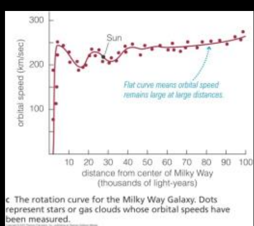
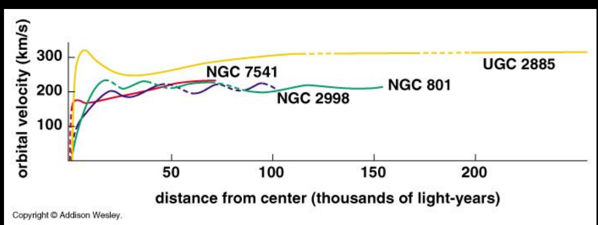
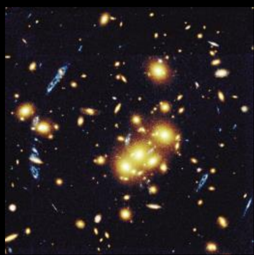
Upcoming Astronomy-themed Talks and Events

Thursday, 3/5, 3:30-5:00p Astronomy Colloquium – Phys-Astr A102 – Cancelled!



c The rotation curve for the Milky Way Galaxy. Dots represent stars or gas clouds whose orbital speeds have been measured.



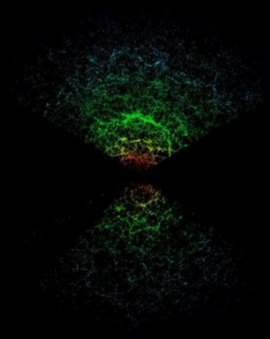


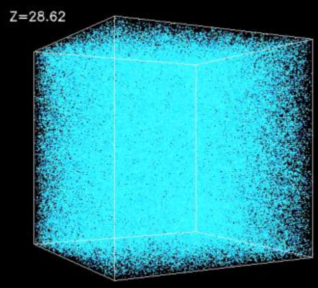
We saw last week that despite the activity in the centers of galaxies, most of the mass of a galaxy actually lies far out in its halo – not tightly concentrated in the center, the way that the luminous matter – the stars, gas, and dust – clearly are.

Study after study has confirmed the presence of this ***Dark Matter***, which seems to represent about 90% of the total amount of matter in galaxies. That dominance makes it *the* primary driver in producing and shaping galaxies, as well as the groups, clusters, and superclusters that galaxies are found in.

Cluster Abell 1689 – the radial velocities of the individual galaxies, the x-rays (purple) from intergalactic gas, and lensed images of background galaxies all point to dark matter.

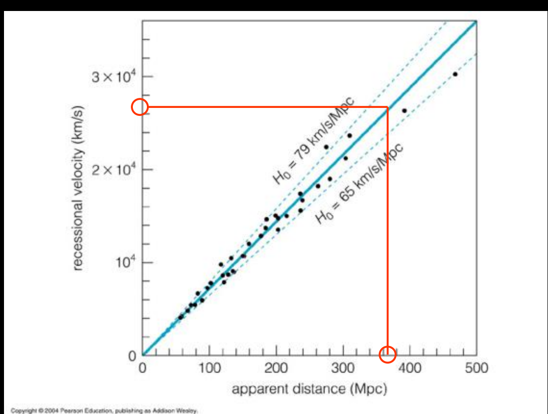
What is the stuff? It appears most likely to be some previously undetected subatomic particle – a Weakly Interacting, Massive Particle, or WIMP for short. Such things have certainly been predicted and found before, and the race is on to figure this out now! Any answer we find – even if it turns out to be that there really ***isn't*** dark matter – will be revolutionary.





A good way to constrain the characteristics of this dark matter – to set limits on how massive the particles are, or how they interact with each other – is to make simulations of how various ‘types’ of dark matter would coalesce to form galaxies, and then compare them to observed reality – like the map above, showing the positions of millions of galaxies in the Sloan Digital Sky Survey.

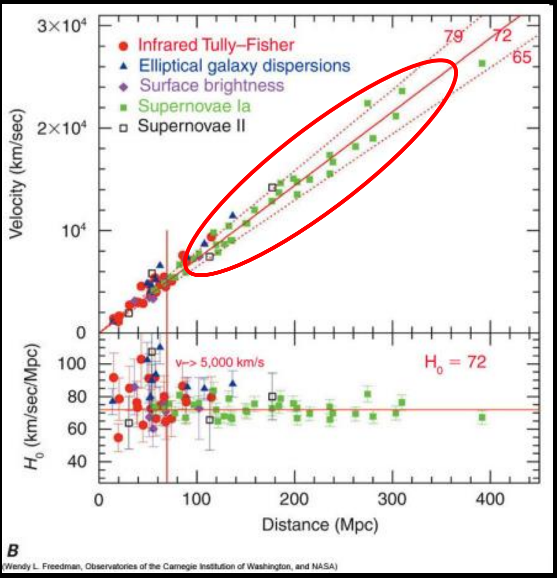
Those maps are largely made using the “Hubble Law”, which ties a galaxy’s (easily measured) redshift to it’s distance.



Step 1: Measure redshift

Step 2: Lookup redshift on graph

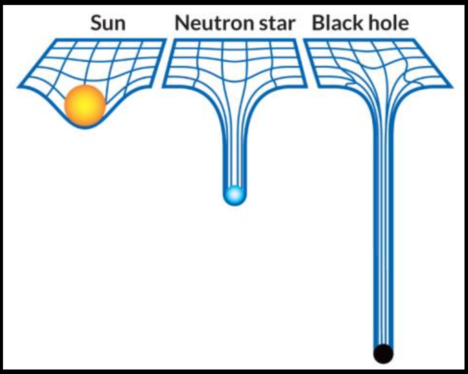
Step 3: Read off distance!



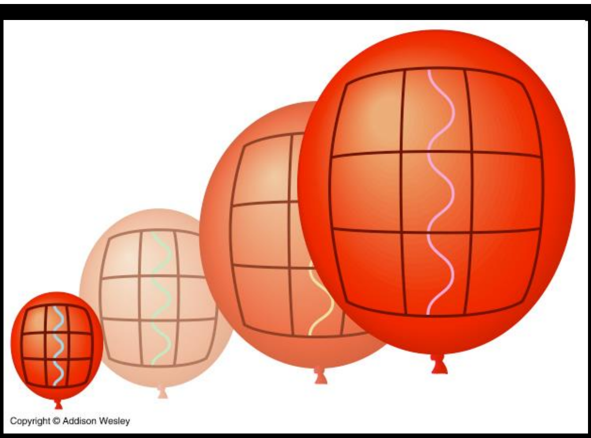
And if White Dwarf supernovae are true standard candles, the Hubble Law remains valid to very large distances in the universe – albeit with some subtle but ***extremely*** interesting modifications that we'll see in a bit!

But for now I'd like to focus on something else you may have noticed (!!!) about Hubble's Law – essentially <u>all</u> galaxies are moving away from us – is the Milky Way therefore at the center of the Universe? Are all galaxies outside of our local group running madly away from us?

This result may seem very strange, but it was ***not*** that surprising to those who discovered it in the late 1920s. The postulates of General Relativity had suggested that spacetime itself ***could*** contract or expand globally, depending on the distribution of matter and energy in the universe.

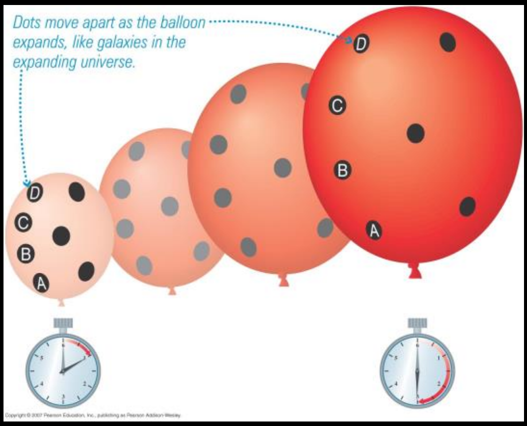


We've already seen *contracting* spacetime – in the vicinity of a black hole!

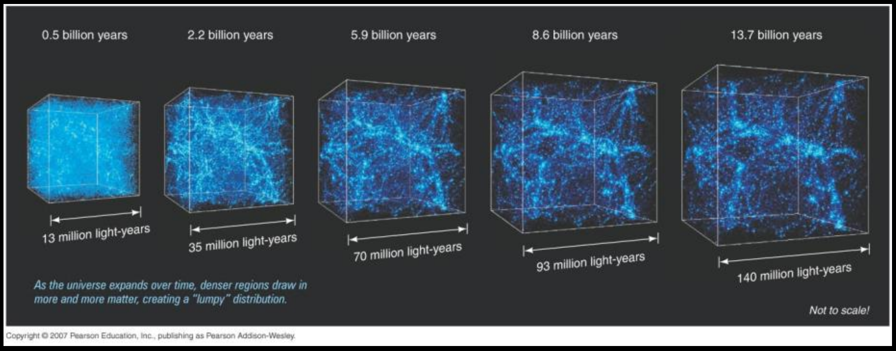


The apparent "motions" seen in distant galaxies were attributed to just such an *expansion* – the observed "velocities" weren't true velocities, but were caused by spacetime literally *stretching* apart in the vast, empty expanses between galaxies, and affecting the wavelength and frequency of the light passing through it.

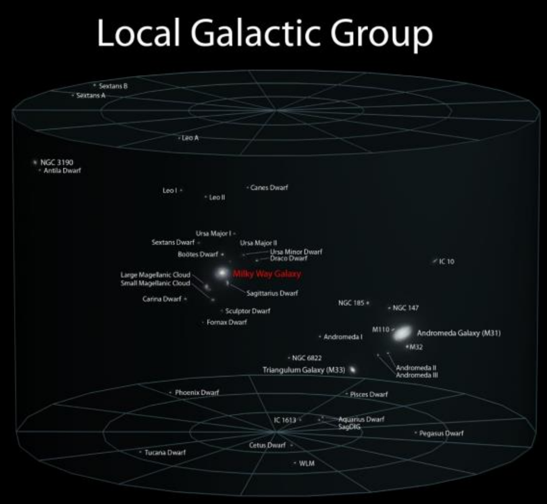
Spacetime itself is expanding, and galaxies are merely riding this wave of expansion, appearing to move away from us. So there is no center we're all moving from – from any galaxy's point of view, all other galaxies are moving away from it.



Our universe is the 2-dimensional ***surface*** of the balloon in these analogies – and there is no center or edge to the surface of a balloon!

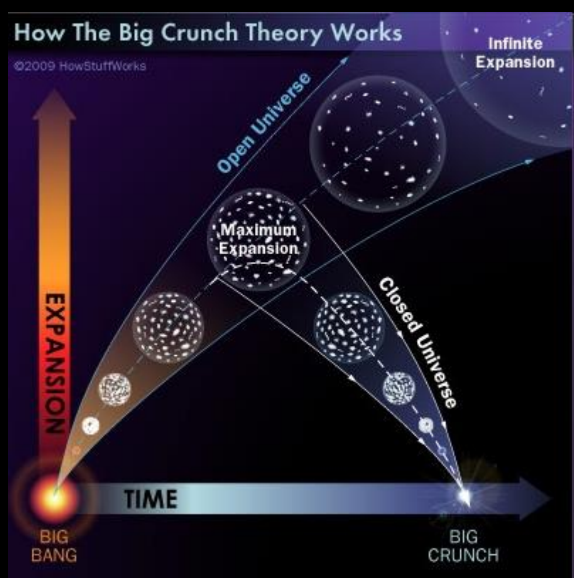


However, gravity can overcome the expansion of spacetime in localized regions and pull matter together. This is how clusters and superclusters of galaxies form in the early universe, from regions of the cosmos that have so much matter in them that they collapse – in defiance of the expansive properties of spacetime.



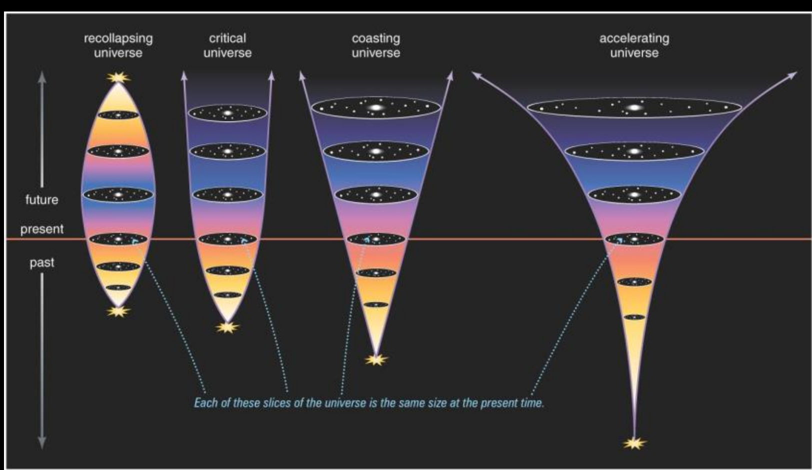
The Local Group of Galaxies is one such region – the Milky Way, the Solar System, and the Earth are not expanding apart in any way. The density of gravitating material within a few million light years of us is simply too great for the expansion to overcome.

Gravity always acts to slow down the expansion of the universe – and if the total amount of matter in the universe is large enough it should eventually collapse on itself in a “Big Crunch”. Is that what our future holds?

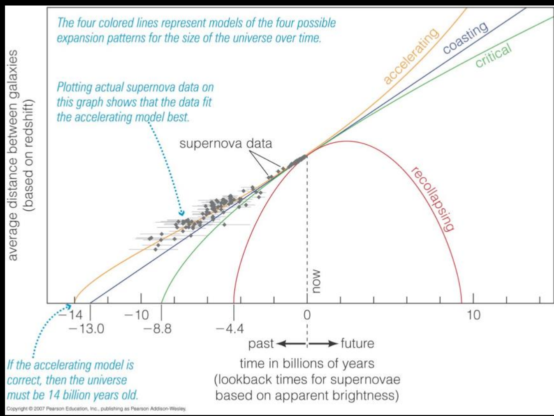


The degree to which the gravitating matter in our universe contains and limits its expansion defines four categories of "Models for the Future of the Universe":

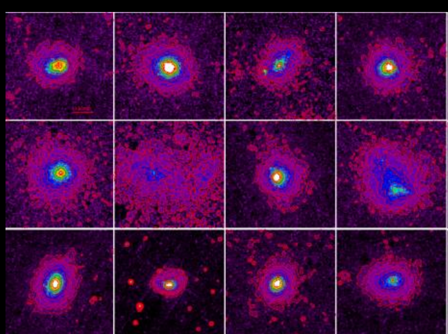
1) ***Recollapsing Universe***: the expansion will someday halt and reverse; "Big Crunch".
2) ***Critical Universe***: the universe will not collapse, but will expand ever more slowly with time, approaching a "stop" in the infinite future.
3) ***Coasting Universe***: the universe will expand forever at the current rate, or with little slowdown.
4) ***Accelerating Universe***: the expansion will not only continue, but will actually accelerate with time.



A key point is that the "age" of the universe is different in each of these models – denser universes ***must*** have shorter overall histories. Had they been around longer, their self-gravity would already have slowed the universe down beyond its current rate of expansion.

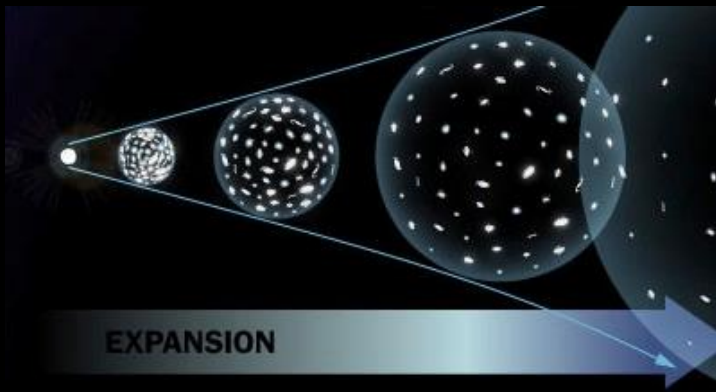


This all suggests a way to determine which of these models is correct, since each predicts a different age for the universe. The "recollapsing" model, for example, suggests that the universe cannot be more than 5 billion years old – and since we see star clusters that are clearly older than that, we can rule this model out.



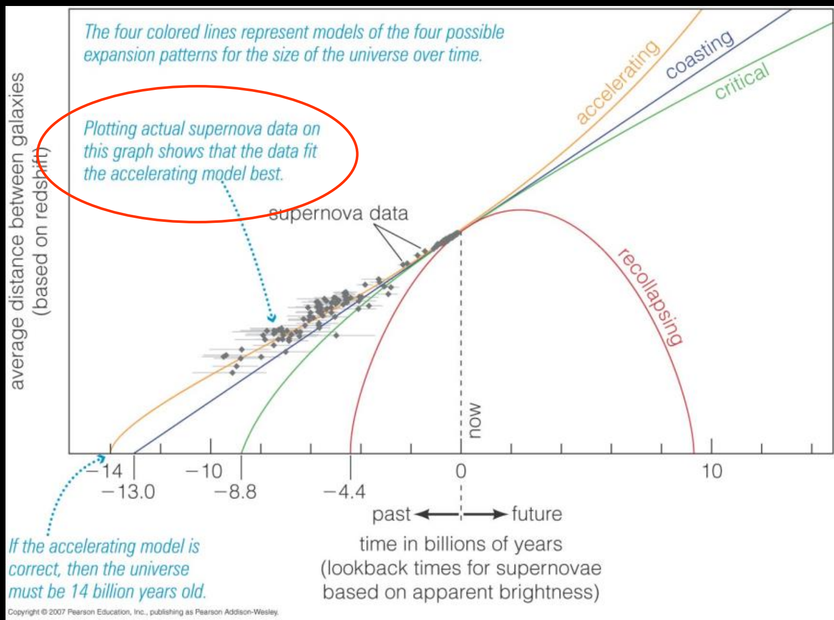
Images of x-rays from hot gas trapped by gravity in a dozen different galaxy clusters – lots of Dark Matter, but not enough to collapse the Universe!

The "critical" universe is eliminated by similar observations, along with the fact that the *critical density* that's needed in that model – 10^{-29} g cm^{-3} – is much greater than our largest reasonable estimates on how dense the Universe really is – which is more like around 10^{-31} g cm^{-3} (including dark matter).

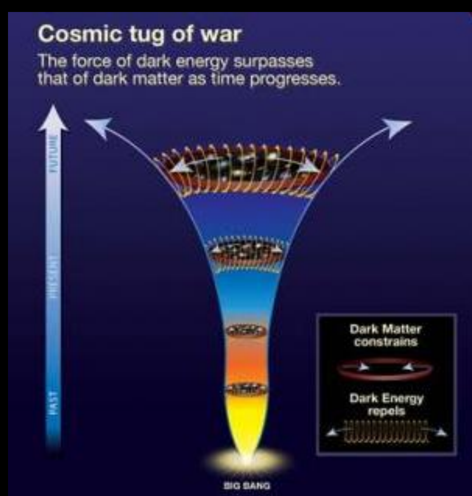


The age of the Universe and its low density suggest we live in a universe that will not collapse on itself due to the gravity of its own matter – but will the universe keep expanding at the same rate? Or could the expansion possibly increase over time somehow?

Until recently, that last idea had very little physical reason to support it, as ***accelerating*** galaxies apart would require some additional, previously unknown force to repel against gravity in some way. But recent observations of very distant galaxies seem to be leaning towards precisely that model.



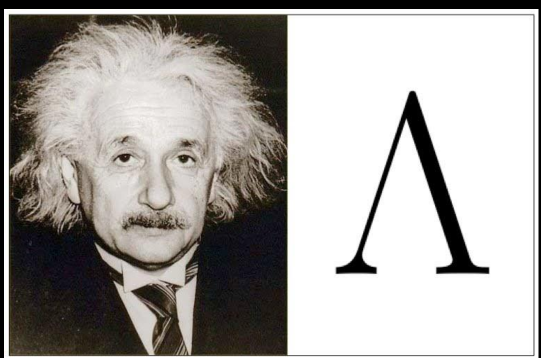
These results have caused considerable turmoil in astrophysics. What could be causing this acceleration in universal expansion, in the face of the resistance of gravity? The answer is very unclear – our best current theories about this involve changes to our understanding of the physics of spacetime at a fundamental level, and are generally lumped into a broad category of ideas called ***Dark Energy***.



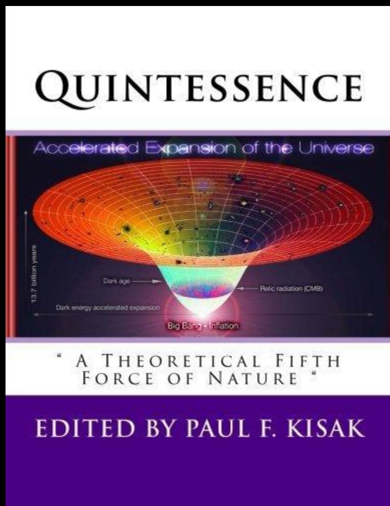
The apparent role of Dark Matter and Dark Energy

This is a bit poorly named, as whatever this energy is, it's not likely to give off light anyway, so "dark" seems unnecessary– but it does capture two key components of the evidence so far:

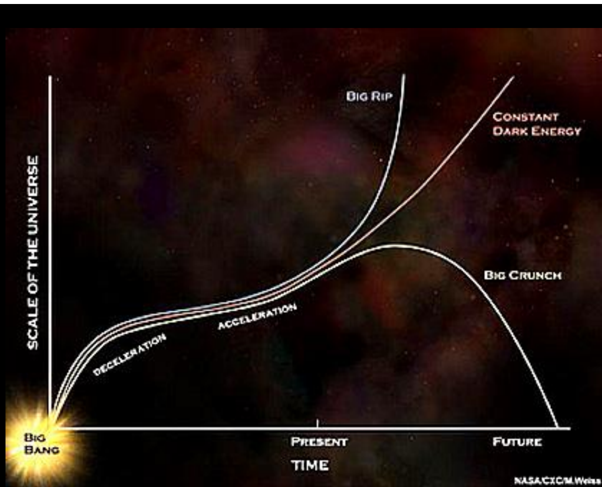
1) Some source of ***energy*** is required
2) We're in the ***dark*** as to what it is!



It remains highly, highly uncertain at this time what the explanation for dark energy is – perhaps a cosmological constant energy to 'empty' spacetime (as Einstein himself once postulated, before he knew of the universe's expansion)? This idea has a lot of history, and is popular amongst many scientists.

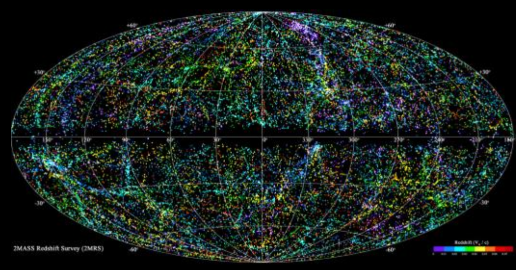


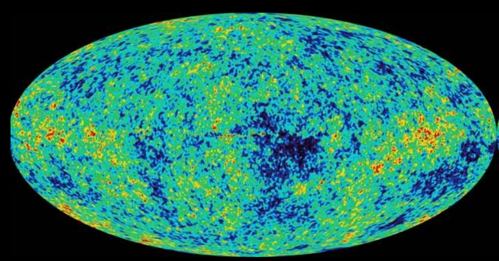
Or maybe there's something more unexpected at work – perhaps a new physical 'force' ("quintessence"), or some subtle new wrinkle to gravity, one that could possibly explain Dark Matter too?



Might this dark energy change again? Will its expansive pressure fade or reverse with time? Or grow to the degree that it rends apart even galaxies, stars, planets and protons– the "Big Rip"?

The answer remains ***very*** unclear – but as we've seen, we can find clues to our deep future by studying light from the very distant past, light that emerged in regions many billions of light-years from the present Earth.





Many of these observations are complex and difficult to understand, but at least one simple observation you have all made tells us something very profound about the early universe…

the Sky is Dark at Night.

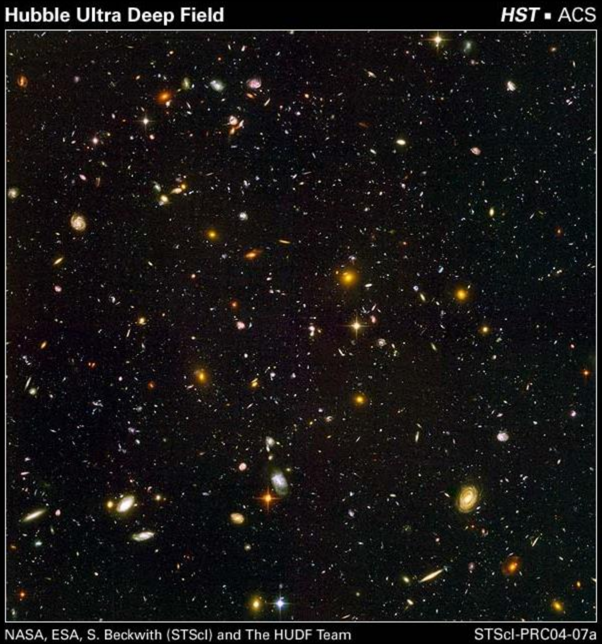
Now this may not *seem* profound, but in 1610 our old friend Johannes Kepler pointed out that it says something very important about the history and extent of our universe!

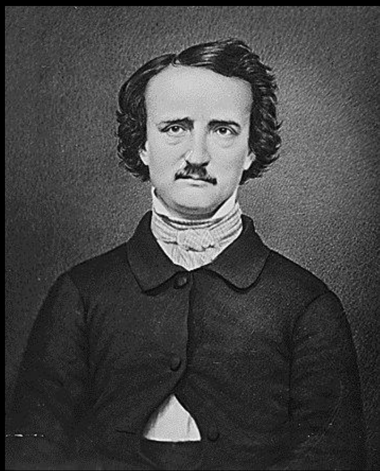
Imagine, Kepler wrote, that the Universe is infinite in both time and space, with an infinite number of stars in all directions. If that were the case, then looking out at the stars would be somewhat like looking around from inside a great forest. In such a forest, every sightline eventually encounters a tree, so that your entire field of vision is filled with… well… trees!

Similarly, when one looks out at the stars, every line of sight should eventually encounter one of the infinite numbers of stars in the universe, so that the entire sky should shine like the surface of the Sun – all day, and all of the night!

Kepler believed that the solution to this paradox (later named *Olber's Paradox*) was that the number of stars was small, and that they were only located close to the Earth – like a small forest through which you could see the background sky.

However, in the last 100 years we've learned that the universe is ***much*** larger than Kepler believed – large enough to make an "infinitely" large universe at least something worth seriously considering!



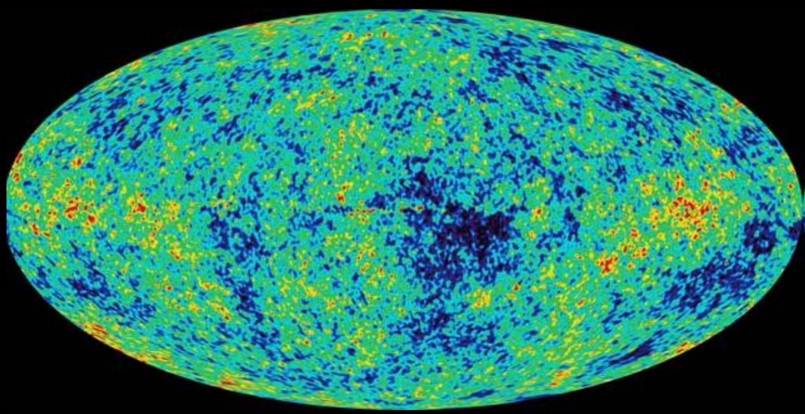


Quoth the Raven:
"The Universe can't be infinite!"

A more accurate solution was proposed by Edgar Allen Poe (yes, that Edgar Allen Poe!) in 1848. He noted that because light travels at a finite speed, if the universe were finite in ***age***, it would be finite in its ***observable size***. Light from very distant stars simply would not have had time to reach us since the universe began, thus limiting the size of the "forest" we're able to look through.

So from these simple observations, he concluded that the universe must have had some 'beginning' – some point before which the stars and galaxies did not exist in the way we see them now!

What was that early time like? How did our Universe ‘begin’, and what does our future hold?



We’ll pick up there next time!