

# **Sun's position for navigation with DM15L Manual**

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## Overview

The handheld calculator DM15 (a HP-15c look-a-like with more memory) can be used for determining the sun's position with precision enough for celestial navigation purposes. The accompanying program, listed in the Appendix, constitutes a handy tool for either finding the *Nautical Almanac*'s entries GHA (*Greenwich Hour Angle*) and Declination, or — with AP (*Assumed Position*) — directly calculate the sun's Altitude  $Hc$  and Azimuth  $Az$  for this position.

The algorithm relies on pure Keplerian motion of the sun. No planetary perturbations are taken into account. Resulting angular accuracy is about 1 minute of arc, which is adequate for general navigation at sea.

# 1. Usage

Before use, notice that:

- All times entered are UT ("GMT") even if observer's longitude is not the prime meridian. Of course, local hour angles take longitude into consideration, but all times are still UT. Time format is *hh.mmss*, where *mm* and *ss* must be two-digit numbers.
- The program makes use of the calculator's internal decimal to degrees, minutes and seconds routines both for **entry** and **displayed result**. In navigation a more common format of degrees, minutes and tenths of a minute is used. That conversion, if needed, is readily done by dividing the arc-seconds number or multiplying the minute's decimal by 6.

## Example

Convert angle in *ddd.mmss* to *ddd.mm.t*

$98^{\circ} 26' 12''$ , entered as 98.2612, is  $98^{\circ} 26.2'$  where  $12''/6 = 2$

$98^{\circ} 26' 43''$ , entered as 98.2643, is  $98^{\circ} 26.7'$  where  $43''/6 \approx 7$

■

## Example

Convert angle in *ddd.mm.t* to *ddd.mmss*

$14^{\circ} 7.3'$  is  $14^{\circ} 7' 18''$  where  $3 \cdot 6 = 18$

$277^{\circ} 4.5'$  is  $277^{\circ} 4.30'$  where  $5 \cdot 6 = 30$

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## 1.1. User-defined buttons

The programs user-defined functions are accessed via the buttons below

## 1. Usage

Button	Function
<b>A</b>	Date for Aries angle at UT=0h
<b>B</b>	Time for Sun Altitude and Azimuth
<b>C</b>	SHA and declination for <i>own object</i>
<b>D</b>	Time for <i>own object</i> 's Altitude and Azimuth
<b>E</b>	Time for GHA Aries and LHA Aries
<b>.5</b>	After <b>B</b> for GHA and declination (as a Nautical Almanac entry)

## 1.2. Assumed Position

An AP (*Assumed Position*) is entered in registers 8 and .8 before any calculations can be performed.

### Example

Entering AP.

A location of Lat N58° 34', Long E14° 34' 12" is entered into registers 8 and .8:

Data	Format	Key	Display shows	Meaning
58.3400	$\pm dd.mmss$	g→H STO 8	58.5667	Decimal degrees
14.3412	$\pm dd.mmss$	g→H STO .8	14.5700	Decimal degrees

East and North are positive, West and South are negative.

The position is permanently stored until manually changed and need only be set once.

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## 1.3. Daily entry

Every day has its own parameters that require the A-routine to be run once for each day.

### Example

Entering the date.

Enter June 12th 2022, i.e. year 2022, month 6 and day 12.

Data	Format	Key	Display shows	Meaning
2022	YYYY	ENTER	2022.0000	
6	mm	ENTER	6.0000	
12	dd	f A	260.1816	260° 18' 16", GHA Aries at 0h ( <i>Nautical Almanac 2022</i> : 260° 18'.1)

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## 1.4. Sun's Altitude and Azimuth

Next the sun's position for time of date UT/GMT can be calculated.

### Example

Find sun's Hc and Az for UT 09h 54m 48s. Date as above.

Enter time in format *hh.mmss* then use routine B.

Data	Format	Key	Display shows	Meaning
9.5448	<i>hh.mmss</i>	f B	52.3845	Hc = $52^{\circ} 38' 45''$
		x<>y	154.1140	Az = $154^{\circ} 11' 40''$

**Result:** Hc =  $52^{\circ} 38.7'$ , Az =  $154^{\circ}$

A new time can be entered directly. For example, also find sun's Hc and Az a few minutes later at UT 10h 02m 30s.

Data	Format	Key	Display shows	Meaning
10.0230	<i>hh.mmss</i>	f B	53.0338	Hc = $53^{\circ} 03' 38''$
		x<>y	157.0236	Az = $157^{\circ} 2' 36''$

**Result:** Hc =  $53^{\circ} 03.6'$ , Az =  $157^{\circ}$

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## 1.5. GHA and declination

The program can also produce values for GHA and declination imitating the *Nautical Almanac*.

### Example

Find GHA and decl for 10h on June 12th 2023

After calculating Hc and Az as above, use GSB .5 to get GHA and declination  $\delta$ :

Data	Format	Key	Display shows	Meaning
10.0000	<i>hh.mmss</i>	f B	52.5508	Hc = $52^{\circ} 55' 08''$
		GSB .5	330.0248	GHA = $330^{\circ} 2' 48''$
		x<>y	23.0901	$\delta = 23^{\circ} 09' 01''$

**Result:** GHA =  $330^{\circ} 2.8'$ , Decl =  $23^{\circ} 09.0'$  (*Nautical Almanac* gives  $330^{\circ} 2.8'$  and  $23^{\circ} 8.8'$ ).

GHA and Decl can of course be calculated for any other time during the day in the same manner.

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## 1. Usage

### Specify and calculate position for an object with known SHA and declination

The coordinates of a celestial object, for example a star, are given as SHA (*Sidereal Hour Angle*) and declination.<sup>1</sup>

#### Example

Enter coordinates of *Vega* (SHA  $80^{\circ} 34.3'$ , declination  $38^{\circ} 48.2'$ ).

Data	Format	Key	Display shows	Meaning
80.3418	<i>ddd.mmss</i>	ENTER	80.3418	SHA
38.4812	<i>ddd.mmss</i>	f C	279.4283	RA in decimal degrees

Now find *Vega*'s calculated position for UT = 23h 02m 10s on June 12th 2023 already entered above.

Data	Format	Key	Display shows	Meaning
23.0210	<i>hh.mmss</i>	f D	67.0015	$Hc = 67^{\circ} 00' 15''$
		x<>y	141.1224	$Az = 141^{\circ} 12' 24''$

**Result:** Vega can be expected at  $Hc = 67^{\circ} 0.2'$  and  $Zn = 141^{\circ}$ . Set the sextant for  $67^{\circ}$  and search for it in south-east.

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### GHA Aries and LHA Aries

Find GHA Aries on 4 October 2022 at 7h 57m 20s. Also find LHA Aries longitude in .8 ( $14^{\circ} 34' 12''$  E as before).

Data	Format	Key	Display shows	Meaning
2022	<i>YYYY</i>	ENTER	2022.0000	Year
10	<i>mm</i>	ENTER	10.0000	Month
4	<i>dd</i>	f A	12.4006	$12^{\circ} 40' 6''$ , GHA Aries at 0h
7.5720	<i>hh.mmss</i>	f E	132.1942	GHA Aries = $132^{\circ} 19' 42''$
		x<>y	146.5354	LHA Aries = $146^{\circ} 53' 54''$

<sup>1</sup>Right Ascension can be entered as  $\alpha = 360 - SHA$  if needed.

## Use as Sight Reduction Table

The program can also solve the navigational triangle and be used as a *Sight Reduction Table* replacement (Ho-214/Ho-229 etc). To solve the triangle 1) AP latitude, 2) object's declination and 3) hour angle need to be entered.

AP latitude is entered in register 8 as before, declination is set via **C** and hour angle is entered into register .2. The hour angle is positive if westward.

### Example

Find Hc and Az as in Ho-214

Assume latitude N58°, Declination 8° 30' and an hour angle of 54° (object to the west of observer).

Data	Format	Key	Display shows	Meaning
58	<i>dd.mmss</i>	STO 8	58.0000	Decimal latitude
8.3000	<i>dd.mmss</i>	<b>C</b>	8.5000	Decimal declination
54	<i>dd.mmss</i>	$g \rightarrow H$	54.0000	Decimal Hour angle
		STO .2	54.0000	
		GSB 7	25.4102	$H_c = 25^\circ 41' 02''$
		$x \leftrightarrow y$	242.3616	$A_z = 242^\circ 36' 16'' = 242.6^\circ$

Ho-214 gives Alt. = 25° 41.0' and Az. = 117.4°. Where true azimuth is  $360 - 117.4 = 242.6^\circ$ .





# A. Program and information

## Register usage

The lower registers `r0..r7` are used by the calculator's statistics functions and are not *permanently* used by this program. They *are* used however for intermediate results via the normal operating sequences **A-B** or **A-C-D** or **A-E**.

In short: Use `r0..r7` as you wish but they will be altered by **A**.

## Program installation

For a fresh install of the program perform steps 1–6 below.

1. Make space on the DM15 for program and registers:
  - Enter 21 f DIM (i)
  - Double check: g MEM should read 21.209
2. In HP-15C/Preferences/DM15 menu: Select 229 as Number of registers.
3. File/Open Program: file.15c
4. Write program to DM15.
  - On device enable serial communication (hold C while pressing ON-button)
  - File/Write DM15
5. Before use enter the following constants into the respective registers:

Register	Constant	Meaning
.3	279.4055638	Longitude at epoch JD=2459944.5
.4	283.3328093	Longitude of perigee for epoch
.5	1.016860112	$\sqrt{\frac{1+e}{1-e}}$
.6	23.44188400	Ecliptic obliquity
.7	0.002737909	$\frac{1}{365.2422}$

6. That's it. Now the samples in this document give expected results.

## Program listing

Note: In the listing below some minor self explanatory key appearances have changed.  $\text{SIN}^{-1}$  is replaced with ASIN etc,  $x \leftrightarrow y$  is  $x \leftrightarrow y$  and  $R \downarrow$  is Rv.

000 {				}		059 {			8 }	g RAD		
001 {	42	21	48	8 }	f LBL .8	060 {			36 }	ENTER		
002 {				3 }	3	061 {			1 }	1		
003 {				6 }	6	062 {			0 }	0		
004 {				0 }	0	063 {		42	7	9 }	f FIX 9	
005 {			43	32 }	g RTN	064 {		42	10	8 }	f SOLVE 8	
006 {		42	21	4 }	f LBL 4	065 {		42	7	4 }	f FIX 4	
007 {				23 }	SIN	066 {			2 }	2		
008 {				34 }	x<>y	067 {			10 }	/		
009 {				23 }	SIN	068 {			25 }	TAN		
010 {		22	48	6 }	GTO .6	069 {		45	48	5 }	RCL .5	
011 {		42	21	5 }	f LBL 5	070 {			20 }	*		
012 {				24 }	COS	071 {		43	25 }	g ATAN		
013 {				34 }	x<>y	072 {			2 }	2		
014 {				24 }	COS	073 {			20 }	*		
015 {		22	48	6 }	GTO .6	074 {		43	3 }	g ->DEG		
016 {		42	21	2 }	f LBL 2	075 {		43	7 }	g DEG		
017 {		32	48	8 }	GSB .8	076 {		45	48	4 }	RCL .4	
018 {				10 }	/	077 {			40 }	+		
019 {			42	44 }	f FRAC	078 {		44	48	0 }	STO .0	
020 {			43	30	1 }	g TEST x>0	079 {		45	48	0 }	RCL .0
021 {			22	3 }	GTO 3	080 {			23 }	SIN		
022 {				1 }	1	081 {		45	48	6 }	RCL .6	
023 {				40 }	+	082 {			24 }	COS		
024 {		42	21	3 }	f LBL 3	083 {			20 }	*		
025 {		32	48	8 }	GSB .8	084 {		45	48	0 }	RCL .0	
026 {	42	21	48	6 }	f LBL .6	085 {			24 }	COS		
027 {				20 }	*	086 {		43	1 }	g ->P		
028 {			43	32 }	g RTN	087 {			33 }	Rv		
029 {	42	21	48	2 }	f LBL .2	088 {		44	9 }	STO 9		
030 {				1 }	1	089 {		45	48	0 }	RCL .0	
031 {				5 }	5	090 {			23 }	SIN		
032 {		22	48	6 }	GTO .6	091 {		45	48	6 }	RCL .6	
033 {		42	21	12 }	f LBL B	092 {			23 }	SIN		
034 {			32	15 }	GSB E	093 {			20 }	*		
035 {			45	6 }	RCL 6	094 {			43	23 }	g ASIN	
036 {				2 }	2	095 {		44	48	0 }	STO .0	
037 {				4 }	4	096 {			45	9 }	RCL 9	
038 {				5 }	5	097 {	42	21	48	1 }	f LBL .1	
039 {				9 }	9	098 {			45	5 }	RCL 5	
040 {				9 }	9	099 {		32	48	8 }	GSB .8	
041 {				4 }	4	100 {			45	9 }	RCL 9	
042 {				4 }	4	101 {			30 }	-		
043 {			48 }	.	.	102 {			40 }	+		
044 {			5 }	5	5	103 {			32	2 }	GSB 2	
045 {			30 }	-	-	104 {		44	48	2 }	STO .2	
046 {		45	4 }	RCL 4	RCL 4	105 {			32	7 }	GSB 7	
047 {			2 }	2	2	106 {			43	32 }	g RTN	
048 {			4 }	4	4	107 {		42	21	7 }	f LBL 7	
049 {			10 }	/	/	108 {		45	48	2 }	RCL .2	
050 {			40 }	+	+	109 {			24 }	COS		
051 {		32	48	0 }	GSB .0	110 {			45	8 }	RCL 8	
052 {			20 }	*	*	111 {		45	48	0 }	RCL .0	

118 {		43	23	}	g	ASIN	177 {	32	48	2	}	GSB	.2				
119 {			36	}	ENTER		178 {		45	1	}	RCL	1				
120 {			36	}	ENTER		179 {			40	}	+					
121 {		44	48	1	}	STO	.1	180 {			36	}	ENTER				
122 {			45	8	}	RCL	8	181 {			36	}	ENTER				
123 {			32	4	}	GSB	4	182 {		45	48	8	}	RCL	.8		
124 {				16	}	CHS		183 {			40	}	+				
125 {		45	48	0	}	RCL	.0	184 {			32	2	}	GSB	2		
126 {				23	}	SIN		185 {			44	5	}	STO	5		
127 {				40	}	+		186 {				34	}	x<>y			
128 {				34	}	x<>y		187 {			32	2	}	GSB	2		
129 {			45	8	}	RCL	8	188 {				34	}	x<>y			
130 {			32	5	}	GSB	5	189 {		42	21	9	}	f	LBL	9	
131 {				10	}	/		190 {			42	2	}	f	->H	.MS	
132 {			43	24	}	g	ACOS	191 {				34	}	x<>y			
133 {	42	4	48	2	}	f	x<>	.2	192 {			42	2	}	f	->H	.MS
134 {				23	}	SIN		193 {			43	32	}	g	RTN		
135 {		43	30	2	}	g	TEST	x<0	194 {		42	21	0	}	f	LBL	0
136 {			22	6	}	GTO	6	195 {				1	}	1			
137 {		32	48	8	}	GSB	.8	196 {				36	}	ENTER			
138 {		45	48	2	}	RCL	.2	197 {				0	}	0			
139 {				30	}	-		198 {			32	1	}	GSB	1		
140 {		44	48	2	}	STO	.2	199 {				2	}	2			
141 {		42	21	6	}	f	LBL	6	200 {			4	}	4			
142 {		45	48	1	}	RCL	.1	201 {				1	}	1			
143 {		45	48	2	}	RCL	.2	202 {				5	}	5			
144 {			22	9	}	GTO	9	203 {				0	}	0			
145 {		42	21	8	}	f	LBL	8	204 {			2	}	2			
146 {				23	}	SIN		205 {				0	}	0			
147 {			48	}	.			206 {				30	}	-			
148 {			0	}	0			207 {		32	48	0	}	GSB	.0		
149 {			1	}	1			208 {				20	}	*			
150 {			6	}	6			209 {				9	}	9			
151 {			7	}	7			210 {				9	}	9			
152 {			1	}	1			211 {				48	}	.			
153 {			8	}	8			212 {				4	}	4			
154 {			20	}	*			213 {				1	}	1			
155 {			16	}	CHS			214 {				3	}	3			
156 {			40	}	+			215 {			43	2	}	g	->H		
157 {		45	9	}	RCL	9		216 {				40	}	+			
158 {			30	}	-			217 {			32	2	}	GSB	2		
159 {		43	32	}	g	RTN		218 {			44	3	}	STO	3		
160 {		42	21	13	}	f	LBL	C	219 {			45	6	}	RCL	6	
161 {			43	2	}	g	->H		220 {			44	0	}	STO	0	
162 {		44	48	0	}	STO	.0		221 {			43	32	}	g	RTN	
163 {				33	}	Rv			222 {		42	21	11	}	f	LBL	A
164 {			43	2	}	g	->H		223 {			44	4	}	STO	4	
165 {		32	48	8	}	GSB	.8		224 {				33	}	Rv		
166 {				34	}	x<>y			225 {			44	5	}	STO	5	
167 {				30	}	-			226 {				33	}	Rv		
168 {			44	9	}	STO	9		227 {			32	0	}	GSB	0	
169 {			43	32	}	g	RTN		228 {			45	1	}	RCL	1	
170 {		42	21	15	}	f	LBL	E	229 {			45	5	}	RCL	5	
171 {			43	2	}	g	->H		230 {			45	4	}	RCL	4	
172 {			44	4	}	STO	4		231 {			32	1	}	GSB	1	
173 {		45	48	7	}	RCL	.7		232 {			45	0	}	RCL	0	
174 {				1	}	1			233 {				30	}	-		
175 {				40	}	+			234 {		32	48	0	}	GSB	.0	
176 {				20	}	*			235 {				20	}	*		

# A. Program and information

236 {	45	3	}	RCL	3	273 {		7	}	7		
237 {		40	}	+		274 {		20	}	*		
238 {	32	2	}	GSB	2	275 {		4	}	4		
239 {	44	1	}	STO	1	276 {		10	}	/		
240 {	42	2	}	f	->H.MS	277 {	43	44	}	g INT		
241 {	43	32	}	g	RTN	278 {		16	}	CHS		
242 {	42	21	}	f	LBL 1	279 {		40	}	+		
243 {		1	}	1		280 {	45	1	}	RCL 1		
244 {		7	}	7		281 {		3	}	3		
245 {		2	}	2		282 {		6	}	6		
246 {		1	}	1		283 {		7	}	7		
247 {		0	}	0		284 {		20	}	*		
248 {		1	}	1		285 {		40	}	+		
249 {		3	}	3		286 {	44	6	}	STO 6		
250 {		48	}	.		287 {	43	32	}	g RTN		
251 {		5	}	5		288 {	42	21	14	}	f LBL D	
252 {		40	}	+		289 {		32	15	}	GSB E	
253 {		34	}	x<>y		290 {	32	48	1	}	GSB .1	
254 {	44	1	}	STO 1		291 {		43	32	}	g RTN	
255 {		2	}	2		292 {	42	21	48	5	}	f LBL .5
256 {		7	}	7		293 {		45	5	}	RCL 5	
257 {		5	}	5		294 {	45	48	8	}	RCL .8	
258 {		20	}	*		295 {		30	}	-		
259 {		9	}	9		296 {	32	48	8	}	GSB .8	
260 {		10	}	/		297 {		45	9	}	RCL 9	
261 {	43	44	}	g INT		298 {		30	}	-		
262 {		40	}	+		299 {		40	}	+		
263 {		34	}	x<>y		300 {		32	2	}	GSB 2	
264 {		36	}	ENTER		301 {	45	48	0	}	RCL .0	
265 {	42	4	}	f x<> 1		302 {		22	9	}	GTO 9	
266 {		9	}	9		303 {	42	21	48	0	}	f LBL .0
267 {		40	}	+		304 {		45	48	7	}	RCL .7
268 {		1	}	1		305 {	32	48	8	}	GSB .8	
269 {		2	}	2		306 {		20	}	*		
270 {		10	}	/		307 {		43	32	}	g RTN	
271 {	43	44	}	g INT								
272 {		40	}	+								