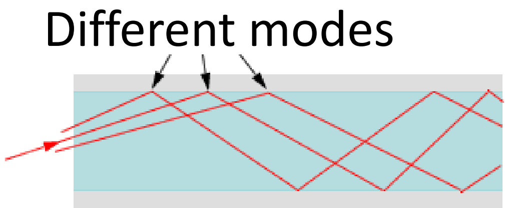
(a)


z
y
x

(b)

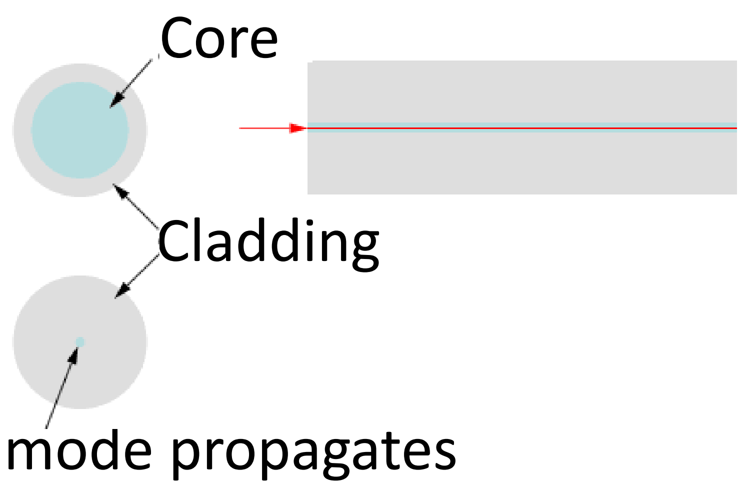
Single mode vs Multimode – ray model

Multimode fiber



Credit: www.fiberoptics4sale.com

Single mode fiber

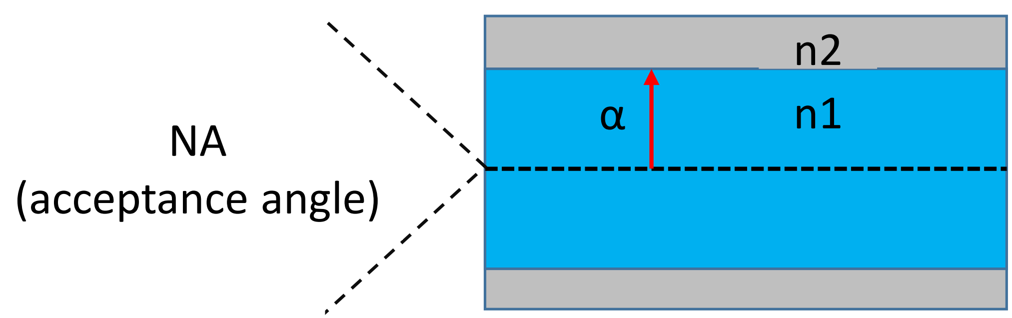


Normalised Frequency / V number

$$V = \frac{2\pi\alpha}{\lambda}\sqrt{n_1^2 - n_2^2} = \frac{2\pi\alpha}{\lambda} NA$$

Number of supported modes

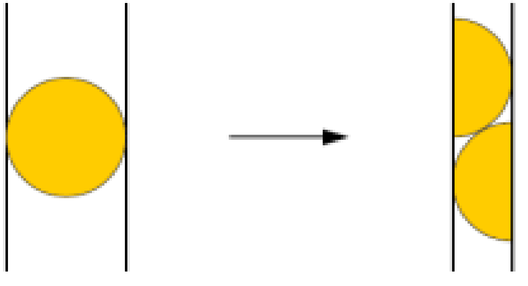
$$M = \sim \frac{4V^2}{\pi^2}$$



Suggested solutions

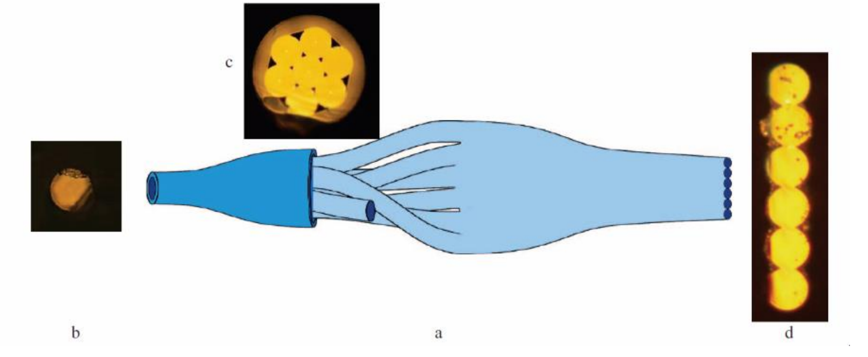
Image slicer

+ High throughput
- Modal noise
- Dificult align

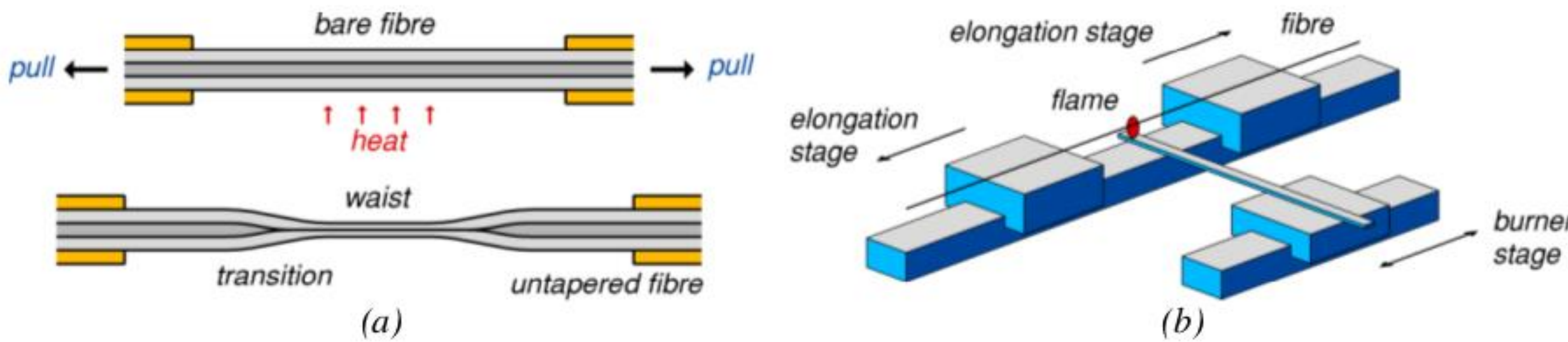


Astrophotonic Reformatters

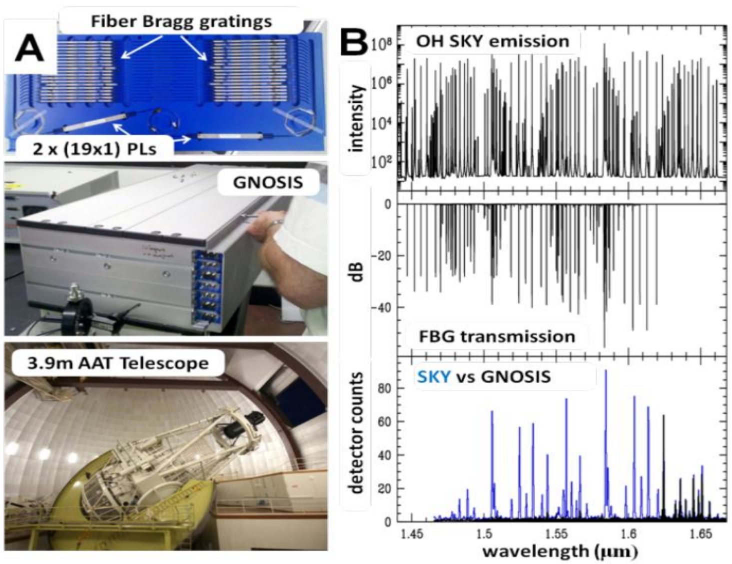
+ Easy to align
+ Elimination of modal noise
+ Free geometry
- Moderate throughput



Credit: Yerolatsitis et al 2016


bare fibre
pull
pull
heat
waist
transition
untapered fibre
(a)
elongation stage
fibre
flame
elongation stage
burner stage
(b)

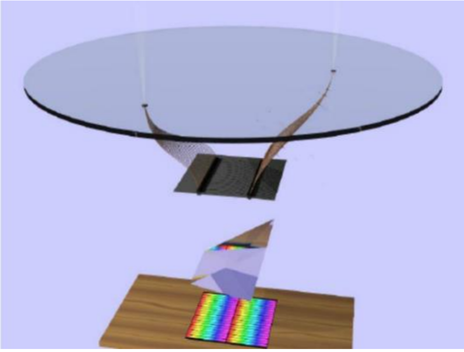
- OH Background Suppression
  GNOSIS-PRAXIS AAT



- Space Applications

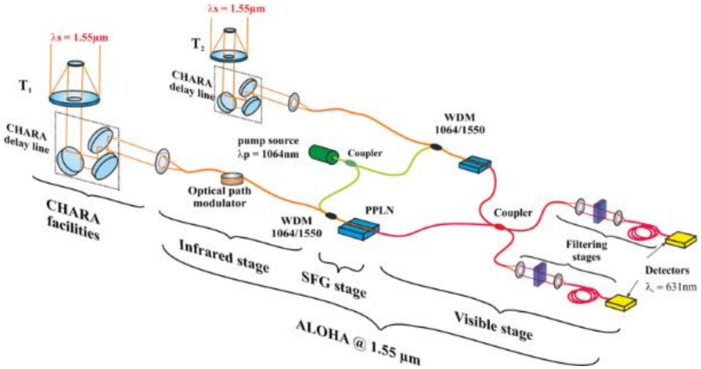
Credit: Montana State University/NASA

- Integral field spectroscopy-eg. SAMI AAO



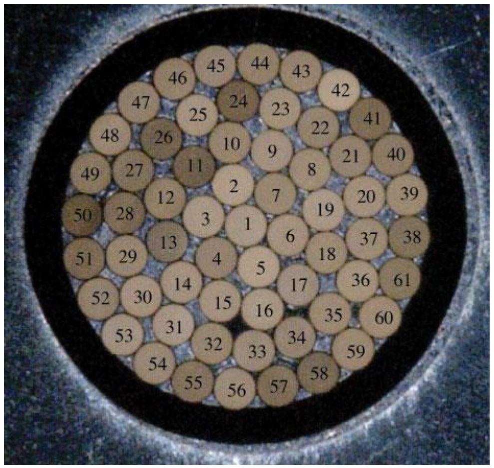
Credit: researchgate.net

- Interferometry



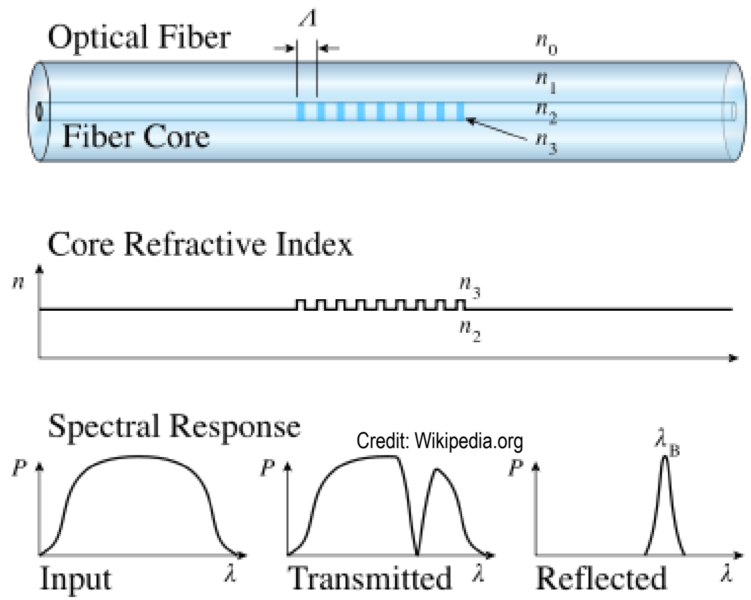
Credit: P. Darré et al., Phys. Rev. Lett. (2016)

- Hexabundle fibres AAT



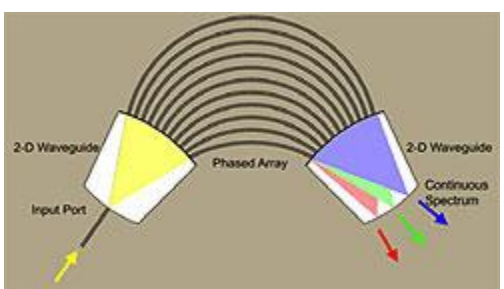
Credit: sydney.edu.au

- Fibre Bragg gratings



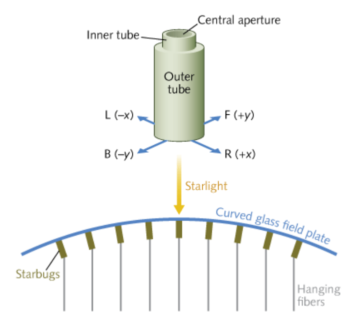
Credit: Wikipedia.org

- Array Waveguide Grating

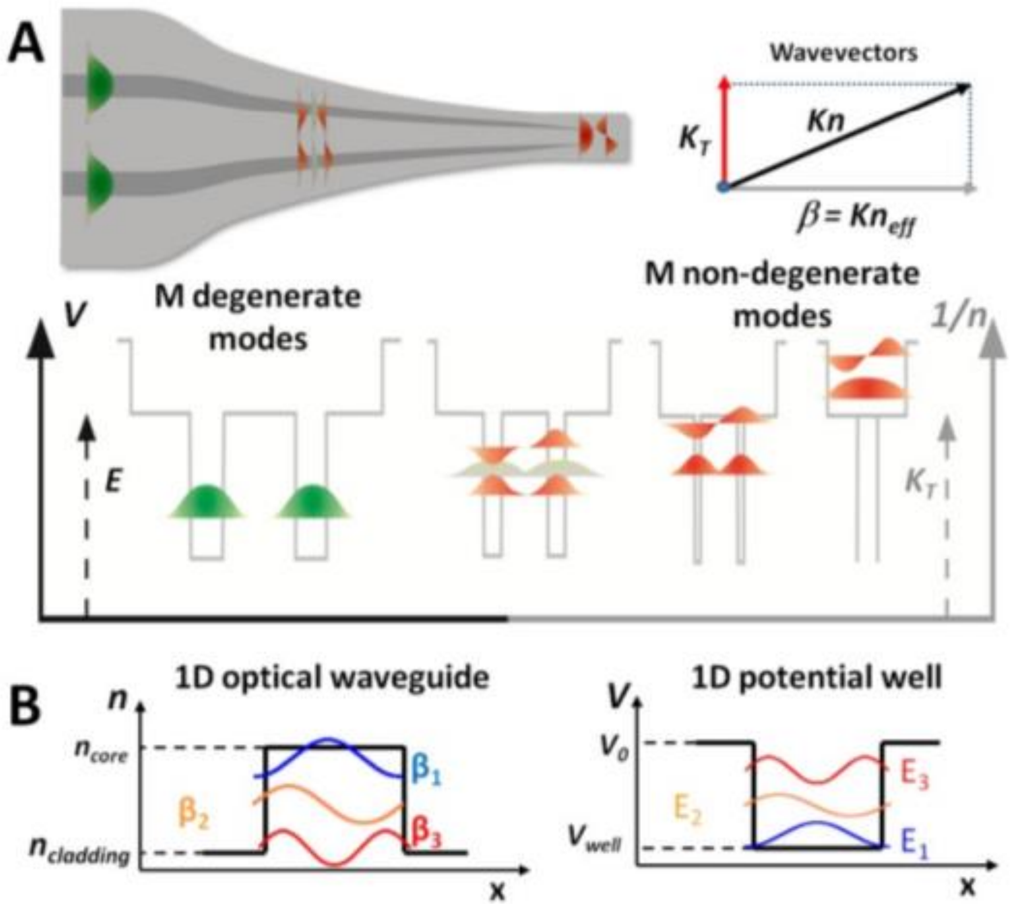


Credit: sydney.edu.au

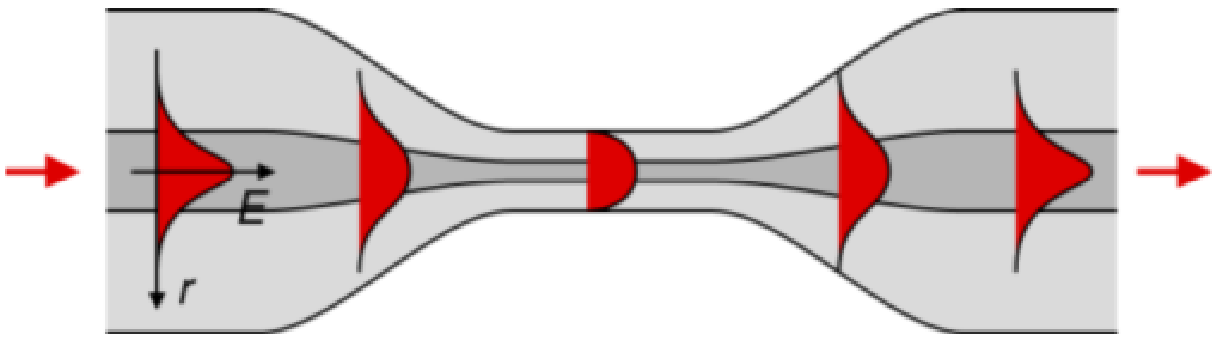
- Fibre Positioning Technology



Credit: AAT



Credit: Leon-Saval S.G. et al.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