Last Night!
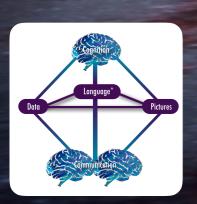
OPEN SPACE

WorldWide Telescope

glue
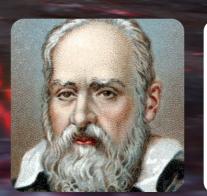multidimensional data exploration

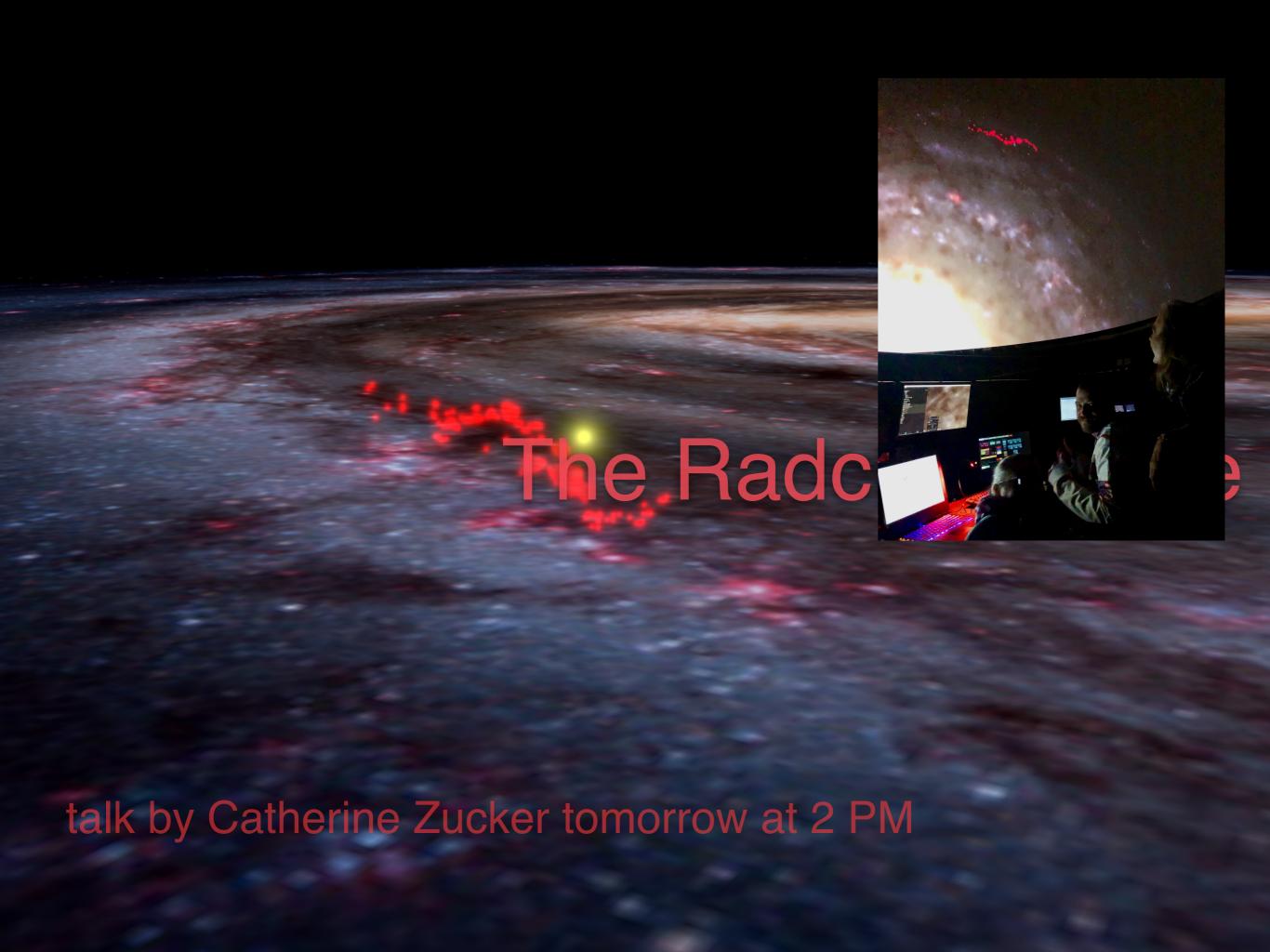# Seeing, Exploring, Explaining, and Sharing our Universe



# Alyssa A. Goodman
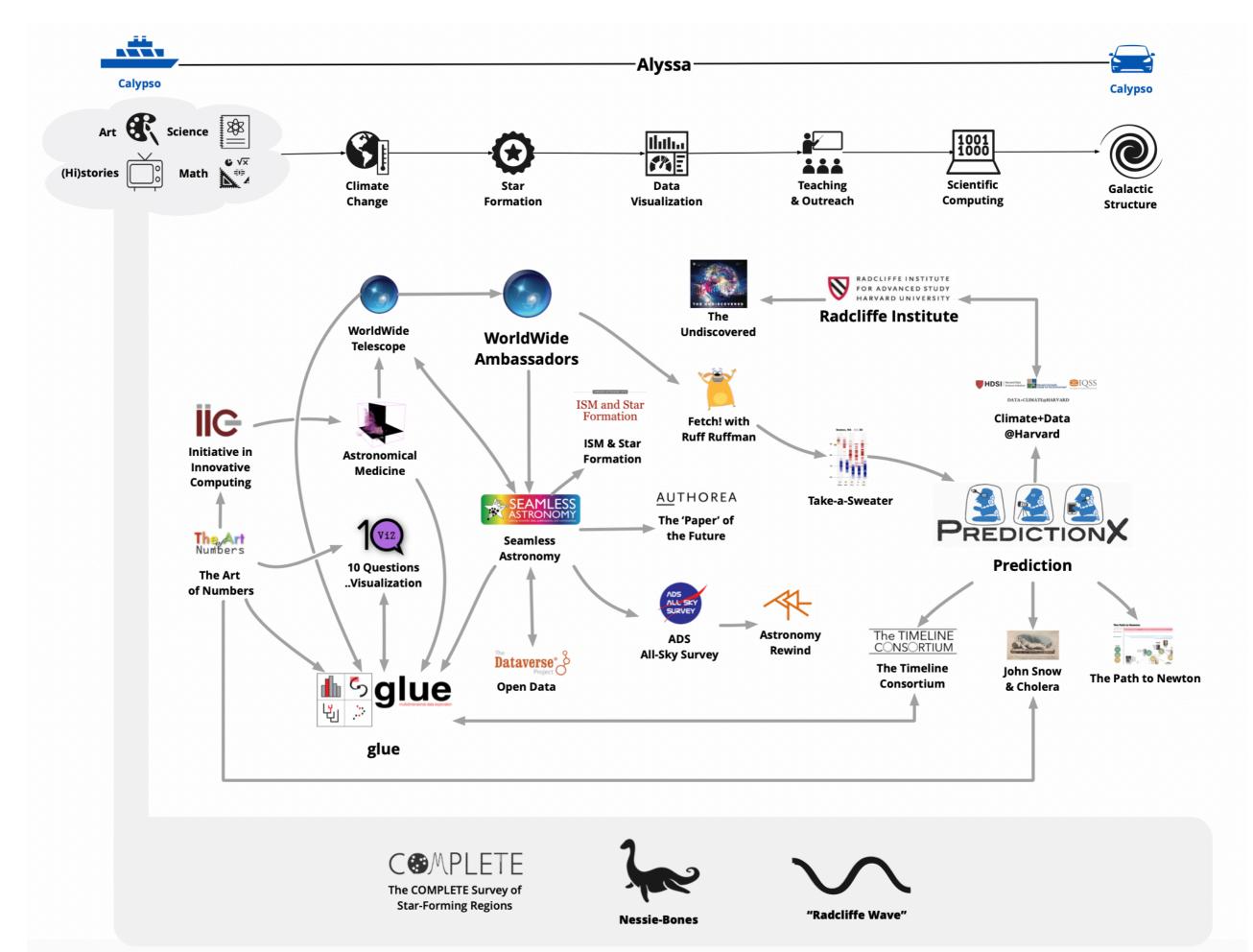
Center for Astrophysics | Harvard & Smithsonian

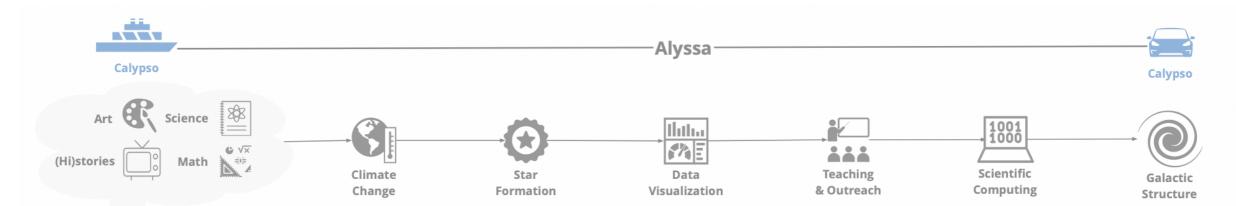Radcliffe Institute for Advanced Study

Apology/Disclaimer

Images of "The Radcliffe Wave" in this talk are embargoed by Nature until January 8, 2020. Please do not record or share them.

Talks slides will be posted at Alyssa Goodman's web site after January 8.

The Radcliffe

talk by Catherine Zucker tomorrow at 2 PM

The Radcliffe Wave

Alyssa

Calypso · Calypso

Art · Science · (Hi)stories · Math

Climate Change → Star Formation → Data Visualization → Teaching & Outreach → Scientific Computing → Galactic Structure

WorldWide Telescope

WorldWide Ambassadors

The Undiscovered

Radcliffe Institute

Initiative in Innovative Computing

Astronomical Medicine

The Art of Numbers

10 Questions ..Visualization

ISM and Star Formation

ISM & Star Formation

Fetch! with Ruff Ruffman

Take-a-Sweater

Climate+Data @Harvard

SEAMLESS ASTRONOMY

Seamless Astronomy

AUTHOREA

The 'Paper' of the Future

PREDICTIONX

Prediction

The Dataverse Project

Open Data

ADS ALL SKY SURVEY

ADS All-Sky Survey

Astronomy Rewind

The TIMELINE CONSORTIUM

The Timeline Consortium

John Snow & Cholera

The Path to Newton

glue

glue

COMPLETE

The COMPLETE Survey of Star-Forming Regions

Nessie-Bones

"Radcliffe Wave"

Climate Change

Temperatures before and after Hansen's Senate testimony

Temperature anomaly (°F), 1901-2000 baseline

-1    0    +1    +2.5    +5

1959–1988          Spin me          1988–2017

Data: NASA's Goddard Institute for Space Studies; Graphic: Harry Stevens/Axios

TOM'S RESTAURANT          RESTAURANT

CARMONAT

# Temperatures before and after Hansen's Senate testimony

Temperature anomaly (°F), 1901-2000 baseline

-1    0    +1    +2.5    +5

### 1959–1988

Spin me

### 1988–2017

"…how traditional and modern approaches to visualizing information are best combined to leverage human creativity in our quest to understand the world around us…"

see Alves, Zucker, Goodman, Speagle, Meingast, Robitaille, Finkbeiner, Schlafly & Green 2020 (January release in Nature)

see felicefrankel.com

Authorea

FEATURED ARTICLES    ABOUT    PLANS    BLOG    FEEDBACK

🔓 PUBLIC   🔖 ROUGH DRAFT     ≡ Index   ⚙ Settings   ⑂ Fork   ✎ Quickedit   ⓘ Word Count   💬 42 Comments   ⬇ Export   ★ Unfollow

# The "Paper" of the Future

Alyssa Goodman, Josh Peek, Alberto Accomazzi, Chris Beaumont, Christine L. Borgman, How-Huan Hope Chen, Merce Crosas, Christopher Erdmann, August Muench, Alberto Pepe, Curtis Wong   ➕ Add author   ⤬ Re-arrange authors

*A 5-minute video demonsration of this paper is available at this YouTube link.*

## 1 Preamble

A variety of research on human cognition demonstrates that humans learn and communicate best when more than one processing system (e.g. visual, auditory, touch) is used. And, related research also shows that, no matter how technical the material, most humans also retain and process information best when they can put a narrative "story" to it. So, when considering the future of scholarly communication, we should be careful not to do blithely away with the linear narrative format that articles and books have followed for centuries: instead, we should enrich it.

Much more than text is used to commuicate in Science. Figures, which include images, diagrams, graphs, charts, and more, have enriched scholarly articles since the time of Galileo, and ever-growing volumes of data underpin most scientific papers. When scientists communicate face-to-face, as in talks or small discussions, these figures are often the focus of the conversation. In the best discussions, scientists have the ability to manipulate the figures, and to access underlying data, in real-time, so as to test out various what-if scenarios, and to explain findings more clearly. **This short article explains—and shows with demonstrations—how scholarly "papers" can morph into long-lasting rich records of scientific discourse**, enriched with deep data and code linkages, interactive figures, audio, video, and commenting.

**Paper of the Future**

Cognition

**Konrad Hinsen** 3 days ago · Public
Many good suggestions, but if the goal is "long-lasting rich records of scientific discourse", a more careful and critical attitude towards electronic artifacts is appropriate. I do see it concerning videos, but not a word on the much more critical situation in software. Archiving source code is not sufficient: all the dependencies, plus the complete build environment, would have to be conserved as well to make things work a few years from now. An "executable figure" in the form of an IPython notebook wil...
more

**Merce Crosas** 3 days ago · Public
Konrad, good points; this has been a concern for the community working on reproducibility. Regarding data repositories, Dataverse handles long-term preservation and access of data files in the following way: 1) for some data files that the repository recognizes (such as R Data, SPSS, STATA), which depend on a statistical package, the system converts them into a preservation format (such as a tab/CSV format). Even though the original format is also saved and can be accessed, the new preservation format gua...
more
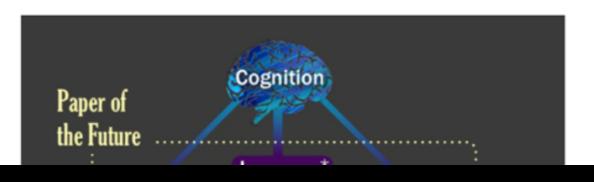
**Konrad Hinsen** 1 day ago · Public
That sounds good. I hope more repositories will follow the example of Dataverse. Figshare in particular has a very different attitude, encouraging researchers to deposit as much as possible. That's perhaps a good strategy to change habits, but in the long run it could well backfire when people find out in a few years that 90% of those deposits have become useless.
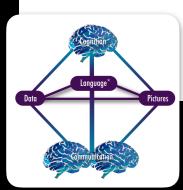
**Christine L. Borgman** 4 months ago · Private
"publications"

Cognition

Language*

Data   Pictures

Communication
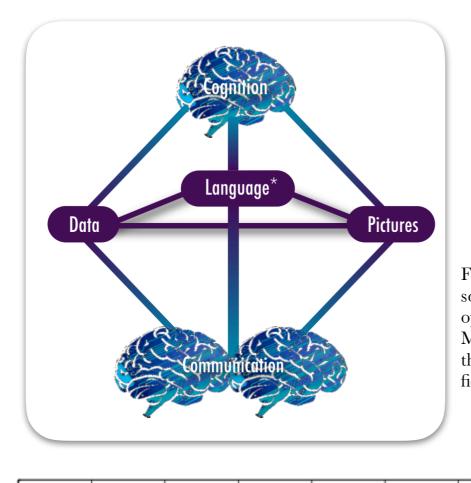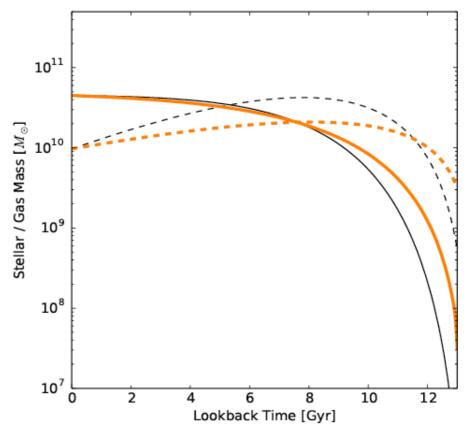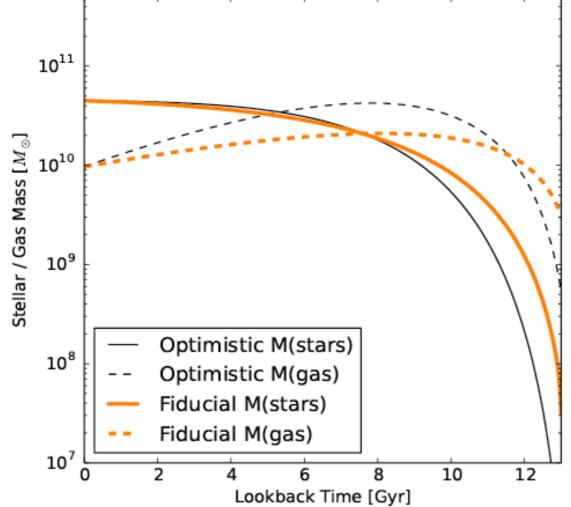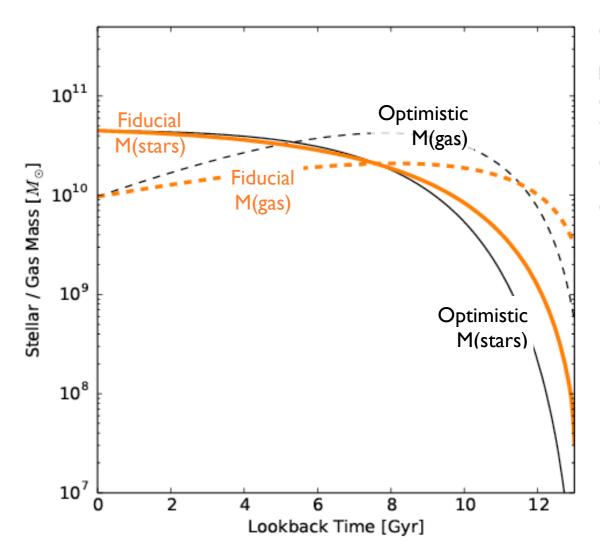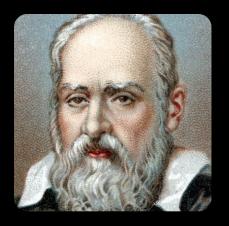
Figure Caption: The solid/ solid black line shows the optimistic case for M(stars)/ M(gas). The orange lines show the same quantities, for the fiducial case.



Optimistic M(stars)
Optimistic M(gas)
Fiducial M(stars)
Fiducial M(gas)



Fiducial M(stars)
Optimistic M(gas)
Fiducial M(gas)
Optimistic M(stars)

"…how traditional and modern approaches to visualizing information are best combined to leverage human creativity  in our quest to understand the world around us…"

Galileo Galilei

Alyssa Goodman

Felice Frankel

# Galileo Galilei
## (1564-1642)



Notes for & re-productions of Siderius Nuncius

# Galileo Galilei

WorldWide Telescope

GALILEO'S "NEW OR...

Created by Alyssa Goodman, Curtis Wong...
with advice from Owen Gingerich and Da...

Microsoft WorldWide Telescope

Explore     Guided Tours     Search     Community     Telescope     View     Se

Use Layer Manager to
Control User Settings

Observing Location
Name:   Milan, Italy
Lat :         45:28:37
Lng:          09:10:59
☐ View from this location     Setup

Observing Time
1610/01/07  15:43:16
Real Time
☑ UTC
Now

E

*Galileo's New Order,  A WorldWide Telescope Tour by Goodman, Wong & Udomprasert 2010*

# Galileo Galilei



January 11, 1610

# "DATA, DIMENSIONS, DISPLAY"
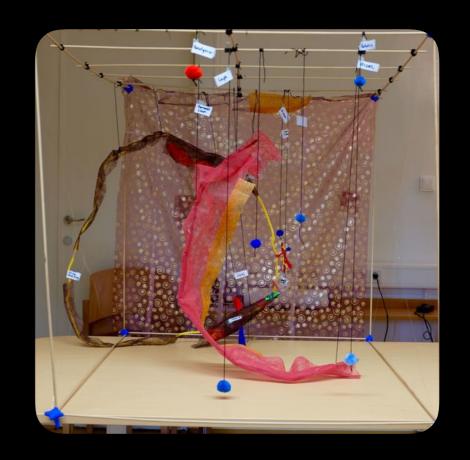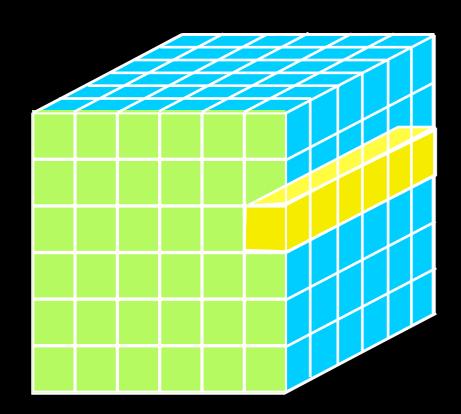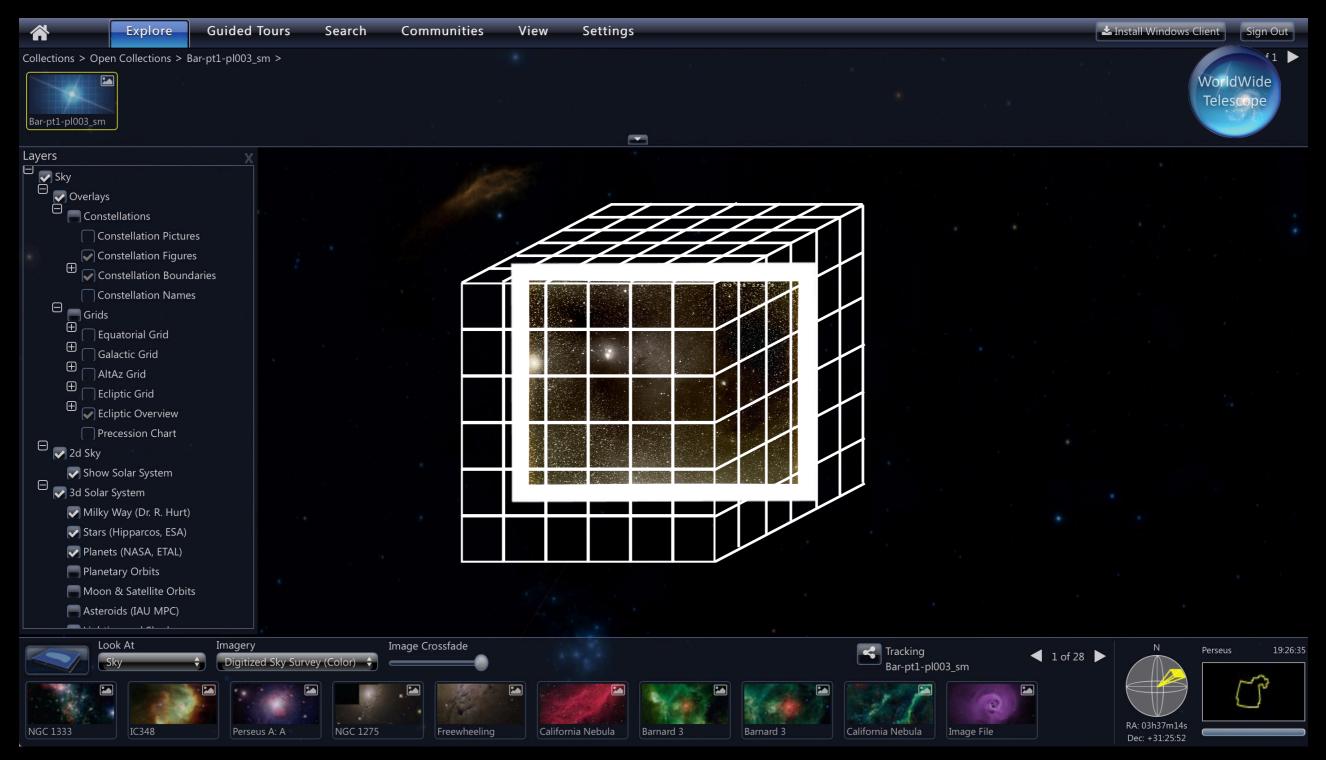
**1D**: Columns = "Graphs"

**2D**: Faces or Slices = "Images"

**3D**: Volumes = "3D Renderings", "2D Movies"
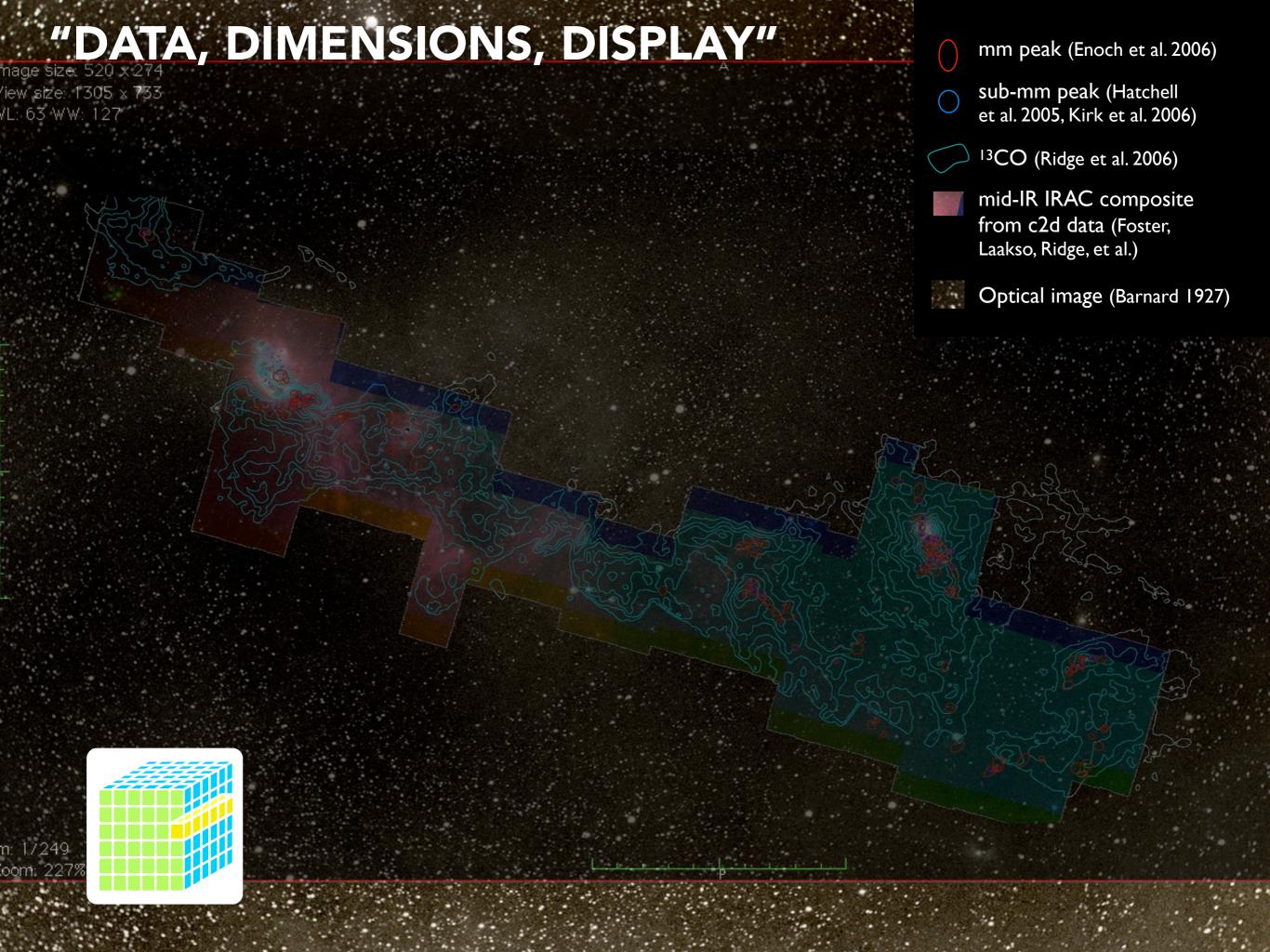
**4D**: Time Series of Volumes = "3D Movies"

# "DATA, DIMENSIONS, DISPLAY"

# "DATA, DIMENSIONS, DISPLAY"

Image size: 520 x 274
View size: 1305 x 733
WL: 63 WW: 127

○ mm peak (Enoch et al. 2006)

○ sub-mm peak (Hatchell et al. 2005, Kirk et al. 2006)

○ $^{13}$CO (Ridge et al. 2006)

mid-IR IRAC composite from c2d data (Foster, Laakso, Ridge, et al.)

Optical image (Barnard 1927)

m: 1/249
Zoom: 227%

3D Viz made with VolView

AstronomicalMedicine@ IIC

COMPLETE

# LINKED VIEWS OF HIGH-DIMENSIONAL DATA



3D

2D

Data Abstraction

Statistics

# LINKED VIEWS OF HIGH-DIMENSIONAL DATA, IN PYTHON



*video by Tom Robitaille, lead glue developer*
*glue created by: C. Beaumont,  M. Borkin,  P. Qian, T. Robitaille, and A. Goodman, PI*

# LINKED VIEWS OF HIGH-DIMENSIONAL DATA, IN PYTHON

# glue
multidimensional data exploration

**built-in**

standard data loaders

Data File 1

define new variables, import/export insights, interactive plots for the web, save state, all from GUI

Data File 2

link data files' attributes

highlight live or algorithmic selections
with Boolean logic

standard 1D, 2D & 3D plots

**plug-in**

custom data loaders

Data File N

custom buttons, features

custom plots

**+options**

user config.py file (loaders, colors, plot types, +)

IP[y]: access to all matplotlib functions through built-in IPython terminal

jupyter

run & interact with glue from Jupyter notebook & other tools

glueviz.org

GLUE PLOTS • GLUE DATA SETS • GLUE TOOLS

# WorldWide Telescope



*Experience WorldWide Telescope, free, at* **worldwidetelescope.org**

[demo]

# The Path to Newton

## The Path to Newton

PREAMBLE:

Isaac Newton's theory of gravity was truly revolutionary. For the first time in history, all motion -- from celestial bodies in Space to objects on Earth -- could be mathematically described and predicted. Newton's theory necessitated new mathematics, Calculus, as well as a trove of empirical observations from which to derive and against which to test the math. The observations required instruments, the instruments required inventors, and the inventors required ideas, models, and conceptual systems that tried to make sense of the world and its physical phenomena. Over millennia, the ideas that led to Newton's built on earlier ideas through critique, amendment, and refutation. Newton's theory of gravity was not quite like the other ideas that drove our understanding of how the Universe moves forward, though--it was a monumental paradigm shift, from a world described by empirical rules, like those Kepler had discovered, to a world that could be predicted a priori--with no prior data about a system.

The Path to Newton is an attempt to demonstrate (some) of history behind how Newton knew what he knew and thought what he thought about motion. For many centuries, motion of objects in the Heavens (what we now think of as celestial mechanics) was considered categorically distinct from motion of objects on Earth (what was known as kinematics and, later, dynamics), so the Path focuses on philosophical and mathematical conceptions of the Universe and of how and why objects move on Earth, in order to explain how an ultimately unified theory of motion came to be.

Steps along the Path were facilitated by material technologies and greatly affected by religious doctrine, cultural exchange, and the migration and translation of ideas. The Path highlights the cultures, thinkers and tinkerers who wrestled ideas about motion into the stories, cosmologies, mathematics, tools, and data that lay before Newton as he worked. Each person highlighted along the Path stands in for a constellation of factors, often groups of people, that led to the historical recording or transmission of key ideas. While The Path employs these contributors as representatives and access points to seminal ideas and innovations necessary for a predictive theory of gravity, the immensity of the

# The Path to Newton

## BIG IDEAS

**Correct**

**Partial credit**

**Wrong**

**CONNECTIONS BETWEEN IDEAS**

━━━━➤

━━━━➤

┈┈┈┈➤ Teacher-Pupil or Senior-Junior Researcher

🚶 Travel between cultures

**Published works**

---

**BABYLONIANS**
c. 2000–300 BCE

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

Natural, not supernatural.

**THALES**
624–546 BCE
Greek

**Nature can be explained**

Motion needs a little push.

**ANAXAGOROS**
510–428 BCE
Greek

**Motion must have a cause**

**SOCRATES**
470–399 BCE
Greek

Symmetry rules.

**PLATO**
427–347 BCE
Greek

💕Circles spheres, beauty, eternity...

**ARISTOTLE**
383–322 BCE
Greek

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

**The air moves objects through it**

**All things move to their natural place**

I can prove it!

**EUCLID**
300? BCE
Greek

**A single framework for all geometry**

Circles ARE the best! We just need more!

**PTOLEMY**
100–170
Greek living in Roman Egypt

Celes
an
terres
pheno
simi

**Motion and change are illusions**

Question all you "see."

**PARMENIDES**
515–450 BCE
Greek

The universe is WAY bigger than you might think.

**ANAXIMANDER**
610–546 BCE
Greek

**Earth generated by boundless eternity**

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

**Rearranging "atoms" allows motion**

**DEMOCRITUS**
460–370 BCE
Greek

**Earth is stationary center of the universe**

**EUDOXUS**
390-337 BCE
Greek

It's spheres all the way down.

**ARISTARCHUS**
310–230 BCE
Greek
☉

Hello? Is this thing on?

**Epicycles, equants, eccentrics**

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

If circles are perfect, spheres are sublime.

**Universe is spherical**

**PYTHAGORAS**
570–495 BCE
Greek

**Planets, Moon, Sun, move on spheres**

**Sun at center**

**Math can model the universe**

**HIPPARCHUS**
190-120 BCE
Greek living in Rome

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

Some "stars" move more than others

**Astronomical Diaries**

**On the Heavens**
Aristotle
c. 350 BCE

**Physics**
Aristotle
c. 320 BCE

**Elements**
Euclid
c. 300 BCE

**The Almagest**
Ptolemy
c. 150

**Aryab**
Aryab
c. 4

SUN AT CENT[ER]

GNOMON
ASTROLABE

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

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

**Motion caused by self-exhausting force**

**Celestial and terrestrial phenomena similar**

Aristotle is wrong about space, time, and matter.

**JOHN PHILOPONUS**
490–570
Greek living in Roman Egypt

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

**IBN SINA (AVICENNA)**
980–1037
Persian

What did Aristotle really mean? We need to question.

**IBN RUSHD (AVERROES)**
1126–1198
Arab

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

**NICOLE ORESME**
1320–1382
French

**Objects are "set into" motion**

Circles ARE the best! We just need more!

**PTOLEMY**
100–170
Greek living in Roman Egypt

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

**VĀRĀHAMIHIRA**
505–587
Indian

**Motion is indefinite without external forces**

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

**Motion is a chain of an object's locations**

**AL-TUSI**
1201–1274
Persian

Bigger observatories, better observations.

**Motion explained with "impetus theory"**

Math first, philosophy later.

**NICHOLAS COPERNICUS**
1473–1543
Polish

**Epicycles, equants, eccentrics**

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

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

**Models matching data is paramount**

If I use a teeny unit of time...

**BHĀSKARA II**
1114–1185
Indian

This is math, not philosophy.

**JEAN BURIDAN**
1295–1358
French

**Simple circular orbits work with better math**

**The Earth might actually rotate**

Earth need not be at rest, Ptolemy!

**ALI QUSHJI**
1403–1474
Turkic

**Sun at center of Earth's & planets' orbits**

I can [...] the [univ]erse

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

[HIPP]ARCHUS
[190–]120 BCE
[Gr]eek living [i]n Rome

**Sines improve accuracy**

**Zero is a numeral unto itself**

**Much of what we today call calculus**

I can improve Ptolemy! To the printing press!

**REGIOMONTANUS**
1436–1476
German

**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 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

**PredictionX**

SUN AT CENTER (⊕ BELIEVED EARTH AT CENTER)

GNOMON
ASTROLABE
PRINTING PRESS

GNOMON
ASTROLABE
PRINTING PRESS
TELESCOPE

ARITHMETIC
ZERO AS NUMERAL
PLANAR GEOMETRY
SPHERICAL GEOMETRY
TRIGONOMETRY
SPRERICAL TRIGONOMETRY
ALGEBRA

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PLANAR GEOMETRY
SPHERICAL GEOMETRY
TRIGONOMETRY
SPERHICAL TRIGONOMETRY
ALGEBRA
SPECIAL FORMS
LOGARITHMS

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

TUSI COUPLE AND OTHER SPECIAL FORMS

**IBN RUSHD (AVERROES)**
1126–1198
Arab

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

**NICOLE ORESME**
1320–1382
French

*Objects are "set into" motion*

*Bigger observatories, better observations.*

**AL-TUSI**
1201–1274
Persian

*With giant spendy instruments, I can get GREAT data.*

*Math first, philosophy later.*

*Oooh, I like this Dutch spyglass!*

*Sorry, Aristotle, you're just wrong.*

*Aristotle, mon ami, above and below, it's all matter in motion.*

*We're gonna need better math.*

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

**ISAAC NEWTON**
1642–1726
British

*Motion explained with "impetus theory"*

**Planets orbit the Sun, but Sun orbits Earth**

**NICHOLAS COPERNICUS**
1473–1543
Polish

⊕ **TYCHO BRAHE**
1546–1601
Danish

**GALILEO GALILEI**
1564–1642
Italian

**RENÉ DESCARTES**
1596–1650
French

*This is math, not philosophy.*

**JEAN BURIDAN**
1295–1358
French

**Motion is a chain of an object's locations**

**Sun at center of Earth's & planets' orbits**

**Jupiter has moons, which orbit like our Moon**

**All bodies on Earth have (circular) inertia**

**GRAVITY GOVERNS ALL**

**Simple circular orbits work with better math**

*Earth need not be at rest, Ptolemy!*

**The Earth might actually rotate**

**ALI QUSHJI**
1403–1474
Turkic

*I have Tycho's fancy data!*

*Hmm... circles are a problem.*

**JOHANNES KEPLER**
1571–1630
German

**Sun is the center**

**All bodies have inertia**

*I must make Newton publish!*

**EDMOND HALLEY**
1656–1742
British

*I can improve Ptolemy! To the printing press!*

**REGIOMONTANUS**
1436–1476
German

**Orbits are ellipses, not circles**

**Some comets return, predictably**

**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

**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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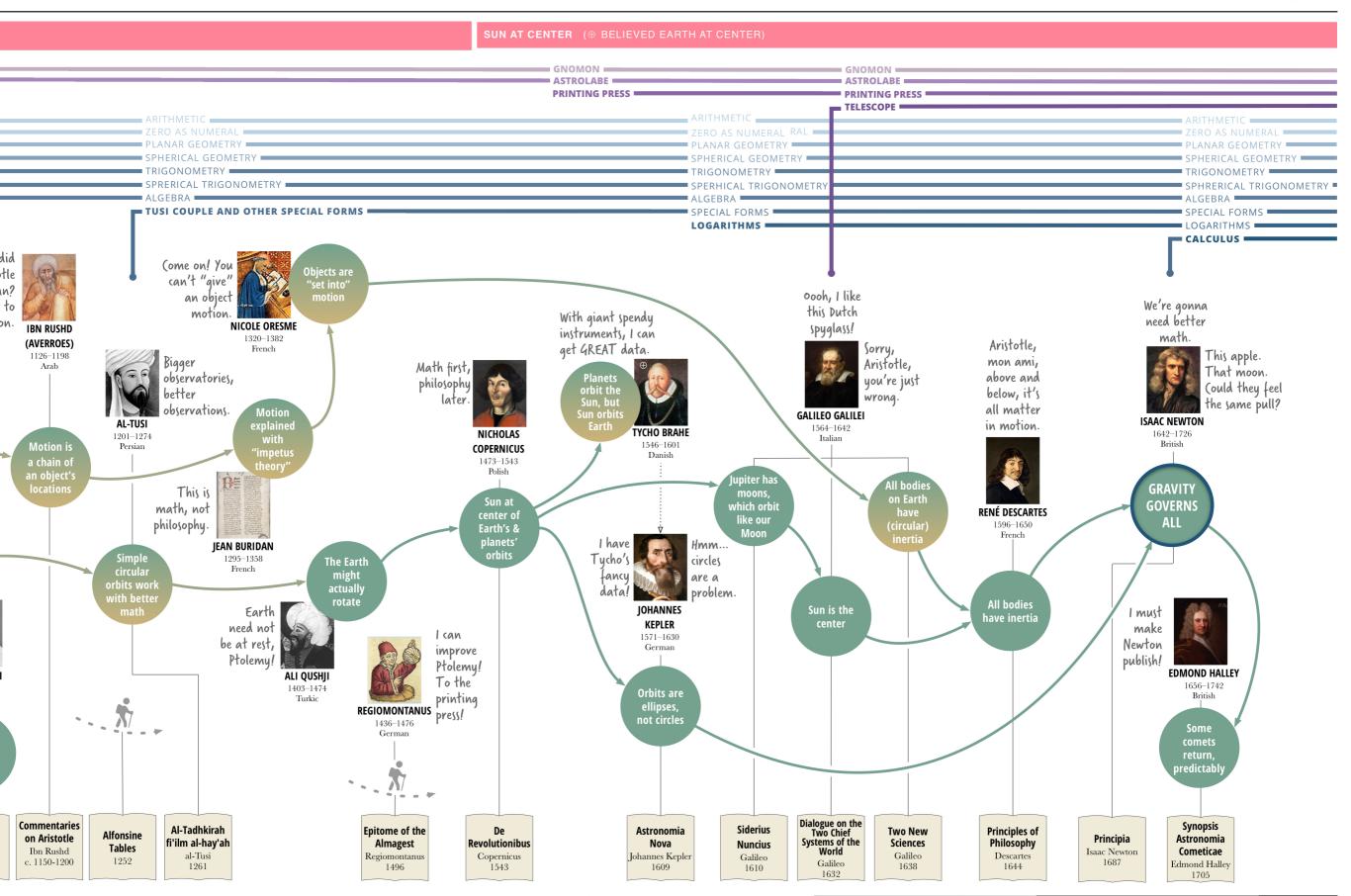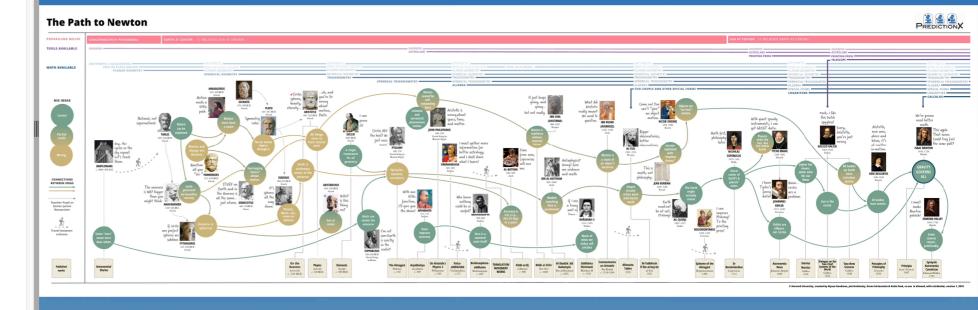# The Path to Newton



## The Path to Newton

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The Path to Newton is an attempt to demonstrate (some) of history behind how Newton knew what he knew and thought what he thought about motion. For many centuries, motion of objects in the Heavens (what we now think of as celestial mechanics) was considered categorically distinct from motion of objects on Earth (what was known as kinematics and, later, dynamics), so the Path focuses on philosophical and mathematical conceptions of the Universe and of how and why objects move on Earth, in order to explain how an ultimately unified theory of motion came to be.

Steps along the Path were facilitated by material technologies and greatly affected by religious doctrine, cultural exchange, and the migration and translation of ideas. The Path highlights the cultures, thinkers and tinkerers who wrestled ideas about motion into the stories, cosmologies, mathematics, tools, and data that lay before Newton as he worked. Each person highlighted along the Path stands in for a constellation of factors, often groups of people, that led to the historical recording or transmission of key ideas. While The Path employs these contributors as representatives and access points to seminal ideas and innovations necessary for a predictive theory of gravity, the immensity of the
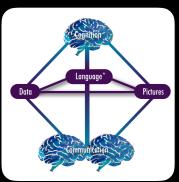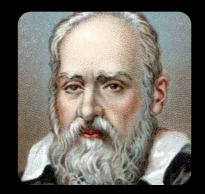
+Ask me about the

# The TIMELINE CONSORTIUM

timelineconsortium.org

TEN QUESTIONS TO ASK WHEN CREATING A VISUALIZATION

# The 10 Questions

1. **Who** | Who is your audience? How expert will they be about the subject and/or display conventions?
2. **Explore-Explain** | Is your goal to explore, document, or explain your data or ideas, or a combination of these?
3. **Categories** | Do you want to show or explore pre-existing, known, human-interpretable, categories?
4. **Patterns** | Do you want to identify new, previously unknown or undefined patterns?
5. **Predictions & Uncertainty** | Are you making a comparison between data and/or predictions? Is representing uncertainty a concern?
6. **Dimensions** | What is the intrinsic number of dimensions (not necessarily spatial) in your data, and how many do you want to show at once?
7. **Abstraction & Accuracy** | Do you need to show all the data, or is summary or abstraction OK?
8. **Context & Scale** | Can you, and do you want to, put the data into a standard frame of reference, coordinate system, or show scale(s)?
9. **Metadata** | Do you need to display or link to non-quantitative metadata? (including captions, labels, etc.)
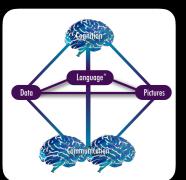10. **Display Modes** | What display modes might be used in experiencing your display?

💬   **Now, visit the 10QViz conversation!  There's so much more to talk about.**   💬

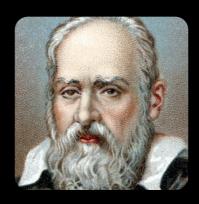Curious about  the **origins** of 10QViz? Try the About page.
Want to learn **how best to use** and **participate** in 10QViz? Try the How to page.
Want to read about the **scholarship** behind 10QViz.org's questions?  Write to ask for a draft of our research paper, Coltekin & Goodman 2019.

10QViz.org

"Seeing, Exploring, Explaining, and Sharing our Universe"

citizen science

shared data

modular, software

collaborative software development

glue

combined data sources

public outreach

Orion in CO

scholarly publication

new findings

plug-in architecture

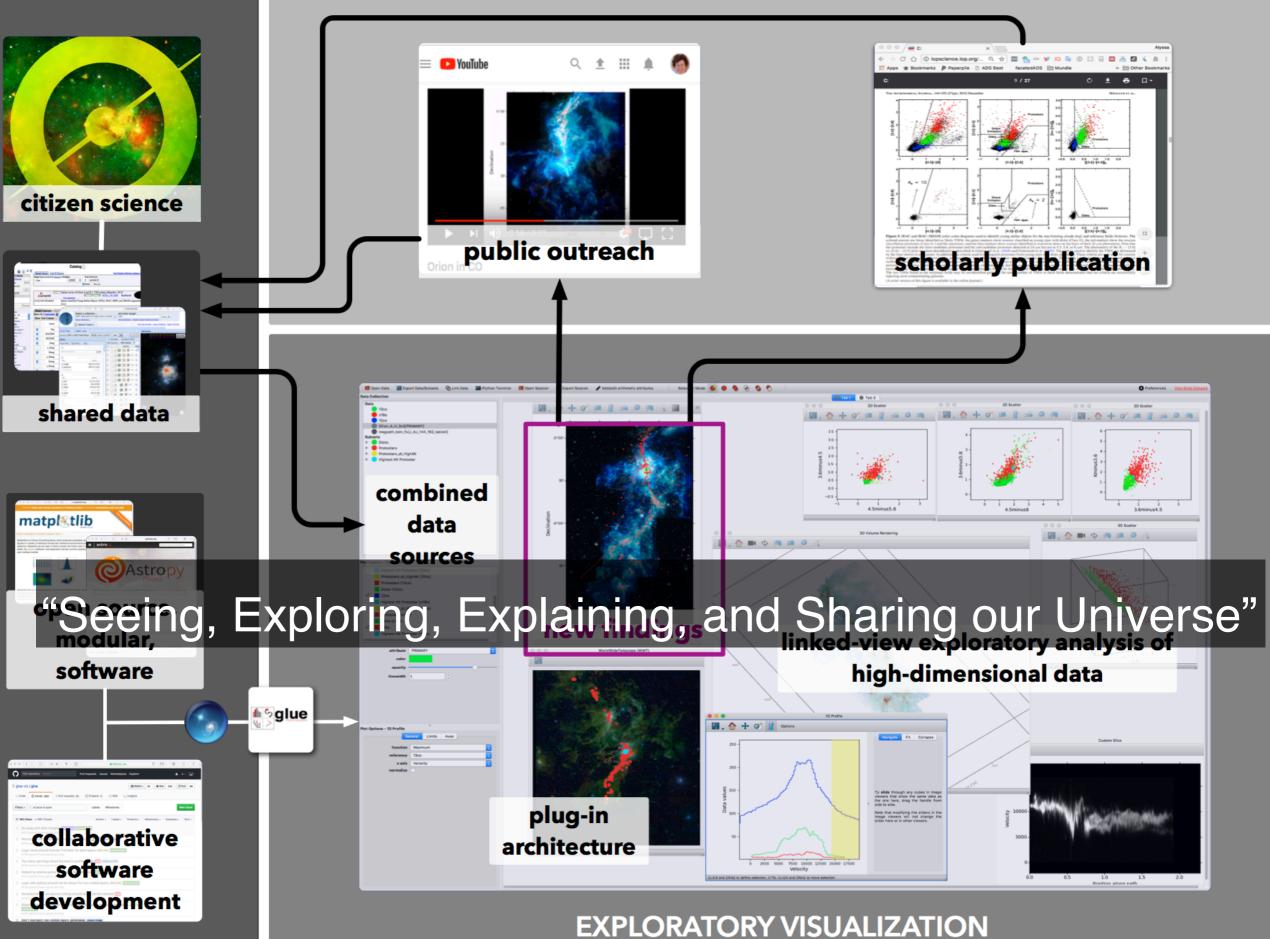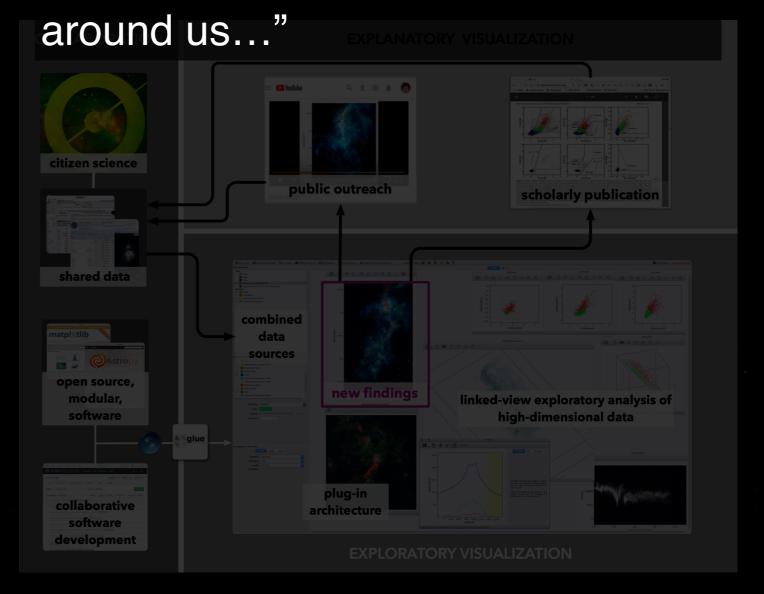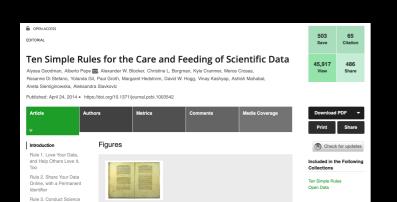linked-view exploratory analysis of high-dimensional data

"Seeing, Exploring, Explaining, and Sharing our Universe"

"...how traditional and modern approaches to visualizing information are best combined to leverage human creativity  in our quest to understand the world around us..."

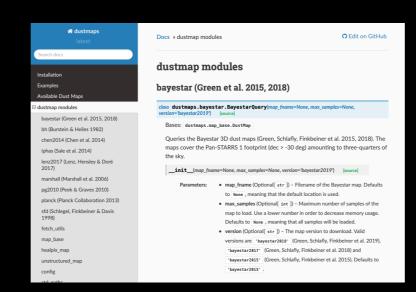# Seeing, Exploring, Explaining, and Sharing our Universe

## OPEN DATA



## OPEN CODE



## OPEN SCIENCE

More this afternoon…

OPEN SPACE

WorldWide Telescope

glue
multidimensional data exploration