Southern African Large Telescope

PI Tool Spectrum Simulator Requirements

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Document Number: SALT-3172AS0005

Revision 1.1
27 Feb 2004

Change History

Rev	Date	Description
1.0	21 Jan, 2004	Original
1.1	27 Feb, 2004	Correct Zodiacal Light, Airglow, and Moonlight formulae

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1 Interfaces

The SALT PI tool consists of a telescope simulator, to be developed by the SALT team, the instrument simulators, to be developed by the instrument teams, and a spectrum input simulator, which is being developed by the PFIS team and supplied to SALT. The spectrum input simulator will obtain target and Moon data from the telescope or from user inputs, and output to the instruments a target and sky spectral power as seen at the focal plane of the telescope. The spectra will be sampled on a 0.0625 Å grid over a range of 3140 - 9000 Å. The spectra and their UBVRI magnitudes will be displayed on the spectrum generator tool.

Global Inputs:

A_{tel} = Telescope geometric area (cm^2)	default: 61.1 m^2
Z = Target zenith distance (deg)	default: 37°
ℓ-ℓ_{sun}, b = Target ecliptic coordinates (deg)	default: Ecliptic South Pole
t = Observation JD	default: 2453371.5 [2005.0]
Z_M = Lunar zenith angle (deg)	default: 180° [nadir]
β = Lunar phase angle (deg)	default: 180° [new Moon]
ρ = Target- Moon Separation (deg)	default: 180°

Global Data:

$k(\lambda)$ = Sutherland mean extinction (mag/airmass)

$C_{mir}(\lambda)$ = Telescope coating efficiency (roughly 0.76)

$S_{A1}(\lambda)$ = Airglow spectrum at zenith, solar maximum

$F_{sun}(\lambda)$ = solar flux

2 Target Object.

The target object may be either a point target or a uniform diffuse target, in which case the spectrum will be per $arcsec^2$. It will be any of six types of spectra, or, optionally, their sum:

$$P_t(\lambda) = A_{tel}\, C_{mir}(\lambda)\, 10^{-0.4\, k(\lambda) \sec Z} \times$$

$$(O_B(T,V) + O_P(\mathrm{Index},V) + O_C(V) + O_{L,i}(F_i,\lambda_i,\sigma_i) + O_*(T,g,Z.V.E(B\text{-}V)) + O_U)$$

(erg/s-Å. or erg/s-Å-$arcsec^2$ at focal plane)

The spectrum types are:

2.1 BlackBody

$O_B\ (T,V) = a\ \lambda^{-5} / (e^{hc/\lambda kT} - 1)$

T = Temperature, (° K) (default: solar)

V= V magnitude normalization (above atmosphere) (default: 20)

2.2 Power Law

$O_P\ (\nu, V) = b\ \lambda^{\nu}$

ν = power law index (default: -2)

2.3 Flat Continuum

$O_C(V) = c$

2.4 Gaussian Emission Line

$O_{L,i}\ (F_i\ , \lambda_i\ , \sigma_i\ )$. i = 1,...,n lines

F_i = Flux of i^{th} line (erg/s/cm^2) (default: TBD)

λ_i = central wavelength of i^{th} line (default: Hα)

σ_i = guassian width of i^{th} line (default: very small)

2.5 Kurucz Model

O_* (T, g, z, V, E(B-V))

g = log Gravity (default: solar)

z = log metallicity/ solar (default: 0)

E(B-V) = interstellar extinction (CCM, R = 3.1) (default: 0)

2.6 User Supplied Spectrum

O_U is given in an ASCII file of multiple columns of which the first column is wavelength (Å) and the second column is $F_{\lambda;}$ subsequent columns are ignored.

3 Sky

The sky spectrum will be the predicted sky spectral power per arcsec^2 at the focal plane in the direction of the target. It will be modeled as three components, airglow, zodiacal light, and moonlight.

$$P_S\ (\lambda) = A_{tel}\ C_{mir}\ (\lambda)\ (S_A(t, Z) + S_z(b, \ell\text{-}\ell_{sun}\ , Z) + S_M(Z_M, \beta, \rho, Z))$$

(erg/s-Å-arcsec^2 at the focal plane)

This model is considerably more sophisticated than other PI tools we have seen, which (at best) model the sky as a continuum depending only on the lunar phase. We believe a good sky model is important for SALT since it is completely queue scheduled, and allowing the PI to specify the required sky darkness more precisely than lunar phase will make more efficient use of telescope grey time and will decrease the likelihood of poor signal/ noise due to sky conditions. If the maximum sky brightness is specified by the PI in V magnitudes based on running this tool, the queue scheduler can determine each night whether the sky brightness criterion is met.

3.1 Airglow

The airglow spectrum will be based on the high resolution moonless sky spectrum obtained by UVES (Hanischik 2003). These data must be corrected to the zenith by removing the correction to above the atmosphere that was applied by Hanischik, and re-correcting to the zenith (airmass 1) using the extinction correction more appropriate for airglow (Krisciunas & Schaefer 1991). This spectrum is then adjusted to the dark sky UBVRI for Sutherland (factor $e(\lambda)$)

$S_{cor}(\lambda) = S_{UVES}\ e(\lambda)\ 10\hat{}[-0.4\ k(\lambda)\ X_{UVES}]/(X_{UVES}\ 10\hat{}[-0.4\ k(\lambda)\ (X_{UVES}-1)]\ )$ (erg/s-cm^2-Å-arcsec^2)

λ	$e(\lambda)$	$X_{UVES}(\lambda)$
$\lambda < 3750$	0.6	1.143
$3750 < \lambda < 4810$	0.6	1.241
$4810 < \lambda < 6750$	0.8	1.144
$\lambda > 6750$	0.8	1.108

Next, we assume the UVES spectrum is at solar maximum, and remove the appropriate amount of zodiacal light: We find the typical zodiacal light in the anti-solar hemisphere (section 3.2 below) to be 60 S_{10} units (10^{th} mag stars per deg^2) in the V-Band. The corrected UVES spectrum above is 280 S_10. Hence zodiacal light is 60/ 280 = 0.21 of the dark sky at solar maximum and may be removed at all wavelengths as follows:

$$S_{A1} = S_{cor} - 0.21 <S_{cor}(V)> (f_{sun}(\lambda)/f_{sun}(5500))$$

where $<S_{cor}(V)>$ is the mean of S_{cor} over the V band: 280 S_10 = 8.18×10^{-18} erg/s-cm^2-Å-arcsec^2, and $f_{sun}(\lambda) = F_{sun}(\lambda)\times10\hat{}[-0.4\ k(\lambda)]$, the solar spectrum at the zenith. S_{A1} is stored as data in the program.

To simulate the airglow contribution to the sky at zenith distance Z and time t,

$$S_A(\lambda) = S_{A1}(\lambda)\ X(Z)\ 10\hat{}[-0.4\ k(\lambda)\ (X(Z)-1)]\ \ g(t)$$

where

$$X(Z) = (1 - 0.96 \sin^2 Z)^{-0.5}$$

is the effective airmass for atmospheric radiation (Krisciunas & Schaefer 1991), and

$$g(t) = (1 + C_s \cos 2\pi(t - t_0)/P_s)]/(1+ C_s),$$

is a fit to data in Krisciunas (1997) to model the effect of the solar cycle. Here

C_S = amplitude of solar modulation of airglow = 0.37

P_S = current period of solar cycle = 9.67 yrs

t_0 = time of cycle 23 maximum = 2001.5

3.2 Zodiacal Light

The zodiacal light model takes the solar spectrum normalized at 5500 Å, corrects for atmospheric extinction, and multiplies by a fit of zodiacal light photometry by Levasseur-Regourd & Dumont (1980) vs ecliptic latitude b and solar elongation $\ell - \ell_{sun}$ for $\ell - \ell_{sun} > 60°$

$$S_z(\lambda) = 2.35\times10^{-20}\ (F_{sun}(\lambda)/F_{sun}(5500)) \times 10\text{^}(-0.4\ \ k(\lambda)\ \ \sec Z) \times h(\ell-\ell_{sun},b)$$

where

$$h(\ell-\ell_{sun},b) = (C_{z0} + C_{z1}\ (1 - |\sin b|) +$$
$$C_{z2}\ (100° - (\ell-\ell_{sun}))/40° \times (\sin 45° - |\sin b|)/\sin 45°\ )\ (1 - |\sin b|),$$

in $S_{10}(V)$ units = 2.35×10^{-20} erg/s-cm^2-Å-arcsec^2, with

C_{z0} = 56.5 (S_{10} at ecliptic pol)

C_{z1} = 92.0 (additional S_{10} in ecliptic)

C_{z2} = 219.2 for $\ell < 100°$ and $b < 45°$, and = 0 otherwise (additional S_{10} in the ecliptic plane for $60° < \ell-\ell_{sun} < 100°$)

3.3 Moonlight

Finally, the moonlight simulation is based on a model for the V-Band brightness of moonlight in Krisciunas & Schaefer (1991), extrapolated to other wavelengths:

$$S_M\ (\lambda) = 1.12\ \times10^{-19}\ a(\lambda) \times (F_{sun}(\lambda)/F_{sun}(5500)) \times 10\text{^}[-0.4\ k(\lambda)\ X(Z_m)] \times$$
$$10\text{^}[-0.4(V_M\ (\beta) + 16.37)] \times (1 - 10\text{^}[-0.4\ k(\lambda)\ X(Z)]) \times f(\rho) \qquad (Z_m < 90°)$$

and S_M = 0 when the Moon is below the horizon.

Where

$$a(\lambda) = (1 + 2.1\times10^{-4}\ (\lambda - 5500)),$$

is a fit of the lunar albedo based on data in Dobber, et al (1998), normalized at λ = 5500 Å,

$$V_M\ (\beta) = -12.73 + 0.026\ |\beta| + 4\times10^{-9}\ \beta^4,$$

is the Lunar V magnitude as a function of phase β;

$$10\text{^}[-0.4(V_M(\beta) + 16.37]$$

is the illuminance of the Moon in footcandles, and

$$f(\rho) = (10^{5.36} (1.06 + \cos^2 \rho) (\lambda/5500)^{-4} + 10^{6.15 - \rho/40} (\lambda/5500)^{-0.5}) / (k(\lambda) / k(5500))$$

is the scattering phase function as a function of the target - Moon separation angle ρ. $f(\rho)$ is normalized in Krisciunas & Schaefer (1991) to give the brightness of Moonlight in nanoLamberts = 1.12×10^{-19} erg/s-cm^2-Å-arcsec^2. The extrapolation to wavelengths beyond the V-band is treated by the wavelength dependent albedo $a(\lambda)$ and the λ factors in $f(\rho)$, which assumes the Rayleigh scattering ~ λ^{-4} and the aerosol Mie scattering ~ $\lambda^{-0.5}$. The approximate correctness of this extrapolation was verified using moonlight data from Patat (2004). However, the observed moonlight appears to vary randomly by about a factor of two around the model, possibly because of natural variations in aerosol scattering,

3.4 Limitations

The sky model does not include the following effects

• the effect of the different heights of the various components of the airglow emission on the extinction correction. This is a < 15% effect at SALT's zenith distance.

• the zodiacal light "Gegenschein" for $\ell-\ell_{sun} > 150°$. This is a <30% effect. We approximate the zodiacal light as being constant with longitude for $\ell-\ell_{sun} > 100°$, which is good to about ±15%.

• The zodiacal light is underpredicted for $\ell - \ell_{sun} < 60°$. This is not a problem with SALT, since the minimum solar elongation out of astronomical twilight is 18° + (90° - 37°) = 71°.

• the lunar "opposition brightening" for $|\beta| < 7°$. This is only for one night out of the month. When exactly full, the Moon is about 35% brighter than the model. Given the observed random variations noted above, this is insignificant.

• moonlight when the Moon is below the horizon. This is possibly a more serious problem. An improvement would be to scale the Moonlight from the model to 0 as the Lunar elevation goes from 0 to -18°, the equivalent of astronomical twilight.

• twilight from the Sun. Another possible improvement.

4 References:

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