

Hot Science - Cool Talk # 117

Investigating Our Cosmic Origins

Dr. Caitlin Casey February 15, 2019

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Investigating our Cosmic Origins

The story of three groundbreaking measurements of the Universe's scale and our place within it

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Light is our primary tool in astronomy.

Maya Astronomy — Mexico c. 250-900 CE accurate accounting of astronomical calendar

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Astronomy: the Oldest Science

Nebra Sky Disk — Germany 1600BCE

Astronomy: the Oldest Science

Babylonian Tablet describing Halley's comet observation 164 BCE

Astronomy: the Oldest Science

Antikythera Mechanism — Greece 100-200 BCE

Astronomy: the Oldest Science

Su Song's map of southern celestial pole — China 1100s CE



Turning the static, flat sky into the story of our cosmic origins.

Three stories from three centuries.



Scale of the Solar System



Mystery of the Spiral Nebulae





A Universe no one predicted







Scale of the Solar System



Copernicus (early 1500s)



The planets orbit the Sun and not the Earth.



Copernicus (early 1500s)



Length of the year gives planets' *relative* distance from the sun.



Johannes Kepler (early 1600s)

(jupiter)

The planets' orbits follow a distinct pattern.

The length of a planet's year squared was found to be equal to its relative distance from the Sun compared to Earth.



The scale of the Universe was unknown, rooted in our lack of perspective on the solar system.



historical estimates on the distance to the sun

estimated by	earth radii
Archimedes 3rd century BCE	10,000
Aristarchus 3rd century BCE	380-1,520
Hipparchus 2nd century BCE	490
Posidonius 1st century BCE	10,000
Ptolemy	1,210
Christiaan Huygens (1659)	24,000
Jerome Lalande (1771)	24,000
Modern Astronomy	23,455

Geometry of Venus



The scale of the Universe was unknown, rooted in our lack of perspective on the solar system.

Transit of Venus (like an eclipse)







1639

predicted by Kepler observed by Horrocks

1631















HOT





Stars were decoded: their lifecycle understood.

Stars show chemical signatures of many elements found on earth... Larger stars burn much brighter and hotter and die young...

Stars are born together and migrate from their birthplace as they live...

Simon Newcomb, President & Founder of the American Astronomical Society

"We are probably nearing the limit of all we can know about astronomy." -1888

"Flight by machines heavier than air is unpractical and insignificant, if not utterly impossible." -1902





Edward Pickering and the Harvard "Computers"

1913 Meticulously cataloged every star in the night sky visible through a pair of binoculars.







Annie Jump Cannon

developed our stellar classification scheme, also a prominent suffragist, member of deaf community.

Henrietta Swan Leavitt

found a unique set of stars that pulsated and were of special use to measure intergalactic distances, also a member of deaf community.

Cecilia Payne

inferred the true composition of stars as primarily hydrogen and helium, first woman to earn a PhD in astronomy from Harvard (Radcliffe).







Annie Jump Cannon

developed our stellar classification scheme, also a prominent suffragist, member of deaf community.

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Not everything in the sky is a star! Figuring out the rest was puzzling.

The Great Debate of 1920





Measuring distances beyond parallax: standard candles





Measuring distances beyond parallax: standard candles



Annie Jump Cannon with Henrietta Swan Leavitt



Cepheid Variables established as the best "standard candle" nearby. Measure period and apparent brightness, get distance.



The Scale of the Universe comes into focus

1920s: Edwin Hubble uses Leavitt's standard candles to show that spiral "nebulae" are much more distant than previously imagined:

10's — 1000's of times more distant than the farthest part of our Milky Way.

An independent survey of the spiral nebulae suggested something odd about their motion...



Measuring the motion of objects in the sky: towards us or away from us?

The Doppler effect is audible with cars traveling toward/away from us. Redder/bluer than normal light is used for astronomical objects!



Blue light! Towards us!

Red light! Away from us!

An independent survey of the spiral nebulae suggested something odd about their motion...





Known as "Hubble's Law."

The mind-boggling implications of Hubble's Law

Why is everything receding away from the Milky Way Galaxy? Are we at the center of the universe?



The mind-boggling implications of Hubble's Law

Why is everything receding away from the Milky Way Galaxy? Are we at the center of the universe?



The mind-boggling implications of Hubble's Law

Why is everything receding away from the Milky Way Galaxy? Are we at the center of the universe?



From this perspective, all galaxies also appear to be moving away, similar to what we see from the Milky Way.

The same holds true from all perspectives.



Not favored by prominent astronomers of the era: Fred Hoyle, Thomas Gold, Hermann Bondi...

The Universe is EXPANDING.

EXPANDING.

EXPANDING.

The Big Bang!

If you rewind this process, everything was contained in a point ~14 billion years ago....



cosmic time

Einstein's "Greatest Blunder"

 $R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} + \Lambda g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$

A Universe no one predicted

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The Project of the 20th Century: going as far as possible!





A brighter standard candle needed...



White Dwarf Supernovae (Type Ia) Emit more than energy than an entire galaxy over the span of a ~day, can be seen halfway across the observable Universe.

SN 2013cu (iPTF13ast)





SPEED LIMIT 299 792 458 m/s

More distant galaxies? Millions to billions of years...

The Sun's light takes ~8 minutes to reach Earth. Reflected light from Satrun takes ~1 hour. Light from the nearest star outside of the solar system takes 4.3 years. Light from the Andromeda galaxy takes 2 million years (longer than humans have been around).

Light from nearby galaxies used to infer cosmic expansion has taken several 10s-100s of millions of years to reach us (think dinosaurs).

Supernova Refsdal (so distant it happened 9.4 billion years ago, before the solar system existed.)

Maybe the Universe was different in the distant past?

Maybe the Universe was different in the distant past?

is the expansion slowing down with time?

is the slope of Hubble's Law getting shallower?

cosmic time

The Project of the 20th Century:

going as far as possible!

The Universe used to expand at a slower rate, and the expansion is SPEEDING UP.

The leaders of these teams won the 2011 Nobel Prize in Physics for this discovery.

Saul Perlmutter, Brian Schmidt, Adam Riess

What is the last frontier?

The scales of the Universe are daunting, yet we endevour to understand it and be a part of it.

Thank you. (and don't forget to look up!)

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