

Description of RoBoTT Image Files

Julia Blex (julia.blex@rub.de) — March 31, 2026

The Robotic Bochum Twin Telescope (RoBoTT) was in operation from December 2008 to September 2019. Most projects were continuous observations of particular fields to record light curves covering an extended period. The GAVO image services provide the reduced images (see Sec. 2). In addition, links to all used raw frames (see Sec. 1) for each reduced image are given.

1 Raw Frames

Remarks on particular header keys:

NAXIS2, ZNAXIS1, ZNAXIS2: Dimensions of the raw frame, either 4096 or 4098 pixels.

TARGET: Target name given in the observational proposal.

TELESCOP: Telescope VYSOS6, VYSOS6_a, or VYSOS6_b (see Sec. 3.1).

FILTER: Abbreviation of the filter, see Tab. 1 for the corresponding wavelength.

OBJCTAZ, OBJCTALT: Centre coordinates of the telescope's pointing position during the observation, which may differ considerably from the planned coordinates.

1.1 Calibration Frames

Dark, bias, and flat field observation series each consist of 5 frames and are scheduled at the start and end of each night's observation window.

Bias Frames

File naming convention: YYYYMMDD_NNNNNN_BIAS{,_V6a,_V6b}.fit.fz

Bias frames should be taken with an exposure time of 0 s. Bad images (with exposure times $t_{\text{exp}} > 0$ s or a median count of all pixels $N_{\text{med}} > 1500$) are removed from the linked bias files, including the first bias frame taken each night since April 2012, as these frames are suspected to be corrupted.

Dark Frames

File naming convention: YYYYMMDD_NNNNNN_DARK{,_V6a,_V6b}.fit.fz

Dark frames were observed with different exposure times. Given the linear correlation between dark current and exposure time, the dark current for any exposure time can be extrapolated and separate dark frames for each exposure time of the light frames are not necessary (see Fig. 2.3 and Sec. 2.1.3 in Watermann 2012, only available in German).

Although dark frames have been taken, they are currently not used for the dark current corrections. Dark current is taken into account for the correction of the light frames by subtracting a fixed base value that depends on the date and the telescope, scaled by the exposure time, from each pixel of the image. Therefore, dark frames are not included in the lists of calibration files used for reduced images, but they can be provided on request.

Flat Field Frames

File naming convention: YYYYMMDD_NNNNNN_FLAT{,_V6a,_V6b}.fit.fz

The observed flat fields are sky flats; observation series in 2 filters per telescope, with exposure times depending on the filter combination, can be scheduled at dusk and dawn, respectively.

1.2 Light Frames

File naming convention YYYYMMDD_NNNNNN_LIGHT{,-V6a,-V6b}.fit.fz

An observation series consists of dithered images with an exposure time of each image of up to 10 minutes (limited by the mount's tracking accuracy since no guiding camera is used) that are combined into reduced images. There may be a noticeable overhead between exposures within an observation series, for example, the overhead between exposures in the 9×10 s observation series taken with the r_s and i_s filters of Galactic Disk survey (GDS, described in Sec. 2.1) fields is on the order of a minute.

The headers of the raw files remain unchanged from their original state as recorded during the observation, including rare cases where the field name in an image's header does not match the image coordinates.

2 Reduced Images

File naming convention: YYYYMMDD.comb_avg.NNNN.fits.fz

The raw data are reduced using the Bochum OCA VYSOS Interactive Pipeline (BOVIP). In short, the reduction process includes the following steps: Nightly and monthly master bias and master flat files are created. A dark current (see Sec. 1.1) is subtracted from light frames and bias and flat field corrections (using the nightly master files where available and the monthly master files otherwise) are applied to the frames. A catalogue of star positions is derived using SourceExtractor and then matched with UCAC4 as a reference catalogue using SCAMP. The light frames are corrected for astrometric distortion and resampled onto a common coordinate grid with SWarp, usually to a spatial resolution of $0.8''/\text{pixel}$, except for fields targeting active galactic nuclei that are resampled to $0.75''/\text{pixel}$, which is beneficial for aperture photometry. Individual frames are combined with the IRAF task imcombine. The data reduction pipeline is comprehensively described in Haas et al. (2012).

Remarks on particular header keys:

NAXIS2, ZNAXIS1, ZNAXIS2: Dimensions of the reduced image, either 10 800 or 11 520 pixels for an image with a resolution of $0.8''/\text{pixel}$ or $0.75''/\text{pixel}$.

TARGET: Field defined for the image reduction, which is not necessarily identical to the target name used for light frames (see Sec. 2.3).

TELESCOP: Telescope VYSOS6, VYSOS6_a, or VYSOS6_b (see Sec. 3.1).

FILTER: Abbreviation of the filter, see Tab. 1 for the corresponding wavelength.

OBJCTAZ, OBJCTALT: Centre coordinates of the field listed as TARGET. These coordinates do not require to match the planned coordinates (see Sec. 2.3) or the pointing positions during the observation of the individual frames. In case of pointing errors the image dimension is not reduced, but a section of the reduced image is left empty.

EXPTIME: Exposure time, in seconds, for each individual light frame in the observation series.

NCOMBINE: Number of light frames from the observation series used to produce the reduced image.

The headers of the reduced FITS files contain the necessary keys for World Coordinate System (WCS) transformations, enabling straightforward assignment of coordinates to the pixel values with `astropy`. A brief example using a reduced image of field GDS_1749-3339:

```
from astropy.io import fits
from astropy.wcs import WCS
import matplotlib as mpl
import matplotlib.pyplot as plt
import numpy as np

hdul = fits.open("20180812.comb_avg.0001.fits.fz")
header = hdul[1].header
data = hdul[1].data
```

```
w = WCS(header)
ny, nx = data.shape
y, x = np.mgrid[0:ny, 0:nx]
ra, dec = w.all_pix2world(x, y, 0)
```

Empty pixels due to pointing errors are set to 0 in the uncompressed images, but the pixel values slightly deviate from the original values after the fpack compression.

```
data[data < 1.0] = np.nan # make empty pixels transparent
pixel_min = np.nanmin(data)
pixel_max = np.nanmax(data)
data = (data - pixel_min) / (pixel_max - pixel_min) # normalisation
```

Because of the varying number of empty border pixels across images, it is convenient to use cut-outs. A recommended size is $10\,000 \times 10\,000$ pixels for images with a resolution of $0.8''/\text{pixel}$, as used in the GDS (see Sec. 2.1) to create light curves of a field.

```
cut_size = 10000
c0, c1 = nx // 2 - cut_size // 2, nx // 2 + cut_size // 2
cutout_data = data[c0:c1, c0:c1]
cutout_ra = ra[c0:c1, c0:c1]
cutout_dec = dec[c0:c1, c0:c1]

fig = plt.figure()
ax = fig.add_subplot(111, projection=w)
im = ax.imshow(cutout_data, cmap='gray', norm=plt.colors.LogNorm())
ax.set_xlabel("RA")
ax.set_ylabel("Dec")
plt.savefig("GDS_1749-3339_i_s_20180812.pdf", transparent=True)
```

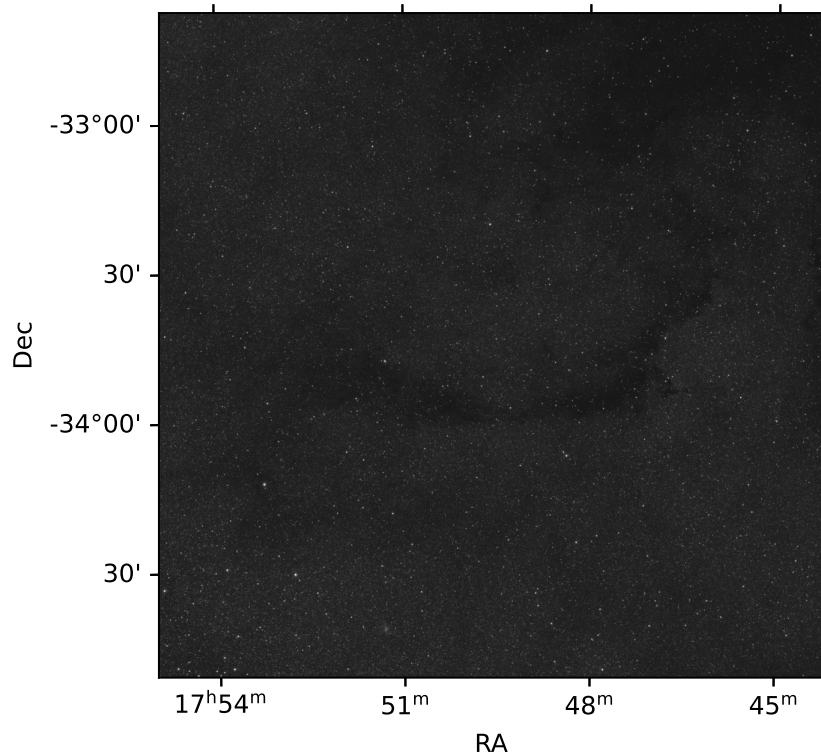


Figure 1: $10\,000 \times 10\,000$ pixel cut-out of field GDS_1749-3339 in *i*-s on 12 August 2018

Occasionally, artifacts are visible in the reduced images. The linked raw images can be used to check whether the artifacts were introduced by the reduction, or if there is possibly a physical cause. If you need enhanced reduced images or reduced images for specific uses (resampling at a different resolution, combined images from fewer light frames) of particular fields, please contact me directly.

2.1 GDS Fields

Field names: GDS_HHMM+DDMM

GAVO services: Bochum Galactic Disk Survey (BGDS) images, Bochum Galactic Disk Survey (BGDS) DR2 light curves, BGDS DR2 Median Photometry Cone Search, BGDS DR2 Matched Photometry Cone Search

The GDS monitored a mosaic of 268 fields along a 6° -wide stripe in the southern Galactic disk in *r_s* and *i_s*. Additionally, several observations in *U_j*, *B_j*, *V_j*, and *z_s* per field were made. A list of all GDS fields is given in Tab. A1 of Hackstein et al. (2015).

2.2 SA Fields

Field names: SA_NNN

GAVO service: Bochum Galactic Disk Survey (BGDS) images

Observations of Landolt’s standard star (SA) fields are used to calibrate the light curves and median photometry of the GDS and other RoBoTT fields, and may also be treated like any other field for deriving light curves and median photometry of the sources within.

Currently, a linear relationship between the calibration constant and time is usually assumed in the standard star analysis. In reality, the relation is not strictly linear, for example, counts per second may rise abruptly after lens cleaning.

2.3 RoBoTT Fields

Field names: RoBoTT_{0.75,0.80}px_HHMM+DDMM

GAVO service: Robotic Bochum Twin Telescope (RoBoTT) images

Apart from the GDS and SA fields, all other proposals are grouped under RoBoTT fields. Most of these observations were single-pointing rather than mosaics, mainly targeting active galactic nuclei and Milky Way stars. The proposals followed different target naming conventions and partly, identical coordinate fields were given different target names, and fields with negligibly deviating coordinates (differing by less than caused by the dithering) were observed. Therefore, RoBoTT fields cover observations with one or more target names (to be found at the TARGET key in the light frames’ headers).

3 Technical Specifications of RoBoTT

Telescopes: $2\times$ Takahashi TOA-150 OTA (15 cm aperture, $2^\circ 42' \times 2^\circ 42'$ FoV, focal length of 82.5 cm using a focal reducer as detailed in Sec. 2.1.1 of Watermann 2012)

Cameras: $2\times$ Apogee Alta U16M with a KAF-16801 CCD (CCD size of 38.86×38.86 mm, image dimensions of 4096×4096 pixel, pixel size of $9 \mu\text{m}$, spatial resolution of $2.37''/\text{pixel}$, the quantum efficiency as a function of wavelength can be found in Fig. 5 of the CCD’s data sheet)

Mount: Bisque Paramount ME (German equatorial mount)

Observational site: Rolf Chini Cerro Murphy Observatory (OCM), formerly Cerro Armazones Observatory (OCA), in the Chilean Atacama Desert

3.1 Extension to a Double Refractor

RoBoTT started as a single telescope named Vysos 6 (V6) with the broadband filters B, V, R, I and the narrowband filters OIII, H α , SII in 2008. For the extension, an additional telescope and CCD identical to the original were acquired and both telescopes were installed on the mount that had already been used for the single telescope, whereby the original telescope Vysos 6a (V6a) was equipped with the new CCD and the new telescope Vysos 6b (V6b) with the old CCD previously used by V6a. The original filters were split between both telescopes, and the filters were complemented by an U broadband filter, a further narrowband filter (NB), and additional filters similar to the Sloan Digital Sky Survey (SDSS)

filters (see Tab. 1). For distinction from the SDSS filters, the filters U, B, V, R, and I (similar to those of the Johnson system) were renamed to U_j, B_j, V_j, R_j, and I_j (see the FILTER key in the headers of light frames and reduced images). Simultaneous observations in two filters started on 24 November 2010.

Table 1: RoBoTT filters. Centre wavelengths and FWHM values are adopted from Ramolla et al. (2016).

Filter	FITS Header abbreviation	Telescope	Centre wavelength (nm)	FWHM (nm)
Johnson U	U _j	V6a	365	52
Johnson B	B _j	V6b	445	101
Johnson V	V _j	V6a	550	82
Johnson R	R _j	V6a	641	158
Johnson I	I _j	V6b	798	154
SDSS u'	u _s	V6b	355	60
SDSS g'	g _s	V6a	483	99
SDSS r'	r _s	V6b	626	138
SDSS i'	i _s	V6a	767	154
SDSS z'	z _s	V6b	910	137
Astrodon OIII	OIII	V6b	500.7	6.0
Astrodon NB	NB	V6b	645.0	6.0
Astrodon Halpha	Halpha	V6a	656.3	6.0
Astrodon SII	SII	V6a	672.1	6.0