If You Give the Sun a Telescope:

Imaging Alien Earths with the Solar Gravitational Lens

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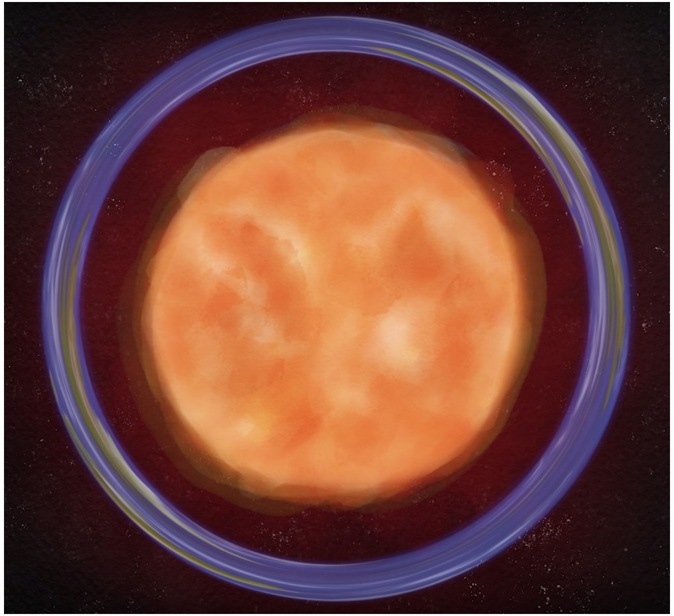


Source: YouTube: Jimiticus

What is it?

- Consists of a 1m-class telescope placed at the minimum gravitational focus of the Sun (550 au)
- Perfect alignment produces an Einstein ring

Optical properties

- Magnification factor $\mu(\lambda)$ of 10^{10}-10^{13}
- Angular resolution on the order of 10^{-10} arcsec

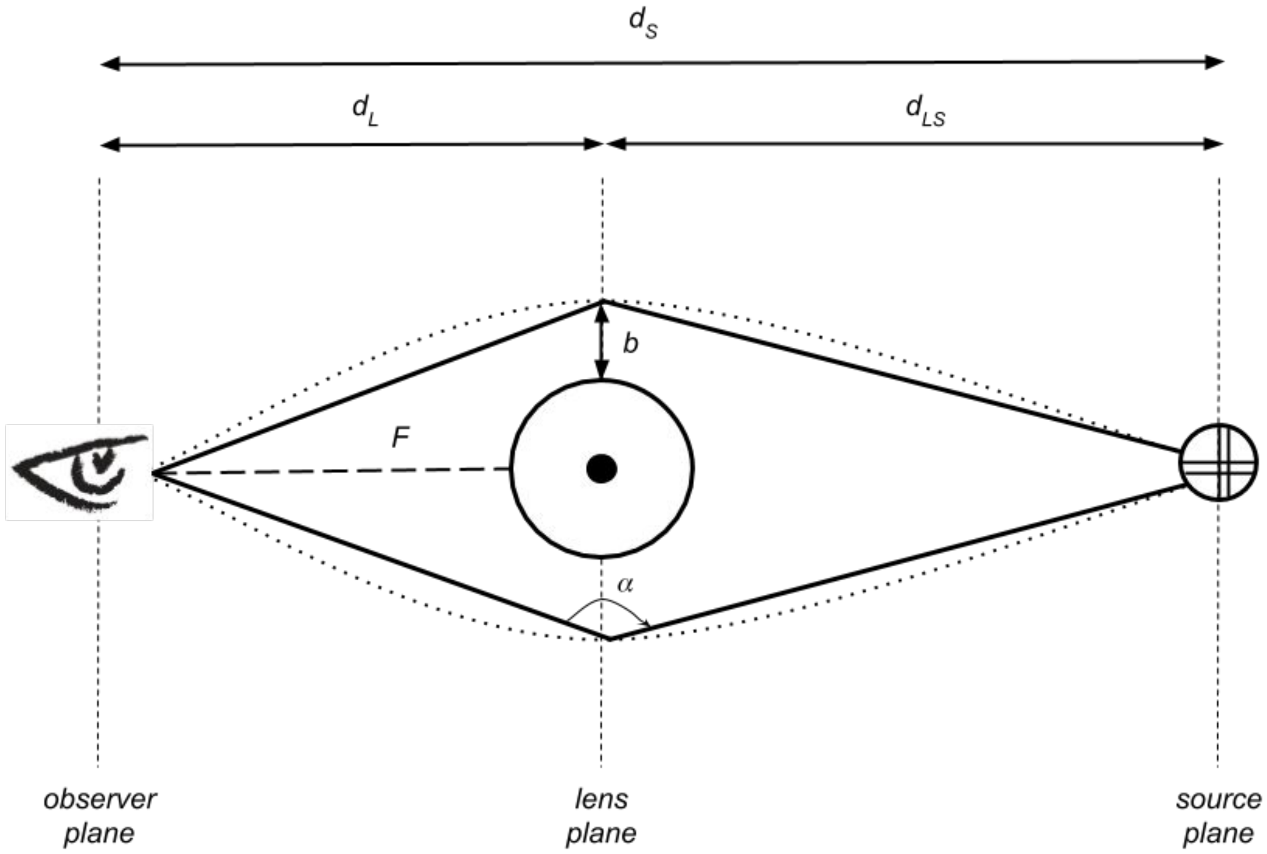
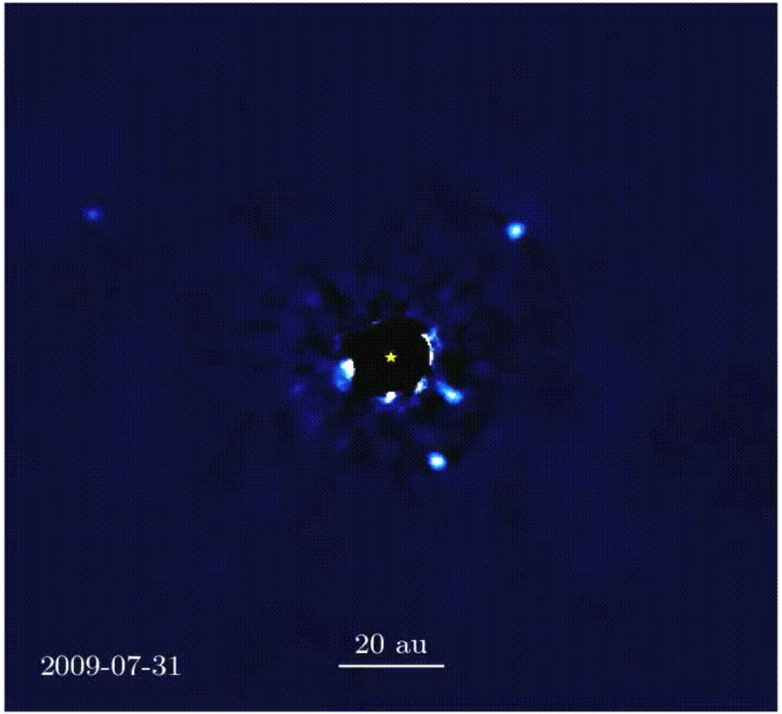


Fig. 1 — *Diagram of the Solar Gravitational Lens.*

2 *Why we need the SGL*

<u>Exoplanet direct imaging challenges</u>

- ➢ Small, dim and distant
- ➢ Low angular resolution
- ➢ Large orbits, radii on the order of 1-10 R_J (Marois et. al 2019)
- ➢ Exo-earth at d = 30 pc...
  - ○ Single pixel: 90 km aperture
  - ○ 1000 sq. pixels: $12R_\oplus$ baseline interferometer



Source: Wang & Marois (Herzberg Astrophysics), NExSS (NASA), Keck Obs.

3 *Photon mapping an exoplanet*

SunTracer

- General-relativistic, raytracing gravitational lensing simulation of SGL
- Adapted from Jorge Jiménez-Vicente's inverse ray-shooting code (Jiménez-Vicente, 2016)
- One-to-one photon map from source plane to image plane
- Purpose: generate a set of test images for deconvolution algorithm

Constraints

- Alignment must be perfect for Einstein ring conditions
  - Telescopic motion
  - Planetary motion (orbital)
- Point-spreading

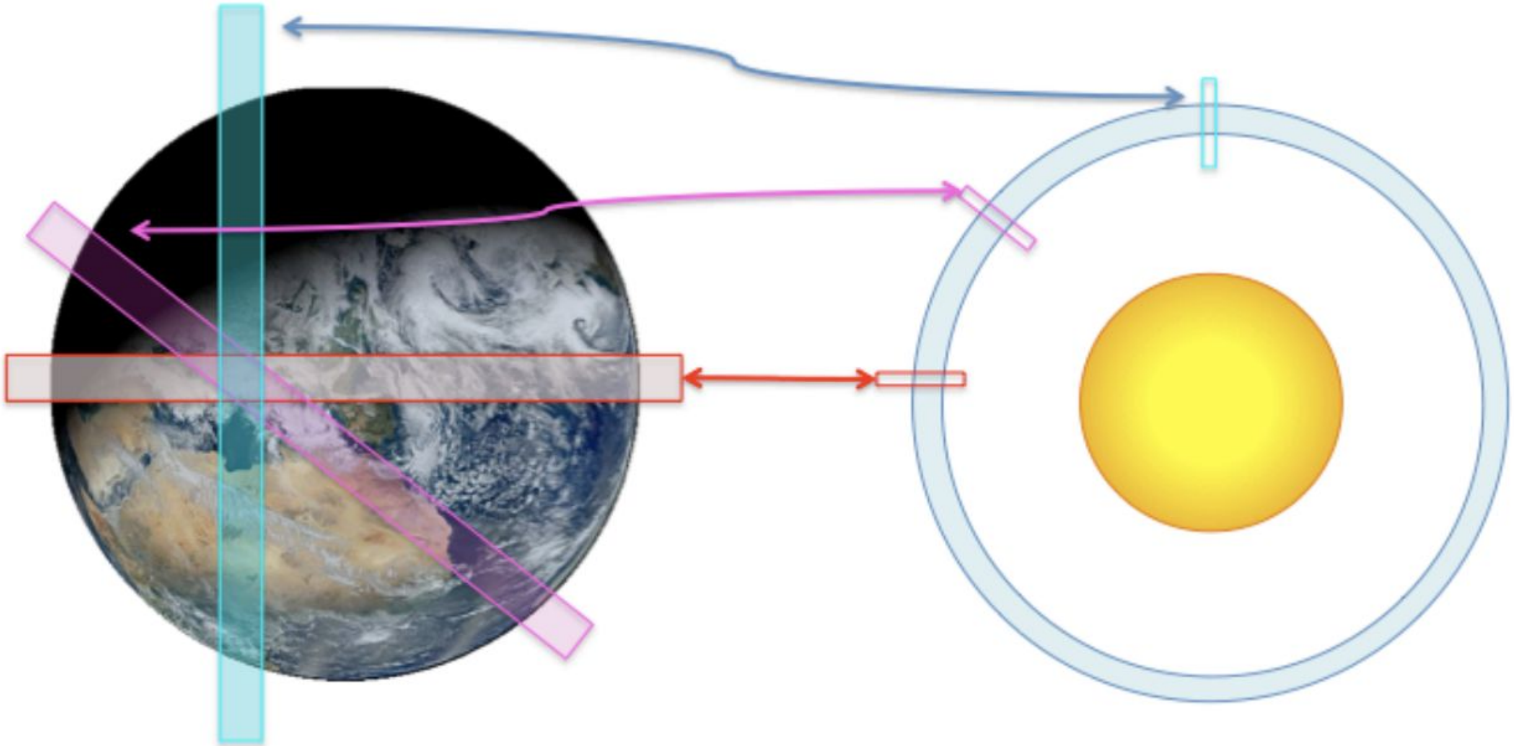


Fig. 2 — *Surface map of an exoplanet surface onto an Einstein ring. Source: Landis (2016)*

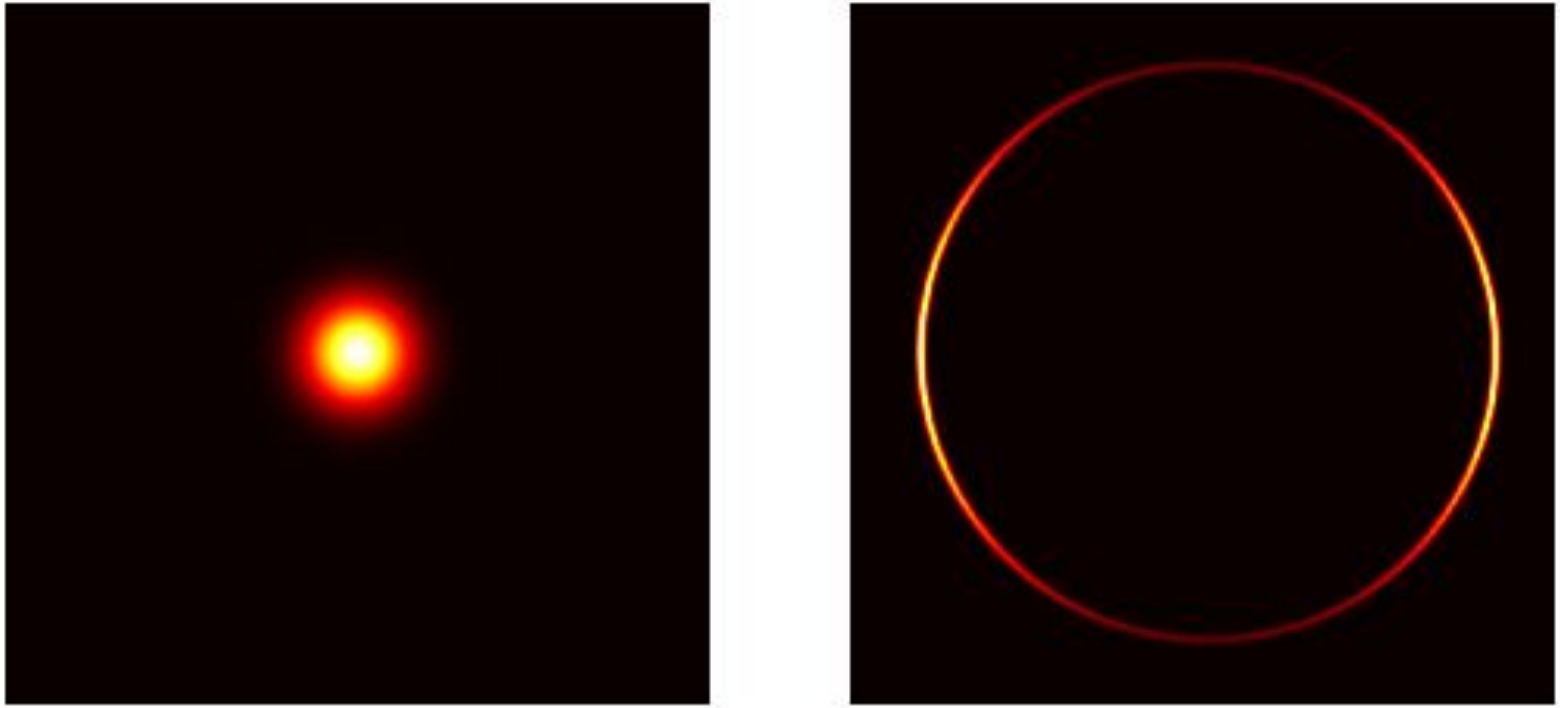


Fig. 3 — *A simple 2D Gaussian (left) and it's image as lensed by* **`SunTracer`** *(right)*.

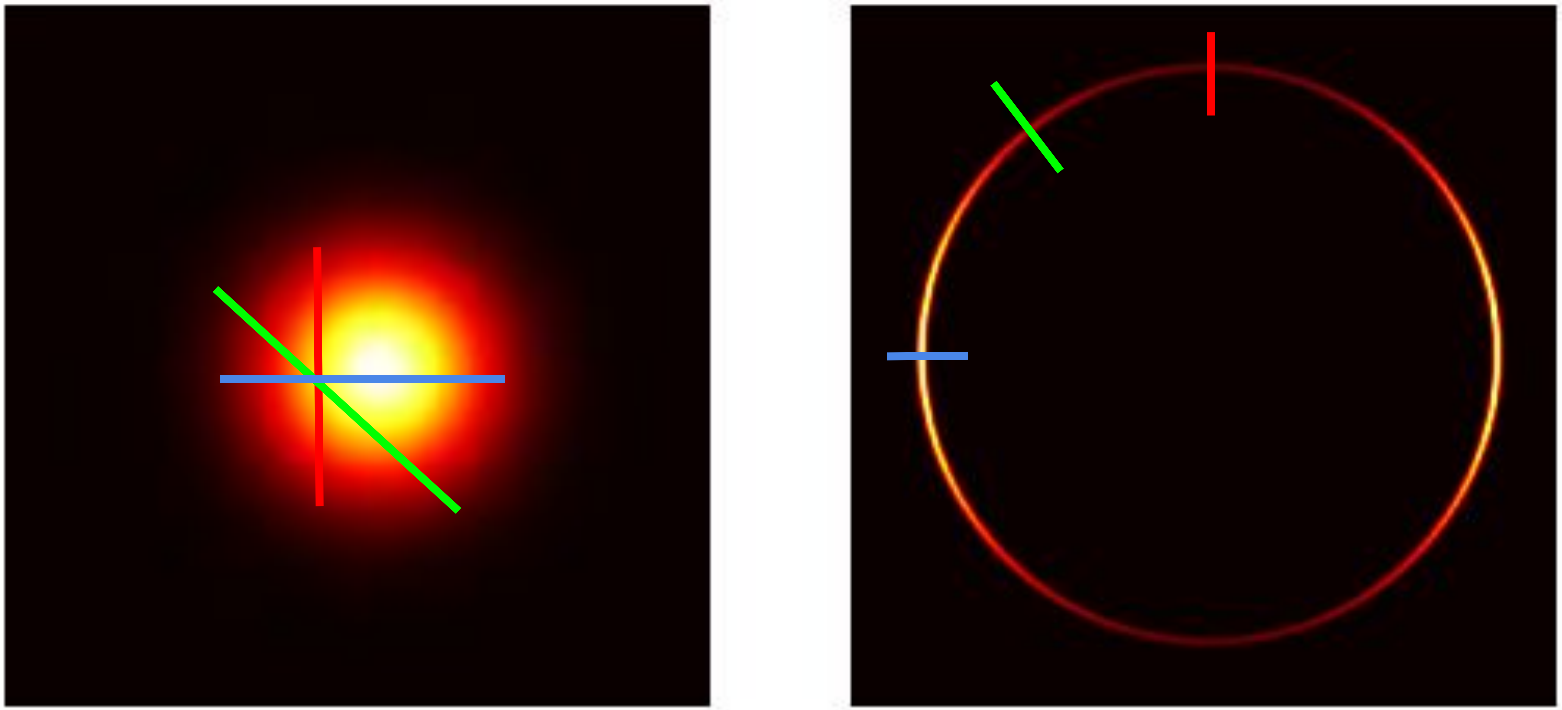


Fig. 4 — *A simple 2D Gaussian (left) and it's image as lensed by* **`SunTracer`** *(right)*.

Fig. 5 — *Images of a habitable planet as seen by the SGL.* Here, we used RGB data from NASA's EPIC camera aboard the DSCOVR satellite as the source for **`SunTracer`**.

4 *Next steps*

Verifying **`SunTracer`**

- ➢ Confirm optical properties (focal line, magnification, point spreading)

Spectroscopy

- ➢ Extract spectra from lensed data
- ➢ Use spectral data to characterize exoplanet atmosphere

Reconstruction

- ➢ Point spreading effects
- ➢ Exoplanet rotational, atmospheric effects
- ➢ Einstein ring → surface pixel → full surface image

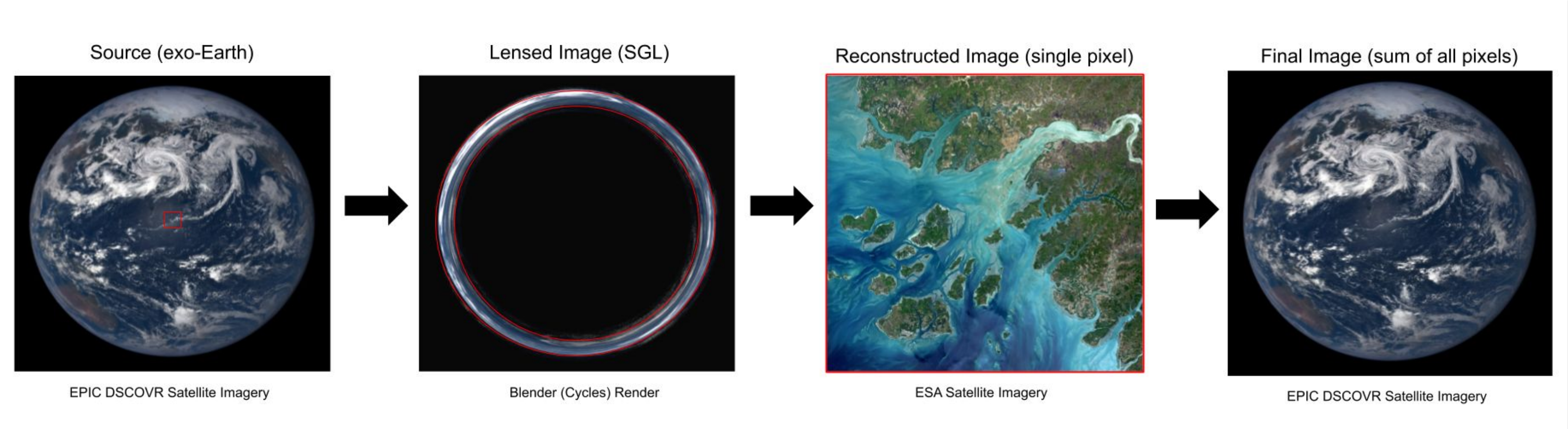


Fig. 6 — *A schematic of imaging and deconvolution for an exoplanet with the SGL.*

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