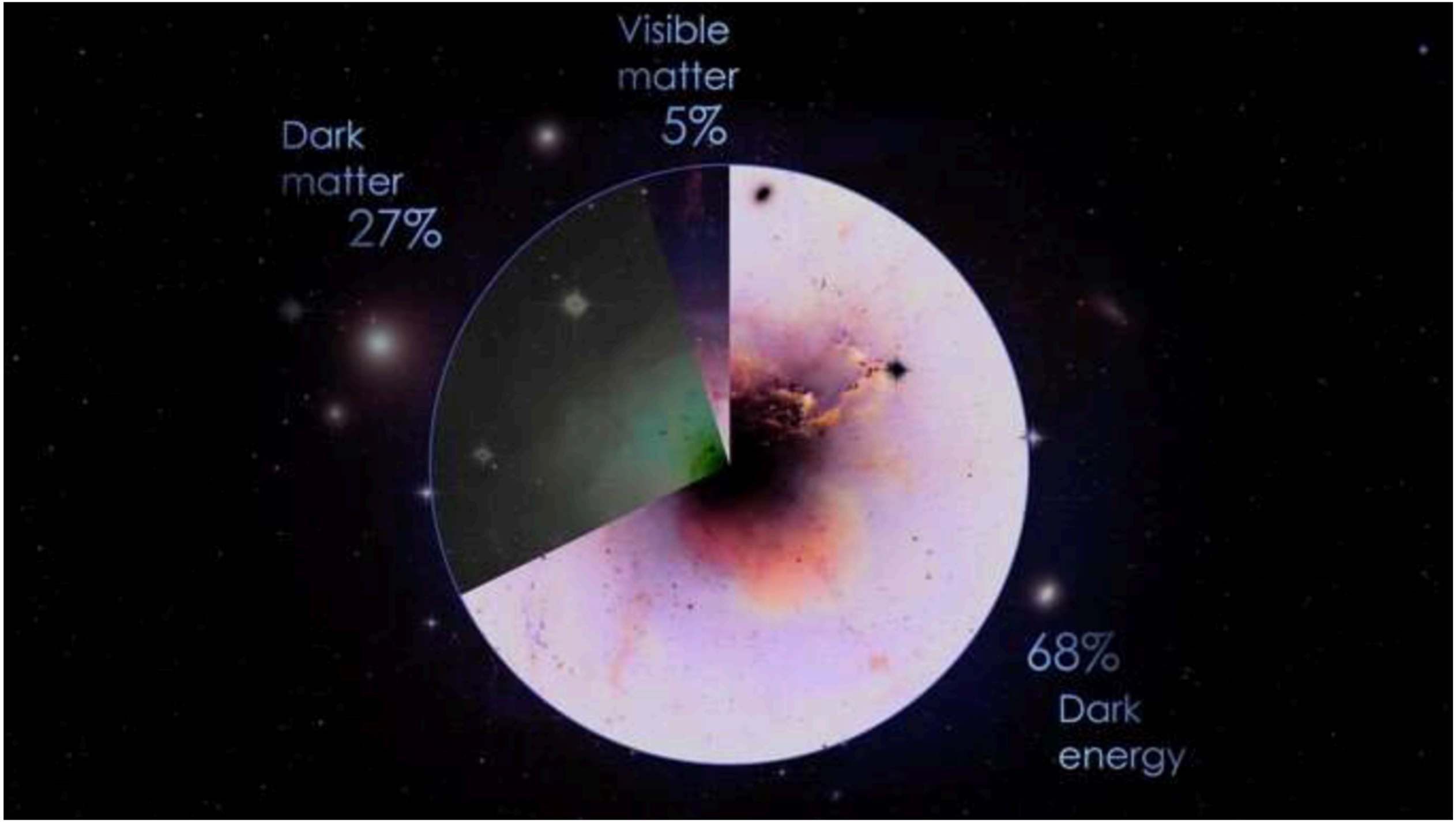
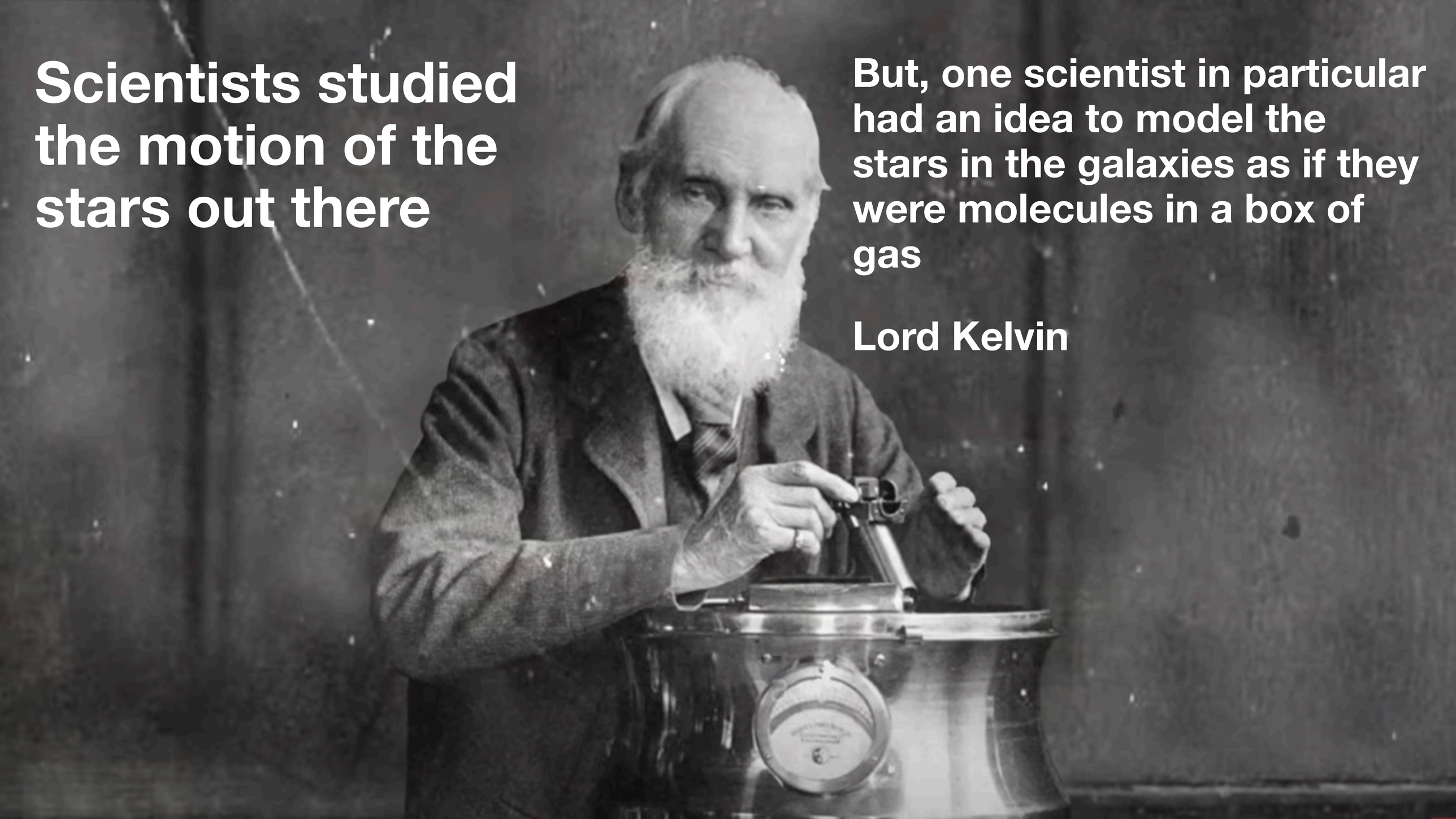

Most of the Universe is Invisible.
- Aman Shrivastava


Visible
matter
5%
Dark
matter
27%
68%
Dark
energy

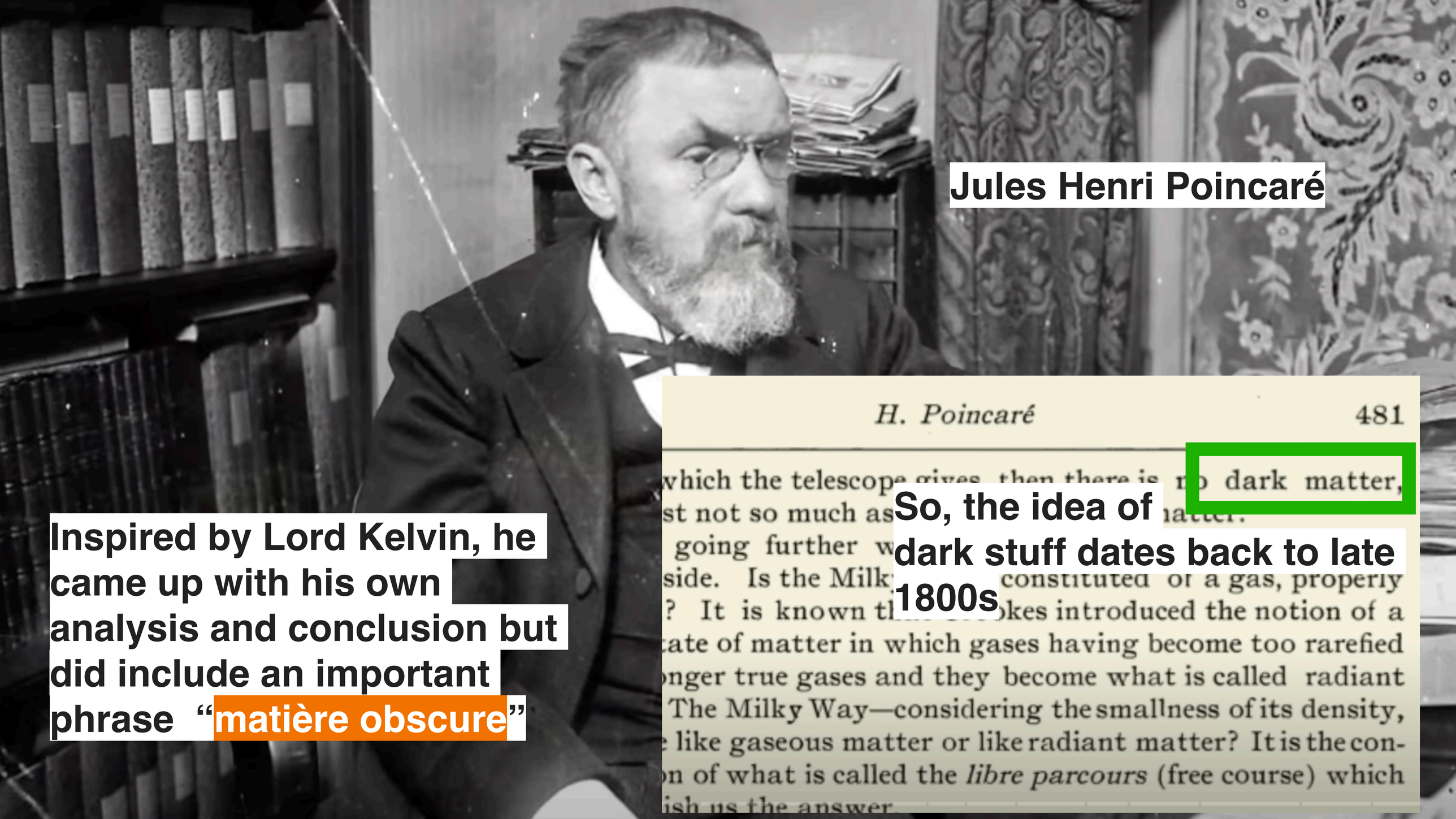


Scientists studied the motion of the stars out there

But, one scientist in particular had an idea to model the stars in the galaxies as if they were molecules in a box of gas

Lord Kelvin

“It is nevertheless probable that there may be as many as a billion stars but many of them may be extinct and dark, and nine-tenths of them though not all dark may not be bright enough to be seen by us at their actual distances. Many of our stars perhaps a great majority of them may be "**dark**" **bodies**.



Jules Henri Poincaré

Inspired by Lord Kelvin, he came up with his own analysis and conclusion but did include an important phrase “matière obscure”

H. Poincaré 481

which the telescope gives, then there is no dark matter,
st not so much as
going further w
side. Is the Milk
constituted of a gas, properly
? It is known th
kes introduced the notion of a
tate of matter in which gases having become too rarefied
onger true gases and they become what is called radiant
The Milky Way—considering the smallness of its density,
like gaseous matter or like radiant matter? It is the con-
n of what is called the *libre parcours* (free course) which
ish us the answer

So, the idea of dark stuff dates back to late 1800s

In the coming decades

Fritz Zwicky also concluded that there had to be additional dark stuff that was out there that would be responsible for the gravity that was pushing and pulling these galaxies around.

Fritz Zwicky, a Swiss astronomer at Caltech studied the motion of the galaxies in coma cluster which is a few hundred light years away.

LSST is now known as Vera R. Rubin Observatory

Vera Rubin

It was actually her efforts to study the motion of stars in swirling galaxies that she found that the galaxies are swirling too quickly and that the stars should be sort of ejected out

Where there is a Will, there is a Way!


THE WORLD'S LARGEST CAMERA

Centre national de la recherche scientifique (CNRS)

The Vera C. Rubin Observatory unveils the first images of the sky obtained with the world's largest camera

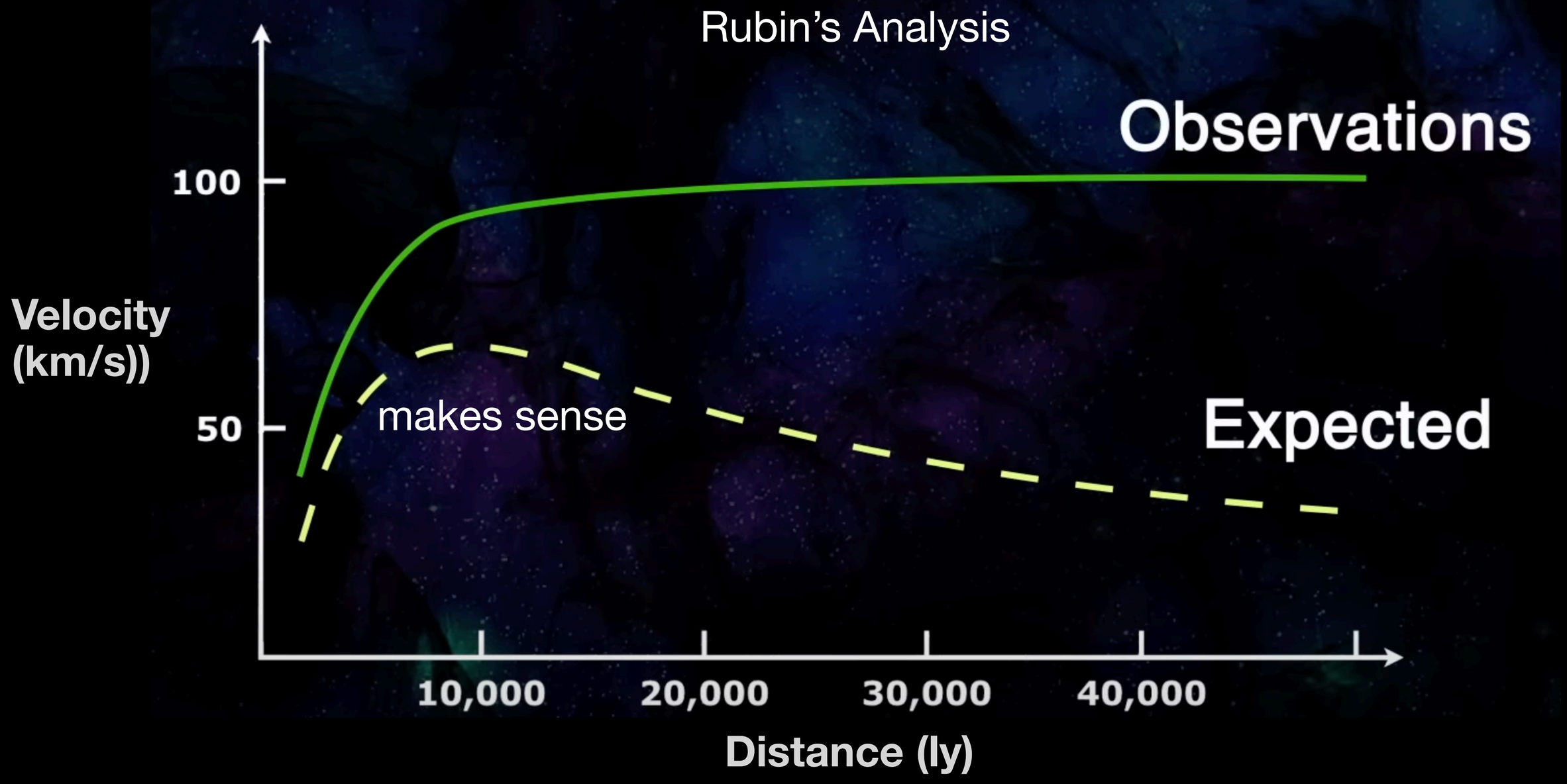
The NSF-DOE Vera C. Rubin Observatory in Chile has unveiled the very first "mega" images of the cosmos obtained thanks to the extraordinary...

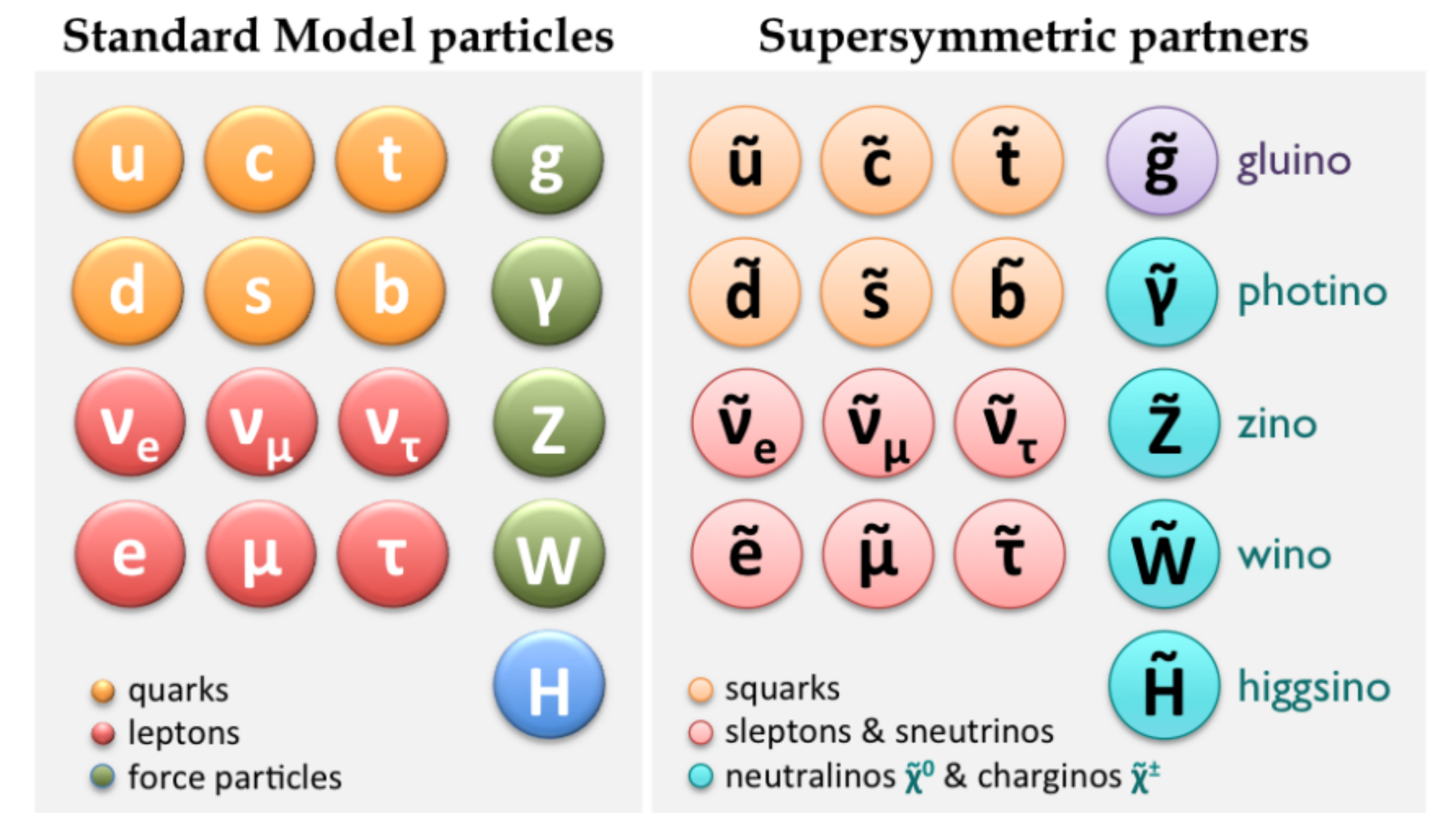
Jun 23, 2025

The rotational velocity is so high that the stars near the edge of the galaxy should be ejected tangentionally.

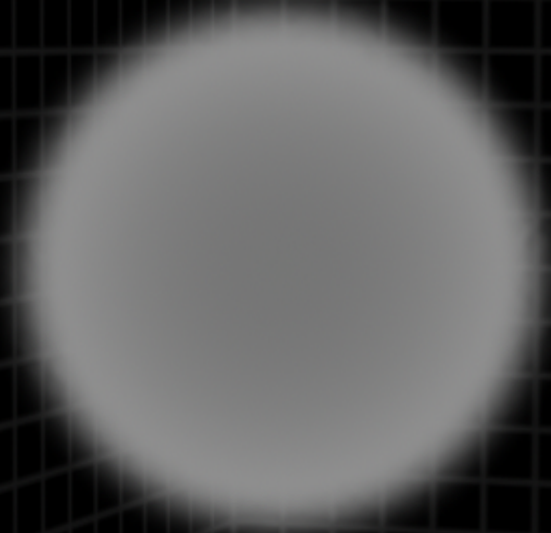
But, there is something in the dark which is holding it together.

Mathmatically, velocity of stars at the outskirts of galaxy should be lower relative to the ones at the centre.




Standard Model particles
Supersymmetric partners
u
c
t
g
d
s
b
γ
ν_e
ν_μ
ν_τ
Z
e
μ
τ
W
H
quarks
leptons
force particles
$\tilde{u}$
$\tilde{c}$
$\tilde{t}$
$\tilde{g}$
gluino
$\tilde{d}$
$\tilde{s}$
$\tilde{b}$
$\tilde{\gamma}$
photino
$\tilde{\nu}_e$
$\tilde{\nu}_\mu$
$\tilde{\nu}_\tau$
$\tilde{Z}$
zino
$\tilde{e}$
$\tilde{\mu}$
$\tilde{\tau}$
$\tilde{W}$
wino
$\tilde{H}$
higgsino
squarks
sleptons & sneutrinos
neutralinos $\tilde{\chi}^0$ & charginos $\tilde{\chi}^\pm$

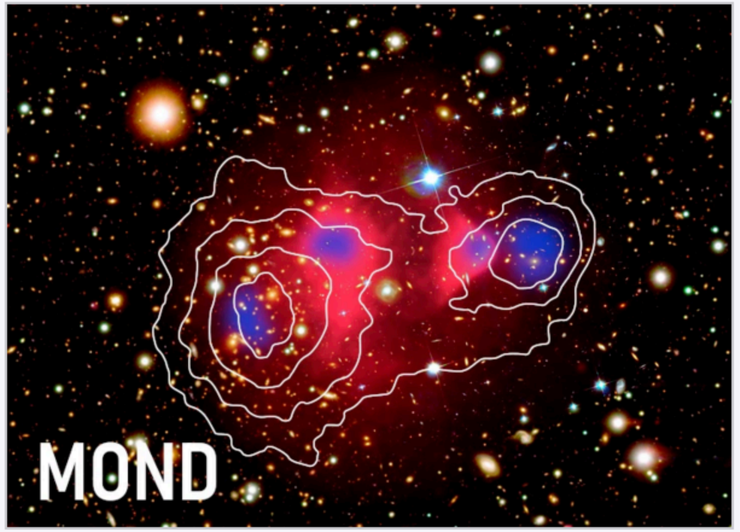
Weakly interacting because it rarely shows any electromagnetic interaction which simply means they do no absorb, emit or reflect light like normal matter.



Weakly Interacting Massive Particle because it has extremely large mass.

As evidence against modified gravity [edit]

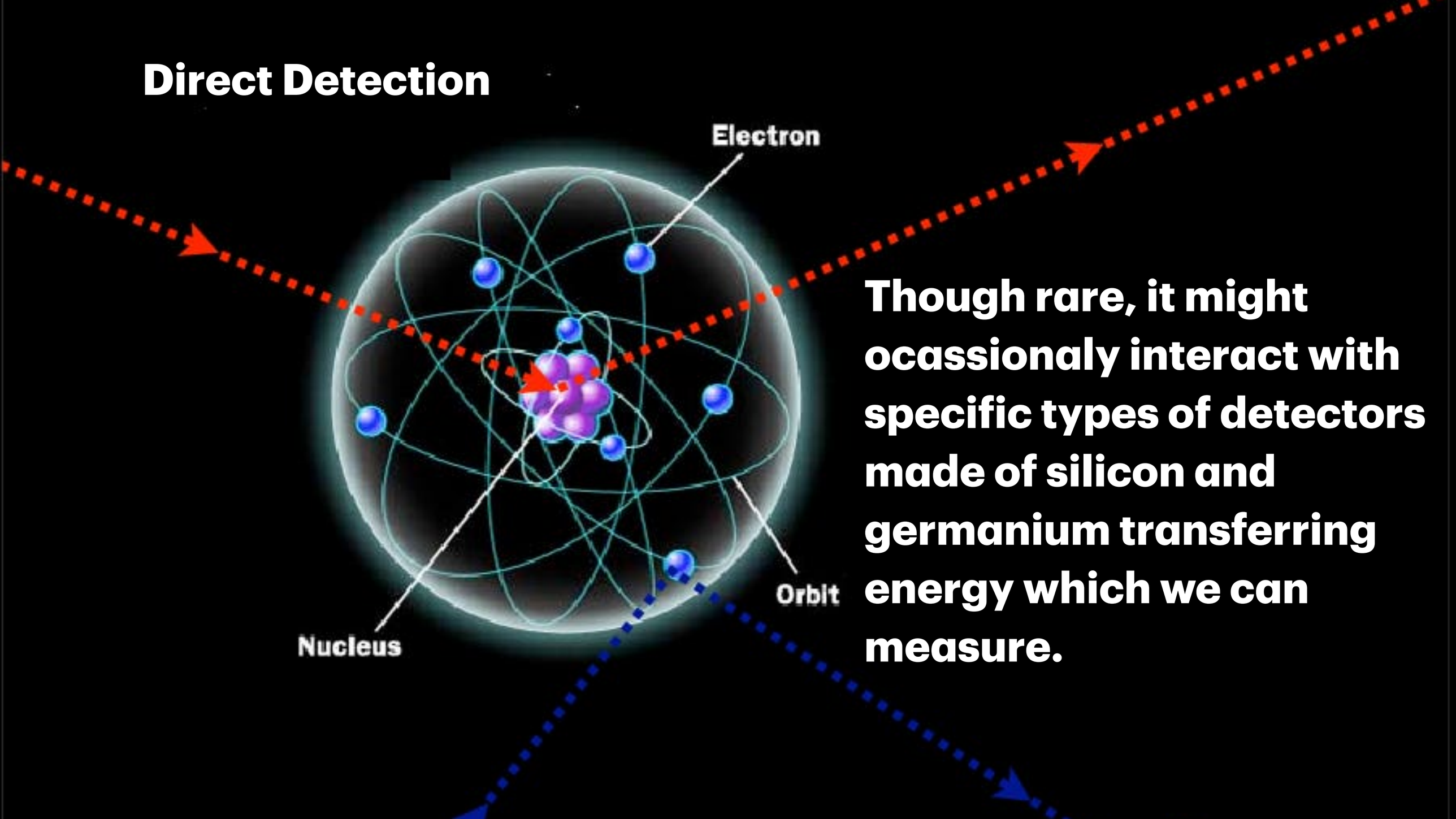
The Bullet Cluster has been claimed as a significant challenge for all theories proposing a modified gravity solution to the missing mass problem, including modified Newtonian dynamics (MOND).[15] Astronomers measured the distribution of stellar and gas mass in the clusters using visible and X-ray light, respectively, and also mapped the gravitational potential using gravitational lensing. As shown in the images on the right, the X-ray gas is in the center, while the galaxies are on the outskirts. During the collision, the X-ray gas interacted and slowed down, remaining in the center, while the galaxies largely passed by one another, as the distances between them were vast. The gravitational potential reveals two large concentrations centered on the galaxies, not on the X-ray gas, where most of the normal matter is located. In ΛCDM one would also expect the clusters to each have a dark matter halo that would pass through each other during the collision (assuming, as is conventional, that dark matter is collisionless). This expectation for the dark matter is a clear explanation for the offset between the peaks of the gravitational potential and the X-ray gas which was detected at a statistical significance of 8σ.



Despite modifying gravity MOND still requires dark matter to fit the observations. The white lines trace the gravitational potential measured by lensing, the pink clouds show hot X-ray emitting gas, the full color dots are galaxies and some foreground stars, the blue is the inferred dark matter distribution. Image based on data from Angus et al. 2006.[14]

It is this offset between the gravitational potential and normal matter that was claimed by Clowe et al. as *"A Direct Empirical Proof of the Existence of Dark Matter"* arguing that modified gravity theories fail to account for it.[15] However, this study by Clowe et al. made no attempt to analyze the Bullet Cluster using MOND or any other modified gravity theory. Furthermore, in the same year, Angus et al. demonstrated that MOND does indeed reproduce the offset between the gravitational potential and the X-ray gas in this highly non-spherically symmetric system.[16] In MOND, one would expect the "missing mass" to be centred on regions which experience accelerations lower than a_0, which, in the case of the Bullet Cluster, correspond to the areas containing the galaxies, not the X-ray gas. Nevertheless, MOND still fails to fully explain this cluster, as it does with all other galaxy clusters, due to the remaining mass residuals in several core regions of the Bullet Cluster.[14] Mordehai Milgrom, the original proposer of MOND, has posted

Direct Detection



Though rare, it might ocassionaly interact with specific types of detectors made of silicon and germanium transferring energy which we can measure.

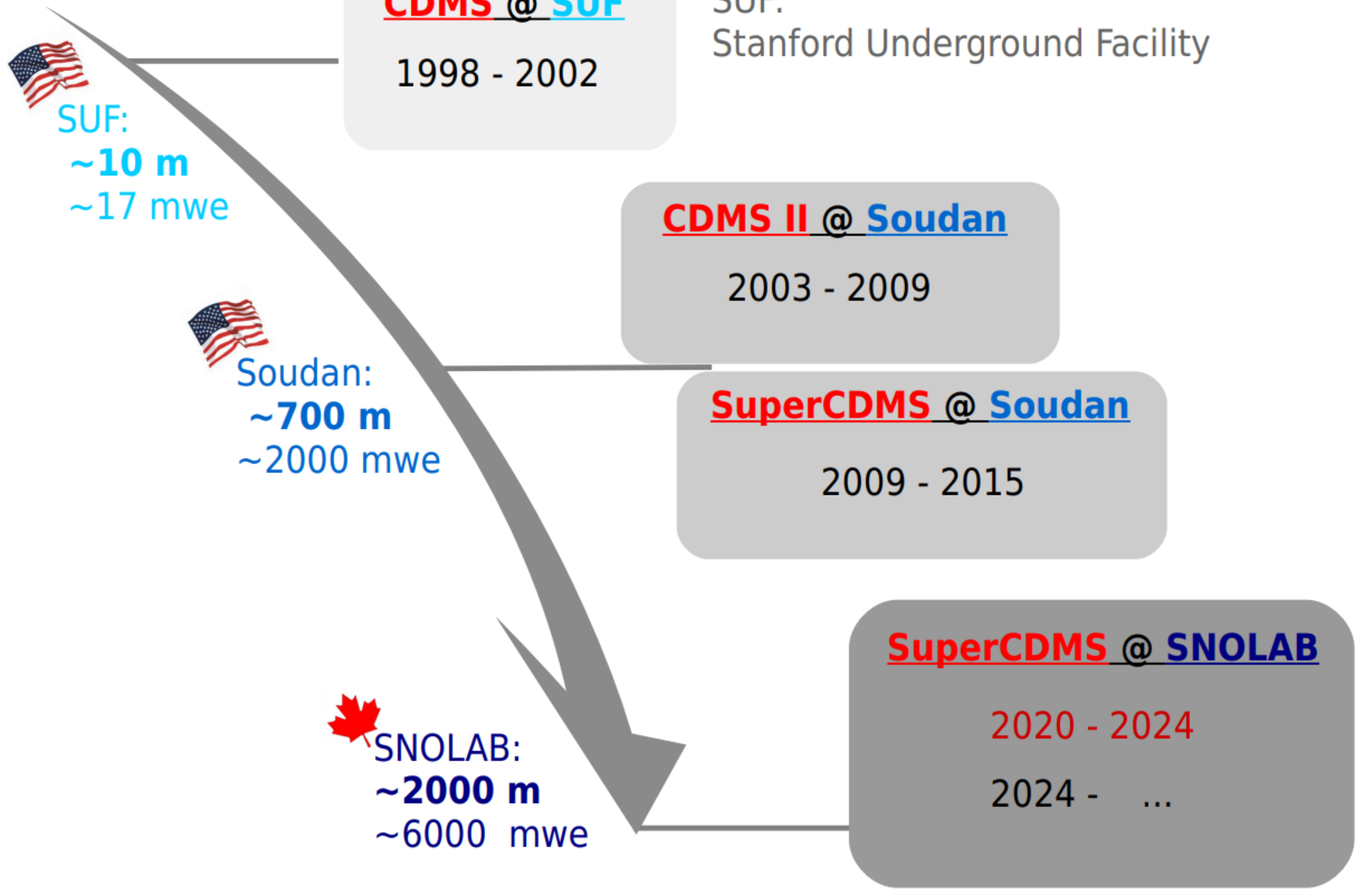
The SuperCDMS Collaboration

2022 Collab Mtg at U. Toronto

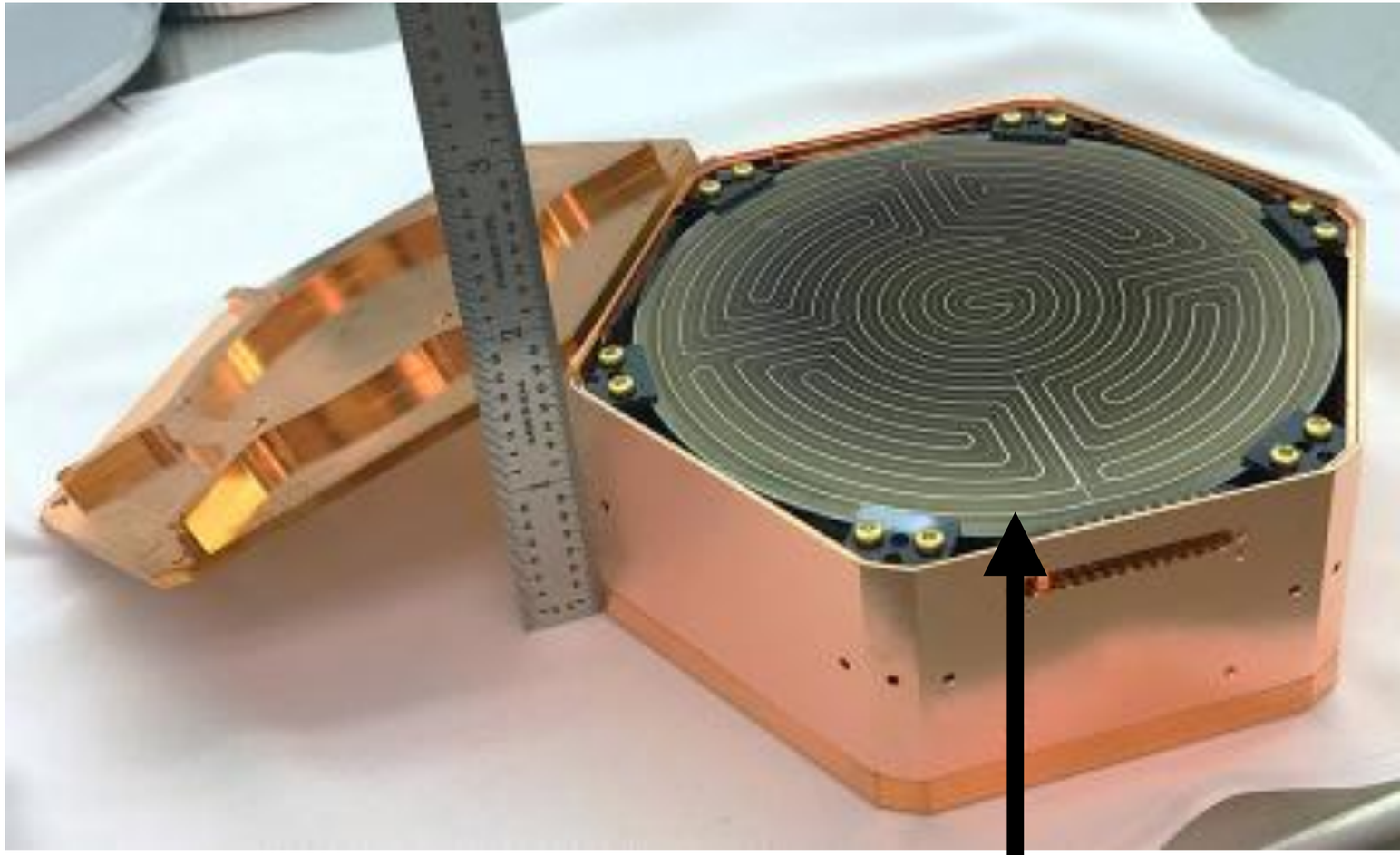
>130 scientists at 28 institutions & 6 Countries, including 3 US national labs and 2 Canadian labs

Caltech · C2N · KIT · NIST · Pacific Northwest National Laboratory · SLAC · South Dakota School of Mines & Technology · SNOLAB · UBC · Cal · UF · University of South Dakota · Zayed University · NSF · DAE · Emmy Noether-Programm

SUPER CDMS Cryogenic Dark Matter Search

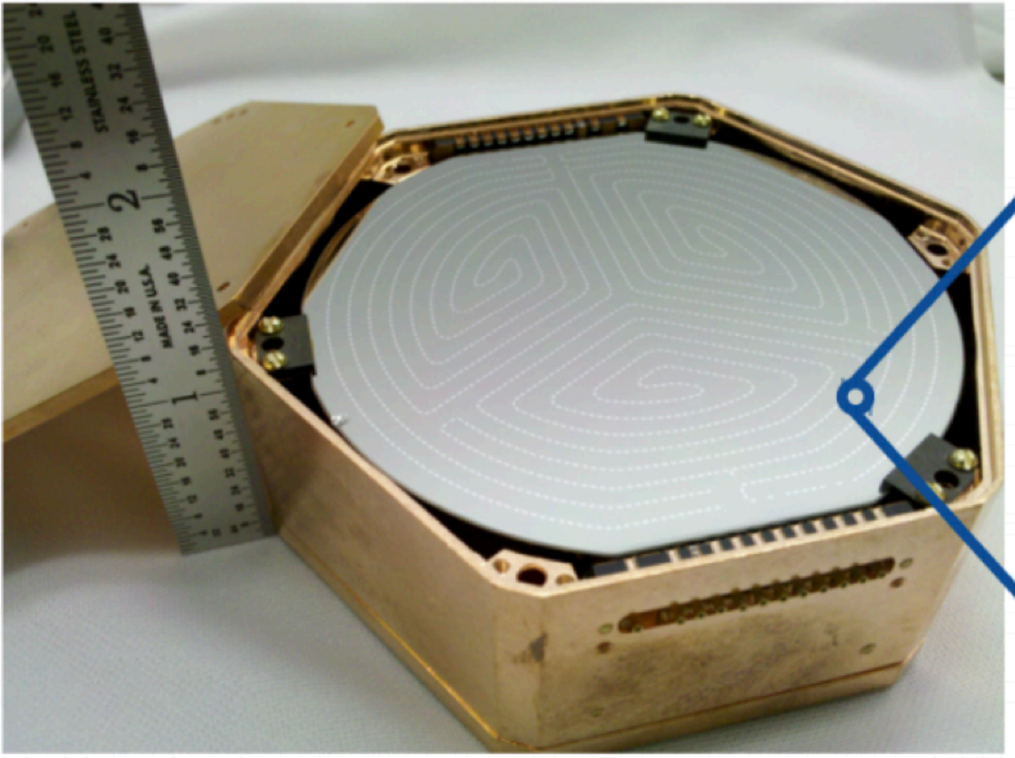

CDMS @ SUF
1998 - 2002
SUF:
Stanford Underground Facility
SUF:
~10 m
~17 mwe
CDMS II @ Soudan
2003 - 2009
Soudan:
~700 m
~2000 mwe
SuperCDMS @ Soudan
2009 - 2015
SNOLAB:
~2000 m
~6000 mwe
SuperCDMS @ SNOLAB
2020 - 2024
2024 - ...

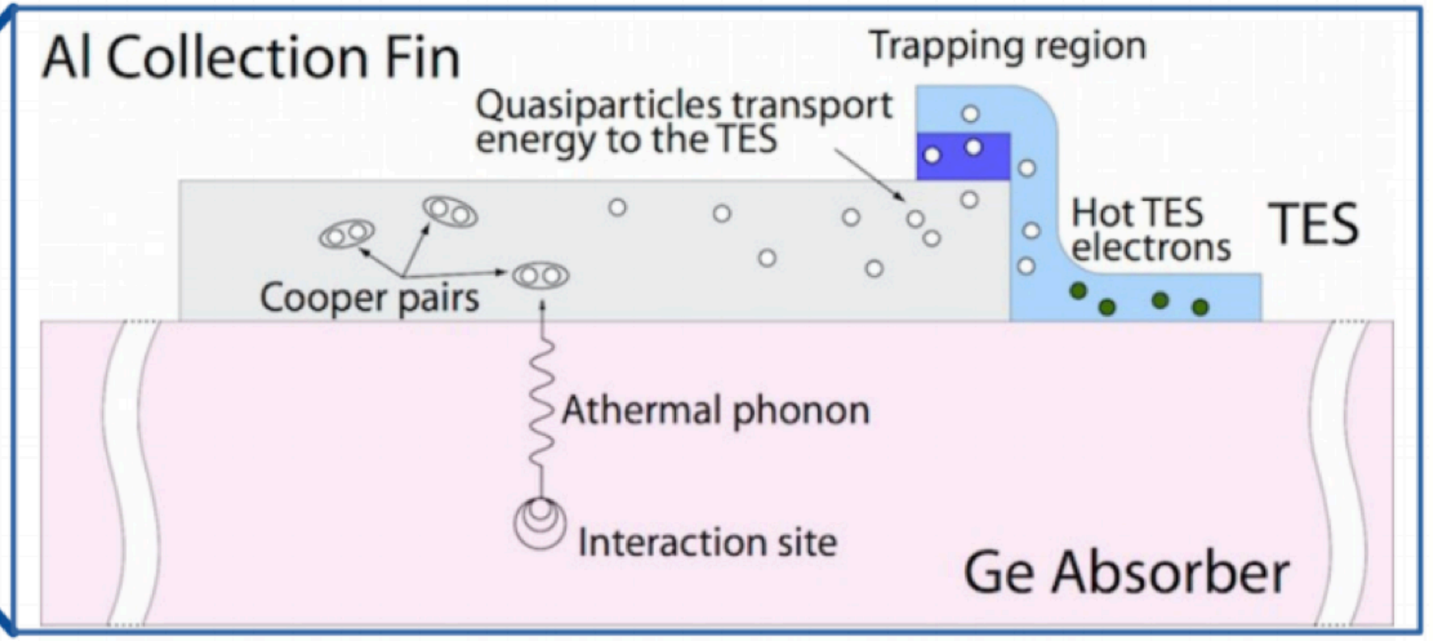
- Can be cooled down to 60 milliKelvin or below to reduce thermal noise to 0.
- Produce clean phonon + ionisation signals.
- Modular but tens of Kilograms of Detector mass.
- Can be scaled.

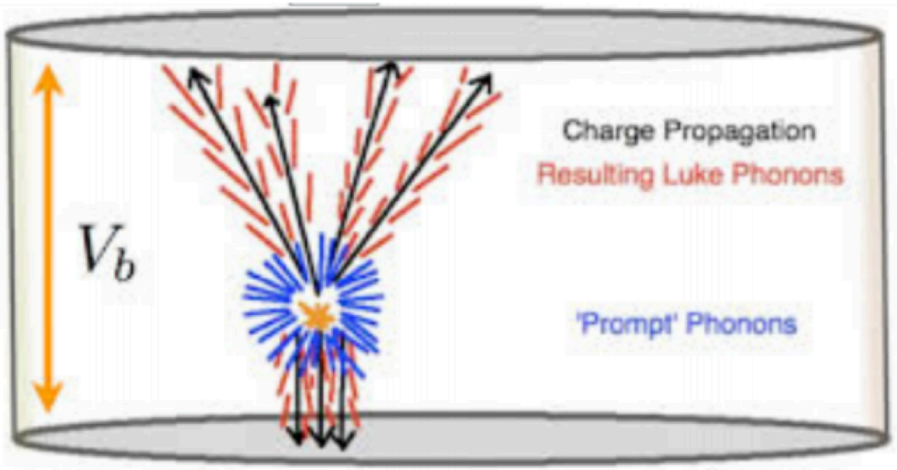


Germanium and Silicon Detector

Low-mass dark matter (0.1–1 GeV) produces very small recoil energies — so you need ultra-sensitive detectors.

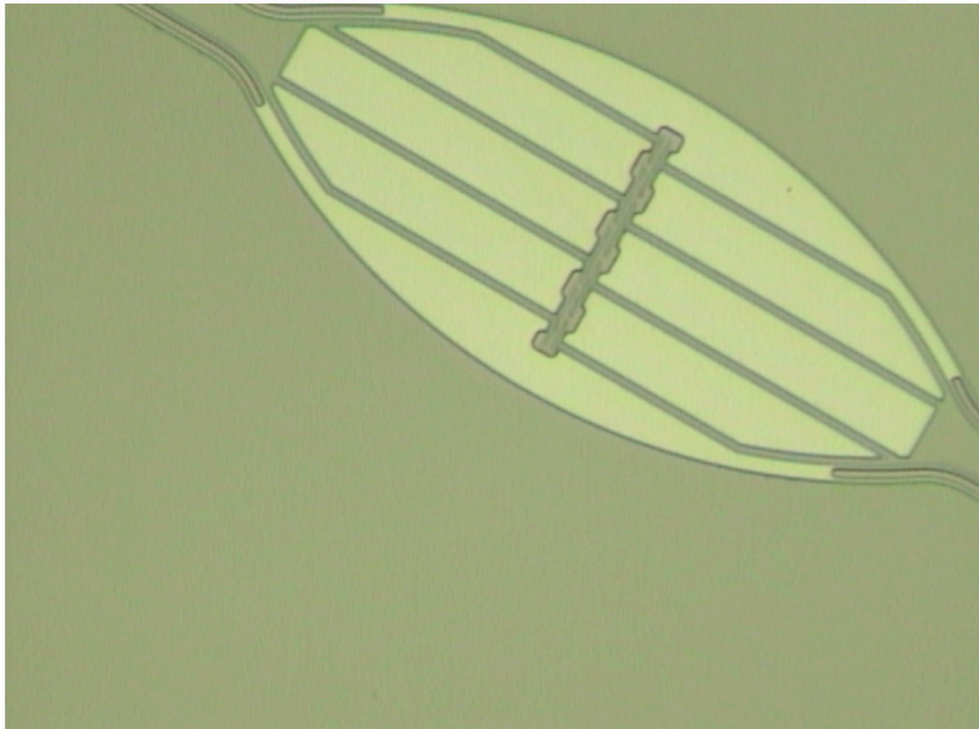


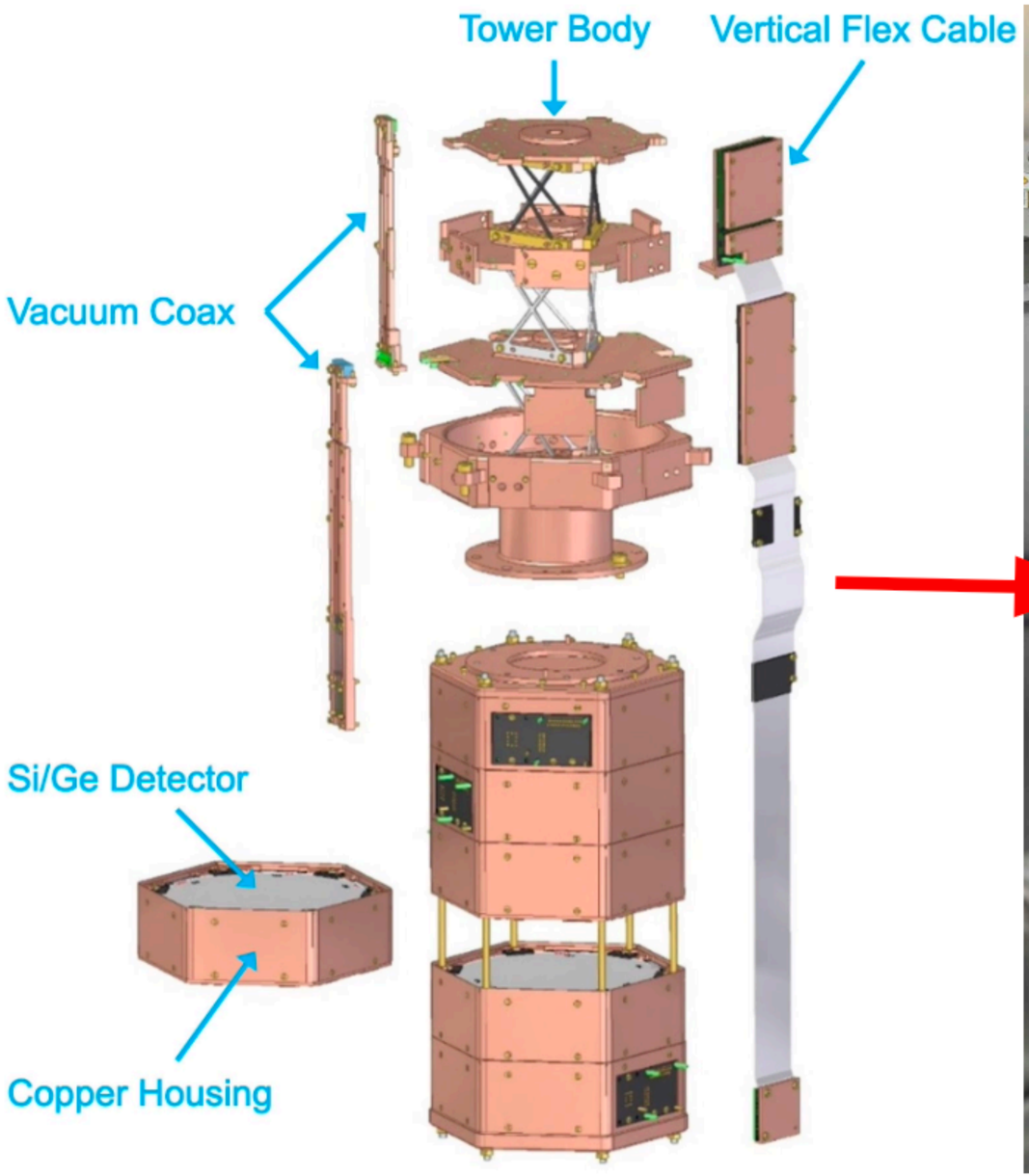


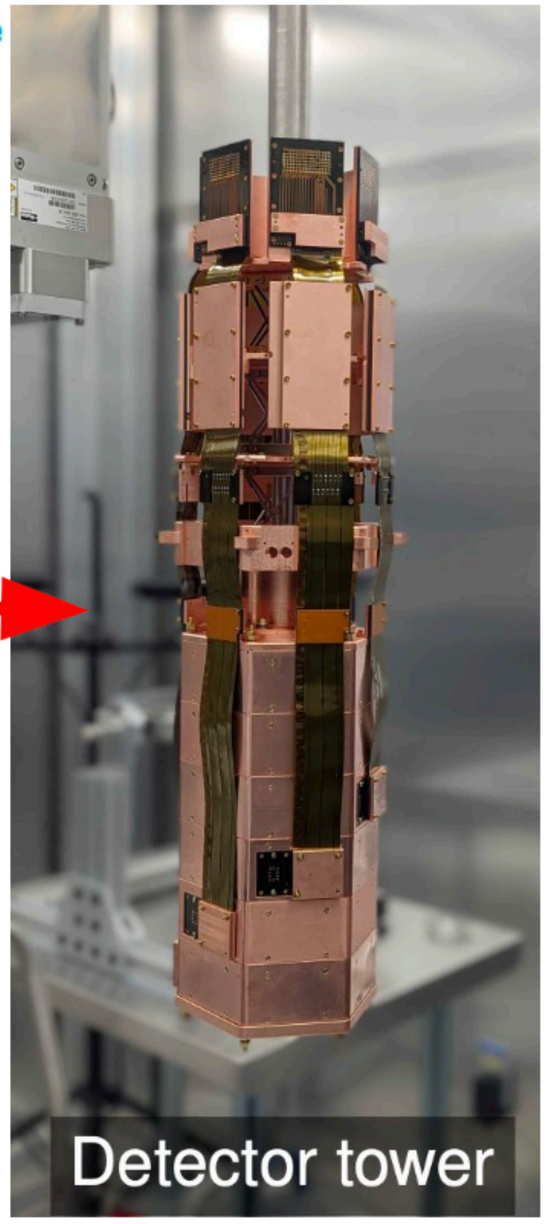


Transition Edge Sensors (TES)

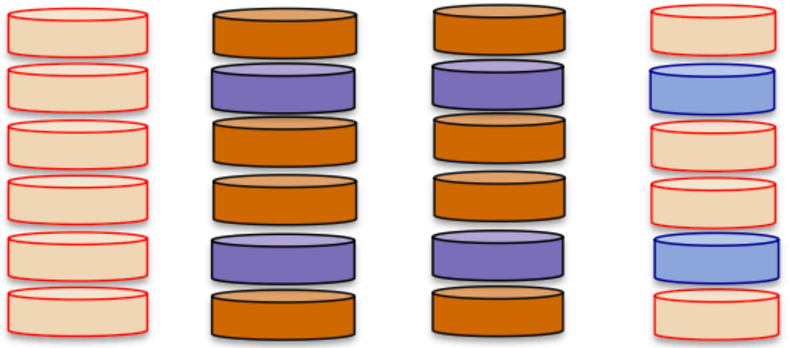
Ultra-sensitive Thermometers



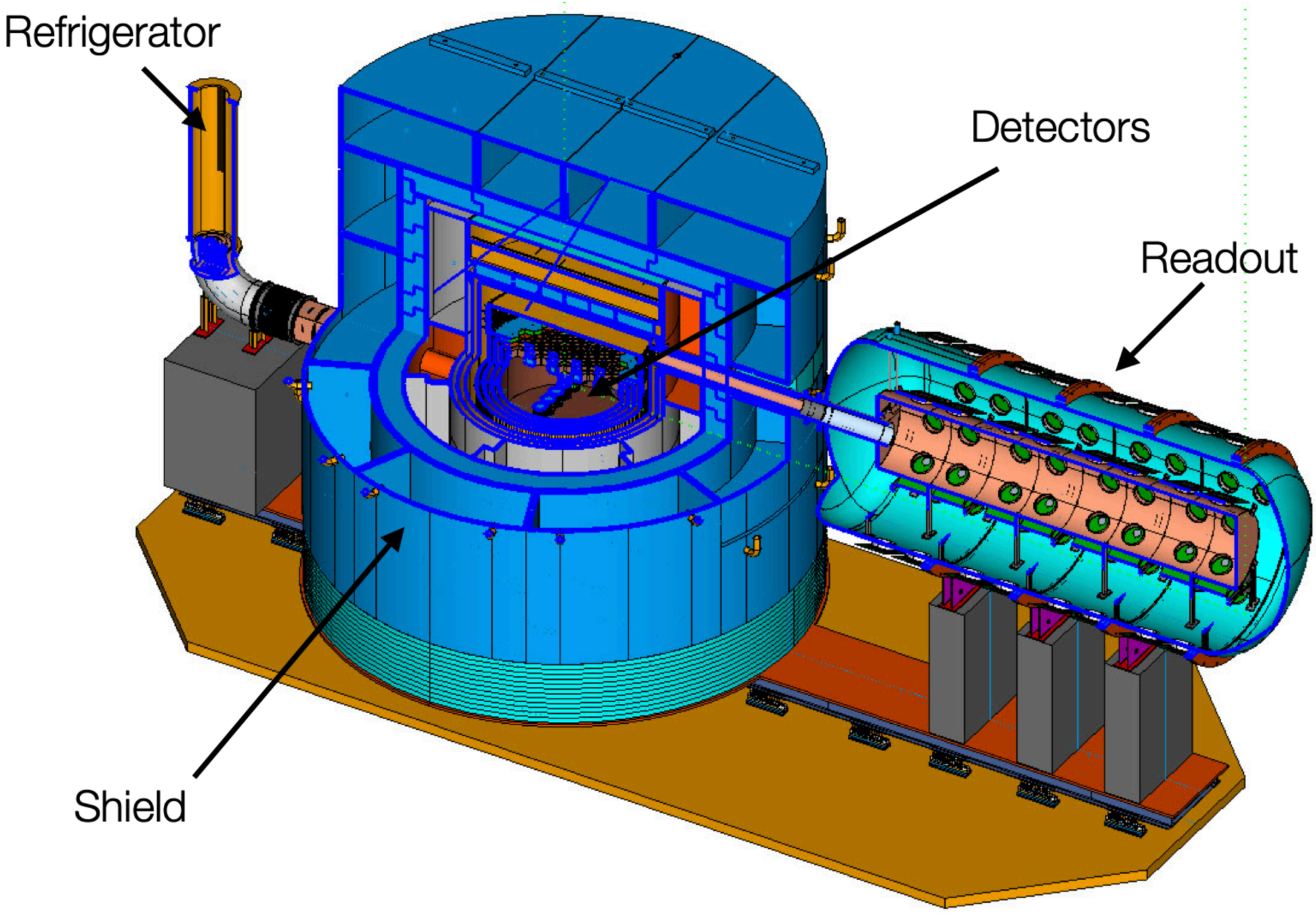




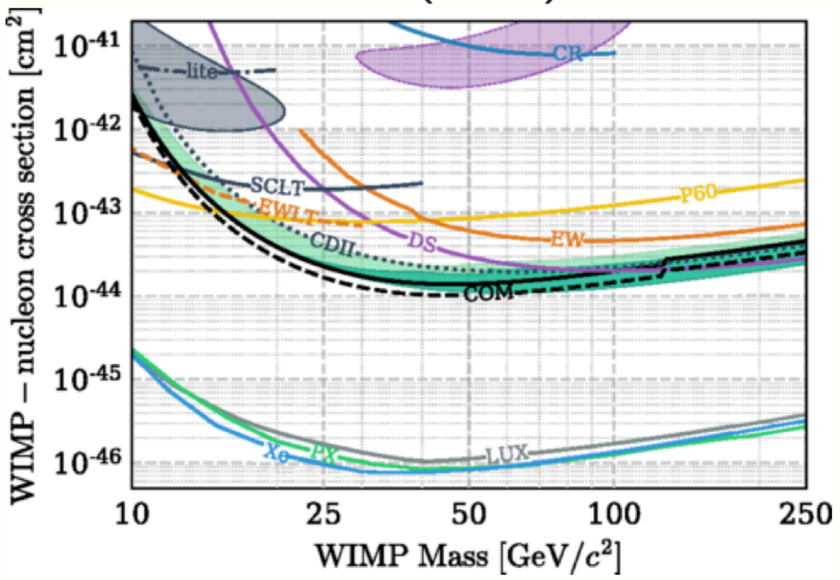
Initial 4-tower payload



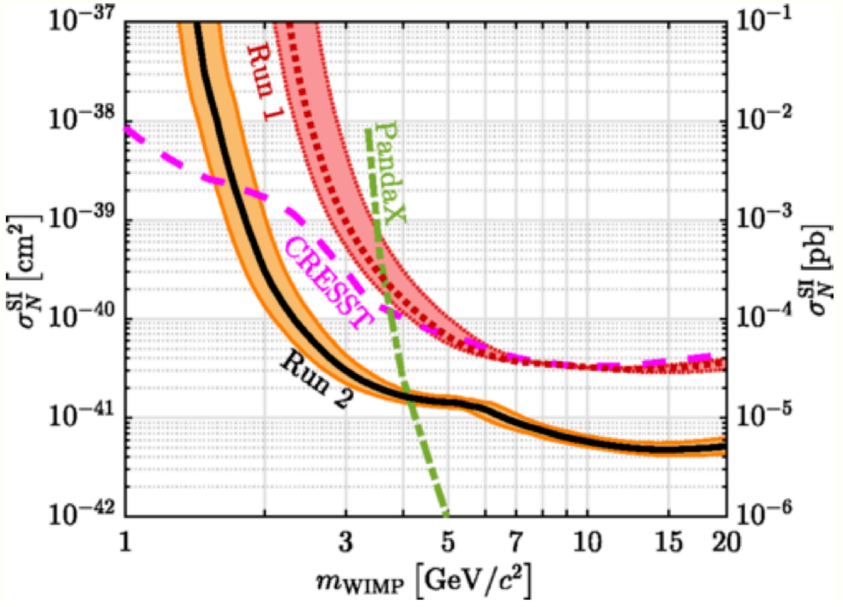
Tower 1	Tower 2	Tower 3	Tower 4
6 Ge iZIPs	4 Ge HV 2 Si HV	4 Ge HV 2 Si HV	4 Ge iZIPs 2 Si iZIPs


Refrigerator
Detectors
Readout
Shield

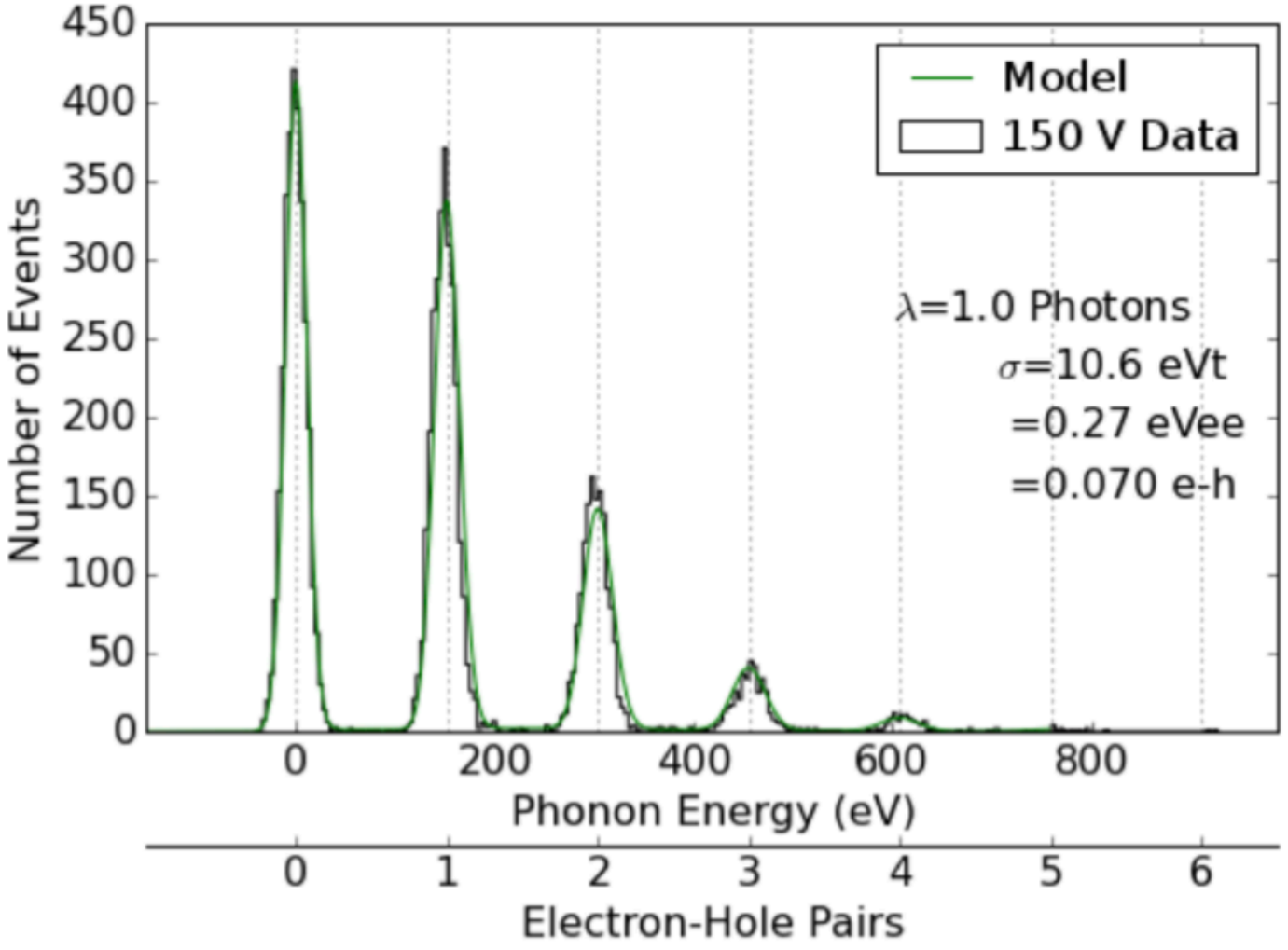
PRL 120, 061802 (2018)

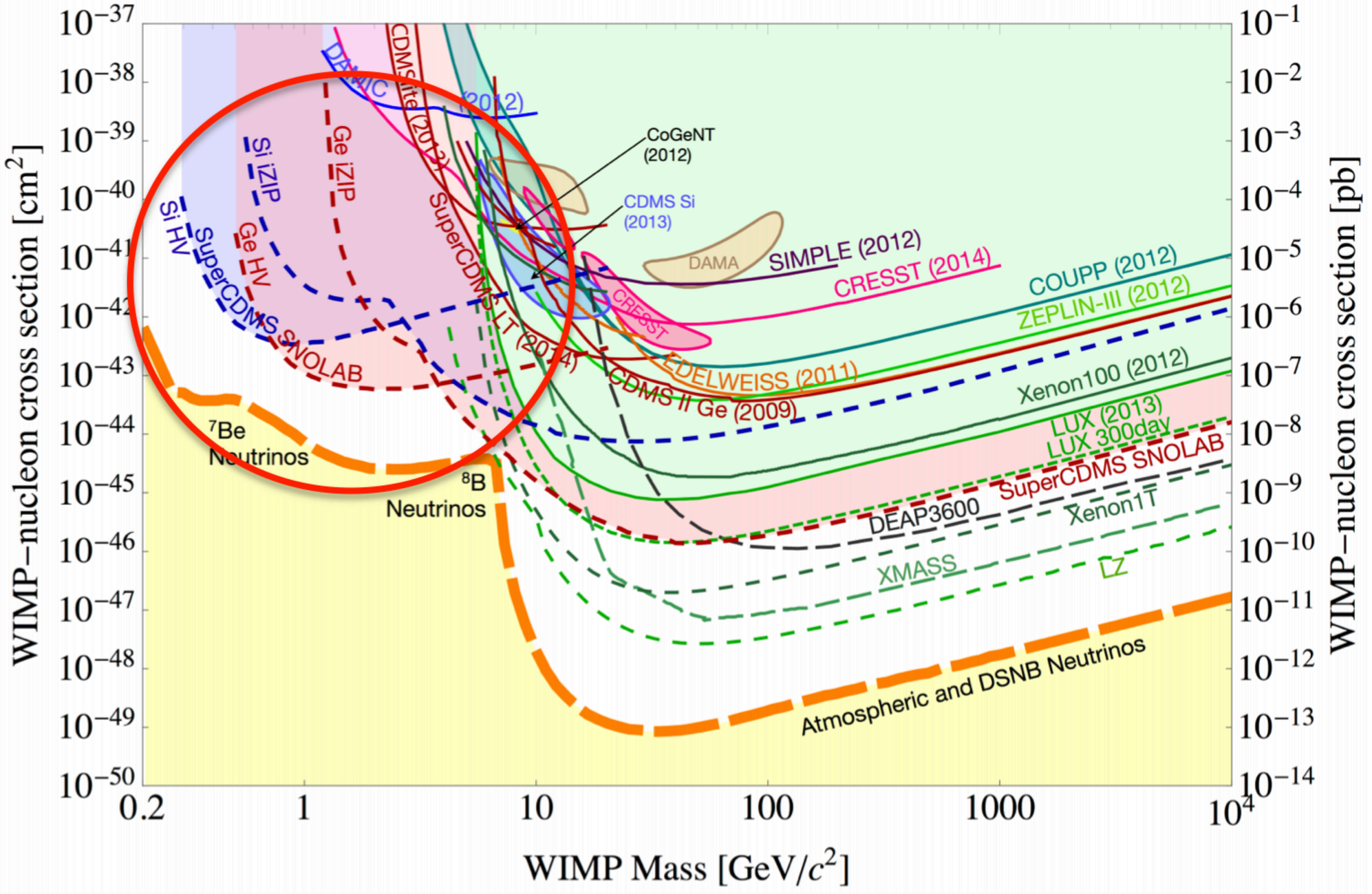


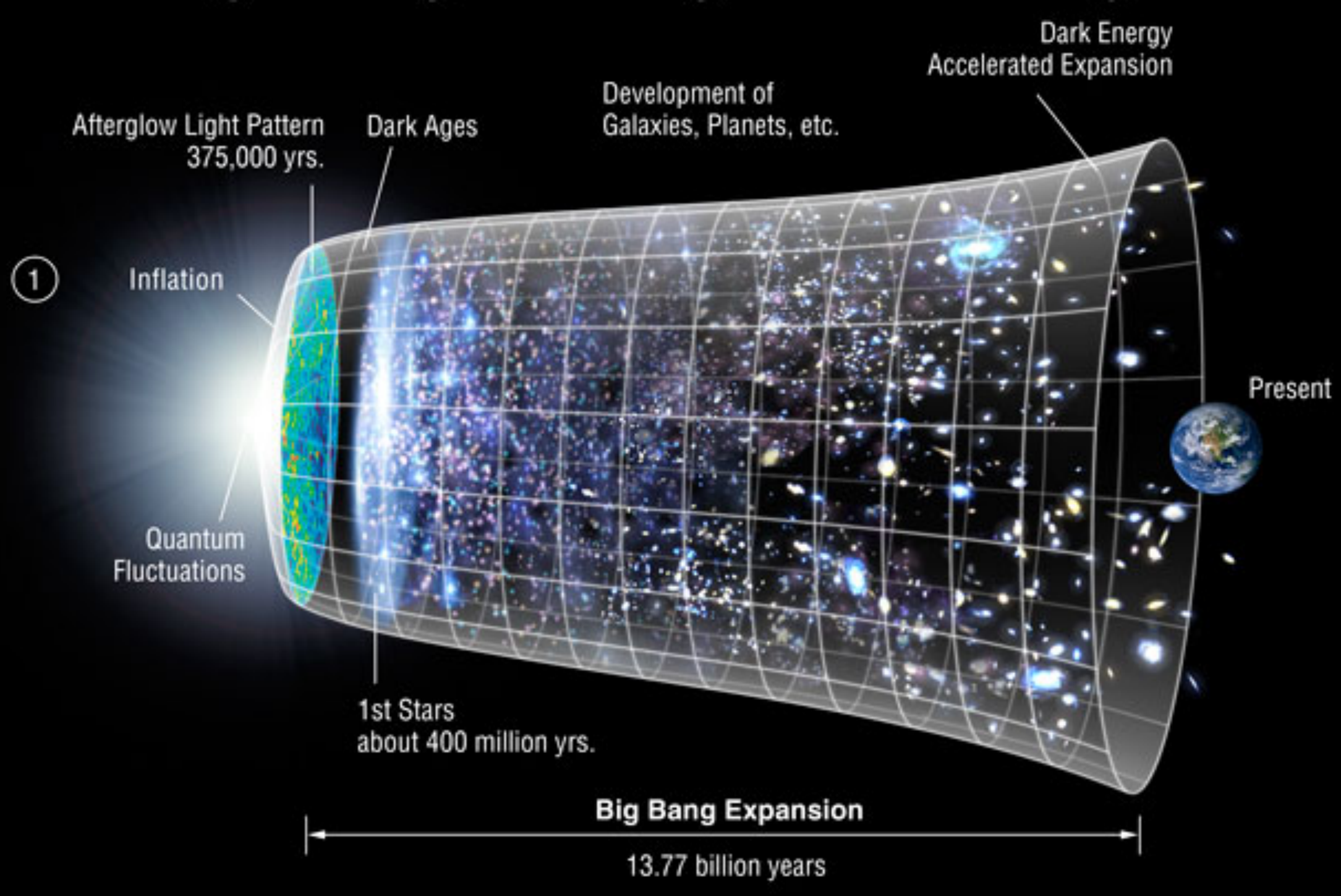
PRD 97, 022002 (2018)



arXiv:1804.10697




WIMP–nucleon cross section [cm^2]
WIMP–nucleon cross section [pb]
WIMP Mass [GeV/c^2]
10^{-37}
10^{-38}
10^{-39}
10^{-40}
10^{-41}
10^{-42}
10^{-43}
10^{-44}
10^{-45}
10^{-46}
10^{-47}
10^{-48}
10^{-49}
10^{-50}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10^{-14}
0.2
1
10
100
1000
10^4
Si iZIP
Ge iZIP
Si HV
Ge HV
SuperCDMS SNOLAB
CDMSlite (2012)
(2012)
CoGeNT (2012)
CDMS Si (2013)
DAMA
SIMPLE (2012)
CRESST (2014)
CRESST
EDELWEISS (2011)
SuperCDMS LT (2014)
CDMS II Ge (2009)
COUPP (2012)
ZEPLIN-III (2012)
Xenon100 (2012)
LUX (2013)
LUX 300day
SuperCDMS SNOLAB
DEAP3600
Xenon1T
XMASS
LZ
^{7}Be Neutrinos
^{8}B Neutrinos
Atmospheric and DSNB Neutrinos


Dark Energy
Accelerated Expansion
Development of
Galaxies, Planets, etc.
Afterglow Light Pattern
375,000 yrs.
Dark Ages
1
Inflation
Present
Quantum
Fluctuations
1st Stars
about 400 million yrs.
Big Bang Expansion
13.77 billion years

REFERENCES

Saab T. (2024). *SuperCDMS SNOLAB*. [PowerPoint slides]. SNOLAB. https://indico.snolab.ca/event/1/sessions/3/attachments/14/53/SuperCDMS SNOLAB EAC Presentation Feb 08 2024.pdf

Hong Z. (2018). *SuperCDMS in 10 Minutes.* [PowerPoint slides]. Fermilabs. https://lss.fnal.gov/archive/2018/slides/fermilab-slides-18-066-ae.pdf

World Science Festival. 2019, October 11. *Physics in the Dark: Searching for Missing Matter.* [Video]. YouTube. https://www.youtube.com/1VajnuxMJmU