X-ray Polarimetry Mission PRAXyS

Toru Tamagawa,[1]
on behalf of the PRAXyS team

[1] RIKEN Nishina Center, 2-1 Hirosawa, Wako, Saitama 351-0198, Japan
E-mail(TT): tamagawa@riken.jp

Abstract

PRAXyS is a recently proposed NASA's small explorer mission which aims to open a new window in astrophysics, X-ray polarimetry. In this paper, we are presenting the importance of X-ray polarimetry, the PRAXyS mission, and performance of flight instrumentation on board PRAXyS.

Key words: X-ray polarimetry — PRAXyS — Time projection chamber

1. Introduction

X-ray photons carry four physical quantities: position (imaging), timing (light curve), energy (spectroscopy), and polarization. X-ray astrophysics has grown by mainly using the former three quantities, but not polarization. Although several polarimetry missions were performed, polarization was positively detected from only one bright and highly polarized source, Crab Nebula, with the OSO-8 satellite (Weisskopf et al. 1976).

Owing to recent technological developments, a highly sensitive X-ray polarimeter was realized (Costa et al. 2001). Combining with high throughput X-ray mirrors, such X-ray polarimeters allow us to observe faint (∼mCrab) sources with good polarization sensitivity (∼1%) within a realistic observation time (0.1–1 Msec). The sensitive X-ray polarimetry telescope is a powerful tool to explore the space-time structure and spin of black holes (Schnittman et al. 2013), vacuum birefringence in the atmosphere of highly magnetized neutron stars (Ghosh et al. 2013), emission mechanism of AGN jets (Krawczynski et al. 2013) etc.

Polarimeter for Relativistic Astrophysical X-ray Sources (PRAXyS) led by NASA's Goddard Space Flight Center is the highly sensitive X-ray polarimetry satellite, recently proposed as a NASA's small explorer mission (Jahoda et al. 2016). NASA selected the PRAXyS project for the Phase A study in July, 2015, together with another polarimetry mission Imaging X-ray Polarimetry Explorer (IXPE) led by NASA's Marshall Space Flight Center (Weisskopf et al. 2016).

2. PRAXyS mission

Figure 1 shows a schematic view of the PRAXyS satellite. There are two identical X-ray mirrors on top of the optical bench, and two identical X-ray polarimeters at those foci. The optical boom will be deployed in space just after the launch. The satellite will rotate around the optical axis at the rate of 10 rpm for canceling systematic uncertainties of the telescopes.

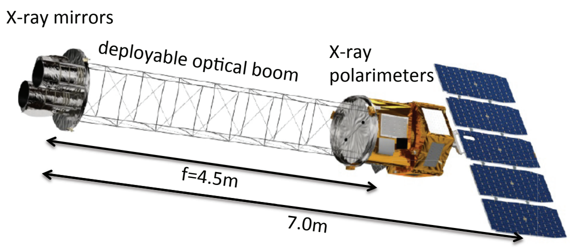

Fig. 1. A schematic view of the PRAXyS satellite. The satellite carries two identical X-ray polarimetry telescopes.

PRAXyS will observe about 30 stellar objects in categories of massive and stellar mass black holes, neutron stars, pulsar wind nebulae, and supernova remnants in the first 9 months after launch with a minimum detectable polarization of down to 1% for a 2 mCrab source with 3.4×10^6 s observation in the 2–10 keV energy band. Japanese contribution to the PRAXyS mission was approved as a JAXA's small project (MoO) in 2016, and NASA's final decision will be made in February 2017 for a launch in 2020.

3. Polarimeter performance

A conceptual design of the X-ray polarimeter on board PRAXyS is described in figure 2. An incident X-ray reacts with a target molecule in the gas cell filled with 190 Torr dimethyl ether (DME). The differential cross-

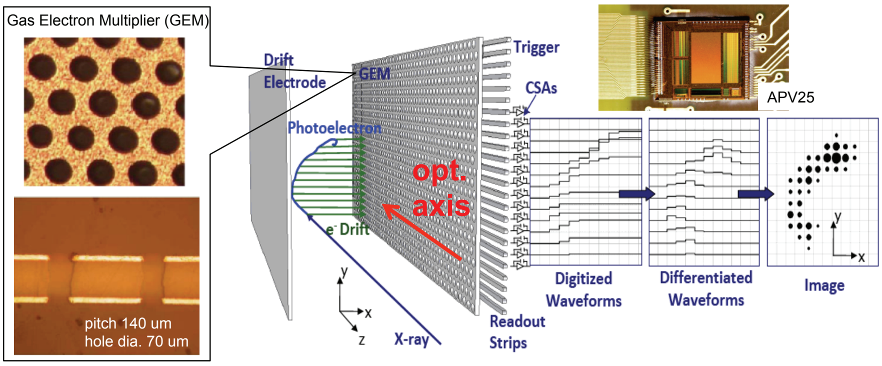

Fig. 2. A conceptual drawing of the X-ray polarimeter on board PRAXyS. The time projection chamber technique is employed for imaging photoelectron tracks. The electron cloud produced along the photoelectron will be amplified with gas electron multiplier foil (Tamagawa et al. 2009) and fed into the APV25 digitizing ASIC.

section of photoelectron emission is

$$d\sigma = r_0^2 \alpha^4 Z^5 \left(\frac{mc^2}{h\nu}\right)^{\frac{7}{2}} \frac{4\sqrt{2}\sin^2\theta\cos^2\phi}{(1-\beta\cos\theta)^4} d\Omega, \quad (1)$$

where ϕ is the azimuth angle of photoelectron with respect to the X-ray polarization vector, θ is the polar angle between the incident photon and emitted photoelectron (Heitler 1970). Obviously known from the equation 1, photoelectrons tend to be emitted to the direction of X-ray polarization vector.

To maximise the sensitivity, we have employed a time projection chamber technique to image the photoelectron tracks (Fig. 2). In this configuration, longer active volume along the optical axis can be realized, increasing quantum efficiency easily even with a gas detector. We have efficiencies of 0.55 and 0.10 at 3 and 8 keV, respectively, with a 31 cm-long active volume for PRAXyS. The "modulation factor" of the TPC polarimeter is μ=0.52 at 6 keV. Systematic uncertainty is less than 1%. The polarimeter performance derived from NSLS experiments was summarized in Iwakiri et al. (2016).

The minimum detectable polarization of a polarimeter (99% C.L.) is described as

$$P_{mdp} = \frac{4.29}{\mu\sqrt{R_s T}}\sqrt{1+\frac{R_b}{R_s}}, \quad (2)$$

where R_s and R_b are the source and background count rates, respectively, and T is the observation time. Combining with the mirror effective area, we estimated P_{mpd} for PRAXyS as shown in figure 3. Beside Crab Nebula we expect positive detections from many astrophysical sources of several categories at polarization degrees down to about 1% level.

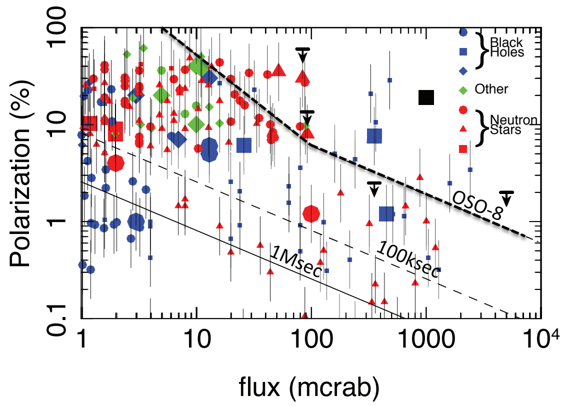

Fig. 3. Minimum detectable polarization P_{mdp} of PRAXyS for 100 ks and 1 Ms observations. Theoretically expected polarization degrees from several categories of stellar objects are superposed in the figure.

After the conference, the result of NASA's downselection was announced. PRAXyS was not selected, but IXPE was selected. A new field will be pioneered soon.

References

Black, J. K. et al. 2007, NIMA, 581, 755
Costa, E. et al. 2001, Nature, 411, 662
Krawczynski, H. et al. 2013, arXiv:1303.7158
Ghosh, P. et al. 2013, arXiv:1301.5514
Heitler, W. 1970, The Quantum Theory of Radiation, Oxford University Press.
Iwakiri, W. B. et al. 2016, NIMA, 838, 89
Jahoda, K. et al. 2016, Proc. SPIE, 9905, 990516
Schnittman, J. et al. 2013, arXiv:1301.1957
Tamagawa, T. et al. 2009, NIMA, 608, 390
Weisskopf, M. et al. 1976, ApJL, 208, 125
Weisskopf, M. et al. 2016, Proc. SPIE, 9905, 990517