Exploring the Dynamic X-ray Universe

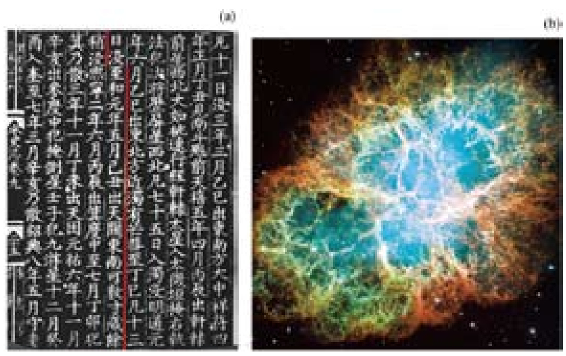
— An Interview with YUAN Weimin on the Einstein Probe Mission

The Einstein Probe (EP) mission is a small scientific satellite dedicated to time-domain high-energy astrophysics. It aims at discovering violent cosmic events and monitoring variable objects in 0.5-4 keV, for which it will employ a large instantaneous field-of-view (60°×60°, or 3600 square degrees), along with moderate spatial resolution and energy resolution. It will also carry a follow-up observation X-ray telescope with a smaller field-of-view, capable of much larger light-collecting power and better energy resolution than the main survey telescope. Public transient alerts will also be issued rapidly, in order to trigger multi-wavelength follow-up observations from the world-wide community. Its wide-field imaging capability is achieved by using established technology of novel micro-pore "lobster-eye" optics, thereby offering unprecedentedly high sensitivity and large Grasp superseding previous and existing X-ray all-sky monitors and survey missions.

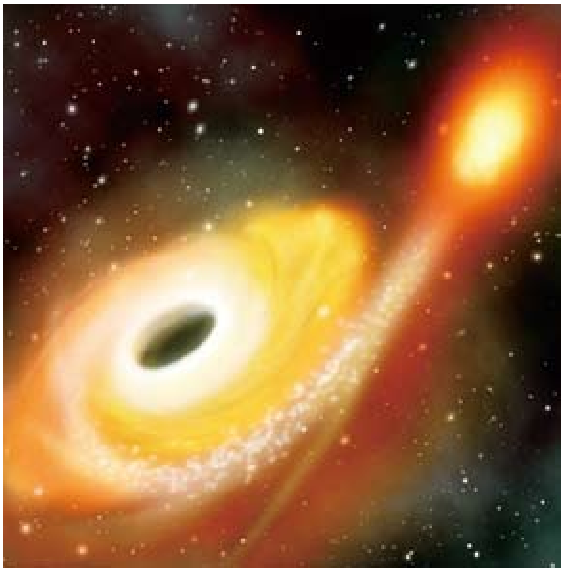
Dr. YUAN Weimin, an astrophysicist on black holes and high energy astrophysics from the Space Science Division, NAOC and Principal Investigator of the EP mission, explains to BCAS reporter XIN Ling the satellite's science objectives, payloads, development status and challenges, as well as how such an idea came into being in the first place.

BCAS: How was the Einstein Probe mission proposed in the first place?

YUAN: When I worked as a postdoc at Tsukuba Space Center, JAXA in Japan many years ago, I was involved in the development of the MAXI mission, which is an X-ray all-sky monitor currently operating onboard the International Space Station. During this exceptional and valuable working experience, I became fascinated by the power of monitoring the sky in the X-ray wavelength from space, which is pervaded by variable, flaring or even burst celestial objects. For many years I have been dreaming of building an X-ray all-sky monitor to detect giant X-ray flares from otherwise quiescent massive black holes lurking at the center of other galaxies in the process of swallowing a captured nearby star, which is an emerging new class of X-ray transients first discovered about 20 years ago by Stefanie Komossa, a German astrophysicist and one of my classmates of doctoral study and also a close friend.



"History of Song" documented the observation of a guest star in the constellation Taurus on July 4, 1054 in the Chinese Song Dynasty (Panel a, Credit: Encyclopedia of China, 1999), which was later known to be a supernova explosion leading to the well-known leftover remnant known as the Crab Nebula (Panel b, Credit: Hubble Space Telescope).


Artist's impression of a stellar tidal disruption event by a massive black hole (Credit: NASA)

Back in 2010, an X-ray imaging laboratory was already built up at NAOC, initiated and led by Prof. ZHANG Shuangnan and set out to develop a new technique for X-ray imaging called lobster-eye micro-pore optics (MPO). Remarkably, this is a promising technology applicable to X-ray monitors with even higher sensitivity than the current ones, such as MAXI. At that time, a mission concept of MPO-based X-ray All-sky Monitor has been suggested to the CAS jointly by NAOC and IHEP, as one of the scientific utilization payloads for the future Chinese space station. Soon after I joined NAOC in 2010, I was lucky enough to take the lead of the design and proposal of the All-sky Monitor. This procedure somehow came to a suspension during 2012/13.

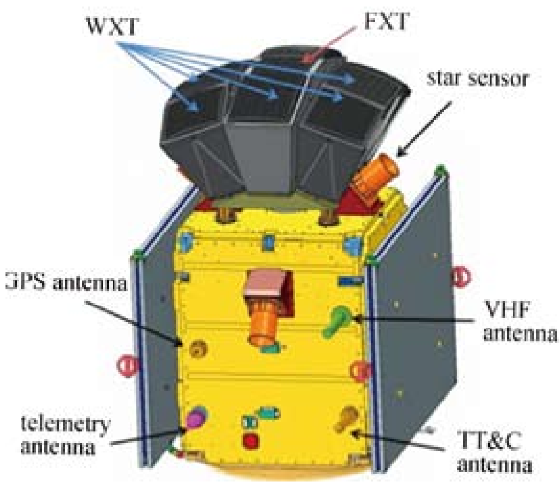
Fortunately, in December 2012, the CAS timely announced a call for the second batch of candidate missions of its Pilot-A Strategic Priority Program in Space. I considered it a great opportunity and proposed to a few colleagues, including Prof. ZHANG and Prof. HU Jingyao, an idea of a free-flying satellite mission by combining a wide-field monitor with a follow-up X-ray telescope, which would greatly enhance the scientific capability over a simple all-sky monitor for the discovery and characterization of transients. This suggestion was enthusiastically welcomed and encouraged by all of the colleagues and we immediately got together for a brainstorming. At that time, the gravitational wave detector Advanced LIGO was expected to finish its upgrade and to start operation soon, followed by Advanced VIRGO. Detection of any potential X-ray signals associated with gravitational wave events would be of extreme scientific significance, which was considered as another key scientific goal at the discussion, along with quiescent black holes and other energetic transient events. Since black holes and gravitational waves are both predictions of Einstein's General Theory of Relativity (and no direct detection of gravitational waves had been achieved at that time yet), the mission was named "Einstein Probe" , or EP, which was coined by Prof. ZHANG at the end of the brainstorm. The proposal was submitted to NSSC in mid-January 2013, after one-month's hard work.

BCAS: What are the main scientific goals of EP?

YUAN: The basic scientific goal is to perform systematic, sensitive surveys to discover diverse types of X-ray transients or outbursts and monitor the variability of X-ray sources in the Universe over a wide range of timescales and at high cadence.

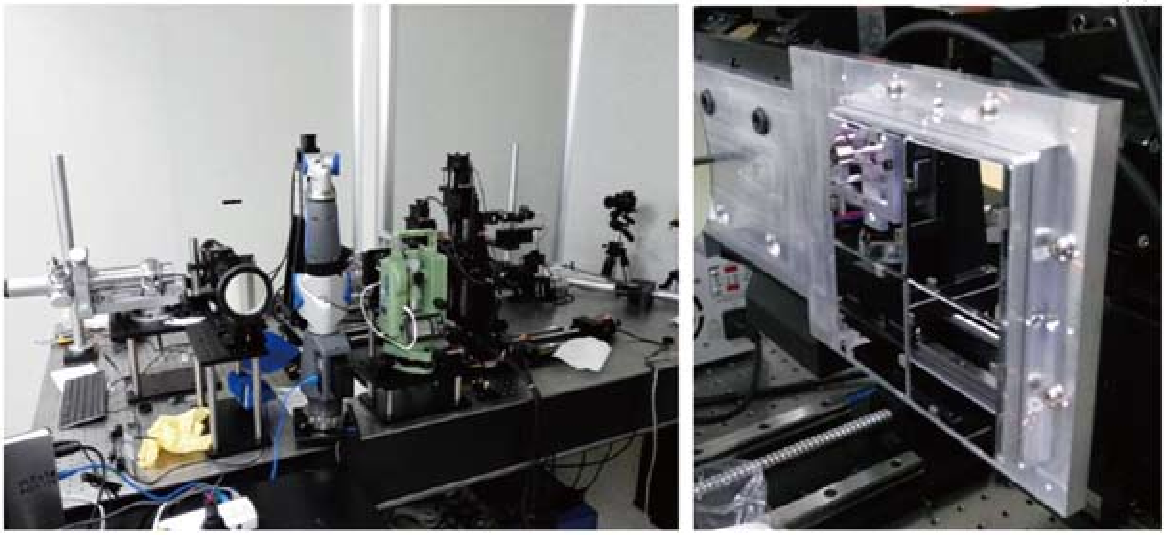
Particularly, Einstein Probe is expected to reveal quiescent black holes over almost all astrophysical mass scales and study how matter falls onto them by detecting their rare X-ray flares, especially those produced as stars tidally disrupted by otherwise dormant massive black holes at the center of galaxies.

Detect and locate possible electromagnetic-wave counterparts of gravitational-wave events to be detected with gravitational-wave detectors.



Layout of the Einstein Probe satellite (Credit: NAOC and MicroSat, CAS)

(a) (b)



Laser-guided MPO assembling facility and contactless online quality-monitoring system for the assembly of the EP/WXT prototype module at NAOC (a). Currently an assembling precision of micro-meter or arc-second has been achieved for a 2×2 MPO pieces array using a quasi-stress-free control system (b) (Credit: ZHANG Chen, X-ray Imaging Lab, NAOC)

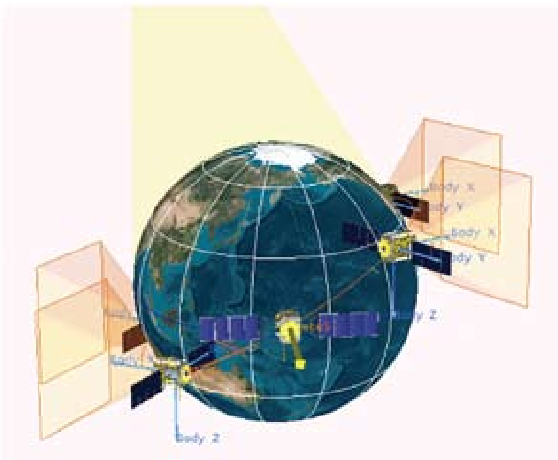


Illustration of the survey mode of Einstein Probe in orbit as a series of pointed observations for 10~20 min exposure each, with its large instantaneous field-of-view. It will cover half of the entire sky (anti-solar direction) in 3~5 orbits.

BCAS: What is the status of the R&D work — and technical readiness?

YUAN: As a rule of thumb, almost all science-driven space missions with cutting edge scientific goals possess certain unprecedented scientific performance and capability to explore a new parameter space or even a new dimension. Such capability is usually enabled only by progresses and even breakthroughs in relevant detection technology.

The same is true for the Einstein Probe mission, and there are several key technologies involved, including the micro-pore optics (MPO), the large-format focal plane detector and on-board data reduction and analysis on the fly. These are all challenges at the international level, not only for us in China. We have already achieved the application of MPO, including the design of a wide-field telescope and its assembly and testing. As results of the "Advanced Study" phase in the past two years, we have succeeded in building a prototype of the MPO telescope at NAOC. The X-ray detector at the focal plane, once built successfully, would be one of the largest size detectors of this kind ever built. Currently newly developed scientific CMOS sensors produced by the Changchun Institute of Optics, Fine Mechanics and Physics, CAS are considered as the detector. Though its off-the-shelf products currently available would meet the basic needs, we are still working with the institute to further develop a new model for better performance, with larger format and size, and optimized for X-ray detection. For on-board data analysis we have also come up with a prototype solution. As far as the follow-up telescope is concerned, although this is a widely used technology abroad and is also available commercially, this technology is also getting matured and can be available in China.

As for the overall technical readiness of the mission, though some of these are challenging technologically, there is none deemed insurmountable.

The Forum "Exploring the Dynamic X-ray Universe" was held at the International Space Science Institute - Beijing from May 6 to 7, 2014. At this forum, the science objectives, instrumentation and mission concept of the Einstein Probe were discussed in detail.

BCAS: What could be the biggest challenge or risk before the satellite is launched?

YUAN: The biggest challenges would be the new technologies adapted, for instance, the micro-pore optics and CMOS sensors, since so far EP is deemed to be the very first of this kind technology applied to X-ray all-sky monitors to fly worldwide. On the other hand, great scientific returns always come with big challenges. Almost no great science is done without any risk. Someone has to do it first. Another uncertainty in science is about the detectability of the electromagnetic counterparts of gravitational-wave events, since this has never detected before and no one knows whether they are really detectable or not, except for theoretical predictions.

In China, we have been used to be followers in many fields in science for way too long. This has to be changed. The good sign is that innovation is now greatly encouraged by the CAS as well as the government at an unprecedented level.

BCAS: Is there any international collaboration involved in EP?

YUAN: EP has attracted the attention of many scientists in this field worldwide. So far there is collaboration with University of Leicester, UK on the development of MPO related technology, etc. which has good expertise in this field. The French space agency is also interested in getting involved via providing us with its VHF network, which is used to downlink fast alert telemetry data in real time once X-ray transient events are detected by the instrument on the fly. More international collaboration may also be possible as the project moves ahead.