The Brightness of the Night Sky

Introduction

"When darkness is at its darkest, that is the beginning of all light."
- Lao-Tzu

The darkness, or brightness, of the night sky is a topic of interest to all amateur astronomers and astrophotographers. With growing light pollution we wonder how far do we have to travel to reach "dark" skies, and how much farther do we have to go to reach really dark skies?

How do factors such as man-made light pollution, natural air glow and light from interplanetary dust affect the darkness of the night sky? What about elevation, transparency and atmospheric particles?

What color, if any, does the dark night sky have?

The following material was posted to the newsgroup sci.astro.amateur in 1996 and 2001 by Brian Skiff, of Lowell Observatory. He has recently re-edited and updated the material and graciously granted permission to post it here.

- Jerry Lodriguss

How Dark Can the Night Sky Get?

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Steve Mencinsky has suggested that I might have opinions about comparative sky brightness at different sites. Indeed I do, and also can supply some facts, which have been in short supply in this thread. The only person who has bothered to pursue the problem of night-sky brightness from an analytical viewpoint is Roy Garstang of the University of Colorado at Boulder. His results are most fully developed in the following publications:

Citations in the Scientific Literature


All three can be obtained on-line via the ADS article service at:

http://adsabs.harvard.edu/article_service.html

In these articles you will find the equations that allow you to compute highly accurate predictions of sky brightness for any site. The equations include some "hairy integrals", but are quite amenable to being coded into a piece of software. The required inputs are radii to and populations of towns near a site of interest (and if the cities are physically large, also the radius of the city itself), and the altitude of the site. All you software jockeys should add this feature to your programs! It would certainly be of interest to have values calculated for Riverside, Stellafane, Astrofest, and other star party sites. I might mention that light-pollution guru Chris Luginbuhl at USNO-Flagstaff (cbl@nofs.navy.mil) has a program to do these calculations given the necessary inputs.

Another first-rate source of information about the night sky in general is the marvelous little book by Roach and Gordon, "The Light of the Night Sky" (Reidel, 1973), which outlines the hard science of the matter with a refreshing aesthetic attitude.

And while we're at it, I may as well mention primary sources of data about the related subject of dark-adaptation (as far as I know, these are not available on-line):

Smith et al. 1955, "Effects of Exposure to Various Red Lights upon Subsequent Dark Adaptation Measured by the Method of Constant Stimuli," JOSA 45, 502

Kinney 1955, "Sensitivity of the Eye to Spectral Radiation at Scotopic and Mesopic Intensity Levels," JOSA 45, 507


Dark Adaption and Exposure to Bright Lights

The bottom line of these papers is: red lights are best, but if you can see that it's red on the paper your looking at, it's too bright; if you go out on for long on a sunny day, expect to lose about three-quarters of a magnitude in your magnitude threshold the succeeding night---after extended exposure to high-intensity scenes (beach, snow-skiing on sunny days), it takes more than 24 hours to become fully dark-adapted! The usual half-hour or hour won't do. Wear "glacier glasses" when outside during daytime.

It Can Only Get So Dark

Before proceeding, it is worth noting that the s.a.a. thread so far seems to contain the implicit notion that you can find darker and darker sites if you get progressively farther from anthropogenic sources of light. This is not true, particularly from a practical standpoint. The Australian Outback, the coast northwest of Perth, the Chilean observatory sites, and isolated places in the US Southwest, plus many others have sky brightness negligibly different from the natural background, which sets a fundamental (and more-or-less inescapable) limit on how dark a site can be. The main contributions to the natural skyglow are: the zodiacal light, the night-airglow ("permanent aurora"), and scattered starlight in the atmosphere. There are also contributions from such things as scattered extragalactic "cosmic" light, but these are so small that even now their actual values are known only as upper limits.

Despite the fact that many folks have not seen the zodiacal light, much less the gegenschein or zodiacal band, it is the main contribution to the natural sky brightness even the ecliptic poles. The night-airglow varies considerably due to solar activity on the time scale of minutes/hours as well as over the 11-year solar cycle, and can greatly compromise the darkness at a site on any particular night. The zodiacal light, zodiacal band, and gegenschein are prominent features of the night sky at true-dark sites. They are not tests of visual acuity, but of sky brightness. The night-airglow is also easy to see at dark sites, at least where there is little scattered light from atmospheric dust and aerosols. There are many reported visual sightings of the rippled structure in this phenomenon, looking like banded very thin altocumulus clouds. This light is visible mostly from a forbidden line of ground-state oxygen which emits at 5577, where most light-pollution filters have their red cutoff. Gordon Garradd has some nice photos of structured airglow at his Web site:


This is the sort of thing you never see except at a "true-dark" site. The main night-sky brightness contribution---the zodiacal light---is of course just scattered sunlight, and thus is not improved by light-pollution filters.

Hard Numbers on the Measure of Darkness

So what's the answer? The widely accepted value for sky brightness at the zenith at a site completely free of man-made light sources and near solar activity minimum is: V mag. 22.0 per square arcsecond = mag. 13 per square arcminute. In other words, a perfect site has a sky brightness equivalent to having a mag. 22 star in every square arcsecond box (hardly bigger than the star image itself) over the entire sky. Garstang has adjusted the zero-points of his model to fit this value, which is based on actual measurements at several observatory sites around the world, and from actual experience is unexpectedly accurate. When the airglow is bright, the brightness can increase often by a full magnitude in V, but somewhat less for the dark-adapted eye, which is less sensitive to the 5577A emission than the standard photometric V filter passband. Thus even a site without light-pollution can appear "bright" to the eye depending on the state of the geomagnetic field. To escape these major effects completely you'd have to go into space well out of the plane of the solar system. Just going into Earth orbit doesn't gain you much as far as dark sky since the zodiacal light is still there.
Well, what does mag. 22 per square arcsec mean for the observer? If you've been to TSP, or the Nebraska Star Party, or been on Kitt Peak or to McDonald Observatory or other similar sites on a cloud free night, then you've seen it! That's as dark as it gets.

What about brighter sites, any comparisons? Here are some values from Garstang's 1989 PASP paper for some brighter sites (all the following are based on 1980 census data; adjust as you see fit):

- Mount Wilson 19.8
- Palomar Mountain 21.5
- Lick Obs. 20.7
- Mount Lemmon 21.5 (near Tucson)
- Lowell (Mars Hill) 20.5
- Van Vleck 18.7 (Connecticut)
- David Dunlap 18.4 (Toronto)
- Haute Provence 21.8 (southern France)

How bright is really bright? From Flagstaff the night sky at Full Moon is about mag. 18.0. My meager experience from the centers of large cities indeed suggests the Full Moon does very little to sky brightness---rather than being the focal point of the nocturnal landscape, it's just one more street light. Recently the sky brightness was measured on V-filtered CCD frames taken for the TASS project by Tom Droege in "suburban" Batavia, Illinois in the Chicago conurbation. His value was also around V=18.0. Figure from there.

Having observed as a professional and an amateur from a bunch of places in the southwest US and in Chile, I consider a "true-dark" site (specifically for visual deep-sky observing) to be one where the sky brightness is less than half a magnitude brighter than natural (again, at the zenith), i.e. about mag. 21.5/square arcsec or fainter.

By comparison, consider Lowell's Mars Hill site, immediately above downtown Flagstaff. Thanks to having a tough and enforced lighting ordinance, the sky brightness in the year 2000 is still only 20.3 (versus 20.5 for 1980) despite a doubling of the city population (to 60,000), which I know because I have been measuring it most clear nights since 1983 with our 53cm photometric telescope on Mars Hill. My limiting naked-eye magnitude here is V mag. 6.3-6.5; it is as faint as this probably because of our altitude (2200 meters = 7250 feet) and consequent relative freedom from aerosols to scatter the city lights. Because I am quite finicky in this matter, I consider this site too bright for deep-sky observing. But many visiting amateur observers from the eastern US have commented consistently along the lines of "this is about as good as it ever gets back home from our dark-site site." As an aside, the Flagstaff lighting ordinance, by the way, has recently been made even tougher, and can be read at the IDA Web site:

http://www.darksky.org/ida/info94.html

Note also their comprehensive lighting code handbook, drafted by Chris Luginbuhl:


When these visitors from "Back East" are taken to our dark site on Anderson Mesa outside of town, they are simply gaga at a site with zenithal sky brightness about 21.8, and a naked-eye limit close to mag. 8.0. (The limit from dark sites seems to depend strongly on visual acuity.) Although I have not been to Australia, I am confident that dark sites there are not any darker than good places elsewhere. Steve Mencinsky mentions Siding Spring as being a superbly dark Australian site. Garstang's computed sky brightness is 21.985 (!), i.e. perfectly dark, but not any darker than other places as remote as it is. Having seen data from the UK Schmidt autoguider, which produces values for sky brightness during plate exposures, I can confirm that this value is correct.

**Chile vs Arizona**

More anecdotal remarks. People don't seem to question that the Chilean observatories have perfectly dark skies. Yet on my two visits to Las Campanas Observatory, totalling five weeks on the mountain, I found the sky to be quite similar in appearance to Anderson Mesa. Tom Polakis can also testify that Las Campanas is not much different even from "best" sites on Arizona's low deserts. The contents of the southern sky are without a doubt impressive, but coming from the US southwest you don't go outside in Chile and get awed by the sky quality itself. The difference in Chile is that those nice "photometric" nights go on for weeks and weeks at a stretch during the November-March austral summer. It is also worth noting that the seeing at Las Campanas (and
the other sites at La Silla, Paranal, and Cerro Tololo) has been measured extensively: median seeing is 0.6 full-width half-maximum, meaning more than half the time in your 8-inch telescope there will be no discernible "seeing"---as though you were observing from space. Again, Tom can testify that the performance of his 13-incher was impressive under those conditions.

Cloudiness and Atmospheric Transparency

The discussion so far does not include the subjects of cloudiness and atmospheric transparency at different sites. As far as clouds in the US, the Southwest wins hands down in the long term. Period. Transparency is almost solely a function of altitude: the higher the better. However, for visual observing, if you go too high, you'll lose visual sensitivity simply because not enough oxygen is getting to your brain. The optimum altitude range seems to be from about 1500 up to perhaps 3000 meters (5000 to 9000 feet). Below 1500m, the amount of crud increases dramatically, and above 3000m most people have at least mild effects from lack of oxygen. Visual observing from Mauna Kea without bottled oxygen is pretty crummy. Remember that astrophotography is mostly at the threshold of acuity, so even small physiological effects from altitude (or ill health etc) will have pronounced effects on your vision in these circumstances. (When you're observing sometime at high power, try exhaling and not taking a breath for a good chunk of a minute: before you get dizzy, the eyepiece view will fade out and go grainy.) For what it's worth, acclimation to altitude appears to be independent of age, gender, or physical condition---but the genetic engineering necessary for high altitude living has already been worked out: they're called Bolivians!

Making the Best of What We Have

At this point I can imagine people saying: "Well, since I can't afford to get to any of these places, and I don't have Bolivian parents, do I just blow it off and go play pool? Does all this mean I should get another hobby?" No, you work with what you've got! As has been pointed out in this newsgroup, and in such places as Alan MacRobert's excellent "star-hop" series in Sky and Telescope, there's plenty of observing to do from urban skies, although you might have to think a little bit about it and worker harder at it. You can also join the IDA (International Dark-Sky Association) both to learn about lighting problems and to become involved in working with your local political officials on producing a workable lighting ordinance for your town. Help make things better! These codes are proven effective in places such as Tucson and Flagstaff in greatly reducing the increase in sky brightness despite population growth. Work in several places in the northeast US is yielding real results for reducing light pollution.

So is it Texas Star Party or Nebraska Star Party? Having attended both, I can confirm they are "true-dark" sites by the criterion above. Attendees will not be disappointed at either in this respect. Statistically over the long term (like a decade or more), TSP is more likely to have cloudfree sky, but on any given year it's a toss of the coin. As noted by previous posters, other factors such as time of year (which part of the sky you're interested in), scenic attractions (both regions have understated landscapes of great beauty), and how you get along with the folks you meet will probably take precedence over sky darkness.

Particulates, Altitude and Transparency

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What about the amount of particulates in the air versus altitude, and whether island sites like Mauna Kea and the Canary Islands are better than the Southwest US? Is the southern hemisphere better than the north? Luckily, there are some answers.

To deal with this quantitatively, we need to introduce "extinction". In astronomical usage, this is the amount of light absorbed by the atmosphere, and is usually measured as a normal and necessary part of photometric observations from any site (although you'd be surprised how many of us try to get away without bothering to measure it!). The units are in magnitudes per airmass, where 1.0 airmasses is looking exactly at the zenith. (The airmass increases closely as the secant of the zenith distance, so at 30 degrees above the horizon [60 deg zenith angle], you're looking through the equivalent of two atmospheres worth of air.) As long as it's not cloudy, this number is something less than about 0.5 magnitudes per airmass in the yellow part of the spectrum where the eye is most sensitive. So a cloud-free atmosphere makes the stars a few tenths of a
Causes of Extinction

The extinction arises in the visible part of the spectrum from three main components. First is what's called Rayleigh scattering, which happens because the sizes of air molecules are not a lot different from the wavelengths of visible light. Lord Rayleigh got his name attached to this effect because he determined that the amount of scattering changes as the inverse fourth-power of the wavelength: the scattering is way higher in the blue than in the red. This is, for instance, why landscape scenes taken with infrared film look like there's no atmosphere: very little scattered light at these wavelengths compared to regular pictures. It's also why the sky is blue: the blue part of Sunlight getting scattered much more than the redder wavelengths. Rayleigh scattering obviously also depends on altitude: higher places have less air to cause the scattering.

Next is absorption of light caused by the ozone layer, which is concentrated at the base of the stratosphere, up about 20km. The main effect here is a small additional extinction right in the yellow-green. (This was found by a guy named Chappuis.) The result is to flatten out the extinction curve in this part of the spectrum. Since the source of this is so high in the atmosphere, it is a nearly-fixed additional extinction for any site regardless of altitude. (We are, of course, doing our best to get rid of this ozone layer through our chemical usage, never mind the collapse of the base of the food chain that depends on it being there, and other unknown complications.)

The Rayleigh + ozone extinction then can be seen as forming the desired minimum extinction for any site, and since it's based on well-understood physics, can be calculated for a site just from the altitude. At sea level, the value is around 0.25 mag. per airmass; for 2000m it's around 0.11 or 0.12, for Mauna Kea it's 0.09. All these numbers apply specifically for the standard V passband. The dark-adapted eye response is somewhat to the blue of this, so we see higher extinction, but nobody measures it there, so it's easiest just to calibrate things relative to the V-band extinction. (The "dark-adapted visual" value is about 0.03 larger than the V extinction.)

Now on top of this baseline value is the "aerosols," basically everything except the gaseous air, like dust, humidity, and the stuff humans, volcanoes, and other things dump into the atmosphere. Here's where things are variable from site to site. From Flagstaff, this ranges from zero extra extinction up to (on average) about 0.06 mag. extra. The changes follow a seasonal pattern: we get the baseline 0.11-0.12 values commonly during December and January. (Right after snowstorms, the sky is deep blue right up to the edge of the Sun.) There is a gradual increase through the spring, which we attribute to springtime winds stirring up desert dust to our west, as Jerry surmised. This peaks in June, with mean extinction of 0.18 mag. per airmass, just before the summer "Monsoon" rains arrive. The summer rainy season cleans the lower troposphere, and we return to extinction of something like 0.15, which is our annual average. If you look in the Kitt Peak manual, you'll find the identical value.

I recall visiting an astronomer at the University of Nebraska, who had been observing the night before with their 30-inch telescope located at Behlen Observatory among the corn fields outside Lincoln. The sky that day was cloud free but hazy-white, with only a pale blue patch at the zenith--typical American Midwest sky for August. He had just reduced his extinction data for the night prior, and had obtained a value of 0.35. Even though it was very high, he was happy because it stayed constant all night, so the data on his program stars was good. Observations from Germany and Poland published in a (former) East German publication give similar values outside of midwinter clear spells. Perhaps someone who does backyard CCD or photoelectric photometry in the eastern US can supply some ranges from their data.

Extinction at the World's Best Observing Sites

It appears that indeed the southern hemisphere is cleaner as far as aerosols, presumably because there is both less human activity and just less land to generate dust from. For the European Southern Observatory (La Silla, Chile), which is the only Chilean site with a lot of published data, the extinction values are slightly lower than the US Southwest (for the same altitude), averaging about 0.14, and also show a smaller inter-seasonal range. The difference for visual and photographic observing is very small. The first week Tom Polakis and I were at Las Campanas (across the valley from La Silla) in 1993, a visiting grad student happened to be getting extinction data. She sent me the values later, which were about 0.15-0.16 in V (the data were on an uncommon photometric system, so I'm converting a bit here). She noted that it it remained sensibly constant the entire week of her run, even though we noticed subtle variations in the amount of aerosols each day at sunset. This is because it is difficult to actually measure the extinction to better than about +/- 0.015 or 0.02 mag. accuracy. As I mentioned in the first post, it
looked the same as nice nights in Flagstaff. There was some Pinatubo residuum still then, accounting for the slightly elevated values, but not really anything to worry about.

Kevin Krisciunas has published some nice data for Mauna Kea, including numbers for the Hale Pohaku lodge at 9500 feet. There is not enough data, however, to look for seasonal effects. My guess would be that as long as Pu'u O'o isn't erupting and its plume blowing in the wrong direction, things are pretty stable there.

The Canary Islands have a serious local source of dust---the Sahara. I've seen published photometry where the authors measured the extinction to be 0.5 and higher just from high-level sand suspended over the summit where the telescopes are. This is a summertime phenomenon, so it's probably alright there much of the year, although I gather it's not less cloudy than the US Southwest (~30% cloud free nights).

**The Flagstaff Thumbnail Test of Extinction**

Finally, it is not necessary to have photometric equipment to measure the extinction, at least in a qualitative way. You can use the "Flagstaff thumbnail test"! On a casual basis, examine the sky close to the Sun by holding your thumb at arm's length to block the Sun. (If you do this sort of thing a lot, it helps to have some very dark sunglasses handy.) You can also use the edge of a building, tree branch, etc. It's easy to do this often, since takes only a few seconds. Simply note the relative amount and brightness of the scattered light close to the Sun when there are no clouds interfering. Compare the scattered light level with weather patterns (wind direction, humidity, etc.), time of year, and with nighttime sky quality. If you do this in a consistent way (same time of day, or same solar elevation), pretty soon you'll see what the range of variation in crudeness is, and even be able to predict the sky quality on the night following, and know when extraordinarily good or bad conditions have arrived. You'll also see some interesting near-Sun atmospheric phenomena you probably didn't know about. Likewise, try it with a bright Moon at night.

**Summary**

To summarize, yes, the amount of dust in the lower atmosphere affects visibility from low-altitude sites significantly; but the differences between dry, high-altitude continental and mid-oceanic sites is fairly small. The high extinction at low sites is also why you can't see stars as faint nor as low surface brightness on galaxies and nebulae even though the sky might be acceptably dark. "True-dark" as defined in the first section, probably helps more than anything, but getting up fairly high helps too.

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**Why the Dark Night Sky Is Not Black**

**Introduction**

The night sky from light-polluted areas can be quite bright, and naturally acquires the color of the predominant source of light pollution. It is a reddish-orange for sodium vapor lighting, and greenish for mercury vapor lighting.

The moonless night sky at a remote location far from any man-made light pollution is, however, still not completely black. To most people who are fully dark adapted, it appears a dark gray, but it may also have some faint color.

What color could it be and where does that color originate?

The dark night sky is illuminated by a natural skyglow that is composed of four parts.

1. Airglow is the brightest component and is caused by oxygen atoms glowing in the upper atmosphere which are excited by solar ultraviolet radiation. Airglow gets worse at solar maximum. Airglow can add a faint green or red color to the sky background. The color may be vivid if there is a strong aurora occuring.

2. Interplanetary dust particles reflect and scatter sunlight and make up the zodiacal light and gegenschein.
3. At night starlight is scattered by the atmosphere, just as sunlight is during the daytime. Air molecules scatter short blue wavelengths more, which is why the daytime sky is blue. The night sky also has a very faint blue component from scattered starlight.

4. Countless stars and nebulae in our own galaxy also contribute to the brightness of the night sky, most easily seen in the form of the Milky Way.

- Jerry Lodriguss

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**Colors of the Night Sky**

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**Is the color of the faint natural airglow green?**

Yes. Usually you see the 5577\(\text{A}\) line emission as green as seen in the Gordon Garradd photos mentioned above.

**What color are the Gegenschein and Zodiacal light?**

They are simply scattered Sunlight, so they are exactly the color of the Sun. (The Zodical Light dust particles are "big" so they don't scatter blue preferentially, unlike the small particles of air, which are roughly the same size as the wavelength of light.)

I've been able to convince myself that the very brightest part of the zodiacal light near the horizon, probably close to the time of astronomical twilight, is right at the threshold of color for me and is a funny turquoise blue-green, i.e. right at the peak dark-adapted color.

If you've ever looked at a discharge tube of oxygen with a simple cheapo replica grating and seen that gorgeous line at 5007\(\text{A}\), that's the color, but barely perceived. Chris Schur told me once he sees the color very strongly, but for me it's a marginal thing.

**Could the dark night sky background be seen as blue from a dark sky site?**

Unfortunately the moonless dark night sky simply isn't this color---there's practically no emission blueward of the 5577\(\text{A}\) line (which in daylight appears a lime- or chartreuse-green), only scattered Sunlight (from the zodiacal cloud, which dominates even at the ecliptic poles). Typical photometric B-V color of the sky is 0.9, slightly on the yellow side of white (the Moon has B-V of about 0.9).

The night sky at Full Moon (about magnitude 18 per square arcsecond or about magnitude 9 per square arcminute) must be very close to the color threshold for at least some people to see the night sky as "sky blue".

Several times I've got impressions that it seems blue, but haven't been able to convince myself. Probably just a little brighter would do it. I think the canonical "textbook" figure is magnitude 15 per square arcsecond as the color threshold, which really isn't all that much different from the Full Moon level, so the "slightly brighter than magnitude 18" value doesn't seem unreasonable to me.

**Is it possible for someone with extremely unusual vision, like Steve O'Meara, to see the color blue in the night sky background?**

Nope. Steve and I (and John Bortle) once made mag limit checks at the Texas Star Party using a photometric sequence around M3 in a 7-inch Starfire refractor. All three of us saw to the same limit---none of us has unusual vision, just a lot of experience. Steve's vision is unusual only in that he knows how to use it!

**Could the scatter of starlight be bright enough that the sky background would turn blue or is it just too faint to be seen at all?**

It is too faint to be seen.

**Is it possible to read by starlight or the Milky Way?**

You can read newspaper headline type (not just huge disaster banners, but small headlines).
Roach and Gordon talk about this in the "Light of the Night Sky" book. The classic Sky and Telescope article by Roach and Jamnick "The Sky and the Eye" (Sky and Telescope, vol 17, February 1956, page 165) about the night sky mentions this, too. I don't know what the small limit is, and I'm not sure it would be terribly relevant to astronomical viewing.

The incident light within about 24 hours of the moment of Full Moon allows me to see colors (on paper, pavement markings, etc.) without ambiguity from a place without other lights. But that light level is much higher than for the sky itself (paradoxical as it may seem).

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Other Interesting References and Resources

Night Sky Brightness at Cerro Pachon - Alistair Walker & Hugo E. Schwarz, Cerro Tololo Inter-American Observatory


International Dark Sky Association

V-band sky brightness at Mauna Kea and the solar cycle - Kevin Krisciunas

CFHT Observatory Site Characteristics - Observatory Manual

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