Performances of COMIC, the New Infrared Camera for ADONIS

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1. Introduction

COMIC is a new 1–5 µm high-resolution camera dedicated to the ESO adaptive optics system ADONIS, developed by a group from Meudon Observatory, in collaboration with the Grenoble Observatory. The 128 × 128 HgCdTe/CCD array detector is optimised in the 3–5 µm range. Two image scales are available: 36 mas/pixel (for J, H, short-K and K) and 100 mas/pixel (for L, L' and M), leading to fields of view of 4.5 × 4.5 arcsec and 12.8 × 12.8 arcsec, respectively.

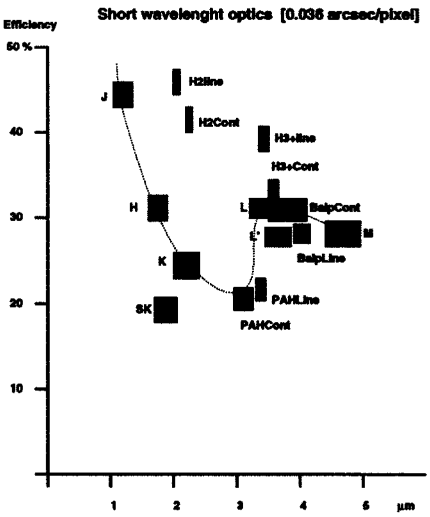

Figure 1: Efficiency for all the filters, with the short wavelength optics. The rectangles indicate the bandwidth (horizontally) and the measurement error (vertically).

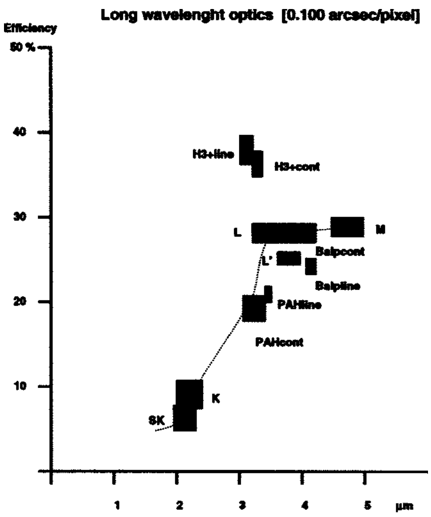

Figure 2: Efficiency for all the filters, with the long-wavelength optics. The rectangles indicate the bandwidth (horizontally) and the measurement error (vertically).

Several narrow-band filters are also available: H_2 1-0 S(1), PAH, H3+, Brα and 2 CVF (1.2–2.5 µm and 2.4–4.8 µm with a spectral resolution of 60). It can be used in conjunction with a polarimeter unit. The measured dark current of 2000 e^-/s/pixel at the operating temperature of 77 K allows long exposure times at short wavelengths ($\lambda < 3$ µm), as the limiting factor is the read-out noise (1000 e^- RMS). This camera is used at the F/45 output focus of the adaptive optics system ADONIS on the ESO La Silla 3.6-m telescope.

The quantum efficiency ranges from 60 % at 1.2 µm to 40 % at 4.5 µm. The full efficiency (including the detector and the optics) for all the filters available with COMIC (with the theoretical bandwidth and for a transmission of 1) is presented in Figure 1 for the short-wavelength optics, and in Figure 2 for the long-wavelength optics. The detector pixels have a size of 43 µm, with a pitch of 50 µm, which gives a filling factor of 74 % not reported in Figures 1 and 2.

2. The Technical Run

The COMIC technical run took place on the 3.6-m telescope with the ADONIS adaptive optics system from 1 to 5 November 1995. The adaptive optics correction was performed on the standard stars, which were chosen bright enough to provide a good signal-to-noise ratio, and an optimum wavefront correction. Standard stars, of different brightness, were observed sequentially at J, H, K, L, L' and M. For all of them, at any wavelength, we used a chopping mode: sky (OFF) positions were always taken at symmetric positions with respect to the star (ON). The distance between ON and OFF positions was always of 10″, so as the star was at the field centre of the ON position, there was no contribution from the star on the OFF position. The detector integration time per frame (DIT) was taken as long as possible at long wavelengths (L', L or M), to make sure we were observing in background limiting performances (BLIP) conditions. At short wavelengths, it was reasonably long (2 to 4 seconds), but short enough to allow an eventual analysis of background fluctuations, thermal at K, or due to the air glow at J or H.

3. Observing Procedure

As this infrared camera ranges from 1 to 5 µm, the best way to observe depends on the limiting performance factors.

At short wavelengths (J, H, K), the dark current dominates the background. The detector integration time (DIT) from which the detector is limited by the dark current is:

$$T_{dark\ limited} = 2 \times \frac{RON^2}{DC}$$

where RON is the read-out noise and DC the dark current. Based on the integration tests in Meudon, we find $T_{dark\ limited}$ = 1000 s, which means that the images are RON limited at these wavelengths. As there is a large dynamic, one can have long-exposure images, but to keep the adaptive optics correction as good as possible (the seeing is changing with short time scales), we advise a maximum detector integration time of 30 s (see Table 1).

At long wavelengths (L, L', M), the instrumental emission dominates upon the dark current. The minimum time to be in background-limited performances (BLIP) condition is:

$$T_{BLIP} = 2 \times \frac{RON^2}{BG}$$

where BG is the thermal background from the instrument and the sky. We report in Table 1 the time T_{BLIP} and the maximum exposure time, corresponding to the detector saturation.

4. Imaging Performances

Based on the data from the technical nights in November 1995, we derive the imaging performances with that camera and ADONIS, under realistic observing conditions. We compute the limiting magnitude for two kinds of sources, point-like and extended. For the first

TABLE 1: Observing limitations for the standard bands.

Band	J	H	K	L	L'	M
Limitation	RON	RON	RON	BLIP	BLIP	BLIP
T_{BLIP} (ms)				500	260	150
T_{max} (s)	30	30	30	7	3.5	1.5

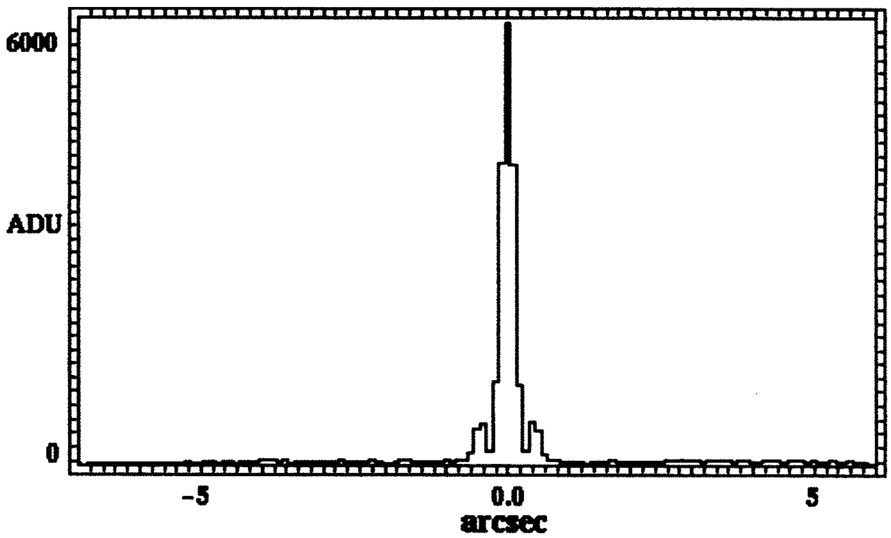

Figure 3: Cut of the bright star HR 8720 in the M band with ADONIS and COMIC. The strehl ratio is 61% for an integration time of 0.5s.

TABLE 2.

Band	J	H	K	L	L'	M
Z_0 dZ_0	18.6 0.17	18.4 0.21	17.8 0.22	17.7 0.16	17.2 0.12	15.7 0.44

one, we take into account the correction quality (which is measured by the Strehl ratio), and for the second one the pixel size and the detector filling factor.

4.1 The zero point

For any band, the zero point is defined as the star magnitude which corresponds to a detected flux of 1 ADU/s at an airmass = 0:

$$Z_0 = 2.5 \times \log(F_0[ADU/s])$$

Using the mean known extinction coefficients for La Silla, a conversion factor is derived from the flux measurement in circular apertures for the standard stars. The signal is taken as the mean (temporal) value of the flux integrated in given diaphragms for each star, and the noise is taken as the temporal fluctuations of the same quantity.

From the signal/noise ratio, we derive the photometric accuracy of the Zero point determination:

$$dZ_0 = 2.5 \times \frac{dF_0}{F_0}$$

Knowing the airmass and the atmospheric absorption, one can then compute any magnitude for a given wavelength λ and for a detector integration time as:

$$m_\lambda = Z_0 - 2.5 \times \log(F_\lambda\ [ADU/s])$$

$$- M\ [airmass] \times K_\lambda\ [Mag/airmass]$$

The results are summarised in Table 2:

4.2 The limiting magnitudes

Since different users will observe different kinds of objects (point-like or extended), looking for different photometric accuracy, we decide to derive the limiting magnitude:

1. from the noise equivalent power on one pixel, which is called the noise equivalent magnitude (NEM)
2. for a point-like source
3. for an extended source

As ADONIS is expected to provide a good correction, we compute all the limiting magnitudes at the angular resolution limit and for a signal-to-noise ratio of 5. As for the zero point, the results are given for an airmass = 0.

4.2.1 Evaluating the NEM

To evaluate the NEM, we compute the standard time deviation for each pixel. We take a spatial average of it, outside the circular aperture where the star is, of course. This, we assume, is representative of the limiting power we can detect for a given DIT on one pixel, with that camera and under the given observing conditions:

$$NEM_{DIT} = Z_0 - 2.5 \times \log\left(\frac{noise[ADU]}{DIT[s]}\right)$$

To derive the limiting magnitude after a longer observing time, we extrapolate this result to a typical time of 15 minutes, taking into account that:

• at short wavelengths, we increase the DIT to a typical value of $T_{max} = 30$ s where the signal/noise ratio increases as DIT (RON limited), and then we co-add N images for which signal/noise increases as $\sqrt{N}$:

$$NEM_{900s} = NEM_{DIT} + 2.5 \times \log \frac{T_{max}}{DIT} + 2.5 \times \log \sqrt{\frac{900}{T_{max}}}$$

• at long wavelengths, this will be done by coadding N frames, and the signal/noise ratio increases as $\sqrt{N}$ since the background is the limiting factor (BLIP conditions):

$$NEM_{900s} = NEM_{DIT} + 2.5 \times \log \sqrt{\frac{900}{DIT}}$$

This gives the noise equivalent magnitude corresponding to the noise equivalent power, for one pixel, for a signal/noise ratio of 1, and for an equivalent integration time T_{eq} of 15 minutes. We then scale it to a signal/noise ratio of 5.

All the results are given in Table 3.

4.2.2 Point-like sources

We have calculated the NEM for 1 pixel. There are two factors decreasing the limiting magnitude for a point-like source:

1. All the energy is not in only one pixel because of the diffraction, and there is a detector filling factor of 74 %. The pixel sampling is fixed by the two optics available, which leads to an oversampling in K, M, . . . We compute this diffraction dilution coefficient (DDC) as (E. Gendron, 1995, PhD, Université Paris 7):

$$DDC = \frac{\pi}{4} \times \frac{1 - o^2}{u^2}$$

where

Table 3: Limiting Magnitudes, $\frac{S}{N} = 5$, $T_{eq} = 900$ s.

Band	NEM	Point source Mag	 Strehl %	Extended source Mag/arcsec^2
J	16.8	13.0	30	9.3
H	16.9	12.5	30	9.4
K	16.5	11.8	40	9.0
L	13.9	10.7	50	8.6
L'	13.5	10.1	50	8.2
M	11.6	7.7	50	6.3

o = 0.47 (cold diaphragm occultation)

u = $\frac{\lambda}{D}$ [pixel units] D = primary mirror diameter.

2. Diffraction theory indicates that for a *perfect* PSF, with a Strehl Ratio of 1, and without any central occultation, 84% of the energy is in the central core, i.e. within 2.44 FWHM diameter, 45.6% within the core FWHM diameter. When an adaptive optics servo-loop is aiming at diffraction-limited images, residual errors are present which leave higher energies in the surrounding halo of the long-exposure PSF, and less energy in the central core: when the Strehl ratio is less than 1, the energy is spread on more pixels. Therefore, we calculate the limiting magnitude for a significant Strehl ratio, based on our experience.

We calculate the limiting magnitude for a given sampling and a given Strehl ratio, but not as a function of the FWHM which is not the relevant information for such an estimation: for a Strehl ratio of about 30 %, the FWHM is the same as the Airy pattern of the instrument, but the image is not the theoretical one, as the correction can still be improved.

Assuming that, we estimate the equivalent magnitude of the star as:

$$m_{lim}[\text{Mag}] = \text{NEM} + \Delta m_{sampling} + 2.5 \log(\text{Strehl})$$

where

$$\Delta m_{sampling} = 2.5 \log 0.74 + 2.5 \log DDC$$

4.2.3 Extended sources

For an extended source, we need to scale the NEM to the pixel size, taking into account the filling factor:

$$m_{lim}[\text{Mag/arcsec}^2] = NEM + \Delta m_{sampling} + 2.5 \log(Pix_{scale})^2[\text{arcsec}^2]$$

where

$$\Delta m_{sampling} = 2.5 \log 0.74$$

5. Conclusion

The main characteristics of the COMIC detector, as measured during the acceptance tests in Meudon and during the commissioning run in November 1995 show that this camera, in conjunction with the adaptive optics system ADONIS, is fully adapted to imaging operation in the 1–5 µm spectral band. The large dynamic range of the detector allows long exposure time imaging at all wavelengths, which is possible regarding the good quality of the images provided by the adaptive optics system. A new software, including real-time facilities such as shift-and-add, dead pixels removal, sky subtraction and flat fielding, statistics (S/N, histogram, diaphragm photometry), 3D view, zoom, one pixel versus time, batch sequences, automatic log-book, ..., allows the astronomers to evaluate and improve in real time the scientific output of their observations.

The first astronomical object observed with COMIC, the bright (M_V = 5.40) solar type star 51 Pegasus, clearly demonstrates the excellent imaging quality of ADONIS with the COMIC camera (see *The Messenger* No. 82, December 1995). The Figure 3 clearly demonstrates the excellent imaging quality of ADONIS with the COMIC camera, on the star HR 8720: the Strehl ratio is up to 60%, and the diffraction limit is achieved, in the M band, under a median seeing condition (not better than 1.5″).

Additional information is available on the ESO WEB site where under Adaptive Optics/Adonis there is an updated description of the instrumentation: www.hq.eso.org/aot/adonis/adonis.html#comic

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OTHER ASTRONOMICAL NEWS

5th ESO/OHP Summer School in Astrophysical Observations

Observatoire de Haute-Provence, France, 15–26 July 1996

M.-P. Véron, CNRS – Observatoire de Haute-Provence; P. Crane, ESO

The 5th ESO/OHP Summer School was hosted again at the Observatoire de Haute-Provence from 15–26 July. The school which has so far only been offered bi-annually, selects 18 of Europe's most promising young doctoral students in astronomy. Courses of lectures, observations and analysis form the intellectual menu. These are aimed at the

Figure 1: As in past years, the official group photo is taken during the break in the talk by Ray Wilson. The organisers are still trying to explain this occurrence. From left to right in the first row: Ray Wilson, M.-P. Véron, K. Eriksson, V. D'Odorico. Second Row: A. Fishburn, W. Gacquer, O. Barziv, N. Christlieb, D. Russeil, G. Dudziak, H. Gleisner, E. Pompei, C. Laffont, and C. Moutou. Third row: P. Crane, T. Stanke, A. Mathieu, M. Dennefeld, R. Voors, P. Royer, J.M. Perrin, J. Fynbo, S. Darbon, P. Goudfrooij, L. Kaper, B. Geiger, H. Schmidt. Missing: Torsten Böhm.