# A Multi-Instrument Focal Station for a 2m-Class Robotic Telescope

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## ABSTRACT

The design of a multi-instrument Nasmyth port for a 2m class telescope, located near Munich, Germany is presented in this paper. A three channel optical and infrared camera will be located at this Nasmyth focus together with an IFU spectrograph, a high resolution Echelle spectrograph, and a Shack-Hartmann sensor for instrument alignment. Fast switching between the instruments and compact design in a small dome are boundary conditions of the project.

Precise guiding and acquisition is made possible for all instruments. Calibration sources are fed to the fiber coupled instruments using a built in telescope simulator.

**Keywords:** Multi channel camera, imaging, integral field unit (IFU), fiber coupling, spectrograph, Fraunhofer Telescope Wendelstein

## 1. INTRODUCTION

Small and medium size telescopes still contribute to a majority of the scientific publications in the field of astronomy and astrophysics. Furthermore large benefits in educating young scientists can be received using these telescopes, especially if they belong to an university institute and offer direct access for PhD and other education projects.

The FRAUNHOFER TELESCOPE WENDELSTEIN is a telescope project of Munich University Observatory that is currently being built at 1838 m heigh Mt. Wendelstein in the German Alps having its first light planned for late 2010.

### 1.1 The Telescope

The telescope is designed as a modern 2m aperture Richey-Chretian type telescope using an Alt-Az mount. Kayser-Threde GmbH, Munich is contracted as manufacturer for the telescope. As shown by Hopp et. al.[1] (figure 1-right) the seeing at Mt. Wendelstein is exceptionally good, showing a median of ≈ 0.7" and reaching ≈ 0.4" in a significant number of nights. The telescope is therefor optimized to making use of these good environmental conditions. (For a more detailed description of the telescope and site conditions see Hopp et. al.[1].)

The good seeing and the limited space available on the top of Mt. Wendelstein leads to the boundary conditions that are applied when optimizing the telescopes parameters. This process led to the RC design with a primary f-ratio of 2.0, an ≈65 cm diameter secondary and an overall f-ratio of 7.8.

The telescope has two Nasmyth focal stations. Both of these ports have a derotator. While one is equipped with a 0.7° field of view optical and near infrared imager the second port is equipped with a number of imaging, spectroscopic and calibration purpose devices. This paper is concentrating on this second port.

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## 1.2 The Multi-Instrument Nasmyth Port

Having no field correction lens system Nasmyth port number two offers a field of view of 0.2° diameter. The image scale of this port is 74 $\mu$m per arc-second. The image quality delivered by the telescope mirrors is 80% encircled energy within 0.4" within 0.14° field diameter.

This focal station delivers light to a number of instruments.

**3KK** A three channel visible and infrared camera. There is the option to operate only the infrared part and decouple the visual channels from the path of light.

**FOCES** A visual and near infrared Echelle spectrograph. (For a description of the instrument see Pfeiffer et. al. [2].)

**Virus-W** A 267 channel visual integral field spectrograph. (For a description of the instrument see Fabricius et. al. [3].)

**SHS** A Shack-Hartmann sensor used for telescope alignment and seeing tests.

Basic data of the scientific instruments are given in table 1.

Table 1. Basic data of the scientific instruments at Nasmyth port number two.

| Instrument | Image sampling/ Resolving power | Wavelength range | FOV | Detector |
|---|---|---|---|---|
| 3KK | 2 x VIS: 0.4" per 2 pixels<br>1 x IR: 0.5" per 2 pixels | 340 - 970 nm<br>970 nm - 2.3 $\mu$m | 0.14°<br>0.20° | 2x2K 15 $\mu$m CCD<br>2x2K 18 $\mu$m Hawaii detector |
| FOCES | R≈70000 | 380 - 900 nm | 1.35" | 2x2K 13.5 $\mu$m CCD |
| VIRUS-W | R≈2500<br>R≈6800 | 475 - 560 nm<br>493 - 544 nm | 150"x76" | 2x4K 15 $\mu$m CCD |

## 1.3 Scientific Goals

Covering imaging capabilities in a wavelength range from the near UV at 340 nm to around the edge of the thermal infrared region at 2.3 microns and various spectroscopic resolving powers and wave-bands all three instruments offer a wide variety of scientific usability.

Regarding 3KK the three channel camera, the afterglow of gamma ray bursts in the optical and infrared are of special interest. 3KK is therefore a similar but smaller implementation of the GROND concept described by Greiner et. al. [4].

The high resolution Echelle spectrograph FOCES has been successfully in use since more than 10 years at the Calar Alto observatory in southern Spain. Designed with the focus on cool stars science FOCES will be moved and adopted to the Wendelstein telescope. Offering high resolving power over the entire visible spectrum, FOCES can act as a sufficient tool for stellar astronomy and all sorts of high resolution spectral line analysis.

VIRUS-W, an adopted version of the VIRUS spectrograph (see Hill et. al. [5]) designed for the Hobby-Eberly telescope in Texas/USA, is another medium and low resolution visible wavelength spectrograph. Its primary scientific focus will address the bulges of galaxies. As VIRUS-W is an integral field spectrograph, extended objects are by nature the primary target for this instrument.

## 2. OPTICAL LAYOUT

The optical layout of the multi-instrument Nasmyth port tries to optimize with respect to five boundary conditions.

**Spot quality:** Its a design goal to achieve 80% encircled energy within two pixels inside a radius of 0.07° FOV. This FOV radius corresponds to the side of the largest detector (in the infrared camera path).

**Field distortion:** Geometric field distortion in the optical channels is desired to be below 0.2 pixels over the whole field. This corresponds to a maximum relative distortion of 0.014%.

**Low ghost intensity:** The intensity of the ghost corresponding to a bright point source (star) should be below 1E-4 of the source central intensity. Image and ghost image are desired to be well separated.

**Easy alignment and maintenance:** The system has to be compact, rugged and easy to align and maintain.

**Fast and flexible:** The switching time between the instruments is required to be below 1 minute. The integration and exchange of instruments in future has to be possible.

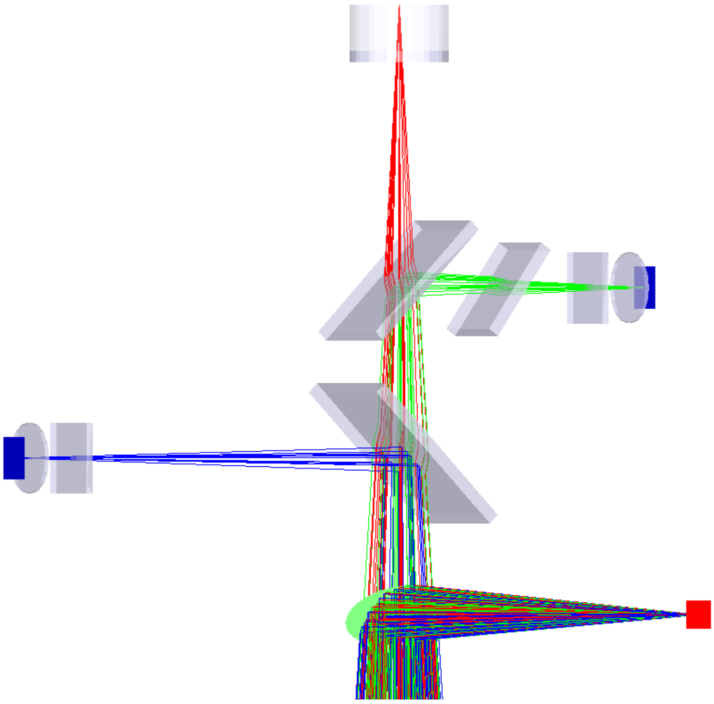


Figure 1. 3D model of the multi instrument focal station with 3 channel camera and fold mirror to distribute light to the fiber instruments and the Shack-Hartmann sensor. The IR camera is not completely shown. This picture ends at the cold stop surface of the IR camera.

Figure 1 gives an overview over the instrument. A retractable and revolvable fold mirror in the front delivers light to the fiber instruments and the Shack-Hartmann sensor, while two wedge plates further down the path of light separate the wave-bands and deliver light to the two visible channel cameras while the infrared light passes through to the entrance window of the IR camera. Please note that the IR camera is not fully shown, the drawing ends at the cold stop surface of the IR camera system.

In the following we will describe both parts of the system, fiber feed and three channel camera separately. Interfaces between the systems will be presented together with the fiber feed.

### 2.1 3KK - a Three Channel Visible and Infrared Camera

The field of view and detector properties of 3KK are described in table 1. Two wedge prism beam splitters deliver the light to the two visible camera arms. The transition wavelengths of the beam splitters are given in table 2. We follow the idea of Woche et. al. [6] to correct for the optical abberations introduced by the 45° beam splitter plate by using wedged plates under different angels. Corrector plate 3 is needed to correct splitter plate 1 as splitter plate 2 acts as a mirror from the view of the second visible camera.

Table 2. Transition wavelength and wedge angle of the wedge plates used for beam splitting and image correction.

| Plate number | Transition wavelength | Plate angle | Thickness | Wedge angle |
|---|---|---|---|---|
| Splitter plate 1 | 690nm | 45° | 9 mm | -694” |
| Splitter plate 2 | 970nm | -45° | 9 mm | 1064” |
| Corrector plate 3 | full transparent | -35° | 9 mm | -1610” |

The backsides of the beam splitters and both sides of corrector plate 3 carry an anti reflection coating designed for the transmissive waveband of each plate. All plates are made from fused silica.

The two visible waveband CCD cameras are using a commercial Apogee/ALTA CCD system equipped with 2x2K 15 microns CCD detectors. A seven position filter wheel is mounted in front of both cameras. The blue camera holds the Sloan filters u’, g’ and r’ the other visible band camera is equipped with the Sloan filters i’ and z’. All wavelengths above 970nm are passing both splitter plates and enter the IR camera system (see unbent beam in figure 1).

As there are science cases where the ghost images and throughput performance losses due to the two beam splitters on the way to the IR camera are not acceptable it is possible to remove the beam splitters from the path of light. The change in optical path length introduced by moving in and out of the fused silica plates is compensated by focusing the system using the secondary mirror of the telescope.

Guiding, derotation and acquisition is performed using the IR camera. As this channel is read out in short intervals anyhow (due to the large thermal background in this wavelength region) no additional guiding is needed.

In order to avoid that the IR camera ”sees” the environment-temperature structures of the camera housing through reflections at the back side of the beam splitters 1 and 2 we use two spherical mirrors to image the cold space between entrance window and cold stop of the IR camera back into the cameras field of view. This optical approach is shown in figure 2.

### 2.2 Fiber Feed System

A small retractable and revolvable mirror in front of beam splitter plate 1 is used to redirect the central 3’=0.05° field towards the fiber instruments FOCES and VIRUS-W on the one hand and towards a Shack-Hartmann sensor for telescope alignment on the other. Another, third position for future instrumentation is possible but not yet equipped.

The layout of the flat fold mirror allows the outer part of the FOV to pass the mirror and thus be used for guiding and de-rotation using 3KK.

Calibration light for flatfielding and wavelength determination is needed for both spectrographs. Using fiber instruments it is essential to couple these calibration sources to the fibers in the same way as the scientific object light enters the fiber. We therefore use a telescope simulator mimicking the telescope f-ratio and central obstruction to feed a realistic calibration light cone to the fibers. This telescope simulator is located opposite the fiber feed focal plane and feeds the fibers while the folding mirror is retracted. A sketch of the calibration system is shown in figure 3.

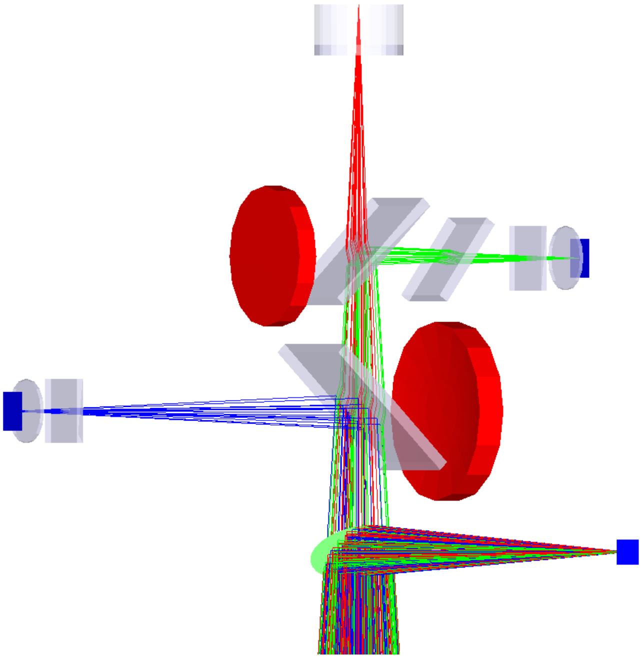


Figure 2. ZEMAX non sequential model showing the two spherical mirrors, that prevent the IR camera from seeing reflections of the camera housing through the back faces of the beam splitters.

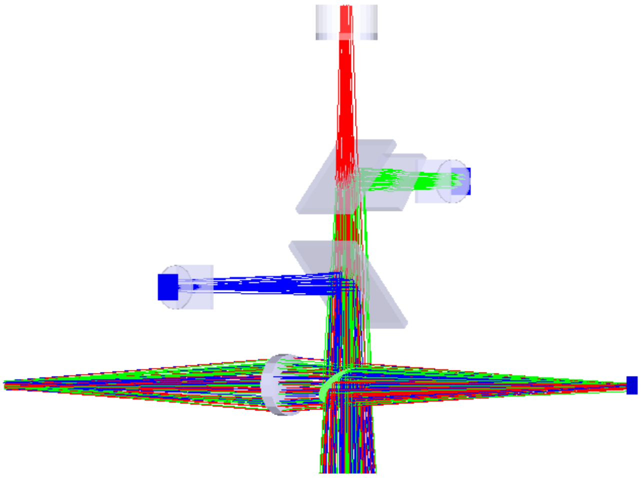


Figure 3. Telescope simulator used to feed the fibers with a realistic light cone mimicking the telescopes f-ratio and central vignetting.

## 3. PERFORMANCE

The spot quality of the three channel camera system is determined by the telescope and the beam splitter/corrector wedge plates. Figures 4 and 5 present the diffractive encircled energy along the 0.07° FOV of the red camera for the telescope alone and with beam splitter 1 and corrector plate 3 in place. The design goal being 80% EE within two 15 micron pixels across the field is therefore reached.

Regarding distortion, our design leads to a maximum distortion for IR, red and blue channel of 0.0021%, 0.0007% and 0.0003% respectively. The design goal of a maximum of 0.014% is therefore reached. Nevertheless

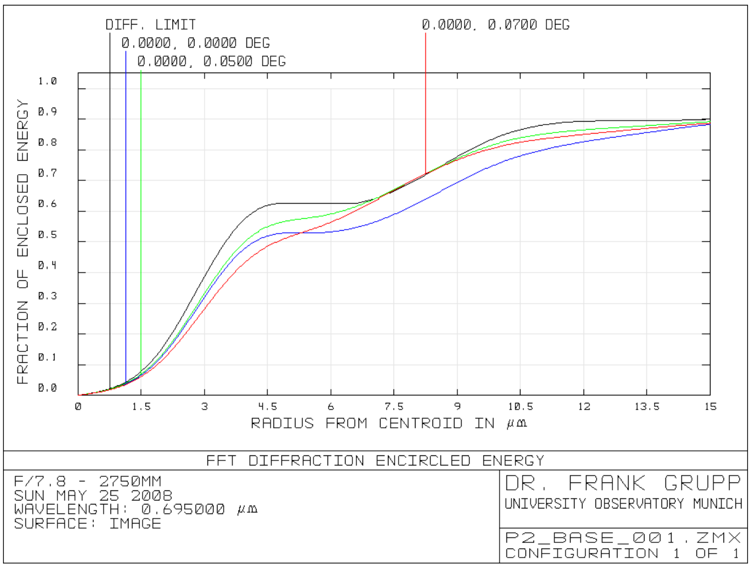


Figure 4. Diffractive encircled energy of the telescope alone (pure reflective system) for 3 field points of the red camera FOV.

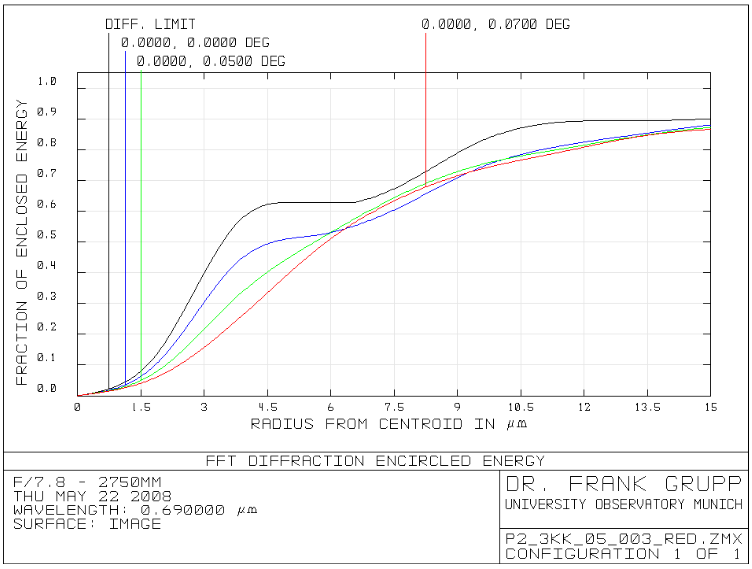
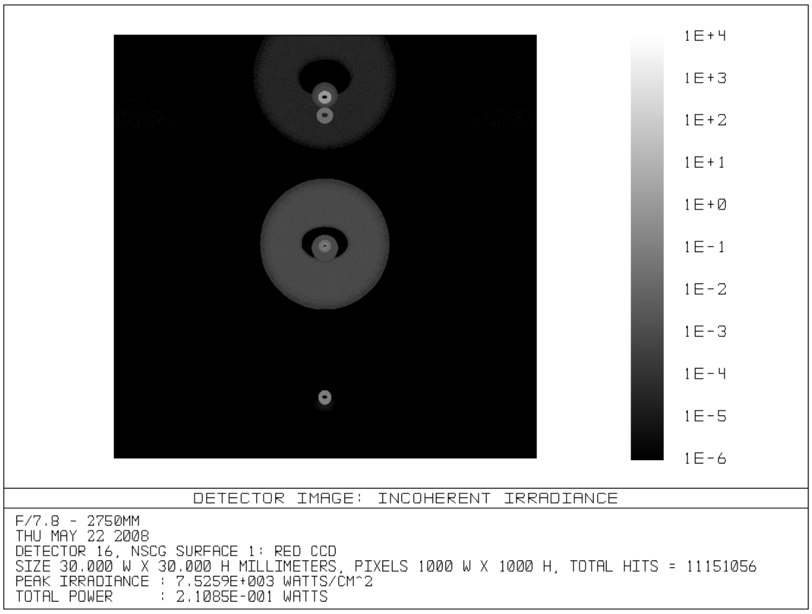


Figure 5. Diffractice encircled energy of the telescope and beam splitter/corrector system for the same field points as in figure 4.

we have to state, that the value for the IR camera does not yet include the IR re-imaging system. This part is still under design in close collaboration with K. Hodapp (IfA, Hawaii/USA).

Turning to ghost image analysis we have constructed a full non-sequential ZEMAX model of the 3KK camera system. Preliminary ghost analysis was carried out assuming conservative boundaries of the yet not manufactured beam splitter, corrector and filter surfaces. We assume 95% reflectivity and 5% transmission in the reflective part of the beam splitter as well as 95% transmission and 5% reflectivity at the transparent waveband. In addition we assumed simple AR coatings on all other optical surfaces. This leads to a conservative result that gives good upper estimates for the real system.

Figure 6 shows a ZEMAX run with 1 million rays.



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DETECTOR IMAGE: INCOHERENT IRRADIANCE
F/7.8 - 2750MM
THU MAY 22 2008
DETECTOR 16, NSCG SURFACE 1: RED CCD
SIZE 30.000 W X 30.000 H MILLIMETERS, PIXELS 1000 W X 1000 H, TOTAL HITS = 11151056
PEAK IRRADIANCE : 7.5259E+003 WATTS/CM^2
TOTAL POWER     : 2.1085E-001 WATTS
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Figure 6. Detector view of the red CCD camera arm of 3KK assuming conservative design data for all optical surfaces. The object is located in the field center.

## 4. STATUS

The optical design of 3KK and the fiber feeding system is basically finished. A basic mechanical design exists and is shown in figure 7.

While filters and cameras are already being manufactured we are in the status of ordering the wedge plates and finishing the design of the retractable fold mirror. The complete system shall be ready in late 2010 together with the Fraunhofer Telescope Wendelstein.

## 5. SUMMARY

The presented design of a multi instrument focal station for the new 2m telescope at Wendelstein is shown to reach its design goals emerging from scientific questions addressed by the user community. 3KK, the three channel visible and IR camera is able to make use of the excellent seeing conditions at Mt. Wendelstein resolving 0.4" (0.5" IR) at the sky by two pixels on the detector. The wedge plate beam splitters preserve the image quality successfully.

The fiber feeding system used to connect the two powerful spectrographs FOCES and VIRUS-W carries its own telescope simulator for calibration light coupling. This design allows accurate flat fielding and precision wavelength calibration.

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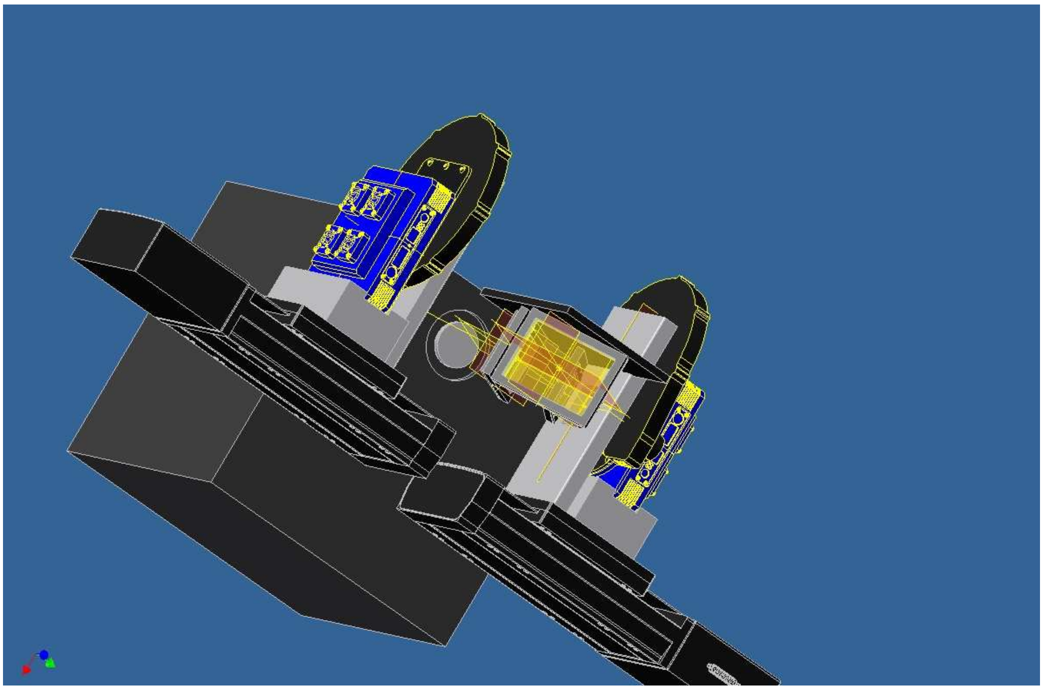

Figure 7. Mechanical design of 3KK, showing the beam splitters in their holder, the filter wheels and cameras along with their alignment and focusing equipment. The black box in the back part of the image symbolizes the IR camera dewar.

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