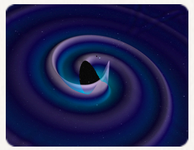
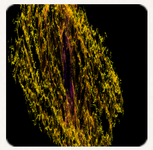
The New Universe

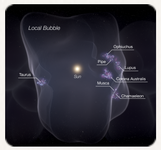
MEMPHIS, SUNDAY OCTOBER 23, 2022

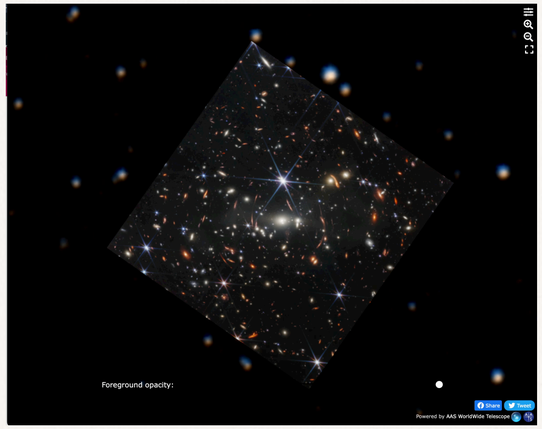
WHAT DO EXPENSIVE NEW TELESCOPES DO FOR HUMANITY TODAY?

Are mega-projects like ALMA, LIGO, JWST, and Gaia worth the billions?



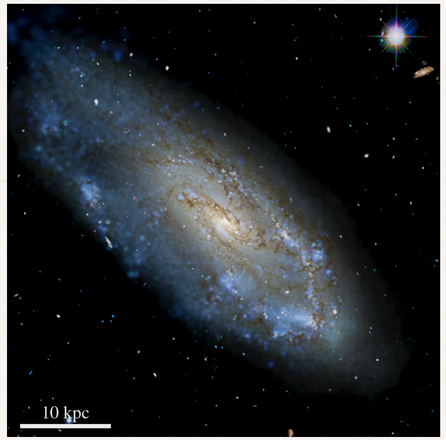


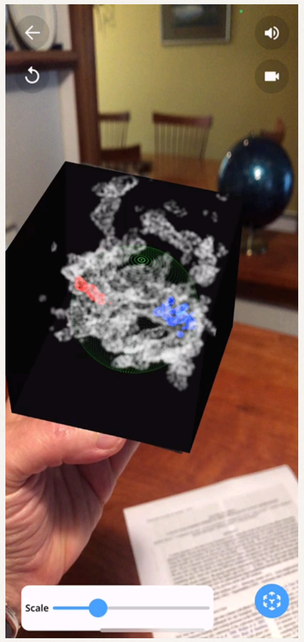




ARE COMPUTERS THE NEW TELESCOPES?

New galaxies in-silico, the early Universe "learned" without physics, and new stars forming in your hand.



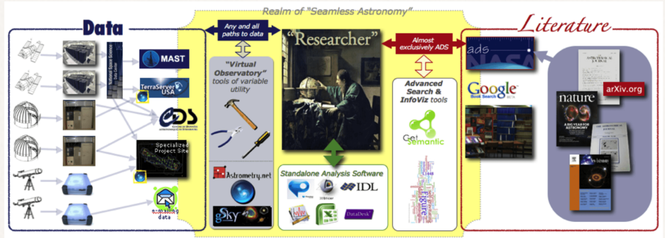


IS ASTROPHYSICS BEING (RE)ORGANIZED?

Lone stargazers are a rarer and rarer breed in professional astronomy. Teams and data scientists seem the way of the future, and tools that talk to each other are essential.

SEAMLESS ASTRONOMY

Linking scientific data, publications, and communities

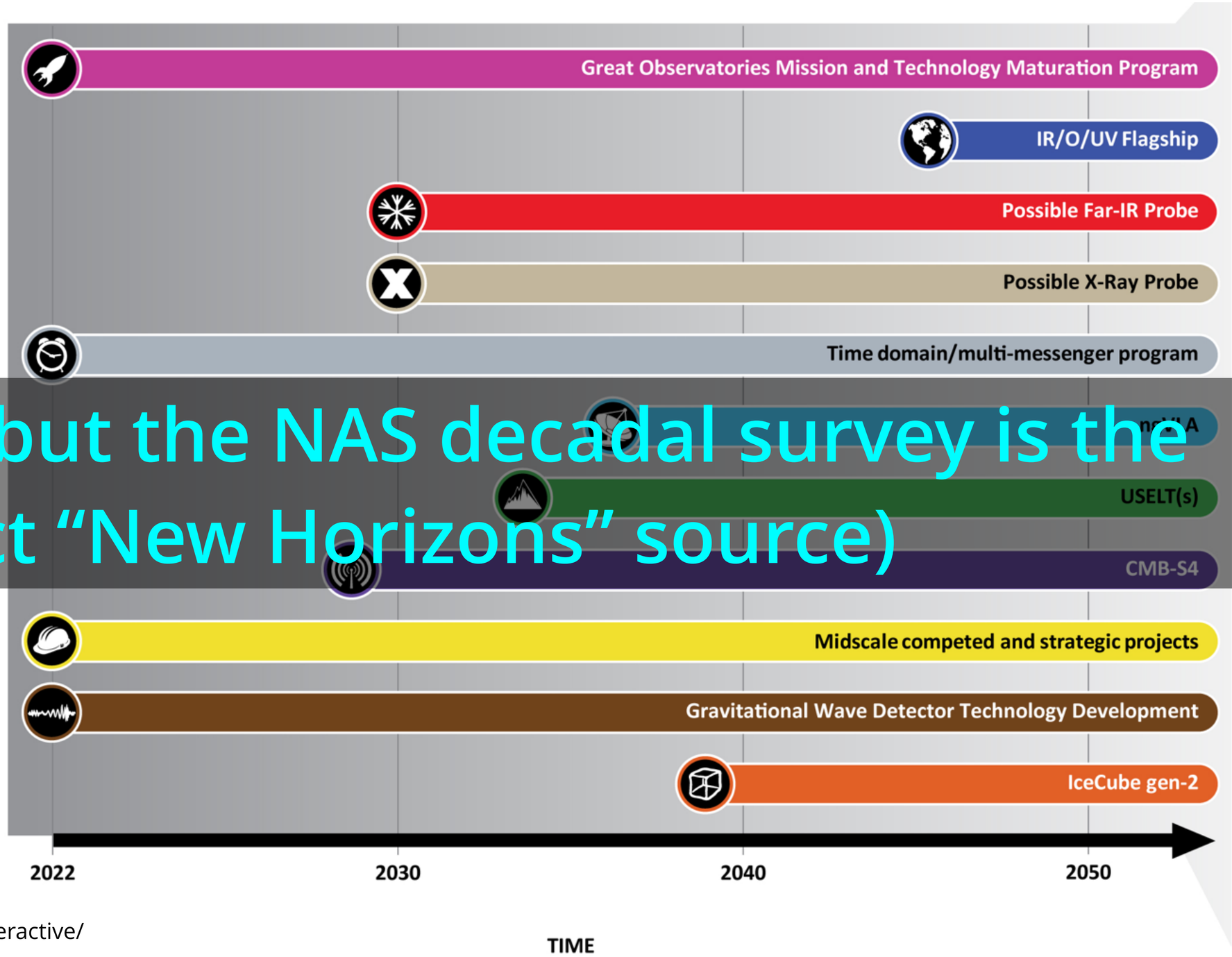


Editor: Alyssa Goodman, Center for Astrophysics | Harvard & Smithsonian, @AlyssaAGoodman

Key Category	ASTRONOMY IN 1992	ASTRONOMY IN 2022	SO WHAT?	
Discovery	The Universe is likely decelerating.	The **Universe** is **accelerating**.	Oh no, **dark energy** AND dark matter! Or MOND?	**Nobel 2011**
Discovery	gravity waves were theoretical	**gravitational-wave detections** (LIGO) give rise to true "multi-messenger" astrophysics	wide range of discoveries in studies of "compact" objects, where **general relativity** is best tested, observation of **gravity waves**	**Nobel 2017**
Discovery	no planets known beyond the Solar System, circumstellar disks barely detected	Thousands of **exoplanets**, brilliant images of disks forming them	(exoplanetology+exoclimatology+ astrobiology)=humans can legitimately study the **Origins of Life in the Universe**	**Nobel 2019**
Discovery	black holes were theoretical	black holes observed in the center of the Milky Way, and in other galaxies, using high-resolution time-resolved observations	significant **tests of general relativity,** all of which have been passed (no huge surprises—bad for MOND)	**Nobel 2020**
Technology	spectroscopy one spectrum at a time	**MANY spectra at a time**: focal-plane arrays, fiber-fed spectrographs, interferometers, IFUs	thousands or more spectra simultaneously, instead of 1 at a time give details on **motion** & **composition** of all components of the **Universe**	❤
Technology	UNIX, LatTeX on Suns, MacOS best for graphics	Python on anything, many other languages, collaboration via Jupyter notebooks etc.	**Astronomy=Data Science**; HUGE wealth of new techniques enabling new discoveries (Bayesian statistics, Machine Learning, much more…)	❤
Technology	early supercomputers (CRAY)	ubiquitous subject to cheap **high-performance computing**	**Simulations** as essential "third branch" of astronomy beyond "observations" and "theory"	❤
Technology	IRAS success, Hubble launched, mirror flawed	**numerous** space missions, some **HUGE** (e.g. JWST)	multi-wavelength coverage, ultra-sharp, ultra **deep images**, w/no concern about atmospheric effects	❤
Technology	infrared cameras with 4 MP were "amazing"	JWST NIRCam camera has **122 million pixels**	MUCH **higher resolution, over wider areas**	❤
Technology	software one-offs, except for big projects	**open-source modular software**	re-usable code, "**Seamless Astronomy**"	❤
Technology	draftspeople draw graphs	computer **graphics** for all, even **interactive**, and **augmented** reality	Explore-Explain approach made possible by **rich data display**	❤
Technology	Exploratory Data Analysis: DataDesk	Exploratory Data Analysis: glue	**Explore-Explain approach** made possible by rich data interactions	❤
Technology	glass plate archives, disks, tapes	**Internet access to "all" data** (e.g. WWT, NASA Skyview)	"**Seamless Astronomy**" made possible by **readily accessible**	❤
Technology	3D meant "position-position-velocity" space, at best, except in Hubble flow or rare astrometric measurements	3D means 3D: Gaia for stars, 3D Dust for ISM	unprecedented **maps of the Milky Way's gas, dust, and stars, in true 3D** (sometimes even **4D, 5D or 6D!**)	❤
Nature of Science	interest in outreach/education among research scientists	**outreach** components of PhDs & postdocs **desirable**, or even **required**	**improvement in Sci Comm**? (Cosmicism)	❤
Technology	printed indices in journals used to search literature	ADS launched 1992, arxiv, 1991, ADS All-Sky Survey 2012	find any **literature**, including on the Sky, more **"Seamless Astronomy"**	
Technology	X-rays detected, not quite images	X-ray images (**Chandra** launched 1999)	MUCH higher sensitivity in detectors, seeing "fainter objects"	
Technology	actual telescope observing, in real-time	**remote** telescope **observing, queue scheduling**	telescope **access expanded**, *but* students less well-trained in mechanics of observing	
Nature of Science	Astronomy ~80% white males	Fraction of non-white non-male astronomers ~40%	**diversity of approaches to science** and how to be a scientist, more **role models**	
Nature of Science	secret science the norm	**open-science** more popular	improved data **re-use** and **reproducibility**; astronomy as a poster-child	❤
Funding	funding proposal success 30-50%	funding proposal success 5-15%	much ***harder* to secure funding;** more time spent writing proposals	
Funding	expensive telescope= tens of millions (until Hubble)	expensive telescopes = **billions**	***fewer* opportunities** for hands-on observing, and for training "instrumentalists" — **higher and higher *stakes*** for space-based missions	
Technology	glass plate measuring machines used to do "astrometry"	astrometry.net (2012), Gaia 2018	"register" **positions** of astrophysical sources and images with **ease**	
Nature of Science	typical collaboration size ~5 people at most, except large instrument projects	**collaboration size often >>10 people**, often international	*difficulty* in assigning "**credit**" to individuals	

I will NOT subject you to this,
but the slides will be online
in case you'd like to know more
about the past 30 years of Astronomy!

Timeline for the medium and large programs and projects recommended and endorsed by the NAS decadal survey



(also not this, but the NAS decadal survey is the perfect "New Horizons" source)

nap.nationalacademies.org/resource/26141/interactive/

Opinion

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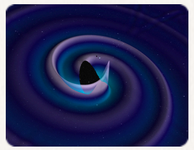

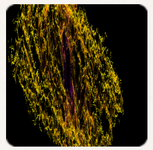

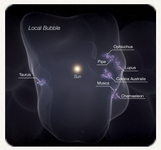

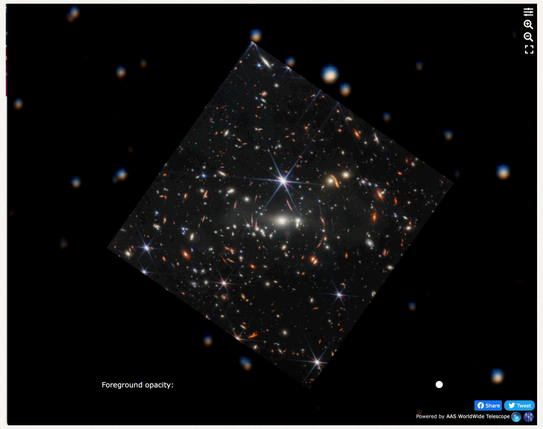

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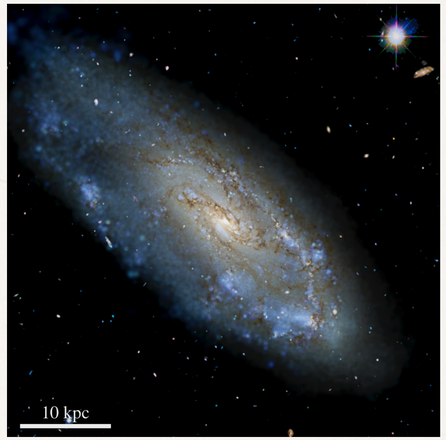

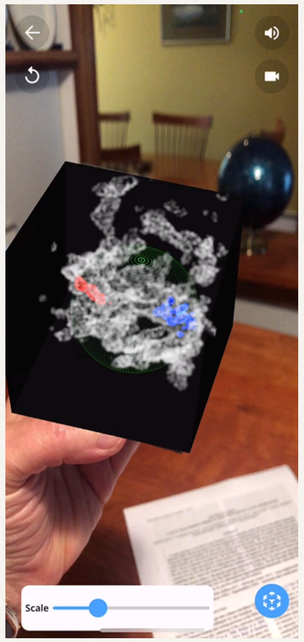

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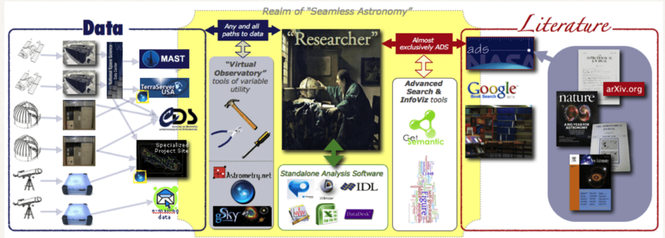

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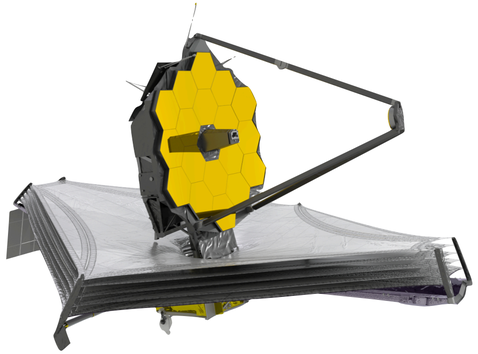

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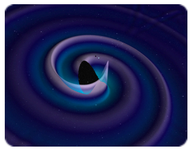
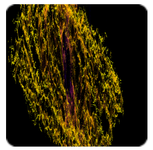
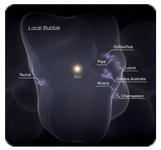
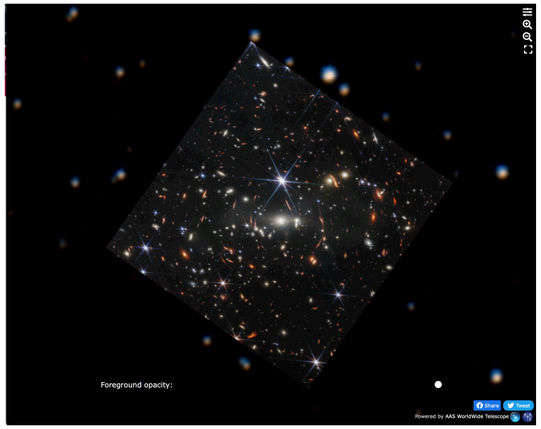








Foreground opacity:

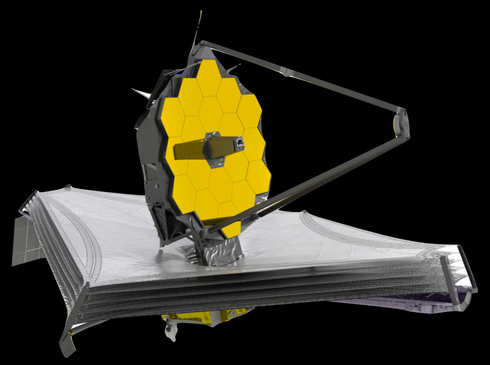
Share Tweet

Powered by AAS WorldWide Telescope

Alyssa A. Goodman
@AlyssaAGoodman

Here's a 1-minute video showing--in the words of visualization hero @EdwardTufte--the "compared to what" factor for today's amazing @NASAWebb image. Thanks to the @WWTelescope for making this possible, and @ADavidWeigel. I only wish @NASA and @POTUS had shown the image this way!

A David Weigel @ADavidWeigel · Jul 11
Replying to @AlyssaAGoodman and @NASAWebb
And you can zoom on the first one (SMACS 0723) interactively here in @WWTelescope: web.wwtassets.org/specials/2022/...



WEBB
SPACE TELESCOPE

NASA | ESA
hubble

WEBB
SPACE TELESCOPE
NASA/ESA/CSA

JWST Carina NIRC...

JWST Carina MIRI

JWST Southern Ri...

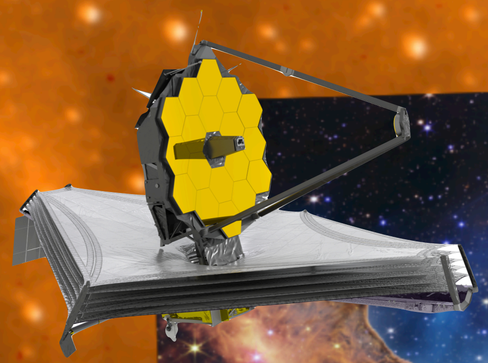
JWST Southern Ri...

JWST SMACS 0723

JWST Stephan's Q...

JWST Stephan's Q...

AAS
WorldWide
Telescope



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Share Tweet Support WWT

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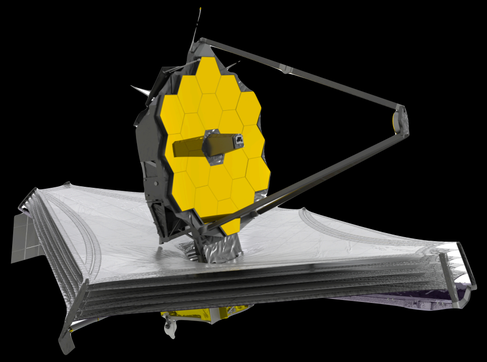

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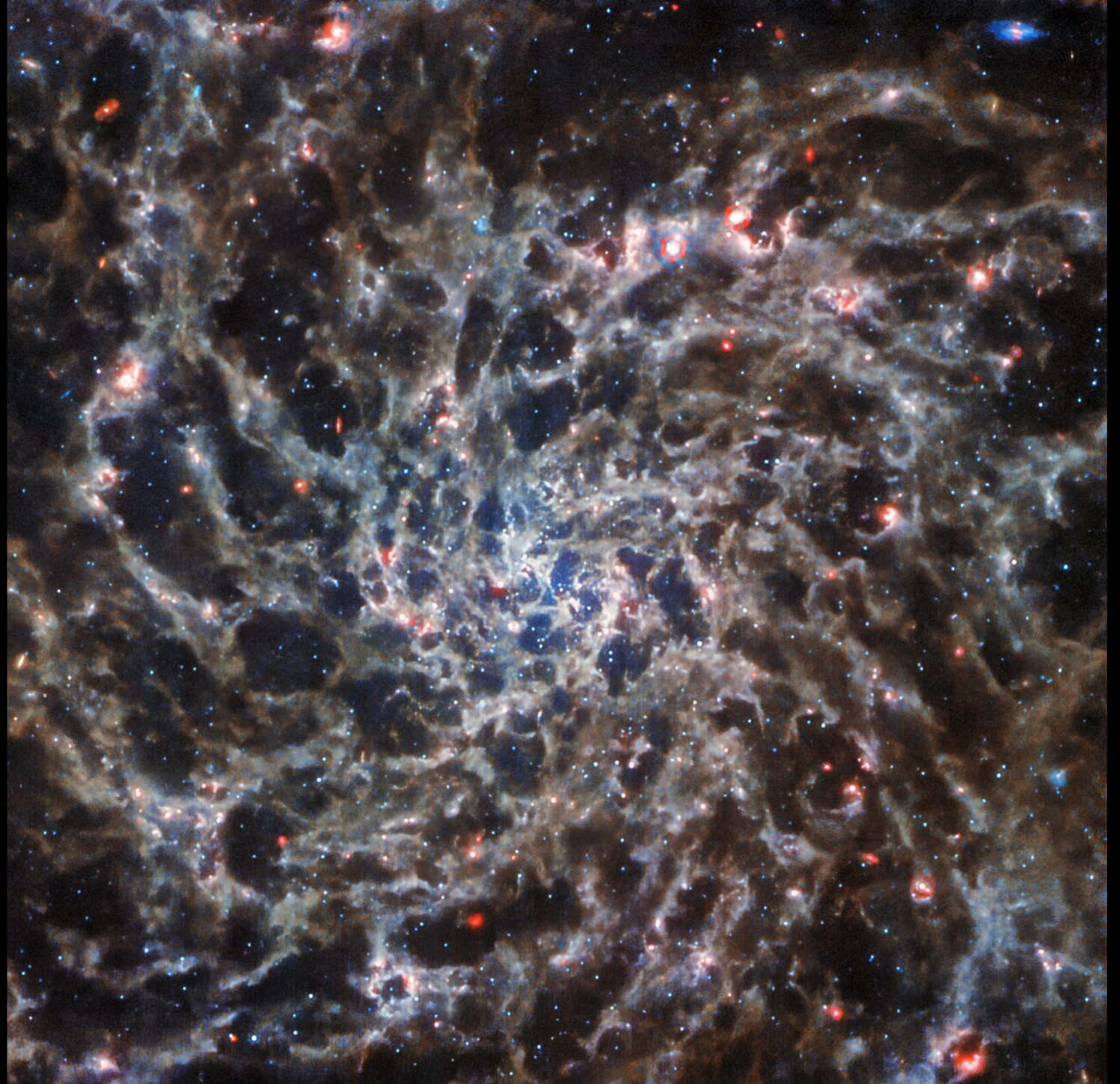
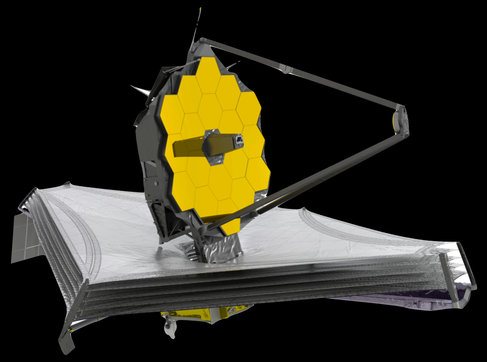


Image of the spiral galaxy IC 5332, taken by NASA/ESA/CSA's JWST with its MIRI instrument. Image Credit: ESA/Webb, NASA & CSA, J. Lee and the PHANGS-JWST and PHANGS-HST Teams



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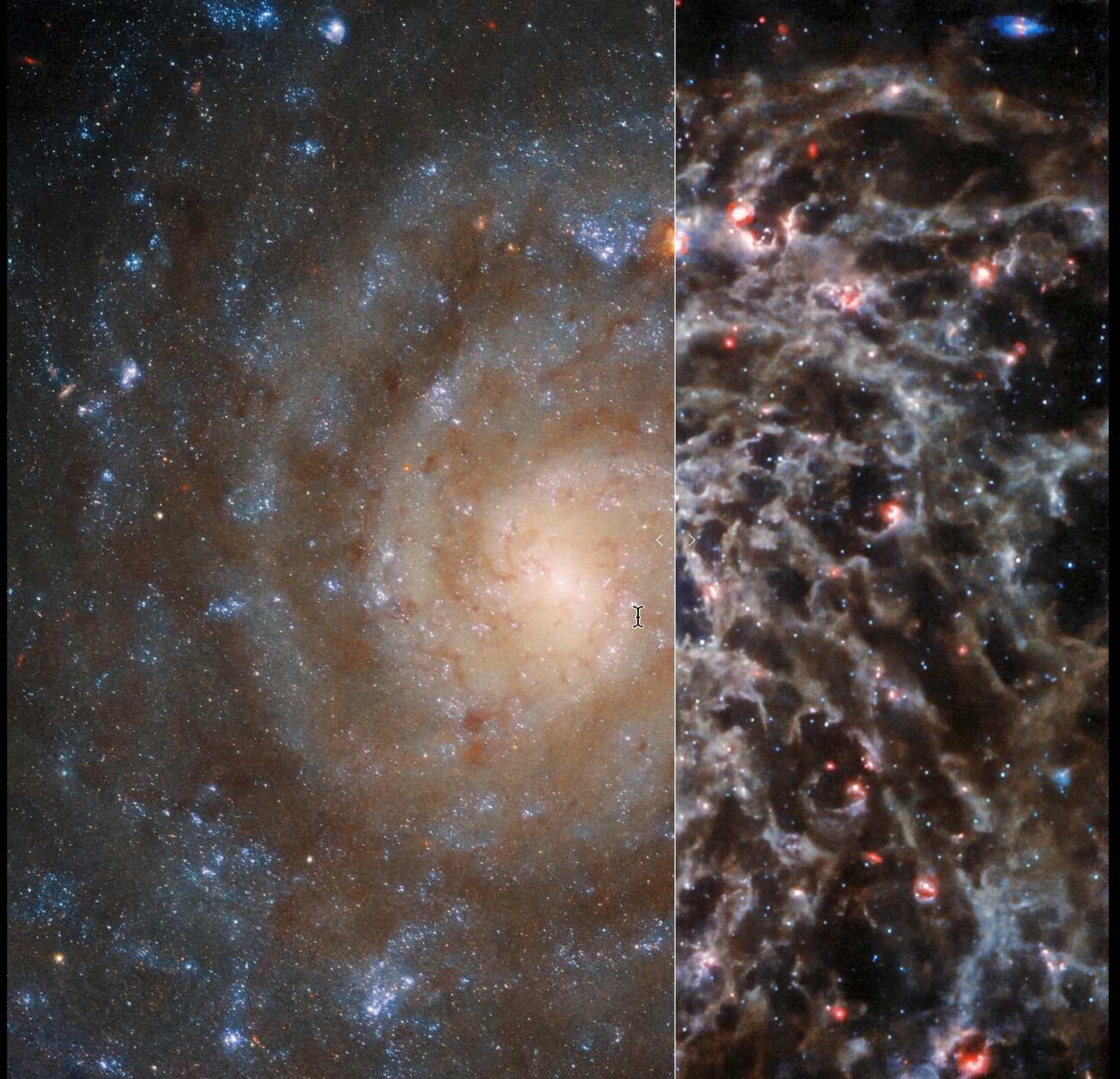
This extravagantly detailed mid-infrared image is juxtaposed here with a beautiful ultraviolet and visible-light image of the same galaxy, created using data collected by Hubble's Wide Field Camera 3 (WFC3) [link]

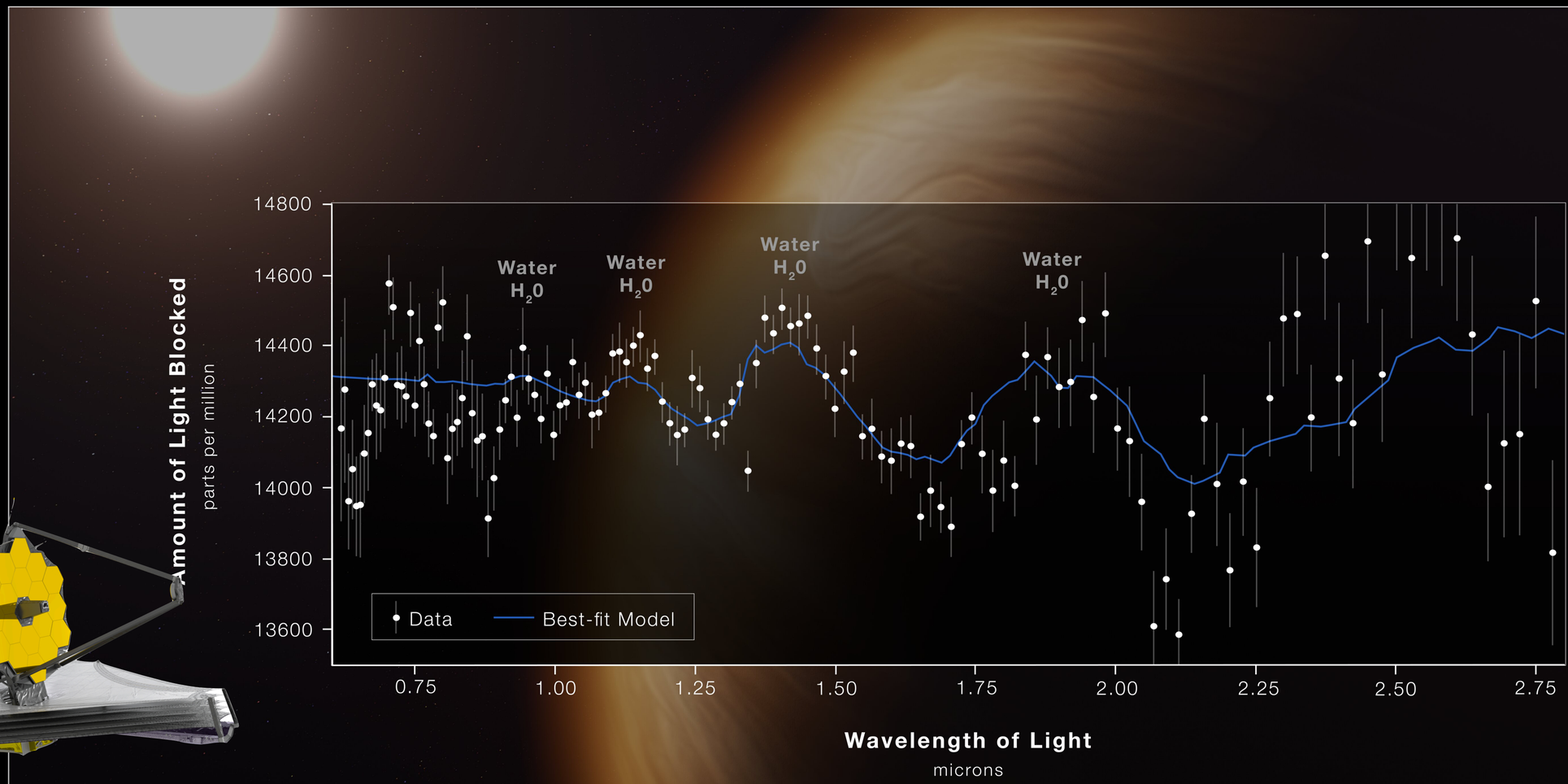


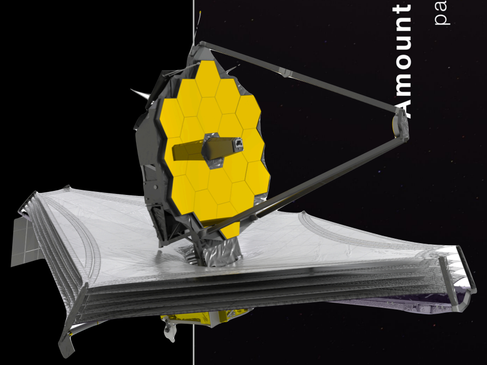
HOT GAS GIANT EXOPLANET WASP-96 b

ATMOSPHERE COMPOSITION

SPECTROSCOPY IS ESSENTIAL!

NIRISS | Single-Object Slitless Spectroscopy





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#UnfoldTheUniverse
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on your
mart speaker.
esa
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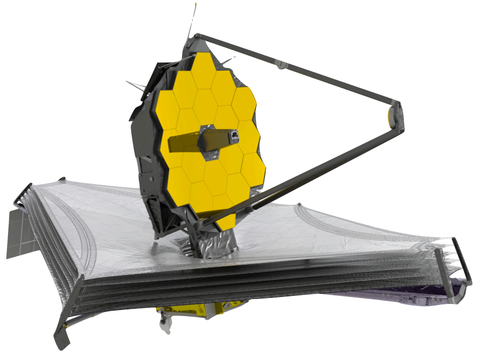
SPACE TELESCOPE
July 2022
Times Square, New York



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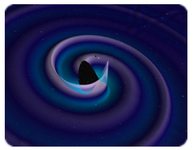
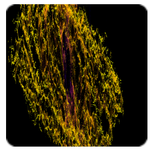
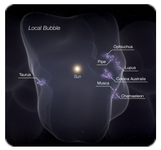
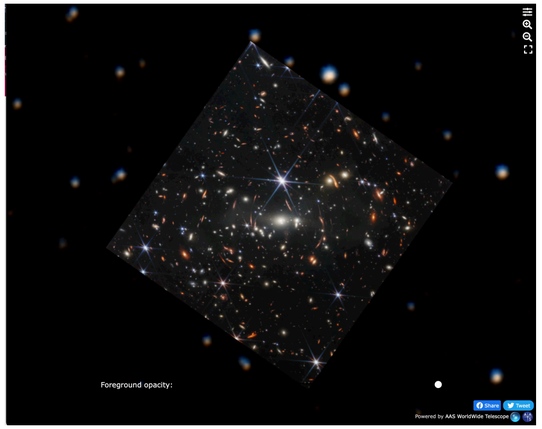
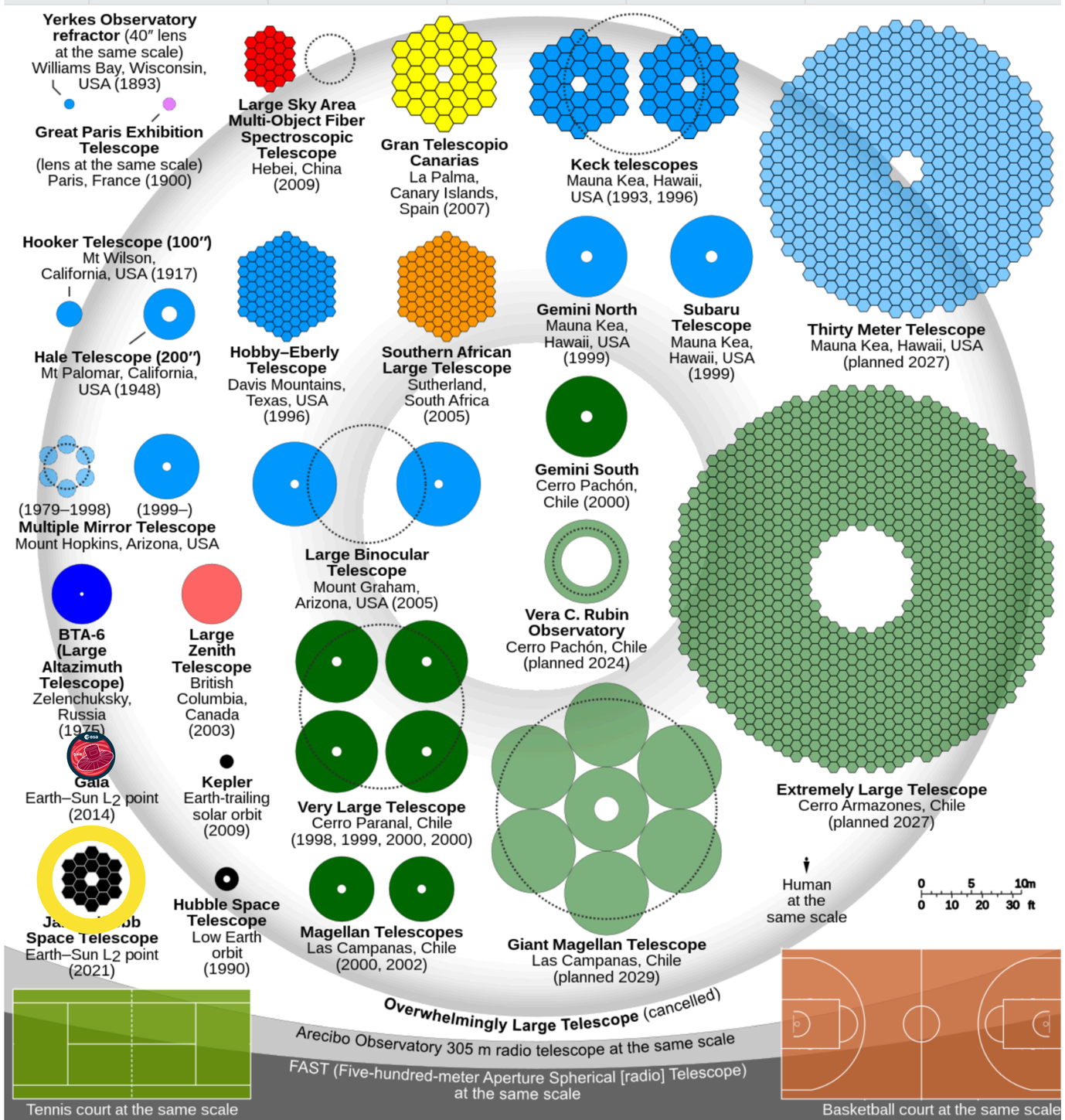
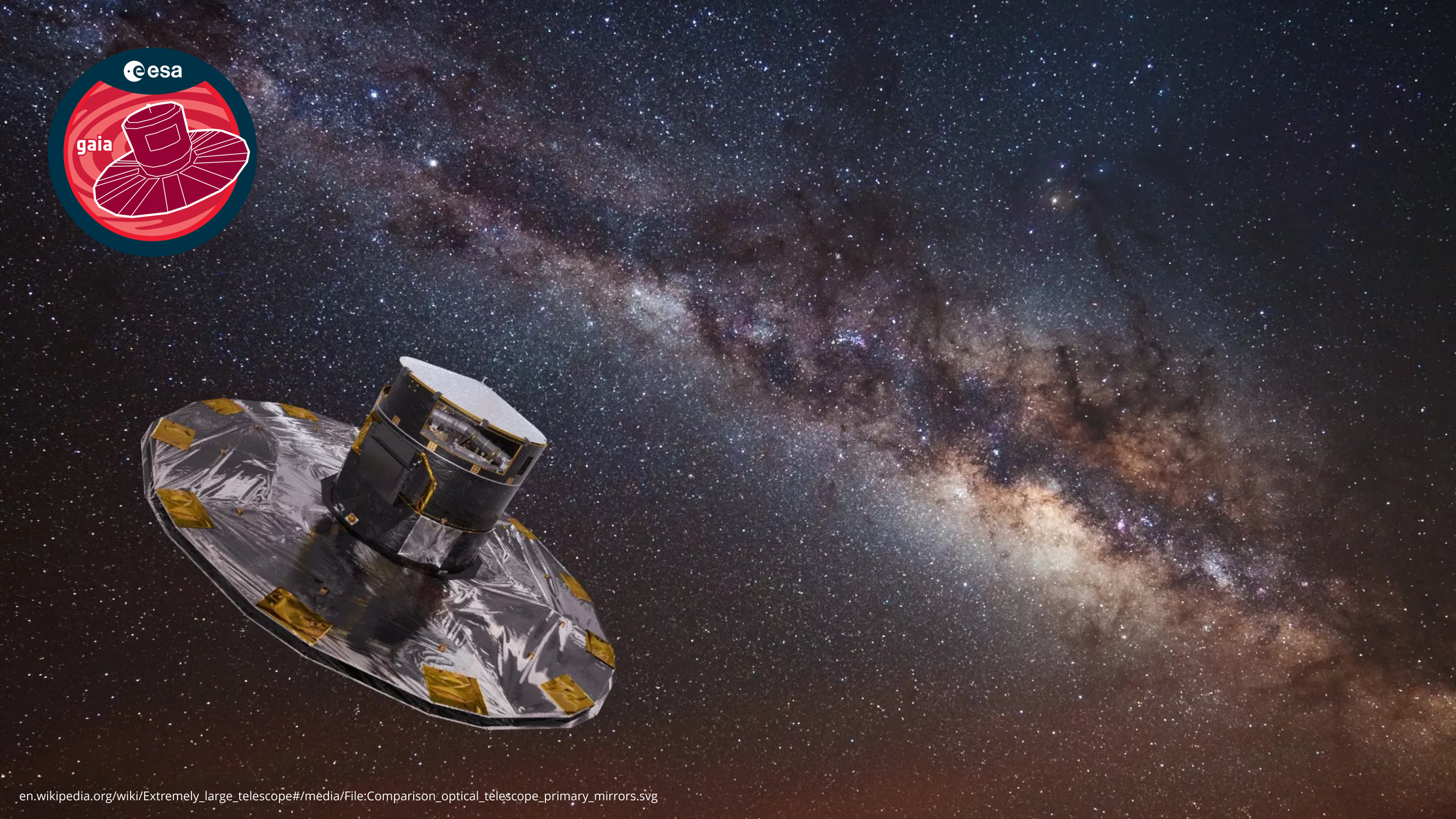




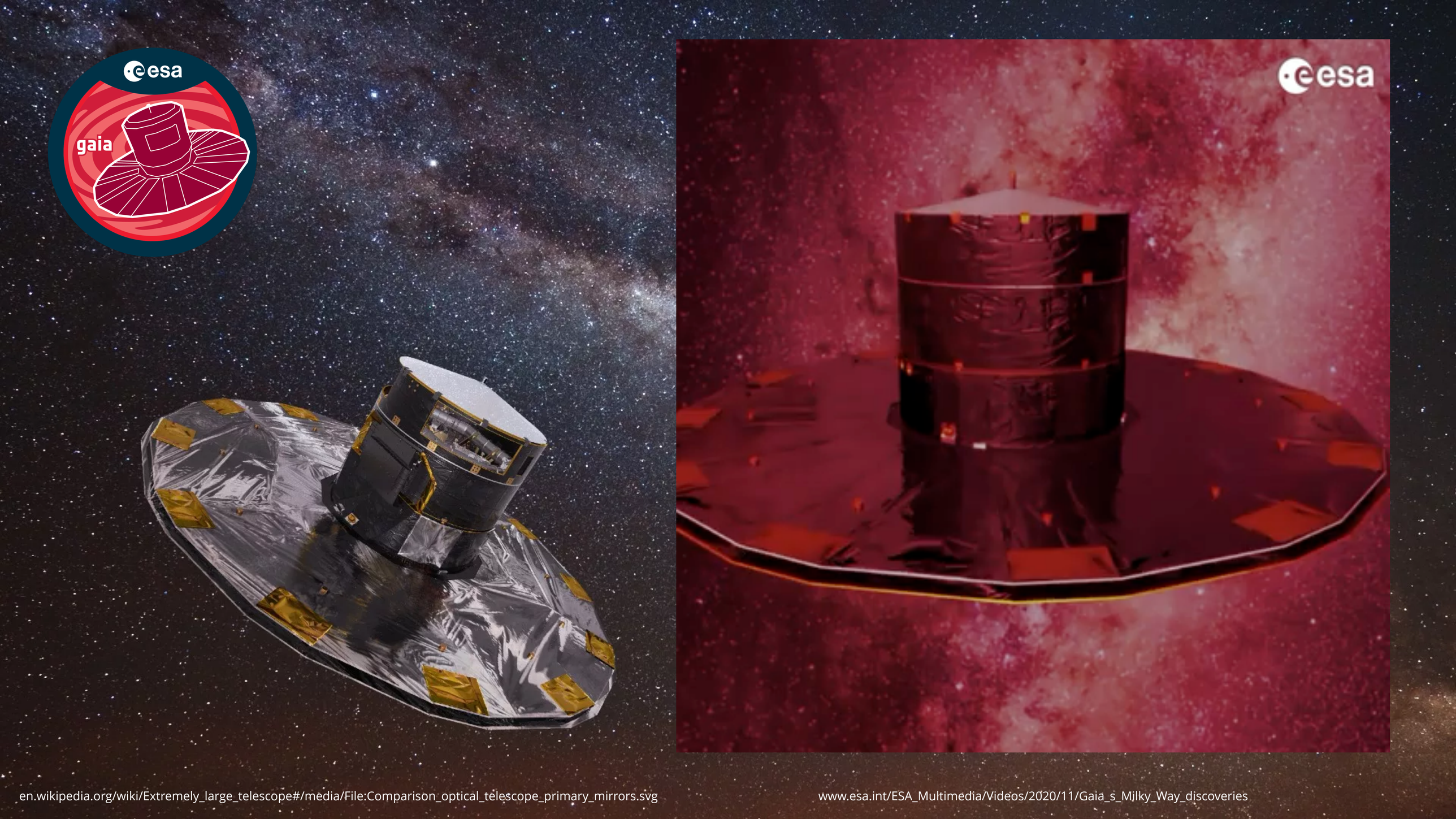








en.wikipedia.org/wiki/Extremely_large_telescope#/media/File:Comparison_optical_telescope_primary_mirrors.svg



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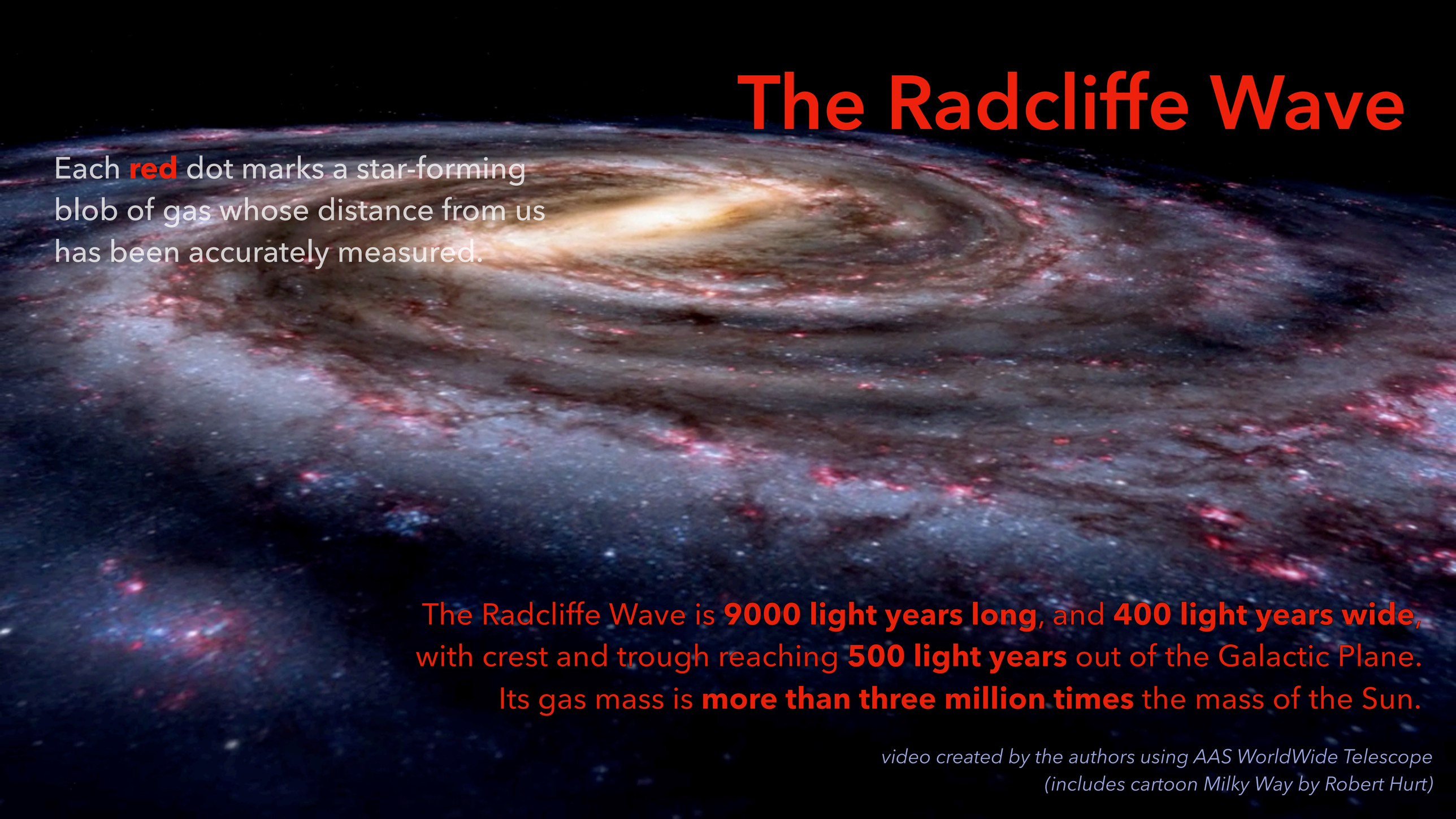
www.esa.int/ESA_Multimedia/Videos/2020/11/Gaia_s_Milky_Way_discoveries

The Radcliffe Wave



Each **red** dot marks a star-forming blob of gas whose distance from us has been accurately measured.

The Radcliffe Wave is **9000 light years long**, and **400 light years wide**, with crest and trough reaching **500 light years** out of the Galactic Plane. Its gas mass is **more than three million times** the mass of the Sun.

video created by the authors using AAS WorldWide Telescope (includes cartoon Milky Way by Robert Hurt)

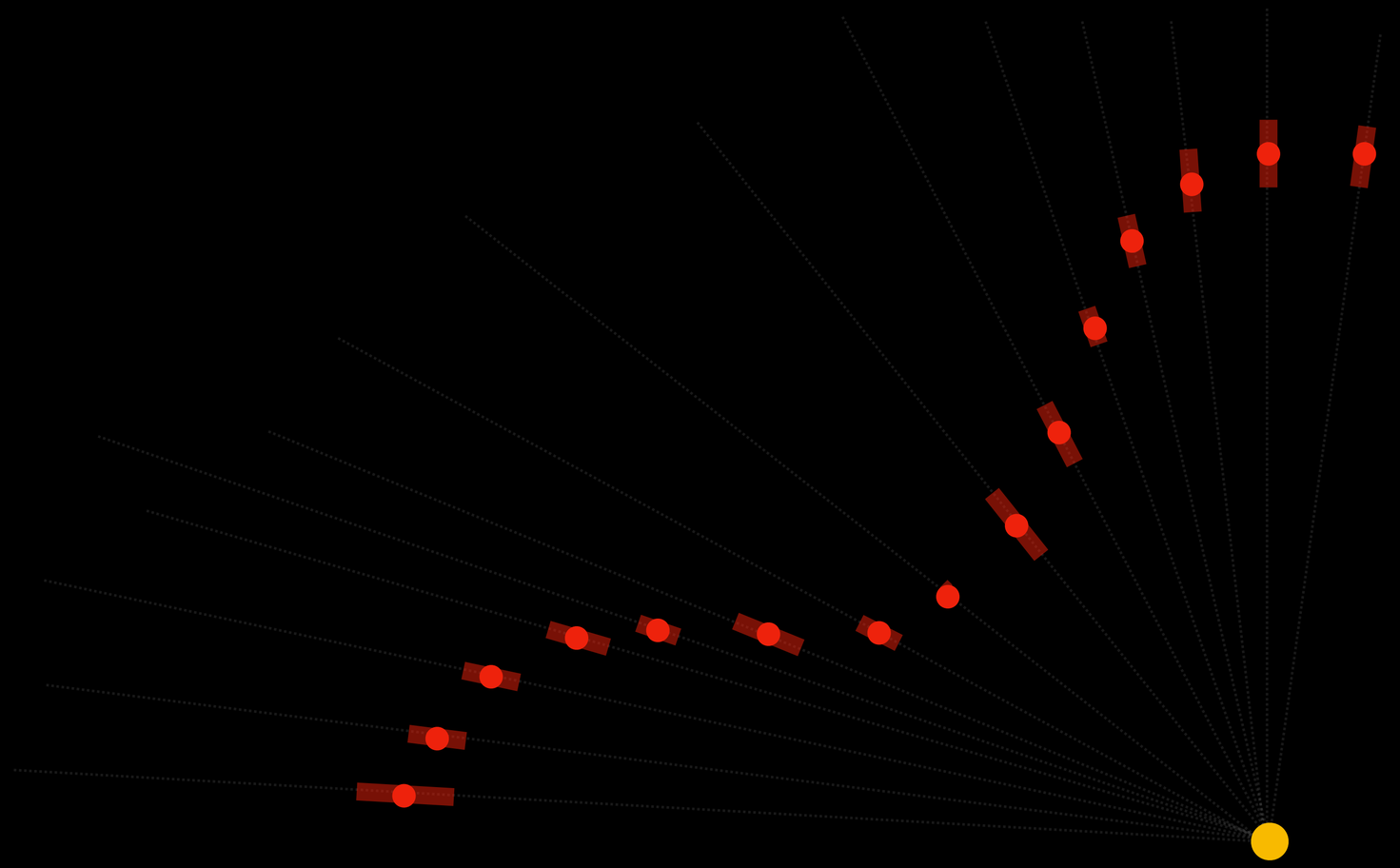
DISTANCES!!

We can now measure distances to gas clouds in our own Milky Way galaxy to ~5% accuracy.

Uncertain Distances

SCHEMATIC CARTOON(!)

Distances estimates **BEFORE** 3D dust mapping & Gaia (~30%)



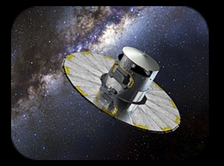
"The Radcliffe Wave"

SCHEMATIC CARTOON(!)

Distances estimates **AFTER** 3D dust mapping & Gaia (~5%)

HOW= 3D dust mapping*

+ Gaia*



+ glue*

+ WorldWide Telescope

*2 million CPU hours, Harvard *800 million stars, ESA *NASA/JWST, NSF *Microsoft Research, NSF, AAS

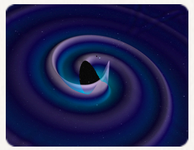
Opinion

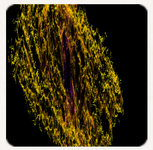
The New Universe

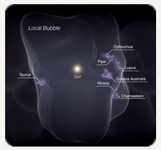
MEMPHIS, SUNDAY OCTOBER 23, 2022

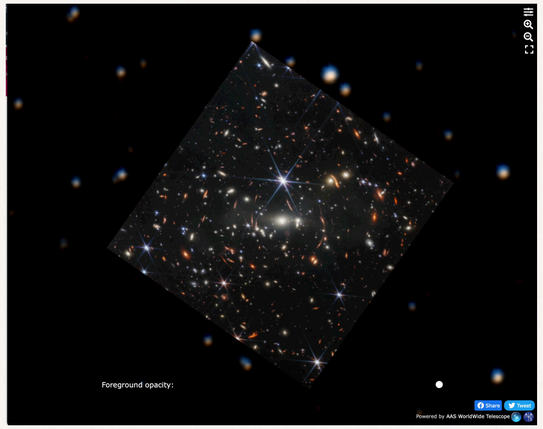
WHAT DO EXPENSIVE NEW TELESCOPES DO FOR HUMANITY TODAY?

Are mega-projects like ALMA, LIGO, JWST, and Gaia worth the billions?



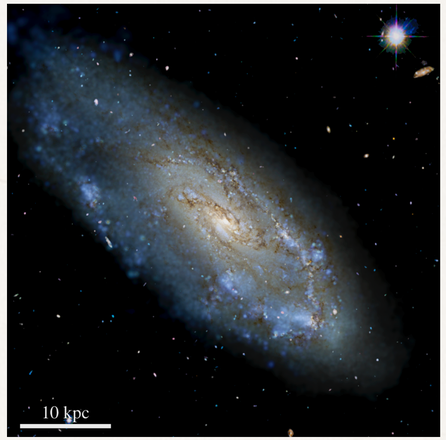


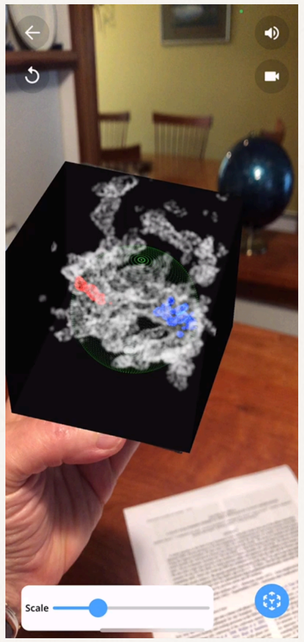




ARE COMPUTERS THE NEW TELESCOPES?

New galaxies in-silico, the early Universe without physics, and new stars forming in your hand.



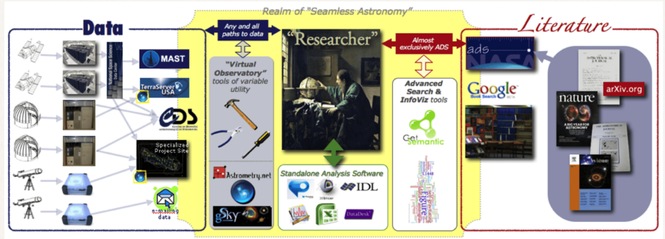


IS ASTROPHYSICS BEING (RE)ORGANIZED?

Lone stargazers are a rarer and rarer breed in professional astronomy. Teams and data scientists seem the way of the future, and tools that talk to each other are essential.

SEAMLESS ASTRONOMY

Linking scientific data, publications, and communities



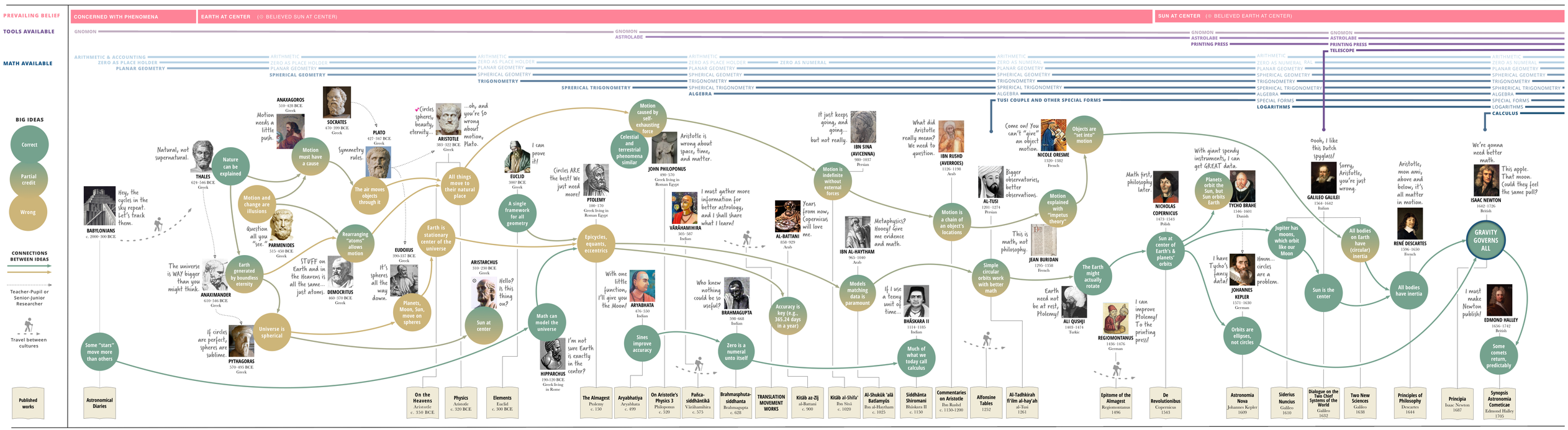
Editor: Alyssa Goodman, Center for Astrophysics | Harvard & Smithsonian, @AlyssaAGoodman

ARE COMPUTERS THE NEW TELESCOPES?

The Path to Newton

PREDICTIONX
predictionx.org

The Path to Newton



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demo: path-to.org or LabXchange™ Science and learning–connected.

The Path to Newton

PREVAILING BELIEF | CONCERNED WITH PHENOMENA | EARTH AT CENTER (☉ BELIEVED SUN AT CENTER)

TOOLS AVAILABLE

GNOMON

GNOMON
ASTROLABE

MATH AVAILABLE

ARITHMETIC & ACCOUNTING
ZERO AS PLACE HOLDER
PLANAR GEOMETRY
SPHERICAL GEOMETRY

ARITHMETIC
ZERO AS PLACE HOLDER
PLANAR GEOMETRY
SPHERICAL GEOMETRY
TRIGONOMETRY
SPRERICAL TRIGONOMETRY

ARITHMETIC
ZERO AS PLACE HOLDER
PLANAR GEOMETRY
SPHERICAL GEOMETRY
TRIGONOMETRY
SPHERICAL TRIGONOMETRY
ALGEBRA

ARITHMETIC
ZERO AS PLACE HOLDER
ZERO AS NUMERAL
PLANAR GEOMETRY
SPHERICAL GEOMETRY
TRIGONOMETRY
SPHERICAL TRIGONOMETRY
ALGEBRA

BIG IDEAS

Correct

Partial credit

Wrong

CONNECTIONS BETWEEN IDEAS

Teacher-Pupil or Senior-Junior Researcher

Travel between cultures

Published works

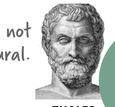
Hey, the cycles in the sky repeat. Let's track them.

BABYLONIANS
c. 2000–300 BCE

Some "stars" move more than others

Astronomical Diaries

Natural, not supernatural.



THALES
624–546 BCE
Greek

Nature can be explained

Earth generated by boundless eternity

The universe is WAY bigger than you might think.

ANAXIMANDER
610–546 BCE
Greek

If circles are perfect, spheres are sublime.

PYTHAGORAS
570–495 BCE
Greek

Universe is spherical

Motion and change are illusions

Question all you "see."

PARMENIDES
515–450 BCE
Greek

Motion needs a little push.

ANAXAGOROS
510–428 BCE
Greek

Motion must have a cause

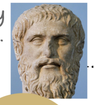
Rearranging "atoms" allows motion

STUFF on Earth and in the Heavens is all the same... just atoms.

DEMOCRITUS
460–370 BCE
Greek

SOCRATES
470–399 BCE
Greek

Symmetry rules.



PLATO
427–347 BCE
Greek

The air moves objects through it

Planets, Moon, Sun, move on spheres

It's spheres all the way down.

EUDOXUS
390–337 BCE
Greek

Earth is stationary center of the universe

Circles spheres, beauty, eternity...

ARISTOTLE
383–322 BCE
Greek

...oh, and you're so wrong about motion, Plato.

All things move to their natural place

Sun at center

ARISTARCHUS
310–230 BCE
Greek

Hello? Is this thing on?

Math can model the universe

HIPPARCHUS
190-120 BCE
Greek living in Rome

I'm not sure Earth is exactly in the center?

EUCLID
300? BCE
Greek

I can prove it!

A single framework for all geometry

Motion caused by self-exhausting force

Celestial and terrestrial phenomena similar

JOHN PHILOPONUS
490–570
Greek living in Roman Egypt

Aristotle is wrong about space, time, and matter.

Circles ARE the best! We just need more!

PTOLEMY
100–170
Greek living in Roman Egypt

Epicycles, equants, eccentrics

VĀRĀHAMIHIRA
505–587
Indian

I must gather more information for better astrology, and I shall share what I learn!

AL-BATTANI
858–929
Arab

Years from now, Copernicus will love me.

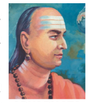
It just kee going, ar going

but not reall

Motion is indefinite without external forces

Accuracy is key (e.g., 365.24 days in a year)

With one little function, I'll give you the Moon!



ARYABHATA
476–550
Indian

Sines improve accuracy

Who knew nothing could be so useful?

BRAHMAGUPTA
598–668
Indian

Zero is a numeral unto itself

On the Heavens
Aristotle
c. 350 BCE

Physics
Aristotle
c. 320 BCE

Elements
Euclid
c. 300 BCE

The Almagest
Ptolemy
c. 150

Aryabhatiya
Aryabhata
c. 499

On Aristotle's Physics 3
Philoponus
c. 520

Pañca-siddhāntikā
Vārāhamihira
c. 575

Brahmasphuta-siddhanta
Brahmagupta
c. 628

TRANSLATION MOVEMENT WORKS

Kitāb az-Zīj
al-Battani
c. 900

Kitāb
Ibn

SUN AT CENTER (⊕ BELIEVED EARTH AT CENTER)

GNOMON
ASTROLABE
PRINTING PRESS

ARITHMETIC
ZERO AS PLACE HOLDER
ZERO AS NUMERAL
PLANAR GEOMETRY
SPHERICAL GEOMETRY
TRIGONOMETRY
SPRERICAL TRIGONOMETRY
ALGEBRA
TUSI COUPLE AND OTHER SPECIAL FORMS
LOGARITHMS

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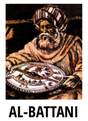


Years from now, Copernicus will love me.

AL-BATTANI
858–929
Arab

Metaphysics? Hooey! Give me evidence and math.

IBN AL-HAYTHAM
965–1040
Arab

Accuracy is key (e.g., 365.24 days in a year)

With one little function, I'll give you the Moon!

ARYABHATA
476–550
Indian

Who knew nothing could be so useful?

BRAHMAGUPTA
598–668
Indian

Zero is a numeral unto itself

If I use a teeny unit of time...

BHĀSKARA II
1114–1185
Indian

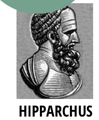
Much of what we today call calculus

Hello? Is this thing on?

ARISTARCHUS
310–230 BCE
Greek

Sun at center

Math can model the universe



I'm not sure Earth is exactly in the center?

HIPPARCHUS
190-120 BCE
Greek living in Rome

Sines improve accuracy

It just keeps going, and going... but not really.

IBN SINA (AVICENNA)
980–1037
Persian

Motion is indefinite without external forces

What did Aristotle really mean? We need to question.

IBN RUSHD (AVERROES)
1126–1198
Arab

Motion is a chain of an object's locations

Bigger observatories, better observations.

AL-TUSI
1201–1274
Persian

Simple circular orbits work with better math

This is math, not philosophy.

JEAN BURIDAN
1295–1358
French

Motion explained with "impetus theory"

Come on! You can't "give" an object motion.

NICOLE ORESME
1320–1382
French

Objects are "set into" motion

Earth need not be at rest, Ptolemy!

ALI QUSHJI
1403–1474
Turkic

The Earth might actually rotate

I can improve Ptolemy! To the printing press!

REGIOMONTANUS
1436–1476
German

Sun at center of Earth's & planets' orbits

Math first, philosophy later.

NICHOLAS COPERNICUS
1473–1543
Polish

With giant spendy instruments, I can get GREAT data.

Planets orbit the Sun, but Sun orbits Earth

TYCHO BRAHE
1546–1601
Danish

I have Tycho's fancy data!

Hmm... circles are a problem.

JOHANNES KEPLER
1571–1630
German

Orbits are ellipses, not circles

Jupiter has moons, which orbit like our Moon

Physics
Aristotle
c. 320 BCE

Elements
Euclid
c. 300 BCE

The Almagest
Ptolemy
c. 150

Aryabhatiya
Aryabhata
c. 499

On Aristotle's Physics 3
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Vārāhamihira
c. 575

Brahmasphuta-siddhanta
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c. 628

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c. 900

Kitāb al-Shifa'
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Ibn al-Haytham
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Siddhānta Shiromani
Bhāskara II
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Commentaries on Aristotle
Ibn Rushd
c. 1150-1200

Alfonsine Tables
1252

Al-Tadhkirah fi'ilm al-hay'ah
al-Tusi
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Epitome of the Almagest
Regiomontanus
1496

De Revolutionibus
Copernicus
1543

Astronomia Nova
Johannes Kepler
1609

Siderius Nuncius
Galileo
1610

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PREDICTIONX

SUN AT CENTER (⊕ BELIEVED EARTH AT CENTER)

GNOMON
ASTROLABE
PRINTING PRESS
TELESCOPE
ARITHMETIC
ZERO AS NUMERAL
PLANAR GEOMETRY
SPHERICAL GEOMETRY
TRIGONOMETRY
SPHERICAL TRIGONOMETRY
ALGEBRA
SPECIAL FORMS
LOGARITHMS
CALCULUS
TUSI COUPLE AND OTHER SPECIAL FORMS

Zero is a numeral unto itself

Accuracy is key (e.g., 365.24 days in a year)

Models matching data is paramount

Much of what we today call calculus

Motion is indefinite without external forces

Motion is a chain of an object's locations

Simple circular orbits work with better math

Motion explained with "impetus theory"

Objects are "set into" motion

The Earth might actually rotate

Sun at center of Earth's & planets' orbits

Orbits are ellipses, not circles

Sun is the center

Jupiter has moons, which orbit like our Moon

All bodies on Earth have (circular) inertia

All bodies have inertia

GRAVITY GOVERNS ALL

Some comets return, predictably

BRAHMAGUPTA
598–668
Indian

IBN SINA (AVICENNA)
980–1037
Persian

AL-BATTANI
858–929
Arab

IBN AL-HAYTHAM
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1473–1543
Polish

TYCHO BRAHE
1546–1601
Danish

JOHANNES KEPLER
1571–1630
German

GALILEO GALILEI
1564–1642
Italian

RENÉ DESCARTES
1596–1650
French

ISAAC NEWTON
1642–1726
British

EDMOND HALLEY
1656–1742
British

Zero as a numeral unto itself
Brahmagupta
c. 628

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Johannes Kepler
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Siderius Nuncius
Galileo
1610

Dialogue on the Two Chief Systems of the World
Galileo
1632

Two New Sciences
Galileo
1638

Principles of Philosophy
Descartes
1644

Principia
Isaac Newton
1687

Synopsis Astronomia Cometicae
Edmond Halley
1705

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PREDICTIONX

“ARE COMPUTERS THE NEW TELESCOPES?”

GNOMON
ASTROLABE
PRINTING PRESS
TELESCOPE

ARITHMETIC
ZERO AS NUMERAL
PLANAR GEOMETRY
SPHERICAL GEOMETRY
TRIGONOMETRY
SPHRERICAL TRIGONOMETRY
ALGEBRA
SPECIAL FORMS
LOGARITHMS
CALCULUS

ELECTRONIC COMPUTERS

NUMERICAL SIMULATION
BAYESIAN STATISTICS
INTERACTIVE DATA VISUALIZATION
AI/MACHINE LEARNING

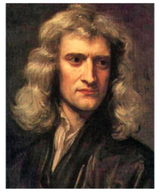
I like Dutch glass!

Sorry, Aristotle, you’re just wrong.

GALILEI

Aristotle, mon ami, above and below, it’s all matter

We’re gonna need better math.

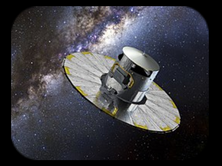


This apple. That moon. Could they feel the same pull?

SEAMLESS ASTRONOMY
Linking scientific data, publications, and communities

= 3D dust mapping*

+ Gaia*



+ glue*

+ WorldWide Telescope

*2 million CPU hours, Harvard

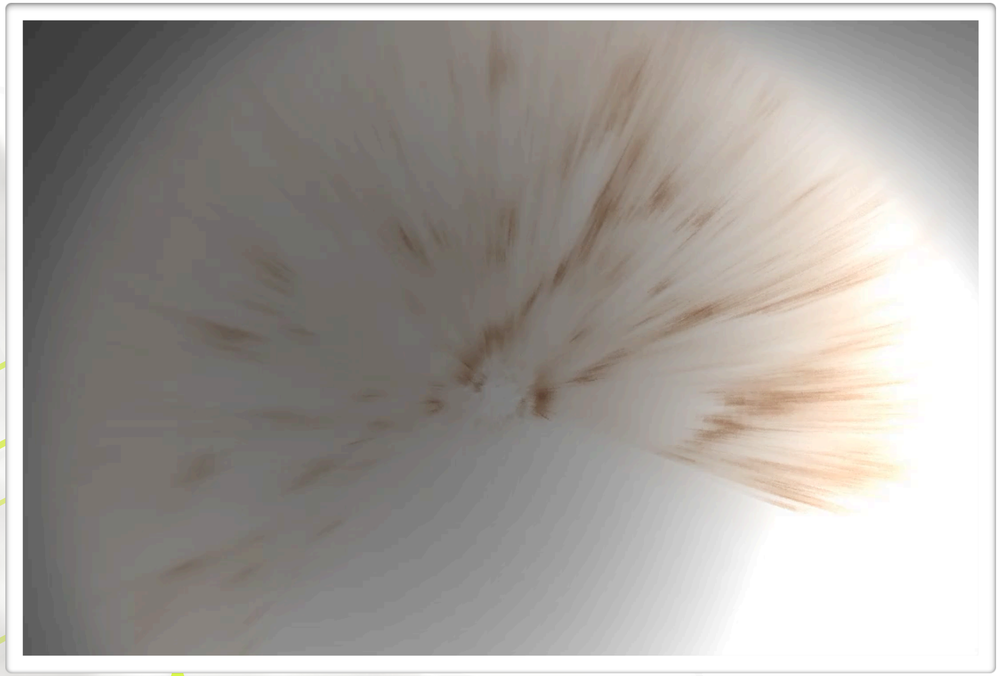
*800 million stars, ESA

*NASA/JWST, NSF

*Microsoft Research, NSF, AAS

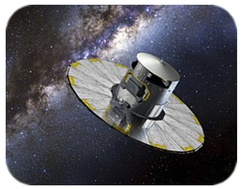
3D dust mapping

Extinction & Reddening, from Color Imaging



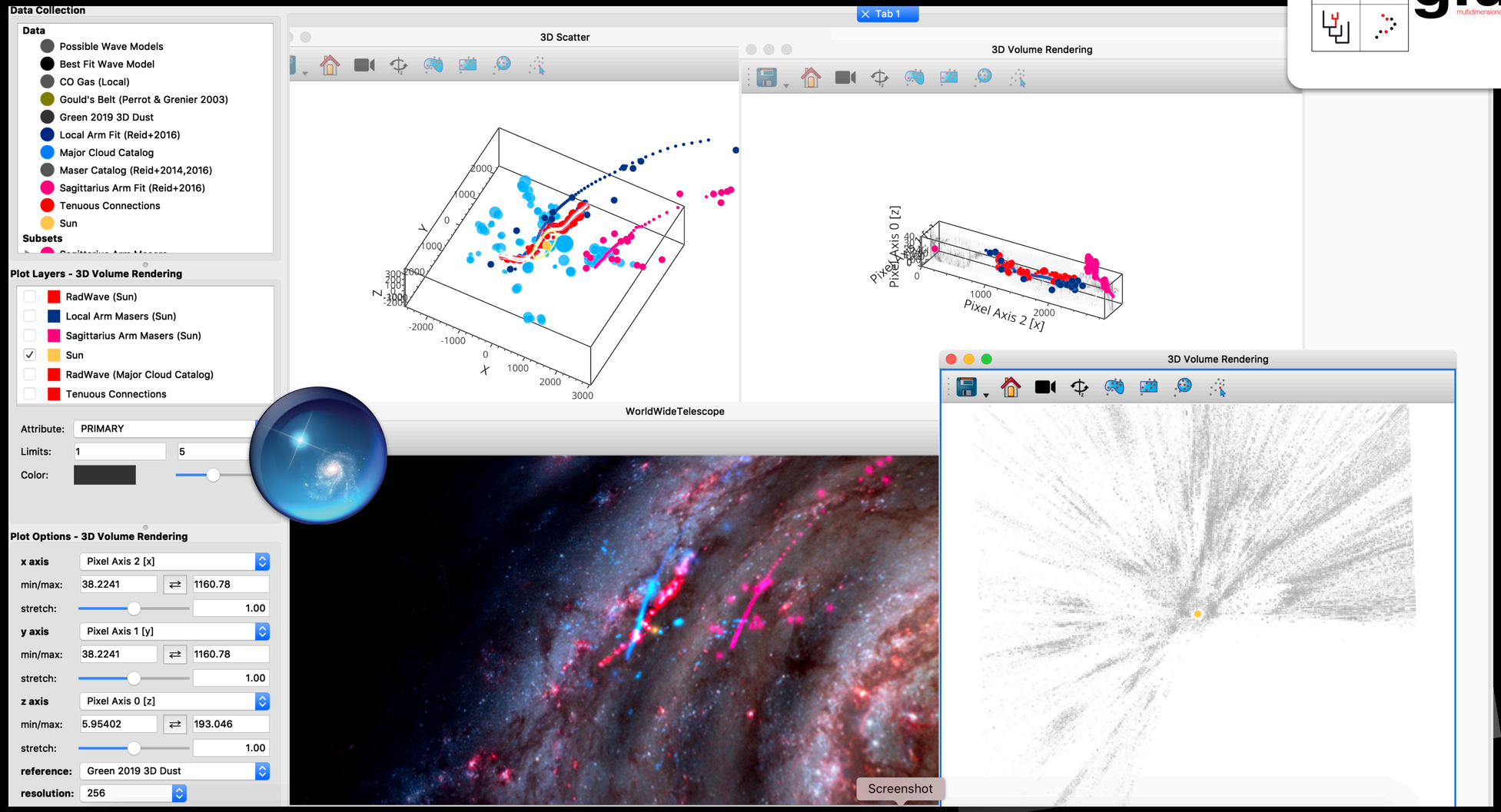
Green et al. 2019

Can infer matter's distance from *dust's* effects on stars.



WARNING: schematic diagram, NOT to scale (credit A. Goodman, 2019)

“Seeing” The Radcliffe Wave, in 3D



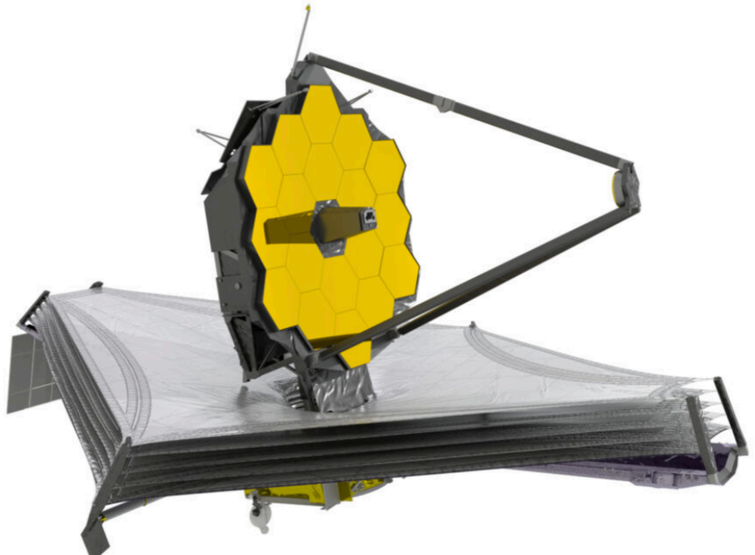
AAS WorldWide Telescope: worldwidetelescope.org

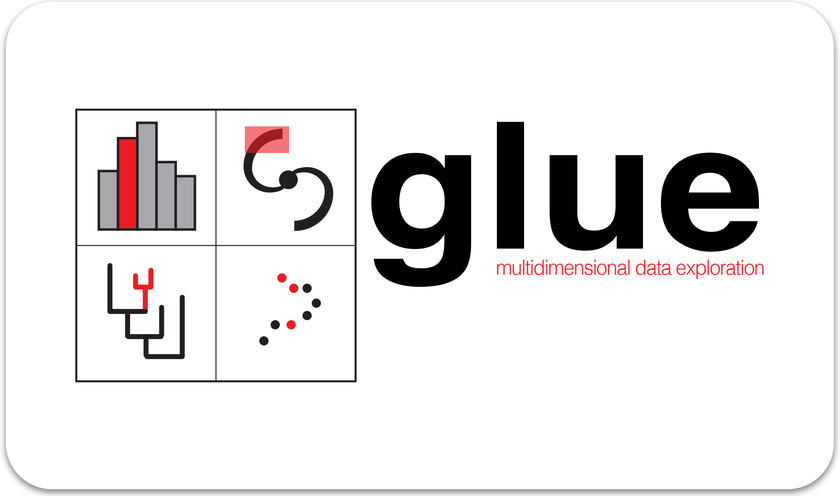
glue: glueviz.org

glue & the Webb Telescope ❤ a match made for the heavens!

All 10QViz Posts
Who
Explore-Explain
Predictions & Uncertainty
Dimensions
Patterns
Abstraction & Accuracy
Context & Scale
Display modes
Other
SUCCESSES

10QVizTeam July 11, 2022





10qviz.org/glue-how-did-they-meet/

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Choose by Question

Select Category

Combined Searches

You may select any of the categories below to find content of interest that addresses multiple questions.

Tags

3DPDF asteroid astronomy color colour communication COVID-19 epidemiology fun glue high-dimensional data JWST pie charts presentation rainbow research software storytelling time-lapse timelines Webb

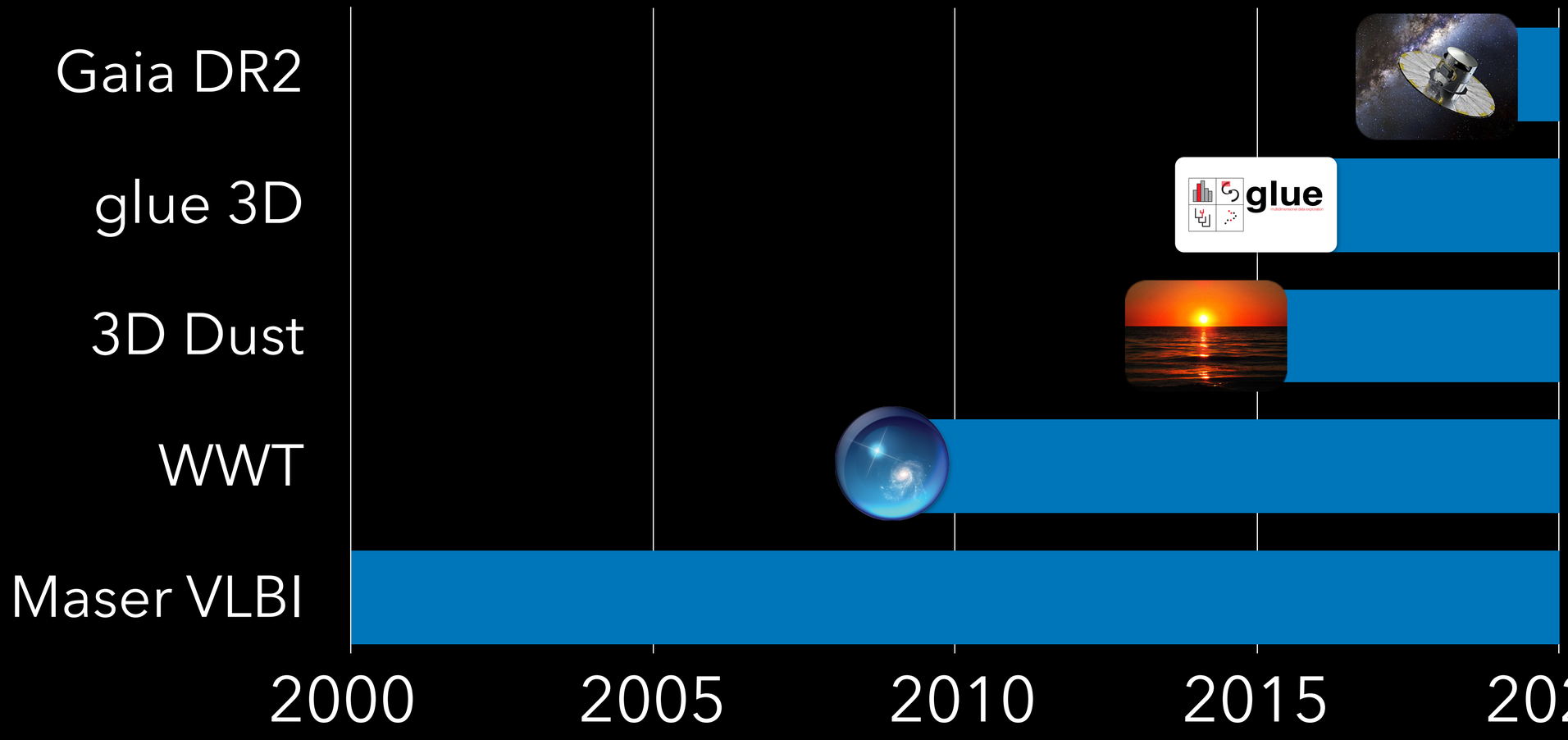
WHY DIDN'T WE FIND THE RADCLIFFE WAVE SOONER?

It's not apparent in 2D on the Sky. 3D is *REQUIRED*.

AAS WorldWide Telescope: worldwidetelescope.org glue: glueviz.org

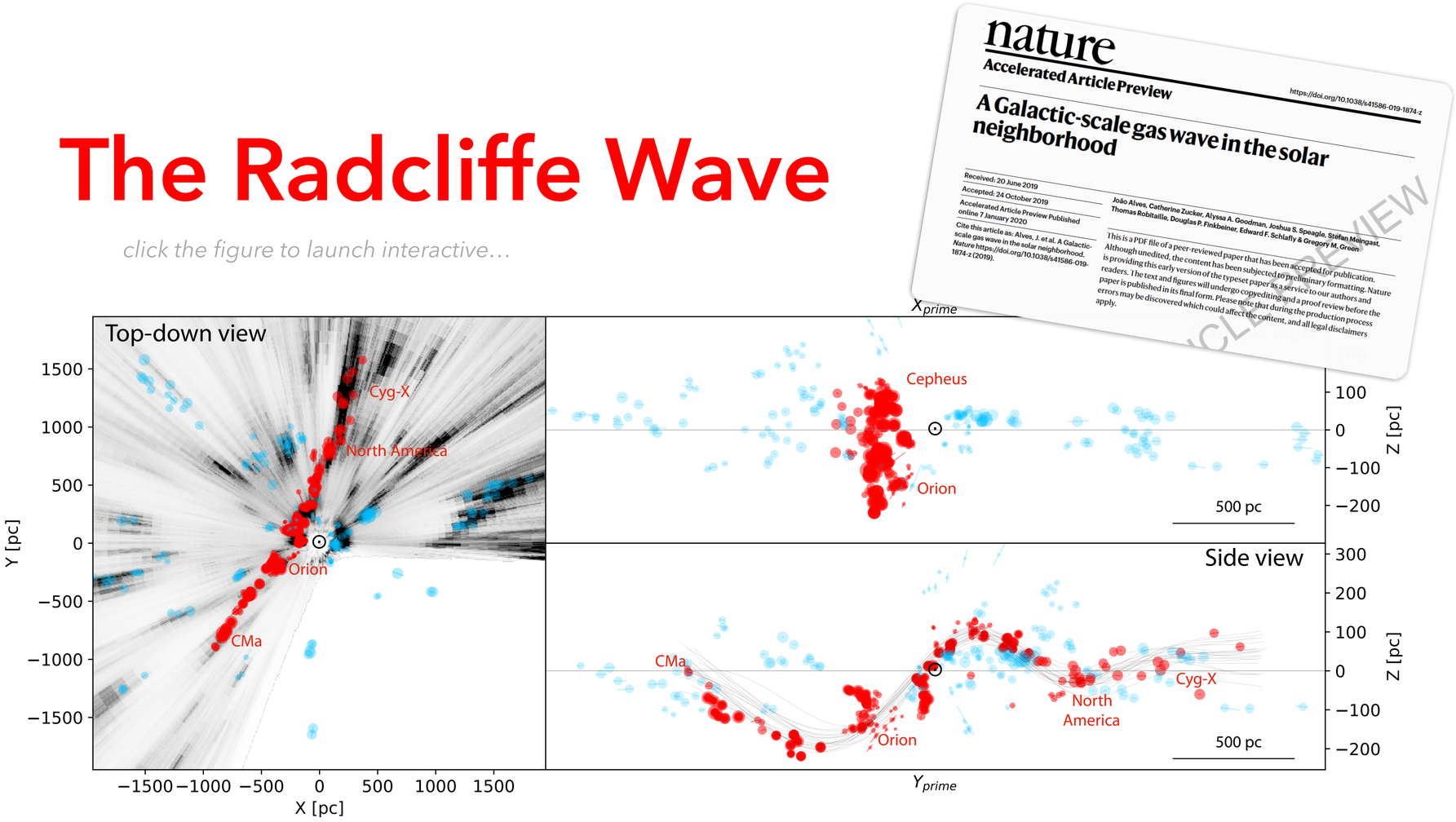
SEAMLESS ASTRONOMY
Linking scientific data, publications, and communities

WHY DIDN'T WE FIND THE RADCLIFFE WAVE SOONER?



The Radcliffe Wave

click the figure to launch interactive…



RADWAVE

Surprising wave-like arrangement of star-forming gas *is* the "Local Arm" of the Milky Way.

João Alves, Catherine Zucker, Alyssa Goodman, Joshua Speagle, Stefan Meingast, Thomas Robitaille, Douglas Finkbeiner, Edward F. Schlafly, and Gregory Green 2020, *Nature* (today)

Alves et al. *Nature* paper & two distance catalog papers by Zucker et al. (2019, 2020) include several interactive figures (via plot.ly & bokeh), and deep links to data (on Dataverse) and code (on GitHub) inspired by AAS "Paper of the Future" (Goodman et al. 2015)

Open Questions

What is the ORIGIN of the Radcliffe Wave? Collision?

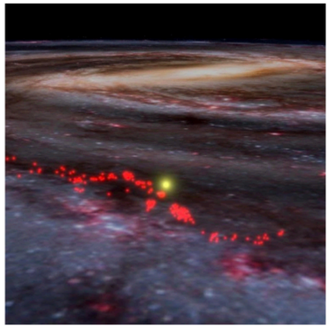
Do other parts of the Milky Way show this wavy structure? How about other galaxies? How can we SEARCH?

What do “waves “ mean for the STAR-FORMING HISTORIES of galaxies?

DIMENSIONS OF DISCOVERY

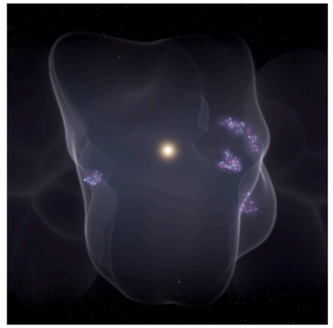
A web page created by Alyssa Goodman to showcase the use of technology in research, education, and communication, of science and more.

What's happening "these days?" A sampler of ongoing and recent projects.



The Radcliffe Wave

A gigantic "wave" of dense gas that forms the spine of the Local Arm of the Milky Way. (Alves et al. 2020, *Nature*)



The Local Bubble

A 1000-light-year-wide bubble surrounding the Sun and Earth is apparently responsible for the formation of all nearby, young stars. (Zucker et al. 2022, *Nature*)

PredictionX

The best place to learn more about the past, present, and future of the future. Through dynamic online learning, PredictionX uncovers the role of uncertainty in the world around us.

Data + Climate

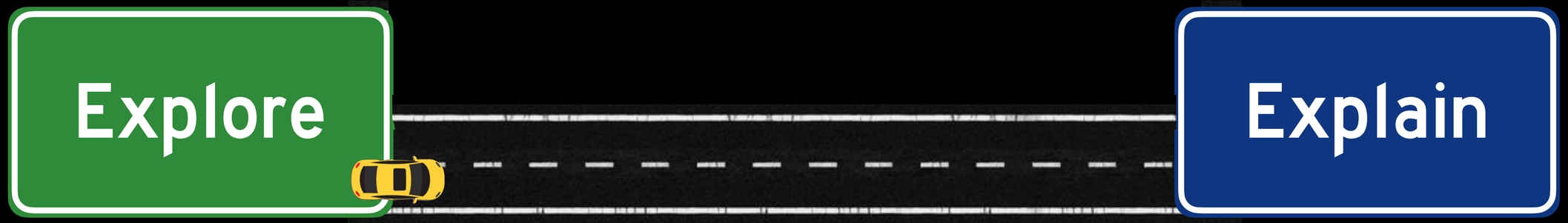
A collaboration of researchers at Harvard and Google, making data discoverable and available to researchers seeking to uncover novel solutions to climate and su

tinyurl.com/dimensionsofdiscovery

When to use what technology?

DIMENSIONS OF DISCOVERY

Traditionally, travel from exploration to explanation is called
"Scholarly Publishing" if its *dry*, and "Public Outreach," if it's *beautiful*.



It’s much harder to go the other way.

Explore
And, the *best* roads are two-way.
Explain

DATA,
CODE,
COLLABORATION

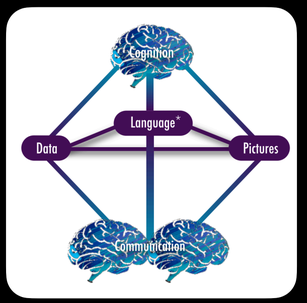
DATA-DRIVEN STORYTELLING

This is all possible, and happening now.

Not for everyone, though.

read how & why in *"New Thinking on, and with, Data Visualization"*
(Goodman, Borkin & Robitaille arxiv.org/abs/1805.11300)

Learn more in the "Seeing More of the Universe"
playlist on YouTube.

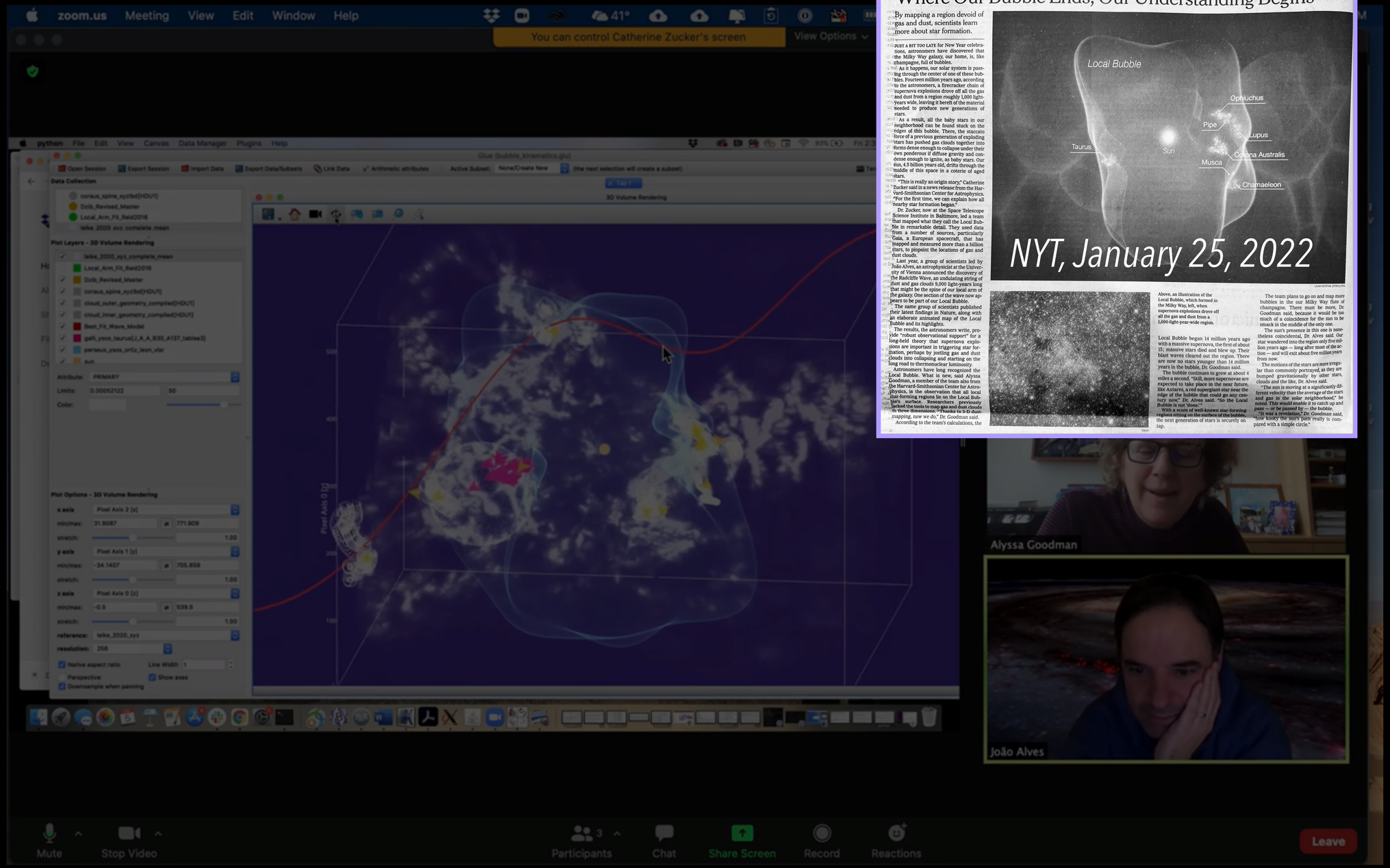


collaborative
software
development

plug-in
architecture

EXPLORATION | EXPLANATION

Explore-Explain: glue-WWT-plot.ly



Explore-Explain: glue-WWT-plot.ly

Article

Star formation near the Sun is driven by expansion of the Local Bubble

https://doi.org/10.1038/s41586-021-04286-5

Received: 18 August 2021

Accepted: 26 November 2021

Published online: 12 January 2022

Check for updates

Catherine Zucker[1,2]✉, Alyssa A. Goodman[1], João Alves[3], Shmuel Bialy[1,4], Michael Foley[1], Joshua S. Speagle[5,6,7], Josefa Großschedl[3], Douglas P. Finkbeiner[1,8], Andreas Burkert[9,10], Diana Khimey[1] & Cameren Swiggum[3,11]

For decades we have known that the Sun lies within the Local Bubble, a cavity of low-density, high-temperature plasma surrounded by a shell of cold, neutral gas and dust[1–3]. However, the precise shape and extent of this shell[4,5], the impetus and timescale for its formation[6,7], and its relationship to nearby star formation[8] have remained uncertain, largely due to low-resolution models of the local interstellar medium. Here we report an analysis of the three-dimensional positions, shapes and motions of dense gas and young stars within 200 pc of the Sun, using new spatial[9–11] and dynamical constraints[12]. We find that nearly all of the star-forming complexes in the solar vicinity lie on the surface of the Local Bubble and that their young stars show outward expansion mainly perpendicular to the bubble's surface. Tracebacks of these young stars' motions support a picture in which the origin of the Local Bubble was a burst of stellar birth and then death (supernovae) taking place near the bubble's centre beginning approximately 14 Myr ago. The expansion of the Local Bubble created by the supernovae swept up the ambient interstellar medium into an extended shell that has now fragmented and collapsed into the most prominent nearby molecular clouds, in turn providing robust observational support for the theory of supernova-driven star formation.

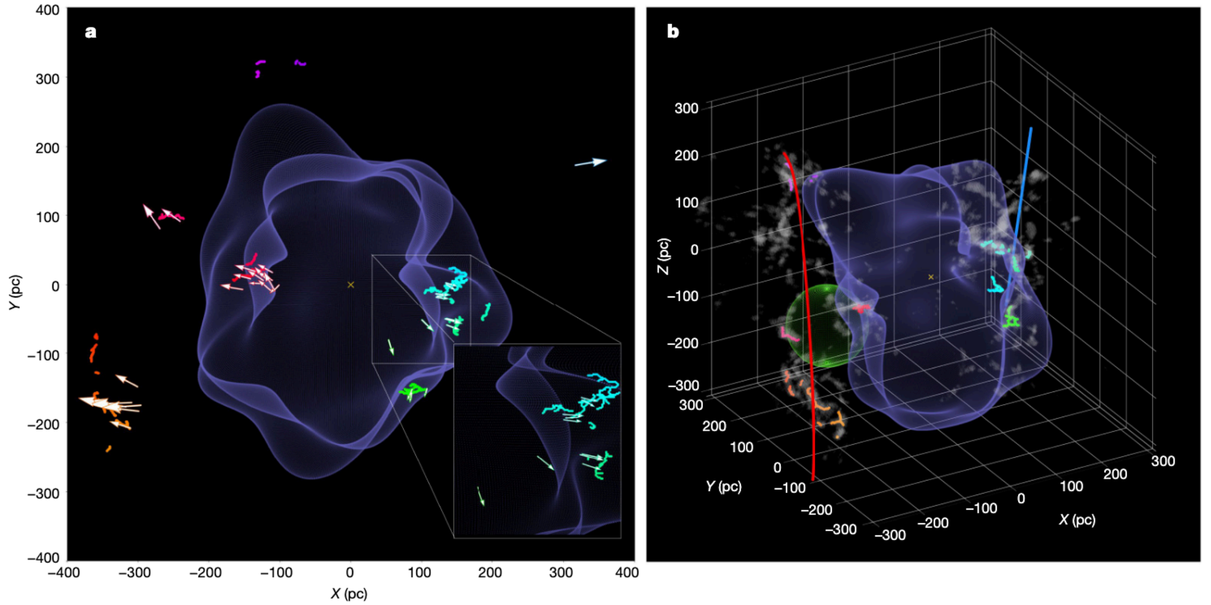


Fig. 1 | A 3D spatial view of the solar neighbourhood. For the best experience, please view the online 3D interactive version available in Supplementary Fig. 1. **a**, A top-down projection of star-forming regions on the surface of the Local Bubble, whose young stars show motion mainly perpendicular to its surface. The surface of the Local Bubble[13] is shown in purple. The short squiggly coloured lines (or 'skeletons') demarcate the 3D spatial morphology of dense gas in prominent nearby molecular clouds[11]. The 3D arrows indicate the positions of young stellar clusters, with the apex of the arrow's cone pointing in the direction of stellar motion. Clusters are colour-coded by longitude, as in Extended Data Table 1. The Sun is marked with a yellow cross. The enlargement to the lower right shows a close-up of Ophiuchus, Pipe, Lupus and Corona Australis on the bubble's surface, along with arrows illustrating the outward motion of their young stellar clusters. **b**, A 3D view of the relationship between the Local Bubble, prominent nearby star-forming regions and Galactic structure. The Local Bubble and cloud skeletons are the same as in **a**. We also overlay the morphology of the 3D dust (grey blobby shapes[9]) and the models for two Galactic scale features—the Radcliffe Wave (red)[16] and the Split (blue)[10]. The Per-Tau Superbubble[15] (green sphere) is also overlaid. The interactive version offers views from any direction (not just top-down), provides floating labels for star-forming regions and includes additional layers (some not shown in this snapshot), which can be toggled on/off.

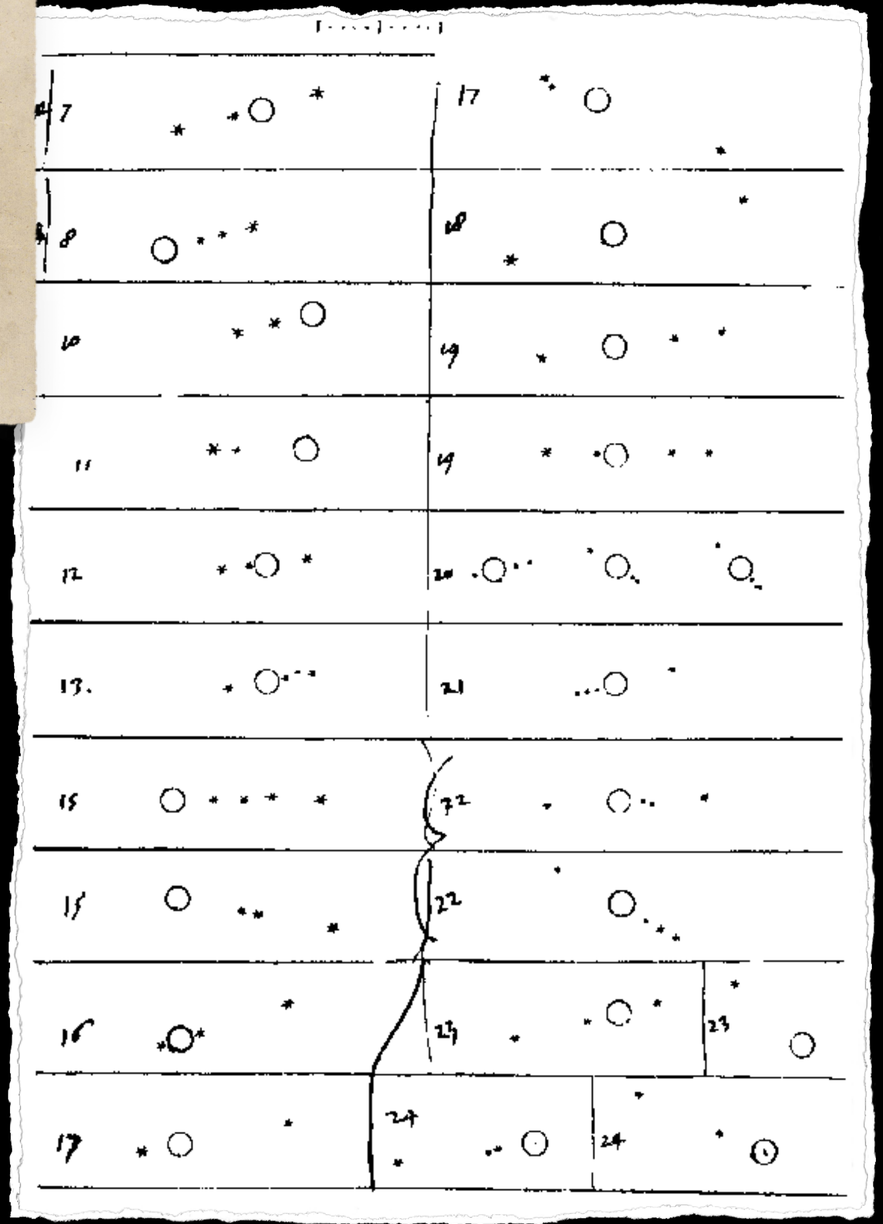
[try the interactive figure]

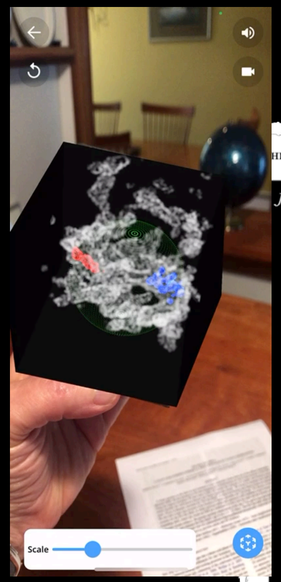
ARE COMPUTERS THE NEW TELESCOPES?

(GALILEO →) AUGMENTED REALITY

SIDEREVS
NVNCIVS
MAGNA, LONGEQVE ADMIRABILIA
Spectacula pandens, suspiciendaque proponens
vnicuique, præsertim verò
PHILOSOPHIS, atq; ASTRONOMIS, quæ à
GALILEO GALILEO
PATRITIO FLORENTINO
Patauini Gymnasij Publico Mathematico
PERSPICILLI
Nuper à se reperti beneficio sunt obseruata in IVNÆ FACIE, FIXIS IN-
NVMERIS, LACTEO CIRCVLO, STELLIS NEBVLOSIS,
Apprime verò in
QVATVOR PLANETIS
Circa IOVIS Stellam disparibus interuallis, atque periodis, celeri-
tate mirabili circumuolutis; quos, nemini in hanc vsque
diem cognitos, nouissimè Author depræ-
hendit primus; atque
MEDICEA SIDERA
NVNCVPANDOS DECREVIT.
VENETIIS, Apud Thomam Baglionum. M D C X.
Superiorum Permissu, & Priuilegio.
M VIIII 22. 14.

Galileo, **1610**





Bialy et al., **2021**

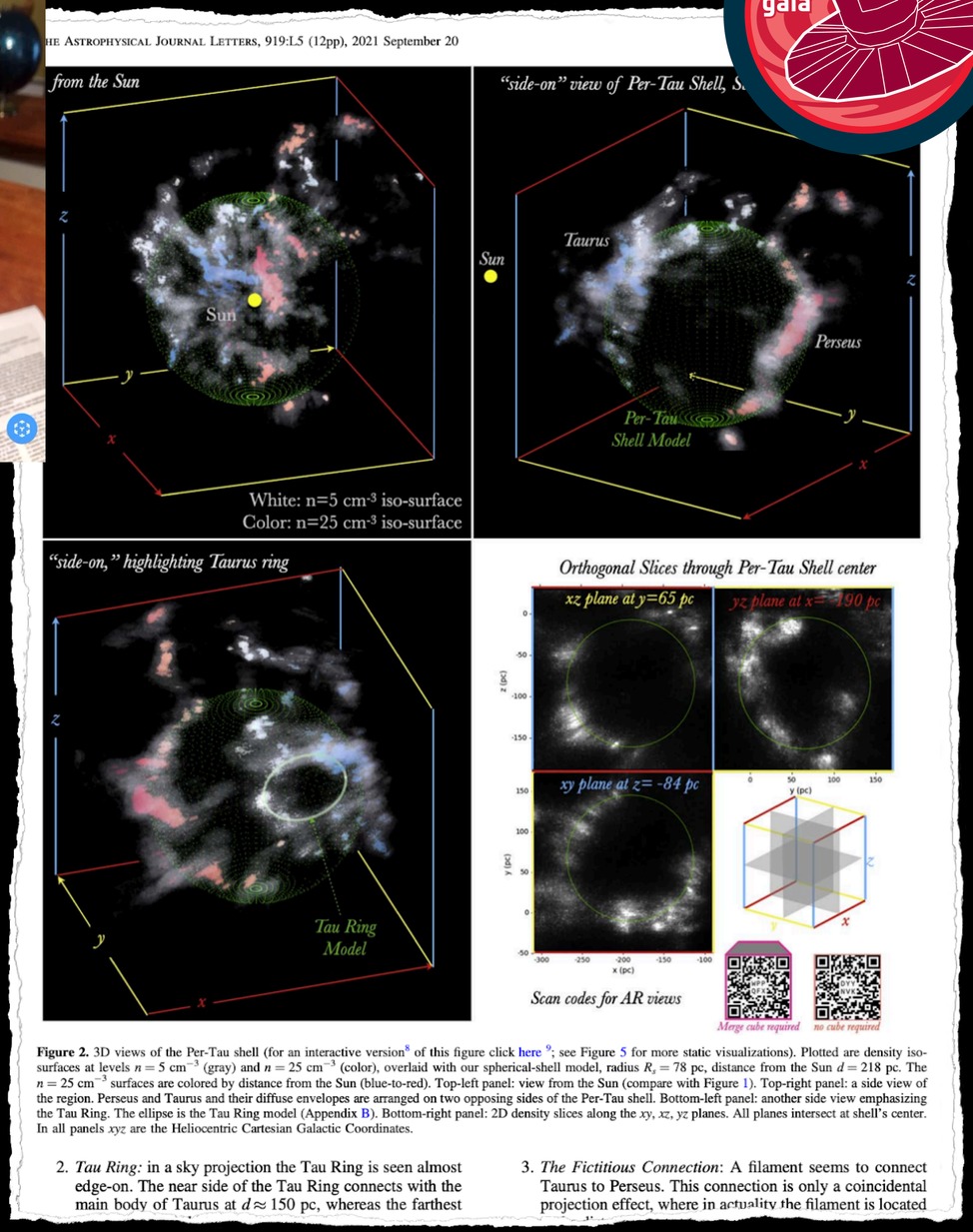
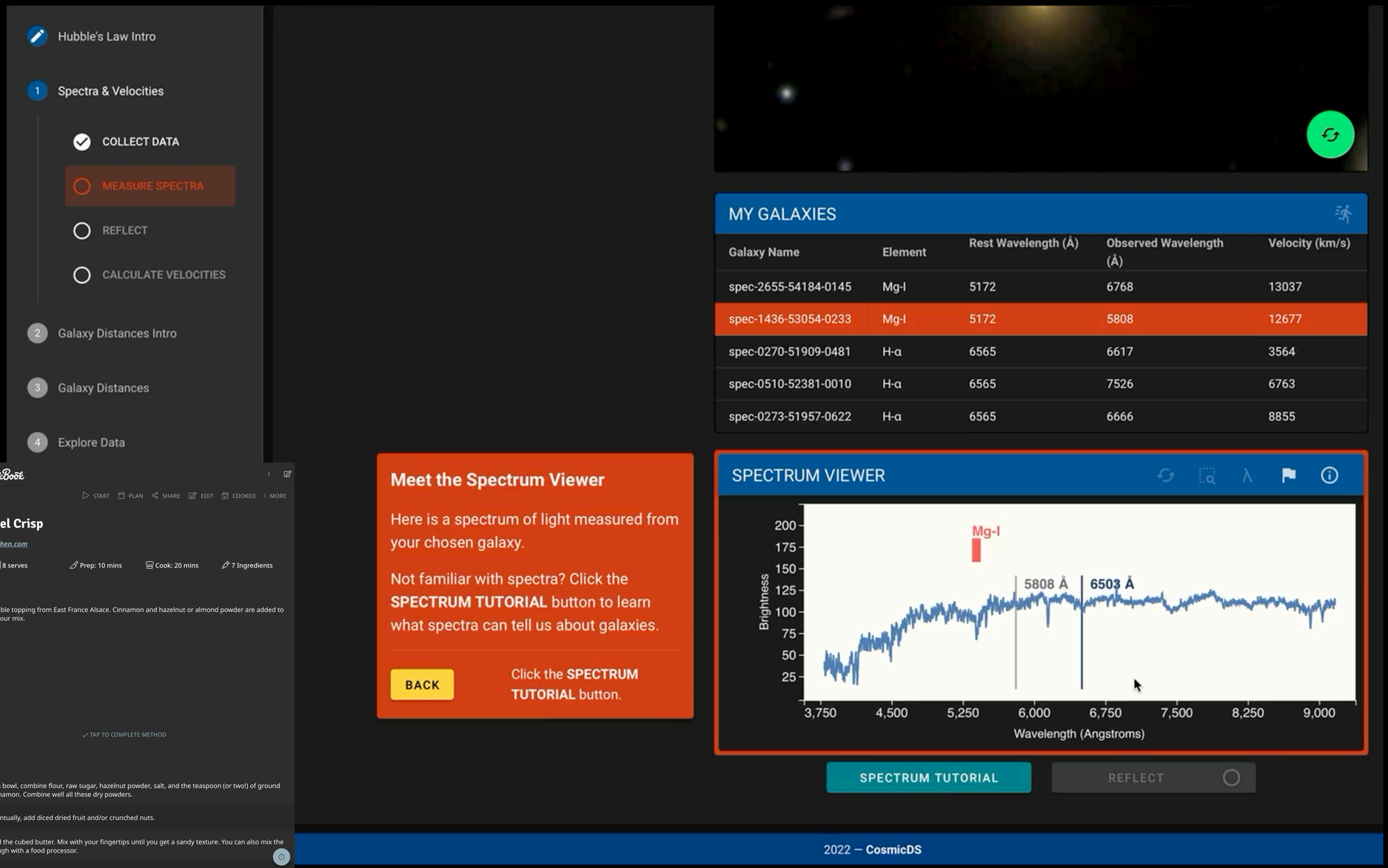

HE ASTROPHYSICAL JOURNAL LETTERS, 919:L5 (12pp), 2021 September 20

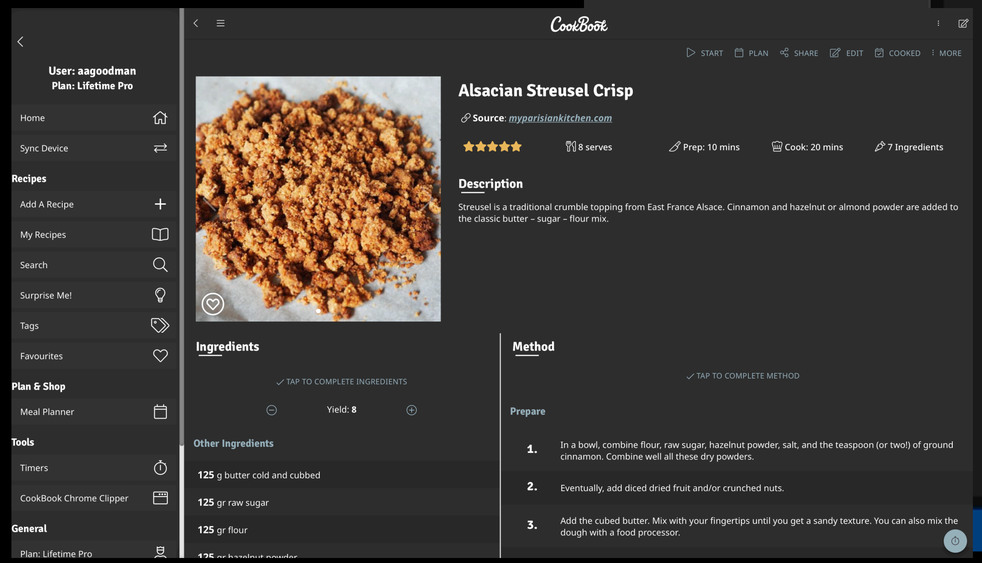
Figure 2. 3D views of the Per-Tau shell (for an interactive version[8] of this figure click here [9]; see Figure 5 for more static visualizations). Plotted are density iso-surfaces at levels $n = 5$ cm^{-3} (gray) and $n = 25$ cm^{-3} (color), overlaid with our spherical-shell model, radius $R_s = 78$ pc, distance from the Sun $d = 218$ pc. The $n = 25$ cm^{-3} surfaces are colored by distance from the Sun (blue-to-red). Top-left panel: view from the Sun (compare with Figure 1). Top-right panel: a side view of the region. Perseus and Taurus and their diffuse envelopes are arranged on two opposing sides of the Per-Tau shell. Bottom-left panel: another side view emphasizing the Tau Ring. The ellipse is the Tau Ring model (Appendix B). Bottom-right panel: 2D density slices along the xy, xz, yz planes. All planes intersect at shell's center. In all panels xyz are the Heliocentric Cartesian Galactic Coordinates.

2. *Tau Ring:* in a sky projection the Tau Ring is seen almost edge-on. The near side of the Tau Ring connects with the main body of Taurus at $d \approx 150$ pc, whereas the farthest

3. *The Fictitious Connection*: A filament seems to connect Taurus to Perseus. This connection is only a coincidental projection effect, where in actuality the filament is located

COMPUTERS & DATA SCIENCE AS THE NEW TELESCOPES FOR LEARNERS





app.thecookbookapp.com

Cosmic DS

from Hubble to HST

LET'S RE-MAKE EDWIN HUBBLE'S GRAPH

What do graphs really mean?

USING HUBBLE'S DATA

	Galaxy	Distance (Mpc)	Velocity (km/s)
0	SMC	0.032	170
1	LMC	0.03	290
2	NGC6822	0.214	-130

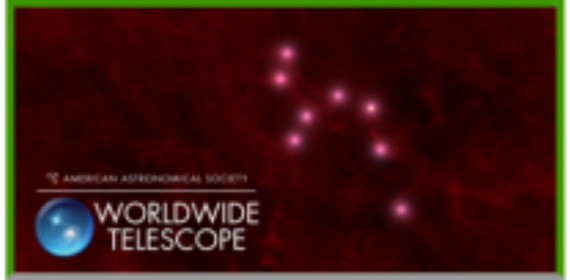
How do rows in a table relate to points on a graph or map?

glue

HOW BRIGHT ARE THE GALAXIES?

What's a "distribution"?

WHERE ON THE SKY ARE HUBBLE'S GALAXIES?

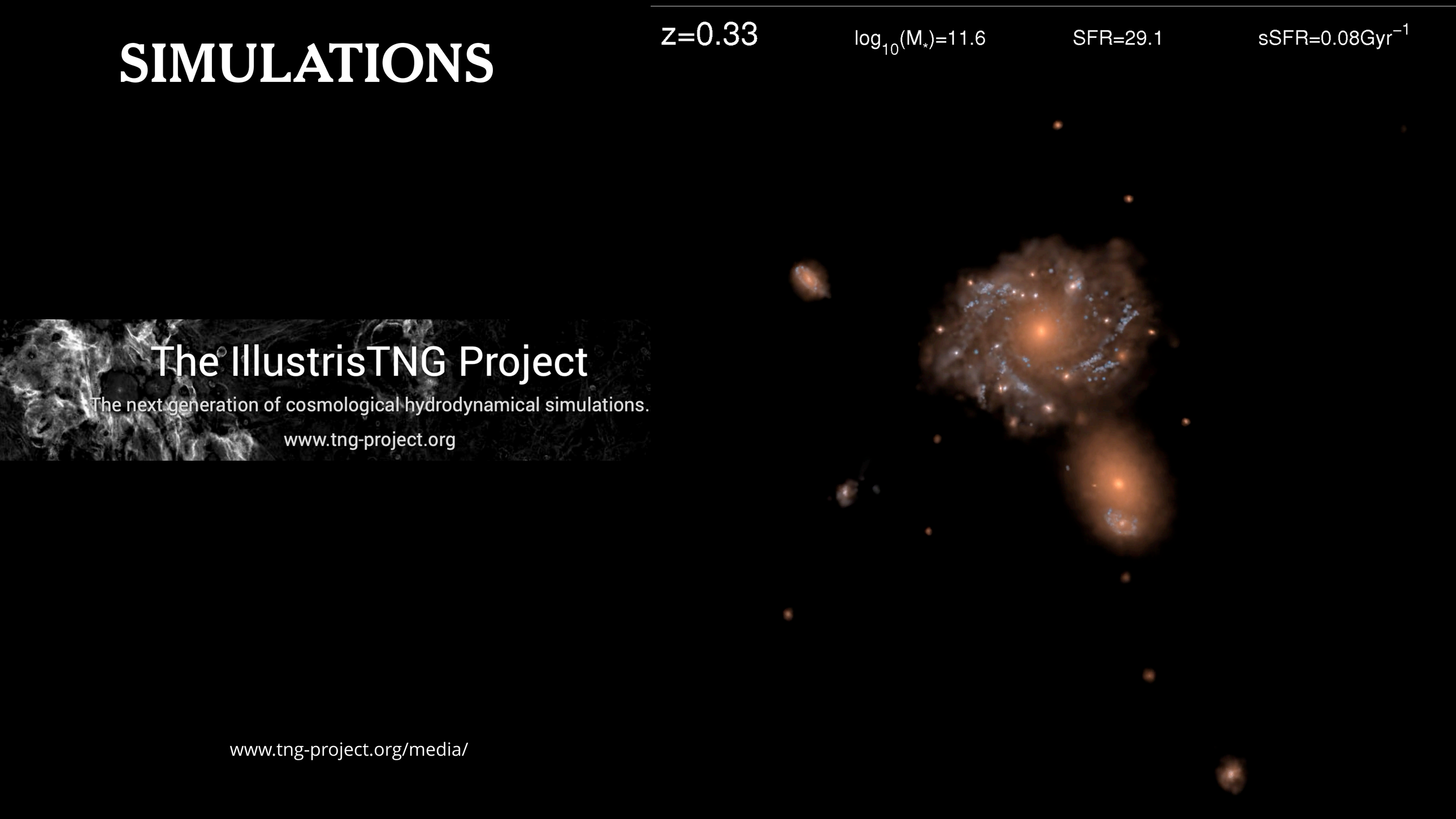


How to show data using a map or an image.

ARE COMPUTERS THE NEW TELESCOPES?

SIMULATIONS & LEARNED UNIVERSES

SIMULATIONS

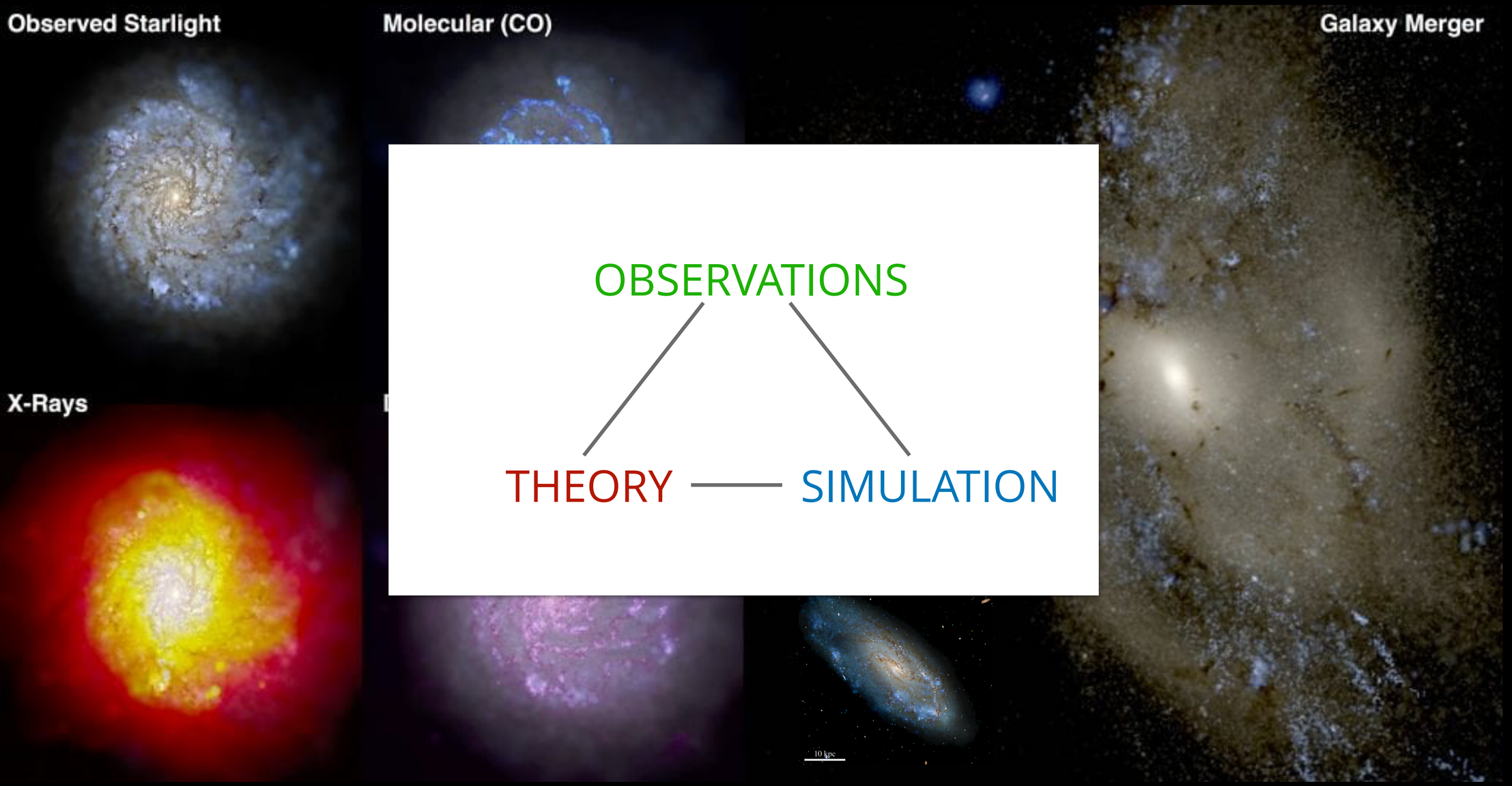


www.tng-project.org/media/

SIMULATIONS

FIRE: Feedback In Realistic Environments

Increasing the predictive power of galaxy formation simulations



OBSERVATIONS

THEORY —— SIMULATION

fire.northwestern.edu/visualizations/

LEARNED UNIVERSES

RESEARCH ARTICLE | ASTRONOMY |

AI-assisted superresolution cosmological simulations

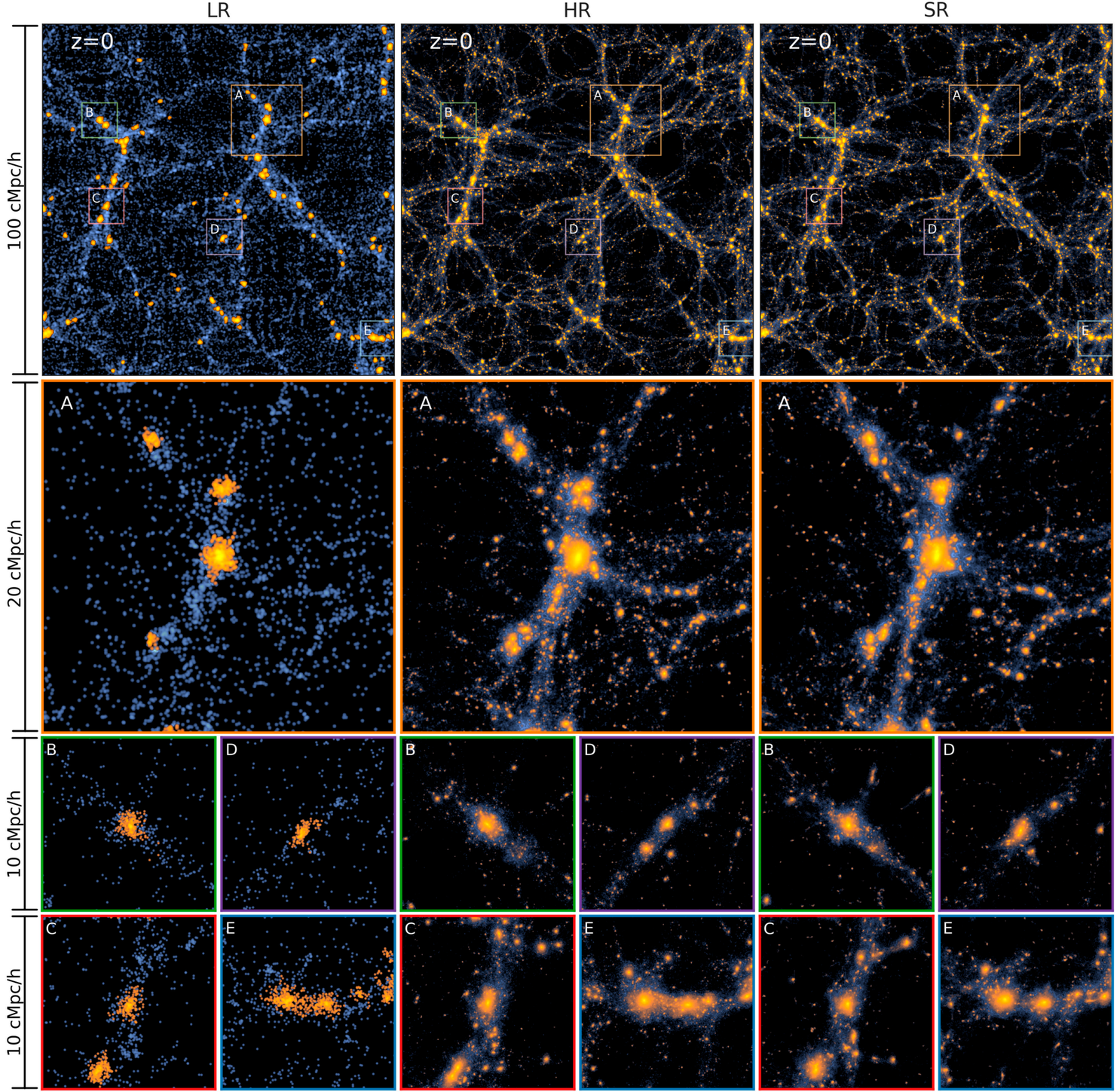
Yin Li, Yueying Ni, Rupert A. C. Croft, +2, and Yu Feng Authors Info & Affiliations

Edited by Neta A. Bahcall, Princeton University, Princeton, NJ, and approved March 11, 2021 (received for review October 26, 2020)

May 4, 2021 | 118 (19) e2022038118 | https://doi.org/10.1073/pnas.2022038118

Significance

Cosmological simulations are indispensable for understanding our Universe, from the creation of the cosmic web to the formation of galaxies and their central black holes. This vast dynamic range incurs large computational costs, demanding sacrifice of either resolution or size and often both. We build a deep neural network to enhance low-resolution dark-matter simulations, generating superresolution realizations that agree remarkably well with authentic high-resolution counterparts on their statistical properties and are orders-of-magnitude faster. It readily applies to larger volumes and generalizes to rare objects not present in the training data. Our study shows that deep learning and cosmological simulations can be a powerful combination to model the structure formation of our Universe over its full dynamic range.



www.pnas.org/doi/10.1073/pnas.2022038118

Opinion

The Next Universe

MEMPHIS, SUNDAY OCTOBER 23, ***2042***

PHYSICISTS HAD GRAVITY "WRONG"

ARTIFICIAL INTELLIGENCE BUILDS ITS OWN UNIVERSE

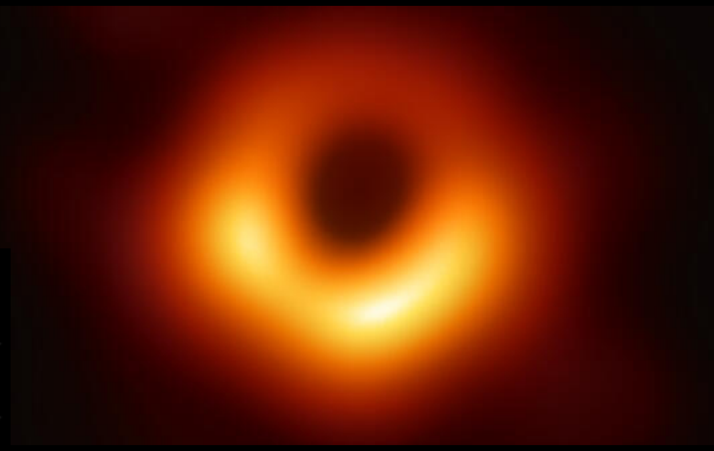
VIRTUAL PLANET TOURISM BOOMING GALAXIES COME SECOND

Editor: Alyssa Goodman, Center for Astrophysics | Harvard & Smithsonian, @AlyssaAGoodman

The Next Universe

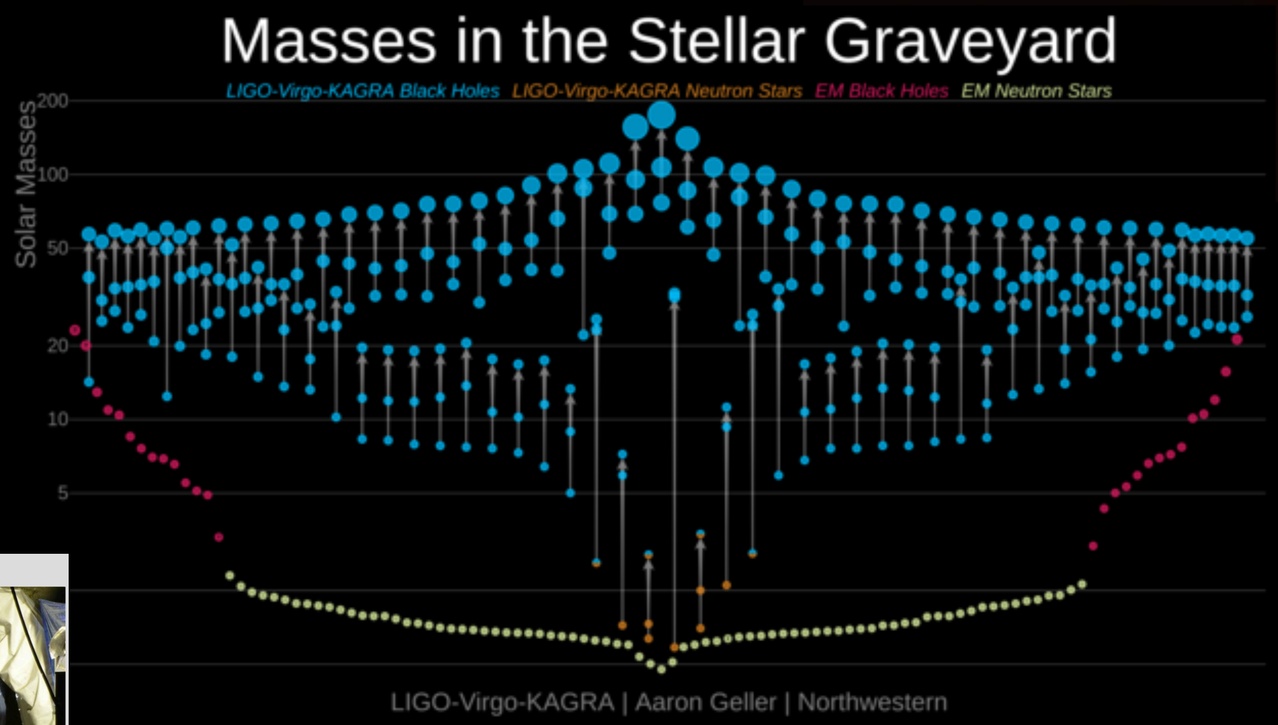
Nancy Grace Roman Telescope, “Late 2020s”

IS EINSTEIN'S THEORY OF GRAVITY ENOUGH?

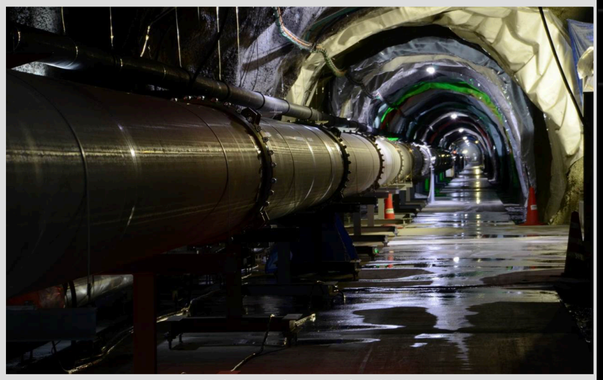


Event Horizon Telescope

LIGO



KAGRA



KAGRA's Y-arm under construction. (KAGRA)

Japan is currently building a 3 km interferometer inside of the Kamioka mine (also home to the Super Kamiokande neutrino detector). Being underground, the detector will be exposed to much less seismic vibration than surface instruments like LIGO, Virgo and GEO600. **KAGRA** will also use cryogenic systems, meaning that the optics will be cooled to such a degree that molecular vibrations within the material itself will be brought almost to a stop (the key to detecting gravitational waves is to isolate the detector from any and all Earthly vibrations that might mimic or mask a gravitational wave vibration; that includes vibrating molecules in mirrors and their coatings). Full-scale operation of this observatory is expected to commence in 2020.

www.ligo.caltech.edu/LA/page/ligo-sister-facilities

VIRGO

KAGRA Observatory

Testing Einstein's theory of gravity from the shadows and collisions of black holes

by Ethan Payne, ARC Centre of Excellence for Gravitational Wave Discovery

Artist's impression of binary black holes about to collide. Credit: Mark Myers, OzGrav-Swinburne Univer…

General relativity, Einstein's theory of gravity, is best tested at its most extreme—close to the event horizon of a black hole. This regime is accessible through observations of shadows of supermassive black holes and gravitational waves—ripples in the fabric of our Universe from colliding stellar-mass black holes. For the first time, scientists from the ARC Center of Excellence for Gravitational Wave Discovery (OzGrav), the Event Horizon Telescope (EHT) and the LIGO Scientific Collaboration, have outlined a consistent approach to exploring deviations from Einstein's general theory of relativity in these two different observations. This research, published in *Physical Review D*, confirms that Einstein's theory accurately describes current observations of black holes, from the smallest to the largest.

phys.org/news/2021-04-einstein-theory-gravity-shadows-collisions.html

Astronomers Gear Up to Grapple with the High-Tension Cosmos

A debate over conflicting measurements of key cosmological properties is set to shape the next decade of astronomy and astrophysics

By Anil Ananthaswamy

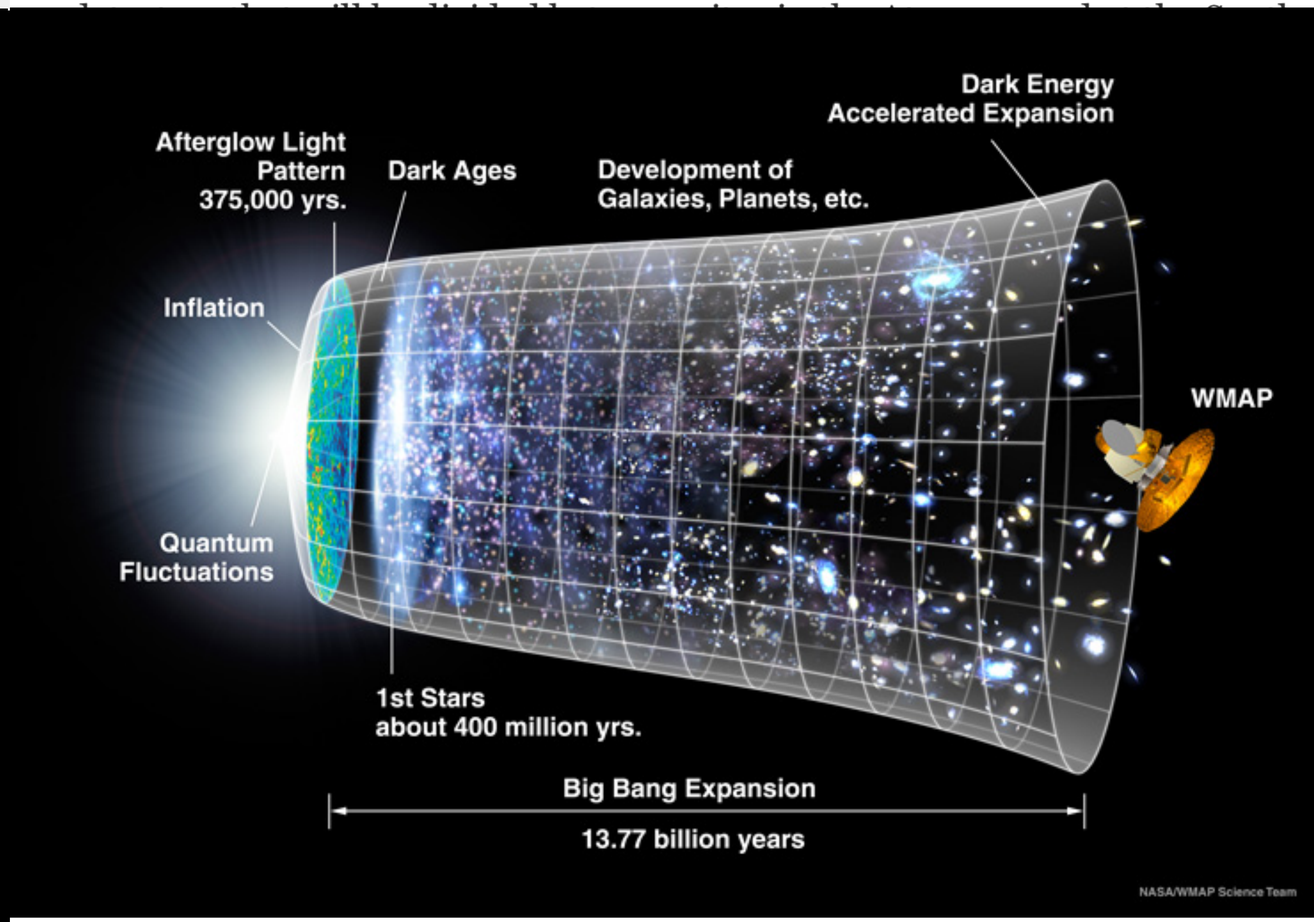
*“These twin tensions—between expectation and observation, between the early and late universe—may reflect some **deep flaw in the Standard Model of cosmology**, which encapsulates our knowledge and assumptions about the universe. Finding and fixing that flaw could transform our understanding of the cosmos."*

JWST
Simons Observatory
CMB-S4

Euclid
Nancy Grace Roman Telescope
Vera C. Rubin Observatory

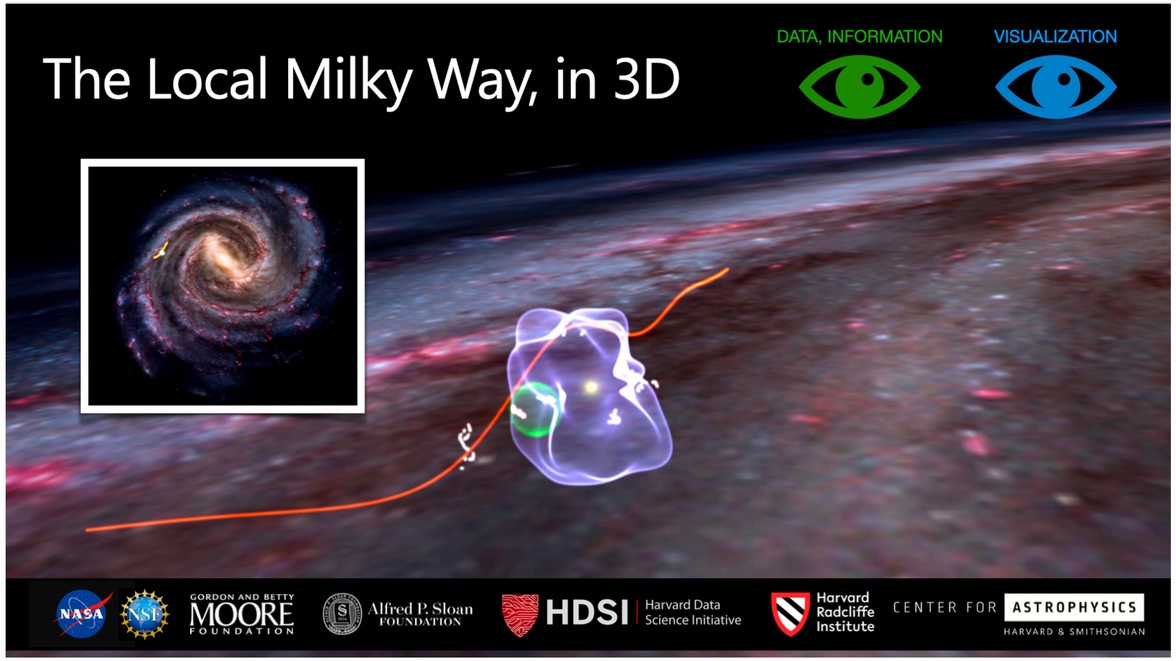
www.scientificamerican.com/article/astronomers-gear-up-to-grapple-with-the-high-tension-cosmos/

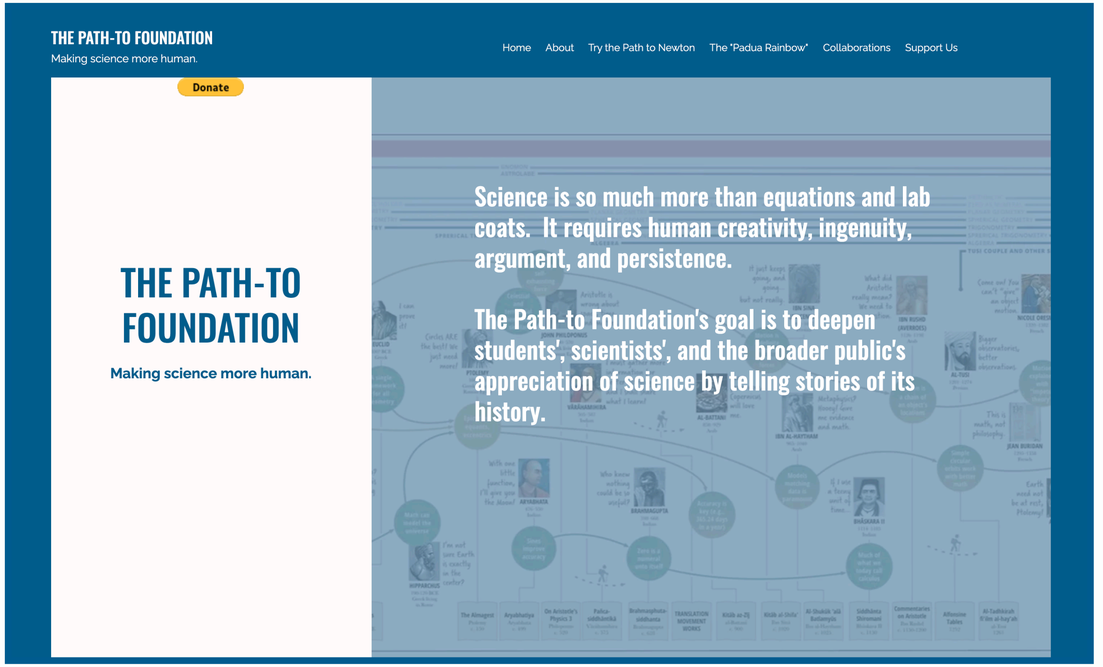
The third generation is only now starting to take the stage with the successful launch and deep-space deployment of Hubble's successor, the James Webb Space Telescope (JWST). On Earth, radio telescope arrays such as the Simons Observatory in the Atacama Desert in Chile and the CMB-S4, a future assemblage of 21 dishes and half a million cryogenically cooled

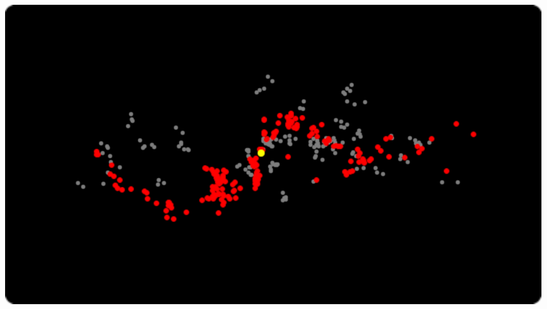


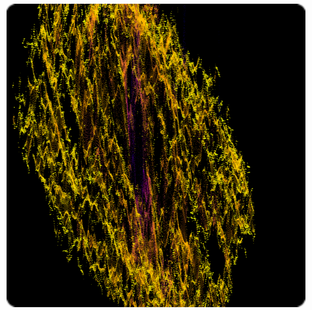
because these are independent observatories,” says astrophysicist Priyamvada Natarajan of Yale University. “Even if we have a systematic in our framework, we should [be able to] figure it out.”

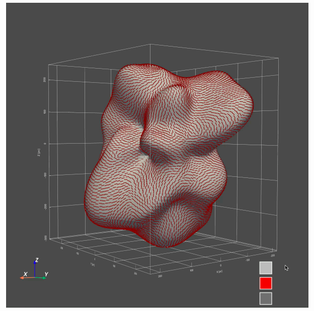
Next in My Universe

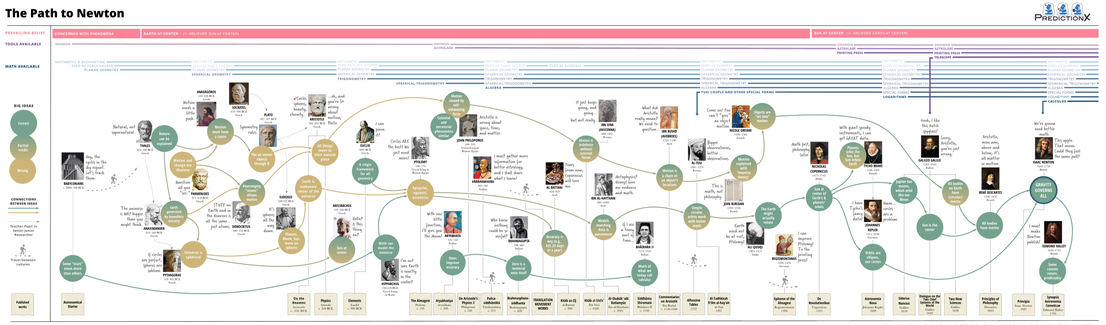












The Path to Newton

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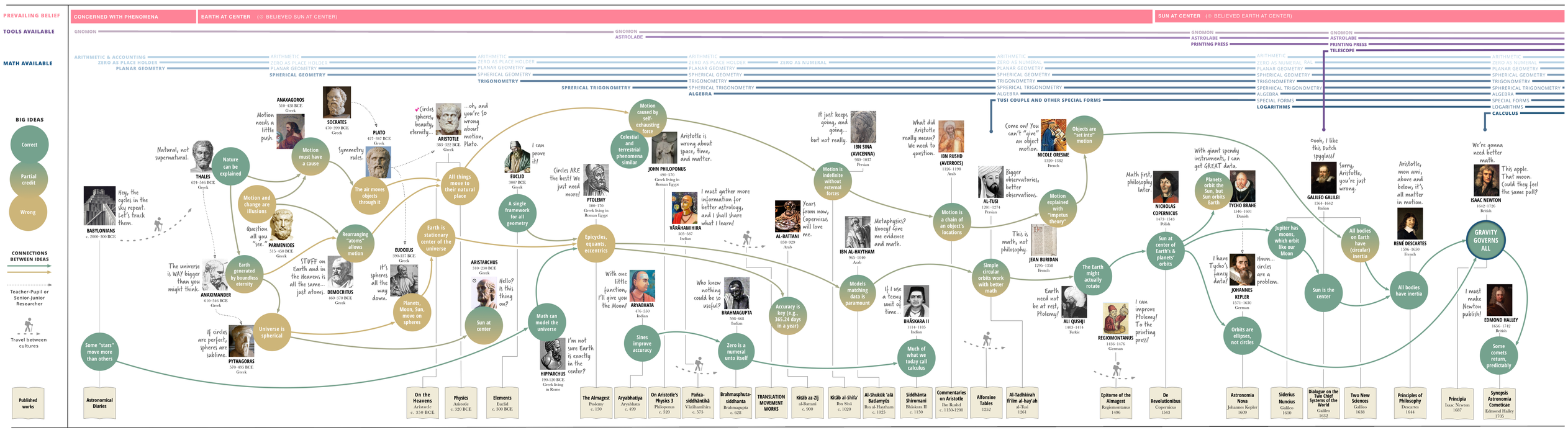
predictionx.org

The Path to Newton



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demo: path-to.org or LabXchange™ Science and learning–connected.

PredictionX
predictionx.org

PredictionX: The Past & Present of the Future

Essentials

Predictive Systems Framework

Phenomena →Predictions

Understanding Uncertainty

Study Design

Timelines

Why predict?

Omens,

Mesopotamia Haruspicy

Roman Augury

Chinese Oracle Bone

Oracle of Delphi

Aztec Rituals

Spacetime

of Doom

cross-cultural conversations

OBSERVATIONS

THEORY — SIMULATION

European Renaissance

Tools of the Navigator

The Royal Society

Modern Prediction

Snow
olera
a Map

Health
- *Epidemiology*
- *Personal Genomics*
- *Population Genetics*

Wealth
- *Climate & Wealth*
- *Behavioral Economics*

The Future of the Future
- *AI, Derek's Day*
- *Philosophy*
- *Uncertainty*

Earth
- *Climate & Energy*
- *Climate Policy*
- *Tent Tarot*
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Coming Soon

Interactive Resource

▶ video(s)

edX available on edX

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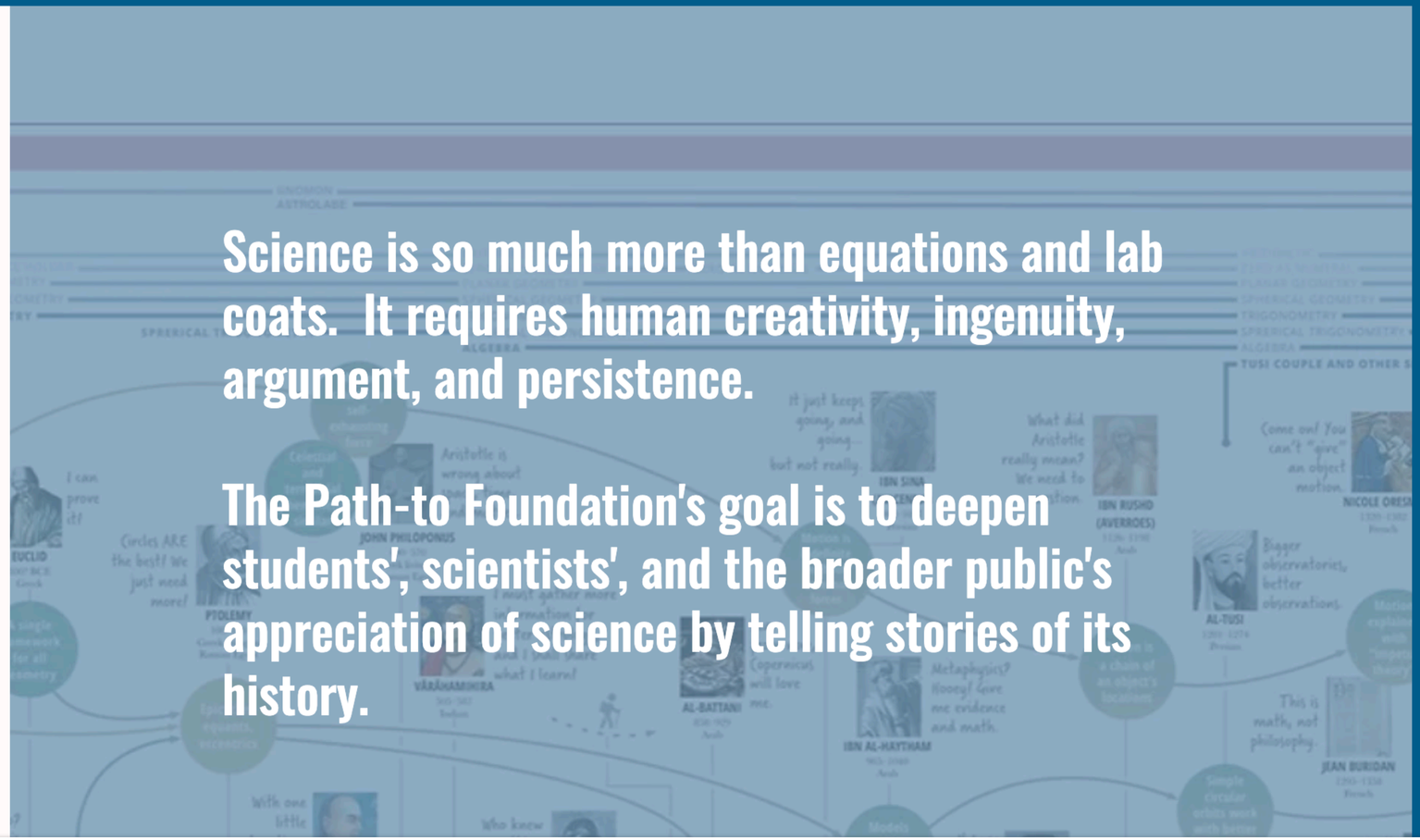


Science is so much more than equations and lab coats. It requires human creativity, ingenuity, argument, and persistence.

The Path-to Foundation's goal is to deepen students', scientists', and the broader public's appreciation of science by telling stories of its history.

Please do let me know if you'd like to write for this new PREDICTIONX spinoff!

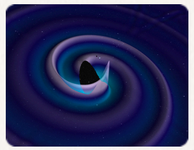
path-to-foundation.org

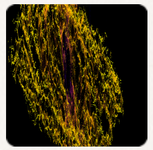
The New Universe

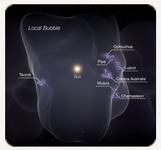
MEMPHIS, SUNDAY OCTOBER 23, 2022

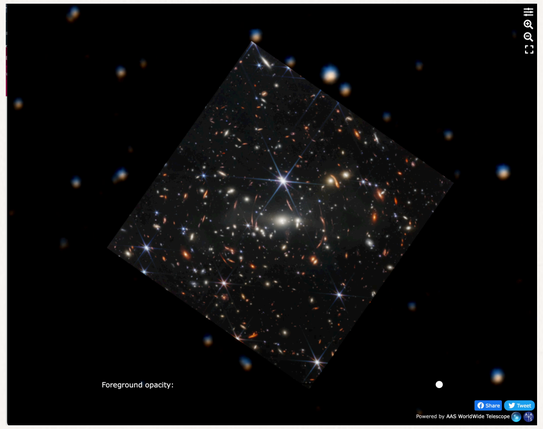
WHAT DO EXPENSIVE NEW TELESCOPES DO FOR HUMANITY TODAY?

Are mega-projects like ALMA, LIGO, JWST, and Gaia worth the billions?



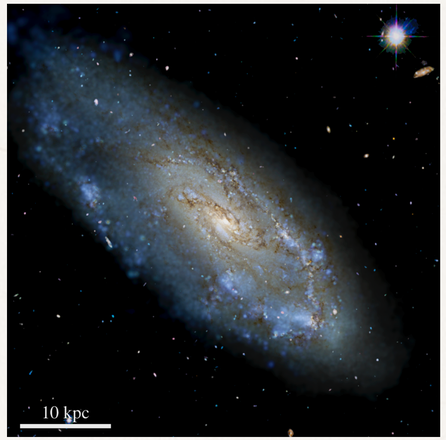


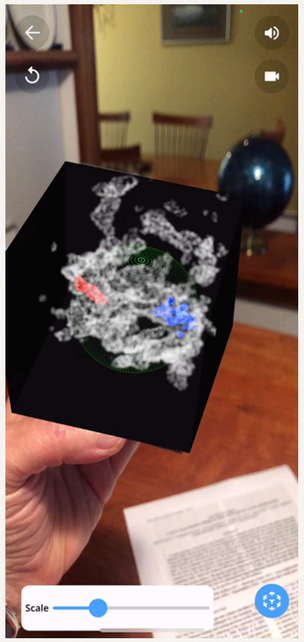




ARE COMPUTERS THE NEW TELESCOPES?

New galaxies in-silico, the early Universe "learned" without physics, and new stars forming in your hand.



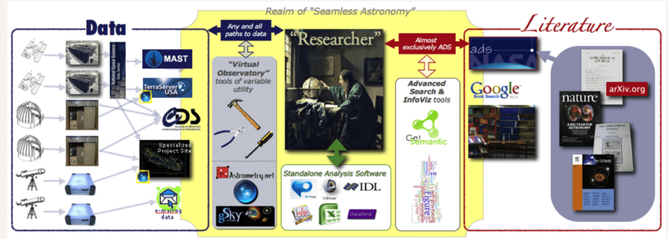


IS ASTROPHYSICS BEING (RE)ORGANIZED?

Lone stargazers are a rarer and rarer breed in professional astronomy. Teams and data scientists seem the way of the future, and tools that talk to each other are essential.

SEAMLESS ASTRONOMY

Linking scientific data, publications, and communities



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Thanks.

seamlessastronomy.org