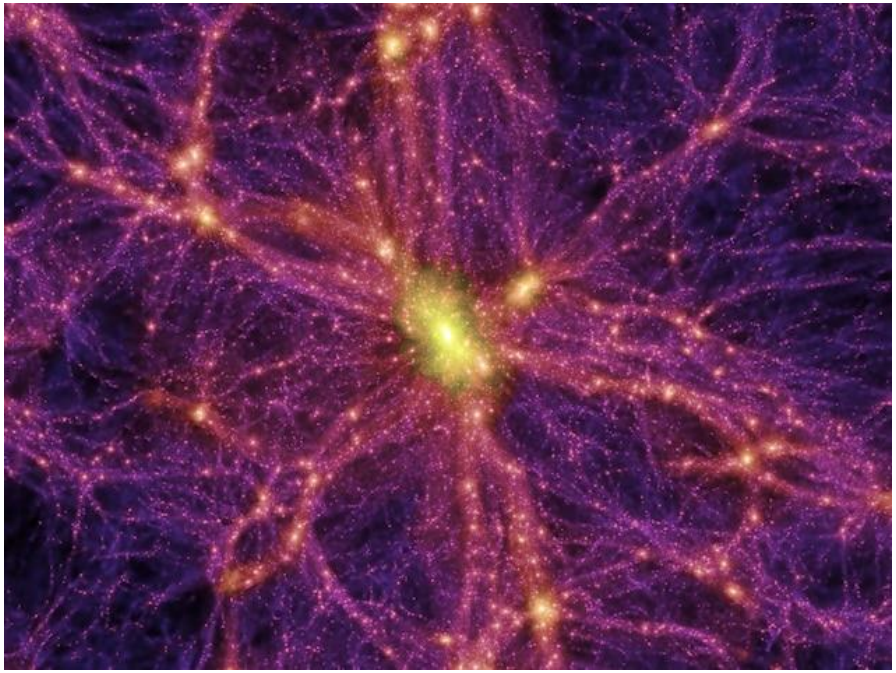
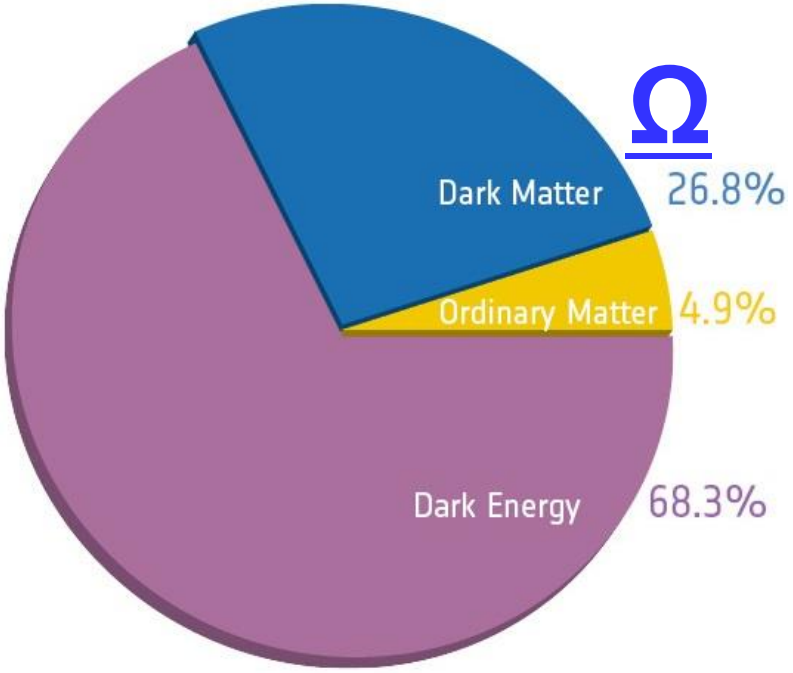
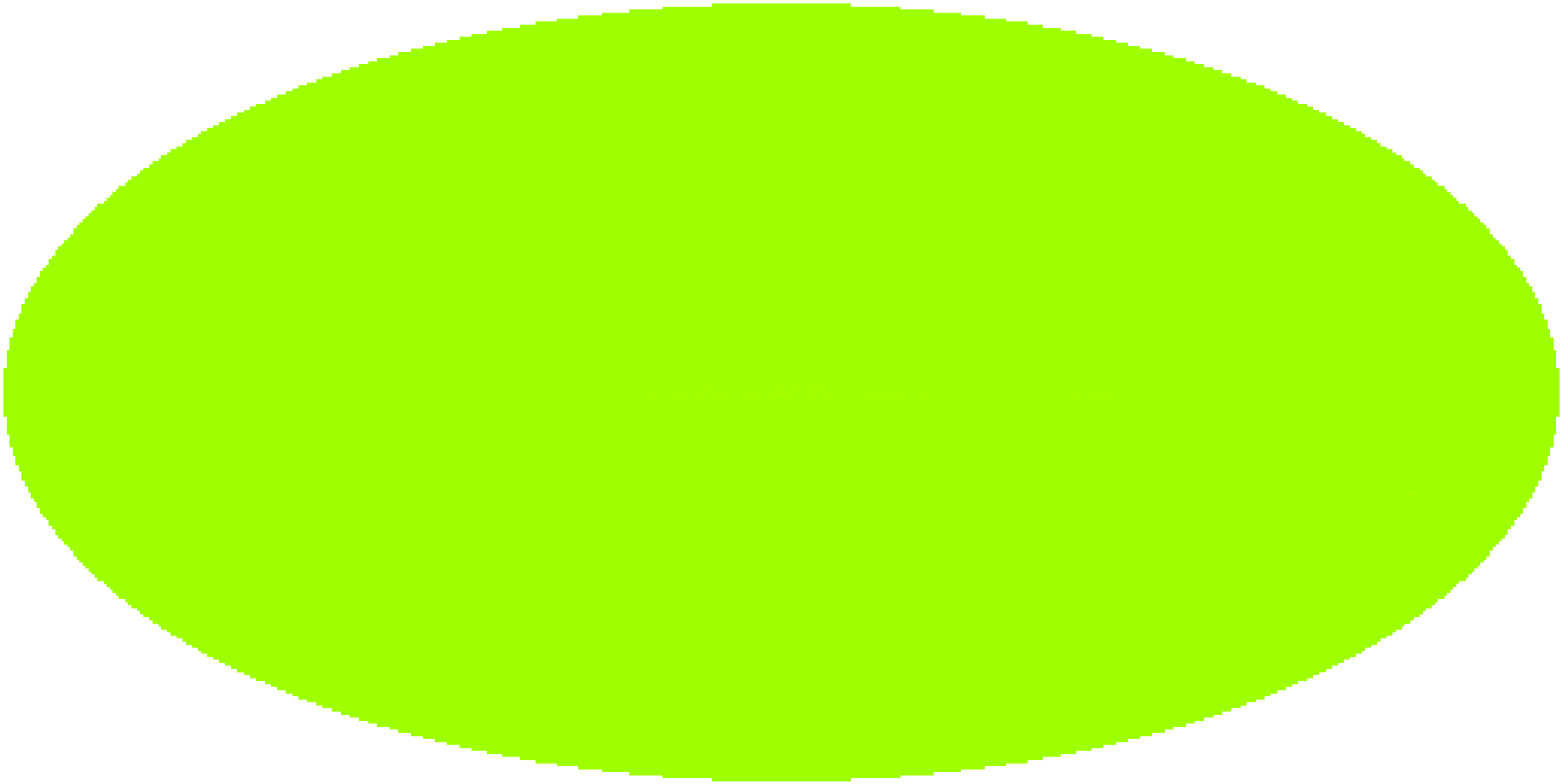
Nuclear & Particle Physics of Dark Matter

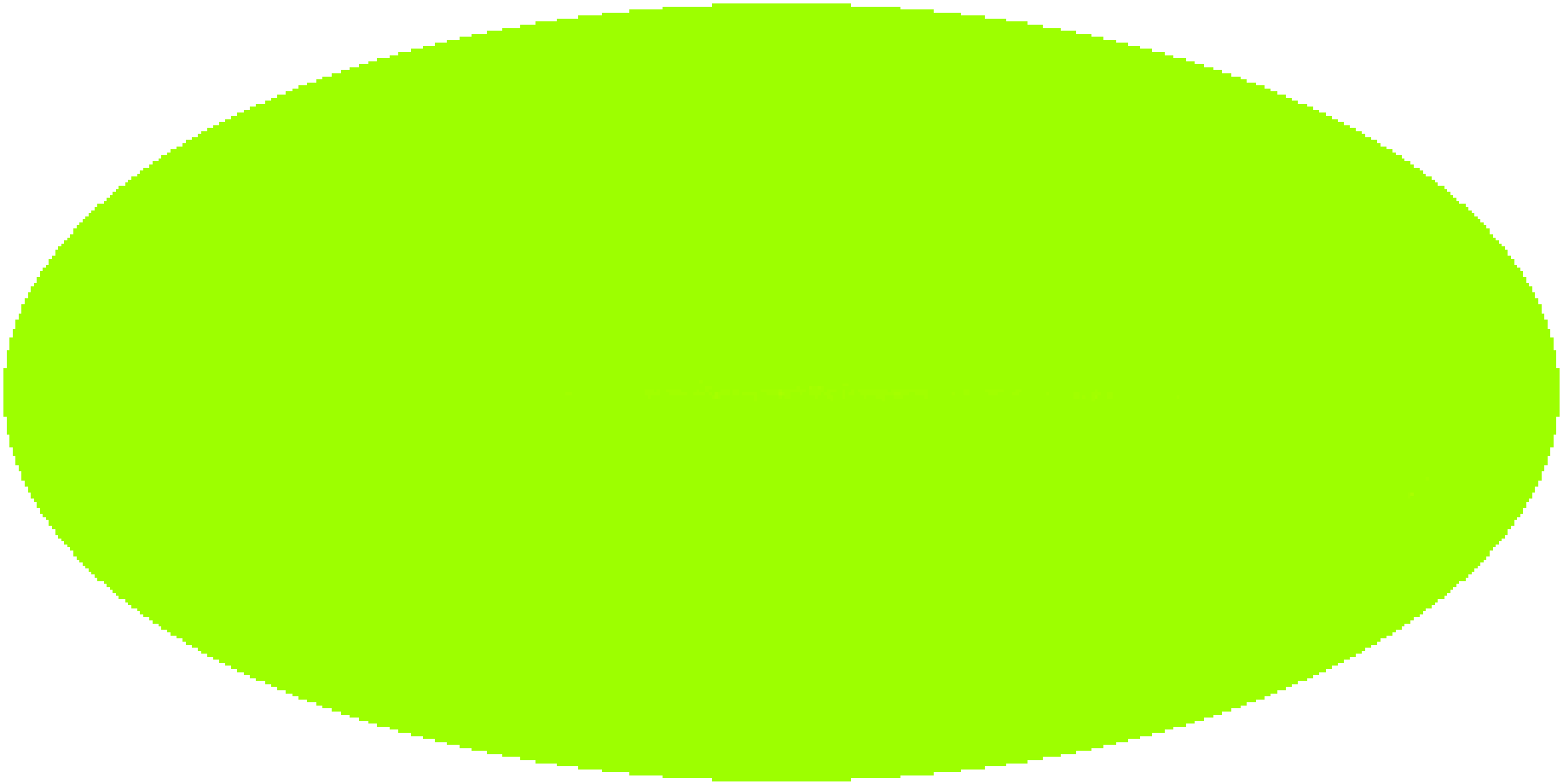
PHYS 441, April 23, 2026
Carter Hall





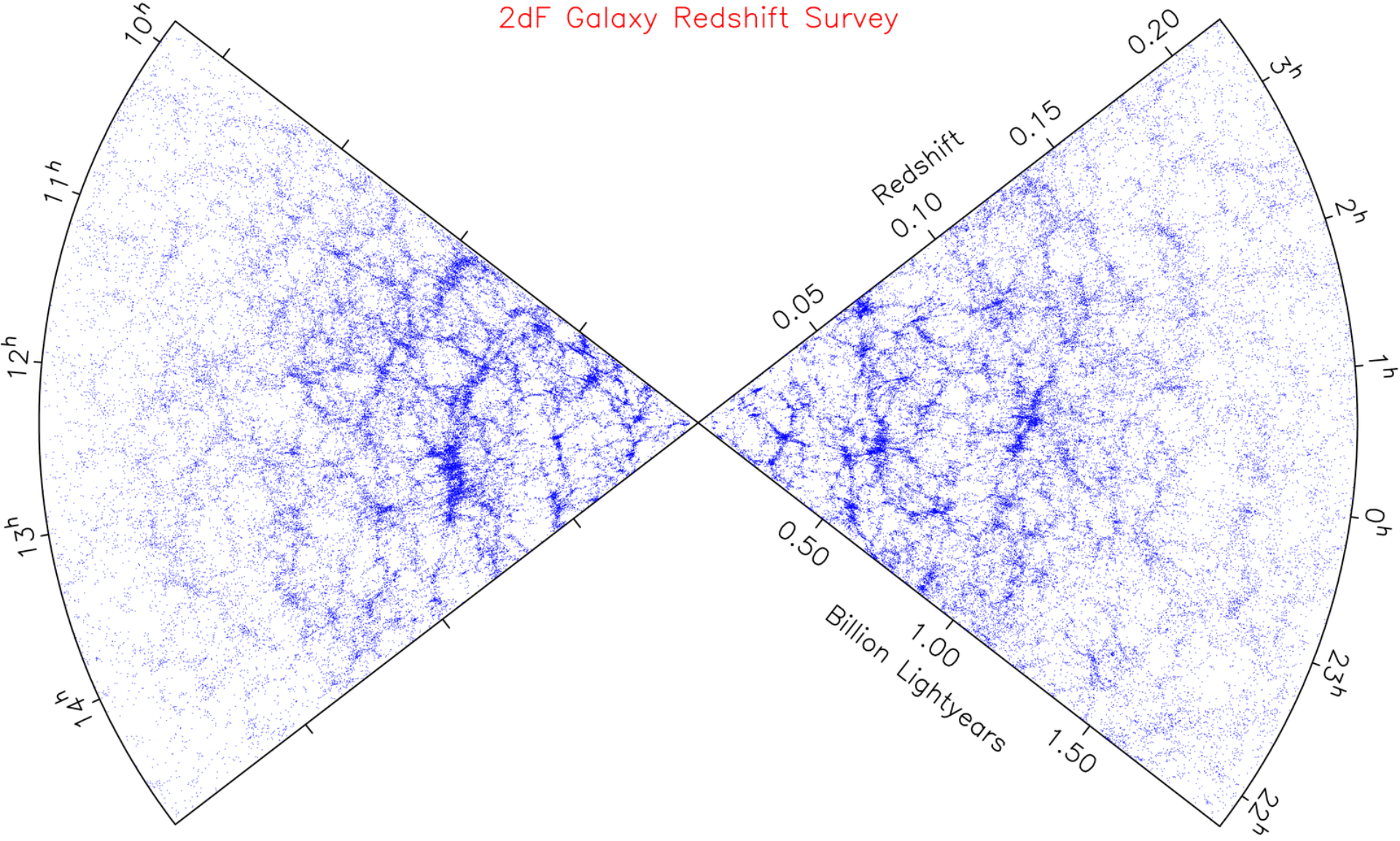


A picture of the universe 400,000 years after the big bang



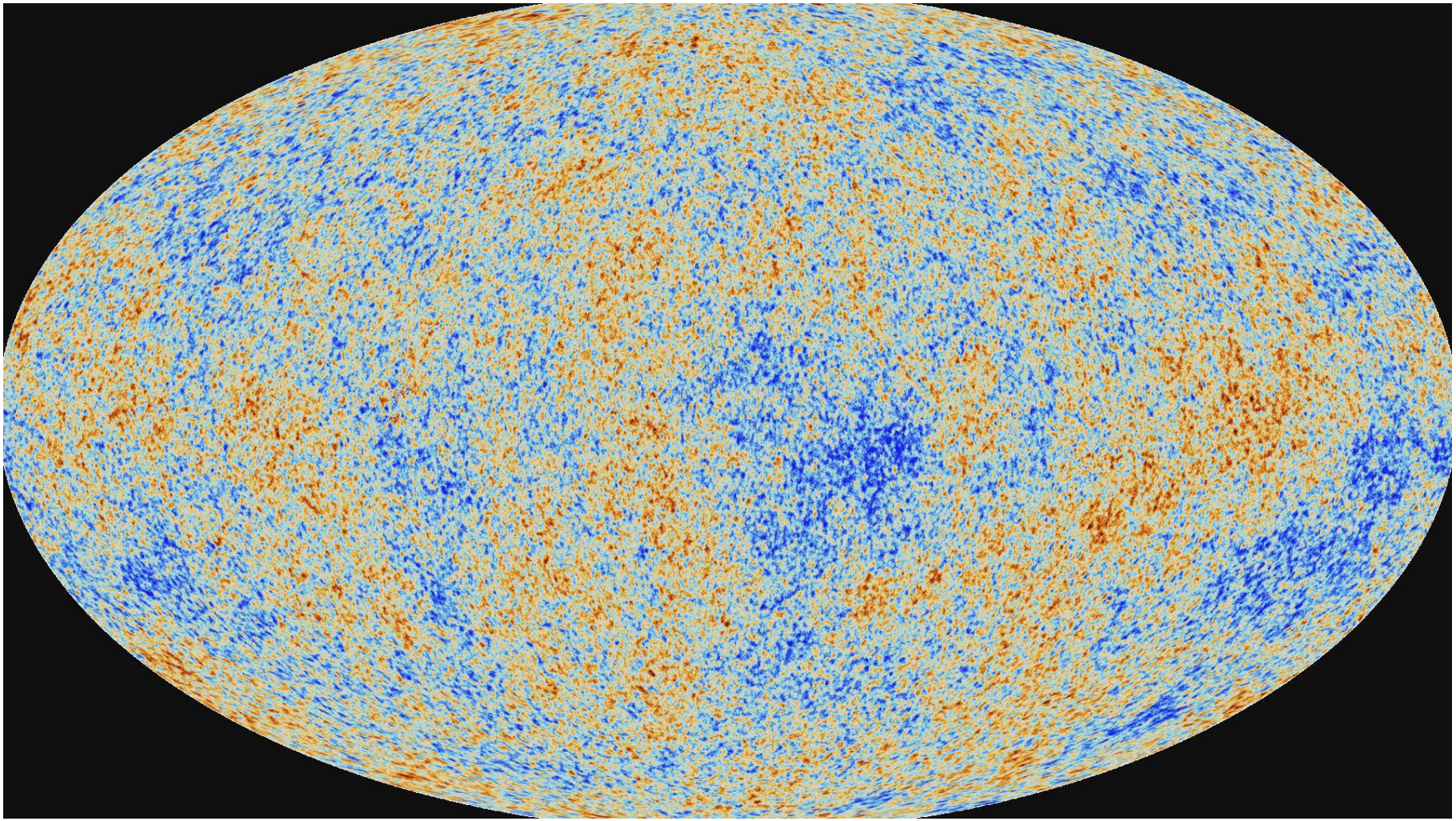
The cosmic microwave background isotropy as seen by Planck (no contrast enhancement).

A picture of the universe as it appears today.



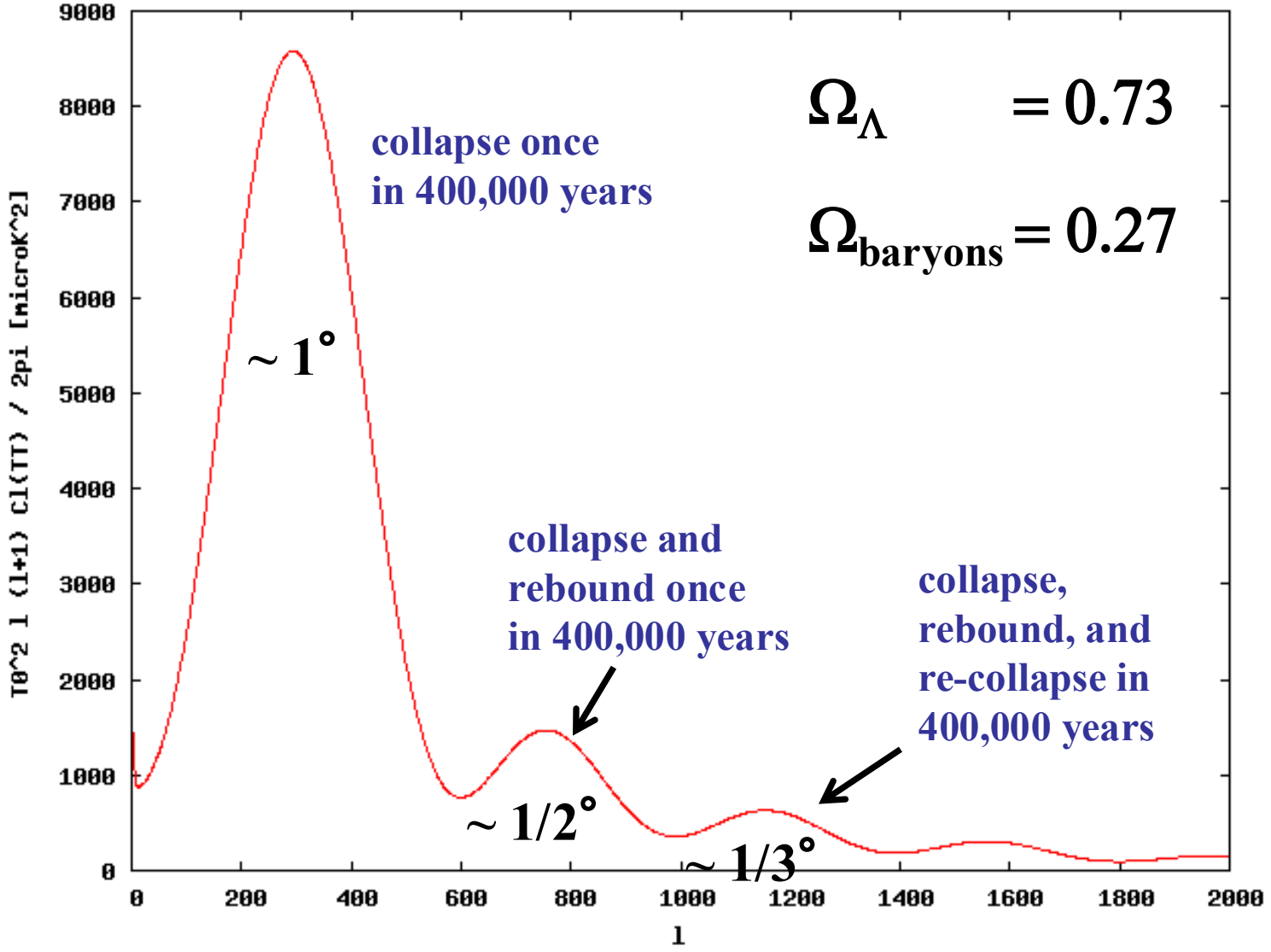
Each dot is a galaxy with hundreds of billions of stars.

A picture of the universe 400,000 years after the big bang

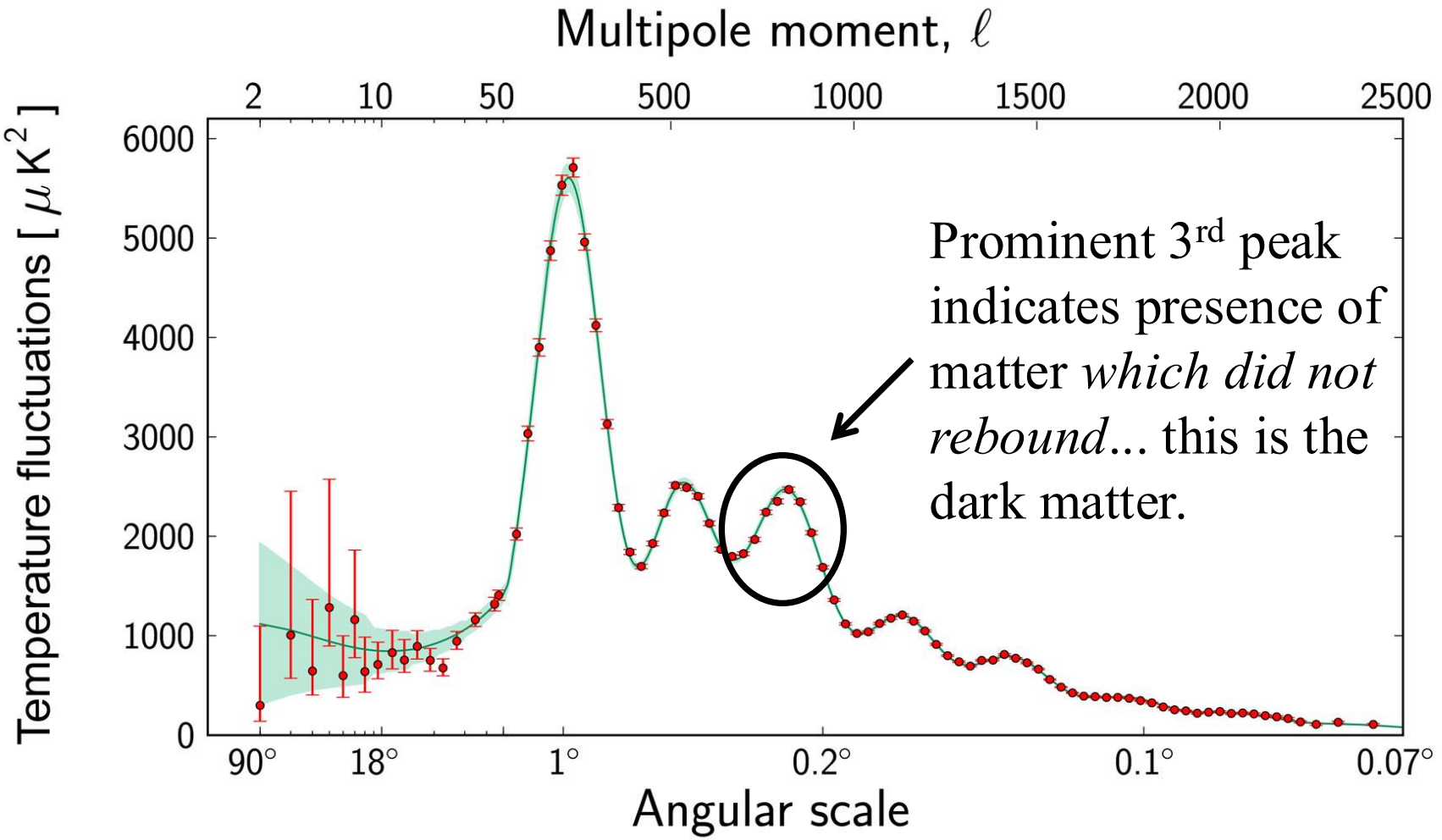


The cosmic microwave background **anisotropy** (Planck data)
Contrast enhancement of ~10^5.

In a universe with no dark matter – CMB multipole expansion



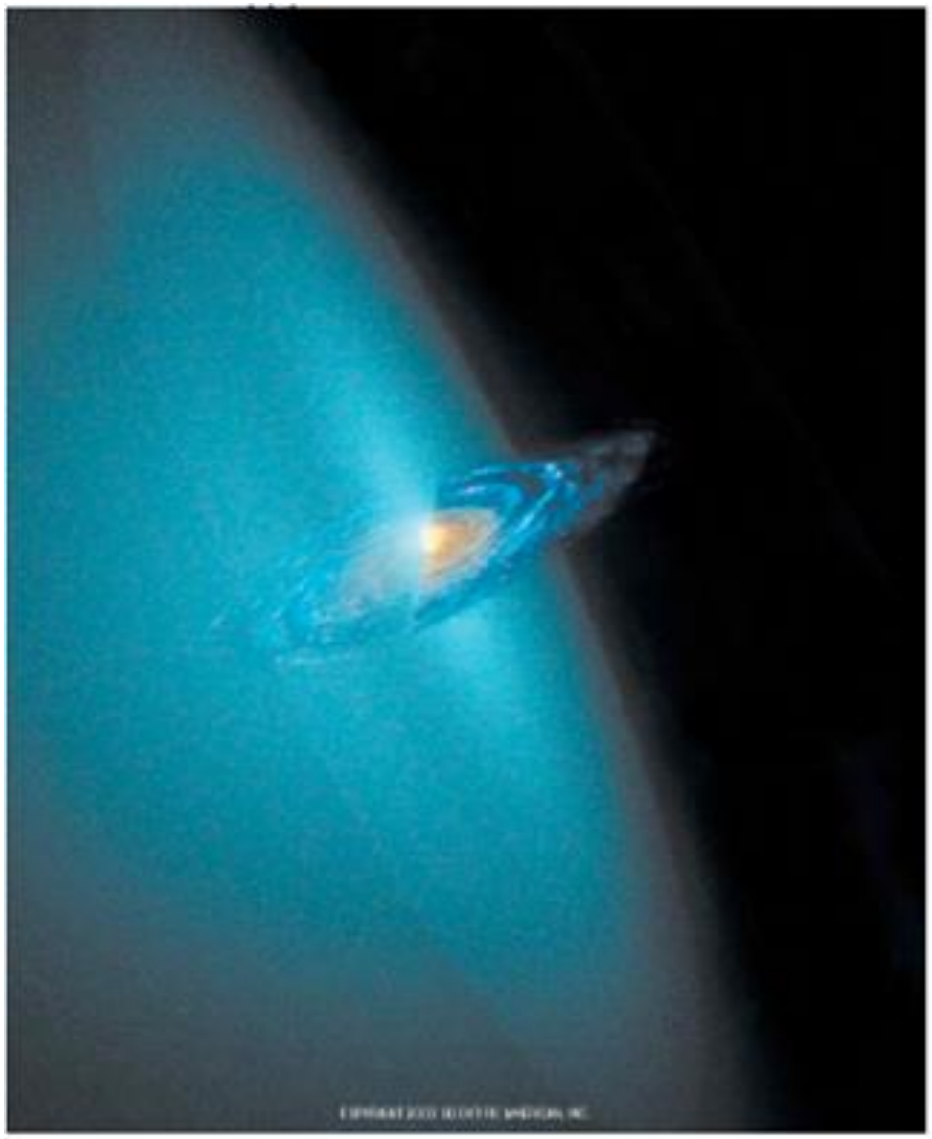
CMB multipole expansion as measured by Planck

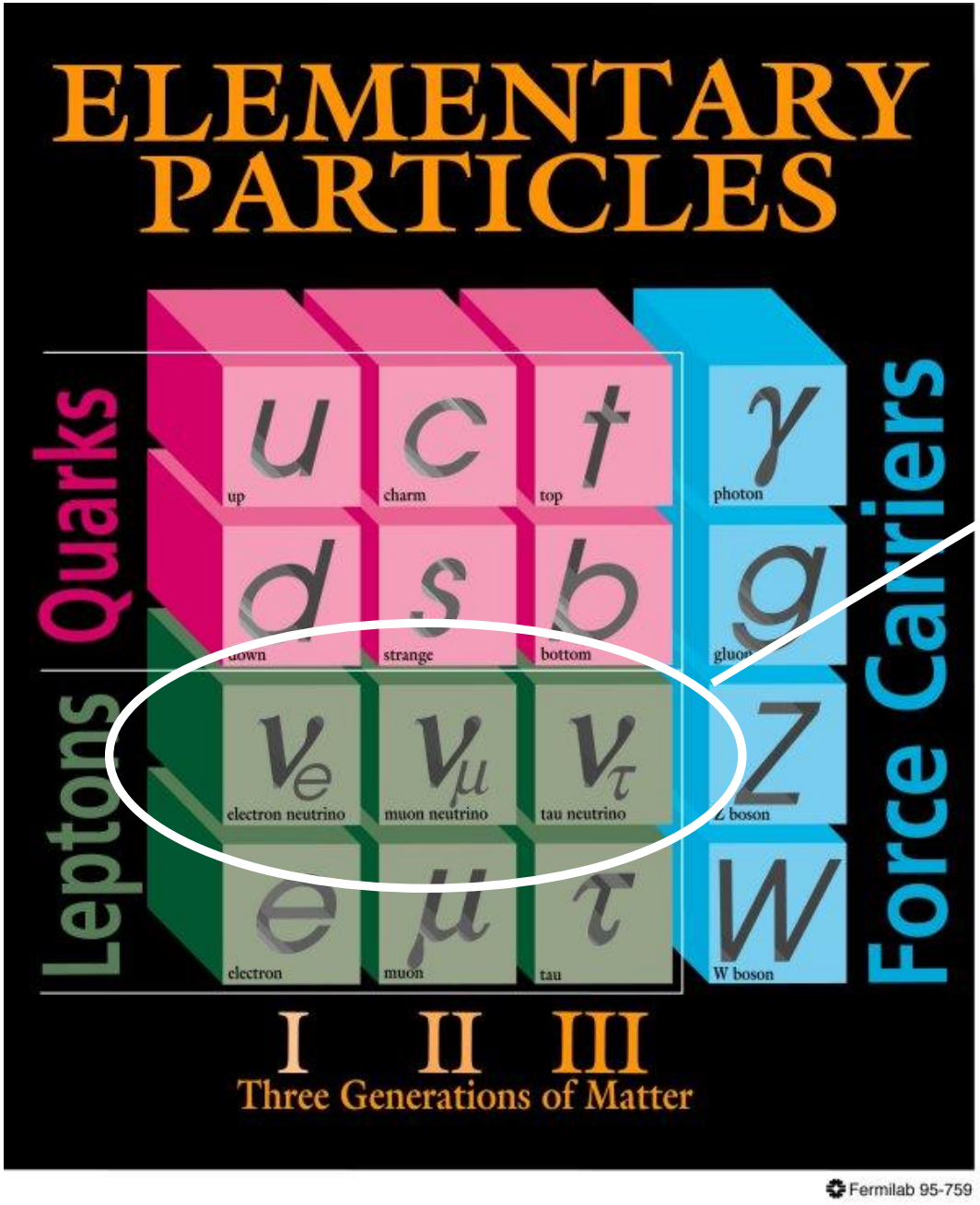


The Milky Way's dark matter halo

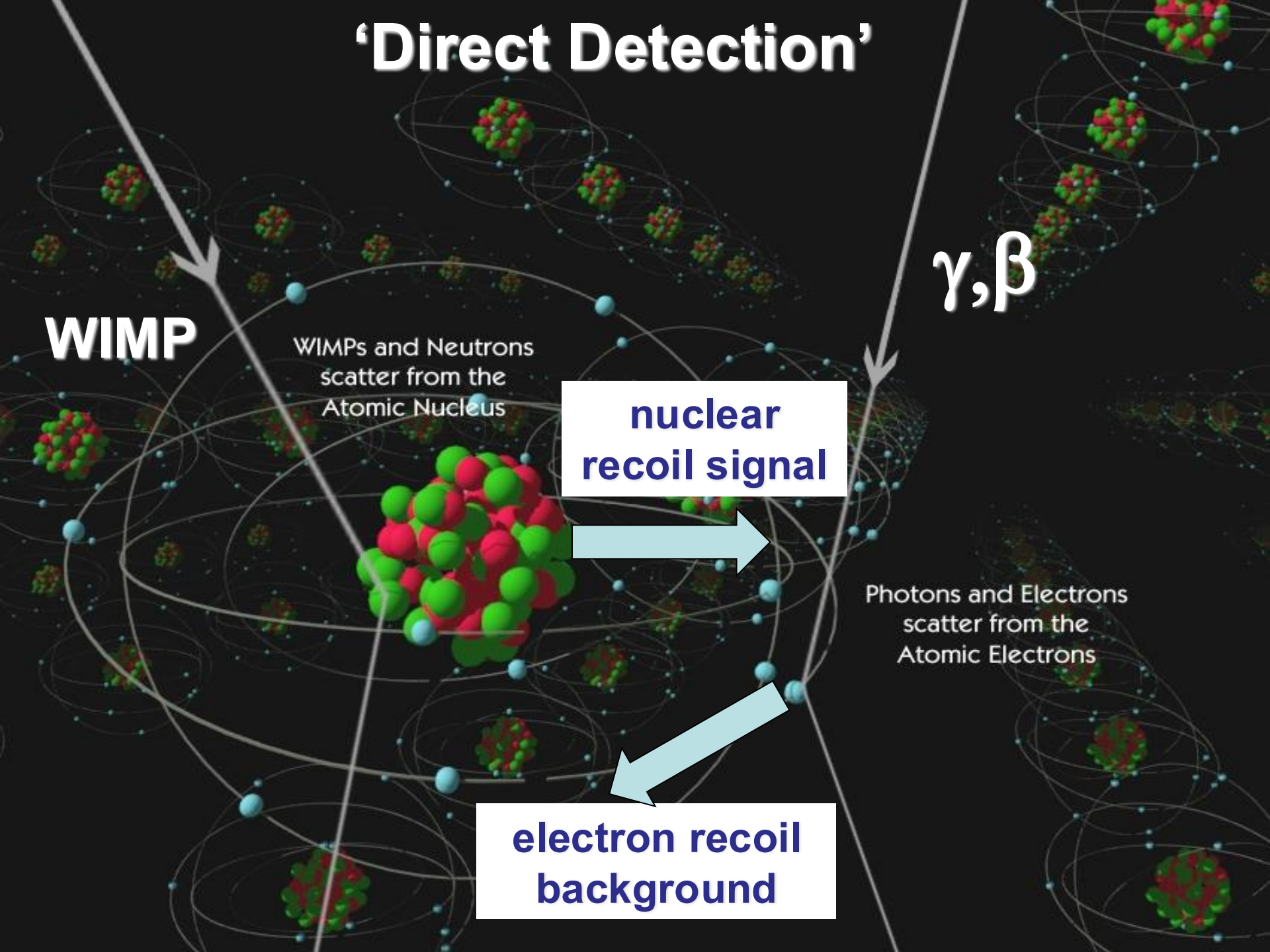
- Typical orbital vel. = 230 km/sec
  ~ 0.1% speed of light

- Density: ~ 300 m_{proton} / liter

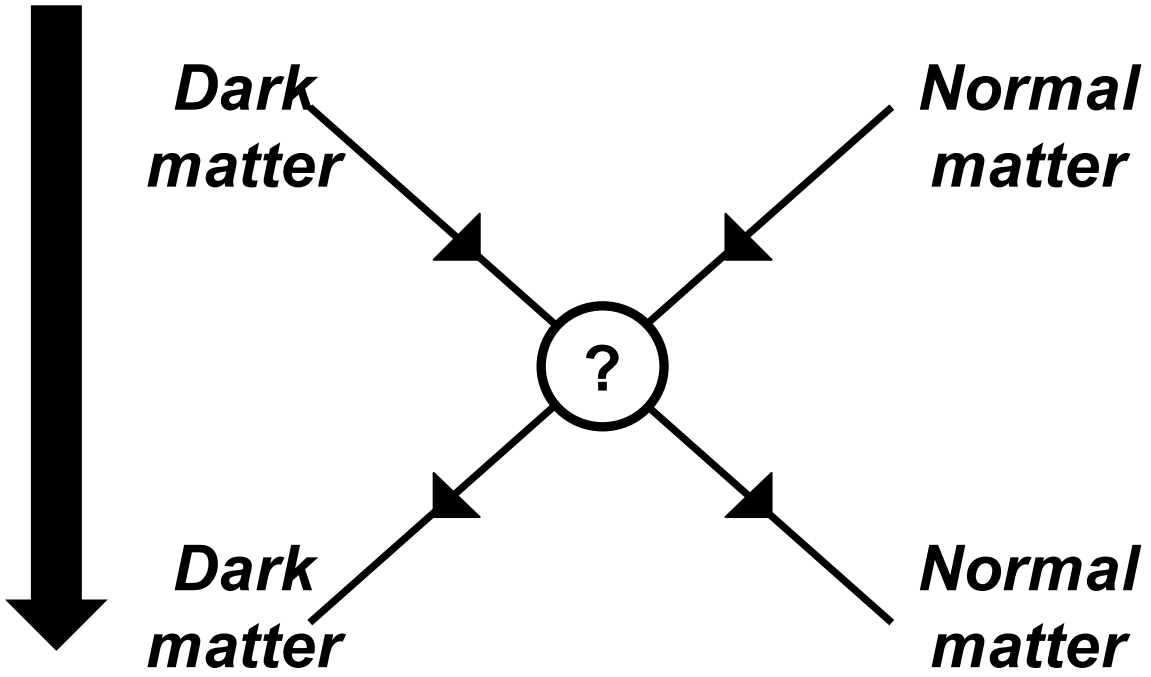




Neutrinos? – Seem to be too light

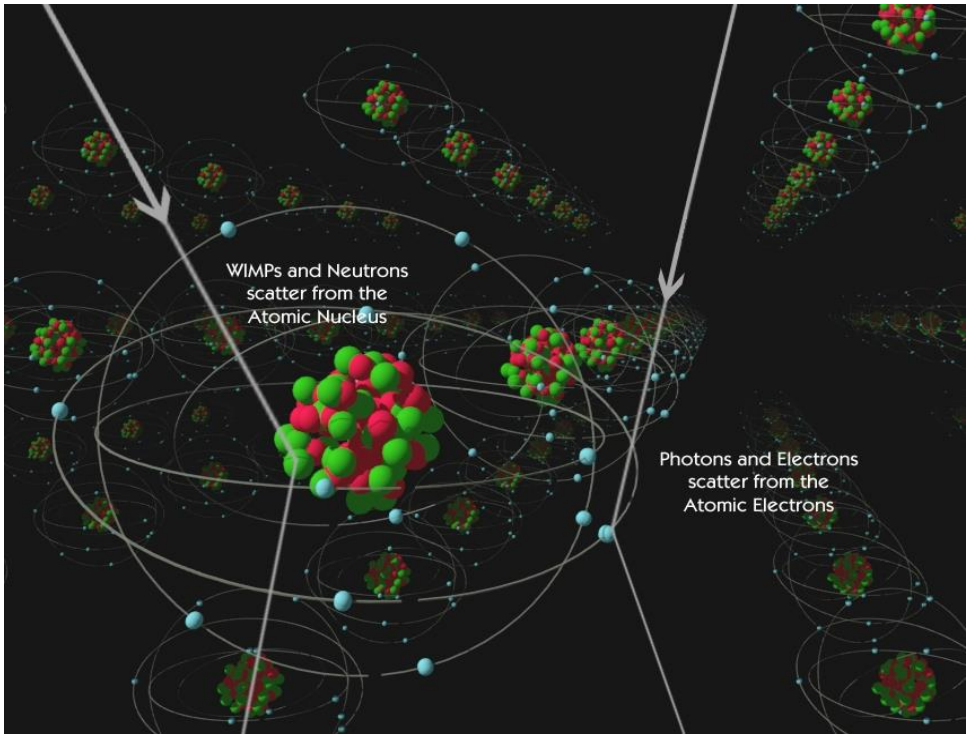

‘Direct Detection’
WIMP
γ,β
WIMPs and Neutrons scatter from the Atomic Nucleus
nuclear recoil signal
Photons and Electrons scatter from the Atomic Electrons
electron recoil background

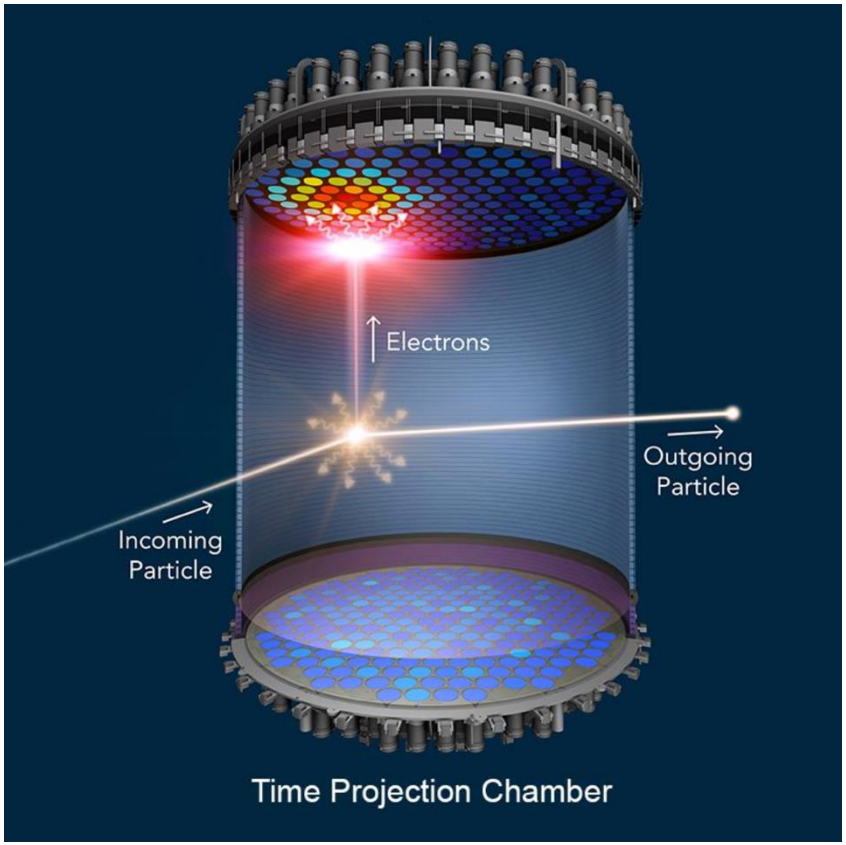
'Direct detection'



Cross section of ????

A WIMP search with 10 tonnes of Liquid Xenon

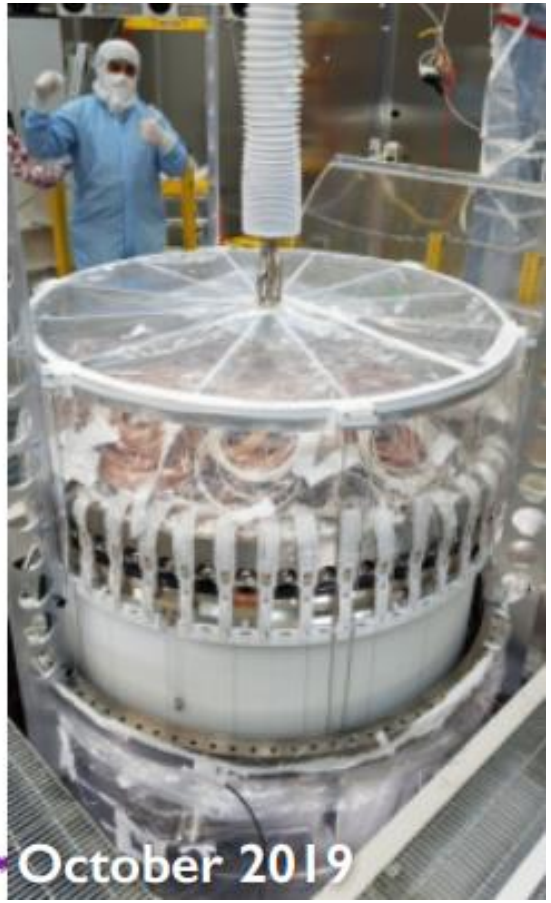




Search for anomalous low-energy nuclear recoils

Requirements: large target mass + low energy threshold + background control.

Xenon Detector Surface Assembly



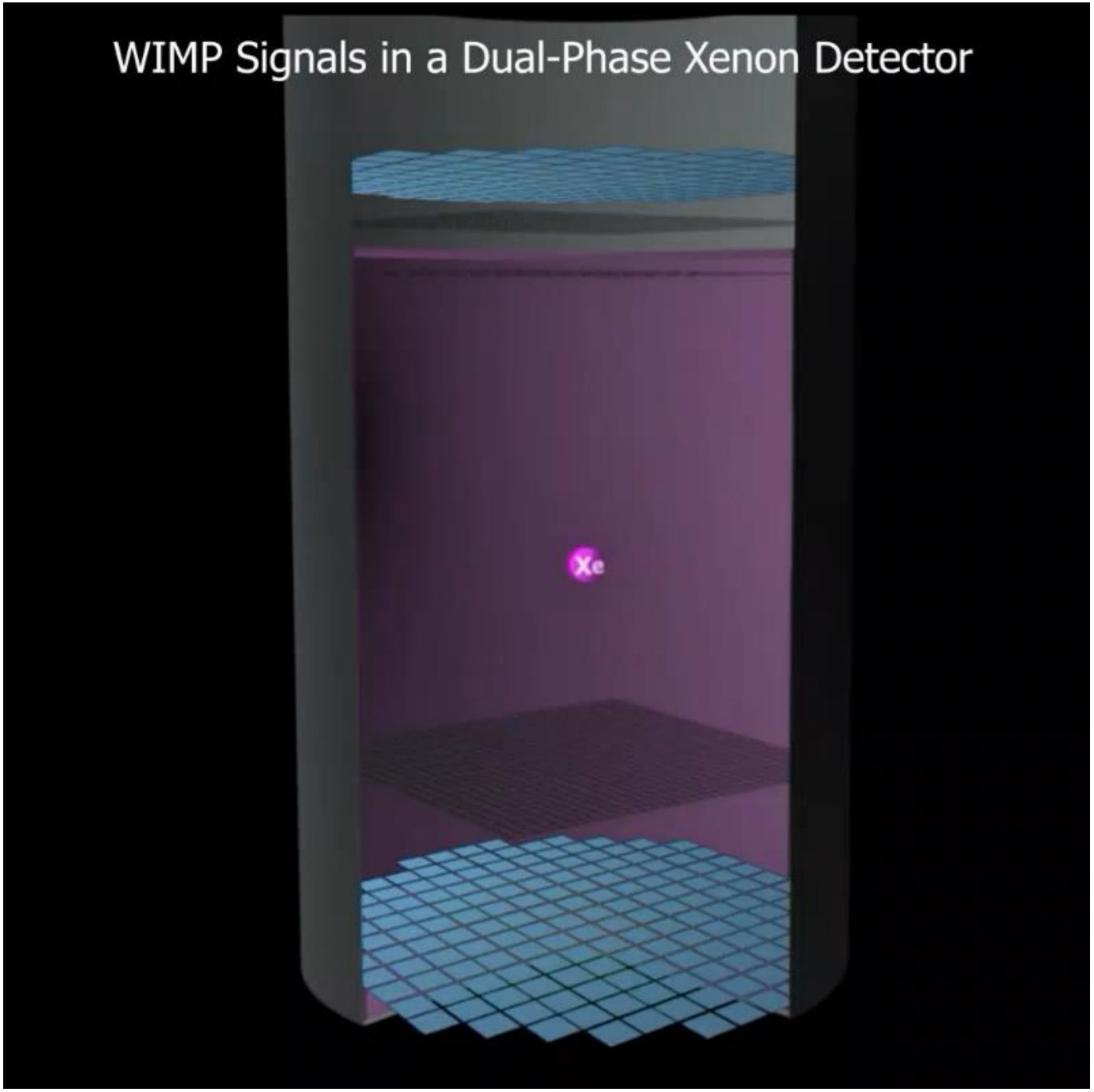
Sanford Underground Research Facility

Davis Cavern 1480 m
(4200 mwe)
Lead, South Dakota

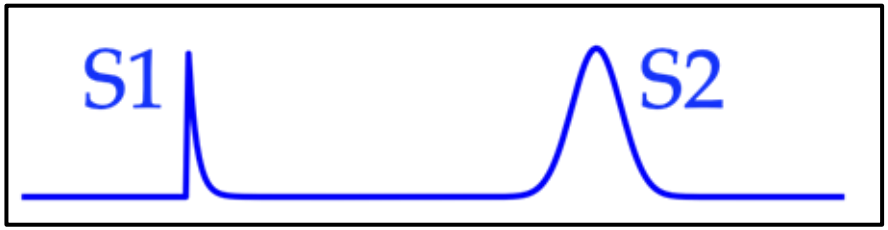
Closing Up

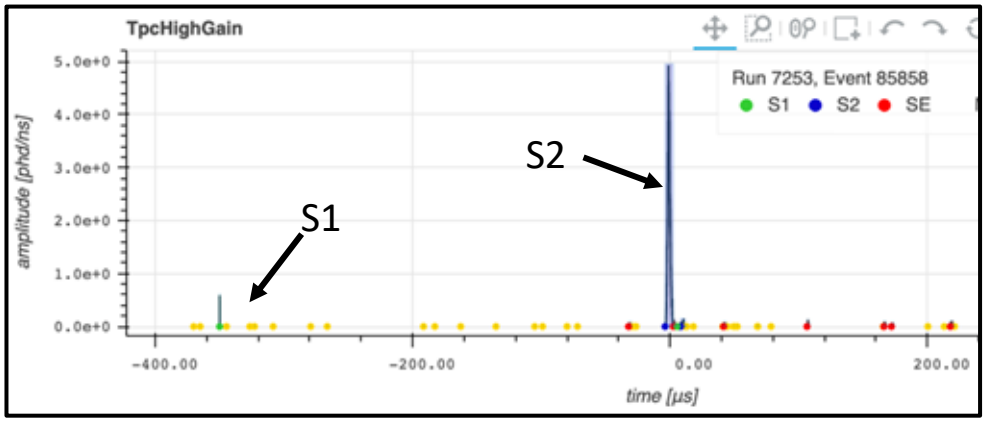
Lower inner cryostat vessel into outer cryostat vessel

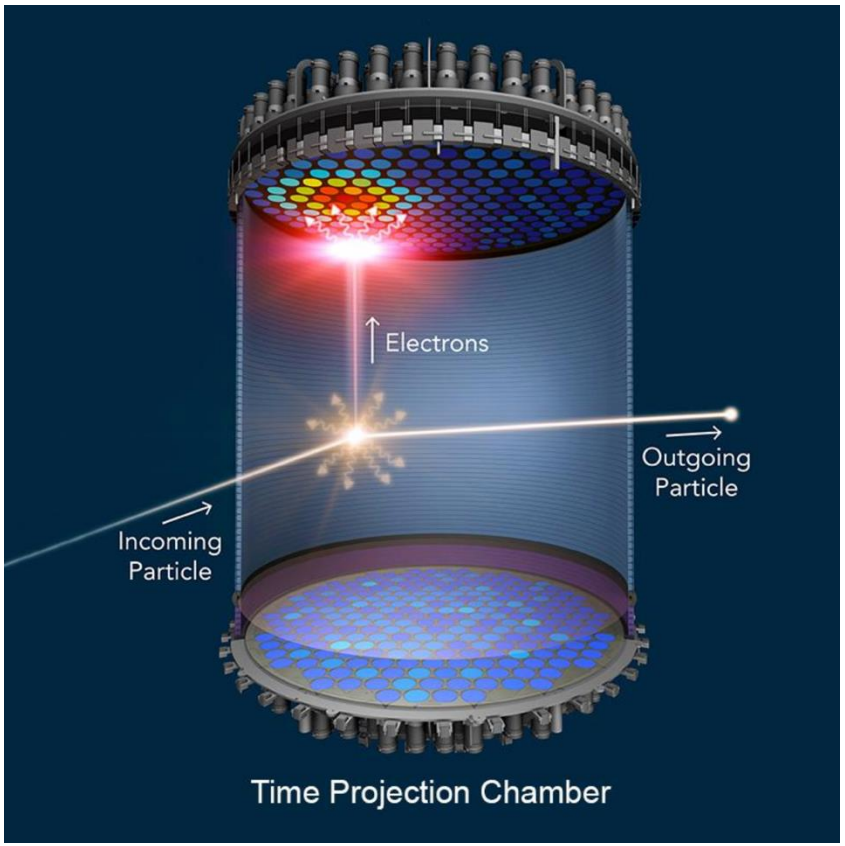
Making up cathode connections (under N2 purge)


WIMP Signals in a Dual-Phase Xenon Detector
Xe

A WIMP search with 10 tonnes of Liquid Xenon



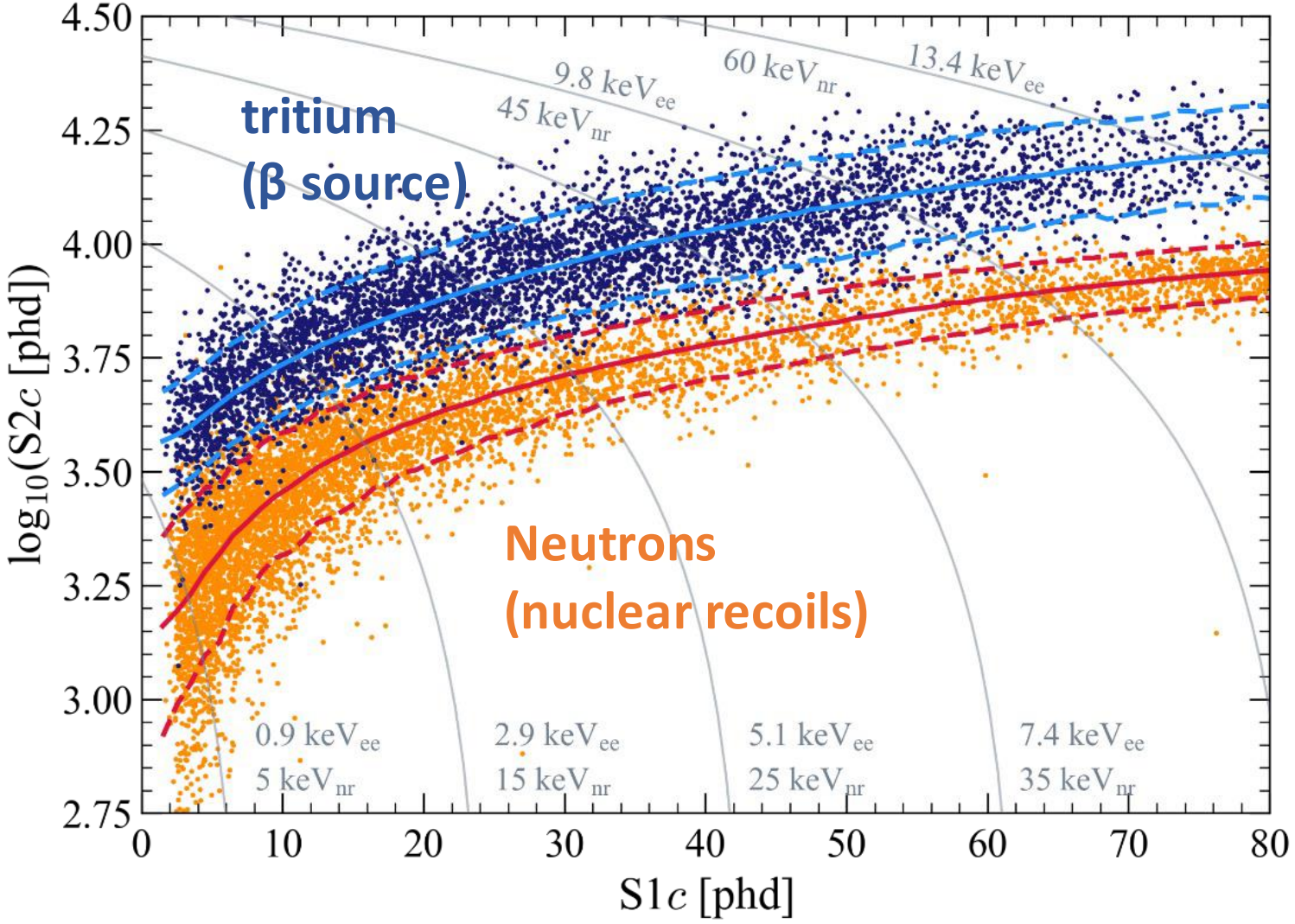


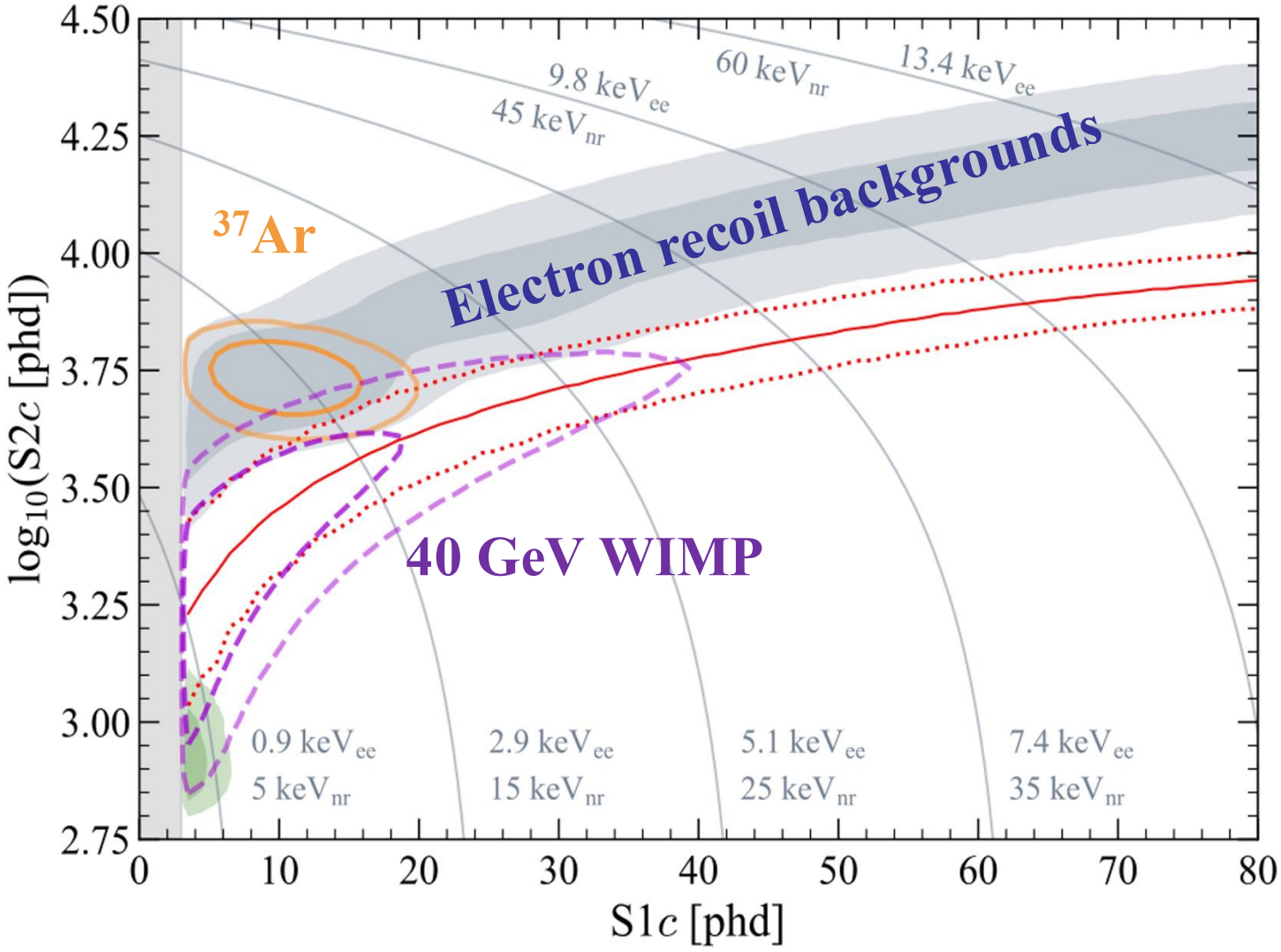


Search for anomalous low-energy nuclear recoils

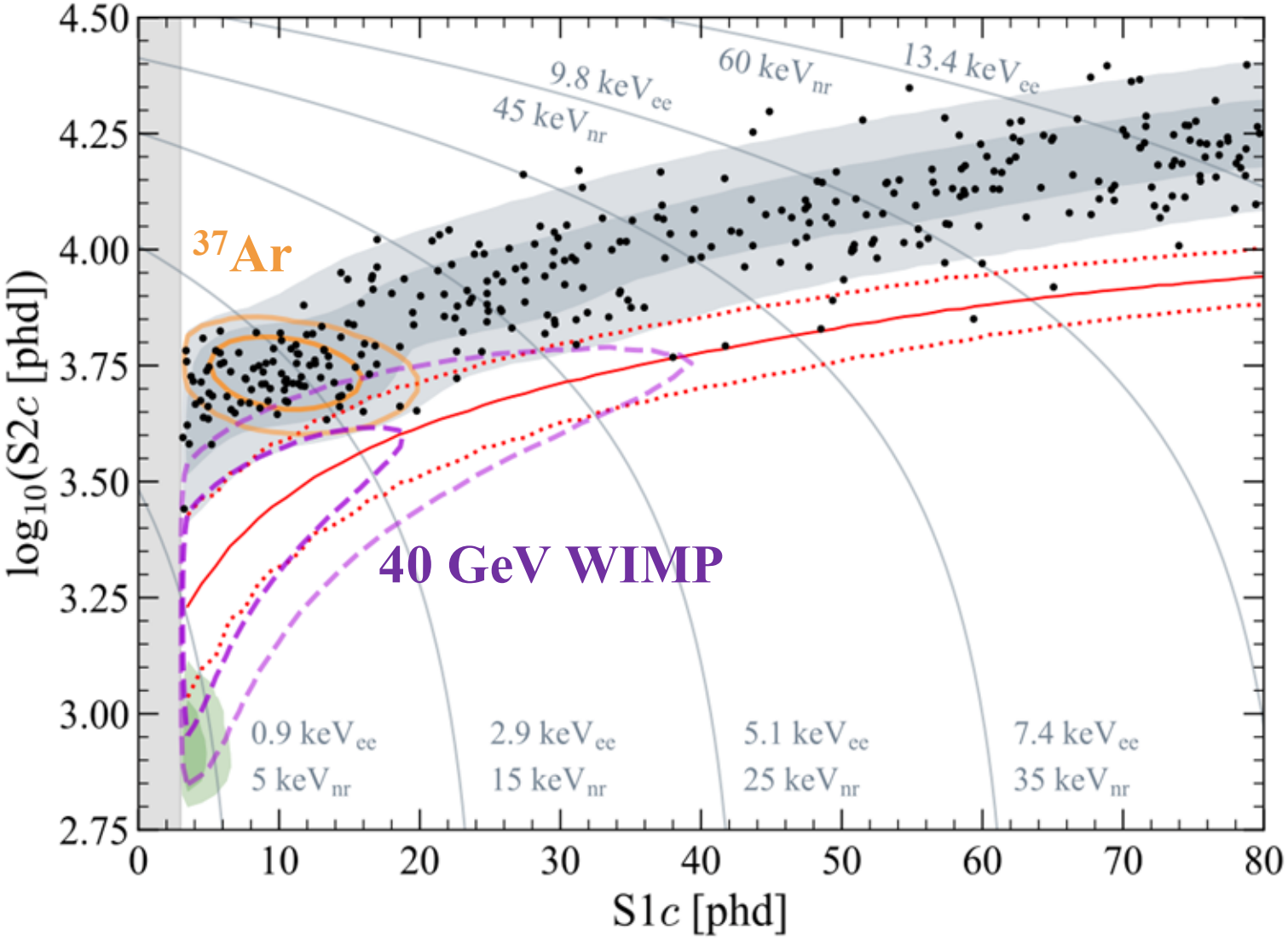
Requirements: large target mass + low energy threshold + background control.

LZ calibration data – April 2022

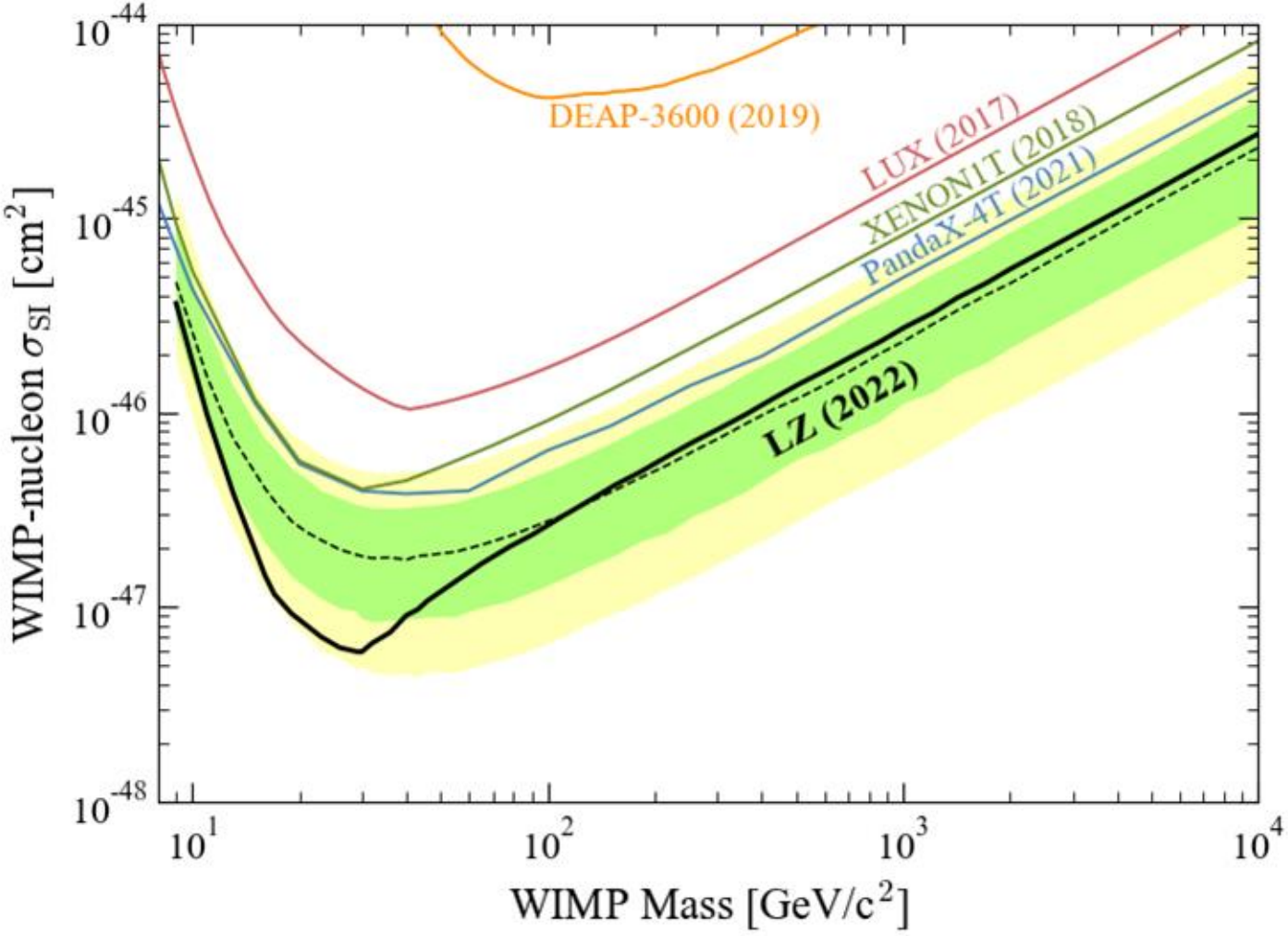


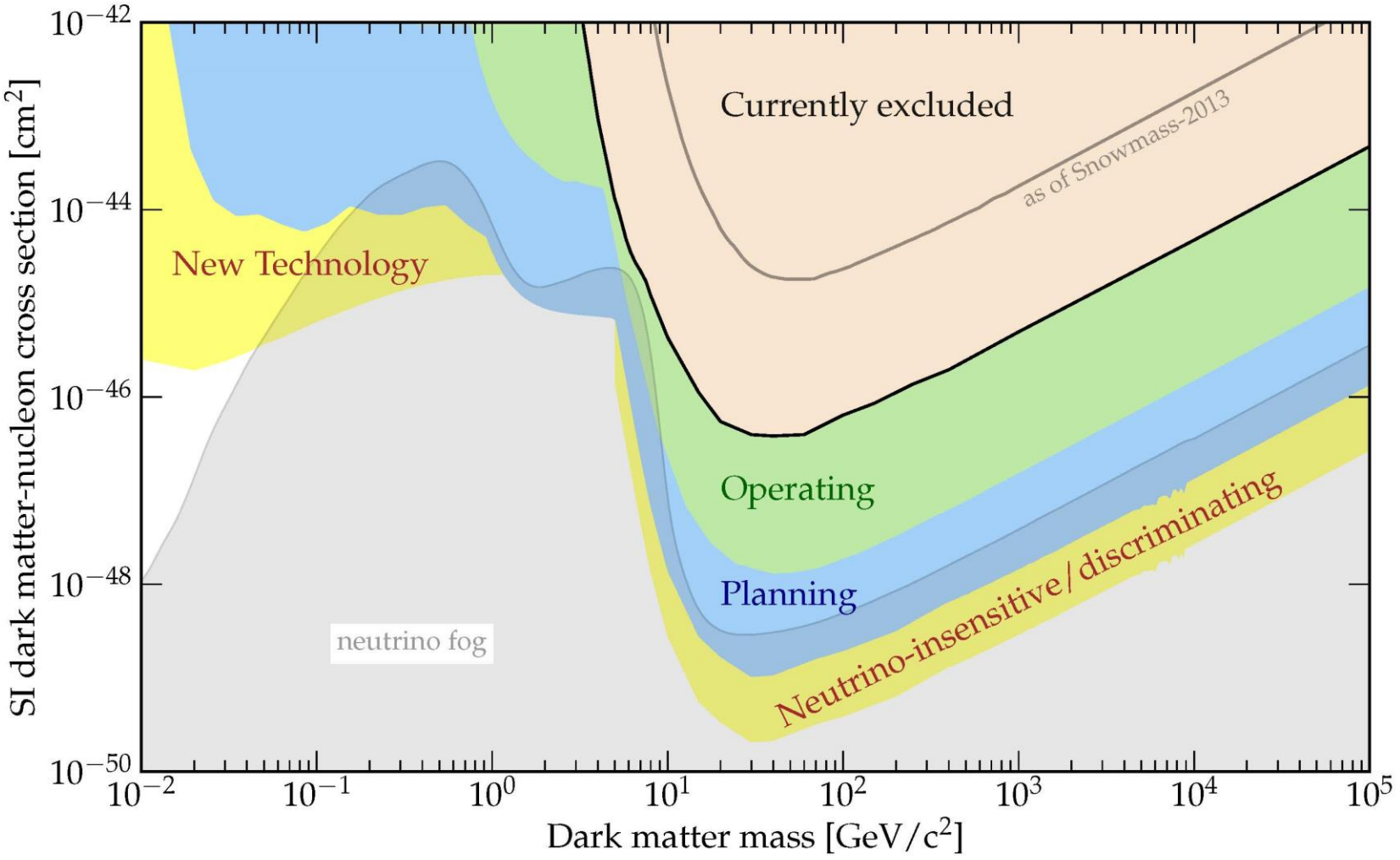

4.50
4.25
4.00
3.75
3.50
3.25
3.00
2.75
0
10
20
30
40
50
60
70
80
log10(S2c [phd])
S1c [phd]
9.8 keVee
45 keVnr
60 keVnr
13.4 keVee
37Ar
Electron recoil backgrounds
40 GeV WIMP
0.9 keVee
5 keVnr
2.9 keVee
15 keVnr
5.1 keVee
25 keVnr
7.4 keVee
35 keVnr

LZ WIMP Search Data – 60 days
Final Event Selection – 335 events

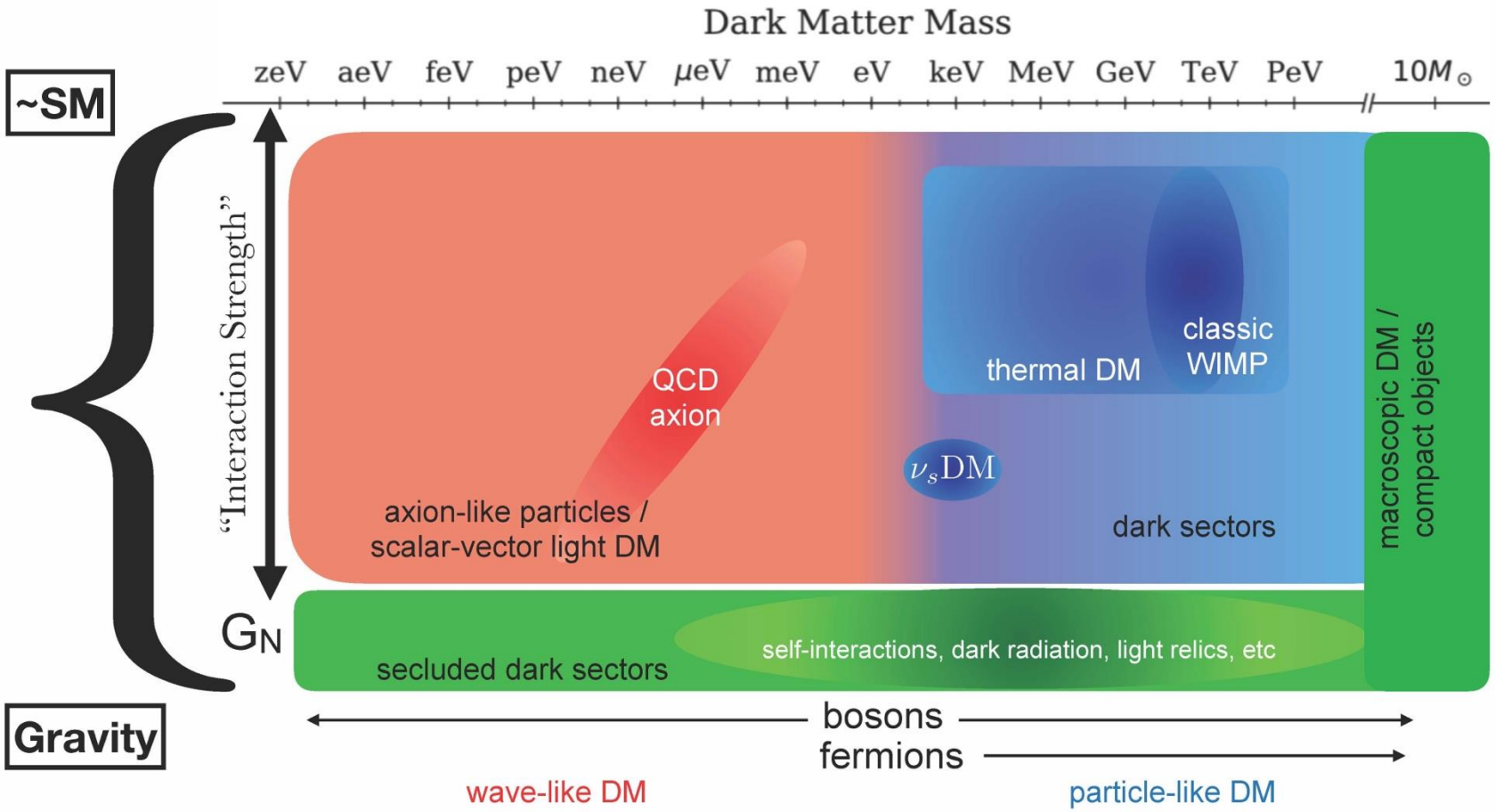


LZ WIMP Limit
60 days – July 2022



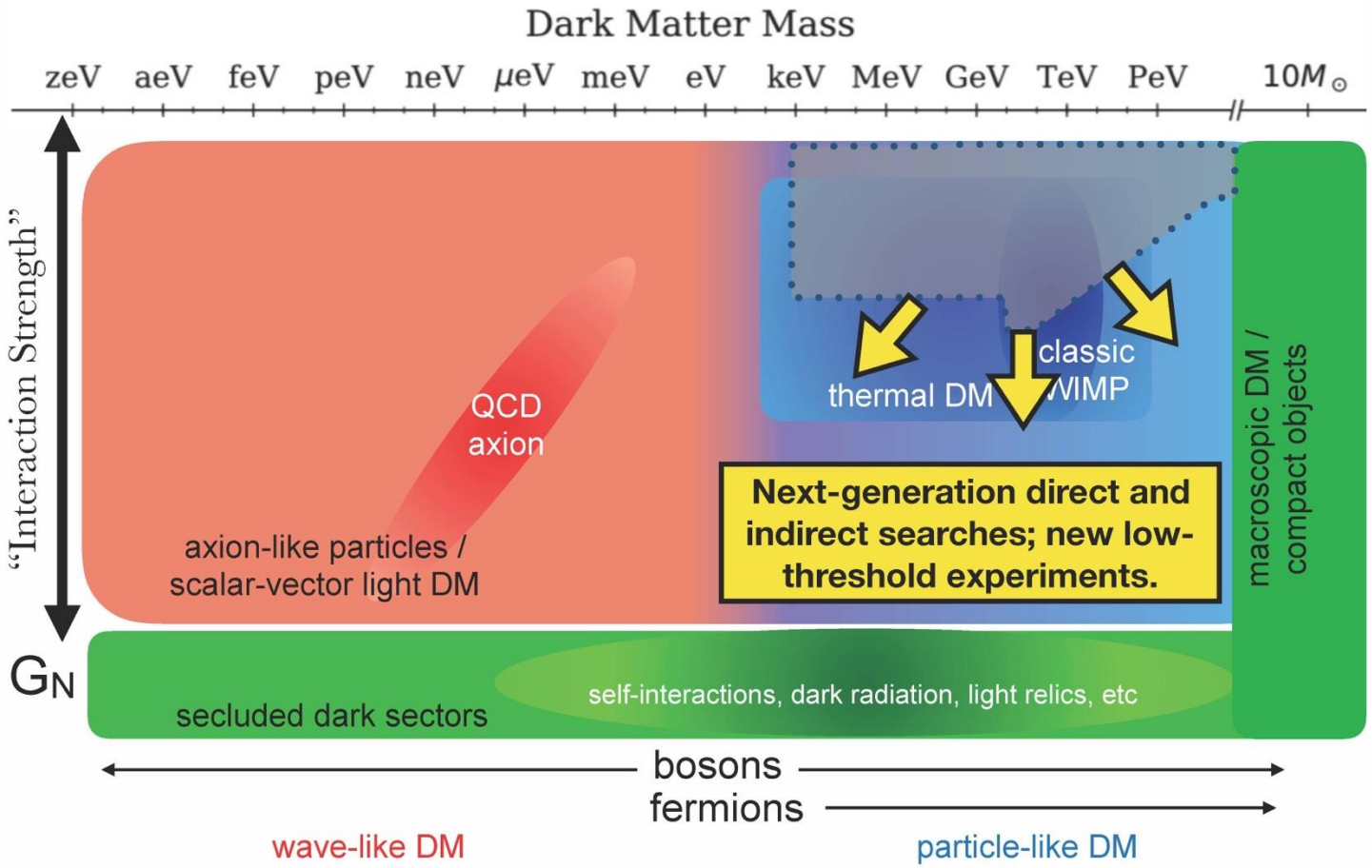

Currently excluded
as of Snowmass-2013
New Technology
Operating
Planning
Neutrino-insensitive/discriminating
neutrino fog
SI dark matter-nucleon cross section [cm^2]
Dark matter mass [GeV/c^2]
10^{-42}
10^{-44}
10^{-46}
10^{-48}
10^{-50}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}
10^{5}

Possible interaction strengths range from the scale of the standard model to the scale of gravity

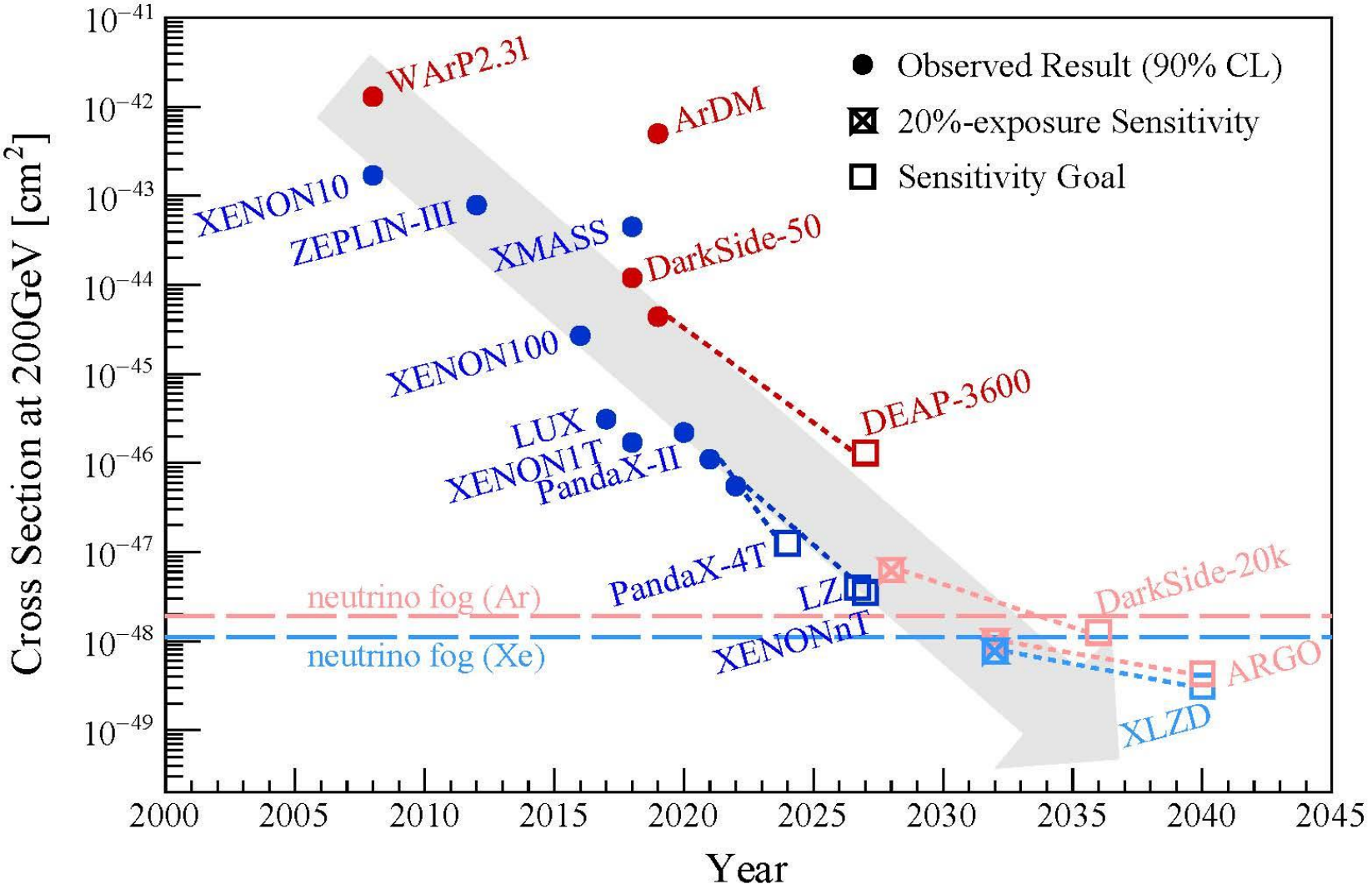


Aaron Chou, Snowmass 2022

Above ~1 eV, use sensitive detectors to search for the scattering, absorption, decay, and annihilation of particle DM



Aaron Chou, Snowmass 2022


Observed Result (90% CL)
20%-exposure Sensitivity
Sensitivity Goal
WArP2.3l
ArDM
XENON10
ZEPLIN-III
XMASS
DarkSide-50
XENON100
DEAP-3600
LUX
XENON1T
PandaX-II
PandaX-4T
LZ
DarkSide-20k
neutrino fog (Ar)
neutrino fog (Xe)
XENONnT
ARGO
XLZD
Cross Section at 200GeV [cm^2]
Year
10^{-41}
10^{-42}
10^{-43}
10^{-44}
10^{-45}
10^{-46}
10^{-47}
10^{-48}
10^{-49}
2000
2005
2010
2015
2020
2025
2030
2035
2040
2045