

The Terrascope: using the planet as a telescope

Master End Project

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The idea

On Earth we can still see the Sun after it actually has sunk below the horizon, because light is bent towards regions of higher index of refraction. David Kipping [1] proposed to use the refraction to turn the entire Earth atmosphere into the principal lens of a giant telescope.

The effect that a star is actually amplified when it is precisely behind a planet or moon with an atmosphere is called the central flash. Unfortunately, there are many effect that can destroy the amplification. The most important ones are: non-sphericity of the atmosphere, turbulence and absorption.

Is it still possible to create an optical (i.r., or radio) telescope in this way?

Research questions

(i) How is the focus deformed by the planet's oblateness? (ii) How bad is the influence of atmospheric turbulence? (iii) How bad is the scattering and absorption? (iv) Can we use Titan in Saturn's shadow?

Project steps

- (i) Study the observation of Titan's central flash [2].
- (ii) Study gradient-index optics [3].
- (iii) Model the atmosphere as a spherical or an oblate gradient-index lens.
- (iv) Create fast code (Python, C) for ray tracing, to calculate the bending and focussing of light rays.
- (v) Construct, using the code, the image of the distant star, called the *central flash map*.
- (vi) Construct the optical diffraction pattern of the star by using the optical pathlengths of the rays.
- (vii) Study how cells in the atmosphere with different refractive indices destroy the interference pattern and ultimately destroy the amplification. [4]
- (viii) Make a simple model Titan's atmosphere (density plus fluctuations), and use the code to simulate the central flash map.

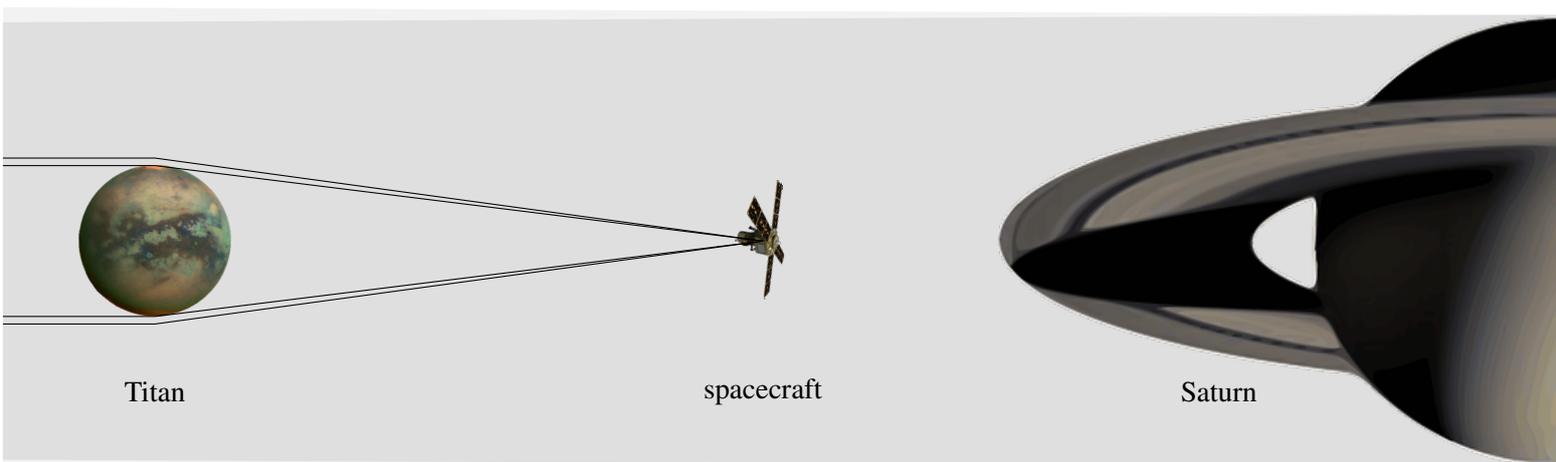


Figure: Rays of light from a distant source are refracted by Titan's atmosphere and focussed onto the instruments in the spacecraft. As Titan moves in the shadow of Saturn, scattered sunlight no longer outshines the signal.

We model the refractive index as function of radial distance $r = \sqrt{x^2 + y^2 + z^2}$, as

$$n(r) = 1 + \eta_0 e^{-(r-R)/H}, \quad \eta_0 = 4.4 \times 10^{-4}, \quad R = 2575\text{km}, \quad H = 54\text{km}, \quad L = 9.5\text{au}.$$

The density at sea level on Titan is comparable to Earth. We therefore took $\eta_0 = 1.5 \times 2.9 \times 10^{-4}$. The density drops 8 orders of magnitude over 1000km [5], giving a scale height $H = 54\text{km}$. The bending angle for a ray that reaches a minimal altitude h is then calculated by:

$$\Delta\theta = \left| \nabla \int_{-\infty}^{\infty} \eta_0 \exp \frac{-\sqrt{R^2 + h^2 + z^2} + R}{H} dz \right| = \eta_0 \sqrt{\frac{2\pi R}{H}} e^{-h/H} = 0.8 \text{ degrees} \quad \text{at } h = 0$$

References

- [1] Kipping, D. 2019, *The Terrascope: on the possibility of using the Earth as an atmospheric lens* Astronomical Society of the Pacific
- [2] Sicardi, B. et al. 2006, *The two Titan stellar occultations of 14 November 2003*
- [3] Gomez-Reino, C. and Perez, M.V. and Bao, C. 2002, *Gradient-Index Optics*, Springer
- [4] Schroeder D.J. 1987, *Astronomical Optics*, Academic Press
- [5] Yelle, R.V. and Strobell, D.F. and Lellouch, E. and Gautier, D.M. 1998, *Engineering Models for Titan's Atmosphere*