

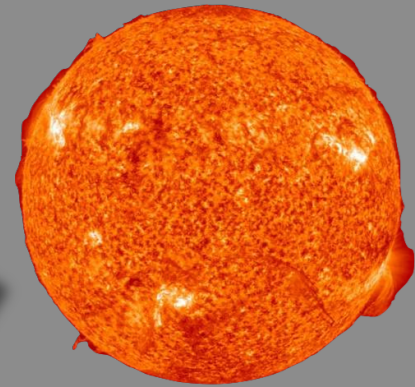
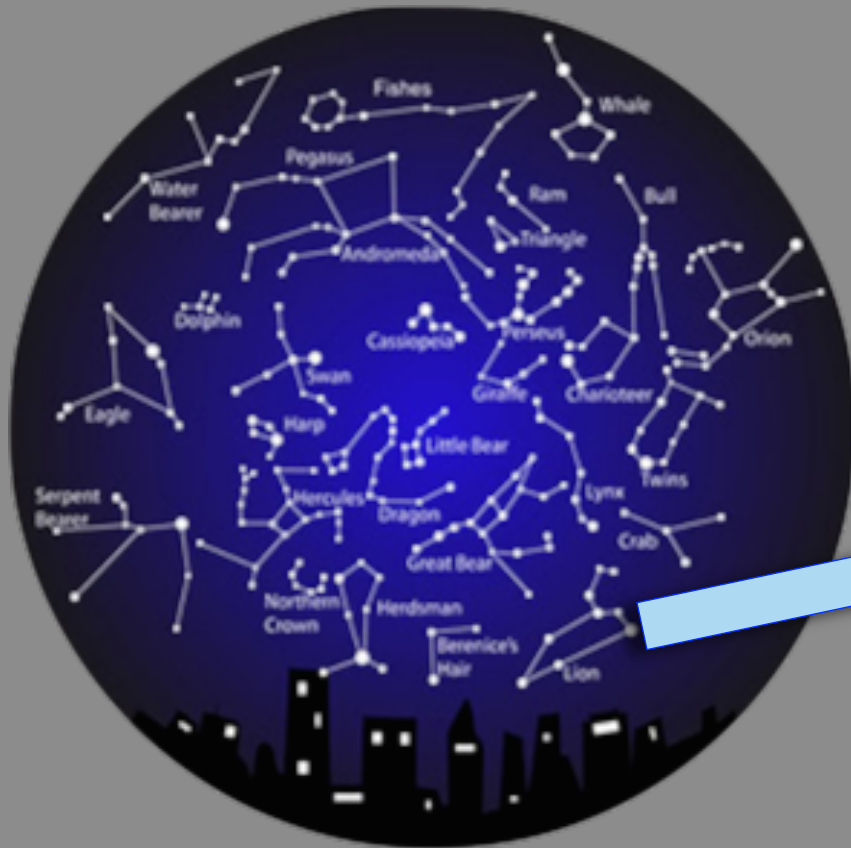
Demystifying Dark Matter

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



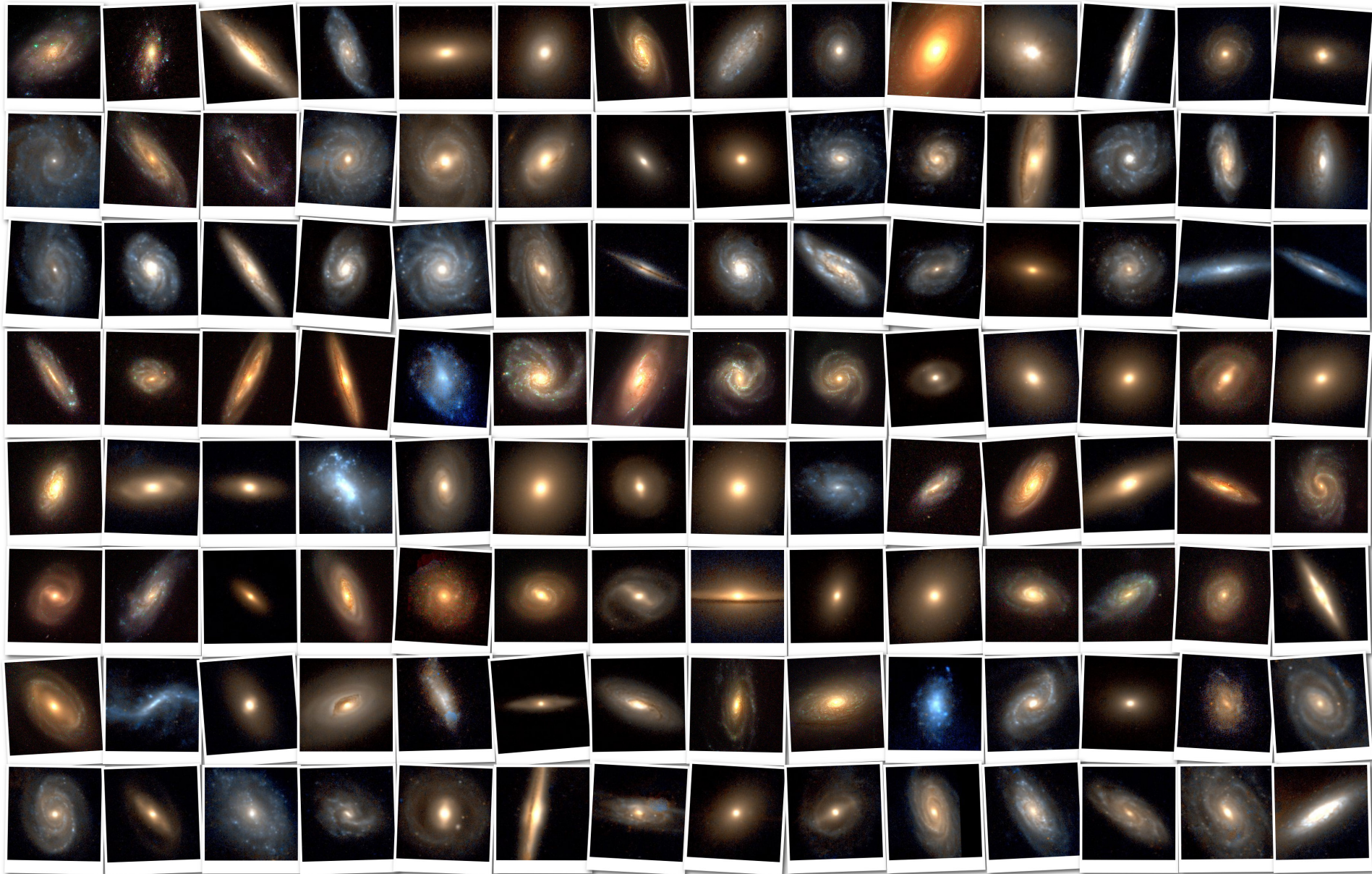
Over 100 billion stars
make up our home
galaxy, the Milky Way





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”

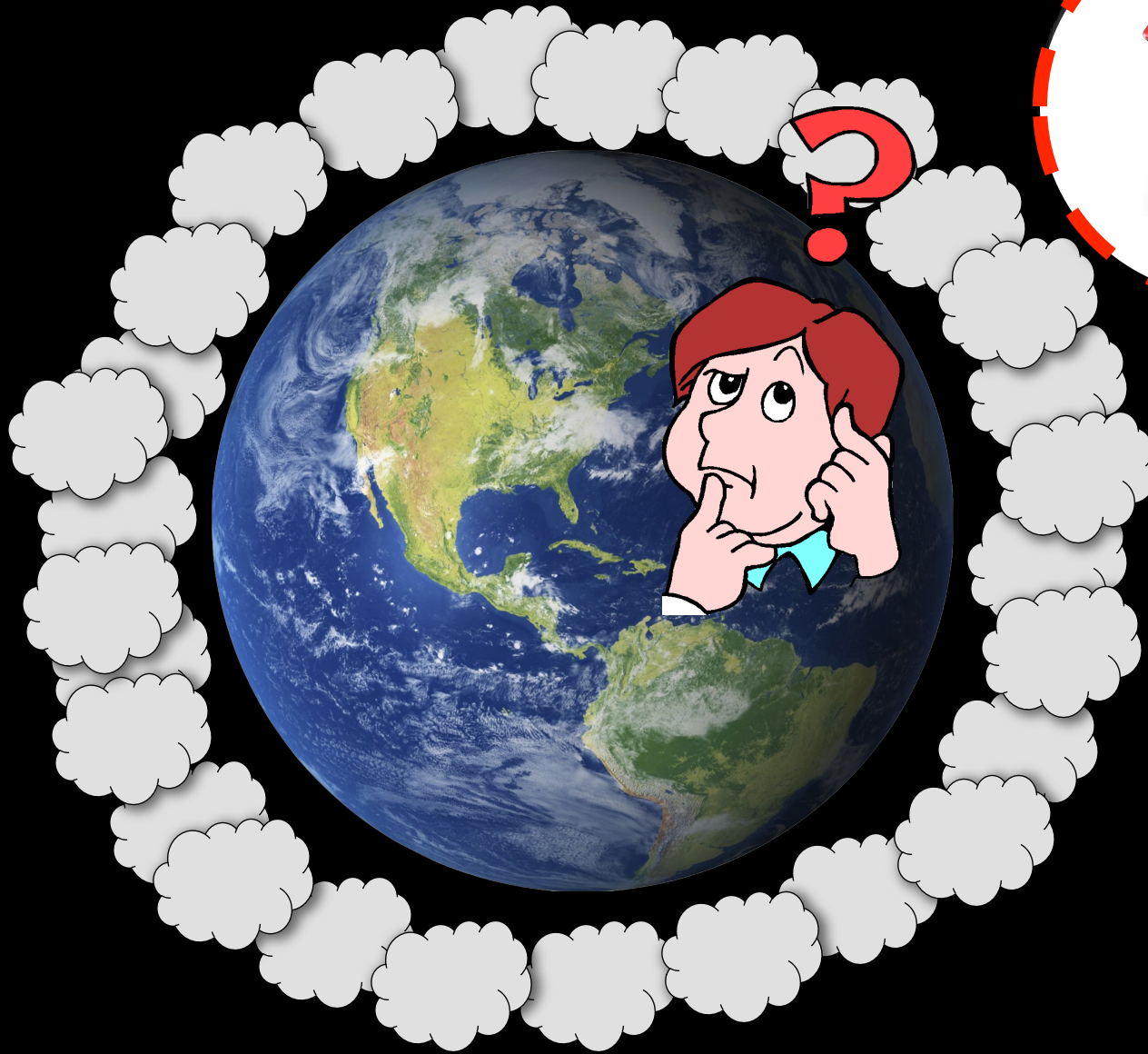
Galaxies like the Milky Way are thought to be surrounded by a “cloud” of dark matter



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



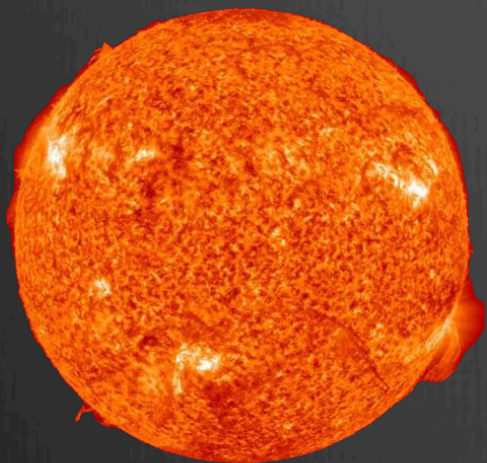
mass of the Sun

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

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?

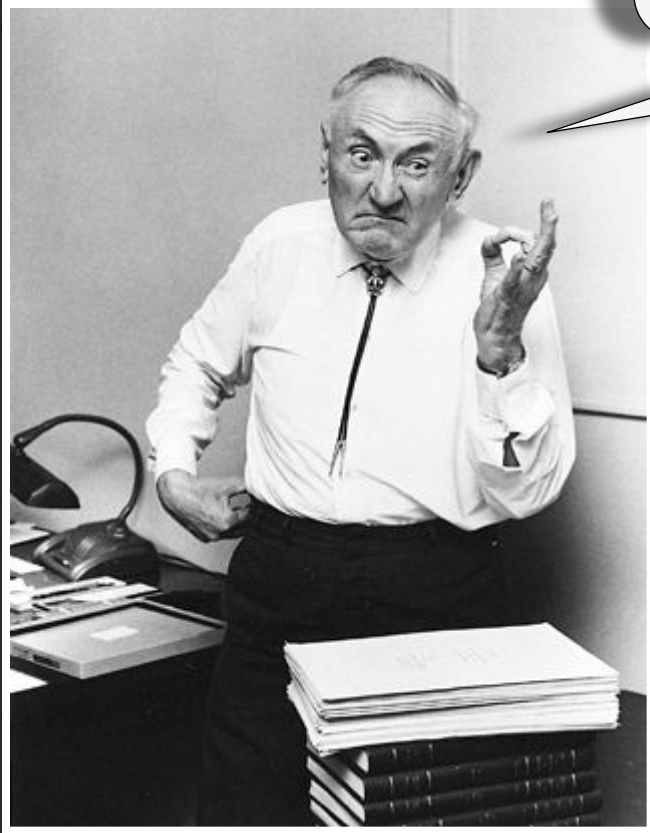
→ dark matter!



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

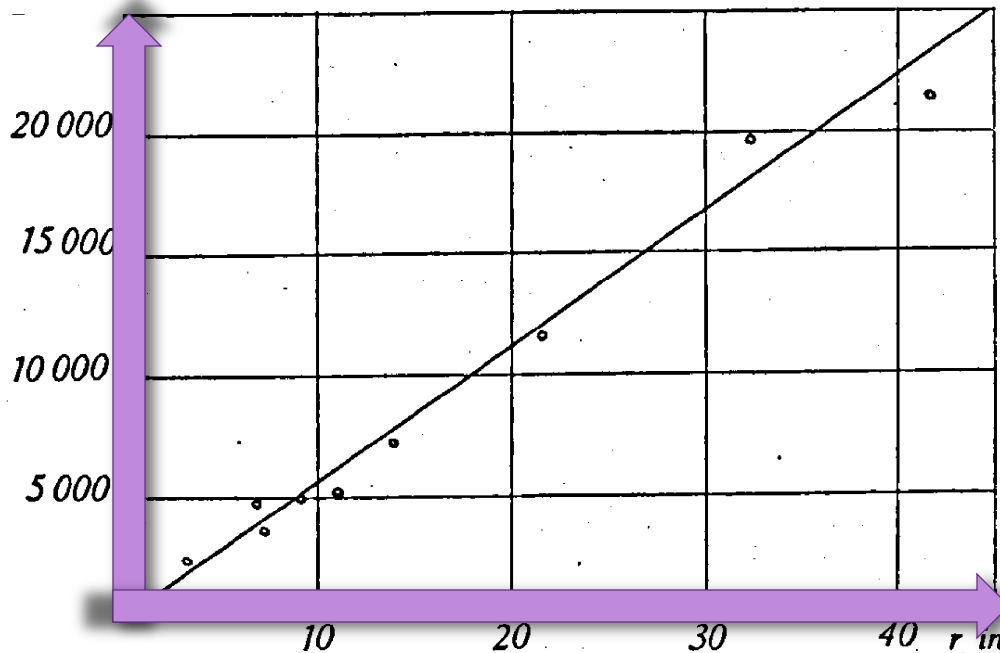


Fig. 2.

farther
from center

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

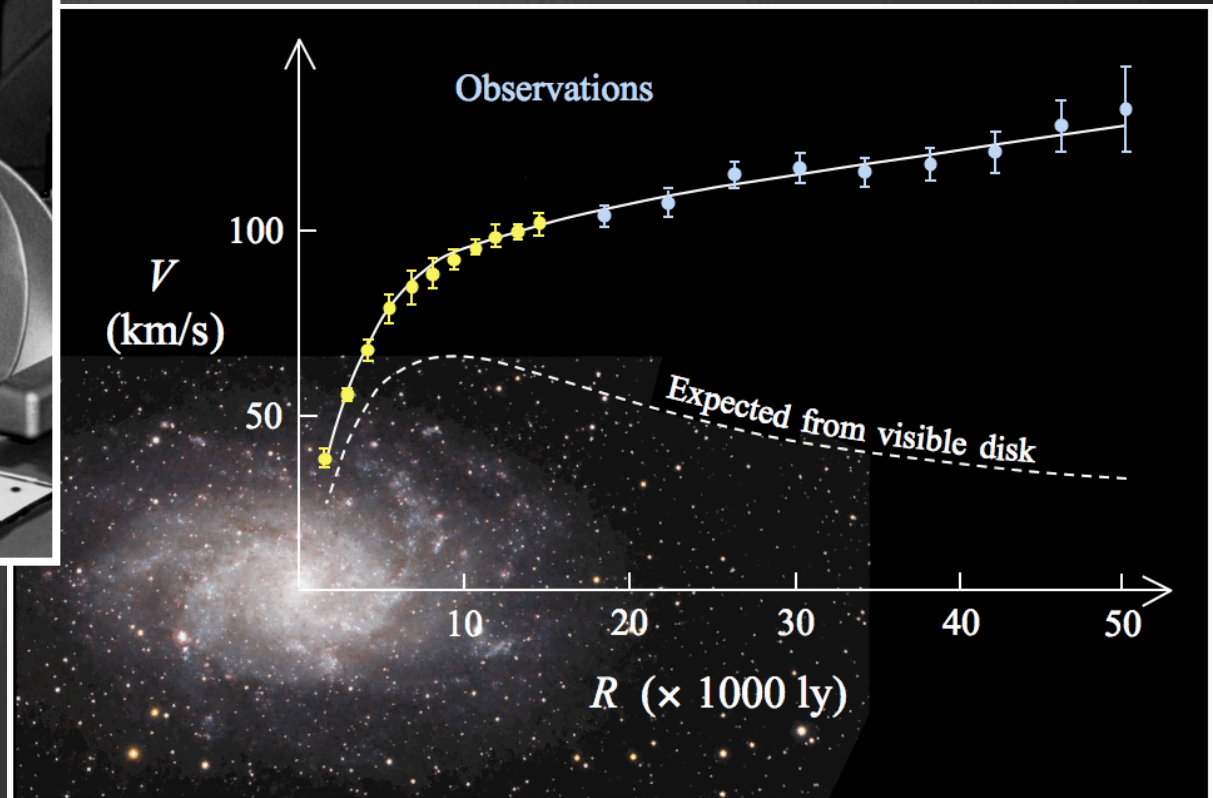
ten Merk-
nung der-
extragalak-
Erklärung
esprochen.
Studium
t.

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!

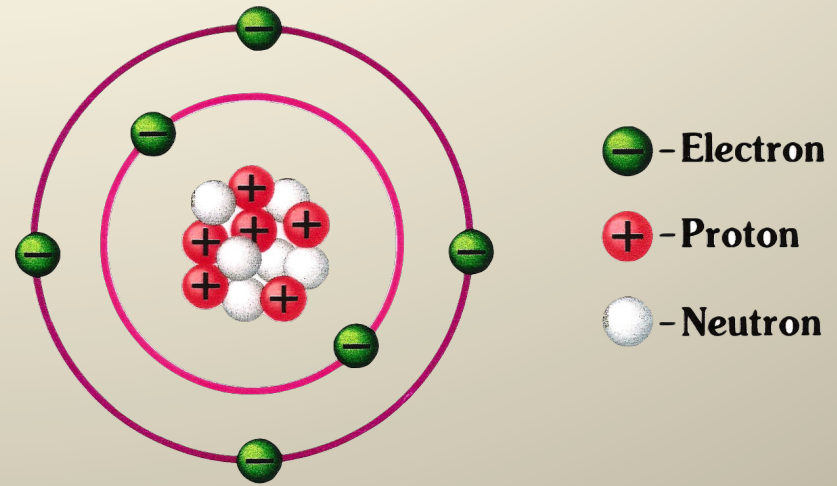
What is it?

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 NEUTRINO TACHYON ELECTRON UP QUARK DOWN QUARK TAU GLUON
NEUTRON DOWN QUARK TAU GLUON PHOTON NEUTRINO TACHYON ELECTRON UP QUARK DOWN QUARK TAU
DOWN QUARK TAU NEUTRON DOWN QUARK TAU GLUON PHOTON NEUTRINO TACHYON ELECTRON UP
UP QUARK PROTON NEUTRON DOWN QUARK TAU GLUON PHOTON NEUTRINO TACHYON ELECTRON UP

The **PARTICLE ZOO**

Can we make it?

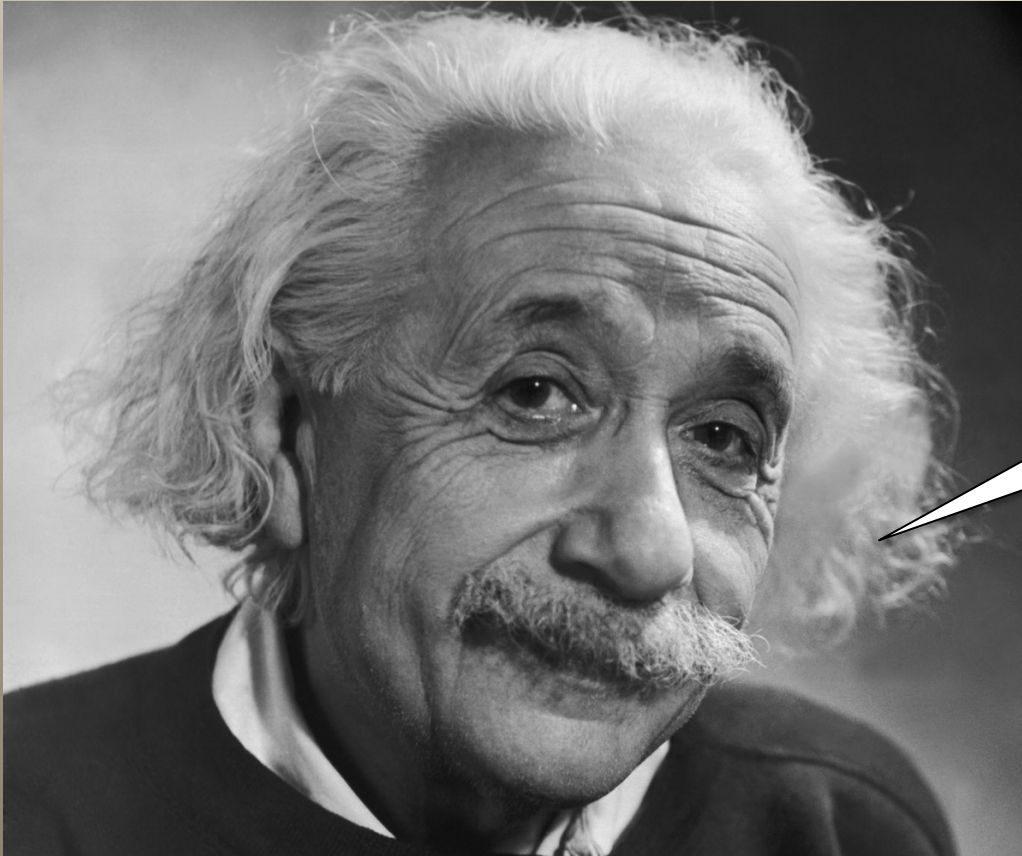
Chemists make new molecules and atoms all the time



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!*

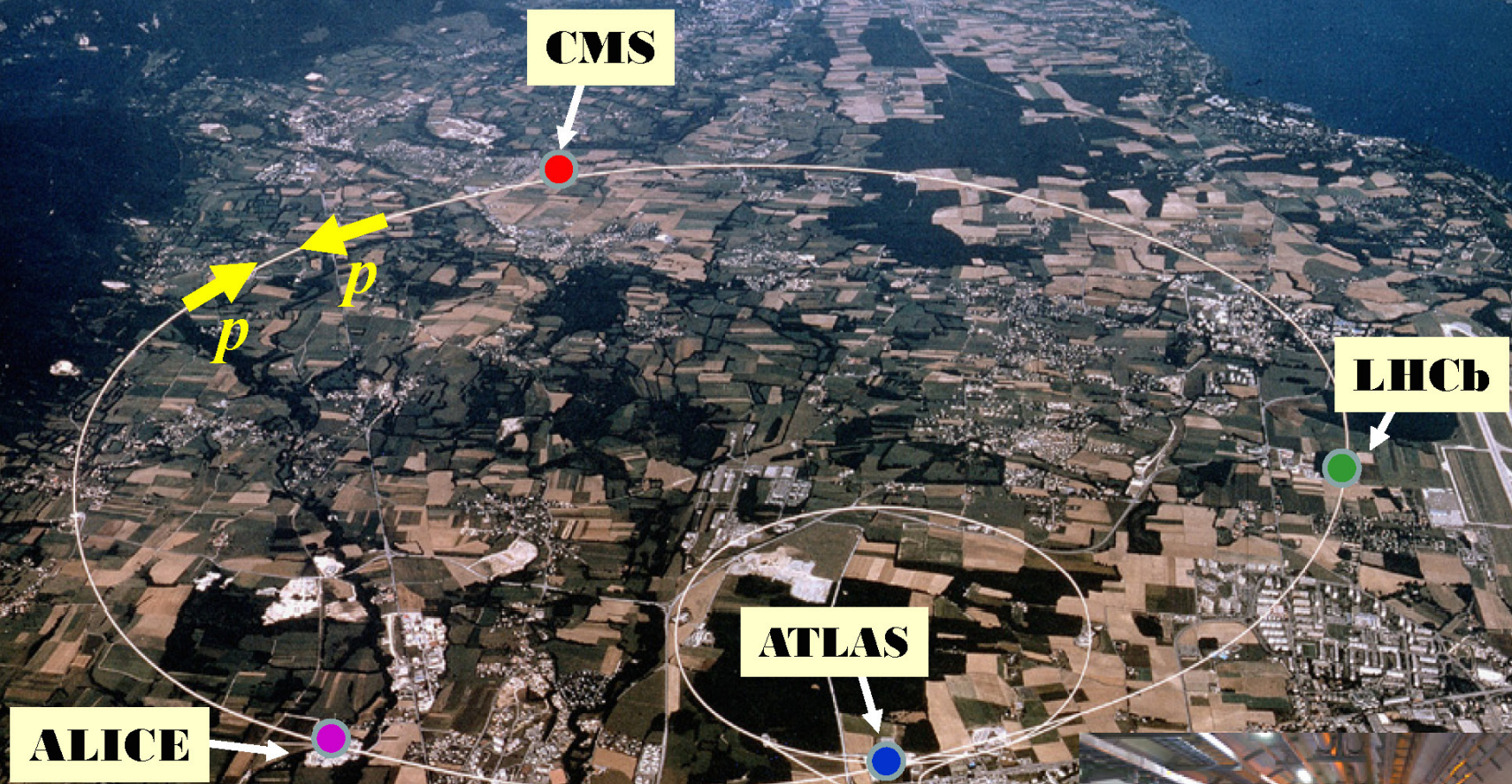
slow collision



fast collision



Large Hadron Collider

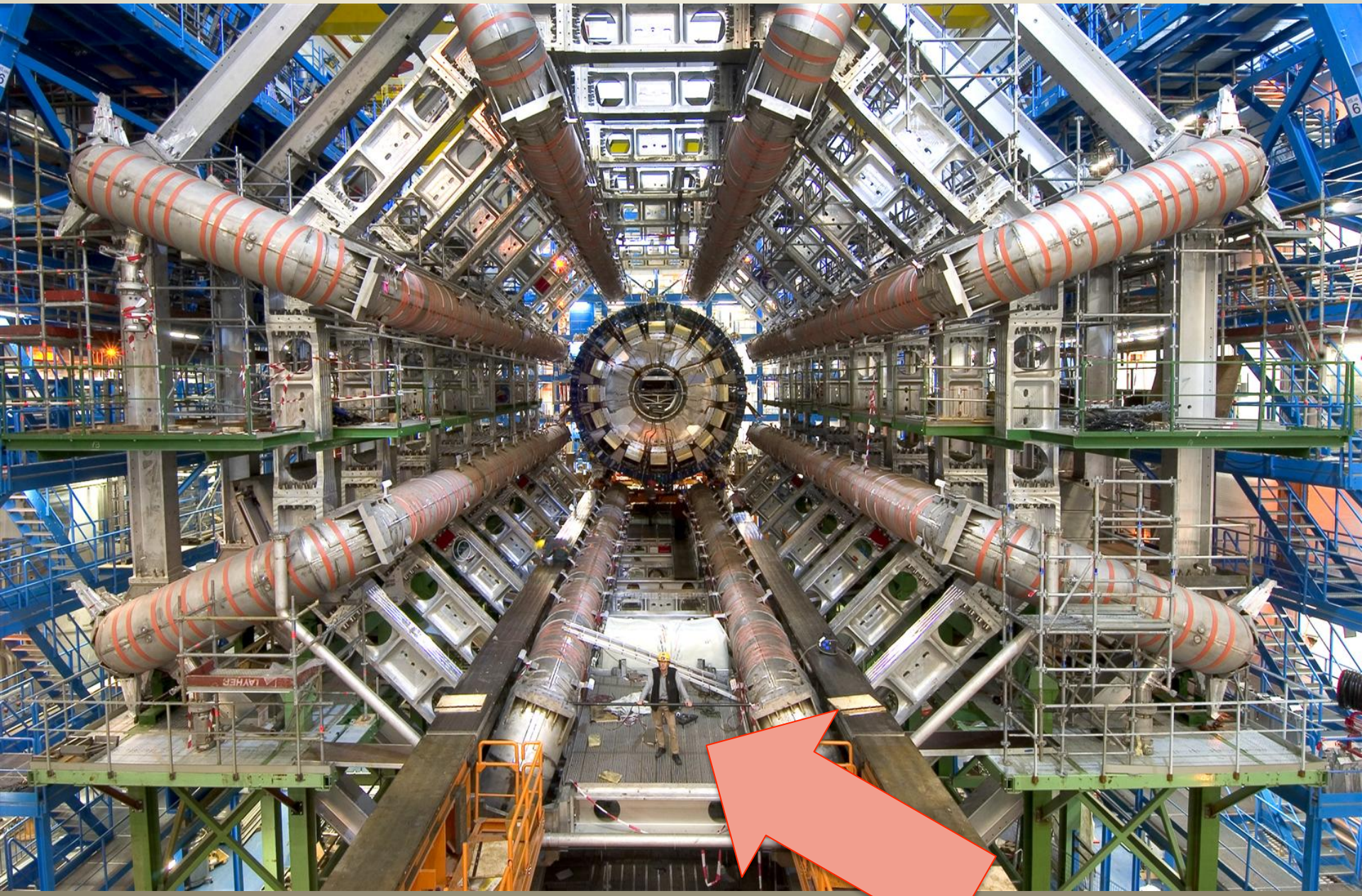




France

Switzerland

A





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?



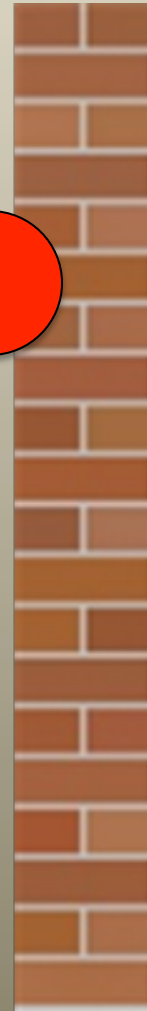
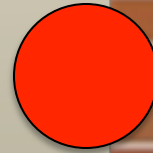
about 1 particle per cm^3
... that's a lot!

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

air molecule

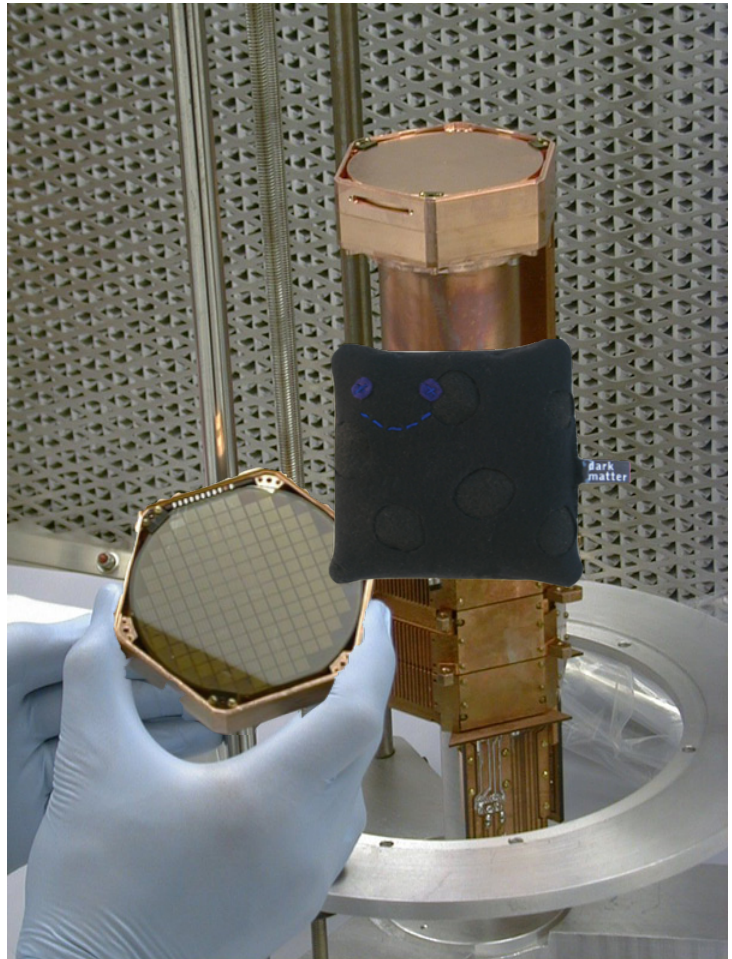


dark matter



“the ghost particle”

Collisions are
rare, but they
do occur

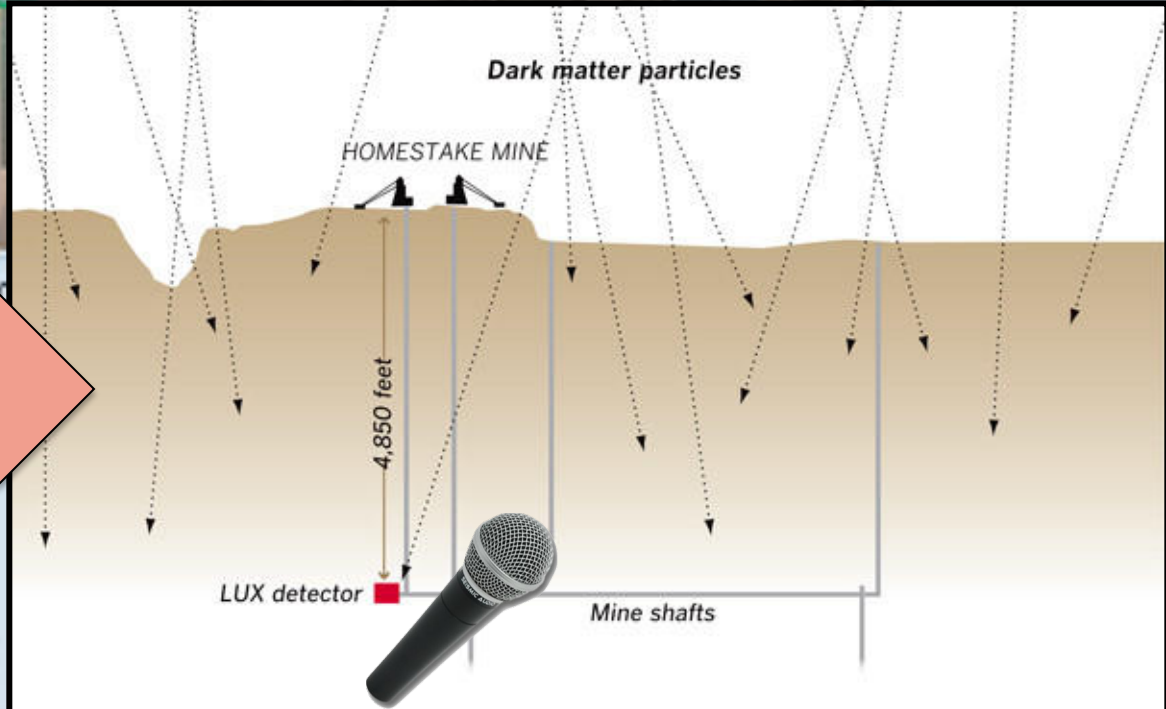
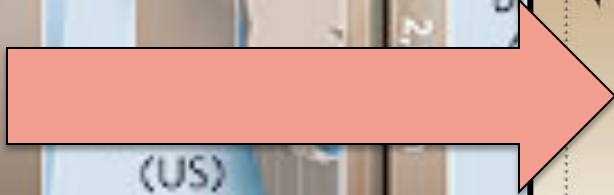
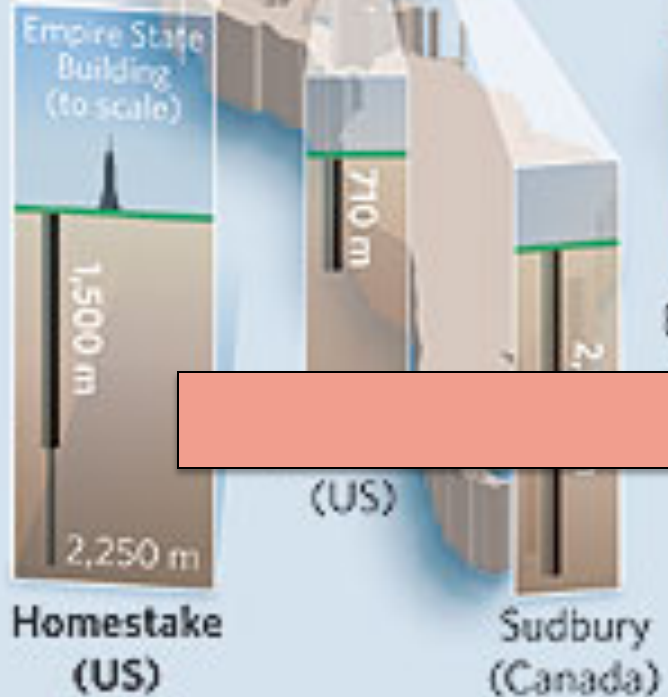


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It's more "quiet" underground...

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

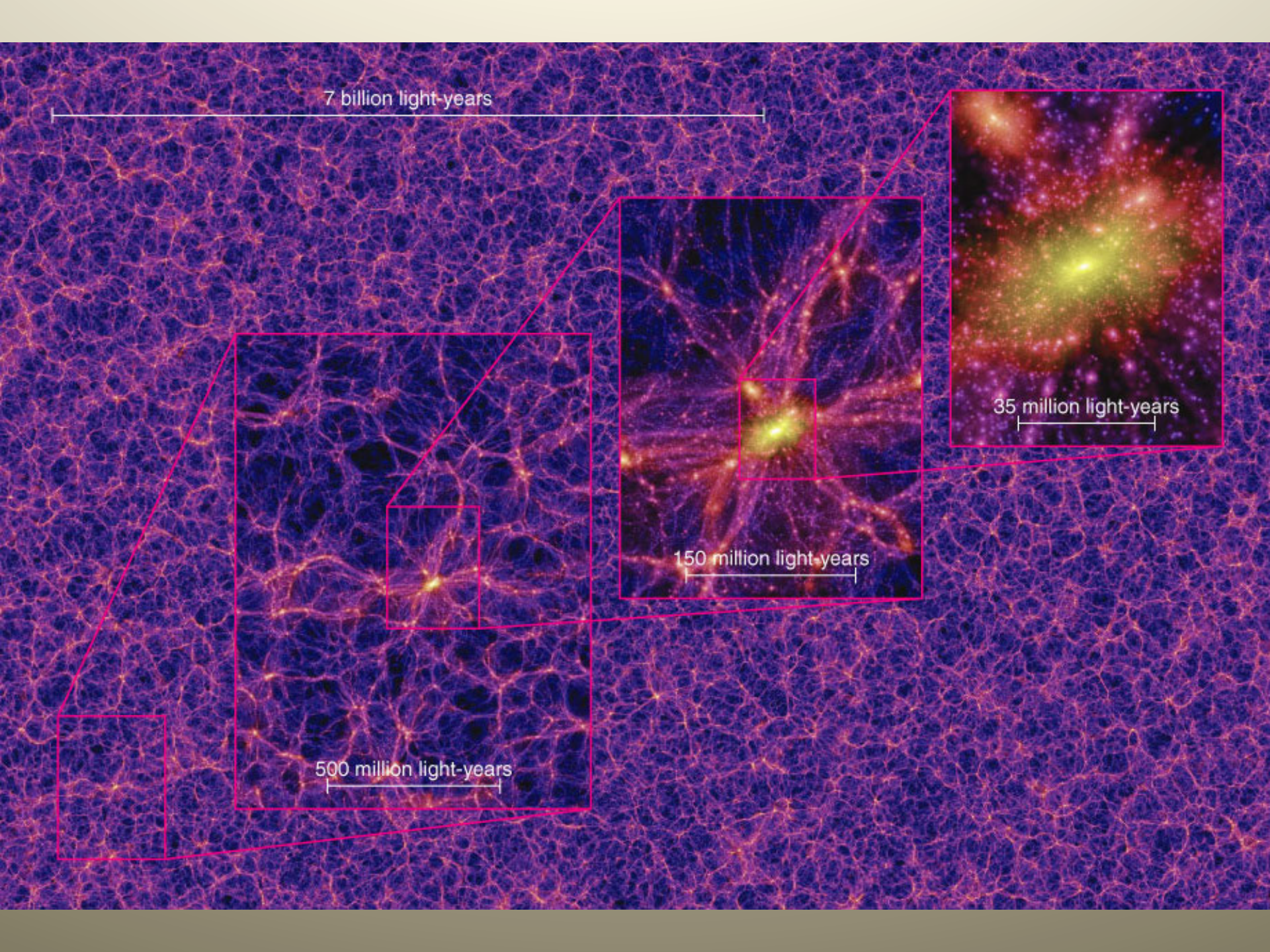


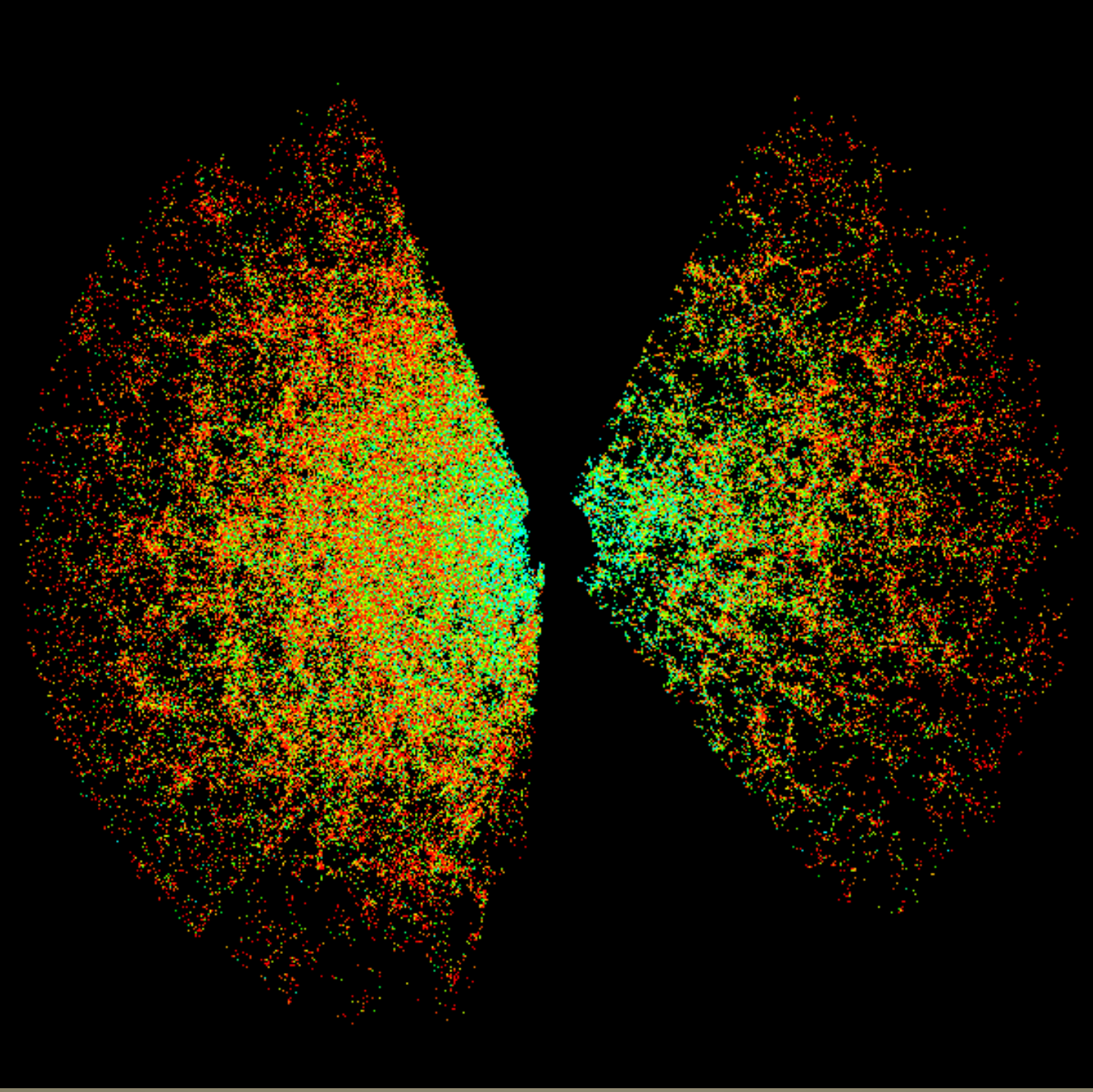


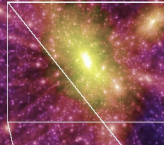
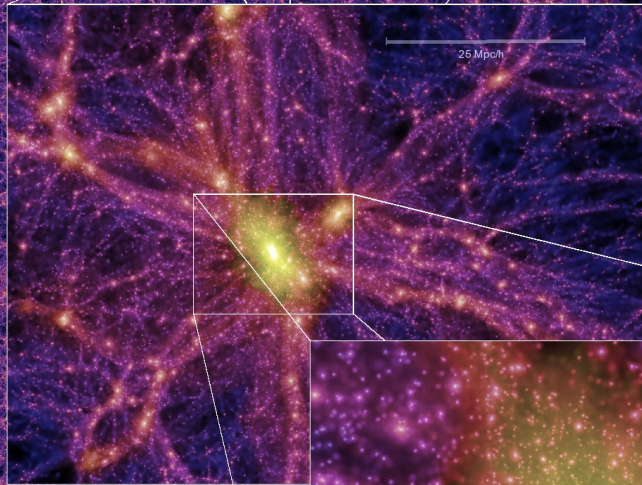
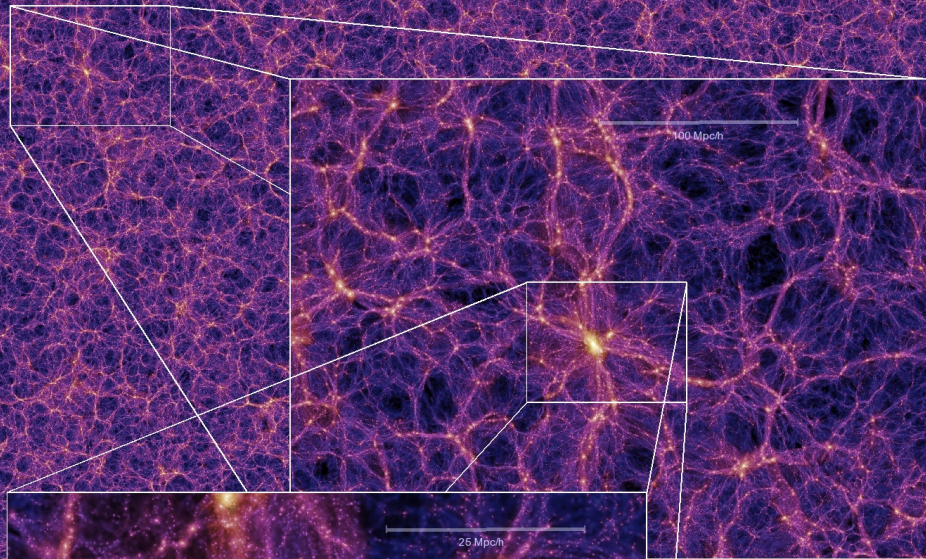
We encountered a new mystery, simply by looking upward.

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

What other mysteries might we uncover?





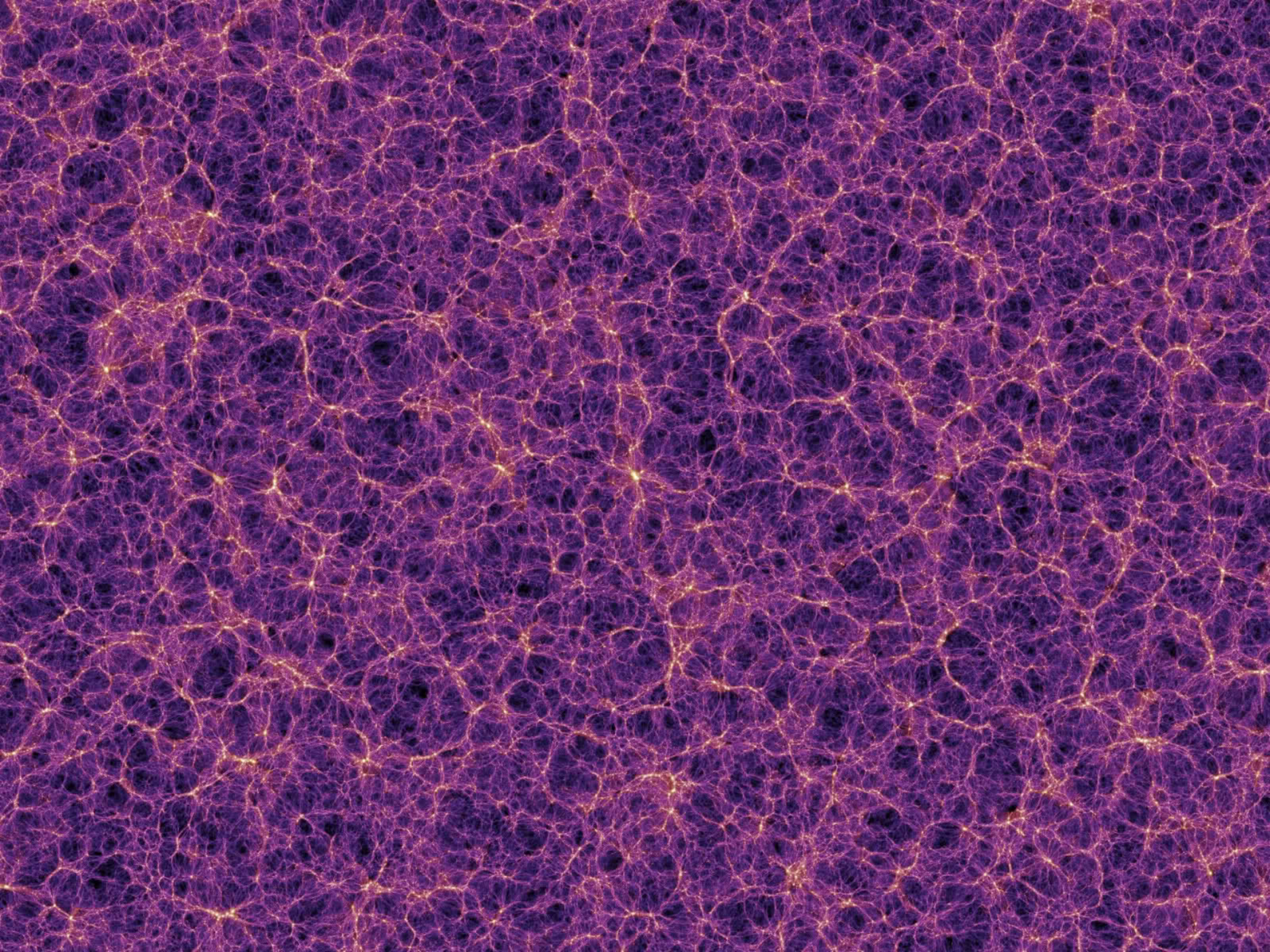


1 Gpc/h

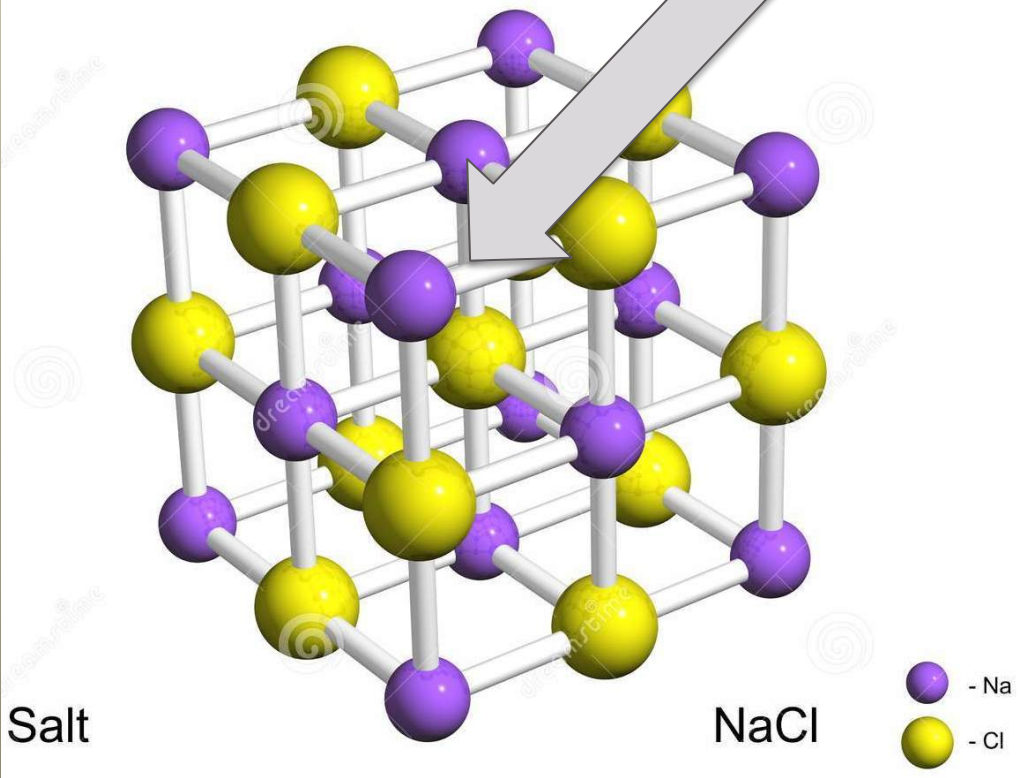
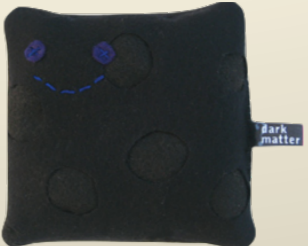
Millennium Run
10,077,696,000 particles

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





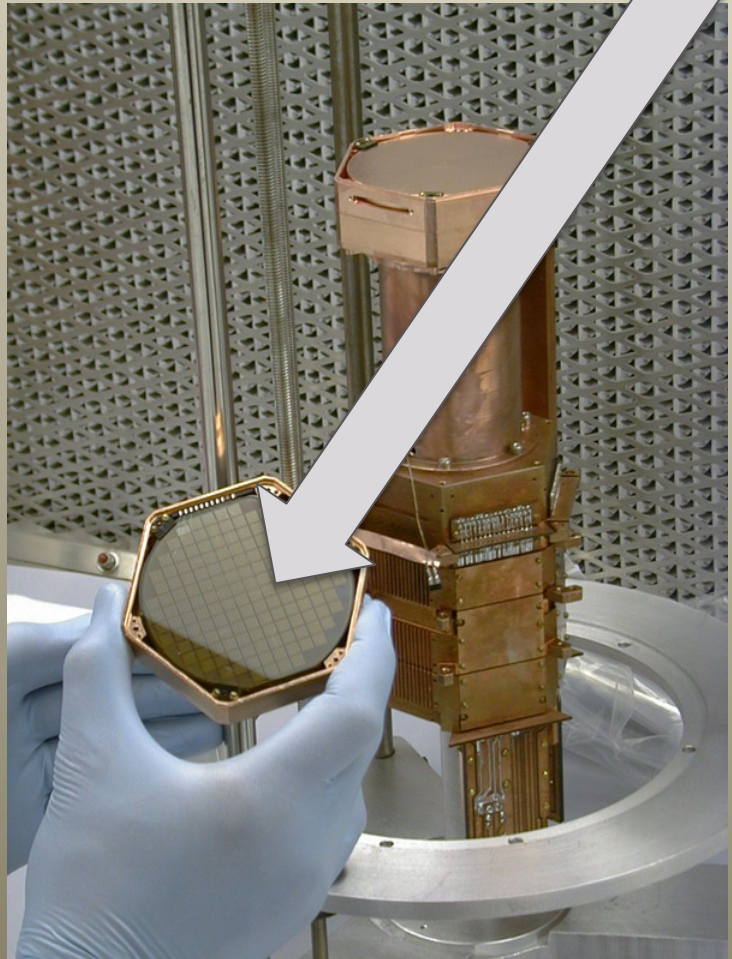
Collisions are rare, but they do occur



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Collisions are rare, but they do occur



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