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Progress of Planetary Defense Research in China*

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Abstract Near-Earth Asteroids (NEA) impose potential major disaster to humanity. Planetary defense is an inevitable requirement for the survival of human civilization. In recent years, China has made rapid progress in planetary defense research, which has won the attention of the government and attracted more and more scholars and organizations. This paper summarizes the research progress in planetary defense in China in recent years, including the fireball events in China, academic activities and policy planning, monitoring and warning technology, on-orbit defense technology, impact hazard assessment, international cooperation and science popularization.

Key words Near-Earth asteroids, Planetary defense, Kinetic impact, Space-based observation, Hazard assessment

Classified index P13

1 Introduction

Near-Earth Asteroid (NEA) impact is a major potential threat to human society. NEA have impacted our planet Earth numerous times in history, profoundly shaping the evolution of the Earth's climate and ecological environment, and triggering the extinction and evolution of species. 66 million years ago, an NEA with a diameter of about 10 kilometers impacted the Gulf of Mexico in North America, resulting in the extinction of more than 70% of the global species, including dinosaurs[1]. It is also because of this impact that human beings have the opportunity to dominate the Earth and develop today's highly developed human civilization. If we do not want to repeat the fates of dinosaurs, we must pay attention to the threat of NEA impacts.

Even if a small-scale NEA impact will bring significant disaster. On 15 February 2013, an NEA with a diameter of about 18 m exploded above the Chelyabinsk region of Russia, causing damage to nearly 1500 people and 3000 houses[2]. If it happened in densely populated regions, the consequences will be even more serious.

It has become a consensus all over the world to strengthen the response to NEA impact risk. After the Chelyabinsk impact in 2013, two organizations, IAWN (International Asteroid Warning Network) and SMPAG (Space Mission Planning Advisory Group), were established under the promotion of the United Nations Office for Outer Space Affairs (UNOOSA). IAWN aims to coordinate global organizations to discover and warn potential threat NEA that may impact the Earth; SMPAG aims to research and develop defense means against NEA impact. At present, the United States and Europe are leaders in global planetary defense. The United States has discovered 98% of the total discovered NEA, and has launched the DART (Double Asteroid Redirection Test) mission on 24 November 2021. It is expected that it will impact the moonlet of the Didymos double asteroid system by the end of September 2022. This is also the world's first dedicated planetary defense mis-

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sion. As part of the AIDA (Asteroid Impact Deflection Assessment) program of the US Europe cooperation, Europe will launch the Hera mission in 2024 to conduct a detailed rendezvous survey of the Didymos double asteroid system to better evaluate the impact effect.

In recent years, China has made rapid progress in planetary defense. The Chinese government joined IAWN and SMPAG[3] in 2018. On the China Space Day in 2021, ZHANG Kejian, director of the China National Space Administration(CNSA), pointed out in his speech that China would build a NEA defense system. Chinese scholars have also made significant progress in NEA monitoring and warning, on-orbit defense means, risk assessment, *etc*. This report will provide an overview of the above progress, focusing on the achievements since 2020.

2 Recent Fireball Events

From 2017 to 2021, there were five eye-catching fireball events, including the Shangri-La event in 2017, the Xishuangbanna event in 2018, the Songyuan event in Jilin in 2019, the Yushu event in Qinghai in 2020 (see Fig.1), and the Henan event in 2021.

These fireball events did not cause any threat or property damage, but they attracted public attention and were widely spread on the internet. At the same time, these fireball events also attracted the attention of scientific research experts and governments. Scientists studied and interpreted the fireball event. The government has gradually paid attention to the threat of NEA impacts as a serious scientific issue and potential disasters that may occur in the future.

3 Academic Activities and Policy Planning

In the past few years, Chinese academia has paid more and more attention to the issue of NEA defense.

In 2018, the China Aerodynamics Research and Development Center (CARDC) organized a seminar on "Hypervelocity Problem of Asteroid Impacting the Earth". The seminar later evolved into a National Symposium on Planetary Defense (NSPD). The 2nd NSPD was held in Beijing in 2019, also organized by CARDC; and the 3rd NSPD was held in Nanjing in 2020 by Purple Mountain Observatory, Chinese Academy of Sciences (PMO, CAS). In 2021, the fourth NSPD, also the 1st China Planetary Defense Conference (CPDC) was held in Guilin, Guangxi province. Academician WU Weiren of the Chinese Academy of Engineering served as the chairman of the conference, with more than 300 participants.

In 2018, the 634th Xiangshan Science Conference was held, with the theme of frontier scientific issues and key technologies in NEA monitoring and warning, defense and resource utilization[4]. More than 40 experts and scholars from nearly 30 organizations attended the meeting. China National Space Administration (CNSA) also had representative in the meeting.

In terms of government activities and policy planning, there is also much progress.

In 2018, CNSA officially joined IAWN and SMPAG, marking that the government officially paid attentions to NEA impacts. In 2019, "Investigation, Defense and Utilization of Small Bodies" were selected as one of the 20 major scientific issues and key technical problems issued by the China Association for Science and Technology (CAST)[5].

On China space day in 2021, ZHANG Kejian, director of the CNSA, pointed out in his speech that China would build an NEA defense system. This was the first time that NEA defense system was announced by Chinese government.

On China Space Day in 2022, WU Yanhua, deputy

Fig. 1 Yushu fireball event in 2020

director of CNSA, pointed out that a NEA impact mission would be implemented in 2025 or 2026. This was the first time that a NEA impact mission was announced by Chinese government.

In 2022, the Information Office of the State Council issued the white paper "China's Space Activities in 2021", pointing out that the NEA defense system would be constructed in future.

In 2022, the Deep Space Exploration Laboratory (DSEL) was kicked off in Hefei, Anhui province. It was mentioned in the press release that DSEL would be responsible for leading the feasibility study and implementation of major projects such as the NEA defense system.

In 2022, academician WU Weiren published an article in Strategic Study of CAE journal[6], presenting the strategic thoughts on NEA impact risk mitigation, including monitoring and warning, on-orbit defense and hazard assessment, and making a prospect for future development.

4 Monitoring and Warning Technology

In 2018, the 2.5 m large field of view sky survey telescope jointly operated by the University of Science and Technology of China (USTC) and PMO was kicked off in Lenghu and was expected to be completed in 2022. In 2021, the National Astronomical Observatory, Chinese Academy of Sciences (NAO, CAS) and other organizations discovered that Lenghu is a world-class optical observatory site, laying the foundation for the construction of optical sky survey telescopes in China.

China is developing the Chinese Space Station Telescope (CSST), which is expected to have powerful capability to make follow-up observations of NEA. The CSST also has the potential to discover NEA if the survey strategy is dedicatedly designed. The commercial space enterprise "Origin Space" launched the "Yangwang 1st" space-based telescope in 2021, which claimed to have performed the survey and observation of NEA. Optical satellites of other commercial space enterprises are also said to have the capability to observe brighter NEA.

In terms of NEA discovery, China now has only one dedicated ground telescope, the Chinese Near-Earth Objects Survey Telescope (CNEOST) of PMO. CNEOST is a 1.2 m aperture telescope in Xuyi, Jiangsu Province. Using CNEOST, PMO has discovered 5, 5 and 1 NEA in 2020, 2021 and 2022 respectively. PMO, Yunnan Observatory, and NAO also studied the NEA characteristics observation, including spectral observation and light curve observation.

Qianxuesen Space Technology Laboratory (QianLab)[4], National Space Science Center, Chinese Academy of Sciences (NSSC, CAS)[7], PMO[7], NAO[8] and other organizations studied space-based monitoring mission concepts. QianLab proposed Constellation of Heterogeneous Wide-field Near-Earth Object Surveyors (CROWN) mission concepts[4], a hybrid constellation including a main satellite telescope and several micro satellite telescopes in the Venus-like orbits.

The NSSC and PMO have cooperated to propose the Earth-leading orbit telescope mission concept[7]. The telescope is proposed to be deployed about ten or twenty million kilometers in front of the Earth. Simulation shows that it has a good warning efficiency on NEA approaching the Earth from the direction of the Sun. It is of great significance to compensate for the blind sky region of ground-based optical observatories and improve the completeness and integrity of the NEA monitoring and warning system. Fig.2 showed Earth leading orbit telescope mission concept.

5 On-orbit Defense Technology

NSSC[9, 10], Beijing Institute of Spacecraft Environmental Engineering (BISEE)[11], CARDC[12,13] and other organizations have researched on on-orbit defense technology of NEA. Progress has been made on the evaluation of applicable scenarios of typical planetary defense means, and new concepts on-orbit defense mission concepts.

In view of the disadvantages of the traditional kinetic impact means that is difficult to deal with large-scale NEA under short-term warning time, NSSC proposed two new mission concepts, namely the "Enhanced Kinetic Impactor (EKI)"[8] and "Assembled Kinetic Impactor (AKI)"[9], the orbital deflection distance of NEA can be increased to 3–10 times, providing innovative solutions for dealing with large-scale NEA under

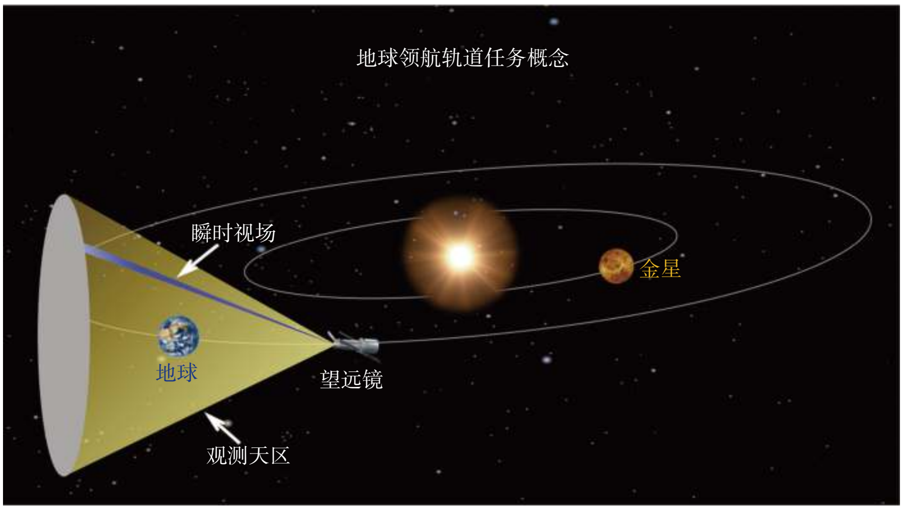

Fig. 2 Earth leading orbit telescope mission concept

short-term warning time.

The EKI mission captures a stone with the mass of about 200 tons to form an enhanced kinetic impactor, the orbit deflection distance can be increased to 10 times compared with the traditional kinetic impactor (see Fig.3). The AKI mission will impact the asteroid with a satellite in combined with the final stage of the launch vehicles. The orbital deflection distance of the AKI launched by a single Long March 5 launcher to the asteroid is equivalent to that of three traditional impactors launched by three Long March 5 launchers.

6 Impact Hazard Assessment

National Institute of Natural Hazard of the Ministry of Emergency Management (NINH, MEM), NSSC[14], PMO[15], CARDC[16,17], Beijing Institue of Technology (BIT) and BISEE[18,19] and other organizations have researched on NEA hazard assessment. Significant Progress has been made in NEA atmospheric entry process.

In 2021, NSSC revealed 5 typical atmospheric entry modes of NEA impacts[10], including the asteroids entering the atmosphere layer at a small angle, which may be temporarily captured by the gravity of the Earth and finally impact the Earth, resulting in a particularly long flight range of asteroids, which poses a challenge to the prediction of asteroid impact and impact sites.

In 2022, PMO analyzed the Aletai meteorite super long strewn field in Xinjiang, and confirmed that asteroids can impact the Earth by skipping[11]. Numerical modeling suggests that the stone skipping-like trajectory (see Fig.4) associated with a shallow entry angle is responsible for Aletai's exceptionally long strewn field if a single-body entry scenario is considered. The stone skipping-like trajectory would not result in the deposition of large impact energy on the ground but may lead to the dissipation of energy during its extremely long-distance flight.

7 International Cooperation and Science Popularization

In 2018, CNSA officially joined IAWN and SMPAG. The PMO and NAO have been participating in the international joint NEA observation activities organized by IAWN.

In 2021, CARDC, as a co-organizer, participated in the organization of the 7th IAA Planetary Defense Conference (PDC), which was the first time that China participated in the organization of PDC.

In 2022, a group of graduate students of NSSC won the graduate student grant of the 8th PDC through professional review, and was invited to present the study on the conference.

In terms of science popularization, NSSC[20], PMO and other organizations have created a large number of science popularization works. A special WeChat platform “Planetary Defense and Utilization” has been established to spread science popularization works and news related to planetary defense.

Fig. 3 EKI mission concept

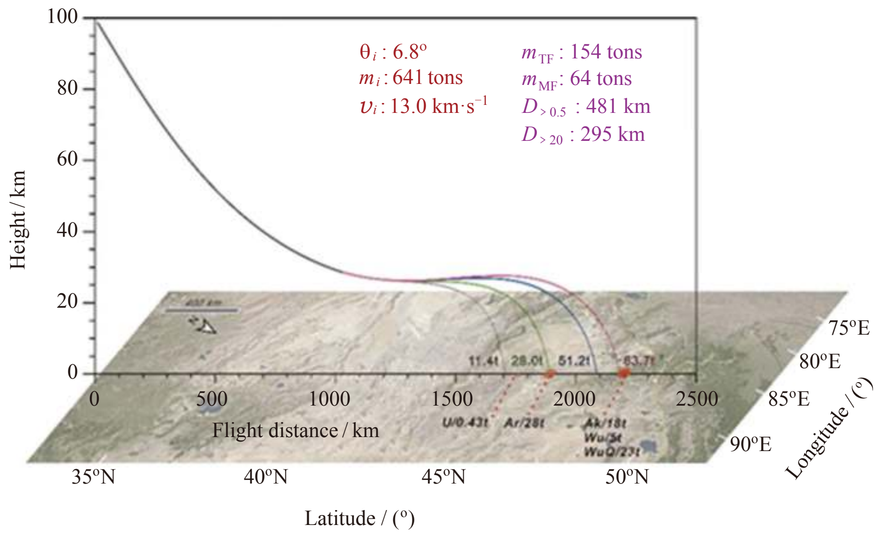

Fig. 4 Skipping-like trajectory of Aletai's meteorite (Source: *Science Advances*)

8 Conclusion

In the past few years, China's planetary defense has made rapid progress. Chinese scholars have successfully held the first China Conference on Planetary Defense, attracting more and more researchers to engage in planetary defense research. The Chinese government announced to build an NEA defense system and planned the implementation of the on-orbit demonstration mission of NEA defense. In terms of monitoring and warning, world-class optical observation site has been found, new observatories will soon be put into operation, and innovative space-based monitoring and warning missions have been proposed. In the aspect of on-orbit defense technology, the applicable scenarios of typical on-orbit defense technologies are analyzed, and new concepts on-orbit defense means are proposed. In the aspect of hazard assessment, the impact hazard evolution chain is analyzed, and a new mechanism of NEA entry into the atmosphere is analyzed and verified. China has more extensively participated in international planetary defense cooperation and has made remarkable progress in science popularization.

It is expected that in the next five years, China's planetary defense will make greater breakthroughs and make greater contributions to safeguarding the security of the Earth life and building a community with a shared future for mankind.

References

[1] BOTTKE W, VOKROUHLICKÝ D, NESVORNÝ D. An asteroid breakup 160 Myr ago as the probable source of the K/T impactor[J]. *Nature*, 2007, **449**: 48-53

[2] BROWN P, ASSINK J, ASTIZ L, *et al.* A 500-kiloton airburst over Chelyabinsk and an enhanced hazard from small impactors[J]. *Nature*, 2013, **503**(7475): 238-241

[3] ROMANA Kofler, GERHARD Drolshagen, *et al.* International coordination on planetary defence: the work of the IAWN and the SMPAG[J]. *Acta Astronautica*, 2019, **156**: 409-415

[4] GONG Zizheng, LI Ming, CHEN Chuan, ZHAO Chang yin. The frontier science and key technologies of asteroid monitoring and early warning, security defense and resource utilization[J]. *Chinese Science Bulletin*, 2020, **65**(5): 346-372 (龚自正, 李明, 陈川, 赵长印. 小行星监测预警、安全防御和资源利用的前沿科学问题及关键技术[J]. 科学通报, 2020, **65**(5): 346-372)

[5] LIU Huigen, ZHAO Haibin, ZHOU Jilin. Survey, defence and resource development of NEO[J]. *Chinese Science Bulletin*, 2020, **65**(9): 757-763 (刘慧根, 赵海斌, 周济林. 近地小天体调查、防御与开发[J]. 科学通报, 2020, **65**(9): 757-763)

[6] WU Weiren, GONG Zizheng, TANG Yuhua, ZHANG Pinliang. Response to risk of near-Earth asteroid impact[J]. *Strategic Study of CAE*, 2022, **24**(2): 140-151 (吴伟仁, 龚自正, 唐玉华, 张品亮. 近地小行星撞击风险应对战略研究[J]. 中国工程科学, 2022, **24**(2): 140-151)

[7] WANG Xintao, ZHENG Jianhua, LI Mingtao, *et al.* Warning of asteroids approaching Earth from the sunward direction using two Earth-leading heliocentric orbiting telescopes[J]. *Icarus*, 2022, **377**: 114906

[8] YANG Xu, ZHAO Kexin, GAN Qingbo, *et al.* Analysis of ground-based and space-based optical observation system warning capability of near-Earth asteroids[J]. *Transactions of Beijing Institute of Technology*, 2021, **41**(12): 1307-1313 (杨旭, 赵柯昕, 甘庆波, 刘静, 姚永强. 近地小行星天地基光学监测系统预警能力分析[J]. 北京理工大学学报, 2021, **41**(12): 1307-1313)

[9] LI Mingtao, WANG Yirui, WANG Youliang, *et al.* Enhanced Kinetic impactor for defecting large potentially hazardous asteroids via maneuvering space rocks[J]. *Scientific Reports*, 2020, **10**: 8506

[10] WANG Yirui, LI Mingtao, GONG Zizheng, *et al.* Assembled kinetic impactor for deflecting asteroids by combining the spacecraft with the launch vehicle upper stage[J]. *Icarus*, 2021, **368**: 114596

[11] SONG Guangming, WU Qiang, CHEN Chuan, *et al.* Advances on mission analysis and design software for active planetary defense against near Earth asteroids[J]. *Space Debris Research*, 2021, **21**(2): 27-34 (宋光明, 武强, 陈川, 等. 国外近地小行星在轨处置任务分析与设计软件研究进展[J]. 空间碎片研究, 2021, **21**(2): 27-34)

[12] LI Yi, CHEN Hong, LAN Shengwei, *et al.* A method to improve interception efficiency in the defense against near-Earth asteroids[J]. *Spacecraft Environment Engineering*, 2017, **34**(6): 585-592 (李毅, 陈鸿, 兰胜威, 等. 一种提升近地小行星防御中拦截效率的方法[J]. 航天器环境工程, 2017, **34**(6): 585-592)

[13] LI Tao, QIN Jingui, REN Leisheng, LI Yi. Optimal interception orbit analysis in the kinetic impact of near Earth asteroids[J]. *Space Debris Research*, 2021, **21**(4): 49-54 (李涛, 覃金贵, 任磊生, 李毅. 近地小行星动能撞击的最优撞击方案分析[J]. 空间碎片研究, 2021, **21**(4): 49-54)

[14] GENG Shujuan, ZHOU Binghong, LI Mingtao. On the capture of small stony asteroids into the Earth's orbit by atmospheric grazing[J]. *Monthly Notices of the Royal Astronomical Society*, 2021, **507**: 4661-4668

[15] LI Ye, LI Bin, HSU Weibiao, *et al.* A unique stone skipping–like trajectory of asteroid Aletai[J]. *Science Advances*, 2022, **8**: 25

[16] DANG Leining, LIU Sen, BAI Zhiyong, *et al.* Sensitivity research on models of Earth entry and impact effects by asteroids[J]. *Chinese Journal of Theoretical and Applied Mechanics*, 2021, **53**(1): 278-292 (党雷宁, 柳森, 白智勇, 石义雷. 小行星进入与撞击效应评估模型敏感性研究[J]. 力学学报, 2021, **53**(1): 278-292)

[17] DANG Leining, LIANG Shichang, HUANG Jie, LIU Sen. Analysis on Earth entry process and influence on ground of Songyuan meteor[J]. *Space Debris Research*, 2021, **21**(4): 62-71 (党雷宁, 梁世昌, 黄洁, 柳森. 吉林松原流星进入大气层过程及对地面的影响分析[J]. 空间碎片研究, 2021, **21**(4): 62-71)

[18] REN Jiankang, ZHANG Qingming, LIU Wenjin, *et al*. Numerical simulation of Yilan crater formation process[J/OL]. *Explosion and Shock Waves*: 1-12 (任健康, 张庆明, 刘文近, 等. 依兰陨石坑形成过程数值模拟研究[J/OL]. 爆炸与冲击: 1-12)

[19] LIU Wenjin, ZHANG Qingming, MA Xiaohe, *et al.* A review of the models of near-Earth object impact cratering on Earth[J]. *Explosion and Shock Waves*, 2021, **41**(12): 119-134 (刘文近, 张庆明, 马晓荷, 等. 近地小天体对地撞击成坑模型研究进展[J]. 爆炸与冲击, 2021, **41**(12): 119-134)

[20] LI Mingtao. 2016 HO3 asteroid may be the "little Moon" of the Earth[N]. *Science and Technology Daily*, 2021-11-23(008) (李明涛. 2016 HO3小行星或是地球的"小月亮"[N]. 科技日报, 2021-11-23(008))