

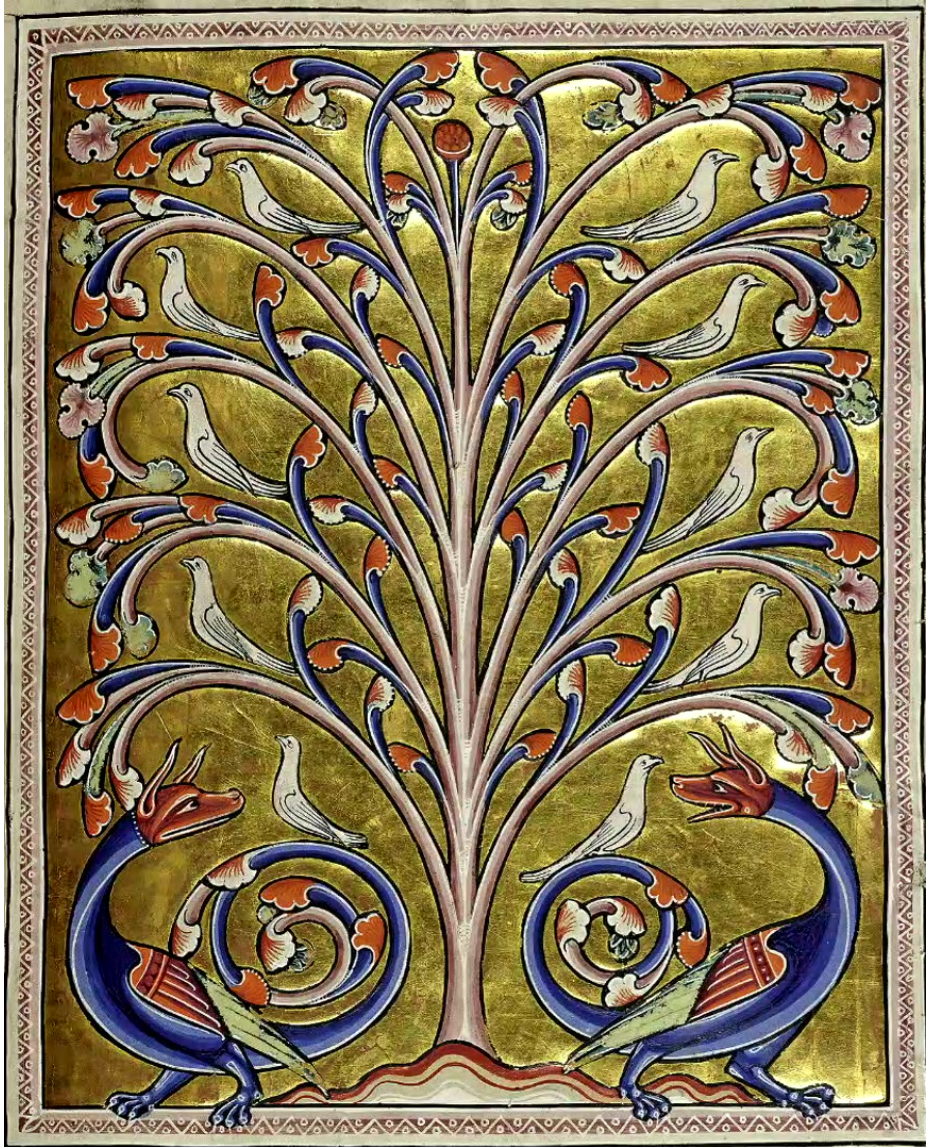
Title: Dark Matter and Particle Physics

Speakers: Luna Zagorac

Collection: Scicomm Collider

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# A Bestiary OF Dark Matter Candidates



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@cosmoloony

# A BRIEF OVERVIEW



The standard model particle zoo

The concordance model and dark matter

- ❖ Motivation
- ❖ Baryonic or non-baryonic?
- ❖ Hot, warm, or cold?

(Some) popular candidates for dark matter

# The Standard Model



## Particle Zoo

# The Standard Model

Force / Bosons

Matter / Fermions

# The Standard Model

## Force / Bosons

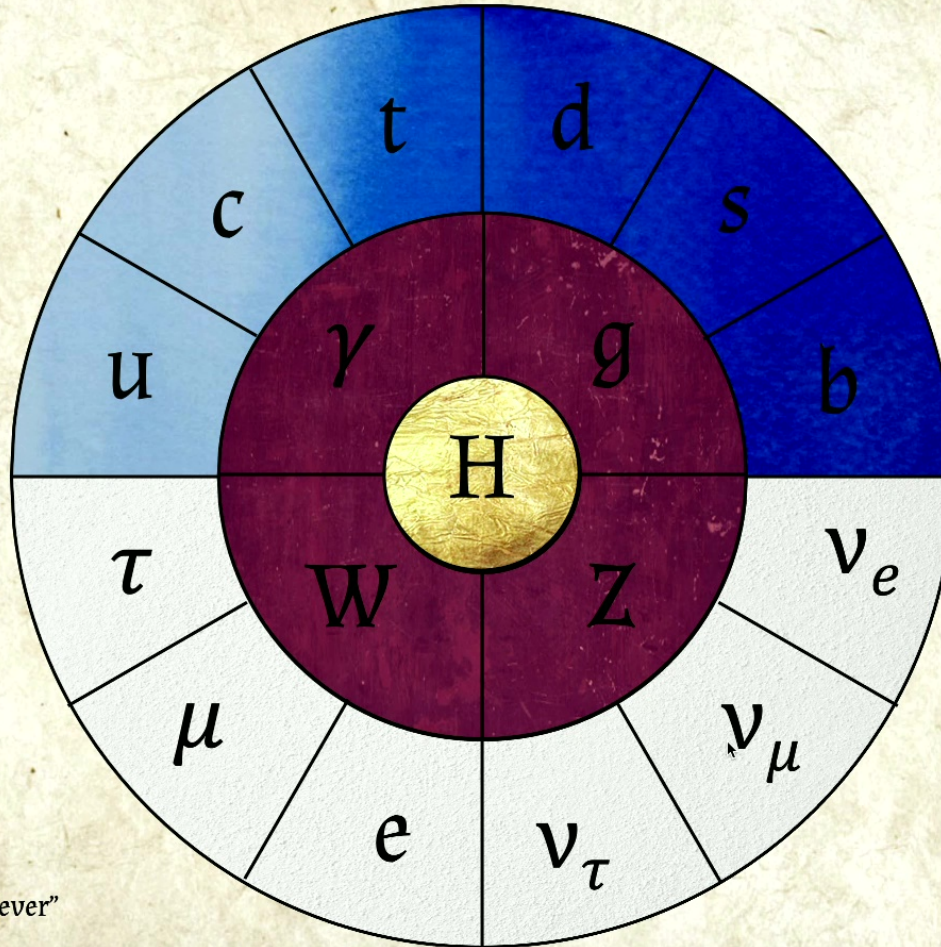
H = Higgs boson

$\gamma$  photon

$g$  gluon

W, Z-bosons

Inspiration from the film "Particle Fever"  
via Quanta Magazine



## Matter / Fermions

u, c, t  
d, s, b quarks

e,  $\mu$ ,  $\tau$  charged leptons

$\nu_e, \nu_\mu, \nu_\tau$  neutral leptons

# Takeaway: what is a baryon?



**Baryons:** a type of composite subatomic particles which contains an odd number of valence quarks and are subject to the strong force.

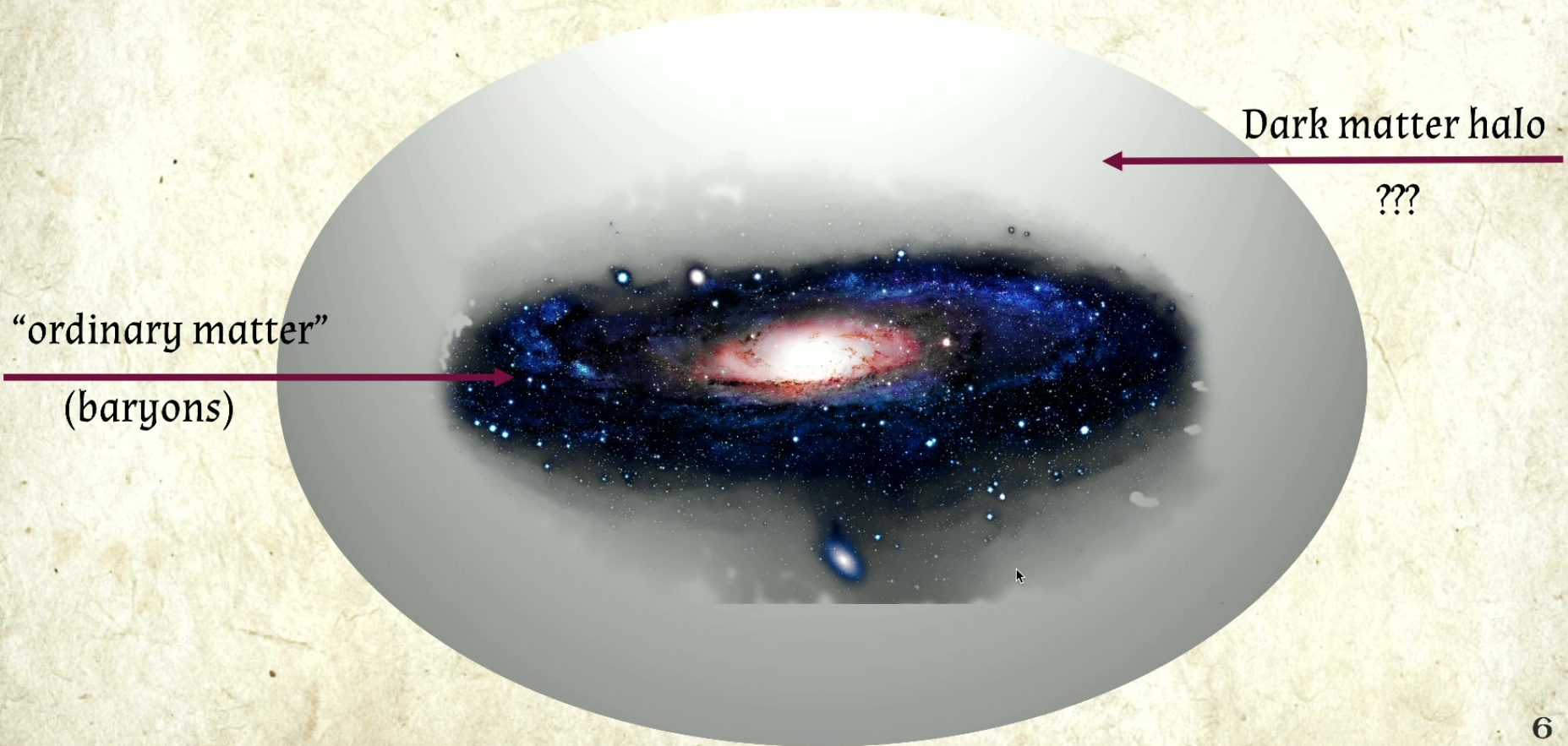
— a particle physicist



**Baryons:** “ordinary matter.”

— a cosmologist

# Takeaway: what is a baryon?



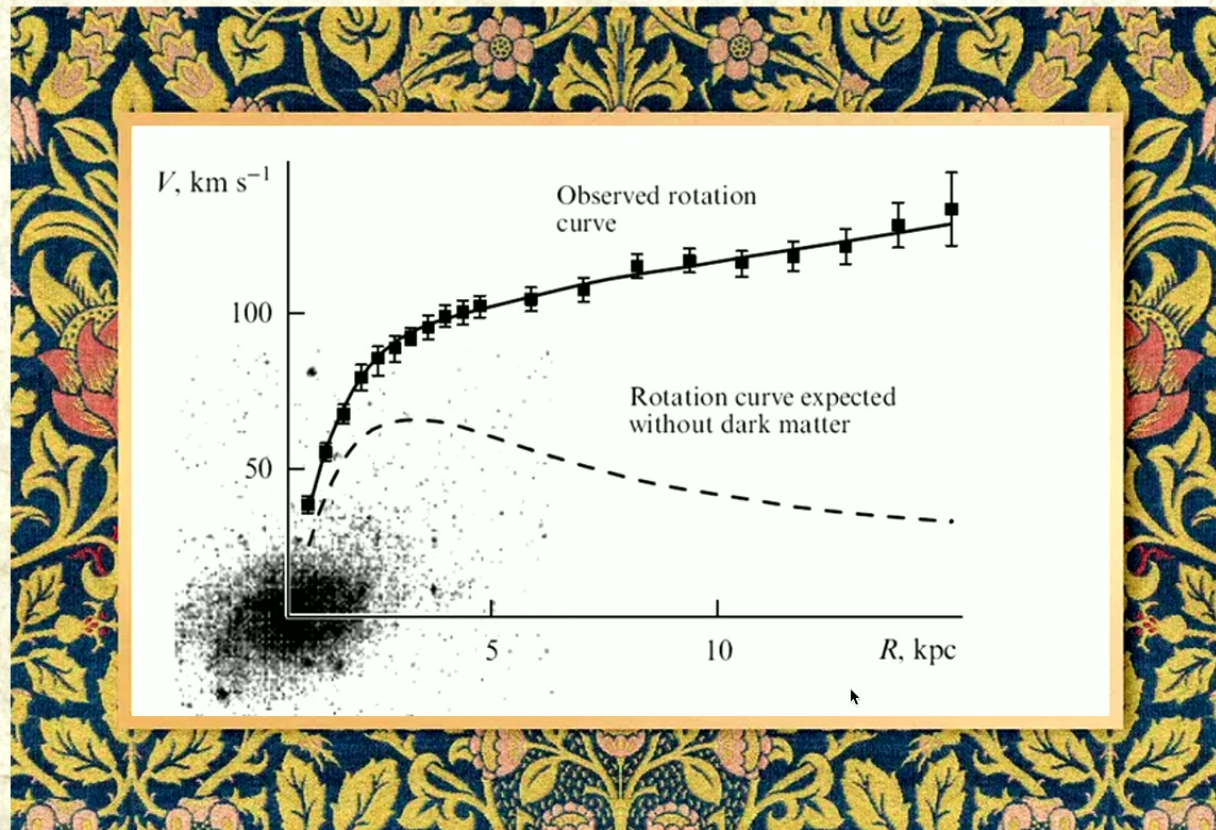


# The Concordance Model



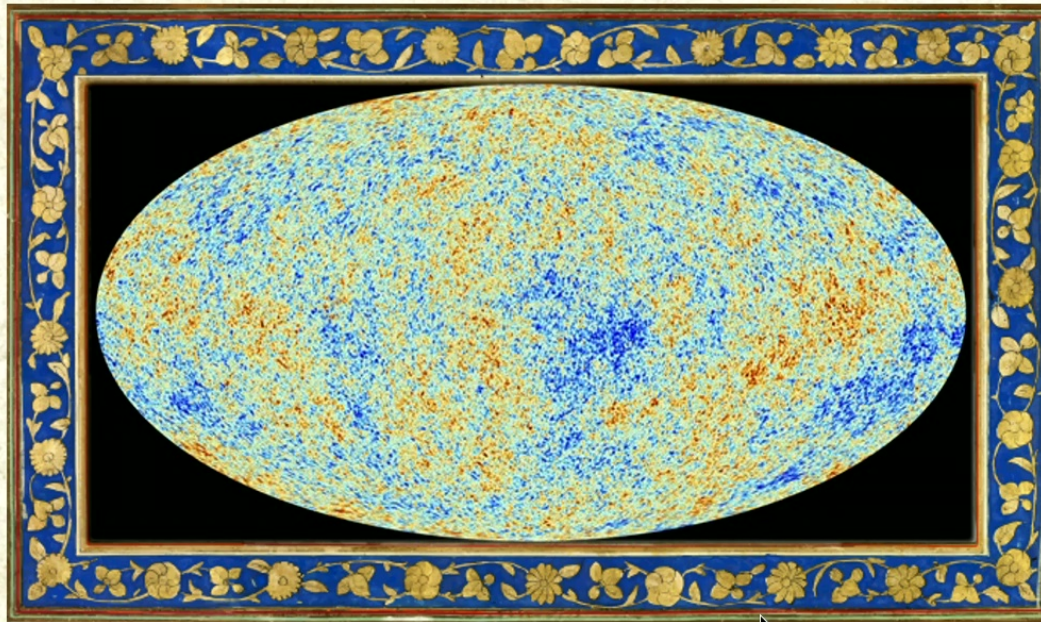
& Dark Matter

# Motivation for dark matter



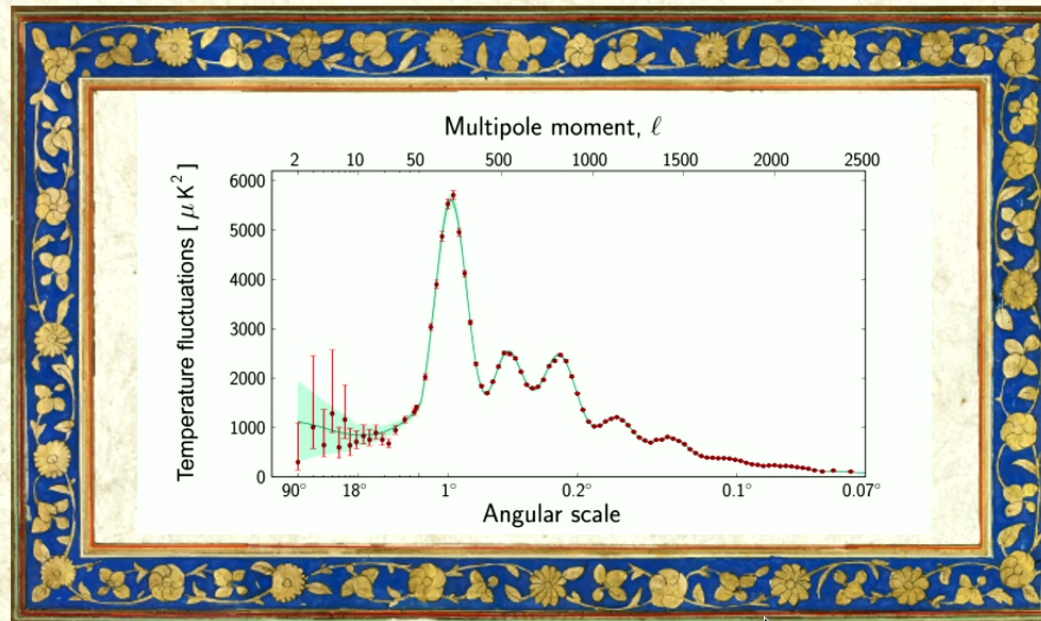
[1710.10630] Dark matter in galaxies

# Motivation for dark matter



Planck 2018

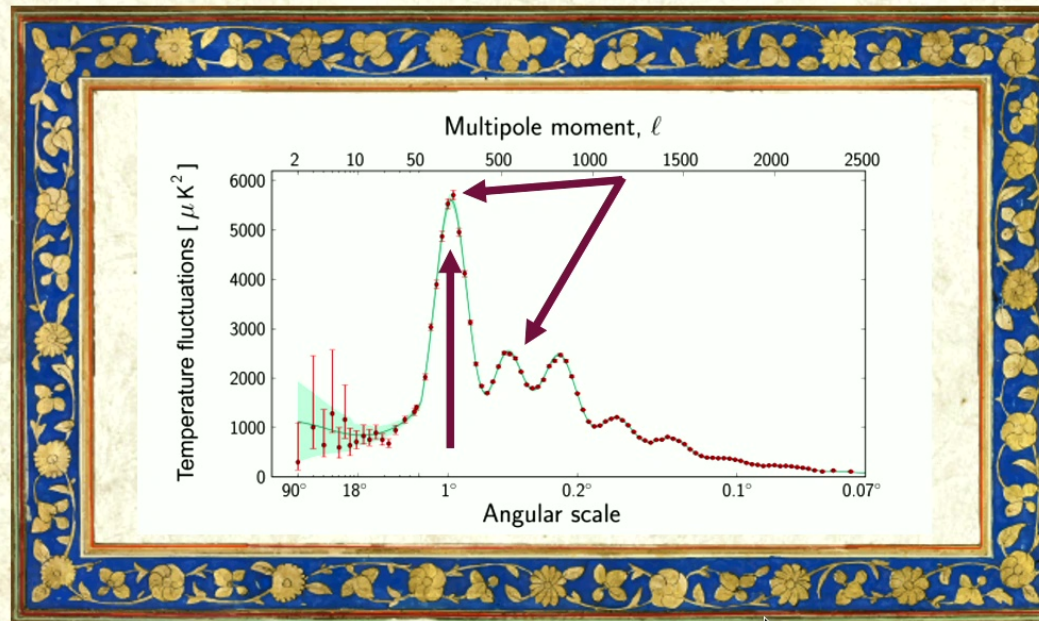
# Could $\delta\mathcal{M}$ be baryonic?



Planck 2018 (figure from ESA website)

# Could $\delta\mathcal{M}$ be baryonic?

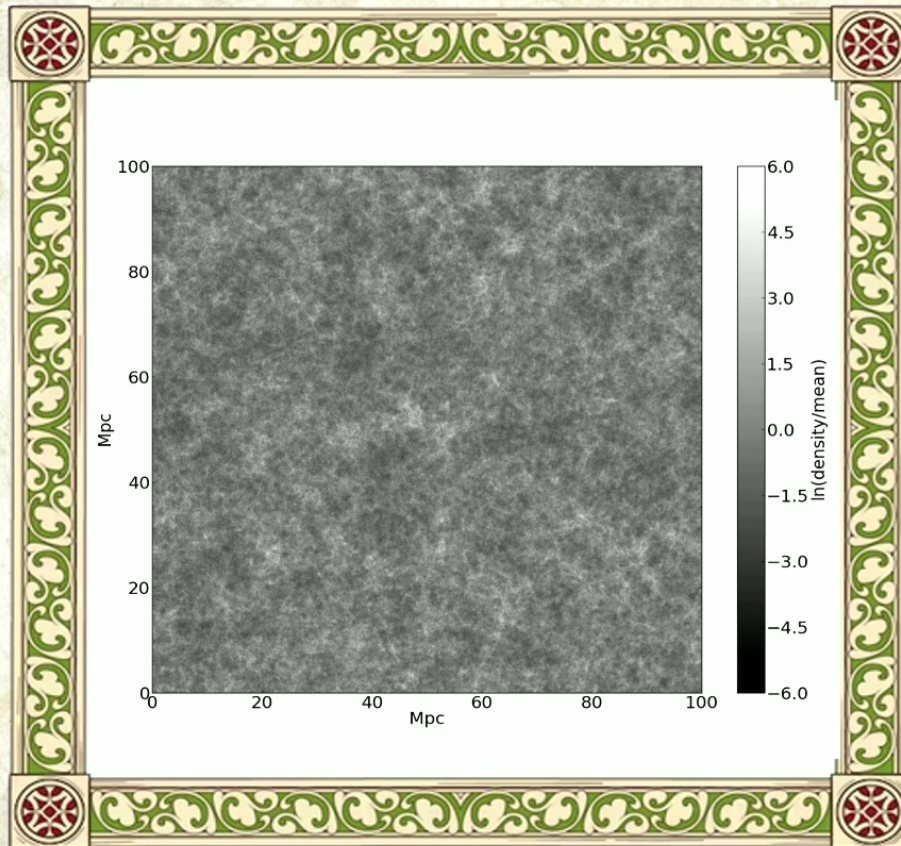
$$\Omega_m \cong 30\%$$



$$\Omega_b \cong 5\%$$

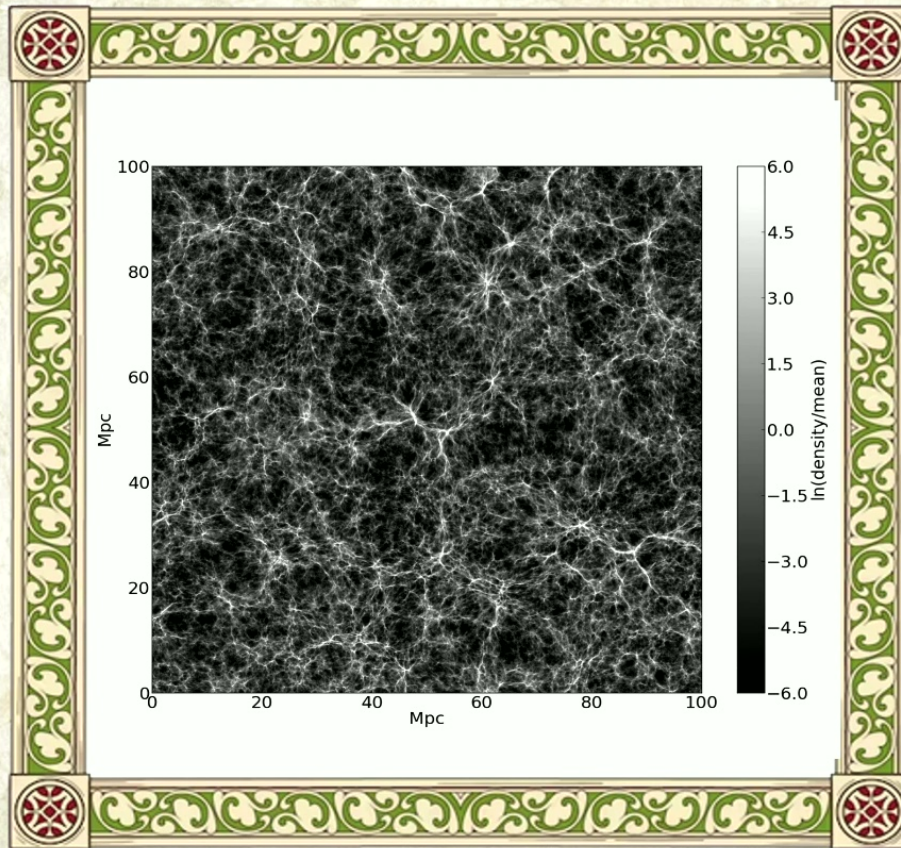
Planck 2018 (figure from ESA website)

# $\delta M$ in the Concordance Model



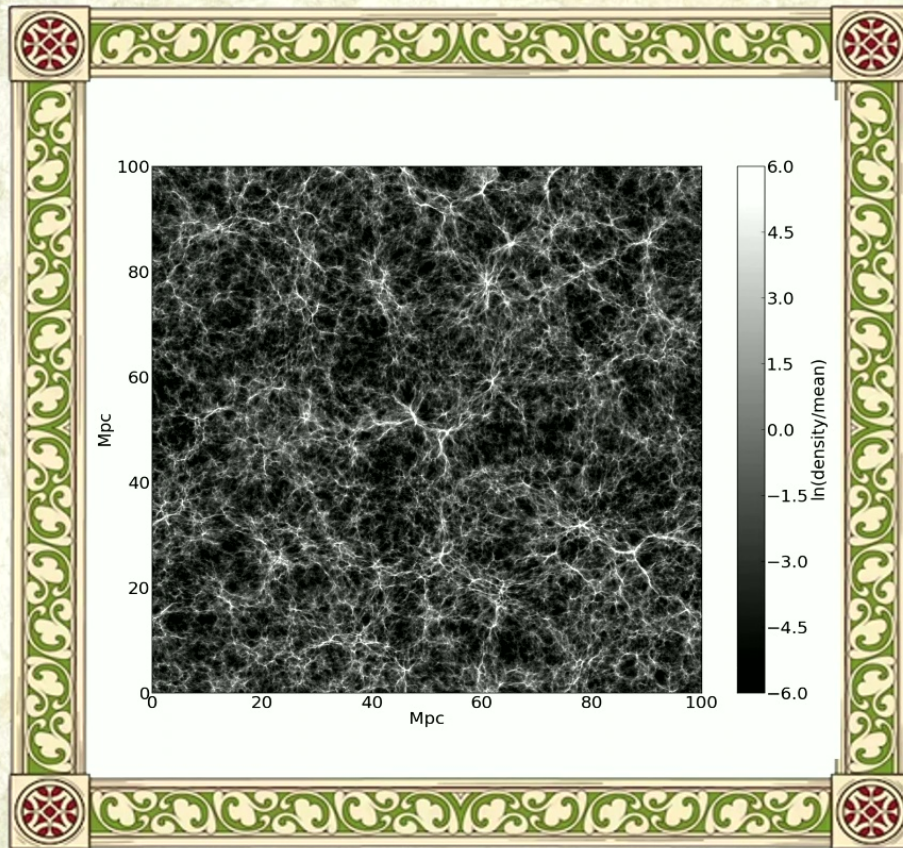
Animation credit: Paul Angel, Tiamat simulation

# $\delta M$ in the Concordance Model



Animation credit: Paul Angel, Tiamat simulation

# $\delta\mathcal{M}$ in the Concordance Model



Animation credit: Paul Angel, Tiamat simulation

$\Lambda$ CDM

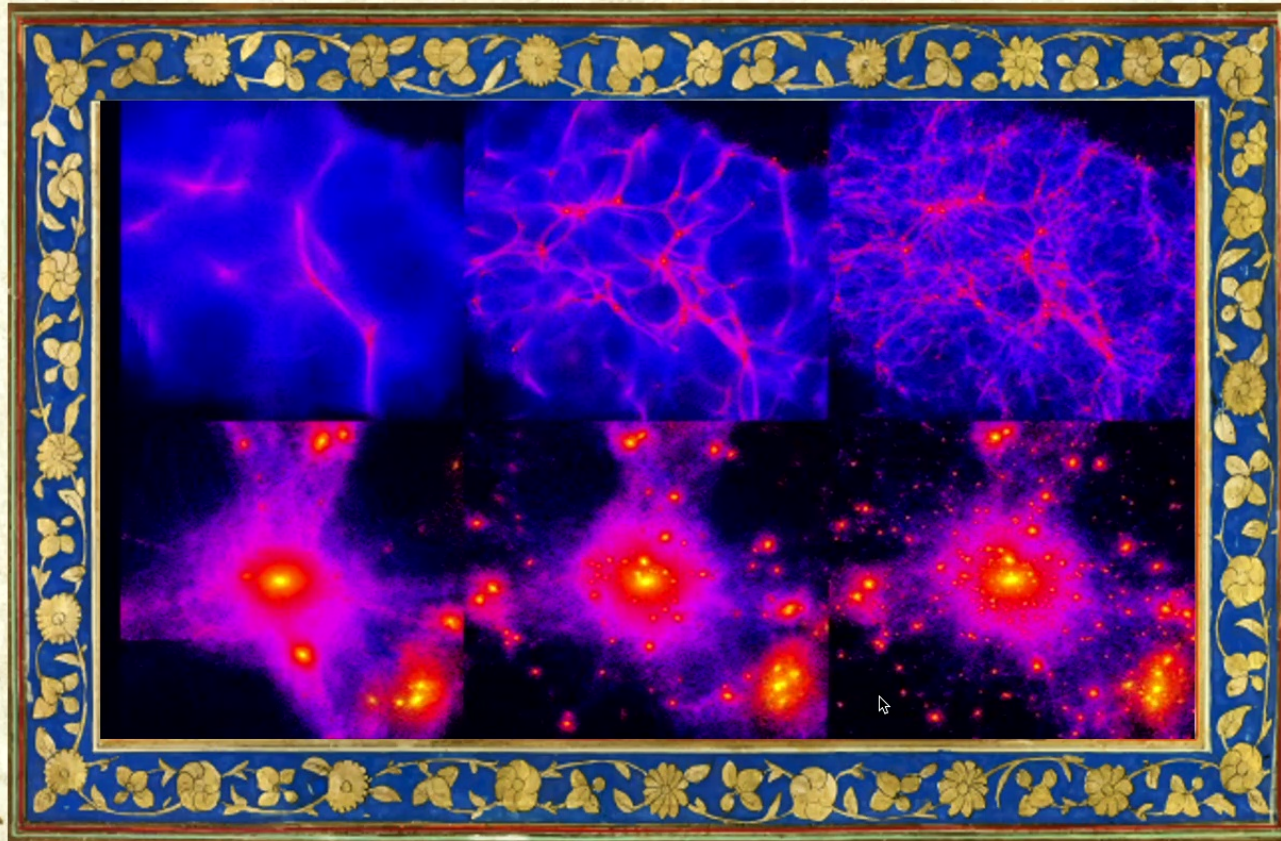
↓     ↓  
dark energy =  
cosmological constant

↓  
cold dark matter

⌈ A generic description of dark matter that reproduces the cosmic web pretty well. ⌋

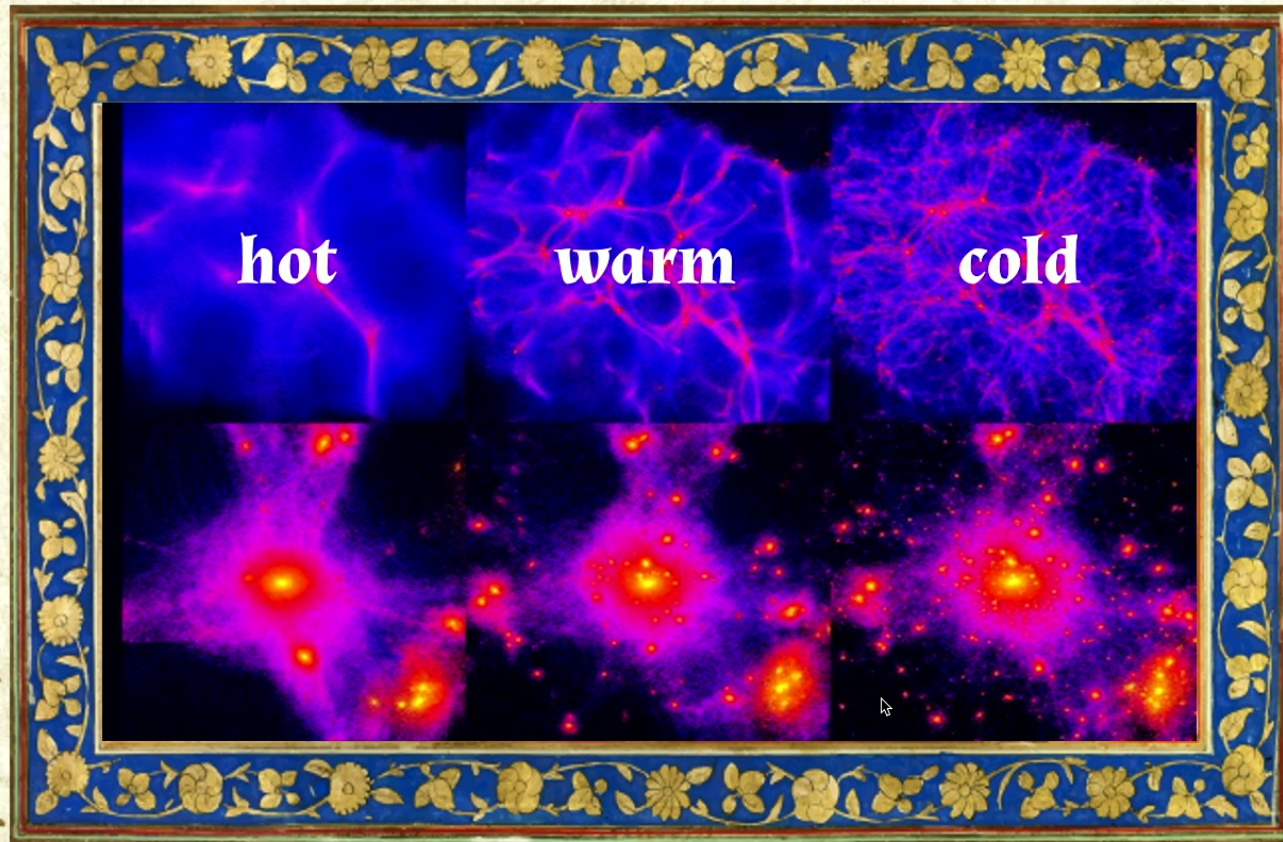


# Hot, Warm, or Cold DM?



Simulations by Ben Moore (University of Zurich)

# Hot, Warm, or Cold DM?



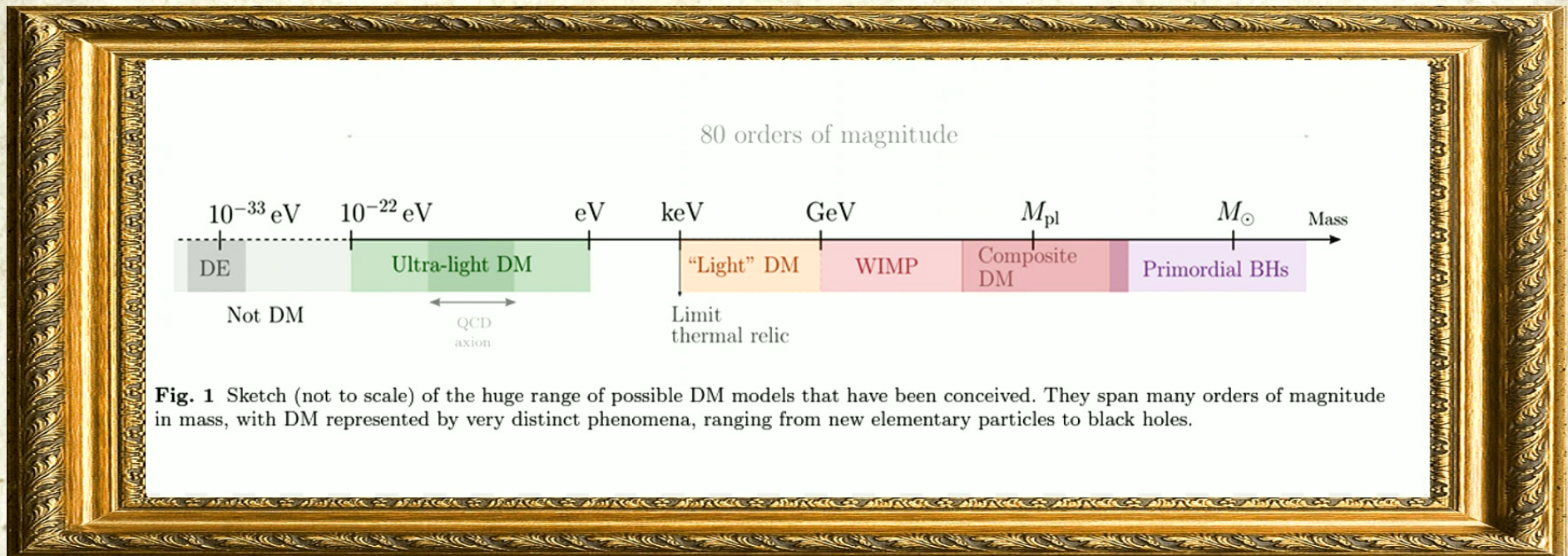
Simulations by Ben Moore (University of Zurich)

# A Bestiary of



# Dark Matter Candidates

“We’ve narrowed it down...”



**Fig. 1** Sketch (not to scale) of the huge range of possible DM models that have been conceived. They span many orders of magnitude in mass, with DM represented by very distinct phenomena, ranging from new elementary particles to black holes.

Elisa Ferreira, 2005.03254

“...to ninety orders of magnitude”

# (Some) Popular Candidates



WIMPs



AXIONS



Modified  
Gravity



MACHOS

# WIMPs

“If you hear hoofbeats think horses, not zebras”



- ❖ **Weakly Interacting Massive Particles**
- ❖ Interact with gravity & the weak force (a bit)
- ❖ miraculous prediction of supersymmetry
- ❖ so far, no supersymmetry at the LHC
- ❖ more than one way to make a WIMP!
  - ❖ non-miraculous WIMPs are still a possibility

# Modified Gravity

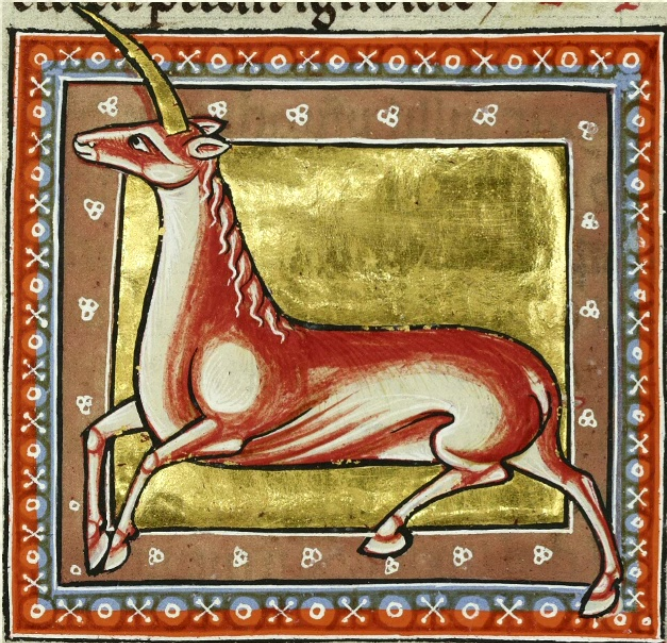
Zebras are actually quite MONDane, depending on where you live and work



- ❖ what if gravity is different other scales?
- ❖ many alternatives to General Relativity
- ❖ e.g. **Modified Newtonian Dynamics** (MOND)
- ❖ still an active field of research, but not favored
  - ❖ data from EHT, LIGO, Gaia...all favor GR
  - ❖ has a hard time explaining the Bullet Cluster

# AXIONS

Another popular creature with hooves.



- ❖ originally proposed to solve a completely different problem in physics (strong CP violation)
  - ❖ This is the so-called QCD axion ( $10^{-5} - 10^{-3}$  eV)
- ❖ a whole family of axion-like particles (ALPs):
  - ❖  $m_a > 10^{-18}$  eV: cold dark matter
  - ❖  $m_a > 10^{-23}$  eV: fuzzy dark matter (FDM)
  - ❖  $m_a \sim 10^{-33}$  eV: dark energy



# MACHOs

Maybe the hoofs are really, really big.



- ❖ **Massive Compact Halo Objects**
- ❖ Black holes (BH), neutron stars, red dwarfs...
  - ❖ but can't have all DM be made of baryons!
- ❖ non-baryonic MACHOs: primordial BHs
  - ❖ got very popular with LIGO
  - ❖ Still possible, but with very specific mass distributions...
  - ❖ looking forward to LISA to get some answers!

# MORE INTERESTING BEASTIES



## Atomic Dark Matter

A system of atomic-like bound states of dark particles.

A system of gravitons bound together by their self-interaction.

## Graviballs

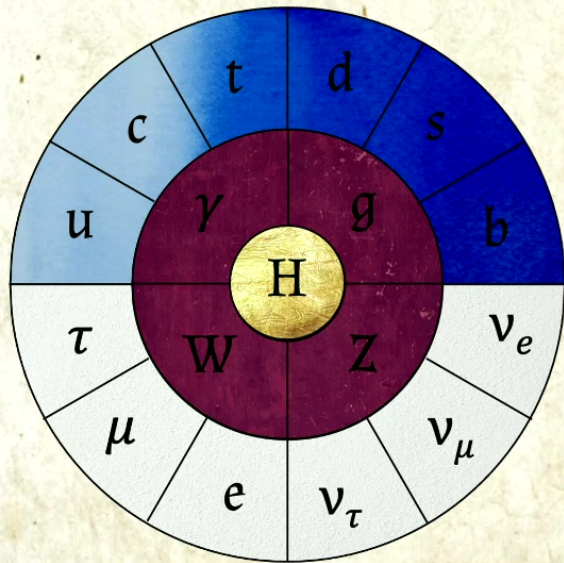


## Self-Interacting Dark Matter

Like CDM, but with strong self-interactions.

# The Universe Consists of

AROUND 5%



The Standard Model Particle Zoo

AROUND 25%

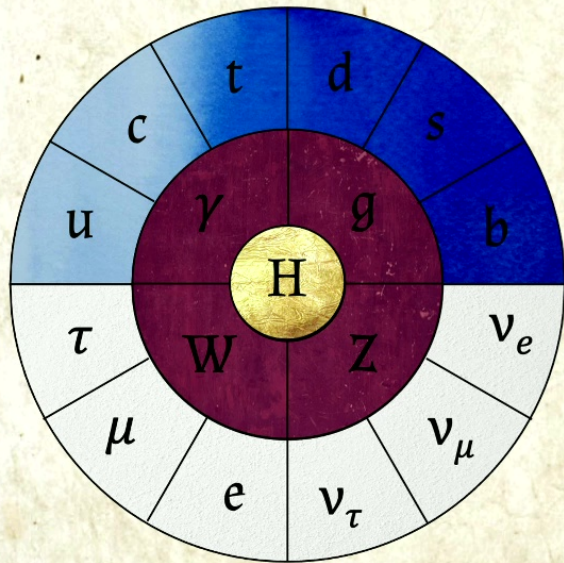


Cold Dark Matter  
(or something as good or better)

22

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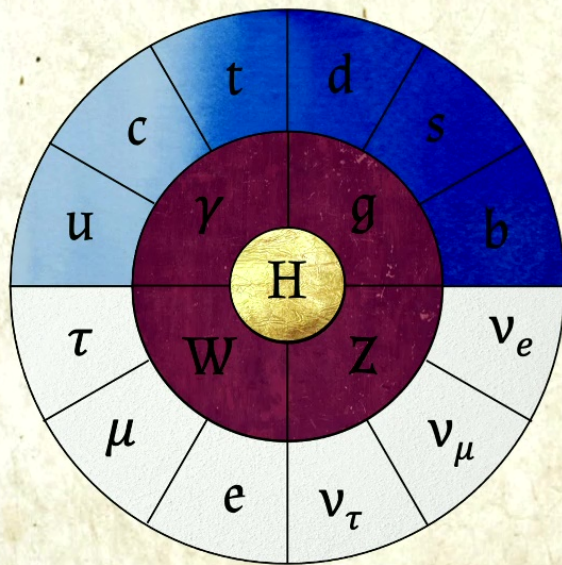
- ❖ A huge swatch of parameter space to search ( $> O(10^{80})!$ )

Cold Dark Matter  
(or something as good or better)

23

# The Universe Consists of

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The Standard Model Particle Zoo

AROUND 25%

- ❖ A huge swatch of parameter space to search ( $> O(10^{80})!$ )
- ❖ A variety of possible explanations
- ❖ No obvious best candidate

Cold Dark Matter  
(or something as good or better)

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# Some closing thoughts

The open-boundedness leaves a lot of room for creativity!



- ❖ the Universe doesn't owe us a simple explanation
- ❖ Could dark matter actually be a dark sector?
- ❖ we may be seeing cracks appearing in the CDM model
  - ❖ JWST and early halos
- ❖ further study of how DM and baryons interact might be necessary



# Ye Olde Ende



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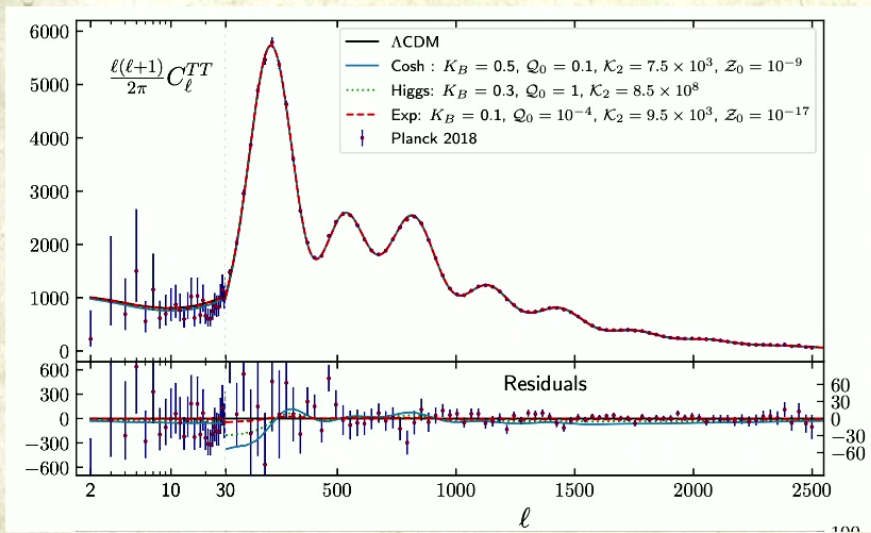
@cosmoloony

# MORE ON MOND

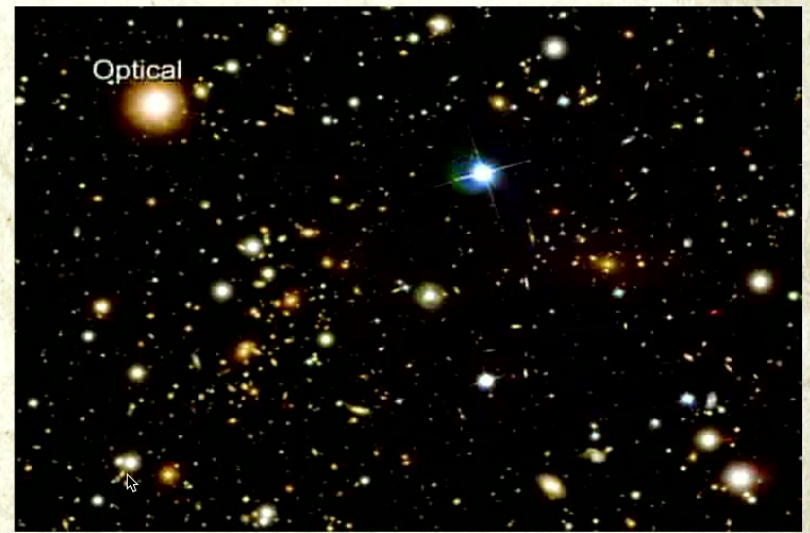
X-ray image (pink) superimposed over a visible light image (galaxies), with matter distribution calculated from gravitational lensing (blue)

Solved problem: CMB

Unsolved problem: Bullet Cluster



arXiv:2007.00082



Chandra X-ray observatory website

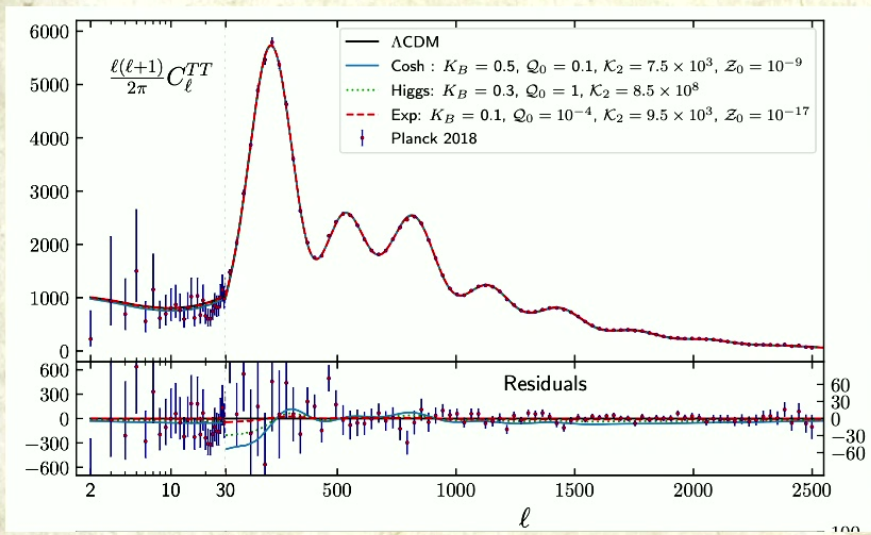


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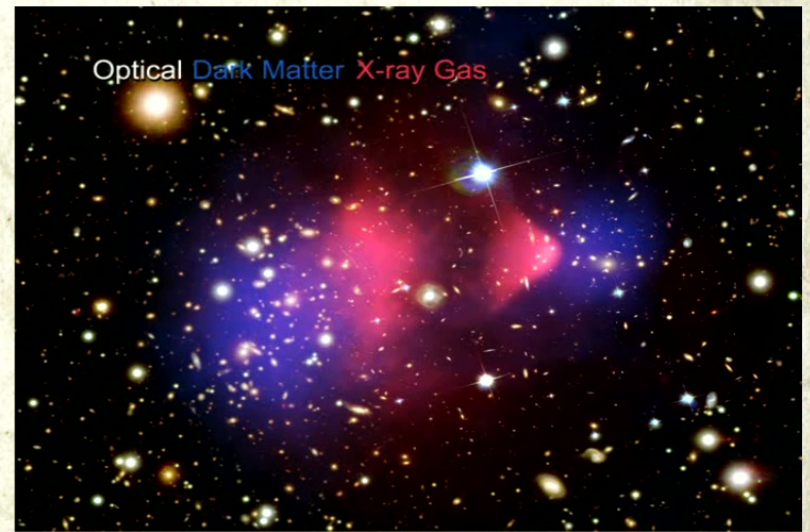
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