GRAVITATIONAL LENSING

R. Benton Metcalf
2022-2023

BRIEF COURSE OUTLINE

BASIC GRAVITATIONAL LENSING THEORY

APPLICATIONS:

- MICROLENSING IN OUR GALAXY
  - DARK MATTER IN COMPACT OBJECTS
  - PLANETS & BINARY STARS
- STRONG LENSING OF QUASARS AND GALAXIES BY GALAXIES
  - LENS MODELS
  - FITTING LENS MODELS
  - MICROLENSING
  - TIME-DELAYS AND COSMOLOGICAL PARAMETERS
- LENSING BY GALAXY CLUSTERS
  - MASS DENSITY RECONSTRUCTION
- WEAK LENSING : COSMIC SHEAR
  - CONSTRAINING COSMOLOGY & DARK MATTER

PYTHON EXAMPLES

COURSE MATERIALS

PRIMARY TEXT : “INTRODUCTION TO GRAVITATIONAL LENSING WITH PYTHON EXAMPLES”, bu Massimo Meneghetti, Springer

AVAILABLE COURSE MATERIALS : https://virtuale.unibo.it

- LECTURE SLIDES
- PYTHON NOTEBOOKS from Menenghetti

OTHER SUGGESTED TEXTS :

- “GRAVITATIONAL LENSING: STRONG, WEAK & MICRO”, Schneider, Kochaneck & Wamsganss
- “PRINCIPLES OF GRAVITATIONAL LENSING”, Congdon & Keeton
- “GRAVIATATIONAL LENSING”, Dodelson

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1 – Deflection of Light I

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LECTURES THIS WEEK

SOME HISTORY

DEFLECTION OF LIGHT IN THE NEWTONIAN LIMIT

DEFLECTION OF LIGHT IN GENERAL RELATIVITY

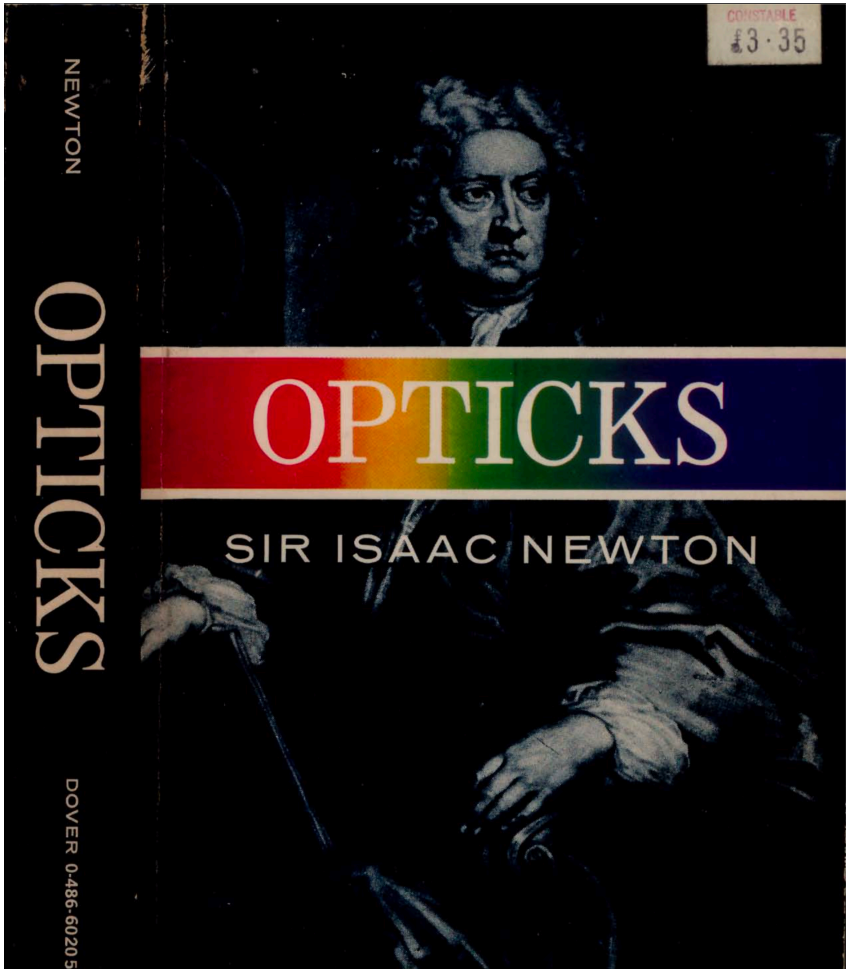
DEFLECTION OF LIGHT BY THE SUN

CORPUSCULAR THEORY OF LIGHT

- I. Newton, Opticks (1704-1730)
- Third volume ends with 31 queries:

Query 1. Do not Bodies act upon Light at a distance, and by their action bend its Rays; and is not this action (*cæteris paribus*) strongest at the least distance?

Qu. 29. Are not the Rays of Light very small Bodies emitted from shining Substances? For such Bodies will pass through uniform Mediums in right Lines without bending into the Shadow, which is the Nature of the Rays of Light. They will also be capable



- 1678: wave theory, Huygens

TIMELINE

- 1783: John Michell writes to Henry Cavendish. A light corpuscle might not be capable of escaping a massive star if

$$E \equiv \frac{1}{2}mv^2 - \frac{GmM}{R} \leq 0 \qquad v = c \qquad R < R_s \equiv \frac{2GM}{c^2} \, .$$

- 1784: Henry Cavendish calculates the deflection of a light corpuscle by a mass M. Unpublished until beginning of ‘900.
- 1801: Johan Soldner independently repeats the same calculation and publish it
- 1801: Thomas Young demonstrates the wave nature of light using diffraction

DEFLECTION OF A PHOTON GRAZING THE SURFACE OF THE SUN

"Newtonian" approximation

$$G = 6.67 \times 10^{-11} N\, m^{-2}\, kg^{-2}$$

$$c = 299792 \text{ km } s^{-1}$$

$$R_\odot = 695700 \text{ km}$$

$$M_\odot = 1.989 \times 10^{30}\, kg$$

$$\hat{\alpha}(R_\odot) = \frac{2GM_\odot}{c^2 R_\odot} = 0.875''$$

TIMELINE

- 1907-1911: Einstein resumes the idea of light deflection using special relativity and equivalence principle: *"In an arbitrary gravitational field, at any given spacetime point, we can choose a locally inertial reference frame such that, in a sufficiently small region surrounding that point, all physical laws take the same form they would take in absence of gravity, namely the form prescribed by Special Relativity"*