Understanding the Universe with AI
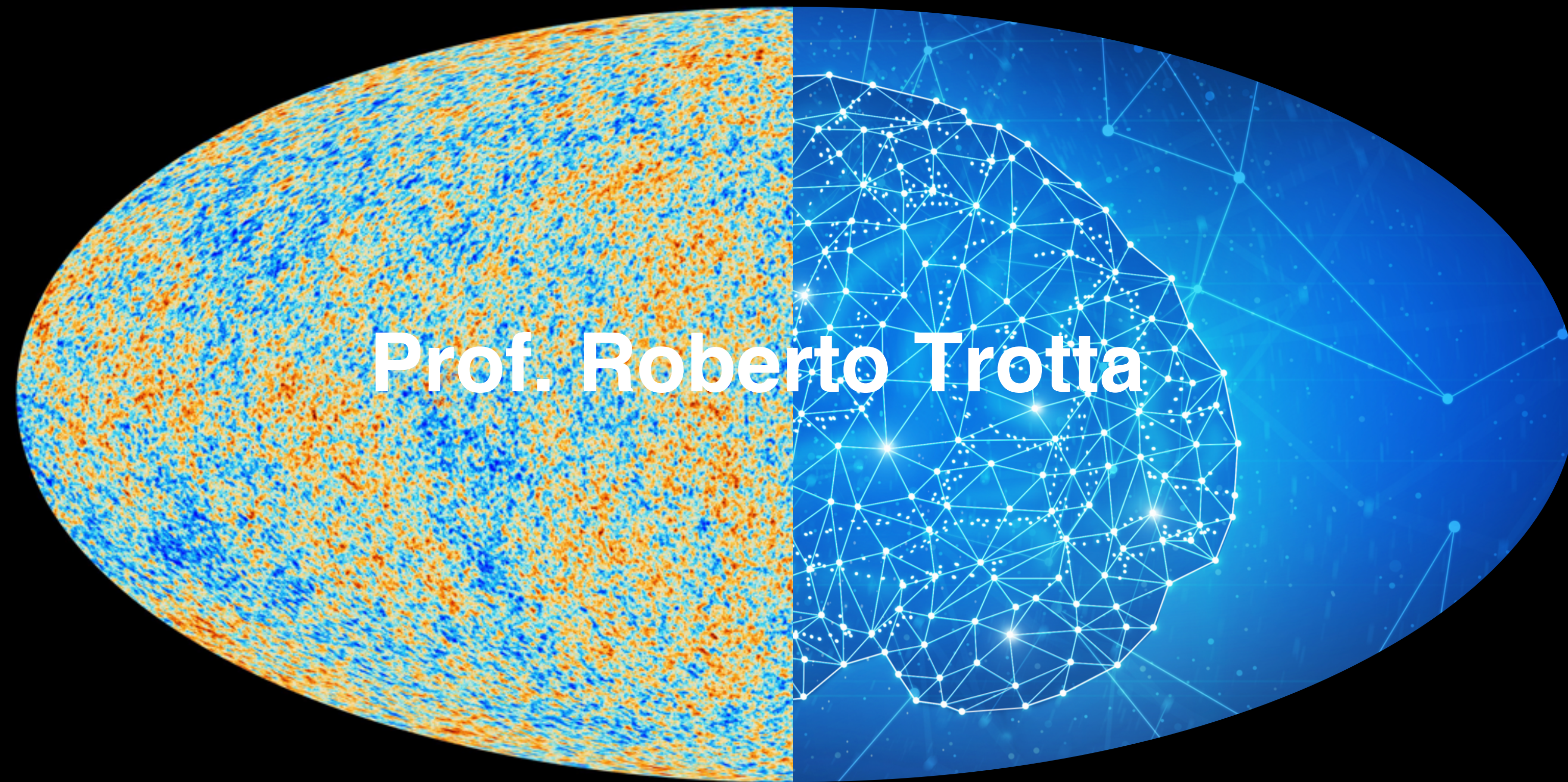
Prof. Roberto Trotta

🐦 @R_Trotta

Imperial College London
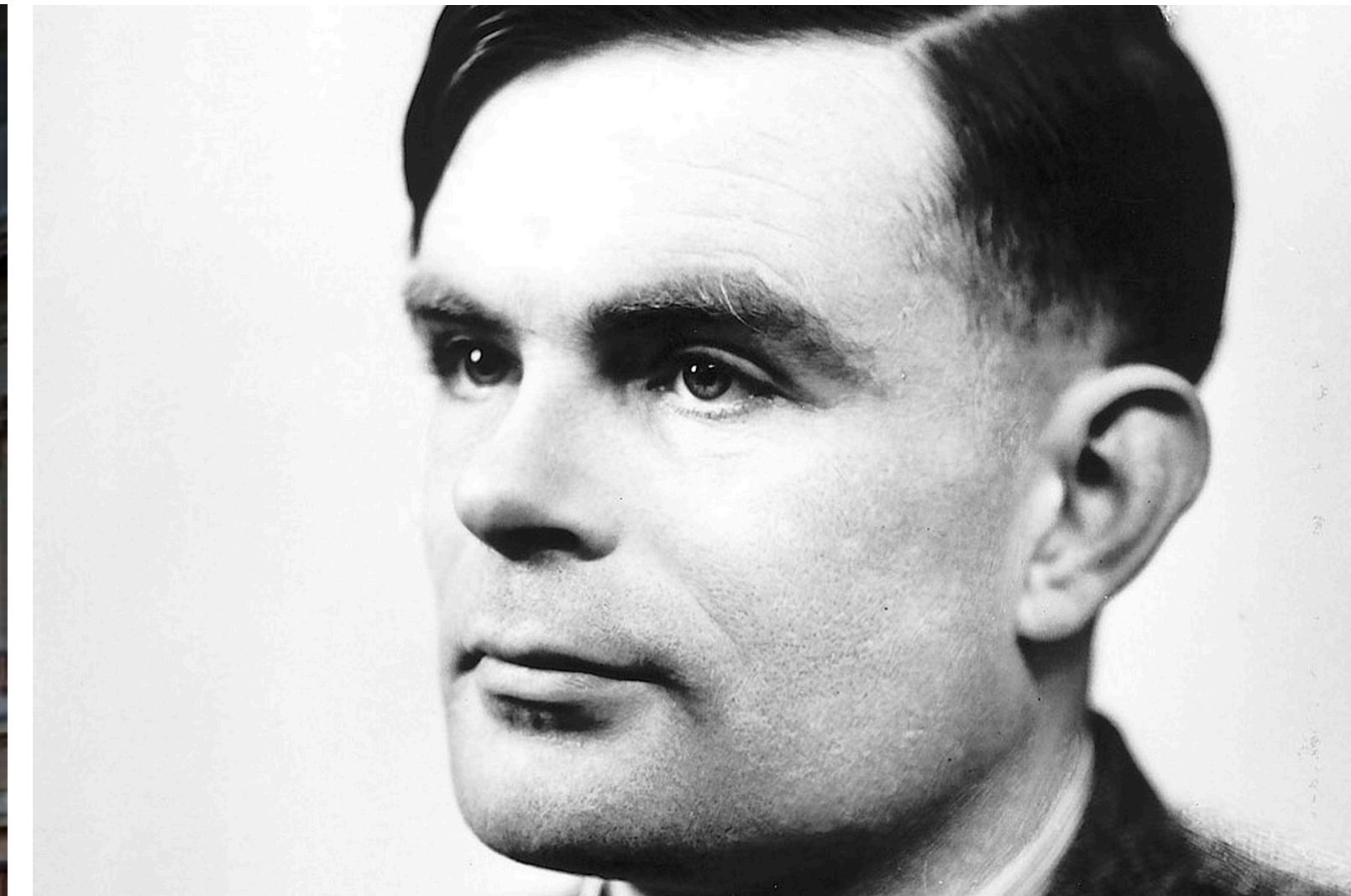
www.robertotrotta.com
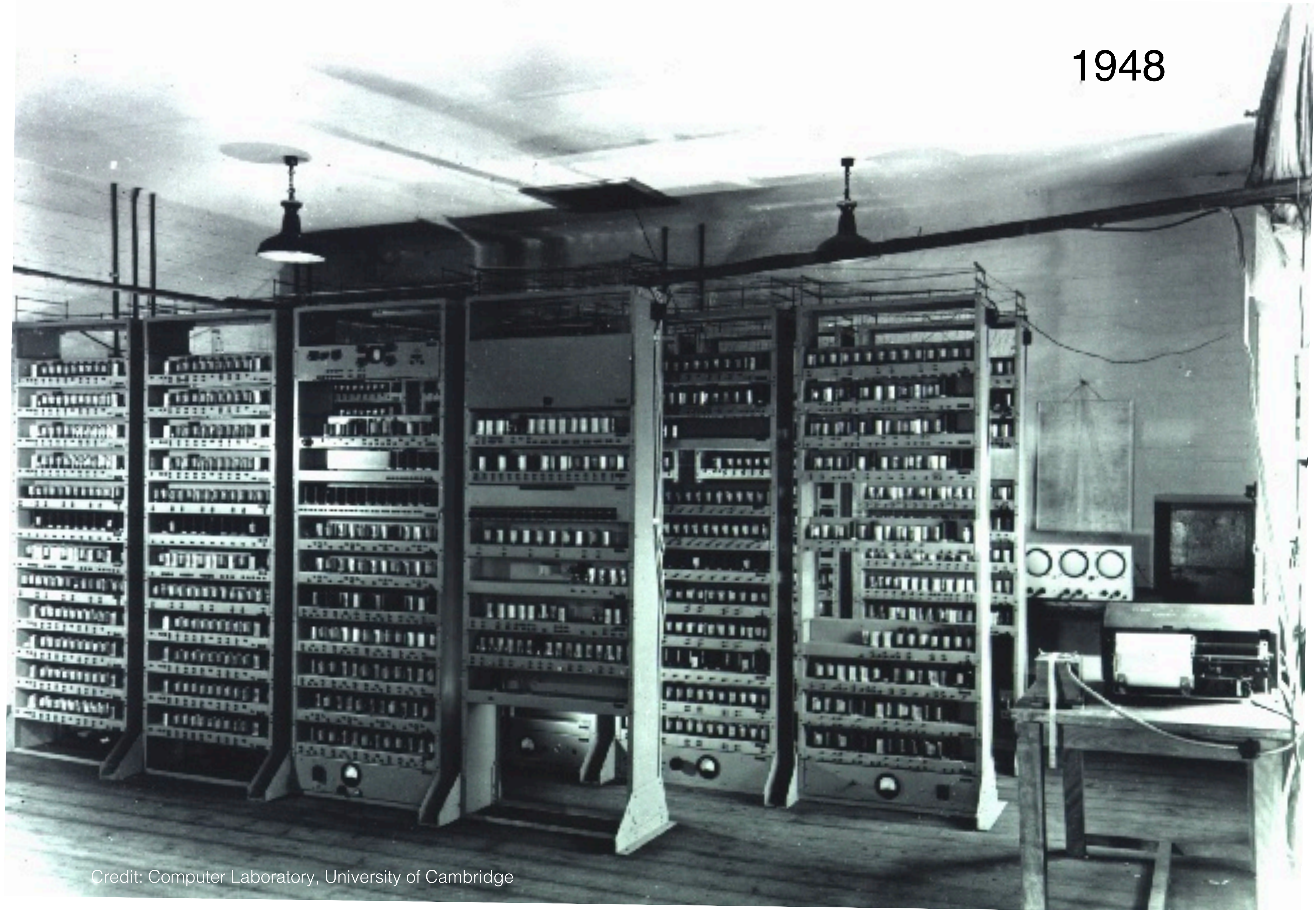
SISSA
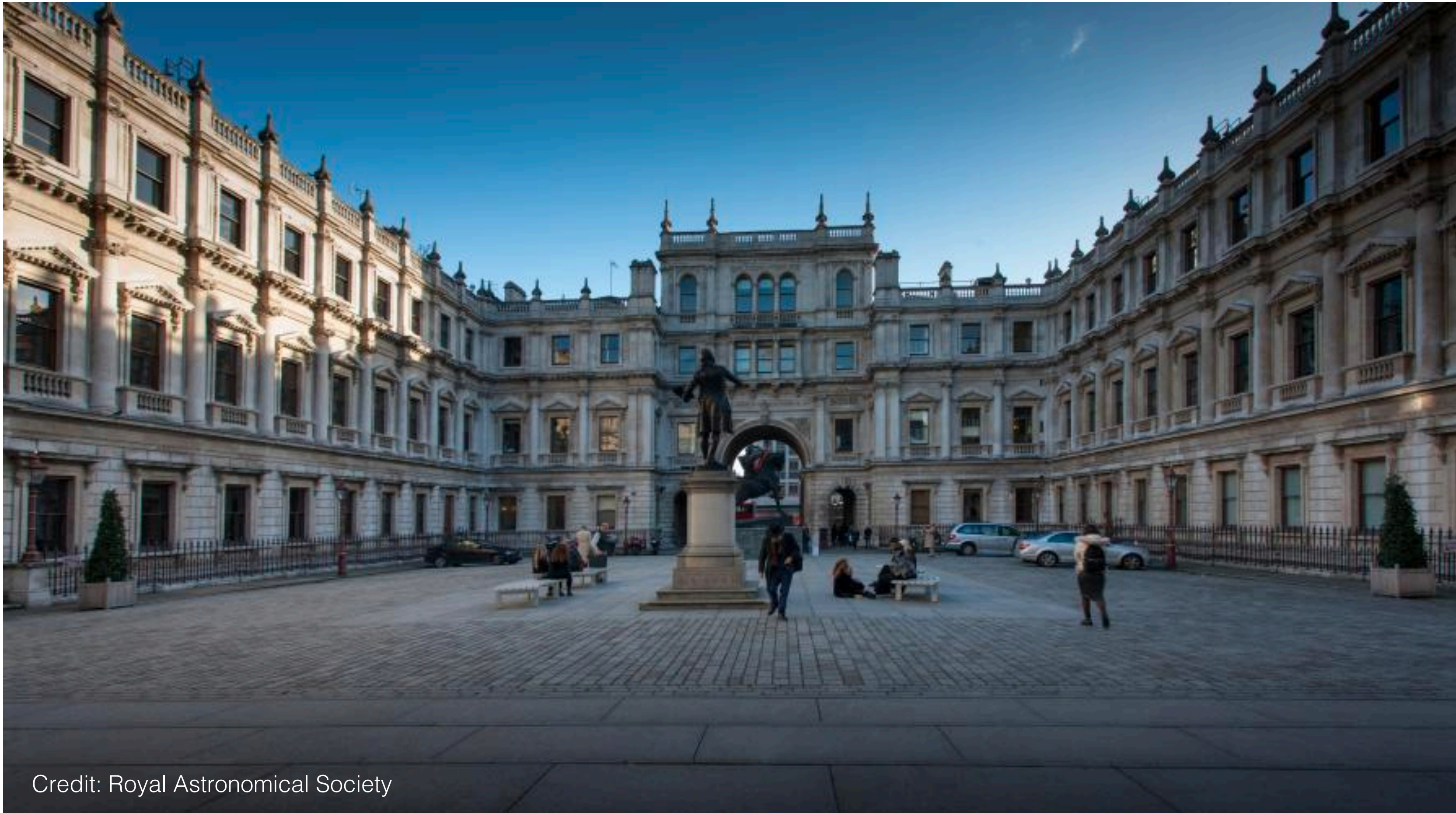
Credit: Royal Astronomical Society

Alan Turing
Source: Wikimedia

"What we want is a machine that can learn from experience"
– Alan Turing (1947)

1948

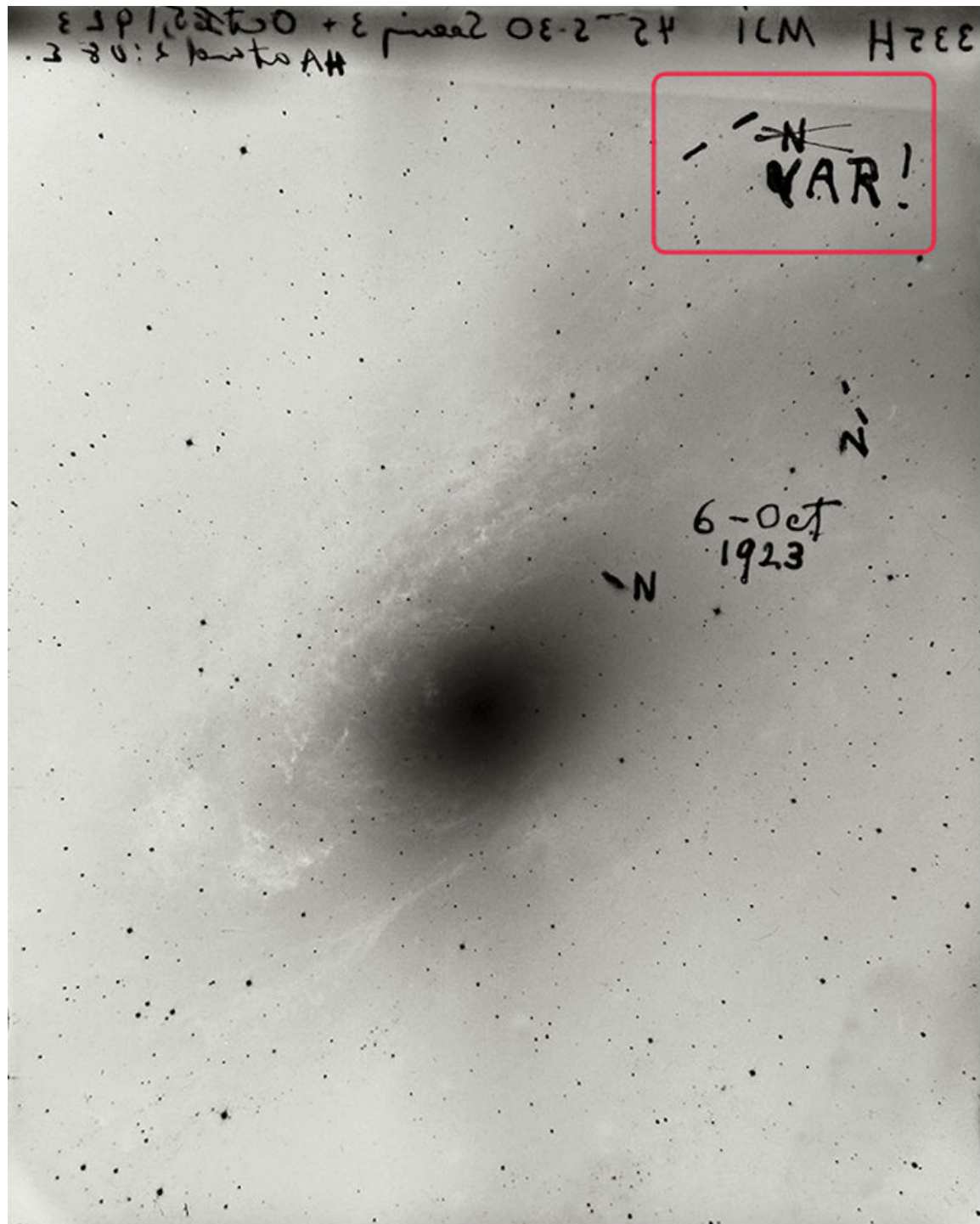Credit: Computer Laboratory, University of Cambridge
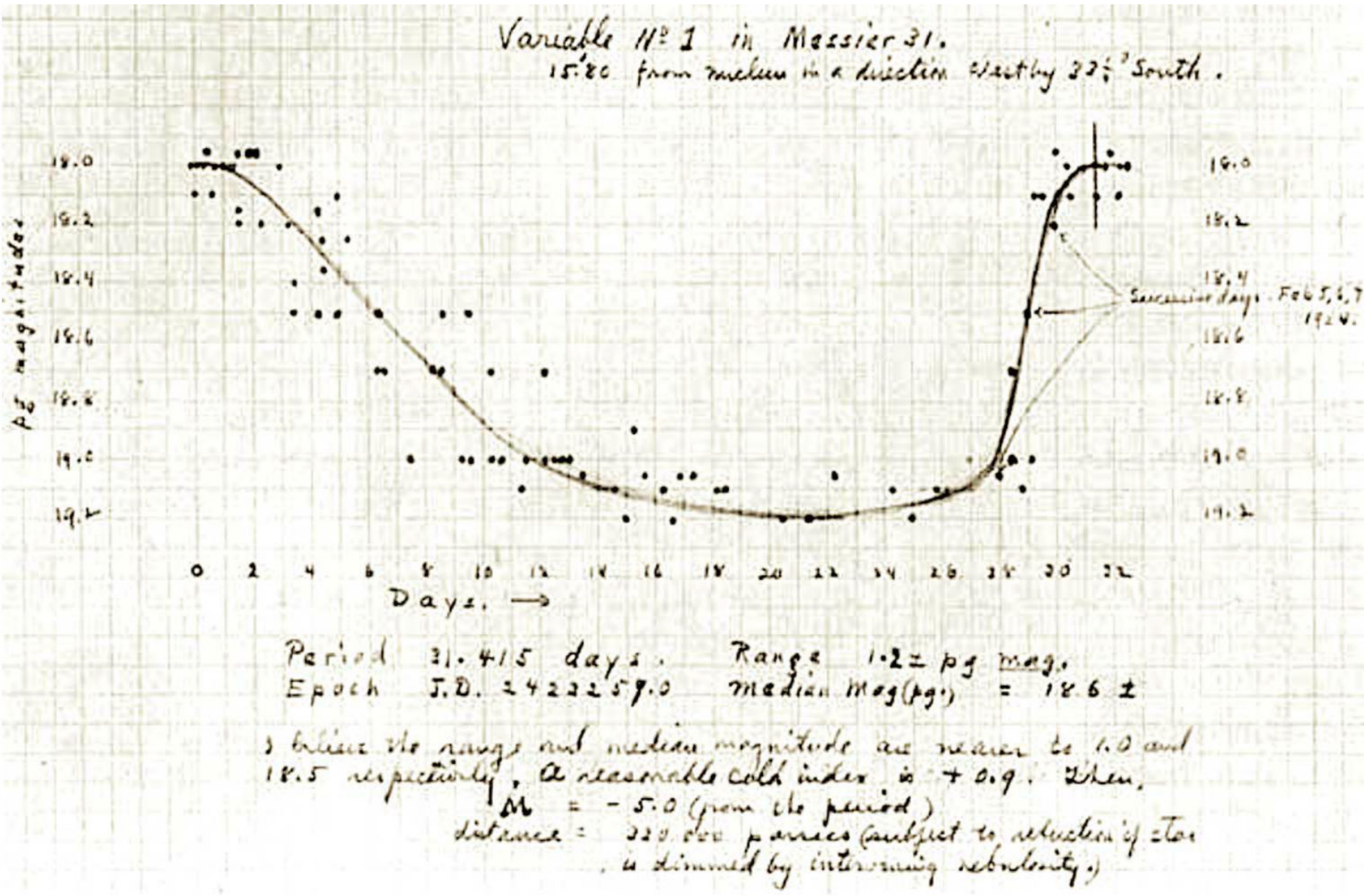
Oct 6th, 1923

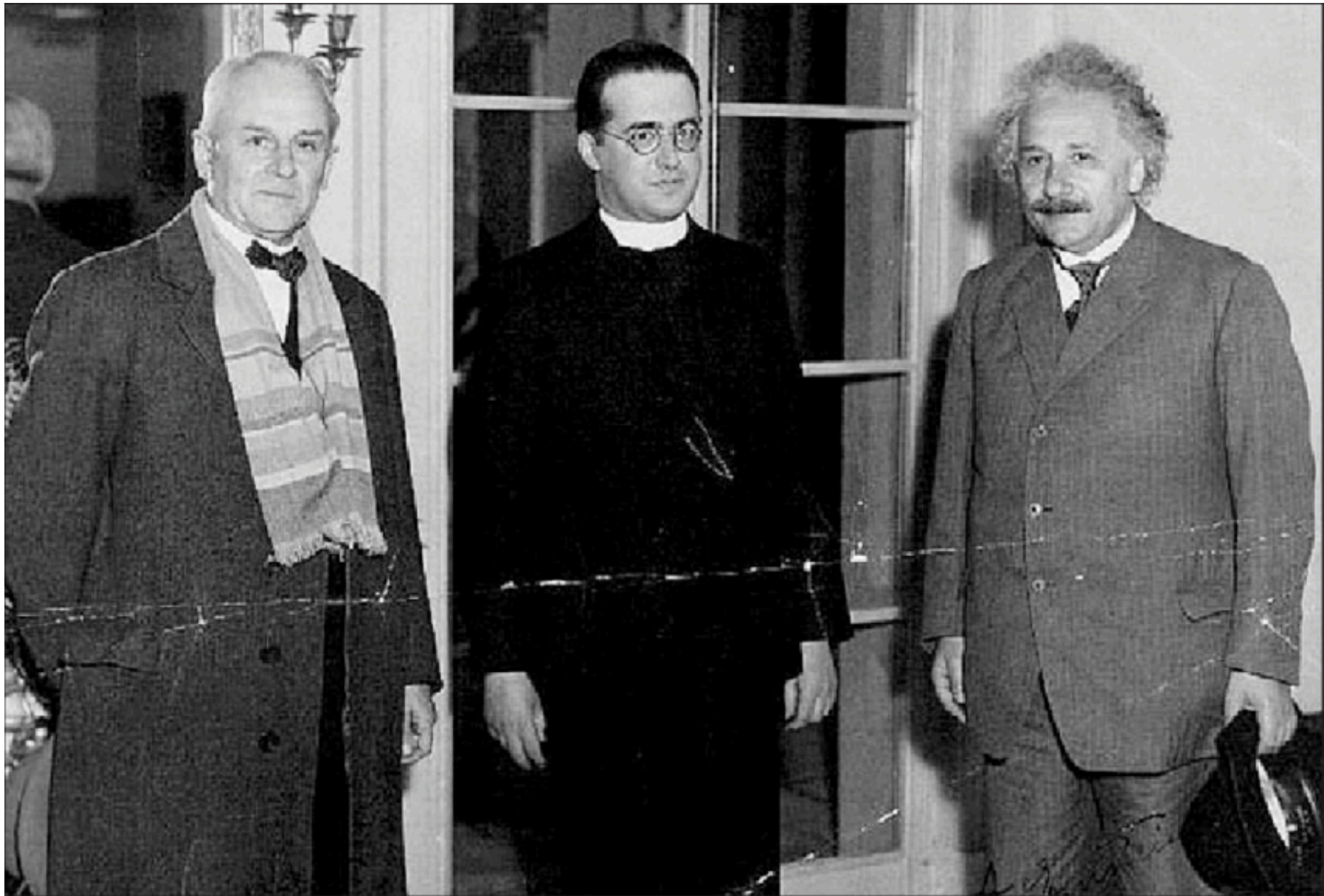Henrietta Swan
Leavitt
1921
Credit: public domain

Edwin Hubble
ca 1922
Credit: Huntington Library
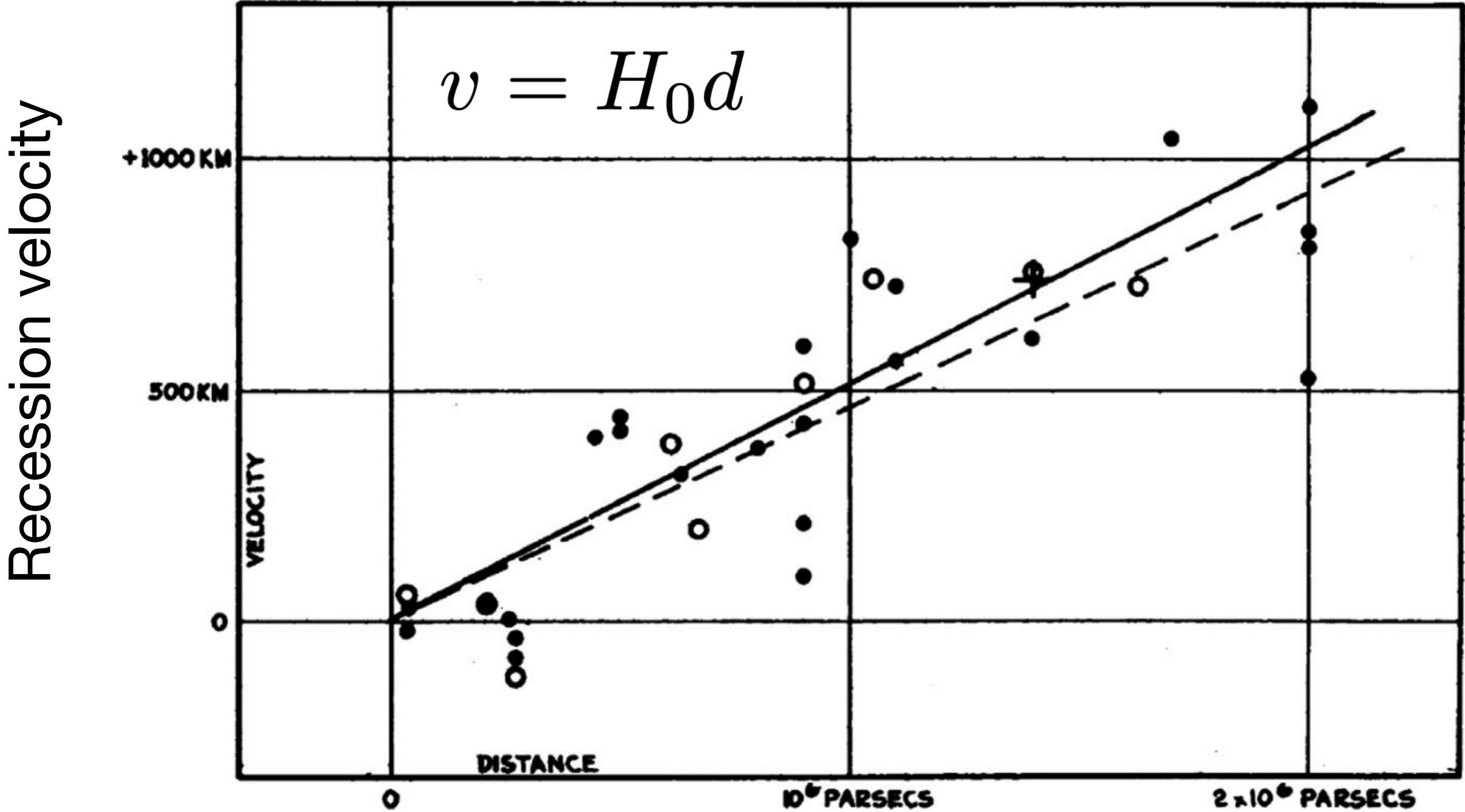

Credit: Carnegie Observatories

The Hubble-Lemaître Law

Georges Lemaître (centre), 1933
Credit: Archives Louvain, Mitton (2020)
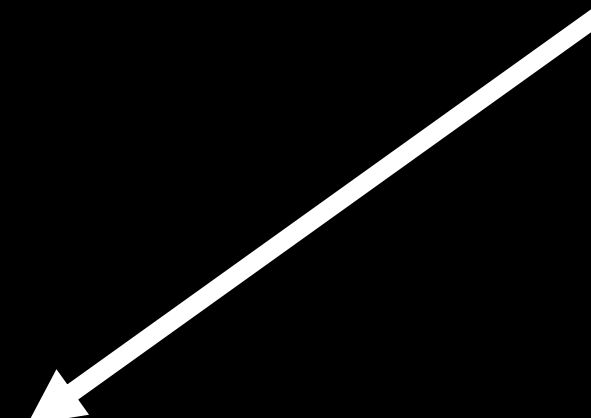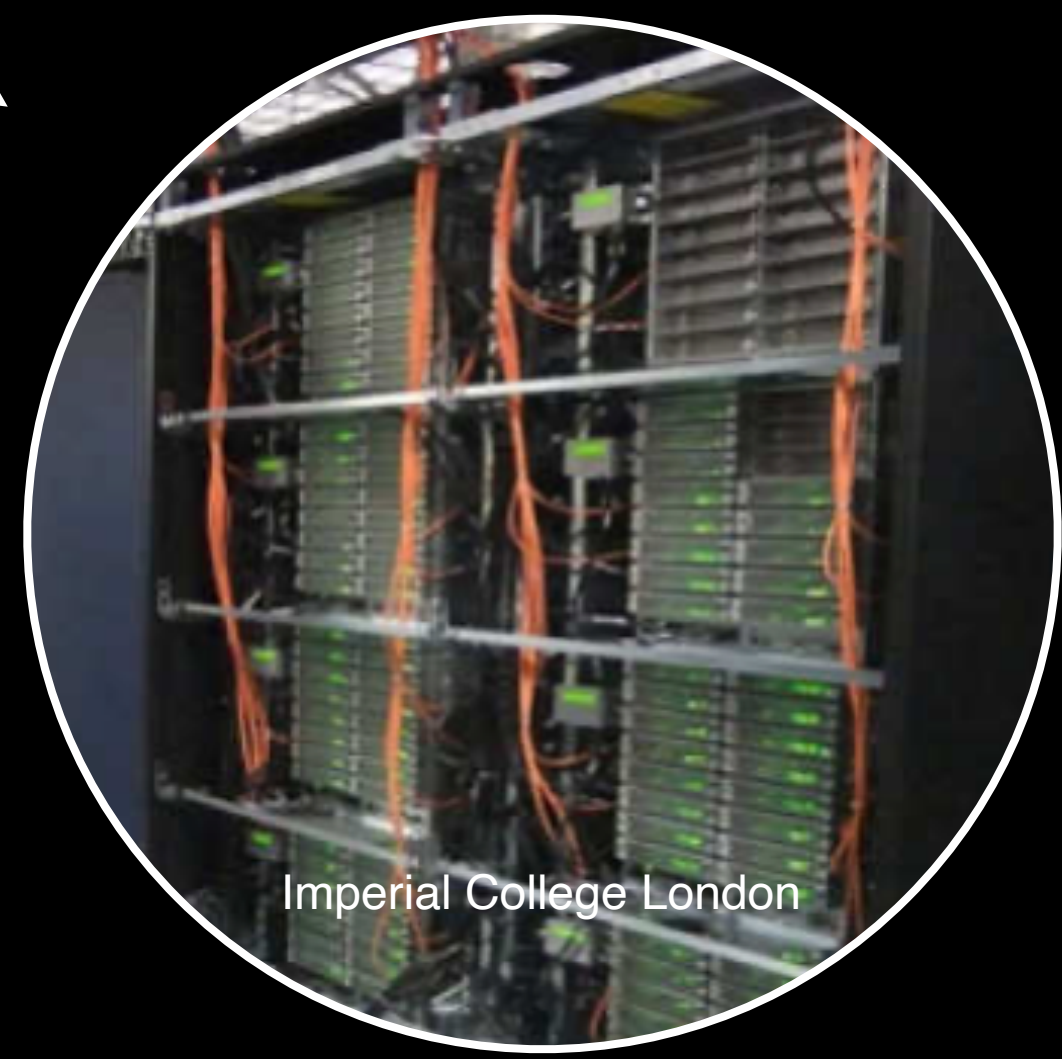

Velocity-Distance Relation among Extra-Galactic Nebulae.

$$v = H_0 d$$

Recession velocity

Distance   Hubble (1929)

Estimated age of the universe:

Lemaître, then Hubble: 2 Bn years
Today's value: 14 Bn years

21st century cosmology

@R_Trotta

Planck/ESA

A. Duro/ESO

E. Jacobi/NSF

Imperial College London
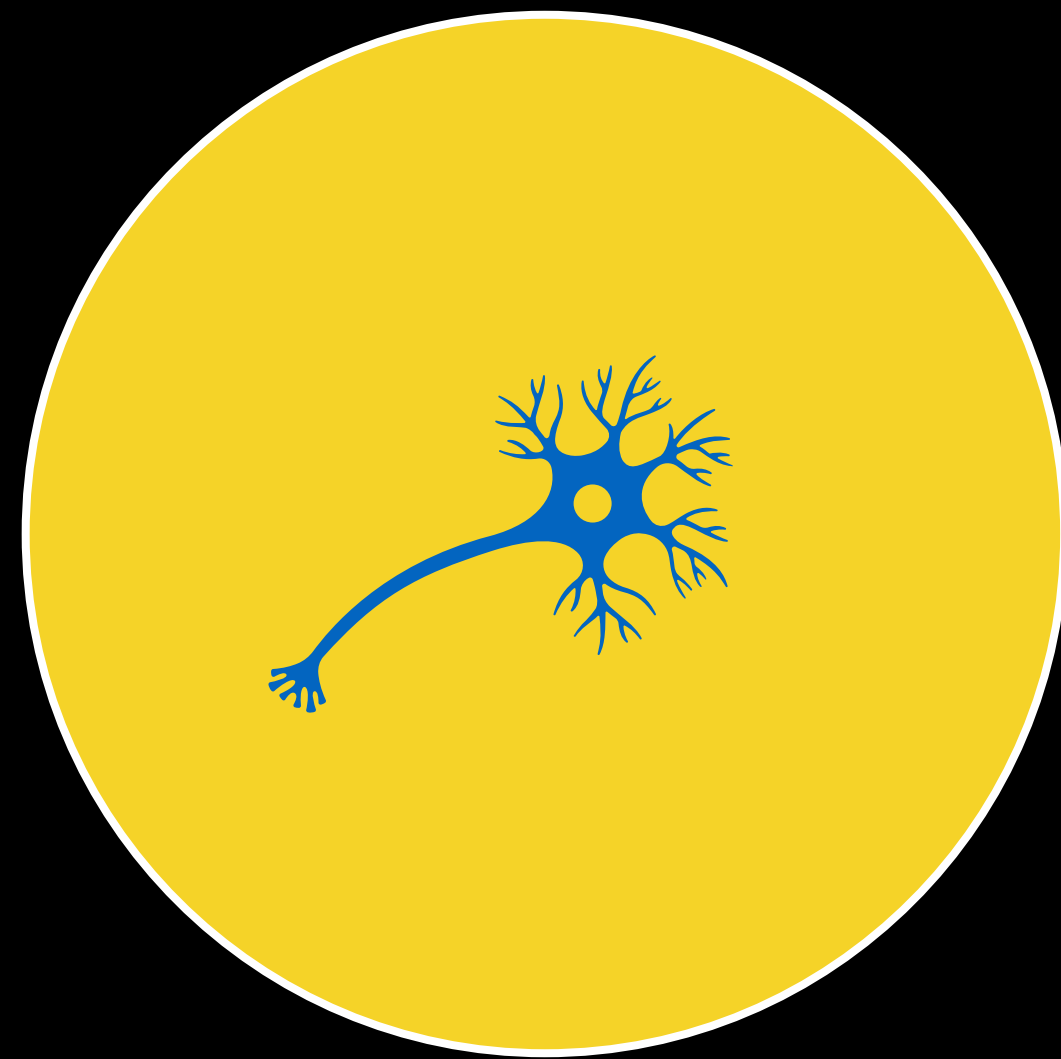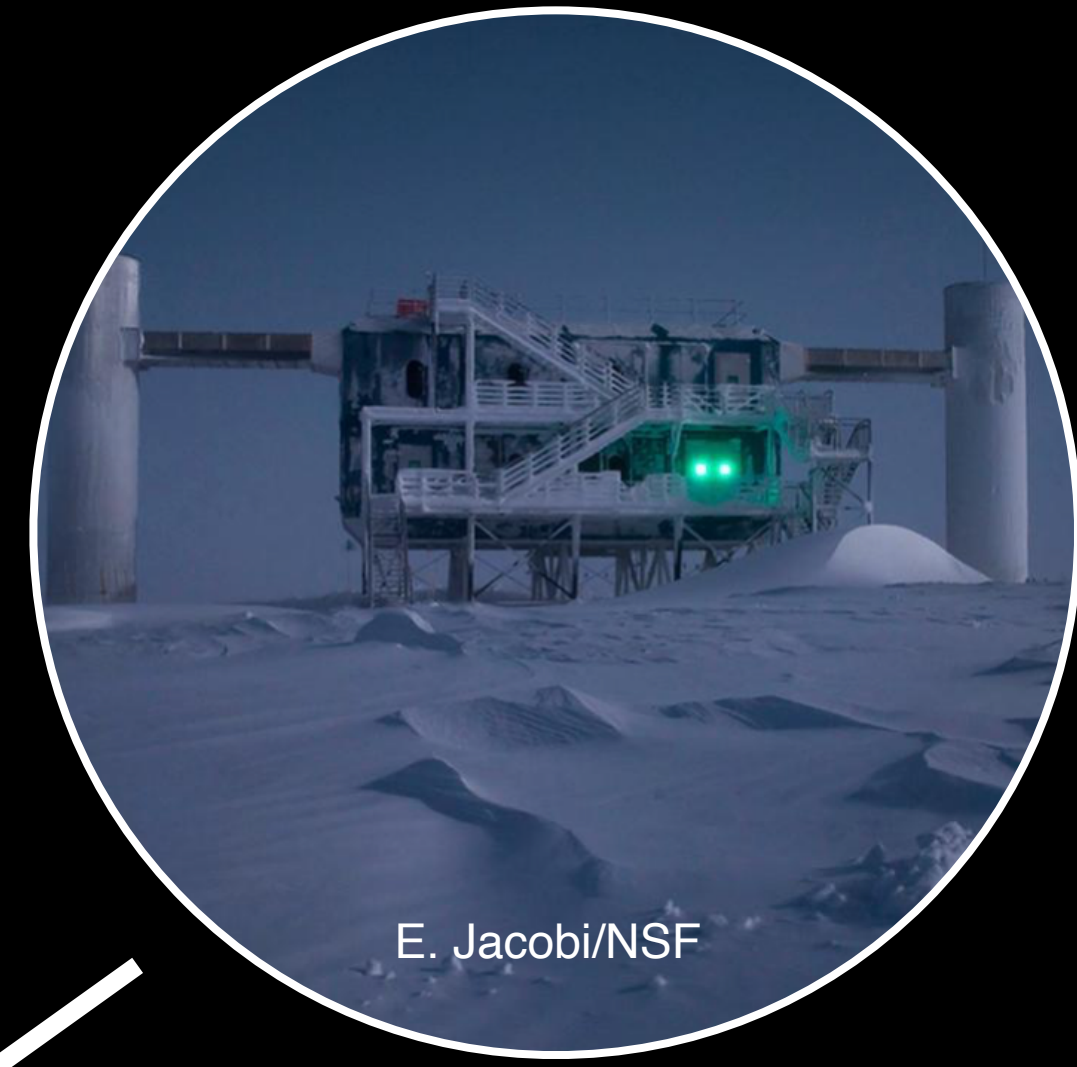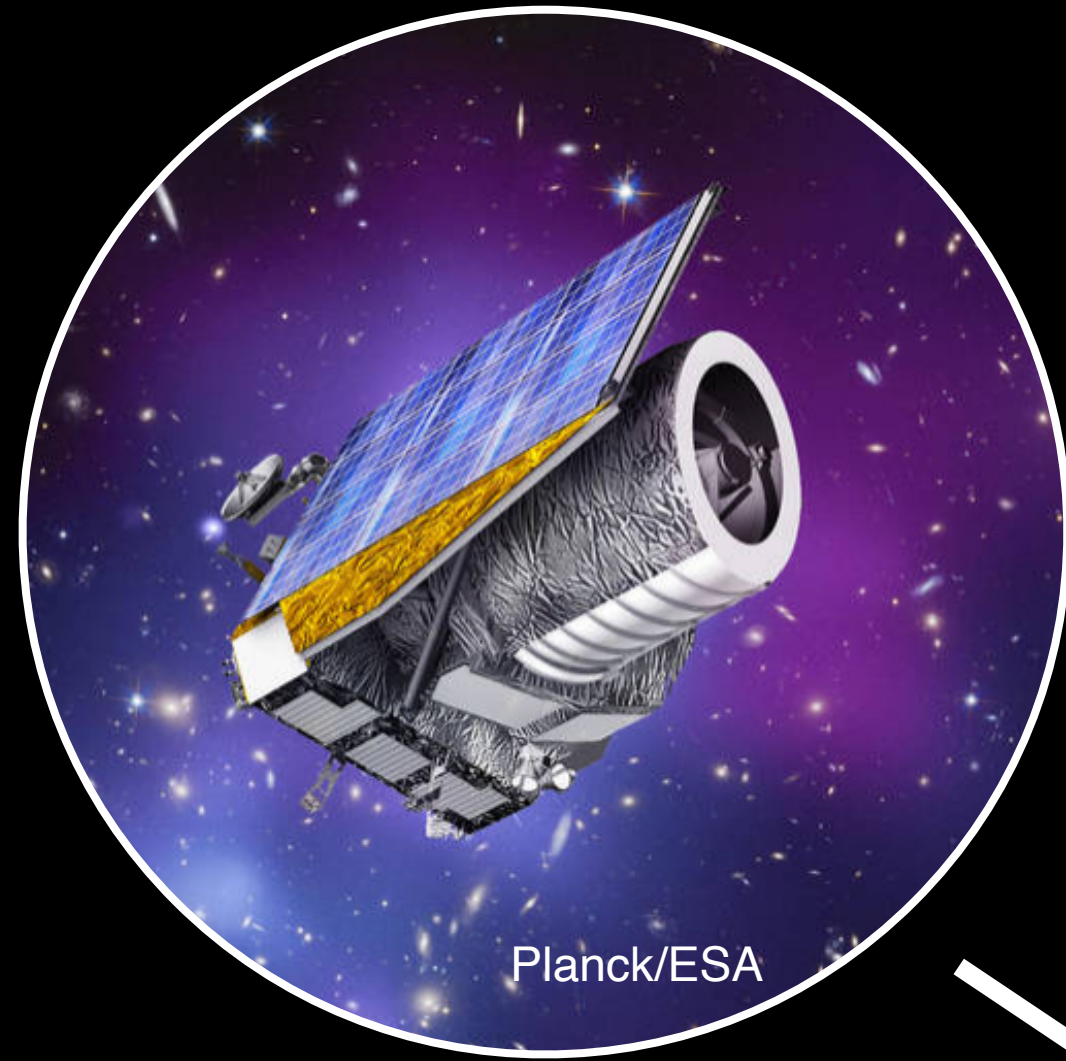
AI and Machine Learning
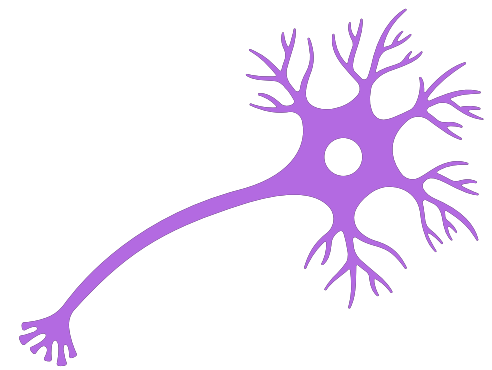
Research

Education

Applications

Astrophysics and Cosmology

What is dark matter?

Credit: M. Markevitch

What makes the cosmos accelerate?

Credit: NASA

Is there life elsewhere?

Credit: Ricardo Ramirez

5% Normal Matter

25% Dark Matter

70% Dark Energy

Year : 1800

Only a subset of the data shown for clarity

Distant Universe
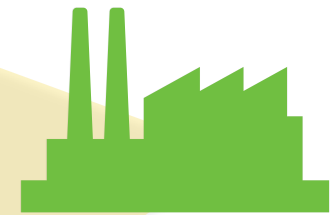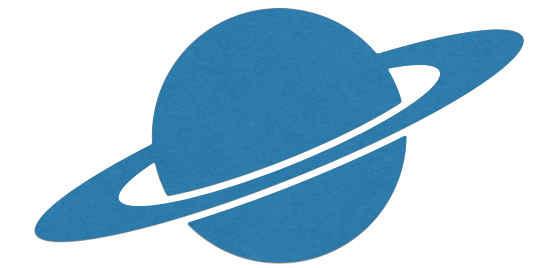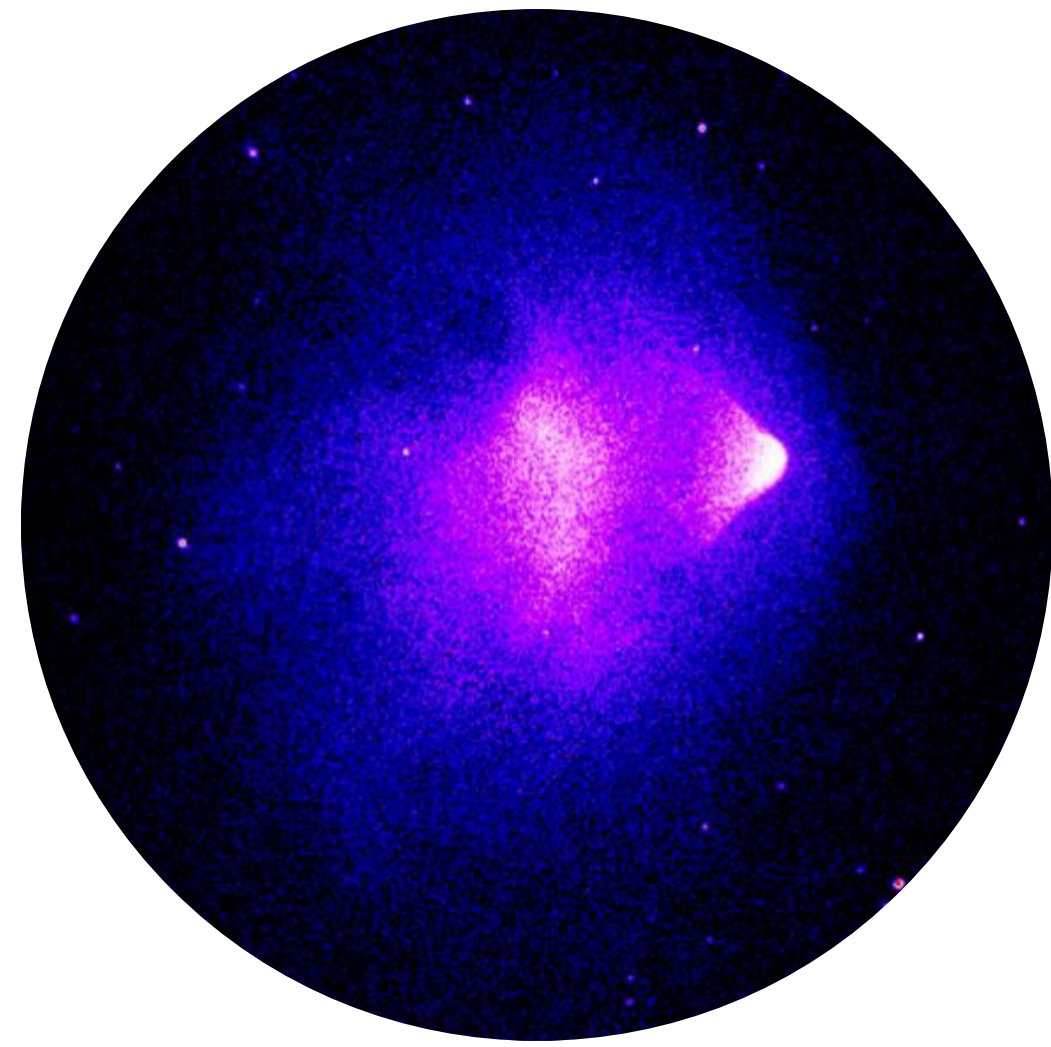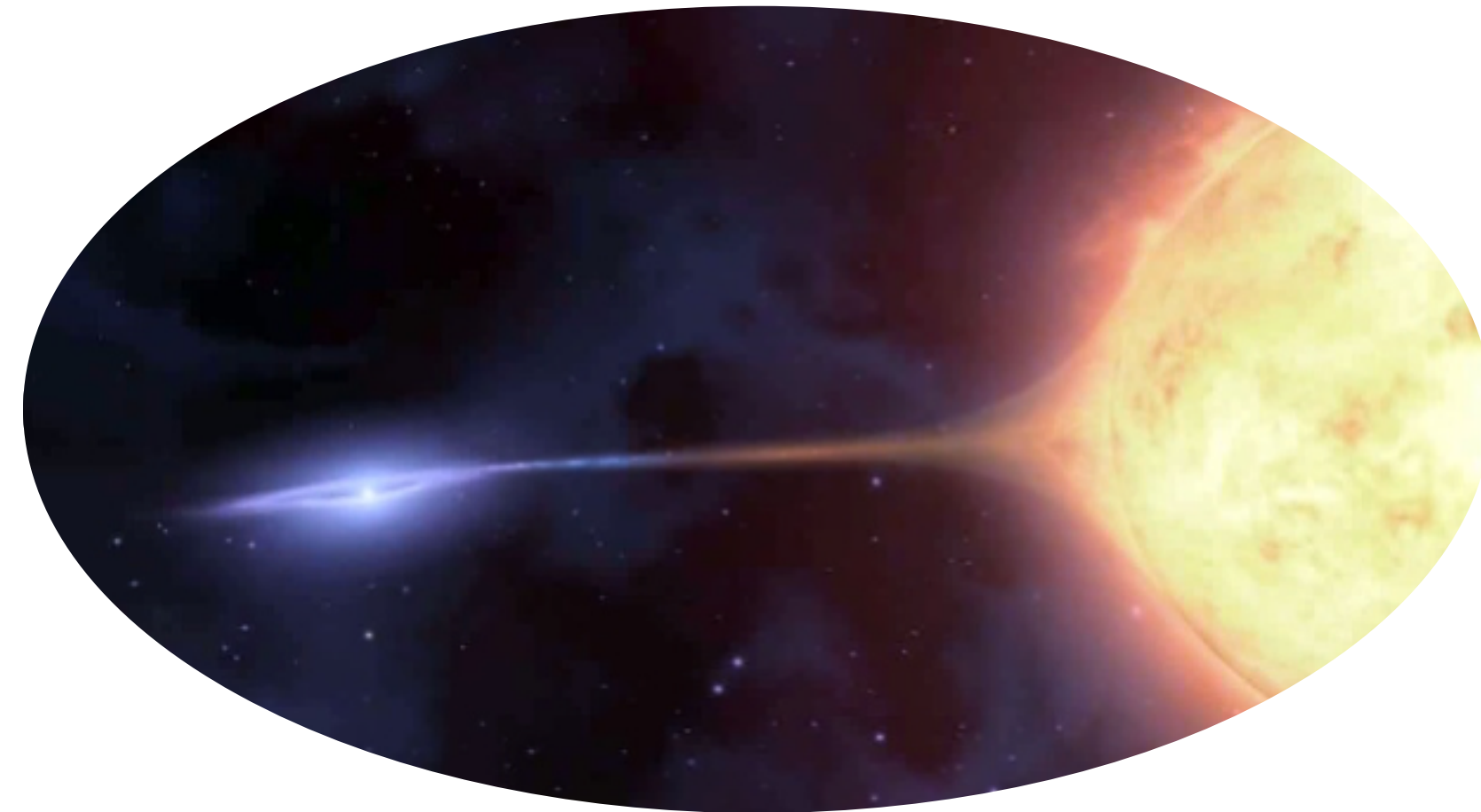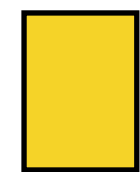
Our Galaxy

Solar system

Earth orbit

@R_Trotta
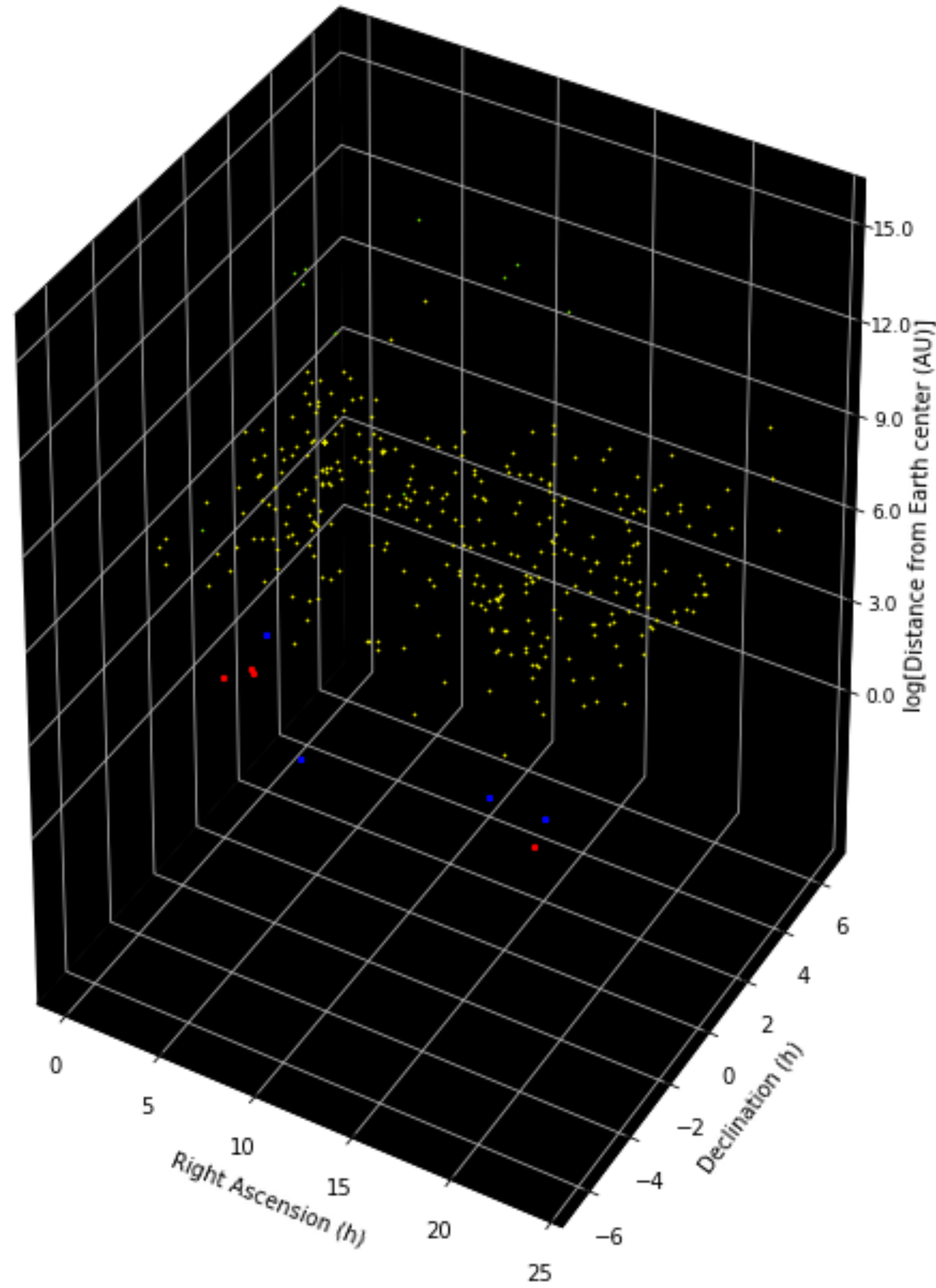
Category	# known
Stars	455,167,598
Galaxies	1,836,986
Asteroids	780,525
Quasars	544,103
Supernovae	17,533
Artificial satellites	5,524
Comets	3,511
Exoplanets	2564
Moons	169
Black holes	62
Solar system large bodies	13

Legend:
- Mainbody (red)
- Galaxy (green)
- Star (yellow)
- Blackhole (orange)
- Asteroid (grey)
- Exoplanet (purple)
- Satellite/Spacecraft (pink)
- Moon (blue)
- Quasar (cyan)
- Supernova
- Other (grey)

Cosmic Acceleration
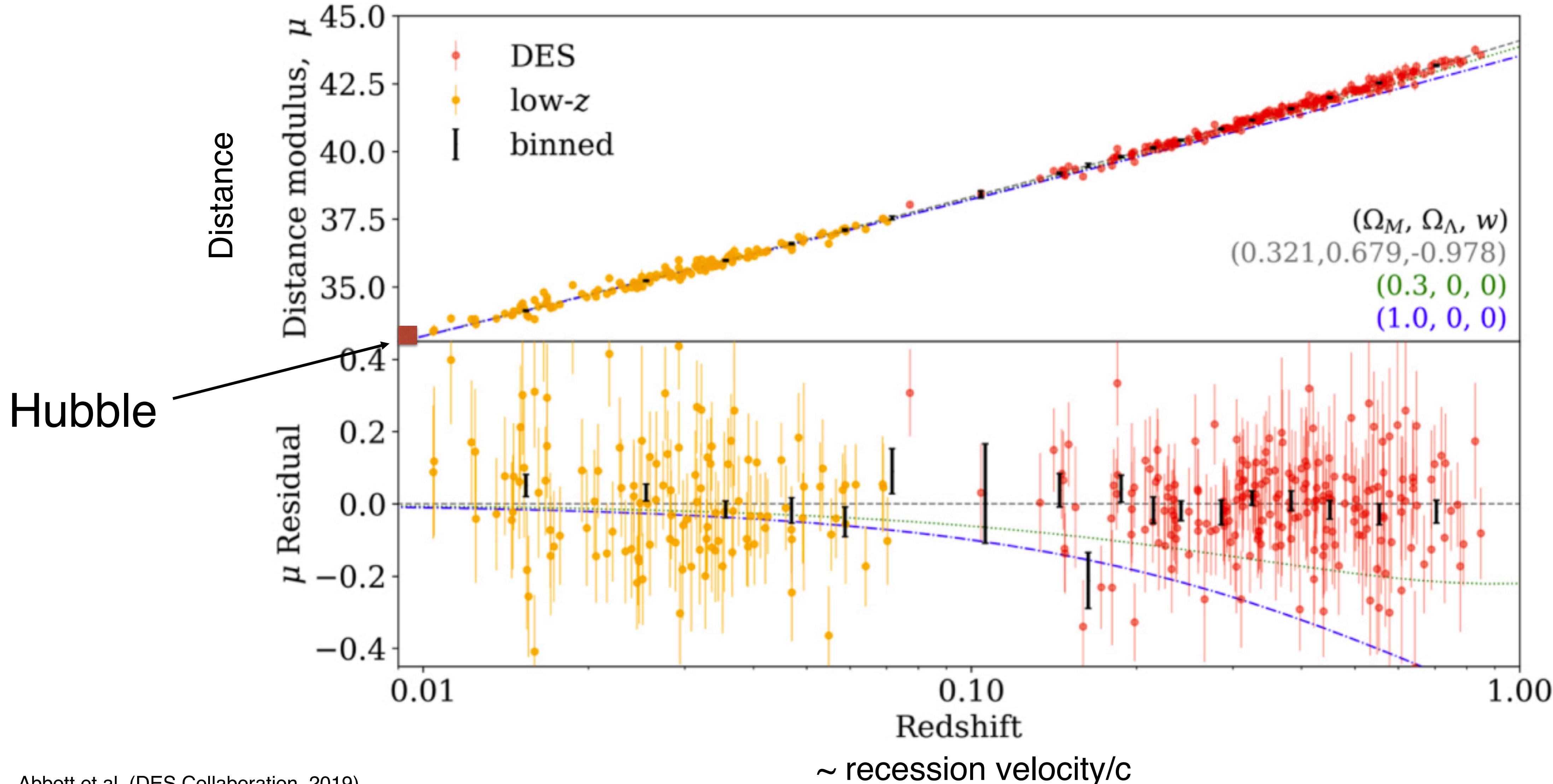
Abbott et al (DES Collaboration, 2019)

Supernovae Discovered Over Time
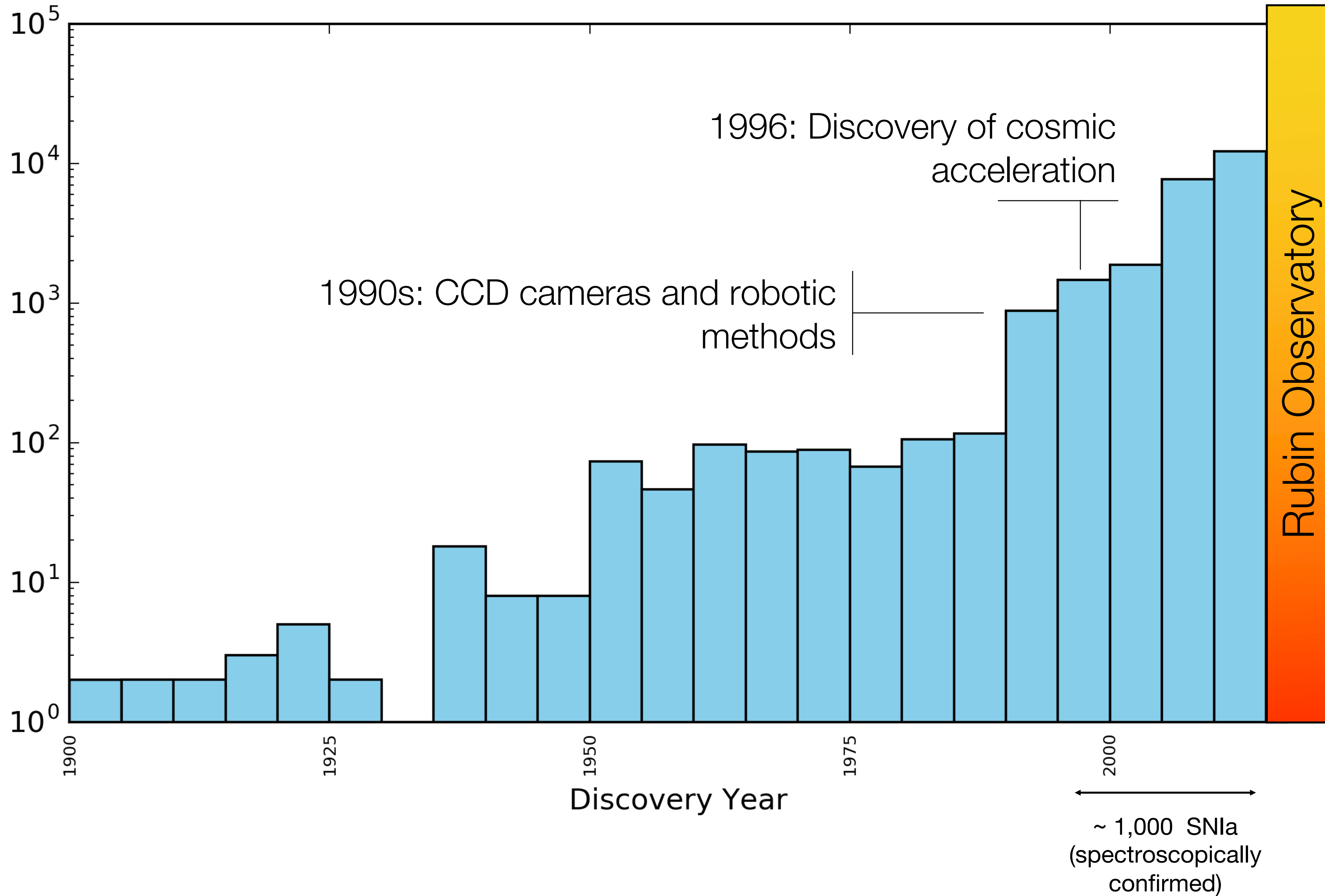
The Vera C. Rubin Observatory

Science first light: 2021-2
Mirror: 8.4m
Camera: 3,000 MPixels
Data flow: 30 TB/night
Yearly data: 200,000 images, 1.3 PB
Computing: 100 teraflops

Credit: Rubin Observatory/LSST Science Collaboration
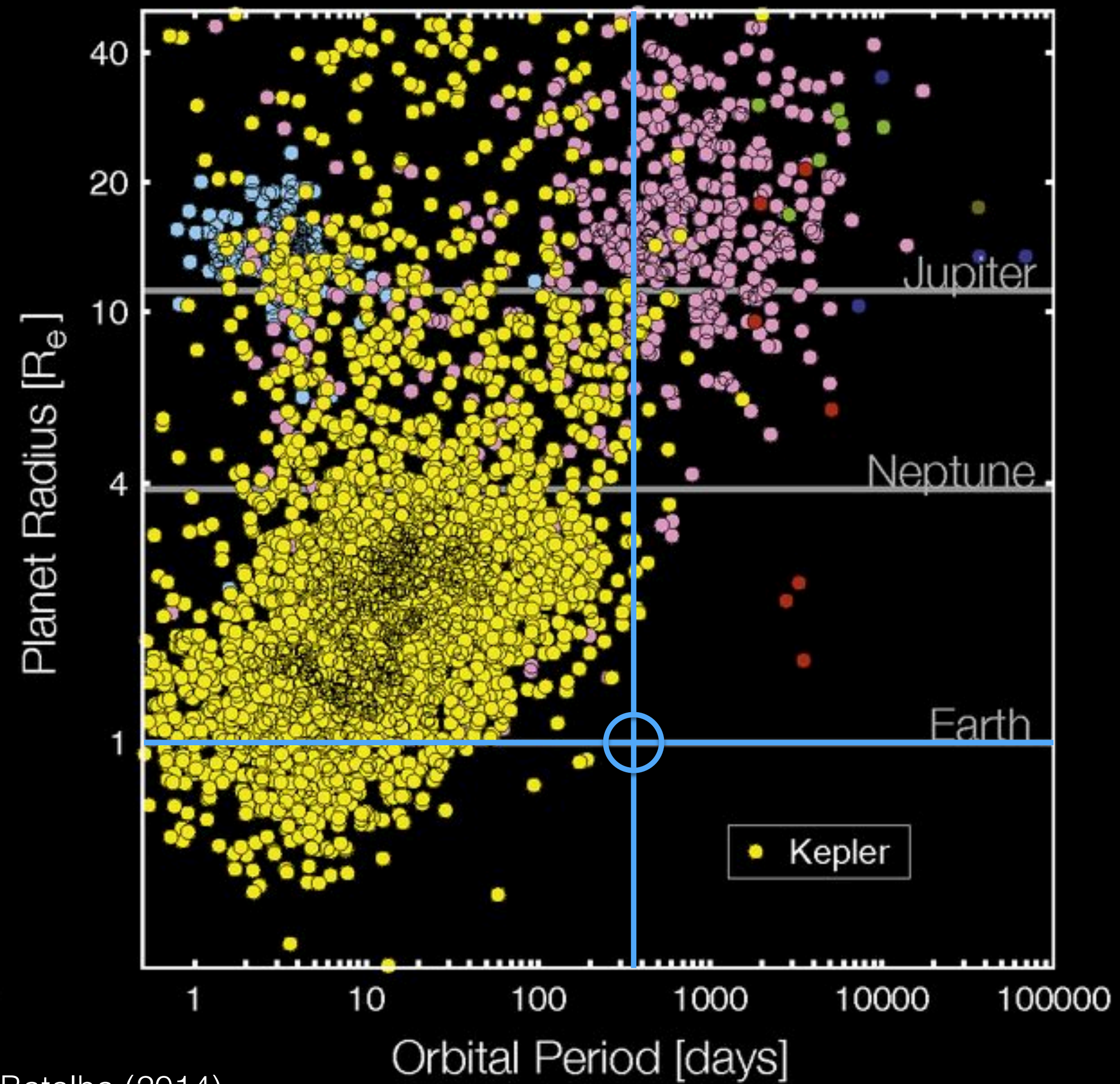
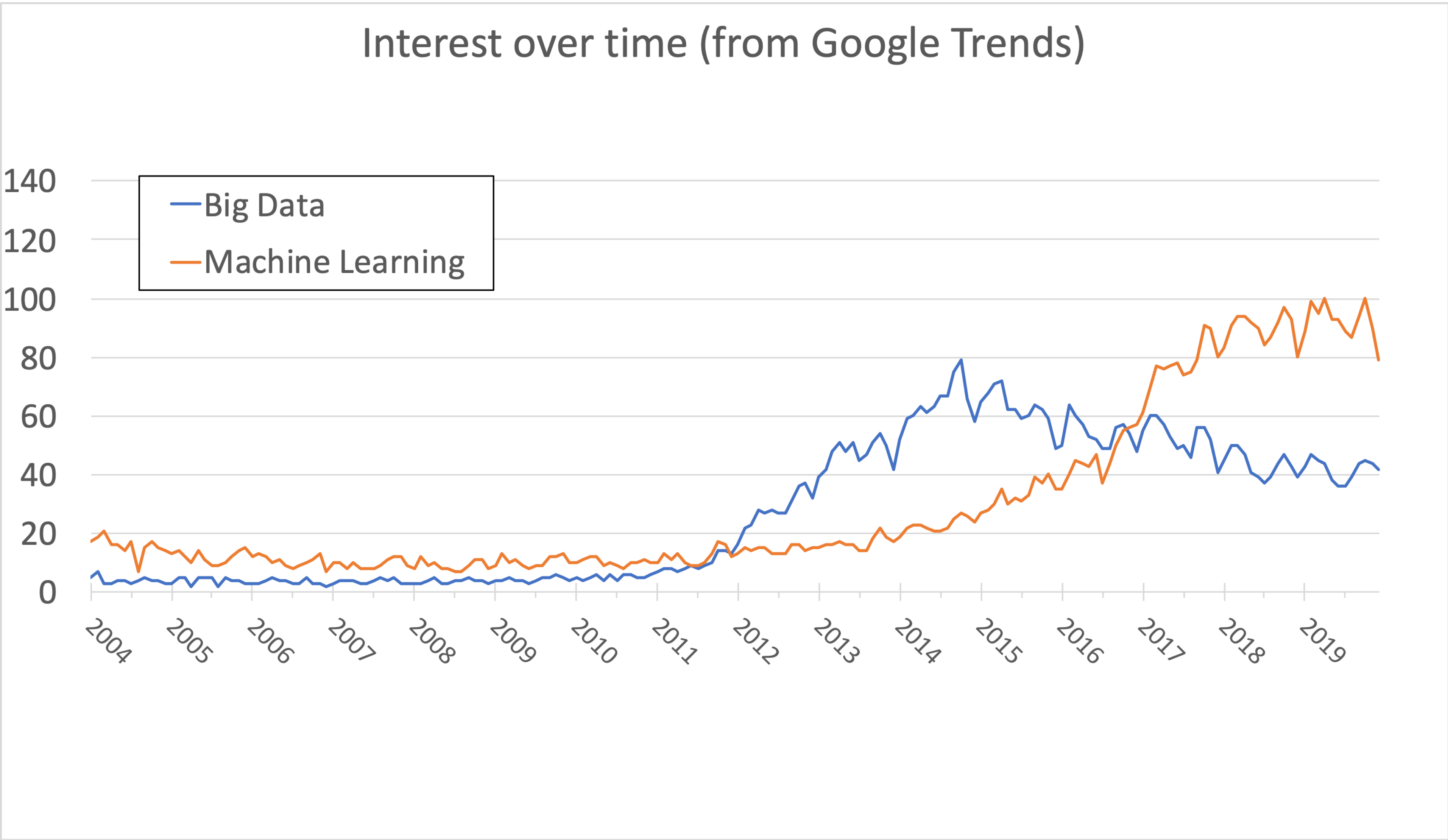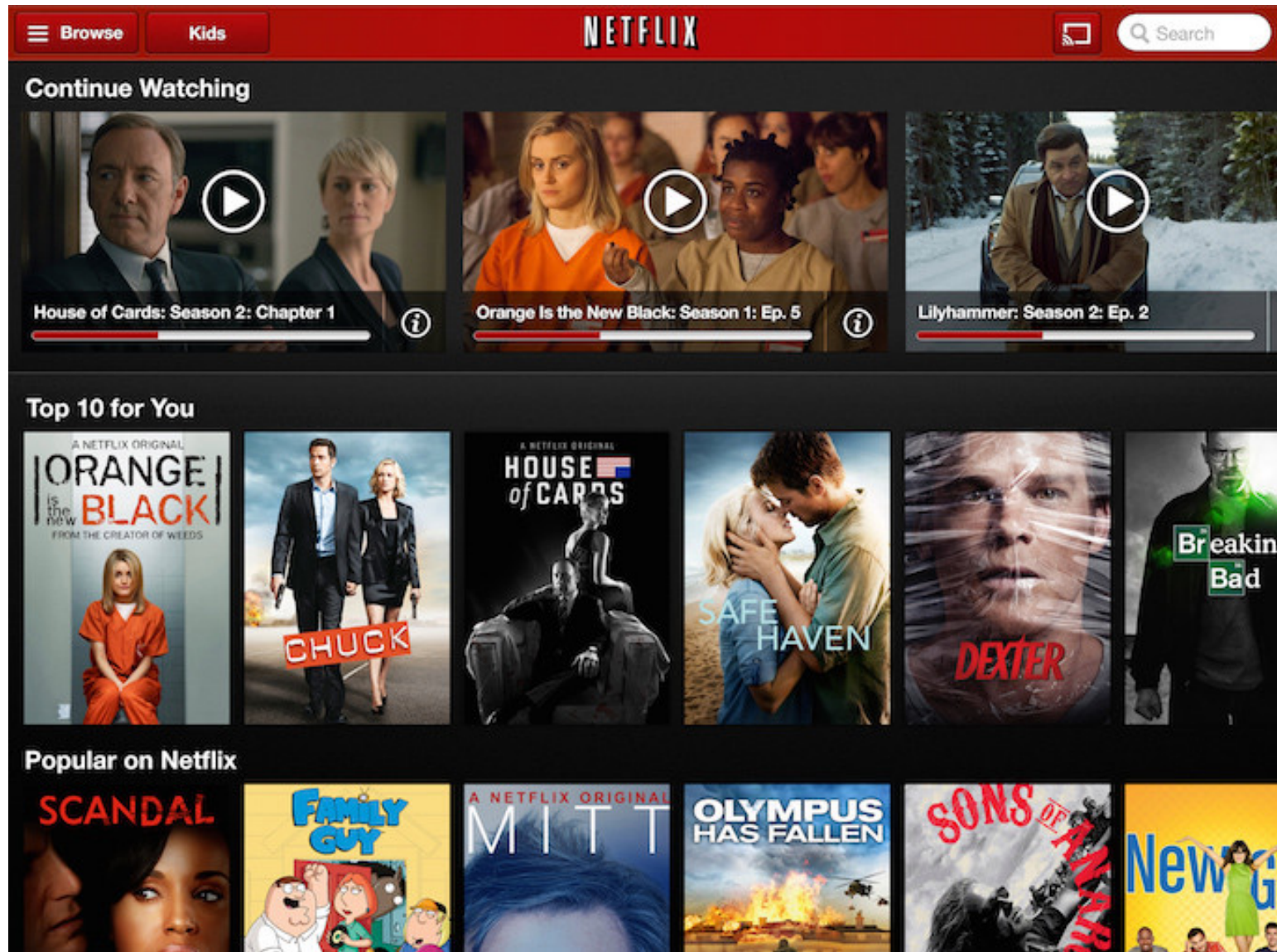Batalha (2014)

There are probably more planets than stars in the galaxy!

200 kpc

z = 10.0

Credit: IllustrisTNG Simulation

The Era of Machine Learning

Interest over time (from Google Trends)

What is Machine Learning?

Computer learns to detect skin cancer more accurately than doctors

Artificial intelligence machine found 95% of melanomas in study compared to 86.6% for dermatologists
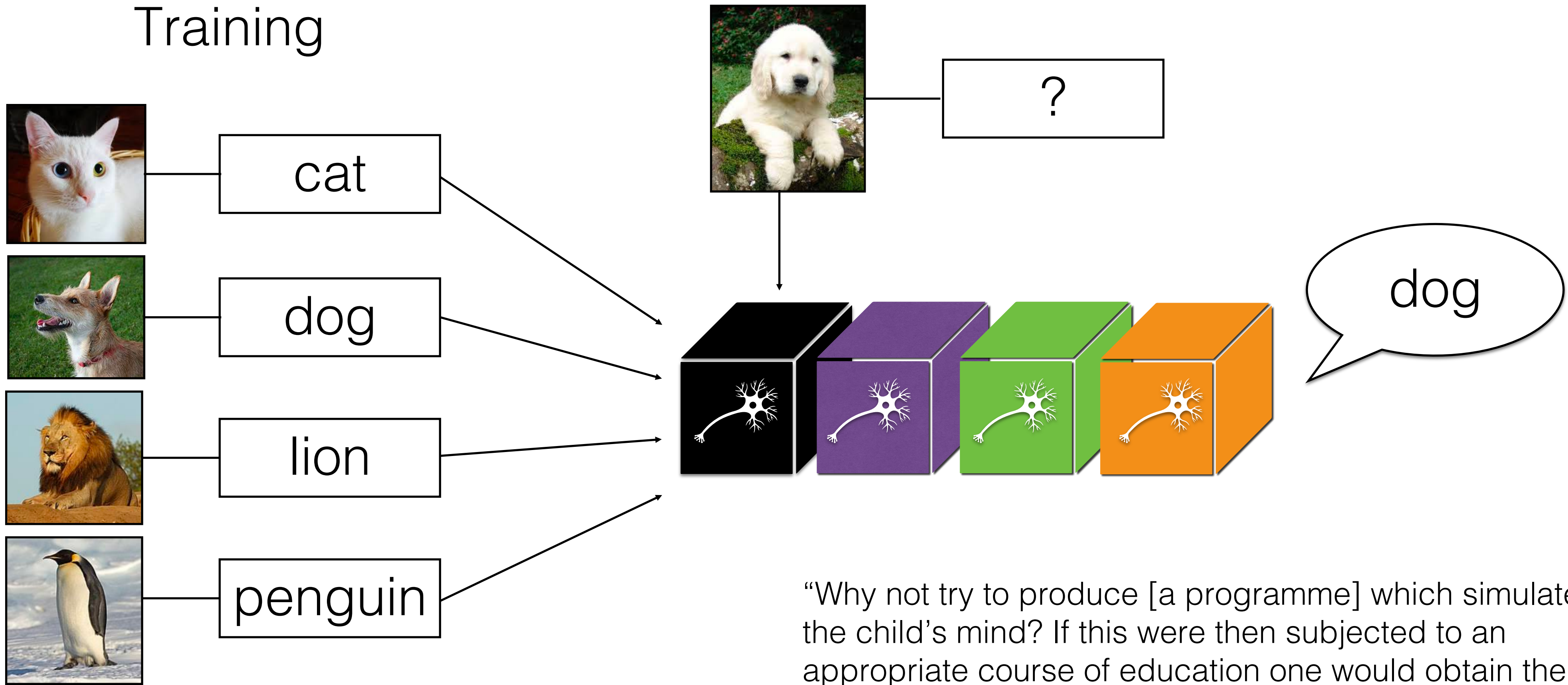

▲ An computer that was taught to distinguish malignant moles from benign ones outperformed dermatologists. Photograph: Dan Himbrechts/AAP

The Guardian, May 29th 2018
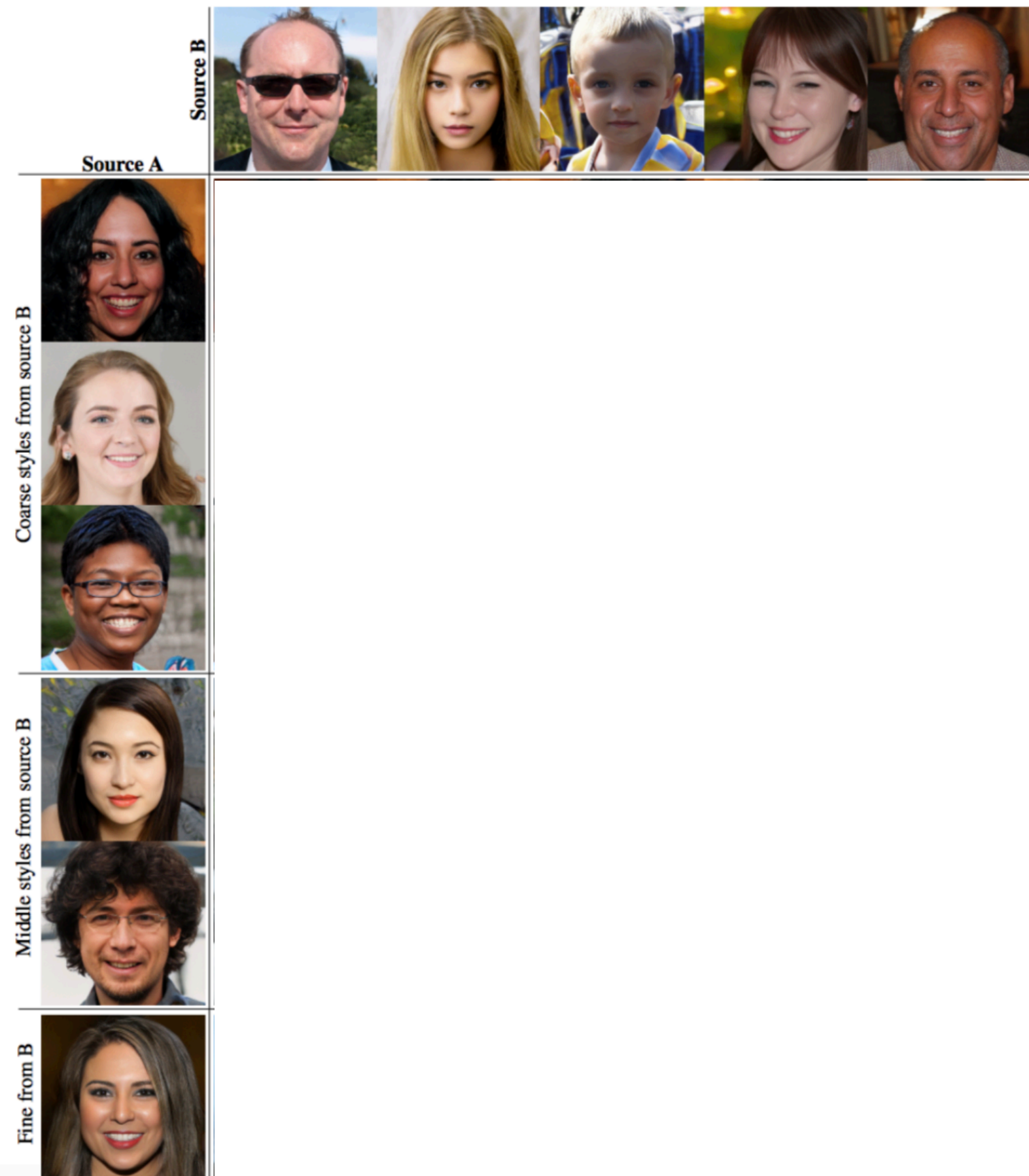
How Does Machine Learning* Work?

Training

cat

dog

lion

penguin

+ a few more millions…

?

dog

"Why not try to produce [a programme] which simulates the child's mind? If this were then subjected to an appropriate course of education one would obtain the adult brain"
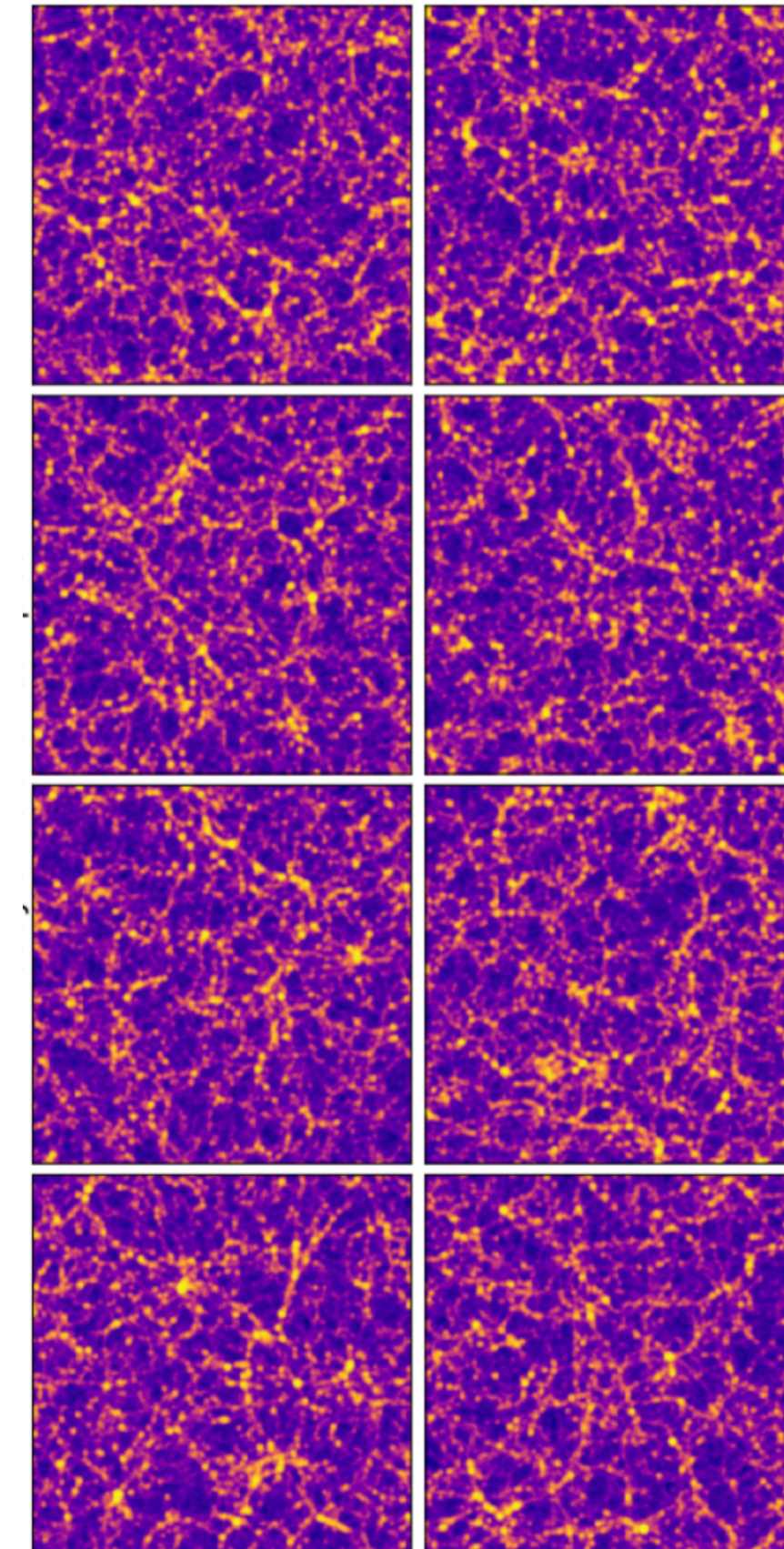
– Alan Turing (1950)

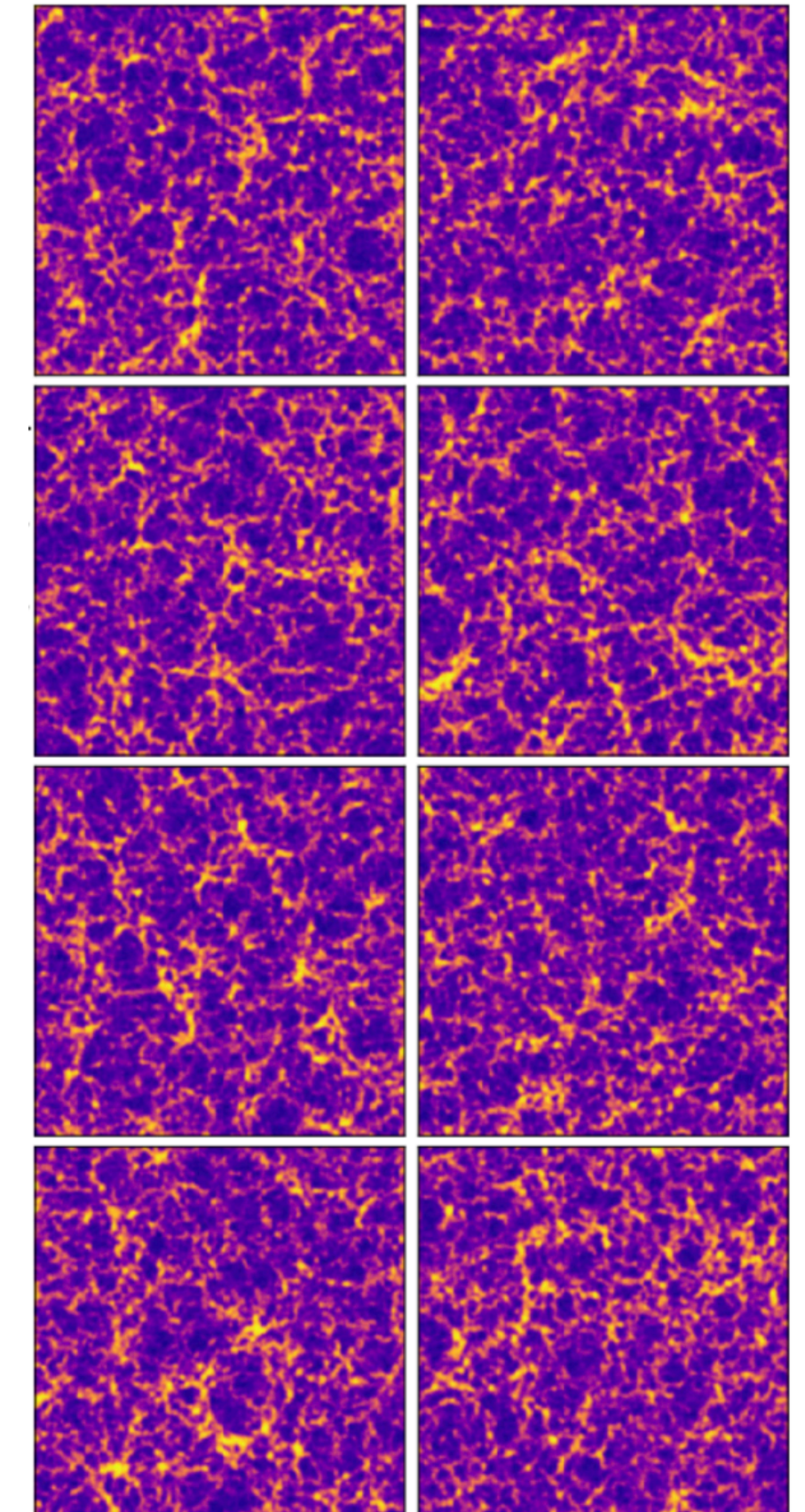* *Supervised* machine learning; there are many other techniques.

Credit: O'Reilly Media

Dark Matter Simulation
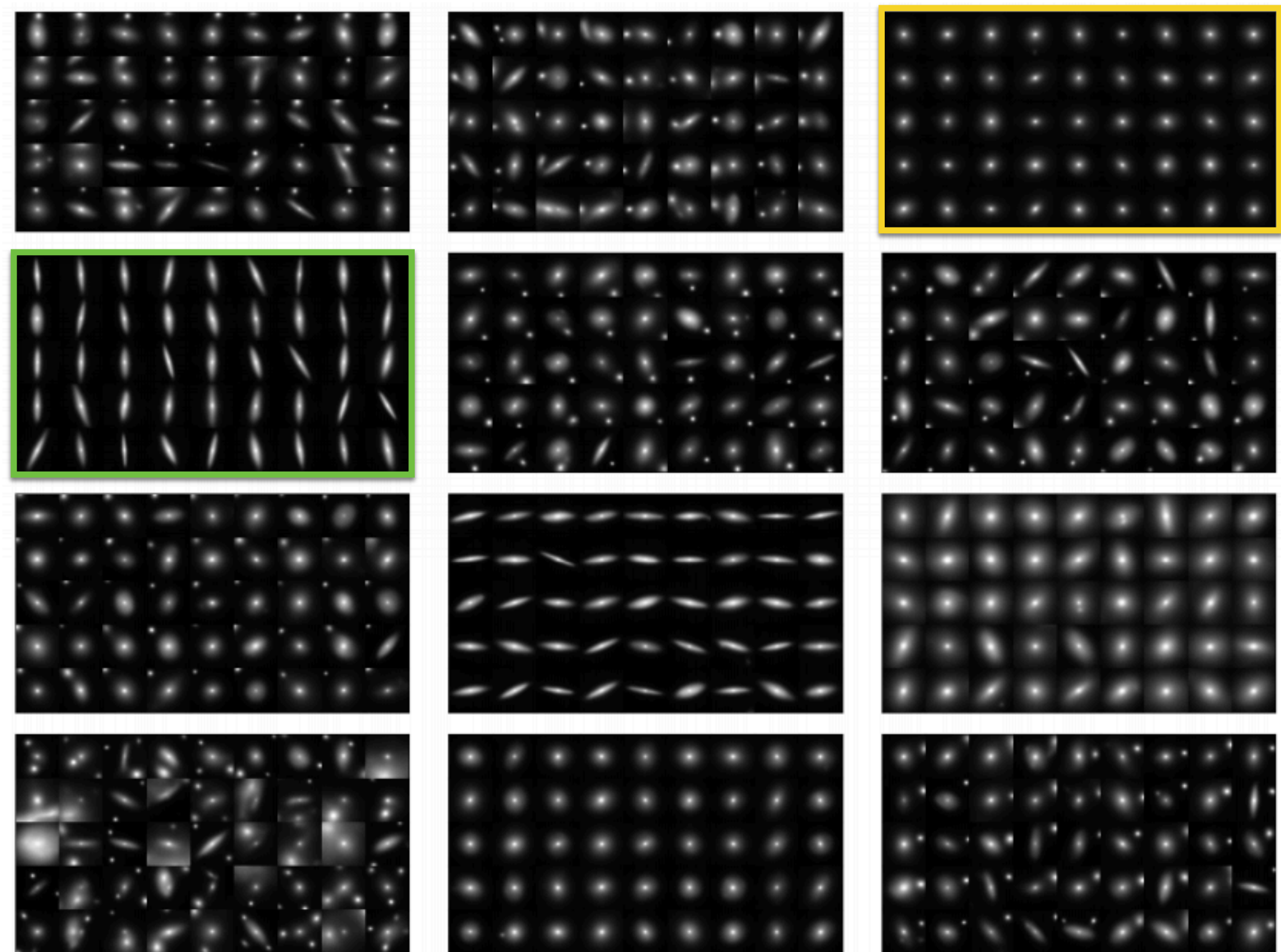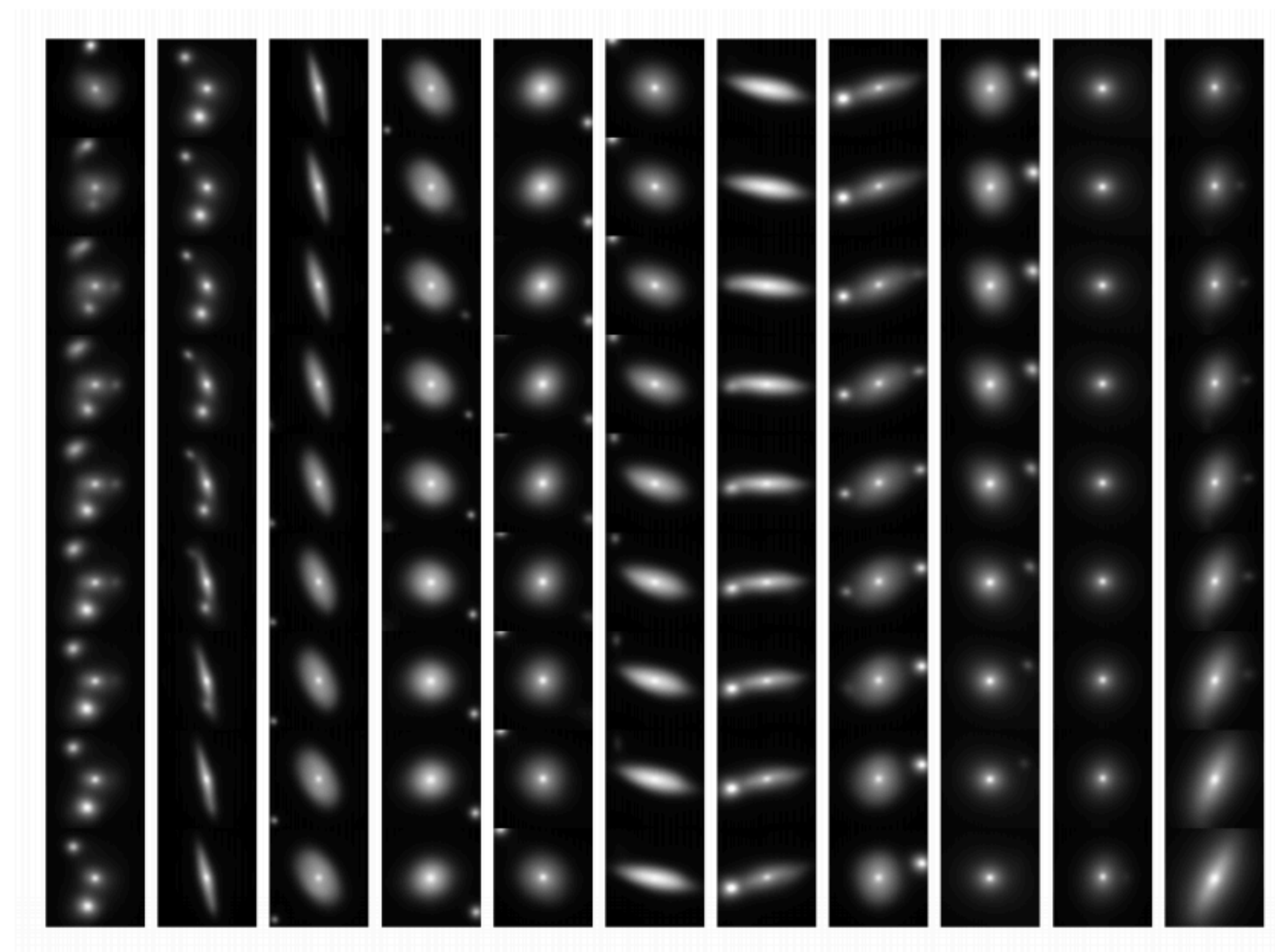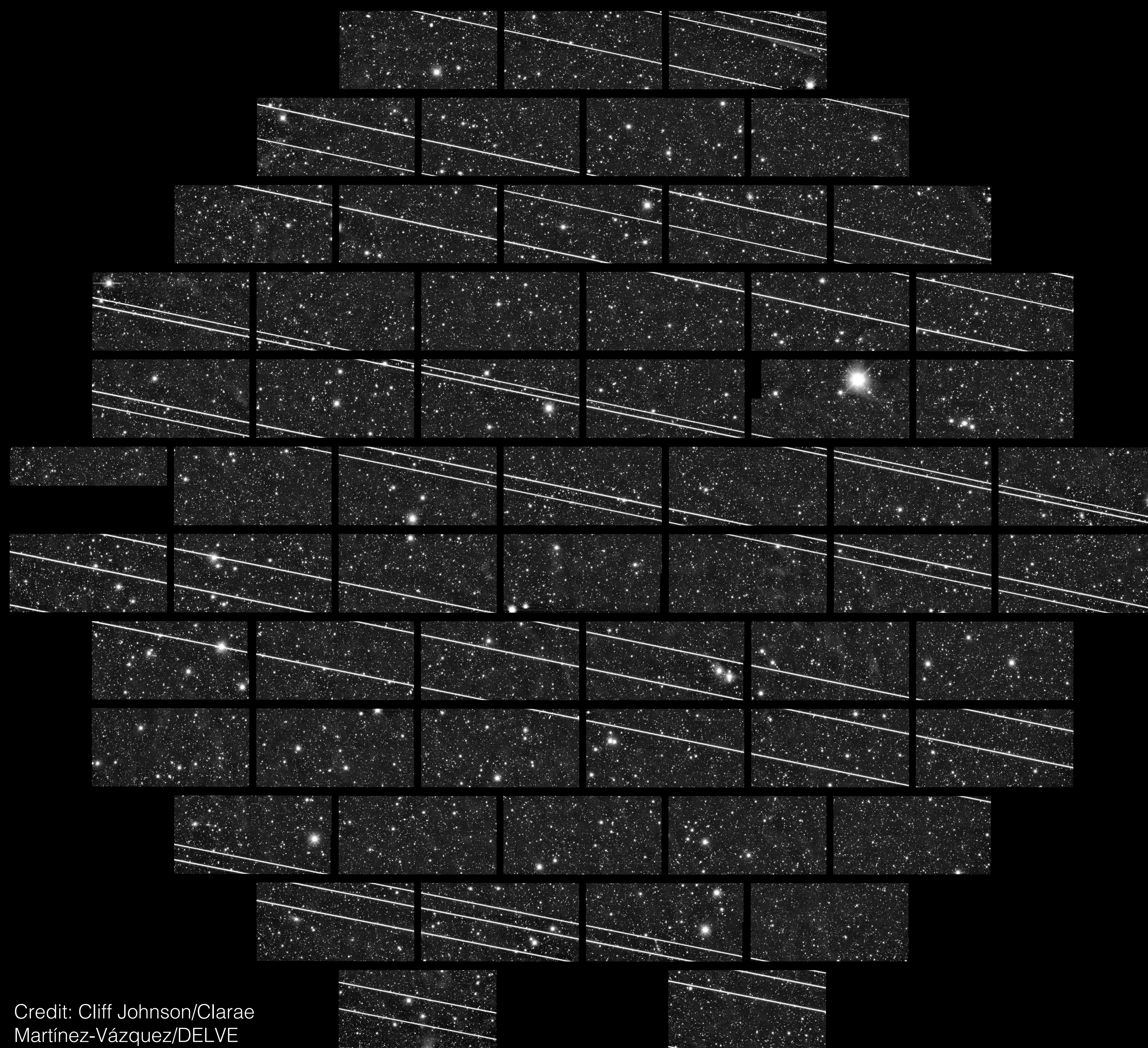
Machine Learning "Guess"

Perroudin et al (2019)

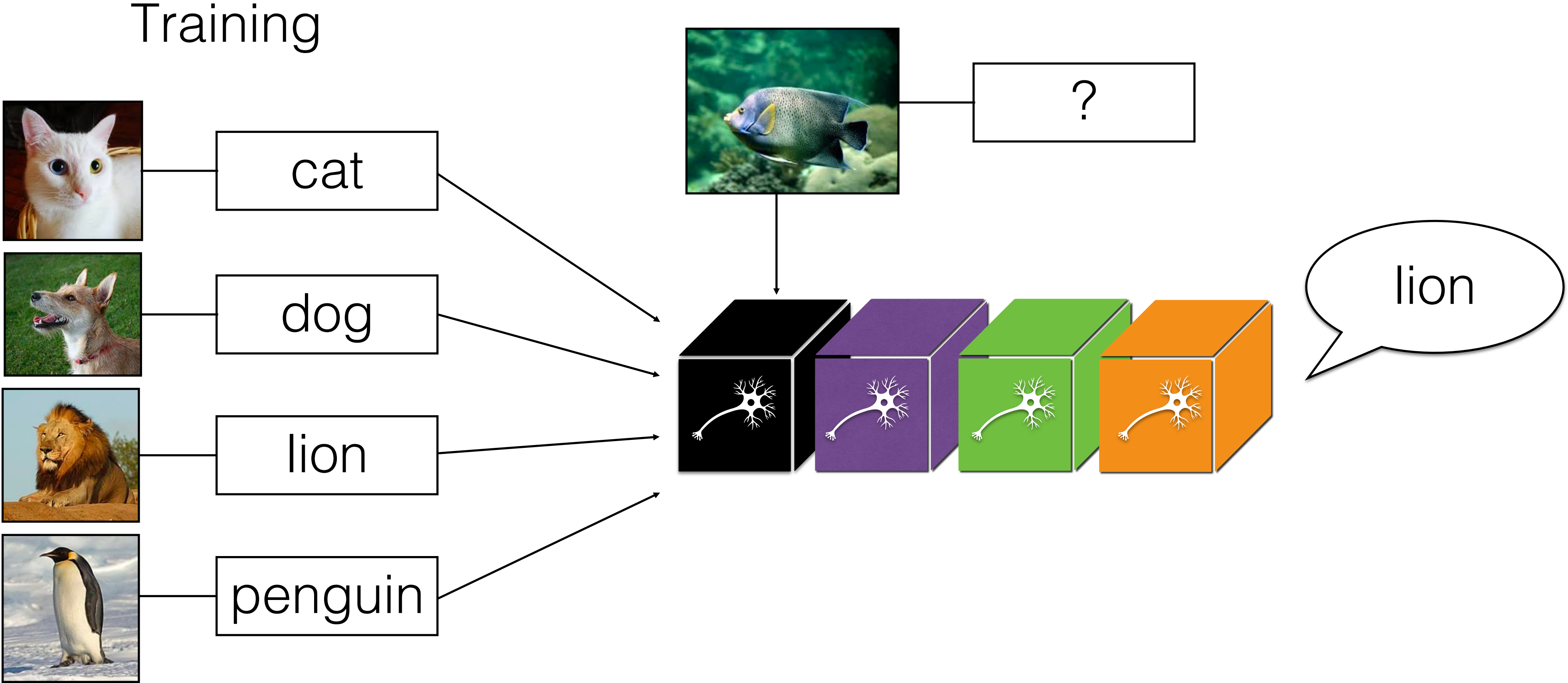# Grouping galaxies by shape without human input
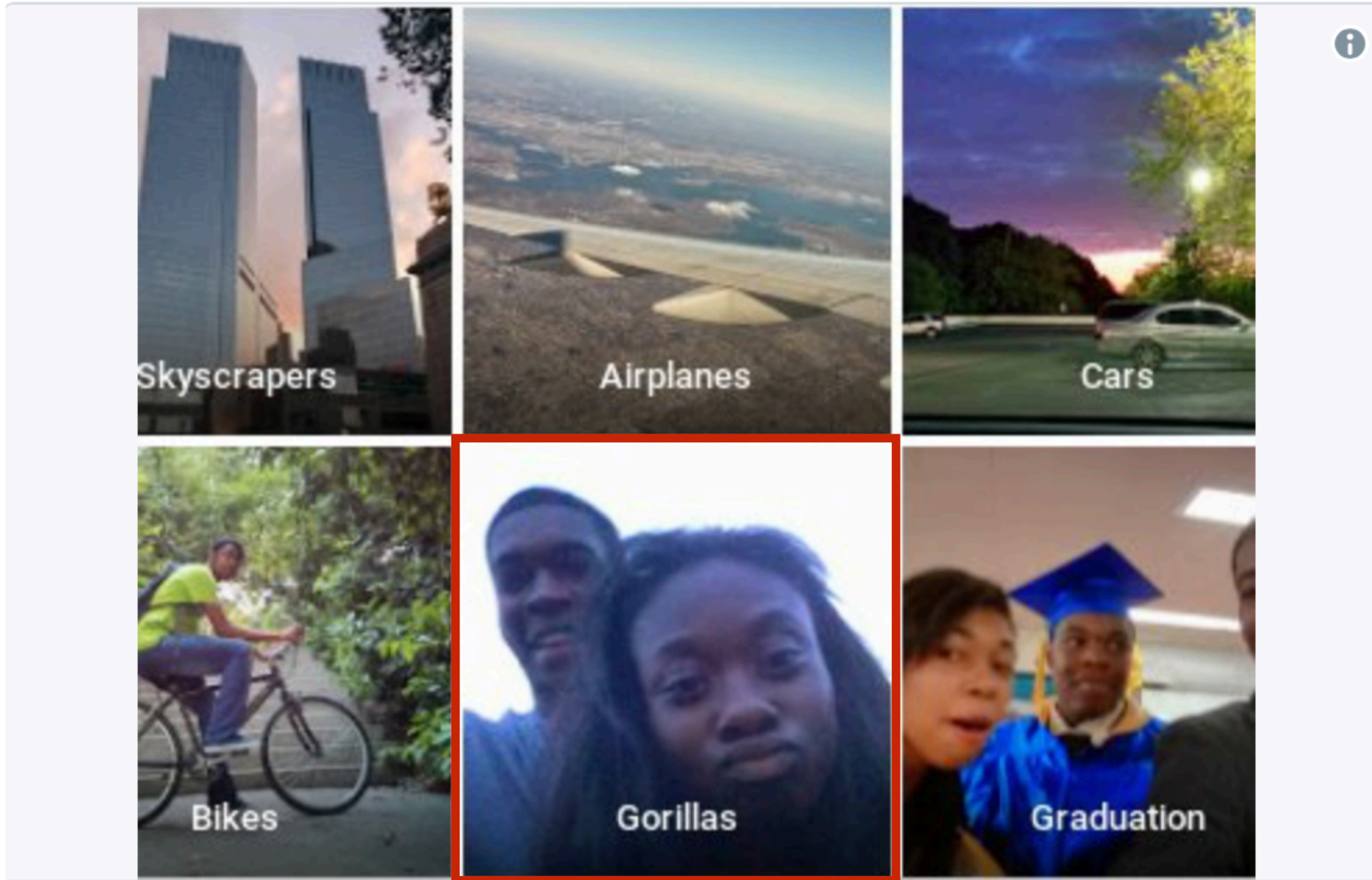

Spindler et al (2020)

Generating synthetic galaxies

Credit: Cliff Johnson/Clarae
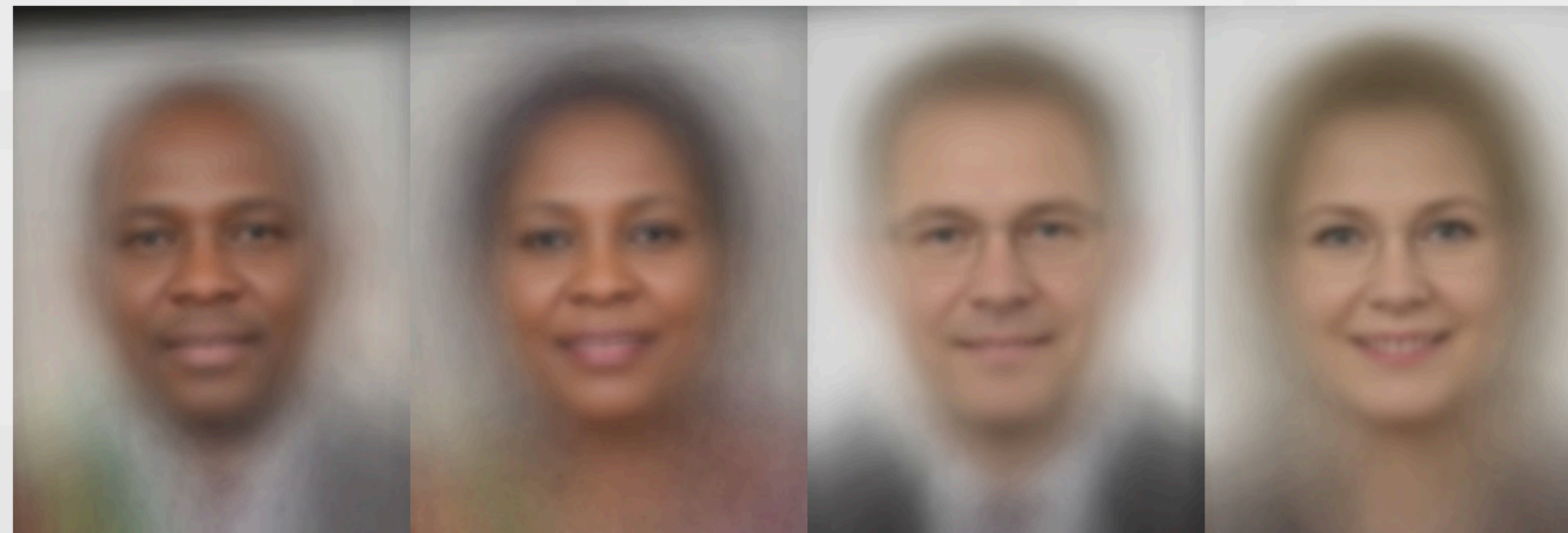Martínez-Vázquez/DELVE

The Limits of Machine Learning

2015

Jacky lives on @jalcine@playvicious.social now.
@jackyalcine

2019

Gender Shades (MIT Media Lab, 2019)

Gender Classifier	Darker Male	Darker Female	Lighter Male	Lighter Female	Largest Gap
Microsoft	94.0%	79.2%	100%	98.3%	20.8%
FACE++	99.3%	65.5%	99.2%	94.0%	33.8%
IBM	88.0%	65.3%	99.7%	92.9%	34.4%

Poor accuracy in facial recognition for dark skinned females

2018

TOM SIMONITE   BUSINESS   01.11.2018 07:00 AM

When It Comes to Gorillas, Google Photos Remains Blind

Google promised a fix after its photo-categorization software labeled black people as gorillas in 2015. More than two years later, it hasn't found one.

"Our findings suggest that if we build an intelligent system that learns enough about the properties of language to be able to understand and produce it, in the process it will also acquire historical cultural associations, some of which can be objectionable."

Caliskan et al., Science 356, 183–186 (2017)

De-biasing AI: a Cosmological Solution

Imperial College London

HEALTH
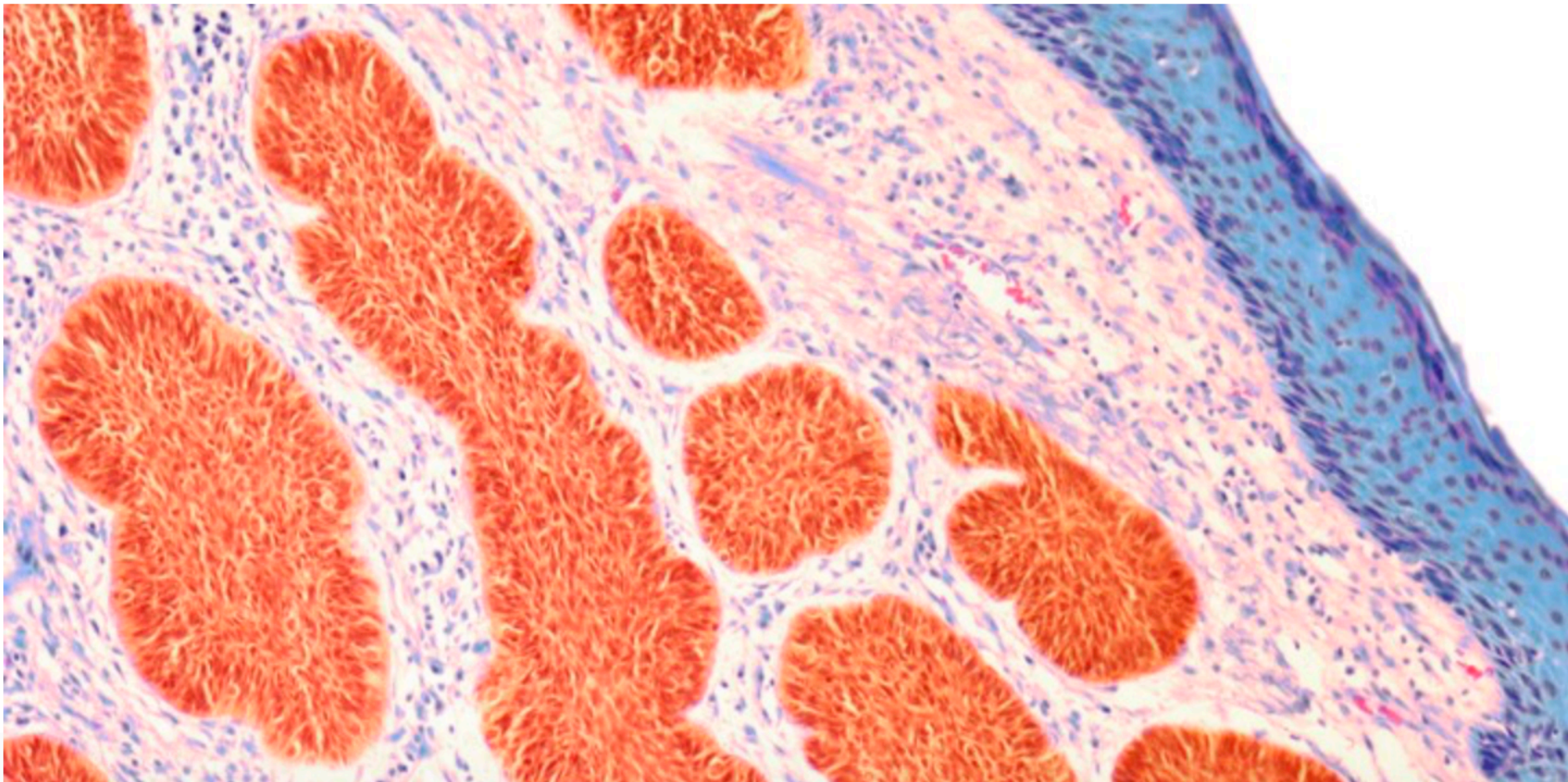
AI-Driven Dermatology Could Leave Dark-Skinned Patients Behind

Machine learning has the potential to save thousands of people from skin cancer each year—while putting others at greater risk.
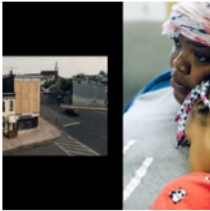
ANGELA LASHBROOK AUG 16, 2018
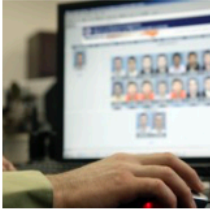
MORE STORIES

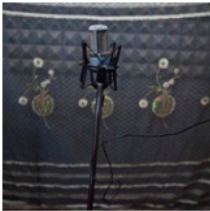**Being Black in America Can Be Hazardous to Your Health**
OLGA KHAZAN

Facial-Recognition Software Might Have a Racial Bias Problem
CLARE GARVIE AND JONATHAN FRANKLE

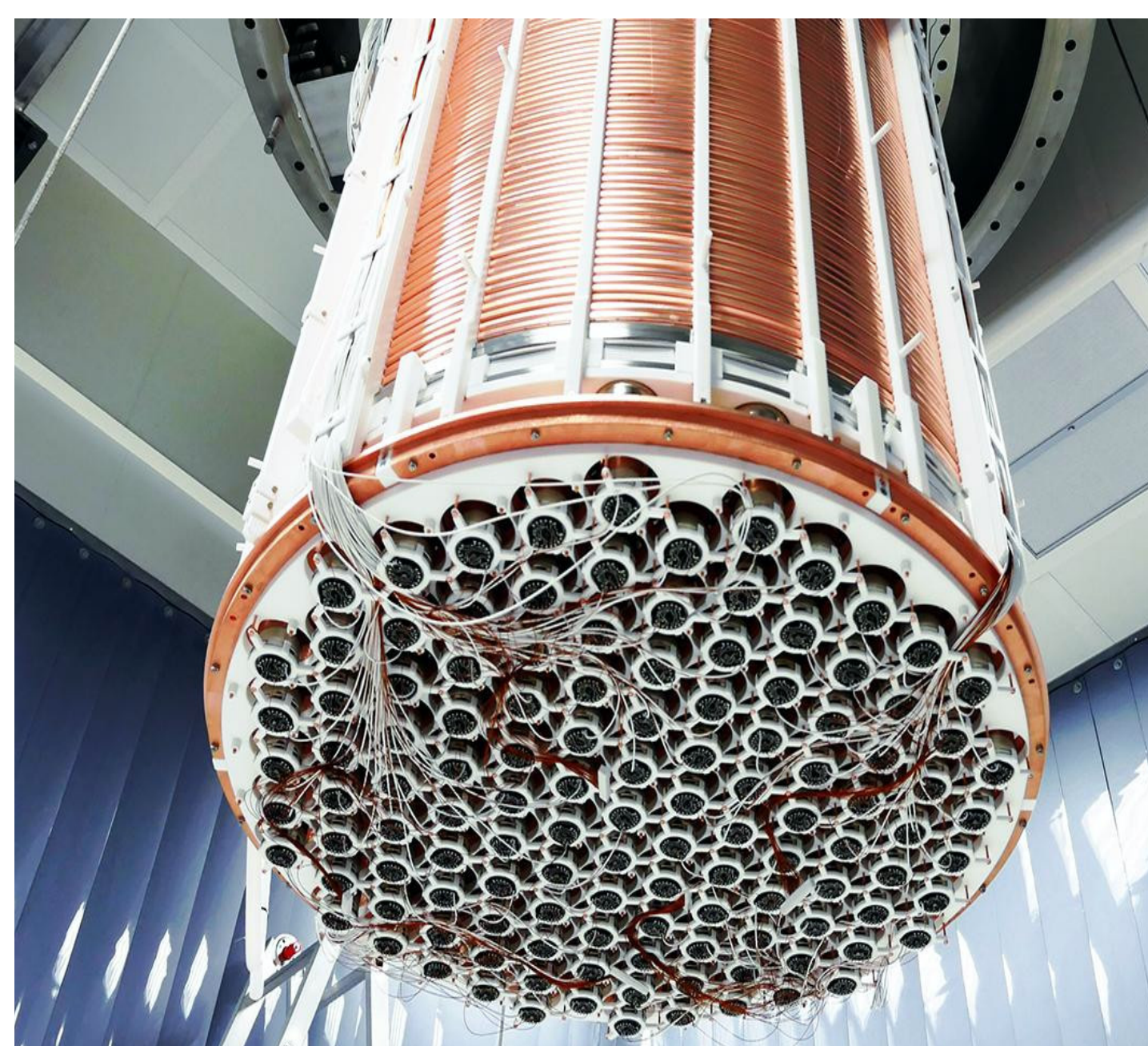**How Artificial Intelligence Could Help Diagnose Mental Disorders**
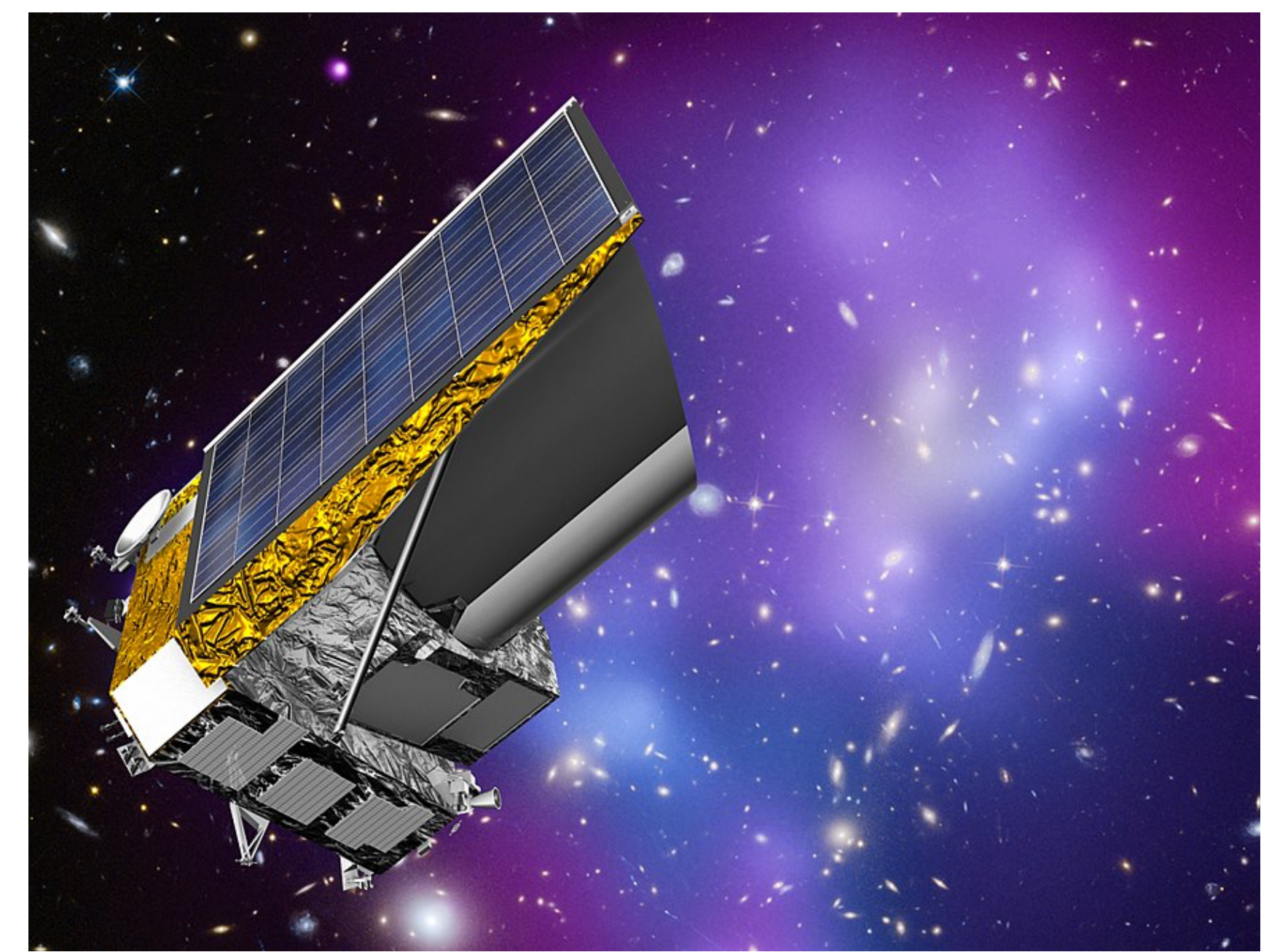JOSEPH FRANKEL

High z SN Team/NASA/HST

Similar (if less societally damaging) biases present in our astrophysical data

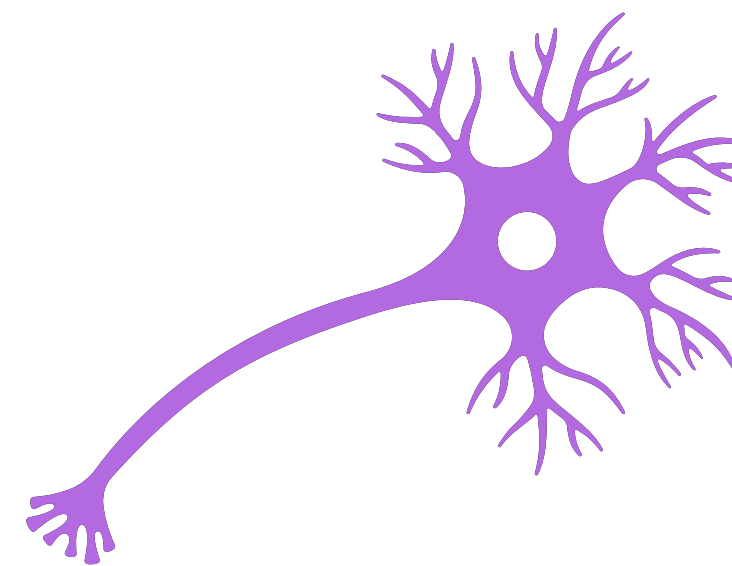Solutions are equally applicable

Revsbech, Trotta & van Dyk (2018)

The Vera Rubin observatory

The XENONnT dark matter detector

The Euclid space telescope

AI and Machine Learning

Thank you!

🐦 @R_Trotta

www.robertotrotta.com

[Im