# MAGIC: A New Near Infrared Camera for Calar Alto

T. M. Herbst, S. V. W. Beckwith, Ch. Birk, S. Hippler, M. J. McCaughrean, F. Mannucci, and J. Wolf,
Max–Planck–Institut für Astronomie, Königstuhl 17, 69117 Heidelberg, Germany.

## Introduction

This paper describes the basic design, operation, and initial performance of MAGIC, the new **M**PI für **A**stronomie **G**eneral–purpose **I**nfrared **C**amera. MAGIC uses a 256x256 NICMOS3 HgCdTe detector array and has flexible optics and drive electronics that permit a variety of observing configurations. The camera was designed and built to MPIA specifications by Infrared Laboratories of Tucson, Arizona. MAGIC is based at the 3.5 meter telescope on Calar Alto, although it may be used at a number of other sites, including the 2.2 and 1.2 meter telescopes on Calar Alto and the 2.2 meter MPIA / ESO telescope at La Silla.

The design of MAGIC places particular emphasis on wide field, deep imaging at the f/10 focus of the 3.5 m telescope and on providing some spectroscopic and speckle interferometric capability. The following paragraphs describe how the optical, mechanical, and electronic design of MAGIC addressed these goals.

## Optical Design

Figure 1 shows the optical layout of the camera. Light from the telescope secondary mirror passes through the $CaF_2$ entrance window and comes to a focus on a cold aperture mask within the cryostat. A ZnS–Silica–ZnS triplet lens collimates the radiation, which then passes through two filter wheels, each holding up to 8 filters (see Table 1). A second ZnS–Silica–ZnS triplet images the focal plane onto the infrared detector. All the optics are anti–reflection coated for operation between 1 and 2.5 µm. The collimator lens forms an image of the secondary mirror between the two filter wheels. A third wheel at this location contains a cold Lyot stop to reduce unwanted background radiation. This stop includes a central obscuration and spider vanes to block thermal emission from the telescope structure. Light baffles throughout the optical path also help to eliminate stray radiation.

The optical configuration of MAGIC is flexible. There are two separate collimator lens assemblies for wide field and high angular resolution imaging, respectively. In addition, the Lyot stop wheel contains apertures matched to several telescopes, including both the f/10 and f/45 configurations of the 3.5 meter on Calar Alto. Although switching collimators requires opening the cryostat, the observer can switch focal ratios at this facility in approximately 20 minutes. The combination of interchangeable camera and telescope optics provides four different image scales suitable for a variety of scientific programs (see Table 2).

Figure 1: MAGIC Optical and Mechanical Layout

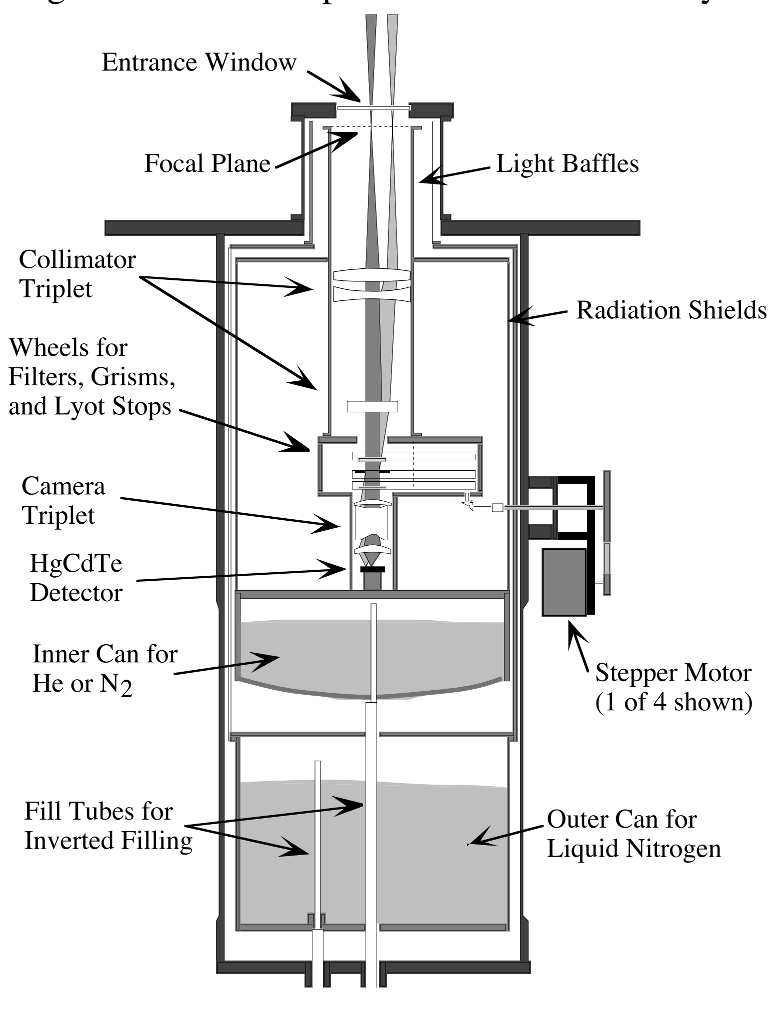


Table 1

| Filter/Grism | Wavelength | |
|---|---|---|
| J | 1.11 – 1.39 μm | |
| H | 1.50 – 1.80 | |
| K | 2.00 – 2.40 | |
| $K_S$ | 2.00 – 2.32 | |
| $K_{Mauna\ Kea}$ | 1.95 – 2.30 | |
| He I | 1.083 | 1 % |
| Pa γ | 1.094 | 1% |
| OII | 1.237 | 1% |
| Pa β | 1.282 | 1% |
| Fe II | 1.644 | 1 % |
| $H_2$ 1–0 S(1) | 2.122 | 1% |
| Br γ | 2.166 | 1% |
| K Cont | 2.26 | 3% |
| $H_2$ 2–1 S(1) | 2.248 | 1% |
| CO Band | 2.295 | 1% |
| Grism 1 | K, J band | 0.3% |
| Grism 2 | H band | 0.3% |

Long slit spectroscopy is possible using either of two grisms mounted in the Lyot stop wheel. The grisms are directly ruled gratings on a prism of ZnSe. In combination with the appropriate broad band blocking filter, the grisms provide complete J, H, or K band coverage at a spectral resolution $\lambda/\Delta\lambda \sim 400$. The grisms work with the high angular resolution (0.33"/pixel) image scales, providing a slit 84 arcseconds long at the 3.5 meter telescope. The focal plane wheel contains slits 2 and 4 pixels wide, as well as a coronagraphic mask for imaging near bright objects. Since both the focal plane and Lyot stop wheels are motorized, observers can switch rapidly (<30 seconds) between direct imaging, coronagraphic, and spectroscopic mode.

With the wide field optics at the f/10 focus of the 3.5 meter telescope, MAGIC has a large (210"x210") unvignetted field of view and a high étendue (A–Ω product). This configuration is well suited to deep imaging and surveys of large regions. Preliminary tests (see below) indicate excellent image quality from the center to the corners of the field. The image scale is identical across the entire operating wavelength range (1–2.5 μm) to within a fraction of a pixel per frame. This consistency of image quality and pixel scale greatly facilitates surveys, which depend on a uniform point spread function throughout the field.

Table 2 – Image Scales

| Pixel Scale with | Wide Field | High Res. Optics |
|---|---|---|
| f/10 Secondary | 0.81 arcsec/pixel | 0.33 |
| f/45 Secondary | 0.18 | 0.073 |

**Mechanical Design**

MAGIC's cryostat is an Infrared Laboratories dual tank HD–10 which can operate either up or down–looking. The detector array and optics are at liquid nitrogen temperature, although the double tank permits future use of liquid helium. The cryostat can be refilled on the telescope. Additional benefits of the dual tank design include temperature stability without active control and a long hold time (outer can > 30 hours, inner can and detector many days). No mylar "superinsulation" is required.

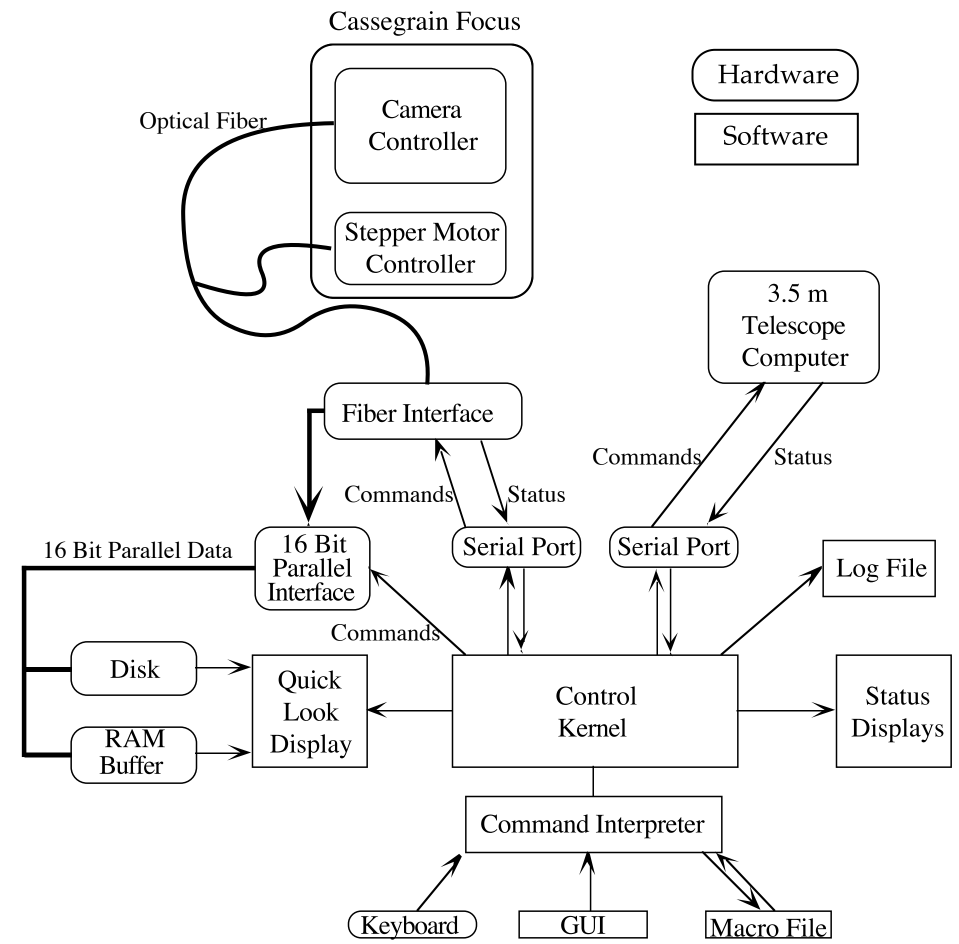
Changing optics, masks, and filters requires minimal disassembly of the cryostat. For example, the collimator lens assemblies can be exchanged in less than 30 minutes without disturbing the other components of the camera, and access ports on the filter wheel enclosure permit filter exchanges without removing the wheels.

**Electronics and Software**

Figure 2 is a schematic drawing of the drive electronics and control system. Intelligent controllers for the detector readout and stepper motors are mounted on the telescope next to the cryostat. A single optical fiber cable connects these devices to the interface in the warm room. The observer issues commands and views incoming images at the control computer, a Sun Microsystems workstation. The fiber optic cable is the only connection between the back of the telescope and the observer's area.

A typical integration proceeds as follows: The operator selects observing parameters and initiates the exposure from the keyboard, the graphical user interface, or a pre–recorded macro file. A command interpreter parses the input and passes legitimate instructions to the control kernel, which also receives information from the camera and telescope and prevents conflicts between the various hardware and software units.

Figure 2 : MAGIC Electronics and Software Overview




The control kernel passes the user commands to the camera and stepper motor controllers via the fiber optic cable. Both controllers are independent, releasing the Sun computer for other tasks while motor moves or integrations are underway. At the end of the exposure, the camera controller transmits the image data down the same optical fiber to the control room. The fiber interface extracts the pixel values and passes them to a 16 bit parallel controller card mounted in the Sun workstation. This card writes the data to a block of shared memory without CPU intervention (Direct Memory Access) and signals the control computer when valid image data are present. Archiving to disk takes place either automatically or under observer control. This arrangement allows very high data rates without difficulties arising from the multitasking nature of the Unix operating system. We have demonstrated data rates in excess of twenty full frames per second. With a large block of shared memory, the camera system can sustain this rate for 20 to 30 seconds, a time span well suited to speckle interferometry. Sub–frame readouts allow much longer sequences for occultations.

As a general purpose facility instrument, MAGIC must be readily accessible to observers with a variety of backgrounds. The control software presents a simple visual interface and minimal online reduction facilities. A second workstation in the control room can mount and access the data disk. This permits the observer to take data and reduce it nearly simultaneously using the analysis software with which he or she is most comfortable. This configuration also facilitates “offline” tape backup of recent measurements.

**Performance**

Table 3 lists the important performance characteristics of MAGIC. Unless otherwise noted, these figures come from measurements made at the 3.5 m telescope under observing conditions. The dark current value was measured without a special detector covering, and therefore includes thermal emission and light leaks within the cryostat.

Our observations in February 1993 demonstrate good optical performance. The image quality appears excellent out to the corners of the field, even in the wide field configuration. The measured point spread function is seeing limited to < 0.5 arcseconds. Ghosting can be a problem with this type of optical design, since the detector array reflects a fraction of the incoming radiation. Reflected starlight is collimated by the camera optics, then bounces off a filter and is reimaged onto the detector. We have eliminated ghosts in the broad band filters by tilting them approximately 7°. The narrow band filters cannot be tilted without severely affecting their response, and some ghosting occurs with these filters.

The camera is quite rigid: there is no evidence of flexure or focus shifts at different points on the sky. The electronics and software also performed well during the commissioning run. Creating camera and telescope control macros is straightforward, enabling an observing efficiency in excess of 90%.

At the time of this writing, we have had the camera in the lab for less than a month, so we anticipate improvements in performance as we optimize operating conditions and readout modes.

Table 3 – MAGIC Performance

| | | |
|---|---|---|
| Bad Pixel Fraction | 650 / 65536 less than 1% | |
| Read Noise | 35 $e^-$ single read | |
| | 14 $e^-$ multiple end–point sampling (100 reads) | |
| Dark Current * | < 0.3 $e^-$ / sec @ 77 K | |
| Nonlinearity | < 4 % at 90 % full wells | |
| Limiting Magnitude† | J | 22.5 |
| | H | 21.4 |
| | K′ | 20.8 |
| Throughput†† | J | 15 % |
| | H | 26 % |
| | K′ | 32 % |
| Maximum Frame Rate | 20 / sec | |
| Image Quality | Seeing limited to < 0.5″ | |

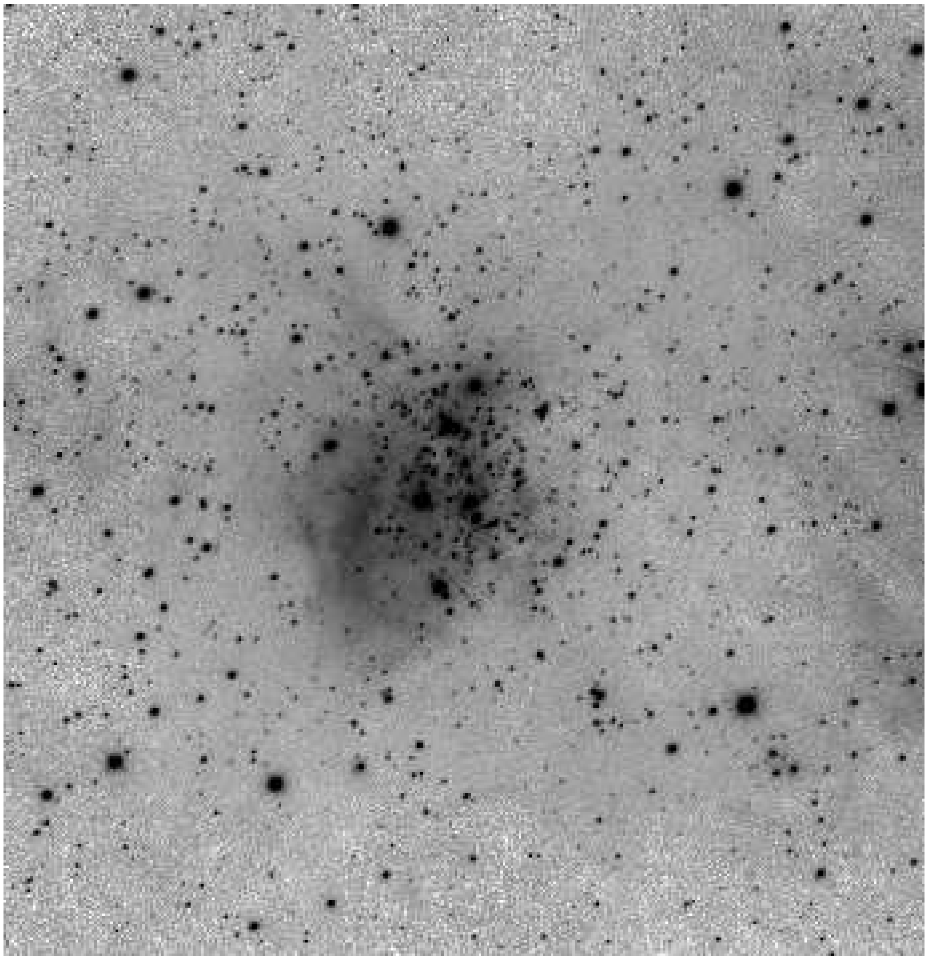
* Lab measurement. Includes thermal emission and light leaks.
† Point Source S/N of 5 in 1 hour with 1 arcsec seeing.
†† Includes atmosphere, telescope, optics, and detector.

**Sample Image**

Figure 3 shows a K´ band (2.1 µm) image of the embedded cluster S252C. We took this 9.7x9.7 arcminute mosaic during the February, 1993 commissioning run on the Calar Alto 3.5 meter telescope. The image scale is 0.81 arcseconds per pixel and the integration time was one minute for each of the nine frames. The faintest objects visible have K´~17.

Lower mass and deeply embedded stars appear in this K´ band image while hot OB stars dominate the view at J (1.25 µm) and H (1.65 µm). S252C is a radio knot in the S252 HII region (Felli *et al.* 1977, Astron. Astrophys. **59**, 43.). At visible wavelengths, S252C shows considerable nebulosity and a few stars. Low resolution infrared scanning of the region revealed thirteen stellar objects (Chavarría *et al.* 1989, Astron. Astrophys. **215**, 51). Several hundred appear in our new infrared image. These data will form part of an ongoing comparative study of the ages and mass functions of several embedded clusters in this region.

Figure 3 – K′ Band Image of Sharpless 252C



**Conclusions**

MAGIC went from conception to commissioning in less than one year. Laboratory and telescope measurements indicate that the camera has met or exceeded all of its design specifications. MAGIC should add valuable infrared capabilities to Calar Alto.

The authors wish to acknowledge the contributions of the MPIA workshop and support personnel, as well as the help provided by the Calar Alto staff. We are also grateful for the heroic efforts of Infrared Laboratories in producing the camera on time and within budget.