

SEEING MORE OF THE UNIVERSE

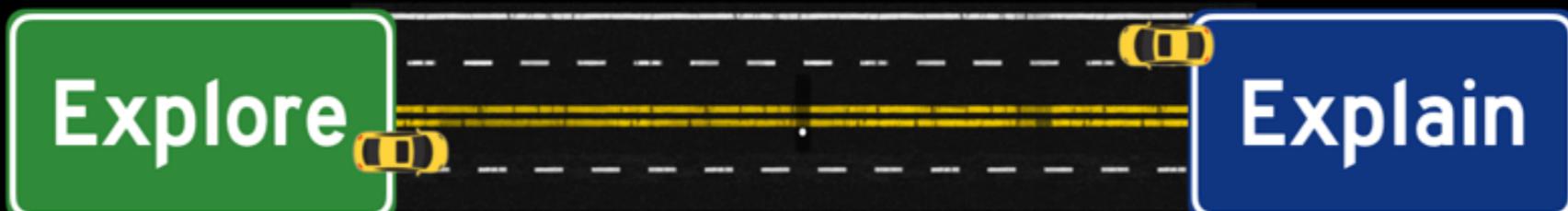
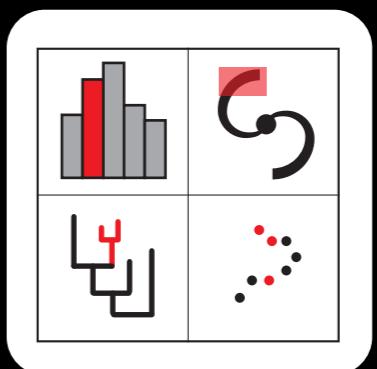
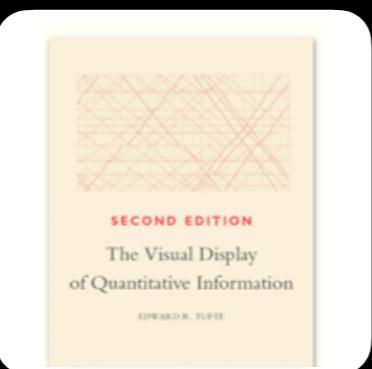
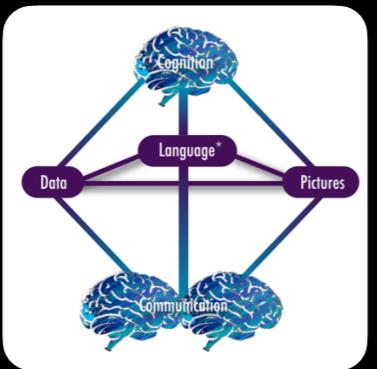
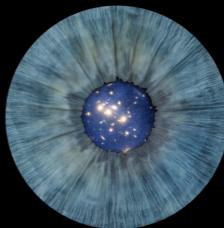


Explore

Explain

Alyssa A. Goodman
Harvard-Smithsonian Center for Astrophysics & Radcliffe Institute for Advanced Study

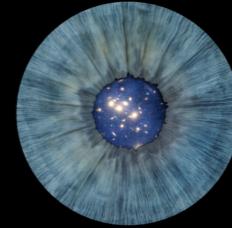
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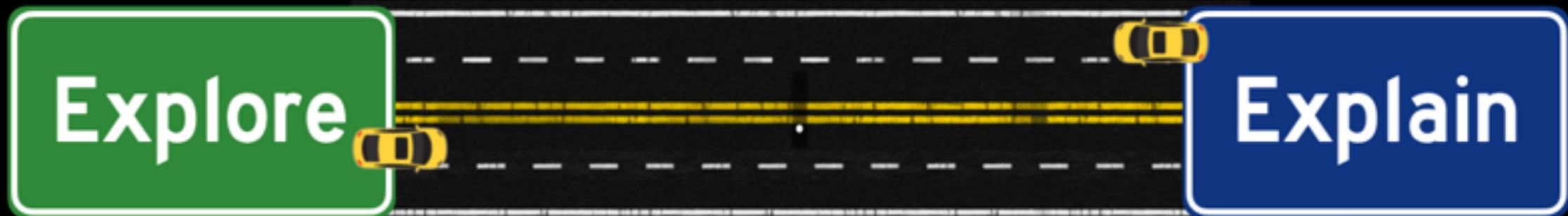
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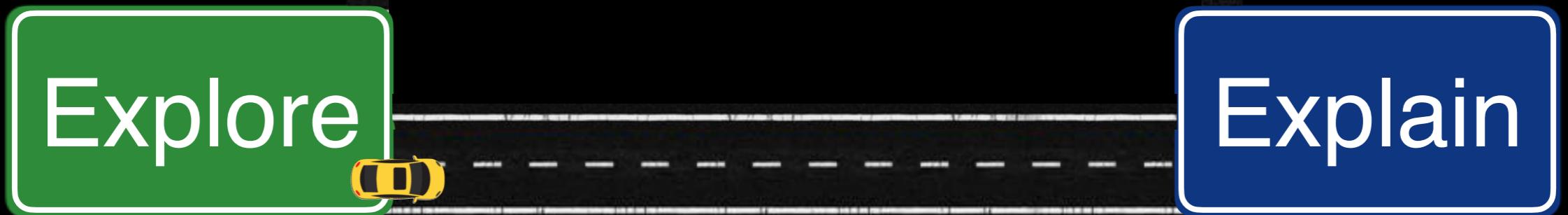


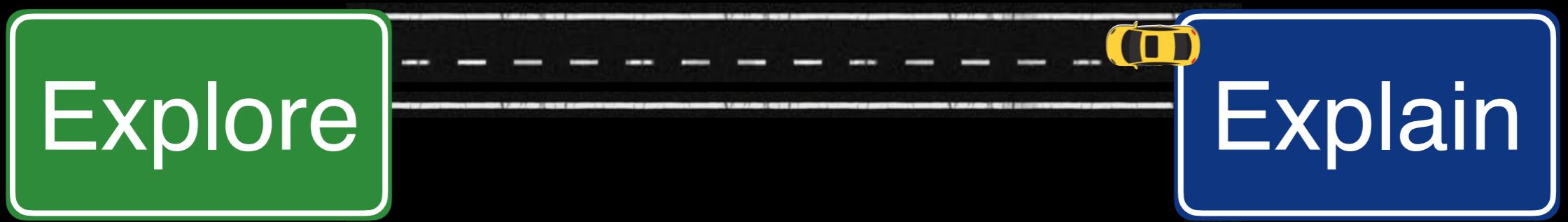
“THE ROAD FROM EXPLANATION TO EXPLORATION, AND BACK...”



Alyssa A. Goodman
Harvard-Smithsonian Center for Astrophysics & Radcliffe Institute
for Advanced Study

Traditionally, travel from exploration to explanation is called
“Scholarly Publishing” if its *dry*, and “Public Outreach,” if it’s
beautiful





Explore

Explain

It's much harder to go the other way.

Explor
And, the *best* roads are two-way.xplain

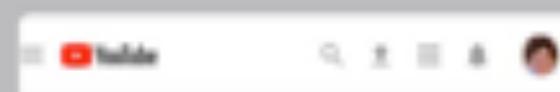


DATA,
CODE,
COLLABORATION

DATA-DRIVEN STORYTELLING



sl

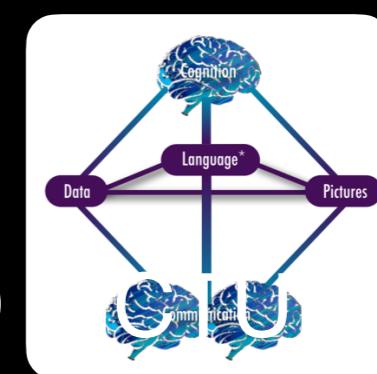


This is all possible, and happening now.

Not for everyone, though.

see “*New Thinking on, and with, Data Visualization*”
(Goodman, Borkin & Robitaille arxiv.org/abs/1805.11300)

Learn more in our next episode...
“CONNECTING DATA, LANGUAGE AND PICTURES”



collaborative
software
development

program
architecture



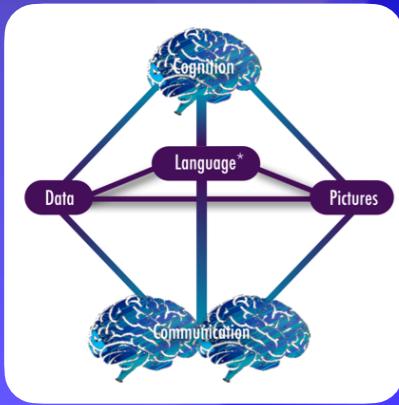
EXPLORATION



EXPLANATION



Want a fuller story? Try “The Road from Explanation to Exploration, and Back”



Alyssa Goodman

Harvard
Smithsonian Institution

AG's talk at the 2018
NAS Cybernetic Serendipity Coll
links below

The logo for the Arthur M. Sackler Colloquia of the National Academy of Sciences. It features a red stylized 'S' icon, the text "Arthur M. Sackler COLLOQUIA OF THE NATIONAL ACADEMY OF SCIENCES", and a small illustration of a bird's head next to a colorful abstract pattern.

Creativity and Collaboration: Revisiting Cybernetic Serendipity

This colloquium was held March 13-14 2018 in Washington, DC
Organized by Ben Shneiderman, Maneesh Agrawala, Alyssa Goodman, Youngmoo Kim, and Roger Malina

Our ambition is to redirect the history of ideas, restoring the Leonardo-like close linkage between art/design and science/engineering/medicine. We believe that internet-enabled collaborations can make more people more creative more of the time.

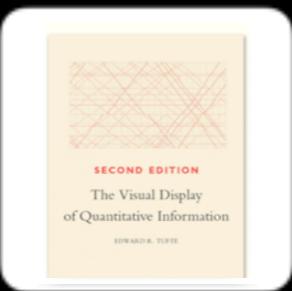
Slides & video: scholar.harvard.edu/agoodman/presentations/road-exploration-explanation-and-back
Just video: tinyurl.com/AGExploreExplain

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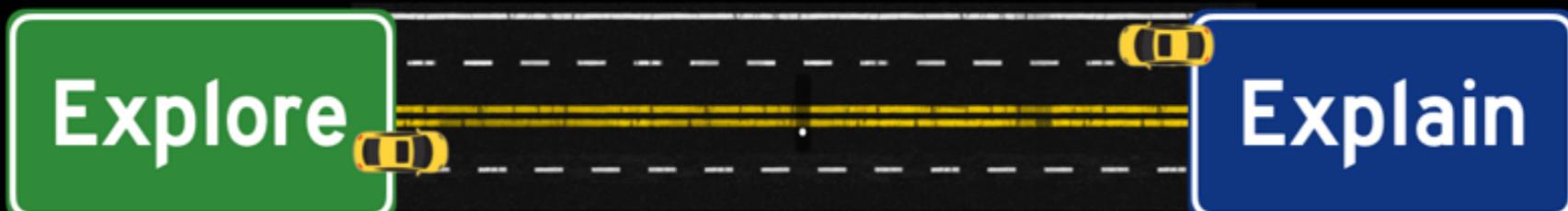
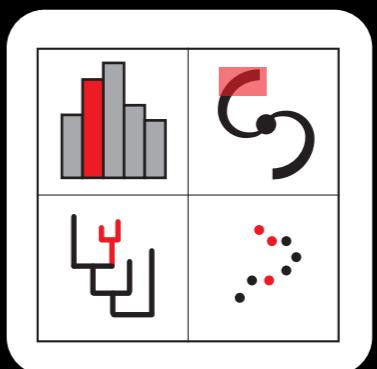
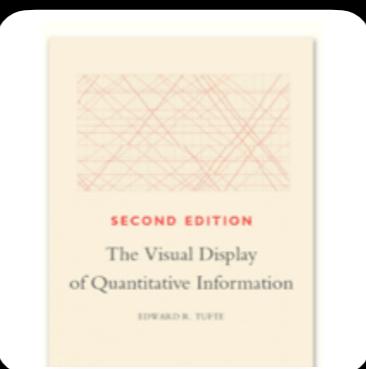
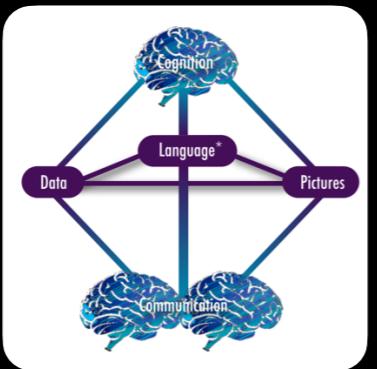
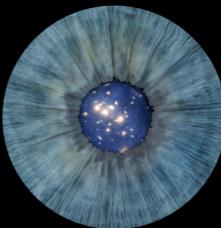
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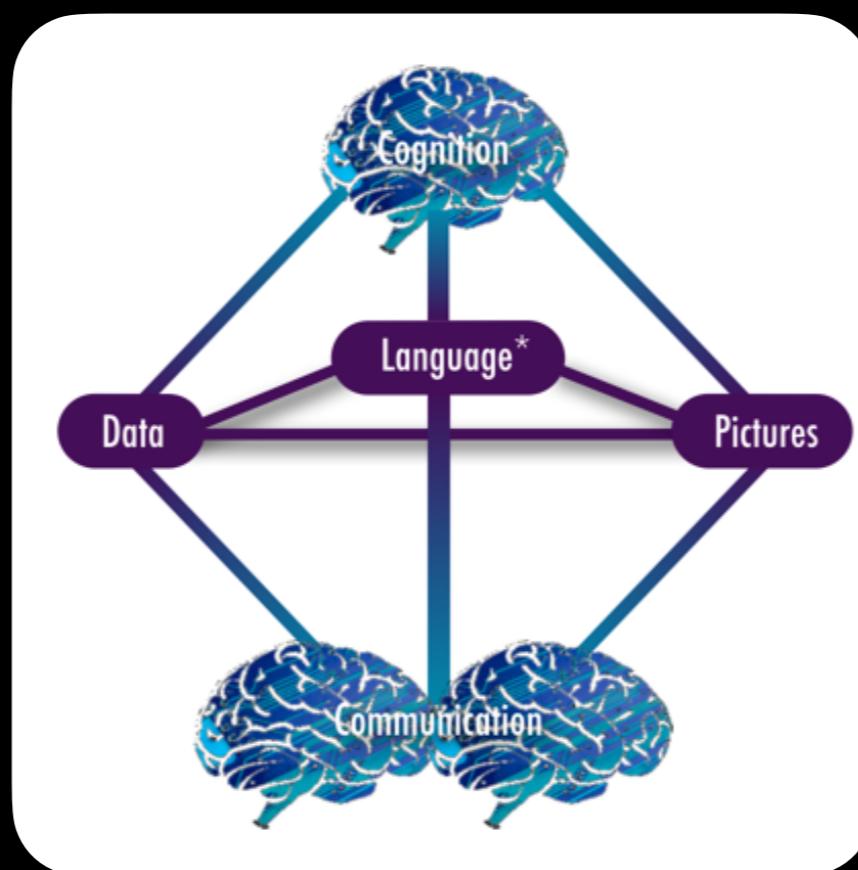
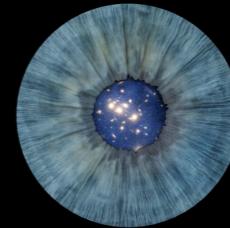


Alyssa A. Goodman

Harvard-Smithsonian Center for Astrophysics & Radcliffe Institute
for Advanced Study

SEEING MORE OF THE UNIVERSE

“CONNECTING DATA, LANGUAGE AND PICTURES”



Alyssa A. Goodman

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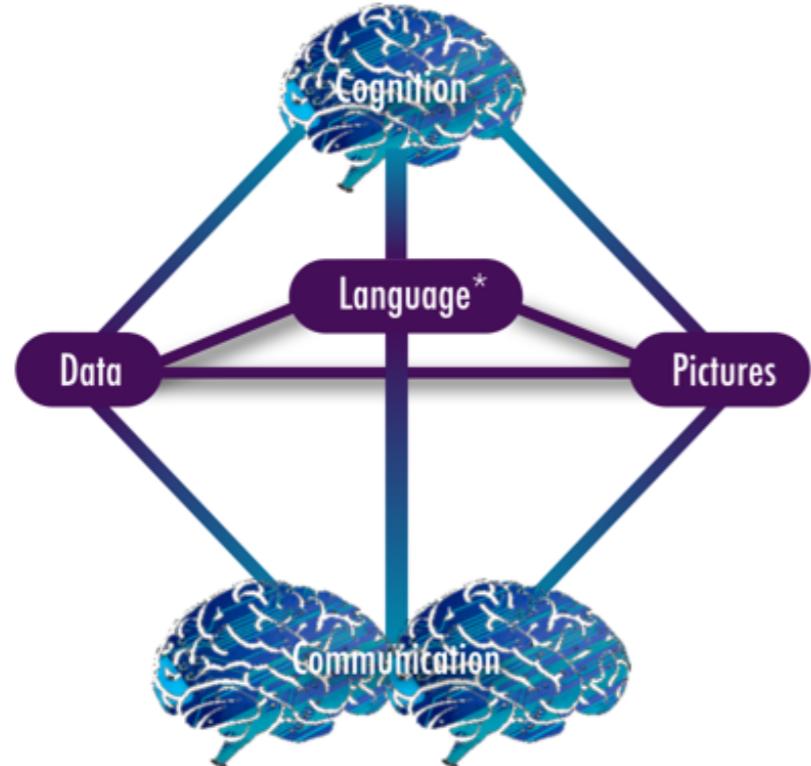
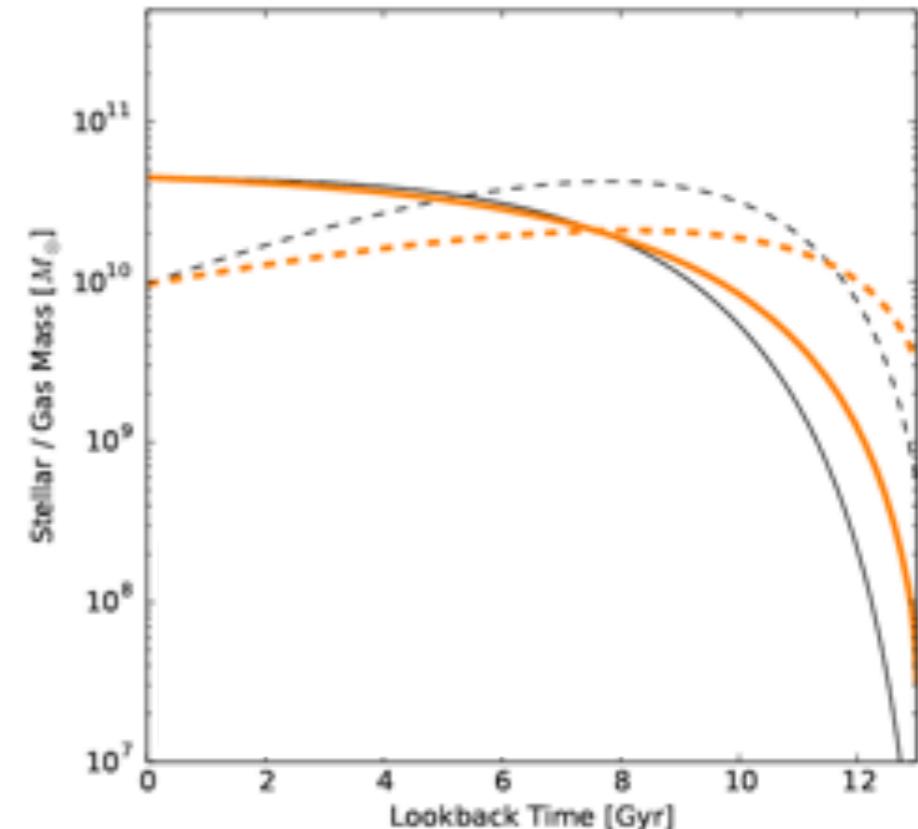
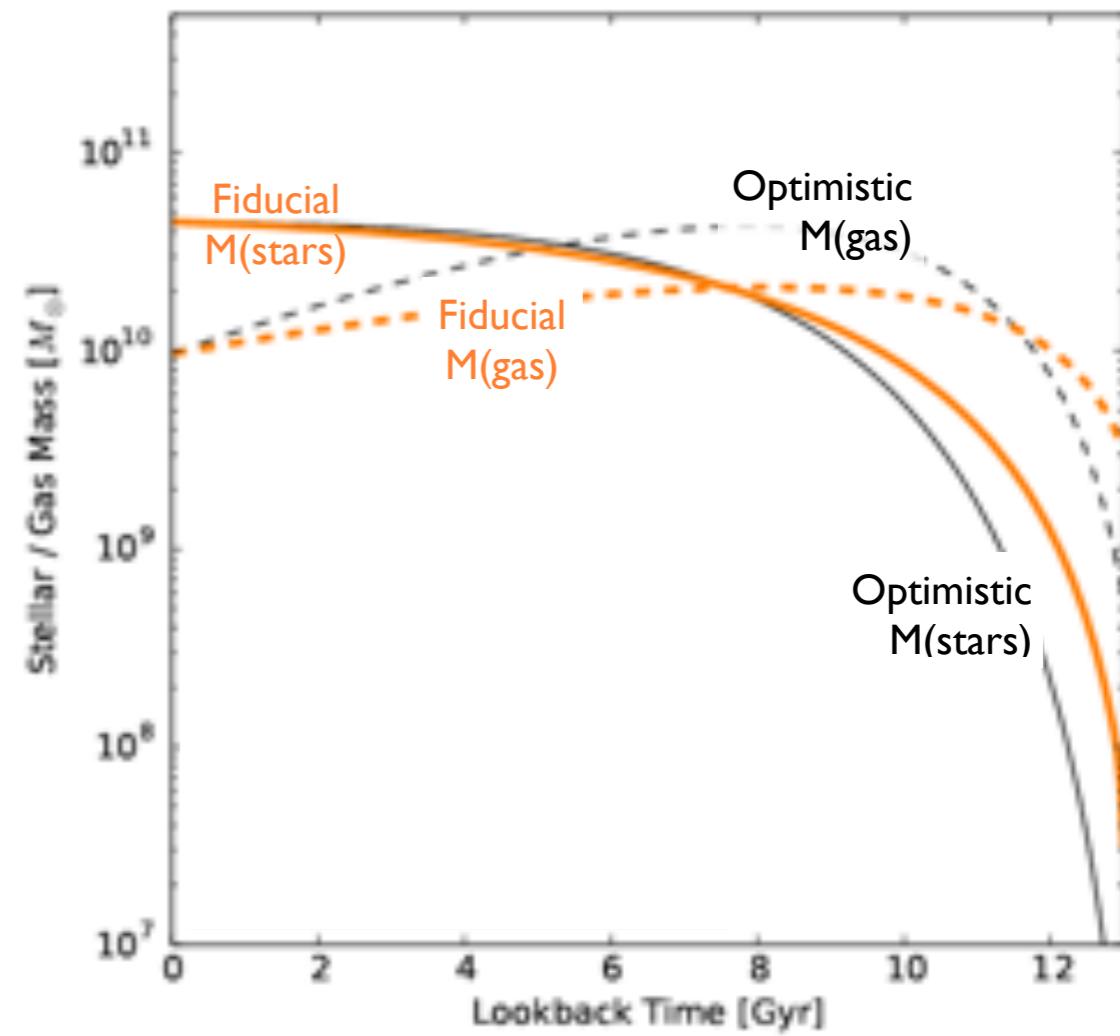
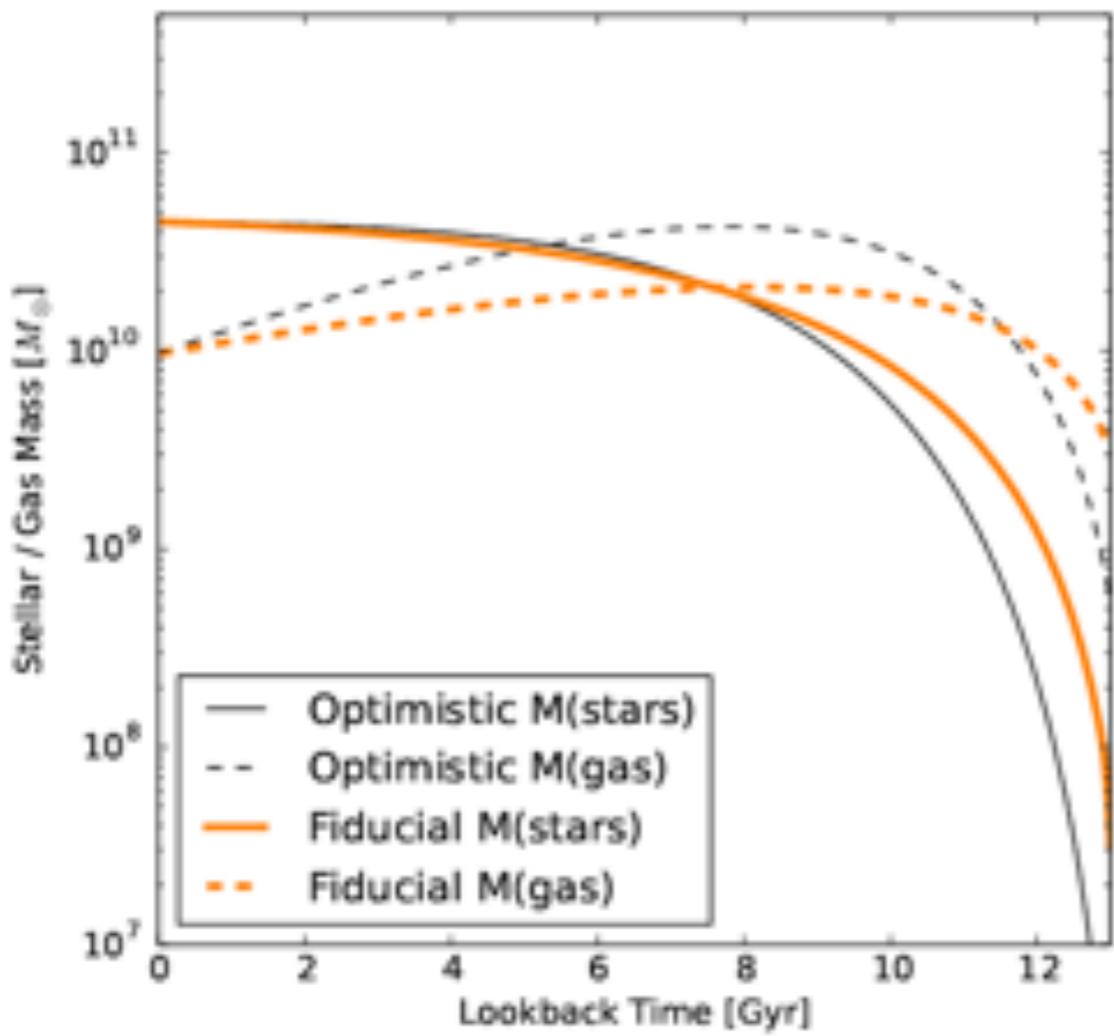
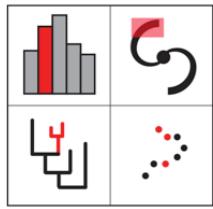


Figure Caption: The solid/solid black line shows the optimistic case for $M(\text{stars})/M(\text{gas})$. The orange lines show the same quantities, for the fiducial case.





glue
multidimensional data exploration

enabled by d3.js (javascript) outputs →



plotly

d3po

d3po is a project designed to allow an astronomer (or anyone) to build an interactive, publication-quality figure that has staged built-in interactivity. It can be previewed at d3po.org, and represents a figure from a paper that describes how metallicity affects color in cool stars, allowing users to drag in the scatter plots to understand the power of linear regression.

Right now we are in search of alpha testers, who have figured their hands a little dirty (No javascript skills needed). In future figures interactively. We are also exploring implementation of features expected in January 2014.

Installing your own d3po server

```
git clone git@github.com:adrn/d3po.git
cd d3po
virtualenv --no-site-packages venv
source venv/bin/activate
pip install -r pip-requirements.txt
python run.py
```



Four Centuries of Discovery A Chasm in Mass Little Siblings Close Cousins The Strangers

After Galileo discovered the first four moons of Jupiter, it took nearly three hundred years to discover the next one.

The "Paper" of the Future

Authorea preprint 02/21/2017 DOI: [10.22541/au.148769949.92783646](https://doi.org/10.22541/au.148769949.92783646)

Alyssa Goodman (Harvard University)
Josh Peek (Space Telescope Science Institute)
Alberto Accomazzi (Harvard-Smithsonian Center for Astrophysics (CFA))
Chris Beaumont (Harvard-Smithsonian Center for Astrophysics (CFA))
Christine L. Borgman (UCLA - University of California, Los Angeles)
Hope How-Huan Chen (Harvard University)
Merce Crosas (Harvard University)
Christopher Erdmann (North Carolina State University)
And 3 more...

Add Collaborator Manage

A 5-minute video demonstration 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 communicate 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.

Fig. 1
The Paper of the Future should include seamless linkages amongst data, pictures, and language, where "language" includes both words and math. When an individual attempts to understand each of these kinds of information, different cognitive functions are utilized: communication is inefficient if the channel is restricted primarily to language, without easy interconnection to data and pictures.

WATCH a DEMO video, and find S/W links on YouTube at tinyurl.com/PotF-Demo



tinyurl.com/PotF-Demo

many thanks to Alberto Pepe, Josh Peek, Chris Beaumont, Tom Robitaille, Adrian Price-Whelan, Elizabeth Newton, Michelle Borkin & Matteo Cantiello for making the PotF possible.

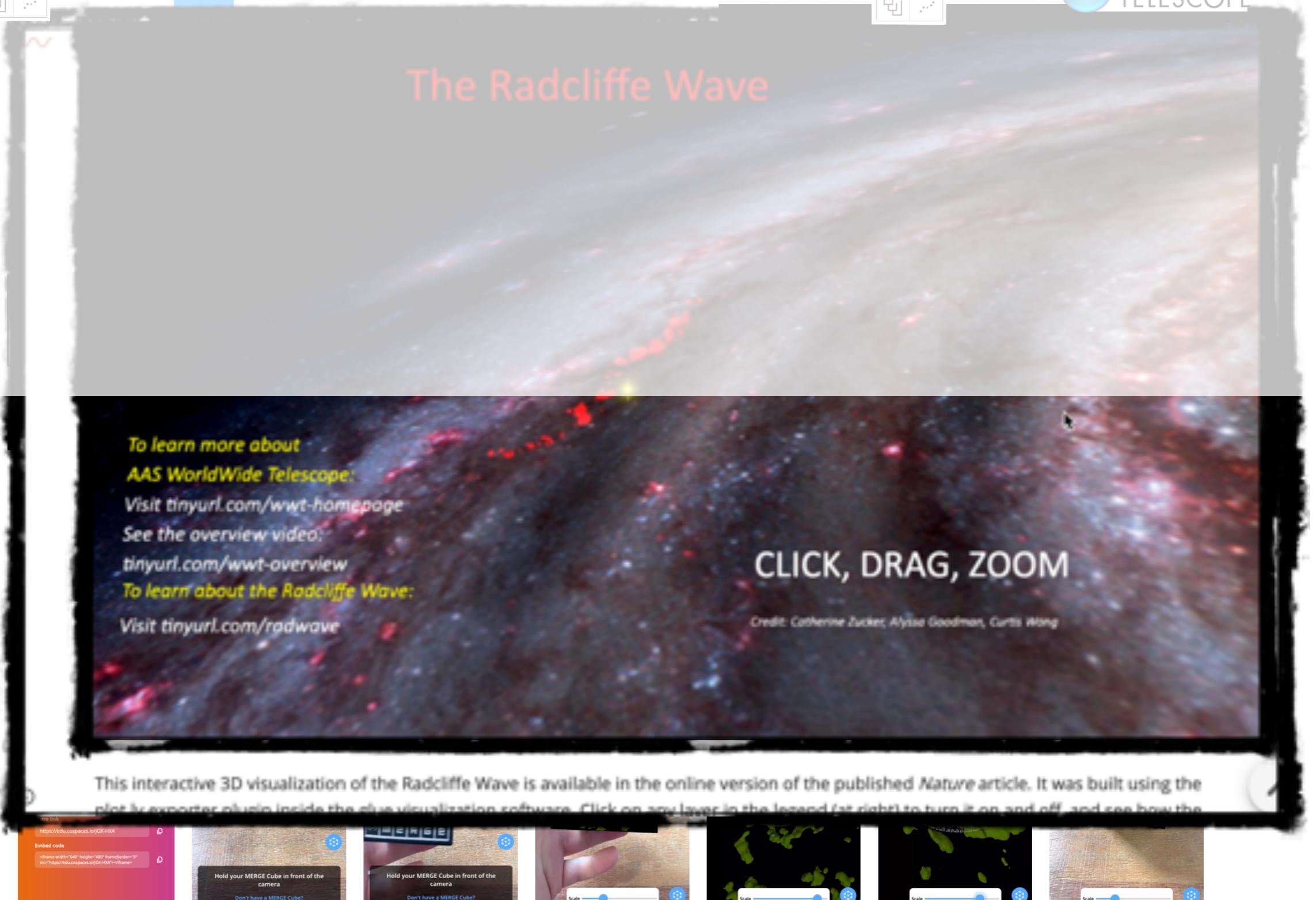
PUBLISHING'S INTERACTIVE CUTTING-EDGE & (AUGMENTED) FUTURE



**nature
PUBLISHED
IN NATURE
1-2020
ALVES ET
AL.
(THE RADCLIFFE
WAVE)**



AUGMENTED REALITY PROPOSED TO NSF 11-2020



This interactive 3D visualization of the Radcliffe Wave is available in the online version of the published *Nature* article. It was built using the plotly-express plugin inside the r3d visualization software. Click on any layer in the legend (at right) to turn it on and off, and see how the



a

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C

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f

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PUBLISHING'S INTERACTIVE CUTTING-EDGE & (AUGMENTED) JRE

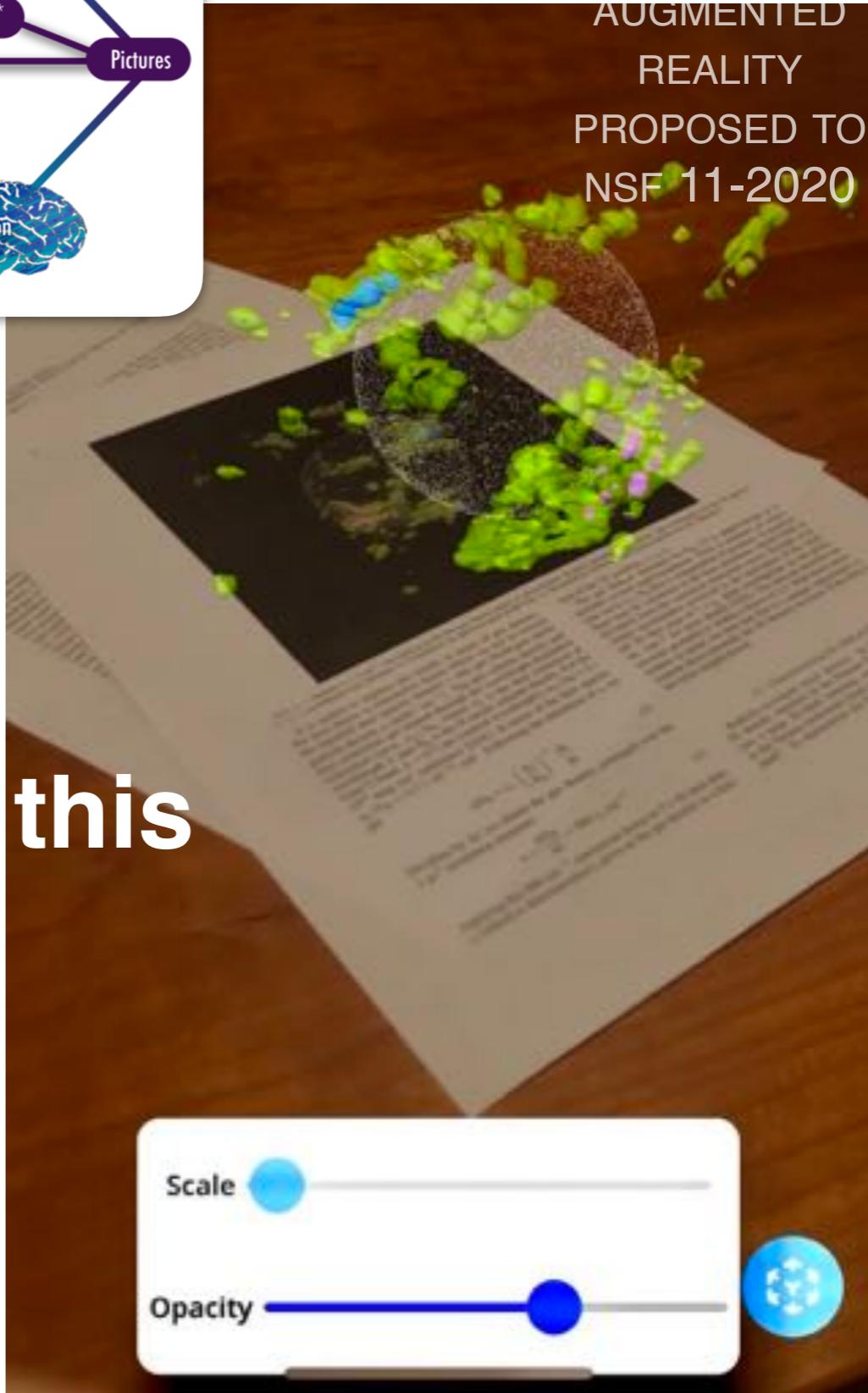
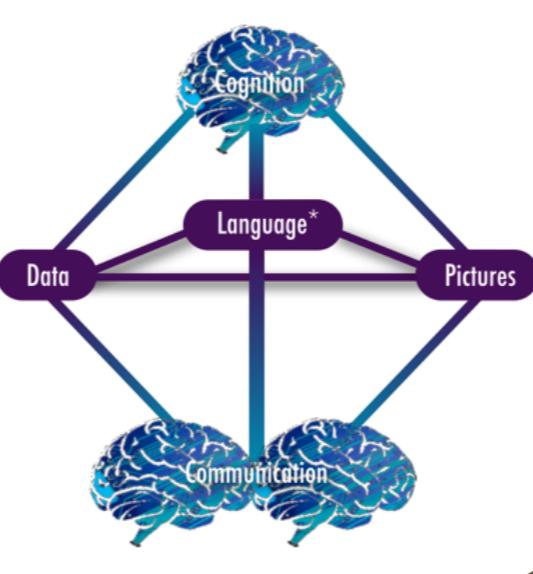
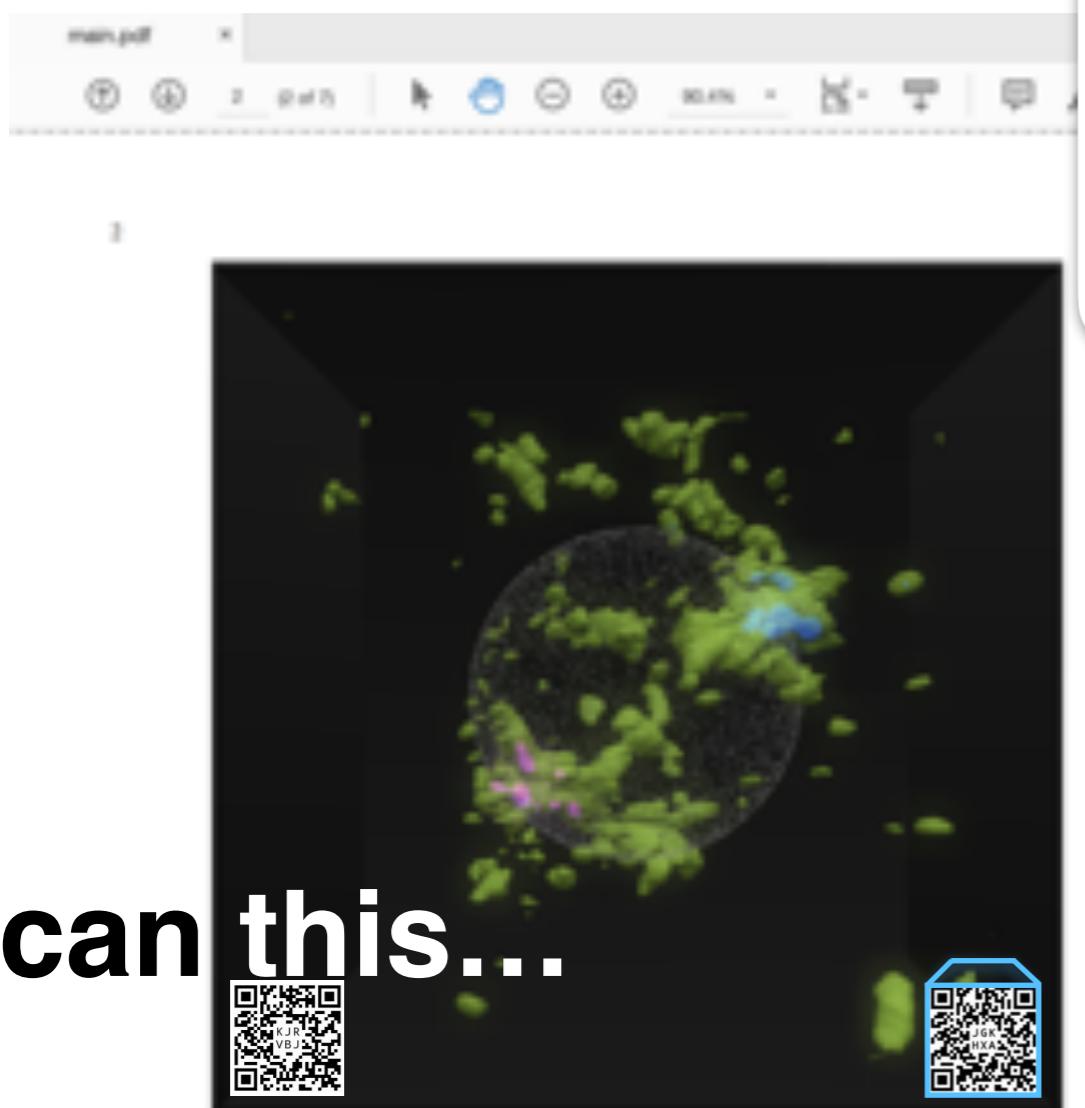


FIG. 1.— Density $\approx 7 \text{ cm}^{-3}$ gas surface in the Perseus-Taurus region as derived from 3D-dust extinction observations. The coordinates are the 100 pc line of sight $x-y-z$ axes and our location is enclosed in our spherical shell model (Fig. 6). The positions of Perseus and Taurus and the core are indicated.

It is useful to express the results in terms of gas density. We first derive a conversion factor which we use to convert the reported dust opacity density κ , into gas/Hydrogen nuclei particle density α (cm $^{-3}$): The gas-column density and dust extinction are related through the wavelength-dependent extinction curve, A_{λ}/N_H , where A_{λ} is the dust extinction at wavelength λ and N_H is the H nuclei column density. For the Gaia-L-band, $\lambda = 673$ nm (central wavelength), $A_{\lambda}/N_H = 4 \times 10^{17} \text{ mag cm}^2$ (reference XXX). In terms of the dust opacity $\kappa_0/N_H = 3.7 \times 10^{-10} \text{ cm}^2$. Following the definition of κ_0 we get

$$\Delta N_H = \kappa_0 \left(\frac{N_H}{\kappa_0} \right)^{-1} \frac{\Delta \kappa}{\kappa_0}. \quad (2)$$

(Dividing by $\Delta \kappa$, we obtain the gas-density averaged over the 1 pc^2 resolution element)

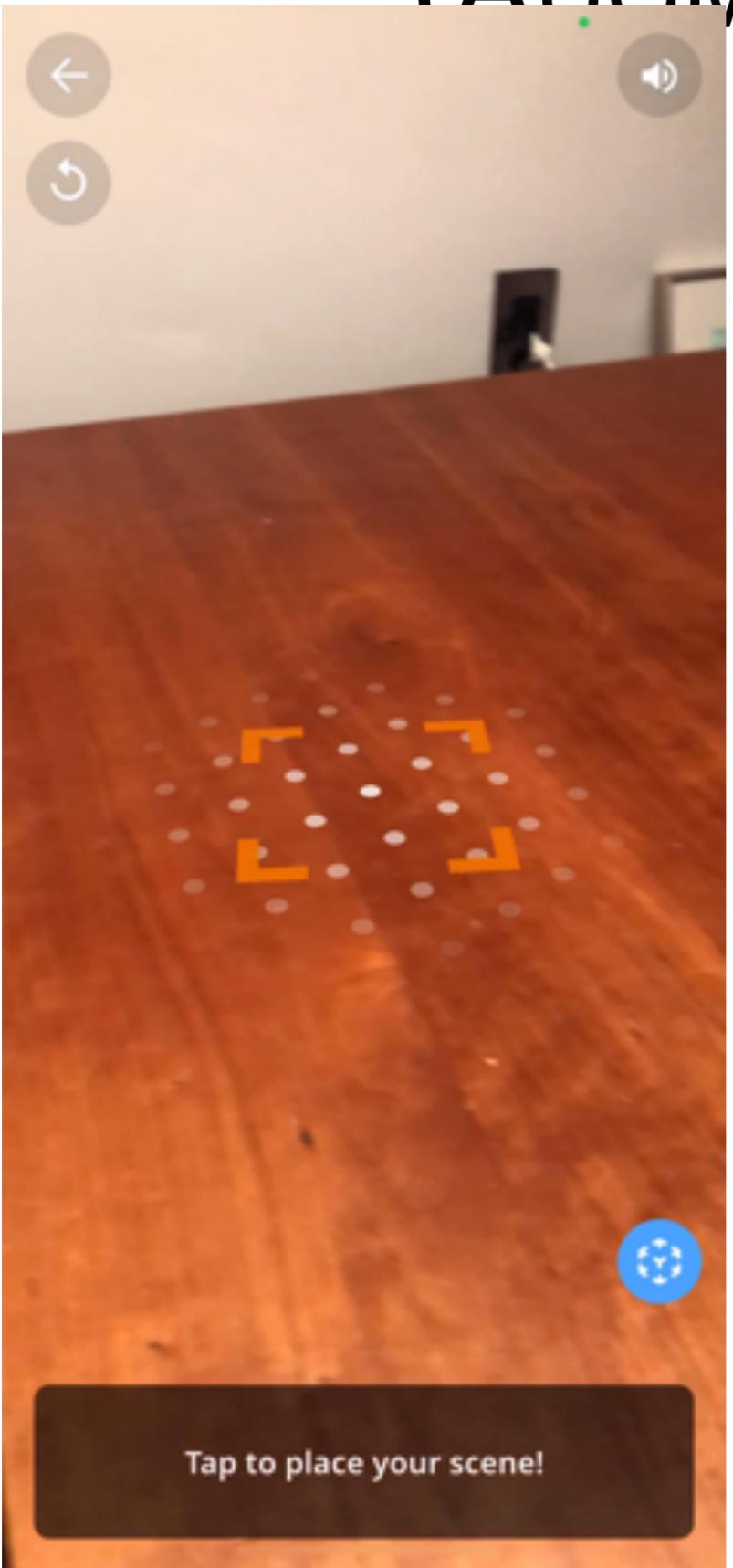
$$\alpha = \frac{\Delta N_H}{\Delta \kappa} = 100 \kappa_0 \text{ cm}^{-3}. \quad (3)$$

tion of the 3D position, (x,y,z) . The gas density obtained via Eq. (3) is approximate as it includes several approximations. First, it assumes an extinction curve A_{λ}/N_H that is independent of position. In practice, there may be variations in the dust properties which result in deviations from the canonical extinction curve. Second, it includes uncertainties involved in the derivation of the original 3D dust map of T, e.g., their assumptions on the priors, are case T (far more details XXX). The derived densities are accurate probably to within a factor of 2-3. With these uncertainties in mind, we note that this is a unique opportunity to explore observationally the 3D density structure of the ISM in the solar neighborhood.

3.3. Characterizing the shell profile

Radially averaged mean density: In §4 we explore the 3D density structure in the Perseus-Taurus region, and discuss a large 3D-shell structure, extending from the Taurus

PUBLISHING'S INTERACTIVE CUTTING-EDGE & (AUGMENTED) FUTURE



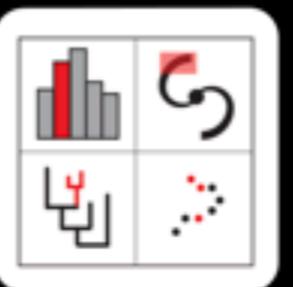
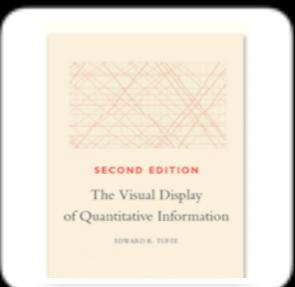
DEMO DATA WILL APPEAR IN BIALY ET AL. 2021, AR TECHNOLOGY WILL PREMIERE
IN ZUCKER ET AL. 2021

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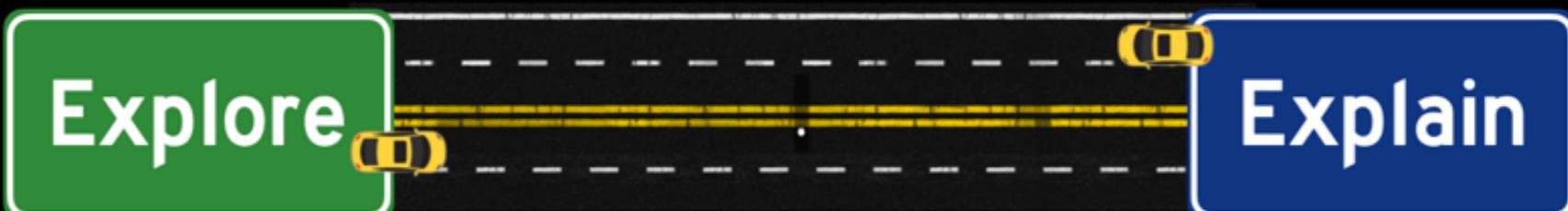
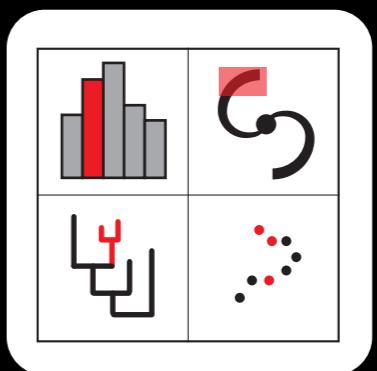
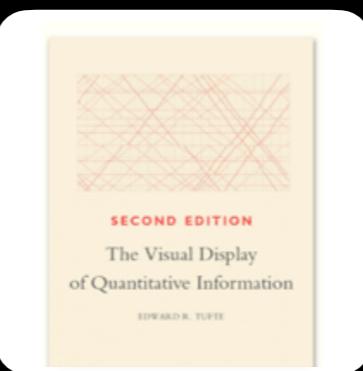
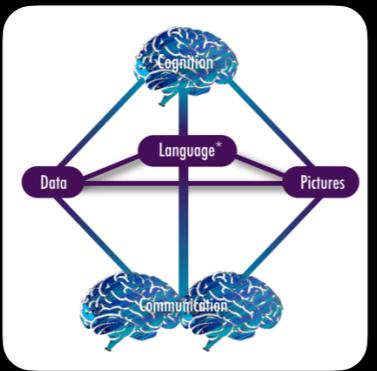
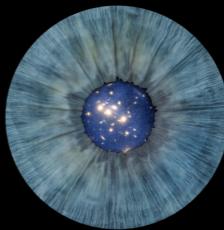
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Explore

Explain

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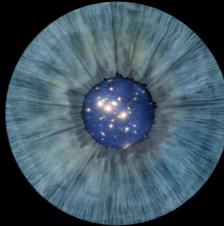


Alyssa A. Goodman

Harvard-Smithsonian Center for Astrophysics & Radcliffe Institute
for Advanced Study

SEEING MORE OF THE UNIVERSE

“TEN QUESTIONS TO ASK WHEN CREATING A VISUALIZATION”



Alyssa A. Goodman

Harvard-Smithsonian Center for Astrophysics & Radcliffe Institute
for Advanced Study



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 10Viz conversation! There's so much more to talk about.



Arzu Çöltekin
10Viz co-founder
(with Alyssa Goodman)

Curious about the **origins** of 10Viz? Try the [About](#) page.

Want to learn **how best to use** and **participate** in 10Viz? Try the [How to](#) page.

Want to read about the **scholarship** behind 10Viz.org's questions? Try [Coltekin & Goodman 2018](#).





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The 10 Questions

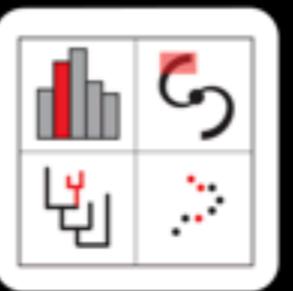
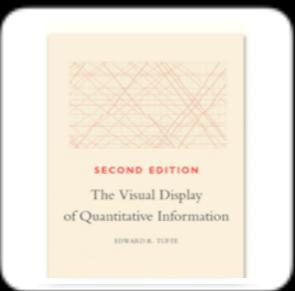
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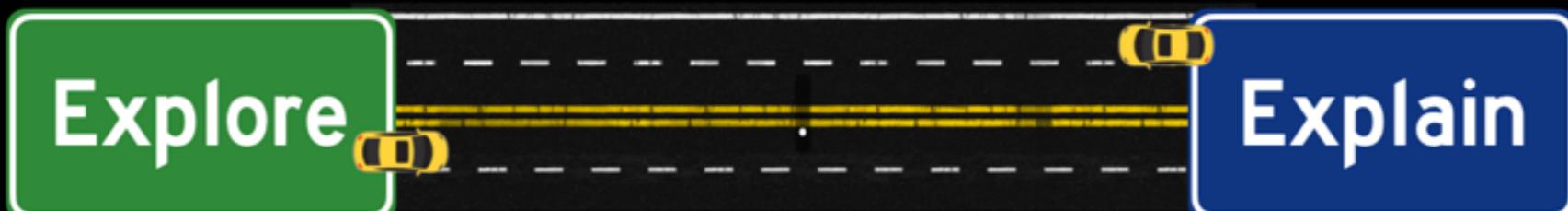
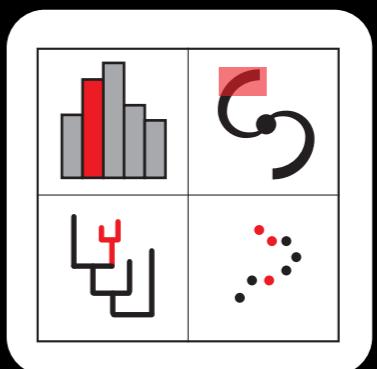
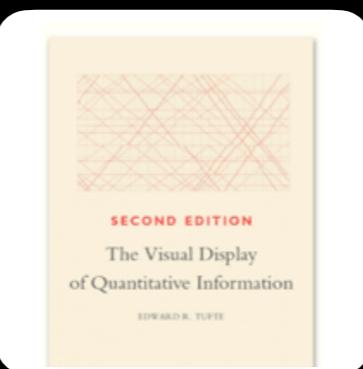
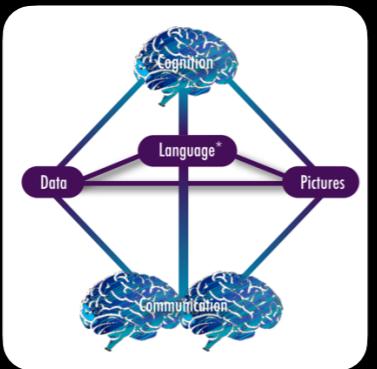
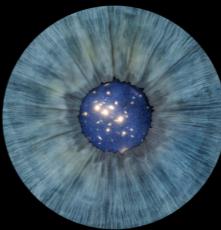
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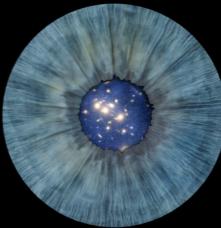
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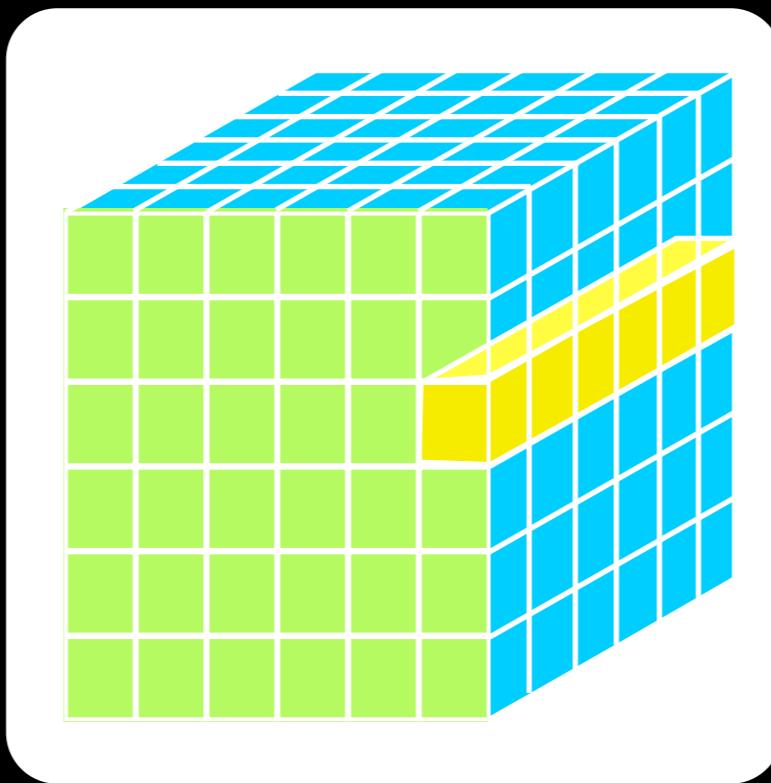
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SEEING MORE OF THE UNIVERSE



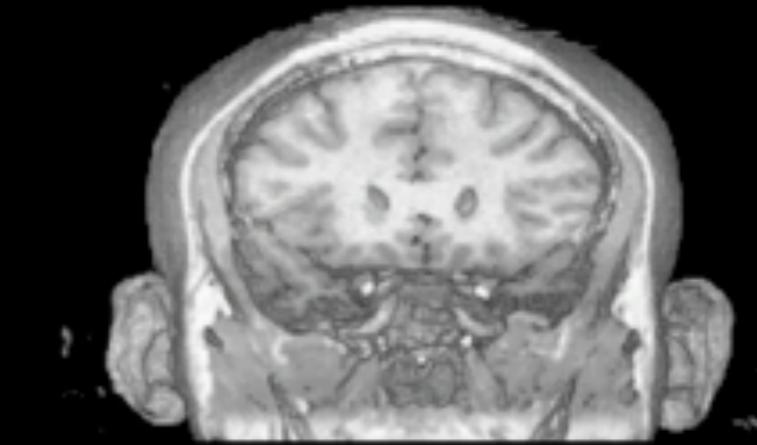
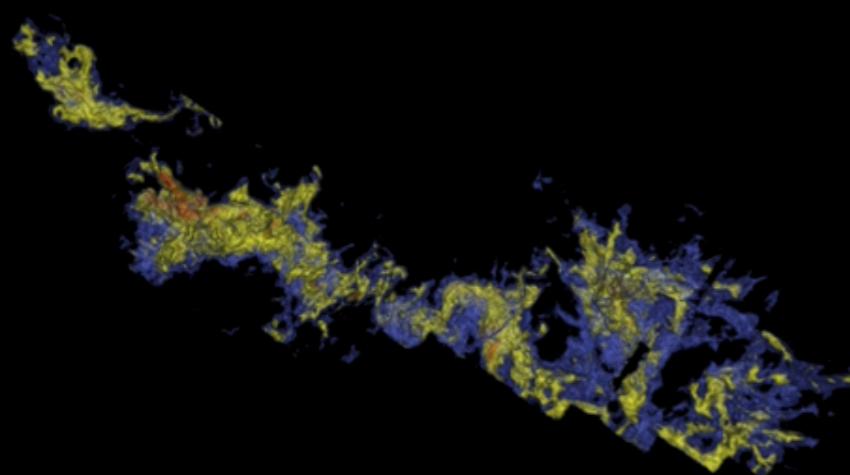
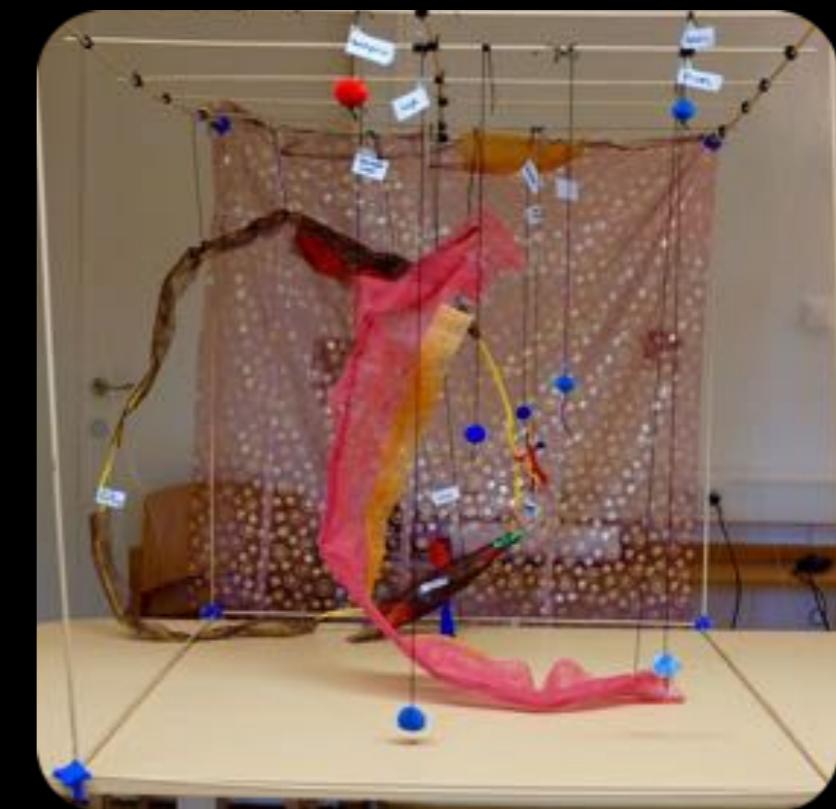
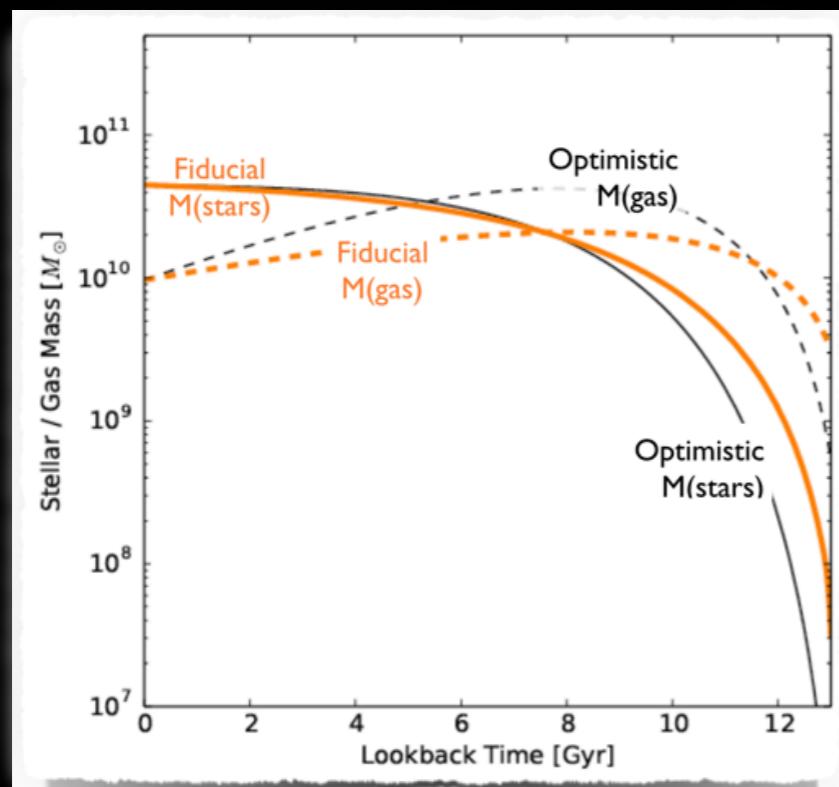
“DATA, DIMENSIONS, DISPLAY”



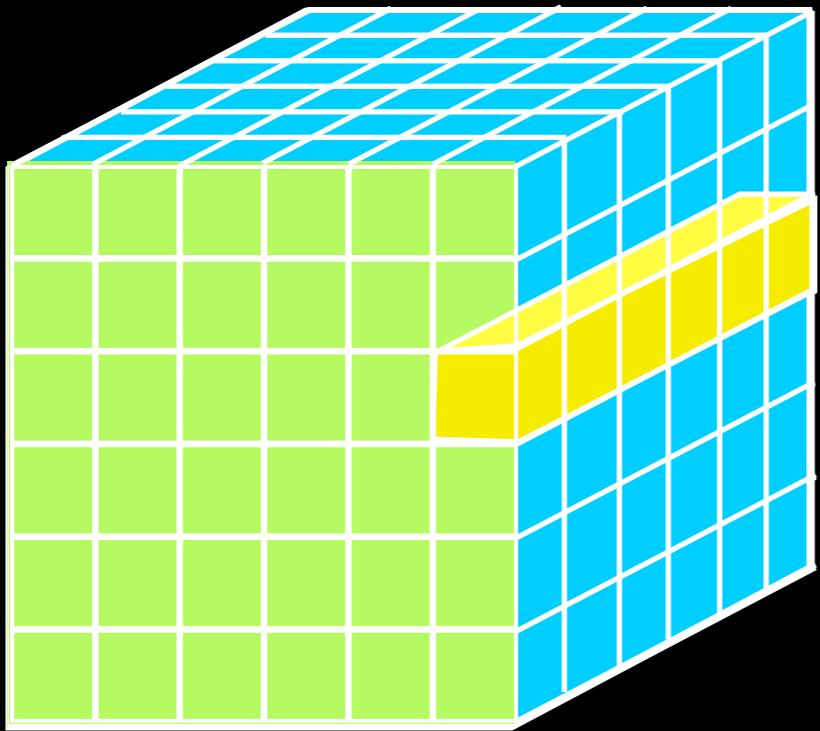
Alyssa A. Goodman

Harvard-Smithsonian Center for Astrophysics & Radcliffe Institute
for Advanced Study

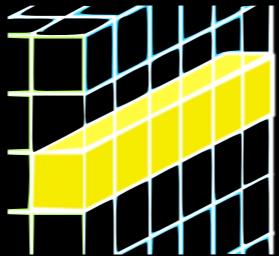
"DATA, DIMENSIONS, DISPLAY"



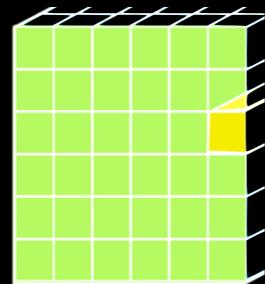
"DATA, DIMENSIONS, DISPLAY"



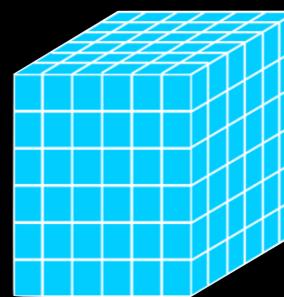
1D: Columns = "Graphs"



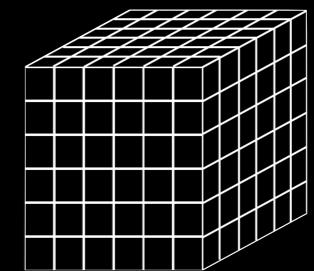
2D: Faces or Slices = "Images"



3D: Volumes = "3D Renderings", "2D Movies"



4D: Time Series of Volumes = "3D Movies"



"DATA, DIMENSIONS, DISPLAY"



Sky
Guided Tours Search Communities View Settings

Collection > Open Collections > [Berkeley Galaxy Zoo](#) >



Layers

- Overlay
 - Concentrations
 - Concentration Pictures
 - Concentration Images
 - Concentration Boundaries
 - Concentration Names
- Grid
 - Frequency Grid
 - Scale Grid
 - Angle Grid
 - Brightness
 - Position Chart
- 3D Sky
 - Moon Solar System
 - 3d Solar System
 - Milky Way (Dr. K. Hurt)
 - Dark Hyperspace (SAO)
 - Planets (NASA, CTAG)
 - Planetary Grids
 - Moon & Satellites (SAO)
 - Asteroids (GU MPO)

Image Classification

Facking [Berkeley Galaxy Zoo](#) 1 of 28

Period: 00:00:00



"DATA, DIMENSIONS, DISPLAY"



A screenshot of the AAT WorldWide Telescope software interface. The main window shows a dark star field with several bright stars and a prominent yellow/orange nebula. A large, rectangular inset in the center provides a detailed view of a cluster of stars. On the left, a 'Layers' panel is open, displaying a hierarchical tree of astronomical data layers such as Sky, Grids, and Solar System objects. At the bottom, there are several panels: 'Look In' showing image thumbnails, 'Image' showing a preview of the current view, 'Image Coordinate' showing coordinates, 'Tracking' showing a tracking bar, and 'Review' showing a small circular preview. A purple speech bubble icon containing the number '10' and the word 'Viz' is overlaid on the right side of the interface.

"DATA, DIMENSIONS, DISPLAY"



A screenshot of the A|A WorldWide Telescope software interface. The main window displays a 3D cube visualization of a star field, with a white grid overlay. The cube is positioned in the center of the screen, set against a dark background with numerous small stars. On the left side of the interface, there is a vertical "Layers" panel containing a hierarchical list of astronomical datasets. Some items are checked (indicated by a blue square icon). The list includes categories like "Sky", "Galaxy", "Galaxy Catalogs", "Galaxy Pictures", "Galaxy Images", "Galaxy Boundaries", "Galaxy Names", "Grids", "Fiducial Grid", "Solar Grid", "Mete Grid", "Antenn Grid", "Galaxy Distance", and "Proper Motion Chart". Other sections include "3D Sky", "Our Solar System", "3D Solar System", "Milky Way (Dr. K. Hunt)", "Dark Matter (SDSS)", "Planets (NASA, DTAG)", "Planetary Grids", "Moon & Satellites (SDSS)", and "Asteroids (SDSS/MPC)". At the bottom of the interface, there is a toolbar with various icons for navigating through images and a map view.

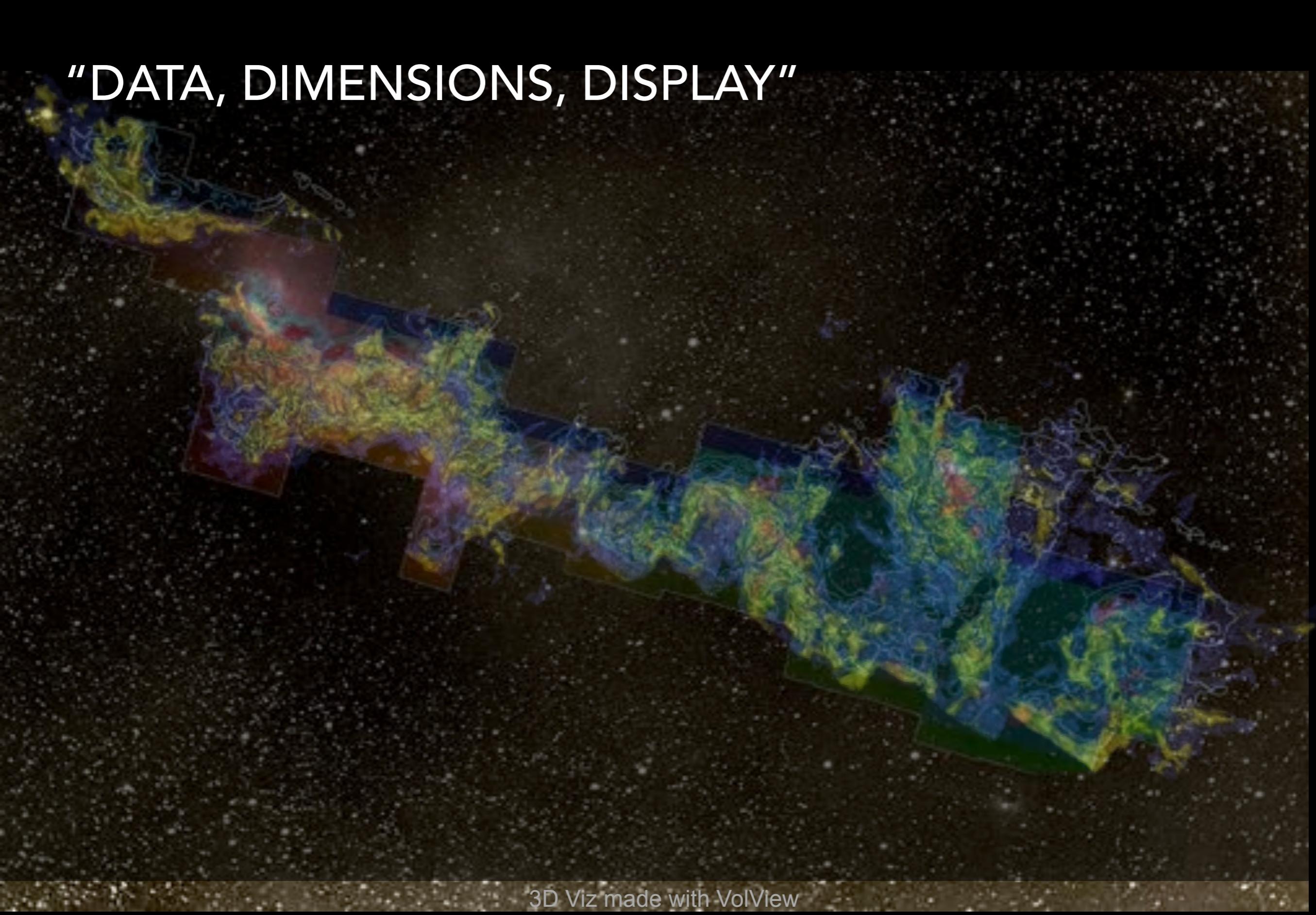
Image size: 520 x 274
View size: 1395 x 753
WL: 63 WW: 127

"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)

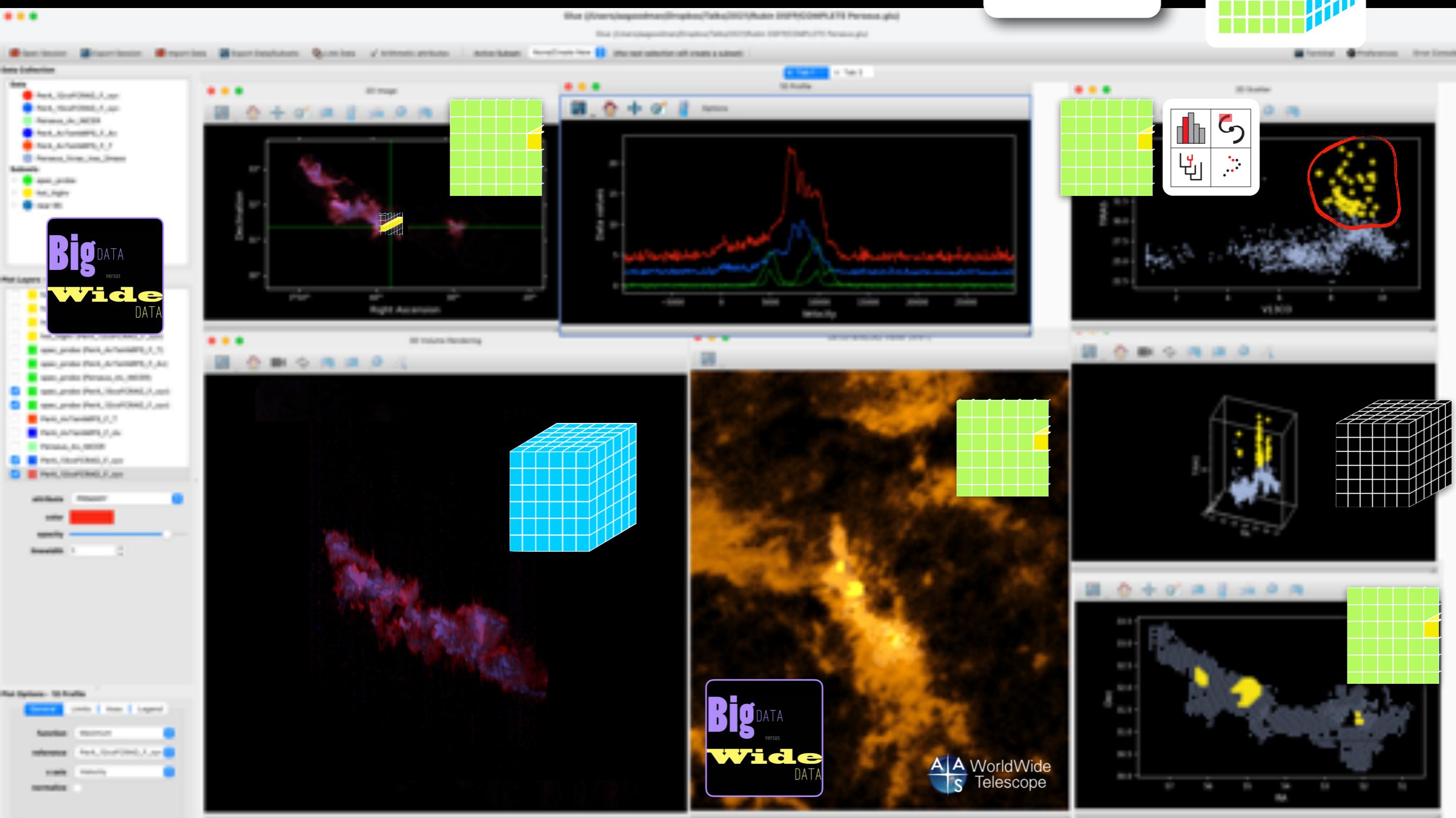
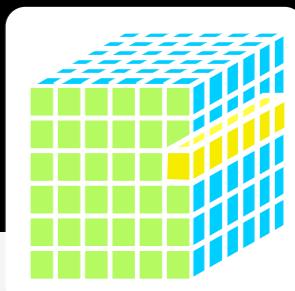


"DATA, DIMENSIONS, DISPLAY"



3D Viz made with VolView

"DATA, DIMENSIONS, DISPLAY" IN



COMPLETE

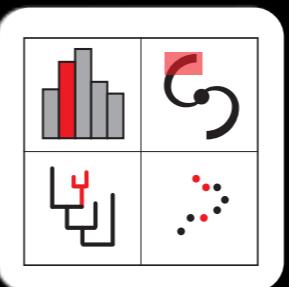
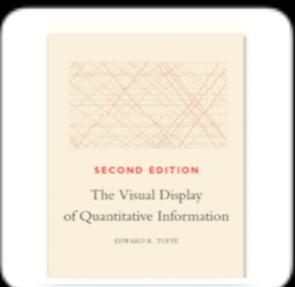
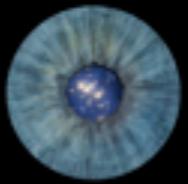
V. 2021—FULLY INTERACTIVE & TIED TO EVER-WIDER DATA VIA WWT SKY BROWSER

FIND THE
FULL
SERIES ON



TINYURL.C
OM/
10QVizVID
EOS

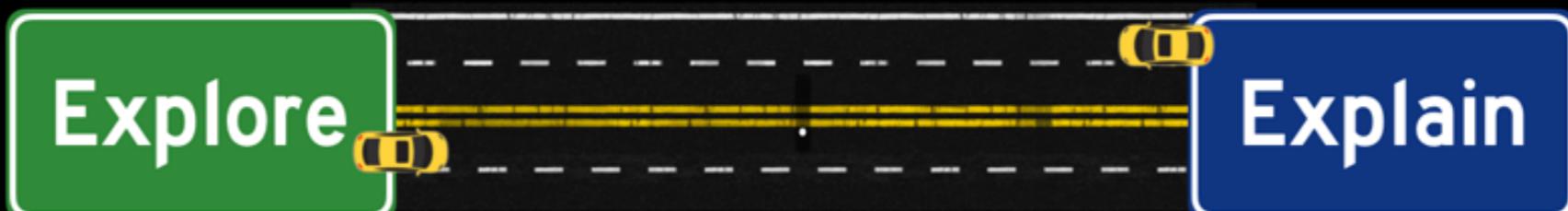
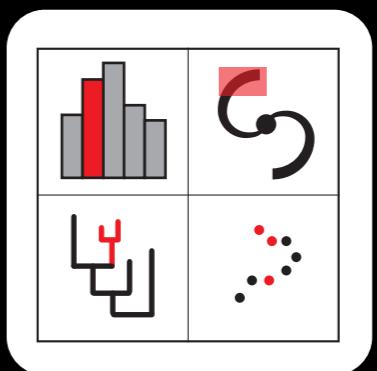
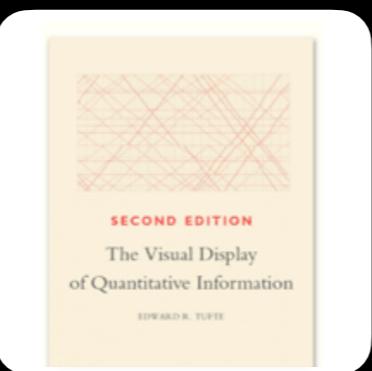
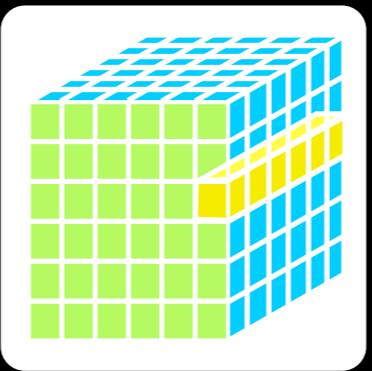
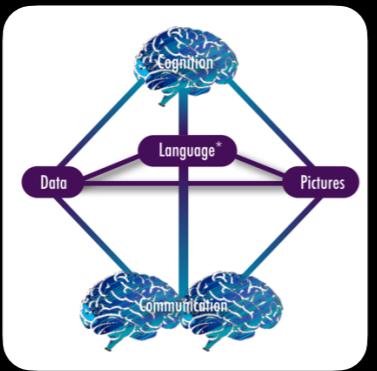
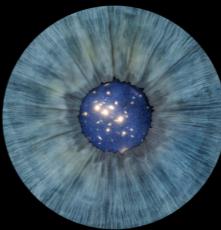
SEEING MORE OF THE UNIVERSE



Explore

Explain

SEEING MORE OF THE UNIVERSE

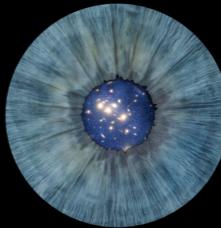


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SEEING MORE OF THE UNIVERSE

“BIG DATA VS. WIDE DATA”



Alyssa A. Goodman

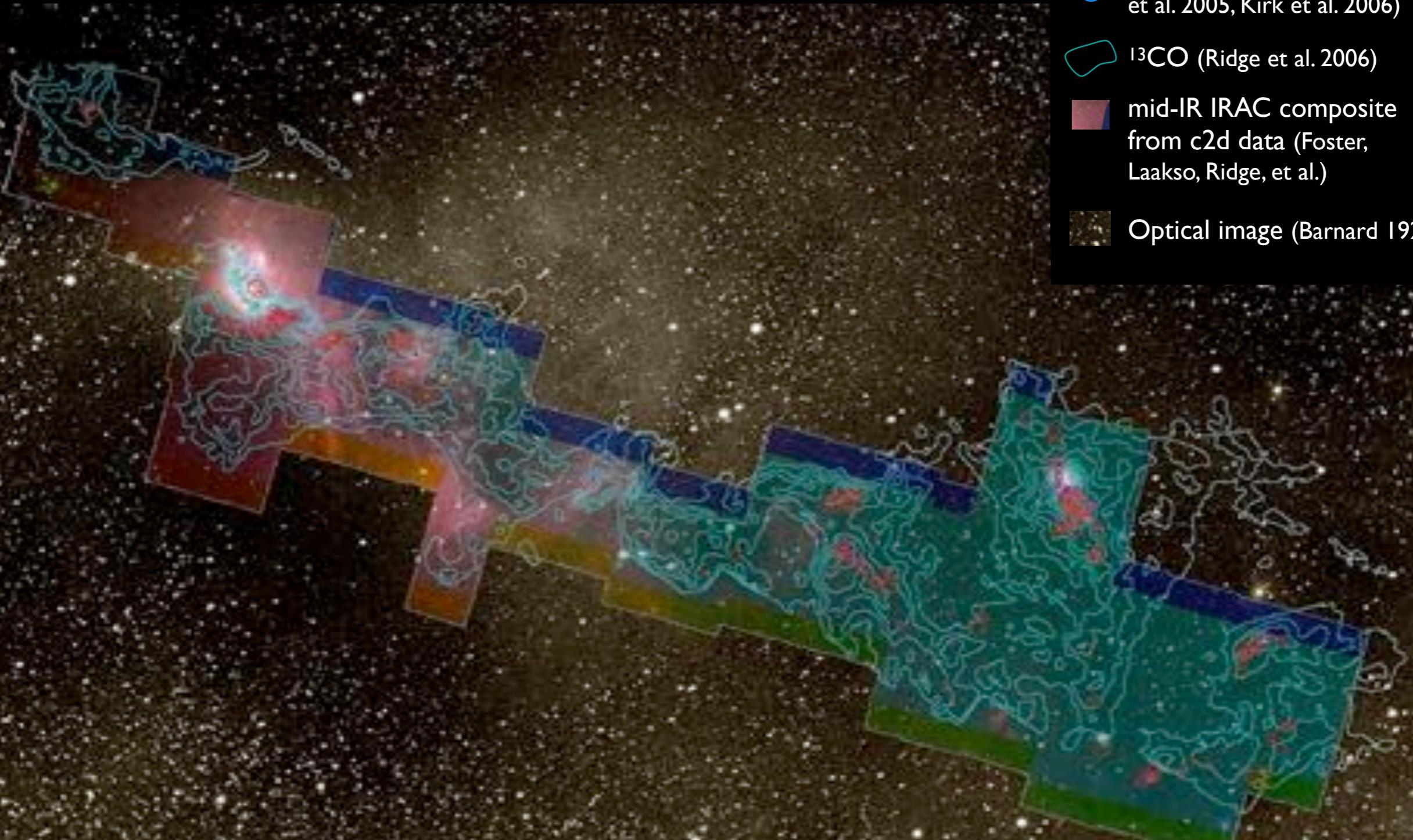
Harvard-Smithsonian Center for Astrophysics & Radcliffe Institute
for Advanced Study

WIDE DATA

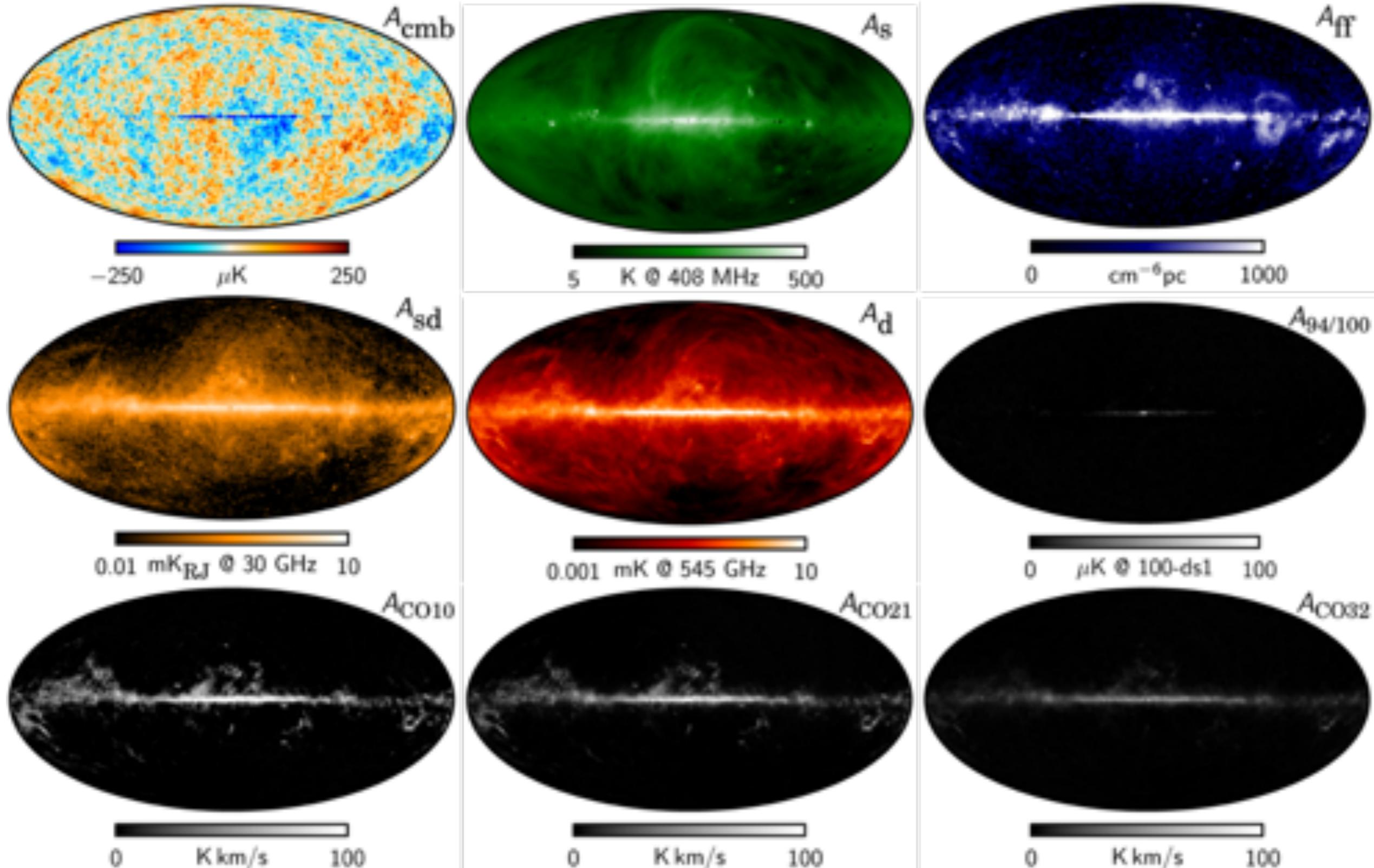


COMPLETE

- 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)



WIDE DATA



Temperature Foreground amplitudes from Commander, Planck Data [Feb 2015]

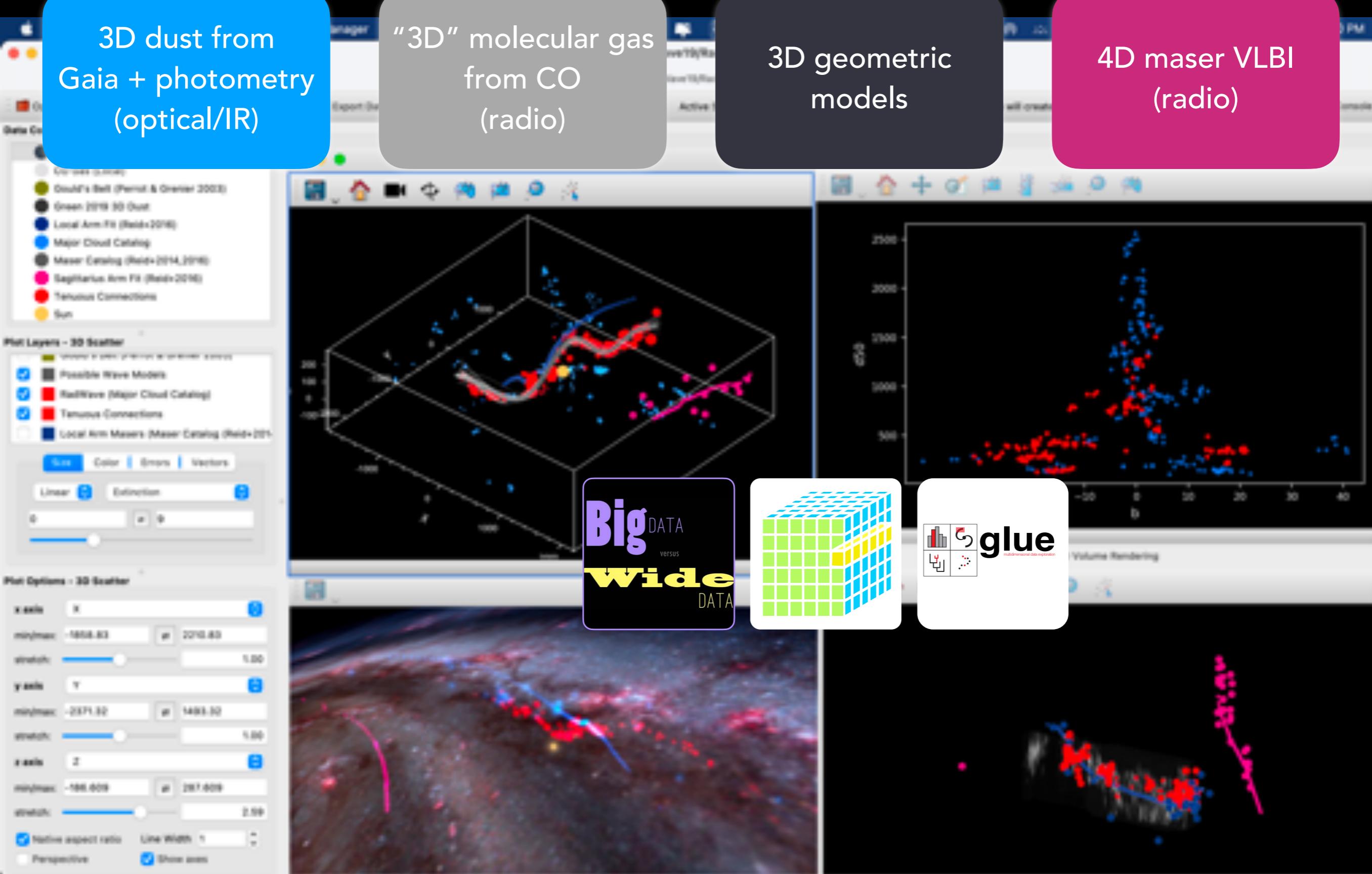
WIDE DATA DISCOVERY: THE RADCLIFFE WAVE

3D dust from
Gaia + photometry
(optical/IR)

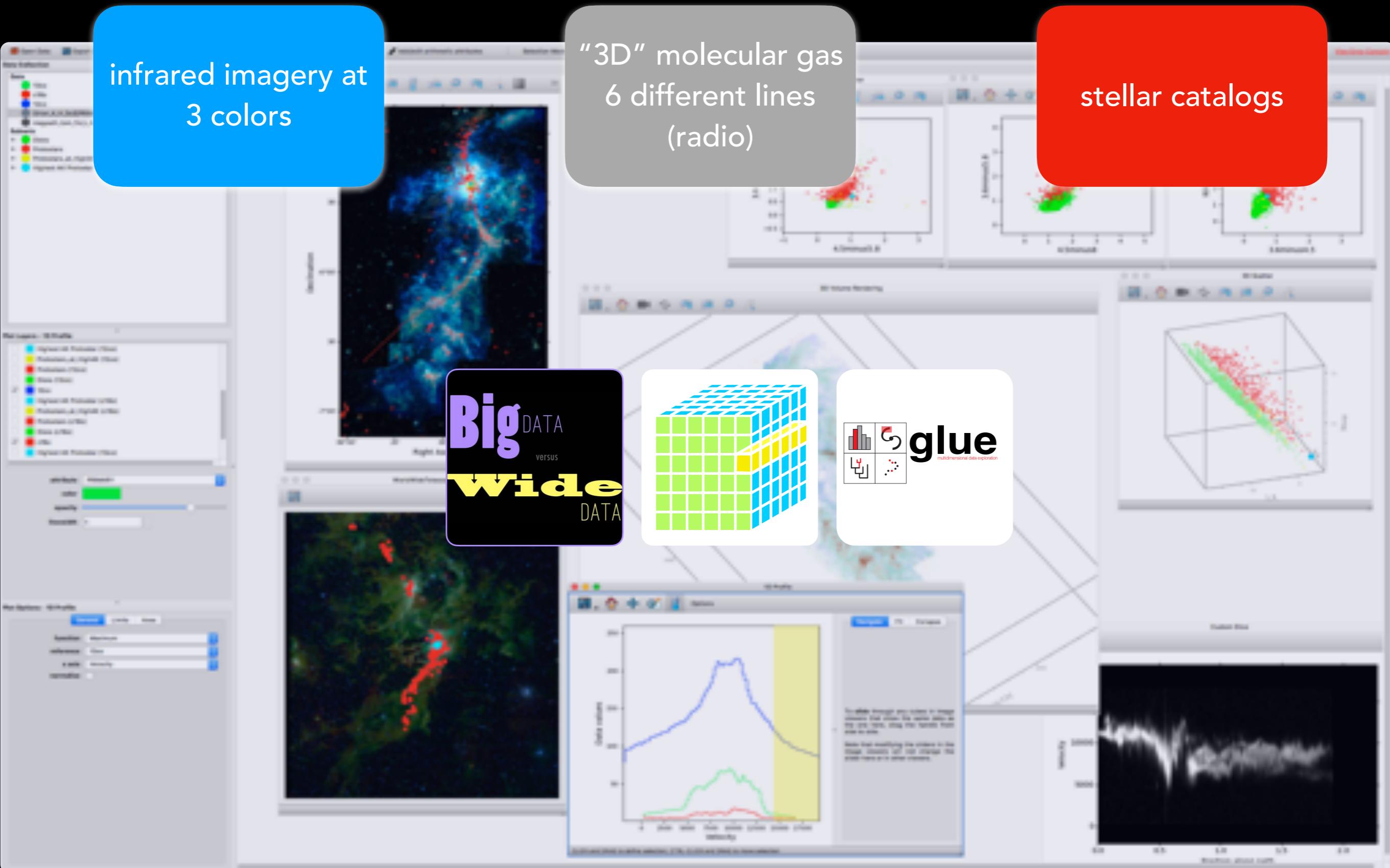
"3D" molecular gas
from CO
(radio)

3D geometric
models

4D maser VLBI
(radio)



EVEN “BIGGER & WIDER” DATA: ORION IN GLUE



DATA,
CODE,
COLLABORATION

DATA-DRIVEN STORYTELLING



0000000
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public outreach



scholarly publication

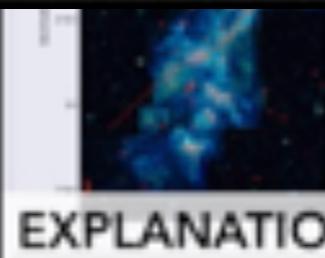
Explore

Explain

open source,
modular,
software

glue

data
sources



collaborative
software
development

plug-in
architecture

linked-view EXPLORATORY
analysis of high-dimensional data

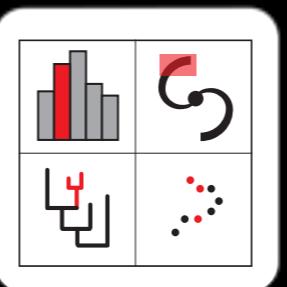
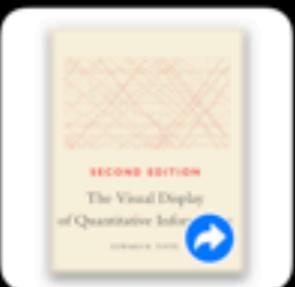
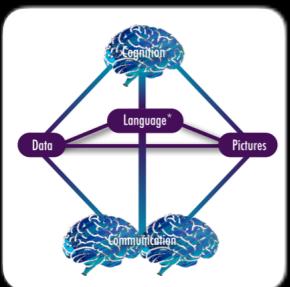
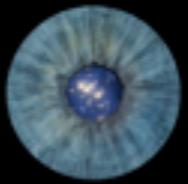
EXPLORATION ← → EXPLANATION

FIND THE
FULL
SERIES ON



TINYURL.C
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10QVIZVID
EOS

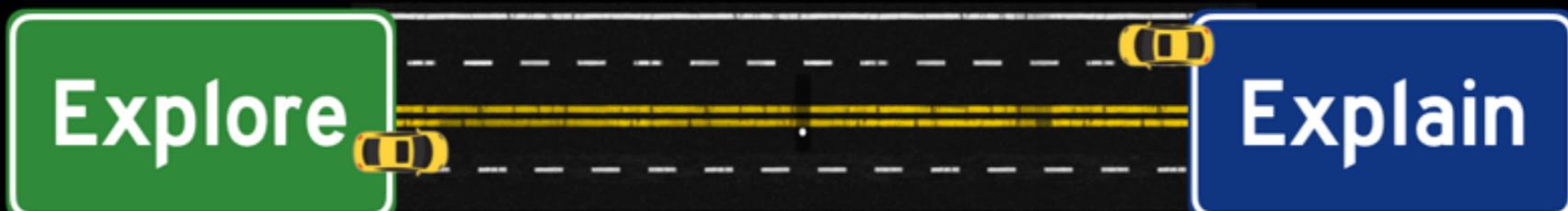
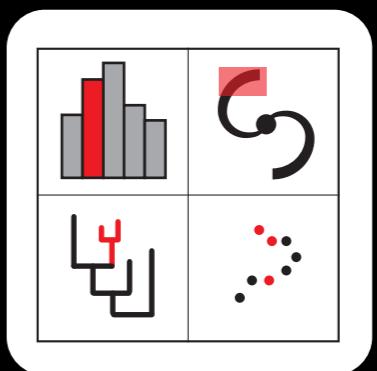
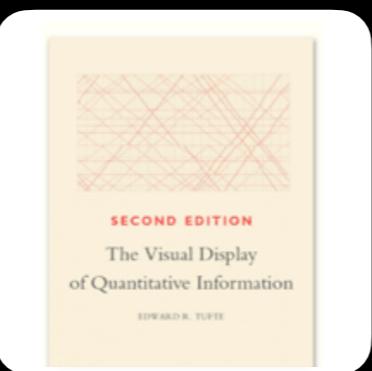
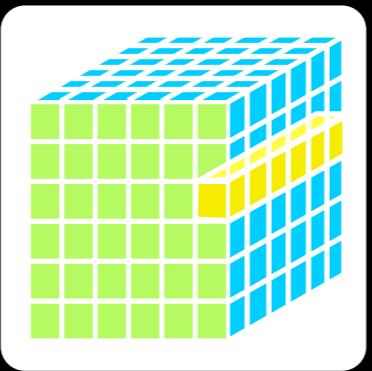
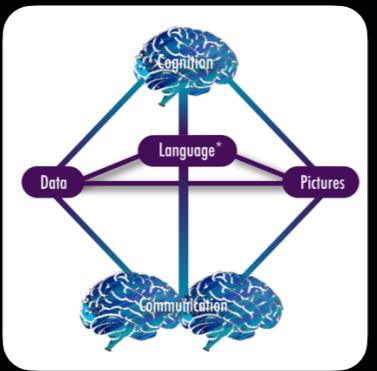
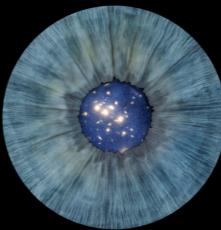
SEEING MORE OF THE UNIVERSE



Explore

Explain

SEEING MORE OF THE UNIVERSE

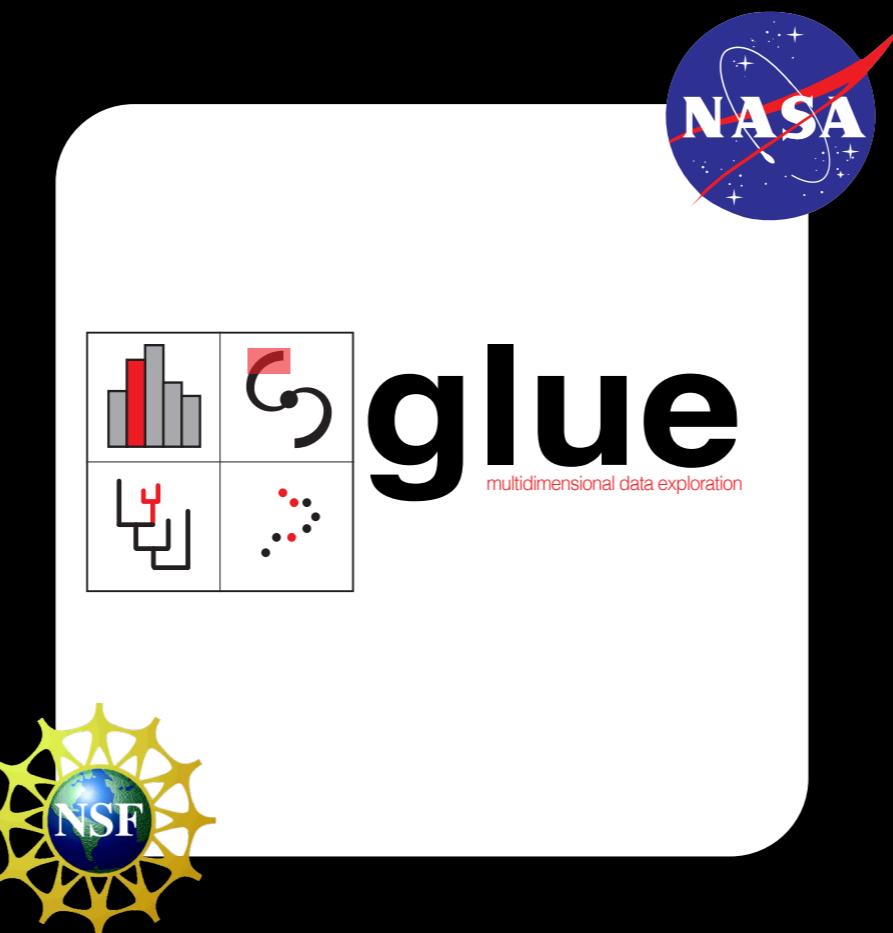
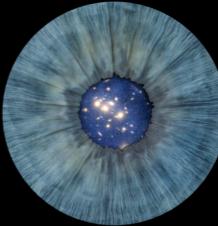


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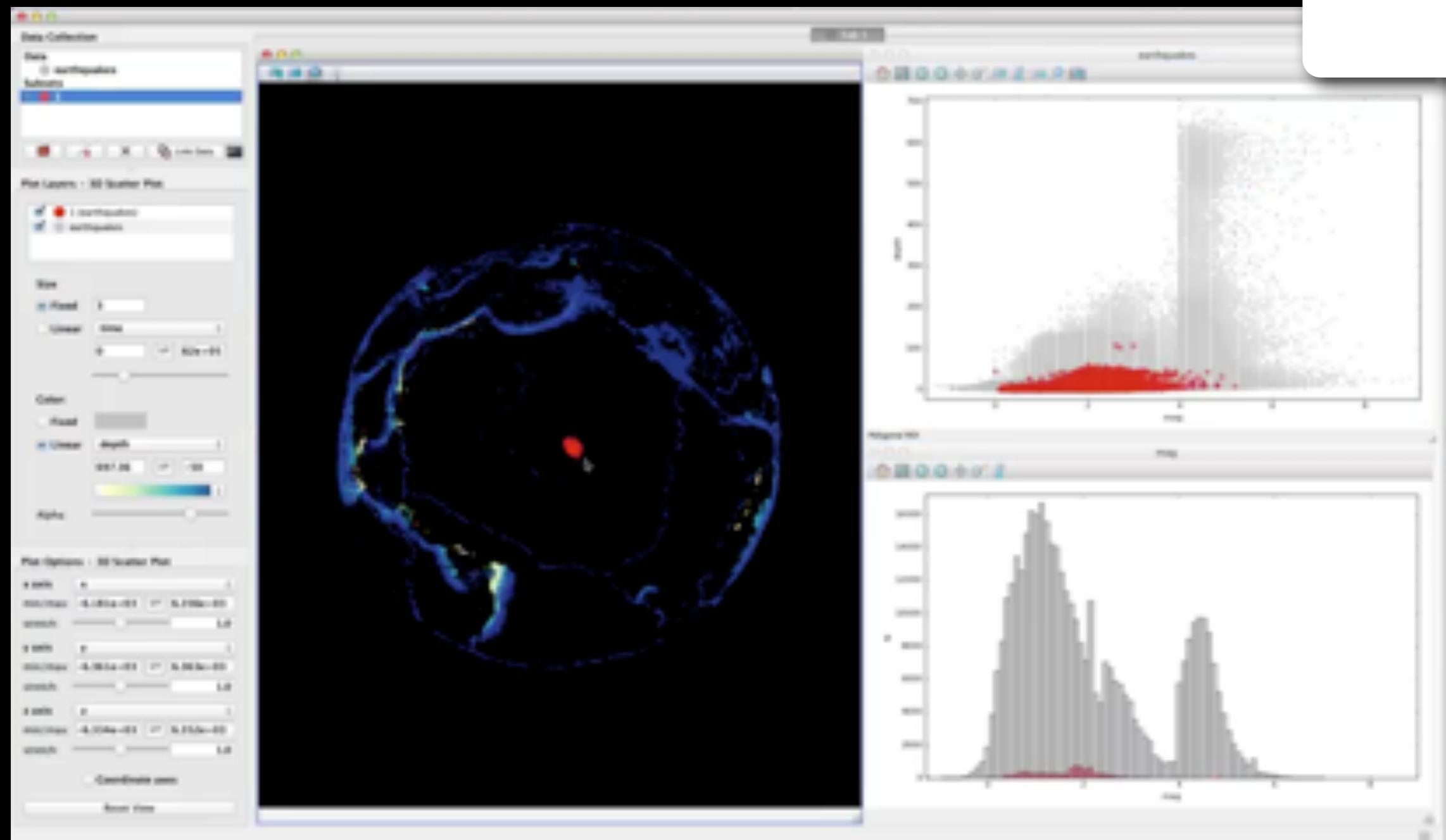
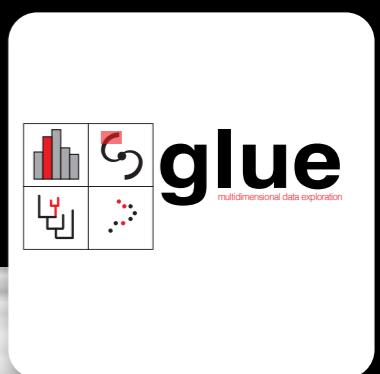
SEEING MORE OF THE UNIVERSE

“LINKED-VIEWS, IN GLUE”



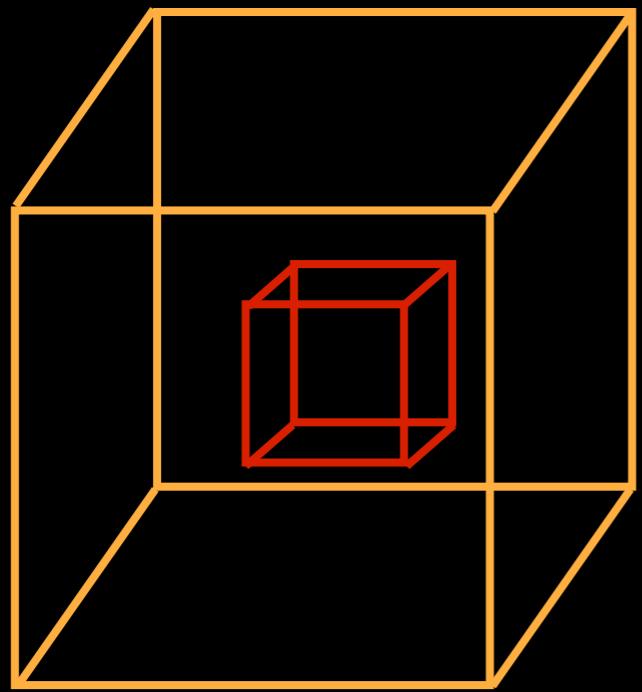
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Harvard-Smithsonian Center for Astrophysics & Radcliffe Institute
for Advanced Study

LINKED VIEWS OF HIGH-DIMENSIONAL DATA, IN PYTHON

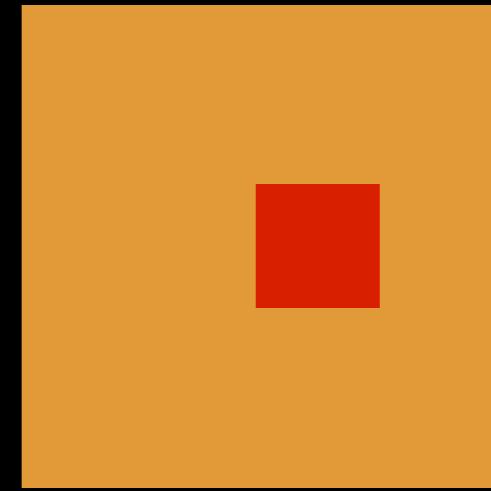


*video by Tom Robitaille, lead glue developer
glue created by: C. Beaumont, M. Borkin, A. Goodman (PI), T. Robitaille, C. Zucker, et al.*

LINKED VIEWS OF HIGH-DIMENSIONAL DATA

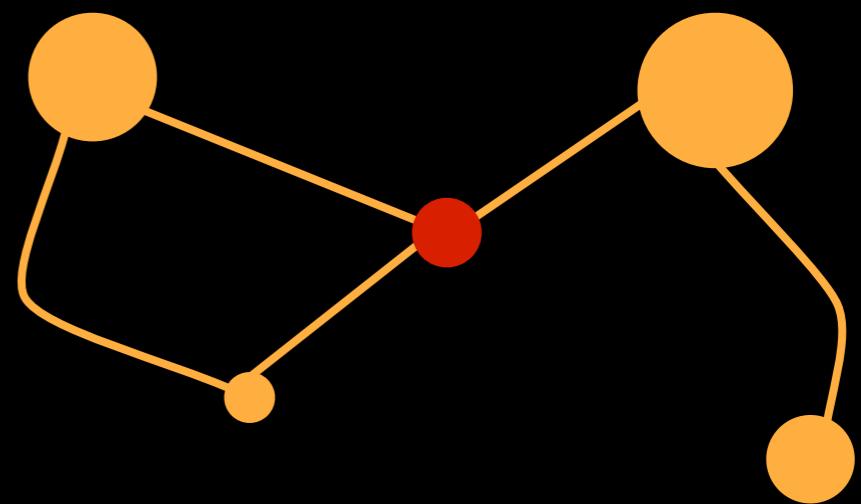
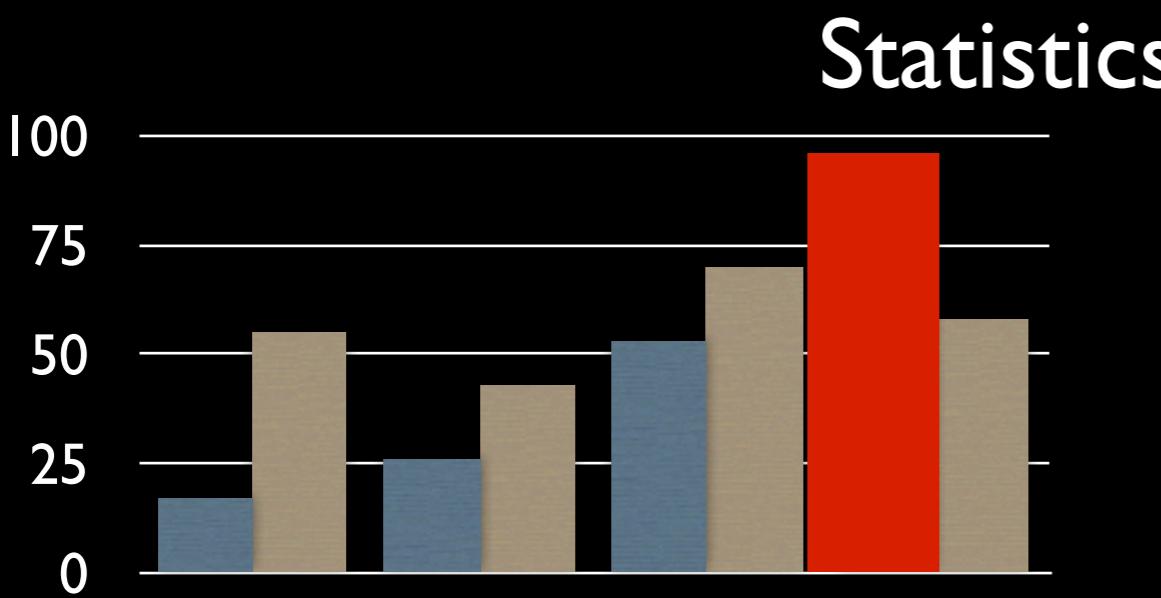


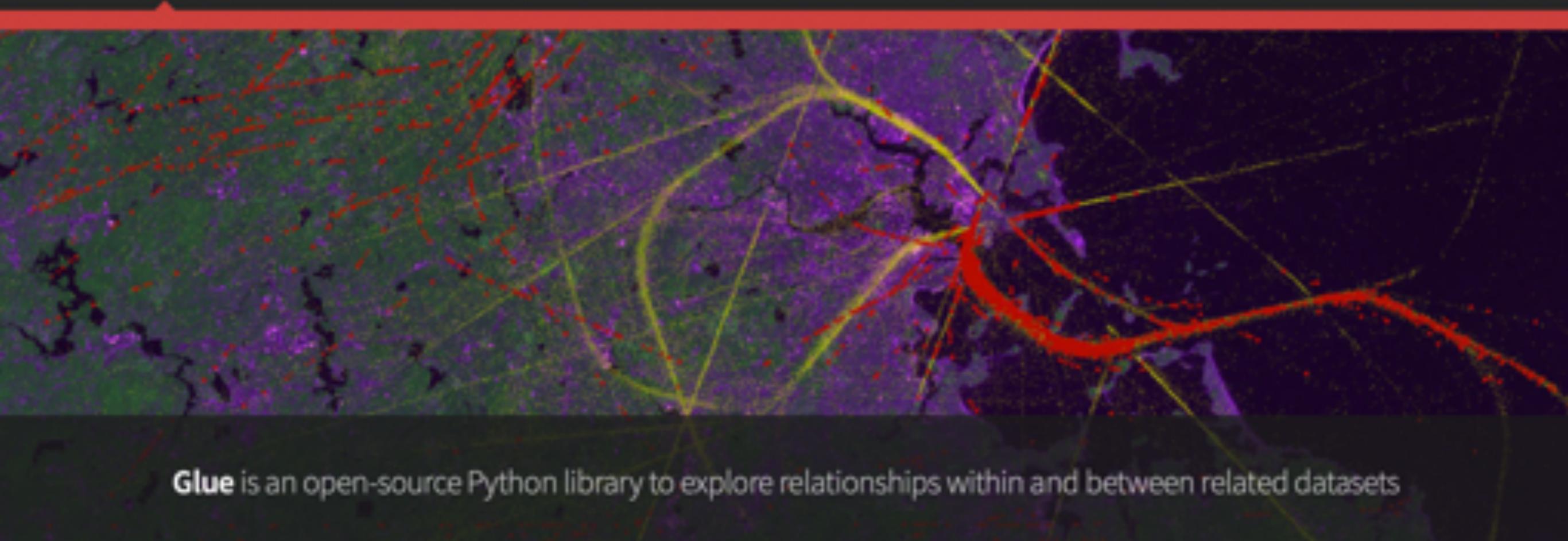
3D



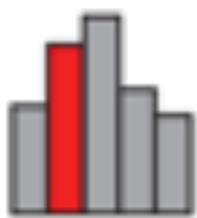
2D

Data Abstraction





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



Linked Visualizations

With Glue, users can create scatter plots, histograms and images (2D and 3D) of their data. Glue is focused on the



Flexible linking across data

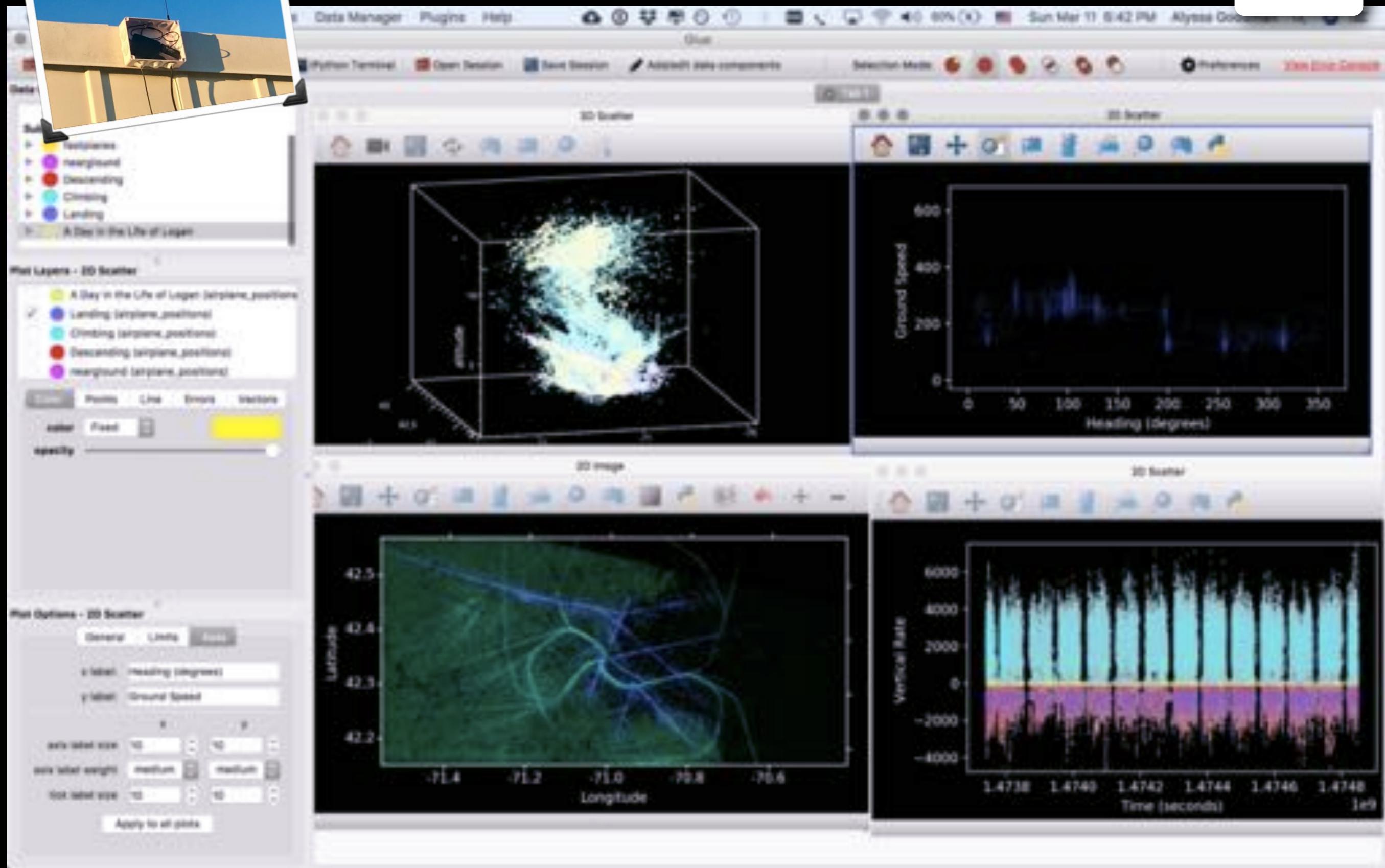
Glue uses the logical links that exist between different data sets to overlay visualizations of different data, and to



Full scripting capability

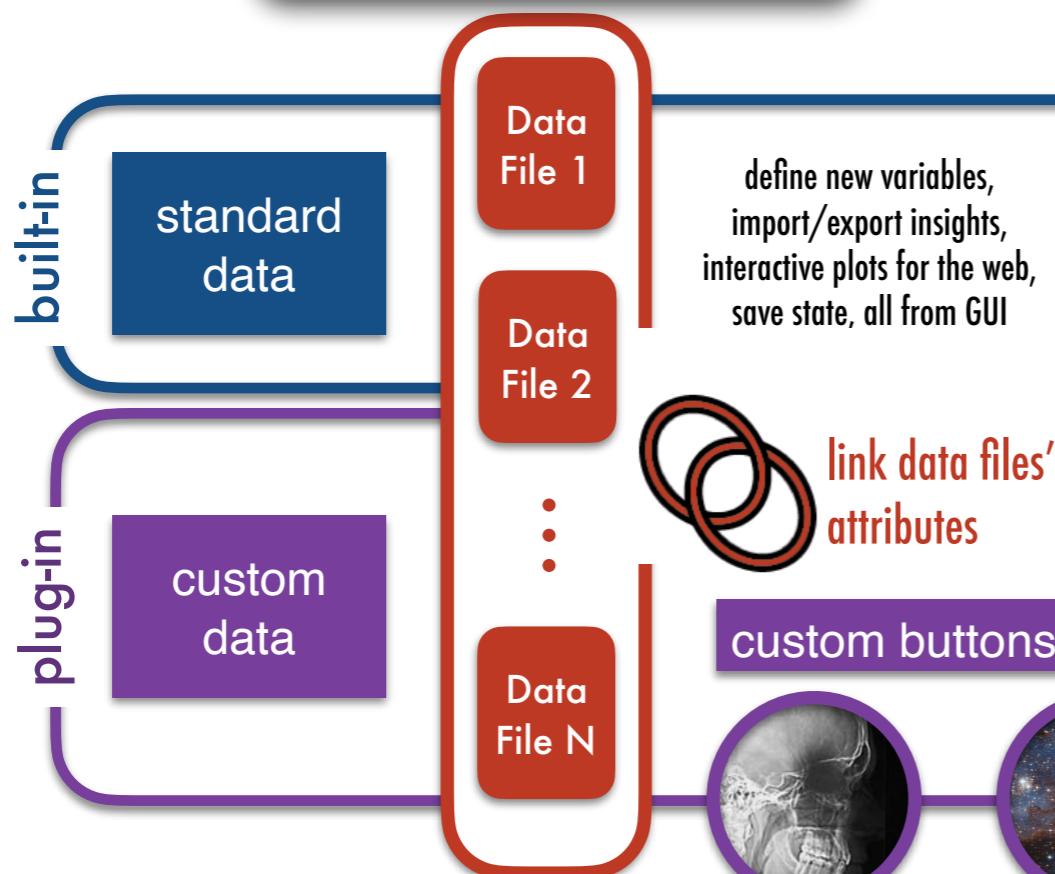
Glue is written in Python, and built on top of its standard scientific libraries (i.e., NumPy, Matplotlib, SciPy). Users can

LINKED VIEWS OF HIGH-DIMENSIONAL DATA, IN PYTHON

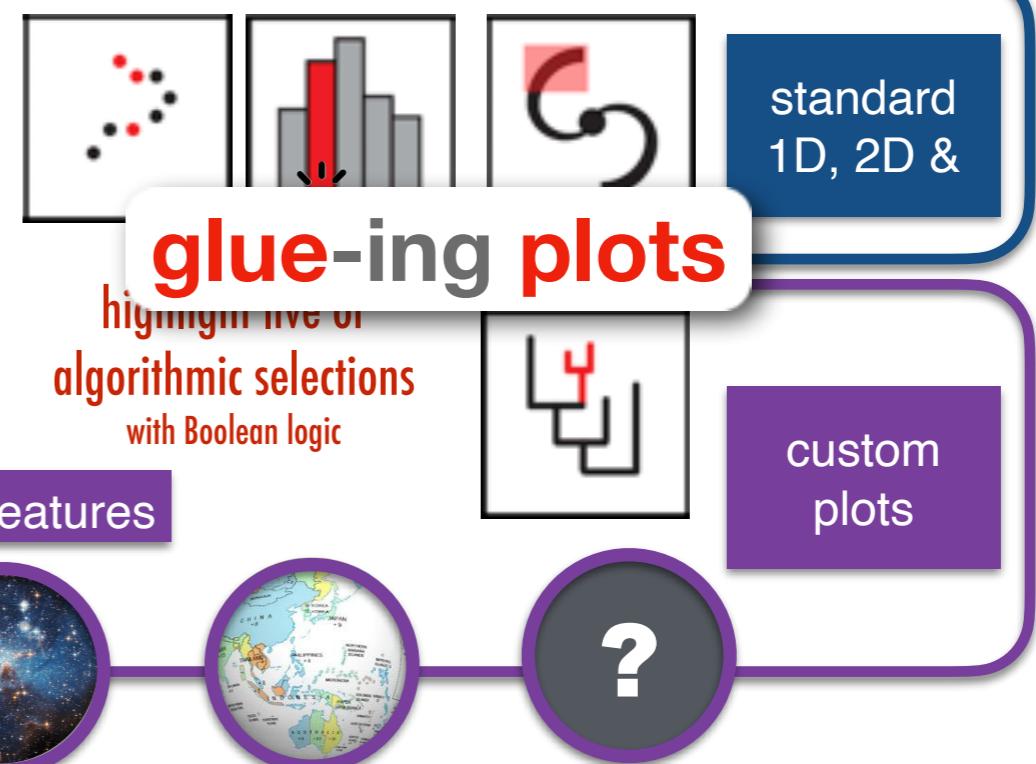




glue-ing data

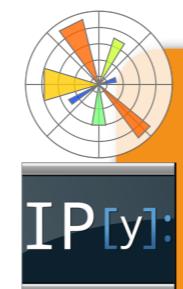


custom buttons, features



glue-ing plots

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



access to all matplotlib functions
through built-in IPython terminal



run & interact with glue from
Jupyter notebook & other tools

glue-ing tools

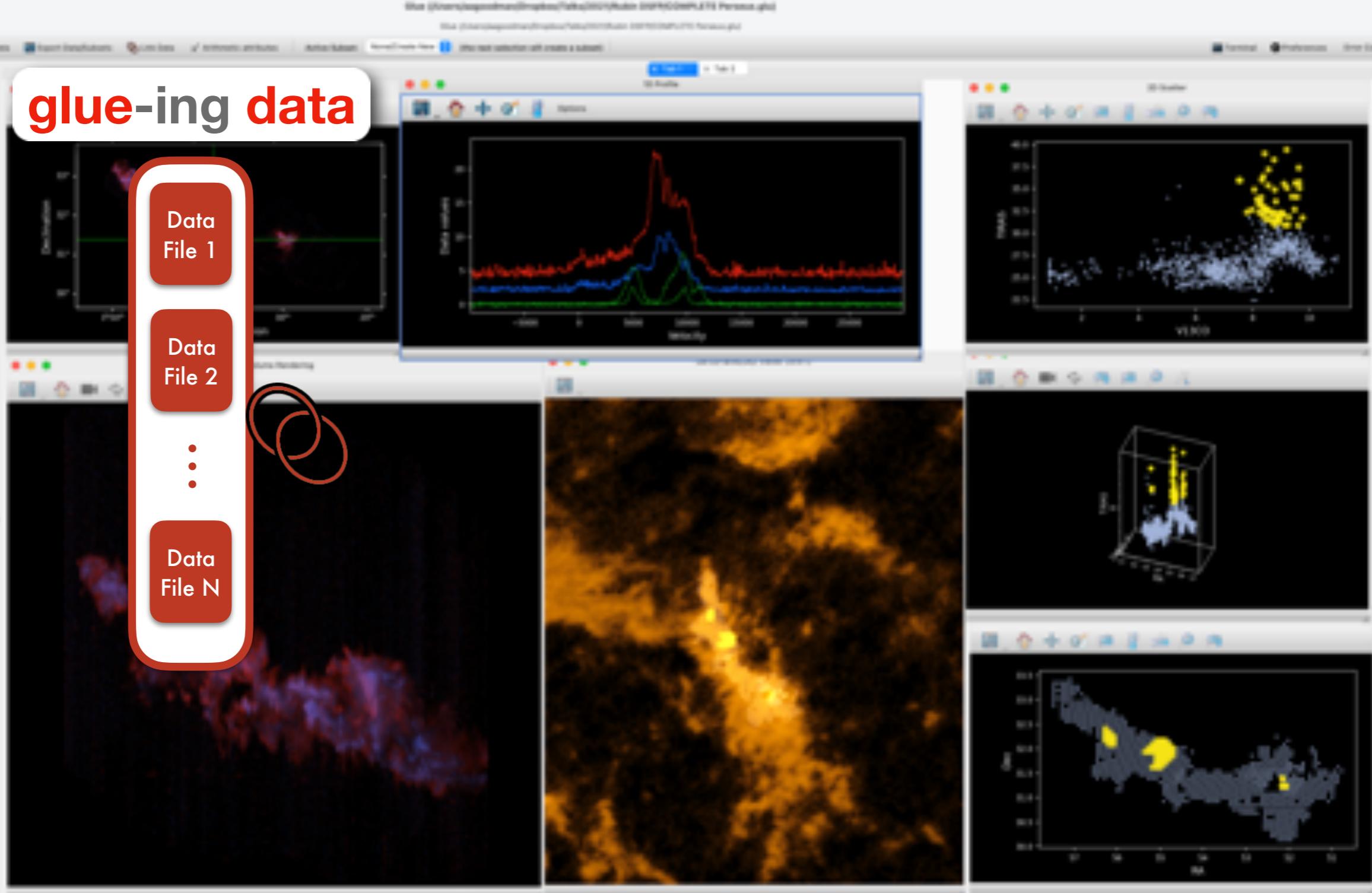
glue-ing data

Data
File 1

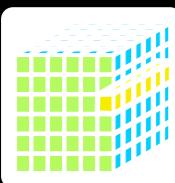
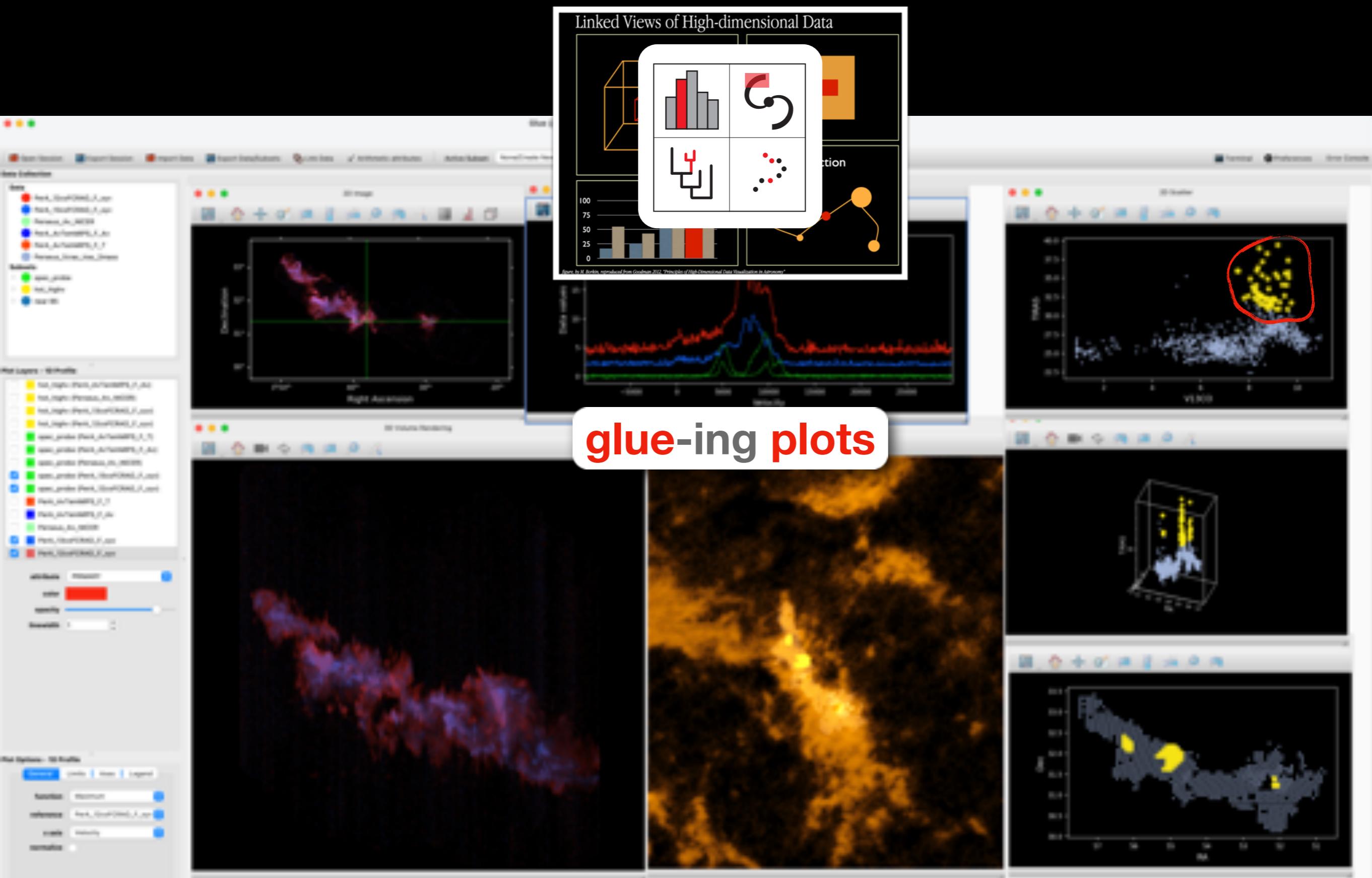
Data
File 2

⋮

Data
File N



COMPLETE



SEE "DATA, DIMENSIONS, DISPLAY" AND "BIG DATA, WIDE DATA" FOR MORE ON THIS EXAMPLE





glue-ing tools

Glue: multi-dimensional linked-data exploration

[Home](#) [Install](#) [Documentation](#) [Team](#) [Get involved](#) **Plugins** [glue-con events](#) [Consulting services](#)

Glue Plugins

Glue is designed to make it easy to customize various aspects via plugins, including customized data viewers on top of the standard ones, readers/writers for new file formats, and more. Developers are building glue plugins for a variety of fields from astronomy to medicine. The items below are currently available on the [GitHub](#) repository and most include instructions and sample data on how to install and use.

Plugins

[glue-aladin](#): Experimental [Aladin Lite](#) viewer plugin

[example_data_viewers](#): A collection of user-defined Glue data viewers including basketball shots, earthquakes, and Mario

[glue-geospatial](#): Experimental plugin to support satellite imagery

[glue-h5part](#): Experimental plugin to deal with h5part data

[glue-jupyter](#): Jupyter interface for Glue

[glue-medical](#): Experimental Glue medical plugin

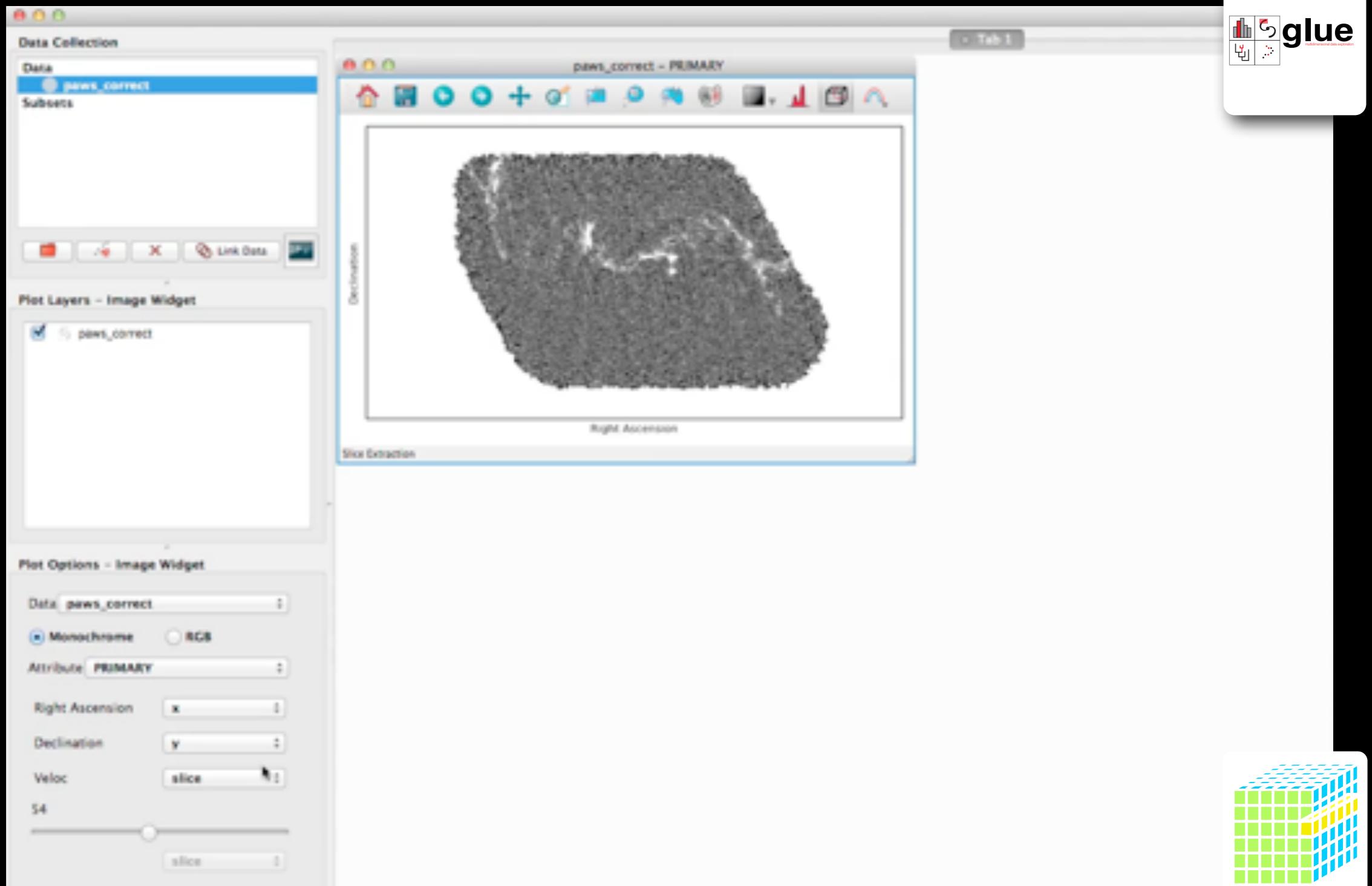
[glue-openspace](#): Experimental [OpenSpace](#) plugin

[glue-samp](#): Experimental [SAMP](#) plugin

[glue-specviz](#): Experimental plugin to wrap [specviz](#) spectroscopy tool

[glue-vtkviewsource](#): Plugin for 3D viewers using [VTK](#)

REMEMBER, "DIMENSIONS" NEED NOT BE ORTHOGONAL (OR EVEN SPATIAL)



video by Chris Beaumont

glue created by: C. Beaumont, M. Borkin, A. Goodman (PI), T. Robitaille, C. Zucker, et al.

COMING NEXT: GLUE IN THE BROWSER



The screenshot shows a web browser window displaying a Jupyter Notebook interface. On the left, there's a sidebar with a logo for 'glue solutions inc.' and a bar chart. The main content area shows a Python code cell with the output 'In [1]:' and 'Out[1]:'. Below this, there's a navigation bar with links to Home, Gallery, Our Team, The Software, glue-con, Social Impact, Working with Us, and a search icon.

glue-con On behalf of the glue and glupyter communities, glue solutions, inc. helps host a series of hackathon get-togethers known as "glue-con."

Upcoming Events
glue-con 2021 (online) [program will focus on Juptyer and web integration]

Past Events
glue-con 2020 (CCA/AMNH) [program/outcomes]
glue-con 2019 (CfA) [site] [program/outcomes]
glue-con 2018 (CfA) [program/outcomes]



get glue

glueviz.org

Glue

stable

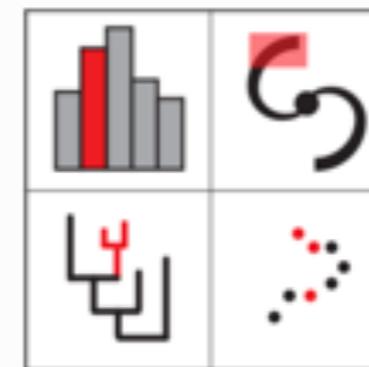
Search docs

- Installing and running glue
- Getting started
- Advanced User Interface Guide
- Using the IPython terminal in Glue
- Working with Data objects
- Starting Glue from Python
- Visualizing Astronomical Dendograms
- Introduction to customizing/extending glue
- List of available plugins
- Configuring Glue via a startup file
- Customizing your Glue environment
- Distributing your own plugin package
- Customizing the coordinate system of a data object
- Programmatically configuring viewers
- Writing a simple custom data viewer
- Watching data for changes

Docs > Glue Documentation

Edit on GitHub

Glue Documentation



glue
multidimensional data exploration

Glue is a Python library to explore relationships within and among related datasets. Its main features include:

- **Linked Statistical Graphics.** With Glue, users can create scatter plots, histograms and images (2D and 3D) of their data. Glue is focused on the brushing and linking paradigm, where selections in any graph propagate to all others.
- **Flexible linking across data.** Glue uses the logical links that exist between different data sets to overlay visualizations of different data, and to propagate selections across data sets. These links are specified by the user, and are arbitrarily flexible.
- **Full scripting capability.** Glue is written in Python, and built on top of its standard scientific libraries (i.e., Numpy, Matplotlib, Scipy). Users can easily integrate their own python code for data input, cleaning, and analysis.

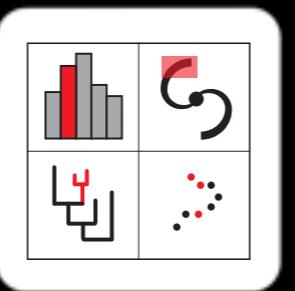
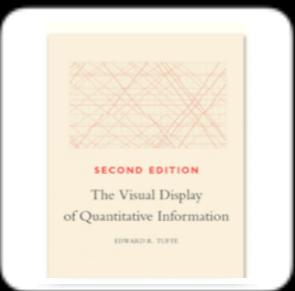
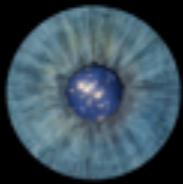


FIND THE
FULL
SERIES ON



TINYURL.C
OM/
10QVizVID
EOS

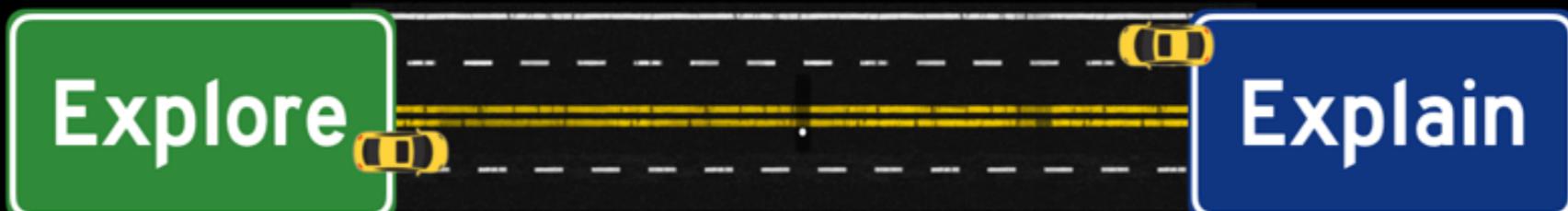
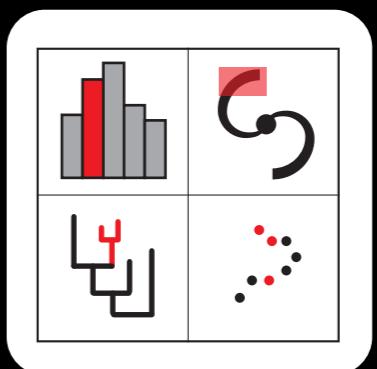
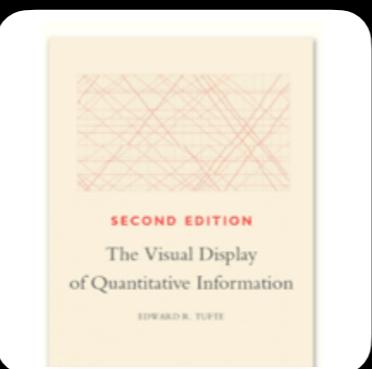
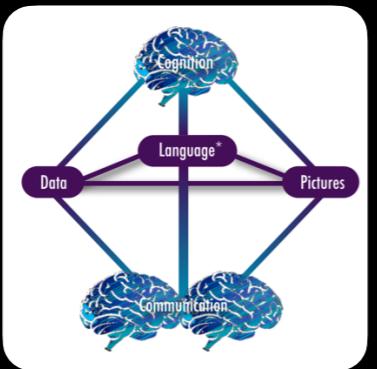
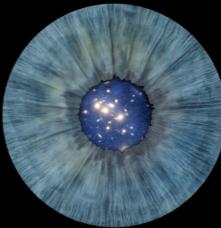
SEEING MORE OF THE UNIVERSE



Explore

Explain

SEEING MORE OF THE UNIVERSE

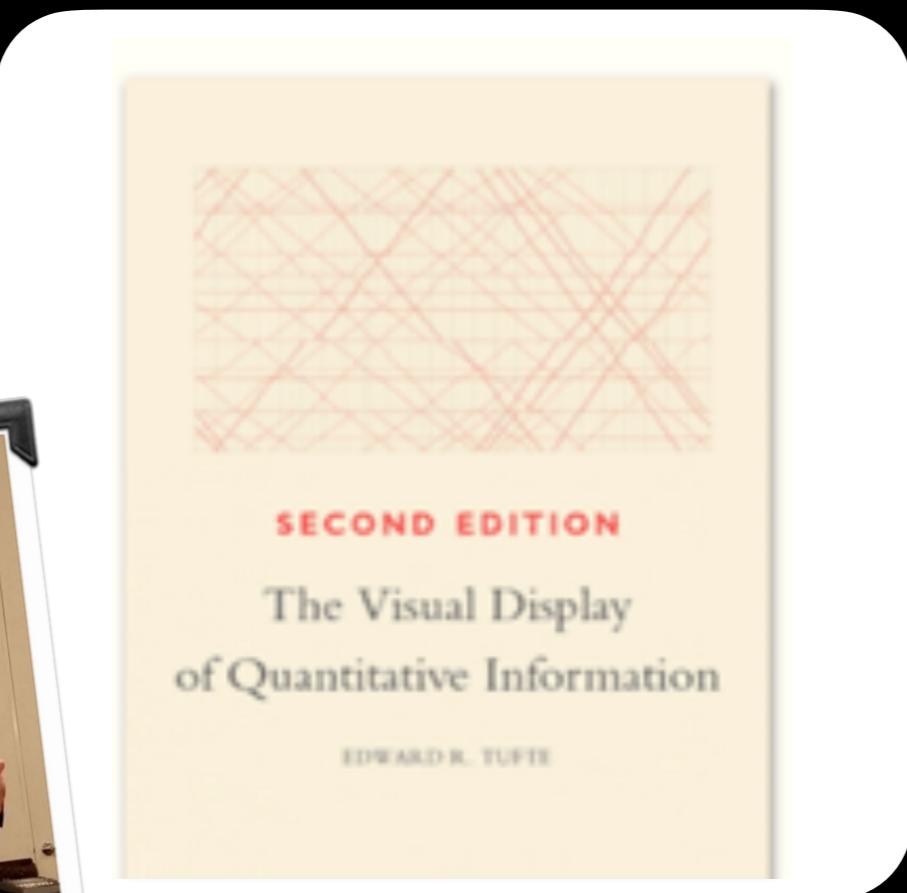
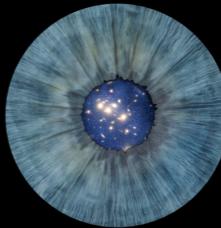


Alyssa A. Goodman

Harvard-Smithsonian Center for Astrophysics & Radcliffe Institute
for Advanced Study

SEEING MORE OF THE UNIVERSE

“THE WISE WORDS OF EDWARD TUFTE”

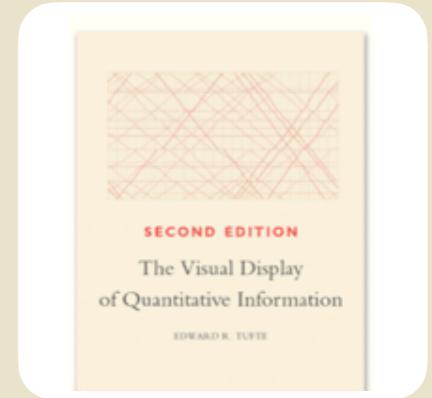


Alyssa A. Goodman
Harvard-Smithsonian Center for Astrophysics & Radcliffe Institute
for Advanced Study

The wise words of Edward Tufte

Key concepts from

The Visual Display of Quantitative Information, Tufte 1983



Graphical Excellence

Graphical Integrity
& "The Lie Factor"

Chartjunk
& Subtraction

Data-ink Ratio

Multi-functioning
graphical elements

Data density

Small multiples

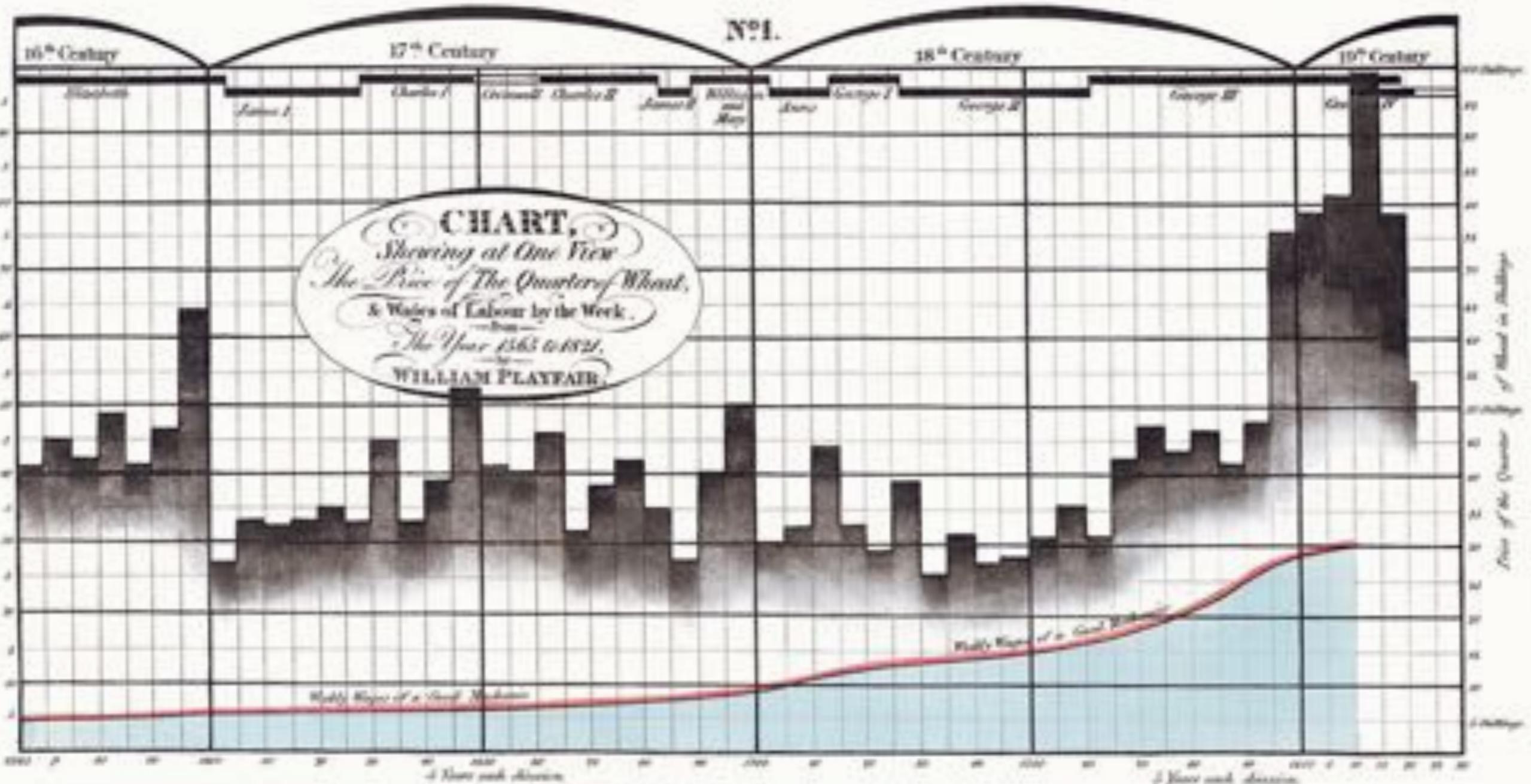
Edward Tufte's Ideas

from *The Visual Display of Quantitative Information*, Tufte 1983

Graphical Excellence – displays should...

- **show the data**
- induce the viewer to **think** about the **substance** rather than about methodology, graphic design, the technology of graphic production, or something else
- **avoid distorting** what the data have to say
- present **many numbers** in a small space
- make large data sets **coherent**
- encourage the eye to **compare** different pieces of data
- reveal the data at **several levels of detail**, from a broad overview to the fine structure
- serve a reasonably clear **purpose**: description, exploration, tabulation, or decoration
- be closely **integrated** with the statistical and **verbal descriptions** of a data set

Graphical Excellence



William Playfair (1759-1823)

Edward Tufte's Ideas

from *The Visual Display of Quantitative Information*, Tufte 1983

Graphical Excellence

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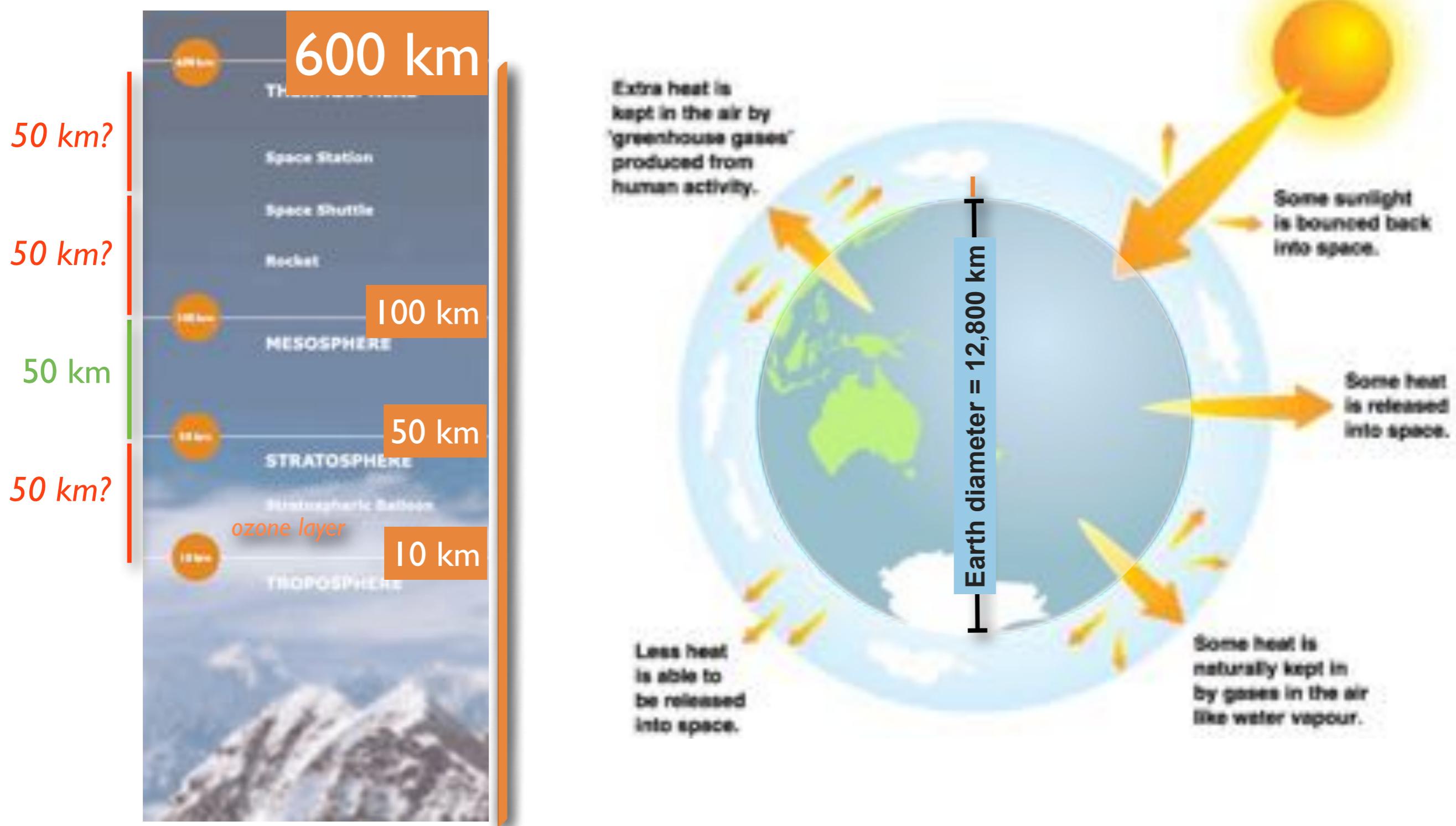
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Graphical Integrity & "The Lie Factor"



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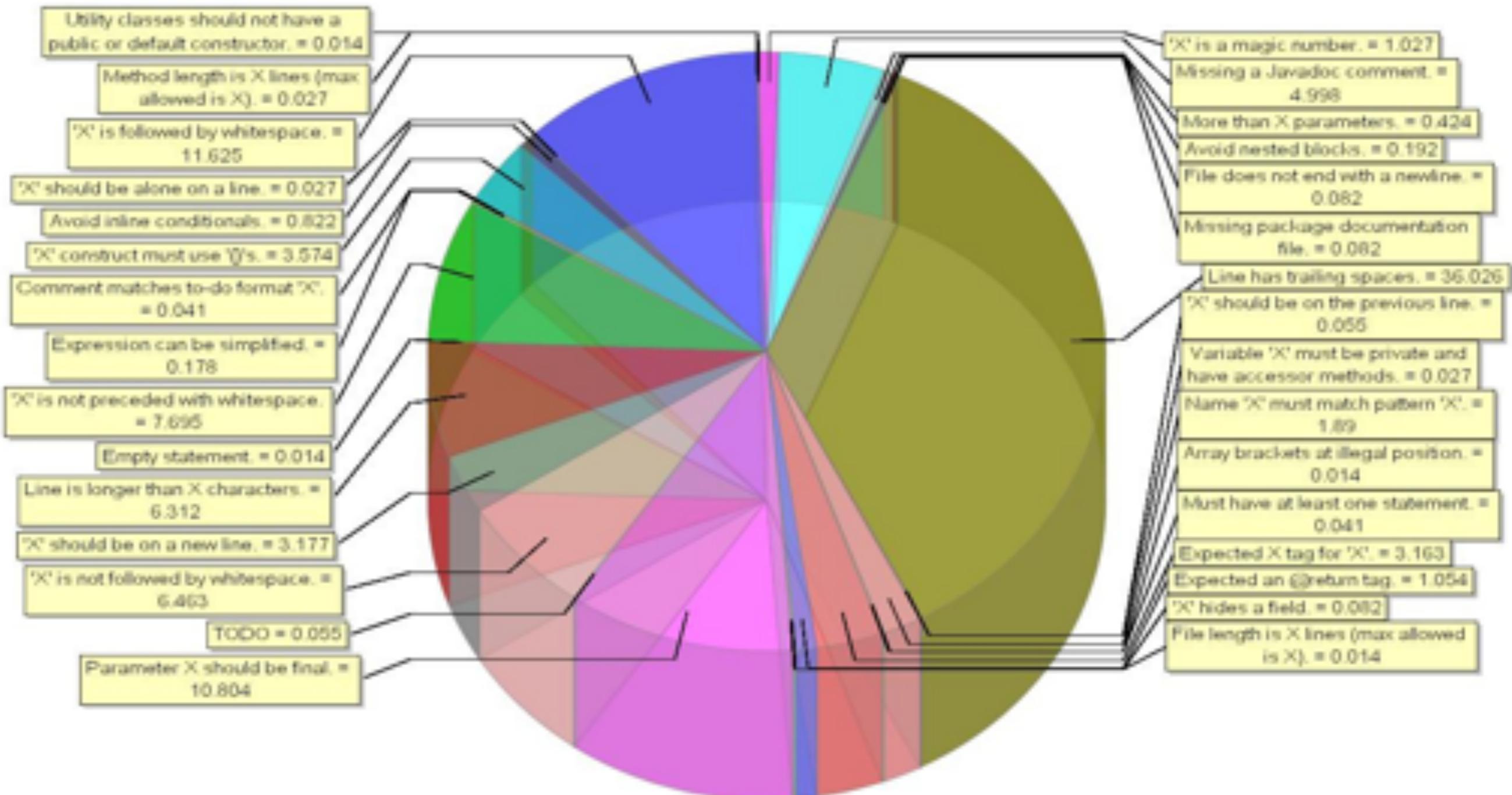
Data-ink Ratio

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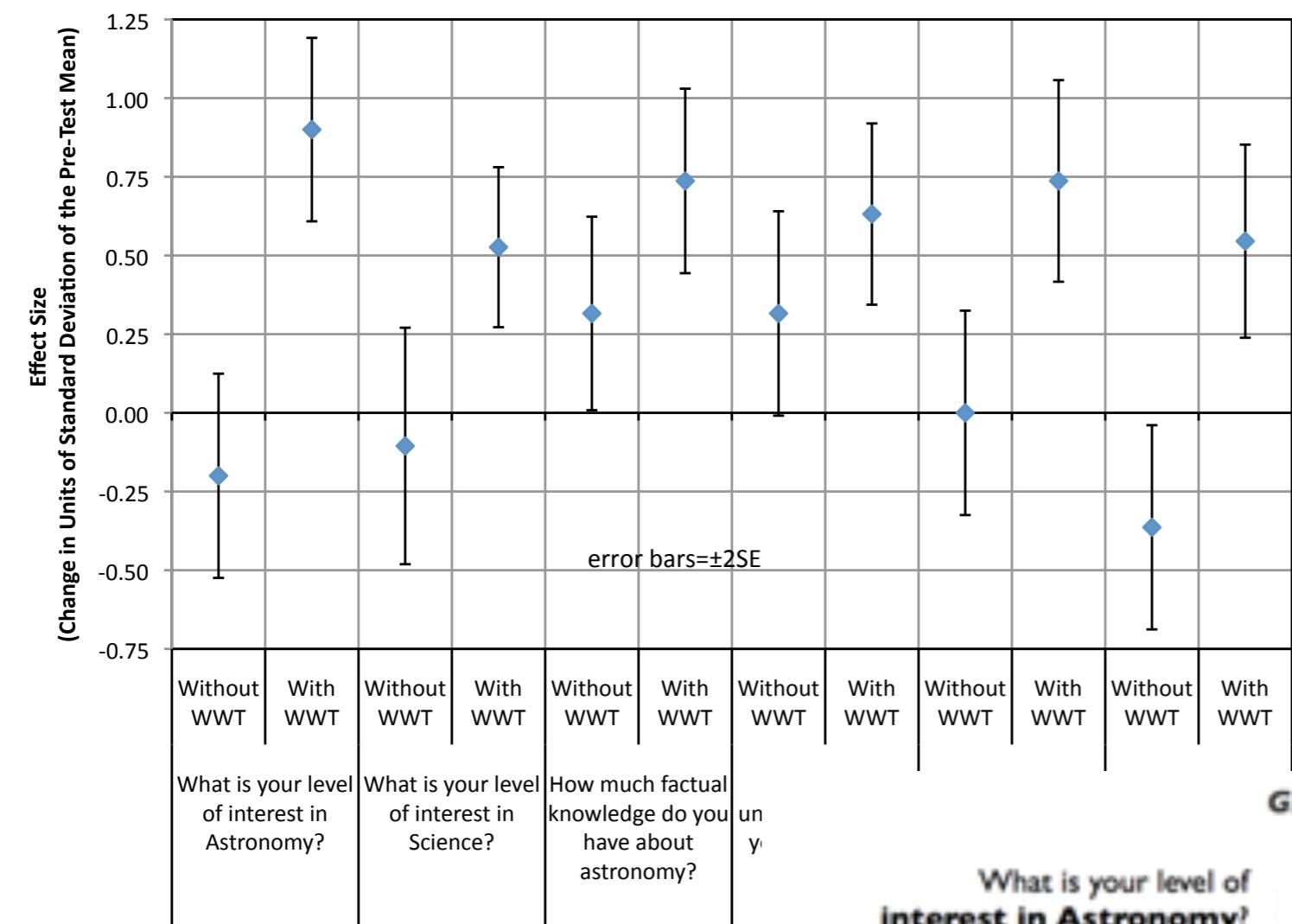
Data-ink Ratio

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Data density

Small multiples

Data-ink Ratio



What is your level of
interest in Astronomy?

What is your level of
interest in Science?

How much **factual knowledge**
do you have about astronomy?

How much **understanding** do you
have about topics in astronomy?

How well can you **visualize**
Sun-Earth-Moon relationships?

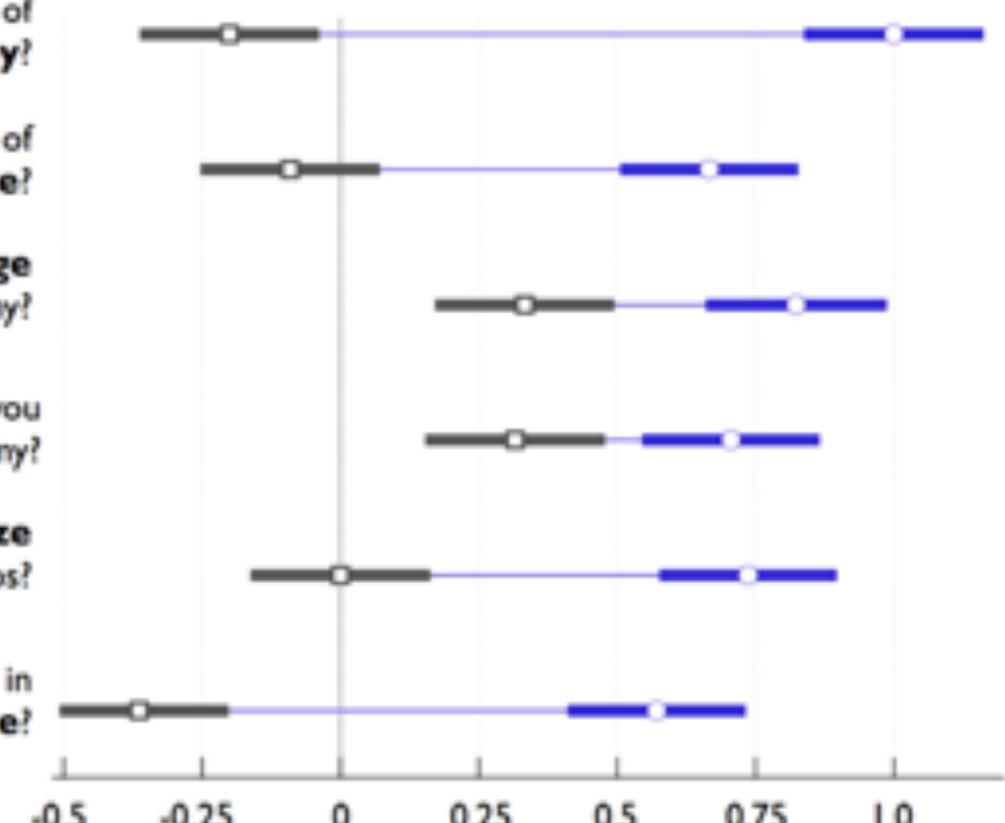
How interested are you in
using a real **telescope**?

from AG
example
used in



Group B (Traditional)
N_{before}=77; N_{after}=75

Group A (With WWT)
N_{before}=75; N_{after}=81



Effect Size: Gain (or Loss) in Units of Pre-Test Standard Deviation
(Error bars show ± 1 Standard Error of the Mean)

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Multi-functioning graphical elements

Live Scoreboard | Celtics.com

DEN 116 WAS 72 POR 87 PHI 46 MIL 34 DAL 26-11 DAL 25-11
OKC 119 BOS 79 NOV 79 WAS 102 UTA 104 SAC 14-21 SEA 9-27
MIL 2-34 49 0-50 40 1st 100 100 2nd

SCOREROAD

COURTSIDE LIVE

19-16 STANDINGS

72 02:46

1	2	3	4	OT	T
18	17	24	13		72
18	18	26	16		78

79 30-5

1 **3** **1** STANDINGS

COURTSIDE LIVE **BOX SCORE** **PLAY-BY-PLAY** **Highlights** **Watch the Game** **Listen to the Game**

WAS SELECT: ALL ACTIVE INJ

PLAYER NAME	PTS	REB	AST	F
Donald, Anthony	9	2	0	0
McNealy, DeShawn	9	3	4	0
Johnson, Detroy	10	0	0	0
Brown, Carson	14	3	1	0
Haywood, Brandon	12	3	0	0
Malone, Rodney	3	5	0	0
Moss, Roger	3	1	1	0
Songaila, Dennis	2	1	1	0
Young, Nick	2	0	0	0
Pritchard, Detroy	0	1	0	0
Braves, Gilbert				
Melvin, Dennis				

BOS SELECT: ALL ACTIVE INJ

PLAYER NAME	PTS	REB	AST	F
Rondo, Rajon	4	2	2	0
Allen, Ray	10	0	2	0
Garnett, Kevin	25	6	6	0
Perry, Fred	10	4	2	0
Pennant, Randolph	9	3	1	0
Hayes, Jason	1	0	0	0
Allen, Tony	4	4	0	0
Doyle, Ben	1	0	0	0
Perry, Jason	3	2	0	0
Polk, Scott				
Souder, Brian				
Poule, Leon				

TD Banknorth GARDEN

WIZARDS **CELTICS**

WAS **BOS**

made shot missed shot

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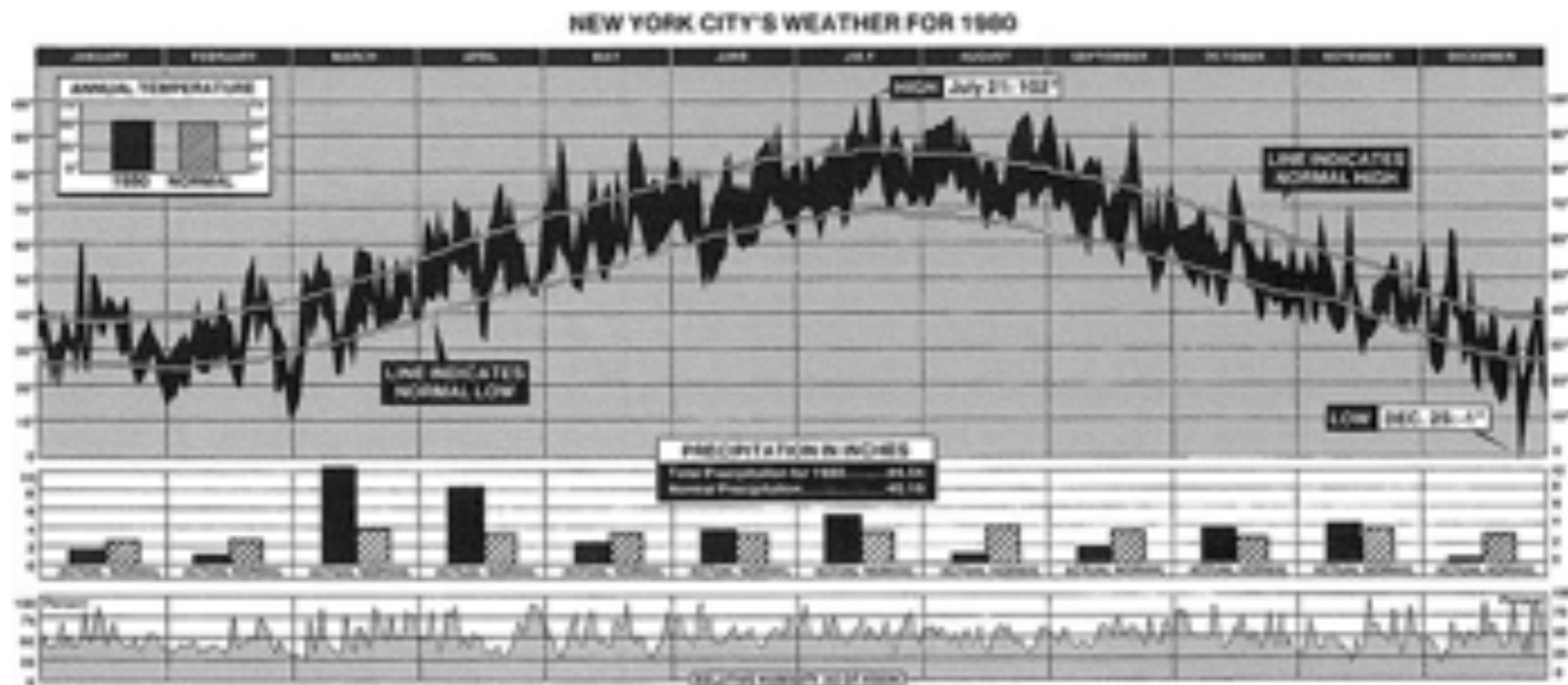
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graphical elements

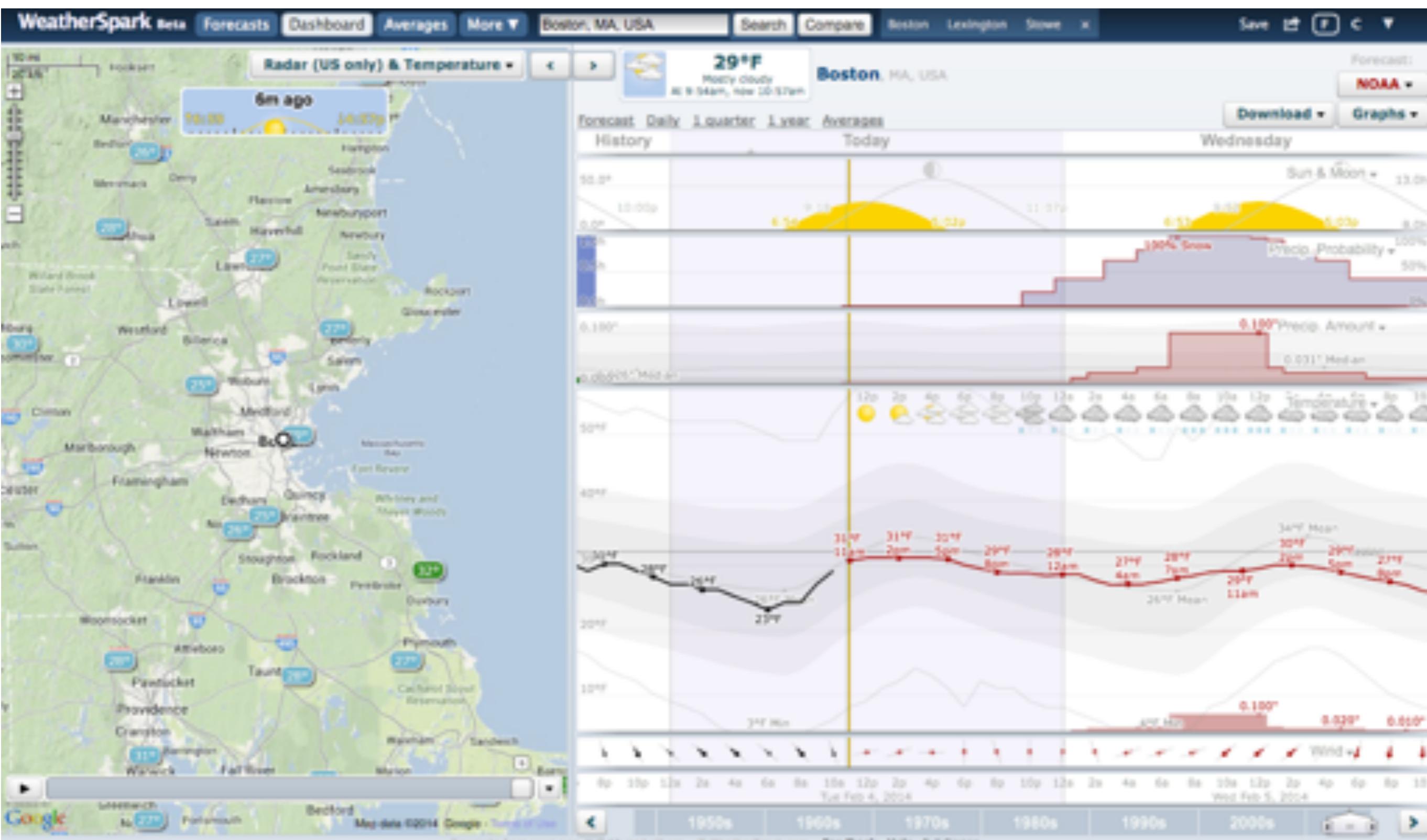
Data density

Small multiples

Data density



Data (over?) density



<http://weatherspark.com/#!dashboard;a=USA/MA/Boston>

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Galileo Galilei

(1564-1642)

Small multiples

7	* * O *	17	* O
8	O ***	18	O
19	* * O	19	O *
"	* * O	20	O * *
21	* O *	21	O * O * O
13.	* O **	22	O
15	O *** *	23	O * *
16	O ..	24	O ..
17	O ..	24	O ..

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

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 spider, two to the east and two to the west, and arranged precisely as shown in the figure.

in a straight line, as in the adjoining figure. The easternmost was about 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 are nearly equal; the one closest to Jupiter appeared a little smaller than the rest. But at the seventh hour the eastern stars were only 3 seconds apart. Jupiter was 2 minutes from the nearer eastern

ec., 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 basis, only two stars appear to ranking Japan, as it will

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, - look to the east.

Composite Table*

*how AG met ET, 1995



from left: Jonathan Corum, Edward Tufte,
Alyssa Goodman, Mike Bostock (2015)

Table 1: Summary of VLA NH₃ Observations in Low-Mass Dense Cores as of 1994
 (double-boxed sources to be observed in this proposal)

New Sources to be Observed in this Proposal

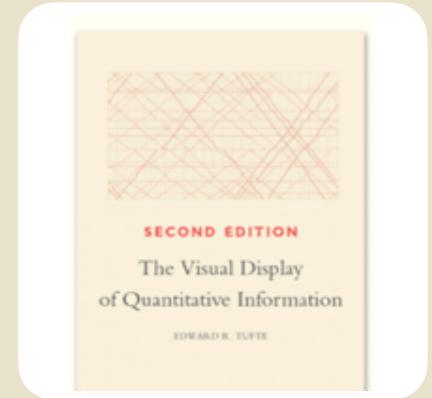
L1527			1995	infall candidate
L483			1995	infall candidate
B133	NO	NO	1995	strong extended sub-mm continuum, no known point source

*determination is unclear from existing data

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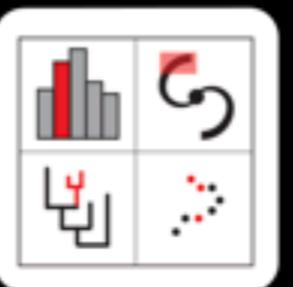
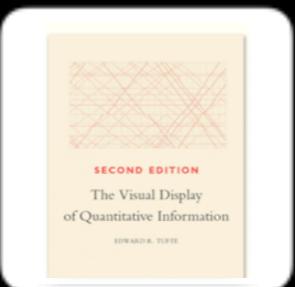
Small multiples

FIND THE
FULL
SERIES ON

You Tube

TINYURL.C
OM/
10QVizVID
EOS

SEEING MORE OF THE UNIVERSE



Explore

Explain