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ORIGINAL ARTICLE

Gravitational lenses in the dark Universe

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Abstract We discuss how different cosmological models of the Universe affect the probability that a background source has multiple images related by an angular distance, i.e., the optical depth of gravitational lensing. We examine some cosmological models for different values of the density parameter Ω_i: (i) the cold dark matter model, (ii) the ΛCDM model, (iii) the Bose-Einstein condensate dark matter model, (iv) the Chaplygin gas model, (v) the viscous fluid cosmological model and (vi) the holographic dark energy model by using the singular isothermal sphere (SIS) model for the halos of dark matter. We note that the dependence of the energy-matter content of the universe profoundly modifies the frequency of multiple quasar images.

Keywords Gravitational lensing · Cosmology · Dark energy · Dark matter

1 Introduction

During the last years strong evidences for an accelerated expansion of the Universe has been found through several independent cosmological tests (Riess et al. 1998; Perlmutter et al. 1998; Bennett et al. 2011). On the other hand, dynamical estimations of the amount of matter in the Universe seem to indicate the picture provided by the standard cold dark matter (CDM) scenario (Ostriker and Steinhardt 2003). The combination of these evidences leads to the so called dark sector of the Universe, whose essential nature is still unknown. Actually there is a great number of cosmological models that try to account the dark sector of the Universe. The most known are: ΛCDM (Armendariz-Picon et al. 2000), quintessence cosmological model (Caldwell et al. 1998), Chaplygin gas model (Kamenshchik et al. 2001), viscous fluid cosmological model (Belinskii and Khalatnikov 1975; Colistete et al. 2007; Kremer and Devecchi 2003), holographic dark energy model (del Campos et al. 2011), etc. Each one solves some problems but creates other questions. A possible way to improve these models and to shed light on these questions is to test them against the available observational cosmological data. The confrontation between theoretical models and observational data enable us to constraint the cosmological parameters, which is the greatest goal of the modern cosmology. There are some tools that can be used for in this aim: the distance measurements of type Ia supernovae (Conley et al. 2011); the power spectrum fluctuations in the cosmic microwave background radiation (de Bernardis et al. 2000; Bennett et al. 2003), nucleosynthesis constraints (Turner 2000) and so on.

The gravitational lens can be other important tool for determining the cosmological parameters of our Universe. Einstein's General Theory of Relativity predicts that a massive object curves space-time in its vicinity. As a consequence of this curvature, the light emitted from a background source is deflected and its image is distorted when the light passes near massive objects, such as galaxies and galaxy clusters. The lens effect can distort and magnify the image of the source. Thus, the gravitational lensing effect provides a method for probing the mass distribution of the Universe, without any dependence on luminous tracers or

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