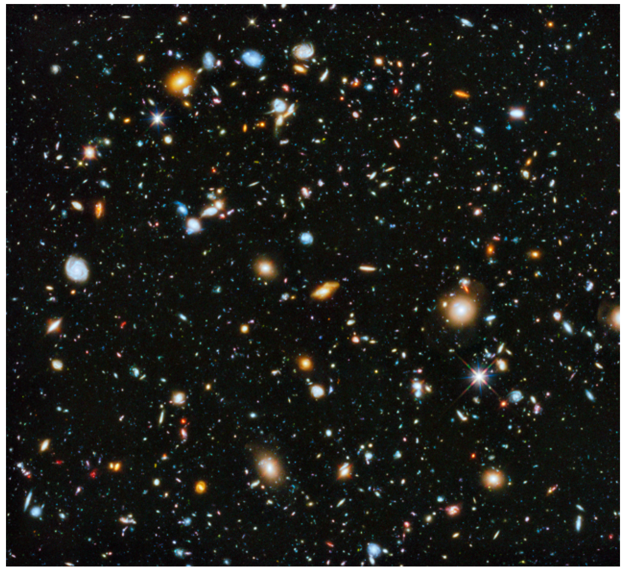
Nobel Prize in Physics 2019



Jim Peebles, Michel Mayor, Didier Queloz

"for contributions to our understanding of the evolution of the universe and Earth's place in the cosmos"

Jim Peebles

Princeton University, USA

"for theoretical discoveries in physical cosmology"

One half of the award

Michel Mayor
University of Geneva, Switzerland

and

Didier Queloz
University of Geneva, Switzerland
University of Cambridge, UK

"for the discovery of an exoplanet orbiting a solar-type star"

Sharing the other half of the award

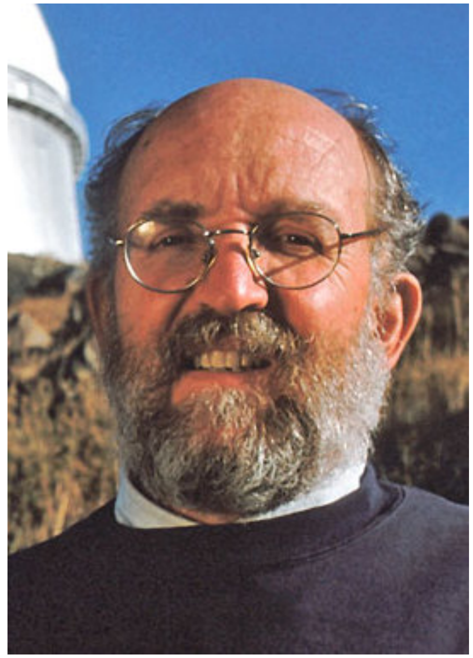
Phillip James Edwin “Jim” Peebles

Princeton University

Canadian-American Astrophysicist

84 years old, born in Winnipeg, Manitoba, Canada

PhD Princeton 1962, Thesis Advisor Robert Dicke



Michel Gustave Édouard Mayor

University of Geneva

Swiss Astrophysicist

77 years old, born in Lausanne, Switzerland

PhD Geneva Observatory 1971

Didier Queloz

University of Geneva and Cambridge University (UK)

Swiss Astronomer

53 years old, born in Switzerland

PhD University of Geneva 1995, Thesis advisor Michel Mayor

Exoplanets

Planets outside of our Solar System

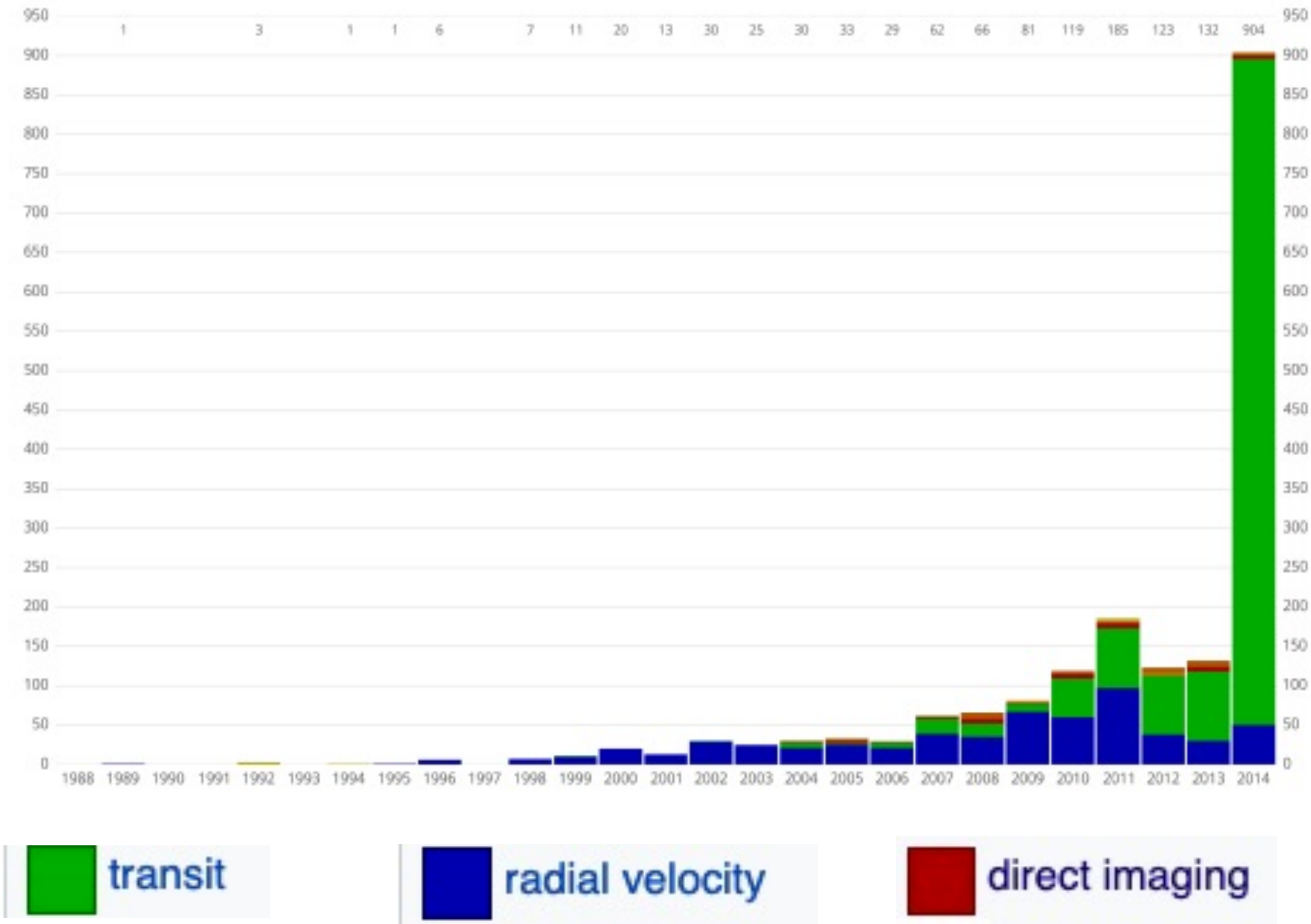
At the present time over 4100 exoplanets have been discovered in our galaxy. Some of these have already been found to be in the "Goldilocks Zone" where liquid water can exist. If these exoplanets are earth-like then they could support life. These planets are in the Circumstellar Habitable Zone and are called CHZ Planets. Depending upon the assumptions there are between 11 Billion and 40 Billion CHZ Planets in our galaxy and similar numbers in other galaxies.

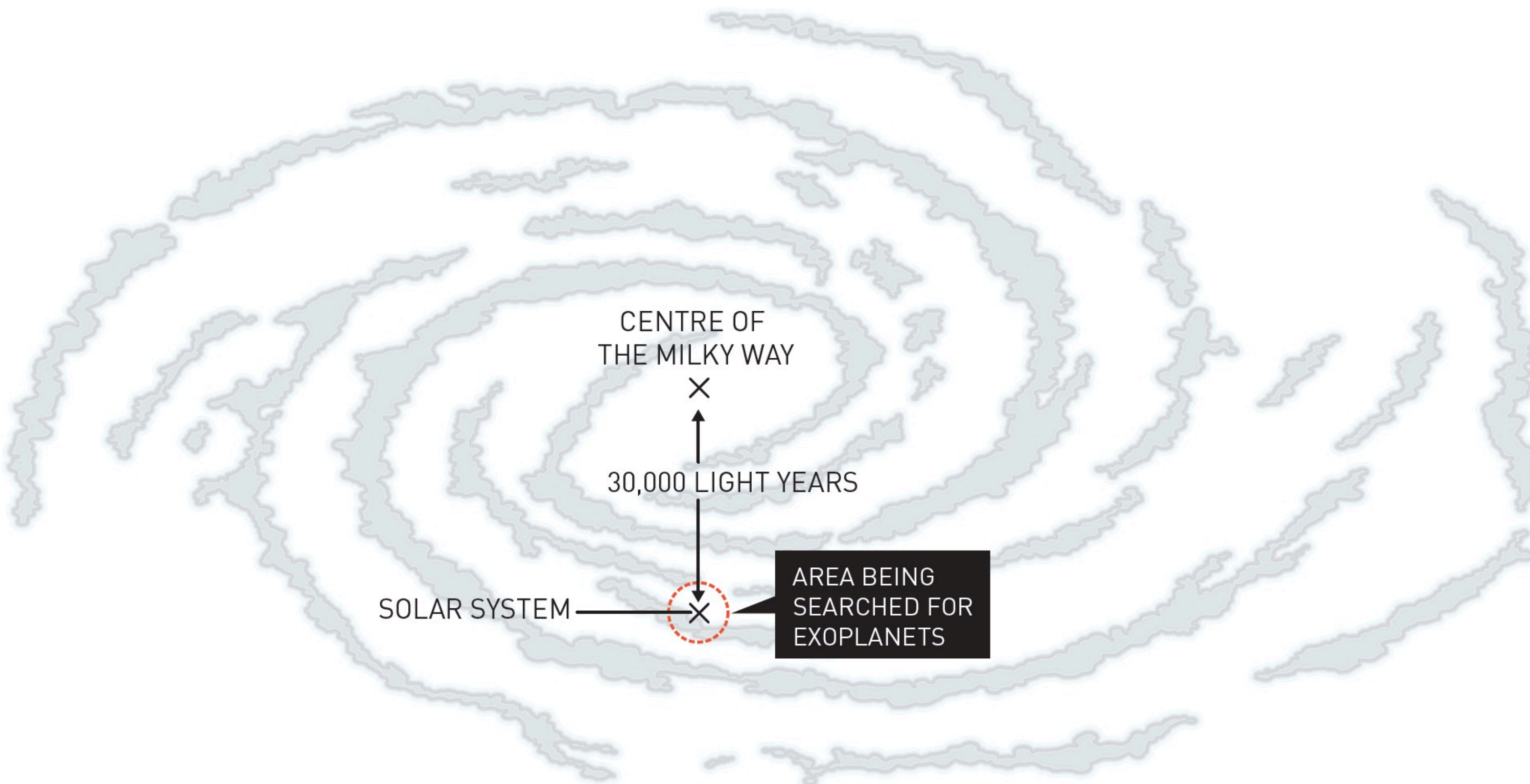
Detection Methods

The four major detection techniques listed by the percent of the exoplanets found

Transit	78%
Radial Velocity	19%
Direct Imaging	1%
Gravitational Microlensing	2%

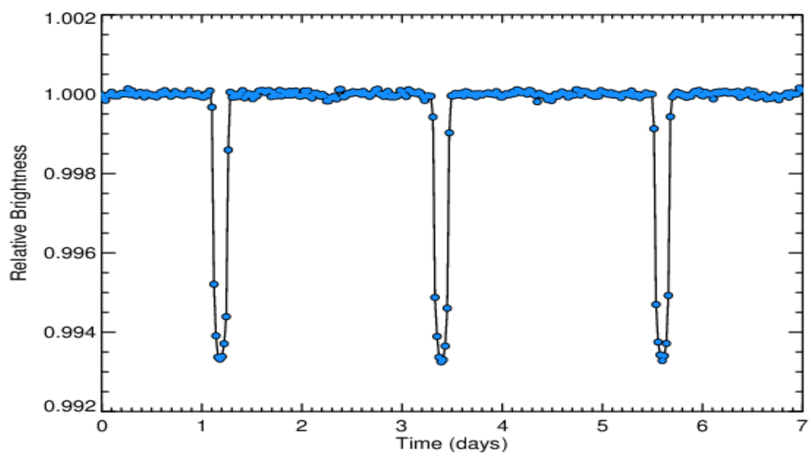
Exoplanet Discoveries by Method

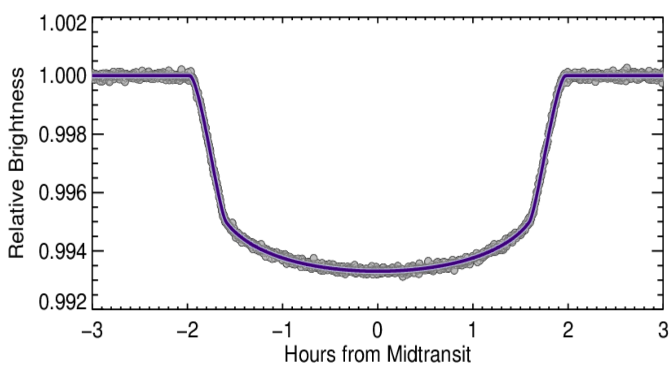


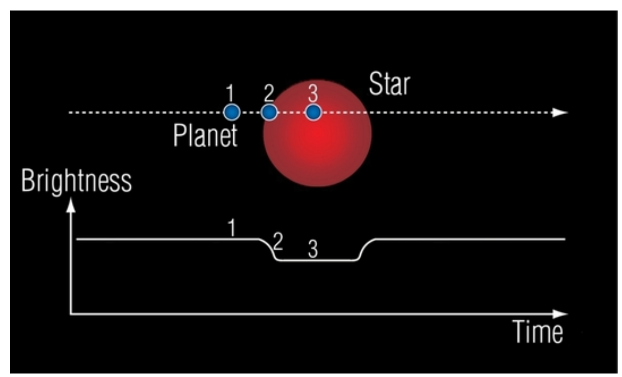


All of the detected exoplanets are in this small spherical region. Just imagine how many are in the whole galaxy and the rest of the Universe.

Transit Method



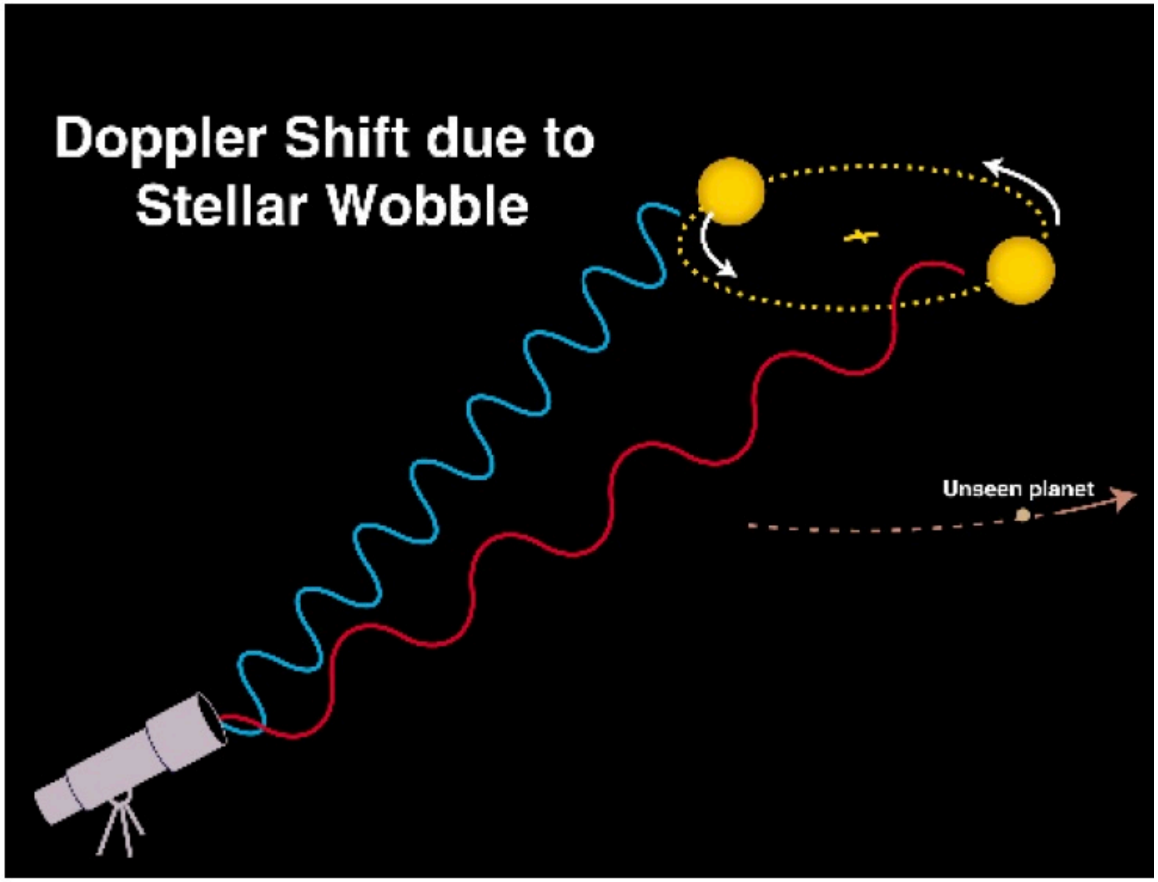




Radial Velocity Method

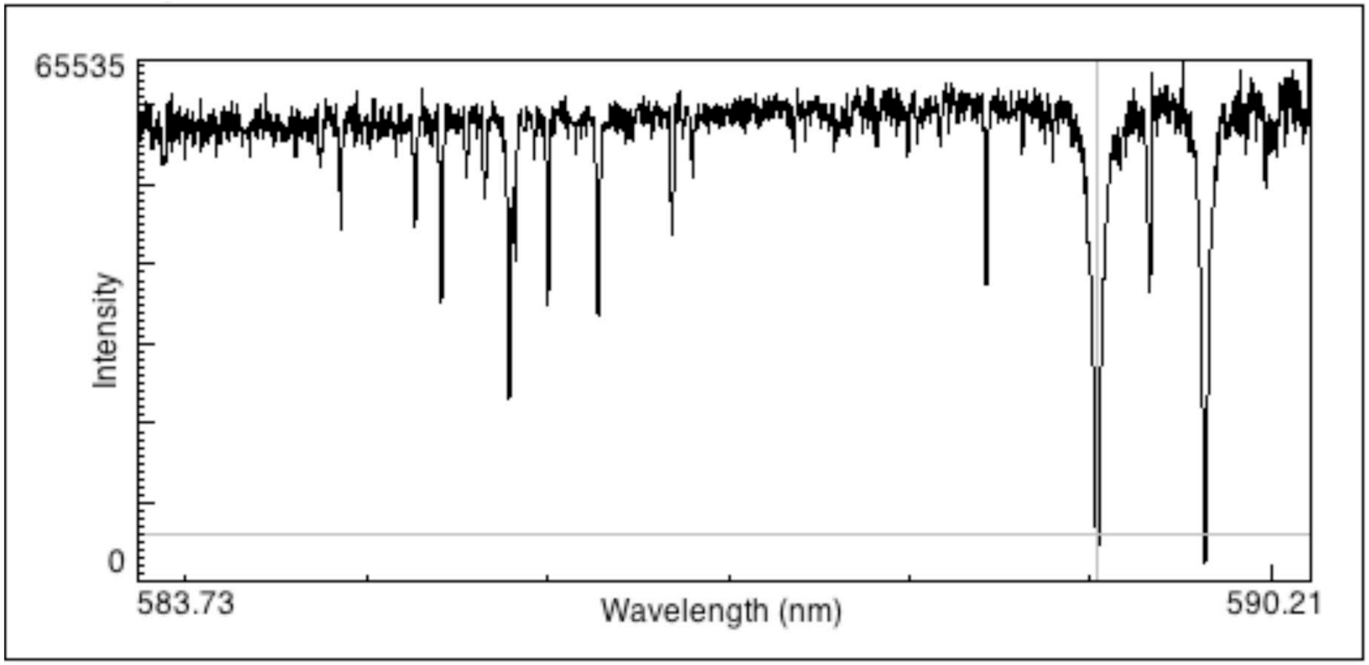
The basis for this technique is the Doppler Effect.

The star and its unseen planet orbit about their center of mass.



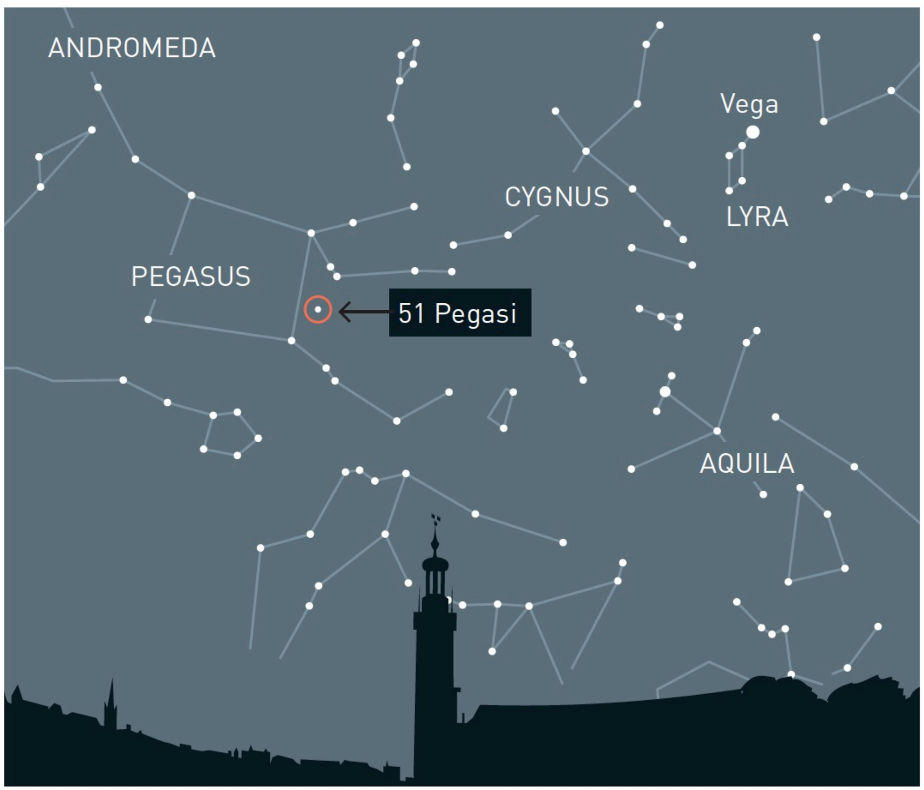
Stellar Spectra: Light Intensity versus Wavelength

Spectrographs permit measurements like these:

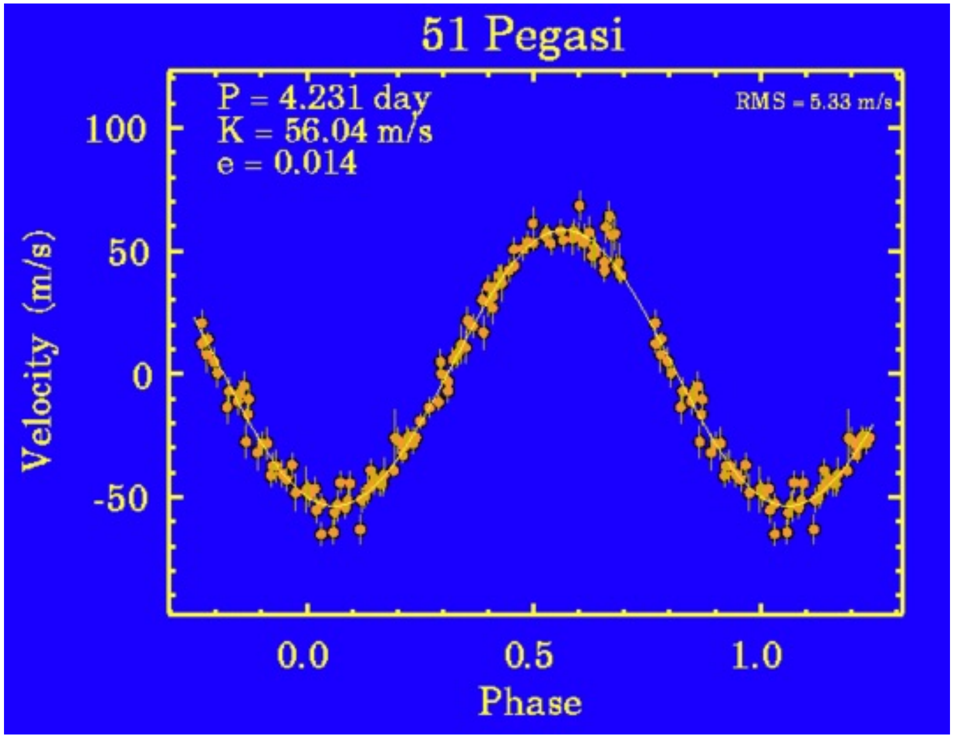


The sharp intensity dips are spectral absorption lines from known chemical species. Extremely accurate measurements of the wavelengths over time can determine the Doppler Shift.

51 Pegasi (51 Peg) is in the constellation Pegasus in the northern sky. Queloz and Mayor studied the spectrum of this star with Elodie, an instrument designed to measure very accurate radial velocities.



Their measurements of the radial velocity over many cycles gave rise to this curve. The wobble allows extraction of data about the unseen planet.



51 Pegasi has a spectral classification of G2, the same as our sun. Its planet is designated as 51 Pegasi b, has a mass of about half of that of Jupiter, has a period of a little over four days, and it's very near to its star. (~5% of our distance to the sun)

The **significance** of the discovery of 51 Pegasi b in 1995 is both the existence of planets around solar type stars and the confirmation that the radial velocity method can find exoplanets. This planet was subsequently named Dimidium as the first one of its species. As pioneers in this type of exoplanet searches Mayor and Queloz were awarded half of the Physics Nobel Prize for 2019.

Modern Physical Cosmology

is based upon the Big Bang,

an event that we believe occurred

about 13.8 Billion years ago.

Since antiquity there has been a debate as to whether the Universe has had a finite or an infinite past. Among others theologian Robert Grosseteste in 1225 suggested that the Universe was born in an explosion and later crystallized.

In 1848 Edgar Allen Poe in “Eureka” proposed that the Universe began from a single primordial particle that divides into all of the rest of the particles that we see.

In 1931 Father Georges Lemaître conjectured that the Universe began with the idea of an exploding primeval atom based upon the mathematical model of Edwin Hubble and the expanding Universe (Eventually dubbed the Big Bang)

Cosmic Microwave Background (CMB)

CMB is the relic radiation left over from the Big Bang.

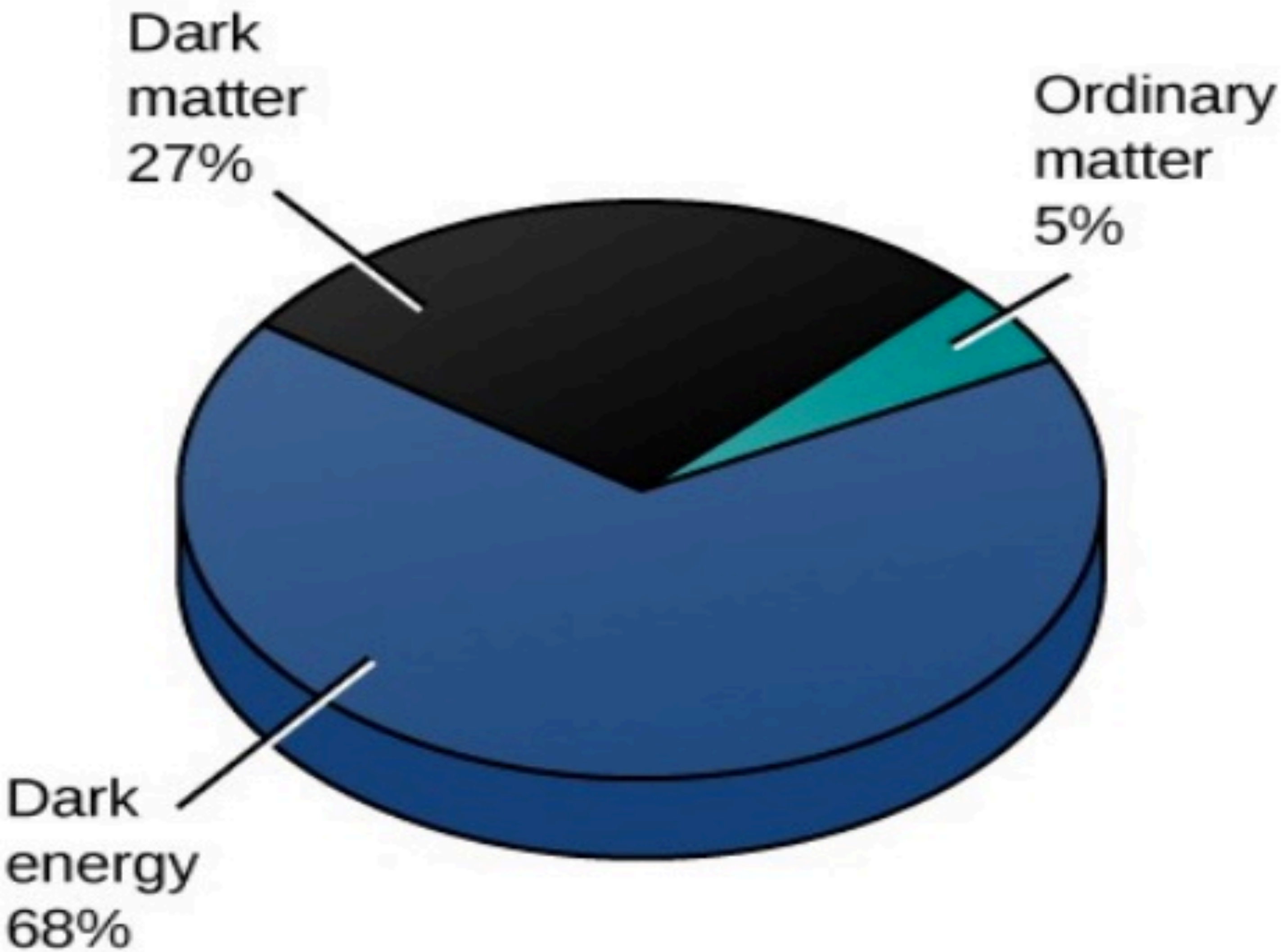
As the Universe expanded this very hot radiation cooled down and is currently at an average temperature of about 2.7 K (kelvins). This is only 2.7° Celsius above absolute zero. CMB was predicted several times from the 1940s to the 1960s (Including by Jim Peebles). The CMB was accidentally discovered by Penzias and Wilson in 1965 (Nobel Prize 1978), after which most cosmologists came to believe that the Big Bang was the best cosmology.

Prior to the CMB detection there existed two main serious cosmological models: The Steady-State Universe (With no beginning) and The Big Bang (Finite lifetime). After CMB most people from the ageless model moved to the Big Bang. The most influential person staying with the Steady-State model was Fred Hoyle. (Ironically he named the “Big Bang”.) He was faced with explaining the observations which the Big Bang could do easily. He never gave up but lost the debate.

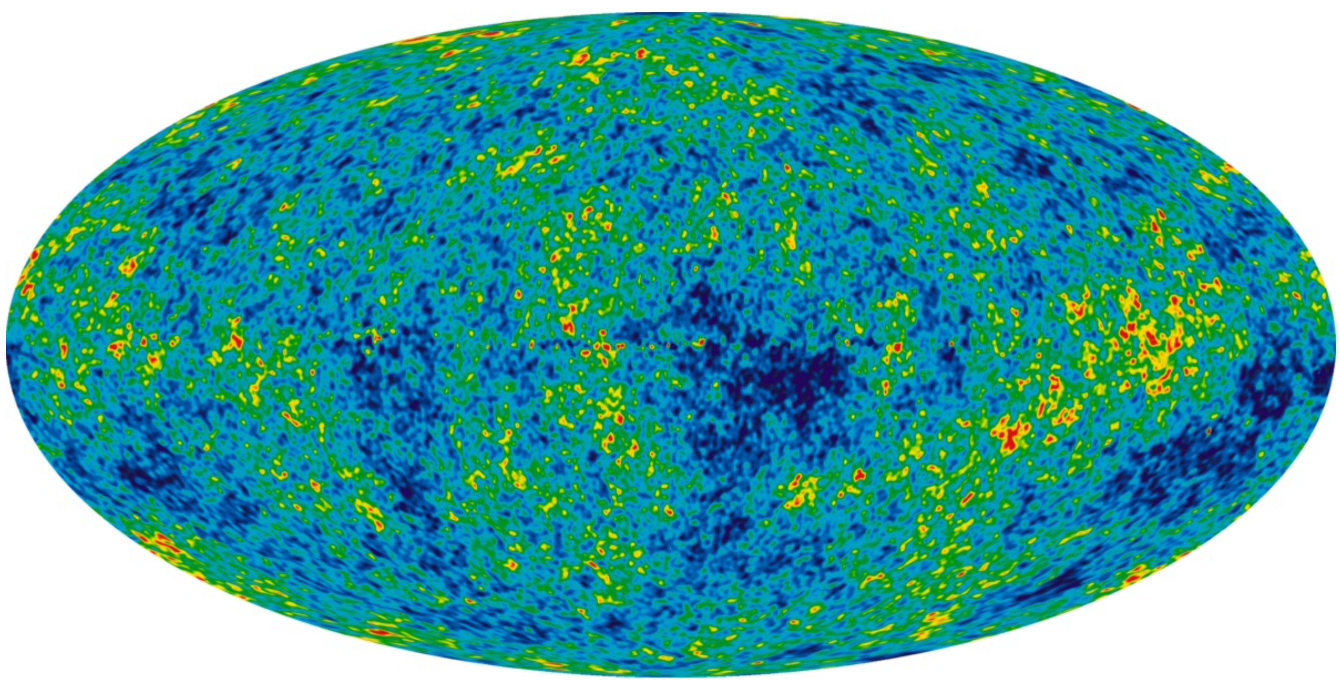
Our Big Bang cosmological model owes much to Peebles.
The current name is the ΛCDM or Lambda-CDM Model.
The underlying structure of the model is General Relativity.
Λ is a term that Einstein inserted into General Relativity in 1917 which he later called his greatest blunder. (Einstein thought the Universe was static and adding Λ would do this. But the Universe was expanding and also Λ didn't work.)
Peebles resurrected Λ and identified it with Dark Energy.
CDM is Cold Dark Matter. The Universe is filled with Dark Matter (DM) but neither Hot nor Warm DM fit observations.
Peebles has been important in advancing CDM.

Einstein’s General Relativity (GR) is consistent with a Universe that could be expanding or contracting. Edwin Hubble and others determined that the Universe is expanding and its rate of expansion is called the Hubble Constant, H_0. GR also allows the Universe to be curved. There are three possible curvatures: k=+1 (Positive, like a sphere), k=0 (Flat, Euclidean), and k=–1 (Negative, like a saddle). All of our observations are consistent with a flat Universe. This is only possible if the its density is extremely close to a certain critical value, but that appears to be the case both with theory and observation.

Composition of the Universe



This is a map of the entire sky showing the very slight temperature deviations from the average at each location. These fluctuations are key in determining the important parameters of physical cosmology.



Peebles and others realized that looking at the fluctuations in the CMB could yield important quantitative details about the Universe. The COBE satellite explorer found the predicted fluctuations. J. Mather and G. Smoot were awarded the 2006 Physics Nobel Prize for COBE. Even more accurate details were measured by the later WMAP and Planck Explorers. Analysis of the details allowed the determination of the age of the universe, its composition, its curvature (flat), the early Inflation Scenario, and formation of the galaxies.

Very Early Big Bang History

$t < 10^{-43}$ s, Planck Era, currently *terra incognita*
(We can't describe anything at t=0)

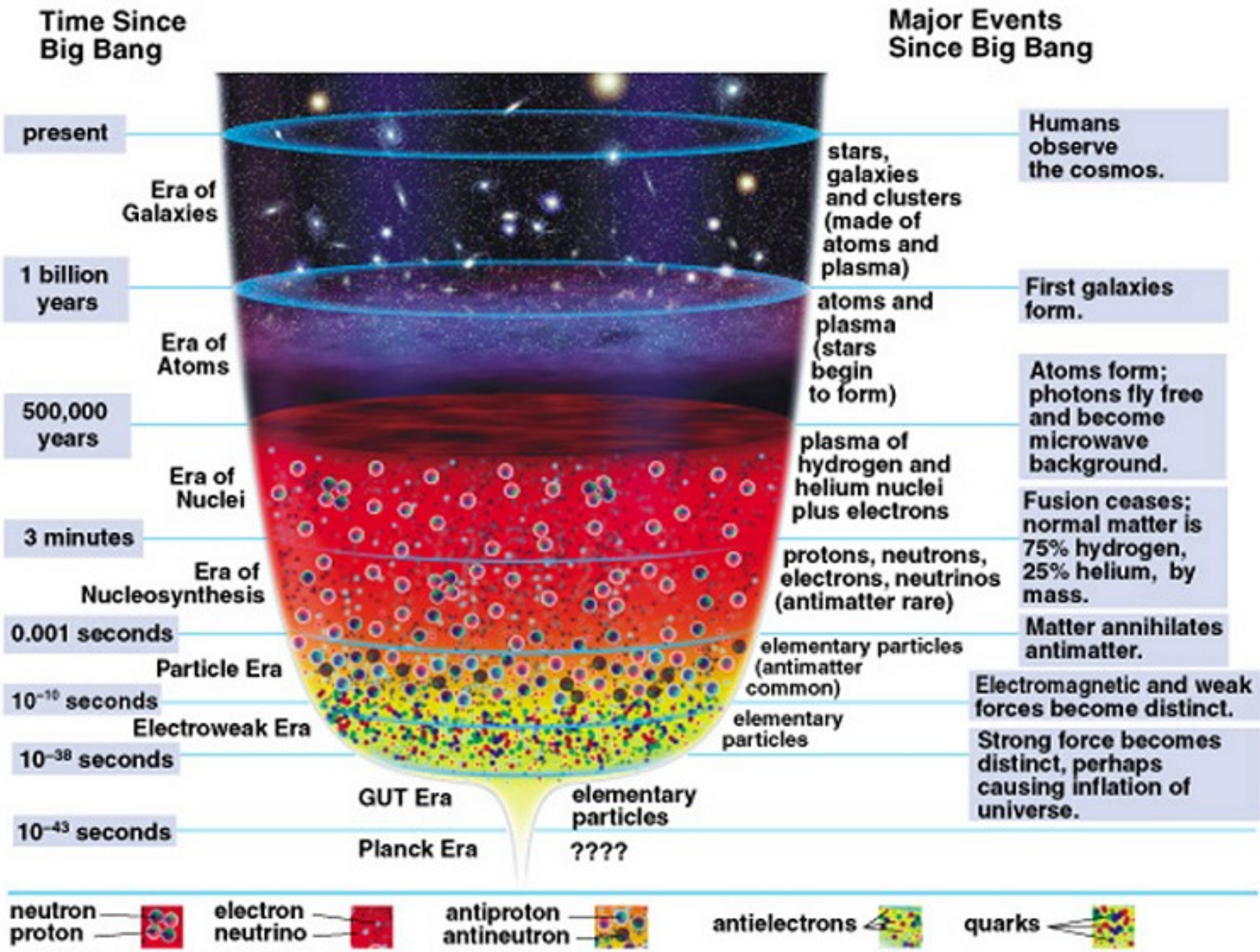
10^{-43} s $< t < 10^{-36}$ s, start of particle creation

10^{-36} s $< t < 10^{-32}$ s, Inflation, size increases by $x10^{26}$

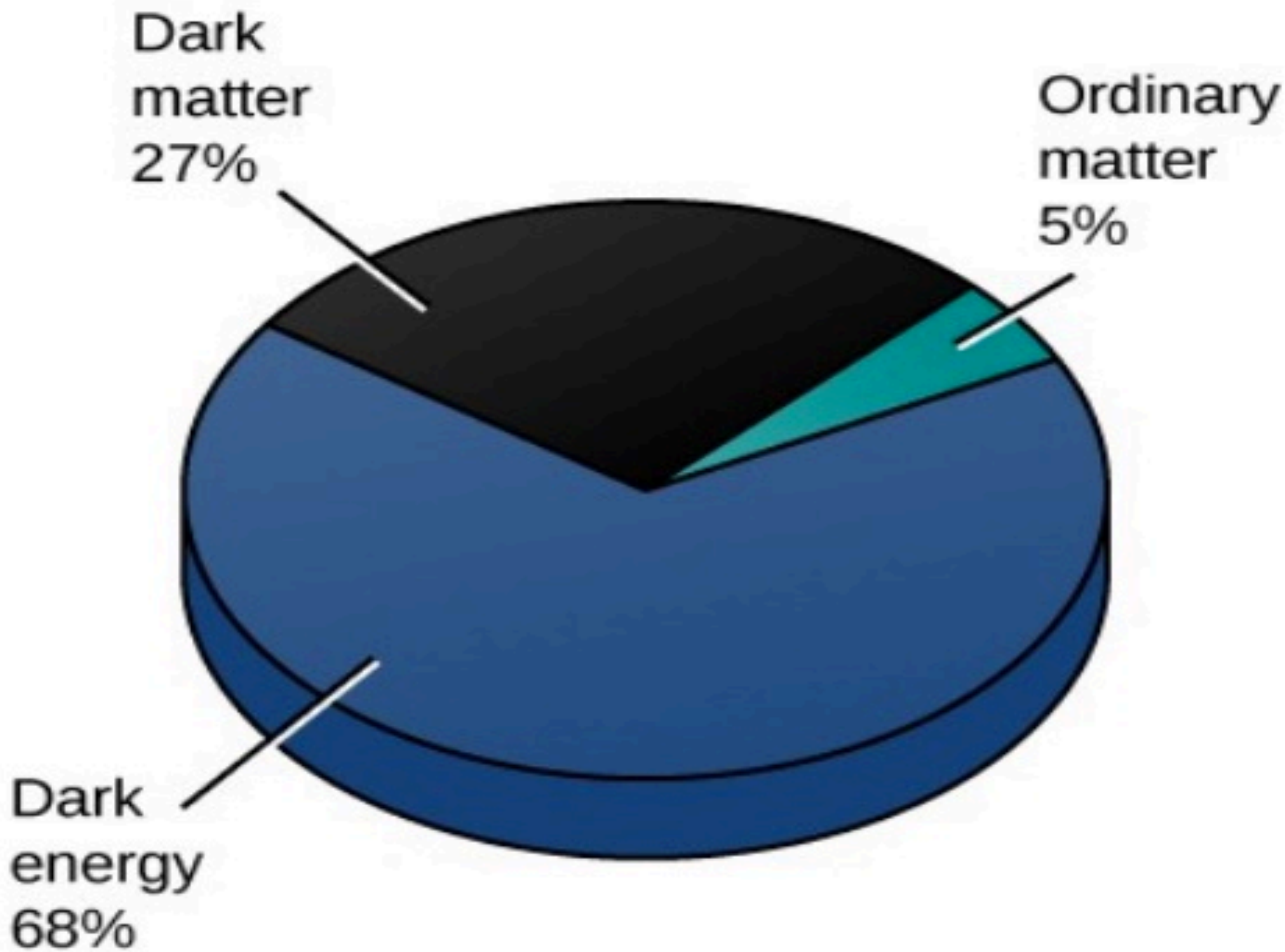
10^{-32} s $< t < 10^{-6}$ s, quarks, gluons, bosons, "plasma"

10^{-6} s $< t < 10^{2}$ s, protons and neutrons form
(why did the anti-matter disappear?)

10^{1} s $< t < 10^{3}$ s, Nucleosynthesis, Chemical elements
(mostly Hydrogen and Helium and a tiny ^{7}Li component)


Time Since Big Bang
Major Events Since Big Bang
present
Era of Galaxies
1 billion years
Era of Atoms
500,000 years
Era of Nuclei
3 minutes
Era of Nucleosynthesis
0.001 seconds
Particle Era
10^{-10} seconds
Electroweak Era
10^{-38} seconds
GUT Era
10^{-43} seconds
Planck Era
stars, galaxies and clusters (made of atoms and plasma)
atoms and plasma (stars begin to form)
plasma of hydrogen and helium nuclei plus electrons
protons, neutrons, electrons, neutrinos (antimatter rare)
elementary particles (antimatter common)
elementary particles
elementary particles
????
Humans observe the cosmos.
First galaxies form.
Atoms form; photons fly free and become microwave background.
Fusion ceases; normal matter is 75% hydrogen, 25% helium, by mass.
Matter annihilates antimatter.
Electromagnetic and weak forces become distinct.
Strong force becomes distinct, perhaps causing inflation of universe.
neutron
proton
electron
neutrino
antiproton
antineutron
antielectrons
quarks

Composition of the Universe



Dark Energy

Contrary to expectations, the expansion rate of the Universe is increasing, not decreasing. The 2011 Nobel Prize was awarded to Perlmutter, Schmidt, and Riess for this discovery. The "explanation" for this behavior is the invention of Dark Energy. We don't know what it is but we can parameterize it using the Λ from Einstein's modified version of General Relativity. It has the property to oppose the normally attractive force of gravity. As important as Λ is, it is really tiny in our usual (SI) units ($\sim 10^{-52}/m^2$)

Dark Matter

The evidence for Dark Matter is exceedingly strong. The best candidate is Cold Dark Matter (CDM). However we still do not know what the CDM might be. CDM has a significant gravitational interaction but no detected interactions that entail light or electromagnetism. The CU Denver Physics Department is part of a group of institutions involved in the CDM search. Our faculty that are involved include Professors Martin E. Huber, Amy Roberts, and Anthony Villano.

Examples of evidence for dark matter:

- Dynamics of galaxy motion in Galactic Clusters
- The rotation rate of many galaxies
- Observations in gravitational lensing
- Details of the CMB anisotropy/fluctuations
- The stability of Spiral Galaxies
- The formation and evolution of galaxies
- The location of mass during galactic collisions

The best (but not the only) candidates for CDM are WIMPs (**W**eakly **I**nteracting **M**assive **P**articles).

What is the possible predicted future of the Universe?

If the ΛCDM model prevails then the best description of the future is called the "Big Chill". Expansion will continue to occur at an increasing rate. Stars will live out their lives and stop shining. Black holes will evaporate. All matter may decay. Spacetime itself may be torn apart (The Big Rip).

Happy Halloween!

October 31, 2019

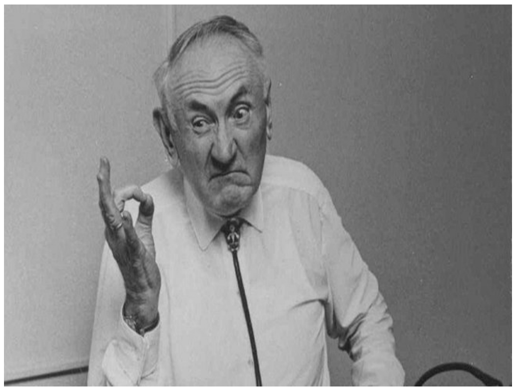
Clyde Zaidins

Dark Matter

Presented by

Dr. Anthony Villano

85 Years Ago …

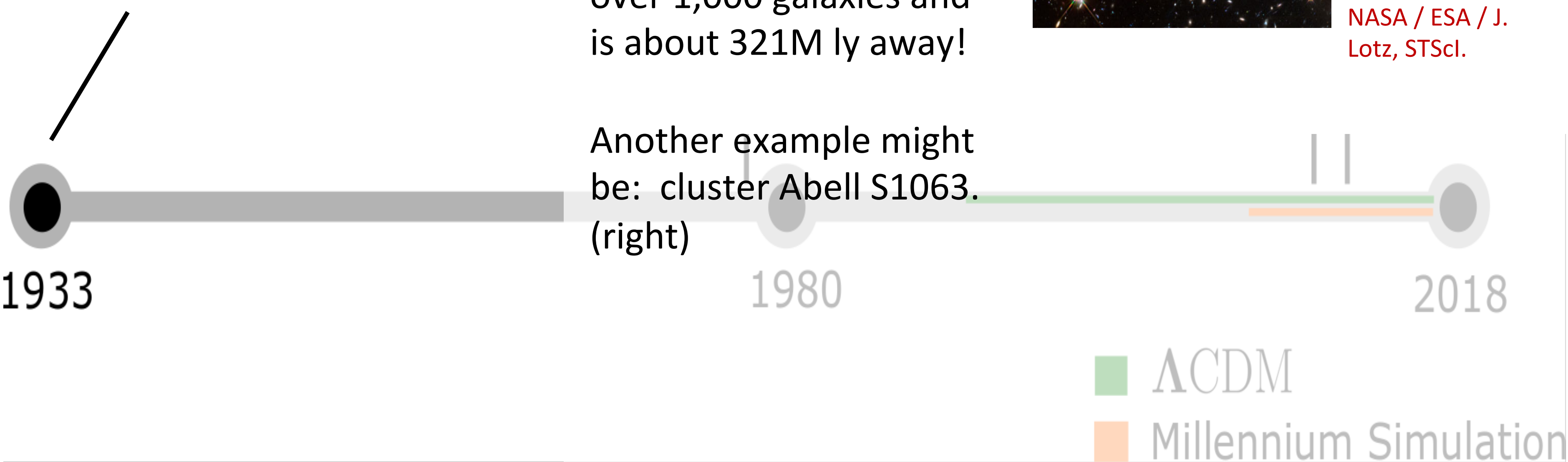


Fritz Zwicky (left) began measuring velocities of galaxies in galaxy clusters:

One example: the Coma Cluster which has over 1,000 galaxies and is about 321M ly away!

Another example might be: cluster Abell S1063. (right)

Image credit: NASA / ESA / J. Lotz, STScI.

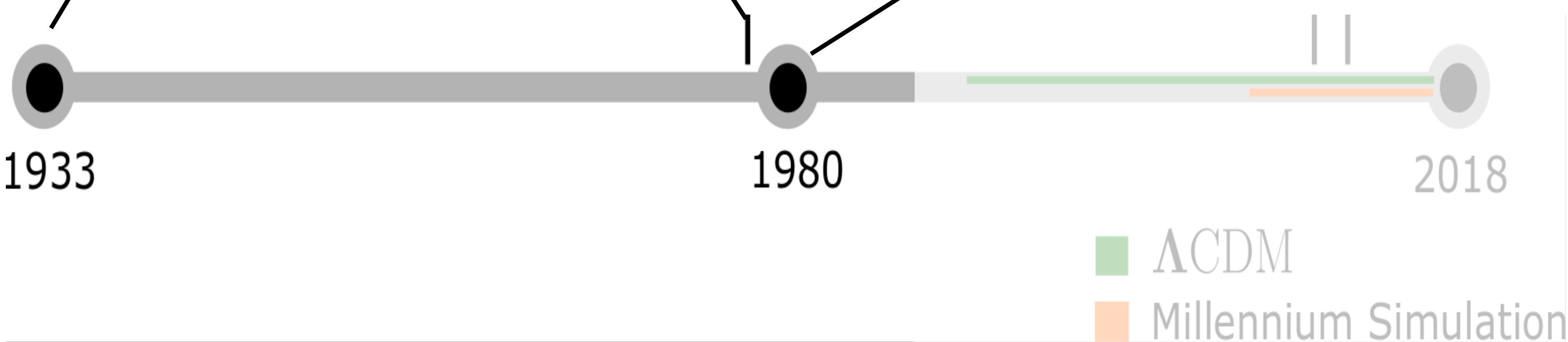


Nearly 50 Years Lat

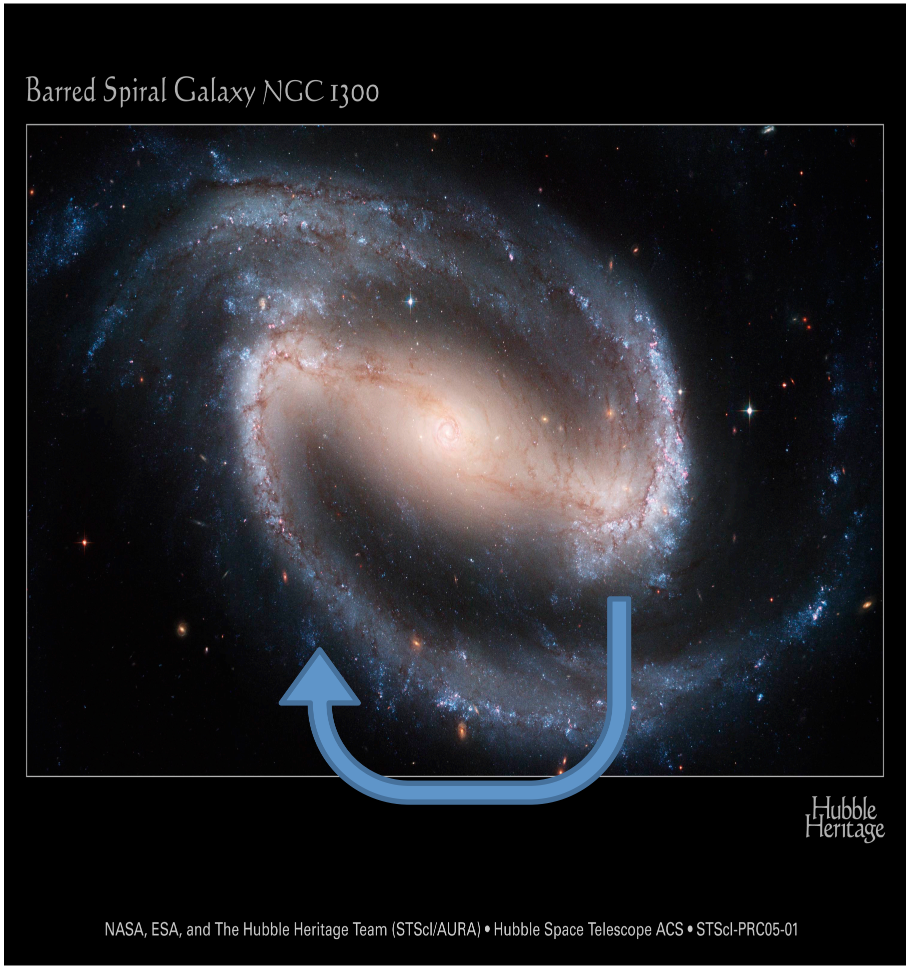
Vera Rubin (right) continues her work measuring how stars bound to a spiral galaxy move… but something is amiss.

A **very** interesting paper by Lee & Weinberg (a possible "WIMP" miracle!)

Zwicky finds something peculiar!



Rotation of Galaxies



$$\frac{GM(r)}{r^2} = \frac{v_c^2}{r}$$

We know that many galaxies rotate, and, if we understand gravity, they should rotate in a certain way:

The rotational speed of a star at a given radius should be related to the total mass inside the galaxy up to that radius

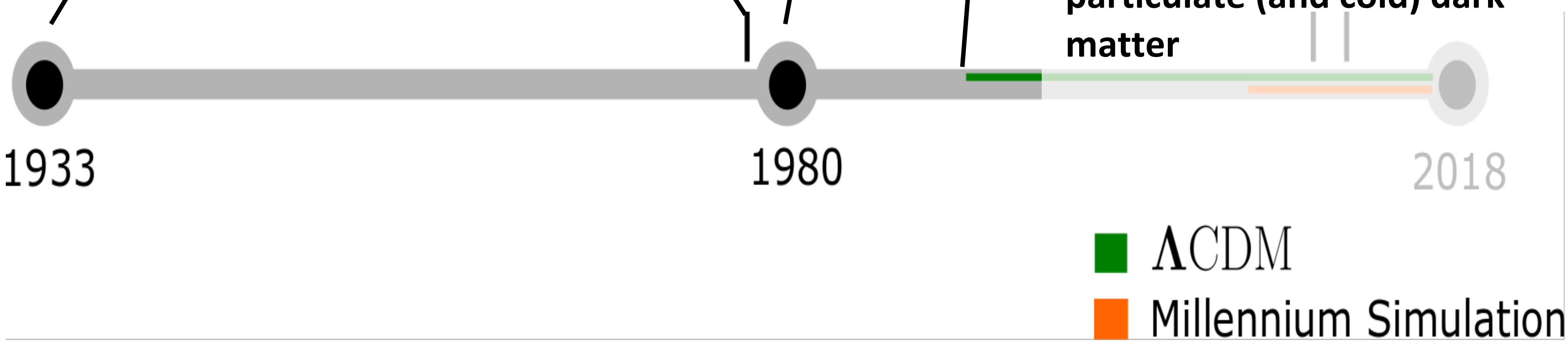
People Start to Believe in Particle Dark Matter

A **very** interesting paper by Lee & Weinberg

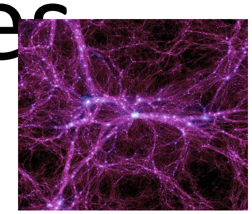
Zwicky finds something peculiar!

Rubin finds something peculiar!

- ΛCDM, a cosmological model of the Universe is born
- Energy content and precise history of Universe
- Measured/confirmed by the Cosmic Microwave Background, Big Bang Nucleosynthesis
- **A main component is particulate (and cold) dark matter**



And Other Evidence Emerges



People start believing in ΛCDM

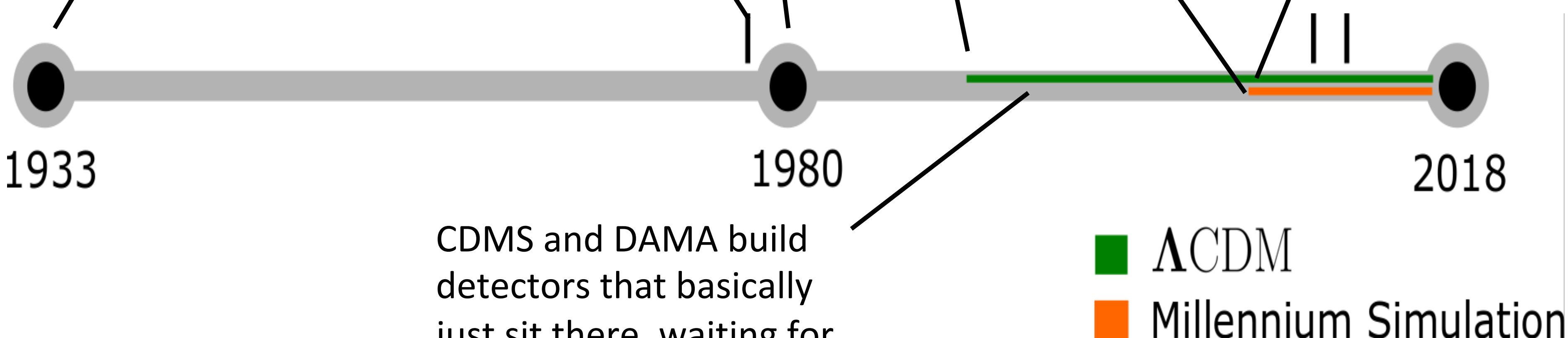
Millennium simulation

A **very** interesting paper by Lee & Weinberg

Rubin finds something peculiar!

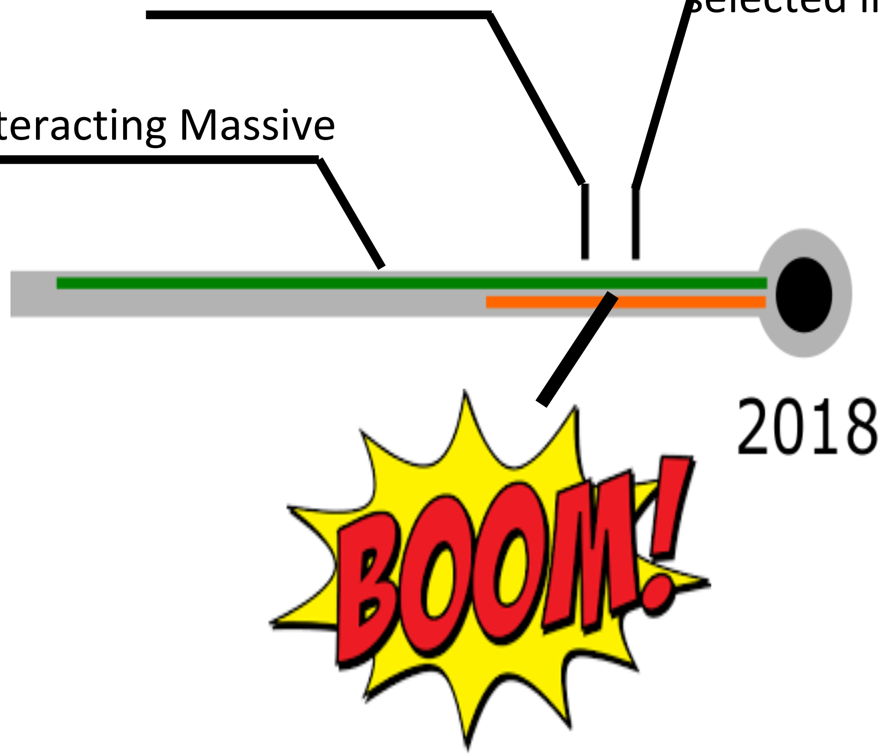
Zwicky finds something peculiar!

Colliding cluster observation!



CDMS and DAMA build detectors that basically just sit there, waiting for the WIMP wind to tickle them

We Now Have Two Branches in a Way



We are now entering a post-WIMP era; because we have not confirmed directly the existence of a particle WIMP.