CHAPTER 16

THE CELESTIAL GLOBE AND AIDS THAT REPLACE IT

SEC. 86. THE CELESTIAL GLOBE, DESIGNATION AND CONSTRUCTION

Many problems of nautical astronomy may be solved approximately with the aid of a map and the celestial sphere, as in Sec. 5. But if the same pattern is made in the form of a model of the celestial sphere with stars indicated appropriately, these problems can be solved more simply and accurately.

The celestial globe is an instrument that models the celestial sphere and is designed for approximate solutions of problems in nautical astronomy. With a globe, one can give an approximate solution of nearly all problems of nautical astronomy, yet it is mostly used for star identification (particularly for cases of poor visibility of the sky) and choice of stars for determining positions at sea. Globes come in a variety of designs. One of the best designs is the Soviet "ЗГ" globe (Fig. 139).

The globe is a hollow plastic (or metallic) sphere of diameter 168 mm, containing pasted-on star maps, section by section, in projections such as to practically eliminate distortions. The maps contain the principal circles: the celestial equator, parallels (at intervals of 10°), meridians (at intervals of $15° = 1h$) and the ecliptic. The celestial equator is divided into degrees (at 1° intervals) and in addition, at 15m intervals below with every hour numbered. These divisions represent a scale of right ascensions α, and since the right ascension of zenith $\alpha_Z = S_{loc} = t^{\Upsilon}_{loc}$, this same scale, when setting, yields local sidereal time. Reckoning begins with Aries and is indicated by number XXIV (360°). At this point, the ecliptic intersects the equator, that is, the sun passes from the southern hemisphere into the northern. The ecliptic and the meridians of points with $\alpha = 360° - 180°$ and $90° - 270°$ are also divided into 1° intervals.

At the poles, the sphere has depressions for the axis of a metallic ring that encompasses the sphere and indicates an arbitrary meridian. When the sphere is set in its box, the horizontal metal ring inside the box depicts the celestial horizon; the ring of the meridian is inserted into the slots at points N and S of the horizon and will now represent the *meridian of the observer.*

On top of the globe, a crosspiece of vertical circles is mounted with movable index; the zenith of the observer is represented by a ball on top of the crosspiece.

The celestial globe portrays the celestial sphere (with centre in the eye of the observer) as if looked at from *outside*. As a result, the figures of all constellations are in positions the reverse of those seen on the celestial sphere.

So that the globe should reproduce the stellar sky as seen by the observer at a given time, set the globe for the latitude of the observer and turn the sphere to the time of observations. Since the globe is a model of the celestial sphere, remember when setting it in latitude that the name of the elevated pole always corresponds to the name of the latitude of the observer, whereas the altitude is equal to the latitude of the observer (φ). Thus, if the latitude is N, set P_N of the globe over point N of the ring; P_N is identified by the star Polaris (constellation Ursa Minor); but if the latitude is S, then set P_S of the globe (opposite P_N) over point S of the ring. *The inclination of the globe axis to the horizon must equal φ of the observer.* Remember that the reading on the arc of the ring will

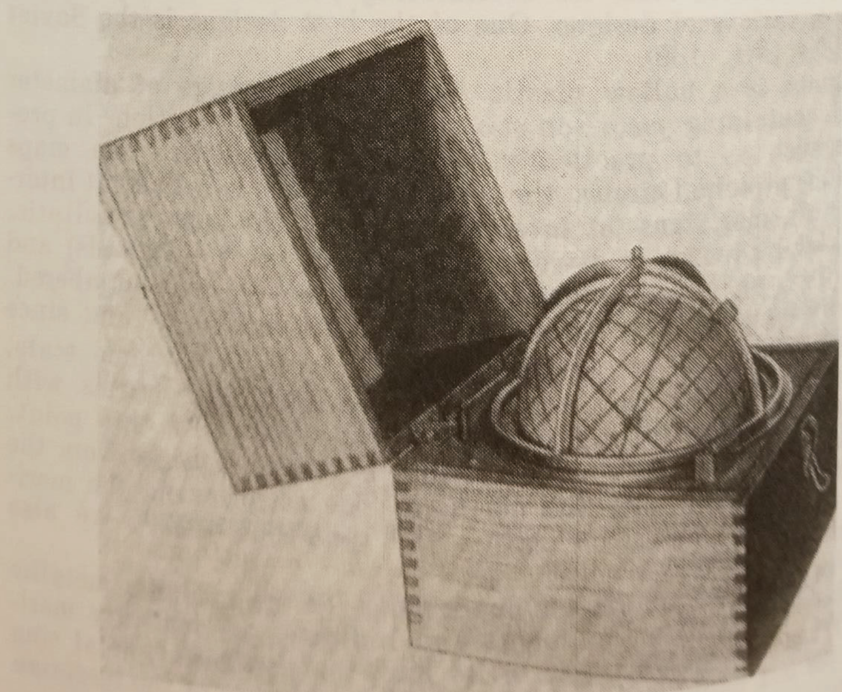

Fig. 139

be $90° - \varphi$, since the division marks on the meridian ring are meant for declinations and proceed from the equator. From the relation $\varphi = \delta_Z$, the reading on the ring of the meridian near the zenith is also equal to φ.

To set the globe to the time of observation, turn it relative to the meridian of the observer to a position corresponding *to local sidereal time* $S_{loc} = t^{\Upsilon}_{loc}$.

To do this, turn the globe so that under the arc of the observer's meridian (the upper branch) we have the equatorial reading equal to t^{Υ}_{loc} in degrees of hours. The globe will not turn on its own due to friction of the sphere against the cushion and spring inside the box.

The value of $t^{\Upsilon}_{loc} = S_{loc}$ may be computed from the MAE in the usual way (see Sec. 46, Item I) or approximately (to 4m), utilizing the time of transit of Aries (T^{Υ}_{tr}) on the Greenwich meridian as given in the daily tables of the MAE. Subtracting this time from T_{loc}, we get S_{loc} approximately. However, this procedure is no simpler than the first due to the trouble in getting T_{loc} under ordinary conditions.

A number of other problems may also be solved by turning the sphere: to bring a celestial body to the horizon, the prime vertical, the observer's meridian, to a given azimuth or altitude, and so forth.

The horizontal coordinates h and A are reproduced on the globe by means of the *crosspiece of vertical circles*. To set the crosspiece in azimuth, turn one of the vertical circles along the ring of the horizon to a reading equal to azimuth A in quadrantal reckoning; the altitude is laid off along the vertical circle and is fixed by the index.

As already mentioned, the globe indicates the *fixed positions* of 167 bright stars. Star movements on the celestial sphere are slight (see Sec. 23) and these positions will be sufficiently accurate for approximate solutions for 20 to 30 years.

Bodies that have noticeable proper motions (the sun, moon and planets) *are positioned on the globe by the observer himself* as needed or at periodic intervals. To fix these bodies on the globe, take their declinations and right ascensions from the MAE. Remember that to obtain α of the moon or sun, and also for more precise computation of planetary α, select t_{gr} of the body and t^{Υ}_{gr} for the same hour, then: $\alpha_{body} = t^{\Upsilon}_{gr} - t^{body}_{gr}$ (see Sec. 47, Item IV).

The α of the body thus obtained is reckoned from point XXIV (360°) of the globe on the scale of the equator; but the declination is laid off along the ring of the meridian to the N or S. Use a special wax pencil to mark the point on the surface of the globe and indicate the astronomical symbol of the celestial body. The planets and the moon should be located near the ecliptic. For better orientation the planetary positions are indicated periodically: Venus every week, Mars every two weeks, Jupiter and Saturn every month.

However, when solving a specific problem, the position of a given body should be revised for the given 24-hour period, and, with respect to the moon, for the given hour. The position of the sun is always on the ecliptic, which makes it easy to indicate it on the basis of $\alpha_{\odot}$.

Example 1. On 12.09.62, indicate for evening twilight, $T_{sh} = 18h\ 40m$ (ZD = 11E), the position of the moon and the planets Jupiter and Saturn which are visible at this time.

(1) Approximately, from MAE

	Jupiter	Saturn
	$\alpha = 22h\ 34m$	$\alpha = 20h\ 32m$
	$\delta = 10°.5S$	$\delta = 19°.5S$

(2) Exactly, from MAE.

$$\begin{array}{r|l} T_{sh} & 18h\ 40m\ 12.09 \\ -\ ZD & 11 \\ \hline T_{gr} & 7h\ 40m \approx 8h \end{array}$$

	Jupiter	Saturn	Moon
t_T^{Υ}	110°51′	110°51′	110°51′
t_T^{body}	132 22	162 56	144 53
α_{body}	338°29′	307°55′	325°58′
δ_{body}	10°32′S	19°39′S	15°3′S

Problem solving by the "ЗГ" celestial globe is done with an accuracy to within ±0°.5-1°.5. Therefore, the requisite data (α and t^{Υ}_{loc} and also α and δ of the celestial bodies) do not need to be more accurate than ±0°.3-0°.5.

Many firms in other countries manufacture globes that differ in design from the "ЗГ" globe. In some cases, the box is replaced by a support made up of two half-rings; in others there is no crosspiece of vertical circles, a mobile ring taking its place, and so forth. Yet they function in similar fashion to the "ЗГ" globe.

SEC. 87. SOLVING PROBLEMS WITH THE CELESTIAL GLOBE

The celestial globe is used to solve three basic types of problems:

(1) determining the names of observed but unidentified stars or planets;

(2) obtaining h and A of stars or planets at a given time, and varieties of this problem, such as: (a) choosing stars for observations, (b) finding ΔK;

(3) determining the time of arrival of a body at a given position; for example, the time a body rises, crosses the prime vertical, transits, etc.

I. DETERMINING THE NAME OF AN UNIDENTIFIED STAR OR PLANET

There are cases when the sky is overcast with breaks in the clouds showing separate stars. In such cases it is rather difficult to identify a star that has been observed, so the celestial globe is resorted to. Also, problems of this kind are solved in studies of the stars.

This problem is solved in the following sequence:

(1) After measuring the altitude of the star, determine its bearing by compass and note T_{sh}. From the map take φ and λ.

(2) Compute T_{gr}; take t_{gr}^{Υ} out of MAE and compute $t_{loc}^{\Upsilon} = t_{gr}^{\Upsilon} \pm \pm \lambda_{W}^{E}$.

(3) Set globe for φ and t_{loc}^{Υ} (see preceding section).

(4) Transfer bearing to A in quadrantal reckoning. Set arc of vertical circle in azimuth and the index of the vertical circle in altitude.

(5) Under the index find the star by its *position in the constellation*, which is given in Latin, for instance, α of the constellation of Taurus (α Tauri). Using the star list in the MAE, find the Russian name of the constellation and the number of the star. Using this name (or number) take the coordinates out of the MAE. Thus, Taurus α is Телец α, No. 24 (Aldebaran).

(6) If there is no star under the index, or a bright body was observed, then a blunder has been made in solving the problem, or a planet was observed. When you are sure the solution is correct, identify the planet. This may be done by one of two procedures: approximate or exact.

(a) In the approximate procedure, use the table of "Planet Visibility" given at the beginning of the MAE; to identify by the globe, find the name of the constellation near the index of the vertical circle and using the constellation find the name of the planet in the table.

(b) In the exact procedure, take α and δ of the point under the index from the globe. With these data and the date enter the daily tables of the MAE and find the planet for which δ and α are closest to those given.

Example 2. 13 September 1962 at $\varphi_c = 56°20'$N; $\lambda_c = 20°54'$E at $T_{sh} = 18$h 35m observed unidentified body: $sr = 38°7'.5$; $RCB = 330°$; $\Delta K = +3°$. Find the name of the body.

− T_{sh}	18h 35m
ZD	1
T_{gr}	17h 35m 13.09

t_T^{Υ}	247°12′
Δt	8 46
+ t_{gr}^{Υ}	255°58′
λ	20 54
t_{loc}^{Υ}	276°52′ $\approx$ 277°

− RCB	330°
180°	180
CB	150°
ΔK	+ 3
TB	153° = 27°SE

Set globe in latitude; to do this, raise P_N above point N of the horizon 57°.3 (32°.7 as reckoned from the meridian). To set by time, turn globe to 277° on the meridian ring. Then place crosspiece of vertical circles and turn in azimuth 27°SE, and the index to $h \approx 38°$. We find the star α Aquilae. In the star list of the MAE we have α Aquilae, Altair, No. 146.

Example 3. On 27.09.62 at $\varphi_c = 33°58'$N; $\lambda_c = 148°30'$E at $T_{sh} = 18$h 10m (ZD = 10) observed body: $sr = 28°35'$, $CB = 327°$; $\Delta K = -2°$. Find name of celestial body.

− T_{sh}	18h 10m
ZD	10
T_{gr}	8h 10m 27.09

t_T^{Υ}	125°38′
Δt	2 30
+ t_{gr}^{Υ}	128 8
λ	148 30
t_{loc}^{Υ}	276°38′ = 276°.5, $\varphi_c = 34$N

± RCB	327°
180°	180
CB	147°
ΔK	−2
TB	145° = 35°SE, $h = 28°.5$

Star not found under index; from table of "Planet Visibility" we see what planet could be in the constellation near the index. But since the index stopped between the two constellations Capricornus and Sagittarius, we have to apply a different procedure. Take the coordinates of the point: $\alpha \approx 308°$, $\delta \approx 20°$S. From the MAE on 27.09 we find that these coordinates belong to Saturn.

II. OBTAINING ALTITUDE AND AZIMUTH OF A BODY FOR A GIVEN TIME

(1) Compute T_{sh} and T_{gr} for the instant of proposed observations, take φ_c and λ_c from map for this time. Stars are mostly observed in twilight, so compute T_{sh} at twilight.

(2) Compute $t^{\Upsilon}_{loc} = t^{\Upsilon}_{gr} \pm \lambda_c$.
(3) Set globe for φ and t^{Υ}_{loc}.
(4) Set crosspiece so that numbered vertical circle is at star; direct index to position of star, then note and record readings of h and A of star.
(5) If it is required to obtain h and A of a planet, first mark its position on the globe by α and δ, as indicated in the preceding section.

Example 4. On 10.10.62 at T_{sh}=6h 05m in φ_c=62°5′N; λ_c=11°57′W. Determine h and A_{*} α Orionis (Betelgeuse).

T_{sh}	6h 05m
+ ZD	1
T_{gr}	7h 05m 10.10

t^{Υ}_{T}	123°24′
Δt	1 15
t^{Υ}_{gr}	124°39′
− λ	11 57
t^{Υ}_{loc}	112°42′ = 112°.7

Setting globe by φ and t^{Υ}_{loc}, we have $\begin{cases} h_{*} = 32° \\ A_{*} = 30°\text{SW} \end{cases}$

Determining the compass correction ΔK also reduces to this problem. However, here it is first necessary to find the CB of the body and note T_{sh}, φ_c, λ_c, which are used to obtain the TB of this body from the globe.

Example 5. On 12.09.62 in φ_c=52°24′N; λ_c=156°41′E observed $*$ Capella (α Aurigae); RCB=203°.5; T_{sh}=20h 15m (ZD=11E); altitude of star does not exceed 15°. Find ΔK.

Solution.

(1)

T_{sh}	20h 15m
− ZD	11
T_{gr}	9h 15m 12.09

t^{Υ}_{T}	125°53′
Δt	3 46
t^{Υ}_{gr}	129°39′
+ λ	156 41
t^{Υ}_{loc}	286°20′ ≈ 286°.5
φ_c	52°.5

(2) From globe for $*$ α Aurigae we have A=19°.5NE

(3)

TB	19°.5
CB	23 .5
ΔK	−4°.0

When determining position by two stars, the difference of their azimuths must be as close as possible to 90°; when using three stars, the difference in each pair should be close to 120°, and for four stars, close to 180° in each pair, and close to 90° between pairs. Besides that, take into account the brightness of the horizon, its visibility in these parts, and so forth. The altitudes of the stars should not exceed 60° to 70°. These are the conditions that should be borne in mind when choosing stars. Otherwise, the problem consists in obtaining and recording h and A of stars, which means that it reduces to the preceding problem. The positions of the planets are marked beforehand. It is particularly important to predetermine h and A of the stars (planets) for observations immediately after sunset, when the stars are not visible to the naked eye and have to be found in the sextant telescope.

Example 6. On 10 May, 1962, in $\varphi_c=9°38'$S; $\lambda_c=98°15'$E choose three stars for observations in morning twilight. $T_{twi}=5$h 45m (ZD=7); $\Delta K=-5°$

T_{twi}	5h 45m	10.05		t_T	197°14′
$-$ZD	7			Δt	11 17
T_{gr}	22h 45m	9.05		t^{Υ}_{gr}	208°31′
				$+\lambda$	98 15
				t^{Υ}_{loc}	306°46′ ≈ 306°.8; $\varphi\approx 9°.5$S.

Over S, place the *south celestial pole* (P_S) at an altitude of 9°.5 and set the globe for t^{Υ}_{loc}. Using the vertical circles, choose the stars and tabulate the data found.

No.	Constellation and star	h	A	CB
1	α Lyrae (Vega)	35°	28°NW	337°
2	α Piscis Aust. (Fomalhaut)	50	54 SE	131
3	α Scorpii (Antares)	30	64 SW	249

III. DETERMINING TIME OF ARRIVAL OF A CELESTIAL BODY AT A GIVEN POSITION (AT RISING, PRIME VERTICAL, TRANSIT, ETC.)

(1) Take φ_c and λ_c from map for proposed T_{sh} of phenomenon.
(2) Set globe to latitude.
(3) Turn sphere and bring indicated star or planet to required position (on horizon, on prime vertical, etc.).

(4) Take reading of $t_{loc}^{\Upsilon} = S_{loc}$ on upper branch of observer's meridian ring.

(5) Compute $t_{gr}^{\Upsilon} = t_{loc}^{\Upsilon} \mp \lambda_{W}^{E}$ and with aid of MAE obtain T_{gr} and T_{sh} of the phenomenon (see Sec. 47).

Example 7. On 27.09.62, in the evening in $\varphi_c \approx 44°N$, $\lambda_c \approx 137°20'E$, find the time (ZD=10E) when ⁎ Sirius rises.

Solution. Set globe for $\varphi_c = 44°N$ and reduce ⁎α Canis Majoris (Sirius) to eastern part of horizon, then take at the meridian ring $S_{loc} = t_{loc}^{\Upsilon} = 27°.5$.

	t_{loc}^{Υ}	27°.5
−	λ_E	137 .3
	t_{gr}^{Υ}	250°.2
MAE	t_{T}^{Υ}	245 .9 ...
Table 1	Δt^{Υ}	4°.3 ...

	T'_{gr}	16h
	ΔT	17m
	T_{gr}	16h 17m
+	ZD	10
	T_{sh}	2h 17m 28.09

By computation we find that the star will rise next at 2h 17m on 28.09; the previous time was at 2h 21m on 27.09

Somewhat simpler is the approximate solution of this ploblem using the time of transit of Aries (T_{tr}^{Υ}). In this case, the sidereal time obtained from the globe, t_{loc}^{Υ}, is added to T_{tr}^{Υ} taken from the MAE and we obtain the approximate (to within ±6m) local time (T_{loc}^{Υ}) of the phenomenon. For instance, in Example 6 we will have

	T_{tr}^{Υ}	23h 35m
	t_{loc}^{Υ}	1h 50m (27°.5)
	T_{loc}	1h 25m 28 .09
+	ZD−λ	51
	T_{sh}	2h 16m 28 .09

This solution is most advantageously used when the correction (ZD−λ) is constant, that is, when standing for a long time.

SEC. 88. AIDS THAT REPLACE THE CELESTIAL GLOBE

The celestial globe, despite the small size of the sphere, is still somewhat unwieldy, and it is inconvenient to work with in confined spaces on shipboard or in aircraft. *Flat images* of the celestial sphere are then used in the form of special charts and grids or, finally, special tables for star identification. The solutions obtained are not so accurate or pictorial, but there are other advantages, such as compactness and the possibility of comparison with the sky (in some types). Such aids are called star charts and star finders.

I. THE SOVIET STAR CHART FOR AIR NAVIGATION (БКН)

In this chart (Fig. 140), part of the sphere, which is visible in the given latitude, is depicted in a polar equidistant projection, with the brightest stars, the outlines of constellations and the principal circles of the sphere indicated. The equator and meridian of Aries ♈ are graduated in 10° intervals, so that planetary positions can also be indicated approximately. Around the circumference of the chart is a date scale computed from values of right ascension of the mean sun ($\alpha_{\oplus}$). БКН charts are designed for medium latitude of a definite zone. Three (sometimes more) zones are taken for the territory

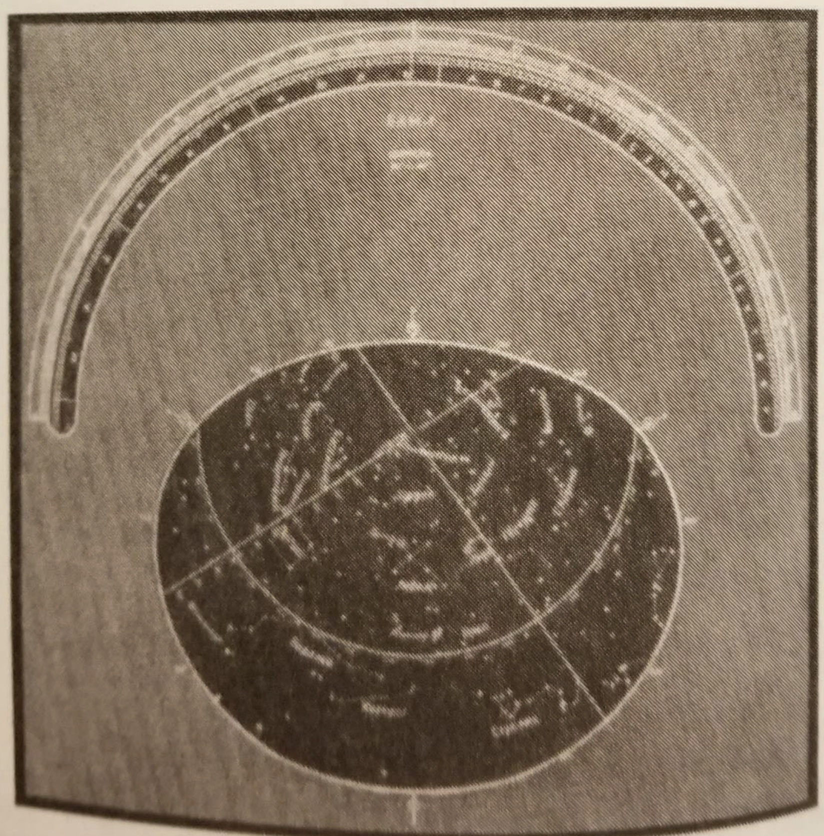

Fig. 140

of the U.S.S.R.: I for φ from 30° to 44°N, II for 46° to 60°N, III for 62° to 76°N. The appropriate chart is chosen closest to the given φ_c.

The chart comes in a cardboard case, in which it can be rotated about the centre (P_N). In the case is an oval slot, the edge of which depicts the horizon for mid-latitude of the zone. It contains the points N, E (O^{st}), S, W and scale of azimuths every 30°. The horizon slot is based on the declinations of points of the horizon ($h = 0$) which are computed from the formula $\tan\delta = -\cot\varphi\cdot\cos t$, where t represents the hour angles of points of the horizon and δ their declinations.

At the top of the case, round the periphery is a slot for the scale of dates; near the slot is a scale of local civil time, T_{loc}.

To set the chart to the time,

(a) compute T_{loc} from formula (8.28);

(b) rotate chart to bring the date (on the date scale) to T_{loc} of the time scale.

The chart sky will then approximate the actual sky. To identify constellations, put the chart over your head and, aligning it N—S by compass, look at the chart and the sky.

The БКН chart yields only rough azimuths and altitudes of celestial bodies, particularly for bodies at small altitude. This is due to a lack of correspondence of latitudes and to distortions, and makes identification of individual stars difficult. Using the БКН chart, one can make a rapid and easy determination of time of transit of a star and the approximate time that it rises and sets.

II. STAR IDENTIFIER*

The star identifier shown in Fig. 141 consists of two charts of stars on two sides of a plastic sheet: one side contains the northern hemisphere including a belt to $\delta = 60°$S, the other, the southern hemisphere to 60°N. On the outer circumferences of the charts are scales of sidereal time. The charts are compiled in polar equidistant projection and contain the brightest navigational stars and also a grid of parallels with 10° intervals. In addition, the separate transparent plastic templates contain seven grids of vertical circles and parallels of altitude in the same projection at 5° intervals of h and A for medium latitudes 0°, 10°, 20°, 30°, 40°, 50°, 60°, that is, for 10° latitude zones. The outer curve of these grids represents the observer's horizon.

When using the star finder, choose the grid for the latitude closest to the computed one. The 180°-360° line of the grid is set in the

* By way of illustration we describe the "Star Identifier" widely used in the U.S.A. and elsewhere. It is similar to the "Rude Star Finder" (H. O. No. 2102-D).

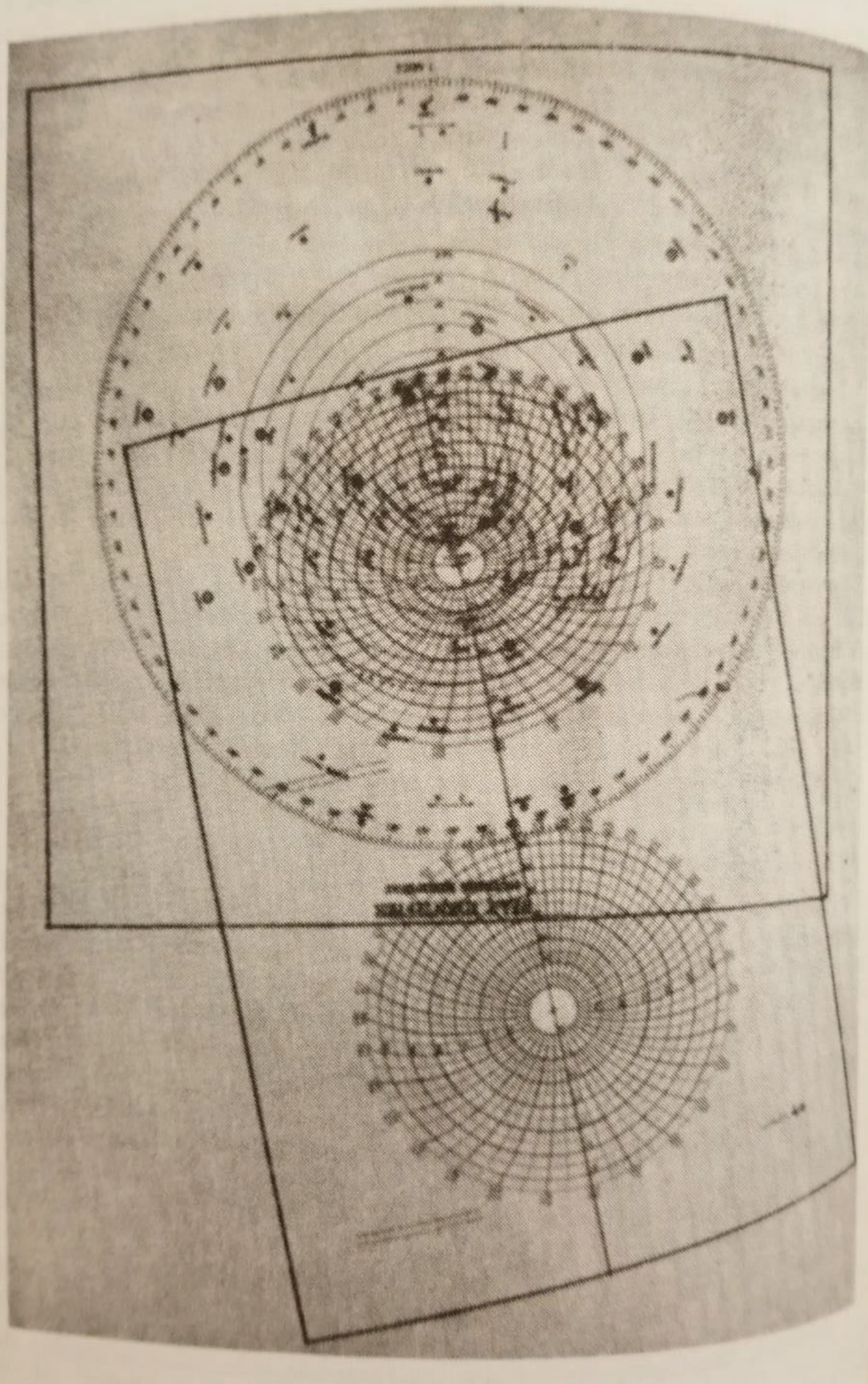

Fig. 141

direction: pole—computed sidereal time S_{loc}. The centre of the grid, indicated by a cross (×) and depicting the zenith, is placed by eye on a parallel of the chart equal to φ. The altitudes are taken from the grid of parallels of altitude, while the azimuths are taken from the grid of vertical circles. Accuracy obtained by a star identifier is of the order of ± 3°-5°. Its advantage lies in handiness.

Example 8. On 10 July, 1962, at $\varphi=49°S$; $\lambda=61°W$; $T_{sh}=17h\ 34m$ (ZD=4W). Determine h and A of ✱ Spica.

T_{sh}	17h 34m	t_T^{Υ}	243°18′
+ ZD	4	Δt^{Υ}	8 31
T_{gr}	21h 34m 10.07	t_{gr}^{Υ}	251°49′
		− λ	61
		$t_{loc}^{\Upsilon} \approx$	190°8

Choose a grid for $\varphi=50°$. Set the 180°-360° line of the grid on the reading $t_{loc}^{\Upsilon}=190°.8$ on the chart, the cross + (zenith) between the parallels 40° and 50° of the chart (on 49°). Through the grid, find Spica on the chart and record $h=50°$, $A=14°$ from the grid (see Fig. 141).

The foregoing are only a few of many aids in the identification of constellations and stars. The basic principles are much the same in all of them.

III. STAR IDENTIFICATION BY MEANS OF TABLES

An observed star may also be identified by means of special or conventional tables and lists of stellar coordinates. To do this, measure the altitude and azimuth of the star, note the watch time, and take φ_c, λ_c. From known h, A, φ_c it is possible to solve the astronomical triangle for δ_* and t_* using formulas (2.5) and (2.6) or the tables TBA-57; enter these tables with h instead of δ, and azimuth in semicircular reckoning in place of t. Having computed t_{loc}^{Υ} for the noted instant T_{gr}, we readily get: $\alpha_* = t_{loc}^{\Upsilon} - t_*$; then with δ_* and α_* we choose the name of the observed star from a list of stars (in the MAE, for instance) or from any star chart. Solution via formulas (2.5) and (2.6) or TBA-57 is rather involved. Instead, one can use special rude "tables of star identification" that appear in a number of publications, for example, H.O. No. 214 which contains the values of δ and t on the basis of A and h at 4° intervals for each degree of latitude. For the same problem, one can use a coordinate grid, or simply any hand drawing of the sphere to scale.