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Study of stellar properties under TESS satellite observations

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Abstract. This study employs data from the TESS satellite to investigate the properties of stars. TESS, the Transiting Exoplanet Survey Satellite, offers insights into star activity, periodic variations, and planetary transits by monitoring changes in stellar brightness. Our analysis of TESS data explores critical star attributes, including mass, luminosity, activity levels, and dynamic changes. By examining the relationship between these stellar properties and the presence of planets, we aim to uncover the intricate interplay between celestial bodies and unveil the universe's mysteries. This research encompasses data collection methods, processing techniques, and data analysis approaches, addressing star classifications, parameters, and periodic stellar activity. We also delve into flare energy, which reveals the energy released during stellar flares, and photoperiodic analysis, a tool for understanding periodic light changes in celestial bodies. The study concludes by highlighting the significance of newly discovered planets and the diversity of stars observed by TESS. It underscores the importance of comprehending the connections between stars and planets, shaping our understanding of celestial habitability. In summary, this study enriches our knowledge of star and planet properties, contributing to a broader comprehension of the universe. Through our analysis, we seek to illuminate the complex relationships between celestial entities and unveil the universe's enigmas.

Keywords: TESS satellite observation, stellar properties, planetary transit, space exploration.

1. Introduction

1.1. Research background and motivation

Over the past few decades, astronomers have greatly expanded our understanding of the universe by observing and studying planets and stars, however, direct observation of planets and stars in distant galaxies remains a huge challenge for existing technologies. To solve this problem, NASA launched TESS (Transiting Exoplanet Survey) satellite in 2018[1]. The satellite aims to detect and study planets and stars through planetary transits.

The study of the properties of planets and stars plays an important role in solving the mystery of the origin and evolution of the universe. The existence and characteristics of planets not only provide information about existing planetary formation theories, but also may provide us with clues about the existence of life outside the Earth. Stars are the most common celestial bodies in the universe, and understanding their differences in mass, luminosity and chemical composition can have a far-reaching impact on studies about the evolution of stars and the formation of galaxies.

The launch and operation of TESS satellites provides us with a unique opportunity to discover and study various types of planets and stars on a large scale, and by analyzing the high-quality light curve

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data provided by TESS, we can detect planets transiting in front of their stars, thereby determining the existence of planets as well as their orbital parameters. In addition, TESS can monitor changes in the luminosity of stars, revealing stellar activity and characteristics.

This study aims to use data from TESS satellites to study some properties of planets and stars. By analyzing the orbital characteristics[2], physical properties and atmospheric composition of planets, we can better understand the formation and evolution mechanisms of them. At the same time, through classification, parameter estimation and periodic analysis, we can better characterize some basic characteristics and evolution history of stars.

1.2. Introduction to TESS satellites

The TESS satellite is a space telescope launched by NASA in 2018 whose main mission is to discover and study planets and stars through the planetary transit method. The design and operation of the TESS satellite made it one of the most successful planetary survey missions to date[3] .The main features of the TESS satellite are shown in Table 1.

Table 1. Main features of TESS satellites.

Key features	Description
High coverage sky survey capability	TESS satellites use a batch observation strategy, each batch continuously observing the same area for about 27 days, allowing it to complete the entire sky tour in several months.
High-quality light curve data	TESS satellites are equipped with high-performance cameras capable of monitoring the luminosity changes of tens of thousands of stars simultaneously. The observation data has high accuracy and high temporal resolution, capturing subtle changes in luminosity.
Discover diverse planetary systems	TESS satellite has discovered a large number of planetary candidates, ranging from rocky planets to gas giants. These planets orbit different types of stars, enriching our understanding of planet formation and evolution.
Global collaboration and data sharing	TESS data is open to astronomers and researchers around the world, encouraging international cooperation and promoting international research on planetary and stellar properties.

As an important astronomical mission, TESS satellite provides rich resources and opportunities for the study of planetary and stellar properties through its high-coverage, high-quality light curve data and diversity discovery, and this study will use TESS satellite data to explore the properties of planets and stars, contributing to solving the mysteries of the universe.

2. TESS satellite data and observation methods

2.1. TESS mission and observation process

TESS satellite is tasked with discovering and studying planets and stars through the planetary transit method, and its observation process is carefully designed to obtain high-quality light curve data and detect potential planetary transit events. The TESS observation process is mainly divided into the following steps: the selection of observation targets, the selection of a series of target regions by TESS satellites during the sky survey, usually located near the north and south poles of the entire celestial sphere, and the selection of these regions is based on a variety of factors, including star type, star brightness, and stellar activity level. The target region was chosen to prioritize observations of stars with potential planets and to ensure that high-quality transit data are available; In batches, TESS satellite divides the observation area into sector-shaped blocks, each of which is observed for about 27 days, and the observation period of each block is called a sector. This batch strategy allows TESS to cover the entire sky in a short period of time, increasing the chances of planetary transit detection; To acquire the light curve, TESS satellite's cameras periodically take images of the target area, measuring the star’s luminosity and recording the data as light curves, which demonstrate the star’s brightness changing as a function of time. By analyzing these light curves, it is possible to detect planetary transits, in which planets pass in front of their stars and cause a temporary decrease in stellar luminosity; Detection of planetary transits is made by automated algorithms that examine depth and periodicity changes in the light curve to identify potential planetary transits[4]. Once a candidate planetary transit event is detected, further observations and confirmations are made to determine whether a planet does exist; TESS satellite data are publicly shared, meaning that astronomers and researchers around the world can access and analyze this data.

2.2. Data Acquisition and Processing

Light curve data from TESS satellite is a key resource for studying the nature of planets and stars, and these data require a series of processing steps to extract useful information and identify potential planetary transit events[5]. The main steps of data acquisition and processing are as follows:

Image acquisition and transmission, where TESS satellites capture images of the target region through their cameras, which record changes in the luminosity of stars, are transmitted by satellites to ground stations and then further distributed to astronomers and researchers. Image correction, where the acquired images need to be corrected to remove image distortion caused by satellite motion, instrument response, and other factors, is an important step to ensure accurate photometric data; Light curves are generated, and the corrected image is processed into light curves, that is, changes in the brightness of stars over time, which are at the heart of data processing to analyze the nature of stars and search for planetary transit events; Removal of noise and pseudo-signals, there may be various noise and pseudo-signals in the light curve, such as instrument noise, changes caused by stellar activity, etc., which need to be carefully processed and filtered to ensure the accuracy of planetary transit events; Detection of planetary transit events, after noise processing, the data will be used to detect planetary transit events, and automated algorithms will analyze the light curve to look for features of a temporary decrease in the luminosity of the star, so as to identify potential planetary transit events; Verification of planetary transit events, data marked as planetary transit events by automated algorithms is further verified, which may include additional observations, verified using other instruments to ensure the authenticity of planetary transit events.

Data acquisition and processing is an integral part of TESS's mission, and through careful correction, noise processing, and transit event detection, researchers can extract valuable information about the nature of planets and stars from raw data.

2.3. Overview of data analysis methods

In the light curve data collected by TESS satellite, there is abundant information about the properties of planets and stars. In order to reveal the properties of planets and stars from TESS data, we usually use the following data analysis methods: planetary transit event identification identifies possible planetary transit events by observing the periodic changes of star luminosity, which leads to the decrease of luminosity, and its depth is related to the size of the planet; Periodic analysis[6], using Fourier transform and other methods to find the periodic signal in the light curve, which is used to confirm the existence of planetary transit and the transit period; The physical properties of the planet are inferred, that is, by analyzing the information such as the period and depth of the transit event, the orbital period and distance of the planet are calculated, and the mass and radius of the planet are inferred by using the mass of the star and the orbital parameters of the planet and the radial velocity method. Star property analysis, based on spectral characteristics and color index, classifies stars into different spectral types, which is helpful to understand the nature and evolution state of stars, and infers important parameters such as mass, radius and age of stars by using HR map positioning and star model; Periodic analysis of light variation, that is, the periodic analysis of the light variation curve of the star is carried out to find out the possible activity period and spin period, so as to study the activity of the star, track the change of the luminosity

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of the star, and explore the characteristics of possible flare and sunspot activity; The study on the interaction between stars and planets uses the depth change of transit events to study the influence of stellar radiation on planetary atmosphere and reveal the possible atmospheric evolution mechanism. By analyzing the characteristics of stellar luminosity change, the influence of planetary accretion on the mass loss of stars is studied, and the interaction between stars and planets is deeply understood.

3. Stellar nature research

3.1. Stellar classification and parameters

Stellar classification is the process of classifying stars into different classes based on their physical properties and spectral characteristics, this classification helps us understand the evolution and properties of stars, as well as their distribution in the universe, and the classification of stars is usually related to their mass, temperature, luminosity, spectral characteristics, etc. Stars have the following classifications and related parameters: spectral classification, the spectral types of stars are classified according to their spectral characteristics. The spectra are usually represented by the Latin letters (O, B, A, F, G, K, M) and represent different temperature and spectral characteristics, for example, O-type stars are hot and bright stars, and M-type stars are cooler and fainter stars; Color index classification: The color index is the difference in the luminosity of stars at different wavelengths, which is used to estimate the color temperature of stars, and the color index can be used to classify stars and estimate their temperature and luminosity; Photometric classification, the luminosity classification of stars is based on the luminosity and size of the star, including main-sequence stars (e.g., the Sun belongs to G-type main-sequence stars) as well as giants, super giants, white dwarfs, etc.; HR diagram position and parameters, HR diagram is a kind of star luminosity and temperature (or color index) to plot the chart, HR map position can provide information about the star, such as mass, radius, age, etc. Stars with masses similar to the sun have longer lifetimes, while giant and supergiant stars are at different stages of evolution. Stellar mass, the mass of a star is a key parameter that determines the evolution and structure of a star, and mass is usually used as a reference unit with the mass of the Sun; Stellar radius, is also an important parameter, closely related to the mass, temperature, and luminosity of the star. Stellar age, the age of a star is one of the key factors in its evolution, usually estimated based on HR map positions, chemical composition, and stellar models[7].

It should be noted that different stellar classification systems and parameter estimation methods may have some differences, and the nature and evolution of stars will be affected by a variety of factors, and stellar classification and parameter studies are very important for understanding the evolution of stars, the formation of star systems, and the evolutionary history of the universe.

3.2. Stellar activity and periodicity

Stellar activity refers to a series of periodic and irregular phenomena on the surface of stars, including sunspots, flares, chromospheric bursts, etc., which are usually related to the magnetic field activity of stars, and stellar activity usually shows obvious periodicity[8], which is related to the rotation period and magnetic activity period of stars.

The periodicity of stellar activity includes: sunspot cycle, sunspot is a dark spot on the surface of the sun, formed in the region of the sun's magnetic field, the number of sunspots with time shows a periodic change of about 11 years, which is called the solar activity cycle, during the active period, the number of sunspots increases, and the activity is strong, the inactive period is relatively calm; Flares are periodic, flares on the Sun and other stars are brief intense bursts that release large amounts of energy and radiation, and the activity of flares shows changes in the solar cycle of activity, and flares occur frequently during active periods; Starbursts are periodic, which are strong eruptions on or around the surface of a star that produce intense radiation, and certain star systems, such as the M dwarf system, show activity periodicity, in which the frequency of the starburst changes over time.

The driving force of stellar activity, the periodicity of stellar activity is usually related to the rotation and magnetic field activity of the star, which is generated by the internal movement of the star, causing

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the magnetic field to change, distort and reconnect, this magnetic activity can lead to phenomena such as dark spots, flares and bursts on the surface of the star. Rotation affects the structure and activity of the magnetic field, and distortion and reconnection of the magnetic field at different levels can lead to periodic activity phenomena.

Studying the periodicity of stellar activity is essential to understanding the internal structure of stars, the evolution of magnetic fields, and the relationship between activity and stellar parameters. This is also closely related to issues such as the habitation conditions of the planets and the origin of life in the universe, because stellar activity can affect the planet's atmosphere and environment.

3.2.1. Flare energy. Flare energy refers to the energy released when flares occur on the surface of a star, which are brief bursts on the star, usually accompanied by the release of intense radiation and energetic particles. Flare energy can be estimated by observing the luminosity, radiation intensity, and duration of the flare's activity. Due to the wide range of energy of flare activity, from small flares of low energy to large flares of high energy, the unit of flare energy is usually expressed using erg (energy unit). The estimation of flare energy usually involves the following factors, luminosity, the change in luminosity during the observation of the flare, and by measuring the intensity of radiation at different wavelengths in the spectrum, the total radiant energy of the flare can be estimated; Area, the energy of the flare is related to the surface area it affects, a large flare may cover a larger surface area and therefore have more energy; Duration, the duration of the flare activity also affects its total energy, the longer the duration, the more energy is released; Energy spectrum analysis, by analyzing the energy spectrum of the flare, that is, the distribution of radiation in different energy ranges, can more accurately estimate the energy of the flare.

It should be noted that the estimation of flare energy may have some uncertainty, because factors such as the complexity and diversity of flare activity itself, as well as observation limitations, affect the accuracy of energy estimation. However, the study of flare energy has important implications for understanding stellar activity, magnetic field action, and the release of energetic particles in interstellar space.

The formula for the total amount of radiation during an outbreak of a specific flare is as follows:

$$E_{flare,bol} = L_{star} \int F_{flare}(t)dt(erg) \tag{1}$$

In the formula:

$E_{flare,bol}$: Total radiated energy during the outbreak, in erg;

L_{star}: The total luminosity of the star, in erg/s;

$F_{flare}(t)$: The change in radiation flux over time during an outbreak in erg/(cm^2·s);

t: Time, which is standard in a certain unit of time, such as seconds.

By looking up TESS satellite data, we calculate the total amount of radiation during an explosion of a star as follows:

$$F_{flare}(t) = 2 \times 10^{31} \cdot e^{-0.5t} erg/(cm^2 \cdot s) \tag{2}$$

L_{star}: The total luminosity of the star is 1×10^{33} erg/s.

$F_{flare}(t)$: The change in radiation flux over time during an outbreak is a simplified function.

t: Time in seconds, from 0 to 10 seconds.

First, we divide the time interval into several small intervals, then calculate the radiant flux in each interval multiplied by the integral of the time interval, and add the results of all intervals. Suppose we divide the time interval into n=100, which is calculated as follows:

$$\Delta t = \frac{10}{100} = 0.1s$$

Then, calculate the integral approximation:

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$$E_{flare,bol} = 1 \times 10^{33} erg/s \times \left(\sum_{i=1}^{100} (2 \times 10^{31} \cdot e^{-0.5t_i}) \cdot 0.1 erg/(9cm^2 \cdot ps) \right) \cdot s \qquad (3)$$

3.2.2. Photoperiod analysis. Photoperiodic analysis is a method used to determine the periodic characteristics of light changes (brightness changes) of stars or other celestial bodies, which can reveal periodic changes caused by different physical processes such as stellar activity, planetary orbits, binary star systems, pulsars, Fourier transforms. Methods such as periodograms and autocorrelation functions are commonly used for photoperiodic analysis. Common photochange period analysis methods are: Fourier transform, Fourier transform can convert the light curve in the time domain into frequency domain, so as to analyze the contribution of different frequency components. Through the Fourier transform, you can find the main frequency component, the reciprocal of which is the period of light change. However, the Fourier transform can be affected by noise in some cases and requires proper data processing and signal-to-noise analysis; Periodogram, a periodogram is a graph that analyzes frequency components and can show signal strength at different frequencies. A periodic graph measures the periodicity of a signal in the time domain and shows the relative strength of the frequency components, which can be used to determine the main periods and frequencies; Autocorrelation function, autocorrelation function can be used to measure the correlation of the signal with itself, in the light curve, the autocorrelation function can be used to identify possible periodic changes, if there is a periodic signal, the autocorrelation function will show a significant peak at the corresponding period;Least squares fitting, for some periodic changes of the light curve with relatively regular regularity, the period can be estimated using the least squares fitting method, which tries to find the best-fitting period so that the difference between the light curve and the fitted curve is minimized; Fast Fourier Transform (FFT), FFT is an algorithm for efficient calculation of Fourier transform, suitable for digital signal processing and frequency domain analysis, which can accelerate the calculation of Fourier transform, making periodic analysis faster and more efficient. Below we will focus on the Fourier transform method.

The Fourier transform method can be used to analyze periodic signals in the light curve to help determine the period of light change. In the light curve, if there is a periodic change, the Fourier transform can convert this periodic change from the time domain (time domain) to the frequency domain (frequency domain), thereby identifying the main frequency components, corresponding to the period of the light change, the basic formula of the Fourier transform method is:

$$X(f) = \int_{-\infty}^{\infty} x(t) \cdot e^{-i2\pi ft} dt \qquad (4)$$

where the X(f) complex function of the frequency domain represents the component of the signal at frequency; is the signal in the time domain; is the f imaginary unit x(t); i is the f frequency.

For light curve analysis, you can calculate the period with the following steps: get light curve data, collect time series data on light curves, usually the brightness of stars over time; Apply the Fourier transform to the light curve data to convert the time domain data to the frequency domain data; Identify frequency components, in the frequency domain, by looking for frequency components with large amplitudes, periodic signals in the light curve can be determined, and the amplitude spectra of the Fourier transform show the amplitude of different frequency components; Determine the main frequency, by analyzing the amplitude spectrum, you can determine the main frequency component of the light change curve, the reciprocal of this frequency is the period of light change.

4. Results and Discussion

4.1. Properties and significance of newly discovered planets

The properties and significance of newly discovered planets have important implications in astronomy and scientific research, and each discovery of a new planet can provide us with more information about

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the universe, as well as a deeper understanding of the formation, evolution and distribution of planets and galaxies. Newly discovered planets have many properties and meanings, for example, the diversity of planetary properties, newly discovered planets can have different properties, such as mass, radius, orbital characteristics, atmospheric composition, etc., which can help us better understand the mechanisms of planet formation, their physical properties, and possible habitability; Diversity of planetary systems, newly discovered planets are usually found in planetary systems around other stars, and different planetary systems can exhibit a variety of different structures and characteristics, helping us to study the diversity and evolutionary history of planetary systems; Potential habitability, the possibility of finding terrestrial planets (planets similar to Earth's size and orbit) have aroused interest in the existence of life in the universe, and studying the atmospheric composition, temperature and other environmental characteristics of planets can help us determine whether there are conditions suitable for life; Planet formation and evolution, by looking at different types of planets, we can delve into the process of planet formation and evolution, and understanding the properties of different planets in planetary systems can reveal how they formed and evolved from primordial nebulae; Validating theories of planet formation, newly discovered planets can help validate theoretical models of planet formation and evolution, for example, whether the observed distribution of planets is consistent with existing theories of planet formation, which can verify the validity of these theories; Each newly discovered planet is a unique sample of the universe, demonstrating the diversity of the universe, which helps us better understand the evolutionary history of the universe, the formation of galaxies, and the status of planets. Providing new perspectives on scientific issues, newly discovered planets can lead to new scientific questions and research directions, they may bring new questions about planetary atmospheres, surface characteristics, interplanetary communication, etc., to push the frontiers of scientific research;

The properties and significance of newly discovered planets are not limited to the field of astronomy, but also involve many fields such as life sciences, Earth sciences and cosmology, and by delving into these planets, we can better understand the mysteries of the universe and our place in it.

4.2. Stellar diversity under TESS observations

TESS (Transiting Exoplanet Survey Satellite) is a space telescope specifically designed to find exoplanets, and thanks to TESS's high-quality data, it can be used not only to find planets, but also to provide us with a wealth of information on the diversity of stars.

TESS focuses primarily on stars on the main sequence, which are similar in mass and luminosity to the Sun, which are in a nuclear fusion stable state in stellar evolution and are the type of star that may have planets. TESS observations include stars of varying luminosity, from Sun-like stars to red dwarfs, and even brighter giants and supergiants, allowing us to study planetary properties and environments on different types of stars. TESS observations can help us understand the light changes and activities of stars, which may be caused by stellar rotation, stellar sunspots, flares, etc. By observing these changes, we can gain a deeper understanding of the physical properties and activity mechanisms of stars; The luminosity curves of stars, under TESS observations, the change in the luminosity of each star over time are recorded, forming luminosity curves that can help us identify planetary transit events and thus discover potential exoplanets; TESS observations can provide data on the luminosity of a star, helping to determine the stage of evolution of a star, and stars at different stages of evolution may have different effects on the planetary environment around them; TESS's observations can also cover binary systems, that is, systems in which two stars orbit each other, and planetary discoveries in these systems can be affected by the stellar two-body effect and require special handling.

TESS's observational data provide us with the opportunity to study various types of stars and their planetary systems, helping to reveal the relationship between stars and planets, as well as the diversity of stars in the universe.

4.3. Discovery of planetary associations with stellar properties

The association between planetary and stellar properties is an important area of astronomical research. By observing stars and the planets around them, scientists can discover the interplay and correlations

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between different properties that are important for understanding planet formation, evolution and habitability.

Studies have found a correlation between a star's metal abundance (metal content) and the mass of the planets around it. Stars with higher abundance of metals are more likely to host more massive planets, which may be related to the influence of metal elements in the formation of planets, such as metal elements may promote the formation of planetary cores; Stellar activity, such as sunspots, flares, etc., may have an impact on the atmospheres of surrounding planets, and strong stellar radiation and storms may deprive planets of their atmospheres and affect their habitability. A star's age may affect the evolution of the planets around it, younger stars may produce more stellar activity, affecting the nature of the planet's atmosphere, and age may also be related to parameters such as the inclination and eccentricity of the planet's orbit; The luminosity of a star is closely related to its surface temperature, while the surface temperature of a planet can be affected by stellar radiation, and the closer the planet is to the star, the higher its surface temperature may be, which is related to the question of whether the planet is suitable for life; Stellar radiation can affect the escape of a planet's atmosphere, and energetic particles and ultraviolet radiation can deprive a planet's atmosphere, especially light gases such as hydrogen and helium. The speed of a star's rotation may affect the orbit of the surrounding planets, and a rapidly rotating star may have an impact on the evolution of the planet's orbit, such as triggering orbital resonances.

These findings highlight the close interactions between planets and their surrounding stars, and how planetary properties are influenced by stars, and by delving into these associations, we can gain a fuller understanding of the evolution of planets and galaxies, as well as planetary habitability and the possibility of life.

5. Conclusion

In astronomical research, we increasingly recognize that the interrelationships between planets and stars are essential for understanding all aspects of the universe. By studying the properties of stars and planets, we can delve deeper into the mysteries of the universe, revealing the complex and subtle connections between planets and stars.

Our universe is full of diverse stars and planets that exhibit diversity in mass, size, composition, orbit, etc., thus providing us with the opportunity to delve into the diversity of the universe; The relationship between stars and planets reveals how planets form and evolve around different types of stars, and how planetary physical properties, atmospheric composition, and orbital characteristics can be influenced by stars, giving us clues to the study of planet formation and evolution; Planets are closely related to the habitability of stars, and the radiation, luminosity, and other properties of stars affect the habitability of planets, and by studying these associations, we can determine whether there are Earth-like planets that may support the existence of life; Stellar activity, sunspots, flares and other phenomena affect the interstellar environment around planets, which may have an impact on the planet's atmosphere, magnetic field, and escape processes, helping us understand the evolution and properties of planets; The interrelationships between stars and planets also provide directions for further exploration, and the study of these connections can lead to new scientific questions, facilitate cross-study between different fields, and expand our understanding of the universe.

The relationship between stars and planets is an important topic in astronomical research, expanding our horizons and helping us better understand the origin, evolution and diversity of the universe. Through continuous observation, analysis, and simulation, we will be able to explore these relationships more deeply, providing more answers to the mysteries of our universe.

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