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Optical polarization observations with the MASTER robotic net

M.V. Pruzhinskaya [a,b,*], V.V. Krushinsky [c], G.V. Lipunova [a], E.S. Gorbovskoy [a], P.V. Balanutsa [a], A.S. Kuznetsov [a], D.V. Denisenko [a], V.G. Kornilov [a], N.V. Tyurina [a], V.M. Lipunov [a], A.G. Tlatov [d], A.V. Parkhomenko [d], N.M. Budnev [e], S.A. Yazev [e], K.I. Ivanov [e], O.A. Gress [e], V.V. Yurkov [f], A.V. Gabovich [f], Yu.P. Sergienko [f], E.V. Sinyakov [f]

[a] Lomonosov Moscow State University, Sternberg Astronomical Institute, Universitetsky pr., 13, Moscow 119991, Russia
[b] Faculty of Physics, Lomonosov Moscow State University, Moscow, Russia
[c] President Yeltsin Ural Federal University, Ekaterinburg, Russia
[d] Mountain Astronomical Station, Main (Pulkovo) Astronomical Observatory, Russian Academy of Sciences, St. Petersburg, Russia
[e] Irkutsk State University, Irkutsk, Russia
[f] Blagoveshchensk State Pedagogical University, Blagoveshchensk, Russia

HIGHLIGHTS

- For GRB100906A, GRB110422A, GRB121011A the dimensionless Stokes parameter is obtained.
- The polarization of SN 2012bh at the early stage of the envelope expansion was <3%.
- Polarization measurements for the blazars OC 457, 3C 454.3 are presented.
- Polarization degree for the blazars QSOB1215+303, 87GB 165943.2+395846 are presented.
- MASTER telescopes can safely register linear polarization in excess of 10%.

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ABSTRACT

We present results of optical polarization observations performed with the MASTER robotic net (Lipunov et al., 2004, 2010; Kornilov et al., 2012) for three types of objects: gamma-ray bursts, supernovae, and blazars. For the Swift gamma-ray bursts GRB100906A, GRB110422A, GRB121011A, polarization observations were obtained during very early stages of optical emission. For GRB100906A it was the first prompt optical polarization observation in the world. Photometry in polarizers is presented for Type Ia Supernova 2012bh during 20 days, starting on March 27, 2012. We find that the linear polarization of SN 2012bh at the early stage of the envelope expansion was less than 3%. Polarization measurements for the blazars OC 457, 3C 454.3, QSO B1215+303, 87GB 165943.2+395846 at single nights are presented. We infer the degree of the linear polarization and polarization angle. The blazars OC 457 and 3C 454.3 were observed during their periods of activity. The results show that MASTER is able to measure substantially polarized light; at the same time it is not suitable for determining weak polarization (less than 5%) of dim objects (fainter than 16^m). Polarimetric observations of the optical emission from gamma-ray bursts and supernovae are necessary to investigate the nature of these transient objects.

1. Introduction

Polarimetry plays an important role in modern astrophysics. Polarization measurements provide information about the nature of radiation sources, geometrical properties of the emitting regions, the spatial distribution of matter around sources, magnetic fields.

In the last two decades, the polarimetry, especially spectropolarimetry, has advanced a lot. Different polarization techniques and devices have been developed. Fast CCD cameras and new polarizing materials made polarimetric observations possible for

* Corresponding author at: Lomonosov Moscow State University, Sternberg Astronomical Institute, Universitetsky pr., 13, Moscow 119991, Russia.

E-mail addresses: pruzhinskaya@gmail.com (M.V. Pruzhinskaya), krussh@gmail.com (V.V. Krushinsky), galja@sai.msu.ru (G.V. Lipunova), gorbovskoy@gmail.com (E.S. Gorbovskoy), bala55@mail.ru (P.V. Balanutsa), ingell@bk.ru (A.S. Kuznetsov), d.v.denisenko@gmail.com (D.V. Denisenko), victor.kornilov@gmail.com (V.G. Kornilov), tiurina@sai.msu.ru (N.V. Tyurina), lipunov2007@gmail.com (V.M. Lipunov), tlatov@mail.ru (A.G. Tlatov), gas-ran@mail.ru (A.V. Parkhomenko), nbudnev@api.isu.ru (N.M. Budnev), uustar@star.isu.ru (S.A. Yazev), ivorypalace@gmail.com (K.I. Ivanov), grol08@rambler.ru (O.A. Gress), stella@ascnet.ru (V.V. Yurkov), stella@ascnet.ru (A.V. Gabovich), sergienkoyp@mail.ru (Yu.P. Sergienko), marginalis44@yandex.ru (E.V. Sinyakov).

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a rising number of optical telescopes. In particular, polarization measurements are important for short-living or fast variable objects such as gamma-ray bursts (GRBs) and supernovae.

The first polarization measurements of GRBs afterglow were realized by large telescopes: the 8.2-m Unit Telescopes of VLT (Covino et al., 1999; Rol et al., 2000; Covino et al., 2002), the 10-m Keck I telescope (Barth et al., 2003), the 6.5-m Multiple Mirror Telescope (Bersier et al., 2003). It's remarkable that the first detections of the early optical polarization were performed by a robotic telescope: the 2-m robotic Liverpool telescope (Mundell et al., 2003; Steele et al., 2009). There are also several telescopes with average-size aperture that measure GRBs polarization: the 2.56-m Nordic Optical Telescope (Rol et al., 2003; Greiner et al., 2003), the 2.2-m telescope of Calar Alto Observatory (Greiner et al., 2003), the Kanata 1.5-m telescope at Higashi-Hiroshima Observatory (Uehara et al., 2012), and the 1-m USNO telescope in Flagstaff (Greiner et al., 2003).

The early attempts to measure polarization of Type Ia supernovae were made by using the 2.6-m Shain reflector built for the Crimean Astrophysical Observatory (Shakhovskoi, 1976). The first spectropolarimetric data were obtained on the 3.9-m Anglo-Australian Telescope (McCall et al., 1984). The program of polarimetric observations of SN Ia was begun on the 2.1-m Struve Telescope at McDonald Observatory (Wang et al., 1996; Howell et al., 2001). This program was continued on the 8.2-m unit telescopes of the VLT (Wang et al., 2007). Spectropolarimetry is also carried out on the Keck I 10-m telescope (Chornock et al., 2006).

The first MASTER telescope was mounted in 2002 near Moscow. The MASTER net began operating in full mode in 2010 (Lipunov et al., 2004; Lipunov et al., 2010; Kornilov et al., 2012; Gorbovskoy et al., 2013). More than 100 alert pointings at GRBs were made by MASTER. The MASTER net holds the first place in the world in terms of the total number of first pointings, and currently more than a half of first pointings at GRBs by ground telescopes are made by the MASTER net. More than 400 optical transients have been discovered, among them cataclysmic variables, supernovae, blazars, potentially hazardous asteroids, transients of unknown nature. Photometry of 387 supernovae has been carried out. Polarization measurements is one of the purposes for us to design and construct the MASTER II robotic telescopes. The linear polarization measurements with the MASTER net involve simultaneous observations of an object by several telescopes equipped with cross linear polarizers. Since each telescope of the net has two wide-FOV astronomical tubes, we have to point at least two telescopes[1] to an object simultaneously in order to determine its Stokes parameters.

The unique design of MASTER II makes it the only wide-FOV fully robotic instrument in the world able to measure polarization. In this work we report the results of the examination of its accuracy and analyze its capability to measure polarization of different types of astrophysical objects: gamma-ray bursts, supernova, blazars.

2. MASTER instruments and reduction of observations

Each MASTER II telescope contains a two-tube aperture system with a total field of view of 8 square degrees, equipped with a 4000 pixel $\times$ 4000 pixel CCD camera with a scale of $1.85''$/pixel, an identical photometer with B, V, R, and I filters representing the Johnson–Cousins system, and polarizing filters. Both optical tubes are installed on a high-speed mount with position feedback, which does not require additional guide instruments for exposures not exceeding three to ten minutes. The setup has an additional degree of freedom: the variable angle between the optical axes of the two tubes. This allows us to double the field of view during survey observations if the tubes are deflected from each other, or to conduct synchronous multi-color photometry with parallel tubes. A single telescope of the MASTER II net provides a survey speed of 128 square degrees per hour with a limiting magnitude of 20^m on dark moonless nights.

Astrometric and photometric calibration is made by a common method for all MASTER observatories (Gorbovskoy et al., 2013; Kornilov et al., 2012). Bias and dark subtraction, flat field correction, and astrometry processing are made automatically. Bias and dark images obtained before the beginning of observations and the closest in time flat field images, obtained on the twilight sky, are used. To convert magnitudes into absolute fluxes, zero points of the MASTER bands should be used. They can be found at http://master.sai.msu.ru/calibration/.

The first MASTER polarizers were high contrast Linear Polarizing Films combined with usual glass (in January–July 2011 they were combined with R filter instead). Since July 2011 all polarizers have been replaced by new broadband polarizers manufactured using linear conducting nanostructure technology (Kornilov et al., 2012; Ahn et al., 2005). Magnitudes obtained from broadband photometry correspond to $0.2B + 0.8R$ where B, R are the standard Johnson filters (Gorbovskoy et al., 2013). Each tube is equipped with one polarizer, the polarization directions of two tubes in a single assembly being perpendicular to one another. Polarizers' axes are set in two ways with respect to celestial sphere: in the MASTER Kislovodsk and the MASTER Tunka sites, the axes are directed at positional angle 0° and 90° to the celestial equator (polarizers oriented at 45° and 135° were added in Kislovodsk in April 2012), in the MASTER Blagoveshchensk and the MASTER Ural, at angles 45° and 135°. Thereby, using several MASTER telescopes one can realize observations with different orientation of the polarizers. Such a construction is very effective for fast events with significant intrinsic polarization. These events are mostly of extragalactic origin. In spite of the fact that all MASTER telescopes have a similar construction, optical scheme, and polarizers, there are some uncertainties in the channels responses. These limit the precision of polarization measurements. Also, the calibration using known polarized galactic sources is not possible, as any measurement of polarization involves subtraction of nearby field stars between at least three images, obtained with tubes with differently oriented polarizers. Thus the derived polarization of a target object is always relative to the nearby field stars. They are usually chosen from the area around the target source in a radius of $10'$ and bound to have the same polarization due to the similar interstellar matter properties toward them. The original stellar radiation is not polarized, polarization appears when light passes through the interstellar dust. Interstellar polarization can reach high values and strongly depends on the galactic direction and wavelength (Voshchinnikov, 2012).

The goals of the MASTER polarimetric analysis, when observing highly-polarized extragalactic events, are: to (1) find polarization of an event in excess of the average polarization of galactic stars in that direction, (2) remove additional systematic polarization introduced by the instruments, (3) estimate the uncertainty of polarimetric measurements by MASTER.

Stars with zero polarization are required for the channel calibration. We assume the polarization of light from stars in the field of view is small. This can be checked using Serkowski law (Serkowski et al., 1975). The difference in magnitudes between two polarizers orientations averaged for all reference stars gives the correction that takes into account different channel responses.

3. GRB polarization observations

Gamma-ray bursts are the most powerful explosions in the Universe. Unfortunately, the physics of the process is not fully

[1] The photometer in Kislovodsk contains 4 differently oriented polarizers, which allows us to measure linear polarization at this site alone.