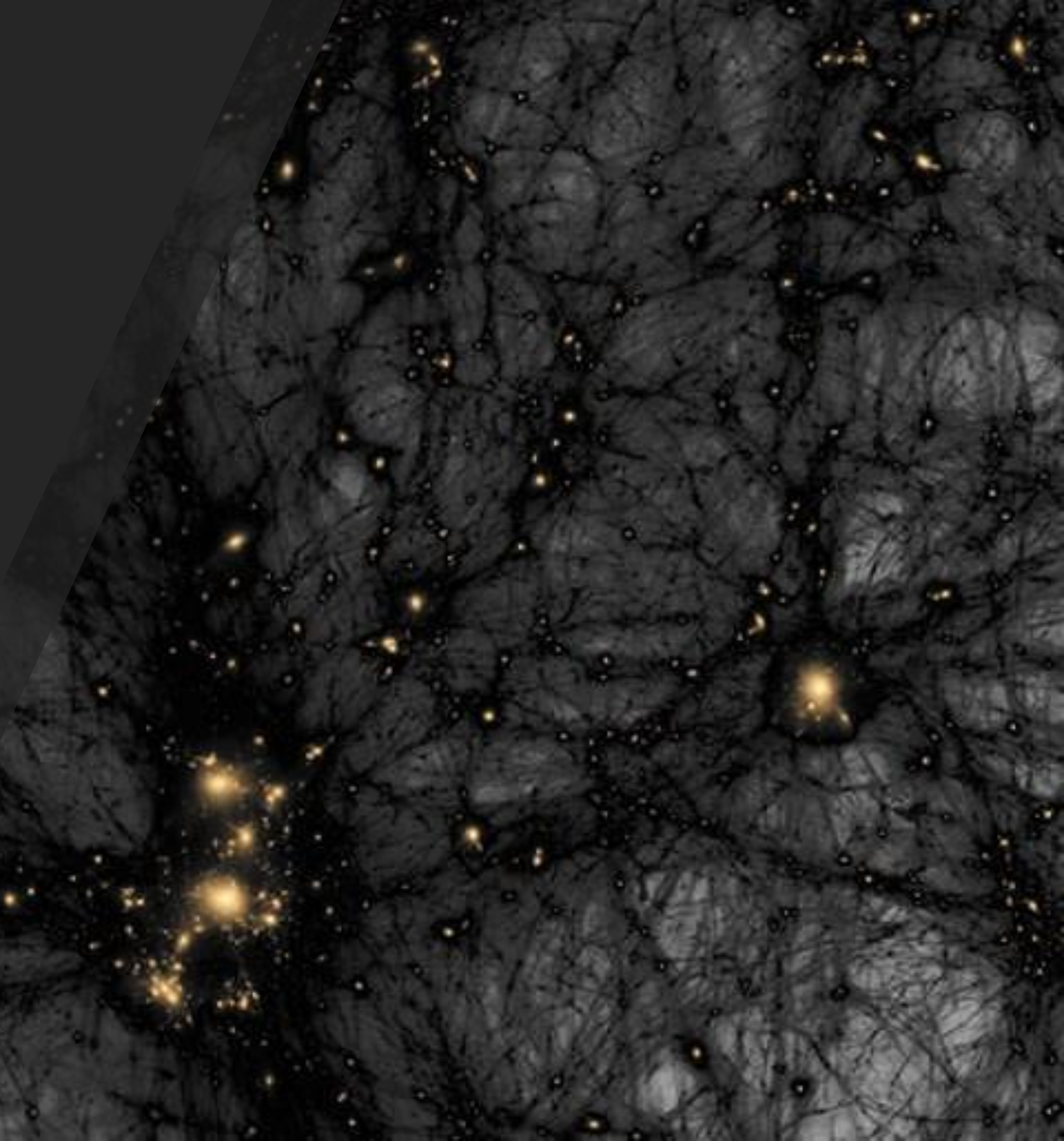
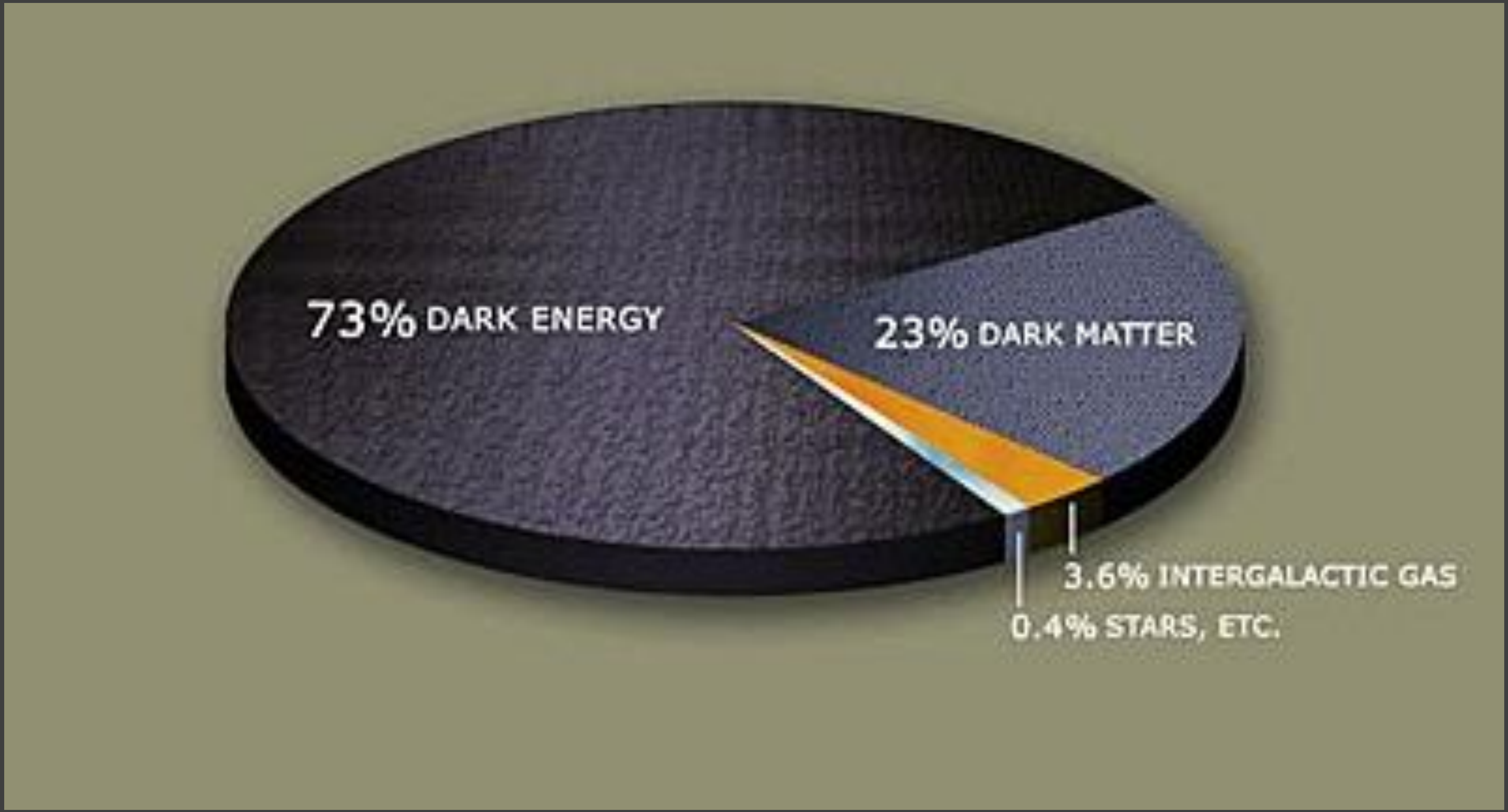
Stumbling in the Dark:
searching for dark matter



- What is dark matter and why it’s important?
- What evidence do we have that it exists?
- Experiments for detecting it
- Astrophysical probes


73% DARK ENERGY
23% DARK MATTER
3.6% INTERGALACTIC GAS
0.4% STARS, ETC.

@reimers

WANTED

- It is everywhere

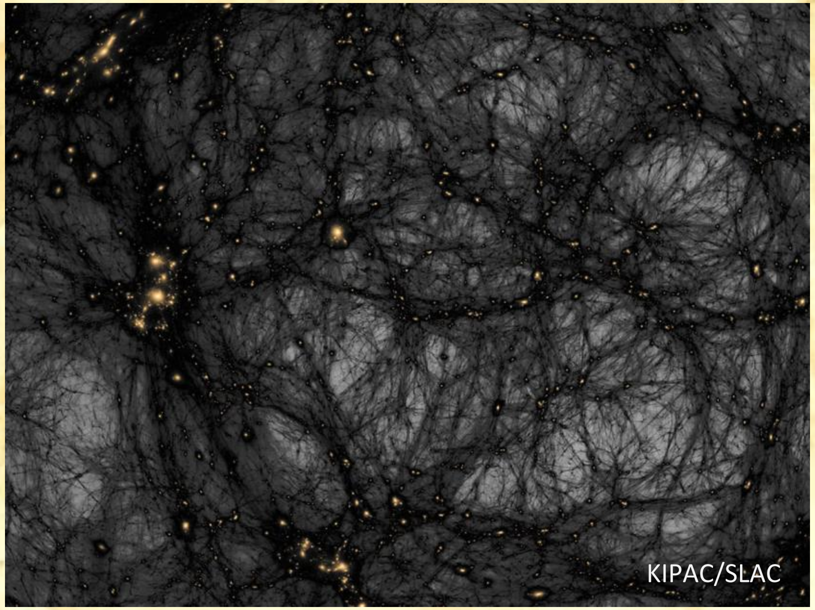
- It does not absorb or emit light (doesn't feel the electromagnetic force)

- It interacts only through gravity (and maybe the weak force)

- Known to: bend light, form and destroy galaxies and many other mischiefs.

REWARD

HAVE YOU SEEN THIS WIZARD?



APPROACH WITH EXTREME CAUTION
DO NOT ATTEMPT TO USE
MAGIC AGAINST THIS WIZARD

Any information leading to the arrest of this Wizard shall be duly rewarded.
Notify immediately by owl the Ministry of Magic- Witch Watchers department.

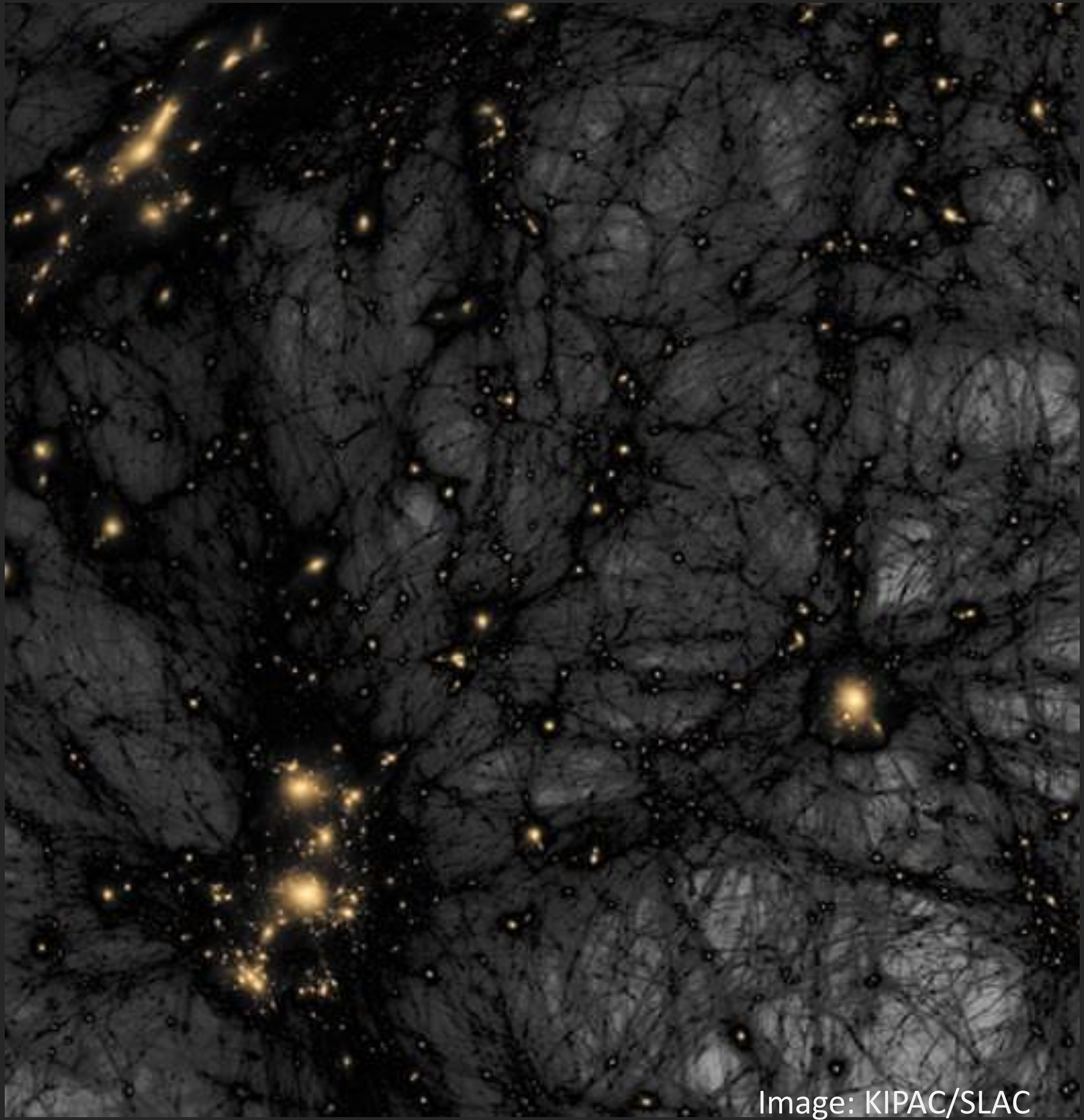
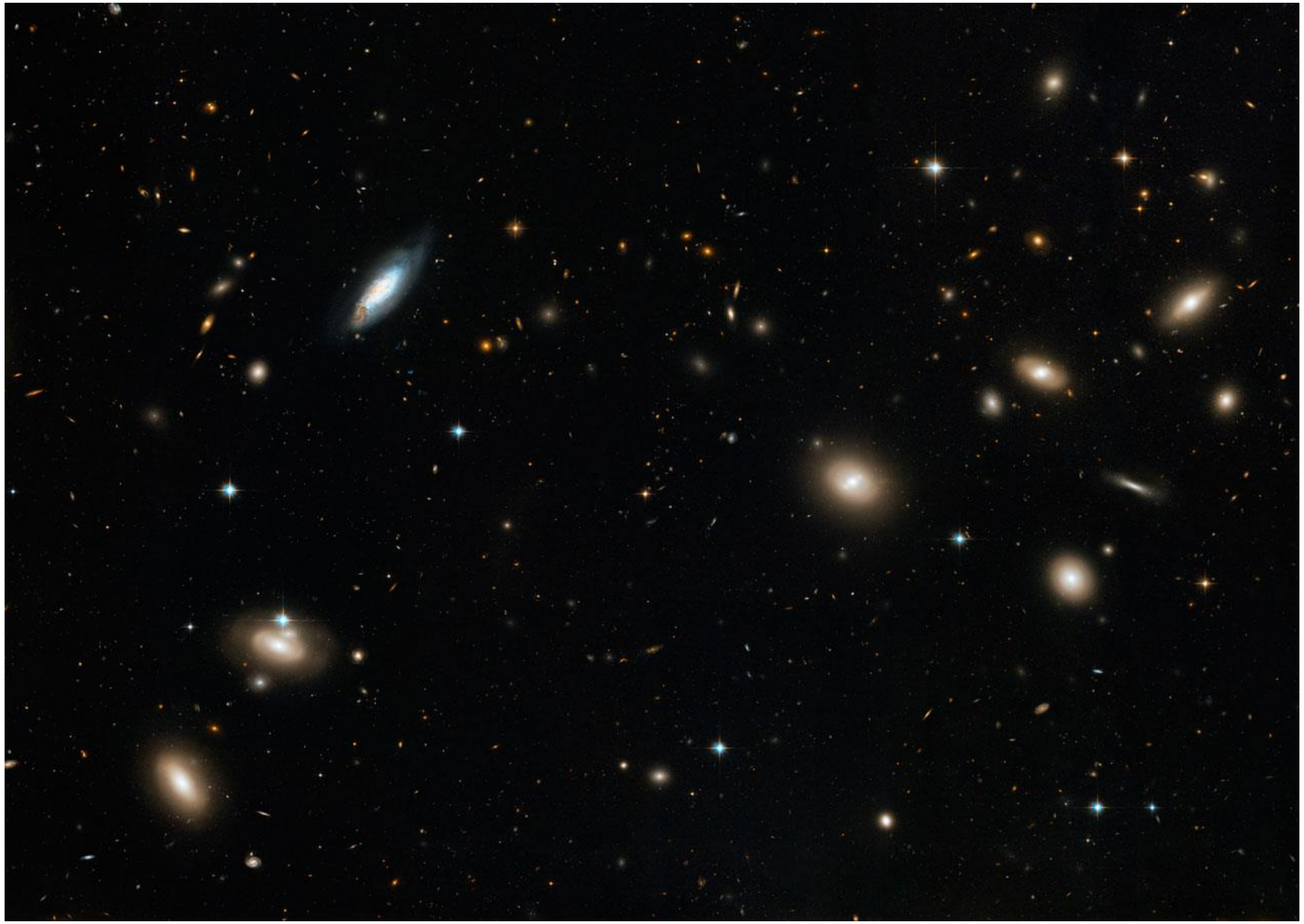
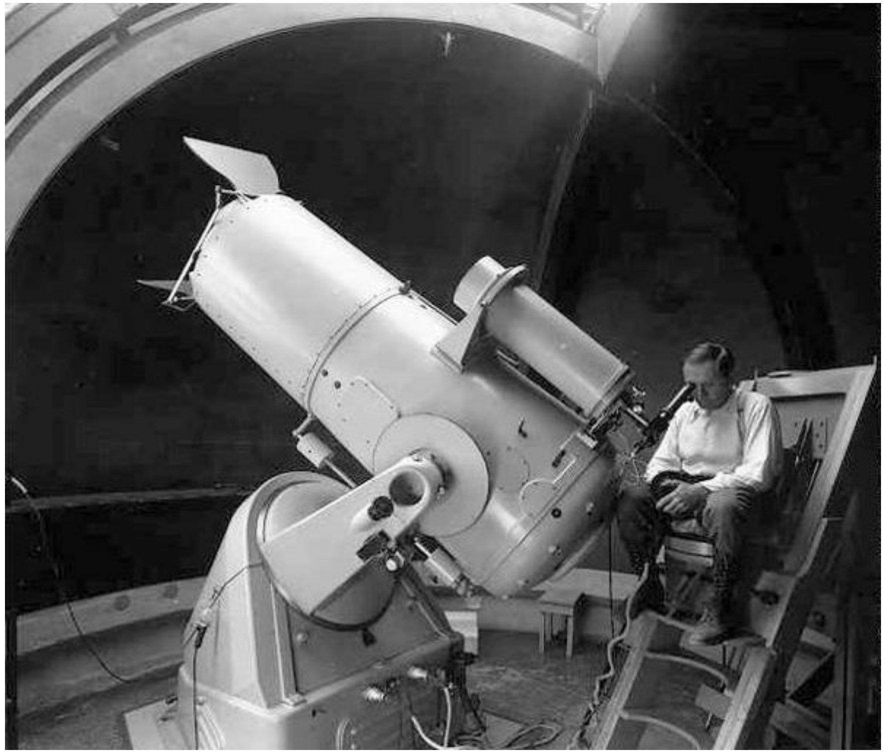


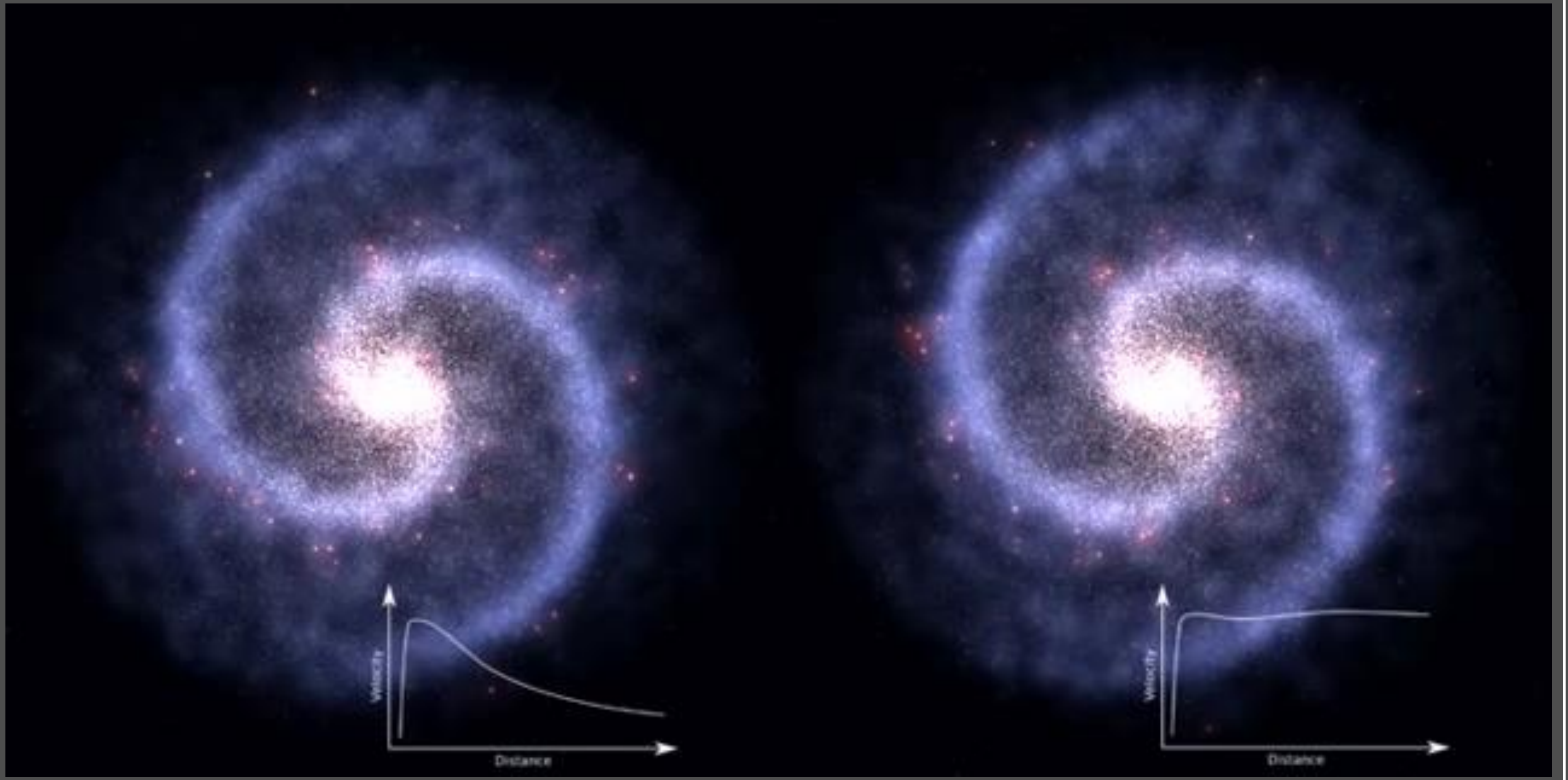
Image: KIPAC/SLAC



Credit: NASA, ESA, and the Hubble Heritage Team (STScI/AURA).



Credit: Palomar Observatory/Caltech



Source: ESO/L. Calçada

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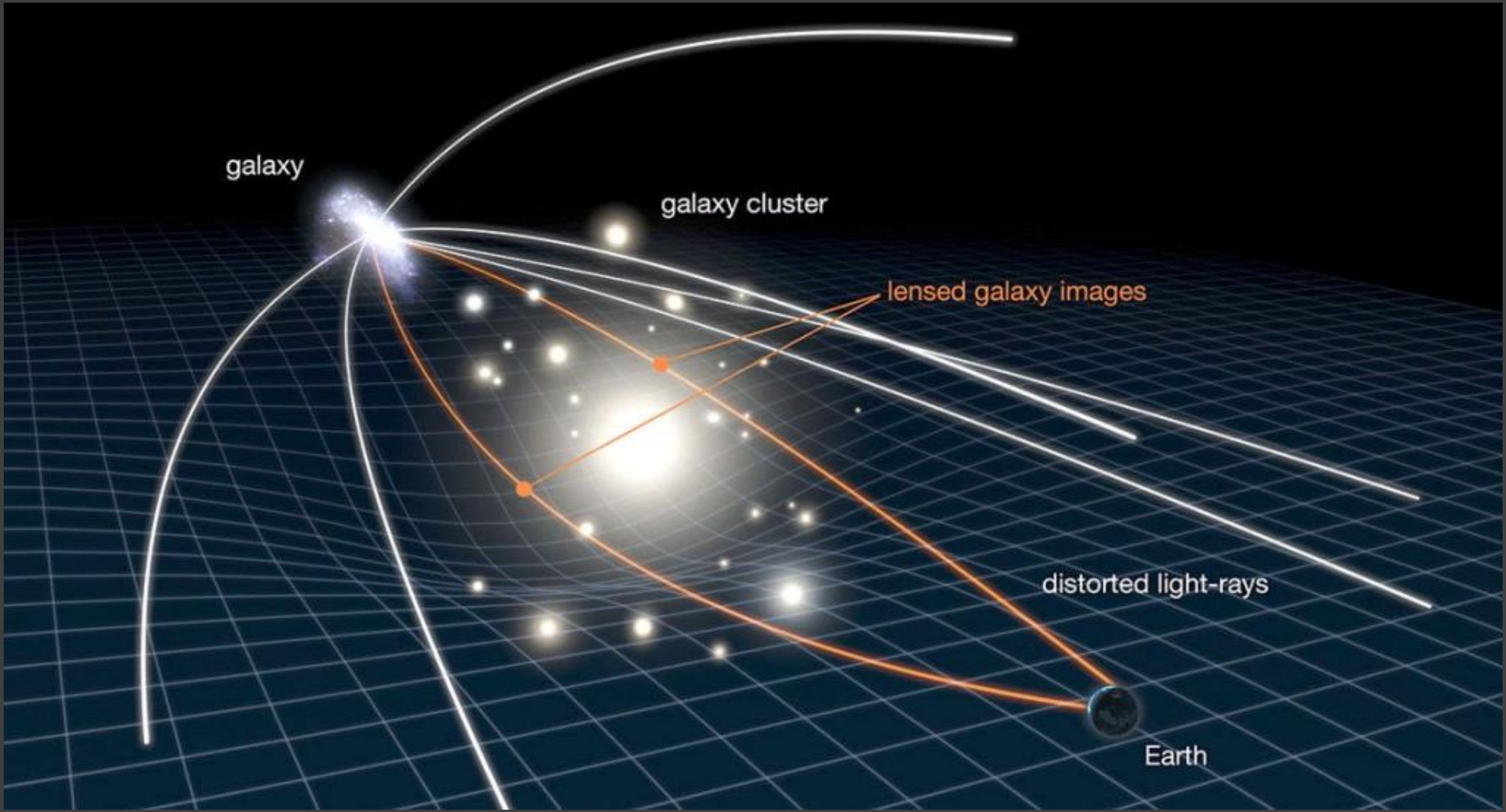
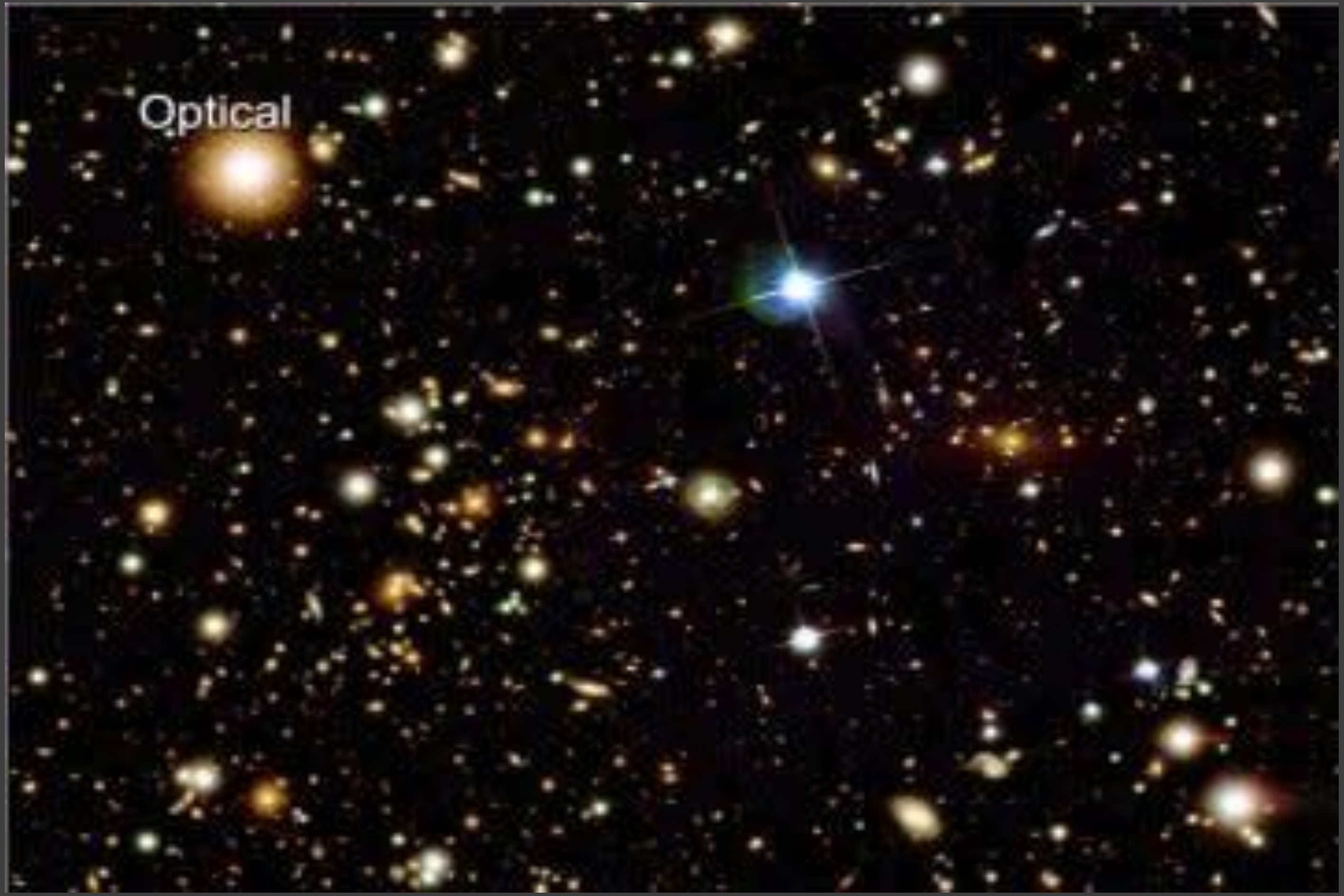
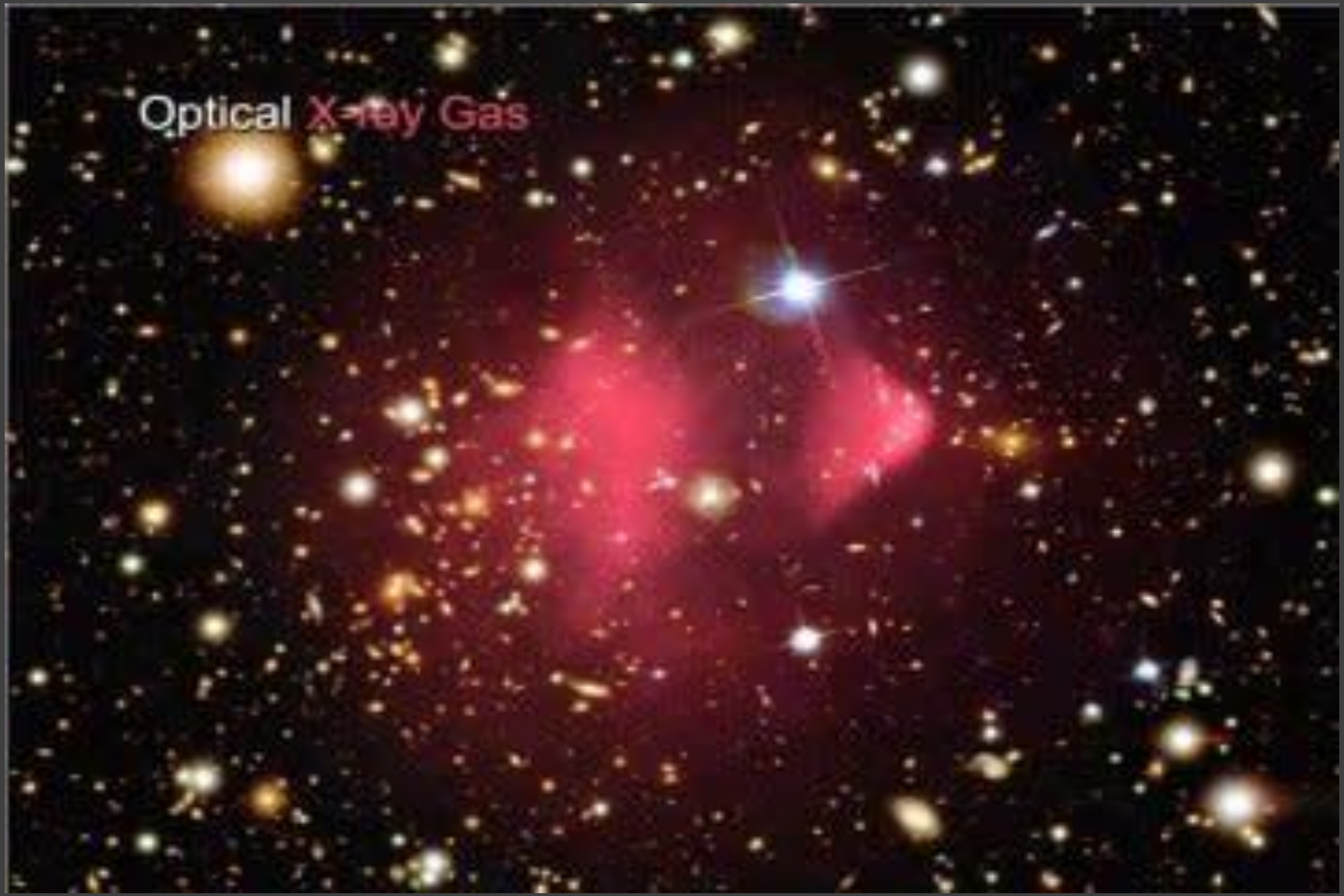


Image: NASA/ESA

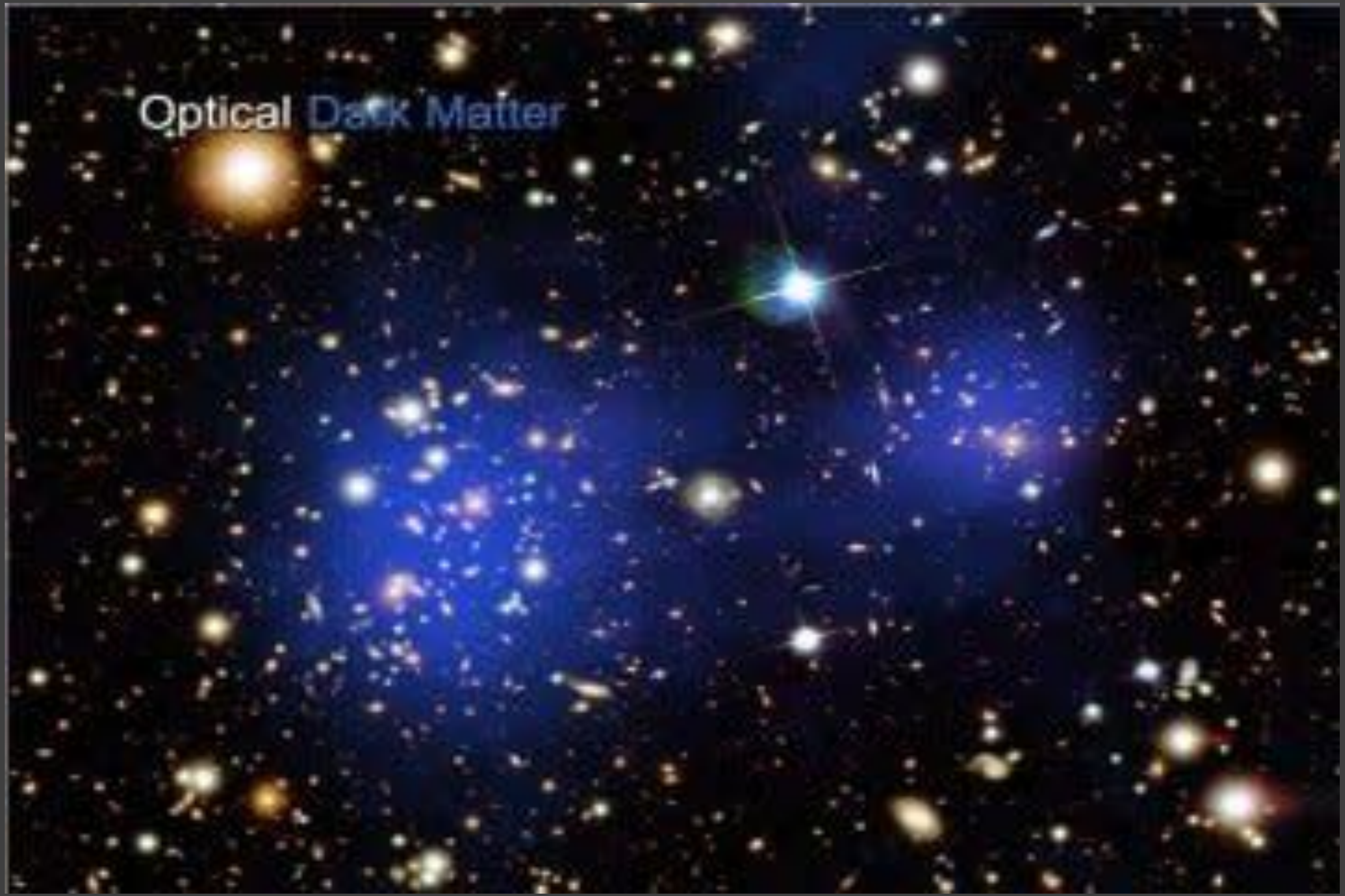
The Bullet Cluster



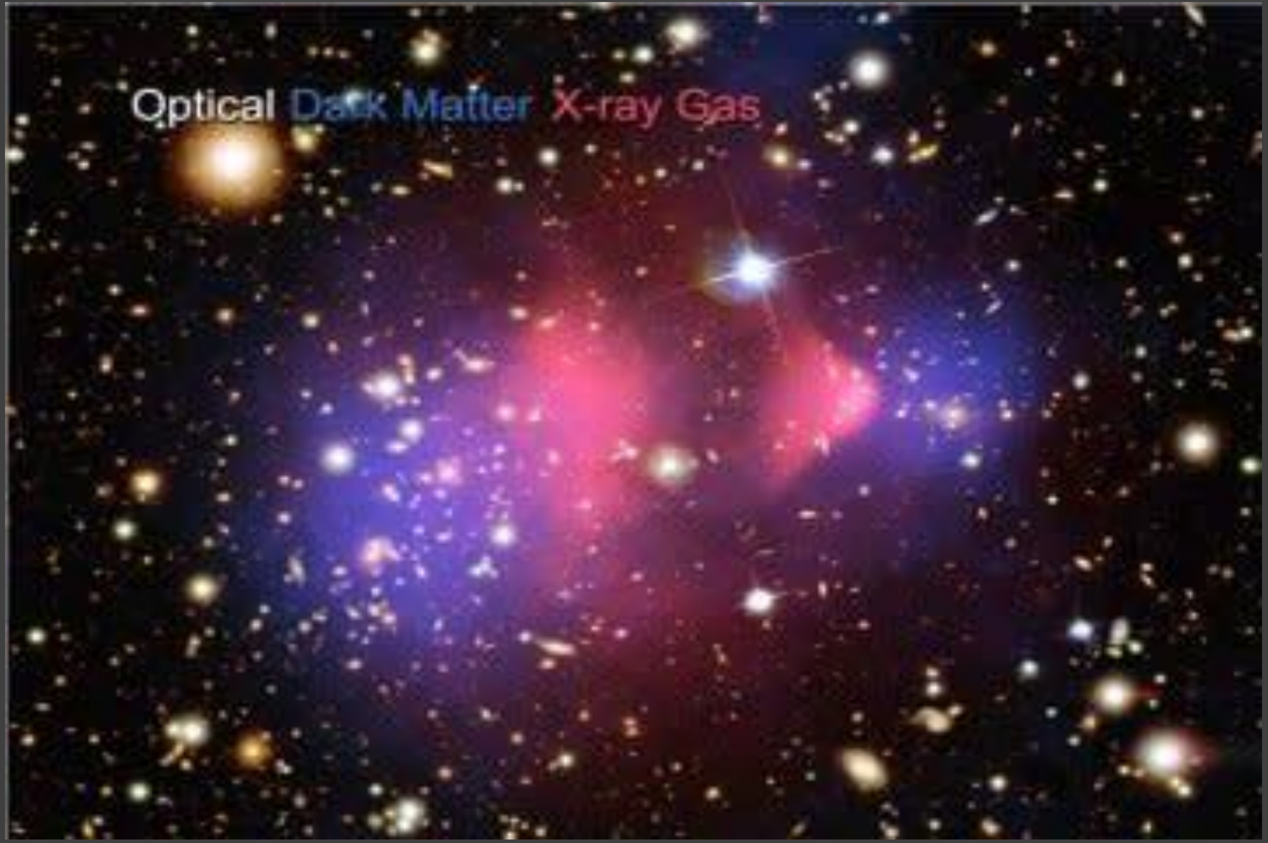
NASA/STScI; Magellan/U.Arizona/D.Clowe et al.

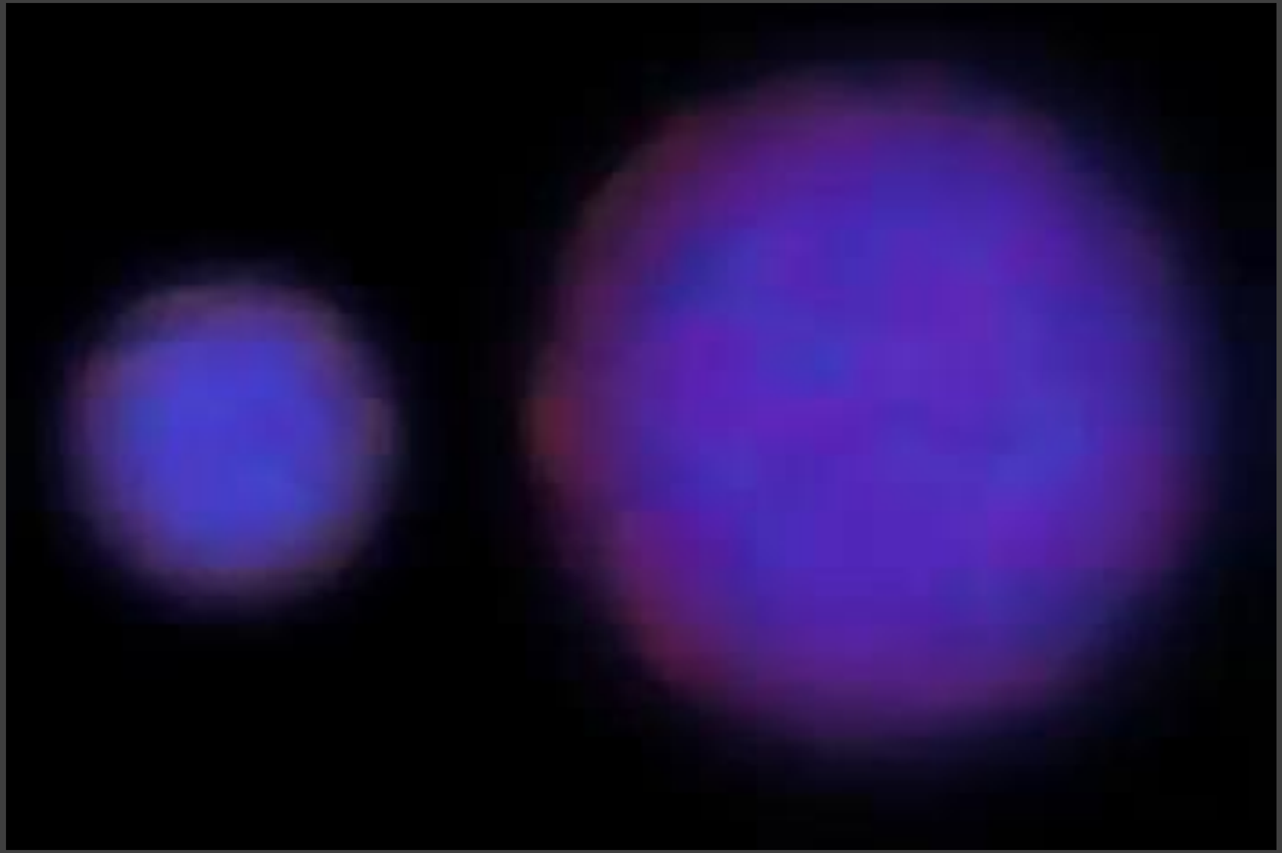


NASA/CXC/CfA/M.Markevitch et al



NASA/STScI; ESO WFI; Magellan/U.Arizona/D.Clowe et al.





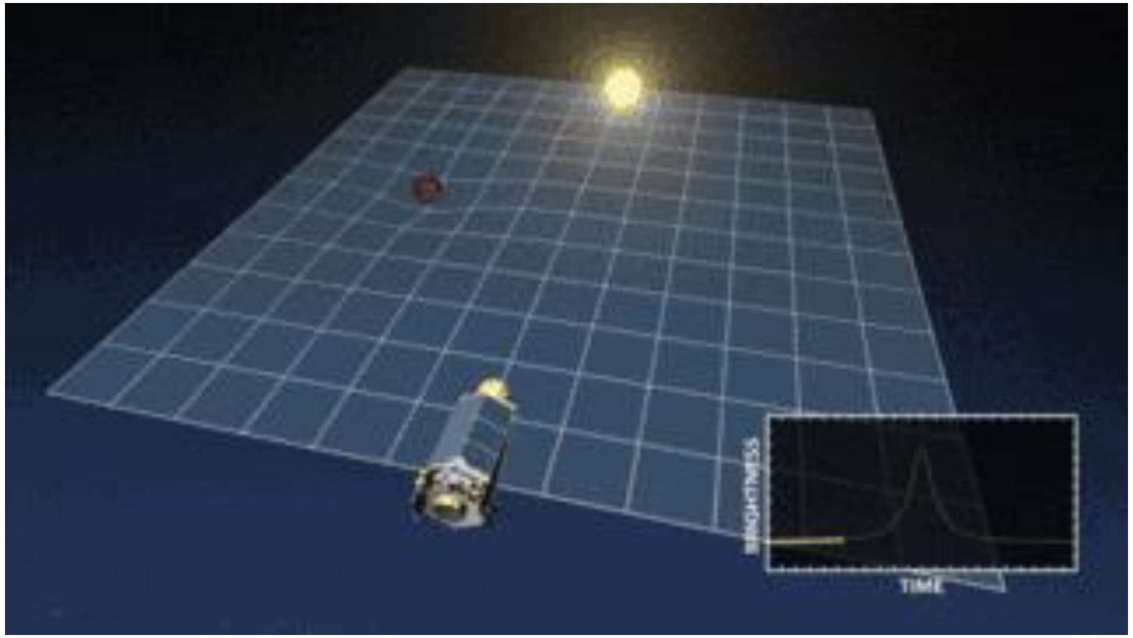
NASA/CXC/M.Weiss

Can dark matter be baryonic?

(e.g. of protons, neutrons, electrons, etc)

- **Brown dwarfs**
- **Dead stars**
- **Rogue planets**
- **Cold gas, dust**
- **Primordial black holes**
- **…?**

Artist's portrayal of a rogue planet. *NASA / Caltech*



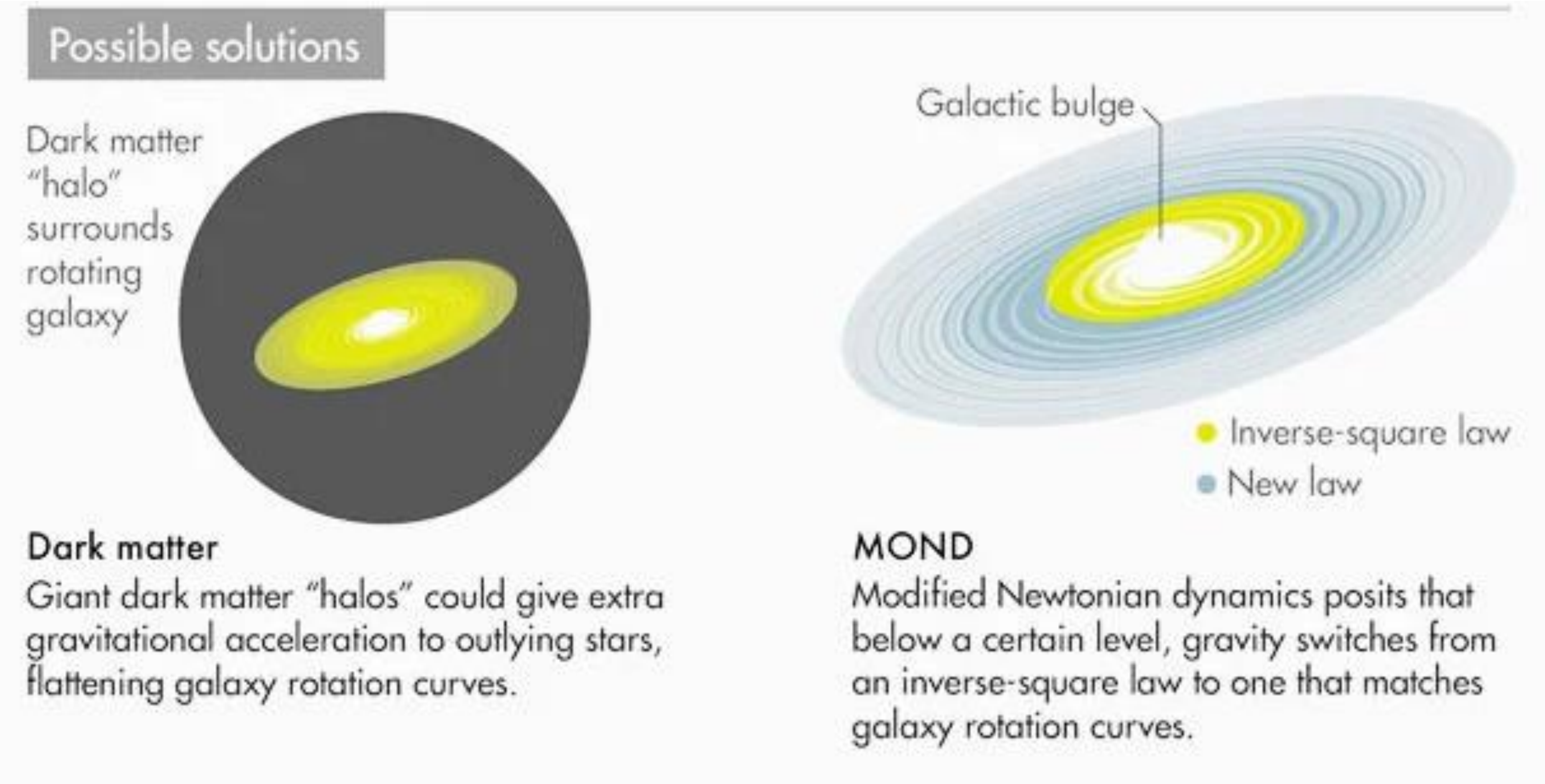
NASA Ames / JPL-Caltech / T. Pyle

Massive compact halo objects (MACHOs) cannot make most of dark matter.

only a few percent of all dark matter …

What if we don't understand the force of gravity?

Modified Newtonian Dynamics (MOND) theory



Lucy Reading-Ikkanda/Quanta Magazine

What if we don't understand the force of gravity?

Modified Newtonian Dynamics (MOND) theory

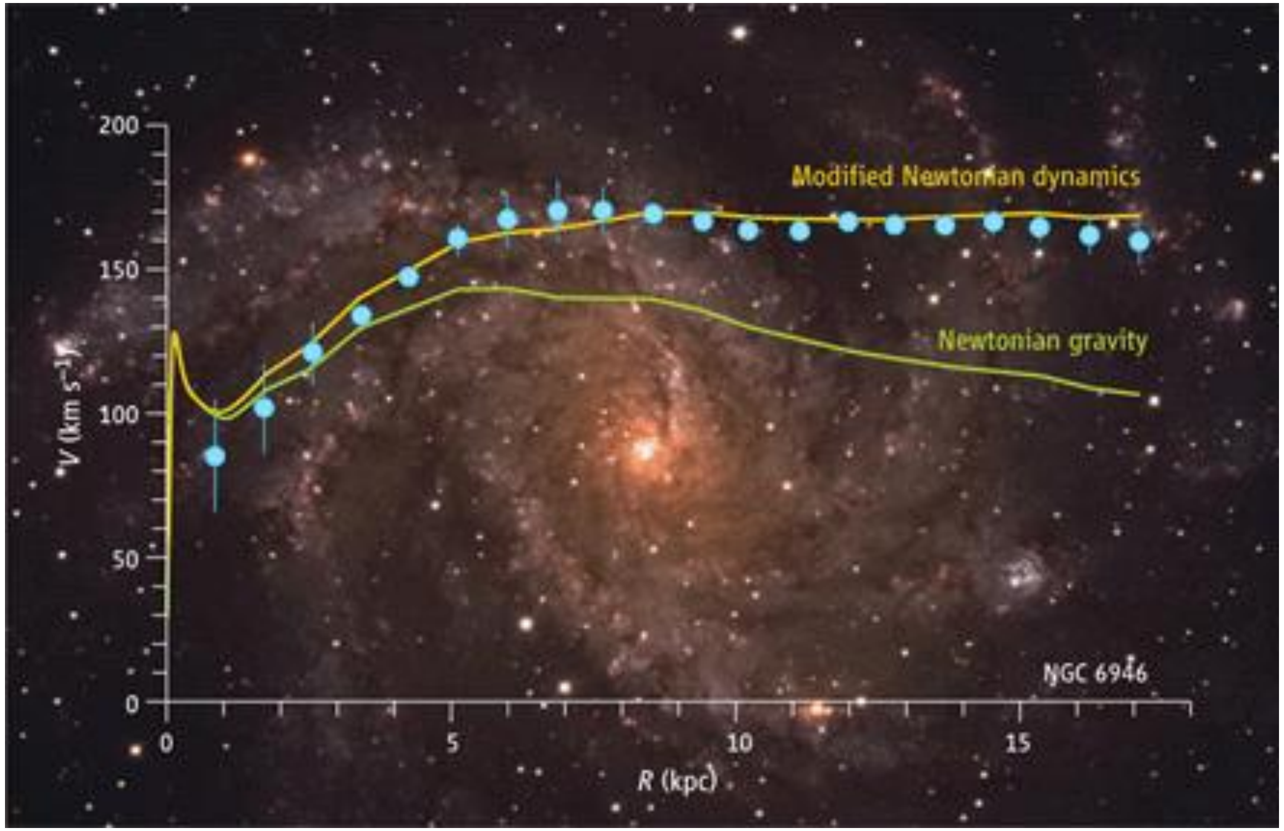
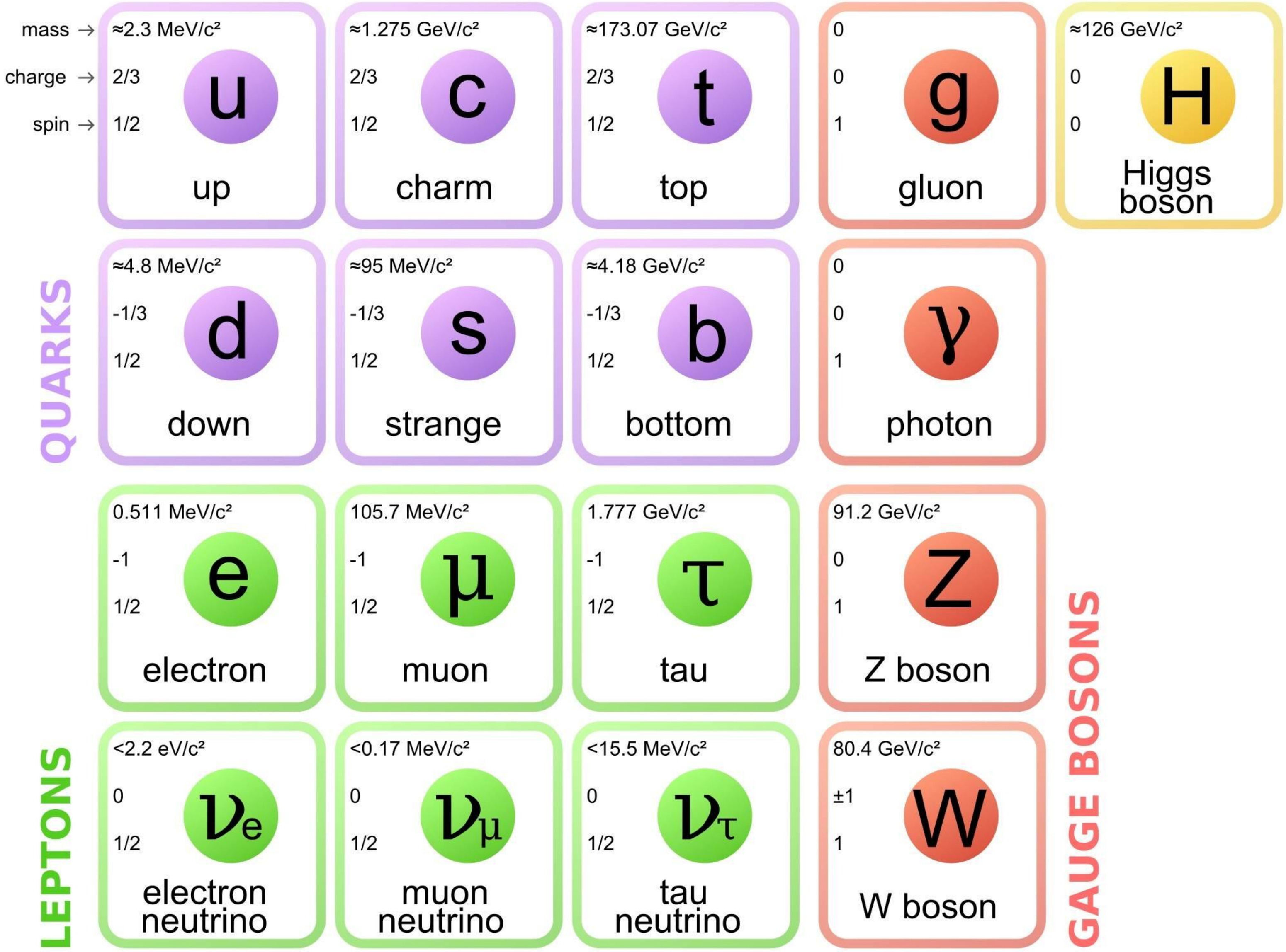
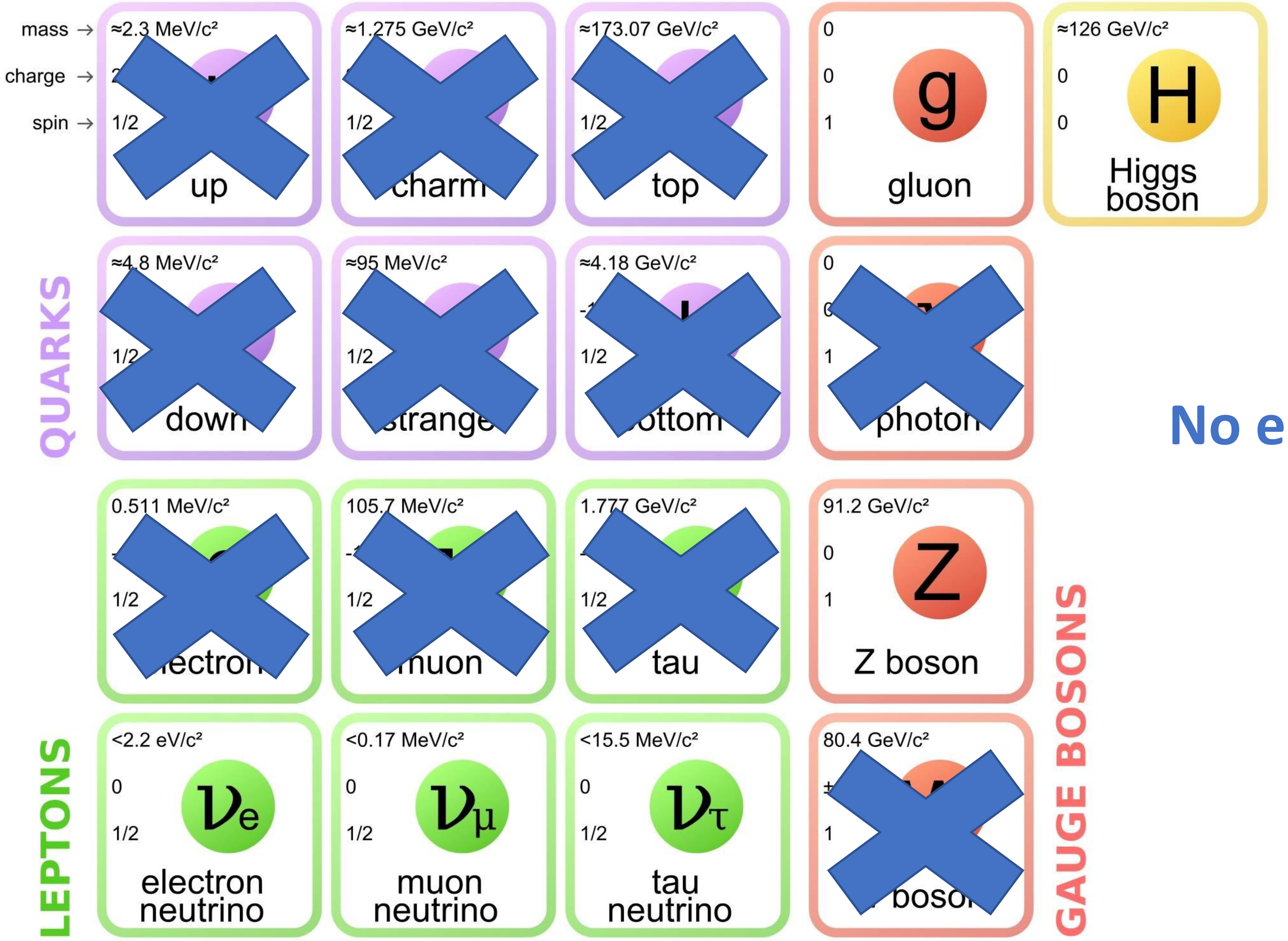
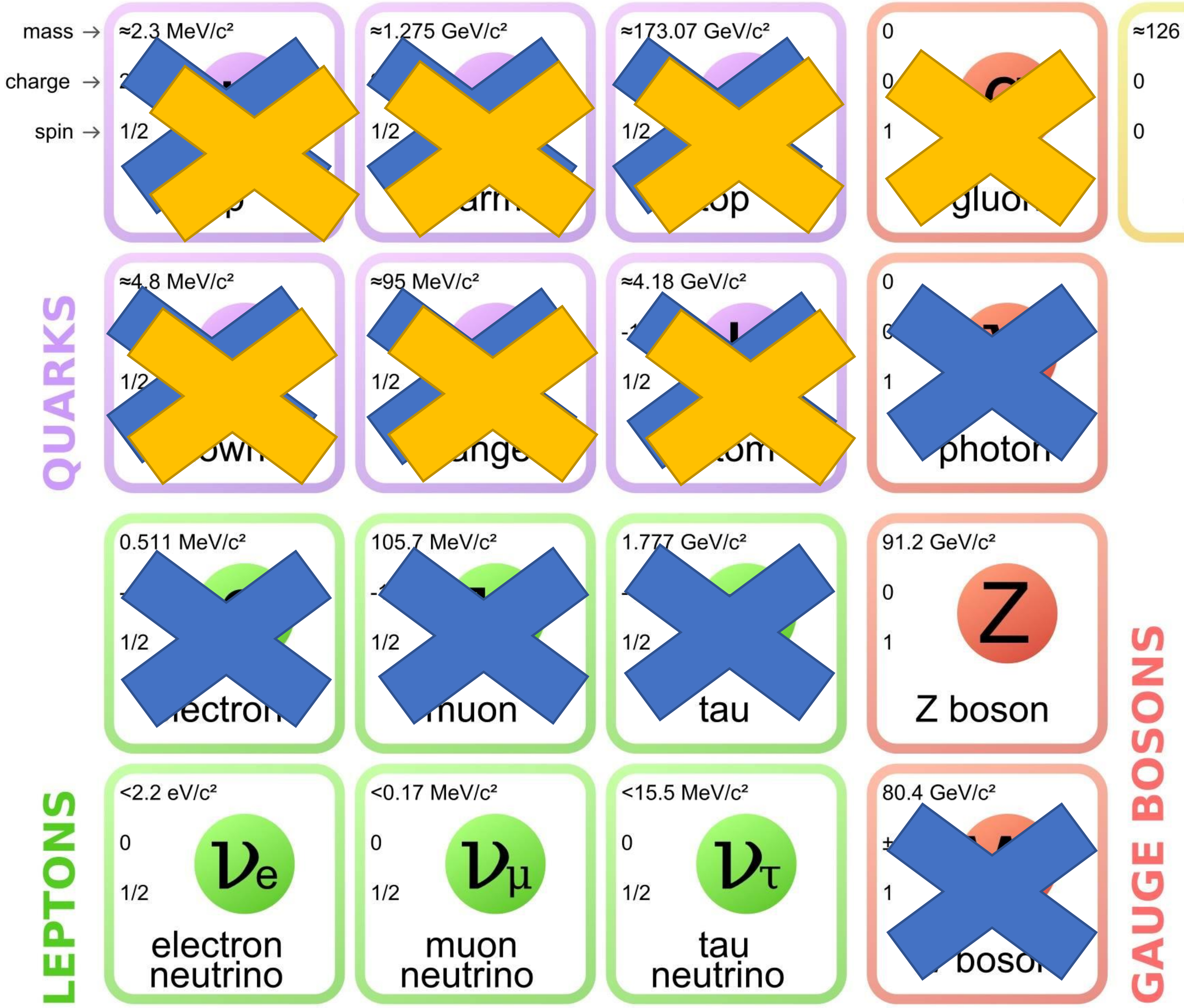


PHOTO CREDIT: STACY MCGAUGH


mass →
charge →
spin →
≈2.3 MeV/c²
2/3
1/2
u
up
≈1.275 GeV/c²
2/3
1/2
c
charm
≈173.07 GeV/c²
2/3
1/2
t
top
0
0
1
g
gluon
≈126 GeV/c²
0
0
H
Higgs boson
QUARKS
≈4.8 MeV/c²
-1/3
1/2
d
down
≈95 MeV/c²
-1/3
1/2
s
strange
≈4.18 GeV/c²
-1/3
1/2
b
bottom
0
0
1
γ
photon
0.511 MeV/c²
-1
1/2
e
electron
105.7 MeV/c²
-1
1/2
μ
muon
1.777 GeV/c²
-1
1/2
τ
tau
91.2 GeV/c²
0
1
Z
Z boson
LEPTONS
<2.2 eV/c²
0
1/2
νe
electron neutrino
<0.17 MeV/c²
0
1/2
νμ
muon neutrino
<15.5 MeV/c²
0
1/2
ντ
tau neutrino
80.4 GeV/c²
±1
1
W
W boson
GAUGE BOSONS

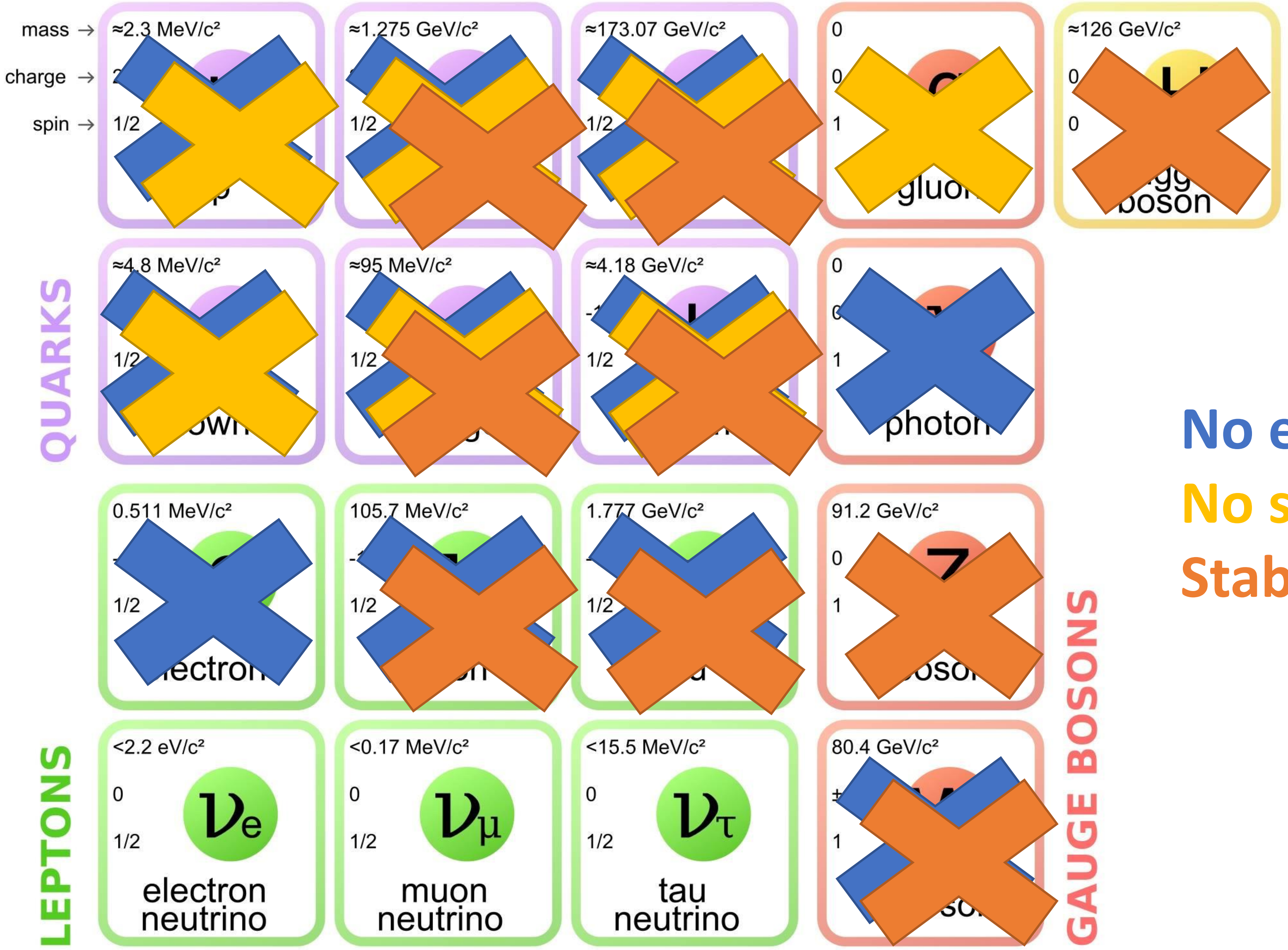


No electromagnetic force



No electromagnetic force

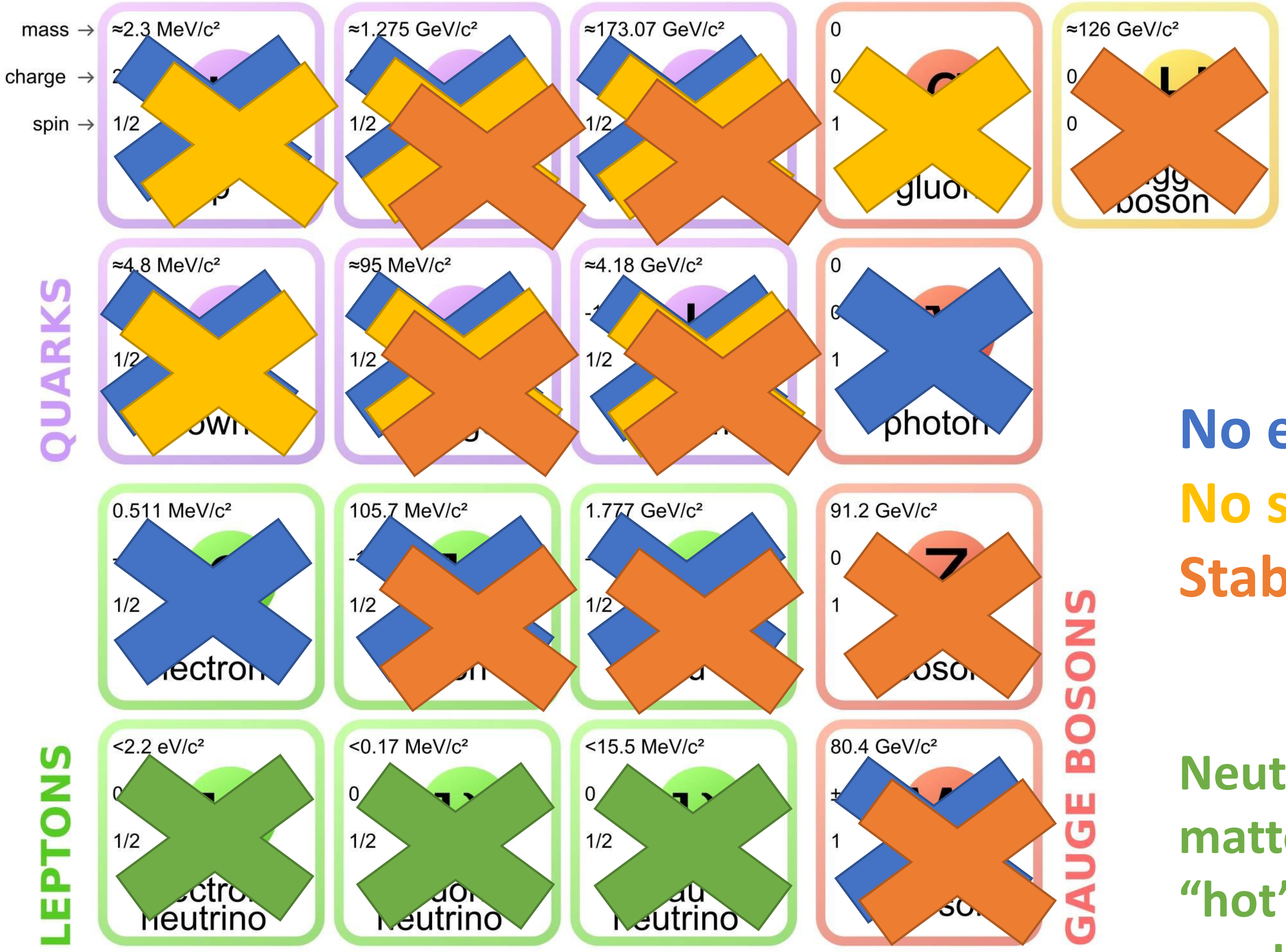
No strong force



No electromagnetic force

No strong force

Stable

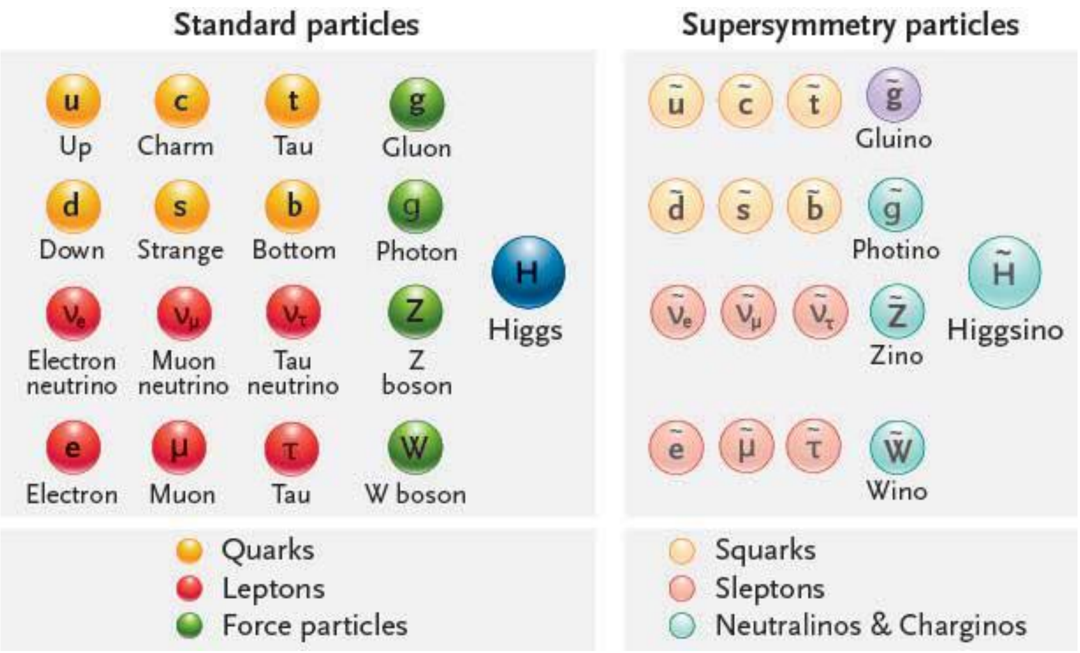


No electromagnetic force

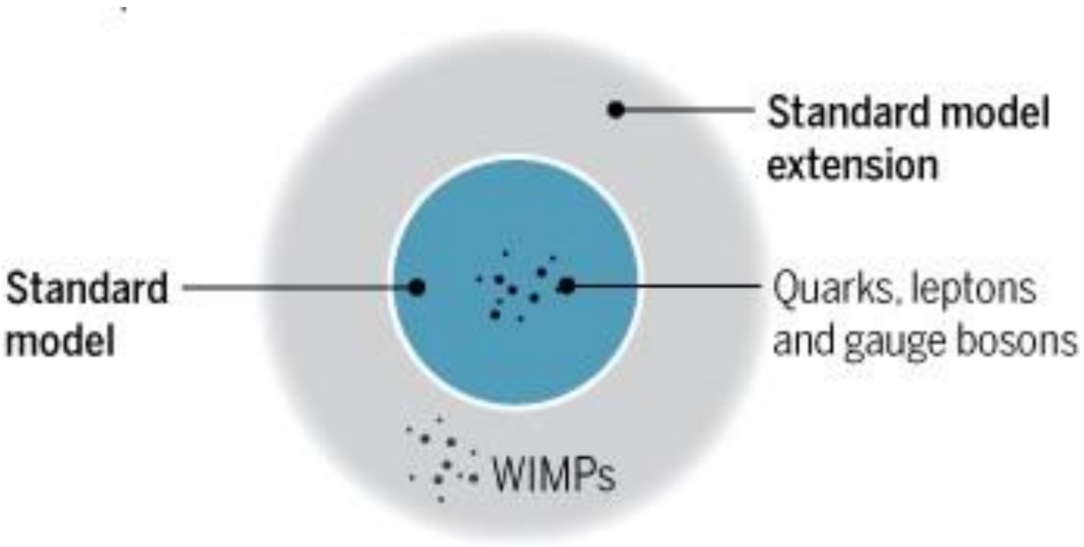
No strong force

Stable

Neutrinos can't be all of dark matter: they move too fast (are "hot") and they do not contribute much by mass.

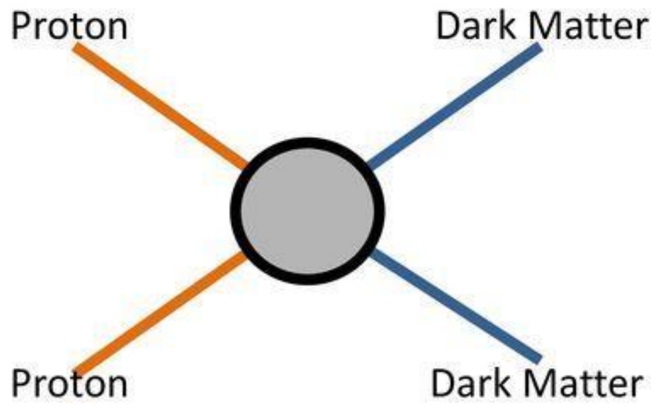


SUPERSYMMETRY

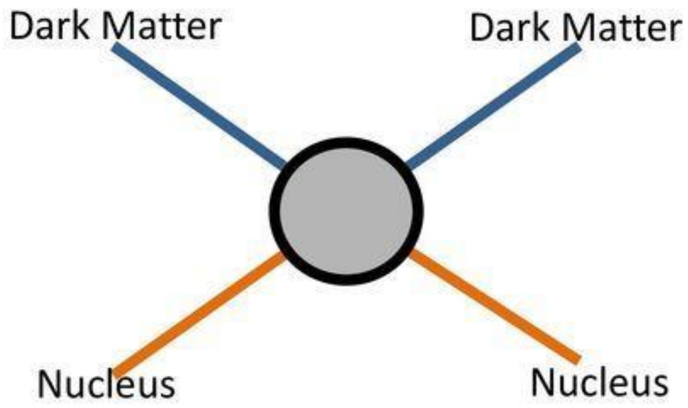


C.BICKEL/*SCIENCE*

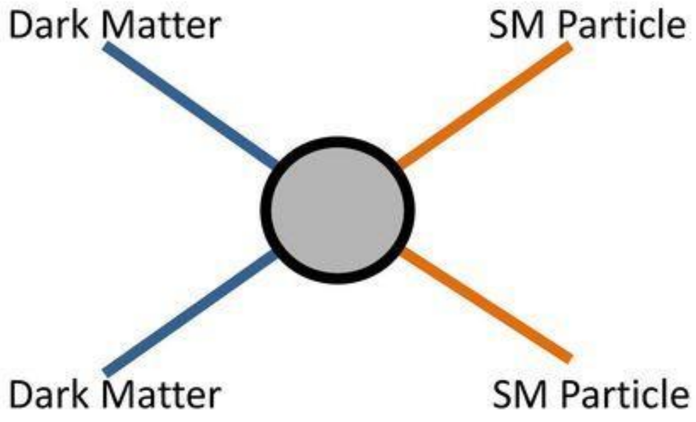
Ways to Detect Dark Matter – *Make, Shake and Break*



Make – *collider production*

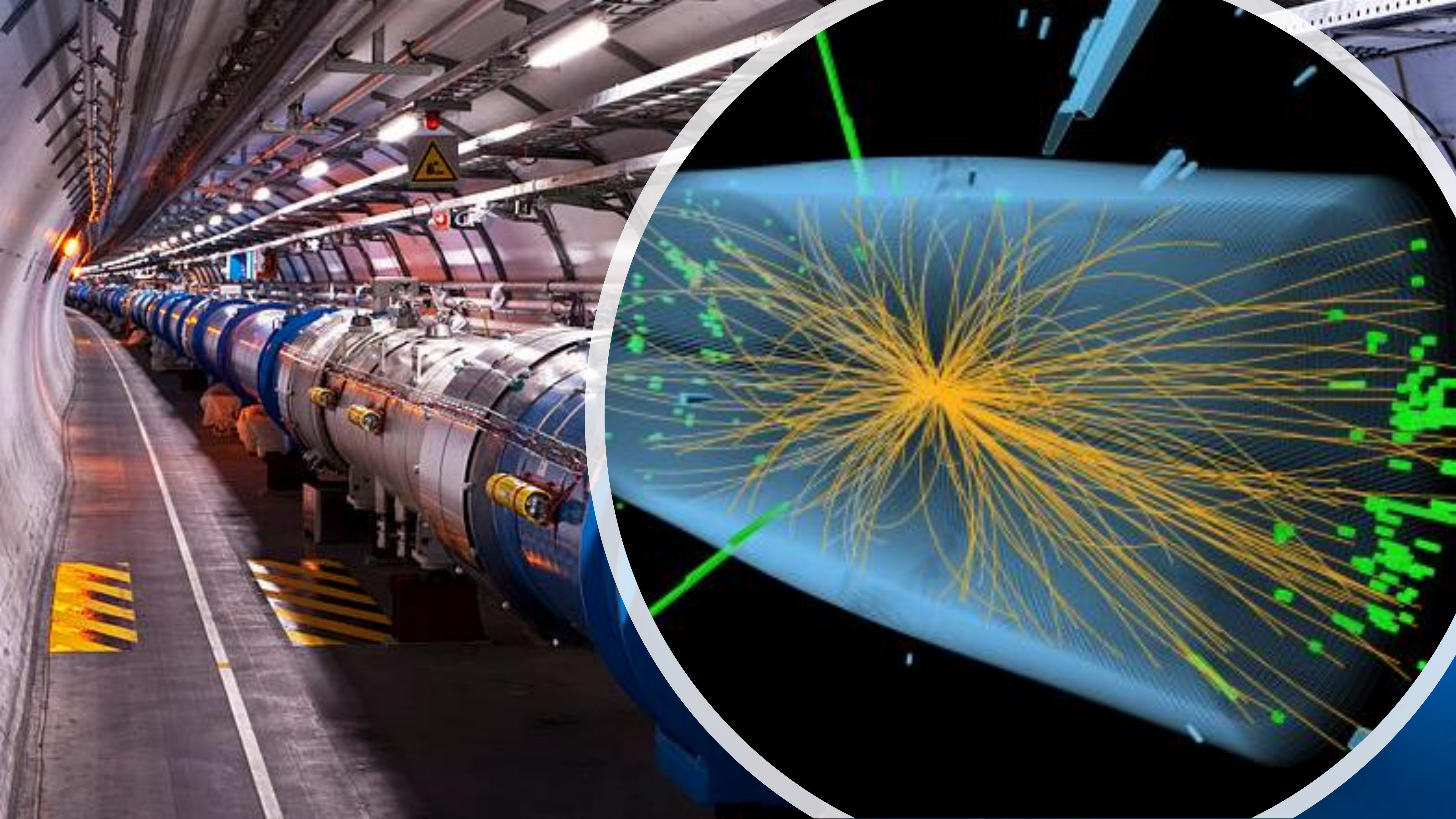


Shake – *direct detection scattering*

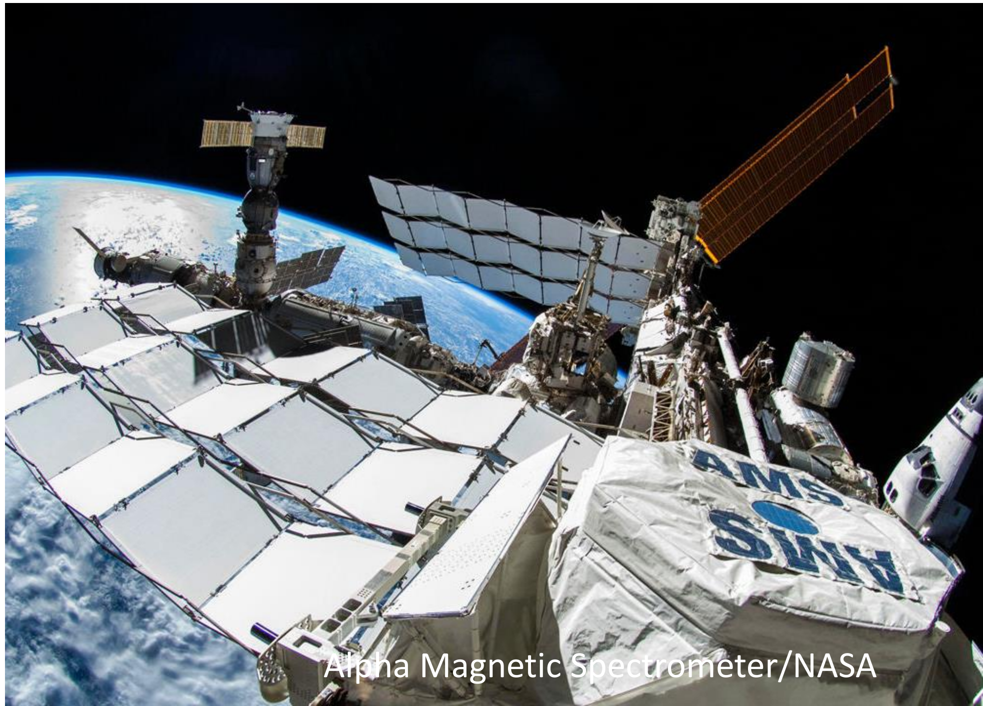


Break – *indirect detection of annihilation*

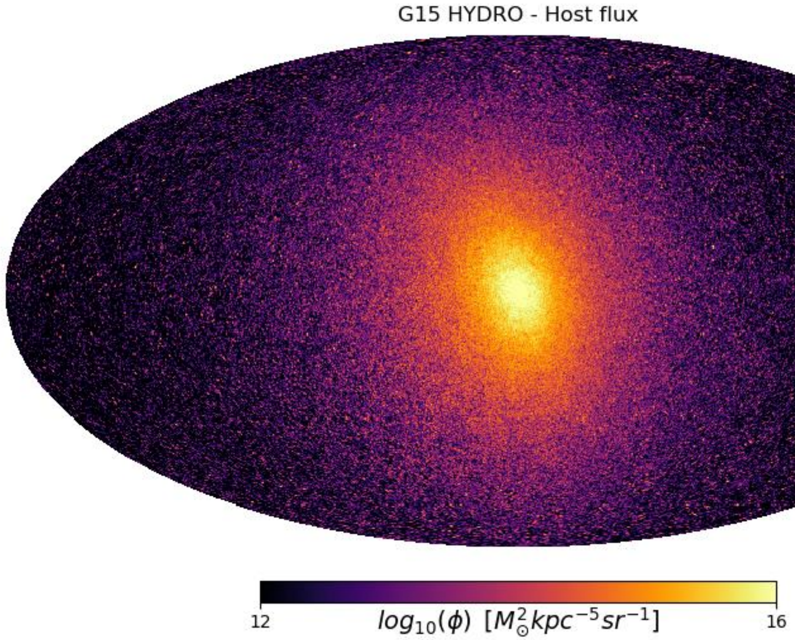
Credit: Malcolm Fairbairn



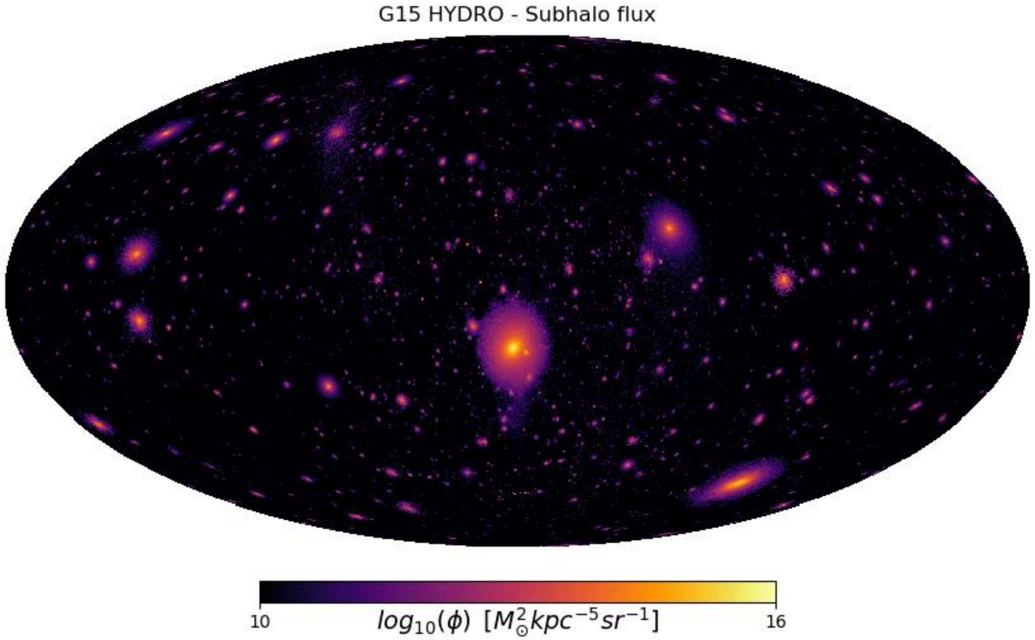

Fermi Space Satellite/ NASA. Photo: Sandbox Studio



Alpha Magnetic Spectrometer/NASA

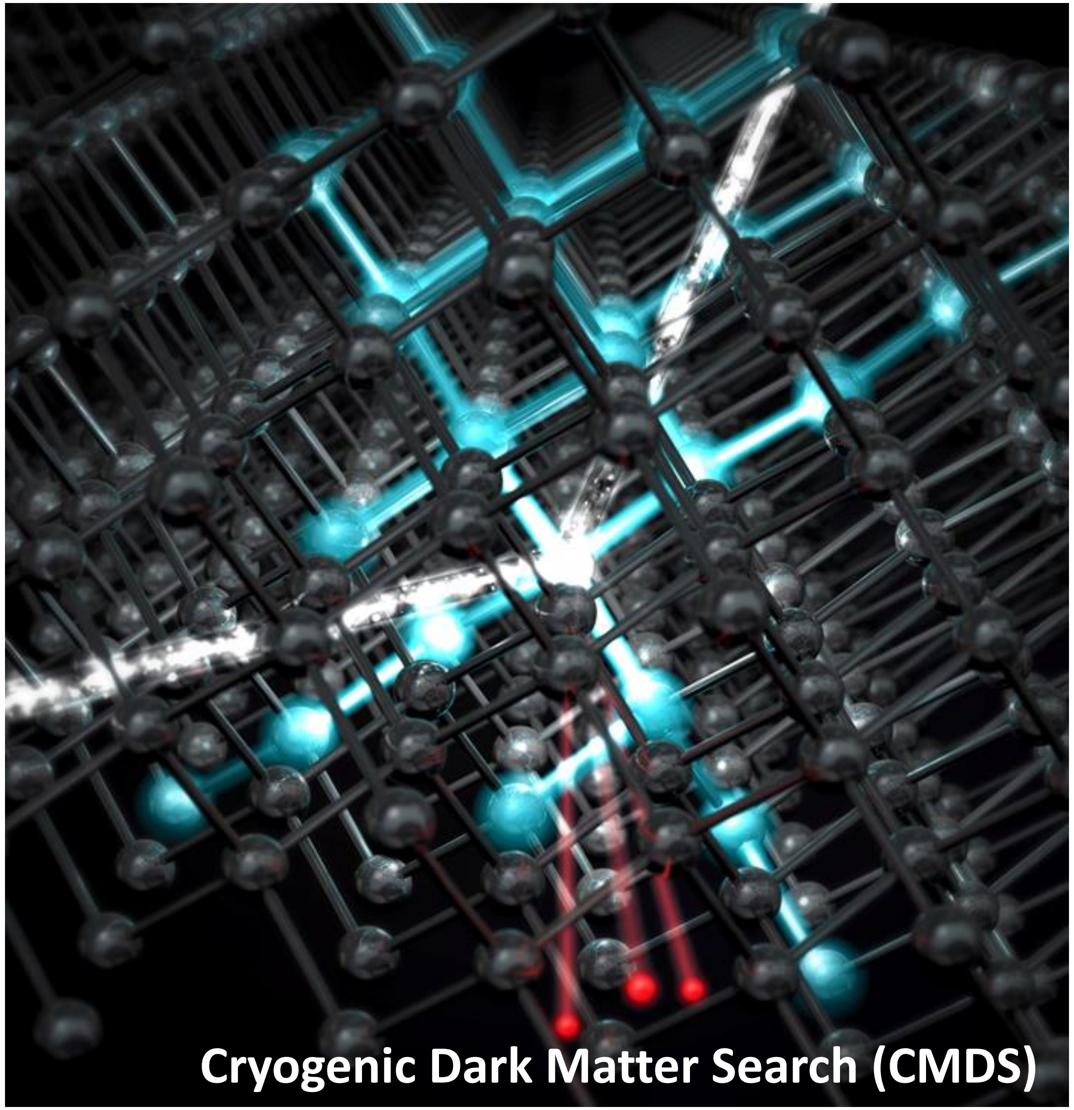


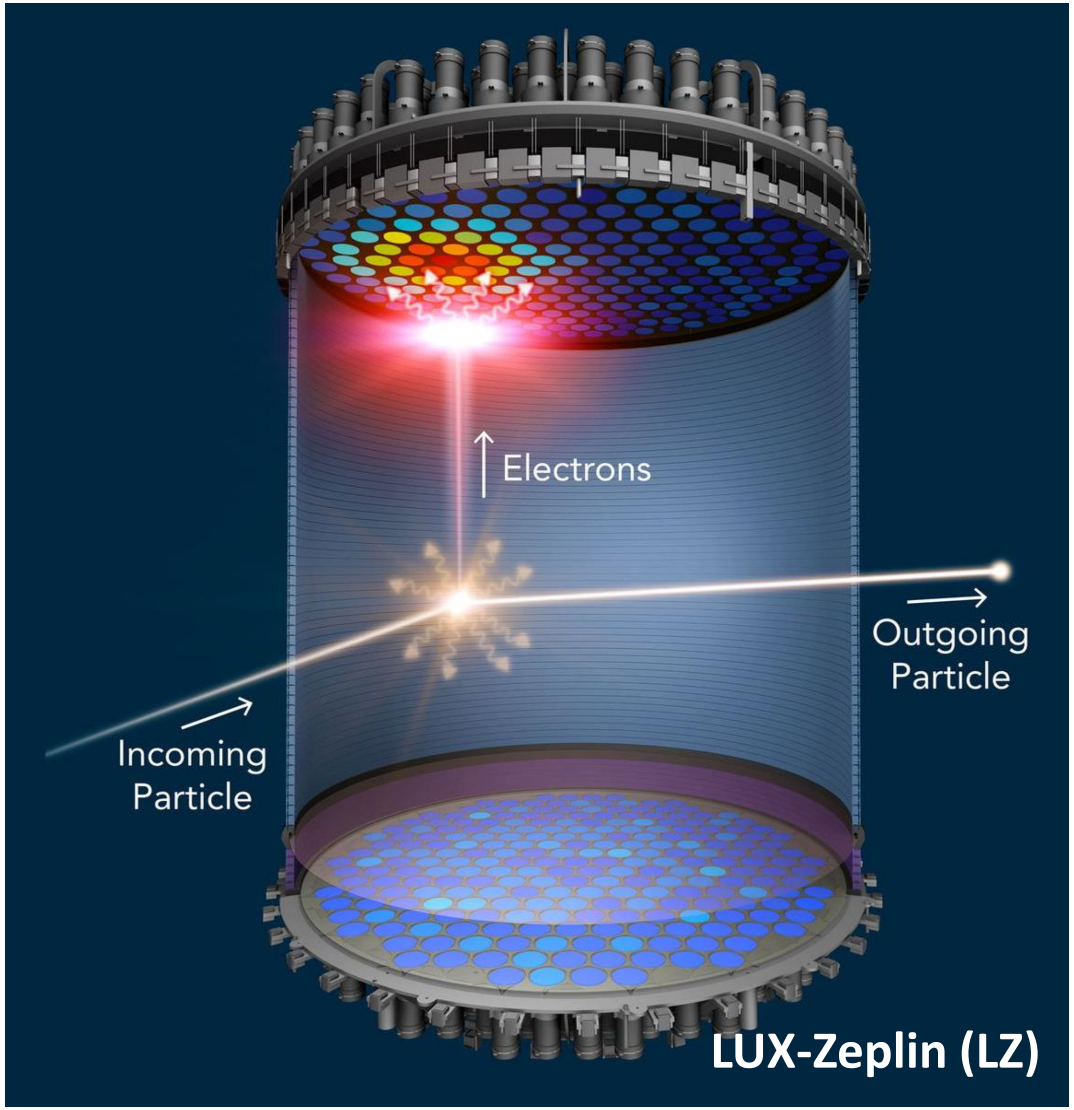
ARTEMIS simulations (Font et al 2020):
Gamma-rays from the galaxy

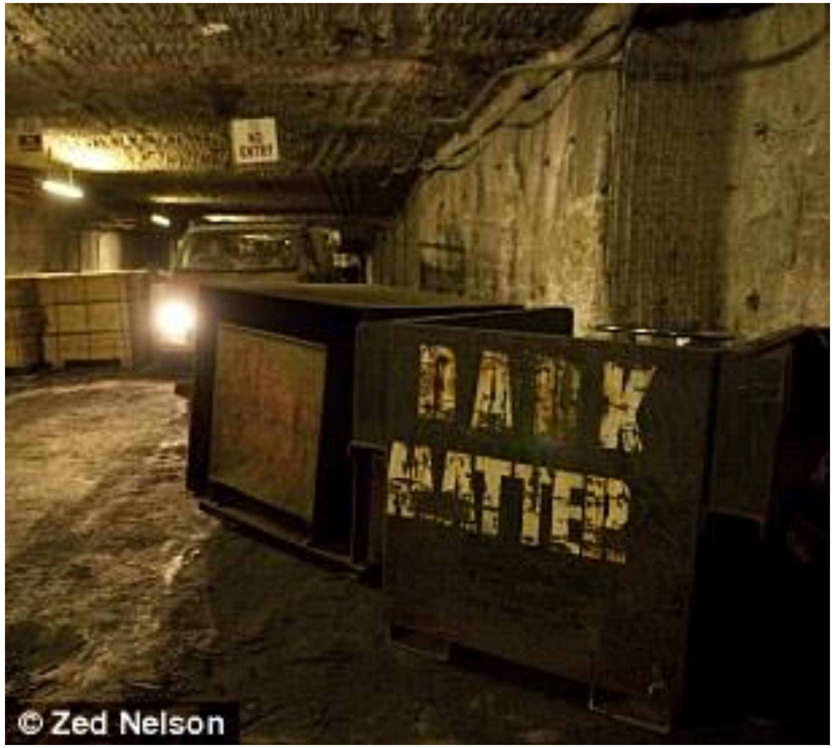


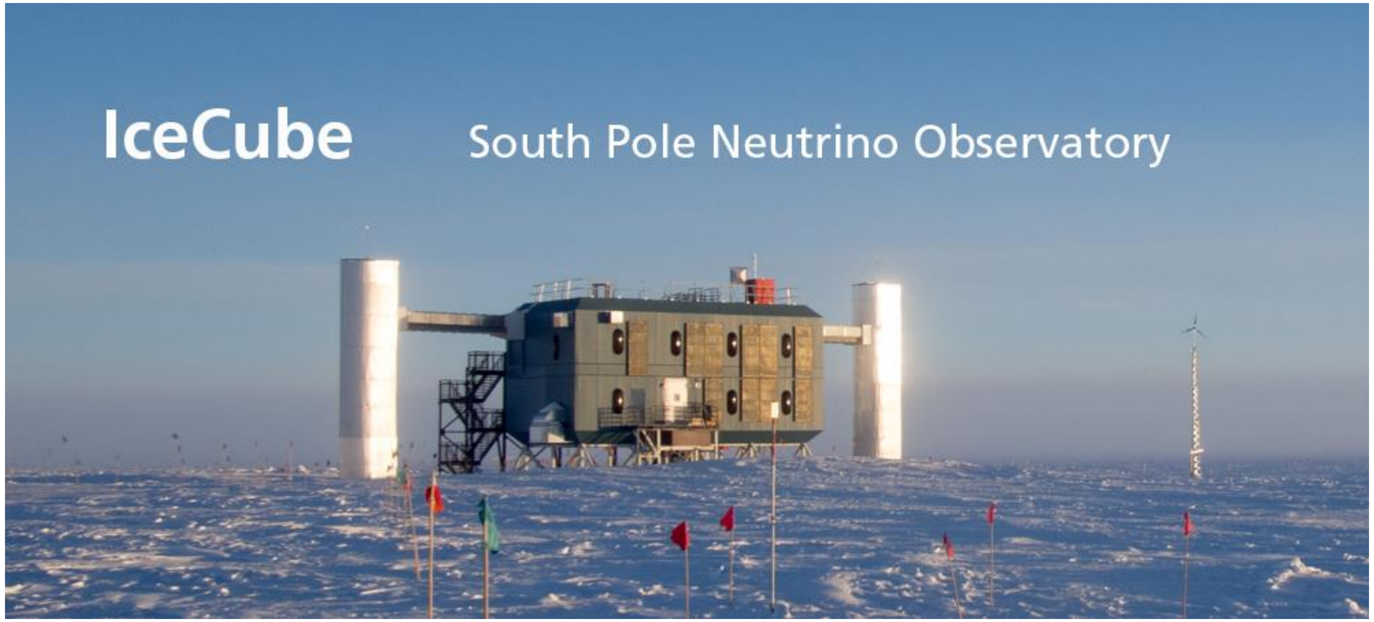
ARTEMIS simulations:
Gamma-rays from satellite galaxies

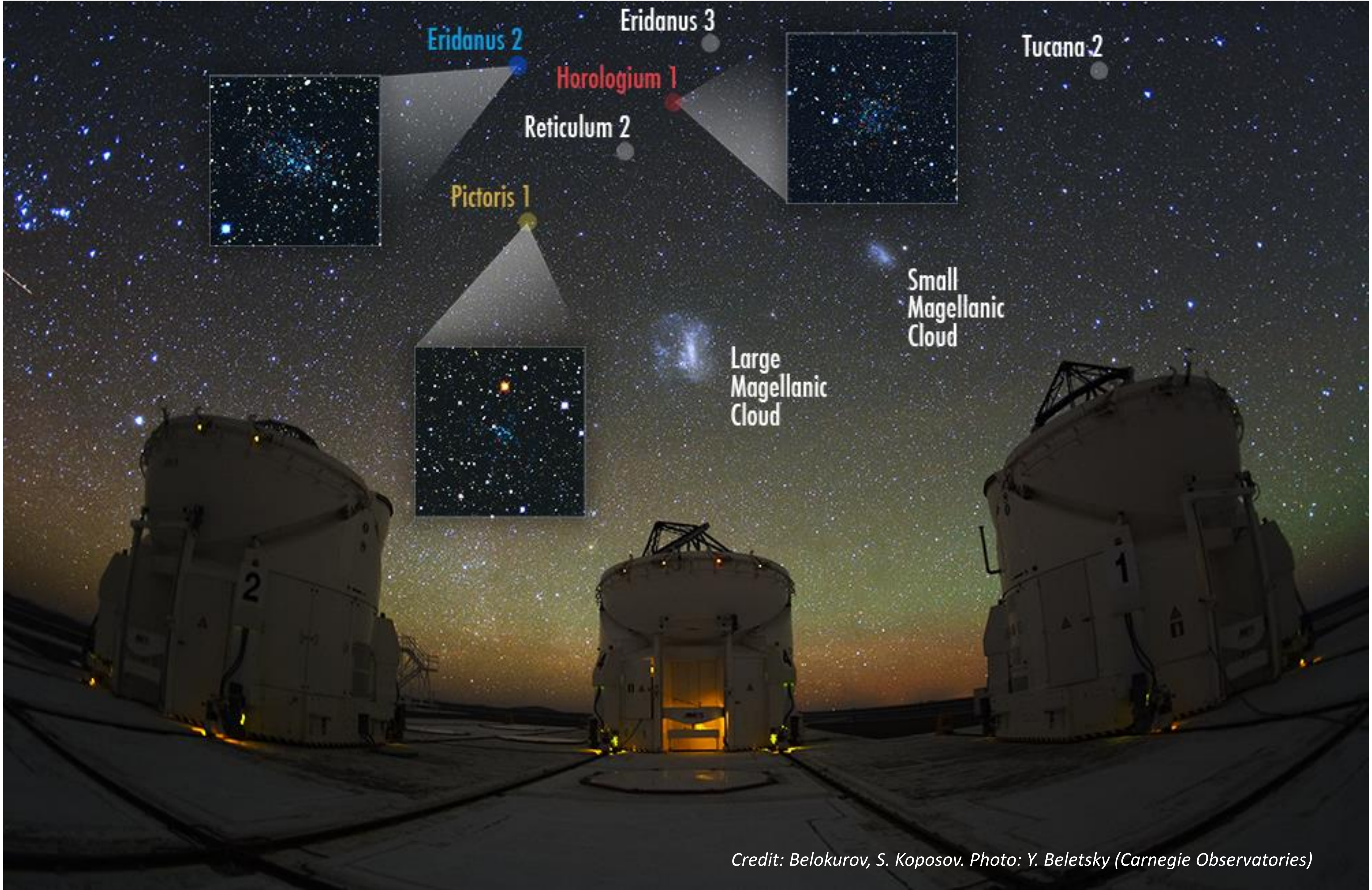
(Images: Rob Poole-Mckenzie)


Cryogenic Dark Matter Search (CMDS)


Electrons
Outgoing Particle
Incoming Particle
LUX-Zeplin (LZ)


DARK
MATTER
© Zed Nelson


IceCube
South Pole Neutrino Observatory


Eridanus 3
Eridanus 2
Horologium 1
Tucana 2
Reticulum 2
Pictoris 1
Small Magellanic Cloud
Large Magellanic Cloud
2
1
Credit: Belokurov, S. Koposov. Photo: Y. Beletsky (Carnegie Observatories)

COLD

WARM

C. Boehm et al. 2014

Conclusions

- The search for dark matter continues. There are many ongoing and planned experiments that may detect it.
- If WIMPs are not the answer, there are lots of theories for what dark matter might be. [Yours here?]
- Theory and experiment need to go hand in hand for final confirmation.
- Dark matter may end up to be something very simple. It will be great when we'll find it, but searching for it is also exciting!