TELESCOPE TIME

A New Definition of Dark, Grey and Bright Time at ING

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The legacy method used to define dark, grey and bright time at ING is based on the fraction of the night for which the Moon is below the horizon. Although this is perfectly adequate for characterising dark time, it is less so for characterising grey and bright time. As the Moon ages the focus should change to quantifying the enhanced sky surface brightness from scattered moonlight.

The optical sky surface brightness of the moonlit sky in some line-of-sight depends primarily on the Fractional Lunar Illumination, FLI, followed in significance by the angular separation between the line-of-sight and the Moon, and by the altitude of the Moon. The FLI is given to a good approximation by

$$2\times FLI = 1 - \cos\beta \cos(\lambda - \lambda_{\odot})$$

where λ, $\lambda_{\odot}$ are the longitudes of the Moon and Sun respectively, and β is the latitude of the Moon. Partitioning a lunation by the fraction of each night for which the Moon is below the horizon correlates strongly with partitioning the Moon's longitude, since $|\beta| \leq 5.3°$, *but ignores the change in longitude of the Sun by* ~1° *per day*, and therefore does not give a consistent mapping onto FLI. As a result of this and the non-uniform motion of the Moon in its orbit, the FLI on, for example, the first and last bright nights in a given lunation can be as small as 0.45 and as large as 0.80. The difference in FLI on first and last bright nights exceeds 0.20 in ~30% of lunations, and exceeds 0.30 in ~5% of lunations. An important consequence of this is that the sky surface brightness on first and last bright nights can differ by as much as ~1.2 mag/arcsec^2 *with the Moon being present in the sky for the same fraction of each night*. Furthermore, in such asymmetric lunations the sky brightness in the moonlit part of grey nights can be up to ~1 mag/arcsec^2 *brighter* than in the moonlit part of the darkest bright night in the same lunation.

Inconsistent partitioning of lunations can lead to a mis-match between observing programme *requirements and actual* conditions. A programme allocated, for example, a specific grey-time award, based on some assumed "typical" grey-time sky background, can be scheduled in significantly brighter conditions, and vice versa, and this is detrimental to observing efficiency. These considerations prompted a reappraisal of the legacy method, and the derivation of a better alternative to it.

Sky Surface Brightness

The direct way to partition classically-scheduled time is in terms of the sky surface brightness itself, since it is this which impacts the signal-to-noise ratios for observations of a given integration time. The main contributors to the moonless sky optical surface brightness in a line-of-sight and in a specific bandpass are airglow, the zodiacal light and starlight. Benn and Ellison (1998) find the high galactic latitude, high ecliptic latitude, zenith V_{sky} brightness at solar minimum at the ORM to be V_{sky}=21.9 mag/arcsec^2. The sky is brighter at low latitudes by ~0.4 mag/arcsec^2, and at higher airmasses by ~0.3 mag/arcsec^2 (at X~1.5), and because of variable solar activity, the airglow component is brighter by ~0.4 mag/arcsec^2 at solar maximum. There is no dependence on extinction, A_V, for $A_V < 0.25$ mag/airmass. The contribution to the sky surface brightness from scattered moonlight when FLI ≥ 0.15 exceeds the spatial variations from airglow, zodiacal light and starlight, and so to partition classically-scheduled telescope time it is sufficient to partition by the illuminated fraction of the Moon's disc, acting as a proxy for the sky surface brightness from scattered moonlight.

Two scattering mechanisms dominate the background from moonlight; Mie scattering by aerosols and Rayleigh scattering by molecules. Mie scattering is highly forward, and so Rayleigh scattering dominates for scattering angles (i.e. angular distances from the Moon) ≥ 90°. Krisciunas & Schaefer (1991) derived scattering formulae to compute the contribution of moonlight to the sky background at some airmass as a function of lunar phase, lunar zenith distance, distance from the Moon and extinction. The uncertainty in these formulae is estimated to be ~0.25 mag/arcsec^2; local prevailing conditions such as enhanced levels of atmospheric dust will of course reduce their precision.

The mean ΔV_{Moon} from the V_{sky} = 21.9 mag/arcsec^2 dark sky is computed from these formulae for the Moon at a zenith distance of 60° (so that scattering angles of up to 120° are accommodated at airmasses ≤ 2), as a function of FLI in increments of 0.1, and at scattering angles ranging from 30° to 120° in increments of 5°, measured both in the azimuthal direction and in altitude (see Figure 1). The computed differences in both directions at a given scattering angle are only a few per cent. These calculations have been normalised to JKT *observations* of the moonlit sky, made by Chris Benn on dust-free nights in 1998. The effect of decreasing the Moon's zenith distance on ΔV_{Moon} at a given angular distance from it is small, $\lesssim 0.1$ magnitude, i.e roughly the same size as the points in Figure 1. ΔV_{Moon} *does* however fall off rapidly by ~1 magnitude/arcsec^2 when the Moon is low on the horizon. Therefore, Figure 1 forms a consistent basis for quantifying the effects of moonlight on the sky background at specific scattering angles from the Moon.

Several aspects of this Figure are noteworthy. As the scattering angle increases, the contribution of scattered moonlight to the sky surface brightness decreases up to ~90°, and then begins to increase again when Rayleigh scattering dominates. Therefore, in the presence of moonlight, a good strategy for optical observations is to observe in a broad annulus centred ~90° from the Moon whenever possible, in order to minimise the effects of scattered moonlight.

The gradient of scattered moonlight is remarkably flat at scattering angles ~90°. In fact, even at full Moon, the range in scattered moonlight within 70°–110° of the Moon is $\Delta V_{Moon} \lesssim \pm 0.1$. Therefore, it is sensible to quantify the contribution of scattered moonlight to the sky surface brightness in terms of ΔV_{Moon} computed ~90° from the Moon.

The FLI assumes greater importance in determining the sky surface brightness than angular distance from the Moon, for Moon separations $\gtrsim 50°$. The change in FLI is ~0.1 per day in the neighbourhood of quadratures, and therefore this emphasises the importance of having consistent partitions into grey and bright categories; inconsistent partitions are in general not compensated for by the distribution of targets on the sky in relation to the Moon.

The sky brightness approaching full Moon, i.e. zero lunar phase angle, increases strongly due to the opposition effect, which arises from a combination of shadow-hiding (the shadows of lunar particles are occulted by the particles themselves) and coherent backscattering (multiple scattering of sunlight off lunar dust grains, predominantly in the backward direction to the incident sunlight).

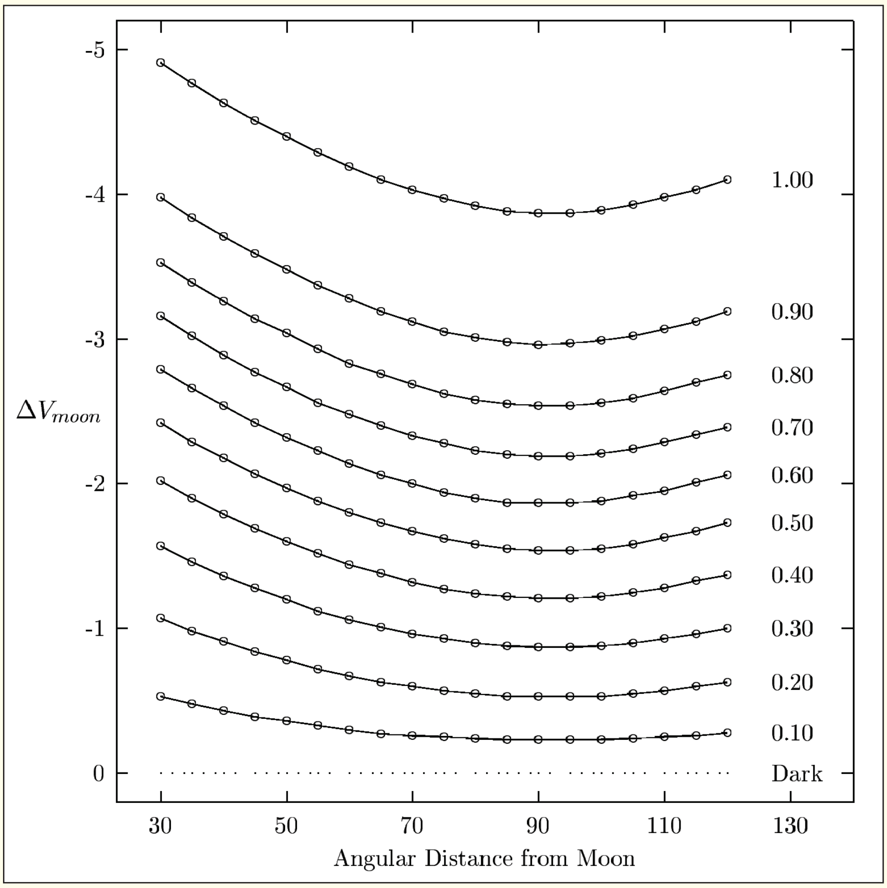

Figure 1. The brightening of the dark sky (V_{sky}=21.9 mag/arcsec^2, corresponding to low airmass, high ecliptic and galactic latitude, and solar minimum) by scattered moonlight, calculated as a function of fractional lunar illumination and angular distance from the Moon.

Dark, Grey and Bright Time

The definition of grey and bright thresholds is to some extent arbitrary. What is important is that the definition is both *sensible* and *consistent*, and that it is understood and agreed by applicants and TAC's, and adhered to in the scheduling process. Consistency in terms of sky surface brightness is achieved by partitioning on the fractional lunar illumination, acting as a proxy for sky surface brightness 90° distant from the Moon. In terms of sensibleness, the numbers of nights in each category should not be greatly different from the legacy method, but a small increase in the number of *grey* nights, at the expense of bright nights, is desirable to better match demand.

Averaged over a Saros cycle (~37 semesters), the *same* number of dark nights (9.6), 0.7 *additional* grey nights (7.9) and 0.7 *fewer* bright nights (12.0) *per lunation* result from the adopted partitioning scheme:

Dark: $0.00 \leq FLI < 0.25$
Grey: $0.25 \leq FLI < 0.65$
Bright: $0.65 \leq FLI \leq 1.00$

where the FLI is computed for 0h UT. Illuminated fraction changes by ~0.1 per day in the region of these thresholds, and this "resolution effect" means that inconsistencies in the FLI are constrained to be $\lesssim 0.1$ at the dark/grey and grey/bright boundaries.

For a given FLI, the fraction of the night for which the Moon is in the sky can vary by as much as ~25%, for the same reasons that the fraction of the night which is moonless does not consistently estimate the FLI. For example, at FLI=0.65 the Moon can be in the sky for between ~65% and ~90% of astronomical darkness. This could be taken into account for each night by scaling the moonlit sky surface brightness by this fraction to give a weighted background for the night, but on balance it is considered better to partition telescope time solely in terms of the *worst case* sky surface brightness computed ~90° from the Moon.

The predicted ranges in the zenith V sky surface brightness at high galactic and ecliptic latitudes, and solar minimum, and at an angular distance from the Moon of ~90°, are 21.2–21.9 mag/arcsec^2 for dark time, and 19.9–21.2 and 18.0–19.9 mag/arcsec^2 respectively for the *moonlit parts* of grey and bright time. For the mean sky, i.e. over all latitudes ~90° from the Moon, these ranges are ~0.5 mag/arcsec^2 *brighter* because of the larger contributions of airglow, zodiacal light and starlight.

This definition of dark, grey and bright time will be used in constructing the ING schedules from Semester 2002B onward. The exposure time calculator, `SIGNAL`, has been modified to offer an option specifying 'typical' sky surface brightnesses for dark, grey and bright time, corresponding to V_{sky}=21.50, 19.75 and 18.50 mag/arcsec^2 respectively.

A longer version of this article is available as *ING Technical Note No. 127*, available at URL `http://www.ing.iac.es/Astronomy/` `/observing/manuals/man_tn.html`

Acknowledgements

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References:

Benn, C. R. & Ellison, S. L., 1998, *ING Tech. Note*, **115**.

Krisciunas, K. & Schaefer, B. E., 1991, *PASP*, **103**, 1033.

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Important Dates

Deadlines for submitting applications

UK PATT:
15 March, 15 September

NL NFRA PC:
31 March, 30 September

SP CAT: **1 April, 1 October**

ITP: **30 June**

Semesters

Semester A:
1 February – 31 July

Semester B:
1 August – 31 January

Telescope Time Awards Semester 2002A

For observing schedules please visit this web page:
`http://lpss33.ing.iac.es:8080/cgi-bin/schedules.pl`

ITP Programmes on the ING Telescopes

- Doressoundiram (Paris), Multi-color taxonomy of trans-Neptunian objects. **ITP/2002/1**
- Ruiz-Lapuente (Barcelona), Supernova and the physics of supernova explosions. **ITP/2002/4**

William Herschel Telescope

UK PATT

- Axon (Hertfordshire), The Black Hole Mass-Velocity Dispersion Correlation. **W/2002A/38**
- Barcons (IF Cantabria), An XMM-Newton international survey (AXIS-II): unveiling the hard X-ray source populations. **ITP/2001/2 PB**
- Barnes (St Andrews), Starspot tracking on the W Ursae Majoris system BW Dra. **W/2002A/41**
- Benn, (ING), Adaptive-optics imaging of QSO host galaxies. **W/2002A/6**
- Bower (Durham), The Sauron Deep Survey. **W/2002A/50**
- Boyce (Bristol), K-band imaging of gas-rich low surface brightness galaxies found at 21cm. **W/2002A/52**
- Coggins (Nottingham), Mapping Elliptical Galaxy Mass Distributions using Gravitational Redshift. **W/2002A/35**
- Davies (Durham), Mapping Early Type Galaxies along the Hubble Sequence. **W/2002A/21**
- Dhillon (Sheffield), Coordinated optical and X-ray observations of the eclipsing polar HU Aqr. **W/2002A/9**
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- Gledhill (Hertfordshire), AO imaging of post-AGB circumstellar envelopes. **W/2002A/11**
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- Kleyna (IoA,Cambridge), Dark matter in the UMi dwarf spheroidal. **W/2002A/46**
- Kodama (Tokyo), History of Galaxy Mass Assembly in the Hierarchical Universe at $z\sim1$. **W/2002A/58**
- Marsh (Southampton), Magnetic braking and solar cycles in detached binary stars. **W/2002A/7**
- McMahon (IoA, Cambridge), Constraining the contribution to the UV background from $z=3$ and $z=5$ quasars. **W/2002A/78**
- Meikle (Imperial College), Detection and Study of Supernovae in Nuclear Starburst Regions. **W/2001B/34 (Long term)**
- Meikle (Imperial College), Detailed study of the physics of nearby Type Ia Supernovae. **W/2002A/49**
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- Miller (Oxford University), A Survey for wide-separation gravitational lenses from the 2dF QSO Redshift Survey. **W/2002A/33**
- Page (Mullard Space Science Lab/UCL), Optical identification of faint X-ray sources in a deep XMM-Newton/Chandra survey. **W/2002A/43**
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- Tanvir (Hertfordshire), Rapid imaging of GRB error boxes and spectroscopy of GRB-related optical/IR transients. **W/2002A/65**
- Unda Sanzana (Southampton), A new structure on U Gem? **W/2002A/51**