

Confronting the Invisible Universe

Jesse Thaler



May 2, 2018



DorsetScouser Photography (www.dorsetscouser.com)

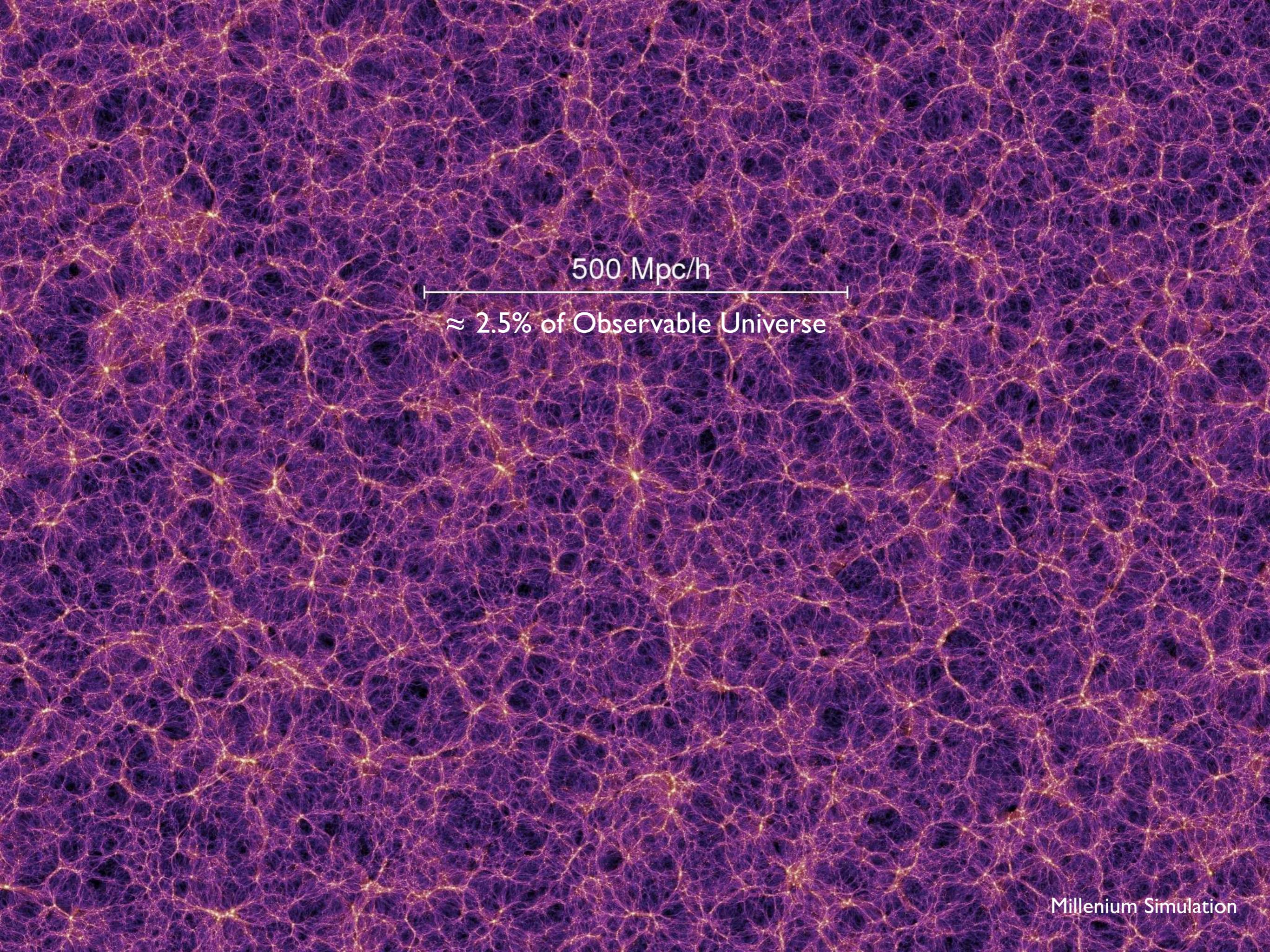
Stars

Dark Matter

Visible Matter (mostly H and He)

Dark Energy

Invisible Stuff



500 Mpc/h

$\approx 2.5\%$ of Observable Universe

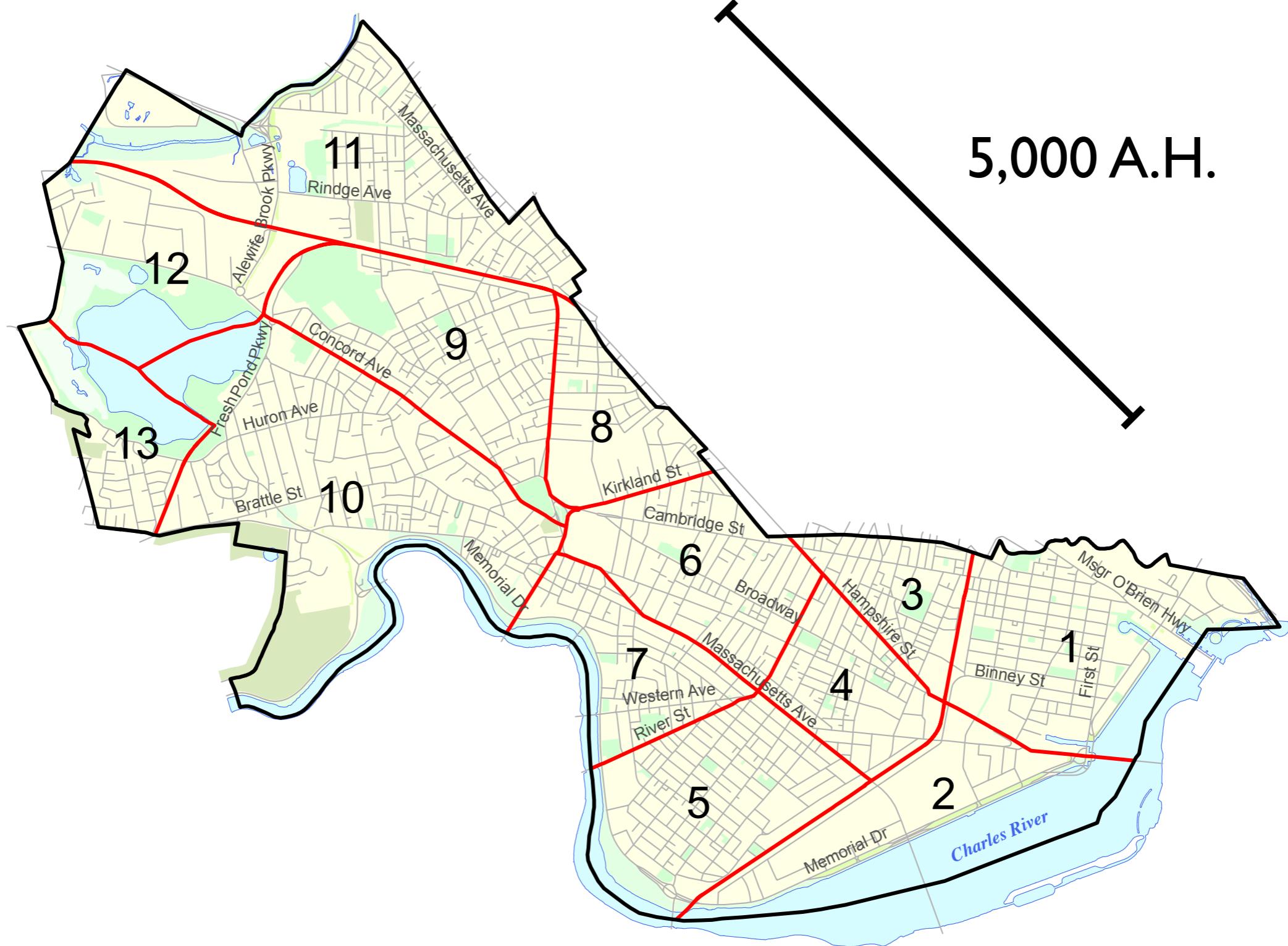
Millenium Simulation



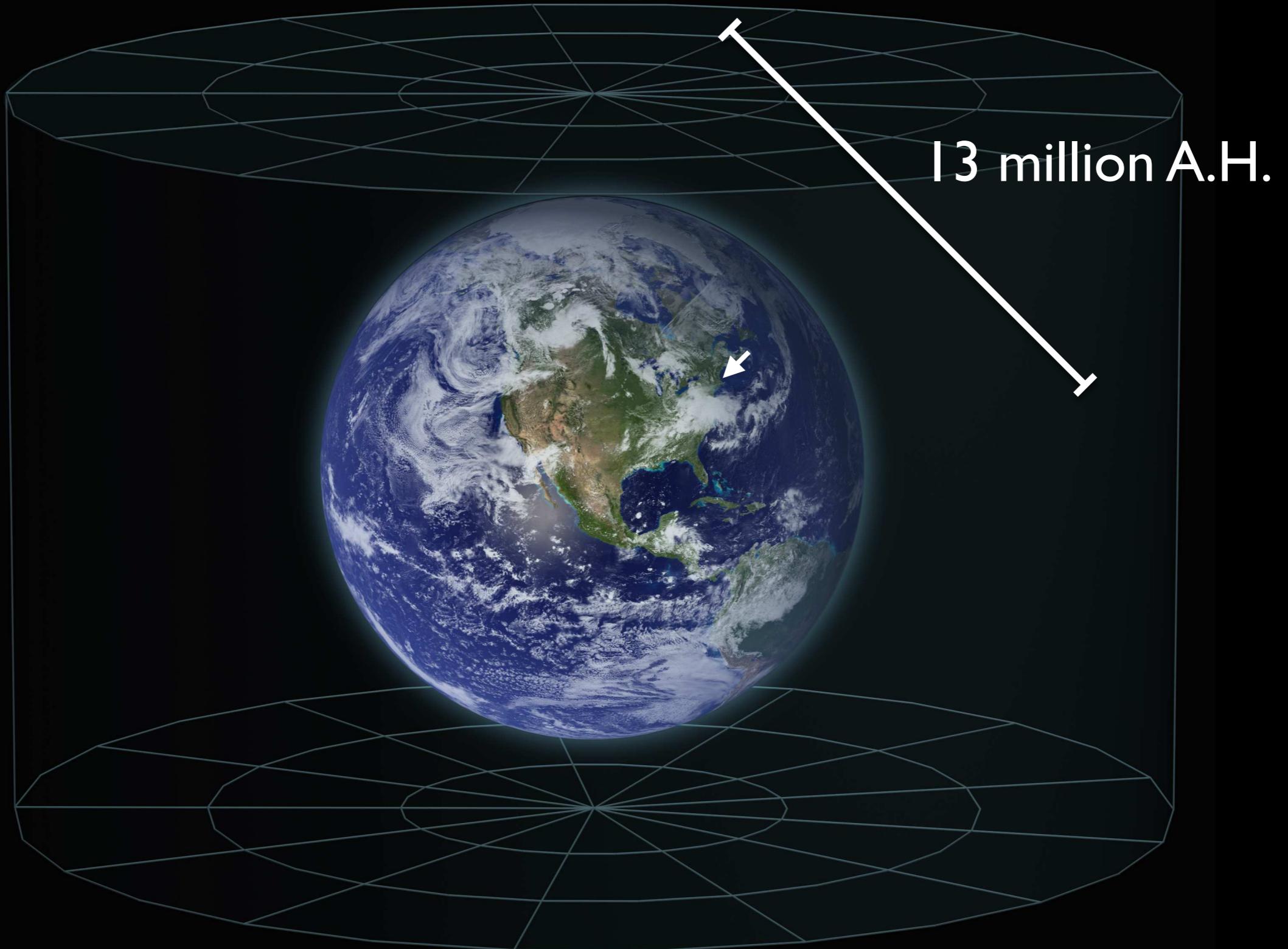
Adrian
Height

50A.H.

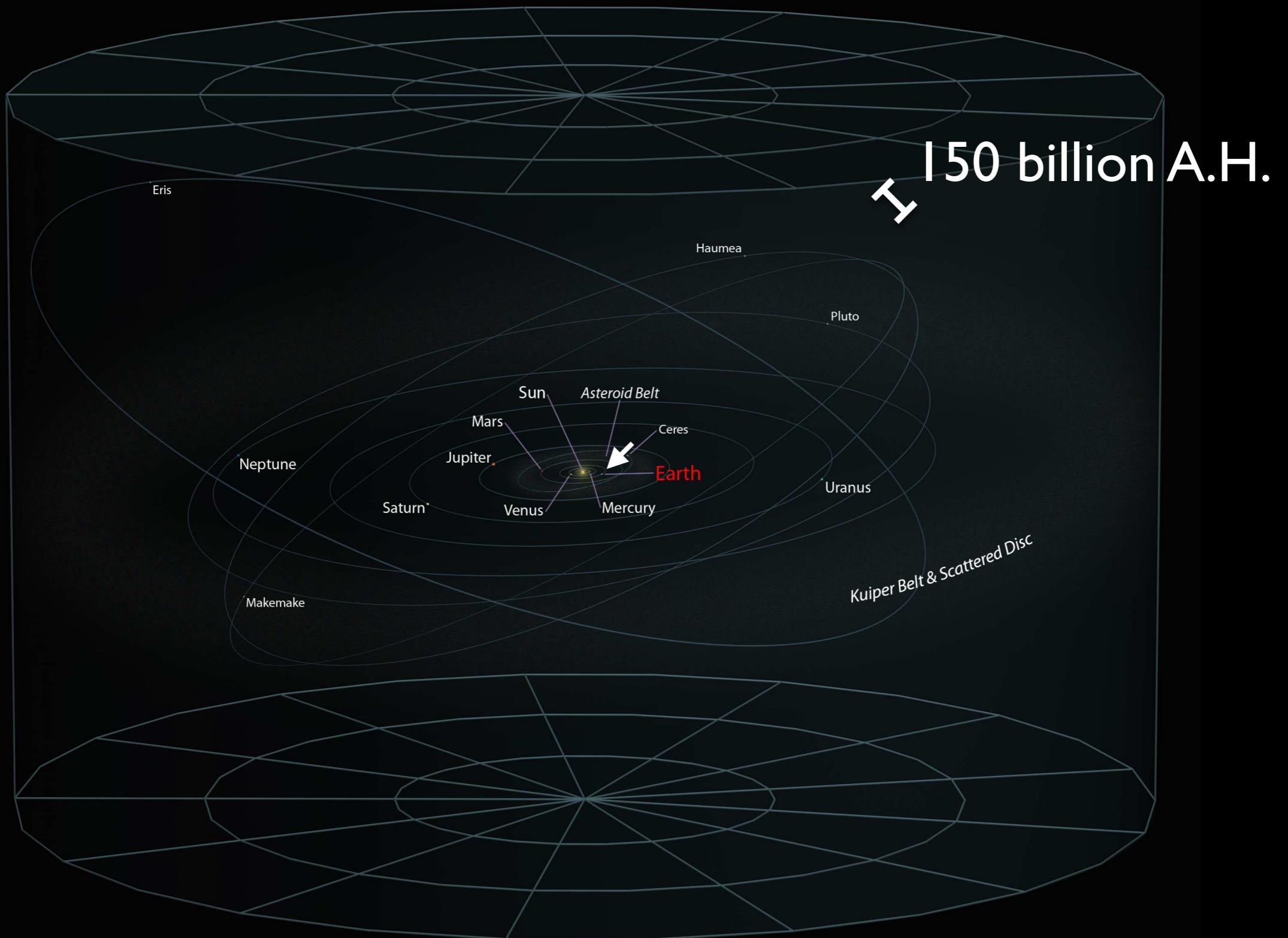




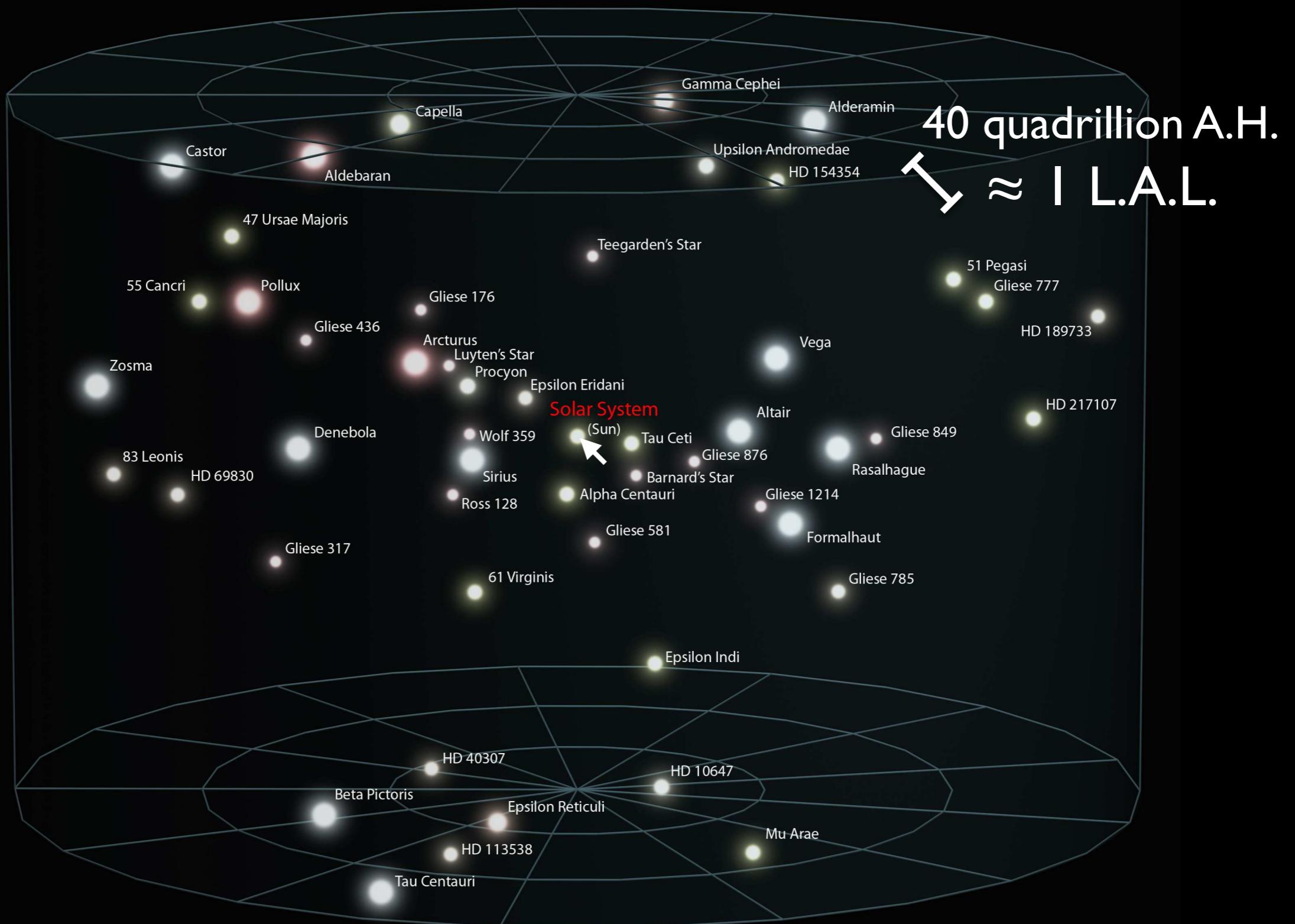
EARTH



SOLAR SYSTEM

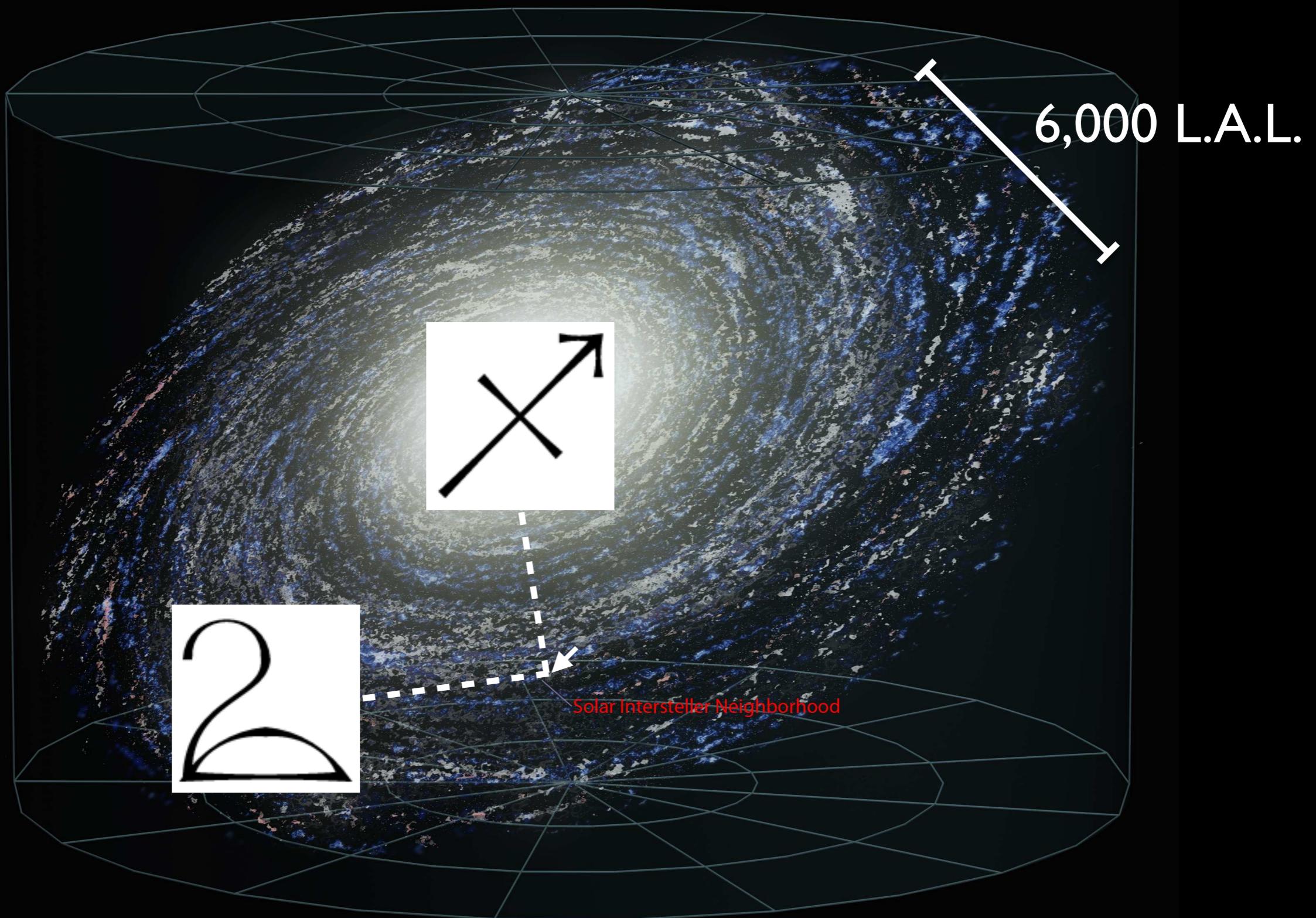


INTERSTELLAR NEIGHBORHOOD

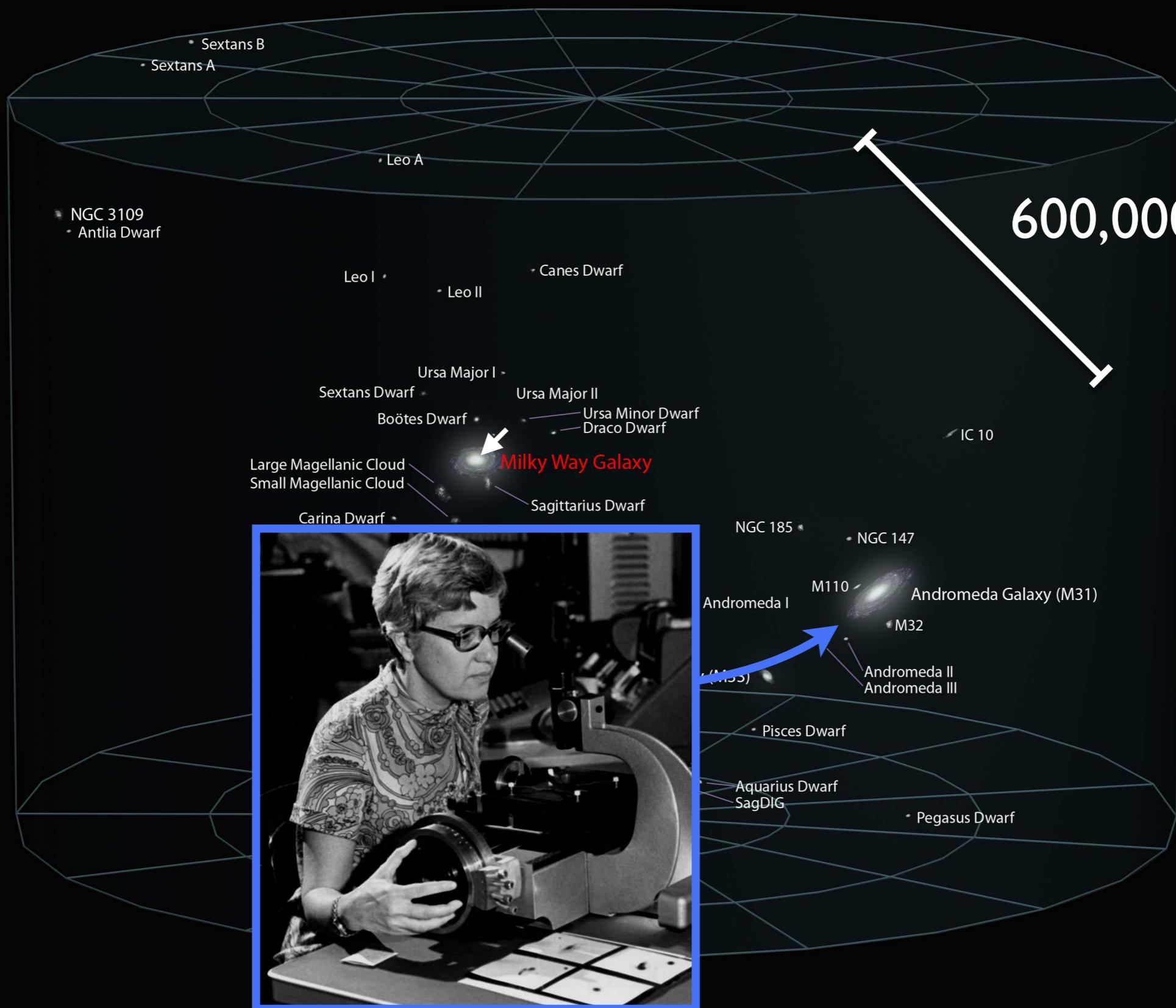


Andrew Z. Colvin

MILKY WAY GALAXY

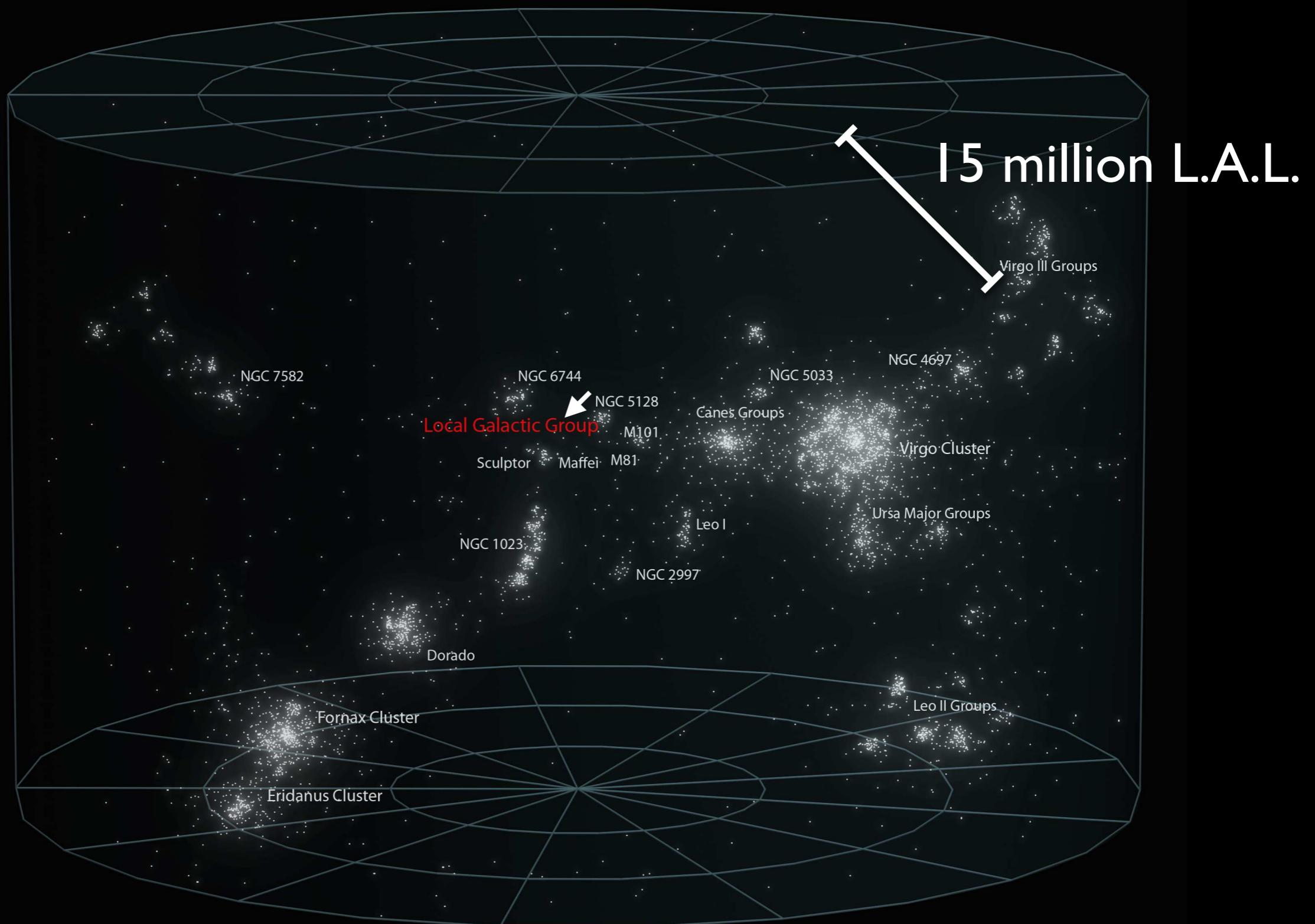


LOCAL GALACTIC GROUP

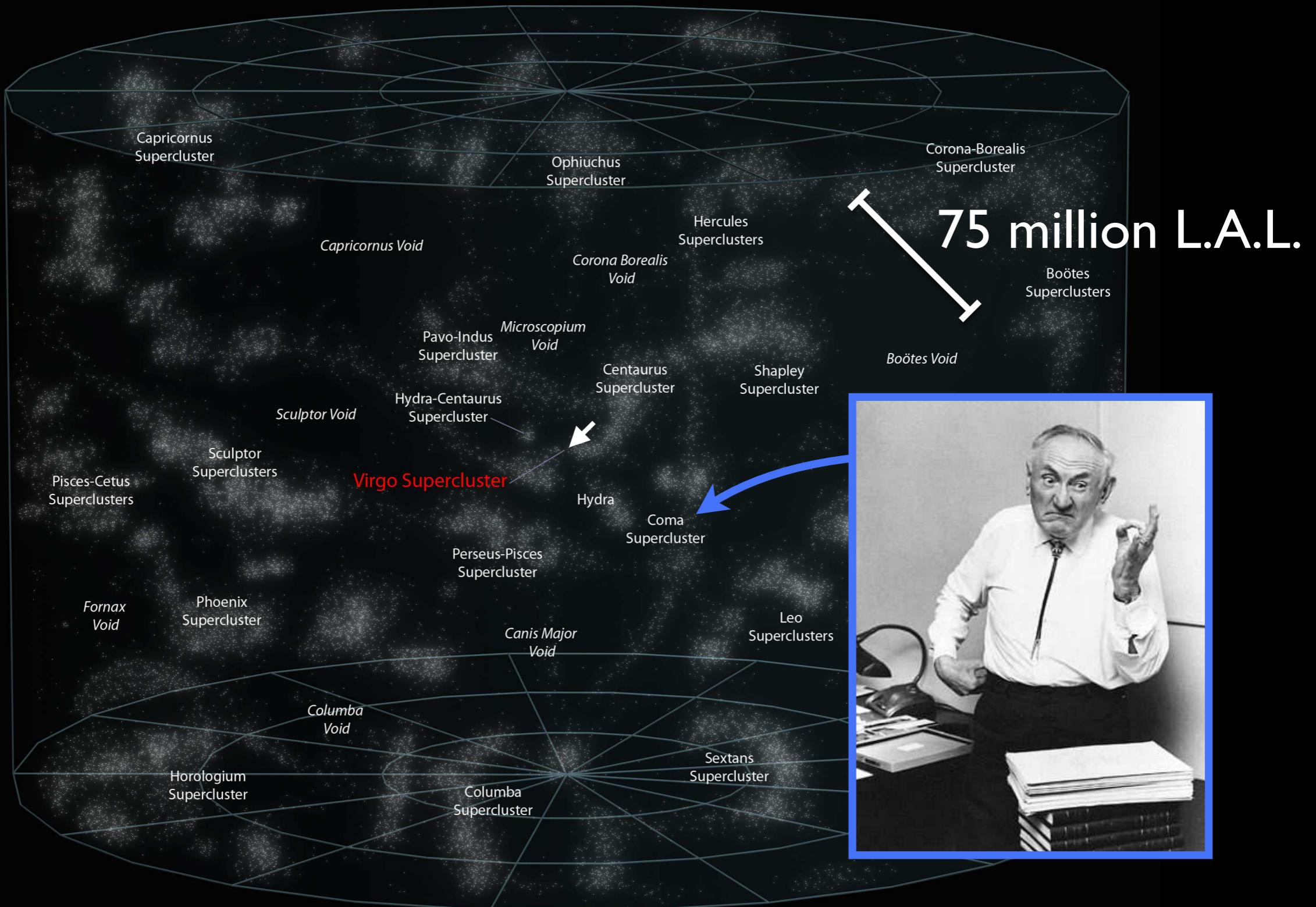


Andrew Z. Colvin

VIRGO SUPERCLUSTER

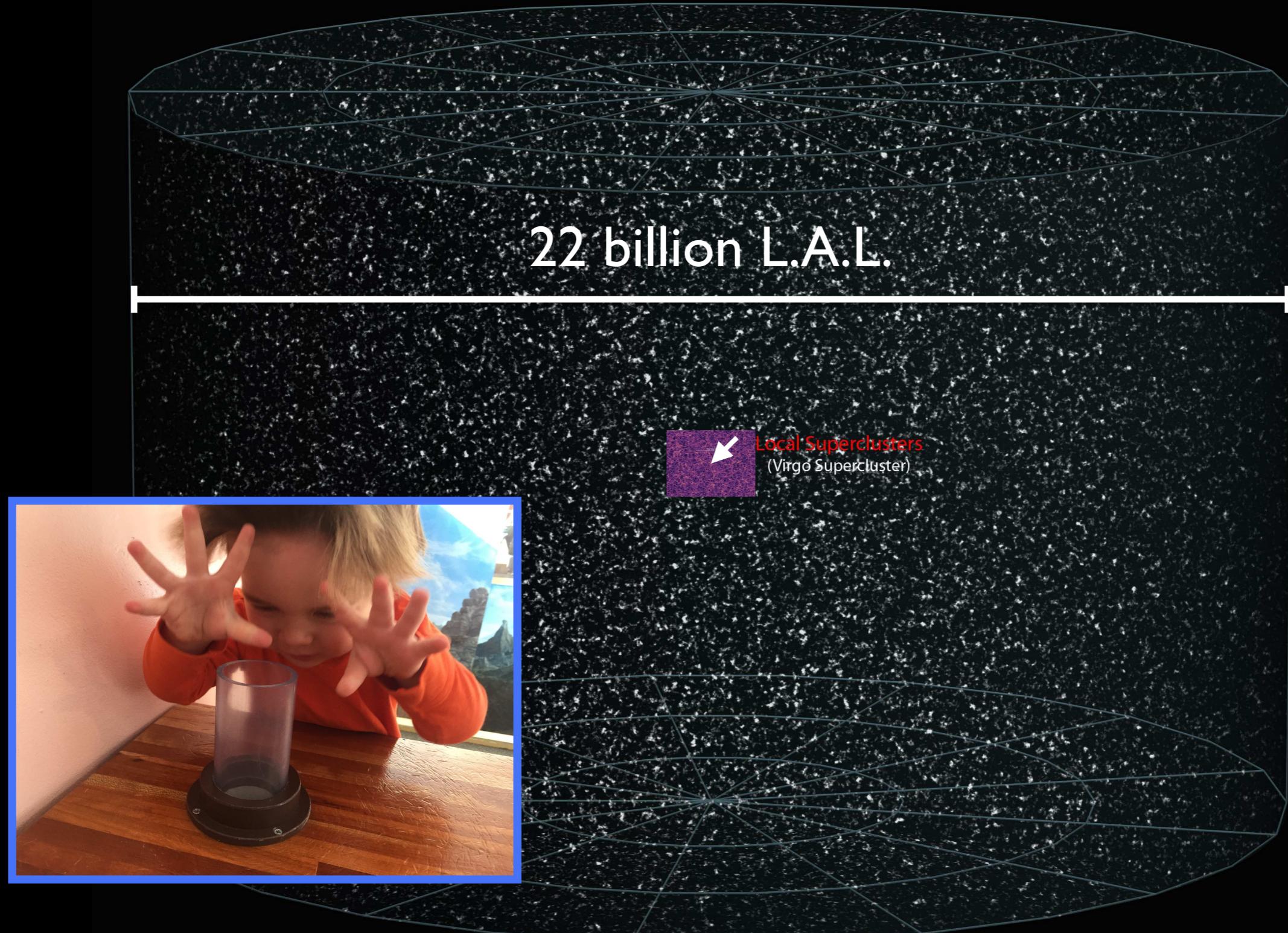


LOCAL SUPERCLUSTERS



Andrew Z. Colvin

OBSERVABLE UNIVERSE



Invisible Stuff

What?

Substance

Mechanism

Why?

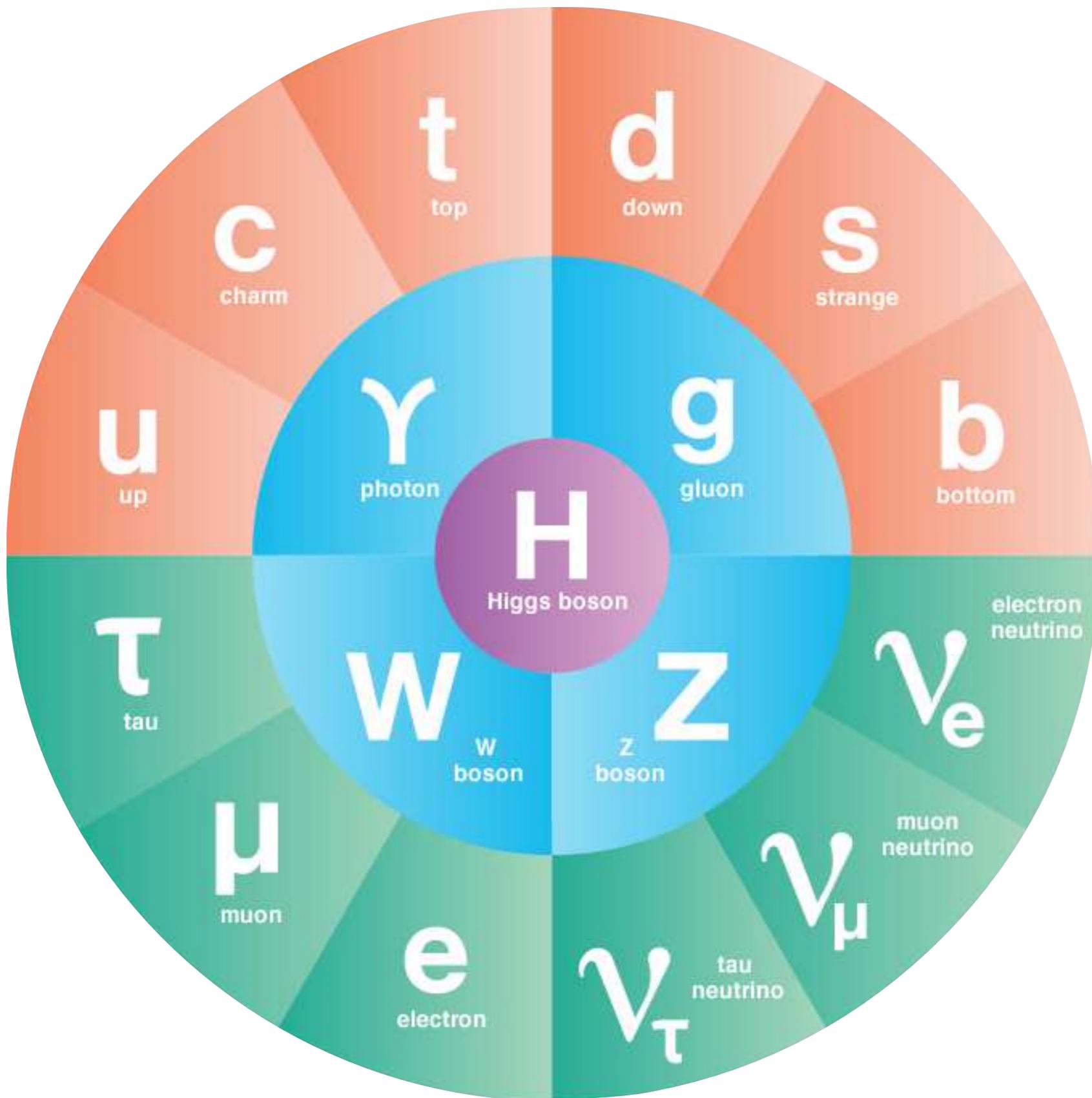
Purpose

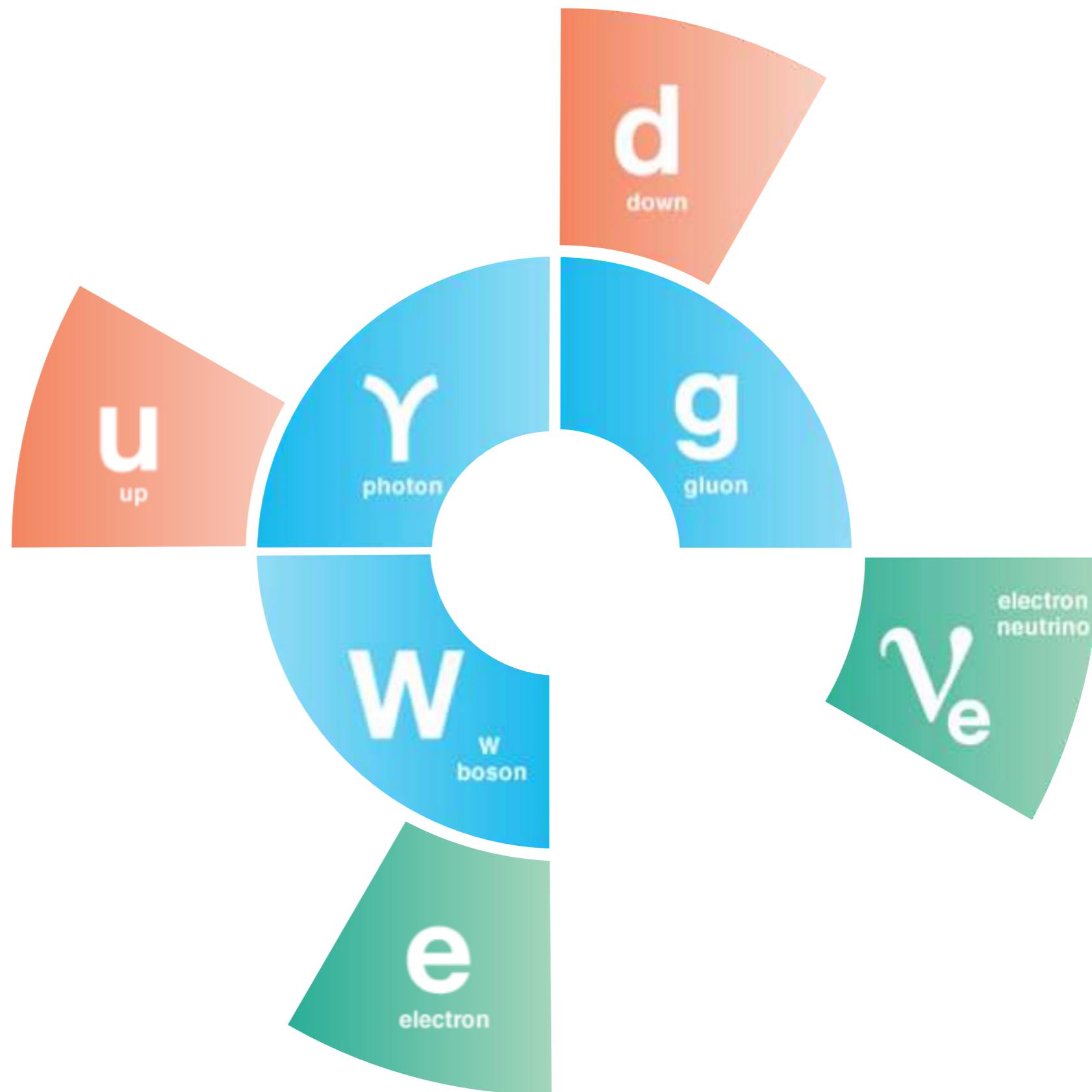
Implication

(And how do we know?)

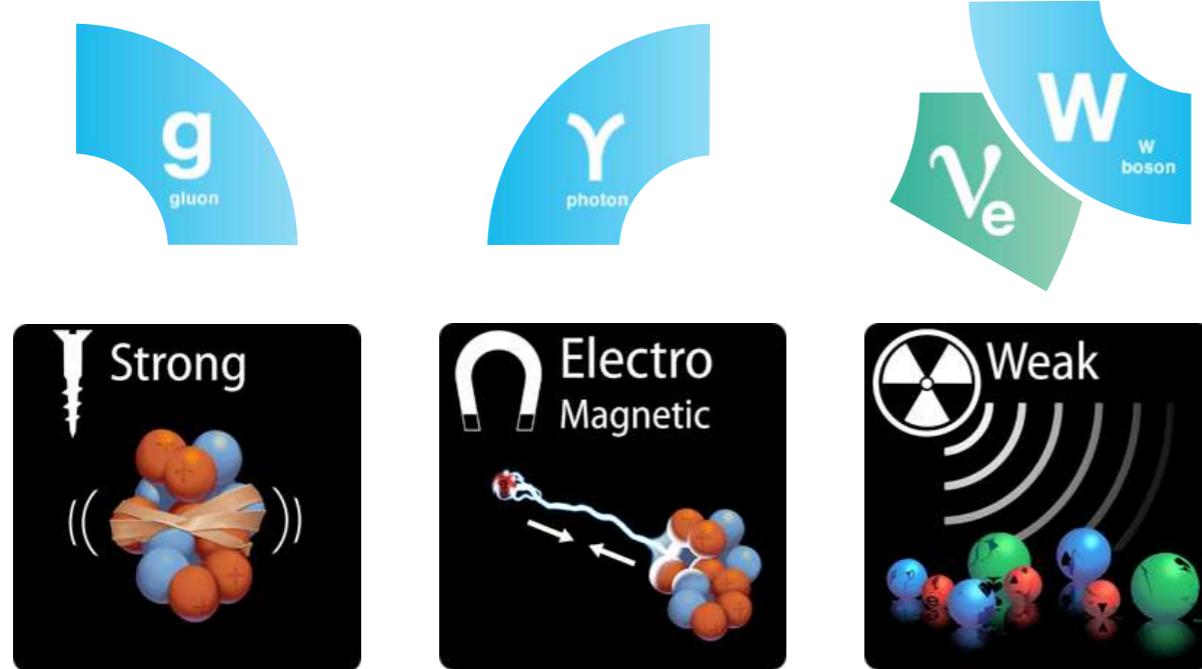
Evidence

What is Dark Matter?





Ordinary Matter

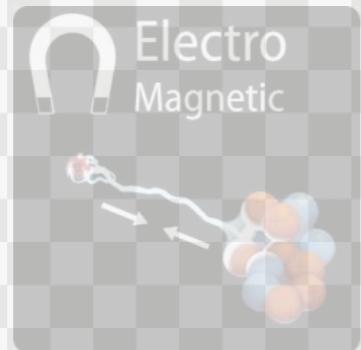


Invisible Stuff

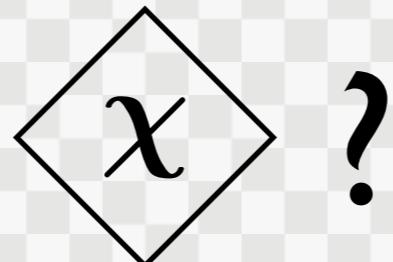
Inert

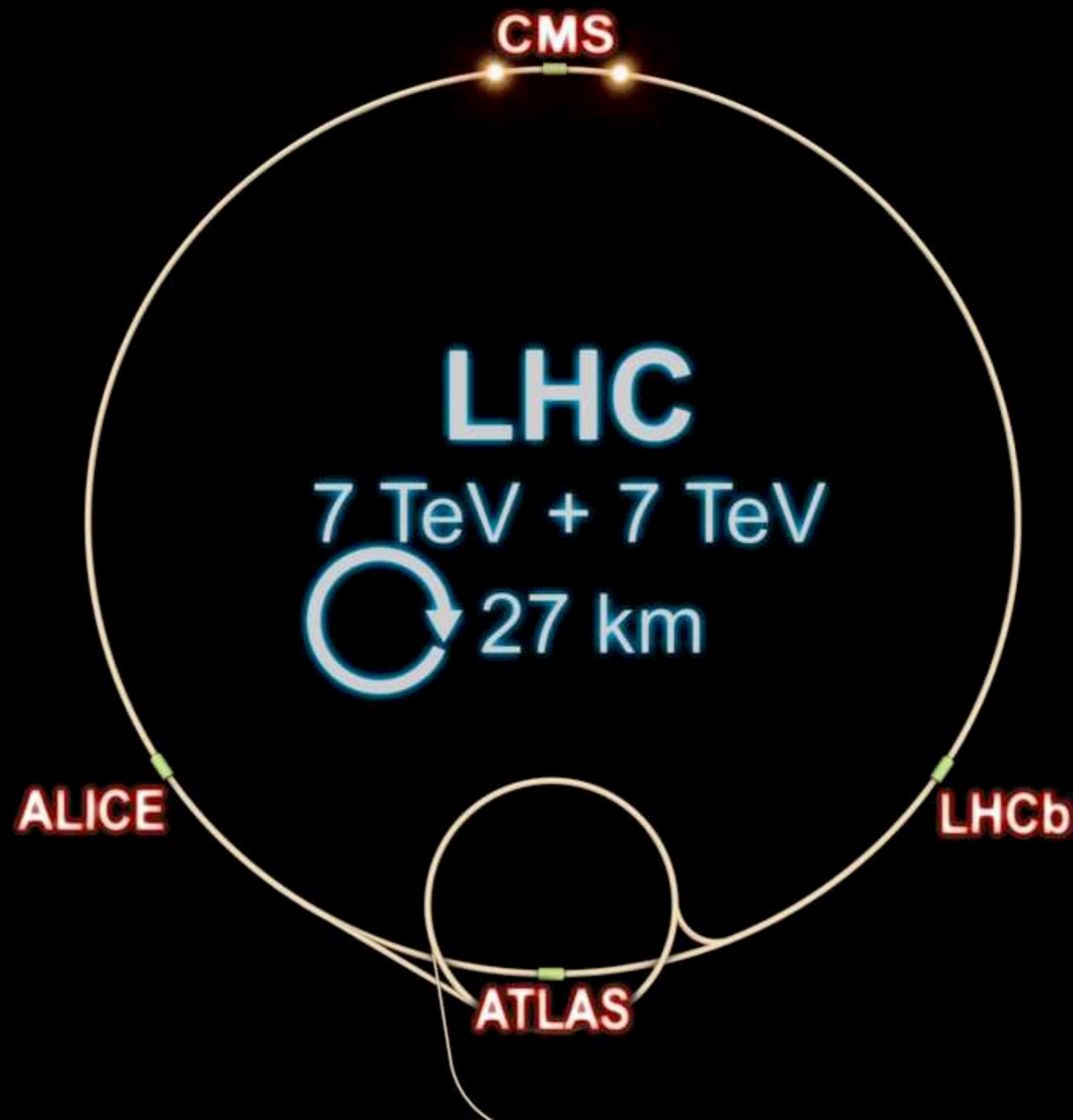
Stable

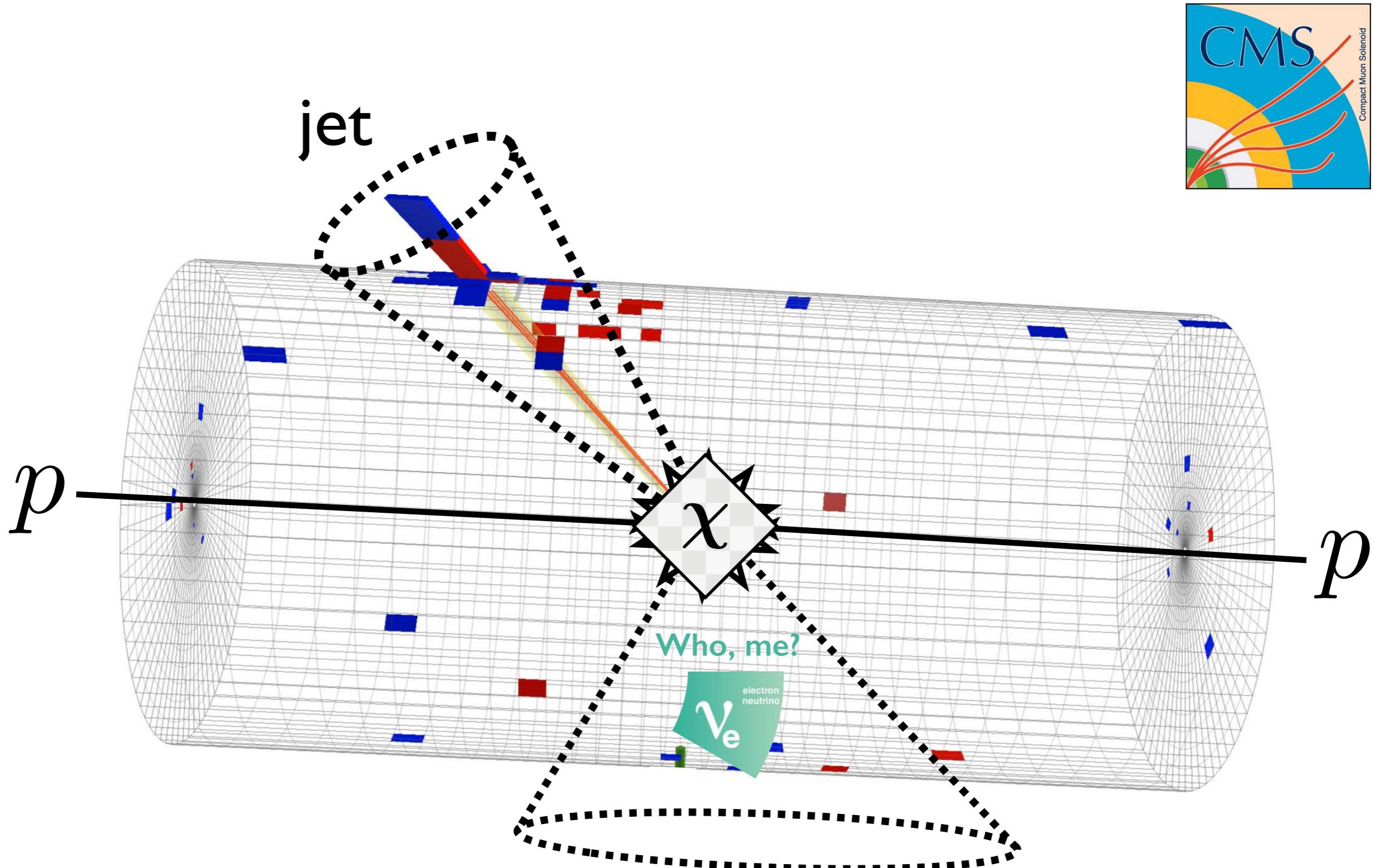
Slow



But what *is* Dark Matter?

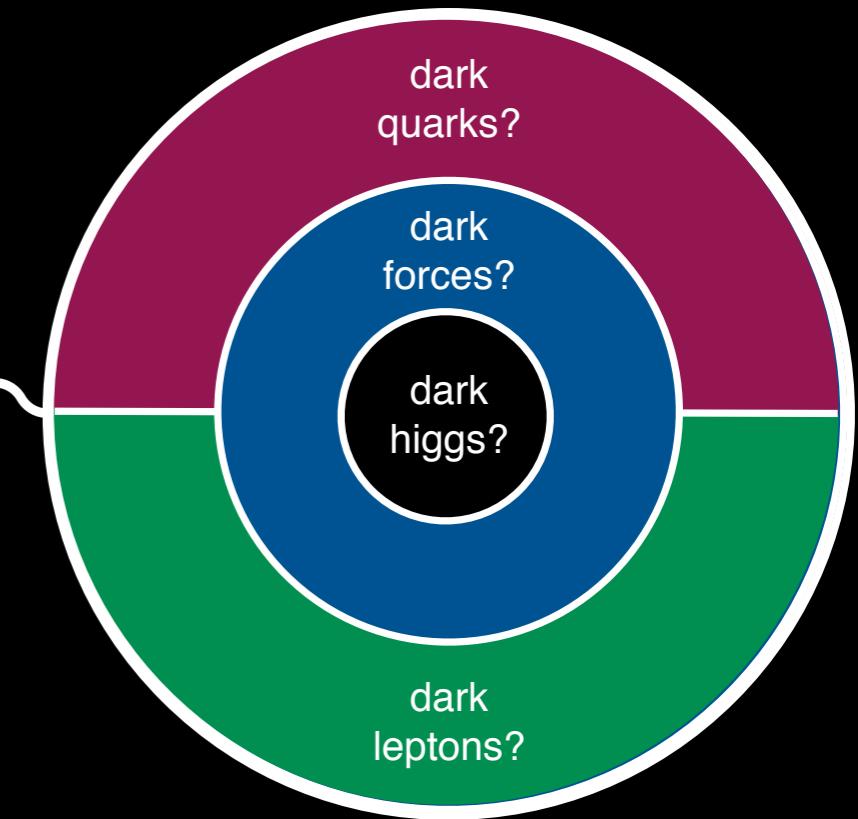
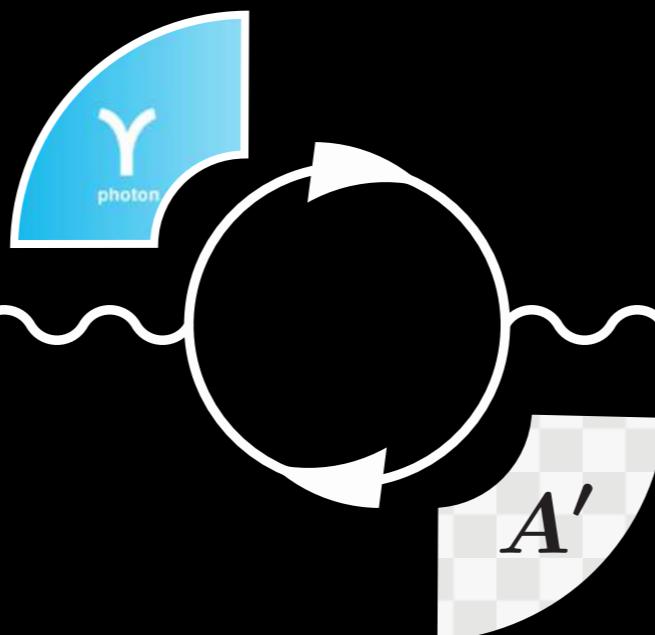
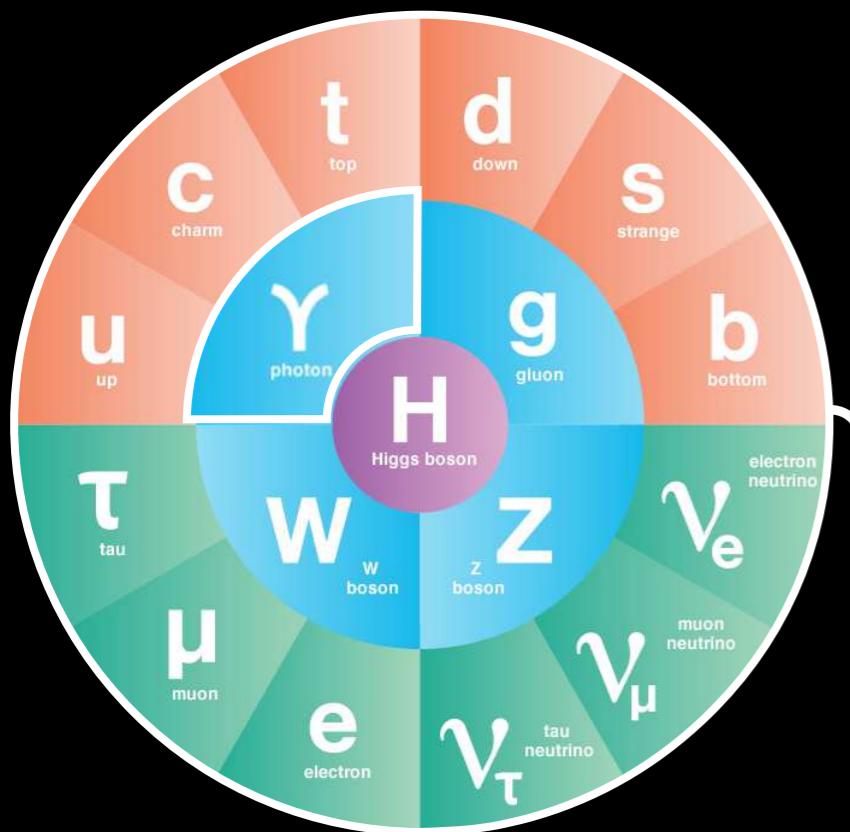






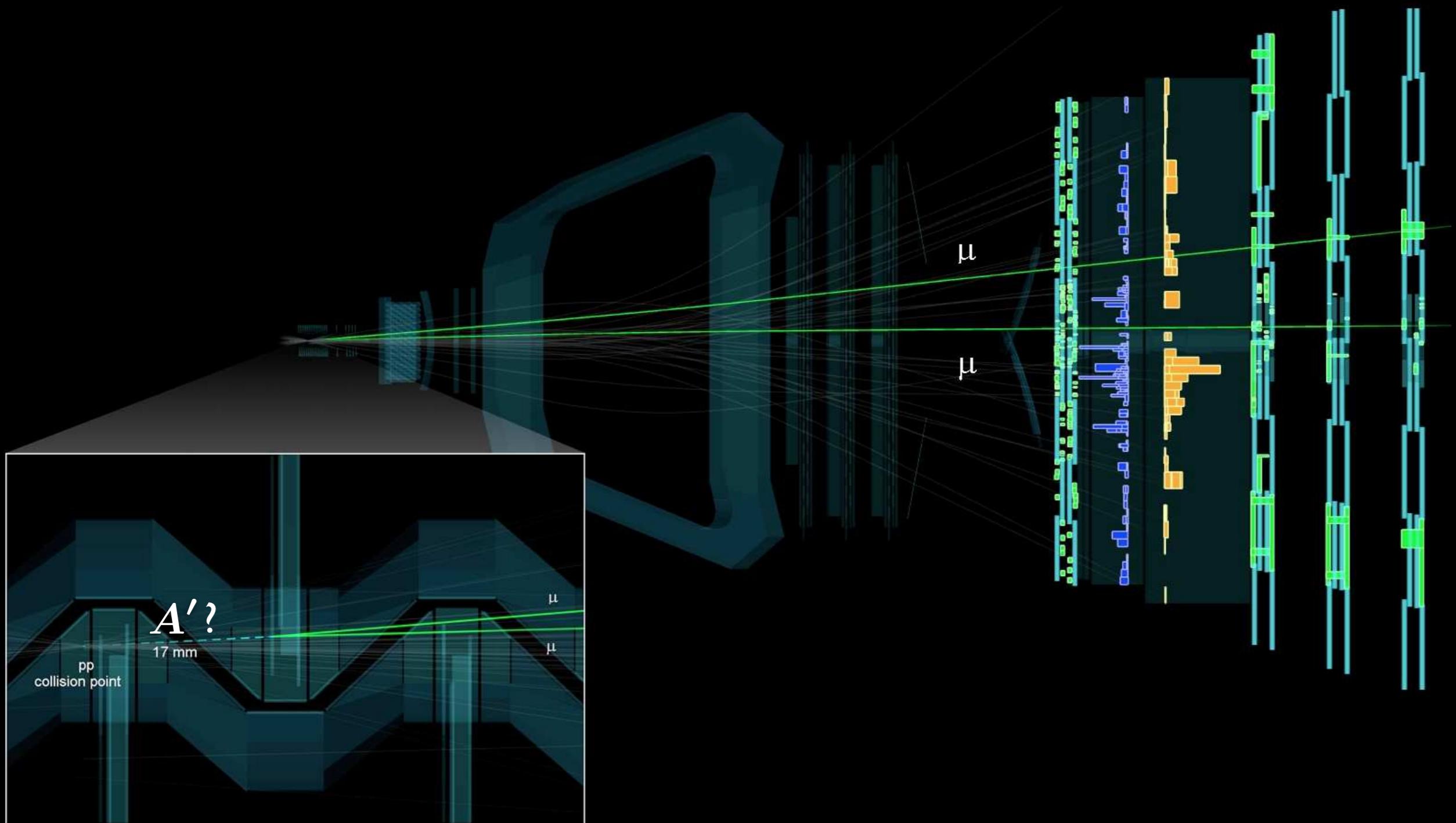
nothing?!

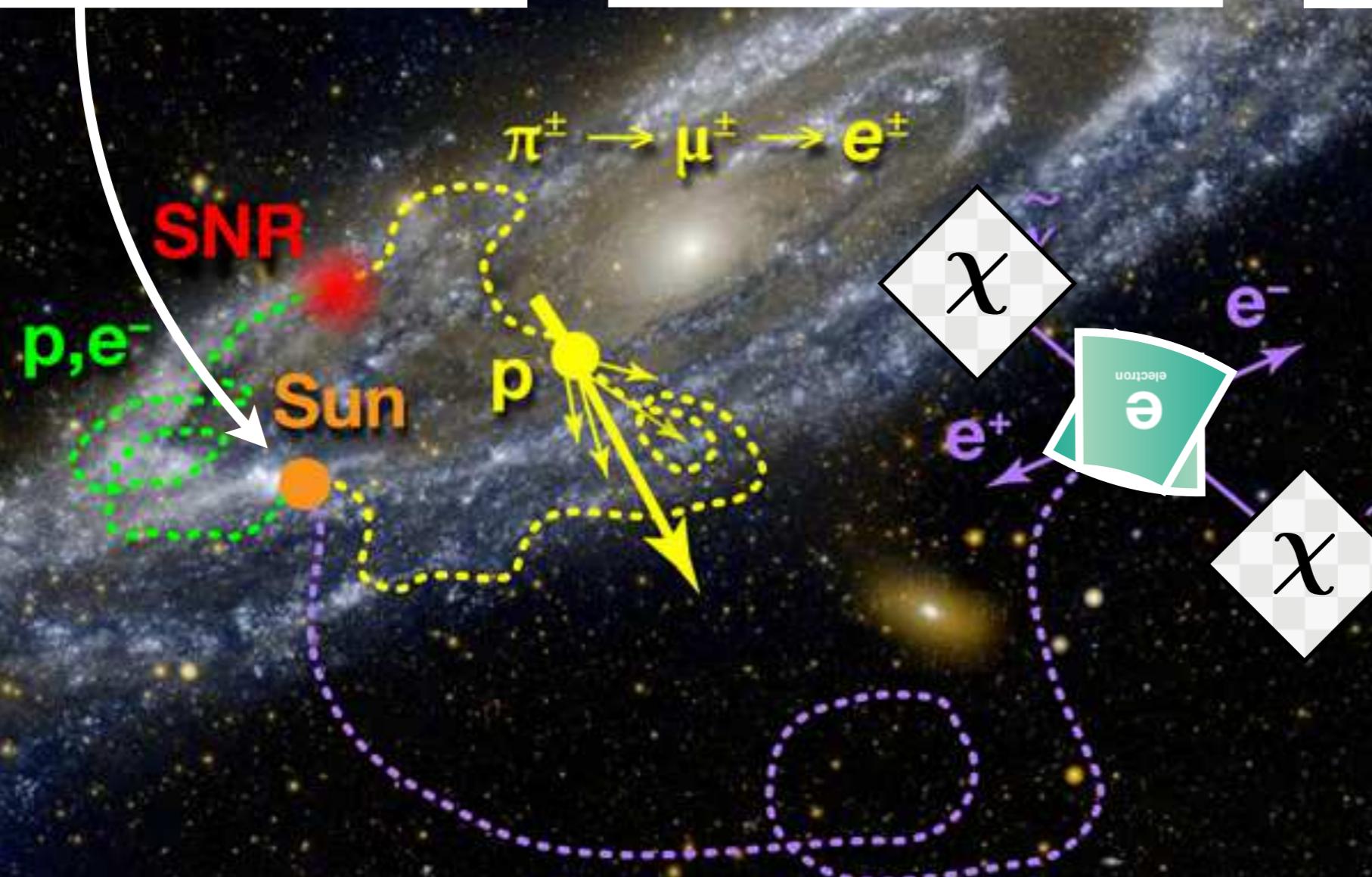
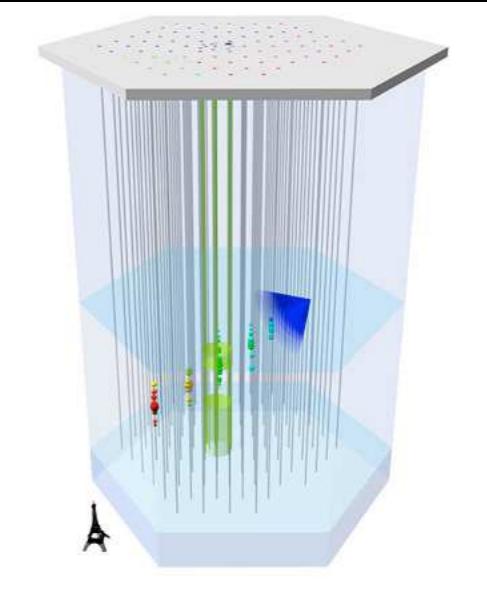
Prof. Phil Harris
Prof. Markus Klute
Prof. Christoph Paus



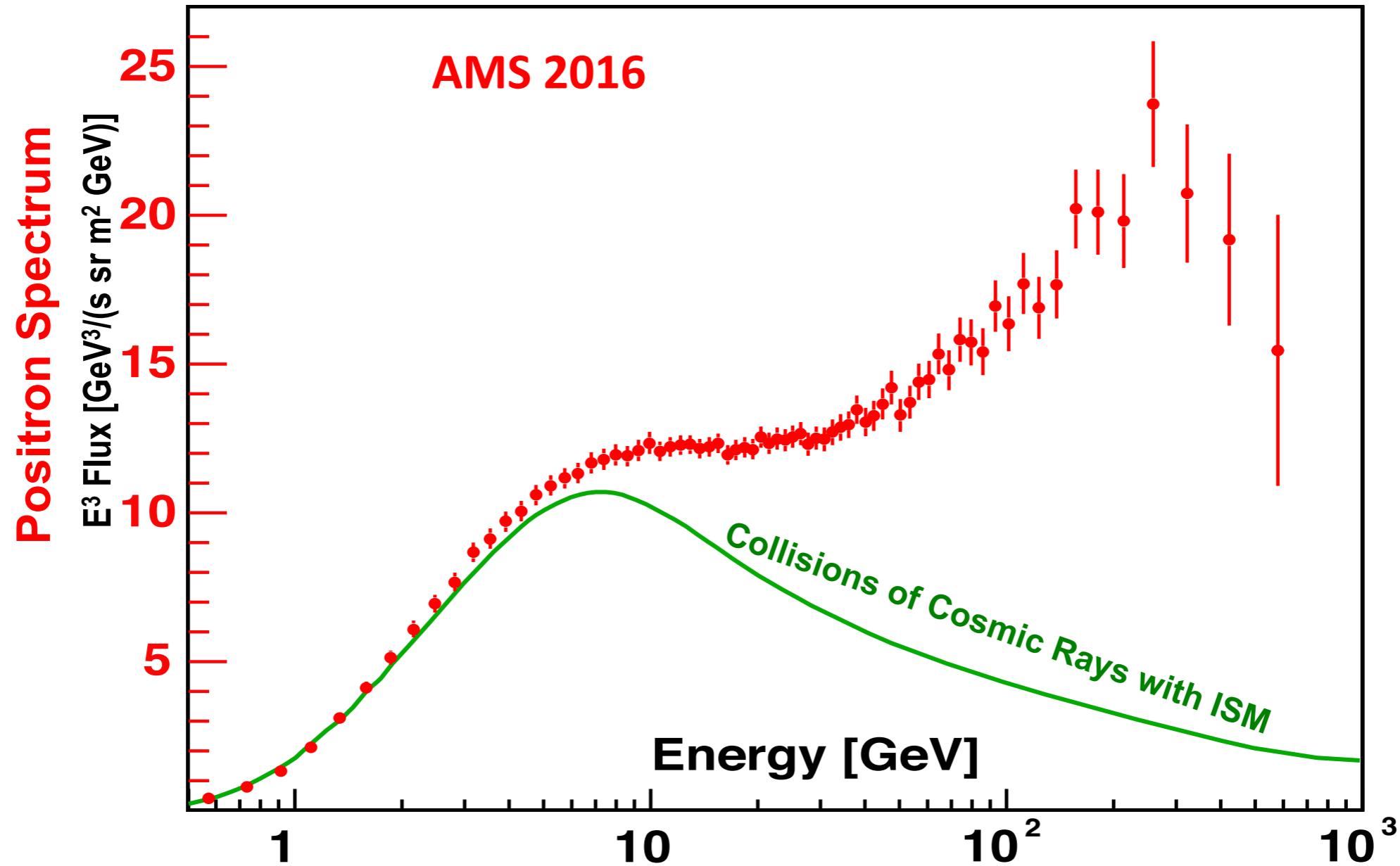
DARKLIGHT

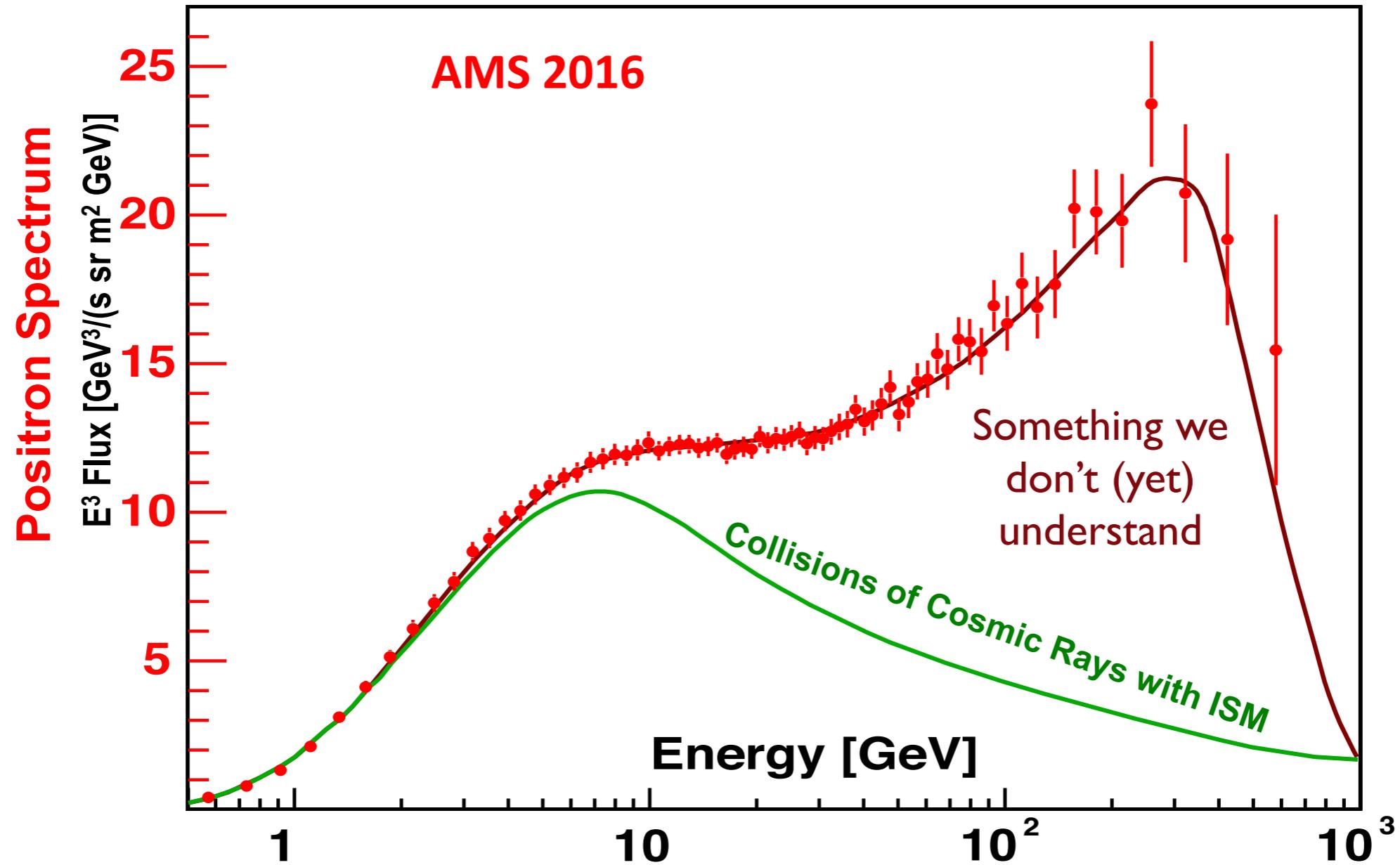
Prof. Peter Fisher
Prof. Richard Milner

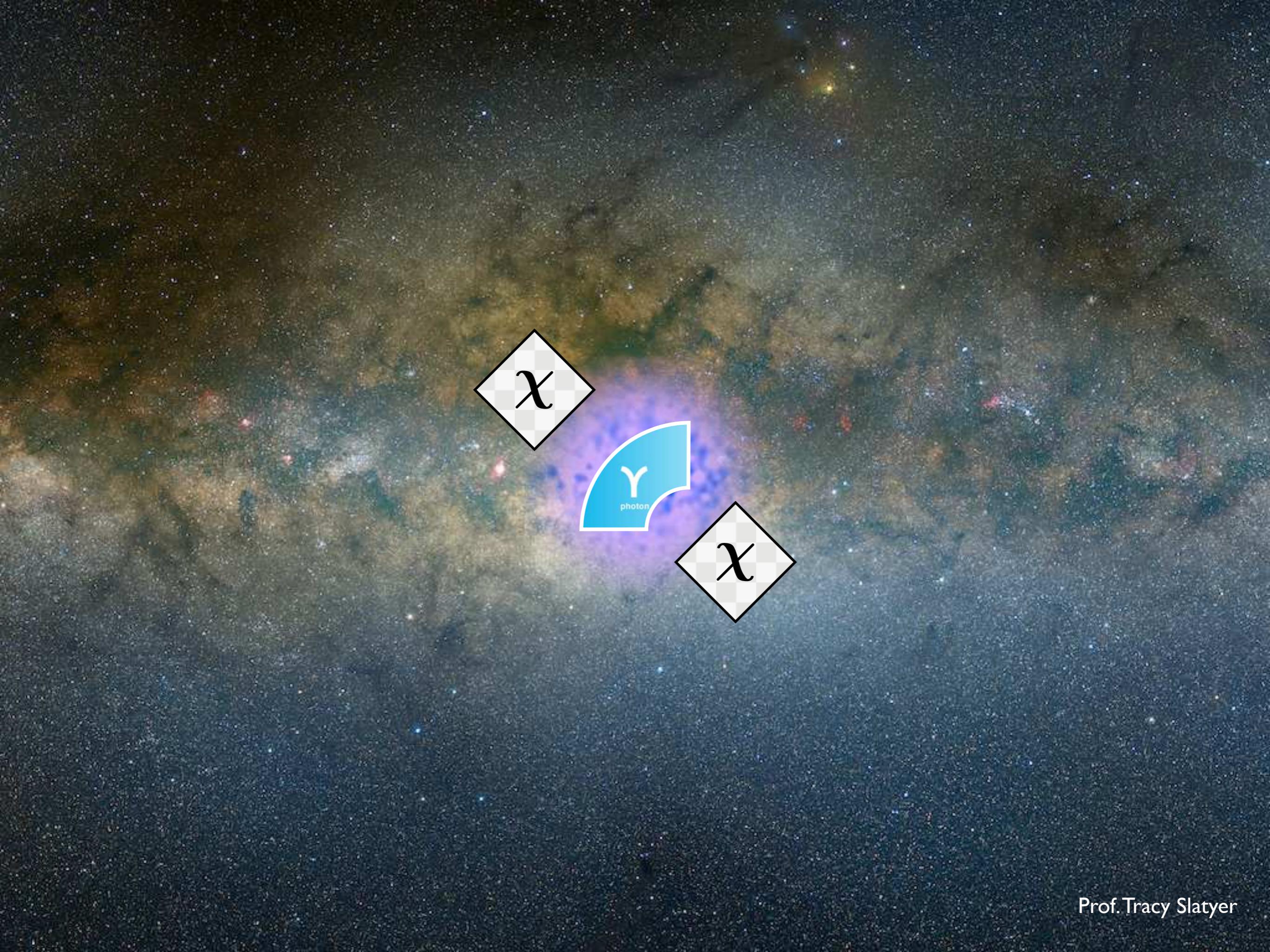




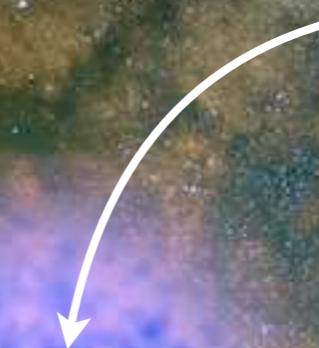
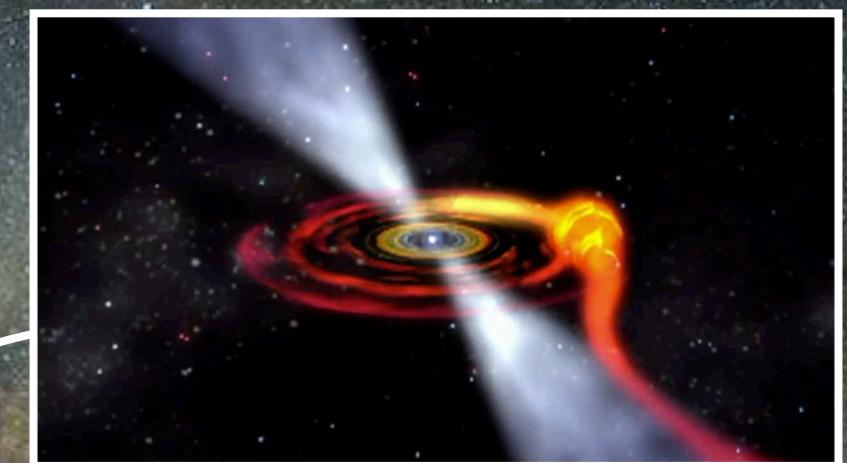
AMS (Prof. Sam Ting)
GAPS (Prof. Kerstin Perez)
IceCube (Prof. Janet Conrad)





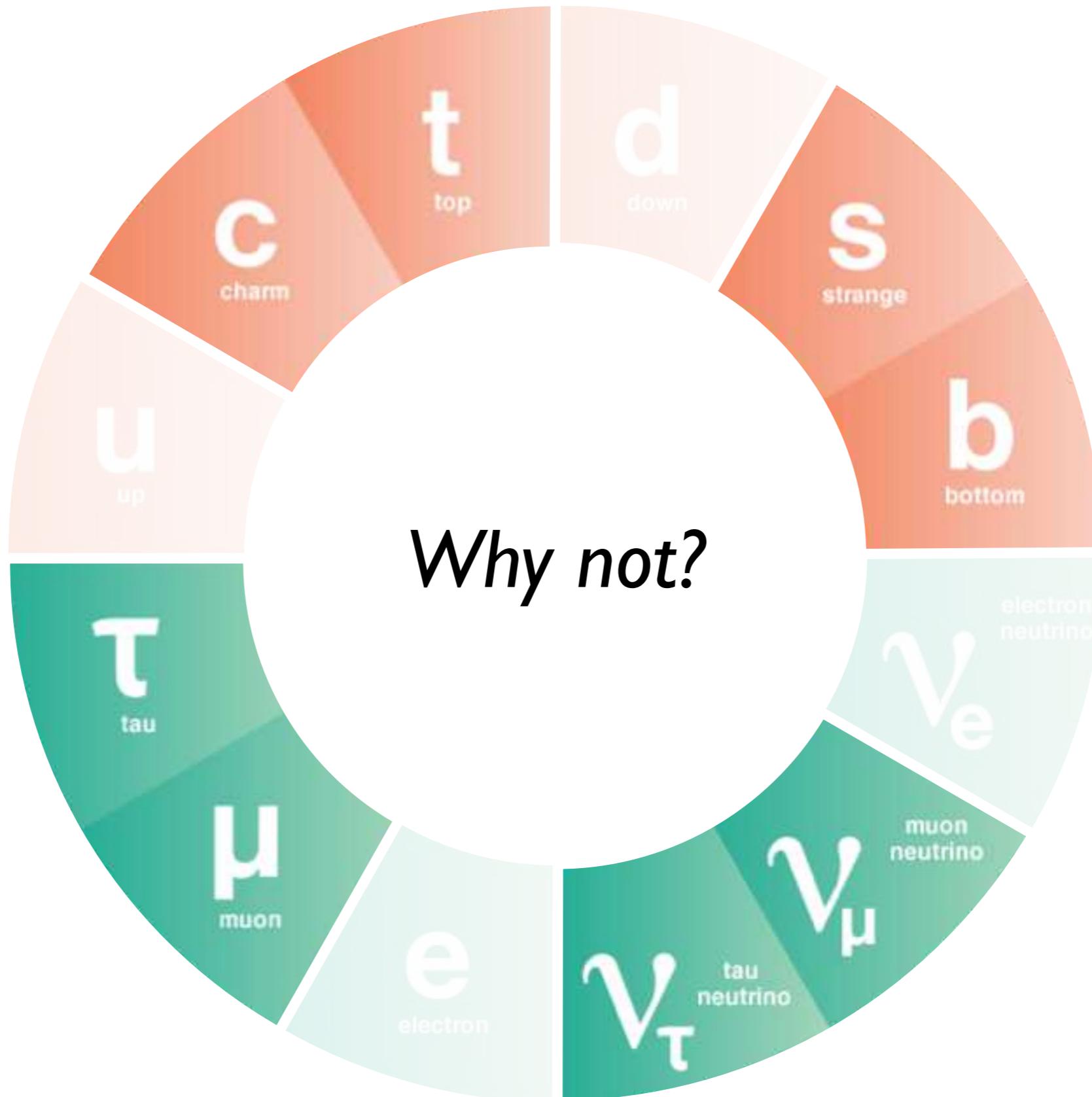


NRAO

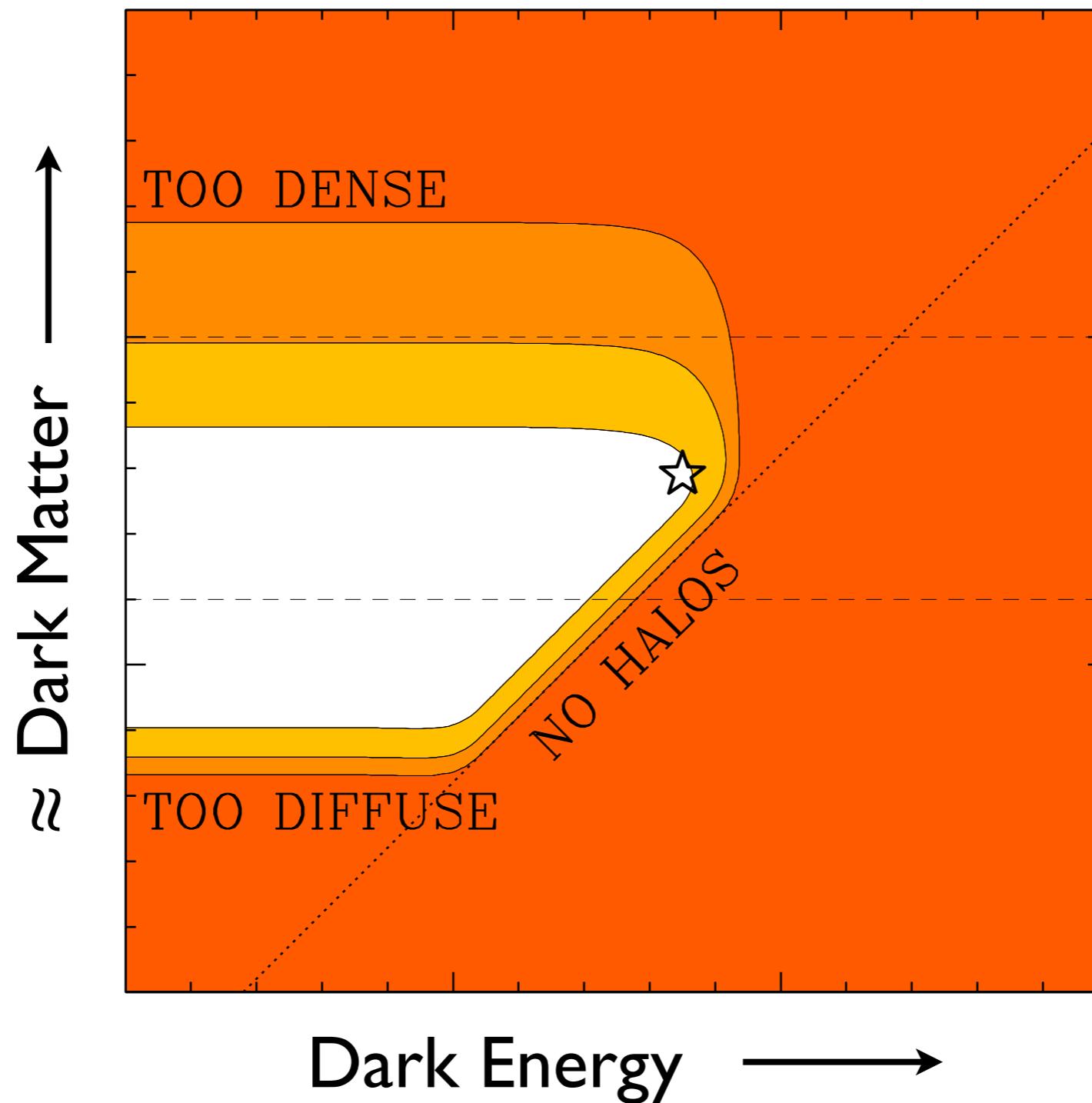


Prof. Tracy Slatyer

Why is there Dark Matter?



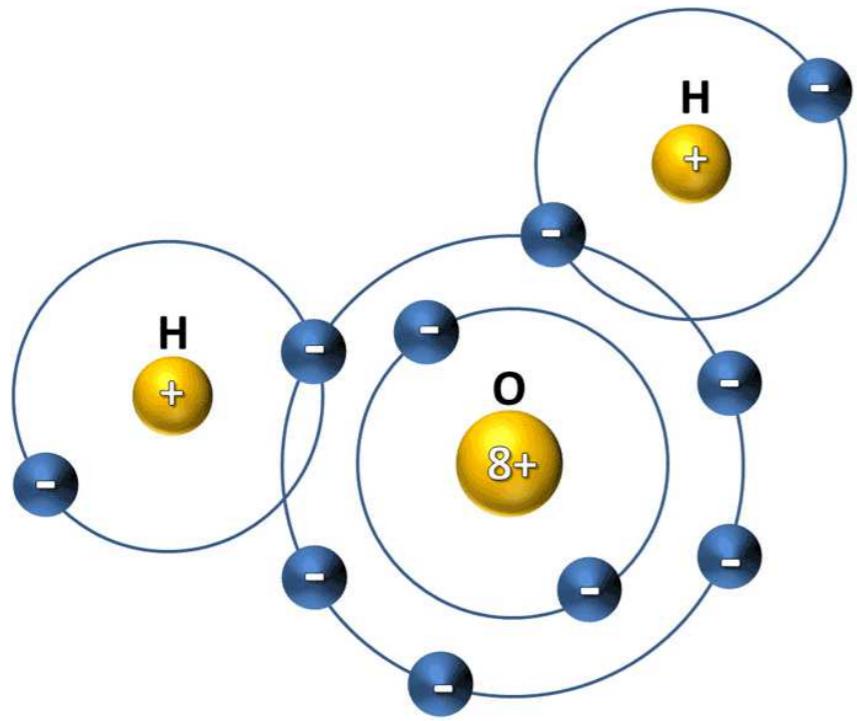
A Curious Coincidence



Tegmark, Aguirre, Rees, Wilczek (2005)

**Is Dark Matter related
to other Mysteries
of the Universe?**

Water



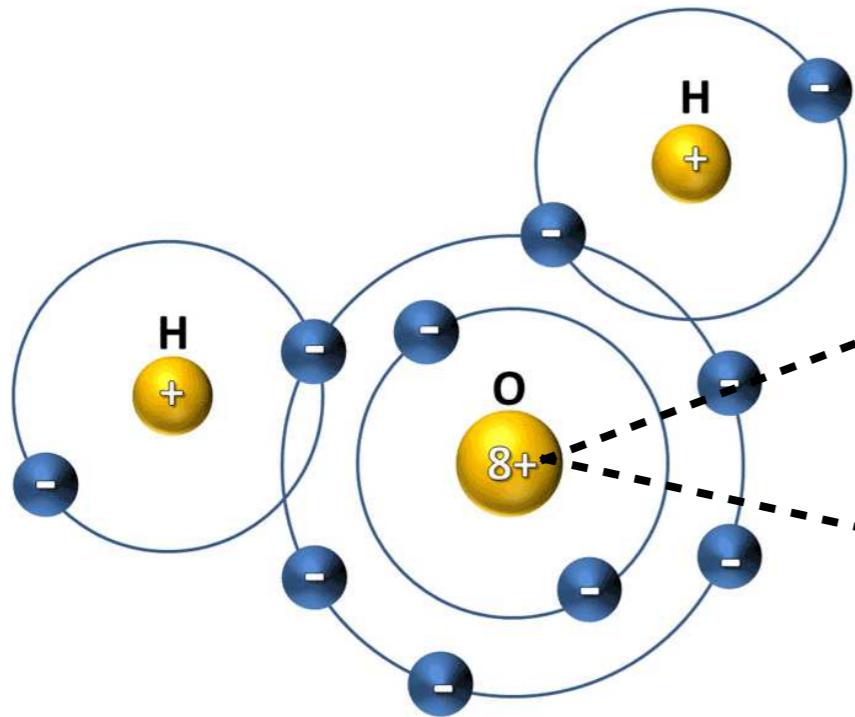
1.85 D



Who, me?

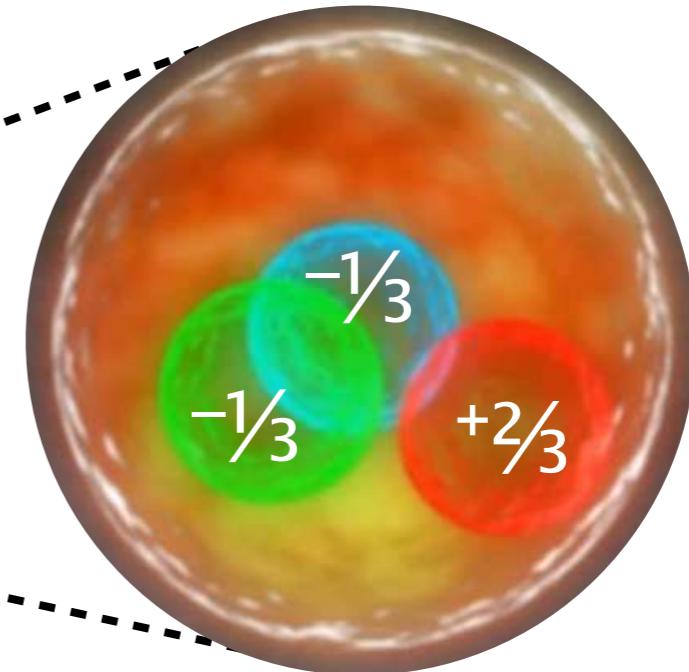


Water



1.85 D

Neutron



< 0.00000000000000 | 4 D





Peccei, Quinn; Weinberg; Wilczek; ...



CASPER Experiment

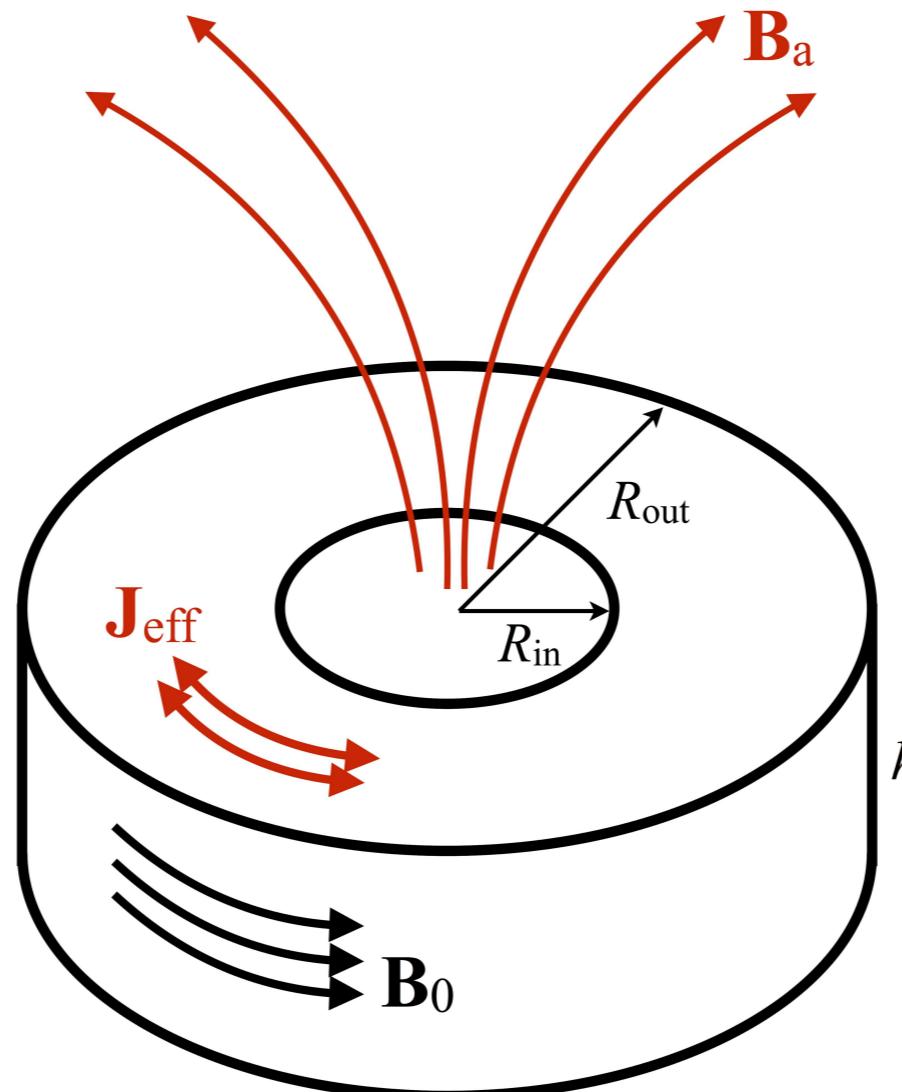
Broadband and Resonant Approaches to Axion Dark Matter Detection

Yonatan Kahn,^{1,*} Benjamin R. Safdi,^{2,†} and Jesse Thaler^{2,‡}

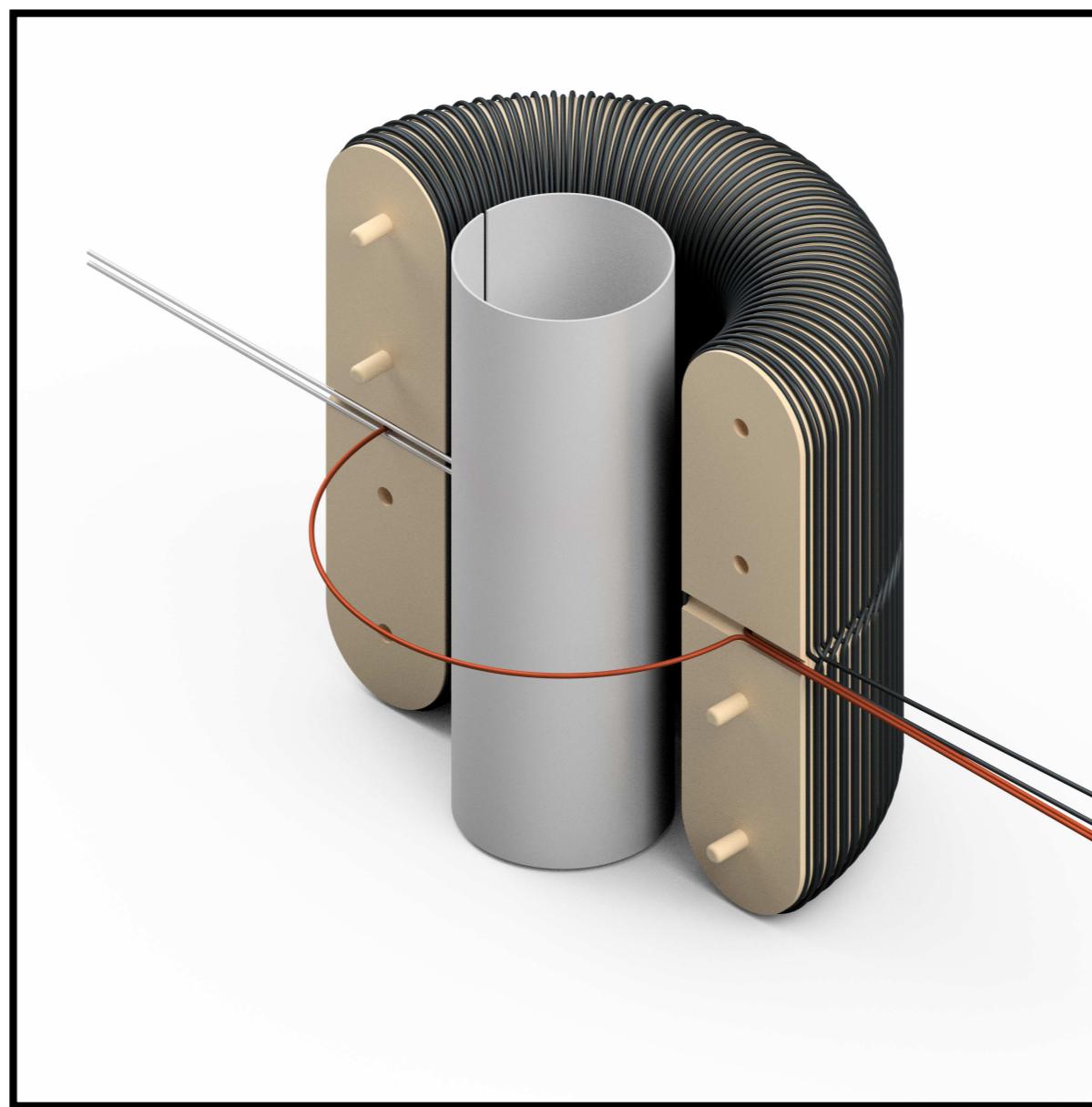
¹*Department of Physics, Princeton University, Princeton, New Jersey 08544, USA*

²*Center for Theoretical Physics, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA*

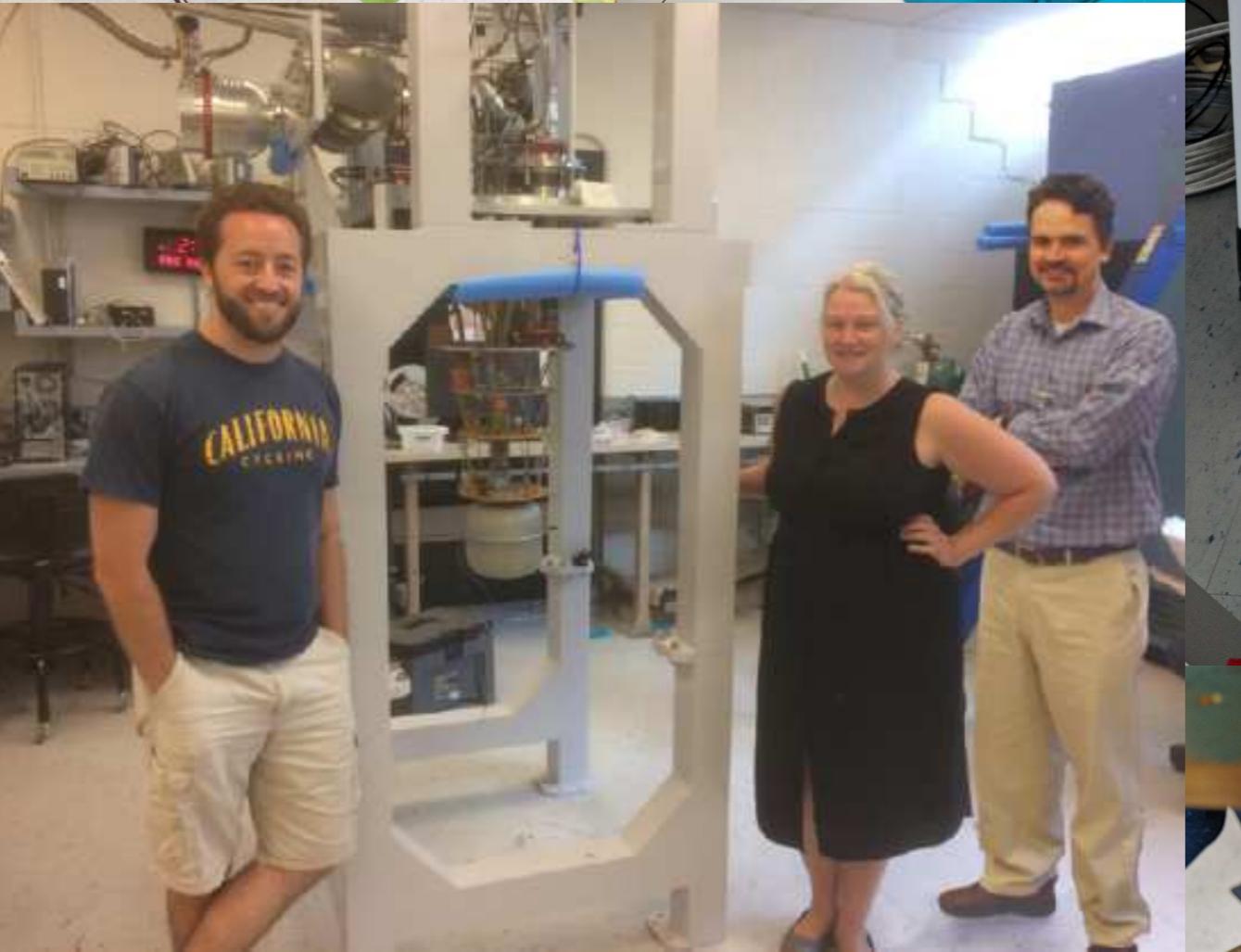
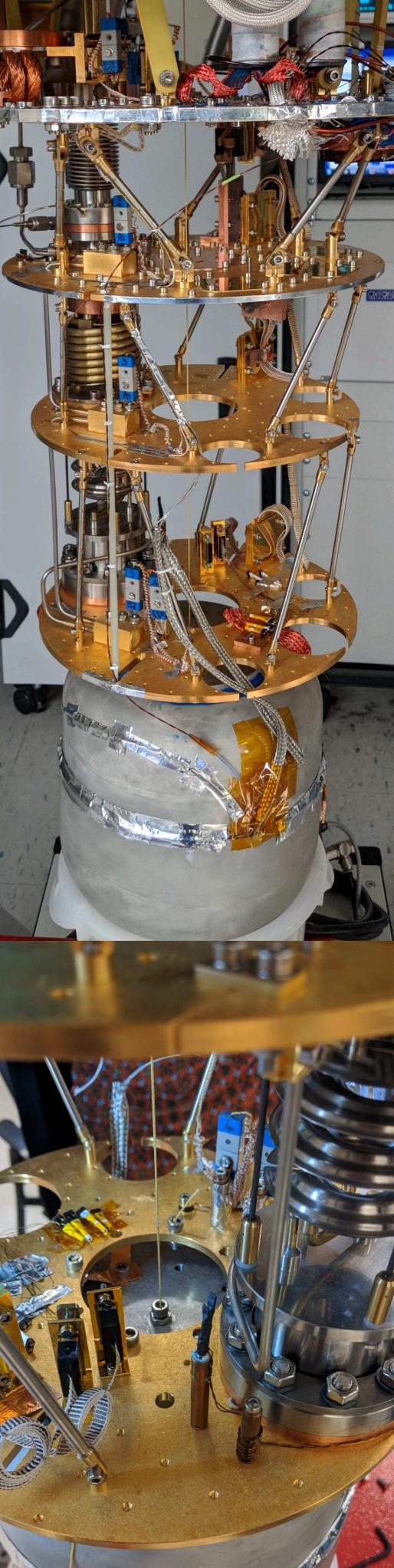
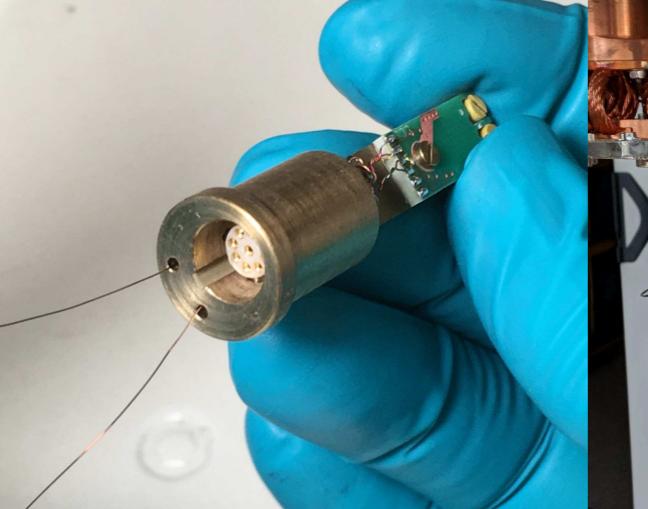
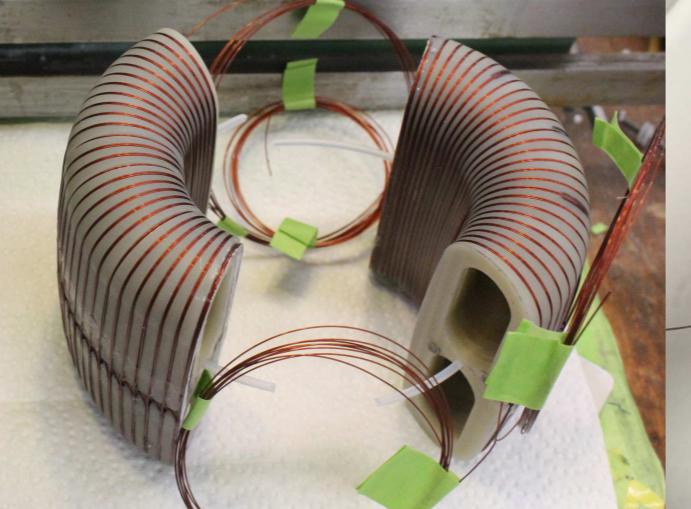
(Received 3 March 2016; published 30 September 2016)

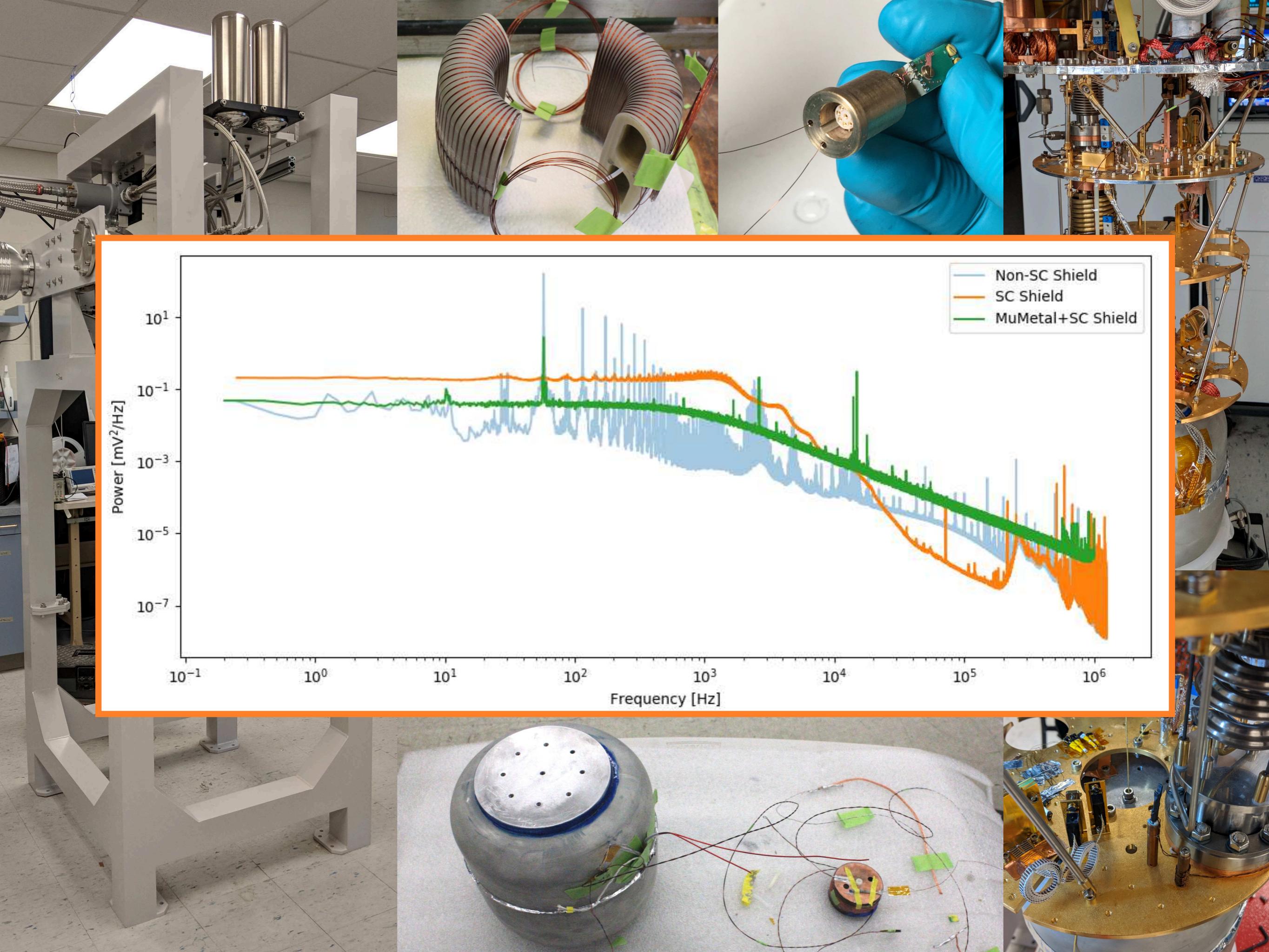


. Abracadabra →



Prof. Lindley Winslow





Invisible Stuff

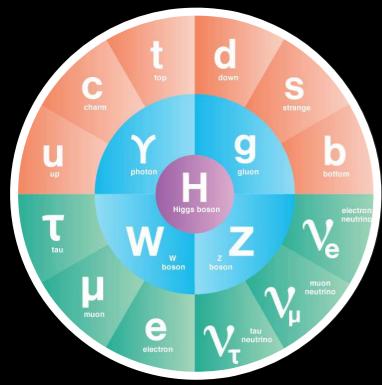
What?

Why?

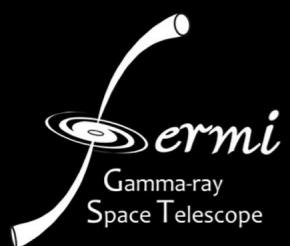
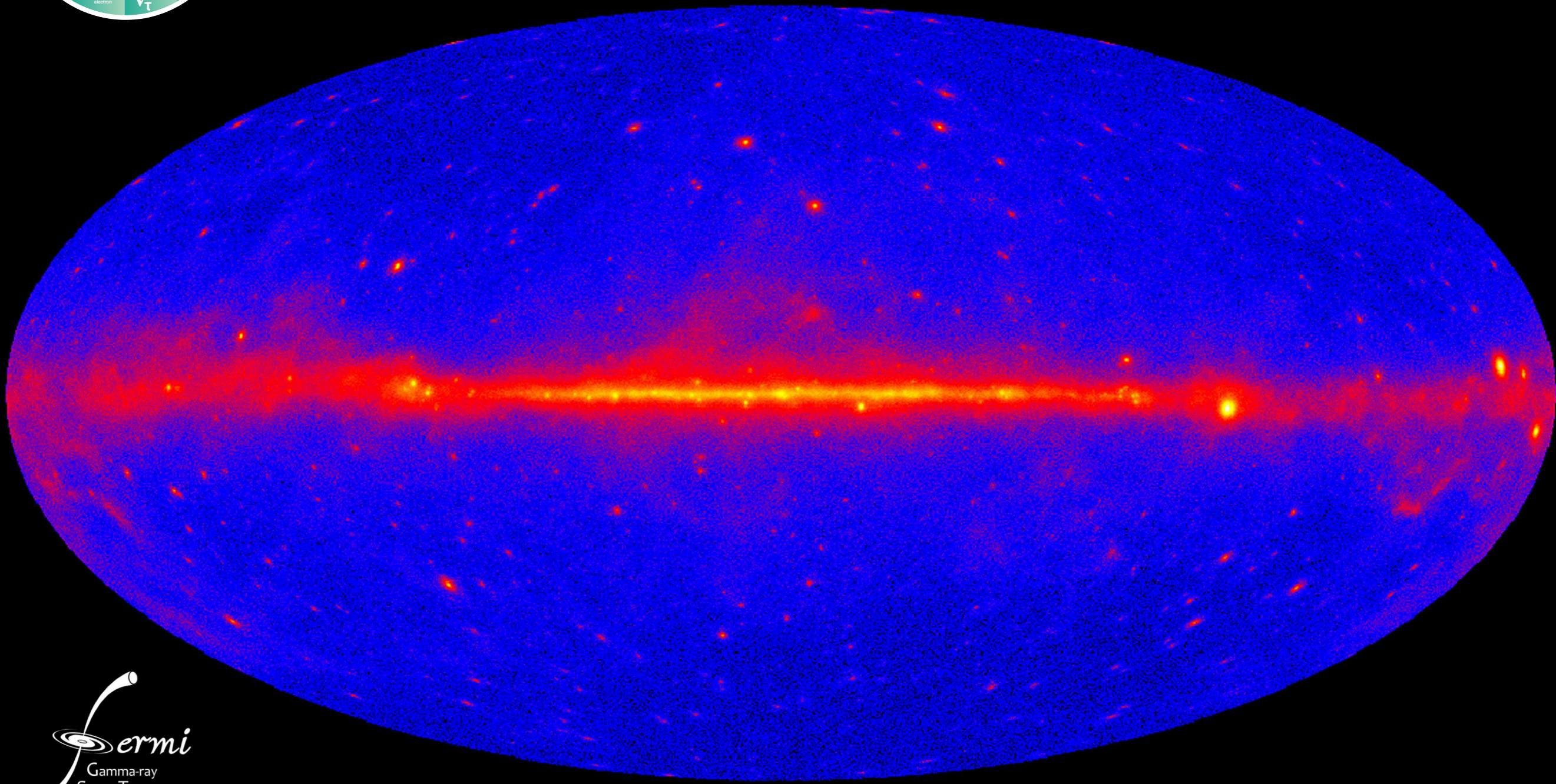
How do we know?

What will we know soon?

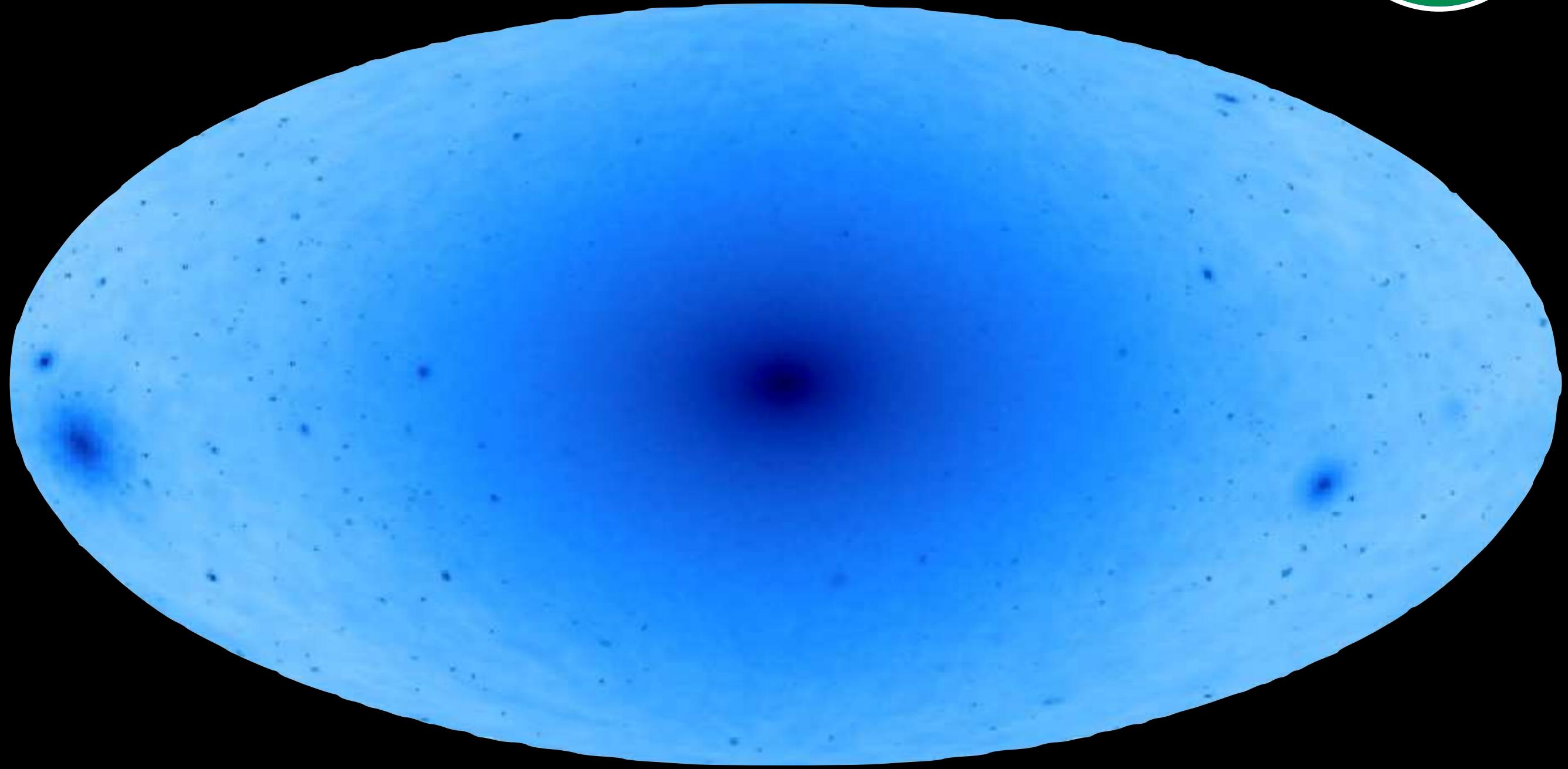
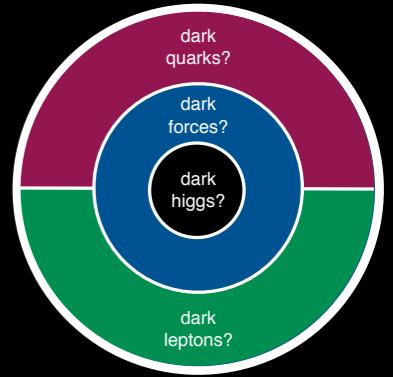
What more do you want to know?

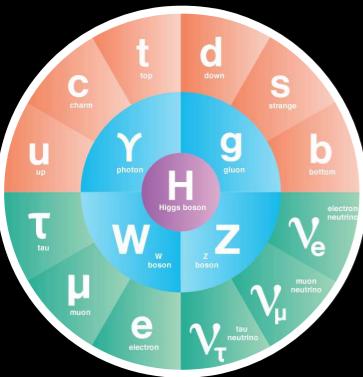


The Visible Milky Way

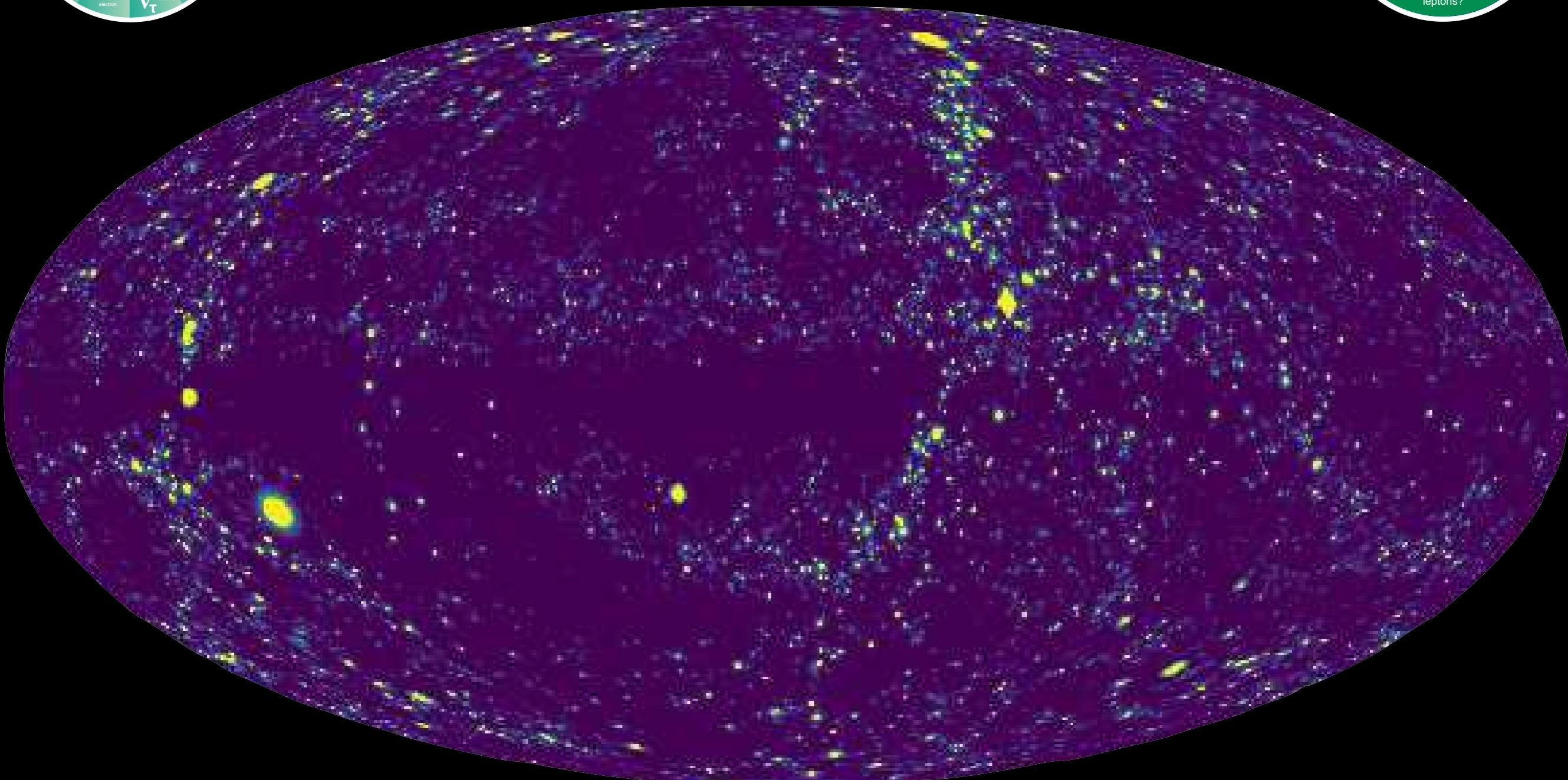


The Invisible Milky Way



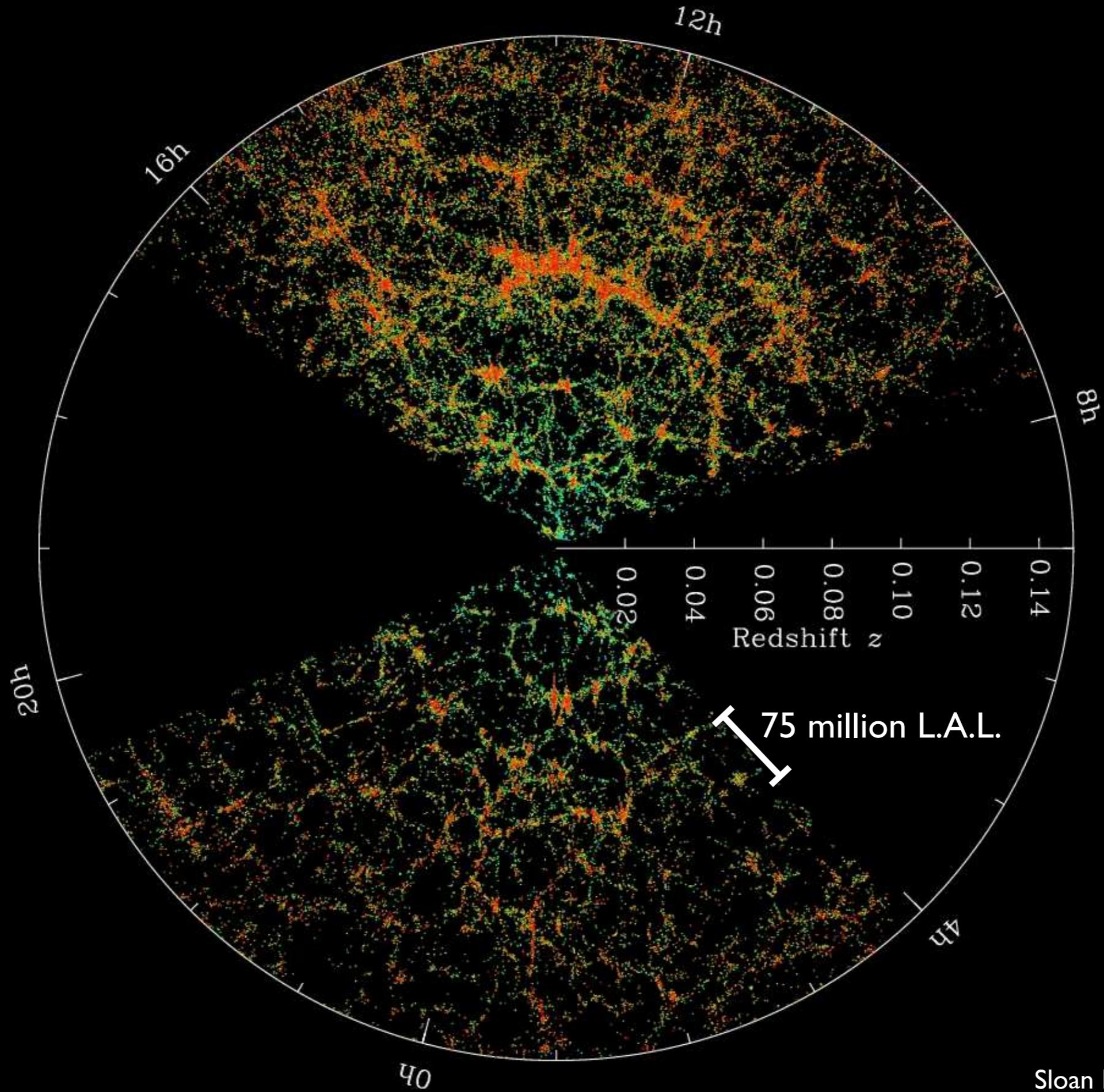


The (In)visible Universe



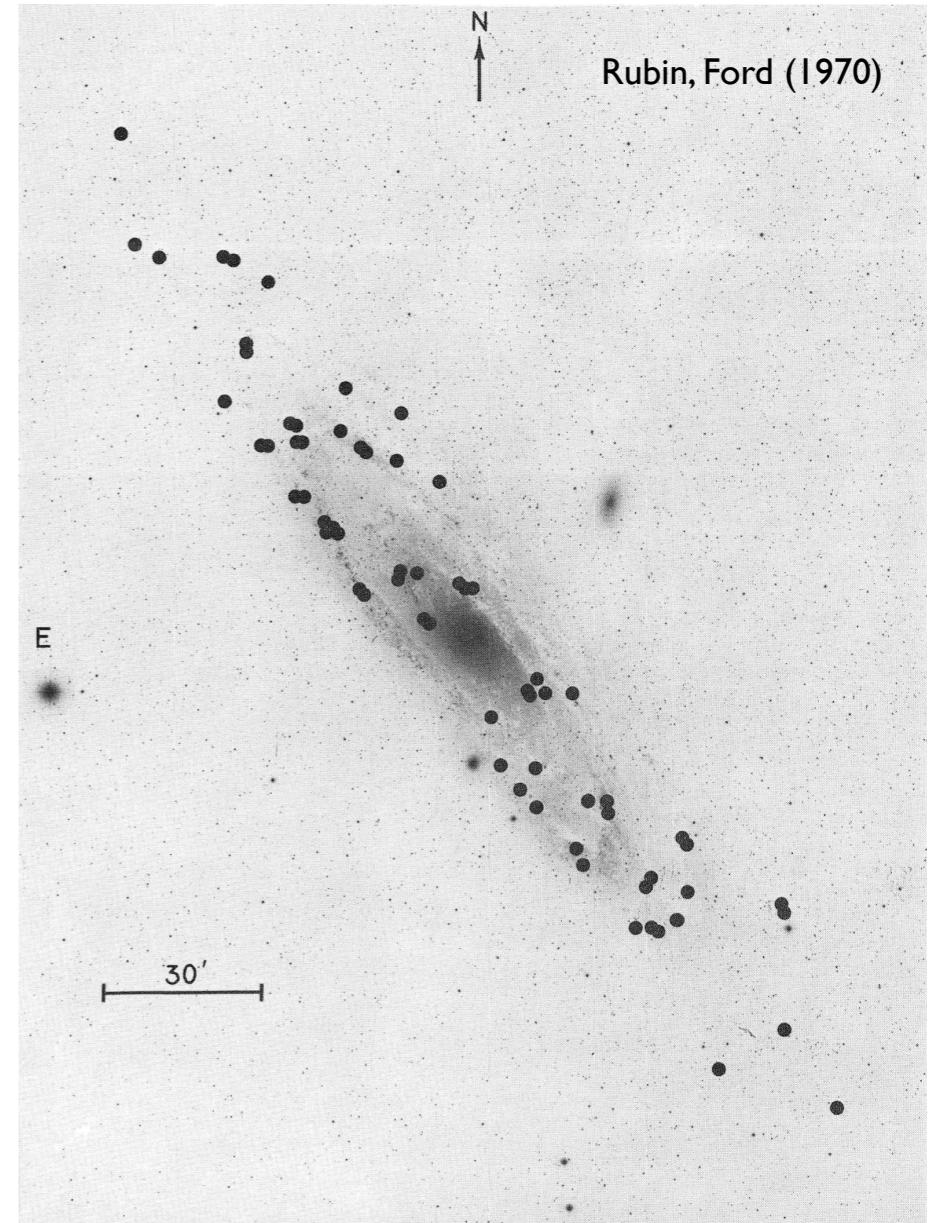
from Dr. Nick Rood (as of April 20, 2018!)

Bonus Slides





Vera Rubin, 1928–2016



Andromeda (M31)

M 31

4958

NE 80'

70'

54'

51'

25'

23'

16'

SW 23'

34'

55'

67'

71'

$H\beta'$ [O II]
NS
NS
NS
 $H\alpha''$ [N II] [S II]

5852

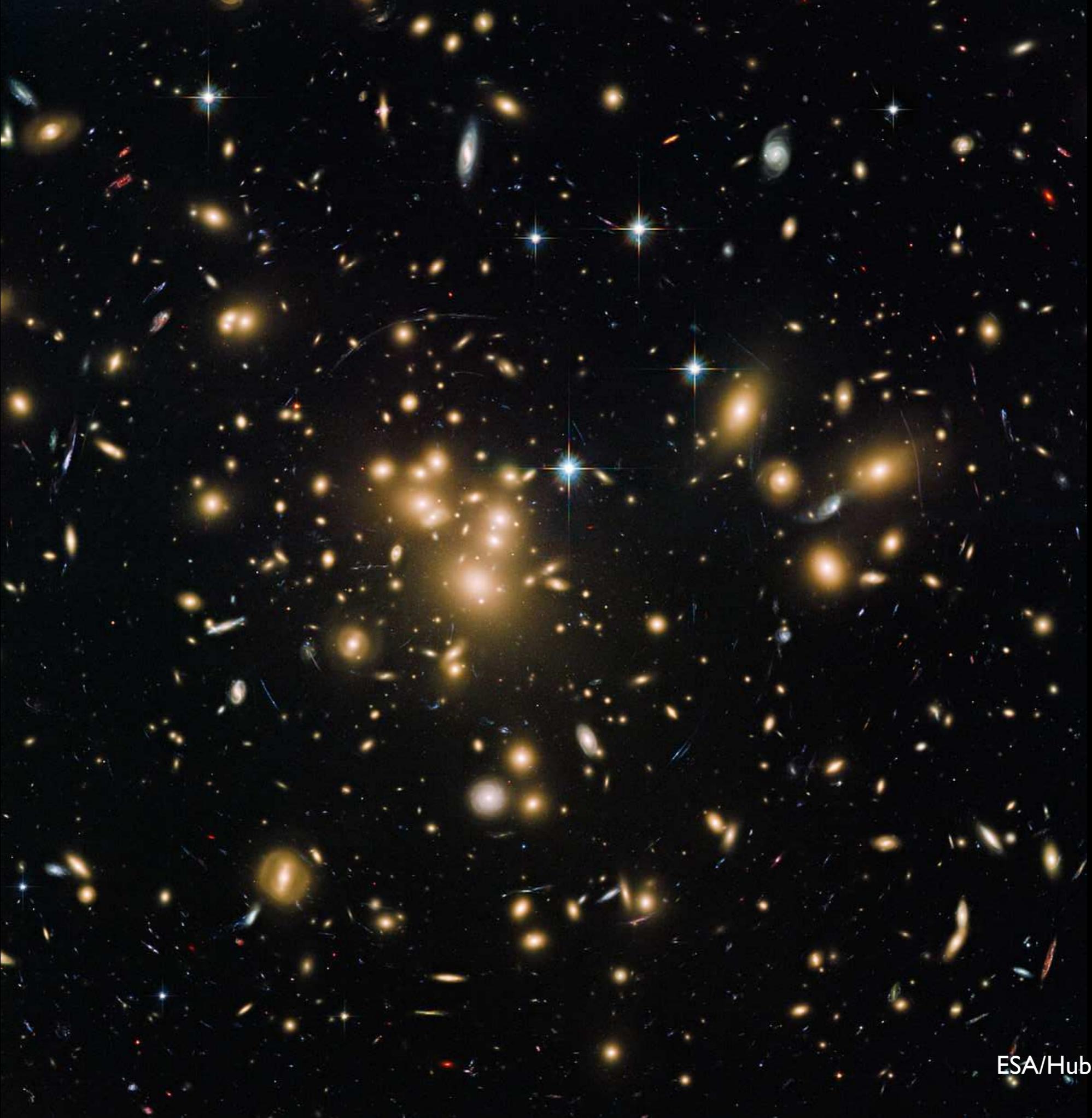
6598

Visible Only

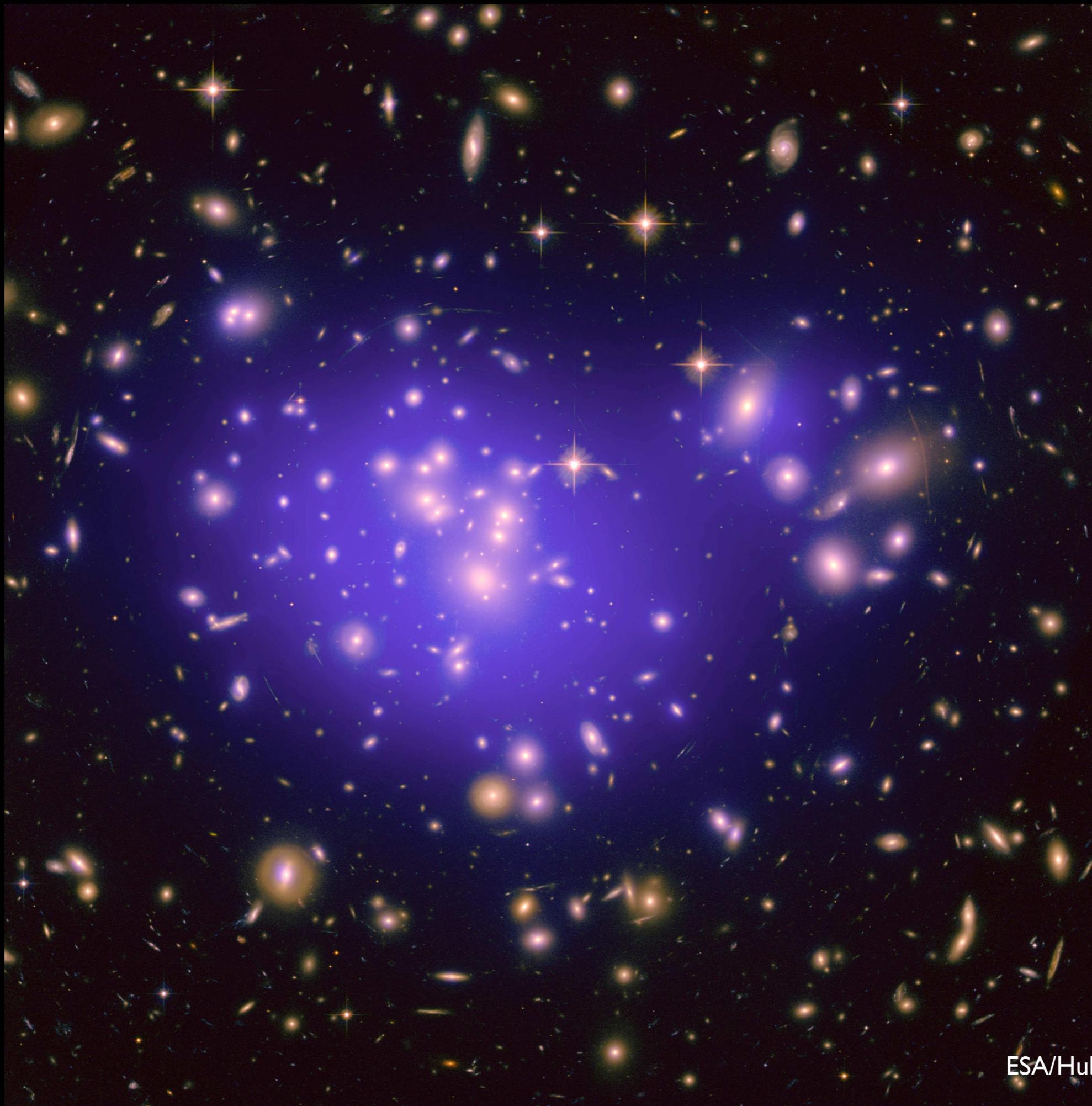




Kevin Hickerson



ESA/Hubble: Abell 1689



ESA/Hubble: Abell 1689

**Visible Matter
Photons & Neutrinos**

Dark Matter

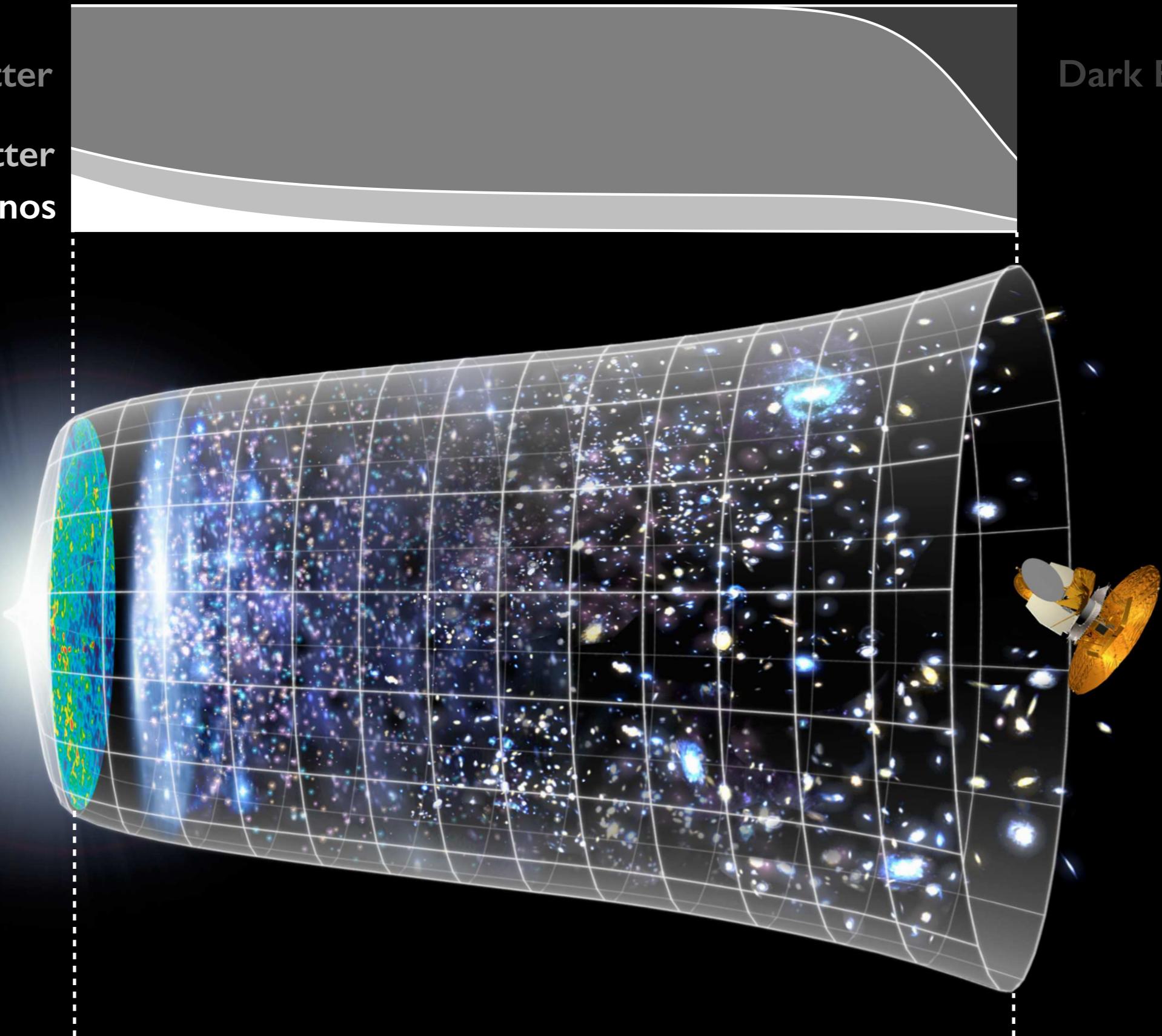
Dark Energy

time →

90,000 A.L.

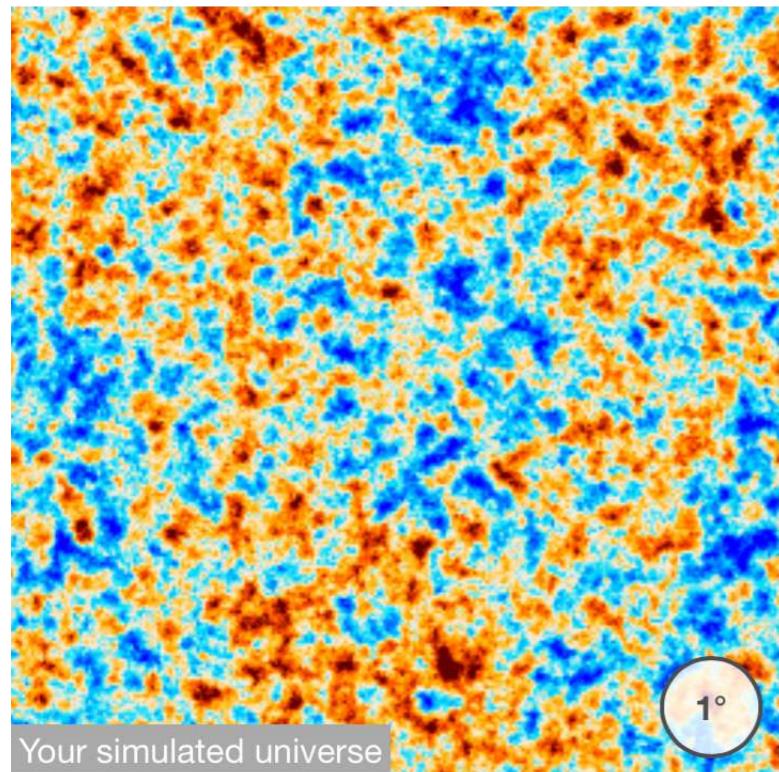
3.3 billion A.L.

NASA/WMAP

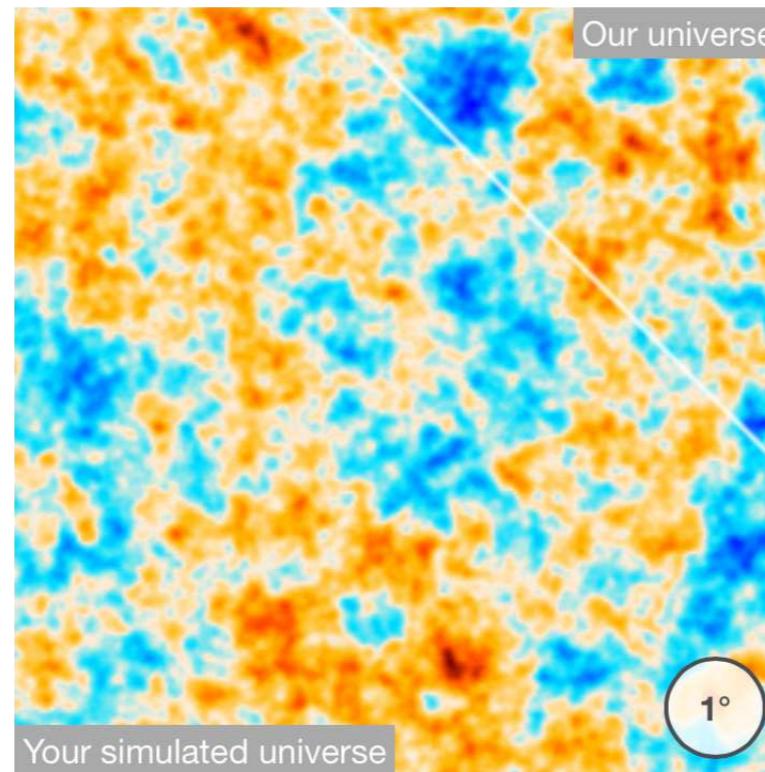




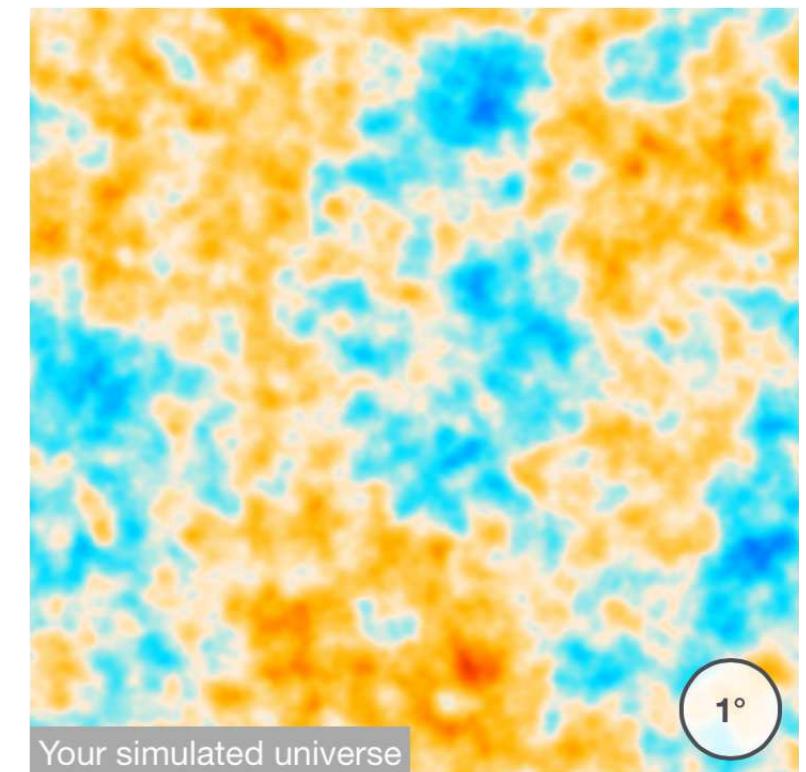
planck CMB Simulator



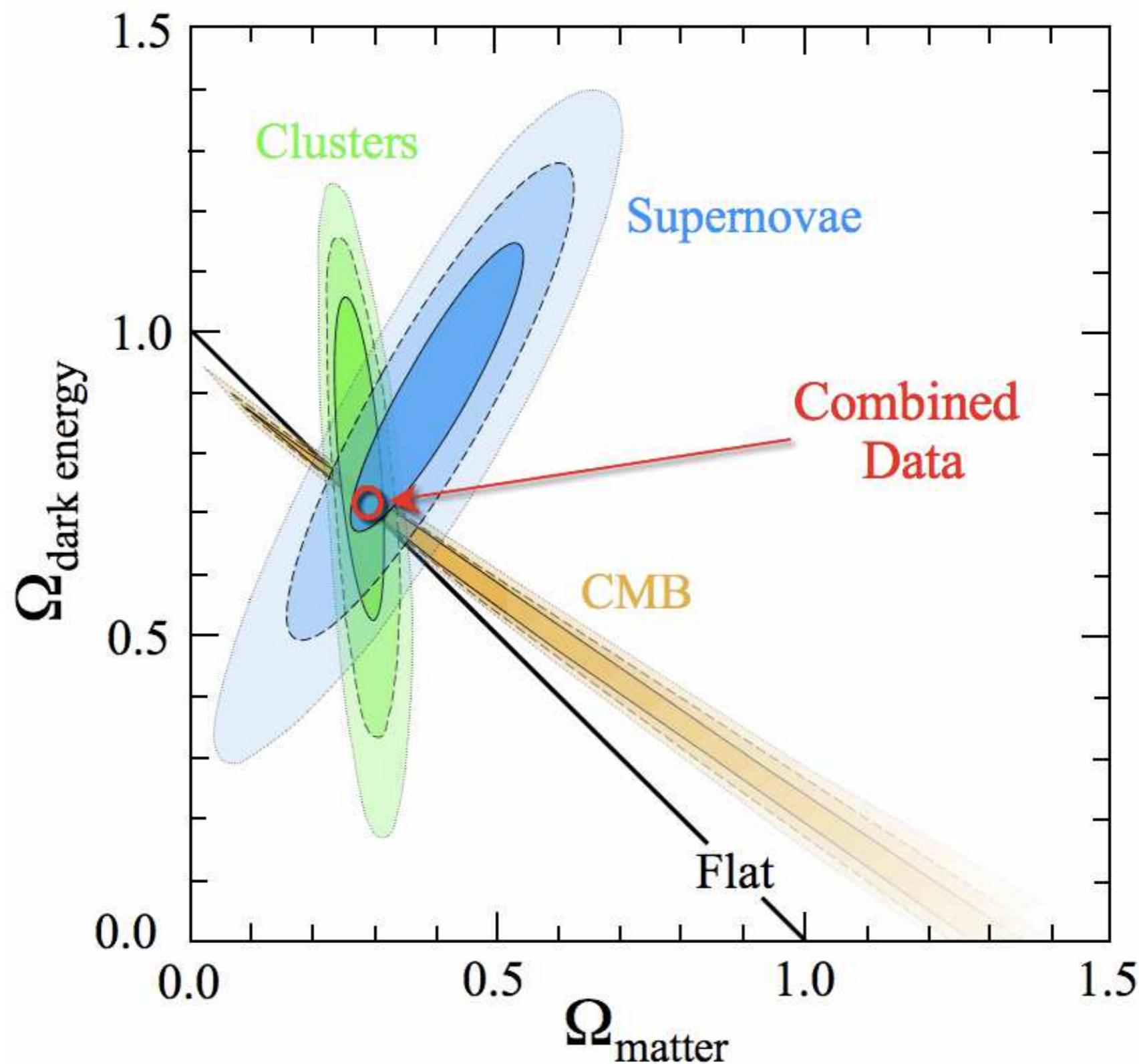
No Dark Matter



Measured Dark Matter



3x Dark Matter

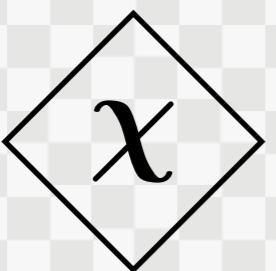




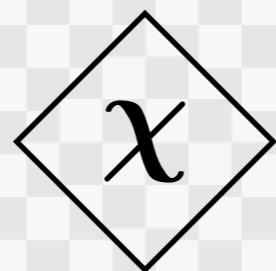
Composite Image: Bullet Cluster

Particle?

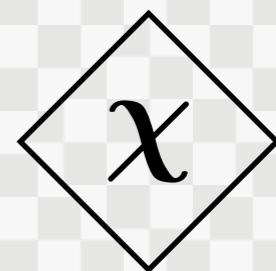
Make It

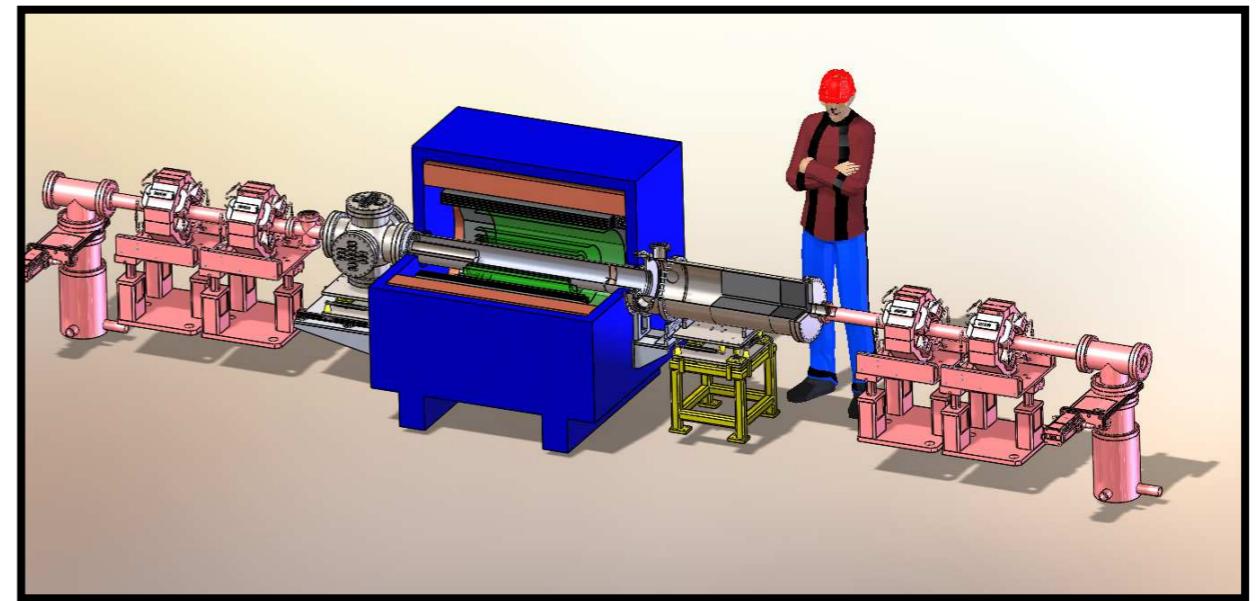


Break It



Shake It

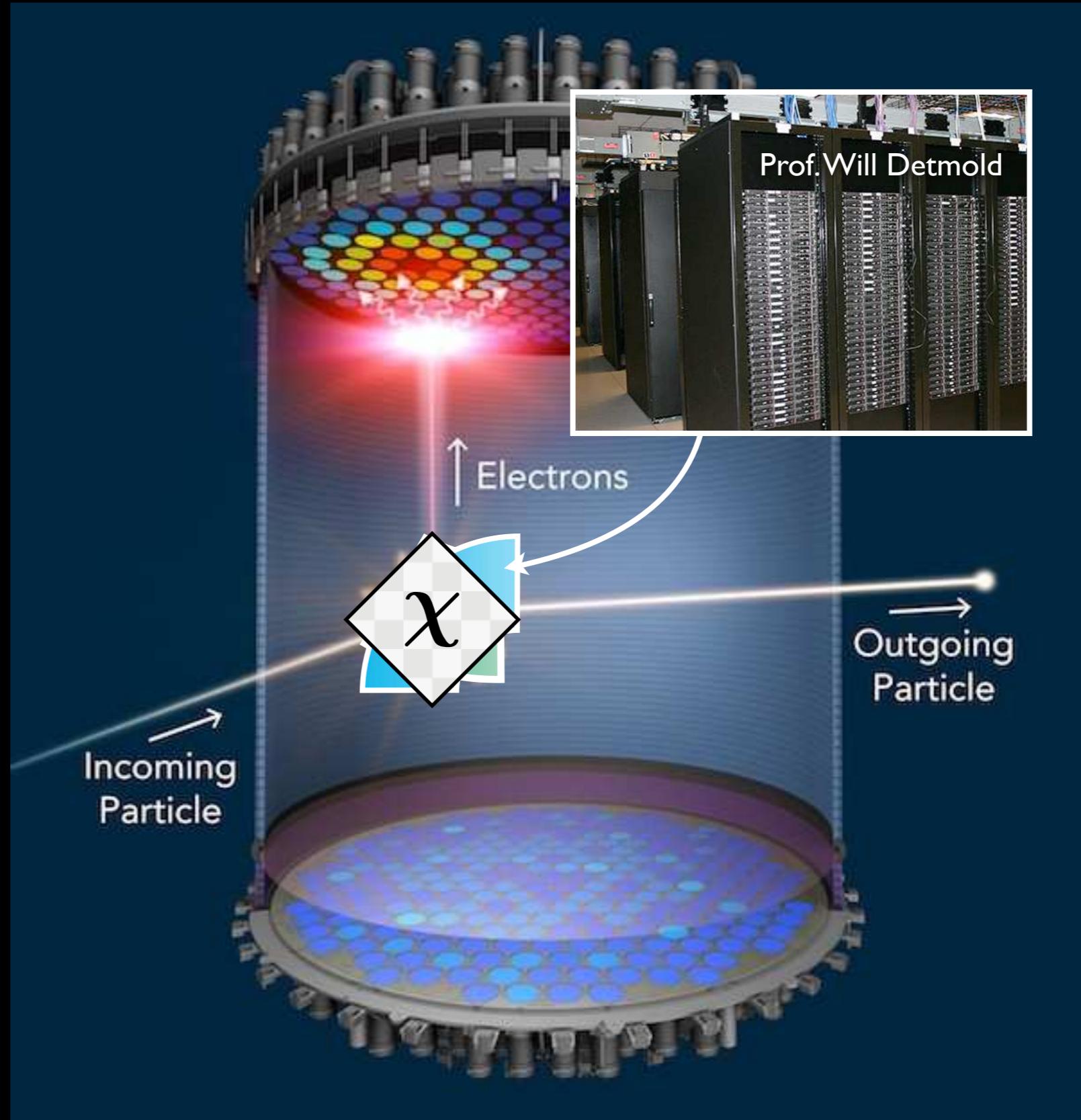




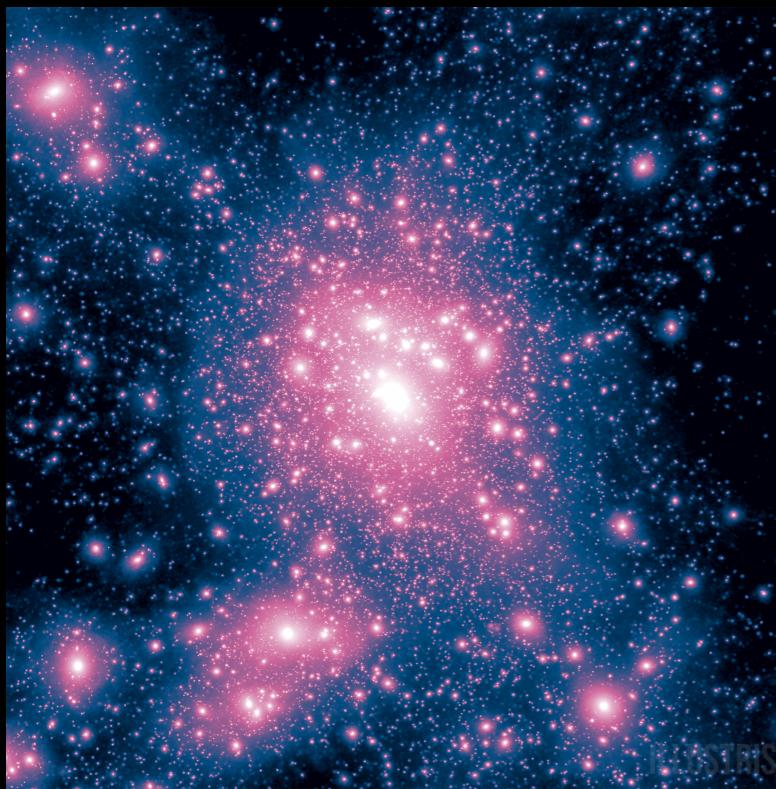
Prof. Peter Fisher and Prof. Richard Milner

↓
1,500 A.H.
underground

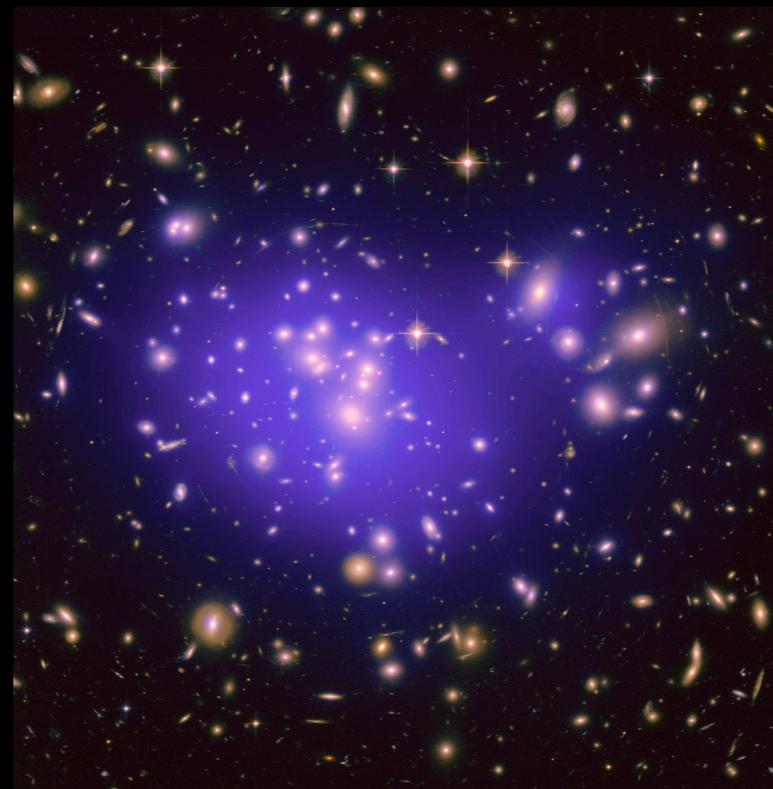
1.5 A.H.



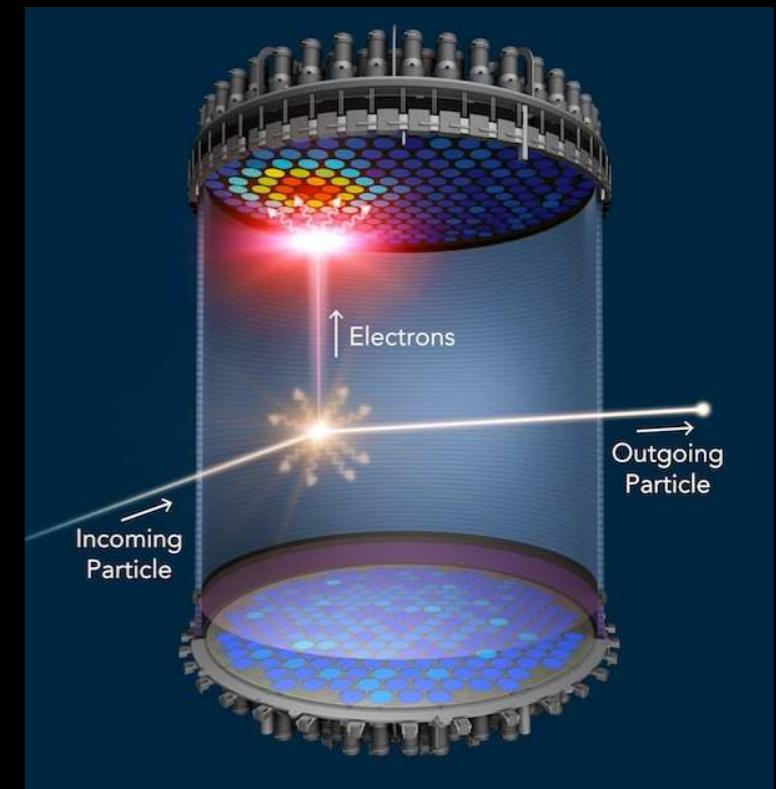
e.g. LZ Experiment



Simulation



Observation



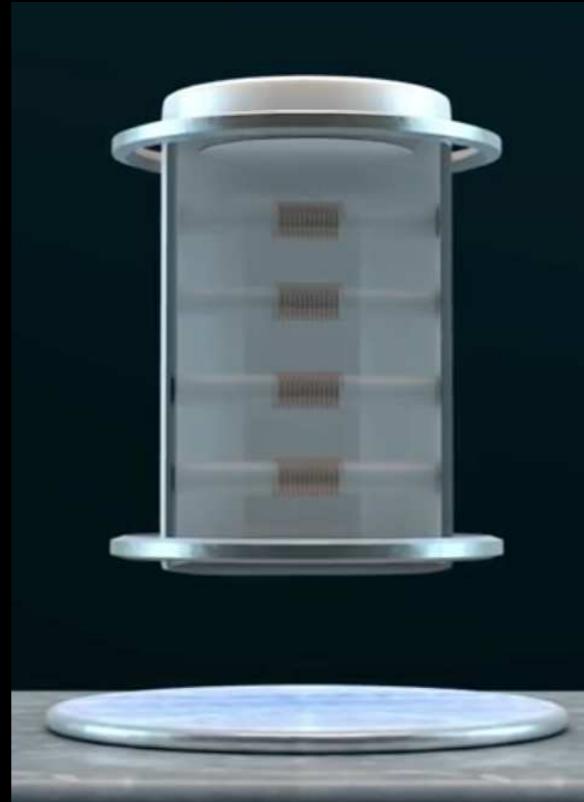
Opportunities



Prof. Lindley Winslow



ADMX



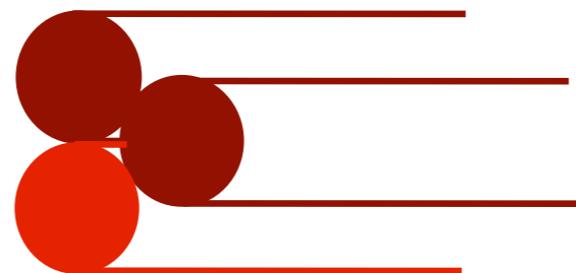
CASPER



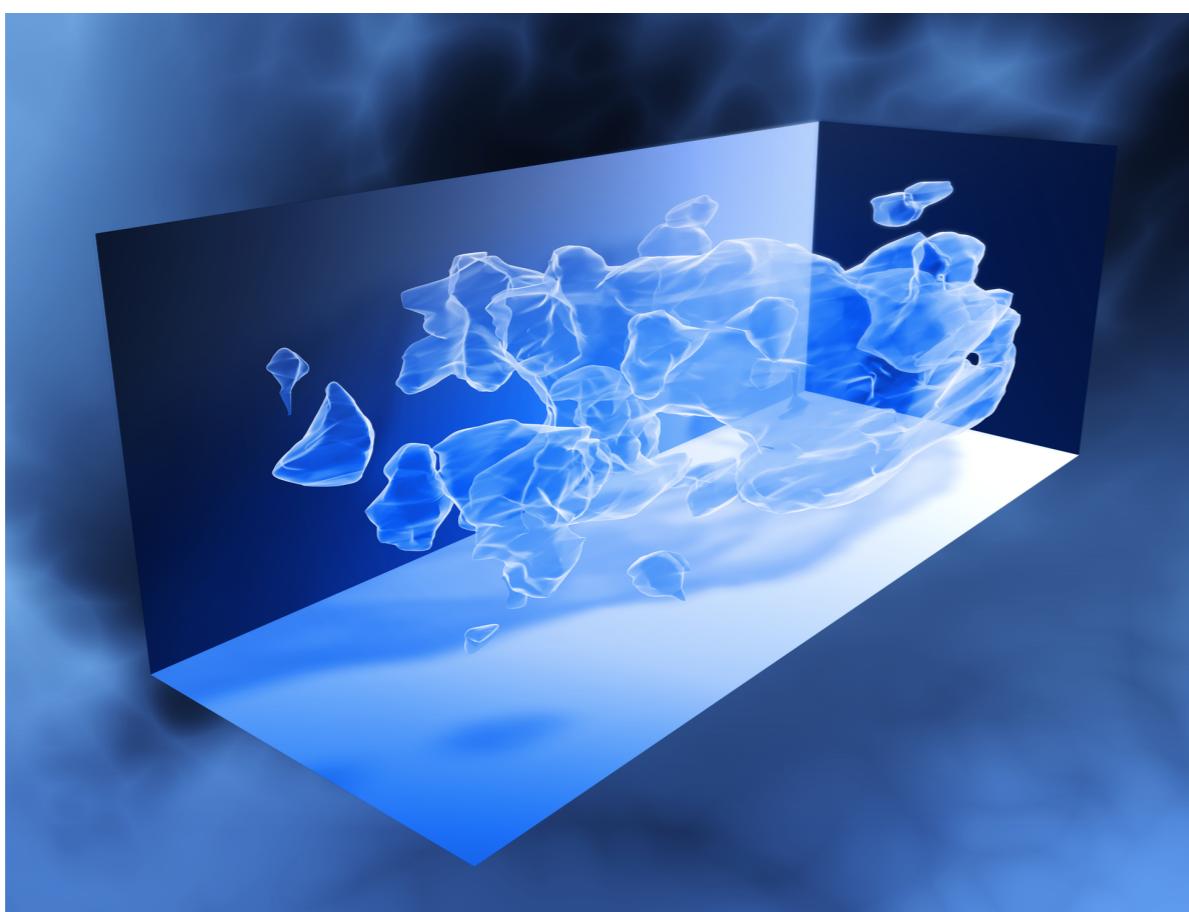
ABRACADABRA

...

Why does
Dark Matter matter?



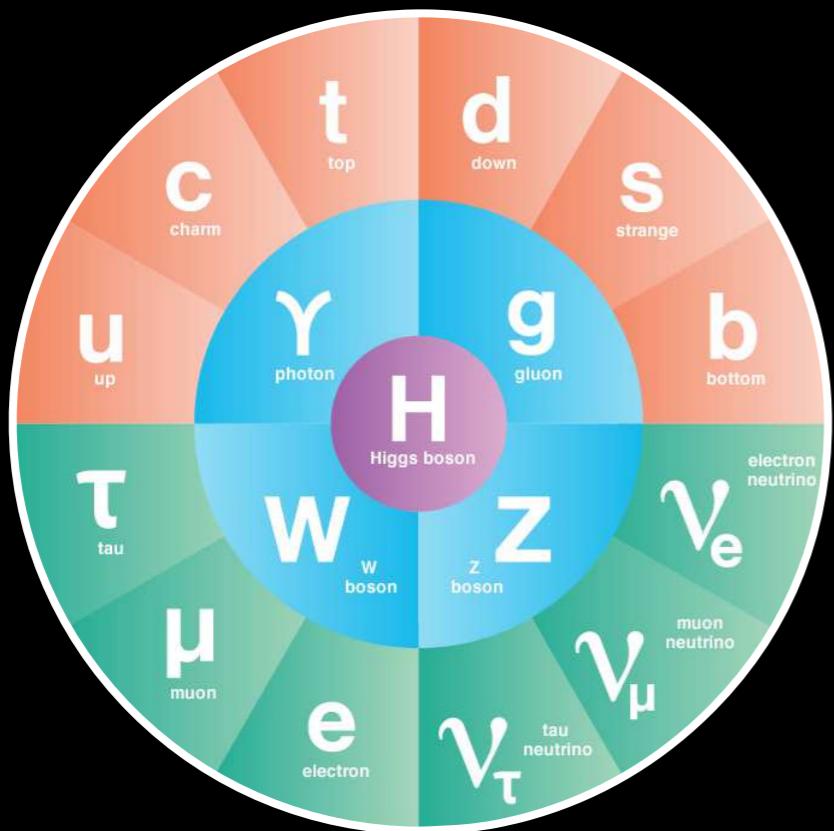
Superconducting Systems, Inc.



*Why has the pursuit of science for its own sake
had such a remarkable track record in
generating transformative new technology?*

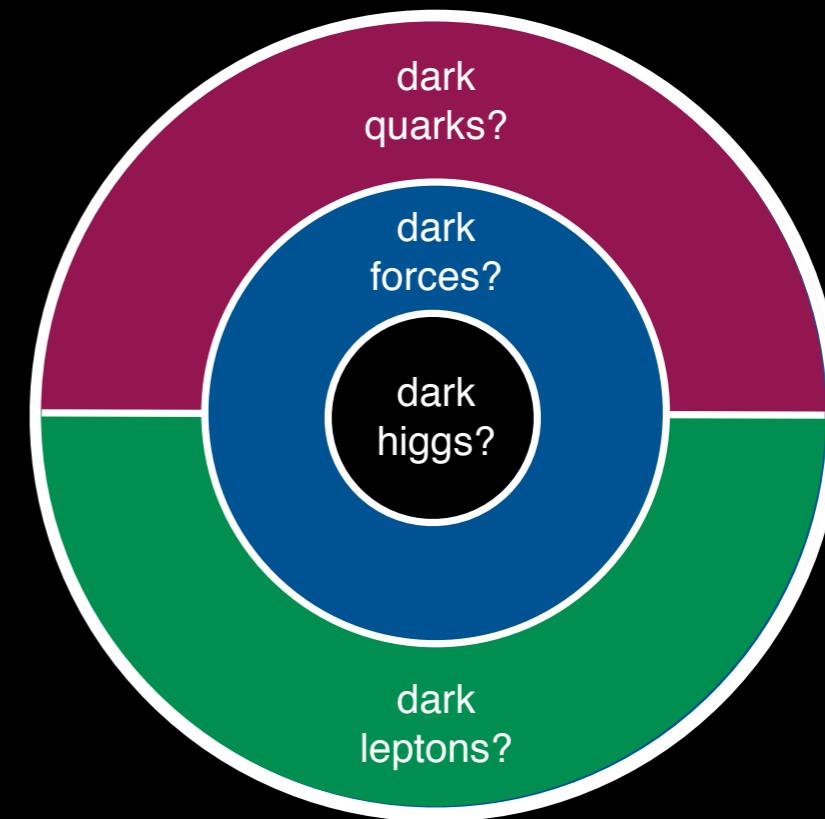
The reason must be that Nature poses deeper and more challenging questions than humans can do, and the struggle to understand Nature forces us to invent better and deeper ideas than we would if left to our devices.

The Standard Model

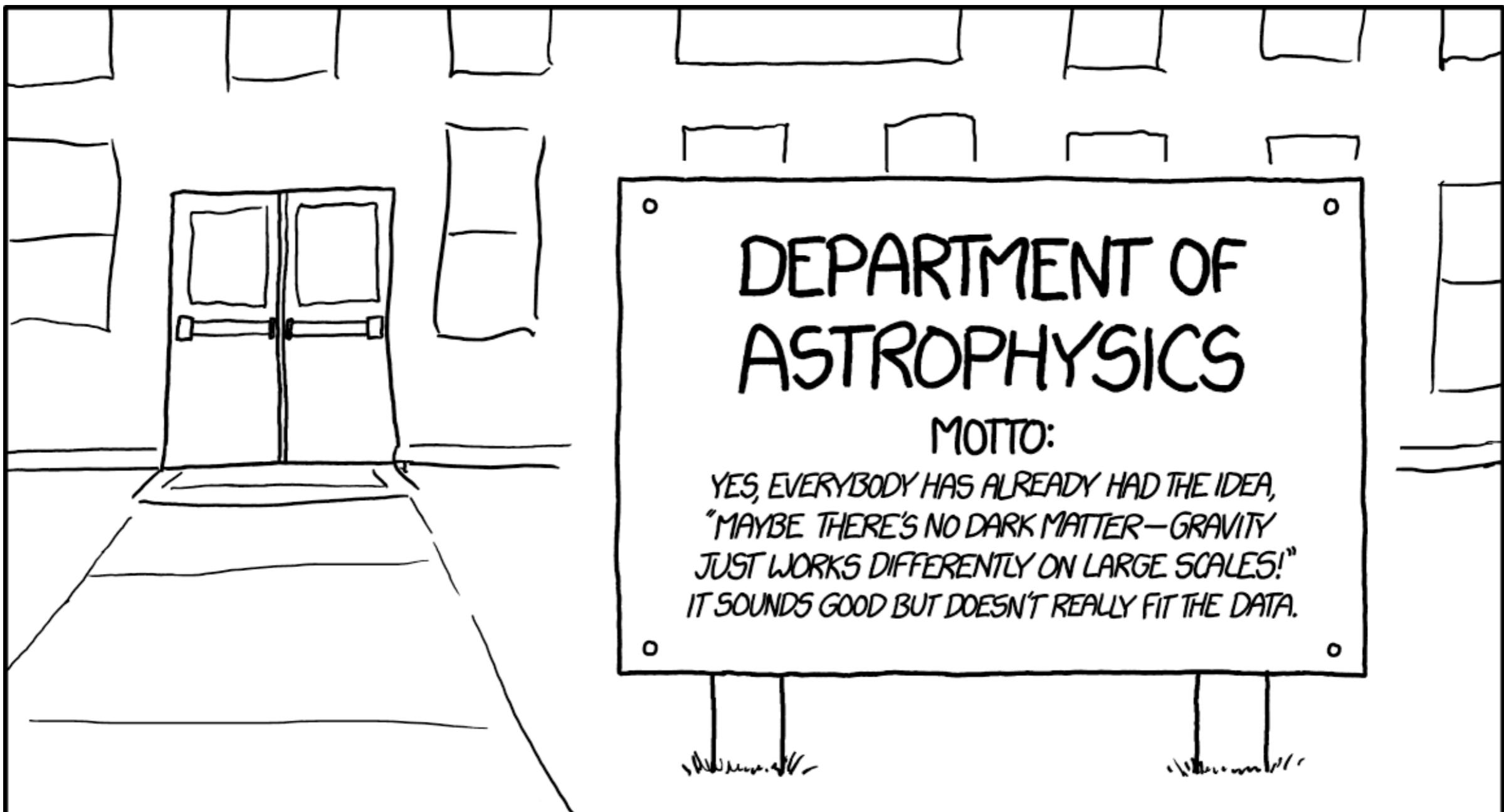


c. 1967

The Invisible Universe



????



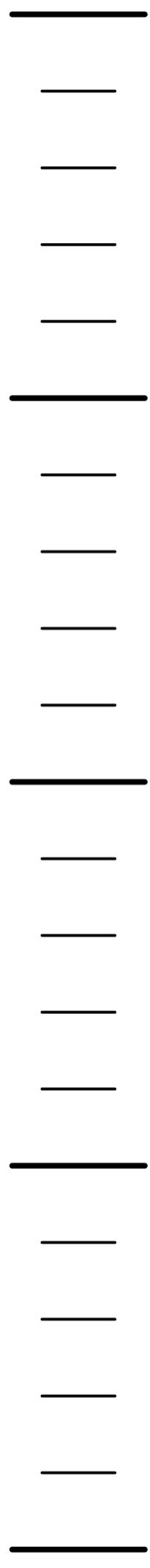
Quantum Gravity Grand Unification

The TeV Scale
Protons
Electrons
Molecules

Cells
Hairs
Us

Planet
Solar System
Galaxy

The Universe



10^{26} m 10^{11} m 10^0 m 10^{-4} m 10^{-19} m 10^{-34} m



Dark Matter

Dark Energy

