# Implications from Yale University' s Astronomy Development for Building World-Class Disciplines in China (Postprint)

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## Abstract

The development and innovation level of disciplines in higher education institutions constitute a comprehensive reflection and important indicator of a nation' s scientific and technological strength. In conjunction with the Ministry of Education' s "Double First-Class" construction initiative, referencing five major domestic and international mainstream discipline evaluation systems, and benchmarking against the overall development of the astronomy discipline at Yale University in the United States, this paper comprehensively analyzes two core strategies: first, emphasizing both selection and cultivation to build a high-quality faculty team with institutional guarantees; second, promoting both development and research to support high-level scientific research with quality astronomical observation resources. Based on this analysis, the implications for enhancing the comprehensive strength of Chinese astronomy are summarized as follows: supporting development with a high-quality faculty team; while participating in world-class telescope projects, fully leveraging the advantages of characteristic "small-scale equipment" to ensure internationally first-class research standards; strengthening cooperation to achieve mutual benefits; fully utilizing the planning and guiding role of academic committees; and enriching external publicity and presentation.

## Full Text

## Preamble

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**Strategy for the Development of Astronomy at Yale University and its Enlightenment for China' s First-Class Discipline Construction**

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## Abstract

The development and innovation level of academic disciplines in higher education institutions serve as a comprehensive reflection and key indicator of national scientific and technological strength. Grounded in China' s Ministry of Education "Double First-Class" construction initiative and drawing upon five major domestic and international disciplinary evaluation systems, this paper examines the overall development of astronomy at Yale University. It analyzes two core strategies: first, emphasizing both selection and cultivation to build a high-quality faculty through institutional guarantees; and second, balancing development and research to support high-level scientific research with superior astronomical observation resources. Based on this analysis, we summarize key implications for enhancing China' s comprehensive strength in astronomy: supporting development with high-quality faculty; leveraging distinctive "small equipment" advantages while participating in world-class telescope projects to maintain internationally competitive research standards; strengthening cooperation for mutual benefit; fully utilizing the planning and guidance role of academic committees; and enriching external publicity and presentation.

**Keywords:** Double First-Class; astronomy; Yale University; international competitiveness

## 1 Introduction

In September 2016, when the Five-hundred-meter Aperture Spherical radio Telescope (FAST), a major national scientific infrastructure, was completed and put into operation, President Xi Jinping noted in his congratulatory message that "astronomy is a frontier science that nurtures major original discoveries and a strategic high ground for promoting scientific and technological progress and innovation."Although astronomy departments in Chinese universities are relatively small in scale, they shoulder important responsibilities in talent cultivation, scientific research, and cultural inheritance, representing the backbone of Chinese astronomy.

Over the past decade, university astronomy departments in China have entered a golden period of development, achieving substantial progress in personnel, equipment development, and scientific innovation. However, significant gaps remain compared to international advanced levels. Therefore, analyzing the characteristics of world-class university astronomy departments based on mainstream domestic and international disciplinary evaluation indicators and weightings, and drawing lessons from their advanced concepts and practices, holds important reference value for enhancing the international competitiveness of Chinese astronomy.

In September 2017, the Ministry of Education and other ministries jointly announced the list of "World-Class Universities" and "World-Class Disciplines" (the Double First-Class initiative), triggering widespread public attention to the Double First-Class evaluation system. Currently, five major evaluation systems enjoy relatively high recognition both domestically and internationally: the QS World University Rankings (QS), ShanghaiRanking' s Academic Ranking of World Universities (ARWU), Times Higher Education World University Rankings (THE), US News & World Report Best Global Universities Rankings (USNWR), and the Research Center for Chinese Science Evaluation (RCCSE) rankings. Given the differences in indicators and weightings across these systems, Table 1 lists the total number of indicators and weight proportions in the five evaluation systems [1{3].

As shown in Table 1, scientific research capability is the most heavily weighted and important indicator, followed by reputation, teaching quality, and internationalization level. In reality, however, the level of scientific research capability, reputation, and teaching quality primarily depends on the quality of faculty and resource conditions available to the discipline. Based on this, this paper focuses on these two key elements—personnel and resources—to explore approaches for enhancing the comprehensive strength of astronomy departments in Chinese universities.

Section 2 introduces the general situation and characteristics of Yale University' s astronomy discipline; Section 3 summarizes enlightenment for constructing world-class astronomy disciplines in terms of institutional mechanisms, equipment development, interdisciplinary collaboration, planning guidance, and publicity; and Section 4 provides a brief conclusion.

## 2.1 General Situation

In the 2022 QS World University Rankings for Physics and Astronomy, the 2022 THE World University Rankings for Physics, and the 2022 ARWU World University Rankings for Physics, Yale University ranks 13th, 10th, and 51st, respectively. Unlike most other first-rate astronomy departments, Yale' s astronomy discipline does not possess its own large-scale terminal equipment, making it highly similar to astronomy departments in Chinese universities in this regard.

As of September 2022, Yale University' s astronomy discipline comprises the Department of Astronomy and the Yale Center for Astronomy and Astrophysics (YCAA), with a total of 22 permanent faculty members, including 18 professors (3 emeritus), 2 associate professors, 1 assistant professor, and 1 lecturer. Additionally, there are 9 postdoctoral researchers, including 3 YCAA distinguished postdoctoral fellows. The Yale Astronomy Department describes itself as "a small department with a large range of science interests," with research areas covering cosmology, exoplanets, Galactic astronomy, extragalactic astronomy, high-energy astrophysics, solar and stellar astrophysics, and star formation and interstellar medium. From January 2016 to September 2022, Yale astronomers led or co-authored 1,001 research papers, including 11 published in *Nature* (5 as first-author papers), with approximately 120 papers published annually in mainstream international journals such as *ApJ* [4]. The journal distribution is shown in Figure 1 [Figure 1: see original paper].

## 2.2 Development Characteristics

Yale astronomy' s development characteristics are primarily reflected in two aspects: team building and resource utilization.

First, emphasizing both selection and cultivation to build a high-quality faculty through institutional guarantees. Since the 1960s, the Faculty of Arts and Sciences at Yale University, which houses the astronomy department, has implemented a tenure-track faculty appointment system and has revised the evaluation scheme several times [5]. Figure 2 [Figure 2: see original paper] summarizes the faculty hierarchy structure and promotion requirements at Yale' s Faculty of Arts and Sciences.

Similar to other world-class universities, Yale sets extremely high standards for faculty appointment and promotion to ensure faculty quality. Assistant professor candidates should demonstrate potential for conducting significant academic research and publishing high-level papers, significantly expand their research direction during their appointment period, and grow into internationally leading scholars in their field. They should also possess efficient and creative teaching, talent cultivation, and management and service capabilities. Promotion from tenure-track to tenured positions evaluates not only candidates' achievements but also their future development momentum. For tenured professors and associate professors, Yale explicitly requires them to be international leaders in their field, with tenured professors having achieved outstanding research accomplishments and international reputation while providing excellent teaching and service to the university. Even after obtaining tenure, faculty must continuously engage in high-level teaching, research, and service to maintain their positions, eliminating the phenomenon of "lazy professors."

Under this highly competitive and demanding evaluation system, Yale has attracted and retained a group of outstanding talents, maintaining a relatively stable faculty structure. Table 2 summarizes the composition of faculty positions in the Faculty of Arts and Sciences over the past six years.

To help new faculty quickly adapt to the environment and develop personal career plans, the Faculty of Arts and Sciences provides a series of targeted development training programs after faculty members join, including orientation programs, professional development programs, and individual mentoring programs. Junior faculty in the astronomy department enjoy priority in applying for telescope observing time, funding support for recruiting PhD students and postdocs, and invitations to participate in telescope time allocation committees and research project reviews, thereby earning service-related evaluation credits during their "1+1" appointment period. Additionally, assistant professors who complete their first three-year term of research and teaching are eligible to compete for a one-year paid sabbatical.

In 2008, female scientist Marla Geha joined Yale as an assistant professor and immediately obtained observing time on the Keck Observatory' s 10-meter telescope, co-discovering the faintest dwarf galaxy near the Milky Way and winning *Popular Science* magazine' s "Brilliant 10" award the following year. Building on this foundation, with Yale' s combination of salary, research funding, sabbatical policies, and professional development opportunities, Marla Geha successfully launched "The SAGA Survey" [6] with Stanford University' s Professor Risa Wechsler to address the question of whether the Milky Way is special compared to other galaxies, attracting widespread attention from international peers. This exemplifies how Yale' s astronomy department creates development engines and broadens growth pathways for young talent, demonstrating the discipline' s strong support role.

Notably, research group leaders in the astronomy department provide complete "growth portfolios" for junior faculty and students through group webpages, sharing academic resources and recording research achievements while reflecting incentive policies, creating an excellent external environment and strong academic atmosphere to help young scholars grow rapidly.

Yale' s astronomy department also effectively leverages interdisciplinary strengths. In July 2001, the YCAA was jointly established by the Physics and Astronomy Departments to strengthen closer collaboration between physics and astronomy. YCAA Director Professor Meg Urry stated, "Physicists are very good at building instruments that astronomers love to use, and astronomers' understanding of the universe is essential for developing physics experiments that allow physicists to understand the latest discoveries" [7]. After joining YCAA, Yale' s renowned physicist Professor Charles Baltay shifted his research focus to astrophysics and cosmology, collaborating with the then department chair to achieve fruitful results.

Yale' s astronomy department places great emphasis on supporting postdoctoral young talent, with an average of about 10 postdocs annually, including 2-3 YCAA distinguished postdoctoral fellows. YCAA regularly holds postdoctoral career development exchange meetings, inviting the center director to provide career planning advice to all postdocs through lunch seminars. YCAA distinguished postdocs organize weekly Yale Astronomy Center academic forum presentations, ensuring that the younger generation' s research remains at the same starting line as international frontiers and maintains high scientific sensitivity to capture the latest research topics. According to NASA ADS statistics, Yale astronomers published 54 papers in the first half of 2021, with one YCAA distinguished postdoc contributing up to 13% (co-authoring 7 papers). Approximately 50% of postdocs successfully obtain tenure-track positions at world-class universities.

Additionally, Yale' s astronomy department maintains strict requirements for faculty in talent cultivation, with faculty required to devote at least half their working time to teaching and mentoring students. The astronomy department graduates approximately 12 undergraduates, 5 master' s students, and 2 PhD students annually, along with 5 visiting degree students. The characteristic of having more faculty than students is one of Yale astronomy's features, providing each student with more time and opportunities to interact with faculty, creating conditions for knowledge accumulation and innovative thinking. In student cultivation, beyond general education and professional theoretical knowledge transmission, the department emphasizes training in equipment development, data processing, and hands-on observation. Teaching methods stress independent student learning processes, integrating research practice into the classroom. The department offers inquiry-based courses such as "Independent Project in Astronomy" and "The Two-term Senior Project," providing both undergraduate and graduate students with opportunities to use world-class telescopes. Rather than limiting students to a "single mentor" system, the department encourages resource sharing and leads student growth through teamwork.

Second, balancing development and research to support high-level scientific research with superior astronomical observation resources. Astronomy is an observation-driven discipline, and using first-class observation equipment is the primary condition for achieving high-level research results. In 2009, Yale University invested $12 million to purchase observing time on the Keck Observatory' s 10-meter telescope—150 nights over 10 years—pioneering large-scale paid use of top-tier telescope observations. Currently, Yale astronomers regularly obtain telescope observing time including: (1) 24 nights annually on the Keck Observatory' s 10-meter telescope, plus 5 optional nights for collaborative projects with Caltech; (2) one-eighth share of annual observing time on the Palomar Observatory' s 5.1-meter telescope; (3) formal membership in the Sloan Digital Sky Survey; and (4) individually awarded observing time on large telescopes such as the Hubble Space Telescope, Chandra X-ray Observatory, Kepler Telescope, Spitzer and Herschel infrared telescopes, and Fermi Gamma-ray Telescope.

The astronomy department has established an Astronomical Telescope Time Allocation Committee to ensure rational distribution of public observation resources. Composed of faculty, postdoc, and graduate student representatives, the committee evaluates and selects each observing proposal. Given significant research differences across various fields that make uniform treatment difficult, the primary consideration in allocating observing time is the "impact on Yale astrophysics" —that is, the role of Yale scholars in the project, whether it can train students, the importance of the scientific question, and project feasibility.

To obtain high-quality astronomical observation resources, Yale' s astronomy department has developed deep cooperation with the Chilean astronomical community. The Andes Mountains in Chile occupy unique geographical advantages and host multiple large telescopes, thus having fixed observing time quotas. However, Chile' s talent cultivation and scientific research level in astronomy lag behind. Yale obtains discounted access to observation facilities by admitting Chilean students into its astronomy department and helping the country develop astronomical research. Before purchasing Keck Observatory 10-meter telescope time, Yale astronomers primarily used a 3.5-meter telescope for observation data, jointly managed by Yale University, the Chilean Small and Medium Aperture Research Telescope System, the University of Wisconsin, and the National Optical Astronomy Observatory.

Access to top-tier telescope observing time has greatly ensured that Yale' s astronomical research remains at the frontier and has injected a source of vitality into young talent development. Over the past five years, Yale' s astronomy department has published approximately 200 papers in international first-class journals through shared telescope observations from the Keck Observatory 10-meter telescope, Palomar Observatory 5.1-meter telescope, and Sloan Digital Sky Survey. On this basis, more external resources have been obtained through free competition. Figure 3 [Figure 3: see original paper] shows the output distribution of individually competitively obtained telescope observing time.

In observational astronomy development, large equipment is undoubtedly the main force. Nevertheless, specialized "small equipment" dominated by specific research objectives, characterized by low cost, short development cycles, and strong targeting, drives the output of original results. Unlike astronomy departments at world-class universities such as Caltech and Harvard, Yale's astronomy department does not possess independently developed large-scale terminal equipment, but this has not become a constraint on its development. Although the astronomy faculty comprises only about 20 members, four scientists (including three active professors and one emeritus professor) are proficient in astronomical instrumentation, observation, and big data analysis.

Yale astronomers have made significant achievements in small equipment development. The "Dragonfly Telephoto Array" developed by Professor Pieter van Dokkum and colleagues consists of two groups totaling 48 modified Canon 400mm f/2.8 II telephoto lenses, specifically designed for optical imaging observations of large celestial objects with extremely low surface brightness. This telescope array discovered numerous ultra-diffuse galaxies in the Coma cluster, reigniting astronomers' interest in low surface brightness galaxies and contributing to deeper understanding of dark matter properties and distribution [8]. In recent years, Pieter van Dokkum' s team has published over 20 high-level academic papers using the Dragonfly Telephoto Array. Similarly, in 2018, Professor Debra Fischer led the development of the "Extreme Precision Spectrometer"(EXPRES) installed on the Discovery Channel Telescope at Lowell Observatory in Arizona, primarily tasked with finding Earth-like planets through detecting subtle gravitational effects on stars. Since its operation began in 2019, EXPRES has achieved remarkable scientific results, publishing 9 papers in journals such as *ApJ*, *A&A*, and *AJ*, including the discovery of evaporating gaseous metals in the atmosphere of an exoplanet 456 light-years from Earth [9]. This demonstrates that tailored small equipment can also achieve major results under the guidance of advanced scientific thinking.

## 3 Enlightenment for China' s First-Class Discipline Construction

In February 2017, the Central Committee of the Communist Party of China and the State Council issued the "Opinions on Strengthening and Improving Ideological and Political Work in Higher Education under New Circumstances," clearly defining five important missions for universities: talent cultivation, scientific research, social service, cultural inheritance and innovation, and international exchange and cooperation. Chinese university astronomy departments should draw lessons from others' experiences to forge a path of first-class discipline construction with Chinese characteristics.

(1) **Renew the mechanism for faculty team construction.** Team building is the core of discipline development. Compared with world-class astronomy departments, Chinese university astronomy departments have much smaller research teams, unable to form cluster advantages, and the overall academic innovation level and activity of astronomers are at a disadvantage. The tenure-track system in American research universities has a history of over a century [10]. Under the background of Double First-Class construction, this system is rapidly advancing in China, with many universities piloting "up-or-out" faculty appointment and evaluation mechanisms. The "up-or-out" system should emphasize "up," focusing on controlling entry to provide development space for outstanding talent. The emergence of a group of young leading talents and innovative teams is the best manifestation of this mechanism' s successful operation.

On one hand, disciplines should provide promising young talent with immediate access to international frontier research topics, guide them to participate in major research programs, and encourage interdisciplinary research, particularly regarding understanding and mastery of instrumentation and technology. On this basis, they should engage in exploratory and pioneering work, integrate research results into classroom teaching, and cultivate undergraduate and graduate students to reserve backup research forces, thereby forming an effective cyclical development model where team building facilitates talent cultivation and talent cultivation boosts team building.

On the other hand, the approach to "up" deserves careful consideration. While rapid advancement strategies can address immediate needs, sustainable development that allows for gradual, deep progress better withstands the test of time. Allowing faculty to focus on academics in a healthy competitive environment, maintaining enthusiasm for scientific research and talent cultivation, and growing through competition helps create a dynamic situation of vigorous development. Additionally, universities should provide more positions and opportunities so that young talent can devote themselves to scientific research without distractions, while expanding postdoctoral and full-time research staff to increase the base of astronomy researchers and promote overall strength enhancement.

(2) **Implement a complementary strategy of "large" and "small" equipment.** Currently, China' s major astronomical observation facilities include the Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST), the Five-hundred-meter Aperture Spherical radio Telescope (FAST), the Dark Matter Particle Explorer satellite "Wukong," the Hard X-ray Modulation Telescope "Insight," and the Advanced Space-based Solar Observatory. Major facilities under construction include the "Kuafu-1" space station optical survey telescope and the 110-meter fully steerable radio telescope. These are all led by the Chinese Academy of Sciences. While university astronomy departments participate in using these facilities for research, they are also actively developing independent observation equipment, such as Tsinghua University' s 6.5-meter Wide-Field Spectroscopic Survey Telescope, Nanjing University' s 2.5-meter Wide-Field High-Resolution Optical Telescope, University of Science and Technology of China' s 2.5-meter Wide-Field Survey Optical Telescope, Beijing Normal University' s 1.9-meter Optical Telescope, Yunnan University' s 1.6-meter Multi-Channel Photometric Survey Telescope, the 1.26-meter Optical/Infrared Telescope jointly built by Guangzhou University and the National Astronomical Observatories, and Shandong University' s 1-meter Reflecting Optical Telescope at its Weihai campus.

Developing "large equipment" requires long cycles, while "small equipment" has clear design objectives, is research-project-driven, facilitates relatively rapid output of results, and can be upgraded and renovated based on results to continuously optimize design. University astronomy departments can break through development bottlenecks by leveraging their own characteristics and strengths under the complementary effects of "large" and "small" equipment. Additionally, while emphasizing domestic development, it is also necessary to expand channels for cooperative use and paid purchase of foreign first-class telescope observing time to achieve outstanding scientific results through access to first-hand observation data.

(3) **Strengthen cooperation for mutual benefit.** First, major university astronomy departments must achieve complementary advantages while leveraging their own characteristics and strengths. To this end, they should actively seek support from national ministries to establish university astronomy alliances or similar institutions, sharing teaching and research resources and telescope observation facilities, jointly building medium-to-large telescopes, and promoting cross-university and cross-disciplinary talent mobility. In the space and aerospace fields, they should develop space astronomy exploration projects, promote university-led project organization and cooperation mechanisms, and use this as an opportunity to establish and improve relevant evaluation and assessment mechanisms. Universities should regularly hold discipline development

seminars to formulate unified and complete talent cultivation curriculum systems, accurately grasp and communicate frontier trends in astronomy, and enhance the connotation and international visibility of astronomy disciplines.

Second, it is necessary to optimize and deepen platform construction mechanisms between universities and astronomical observatories/institutes by establishing joint centers and other physical institutions to cooperatively apply for national key laboratories. Relying on these physical institutions, domestic and international scholars can be connected through regular members, project-employed members, and jointly-employed members to gather talent for research in astronomy, astrophysics, space science, and other directions. High-level named postdoctoral fellows should be attracted and selected to transform these physical institutions into world stages that gather first-class scholars and produce first-class results.

Furthermore, astronomy deeply intersects with numerous disciplines. For example, mathematical and mechanical methods are used to study celestial positions and motions; various physics theories are widely applied to astronomical research as observation technology advances; and astronomy is closely integrated with geology, geophysics, and space science in deep space exploration. University astronomy departments should also achieve boundaryless interdisciplinary integration with other disciplines through jointly applying for or participating in major projects, holding academic seminars, and other forms of collaborative research, promoting international platforms for interdisciplinary integration and adding momentum to national economic development.

(4) **Fully utilize the planning and guidance role of academic committees.** Yale' s Astronomical Telescope Time Allocation Committee plays a pivotal role in purchasing and allocating top-tier telescope time and even in the development of observational science. Most Chinese university astronomy departments and schools have academic committees, which should fully exert their planning and guidance role in the process of "first-class" discipline construction, emphasizing top-level responsibility, streamlined implementation, coordinated management, and comprehensive advancement. For discipline construction plans proposed by various fields and research groups, academic committees should be responsible for formulating complete and thorough regulations, comprehensively evaluating them from aspects of scientific validity, urgency, expected output, and input-output ratio, and implementing a scoring system for prioritized development. Resources, manpower, and materials should be concentrated to accomplish major and practical matters, avoiding the drawbacks of equalization where "everyone gets a share." During project implementation, coordination and execution decisions should be exercised, with strict assessment and evaluation to ensure project construction takes root and bears fruit.

(5) **Enrich external publicity and presentation to "tell China' s story**

**well."** Overseas dissemination of a discipline plays an important role in enhancing international influence. One of the most effective methods is building and maintaining English websites. In addition to regular reports on academic exchanges, scientific research achievements, project progress, and science popularization, presenting content on talent cultivation characteristics, innovative and entrepreneurial practice courses, second classroom culture, and social service cases also helps improve discipline reputation and reflect connotation soft power. Astronomy departments can fully utilize online media to expand publicity influence and reach, rooted in Chinese culture, striving to be proactive actors against "de-globalization."

## 4 Summary and Outlook

By the end of 2021, 23 universities nationwide were conducting astronomy education and research, among which 18 universities (Nanjing University, Beijing Normal University, Peking University, University of Science and Technology of China, University of Chinese Academy of Sciences, Shanghai Jiao Tong University, Tsinghua University, Guangzhou University, Sun Yat-sen University, Xiamen University, Yunnan University, Shandong University, Tianjin Normal University, Yunnan Normal University, China West Normal University, Hebei Normal University, Guizhou Normal University, and Qiannan Normal College for Nationalities) have established Schools of Astronomy and Space Science, Departments of Astronomy, or Schools of Physics and Astronomy. Seven universities have first-level doctoral programs, nine have first-level master' s programs, and 12 have undergraduate astronomy programs. The total number of faculty is nearly 600, with approximately 80% holding senior or associate senior titles; the total number of students is nearly 3,500, with doctoral students, master' s students, and undergraduates accounting for 41%, 28%, and 31%, respectively.

Due to historical reasons, university astronomy departments started late and have weak foundations in research equipment construction, lacking independent or jointly built large-scale observation instruments. Currently, most operating or under-construction astronomical telescopes have apertures of 2 meters or below, including more than 170 various optical telescopes, of which 146 are small-aperture teaching telescopes. In platform construction, Chinese universities have 12 various laboratories, with only 1 being a Ministry of Education key laboratory. Furthermore, the scale of high-level research teams is relatively small, lagging behind the development trend of international astronomy disciplines, unable to form disciplinary advantages, and still lacking the collective ability to tackle major frontier scientific problems. In particular, there is a shortage of professionals familiar with hardware and software, with scientists proficient in astronomical instrumentation and capable of high-level astronomical observations and big data analysis being relatively scarce. This indicates that China' s astronomy discipline still has considerable room for improvement in international competitiveness.

This paper benchmarks Yale University' s astronomy discipline, which focuses on small equipment development and talent cultivation. Chinese university astronomy departments should learn from this experience, facing modernization, the world, and the future to build distinctive world-class astronomy disciplines.

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*Note: Figure translations are in progress. See original paper for figures.*