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# The Distance to Exoplanet Systems with Imaging and Spectral Measurement

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**Abstract** The distance $D$ to an exoplanet system with imaging and spectral measurement can be obtained by using the orbit as a ruler. The measurement of the Distance to a typical exoplanet system with imaging and spectral measurement can be accurate to $\delta D/D \sim 0.2$, if the orbital velocity of the planet can be accurate to $\sim 3\ \mathrm{km/s}$.

**Key words:** stars: distances, techniques: high angular resolution, techniques: spectroscopic

## 1 INTRODUCTION

Distance is a parameter of fundamental importance in astrophysics. Distances of different magnitudes are measured with different methods. For objects in solar system, radar ranging can be used. For nearby stars, trigonometric parallax is usually used. At larger distance, standard candles and standard rulers are often applied. Redshift-distance relation is also used to estimate the distance, but it is model dependent.

In the distance measurements with standard rulers, galaxies with megamaser disk are typical examples. The angular-size distance has been measured for, e.g., NGC 4258 ($7.60 \pm 0.17 \pm 0.15$ Mpc, Humphreys et al. 2013), UGC 3789 ($49.9 \pm 7.0$ Mpc, Braatz et al. 2010), NGC 6264 ($144 \pm 19$ Mpc, Kuo et al. 2013), CGCG 074-064 ($87.6^{+7.9}_{-7.2}$ Mpc, Pesce et al. 2020), NGC 5765b ($123.6 \pm 11.6$ Mpc, Gao et al. 2016). This method relies on the measurement of the orbital motion of the maser disk around the central black hole and the angular size of this disk.

This method can also be used to other systems with the measurement the size of the orbit and the orbital motion. Besides binary stars, the distance to stars with planetary systems around can also be determined with this method.

## 2 METHODS

With monitoring of the spectra of a planet orbiting a star, the orbiting velocity $v$ at different orbital phase can be obtained. With the phase-resolved orbital velocity, the acceleration $a$ can be known. The orbital velocity

$$v = \sqrt{\frac{GM}{r}}, \tag{1}$$

where $G$ is the gravitational constant, $M$ is the mass of the star, and $r$ is the radius of the orbit of the planet. On the other hand, the acceleration can be written as

$$a = \frac{GM}{r^2}. \tag{2}$$

With these two equations, we can solve for $r$ and $M$,

$$r = \frac{v^2}{a}, M = \frac{1}{G}\frac{v^4}{a} \tag{3}$$

With imaging observation, we can measure the angular size of the orbit, $\theta$. The distance $D$ can then be obtained,

$$D = \frac{r}{\theta} = \frac{v^2}{a\theta}. \tag{4}$$

## 3 THE ACCURACY OF MASS AND DISTANCE MEASUREMENTS

The accuracy of mass and distance measurements depend on the accuracy of measurements of orbital size, velocity and acceleration, $\delta\theta$, $\delta v$, and $\delta a$. The relative accuracies can be written as

$$\frac{\delta M}{M} = \sqrt{4\left(\frac{\delta v}{v}\right)^2 + \left(\frac{\delta a}{a}\right)^2} \tag{5}$$

$$\frac{\Delta D}{D} = \sqrt{\left(\frac{\delta\theta}{\theta}\right)^2 + 2\left(\frac{\delta v}{v}\right)^2 + \left(\frac{\delta a}{a}\right)^2}. \tag{6}$$

The acceleration can be calculated with the orbital velocity and the orbital period $T$. So

$$\frac{\delta a}{a} \sim \sqrt{\left(\frac{\delta v}{v}\right)^2 + \left(\frac{\delta T}{T}\right)^2}. \tag{7}$$

Usually, $\delta T/T \ll \delta v/v$.

To make a measurement of the mass and the distance with $\delta D/D \sim 0.2$, $\delta M/M \sim 0.2$, the relative errors $\delta\theta/\theta, \delta v/v$ should be smaller than $\sim 0.1$. For imaging observation, the accuracy of measuring the angular size of the orbit is determined by the angular resolution of the telescope. The angular resolution of optical interferometer can reach $1\ \mathrm{mas}$ (GRAVITY Collaboration et al. 2017).

For a typical planetary orbit like the Earth orbit at a distance of $\sim 100\ \mathrm{pc}$, the distance can be measured to an accuracy of $D \sim 20\ \mathrm{pc}$, if the orbital velocity can be measure to an accuracy of $\sim 3\ \mathrm{km/s}$ (0.05 Å at 5000 Å). With current telescopes, it is still hard to reach this value (Holmberg & Madhusudhan 2023).

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## 4 DISCUSSION

Based on the imaging and spectral observations, the distance to an exoplanet system can be measured. The mass of the central star is also measured at the mean time.

The measurement of the Distance to a typical exoplanet system with imaging and spectral measurement can be accurate to $\delta D/D \sim 0.2$, if the orbital velocity can be measure to an accuracy of $\sim 3\ \mathrm{km/s}$. At the mean time, the mass of the central star can be measured to accuracy of $\delta M/M \sim 0.2$.

The methods of distance and mass measurement proposed in this work are independent to conventional methods. They can serve as auxiliaries to other methods.

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