

## **Influence of moon light on tip-tilt sensing accuracy using STRAP**

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### **Abstract**

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AO observations performed in the vicinity of the moon lead to significant background on the STRAP tip/tilt wave front sensor and hence severe drawbacks in terms sensing accuracy of a tip/tilt star. By analyzing all suitable LGS data sets from Jan 2006 to Oct 2006, we evaluated the amount of background photons detected with STRAP as a function of radial distance to the Moon. Moreover we estimated their impact in tip/tilt sensing capability and resulting limiting magnitudes of the tip/tilt guide stars. While for distances  $< 25$  degrees we report a loss of limiting magnitude up to 2 magnitudes for distances  $> 25$  degrees the impact of the moon is negligible (assuming no cirrus clouds).

### **1 Introduction**

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Various background sources are limiting the centroiding accuracy of the STRAP tip/tilt sensor and are considered as main reason for the loss in sensing capability. Prior KAONs traced different aspects of occurring background and dealt with topics such as photons origin from the encoders on the AO bench<sup>[1]</sup> or the increase of sky background when observing close ( $< 300''$ ) to bright planetary targets<sup>[2]</sup>. However the major background source on STRAP is definitely the moon (with a vmag of up to -12.8mag) assuming an observation at its vicinity. This KAON deals with the question to what extent moonlight limits STRAPs sensing performance of tip/tilt stars. In that framework we additionally evaluated the amount of measured “dark” sky background in the case of several moonless nights.

### **2 “Dark” sky background on STRAP**

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We investigated all data sets taken during LGS-AO nights obtained while Jan. 2006 and Aug. 2006. We finally evaluated only nights where a dark time of at least 90% (days around new moon) was guaranteed. In total 40 data sets have been extracted from the TssParamsLog (see section 3) files, which include the recorded number of background counts per second per APD. The results are depicted in Figure 1 and Table 1. Figure 2 shows the number of counts per second averaged over all 4 APDs.

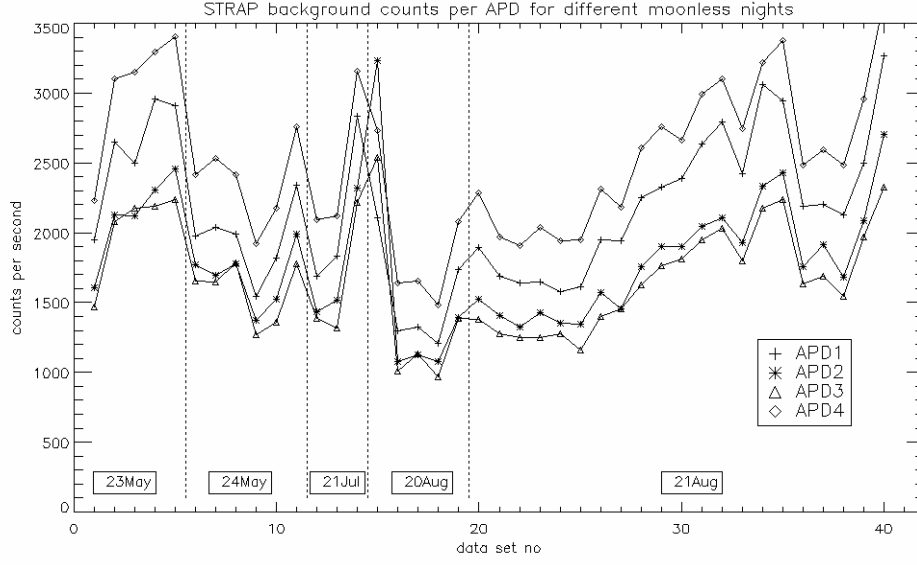


Figure 1: Measured counts per APD on STRAP for various nights.

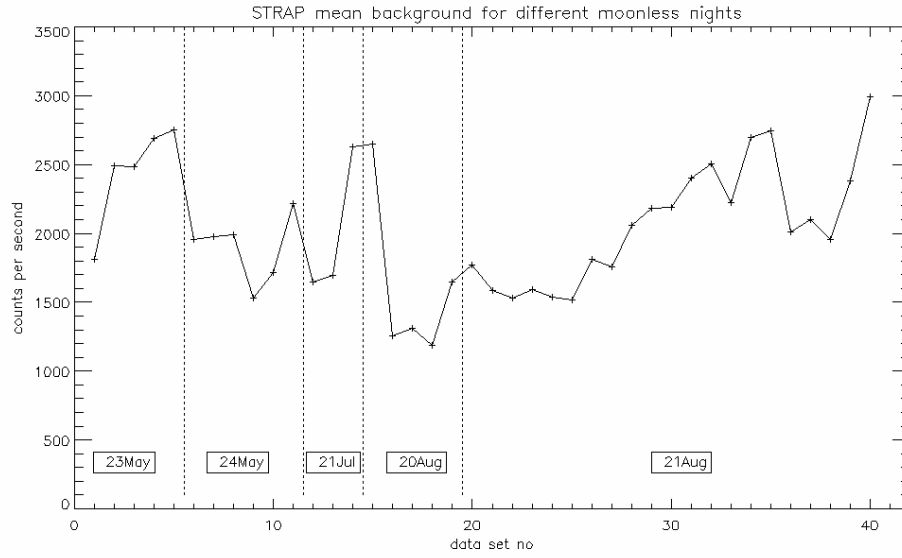


Figure 2: (Top) Measured background averaged over all 4 APD.

Median APD1:  $2106 \pm 515$  cts/s

Median APD2:  $1759 \pm 458$  cts/s

Median APD3:  $1649 \pm 399$  cts/s

Median APD4:  $2484 \pm 537$  cts/s

**AVERAGE: 1999 cts/s**

Table 2: Computed median counts per APD over all 40 available dataset.

The obtained number of average counts is not dominated by background photons origin from the AO bench. Their amount was estimated in [1] and ranges around 300 cts/s. Figure 1 and 2 point out two interesting details. First, the data verifies the expected high variability of measured sky; hence using an average value to estimate the sky contribution could cause significant residual error. Furthermore there exists a (already known) variability in the counting rate between all 4

APD. It might stem from a decentering of the STRAP diaphragm. We extracted from Figure 2 the measured maximum and minimum number of counts (2800 cts/s and 1100 cts/s) and used the calculated average from Table 3 to compute their corresponding magnitudes what leads to 18.4mag, 17.4mag and 17.7mag, respectively. Taking into account STRAPs FoV of 2.8'' x 2.8'' and removing additionally the measured pure bench background, the resulting dark sky background values per arcsecond<sup>2</sup> are 19.7mag , 21.0mag and 20.2mag.

### 3 Moon background data acquisition and data reduction

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#### 3.1 Data acquisition

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We checked all available data obtained at each LGS run from Jan 2006 to Oct 2006. The most valuable information was obtained while the nights of 06/07 Feb 2006 and 04/05 May 2006, where several targets have been observed within a radial distance of 40 deg to the moon. We finally analyzed all data sets of clear (according to the stored K2 night logs) nights exhibiting at least 2.5 hours of moon visibility:

06/07 Feb.	16/17 Jun.
19/20 Apr.	03/04 Jul.
02/03/04/05 May	02/03 Aug.
03/04/05 Jun.	02/10/11 Sep.

Table 3: Evaluated LGS nights containing moon background measurements

A data reduction pipeline has been built in order to almost automate the data processing. The pipeline uses 4 different input files:

- a) TssParamsLog.dat, which contains the information on number of background counts per APD.
- b) DcsParamsLog.dat to resolve the name of the observed target.
- c) The starlist of each night to trace the target coordinates (stored in /kics/starlists/ or /kroot/starlist/)
- d) A table (created by NASA's horizon web interface [<http://ssd.jpl.nasa.gov/horizons.cgi>]) including moon positions for the observed night in 1min incremental steps.

#### 3.2 Data reduction pipeline

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The TssParamsLog file and DcsParamsLog file are automatically created by the IDL systemlog.pro tool and stored in the nightly directory. In both files each table row contains the exact UT time stamp when the data was taken. That information was used as primary key to associate the number of background counts stored TSSParamsLog with the currently observed target name stored in the DcsLogParams file. In order to obtain the target coordinates, the pipeline looks up in the starlist. In the next step the distance to the moon has been calculated only for datasets taken after 12deg twilight and before the moon has set. In order to estimate the correct distance to the moon, the hour and minute of the UT time stamp in the TssParamsLog files is used to pick from the horizon moon position table the corresponding entry. The overall brightness of the moon is a function of Moon's phase and varies from day to day. In order to take into account this effect, the measured counts were scaled to full moon brightness equivalent using the apparent moon magnitude additionally stored in the horizon table. We assumed a full moon brightness of  $v_{\text{mag}} = -12.8$ . To ensure a proper scaling of the pure Moon contribution the averaged "dark" night sky component (see Table 1) has been subtracted before the scaling and afterward add again.

### 3.3 Calculation of limiting magnitude

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In this section, we explain how to compute the effect of background photons on STRAPs centroiding accuracy. The expected number of photons per second per APD for a given guide star brightness can be calculated according to:

$$m_R = 26.0 - 2.5 \log_{10}(\text{counts}_{APD})$$

$m_R$  is the R-band magnitude of the star,  $\text{counts}_{APD}$  the average number of counts per APD per second and 26.0 the STRAP photometric zero-point. The resulting centroiding variance can be modeled by (for details see[3]):

$$\text{var} = \frac{(\text{counts}_{APD} + d + b)}{4(\text{counts}_{APD} \cdot T)^2} \cdot T$$

where  $d$  is the average dark current of the APDs per second,  $T$  the integration time in seconds and  $b$  the additional background photons from the night sky and further bright objects. An upper limit for the variance, where the tip/tilt-loop still can be closed, is given assuming only night sky background. In such a case, the reached limiting visual magnitude is between 18 and 19 mag (average to good seeing).

## 4 Results

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Figure 3 plots the number of counts per second (scaled to full moon equivalent) measured by STRAP as a function of the radial distance to the moon. The plot verifies that the moon definitely affects the count rate on STRAP up to radial distances of 20-25 degrees. For greater radial distances the count rate reduces fairly fast to the level of the sky, but seems to stay above the average sky level deduced in Table 1. We cannot rule out that this effect and the high scatter of the data points may be residual of the sky subtraction performed while the full moon scaling process. Due to the high variability of sky, a subtraction of an average sky level leads very likely to an underestimation or overestimation for the moon background taken at different observing nights. Moreover the amount of scattered moon light is not only a function of moon phase, but also a function of zenith distance of the moon, zenith position of the observed sky and the local extinction coefficient. Such effects were not taken into account for the data reduction process. Furthermore the plot contains data points obtained at low telescope elevation. In that case the measured sky background might be reduced to due shielding effects caused by the telescope shutter or the K1 dome.

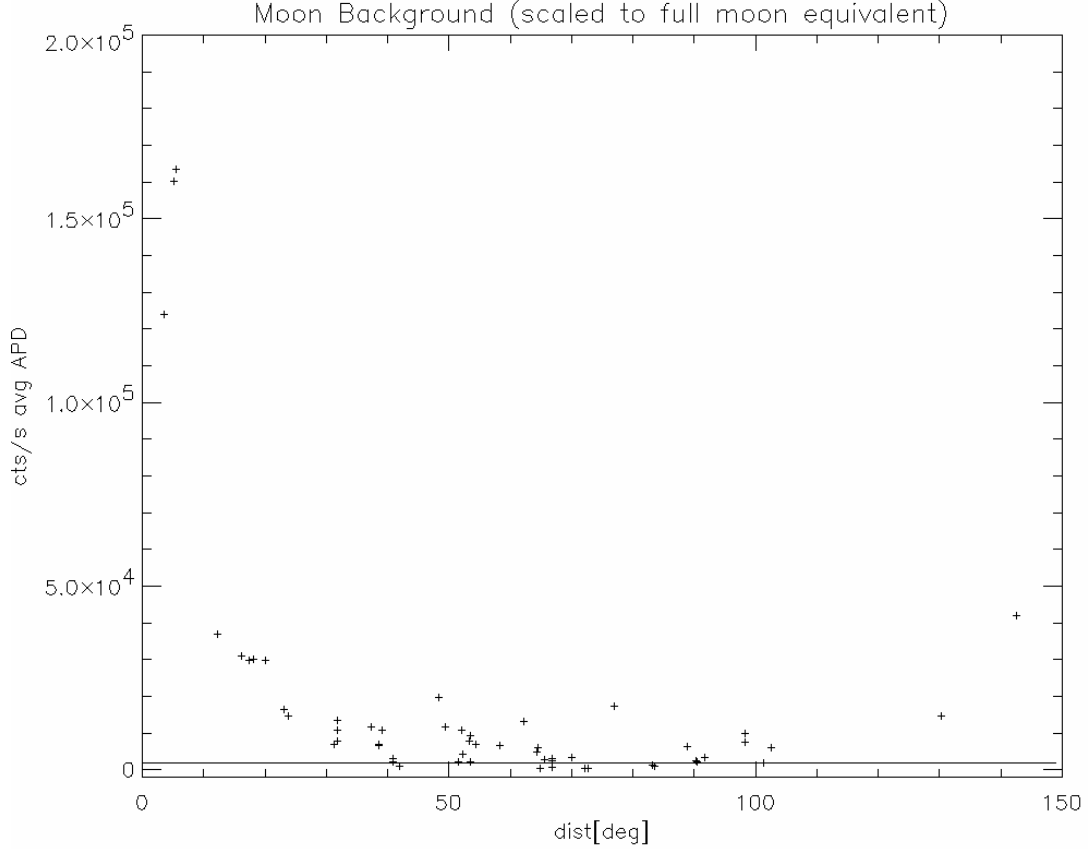


Figure 3: Absolute number of averaged counts measured by STAP as function of distance to the moon. All counts are scaled to full moon equivalent. The horizontal line indicates the assumed averaged sky background subtracted when performing the scaling.

Figure 4 and Figure 5 depict the impact of moon background photons on STRAP in a more practical way: Figure 4 shows the reached equivalent limiting magnitude by performing centroiding computations following the calculations discussed in section 3.3. The variance was computed for a hypothetical integration time of 1 s. As a reference for the limiting magnitude, the resulting centroid variance for an 18<sup>th</sup> magnitude TT-guide star has been chosen assuming only pure night sky background illumination. Hence, the plotted limiting magnitude denotes that particular star magnitude which would lead to the same centroiding variance, taking into account additional background photons from the Moon.

Figure 5 depicts the impact of moon background on the estimated centroid standard deviation assuming the tip/tilt guide star magnitude varying from 14<sup>th</sup> to 19<sup>th</sup> mag. We averaged all obtained data points within a 10deg binning interval and used that number as input for the additional contribution of Moon light on the sky. The solid line is used as reference showing the expected centroid standard deviation assuming only dark night sky of 1999 cts/s.

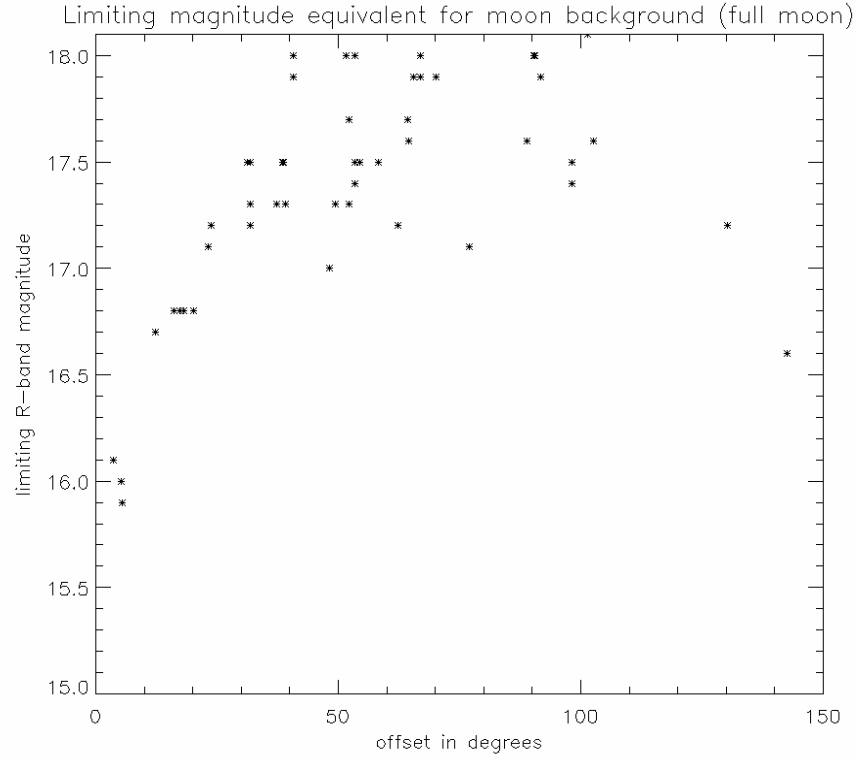


Figure 4: Corresponding limiting magnitude taking into account additional contribution of Moon background.

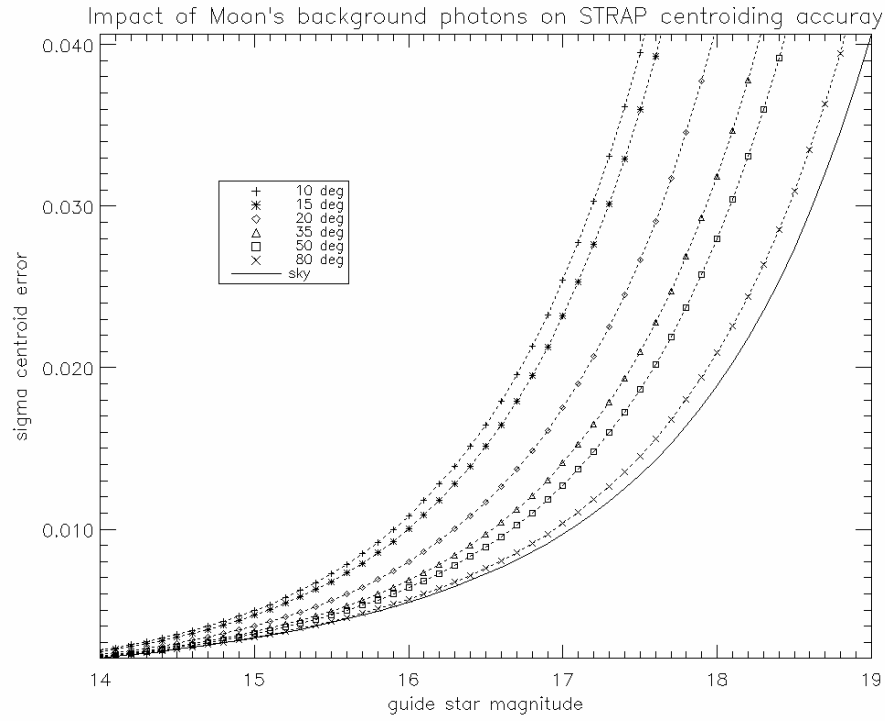


Figure 5: Expected centroid error as a function of guide star magnitude taking into account moon background illumination. The used background value is an average over a 10deg radial distance bin. The

*solid line represents the expected centroid error in the case of “dark” night sky*

As seen in Figure 5, background photons of the moon lead to reduced centroiding accuracy of STRAP. Practically, that means: In the presence of the Moon the tip/tilt sensor give a worse wave front estimate and practically it look like that it “sees” a fainter tip/tilt star.

Figure 6 depicts this effect more quantitatively and plots the resulting equivalent tip/tilt guide star magnitude as a function of radial distance to the moon for various reference tip/tilt guide star brightness. According to that a 16<sup>th</sup> magnitude guide for instance at radial distance of 10 degrees with respect to the Moon appears for the wavefront sensor to be as bright of a 17.1mag guide star assuming a dark night sky.

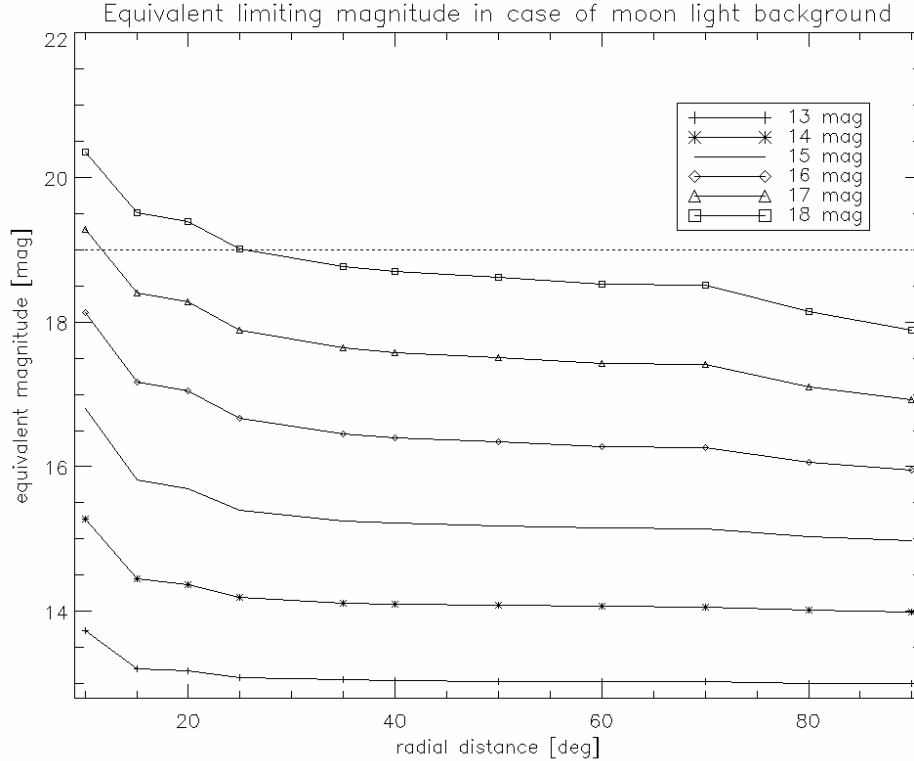


Figure 6: Resulting equivalent magnitude for various tip/tilt guide star brightness as a function of radial distance to the moon and various equivalent reference magnitudes. The dashed line at 19<sup>th</sup> mag represents the currently archived limiting magnitude of the STRAP tip/tilt sensor.

## 5 Impact of cirrus clouds on Moon background

All results discussed in the previous section are based on data set obtained while clear nightly sky conditions in the absence of ant clouds. However, the 2006 LGS data contained several nights exhibiting cirrus clouds contamination. Unfortunately, the data does not allow giving a quantitative estimate of this issue. Qualitatively we encountered an increase of measured background counts on STRAP up to a factor 3 (conservative assumption) within a radial distance of 30 degrees with respect to the moon. But cirrus clouds do not only lead to an increased Moon background. The observer may take into account an additional decrease of tip/tilt guide star brightness of up to 1mag due to extinction.

## 6 Conclusion and Discussion

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The data allows us to give the observer some hints on the 2 key questions when planning K2 LGS observations. Observing scientific targets close to the moon at radial distances of 25 degrees or more does not lead to any significant limitations of the overall sensing accuracy, since background illumination on the TT sensor is fairly close to the sky level. Conducting observations within a radial distance 10 to 20 deg still seems to be feasible as long as the guide is brighter than 17<sup>th</sup> magnitude. However, it results in loss of correction performance since practically the star generates centroiding errors according to a star of up to 2 magnitudes fainter. In the case of cirrus clouds this may further drop down for 1-2 magnitudes caused by effects such as increase Moon background due to reflection at the clouds and extinction. Nevertheless it is strongly recommended to measure the STRAP background as a function of distance to the moon in a systematic manner to get some further data and a more reliable dataset. That can be scaled to the expected observing conditions (moon phase, radial distance Moon science target, distance moon to zenith, distance TT star to zenith).

## 7 References

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- [1] KAON 326, A. Bouchez, "Background light on the STRAP TT sensor"
- [2] KAON 385, S. Kellner and M. van Dam, "Feasibility of LGS AO observations in the vicinity of Jupiter"
- [3] van Dam, Applied Optic, "Performance of the Keck Adaptive Optics System", Vol. 43, 29, 2004