

SPACE

SIGHT

SOUND

# Listening to the Invisible Universe

Jesse Thaler



*A Far Cry Open Rehearsal, “Preparing Gravity”, Harvard Ed Portal — April 10, 2019*



Milky Way Chasers, Michael Bentz at Cape Neddick

*My research →*

Stars

Dark Matter

Visible Matter (mostly H and He)

Dark Energy

SPACE

SIGHT

SOUND

*We are very small*



Adrian  
Height

50 A.H.

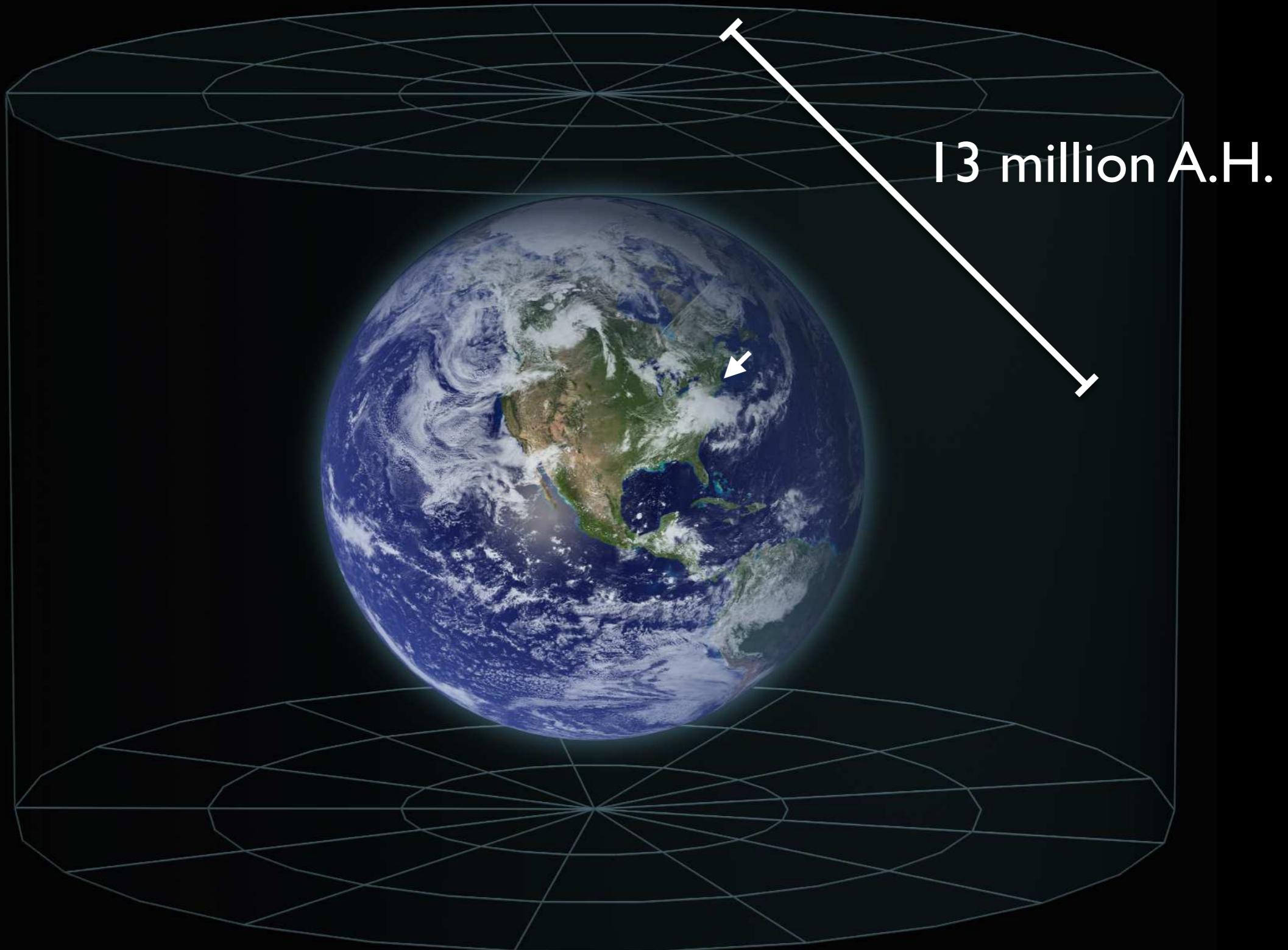
T



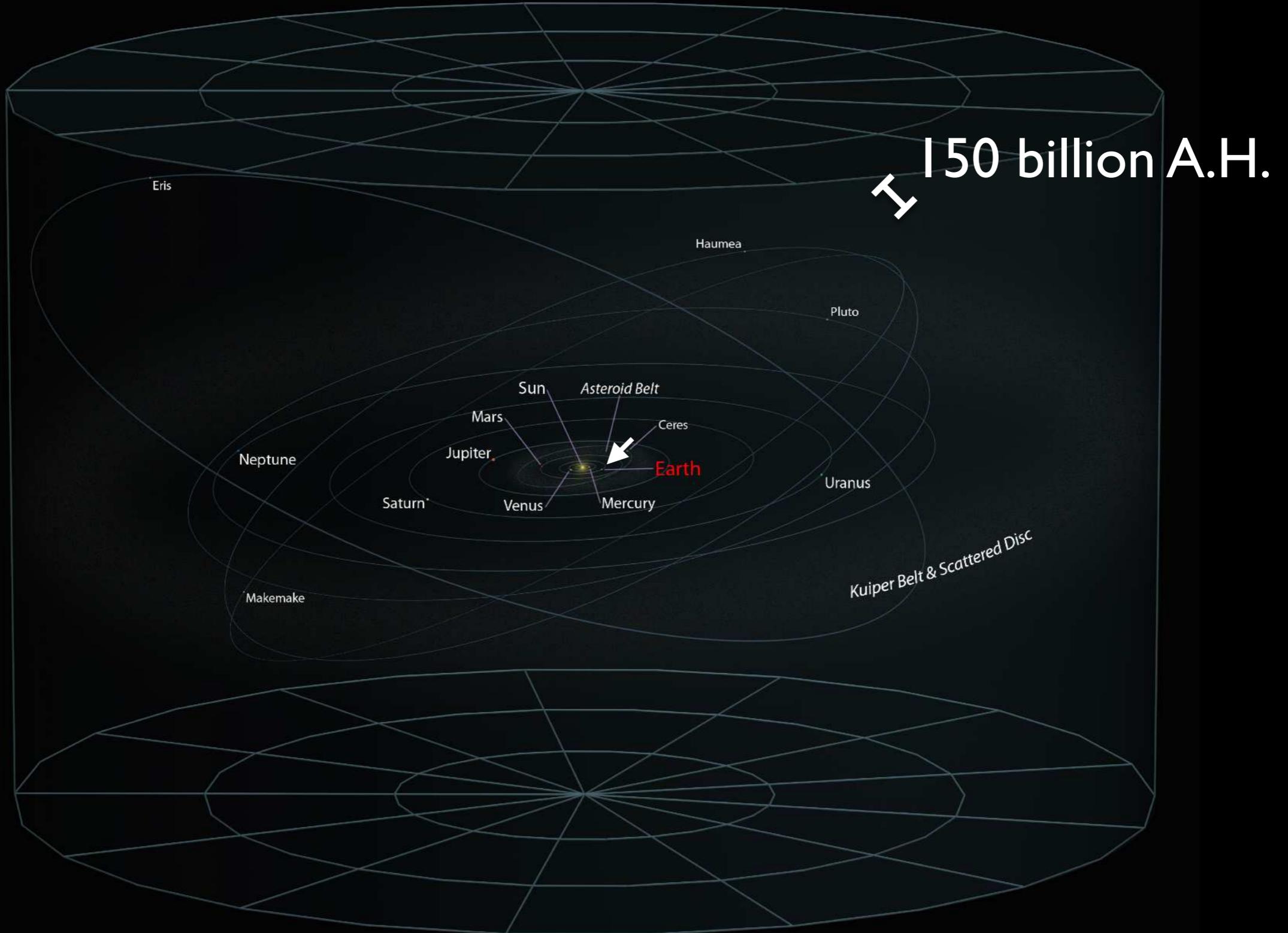


3,500 A.H.

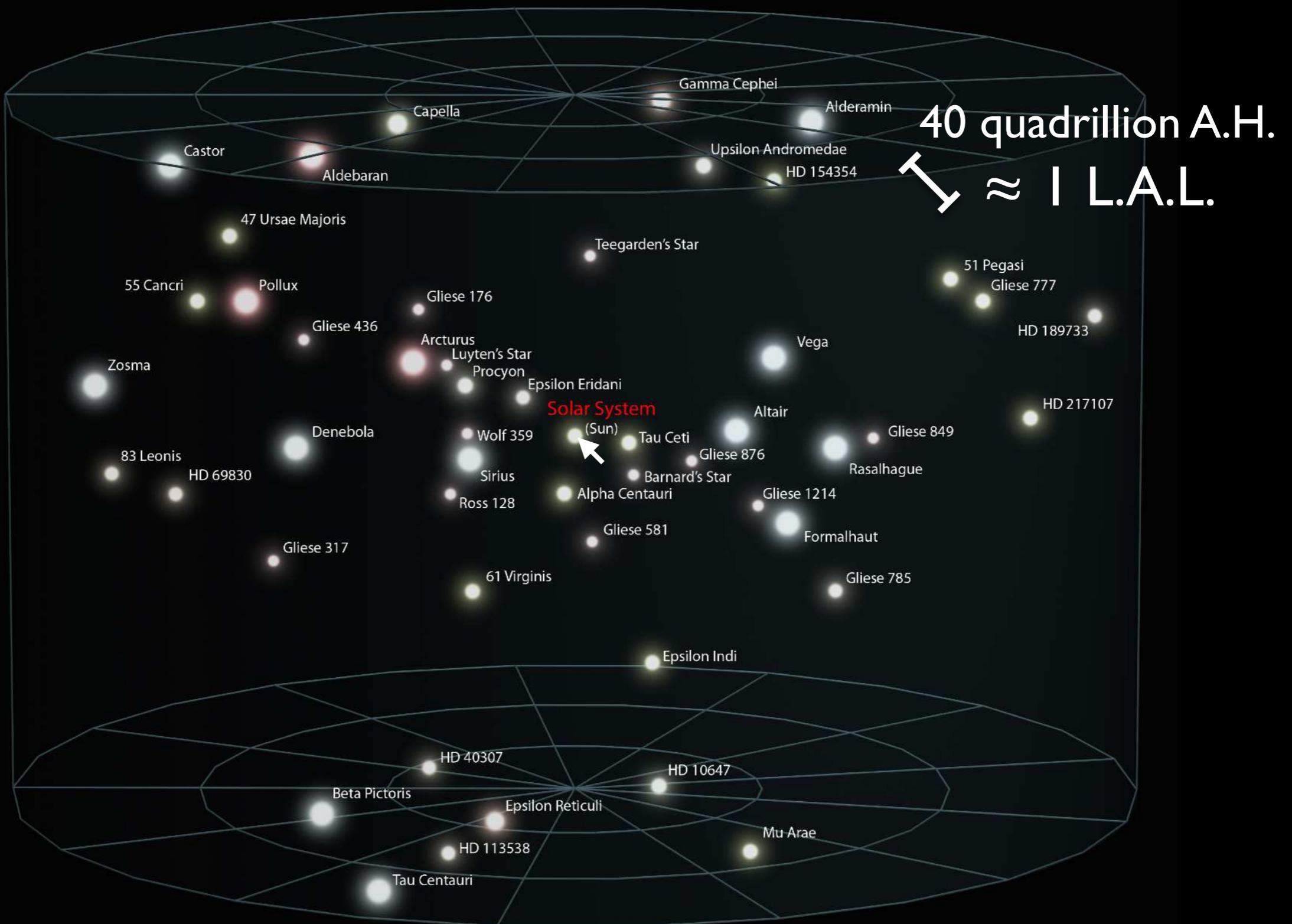
# EARTH



# SOLAR SYSTEM

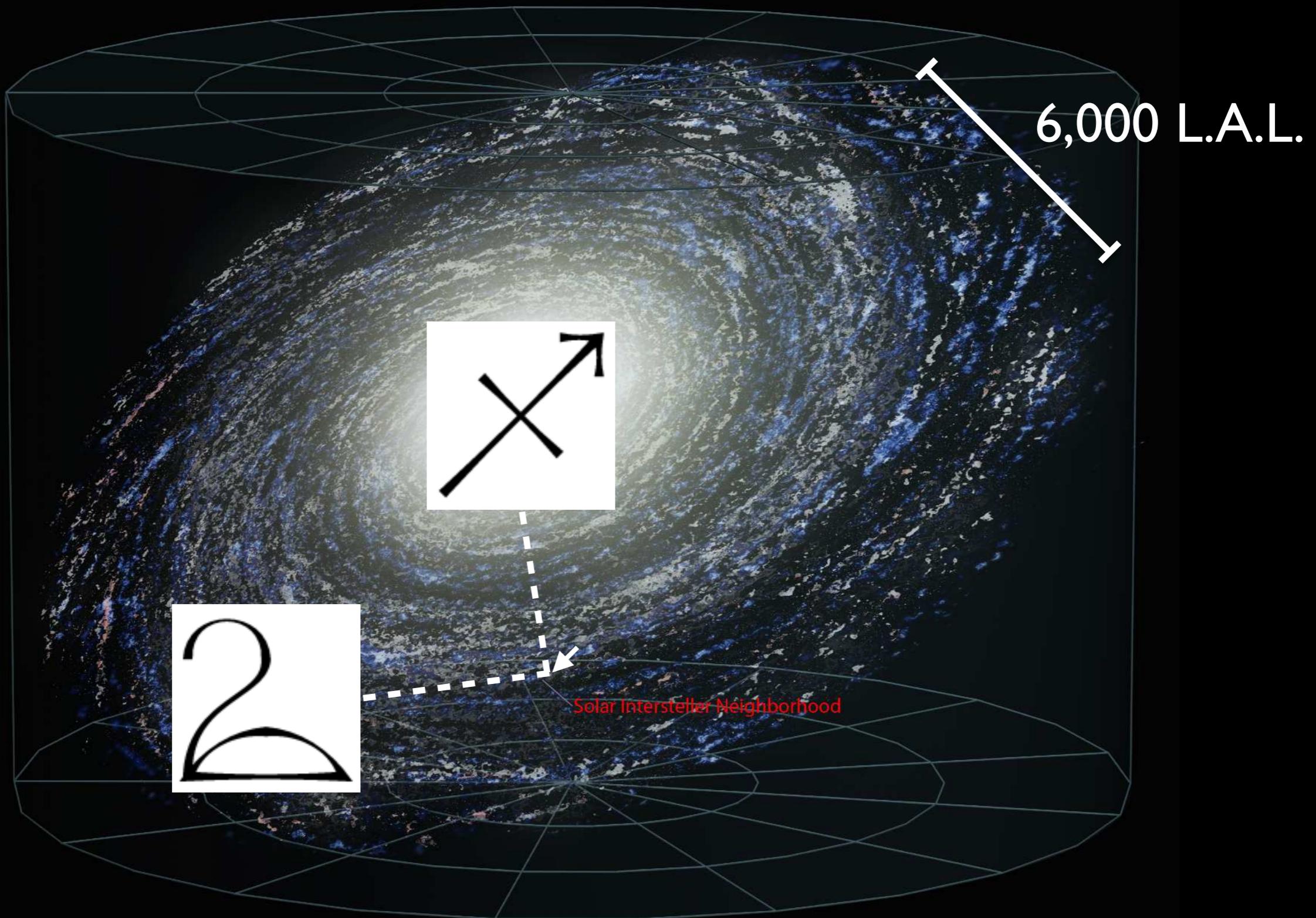


# INTERSTELLAR NEIGHBORHOOD

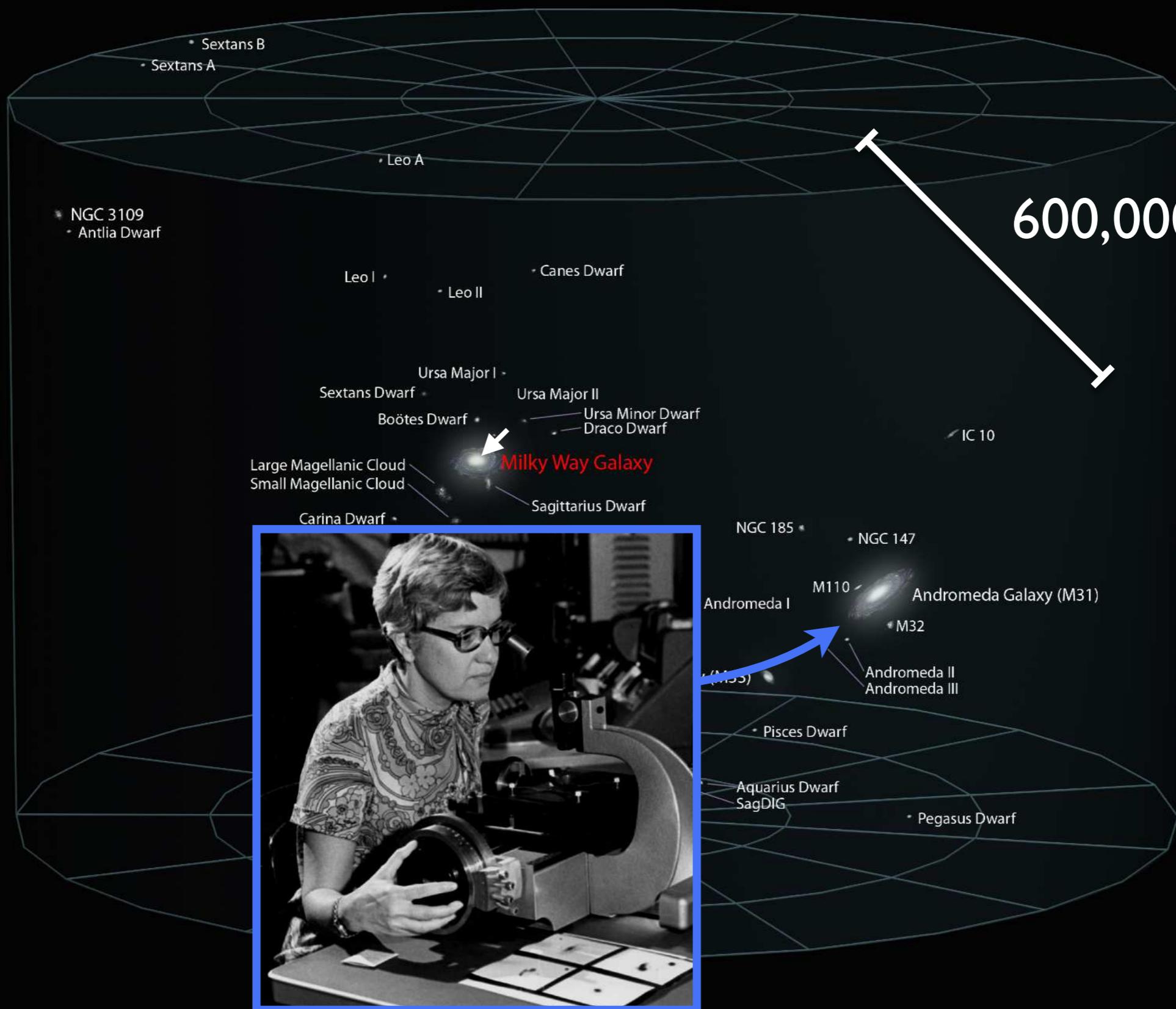


Andrew Z. Colvin

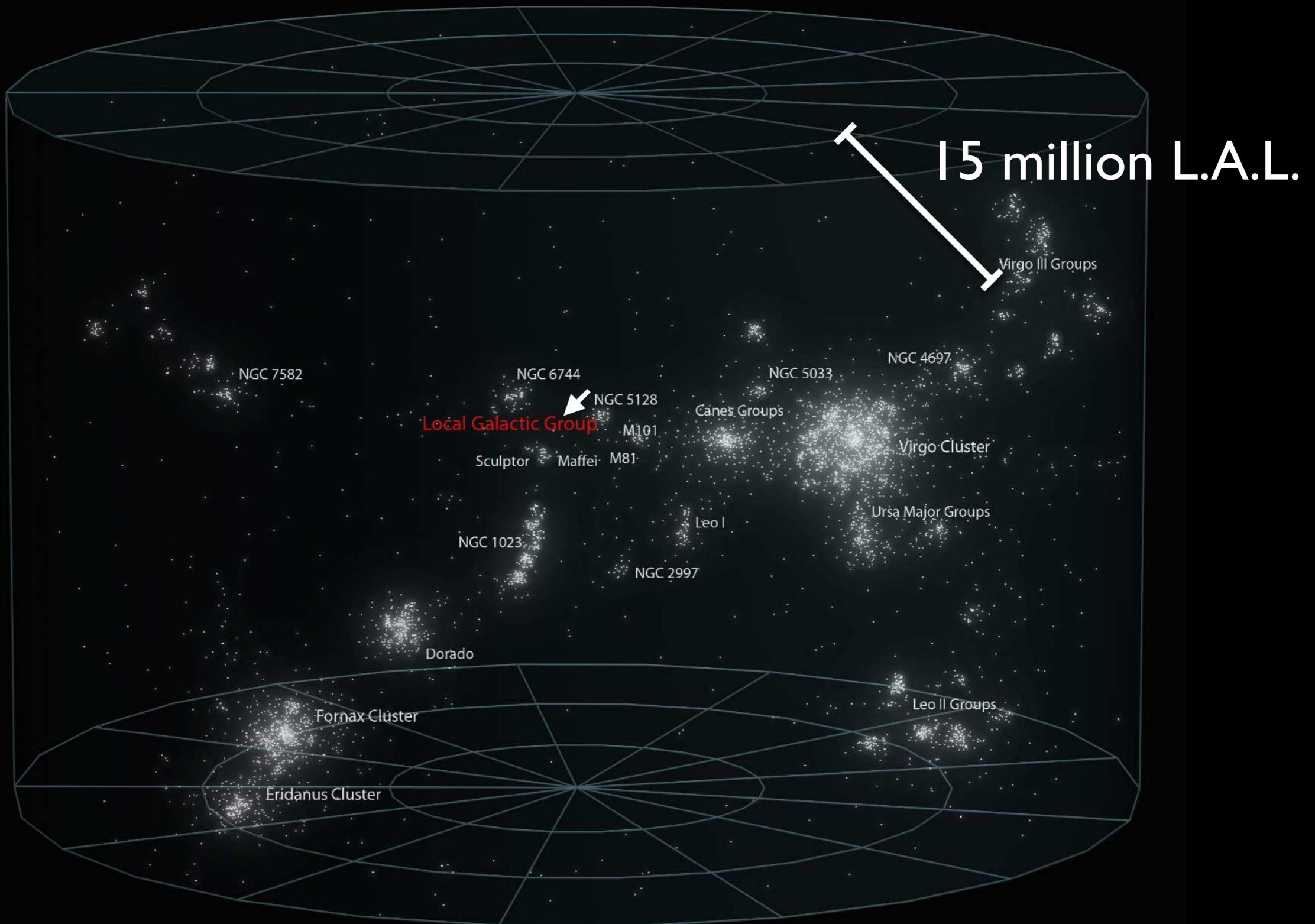
# MILKY WAY GALAXY



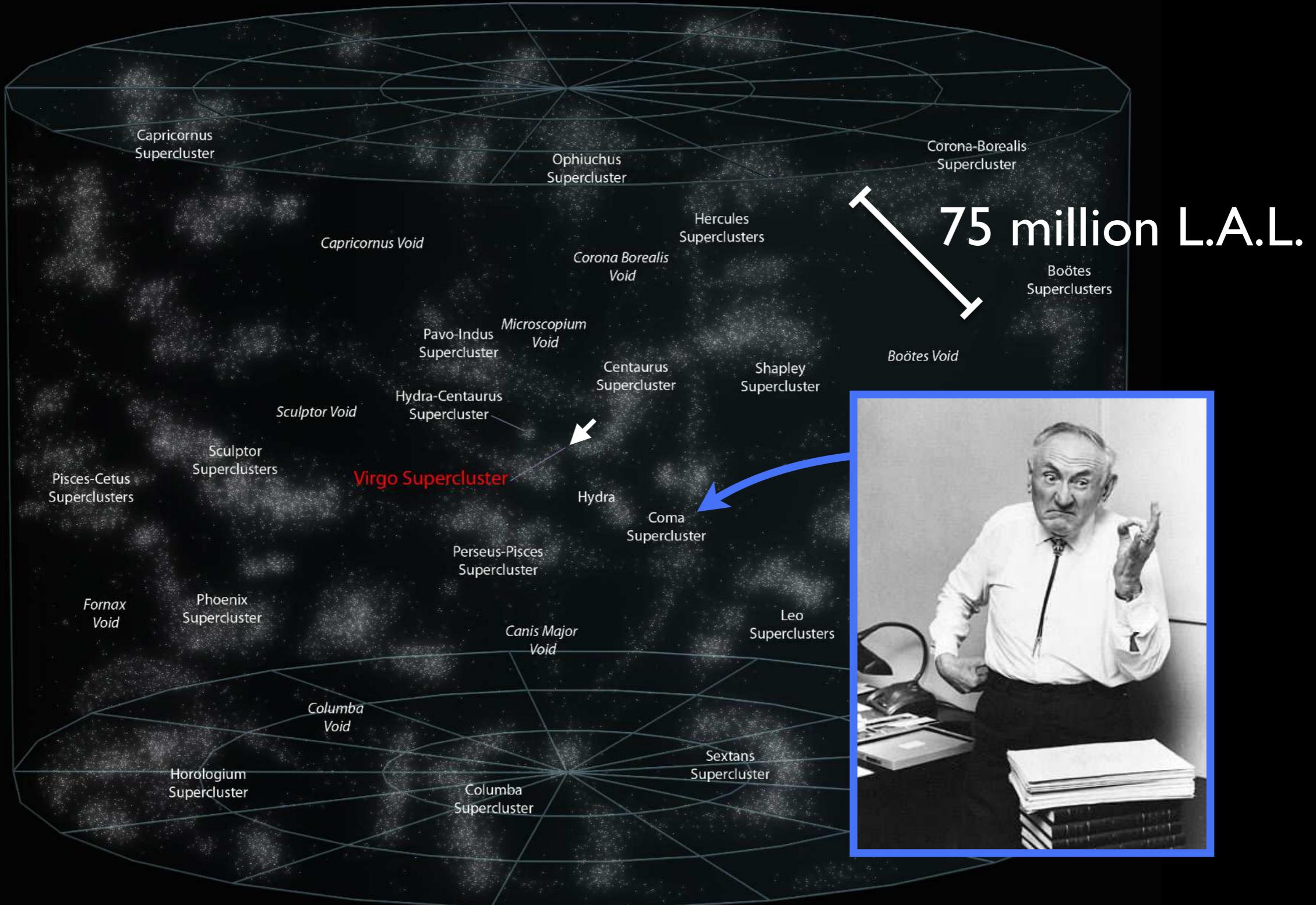
# LOCAL GALACTIC GROUP



# VIRGO SUPERCLUSTER



# LOCAL SUPERCLUSTERS



# OBSERVABLE UNIVERSE

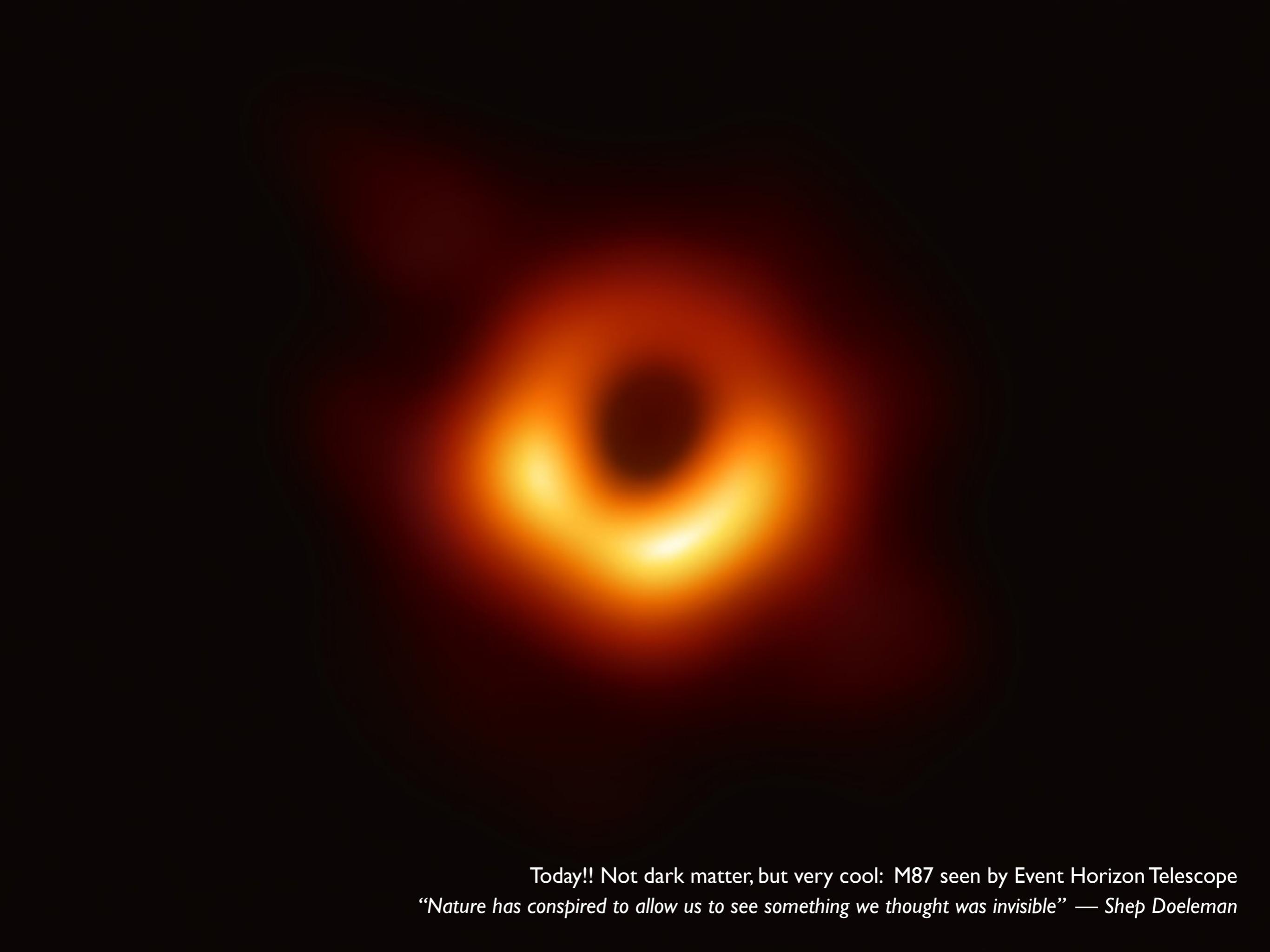


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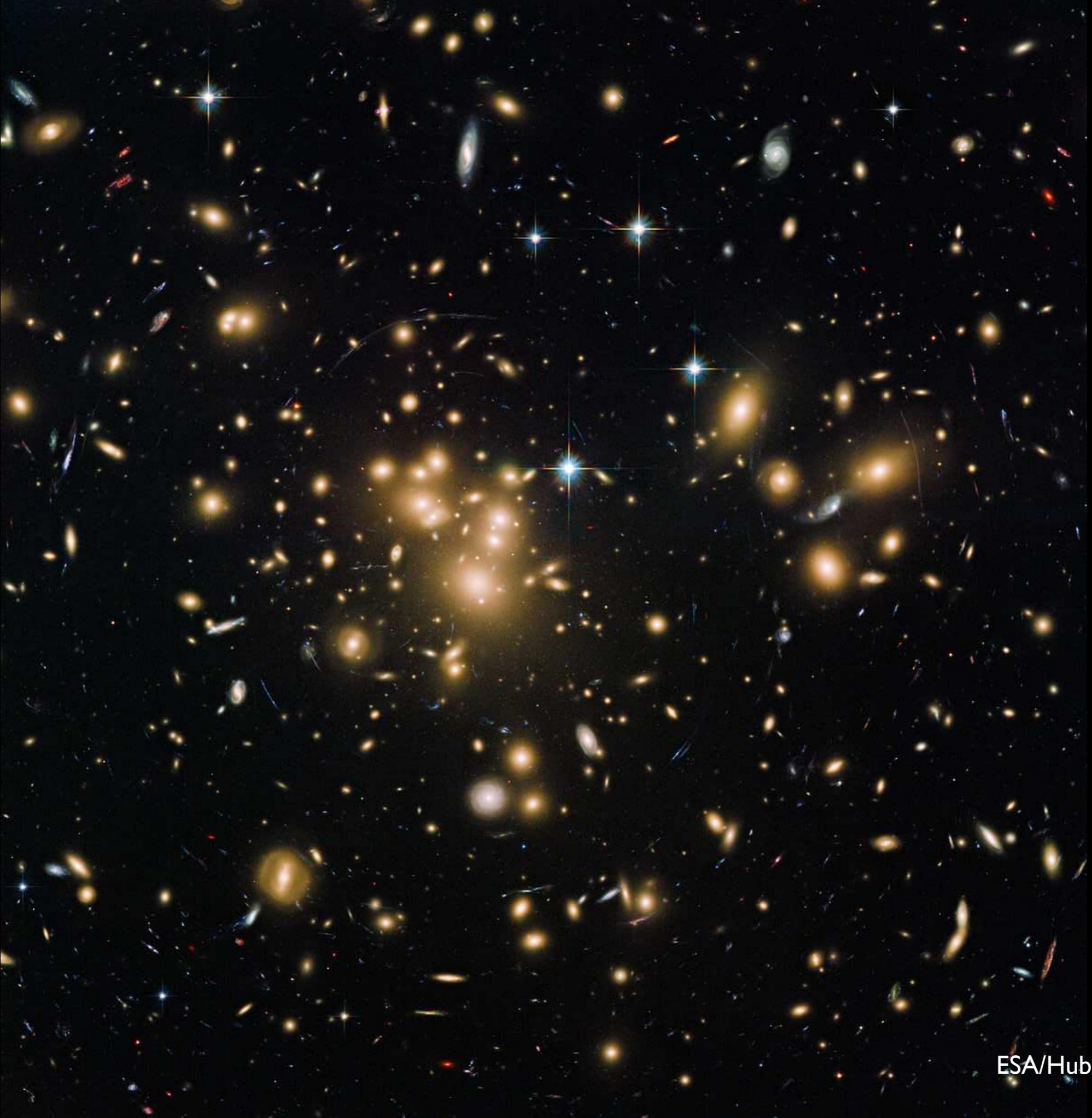
*We can see the invisible*



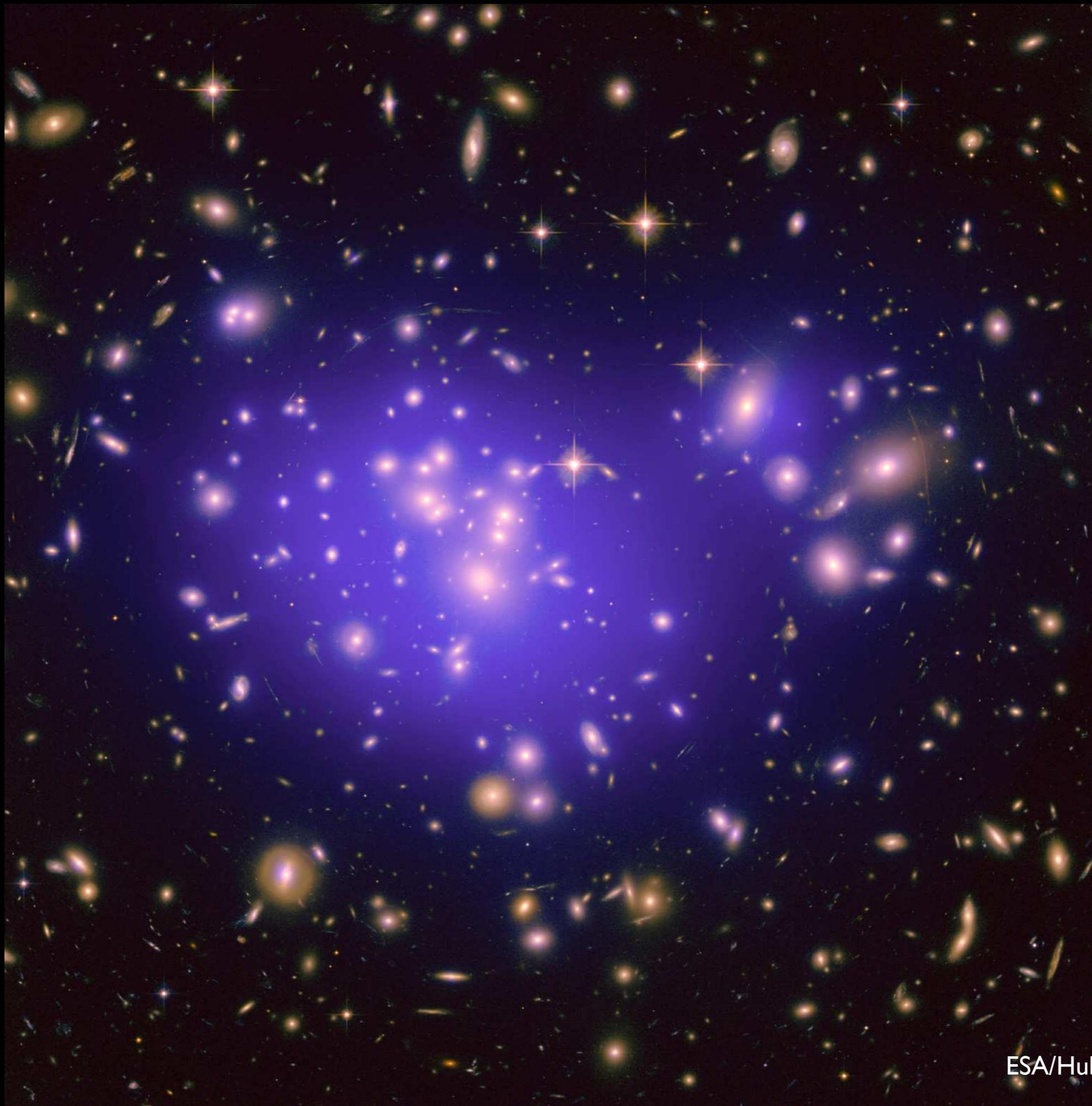
Today!! Not dark matter, but very cool: M87 seen by Event Horizon Telescope  
“Nature has conspired to allow us to see something we thought was invisible” — Shep Doeleman



Kevin Hickerson



ESA/Hubble: Abell 1689



ESA/Hubble: Abell 1689

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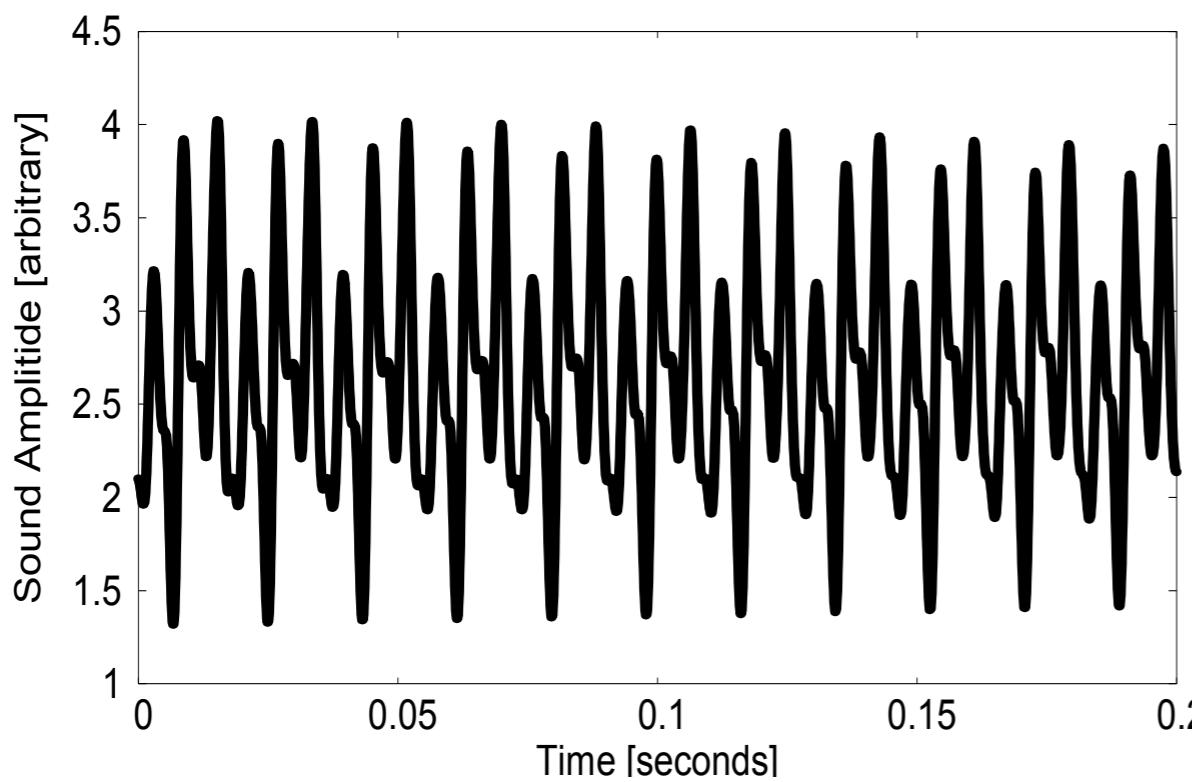
*We are listening to the universe*



# Open A String

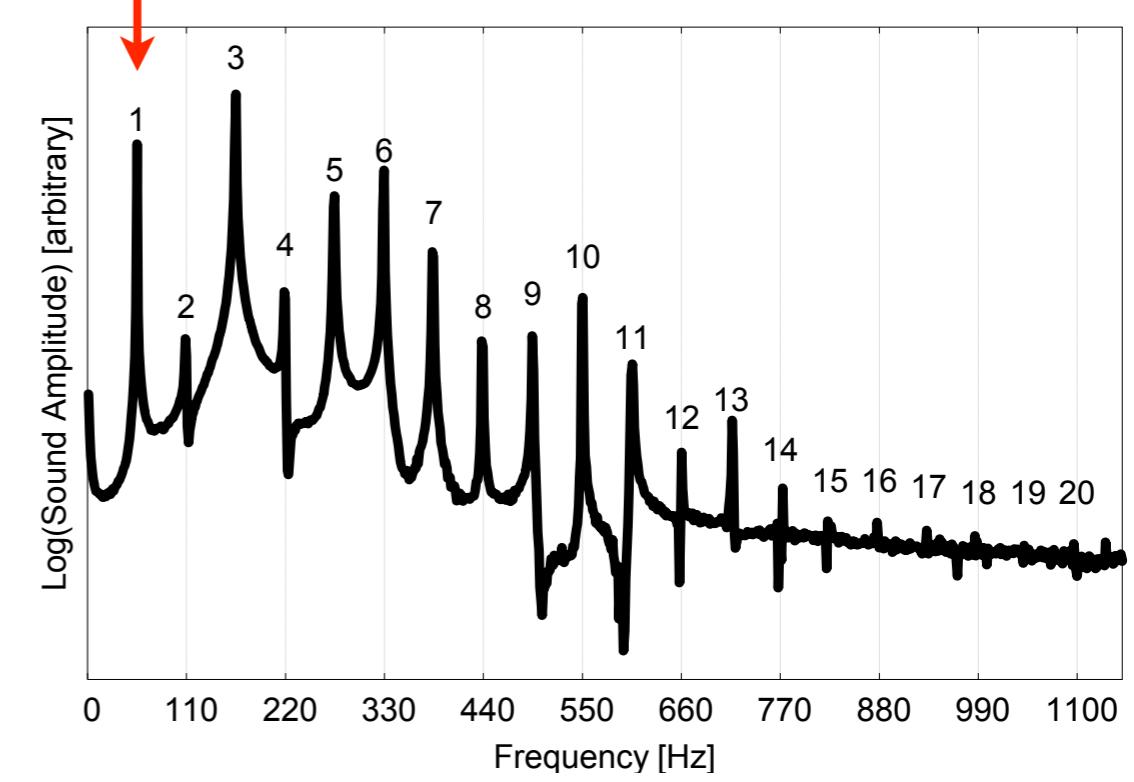


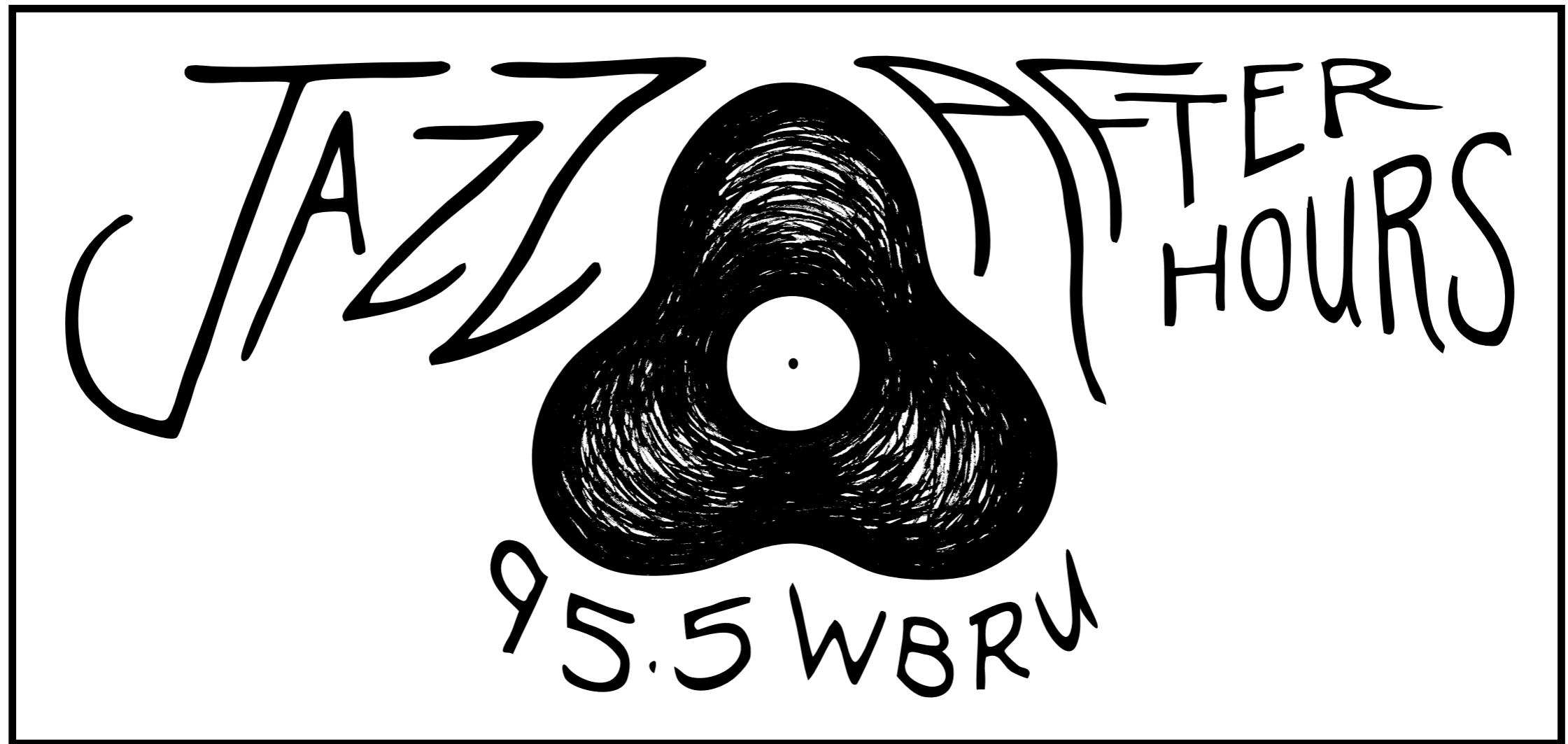
Waveform



55 Hz

Spectrum

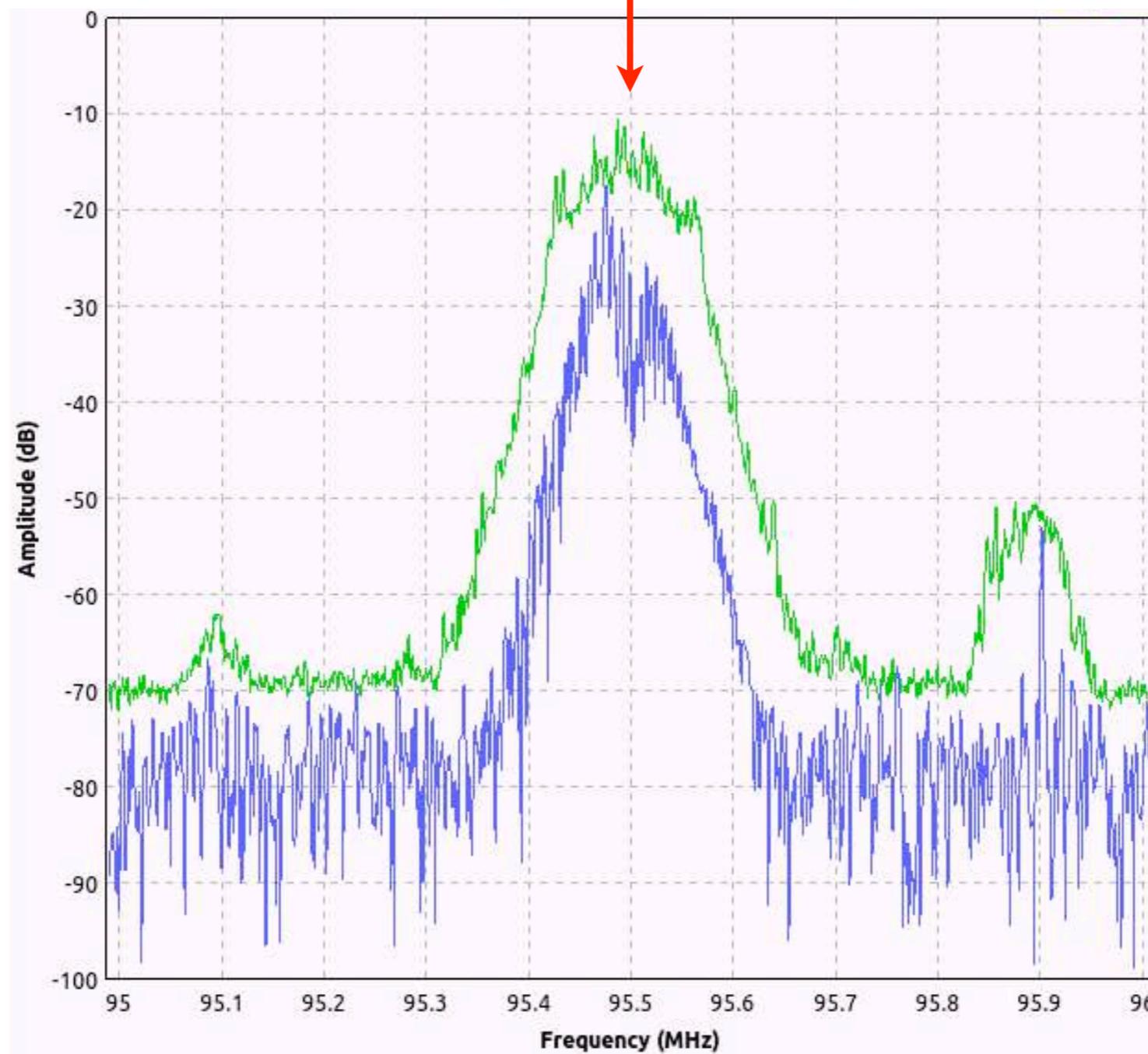


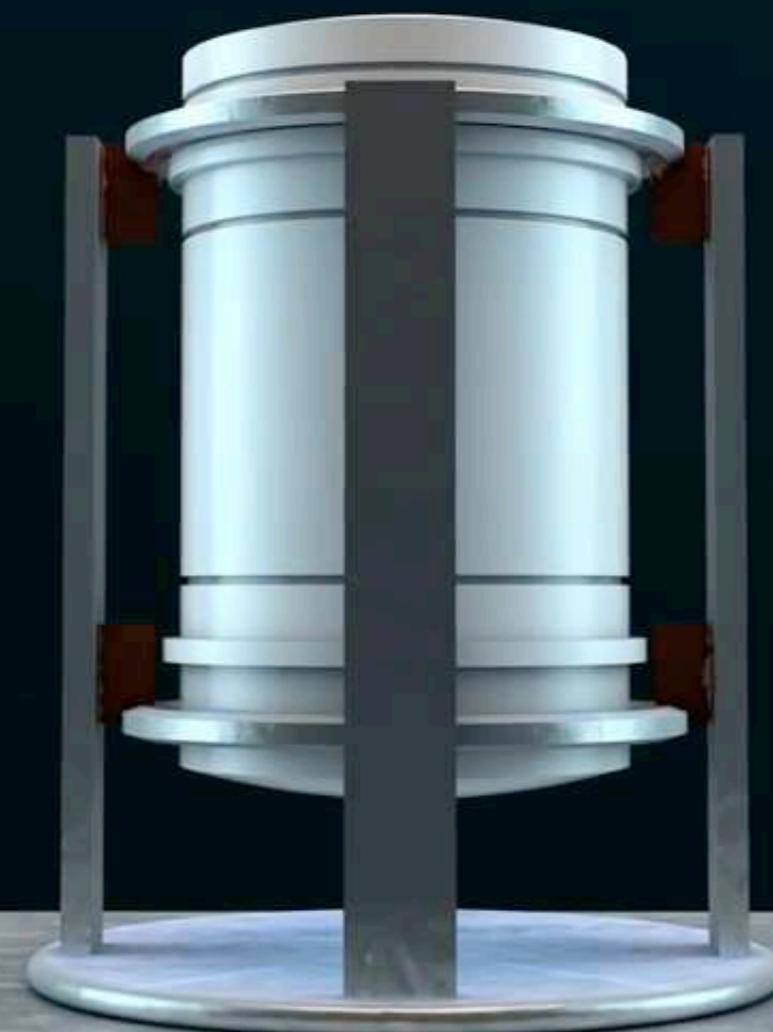


Andrea Brayboy

**95,500,000 Hz**

Electromagnetic waves  
instead of sound





Alex Sushkov, CASPER Experiment

# Broadband and Resonant Approaches to Axion Dark Matter Detection

Yonatan Kahn,<sup>1,\*</sup> Benjamin R. Safdi,<sup>2,†</sup> and Jesse Thaler<sup>2,‡</sup>

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<sup>2</sup>*Center for Theoretical Physics, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA*

(Received 3 March 2016; published 30 September 2016)



**! → First Results from ABACADABRA-10 cm: A Search for Sub- $\mu$ eV Axion Dark Matter**

Jonathan L. Ouellet,<sup>1,\*</sup> Chiara P. Salemi,<sup>1</sup> Joshua W. Foster,<sup>2</sup> Reyco Henning,<sup>3,4</sup> Zachary Bogorad,<sup>1</sup> Janet M. Conrad,<sup>1</sup> Joseph A. Formaggio,<sup>1</sup> Yonatan Kahn,<sup>5,6</sup> Joe Minervini,<sup>7</sup> Alexey Radovinsky,<sup>7</sup> Nicholas L. Rodd,<sup>8,9</sup> Benjamin R. Safdi,<sup>2</sup> Jesse Thaler,<sup>10</sup> Daniel Winklehner,<sup>1</sup> and Lindley Winslow<sup>1,†</sup>

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<sup>3</sup>University of North Carolina, Chapel Hill, North Carolina 27599, USA

<sup>4</sup>Triangle Universities Nuclear Laboratory, Durham, North Carolina 27708, USA

<sup>5</sup>Princeton University, Princeton, New Jersey 08544, USA

<sup>6</sup>Kavli Institute for Cosmological Physics, University of Chicago, Chicago, Illinois 60637, USA

<sup>7</sup>Plasma Science and Fusion Center, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA

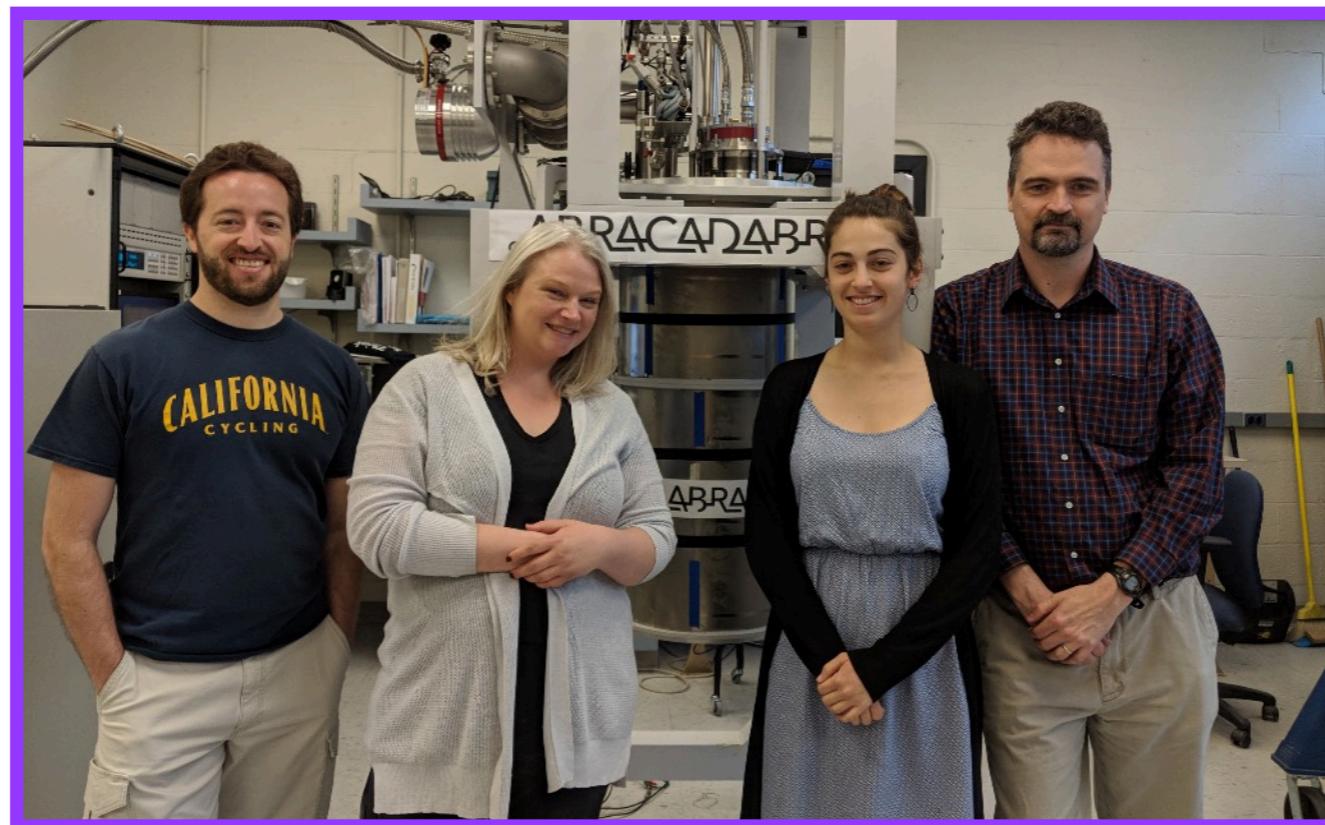
<sup>8</sup>Berkeley Center for Theoretical Physics, University of California, Berkeley, California 94720, USA

<sup>9</sup>Theoretical Physics Group, Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA

<sup>10</sup>Center for Theoretical Physics, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA



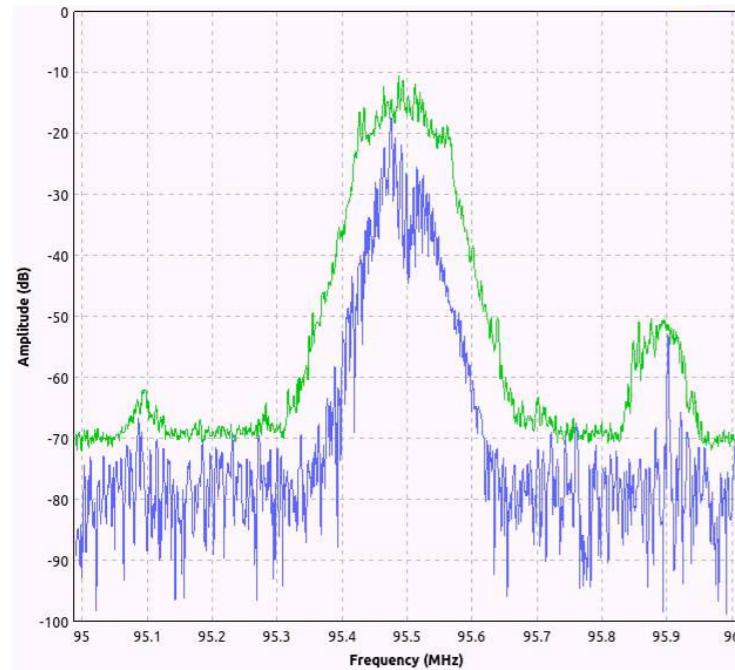
(Received 30 October 2018; published 29 March 2019)



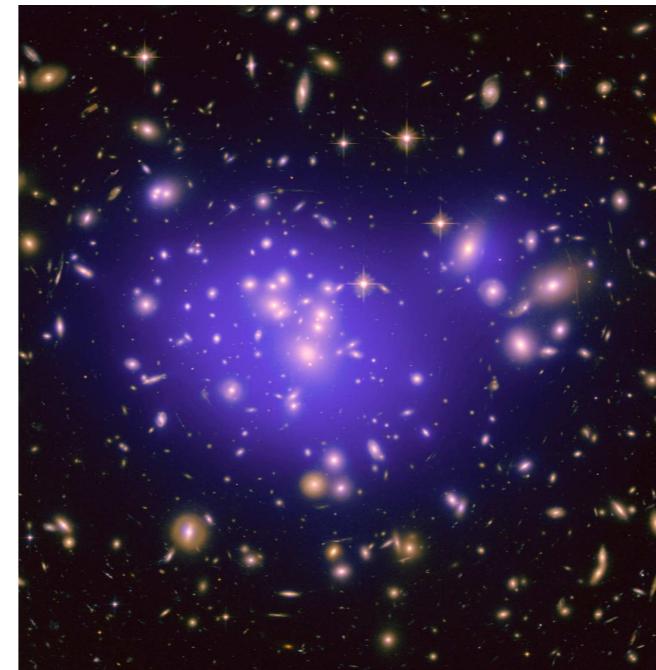
# ABRACADABRA →

A Broadband or Resonant Approach to Cosmic Axion Detection  
with an Amplifying B-field Ring Apparatus

*Listening...*

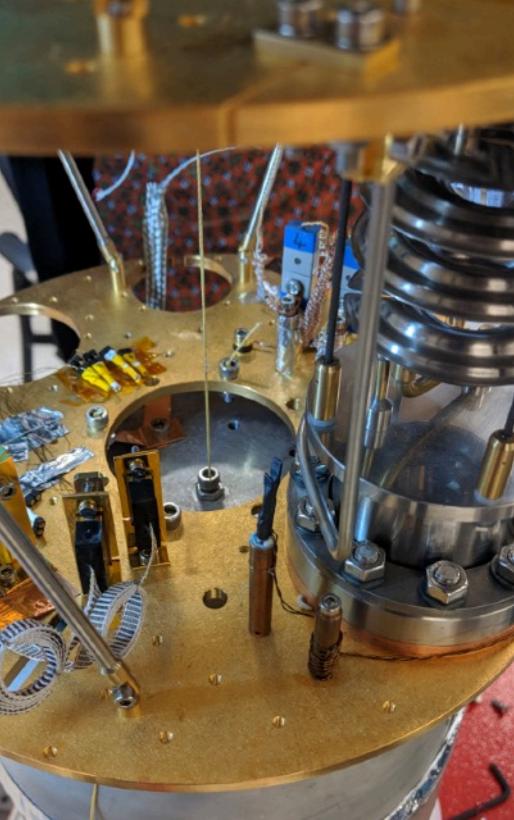
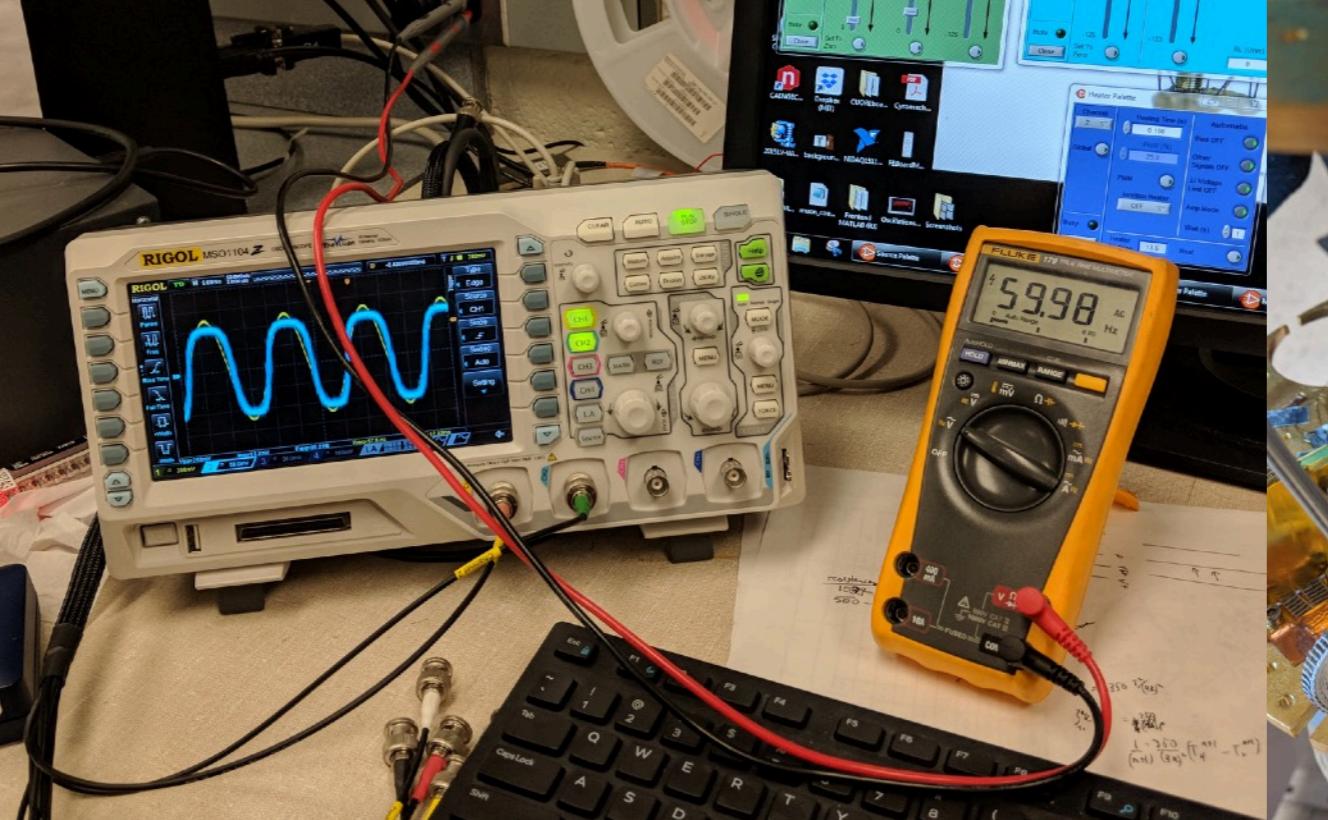
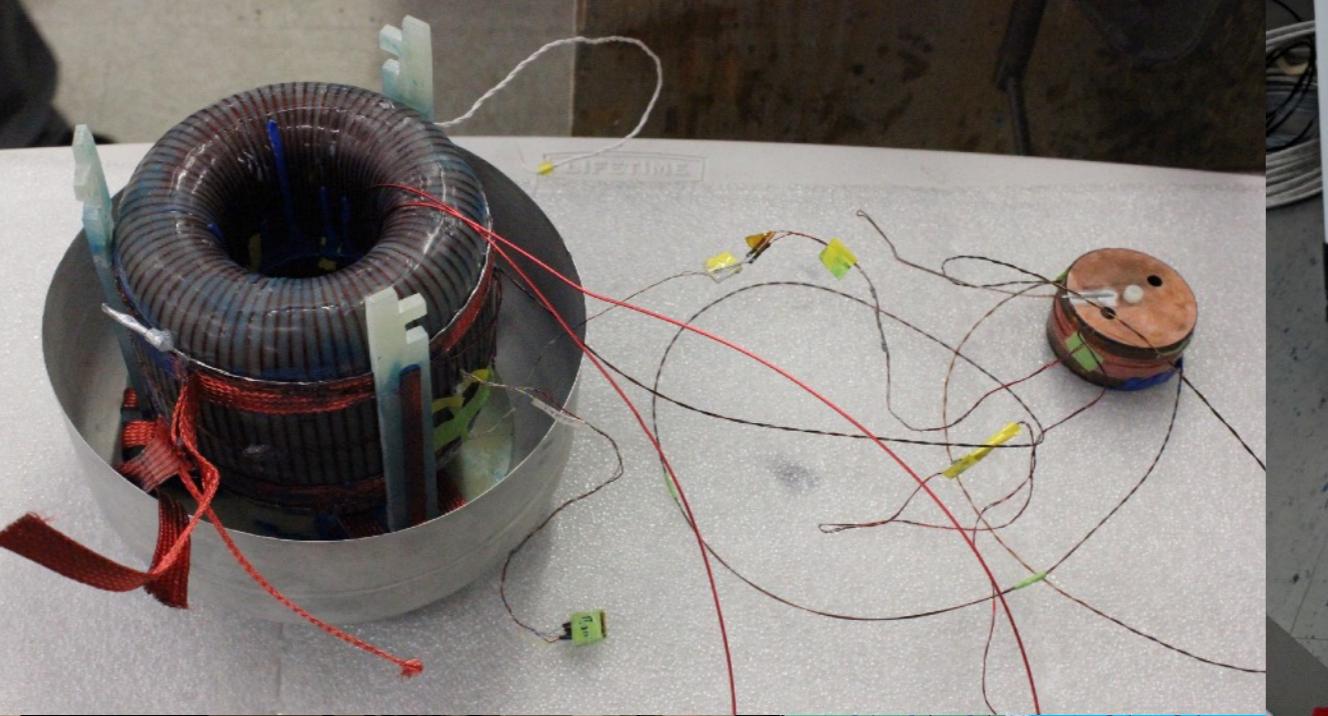
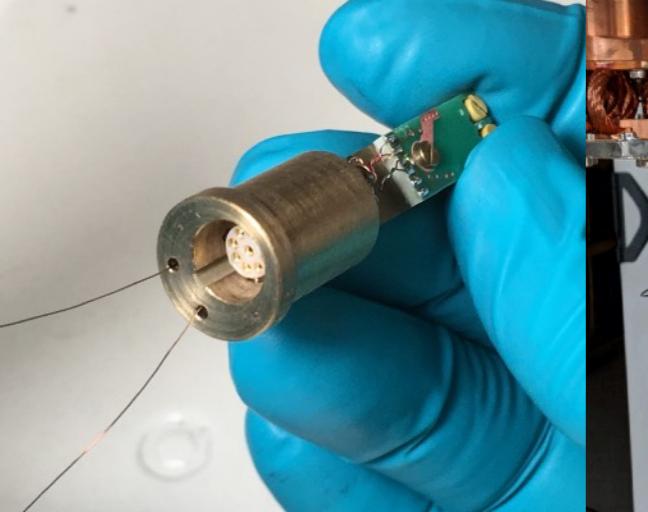
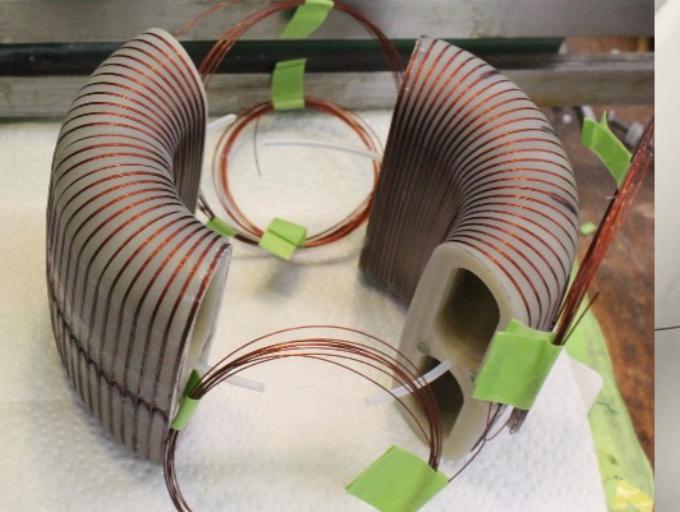
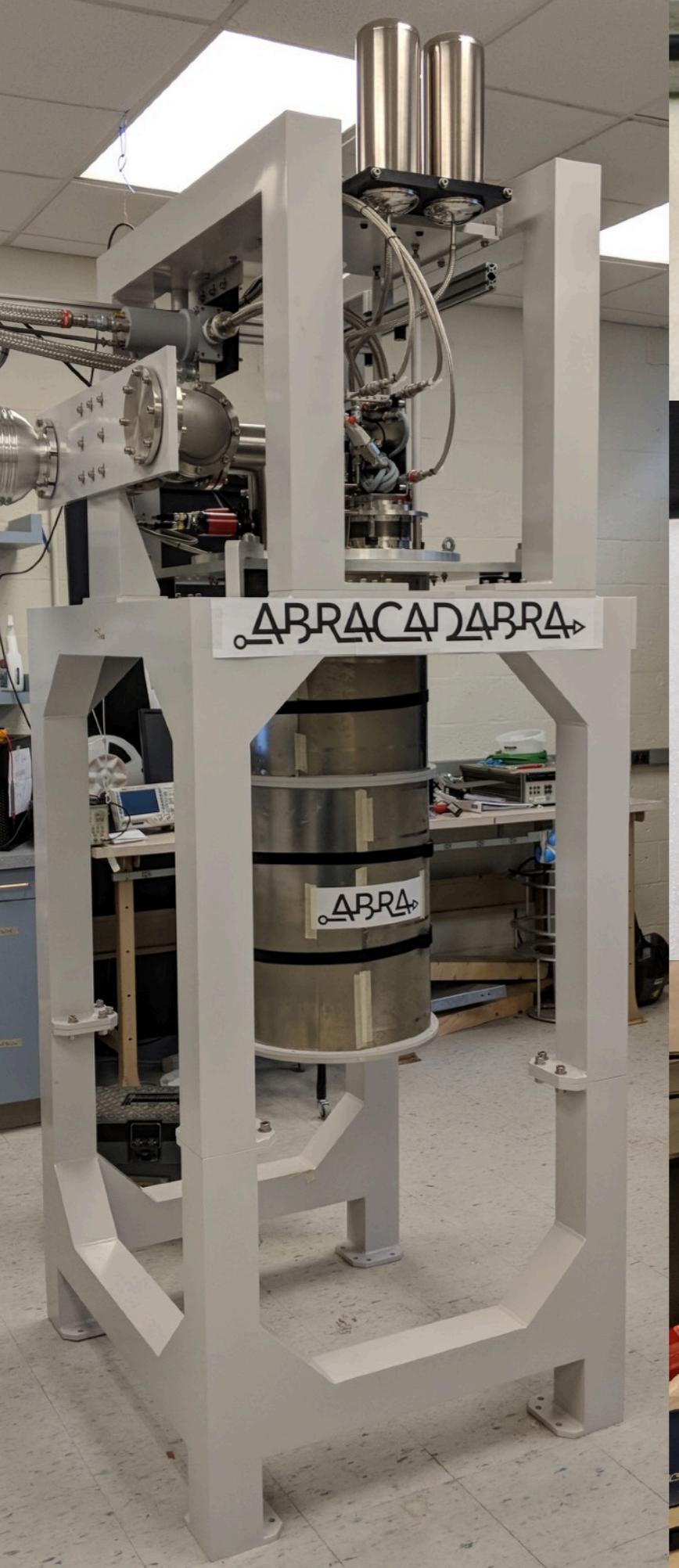


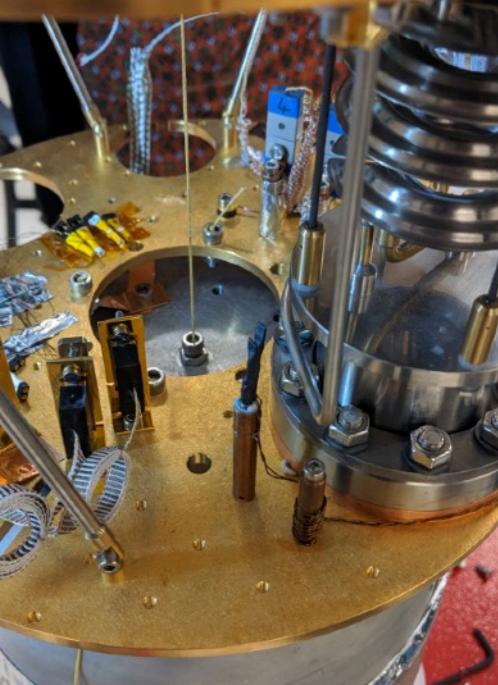
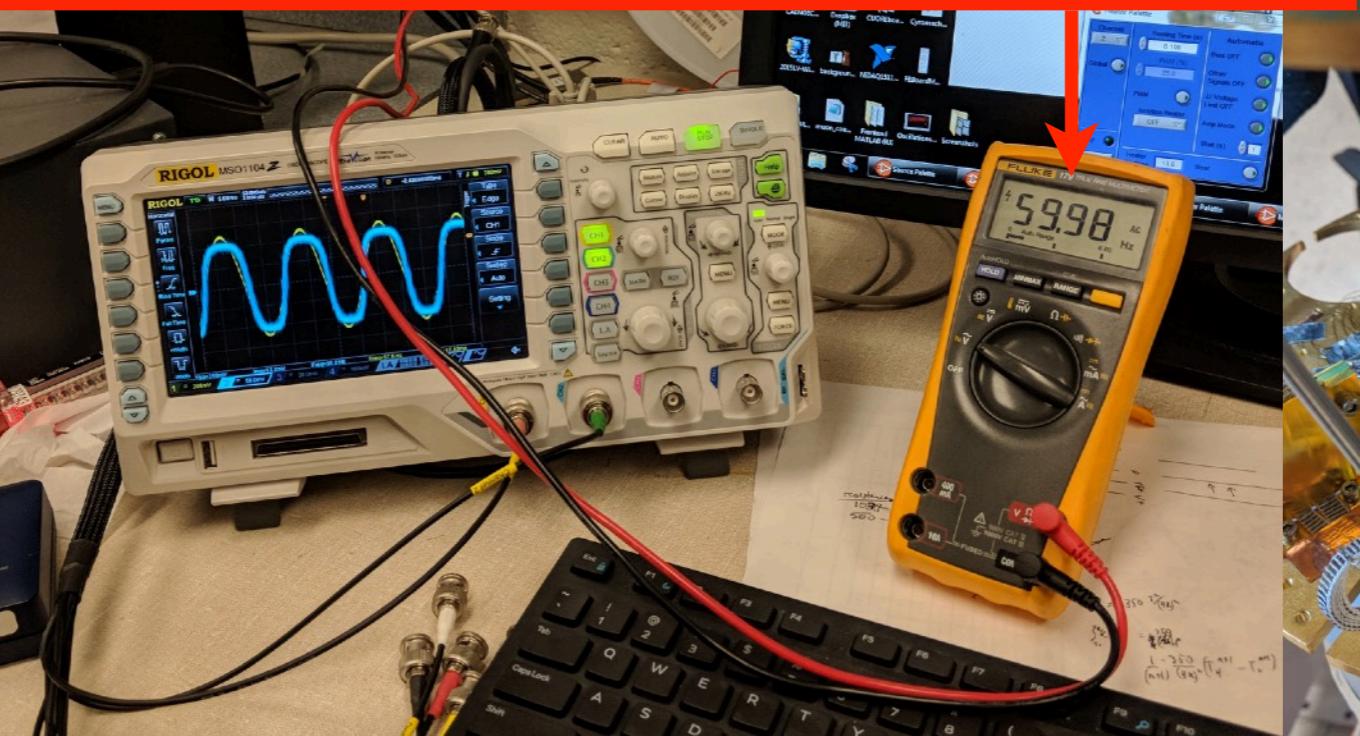
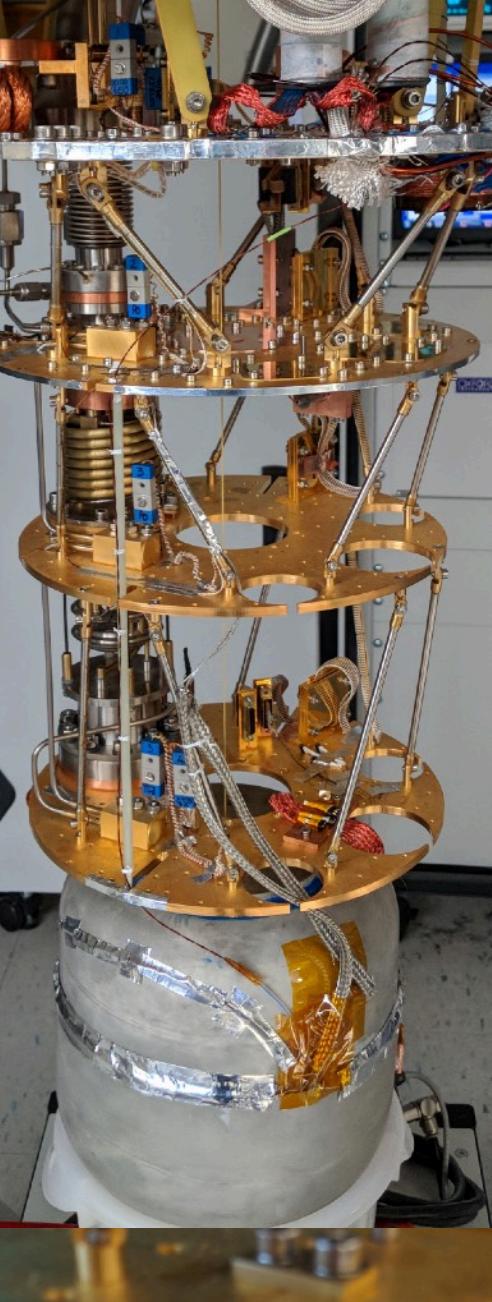
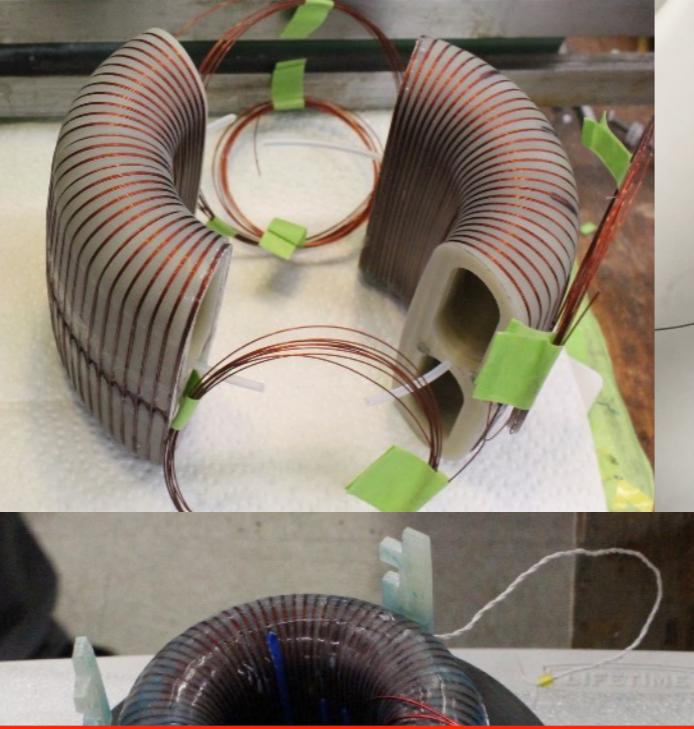
*...to the universe...*



*...very carefully*







*Listening... to noise*

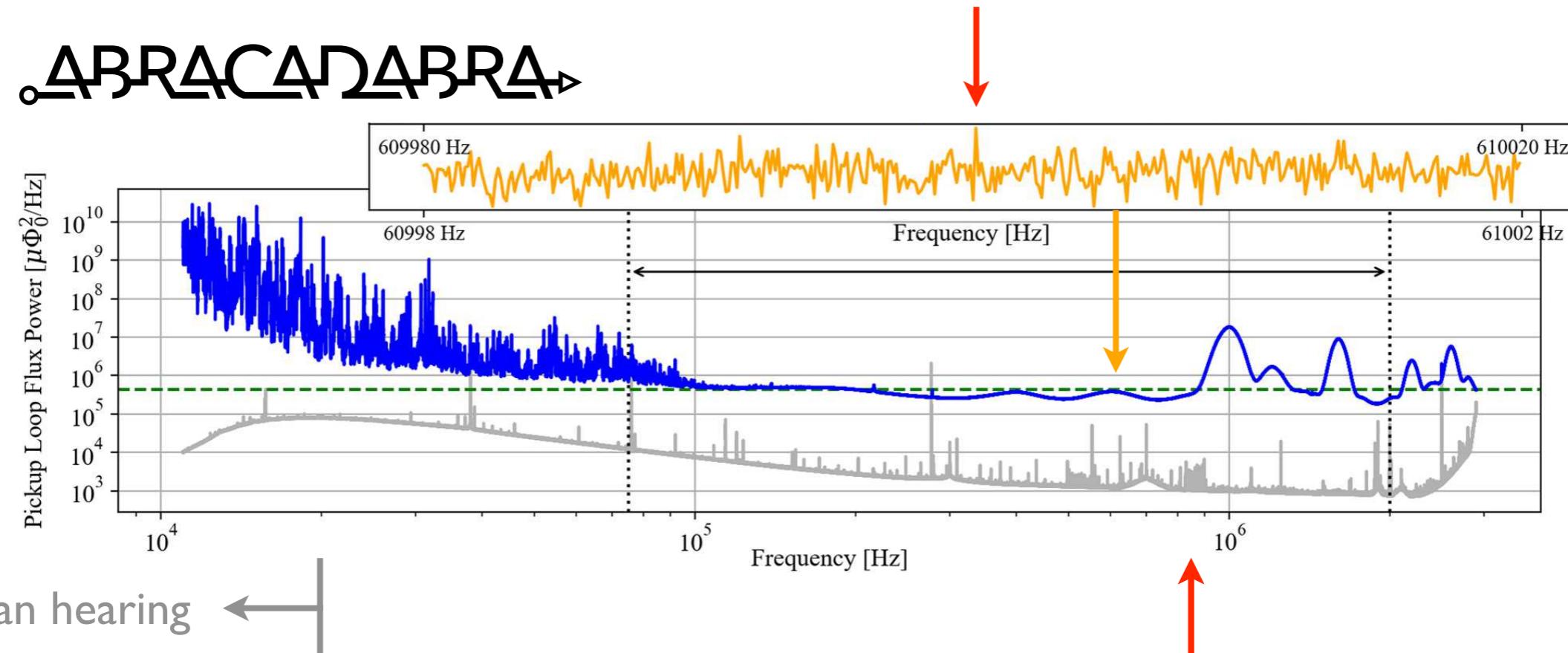
*Listening...*

now with  
noise-cancelling  
headphones

# *The sound of dark matter?*

## 610,000 Hz

„ABRACADABRA“



## 850,000 Hz

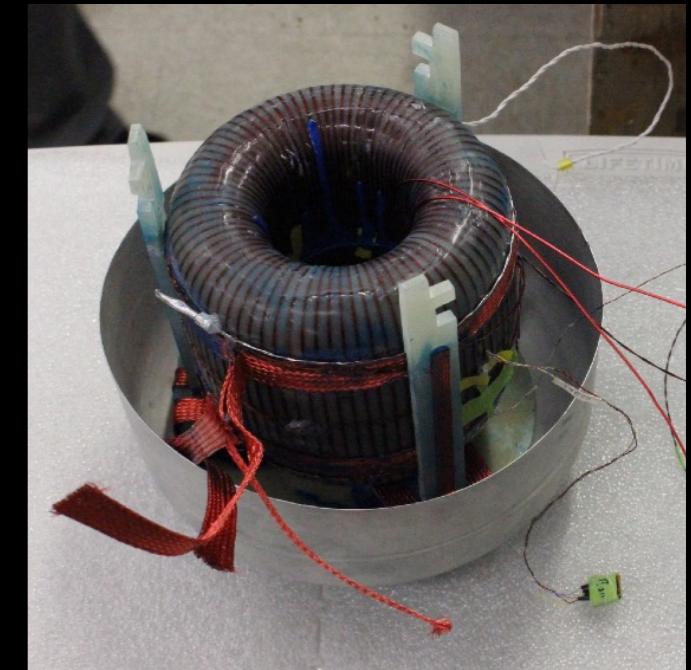
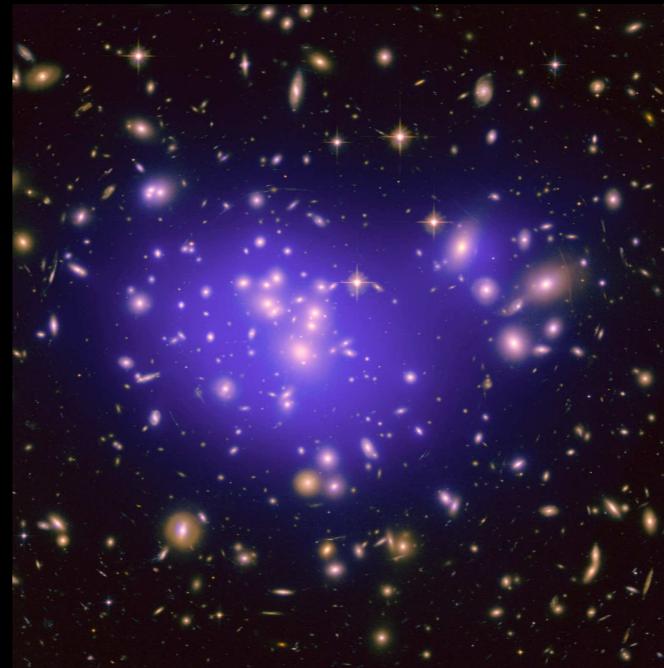
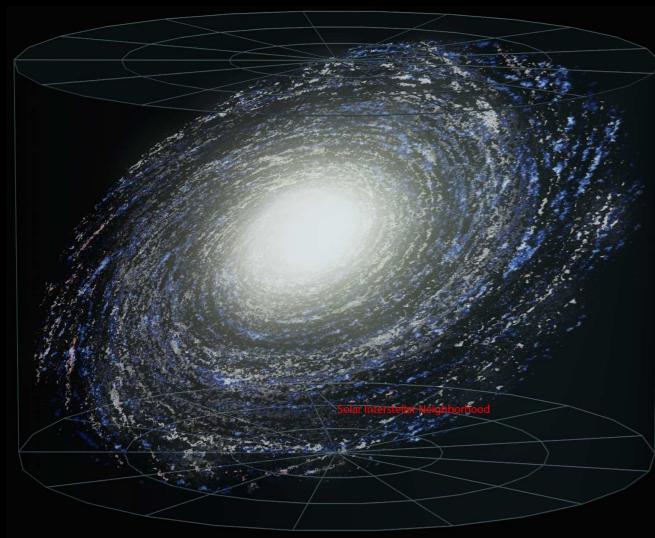
**WEEI**  
((850))



SPACE

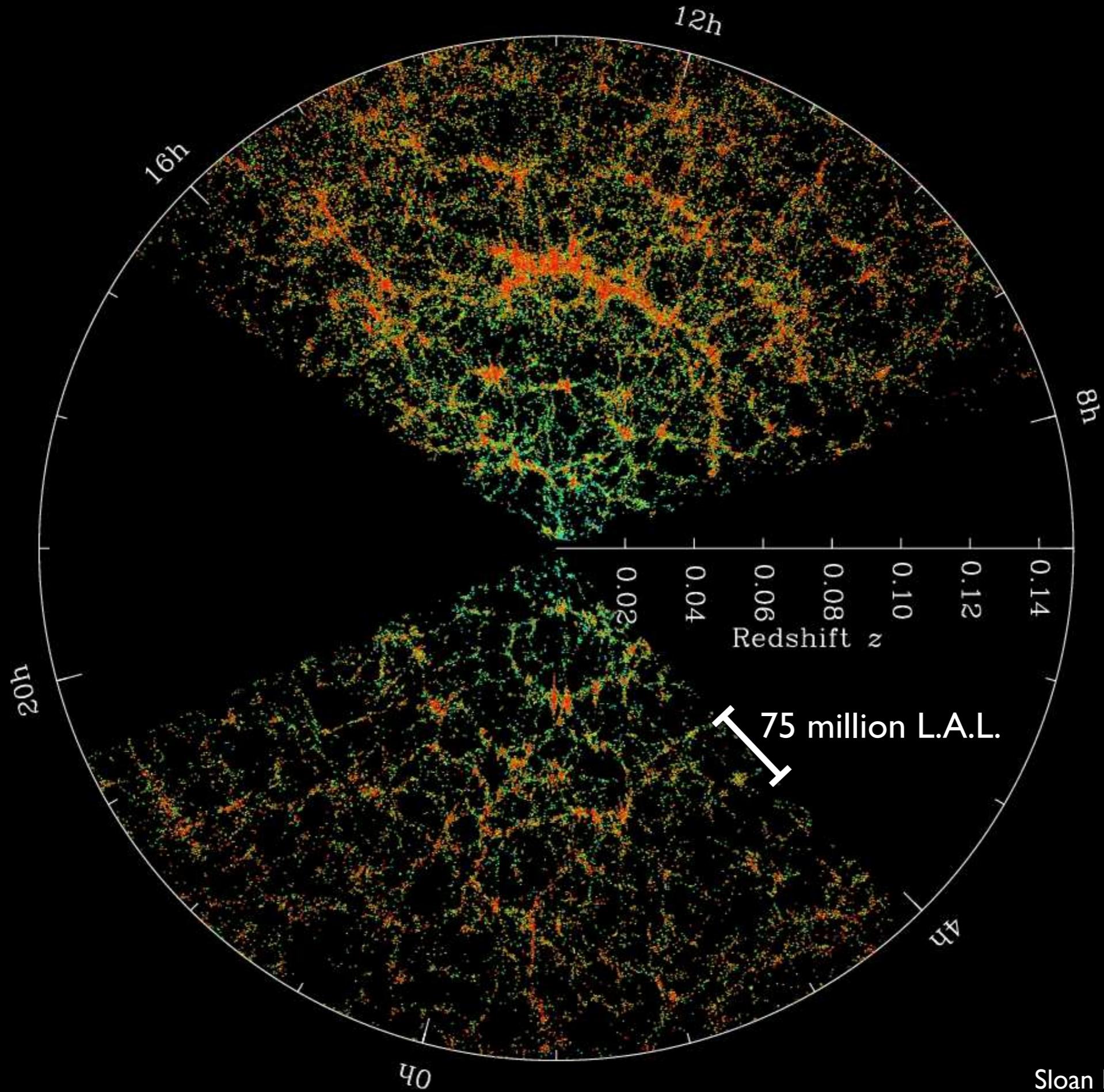
SIGHT

SOUND



*Listening to the Invisible Universe*

*Pretty Pictures for Q&A*



Sloan Digital Sky Survey

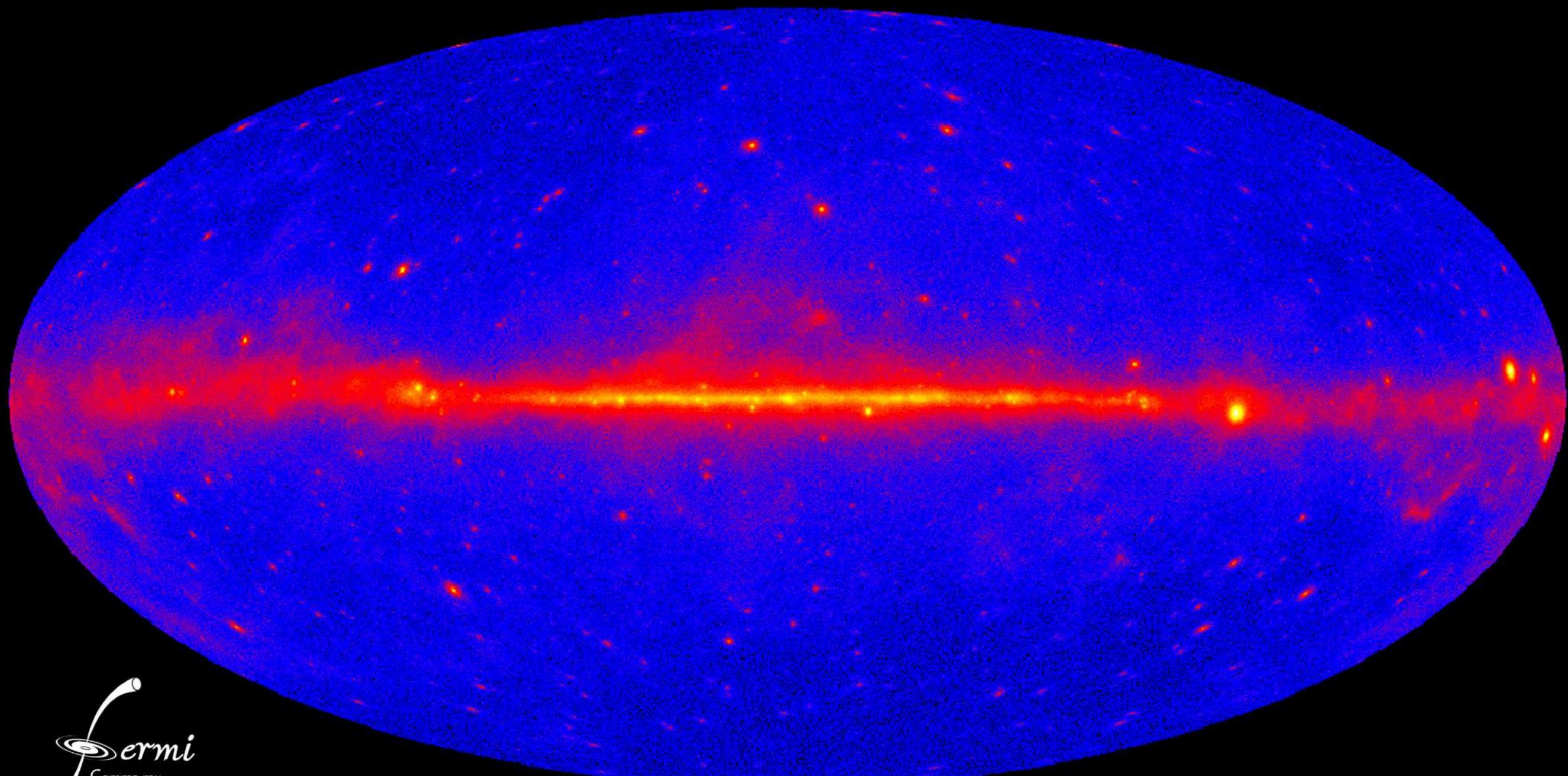
*Visible Only*



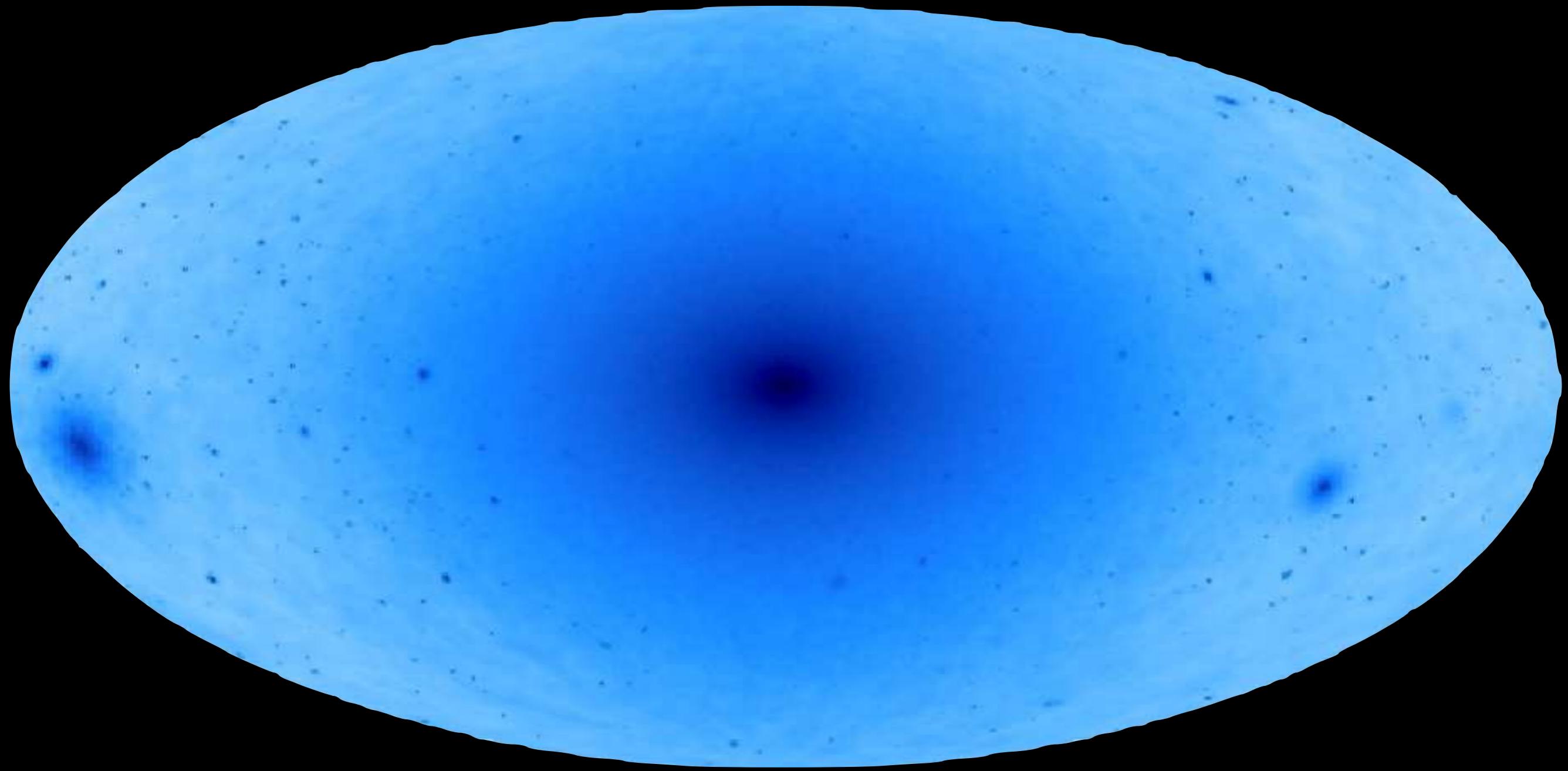


Composite Image: Bullet Cluster

# The Visible Milky Way

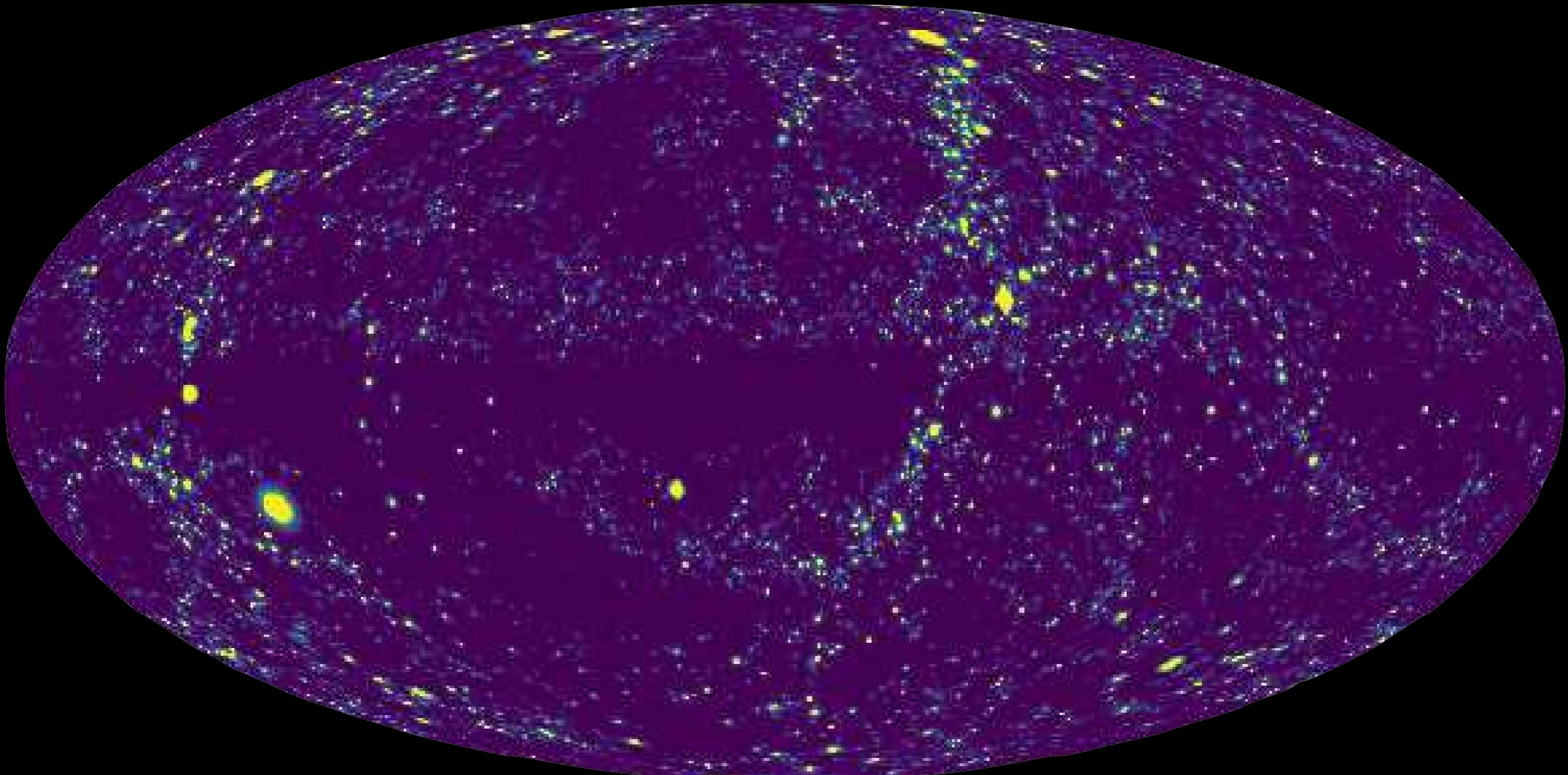


# The Invisible Milky Way



Snowmass Dark Matter Study (2013)

# The (In)visible Universe



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

**Visible Matter  
Photons & Neutrinos**

**Dark Matter**

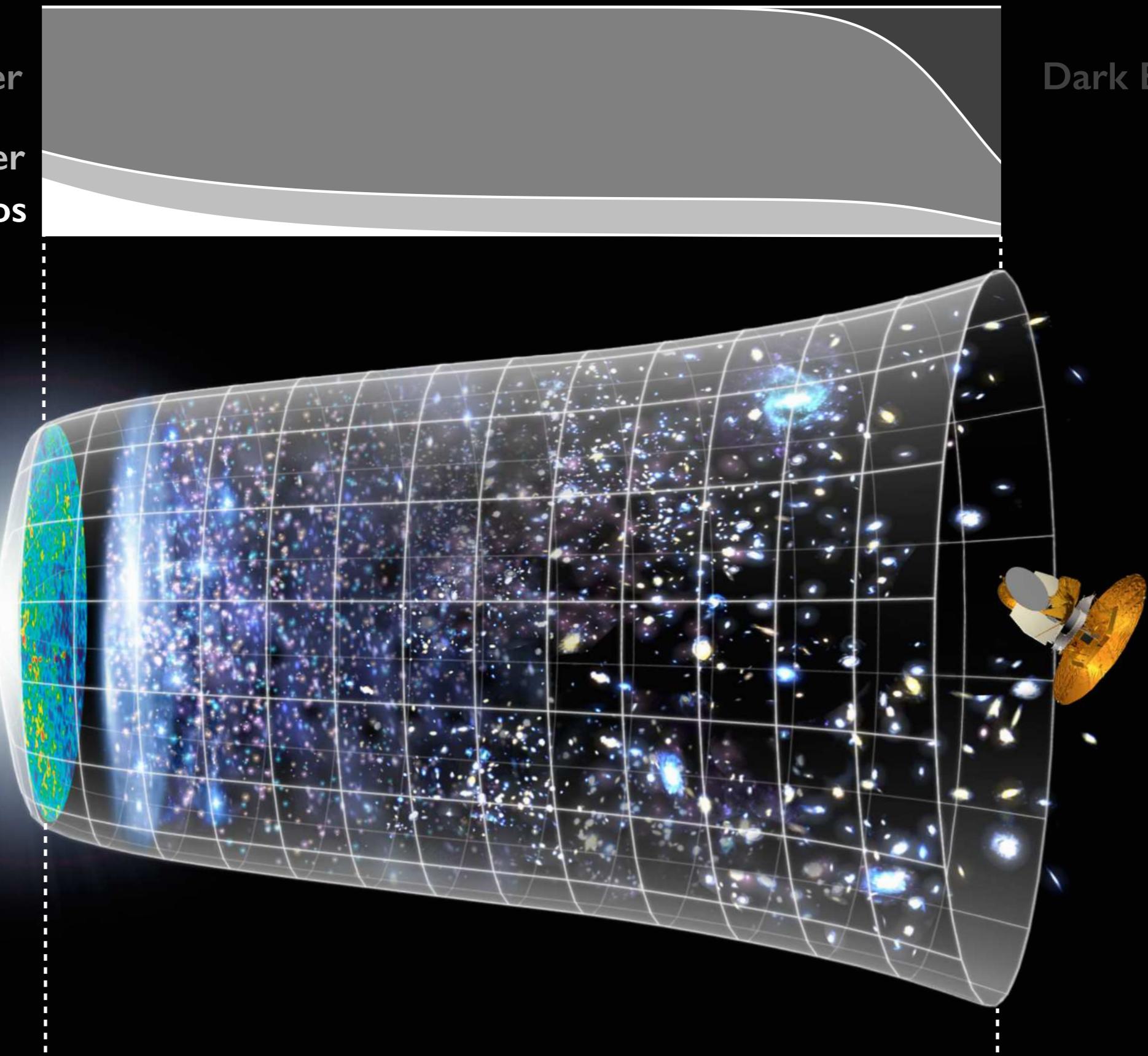
**Dark Energy**

time →

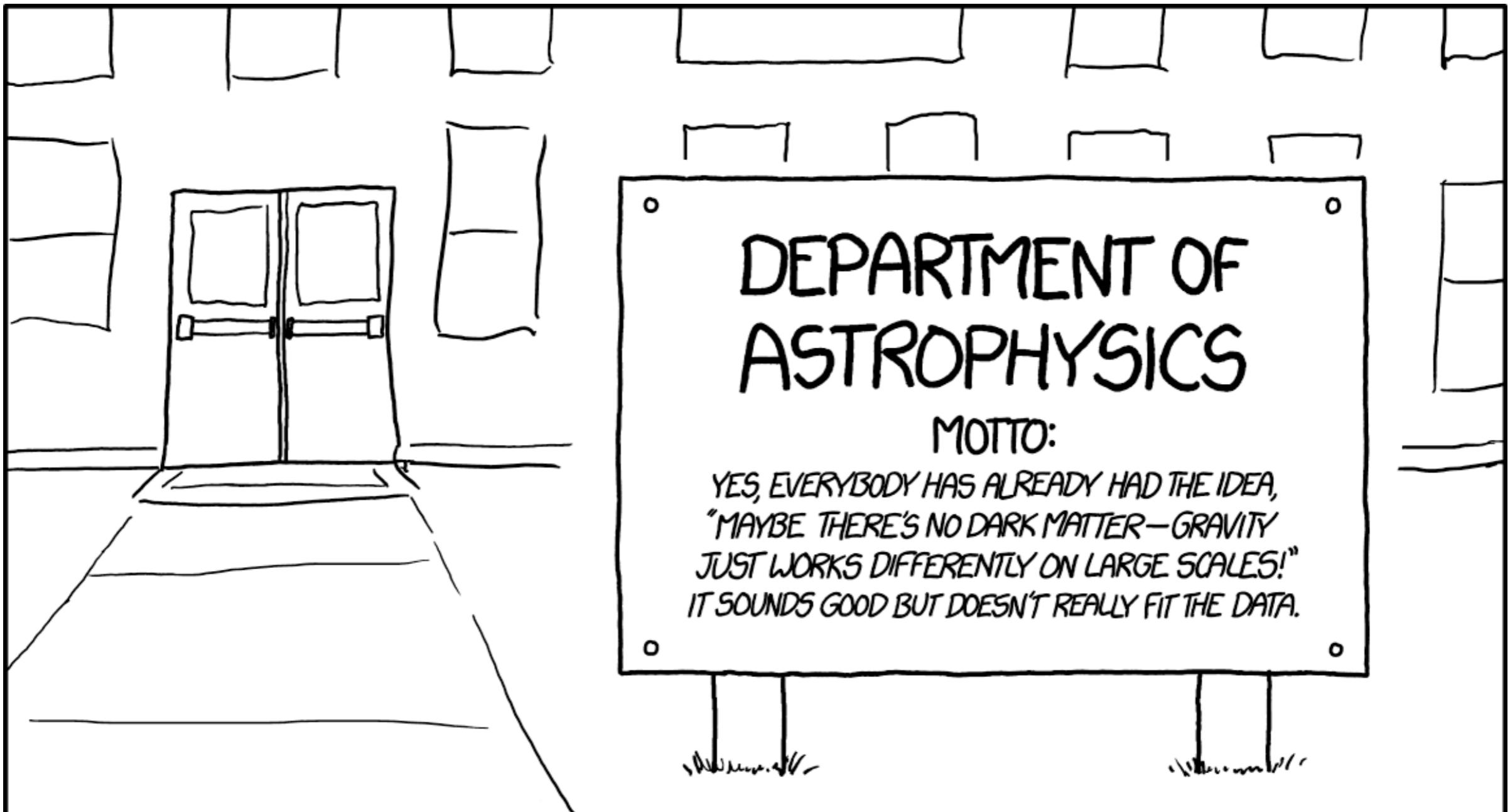
90,000 A.L.

3.3 billion A.L.

NASA/WMAP

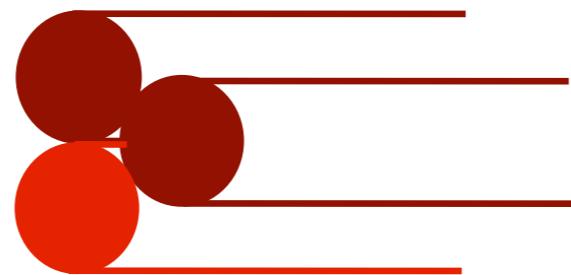




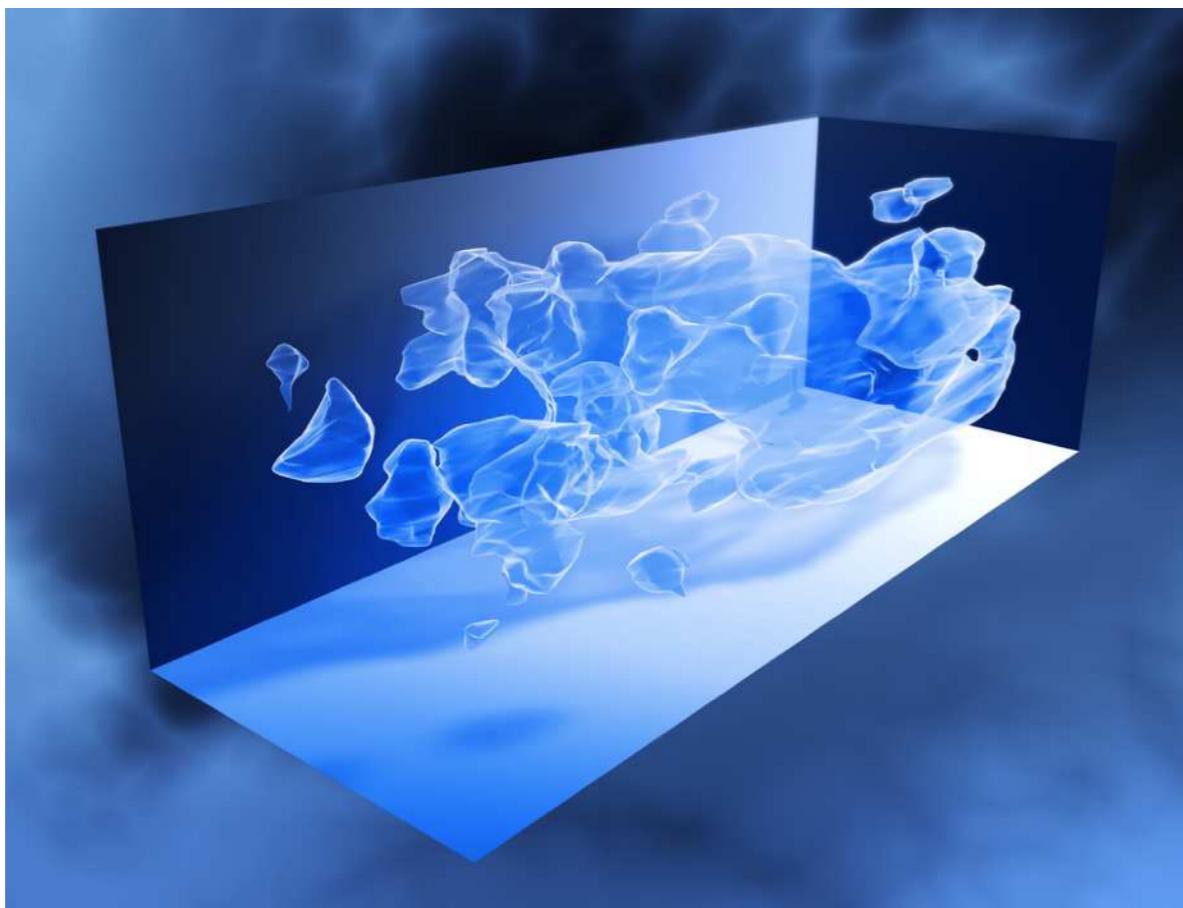


# *Listening to dark matter?*

$$\left. \begin{array}{l} E = m c^2 \\ E = h \nu \end{array} \right\} \quad \begin{array}{c} \text{frequency} \\ \downarrow \\ \nu = m \frac{c^2}{h} \end{array} \quad \begin{array}{c} \text{mass} \\ \downarrow \\ c^2 \end{array}$$



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.