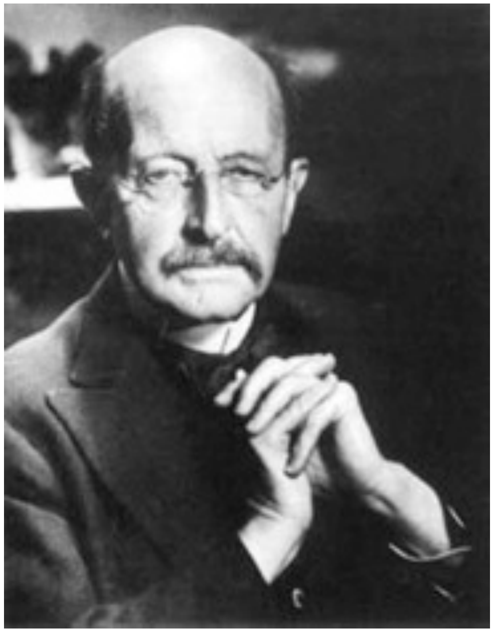
The Measure of the Universe
A Crisis for Cosmology

- **Why is the Universe so big?**
- **'Universe' or 'Multiverse'?**
- **Is the 'Multiverse' science?**
- **The Measure Problem.**
- **Are we asking the right question?**

Why is the Universe so big?

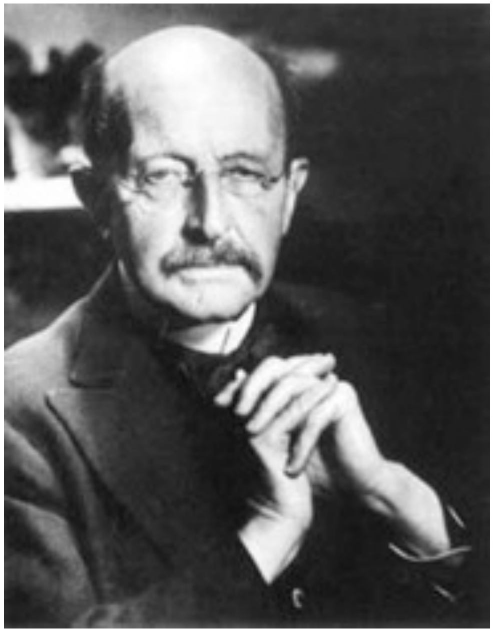
Planck Units



"These necessarily retain their meaning for all times and for all civilations, even extraterrestrials and non-human ones and can therefore be designated as natural units"

$$\hbar, \quad c, \quad G$$

Why is the Universe so big?



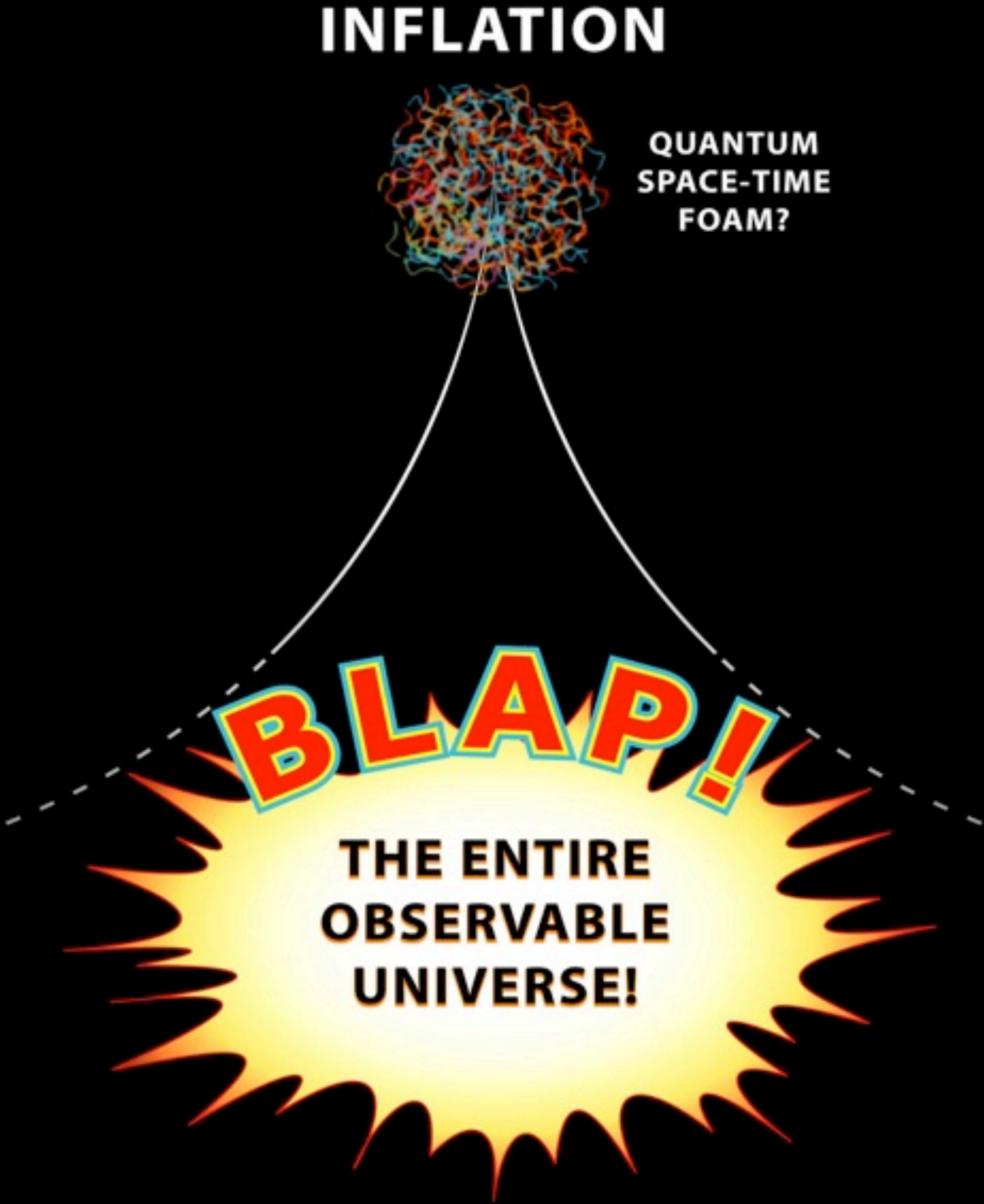
$$\hbar, \quad c, \quad G$$

$$\text{Planck length}: \left(\frac{\hbar G}{c^3}\right)^{1/2} = 1.6 \times 10^{-35} \text{ metres}$$

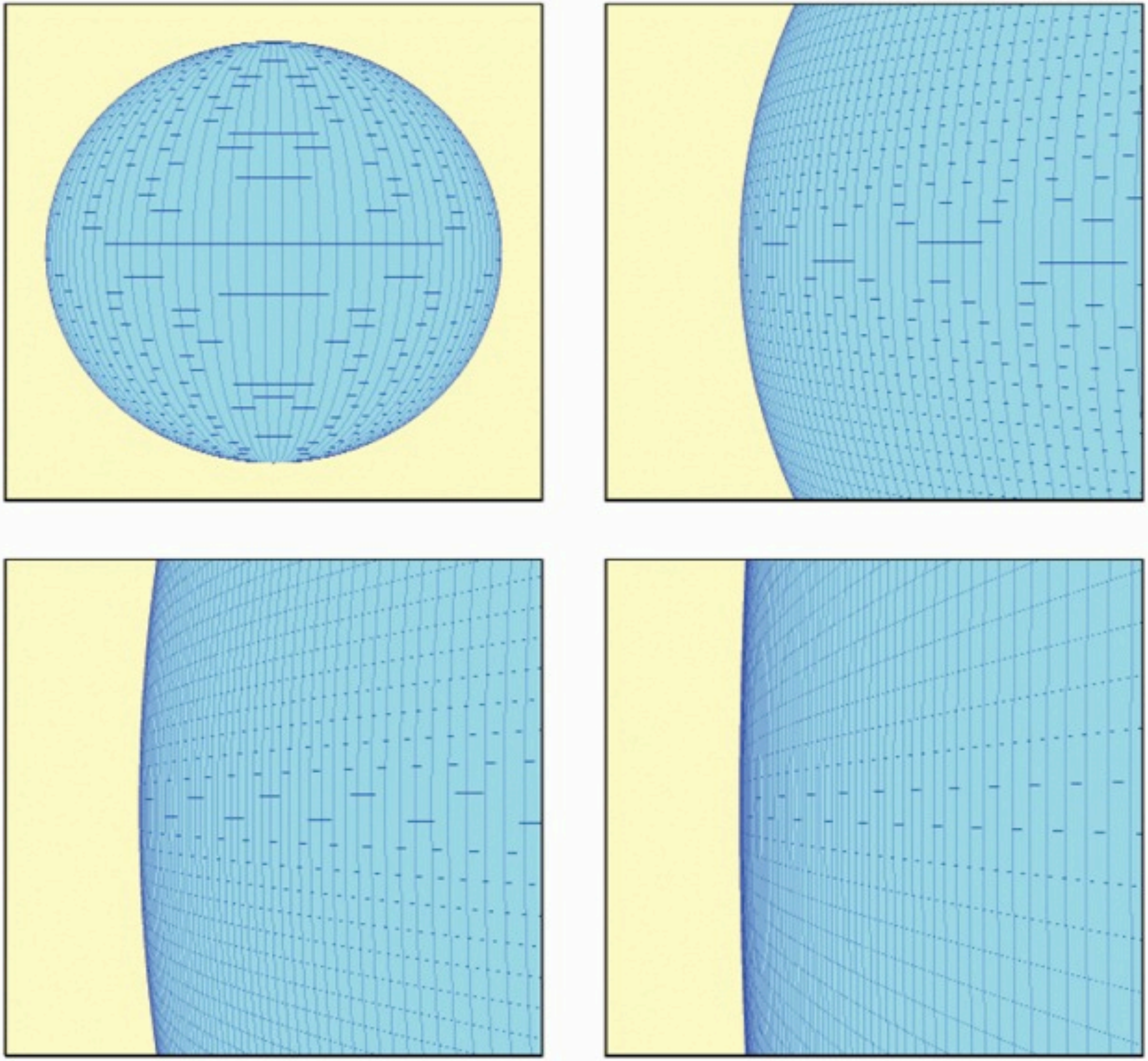
$$\text{Planck mass}: \left(\frac{\hbar c}{G}\right)^{1/2} = 2.1 \times 10^{-8} \text{ kgrams}$$

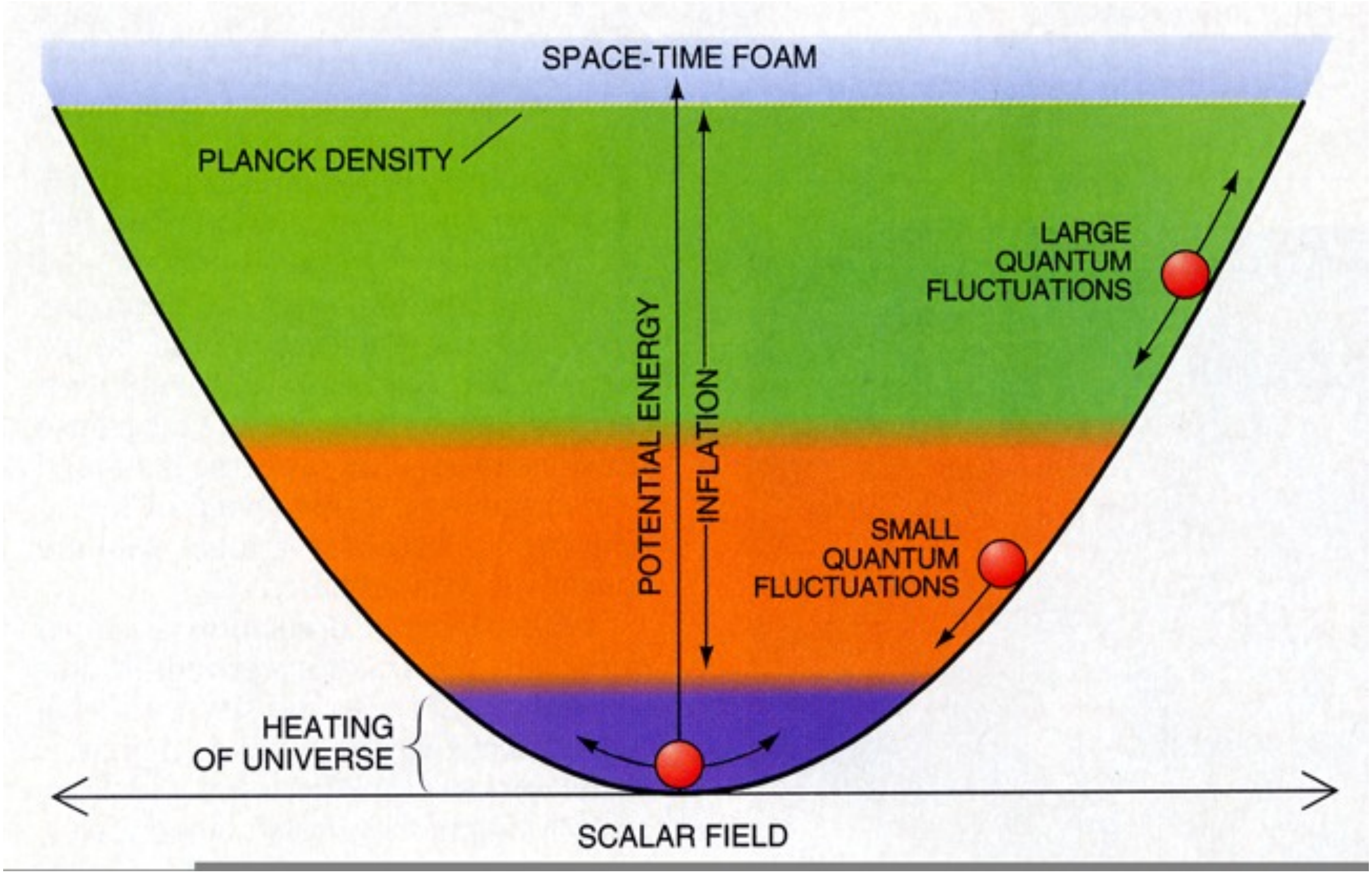
$$\text{Planck time}: \left(\frac{\hbar G}{c^5}\right)^{1/2} = 5.4 \times 10^{-44} \text{ seconds}$$

$$\text{Planck energy}: \left(\frac{\hbar c^5}{G}\right)^{1/2} = 1.2 \times 10^{19} \text{ GeV}$$

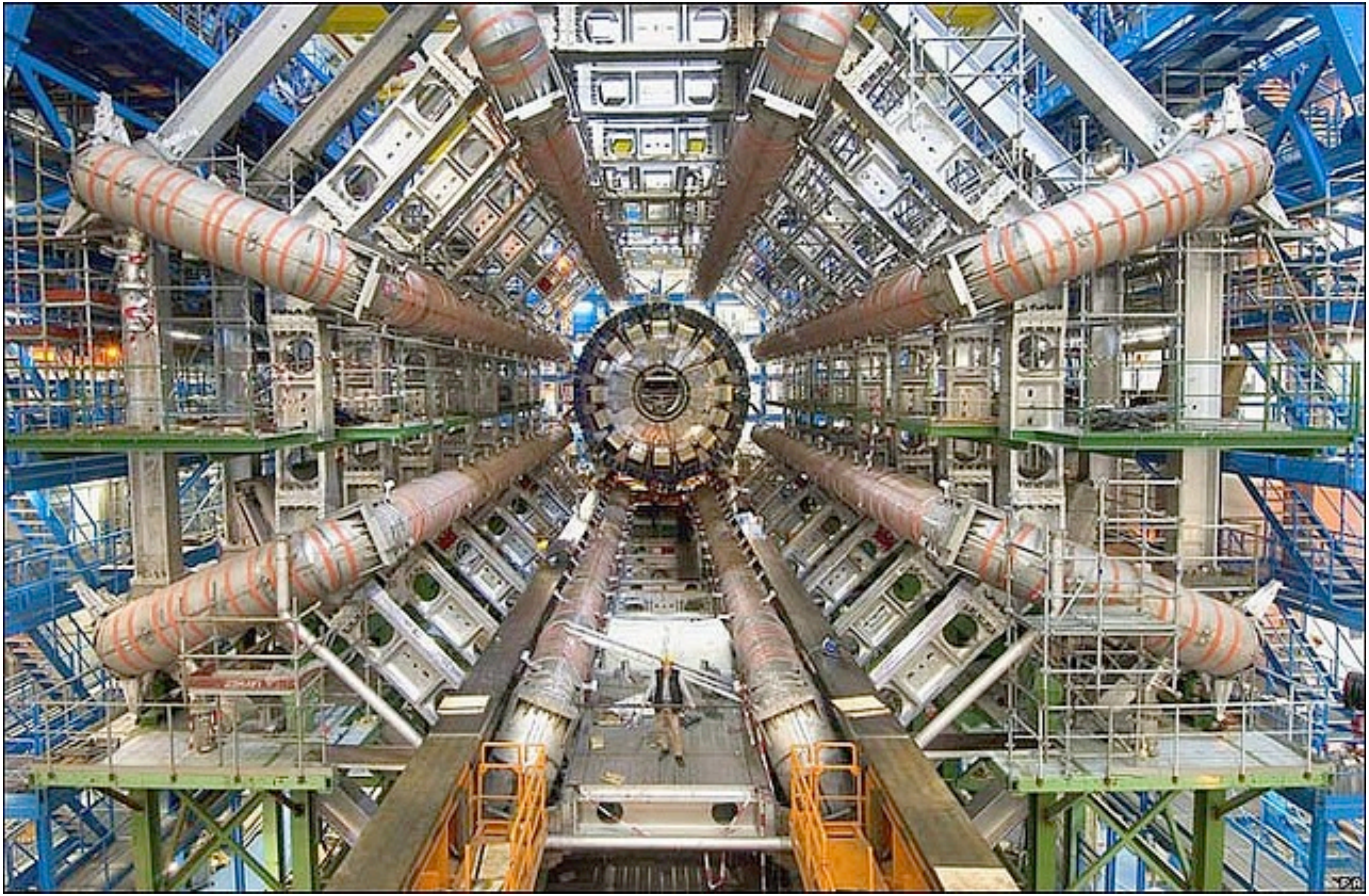

INFLATION
QUANTUM SPACE-TIME FOAM?
BLAP!
THE ENTIRE OBSERVABLE UNIVERSE!

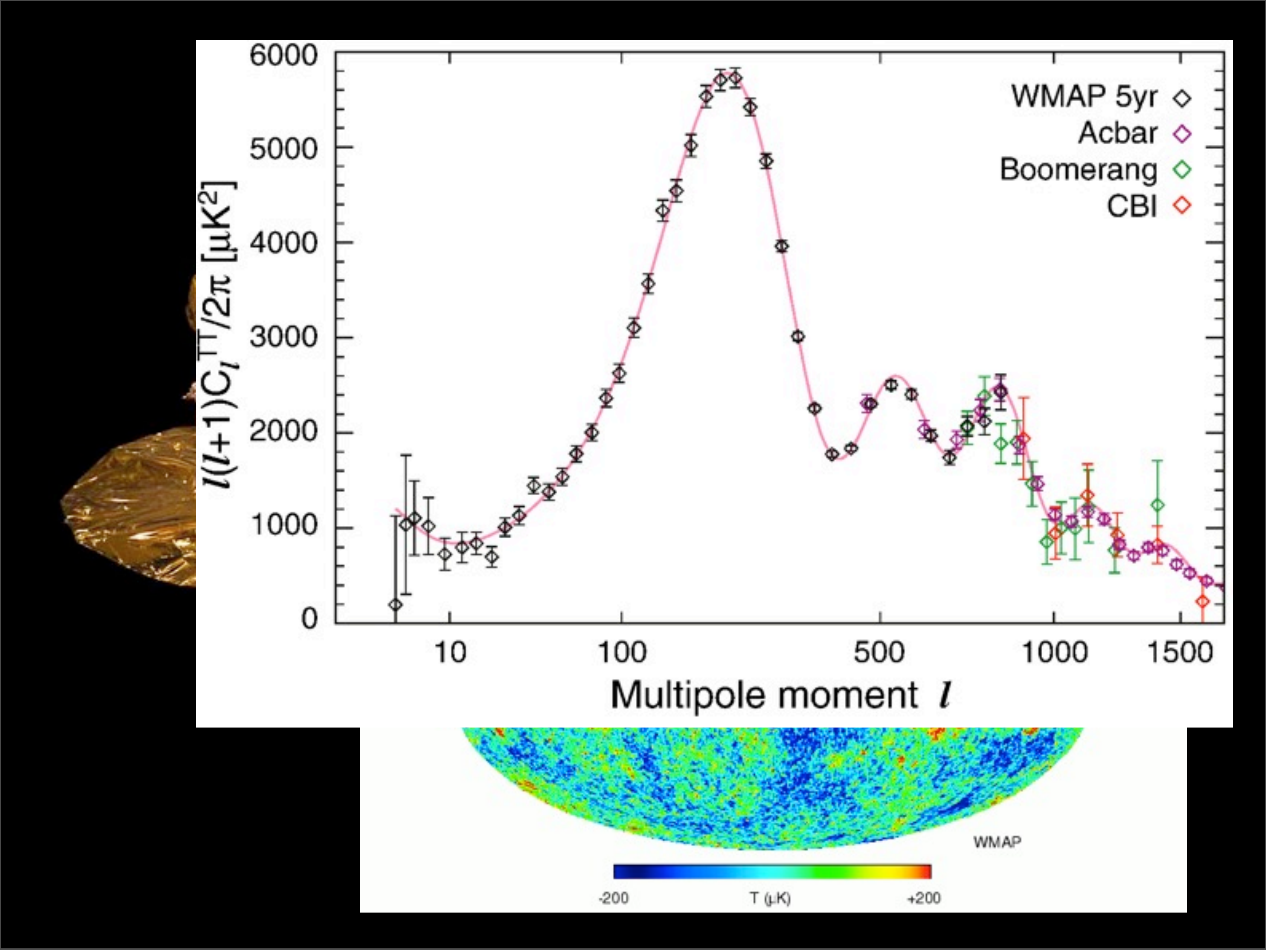
$p = -\rho$



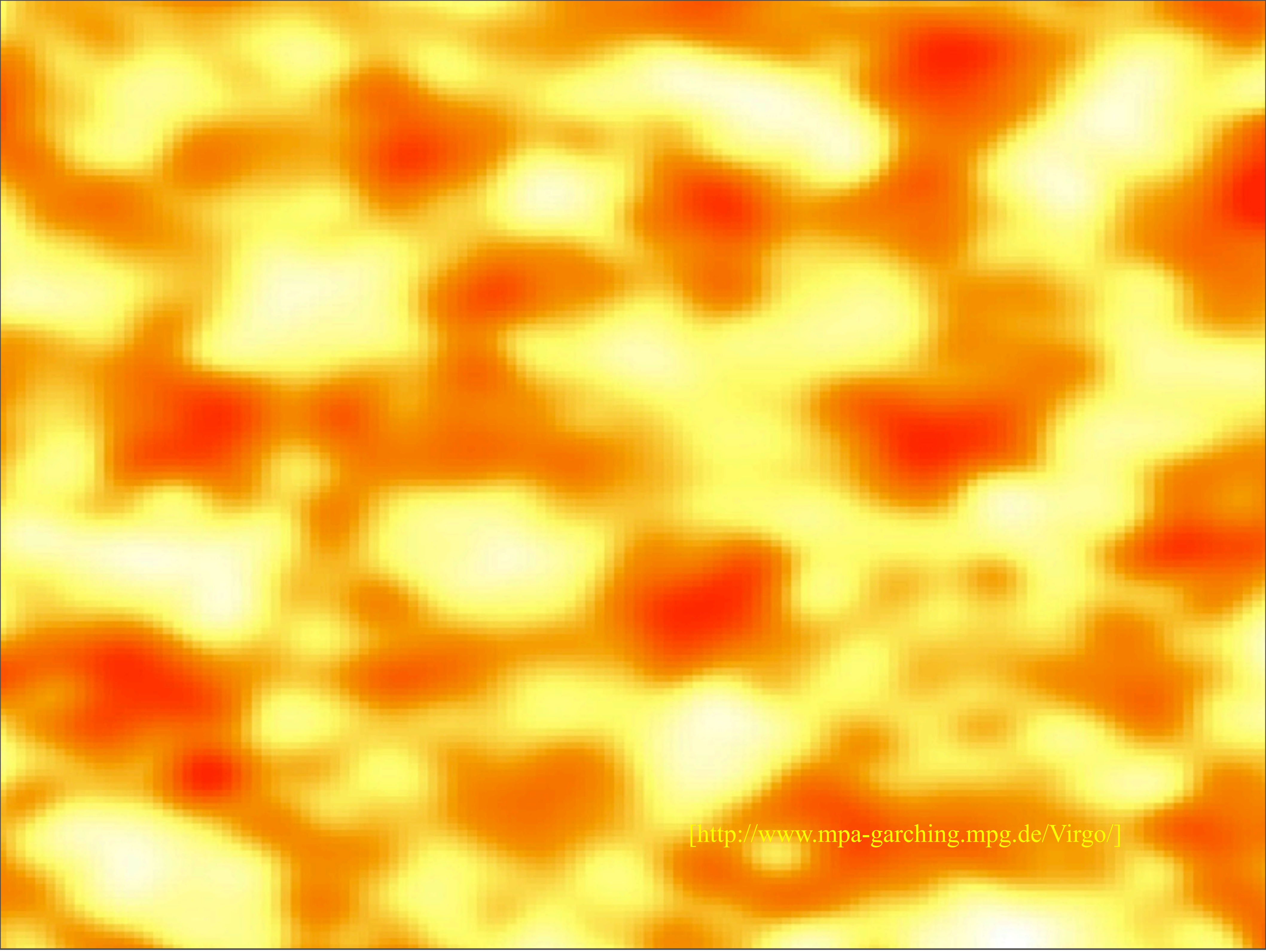


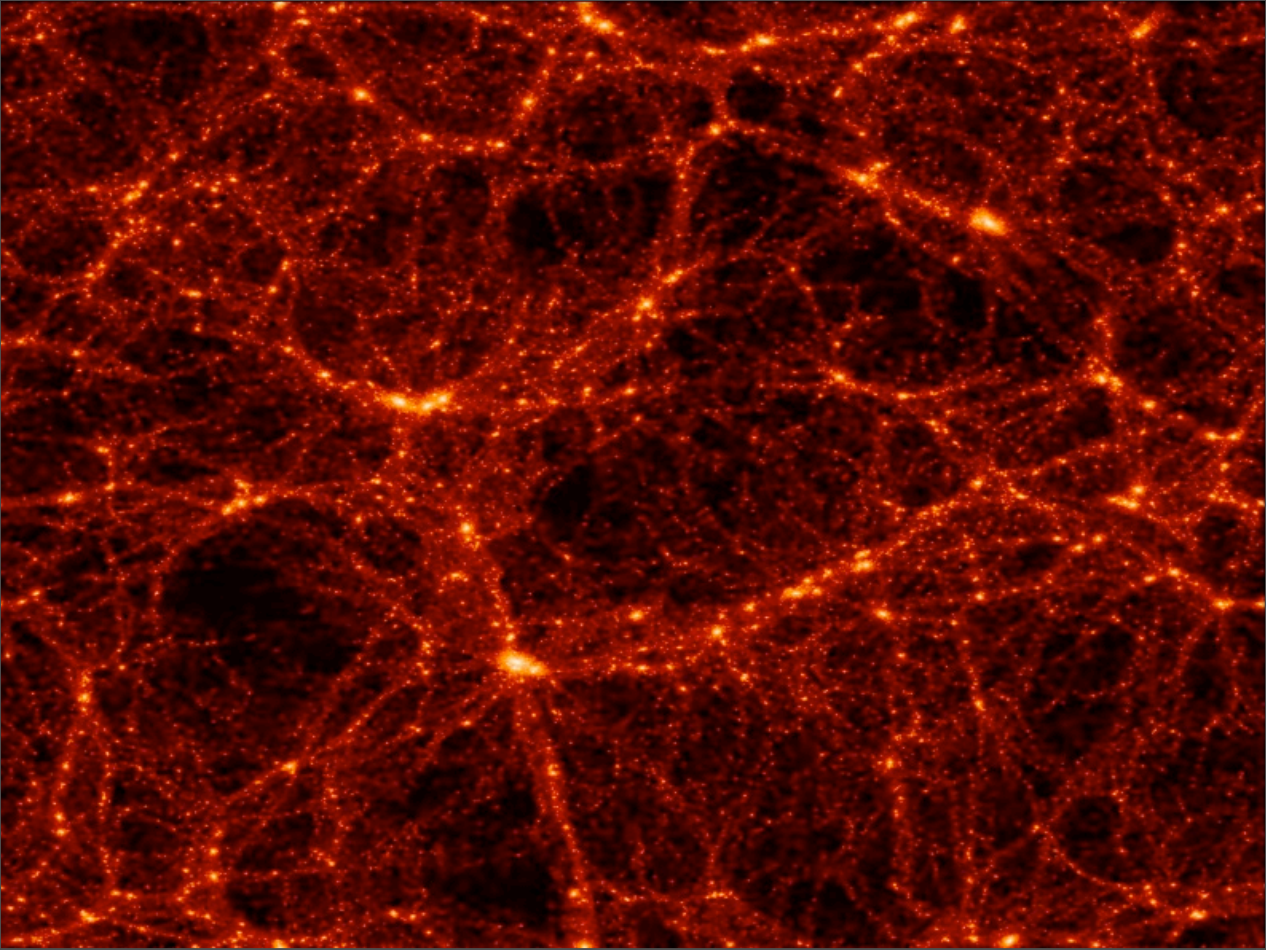
scalar field ϕ





6000
5000
4000
3000
2000
1000
0
$l(l+1)C_l^{TT}/2\pi$ [μK^2]
10
100
500
1000
1500
Multipole moment l
WMAP 5yr
Acbar
Boomerang
CBI
WMAP
-200
T (μK)
+200

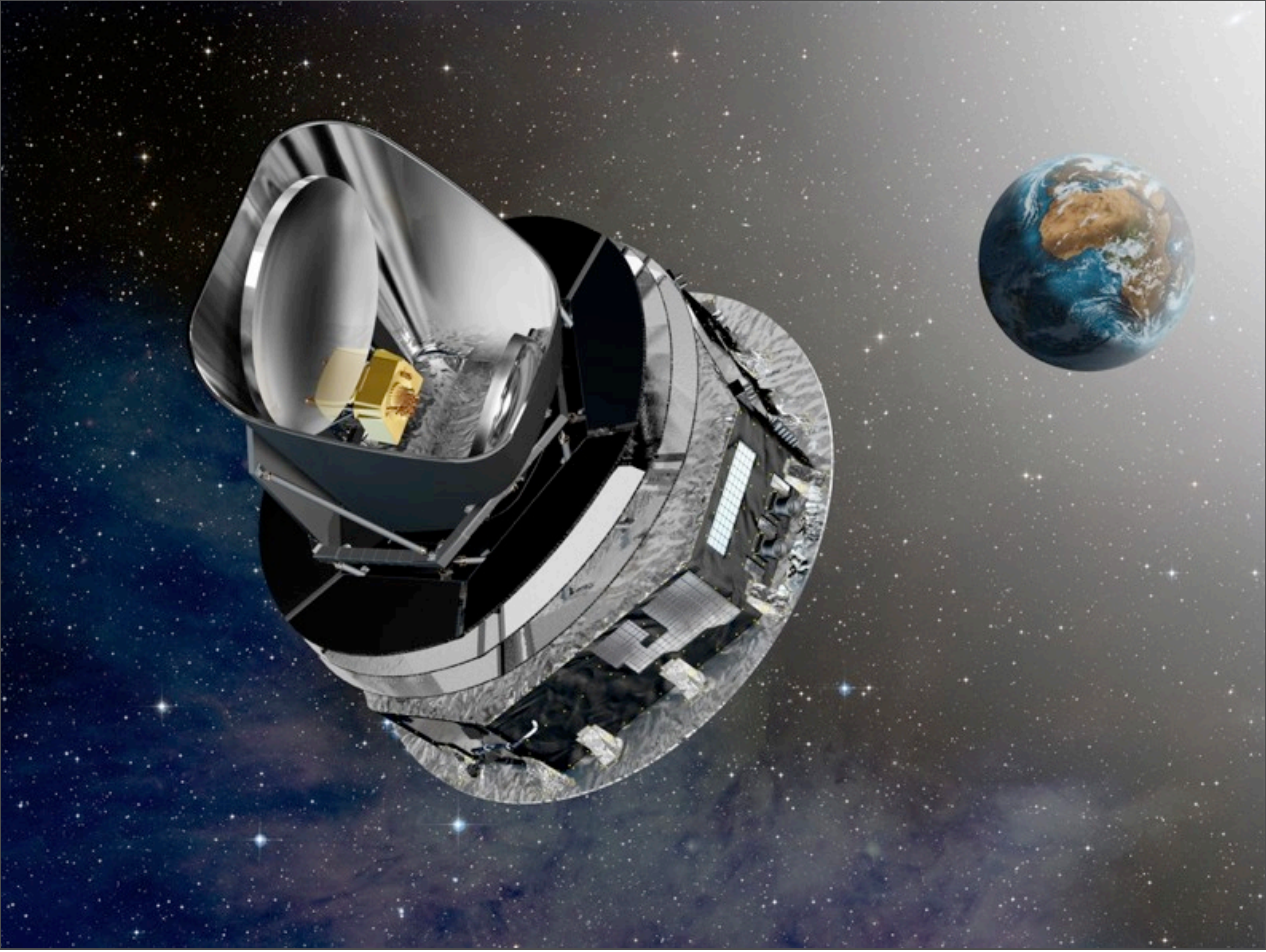

[http://www.mpa-garching.mpg.de/Virgo/]



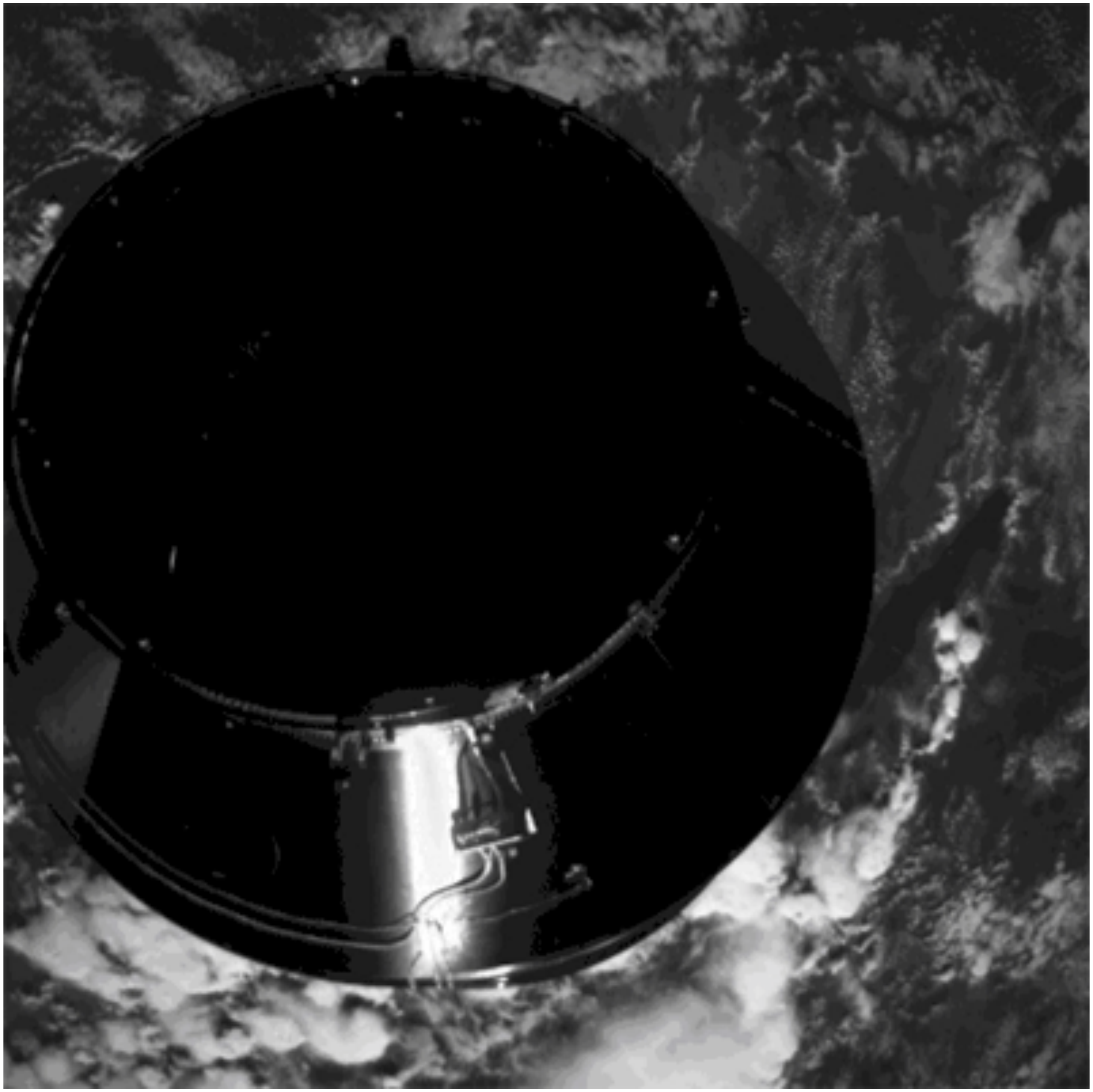
Virgin
media

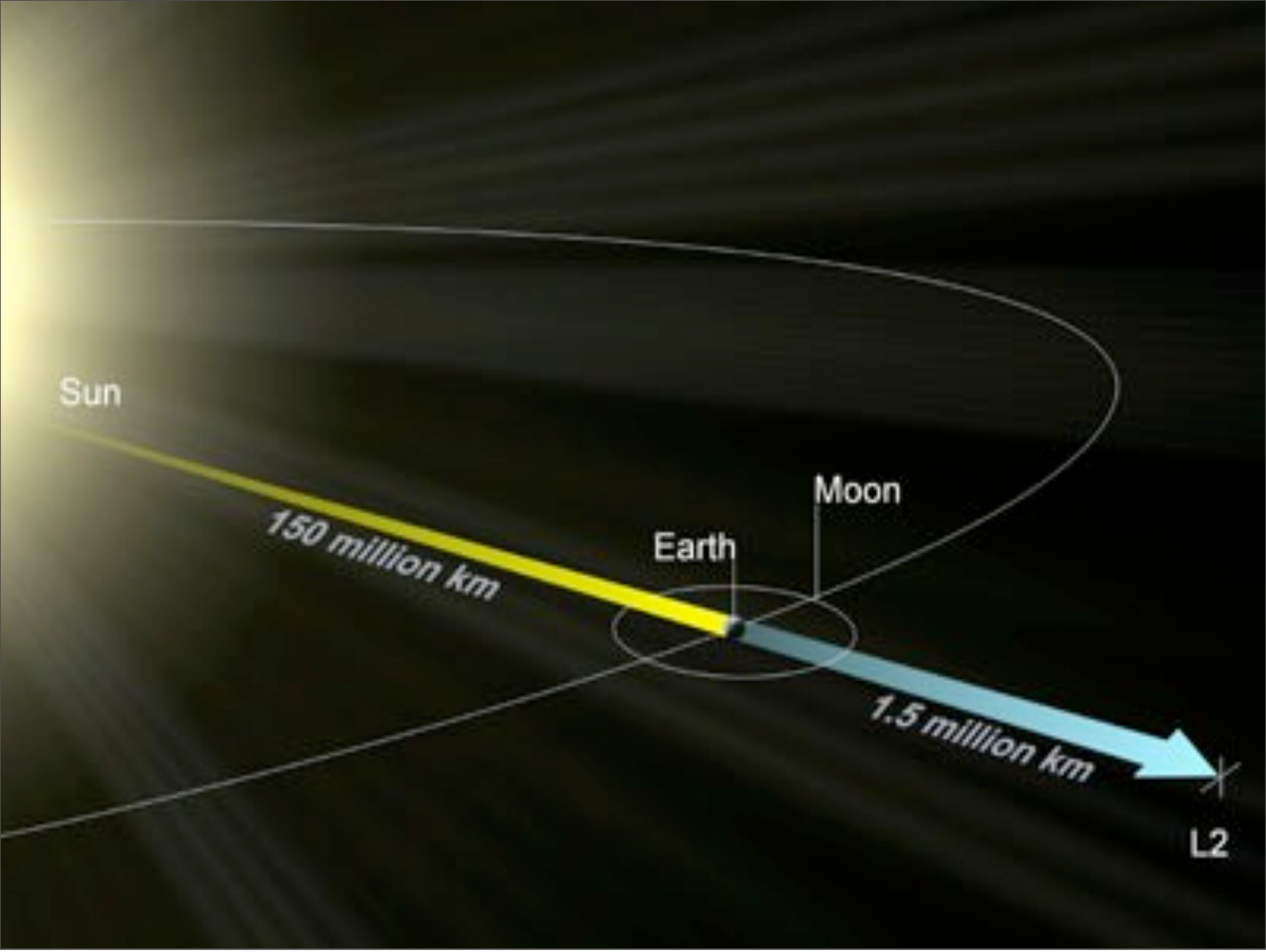
Virgin media

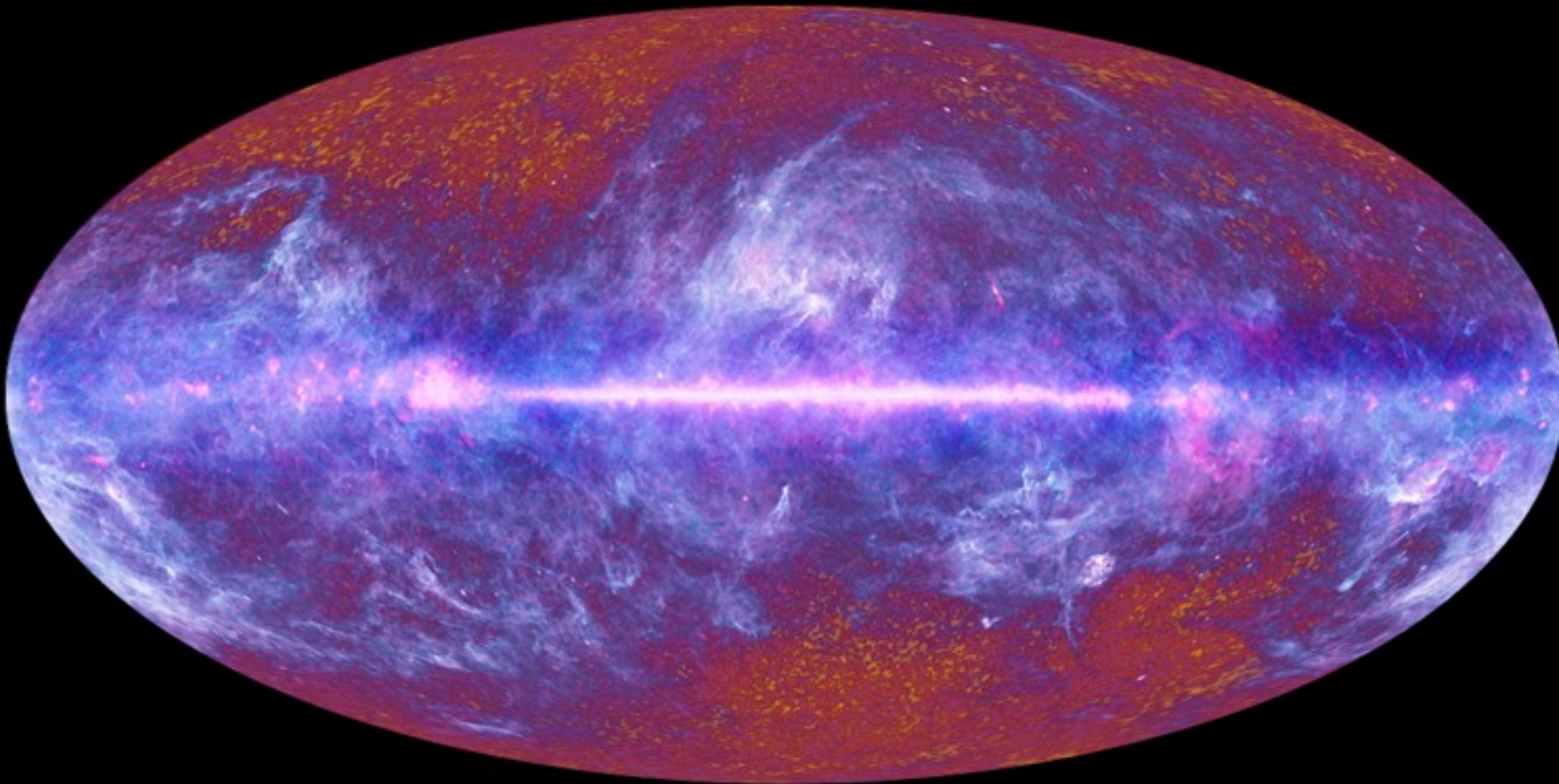
Virgin media

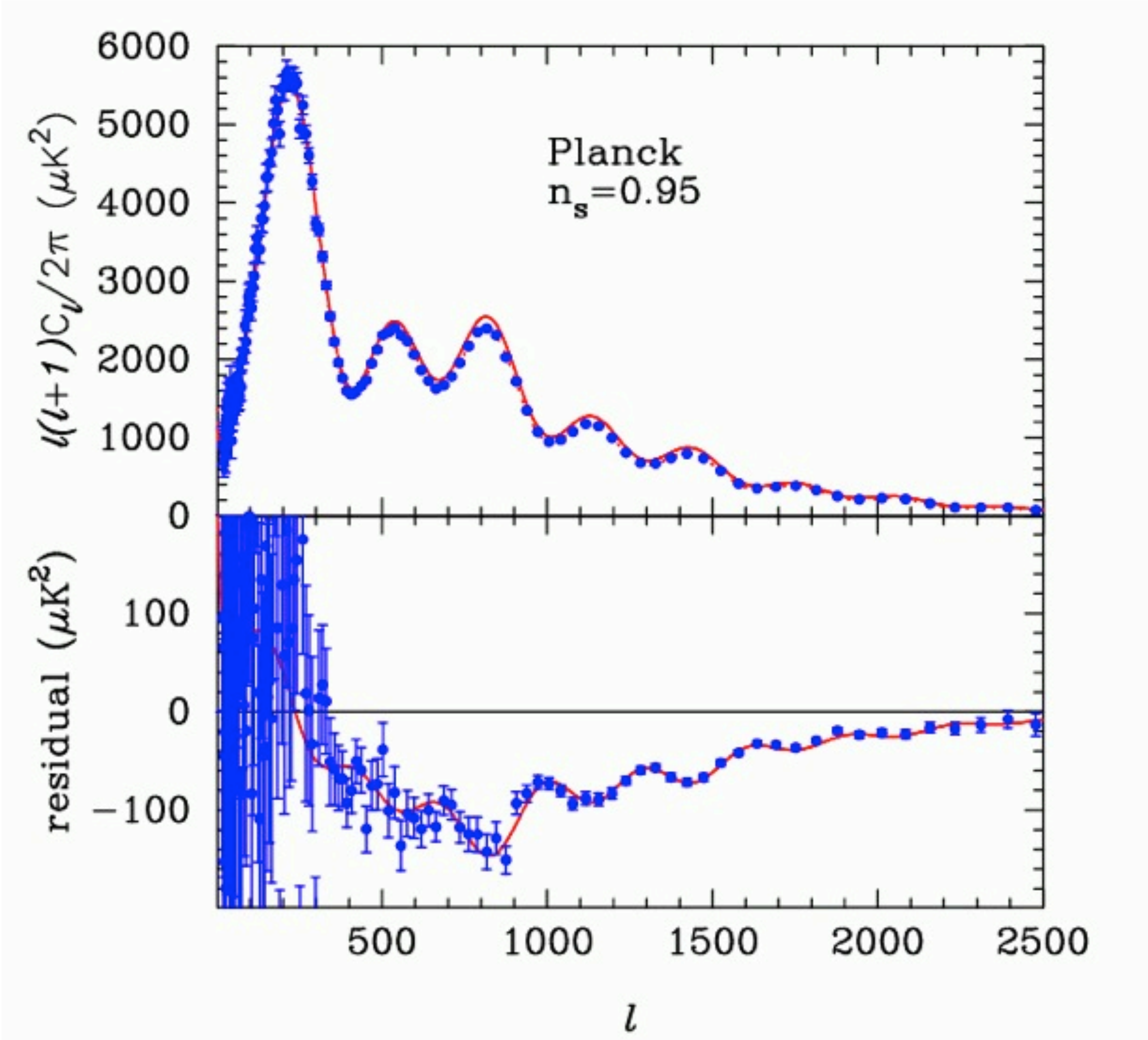




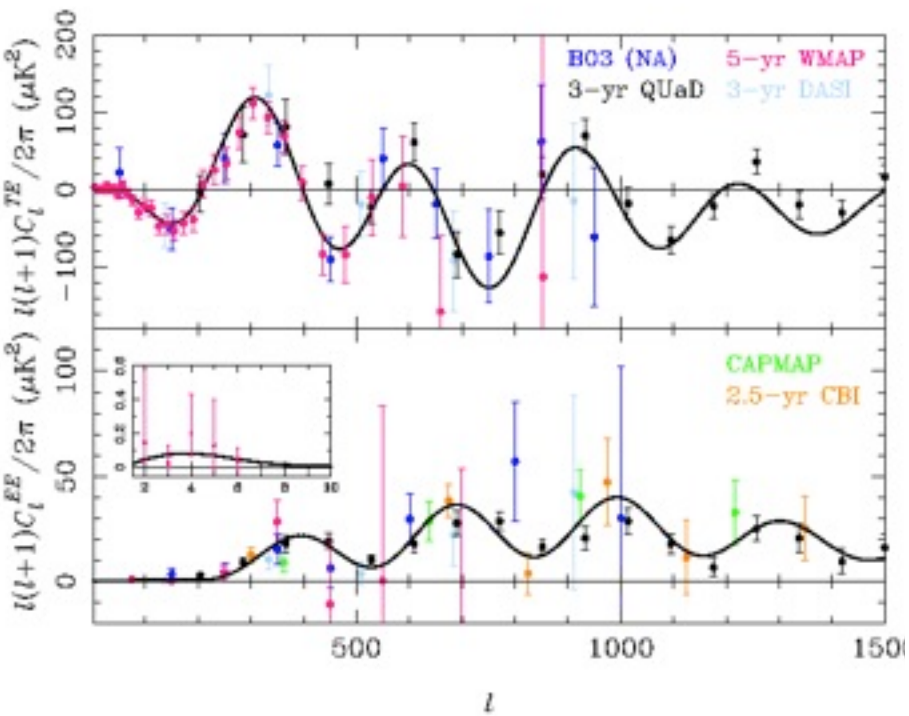



Sun
150 million km
Earth
Moon
1.5 million km
L2

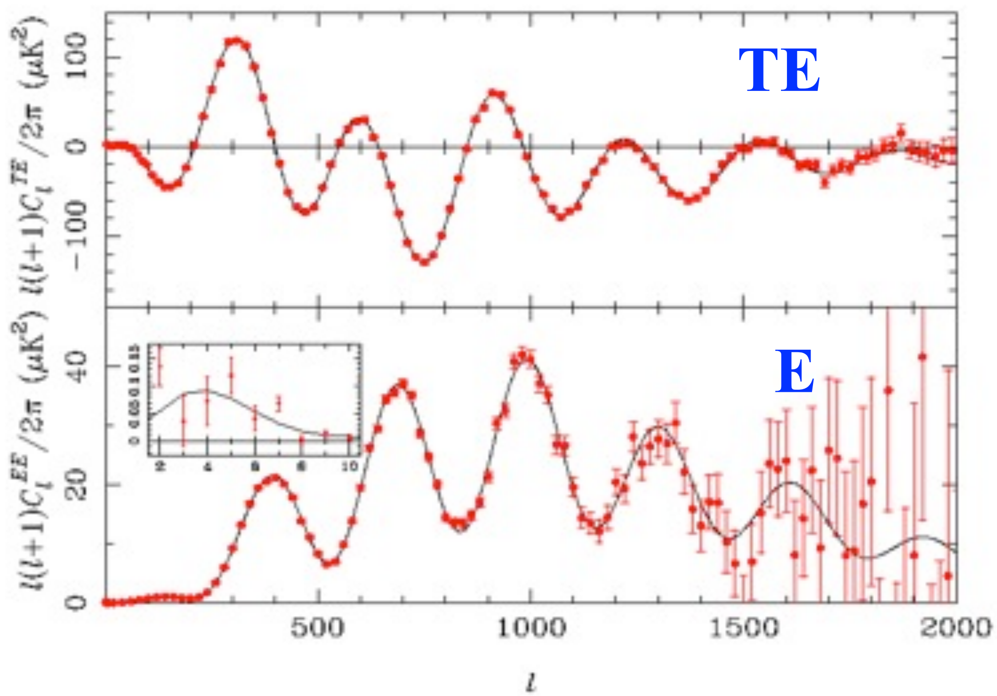



6000
5000
4000
3000
2000
1000
0
100
0
−100
Planck
n_s=0.95
$l(l+1)C_l/2\pi$ (μK^2)
residual (μK^2)
500
1000
1500
2000
2500
l

CURRENT OBSERVATIONS

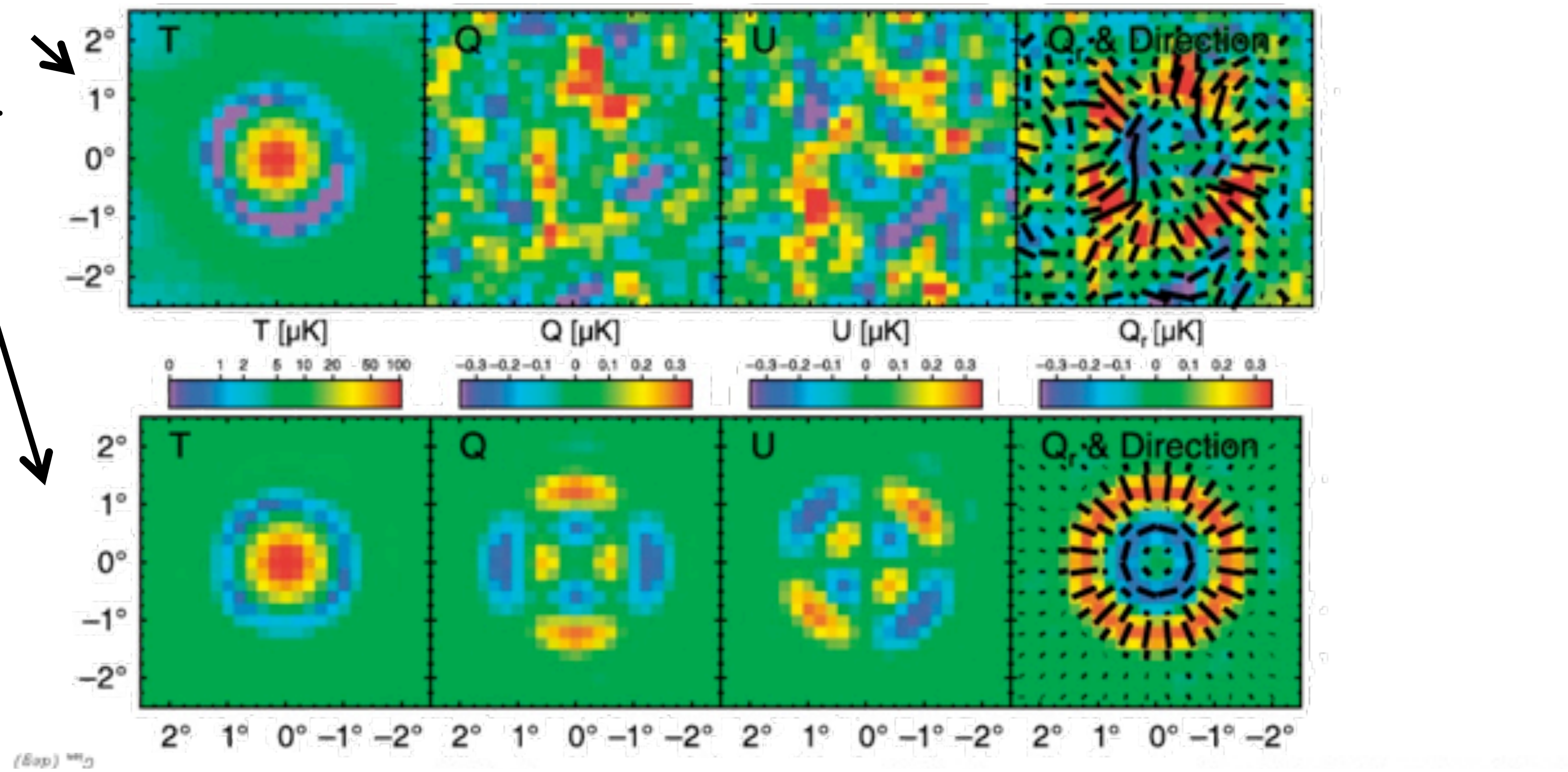


PLANCK FORECAST



“A typical CMB Hot spot”
Illustration of polarization sensitivity

WMAP 7years
(Komatsu et al. preprint 2010)
& simulations



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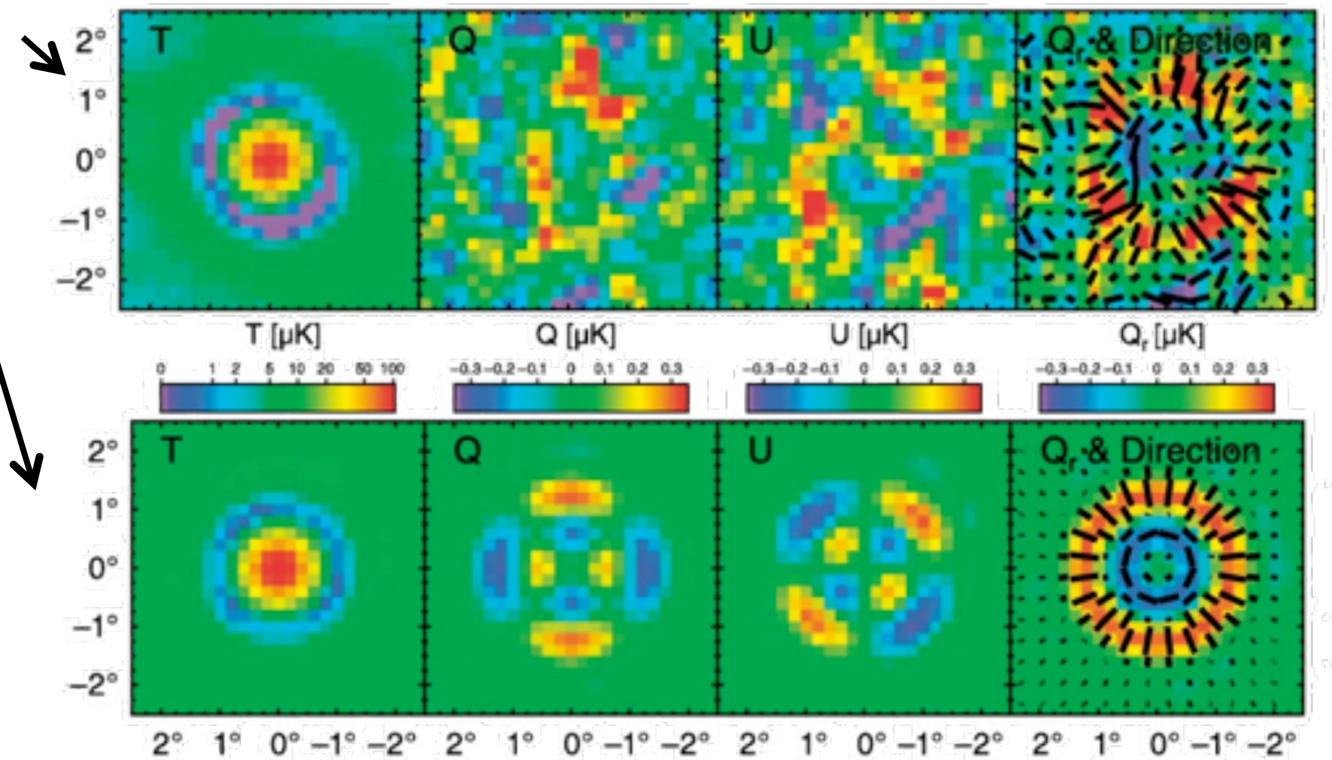
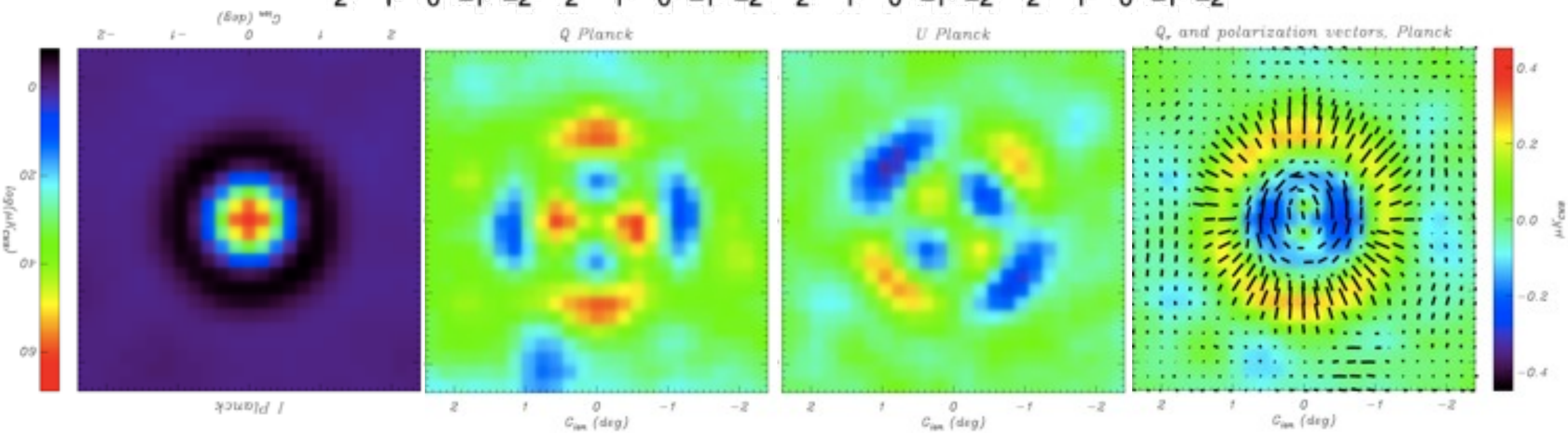
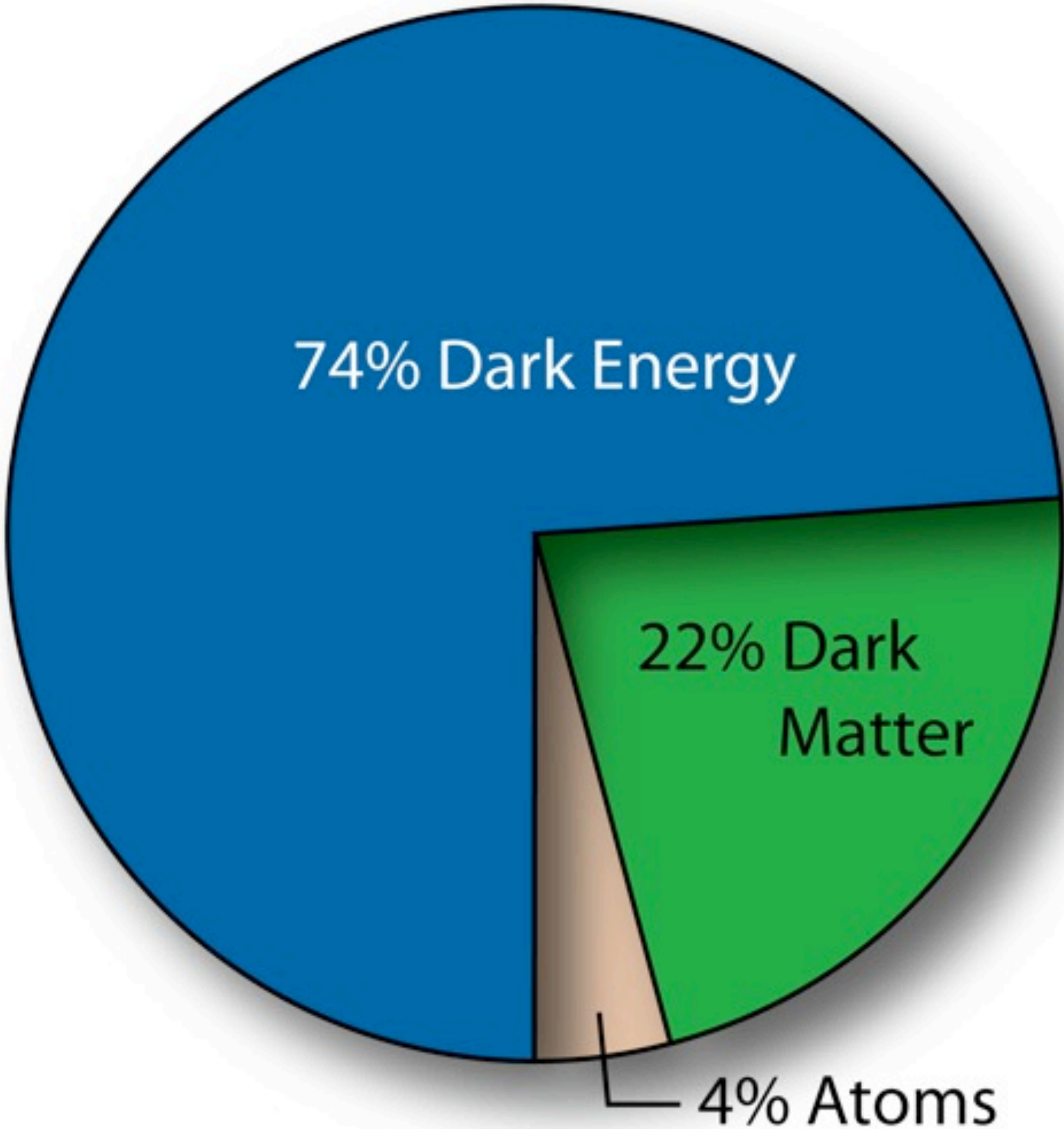
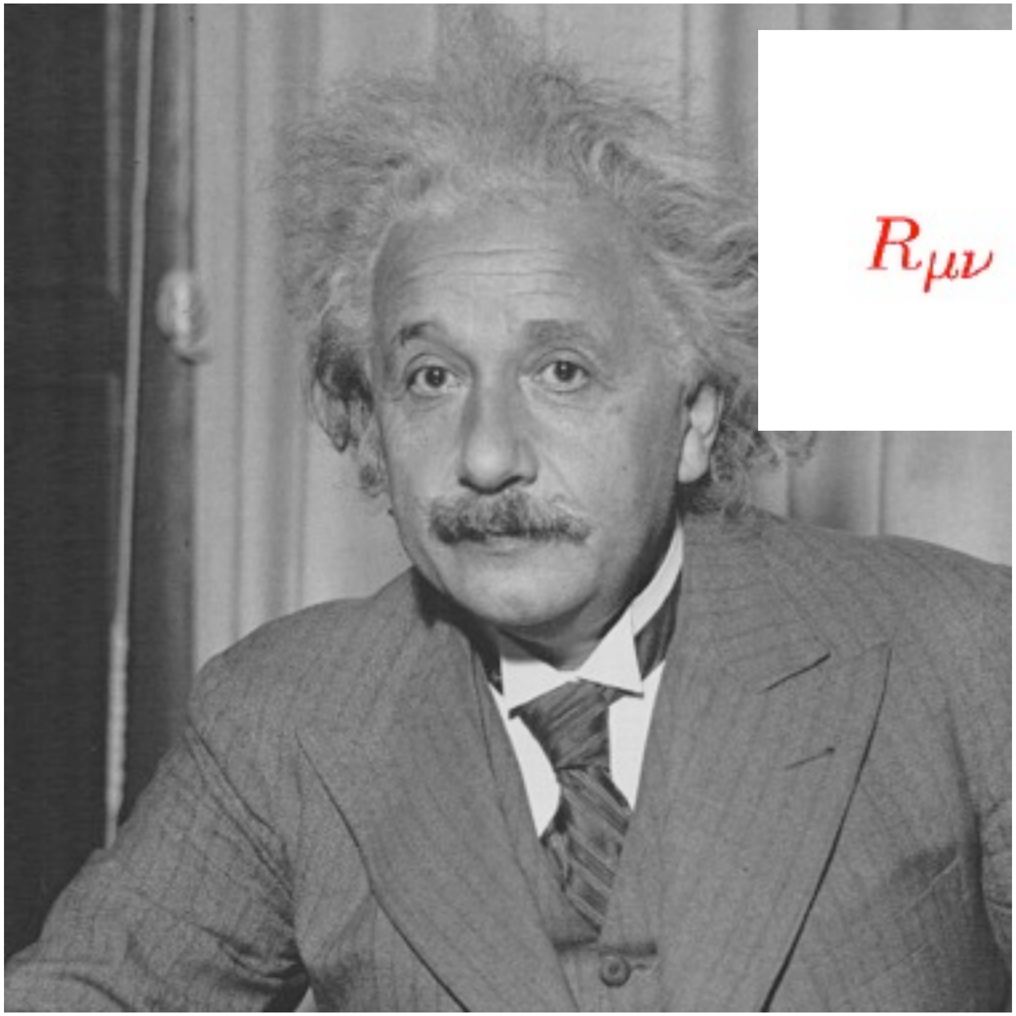
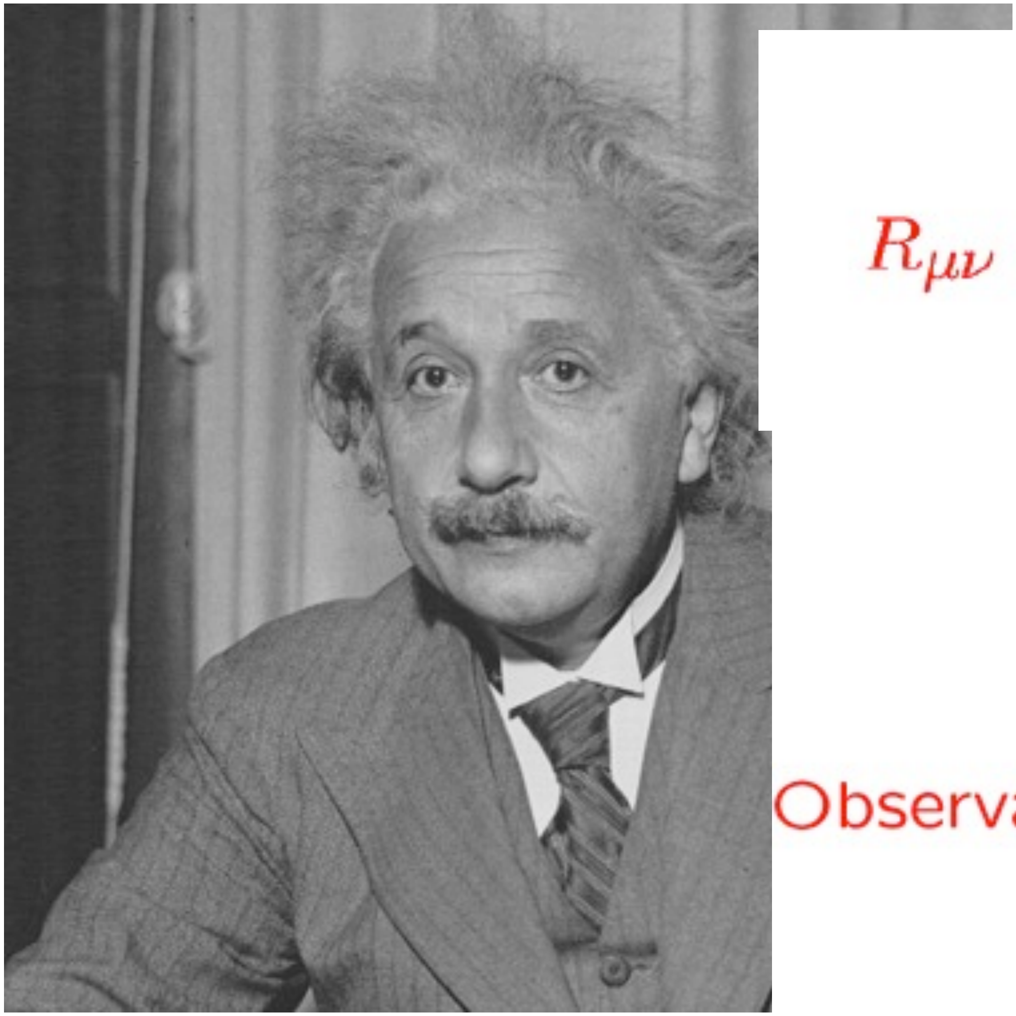





74% Dark Energy
22% Dark Matter
4% Atoms



$$R_{\mu\nu} - \frac{1}{2}g_{\mu\nu}R - \Lambda g_{\mu\nu} = 8\pi G T_{\mu\nu}$$



$$R_{\mu\nu} - \frac{1}{2}g_{\mu\nu}R - \Lambda g_{\mu\nu} = 8\pi G T_{\mu\nu}$$

Observations:

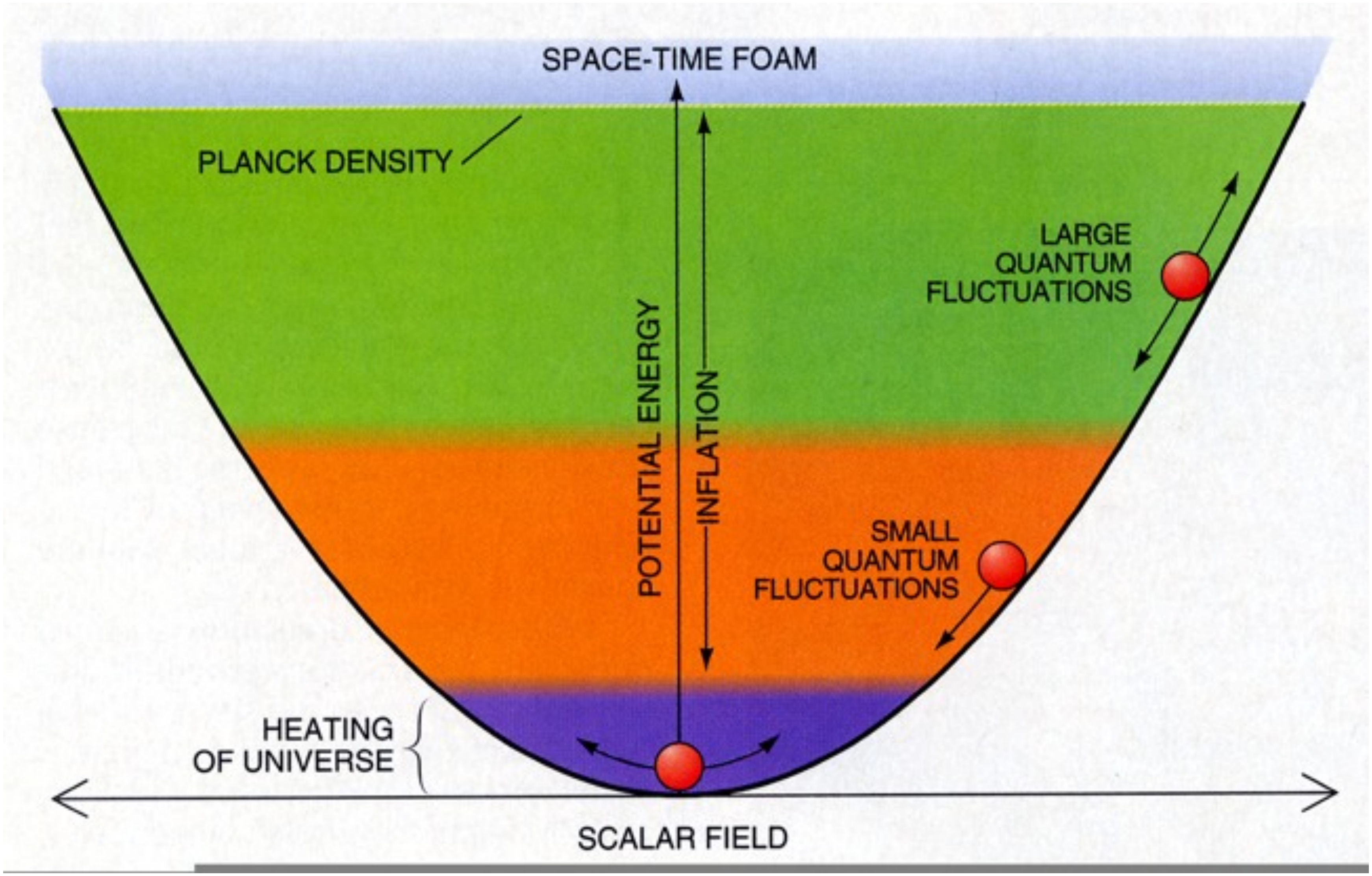
$$\rho_\Lambda \sim H_0^2 m_{\rm pl}^2 \sim (10^{-3}{\rm eV})^4$$

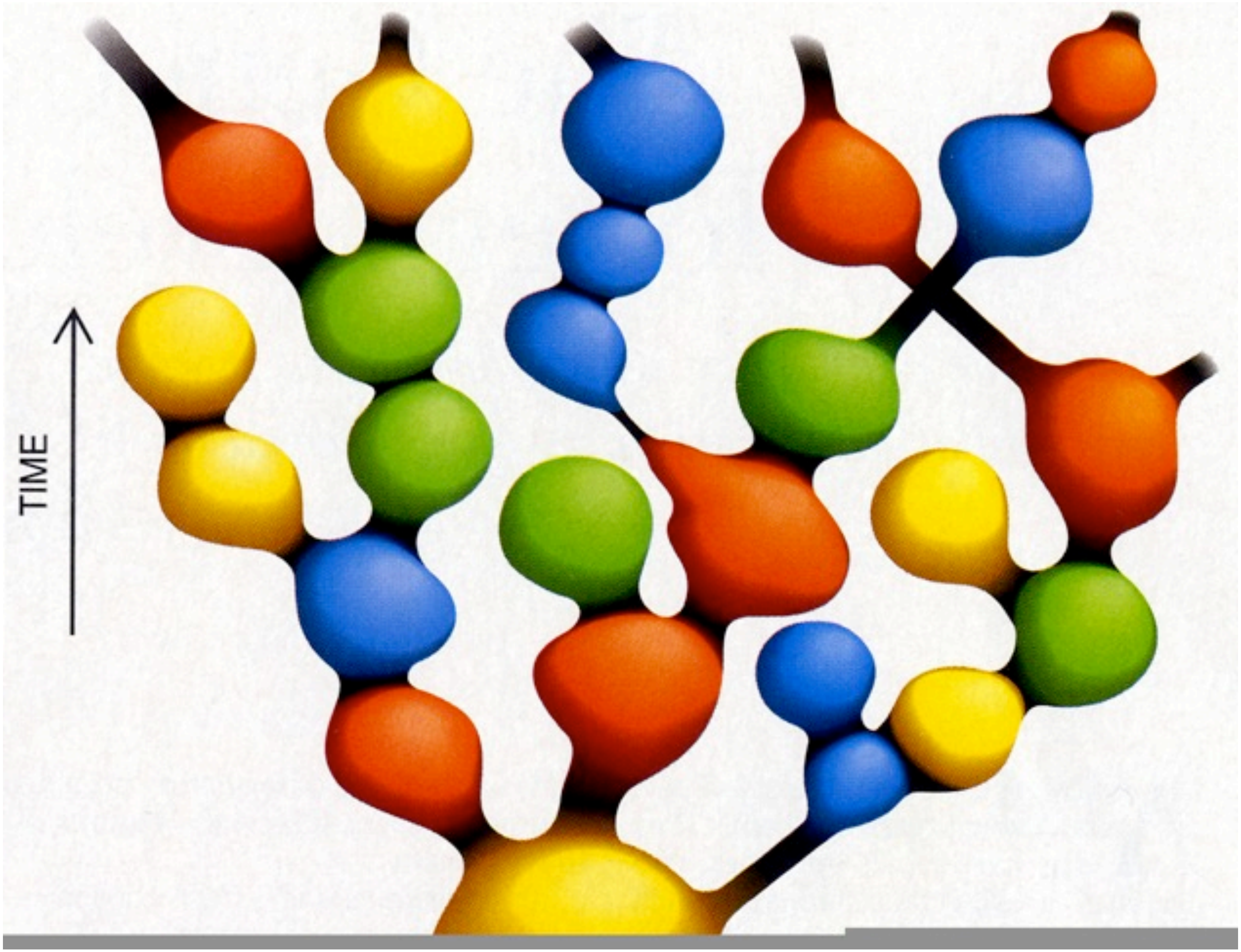
Theory:

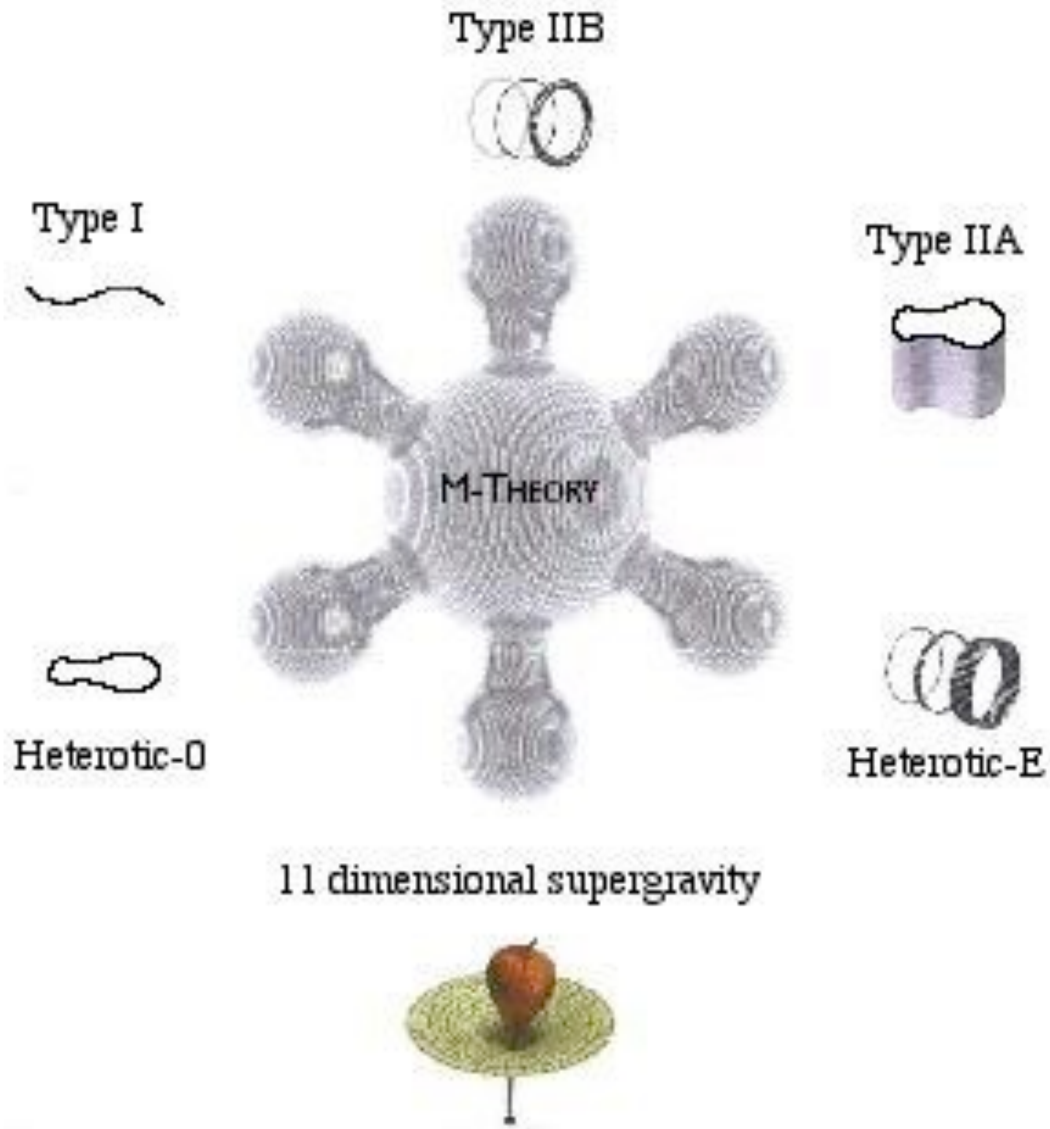
$$\rho_\Lambda \sim m_{\rm pl}^4 \sim (10^{19}{\rm GeV})^4$$

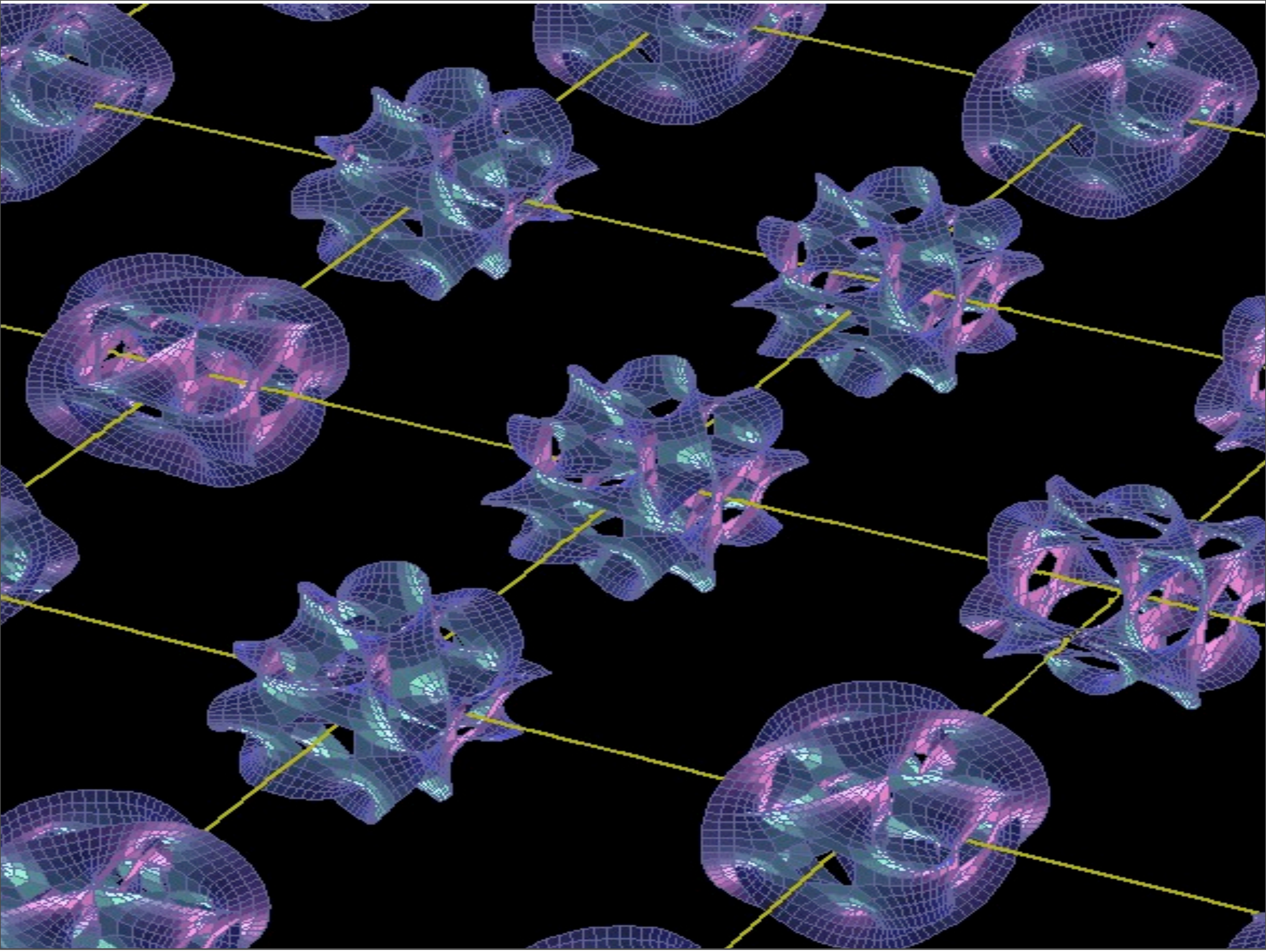
Universe or Multiverse?

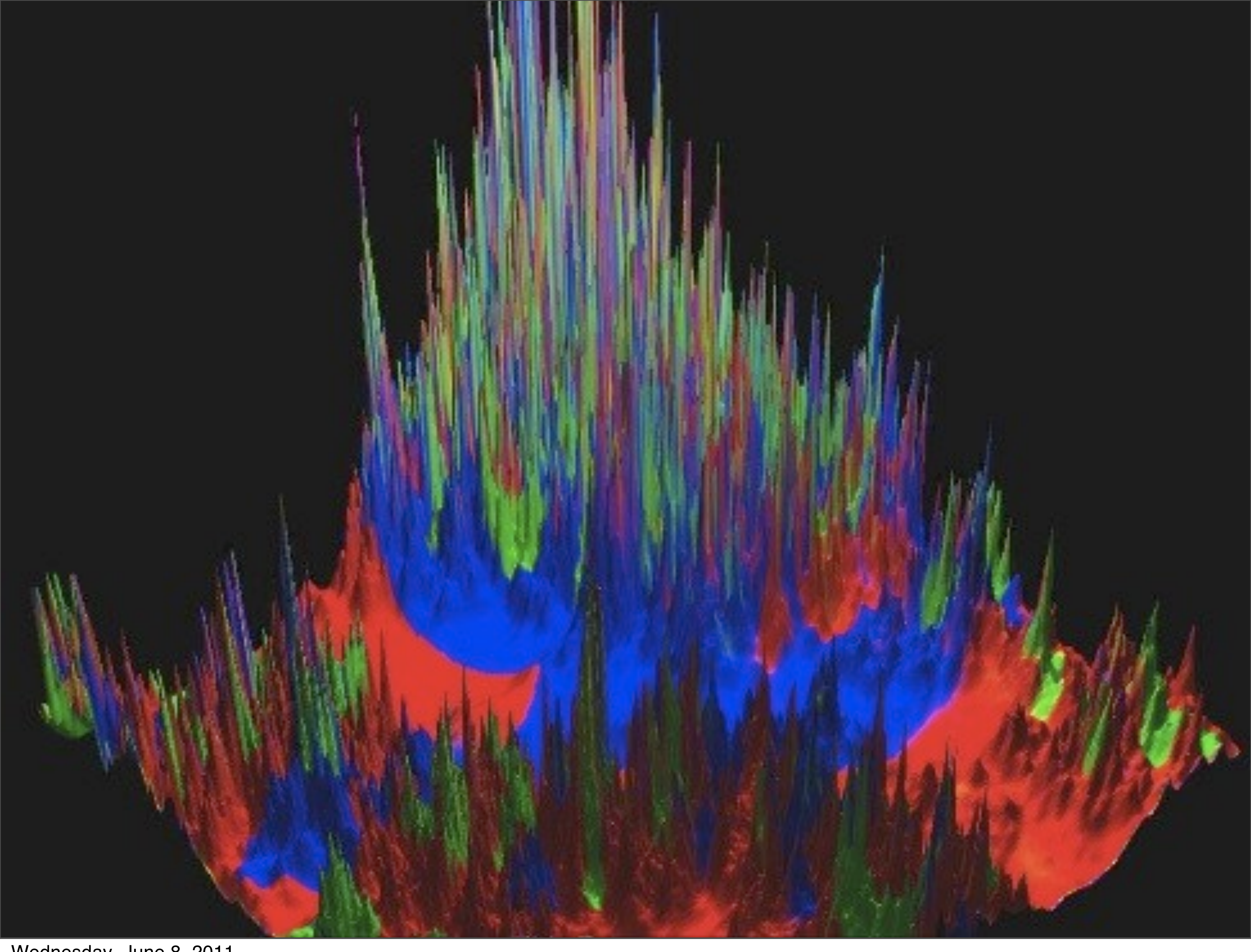
Universe or Multiverse?

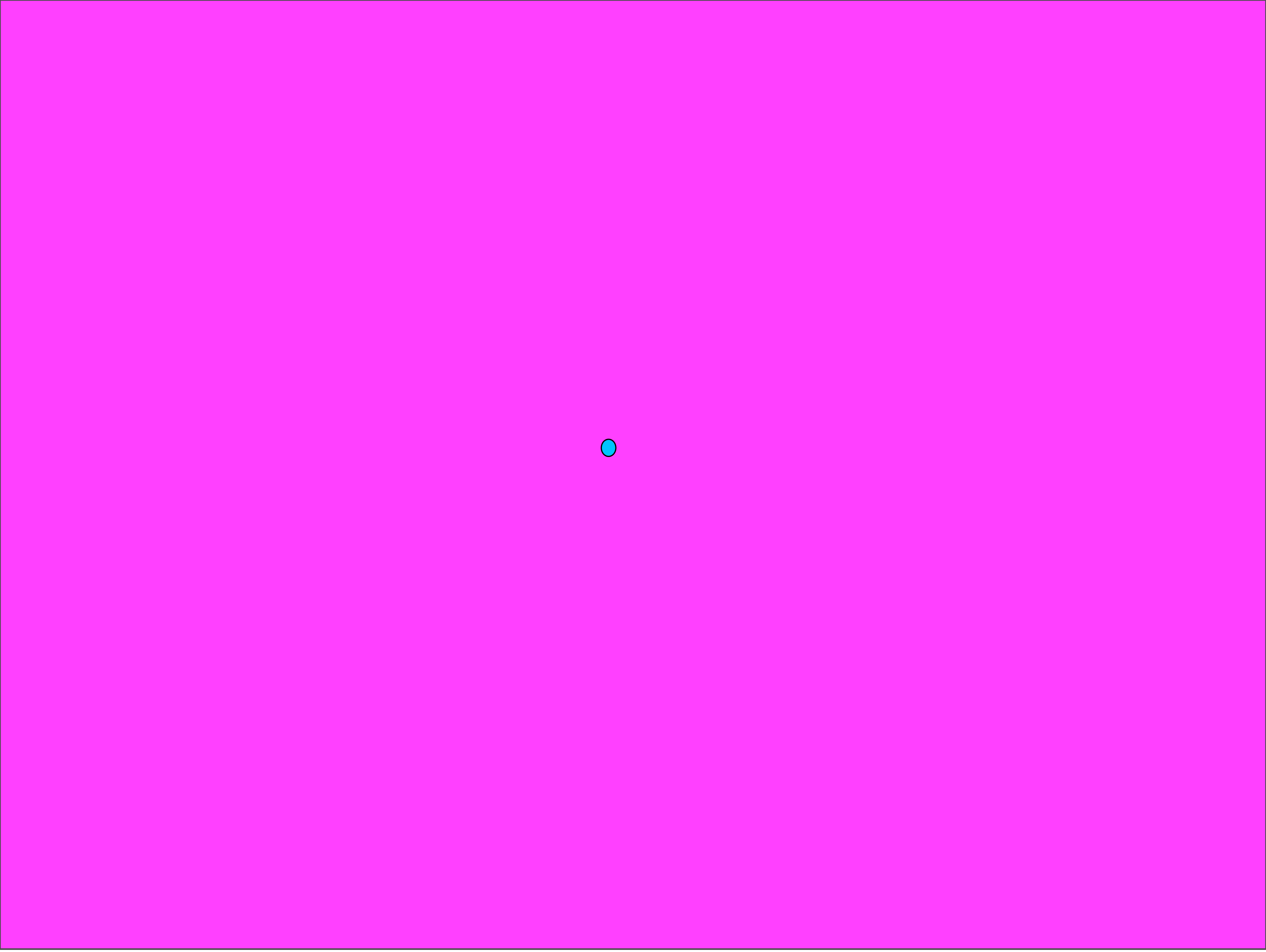


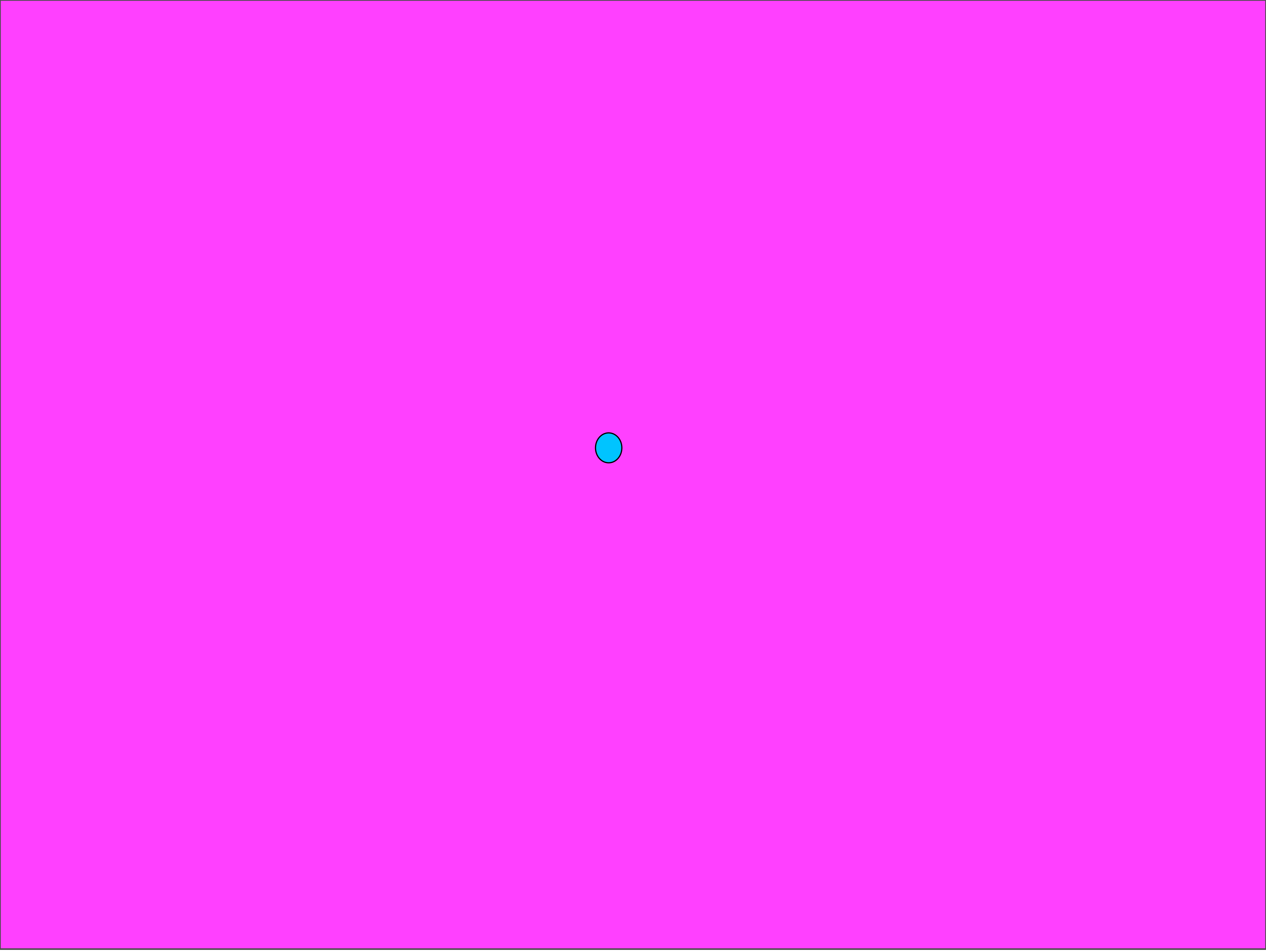

TIME

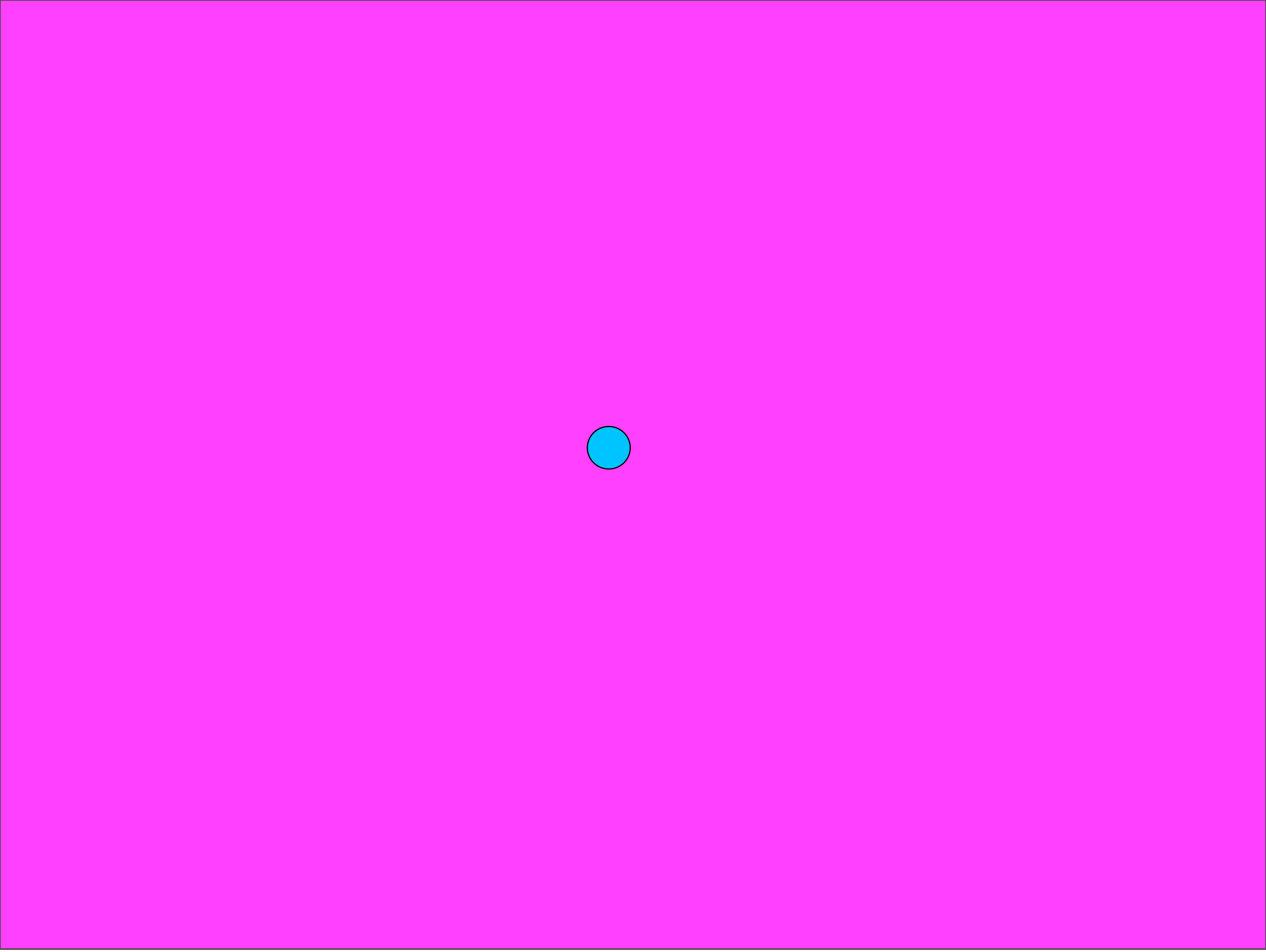

Type IIB
Type I
Type IIA
M-Theory
Heterotic-0
Heterotic-E
11 dimensional supergravity

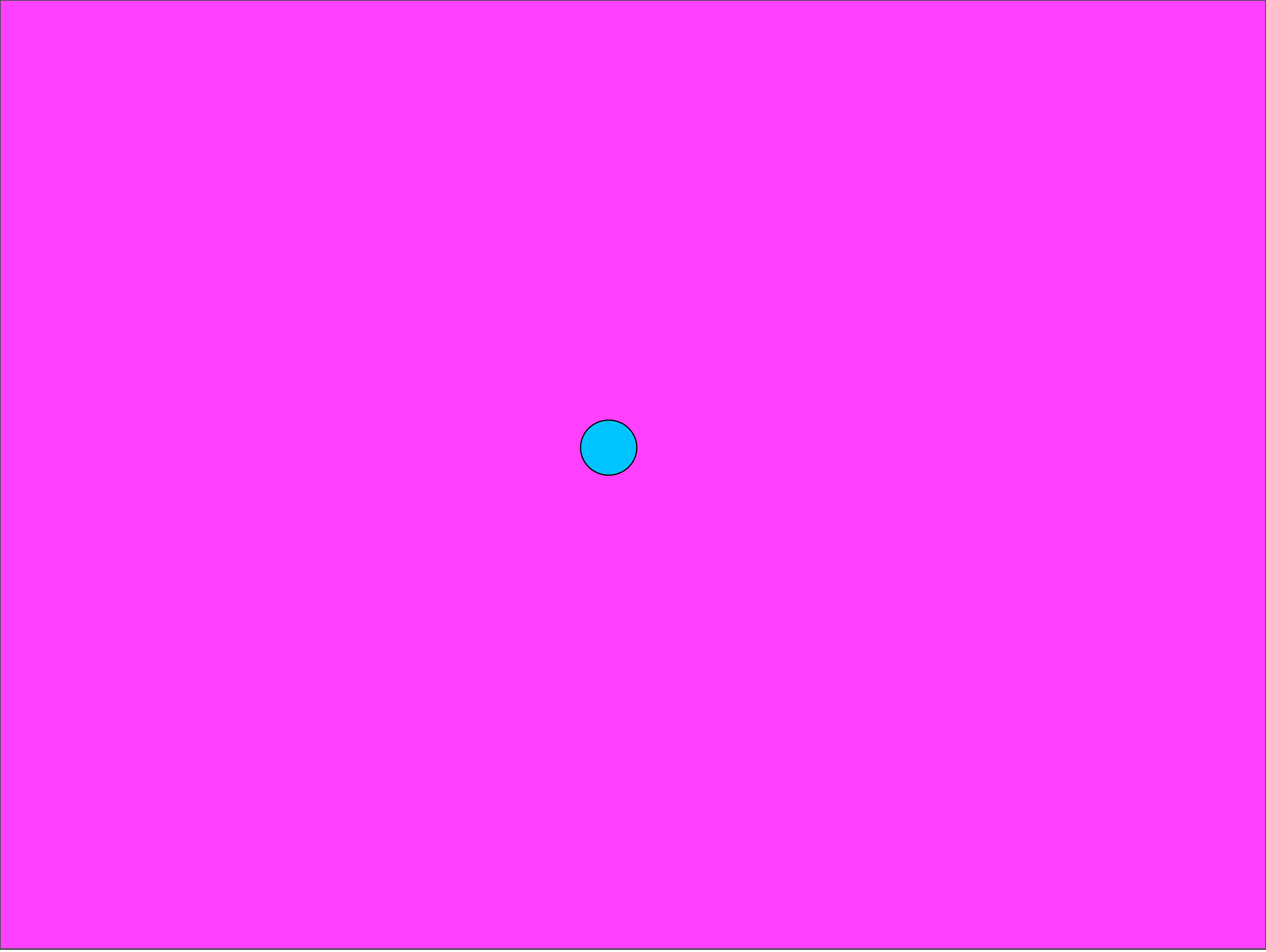


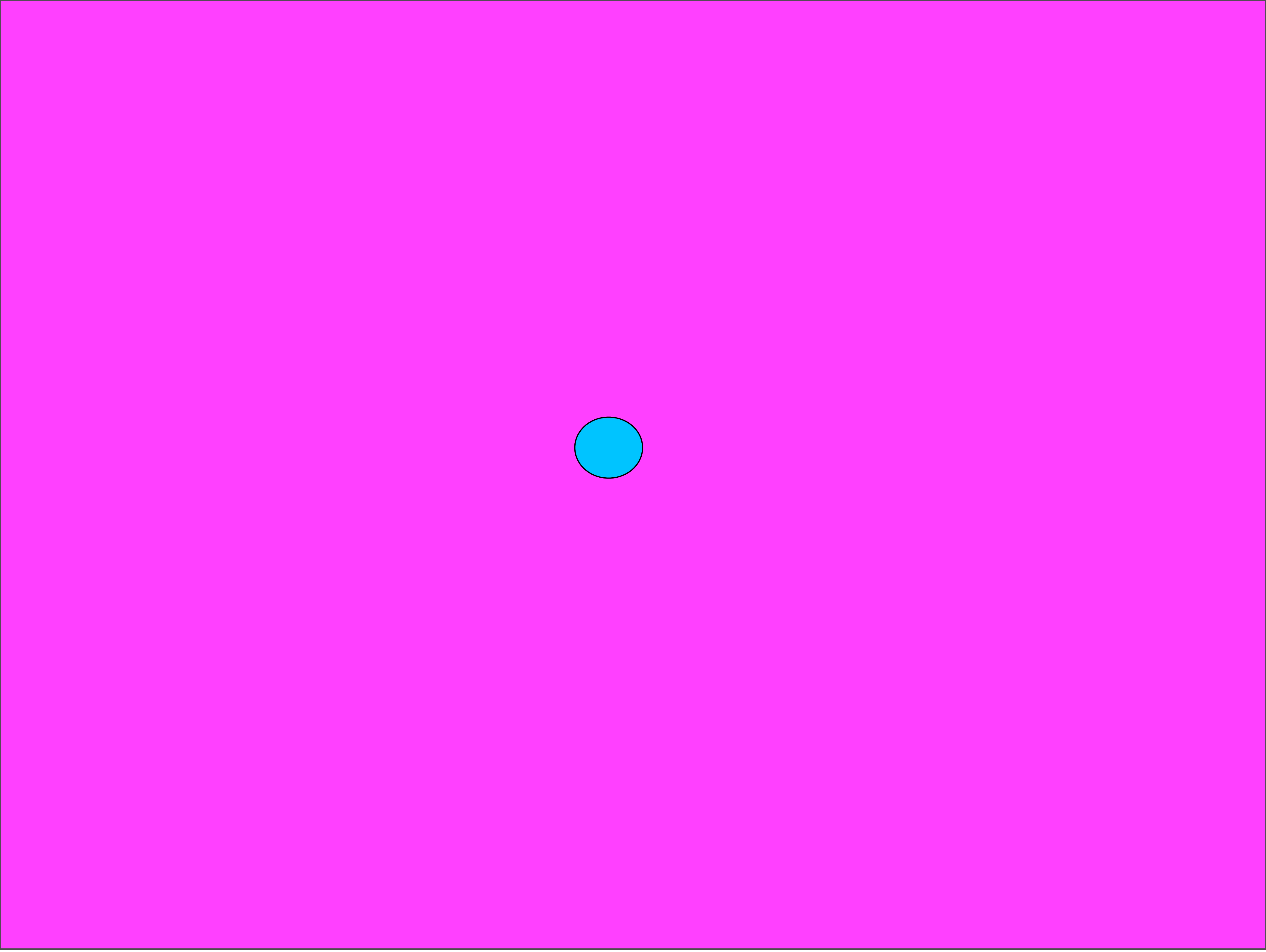


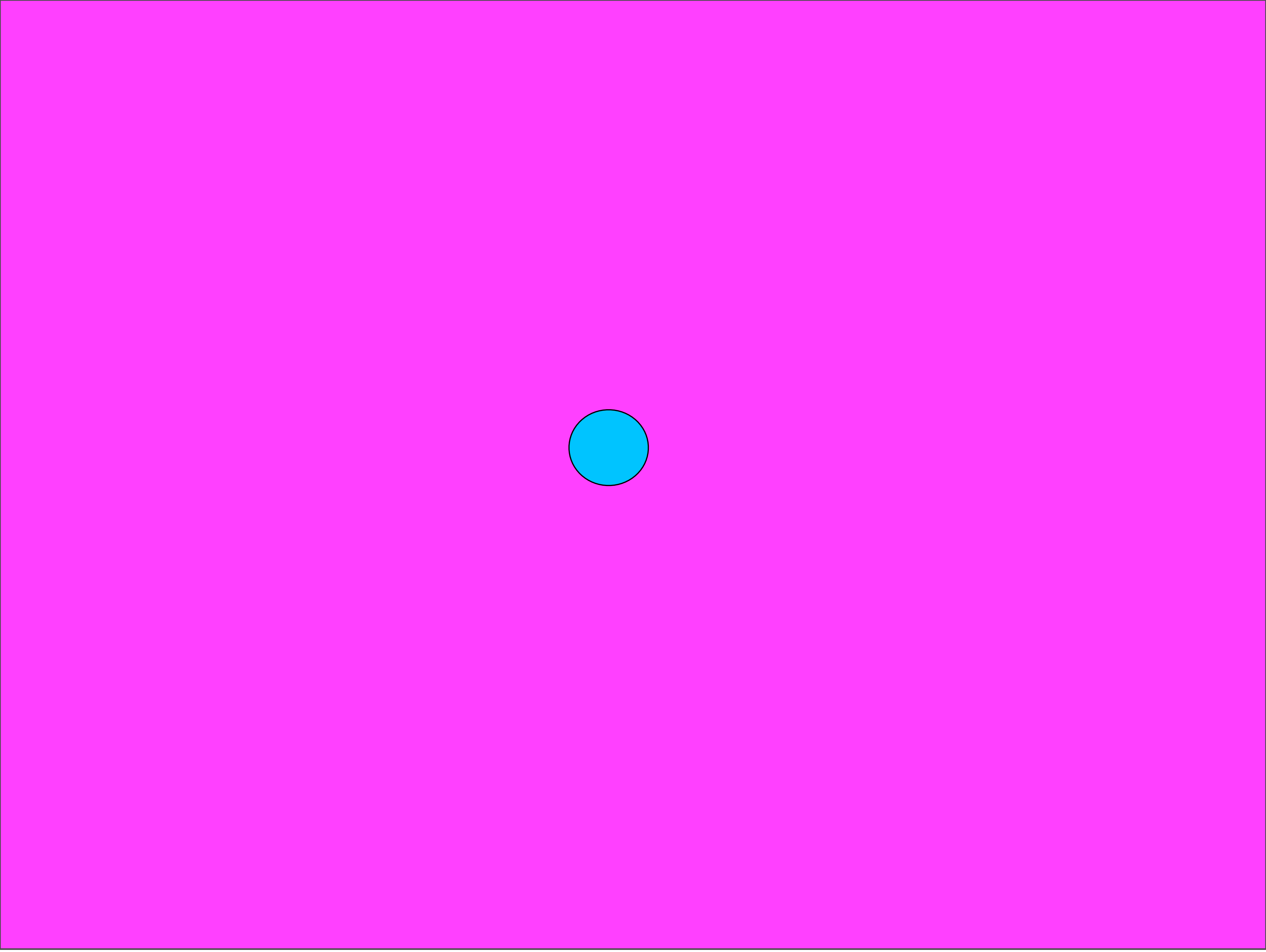


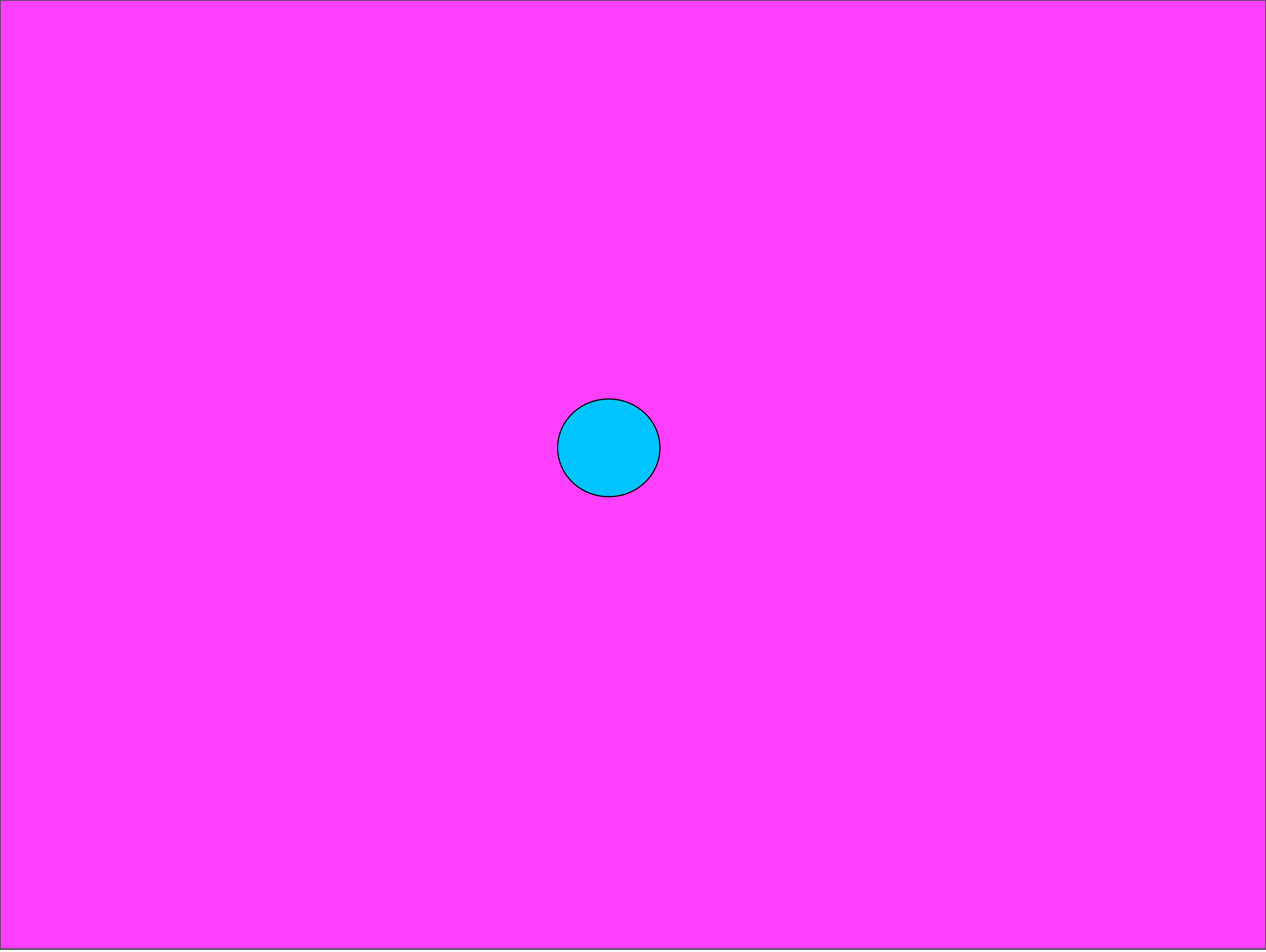


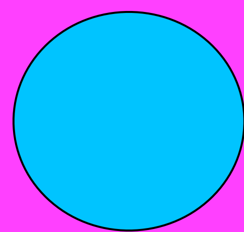


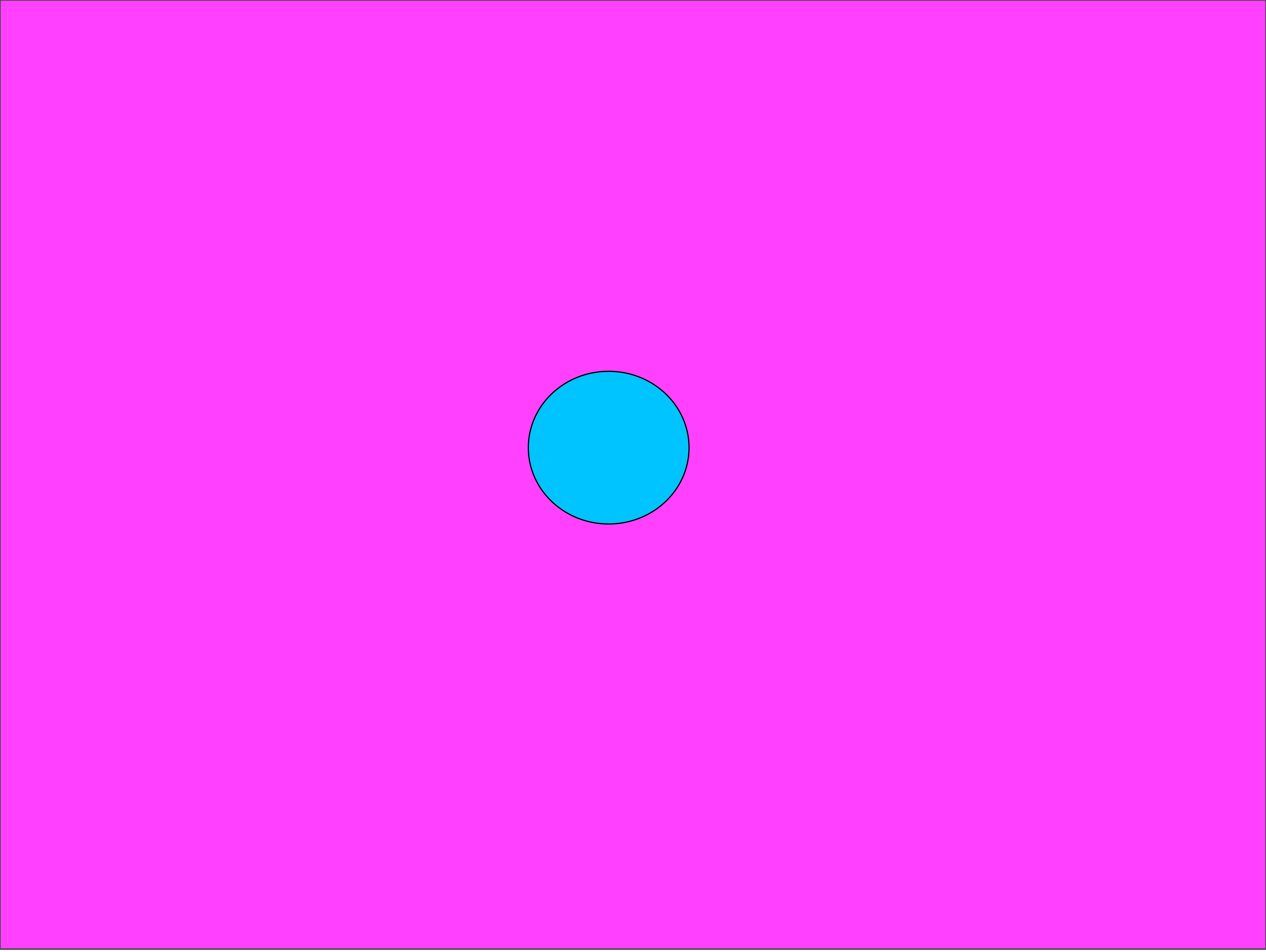


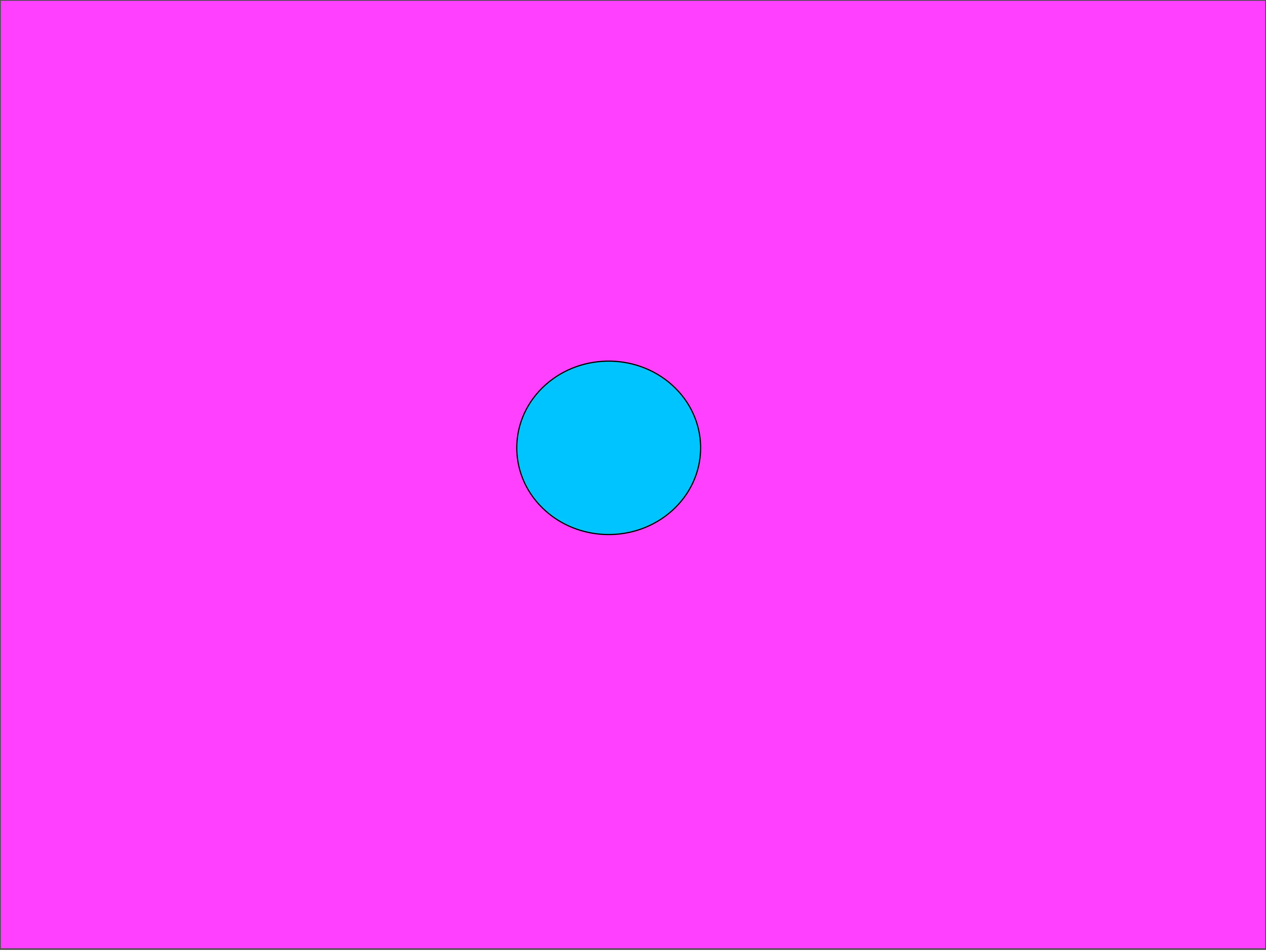




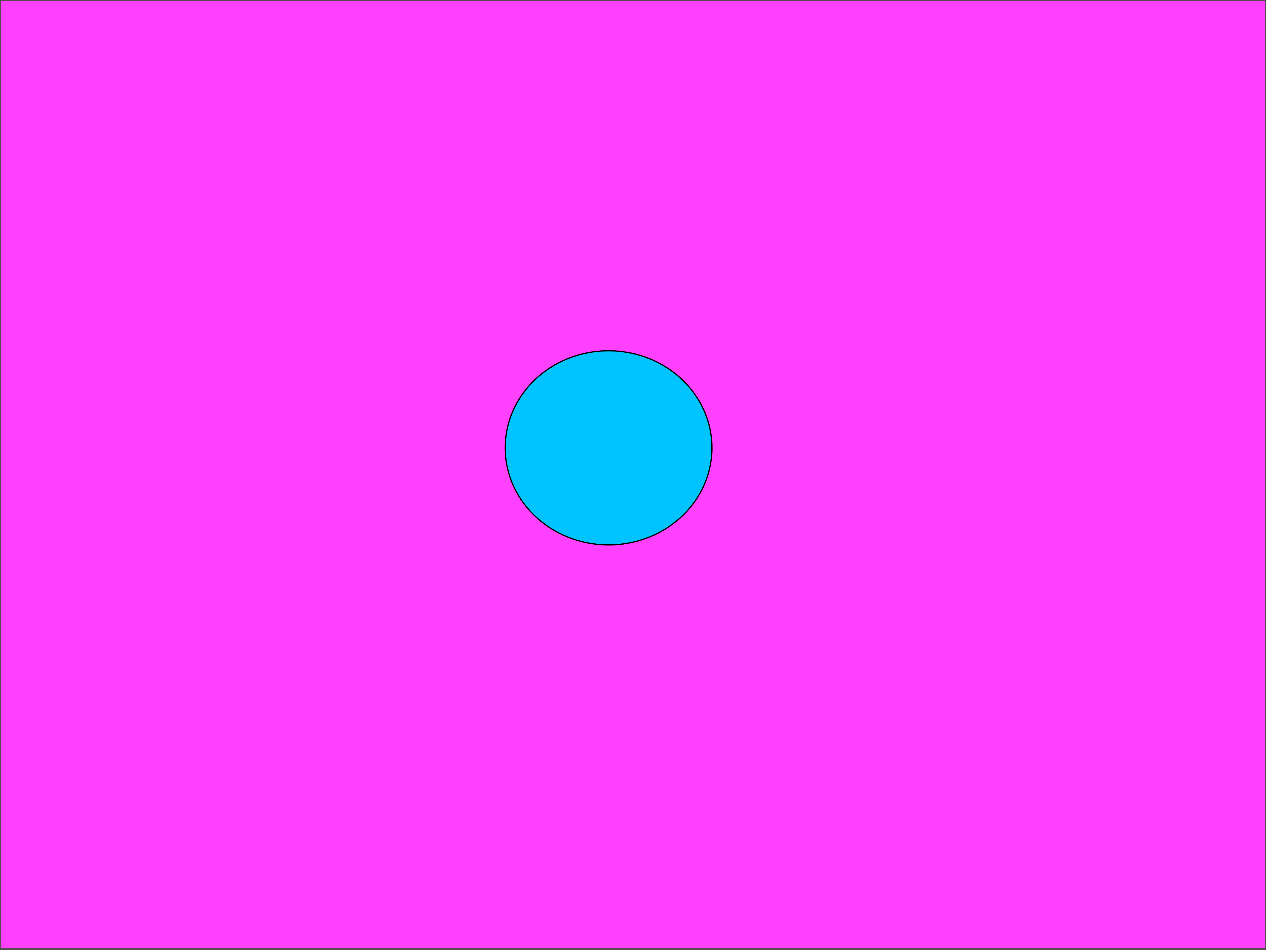


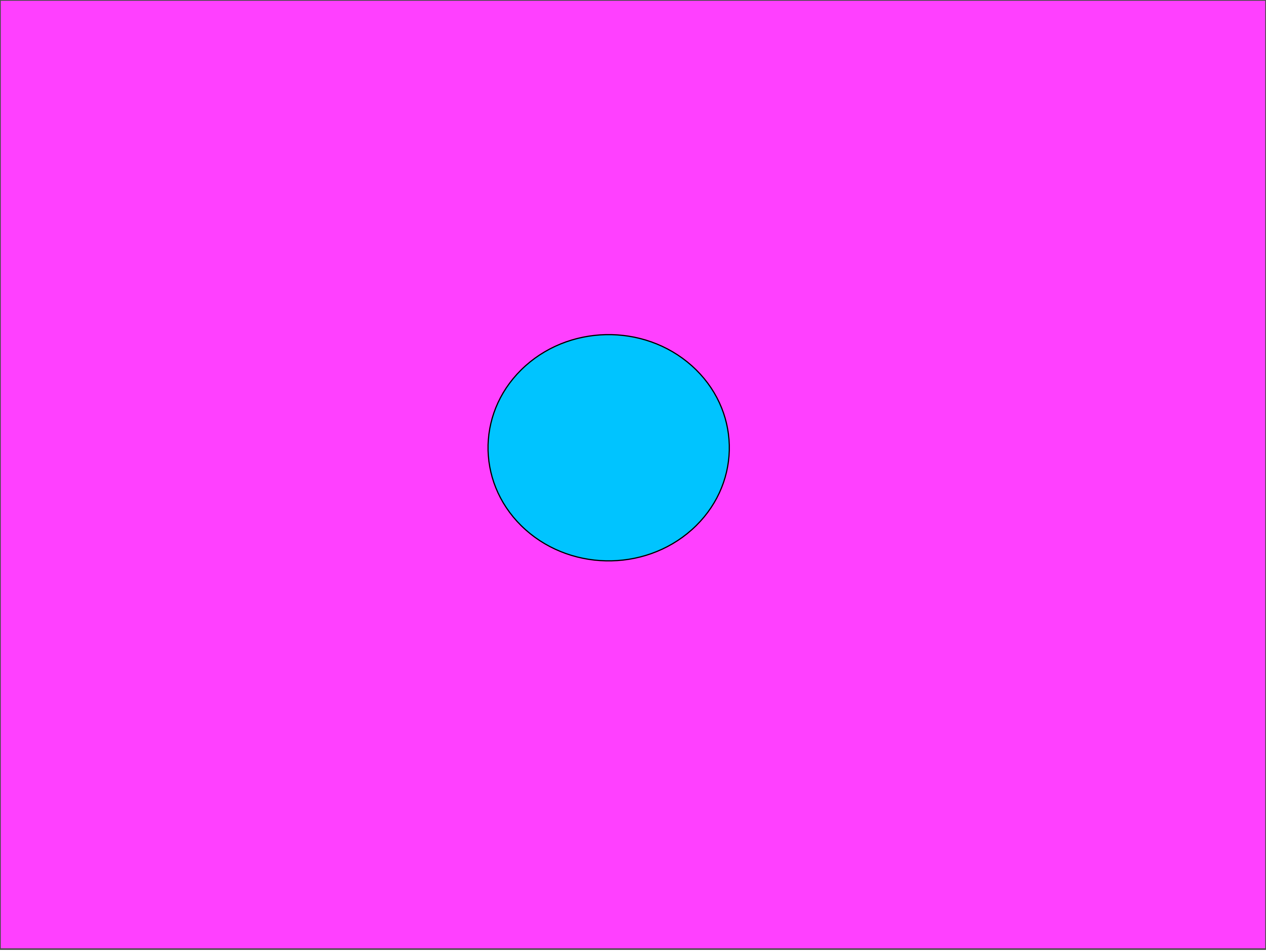


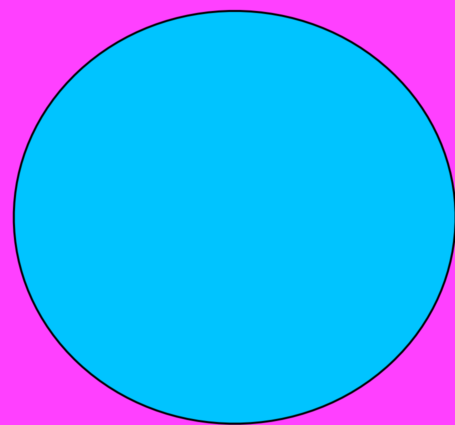


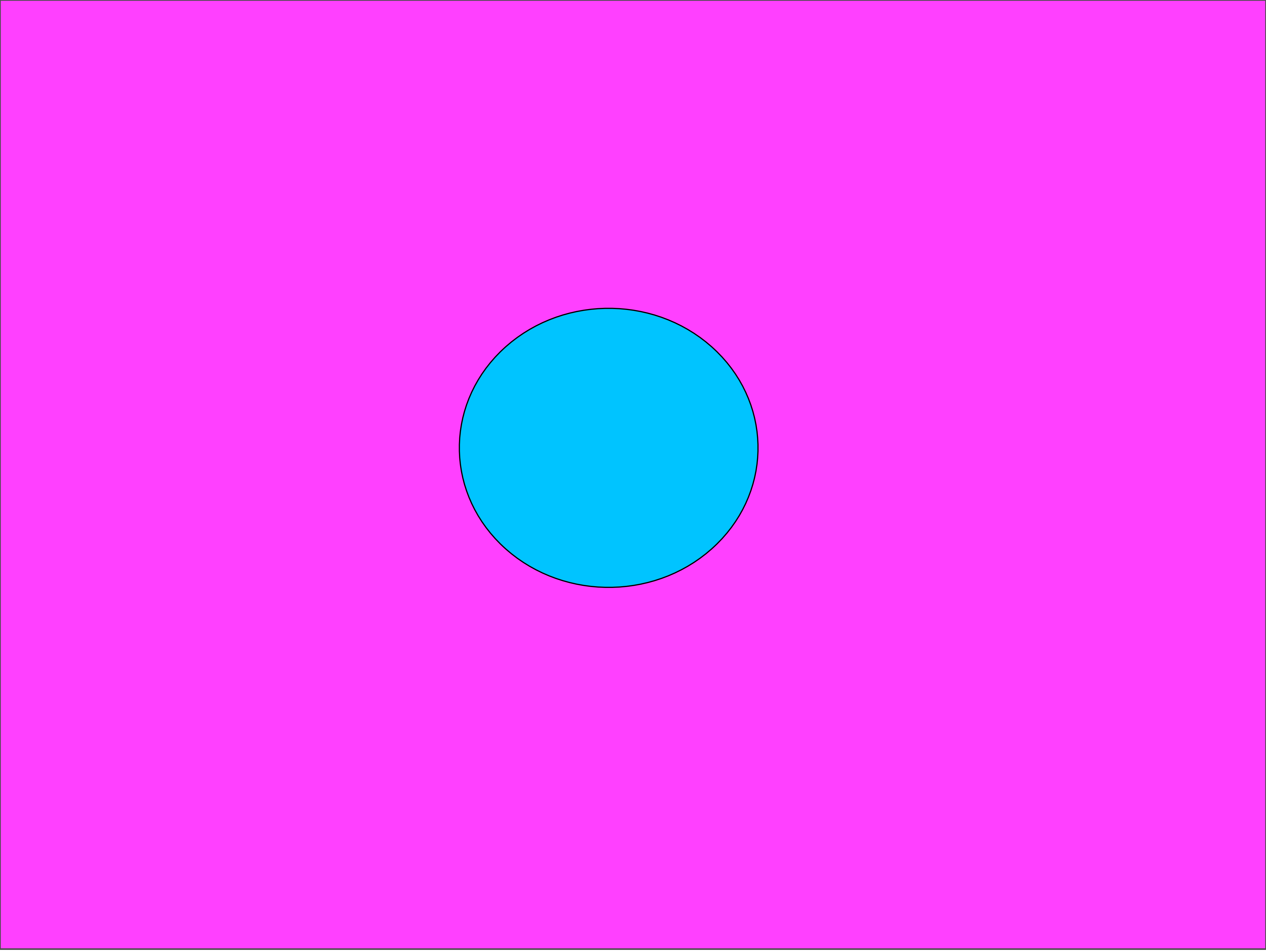


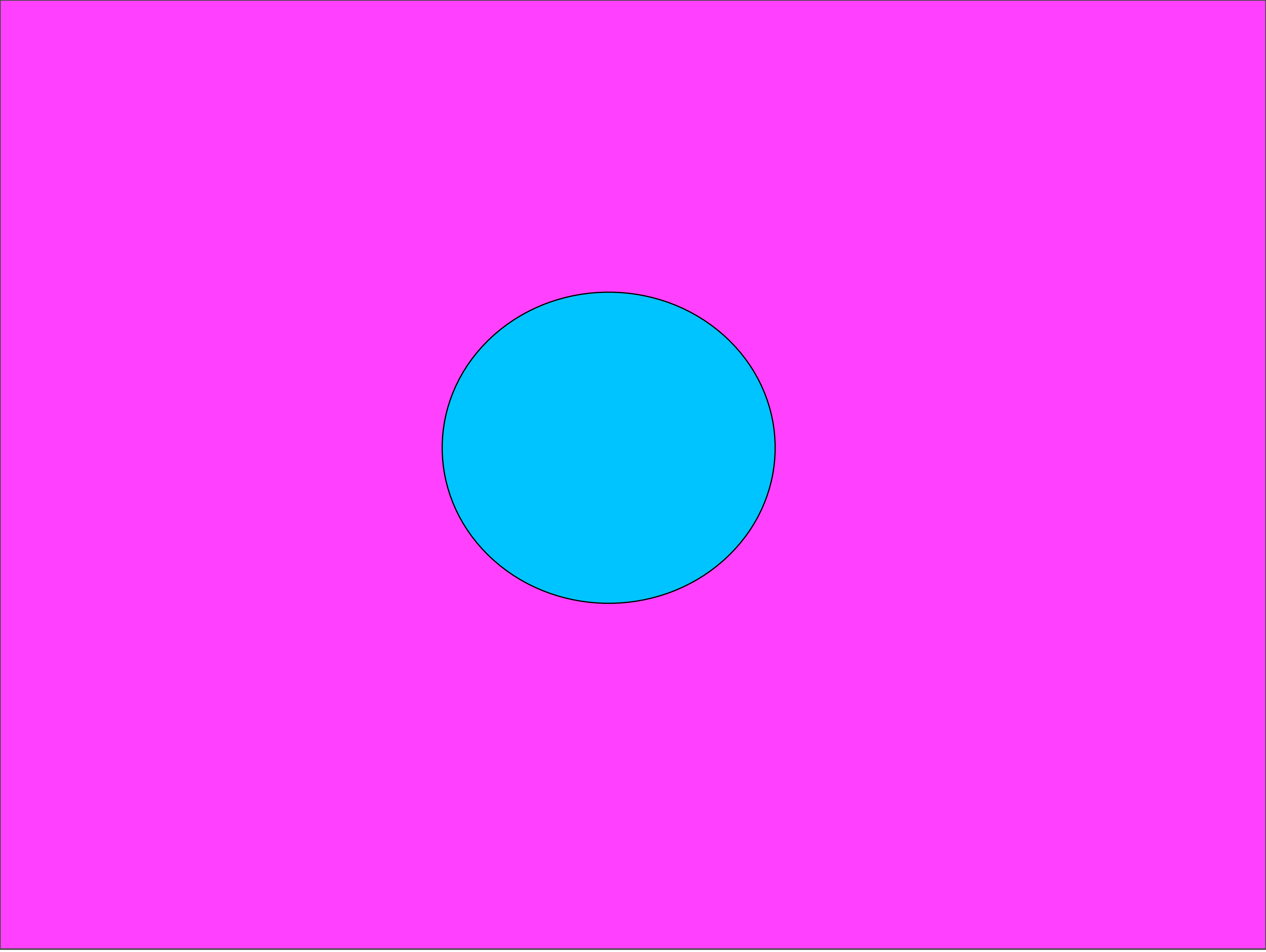
Wednesday, June 8, 2011

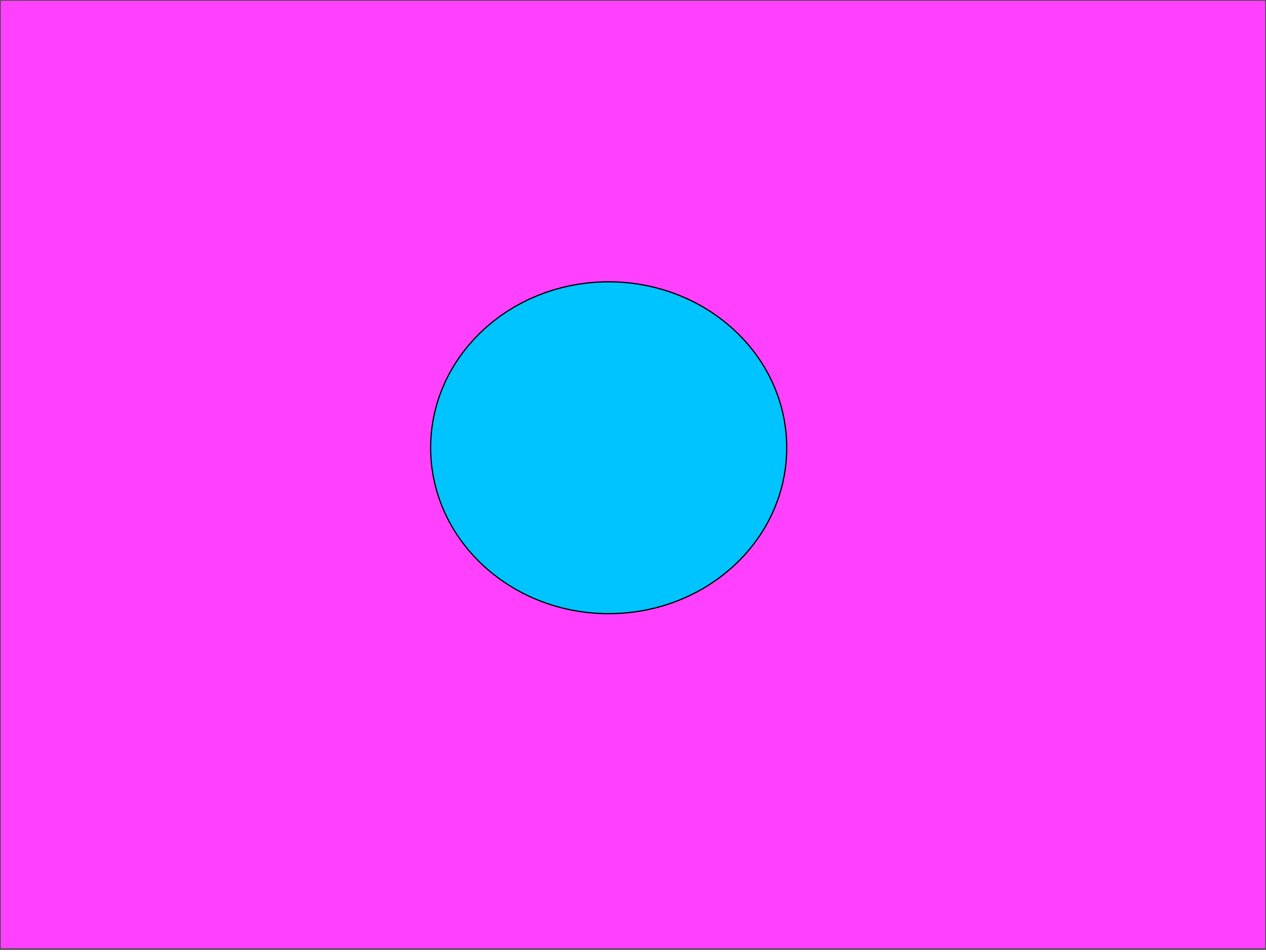


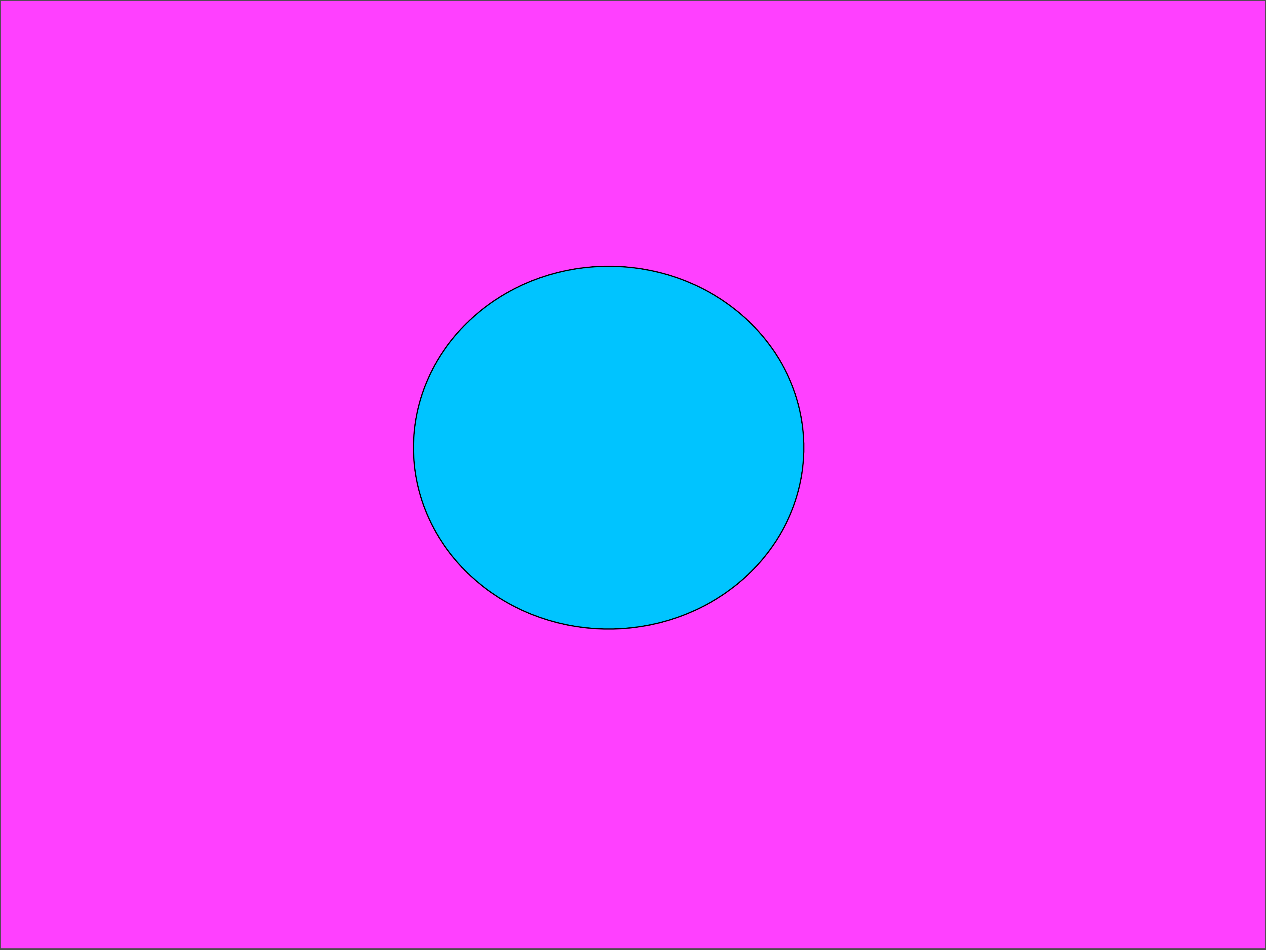


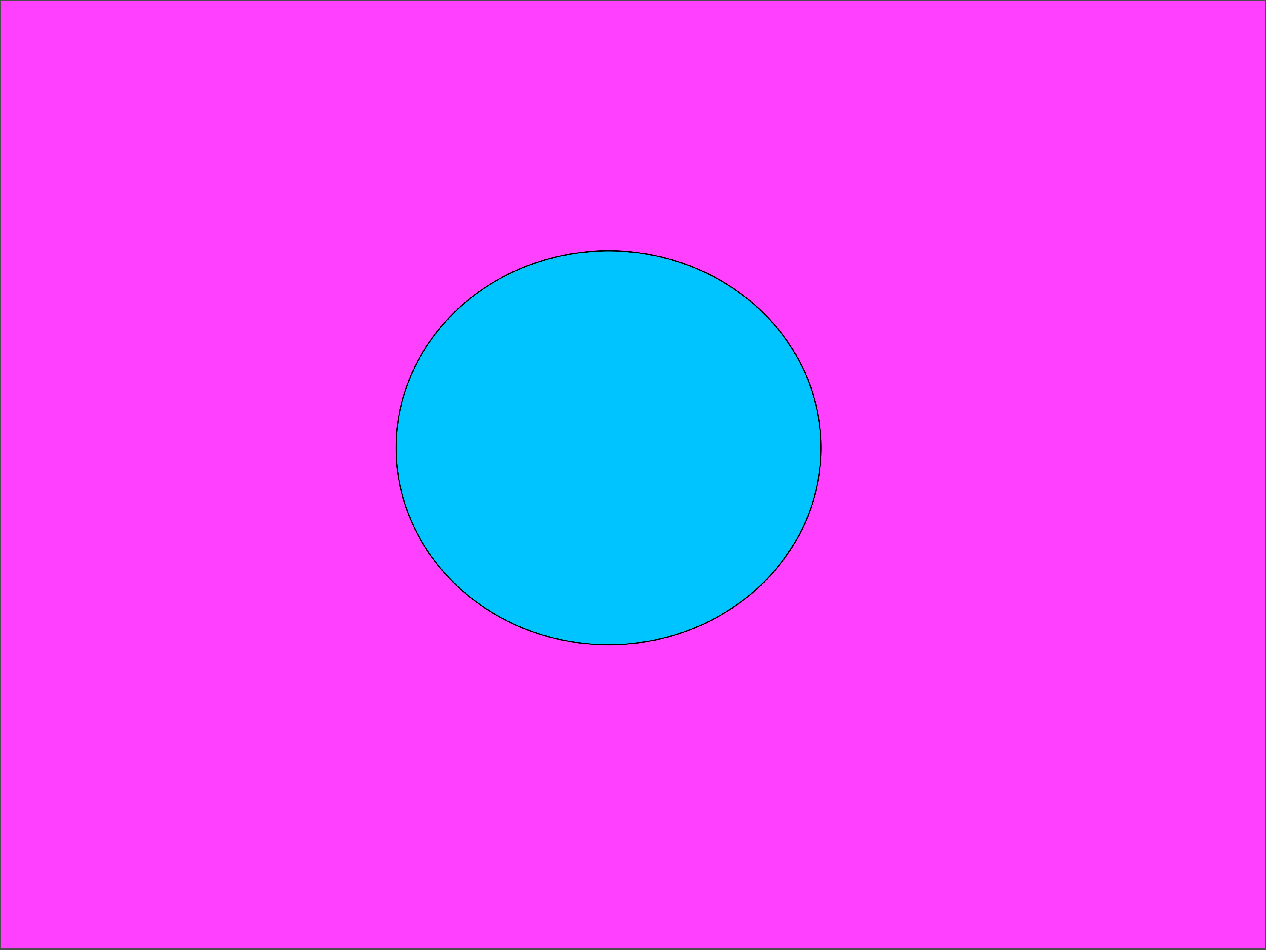


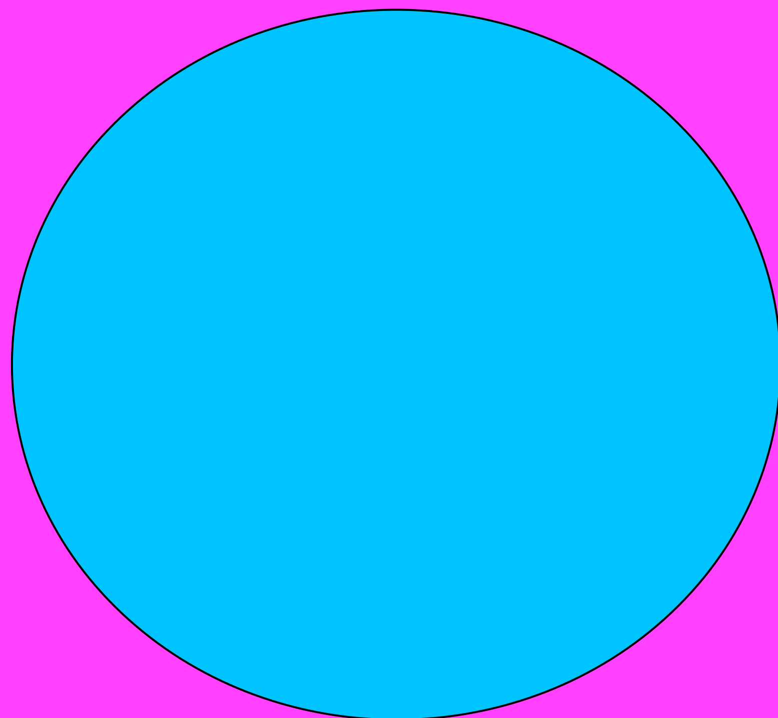


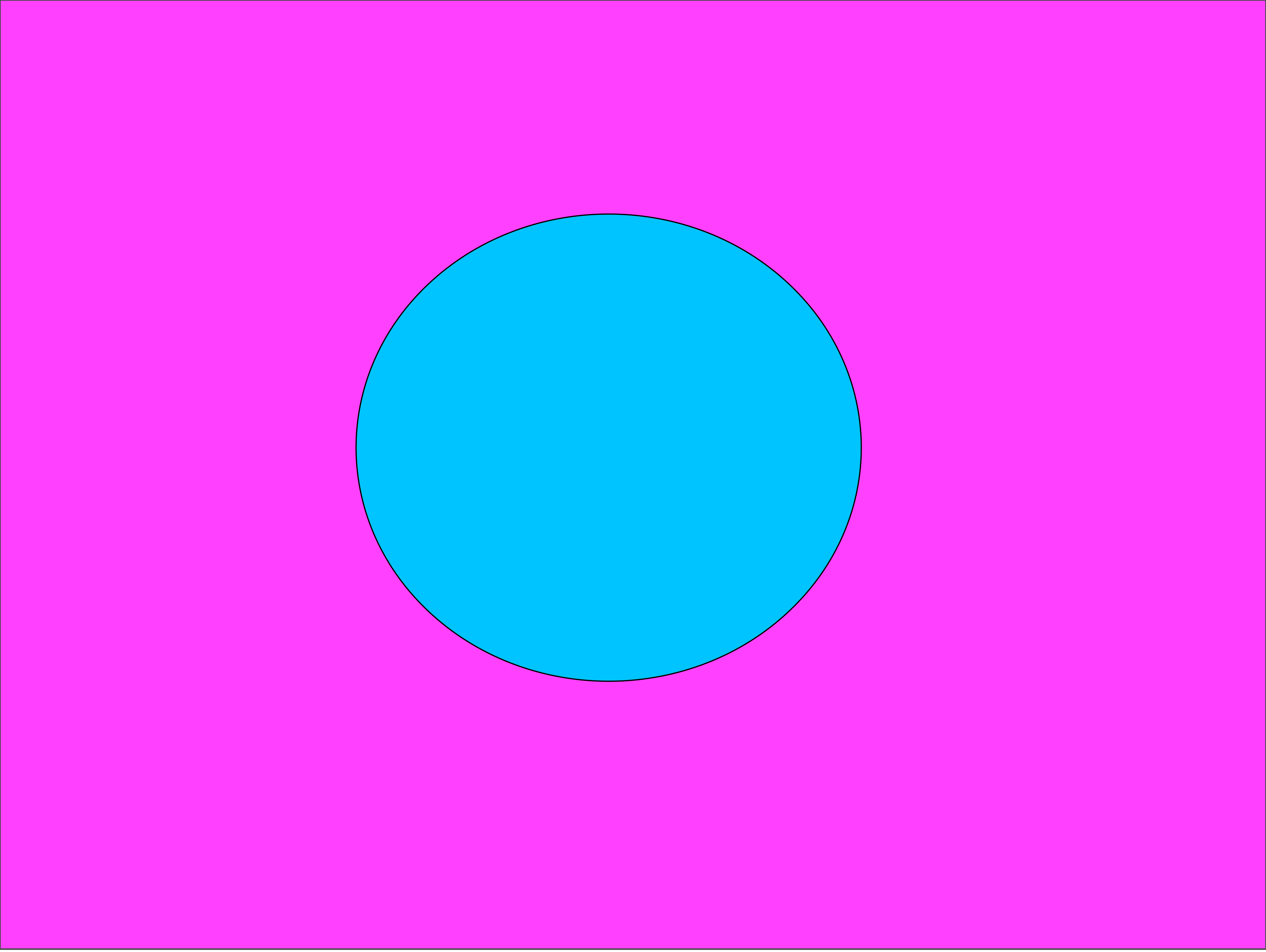


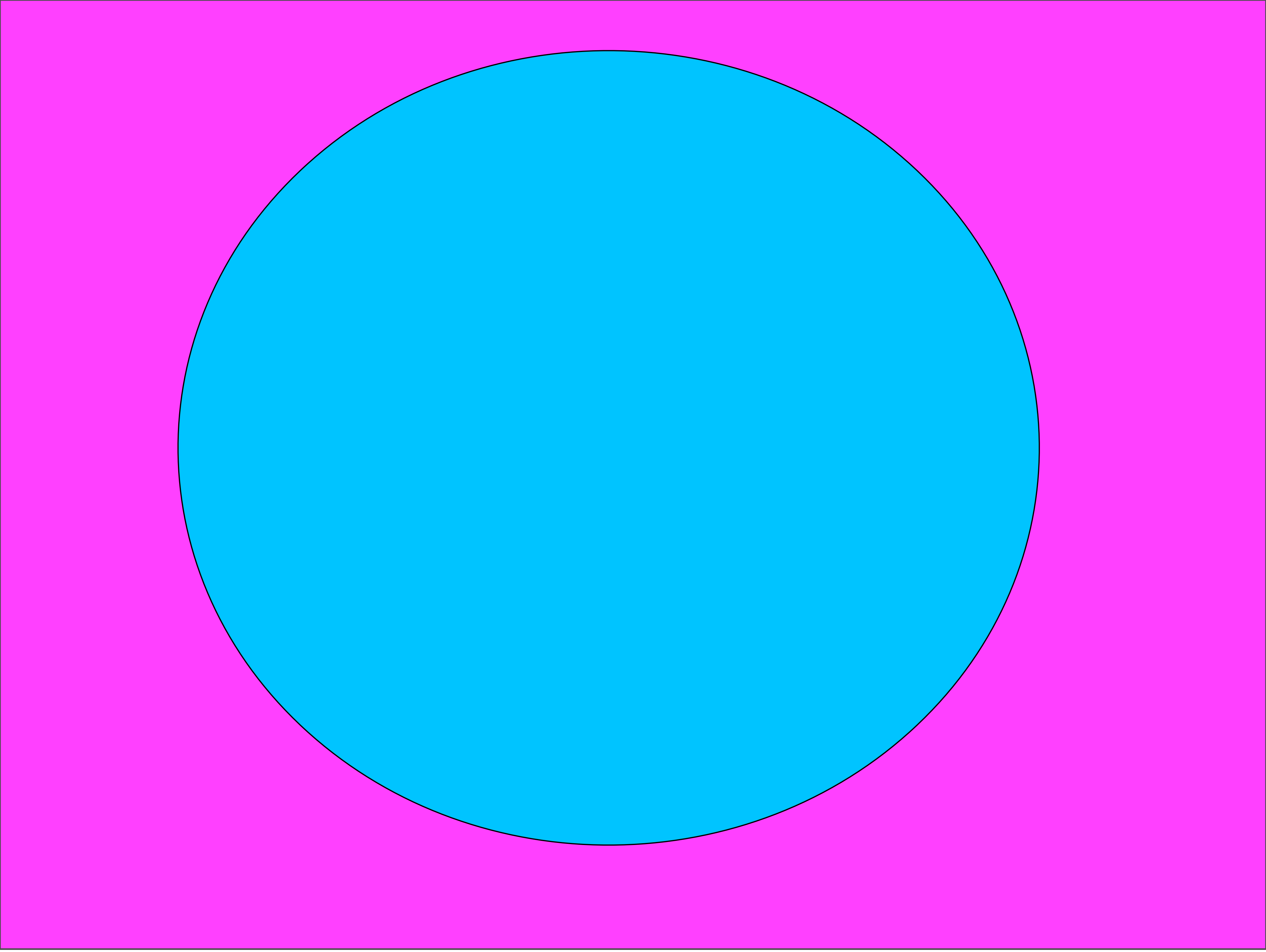


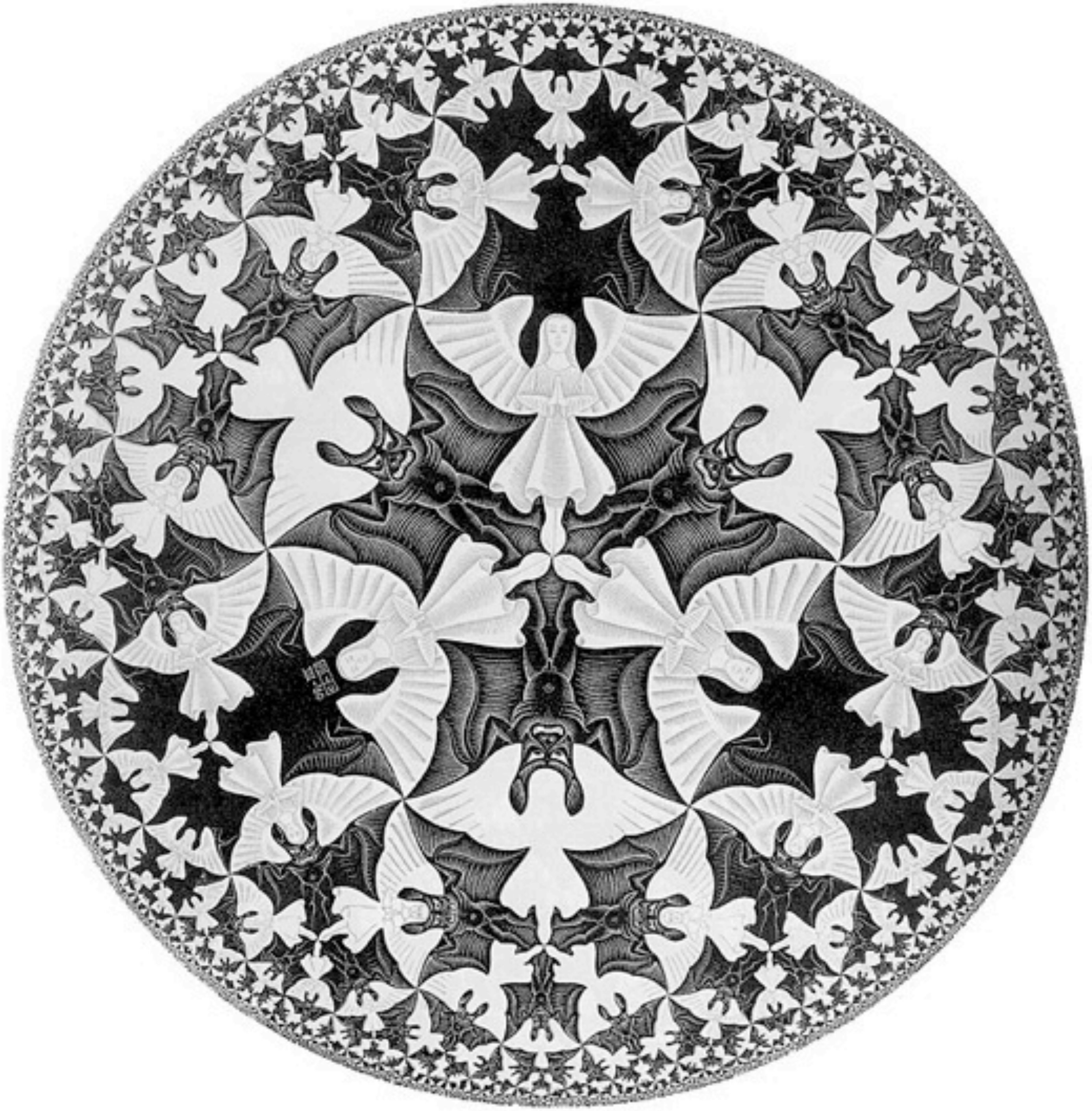




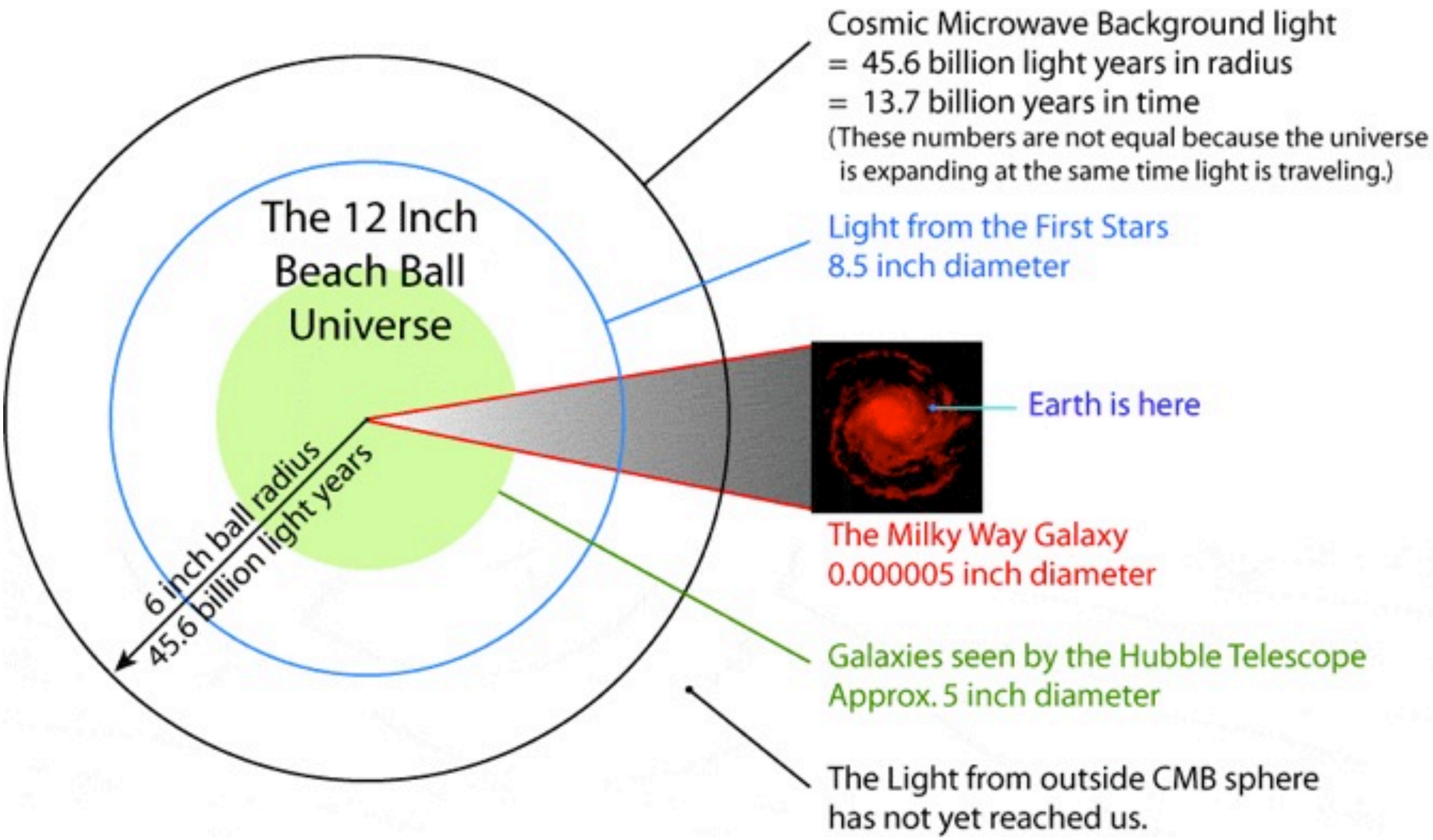




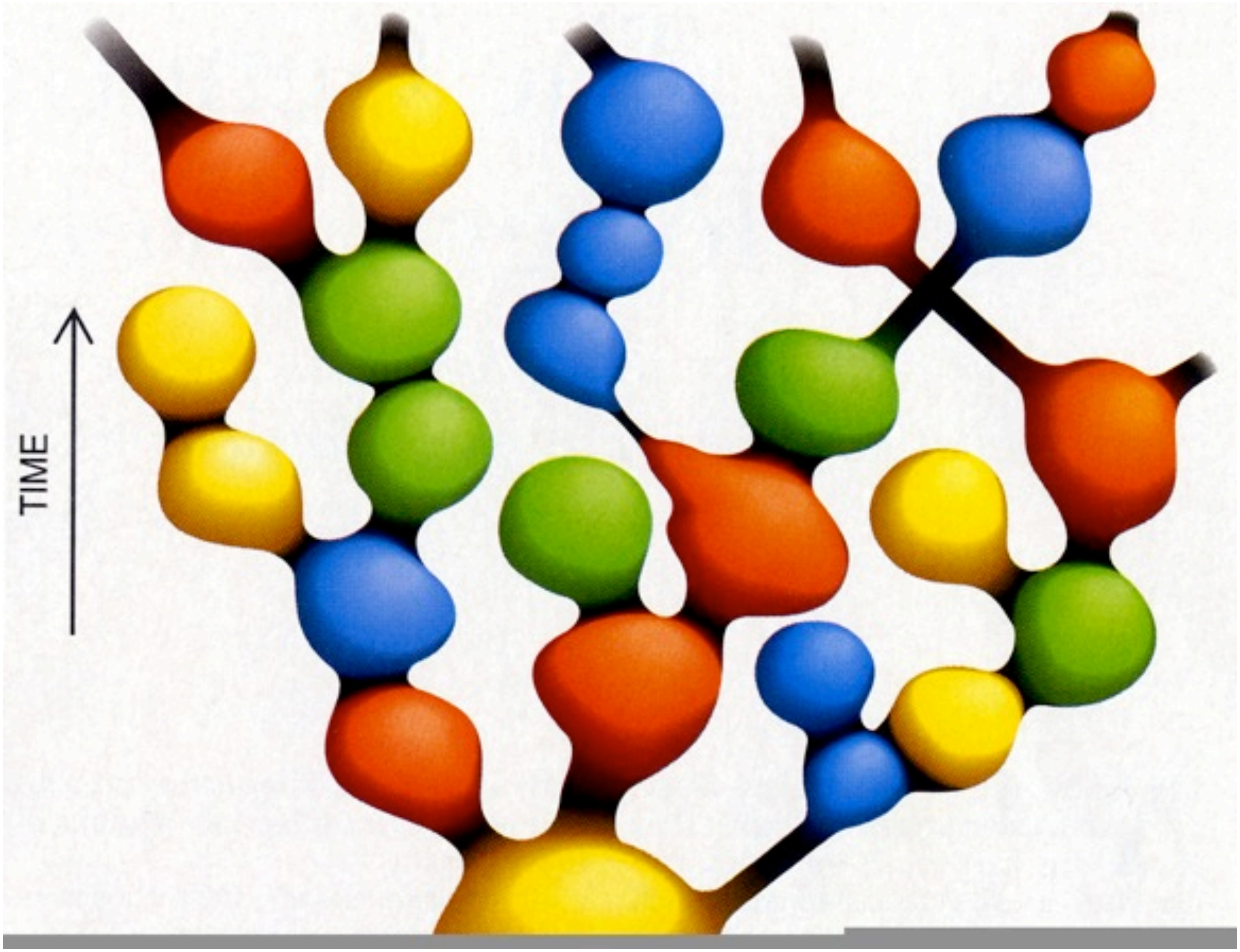


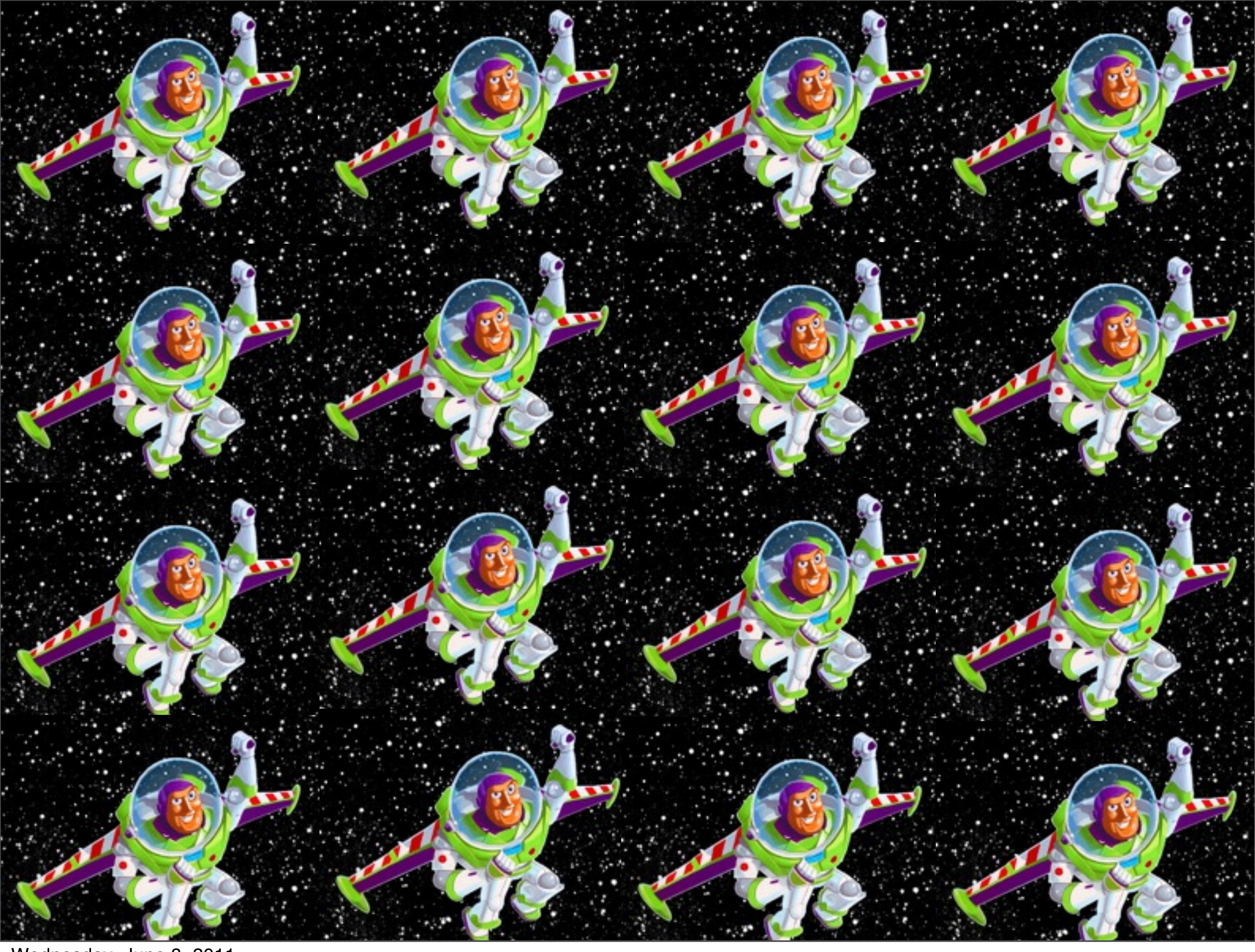


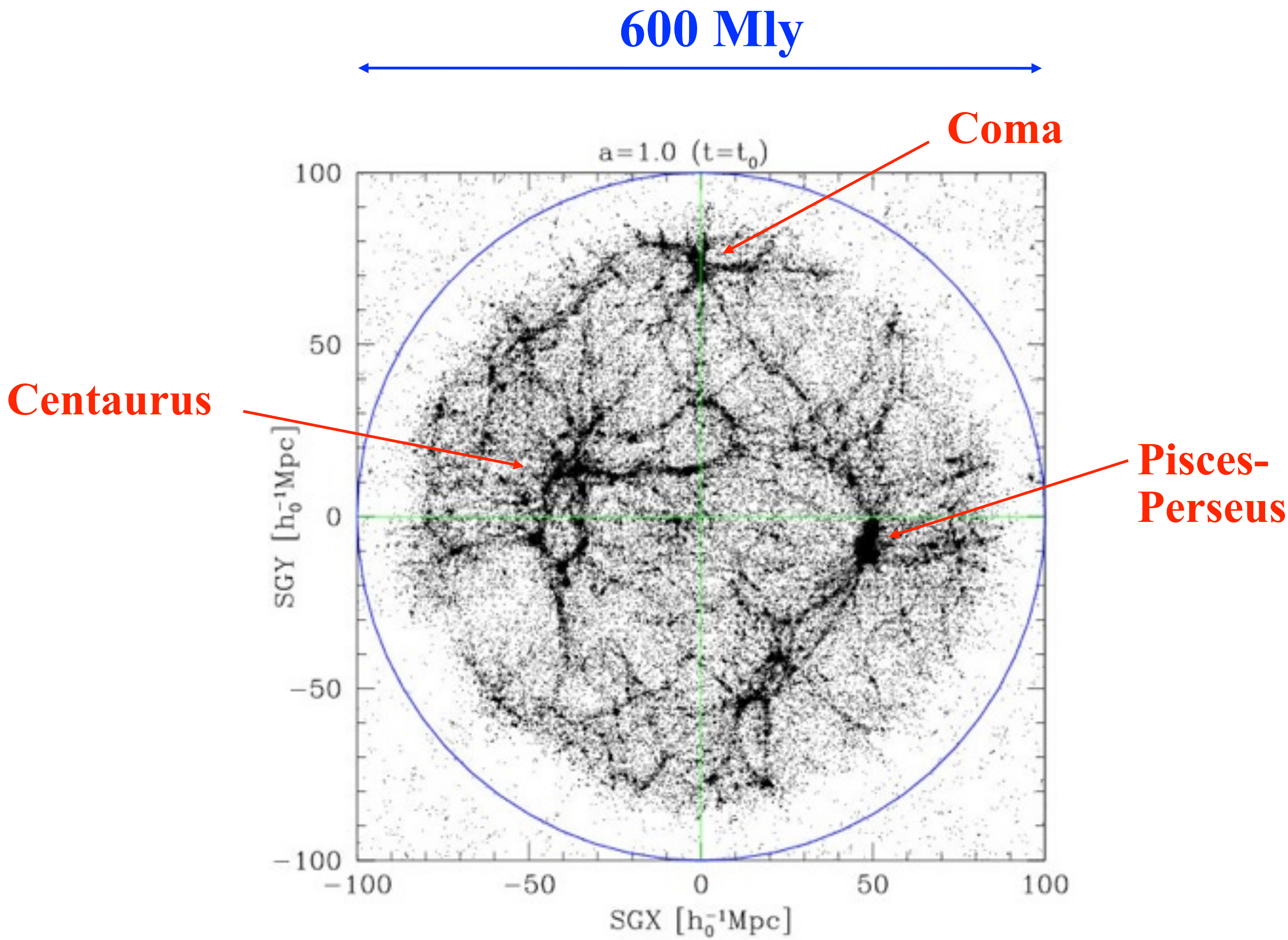
Is the Multiverse Science?

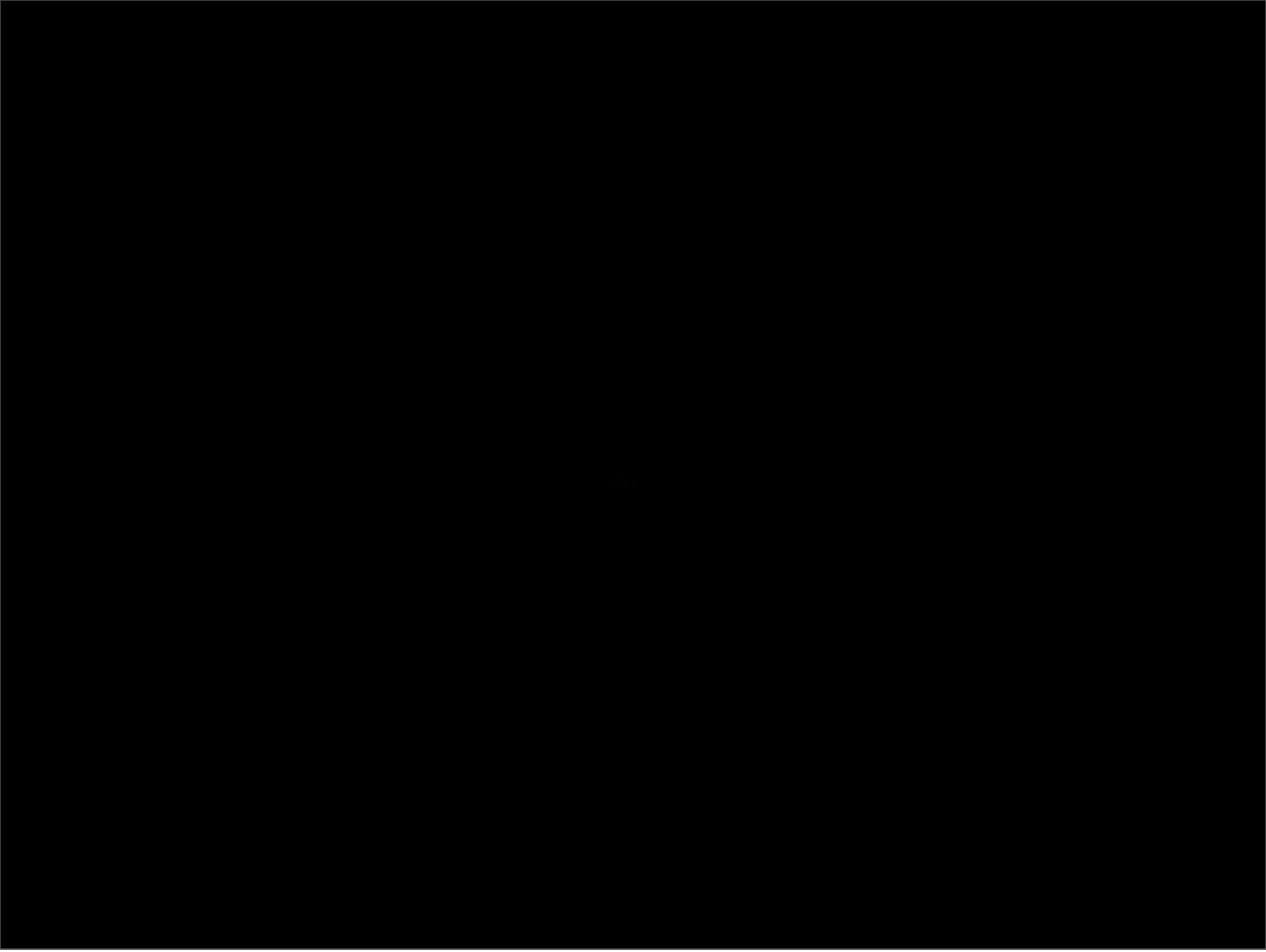


The Measure Problem






600 Mly
Coma
Centaurus
Pisces-
Perseus
a=1.0 (t=t_0)
100
50
0
−50
−100
SGY [h_0^{-1}Mpc]
−100
−50
0
50
100
SGX [h_0^{-1}Mpc]

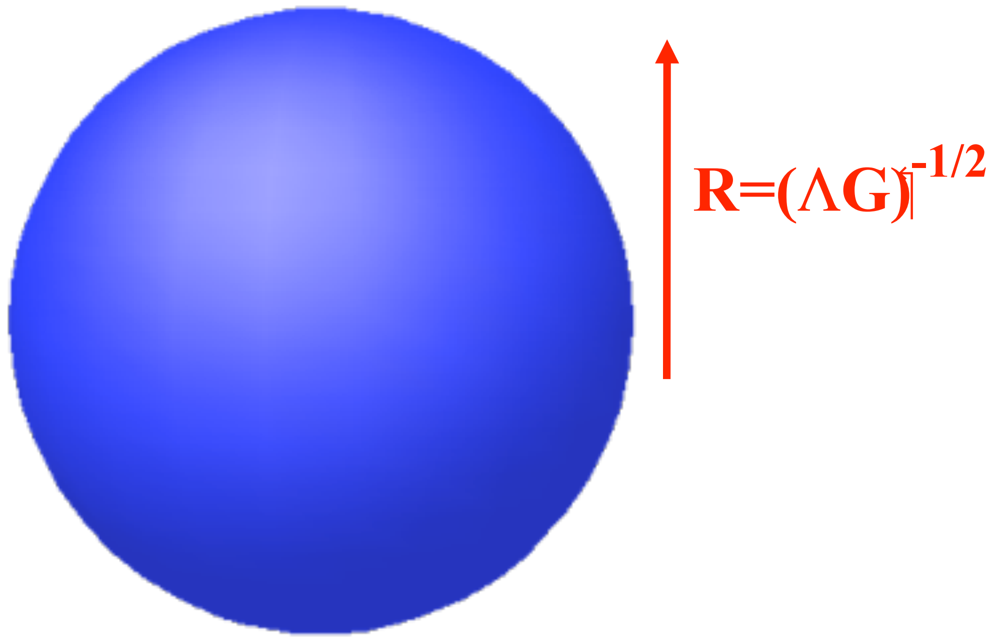


de Sitter space is a finite cavity with temperature

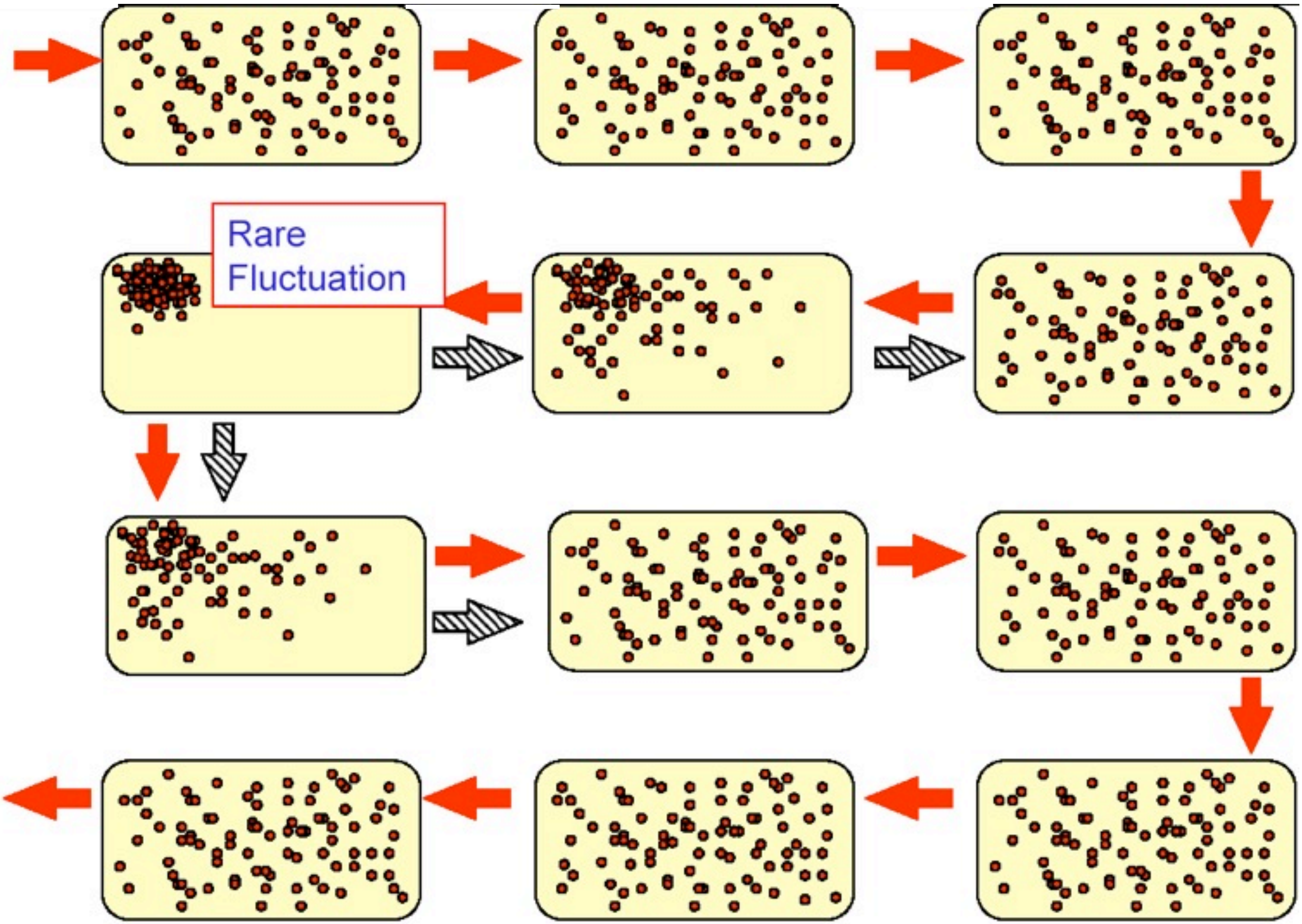
$$T = 1/2\pi R$$

and entropy

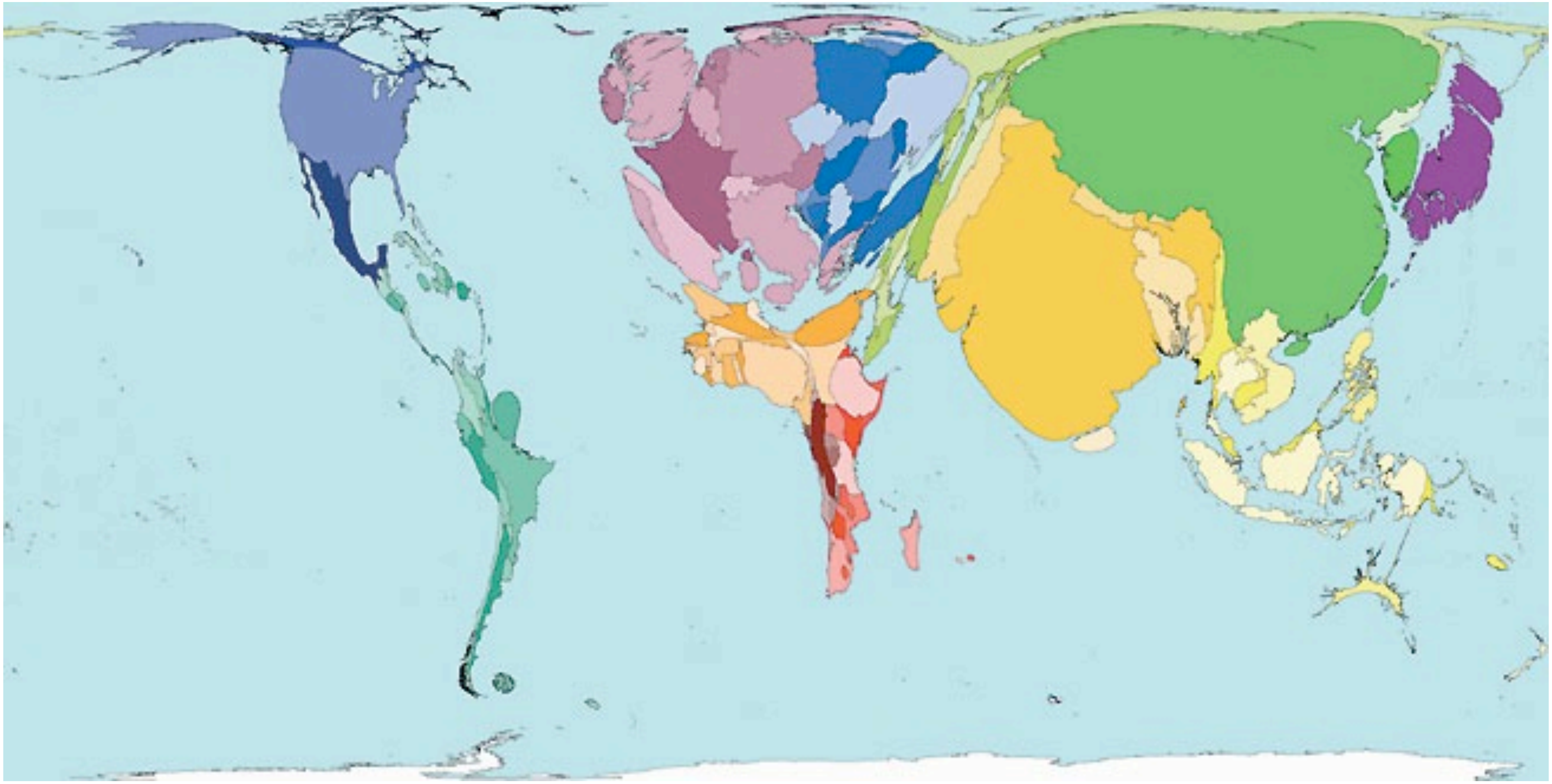
$$S = \pi R^2/G$$



Ludwig Boltzmann
1844-1906


Rare
Fluctuation

Are we asking the right question?



FERMIONS

matter constituents
spin = 1/2, 3/2, 5/2, ...

Leptons spin = 1/2		
Flavor	Mass GeV/c^2	Electric charge
ν_e electron neutrino	$<1\times10^{-8}$	0
e electron	0.000511	–1
ν_μ muon neutrino	<0.0002	0
μ muon	0.106	–1
ν_τ tau neutrino	<0.02	0
τ tau	1.7771	–1

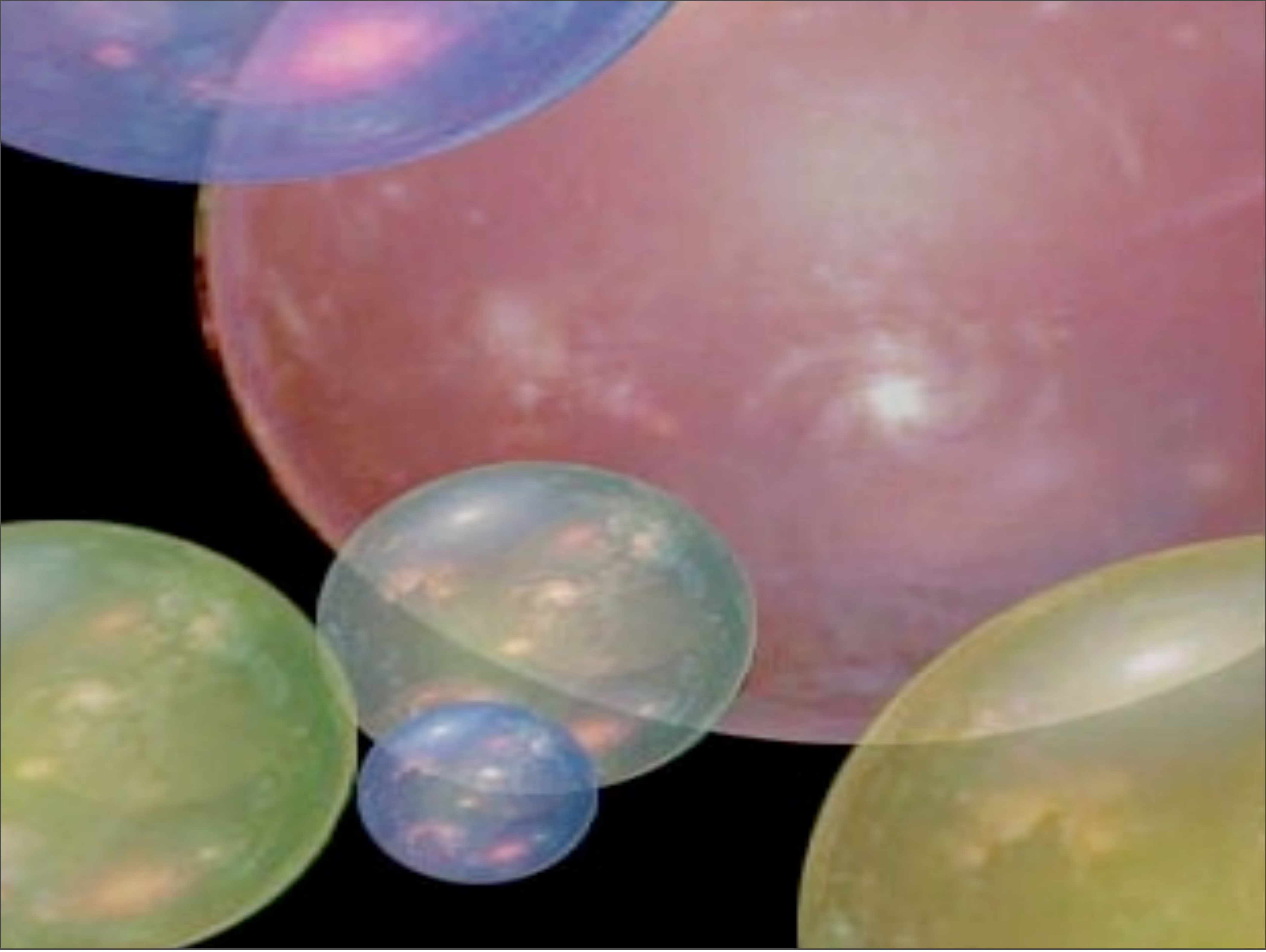
Quarks spin = 1/2		
Flavor	Approx. Mass GeV/c^2	Electric charge
u up	0.003	2/3
d down	0.006	–1/3
c charm	1.3	2/3
s strange	0.1	–1/3
t top	175	2/3
b bottom	4.3	–1/3

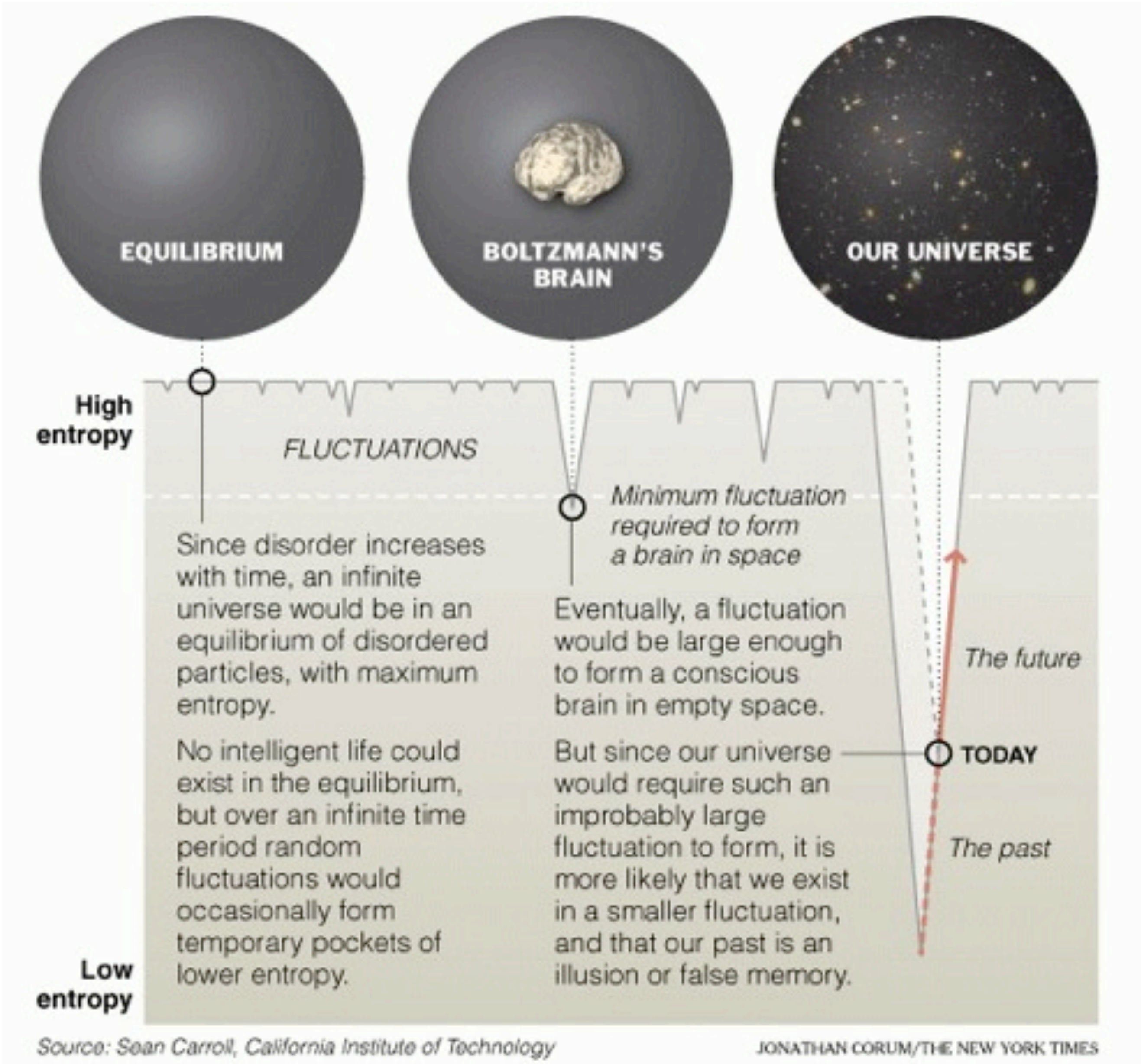
BOSONS

force carriers
spin = 0, 1, 2, ...

Unified Electroweak spin = 1		
Name	Mass GeV/c^2	Electric charge
γ photon	0	0
W^-	80.4	–1
W^+	80.4	+1
Z^0	91.187	0

Strong (color) spin = 1		
Name	Mass GeV/c^2	Electric charge
g gluon	0	0




EQUILIBRIUM
BOLTZMANN'S BRAIN
OUR UNIVERSE
High entropy
FLUCTUATIONS
Minimum fluctuation required to form a brain in space
Since disorder increases with time, an infinite universe would be in an equilibrium of disordered particles, with maximum entropy.
No intelligent life could exist in the equilibrium, but over an infinite time period random fluctuations would occasionally form temporary pockets of lower entropy.
Eventually, a fluctuation would be large enough to form a conscious brain in empty space.
But since our universe would require such an improbably large fluctuation to form, it is more likely that we exist in a smaller fluctuation, and that our past is an illusion or false memory.
The future
TODAY
The past
Low entropy
Source: Sean Carroll, California Institute of Technology
JONATHAN CORUM/THE NEW YORK TIMES