Stars over Ancient Babylon

Produced for the

Cosmology and Cultures Project

of the

OBU Planetarium

by

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Credits

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Special thanks to...	Mike Keas, Hannah Magruder, Rachel Magruder, Susanna Magruder, Candace Magruder
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1. Contents

2. Introduction

A. Summary

Length	47 minutes
Presentation mode	May be presented in either of two ways: 1. Self-contained DVD presented on a TV or data projector, or 2. Planetarium show using star projector and video projector, with optional whole-dome effects
Audience	General undergraduate
Classes	History of Science; Astronomy; History of Mathematics; Ancient History
Periods	Ancient
Observational emphases	Annual motion of the Sun, Ecliptic, Zodiac Heliacal risings of bright stars near the ecliptic Synodic cycle of Venus Direct and retrograde planetary motion
Constellations	Leo, Taurus, Virgo, Scorpius, Libra, Capricorn, Cancer, Gemini
Astronomical Terms	Ecliptic, Zodiac, heliacal rising Sexagessimal system Retrograde motion, Stationary points, opposition Lunar eclipse Star calendar, luni-solar calendar Ephemerides Zig-zag functions Astronomy, astrology
Other Topics	Historiography
Dome special effects	None required. Optional: Precession grid, fog. Note: This show is designed to be paused between major sections for live demonstrations. If it will be shown without pauses, use swirling cloud or fog SFX projectors during transitions, and project a background starfield whenever the video is dark.

B. Synopsis

1. Prologue; "Welcome to Babylon"

2. Sumerian period, 3200 - 2350 BC
   A. Culture and cuneiform writing
   B. Ecliptic and Constellation names

3. Old Babylonian period, 1800-1600 BC
   A. Planetary cycles: Venus tablet of Ammizaduqa
   B. Babylonian mathematics: place value, sexagessimal system
   C. Pythagorean triplets: Plimpton 322 tablet
   D. Square root of 2: Yale University tablet

4. Intervening dynasties, 1600 - 700 BC
   A. Astronomy and Astrology: Tablets of Enuma Anu Enlil
   B. Heliacal risings of bright stars
   C. Direct motion of planets
   D. Retrograde motion of planets: First Station, Second Station, Opposition
   E. Lunar eclipse records

5. Assyrian period, 700-609 BC
   A. Library of Ashurbanipal: Mul Apin tablets; star calendar, luni-solar calendar
   B. Goal-year texts
   C. Predictions of lunar eclipses

6. New Babylonian (Chaldean) period, 626 - 539 BC
   A. Astronomical Diaries: observations of the Moon, planets, heliacal risings

7. Persian empire, 559 - 331 BC

8. Seleukid (Greek) period, 335 - 141 BC
   A. Ephemerides tablets
   B. Procedure texts
      i. Mathematical control, not merely empirical extrapolation
      ii. Zig-zag functions

9. Epilogue: The Historical Significance of Babylonian Mathematical Astronomy

C. Instructor Notes

The ideal setting for this show is a two-hour planetarium laboratory exercise for undergraduate students. After playing a given section of the show (listed in the Synopsis), the instructor will pause the DVD playback to provide a live demonstration, using the star projector, of the basic celestial phenomena that were introduced in that part of the show. After the live demonstration with the star projector, the instructor will restart the DVD and repeat the process with subsequent sections. On the other hand, the show may also be presented in the planetarium or in a classroom as a 47-minute self-contained DVD, without the star projector demonstrations. In either case, the show is designed to introduce students to the basic appearances of the heavens which early mathematical astronomers sought to explain (see "observational emphases" and "astronomical terms" on the Summary page, and the sequence of show sections and topics on the Synopsis page).

For introductory courses in observational astronomy, this show provides an overview of some very basic sky phenomena. For this reason it is well suited to contribute to the first unit of the semester. The show is accessible, requiring no prior instruction in ancient Near Eastern mathematical techniques. Nor does the presentation delve into detail about those mathematical techniques. Rather, the show emphasizes the basic sky phenomena. Once celestial appearances are introduced, the show then states that in many cases the Babylonians could predict them, leaving the careful explanation of the mathematical techniques to the discretion of the instructor in the classroom. The show is meant rather to inculcate a basic awareness of the celestial phenomena and an appreciation of the impressiveness of the ancient Near Eastern accomplishments. Of course, the show may awaken student interest in the mathematical techniques; for this purpose several introductory tutorials are listed under "Further Reading."

For history of science survey courses, this show also fits into the beginning of the semester. There is little time to establish much of a cultural context; the show provides just a bare bones outline of Mesopotamian chronology. There is far less historical (and archaeological) context than one might wish. However, this show is designed only to convey an introductory historical overview in order to counter several widespread misunderstandings, particularly a persistent ignorance of the Mesopotamian influence on later Greek astronomy. The significance of this Mesopotamian influence is best clarified within a chronological framework, and that is why this show follows a temporal rather than topical organization. Babylonian astronomers were essential sources for Greek astronomy. Without the Babylonian contributions, later Greek astronomy such as we find in Hipparchos (150 BC) and Ptolemy (150 AD) would have been inconceivable.

The narrative strategy of the show features an imaginary conversation with a scribe named Kidinnu who lived in the Seleukid period. Kidinnu speaks to the audience, who are presumed to be Greek travelers in Babylon. The aim is to spread acknowledgment of the fact that Greek soldiers, musicians, businessmen and others did travel to Mesopotamia, even before Alexander the Great. Kidinnu himself is not imaginary but was a real Babylonian astronomer. He is sometimes given credit for inventing the more advanced *System B* method of predicting planetary positions, stationary points, retrograde motion, etc. The question of who invented *System B* is not explicitly addressed in the show, because the attribution on the tablets is inconclusive, and the show does not enter into that level of technical detail. And more importantly, I did not want to give the impression that everything Kidinnu says in the show is historically accurate. My initial plan was to have Kidinnu say nothing but quote the primary texts *verbatim*, but at the last I gave up that idea in favor of emphasizing the reality, whether Kidinnu was involved or not, of the cultural interchange with the Greeks.

Because later Greek astronomers after Hipparchos relied upon Babylonian methods and used Babylonian parameters in their models, the big unsolved question is how the Greeks learned Babylonian astronomy. There is no evidence that it was Kidinnu who "spilled the beans" to the Greeks, as the show suggests. This idea is purely imaginative dramatic license. Indeed, the Babylonian scribes were under oaths of secrecy, so one wonders why they would have been willing to share their mathematical arts with foreigners (I make a suggestion about this motive in the show, however, but it is purely speculative). Gerald Toomer suggests that Hipparchos must have traveled to Babylon himself; Alexander Jones argues that the presence and widespread use of Babylonian arithmetical techniques in the Roman period shows that sufficient numbers of Babylonian astronomers must have emigrated to the Hellenistic and Roman worlds. In any case, we do not know, but Jones' work is very interesting in showing that Greek astronomers in the Roman period did continue to use the zig-zag arithmetical progressions of System A and System B to predict planetary positions, even when they had models using spherical trigonometry. These older arithmetical methods were often easier and faster to use than the quantitatively equivalent spherical models (which the Greeks used in their published works). Historians of science have only recently begun to appreciate the pervasive extent of ancient Near Eastern mathematical astronomy and its importance for the development of Greek science.

3. Before the Show

In addition to the discussion questions, vocabulary and pre-test offered below, the online sources described in "Further Reading" provide excellent resources for exploratory discovery before viewing the show.

A. Pre-Show Discussion Questions

1. What most interests you about the historical context of the ancient Near East, including ancient Mesopotamia, Babylonia, Persia or Assyria?
2. What comes to mind when you think of "Babylon"? Have you studied Mesopotamian culture or civilization?
3. Do you know anything about ancient Near Eastern history, mythology or religion?
4. What are some of the best-known artifacts or discoveries from the ancient Near East? The Code of Hammurabi? Ziggurats?
5. Can you read any cuneiform signs? Do you know much about the early history of writing?
6. Have you read the Epic of Gilgamesh? What did you think of it? Have you seen the Star Trek Next Generation episode "Darmok" where Captain Jean-Luc Picard retells the story of Gilgamesh?
7. Do you know of any movies that relate to ancient Babylonian science, history or mythology?
8. Can you recognize very many constellations? Would you like to know more about skywatching and skylore? Do you enjoy learning the literature and stories of the constellations? What are your favorite constellations or skylore stories? Do you know the stories of any of the following constellations? Orion, Andromeda, Cassiopeia, Pegasus, Perseus, Argo navis?
9. Babylonian culture was very religious. How do you think this might have affected their science?

B. Vocabulary and Definitions

These are some of the terms and definitions used to describe basic celestial phenomena explained in "Stars over Ancient Babylon."

1. Diurnal or Daily motion
2. Ecliptic: the annual path of the Sun as it moves around the sky against the background of fixed stars.
3. Zodiac constellation: a constellation that contains the ecliptic.
4. Angular degrees: Apparent distances between objects in the sky are measured by angular degrees, just like the degrees marked off on a protractor.
    - Example: If one body is rising on the eastern horizon, and the other is directly overhead, what is the distance between them in angular degrees? Right, it is 90 degrees. (90° is also called "quadrature.")
    - Second example: If the Moon is rising while the Sun is setting on the opposite horizon, their distance is 180 degrees. (180° is also called "opposition.")
5. Elongation: How far a planet lies from the Sun, measured in angular degrees. For example, Venus never moves farther than 46 degrees from the Sun, so its elongation is said to be "bounded."
6. Direct motion: The ordinary eastward motion of the Sun, Moon and planets along the ecliptic against the background of fixed stars.
    - For example, the Sun moves about 1 degree a day roughly eastward along the ecliptic, completing an entire circle around the sky in about a year.
    - The Moon moves an average of about 10 degrees a day roughly eastward along the ecliptic, completing an entire circle around the sky in about a month.
    - The motion of any planet in a roughly eastward direction along the ecliptic is called its direct motion.
7. Retrograde motion: "Retrograde" means to reverse direction. For a planet, retrograde motion occurs in a roughly westward direction, reversing the usual direct motion.
8. Heliacal rising: The rising of a star or planet just before sunrise. (From "helios," = Sun.) A heliacal rising occurs after the star or planet has been invisible for a while in the daytime sky, and marks the reappearance of the star or planet as a body visible in the pre-dawn sky (thereafter it appears as a morning star).
9. Ephemerides: Calculated tables predicting the times and locations of planets during significant planetary events (for example, contained in every issue of *Sky & Telescope*).
10. Astrology: Divination, or the attempt to predict the future, on the basis of celestial events, particularly planetary motions (e.g., daily horoscopes). Astrology served as the chief motivation for the development of mathematical astronomy up through early modern times, but has no physical basis in modern astronomy.

C. Pre-Test

You may or may not know the answers to many of these questions before viewing "Stars over Ancient Babylon." It does not matter if you do not know very many answers now. Read over them, and take your best guess, so that you will be better able to remember the answers as they are explained in the show.

1. T or F? Diurnal motion is motion that occurs roughly weekly.
2. T or F? Roughly once each day, the Sun, Moon, planets and stars appear to rise in the west and set in the east.
3. T or F? Diurnal motion is roughly westward.
4. T or F? Direct motion of a planet in the zodiac is roughly westward.
5. T or F? Retrograde motion of a planet in the zodiac is roughly westward.
6. T or F? Zodiac constellations include the path of the Sun, or the ecliptic.
7. T or F? A planet or star that rises at the same time the Sun sets is at opposition.
8. T or F? A planet or star that rises just before the Sun rises is at its heliacal rising.
9. T or F? Babylonian mathematics was more advanced than Egyptian mathematics.
10. T or F? Babylonian numbers, like Roman numerals, did not have a place value system.
11. T or F? Babylonian mathematics was sexagessimal, or based on the number 60.
12. T or F? Babylonian mathematicians could solve problems involving fractions.
13. T or F? Depending on where it is found in a number, a single vertical wedge-mark can equal 1, or it can also equal 60.
14. T or F? A single horizontal wedge mark equals 10.
15. T or F? Babylonian mathematicians could solve problems that we would solve using quadratic equations.
16. T or F? The band of constellations that contain the motions of the planets is called the zodiac.
17. T or F? The Babylonian zodiac contained 30 signs, each 12 degrees long.
18. T or F? Because Babylonian astronomers used sophisticated mathematics, they shunned astrological interpretations.
19. T or F? Later Babylonian astronomers could accurately predict important planetary phenomena, including lunar eclipses.
20. T or F? Unlike the early Greek astronomers, whose models were strictly qualitative, the Babylonian scribes attempted and achieved the ideal of quantitative prediction.
21. T or F? The Sumerians invented alphabetic writing.
22. T or F? Before 1000 BC, cuneiform texts were simply accounting and business records; literary and scientific texts date only from after contact with Greek civilization ca. 400 BC.
23. T or F? The Bull, the lion, the goat-fish and the scorpion are examples of constellations of early Mesopotamian origin.
24. T or F? When Venus is west of the Sun, it appears as a morning star.
25. T or F? Skywatchers of the Old Babylonian period discovered the 8 year cycle of Venus.
26. T or F? In the Babylonian number system, the number 60 is written with a sign for "1" in

the 60's place.

27. T or F? In the Babylonian number system, the number 61 is written with a sign for "1" followed by a space and another "1."
28. T or F? Babylonian mathematics was a place-value system.
29. T or F? Babylonian mathematicians could generate numbers to satisfy what we call the Pythagorean theorem.
30. T or F? Babylonian mathematicians accurately determined the square root of 2.
31. T or F? Astrological beliefs were the motivation for much of the development of ancient mathematical astronomy.
32. T or F? The tablets of Enuma Anu Enlil provided guidelines for interpreting astrological omens.
33. T or F? The path of the Moon is called the ecliptic.
34. T or F? Against the background of the fixed stars, the Sun, Moon and planets all move slowly in a roughly eastward direction through the zodiac.
35. T or F? After its heliacal rising, a star moves into the daytime sky.
36. T or F? The Sun moves about 10 degrees each day against the background of fixed stars.
37. T or F? The Moon moves about 1 degree each day against the background of fixed stars.
38. T or F? Retrograde motion occurs between the first and second stationary points.
39. T or F? Retrograde motion occurs when a planet reverses its usual direction, and moves roughly westward against the background of fixed stars.
40. T or F? Planets move with retrograde motion when they are visible all night long.
41. T or F? A lunar eclipse occurs when the Moon's shadow falls upon one side of the Earth.
42. T or F? Babylonian records of lunar eclipses go back to the 8th century BC.
43. T or F? Goal-year tablets contain a star calendar based on the risings and settings of important constellations.
44. T or F? Mul Apin tablets match the current motions of any planet with the pattern it showed during a similar year in the past.
45. T or F? Astronomical diaries recorded Babylonian observations of the Moon, planets, heliacal risings of stars and other celestial phenomena for at least 600 years.
46. T or F? Alexander the Great died in Alexandria, Egypt, not far from the great Library he founded.
47. T or F? Alexander's four generals divided his conquests. Ptolemy controlled Egypt; and Mesopotamia was given to Seleukis.
48. T or F? Seleukid-era cuneiform texts accurately predicted complex planetary events, including retrograde motion, on the basis of mathematical calculations rather than just extrapolating from past observations of goal year motions.
49. T or F? When we tell time by minutes and hours, or measure angles in degrees, we are still today heirs of Babylonian sexagessimal mathematics.
50. T or F? Unlike the early Greek astronomers, whose models were strictly qualitative, the Babylonian scribes attempted and achieved the ideal of quantitative prediction.

4. Production Script

A. Production Notes

1. The DVD is designed for dual use, either in a planetarium or on a TV in the classroom (see the first paragraph in the Instructor Notes page). Many of the images projected by a planetarium's video projector may be too bright unless the video projector's intensity is reduced. Experiment by trial and error to find the level of video intensity that works best in your theater or classroom.

2. The presentation of this show in a planetarium theater requires a video projector. If you wish to supplement the video projection with slides, images listed (without bullets) in the Audio-Visuals column of the script may be found on an accompanying CD.
    - These images all appear in the video, but for your own theater choreography one may wish, in some cases, to dim the video projector and display them in different fields of view using slide projectors. If so, the Audio-Visuals column serves as an image list, making it easy to identify the images you want and convert them to slides. (Alternatively, an economical way to convert them to film is to pause the DVD at the desired point and, using an extremely long shutter speed, photograph the image displayed on a high resolution monitor.)
    - You may also use these images for publicity and for your own educational purposes (see the "Distribution" section at the end of this packet).

3. Footnotes in the script are of three types:
    - numbered citations or pedagogical notes for the Narration column,[1]
    - alphabetical notes with production tips for the Audio-Visuals column,[a] and
    - image credit information for images in the Audio-Visuals column,[*] as needed.

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1. This is an example of a narration note.
a. This is an example of a production note.
*- This is an example of an image attribution credit.

B. Theater Preparation

1. The introductory paragraph of the Instructor Notes page describes an ideal mode of presentation.
2. Move the star projector to latitude 33° N (longitude 44°E), to project the stars over Babylon. Milky Way on. Clouds on.
3. Set precession to 600 B.C.
4. Prepare to demonstrate the motions of Venus to the west and east of the Sun; the heliacal rising of Regulus; direct and retrograde motion of Mars.
5. Optional whole-dome effects: Besides a momentary use of the precession grid, the only other whole-dome effects suggested are swirling fog or clouds during transitions between main sections, and a sunset and sunrise special effects projector to begin and end the show.

C. Script

Mins	Secs	Audio-Visuals	Narration
0	18	show/intro/cc	The Cosmology and Cultures Project of the OBU Planetarium
		show/intro/acls	with a grant from the American Council of Learned Societies
			presents
		show/intro/title	Stars over Ancient Babylon
Prologue			

1	14	Archaeologist: Accordance/map[2] •Sunset on Babylon.	The science of mathematical astronomy began four thousand years ago in ancient Mesopotamia, the land "between the rivers."[3] The Tigris river winds southward from Ninevah, capital of the ancient Assyrian empire. To the south lie the lands of the ancient Sumerian, Akkadian, and Babylonian empires. The Euphrates River rolls past Babylon and onward to Ur. It joins with the Tigris river, then empties into the Persian Gulf. To the east lies the homeland of ancient Persia. In these ancient civilizations, pursuing the practice of their priestly arts, the Scribes of Enuma Anu Enlil created mathematical astronomy.
		Kidinnu: RachelMagruder/ziggurat •Stars appear	Come join with me as a watcher of the night. Above the splendor of Babylon, as we look out from these heights, our vision rises to things beyond mortal human life. We fly to the stars, the home of the gods. With our secret mathematical arts, guided by the sacred writings of long ago scribes, we shall interpret the signs of the motions of the planets, for the good of the king and empire.
	Title slide, musical transition		
Welcome to Babylon			
2	55	Archaeologist: Enuma Anu Enlil tablet (British Museum)	The Scribes of Enuma Anu Enlil were not merely astronomers and scholars; they offered counsel on affairs of state as powerful advisors to kings and emperors. Their specialty was divination, the art of interpreting omens, dreams, and the motions of the stars.

2. This map was made using the Atlas module of Accordance Bible software; *http://www.accordancebible.com/*.
3. Gk. "mesos" = middle; "potamoi" = rivers; Mesopotamia = "between the rivers."

		Archaeologist: RachelMagruder/BabylonGardens	Seneca reported that Mesopotamian scribes visited Athens to offer sacrifices after Plato's death.[4] In the century of Plato, a millenium after the birth of Mesopotamian astronomy, the mathematical techniques of Mesopotamians were far more advanced than those of their Greek contemporaries. Without the Scribes of Mesopotamia, the works of Greek astronomers like Hipparchos and Ptolemy would have been inconceivable.
		Archaeologist: RachelMagruder/BabylonGardens	In the first century BC, Strabo told of mathematical astronomers residing in Uruk, Ninevah, and Babylon. In Babylon, the Temple of Esagila, mentioned by Herodotos in the 5th century BC, was still a center of astronomical practice in the 1st century AD. According to Strabo, Kidenas was the leader of astronomers in Babylon. Confirming this report, several astronomical tablets from Babylon bear the name Kidinnu.[5] One can only wonder, how did the ancient Greeks hear of Mesopotamian astronomy? What might a Greek traveler have learned if he had talked with Kidinnu in ancient Babylon?
		Kidinnu: RachelMagruder/Ziggurat	Welcome. I am Kidinnu, leader of the Scribes of Enuma Anu Enlil, watchers of the night. We are sworn to secrecy, and serve our king alone. Yet I have heard tales of you Greeks, and I would wish to hear more. Are you a musician or a soldier? Either way, I would have you send a message to your countrymen, but I much prefer music to swordplay. Music and astronomy share certain... harmonies. Come with me tonight: play your harp as the constellations rise, and I will show you some of the secrets of our arts. Listen carefully, remember what we do, and tell these things to your best astronomers. Perhaps someday one of them will return to Babylon to learn from us.

4. Seneca, Epistle 58.
5. See the introductory chapters of Otto Neugebauer, *Astronomical Cuneiform Texts* (1983).

		Kidinnu: RachelMagruder/BabylonGardens RollerOU-IshtarGate	Look upon Babylon, our great city. I saw you cross the Euphrates on the stone bridge. From the northwest you beheld the terraced gardens built by Nebuchadrezzar, a former king, for his wife, to remind her of her Median homeland. You proceeded along the Procession way, a paved road lined with enamelled bricks showing lions, dragons and bulls.[6] When you came before the majestic gates of Ishtar, you saw chariots pass abreast atop the double walls. When you entered the city you found your way to the Temple of Esagila, the center of Babylon, the center of the universe and the shrine of Marduk our god. Here we re-enact the creation at the birth of each new year.
		Kidinnu: RachelMagruder/Ziggurat	How, you ask, have we come to our knowledge of the stars? What is the story of our discoveries? Climb seven stories with me to the top of the ziggurat, this sacred mountain, our stairway to heaven. I will show you some of the ancient writings, and tell you stories of the night.
Sumerian culture			
6	38	Archaeologist: show/revs/1-ur	Mesopotamian civilization is a long succession of the revolutions of empires, a story that begins with ancient Sumer, Akkad, and Ur.
		Archaeologist: RollerOU/Ur-Ram (British Museum)	Charles Leonard Woolley excavated the royal tombs of Ur. A “Ram in the Thicket,” as he called it, is made of gold foil and blue lapis lazuli. This and other treasures of the tombs of Ur date to 2,600 BC. They now reside in the British Musuem.
		RollerOU/Ur-Standard-a RollerOU/Ur-Standard-a-Harp (British Museum)	Woolley called this mosaic of shell, lapus lazuli, and red sandstone the "Royal standard of Ur." This side shows a celebration of victory in warfare, a banquet served with the accompaniment of a singer and a harpist.
		RollerOU/Ur-Harp (British Museum)	The harpist in the mosaic plays an instrument like this, one of four found in the largest royal tomb.

6. Lions represented Ishtar, dragons Marduk, and bulls Bel.

		RollerOU/Ur-Head (British Museum)	Golden ear-rings complete this headdress adorned with ribbons and pendants of gold.
		Archaeologist:	The archaeologist prizes one treasure above all others: inscriptions are far greater than jewels and gold. When Woolley proclaimed that "History begins in ancient Sumer," he announced the discovery of the oldest known written records.
		pictograms/	From pre-history to the present day, people everywhere communicate with pictograms. A person who is illiterate can understand the meaning of a pictogram. Pictograms are signs, but are not phonetic; one cannot use pictograms for dictation, to write down whatever another person says.
		show/syllabary	In contrast, written history began with the syllabary. More complex than an alphabet, a syllabary is a collection of about 300 symbols, where each symbol represents the sound of a particular syllable. The signs of a syllabary are phonetic, so that for the first time, when one person spoke, another could write it down. Syllabaries emerged in Sumer in the fourth millenium BC, and in Egypt not long afterward. Because a syllabary must represent several hundred sounds, it took time to learn. Reading and writing were secret arts, restricted to educated scribes.
		Cuneiform tablets show/signs	Sumerian scribes wrote on small clay tablets, often about the size of one's hand. Their signs are "cuneiform," which is Latin for wedgelike. Scribes marked these signs by pressing (rather than scratching) with a reed. Signs may be vertical or horizontal. After filling up one side, the scribe would write on the back. Texts too long to fit on a single tablet were written on multiple tablets, numbered in sequence. Titles, prayers and colophons could be written on a tablet's sides.

		cuneiform tablets	Archaeologists have found many works of literature in ancient cuneiform tablets. There are epics, proverbs, parables, fables, love songs, essays, disputations, solemn hymns, prayers, mythological poetry, handbooks of grammar, lists of signs, records of place-names, historical chronicles, letters, and laws.
		Kidinnu: Enuma Elish (British Museum)	Listen to Enuma Elish, our epic of creation. This tablet tells how Marduk brought order to chaos in the creation: "WHEN on high the Heavens had not been named, Firm ground below had not been called by name, Nothing but 'Primordial Apsu' the Begetter, [Fresh Water]; and 'Mummu Tiamat', She Who Bore them All, [Salt Water]; --their waters commingling as a single body-- No reed hut had been matted, no marsh land had appeared, Uncalled by name, their destinies undetermined-- THEN it was that the Gods were formed within Them."
		Kidinnu: Gilgamesh (British Museum)	Now hear the story of the hero Gilgamesh: "I will proclaim to the world the deeds of Gilgamesh. This was the man to whom all things were known; this was the king who knew the countries of the world. He was wise, he saw mysteries and knew secret things, he brought us a tale of the days before the flood. He went on a long journey, was weary, worn-out with labor, returning he rested, he engraved on a stone the whole story."
		Archaeologist: RachelMagruder/ziggurat	Traditions of literature and astronomy were nearly as old to Kidinnu as Kidinnu is to us. From early Ur to later Babylon, ziggurats connected Earth and Sky. Through long nights at the tops of these towers the Scribes passed 20 centuries watching the skies.

		Kidinnu ou-hsci/constellations/† •Use arrow to point to bright stars on the atlas images, as they are mentioned.	Many constellations have Sumerian origins, particularly those with bright stars near the annual path of the Sun. Taurus the bull of heaven, with bright star Aldebaran. Leo the lion, and bright star Regulus. Antares, the red heart of Scorpius. Virgo with the barley stalk, and bright star Spica. These bright stars and ancient constellations mark the ecliptic, the annual path of the Sun around the sky. The planets follow near the ecliptic in a wider band, the zodiac.[7] Additional zodiac constellations of early Babylonian origin include Gemini, the great twins... Cancer the crab... Libra the balance... and the goat-fish Capricorn...
Old Babylonian, 1800-1600 BC			
12	41	show/revs2-oldBabylonian	In the 18th century BC, the Old Babylonian period, Hammurabi conquered the Fertile Crescent. From his capital in Babylon, Hammurabi ruled an empire stretching from the Mediterranean to the Persian Gulf.
		Law code of Hammurabi (Louvre)	With a code of law inscribed on a black basalt pillar 8 feet high, Hammurabi imposed order throughout the realm.

7. Some of the Babylonian constellations equivalent to modern ones are the following: The hired man = Aries; the stars = Pleiades; the bull of heaven = Taurus; the true shepherd of Anu = Orion; the old man = Perseus; the great twins = Gemini; the crab = Cancer; the lion = Leo; the barley-stalk = Virgo; the balance = Libra; the scorpion = Scorpius; Pabilsag (a god) = Sagittarius; the goat-fish = Capricorn; the field = Pegasus; the giant = Aquarius; and the tails = Pisces.

†- Constellation images in the show are all taken from Bayer, *Uranographia*, a 17th-century star atlas, provided by the History of Science Collections, University of Oklahoma Libraries.

		Kidinnu Venus morning star, evening star. In between it is invisible in the daytime sky.	Scribes searching for the laws of the heavens discovered that Venus, the image of Ishtar, the queen of heaven, never moves far from the Sun. First Venus appears on one side of the Sun, and then on the other. When Venus appears east of the Sun, it is the evening star, setting in the west just after sunset. When Venus appears west of the Sun, it is the morning star, rising in the east before sunrise.
			The Babylonians recognized that the evening star and the morning star are the same star. They knew that between its evening and morning appearances, Venus lies near the Sun, invisible in the daytime sky. To the Babylonians, the motions of the planets were signs from the gods to be interpreted for the king.
		Kidinnu:	"Venus disappears in the West. When Venus grows dim and disappears in Abu there will be slaughter in Elam. When Venus appears in Abu from the first to the thirtieth day, there will be rain, and the crops of the land will prosper...."
		Archaeologist: Venus tablet (British Museum)	By the reign of Ammizaduqa, less than a century after Hammurabi, the scribes of Babylon knew that Venus repeats its motions against the background of fixed stars in an 8-year cycle. They recorded the motions of Venus for 21 years.
		show/numbers10	At least by the time of this Old Babylonian period, the Babylonians had developed a facility with mathematics sufficient for the advance of astronomy.
			Numbers from 1 to 9 were written with vertical marks. A horizontal mark represents 10.
		show/numbers20	Numbers from 11 to 20 combined horizontal 10's and vertical 1's as needed.
		show/numbers38	Therefore, 3 horizontal and 2 vertical marks equals... 32. 3 horizontal and 8 vertical marks equals... 38.

		show/numbers60	Similarly, 5 horizontal and 9 vertical marks equals 59. But a remarkable thing happens when we write 60: instead of marking 6 horizontal signs for six tens, only a simple 1 sign is needed. 61 is a 1 and a space, followed by another 1. In other words, Babylonian mathematics employed a place value system, where the position of the sign in the number determines its value. A vertical mark can represent either 60 or 1, depending on where it is placed.
		show/numbers60 show/635decimal	Because of place-value, Babylonian numbers, quite unlike Roman numerals, are similar to our modern decimal system. For us, the number 63.5 is represented by a 6 in the tens position, a 3 in the ones place, and a 5 in the tenths position. 60 plus 3 plus 5 tenths is 63.5.
		show/635sexagessimal	The Babylonian place value is a sexagessimal system, based not on 10 but on 60. 63.5 is represented by a 1 in the sixties position, a 3 in the ones place, and 30 in the sixtieths position. 60 plus 3 plus 30 sixtieths equals 63.5.
			A place value system enabled Babylonian astronomers to work easily with fractions, reciprocals, multiplication and division. Cuneiform tablets have been found with tables of squares, square roots, cubes and cubic roots.
		Plimpton 322 (Columbia University)	One tablet dating to 1500 BC contains Pythagorean triplets, or numbers which satisfy the relation we know as the Pythagorean theorem. If a right triangle has sides of 3 and 4 units in length, the hypoteneuse must be 5 units long. In general, the square of the hypoteneuse is equal to the sum of the squares of the sides. This tablet, known as Plimpton 322, contains many rows, where each row contains examples of Pythagorean triplets. Given the lengths of two sides of a right triangle, Babylonians could generate the length of the missing side.

		YBC 7298 tablet (Yale University)	Another tablet from the Old Babylonian period shows a value for the square root of 2. If two sides of a right triangle are each 1 unit in length, then the hypoteneuse must equal the square root of 2. This Yale University tablet shows a square with sides 30 units long. The length of the diagonal is recorded, and shows a value for the square root of 2. When translated to decimal notation, the Old Babylonian value is correct to 6 significant figures, with an error of only one in the seventh place.
		Plimpton 322 (Columbia University)	Equipped with a sophisticated mathematics, Babylonians were prepared to develop an equally sophisticated quantitative astronomy.
Intervening dynasties, 1600 - 700 BC			
18	23	show/revs/3-dynasties	For centuries after the Old Babylonian period, amid the tumult of revolutions of empires, through a variety of lesser known dynasties, the scribes sustained their careful inquiry into mathematics and astronomy.
		Astrology and Astronomy	Because the scribes provided counsel for the king, their inquiry was of great importance to the empire. The scribes advised the king by divination, which is the art of interpreting omens such as dreams. The scribes also practiced divination by the stars, or astrology. To interpret the meaning of the stars, astrologers required a knowledge of astronomy as a mathematical science. Ancient astronomy and astrology were thoroughly mixed together. Modern astronomy and astrology have no relation; there is no physical reason to expect the positions of the stars and planets to cause events on the Earth. Yet this modern separation between astronomy and astrology does not mean that astronomy began only when astrology was set aside; rather, astrology remained the most important incentive for the development of mathematical astronomy up through early modern times.

		Enuma Anu Enlil tablet (British Museum)	In the Kassite dynasty, from 1600 to 1200 BC, the scribes of Enuma Anu Enlil compiled 70 tablets containing the interpretations of thousands of omens. These tablets were an experiment to collect observations of the Moon and planets, and then to correlate these various omens with economical prosperity, agricultural prices, civic health, and affairs of state, all of which were assiduously recorded.
		Annual motion of Sun ou-hsci/constellations/leo	The tablets of Enuma Anu Enlil record observations of a wide variety of astronomical phenomena that the scribes believed might serve as possible omens. For example, the scribes observed the heliacal risings of bright stars such as Regulus, in Leo the Lion.
		Heliacal rising, ecliptic, annual motion of the Sun, Leo show/sun-1degree	As the Sun moves around the sky once each year, it will sometimes be found on the opposite side of the sky from a star such as Regulus. When the Sun and Regulus are thus in "opposition," so that the angle between them is 180°, Regulus will rise when the Sun sets, and Regulus will be visible all night long. Each night the Sun moves about one degree in a roughly eastward direction along its annual path known as the "ecliptic." In 10 days, the Sun will move about 10 degrees, roughly the width of one's fist held at arm's length.
		show/heliacalrising	Six months later, as the Sun approaches Regulus, Regulus and the other stars of Leo will disappear into the daytime sky. Eventually, as the Sun continues to travel roughly eastward about a degree a day, the Sun will pass them by. A morning will come when Regulus rises on the eastern horizon, just before sunrise. This first appearance of Regulus after its period of invisibility in the daytime sky is called its "heliacal rising." After its heliacal rising, Regulus is a morning star, visible in the east before sunrise. The Sun returns to the same place against the background of fixed stars each year, and the heliacal risings of important bright stars occur at certain fixed times of the year.

		Direct motion of Moon, planets Enuma Anu Enlil tablet (British Museum) show/direct show/moonFist show/direct-Tau	The scribes of Enuma Anu Enlil also watched the skies to observe the motions of the Moon and planets. We have seen that the Sun moves roughly eastward about a degree a day along the ecliptic, its annual path around the sky. Similarly, each planet and the Moon move roughly eastward, near the ecliptic, with what is called their “direct” motion. For example, on average the Moon moves about 10 degrees a day, roughly the width of one’s fist held at arms length. If tonight the Moon is located a few degrees west of a star, then tomorrow night it will be a few degrees east of the same star. At this pace the Moon completes its journey around the sky in about a month. Jupiter, Saturn, Mars and the other planets also complete journeys around the sky in this direct, roughly eastward motion. They never stray far from the ecliptic as they journey through the constellations of the zodiac.
		First station show/stationary1-Tau	Yet sometimes an outer planet like Mars will stop its direct motion, and rise several nights in a row near the same position against the background of fixed stars. This is its first stationary point.
		Retrograde show/retrograde	On subsequent nights it moves backwards, reversing its path in the sky. This is retrograde motion. Coincidentally, retrograde motion only occurs when the planet is opposite the Sun, visible through the entire night. The planet appears much brighter during retrograde motion than at other times.
		Second station show/stationary2-Tau show/direct-Tau	Eventually, the planet comes to another halt, which is the second stationary point. After rising a few nights near the same position in its second stationary point, it then resumes its ordinary direct motion.

		lunar eclipse ou-hsci/Apian-1540-sphericalEarth‡	Usually the Moon lies a little above or below the line between the Sun and the Earth, but occasionally it may happen to fall exactly on the line. If it does, then the Earth's shadow will move across the face of the Moon, eclipsing the Moon. In the late 8th century BC, during the reign of Nabonassar, the scribes of Babylon initiated an effort to observe every lunar eclipse. Despite the tumults of later conquests and revolutions, the scribes maintained records of lunar eclipses in a continuous sequence down to the first century BC.
Assyrian Period, 700-609 BC			
24	37	show/revs/4-assyrian show/kingsAssyrian	In the late 9th century BC, Assyria ruled northern Mesopotamia from their capital city of Ninevah, on the Tigris river. Tiglath Pileser the Third conquered the Babylon of Nabonassar. Eventually Assyrian forces extended their conquests as far as Palestine and Egypt.
		Palace of Sargon II, Khorsabad (north of Ninevah), Oriental Institute, University of Chicago places/SargonII-wingedBull show/kingsAssyrian	Herodotos, a Greek historian of the Persian Wars in the 5th century BC, knew nothing about earlier Mesopotamian civilizations, and Europeans in 1800 knew little more. Despite the magnitude of the Assyrian empire, it vanished without a trace until a French physician and diplomat named Botta discovered the palace of Sargon II at Khorsabad, on the norhern outskirts of Ninevah, in 1843. Parts of Ninevah are still inhabited, yet finds at the mounds of Ninevah have cast much light on ancient Mesopotamian astronomy. Issar-Sumueres, the chief scribe of Esarhaddon, advised the king to heed the omen of the retrograde motion of Mars:
		Kidinnu Human-headed winged lions (lamassu) from Khorsabad Palace (Metropolitan Museum of Art, New York)	"If Mars, retrograding, enters Scorpius, do not neglect your guard; the king should not go outdoors on an evil day. This omen is not from the Series [of Enuma Anu Enlil]; it is from the oral tradition of the masters.... Wherever else it might retrograde, it may freely do so, there is not a word about it."

‡- Peter Apian, *Cosmographia* (1540).

		show/kingsAssyrian	The 7th century ruler Ashurbanipal amassed a vast library of Sumerian, Babylonian and Assyrian literature. This library was discovered in 1853. Finds included one thousand tablets of planetary omens, sent to the Assyrian king from the scribes of Enuma Anu Enlil in Babylon. For use by the scribes, Ashurbanipal rebuilt the Temple of Esagila.
		Mul Apin tablet (British Museum)	Mul Apin tablets were copies of much older originals, written for the library of Ashurbanipal.[8] The Mul Apin series contains the names of stars and constellations, including the Bull, the Balance, the Lion, Scorpion, Twins, and a Sea-Goat.
		Heliacal risings show/heliacalrising	Mul Apin tablets include a star calendar based on the dates of the heliacal risings of bright stars:
		Kidinnu show/mulapinHiredMan	"On the 1st of Nisannu the Hired Man is visible"
		show/horizon show/mulapinScorpiusSets	In circular star charts, bright stars are listed in three regions (Ea, Anu or Enlil), according to where they rise on the horizon. The Mul Apin star calendar was far more complete and systematic than Works and Days, a comparable Greek calendar by Hesiod. But what if there is bad weather? What if the eastern horizon is obscured by sandstorms or clouds? For this reason the Mul Apin astronomers included a list of simultaneous risings and settings.
		Kidinnu	"The Pleiades rise and the Scorpion sets".
		Simultaneous risings/settings	If the eastern horizon is obscured, then just before sunrise one may look to the west. If Scorpius is setting, then the Pleiades must be rising. In 250 BC, Aratus would write a similar Greek work called the Phenomena.
		Rising intervals show/mulapinCounting1	Mul Apin scribes also tabulated the number of days between morning risings.
		Kidinnu show/mulapinCounting2	"30 days pass from the rising of the Balance to the rising of the She-Goat."

8. "Mul-Apin" is the first word of the tablet, "The Plow-star, Enlil, who goes at the front of the stars of Enlil."

		show/mulapinCounting2	When bad weather prevailed and both horizons were obscured, the Scribes could still infer what bright star must be rising by counting the number of days since the previous month's rising.
		Intercalation rules show/lunarCalendar show/mulapinSimanu	The Babylonian calendar was a "Luni-solar" calendar, where each month began with the the first sighting of the Crescent Moon. First sightings of the Crescent Moon occur either 29 or 30 days apart. Therefore 12 lunar months require 354 days; while the Sun requires slightly more than 365 days to complete its annual cycle. This means that the lunar and solar calendars fall out of sync about 11 days each year. The Mul Apin tablets offered rules for when to add a 13th month:
		Kidinnu	"If the Pleiades become visible on the 1st of Simanu, this year is a leap year"
		Goal year tablet (British Museum)	The Mul Apin tablets are not the only astronomical writings discovered in Ancient Assyria. "Goal Year" texts were records of the motions of planets in the past. The scribes could then match the current motions of any planet with the pattern it showed during a similar year in the past. For example, the goal year of Jupiter is 71; this means that to predict how Jupiter will move this year, one needs records of how it appeared 71 years ago. Similarly, the goal year of Venus is 8 years; this year, Venus will appear to move much as it did 8 years ago.[9] The compilation of goal year texts enabled the scribes to predict the positions of each planet, not by calculation on the basis of theory, but simply by consulting past goal year records.
		Lunar eclipse prediction ou-hsci/Apian-1540-sphericalEarth	The scribes discovered that lunar eclipses occur in patterns so that they could predict when an eclipse could be ruled out, when it might occur, and when it was sure to happen.[10]

9. Jupiter, 71 years; Saturn, 59 years; Mars, 79 and 47 years; Venus, 8 years; Mercury, 46 years; Moon, 18 years.
10. Lunar eclipses frequently occur 6, 12 or 18 months apart. The earliest documented successful lunar eclipse prediction was made in the 7th century BC.

New Babylonian (Chaldean), 626 - 539 BC			
30	31	show/revs/5-newBabylonian	The Babylonian ruler Nabopolassar defeated the Assyrian empire in 612 BC, ushering in the New Babylonian period.
		show/kingsNeoBab	The New Babylonian empire reached its zenith with Nebuchadnezzar's defeat of the Egyptians at Carchemish in 605 BC. Returning home, Nebuchadnezzar took Hebrew captives with him to Babylon, as told in the Book of Daniel. In 587 BC he returned to Palestine to crush Jerusalem, forcing the Jewish people into exile.[11]
		Daily diaries Astronomical diary tablet (British Museum)	For 600 years, beginning in this era, the Scribes of Enuma Anu Enlil maintained a continuous series of Astronomical Diaries. In these diaries they recorded observations of the Moon, planets, heliacal risings of stars and other phenomena. A typical diary entry might take this form:
			"In year x of King y, month z, day n, Mars reached its first stationary point; it was in zodiacal sign z."
			Other records explicitly correlated celestial events with meteorology, economics, politics and warfare, or other potential omens:
		Kidinnu: Astronomical diary tablet (British Museum)	"If you want to make a prediction of the market price of barley, notice the movement of the planets. If you observe the first visibilities, the last visibilities, the stationary points, the conjunctions, ... the faint and bright light of the planets and zodiacal signs and their positive or negative latitude... your prediction for the coming year will be correct." (4th cent)
			The scribes collected observations on a scale not seen again until the statistical and economic surveys of modern states in the 18th-19th centuries. As historian of astronomy Noel Swerdlow explains:

11. In 605, Daniel and his friends were taken captive to Babylon; the fall of Jerusalem, and exile of Judah to Babylon, occurred in 587 BC.

		Noel Swerdlow quote	“Their systematic observation and recording of phenomena ... has remained to this day the longest and most comprehensive program of astronomical observation ever carried out.... extending from the 8th or the 7th to the 1st century, ... the longest continuous scientific research of any kind in all of history, for modern science itself has existed for only half as long.”[12]
Persian period, 559 - 331 BC			
33	11	show/revs/6-persian	From eastern Mesopotamia, the Persian king Cyrus the Great (d. 530 BC) swept upon Babylon, conquering it in 539 B.C. Cyrus freed the Jews in exile there, who returned to Palestine.
		show/kingsPersian livius.org/persepolis-gate	Darius the Great ruled the Persian empire from his palace in Persepolis until 486 BC. Although his palace was later destroyed by Alexander the Great, inscriptions there led to the modern decipherment of cuneiform by Georg Friedrich Grotefend and Henry Rawlinson in 1837.[13]
		livius.org/behistun	On the side of this 1,700 foot mountain near Behistun, dangling from ropes 300 feet above ground, Rawlinson transcribed inscriptions of Darius written in three parallel cunieform scripts: Old Persian, Elamite, and Babylonian.[14]
		show/kingsPersian	The Greek historian Herodotos recounted, in his book The Persian Wars, how the Greek city states united to turn back the Persians’ attempt to conquer them under King Xerxes.
		show/kingsPersian	The Persian King Artaxerxes supported the efforts of the Jews under Ezra and Nehemiah to rebuild their Temple in Jerusalem.[15]
Seleukid (Greek) period, 335 - 141 BC			

12. Here as elsewhere the script relies upon Noel Swerdlow, *The Babylonian Theory of the Planets* (1998).
13. Grotefend, *Beiträge zur Erläuterung der persepolitanischen Keilschrift* (1837). (Contributions to a Commentary on Persepolitan Cuneiform Writing).
14. Henry Rawlinson, *Persian Cuneiform Inscriptions at Behistun* (1846).
15. Artaxerxes I, 464-423; Biblical events: Ezra, Nehemiah in Jerusalem

34	38	show/revs/7-seleukid livius.org/alexander (Louvre) show/revs/7-seleukid	Alexander the Great came like a bolt out of the west and conquered the Persian empire in 331, before dying in Babylon in 323 BC. At his death, Alexander's four generals divided his conquests. Ptolemy controlled Egypt; and Mesopotamia was given to Seleukis. Through the revolutions of empires, under Persian and then Seleukid rule, the scribes of Enuma Anu Enlil continued their astronomical investigations.
		RachelMagruder/BabylonGardens	In the late 19th century, scholars working in the British Museum discovered 300 tablets of Seleukid-era mathematical astronomy, apparently from two locations, Uruk and Babylon. These tablets represent the climax of Mesopotamian cuneiform astronomy, because in them the Scribes of Enuma Anu Enlil, including one named Kidinnu, discovered how to make accurate numerical predictions of complex planetary events.
			The texts include ephemerides, which are calculated tables predicting the times and locations of planets during significant planetary events, and procedure texts, which explain the rules for calculating the ephemerides. In their planetary ephemerides, Scribes accurately predicted the first and last visibility of planets, the first and second stationary points, and the duration of retrograde motion. With these texts Babylonian astronomy became fully mathematical, no longer dependent upon constant empirical input.[16]

16. Ephemerides were more like a computer program than a field notebook. Aaboe asserts (p. 36), "The creation of mathematical astronomy is thus one of the last, as well as one of the finest, original efforts of Mesopotamian culture, an event without precedent anywhere, and with great consequences." Aaboe distinguishes three levels of ancient astronomy, where in the Seleukid period the Babylonian scribes attained the third: 1. Naming and Recognition of celestial phenomena; 2. Recognition of various cyclic patterns or periodic rules for planetary motion; and 3. Numerical functions to predict observations with minimal initial observational input.

		Kidinnu RachelMagruder/Library	Come my friend, let me show you the tablets for this month. Here you can see I have calculated that Mars will begin to retrograde tonight, Jupiter is in Taurus the Bull, and Regulus will rise in the east just before sunrise. The Moon is now moving much faster than usual along the zodiac; tonight it will appear in Gemini. These things will happen just as I have foretold, and we will interpret them for the king.
		Zig-zag function show/zigzag ou-hsci/Apian-1540-cosmicSection	To calculate planetary positions, Kidinnu and the other scribes used a technique of arithmetical progression known today as a zigzag function. This technique accounted for the non-uniform speeds of the Moon and planets, by altering the speed by a prescribed amount at regular intervals. Given the accuracy of these arithmetical functions, the Scribes were not concerned with the geometry of rotating spheres, so central to the models of their Greek successors. Unlike the early Greek astronomers, whose models were strictly qualitative, the Babylonian scribes attempted and achieved the ideal of quantitative prediction.
		RachelMagruder/BabylonGardens	Historians do not know how Greek astronomers learned Babylonian mathematical astronomy, but somehow they did. Greek musicians and mercenary soldiers occasionally visited Babylon during the New Babylonian and Persian empires, but after Alexander's conquest, east-west travel and intellectual exchange intensified.
		Kidinnu RachelMagruder/Library	A former head of our order foretold that your Alexander the Great would capture Babylon. Before he died, Alexander ordered the restoration of our Temple of Esagila. To repay this favor, I am willing to teach one of your Greek sages our astronomical arts. When you return to your city, tell them what you have seen and heard, and send them back to me.
Epilogue			

38	29	show/revs/7-seleukid	At the beginning of the 19th century, the ancient Mesopotamian civilizations were little more than a myth, lost in the remote reaches of time. In the Athens of Aristotle, Mesopotamian civilization was already ancient. Today we know more about ancient Babylon than Aristotle did.
		Discontinuities show/revs/7-seleukid	Much of that story is a dismal succession of destruction, revolution, and rebuilding. Considering the social disruptions of wars, invasions, and revolutions, the diversity of ruling dynasties, and even the variety of ethnicity, language, and capital cities, the remarkable fact is that for two millenia there were any continuities at all.
		Continuities show/continuities	There were continuities of Language, including a persistance of Sumerian and Akkadian vocabulary. Works of literature and mythology were preserved, including the Epic of Gilgamesh. The Scribes continued to serve successive empires as a highly trained intellectual and religious elite.
		Mathematics	Mathematical techniques also persisted from Old Babylonian to the Seleukid period.
		Astrology show/continuities	The idea that heavenly events determine events on earth continued; astrology served as the crucial motivation for Babylonian astronomy. As with literature, art, and architecture, the Scribes maintained continuity despite the great political changes and the devastations of conquest.
		Astronomy show/accomplishments	In so doing, the Scribes of Enuma Anu Enlil created the tradition of mathematical astronomy. They designated the 12 signs of the Zodiac; perfected the luni-solar calendar; accurately determined planetary periods; predicted lunar and solar eclipses; and calculated important events in planetary cycles, including the first and second stationary points and the duration of retrograde motion.

		show/accomplishments	Wherever else one encounters mathematical astronomy, one can detect the influence of the Babylonians.[17] In early Greek natural philosophy, there was nothing comparable to the Babylonian achievement in astronomy, until cultural interchange between Mesopotamia and Greece increased after Alexander the Great.
41	05	•Star projector: project precession grid.	Around 150 BC, Hipparchos of Nicaea discovered the 26,000 year cycle of precession. This discovery was possible only because Hipparchose used Babylonian determinations of the length of the year.[18]
41	15	ou-hsci/Ptolemy-1496-fp; Almagest (Epitome by Regiomontanus, 1496) •Turn off precession grid	Claudius Ptolemy wrote the greatest astronomical work of antiquity, the Almagest, in 150 AD. In the Almagest, Ptolemy relied upon the Babylonian calendar and other Babylonian observations, including lunar eclipses going back to 750 BC.
		show/time	When we tell time by minutes and hours, or measure angles in degrees, we are still today heirs of Babylonian sexagessimal mathematics.
		ou-hsci/constellations	Yet the most important legacy of Babylonian astronomy is the ideal of the exact quantitative prediction of natural phenomena. Historian Asger Aaboe explains: "Babylonian mathematical astronomy was the origin of all subsequent serious endeavour in the exact sciences." (40)

17. "Wherever else we encounter scientific mathematical astronomy we can detect, directly or indirectly, the influence of the Babylonian forerunner." Aaboe, 36.
18. G. J. Toomer argues that Hipparchos traveled to Babylon and learned cuneiform astronomy for himself.

		ou-hsci/constellations show/swerdlow1 ou-hsci/Newton show/swerdlow2	Until recently, many historians dismissed the significance of Babylonian astronomy for the history of science because of its obvious astrological and religious character. Babylonian astronomers predicted the motions of the planets, but because of their religious beliefs they did not attempt to offer physical explanations of the causes of these motions. Yet "mathematical science in the service of the interpretation of omens is still mathematical science."[19] The scribes maintained an indifference to causes, but so did Isaac Newton in the 17th century. Newton set forth mathematical laws describing gravity without specifying the actual physical cause of gravity. "In science causes are ephemeral while mathematics endures."[20] The economist and Newton scholar John Maynard Keynes explains:
		Male voice show/Keynes	"Newton was not the first of the age of reason. He was the last of the magicians, the last of the Babylonians and Sumerians, the last great mind which looked out on the visible and intellectual world with the same eyes as those who began to build our intellectual inheritance rather less than 10,000 years ago."[21]
		Stars over observation level	Today, whenever we use the sexagessimal system, observe the constellations of the Lion or the Bull, rely upon quantitative mathematical science, read our horoscopes, interpret the results of the latest poll, or try to predict the will of the gods, we are modern Babylonians.
		RachelMagruder/ziggurat	Come join with me as a watcher of the night. As we look out from these heights over the splendor of the city, our vision rises to things beyond mortal human life. We fly to the stars, the home of the gods. With our secret mathematical arts, guided by the sacred writings of long ago scribes, we interpret the signs of the heavens, for the good of the king and empire.

19. Swerdlow, 182.
20. Swerdlow, 182.
21. Keynes, "Newton, the Man."

44	12	•sunrise from the ziggurat; stars off	
Credits			
44	19	Written & Produced by Kerry Magruder Narrator: Candace Magruder Kidinnu: Kerry Magruder John Maynard Keynes: Phil Kemp Soundtrack by Eric Barfield Original artwork by Rachel Magruder Cuneiform tablets: British Museum: Enuma Anu Enlil; Enuma Elish; Epic of Gilgamesh; Venus tablet; Mul Apin; Goal year; Diary. Louvre: Law code of Hammurabi Columbia University: Plimpton 322 Yale University: Square Root of 2 Photographs of Places: Duane H.D. Roller, History of Science Collections, University of Oklahoma Jona Lendering and Marcos Prins, livius.org Constellation and Book images courtesy History of Science Collections, University of Oklahoma Libraries Digital photography by Hannah Magruder The Cosmology and Cultures Project of the OBU Planetarium Creative Commons License	
show/credits/			
46 46	24 53	•End of video; Bring up theater lights End of audio	

5. After the Show

A. Theater activities

1. Move the star projector to the latitude of your location, in order to introduce a brief live session pointing out highlights of the sky tonight.
2. How to use a constellation chart: see Kerry Magruder, Basic Celestial Phenomena website, *http://homepage.mac.com/kvmagruder/bcp/instruments/chart/index.htm*.
3. How to use a planisphere: see Kerry Magruder, Basic Celestial Phenomena website, *http://homepage.mac.com/kvmagruder/bcp/instruments/planisphere/planisphere.htm*.
4. How to use a protractor quadrant (or fingers) to measure degrees of angular separation between bright stars near the ecliptic (e.g., Regulus in Leo the Lion, Spica in Virgo the Maiden). See Kerry Magruder, Basic Celestial Phenomena website, *http://homepage.mac.com/kvmagruder/bcp/instruments/quadrant/index.htm*.

B. Discussion Questions

1. Use the mathematics and astronomy of the Babylonians as a case study to explain what your definition of science is. What does your definition of science include (that is, how broad is it)? What does your definition of science exclude (that is, does it mean anything at all)?

2. Critique the following view: "The duties of Mesopotamian priests included gathering omens from stars and livers, exorcising demons, and healing diseases.[22] The scribes of ancient Babylonia developed the art of reading omens and portents in, say, sheep entrails. This does not make them "biologists! Eventually they also devoted themselves to reading omens and portents in the celestial motions. This does not make them astronomers! They were merely practicing a celestial art; a type of priestcraft (technology or magic) analogous to and no more scientific than reading liver entrails. Such astrology is far removed from scientific astronomy. The latter we owe entirely to the Greeks."

3. Asger Åboe's levels of non-Greek astronomy:
    - 1. Naming and Recognition of celestial phenomena.
    - 2. Recognition of various cyclic patterns or periodic rules for planetary motion.
    - 3. Numerical functions to predict observations with minimal initial observational

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22. There is an extensive Mesopotamian medical literature in addition to the astrological traditions.

input.

- For Åboe, Babylonian astronomers meet all three of these criteria, and the last makes their accomplishment "scientific" astronomy.

4. Åboe: "Mathematical astronomy was, however, not only the principal carrier and generator of certain mathematical techniques, but it became the model for the new exact sciences which learned from it their principal goal: to give a mathematical description of a particular class of natural phenomena capable of yielding numerical predictions that can be tested against observations. It is in this sense that I claim that Babylonian mathematical astronomy was the origin of all subsequent serious endeavour in the exact sciences." (41-42).[23]

5. Discuss the following quotation from Anton Pannekoek, A History of Astronomy (Dover, 1989), p. 13: "When the [modern] astronomer looks back at his predecessors, he finds Babylonian priests and magicians, Greek philosophers, Mohammedan princes, medieval monks, Renaissance nobles and clerics—until in the scholars of the seventeenth century he meets with modern citizens of his own kind. To all these men astronomy was not a limited branch of specialist science but a world system interwoven with the whole of their concept of life. Not the traditional tasks of a professional guild but the deepest problems of humanity inspired their work."

C. Lab or Classroom Activities

1. The Paper Plate Astronomy website by Chuck Bueter (*http://analyzer.depaul.edu/paperplate/activities.htm*), sponsored by the Great Lakes Planetarium Association, includes several activities of interest, particularly the "Retrograde Motion" activity to model how planets appear to loop westward against background stars: *http://analyzer.depaul.edu/paperplate/Retrograde%20Motion.htm*

2. Investigate how precession makes today's horoscopes out-of-sync with the current position of the Sun, because astrological methods remain the same as during the Seleukid period. See Kerry Magruder, "Why is your horoscope hopelessly out of date?" Basic Celestial Phenomena website, *http://homepage.mac.com/kvmagruder/bcp/precession/horo.htm*.

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23. Asger Åboe, "Scientific Astronomy in Antiquity," *Philosophical Transactions of the Royal Society of London*, 1974; 276: 21-42.

6. Further Reading

A. Secondary Sources

Historians of science have made great strides in recent years toward understanding Babylonian astronomy and its significance for quantitative mathematical astronomy in other cultures, including Hellenistic Greek astronomy from the time of Hipparchos onward. In this show we have just scratched the surface. Here are a few of the most helpful secondary sources:

1. Asger Åboe, "Scientific Astronomy in Antiquity," *Philosophical Transactions of the Royal Society of London*, 1974; 276: 21-42. A thought-provoking and readable assessment of the historical significance of ancient Babylonian mathematical astronomy.
2. James Evans, *The History and Practice of Ancient Astronomy* (Oxford, 1998). An extremely helpful introductory survey of mathematical astronomy from the ancient Near East to Copernicus.
3. Otto Neugebauer, *The Exact Sciences in Antiquity* (Dover, 1969). A great short introduction to ancient mathematical astronomy, including System A and System B.
4. Hermann Hunger, David Pingree, *Astral Sciences in Mesopotamia* (Brill, 1999).
5. Noel Swerdlow, *The Babylonian Theory of the Planets* (Princeton, 1998).
   The best book-length introductions to Babylonian astronomy are the works by Swerdlow and by Hunger and Pingree.
6. Alexander Jones, *Astronomical Papyri from Oxyrhynchus* (Philadelphia: American Philosophical Society, 1999).

B. Primary sources

1. Otto Neugebauer, *Astronomical Cuneiform Texts*, Sources in the History of Mathematics and Physical Sciences, no. 5 (New York: Springer-Verlag, 1983), 3 vols.
2. Hermann Hunger, *Astrological Reports to Assyrian Kings*, State Archives of Assyria, vol. 8 (Helsinki, 1992).
3. Simon Parpola, *Letters of Assyrian and Babylonian Scholars*, State Archives of Assyria, vol. 10 (Helsinki, 1993).

C. Online Sources

1. Online articles at Wikipedia (*wikipedia.org*) will quickly orient students to the civilizations of the ancient Near East. Look for the articles on these topics: Ancient Near East; Ancient Mesopotamia; Ancient Babylonia; Ancient Persia; and Ancient Assyria.

2. An excellent interactive website on ancient Babylonian astronomy prepared by the British Museum includes translations of portions of some of the cuneiform tablets discussed in "Stars over Ancient Babylon": *http://www.mesopotamia.co.uk/astronomer/home_set.html*. Browse the entire website, including the sections called "Story" and "Explore." Then do the "Challenge" section. Be sure to click on "More..." links, and on highlighted words you don't know.

3. To explore in more depth one example of an early Babylonian mathematical tablet, see Bill Casselman, "The Babylonian tablet Plimpton 322," *http://www.math.ubc.ca/~cass/courses/m446-03/pl322/pl322.html*. Bill Casselman, of the University of British Columbia, walks you line by line through the Plimpton 322 tablet. As you read this web page, do not panic if some of the mathematics is over your head — rather, reflect on the fact that this tablet reflects a more advanced mathematical knowledge than you probably expected to find in the Near East, ca. 1800 BC. Be sure to click on definition links (like the one for "Pythagorean triples") when you are unsure of the meaning.

4. Jona Lendering, a historian of antiquity at the Free University of Amsterdam, sponsors the indispensable *www.livius.org* website. This website includes many pages relating to the ancient Near East, some of which help to amplify the material presented in "Stars over Ancient Babylon." See the following pages by Lendering: Ziggurat, Temple of Esagila, Astronomical Diaries, Kidinnu, Babylonian account of the Battle of Gaugamela, Alexander's Final Days: A Babylonian Perspective, and Berossus.

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