

Title: Why we have not discovered dark matter: A theorist's apology | Public Lecture

Speakers: Flip Tanedo

Date: February 28, 2024 - 7:00 PM

URL: <https://pirsa.org/24020103>

Abstract: A preponderance of astronomical evidence suggests that the galaxy is filled with dark matter. Despite knowing remarkably little about what this dark matter is, we expect that it is not composed of ordinary matter. Though we have spent 30 years expecting that it may be related to pressing open problems in fundamental physics, a heroic experimental program has shown that dark matter is even more elusive than we had initially imagined. On February 28, University of California Riverside faculty member Flip Tanedo will discuss how we got things so wrong, why we can be optimistic about the future, and what it means to "do physics" on something where the only thing we really know is that it probably exists. Flip Tanedo spends his time thinking about dark matter. He grew up in Los Angeles and fell in love with physics after reading *The Physics of Star Trek*. This carried into degrees in mathematics and physics at Stanford, Cambridge, Durham, and a Ph.D at Cornell. After a postdoc at UC Irvine, he is currently faculty at UC Riverside where he is often covered in a layer of chalk dust.

Why we have *not* [yet?] discovered dark matter

a theoretical physicist's apology

Flip Tanedo



28 February 2024



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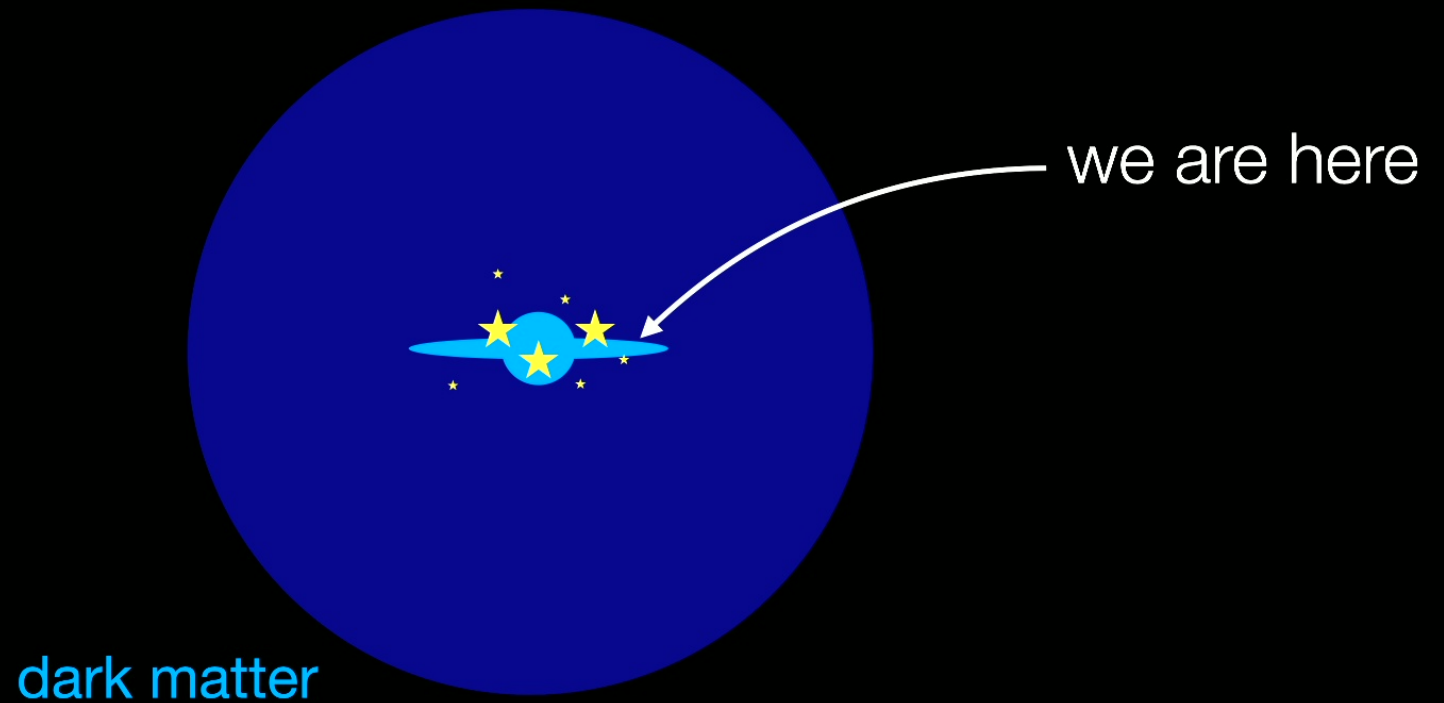
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A realistic picture of **dark matter**

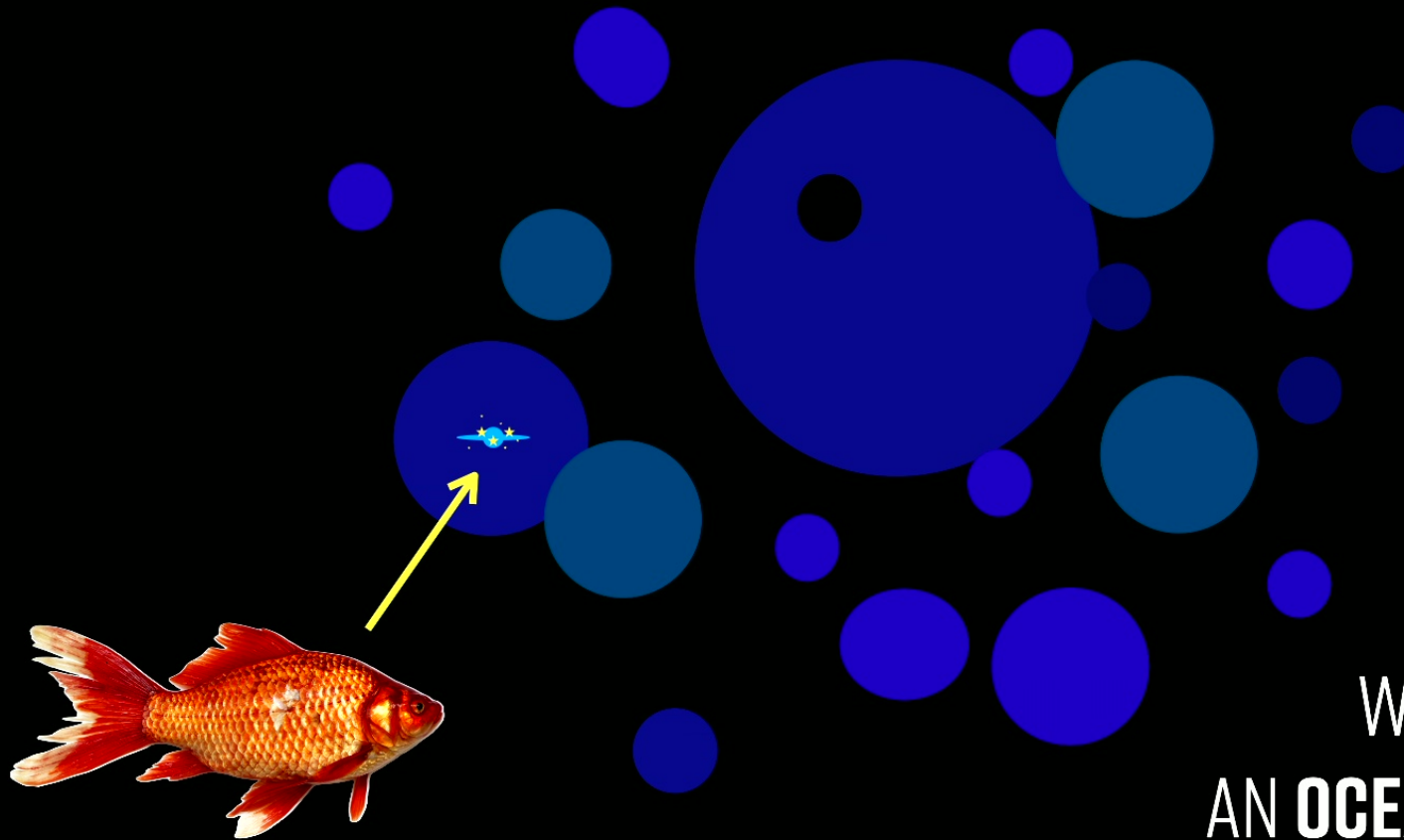
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A cartoon picture of **dark matter**



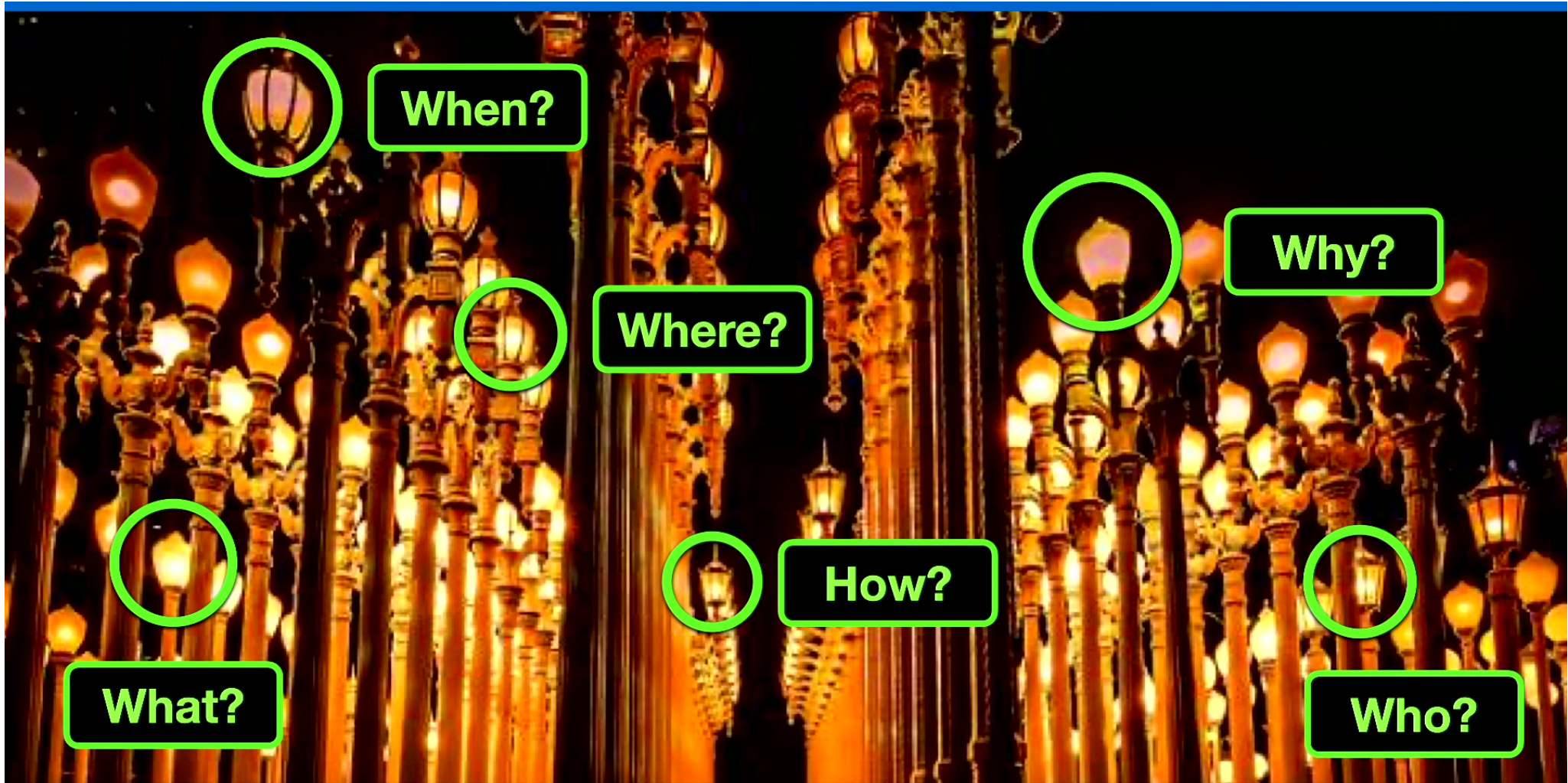
A cartoon picture of **dark matter**, zoomed out



WE ARE SWIMMING IN
AN **OCEAN** OF DARK MATTER

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When?

Why?

Where?

How?

What?

Who?

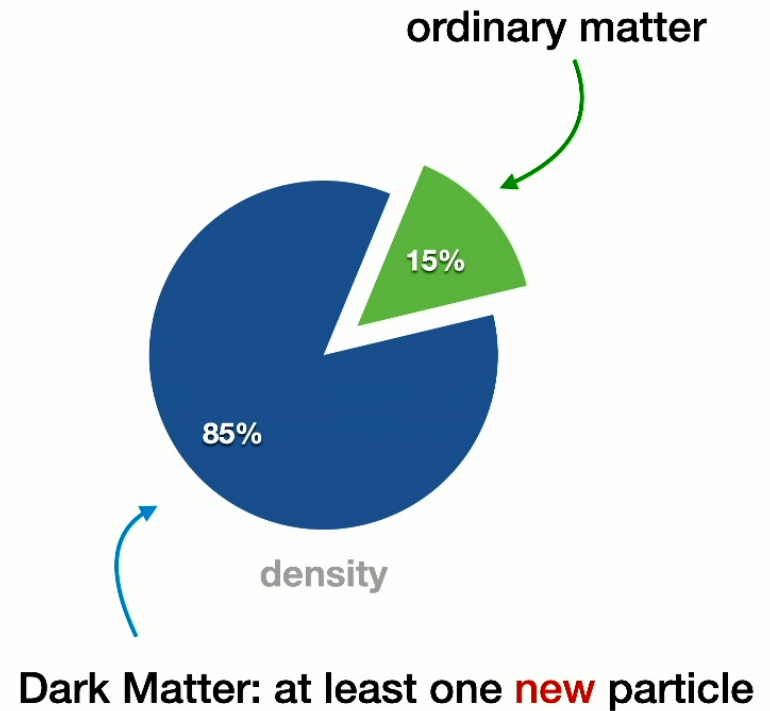
Chris Burden, Urban Light, 2008, Los Angeles County Museum of Art; photo courtesy of @neohumanity via Instagram

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Assumption for this talk: dark matter exists

And we know roughly how much there is



Cham & Whiteson, *We Have No Idea*

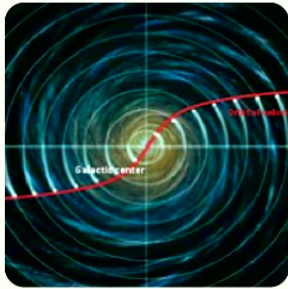
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Astronomy and cosmology: dark matter exists

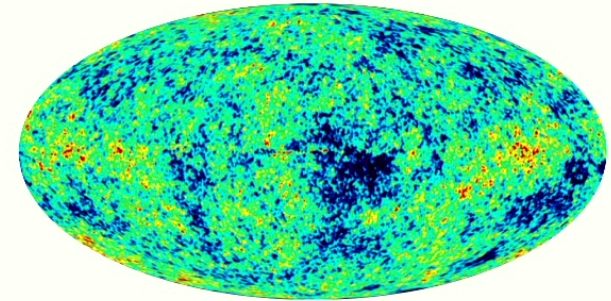
And we know roughly how much there is



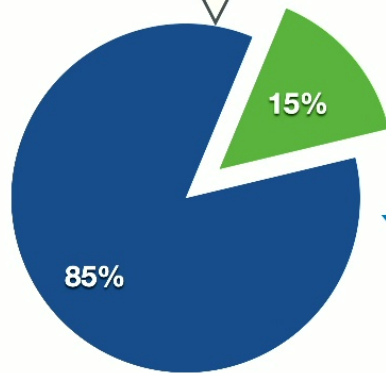
ROTATION CURVES



GRAVITATIONAL LENSING



COSMIC MICROWAVE BACKGROUND



Ordinary Matter: theory is **not** complete

Dark Matter: at least one **new** particle

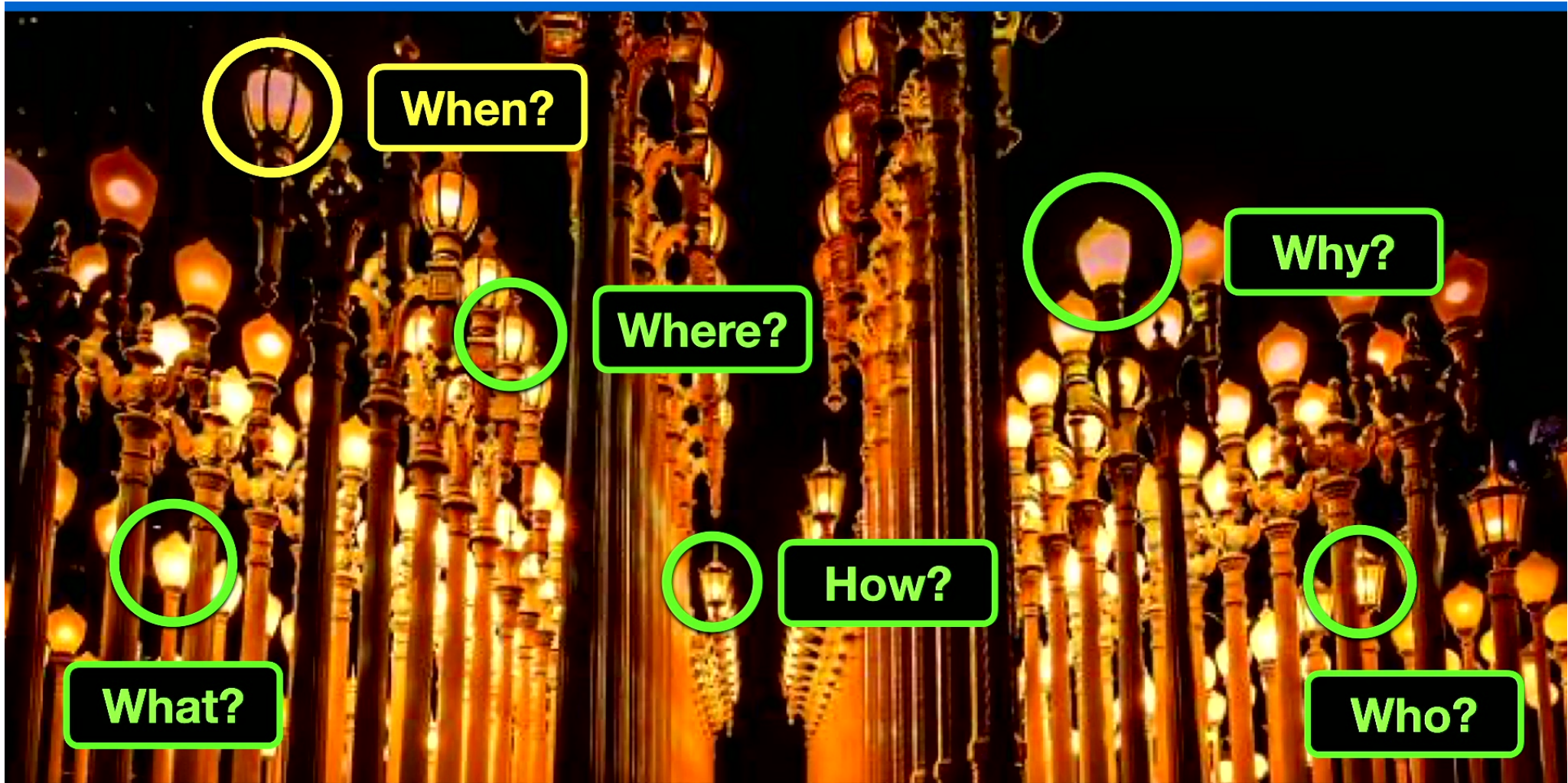
In fact, dark matter is a key reason **why our universe even has galaxies** (like our own!)

Images: Jeff Filippini (Berkeley Cosmology 2005), NASA APOD 2006, NASA WMAP

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Chris Burden, Urban Light, 2008, Los Angeles County Museum of Art; photo courtesy of @neohumanity via Instagram

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A very biased, semi-accurate, recent history

PARTICLE



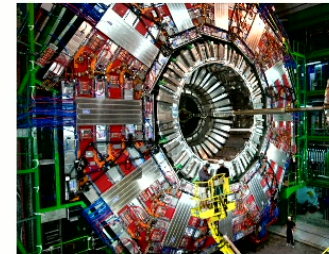
Photo from the Nobel Foundation archive.
Sheldon Lee Glashow
Prize share: 1/3



Photo from the Nobel Foundation archive.
Abdus Salam
Prize share: 1/3



Photo from the Nobel Foundation archive.
Steven Weinberg
Prize share: 1/3

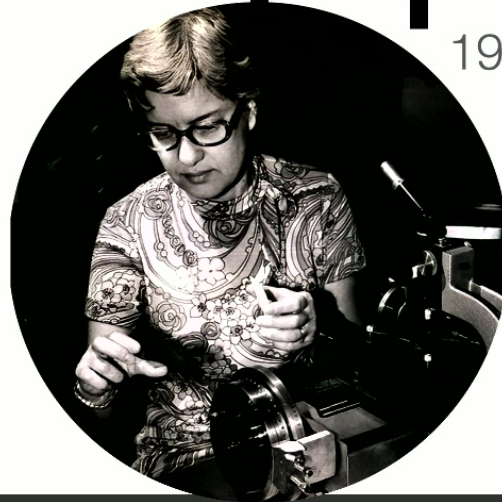


1930s



Fritz Zwicky, Vera Rubin via Wikipedia

ASTRO



1970s

2000s

2010s



Nobel Foundations Archive; Maximilien Brice, CERN via National Geographic (May 2012); Cham & Whiteson *We Have No Idea*

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Particle Physics, circa 1990s

fundamental forces

matter particles

Field	Spin	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$
Q	$1/2$	\square	\square	$1/6$
\bar{u}	$1/2$	$\bar{\square}$	$\mathbb{1}$	$-2/3$
\bar{d}	$1/2$	$\bar{\square}$	$\mathbb{1}$	$1/3$
L	$1/2$	$\mathbb{1}$	\square	$-1/2$
e	$1/2$	$\mathbb{1}$	$\mathbb{1}$	-1
$H ?$	0	$\mathbb{1}$	\square	$1/2$

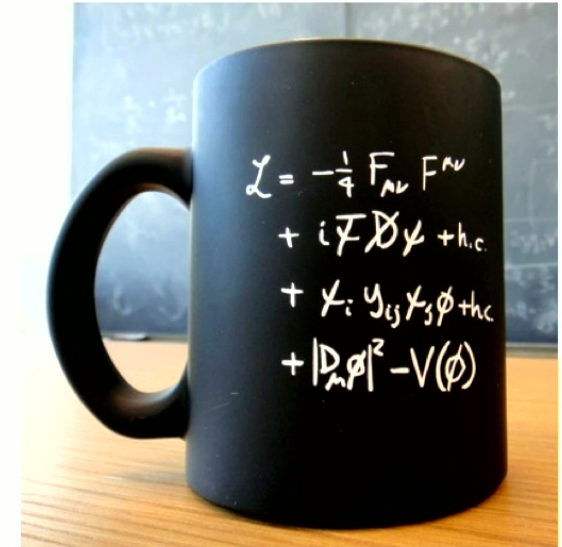


Image: Tanedo; mug from CERN



Conservative option: Higgs boson
... but cannot explain why the mass is so light

Cham & Whiteson *We Have No Idea.*

Two Big Puzzles in Particle Physics

m_h ?

Missing Mass



Weakly Interacting Massive Particle

... and now a *brief* summary of **the WIMP** and its relation to ideas in theoretical particle physics from the 1980s to 2010s

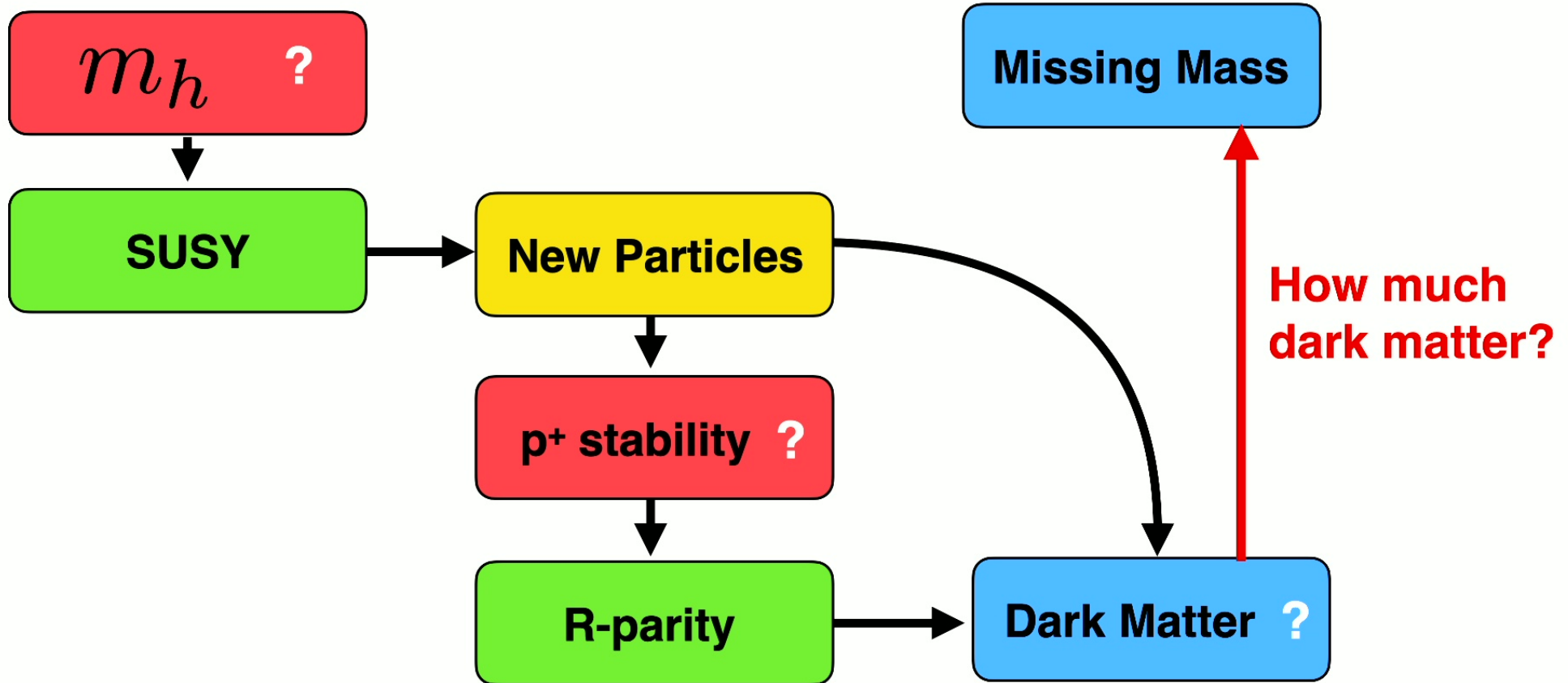
Images: Cham and Whiteson, *We Have No Idea*

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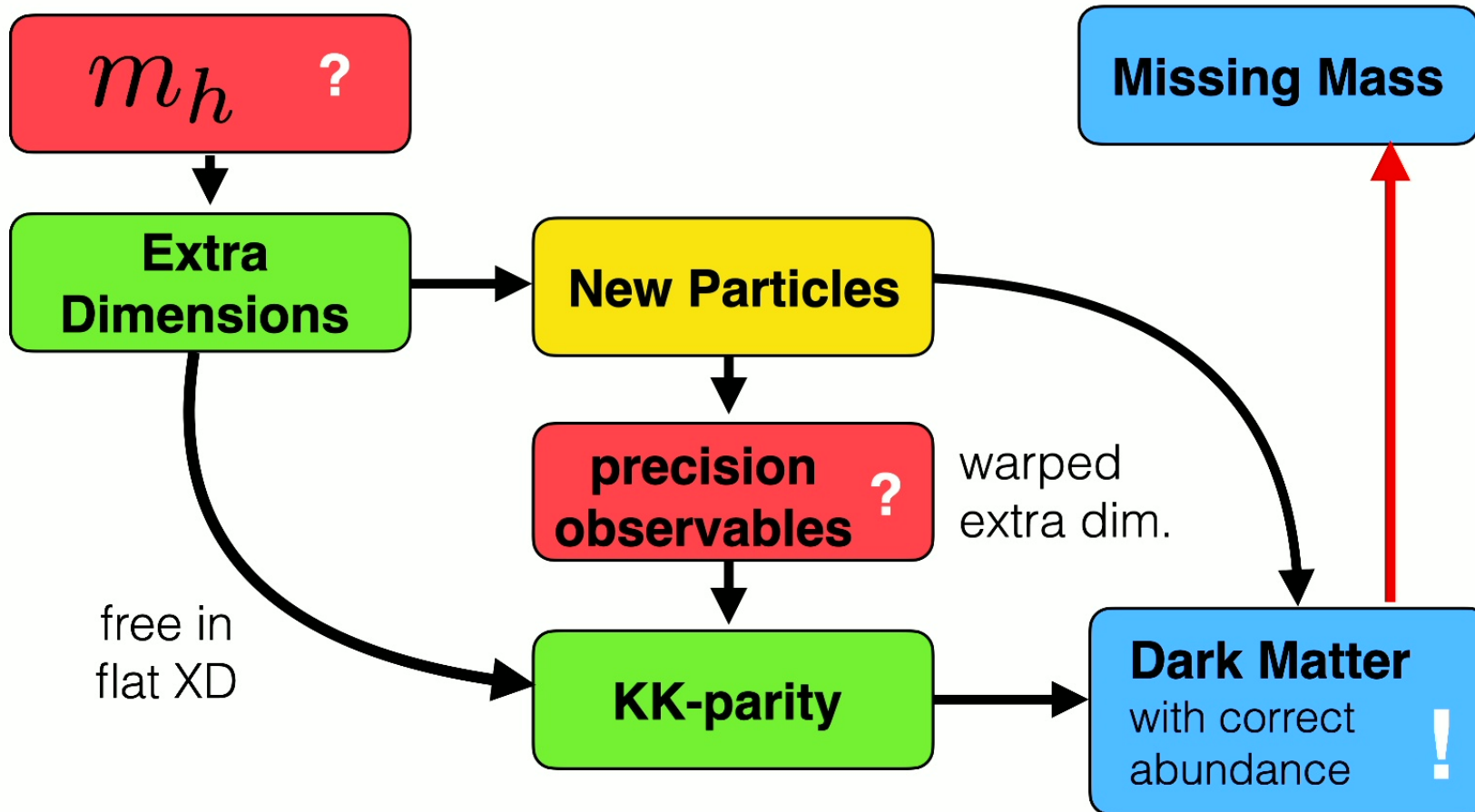
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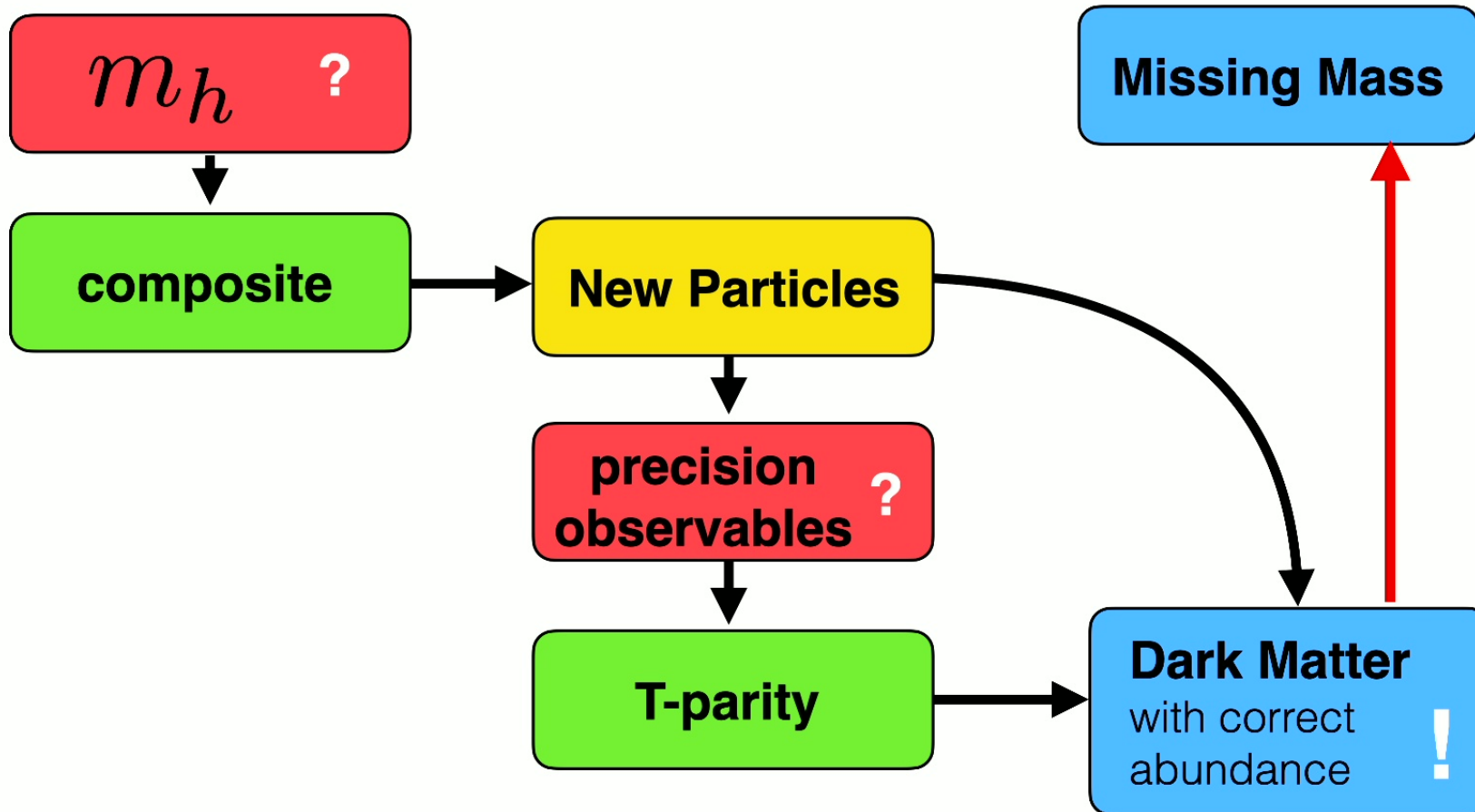
The story of supersymmetry



The story of extra dimensions



The story of **compositeness**

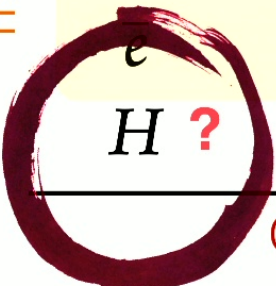


Particle Physics, circa 1990s

fundamental forces

matter particles

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$H ?$	0	$\mathbb{1}$	\square	$1/2$



Conservative option: Higgs boson
... but cannot explain why the mass is so light

Build a collider! It's a no-lose scenario.
Even if it is *just* the Higgs, then we should also see lots of new particles ...



Particle Physicists



Cham and Whiteson, *We Have No Idea*

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Physicists Find Elusive Particle Seen as Key to Universe

By DENNIS OVERBYE JULY 4, 2012



Scientists in Geneva on Wednesday applauded the discovery of a subatomic particle that looks like the Higgs boson.
Pool photo by Denis Balibouse

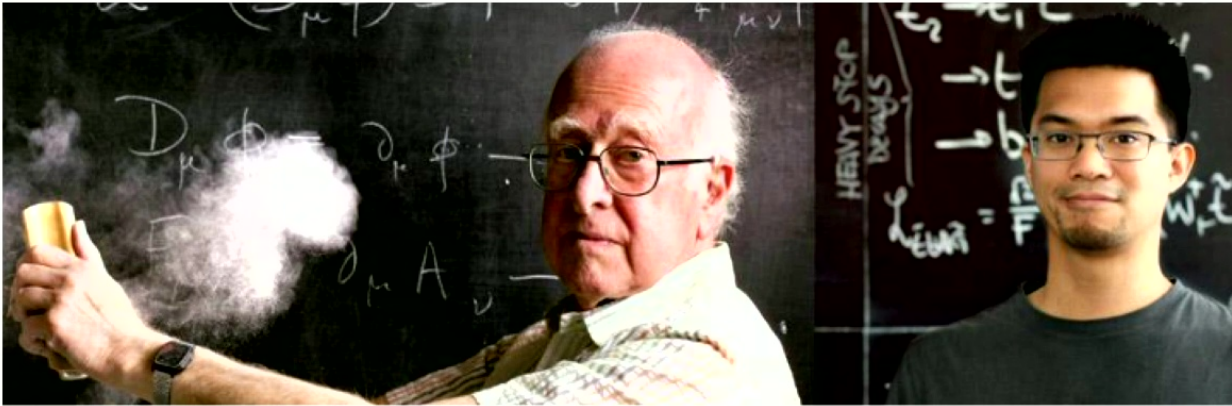
D. Overbye, New York Times, 4 July 2012

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A great love story



AFTER HIGGS In 1964, Peter Higgs (left) proposed the existence of a particle that is now named for him. Now young theorists like Flip Tanedo (right) wonder what's next.



Hard times for theorists in a post-Higgs world

The Large Hadron Collider's big success leaves no clear avenue for new physics

Supersymmetry a no-show

The long-accepted standard model may be extraordinarily successful, but that is not the case for other theoretical attempts to expand it and resolve its shortcomings. Tanedo has spent much of his time in graduate school working on supersymmetry, a set of theories positing that every fundamental subatomic particle has a heavier sibling called a superpartner.

Andrew Grant, Science News, June 2013; cartoons: Cham and Whiteson, *We Have No Idea*

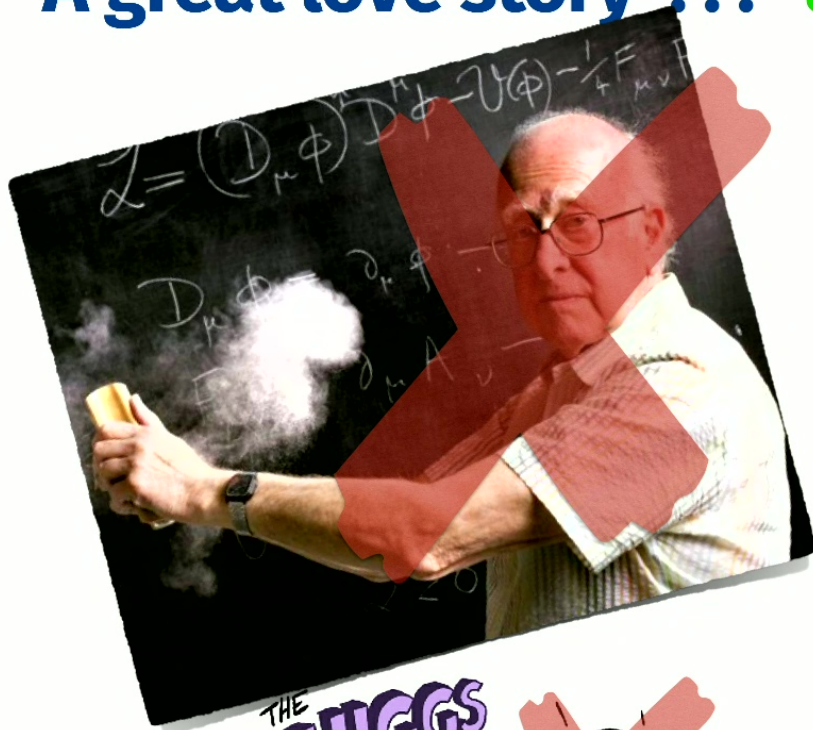
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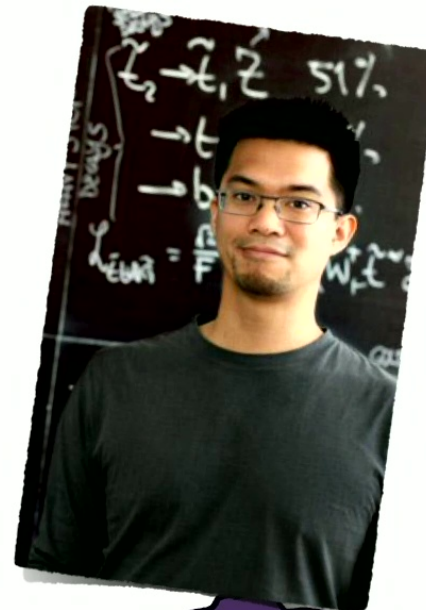
21

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A great love story ... and a break up



THE
HIGGS
BOSON



2013

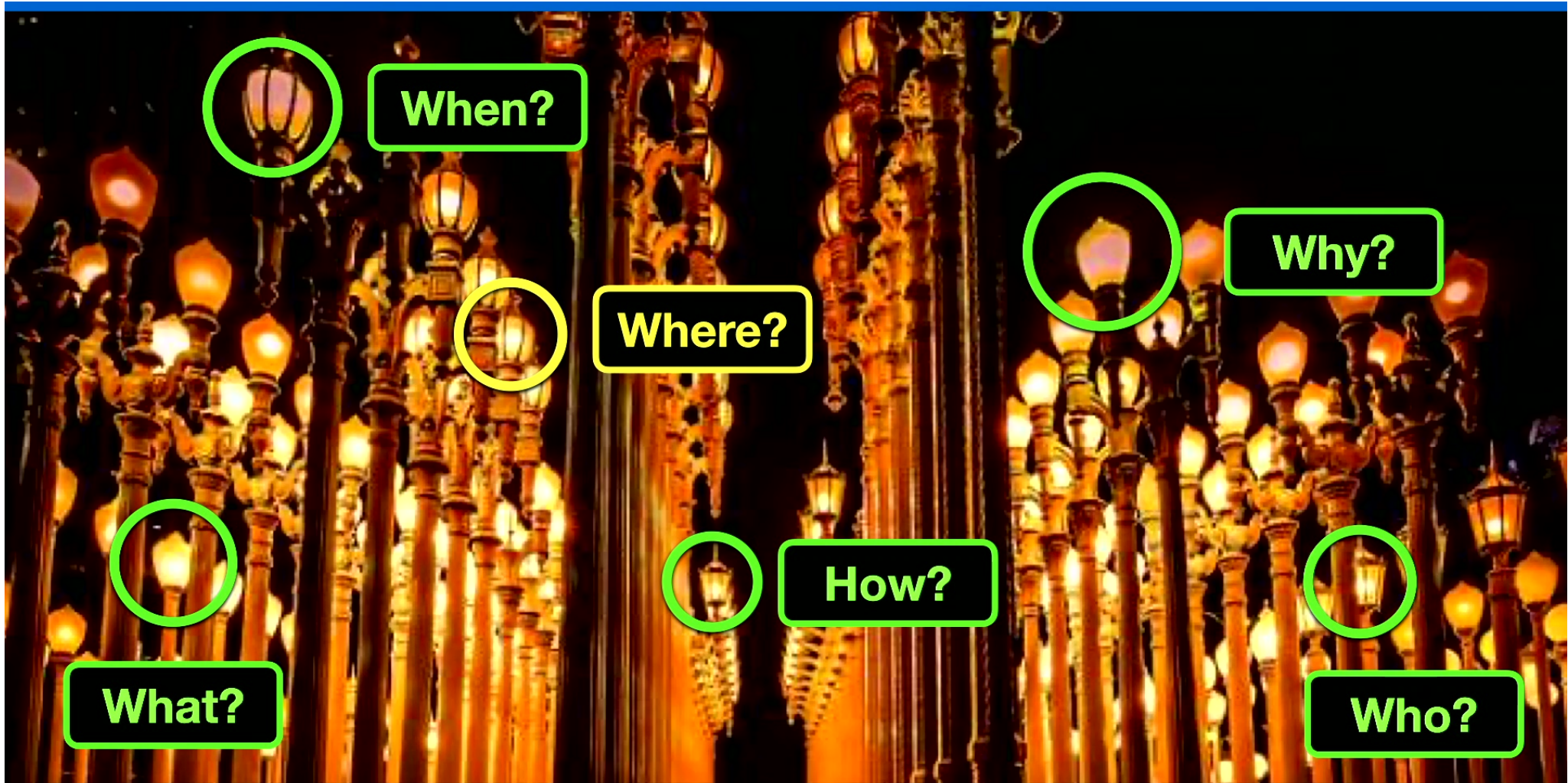
When I broke up with the Higgs and became a “dark matter theorist”

... with apologies to Andrew Grant, Science News, June 2013; cartoons: Cham and Whiteson, *We Have No Idea*

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When?

Why?

Where?

What?

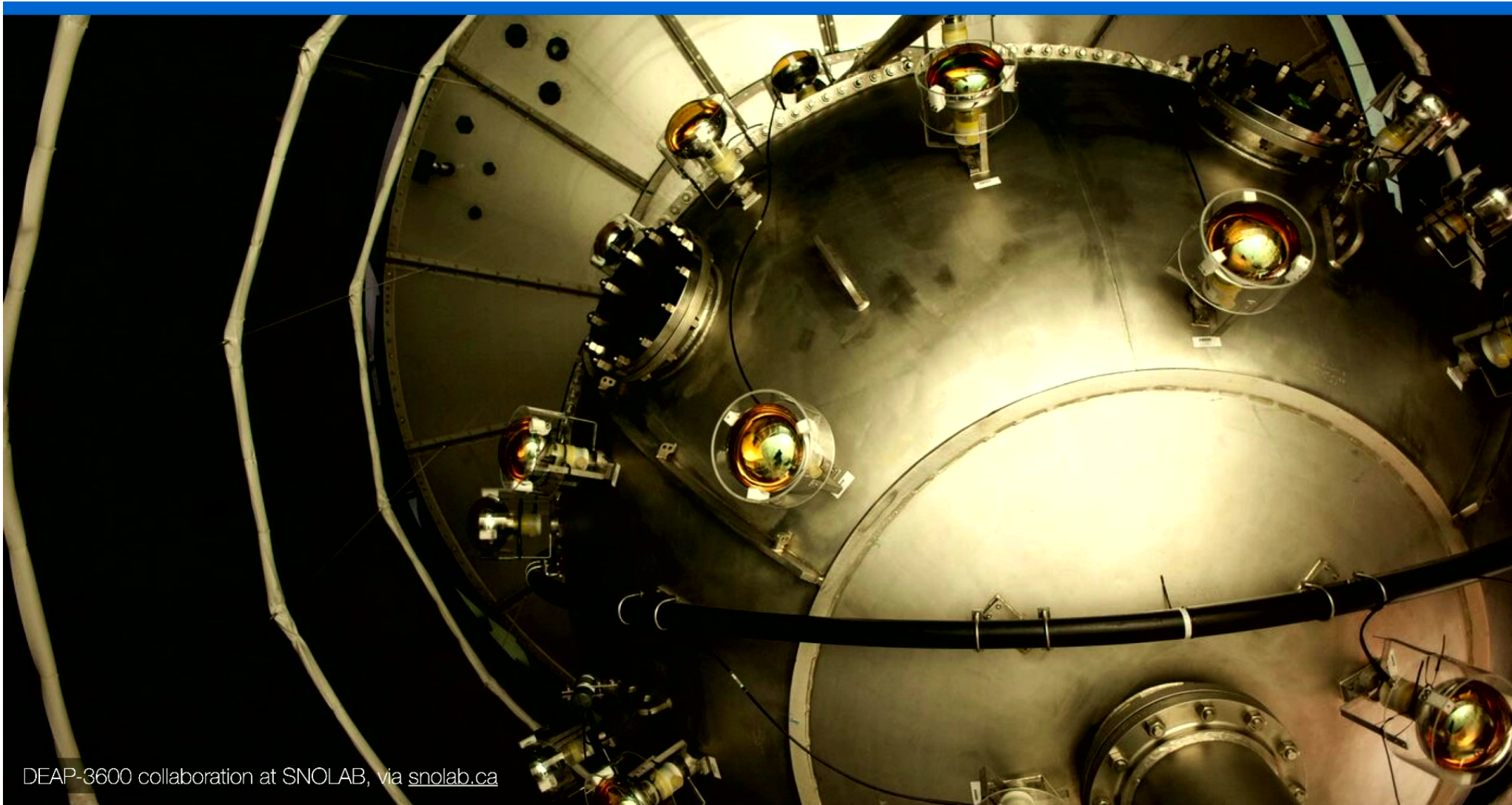
How?

Who?

Chris Burden, Urban Light, 2008, Los Angeles County Museum of Art; photo courtesy of @neohumanity via Instagram

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DEAP-3600 collaboration at SNOLAB, via snolab.ca

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Chilean Atacama CMB stage 4 site, Image: Debra Kellner cmb-s4.org

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Credit: Aurore Simonnet for the NANOGrav Collaboration

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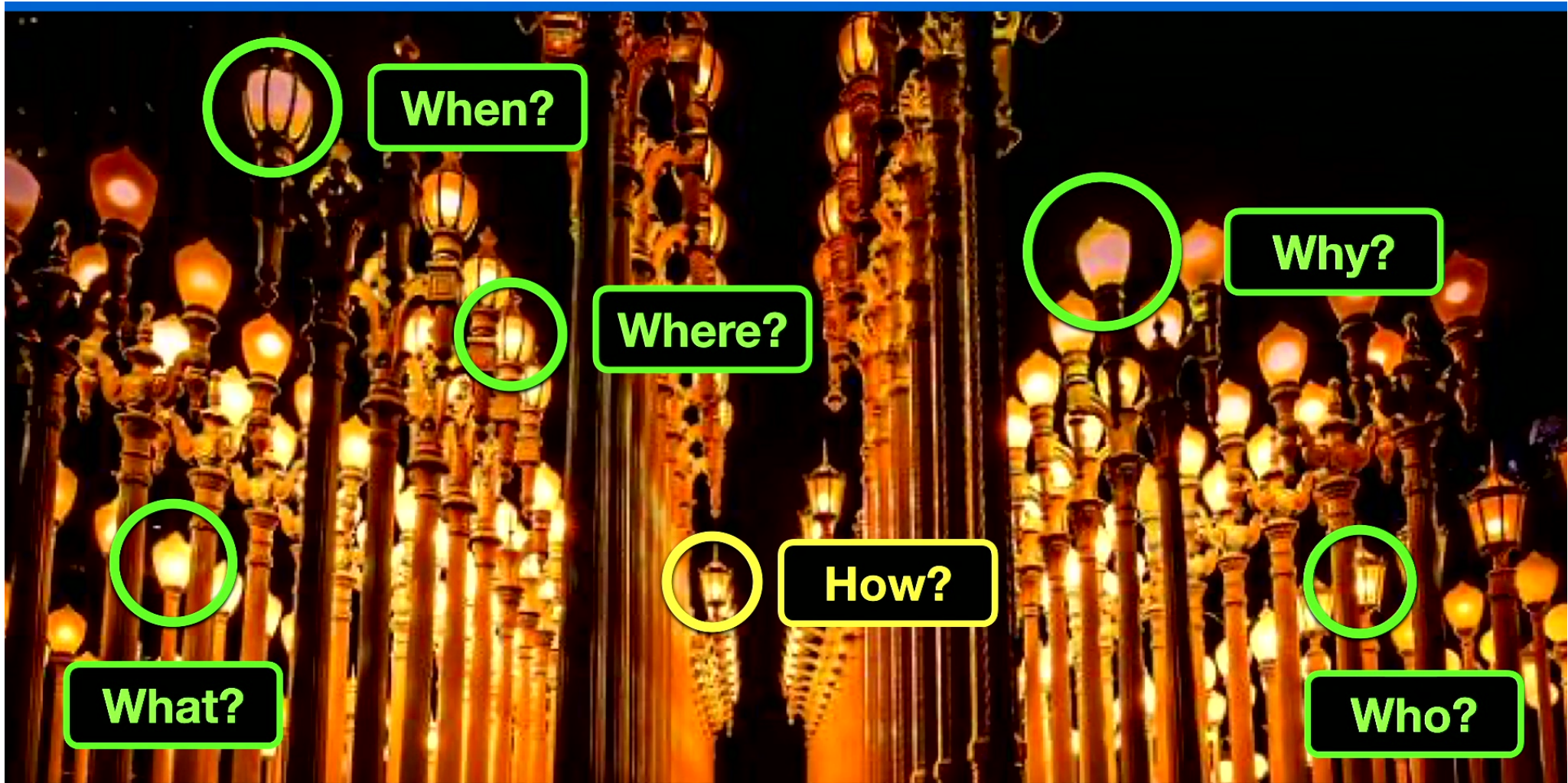
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snowmass21.org | usparticlephysics.org/2023-p5-report

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Chris Burden, Urban Light, 2008, Los Angeles County Museum of Art; photo courtesy of @neohumanity via Instagram

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Question: What's the Difference?

Both are the Millennium Falcon from Star Wars



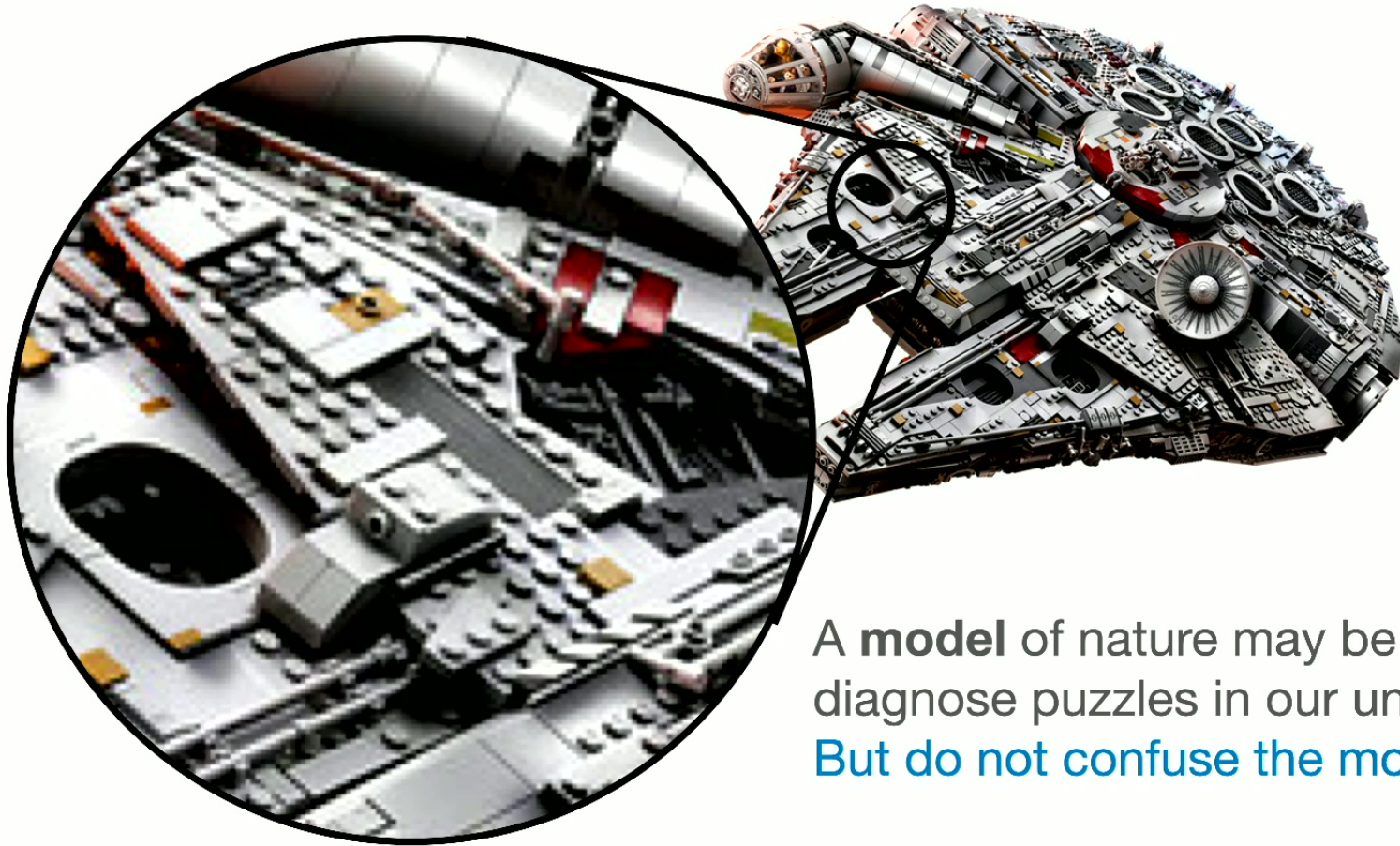
Images: Millennium Falcon: Wookieepedia, Lego (2017)

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Nature vs. Model of Nature



A **model** of nature may be enough to diagnose puzzles in our understanding
But do not confuse the model for nature

Images: Millennium Falcon, Lego (2017)

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Theories are mathematical models

Field	Spin	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$
Q	$1/2$	\square	\square	$1/6$
\bar{u}	$1/2$	$\bar{\square}$	$\mathbb{1}$	$-2/3$
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\bar{e}	$1/2$	$\mathbb{1}$	$\mathbb{1}$	-1
H	0	$\mathbb{1}$	\square	$1/2$

This is not nature



Magritte, "La Trahison des Images" ("The Treachery of Images"), 1929 (LACMA, via Wikipedia)

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Model of dark matter

A checklist for model-builders

MOTIVE

- ✓ **What is it?** Particle(s) and their interactions, written as a Lagrangian.
- ✓ **How did it get here?** Production mechanism.

- ✓ **Why is it still here?** Stability on cosmological scales.
- ✓ **Why isn't it ruled out?** Existing observations.

MEANS

- ✓ **How do we discover it?** New observations, techniques, ...

OPPORTUNITY

Model of dark matter

Typical WIMP

- ✓ **What is it?** Lightest parity-odd partner of an extended EW sector
- ✓ **How did it get here?** Thermal freeze out (miracle)
- ✓ **Why is it still here?** Parity (introduced for other reasons)
- ✓ **Why isn't it ruled out?** ... tuning? (e.g. pure Higgsino)
- ✓ **How do we discover it?** ... (in)direct detection, LHC

SUPERMASSIVE BLACK HOLES

HOW DID THEY GET SO LARGE?

BIG BLACK HOLES USUALLY COME
FROM MERGING LITTLE BLACK HOLES.

EDDINGTON LIMIT: THIS CANNOT
EXPLAIN THE LARGEST BLACK HOLES.



quasar

NASA, ESA and J. Olmsted (STScI) "Quasar Tsunamis Rip Across Galaxies," NASA/Goddard (2020)

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DARK MATTER, FIRST LIGHT



snolab.mass21.org | usparticlephysics.org/2023-p5-report

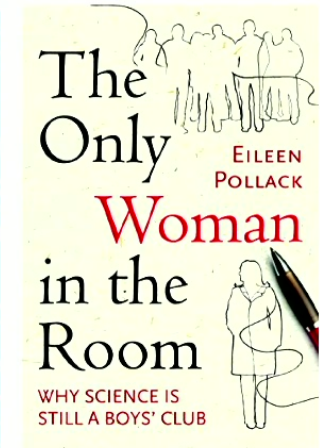
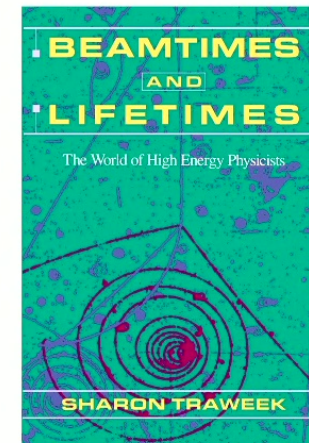
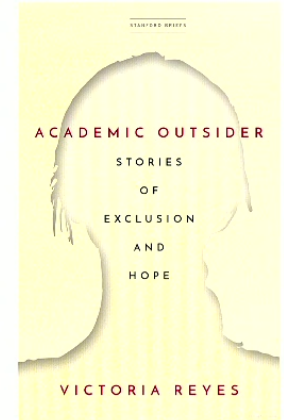
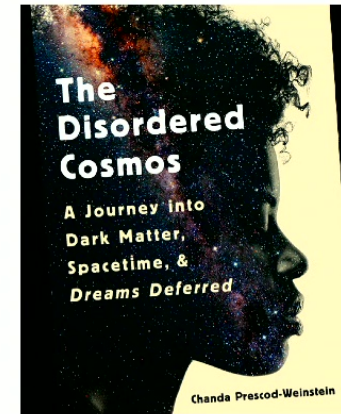
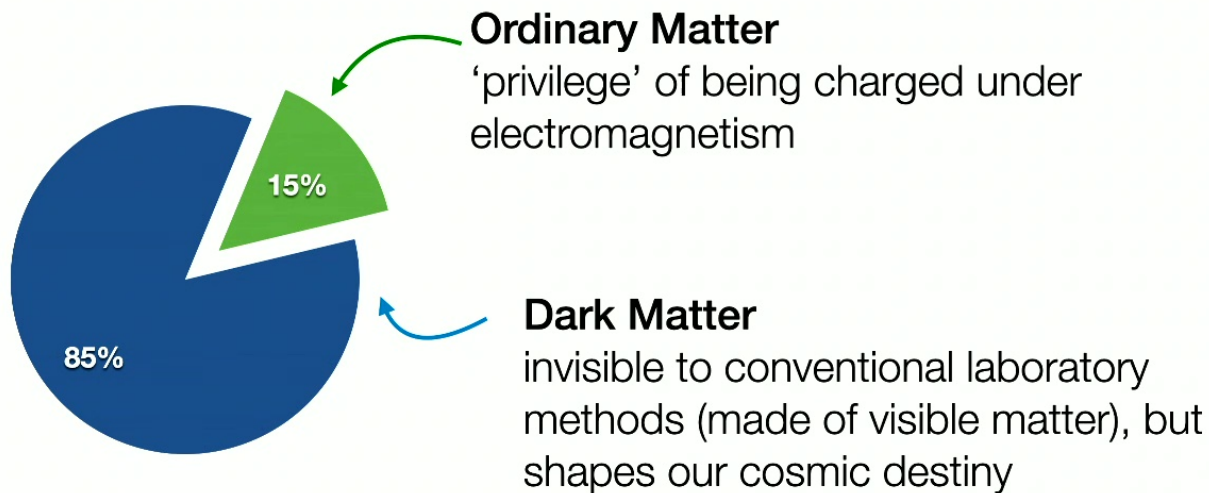


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“Missing talent” puzzle

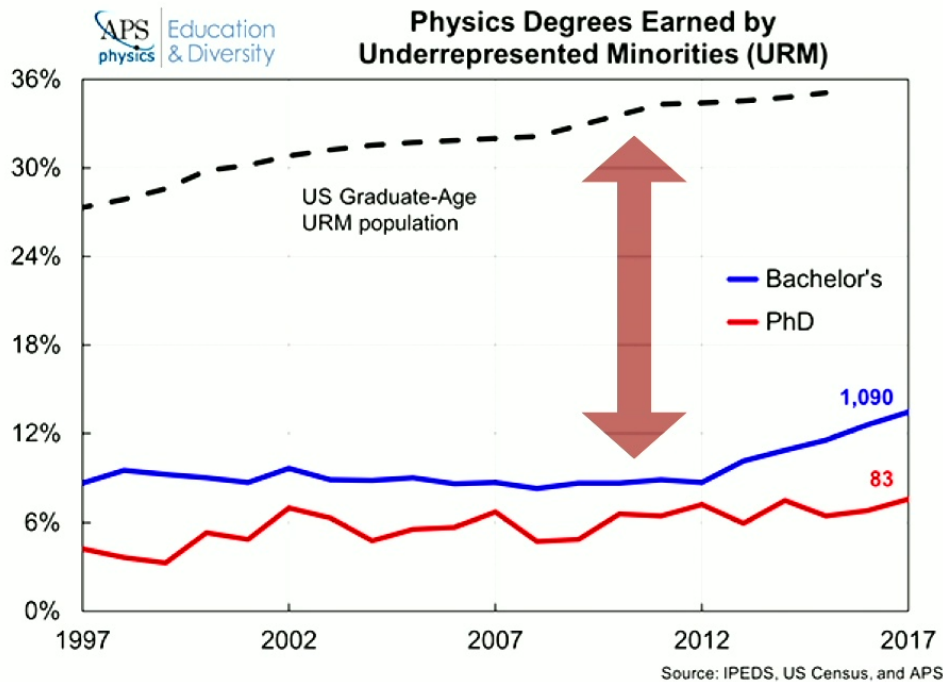
How do we see talent? What do we miss?



Chanda Prescod-Weinstein, *The Disordered Cosmos* (Bold Type Books 2021); Victoria Reyes, *Academic Outsider* (Stanford 2021), Sharon Traweek, *Beamtimes and Lifetimes* (Harvard 1988), Eileen Pollack, *The Only Woman in the Room* (Beacom 2015)

The data is there

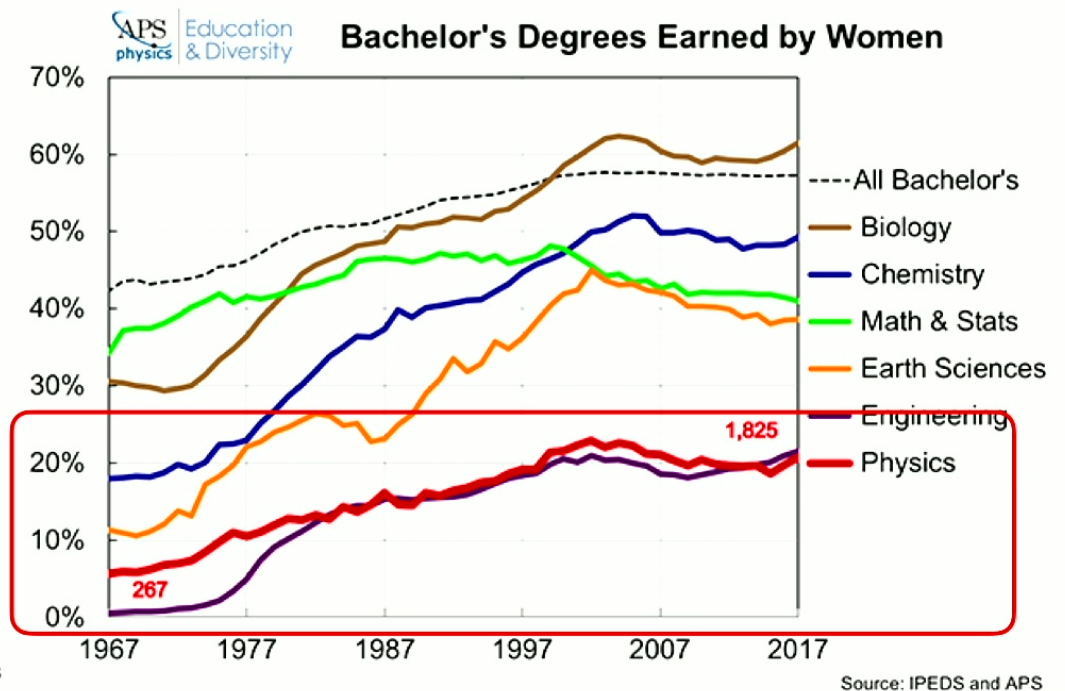
Indirect “astronomical observations”
of underutilized talent



Socioeconomic roots of academic faculty

Allison C. Morgan , Nicholas LaBerge, Daniel B. Larremore, Mirta Galesic, Jennie E. Brand & Aaron Clauset 

Nature Human Behaviour 6, 1625–1633 (2022) | [Cite this article](#)



aps.org/programs/minorities/resources/ and aps.org/programs/education/statistics/womenmajors.cfm

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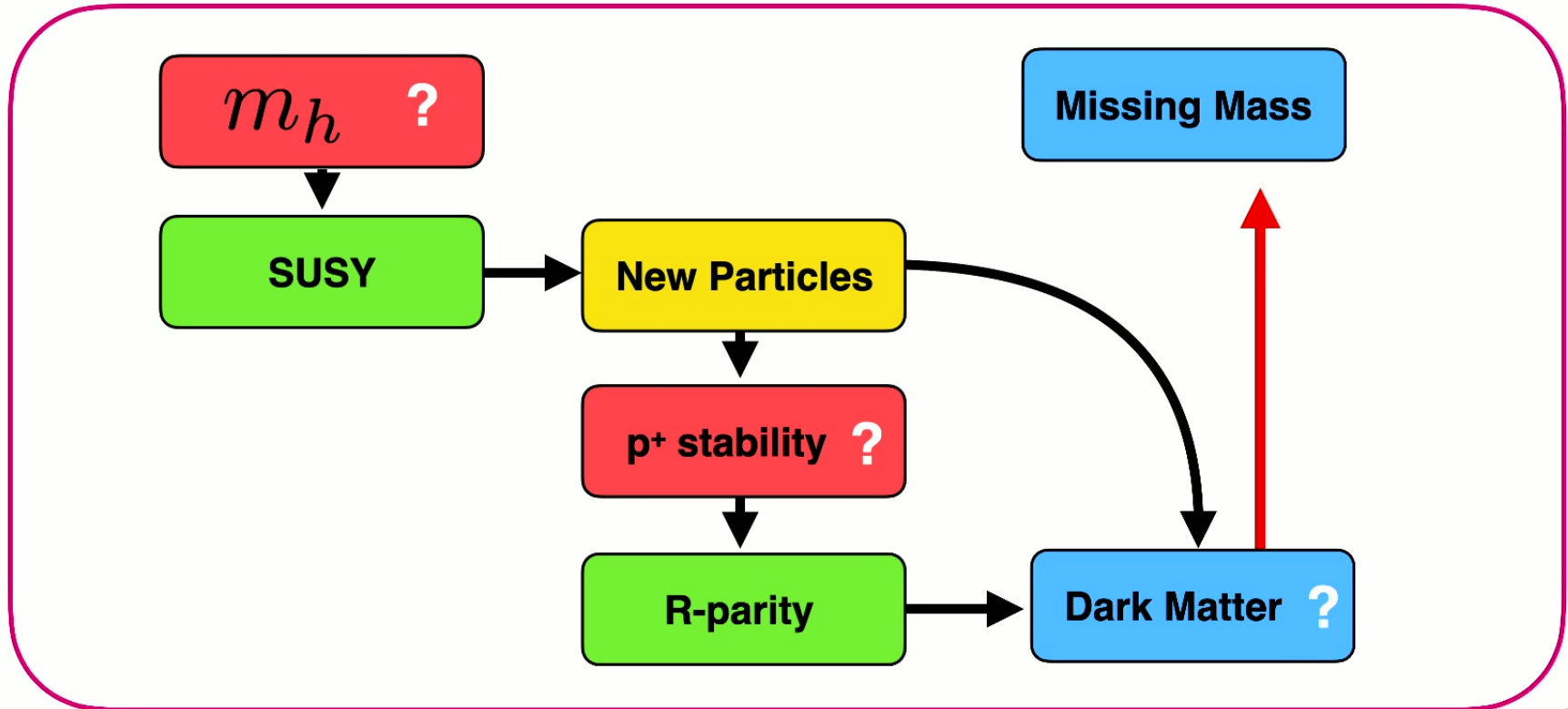
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We need new approaches

... and grace in exchange for earnestness

CAN WE THINK BEYOND THIS PARADIGM?



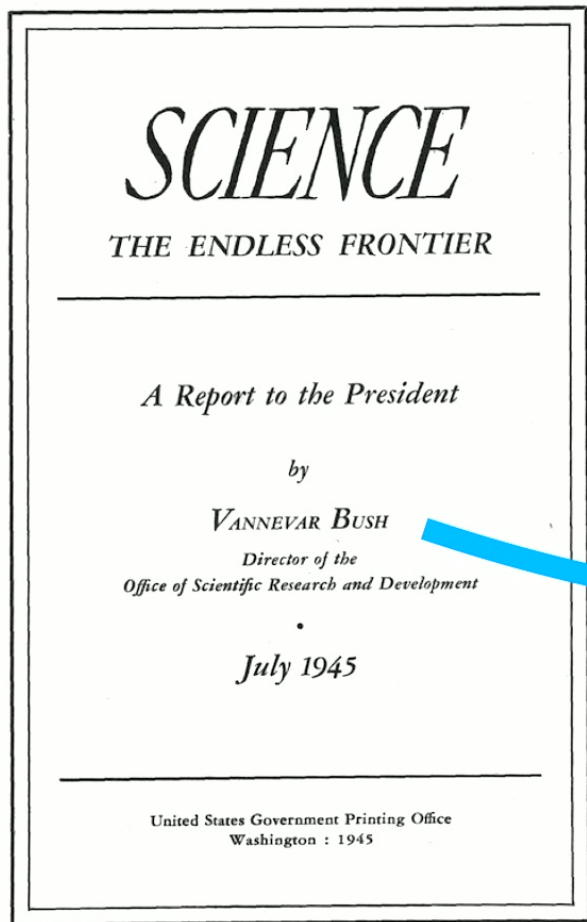
“Maxwell’s equations do not care about your gender, skin color, socioeconomic...”

“Maxwell’s equations do not care about your gender, skin color, socioeconomic...”

“Maybe the committee would have selected me if were from [prestigious institute] and gotten a recommendation from [eminent scholar] ...”

“If only I had [resources/connections] earlier in my career ...”

“I am the only [type] in my subfield / collaboration can be a challenge because people interact with me as a [type] rather than as a scientist...”

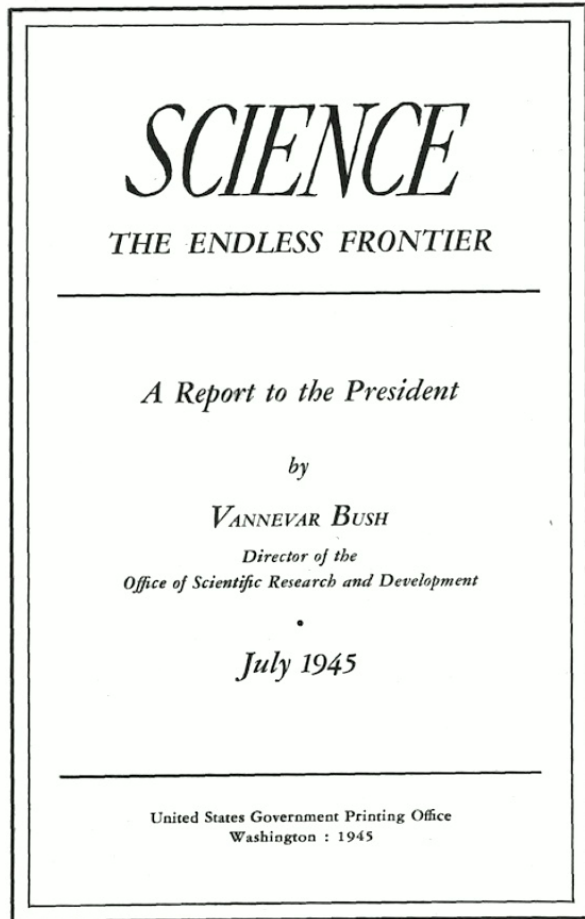


@NSF on Twitter (6 Dec 2018), *Oppenheimer* (2023), Universal Pictures via IMDB

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“... in every section of the entire area where the word science may properly be applied, **the limiting factor is a human one ...**”

(quoting James Conant)

@NSF on Twitter (6 Dec 2018), *Oppenheimer* (2023), Universal Pictures via IMDB

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We need new approaches

We're here to make breakthroughs in our understanding of the universe. Breakthroughs are made by thinking in new ways.

We can't afford to leave any great thinkers, or any great ideas, behind.

Robert Myers, PI Director and BMO Financial Group Isaac Newton Chair
perimeterinstitute.ca/edi



Where Do We Come From? **What Are We?** Where Are We Going?

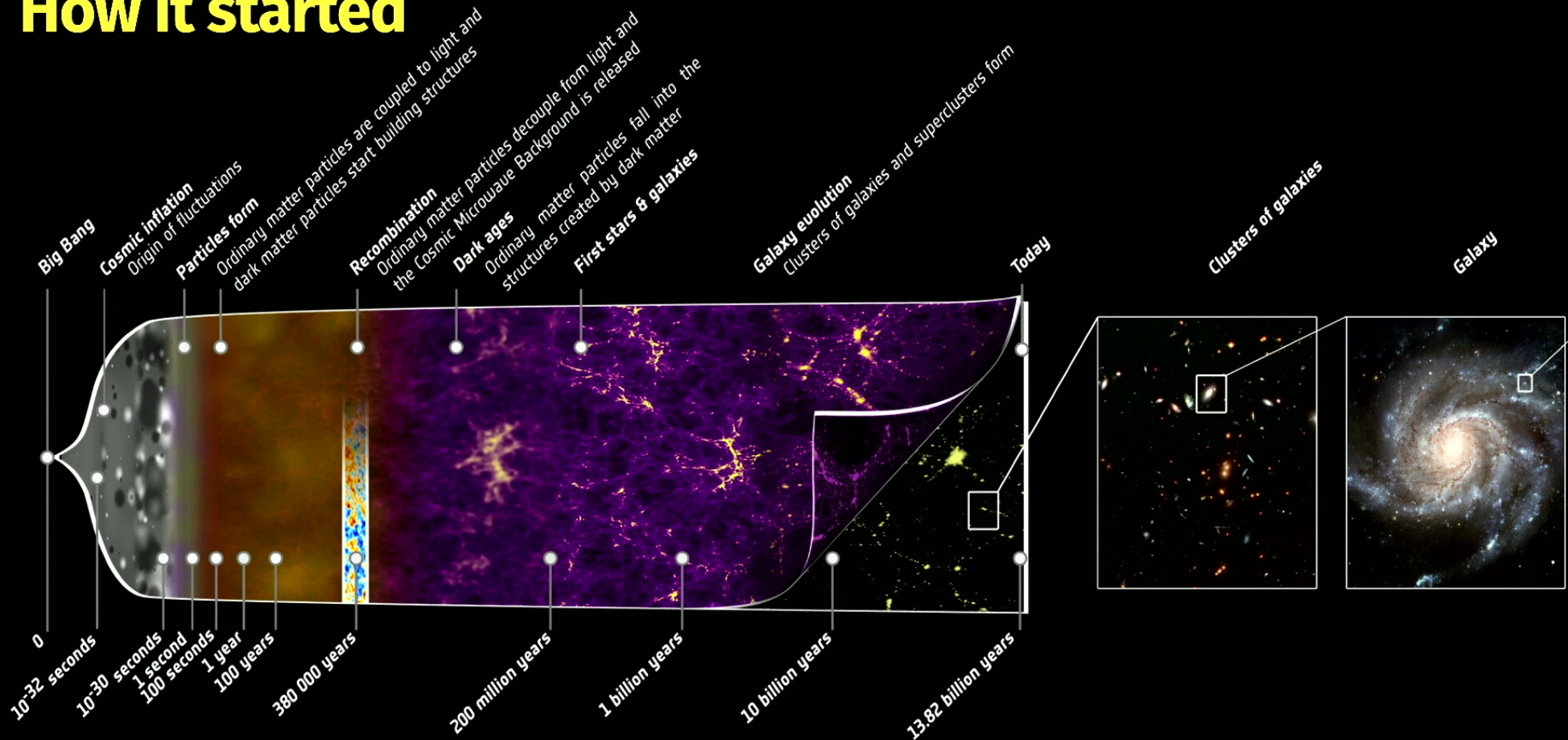
"Where Do We Come From? What Are We? Where Are We Going?" Gauguin, via Wikipedia

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How it started

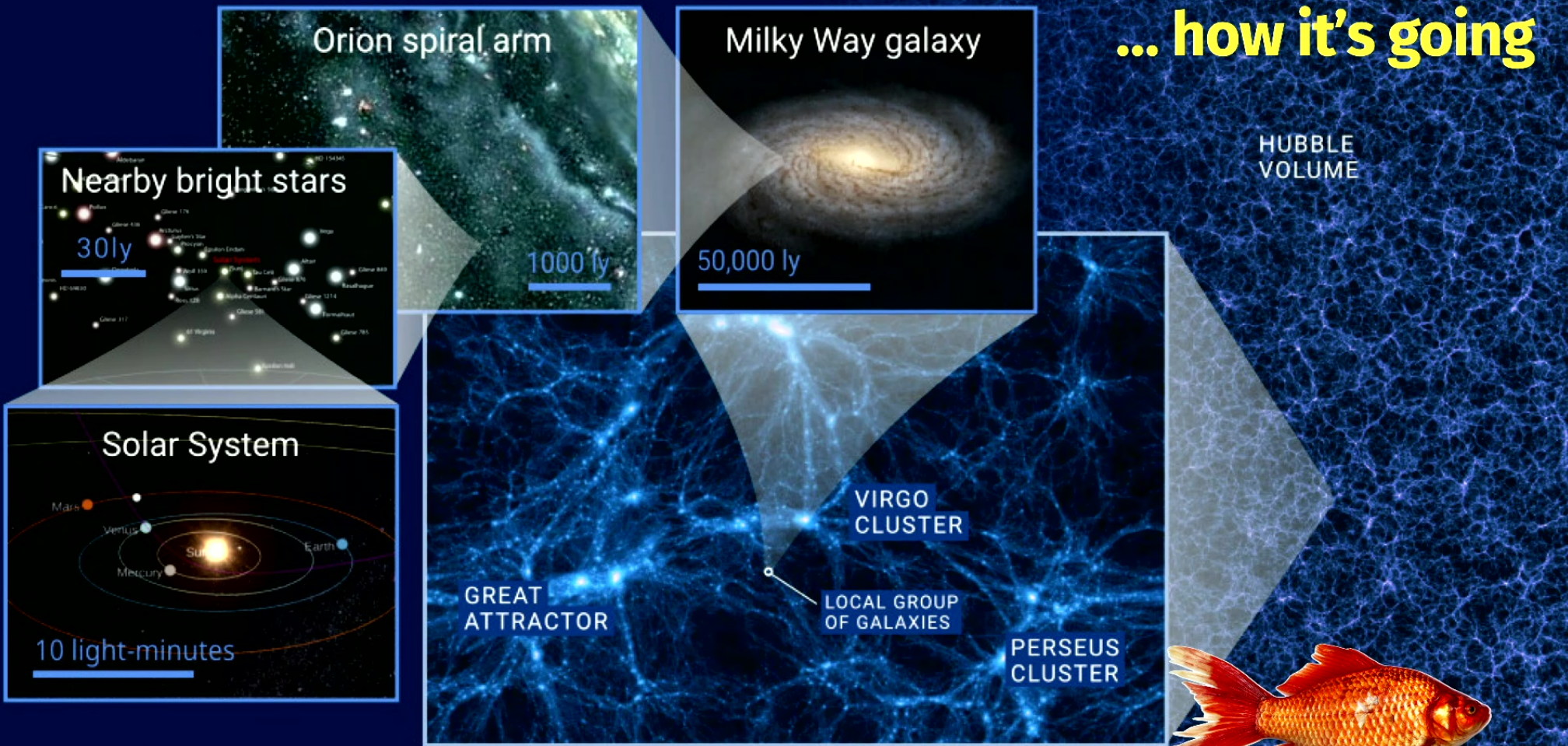


esa.int/Science_Exploration/Space_Science/Planck/History_of_cosmic_structure_formation

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... how it's going



Sebastian Stapelberg structures.uni-heidelberg.de/blog/posts/2022_12_cw/

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Thanks!

Chris Burden, *Urban Light*, 2008, Los Angeles County Museum of Art; photo courtesy of @neohumanity via Instagram

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