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# Light Pollution

## Outdoor lighting is a growing threat to astronomy.

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It is my purpose in this article to delineate astronomical dark sky requirements for scientifically useful observing, to survey the influence on astronomical observing conditions of man-produced electromagnetic radiation, to examine what conditions will probably prevail for the next generation or two of observing astronomers, and to suggest changes in public policy that would alleviate some of the actual and projected damage to the astronomical observing environment. During this century, astronomers have had to contend with the phenomenon of light pollution, defined here as unwanted sky light produced by man, because of population growth and increased outdoor illumination per capita. Both of these causes of increased light pollution are important, the former having been more important early in the century and the latter being of most concern now.

### Survey of the Problem

The last hundred years have been marked by two periods of very rapid growth in astronomical observing facilities in the United States. Both were initiated by the dual factors of improved techniques and favorable funding conditions. The early period, for example, saw the development of photography and spectroscopy when there was something of a fad for private philanthropy to observatories. Technological improvements made much more sensitive and accurate measurements possible at a time when appreciation for the scientific value of astronomical observations was growing. Wealthy benefactors provided the necessary funds to construct such observatories as Leander McCormick (Charlottesville, Virginia), Lick (San Jose, California), Yerkes (Williams Bay, Wisconsin), Mount Wilson (Pasadena, California), and McDonald (Fort Davis, Texas). These observatories were founded at a time when cities were small and dimly lit by today's standards.

During the second period, improvements in technology provided some impetus for the construction of new optical observatories in Hawaii, Arizona, Texas, and Chile. Again, a dramatic increase in available funds was a decisive factor, only now they were mainly public funds and related to the national space program. The latter period of expansion of astronomical facilities was accompanied by rapid expansion of our cities and populated suburban areas, and by technological improvements in outdoor lighting.

It is the goal of the astronomer to deduce as much as he can about the nature of various cosmic sources of electromagnetic radiation. He would like to extend his observations to include as much of the electromagnetic spectrum as possible, since the quantum mechanical correspondence between wavelength and energy implies that physical processes of radically different intrinsic energies produce radiation at widely differing wavelengths. The complete astronomical picture can come only from observations gathered at all wavelengths.

The transmission properties of the earth's atmosphere severely restrict the portions of the spectrum available for ground-based astronomical measurements. Figure 1 shows the atmospheric transmissivity as a function of wavelength. The electromagnetic spectrum is divided into a number of segments called windows, where the transmissivity is near unity. The optical window is the one which has received the most astronomical attention, for the natural reasons that our eyes respond at these visual wavelengths and that solar-type stars emit the bulk of their radiation at these wavelengths. The sun is a common sort of star in this respect, although there are many astronomical objects that emit most of their light at wavelengths outside the optical window.

Over much of the spectrum one must observe from above the earth's atmosphere because of its very high opacity; orbiting astronomical observatories contribute to our knowledge of astrophysics at infrared, ultraviolet, x-ray, and gamma-ray wavelengths. They have the advantage of immunity from scattered atmospheric light since they are in the near vacuum of space. The cost of doing astronomy from above the earth's atmosphere is high, although intelligently planned programs of this type are well worth the expense. Where one has the choice of making astronomical measurements from space or using ground-based facilities, one would always prefer the latter on economic grounds, all other things being equal. Thus, there is some economic justification for preserving our ability to continue to make useful astronomical measurements from the ground. Moreover, many types of observations, such as those involving untried experimental equipment and techniques, or particularly bulky apparatus, cannot be done

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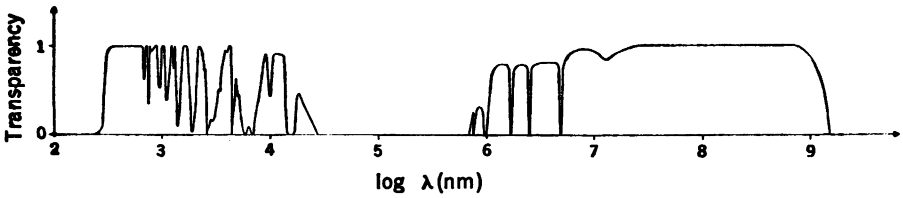


Fig. 1. Transparency of the earth's atmosphere as a function of wavelength (λ). The optical window lies at the extreme left and the radio window at the extreme right.

in orbit. Light pollution renders ground-based observations more and more difficult to perform.

Basically two types of measurements, narrow band and broad band, are made by astronomers. Examples are high-resolution spectroscopy of stars and photography of very distant objects like galaxies and quasars, respectively. The sources of interference are of the same two types. If the interference is narrow band, then most of the spectrum remains free from interference. On the other hand, within the narrow range of wavelengths affected by the interference, the problem will be very serious for a particular power level. If the interference is broad band or consists of a large number of spectral lines then the astronomer cannot escape it. However, for a particular interference power the intensity at a particular wavelength will be less, since the radiation is dispersed throughout a wide range of wavelengths. We may find that in spite of some broad-band (continuum) interference, narrow-band observations of bright cosmic sources are still possible. Moonlight is an example of a source of low-level continuum interference affecting optical measurements at certain times of the month—astronomers routinely do high-resolution spectroscopy of bright stars under such conditions. Narrow-band observations are still possible even with relatively intense interference, if that interference is confined to wavelengths outside the spectral region of interest. As an example, low-pressure mercury vapor lamps produce relatively few but intense spectral lines, with large gaps between them; as long as one is concerned only with details in the spectrum between the interfering lines, there is no serious problem. Unfortunately, this is often not the case; for example, the spectral line for triply ionized oxygen (O III) at 436.3 nanometers, which is critical in the plasma diagnostics of gaseous nebulas, is near the 435.8-nm mercury line.

Broad-band measurements such as astronomical photography and photoelectric photometry are seriously affected by interference, whether it is in spectral lines or spread over a continuum, as long as it falls within the passband being observed. Broad-band observations are extremely useful. Surveys of areas to faint limiting magnitude amount to what we might call "astronomical fishing trips," or observations which are intended to aid in the discovery of new and unsuspected phenomena. The list of fundamentally important constituents of the universe discovered in this way is impressively long.

## Astronomical and Scientific Constraints

The astronomer must be able to detect the source of radiation he is interested in measuring. His detector will always indicate some response, even when it is not directed at the source of interest, because of natural causes including airglow, atmospheric scattered light, ground reflections, zodiacal light, and the light from background stars. In spite of interference from these causes, from noise generated within the detector, and from light pollution, it is still possible to do useful work, provided that the interference is not too strong. A high-resolution spectrum of the night sky at Kitt Peak National Observatory has been published (*1*). In the visible, for example, the zenith brightness is of the order $20 \times 10^{-9}$ stilb (*2*), equivalent to about one star of magnitude 22 per square arc second. This value of the natural sky brightness provides us with a standard against which we can measure the consequences of contaminating the astronomical observing environment with man-made skylight. As long as the component of the local sky brightness which is generated by man is small compared to the natural level, then light pollution is not a serious matter.

It should be emphasized that the sky brightness sets very real limits for astronomers. Studies of the processes that produce the light of the night sky form an area of serious research, and they require dark-sky observing sites. Observations of the zodiacal light, the gegenschein, the airglow, and the aurora represent such studies. Observational cosmology is based on limiting magnitude results on the faintest quasars and galaxies, so an increase in sky brightness has the effect of shrinking the visible universe. For example, at Palomar Observatory on the 200-inch (5.08-meter) telescope, photographic exposures cannot be made for periods of time longer than that required to just record 24th magnitude stars on sensitive photographic emulsions under the best observing conditions. This is because of skylight, which fogs photographic plates when exposure times exceed a certain value. As a practical matter, increasing the telescope size is an expensive and relatively ineffective way to compensate for skylight, beyond the "seeing" limit, which corresponds to image blurring due to atmospheric turbulence and distortion. The limiting magnitude depends on the properties of the detector (*3*).

The natural sky brightness of about 22 magnitudes within a circle whose diameter is 1 arc second is 2 magnitudes brighter than the limiting magnitude given above. This is no coincidence, because 1 arc second is the size

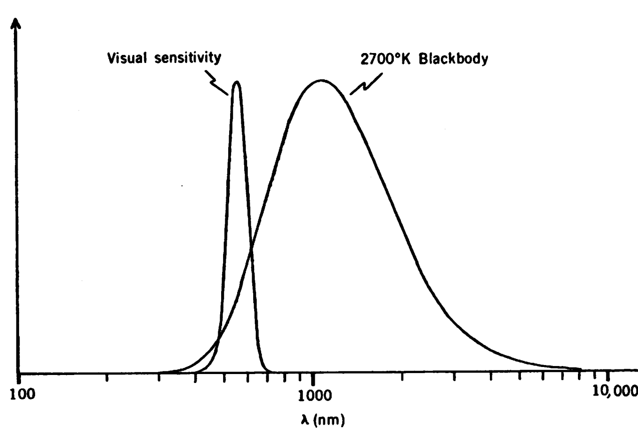


Fig. 2. Wavelength response of the human eye and spectrum of a blackbody at the temperature of a typical incandescent lamp. Most of the radiation produced by incandescent lamps evokes no visual response; hence, they have low luminous efficiency.

of a stellar image under good observing conditions, and the photographic limit is reached when the star brightness drops below some fraction of the sky brightness. The relation between the sky brightness, $B$, and the apparent magnitude, $m$, of a star which contributes light equal to the skylight within the seeing circle diameter, $S$, is

$$B = 14.35S^{-2}10^{-0.4m} \approx 20 \times 10^{-9}$$

where the units of $B$ are stilbs when $S$ is in arc seconds. Thus, the limit set by skylight on the magnitude of the faintest object that can be photographed depends also on turbulence in the atmosphere, in the sense that bad seeing decreases the effective sensitivity. The corresponding limiting magnitudes are several magnitudes fainter, depending on the $f$-ratio of the telescope and on the detector system employed. It is possible to do even better, in principle, by using techniques of photoelectric photometry and multiple exposure photography to give longer integration times and improved signal-to-noise ratios. These techniques are only now coming of age in optical astronomy, but they are not likely to solve the basic problem of interference due to light pollution because they are applied with difficulty and at great expense.

## Outdoor Lighting in the United States

Most outdoor lighting was of the incandescent type until very recently. The filaments of incandescent lights, which operate at only about 2700°K, radiate mostly longward of 550 nm, the peak of the visual response curve. Thus, incandescent lights have a very low luminous efficiency, only about 20 lumens per watt or less. Figure 2 shows the visual sensitivity curve for humans and the spectrum of a typical incandescent lamp. Most astronomical photographic emulsions and photoelectric detectors have their peak sensitivity toward the blue end of the spectrum. Thus, these lamps have two properties which make them desirable to astronomers: (i) they radiate with very low efficiency, producing relatively little light at visible wavelengths, and (ii) very little of the visible light that is produced interferes with blue-sensitive detectors. The first of these properties makes them undesirable to municipal lighting departments.

The high-intensity gas discharge lamp is succeeding the incandescent lamp for most outdoor lighting. The mercury vapor lamp is the most popular. Such lamps usually emit most of their light in a few spectral lines, which is good from the astronomer's point of view. The lighting engineer and the used car salesman consider this a disadvantage, however, since the appearance of objects tends to be more pleasing in light which has a smooth spectrum more closely approximating that of sunlight, perhaps somewhat reddened. In the newest vapor lamps the continuum portion is enhanced and the luminous efficiency is as high as 115 lumens per watt, a very significant change in connection with light pollution.

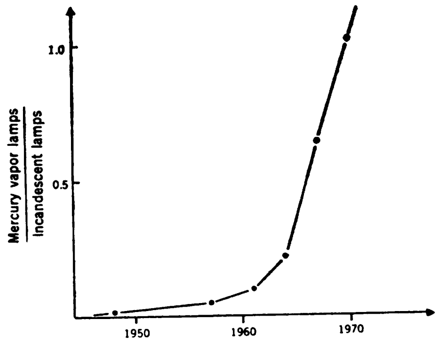


Fig. 3. Number ratio of in-service mercury vapor lamps to incandescent outdoor lamps in the United States for the past 22 years.

Most of the discussion on specific properties of light sources will refer to high-intensity vapor lamps and not the older incandescents. The relative importance of the incandescent lamp has been rapidly declining, as can be seen in Fig. 3, which shows the relative numbers of in-service vapor and incandescent lamps as a function of time (*4*). This conclusion is also supported by data from (*5*), which show that the rate of production of outdoor incandescent bulbs is now virtually constant, reflecting replacement use only; the rate of production of incandescent luminaires has declined drastically as that of high-intensity mercury luminaires has soared.

The growth curve in Fig. 3 can be used together with power consumption data from the same source (*4*) to derive the 1970 mix of lumens due to in-service vapor lamps and incandescent lamps, respectively. This ratio was about 6 in 1970, if it is assumed that the vapor/incandescent number ratio was 1.16 and the vapor/incandescent lumen ratio was 5 for typical street lamps. So, as early as 1970, the bulk of the total luminous radiation in the United States, about 85 percent, was produced by vapor lamps. However, most of the continuum was still produced by incandescents, since almost all of the mercury light occurs at wavelengths of 365.0, 404.7, 435.8, 546.1, and 578 nm. The 435.8-nm line has been most annoying to astronomers, since it is by far the strongest; it lies in the blue; and, most frustratingly, it is on the tail of the standard visual response curve (Fig. 2), where it contributes inefficiently to the lumen output of the lamp.

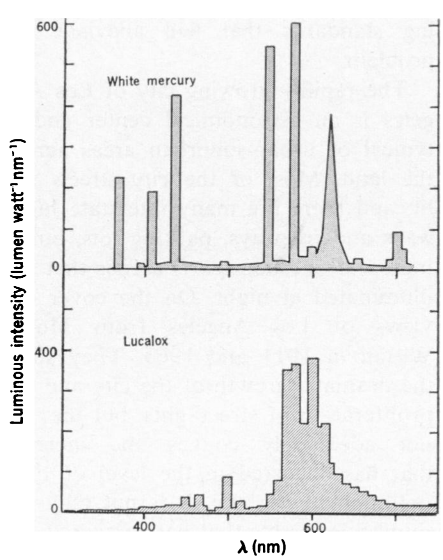


Fig. 4. Spectra of a commonly used mercury vapor lamp and the newer high-pressure sodium (Lucalox) type of lamp. These are low-resolution spectra, with data points only every 10 nm.

The spectrum of a commonly used mercury lamp is presented in Fig. 4. An increasingly popular new type of lamp is the General Electric Lucalox high-pressure sodium lamp, which has a very high luminous efficiency of 115 lumens per watt, or about six times that of ordinary incandescents. The Lucalox spectrum also appears in Fig. 4. Its most interesting characteristic is strong continuum radiation and a much richer line spectrum relative to the cleaner mercury vapor lamp spectrum. One has only to look at the light from these lamps through a hand-held spectroscope to see dozens of spectral lines. These high-pressure sodium lamps do not account for a very high percentage of outdoor lights in operation presently. However, municipalities and commercial light users are beginning to install them at a high rate, and the possibility that much of the skylight near urban areas will someday be from this type of lamp should be considered. Their large numbers of spectral lines would present a serious light pollution problem. A discussion of projected trends for the growth of outdoor lighting appears in the next section.

It is instructive to determine the present severity of the light pollution problem at observatories. Some of the principal research observatories in the United States listed previously are in reasonably good shape; others, such as Mount Wilson, where it is no longer possible to do broad-band work on the faintest stars, are experiencing more difficulty. According to Walker (*6*), Palomar suffered a zenith light pollution level in 1965 which was only about 0.1 magnitude, or roughly 10 percent of the natural light of the night sky. This was contributed to in almost equal parts by Los Angeles and San Diego at quite different distances. At a zenith angle of 45° toward either city, this figure rose to 20 percent. At Kitt Peak in 1972, the lights of Tucson are approaching the 1965 level at Palomar; this is far in excess of the most pessimistic predictions made before the construction of the major telescopes at Kitt Peak.

Unfortunately, accurate quantitive data on skylight levels have not been gathered in any systematic way at most observatories. There have been only a few programs—for example at Kitt Peak for the past 18 months and at Flagstaff for the past 10 years—to monitor sky brightness for urgently needed figures on the rate of increase of light pollution.

There is a dimension to the problem which should not be passed over, and which has to do with the phrase "major research facility." By definition, an observatory is a major research facility by virtue of the fact that competitive research is still possible at its location. For broad-band observations, this is no longer the case at many older observatories in or near major metropolitan areas. Part of the indirect cost of outdoor lighting has, for these cases, included the obsolescence of scientific research facilities, usually gradually over a number of years. Such costs are almost never considered by the agencies that authorize lighting projects.

### Growth of Light Pollution

Accurate quantitative information on the total outdoor illumination in the United States as a function of time is not directly available; one can get rough information only from indirect sources. As with many other man-made environmental factors, no attention was given to the possible harmful effects of outdoor lighting. I am reminded of an all too recent statement by Meinel (*7*), of the University of Arizona, who remarked on observing conditions at Kitt Peak National Observatory: "Most of the city is hidden from view by the Tucson Mountains, west of the city. At present, the city's growth potential is limited by the availability of water and is directed eastward because of the Tucson Mountains. For the foreseeable future there appears to be no serious threat to the astronomical conditions at Kitt Peak." Virtually all would have agreed in 1960. Staff members at Kitt Peak no longer take such a sanguine view of the light pollution problem. In fact, they have mounted a vigorous and successful program in cooperation with the nearby Steward Observatory and the Smithsonian Observatory to persuade the city of Tucson to adopt lighting standards that will alleviate the problem.

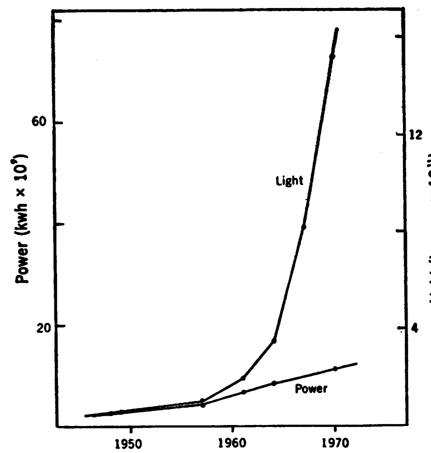

Fig. 5. The growth of power consumption devoted to outdoor public lighting (bottom curve), and the light (top curve) produced by that power, for the past 22 years.

The rapidly growing city of Los Angeles is an astronomical center and is typical of urban-suburban areas across the land. Most of the city streets are lit, and there are many interstate highways and freeways, parking lots, buildings, and outdoor sports arenas that are illuminated at night. On the cover are views of Los Angeles from Mount Wilson in 1911 and 1965. They show the dramatic growth of the city and the proliferation of streetlights, but they do not adequately convey the increase that has occurred in the level of light pollution of the sky. It is not only the number of lights that has increased but also the luminous output per lamp. Similar changing views of many cities could have been obtained, but are not readily available. Not even such a simple monitoring program as photographing the surrounding land area, say every 5 years, has been carried out systematically at most observatories.

Figure 5 is a plot of electrical power consumption devoted to street and highway lighting in the United States, as a function of time (*4*). Although power consumption for this purpose has been steadily rising, the growth has been approximately linear. For comparison, an estimate of the total light production as a function of time has also been plotted in Fig. 5. This was arrived at by using both the power consumption curve and the mix of incandescent and vapor lamps given in Fig. 3. The average incandescent lamp efficiency was assumed to be 20 lumens per watt, the vapor lamps were assumed to be five times as efficient, and all individual lamps were assumed to require the same power. This is a rough but adequate way of determining the shape of the luminosity curve. It should be mentioned also that the power survey figures are likely to be underestimates of the total power consumption for outdoor lighting, since the sample is presumably incomplete and since it does not include the very important component of outdoor lighting not used for public roads, for example, lighting in parking lots.

The lumen growth curve has the familiar exponential form associated with so many environmental factors which can result in stresses of some sort. In this case it is the scientist who plays the role of the highly sensitive system component feeling the stress first. It might also be interesting to attempt an assessment of the biological effects, if any, of outdoor lighting.

In 1970, outdoor vapor and incandescent lamps existed in roughly equal numbers. The present installation rate for new incandescents is essentially zero, and for new vapor lamps it is 6 to 10 percent per year nationwide, with a much higher rate for the Lucalox high-pressure sodium lamp. Figure 5 shows a rate of lumen growth which is exponential at an astonishing 23 percent per year between 1967 and 1970. An earlier examination of light pollution in California (*6*) was based on the assumption that light level and population would grow at approximately the same rate, but the true rate may be six to ten times as large.

If total outdoor lighting continues to grow at a rate of only 10 percent per year, by 1985 the national outdoor light level will have increased by a factor of 300 percent since 1973. A compounding factor is that the growth is likely to take place simultaneously with dispersal over larger suburban areas. These two factors taken together make it not unlikely that some observatories will experience more than a tenfold increase in the light level in the sky by 1985, which will render many observations impossible.

Light pollution has been concentrated for the most part in a few narrow spectral lines of mercury, which are avoidable under some conditions. The new high-pressure sodium lamps have a much richer spectrum, and will affect some kinds of astronomical research more. Thus, astronomy faces a potential hundredfold increase in sky brightness during the coming decade, for some kinds of programs. It is essential that astronomers begin to pay some attention to the spectral distribution of commonly used outdoor lamps, especially with regard to their continuum emission, and to the proportion of light emitted at the blue end of the spectrum. Currently available lamps differ tremendously with respect to these two qualities.

What really matters, of course, is not so much the nationwide pattern of outdoor lighting growth, but rather the proliferation of outdoor lighting in the immediate surroundings of the principal research observatories. Such observing facilities are not scattered uniformly across the country, and their distribution is likely to become even more nonuniform in the future. There are a number of factors which determine whether a location is suitable as a site for an astronomical observatory, aside from the darkness of the sky. These are (i) the quality of the seeing, which is determinated by the stability of the air above the site; (ii) whether there is significant air pollution, such as automotive smog and smoke from power plants (smog can increase light scattering during the daytime, adversely affecting solar observations, and dust is responsible for an increase in the atmospheric extinction of starlight); (iii) cloud cover; (iv) winds; (v) altitude; and (vi) whether the site is on jet routes, since contrails disturb observing.

When all the above factors are considered, there are remarkably few sites in the United States suitable for dark-sky observing. They are almost all in the Southwest. Walker (*6*) surveyed sites in California for a possible future major facility, and concluded that the factor of light pollution alone was enough to rule out more than half the land area of the southern part of that state. The other factors narrowed the possibilities further. One of the sites being given prime consideration for a new observatory in California is Mount Junipera Serra, which is already at the edge of Walker's circle of danger from light pollution projected to the year 1985. He assumed that skylight would grow at the same rate as population. We have seen that his estimate is unfortunately far too conservative. Furthermore, his light pollution estimates were based on measurements at very few locations and extrapolated to other locations mainly on the basis of population. It would be useful to make actual measurements of sky brightness from a great many locations around existing and potential observing sites.

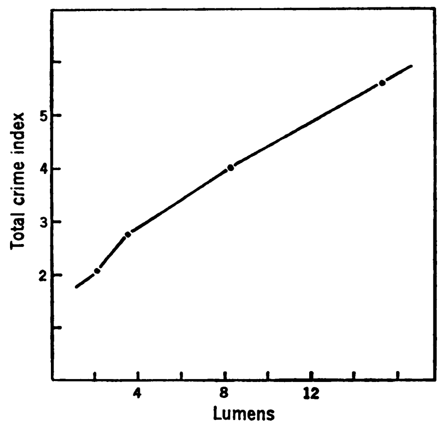

Fig. 6. Total crime index of the Federal Bureau of Investigation as a function of total outdoor illumination for the period 1960 to 1970. Powers of 10 have been dropped for both the ordinate and the abscissa.

## Causes of Light Pollution Growth

There is a startling difference between the growth rates for population (about 1 percent per year) and outdoor lighting (about 23 percent). There are at least five reasons why outdoor lighting has grown faster:

1) The suburbanization of the United States, caused by conversion to the automobile as virtually the only mode of American surface transportation. Areas where the full range of government services such as education, police and fire protection, water, utilities, and sewer service are available have grown much faster than population. The public believes it needs more outdoor lighting, again principally for the automobile. The outdoor areas presently using the most outdoor illumination are streets, highways, and parking lots. Often such outdoor lighting is left to burn all night, even when there is no real need for it. It is common to see empty shopping center parking lots shining brightly and uselessly at 4 a.m.

2) Social factors such as fear of crimes of stealth and violence have contributed to the perceived need. Rising crime rates have been used effectively (see item 5 below) in promotional efforts for increased outdoor lighting. The argument used is that the crime rate will drop where illumination is increased, and there are some statistical studies which are put forward in support of this idea (*8*). Since such studies are usually financed and published by lighting equipment industries, they deserve to be looked at critically. I have two examples of how data supplied by such groups can be used to draw exactly the opposite conclusion from that intended about the desirability of increased outdoor illumination. (i) According to (*9*), only 2 percent of city streets are illuminated to minimum standards; 98 percent are underlit. Since (according to the same source) 80 percent of crimes occur on streets which fail to meet the standard, the conclusion is that we must buy more lights. However, the opposite conclusion results if one compares the crime rates per street for the two categories.

0.80 crimes per 0.98 dim streets =
0.82 crimes per dim street

0.20 crimes per 0.02 bright streets =
10.0 crimes per bright street

Or, crimes are 12 times as likely to occur on brightly lit streets. (ii) There are some studies (*8*) which connect light to reduced crime rates. Such studies have been confined to a few small areas. If one takes the larger view, considering not individual streets but entire cities or the nation at large, an inconsistency looms. One might expect to find that as the general level of outdoor illumination rises, crime rates would drop correspondingly. Figure 6 is a plot of the total crime rate determined by the Federal Bureau of Investigation (*10*) against outdoor lighting luminosity from 1960 to 1970. The sensationalist statistician with an ax to grind might try to use such a plot to conclude that lighting causes crime.

The point of these two examples is not that the unconventional conclusions are true, but that emotionally based or incomplete information can be used to persuade city councils and private businesses to undertake large outdoor lighting projects. The selling has obviously been very successful—most people now believe that outdoor lighting buys them security. I suggest that the deeper sociological roots of crime must be found and treated, and that outdoor lights will not only irritate the astronomer, they will deplete the public treasury possibly without affecting overall public security in any significant way.

It is possible that any demonstrated reduction of the crime rate in a brightly lit area may be negated as criminals simply move on to a softer target area. Evidence that outdoor lighting is largely irrelevant as a factor in residential burglary is given by the increase in daytime over nighttime crime rates (*10*). In the decade from 1960 to 1970 the daytime residential burglary rate rose 337 percent, and it now exceeds the nighttime rate. Factors such as changing life-styles which result in residences being vacant during the day would seem to be more important than illumination.

3) Technological improvements in lighting systems have resulted in luminous efficiencies up to six times higher than in the recent past.

4) An increase in nighttime business and recreational activity.

5) A vigorous, well-financed, and highly effective public relations and promotional campaign for increased outdoor illumination by manufacturers and suppliers of lighting equipment, their trade organizations, and related technical and professional societies. Foremost in this arena are such organizations as the Street and Highway Safety Lighting Bureau, the General Electric Corporation, and the Illuminating Engineering Society.

## What Can Be Done

Factors that will influence the proliferation of outdoor lighting are (i) the rate of growth of the population, (ii) the evolution of zoning practices and the suburban sprawl rate, (iii) whether there is conversion from the automobile to public transportation systems, (iv) changes in lighting technology, and (v) esthetic and protective policies that governments might adopt which will have some bearing on light pollution. The last item on this list is the one that seems most likely to have the largest immediate effect. Most of the remarks in this section will therefore concern changes in public policy that reflect scientific needs.

Of course, outdoor illumination is intended for things like cars, streets, parking lots, and buildings, not the sky. All illuminated surfaces, however, have some reflectivity. Dark black asphalt has low reflectivity and light concrete has a much larger reflection coefficient. Encouraging the use of surface materials of low reflectivity, where possible, would help a little, but this approach is not likely to be very effective.

There is an additional factor of lamp design: how much light is directed downward where it will do some good, and how much goes uselessly up into the sky. The Tucson observatories have given much attention to this phase of the problem (*11*), and have persuaded the city to adopt an ordinance (*12*) setting regulations on the elevation distribution of luminaires—the amount of light that can be directed skyward. Lighting fixture standards of the kind proposed are attractive from a political point of view, since the objective of keeping the light on the ground happens to coincide with the objective of those who use the lights. There are some situations where this is not the case, for example, in outdoor sports stadiums.

The ordinance also requires that new luminaires be equipped with filters which are opaque to the far-blue and ultraviolet lines of mercury, such as the 435.8-nm line. This element of the Tucson ordinance should be considered for adoption in all regions where astronomical research might be affected. It embodies the concept of reserving for astronomy a portion of the spectrum toward the blue end, where visual efficiency is low anyway but where astronomical detectors tend to work very well. This specific ordinance requires that luminaires be equipped with filters which absorb at least 90 percent of radiation of shorter wavelength than 440 nm.

The Tucson example is a valuable precedent for protection of observational astronomical research. A useful model for regional or even federal protection is the situation for radio astronomy. The Federal Communications Commision and international bodies such as the World Administrative Radio Conference for Space Telecommunications have reserved bands at radio wavelengths for astronomical use. Unfortunately, the demand for space in the spectrum for communication and navigation is so intense that some of the frequencies used by radio astronomers are not reserved exclusively for astronomy. To give some additional measure of protection, a radio quiet zone centered on the National Radio Astronomy Observatory in Green Bank, West Virginia, has been established. Thus, the federal government already has a balanced scheme of radio wavelength emissions standards with control over both the spectral and geographical distribution of sources. It seems a ripe time for the astronomical community to seek extension of the same principles, perhaps in modified form, to other parts of the electromagnetic spectrum. An existing federal agency, such as the Environmental Protection Agency, might take the responsibility.

Street lighting is primarily for the benefit of the automobile driver. Since, apart from reasons of crime deterrence, there is no advantage to lighting the streets where and when automobiles are not present, most light might be considered to be wasted. It seems worthwhile then to consider completely new systems for lighting streets. Where only automobiles are involved, it might make sense to abolish streetlights and allow improved automobile headlight systems to do the same job. High-intensity vapor lamps could be developed for automotive use and used in conjunction with polarizers mounted on car lamps and windshields, tilted at 45° to the vertical. The headlights in use today are generally recognized to be inadequate for nighttime driving at high speeds, but if their luminosity were increased by a factor of 20 or so much of the need for perpetual nighttime lighting would disappear. The total amount of light produced would probably be much less than at present, although the fact that it would be horizontally directed is troublesome. A study of the effectiveness of any such system should include the light pollution aspect.

It is possible to make significant progress toward protecting the astronomical observing environment without compromising the legitimate lighting needs of the public. Minimum standards controlling the elevation distribution of light from individual lamps and the spectral and geographical distributions are feasible and should be sought while there is time to preserve useful observing sites.

The scientific community can make an immediate contribution. Every major optical observatory in the country should initiate a routine program to monitor the skylight as a function of position, wavelength, and time. It is essential that astronomers arm themselves with hard data on deteriorating observing conditions so that effective remedial action can be sought and won in the future. Some progress can be made by formulating the problem quantitatively, and by increasing communication on this subject in meetings such as the one organized by project ASTRA (*13*).

Finally, esthetic arguments against useless outdoor lights are beginning to be appreciated. The chairman of the Los Angeles City Planning Commission actually proposed in 1972 that the Santa Monica Mountains be outfitted with many searchlights to scan the skies every night, for their dramatic effect (*14*). Public outrage was instantaneous and nearly unanimous. But aside from this isolated and somewhat bizarre incident, there is some growing feeling that a dark night sky is a nice thing; millions of urban children have never seen the Milky Way. In 1971, the board of directors of the Sierra Club adopted a policy against unnecessary outdoor lighting because it wastes energy, is esthetically unpleasant, and interferes with astronomical research. This point of view should be encouraged.


**Summary**

There have been major qualitative and quantitative changes in outdoor lighting technology in the last decade. The level of skylight caused by outdoor lighting systems is growing at a very high rate, about 20 percent per year nationwide. In addition, the spectral distribution of man-made light pollution may change in the next decade from one containing a few mercury lines to one containing dozens of lines and a significantly increased continuum level. Light pollution is presently damaging to some astronomical programs, and it is likely to become a major factor limiting progress in the next decade. Suitable sites in the United States for new dark sky observing facilities are very difficult to find.

Some of the increase in outdoor illumination is due to the character of national growth and development. Some is due to promotional campaigns, in which questionable arguments involving public safety are presented. There are protective measures which might be adopted by the government; these would significantly aid observational astronomy, without compromising the legitimate outdoor lighting needs of society. Observatories should establish programs to routinely monitor sky brightness as a function of position, wavelength, and time. The astronomical community should establish a mechanism by which such programs can be supported and coordinated.


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# The Genetics of Hereditary Disorders of Blood Coagulation

## Functional and immunological studies provide evidence for the heterogeneity of many familial clotting disorders.


Oscar D. Ratnoff and Bruce Bennett


The dramatic nature of the symptoms of hereditary disorders of blood coagulation and the ease with which the affected tissue, circulating blood, can be studied contribute to the disproportionate interest in these rare conditions. Among the results of many published studies, a large volume of information has been generated which supplies support for principles of heredity adduced from other sources. The discovery that many of these diseases are heterogeneous in nature has overthrown our simplistic views and has raised, in the usual way, more questions than answers. The next few years should see a rapid expansion of our knowledge in this field, and the time seems appropriate for us to take stock and see just where we are.

### Normal Blood Coagulation

In mammals, blood clotting results from the conversion of a soluble plasma protein, fibrinogen (factor I), into fibrin, an insoluble network of fibers. The jelly-like appearance of blood clots is due to the entrapment of cells and serum within the meshes of this network. The formation of fibrin is catalyzed physiologically by a hydrolytic plasma enzyme, thrombin, which cleaves two pairs of small polypeptides, fibrinopeptides A and B, from each fibrinogen molecule (Fig. 1). What remains, so-called fibrin monomer (*1*), then aggregates into an insoluble polymer, fibrin. The monomeric units of fibrin are further bound covalently through the action of another


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