Astronomical Journal-Keeping and Misconceptions in Celestial Navigation

Navigation Symposium:
The History and Future of Celestial Navigation
11/3-5/17, Mystic Seaport, Mystic, CT

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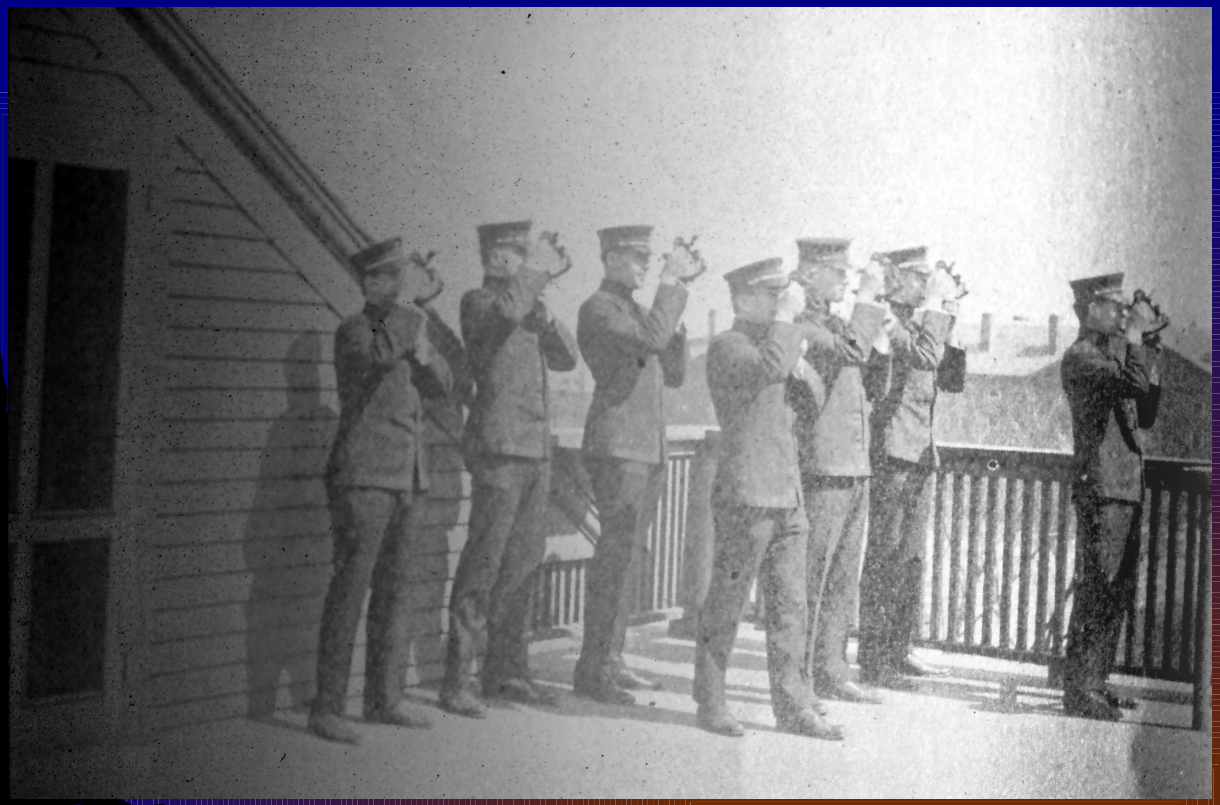
Navigator of Selkie, Winner of the 2017 Marion-Bermuda Race

Celestial Navigation – A Harvard Tradition

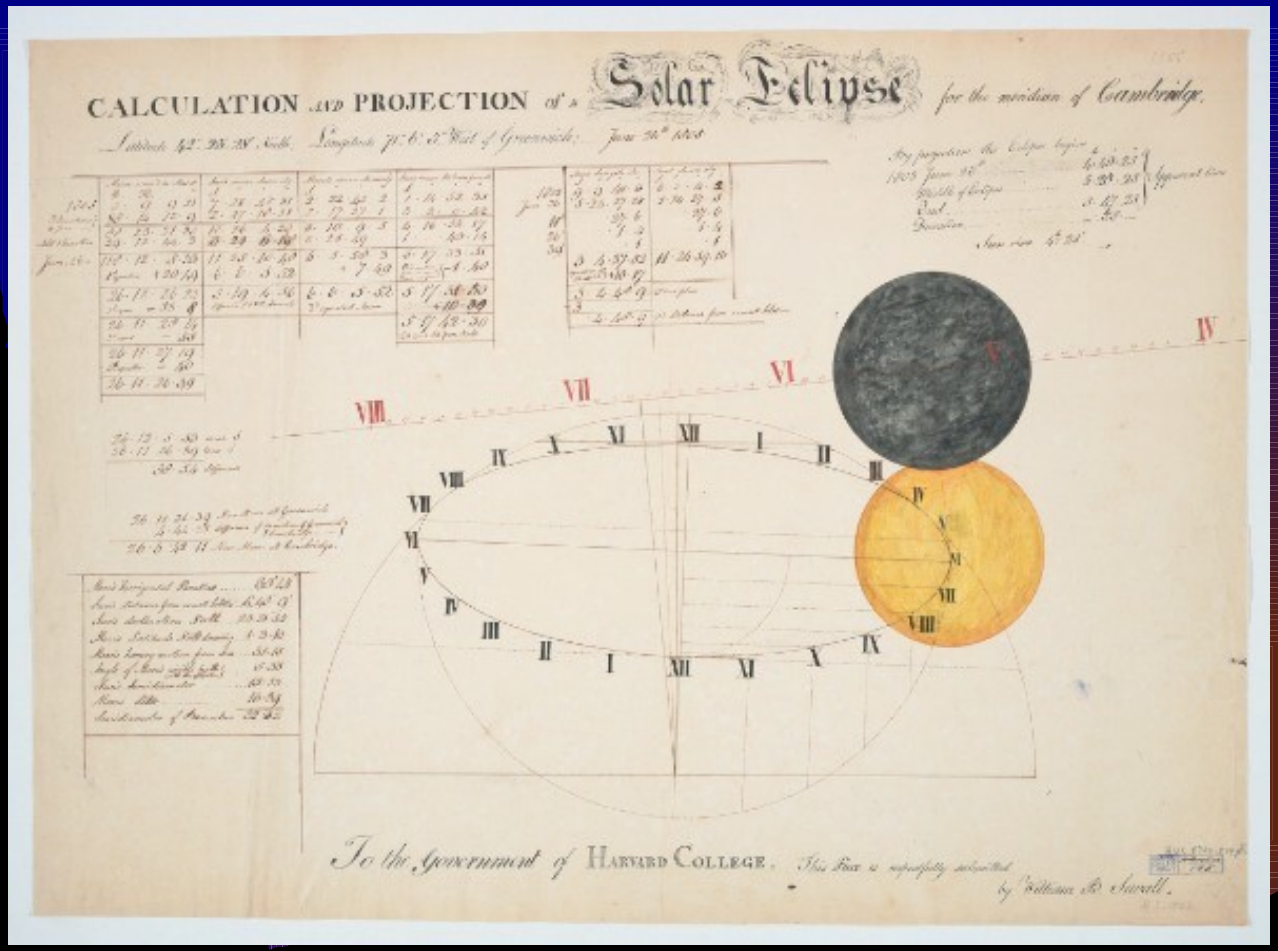


Since 1896, Harvard has trained navigators to sail the seas, map distant shores, and conquer the air.

History at Harvard

- 1652 Early navigation students
- 1718 Earliest texts and notes on navigation
- 1772 Early surviving lectures
- 1806 Offer of Hollis Professorship of Mathematics and Natural Philosophy to Bowditch
- 1807 Professor Farrar's Mathematics Courses
- 1891 Lawrence Scientific School
- 1896 Astronomy 2, An Astronomy Course - to present,

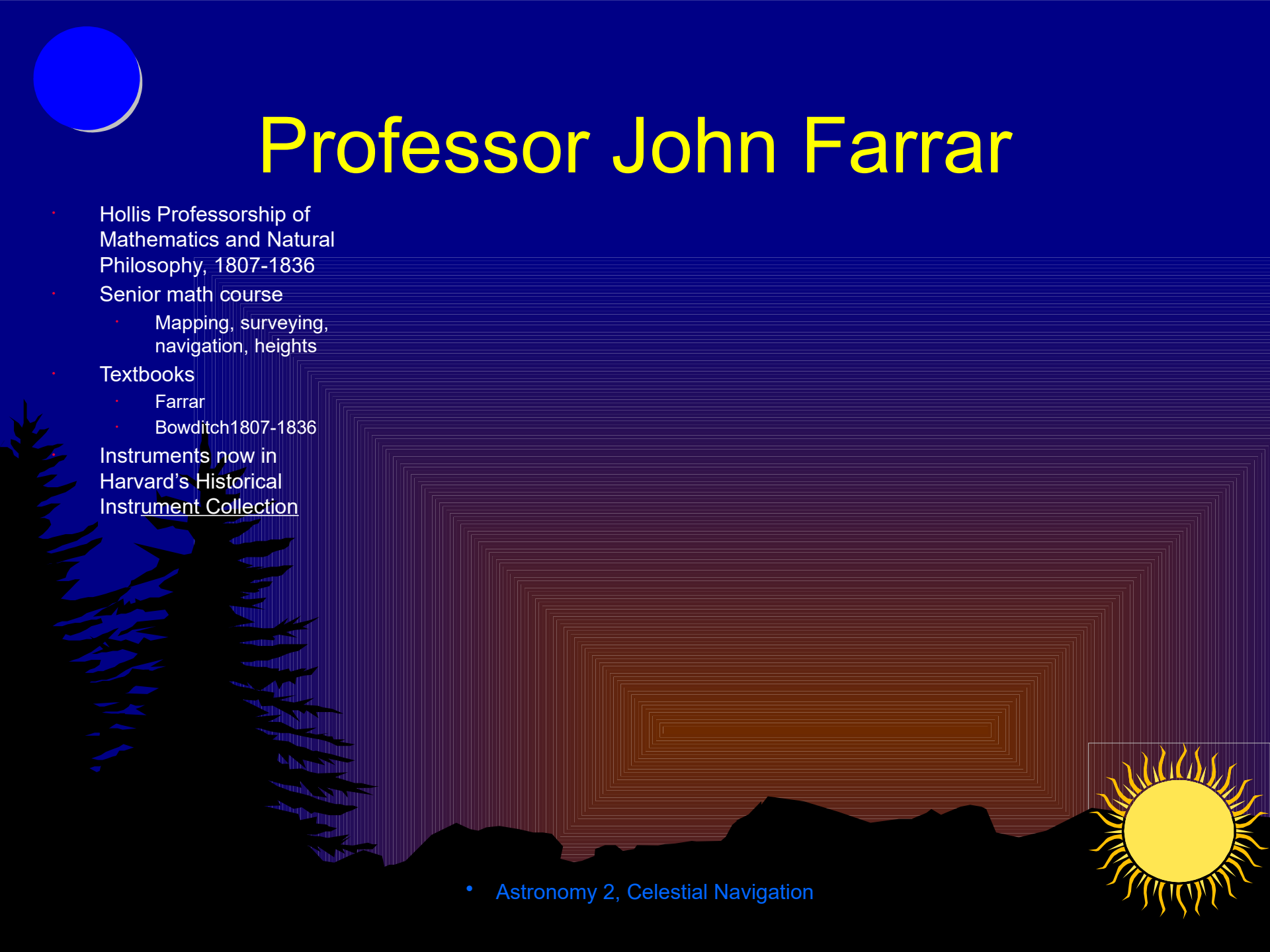
Calculation and Projection of a Solar Eclipse for the Meridian of Cambridge, for June 26, 1805. William B. Sewall A.B. 1803.



- Astronomy 2, Celestial Navigation

Professor John Farrar

- Hollis Professorship of Mathematics and Natural Philosophy, 1807-1836
- Senior math course
  - Mapping, surveying, navigation, heights
- Textbooks
  - Farrar
  - Bowditch1807-1836
- Instruments now in Harvard's Historical Instrument Collection



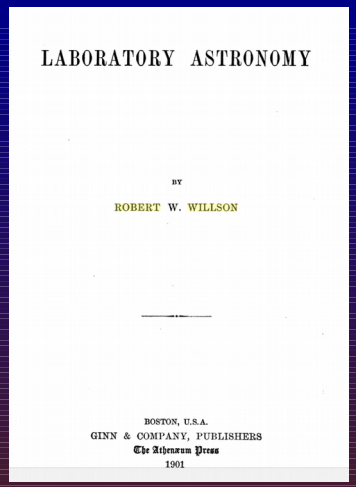
How good was Farrar's course?

- To my astonishment I was informed on leaving [Harvard] college that I had studied navigation!- why, if I had taken one turn down the harbor I should have known more about it.

Walden (1846) Henry David Thoreau

Robert Wheeler Willson

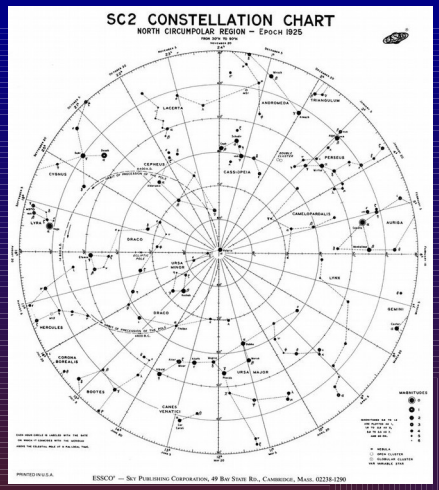
- Reformulated a full “laboratory astronomy” course, 1891
  - Astronomy 1 and 2, 1896
  - Laboratory for students
- Chronometers, sextants, telescopes
- Sun tracking, plotting of movement
- ESSCO Laboratory Exercises


LABORATORY ASTRONOMY

BY

ROBERT W. WILLSON

BOSTON, U.S.A.
GINN & COMPANY, PUBLISHERS
The Athenæum Press
1901



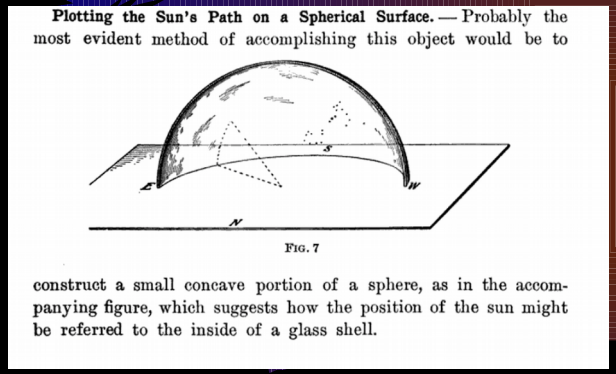

Plotting the Sun's Path on a Spherical Surface. — Probably the most evident method of accomplishing this object would be to

FIG. 7

construct a small concave portion of a sphere, as in the accompanying figure, which suggests how the position of the sun might be referred to the inside of a glass shell.

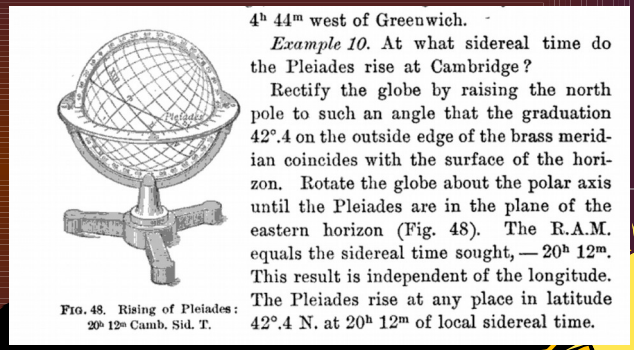


FIG. 48. Rising of Pleiades: 20h 12m Camb. Sid. T.

4h 44m west of Greenwich.

Example 10. At what sidereal time do the Pleiades rise at Cambridge?

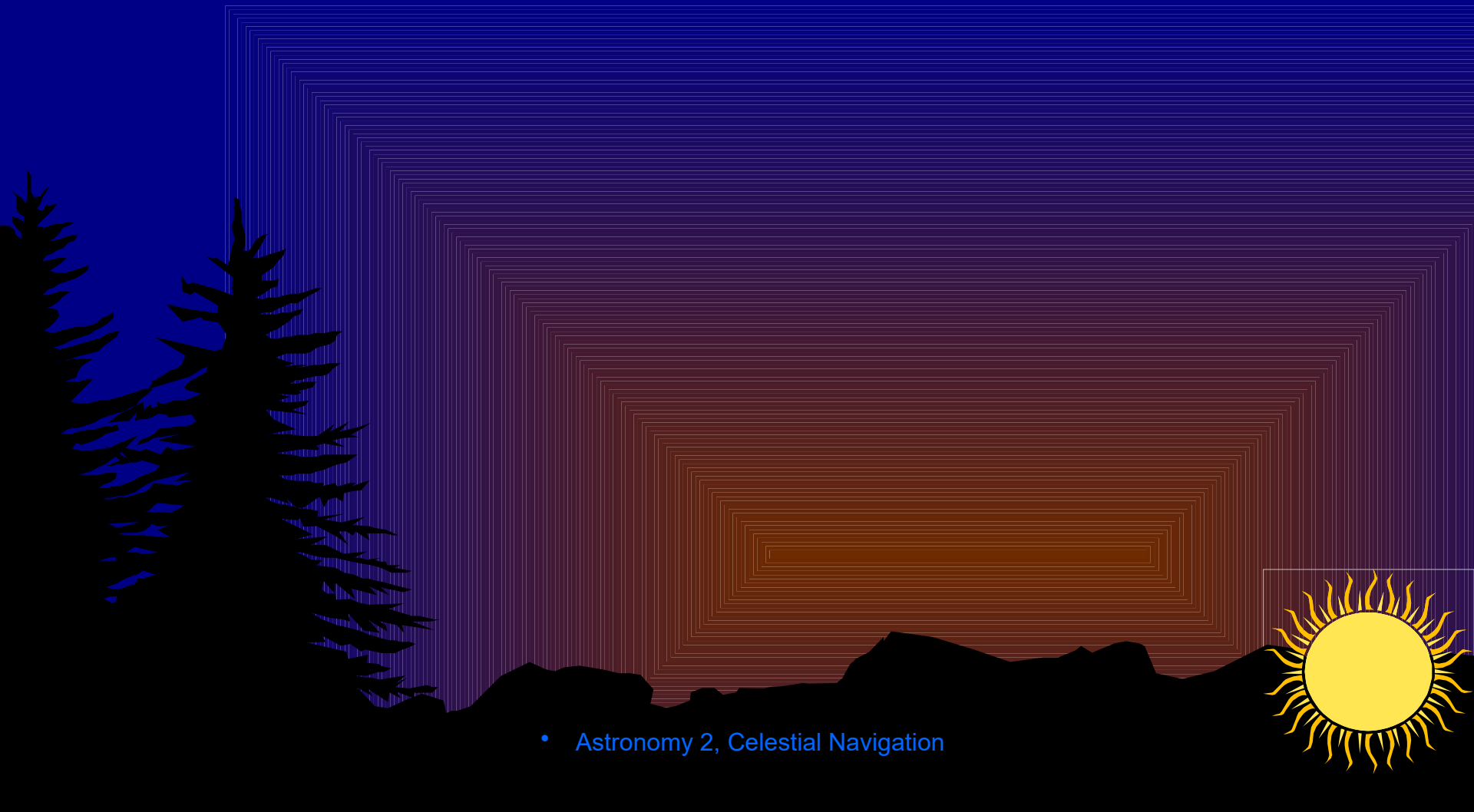
Rectify the globe by raising the north pole to such an angle that the graduation 42°.4 on the outside edge of the brass meridian coincides with the surface of the horizon. Rotate the globe about the polar axis until the Pleiades are in the plane of the eastern horizon (Fig. 48). The R.A.M. equals the sidereal time sought, — 20h 12m. This result is independent of the longitude. The Pleiades rise at any place in latitude 42°.4 N. at 20h 12m of local sidereal time.

- Astronomy 2, Celestial Navigation

Goals of Astronomy 2

- To acquire the practical skill of finding where you are and where you are going
  - By learning the secrets of maps and charts
  - By developing an intimate knowledge of the sky
- To master navigation's history, technologies, and techniques
- To enhance abilities to learn through experience and by teaching others
- To draw upon the Harvard's unique collections in learning a universal art and science
- To connect navigational and astronomical concepts to personal interests

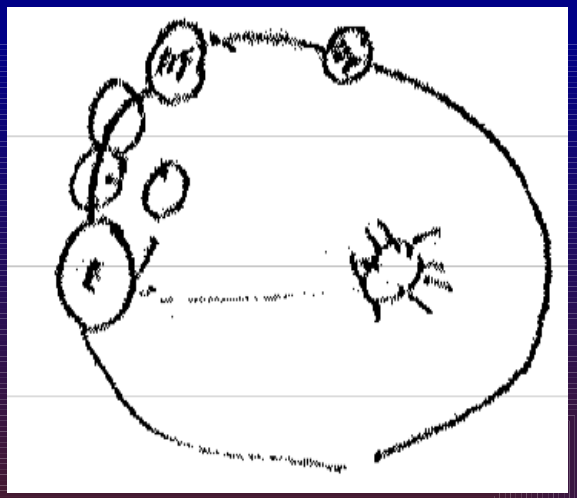
Can Cognitive Science Contribute to the Teaching of Navigation?



- Astronomy 2, Celestial Navigation

Relevant theory: Cognitive change from preconceptions

- Extensive literature
- Exist prior to instruction
- At odds with accepted scientific thought, “misconceptions”
- Commonly held, not idiosyncratic
- embedded in larger knowledge structures, not just an “error”
- resistant to change

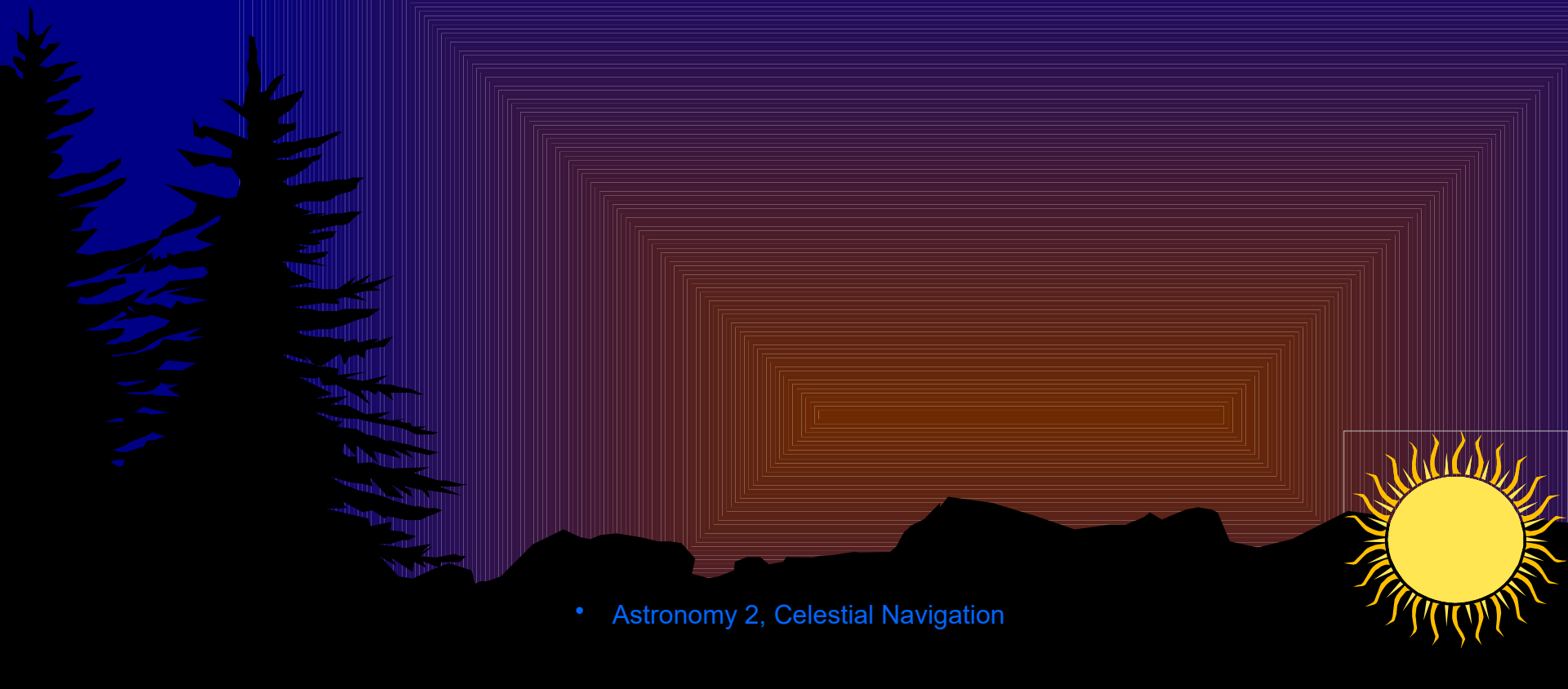


Can Cognitive Science Contribute to the Teaching of Navigation?

1. Are there any common-held preconceptions that students have when starting to study navigation?
2. How are these wrong ideas related to each other? Do they form robust, predictable mental models?
3. What kinds of activities work to cast doubt on novice frameworks and convince students that their ideas are wrong?
4. What kinds of experience help to build more robust mental models that are consistent and highly predictive of nature that help to form a foundation for learning?

Common Navigational Misconceptions

- What conceptual difficulties did you have learning?
- What strange ideas have you heard from others?

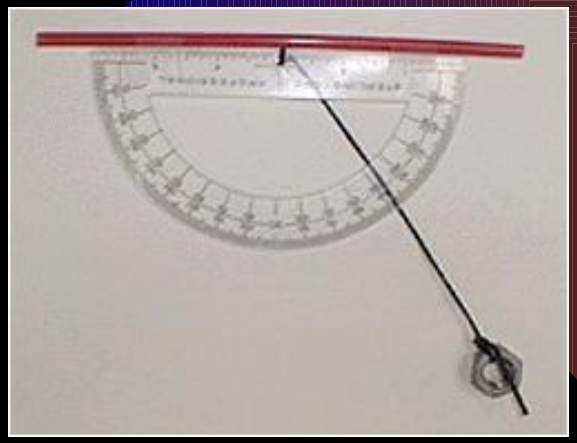


Common Navigational Misconceptions

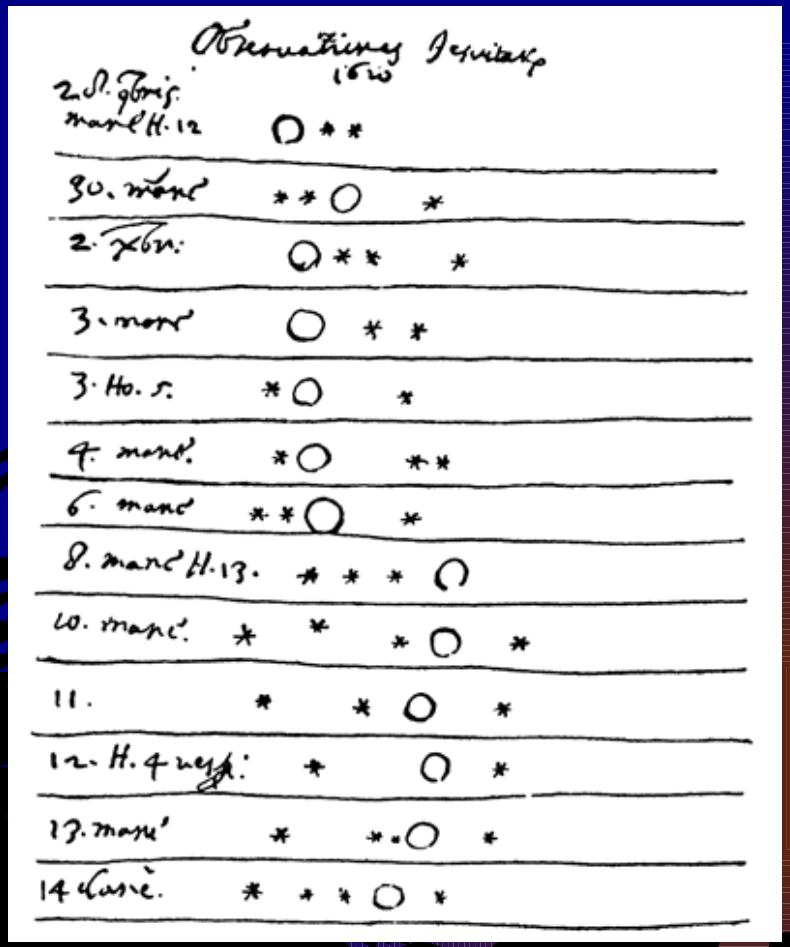
1. Sun is overhead at noon every day, everywhere.
2. Sun rises due east and sets due west, always.
3. Rate of change of altitude is linear with time.
4. Rate of change in azimuth is linear with time.
5. The moon is up only at night.
6. The moon is stationary in the sky.
7. Stars do not move over the course of the night.
8. Sextants read out in longitude and latitude.
9. Polaris is the brightest star in the sky.
10. Polaris is located at your zenith.
11. A magnetic compass points true north.

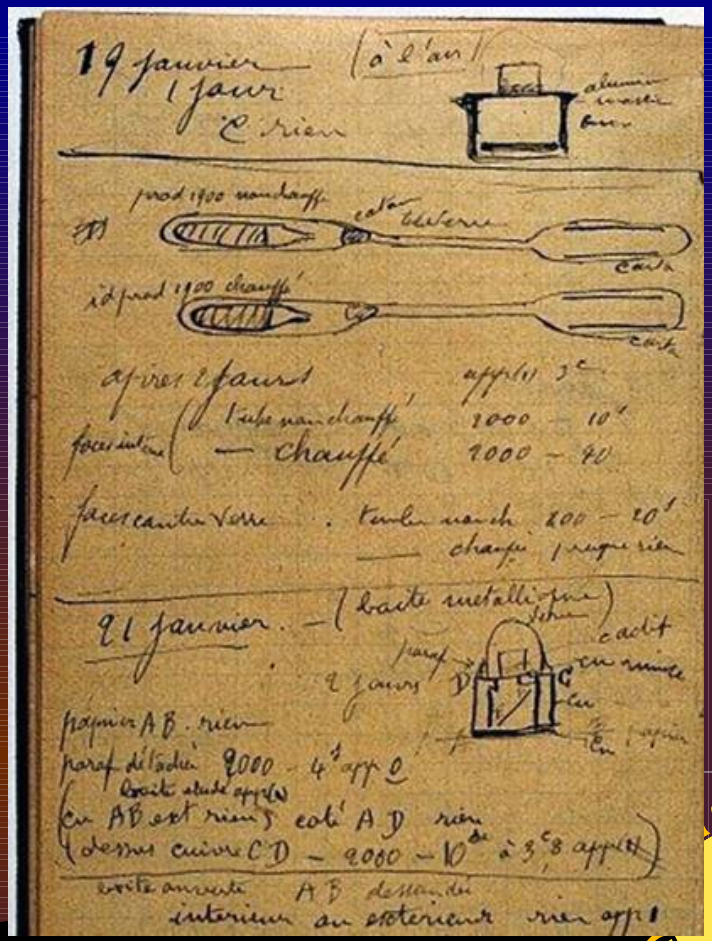
What are Journals?

- Student records of their own
  - Observations
  - Sense-making
  - Attempts to tie course content to the world



Long Tradition of Keeping Careful Records to Make Discoveries





Stage 1 – Seeking Connections

- *I have begun making nightly observations of the moon. I have been a little uncertain as to just what the moon's motion in the heavens is and so I hope to gain a more complete understanding. I was also inspired to begin making observations of the moon because of the spectacularly bright full moon which appeared in the night sky late last week.*
- *C. P. 10/28*

Stage 2 – Disordered Data

- *I'm beginning to not only realize how little I know, but also how many misconceptions I have. This sounds very naive and ridiculous now, but I just assumed the stars and moon moved together-obviously didn't think much about this one! So now that I realized how completely clueless I am, my curiosity is beginning to get the best of me.*
- *R. S., 10/8, 11PM*

Stage 3 – Finding Patterns

- *What I have observed is that the moon starts out (after the new moon) rising at an azimuth of about 220° shortly after the sun sets. It remains low on the horizon and sets shortly after it rises at an azimuth of about 241° Each evening, it appears to rise roughly 50 minutes earlier and at an azimuth 12° east of where it was the day before.*
- R. S. 10/21

- *...What I am predicting, is that the moon will continue this pattern until full moon when it will reach its peak altitude, will be out for the longest period of time and will be its brightest.*
- *R. S. 10/21*

Stage 4 – Modeling

- *“Face south, in the northeast sky the sun comes up at 90°or east. The phase of the moon determines its location. If the moon is full, the hands are at 180° angle from each other, and if the moon is new, the hands are in the same position.” S. F. 5/8*

- Using these points (observations) I will attempt to find a sine wave that will ... predict the sunrise, sunset, moonrise, and moonset for the day. My basic formula is: J. D. 9/30

- y = m*sin(ax +b) +c

- I think the sine curve is too steep ...The model doesn’t allow for variation in the time of the sun’s transit, but this does vary... I think the biggest problem is the sine curve itself.
- J. D. 10/8

Experiences that Help Make Sense of Journal Observations

- Mapping
- Modeling
  - Kinesthetic
  - Celestial Sphere
  - Planetarium
- Journal Feedback
  - Weekly
  - Rubric
- Collections
  - Map
  - Instruments
- Day Cruise
- Project

	1	2	3	4	
Data Collection	No data or "fudged" data. Excuses for not collecting data. Ignores feedback.	Random or sporadic data collection. Little pattern to data collection. Early exploration of too few variables.	Attention to controlling variables. Able to concentrate on at least 1 body. Enough data to find patterns. Careful records of a variety of measurements. Considers teacher feedback in future actions.	Very deliberate data collection. Solid data on at least two bodies. Attempts to improve accuracy of data collection. Building on feedback. Uses unusual opportunities to collect data.	3
Analysis	No idea what to do with data. No visuals, pictures or diagrams.	Little experimentation with representations. Some attempts to build upon earlier data. Inaccurate or sloppy representations. Visuals that do not accurately reflect data.	Uses own and others analysis techniques. Full utilization of data collected earlier. Experimenting with ≥2 different methods of analysis. Accurate and careful work.	Techniques matched to problem. Several methods used to "triangulate." Incorporation of others' data (properly referenced) Analysis of probable error in measurement.	2
Hypotheses	No hypotheses posed. Hypotheses having nothing to do with celestial motion. HYPOTHESIS OFFERED BUT NOT TESTED	Lacks testable hypotheses of celestial events Too readily ignored or excused data. Uses "truths" from books as hypotheses.	Many questions arise from data. Designed further data collection to answer these questions.	Developed important questions. Designed further data collection to make progress toward answering questions. Attention paid to controls. Limitations of measurements considered.	1 1/2
Modeling	No model or taking model from a book.	Generates descriptive model → (explains past data but does not predict what will happen in the sky).	Generates predictive model. Creating at least one model for one of the celestial phenomena followed. Elucidates prior conceptions.	Created at least two models. Compares prior models with current one.	1
Testing	No tests of models.	Attempts to test model with limited use of a small body of data.	Extensive data collection neither proves or disproves model.	Convincing tests. Evaluates fit of model. Suggestions for changes to model.	1

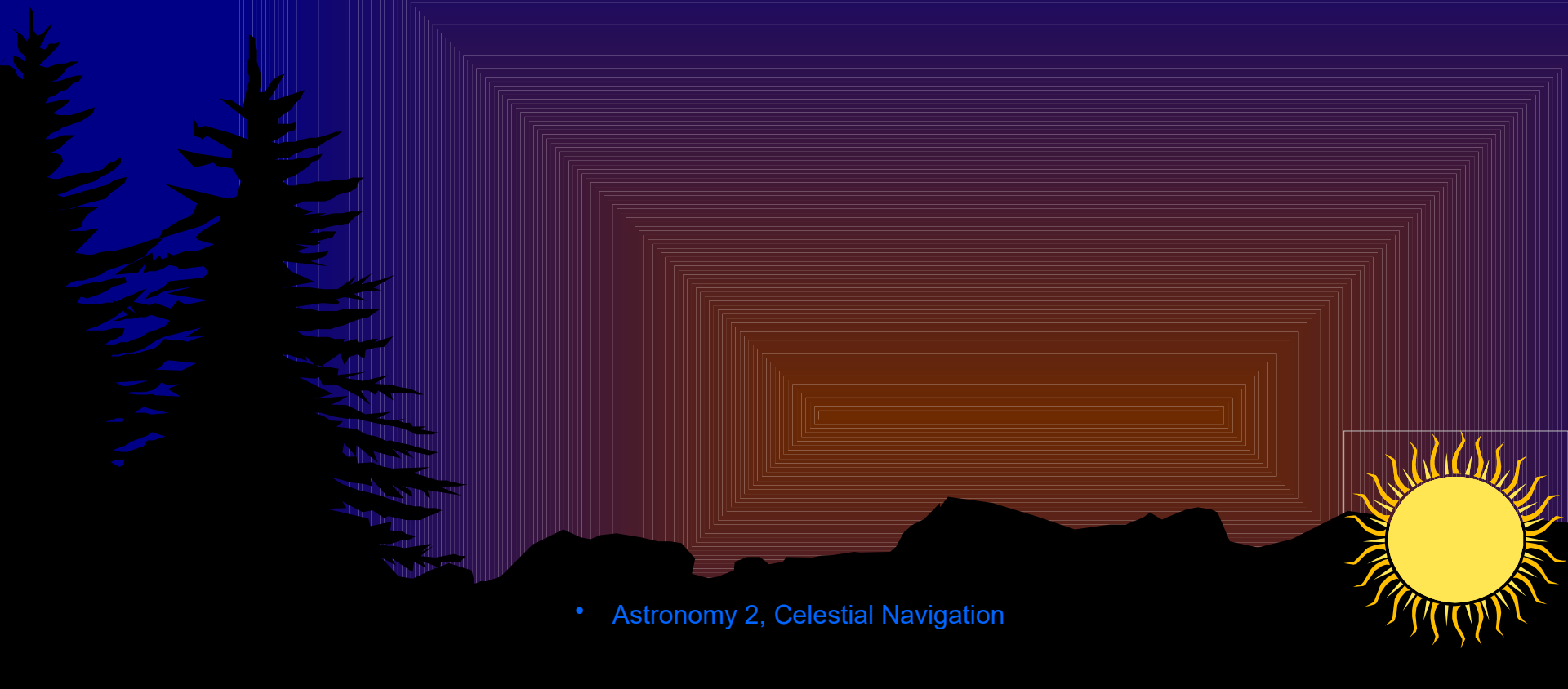
8.5/20

AREAS OF STRENGTHS/WEAKNESSES

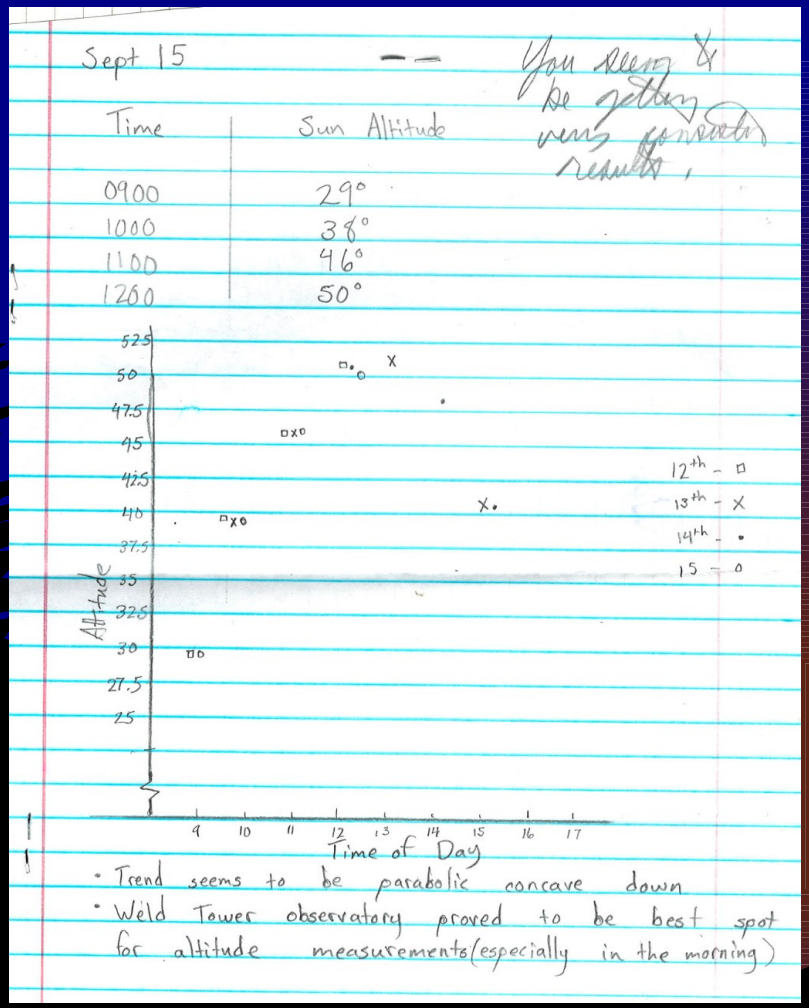
AREAS FOR CONCENTRATION NEXT WEEK

Progression of Journal Sense-Making

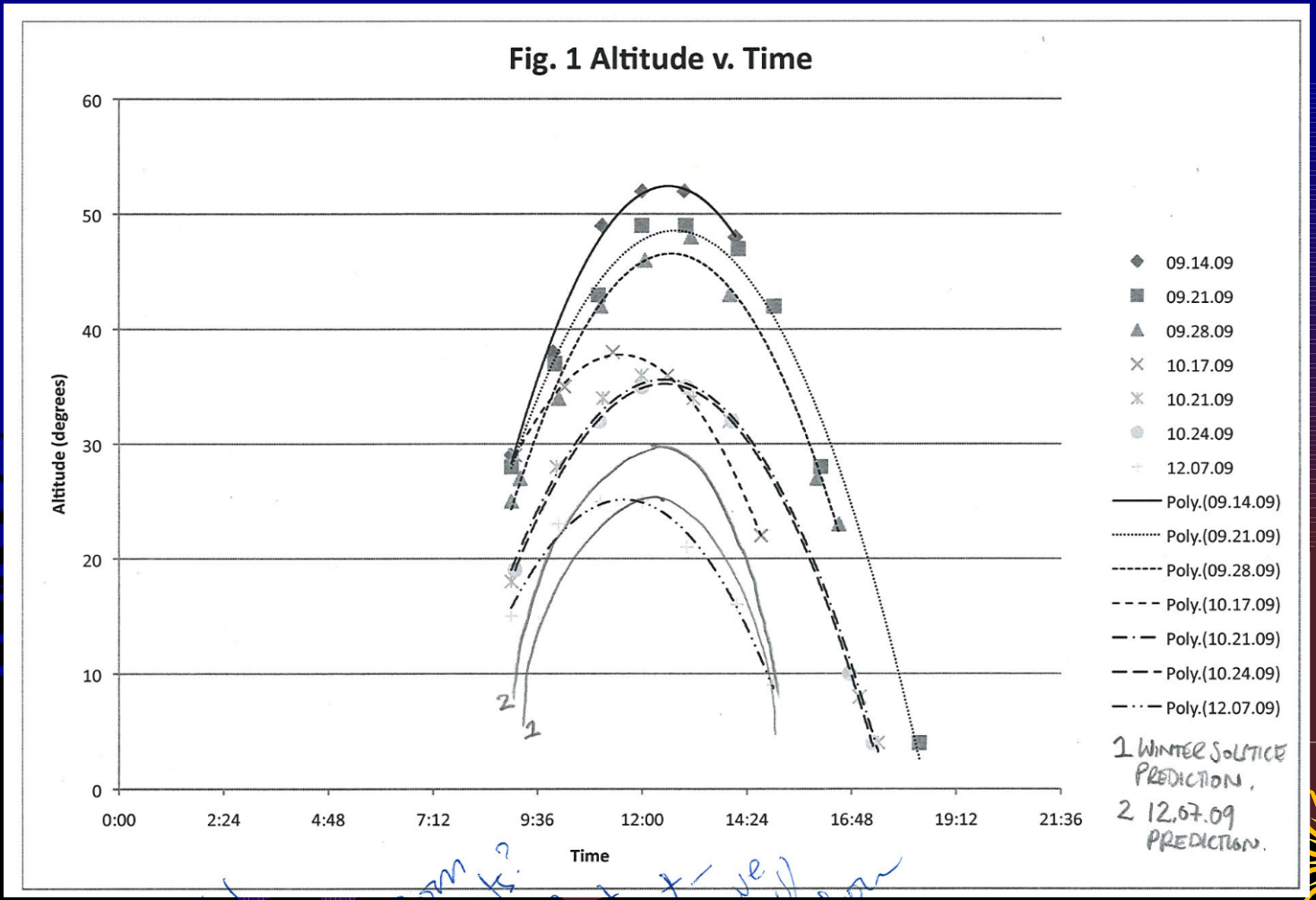
- Examples of student work



Tracking the Sun



Tracking the Sun



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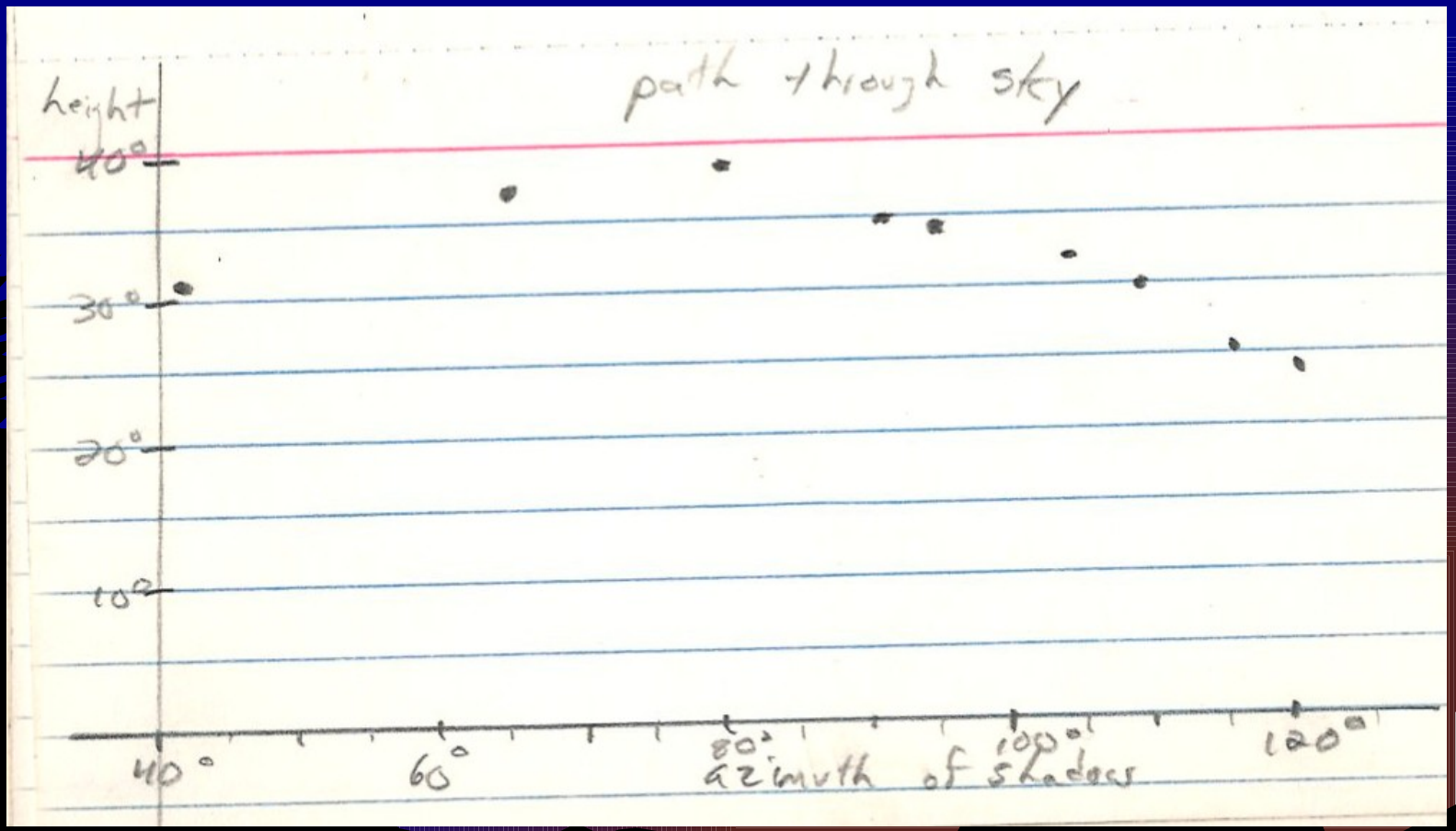
Azimuths



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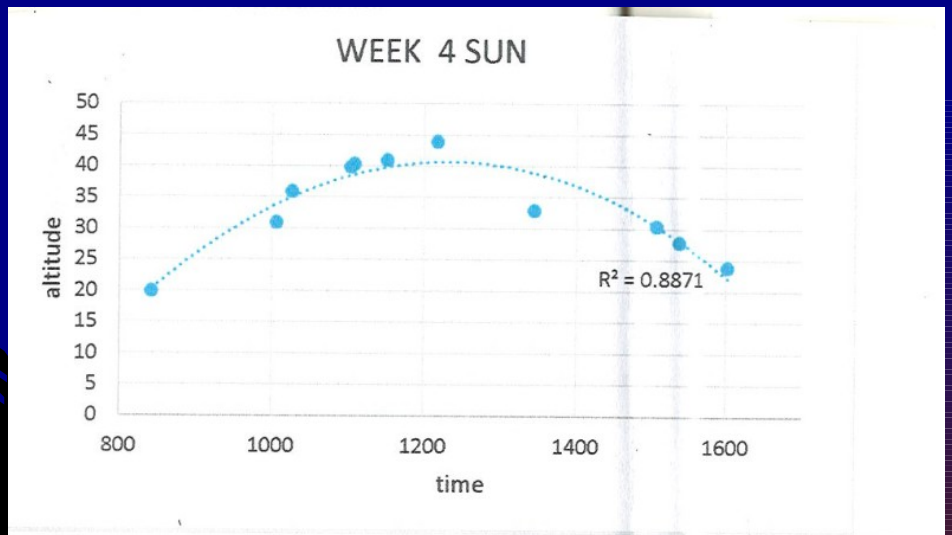
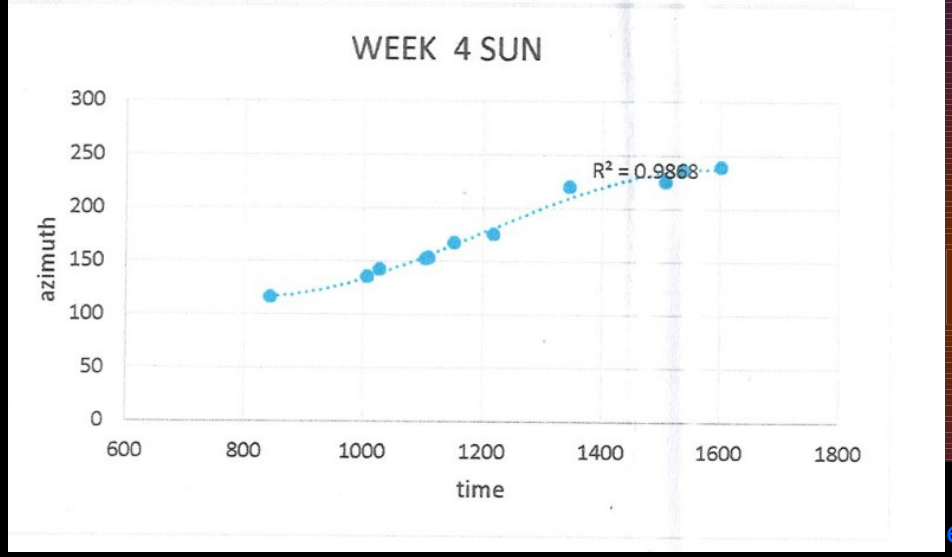
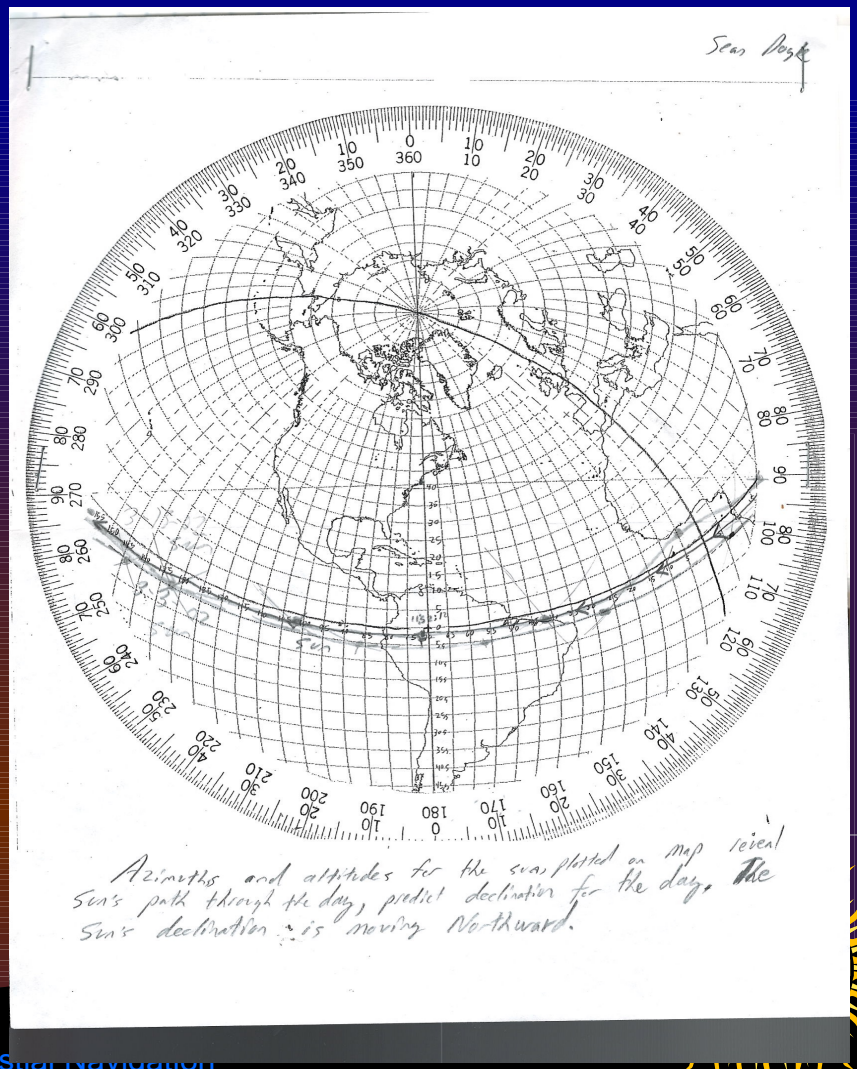
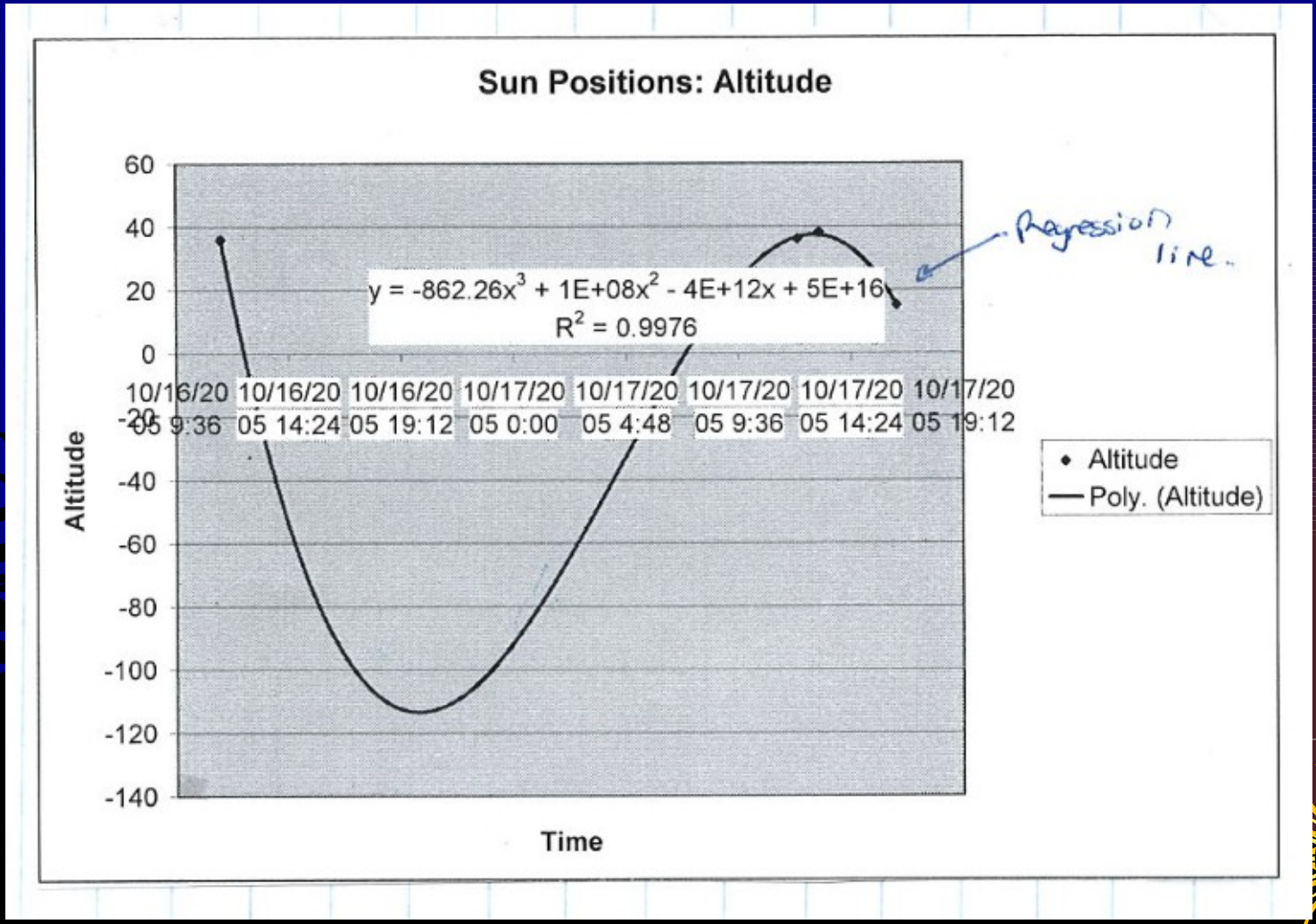
Azimuths


WEEK 4 SUN
altitude
time
R² = 0.8871
50
45
40
35
30
25
20
15
10
5
0
800
1000
1200
1400
1600

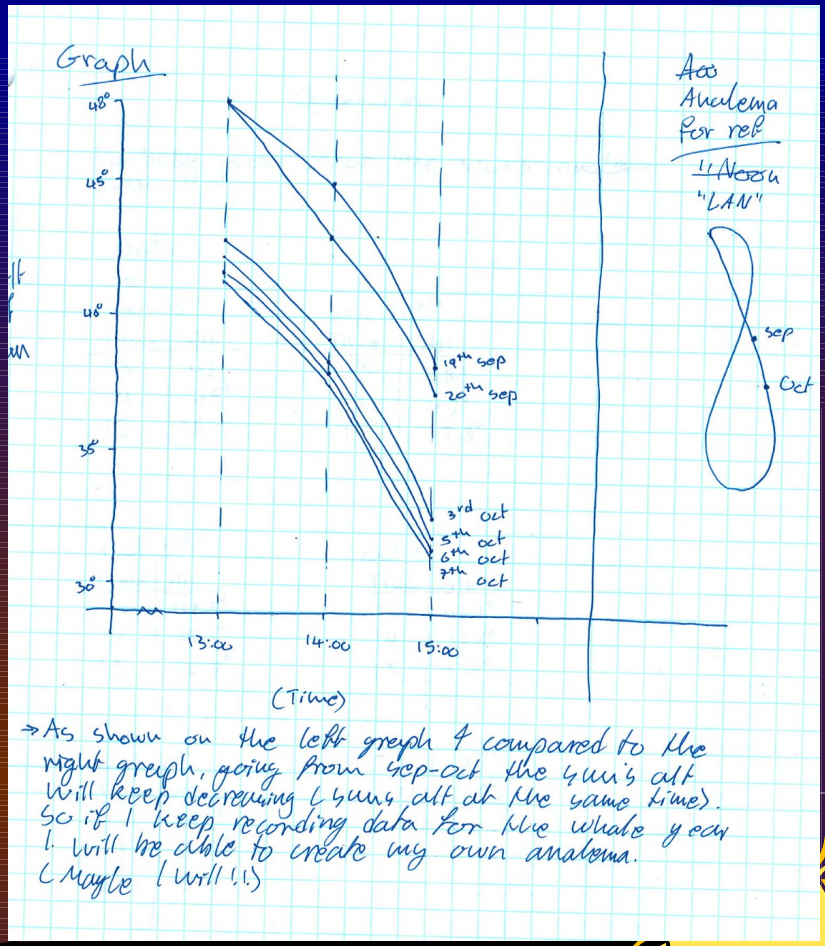

WEEK 4 SUN
azimuth
time
R² = 0.9868
300
250
200
150
100
50
0
600
800
1000
1200
1400
1600
1800


Azimuths and altitudes for the sun, plotted on map reveal Sun's path through the day, predict declination for the days. The Sun's declination is moving Northward.

Curve Fitting in Excel



Sense Making: Analemma



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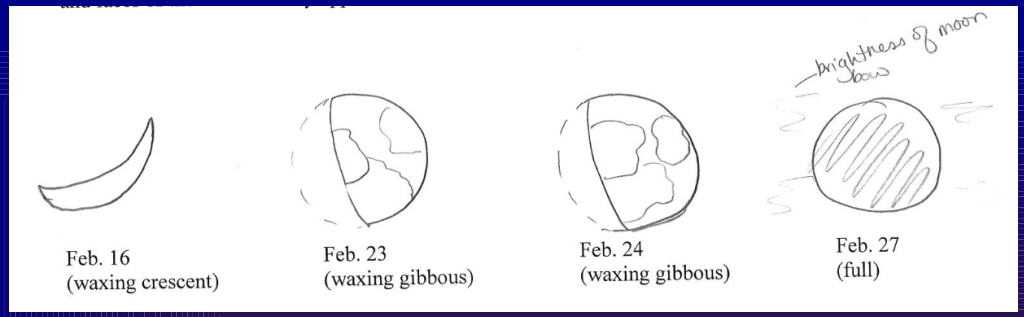
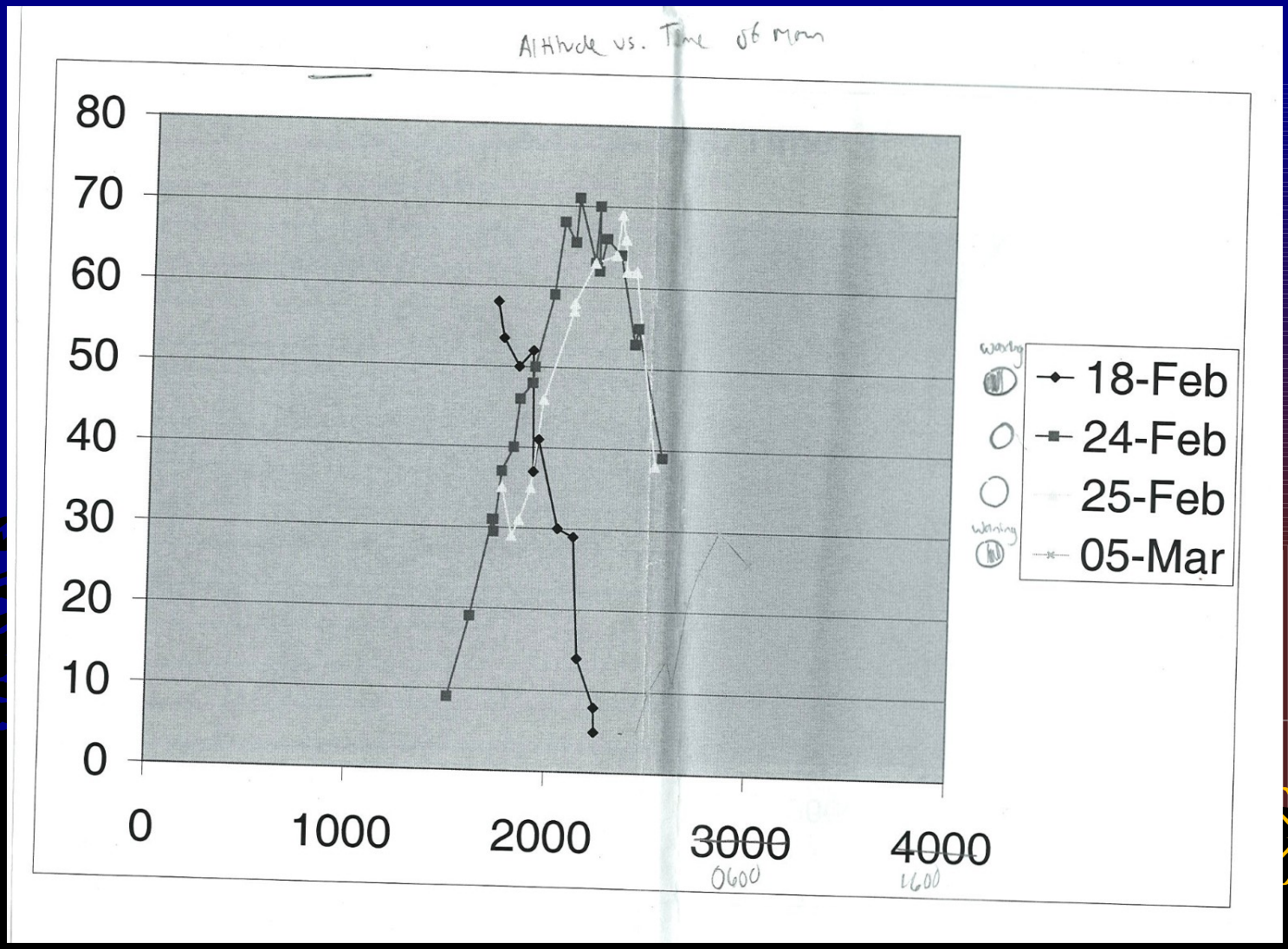
Motion of the Moon

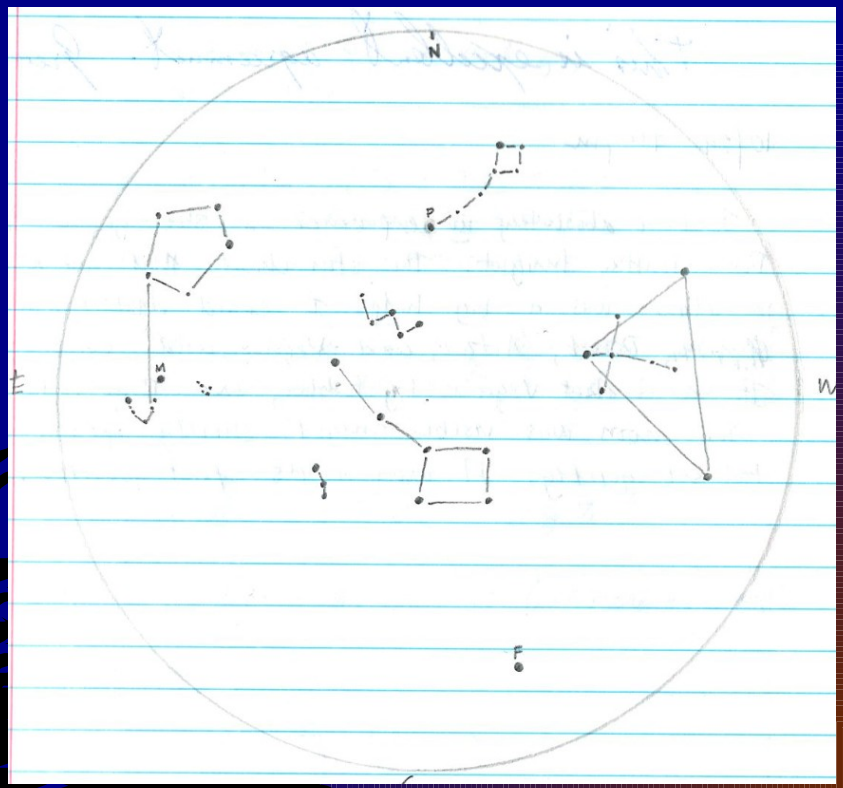


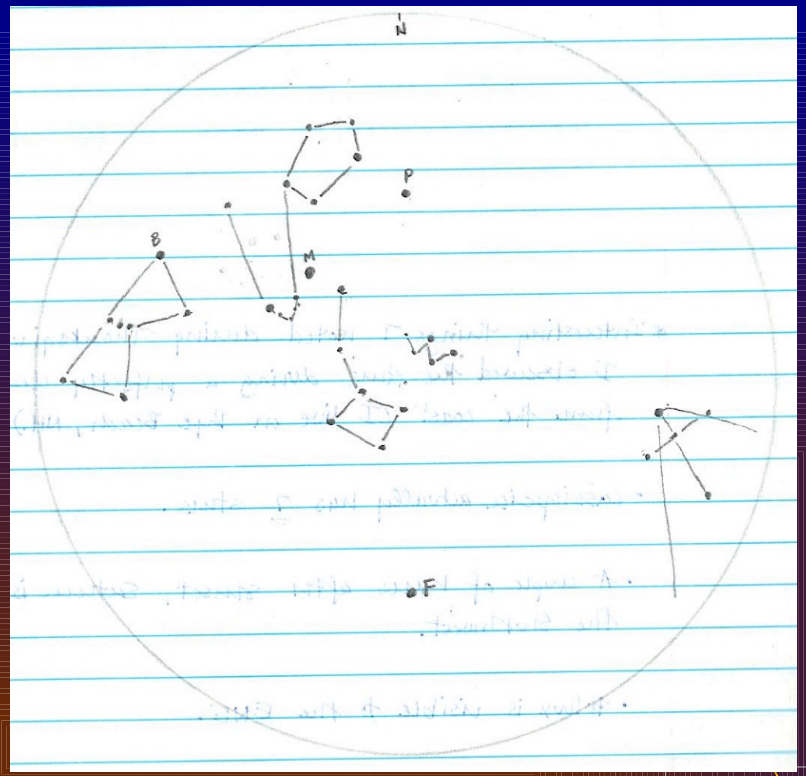
- Astronomy 2, Celestial Navigation

Motion of the Moon



Drawing the Sky from Cambridge





7:00 PM

11:45 PM

- Astronomy 2, Celestial Navigation

Motion of Polaris

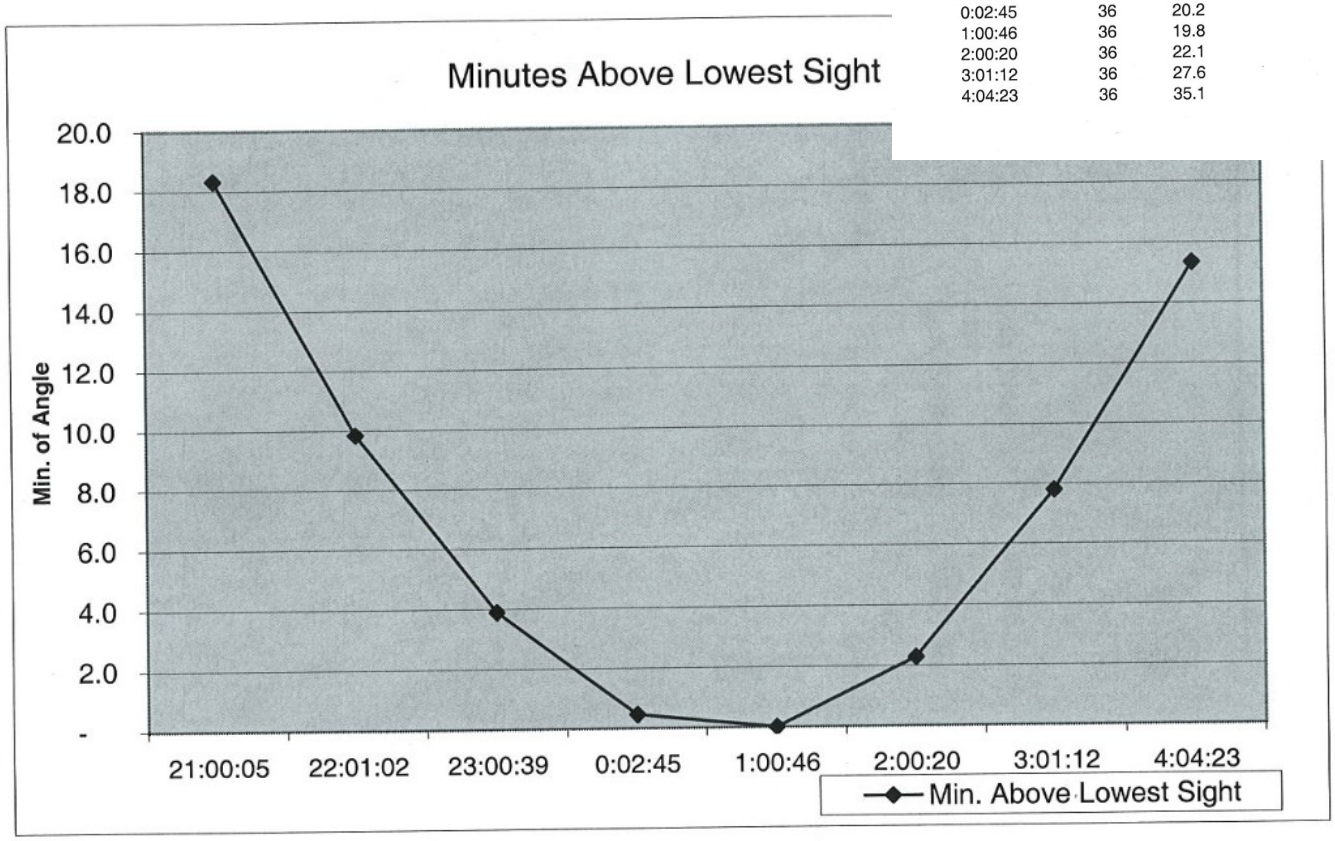
Polaris Sights: West Goshen CT
DR Lat: 41 deg 46 min N
DR Long: 73 deg 15 min W

Raw Data

Time	Degrees	Minutes
21:00:05	36	38.1
22:01:02	36	29.6
23:00:39	36	23.7
0:02:45	36	20.2
1:00:46	36	19.8
2:00:20	36	22.1
3:01:12	36	27.6
4:04:23	36	35.1

Normalized

Time	Min. Above Lowest Sight
21:00:05	18.3
22:01:02	9.8
23:00:39	3.9
0:02:45	0.5
1:00:46	-
2:00:20	2.3
3:01:12	7.8
4:04:23	15.3



Course Schedule

Day	Topic	Noon	Evening I	Evening II
1	Triangles	Angle estimation	Plane table Map	Quadrant making
2	Bearings	Bearings by Pelorus	Darkfish Cruise	Journal Discussion 1
3	Charts	Magnetic Compass	Chart Projections Lab	DR w/ Compass and Watch
4	DR	DR w/ Compass and Watch	Ruchbah Cruise	Planetarium: Constellations
5	Noon Curve	Sextant and Noon Curve I	Ruchbach 2:	Journal Discussion 2
6		CRUISE		
7	Instruments	Sun Dance Lab	Introduction to NA	Planetarium II: Sun
8	NA	Map Collection	Time and NA	
9	Noon Curve	Noon Curve II	MIDTERM EXAM	
10	Sky Models	Moon Phases/Dance	Celestial Sphere Lab	Journal Discussion 3
11	Reductions	GP Sight reductions	Polaris - Vol. 1	Planetarium III, N Triangle
12	Reductions	Star Sights - Vol. 2 and sun	Stars and Planets	Stars and Planets
13	Running Fixes	Instrument Collection	Celestial Running Fixes	Celestial Running Fixes
14	Poster Session	Poster Session	Evaluation of Posters	Educational Discussions
15	Exam		FINAL EXAM	

So what do students think…

- How Astro2 compare to other Harvard courses?
- Do students like or hate the experiential nature?
- What do they say to other students?

Course Experiences

- The learning camaraderie that develops in the group setting is unlike any classroom dynamic I have ever experienced before.
- Truly a course that succeeds in affecting the way I think about my own notions and how I learn things. I wish there were more courses like this.
- Experiential learning at its finest. Loved how we were never told the answers to what was happening in the sky until we had developed and tested our own theories.
- It was fun and (gasp) applicable.
- Incredibly interesting subject matter.
- Helps me understand the world.
- This course provides an incredible, wonderful opportunity to delve into a field of study without much experience and learn important and meaningful theoretical principles as well as experience practical and hands-on approaches to an absolutely fascinating and unconventional study. The teaching styles were masterful and effective.
- Great hands-on approach. Absolutely unique.
- At last, a course where I learn a real skill.
- Very exciting class. You learn a ton…
- Incredibly interesting and something I will remember long after I graduate.

What would you like to tell future students about this class?

- This really is an incredible class, and one you won't find elsewhere. you also get to work a lot with people and you form friendships because classes are pretty much exclusively labs and working together rather than lectures.
- If you're looking for a class to coast and get an A, don't take this class. The work isn't necessarily difficult, but it takes a good deal of time and effort to master the material. If you're looking to learn a lot about navigating without GPS, the course is invaluable. My roommates remarked that this was definitely the class I talked about the most. It was a huge departure from the traditional lecture-hall type class and so engaging because everything was hands-on!
- This is a great, great course. I learned so much and it was a group effort and experience. It wasn't hard but requires a lot of work and concentration during labs and preparing for exams.
- It is a really fun and engaging class, and you will learn so much that is applicable to understanding many aspects of the world around you and how they work!
- This class is AMAZING!!! You learn how to tell where you are anywhere on Earth.. cool right? Plus, it's unlike any class you'll take at Harvard. You get to know the other kids in the class, professor and TFs really well because you work together. Class is not lecture at all, it's really interactive and fun to go to.

Astro 2 – Overall

- Hands down the best class I've ever taken. The ratio of out of class busy-work to things learned approaches zero.
- This is one of the best courses I have taken at Harvard. There is quite a bit of work, but it is absolutely worth the effort.
- This really is an incredible class, and one you won't find elsewhere. You really do learn how to navigate, as well as how the sun, moon, stars, and planets move through the sky at night.
- … I feel it is one of the few classes I will remember for the rest of my life.
- 100% strengths, no weaknesses. Take this course!! Do yourself a favor.
- I feel ashamed of all the other courses I have given a "5." They pale in comparison.
- Best taught course I've taken at Harvard.
- Best class I have ever taken.
- … This course was fantastic! Best course I've ever taken in school, college, or high school.

Acknowledgements

- Drawn from Observational Journals: An Aid to Sky Watching Philip M. Sadler, Haller, Garfield, Journal of College Science Teaching, 29(4), Feb 2000, pp. 245-254.
- I wish to thank my navigational mentors Charles A. Whitney and the late Frances W. Wright. The alumni of Astronomy 2 have supported the continued evolution of the course by building an endowment. Teaching fellows Marc Schwartz, Brett Humphreys, Glen Schleyer, Andy Kuan, Deigo Mardones, Christopher Knight, and Jamie Knox have helped refine the journal component of the course. Colleagues Harold Coyle and Owen Gingerich provided valuable feedback on journals. I thank Judith Peritz and Joelle Pelletier for editing and library research.
- Student work, especially the drawings of Kristin Buchholz