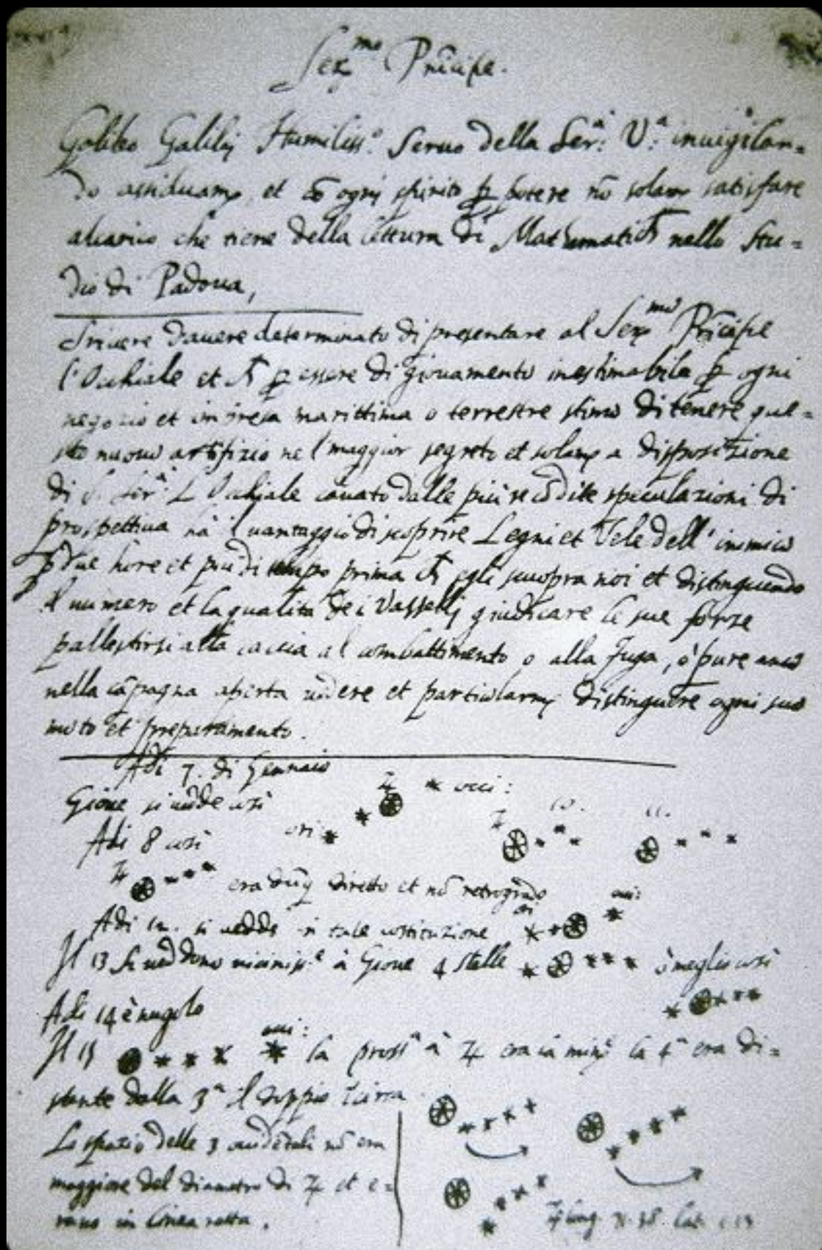
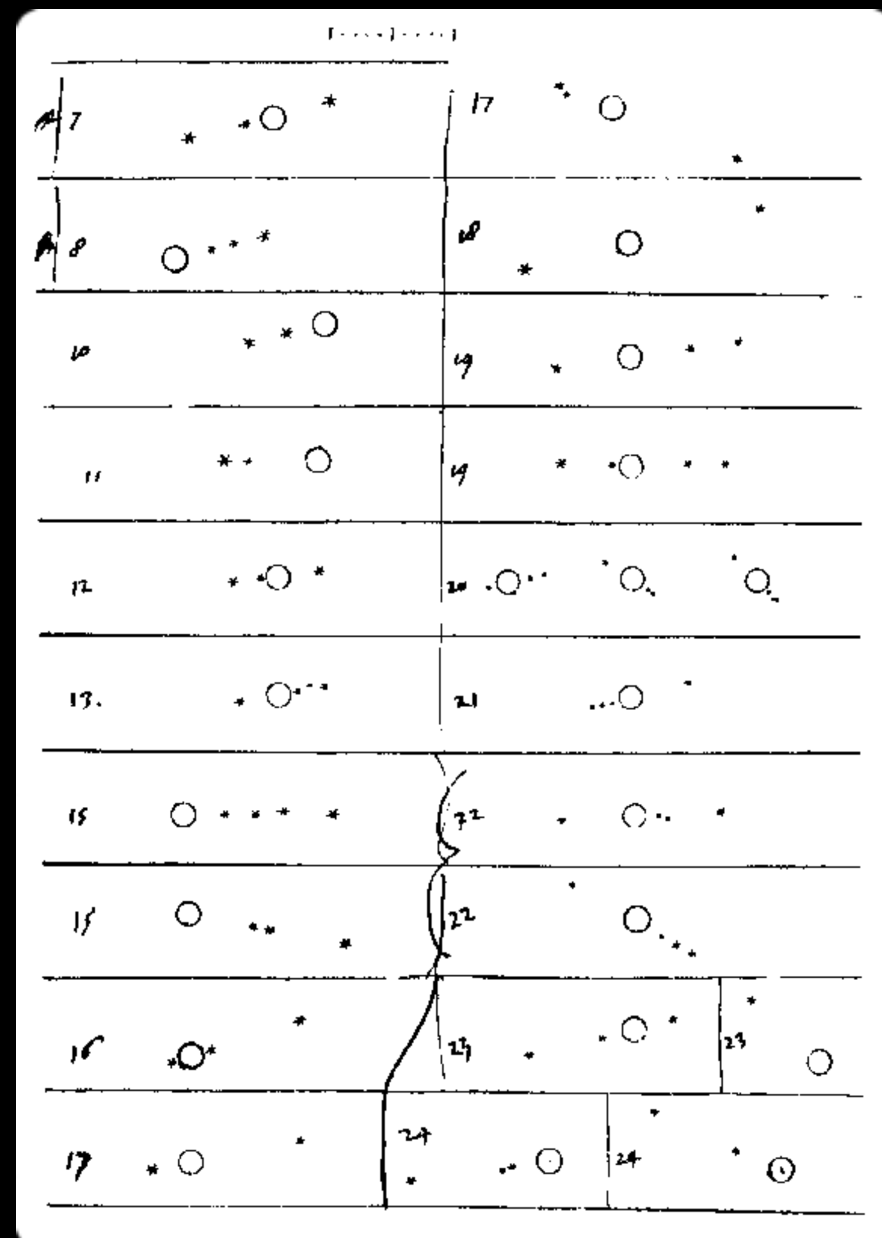
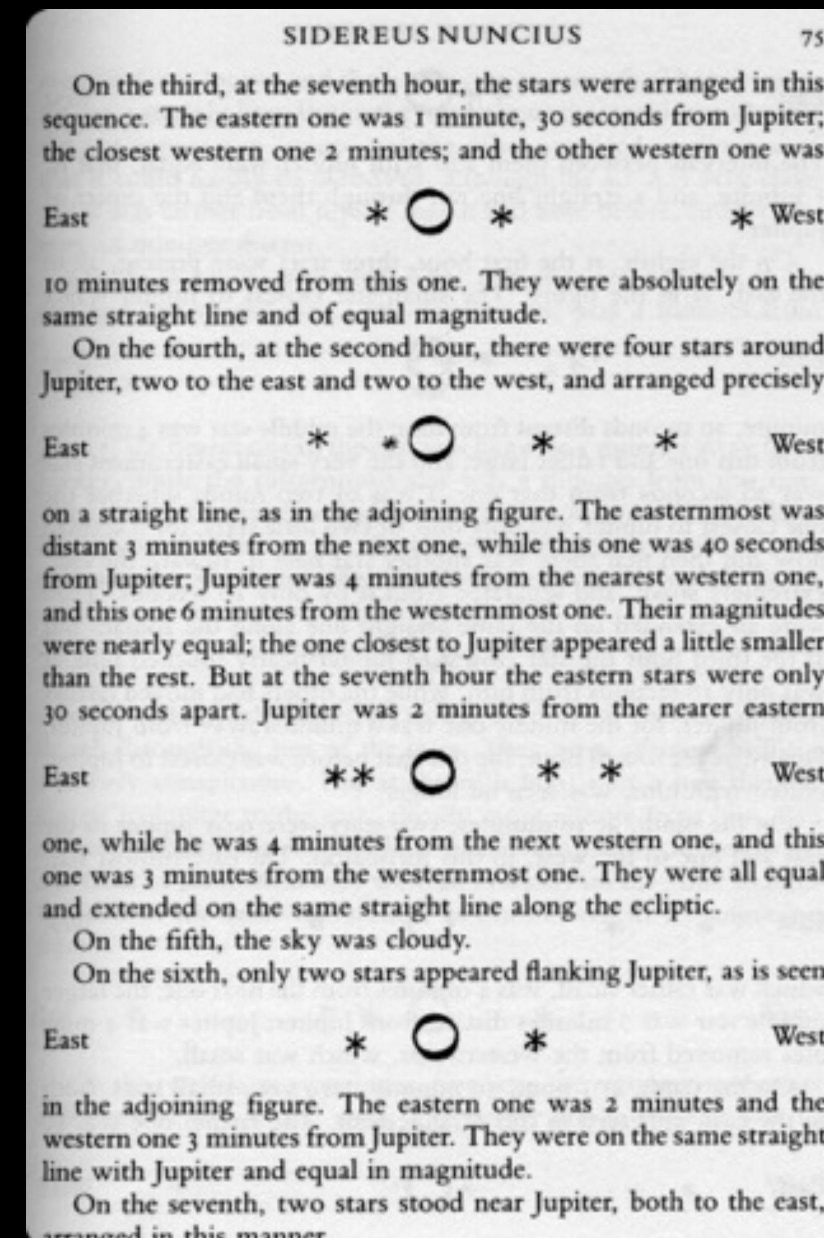
Enhancing astronomers' appreciation for high-dimensional data (visualization)







SIDEREUS NUNCIUS 75

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

East * O * * West

10 minutes removed from this one. They were absolutely on the same straight line and of equal magnitude.

On the fourth, at the second hour, there were four stars around Jupiter, two to the east and two to the west, and arranged precisely

East * *O * * West

on a straight line, as in the adjoining figure. The easternmost was distant 3 minutes from the next one, while this one was 40 seconds from Jupiter; Jupiter was 4 minutes from the nearest western one, and this one 6 minutes from the westernmost one. Their magnitudes were nearly equal; the one closest to Jupiter appeared a little smaller than the rest. But at the seventh hour the eastern stars were only 30 seconds apart. Jupiter was 2 minutes from the nearer eastern

East ** O * * West

one, while he was 4 minutes from the next western one, and this 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

East * O * West

in the adjoining figure. The eastern one was 2 minutes and the western one 3 minutes from Jupiter. They were on the same straight line with Jupiter and equal in magnitude.

On the seventh, two stars stood near Jupiter, both to the east, arranged in this manner.

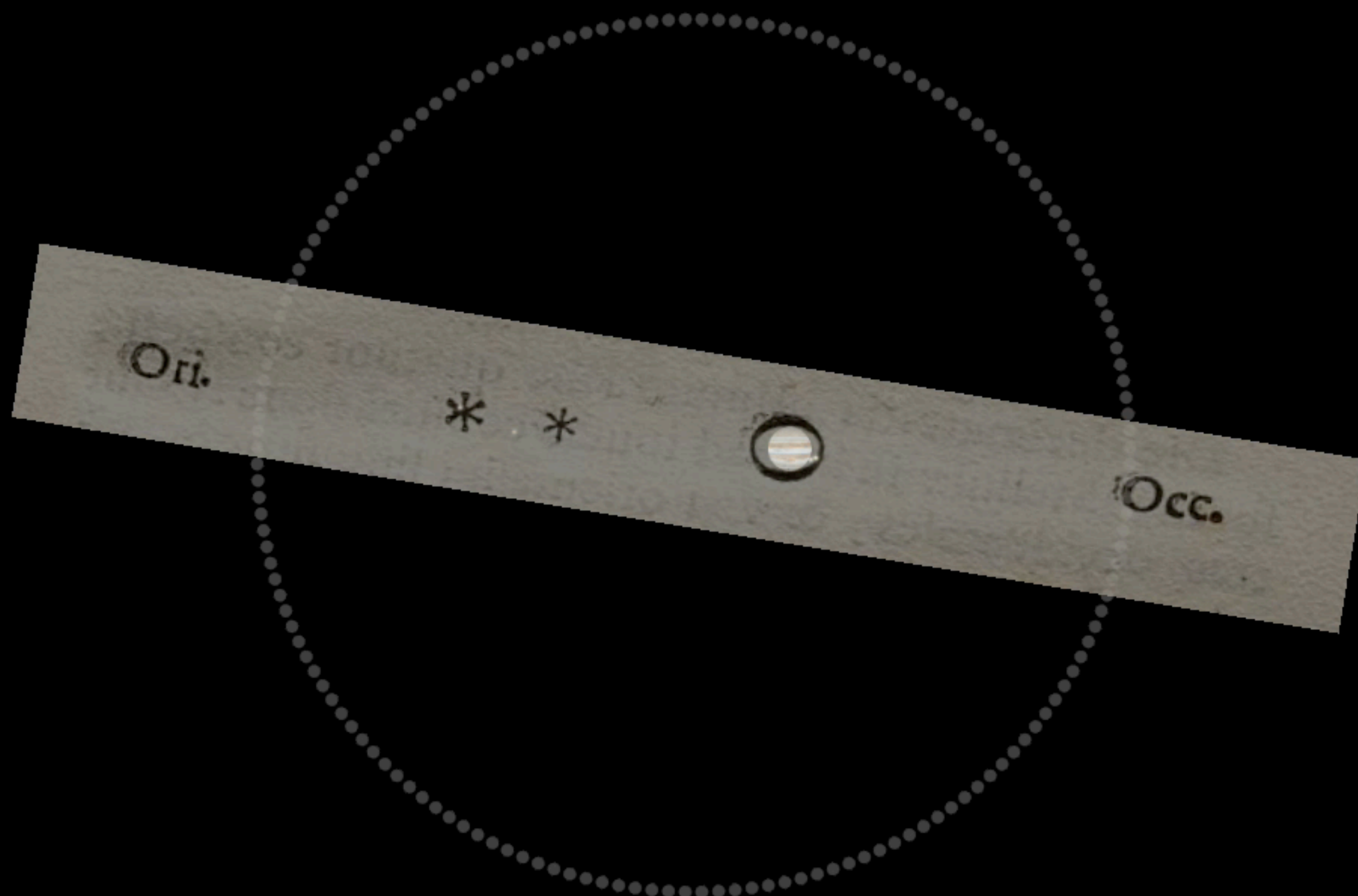
Notes for & re-productions of Siderius Nuncius, Galileo Galilei, c. 1610

Alyssa A. Goodman

Center for Astrophysics | Harvard & Smithsonian • Radcliffe Institute for Advanced Study

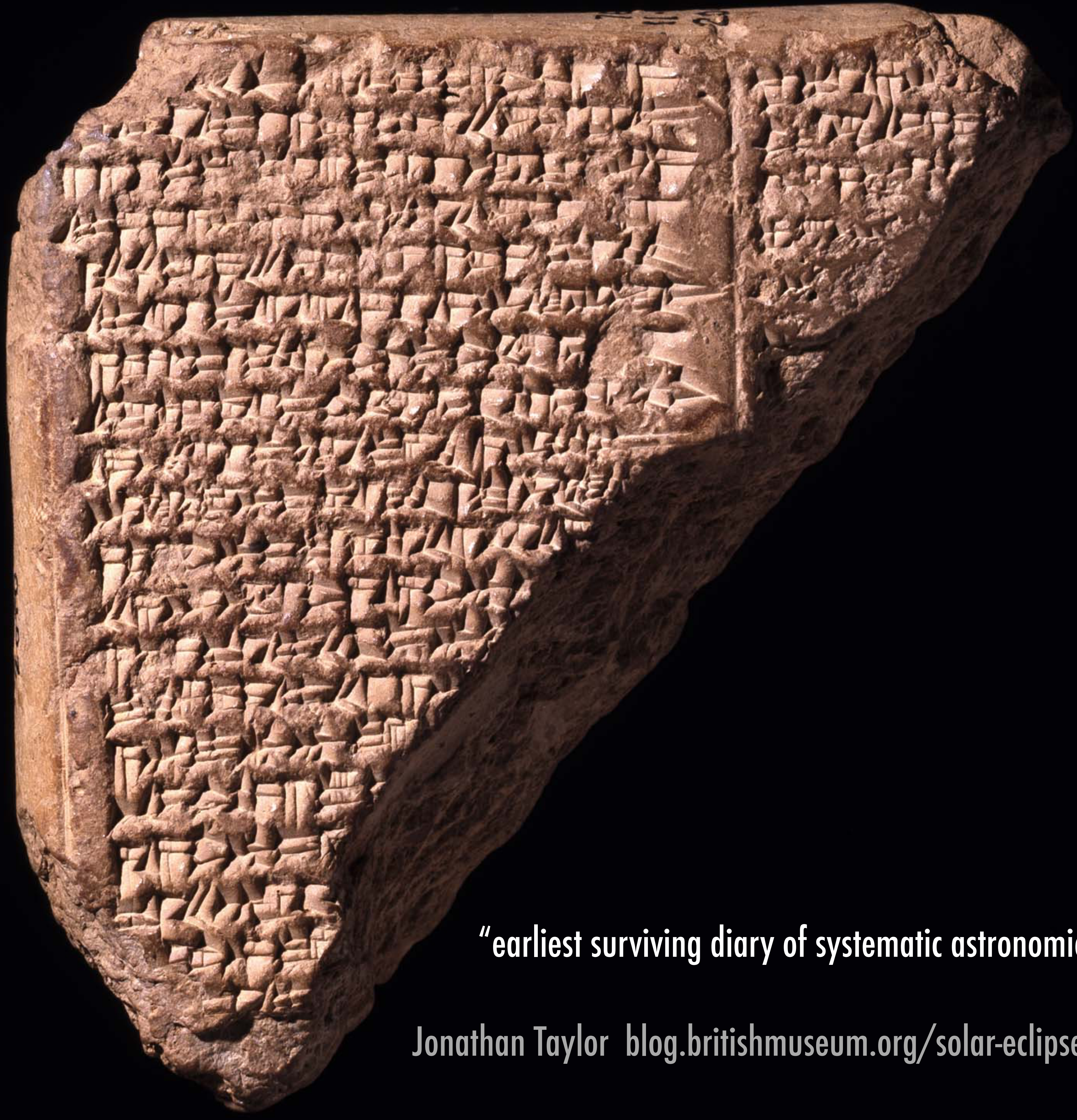
Enhancing astronomers' appreciation for high-dimensional data (visualization)

January 11, 1610



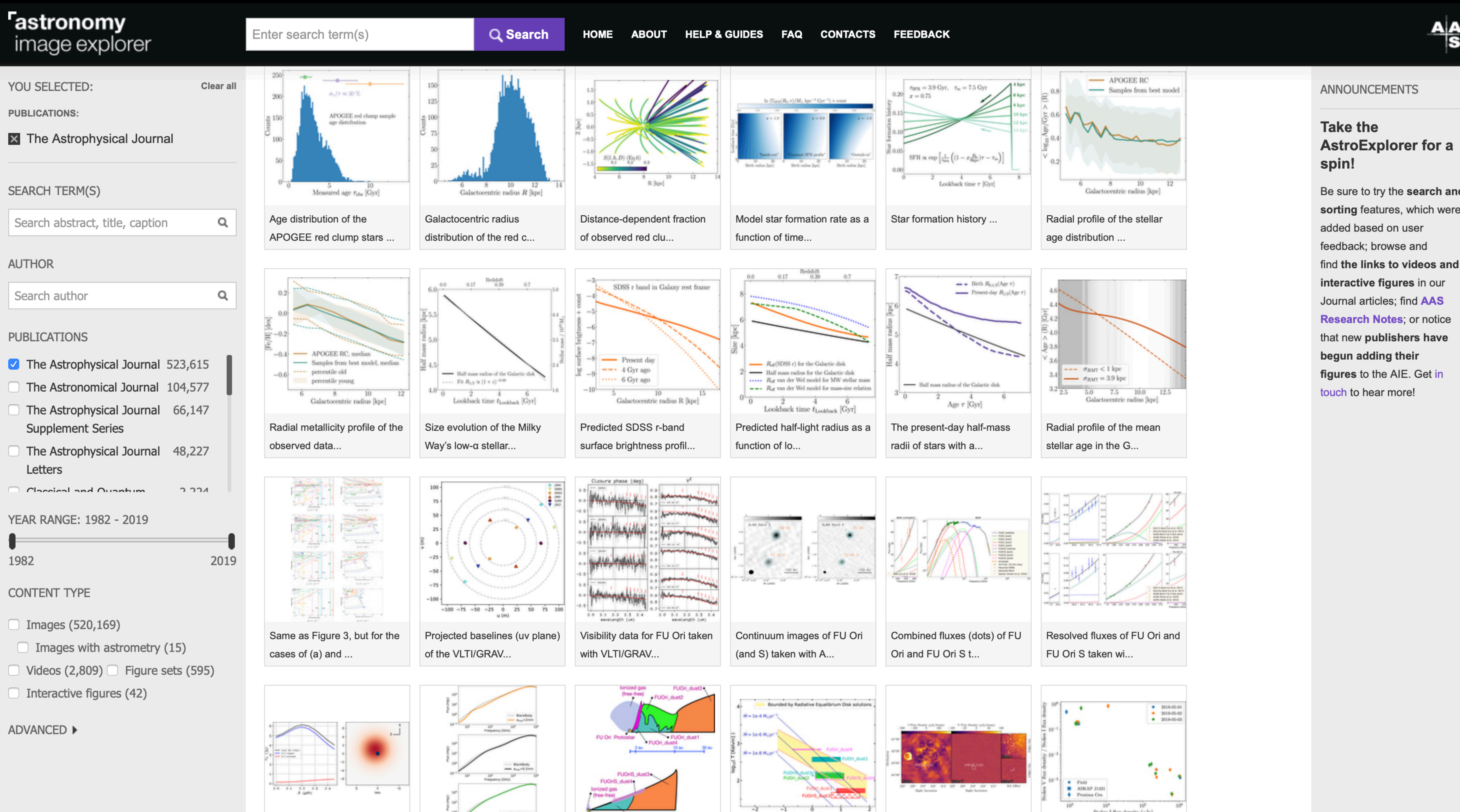
WorldWide Telescope

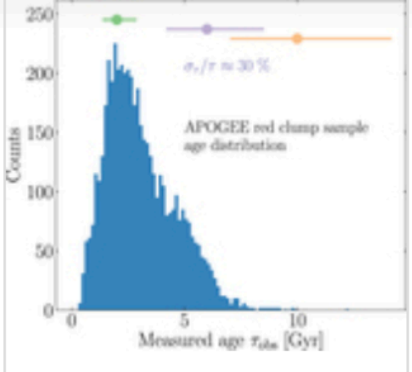
Galileo's New Order, A WorldWide Telescope Tour by Goodman, Wong & Udomprasert 2010
WWT Software Wong (inventor, MS Research), Fay (architect, MS Research), et al., now open source, hosted by AAS
see wwtambassadors.org for more on WWT Outreach



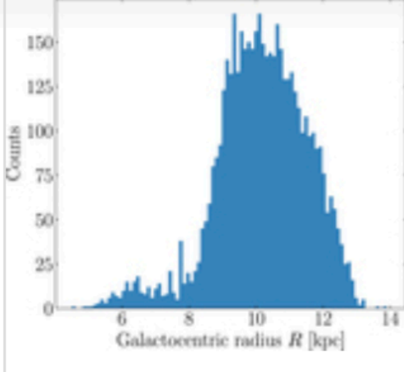
“earliest surviving diary of systematic astronomical observations“
Babylon, 652 BC
Jonathan Taylor blog.britishmuseum.org/solar-eclipses-then-and-now/

A Random Sample of Images from the Astrophysical Journal, 2019

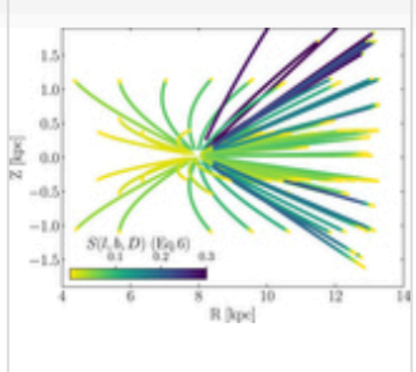




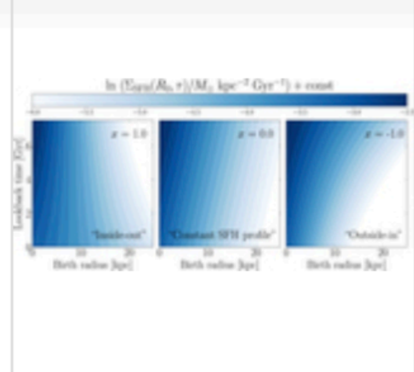
Age distribution of the APOGEE red clump stars ...



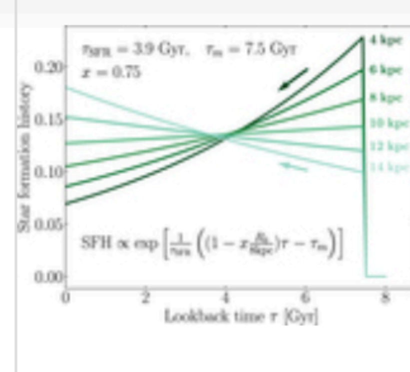
Galactocentric radius distribution of the red c...



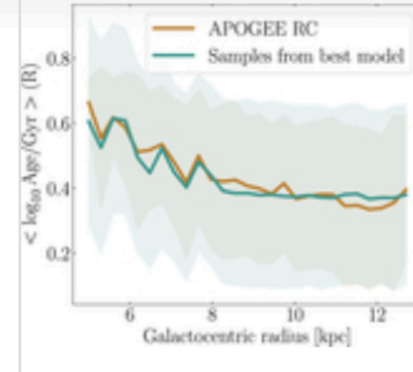
Distance-dependent fraction of observed red clu...



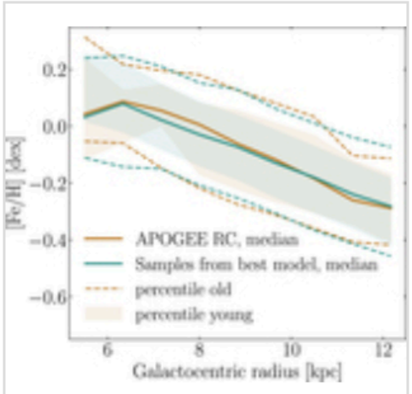
Model star formation rate as a function of time...



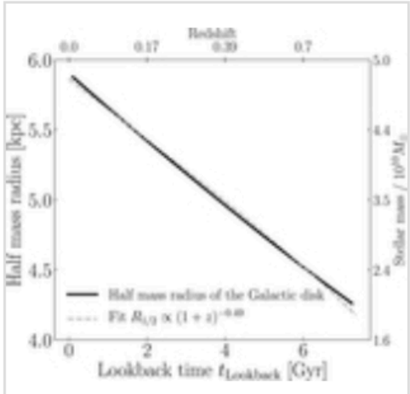
Star formation history ...



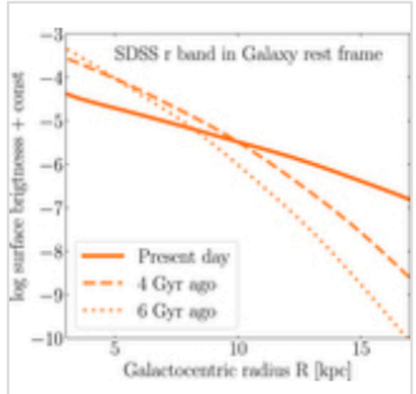
Radial profile of the stellar age distribution ...



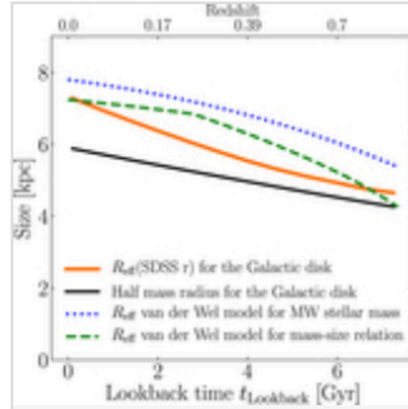
Radial metallicity profile of the observed data...



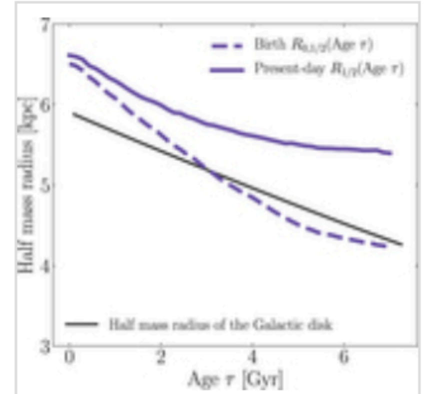
Size evolution of the Milky Way's low-α stellar...



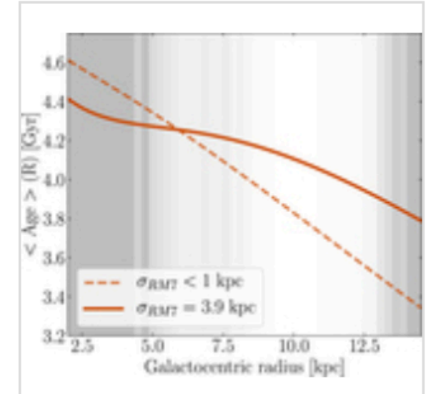
Predicted SDSS r-band surface brightness profil...



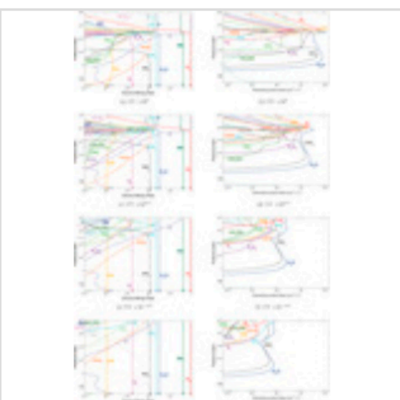
Predicted half-light radius as a function of lo...



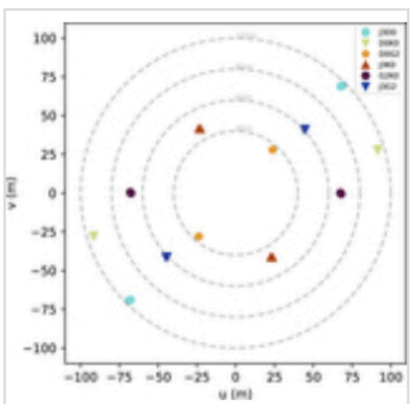
The present-day half-mass radii of stars with a...



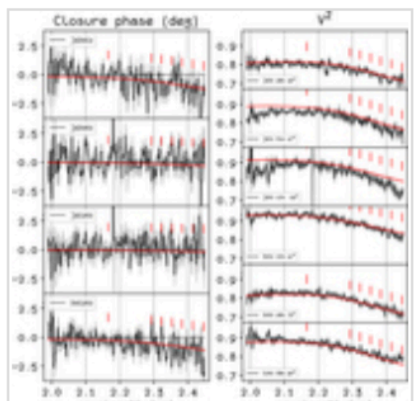
Radial profile of the mean stellar age in the G...



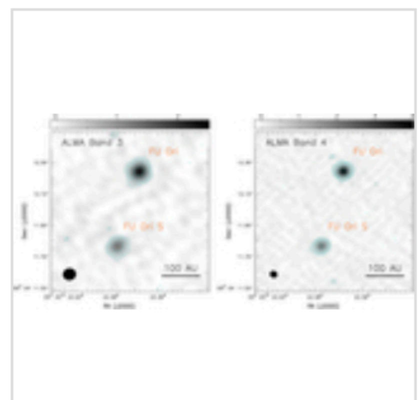
Same as Figure 3, but for the cases of (a) and ...



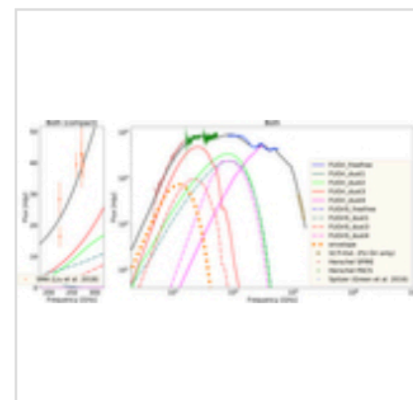
Projected baselines (uv plane) of the VLTI/GRAV...



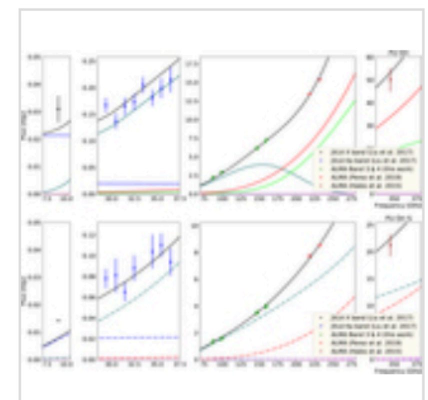
Visibility data for FU Ori taken with VLTI/GRAV...



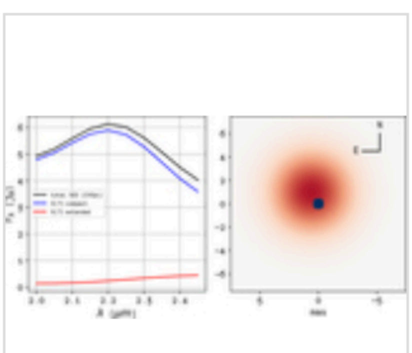
Continuum images of FU Ori (and S) taken with A...

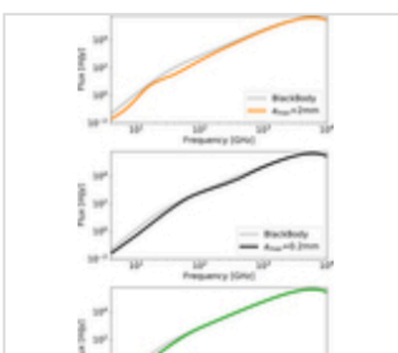


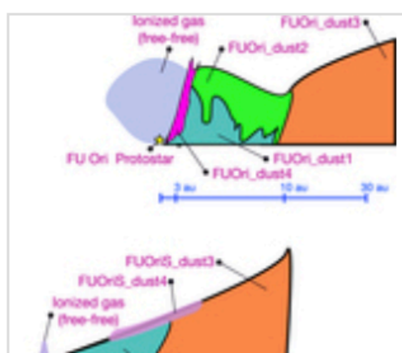
Combined fluxes (dots) of FU Ori and FU Ori S t...

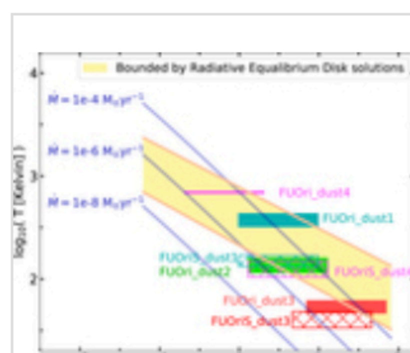


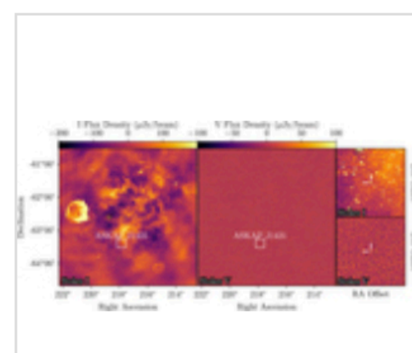
Resolved fluxes of FU Ori and FU Ori S taken wi...

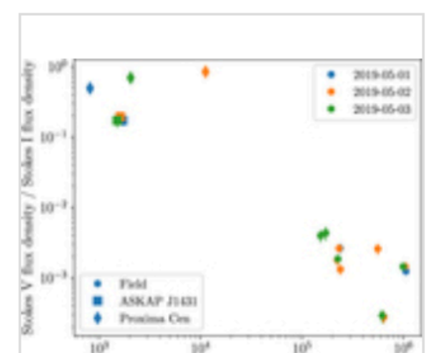








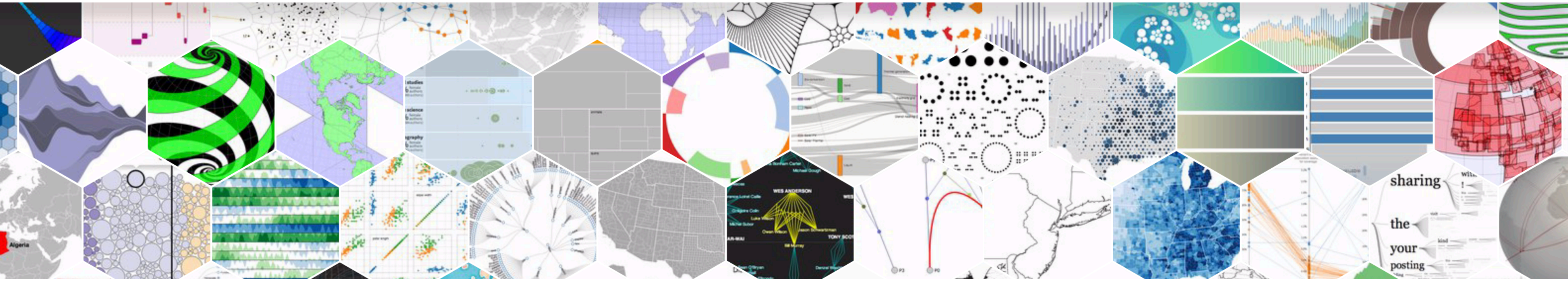




But, what if...

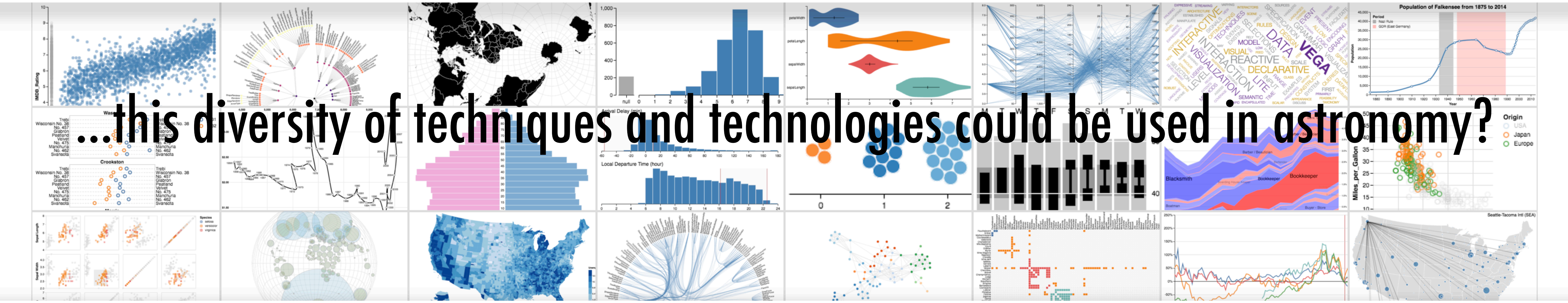
Data-Driven Documents

2011



Vega – A Visualization Grammar

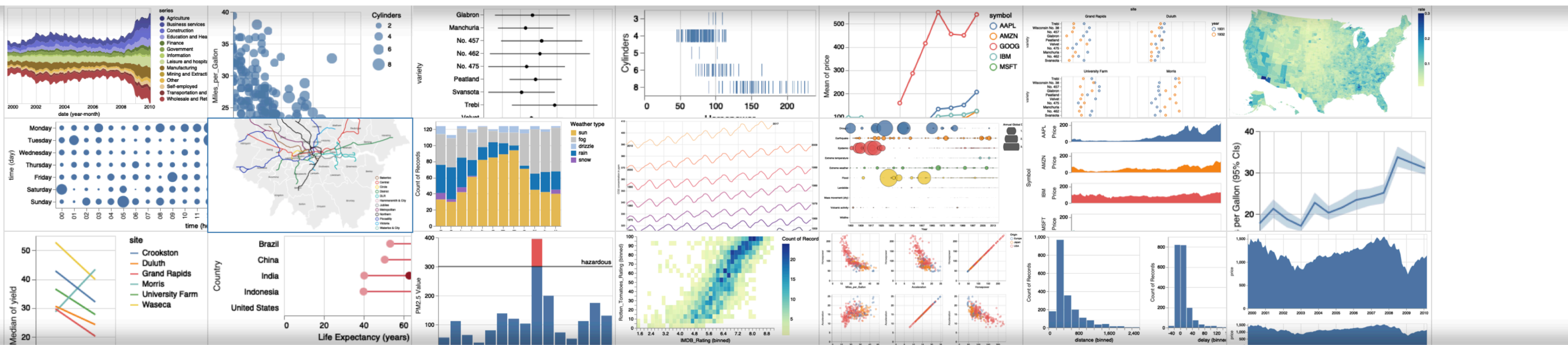
2014



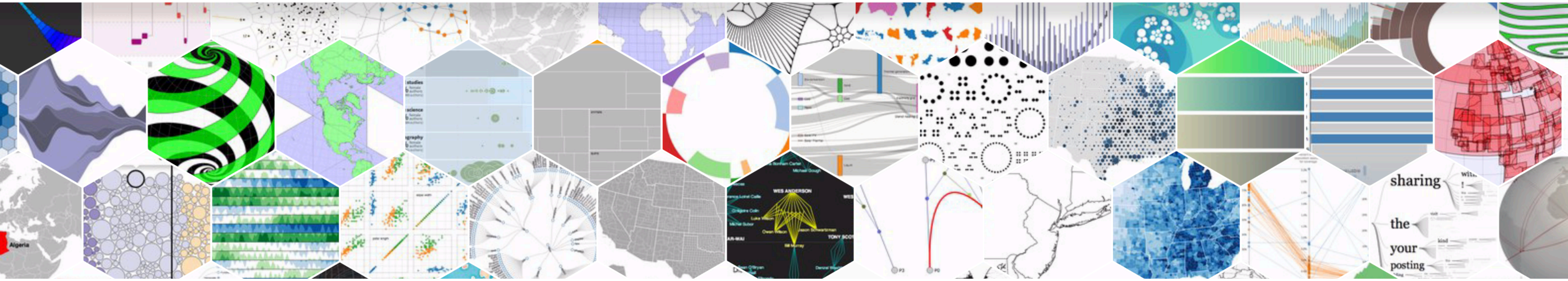
...this diversity of techniques and technologies could be used in astronomy?

Vega-Lite – A Grammar of Interactive Graphics

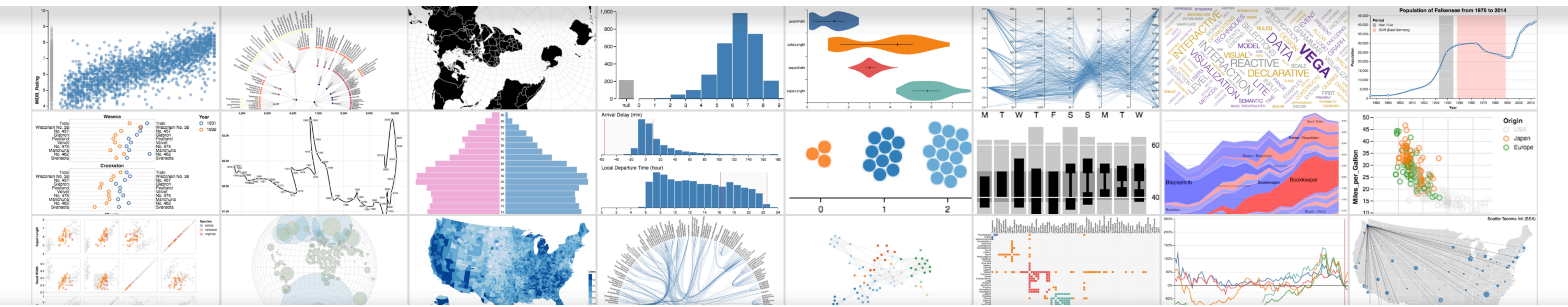
2017



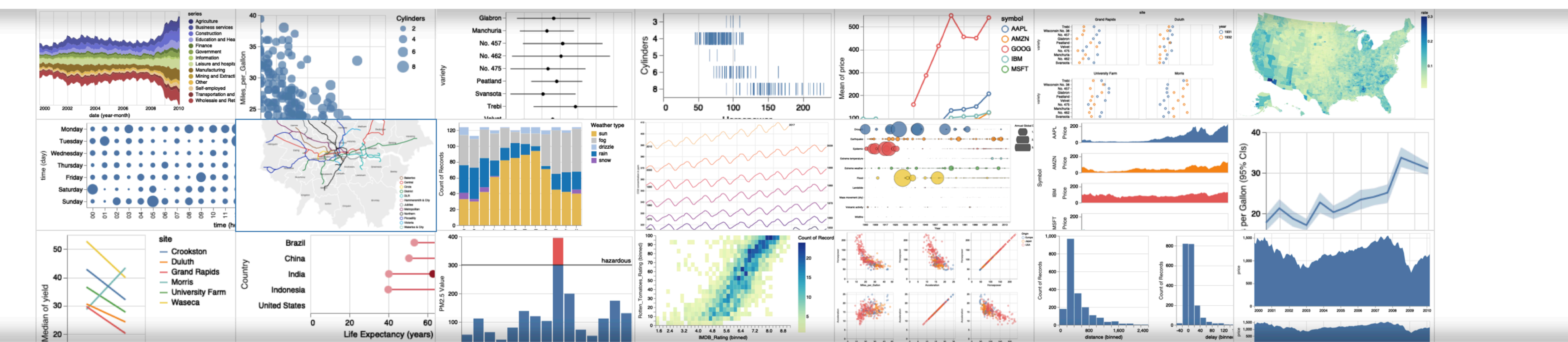
Data-Driven Documents 2011



Vega – A Visualization Grammar 2014



Vega-Lite – A Grammar of Interactive Graphics 2017



Au
Authorea

2015

FEATURED ARTICLES ABOUT PLANS BLOG FEEDBACK HELP ALYSSA GOODMAN ▾

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

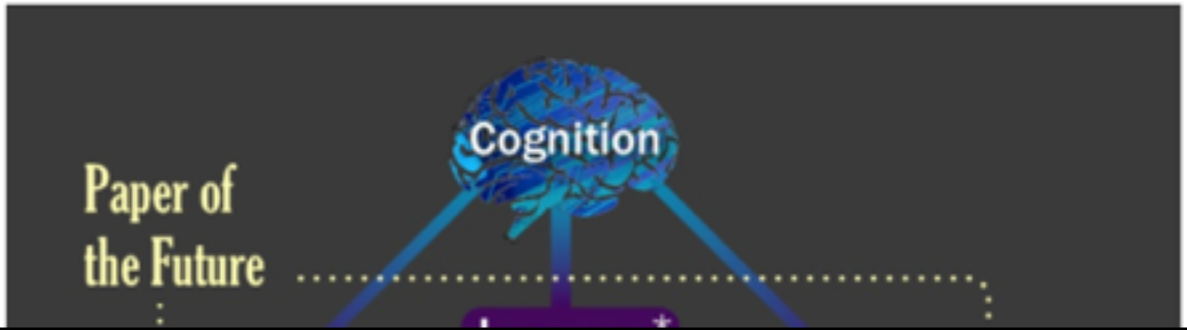
A 5-minute video demonsration of this paper is available at this YouTube link.

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

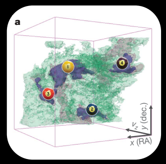
Merce Crosas 3 days ago · Public
Konrad, good points; this has been a concern for the community working on reproducibility. Regarding data repositories, Dataverse handles long-term preservation and access of data files in the following way: 1) for some data files that the repository recognizes (such 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; PoF: Goodman, Peek; WWT: Wong, Fay et al.; Astrometry.net: Hogg, Lang, Roweis et al.

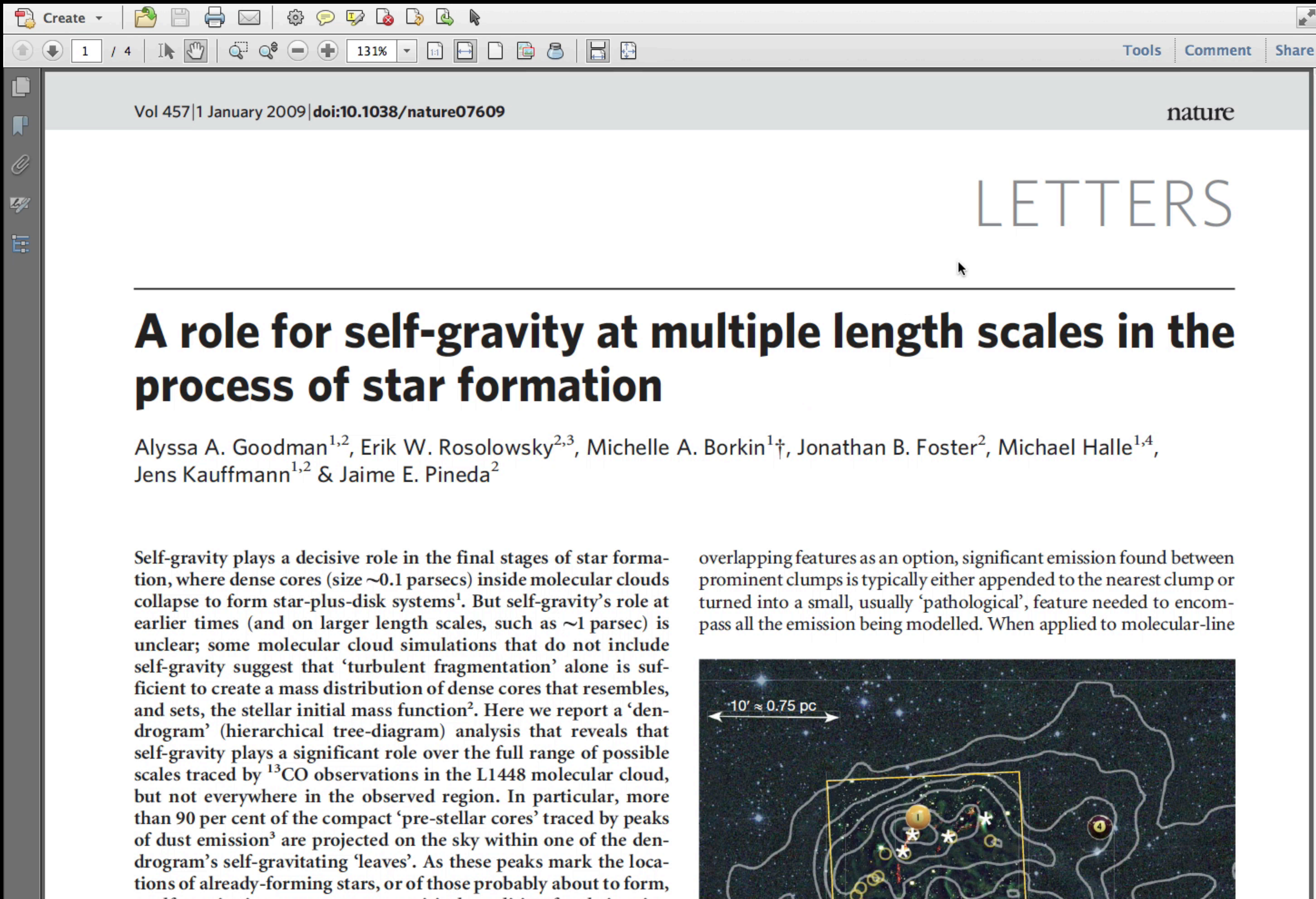
Astrometry.net



glue

[video, demos]

“3D PDF” (Nature, 2009)



Vol 457 | 1 January 2009 | doi:10.1038/nature07609 nature

LETTERS

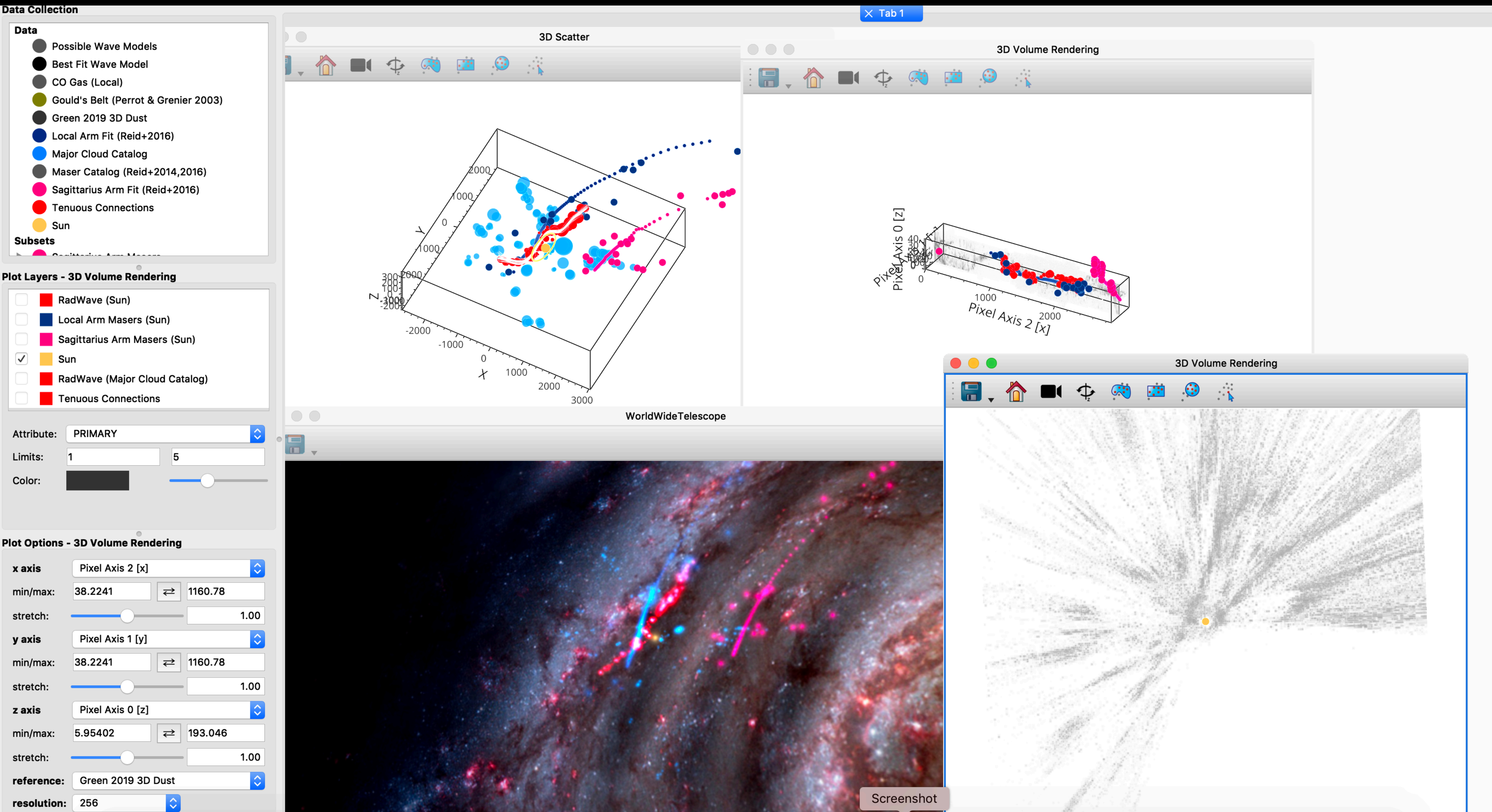
A role for self-gravity at multiple length scales in the process of star formation

Alyssa A. Goodman[1,2], Erik W. Rosolowsky[2,3], Michelle A. Borkin[1]†, Jonathan B. Foster[2], Michael Halle[1,4], Jens Kauffmann[1,2] & Jaime E. Pineda[2]

Self-gravity plays a decisive role in the final stages of star formation, where dense cores (size ~0.1 parsecs) inside molecular clouds collapse to form star-plus-disk systems[1]. But self-gravity's role at earlier times (and on larger length scales, such as ~1 parsec) is unclear; some molecular cloud simulations that do not include self-gravity suggest that 'turbulent fragmentation' alone is sufficient to create a mass distribution of dense cores that resembles, and sets, the stellar initial mass function[2]. Here we report a 'dendrogram' (hierarchical tree-diagram) analysis that reveals that self-gravity plays a significant role over the full range of possible scales traced by ^{13}CO observations in the L1448 molecular cloud, but not everywhere in the observed region. In particular, more than 90 per cent of the compact 'pre-stellar cores' traced by peaks of dust emission[3] are projected on the sky within one of the dendrogram's self-gravitating 'leaves'. As these peaks mark the locations of already-forming stars, or of those probably about to form, a self-gravitating cocoon seems a critical condition for their exist-

overlapping features as an option, significant emission found between prominent clumps is typically either appended to the nearest clump or turned into a small, usually 'pathological', feature needed to encompass all the emission being modelled. When applied to molecular-line

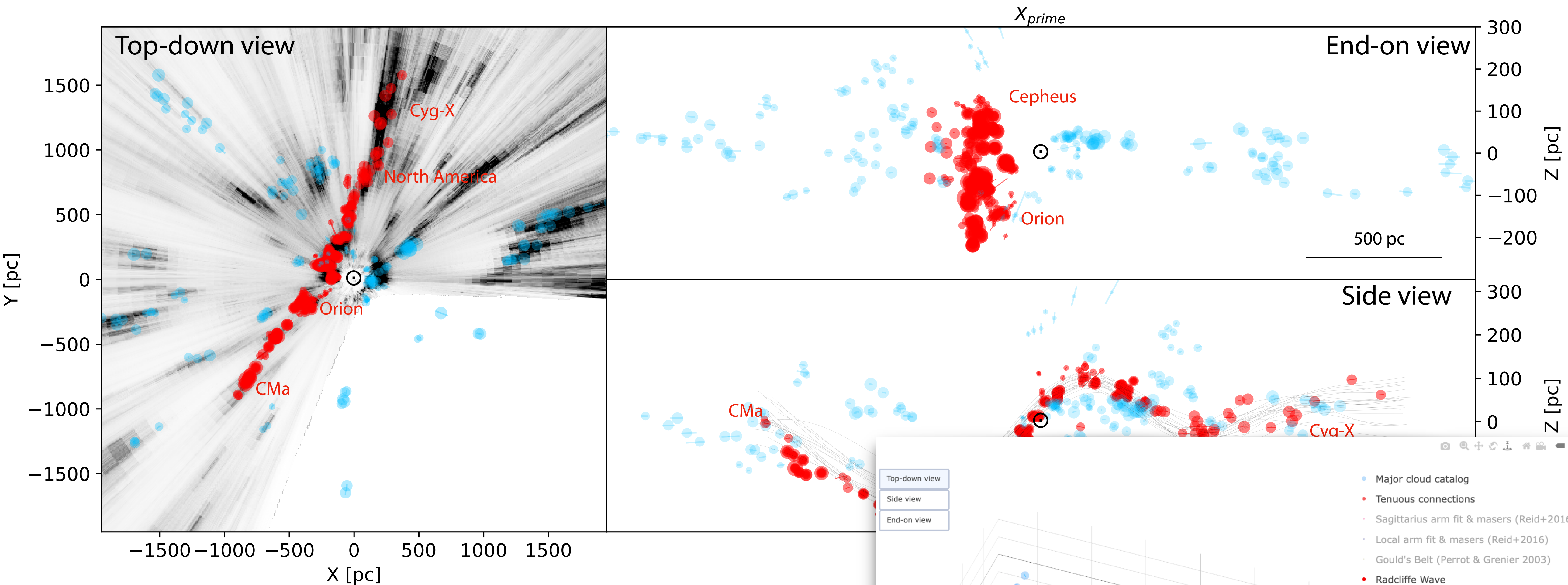
The “Radcliffe” Wave, 2019 [demo]

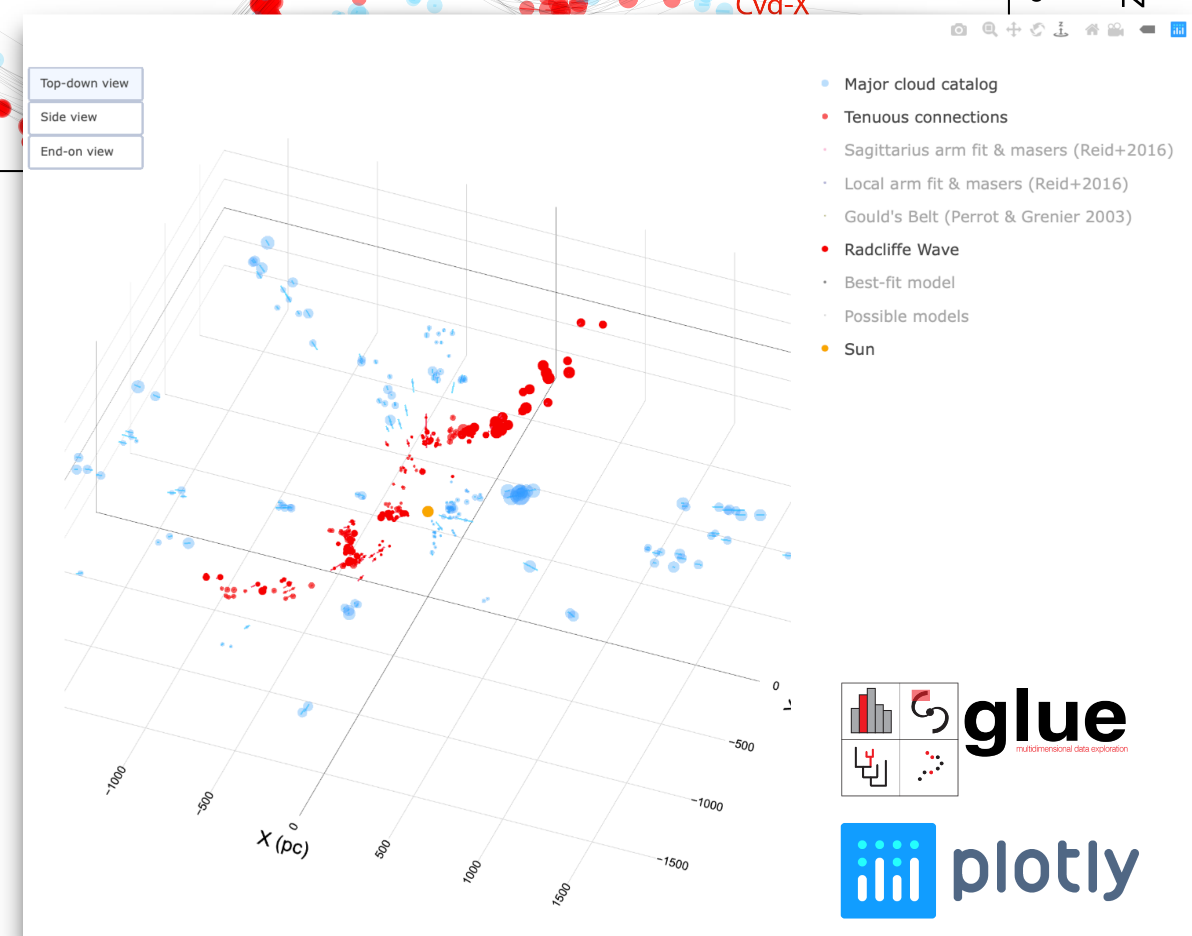


glue: glueviz.org WorldWide Telescope: worldwidetelescope.org

(Publishing) The "Radcliffe" Wave

(embargoed, please do not distribute)

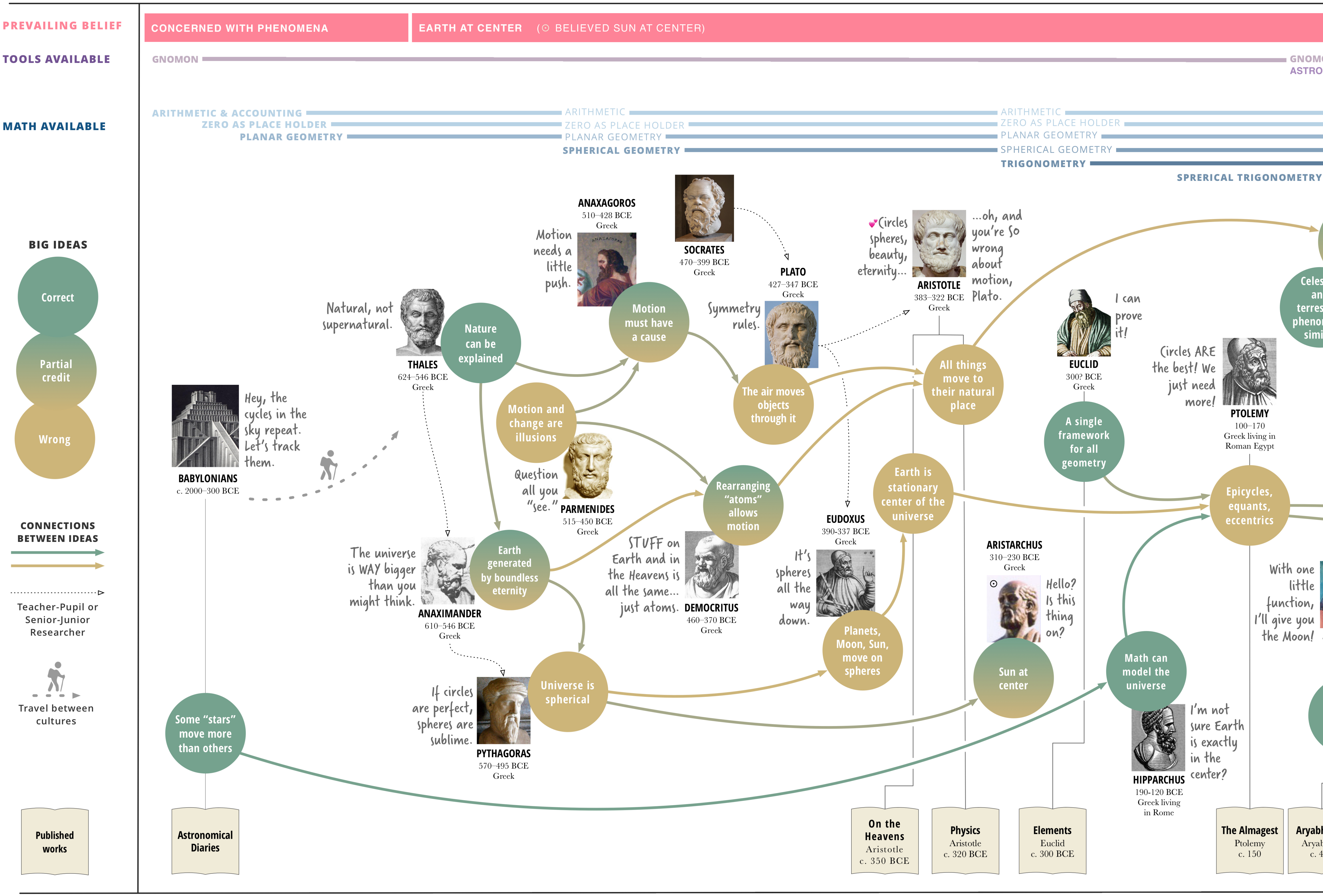


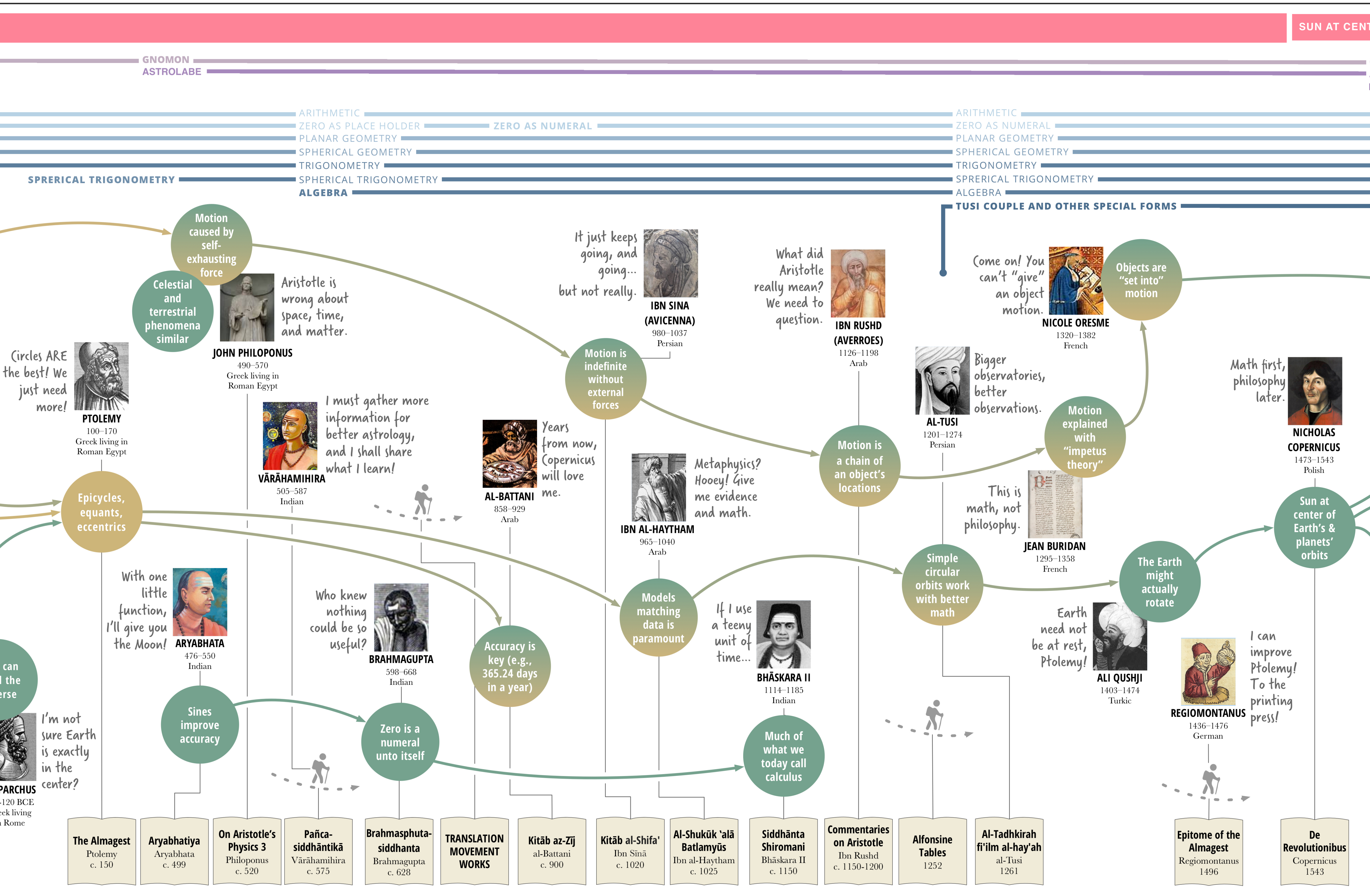


João Alves, Catherine Zucker, Alyssa Goodman,
Joshua Speagle, Stefan Meingast,
Thomas Robitaille, Douglas Finkbeiner,
Edward F. Schlafly, and Gregory Green

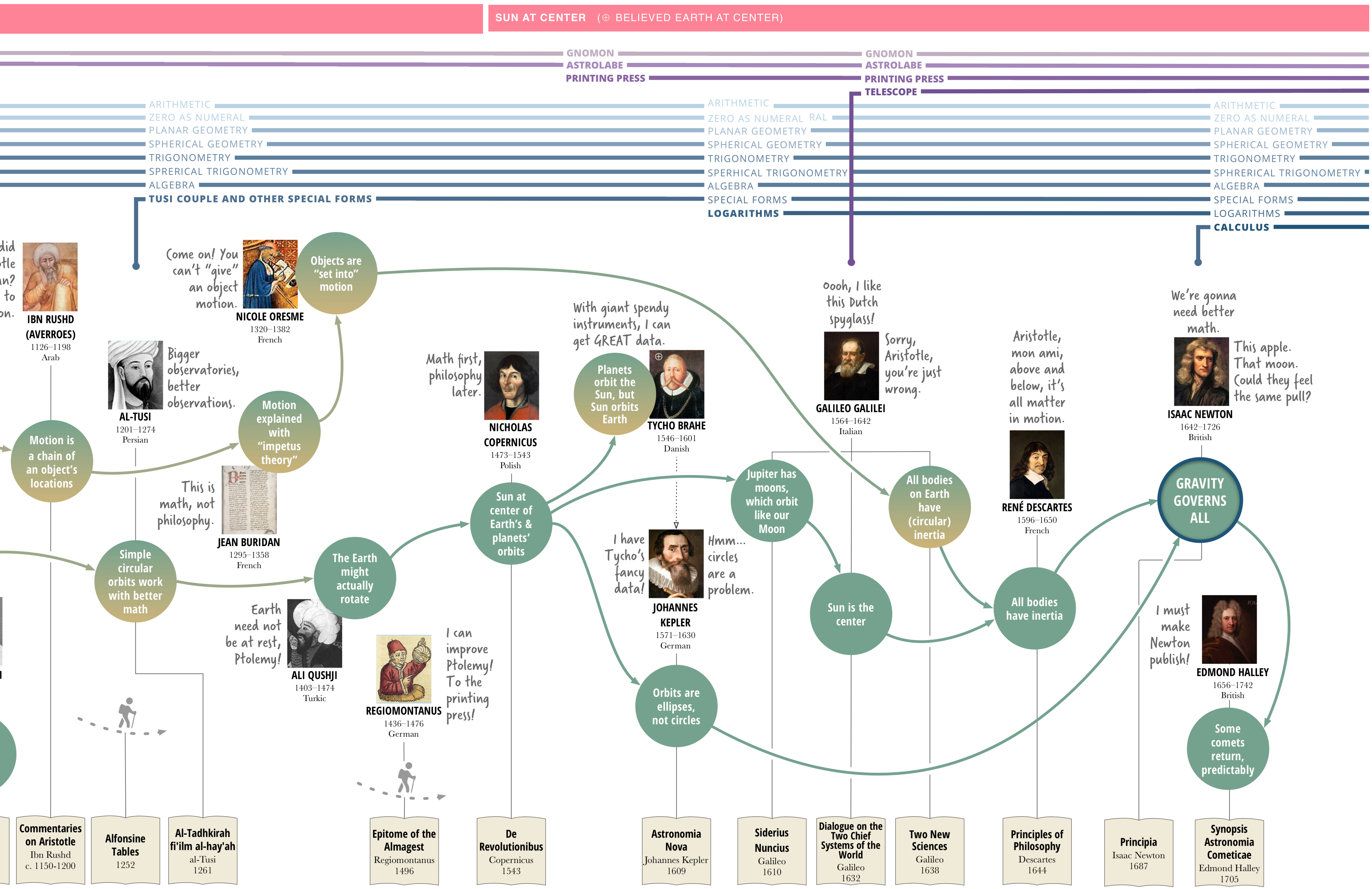
Nature (2019, we hope)

The Path to Newton




SUN AT CENT
GNOMON
ASTROLABE
ARITHMETIC
ZERO AS PLACE HOLDER
ZERO AS NUMERAL
PLANAR GEOMETRY
SPHERICAL GEOMETRY
TRIGONOMETRY
SPRERICAL TRIGONOMETRY
SPHERICAL 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
Circles ARE the best! We just need more!
PTOLEMY
100–170
Greek living in Roman Egypt
Epicycles, equants, eccentrics
I must gather more information for better astrology, and I shall share what I learn!
VĀRĀHAMIHIRA
505–587
Indian
It just keeps going, and going... but not really.
IBN SINA (AVICENNA)
980–1037
Persian
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
What did Aristotle really mean? We need to question.
IBN RUSHD (AVERROES)
1126–1198
Arab
Motion is a chain of an object's locations
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
Motion explained with "impetus theory"
Math first, philosophy later.
NICHOLAS COPERNICUS
1473–1543
Polish
This is math, not philosophy.
JEAN BURIDAN
1295–1358
French
Sun at center of Earth's & planets' orbits
Simple circular orbits work with better math
The Earth might actually rotate
Models matching data is paramount
Earth need not be at rest, Ptolemy!
ALI QUSHJI
1403–1474
Turkic
I can improve Ptolemy! To the printing press!
REGIOMONTANUS
1436–1476
German
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)
If I use a teeny unit of time...
BHĀSKARA II
1114–1185
Indian
Much of what we today call calculus
can
the
erse
I'm not sure Earth is exactly in the center?
PARCHUS
-120 BCE
eek living
Rome
Sines improve accuracy
Zero is a numeral unto itself
The Almagest
Ptolemy
c. 150
Aryabhatiya
Aryabhata
c. 499
On Aristotle's Physics 3
Philoponus
c. 520
Pañca-siddhāntikā
Varāhamihira
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



The Path to Newton

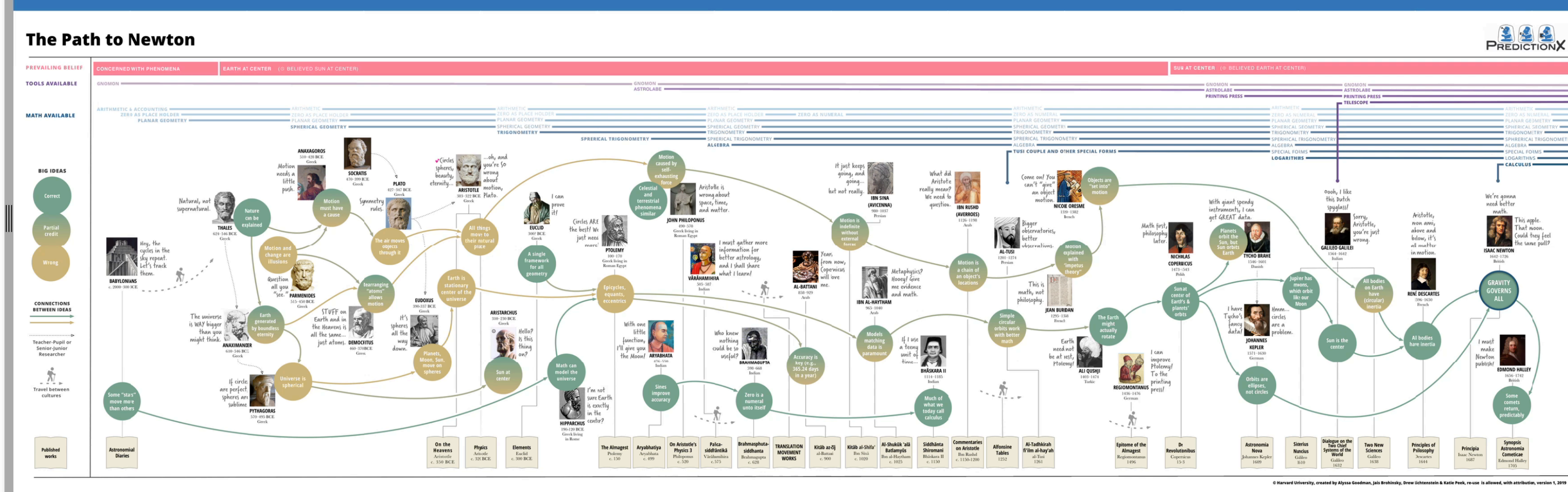
The Path to Newton

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.

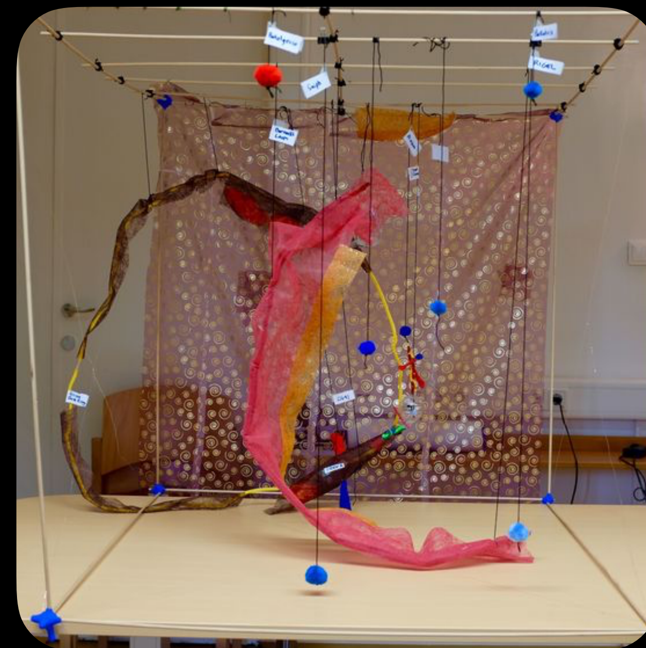
Steps along the Path were facilitated by material technologies and greatly affected by religious doctrine, cultural exchange, and the migration and translation of ideas. The Path highlights the cultures, thinkers and tinkerers who wrestled ideas about motion into the stories, cosmologies, mathematics, 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

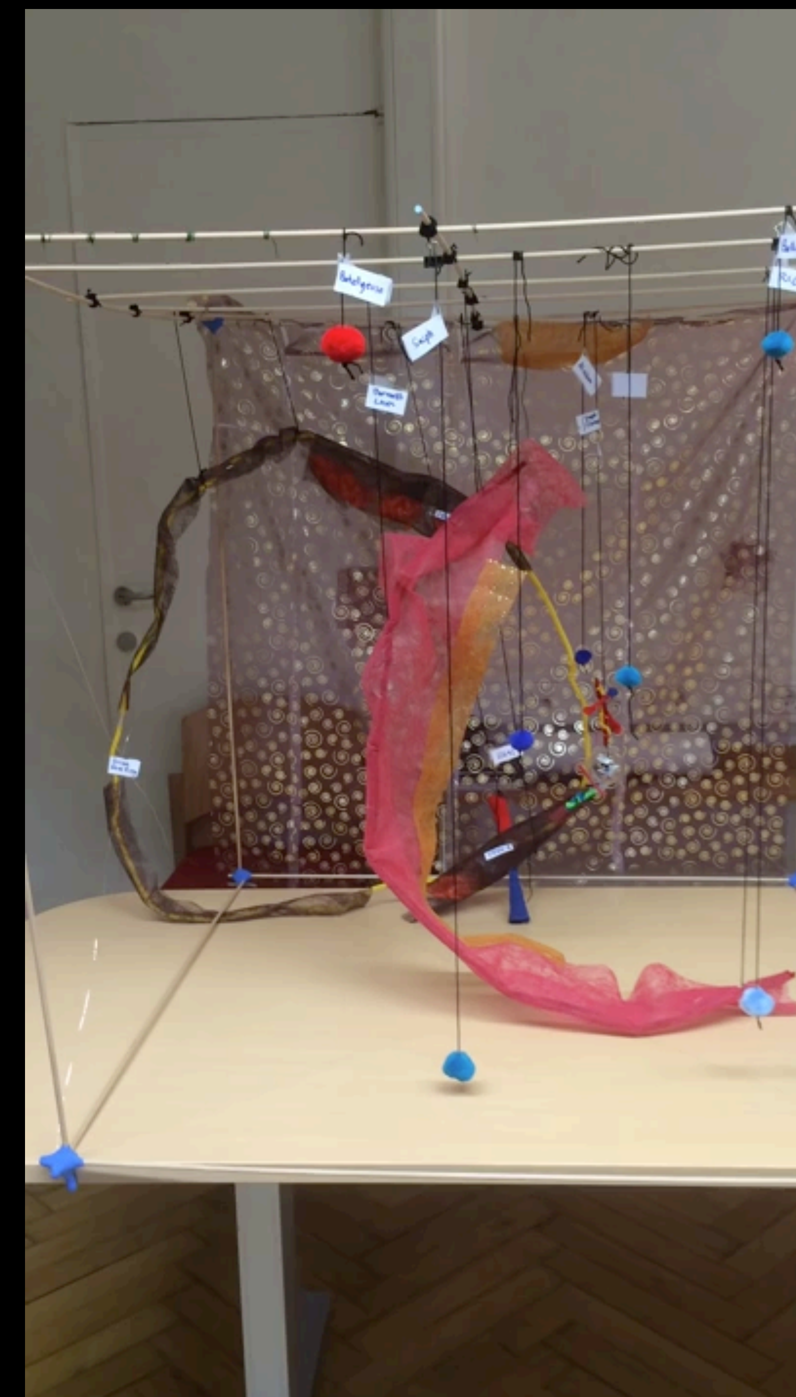


pathto-x.github.io — javascript by Francisco Ortiz

VIENN

2015





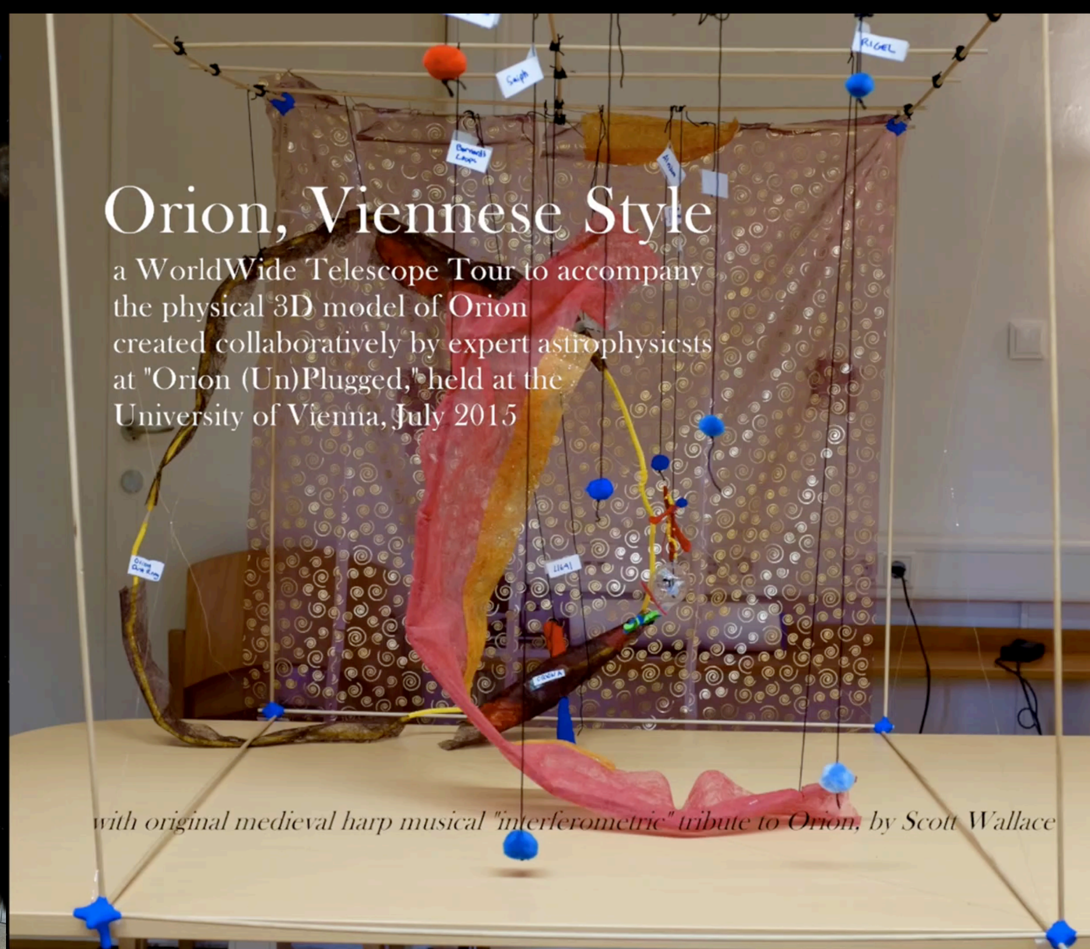
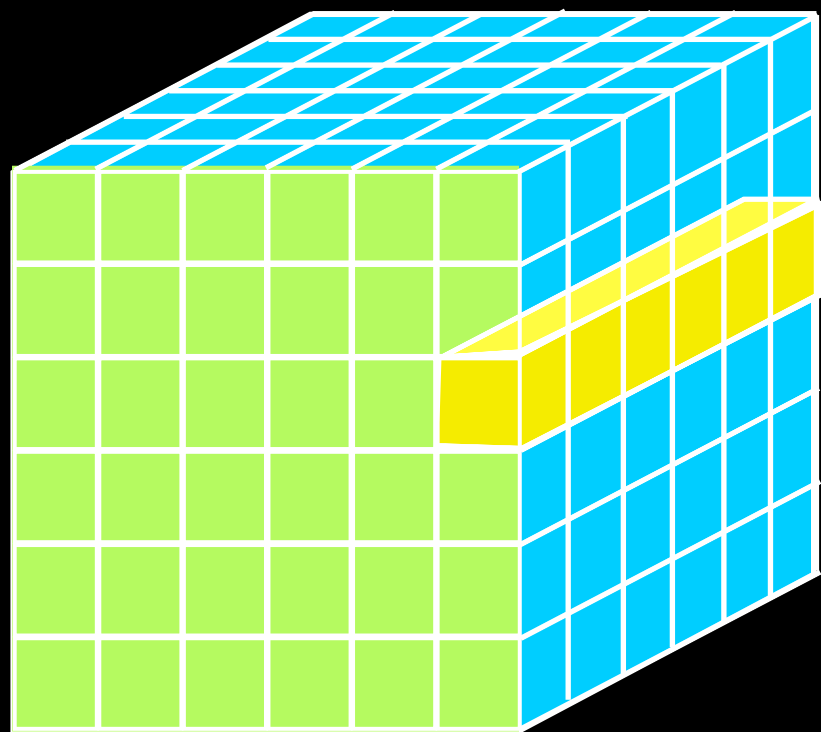
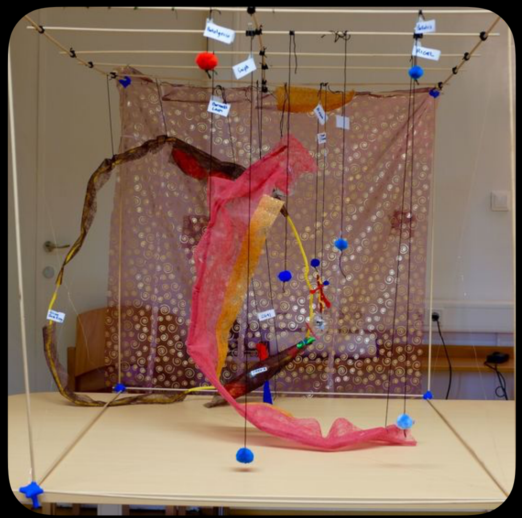

Orion, Viennese Style
a WorldWide Telescope Tour to accompany
the physical 3D model of Orion
created collaboratively by expert astrophysicsts
at "Orion (Un)Plugged," held at the
University of Vienna, July 2015
with original medieval harp musical "interferometric" tribute to Orion, by Scott Wallace

figure from Goodman 2012, "Principles of High-Dimensional Data Visualization in Astronomy"



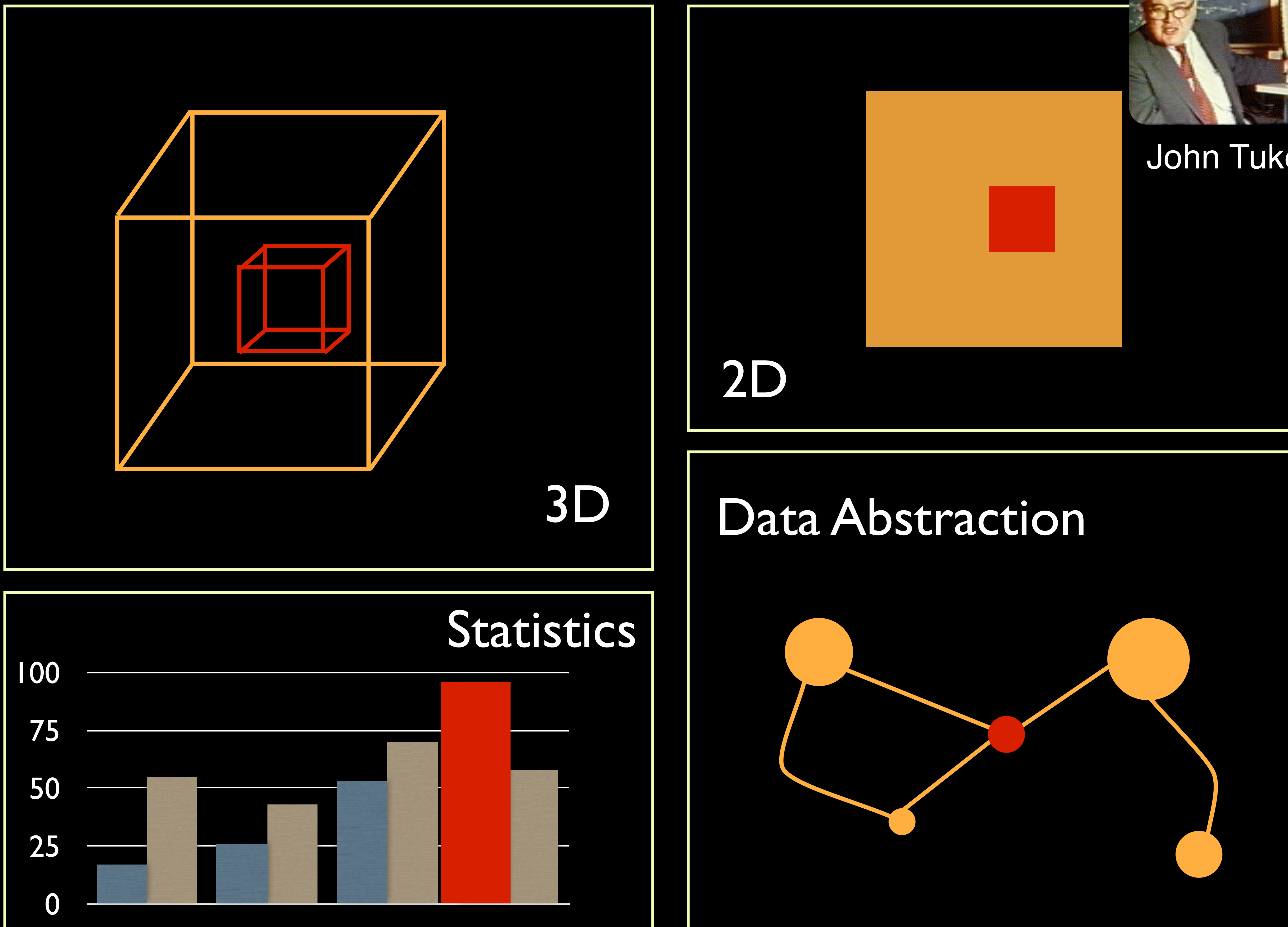
"Data, Dimensions, Display"

1D: Columns = "Spectra", "SEDs" or "Time Series"
2D: Faces or Slices = "Images"
3D: Volumes = "3D Renderings", "2D Movies"
4D: Time Series of Volumes = "3D Movies"



Linked Views of High-dimensional Data

John Tukey



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

Wide Data, “In 3D”

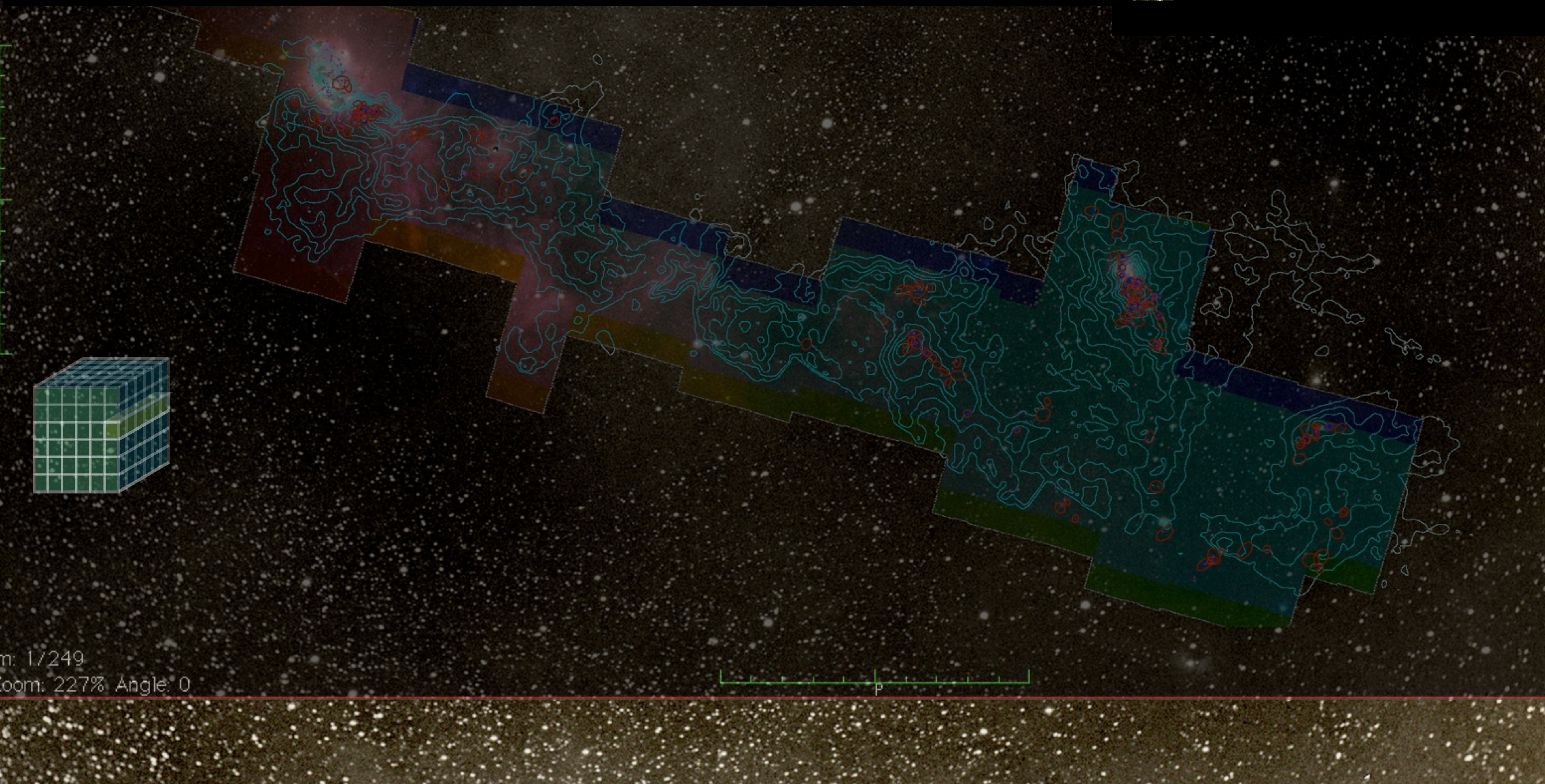
mm peak (Enoch et al. 2006)

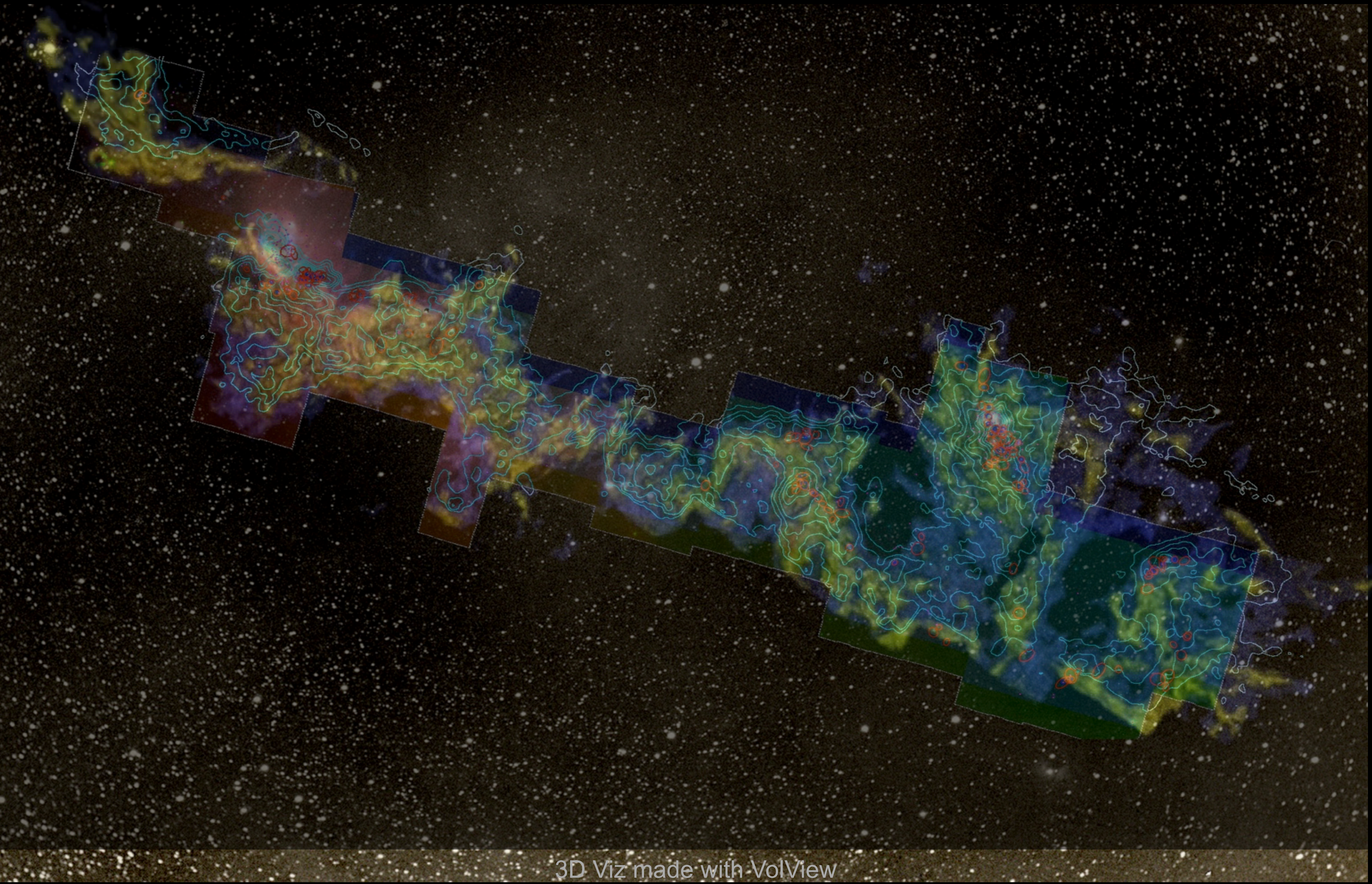
sub-mm peak (Hatchell et al. 2005, Kirk et al. 2006)

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

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

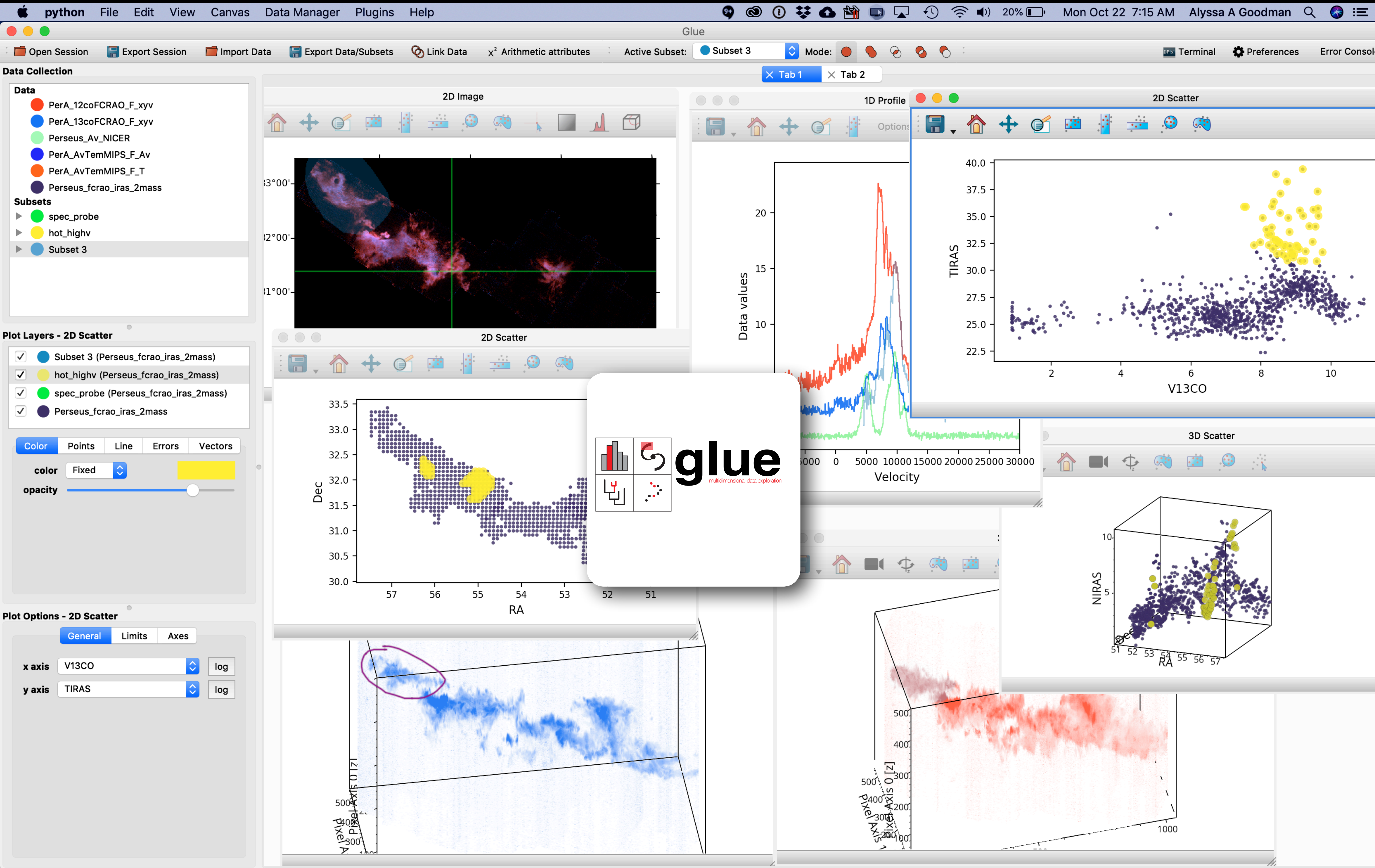
Optical image (Barnard 1927)





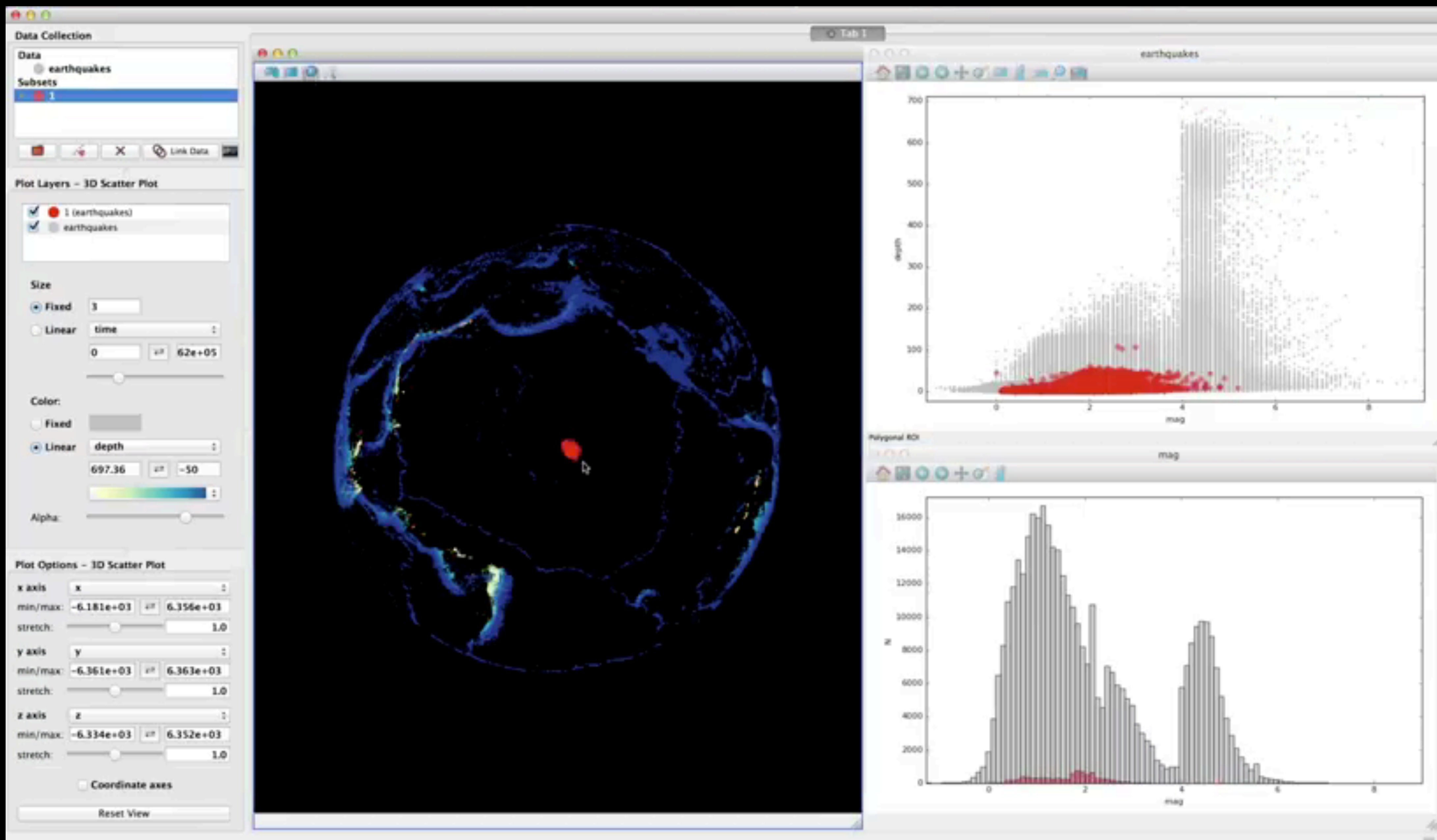
AstronomicalMedicine@IIC ~2008 COMPLETE

2018


python File Edit View Canvas Data Manager Plugins Help
Mon Oct 22 7:15 AM Alyssa A Goodman
Glue
Open Session
Export Session
Import Data
Export Data/Subsets
Link Data
Arithmetic attributes
Active Subset: Subset 3
Mode:
Terminal
Preferences
Error Console
Data Collection
Data
PerA_12coFCRAO_F_xyv
PerA_13coFCRAO_F_xyv
Perseus_Av_NICER
PerA_AvTemMIPS_F_Av
PerA_AvTemMIPS_F_T
Perseus_fcrao_iras_2mass
Subsets
spec_probe
hot_highv
Subset 3
Plot Layers - 2D Scatter
Subset 3 (Perseus_fcrao_iras_2mass)
hot_highv (Perseus_fcrao_iras_2mass)
spec_probe (Perseus_fcrao_iras_2mass)
Perseus_fcrao_iras_2mass
Color
Points
Line
Errors
Vectors
color
Fixed
opacity
Plot Options - 2D Scatter
General
Limits
Axes
x axis
V13CO
log
y axis
TIRAS
log
Tab 1
Tab 2
2D Image
1D Profile
2D Scatter
3D Scatter
Data values
Velocity
TIRAS
V13CO
Dec
RA
NIRAS
glue
multidimensional data exploration

Linked Views of High-dimensional Data (in Python)

glue

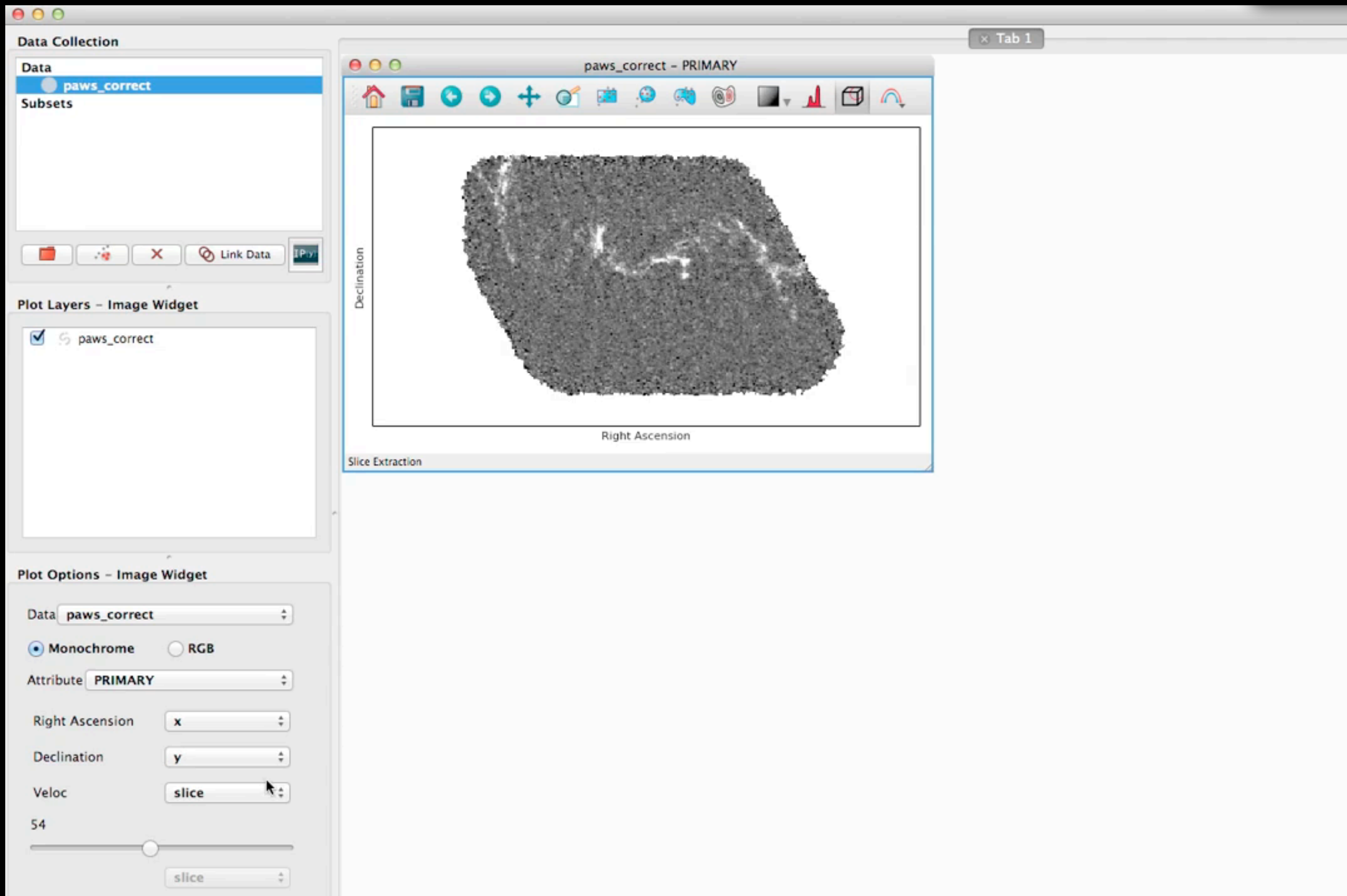


2015 *video by Tom Robitaille, lead glue developer*

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

Linked Views of High-dimensional Data (in Python)

glue



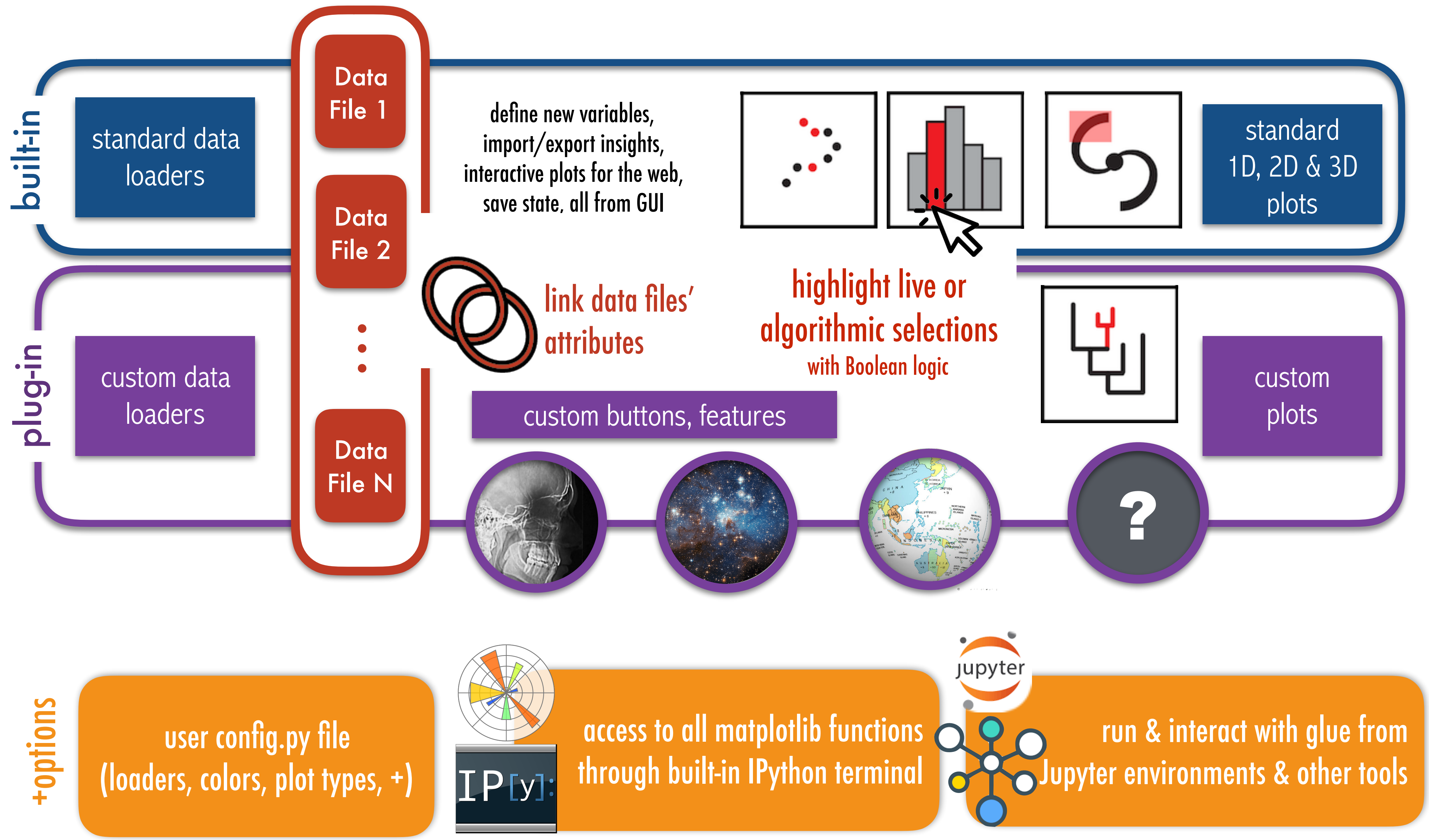
2014 video by Chris Beaumont, glue developer

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

glue

multidimensional data exploration

glueviz.org



glue handout from Crete III, 2019 @glueviz

DEMO: 5 steps to revealing a wispy veil in 3D

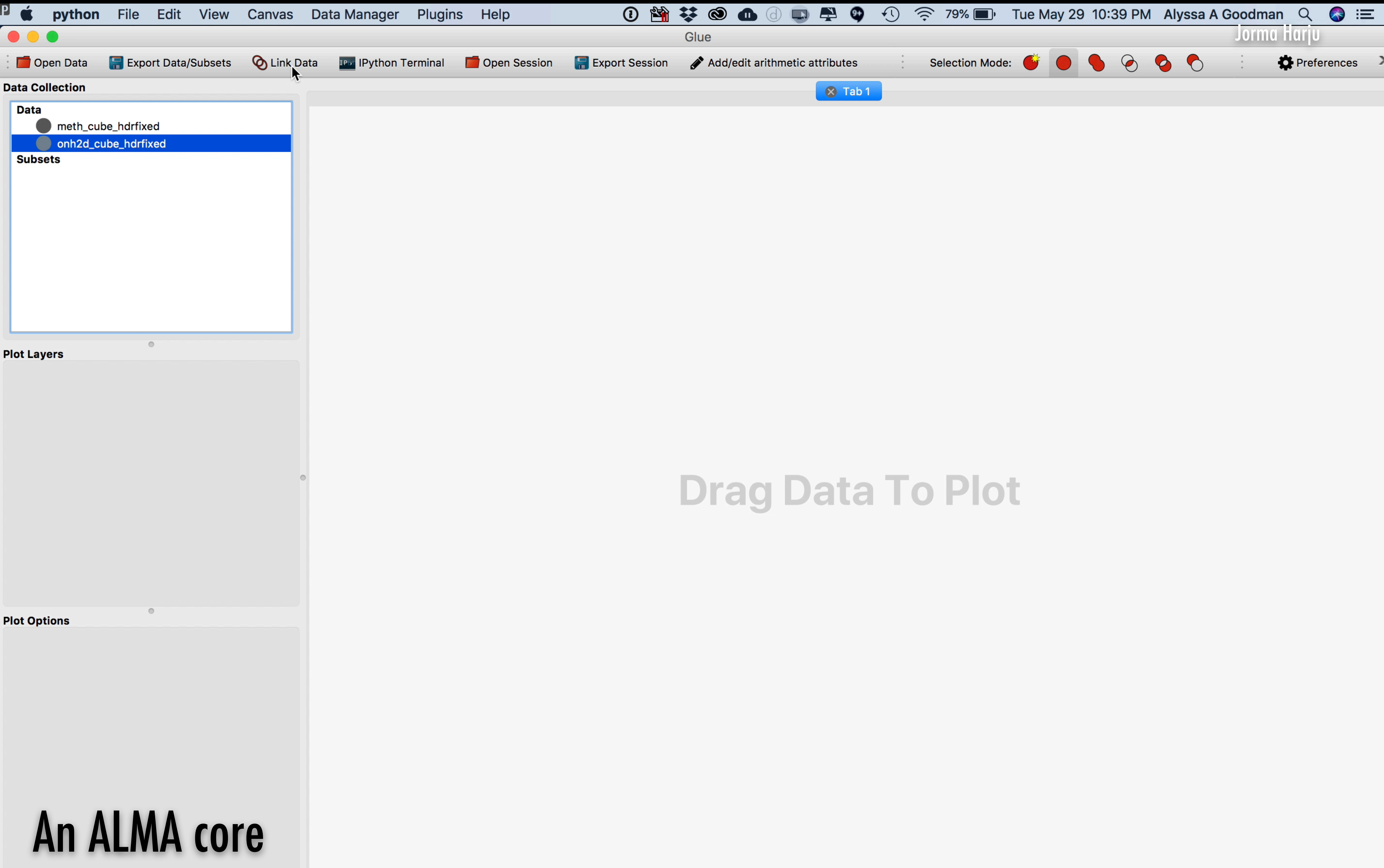
1. "glue" data sets to each other
2. drag data sets to visualize
3. inspect cubes with 2D sliders
4. adjust color
5. inspect cubes as (superimposed) 3D volumes

+ bonus—comparison with traditional views & sliders

sample ALMA (spectral-line) data cubes courtesy of Jorma Harju

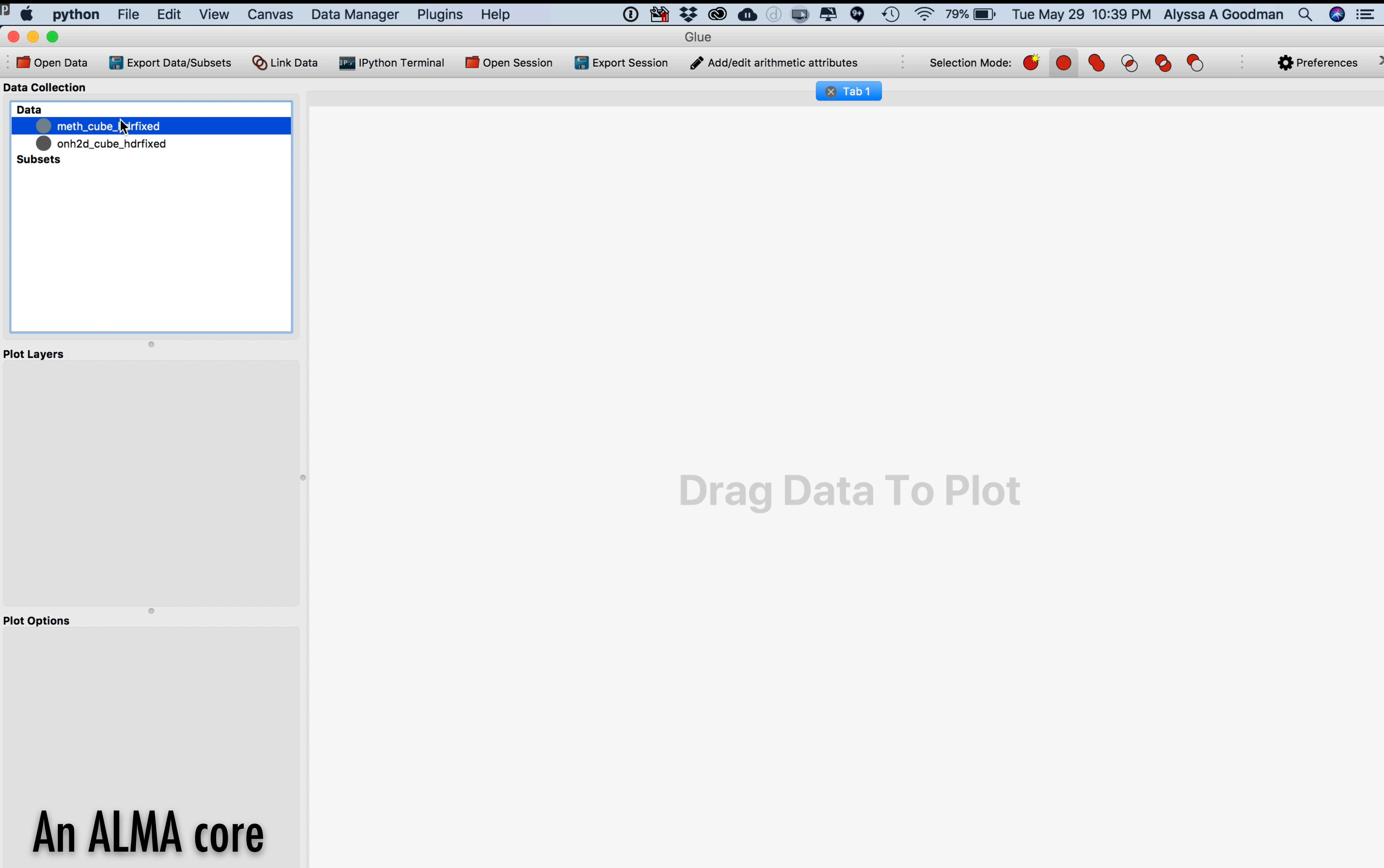
Find out more about glue, and download for free, at glueviz.org

No merging of data sets—just glue them.

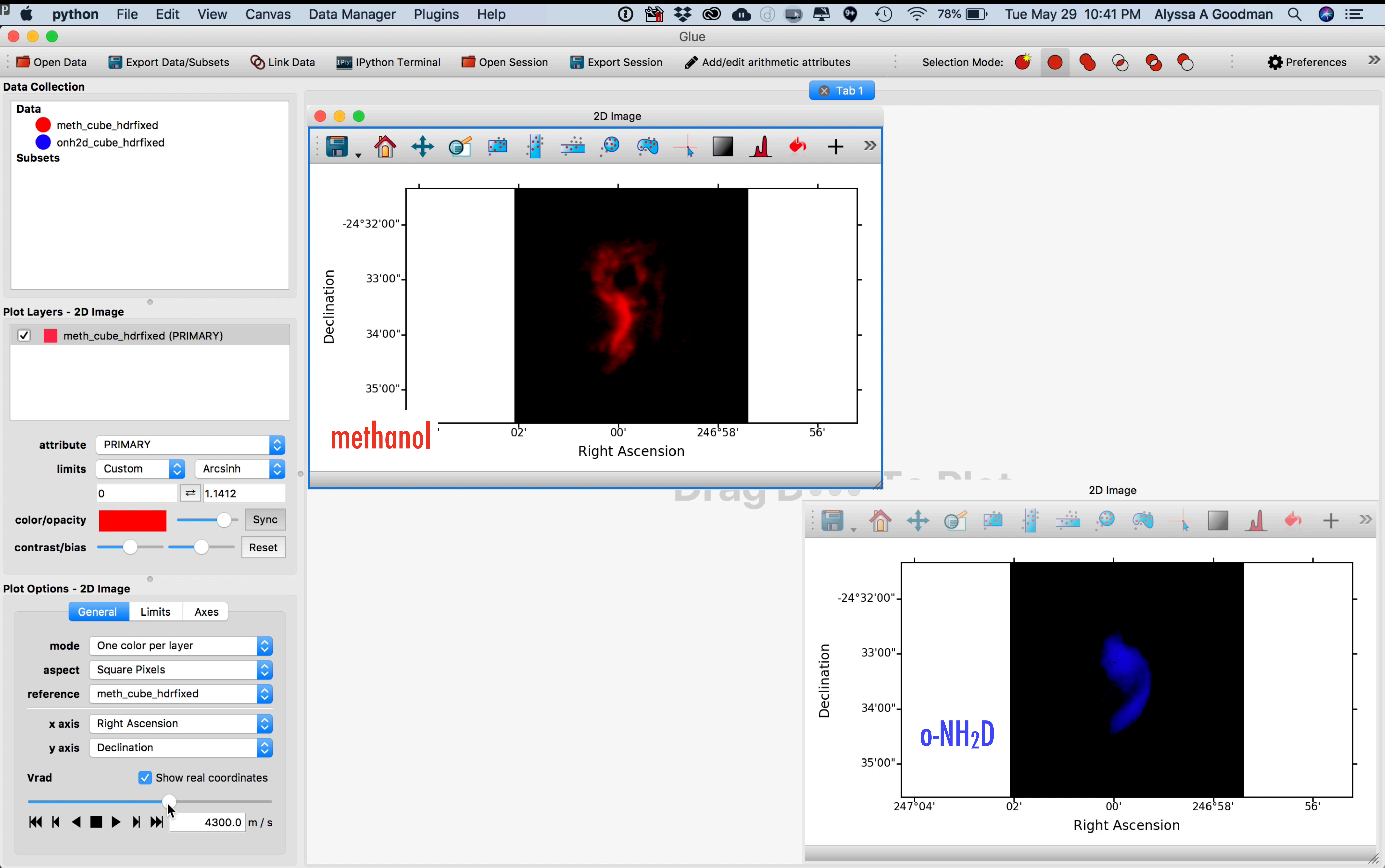


An ALMA core

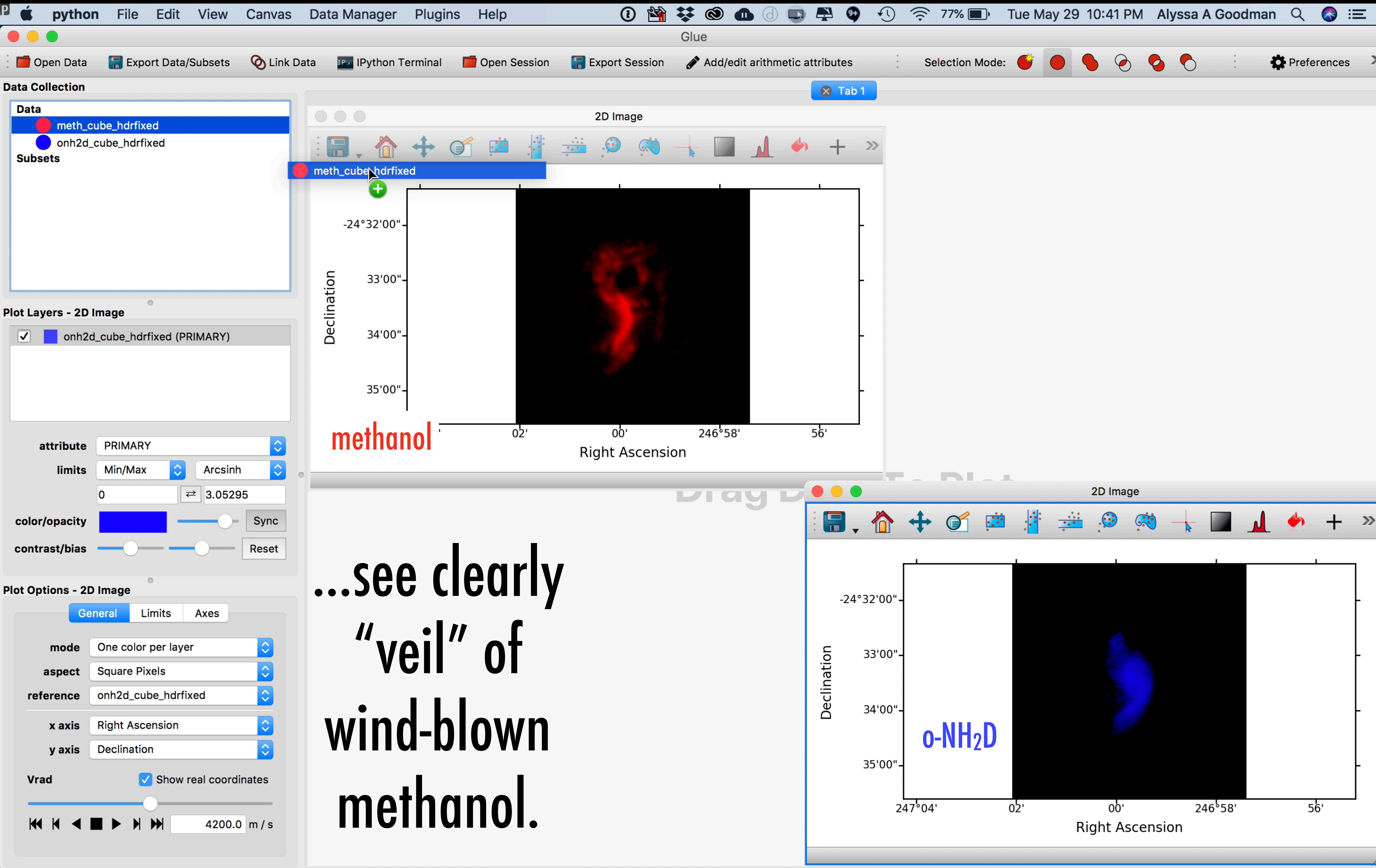
Just drag to visualize, e.g. series of 2D "channel maps."



Adjust so each tracer is a different color.



Create 3D views...

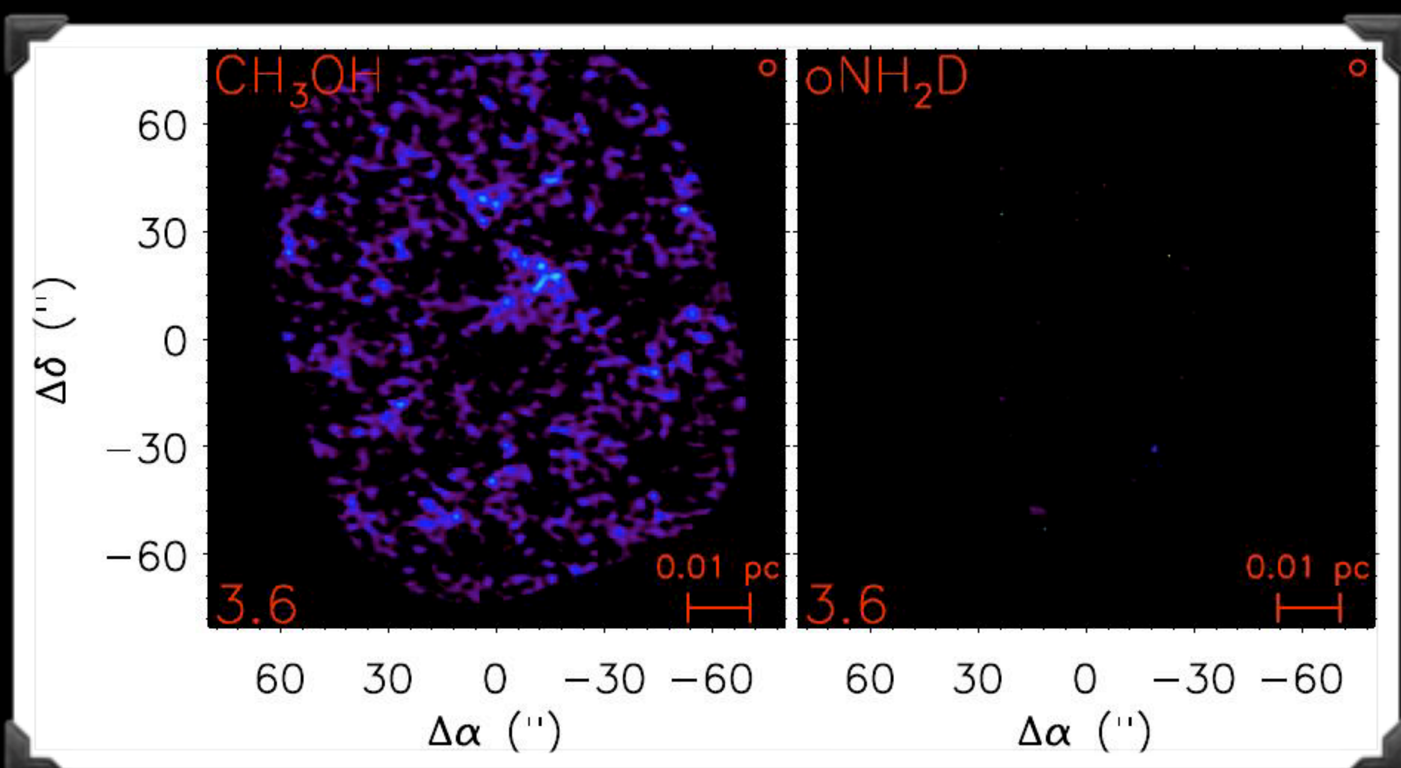


...see clearly "veil" of wind-blown methanol.

COMPARISON

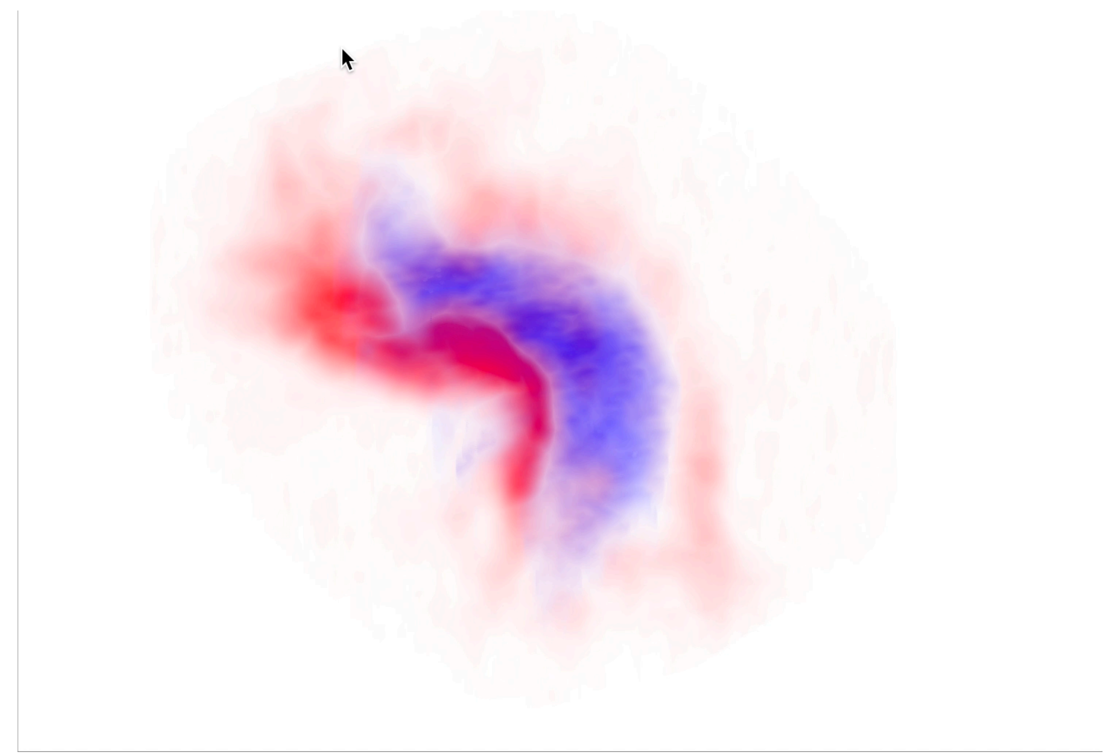
glue

traditional rainbow channel maps



result: happy unicorns

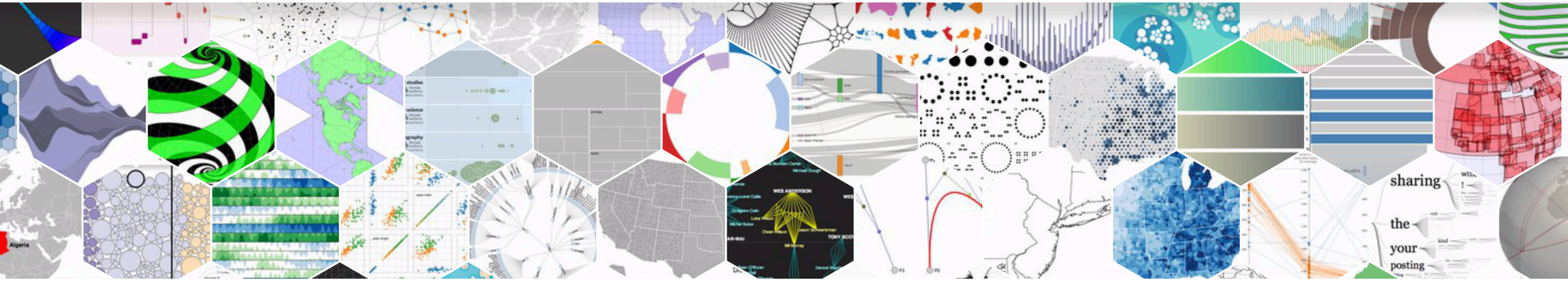
glue volume visualization



result: previously unknown phenomenon (veil of emission) revealed

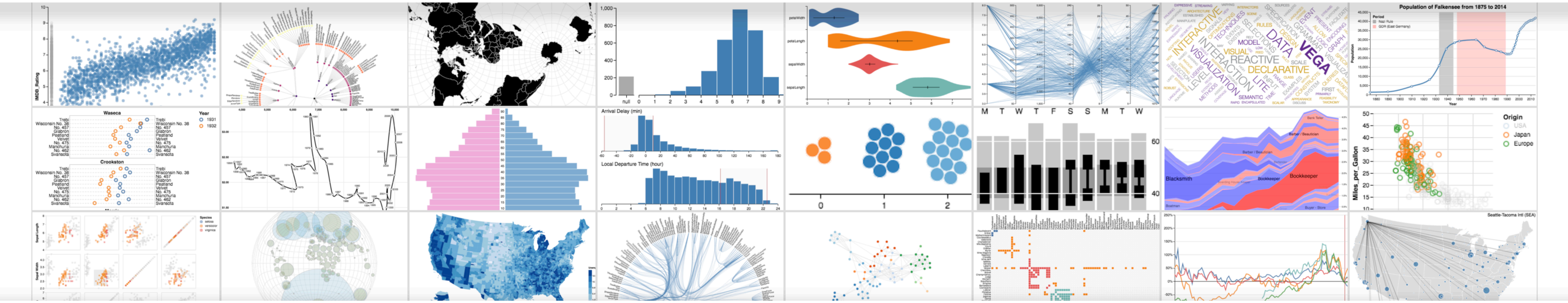
Data-Driven Documents

2011



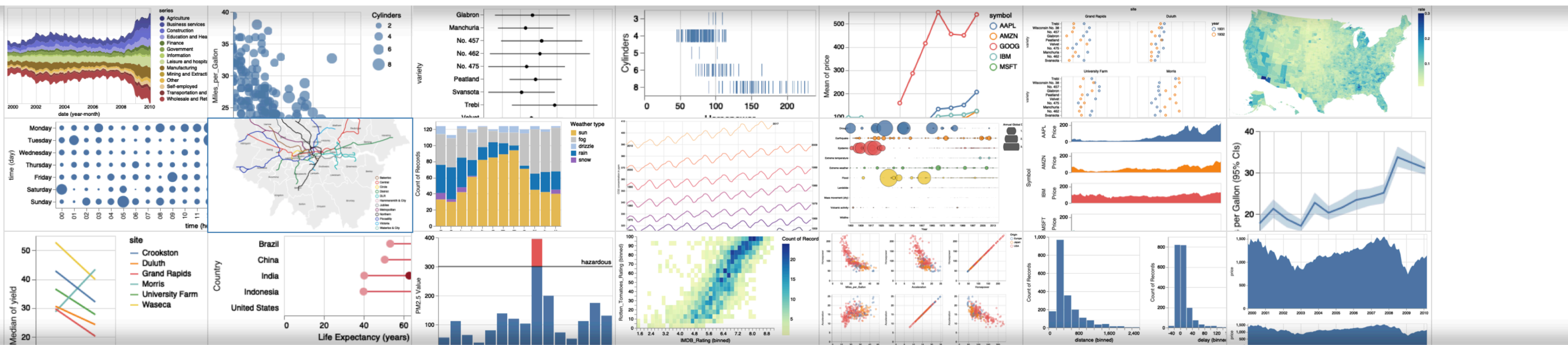
Vega – A Visualization Grammar

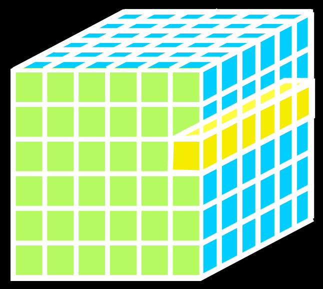
2014



Vega-Lite – A Grammar of Interactive Graphics

2017



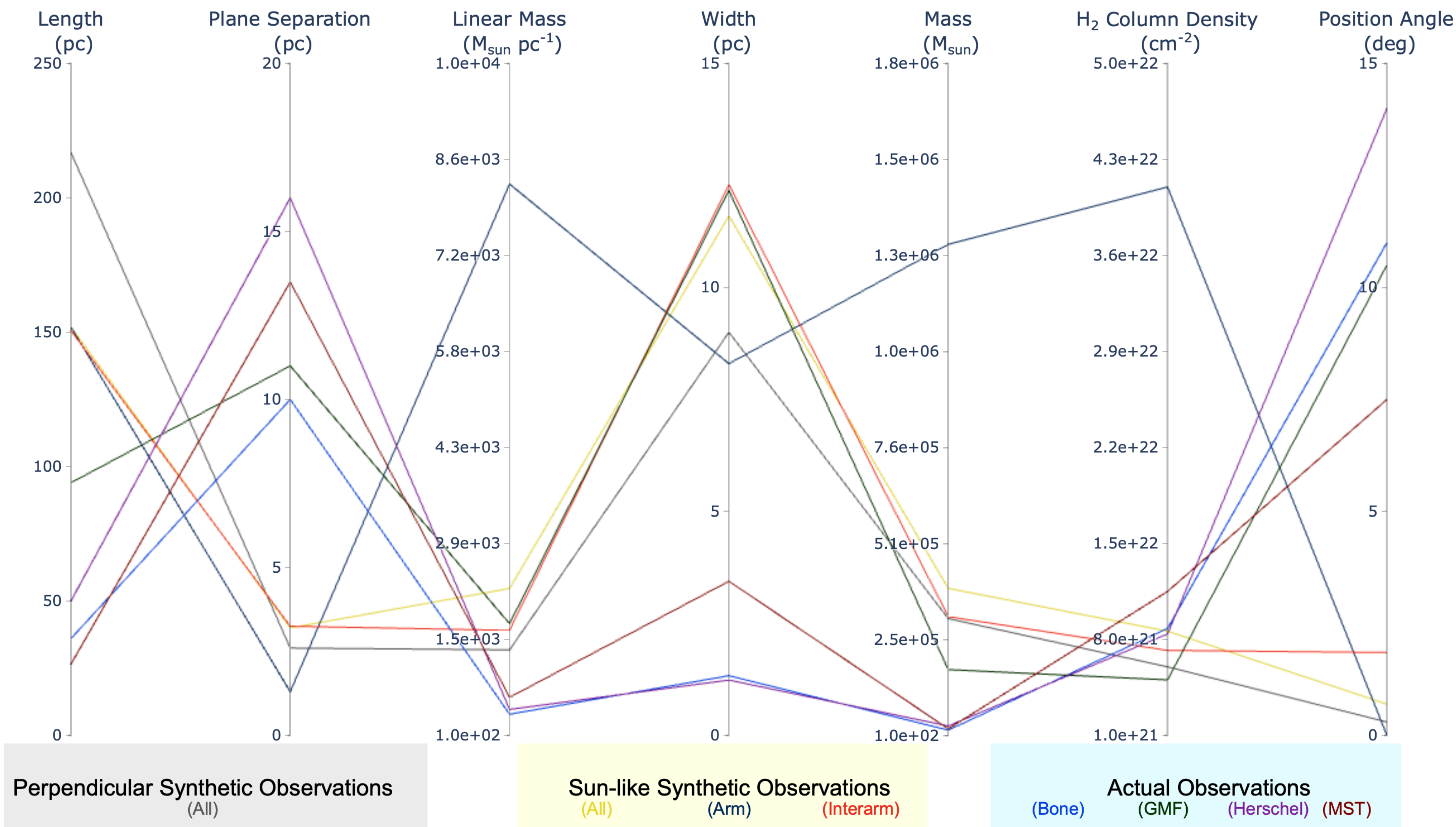


Data, Dimensions, Display

+Dissemination

"Figure 11 - While I appreciate the intention of this figure, it **does not aid in the understanding of the result**. The **main feature of parallel coordinate plots are the steep lines connecting adjacent axes, but these lines have no physical meaning.** Additionally, are these the mean values? What's the dynamic range? Your box and whisker diagrams already do a good job of making these comparisons."

2019



h thanks to our sponsors…