

DARK MATTER

Evan Shockley
University of Chicago

Question: What's dark matter?

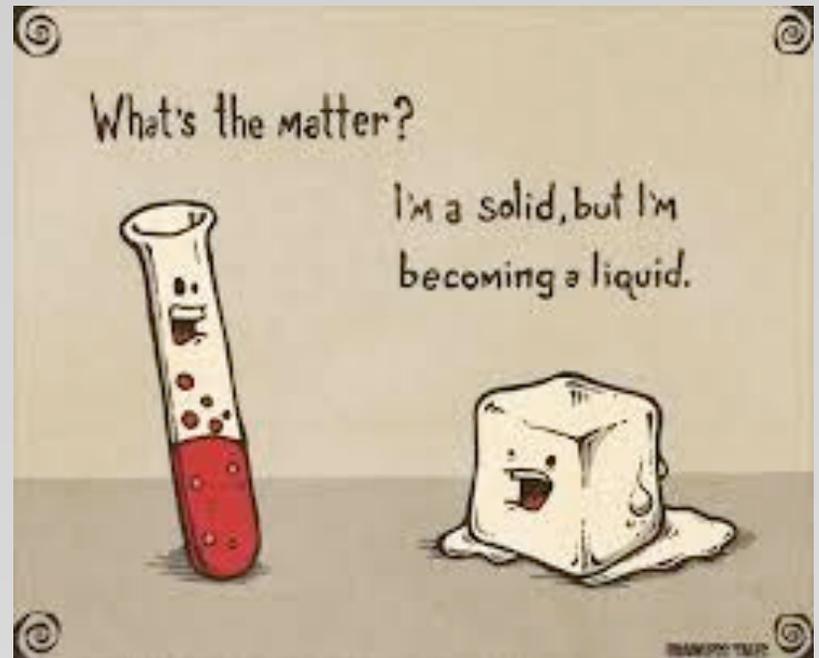


Short Answer: We don't know.
Longer answer...

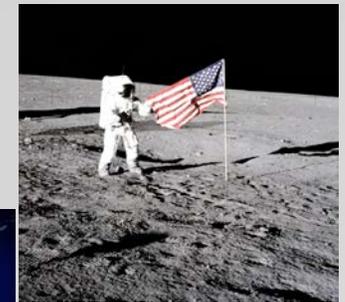
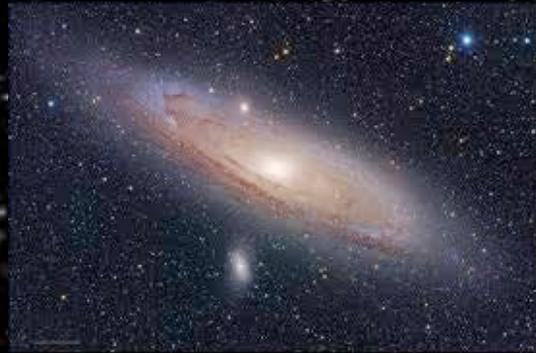
Let's start with a different question

What is matter?

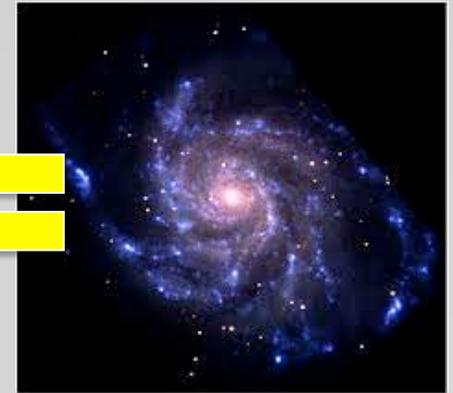
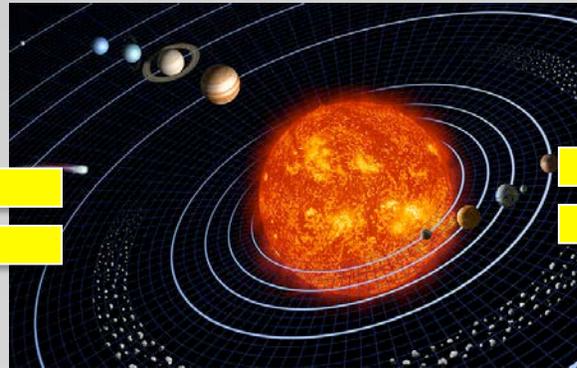
- “stuff”
- made of atoms
- people, planets, stars...
pretty much
everything



We've learned a lot about matter over the years



We've learned that matter causes gravity



“If matter thus draws matter; it must be proportion of its quantity. Therefore the apple draws the Earth, as well as the Earth draws the apple.”

-account from William Stuckley, one of Newton's contemporaries

Mass (amount of matter)

$$F = \frac{GMm}{r^2}$$

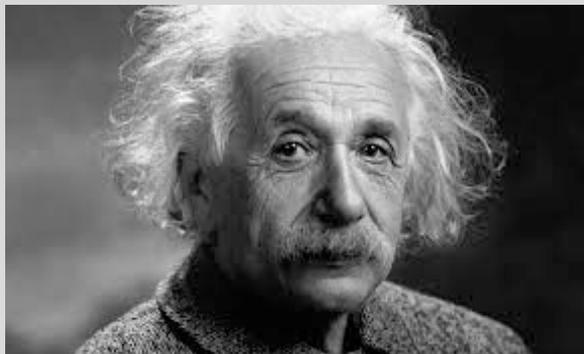
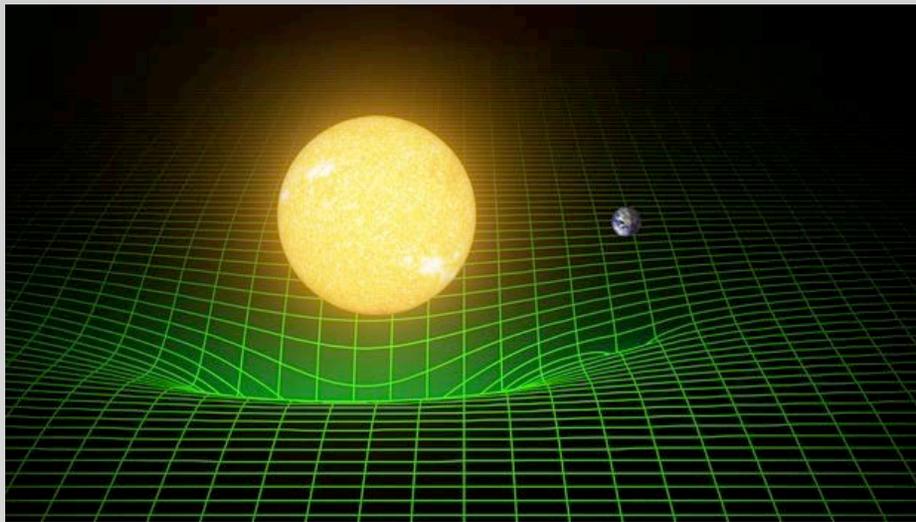
Force

Distance

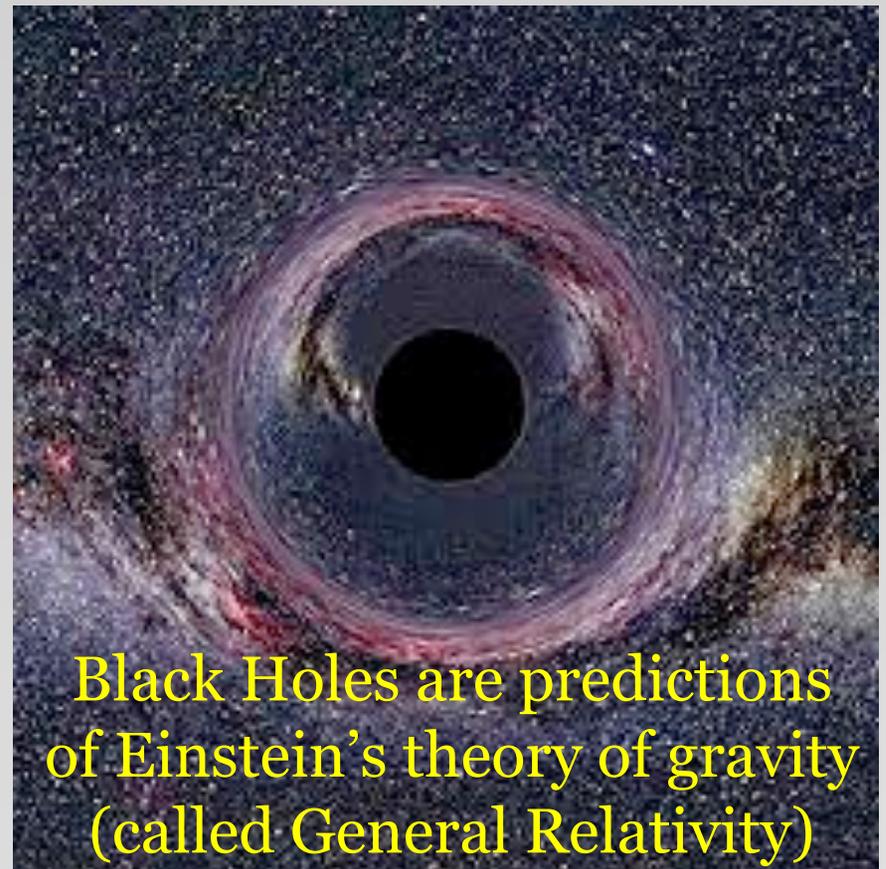


Isaac Newton

Additionally, we've learned that matter distorts space and time itself



Albert Einstein



Black Holes are predictions of Einstein's theory of gravity (called General Relativity)

We know what matter is made of



Periodic Table of the Elements

1 H Hydrogen 1.008																	2 He Helium 4.003
3 Li Lithium 6.941	4 Be Beryllium 9.012											5 B Boron 10.811	6 C Carbon 12.011	7 N Nitrogen 14.007	8 O Oxygen 15.999	9 F Fluorine 18.998	10 Ne Neon 20.180
11 Na Sodium 22.990	12 Mg Magnesium 24.305											13 Al Aluminum 26.982	14 Si Silicon 28.086	15 P Phosphorus 30.974	16 S Sulfur 32.066	17 Cl Chlorine 35.453	18 Ar Argon 39.948
19 K Potassium 39.098	20 Ca Calcium 40.078	21 Sc Scandium 44.956	22 Ti Titanium 47.867	23 V Vanadium 50.942	24 Cr Chromium 51.996	25 Mn Manganese 54.938	26 Fe Iron 55.845	27 Co Cobalt 58.933	28 Ni Nickel 58.693	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.723	32 Ge Germanium 72.631	33 As Arsenic 74.922	34 Se Selenium 78.971	35 Br Bromine 79.904	36 Kr Krypton 84.798
37 Rb Rubidium 84.468	38 Sr Strontium 87.62	39 Y Yttrium 88.906	40 Zr Zirconium 91.224	41 Nb Niobium 92.906	42 Mo Molybdenum 95.95	43 Tc Technetium 98.907	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.906	46 Pd Palladium 106.42	47 Ag Silver 107.868	48 Cd Cadmium 112.414	49 In Indium 114.818	50 Sn Tin 118.711	51 Sb Antimony 121.760	52 Te Tellurium 127.6	53 I Iodine 126.904	54 Xe Xenon 131.294
55 Cs Cesium 132.905	56 Ba Barium 137.328	57-71 Lanthanides	72 Hf Hafnium 178.49	73 Ta Tantalum 180.948	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platinum 195.085	79 Au Gold 196.967	80 Hg Mercury 200.592	81 Tl Thallium 204.383	82 Pb Lead 207.2	83 Bi Bismuth 208.980	84 Po Polonium [208.982]	85 At Astatine 209.987	86 Rn Radon 222.018
87 Fr Francium 223.020	88 Ra Radium 226.025	89-103 Actinides	104 Rf Rutherfordium [261]	105 Db Dubnium [262]	106 Sg Seaborgium [266]	107 Bh Bohrium [264]	108 Hs Hassium [269]	109 Mt Meitnerium [268]	110 Ds Darmstadtium [269]	111 Rg Roentgenium [272]	112 Cn Copernicium [277]	113 Uut Ununtrium unknown	114 Fl Flerovium [289]	115 Uup Ununpentium unknown	116 Lv Livermorium [289]	117 Uus Ununseptium unknown	118 Uuo Ununoctium unknown

“up quark”

“down quark”

Lanthanide Series	57 La Lanthanum 138.905	58 Ce Cerium 140.116	59 Pr Praseodymium 140.908	60 Nd Neodymium 144.243	61 Pm Promethium 144.913	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.925	66 Dy Dysprosium 162.500	67 Ho Holmium 164.930	68 Er Erbium 167.259	69 Tm Thulium 168.934	70 Yb Ytterbium 173.055	71 Lu Lutetium 174.967
Actinide Series	89 Ac Actinium 227.028	90 Th Thorium 232.038	91 Pa Protactinium 231.036	92 U Uranium 238.029	93 Np Neptunium 237.048	94 Pu Plutonium 244.064	95 Am Americium 243.061	96 Cm Curium 247.070	97 Bk Berkelium 247.070	98 Cf Californium 251.080	99 Es Einsteinium [254]	100 Fm Fermium 257.095	101 Md Mendelevium 258.1	102 No Nobelium 259.101	103 Lr Lawrencium [262]

- Alkali Metal
- Alkaline Earth
- Transition Metal
- Basic Metal
- Semimetal
- Nonmetal
- Halogen
- Noble Gas
- Lanthanide
- Actinide



neutrons

electrons

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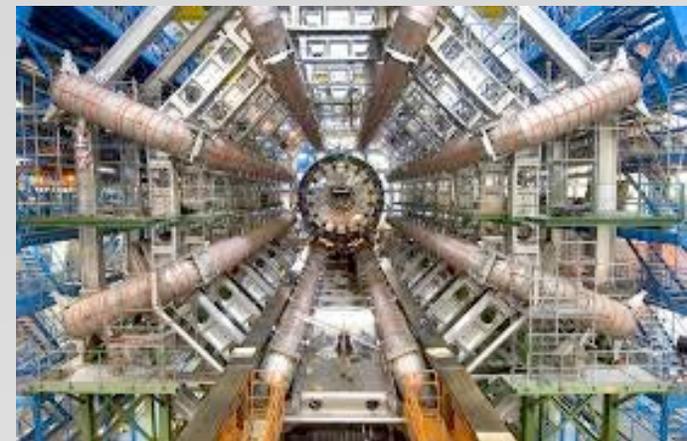
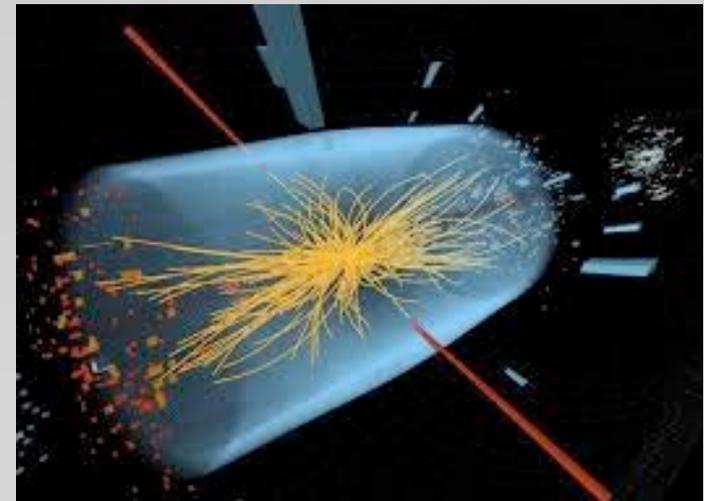
We can even *create* matter in a (big) laboratory



Accelerate protons to
EXTREMELY high
speeds.

$$E = mc^2$$

Collide the
protons to
create
other
particles



Detect these
particles
with a
massive
detector



A particle called the Higgs boson was detected this way in 2012, about 50 years after being *predicted* to exist!

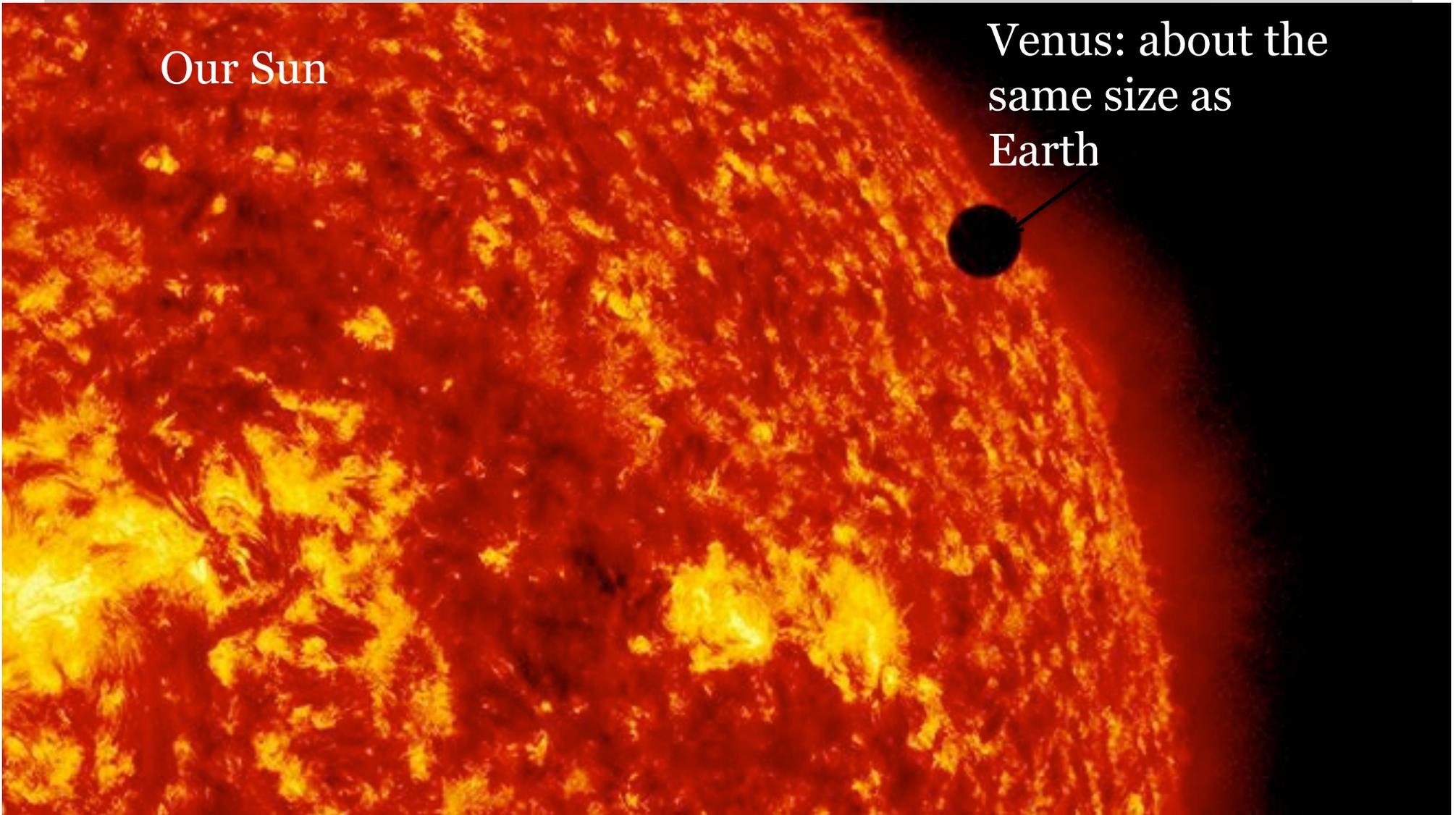
We know there is A LOT of matter
in the universe



We know there is A LOT of matter in the universe

Our Sun

Venus: about the same size as Earth



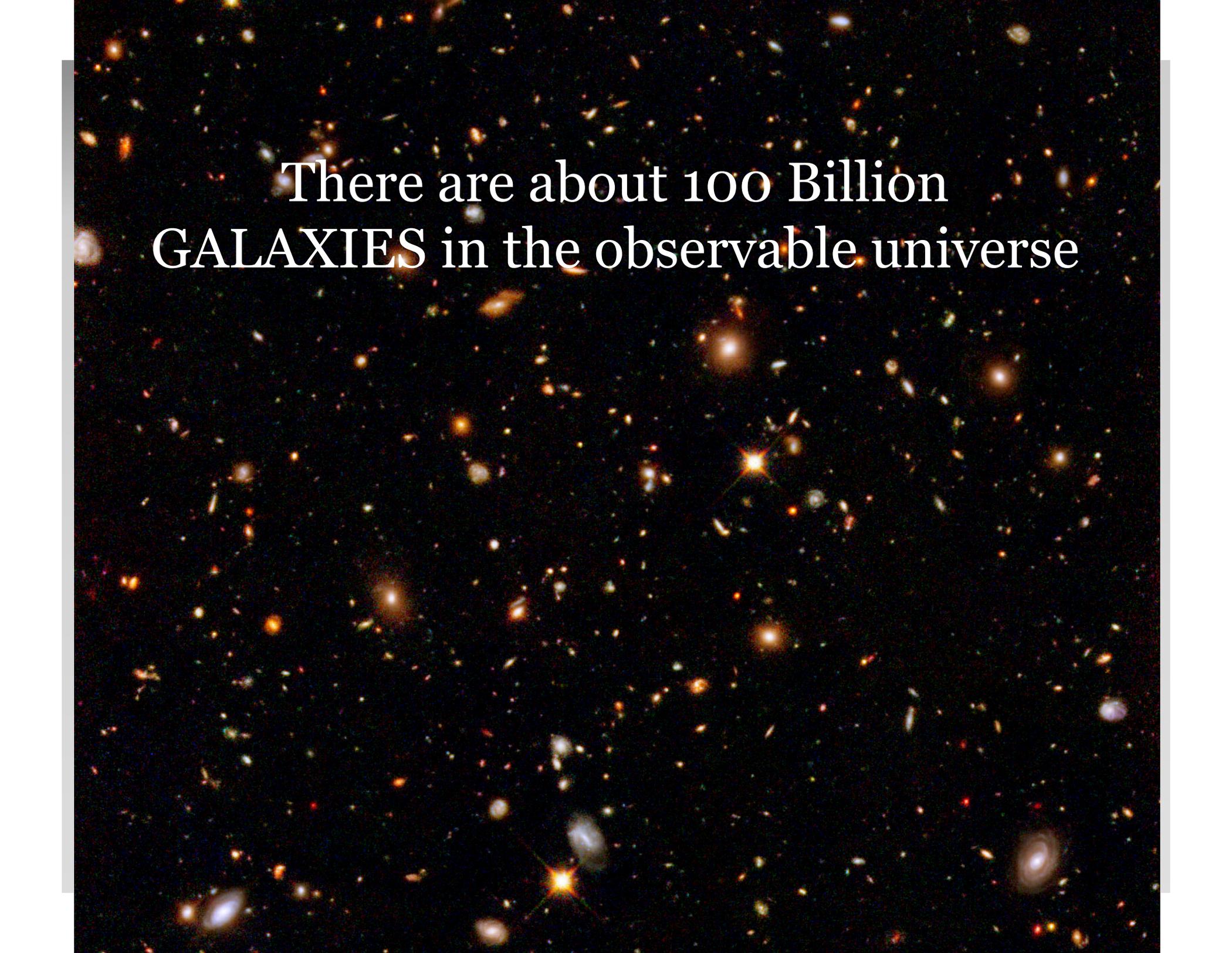
We know there is A LOT of matter
in the universe



The Milky Way galaxy consists of about 100 Billion stars

Our Milky Way galaxy as seen from Earth.

Photo credit: ESO/ S. Brunier

A deep-field astronomical image showing a vast field of galaxies in various colors and shapes against a dark background. The galaxies are scattered across the frame, with some appearing as bright, distinct points of light and others as faint, diffuse clouds. The colors range from warm oranges and yellows to cool blues and purples. The overall appearance is that of a rich, multi-colored population of galaxies.

There are about 100 Billion
GALAXIES in the observable universe

The Universe

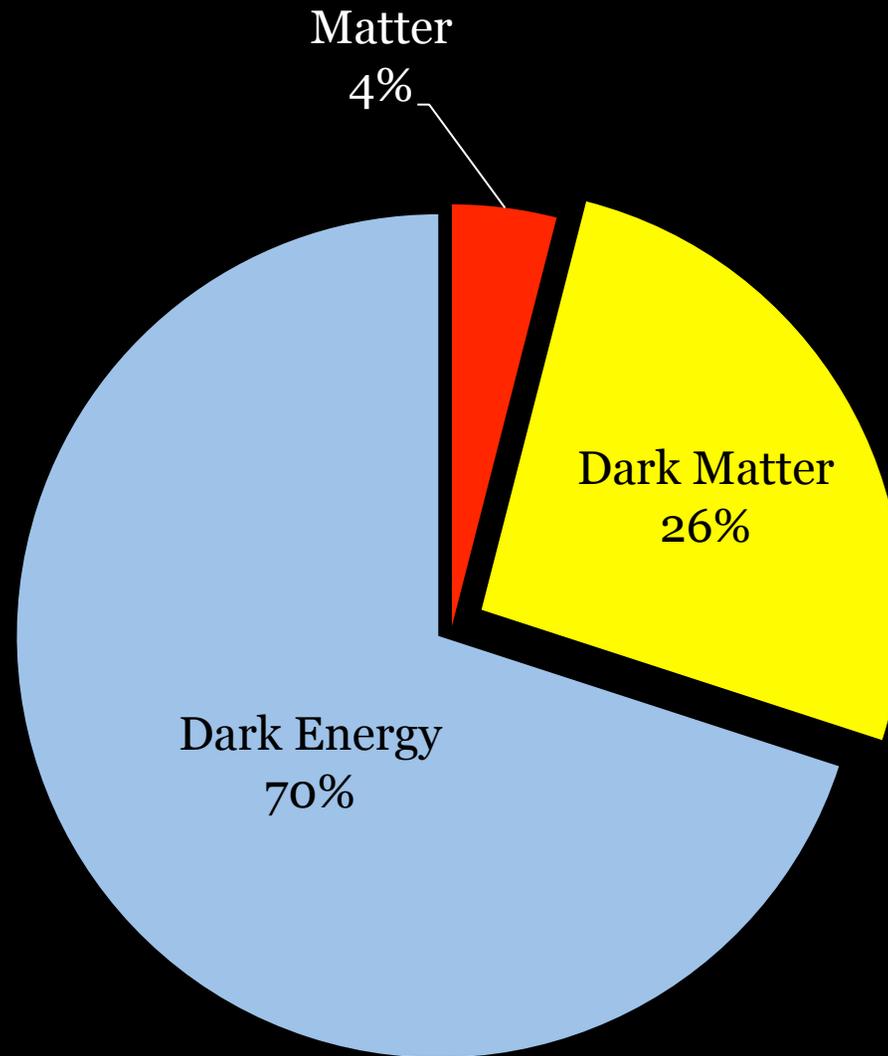
The Universe

Matter

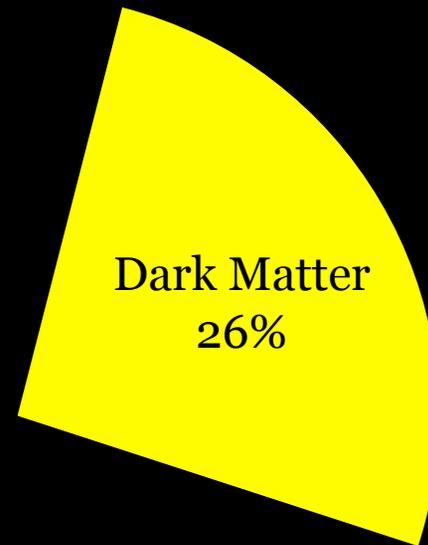
4%



The Universe



The Universe



There is 5 times more Dark Matter than regular matter!

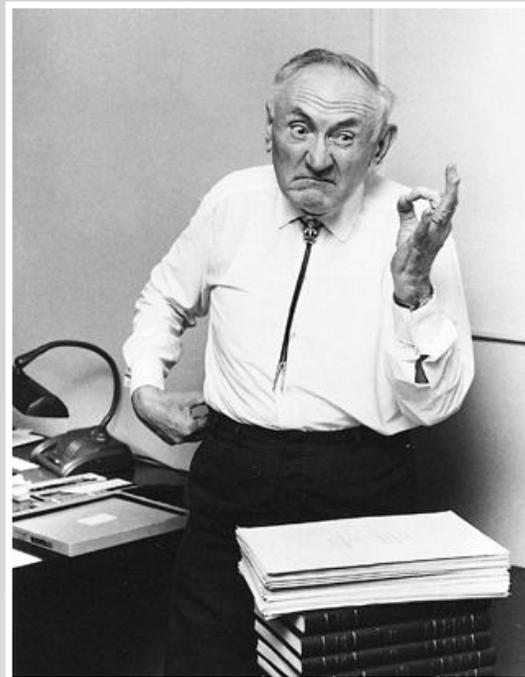
- More questions
 - How do we know dark matter exists?
 - What might dark matter be?
 - What are we doing to “find it”

Evidence for Dark Matter #1

1. Stars and galaxies are moving too fast



Jan Oort
(1932)



Fritz Zwicky
(1933)



Vera Rubin
(1970)

Remember our gravity equation?

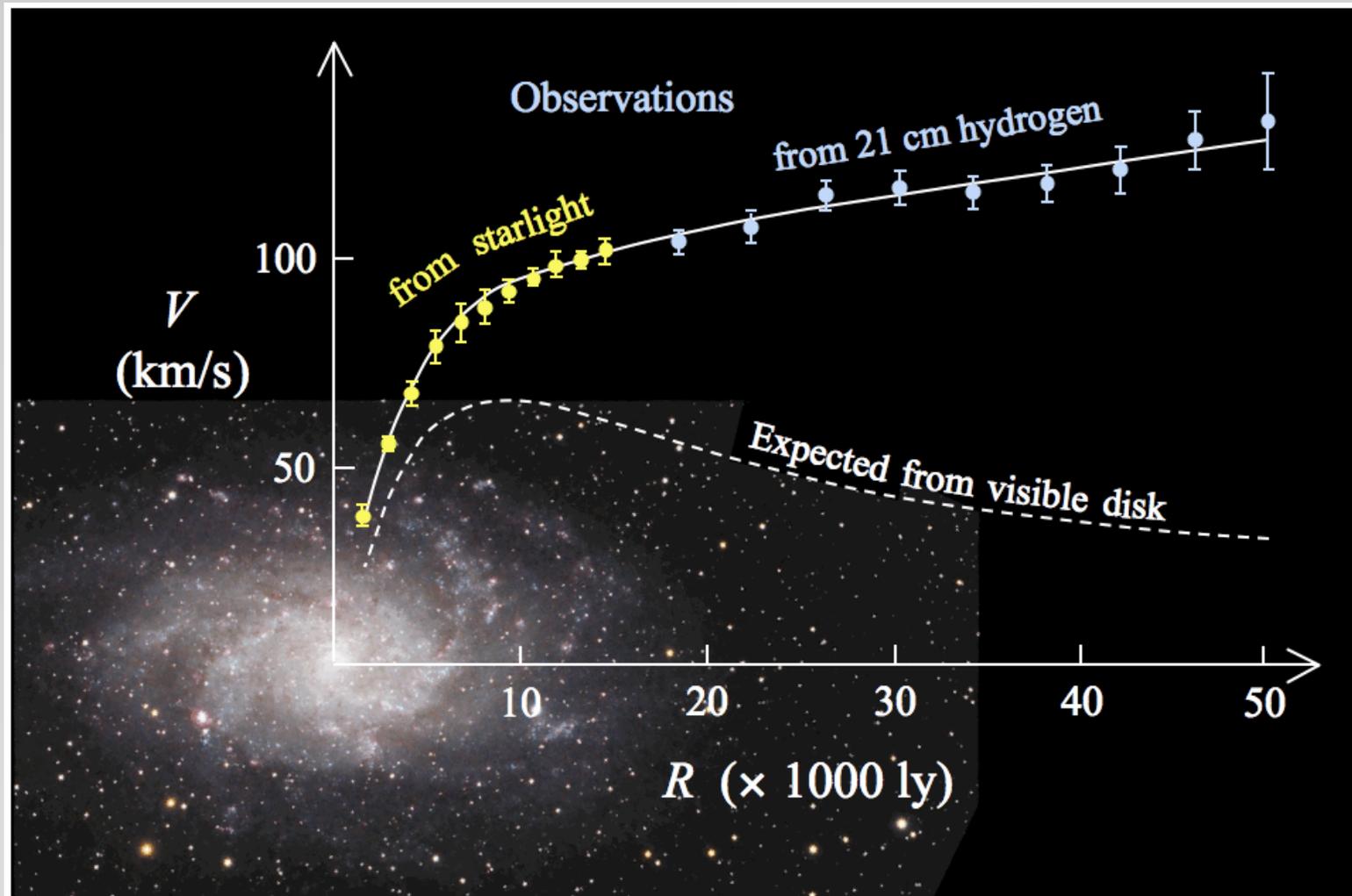
Mass
(amount
of matter)

$$F = \frac{GMm}{r^2}$$

Force

- From this equation we can predict how fast objects *should* move around each other.
- Using telescopes, we can test whether these predictions agree with what we observe

Predictions and measurements don't agree!



Predictions and measurements don't agree!

Mass
(amount
of matter)

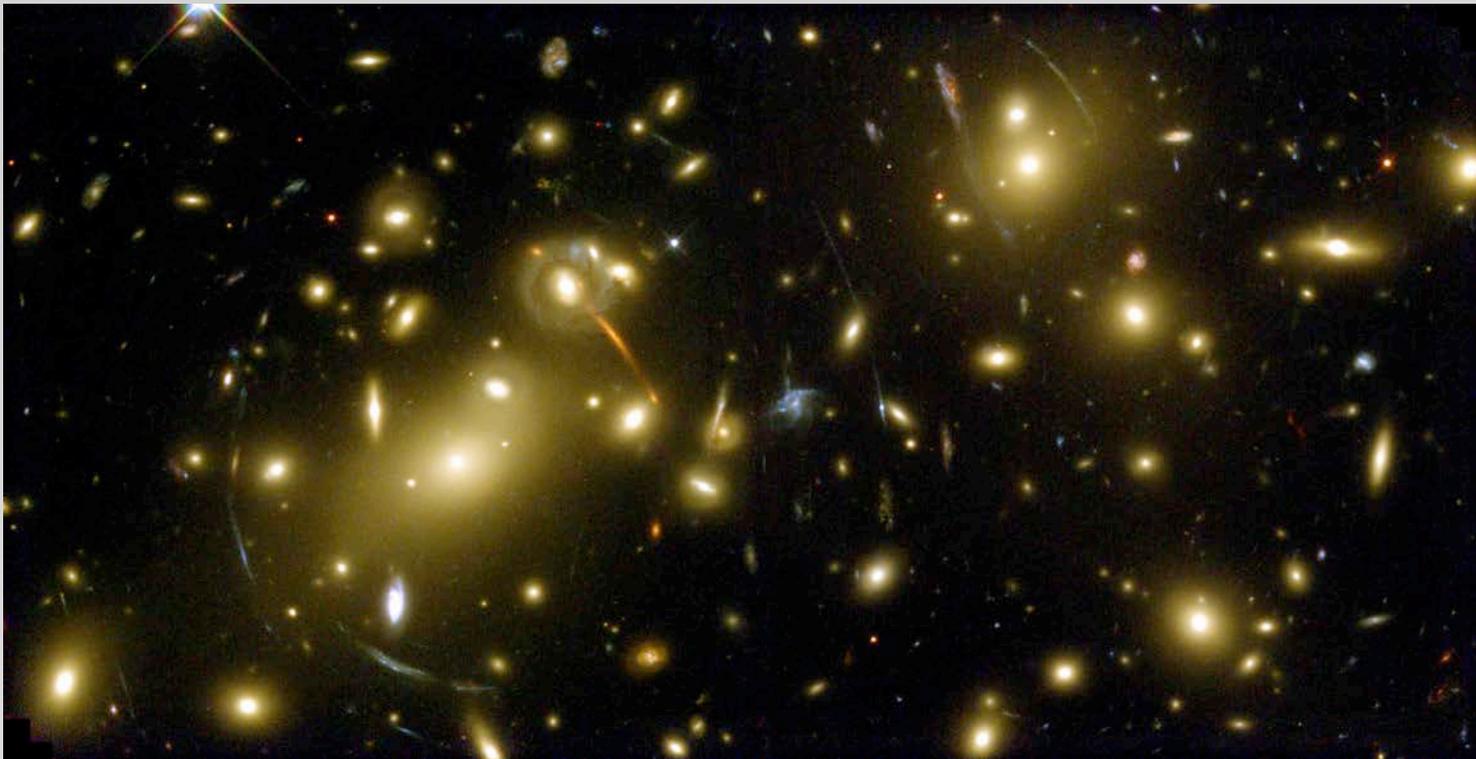
$$F = \frac{GMm}{r^2}$$

Force

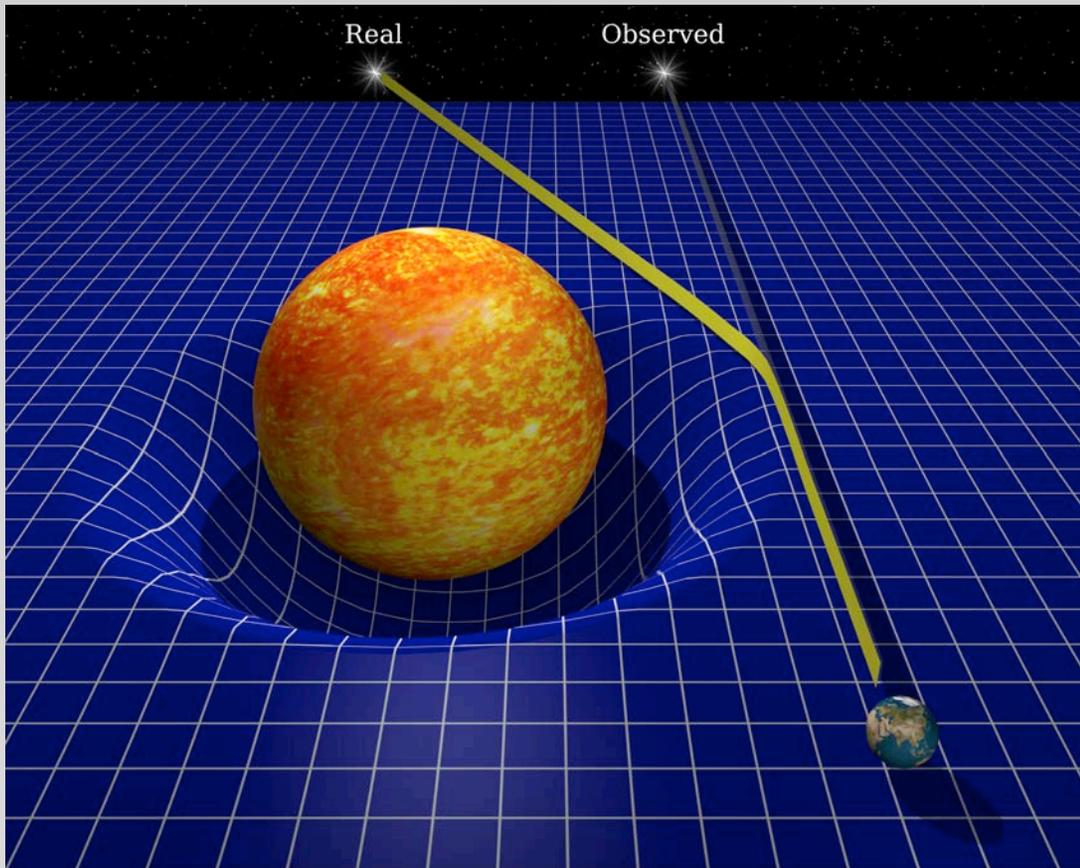
If galaxies and stars are moving too fast, maybe there's more mass (matter) than we can see!

Evidence for Dark Matter #2

2. Something called “gravitational lensing”

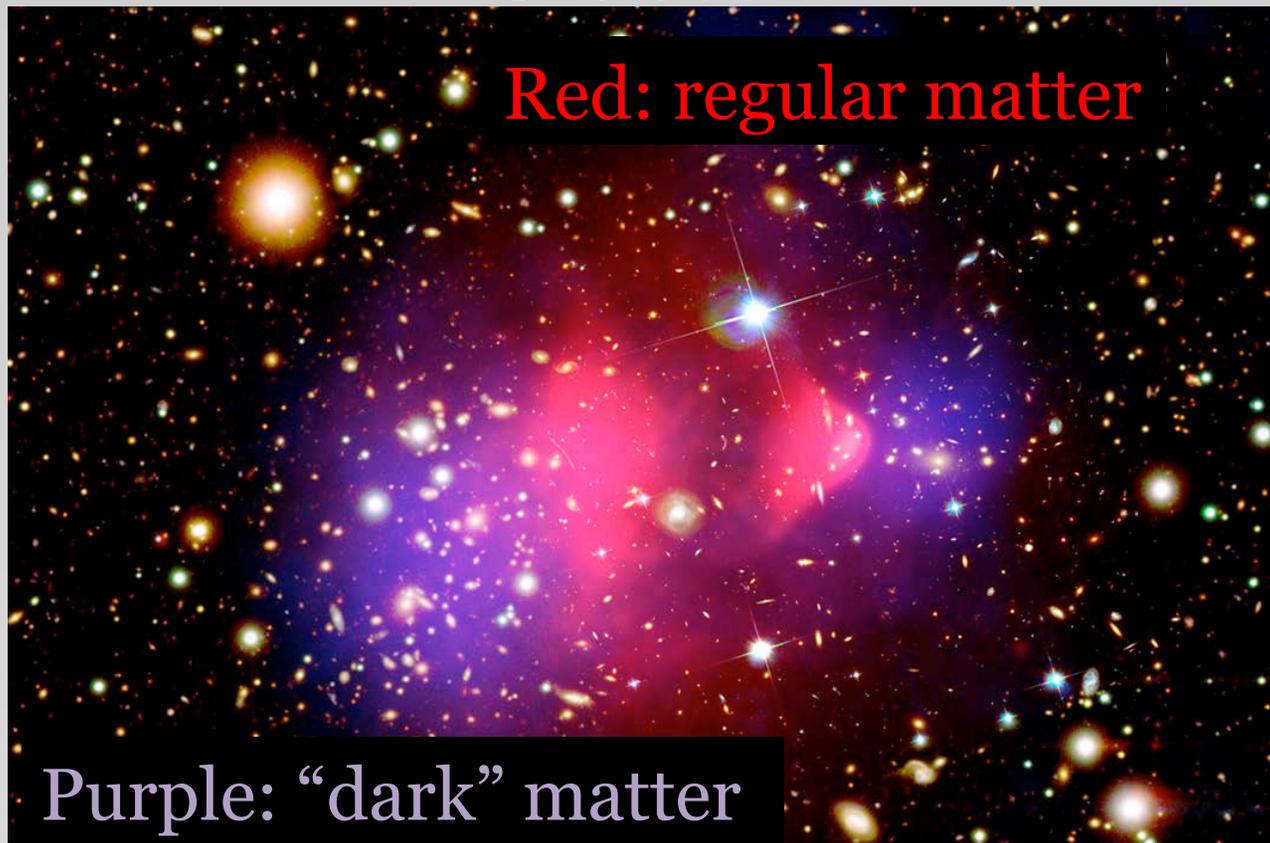


Remember the space distortions?



We can use this effect to determine how much matter is in a particular system

“Proof of Dark Matter” – The Bullet Cluster



A DIRECT EMPIRICAL PROOF OF THE EXISTENCE OF DARK MATTER *

DOUGLAS CLOWE¹, MARUŠA BRADAČ², ANTHONY H. GONZALEZ³, MAXIM MARKEVITCH^{4,5}, SCOTT W. RANDALL⁴,
CHRISTINE JONES⁴, AND DENNIS ZARITSKY¹

ApJ Letters in press

ABSTRACT

We present new weak lensing observations of 1E0657–558 ($z = 0.296$), a unique cluster merger, that enable a direct detection of dark matter, independent of assumptions regarding the nature of the

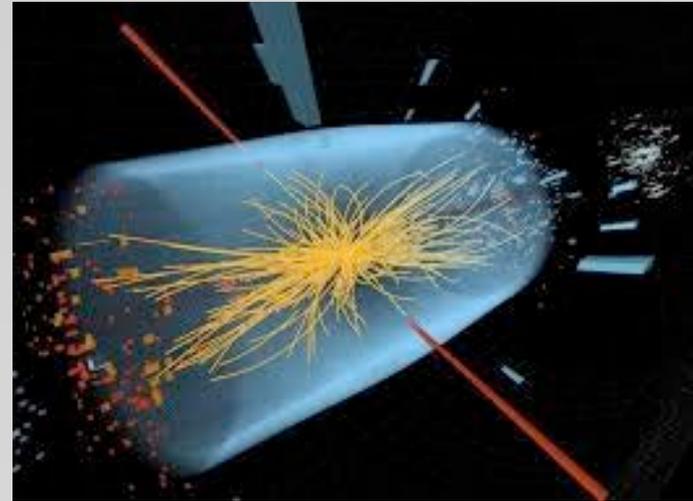
Evidence for Dark Matter #3,4,5,...

- No time to discuss the others here, but the evidence is truly overwhelming
- The evidence all points to a new type of matter that:
 - causes gravity similarly to ordinary matter
 - does not interact with light: it is “dark”

There are a lot of ideas



Can we create dark matter like we have made other particles?



Not yet – but we're trying.

The collider recently turned back on after a large update, so stay tuned!

Galaxies (including our own) are floating in a cloud of dark matter



You are here

So maybe we can detect dark matter directly

- Dark matter is passing through us right now



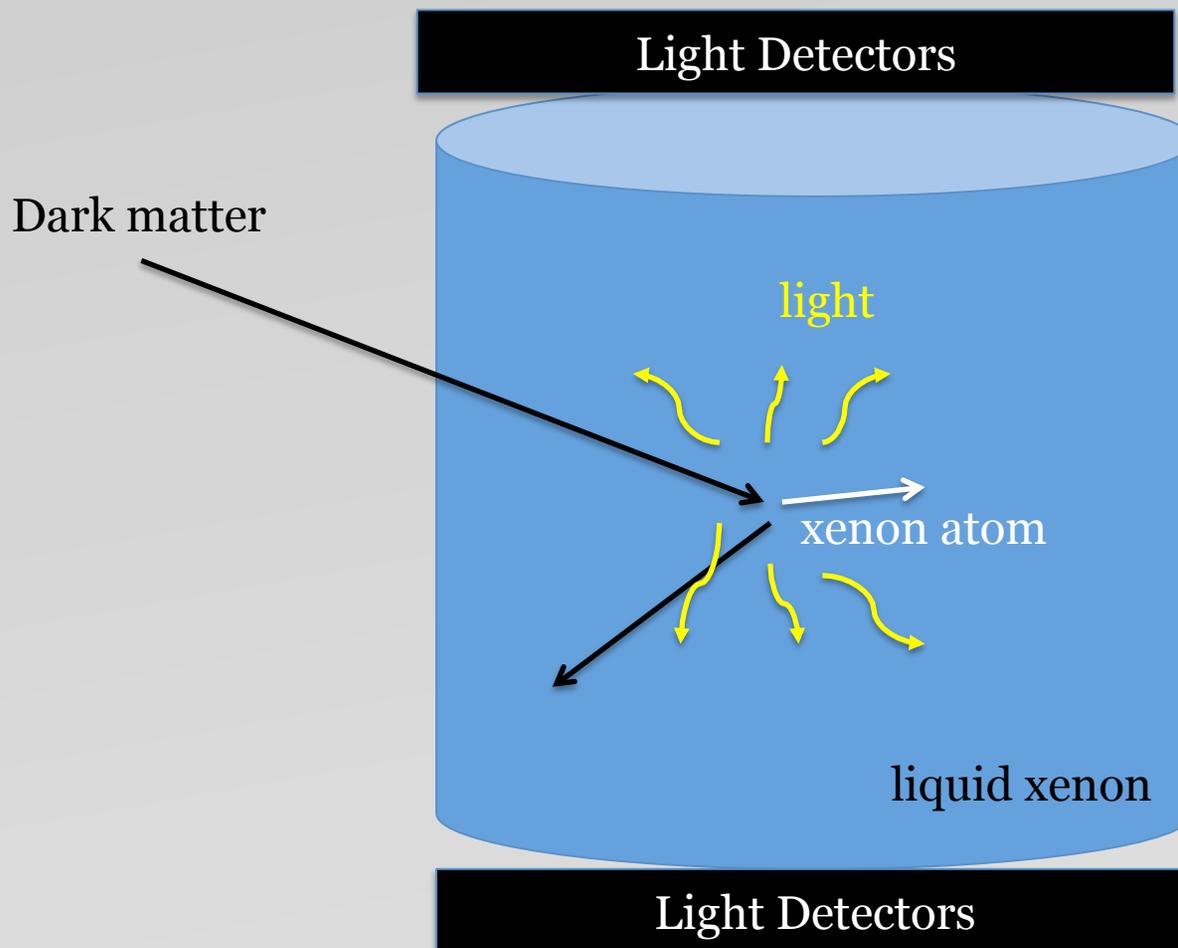
- Occasionally, these particles should interact with ordinary matter
- Let's look for those interactions!



My experiment: XENON1T



XENON1T searches for WIMPs (weakly interacting massive particles) using liquid xenon



We place the detector deep underground to get away from other kinds of interactions



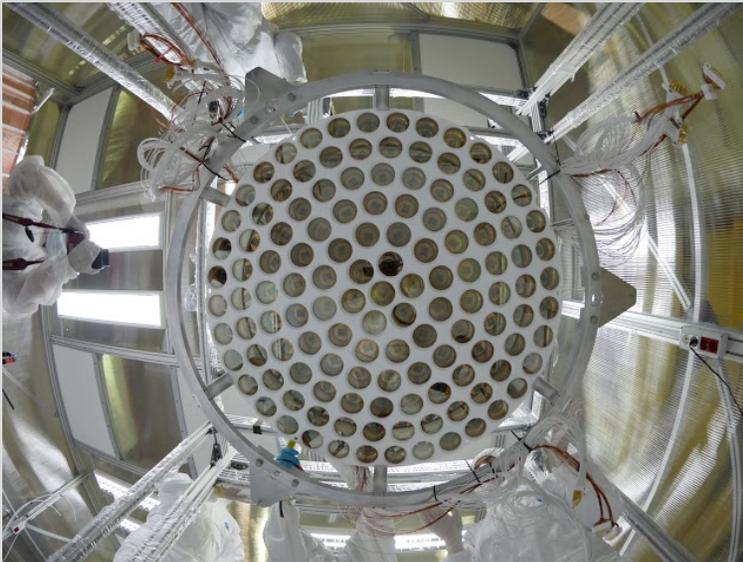
XENON1T is located at Gran Sasso National Laboratory in central Italy



I was able to travel to Italy last fall!



Assembling XENON1T



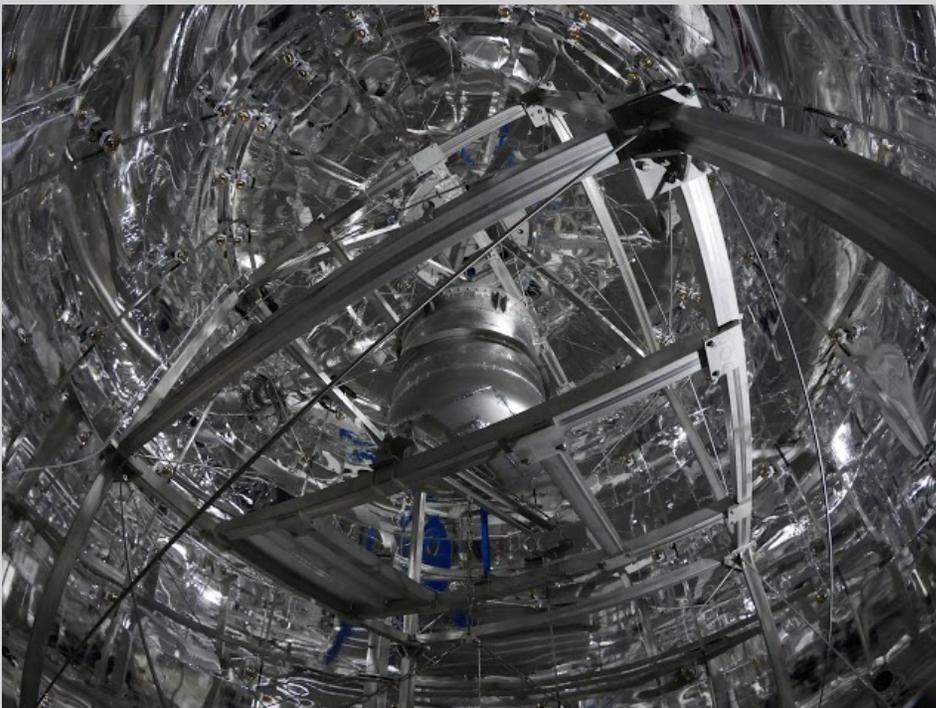
Assembling XENON1T



Assembling XENON1T



Assembling XENON1T



Exciting times!

- XENON1T is now filled with 3.5 tons of liquid xenon and in the commissioning stage
- After about 10 days of science data, XENON1T will be among the most sensitive WIMP detectors in the world



Thank you!