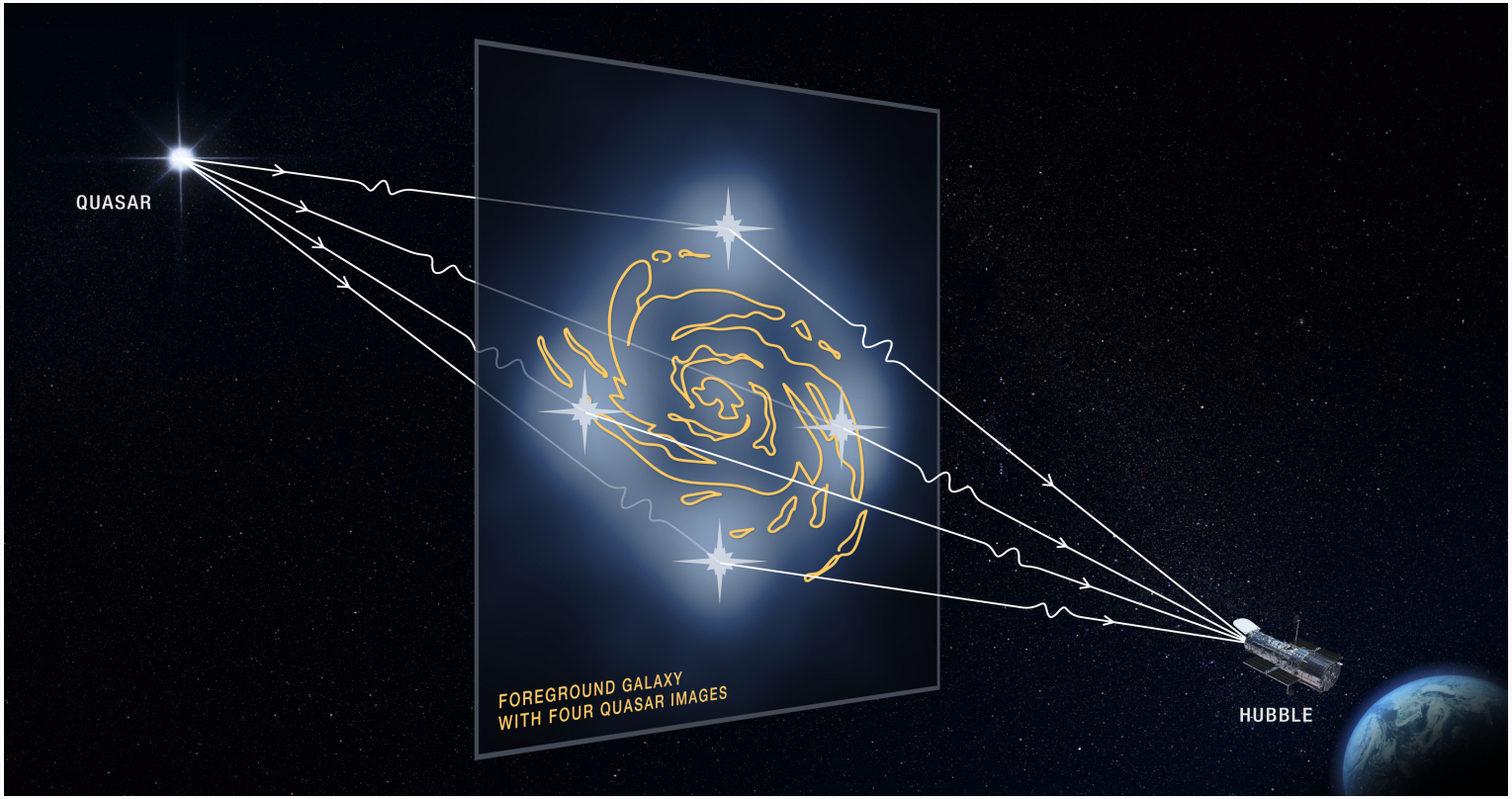
Towards resolving micro-image swarms in gravitational lensing

Ashish K. Meena[1] and Prasenjit Saha[2]

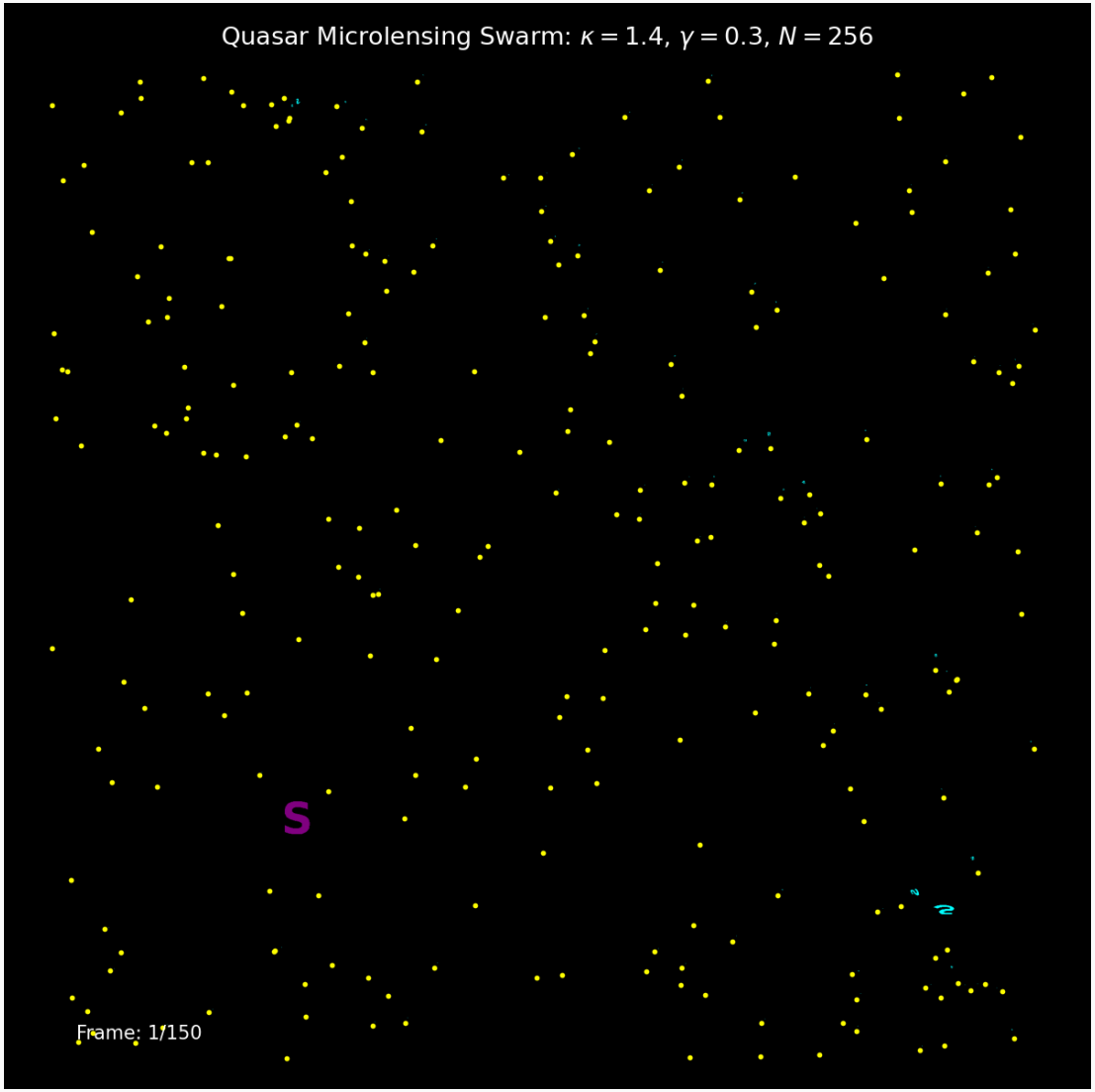
[3] IISc Bengaluru, India, [2] Uni Zurich, CH

A lensed quasar (schematic)



Credit: NASA, ESA and D. Player (STScI)

A micro-image swarm (toy simulation)



Interestingness & Difficulty

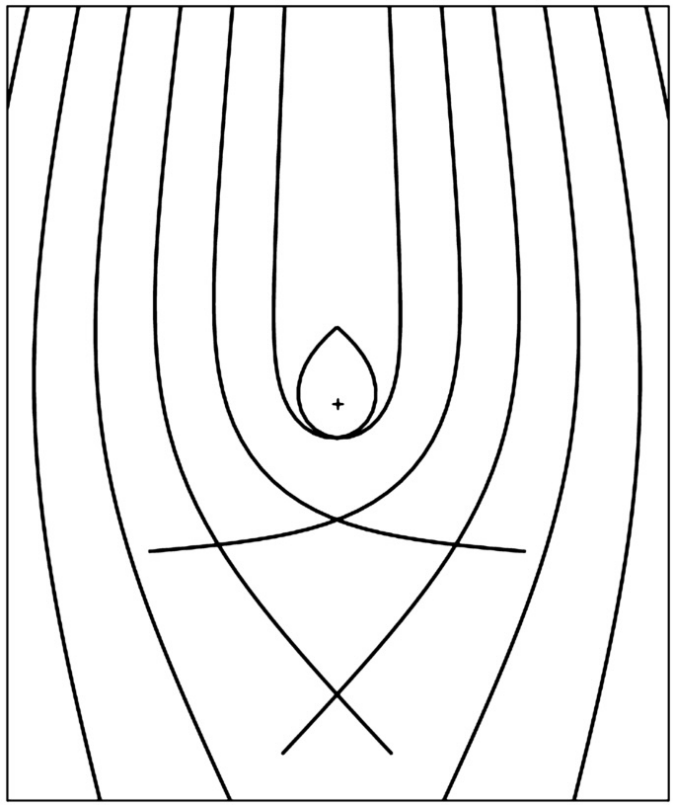


Interestingness & Difficulty



Gravitational Lensing (according to Charles Darwin))

Light rays being deflected by a small mass.

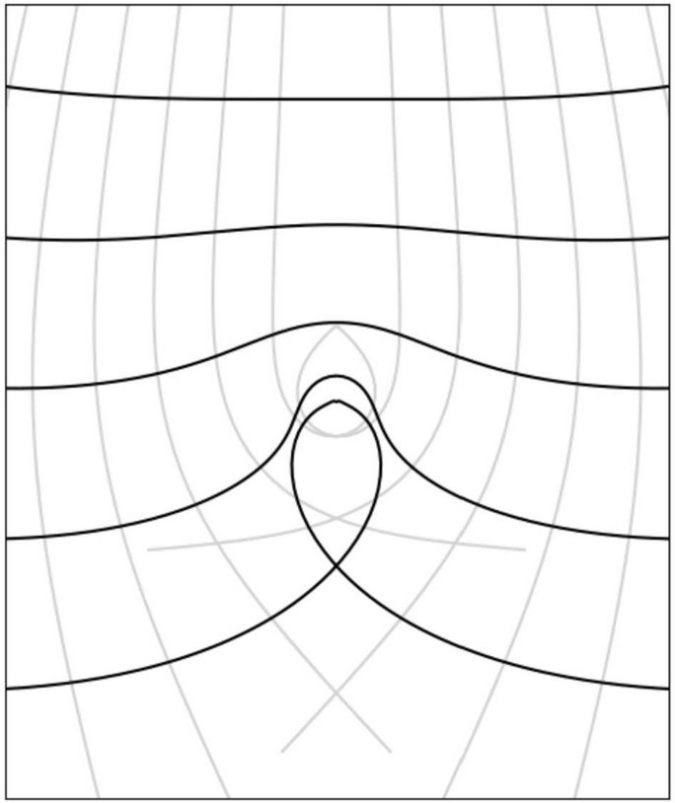


Various illustrations from *Essentials of strong gravitational lensing* arXiv:2401.04165

Gravitational Lensing (according to Sjur Refsdal)

Light rays being deflected by a small mass.

The envelope of light rays is a wavefront.



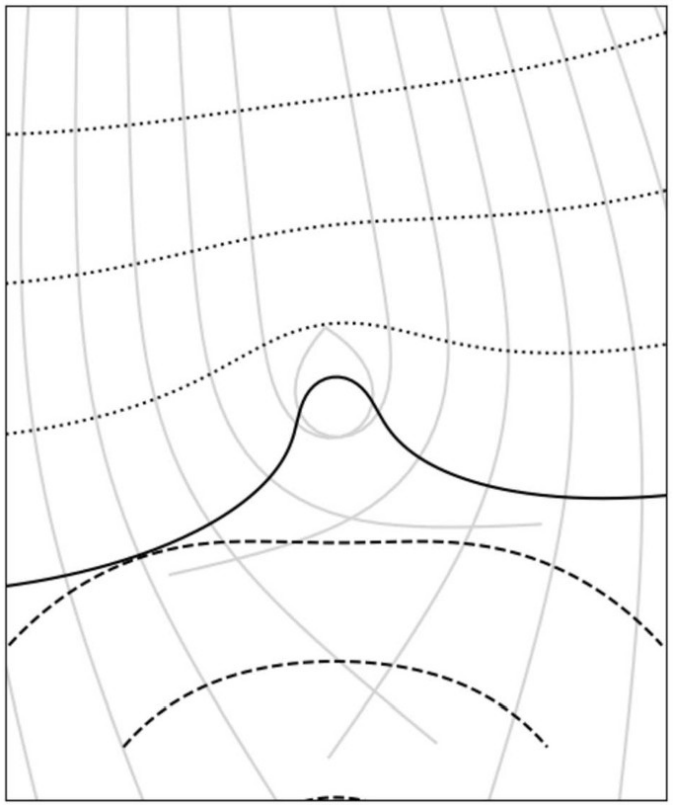
Various illustrations from *Essentials of strong gravitational lensing* arXiv:2401.04165

Gravitational Lensing (according to Rajaram Nityananda)

Light rays being deflected by a small mass.

The envelope of light rays is a wavefront.

The difference of a forward and backward wavefront is the arrival-time surface.



Various illustrations from *Essentials of strong gravitational lensing* arXiv:2401.04165

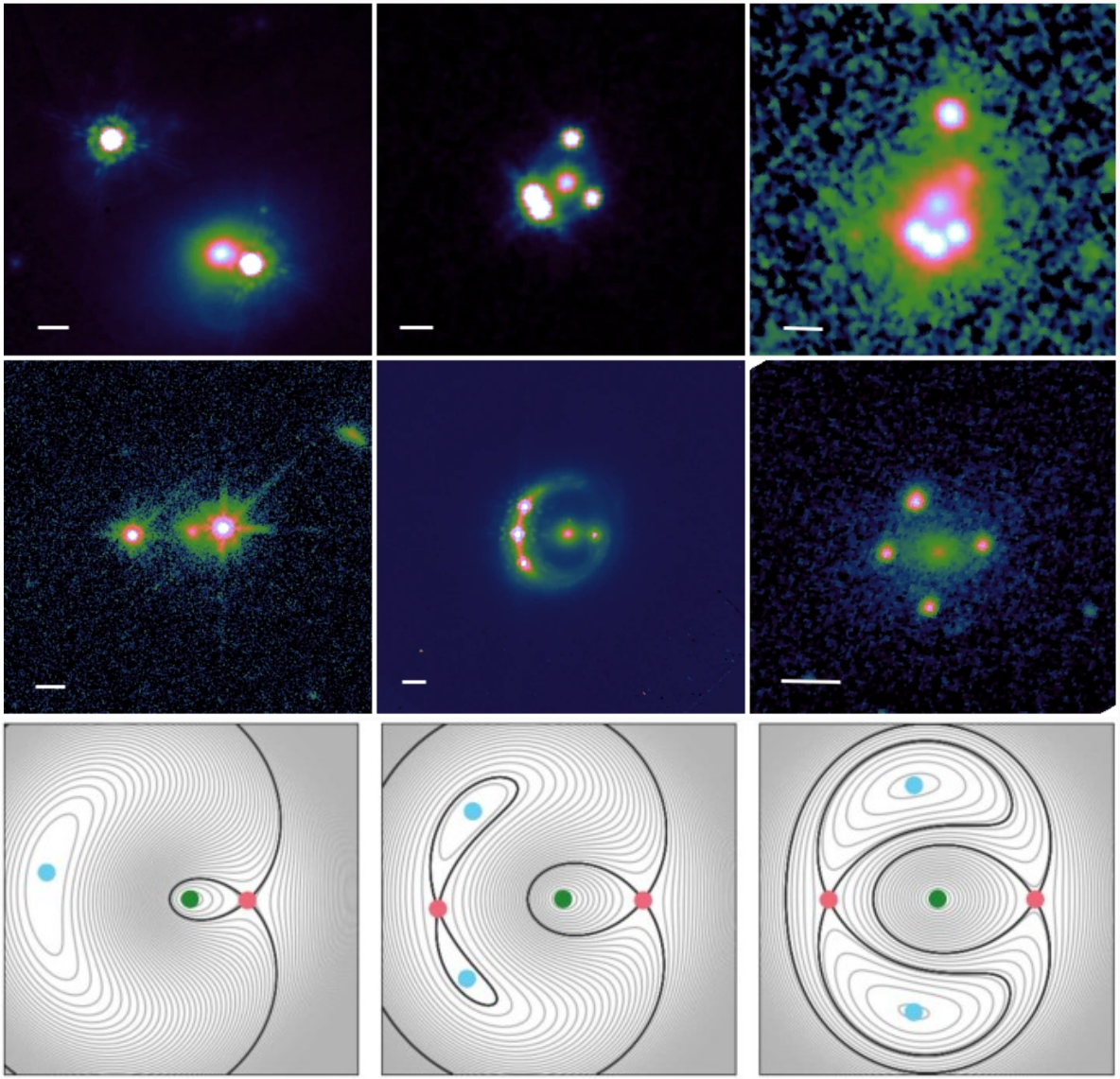
Gravitational-lensing theory

- **Arrival-time surface** (aka Fermat potential):

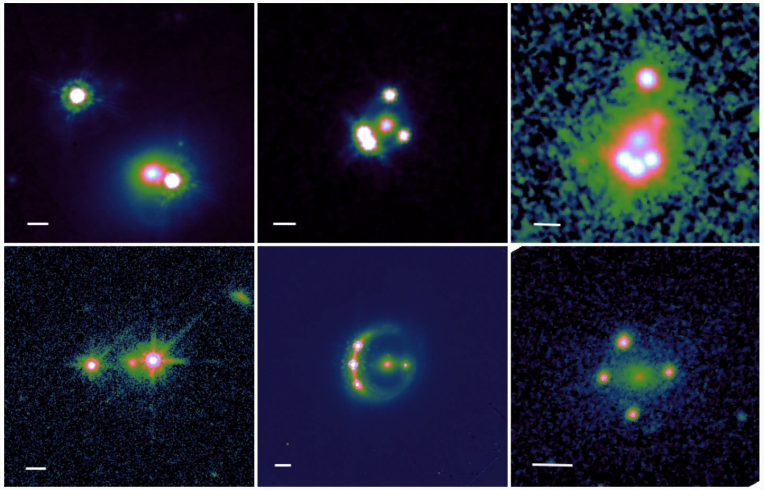
$$ct(\vec{\theta}) = \frac{1}{2}D|\vec{\theta} - \vec{\beta}|^2 - \frac{8\pi G}{c^2}\nabla^{-2}\Sigma(\vec{\theta})$$

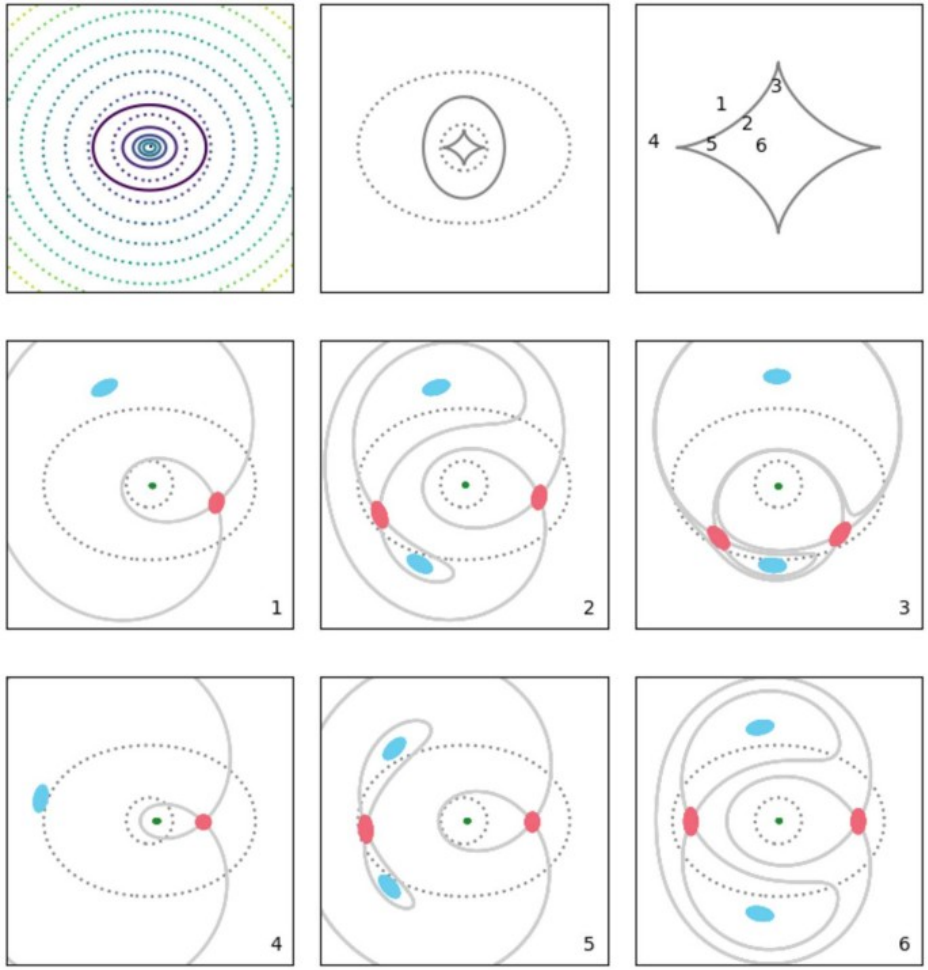
- **Images** form at locations of $\nabla t(\vec{\theta}) = 0$
- **Saddle-point contours** self-crossing contours of $t(\vec{\theta})$
- **Critical curves** locus of $\det|\nabla\nabla t(\vec{\theta})|$ — image-pairs of opposite parity appear and disappear on it.
- **Caustics** formed by ray-tracing critical curves to the source plane — boundaries of regions corresponding to different numbers of images.

Saddle-point contours

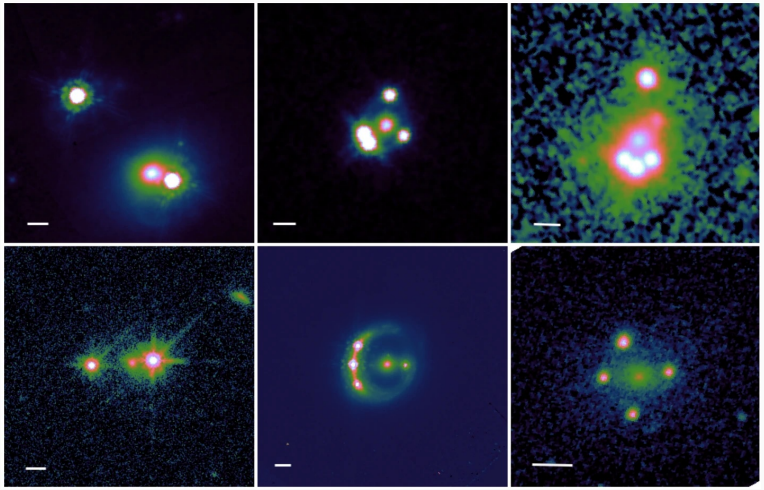


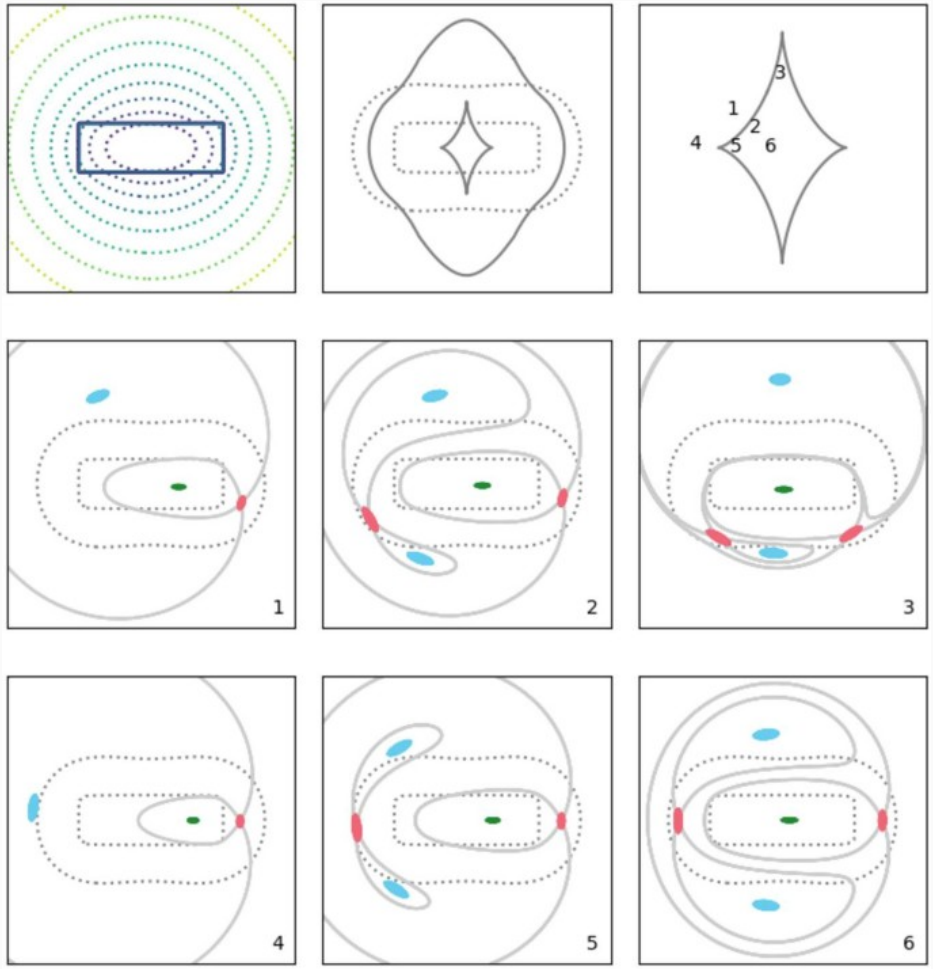
Caustics, critical curves, saddle-point contours



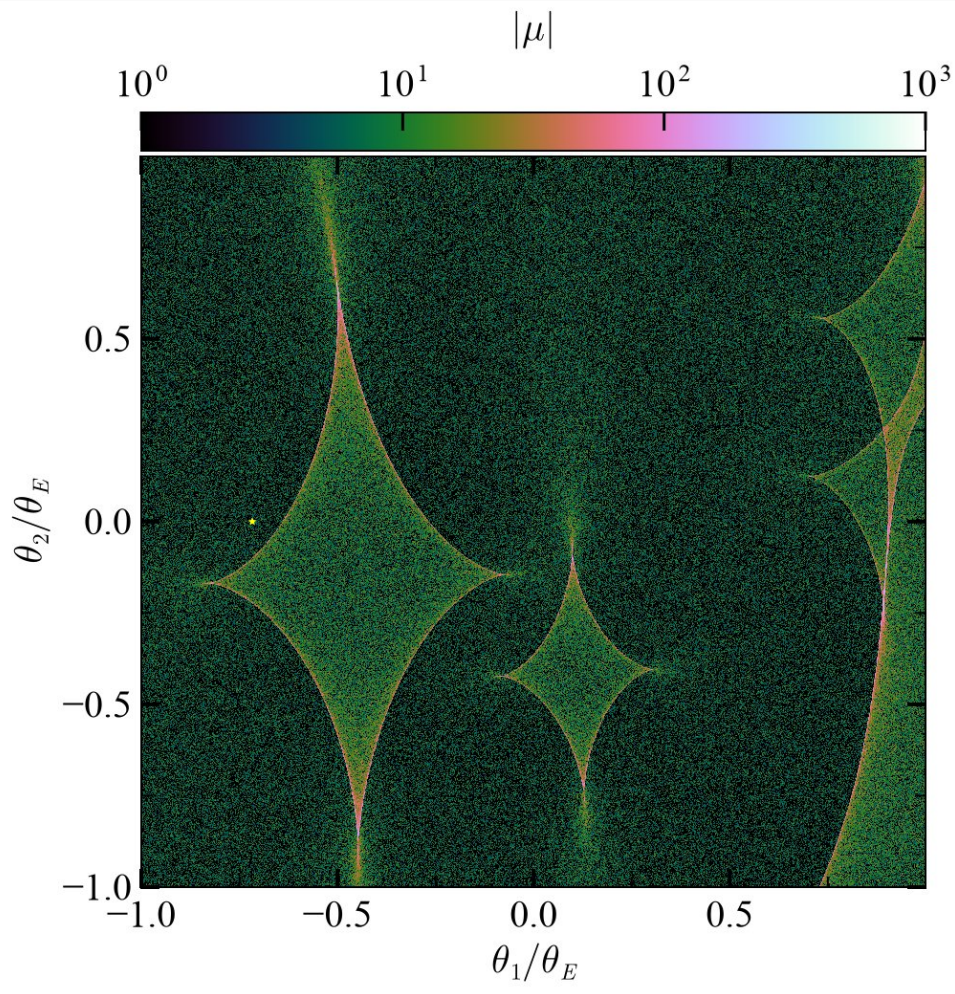


Caustics, critical curves, saddle-point contours

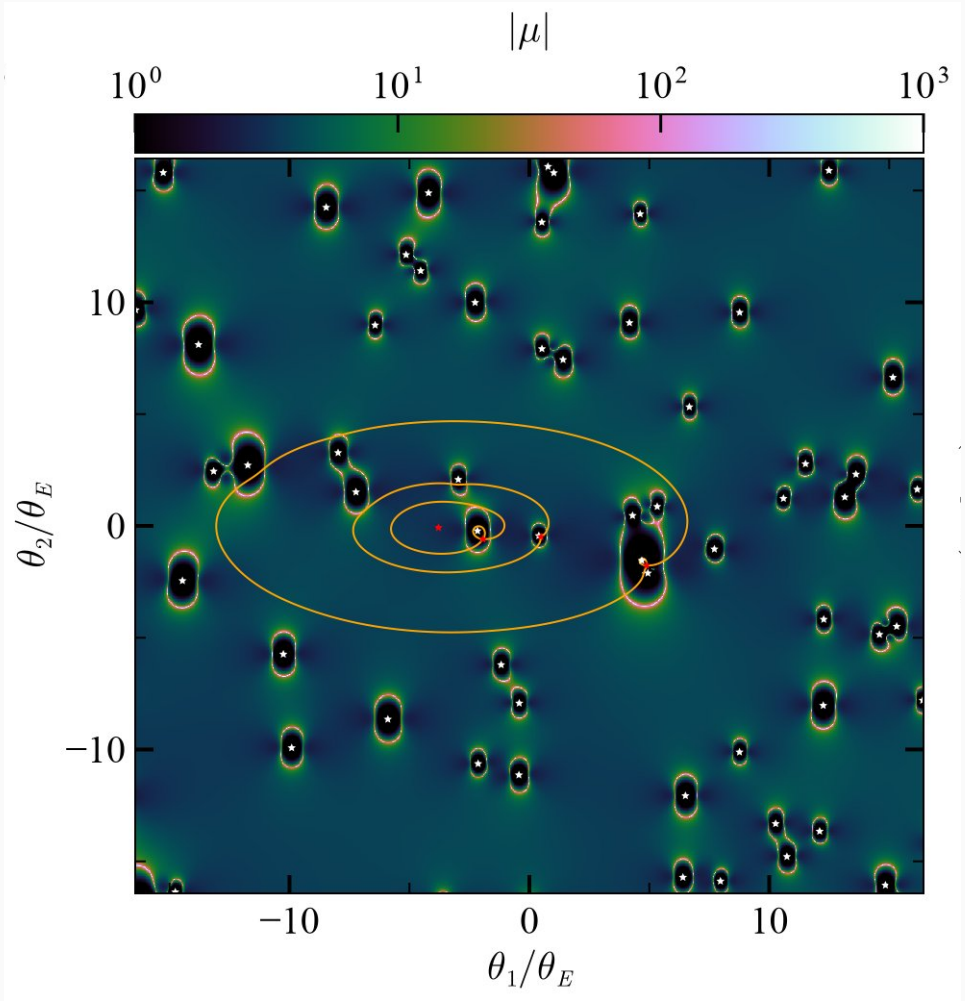




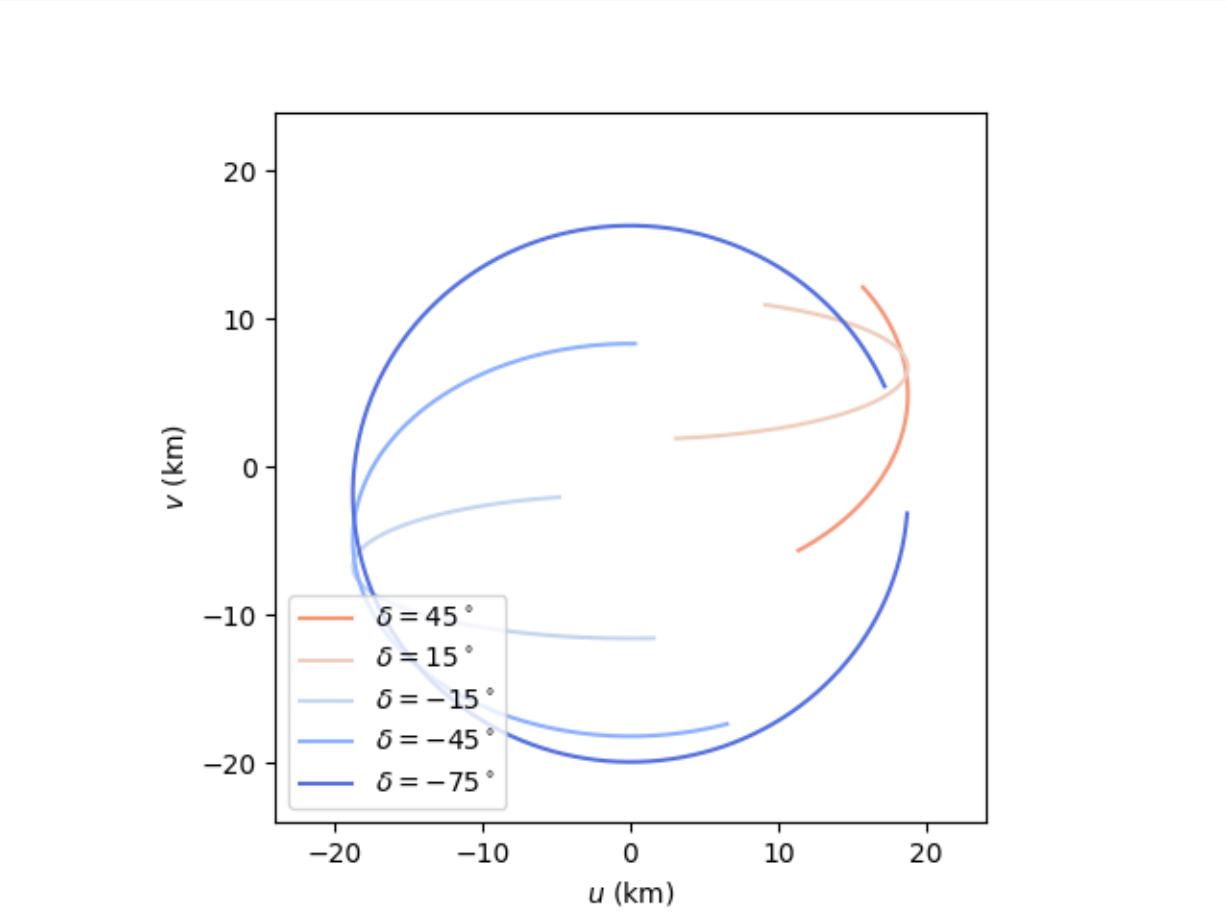
Caustics


$|\mu|$
10^0
10^1
10^2
10^3
0.5
0.0
−0.5
−1.0
θ_2/θ_E
−1.0
−0.5
0.0
0.5
θ_1/θ_E

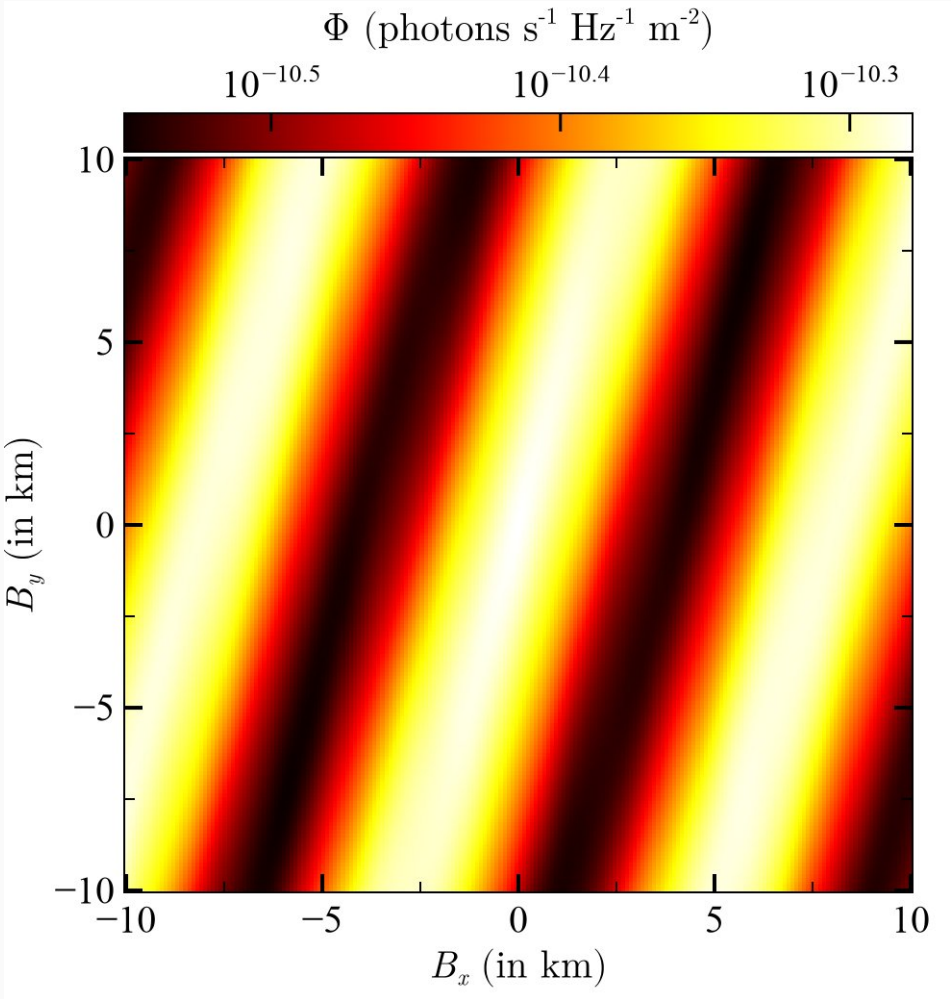
Saddle-point contours



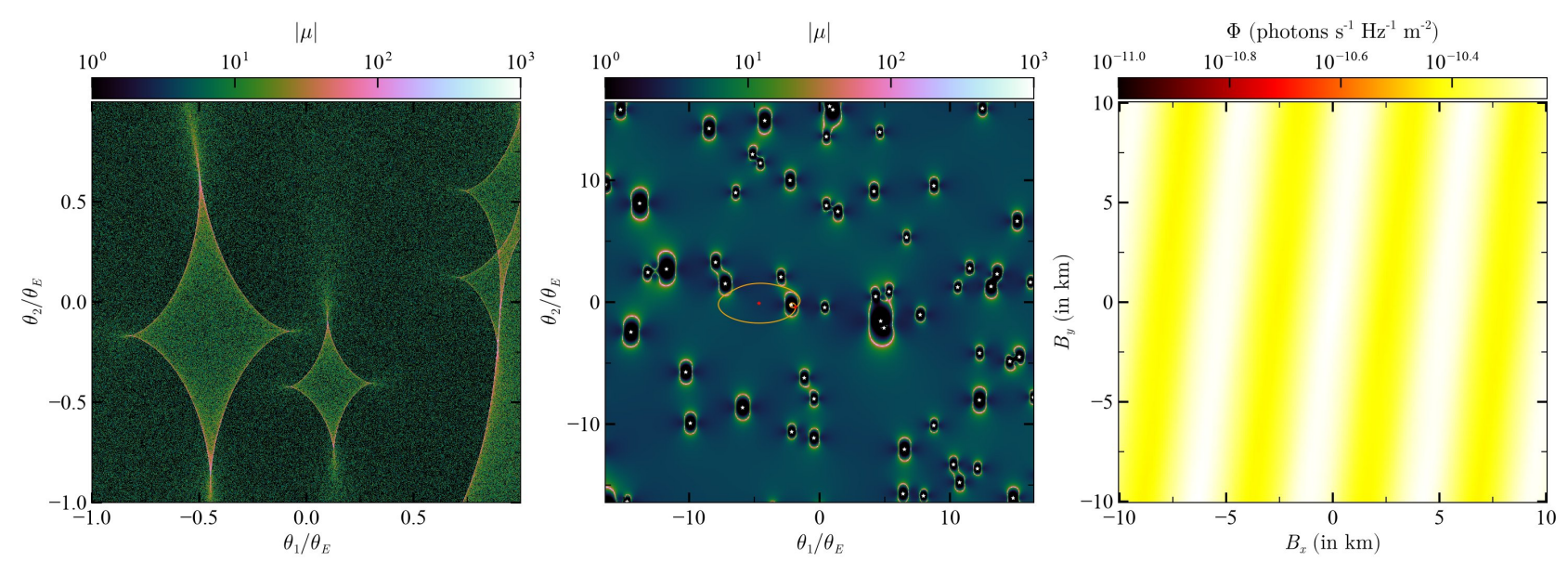
The (u, v) plane from VLT–ELT



The lensing signal



A micro-image swarm (state-of-the-art simulation)



$$\mathrm{SNR} = \frac{A_{eff}}{10^2\,\mathrm{m}^2}\left(\frac{N_{chan}}{10^2}\,\frac{t_{obs}}{10^3\,\mathrm{s}}\,\frac{10^{-11}\,\mathrm{s}}{\Delta t}\right)^{1/2}\frac{\Phi}{10^{-10}\,\mathrm{m}^{-2}\,\mathrm{s}^{-1}\,\mathrm{Hz}^{-1}}\,|V(u,v)|^2$$