Astro 350

Lecture 2

Jan 21, 2022

Announcements:

- **Discussion Question 1** posted on Canvas
  due next Wednesday
- **Homework 1** posted today
  due next Friday
- please turn on video

Last time: overview

Now: **the Great Work begins!**

Program Notes: ASTR 404 Bugs/Features

- notes online–but come to class!
  Notes are posted right before each class
  but best to wait about 1 hour after class:
    updated/corrected notes posted

- class $\in$ diverse backgrounds: ask questions!

- Socratic questions *Q: What's that?*
  note: on Zoom can choose to answer via chat or DM

- typos/sign errors: Dirac story
  please report errors in lectures and especially in homework

- textbook: readings posted. I don't follow them closely.

Class Notes Online: A Good Thing?

Pros:

- you are not a stenographer–can use your brain to think and not transcribe
- don't have to read my bad handwriting

Cons:

- tempting to be cosmo-hypnotized
  so: I'll ask Socratic (=annoying) questions and polls throughout
- might give incorrect impression that there's no reason to come to class
  but: I'll give extra pearls of wisdom verbally
  ...and you'll chances to demonstrate participation
  not to mention demos, music, and movies

Bargain:
- I'll avoid railroading you
- you pay attention, ask questions when confused/interested

Cosmologies

Official Cosmology Membership Certificate

For this semester (at least!):

You are hereby declared to be a cosmologist!

Welcome to the club!

Q: so what does membership involve–what is cosmology?

Cosmologies

Cosmology: study of/ideas about the big picture

$\rightarrow$ origin and nature of "the world/the universe"

- what is the size & shape of the universe?
- what is it made of?
- what rules does it obey?
- how does our everyday experience fit into this picture?

A big subject! And many possible ways to approach it...

ASTR350: *Scientific* or *Physical* Cosmology

Q: what other kinds could there be?

There are many ways to look at the world!

Cosmologies–ideas about the origins and nature of things–existed long before science invented

narratives: "creation myths" give context to experience
each relies on some idea of how the world works,
and what counts as an explanation (turtle story)

A broad, rich subject; we'll focus on the view offered by *science*

The Cosmos Observed: Night Sky

The Night Sky

First step in science: collect **data**

Most basic goal of cosmology (and *main* goal pre-telescopes):
⋆ explain contents of the sky and their *motions*

The Contents of the Sky
Q: What are the main naked-eye *contents of the sky?*
How might these be classified?

Denizens of the Naked-Eye Sky

can classify naked-eye celestial objects into

- *permanent* objects – always there (but sometimes not visible)
  Sun, Moon, planets, stars, also Milky Way and fuzzy "nebulae"
- *transient objects/features* – appear and then are gone
  comets, meteors, auroræ (plus clouds & human-created lights!)
- and *darkness* between stars
  $\rightarrow$ important cosmo-clue!

can also classify by: what moves and what doesn't:

- "fixed" stars–same patterns relative to one another
- sun, moon, planets move relative to the stars, and each other

ancients: "seven wanderers":

- Sun, Moon, 5 bright planets Mercury, Venus, Mars, and Saturn
- enshrined in days of week (Sunday, Monday, ...)

The Fixed Stars

grouped in "constellations"; e.g., Orion
constellations: *regions* in the sky
  $\rightarrow$ not just stars in "connect the dots" patterns
constellations fill sky like states on a US map
$\Rightarrow$ any point in the celestial sphere lies in
  exactly one constellation

Big Dipper (subgroup = "asterism" of Ursa Major):
diagram: big dipper, 'pointer stars", Polaris
Q: how quantify constellation size, star spacings on sky?

Q: do the stars move at all relative to each other? Do they move on the sky (i.e., relative to the horizon)? is change noticeable daily? yearly?

Poll: Star Trails

imagine an expensive, magic machine:
makes each star leave a **trail** behind as it moves
over one night, as seen from Champaign-Urbana.
What pattern would the stars make?

A arcs of circles

B arcs of ovals

C parallel line segments

D none of the above

science: to test prediction, do experiment! *Q: how?*

Measuring Star Motion in the Sky

The Experiment

fix a camera on a tripod, open lens and expose to night sky
as each star moves, leaves "trail" on film

Many such images exist online:

`www: image of star trails`

Q: why do we get this pattern?
Q: what does it mean that it repeats daily?
Q: what does it tell us? special points/regions?
Q: why do telescopes have motors on them?

Q: What is geometry of the sky as seen from Earth's surface?
...recalling that the eye can't tell
depth/distance to celestial objects

Geometry of the Sky

In reality: celestial objects arranged in 3-D space
But: your eye can't tell distance to these objects
no "sense of depth"
So observationally: the sky "flattened" into a 2-D surface

⋆ **Crucial fact of life in science:**
have to connect
(a) what you can actually *observe/measure: data*
(b) with what is "really" going on–*models/theory*

In astronomy: observe objects in sky
can measure position = direction on sky
→ 2-number "address" ⇔ 2-dimensional sky but sky gives *no* direct information about distance
→ observed sky flattens the 3-dimensional arrangements down to **2-D sphere** projection: "cosmic roadkill"

Celestial Sphere

In astronomy: observe objects in sky
can measure position = direction on sky
$\rightarrow$ star positions are 2-number "addresses" (N-S, E-W)
so the sky is *2-dimensional*

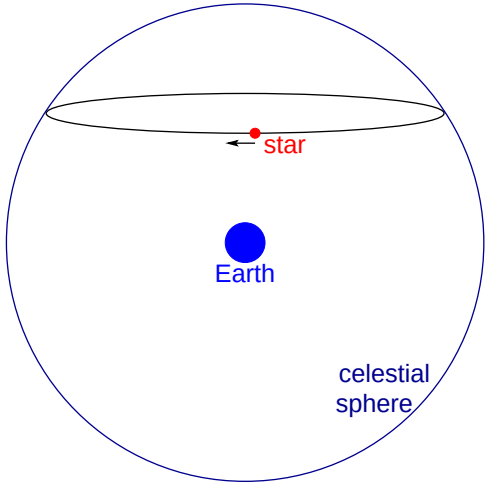
but sky gives *no* direct information about distance
$\rightarrow$ observed sky flattens the 3-dimensional arrangements
down to **2-D sphere** projection

"celestial sphere" defined by stars and their constellations
"hub" of star circles: celestial poles
North star: near N celestial pole ("Polaris")

Dynamics: Star Motions

stars don't seem to move
relative to each other ("fixed")

- i.e., constellations don't morph
  (at least not on human timescales)
- move as if rigid structure on sky
  as if staris are "nailed" to celestial sphere



star motion on sky:

- stars rise in east, set in west once a day
- each star moves in circle on sky (some go below horizon)
- motion is repeating – periodic!
- celestial sphere completes one rotation with *period* $P_{\rm CS} = 1$ day

Sun and Planets: Geometry of Motion

Sun

stays on a circle (a great circle*!) of cel sphere ("ecliptic")

great circle = largest circle on sphere: share same center

great circle = intersection of sphere and plane going thru center

Sun moves among constellations *Q: how would you know?*

`www: Soho coronagraph`

Planets

Greek: "wanderers" – move among constellations

more or less: found on same ecliptic path as Sun

`www: Moon, Mercury, Venus`

Now go from 2-D sky to 3-D space:

Q: what do these observations mean about the 3-D arrangement of solar system?

Sun, Earth, planets, (and Moon) all lie in ≈one single *plane*

`www: Clementine--Sun, Moon, Saturn, Mars, Mercury`

highly ordered! hint as to solar system origin...

Other patterns found:

- Mercury, Venus always near the Sun, never opposite on sky
- other planets can be near or opposite
- planets usually move thru cel sphere *in same direction*
  ...but sometimes backwards "zigzag" → retrograde motion

`www: retrograde animation`

Clearly: then naked-eye sky is highly organized
motions show clear patterns
these cry out for explanation!

Our first task as cosmologists: understand these patterns
We have collected data: on to theories!

retrograde motion not random in occurrence!
key patterns observed:

- for each planet, retrograde onset is *periodic*
  with different periods for different planets
- retrograde occurrence *correlated* with position relative to Sun:

Mercury, Venus	Mars, Jupiter, Saturn (& others)
always stay close to sun on sky *never* seen opposite Sun	can move freely along ecliptic can be opposite sun
retro when in **conjunction** (i.e., when closest to Sun on sky)	retro when in **opposition** (i.e., opposite Sun on sky)

These Patterns Cry Out For Explanation

you may have noticed–I've heaped a lot of facts on you.
Do you have to memorize them? Do *I* have them memorized?
No! There's a simpler way of remembering.
→ build a **model** of the solar system's geometry and dynamics
organize, explain all of this data!

Crucial point:
when making model for motions of planets
have to explain *all* observed features;
turns out the retrograde motion, in all its detail,
gave people the hardest time...