MAGIC: a focal reducer for the study of active galactic nuclei

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1. Intro

MAGIC — is a focal reducer for small optical telescopes, developed under the direction of V.L. Afanasiev for galaxy observations under the MAGIC (Monitoring of Active Galaxies by Investigation of their Cores) project. The MAGIC instrument is a multi-mode instrument, which makes it extremely effective on the telescope, allowing it to respond flexibly to changing weather conditions. Indeed, a conventional polarimeter is unable to make spectral observations when the weather deteriorates, and its efficiency is reduced to zero. At the same time, several observation modes are realized in MAGIC: direct images, polarimetry and long-slit spectroscopy, which technically allows solving different observation tasks according to the current weather conditions.
MAGIC is installed in the focus of the Cassegrain 1-meter telescope Zeiss-1000, is designed for an input focal ratio of F/12.5 and, due to the collimator and camera, increases it to F/6.1, which in turn solves the problem of oversampling for typical modern CCDs in the focus of Cassegrain telescopes and gives an advantage for observations of faint extended objects. On the other hand, since the collimator forms a parallel beam, there is an optimal opportunity to use dispersing elements as well as polarization analyzers. See details in the main article [1].

2. Scheme

In the MAGIC scheme (Fig. 1), the light from the telescope passes through the filter turrets (1) и (2). Each wheel has 9 positions for mounting filters with a diameter of no more than 50 mm and a thickness of no more than 5 mm.

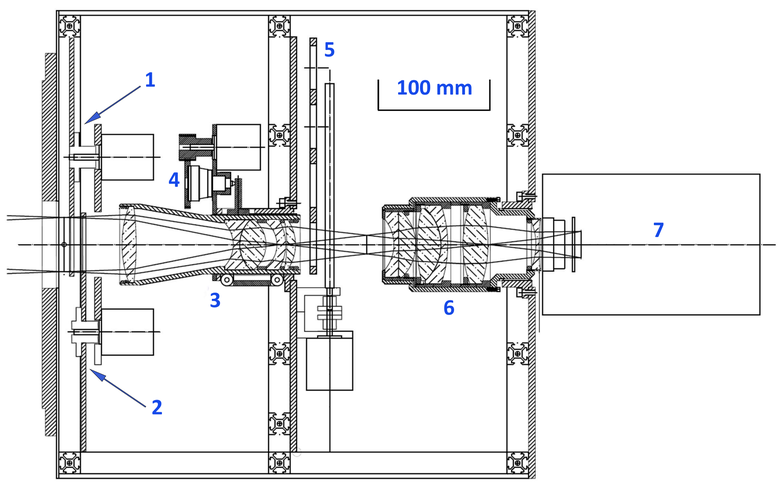

Figure 1: MAGIC device scheme

The zero position in each turret — is always empty, and with the constant presence of the slit, mask, and dot test, we have 13 positions for installing the necessary replacement filters.
Next comes the collimator (3) with the focusing mechanism (4). At the heart of the MAGIC is the mode switching carriage (5) with VPHG grating and Wollaston prism. The switching time between carriage positions is 1 min. After the mode switching carriage, the light is delivered through the camera (6) to the CCD detector (7).

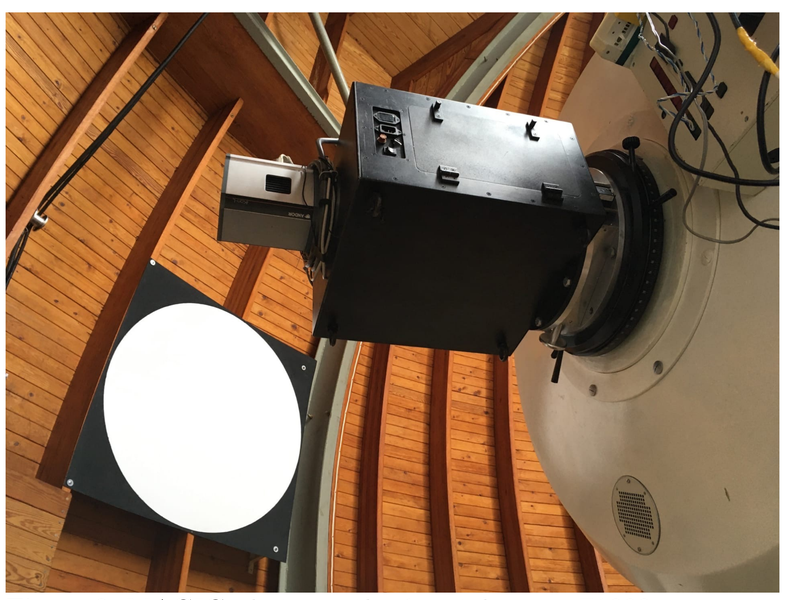

Figure 2: MAGIC photo on the 1-m telescope Z1000.

3. Observational Modes

Photometry

The photometric mode of observations on the MAGIC instrument allows obtaining direct images using different light filters, which are introduced into the beam by means of two turrets. The size of the FoV field of view is limited by the size of the filter and is $\sim 12'$. Note that, as in the other observing modes, in the photometry mode we use a CCD readout mode of 1×1, which gives an image scale of $0''.45$/px and satisfies the Kotelnikov-Nyquist theorem. The instrument uses narrow- and medium-band interference SED filters, as well as broadband BVRI light filters of the Johnson-Cousins [2] system.

Stokes polarimetry

In the MAGIC instrument, the polarization analyzer is installed in a parallel beam. The instrument design allows the use of any type of polarization analyzer – both classical dichroic polaroid and birefringent prisms. At present, we use a double Wollaston prism for polarimetry of weak AGN. The advantage of this analyzer is the possibility to apply the method called in the literature one-shot polarimetry, when several images of the field in several angles of the electric vector oscillation, sufficient for the calculation of Stokes parameters, are simultaneously registered at the receiver. This method minimizes the influence of atmospheric depolarization [3].

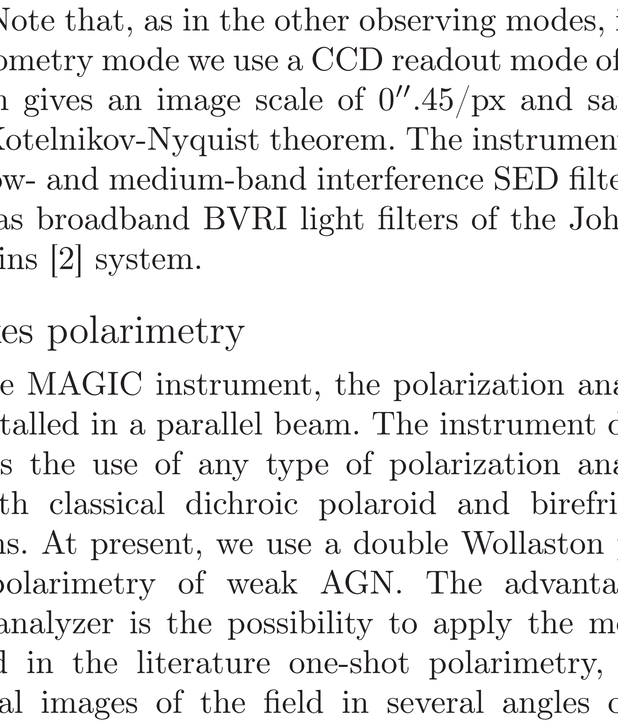

Figure 3: Observations of M1 in four polarization directions (each FoV = $6'.4$) using a quadrupole Wollaston prism in a SED600 filter ($t_{\rm exp}$ = 300 s).

MAGIC device summary table:

MAGIC main parameters	
Input focal ratio of focal reducer	$F/12.5$
Total focal ratio at the Zeiss-1000	$F/6.1$
QE (optics + telescope + CCD)	∼50%
Image quality (FWHM)	$0''.3$
Spectral range	340-990 nm
Weight	23 kg
Dimensions	430 × 440 × 265 mm
CCD system	Andor iKonL-936
CCD	E2V CCD42-40 (BEX2-DD)
Format	2048 × 2048 pix
Pixel size	13.5 × 13.5 μm
2*QE	400-850 nm: >90%
	340-980 nm: >40%
Readnoise (min)	2.2 e^-
Photometry	
FoV	$12'$
Image scale (binning 1 × 1)	$0''.45$/pix
Limiting mag (V, 20 min, seeing ∼ $1''.1$)	$22^{\rm m}.5$
Stokes polarimetry	
FoV	$6'.4 \times 6'.4$
Image scale (binning 1 × 1)	$0''.45$/pix
Accuracy (14 mag, 20 min, seeing ∼ $1''$)	0.6%
Long slit spectroscopy	
Spectral range	400-720 nm
Spectral resolution	$R \sim 1000$
Slit size	$1''.7 \times 12'$
Monochromatic slit image (FWHM)	3.5 pix
Reciprocal dispersion	0.2 nm/pix

Spectroscopy

The spectral mode in MAGIC is realized by introducing a VPHG600@500 — volume phase holographic grism (600 strokes/mm, 500 nm – central wavelength) into the collimated beam, as well as a slit into the converging beam in front of the collimator, which occupies a position in the turret. The efficiency of the instrument in spectral mode with this grating (telescope + optics + grating + CCD) does not exceed 18%.
Note that the slit height of $12'$ allows us to efficiently carry out spectroscopic observations of strongly extended objects, such as comets.

4. Current Status

Scientific Observations

All modes of the MAGIC instrument have been tested during observations as part of official programs. We began with photometry under the program "Determination of BLR Sizes in Distant AGN"(PI: R. Uklein, completed). An advanced version of echo-mapping was conducted using a Wollaston double prism in the program "Echo-Mapping of AGN in Polarized Light"(PI: E. Shablovinskaya, completed).
Long-slit spectroscopy includes a multi-year monitoring list from the program "Spectral Monitoring of Peculiar AGN"(PI: D. Ilic, ongoing), and "Spectrophotometry of Giant HII Regions in Galaxies"(PI: A. Burenkov, completed).
Polarimetry with the double Wollaston prism is conducted under the program "Polarization of Blazars"(PI: V. Amirkhanyan, ongoing). It should be noted that two Wollaston prisms are installed in the mode carriage. One of them, with strong beam separation, is described in the MAGIC article [1], and the other with weaker separation is described in the Stokes Polarimeter article [4]. The Wollaston prism with strong separation leads to a more complex accounting of instrumental polarization.

Perspectives

The instrumentation part of the MAGIC project isn't finished yet, as the final phase of creating a user-friendly offset guiding software interface is underway, and the assembly phase of calibration module and the interferometer operation module ("MaNGaL" mode) is in progress.

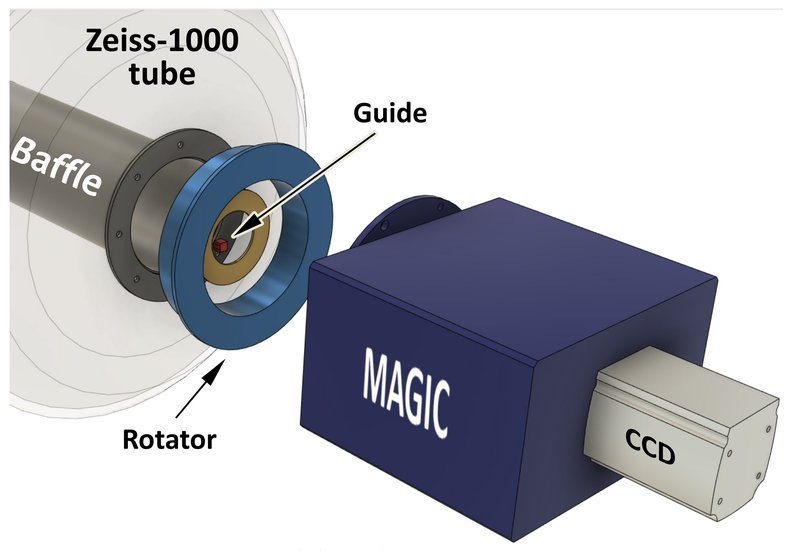

Figure 4: Rotator and Offset Guide

In the summer of 2024, we faced some problems with the Andor iKon-L 936 receiver, and we are forced to switch to CCD with a similar frame characteristics. The summary table of the MAGIC parameters will be updated after the research. The process of adapting the software for the another receiver (Raptor Eagle V) is underway.
We plan to continue working to bring the project to full operational status with all modules.

5. Outro

In 2020, the MAGIC multi-mode focal reducer for the 1-meter Zeiss-1000 telescope of the SAO RAS was designed, manufactured and put into operation. The ability to observe and quickly switch between observing modes allows for flexible response to changing weather conditions during the night, as well as multifaceted study of astrophysical objects, especially AGNs.

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[4] V. L. Afanasiev, E. S. Shablovinskaya, R. I. Uklein, and E. A. Malygin. Stokes-Polarimeter for 1-m Telescope. Astrophysical Bulletin, 76(1):102–108, January 2021.