The ESO ADONIS AO system: Study of the 3-5 μm background emissivity.

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Abstract – In this poster, we present the results on our investigation on the ADONIS instrumental; background in the 3-5μm range. We show that the ADONIS optical bench is the main contributor to this instrumental background and we discuss the consequences on the imaging performances of NIR cameras in the 3-5μm range[1].

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1 Introduction:

- Deep SHARPII+ K band observations or COMIC 3 - 5 μm (L and M band) observations reveal *strong features in the background of the images.* Structures at such level are not coming from the sky but from the instrument and cannot be removed by ADONIS ON/OFF chopping. A nodding-like method (first perform usual chopping using the ON/OFF adonis and then, offset the telescope and re-perform the same chopping procedure) was found to be the best way to correct the images for those structures (Monin & Geoffray, 1997) but this is also time consuming and *does not allow to remove completly the background strucutures* (see also H. Geoffray, " Thermal background blurring by ADONIS system", these proceedings).
- On the other hand, we suspected the 3 - 5 μm COMIC performances to be affected by a rather uniform high level background emission.
- Last background emission measurements were done in 1995 during the COMIC commissioning (Marco, O. 1998).

In this poster, we first present new results from sky measurements. In a second part, we show how bench measurements allow to trace the main contributors to the background emission, and we compare those results with the theoretical bench emissivity. We later discuss the impact of this high background emission on the imaging performances [2].

2 Results from sky measurements

2.1 Method:

In L' and M band, the sky emission has a linear-like response with the airmass ($am = \frac{1}{cos(z)}$), being z the zenith distance. The emission in those bands primarily comes from thermal emission from the atmosphere itself (T≈ 250°K) and from line emission processes (OH, CO_2).
We can disentangle the TELESCOPE contribution by plotting the total emission intensity versus the airmass value: The TELESCOPE contribution only, would be the flux received at zero airmass (Zero Point).

[1] The content of this poster and further implications on the imaging performances in the 3 - 5 μm range are issued in an ESO - 3.60m Telescope Team report on **"The ADONIS bench 3 - 5 μm emissivity and the imaging performances"**
[2] Note that TELESCOPE, written in small capitals, stand here for the 3.60m telescope optics (M1 and M2 mirrors) + ADONIS bench optics (M1 to M9 + dichroic)

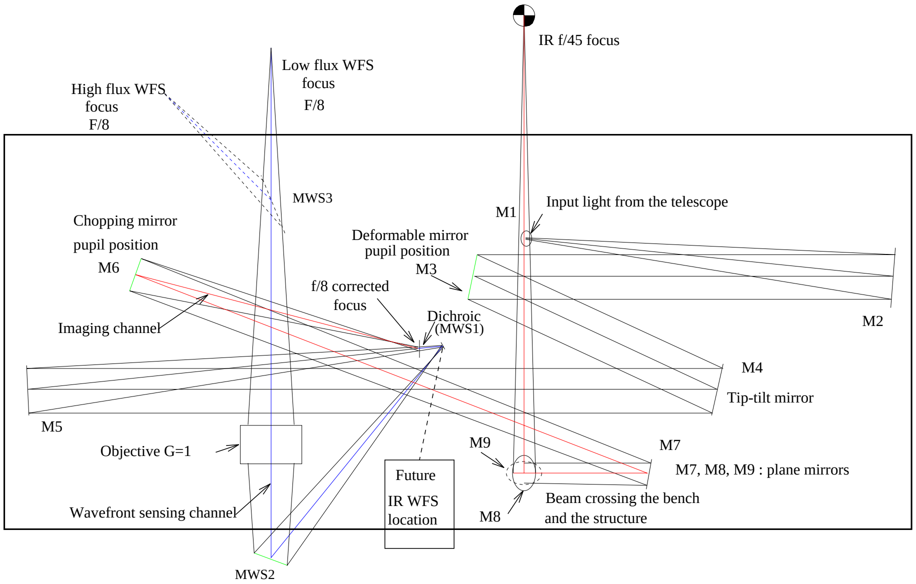

Figure 1: The ADONIS optical layout and characteristics of the mirror: ADONIS bench IR channel is made out of 9 mirrors and one dichroic. Note that ADONIS mirrors are aligned on a vertical plane except for M1 and M9, which are 45° tilted.

One of the main error source may come in this case from strong atmospheric saturated lines. Once those lines get saturated, the intensity will not vary linearly with the zenith distance.
The operating procedure and data reduction are described in the ESO report.

2.2 Results:

The resulting plot with error bars is presented in figure 2.
Error on the frame mean value is around 0.3% of the intensity. From a linear fit of the data points, given a conversion factor of 92 e^-/ADU, we present the background photon flux once corrected for the camera efficiency in both bands. Sky intensity contribution is at most 15 % and 30% of the total intensity respectively for L' and M band. **At least 70% of the background emission is coming from the TELESCOPE (ADONIS + 3.60 TEL.).**

Table 1: COMIC filter characteristics and respective background photon flux

Filter	Central Wavelength of filter in μm	Bandwidth in μm	background photon flux in $ph^{-}.s^{-1}.arcsec^{-2}$
Lstandard	3.480	0.590	
L'	3.809	0.623	$2.67\ .10^8$
M	4.832	0.590	$9.3\ .10^8$

As seen on the figure 2, the sky emission increase is not perfectly linear with airmass. This departure from the linearity may be due to saturated lines, non-uniform atmospheric temperature, or any change in the TELESCOPE emission due to flexure . The effect on the fit would be that we slightly overestimate the zero point value but we do think that those zero point values stand as a reliable first order approximation.

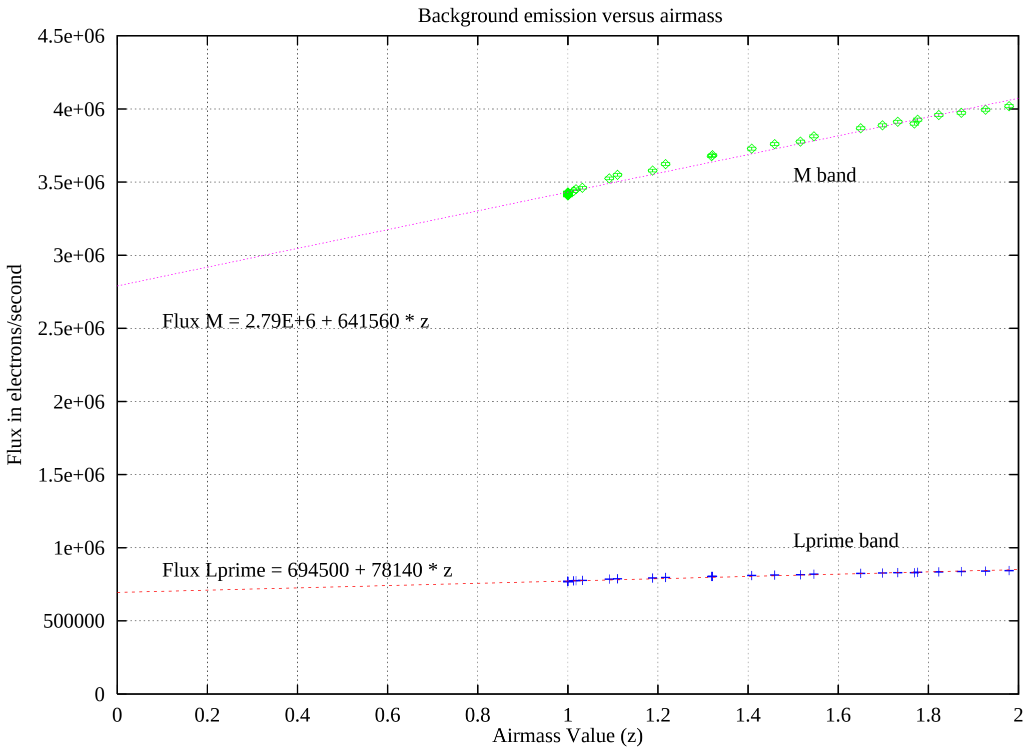

Figure 2: ADONIS + 3.60m TEL. NIR emission, as deduced from sky measurements. Errors are of 0.3% measurements value. Flux is given per units of pixel

3 Bench measurements and emissivity:

In order to get more qualitative understanding of the ADONIS bench, we wanted to measure the bench emissivity using a cold body. The operating procedure and data reduction are described in the ESO report.

3.1 Results from bench measurements:

The results of those measurements are presented in Table 2. The contribution of parts of the bench has been derived by subtracting measurements at different place and this allows to identify which mirrors contribute the most to the high NIR emissivity of ADONIS in L' and M band.

Location	M9	M8 - M7	M6 - Dichroic	M5 - Tip-tilt - DM	M2 - M1
Contribution L' %	28.7	1.5	39.1	16.3	14.3
Contribution M %	33.4	-	32.8	18.3	17.9

Table 2: Result of measurements done at different location on the bench (see figure 1) and inferred contribution for different parts of the optical bench. Errors are of the order of 5% value

The main contributors of ADONIS NIR emissivity are M9 and (M6 + dichroic), that are responsible for 60% of the bench contribution. The set (M5 - Tip-tilt - DM) does emit as much as (M1 + M2). Due to the 45° tilt of M1, it is likely that its dust is contributing much more than for M2 which is in a vertical position. M8 is also tilted by 45° but is downward oriented [3].

[3] As seen in table 2, the measure of the M9 emission seems to be overestimated especially in M band. This comes from the fact that for this position the cold body was in close contact with one ADONIS support that made it warm up very rapidly

3.2 Emission morphology:

The morphology of the emission is revealed for L' and M band in figure 3. We display here the dark image and for each band, image of the cold facing the camera (upper right), image of the M9 + camera window contribution (lower left) and image of the entire bench contribution (lower right).

Since the images have not been flat-field corrected, the hand like structure corresponding to the COMIC gain map pattern modulates the intensity in the images. A few spots can be seen in the image of the cold body, those spots are more visible in the image corresponding to M9 + window emission. We believe those spots to be dust particles, and/or alteration of the coating on the camera window since they are fixed and since M9 is far from a focal plane.

Apart from the bright spots, the emission in L' is quite homogeneous: superimposed on those local bright emission features, we get a rather uniform high level emission coming from the different part of the optical bench.

The situation is different for M band: the ring like pattern is some additional local emission coming from other optical elements before M9 is present in the upper-left corner of the optical bench emission image. From the analysis of the images, this local emission was found to come from either M6 or the dichroic.

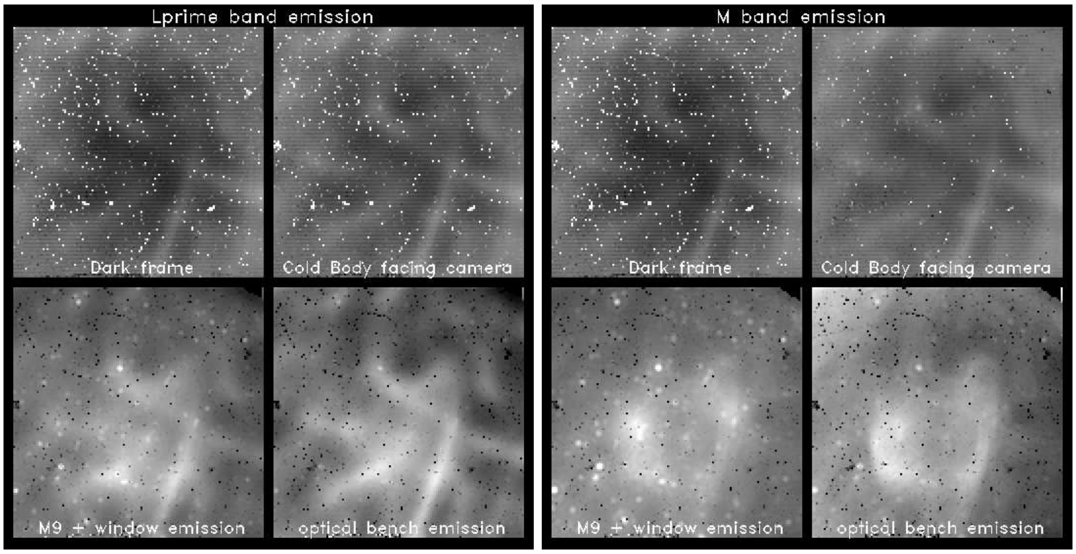

Figure 3: Emission morphology for L' (left) and M band(right).

3.3 Bench emissivity:

As a first attempt to compute the emissivity of the ADONIS bench, we do not want to discriminate each different optical element, but rather consider ADONIS optical bench as one. We computed the theoretical number of electrons $\phi_{\lambda,\Delta\lambda}(T).S.\Omega.\eta_\lambda$ received from a blackbody at the mirrors temperature for both L' and M band.

$\phi(T) = \int_{\lambda_0}^{\lambda 1} \frac{B_\lambda}{h.\nu} d\lambda = \int_{\lambda_0}^{\lambda 1} \frac{2.c^2}{\lambda^4}.\frac{1}{e^{\frac{h\nu}{kt}}-1} d\lambda$ is the photon flux in photon.m^{-2}.St^{-1}.s^{-1}, $S\Omega$ being the integrated *etendue* in m^2.st for the ADONIS configuration at F/45, and the COMIC 100mas pixel scale, η standing for COMIC efficiency (collimator+objectives+detector QE and filling factor).

The emissivity of the bench e will be given by the ratio of the measured flux coming from the ADONIS bench (see Table 2) to the theoretical computed number of photons from a 284.4°K blackbody detected by COMIC[4].

[4]For a detailled description of the calculations, please refer to the ESO report

The theoretical photon flux received by one pixel is found to be 1.63 $.10^6$ and 1.09 $.10^7$ e^-/s for L' and M respectively. This led respectively in L' and M band to 0.30 and 0.15 emissivity. We checked the effect of a mirror temperature fluctuation: a 4°K difference would result in 15% difference in the emissivity values.
An upper limit for the emissivity value can be expressed as $(1-T)$, T being the optical bench transmission value. Given a transmission value of 0.98 for each of the 9 mirrors and a reflection value for the dichroic between 0.75 and 0.9, the **upper limit for the emissivity would be in the range of 0.25 - 0.37** which is in agreement with our measurements.

4 Impact on the imaging performances:

Knowing more about the background emission, it is now interesting to infer how this can affect the camera performances. COMIC is actually used on the telescope and EAGAL is foreseen for the next year.
A camera like COMIC works in BLIP (Background Limited Infrared Photodetector) conditions due to its high linear capacity range, but has very poor performances in J, H, and K bands due to its high read-out noise (RON) (Marco et al. 1996). On the other hand, EAGAL, optimized for J, H, K bands, will still have good efficiency values for L' and M but with a much lower linear capacity range (Currie & Bonaccini 1997).

4.1 Signal to noise ratio:

The S/N ratio for a thermal NIR camera assuming given characteristics can be expressed as:

$$(\frac{S}{B})_{\lambda,i} = \frac{A_i.\eta_{\lambda,i}.S_\lambda.t}{\sqrt{RON_i^2 + A_i.\eta_i.(\Phi_\lambda + S_\lambda).t + DC_i.t}}$$

i stands for the camera, S_λ is the flux received and converted from the astronomical source in $e^-.s^{-1}.arcsec^{-2}$, Φ_λ is the background flux detected at λ in $e^-.s^{-1}.arcsec^{-2}$, A_i is the pixel surface for camera i in $arcsec^2$, $\eta_{\lambda,i}$ is the camera efficiency including collimator, objectives and detector (Q.E and filling factor) for a given band, t is the integration time in s, RON_i is the readout noise value (in e^-) and DC_i is the dark current (in e^-/s).
We express the relative contributions from the dark current and the RON as
$\frac{DC_i}{A_i.\eta_{\lambda,i}.(\Phi_\lambda+S_\lambda)}$ and $\frac{RON_i^2}{A_i.\eta_{\lambda,i}.(\Phi_\lambda+S_\lambda).t}$ for a given camera i.

For COMIC camera, the relative contribution from the dark current is $\ll 1$ and can be neglected but the readout noise contribution cannot be neglected.

4.2 The imaging performances:

Using this simple expression of the S/N, we have computed the sensitivity for a NIR camera in the 3 - 5μm range considering the ADONIS bench conditions for the background emission level. The precise results and the details of the modelisation are not the purpose of this poster but are presented in the ESO report. We will just give here the general conclusions:
The high RON and DC values of COMIC are really a problem in the 1 - 2.5 μm range, but given the high values of the background emission in this 3 - 5μm wavelength range, the photon noise is by far the most important contributor to the total noise (BLIP conditions).

To achieve better sensitivity in the 3 - 5 μm range, it is very important for a given camera to have a large capacity (with RON and DC as low as possible!) and a very short read-out time ($< 50ms$).

Considering that the RON value for an Infrared Detector is proportional to its linear capacity range, an alternative solution should be to pay more attention to reduce the background emission from ADONIS or any adaptive optics system in order to achieve better sensitivity at those wavelengths.

5 Conclusions:

The emission of (ADONIS + 3.60m TEL.) is in agreement with both on-sky and cold body method, as shown in table 3. ADONIS emission represents 70% of the instrument emission in L' and about 60% in M band. The telescope mirrors have a higher contribution in M band which can be interpreted as dust emission contribution from the M1 mirror.

The main contribution of the high level background in the 3 - 5 μm range is coming from the ADONIS optical bench and more precisely from M1, M6 + dichroic and M9. The instrumental background emission represents 30% and 15% of a direct BB emission (see Table 3) in L' and M. Those emissivity values are in agreement with theoretical upper limit for the ADONIS emissivity.

	L' band	M band	Remarks
ADONIS only	$4.88\ .10^7$	$1.64\ .10^8$	Measured with the cold body
ADONIS + 3.60 TEL.	$6.95\ .10^7$	$2.79\ .10^8$	Derived from sky measurements
Sky Flux at airmass 1	$7.73\ .10^7$	$3.43\ .10^8$	Measured on the sky
Black-body at 284.4°K	$1.63\ .10^8$	$1.09\ 10^9$	As seen by the camera

Table 3: Result of the 3 - 5 μm emission measurements in e^-/s/arcsec^2 units

Acknowledgments

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