SPACE AND GROUND-BASED STELLAR SPECTROPHOTOMETRY; A SUMMARY

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1. Introduction

One of the most important results of the present Symposium is the obvious necessity of close cooperation between ground-based and UV stellar spectral observers. Either of the two observational techniques yields only part of the total information about the stars and the interstellar medium; together they enable the scientist to construct the imposing image of modern stellar spectroscopy that we have seen growing during this Symposium.

2. Calibration

It is the purpose of all objective spectrophotometry to express the instrumental output as photon fluxes, either on a relative or an absolute scale. Absolute photometry can only be done through a thorough calibration of the instrument, i.e. the telescope, the spectrograph and the detector. For the calibration one needs a laboratory source or an in-flight calibration source; the latter is often a secondary or tertiary standard, calibrated by means of a well tested laboratory source.

As stated by Boldt, the fundamental problem in the field of absolute intensity calibration is the development of primary standards. Such a standard should be really absolute, constant over long periods, and, if possible, easy to manipulate. Up to now a few primary standards have been developed, which should be able to guarantee an accuracy of the order of $\pm 10\%$. Therefore, the development of other primary standards does not seem of high interest. However, it is highly important to intercompare the available primary standards with each other in order to find out whether they really agree within the above error limit of 10%.

Boldt described three calibration methods based on laboratory sources: the branching ratio method, the synchrotron radiation method, and the blackbody radiation method. Bless described a synchrotron source with electrons of energies up to 240 MeV in a vacuum of 10^{-9} Torr; the electrons can be distinguished individually and have lifetimes of hours, and thus provide a stable source of known flux.

For relative in-flight calibration a Čerenkov source seems to be the best; theoretically the output should be constant with time and known in absolute units. As another secondary standard sodium salicylate was mentioned; it transforms photons from energies below 3000 Å to photons of energies above 4000 Å with an efficiency which is nearly independent of wavelength of the ultraviolet radiation below 3000 Å.

Of certain detectors, like ionization chambers and sodium salicylate, the efficiency should be known *a priori* and be constant in time. Carruthers mentioned that unity

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gain ion chambers, particularly the windowless free-flow variety satisfy this demand fairly well. However, it is well-known and was stressed again by Davis, that the efficiency of photon counters actually may change rapidly and decrease after days, which necessitates regular in-flight calibration.

A remarkable kind of in-flight calibration was mentioned by Severny: occasionally one may use the Sun through its reflection against a satellite with a known UV albedo, at a known distance.

3. Interstellar Extinction

The amount of interstellar extinction can only be determined by comparing the intensities in spectra of two stars of the same spectral type, one being nearby and the other far away. The main problem is how certain one may be that two stars which are seemingly similar in the visual spectral region are still similar in the ultraviolet. A few estimates of the interstellar extinction have been made by comparing a nearby main sequence star with a distant supergiant; this seems a dangerous procedure, but OAO results seem to indicate that early-type stars with the same visual colors and spectral types are indeed similar in the 3000–1000 Å region.

The importance of the new UV stellar spectral observations is, of course, that the region over which extinction is determined extends no longer only from $\lambda^{-1} = 1$ to 3 μ^{-1}, but now up to 9 μ^{-1}. This proves to be important for the determination of properties of the grains.

Stecher showed a fine extinction curve for ζ Per, while Bless and Savage showed extinction curves for ten pairs of stars. There is variation from one star to the other but the general trend is that a hump exists near 2200 Å. The character of the extinction curve for very short wavelengths, around 1100 Å, is not yet certain; most people assume a continued rise for great λ^{-1}, after the peak at $\lambda^{-1} \approx 5\ \mu^{-1}$, but Carruthers showed that in special cases, as in the Orion Nebula region, the extinction law can be drastically different from that found generally applicable, which has also been found true at the longer wavelengths accessible from the ground.

With regard to the interpretation of these results it should be mentioned that the peak in the extinction curve was predicted earlier by theorists, but the wavelength was expected to be longer (near $\lambda^{-1} \approx 3$ or 4 μ^{-1}). This previous broad hump (at $\lambda^{-1} \approx 3.5$) was interpreted by assuming the grains to be large enough that extinction saturation was reached at that wavelength. The narrow new peak near $\lambda^{-1} \approx 5.5\ \mu^{-1}$ would appear to be due rather to absorption characteristics of the grain material – either an absorption band or the beginning of an absorption edge. This hump would be obscured if the particles were too large. However, the principal observed indication that the particles are smaller than assumed previously is that the extinction curve is continuing its rise beyond $\lambda^{-1} \approx 6\ \mu^{-1}$, implying that the *saturation hump* occurs very far out (assuming of course that the extinction at the short wavelengths is still due to the grains).

The composition of the grains is not yet certain. Various models were discussed and seem to be able to explain the observed extinction curves equally well: the graphite core ice mantle (Greenberg and Shah), pure ice or silicate grains, and silicate core-ice mantle particles (Greenberg), a mixture of graphite and silicate particles with or without mantles of ice or solid H_2 (Wickramasinghe). It was suggested that the observed peak in the extinction curve would correspond to a transition to the conduction band of the π-electron in graphite; it seems too narrow for ice (Stecher, Wickramasinghe).

Solomon discussed the possibility of the occurrence of interstellar hydrogen molecules, which might form through the intermediacy of interstellar grains as a catalyser; the resulting expected molecular densities were depressingly low (see also Section 8). The suggestion that solid H_2 could be expected on the grains was questioned by Van de Hulst and Greenberg; they wondered whether the grain temperatures could be low enough to maintain a solid H_2 mantle.

4. Absolute Intensities

For a few stars absolute intensities have been determined; Gingerich and Latham, and Morton presented model-atmosphere calculations of stellar spectral intensity distributions which were compared with Stecher's observations of Sirius and ζ Puppis. The determination of the stellar diameters by Hanbury Brown and his colleagues then enables the effective temperature of the stars to be determined directly.

Generally the observed intensities in the far ultraviolet (around 1200 Å and shorter) are somewhat lower than those predicted by the models; for the main sequence early-type stars the discrepancy is small and may be due to the agglomeration of unresolved Fraunhofer lines in the spectrum, not accounted for in the model calculations. The influence of carbon absorption competes with Lyman α in determining the shape of the stellar intensity curve near 1100 Å.

In the case of bright giant, and supergiant A and F stars the computed ultraviolet intensities are systematically larger than the observed values; in these cases expanding shells of gas may be involved.

There are observational as well as theoretical problems with regard to the absolute intensity in the UV. With regard to the reality of the UV deficiencies various authors stressed that one should be extremely careful in ascertaining that absolute calibration has been done correctly. It is only necessary to recall that the *solar* continuous spectrum in the visual spectral range has been determined now by many authors in long, quiet periods of observations in ideal observing conditions and that even now differences of 20% between one author and the other still occur. Therefore, one should not be surprised about differences of factors of 2 between one author and another in the absolute calibration of UV stellar spectra.

From the theoretical point of view Gingerich noted that the introduction of convective models (should these exist in the range of hot stars!) would not help substantially in changing the spectral continuum intensities. Miss Underhill mentioned that many of the Fraunhofer lines are formed in outer stellar shells with excitation conditions that may strongly deviate from those in the stellar photosphere.

5. Observations of Stellar Spectra

Davis showed TV pictures of star fields obtained by the Celescope experiment in the Orbiting Astronomical Observatory. The observations of line spectra were reviewed by Wilson; the following groups have now obtained line spectra of stars in the UV: Jenkins-Morton (Princeton); Carruthers (Naval Research Laboratory); Stecher (Goddard) and Smith (Goddard); the Wisconsin group with the OAO.

Stecher showed spectrophotometer runs of several stellar spectra between 1150 and 3200 Å with a resolution of 10 Å.

Bless had OAO spectra of similar resolution between 1100 and 1800 Å and showed a slide giving the variation of the strong spectral features with spectral type for main sequence B stars.

Smith showed a photographic spectrum of ζ Puppis extending from 921 to 1360 Å with a resolution of 0.8 Å. There are many weak lines which exhibit a range of ionization (like N III, N IV, N V) and excitation (0–76 eV) essentially in agreement with visual spectral observations of similar type stars. One may assume these lines to arise in a stationary part of the stellar atmosphere. In addition strong P Cygni type profiles were observed for resonance transitions in O VI, N III and S VI. These lines show mean radial velocities between 1000 and 2000 km s^{-1}, and may originate in a circumstellar envelope.

Also other observers stressed the important point that many giant stars show strong lines with P Cygni profiles in the rocket UV. These lines indicate outstreaming motion, at velocities up to several thousand km s^{-1}.

6. Outstreaming Motions

Observational results on outstreaming motions were discussed by Feast and Hutchings. Mass loss is not generally detectable in stars but is evident in very luminous early-type stars in the visible as well as in the UV spectrum; in actual fact for stars with absolute visual magnitudes brighter than -6 mass loss is a normal feature. The P Cygni profiles of far UV spectral lines in giant and supergiant stars were mentioned in Section 5. Many UV velocities are larger than velocities determined in the visual spectral range (Hutchings), which is, of course, only a question of having the proper kind of lines to observe the moving layers; the lines with P Cygni profiles occur mainly in the middle UV. In cool red giants there is clear evidence for chromospheric activity (Deutsch), as is shown by observations of the Balmer lines, the Ca II H and K lines, and the NaD lines. The time scale in these changes is of the order of a few weeks or months. For the K line in α Tauri (K5 III) a quasi period has been found.

The theory of these lines is difficult since existing stellar photospheric models are not appropriate in the range of heights where the strong lines are formed (Underhill); in some cases the opacity in strong lines may be 10^6 to 10^8 times the values for the continuum; obviously these lines should be interpreted by non-LTE physics. Also fluorescence phenomena generated by UV lines in molecules might play a part (Swings and Swings).

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The explanation of the outstreaming motion is perhaps due to radiation pressure exerted by the many strong ultraviolet lines occurring between 900 and 3000 Å. A detailed discussion of this problem was given by Solomon and Lucy, who discussed the hydrodynamic problem of flow and gave theoretical results; a mass loss of a few times 10^{-8} solar masses per year was predicted for O and B stars of high luminosity. A semi-empirical model of an expanding envelope based on Morton's UV spectra in Orion was basically in agreement with this picture (Hutchings).

7. The Sun

Pottasch showed that observations of the solar continuous spectrum in the ultraviolet spectral range may yield a model of the photospheric and chromospheric regions; this is obviously so because the continuous absorption coefficient increases strongly towards shorter wavelengths. This method is even more powerful than the use of center-to-limb observations of the continuous spectrum since the average depth of emission of ultraviolet observations varies over a large range between the visual and the far UV wavelengths. It seems appropriate to apply this method to stellar spectra also. However, one may doubt whether the method would work for hot stars where the continuous extinction is for a great part due to Thompson scattering by free electrons and is virtually constant as a function of the wavelength. The behavior of the Al I discontinuity at 2080 Å was discussed by Bonnet and Gingerich; according to the former the photo-ionization of aluminum must undoubtedly cause an effect on the solar continuous spectrum but quantitatively the discontinuity can only be explained with a fairly large Al abundance, by the introduction of non-LTE physics with regard to the ground level population of Al I, and by introducing inhomogeneities in the transition zone photosphere-chromosphere.

On the other hand Gingerich showed that the new Harvard-Smithsonian Reference model of the photosphere and low chromosphere is able to account for the aluminum discontinuity at the centre of the disc with an LTE model and a 'normal' Al abundance. However, the limb behavior cannot be explained by that model.

Vial and Lemaire tried to use existing chromospheric models to explain the observed limb-behavior of the Lyman α line and the Mg II lines and found it hard to obtain agreement with observations. Splendid spectral observations of the Mg II lines at 2800 Å were shown by Lemaire and by Wilson; the latter was the first who obtained interferometric spectra in the rocket UV. The flare-associated behavior of various groups of lines was studied by Prokofiev and co-workers who found a great diversity in their behavior.

8. Interstellar Absorption Lines

The first interstellar Lyman-α absorption data obtained by OAO were presented and compared with rocket data. The OAO data taken with a resolution of about 10 Å are blended with N V at 1230 Å and Si III at 1200 Å, so that it is difficult to find the real equivalent widths of the Lyman α line. The OAO data yield equivalent widths, about two

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to three times those obtained by rocket spectrographs, where the resolution was generally better than with OAO. This large factor seems not to be due entirely to the above mentioned blending, but may be due to the choice of the height of the continuum level. The problem of where to draw the continuum is not yet solved satisfactorily.

A comparison of the interstellar neutral hydrogen density derived from 21 cm data and from Lyman α is extremely interesting. If one uses the equivalent widths estimated from high resolution spectra, a discrepancy seems to occur between these two data, which is particularly apparent in the Orion complex, but which is also evident for some other parts of the Milky Way. In the Scorpius region, however, the Lyman α data appear in general agreement with the 21 cm data.

Two suggestions were put forward for explaining the apparent weakness of the Lyman α interstellar absorption lines in the Orion regions. Jenkins considered the effect of neutral hydrogen gas clouds with diameters smaller than 0.1 parsec, a mass of 5 $M_{\odot}$, and temperatures between 100 and 1000 K; these clouds would have to be distributed in such a way that up to now all stellar observations have missed the clouds, while the 21 cm observations, taken with a broader detecting angle should integrate over the clouds and the region in between.

The other suggestion is that neutral hydrogen was blown away around the Orion stars, which would certainly reduce the circumstellar component of Lyman α interstellar absorption. This hypothesis may be supported by the observation that there exists a reasonable correlation between equivalent widths of interstellar Lyman α and NaD lines.

Other possibly observable interstellar lines, not yet within the reach of present equipment, but perhaps observable when at a later time higher resolution spectrographs exist, are lines of C, N, Al, Si, P and S; Herbig listed 23 lines of these elements. A problem is the theoretical prediction of the line strengths since several of these lines should be due to highly ionized atoms; the computation of the degree of ionization in interstellar space is difficult. It is remarkable that the Ca/Na abundance ratio in interstellar space seems about 10^3 times smaller than the normal value for most stars. Various suggestions to explain this difference were listed by Herbig.

9. Interstellar Emission Lines

Observations of the interstellar Lyman α emission were reported by Sunyaev (Venera flights) and by Barth (Mariner flights). The spacecraft performed several rolls when on their way to Venus and could thus define the distribution of Lyman α emission along various tracks at right angles to the Milky Way. There are several contributions: the interplanetary component, the galactic component, perhaps mainly due to a circumsolar region with a radius of about 50 pc, and partly also the Lyman α component from the H I regions; theoretical calculations of that latter aspect were shown by Panagia and Fulchignoni. However, it is far from clear how the above three components contribute to the observed Lyman α distribution.

Severny reported Cosmos satellite observations of the emission of the Milky Way in the near UV (about 2700 Å). The field of view was large, and it was not possible to separate the effect of the many faint stars from that of a true diffuse background.

Further, hypothetical, contributions to the UV emission flux were summarized by Sunyaev: low energy cosmic rays could perhaps contribute. Furthermore, there could also be an inter- and an extragalactic component, due to quasars and to young galaxies. All this is highly fascinating and makes one look forward to further observations in this spectral range.

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