

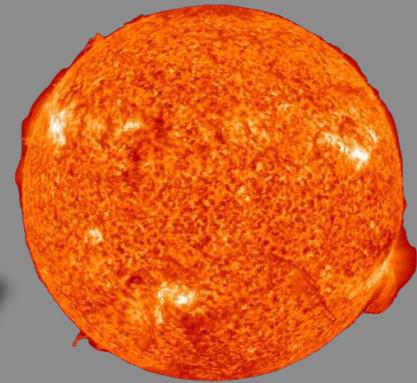
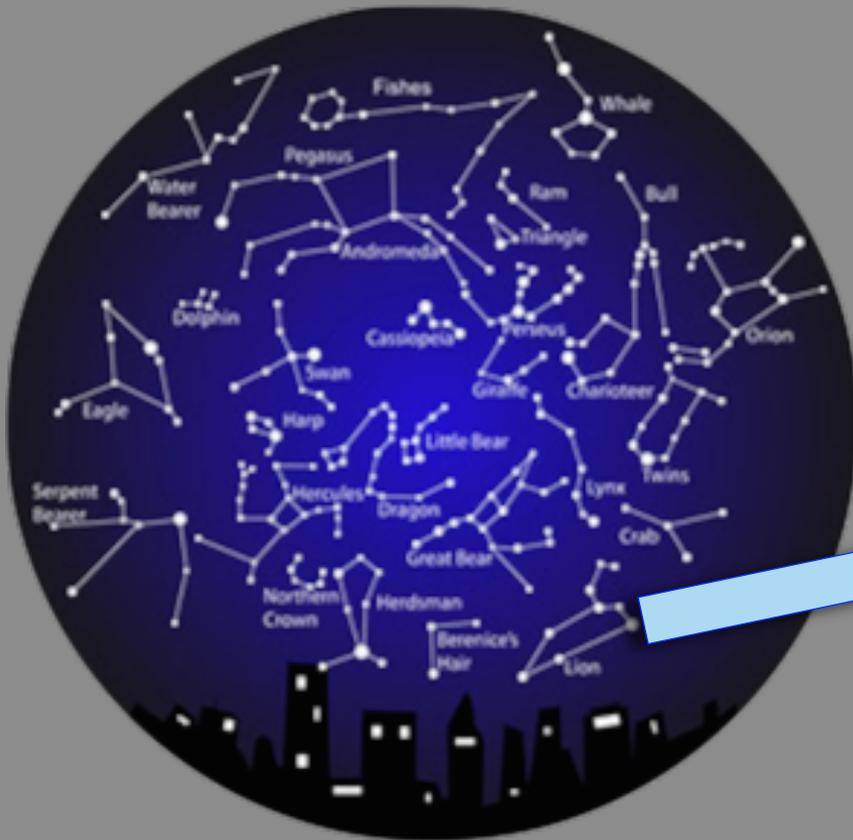
# Demystifying Dark Matter

Dr. Andrew J Long  
Admiral Apartments, Chicago  
March 9, 2016

We look upward,  
because we love mystery



The stars are burning balls of gas, like  
our own Sun



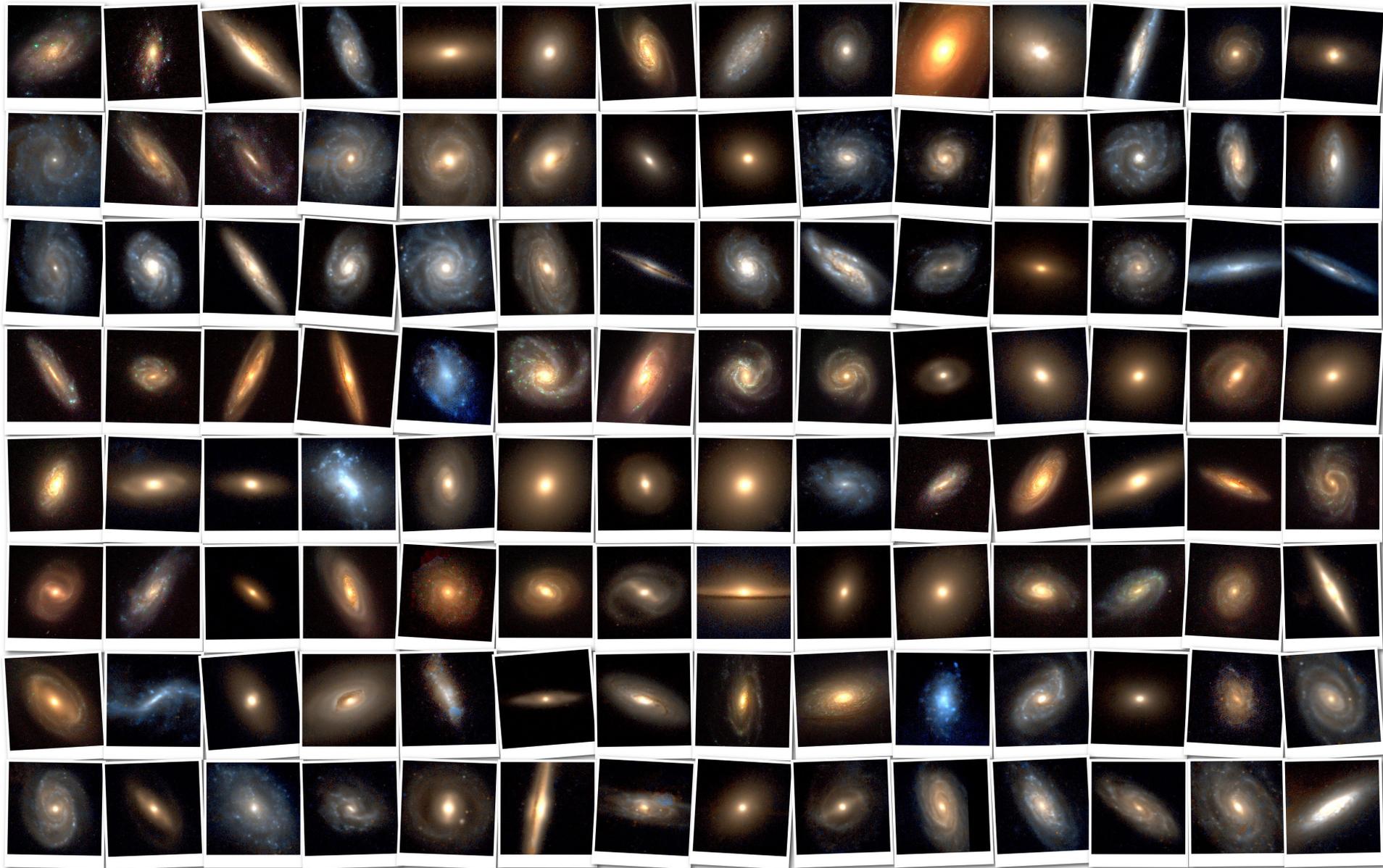
Over 100 billion stars  
make up our home  
galaxy, the Milky Way



To see more distant objects, you need a bigger telescope ... the Hubble!



# Millions of galaxies now discovered...



# Stars & Galaxies Demystified:

Stars are burning balls of gas  
... like our own Sun

The night sky is full of stars  
... these are all part of the Milky Way

The universe is full of galaxies  
...which contain their own stars

# A Modern Mystery...

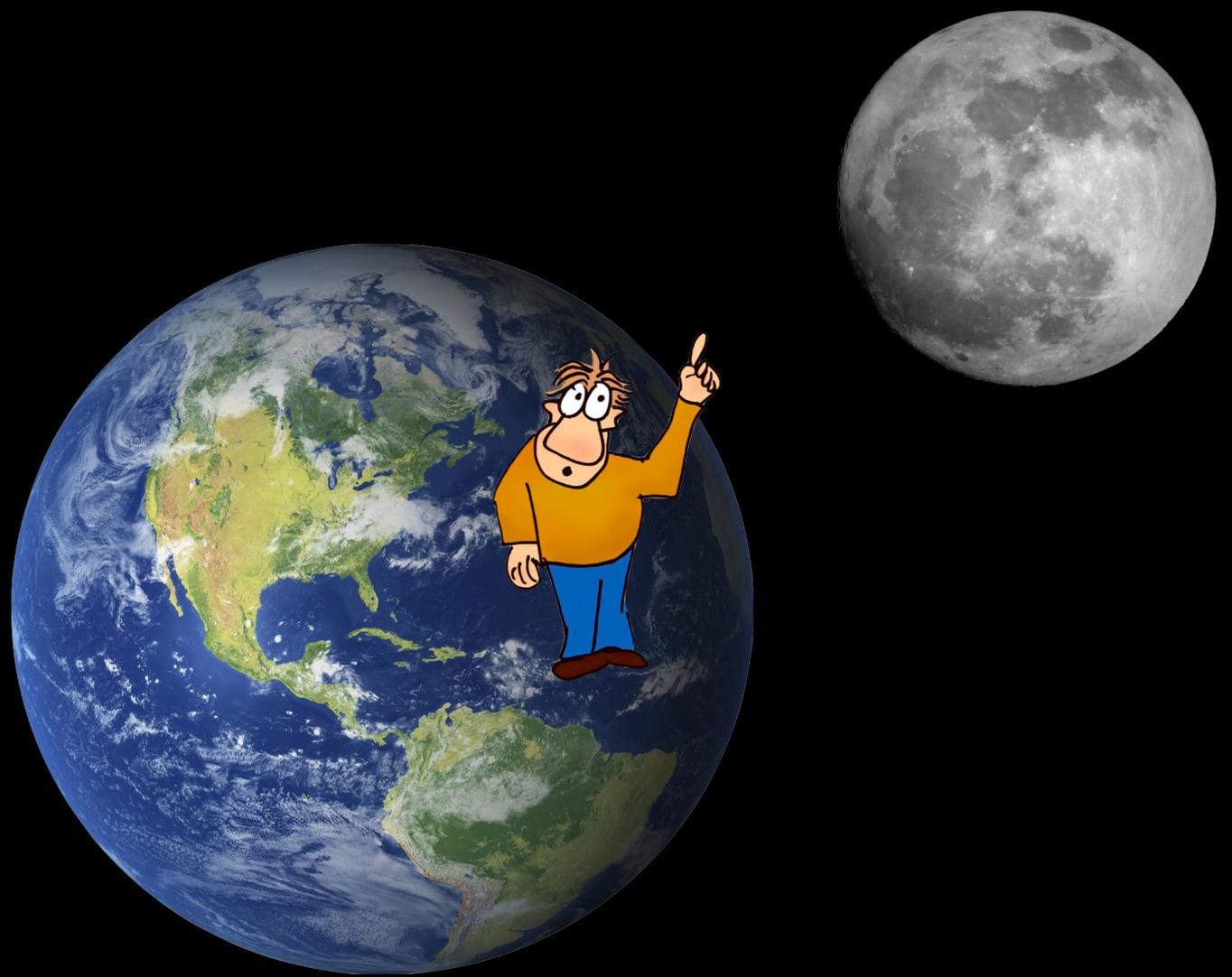
Recent observations indicate that there's **MUCH** more “stuff” in the galaxies than just stars

This extra stuff that we cannot see is called “dark matter”

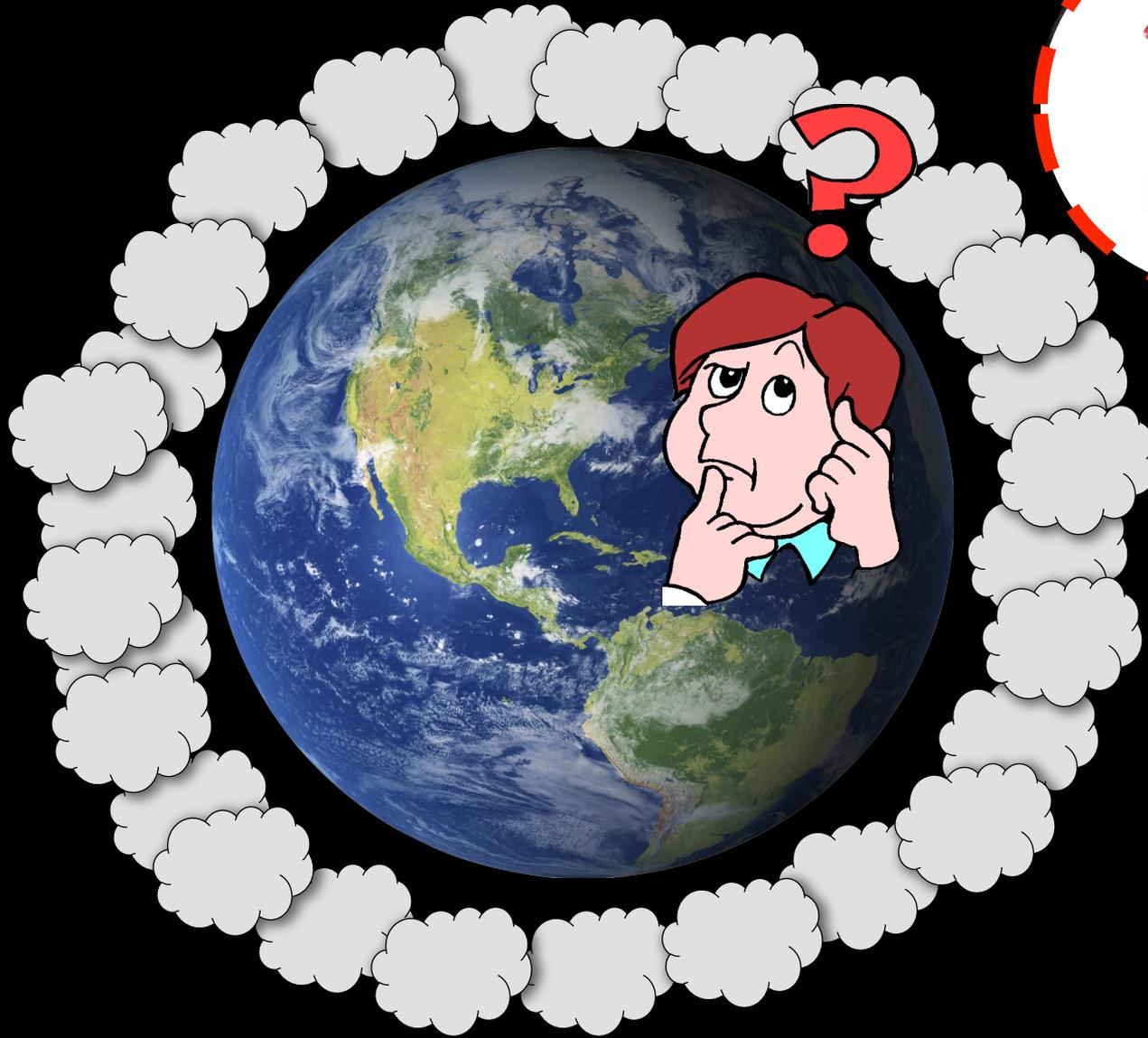
Galaxies like the Milky Way are thought to be surrounded by a “cloud” of dark matter



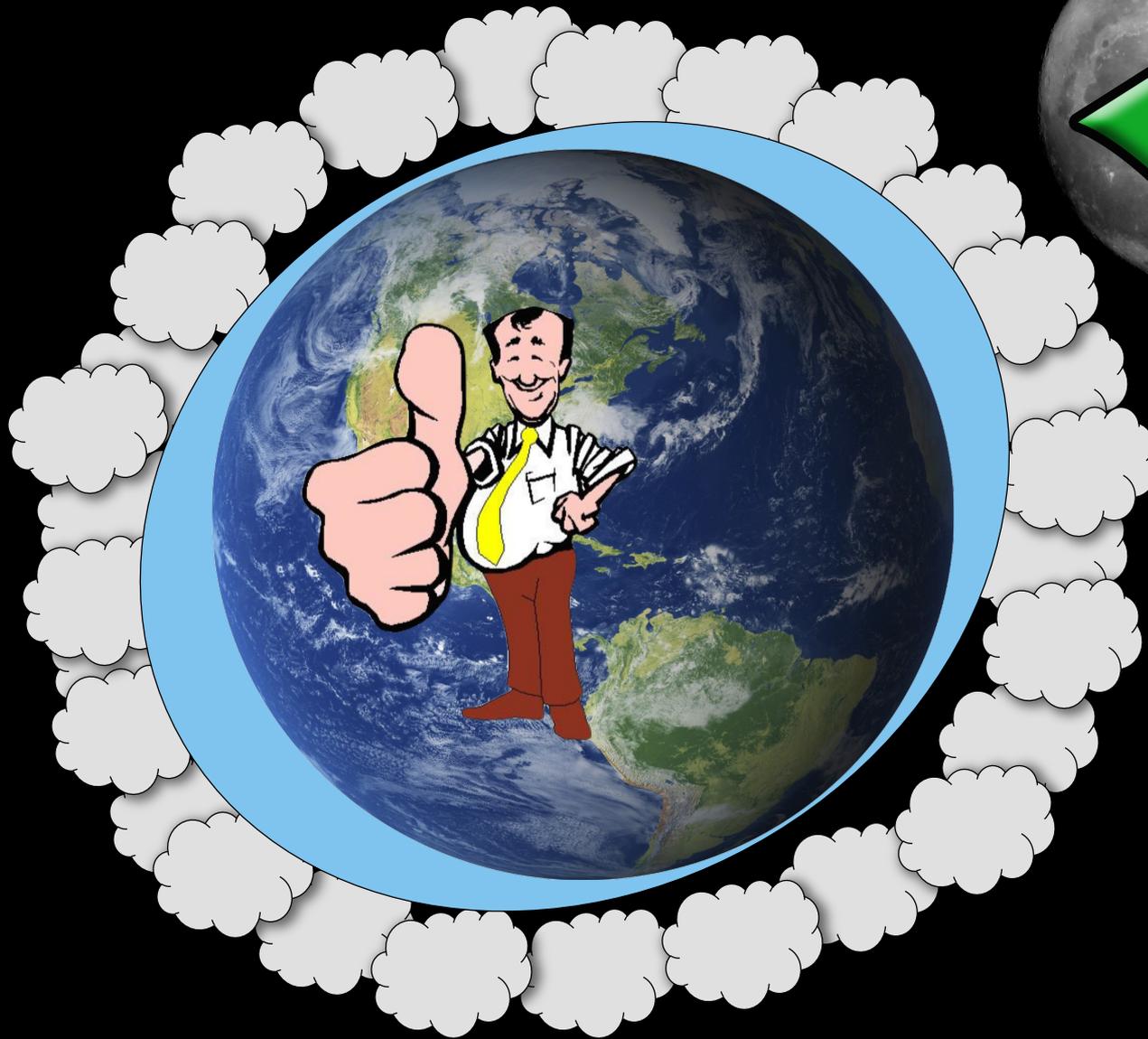
If you can't *see it* how do  
you know it's there?



“Does Earth have a moon?”



What about on a cloudy day?



Look for the tides!

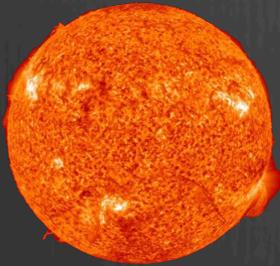
Even though we can't see  
dark matter by eye,  
we see it “by gravity”

Another quick example

...

How do you weigh the sun?

# The Earth orbits in a year



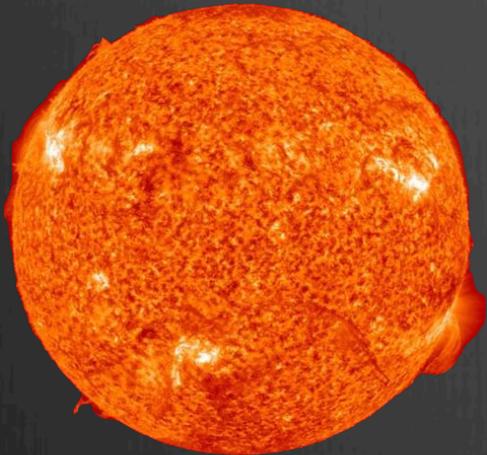
mass of the Sun

$$F = G \frac{Mm}{R^2}$$

force of gravity on Earth

(Isaac Newton's  
Law of Gravity,  
discovered 1687)

# What if the sun were heavier?



mass of the Sun

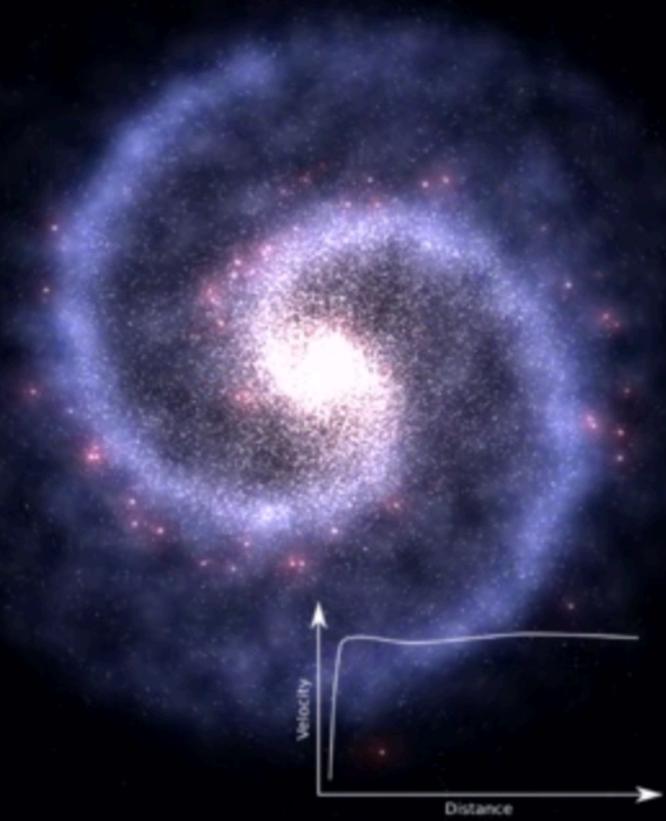
$$F = G \frac{Mm}{R^2}$$

force of gravity on Earth

More Mass → More Force → Faster Orbit

(Isaac Newton's  
Law of Gravity,  
discovered 1687)

# Weighing a galaxy!



How fast are the stars moving?

→ this tells you total matter

How bright is the galaxy?

→ this tells you the star stuff

Anything left over?

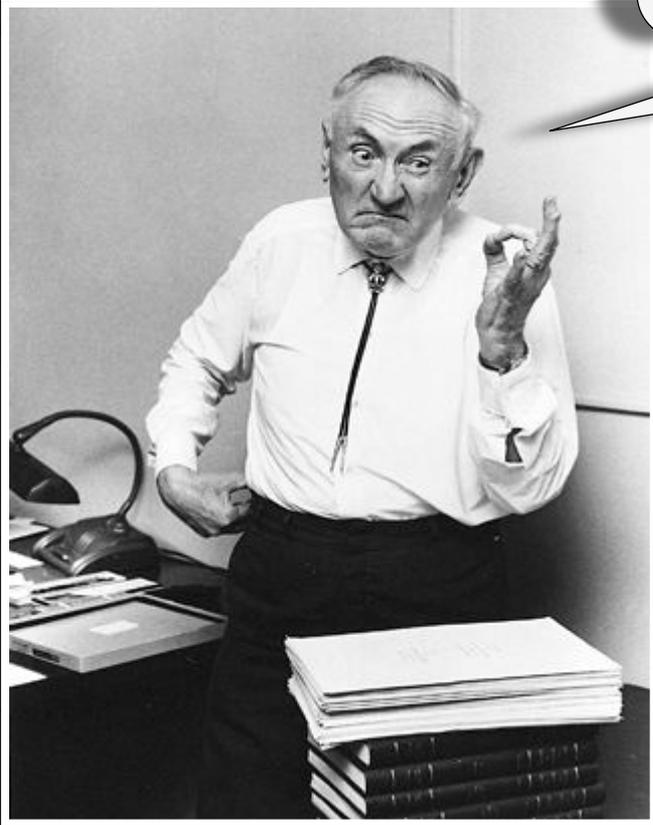
→ dark matter!



These stars are moving too fast!

Jan Oort  
(1932)

These galaxies are moving too fast!  
There must be some “dunkle Materie”



Fritz Zwicky  
(1933)



Coma cluster of galaxies

# Die Rotverschiebung von extragalaktischen Nebeln von F. Zwicky.

faster

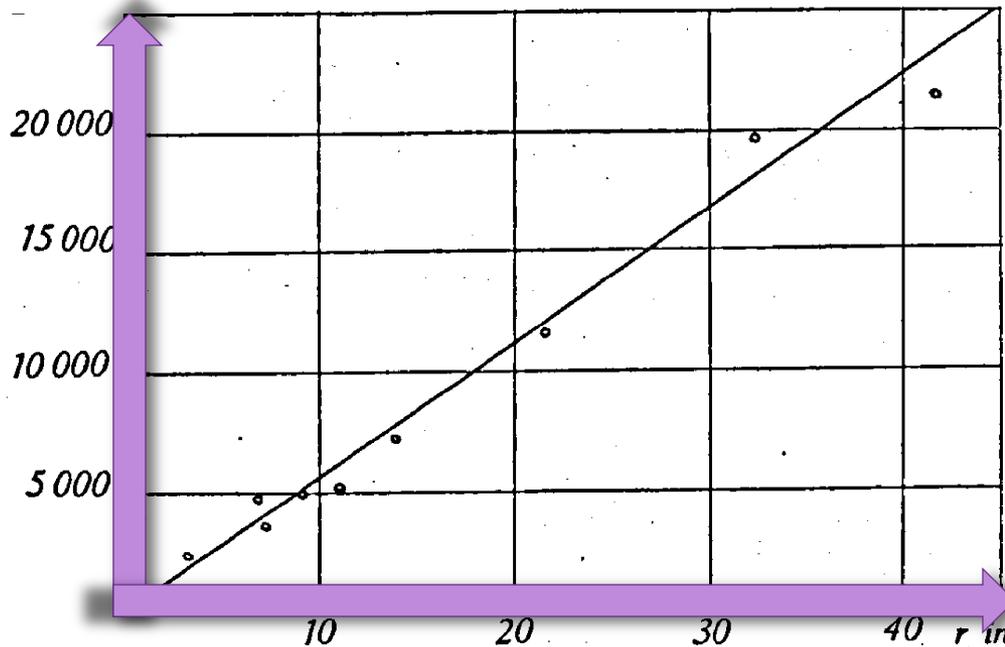


Fig. 2.

farther  
from center

Inhalte  
male extrag  
selben gedie  
tischer Nebel  
dieses wicht  
Schliesslich  
der durchdr

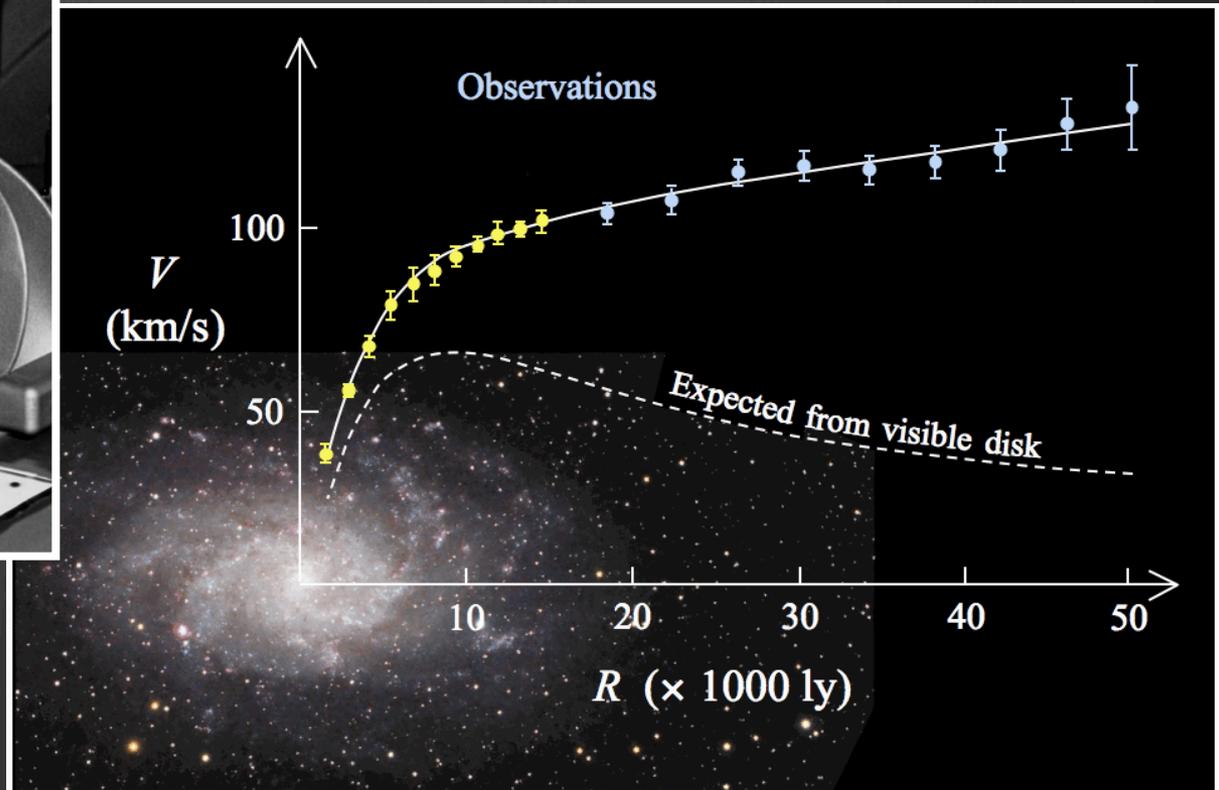
ten Merk-  
nung der-  
extragalak-  
Erklärung  
esprochen.  
Studium  
t.

Resultat ergeben, dass dunkle Materie in sehr viel grösserer Dichte vorhanden ist als leuchtende Materie.

The stars are moving too quickly in every galaxy.  
They must all have some dark matter!



Vera Rubin  
(1970)



From 1970 to today ... a lot has changed

- Hundreds of researchers!
- Dozens of worldwide collaborations!
- Over 13,000 scientific papers about dark matter!

Thanks to the pioneers like  
Zwicky & Rubin we now know

-- there's about five times more  
dark matter than atoms (by  
mass)

-- it's everywhere!

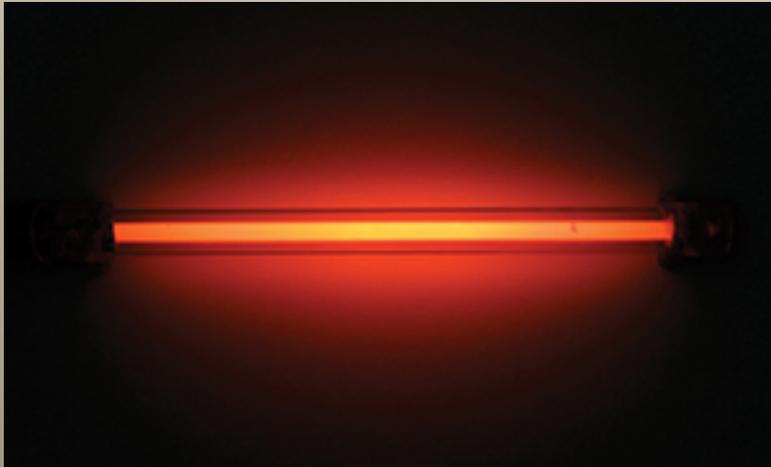
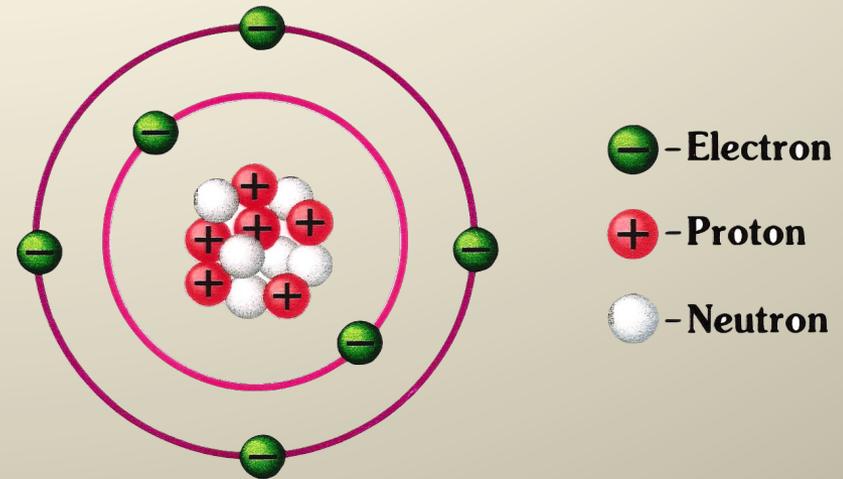
*What is it?*

*Can we make it?*

*Is it here?*

*What is it?*

*Atoms are the  
building blocks  
of matter*



*When you heat  
atoms, they glow  
(like neon lights)*

*Dark matter does not glow*

# *No dark matter here...*

Group→	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
↓Period																		
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	* 71 Lu	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	* * 103 Lr	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Uut	114 Fl	115 Uup	116 Lv	117 Uus	118 Uuo
			* 57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb		
			* * 89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No		

*The dark matter must  
be a new kind of  
particle*

# There are a lot of hypotheses



We might not know what it is, but you can buy it anyway

# DARK MATTER



**DARK MATTER** is the name given to material in the Universe that does not emit or reflect light but is necessary to explain observed gravitational effects in galaxies and stars. Dark matter, along with dark energy, totals 96% of the Universe, yet it remains a mystery as to what exactly it is.

*Acrylic felt, wool felt, and fleece with gravel fill for maximum mass.*

*Packaged in a black opaque bag designed for concealing contents.*



**\$10.49** PLUS SHIPPING

GLUON PHOTON NEUTRINO TACHYON ELECTRON UP QUARK DOWN QUARK TAU NEUTRINO MUON UP QUARK  
NEUTRON DOWN QUARK TAU GLUON **DARK MATTER** NEUTRINO TACHYON ELECTRON UP QUARK DOWN  
NEUTRINO MUON UP QUARK PROTON NEUTRON DOWN QUARK TAU GLUON PHOTON NEUTRINO TACHYON  
UP QUARK DOWN QUARK TAU GLUON PHOTON NEUTRINO TACHYON ELECTRON UP QUARK DOWN QUARK TAU  
NEUTRON DOWN QUARK TAU GLUON PHOTON NEUTRINO TACHYON ELECTRON UP QUARK DOWN QUARK TAU  
DOWN QUARK TAU GLUON PHOTON NEUTRINO TACHYON ELECTRON UP QUARK DOWN QUARK TAU NEU  
UP QUARK PROTON NEUTRON DOWN QUARK TAU GLUON PHOTON NEUTRINO TACHYON ELECTRON UP

The **PARTICLE ZOO**

*Can we make it?*

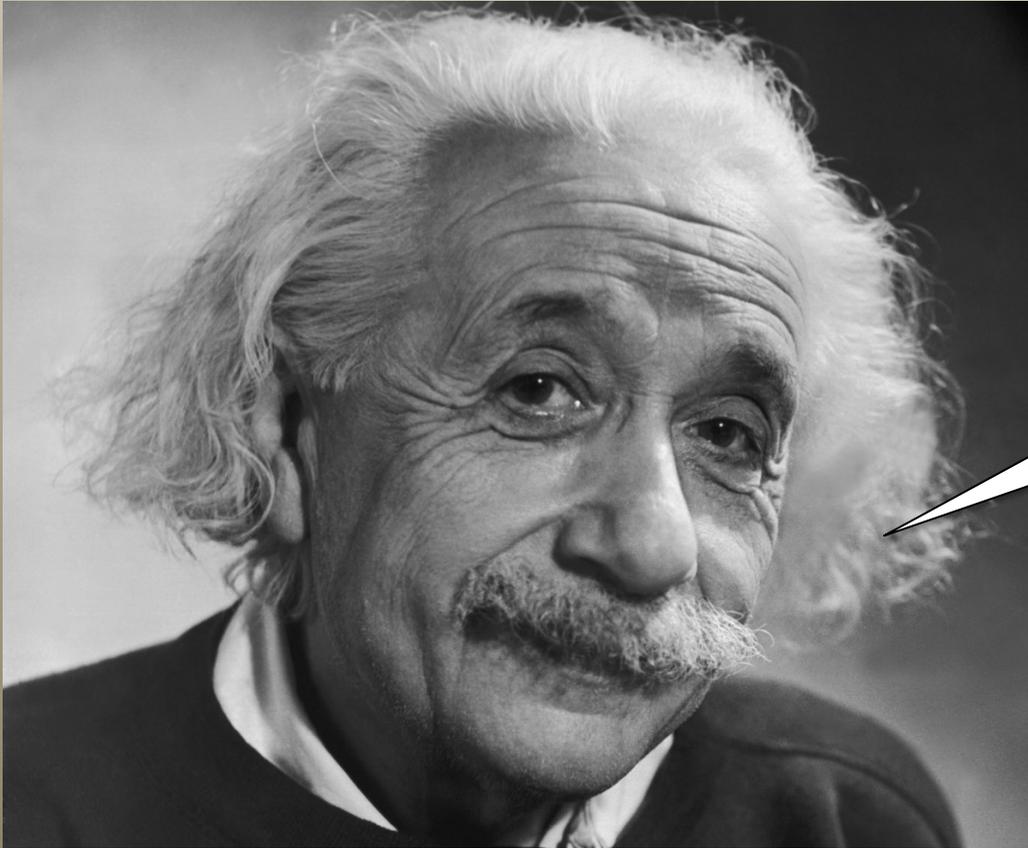
# Chemists make new molecules and atoms all the time



But dark matter is not made of atoms!

It cannot be created using chemistry.

Einstein told us that matter can  
be created from energy



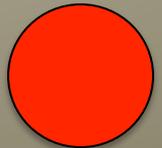
$$E = mc^2$$

*To create heavy particles,  
like dark matter,  
you need a LOT of energy!*

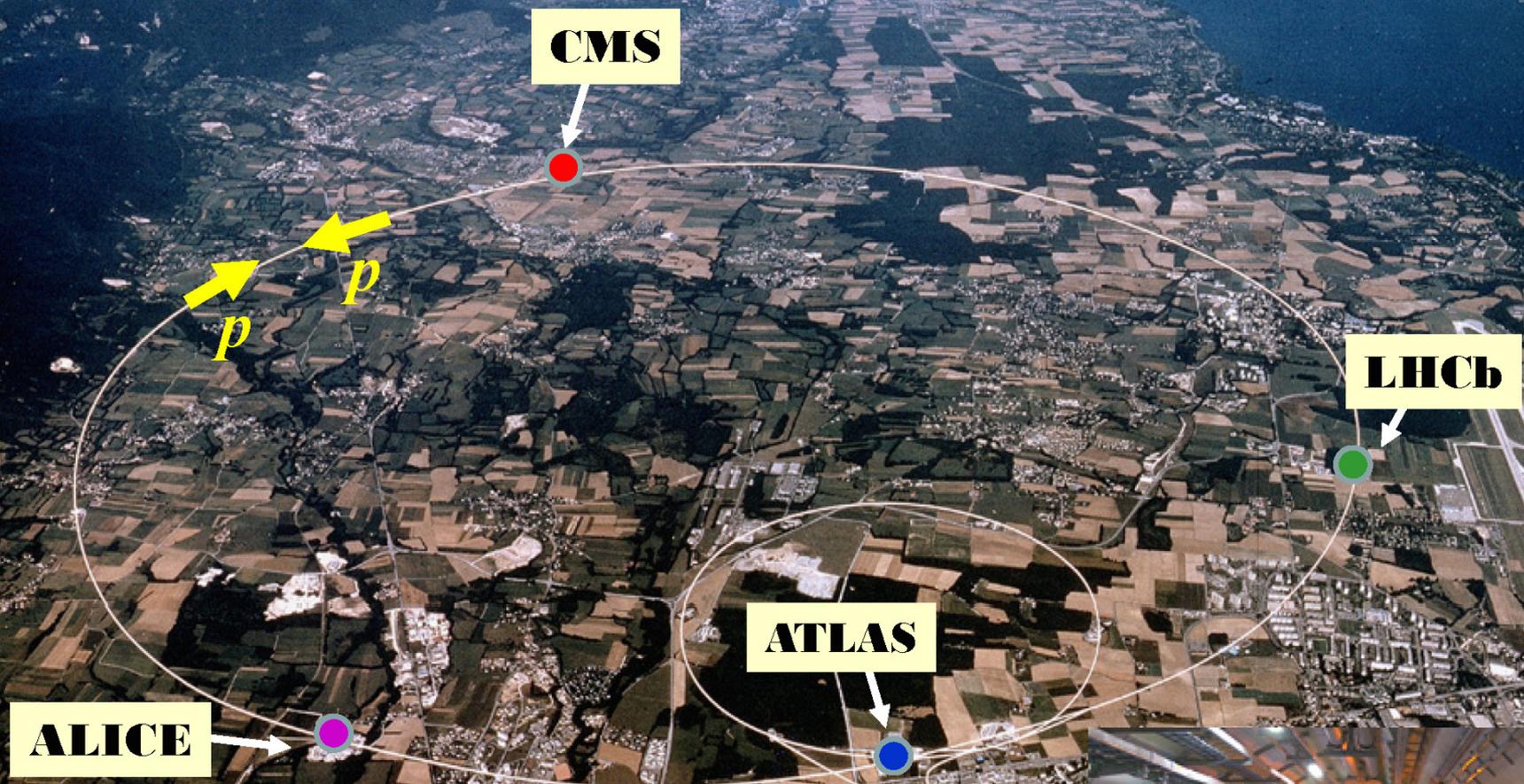
*slow collision*



*fast collision*



# Large Hadron Collider



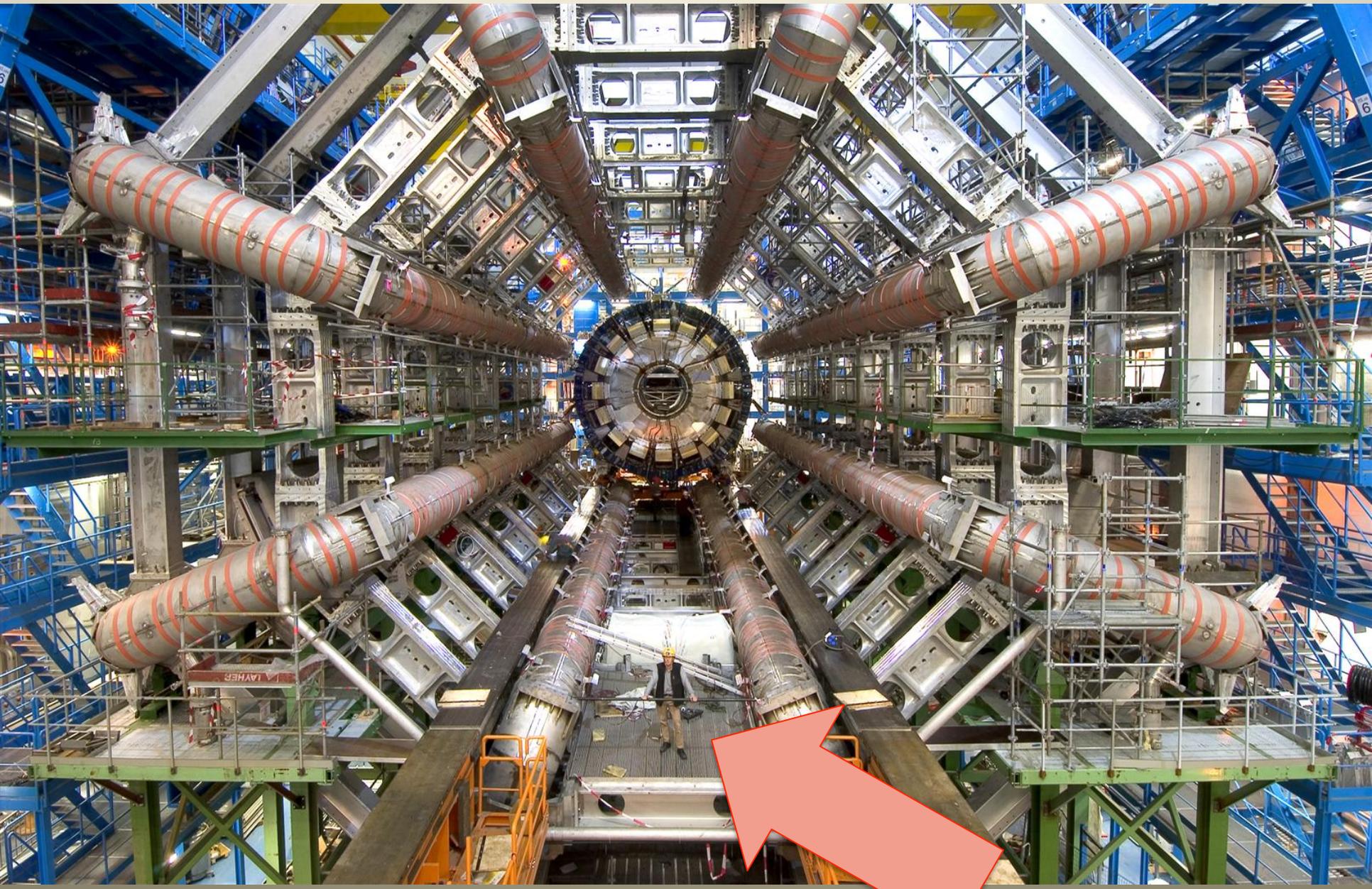


**France**

**Switzerland**

A

Le Havre, Caen, Rouen, Paris, Reims, Luxembourg, Saarbrücken, Nancy, Karlsruhe, Stuttgart, Strasbourg, Troyes, Le Mans, Orleans, Dijon, Freiburg, Zurich, Angers, Tours, Basel, Lausanne, Poitiers, Niort, La Rochelle, Angoulême, Limoges, Bourg-en-Bresse, Roanne, Lyon, Geneva, Milan, Grenoble, Torino, Bordeaux, Bergerac, Agen, Genoa



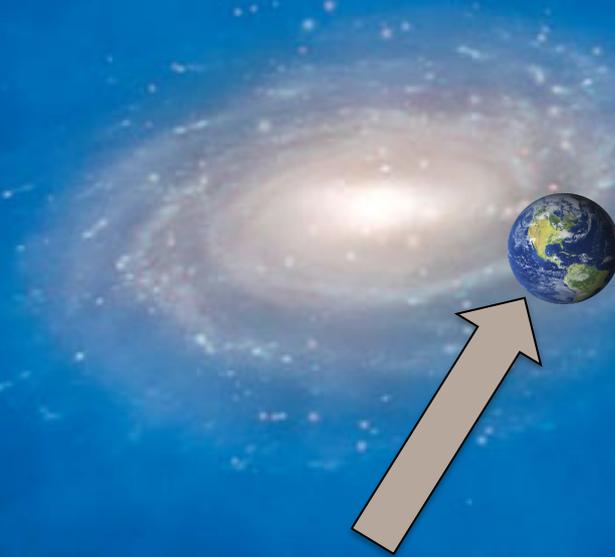


*No dark matter has been created at the LHC ... yet!*

*Creating dark matter in the lab would help to discriminate between competing models*

*Is it here?*

How much dark matter  
is in the vicinity of the Earth?



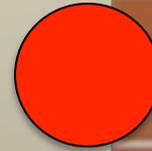
about 1 particle per  $\text{cm}^3$   
... that's a lot!

# *Why aren't we bumping into all this dark matter?*

*air molecule*

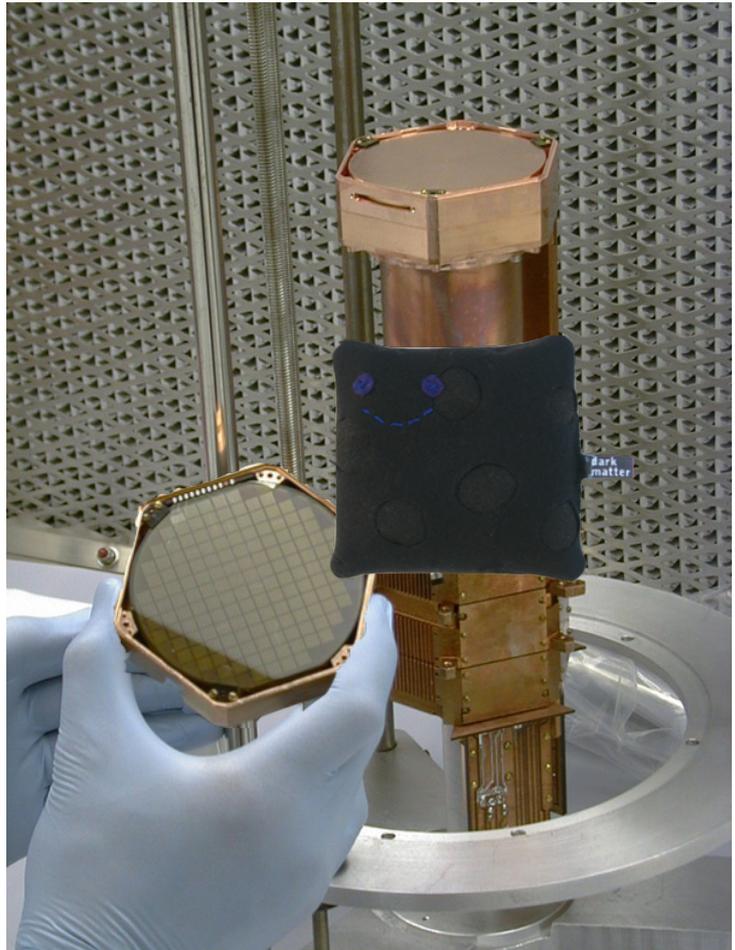


*dark matter*



“the ghost particle”

Collisions are  
rare, but they  
do occur

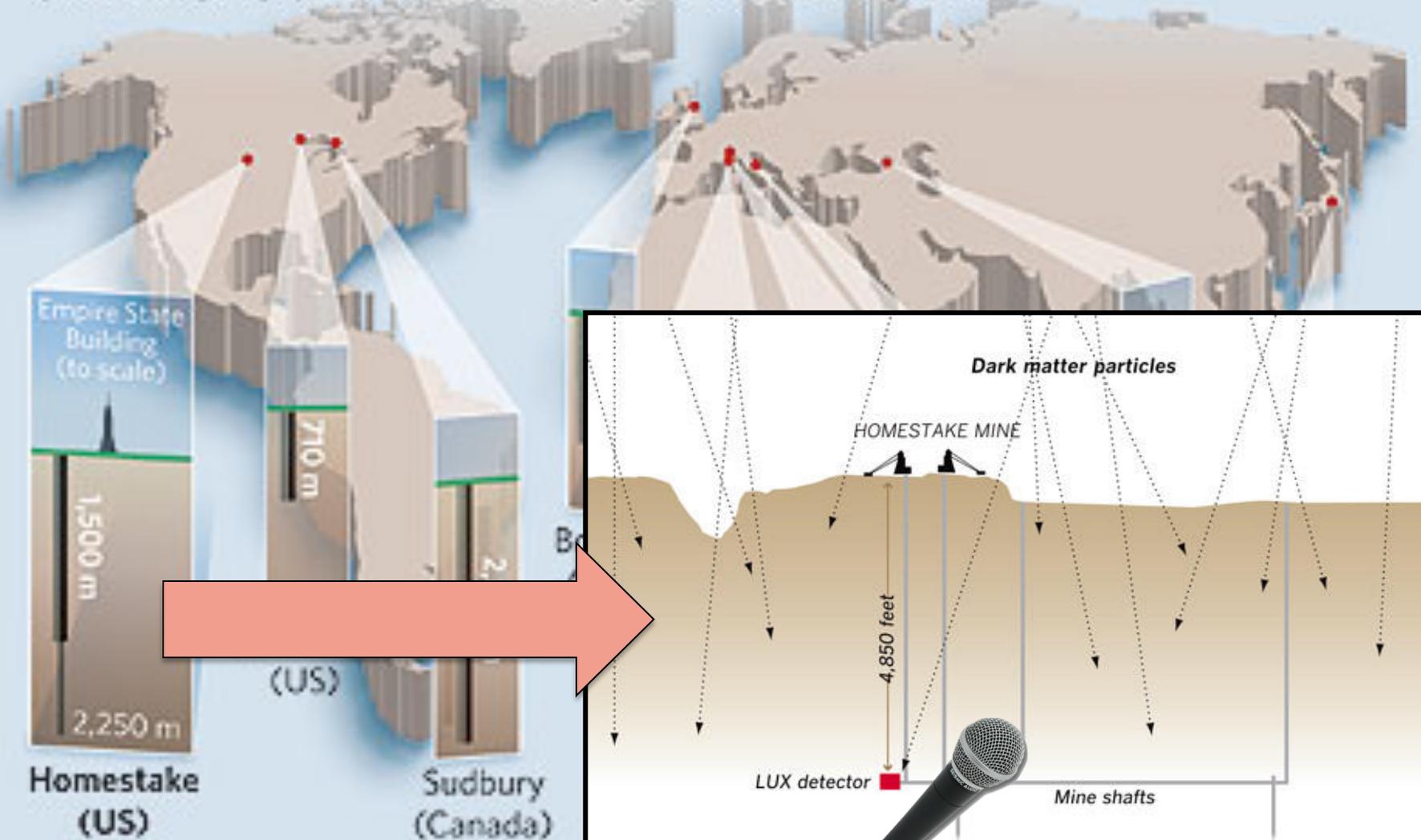


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# It's more "quiet" underground...

## UNDERGROUND LABS AROUND THE WORLD



*Dozens of experimental collaborations are in the race to discover dark matter.*

*Who will be the first?*

*Experimental efforts ongoing!*

# *All Open Questions!*

*What is it*



*Can we make it*



*Is it here*

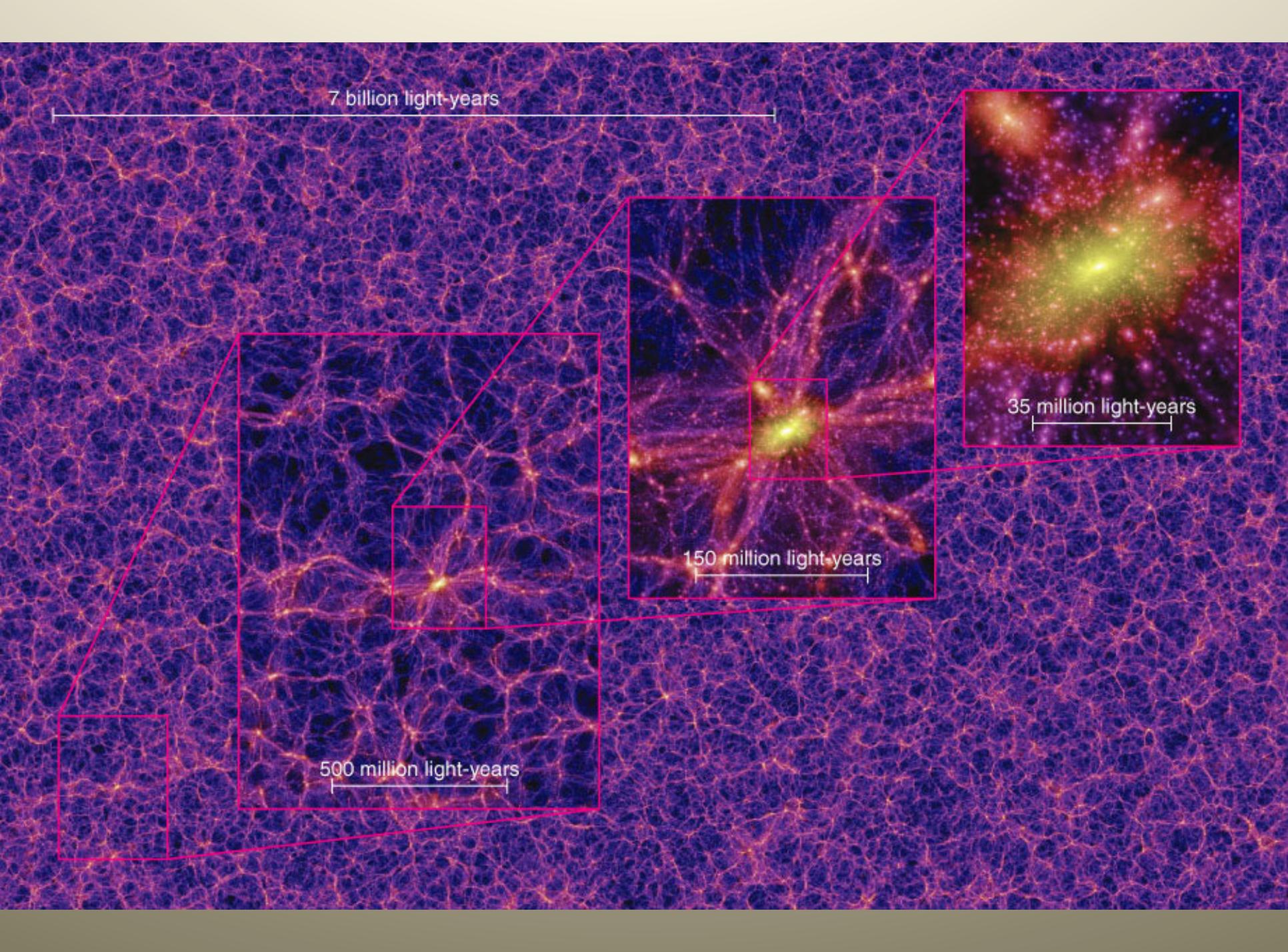


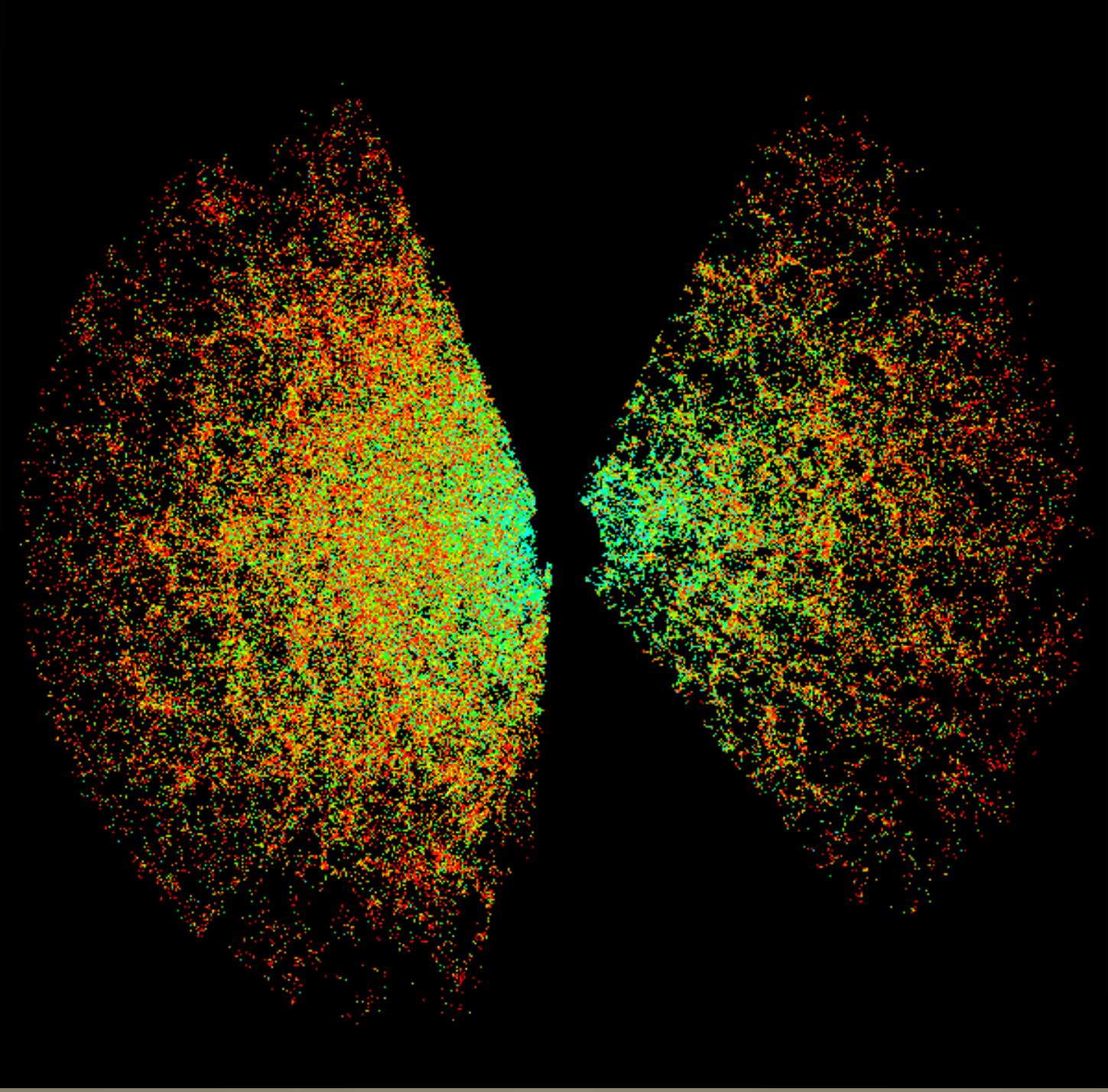


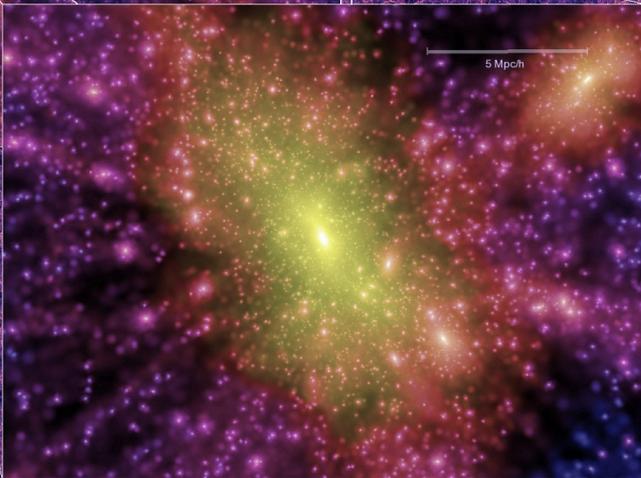
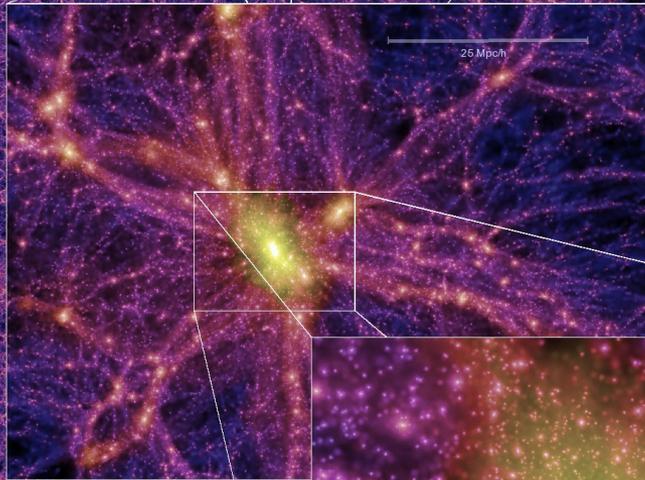
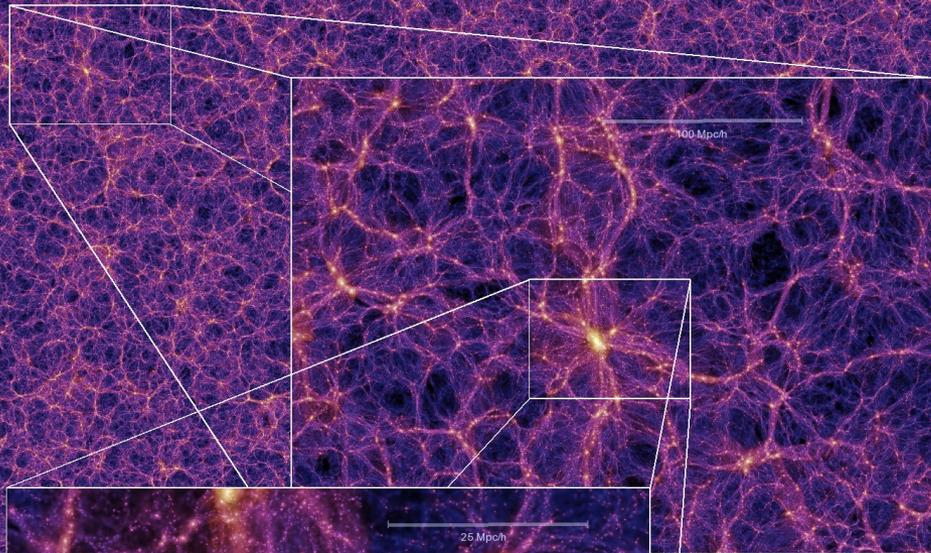
We encountered a new mystery, simply by looking upward.

In trying to demystify dark matter, we are forced to look in some exotic places.

What other mysteries might we uncover?



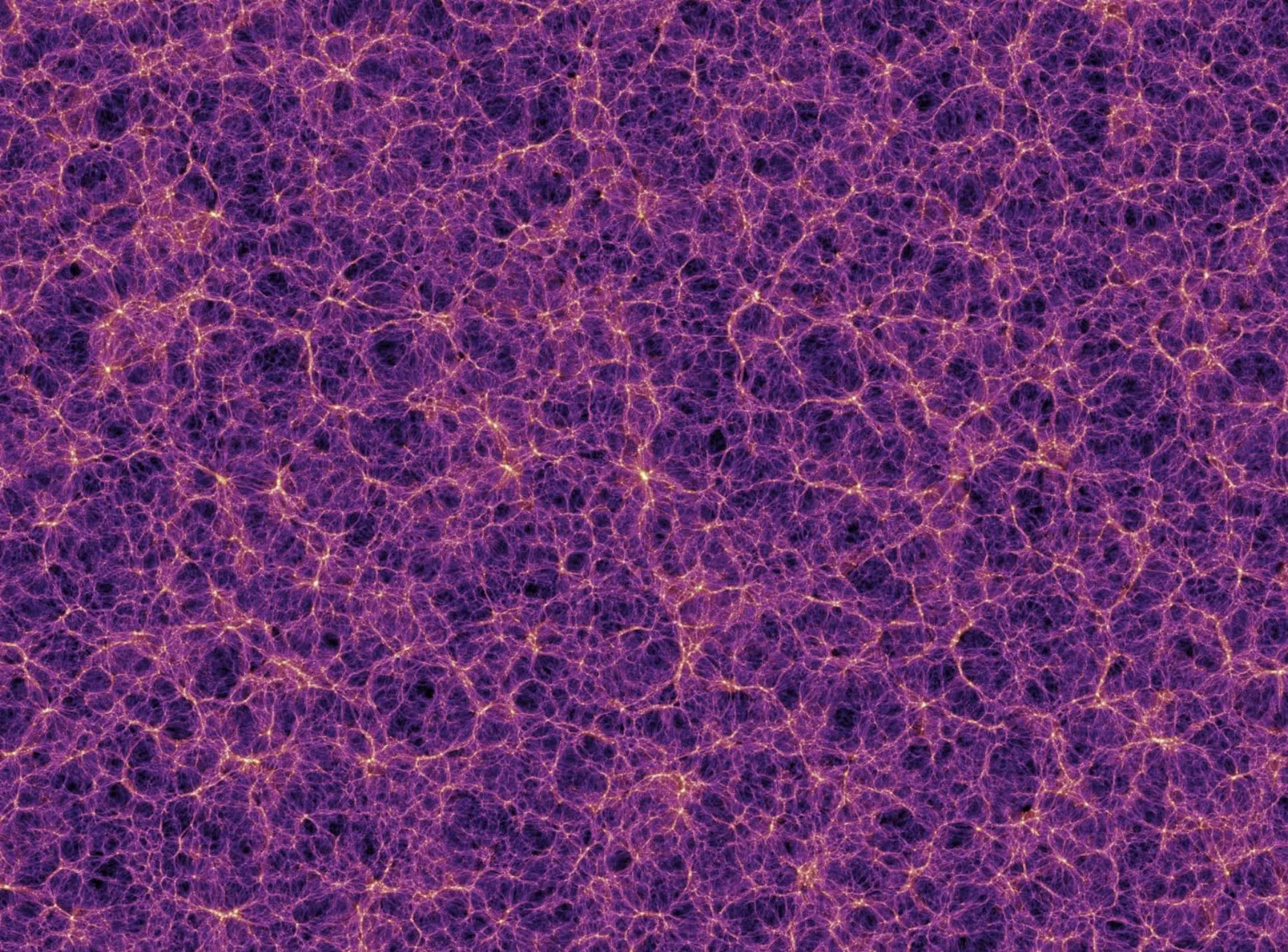




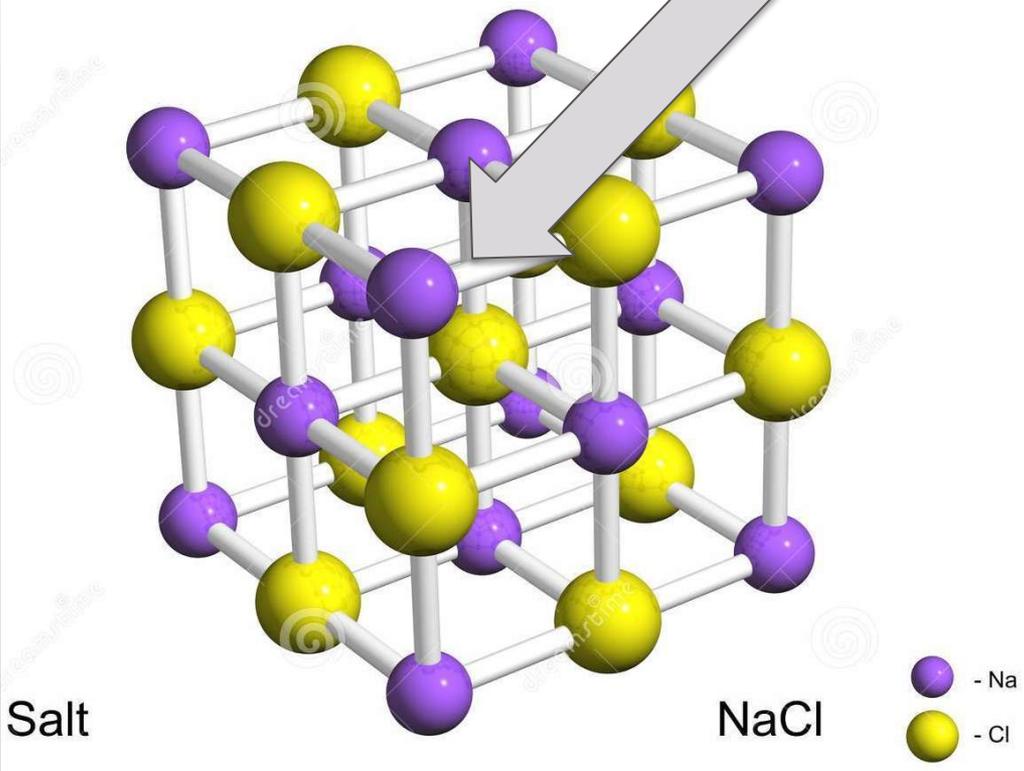
**Millennium Run**  
10,077,696,000 particles

Springel et al. (2004)  
Max-Planck-Institut für  
Astrophysik





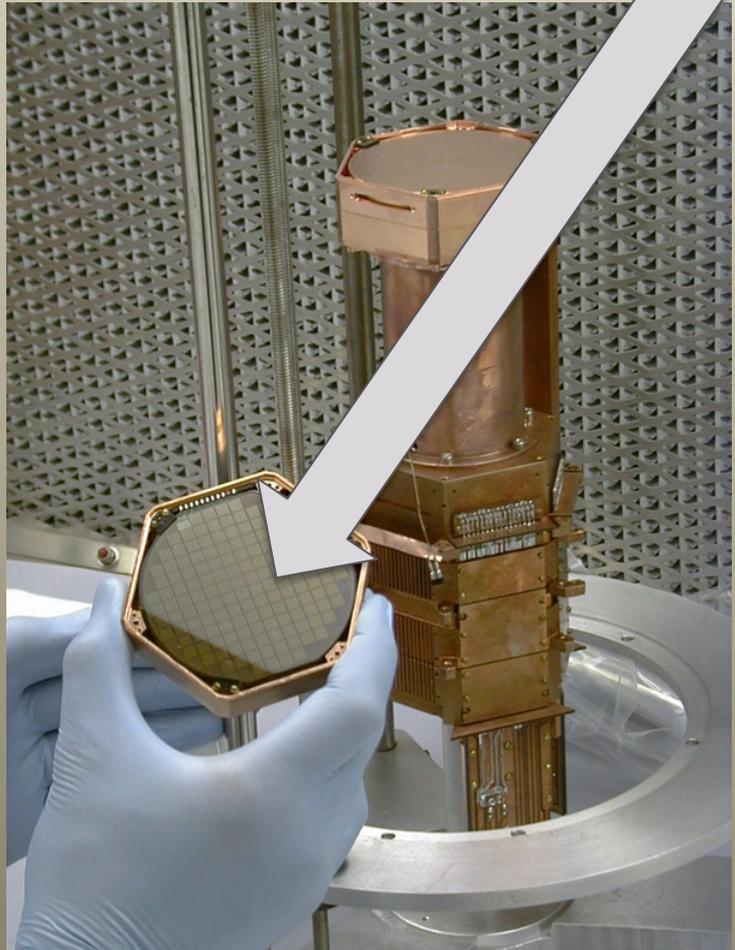
Collisions are rare, but they do occur



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Collisions are rare, but they do occur



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