# E-ELT Imaging ETC: Detailed Description

Jochen Liske

Based on a document originally written by Pascal Ballester, Andrés Jordán, Markus Kissler-Patig & Jakob Vinther.

## 1. Preliminaries

As of Jan 2008 there exist two E-ELT ETCs. This document describes the the original, first E-ELT ETC in its imaging mode. The spectroscopic mode of this first ETC was obsoleted by a new, dedicated spectroscopic ETC which is described elsewhere.

Generally, a S/N calculation depends on a large number of parameters. To separate those parameters that are user inputs from those that are fixed, we use blue text to mark the user input parameters (and the available options for the parameter where applicable).

## 2. Definitions

This section defines all parameters, symbols, terms, units and formulae needed for the S/N calculation. More detailed explanations follow in Section 3.

- $m_{\rm obj}$: Object magnitude (for a point source or extended source) or object surface brightness in a specified band (options: $U$–$Q$) and magnitude system (Vega or AB). [mag or mag/arcsec$^2$]
- $r_h$: Half-light radius for use with an extended source. [mas]
- $F_0 \equiv 10^{-Z}$: Photometric zeropoint. [W/m$^2$/$\mu$m]

  May be either Vega or AB. The various values for the different bands are listed in Table 1.
- $F_{\rm obj}$: Object flux (point source or extended source) or surface brightness at the top of the atmosphere. [W/m$^2$/$\mu$m or W/m$^2$/$\mu$m/arcsec$^2$]

  $F_{\rm obj} = F_0 10^{-0.4\, m_{\rm obj}}$.

  Instead of $m_{\rm obj}$ the user can also directly specify $F_{\rm obj}$ [mJy or mJy/arcsec$^2$].

- Observatory site: Paranal-like or High and Dry.

  The choice of site affects the atmospheric extinction as well as the sky surface brightness in the mid-IR (but not in the optical or near-IR). Site parameters are listed in Table 2.

- $\chi$: Airmass.

  Affects the atmospheric extinction (but not the sky surface brightness).

- $D$: Telescope diameter. [m]

  Options: 8.2, 30 or 42 m. Note that changing this parameter only affects the size of the photon collecting area but *not* the PSF.

- $A$: Photon collecting area of the telescope. [m$^2$]

  $A = \frac{\pi}{4}(D^2 - d^2)$, where $d$ is the diameter of the central obstruction. We assume $d = 0.28\,D$, i.e. that the central obstruction reduces the unobscured collecting area by 8%.

- AO mode: Seeing limited (i.e. no AO), Ground Layer AO (GLAO) or Laser Tomography AO (LTAO). Affects the PSF.

- $\lambda_c$: Central wavelength of the chosen observing band. [$\mu$m]

- $p$: Pixel scale. [mas/pixel]

  Options: 5, 10, 50 or 100 mas.

- $\Omega_p$: Sky aperture per pixel. [mas$^2$/pixel]

  $\Omega_p = p^2$.

- $N_{\rm pix}$: Number of pixel in the S/N reference area.

  For a point source, $N_{\rm pix}$ is an input parameter. Options: $1 \times 1$, $3 \times 3$, $5 \times 5$ or $10 \times 10$ pixel.
  For an extended source or a constant surface brightness: $N_{\rm pix} = \Omega/(10^{-6}\,\Omega_p)$.

- $\Omega$: Size of the S/N reference area. [arcsec$^2$]

  For a point source: $\Omega = 10^{-6}\,N_{\rm pix}\,\Omega_p$.
  For an extended source: $\Omega = 10^{-6}\,\pi\,{r_h}^2$.
  For a constant surface brightness: $\Omega = 1$ arcsec$^2$.

- $\Delta\lambda$: Wavelength range that is used for the integration over wavelength. [$\mu$m]

  The various values for the different bands are listed in Table 1. $\Delta\lambda$ is equivalent to an effective filter width.

- $\xi$: Atmospheric extinction.

  Depends on site, airmass and the chosen observing band. $\xi = 10^{-0.4\,\chi\,k}$, where $k$ is the extinction coefficient for the chosen site and observing band. The various coefficients are listed in Table 3. Note: for now we only consider extinction due to scattering but neglect the atmospheric absorption at mid-IR wavelengths.

- $\hat{F}_{\rm obj}$: Object flux (point source or extended source) or object surface brightness at the telescope entrance. [W/m$^2$/$\mu$m or W/m$^2$/$\mu$m/arcsec$^2$]

  $\hat{F}_{\rm obj} = \xi F_{\rm obj}$.

- $\epsilon$: Total efficiency.

  Set to 0.5. This is the ratio between the number of detected photo-electrons and the number of photons incident at the telescope entrance, i.e. it includes the telescope, instrument and detector, but excludes the atmosphere.

- $E_\gamma$: Photon energy at $\lambda_c$. [J/$\gamma$]

  $E_\gamma = 1.985 \times 10^{-19}/\lambda_c$.

- $c$: Total conversion factor from energy flux incident at the telescope entrance to detected number of photo-electrons. [e$^-$/s per W/m$^2$/$\mu$m]

  $c = \epsilon\ \Delta\lambda\ A/E_\gamma$.

- $T$: Detector exposure time for one exposure (DIT). [s]

- $n_{\rm exp}$: Number of exposures (NDIT).

- $e$: Ensquared energy or fraction of PSF in the S/N reference area.

  For a point source this value is looked up in Table 5, 6 or 7 as appropriate for the chosen AO mode, using the observing band and the linear size of the S/N reference area as input.
  For an extended source: $e = 0.5$.
  For a constant surface brightness this parameter is not needed.

- $N_{\rm obj}$: Number of detected electrons from object in the S/N reference area per exposure. [e$^-$]

  For a point source or an extended source: $N_{\rm obj} = \hat{F}_{\rm obj}\ e\ c\ T$.
  For a constant surface brightness: $N_{\rm obj} = \hat{F}_{\rm obj}\ \Omega\ c\ T$.

- $m_{\rm sky}$: Sky surface brightness in selected observing band. [mag/arcsec$^2$]

  The various values for the different bands are listed in Table 3.

- $F_{\rm sky}$: Sky surface brightness at the top of the atmosphere. [W/m$^2$/$\mu$m/arcsec$^2$]

  $F_{\rm sky} = F_0 10^{-0.4\, m_{\rm sky}}$.

- $\hat{F}_{\rm sky}$: Sky surface brightness at the telescope entrance. [W/m$^2$/$\mu$m/arcsec$^2$]

  $\hat{F}_{\rm sky} = \xi F_{\rm sky}$.

- $N_{\rm sky}$: Number of detected electrons from the background in the S/N reference area per exposure. [e$^-$]

  $N_{\rm sky} = \hat{F}_{\rm sky}\, \Omega\, c\, T$.

- $d$: Detector dark current. [e$^-$/s/pixel]

  Set to 2, 4 and 2000 e$^-$ per hour for the optical, near-IR and mid-IR wavelength regions, respectively. I.e. $d = 0.00056$, 0.0011 and 0.56 e$^-$/s for these regions.

- $r$: Detector read-out noise. [e$^-$/pixel]

  Set to 2, 3 and 200 e$^-$ for the optical, near-IR and mid-IR wavelength regions, respectively.

- $S/N$: Signal-to-noise ratio.

$$S/N = \frac{\sqrt{n_{\rm exp}}\, N_{\rm obj}}{\sqrt{N_{\rm obj} + N_{\rm sky} + N_{\rm pix}\, r^2 + N_{\rm pix}\, d\, T}}.$$

## 3. Explanations

### 3.1. The target

The target's flux is specified by giving its magnitude in any one of the allowed bands ($U$ to $Q$), and its flux distribution. The zeropoints of the magnitude scale may be either Vega or AB (cf. Table 1). The flux distribution determines a colour term which is applied to the input magnitude in case the band in which the object's magnitude is specified differs from the observation band (which can also be chosen from $U$ to $Q$). Unfortunately, no such colour terms are currently available for the $N$ and $Q$ bands. That means that the ETC will only work for these bands when the band of the target's magnitude and the observation band are both set to the same value. Alternatively, the target's flux at the central wavelength of the observation band may be specified directly in mJy.

The source geometry can be chosen to be a point source, an extended source or a constant surface brightness value. For an extended source the user must also specify its half-light radius, $r_h$, which is assumed to include the effects of the PSF (as chosen by the user, see below). Thus, a warning will be issued if the user specifies an $r_h$ smaller than the half-light radius of the PSF of the chosen AO mode. The values for these minimum $r_h$ values are listed in Table 4 and shown in Fig. 1. For the case of constant surface brightness the target magnitude is assumed to denote a surface brightness in mag/arcsec$^2$.

### 3.2. The S/N reference area

The S/N calculation is performed using the light collected in the 'S/N reference area'. For an extended source the ETC assumes that the light from the object (and the sky) is collected over an area $\pi r_h^2$, and that this area contains half of the object's total light as given by the user-specified target magnitude. For a constant surface brightness the light from the object (and sky) is collected over a fixed 1 arcsec$^2$. For a point source the user can choose the size of the S/N reference area as either $1 \times 1$, $3 \times 3$, $5 \times 5$ or $10 \times 10$ pixel. The size of the S/N reference area on the sky is of course further affected by the user's choice of the pixel scale.

The fraction of a point source's flux within a given S/N reference area is determined by the chosen AO mode: Seeing limited (i.e. no AO), Ground Layer AO, or Laser Tomography AO. For a given AO mode and observing band the fractional energy ensquared by the S/N reference area is obtained from a look-up table. The tables for the various AO modes are reproduced in Tables 5, 6 and 7, and are presented graphically in Figs. 2, 3 and 4. The values in these tables were measured from simulated PSFs provided by M. Le Louarn. All PSF simulations assume a DIMM seeing of FWHM = 0.8 arcsec at 0.5 $\mu$m and a 42 m telescope. Note that we do not have simulations for an 8.2 or 30 m telescope, which can also be chosen by the user. Hence, making these choices for the diameter affects only the photon collecting area, but *not* the PSF. Similarly, the PSFs do not change when selecting different sites or airmasses. Finally, we note that the E-ELT is likely to offer AO modes other than those listed above, such as Multi-Conjugate AO or Extreme AO. Currently, we lack appropriate PSF simulations to properly include these AO modes in the ETC. However, in the case of MCAO it is probably not too unreasonable to assume similar performance as for LTAO.

### 3.3. The sky

The broad-band optical sky brightness has contributions from a number of sources, chiefly: diffuse galactic emission, zodiacal light, moonlight scattered by the atmosphere and airglow. Hence, in practice the sky brightness in a given band at a given position in the sky depends on a number of parameters, including the position's location with respect to the galaxy, ecliptic and moon, the moon phase, the phase of the solar cycle, the season, the observatory's geomagnetic latitude and airmass. Compared to the darkest possible sky most of these systematic effects increase the sky brightness by up to several tenths of a magnitude. The moon has the largest effect – up to several magnitudes in the blue. In addition, even when all known systematic effects are accounted for, the sky brightness still fluctuates by $\sim$0.2 mag on timescales of minutes, hours and nights, probably due to airglow variations. Unfortunately, even if we concentrate only on the most prominent effect (the moon) and ignore all others, an accurate model of the sky brightness still requires a complexity that is beyond most ETCs. The above should serve as a warning that the sky brightness values adopted in the following are approximate only.

For the $UBVRI$ bands we adopt the 'standard' ESO ETC sky brightness values for a moon phase of 3 days from new moon. However, at the bottom of the results page the ETC also presents the results using the 'standard' sky values for 0 and 7 days from new moon.

In $JHK$ the sky brightness is dominated by OH airglow and/or thermal emission and is hence independent of the moon's phase. However, the airglow is known to vary systematically as a function of season and time of night, as well as randomly on shorter timescales and as a function of position on the sky. We again adopt the 'standard' ESO ETC values.

Because of the lack of data the sky brightness in the optical and near-IR is assumed to be independent of the site. Any dependence on airmass is also ignored.

From the second half of the $K$-band onwards the background is dominated by the thermal emission from the atmosphere and the telescope. The atmospheric emission was calculated by A. Smette using the HITRAN molecular database and assuming a tropical atmospheric profile. Molecules included are: $H_2O$, CO, $CO_2$, $CH_4$, $O_2$, $O_3$ and $N_2O$. These calculations were performed for two different sites: (i) a Paranal-like site and (ii) a High and Dry site at an altitude of 5000 m. The assumed characteristics of each site are listed in Table 2.

The emission from the telescope is modeled as a grey body, i.e. as a black body multiplied by a constant emissivity of 0.14 (corresponding to 5 aluminium-coated mirrors) and a temperature equal to the selected site's ambient temperature.

All sky values are listed in Table 3. Note that the site only affects the sky brightness at mid-IR wavelengths.

Table 1. Filter definitions

| Band | Central wavelength [$\mu$m] | Effective filter width [$\mu$m] | $Z_{\rm Vega} = -\log F_0$ [W/m$^2$/$\mu$m] | $Z_{\rm AB} = -\log F_0$ [W/m$^2$/$\mu$m] |
|---|---|---|---|---|
| $U$ | 0.36 | 0.068 | 7.38 | 7.09 |
| $B$ | 0.44 | 0.098 | 7.18 | 7.25 |
| $V$ | 0.55 | 0.089 | 7.44 | 7.44 |
| $R$ | 0.64 | 0.220 | 7.64 | 7.58 |
| $I$ | 0.79 | 0.240 | 7.91 | 7.77 |
| $J$ | 1.25 | 0.250 | 8.51 | 8.14 |
| $H$ | 1.65 | 0.330 | 8.94 | 8.39 |
| $K$ | 2.16 | 0.390 | 9.40 | 8.64 |
| $L$ | 3.450 | 0.472 | 10.32 | 9.04 |
| $M$ | 4.800 | 0.450 | 10.69 | 9.32 |
| $N$ | 10.500 | 5.190 | 11.91 | 10.00 |
| $Q$ | 20.100 | 7.800 | 13.17 | 10.57 |

Table 2. Assumed site characteristics

| Site | Altitude [m] | Temperature [K] | Pressure [mb] | PWV [mm] |
|---|---|---|---|---|
| Paranal | 2600 | 285 | 743 | 2.3 |
| High and Dry | 5000 | 270 | 540 | 0.5 |

Table 3. Extinction coefficients and sky brightness values (for 3 days from new moon)

| Band | Paranal-like | | High and Dry | |
|---|---|---|---|---|
| | $k$ [mag/airmass] | $m_{\rm sky}$ [mag/arcsec$^2$] | $k$ [mag/airmass] | $m_{\rm sky}$ [mag/arcsec$^2$] |
| $U$ | 0.46 | 21.87 | 0.28 | 21.87 |
| $B$ | 0.20 | 22.43 | 0.12 | 22.43 |
| $V$ | 0.11 | 21.62 | 0.07 | 21.62 |
| $R$ | 0.07 | 20.95 | 0.04 | 20.95 |
| $I$ | 0.00 | 19.71 | 0.00 | 19.71 |
| $J$ | 0.00 | 16.0 | 0.00 | 16.0 |
| $H$ | 0.00 | 14.0 | 0.00 | 14.0 |
| $K$ | 0.00 | 13.0 | 0.00 | 13.0 |
| $L$ | 0.00 | 5.3 | 0.00 | 6.2 |
| $M$ | 0.00 | 1.3 | 0.00 | 2.3 |
| $N$ | 0.00 | −3.7 | 0.00 | −3.2 |
| $Q$ | 0.00 | −6.5 | 0.00 | −5.8 |

Note. — The extinction does not account for atmospheric absorption which is non-negligible for the $K$ and redder bands. The site only affects the sky brightness at mid-IR wavelengths. Any site dependence at optical and near-IR wavelengths is ignored. Any airmass dependence is also ignored (at all wavelengths). The sky brightness values are given in Vega mags.

Table 4. Minimum $r_h$

| Filter | $r_{h,\rm min}$ [″] No AO | GLAO | LTAO |
|---|---|---|---|
| $U$ | 0.400 | 0.371 | 0.340 |
| $B$ | 0.385 | 0.354 | 0.320 |
| $V$ | 0.365 | 0.332 | 0.292 |
| $R$ | 0.344 | 0.307 | 0.262 |
| $I$ | 0.321 | 0.280 | 0.227 |
| $J$ | 0.291 | 0.243 | 0.169 |
| $H$ | 0.267 | 0.211 | 0.109 |
| $K$ | 0.240 | 0.177 | 0.023 |
| $L$ | 0.201 | 0.132 | 0.017 |
| $M$ | 0.173 | 0.099 | 0.018 |
| $N$ | 0.107 | 0.052 | 0.035 |
| $Q$ | 0.082 | 0.068 | 0.065 |

Note. — $r_{h,\rm min}$ is the smallest allowed half-light radius for extended objects. It is defined as the 50% encircled energy radius of the PSF (simulated for a $D$ = 42 m telescope).

Table 5. Ensquared energies for seeing limited case (no AO)

| Linear size of S/N ref. area [mas] | Percentage of energy enclosed in the S/N reference area $U$ | $B$ | $V$ | $R$ | $I$ | $J$ | $H$ | $K$ | $L$ | $M$ | $N$ | $Q$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 0.00379 | 0.00427 | 0.00465 | 0.00538 | 0.00627 | 0.00784 | 0.00775 | 0.0105 | 0.0241 | 0.0600 | 0.263 | 0.143 |
| 10 | 0.0152 | 0.0168 | 0.0185 | 0.0216 | 0.0251 | 0.0309 | 0.0330 | 0.0448 | 0.0970 | 0.238 | 1.05 | 0.570 |
| 15 | 0.0345 | 0.0377 | 0.0415 | 0.0483 | 0.0571 | 0.0689 | 0.0796 | 0.108 | 0.210 | 0.504 | 2.32 | 1.28 |
| 25 | 0.0958 | 0.104 | 0.116 | 0.136 | 0.157 | 0.198 | 0.241 | 0.313 | 0.565 | 1.32 | 5.69 | 3.57 |
| 30 | 0.138 | 0.149 | 0.167 | 0.194 | 0.227 | 0.287 | 0.347 | 0.454 | 0.793 | 1.79 | 7.59 | 5.09 |
| 50 | 0.383 | 0.418 | 0.465 | 0.534 | 0.625 | 0.777 | 0.964 | 1.21 | 2.12 | 4.14 | 18.2 | 11.8 |
| 100 | 1.52 | 1.66 | 1.86 | 2.12 | 2.46 | 3.07 | 3.68 | 4.78 | 7.86 | 11.8 | 32.2 | 37.5 |
| 150 | 3.36 | 3.67 | 4.11 | 4.68 | 5.42 | 6.66 | 8.04 | 10.1 | 15.4 | 21.7 | 41.6 | 51.2 |
| 250 | 8.98 | 9.76 | 10.8 | 12.3 | 14.0 | 16.9 | 20.0 | 24.0 | 32.9 | 40.1 | 58.2 | 60.8 |
| 300 | 12.6 | 13.6 | 15.1 | 17.0 | 19.3 | 23.0 | 26.9 | 31.7 | 41.1 | 48.4 | 63.2 | 67.0 |
| 500 | 30.2 | 32.2 | 34.9 | 38.2 | 42.1 | 47.6 | 52.6 | 58.0 | 66.1 | 70.7 | 78.6 | 80.6 |
| 1000 | 70.5 | 72.2 | 74.4 | 76.9 | 79.4 | 82.4 | 84.6 | 86.5 | 88.8 | 90.0 | 91.4 | 90.9 |

Note. — Measured from PSF simulations for a $D$ = 42 m telescope. DIMM seeing = 0.8 arcsec at 0.5 $\mu$m.

Table 6. Ensquared energies for GLAO

| Linear size of S/N ref. area [mas] | Percentage of energy enclosed in the S/N reference area | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *U* | *B* | *V* | *R* | *I* | *J* | *H* | *K* | *L* | *M* | *N* | *Q* |
| 5 | 0.00460 | 0.00524 | 0.00613 | 0.00752 | 0.00974 | 0.0155 | 0.0220 | 0.0495 | 0.378 | 0.738 | 0.499 | 0.171 |
| 10 | 0.0184 | 0.0208 | 0.0243 | 0.0300 | 0.0384 | 0.0592 | 0.0884 | 0.188 | 1.25 | 2.60 | 2.00 | 0.683 |
| 15 | 0.0413 | 0.0465 | 0.0550 | 0.0659 | 0.0866 | 0.129 | 0.199 | 0.397 | 2.52 | 5.04 | 4.42 | 1.54 |
| 25 | 0.115 | 0.128 | 0.149 | 0.186 | 0.233 | 0.347 | 0.553 | 1.02 | 4.58 | 11.5 | 10.5 | 4.27 |
| 30 | 0.166 | 0.185 | 0.217 | 0.266 | 0.336 | 0.497 | 0.782 | 1.43 | 5.50 | 13.2 | 14.2 | 6.19 |
| 50 | 0.458 | 0.513 | 0.602 | 0.732 | 0.915 | 1.36 | 2.06 | 3.66 | 9.85 | 18.5 | 34.0 | 14.1 |
| 100 | 1.81 | 2.03 | 2.38 | 2.87 | 3.59 | 5.12 | 7.36 | 11.4 | 22.8 | 34.6 | 51.9 | 44.9 |
| 150 | 4.01 | 4.49 | 5.21 | 6.23 | 7.74 | 10.7 | 14.9 | 21.1 | 34.0 | 45.2 | 61.1 | 59.6 |
| 250 | 10.6 | 11.7 | 13.4 | 15.8 | 19.0 | 24.9 | 31.4 | 39.8 | 52.1 | 60.3 | 74.9 | 68.6 |
| 300 | 14.7 | 16.3 | 18.5 | 21.5 | 25.4 | 32.2 | 39.3 | 47.6 | 59.0 | 66.0 | 77.5 | 74.7 |
| 500 | 34.1 | 36.8 | 40.4 | 44.8 | 49.8 | 56.8 | 62.7 | 68.5 | 75.9 | 79.9 | 85.7 | 86.0 |
| 1000 | 73.7 | 75.4 | 77.6 | 79.9 | 82.1 | 84.7 | 86.6 | 88.3 | 90.3 | 91.5 | 93.2 | 92.7 |

Note. — Measured from PSF simulations for a $D = 42$ m telescope.

Table 7. Ensquared energies for LTAO

| Linear size of S/N ref. area [mas] | Percentage of energy enclosed in the S/N reference area | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *U* | *B* | *V* | *R* | *I* | *J* | *H* | *K* | *L* | *M* | *N* | *Q* |
| 5 | 0.00641 | 0.00850 | 0.0239 | 0.218 | 1.34 | 4.65 | 6.48 | 6.60 | 4.55 | 2.75 | 0.648 | 0.182 |
| 10 | 0.0254 | 0.0338 | 0.0752 | 0.451 | 2.46 | 10.2 | 17.4 | 21.5 | 14.5 | 9.72 | 2.59 | 0.727 |
| 15 | 0.0569 | 0.0748 | 0.148 | 0.676 | 3.39 | 12.2 | 23.0 | 31.2 | 28.8 | 18.9 | 5.83 | 1.64 |
| 25 | 0.156 | 0.201 | 0.353 | 1.10 | 4.48 | 16.5 | 29.1 | 38.4 | 47.3 | 42.4 | 13.7 | 4.54 |
| 30 | 0.224 | 0.285 | 0.482 | 1.33 | 4.86 | 17.4 | 32.3 | 42.2 | 52.3 | 48.1 | 18.2 | 6.54 |
| 50 | 0.619 | 0.774 | 1.19 | 2.49 | 6.58 | 19.6 | 35.5 | 51.6 | 60.7 | 60.0 | 44.8 | 15.1 |
| 100 | 2.42 | 2.96 | 4.15 | 6.86 | 12.5 | 25.1 | 40.3 | 55.9 | 72.5 | 78.8 | 66.2 | 47.8 |
| 150 | 5.31 | 6.37 | 8.44 | 12.4 | 19.2 | 32.3 | 45.0 | 59.0 | 75.5 | 80.6 | 75.0 | 63.2 |
| 250 | 13.5 | 15.7 | 19.4 | 24.8 | 32.4 | 44.7 | 55.3 | 65.6 | 78.8 | 84.4 | 87.1 | 72.0 |
| 300 | 18.4 | 21.2 | 25.3 | 31.2 | 38.5 | 49.9 | 59.5 | 68.6 | 79.9 | 85.3 | 87.9 | 78.4 |
| 500 | 39.5 | 43.0 | 47.7 | 53.0 | 58.6 | 65.4 | 71.3 | 77.3 | 84.7 | 88.3 | 91.7 | 89.0 |
| 1000 | 75.9 | 77.3 | 79.0 | 80.9 | 82.8 | 85.0 | 86.6 | 88.0 | 90.7 | 92.5 | 94.6 | 93.8 |

Note. — Measured from PSF simulations for a $D = 42$ m telescope.

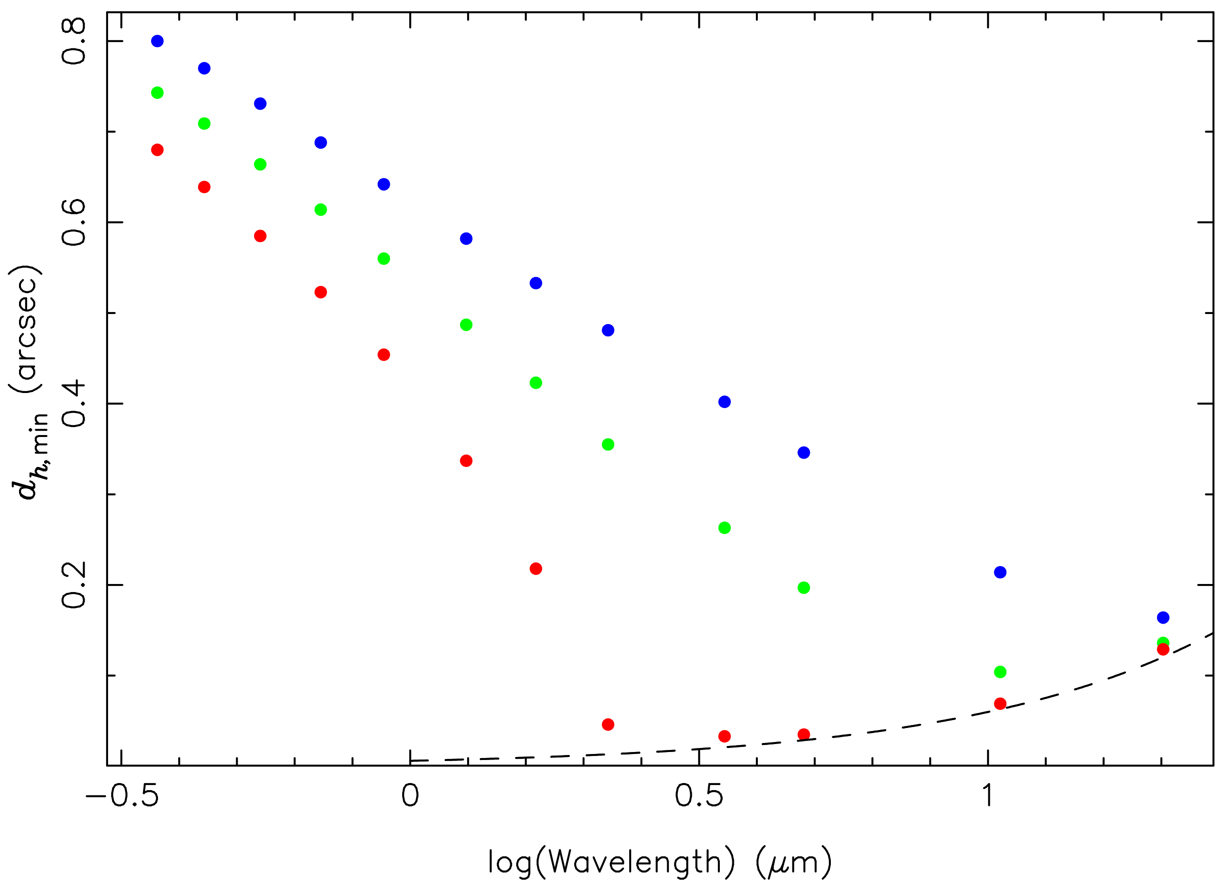


Fig. 1.— $d_{h,\mathrm{min}}$ = 50% encircled energy diameter as a function of band, i.e. a graphical representation of Table 4. Blue = no AO, green = GLAO, red = LTAO. The dashed line shows the radius of the diffraction limited core of a perfect PSF for a $D = 42$ m telescope.

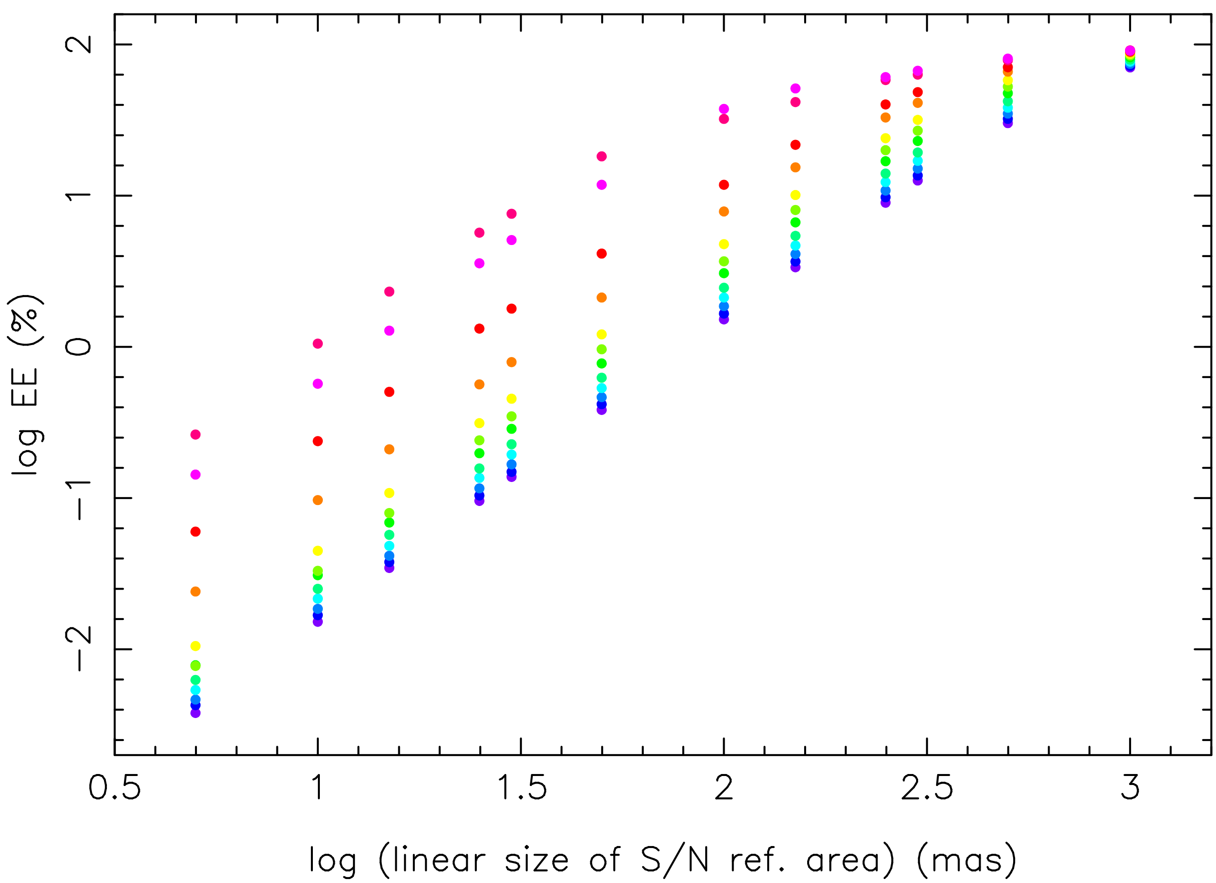


Fig. 2.— Ensquared energy as a function of the linear size of the S/N reference area for no AO, i.e. a graphical representation of Table 5. Different bands are represented by differently coloured points.

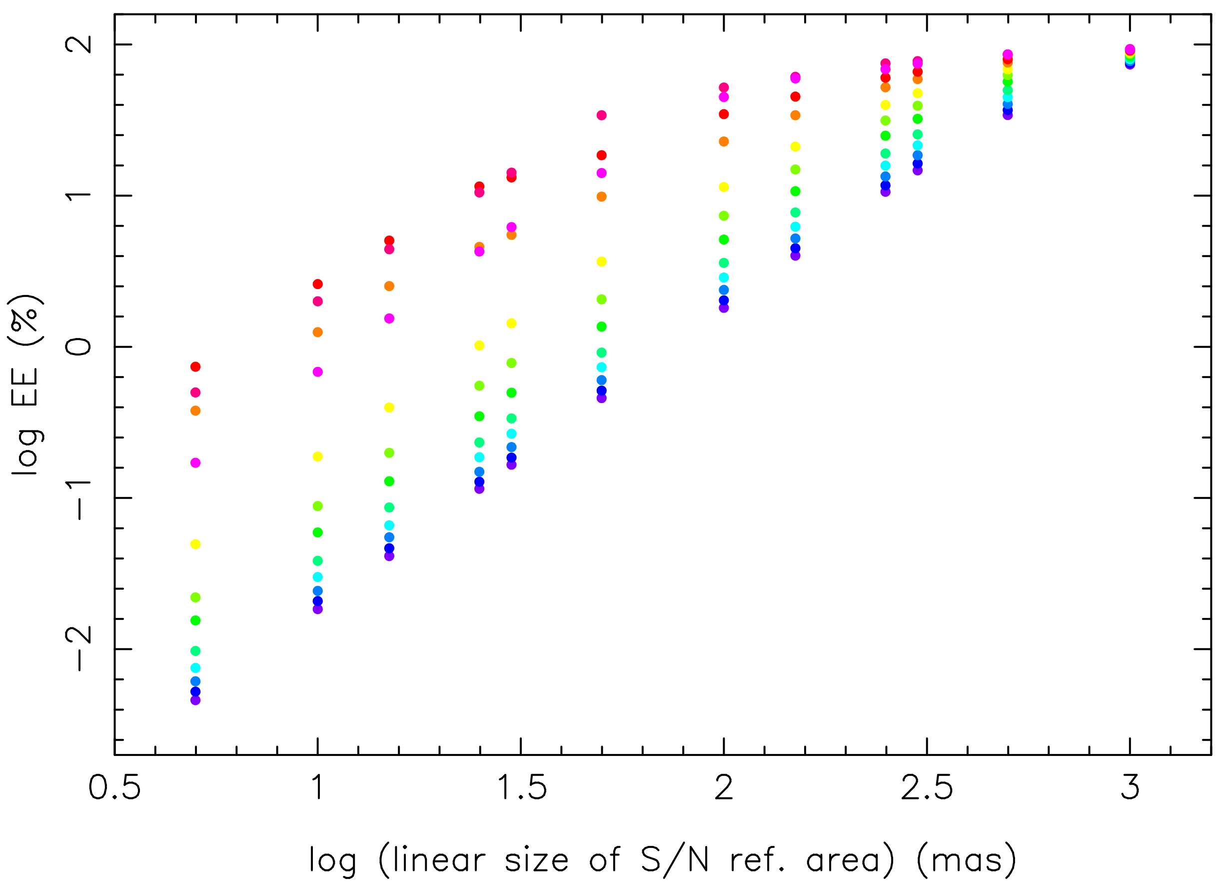


Fig. 3.— Ensquared energy as a function of the linear size of the S/N reference area for GLAO, i.e. a graphical representation of Table 6. Different bands are represented by differently coloured points.

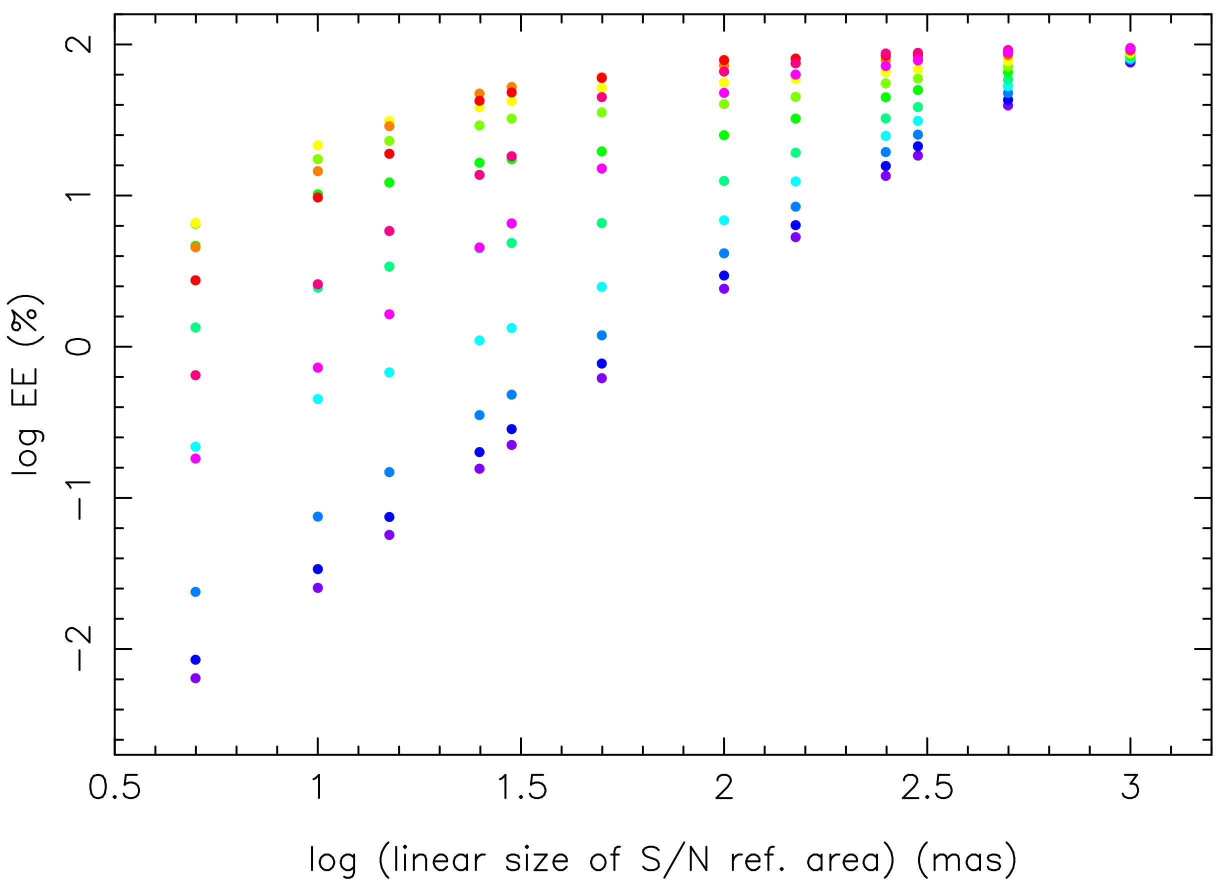


Fig. 4.— Ensquared energy as a function of the linear size of the S/N reference area for LTAO, i.e. a graphical representation of Table 7. Different bands are represented by differently coloured points.