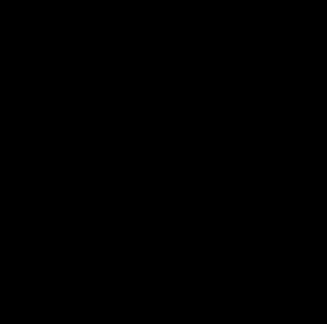
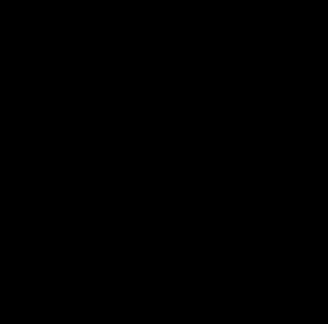
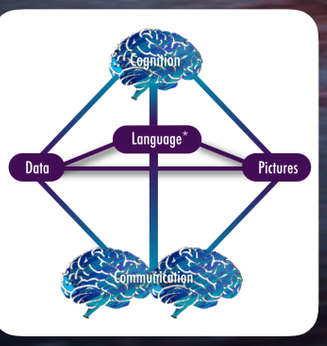
Last Night!

OPEN SPACE





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 Radc e

talk by Catherine Zucker tomorrow at 2 PM

The Radcliffe Wave

Calypso

Alyssa

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 FOR ADVANCED STUDY HARVARD UNIVERSITY

Radcliffe Institute

Initiative in Innovative Computing

Astronomical Medicine

ISM and Star Formation

ISM & Star Formation

Fetch! with Ruff Ruffman

HDSI | IQSS

DATA+CLIMATE@HARVARD

Climate+Data @Harvard

SEAMLESS ASTRONOMY

Seamless Astronomy

AUTHOREA

The 'Paper' of the Future

Take-a-Sweater

PREDICTIONX

Prediction

The Art of Numbers

10 Questions ..Visualization

ADS ALL-SKY SURVEY

ADS All-Sky Survey

Astronomy Rewind

The TIMELINE CONSORTIUM

The Timeline Consortium

John Snow & Cholera

The Path to Newton

Dataverse Project

Open Data

glue

glue

COMPLETE

The COMPLETE Survey of Star-Forming Regions

Nessie-Bones

"Radcliffe Wave"

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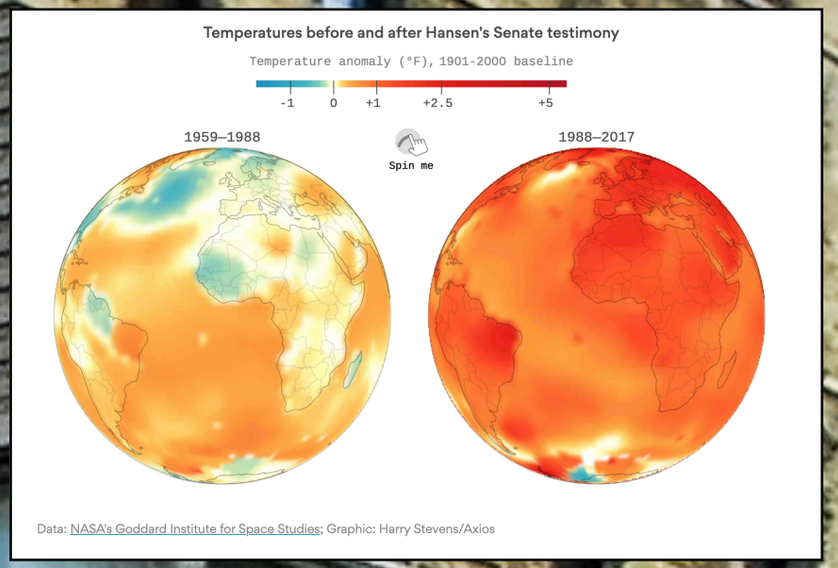
"Radcliffe Wave"

Climate Change



Temperatures before and after Hansen's Senate testimony

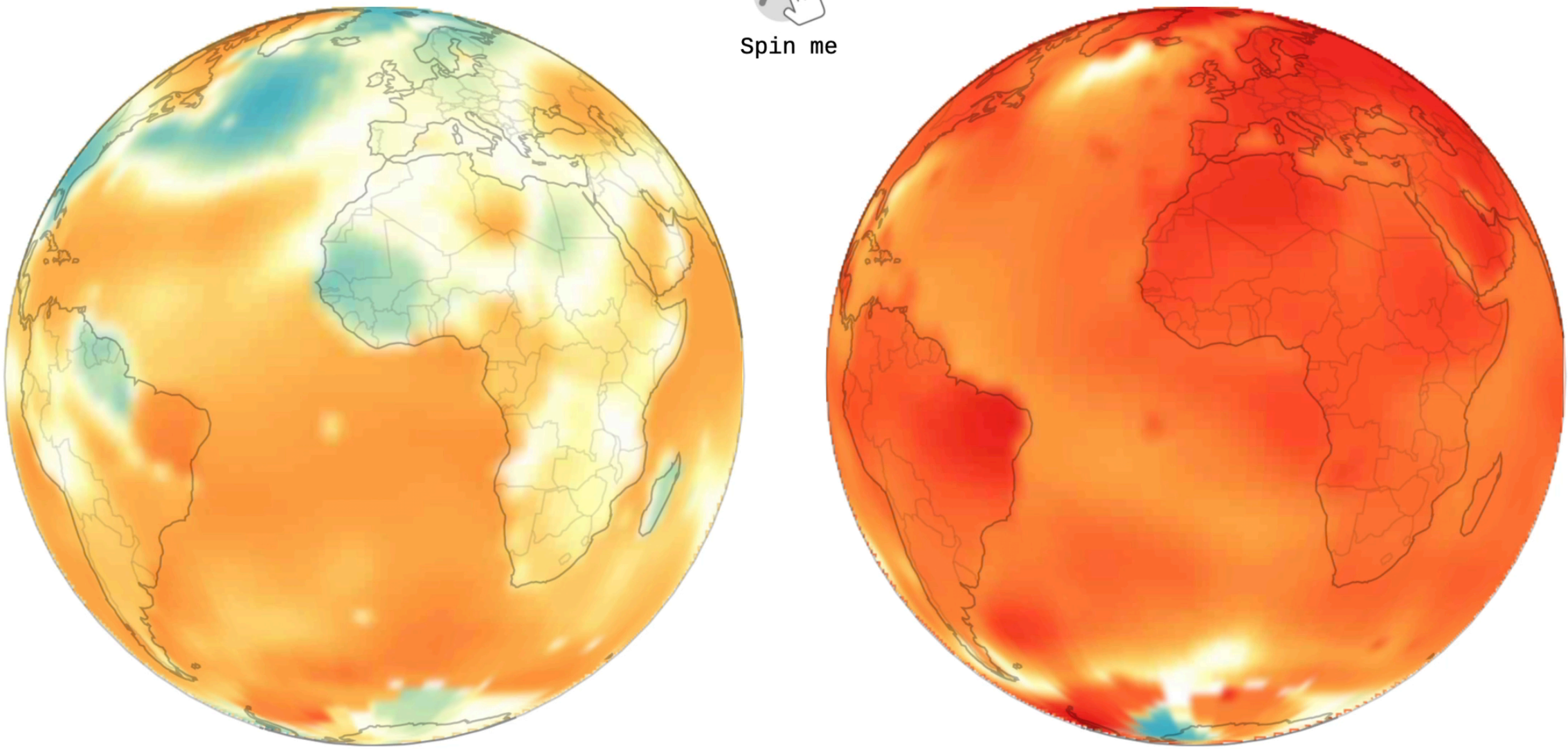
Temperature anomaly (°F), 1901-2000 baseline

-1 0 +1 +2.5 +5

1959–1988

Spin me

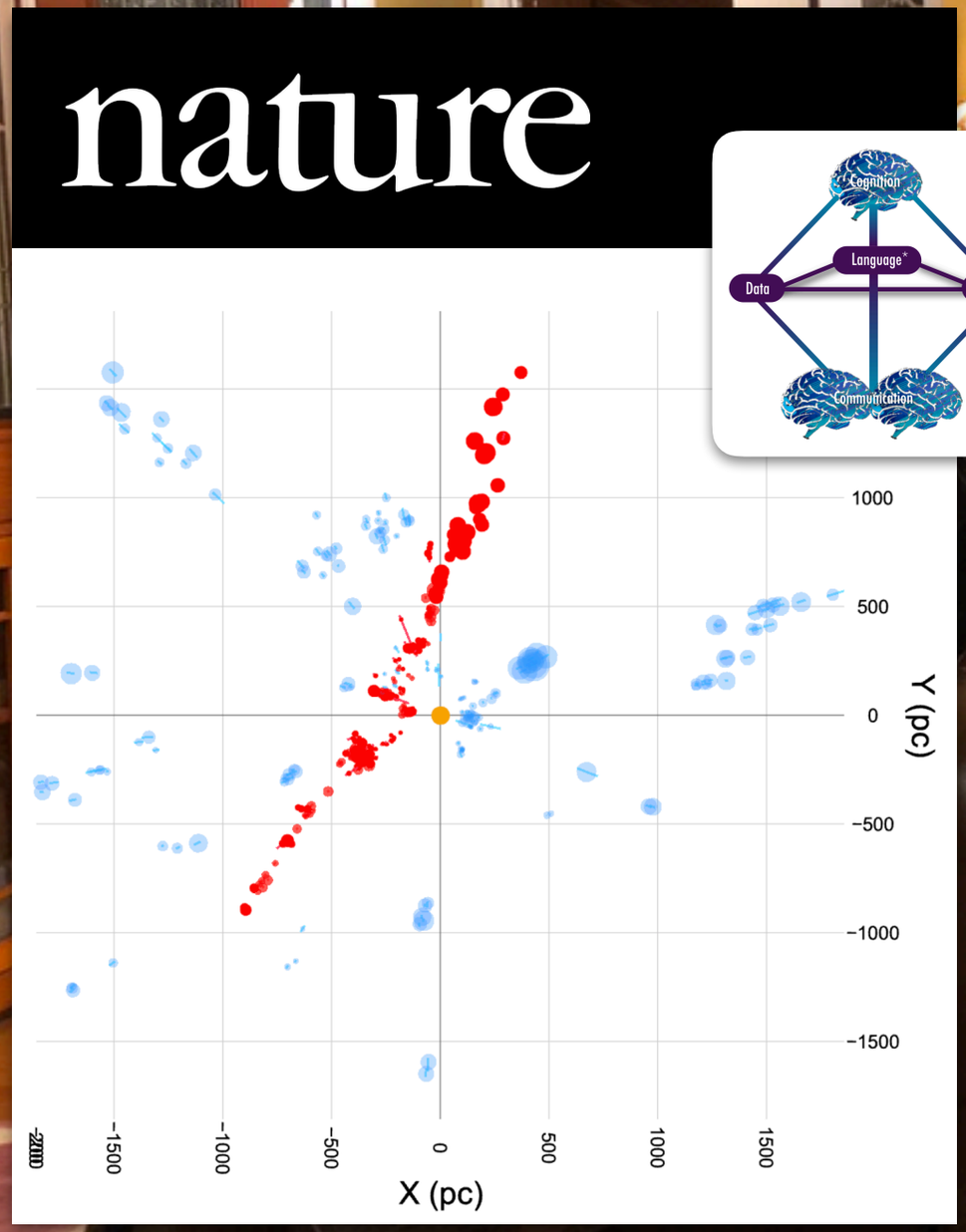
1988–2017



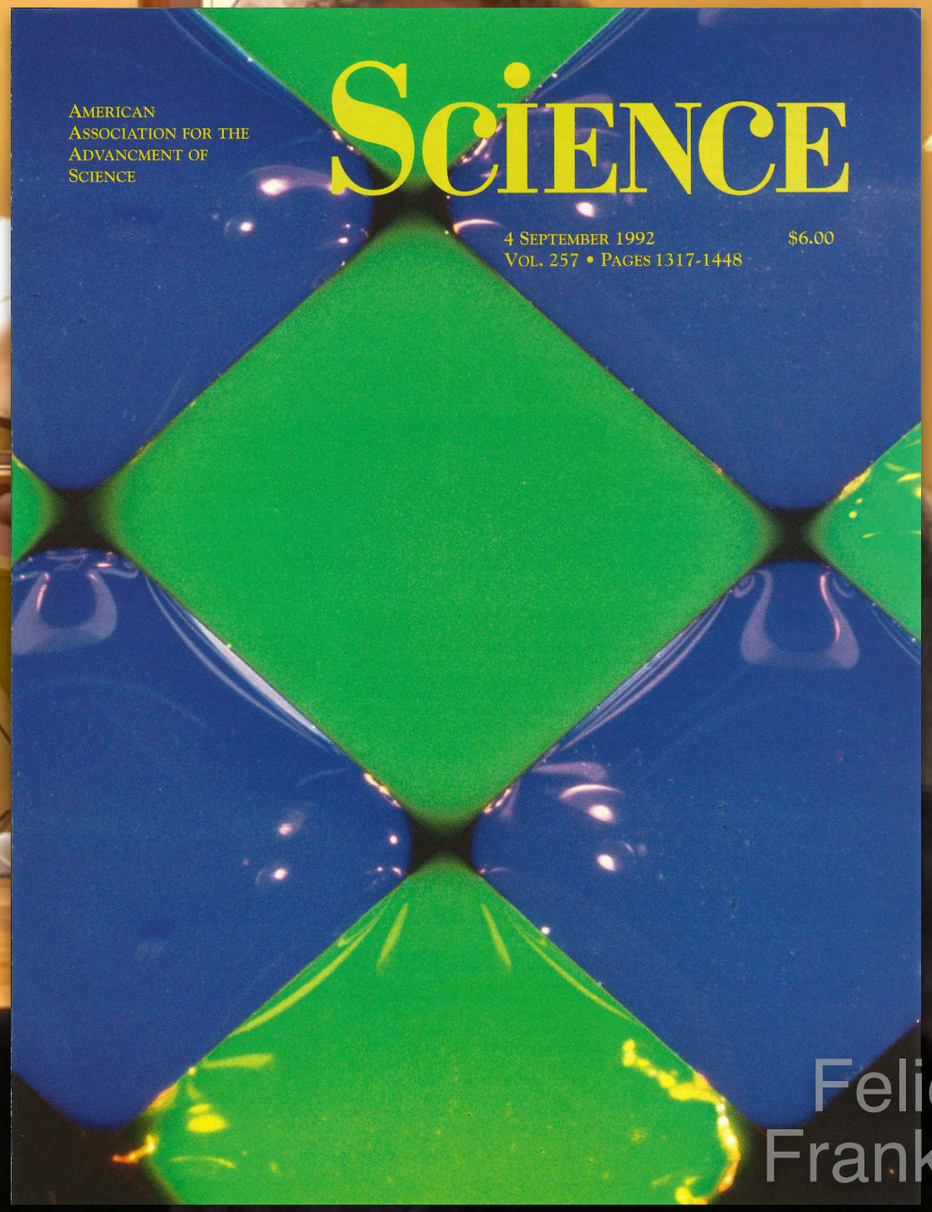
Data: NASA's Goddard Institute for Space Studies; Graphic: Harry Stevens/Axios

www.axios.com/how-much-earth-has-warmed-since-hansen-testified-b6f8fdb4-484e-477f-b8b6-6ee320994dc0.html

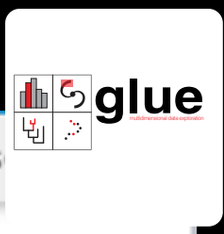
"…how traditional and modern approaches to visualizing information are best combined to leverage human creativity in our quest to understand the world around us…"



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

3

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.

2

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.

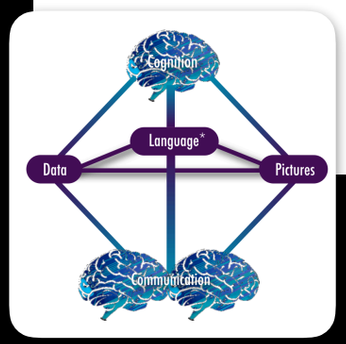
0

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"



d3po/Authorea: Peek, Price-Whelan, Pepe, Beaumont, Borkin, Newton; PotF: Goodman, Peek;
WWT: Wong, Fay et al.; Astrometry.net: Hogg, Lang, Roweis et al.

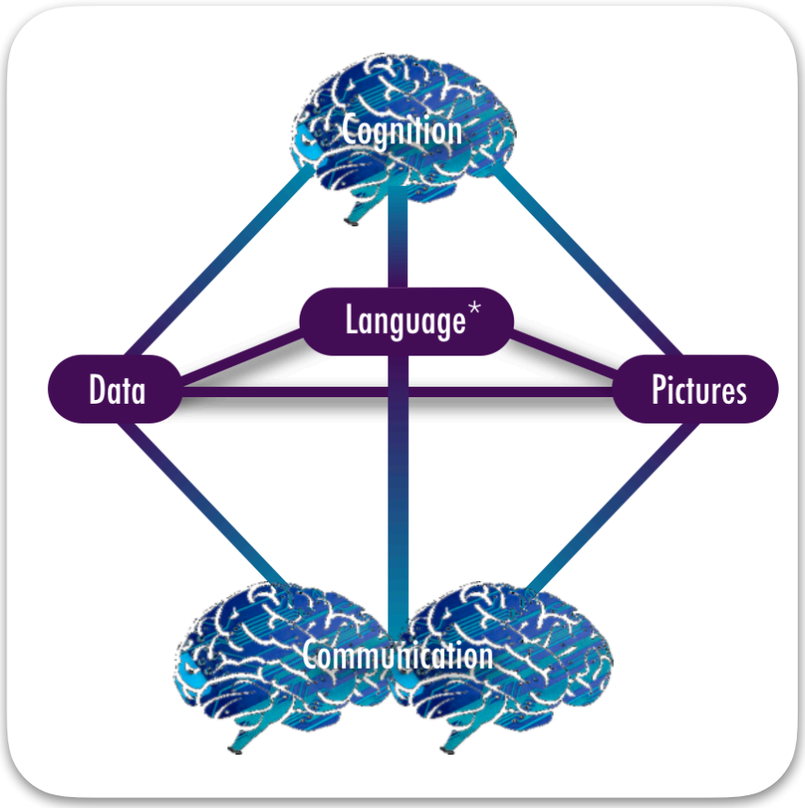
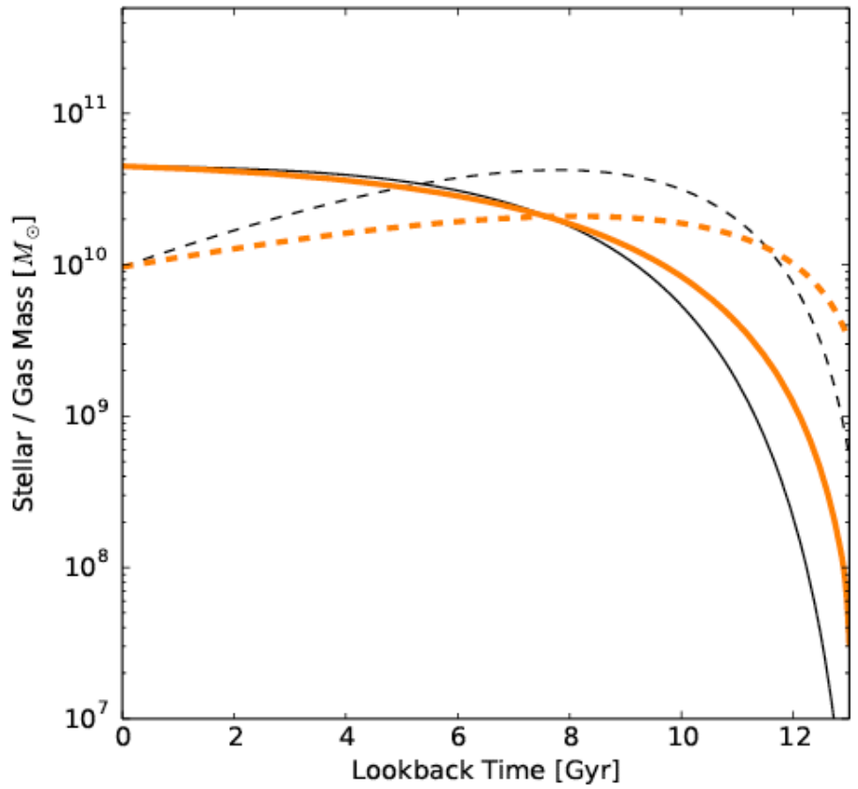
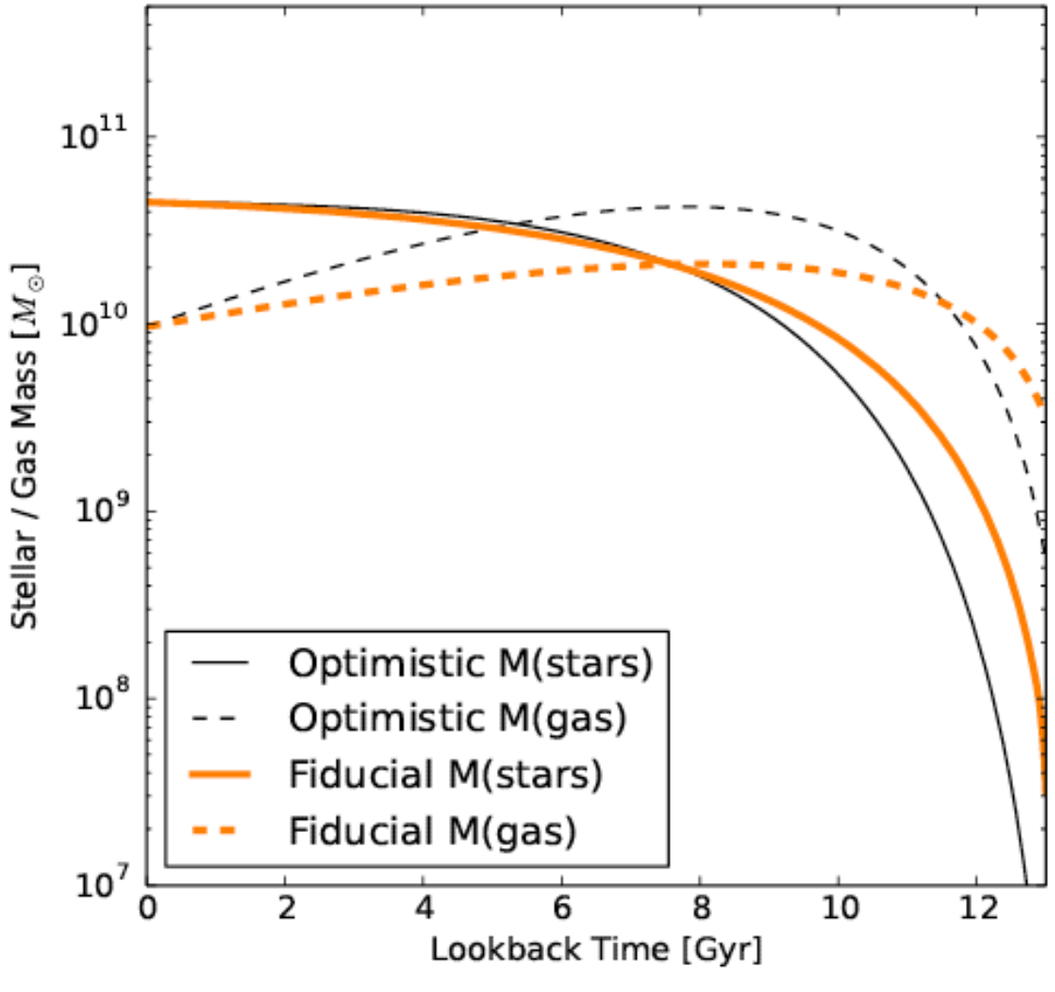


Figure Caption: The solid/ solid black line shows the optimistic case for M(stars)/ M(gas). The orange lines show the same quantities, for the fiducial case.





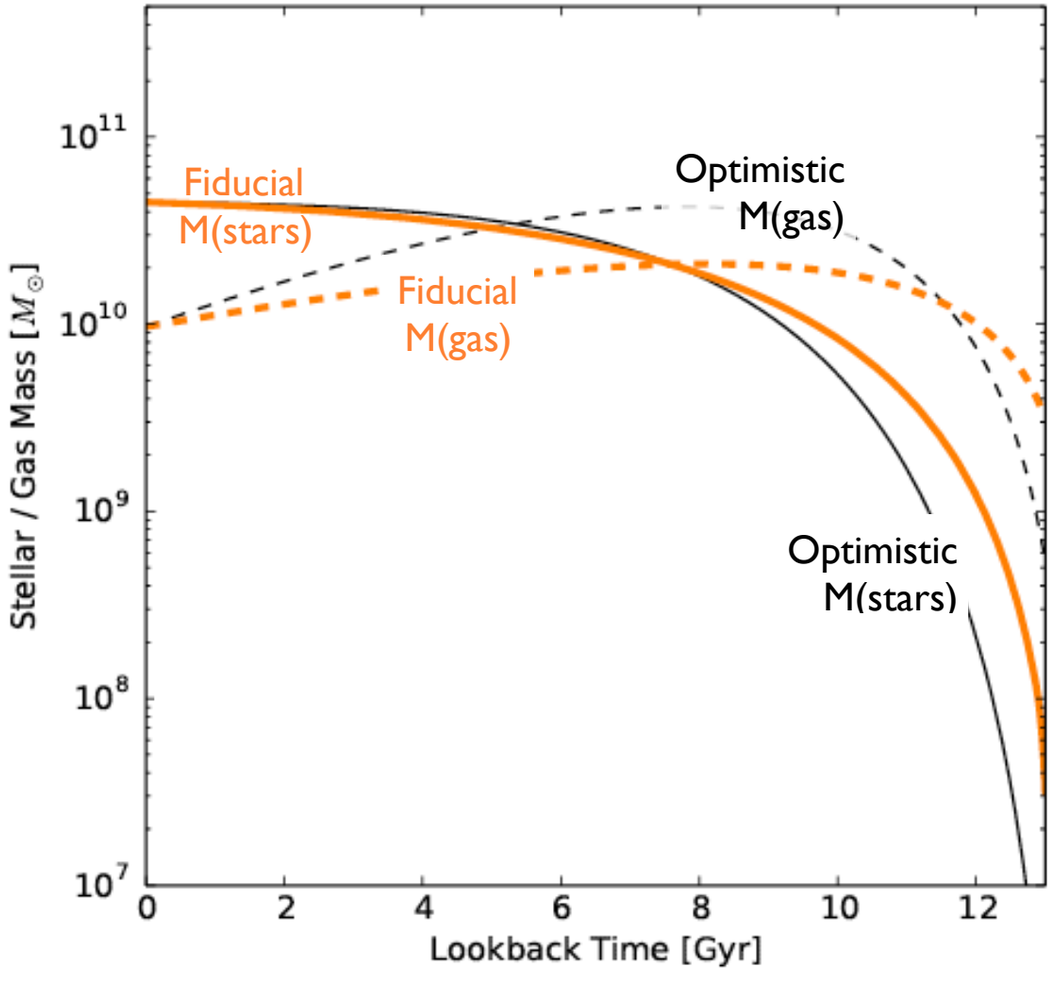
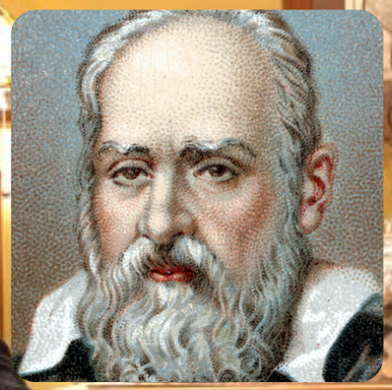


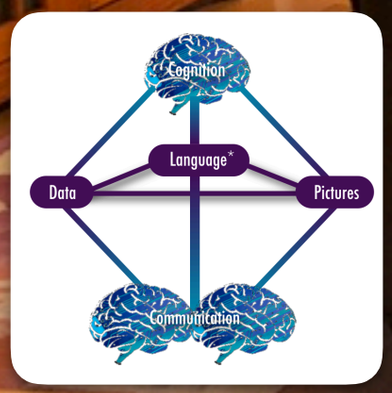
figure from draft of Ting, Conroy & Goodman 2015

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

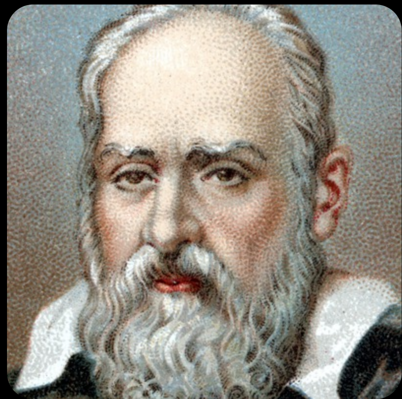


Galileo
Galilei

Alyssa
Goodman

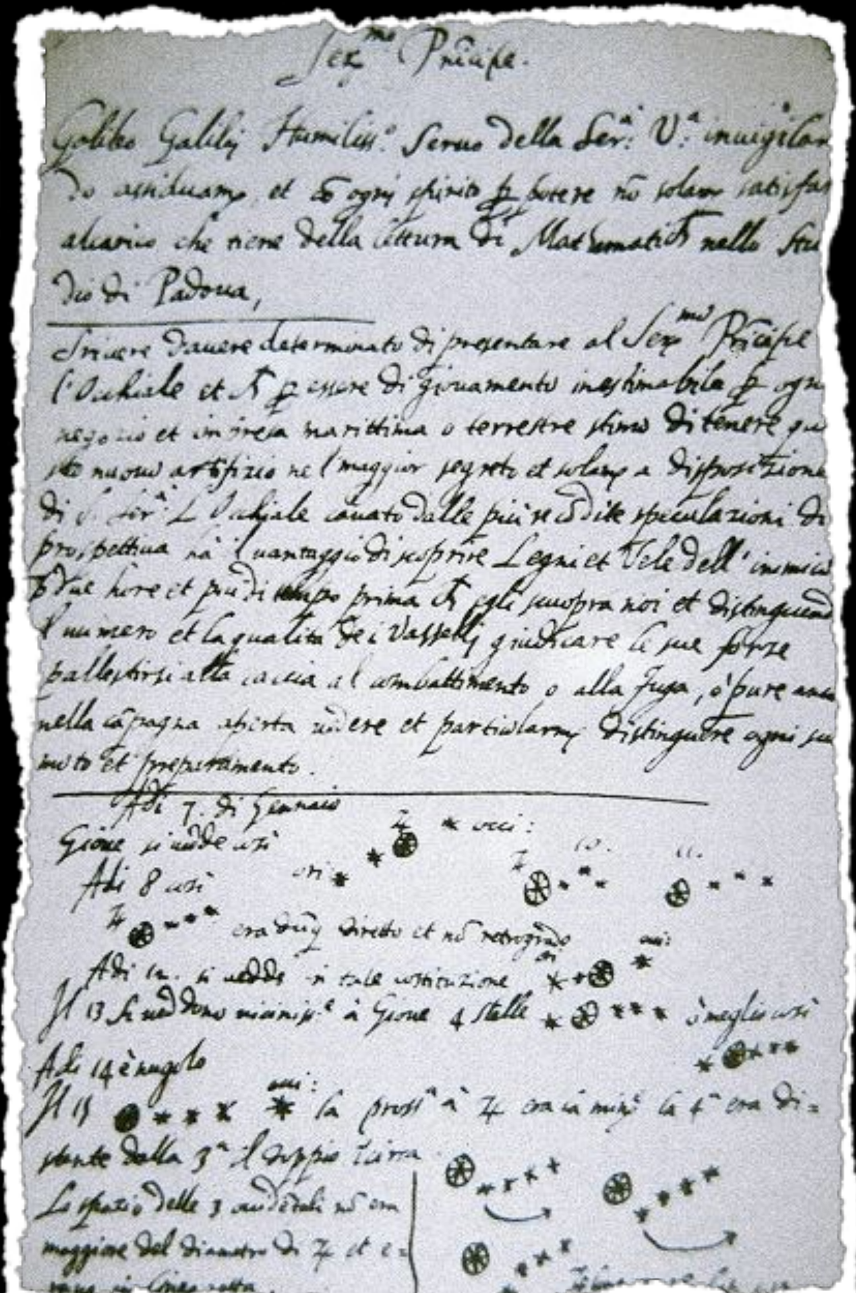


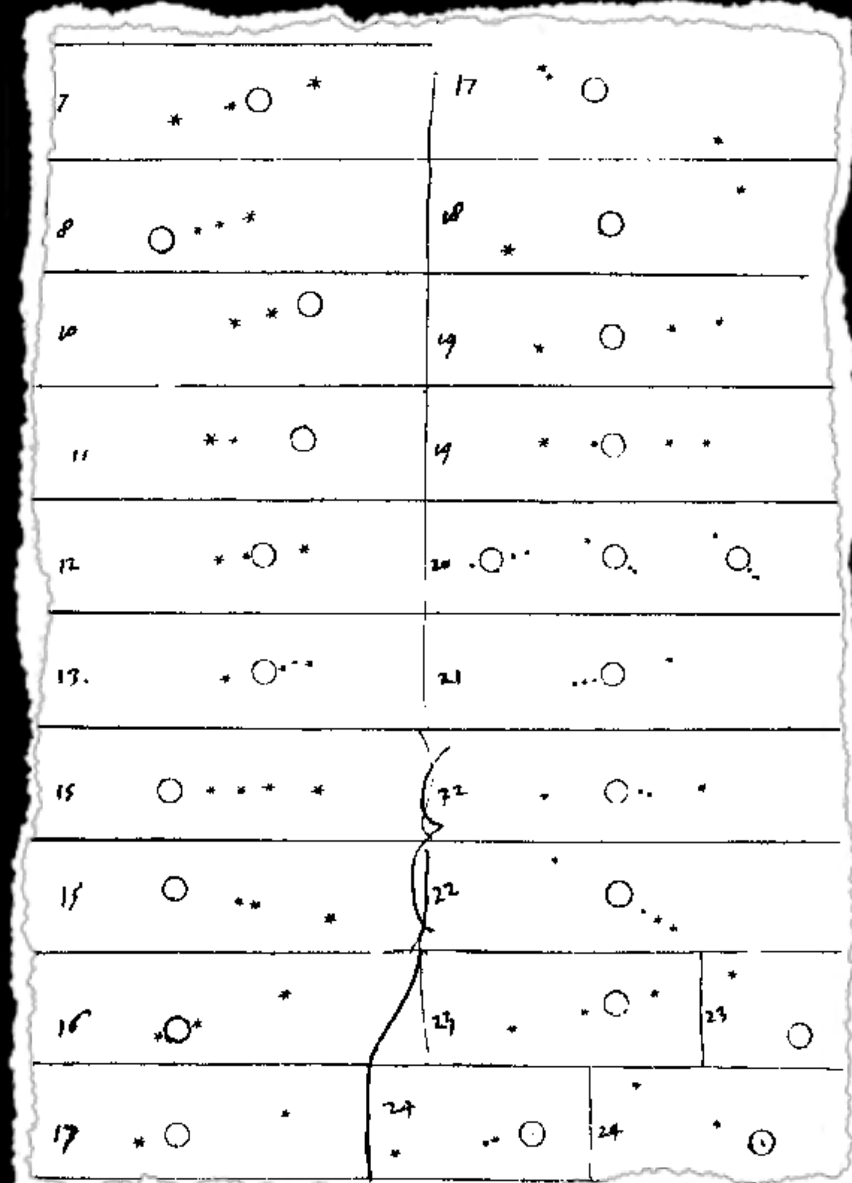
Felice
Frankel

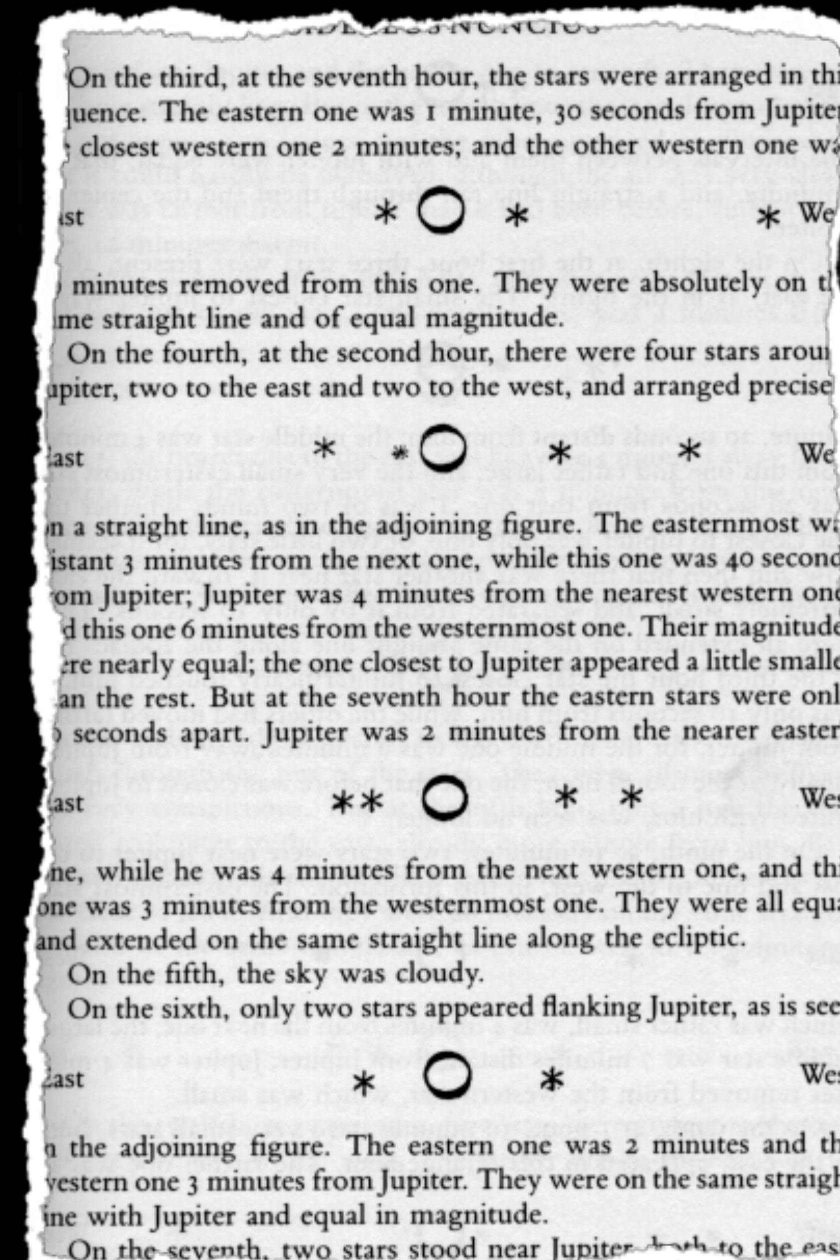


Galileo Galilei

(1564-1642)







On the third, at the seventh hour, the stars were arranged in thi
juence. The eastern one was 1 minute, 30 seconds from Jupiter
closest western one 2 minutes; and the other western one wa

minutes removed from this one. They were absolutely on t
me straight line and of equal magnitude.
On the fourth, at the second hour, there were four stars arou
upiter, two to the east and two to the west, and arranged precise

n a straight line, as in the adjoining figure. The easternmost w
istant 3 minutes from the next one, while this one was 40 second
om Jupiter; Jupiter was 4 minutes from the nearest western one
d this one 6 minutes from the westernmost one. Their magnitude
ere nearly equal; the one closest to Jupiter appeared a little smalle
an the rest. But at the seventh hour the eastern stars were only
seconds apart. Jupiter was 2 minutes from the nearer easter

ne, while he was 4 minutes from the next western one, and thi
one was 3 minutes from the westernmost one. They were all equal
and extended on the same straight line along the ecliptic.
On the fifth, the sky was cloudy.
On the sixth, only two stars appeared flanking Jupiter, as is seen

n the adjoining figure. The eastern one was 2 minutes and the
western one 3 minutes from Jupiter. They were on the same straigh
ine with Jupiter and equal in magnitude.
On the seventh, two stars stood near Jupiter, both to the east

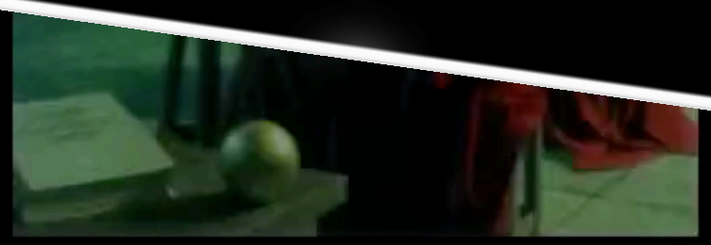
Notes for & re-productions of Siderius Nuncius

Galileo Galilei

GALILEO'S "NEW OR

Created by Alyssa Goodman, Curtis Won

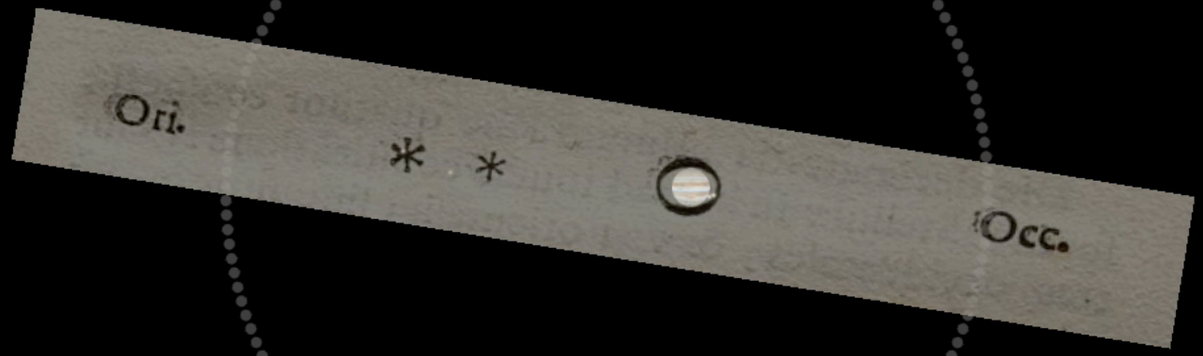
with advice from Owen Gingerich and Da



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

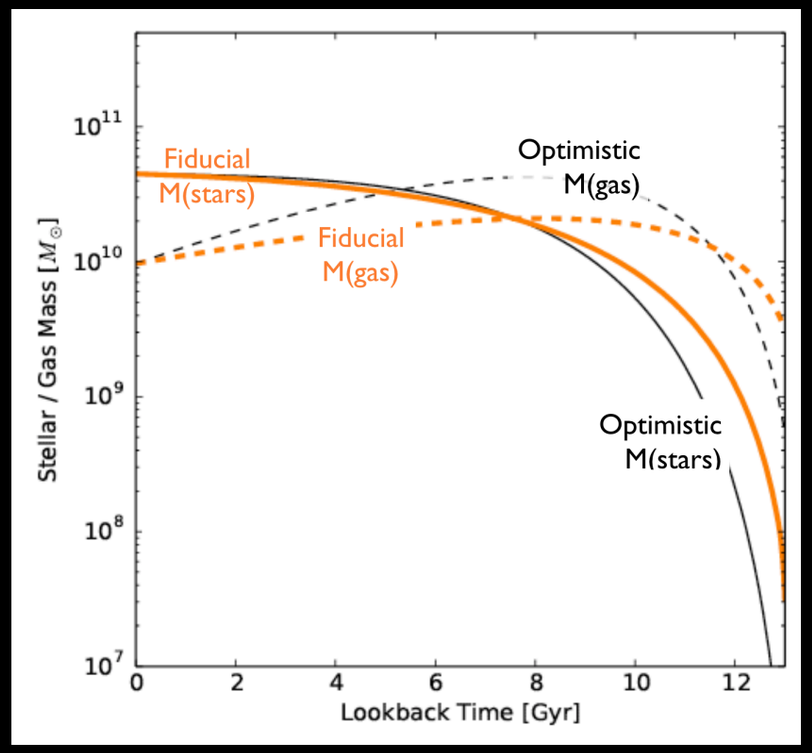
Galileo Galilei

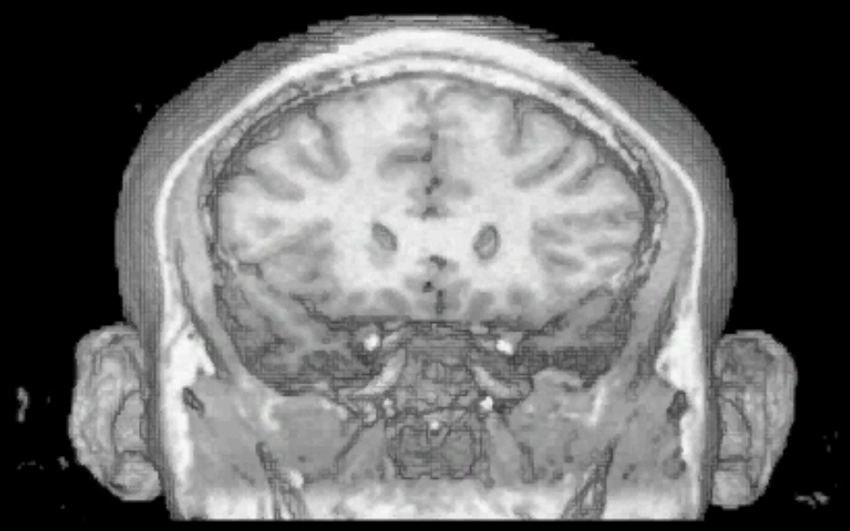
January 11, 1610

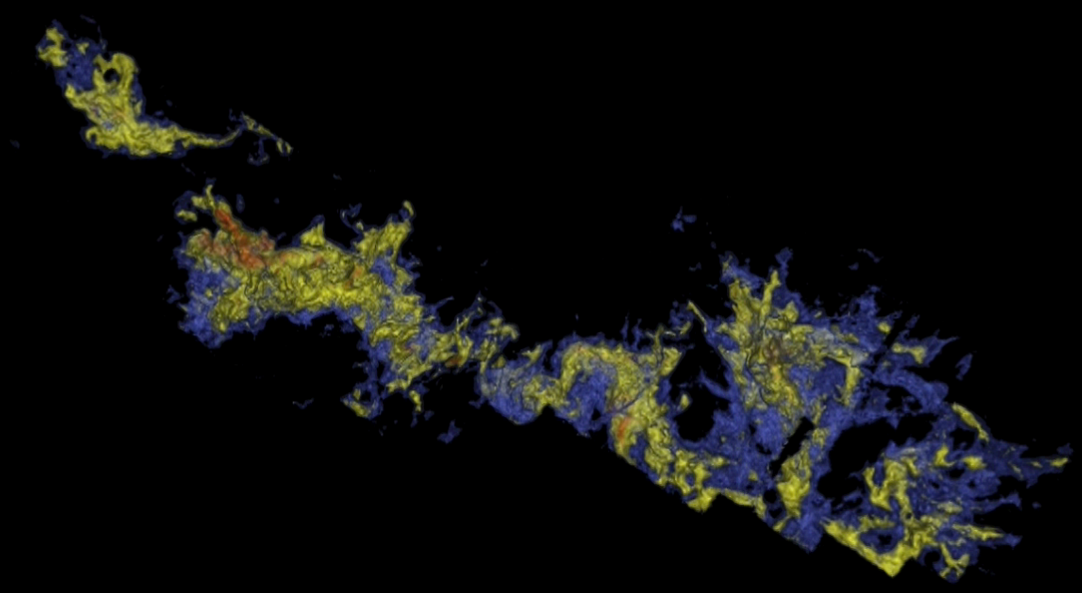


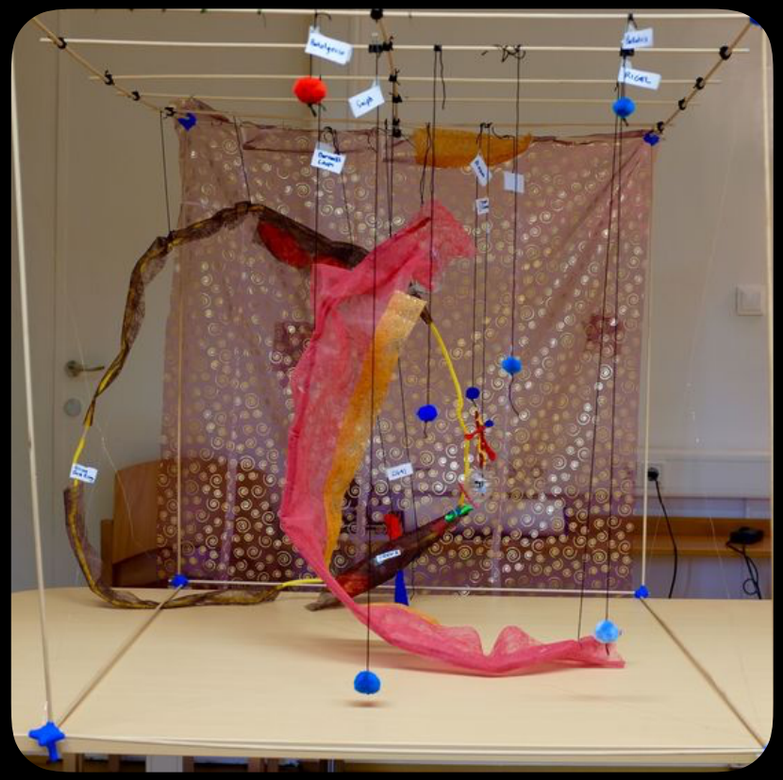
Galileo's New Order, A WorldWide Telescope Tour by Goodman, Wong & Udomprasert 2010

“DATA, DIMENSIONS, DISPLAY”









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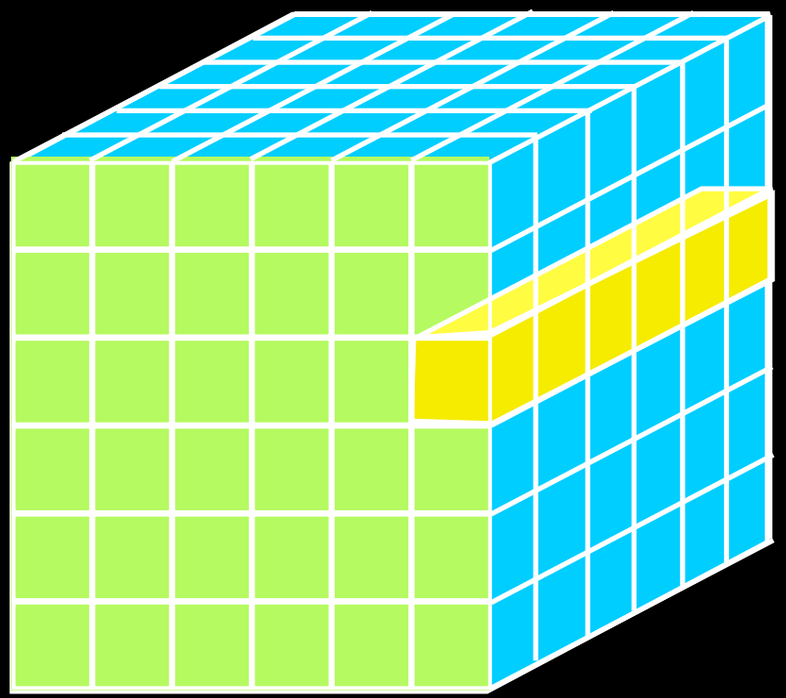
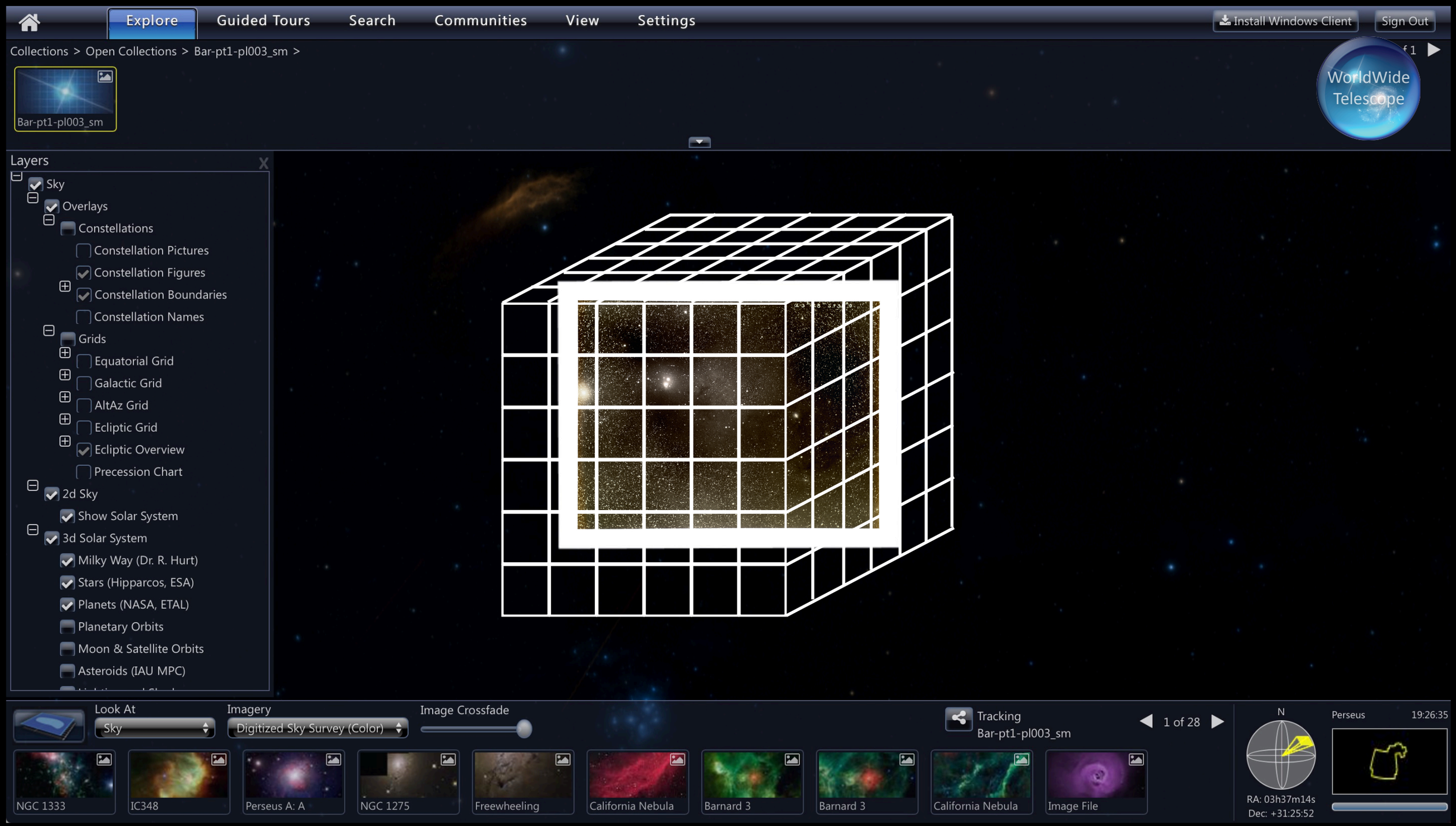


1D: Columns = “Graphs”
2D: Faces or Slices = “Images”
3D: Volumes = “3D Renderings”, “2D Movies”
4D: Time Series of Volumes = “3D Movies”

“DATA, DIMENSIONS, DISPLAY”



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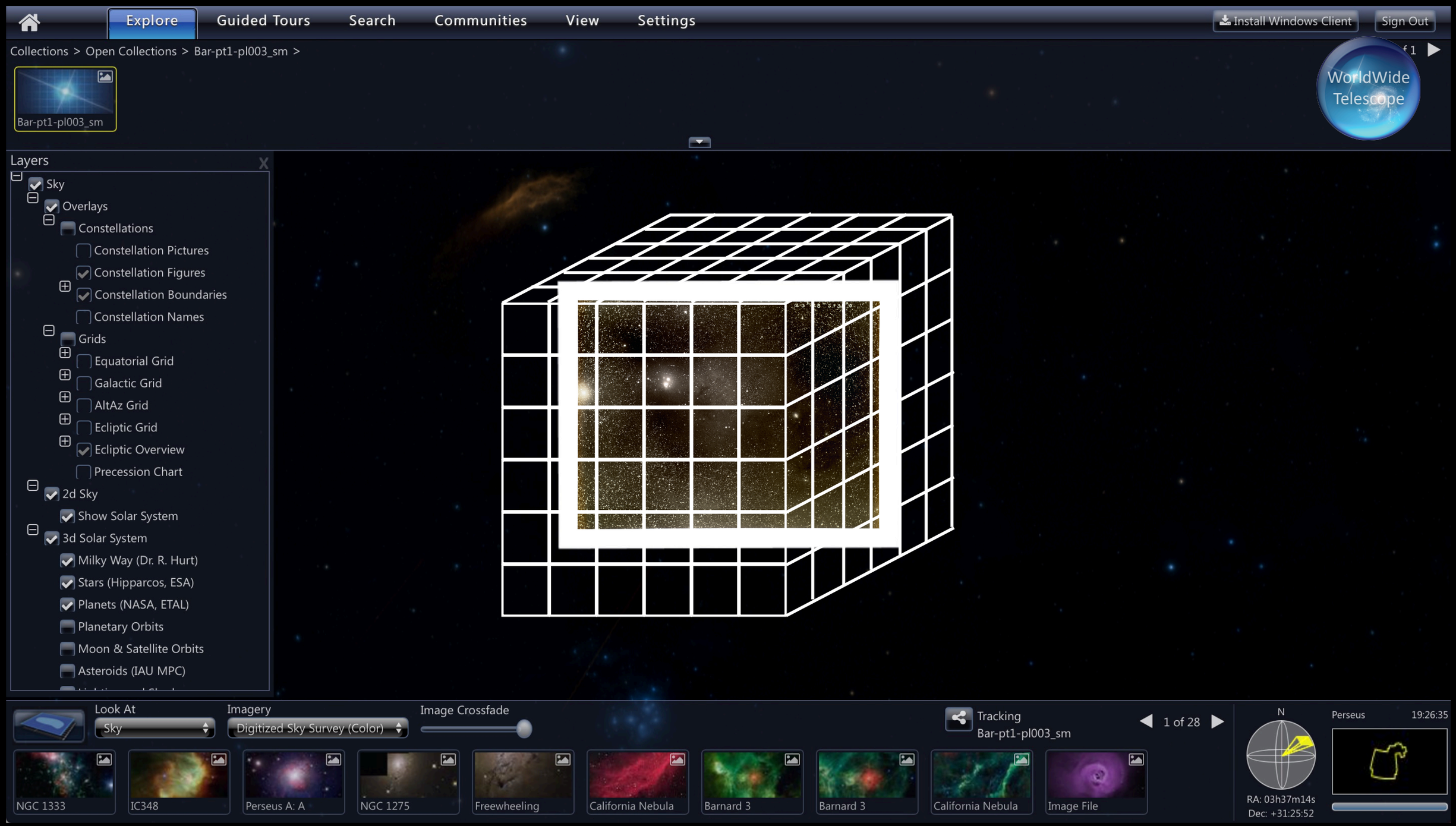


"DATA, DIMENSIONS, DISPLAY"

mm peak (Enoch et al. 2006)

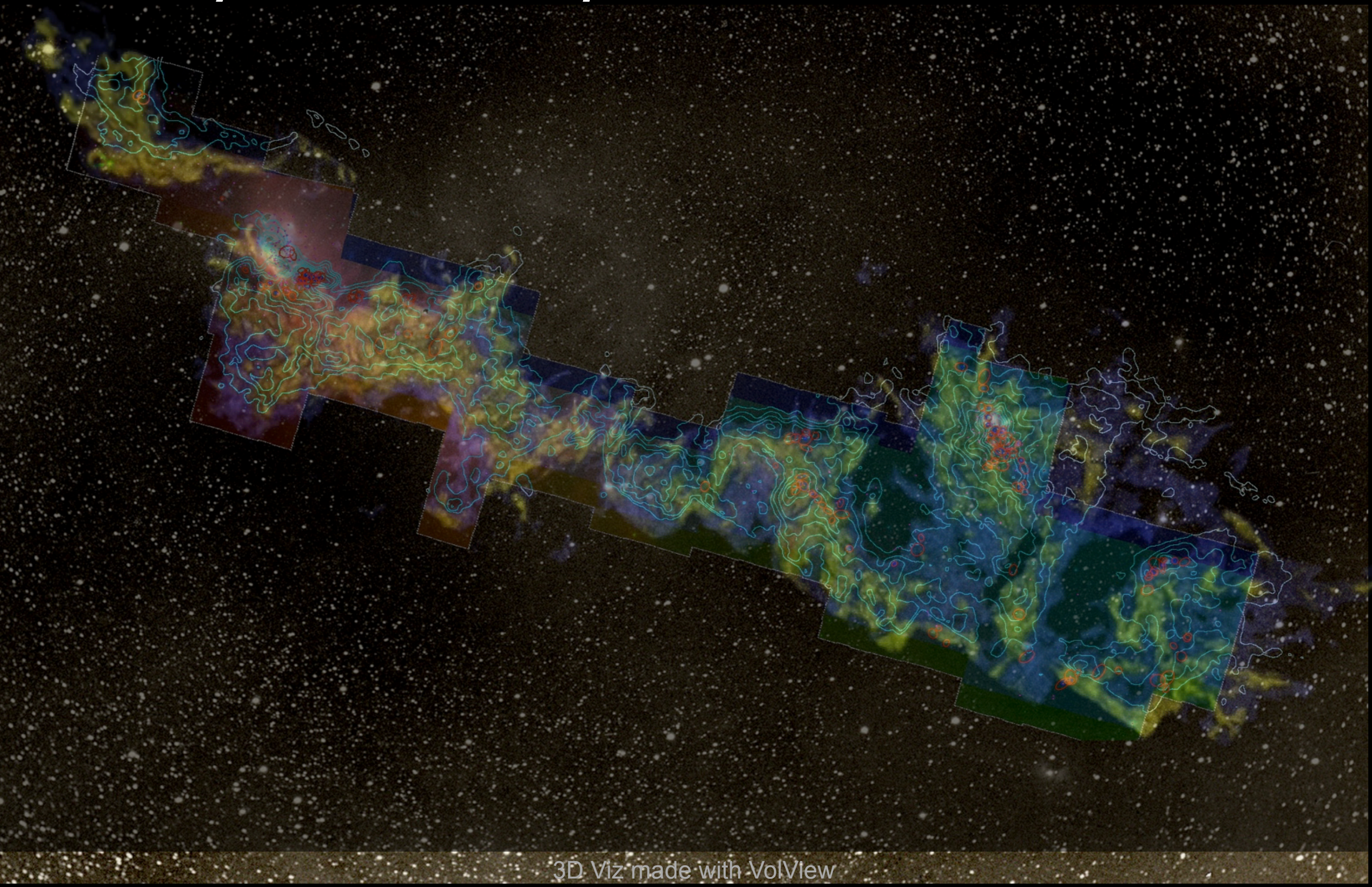
sub-mm peak (Hatchell et al. 2005, Kirk et al. 2006)

^{13}CO (Ridge et al. 2006)

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

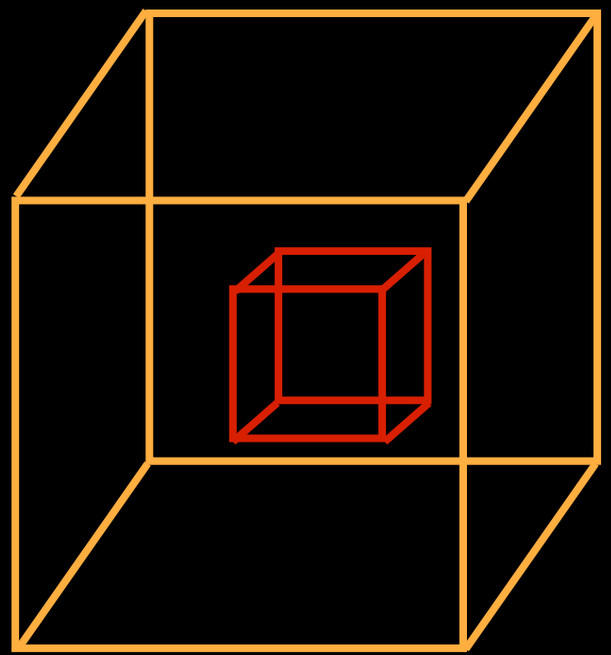
Optical image (Barnard 1927)

“DATA, DIMENSIONS, DISPLAY”

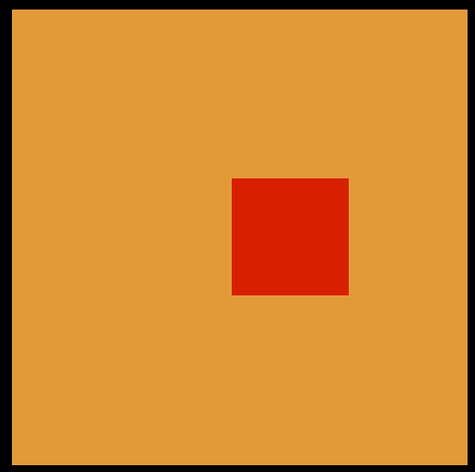


3D Viz made with VolView

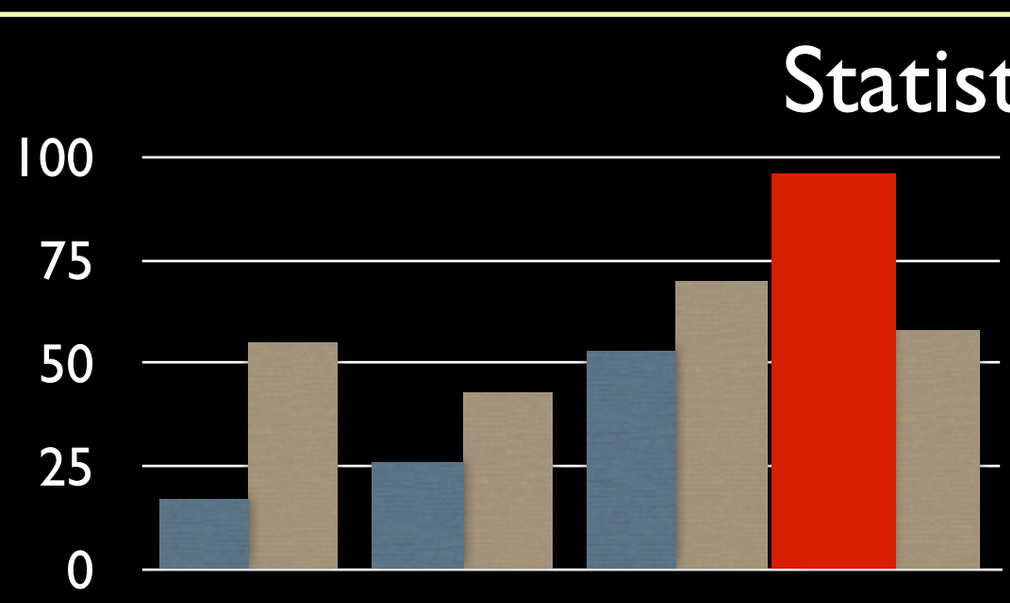
LINKED VIEWS OF HIGH-DIMENSIONAL DATA

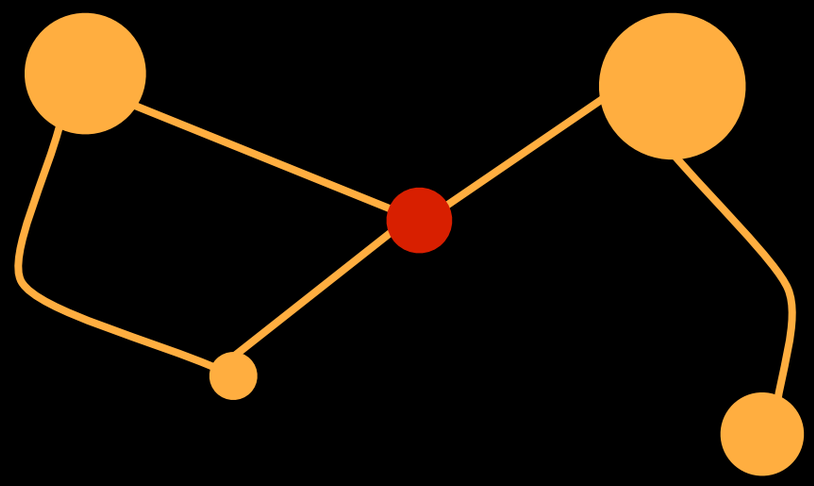


3D



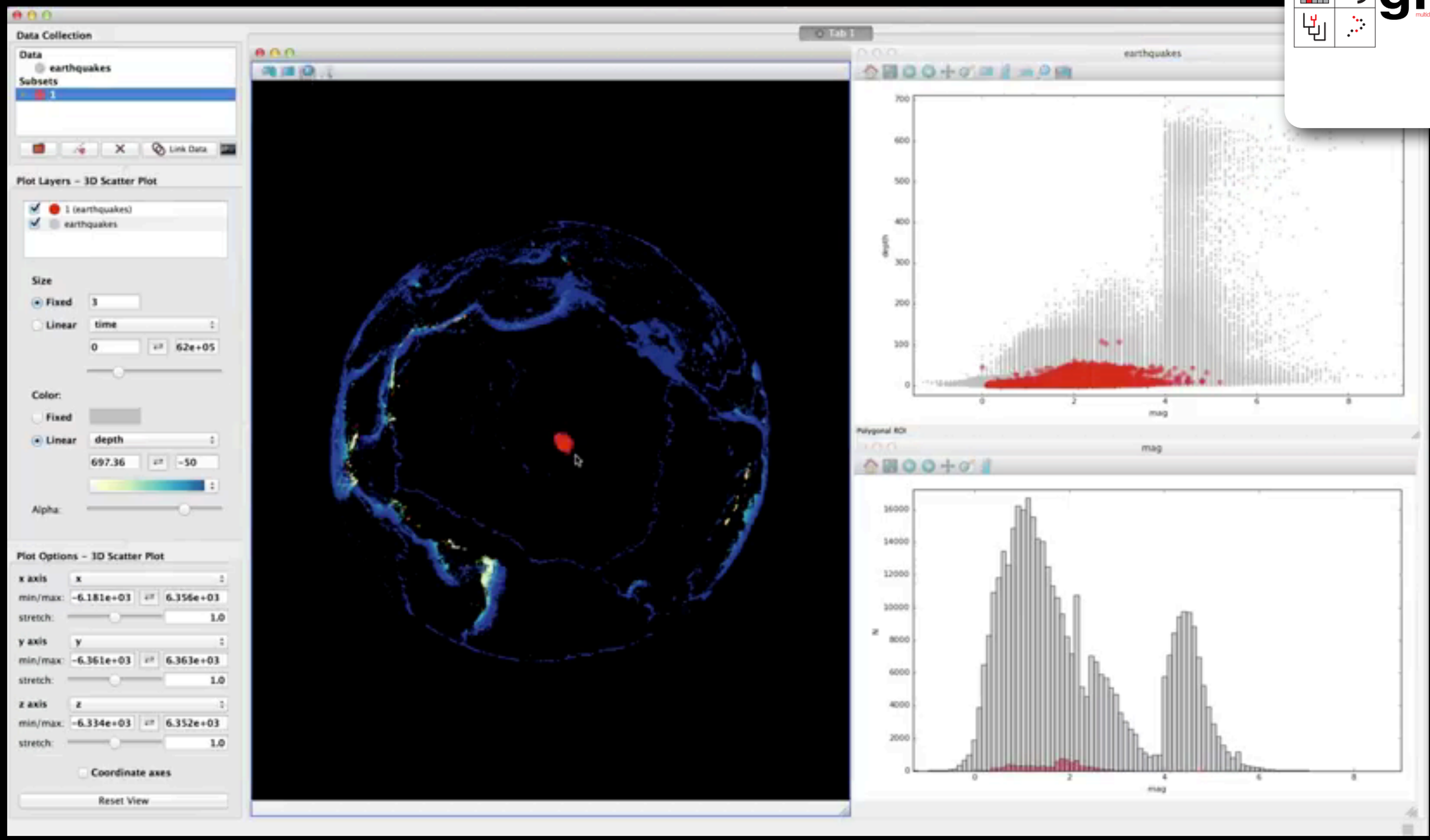
2D





figure, by M. Borkin, reproduced from Goodman 2012, “Principles of High-Dimensional Data Visualization in Astronomy”

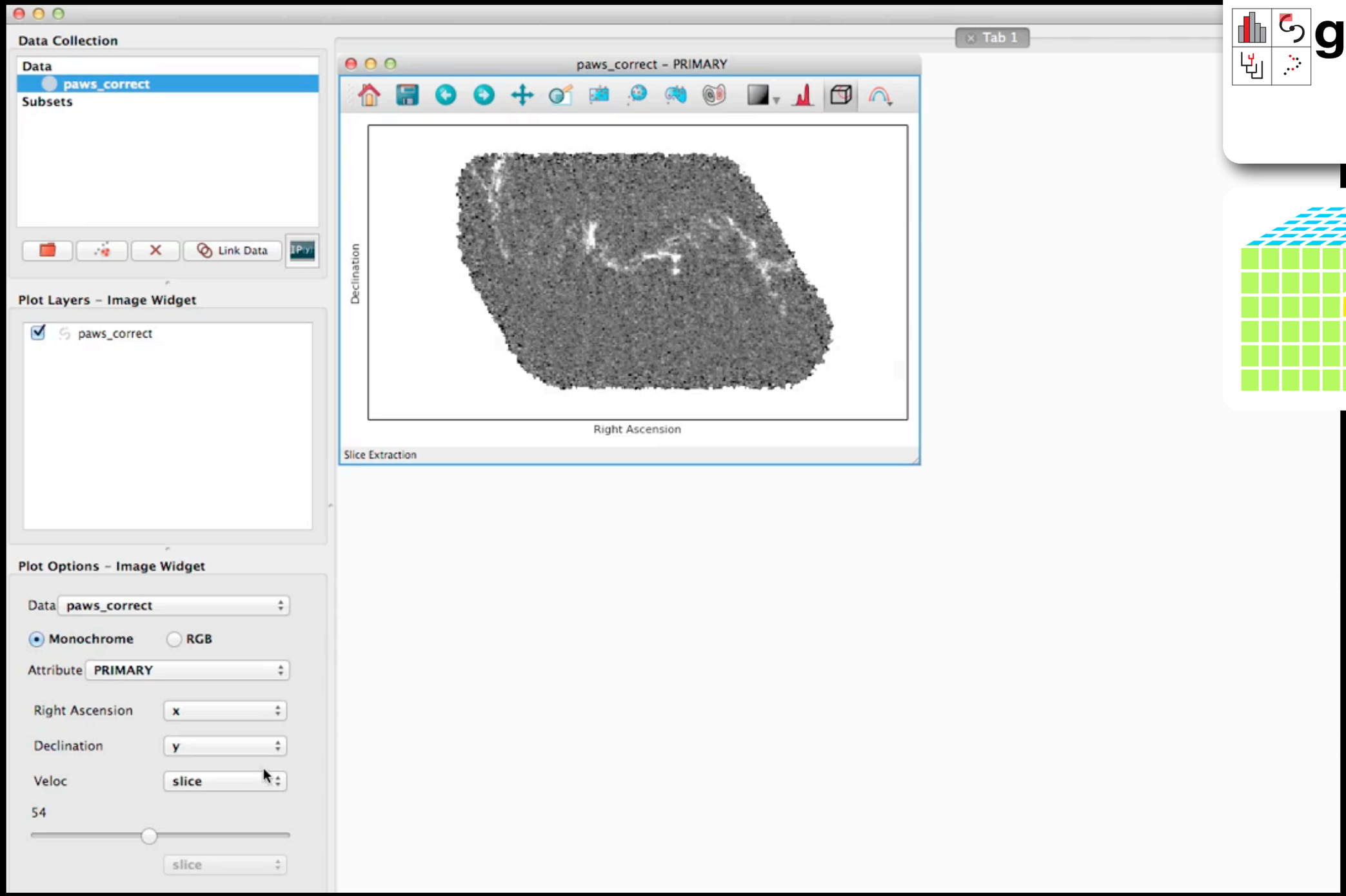
LINKED VIEWS OF HIGH-DIMENSIONAL DATA, IN PYTHON



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

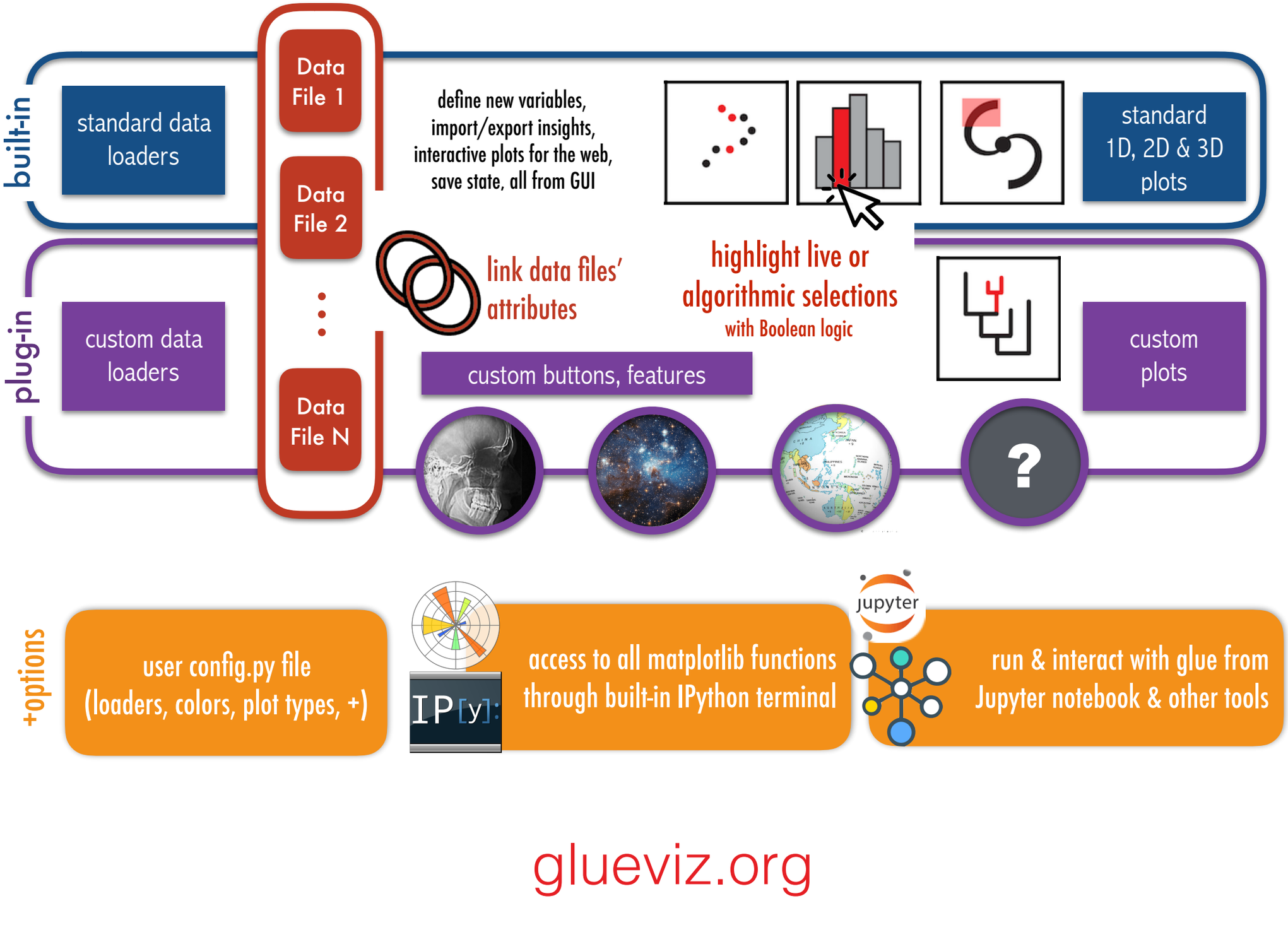


video by Chris Beaumont, glue developer

glue created by: C. Beaumont, M. Borkin, P. Qian, T. Robitaille, and A. Goodman, PI

glue

multidimensional data exploration

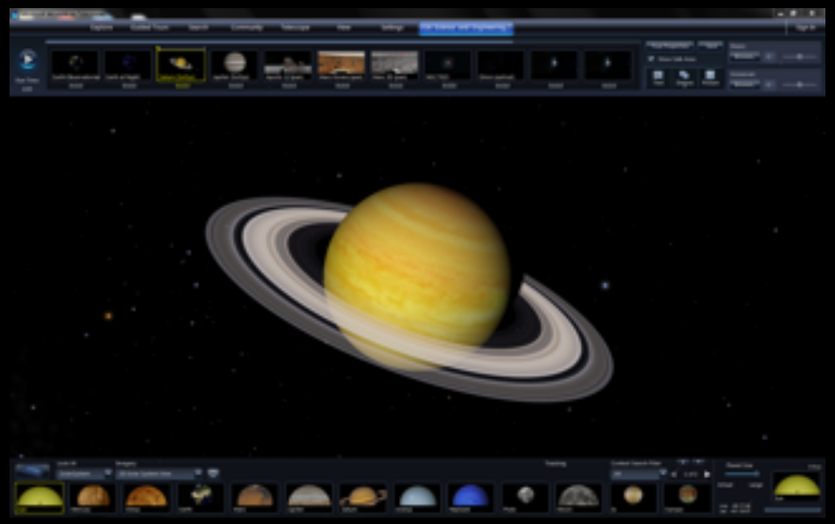


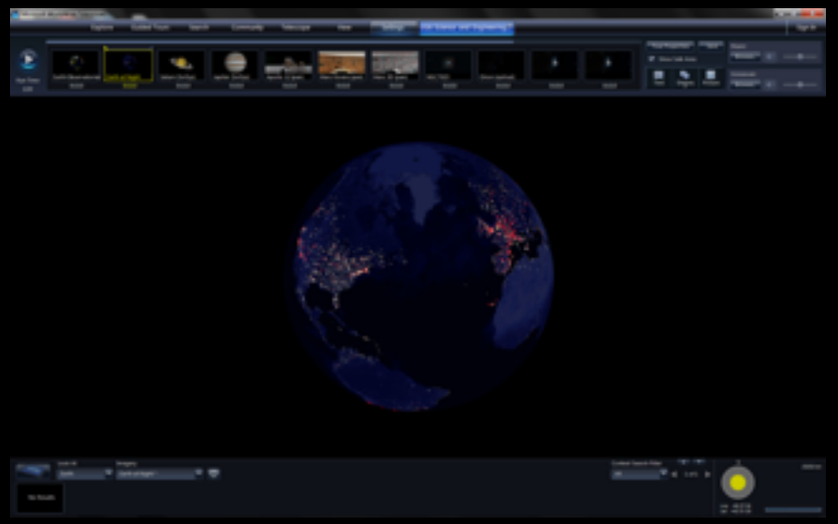
glueviz.org

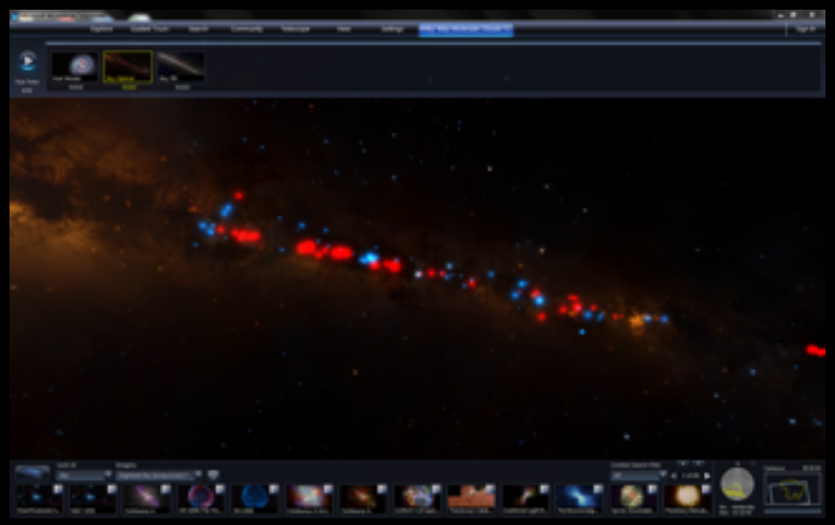
glue
multidimensional data exploration

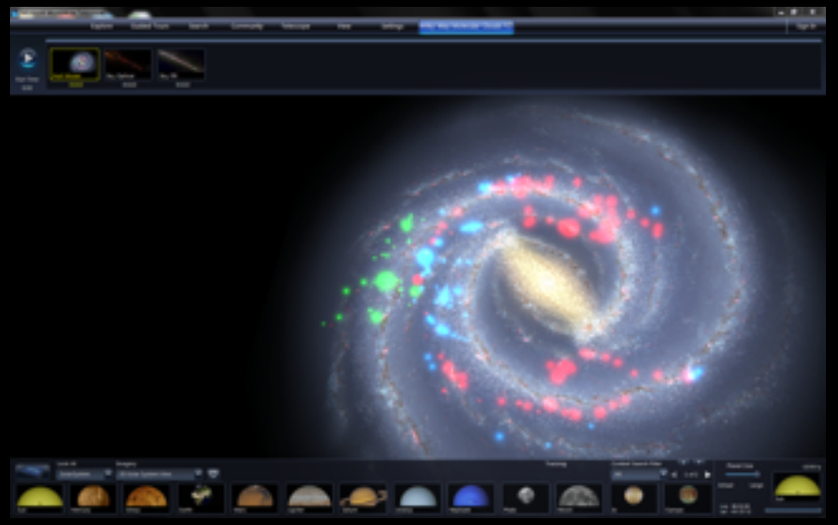
GLUE PLOTS • GLUE DATA SETS • GLUE TOOLS

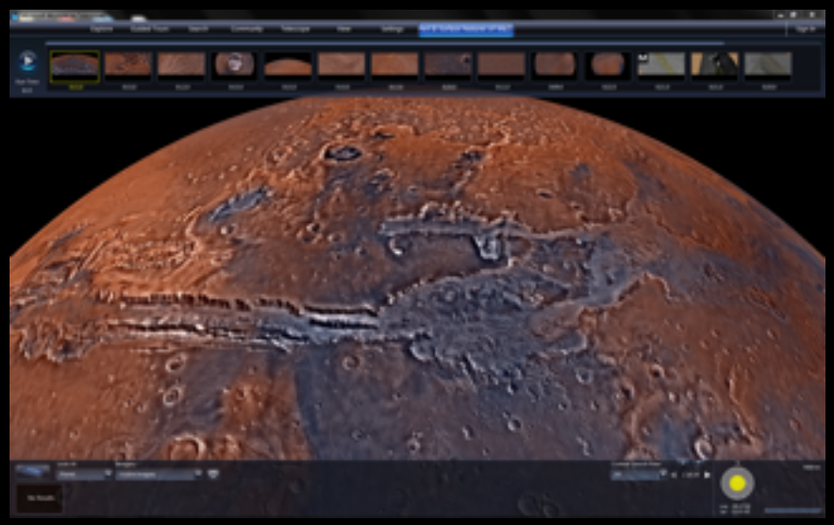
WorldWide Telescope

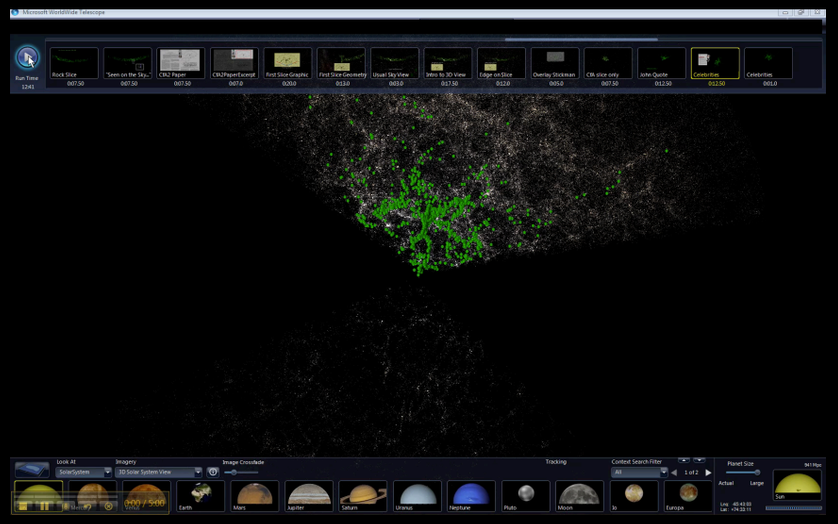


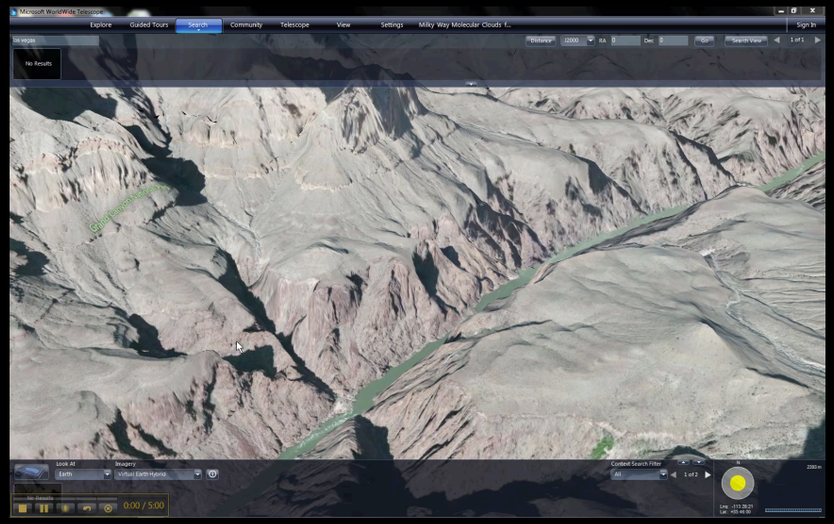












Experience WorldWide Telescope, free, at **worldwidetelescope.org**

[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.

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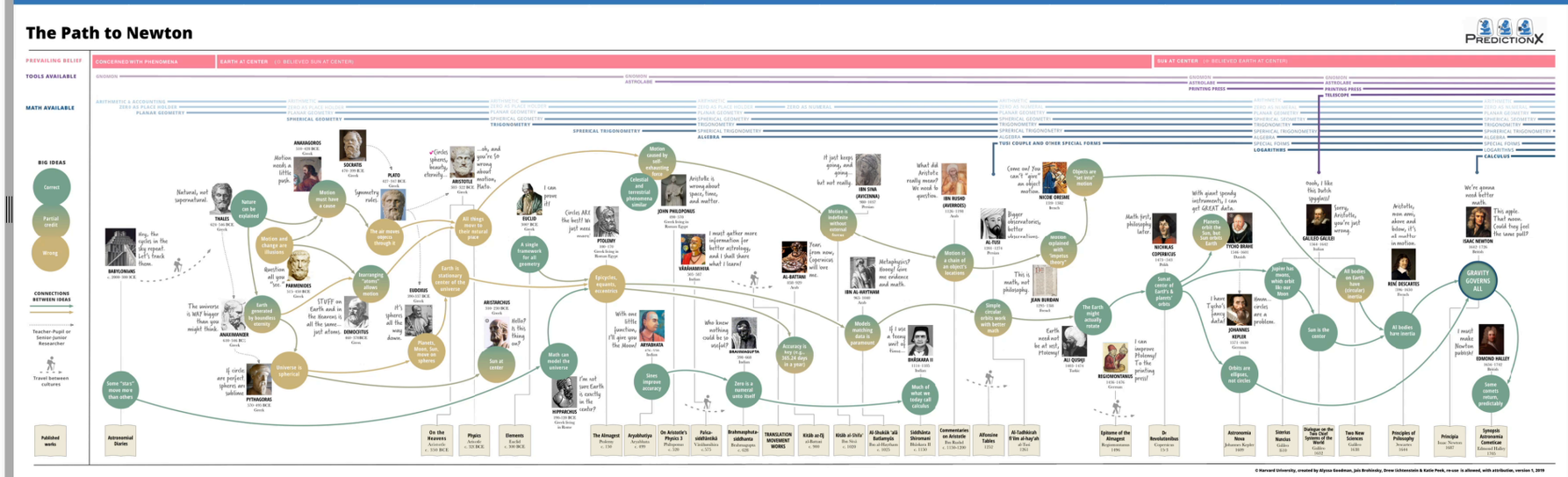


path-to.org — javascript by Francisco Ortiz
for more on the Prediction Project, see predictionX.org, and edX.org

The Path to Newton

PREVAILING BELIEF

CONCERNED WITH PHENOMENA

EARTH AT CENTER (⊙ BELIEVED SUN AT CENTER)

TOOLS AVAILABLE

GNOMON

GNOMON
ASTRO

MATH AVAILABLE

ARITHMETIC & ACCOUNTING
ZERO AS PLACE HOLDER
PLANAR GEOMETRY

ARITHMETIC
ZERO AS PLACE HOLDER
PLANAR GEOMETRY
SPHERICAL GEOMETRY

ARITHMETIC
ZERO AS PLACE HOLDER
PLANAR GEOMETRY
SPHERICAL GEOMETRY
TRIGONOMETRY

SPRERICAL TRIGONOMETRY

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

Motion and change are illusions

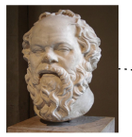
Question all you "see."

PARMENIDES
515–450 BCE
Greek

Motion needs a little push.

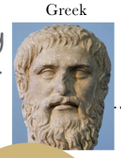
ANAXAGOROS
510–428 BCE
Greek

Motion must have a cause



SOCRATES
470–399 BCE
Greek

PLATO
427–347 BCE
Greek



Symmetry rules.

The air moves objects through it

Rearranging "atoms" allows motion

The universe is WAY bigger than you might think.

ANAXIMANDER
610–546 BCE
Greek

Earth generated by boundless eternity

If circles are perfect, spheres are sublime.

PYTHAGORAS
570–495 BCE
Greek

Universe is spherical

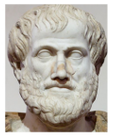
STUFF on Earth and in the Heavens is all the same... just atoms.

DEMOCRITUS
460–370 BCE
Greek

It's spheres all the way down.

EUDOXUS
390-337 BCE
Greek

Planets, Moon, Sun, move on spheres



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

Earth is stationary center of the universe

On the Heavens
Aristotle
c. 350 BCE

Physics
Aristotle
c. 320 BCE

I can prove it!

EUCLID
300? BCE
Greek

A single framework for all geometry

Elements
Euclid
c. 300 BCE

Circles ARE the best! We just need more!

PTOLEMY
100–170
Greek living in Roman Egypt

Epicycles, equants, eccentrics

The Almagest
Ptolemy
c. 150

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

ARISTARCHUS
310–230 BCE
Greek

Hello? Is this thing on?

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

SUN AT CENT

GNOMON
ASTROLABE

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

ZERO AS NUMERAL

SPRERICAL TRIGONOMETRY

ARITHMETIC
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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

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

Epicycles, equants, eccentrics

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

ARYABHATA
476–550
Indian

Sines improve accuracy

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

PARCHUS
-120 BCE
ek living
Rome

Who knew nothing could be so useful?

BRAHMAGUPTA
598–668
Indian

Zero is a numeral unto itself

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

Years from now, Copernicus will love me.

AL-BATTANI
858–929
Arab

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

IBN SINA (AVICENNA)
980–1037
Persian

Motion is indefinite without external forces

Metaphysics? Hooey! Give me evidence and math.

IBN AL-HAYTHAM
965–1040
Arab

Models matching data is paramount

If I use a teeny unit of time...

BHĀSKARA II
1114–1185
Indian

Much of what we today call calculus

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

Motion explained with "impetus theory"

Simple circular orbits work with better math

This is math, not philosophy.

JEAN BURIDAN
1295–1358
French

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

NICOLE ORESME
1320–1382
French

Objects are "set into" motion

The Earth might actually rotate

Earth need not be at rest, Ptolemy!

ALI QUSHJI
1403–1474
Turkic

Math first, philosophy later.

NICHOLAS COPERNICUS
1473–1543
Polish

Sun at center of Earth's & planets' orbits

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

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

GNOMON
ASTROLABE
PRINTING PRESS
TELESCOPE

ARITHMETIC
ZERO AS NUMERAL RAL
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

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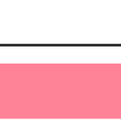

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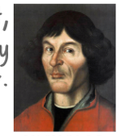

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1473–1543
Polish

Math first, philosophy later.

Sun at center of Earth's & planets' orbits

Objects are "set into" motion

NICOLE ORESME
1320–1382
French

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

With giant spendy instruments, I can get GREAT data.

Planets orbit the Sun, but Sun orbits Earth

TYCHO BRAHE
1546–1601
Danish

JOHANNES KEPLER
1571–1630
German

I have Tycho's fancy data!

Hmm... circles are a problem.

Orbits are ellipses, not circles

Jupiter has moons, which orbit like our Moon

Sun is the center

GALILEO GALILEI
1564–1642
Italian

Oooh, I like this Dutch spyglass!

Sorry, Aristotle, you're just wrong.

All bodies on Earth have (circular) inertia

All bodies have inertia

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

RENÉ DESCARTES
1596–1650
French

GRAVITY GOVERNS ALL

ISAAC NEWTON
1642–1726
British

We're gonna need better math.

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

EDMOND HALLEY
1656–1742
British

I must make Newton publish!

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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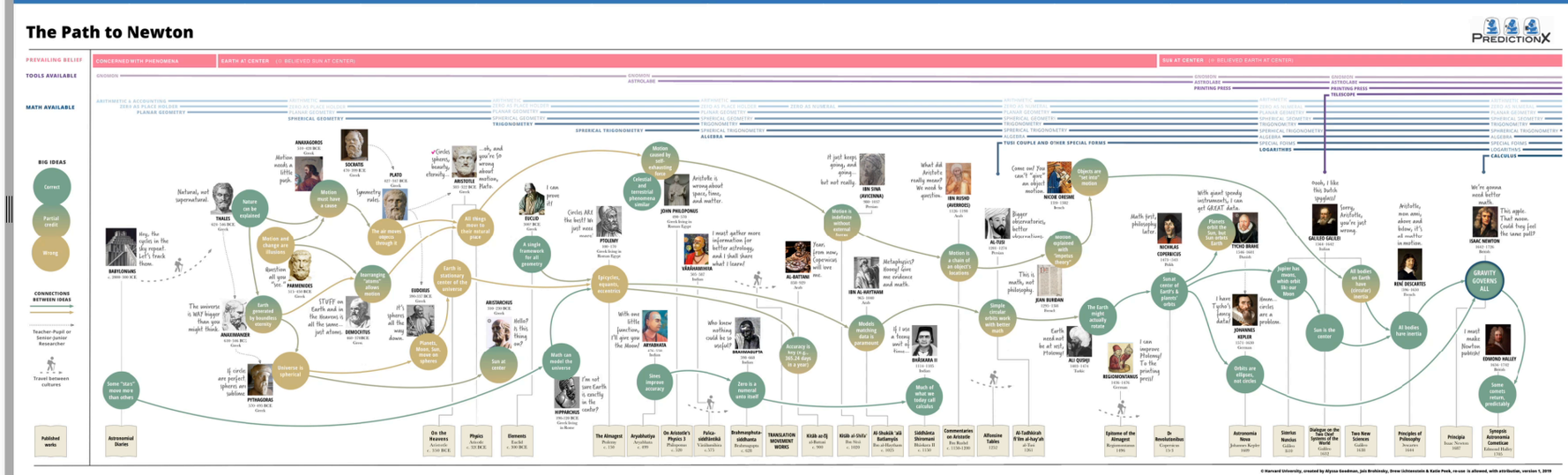

path-to.org — javascript by Francisco Ortiz
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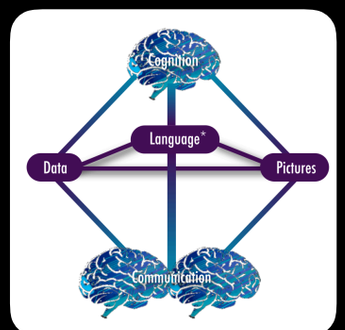
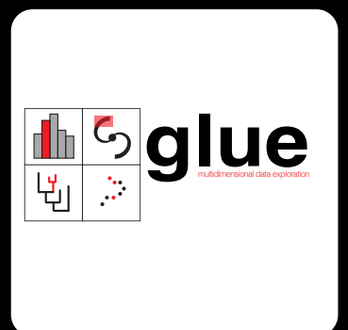
+Ask me about the

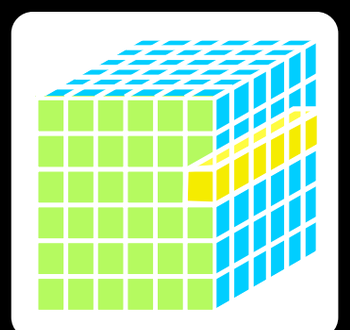
The TIMELINE CONSORTIUM

timelineconsortium.org


Cognition
Language*
Data
Pictures
Communication

WorldWide Telescope


glue
multidimensional data exploration



PREDICTIONX

ViZ

MENU

TEN QUESTIONS TO ASK WHEN CREATING A VISUALIZATION

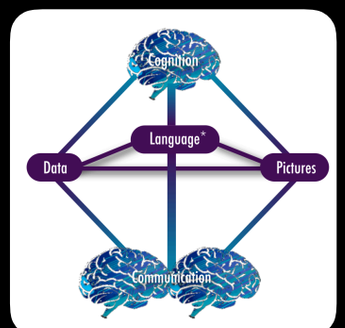
The 10 Questions

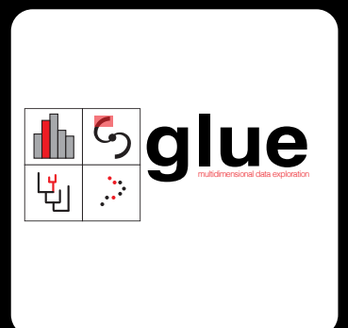
1. **Who** | Who is your audience? How expert will they be about the subject and/or display conventions?
2. **Explore-Explain** | Is your goal to explore, document, or explain your data or ideas, or a combination of these?
3. **Categories** |Do you want to show or explore pre-existing, known, human-interpretable, 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?

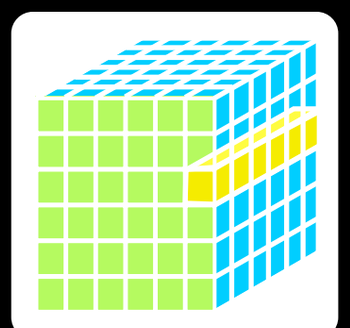
Now, visit the 10QViz conversation! There's so much more to talk about.

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





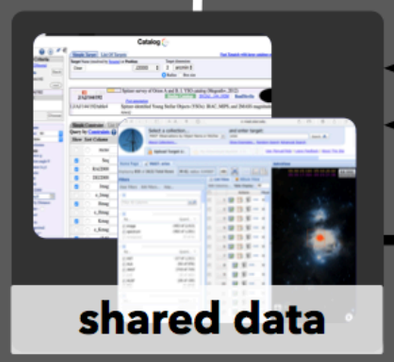


“Seeing, Exploring, Explaining, and Sharing our Universe”

COLLABORATION

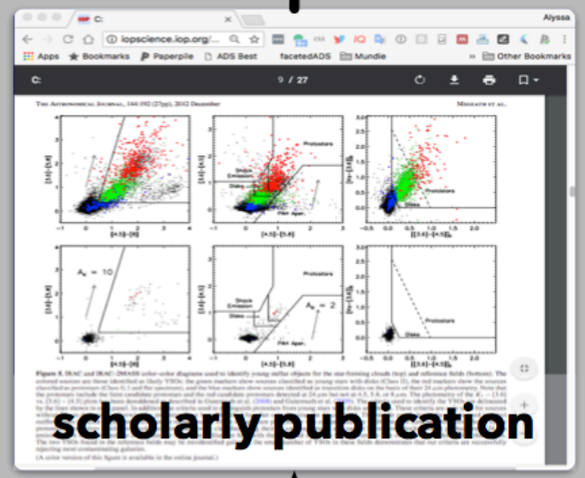
EXPLANATORY VISUALIZATION

citizen science

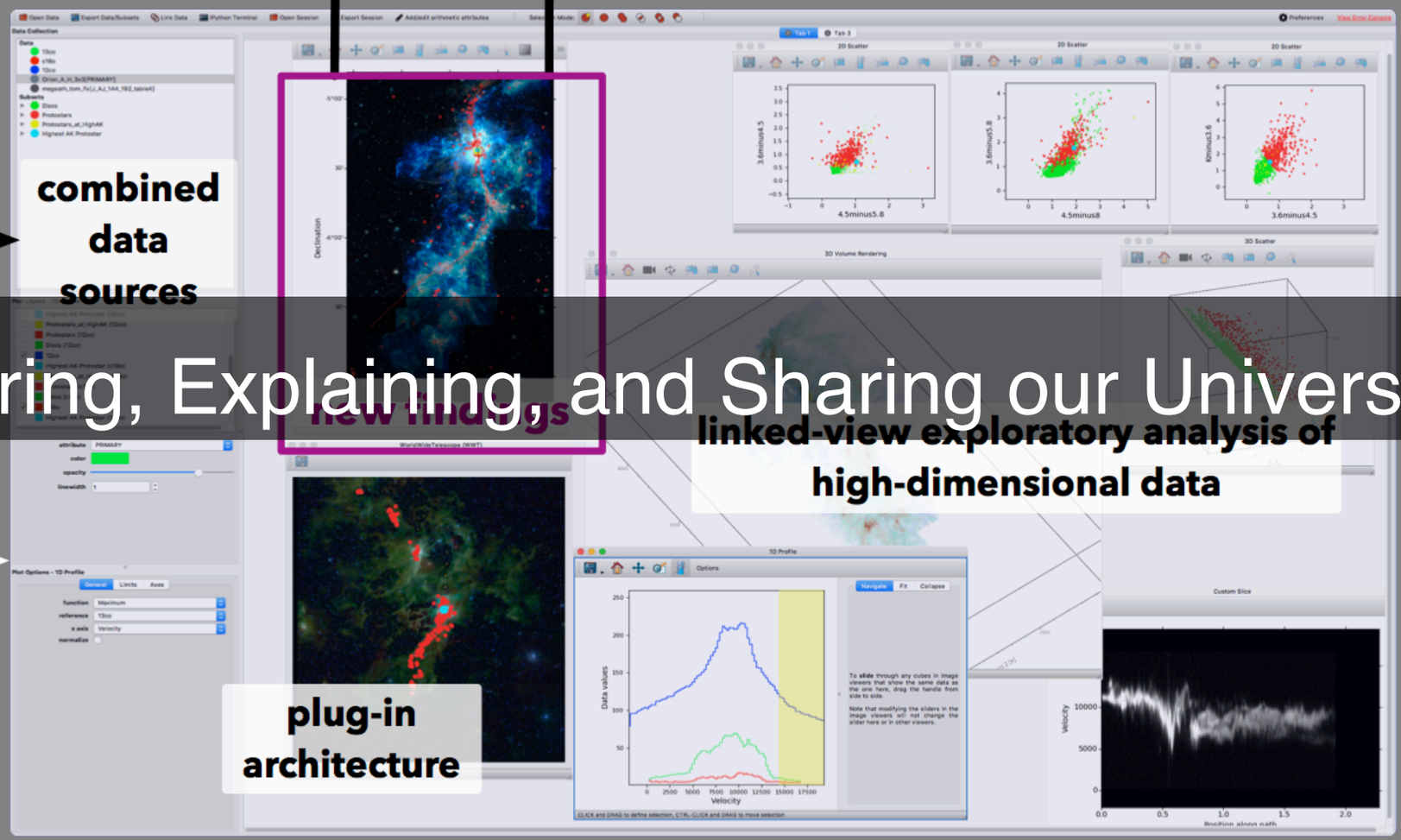


shared data

public outreach



scholarly publication

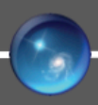


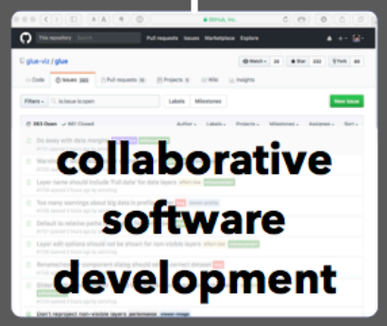
combined data sources

plug-in architecture

linked-view exploratory analysis of high-dimensional data

modular, software





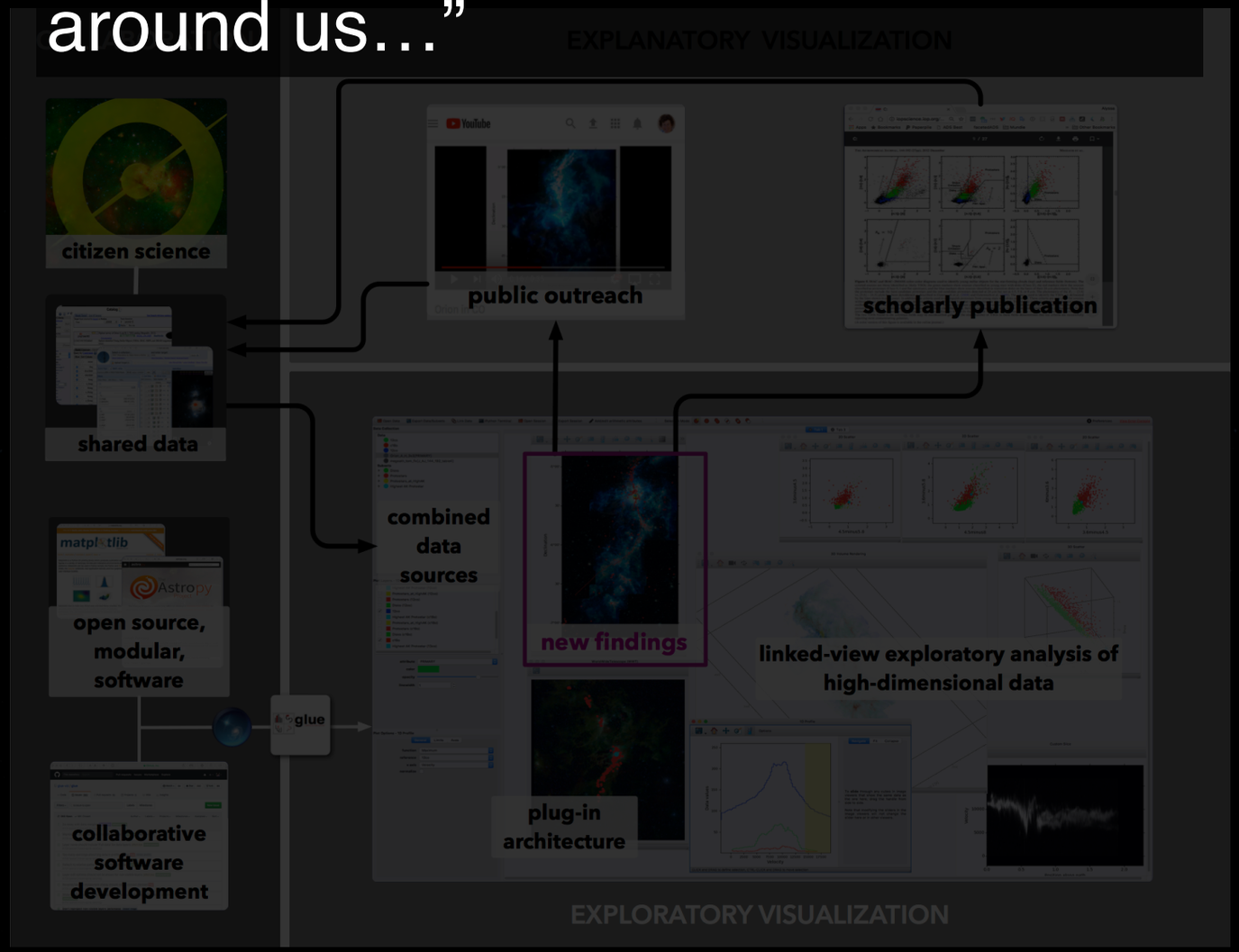
collaborative software development

“Seeing, Exploring, Explaining, and Sharing our Universe”

EXPLORATORY VISUALIZATION

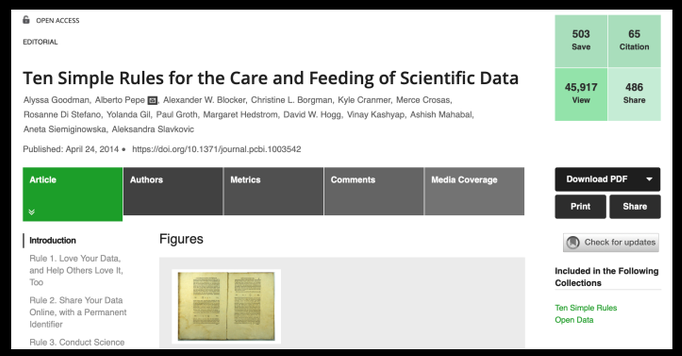
Goodman, Borkin & Robitaille 2020

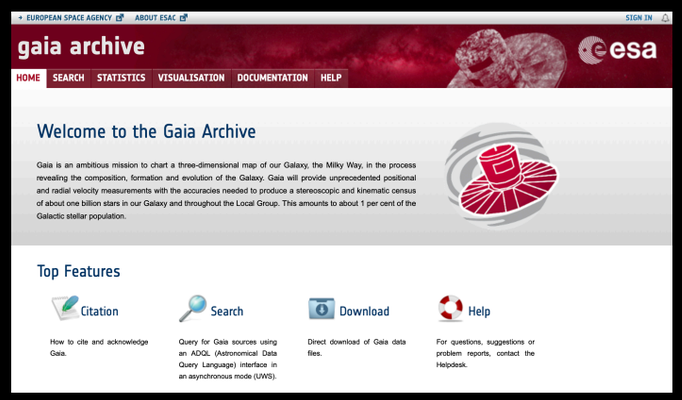
"...how traditional and modern approaches to visualizing information are best combined to leverage human creativity in our quest to understand the world around us..."



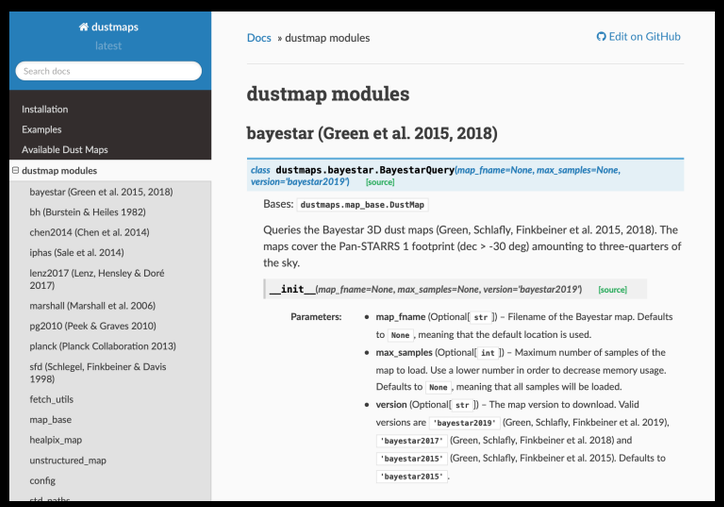
Seeing, Exploring, Explaining, and Sharing our Universe

OPEN DATA





OPEN CODE



OPEN SCIENCE

OPEN SPACE

More this afternoon…

OPEN SPACE

WorldWide Telescope

glue
multidimensional data exploration