Astronomical Techniques and Instruments, Vol. 1, January 2024, 16–30

Review Open Access

The Jiao Tong University Spectroscopic Telescope Project

JUST Team[1,2*], Chengze Liu[2,1], Ying Zu[2,1], Fabo Feng[1,2], Zhaoyu Li[2], Yu Yu[2], Hua Bai[3,4], Xiangqun Cui[3,5], Bozhong Gu[3], Yizhou Gu[1,2], Jiaxin Han[2], Yonghui Hou[3,5], Zhongwen Hu[3,5], Hangxin Ji[3], Yipeng Jing[1,2], Wei Li[6], Zhaoxiang Qi[7], Xianyu Tan[1], Cairang Tian[6], Dehua Yang[3], Xiangyan Yuan[3,4], Chao Zhai[8], Congcong Zhang[7], Jun Zhang[2], Haotong Zhang[9], Pengjie Zhang[1,2], Yong Zhang[9], Yi Zhao[6], Xianzhong Zheng[10], Qingfeng Zhu[8], Xiaohu Yang[1,2]

[1]*Tsung-Dao Lee Institute*, *Shanghai Jiao Tong University*, *Shanghai* 200240, *China*

[2]*Department of Astronomy*, *School of Physics and Astronomy*, *Shanghai Jiao Tong University*, *Shanghai* 200240, *China*

[3]*Nanjing Institute of Astronomical Optics* & *Technology*, *Chinese Academy of Sciences*, *Nanjing* 210042, *China*

[4]*University of Chinese Academy of Sciences*, *Nanjing*, *Nanjing* 211135, *China*

[5]*University of Chinese Academy of Sciences*, *Beijing* 101408, *China*

[6]*Lenghu Technology Innovation Industrial Park Management Committee*, *Lenghu* 817400, *China*

[7]*Shanghai Astronomical Observatory*, *Chinese Academy of Sciences*, *Shanghai* 200030, *China*

[8]*Department of Astronomy*, *University of Science and Technology of China*, *Hefei* 230026, *China*

[9]*National Astronomical Observatories*, *Chinese Academy of Sciences*, *Beijing* 100101, *China*

[10]*Purple Mountain Observatory*, *Chinese Academy of Sciences*, *Nanjing* 210023, *China*

*Correspondence: just.astro@sjtu.edu.cn

Received: December 9, 2023; Accepted: December 24, 2023; Published Online: December 31, 2023; https://doi.org/10.61977/ati2024008

Citation: JUST Team, et al. 2024. The Jiao Tong University Spectroscopic Telescope Project. *Astronomical Techniques and Instruments*, **1**(1): 16−30. https://doi.org/10.61977/ati2024008.

Abstract: The Jiao Tong University Spectroscopic Telescope (JUST) is a 4.4-meter *f*/6.0 segmented-mirror telescope dedicated to spectroscopic observations. The JUST primary mirror is composed of 18 hexagonal segments, each with a diameter of 1.1 m. JUST provides two Nasmyth platforms for placing science instruments. One Nasmyth focus fits a field of view of 10′ and the other has an extended field of view of 1.2° with correction optics. A tertiary mirror is used to switch between the two Nasmyth foci. JUST will be installed at a site at Lenghu in Qinghai Province, China, and will conduct spectroscopic observations with three types of instruments to explore the dark universe, trace the dynamic universe, and search for exoplanets: (1) a multi-fiber (2000 fibers) medium-resolution spectrometer (R=4 000−5 000) to spectroscopically map galaxies and large-scale structure; (2) an integral field unit (IFU) array of 500 optical fibers and/or a long-slit spectrograph dedicated to fast follow-ups of transient sources for multi-messenger astronomy; (3) a high-resolution spectrometer (R~100 000) designed to identify Jupiter analogs and Earth-like planets, with the capability to characterize the atmospheres of hot exoplanets.

Keywords: Astronomical instrumentation; Optical telescopes; Large-scale structure of the universe; Redshift surveys; Time domain astronomy; Exoplanet astronomy

1. INTRODUCTION

Observing facilities play a fundamental role in advancing our understanding of the universe. These facilities, including ground-based telescopes, space observatories, and specialized instruments, provide astronomers the necessary tools to gather data from distant celestial objects and phenomena, and explore the properties, compositions, and behaviors of objects such as stars and galaxies, leading to remarkable discoveries and profound insights into the nature of the universe. Moreover, long-term observations with these facilities enable monitoring of transient events, and probe the cosmos across various wavelengths, which is essential for unveiling cosmic mysteries. Observing facilities are indispensable for pushing the boundaries of astronomical knowledge and fostering scientific breakthroughs. The development of powerful observing facilities, whether for general-purpose use or dedicated surveys, has become a critical requirement for astronomers to achieve groundbreaking advancements. The progress of astronomy hinges on the construction of large telescopes which are currently evolving to possess large apertures, wide fields of view, and high spatial and spectral resolution. Given the disparity in assciated cost between acquiring images and spectra, there is a notable shortfall in high-quality spectroscopic observational facilities compared with the plentiful availability of image-based observational facilities. This gap highlights the need for further attention and investment in advancing spectroscopic capabilities to complement the existing observational landscape.

Astronomical spectroscopy enables the precise measurement of redshift, identification of specific chemical elements, and the determination of kinematics of celestial objects. It leads to a deeper understanding of the nature and characteristics of the observed objects. Spectroscopic observations offer a wealth of information that complements and enhances the insights gained from imaging observations.

To fulfill the scientific needs for spectroscopic observations, as well as owing to the great success of spectroscopic projects such as the Sloan Digital Sky Survey (SDSS, https://sdss.org/)[1], multiple new projects are thriving. The Dark Energy Spectroscopic Instrument (DESI, https://www.desi.lbl.gov)[2] is the first stage-IV dark energy survey project, comprising a 4 meter telescope with 5 000 robotic fiber positioners to feed a collection of spectrographs covering the 360−980 nm wavelength range. It has reportedly finished over 50% of its objectives and is expected to accomplish the total mission before the planned 5 years of run time, demonstrating its high efficiency in observation. Near future 4-meter-class telescope projects include the WHT Enhanced Area Velocity Explorer (WEAVE)[3] and the 4-metre Multi-Object Spectroscopic Telescope (4MOST, https://www.4most.eu)[4]. They will provide the spectroscopic follow-up required for full scientific exploitation of other projects, such as the Gaia, LOFAR and Apertif surveys. The MegaMapper [5] will be a dedicated cosmology facility with highly efficient redshift measurements on a 6.5 m telescope. 8-meter-class projects include the Subaru Prime Focus Spectrograph (PSF, https://pfs.ipmu.jp)[6] project, and the Multi-Object Optical and Near-IR Spectrograph (MOONS, https://vltmoons.org)[7]. With increasing telescope size, the Maunakea Spectroscopic Explorer (MSE, https://mse.cfht.hawaii.edu)[8], SpecTel[9] and the Fiber-Optic Broadband Optical Spectrograph (FOBOS, https://fobos.ucolick.org/)[10] are 10-meter-class projects. All of these large telescopes will equip instruments with thousands to tens of thousands of optical fibers, aiming at simultaneous spectroscopic observations of multiple objects at once.

In China, optical telescopes currently fall behind world-class standards. However, with improved funding availability and technological capabilities, observatories and universities have initiated the construction of optical telescopes with diameters exceeding 2 meters. This initiative is driven by diverse scientific objectives, and aims to facilitate distinctive observational research, enabling universities within China to make substantial progress with medium-sized observing facilities, such as the Wide Field Survey Telescope (WFST or “Mocius”, https://wfst.ustc.edu.cn), currently in its commissioning phase[11]. For spectroscopic observations, there are several telescopes, either proposed or under construction, such as the 4.4 meter Jiao Tong University Spectroscopic Telescope (JUST, https://just.sjtu.edu.cn), and 6.5-meter Multiplexed Survey Telescope (MUST, https://must.astro.tsinghua.edu.cn/must/), as well as the stage II of Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST-II, https://www.lamost.org).

Construction has already begun on JUST, and the first light observations are expected within three years. This telescope will be equipped with dedicated spectroscopic instruments to explore the dark universe, trace the dynamic universe, and search for exoplanets. In this paper, we provide basic information about details such as the site, structure, optical system, and science motivations of JUST. The structure of this paper is outlined as follows. We first introduce the site condition in Section 2, followed by the conceptual design of the JUST telescope in Section 3. An overview of the planned instruments and science motivations is presented in Section 4. We summarize the JUST project in Section 5.

2. GEOGRAPHIC LOCATION AND DOME

Mauna Kea in Hawaii and certain summits and plateaus in northern Chile are among the best observing sites on the Earth. Over the past two decades, much effort has been dedicated to the search for excellent astronomical sites in China. Recently, the summit of Saishiteng Mountain in Lenghu, located on the Tibetan Plateau, was identified as possessing favorable observing conditions. Site monitoring has shown that the summit of Saishiteng Mountain, situated at an altitude of 4 200 to 4 500 meters, experiences clear nights for approximately 70% of the year and boasts good median seeing of 0.75 arcsec[12]. The climate in the surrounding area of the site is extremely arid, and the sky background is exceptionally dark due to minimal light pollution. Furthermore, the time zone of the Lenghu site is distinct from that of nearly all observatories worldwide, facilitating complementary time-domain astronomy.

The planned installation of the JUST telescope is shown in Fig. 1, at position B, situated at an altitude of 4322 m on the summit of Saishiteng Mountain, close to position C where WFST is located. Spectroscopic observations with JUST will complement imaging observations made with WFST, providing essential photometric and spectroscopic data for advancing researches across various domains of astronomy.

Fig. 2 illustrates the design concept of the telescope dome for JUST. It incorporates a classical semi-spherical dome, featuring a shutter that can be opened to allow the telescope to observe. The dome will also integrate ventila-

Fig. 1. Bird's-eye view of Saishiteng Mountain. The largest dome at Position C (at an altitude of 4200 m) houses the WFST, which is dedicated to imaging surveys. JUST will be placed at Position B (at 4322 m). Photo credit: Bin Chen.

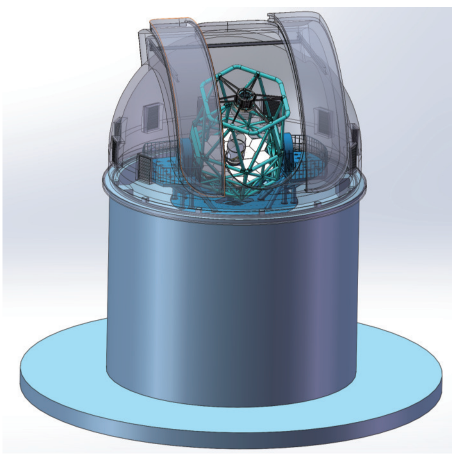

Fig. 2. The conceptual design of the dome for JUST.

tion systems to regulate temperature and air circulation, improving dome seeing. Additionally, it will include lighting and other equipments to support telescope operation and maintenance. The construction of the site infrastructure and telescope dome is scheduled to commence in 2024.

3. JUST CONCEPTUAL DESIGN

3.1. General Parameters

JUST is a 4.4 meter aperture Ritchey-Chretien telescope. The telescope project encompasses three main functional subsystems: telescope optics, support and structure, and telescope control. The telescope optics subsystem comprises optical mirrors and mirror support with active optics. The support and structure subsystem includes a tracking mount and telescope tube. The control subsystem incorporates the telescope control subsystem (TCS), observation control subsystem, and active optics control subsystem. A lightweight telescope design is achieved through the selection of a horizontal tracking mount and a truss-type telescope tube structure. The overall conceptual view of the telescope is illustrated in Fig. 3.

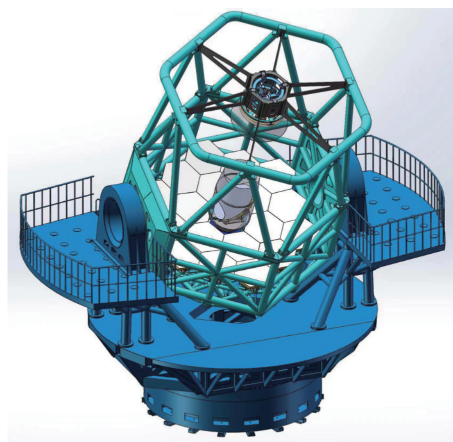

Fig. 3. The conceptual design of the structure of JUST.

JUST has two Nasmyth foci with a focal ratio of *f*/6.0. One Nasmyth focus has a field of view (FoV) of 10′ and the other Nasmyth focus has an extended FoV of 1.2° with correction optics, as shown in Fig. 4. The two Nasmyth foci can be switched by rotating the tertiary mirror (M3). Nasmyth focus 1 is a purely reflecting system, in which high-resolution wide-wavelength instruments or infrared instruments can be mounted. The image quality is defined as the full width at half maximum (FWHM) of the image profile. The intended image quality of Nasmyth focus 1 is 0.09″. With manufacturing, alignment, and control error, this value can be reduced to 0.35″.

Nasmyth focus 2 is used for the Multi-Object Fiber Spectroscopic Survey. The diameter of the focal plane is 570 mm, and about 2 000 optical fibers can be accommodated. At a zenith distance of 60°, observation site alti-

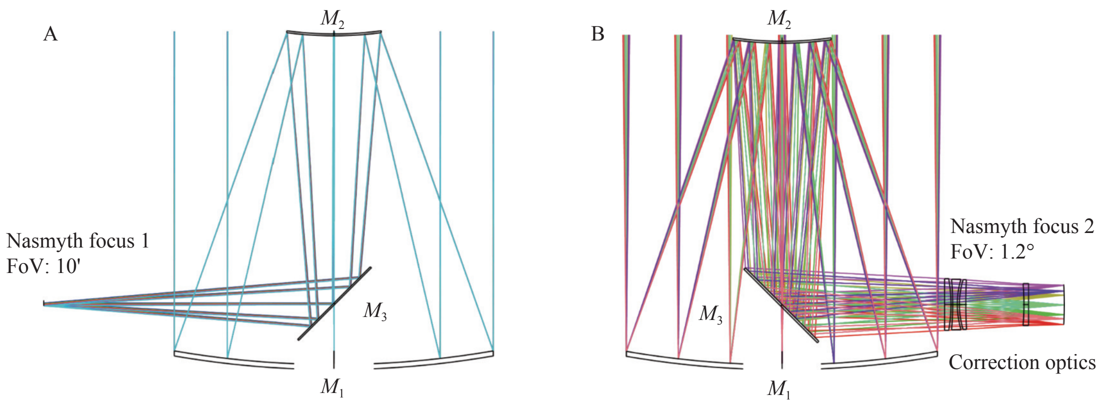

Fig. 4. Optical design of JUST. (A) Nasmyth focus 1 with a FoV of 10'. (B) Nasmyth focus 2 with an extended FoV of 1.2°.

tude of 4 200 m, and the wavelength range of 0.35−1.3 µm, the atmospheric dispersion is 3.1″. However, astigmatism rapidly increases with the square of the FoV, so it is essential to include a corrector for widening FoV and compensating for atmospheric dispersion. The corrector consists of four silica lenses, two of which are the atmospheric dispersion correctors (ADCs). The target image quality of Nasmyth focus 2 is 0.51″. With errors, the delivered image quality will be 0.7 ″, which is close to the value of median seeing at the Lenghu site. As a reference, we list in Table 1 the main optical parameters of JUST.

Table 1. Optical parameters

Parameters	Values
Primary mirror diameter	4.4 m (segmented)
M1 focal length	6.4 m
System *F* ratio	6.0
Focal scale of focus 1 & 2	7.8 arcsec mm^{-1}
Focus 1	Nasmyth focus (high precision)
FoV 1	10′
Wavelength range 1	Purely reflecting
Focus 2	Nasmyth focus (large FoV)
FoV 2	1.2°
Wavelength range 2	0.35−1.3 µm

3.2. The Mirrors

The primary mirror (M_1) is composed of 18 hexagonal segments, with an effective aperture of 4.4 m. The detailed configuration is depicted in Fig.5. Each segment is equipped with its own support system to maintain the correct optical surface. The axial support system utilizes an 18-point whiffletree support for the segments, while the radial support employs a central flexible support. This support system serves the following functions:

• Accurate installation of the segments onto the main truss;

• Support for the segments to meet the requirements for the mirror surface shape;

• Active optical technology to control the closed-loop segmented system of the primary mirror, mitigating the effects of temperature and gravity, and achieving co-focusing/co-phasing of the segments.

The secondary mirror (M_2) support module is designed to preserve its original machining accuracy and stabilize its spatial position. The support system for the secondary mirror includes a bottom support, lateral support, and centering mechanism. The bottom support features a suspended whiffletree support structure, while the lateral support uses a lever-balanced weight support structure. The centering mechanism employs a bi-directional membrane structure in both radial and axial directions.

The tertiary mirror (M_3) uses a whiffletree floating support structure, with the centering mechanism also adopting a bi-directional membrane structure to serve the radial and axial directions, in addition to function as lateral support.

3.3. Active Optics

The M1 is designed to use active optics technology for real-time closed-loop control splicing to join the segments into a single mirror surface. The active optical system primarily comprises core devices such as segment surface support, displacement actuator, and an active optical wavefront sensor.

• Segment surface support system: Ensures that the support surface meets and exceeds the technical requirements for the segment surface shape.

• Displacement actuator: Utilizes nano-electromechanical displacement actuators controlled in parallel by multiple active optical intelligent controllers to achieve nanometer-level displacement resolution and millimeter-level displacement range output accuracy and stroke under the full load of the segments.

• Active optical wavefront sensor: Uses a Shack-Hartmann wavefront sensor based on physical optics. It measures the surface shape, imaging quality of individual segments, and the segmented primary mirror. It uses the central star as a target source, providing precise feedback to continuously drive the displacement actuators for segmented mirror calibration and maintenance.

Upon implementation of active optics technology, the telescope will achieve co-focusing of the primary mirror and obtain imaging quality close to the visibility limit of the telescope's location, in conjunction with the optical sys-

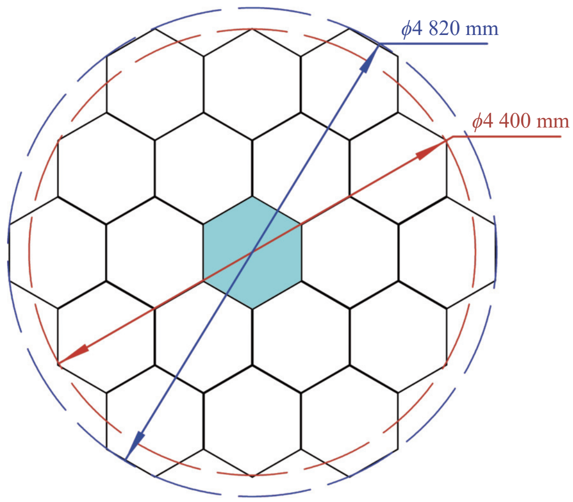

Fig. 5. Configuration of the segments of M1, showing 18 hexagonal segments. The central area of the primary mirror is vacant, where M3 will be installed.

tem design.

4. SCIENCE CASES AND SCIENTIFIC INSTRUMENTS

JUST has two Nasmyth platforms and will be installed with three types of spectrographs on both. The basic parameters of these spectrographs are listed in Table 2.

• Galaxies and large-scale structures: JUST will be equipped with multiple fiber positioners and medium-resolution spectrometers to conduct spectral surveys of a large number of galaxies.

• Multi-messenger astronomy: JUST will be equipped with hundreds of optical fibers to form an Integrated Field Unit (IFU) array and/or a long-slit spectrograph for follow-up observation of a large number of transient sources.

• Exoplanet detection and characterization: JUST will use advanced high-resolution spectrometers to detect cold giant planets and earth-like terrestrial planets, and to provide detailed atmospheric characterization for hot exoplanets.

Table 2. Key parameters of three types of spectrographs

Parameters	Fibers	Resolution
Multi-object spectrograph	2 000	4 000−5 000
IFU array	500	4 000−5 000
Long-slit spectrograph	N/A	4 000−5 000
High-resolution spectrograph	1−3	~100 000

4.1. Exploring the Dark Universe

More than 95% of the universe remains dark to humanity, whether in the form of dark matter or dark energy[13]. The first step toward understanding the dark universe requires the accurate measurement of the growth of cosmic structures on scales ranging from a few kiloparsecs to hundreds of megaparsecs, with highly-multiplexed spectroscopic surveys of galaxies [14]. To complement the current stage-IV surveys that focus on the galaxy distribution at linear scales, JUST will dedicate its multi-object spectroscopic (MOS) capability to the mapping of structures from quasi-linear to highly non-linear scales, centered on massive galaxy clusters at $z < 0.6$. JUST aims for complete spectroscopic coverage of the galaxies at $r <$ 20 mag in the cosmic web surrounding clusters below $z <$ 0.6, complementing DESI spectra.

The JUST spectroscopic cluster survey (SCS) will improve cluster cosmology as one of the most sensitive probes of cosmic growth, through the mitigation of systematic uncertainties in the cluster redshifts, satellite membership assignment, and various projection effects associated with photometric cluster finders [15-18]. The spectroscopic cluster catalogue will provide stringent constraints of key cosmological parameters, including the matter density, the amplitude of matter clustering, the equation-of-state of dark energy, and the sum of neutrino masses[19]. The combination of the redshift-space distortion (RSD) of infalling galaxies[20-23] and the weak lensing of background sources[24-26] by galaxy clusters will enable stringent tests of theories of cosmic acceleration to distinguish between dark energy and modified gravity on inter-cluster scales[27-30]. Meanwhile, JUST-SCS will fully sample cluster galaxies in both the velocity phase space (cluster-centric radius vs. line-of-sight velocity) and the color-magnitude diagram, from infall to the splashback regions, and into the virialized cores of clusters[31-36]. Such spectroscopic coverage of the cosmic web will provide a comprehensive picture of galaxy formation in different environments surrounding galaxy clusters[37].

In recent decades, Chinese astronomers have made significant contributions to revealing the nature of the dark universe with contributions such as measuring and quantifying large scale structure, elucidating the galaxy-halo connection, constraining the cosmological parameters. Among these efforts, representative work includes establishing the halo occupation distribution model[38] based on the Las Campanas Redshift Survey[39], establishing the conditional luminosity function model[40] based on the 2-degree Field Galaxy Redshift Survey (2dFGRS)[41], establishing the halo-based group finder[42,43] based on 2dFGRS and the Sloan Digital Sky Survey [1], and making dark energy model constraints[44] based on the Baryon Oscillation Spectroscopic Survey[45]. Most of these achievements were made based on either public data releases or through international collaborations of large galaxy redshift surveys. With JUST-SCS, we will have greater opportunity to explore the dark universe with our own observational data set. To maximize the science return of the MOS survey on cluster cosmology and galaxy evolution, JUST-SCS will include three layers as summarized by Fig. 6. We will discuss each of the three in the subsections below.

4.1.1. *JUST cluster cosmology survey*

The upcoming China Space Survey Telescope

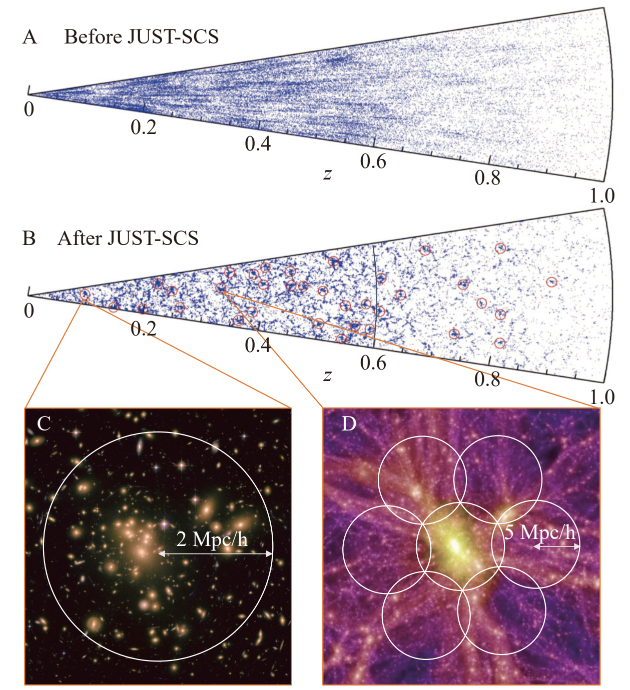

Fig. 6. Illustration of the JUST-SCS program. (A) Distribution of the photometric galaxies within a simulated light cone. Galaxies from the same cluster are dispersed over a large line-of-sight distance due to photometric redshift (photo-z) uncertainties. (B) Distribution of the spectroscopic clusters (highlighted with red circles) that will be observed by the JUST cluster cosmology survey within the same light cone. (C) A cluster at $z = 0.1$ within the JUST FoV (white circle) targeted by the JUST cluster galaxy evolution survey. Background image is Abell 1689 (https://hubblesite.org/contents/media/images/2010/26/2758-Image.html). (D) Cosmic web structure centered on a cluster at $z \approx 0.3$ targeted by the JUST cluster infall survey. The background image is from the Millennium Simulation (https://wwwmpa.mpa-garching.mpg.de/galform/virgo/millennium/).

(CSST)[46] will detect approximately 300 000 photometric halo-based cluster candidates with halo mass above 10^{14} $M_\odot$ /h up to $z < 1.5$[47], serving as the basis of target selection for JUST-SCS. In particular, the JUST cluster cosmology survey will target ≃ 50 000 clusters over 10 000 deg^2 at $z < 0.6$, producing an unprecedented spectroscopic cluster sample for cosmological analysis. For each cluster, JUST will be used to obtain spectra for the brightest cluster galaxy (BCG) and the bright member galaxy candidates down to $r = 20$, including but without re-observing the spectra from the full DESI survey. This program will not only provide secure spectroscopic redshifts for a cosmologically significant volume of individual clusters, but also improve the centering of clusters both perpendicular and along the line-of-sight [48]. Such an accurate localization of individual clusters in three dimensions enables cosmological analyses using massive dark matter haloes, instead of galaxies, as spectroscopic tracers of the large-scale structure.

With spectroscopic redshifts for up to 20 member galaxy candidates, JUST will be able to disentangle the chance alignment of structures along the line of sight, and mitigate interlopers from any correlated structures on the velocity phase diagram. The spectroscopically confirmed satellite galaxies will enable mass estimates of individual haloes through the velocity dispersion[49-51] and caustic boundary[52-54], improving the calibration of the cluster mass-observable relation beyond the optical richness[55]. Meanwhile, JUST will probe the properties of the intracluster medium, particularly the circumgalactic medium of cluster galaxies, by measuring metal absorption lines recorded in the DESI spectra of background quasars in the cluster fields[56-60].

4.1.2. *JUST cluster infall survey*

In the intermediate redshift range between $0.1 < z < 0.4$, JUST-SCS aims to achieve a complete spectroscopic coverage of galaxies within an approximately 20 Mpc/h radius surrounding each cluster down to $r = 20$, on top of the existing spectra from the DESI Bright Galaxy Survey (BGS)[61]. In addition, JUST will spectroscopically cover a large number of non-cluster fields to the same depth, as the control sample of field galaxies for the cluster-galaxy cross-correlation measurements and the galaxy evolution study. The target selection of the non-cluster fields will be optimized based on the signal-to-noise forecast of the cluster RSD analysis.

The JUST cluster infall survey will push the "Estimator of Gravity" (E_G) method [62] from the linear regime to the infall region around clusters, where the potential imprint of modified gravity remains unscreened and the signal-to-noise of the RSD and weak lensing measurements is high. In particular, JUST will accurately measure the cluster-galaxy cross-correlation function in the redshift-space on projected scales below 20 Mpc/h, allowing high-fidelity reconstruction of the galaxy infall kinematics (GIK) as a function of distance to the cluster center. The GIK reconstruction provides a unique probe of the average dynamical mass profile of clusters in the infall region, which will enable stringent tests of the theories of cosmic acceleration when compared with the cluster mass profile measured from weak lensing[27]. In addition, dense spectroscopic sampling of the infall region allows individual measurements of the cluster dynamical mass using the caustics technique.

One of the primary systematics in cluster cosmology is the projection effect due to the 2D aperture adopted by photometric cluster catalogues, leading to the correlation between cluster richness and large-scale overdensity, hence the bias in the large-scale weak lensing signals of clusters [63-65]. The JUST cluster infall survey will mitigate this projection effect by adopting a 3D aperture in the velocity phase space for measuring cluster mass observables. Meanwhile, this program will provide a panorama of the star formation, chemical enrichment, and dynamical evolution of galaxies across the cosmic web. Spectral stacking at different cosmic web environments will allow a robust reconstruction of the average histories of star formation and chemical evolution, as galaxies are funneled through the filaments into clusters [66,67]. By comparing the galaxy population in surrounding clusters with those observed in the non-cluster fields, JUST will provide the key observational evidence on the concept of "nature versus nurture" in galaxy formation.

4.1.3. *JUST cluster galaxy evolution survey*

In the nearby universe below $z < 0.1$, JUST will obtain spectra for galaxies within the virial radius of each SDSS galaxy group [43]above 10^{13} $M_{\odot}$ /h down to a stellar mass of ~10^8 $M_{\odot}$. Focusing on the faint end of the conditional luminosity function of groups[68-70], the JUST cluster galaxy evolution survey will explore the star-forming histories of dwarf galaxies inside the group and cluster-size haloes, and ascertain the existence of a characteristic stellar mass of quenching among the satellites [70]. With the accurate measurement of the group/cluster masses, JUST will provide strong constraints on the stellar-to-halo mass relation of the dwarf satellites via abundance matching and satellite weak lensing[71-75].

The JUST cluster galaxy evolution survey will reveal the co-evolution between cluster galaxies and dark matter haloes, by connecting the spectroscopic observations to the individual halo assembly histories predicted by Exploring the Local Universe with reConstructed Initial Density field (ELUCID) simulation, a state-of-the-art constrained simulation that accurately reconstructed the initial density perturbations within the SDSS volume below $z = 0.1$[76, 77]. Another unique aspect of this program is the exciting synergy with the FAST All Sky HI Survey (FASHI)[78], which will provide the largest extragalactic HI catalogue at $z < 0.1$ using the Five-hundred-meter Aperture Spherical radio Telescope (FAST)[79].

Meanwhile, JUST will reserve a fixed set of fiber assignment for a sample of low-surface brightness targets (e.g., ultra-compact dwarfs) to allow spectral coverage down to ≃ 23 magnitudes per arcsec 2 in the r-band[80, 81]. For extended sources of interest (e.g., including the outskirts of BCGs and bar galaxies), MOS-mode observations can be supplemented by follow-up observations with the IFU instrument[82, 83]. Taking advantage of the synergy with ELUCID and FAST, the versatility of JUST will present an exquisite view of cluster galaxy evolution in the local universe.

4.2. Tracing the Dynamical Universe

The universe is not static. It is in motion and constantly changing. Time-domain astronomy, which focuses on dynamic astronomical events, is a promising method to study this in greater detail.

In the 2020 NASA decadal survey for astronomy and astrophysics, it is considered an important research frontier in astronomy[84]. Rapid follow-up observations of unexpected events is crucial in the era of multi-messenger astronomy, allowing astronomers to combine various observation methods such as neutrinos, electromagnetic waves, and gravitational wave signals, which are of great significance for understanding important high-energy astrophysical processes such as black hole and neutron star mergers. The main targets of time-domain astronomy are sporadic events (such as supernova explosions and tidal collapse events.), and the follow-up spectroscopic observation of these events can help to understand the specific physical processes in these transient sources.

There are currently dozens of time-domain astronomical survey projects, such as the Catalina Survey, PanSTARRS, iPTF, ASASSN, ATLAS and ZTF. In the past decade, the number of transient sources discovered has increased tenfold[85]. The first gravitational wave electromagnetic counterpart was discovered in 2017[86] and confirmed to be a millennium nova (kilonova)[87]. At present, the number of supernovae discovered is increasing year by year, exceeding one thousand per year. Based on large sample studies, new types of supernovae and explosive physical processes have been discovered. At the same time, new processes of active galactic nucleus explosions and tidal disruption events are also being continuously discovered. Time-domain astronomy has evidently become one of the fastest developing frontier astrophysical research fields. The study of time-domain astronomy can answer the following important questions: What is the explosive process of the evolution of massive stars to their final stages? What are the precursor stars of Type Ia supernovae? How did they erupt? Why does the universe accelerate its expansion? What determines the mass, spin, and radius of a dense star? How do supermassive black holes accrete and grow? Although astronomers have made some progress in addressing these issues, they are still far from fully understanding the physical reasons behind these phenomena.

In the future, surveys like LSST, CSST and WFST will obtain larger transient source samples. It is expected that hundreds or thousands of supernovae and other explosive phenomena will be discovered every night. These future surveys will significantly expand the redshift coverage of transient sources and expand the observation wavelength ranges. Space telescopes such as the Einstein Probe (EP), Swift, and Wide-field Infrared Survey Explorer (WISE) will observe the transient sources in X-ray, ultraviolet, and infrared bands, respectively. It can be expected that these larger samples will bring higher statistical significance, to reveal systematic differences among different types of transient sources and to discover extreme cases in each category. For example, in the past decade, the increasing number of transient source events has spawned research on the relationship between Type Ia supernovae and the star formation rate in their host galaxies [88], and the discovery of Type II supernovae that lasted for a year[89], as well as a new type of thermonuclear explosion supernova (SNe lax)[90,91].

The photometric detection of supernovae or other transient sources is only the first step. Only by completing the second step of spectral observation, the physical origin of these transient sources can be clearly explained. According to Blagorodnova et al. [92], compared with photometric observations, the spectroscopic observation of transient sources is still insufficient. With the development of more photometric surveys, this difference will only become more pronounced in the future. JUST, with hundreds of optical fibers, can effectively carry out spectroscopic observations of a large number of transient sources by assigning a fiber to each target. It will also provide information on the two-dimensional kinematics and chemical properties of the host galaxy of the transient sources with the fibers forming an IFU array, providing first-hand data for studying its triggering environment mechanism.

The transient sources may be induced from many different high-energy phenomena. Among them, events such as gamma-ray bursts, supernovae, and tidal disruption events are generated by cataclysmic processes.

AGN flares, X-ray binary bursts, and rapid radio bursts involve periodic and intense physical processes near black holes or compact objects with strong magnetic field. The study of these phenomena not only reveals the specific physical mechanisms, but also helps to test basic theories such as relativity under extreme conditions. JUST will primarily focus on follow-up spectral observations of various transient sources, which is crucial for revealing the driving mechanisms of transient sources.

4.2.1. *Supernova identification and classification*

Important for cosmological research, Type Ia supernovae can serve as standard candles for cosmological distance determination, ultimately leading to the discovery of accelerated expansion of the universe. High redshift supernovae are mainly discovered through photometric methods, and subsequent spectral analysis helps to distinguish different types of supernovae. On one hand, distinguishing the different types of supernovae can reduce the impact of other types of supernovae on the distance measurement of high redshift galaxies, improving the accuracy of galaxy distance measurement, to better constrain on the accelerated expansion of the universe. On the other hand, analyzing supernova subclasses can help in understanding the basic parameters of precursor stars, the physical processes of explosions, and the interaction between the outflow material and the interstellar medium.

JUST is capable of rapid response and subsequent spectral observations of supernovae at moderate redshifts ($z \sim 0.1-0.3$). Within this redshift range, the magnitude of Type Ia supernovae ranges from 18 to 22 magnitudes. The aperture of this telescope is large enough to accomplish this, and the observation conditions at its location (Lenghu) are excellent, which can allow the recording of high signal-to-noise ratio spectra of these sources[12]. This will significantly increase the number of supernova observations in the medium redshift range and may potentially discover new types of supernova.

4.2.2. *Gravitational wave electromagnetic counterpart properties*

The discovery of gravitational wave GW150914 was a milestone event in gravitational wave astronomy, which confirmed the existence of a black hole merger for the first time [93]. However, the electromagnetic wave counterpart of the gravitational event was not discovered until 2017, when global synchronous observations of GW170817 confirmed its electromagnetic counterpart for the first time as a binary neutron star merger event[94]. Within minutes to hours, Chile’s Swope telescope confirmed an optical flare event in NGC 4993 galaxy. In the following weeks, observatories around the world conducted follow-up observations of the event in different wavelengths, providing a panoramic view of the physical process of the binary neutron star merger event[95]. The visual magnitude of the optical counterpart of this binary neutron star merger event varies between 17.5 and 23 magnitudes, and JUST can also perform spectral observations of this source and others like it. In the future, more gravitational wave events will be detected. Timely follow-up spectroscopic observation of the source is very important to provide additional information (such as chemical abundance, redshift, and kinematics) to reveal the physical properties of gravitational wave sources.

4.2.3. *The physical process of tidal disruption events*

If a star is too close to a supermassive black hole, it will be disrupted by tidal forces, causing about half of the material to be accreted, resulting in flares at optical, infrared, ultraviolet, X-ray, and other wavelengths. This is known as a tidal disruption event (TDE), which was theoretically proposed in 1970s [96-101] and observationally confirmed in 1990s[102-105]. It has become one of the most important targets in time-domain astronomy. With the advancement of various photometric surveys (such as South Sky LSST and North Sky WFST), a large number of TDEs will be discovered. For example, WFST in China expects to discover tens to hundreds of TDEs annually and to obtain complete light curves, including the early brightening phase. TDEs are one of the main targets of the Einstein Probe X-ray telescope in China. TDE detection is an important method to observe supermassive black holes (including quiescent ones) and provides information on black hole mass and spin, accretion disk physics, strong field gravity, and black hole environment (gas, dust environment, and stellar properties). TDEs are also useful to identify intermediate mass black holes, with the potential to resolve the mass gap between stellar mass black holes and supermassive black holes, completing the evolutionary landscape of black holes.

JUST can efficiently perform follow-up spectroscopic observations of TDEs detected by WFST and EP. Its 4.4-meter aperture, fast pointing adjustment, same observation location, and medium resolution spectrograph make it perfectly compatible with WFST (a 2.5-meter telescope) to carry out joint measurements of TDEs. The typical brightness of TDEs is ~20−23 mag (with a redshift range of 0.3−1), and the light curve variation period is on the order of months, allowing a considerable success rate in obtaining TDE spectra with redshifts below 1. The acquisition of TDE spectra can provide important information such as accretion disk wind properties, stellar/accretion and disk chemical composition[106,107]. Combined with the light profile curves of other photometric surveys, it will significantly improve the understanding of the physical mechanisms of TDEs, as well as the strong gravitational field properties. JUST can also provide key spectroscopic evidence for the tidal disruption of white dwarfs in intermediate mass black holes that have been discovered.

The IFU observation mode is expected to obtain spectroscopic information on host galaxies, measuring their redshift, dispersion velocity, and chemical composition, to provide further observational constraints on the coevolution of galaxies and supermassive black holes.

4.2.4. *Long term monitoring of active galactic nuclei (reverberation mapping)*

JUST can also monitor the long-term spectral variability of active galactic nuclei (AGN). A considerable number of AGN with redshift less than 1 have r-band magnitudes brighter than 22 mag, suitable for future observation with JUST. By analyzing the time delay between the variability of the emission lines and the continuum, the reverberation mapping method can be used to analyze the structural characteristics of the broad line region (BLR) near the black hole, and to estimate the mass of the black hole. In addition, by observing the post spectral variability of some sudden flare phenomena in AGN, we can understand the physical reasons behind the changes in the continuum, broad line structure, and kinematics of AGN with the variation of the accretion rate, to better understand the physical processes of accretion by supermassive black holes.

4.3. Detection and characterization of exoplanets

The third category of science motivations for JUST is exoplanet detection and characterization. With its high- resolution spectrometer, JUST will enable the discovery of a substantial number of cold giant planets by employing a combination of radial velocity (RV) and astrometric analyses. In its upgraded phase, JUST will feature an exceptionally high-precision spectrograph designed for detecting Earth-like planets. Leveraging these advanced capabilities, JUST will further enable the characterization of the atmospheres of hot exoplanets, contributing valuable insights into their formation and evolution.

4.3.1. *Detection of cold giant planets*

The planets in our solar system, and most known exoplanets, are thought to form in a bottom-up fashion through collisions of dust, pebbles, and planetesimals. This so-called "core accretion" (CA) mechanism is able to form Jovian planets through the processes of core formation, envelope formation, and contraction. However, this formation mechanism is probably not an efficient way to form substellar companions in wider orbits before the dispersion of a protoplanetary disk in ~10 Myr[108]. These objects are more likely to form like stars in a top-down fashion through the so-called "gravitational instability" (GI) mechanism[109]. However, due to the flexibility and ambiguity of the features of substellar companions predicted by CA and GI, it is challenging to determine which formation channel is responsible for specific giant companions such as the four directly imaged giant planets around HR 8799 [110]. Hence, a statistically significant sample of giant planets in wide orbits (i.e., cold giants) will be essential to statistically distinguish between GI and CA and draw a boundary between these two formation channels.

Thanks to the high precision astrometry catalogs released by Gaia[111-114] and the long baseline formed by Gaia and its precursor, Hipparcos [115,116], many substellar companions detected by the radial velocity method have been confirmed, with absolute masses determined by combined analyses of radial velocity(RV) and astrometry data[117-120]. However, these detections are limited to super-Jupiters, or more massive companions due to the limited precision and time span of the current Gaia data and the limited number of stars with high precision RV data. While the precision and time span of Gaia data will be significantly improved in Gaia DR4, it is hard to significantly increase the current sample of stars with high precision RVs because of the limited number of high-resolution spectrographs and the low efficiency of the current high precision RV survey.

To facilitate the detection of large numbers of cold giants with the combined RV and astrometry method, JUST will be equipped with the High Resolution Spectrograph (HRS), which can measure RV with a precision of about 1 m/s.HRS will be a fiber-fed, white-pupil spectrograph with an intended resolution of R = 60 000−80 000 and a wavelength range of 380−760 nm. The instrument design will be based on the successful high resolution spectrograph on LAMOST[121] and High Accuracy Radial Velocity Planet Searcher-North (HARPS-N) [122]on the Telescopio Nazionale Galileo (TNG). To obtain a precision radial velocity (PRV), HRS will be environmentally stabilized in a vacuum enclosure, with two optical fibers providing simultaneous measurement of the scientific source and a spectroscopic calibration source. Like other PRV instruments, the HRS will include three main subsystems: a front-end module to correct for atmospheric dispersion, to reimage the telescope beam onto the science fiber, and to stabilize the image with fast tip-tilt corrections; a calibration unit to enable the injection of different light sources; the vibrational and thermal isolation from the surrounding environment. To ensure optimal performance and superior angular resolution, HRS will be integrated with the first Nasmyth focus of JUST.

4.3.2. *Detection of Earth twins*

One major objective of exoplanetology is to find Earth-like planets. Among these, the so-called Earth twins are Earth-sized planets located in the habitable zones of Sun-like stars [123]. These temperate worlds can sustain liquid water on their surfaces and may also have other habitable conditions such as plate tectonics, magnetic fields, and stable orbits. Earth twins are ideal targets for future missions such as Large UV/Optical/IR Surveyor (LUVOIR)[124], Habitable Exoplanet Observatory (HabEx)[125] and the Habitable World Observatory (HWO)[126].

However, the detection of Earth twins is challenging due to limited instrumental precision and stellar activity. The measurement error of single RVs is typically >0.3 m/s for second-generation spectrometers such as Echelle SPectrograph for Rocky Exoplanets and Stable Spectroscopic Observations (ESPRESSO) on Very Large Telescope (VLT)[127], Maroon-X RV Spectrograph on Gemini-North[128], NN-explore Exoplanet Investigations with Doppler spectroscopy (NEID) on Wisconsin-Indiana-Yale-NOIRLab (WIYN) 3.5-meter Telescope[129], and the Keck Planet Finder[130]. With advanced data analysis techniques, it is possible to detect RV signals as small as 0.3 m/s [131,132].

While instruments like ESPRESSO and KPF have achieved an RV precision of under 1 m/s for detecting habitable Earths, stellar activity introduces noise reaching several m/s, surpassing the planetary signal. The challenge in using RV to detect habitable Earths lies in effectively distinguishing this “red noise” from the planetary signal, given its time dependence. Advanced noise modeling techniques such as Gaussian processes have been used to mitigate such red noise[133,134]. However, these techniques may lead to false negatives due to over-fitting [135,136].

To mitigate the impact of wavelength-dependent stellar activity noise on RV measurements, traditional methods involve measuring the intensity of spectral lines characterizing stellar magnetic fields to remove the velocity variations linearly correlated with these so-called “activity indicators” [137-139]. However, different types of stars respond differently to various stellar activity indicators, and the linear removal of velocity correlated with these indicators introduces inherent noise. Therefore, recent research favors directly selecting spectral lines from the spectrum that are less “contaminated” by stellar activity[140,141].

In the upgraded phase of JUST instrumentation, an ESPRESSO-like spectrograph, named the Extremely high Resolution Spectrograph (ERS), will be built for the detection of Earth twins. ERS will have a resolution of at least 100 000 and can measure RV with a precision of about 0.1 m/s. It will be built following the design of Canary Hybrid Optical high-Resolution Ultra-stable Spectrograph (CHORUS) on Gran Telescopio Canarias (GTC, https://www.nao.cas.cn/gtc/hrs/gkoverview/). With this spectrometer, JUST will survey a sample of 20−40 nearby Sun-like stars over 5 years to discover Earth twins. Given the current uncertainty in the occurrence rate of Earth twins[142], we expect to discover at least 1−3 Earth twins as ideal samples for future direct imaging missions such as LUVOIR and HabEx [124,125].

4.3.3. *Characterization of hot extrasolar giant planets*

A primary goal in exoplanet science is to characterize exoplanetary atmospheres and understand the formation and evolution history of the diverse planetary systems [143]. High-resolution spectroscopy has offered a unique means to measure chemical species in the atmospheres of close-in hot Jupiters because this type of exoplanet so far offers the best signal-to-noise ratio (see a review by Birkby for a full discussion)[144]. Via the same framework used to measure the extremely precise RV of planet-hosting stars, this method can be applied to phase-resolved planetary spectroscopic lines which can be identified using the Doppler effect of the orbiting planets. For a typical hot Jupiter, its thermal emission lines would be Doppler-shifted relative to both its host star and to any telluric contamination due to its Keplerian motion, allowing the planetary spectrum to be disentangled from stellar and telluric components of the spectra. The time-varying components of planetary spectra can then reveal the compositions of planetary atmospheres. Typical constituents expected in the atmospheres of hot Jupiters include major oxygen- and carbon-bearing species such as H_2O, CH_4, CO, and CO_2 which are most easily detected at near-IR and IR wavelengths. In the visible wavelengths, various key heavy elements, including Si, Ti, V, and Fe, have rich spectral features and have been observed in the atmospheres of a dozen hot Jupiters[145]. These refractory elements offer a valuable window to probe the formation and migration history of hot Jupiters[146].

High-resolution spectroscopy has also been applied to the atmospheric characterization of directly imaged exoplanets, i.e., giant planets that are hot, self-luminous, and with large orbital separations. Key molecules including CO and H_2O have been identified in several directly imaged exoplanets, and isotopes are also potentially observable for some of the best targets[147]. In addition to composition measurements, the spin of a directly imaged planet will modify its spectroscopic line shapes. This allows us to determine the spin periods of directly imaged exoplanets, an important piece of information for tracking how planets accreted their angular momentum when they grew within the protolantary disk[148].

The ERS, in the upgraded phase of JUST instrumentation, should be able to carry out spectroscopic surveys of dozens of hot Jupiters, yielding statistical trends of metallicity and carbon-to-oxygen ratios for the hot Jupiter population. Equipped with extreme adaptive optics, we expect to characterize several directly imaged exoplanets and measure their atmospheric chemical inventories and spin states.

5. SUMMARY

JUST is a 4.4-meter telescope equipped with a segmented primary mirror and a lightweight framework, allowing for reduced construction costs and rapid switching between observation targets. It features two Nasmyth foci, each offering a field of view of 10′ and 1.2°, with the ability to alternate between them by rotating the tertiary mirror (M3). The telescope also boasts three types of spectrographs: a multiple-fiber medium-resolution spectrometer, an IFU array and/or a long-slit spectrograph, and a multiple-fiber high-resolution spectrometer.

JUST will be installed and operated at a high-quality site at an altitude of 4 322 meters on Saishiteng Mountain in Lenghu, Qinghai province. Expected to achieve first light in 2026, it is poised to become the most powerful telescope for spectroscopic observations in China for a considerable period. Upon completion, JUST will focus on research in three main directions: (1) Exploring the dark universe through spectroscopic surveys of numerous galaxies in the cosmic web; (2) Tracking the dynamic universe by conducting follow-up spectroscopic observations of various transient sources; (3) Detecting and characterizing exoplanets through the acquisition of high-resolution stellar spectra and the precise measurement of radial velocities below 1 m/s. The JUST project is anticipated to produce impactful research outcomes in the fields of dark matter, dark energy, transient astronomy, and exoplanet searches.

ACKNOWLEDGEMENTS

We thank Shanghai Jiao Tong University for support building the JUST telescope, and Qinghai provincial government and Haixi prefecture for providing the site, dome and infrastructure. This work is supported by “the Fundamental Research Funds for the Central Universities”, 111 project No. B20019, and Shanghai Natural Science Foundation, grant No.19ZR1466800.

AUTHOR CONTRIBUTIONS

Xiaohu Yang, Yipeng Jing and Pengjie Zhang conceived the idea. Xiaohu Yang played the project administration and supervision role. Chengze Liu, Ying Zu, Zhaoyu Li, Fabo Feng, Yu Yu, Xianyu Tan mainly wrote the draft. Jiaxin Han, Wei Li, Zhaoxiang Qi, Cairang Tian, Chao Zhai, Congcong Zhang, Jun Zhang, Haotong Zhang, Yi Zhao and Qingfeng Zhu provided investigation support. Hua Bai, Xiangqun Cui, Bozhong Gu, Yonghui Hou, Zhongwen Hu, Hangxin Ji, Dehua Yang, Xiangyan Yuan, Yong Zhang provided the conceptual design. Yizhou Gu, Xianzhong Zheng and Xiaohu Yang reviewed and edited the manuscript. All authors read and approved the final manuscript.

DECLARATION OF INTERESTS

Yipeng Jing is the steer committee member, Xiangqun Cui is the editor-in-chief and Zhongwen Hu is the associate editor-in-chief for Astronomical Techniques and Instruments, and they were not involved in the editorial review or the decision to publish this article. The authors declare no competing interests.

REFERENCES

[1] York, D. G., Adelman, J., Anderson, J. E. Jr., et al. 2000. The Sloan Digital Sky Survey: technical summary. *The Astronomical Journal*, **120**(3): 1579−1587.

[2] DESI Collaboration, Aghamousa, A., Aguilar, J., et al. 2016. The DESI Experiment Part I: science, targeting. and survey design. *arXiv:1611.00036.*

[3] Jin, S., Trager, S. C., Dalton, G. B., et al. 2023.The wide-field, multiplexed, spectroscopic facility WEAVE: survey design, overview, and simulated implementation. *Monthly Notices of the Royal Astronomical Society*, DOI: 10.1093/mnras/stad557.

[4] de Jong, R. S., Agertz, O., Berbel, A. A., et al. 2019. 4MOST: project overview and information for the first call for proposals. *The Messenger*, **175**: 3−11.

[5] Schlegel, D., Kollmeier, J. A., Ferraro, S. 2019. The MegaMapper: a z>2 spectroscopic instrument for the study of Inflation and Dark Energy. *arXiv.1907.11171*.

[6] Tamura, N., Moritani, Y., Yabe, K., et al. 2022. Prime Focus Spectrograph (PFS) for the subaru telescope: its start of the last development phase. In Ground-based and Airborne Instrumentation for Astronomy IX.

[7] Cirasuolo, M., Fairley, A., Rees, P., et al. 2020. MOONS: The New Multi-Object Spectrograph for the VLT. *The Messenger*, **180**: 10−17.

[8] Hill, A., Flagey, N., McConnachie, A., et al. 2018. The Maunakea Spectroscopic Explorer Book 2018. *arXiv*: *1810.08695*.

[9] Ellis, R., Dawson, K. 2019. SpecTel: a 10-12 meter class spectroscopic survey telescope. In Bulletin of the American Astronomical Society. DOI: 10.48550/arXiv.1907.06797

[10] Bundy, K., Westfall, K., MacDonald, N., et al. 2019. FOBOS: a next-generation spectroscopic facility. In Bulletin of the American Astronomical Society.

[11] Wang, T. G., Liu, G. L., Cai, Z. Y., et al. 2023. Science with the 2.5-meter Wide Field Survey Telescope (WFST). *SCIENCE CHINA Physics, Mechanics & Astronomy*, **66**(10): 109512.

[12] Deng, L. C., Yang, F., Chen, X. D., et al. 2021. Lenghu on the Tibetan Plateau as an astronomical observing site. *Nature*, **596**(7872): 353−356.

[13] Planck Collaboration, Aghanim, N., Akrami, Y., et al. 2020. Planck 2018 results. VI. cosmological parameters. *Astronomy and Astrophysics*, **641**: A6 .

[14] Weinberg, D. H., Mortonson, M. J., Eisenstein, D. J., et al. 2013. Observational probes of cosmic acceleration. *Physics Reports*, **530**(2): 87−255.

[15] Erickson, B. M. S., Cunha, C. E., Evrard, A. E. 2011. Influence of projection in cluster cosmology studies. *Physical Review D*, **84**(10): 103506.

[16] Noh, Y., Cohn, J. D. 2012. Disentangling correlated scatter in cluster mass measurements. *Monthly Notices of the Royal Astronomical Society*, **426**(3): 1829−1844.

[17] Zu, Y., Mandelbaum, R., Simet, M., et al. 2017. On the level of cluster assembly bias in SDSS. *Monthly Notices of the Royal Astronomical Society*, **470**(1): 551−560.

[18] Costanzi, M., Rozo, E., Rykoff, E. S., et al. 2019.

Modelling projection effects in optically selected cluster catalogues. *Monthly Notices of the Royal Astronomical Society*, **482**(1): 490−505.
[19] Sartoris, B., Biviano, A., Fedeli, C., et al. 2016. Next generation cosmology: constraints from the Euclid galaxy cluster survey. *Monthly Notices of the Royal Astronomical Society*, **459**(2): 1764−1780.
[20] Lam, T. Y., Schmidt, F., Nishimichi, T., et al. 2013. Modeling the phase-space distribution around massive halos. *Physical Review D*, **88**(2): 023012.
[21] Zu, Y., Weinberg, D. H. 2013. The redshift-space cluster-galaxy cross-correlation function - I modelling galaxy infall on to Millennium simulation clusters and SDSS groups. *Monthly Notices of the Royal Astronomical Society*, **431**(4): 3319−3337.
[22] Hamabata, A., Oguri, M., Nishimichi, T. 2019. Constraining cluster masses from the stacked phase space distribution at large radii. *Monthly Notices of the Royal Astronomical Society*, **489**(1): 1344−1356.
[23] Shirasaki, M., Egami, E., Okabe, N., et al. 2021. Stacked phase-space density of galaxies around massive clusters: comparison of dynamical and lensing masses. *Monthly Notices of the Royal Astronomical Society*, **506**(3): 3385−3405.
[24] Johnston, D. E., Sheldon, E. S., Wechsler, R. H., et al. 2007. Cross-correlation Weak Lensing of SDSS galaxy clusters II: cluster density profiles and the mass-richness relation. *arXiv: 0709.1159.*
[25] Simet, M., McClintock, T., Mandelbaum, R., et al. 2017. Weak lensing measurement of the mass-richness relation of SDSS redMaPPer clusters. *Monthly Notices of the Royal Astronomical Society*, **466**(3): 3103−3118.
[26] Wang, J. Q., Yang, X. H., Zhang, J., et al. 2022. Halo properties and mass functions of groups/clusters from the DESI legacy imaging surveys DR9. *The Astrophysical Journal*, **936**(2): 161.
[27] Zu, Y., Weinberg, D. H., Jennings, E., et al. 2014. Galaxy infall kinematics as a test of modified gravity. *Monthly Notices of the Royal Astronomical Society*, **445**(2): 1885−1897.
[28] Koyama, K. 2016. Cosmological tests of modified gravity. *Reports on Progress in Physics*, **79**(4): 046902.
[29] Joyce, A., Lombriser, L., Schmidt, F. 2016. Dark energy versus modified gravity. *Annual Review of Nuclear and Particle Science*, **66**(1): 95−122.
[30] Baker, T., Barreira, A., Desmond, H., et al. 2021. Novel Probes Project: Tests of gravity on astrophysical scales. *Reviews of Modern Physics*, **93**(1): 015003.
[31] Fillmore, J. A., Goldreich, P. 1984. Self-similar gravitational collapse in an expanding universe. *The Astrophysical Journal*, **281**: 1−8.
[32] Bertschinger, E. 1985. Self-similar secondary infall and accretion in an Einstein-de sitter universe. *Astrophysical Journal, Supplement Series*, **58**: 39−65.
[33] Kravtsov, A. V., Borgani, S. 2012. Formation of galaxy clusters. *Annual Review of Astronomy and Astrophysics* , **50**: 353−409.
[34] Diemer, B., Kravtsov, A. V. 2014. Dependence of the outer density profiles of halos on their mass accretion rate. *The Astrophysical Journal*, **789**(1): 1.
[35] More, S., Miyatake, H., Takada, M., et al. 2016. Detection of the splashback radius and halo assembly bias of massive galaxy clusters. *The Astrophysical Journal*, **825**(1): 39.
[36] Walker, S., Simionescu, A., Nagai, D., et al. 2019. The physics of galaxy cluster outskirts. *Space Science Reviews*, **215**(1): 7.
[37] Kauffmann, G., White, S. D. M., Heckman, T. M., et al. 2004. The environmental dependence of the relations between stellar mass, structure, star formation and nuclear activity in galaxies. *Monthly Notices of the Royal Astronomical Society*, **353**(3): 713−731.
[38] Jing, Y. P., Mo, H. J., Börner, G. 1998. Spatial correlation function and pairwise velocity dispersion of galaxies: cold dark matter models versus the Las Campanas Survey. *The Astrophysical Journal*, **494**(1): 1−12.
[39] Shectman, S. A., Landy, S. D., Oemler, A., et al. 1996. The Las Campanas Redshift Survey. *The Astrophysical Journal*, **470**: 172.
[40] Yang, X., Mo, H. J., van den Bosch, F. C. 2003. Constraining galaxy formation and cosmology with the conditional luminosity function of galaxies. *Monthly Notices of the Royal Astronomical Society*, **339**(4): 1057−1080.
[41] Colless, M., Dalton, G., Maddox, S., et al. 2001. The 2dF Galaxy Redshift Survey: spectra and redshifts. *Monthly Notices of the Royal Astronomical Society*, **328**(4): 1039−1063.
[42] Yang, X., Mo, H. J., van den Bosch, F. C., et al. 2005. A halo-based galaxy group finder: calibration and application to the 2dFGRS. *Monthly Notices of the Royal Astronomical Society*, **356**(4): 1293−1307.
[43] Yang, X. H., Mo, H. J., van den Bosch, F. C., et al. 2007. Galaxy groups in the SDSS DR4 I. The catalog and basic properties. *The Astrophysical Journal*, **671**(1): 153−170.
[44] Zhao, G. B., Raveri, M., Pogosian, L., et al. 2017. Dynamical dark energy in light of the latest observa- tions. *Nature Astronomy*, **1**: 627−632.
[45] Alam, S., Albareti, F. D., Allende Prieto, C., et al. 2015. The eleventh and twelfth data releases of the Sloan Digital Sky Survey: final data from SDSS-III. *Astrophysical Journal, Supplement Series*, **219**(1): 12.
[46] Miao, H. T., Gong, Y., Chen, X. L., et al. 2023. Cosmological constraint precision of photometric and spectroscopic multi-probe surveys of China Space Station Telescope (CSST). *Monthly Notices of the Royal Astronomical Society*, **519**(1): 1132−1148.
[47] Yang, X. H., Xu, H. J., He, M., et al. 2021. An extended halo-based group/cluster finder: application to the DESI legacy imaging surveys DR8. *The Astrophysical Journal*, **909**(2): 143.
[48] Sohn, J., Geller, M. J., Hwang, H. S., et al. 2021. The HectoMAP Cluster Survey: spectroscopically identified Clusters and their Brightest Cluster Galaxies (BCGs). *The Astrophysical Journal*, **923**(2): 143.
[49] Evrard, A. E., Bialek, J., Busha, M., et al. 2008. Virial scaling of massive dark matter halos: why clusters Pprefer a high normalization cosmology. *The Astrophysical Journal*, **672**(1): 122−137.
[50] Wu, H. Y., Hahn, O., Evrard, A. E., et al. 2013. Virial scaling of galaxies in clusters: bright to faint is cool to hot. *Monthly Notices of the Royal Astronomical Society*, **436**(1): 460−469.
[51] Ntampaka, M., Trac, H., Sutherland, D. J., et al. 2015. A machine learning approach for dynamical mass

measurements of galaxy clusters. *The Astrophysical Journal*, **803**(2): 50.
[52] Diaferio, A. 1999. Mass estimation in the outer regions of galaxy clusters. *Monthly Notices of the Royal Astronomical Society*, **309**(3): 610−622.
[53] Gifford, D., Miller, C., Kern, N. 2013. A systematic analysis of caustic methods for galaxy cluster masses. *The Astrophysical Journal*, **773**(2): 116.
[54] Rines, K., Geller, M. J., Diaferio, A., et al. 2013. Measuring the ultimate halo mass of galaxy clusters: redshifts and mass profiles from the Hectospec Cluster Survey (HeCS). *The Astrophysical Journal*, **767**(1): 15.
[55] Rozo, E., Rykoff, E. S., Evrard, A., et al. 2009. Constraining the Scatter in the mass-richness relation of maxBCG clusters with weak lensing and X-ray data. *The Astrophysical Journal*, **699**(1): 768−781.
[56] Zhu, G. T., Ménard, B. 2013. The JHU-SDSS metal absorption line catalog: redshift evolution and properties of Mg II absorbers. *The Astrophysical Journal*, **770**(2): 130.
[57] Lee, J. C., Hwang, H. S., Song, H. 2021. Searching for Mg II absorbers in and around galaxy clusters. *Monthly Notices of the Royal Astronomical Society*, **503**(3): 4309−4319.
[58] Zu, Y. 2021. Kinematics of Mg II absorbers from the redshift-space distortion around massive quiescent galaxies. *Monthly Notices of the Royal Astronomical Society*, **506**(1): 115−127.
[59] Anand, A., Kauffmann, G., Nelson, D. 2022. Cool circumgalactic gas in galaxy clusters: connecting the DESI legacy imaging survey and SDSS DR16 Mg II absorbers. *Monthly Notices of the Royal Astronomical Society*, **513**(3): 3210−3227.
[60] Napolitano, L., Pandey, A., Myers, A. D., et al. 2023. Detecting and characterizing Mg II absorption in DESI survey validation quasar spectra. *The Astronomical Journal*, **166**(3): 99.
[61] Hahn, C., Wilson, M. J., Ruiz-Macias, O., et al. 2023. The DESI Bright Galaxy Survey: final target selection, design, and validation. *The Astronomical Journal*, **165**(6): 253.
[62] Zhang, P. J., Liguori, M., Bean, R., et al. 2007. Probing gravity at cosmological scales by measurements which test the relationship between gravitational lensing and matter overdensity. *Physical Review Letters*, **99**(14):
[63] McClintock, T., Varga, T. N., Gruen, D., et al. 2019. Dark Energy Survey Year 1 results: weak lensing mass calibration of redMaPPer galaxy clusters. *Monthly Notices of the Royal Astronomical Society*, **482**(1): 1352−1378.
[64] Sunayama, T. 2023. Observational constraints of an anisotropic boost due to the projection effects using redMaPPer clusters. *Monthly Notices of the Royal Astronomical Society*, **521**(4): 5064−5076.
[65] Salcedo, A. N., Wu, H. Y., Rozo, E., et al. 2023. Dark Energy Survey Year 1 Clusters are consistent with Planck. *arXiv:2310.03944.*
[66] Andrews, B. H., Martini, P. 2013. The mass-metallicity relation with the direct method on stacked spectra of SDSS galaxies. *The Astrophysical Journal*, **765**(2): 140 .
[67] Lin, Y. Y., Zu, Y. 2023. Constraints on galactic out- flows from the metallicity-stellar mass-SFR relation of EAGLE simulation and SDSS galaxies. *Monthly Notices of the Royal Astronomical Society*, **521**(1): 411−432.
[68] Lan, T. W., Ménard, B., Mo, H. J. 2016. The galaxy luminosity function in groups and clusters: the faint-end upturn and the connection to the field luminosity function. *Monthly Notices of the Royal Astronomical Society*, **459**(4): 3998−4019.
[69] Golden-Marx, J. B., Zu, Y., Wang, J., et al. 2023. Satellite content and halo mass of galaxy clusters: comparison between red-sequence and halo-based optical cluster finders. *Monthly Notices of the Royal Astronomical Society*, **524**(3): 4455−4471.
[70] Meng, J., Li, C., Mo, H. J., et al. 2023. Galaxy populations in groups and clusters: evidence for a characteristic stellar mass scale at M*109.5 $M_{\odot}$. *The Astrophysical Journal*, **944**(1): 75.
[71] Li, R., Shan, H. Y., Mo, H. J., et al. 2014. First galaxy-galaxy lensing measurement of satellite halo mass in the CFHT Stripe-82 Survey. *Monthly Notices of the Royal Astronomical Society*, **438**(4): 2864−2870.
[72] Niemiec, A., Jullo, E., Limousin, M., et al. 2017. Stellar-to-halo mass relation of cluster galaxies. *Monthly Notices of the Royal Astronomical Society*, **471**(1): 1153−1166.
[73] Sif´on, C., Herbonnet, R., Hoekstra, H., et al. 2018. The galaxy-subhalo connection in low-redshift galaxy clusters from weak gravitational lensing. *Monthly Notices of the Royal Astronomical Society*, **478**(1): 1244−1264.
[74] Dvornik, A., Hoekstra, H., Kuijken, K., et al. 2020. KiDS+GAMA: the weak lensing calibrated stellar-to-halo mass relation of central and satellite galaxies. *Astronomy and Astrophysics*, **642**: A83.
[75] Danieli, S., Greene, J. E., Carlsten, S., et al. 2023. ELVES IV. the satellite stellar-to-halo mass relation beyond the milky way. *The Astrophysical Journal*, **956**(1): 6.
[76] Wang, H. Y., Mo, H. J., Yang, X. H., et al. 2014. ELUCID-exploring the local universe with the reconstructed initial density field I. Hamiltonian Markov Chain Monte Carlo method with particle mesh dynamics. *The Astrophysical Journal*, **794**(1): 94.
[77] Wang, H., Mo, H. J., Yang, X., et al. 2016. ELUCID-exploring the local universe with reconstructed initial density field III: constrained simulation in the SDSS volume. *The Astrophysical Journal*, **831**(2): 164.
[78] Zhang, C. P., Zhu, M., Jiang, P., et al. 2024. The FAST all sky HI survey (FASHI): the first release of catalog. *SCIENCE CHINA Physics, Mechanics & Astronomy*, **67**(1): 219511.
[79] Nan, R. D., Li, D., Jin, C. J., et al. 2011. The Five-Hundred-Meter Aperture Spherical Radio Telescope (FAST) Project. *International Journal of Modern Physics D*, **20**(6): 989−1024.
[80] Liu, C. Z., Côté, P., Peng, E. W., et al. 2020. The Next Generation Virgo Cluster Survey (NGVS) XXXIV. Ultracompact dwarf galaxies in the virgo cluster. *Astrophysical Journal Supplement Series*, **250**(1): 17.
[81] Wang, K. X., Peng, E. W., Liu, C. Z, et al. 2023. An evolutionary continuum from nucleated dwarf galaxies to star clusters. *Nature*, **623**(7986): 296−300.
[82] Gu, M., Conroy, C., Law, D., et al. 2020. Spectroscopic constraints on the buildup of intracluster light in the Coma Cluster. *The Astrophysical Journal*, **894**(1): 32.
[83] Chen, X. K., Zu, Y., Shao, Z. W., et al. 2022. The sphere of influence of the bright central galaxies in the diffuse light of SDSS clusters. *Monthly Notices of the Royal Astronomical Society*, **514**(2): 2692−2706.
[84] National Academies of Sciences, Engineering, and

Medicine. 2021. Pathways to Discovery in Astronomy and Astrophysics for the 2020s. Washington: The National Academies Press.

[85] Gal-Yam, A., Mazzali, P. A., Manulis, I., et al. 2013. Supernova discoveries 2010-2011: statistics and trends. *Publications of Astronomical Society of the Pacific*, **125**(929): 749.

[86] Abbott, B. P., Abbott, R., Abbott, T. D., et al. 2017. GW170817: observation of gravitational waves from a Binary neutron star inspiral. *Physical Review Letters*, **119**(16): 161101.

[87] Coulter, D. A., Foley, R. J., Kilpatrick, C. D., et al. 2017. Swope Supernova survey 2017a (SSS17a), the optical counterpart to a gravitational wave source. *Science*, **358**(6370): 1556−1558.

[88] Jones, D. O., Riess, A. G., Scolnic, D. M., et al. 2018. Should Type Ia Supernova distances be corrected for their local environments?. *The Astrophysical Journal*, **867**(2): 108.

[89] Arcavi, I., Hosseinzadeh, G., Howell, D. A., et al. 2017. Optical emission from a kilonova following a gravitational-wave-detected neutron-star merger. *Nature*, **551**(7678): 64−66.

[90] Foley, R. J., Challis, P. J., Chornock, R., et al. 2013. Type Iax Supernovae: a new class of stellar explosion. *The Astrophysical Journal*, **767**(1): 57.

[91] Jha, S. W. 2017. Type Iax Supernovae. In Handbook of Supernovae. DOI: 10.1007/978-3-319-21846-5_42.

[92] Blagorodnova, N., Neill, J. D., Walters, R., et al. 2018. The SED machine: a robotic spectrograph for fast transient classification. *Publications of Astronomical Society of the Pacific*, **130**(985): 035003.

[93] Abbott, B. P., Abbott, R., Abbott, T. D., et al. 2016. Properties of the Binary black hole merger GW150914. *Physical Review Letters*, **116**(24): 241102.

[94] Abbott, B. P., Abbott, R., Abbott, T. D., et al. 2017. Multi-messenger observations of a Binary neutron star merger. *The Astrophysical Journal Letters*, **848**(2): L12.

[95] Cho, A. 2017. Cosmic convergence. *Science*, **358**(6370): 1520−1521.

[96] Hills, L. D. 1975. Plants. *Nature*, **255**(5504): 102.

[97] Lidskii, V. V., Ozernoi, L. M. 1979. Tidal triggering of stellar flares by a massive black hole. *Soviet Astronomy Letters*, **5**: 16−19.

[98] Rees, M. J. 1988. Tidal disruption of stars by black holes of 106-108 solar masses in nearby galaxies. *Nature*, **333**(6173): 523−528.

[99] Phinney, E. S. 1989. Manifestations of a massive black hole in the galactic center. In The Center of the Galaxy.

[100] Evans, C. R., Kochanek, C. S. 1989. The tidal disruption of a star by a massive black hole. *The Astrophysical Journal Letters*, **346**: L13.

[101] Ulmer, A. 1999. Flares from the tidal disruption of stars by massive black holes. *The Astrophysical Journal*, **514**(1): 180−187.

[102] Bade, N., Komossa, S., Dahlem, M. 1996. Detection of an extremely soft X-ray outburst in the HII-like nucleus of NGC 5905. *Astronomy and Astrophysics*, **309**: L35−L38.

[103] Grupe, D., Thomas, H. C., Leighly, K. M. 1999. RX J1624 9+7554: a new X-ray transient AGN. *Astronomy and Astrophysics*, **350**: L31−L34.

[104] Komossa, S., Greiner, J. 1999. Discovery of a giant and luminous X-ray outburst from the optically inactive galaxy pair RX J1242. *6-1119. Astronomy and Astrophysics*, **349**: L45−L48.

[105] Greiner, J., Schwarz, R., Zharikov, S., et al. 2000. RX J1420. 4+5334 - another tidal disruption event?. *Astronomy and Astrophysics*, **362**(2): L25−L28.

[106] Dai, J., Yang, J., Li, L., Zhang, J. 2018. Current sheets in the wake of an eruption of two crossing filaments. *The Astrophysical Journal*, **869**(2): 118.

[107] Parkinson, E. J., Knigge, C., Long, K. S., et al. 2020. Accretion disc winds in tidal disruption events: ultraviolet spectral lines as orientation indicators. *Monthly Notices of the Royal Astronomical Society*, **494**(4): 4914−4929.

[108] Kratter, K., Lodato, G. 2016. Gravitational instabilities in circumstellar disks. *Annual Review of Astronomy and Astrophysics*, **54**: 271−311.

[109] Boss, A. P. 1997. Giant planet formation by gravitational instability. *Science*, **276**: 1836−1839.

[110] Marois, C., Macintosh, B., Barman, T., et al. 2008. Direct imaging of multiple planets orbiting the Star HR 8799. *Science*, **322**(5906): 1348.

[111] Gaia Collaboration, Prusti, T., de Bruijne, J. H. J., et al. 2016. The Gaia mission. *Astronomy and Astrophysics*, **595**: A1.

[112] Gaia Collaboration, Brown, A. G. A., Vallenari, A., et al. 2018. Gaia data release 2 summary of the contents and survey properties. *Astronomy and Astrophysics*, **616**: A1.

[113] Gaia Collaboration, Brown, A. G. A., Vallenari, A., et al. 2021. Gaia early data release 3 summary of the contents and survey properties. *Astronomy and Astrophysics*, **649**: A1.

[114] Gaia Collaboration, Vallenari, A., Brown, A. G. A., et al. 2023. Gaia data release 3 summary of the content and survey properties. *Astronomy and Astrophysics*, **674**: A1.

[115] Perryman, M. A. C., Lindegren, L., Kovalevsky, J., et al. 1997. The HIPPARCOS Catalogue. *Astronomy and Astrophysics*, **323**: L49−L52.

[116] van Leeuwen, F. 2007. Validation of the new Hipparcos reduction. *Astronomy and Astrophysics*, **474**: 653−664.

[117] Snellen, I. A. G., Brown, A. G. A. 2018. The mass of the young planet Beta Pictoris b through the astrometric motion of its host star. *Nature Astronomy*, **2**: 883−886.

[118] Brandt, T. D., Dupuy, T. J., Bowler, B. P. 2019. Precise dynamical masses of directly imaged companions from relative astrometry, radial velocities, and Hipparcos–Gaia DR2 accelerations. *The Astronomical Journal*, **158**(4): 140.

[119] Kervella, P., Arenou, F., Thévenin, F. 2022. Stellar and substellar companions from Gaia EDR3 Proper-motion anomaly and resolved common proper-motion pairs. *Astronomy and Astrophysics*, **657**: A7.

[120] Feng, F., Butler, R. P., Vogt, S. S., et al. 2022. 3D selection of 167 substellar companions to nearby stars. *Astrophysical Journal, Supplement Series*, **262**(1): 21.

[121] Zhang, T. Y., Zhu, Y. T., Hou, Y. H., et al. 2019. Construction of a LAMOST high resolution spectrograph. *Chinese Optics*, **12**(1): 148−155.

[122] Cosentino, R., Lovis, C., Pepe, F., et al. 2012. Harps-N: the new planet hunter at TNG. In Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series. DOI:10.1117/12.925738.

[123] Kasting, J. F., Whitmire, D. P., Reynolds, R. T. 1993. Habitable zones around main sequence stars. *Icarus*,

101(1): 108−128.
[124] The LUVOIR Team. 2019. The LUVOIR mission concept study final report. *arXiv:1912.06219*.
[125] Gaudi, B. S., Seager, S., Mennesson, B., et al. 2020. The Habitable Exoplanet Observatory (HabEx) mission concept study final report. *arXiv:2001.06683*.
[126] Mamajek, E., Stapelfeldt, K. 2023, NASA ExEP mission star list of plausible targets for a future IROUV direct imaging space observatory. In American Astronomical Society Meeting Abstracts.
[127] Pepe, F. A., Cristiani, S., Rebolo Lopez, R., et al. 2010. ESPRESSO: the Echelle spectrograph for rocky exoplanets and stable spectroscopic observations. In Society of Photo-Optical Instrumentation Engineers Conference Series. DOI:10.1117/12.857122.
[128] Seifahrt, A., Bean, J. L., Kasper, D., et al. 2022. MAROON-X: the first two years of EPRVs from Gemini North. In Society of Photo-Optical Instrumentation Engineers Conference Series. DOI: 10.1117/12.2629428.
[129] Schwab, C., Rakich, A., Gong, Q., et al. 2016. Design of NEID, an extreme precision Doppler spectrograph for WIYN. In Ground-based and Airborne Instrumentation for Astronomy VI.
[130] Gibson, S. R., Howard, A. W., Marcy, G. W., et al. 2016. KPF: Keck Planet Finder. In Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series. DOI: 10.1117/12.2233334.
[131] Feng, F., Tuomi, M., Jones, H. R. A., et al. 2017. Color difference makes a difference: four planet candidates around τ Ceti. *The Astronomical Journal*, **154**: 135.
[132] Faria, J. P., Suárez Mascareño, A., Figueira, P., et al. 2022. A candidate short-period sub-Earth orbiting Proxima Centauri. *Astronomy and Astrophysics*, **658**: A115.
[133] Haywood, R., Collier Cameron, A., Queloz, D., et al. 2014. Planets and stellar activity: hide and seek in the CoRoT-7 system. *Monthly Notices of the Royal Astronomical Society*, **443**(3): 2517−2531.
[134] Rajpaul, V., Aigrain, S., Osborne, M. A.,et al. 2015. A Gaussian process framework for modelling stellar activity signals in radial velocity data. *Monthly Notices of the Royal Astronomical Society*, **452**: 2269−2291.
[135] Feng, F., Tuomi, M., Jones, H. R. A., et al. 2016. A Goldilocks principle for modelling radial velocity noise. *Monthly Notices of the Royal Astronomical Society*, **461**(3): 2440−2452.
[136] Ribas, I., Tuomi, M., Reiners, A., et al. 2018. A candidate super-Earth planet orbiting near the snow line of Barnard's star. *Nature*, **563**: 365−368.
[137] Dumusque, X. 2016. Radial velocity fitting challenge I. Simulating the data set including realistic stellar radial-velocity signals. *Astronomy and Astrophysics*, **593**: A5.
[138] Dumusque, X., Borsa, F., Damasso, M., et al. 2017. Radial-velocity fitting challenge II. First results of the analysis of the data set. *Astronomy and Astrophysics*, **598**: A133.
[139] Zechmeister, M., Reiners, A., Amado, P. J., et al. 2018. Spectrum radial velocity analyser (SERVAL) high precision radial velocities and two alternative spectral indicators. *Astronomy and Astrophysics*, **609**: A12.
[140] Dumusque, X. 2018. Measuring precise radial velocities on individual spectral lines I. Validation of the method and application to mitigate stellar activity. *Astronomy and Astrophysics*, **620**: A47.
[141] Lisogorskyi, M., Jones, H. R. A., Feng, F. 2019. Activity and telluric contamination in HARPS observations of Alpha Centauri B. *Monthly Notices of the Royal Astronomical Society*, **485**(4): 4804−4816.
[142] Ge, J., Zhang, H., Zang, W., et al. 2022. ET white paper: to find the first Earth 2.0. *arXiv:2206.06693*.
[143] Madhusudhan, N. 2019. Exoplanetary atmospheres: key insights, challenges, and prospects. *Annual Review of Astronomy and Astrophysics*, **57**: 617−663.
[144] Birkby, J. L. 2018. Exoplanet atmospheres at high spectral resolution. *arXiv:1806.04617*.
[145] Yan, F., Reiners, A., Pallé, E., E., et al. 2022. Detection of iron emission lines and a temperature inversion on the dayside of the ultra-hot Jupiter KELT-20b. *Astronomy and Astrophysics*, **659**: A7.
[146] Lothringer, J. D., Rustamkulov, Z., Sing, D. K., et al. 2021. A new window into planet formation and migration: refractory-to-volatile elemental ratios in ultra-hot Jupiters. *The Astrophysical Journal*, **914**(1): 12.
[147] Currie, T., Biller, B., Lagrange, A., et al. 2023. Direct imaging and spectroscopy of extrasolar planets. In Astronomical Society of the Pacific Conference Series.
[148] Snellen, I. A. G., Brandl, B. R., de Kok, R. J., et al. 2014. Fast spin of the young extrasolar planet β Pictoris b. *Nature*, **509**(7498): 63−65.