SGL PI talk

Sunday, October 14, 2018 1:15 PM

The theory of the Solar Gravitational Lens

Sketching the problem, one step at a time.

1. Solar gravity focuses light
2. The solar lens has spherical aberration; focal region is a line, not a point
3. The Sun has a shadow; focal line begins at 550 AU
4. Geometric optics yields divergent intensity -- wave optics needed
5. The Sun's surface is not optically smooth -- no Arago spot
6. EM waves travel through the solar corona -- free electron plasma
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7. The Sun is non-spherical - astygmatism changes the problem substantially
8. The Sun is very bright -- use of a coronagraph requires resolving its disk
9. The corona is still bright -- its contribution must be subtracted
10. Shot noise is unavoidable -- long exposure times needed
11. Target may not be stationary - changes in position, illumination, features
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12. Simultaneous sampling of image plane requires 10^6 spacecraft
13. Scanning by one (or few) spacecraft can take impractical amounts of time
14. Image deconvolution
15. Getting there
16. Navigation and positioning
17. Stationkeeping with complex time-dependent geometry
18. Communication

Key steps taken in our papers:

1. Electron number model
2. Maxwell's equations in the metric approximation
3. Spherically symmetric case -> Debye potentials
4. Solution through separation of variables
5. Short-range potential contribution solved for using eikonal
6. Sun represented by fully absorbing boundary condition
7. Evaluation using method of stationary phase
8. Plasma and non-plasma terms can be treated separately

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The idea of using the solar gravitational lens, or SGL, is actively discussed, with the long-term prospect of constructing spacecraft that may obtain megapixel-scale images of distant exoplanets. But before a mission can be designed, many theoretical challenges must be addressed.

Light from a distant source is focused by the SGL onto a half-line that begins at approximately 550 astronomical units from the Sun. The theoretical light amplification is enormous, on the order of 10^{11} at near optical or optical wavelengths. The image of an Earth-sized exoplanet is mapped to a square

kilometer size region in the image plane. The scale of the SGL's point-spread function (PSF) is measured in centimeters. Blocking light from the Sun with a coronagraph at this distance requires a telescope with meter-scale aperture. Such a telescope could, in principle, scan the image plane and obtain a megapixel resolution image of the exoplanet.

But the SGL is far from perfect. In addition to spherical aberration, it is also astigmatic, due to solar oblateness and other deviations from spherical symmetry. Light passing near the Sun is affected by the free electron plasma of the solar corona. The exoplanet itself is not a stationary target: It moves, its illumination changes, even its surface features may change. I discuss our efforts to date to build a comprehensive theoretical model of image formation by the SGL, and briefly touch on the difficulties related to image reconstruction.

References:

- Scattering of light by the gravitational field of the Sun and the solar corona, Slava G. Turyshev and Viktor T. Toth, in preparation
- Wave-optical treatment of the shadow cast by a large gravitating sphere, Slava G. Turyshev and Viktor T. Toth, arXiv:1805.10581 [gr-qc]
- Scattering of light by plasma in the solar system, Slava G. Turyshev and Viktor T. Toth, arXiv:1805.00398 [physics.optics]
- Recognizing the Value of the Solar Gravitational Lens for Direct Multipixel Imaging and Spectroscopy of an Exoplanet, Slava G. Turyshev et al., arXiv:1803.04319 [astro-ph.IM] White Paper to the National Academy of Sciences Committee on an Exoplanet Science Strategy Call for Papers
- Direct Multipixel Imaging and Spectroscopy of an Exoplanet with a Solar Gravity Lens Mission, Slava G. Turyshev et al., arXiv:1802.08421 [astro-ph.IM] Final Report for the NASA's Innovative Advanced Concepts (NIAC) Phase I proposal
- Wave-optical treatment of the shadow cast by a large sphere, Slava G. Turyshev and Viktor T. Toth, arXiv:1801.06253 [physics.optics], Phys. Rev. A 97, 033810 (2018)
- Diffraction of electromagnetic waves in the gravitational field of the Sun, Slava G. Turyshev and Viktor T. Toth, arXiv:1704.06824 [gr-qc], Phys. Rev. D 96, 024008 (2017)

Video: https://youtu.be/Hjaj-Ig9jBs