Two-channel, robotic CCD-Camera

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ABSTRACT

We present the design of a compact two-channel CCD-camera for the 0.8 m Cassegrain telescope operated at the Wendelstein Observatory. To achieve a high efficiency this camera is equipped with two channels, operating in the wavelength range of 400 – 540 nm and 570 – 900 nm, respectively. Each channel is provided with a filter slider for three positions, an independent photometric shutter, and a 2k × 2k CCD (80% peak efficiency). The camera can simultaneously record a red and a blue image of its $10.7' \times 10.7'$ field of view. In addition it has an offset guider and supports robotic operation: Active cooling provides the operating temperature of 160 K avoiding the use of liquid nitrogen. Both CCDs share a single cryostat and can be aligned during operation. The complete vacuum control including pumping and cryopump cleaning can be operated remotely.

Keywords: optical CCD-camera, two-channel CCD-camera, robotic CCD-camera

1. INTRODUCTION

Tests of the seeing conditions at Mt. Wendelstein displayed a seeing statistics mode of $0.5''$ FWHM. The 0.8 m telescope (f/12.4) of the Wendelstein observatory is designed to reach an encircled energy distribution of 80% within a $0.6''$ diameter over a 100 mm diameter field of view (FOV). The CCD-camera employed at present does not comply with those site and telescope characteristics: Its 1k × 1k CCD with 24 μm × 24 μm pixels yields an $8.5' \times 8.5'$ FOV with a 2 pixels / $''$ scale leading to undersampling even for average observing conditions. We therefore decided to build a new camera which can take full advantage of the current situation, and, at the time, will enable robotics operation.

2. OPTICAL LAYOUT

2.1. Design Goals

To specify the design goals for the camera we defined a three-level scheme of favored characteristics, basic conditions, and acceptable trade-offs.

2.1.1. Favored characteristics

The pixel scale of the instrument must be adapted to the optical performance of the telescope and the seeing of the site, which requests at least 2 pixels / $0.6''$. If feasible the FOV should be larger than the present one. Using high efficient CCDs and building a multi-channel camera, which also allows simultaneous multi-waveband observations, increases the telescope efficiency tremendously. A photometric shutter enables short exposures without introducing systematic errors (shutter pattern). Therefore it allows a superb twilight flatfield acquisition for every night.

To minimize the need for on-site manpower by including robotic operation and maintenance features will help to guarantee a future for the observatory.

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2.1.2. Basic design constraints

All basic conditions can be summarized in the need for a compact design: The optics must fit between the focal plane and the telescope flange, which are only 267 mm apart from each other. A massive electro-magnetic shielding for all electronics is mandatory not only because of frequent lightning but moreover to minimize the influence of the intense radio immission of a nearby radio station. The complete instrument (including controllers and EM-shielding) must not exceed a weight of 100 kg. It must apply to the telescope's Cassegrain focus and therefore fit in a volume less then 0.5 m^3.

2.1.3. Acceptable trade-offs

Concessions may be made regarding the filter wave bands: Despite its excellent seeing conditions the observatory site displays only modest transparency and suffers from light pollution of nearby villages. The Hg lines of the street lighting add to the O[I] night-sky line in the V band. The already poor performance of atmospheric cut-off UV band filters, which is mainly due to air pollution, is also hampered by the street lighting, i.e. its UV lines. So the use of both, U and V band filters, should be avoided.

2.2. Design Solution

Because of the compactness constraints we decided to go for a two-channel design. The heart of our design solution is a massive dichroitic beam splitter cube with two reflection prisms attached so that both beams have their focus in the same image plane (Fig. 1). This enables us to place both CCD detectors into a single cryostat with one Cryotiger cooling unit, only. We defined the dichroitic layer to build two optical channels operating in the spectral range of 400 – 540 nm and 570 – 900 nm. The camera has three interchangeable filters per channel and two independent photometric shutters. It is equipped with two LORAL/Lesser 2k × 2k CCDs with 80% peak quantum efficiency, each displaying the same FOV of $10.7' \times 10.7'$ with a resolution of $0.3''$ / pixel.

2.3. Resulting Optical Parameters

The massive design of the dichroitic beam splitter and the reflection prisms elongates the focus distance by 53 mm which gives additional room for the filter and shutter modules. But it also introduces a chromatic error. The thickness of each filter has to be adjusted to compensate for the wavelength dependency of the focus length. Because of the slow f-ratio (f/12.4) of the telescope the intra wave band error of a single filter is rather small. A filter covering the whole blue channel (400 – 540 nm), which is the worst case, results in a image degradation as quantified in Tab. 1. Unlike a design using beam splitter plates no offcenter ghosts, astigmatism, or coma* are inferred.

Table 1. Worst case image quality as derived by raytracing simulation. Radius of 50% and 75% encircled energy are given: A broad blue filter suffers most from the chromatic error introduced by the beam splitter / reflection prism unit. Center = on optic axis, edge = 15 mm ($\hat{=} 5'$) off optic axis and corner = 21 mm ($\hat{=} 7'$) off optic axis. Airy radius (i.e. physical limit of telescope, best case) is 7 μm for a wavelength of $\lambda = 449$ nm. The CCD pixel size is 15 μm × 15 μm ($\approx 0.3'' \times 0.3''$). The focus is adjusted to minimize the influence of the image plane concavity.

	% encircled energy	
CCD	$\geq 50\,\%$	$\geq 75\,\%$
center	$< 2\,\mu\text{m} \hat{=} 0.04''$	$< 7\,\mu\text{m} \hat{=} 0.14''$
edge	$< 5\,\mu\text{m} \hat{=} 0.10''$	$< 10\,\mu\text{m} \hat{=} 0.20''$
corner	$< 8\,\mu\text{m} \hat{=} 0.16''$	$< 10\,\mu\text{m} \hat{=} 0.20''$

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[*] The astigmatism resulting from a beam splitter plate can be corrected with an additional plate rotated by 45° along the optical axis but with the same inclination angle as the beam splitter plate, but will show coma shaped distortions.[1, 2]

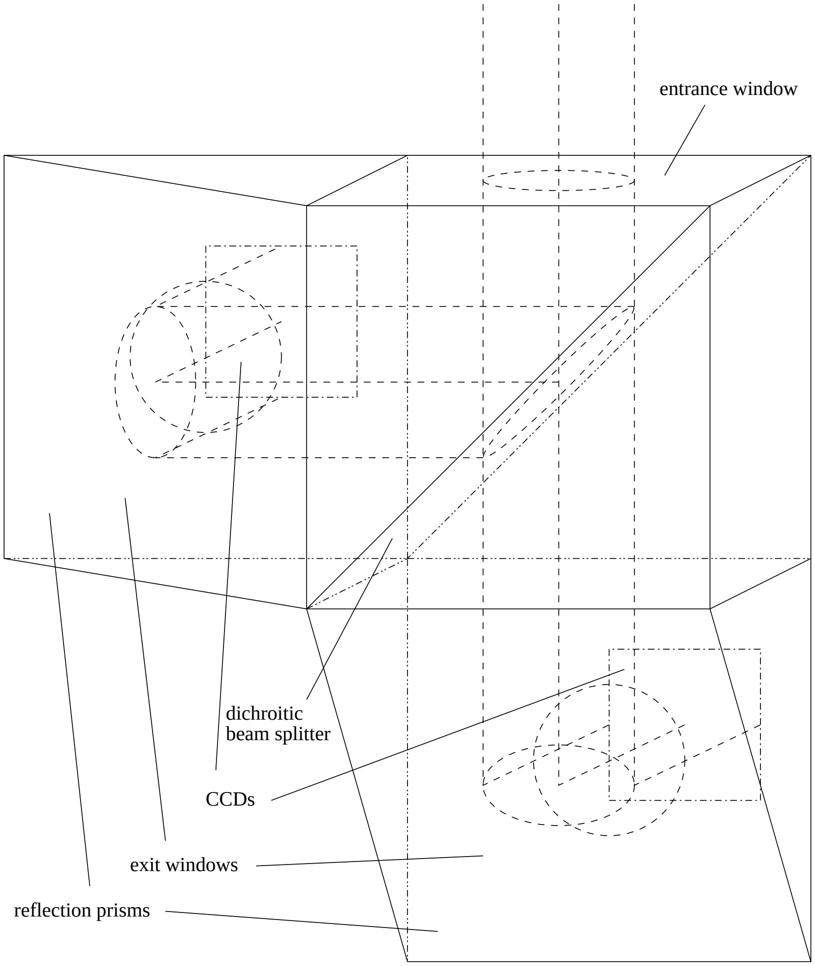

Figure 1. Design sketch [2:3] of the dichroitic beam splitter. Light falling in from "above" is split within the 80 mm × 80 mm × 80 mm beam splitter cube in a reflected, left side, blue beam and a transmitted, downwards, red beam. Both beams are reflected by adjacent reflections prisms and leave the unit "backwards" to fall on their corresponding 30 mm × 30 mm CCDs resting in the same image plane after a 60 mm gap which holds filters, shutters and cryostat windows. The 160 mm massive glass results in having a wavelength dependent focus length. This can be compensated by filters of an individually matched thickness, which are inserted between the beamsplitter and the CCDs.

3. MECHANICAL DESIGN

The optically active parts of the camera are combined to four major units: the cryostat, a filter / shutter unit, the dichroitic beam splitter unit and the offset guiding unit. All units together with controllers and computers are mounted on a basement plate, which is suited to be attached to the telescope flange.

3.1. Cryostat

The cryostat holds two CCDs placed on two independent, three-axis motorized chip mounts: six Newfocus Picomotors enable two-axis tilt plus an independent focus adjustment for each CCD. Together with the six axis alignment of the beam splitter unit (Sect. 3.3) we have 12 axis alignment for two detectors, so every detector can be aligned independently. Active cooling by a Cryotiger cooling device provides the operating temperature of 160 K. A turbomolecular vacuum pump is permanently attached to the cryostat via an electromagnetic vacuum valve. The vacuum is hold between the pumping cycles by a cryopump which has onboard heating resistors to allow cleaning cycles without requiring any additional equipment. Both, active cooling and permanent vacuum control together enable robotic maintenance.

3.2. Filter / Shutter Unit

The complete filter / shutter module is only 40 mm thick and can easily be mounted / dismounted without interfering with any of the other units. In this way the instrument needs no optical readjustment in case filters need to be replaced. The unit holds two three-position motorized filter sliders, which are specified to reproduce their position with below μm accuracy. Each of the two shutters has two motorized linear blades to have equivalent opening and closing movements. We expect to achieve full field photometric exposures at a 0.1% systematic error level for exposure times as short as 0.1 s.

3.3. Dichroitic Beam Splitter Unit

The beam splitter cube / reflection prism module is housed within a six-axis alignment module. Position and position angle have to be manually adjusted once by tuning micrometer screws. The rotational axes cross in one point centered within the beam splitter cube to make the optical adjustment easier. The rotational mount resides within the Cartesian translational mount which again is oriented along the major axes of telescope and instrument. In this way complex differential effects when adjusting the optics are avoided.

3.4. Offset Guiding unit

The offset guide field is deflected by a mirror mounted on the beam splitter unit. The guiding camera rests on a motorized two-axis translation module which enables offset focus adjustment and a one-axis guiding field selection.

4. ELECTRONIC DESIGN

4.1. CCD-Controller

We use a copy of the latest CCD-controller developed at the MPIA Heidelberg.[3]

4.2. Motor-Controllers

Stepper motors and limit switches for filter slider, shutter blades, and guiding camera movement are controlled by a CyberPak module. The Picomotors are controlled by a separate device driver. The vacuum and cooling devices already provide their own controlling systems. All those systems have serial interfaces which are connected to the camera network (Sect. 4.4).

4.3. Offset Guiding Camera

We use a ST7 CCD camera of SBIG controlled by a small Linux PC as guiding camera. This solution has been well tried and tested with the current camera system.

4.4. Network

All Controllers have either Ethernet interfaces, or serial interfaces which are mapped to Ethernet interfaces. The Ethernet interfaces are combined in a switch which has a fiber link connection to the main camera controlling computer. This Linux PC, which also is connected to the telescope controlling system, holds the main storage device and can be remote controlled via Internet. (See also Fig. 4.)

4.5. Electro-Magnetic Shielding

To protect the electronics of the camera against frequent lightning and the high radio immission of a nearby radio station it has a massive EM-radiation shielding. The shielding is made of 0.7 mm thick copper plate sheet and conductively connected to the mirror cell. Therefore this Faraday cage has only one major opening for the infalling light beam. Several minor openings are for wiring and a venting system, which is needed to avoid an heating of the mirror cell by the camera electrics. An uninterruptible power supply (UPS) and the fiber link connection (Sect. 4.4) provide additional safety.

APPENDIX A. DESIGN SKETCHES

A.1. Filter / Shutter Module

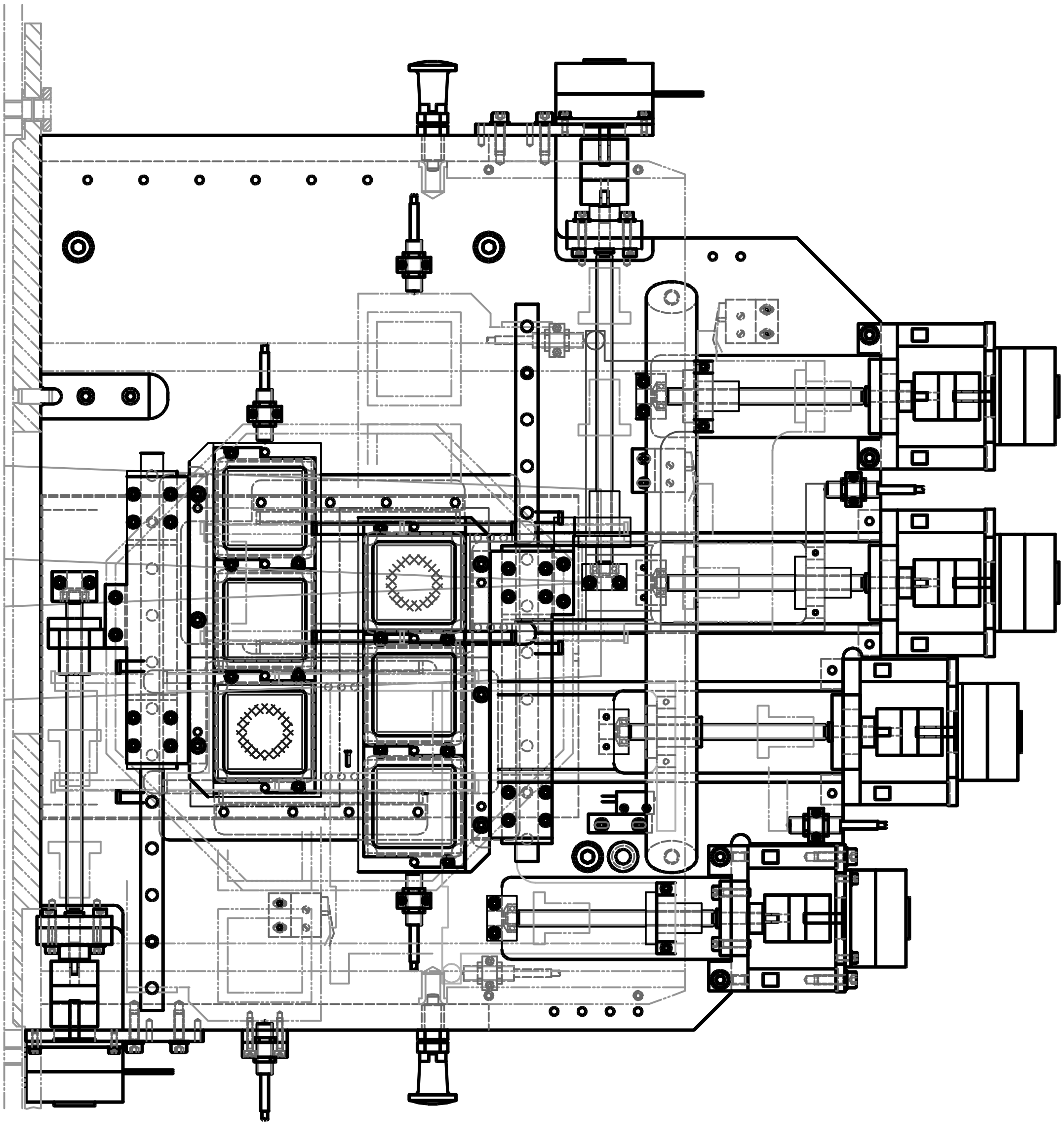

Figure 2. Filter / shutter module [1:4]: The design draw shows a front view of the shutter (background) and filter slider module detailing also the motors and limit switches. The telescope flange side is left on this view.

A.2. Overview

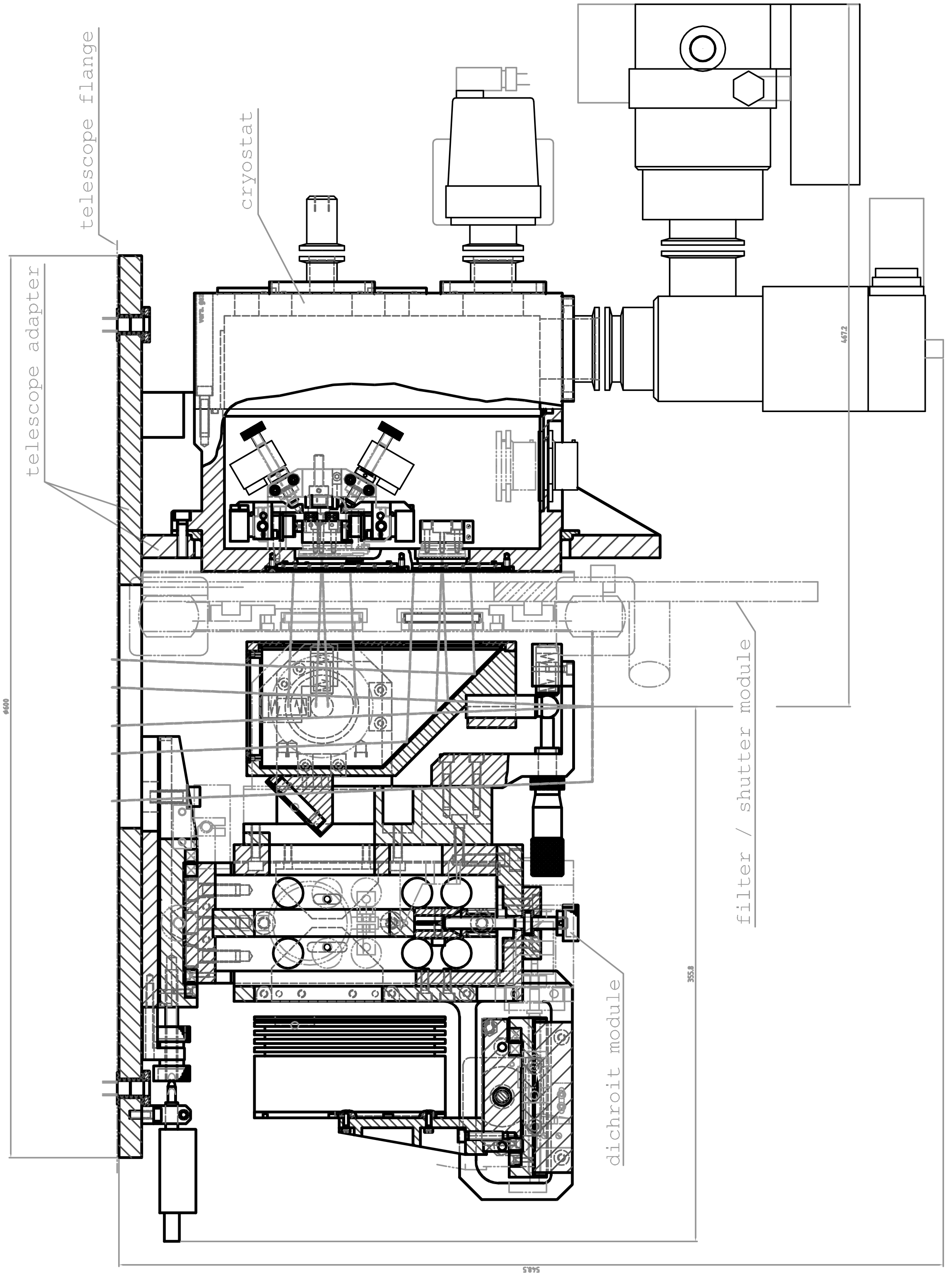

Figure 3. Camera overview [1:4]: The Beam from the telescope enters left and is split and reflected upwards in the dichroit module, then passing through the filter / shutter module and finally focusing in the cryostat module.

APPENDIX B. CAMERA CONTROL FLOWCHART

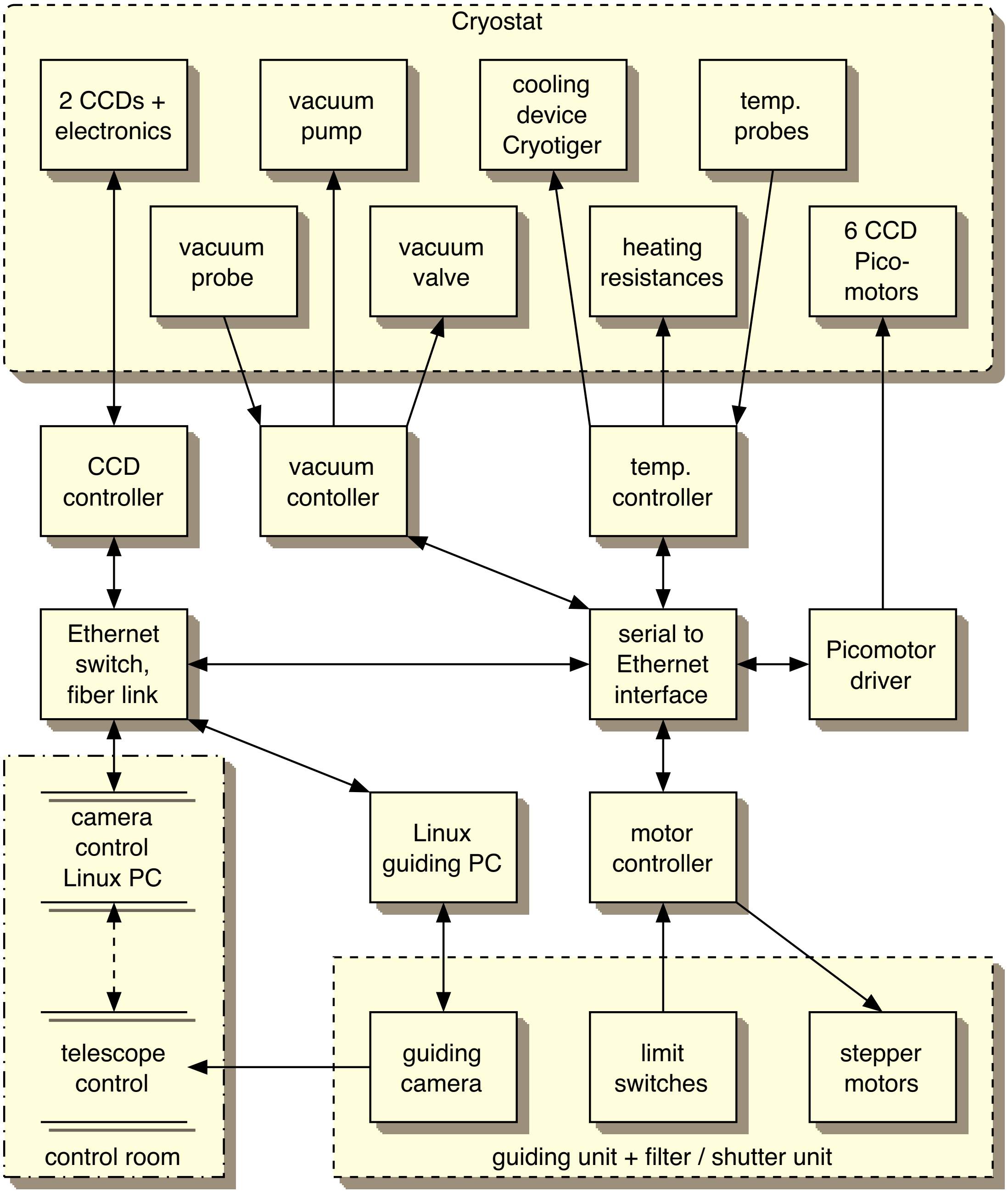

Figure 4. Except for the control room box, all components are mounted at the telescope and reside within the EM-shielding. The components are connected to the camera control by a fiber wire link. The camera control, which also holds the main storage unit, can be accessed via Internet.

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