carmenes — Building a fiber link

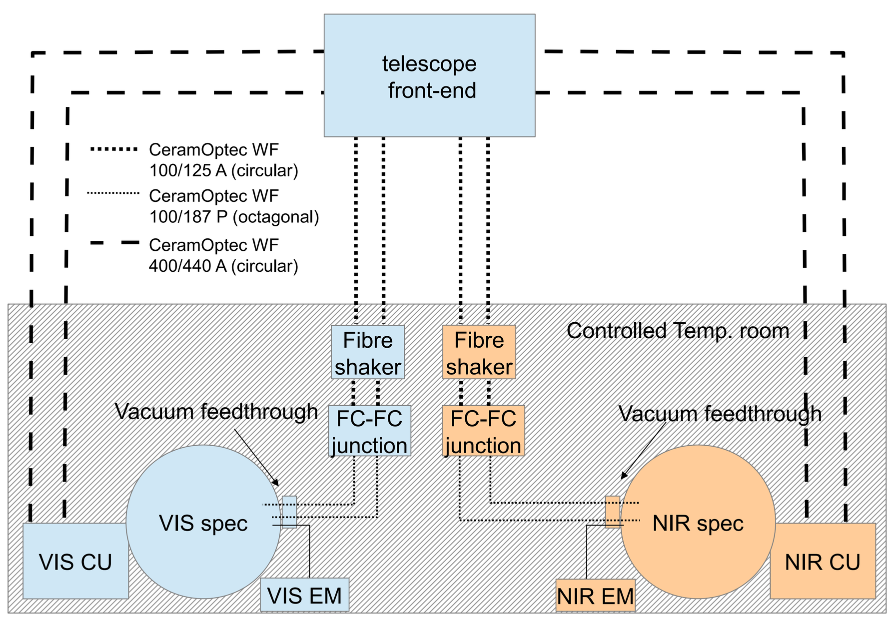
J. Stürmer[3] (j.stuermer@lsw.uni-heidelberg.de), O.Stahl[3], Christian Schwab[12], A. Quirrenbach[3], W. Seifert[3], P. J. Amado[2], I. Ribas[4], A. Reiners[5] J. A. Caballero[10] and the CARMENES Consortium[1,2,3,4,5,6,7,8,9,10,11]

[1]Max-Planck-Institut für Astronomie • [2]Instituto de Astrofísica de Andalucía • **[3]Landessternwarte Königstuhl** • [4]Institut de Ciències de l'Espai • [5]Institut für Astrophysik Göttingen • [6]Instituto de Astrofísica de Canarias • [7]Thüringer Landessternwarte Tautenburg • [8]Universidad Complutense de Madrid • [9]Hamburger Sternwarte • [10]Centro de Astrobiología • [11]Centro Hispano-Alemán – Calar Alto Observatory • [12]Sagan Fellow, Penn State U.

Optical fibers have successfully been used for high-resolution spectrographs for many years. Besides the decoupling of the instrument from environmental influences, fibers provide a substantial increase of the stability of the input illumination of the spectrograph, which makes them a key optical element of CARMENES. The optical properties of appropriate fibers with non-circular cores are investigated, especially their scrambling and focal ratio degradation (FRD) behavior. Related optical simulations of the stability performance of the whole system are presented. The results provide a strong indication that 1 m/s precision, which is the goal of CARMENES, can be reached with a combination of an octagonal and a circular fiber, which allows for a high throughput.

Overview & Introduction

CARMENES is a high-resolution spectrograph for the Calar Alto 3.5 meter telescope. It consists of two R~82000 spectrographs, one in the visual (VIS) from 550-950nm and one in the near infrared from 950-1700nm.
In total, CARMENES uses 14 optical fibers for different purposes as shown in Fig.1. The most critical part are the fibers which transport the light from the front-end of the telescope (FE) to the two spectrographs. These fibers need to have a high throughput, while they must also provide a further stabilization of the illumination of the spectrographs in order to reach the goal of 1 m/s radial velocity precision.



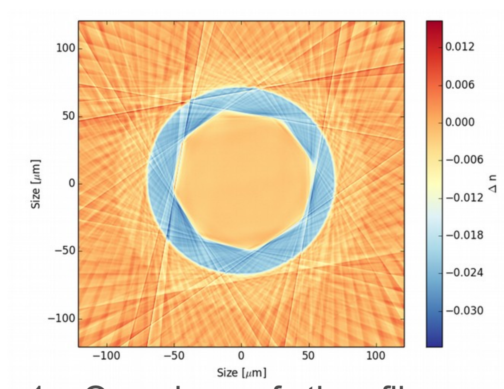


Fig. 1: Overview of the fibers used in CARMENES. CU stands for calibration unit. EM for exposure meter. (left)
Measurement of the difference in refractive index of the octagonal part of the science fibers clearly reveals the octagonal core shape and the double cladding structure (top).

Scrambling and focal ratio degradation

Guiding errors of the telescope, seeing variations and temperature changes effect the radial velocity stability of spectrographs. The stability is increased by the scrambling properties of optical fibers. Non-circular fibers are known to provide good scrambling in the nearfield of the fiber, which is supported by our measurements of octagonal and square fibers. The very good scrambling properties of the octagonal fiber have been further increased by combining it with a circular fiber. All non-circular fibers showed an intrinsically good FRD, while the combined fiber link suffers from a slight increased FRD. At the telescope the fibers are fed by f/3.9, but the spectrograph collimator accepts f/3.5, allowing for FRD. The expected loss due to FRD of the setup is less than 3%.

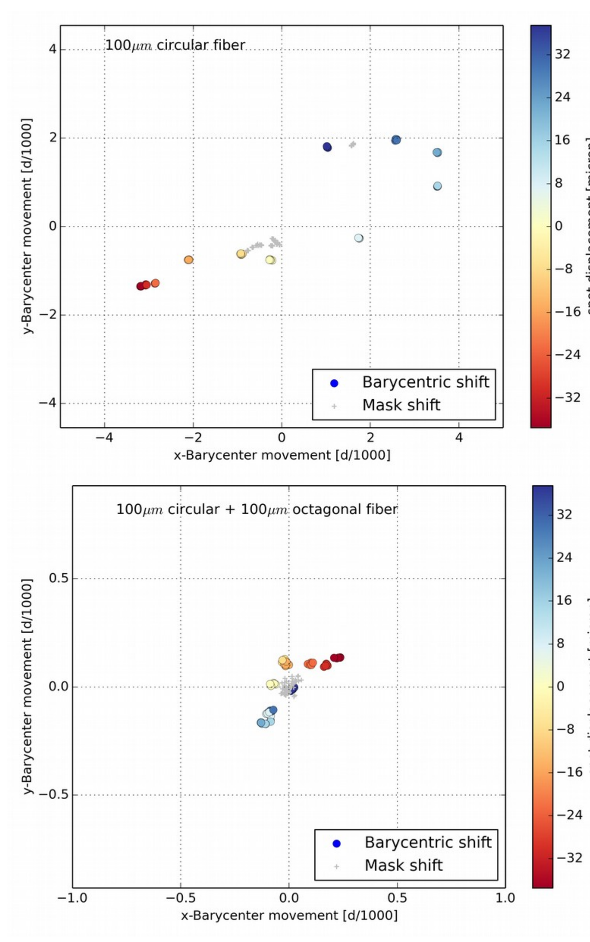
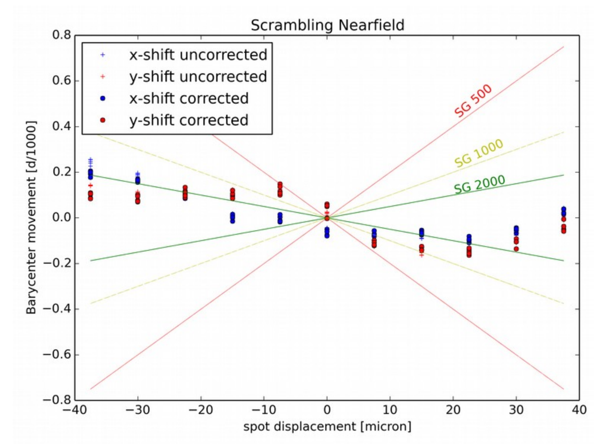
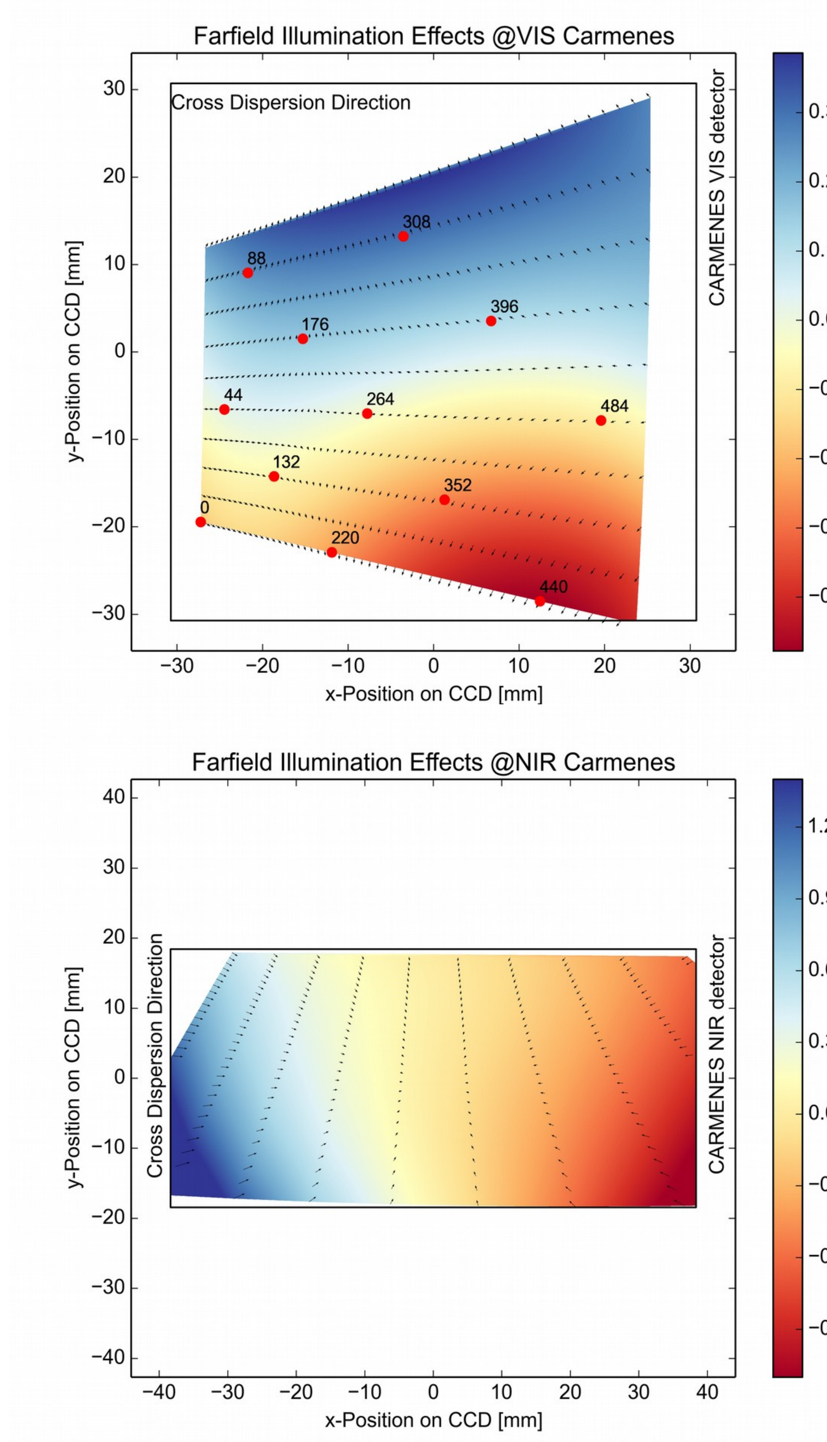


Fig. 2: Barycentric movements of the output of different optical fibers will translate into RV shifts. By combining a circular + octagonal fiber the barycentric shifts for different coupling conditions (simulating a star moving across the fiber) can be reduced significantly (left column). The spot displacement at the entrance of the fiber of ±40 micron corresponds to a movement of the star of ± 0.6 arcsecond on sky.



Farfield illumination effects

While the nearfield of the fiber is well stabilized by the octagonal fibers, the farfield still shows some variation for different coupling conditions. Optical simulations have been performed in order to quantify the effect on radial velocity. In general the impact on radial velocity is larger when optical aberrations are more prominent as in the corners of the detector. As can be seen in Fig. 3, we expect a maximum radial velocity error of ~1.2m/s for a single line.



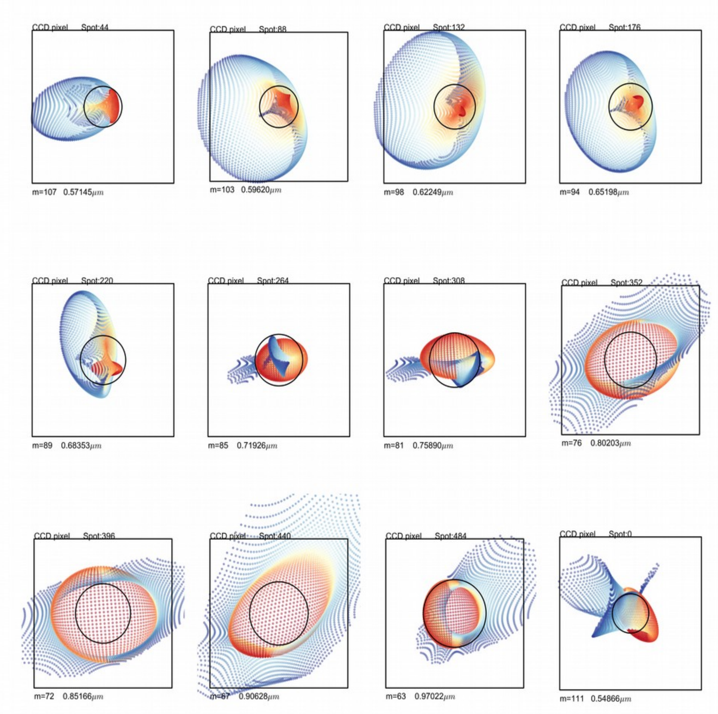
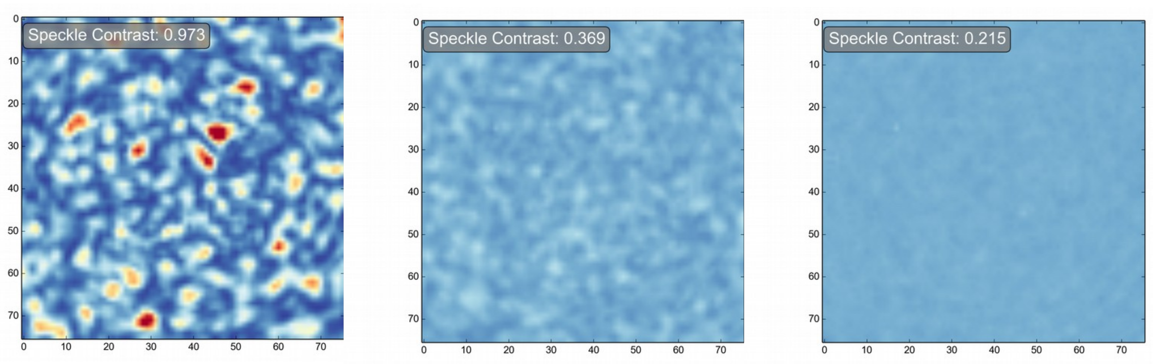


Fig. 3: Spot diagrams with rays of different weights. The weights are indicating the illumination strength of each ray in the pupil plane of the spectrograph. (top) A varying farfield entails a change of the illumination of the pupil plan and therefore a shift of the barycenters on the detector.
Expected radial velocity errors for typical farfield variation in the visual and the near infrared (left column).

Modal noise

Optical fibers only support a limited number of propagating modes, which leads to an additional source of noise in high-resolution spectrographs. The effect is strongly wavelength dependent and it is worst in the red end of the NIR spectrum. Various methods of fiber agitation and manipulation have been tested to reduce this unwanted effect. The results can be compared by carefully analysing the speckle contrast when illuminating the fiber with monochromatic light. Two subsequent mechanical agitators will be used for CARMENES, which reduce the speckle contrast by a factor of ~4.5.

Fig. 4: Different speckle patterns and corresponding speckle contrast values.
Left: un-agitated fiber.
Middle: gentle regular movement
Right: two subsequent mechanical agitators



Acknowledgements: The authors thank Andreas Kelz, Roger Haynes, Dionne Haynes and others from the AIP and innoFSpec in Potsdam for letting us use their fiber preparation facilities and providing helpful advice.

SPIE. CONNECTING MINDS. ADVANCING LIGHT.

http://carmenes.caha.es/

Unión Europea
Fondo Europeo de Desarrollo Regional
"Una manera de hacer Europa"

MAX-PLANCK-GESELLSCHAFT

CSIC

Calar Alto

carmenes