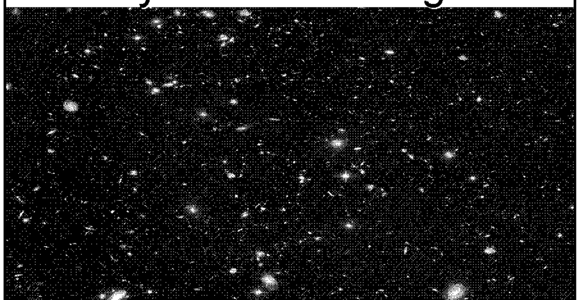
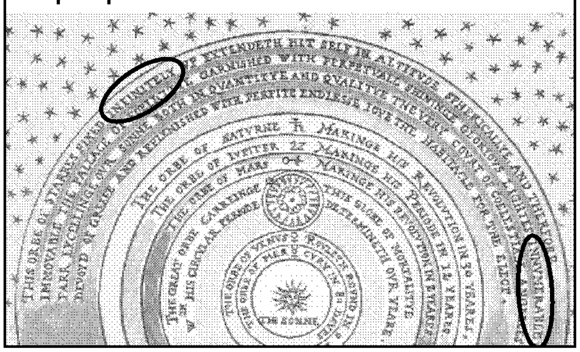
Why is it dark at night?



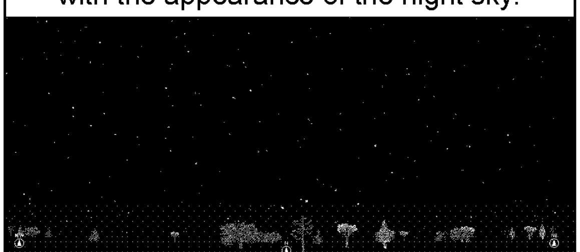
Monday, October 19

Next Planetarium Show: Oct 27 & 28

Thomas Digges (16th century) proposed an **infinite** universe.



An infinite universe is hard to reconcile with the appearance of the night sky.

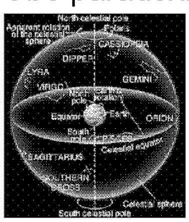


Night sky is **dark**, with stars (small in angular size) scattered across it.

"The night sky is dark." This statement is called **Olbers' paradox**, after astronomer who discussed the subject in 1823.

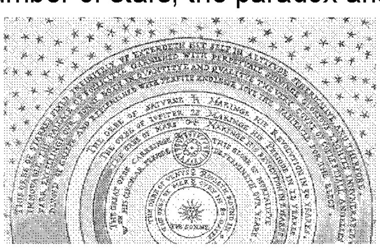
Why is the darkness of the night sky paradoxical?

If stars were stuck on a celestial sphere or dome, darkness would **not** be paradoxical.



Only a finite number of stars on the celestial sphere.

In an infinite universe with an infinite number of stars, the paradox arises.



How bright do we expect the sky to be in such a universe?

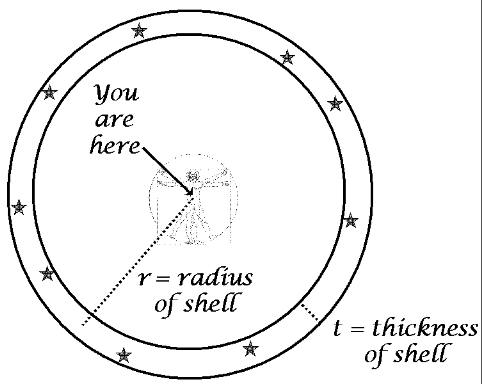
ASSUMPTIONS:

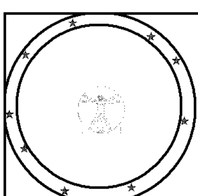
Suppose there are **n** stars per cubic parsec of the universe.

`In Sun's neighborhood, n ≈ 0.1/pc³`

Suppose that an average star has a luminosity L.

`For Sun, L = 4×10²⁶ watts`





What's the **surface area** of the spherical shell?

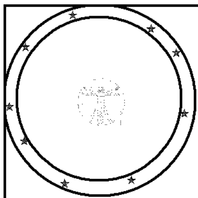
$$\text{Area} = 4 \pi r^2$$

What's the **volume** of the spherical shell?

$$\text{Volume} \approx \text{area} \times \text{thickness} \approx 4 \pi r^2 t$$

How many stars are in the shell?

$$\text{Number} = \text{volume} \times n = 4 \pi r^2 t \, n$$



What's the flux from a **single** star?

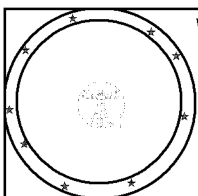
$$\text{Flux} = \frac{L}{4\pi r^2}$$

What's the flux from **all** the shell's stars?

$$\text{Total flux} = \text{Number of stars} \times \text{flux per star}$$

$$\text{Total flux} = 4\pi r^2\, t\, n \times \frac{L}{4\pi r^2}$$

$$\text{Total flux of shell} = t \times n \times L$$



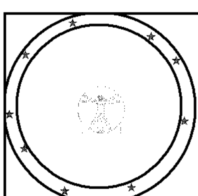
What flux of light do we receive from a single shell of thickness t?

Total flux from shell = t × n × L

\# of stars per cubic parsec

luminosity of single star

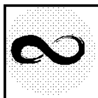
Independent of **r**,
the radius of the shell!



A **single** shell will produce a tiny flux here at Earth.

For a shell 1 parsec thick, flux = t × n × L = 40 nanowatts/meter^2

But we've assumed an **infinite** number of shells!



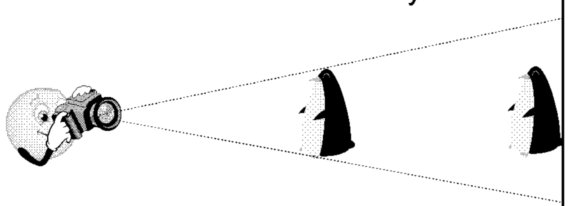
Infinity times any finite number, no matter how tiny, is **infinity**.

Thus, my conclusion is that the night sky has an infinitely high flux.

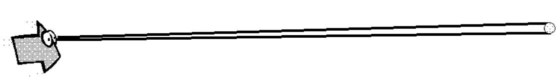
This is crap.

Which of my assumptions is **wrong**?

I assumed **every** star is visible from Earth. Since stars are opaque spheres, distant stars can hide behind nearby stars.



Stars are small compared to the distance between them.



Thus, they appear small in angular size.

The stars in a shell 1 parsec thick cover only 1 quadrillionth (10^{-15}) of the sky.

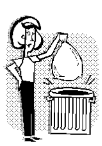
10^{15} (one quadrillion) shells, each covering a quadrillionth of the sky with stars, will completely pave the sky with stars.

Thus, the entire night sky should be as bright as the Sun's surface!

Olbers' Paradox for Trees:

In a large enough forest, every line of sight ends at a tree.

My revised conclusion – that the sky is uniformly bright – is still crap.



The night sky really **is** dark.

Which of my assumptions is **wrong**?

Dubious assumption #1:

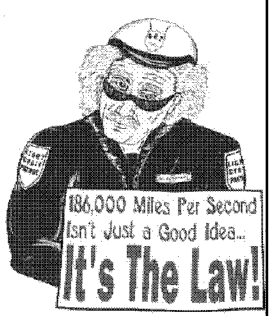
The universe is infinitely large.

Dubious assumption #2:

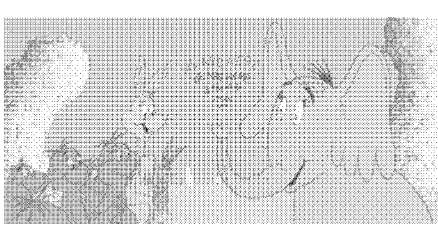
The universe is eternally old.

The speed of light (c) is large but finite.

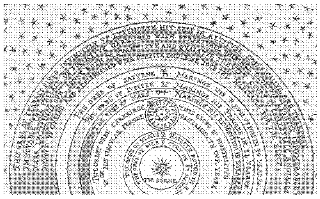
c = 300,000 km/sec (186,000 miles/sec).



If the universe has a finite age, then distant stars haven't had time to send us the message "We're here!"

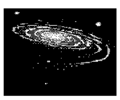
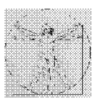
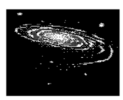


Discussing Olbers' paradox,
we assumed the universe was **static**
(neither expanding nor contracting).

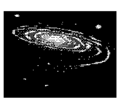
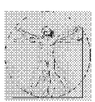
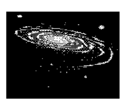


This was the general assumption until the 20th century: but **was it correct**?

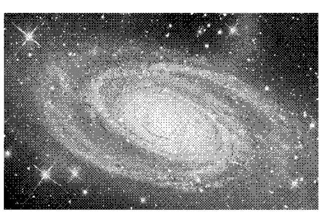
If the universe is **expanding**, distant galaxies will be moving **away from** us.

If the universe is **contracting**, distant galaxies will be moving **toward** us.

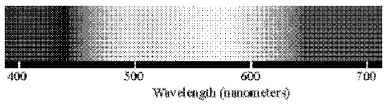
Q: How can we tell if a galaxy is moving toward us or away from us?



A: Look for the **Doppler shift** of light from the galaxy.

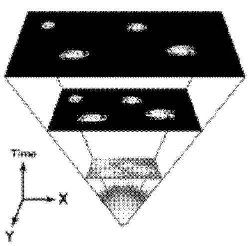
Flashback:

If light source is moving **toward** you, wavelength is shorter (called blueshift).



If light source is moving **away** from you, wavelength is longer (called redshift).

In early 20th century, astronomers were surprised to discover that all distant galaxies are **redshifted**!



Galaxies are moving **away from** each other!

"The Universe is expanding."

Note: Applies only on large scales.

The Solar System is not expanding; it's held together by gravity.

Milky Way Galaxy is not expanding; it's held together by gravity.

Wednesday’s Lecture:

The Expanding Universe

Reminders:

Have you read chapters 1 – 6 ?
Problem Set 3 is due **Wednesday**.
Planetarium shows **Oct 27 & 28.**