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in Science and Technology**

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L. H. Aller · I. Appenzeller · B. Baschek · H. W. Duerbeck  
T. Herczeg · E. Lamla · E. Meyer-Hofmeister · Th. Schmidt-Kaler  
M. Scholz · W. Seggewiss · W. C. Seitter · V. Weidemann

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## Survey

Subvolume a: Methods. Constants. Solar system

- 1 Astronomical instruments
- 2 Positions and time determination, astronomical constants
- 3 The solar system

Subvolume b: Stars and star clusters

- 4 The stars
- 5 Special types of stars
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Subvolume c: Interstellar matter. Galaxy. Universe

- 7 Interstellar matter
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## Übersicht

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- Gesamtregister

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## **Vorwort**

Nach dem kürzlich erschienenen ersten Teilband 2a des Bandes VI/2 „Astronomie und Astrophysik“ wird hiermit der Teilband 2b vorgelegt. Auch für ihn gilt das im Vorwort zum ersten Teilband Gesagte ohne Änderung und Einschränkung.

Der letzte Teilband 2c wird so schnell wie möglich folgen.

Heidelberg und Göttingen, Oktober 1981

**Die Herausgeber**

## **Preface**

This subvolume is the second part, 2b, of volume VI/2, "Astronomy and Astrophysics", the first part of which, VI/2a, has been published a short time ago. Since the preface of vol. VI/2a holds completely also for VI/2b, it will not be repeated here.

The third part, 2c, will be published as soon as possible.

Heidelberg and Göttingen, October 1981

**The Editors**

## List of abbreviations

**Abbreviations, commonly used in Astronomy, and not always explained explicitly in this book.**

|        |                                                                                              |      |                                                                |
|--------|----------------------------------------------------------------------------------------------|------|----------------------------------------------------------------|
| AU     | Astronomical Unit (= Distance Earth–Sun)                                                     | LC   | Luminosity Class                                               |
| B.C.   | Bolometric Correction                                                                        | LF   | Luminosity Function                                            |
| BD     | Bonner Durchmusterung                                                                        | LMC  | Large Magellanic Cloud                                         |
| CLV    | Center-limb variation                                                                        | LTE  | Local thermodynamic equilibrium                                |
| CMD    | Colour-magnitude-diagram                                                                     | M    | Messier Catalogue                                              |
| CNO    | Carbon, Nitrogen, and Oxygen ( <i>not</i> as molecule) e.g. CNO cycle, CNO anomalies         | MHD  | Magneto-hydrodynamics                                          |
| ESA    | European Space Agency                                                                        | MMT  | Multi-Mirror-Telescope                                         |
| ESO    | European Southern Observatory                                                                | MPI  | Max-Planck-Institut                                            |
| ET     | or E.T. Ephemeris Time                                                                       | NASA | National Aeronautics and Space Administration                  |
| EUV    | Extreme ultraviolet                                                                          | NEP  | Noise Equivalent Power                                         |
| FWHM   | Full Width of Half Maximum                                                                   | NGC  | New General Catalogue                                          |
| HD     | Henry Draper Catalogue                                                                       | NLTE | Non-local thermodynamic equilibrium                            |
| HR     | Harvard Revised Catalogue                                                                    | NRAO | National Radio Astronomy Observatory, Green Banks, W. Va., USA |
| HRD    | Hertzsprung-Russell Diagram                                                                  | POSS | Palomar Observatory Sky Survey                                 |
| IAU    | International Astronomical Union                                                             | RV   | Radial velocity                                                |
| IR     | Infrared                                                                                     | SMC  | Small Magellanic Cloud                                         |
| ISM    | Interstellar Matter                                                                          | Sp   | Spectral type                                                  |
| JD     | Julian Date                                                                                  | URSI | International Union of Radio Science                           |
| KPNO   | Kitt Peak National Observatory                                                               | UT   | Universal time                                                 |
| LB, NS | Landolt-Börnstein, Numerical Data                                                            | UV   | Ultraviolet                                                    |
| or LB  | and Functional Relationships in Science and Technology, New Series or: Landolt-Börnstein, NS | VLBI | Very Long Baseline Interferometry                              |
|        |                                                                                              | XUV  | X-ray and ultraviolet region                                   |
|        |                                                                                              | ZAMS | Zero Age Main Sequence                                         |

Abbreviations of further Star Catalogues: see 8.1.1

For abbreviations of special star types (e.g. WR stars), see “Spectralclassification” (4.1.1), “Variable stars” (5.1), “Peculiar stars” (5.2) and subject index.

**Some important Astronomical Artificial Satellites, mentioned in this book**

|      |                                                           |     |                                                  |
|------|-----------------------------------------------------------|-----|--------------------------------------------------|
| ANS  | Astronomical Netherlands Satellite (The Netherlands NASA) | IUE | International Ultraviolet Explorer (NASA–UK–ESA) |
| ATS  | Applications Technology Satellite                         | OAQ | Orbiting Astronomical Observatory (NASA)         |
| COS  | Cosmic Ray Satellite (ESA)                                | OGO | Orbiting Geophysical Observatory                 |
| GIRL | German Infrared Laboratory                                | OSO | Orbiting Solar Observatory                       |
| HEAO | High Energy Astrophysical Observatory (NASA)              | MTS | Meteoroid Technology Satellite (NASA)            |
| HEOS | High Eccentricity Earth-Orbiting Satellite (ESA)          | RAE | Radio Astronomy Explorer                         |
| IMP  | Interplanetary Monitoring Platform                        | SAS | Small Astronomy Satellite (NASA)                 |
| IRAS | Infrared Astronomical Satellite                           |     |                                                  |

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## 4 The stars

### 4.1 Physical parameters of the stars

#### 4.1.0 General remarks

The physical parameters given here are integral values which characterize the physical properties of a star as a whole, especially mass, luminosity, radius, effective surface temperature, age, spectral type, color, absolute magnitude, surface gravity, equatorial rotational velocity. Characteristic diagrams such as the luminosity-temperature (Hertzsprung-Russell) diagram enable us to describe the evolution of stars.

#### 4.1.1 Classification of stellar spectra <sup>1)</sup>

##### 4.1.1.1 The (improved and extended) Harvard classification

The stars can be arranged in a linear sequence according to the general appearance of their line spectra. The essential parameter is the ionisation temperature of the stellar atmosphere. As the color temperature decreases from O to M, the stars become redder.

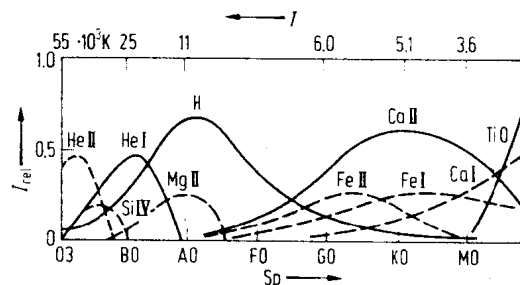
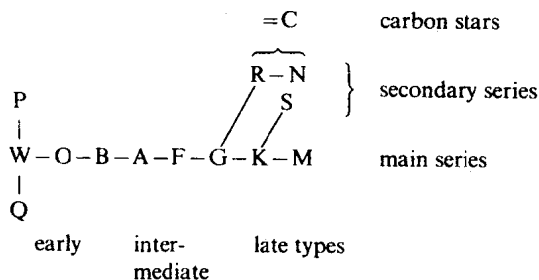


Fig. 1. The relative intensities  $I_{rel}$  of the most important lines in the spectra of the main series O...M (illustrated schematically).

99.95% of the stars brighter than 8<sup>m</sup>0 (completeness limit of the Henry Draper Catalogue) belong to the main series O to M.

The spectral classes SP are given as decimals (e.g. O9, O9.5, O9.7, B0, B1, ...). Agreement is about  $\pm 0.6$  of a subdivision [1]. The classification is made either based upon a summary description, or by determining the intensity ratios between certain (neighbouring) lines, or by comparison with the spectra of standard stars. The classification criteria may vary for spectra of different dispersions and wavelength regions.

Detailed descriptions of the line spectra of selected stars are referenced, e.g. in [2, 3, 4]. A selected list is given in Table 10, p. 7.

Table 1. Spectral classification of stars with predominant emission lines (hot stars) [5].

| Sp | Standards                  | Spectral characteristics                                                                                                                                                            |
|----|----------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| P  | NGC 7027,<br>NGC 6720      | Planetary or planetary nebulae (see 5.4): many emission lines of very high excitation, including forbidden lines                                                                    |
| Q  | GK Per 1901<br>DQ Her 1934 | Novae (see 5.1.3.2) ^                                                                                                                                                               |
| W  | $\gamma^2$ Vel (WC7 + O7)  | Wolf-Rayet stars (=WR stars; see 5.2.1.2): very broad, intensive emission lines of H, He I, He II are superposed on a continuum which is especially intensive in the blue-UV region |
| WN | HD 192163 (WN6)            | a) nitrogen sequence WN5...8 with strong emission lines of N III, IV, V                                                                                                             |
| WC | HD 192103 (WC7)            | b) carbon sequence WC5...8 with strong emission lines of C II, III, IV, O III...O VI                                                                                                |

Details of subclasses of WR stars are given in Table 2, page 3.  
See also 4.1.1.3, Table 9a.

<sup>1)</sup> In the following tables all wavelengths are given in [Å], if not stated otherwise.

For Table 2, see next page.

Table 3. Spectral types with predominant absorption lines (main series O...M).

For any two lines a and b in the third column:

- $a > b$  line a stronger than line b  
 $a = b$  lines a and b have the same intensity  
 $a : \text{max}$  line a has maximum intensity at this spectral type  
 $a \approx 0.5 < A_0 >$  line a has half the intensity of the same line in spectral type A0  
 $a \approx 0.1 \text{ H}\delta$  line a has one tenth of the intensity of the line H $\delta$   
 $a \approx 2 \odot$  line a has twice the intensity as the same line in the solar spectrum

| Sp               | Standards                              | Spectral characteristics                                                                                                                                                                                                     |
|------------------|----------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| O                |                                        | Intensive (blue) continuum, predominant absorption lines of He II, additionally of C III, N III, Si IV [8]. If N III 4634/40/41 appears in emission the star is called Of (see 5.2.1.1), if He II 4686, it is Onfp. See [8]. |
| O3               | HDE 303 308                            | He I 4471/He II 4541 = 0.1                                                                                                                                                                                                   |
| O4 f             | HD 190 429 A                           | = 0.2                                                                                                                                                                                                                        |
| O5 (f)           | HD 15 558                              | = 0.3                                                                                                                                                                                                                        |
| O6 fp            | $\lambda^1$ Cep                        | = 0.6                                                                                                                                                                                                                        |
| O7               | HD 190 864                             | = 0.9                                                                                                                                                                                                                        |
| O8               | $\lambda$ Ori                          | = 1.3                                                                                                                                                                                                                        |
| O9               | $\iota$ Ori                            | = 1.8                                                                                                                                                                                                                        |
| B0               | $\tau$ Sco, $\epsilon$ Ori             | He I > He II; C III 4650 and Si IV 4089/4116: max;<br>H $\delta$ = 1.5 He I 4026.                                                                                                                                            |
| B3               | $\pi^4$ Ori                            | He I: max; H (Balmer lines) $\approx 0.5 < A_0 >$ ; O II and Si IV very weak.                                                                                                                                                |
| B5               | $\phi$ Vel                             | Si II 4128/4131 > He I 4121.                                                                                                                                                                                                 |
| B8               | $\beta$ Per                            | He I 4471 = Mg II 4481; H $\delta$ = 15 He I 4026;<br>metal lines appear.                                                                                                                                                    |
| A0               | $\alpha$ CMa                           | Balmer series dominating (H: max); Mg II 4481 most conspicuous after Balmer lines; K (Ca II 3934) $\approx 0.1 \text{ H}\delta$ ; Si II: max; depression of UV continuum by continuous Balmer absorption.                    |
| A5               | $\beta$ Tri, $\alpha$ Pic              | Ca II (K) = 0.9 {Ca II (H) + H $\epsilon$ } and > H $\delta$ ;<br>Fe I 4299/4303 and Ti II 4303 strong.                                                                                                                      |
| F0               | $\delta$ Gem, $\alpha$ Car             | Balmer series $\approx 0.5 < A_0 >$ ; Ca II (K) = Ca II (H) + H $\epsilon$ = 3 H $\delta$ ;<br>many metal lines; G-band 4307 (Fe, Ti, Ca) appearing.                                                                         |
| F5               | $\alpha$ CMi, $\rho$ Pup               | Balmer lines $\approx 2 \odot$ ; Ca I 4227 = 0.5 H $\gamma$ ; G-band = 0.6 H $\gamma$ .                                                                                                                                      |
| G0               | $\alpha$ Aur, $\beta$ Hyi              | Solar-type spectrum (sun: G 2 or somewhat later); very intense metal lines; Ca I 4227 = H $\delta$ ; G-band = 2 H $\gamma$ = 3 Fe I 4325.                                                                                    |
| K0               | $\alpha$ Boo, $\alpha$ Phe             | Metal lines further enhanced, Balmer lines further weakened;<br>Ca I 4227 = 2 Fe II 4172 = 3 Fe I 4383; Fe I 4325 = 2 H $\gamma$ ;<br>Ca II (H, K): max.                                                                     |
| K5               | $\alpha$ Tau                           | Similar to sunspot spectrum; Ca I and II dominating; G-band dissolved in lines; green TiO-bands appearing.                                                                                                                   |
| M0... 2 (Ma)     | $\beta$ And (M0),<br>$\alpha$ Ori (M2) | TiO-bands dominating (esp. 4762...4956, 5168...5445);<br>Ca I 4227 strongest line.                                                                                                                                           |
| M3... 5 (Mb)     | $\pi$ Aur (M3)                         | Subclassification by increasing intensity of the green and red                                                                                                                                                               |
| M6... 10 (Mc)    | $\rho$ Per (M6)                        | (6651, 7054, 7589) band systems.                                                                                                                                                                                             |
| M0e... M10e (Md) | $\circ$ Cet (M6e)                      | Balmer lines (at least H $\alpha$ ) in emission.                                                                                                                                                                             |

Schmidt-Kaler