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Exoplanet Detection by Astrometric Method

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Abstract As we know, the exoplanets are mostly detected by the methods of radial velocity and transit, up to now only one is found by the astrometric method. As the data of the gaia will be soon released, astrometry will gradually become one of the most important methods for detecting exoplanets. Based on the sequence of star positions obtained by the astrometric method, the solution of the equations of dynamical conditions involving the calculations of planet's mass and orbital parameters is discussed in this paper. Due to the deficiency of the available theory (orbital element method), a new method (coordinate velocity method) is put forward. The differential correction formulae of the two methods, as well as the necessary simulation calculations are presented. In addition, the method established in this paper can be applied to the multi-planet system easily.

Key words exoplanet—astrometry—celestial mechanics: orbit calculation and determination—methods: data analysis

1. INTRODUCTION

At present, the international circle of astronomy is fond of the detection and study of exoplanets. In 1995, Mayor and Queloz found the first exoplanet 51b Pegasi with the Jupiter mass revolving around a main-sequence star near the 51 Pegasi by the radial velocity method

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[1]. Recently, along with the development of astronomical observation techniques, especially the successful launch and observation of the Kepler Space Telescope, the new exoplanets are continuously discovered, and their number increases obviously. According to the statistics of the Exoplanet Network (exoplanets.eu), up to the December first, 2015, have been discovered and confirmed 2004 exoplanets, which belong to 1269 planetary systems including 498 multi-planet systems. In addition, more than 400 exoplanet candidates remain to be identified. Among these discovered exoplanets, the overwhelming majority are gaseous giant planets and hot Jupiter-like planets (about 70%), another part are super-earths (20%) and planets of earth's mass (2%), but no terrestrial exoplanet with life has been verified sofar.

The methods for detecting exoplanets are divided into the indirect detection and direct imaging. The indirect detection includes the radial velocity method, pulsar timing method, transit method and micro-gravitational lens method and so on [2]. Currently, in practical observations the methods of radial velocity and transit are mostly adopted. Up to now, only one exoplanet–HD 176051 b is discovered with the astrometric method [3]. Before 2009, thanks to the application of High Accuracy Radial velocity Planet Searcher (HARPS) [4], the detection gives priority to the radial velocity method; since the launch of the Kepler Space Telescope by National Aeronautics and Space Administration (NASA) in 2009, the transit method has become gradually the principal one, and up to now more than 1200 exoplanets have been discovered with this method (exoplanets.eu). On December 19, 2013, the Gaia Space Telescope of the European Space Agency (ESA) was launched into the space, which aims to observe the billions of stars in the Galaxy, and with the hitherto unknown precision to measure their positions, distances and motions; its observational efficiency is several million times superior to the Hipparcos Satellite equally launched by ESA [5]. Hence, the gaia is entrusted with a great expectation to carry out the exploration of the solar system and the detection of exoplanets.

As far as the astrometric method is concerned, the mass and orbital parameters of an exoplanet near a star are calculated by the inversion of the measured variation of spatial position of the star. Compared with the radial velocity and transit methods commonly used now, the astrometric method has distinct advantages: (1) To determine directly the exoplanet's mass. Although the radial method also derive the orbital parameters of an exoplanet near a star by the inversion of the measured variation of spatial position of the star, but only can the term $m \sin i$ be calculated, because in the equations of observation there exists only the product of m, the mass of the exoplanet, and $\sin i$, the sine of orbital inclination of the exoplanet. Hence, the exoplanet's mass can not be directly determined. But the equations of observation of the astrometric method include not only the term $m \cos i$, but also the term m, the mass and the orbital inclination of an exoplanet may be, therefore, directly calculated with the observational data [6]. (2) To search for long-period planets. It is known from the Kepler's third law that the third power of the semi-major axis of the orbit on which a planet revolves around a star is proportional to the square of the orbital period