INTRODUCTORY REMARKS

(Invited Discourse)

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High flying balloons, rockets and artificial satellites have made available to astronomers the whole electromagnetic spectrum reaching the earth from outer space, most of which was previously denied to them by atmospheric absorption. However, even from above the atmosphere, the astronomer interested in objects beyond the solar system has still to reckon with the attenuation of electromagnetic waves by interstellar matter, i.e., by the interstellar gas and the interstellar dust. For practical purposes,

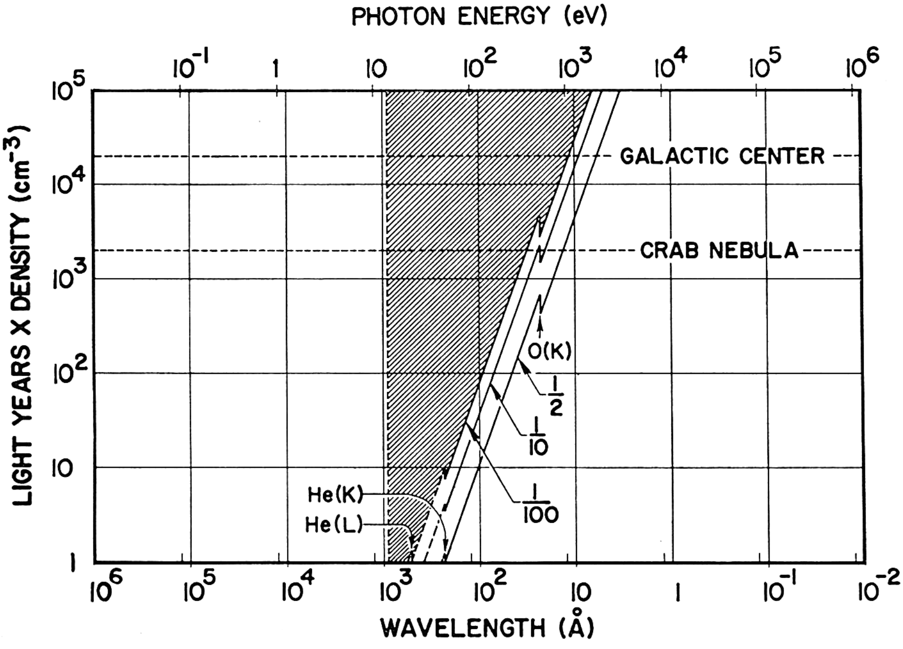

Fig. 1. The absorption of radiations of different wavelengths in interstellar gas. The ordinate is the product of the distance of a given celestial object (in light years) times the average density of interstellar gas (in atoms per cm^{-3}). The curves represent the values of this quantity for which radiations of the various wavelengths are reduced in the ratios 2:1, 10:1 and 100:1 in travelling from the object to the earth.

interstellar gas is completely transparent over galactic distances for all wavelengths from radio waves to the far ultraviolet. In this spectral region the visibility is partially impeded only by the unevenly distributed interstellar dust.

But at 912 Å, i.e., at a photon energy equal to the ionization energy of hydrogen

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(13.5 eV), the interstellar gas becomes suddenly very opaque. Proceeding toward shorter wavelengths, the absorption decreases gradually (see Figure 1), and interstellar space becomes transparent again at photon energies that vary from about 100 eV for he nearby stars to about 1000 eV for the more distant galactic objects. In all of th is spectral region, the absorption of dust is negligible.

Thus interstellar absorption quite naturally divides the electromagnetic spectrum into a *low energy region*, which extends from radio waves to 13.5 eV photons, and a *high-energy region*, which starts somewhere between 100 and 1000 eV, depending on the distance of the object under consideration, and extends to the highest energies at which the photon flux is still above the detection limit of the available instruments.

The subject of our Symposium concerns the high energy region of the electromagnetic spectrum.

From the point of view of the observational requirements, it is convenient to further subdivide this region into the following subregions:

(a) *Soft X-rays* extending from the low-energy cut-off due to interstellar absorption to about 15 keV. Observations of soft X-rays can only be carried out at altitudes above 100 km, and thus require the use of rockets or artificial satellites. Most of the data so far available have been obtained with rockets.

(b) *Hard X-rays* extending from about 15 keV to about 0.5 MeV. Since the spectrum of high-energy photons is very steep, the short observation time provided by rockets is a serious handicap. Satellites, so far, have only been available to a very limited extent for X-ray astronomy. On the other hand, hard X-rays penetrate to a sufficient depth in the atmosphere to be detectable by balloon-borne instruments, which provide observation times of many hours. For these reasons, most of the existing information on hard X-rays has come from balloon observations. These observations are hampered, although not in a crucial way, by a diffuse background of X-rays arising from the interactions of cosmic rays with atmospheric gases.

(c) *γ-rays* extending from 0.5 MeV to several hundreds MeV. The very low intensity of the radiation in this energy range practically rules out the use of rockets. Moreover, since the intensity of high-energy photons of celestial origin decreases with increasing energy more rapidly than that of the secondary photons from cosmic ray interactions in the atmosphere, the background problem that already plagues balloon observations of hard X-rays becomes here even more serious. Thus satellites are essential in γ-ray astronomy.

As you know, high-energy astronomy is a very young science.

A search for extrasolar γ-rays with quantum energies of the order of 100 MeV began in the early 60's, prompted by the prediction that photons in this energy range should originate from the interaction of cosmic rays with interstellar matter. Only two years ago, however, did this search produce unambiguous positive results.

X-ray astronomy had its beginnings in 1962. The early observations revealed the existence of discrete X-ray sources and of a diffuse X-ray background, both many orders of magnitude stronger than anyone had expected to find.

Because of the unexpectedly large intensity of celestial X-rays, X-ray astronomy has evolved with remarkable speed; by now it is well beyond the exploratory stage where γ-ray astronomy still finds itself.

A few words about the program of our Symposium.

The development of new observational techniques of increasing sophistication has played a crucial role in the progress of the new field of astronomy that we are discussing. Thus the organizing committee has considered it appropriate to begin with a brief discussion of these techniques, including not only those that have already been used, but also those that are planned for future experiments. Dr. Gursky will present this discussion immediately after my introductory remarks.

The four subsequent sessions, starting with that of this afternoon, will be devoted to the discrete X-ray sources, which have been the object of most observational programs thus far. One important line of investigation has been a search for new sources and a study of their distribution in the sky. We shall hear a report on this subject from Dr. Friedman, whose group has been responsible for the most extensive surveys, and has been active in other aspects of X-ray astronomy as well. Here I only wish to recall that, while most of the observed sources lie within the Milky Way, a few are located at high galactic latitude. The former sources are clearly galactic objects; the latter are presumably extragalactic objects and one of them, in fact, has been tentatively identified with a radio galaxy.

The general surveys that I have mentioned were performed by means of rockets, which remain above the atmosphere for only a few minutes. Since the flights were designed to cover a large area of the sky, the observation time devoted to each source was very short and the amount of information that could be gathered was correspondingly limited. It was thus necessary to follow the general surveys with a detailed study of individual sources. This has been done by a number of different groups, and we shall hear reports from representatives of these groups, i.e., from Dr. Clark, Dr. Peterson, Dr. Giacconi and Dr. McCracken.

The observations have been directed mainly toward securing the following kinds of information:

(a) Location, for the purpose of attempting an identification with optical or radio objects.

(b) Angular diameter.

(c) Time variations in the X-ray flux.

(d) Gross spectral features.

It is interesting to note that the two sources for which we have most detailed data turned out to be entirely different objects. One of them, of course, is the Crab Nebula; a supernova remnant, whose X-ray emission originates from a region of finite dimensions. These X-rays have a hard spectrum and their flux is constant in time. The other source is Sco X-1. This object appears point-like both to the optical telescopes and to the X-ray detectors with the finest resolution achieved so far (about 20 arc sec). The X-ray spectrum is much softer than that of the Crab and its intensity undergoes large fluctuations.

No reasonable doubt exists today concerning the visible counterpart of Sco X-1 nor concerning the identification of the Crab Nebula as an X-ray source. Other identifications of X-ray sources with visible objects have been suggested, of which some are convincing, others still tentative. These identifications have focussed the interest of optical astronomers upon several faint objects whose peculiar properties had not been noticed previously or had not received much attention. We shall hear about the results of the optical observations of X-ray sources from Dr. Johnson. These observations are of great importance because they place new and very significant limitations on the models of X-ray stars that may be proposed.

A question that still puzzles astronomers is the relation of X-ray stars to other galactic objects. We know that some of the galactic X-ray sources are supernova remnants. But what about the others? Are we to regard them as objects entirely different from all celestial objects previously known? Or are they peculiar members of some known family, such as, for example, old novae? Or do they, perhaps, represent a particular transitory stage in the development of ordinary stars? Some clue to this puzzle may be found in the statistical distribution of the X-ray sources. The observational data concerning this distribution and their possible significance will be discussed by Dr. Gratton at the end of tomorrow's session.

Saturday morning, with the lectures of Dr. Woltjer and Dr. Felten, we shall come to grips with the still unsolved problem of the physical phenomena responsible for the strong X-ray emission by the discrete sources. As far as I know, most theories that have been suggested are based on either one of two assumptions: (1) X-ray emission by optically thin plasmas, locally in nearly thermal equilibrium at temperatures of the order of several tens of millions of degrees; (2) X-ray emission by magnetic bremsstrahlung of very high-energy electrons. Different models have been proposed to account for the large masses of exceedingly hot plasma required by the first assumption, or for the large numbers of exceedingly energetic electrons required by the second assumption. Whether or not any of these models is really convincing is a question about which we may want to reserve judgment until after the discussions that, I am sure, will follow the talks of Dr. Woltjer and Dr. Felten.

The last session, on Saturday afternoon, will be devoted to the background radiation. Dr. Oda will review the observational results concerning the X-ray component of this radiation, Dr. Kraushaar those concerning the γ-ray component. Finally Dr. Setti will discuss the theoretical questions raised by the observations.

I do not wish to anticipate any of the facts or of the conclusions to be presented at this session. I would like, however, to point out that, potentially at least, the diffuse background is of equal, or perhaps even greater cosmological interest than the discrete sources. To support this view I only need to remind you of the suggestion that the X-ray background may be due to inverse compton effect of high-energy electrons colliding, in intergalactic space, with photons of the universal black-body radiation. This radiation is supposed to originate from the big explosion that gave birth to our universe some 15 or 20 billion years ago; and, if the hypothesis is correct, there are reasons to believe that the X-ray photons observed today might have been produced when the Universe was still young.