Let's talk.
A discussion with Harvard PRISE students
July 2023

Alyssa Goodman
Center for Astrophysics | Harvard & Smithsonian

The NEW Milky Way

what it looks like

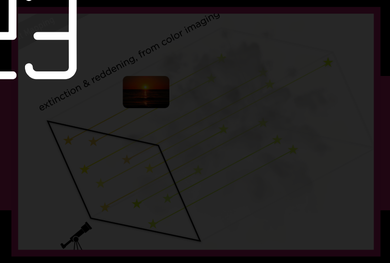
how we know

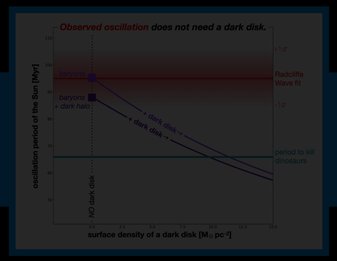
why it matters

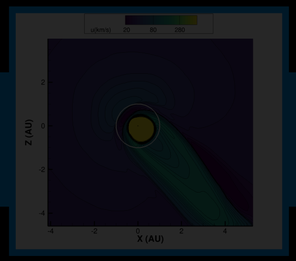
Let's talk.

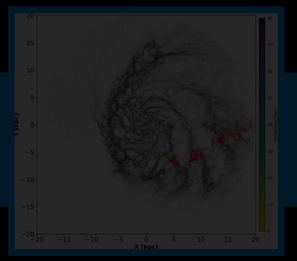
A discussion with Harvard PRISE students

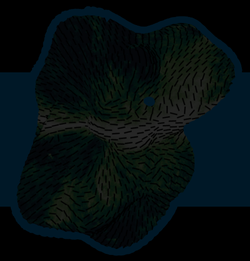
July 2023











“Science done right is fun with friends.”

Catherine Zucker

Pat Udomprasert

A “Cosmic Data Story” about “The Radcliffe Wave”

Jon Carifio

John Lewis

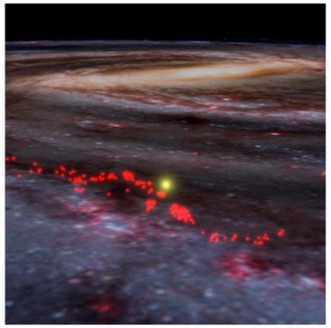
Cambridge, MA

TODAY

DIMENSIONS OF DISCOVERY

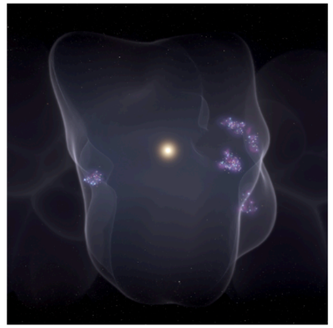
A web page created by Alyssa Goodman to showcase the use of technology in research, education, and communication, of science and more.

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

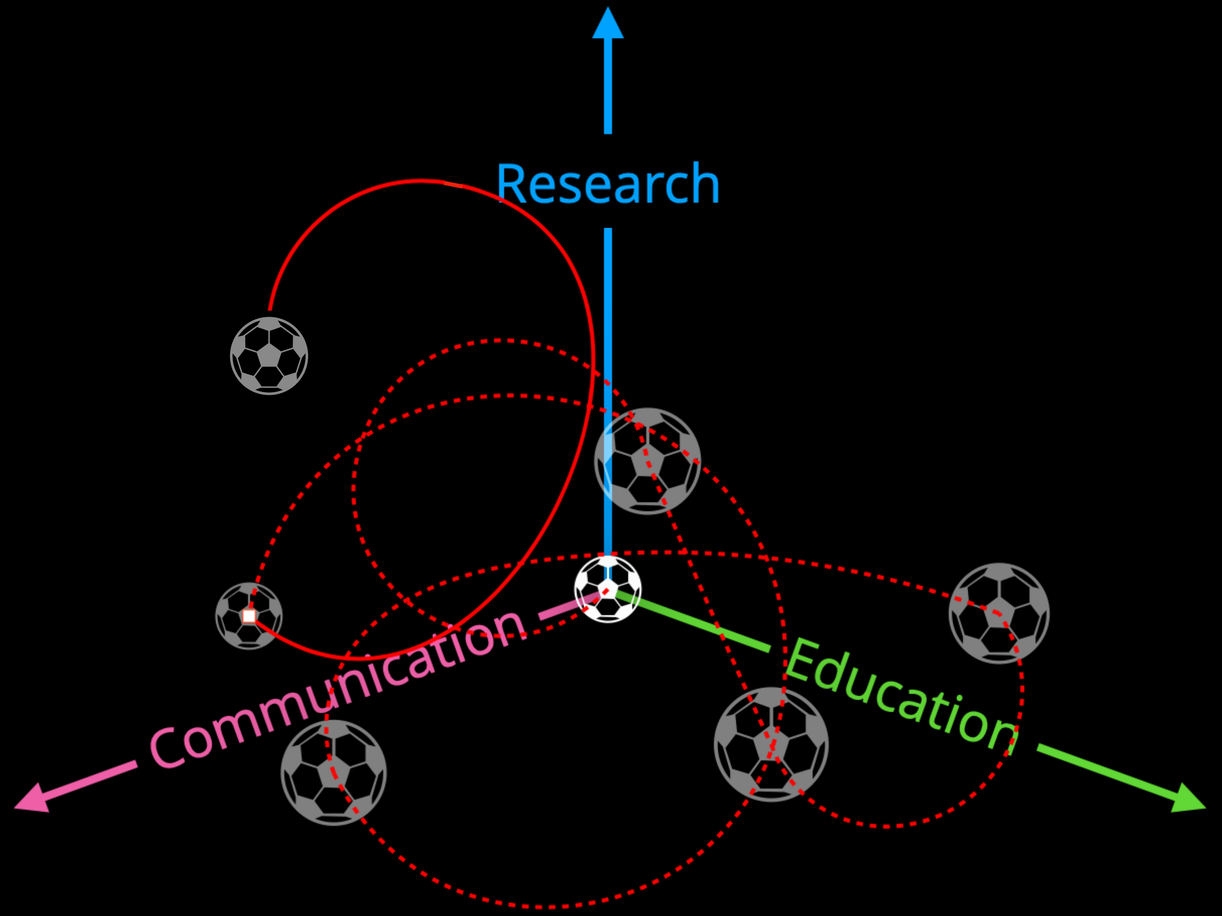
A collaboration of researchers at Harvard and Google, making data discoverable and available to researchers seeking to uncover novel solutions to climate and su

tinyurl.com/dimensionsofdiscovery

When to use what technology?

Science

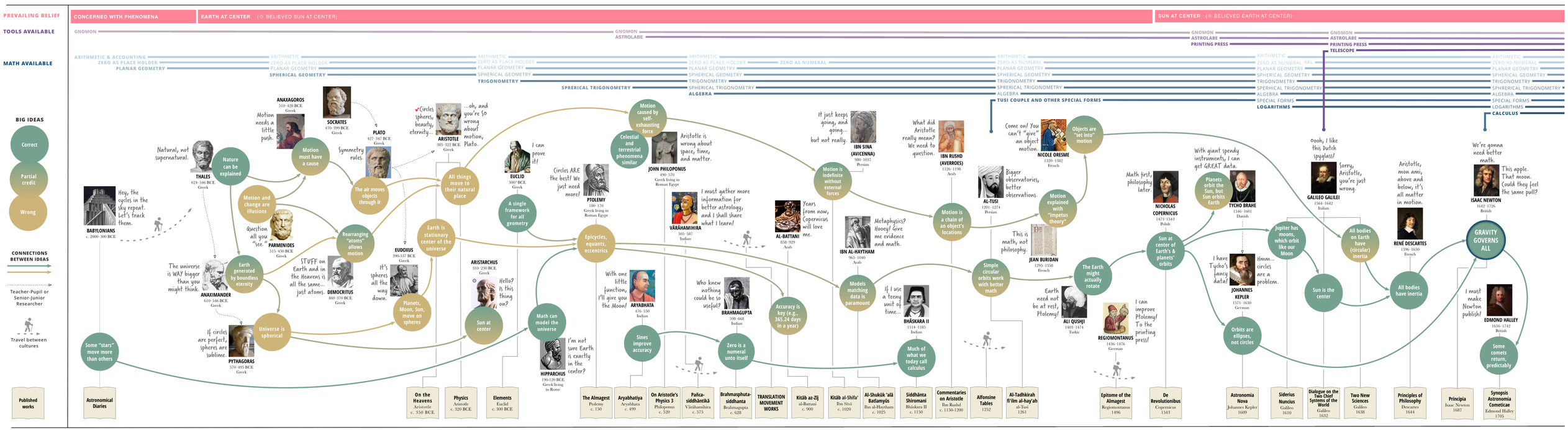
Technology



The Path to Newton

PREDICTIONX
predictionx.org

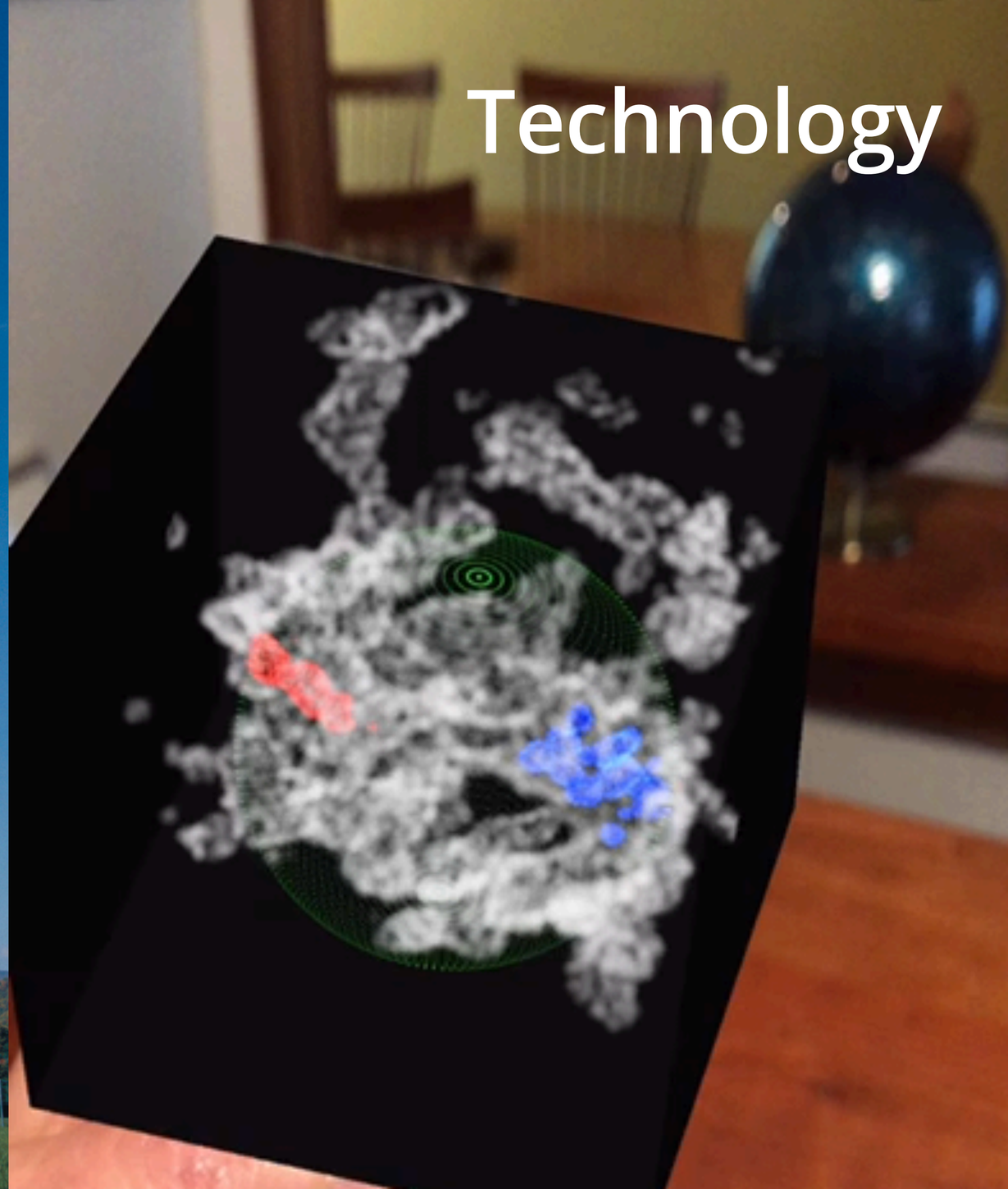
The Path to Newton



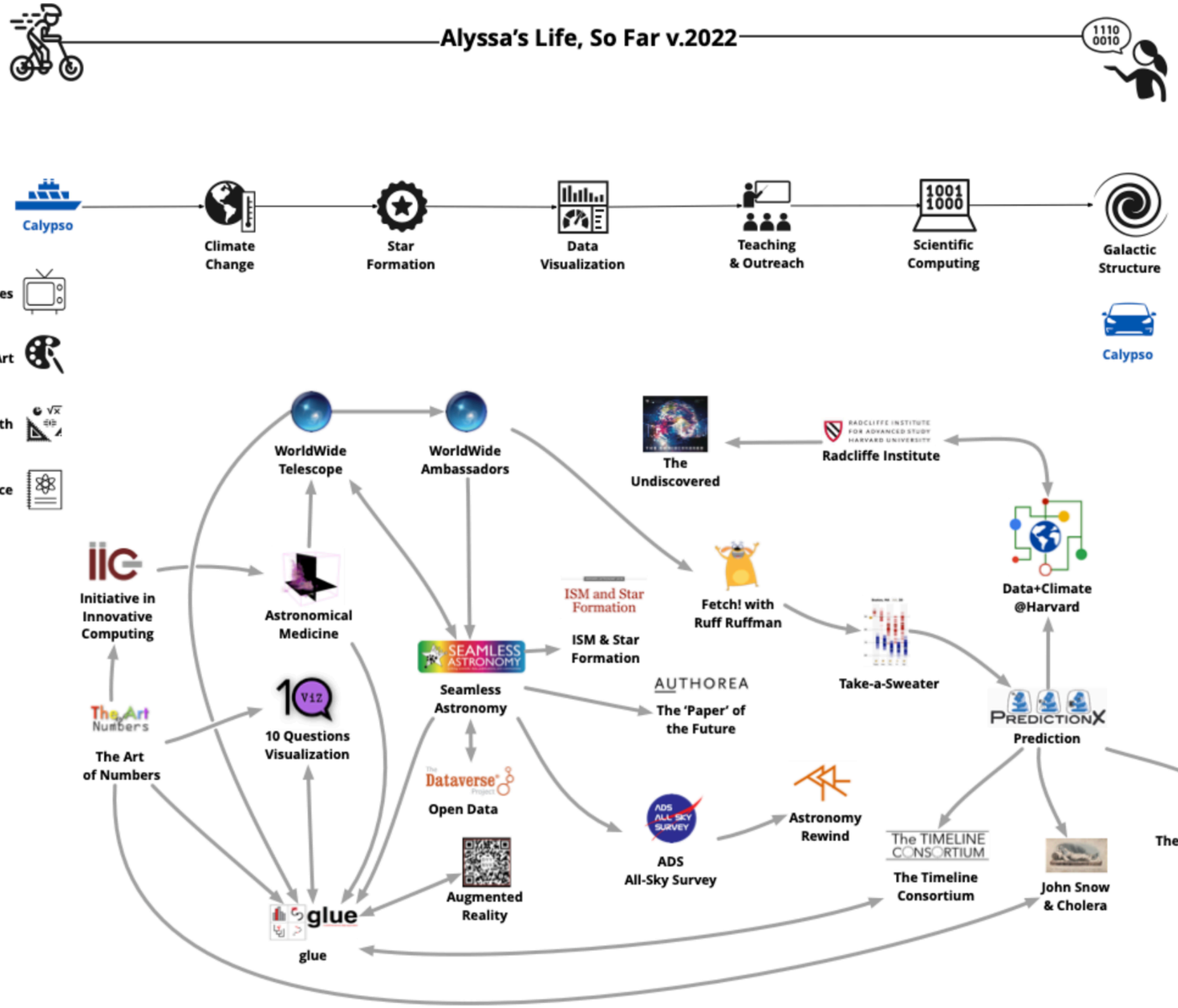
© Harvard University, created by Alyssa Goodman, Jais Brohinsky, Drew Lichtenstein & Katie Peek, re-use is allowed, with attribution, version 1, 2019

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

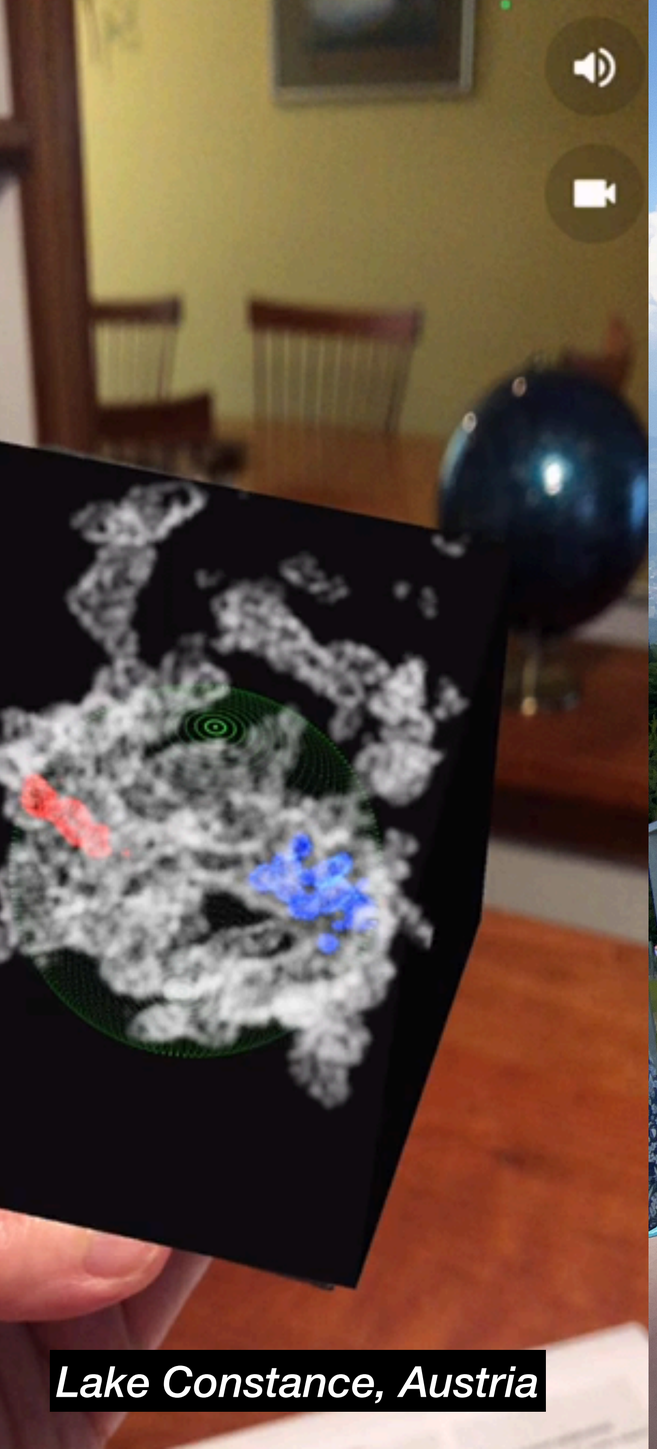
Science


Technology

Alyssa's Life, So Far v.2022



The COMPLETE Survey of Star-Forming Regions · Nessie-Bones · Think Space · Life in the Universe · Radcliffe Wave · PerTau & Local Bubble · Cosmic Data Stories · glue solutions inc.



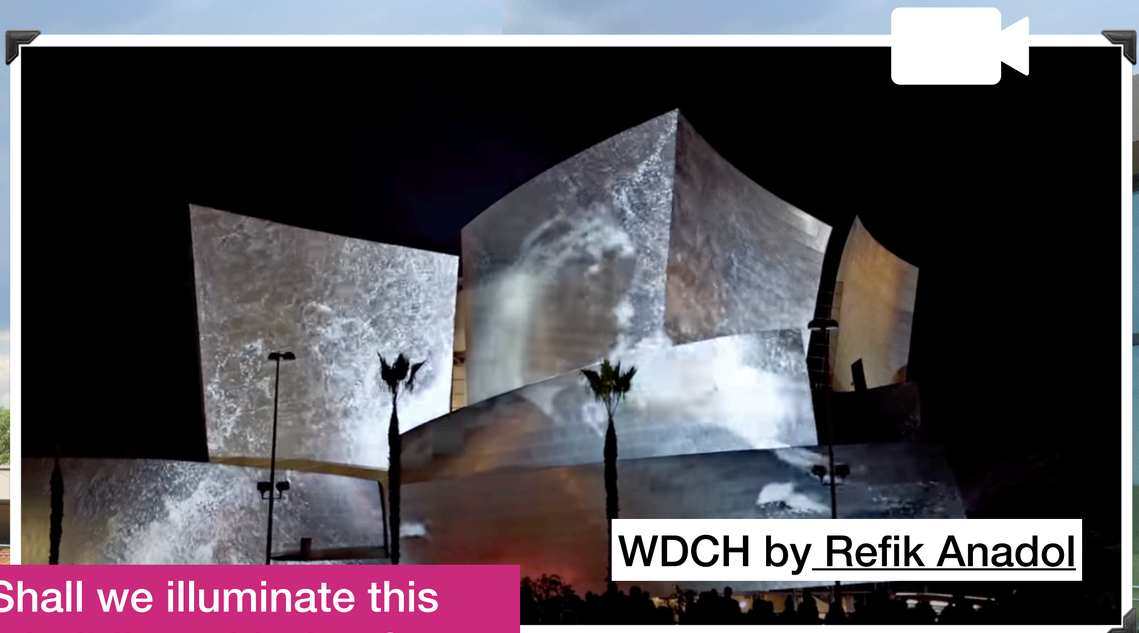
Lake Constance, Austria

June 10, 2023

Alyssa Goodman

Arzu Çöltekin

June 15, 2023



WDCH by Refik Anadol

Shall we illuminate this building with data?

ESO “Supernova” Museum/Planetarium

Alyssa Goodman

Wolfgang Vieser,

Garching, Germany

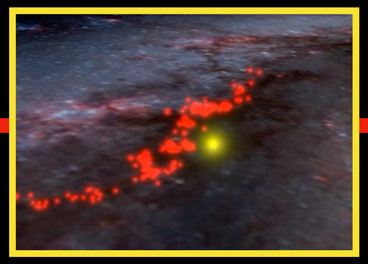
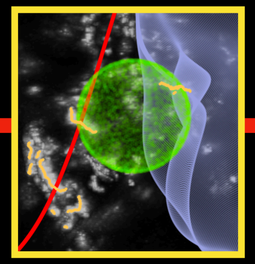
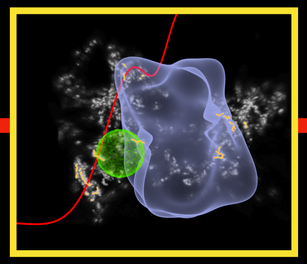
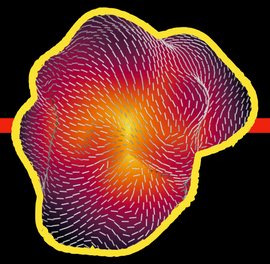
Garching, Germany

June 18, 2023
Click to Show/Hide:
Labels
3D Dust
Local Bubble Model
Magnetic Field Model
PerTau Bubble Model
Orion Shell Model
Radcliffe Wave Model
Split Model
Sun
Nearby Shells
Northern Celestial Pole Loo
Molecular Clouds
Y [pc]
400
300
200
100
0
−100
−200
Theo O’Neil
Catherine Zucker
Ralf Konietzka
Vienna, Austria

Some recent actual talk slides…

glue-ing together the Milky Way

Alyssa Goodman, Center for Astrophysics | Harvard & Smithsonian

Glue (/Users/aagoodman/Library/CloudStorage/GoogleDrive-agoodman@cfa.harvard.edu/My Drive/Milky Way Takeover 2020/MilkyWay3D.ORG/Sessions/cfaspf23demowithco.glu)

Open Session | Export Session | Import Data | Export Data/Subsets | Link Data | Arithmetic attributes | Active Subset: None/Create New (the next selection will create a subset) | Terminal | Preferences | Error Console

Data Collection

- Pelgrims2020_A+A_636_A17_lmax10_MW3D[HDU1]
- Zucker2021_ApJ_919_35_spines_MW3D[HDU1]
- Alves2020_Nat_578_237_MW3D[HDU1]
- Bialy2021_ApJL_919_L5_MW3D[HDU1]
- Foley2022_arXiv_2212.01405_OrionShell_MW3D[HDU1]
- Reid2019_ApJ_885_131_LocalArmFit_MW3D[HDU1]
- Reid2019_ApJ_885_131_SGNArmFit_MW3D[HDU1]
- Reid2019_ApJ_885_131_MW3D[HDU1]
- Hunt2023_arXiv_2303.13424_MW3D[HDU1]
- Lallement2019_A+A_625_A135_Split_MW3D[HDU1]
- Edenhofer_2023_3D_Dust_XYZ_Revised-2

Plot Layers - Earth/Planet/Sky Viewer (WWT)

- [x] distance picker (Bialy2021_ApJL_919_L5_MW3D[HDU1])
- [x] Bialy2021_ApJL_919_L5_MW3D[HDU1]
- [x] distance picker (Hunt2023_arXiv_2303.13424_MW3D[HDU1])
- [x] ONeill2023_LocalBubbleB_VectorPointCloud_MW3D[HDU1]
- [x] Hunt2023_arXiv_2303.13424_MW3D[HDU1]
- [x] Reid2019_ApJ_885_131_SGNArmFit_MW3D[HDU1]
- [x] Reid2019_ApJ_885_131_LocalArmFit_MW3D[HDU1]
- [ ] Lallement2019_A+A_625_A135_Split_MW3D[HDU1]

Size | Color

Fixed

Center view on layer

Plot Options - Earth/Planet/Sky Viewer (WWT)

Mode: Milky Way

Frame: Galactic

Longitude: GLON

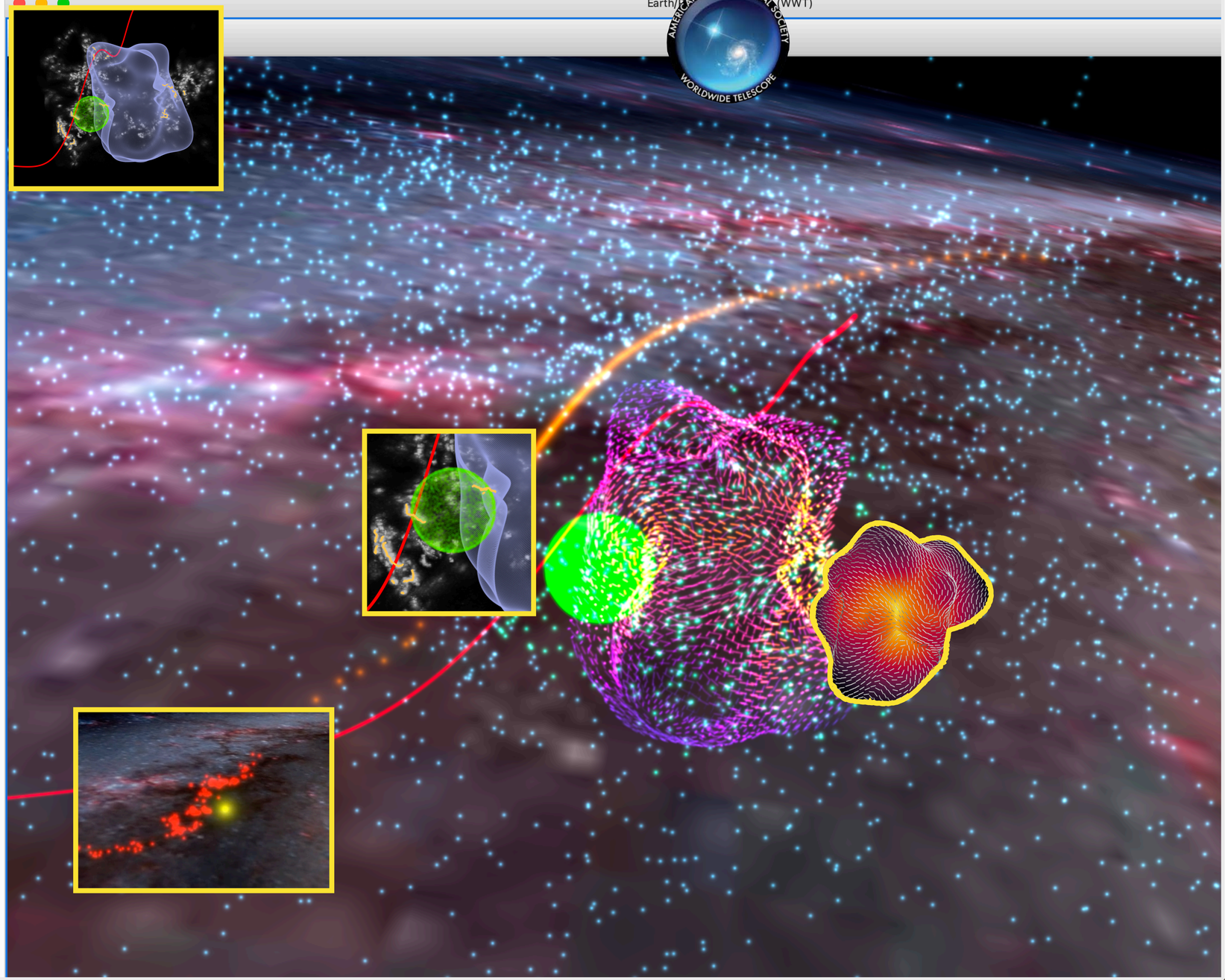
Latitude: GLAT

Distance: Distance

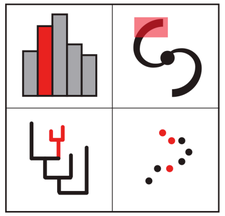
pc

3D overview | WWT 3D | 3D dust stars | WWT overlay | CO

Earth/Planet/Sky Viewer (WWT)



Explore
“The *best* roads are two-way.”
Explain

What is  glue?

multidimensional data exploration

It’s not an acronym.

It is open-source software that

glues data,

glues graphs &

glues tools.

data

numbers (tables, arrays, spreadsheets)

images & maps (FITS, JPEG, GIS and more)

data cubes (3D, 4D, and more)

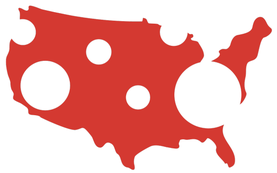
data files' common attributes are **glued**

avoiding the need to merge data files

“graphs”

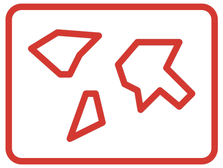
common statistical graphics

(scatterplots, histograms, tables, curves, overlays)



maps & images

(greyscale, color, contours, layer control…)

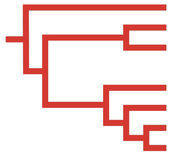


3D displays

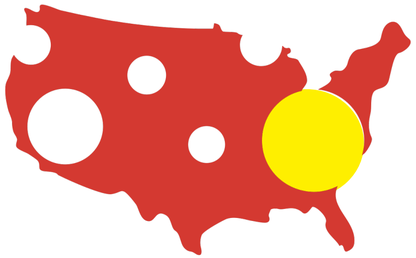
(scatter plots, volumetric rendering, sliders…)

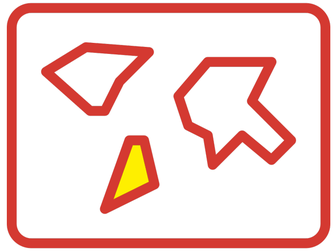
specialized & custom charts

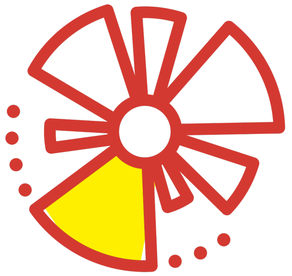
(dendrograms, polar plots, + domain-specific options)



selections propagate across all graphs



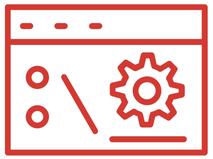




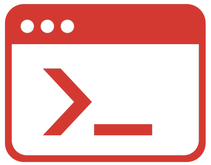
for real-time data exploration & insight

tools

plug-ins (user-defined formats, plots, layouts…)

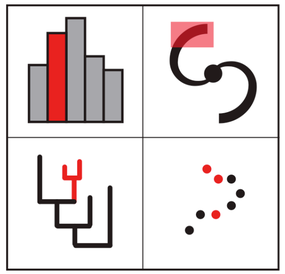


web services (across domains)



command-line (built-in terminal, scriptable)

for easy customization



glue

multidimensional data exploration

glues data,
glues graphs &
glues tools.

glueviz.org

BONUS: **save**, **share**, or **publish** what you learn—

- save “sessions” to continue where you left off
- export graphics
- use/export to Jupyter environments
- export to plot.ly (javascript)
- export to augmented reality

learn how at glueviz.org.

glueviz.org

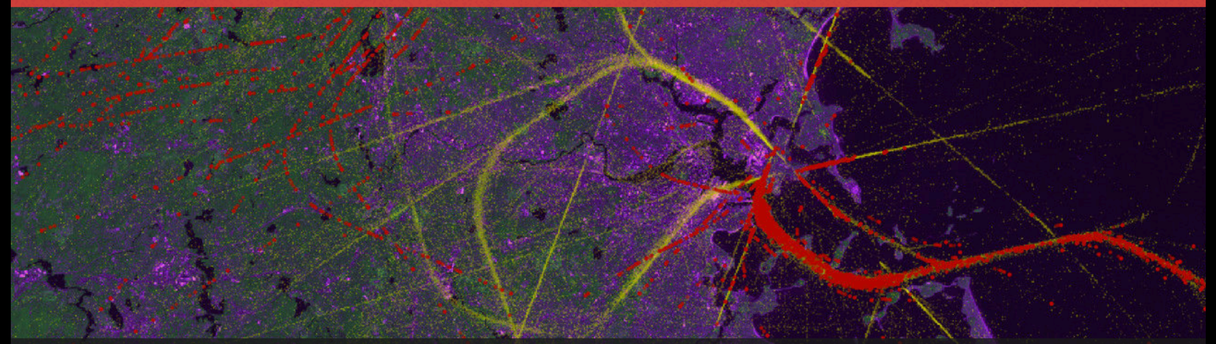
supported by

glue solutions inc.

GORDON AND BETTY MOORE FOUNDATION

Glue: multi-dimensional linked-data exploration

Home | Install | Documentation | Team | Get involved | Packages | glue-con events | Consulting services



Glue is an open-source Python library to explore relationships within and between related datasets

Linked Visualizations

With Glue, users can create scatter plots, histograms and images (2D and 3D) of their data. Glue is focused on the brushing and linking paradigm, where selections in any graph propagate to all others.

Flexible linking across data

Glue uses the logical links that exist between different data sets to overlay visualizations of different data, and to propagate selections across data sets. These links are specified by the user, and are arbitrarily flexible

Full scripting capability

Glue is written in Python, and built on top of its standard scientific libraries (i.e., Numpy, Matplotlib, Scipy). Users can easily integrate their own python code for data input, cleaning, and analysis.

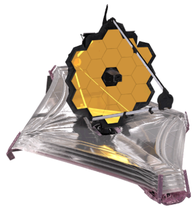
glueviz.org

gluesolutions, inc. | Home | Gallery | Our Team | The Software | glue-con | Social Impact | More

glupyter (a.k.a. "glue jupyter")

"glupyter" is a union of glue and Jupyter software environments. We think it may well be the future of glue, or "glue-qt" as experts sometimes call the desktop app version of glue. This webpage, hosted openly and freely by glue solutions, inc., serves as a clearinghouse for current information about open-source glupyter-related projects. Some of these projects are funded by government agencies (notably NSF and NASA), others by private foundations (e.g. The Gordon and Betty Moore Foundation), some as part of corporate collaborations (e.g. Harvard+Google Data+Climate), and some by open-source consulting work carried out by glue solutions, inc.

The glue-jupyter GitHub repository is fully open,
and more detail can be found on this Read the Docs page.



Quick insights for Images, Spectra

JDAViz

includes: ImViz, CubeViz, SpecViz, MOSViz

Sponsor: NASA, James Webb Space Telescope

Read more (blog post at 10QViz.org)...

GitHub

Open-Source GIS Data Exploration

SAVE

Search-Analysis-Visualization-Environment

Sponsors: Harvard+Google Data+Climate

Read more at Data+Climate site...

GitHub

CosmicDS

Data Science Education

Cosmic Data Stories

Sponsor: NASA, Science Activation Program (funded proposal)

Read more at CosmicDS website...

GitHub

glupyter

bringing glue to JupyterLab

glupyter prototype

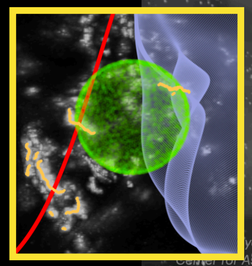
Sponsors: The Gordon and Betty Moore Foundation and the National Science Foundation

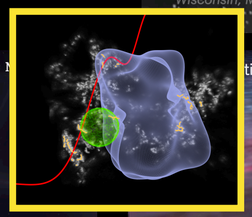
Read more in the justificaiton of the GBF proposal, awarded to Harvard, and watch this 2022 demo video

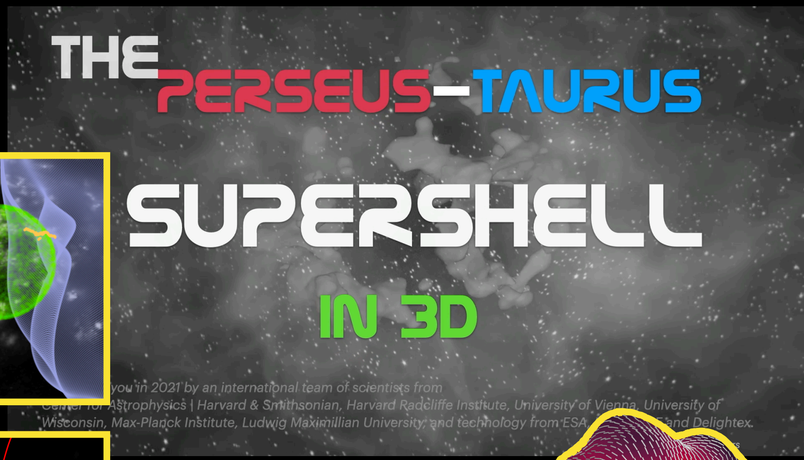
gluesolutions.io/the-software/glupyter

The “New Milky” Way online
(early 2023 edition)

2021

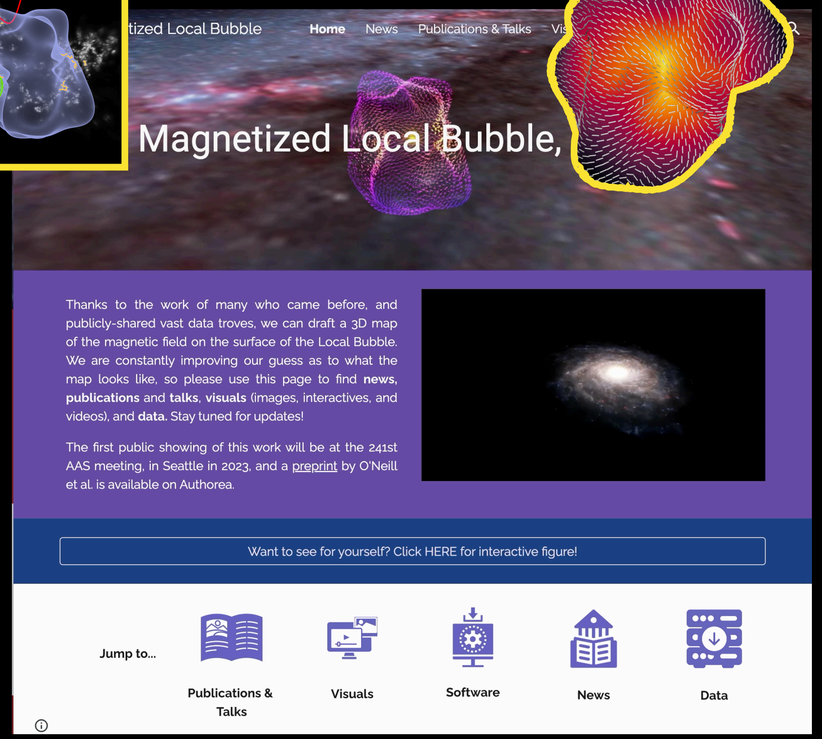






2020

2022



2023

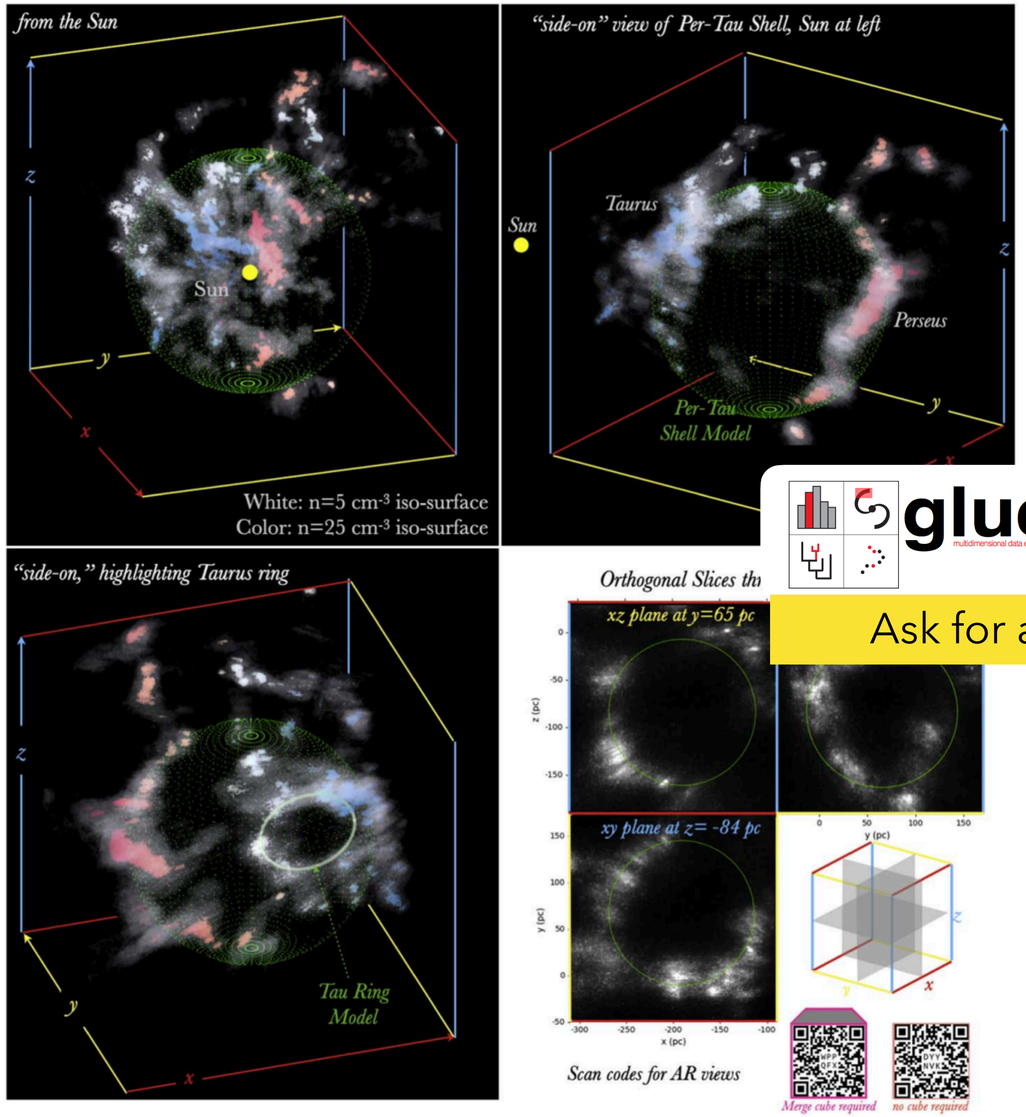


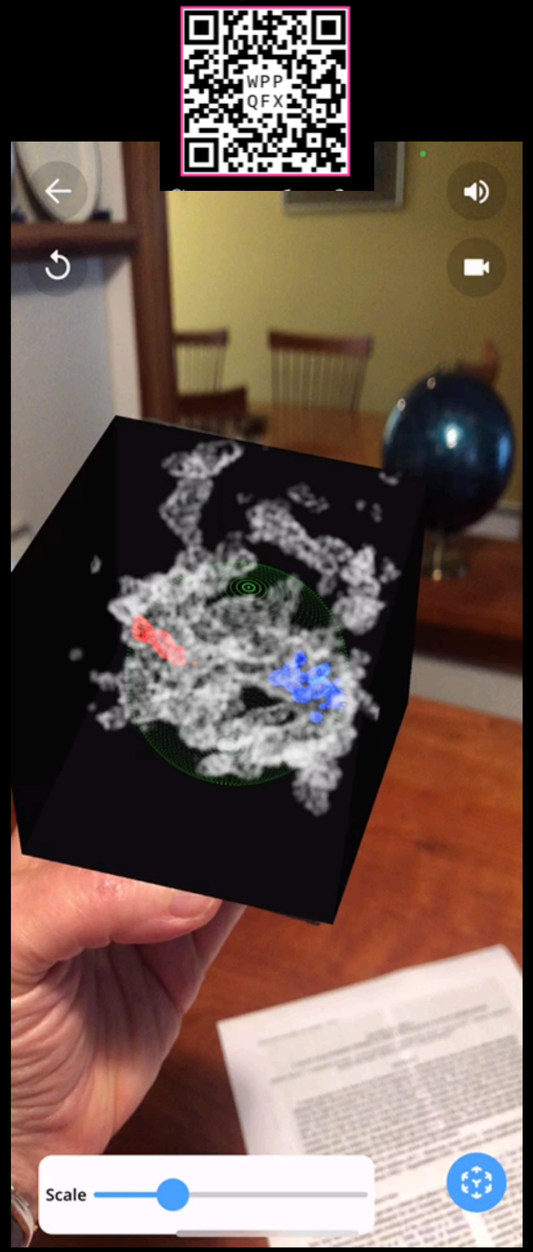
Figure 2. 3D views of the Per-Tau shell (for an interactive version[8] of this figure click here [9]; see Figure 5 for more static visualizations). Plotted are density iso-surfaces at levels $n = 5$ cm^{-3} (gray) and $n = 25$ cm^{-3} (color), overlaid with our spherical-shell model, radius $R_s = 78$ 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 part extends to $d \approx 220$ pc.

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 at the distance of Taurus, and does not physically connect

glue multidimensional data exploration → COSPACES

Ask for a demo later, please.



Bialy et al. 2021

The Dataverse® Project

Embargoed—please do not share—this slide will be removed from slides online.

Phase Space Analysis of the Local Interstellar Medium

The Oscillation of the Radcliffe Wave

Ralf Konietzka

Master's Thesis

at the Faculty of Physics

Ludwig-Maximilians-University of Munich

Submitted by

Ralf Konietzka

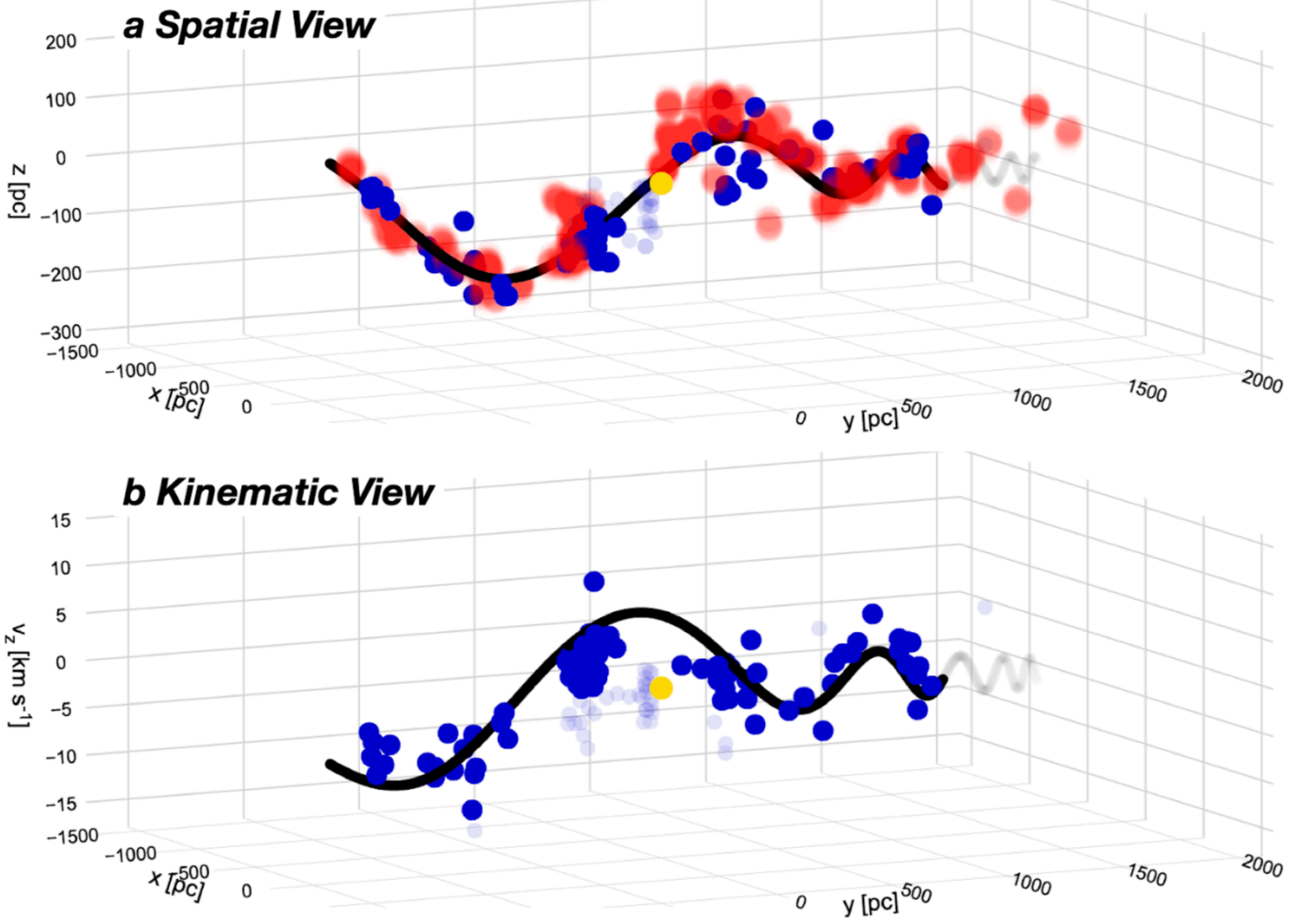
born in Nuremberg

Supervised by

Prof. Dr. Alyssa Goodman

Prof. Dr. Andreas Burkert

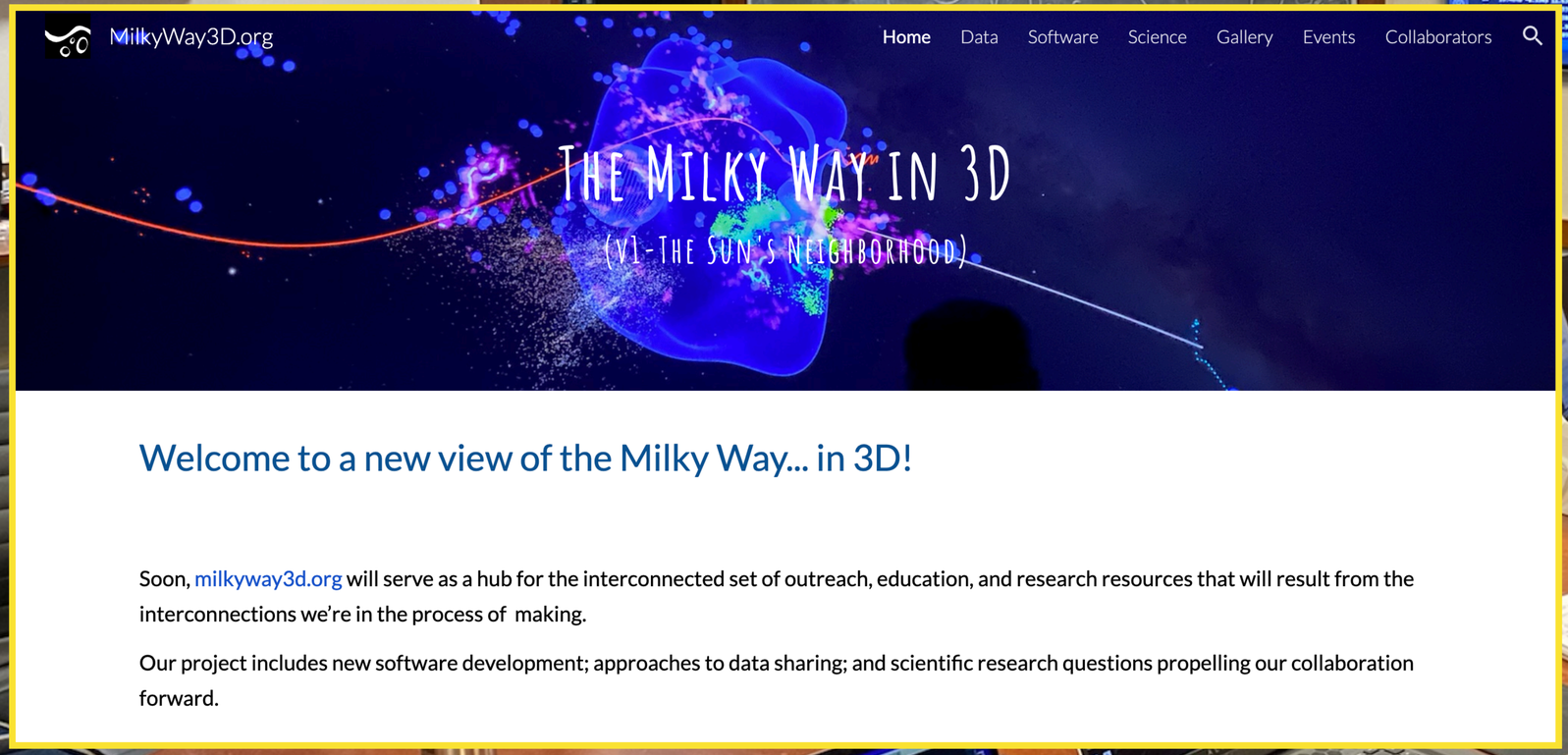
Munich, June 12, 2023

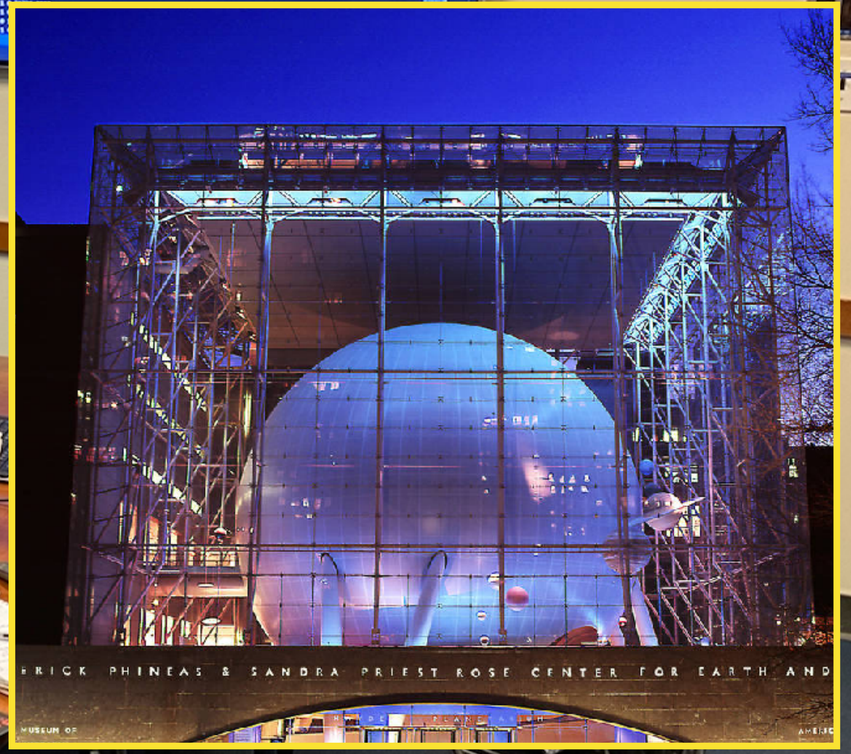


https://ralfkonietzka.github.io/files/RW_final_figures/Figure_1.html

Konietzka, R., Goodman, A., Zucker, C., Burkert, A., Alves, J., Foley, M., Swiggum, C. 2023. To be submitted to Nature, June 2023. The Radcliffe Wave is Oscillating

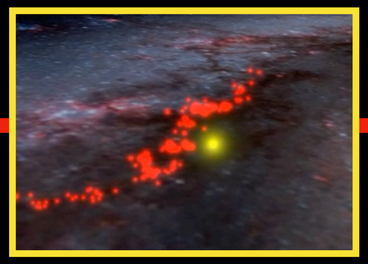
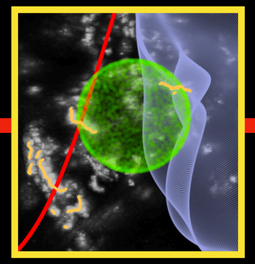
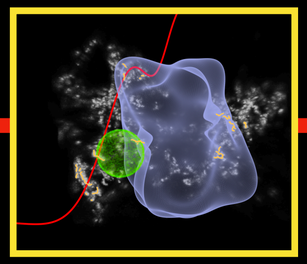
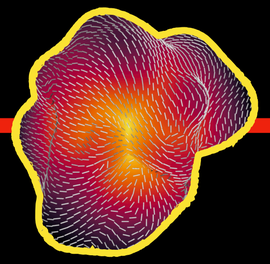
Putting it all together at MilkyWay3D.org





glue-ing together the Milky Way

Alyssa Goodman, Center for Astrophysics | Harvard & Smithsonian

***great* 1D, 2D** and **3D** data manipulation, flexible architecture facilitating plug-ins, data transfer, and interactive data exploration; "glupyter" flavor runs in web pages

glue
multidimensional data exploration

CosmicDS

plug-in in-use on Hayden Planetarium dome

AMERICAN ASTRONOMICAL SOCIETY
WORLDWIDE TELESCOPE

plug-in shows WWT images in context in 3.

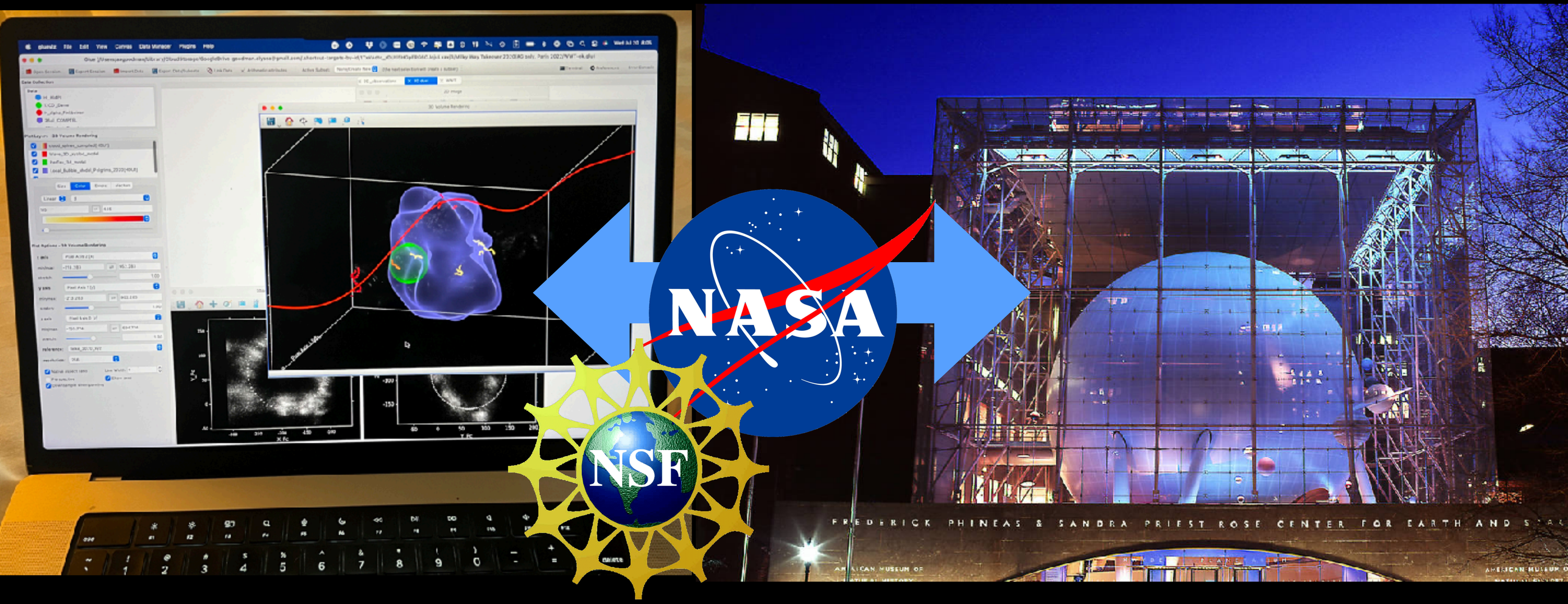
OpenSpace

***great* 2D** object and all-sky images
limited 3D functionality

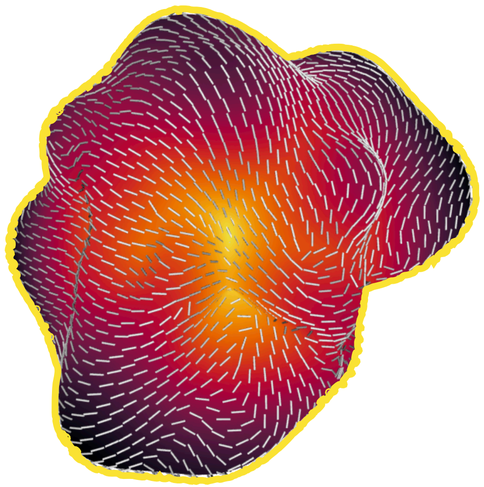
limited 2D all-sky images
***great* 3D** functionality

The "Perseus-Taurus Superbubble"
a demo of the need for 2D-3D contextualization functionality

This video was composited using the WWT and OpenSpace, making some use of prototype plug-ins, but 2D and 3D imagery was aligned manually by experts. As a generalizable STEM concept, it explains the deceptive "forced perspective" made possible in when objects at very different distances, in 3D, appear to touch in 2D.


glue
multidimensional data exploration
OpenSpace
AMERICAN ASTRONOMICAL SOCIETY
WORLDWIDE TELESCOPE
NASA
NSF
FREDERICK PHINEAS & SANDRA PRIEST ROSE CENTER FOR EARTH AND

A 3D Map of the Local Bubble's Magnetic Field



Explore Interactive Figures from the paper

Figure 1: Local-to-total Extinction Ratio

Figure 3: 3D Vector Field

Figure 4: Environment

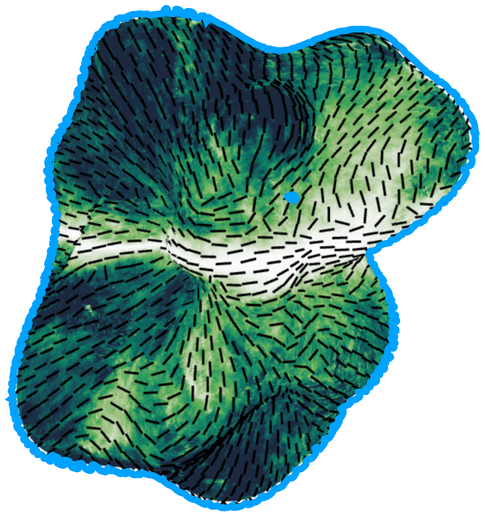
Figure 5: Distance

Figure 6: Inclination from plane-of-the-sky, Gamma

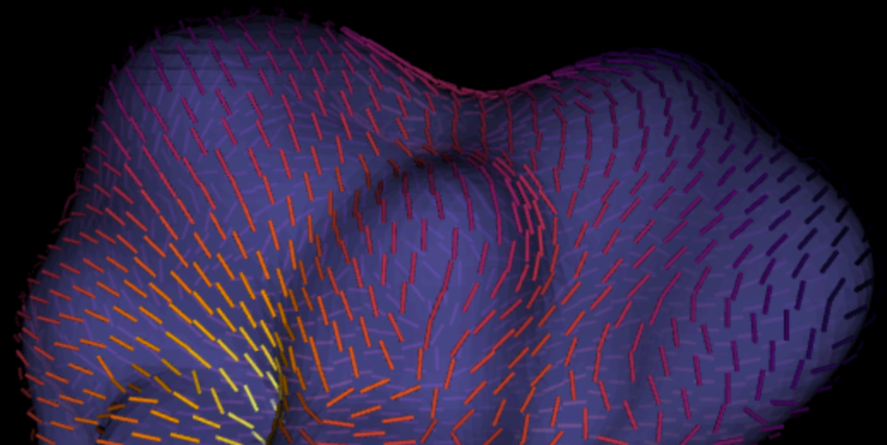
Figure 7: Polarization fraction p

Figure 8: Dispersion S

Figure 12: Background Starlight



https://theo-oneill.github.io/magneticlocalbubble/

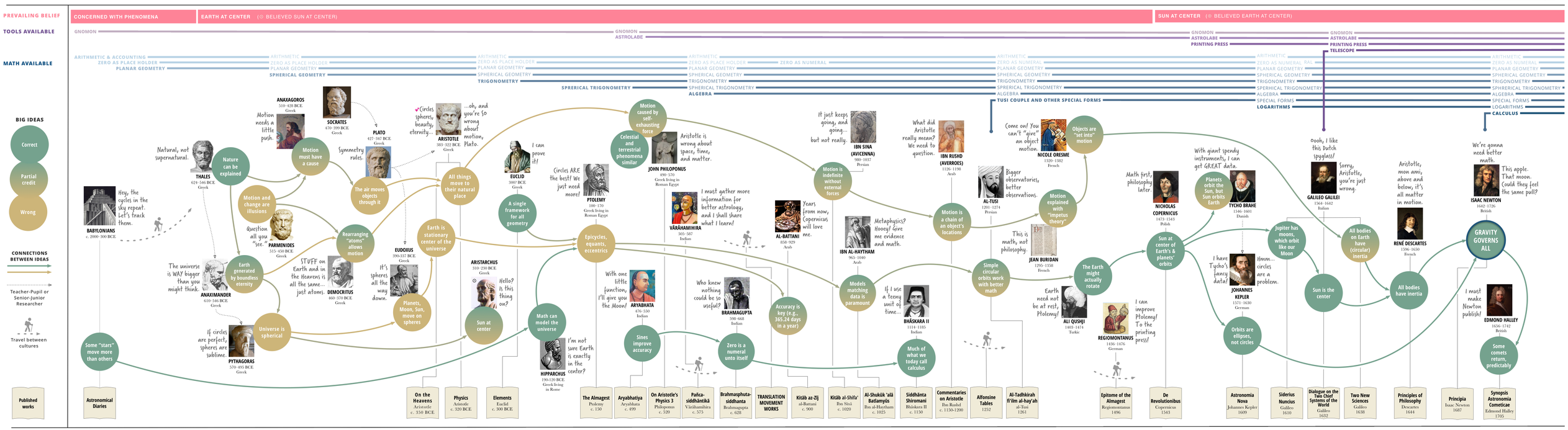


O'Neill et al. 2023

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.

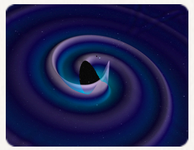
Opinion

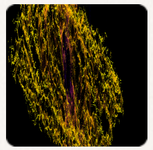
The New Universe

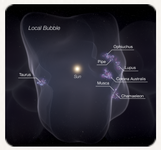
MEMPHIS, SUNDAY OCTOBER 23, 2022

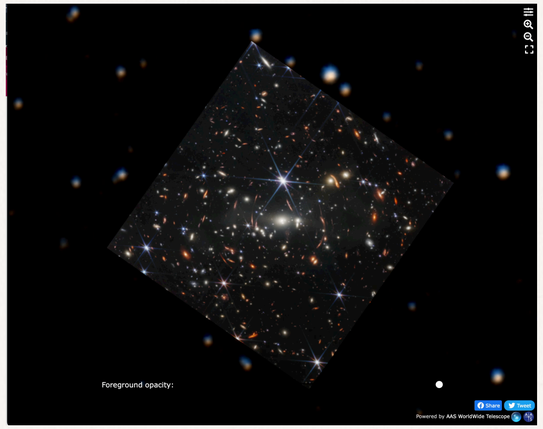
WHAT DO EXPENSIVE NEW TELESCOPES DO FOR HUMANITY TODAY?

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



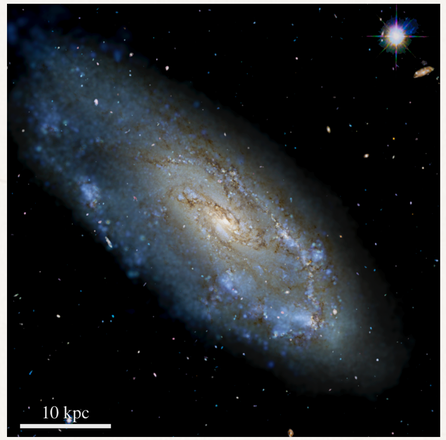


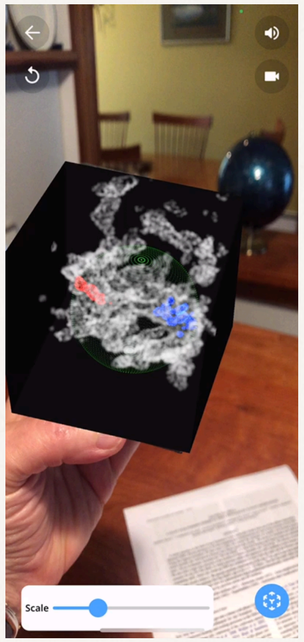




ARE COMPUTERS THE NEW TELESCOPES?

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



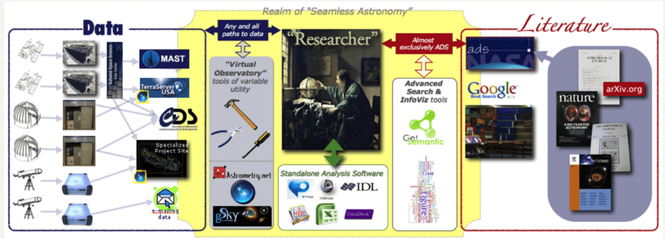


IS ASTROPHYSICS BEING (RE)ORGANIZED?

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

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

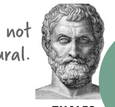
Hey, the cycles in the sky repeat. Let's track them.

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

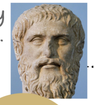
Rearranging "atoms" allows motion

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.

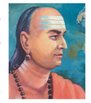
It just kee going, ar going

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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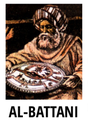

Years from now, Copernicus will love me.

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!

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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?

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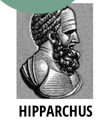
310–230 BCE
Greek

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
Philoponus
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Pañca-siddhāntikā
Vārāhamihira
c. 575

Brahmasphuta-siddhanta
Brahmagupta
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Kitāb az-Zīj
al-Battani
c. 900

Kitāb al-Shifa'
Ibn Sīnā
c. 1020

Al-Shukūk 'alā Batlamyūs
Ibn al-Haytham
c. 1025

Siddhānta Shiromani
Bhāskara II
c. 1150

Commentaries on Aristotle
Ibn Rushd
c. 1150-1200

Alfonsine Tables
1252

Al-Tadhkirah fi'ilm al-hay'ah
al-Tusi
1261

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
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TELESCOPE
ARITHMETIC
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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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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

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Brahmagupta
c. 628

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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

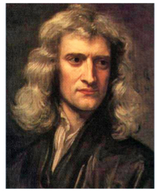
I like Dutch glass!

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?