Insight-HXMT Scientific Research Special Issue: Preface (Postprint)

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Abstract

Since its launch in June 2017, Insight-HXMT has achieved a large number of important scientific results in the field of high-energy astrophysics. Currently, the Insight-HXMT satellite is operating well in orbit and is expected to continue operations for several more years. To enable the domestic astronomical community to more fully understand and utilize the observational advantages of Insight-HXMT, particularly in the context of a series of domestic high-energy astronomical observation satellites that have been launched and will be launched, and to continue exploring the research potential of Insight-HXMT, the Insight-HXMT research team has published this special issue, comprising a total of 11 review papers that systematically introduce the progress of Insight-HXMT across various research directions.

Full Text

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A Special Issue on Insight-HXMT Scientific Research: Preface

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Abstract

Since its launch in June 2017, the Insight Hard X-ray Modulation Telescope (Insight-HXMT) has achieved a substantial body of important research results in high-energy astrophysics. The satellite continues to operate smoothly in orbit and is expected to remain functional for several more years. To enable the

Chinese astronomical community to more fully understand and utilize the observational advantages of Insight-HXMT—particularly in light of the recent launch and upcoming deployment of a series of domestic high-energy astrophysical missions—and to continue exploring its scientific potential, the Insight-HXMT research team has compiled this special issue. Comprising 11 review papers, this issue systematically introduces the progress made by Insight-HXMT across various research directions.

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1. Introduction

International space-based high-energy astronomy has experienced half a century of substantial development since the launch of the first X-ray satellite UHURU in the 1970s. The field has witnessed a technological leap from collimated telescopes to focusing imaging systems, expanding the catalog of X-ray sources from a few hundred to several hundred thousand. The early 21st century has seen the emergence of numerous high-performance space telescopes, notably NASA' s Chandra observatory, whose exceptional spatial resolution and sensitivity in the soft X-ray band (0.5–10 keV) will remain unsurpassed for the foreseeable future. This progress has driven a paradigm shift from "seeing farther and clearer" to "seeing more precise and more accurate," with the latter enabled by detectors featuring large effective areas, broad energy coverage, and high performance that facilitate high-time-resolution light curves and precise measurements of multiple physical parameters.

Launched on June 15, 2017, the Insight Hard X-ray Modulation Telescope (Insight-HXMT) represents China' s first X-ray astronomy satellite. The observatory covers a broad X-ray band extending into the soft X-ray regime, offering good energy resolution at low energies, large effective area, and high time resolution at hard X-ray energies. Its dedicated gamma-ray burst (GRB) mode further extends the energy coverage to the MeV range with an exceptionally wide field of view. These distinctive capabilities position Insight-HXMT to "see more precise and more accurate" when studying eruptive compact objects, enabling significant contributions to understanding their fundamental properties, burst evolution, and radiation mechanisms, as well as facilitating preliminary explorations of extreme physics in the strong-field environments surrounding compact objects.

Insight-HXMT' s detailed studies of compact objects focus on three primary areas: gamma-ray bursts, accretion evolution of Galactic compact objects, and investigations of their fundamental properties, with the overarching goal of understanding physical processes in strong gravitational and magnetic fields. Galactic plane scanning is employed to search for and monitor new eruptive phenomena.

China' s space astronomy has entered an unprecedented era of prosperity. Beyond Insight-HXMT, subsequent missions such as GECAM (Extreme Universe Wide-field Monitor), Einstein Probe (EP, also known as TianGuan), the China-France SVOM satellite, the CATCH experimental satellite, and the flagship eXTP (enhanced X-ray Timing and Polarimetry mission) observatory have been launched or are under development. In this context, to provide readers with a comprehensive understanding of Insight-HXMT's observational capabilities and scientific achievements—and to facilitate the further exploitation of its research potential in synergy with other Chinese space X-ray astronomy projects—this special issue has been compiled.

Insight-HXMT has achieved remarkable success in studying extreme transient events, including the publication of China' s first GRB observation catalog [1], the first confirmation of a magnetar origin for a fast radio burst (FRB) [2], and the detection of the brightest GRB in recorded history [3]; these milestone results have been reported in separate dedicated publications. Since launch, the mission has contributed to approximately 300 scientific papers. As a collimated telescope, Insight-HXMT' s unique design incorporating blind detectors offers advantages over classical ON/OFF collimated systems in background estimation and model construction [4].

This special issue comprises review articles covering three main areas: X-ray binaries (representing 60% of the papers), Galactic plane scanning, background calibration, and instrument performance (15%), and isolated neutron stars (4%). The Insight-HXMT team has developed an innovative "map method" that utilizes observations of numerous blank sky fields to estimate the instrument background, achieving a background model precision sufficient for detailed spectroscopic analysis [5]. As China's first space-based X-ray telescope, Insight-HXMT faced the challenge of establishing detector calibration without prior domestic experience—a critical task since calibration precision directly impacts the physical interpretation of observational data. The mission has achieved in-orbit calibration of its energy and temporal response primarily through observations of bright sources such as Crab, attaining an accuracy of approximately 2% that satisfies scientific analysis requirements [6].

Insight-HXMT has performed more than 3,000 scanning observations of the Galactic plane, representing approximately 30% of its total observing time. These observations have monitored the variability of numerous X-ray sources, resulting in a comprehensive monitoring catalog [7]. The mission has observed seven isolated pulsars and four millisecond pulsars, obtaining high-precision spin-pulse profiles and broad-band, phase-resolved spectra that reveal the evolution of spectral parameters with pulse phase [8].

X-ray binaries constitute the most productive research area for Insight-HXMT, with investigations spanning both neutron star and black hole systems. For weakly magnetized neutron star low-mass X-ray binaries, the mission has constrained the energy limits of quasi-periodic oscillations (QPOs) in sources like Z and Sco X-1 while elucidating the origin of hard X-ray spectral tails [9]. Insight-

HXMT' s unique capabilities enable the use of thermonuclear bursts as probes of accretion environments in X-ray binaries. Notably, observations of a single burst have clearly revealed the cooling of the hot corona by the burst, providing high-quality constraints on coronal geometry and origin [10]. For high-mass accreting neutron star X-ray binaries, the mission has yielded the first observational evidence for radiation pressure-dominated accretion disks, set a world record for the strongest directly measured neutron star magnetic field, and revealed the detailed luminosity-dependent evolution of cyclotron absorption lines from the polar cap region. These findings point toward multipolar magnetic field configurations and intrinsic super-Eddington accretion in ultraluminous X-ray sources, challenging prevailing models of polar cap radiation [11].

Insight-HXMT has achieved remarkable success in studying the outburst evolution of black hole X-ray binaries and constraining their fundamental properties. The mission has, for the first time, extended the detected energy range of quasi-periodic oscillation (QPO) signals from approximately 30 keV to above 200 keV, discovering numerous high-energy QPOs and establishing a physical model linking QPOs to precession of twisted jets. Employing novel analysis techniques, it has also produced the first detailed measurements of QPO-phase-resolved spectral evolution, offering new insights into the physical origin of these variability features [12]. The mission' s high-cadence, high-statistics observing mode enables detailed temporal and spectral characterization throughout all phases of an outburst, providing unprecedented opportunities to comprehensively investigate disk-corona-jet properties and constrain black hole fundamental parameters [13]. Insight-HXMT has delivered numerous measurements of black hole mass and spin, and using data primarily from the mission, has systematically compared the two classical methods for spin determination [14]. Based on observations of MAXI J1820+070, the mission has conducted systematic studies of magnetic field transport in accretion flows and jet properties in black hole X-ray binaries, discovering for the first time that jet outflow velocities increase as the jet' s overall scale shrinks toward the black hole. Combined with multi-wavelength timing analysis of the outburst decay phase, this work has provided the first direct observational evidence for the formation of a magnetically arrested accretion disk [15].

Insight-HXMT has established China' s presence in international space-based X-ray astronomy. The mission' s rich scientific yield, particularly its breakthrough discoveries in several key areas, demonstrates its unique capabilities for compact object research. As illustrated in this special issue, synergies with other satellites and ground-based facilities—through broad energy coverage, multi-wavelength and multi-messenger observations, coupled with innovative analysis methods—promise enormous potential for future scientific breakthroughs with Insight-HXMT. The mission' s data are now essentially fully open, and its continued stable operation will provide ongoing service to the global research community.

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