MODERN SPACE SITUATIONAL AWARENESS
-- It Began with Piazzi, von Zach, and Gauss in 1801

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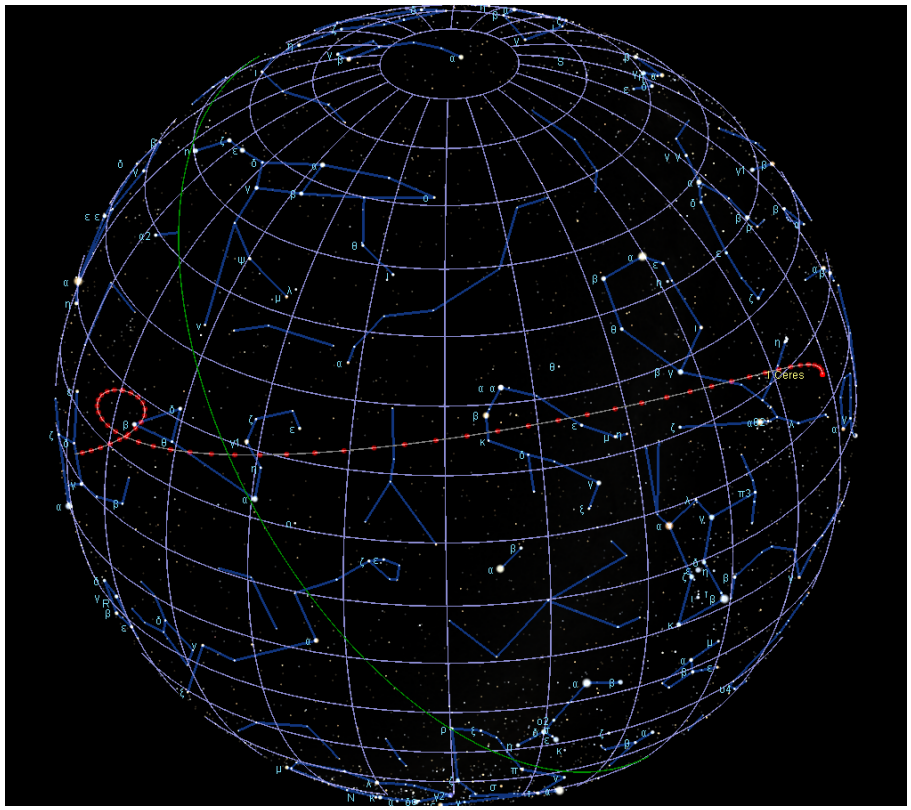
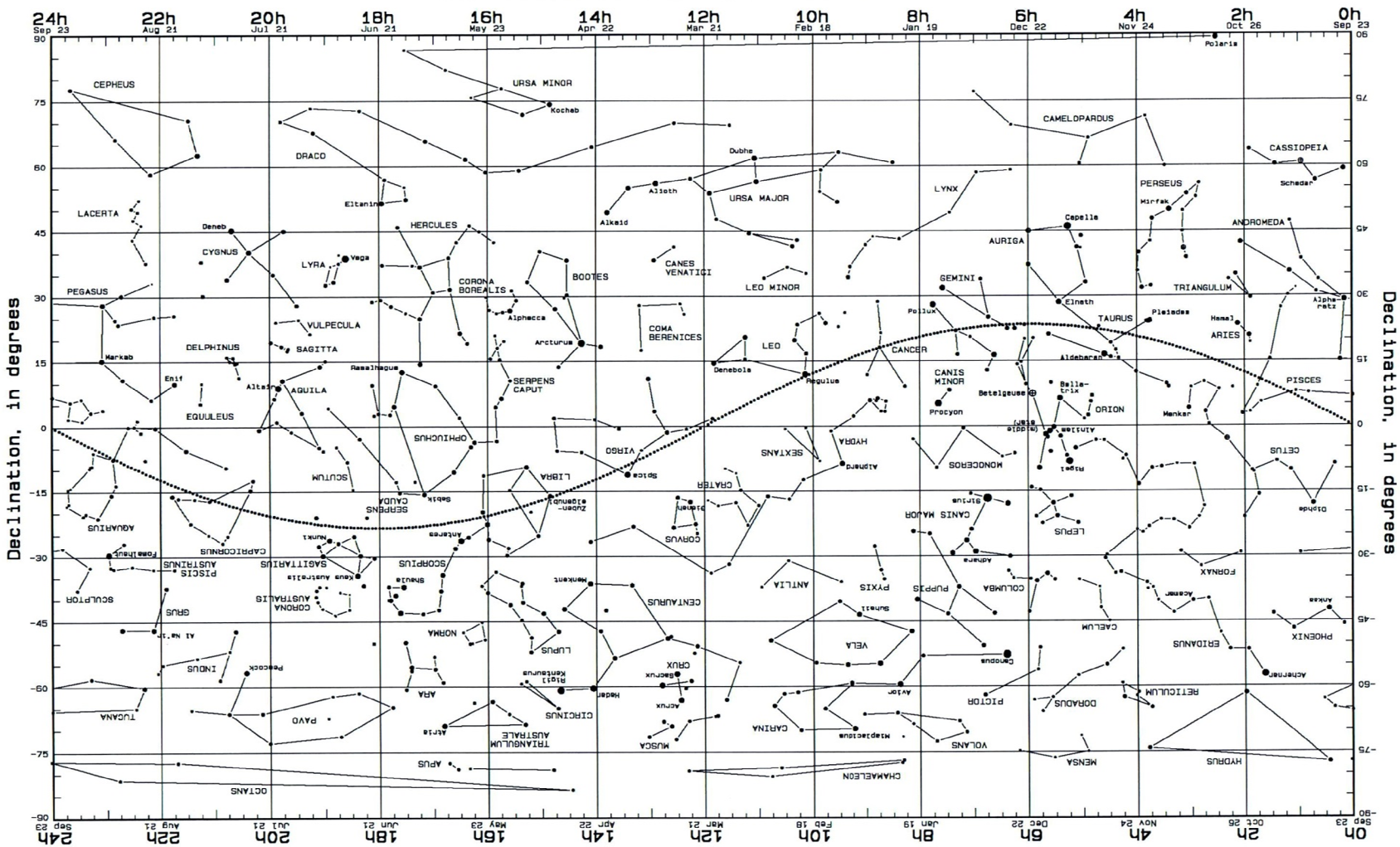


The figure above depicts the path of the minor planet Ceres *(in red) from its discovery the night of 1801 January 1 on into the year 1802*

Space Situational Awareness - Now

- The U.S. Air Force operates a global network of *radar* and *electro-optical* sensors
- These sensors detect and track artificial Earth satellites
- The electro-optical sensors collect observations consisting of time, right ascension (RA), and declination (DEC)
- These observations go to the Joint Space Operations Center (JSpOC) at Vandenberg Air Force Base
- Using these observations, the JSpOC maintains a catalog of all deep-space objects in Earth orbit larger than about 10 cm
  - A *deep-space* object has a mean orbital motion of less than 6.4 orbital revolutions per day, whereas a *near-Earth* object has a mean orbital motion of 6.4 orbital revolutions per day or more
- Next slide is Fig. 1 - Handout Map of the Celestial Sphere

RECTANGULAR MAP OF THE NORTH CELESTIAL HEMISPHERE (J2000)



RECTANGULAR MAP OF THE SOUTH CELESTIAL HEMISPHERE (J2000)

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Space Situational Awareness - Now

- The handout map depicts the entire celestial sphere
  - RA ranges from 0 to 360 degrees (0-24 hours) and DEC ranges from -90 degrees to +90 degrees
- So every observation made by an electro-optical sensor can be plotted on this map
- The purpose of the Air Force's space catalog is to facilitate space situational awareness, i.e.,

  - what is up there in space?

  - what is it doing there?
- You can access this space catalog by going to

  http://space-track.org and creating an account

  see also **http://celestrak.com**

Space Situational Awareness - 1801

- In 1801, the Italian mathematician and astronomer Giuseppe Piazzi was observing the night sky
  - using the highly-precise Palermo (Sicily) meridian circle telescope
- Piazzi's objective was to measure the right ascensions and declinations of stars, in order to compile a star catalog
- But Piazzi found a hitherto-unknown object that was moving slowly from night to night
  - Astronomers of the day, e.g., Baron Franz Xaver von Zach, thought that there might be an undiscovered major planet between Mars and Jupiter. Was this was it?
- Slide 6 depicts Piazzi's observations
  - 19 complete observations taken from the night of 1801 January 1 to 1801 February 11, as published by von Zach in his *Monatliche Correspondenz* (MC) for September 1801
- Slide 7 depicts actual path of Ceres on celestial sphere

Space Situational Awareness - 1801

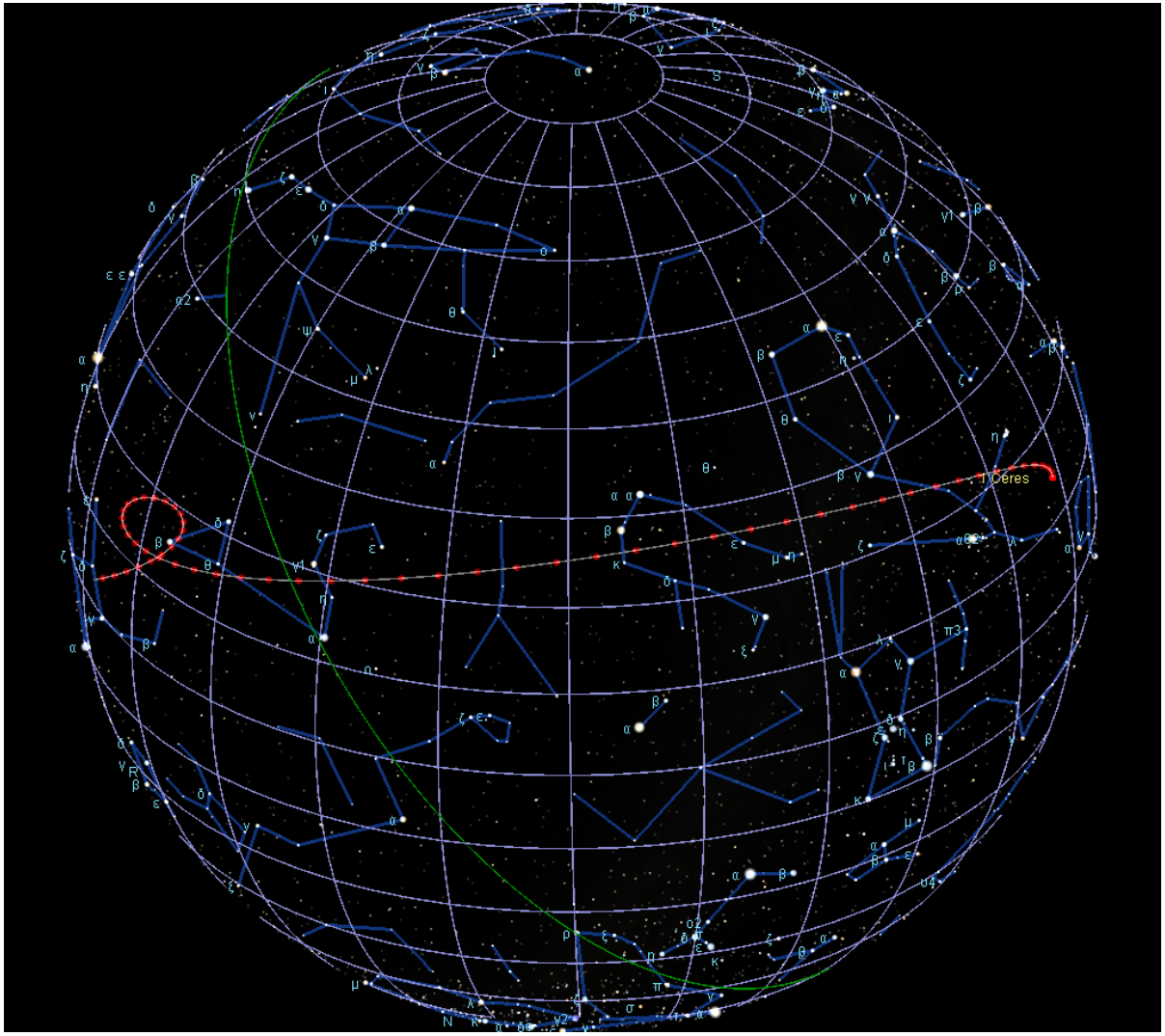
Beobachtungen des zu Palermo d. 1. Jan. 1801 von Prof. *Piazzi* neu entdeckten Gestirns.

1801	Mittlere Sonnen-Zeit	Gerade Aufsteig. in Zeit	Gerade Aufsteigung in Graden	Nördl. Abweich.	Geocentrische Länge	Geocentr. Breite	Ort der Sonne + 20" Aberration	Logar. d. Distanz ☉ ♂
	St ' "	St ' "	° ' "	° ' "	♈ ° ' "	° ' "	♈ ° ' "	
Jan. 1	8 43 27,8	3 27 11,25	51 47 48,8	15 37 43,5	1 23 22 58,3	3 6 42,1	9 11 1 30,9	9,9926156
2	8 39 4,6	3 26 53,85	51 43 27,8	15 41 5,5	1 23 19 44,3	3 2 24,9	9 12 2 28,6	9,9926317
3	8 34 53,3	3 26 38,4::	51 39 36,0	15 44 31,6	1 23 16 58,6	2 58 9,9	9 13 3 26,6	9,9926324
4	8 30 42,1	3 26 23 16	51 35 47,3	15 47 57,6	1 23 14 15,5	2 53 55,6	9 14 4 24,9	9,9926418
10	8 6 15,8	3 25 32,1:::	51 23 1,5	16 10 32,0	1 23 7 59,1	2 29 0,6	9 20 10 17,5	9,9927641
11	8 2 17,5	3 25 29,73	51 22 26,0	. . . . .	. . . . .	. . . . .	. . . . .	. . . . .
13	7 54 26,2	3 25 30,30	51 22 34,5	16 22 49,5	1 23 10 27,6	2 16 59,7	9 23 12 13,8	9,9928490
14	7 50 31,7	3 25 31,72	51 22 55,8	16 27 5,7	1 23 12 1,2	2 12 56,7	9 24 14 13,5	9,9928809
17	. . . . .	. . . . .	. . . . .	16 40 13,0	. . . . .	. . . . .	. . . . .	. . . . .
18	7 35 11,3	3 25 55,::	51 28 45,0	. . . . .	. . . . .	. . . . .	. . . . .	. . . . .
19	7 31 28,5	3 26 8,15	51 32 2,3	16 49 16,1	1 23 25 59,2	1 53 38,2	9 29 19 53,8	9,9930607
21	7 24 2,7	3 26 34,27	51 38 34,1	16 58 35,9	1 23 34 21,3	1 46 6,0	10 1 20 40,3	9,9931434
22	7 20 21,7	3 26 49,42	51 42 21,3	17 3 18,5	1 23 39 1,8	1 42 28,1	10 2 21 32,0	9,9931886
23	7 16 43,5	3 27 6,90	51 46 43,5	17 8 5,5	1 23 44 15,7	1 38 52,1	10 3 22 22,7	9,9932348
28	6 58 51,3	3 28 54,53	52 13 38,3	17 32 54,1	1 24 15 15,7	1 21 6,9	10 8 26 20,1	9,9935062
30	6 51 52,9	3 29 48,14	52 27 2,1	17 43 11,0	1 24 30 9,0	1 14 16,0	10 10 27 46,2	9,9936332
31	6 48 26,4	3 30 17,25	52 34 18,8	17 48 21,5	1 24 38 7,3	1 10 54,6	10 11 28 28,5	9,9937007
Febr. 1	6 44 59,9	3 30 47,2::	52 41 48,0	17 53 36,3	1 24 46 19,3	1 7 30,9	10 12 29 9,6	9,9937703
2	6 41 35,8	3 31 19,06	52 49 45,9	17 58 57,5	1 24 54 57,9	1 4 1,5	10 13 29 49,9	9,9938423
5	6 31 31,5	3 33 2,70	53 15 40,5	18 15 1,0	1 25 22 43,4	0 54 23,9	10 16 31 45,5	9,9940751
8	6 21 39,2	3 34 58,50	53 44 37,5	18 31 23,2	1 25 53 29,5	0 45 5,0	10 19 33 33,3	9,9943276
11	6 11 58,2	3 37 6,54	54 16 38,1	18 47 58,8	1 26 26 40,0	0 36 2,9	10 22 35 11,4	9,9945823

Figure 2. Piazzi's observations of the unknown celestial object (Ceres)

The figure is an orthographic pro-jection of the celestial sphere. 60 points of the ephemeris of Ceres are plotted at 10-day intervals. Note that the path of Ceres looped in the tail of Leo. Ceres was recovered, using the Gauss search ephemeris, as it entered the loop.

Software Bisque's* TheSky *program was used here – see* **http://bisque.com



*

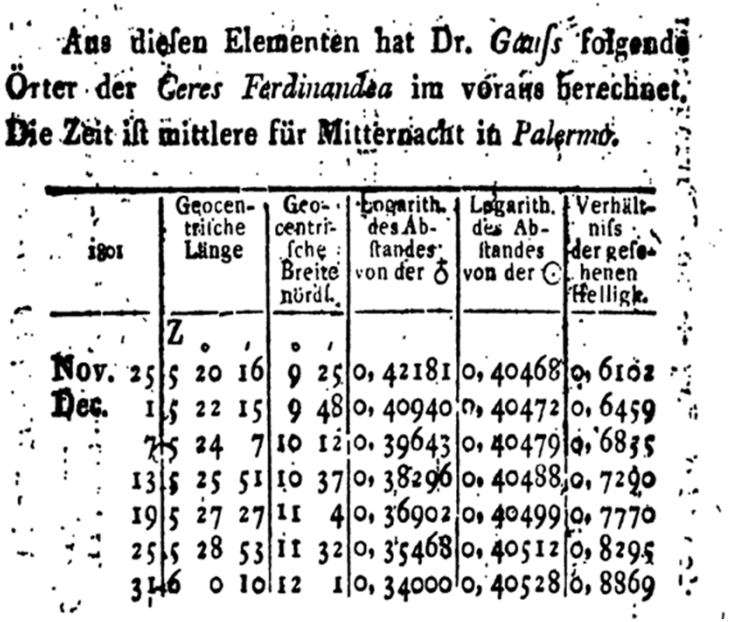
Figure 3. Path of Ceres from discovery in the constellation Taurus to recovery in the constellation Leo

Space Situational Awareness - 1801

- The new celestial object was of great interest, but was lost from observation for almost the entire year 1801
- Carl Friedrich Gauss, mathematician, mathematical physicist, and astronomer took note of these observations and computed an orbit for the object
- Gauss's orbit put the object on a heliocentric path between the orbits of Mars and Jupiter
- Next slide shows Gauss's search ephemeris, as published by von Zach in the December 1801 issue of *Monatliche Correspondenz*

Space Situational Awareness - 1801

Search Ephemeris of Gauss
from *Monatliche Correspondenz,*
Vol. 4, p. 647:



Aus diesen Elementen hat Dr. *Gauss* folgende Örter der *Ceres Ferdinandea* im voraus berechnet. Die Zeit ist mittlere für Mitternacht in *Palermo*.

1801	Geocentrische Länge	Geocentrische Breite nördl.	Logarith. des Abstandes von der ♁	Logarith. des Abstandes von der ☉	Verhältniss der gesehenen Helligk.
	Z ° ′	° ′			
Nov. 25	5 20 16	9 25	0,42181	0,40468	0,6102
Dec. 1	5 22 15	9 48	0,40940	0,40472	0,6459
7	5 24 7	10 12	0,39643	0,40479	0,6835
13	5 25 51	10 37	0,38296	0,40488	0,7240
19	5 27 27	11 4	0,36902	0,40499	0,7770
25	5 28 53	11 32	0,35468	0,40512	0,8295
31	6 0 10	12 1	0,34000	0,40528	0,8869

Z column contains "Zodiac Number" 0 through 11, to be multiplied by 30 degrees and added to degrees column

Table 4, Page 11 of my AMOS 2016 paper
converts Gauss's geocentric ecliptic longitudes and latitudes to right ascensions and declinations*

Gregorian Date	Ecliptic Longitude	Ecliptic Latitude	Right Ascension	Declination
year mo da	deg mn	deg mn	hours	degrees
1801 11 25	170 16	09 25	11.6558	12.5032
1801 12 01	172 15	09 48	11.7885	12.0665
1801 12 07	174 07	10 12	11.9141	11.6897
1801 12 13	175 51	10 37	12.0316	11.3805
1801 12 19	177 27	11 04	12.1417	11.1550
1801 12 25	178 53	11 32	12.2418	11.0116
1801 12 31	180 10	12 01	12.3331	10.9438

*Using formulas in Chapter IV of William Marshall Smart's, *Text-Book on Spherical Astronomy*, 5th edition (Cambridge University Press, 1965), p. 40.

Figure 4. Conversion of the geocentric ecliptic longitudes and latitudes in Gauss's search ephemeris (table on left) to right ascensions and declinations (table on right)

Space Situational Awareness - 1801

- Using Gauss's search ephemeris, von Zach observed (recovered) the new object on the night of 1801 December 31 - 1802 January 1
- Gauss became a "celebrity" throughout Europe as the result of his ingenious and extremely difficult feat of mathematical computation (with quill pen, ink, paper, and log tables!)
- Gauss had devised a method of orbit determination that was not only novel, but also of enduring interest
- See Teets and Whitehead (*Mathematics Magazine,* April 1999) for an award-winning, contemporary article that provides a historical sketch and a summary of Gauss's method:

https://www.maa.org/programs/maa-awards/writing-awards/the-discovery-of-ceres-how-gauss-became-famous

Motivation and Background

- Became interested in the discovery of Ceres because of a project I was doing with Dr. Gim J. Der, whose MIT Ph.D. dissertation advisor was the great astrodynamicist Richard H. Battin (1925-2014)
- Dr. Battin was chief architect of the guidance and control hardware and software for the Apollo missions to the Moon
- Go to this link for an oral history of Dr. Battin's career:

  https://www.jsc.nasa.gov/history/oral_histories/BattinRH/BattinRH_4-18-00.htm

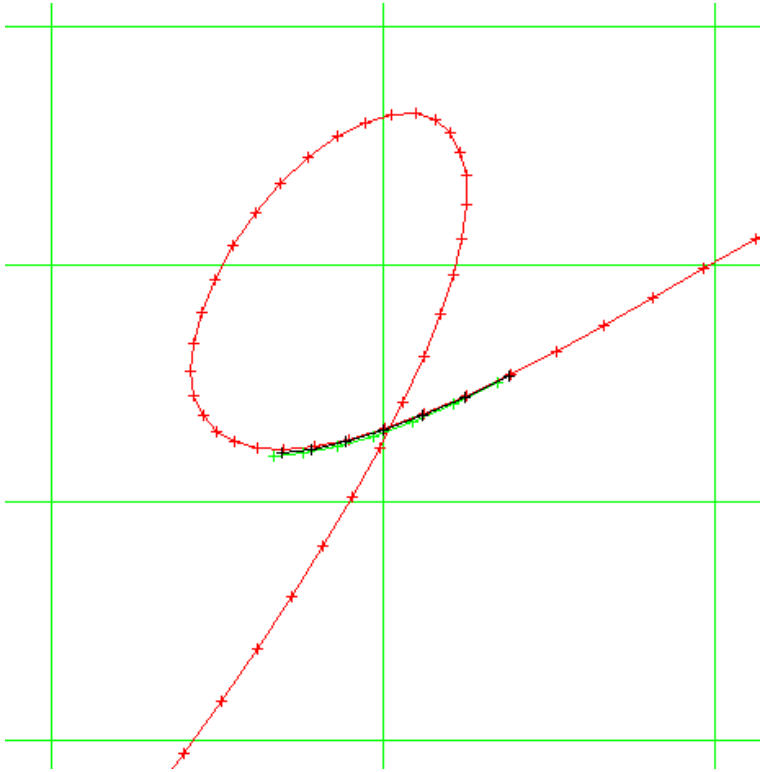
- Dr. Der and I wanted to apply some of the algorithms that we had developed for modern space situational awareness to Piazzi's observations
- We also wanted to compare our results with Gauss's results, if possible

Difficulties, Rewards, and Results of My Research

- Was surprised and pleased to find that a public domain reprint of von Zach's *Monatliche Correspondenz* articles from 1801 had become available in the U.S. (since 2012)
- But my historical research was difficult, because von Zach's articles were
  - in German (not my native tongue, but studied in college)
  - early nineteenth-century German, at that
  - and the printed copy available to me was/is of rather poor quality
- Had not been aware that Gauss‘s search ephemeris had been published by von Zach
  - This was exactly what I needed to validate my own results
- Next slide depicts my results graphically

Comparison of Contemporary vs. 1801 Results

- Red curve in Fig. 5 is the contemporary JPL Horizons-computed path of Ceres for times during 1801-1802 (best available modern ephemeris)
- Green curve is through seven points plotted from Gauss's search ephemeris
- Black curve is through the seven points computed from my own determination and differential correction of the orbit of Ceres from Piazzi's observations



- My "statistically valid" orbit for Ceres, obtained from 17 good Piazzi observations out of 19 possible, was not as good as Gauss's orbit
- But my orbit as depicted in Fig. 5, using the exact same three observations that Gauss used, was slightly better than Gauss's orbit
- I attribute the improvement to my having a better solar ephemeris in 2016 than was available to Gauss in 1801

Figure 5. Comparison of Contemporary Results with Gauss Search Ephemeris

Summary of this MAA/RMS 2018 Presentation

- In 1801, astronomers were scanning the skies with telescopes, compiling star catalogs, and looking for new objects in orbit around the Sun
- Today, the Air Force scans the skies with telescopes -- and with radars as well -- looking for new objects in orbit around Earth
- Piazzi, von Zach, and Gauss pioneered in 1801 the methods and operational techniques of modern space situational awareness
  - because Gauss devised a new method of orbit determination still now in use,
    - for space objects in orbit around the Sun
    - for space objects detected in orbit around Earth
  - and because we use our modern, highly-precise star catalogs
    - to discriminate the unknown from the familiar, as Piazzi did,
    - and to make our observations more accurate

References

[1] von Zach, Franz Xaver, *Monatliche Correspondenz zur Befoerderung der Erd- und Himmelskunde,* Vol. 4 (1801).

Search for the book likely only at Amazon.com, then:

[a] Piazzi's observations - September 1801 (p. 280)

[b] Gauss's search ephemeris for Ceres - December 1801 (p. 647)

[2] Mansfield, Roger L. and Gim J. Der, "Reconstruction of the 1801 Discovery Orbit of Ceres via Contemporary Angles-Only Algorithms," *Advanced Maui Optical and Space Surveillance Technologies (AMOS) Conference 2016,* Maui, Hawaii, September 20-23, 2016.

http://astroger.com/Mansfield Der AMOS 2016 09 15 preprint.pdf

Addenda (Time Permitting)

- How to use the handout star chart (Fig. 1, p. 3)
  - The *celestial meridian* is fixed at any observer's (e.g., your) longitude and extends from celestial north pole to celestial south pole
    - The celestial meridian can be depicted on the map as a vertical line from the upper border of the map to its lower border
  - You can simulate the celestial meridian with a pen placed on the map in vertical orientation
    - Place pen at the point on the map corresponding to tonight's date. This is the location of the celestial meridian at midnight tonight
    - Move pen one hour to the *right* for each hour *earlier* than midnight
    - Move pen one hour to the *left* for each hour *later* than midnight
    - The celestial meridian now tells you which constellations you will see above your local horizon as you look due south
  - See the third link at http://astroger.com for more details
- Next slide provides an overview of the Mathcad PRIME 4.0 worksheet used to convert geocentric ecliptic longitudes and latitudes of Ceres to right ascensions and declinations

Addenda (Time Permitting)

- Conversion of geocentric ecliptic longitudes and latitudes to right ascensions and declinations
  - Let **Lambda** be geocentric ecliptic longitude and let **Beta** be geocentric ecliptic latitude
  - Let **Alpha** be right ascension and let **Delta** be declination
  - Let **ε** be the obliquity of the ecliptic and let **JDT** be the Julian date
  - Then a Mathcad function that does the calculations is:

$$
\begin{aligned}
&\mathbf{RADec}(\mathbf{JDT},\mathbf{Lambda},\mathbf{Beta}) := \\
&\quad n \leftarrow \mathrm{rows}(\mathbf{Lambda}) \\
&\quad \text{for } i \in 1..n \\
&\qquad \varepsilon \leftarrow \mathrm{eps}(\mathbf{JDT}_i) \\
&\qquad \mathbf{Dec}_i \leftarrow \mathrm{asin}\left(\sin(\mathbf{Beta}_i)\cdot\cos(\varepsilon) + \cos(\mathbf{Beta}_i)\cdot\sin(\varepsilon)\cdot\sin(\mathbf{Lambda}_i)\right) \\
&\qquad x \leftarrow \cos(\mathbf{Beta}_i)\cdot\cos(\mathbf{Lambda}_i) \\
&\qquad y \leftarrow -\sin(\mathbf{Beta}_i)\cdot\sin(\varepsilon) + \cos(\mathbf{Beta}_i)\cdot\cos(\varepsilon)\cdot\sin(\mathbf{Lambda}_i) \\
&\qquad \mathbf{RA}_i \leftarrow \frac{\mathrm{angle}(x,y)}{15} \\
&\quad \mathrm{augment}(\mathrm{augment}(\mathbf{JDT},\mathbf{RA}\cdot\mathrm{DegPerRad}),\mathbf{Dec}\cdot\mathrm{DegPerRad})
\end{aligned}
$$

See the Mathcad PRIME 4.0 worksheet at http://astroger.com for further details.

Appendix – Two More Star Maps

- The rectangular projection on p. 3 of this presentation is not a conformal mapping of the celestial sphere to the plane
  - But it does highlight the ecliptic path of the Sun and the twelve Zodiac constellations spread out along the ecliptic
  - At the expense of greatly distorting the star regions around the north and south celestial poles
- The next two slides contain two more maps:
  - Polar equidistant projection of the north celestial hemisphere down to -45 degrees declination
  - Polar equidistant projection of the south celestial hemisphere up to +45 degrees declination
- So the two maps cover the entire celestial sphere, with 90 degrees of overlap, i.e.,
  - The first map extends 45 degrees into the southern hemisphere
  - The second map extends 45 degrees into the northern hemisphere
- And they display the north and south polar regions in the manner that we would expect to observe them

NORTH POLAR EQUIDISTANT PROJECTION OF THE CELESTIAL SPHERE, TO −45 DEGREES DECLINATION

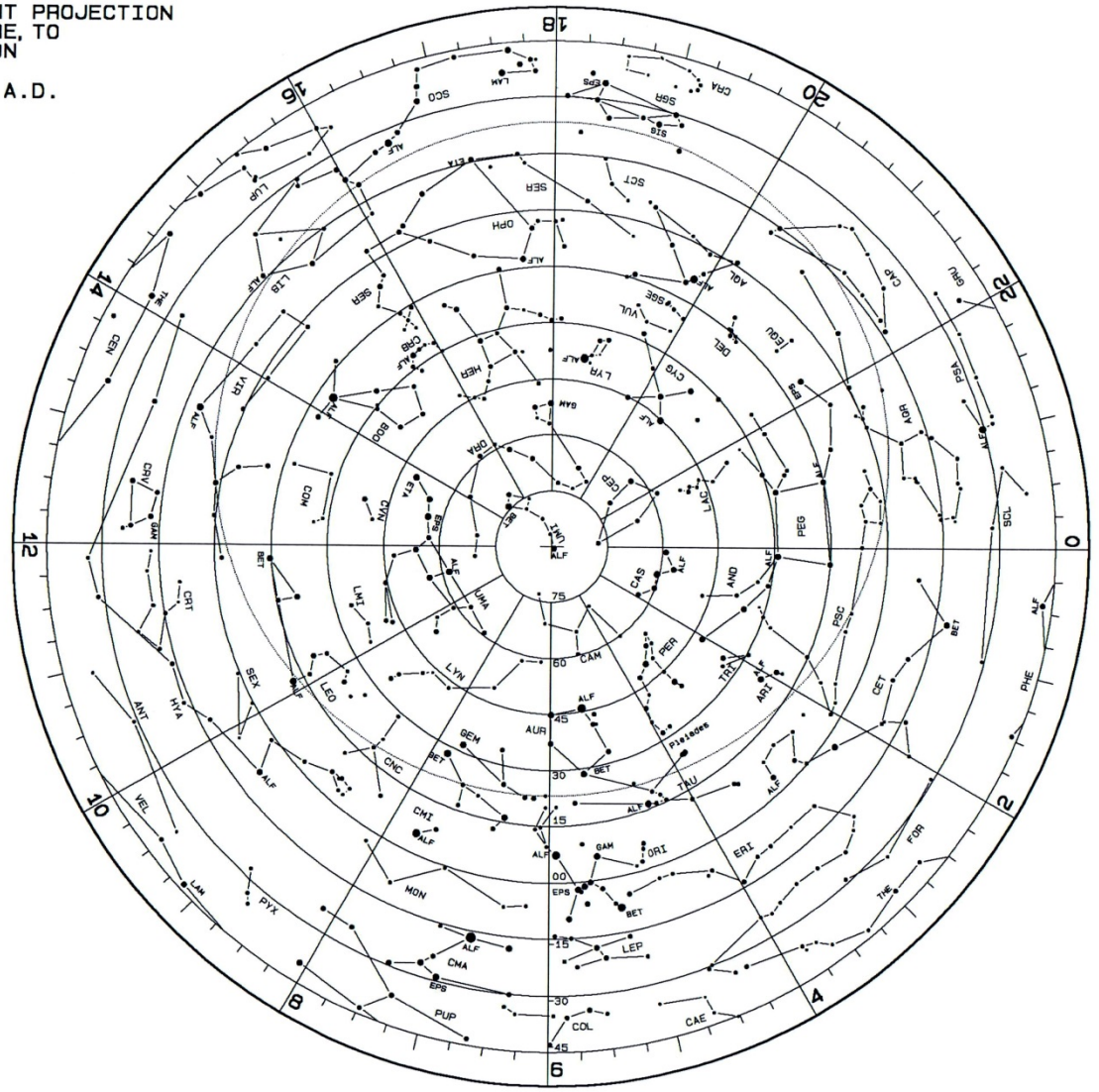
for the epoch J2000.0 A.D.

NAVIGATION STARS

Design.	Name	Mag.	R.A. (h)
ALF-AND	Alpheratz	2.2	00.1
ALF-PHE	Ankaa	2.4	00.4
ALF-CAS	Schedar	2.5	00.7
BET-CET	Diphda	2.2	00.7
ALF-ARI	Hamal	2.2	02.1
ALF-UMI	Polaris	2.1	02.5
THE-ERI	Acamar	3.4	03.0
ALF-CET	Menkar	2.8	03.0
ALF-PER	Mirfak	1.9	03.4
ALF-TAU	Aldebaran	1.1	04.6
BET-ORI	Rigel	0.3	05.2
ALF-AUR	Capella	0.2	05.3
GAM-ORI	Bellatrix	1.7	05.4
BET-TAU	Elnath	1.8	05.4
EPS-ORI	Alnilam	1.8	05.6
ALF-ORI	Betelgeuse*	0-1	05.9
ALF-CMA	Sirius	−1.4	06.8
EPS-CMA	Adhara	1.6	07.0
ALF-CMI	Procyon	0.5	07.7
BET-GEM	Pollux	1.2	07.8
LAM-VEL	Suhail	2.2	09.1
ALF-HYA	Alphard	2.2	09.5
ALF-LEO	Regulus	1.3	10.1
ALF-UMA	Dubhe	2.0	11.1
BET-LEO	Denebola	2.2	11.8
GAM-CRV	Gienah	2.8	12.3
EPS-UMA	Alioth	1.7	12.9
ALF-VIR	Spica	1.2	13.4
ETA-UMA	Alkaid	1.9	13.8
THE-CEN	Menkent	2.3	14.1
ALF-BOO	Arcturus	0.2	14.3
ALF-LIB	Zubenelgenubi	2.9	14.8
BET-UMI	Kochab	2.2	14.8
ALF-CRB	Alphecca	2.3	15.6
ALF-SCO	Antares	1.2	16.5
ETA-OPH	Sabik	2.6	17.2
LAM-SCO	Shaula	1.7	17.6
ALF-OPH	Rasalhague	2.1	17.6
GAM-DRA	Eltanin	2.4	17.9
EPS-SGR	Kaus Australis	2.0	18.4
ALF-LYR	Vega	0.1	18.6
SIG-SGR	Nunki	2.1	18.9
ALF-AQL	Altair	0.9	19.8
ALF-CYG	Deneb	1.3	20.7
EPS-PEG	Enif	2.5	21.7
ALF-PSA	Fomalhaut	1.3	23.0
ALF-PEG	Markab	2.6	23.1

*Variable stars are marked with crosses.

The radius of the circle representing a variable star corresponds to its minimum magnitude (maximum brightness).



CONSTELLATIONS

AND	Andromeda
ANT	Antlia
AQR	Aquarius
AQL	Aquila
ARI	Aries
AUR	Auriga
BOO	Bootes
CAE	Caelum
CAM	Camelopardus
CNC	Cancer
CVN	Canes Venatici
CMA	Canis Major
CMI	Canis Minor
CAP	Capricornus
CAS	Cassiopeia
CEN	Centaurus
CEP	Cepheus
CET	Cetus
COL	Columba
COM	Coma Berenices
CRA	Corona Australis
CRB	Corona Borealis
CRV	Corvus
CRT	Crater
CYG	Cygnus
DEL	Delphinus
DRA	Draco
EQU	Equuleus
ERI	Eridanus
FOR	Fornax
GEM	Gemini
GRU	Grus
HER	Hercules
HYA	Hydra
LAC	Lacerta
LEO	Leo
LMI	Leo Minor
LEP	Lepus
LIB	Libra
LUP	Lupus
LYN	Lynx
LYR	Lyra
MON	Monoceros
NOR	Norma
OPH	Ophiuchus
ORI	Orion
PEG	Pegasus
PER	Perseus
PHE	Phoenix
PSC	Pisces
PSA	Piscis Austrinus
PUP	Puppis
PYX	Pyxis
SGE	Sagitta
SGR	Sagittarius
SCO	Scorpius
SCL	Sculptor
SCT	Scutum
SER	Serpens
SEX	Sextans
TAU	Taurus
TRI	Triangulum
UMA	Ursa Major
UMI	Ursa Minor
VEL	Vela
VIR	Virgo
VUL	Vulpecula

SOUTH POLAR EQUIDISTANT PROJECTION OF THE CELESTIAL SPHERE, TO +45 DEGREES DECLINATION

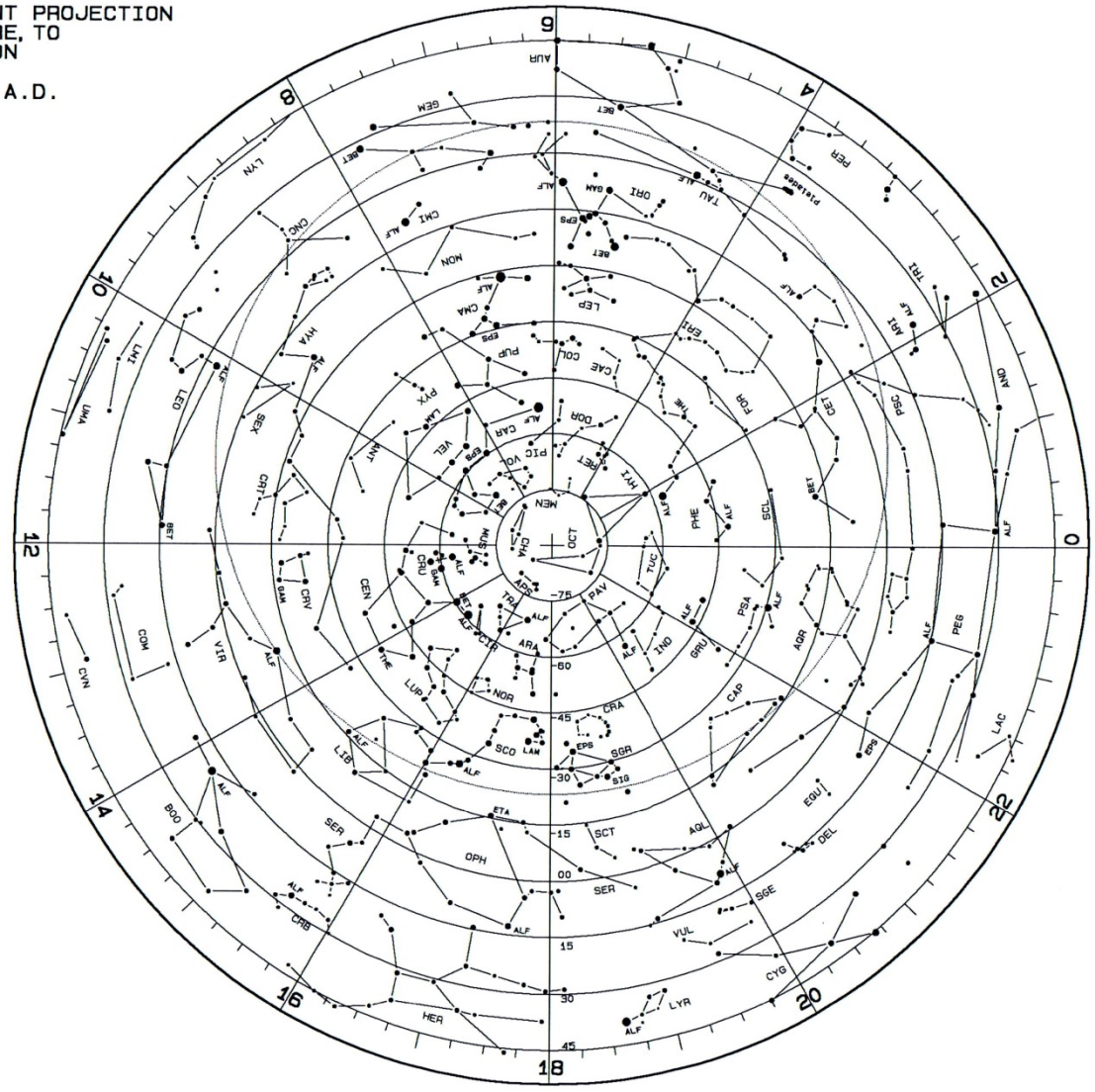
for the epoch J2000.0 A.D.

NAVIGATION STARS

Design.	Name	Mag.	R.A. (h)
ALF-AND	Alpheratz	2.2	00.1
ALF-PHE	Ankaa	2.4	00.4
BET-CET	Diphda	2.2	00.7
ALF-ERI	Achernar	0.6	01.6
ALF-ARI	Hamal	2.2	02.1
THE-ERI	Acamar	3.4	03.0
ALF-CET	Menkar	2.8	03.0
ALF-TAU	Aldebaran	1.1	04.6
BET-ORI	Rigel	0.3	05.2
GAM-ORI	Bellatrix	1.7	05.4
BET-TAU	Elnath	1.8	05.4
EPS-ORI	Alnilam	1.8	05.6
ALF-ORI	Betelgeuse	0-1	05.9
ALF-CAR	Canopus	-0.9	06.4
ALF-CMA	Sirius	-1.4	06.8
EPS-CMA	Adhara	1.6	07.0
ALF-CMI	Procyon	0.5	07.7
BET-GEM	Pollux	1.2	07.8
EPS-CAR	Avior	1.7	08.4
LAM-VEL	Suhail	2.2	09.1
BET-CAR	Miaplacidus	1.8	09.2
ALF-HYA	Alphard	2.2	09.5
ALF-LEO	Regulus	1.3	10.1
BET-LEO	Denebola	2.2	11.8
GAM-CRV	Gienah	2.8	12.3
ALF-CRU	Acrux	1.6	12.4
GAM-CRU	Gacrux	1.6	12.5
ALF-VIR	Spica	1.2	13.4
BET-CEN	Hadar (Agena)	0.9	14.1
THE-CEN	Menkent	2.3	14.1
ALF-BOO	Arcturus	0.2	14.3
ALF-CEN	Rigil Kentaurus	0.1	14.7
ALF-LIB	Zubenelgenubi	2.9	14.8
ALF-CRB	Alphecca	2.3	15.6
ALF-SCO	Antares	1.2	16.5
ALF-TRA	Atria	1.9	16.8
ETA-OPH	Sabik	2.6	17.2
LAM-SCO	Shaula	1.7	17.6
ALF-OPH	Rasalhague	2.1	17.6
EPS-SGR	Kaus Australis	2.0	18.4
ALF-LYR	Vega	0.1	18.6
SIG-SGR	Nunki	2.1	18.9
ALF-AQL	Altair	0.9	19.8
ALF-PAV	Peacock	2.1	20.4
EPS-PEG	Enif	2.5	21.7
ALF-GRU	Al Na'ir	2.2	22.1
ALF-PSA	Fomalhaut	1.3	23.0
ALF-PEG	Markab	2.6	23.1

CONSTELLATIONS

AND	Andromeda
ANT	Antlia
APS	Apus
AQR	Aquarius
AQL	Aquila
ARA	Ara
ARI	Aries
AUR	Auriga
BOO	Bootes



CONSTELLATIONS, CONTD.

CAE	Caelum
CNC	Cancer
CVN	Canes Venatici
CMA	Canis Major
CMI	Canis Minor
CAP	Capricornus
CAR	Carina
CEN	Centaurus
CET	Cetus
CHA	Chamaeleon
CIR	Circinus
COL	Columba
COM	Coma Berenices
CRA	Corona Australis
CRB	Corona Borealis
CRV	Corvus
CRT	Crater
CRU	Crux
CYG	Cygnus
DEL	Delphinus
DOR	Doradus
EQU	Equuleus
ERI	Eridanus
FOR	Fornax
GEM	Gemini
GRU	Grus
HER	Hercules
HYA	Hydra
HYI	Hydrus
IND	Indus
LAC	Lacerta
LEO	Leo
LMI	Leo Minor
LEP	Lepus
LIB	Libra
LUP	Lupus
LYN	Lynx
LYR	Lyra
MEN	Mensa
MUS	Musca
MON	Monoceros
NOR	Norma
OCT	Octans
OPH	Ophiuchus
ORI	Orion
PAV	Pavo
PEG	Pegasus
PER	Perseus
PHE	Phoenix
PIC	Pictor
PSC	Pisces
PSA	Piscis Austrinus
PUP	Puppis
PYX	Pyxis
RET	Reticulum
SGE	Sagitta
SGR	Sagittarius
SCO	Scorpius
SCL	Sculptor
SCT	Scutum
SER	Serpens
SEX	Sextans
TAU	Taurus
TUC	Tucana
TRA	Triangulum Austra
TRI	Triangulum
UMA	Ursa Major
VEL	Vela
VIR	Virgo
VOL	Volans
VUL	Vulpecula