Oddballs in the sky; keeping time

Astronomy 101
Syracuse University, Fall 2022
Walter Freeman

September 20, 2022

And that inverted Bowl we call The Sky,
Whereunder crawling coop't we live and die,
Lift not thy hands to it for help – for It
Rolls impotently on as Thou or I.

–Omar Khayyám (1048-1131), Persian astronomer and poet,
translated into English by Edward FitzGerald (1859)

I'm cheating death
In Stellarium
I'm peeking ahead
To stars I will never see.

–Poetic text message from K. Alice Lindsay,
SU biophysicist, used with permission

A student's comment

One of your colleagues wrote:

...I think in general from the people I've talked to the part of the class that scares them is when the staff says the quizzes aren't the homework because it makes it sound like it's going to [be] something completely different.

I think students would be less scared if that was not said because in my opinion the homework is the quizzes. Its like math homework (it's not going to be the same questions but its the exact some principles) but overall this class is my favorite from the course to the staff to the other students in the class.

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They're right. The quizzes *are* the same principles as the homework, applied to slightly different situations.

Announcements

- Homework 3 on the seasons is due today
- Homework Quiz 2 is today at the end of class
- Homework Quiz 3 will be at the end of class Thursday

You will have opportunities to make up missed homework quizzes, or retake them for a higher score once you have learned the things you didn't know the first time.

Homework 3 recap

Homework 3 is due today.

Do you have any questions or want to discuss anything from it?

Exam 1

Exam 1 is next Tuesday (Sept 27).

It will cover:

- The motion of the stars in the sky (Homework 1; Lab 1)
- The motion of the Zodiac during the day and year (Homework 2)
- The motion of the Sun over the year and the seasons (Homework 3; Lab 2)
- The phases of the Moon (Lab 3)
- The emergence of heliocentrism (Thursday's class)

The format:

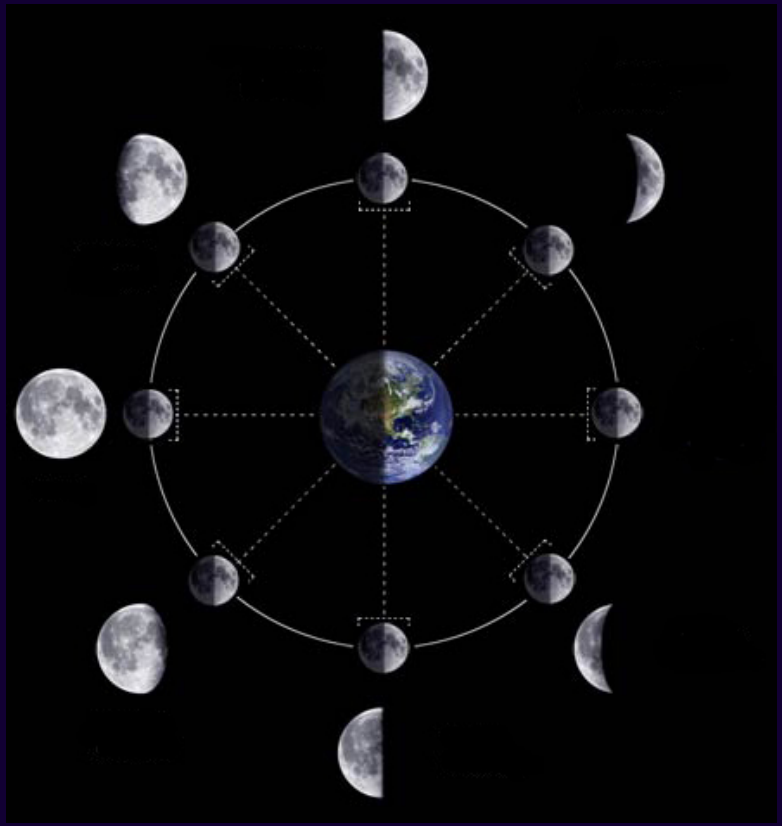
- Around 15 multiple choice questions
- Four free-response questions involving drawing or interpreting diagrams

Exam 1

We will have assigned seats for the exam, and will post a seating chart before class Tuesday.

You may bring *one page* of notes that you have handwritten yourself.

I will have extended help hours Monday (Sept 26), when I will be in the Physics Clinic as much as I can from 10AM-4PM (with a few breaks for lunch, exam printing, etc.)



You can figure all of this out by drawing pictures.

Do this whenever you need to figure something out about the Moon...

Let's make a doodle and see how much we can figure out...

When the full moon is high in the sky, what time of day is it?

What phase of the moon is mostly seen during the day?

What time of day does a full moon rise?

A: 6AM
B: Noon
C: 6PM
D: Midnight

What time of day is a waning crescent moon highest in the sky?

A: Midnight
B: In the morning, after sunrise
C: In the afternoon
D: Around 9PM, in the early night
E: Around 3AM, in the early morning

A past test question

In *The Lord of the Rings*, Frodo and Sam traveled with Sméagol to Mordor. During part of their journey, they needed to hide from the Nazgûl, and Sméagol wanted to travel only during absolute darkness – when neither the Sun nor the Moon were visible in the sky.

If the Moon was waxing gibbous, during what part of the day could they travel?

A: For a short time after sunset

B: For a short time before sunrise

C: During the first half of the night

D: During the last half of the night

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When the waxing half moon is just rising over the horizon, it is closest to:

A: 6AM
B: Noon
C: 6PM
D: Midnight

Unpredictable things in the sky

Why are the changes in the seasons in *Game of Thrones* so terrifying?

Unpredictable things in the sky

Why are the changes in the seasons in *Game of Thrones* so terrifying?

... they're unpredictable!

We've long used the immutability of the sky as a symbol for constancy. The cycles of the Sun, Moon, and stars don't ever change, but some things do!

These unexpected things in the sky once terrified people; now we know why they happen.

Eclipses

You know that during a new moon, the Moon lies roughly between the Earth and the Sun.

However, the Moon's orbit is tilted just a bit, so it usually passes over or under the Sun.

If it passes in front, you get a solar eclipse!
This terrified many of the ancients – "the Sun got eaten! We're doomed!"

Eclipses

You know that during a full moon, the Earth lies roughly between the Moon and the Sun.

Same deal: usually the Earth's shadow misses the Moon. Sometimes it doesn't!

We can still see the eclipsed Moon: some light is refracted by the atmosphere. The blue component is scattered away by the atmosphere; the red component bends and hits the Moon.

Eclipses

Lunar eclipse on May 15, 2022, seen from Syracuse. 700mm, around 1/3 second, f/8, ISO 10000+.

Note the stars visible to the left – this is much darker than the Moon usually is!

Meteors

Orbits of things in the Solar System are not always close to circular.

There are lots of small things in the Solar System, many of which have elongated orbits that sometimes cross ours.

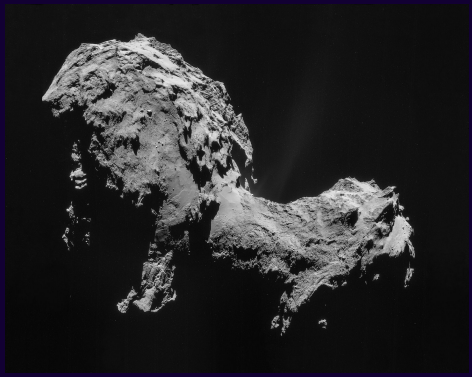
Meteors:

- Little rocky or metallic bits of matter that orbit the Sun
- Sometimes they get to Earth and glow as atmospheric drag heats them
- Sometimes they hit the surface, and we get chunks of space-slag
- Historical cultures sometimes used them as easy access to metal

Comets

Comets are "dirty snowballs" whose orbits are *highly* elongated.

- Mostly made of ice
- When they get close to the Sun, the heat melts bits off of them
- This stream of stuff reflects sunlight and makes the comet's "tail"
- Historical cultures were often terrified of them, but they're just space-snowballs



The planets: semi-predictable

Demo on *Stellarium*

The planets: semi-predictable

Demo on *Stellarium*

Sometimes some planets appear to go backwards ("retrograde motion").

This tells us that celestial sphere model can't be literally true. Why does it work for everything else?

- The celestial sphere model works if things appear to only rotate around the Earth.
- The stars are so far away that only the Earth's rotation matters
- The Earth orbits the Sun, so we just pretend that the Sun is on a different sphere turning a bit slower, taking into account both our revolution around it and our rotation
- The Moon orbits the Earth, so we again put the Moon on a different sphere, turning slower
- ... but how can we get a sphere to go forwards and backwards?
- **The celestial sphere model gets the motion of the planets badly wrong**

Keeping time: the very predictable

The predictable cycles in the sky are the basis for the way we keep time.

One day

- Earth rotating around its axis

One year

- 365 days
- Earth's orbit around the Sun

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One month

- One orbit of the Moon around the Earth

A reminder: Two sorts of day

The *sidereal day* is the amount of time it takes the Earth, and thus the celestial sphere, to rotate once.

One sidereal day $\rightarrow$ 360° rotation of the Earth

The *solar day* is the amount of time from solar noon to solar noon.

Since the Earth orbits the Sun, this requires more than 360° rotation:

- 360° plus a little extra, to compensate for the motion of the Earth around the Sun
- In my animation, with the "fast orbit", this is a lot more than 360°
- In the real world, the Earth moves only $1/365 \approx 1°$ around the Sun each day
- ... so in a solar day the Earth rotates:
  - 360° for the stars to rise and set once...
  - ... plus *one more degree* to compensate for the Earth's movement

One solar day $\rightarrow$ 361° rotation of the Earth

Solar day:

- 361° rotation of Earth
- The Sun returns to its same position (east/west)
- A bit more than a sidereal day → the stars move "too far"
- Exactly 24 hours

Sidereal day:

- 360° rotation of Earth
- The stars return to their same positions (exactly)
- A bit less than a solar day → the Sun moves "too little"
- Four minutes less than 24 hours

What about the moonth?

Is a lunar month...

- One complete cycle of phases of the Moon? (new moon to new moon)
- One orbit of the Moon around the Earth?

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- Synodic month: One complete cycle of phases of the Moon (29.5 days)
- Sidereal month: One orbit of the Moon ("Moon in Libra → Moon in Libra" – 27.3 days)

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- Sidereal month: One orbit of the Moon ("Moon in Libra → Moon in Libra" – 27.3 days)
- Calendar month – it varies depending on the calendar!

What about the year?

Is a year...

- ... from winter solstice to winter solstice?
- ... One orbit of the Earth around the Sun? ("Sun in Sagittarius $\rightarrow$ Sun in Sagittarius")

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The orientation of the Earth's tilt makes one rotation every 26,000 years.

Same deal:

- Tropical (seasonal) year: solstice to solstice
- Sidereal year: one orbit around the Sun; 1/26,000 less than a seasonal year

Now what do we have?

The year

Sidereal year

- One Earth orbit around Sun
- 365.26 24-hour days (1/26,000 *more* than a seasonal year)
- Sun returns to same place relative to stars

The day

Sidereal day

- One Earth rotation
- 23 hours 56 minutes (1/365 *less* than a solar day)
- Stars return to the same places in the sky

The moonth

Sidereal moonth

- One Moon orbit around Earth
- 27.3 days (about 1/12 *less* than a synodic moonth)
- Moon returns to same place relative to stars

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Seasonal year

- One cycle of the seasons (solstice to solstice)
- 365.24 24-hour days (1/26,000 *less* than a sidereal year)
- Sun does not quite return to same place relative to stars!

The day

Sidereal day

- One Earth rotation
- 23 hours 56 minutes (1/365 *less* than a solar day)
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Solar day

- Noon to noon / midnight to midnight
- 24 hours (1/365 *more* than a sidereal day)
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Difference caused by wobble of Earth's axis; seasonal year about 1/26,000 shorter

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... what do we do? Two choices:

- Don't worry about it (Gregorian months aren't lined up with the moonths)
- Intercalation: add extras (about one in four years is a leap year)