Physics Department
Technion - Israel Institute of Technology

TECHNION Israel Institute of Technology Department of Physics | COMPUTATIONAL Physics Group

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From Schrödinger equation to telescope design

Odeia Moshkovich, Joan Adler, Erez N Ribak

Large telescopes give the best images, but large single mirror telescopes are impractical. The alternatives, multiple-aperture or segmented telescopes, such as the James Webb Space Telescope require algorithms to place the segments and phase them so they give clear images. One physics-inspired approach maps the apertures onto a crystal surface which is equivalent to a surface roughening model (Fig. 1). A lab model was built to show its properties (Fig. 2).

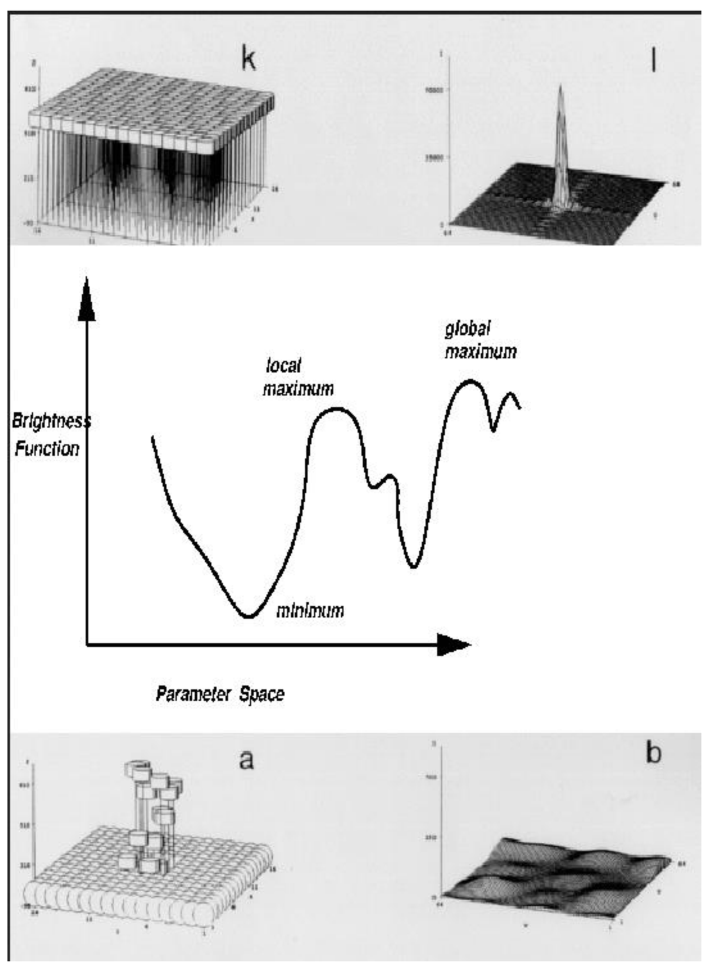

Fig. 1. A phased surface and its image at top, an energy function in the middle and an unphased surface and image at the bottom [1]. The images are the power spectra of the apertures.

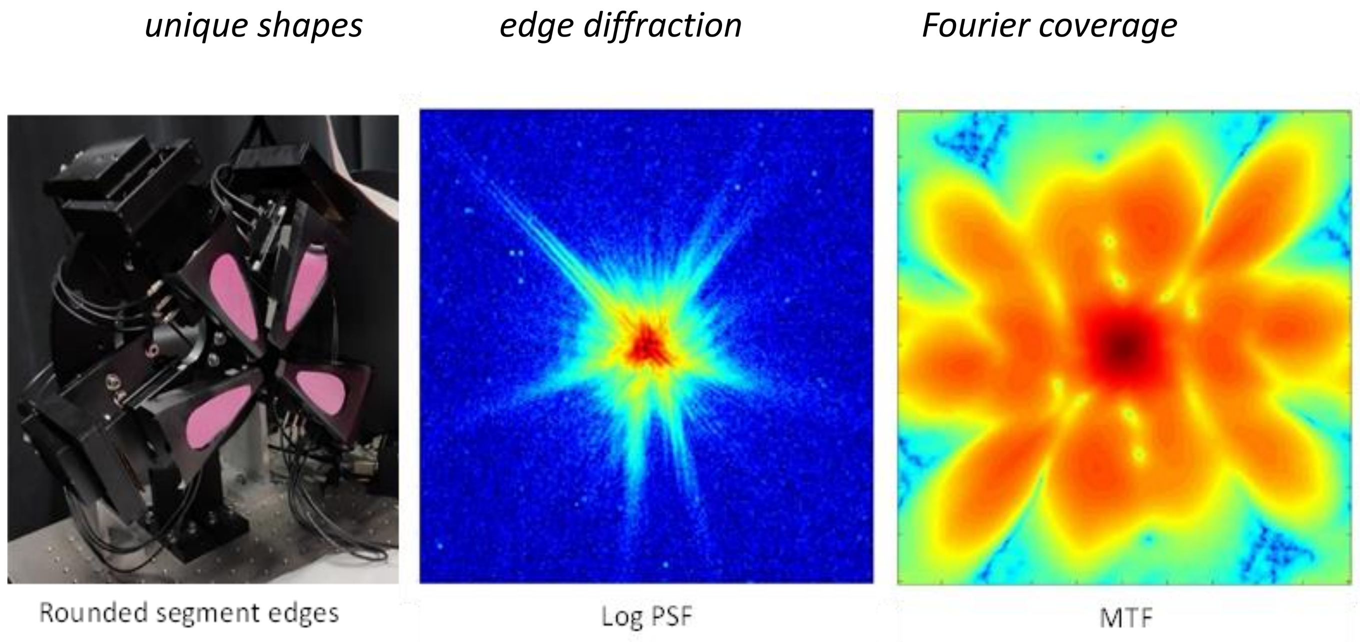

Fig. 2. A segmented non-redundant telescope [2], it's image of a point source (PSF) and In turn Fourier transform (MTF).

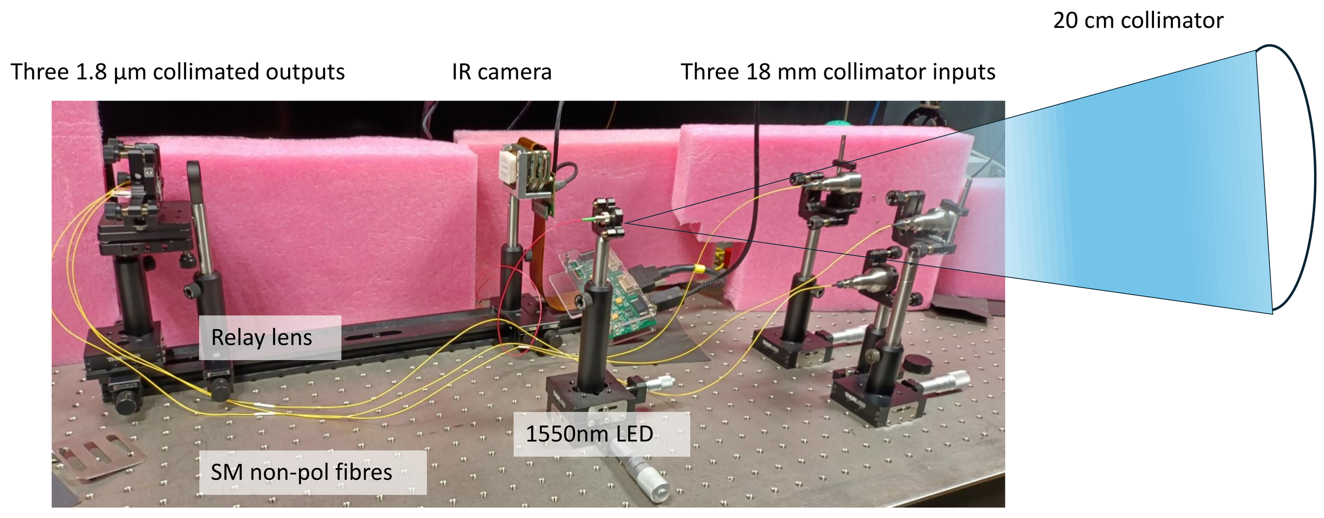

Fig. 3. Fibre-connected telescope

The best configuration was optimized by simulated annealing [1], analogous to the modelling of the smoothing of a rough surface (Fig. 1). However, our present physics-inspired design (Fig. 3) models the system as a set of interacting particles governed by a non-linear Schrödinger-like equation. So, instead of looking for the phasing of the segments, we wish to improve their location when they are non-contiguous.

We can write the energy following Landau theory with reflection and translation symmetries to get an expression similar to the energy in the Schrödinger equation, with no need for a potential function. Our energy is

$$E = \iint \left(c\left|\nabla\rho\left(u,v\right)\right|^2 + \frac{1}{2}g\left|\rho\left(u,v\right)\right|^2 \right) \mathrm{d}u\mathrm{d}v$$

where ρ is the autocorrelation of the segments and g and c are parameters, to be compared with the Schrödinger energy

$$E = \frac{\hbar^2}{2m}\left|\nabla\psi\left(r\right)\right|^2 + V\left(r\right)\left|\psi\left(r\right)\right|^2 + \frac{1}{2}g\left|\psi\left(r\right)\right|^4$$

We aim to improve the telescope resolution in both cases. For both models (segments phase or placement) we calculate the energy values. The earlier model code can be found in [1]. The aim here is to find a set of apertures (pupils) that is non-redundant and optimizes image quality. One famous set of apertures is the Golay [3] (Fig. 4) and derivatives [4, 5]. We are now developing new models which include repulsion between segments to avoid overcrowding and redundancy.

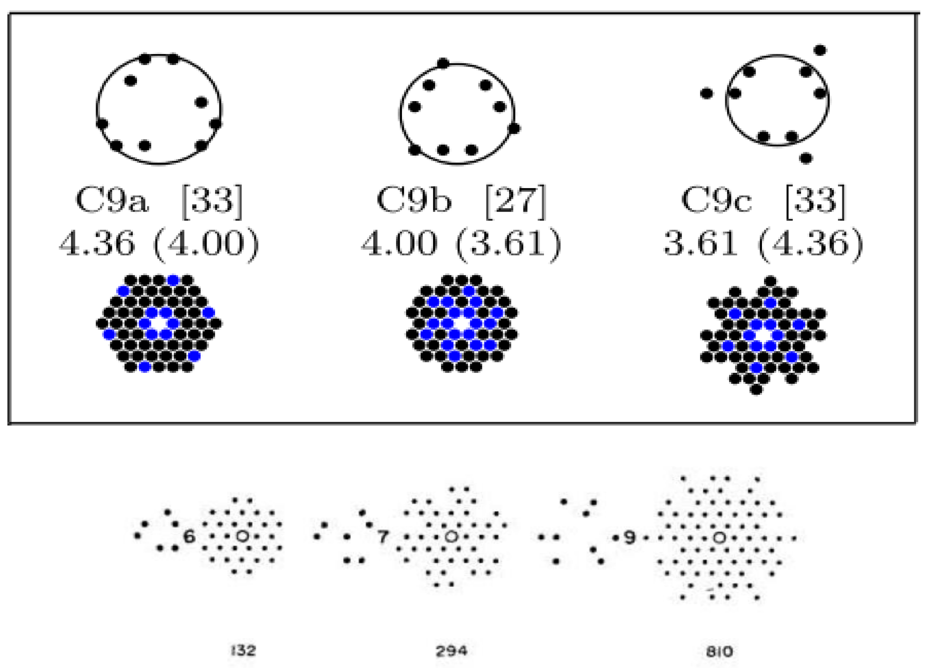

Fig. 4. Top: Mugnier arrangements of few segments and their autocorrelations (MTF) [5]. Bottom: Golay's non-redundant arrangements [3]. Constraints can include minimal MTF gaps (i.e. non-vanishing Fourier components), best resolution (largest expanse of segments), non-redundancy of segments' spacings, and more.

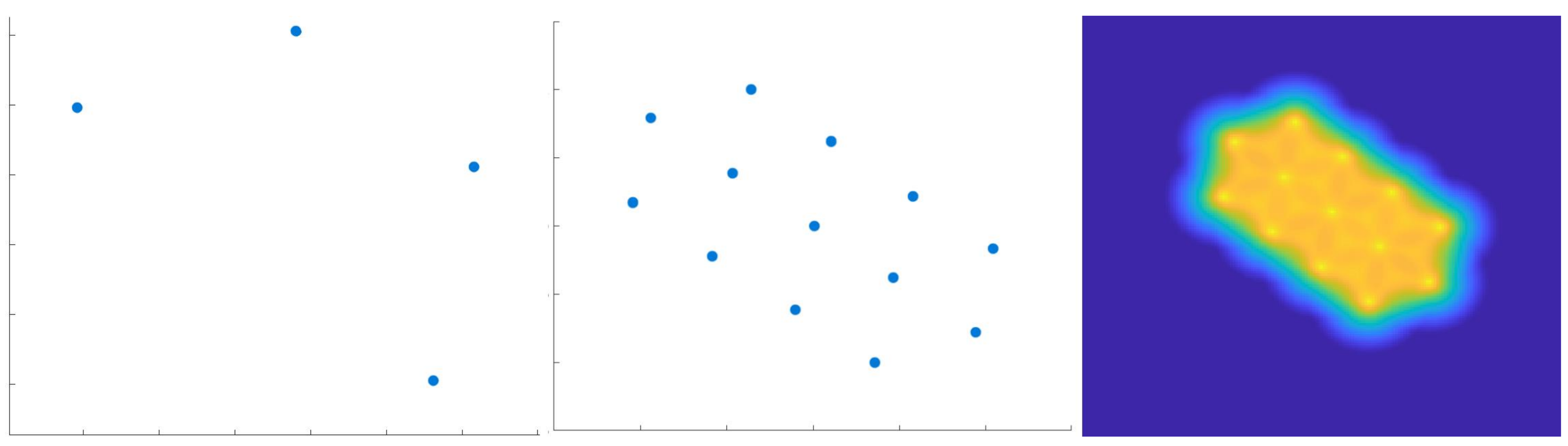

Fig. 5. Simulation of aperture placement using energy optimization. Left: non-redundant arrangements of four lenses; Centre: their autocorrelation, assuming they are single points. Right: Their autocorrelation taking in their actual size.

References

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