What (and How) Can Linked-View Visualization tell us about the Universe, and Brains?

Alyssa A. Goodman
Harvard-Smithsonian Center for Astrophysics & Radcliffe Institute
with Chris Beaumont, Michelle Borkin, Penny Qian & Tom Robitaille

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@aagie
@glueviz
@astrofrog

glueviz.org
github.com/glue-viz
Tom Robitaille, lead developer

NASA James Webb
Space Telescope
+NSF-Scientific Software Elements

3500 YEARS OF OBSERVING

Stonehenge, 1500 BC

Ptolemy in Alexandria, 100 AD

Observatory Tower, Lincolnshire, UK, c. 1300

naked-eye/telescope

Galileo, 1600

The "Scientific Revolution"

multi-wavelength

Reber's Radio Telescope, 1937

ground/space-based

NASA/Explorer 7 (Space-based Observing) 1959

"The Internet"

Long-distance remote-control/ "robotic" telescopes 1990s

21st Century Virtual Observatories & Online Astronomy

VISUAL + DATA-RICH + OPEN

Why Is Astronomy Interesting?

Astronomy has always been data-driven….
Now becoming more accepted in other areas as well

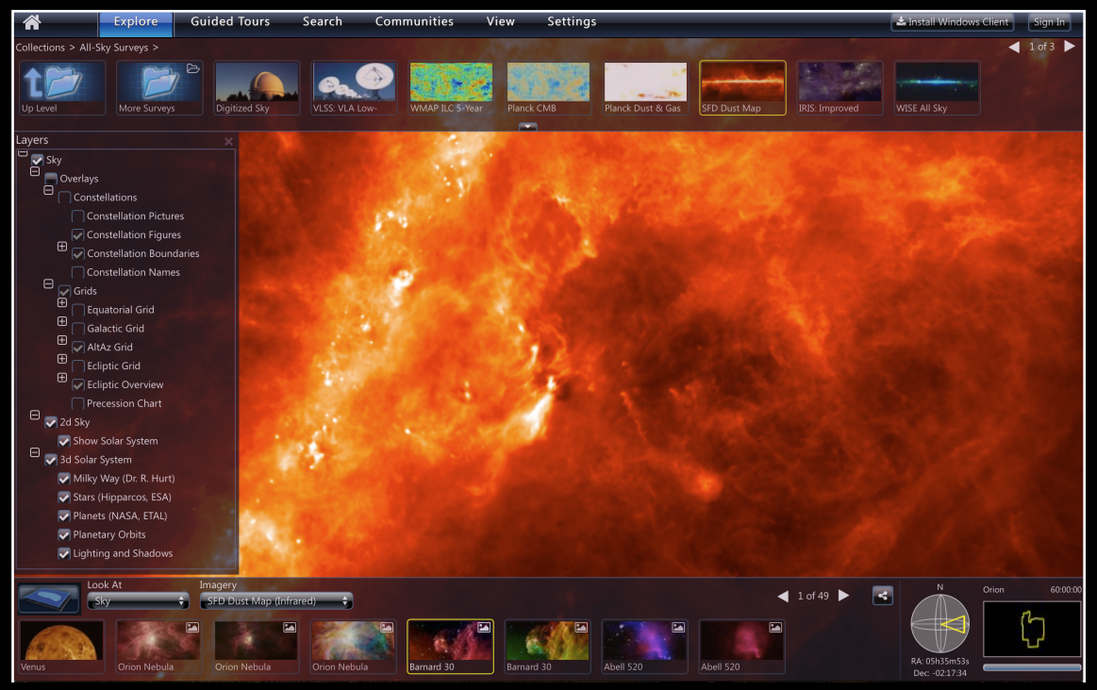
- Important spatio-temporal features
- Very large density contrasts in populations
- Real errors and covariances
- Many signals very subtle, buried in systematics
- Data sets large, pushing scalability
  - LSST will be 100PB

*"Exciting, since it is **worthless**!"*

— Jim Gray

Jim Gray 1944-2007(?)

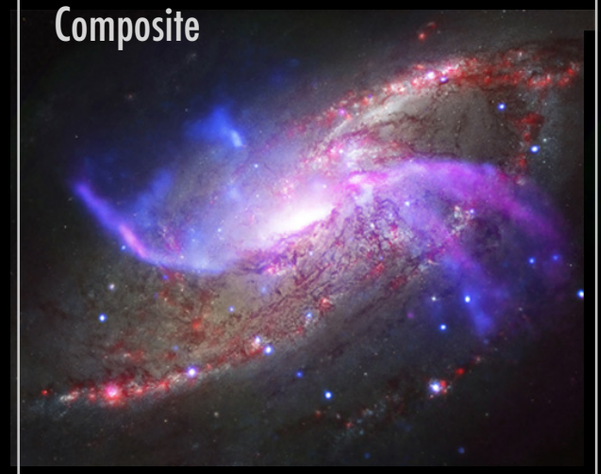
Sloan Digital Sky Survey, est. 1998



WorldWide Telescope, est. 2008

"ASTRONOMICAL MEDICINE"

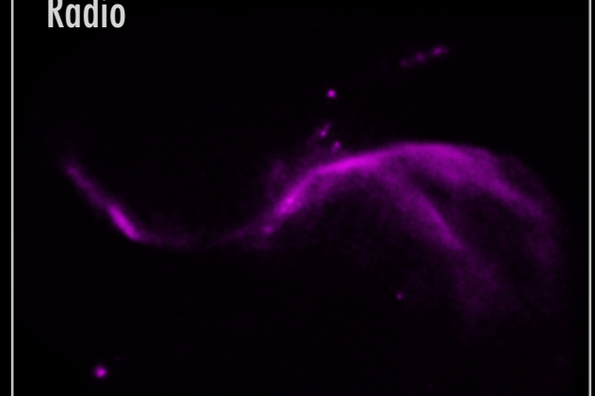
Composite



X-ray

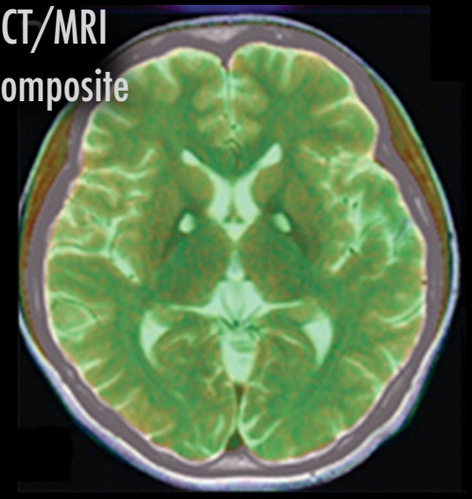
Optical

Radio

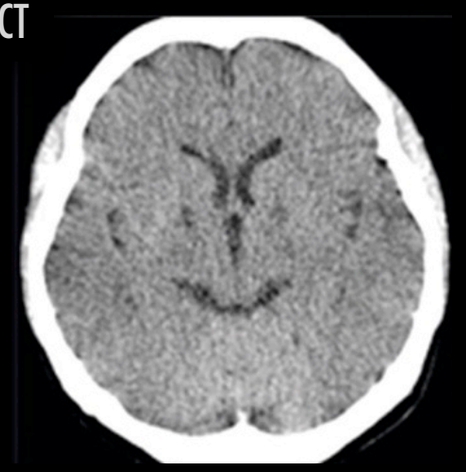


chandra.harvard.edu/photo/2014/m106/

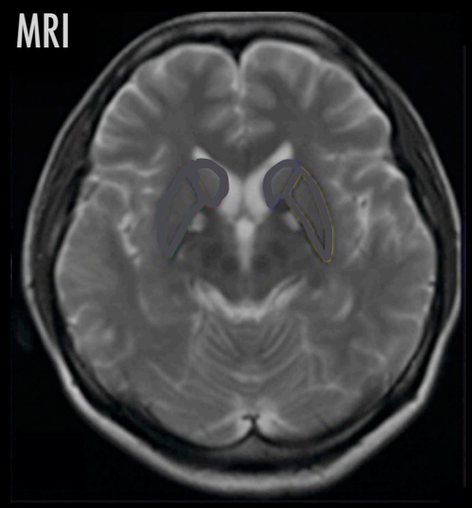
CT/MRI composite



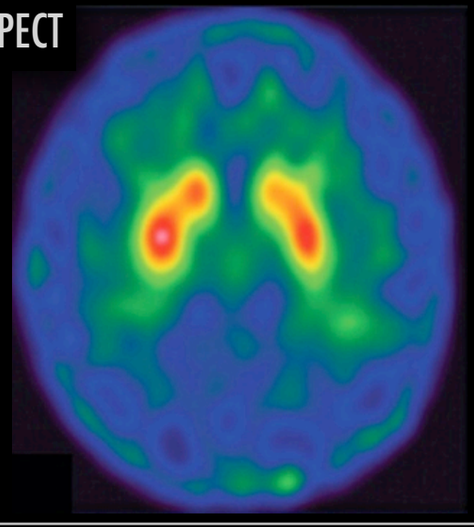
CT



MRI



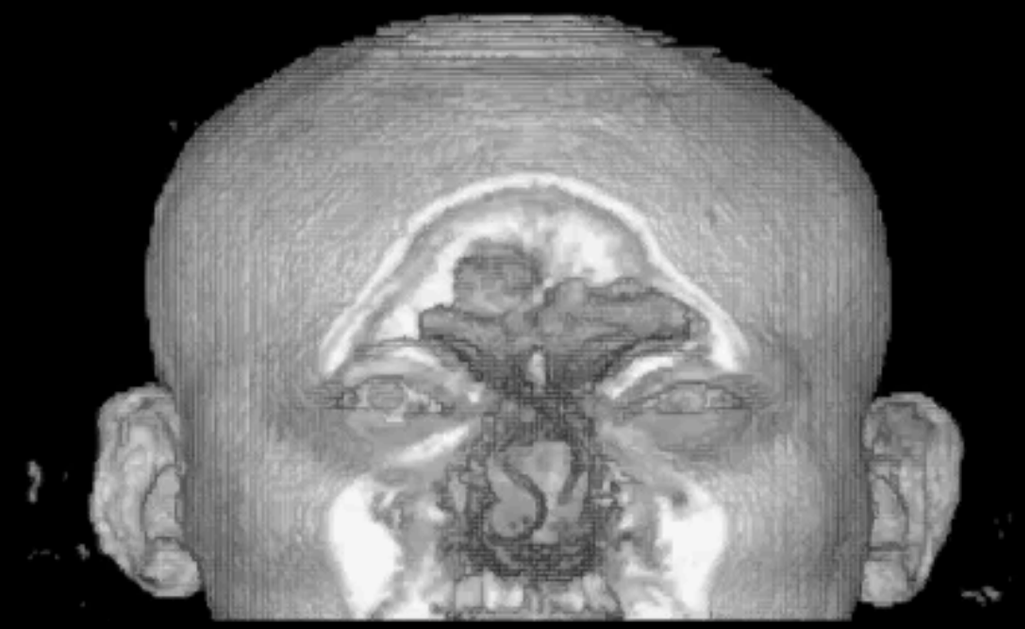
SPECT



Chang, et al. 2011, brain.oxfordjournals.org/content/134/12/3632

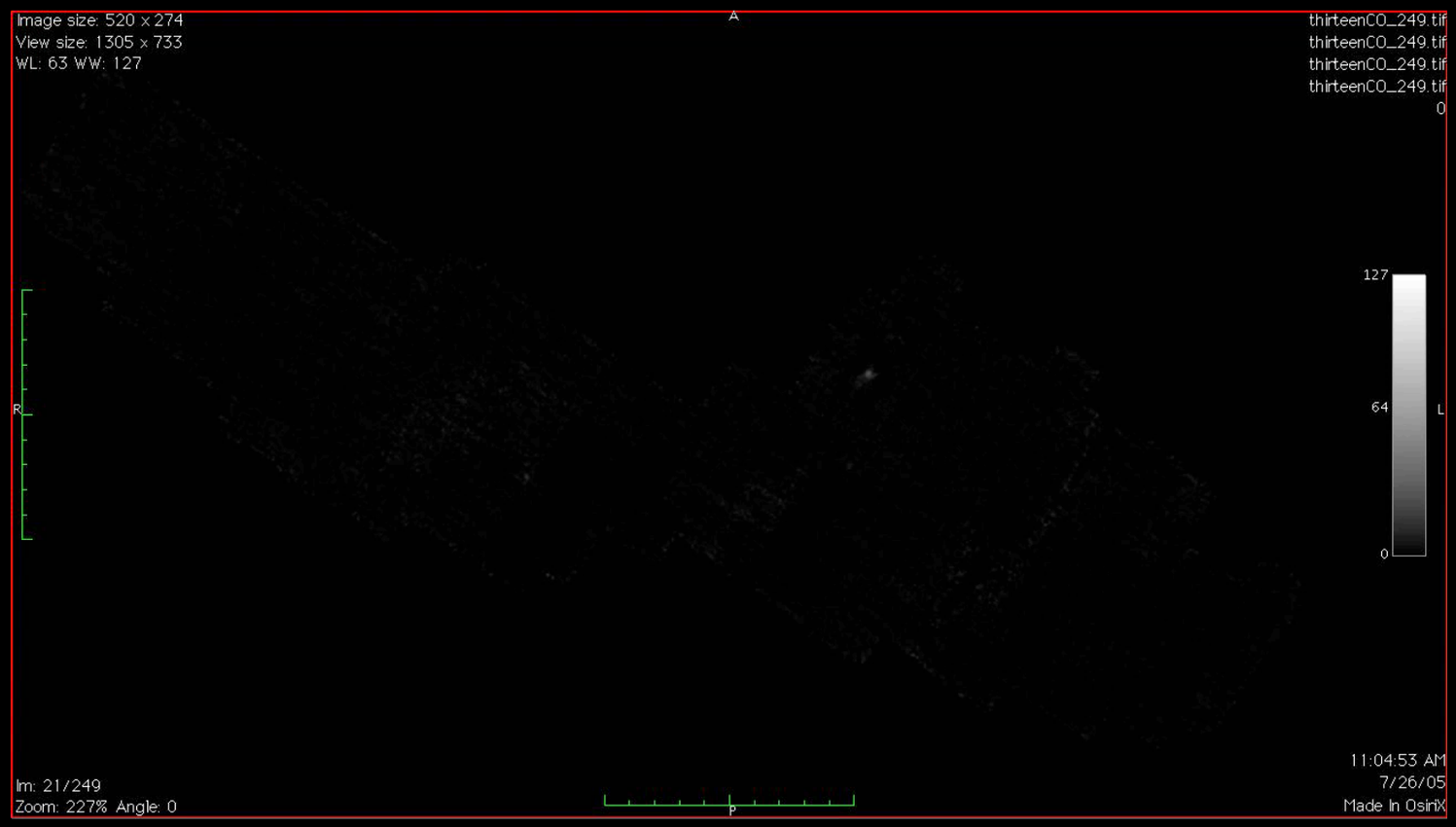
ASTRONOMICAL MEDICINE

“KEITH”



“z” is depth into head

“PERSEUS”



“z” is line-of-sight velocity

ASTRONOMICAL MEDICINE

mage size: 520 x 274
iew size: 1305 x 733
L: 63 WW: 127

mm peak (Enoch et al. 2006)

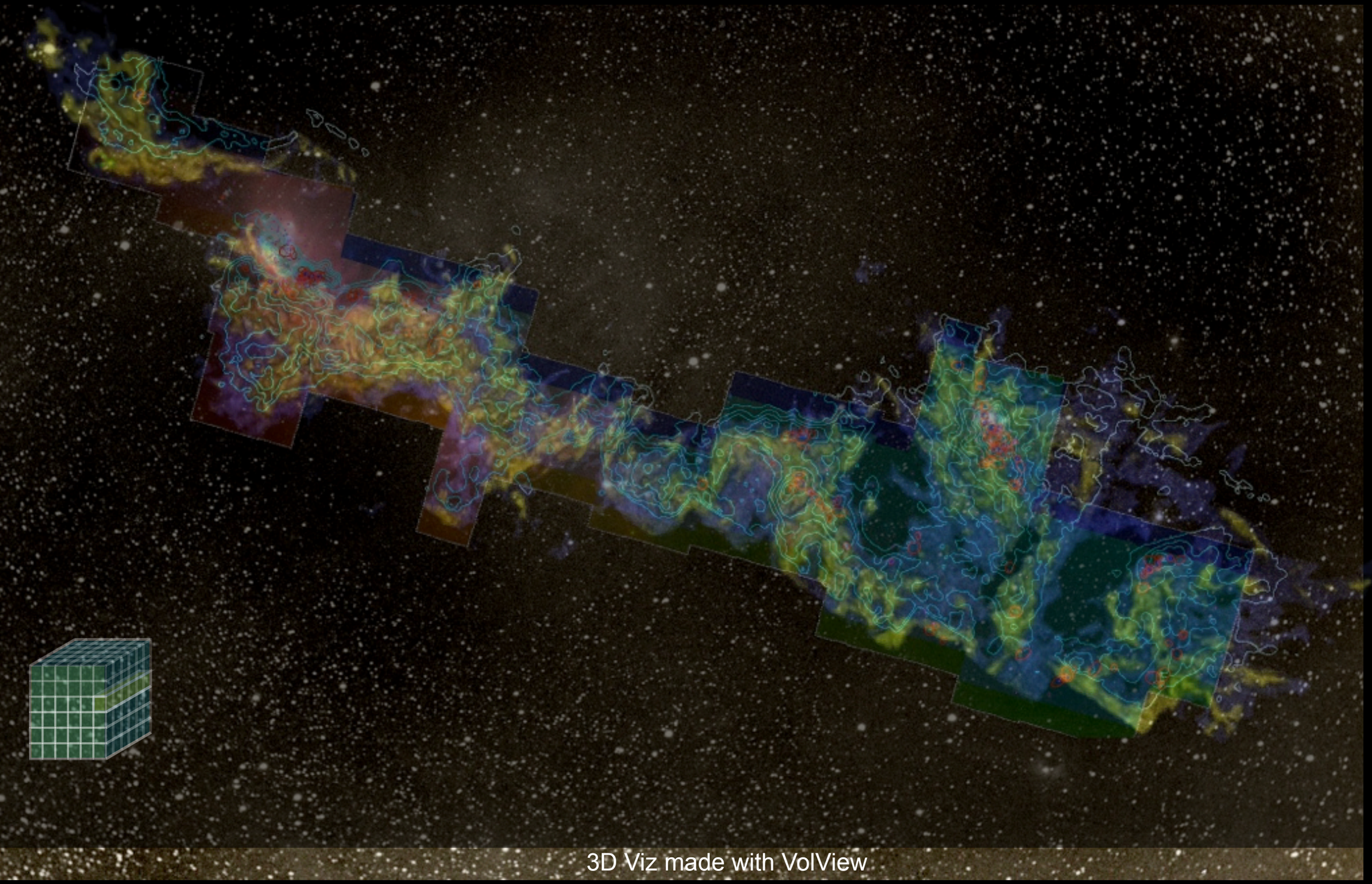
sub-mm peak (Hatchell et al. 2005, Kirk et al. 2006)

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

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

Optical image (Barnard 1927)

m: 1/249
oom: 227% Angle: 0

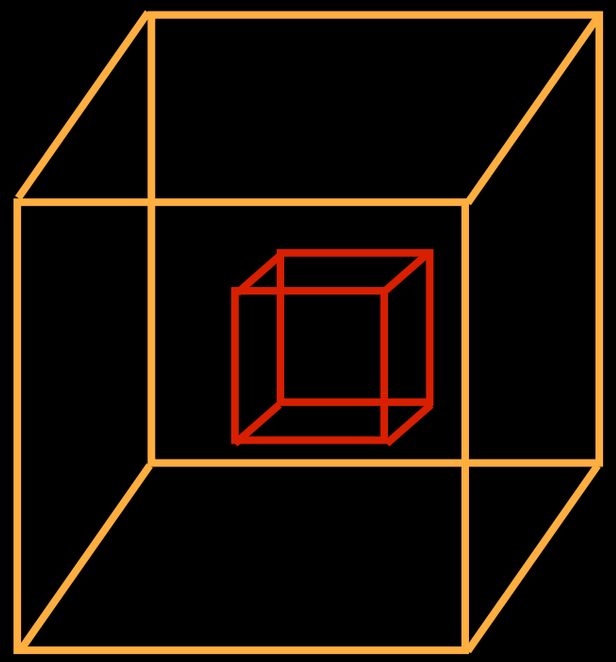


3D Viz made with VolView

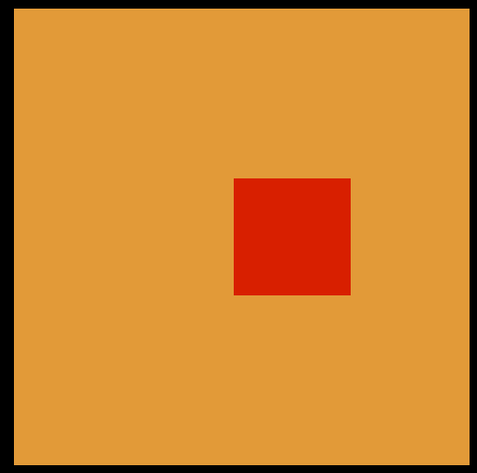
COMPLETE

LINKED VIEWS OF HIGH-DIMENSIONAL DATA

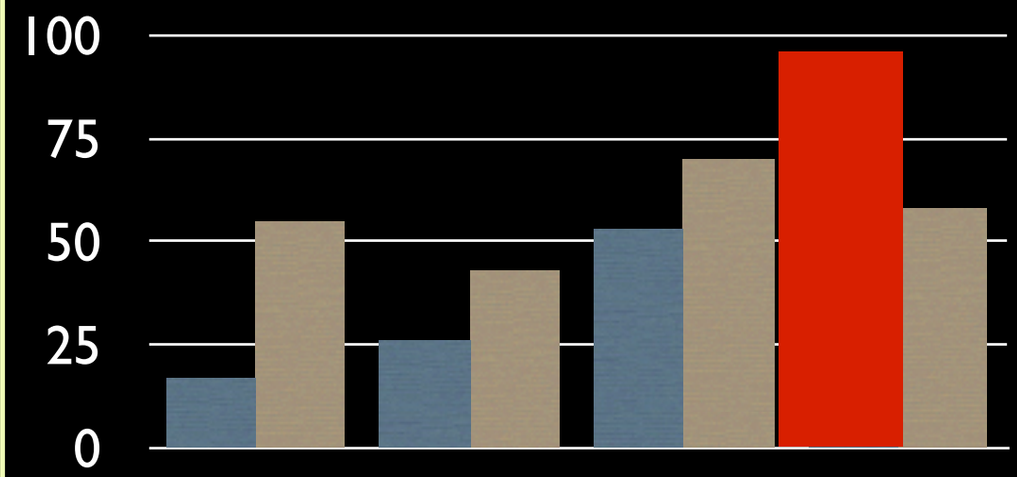
John Tukey



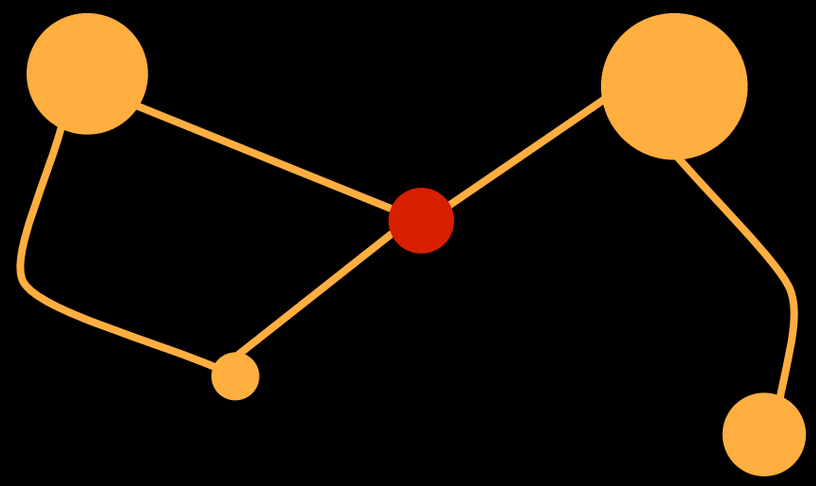
3D



2D

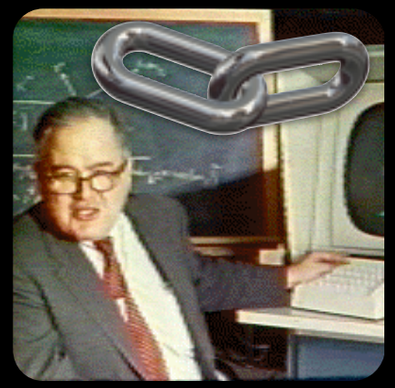


Data Abstraction



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

JOHN TUKEY'S LEGACY



PRIM-9

PRIM-H

DataDesk®

XGobi

GGobi

glue
multidimensional data exploration

RGGobi

Microsoft Power BI

Spotfire®

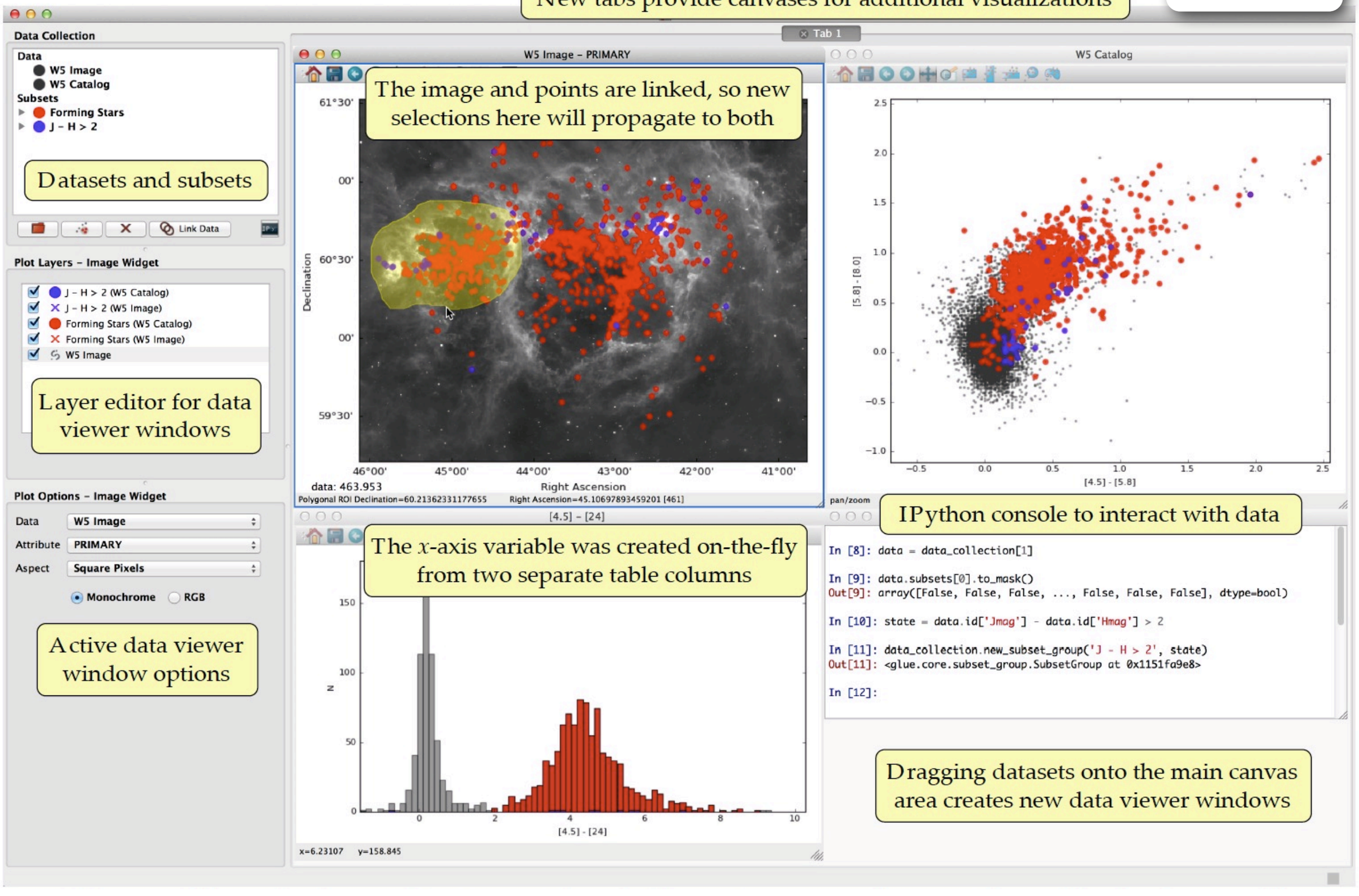
Polaris

+ableau SOFTWARE

1970 1980 1990 2000 2010

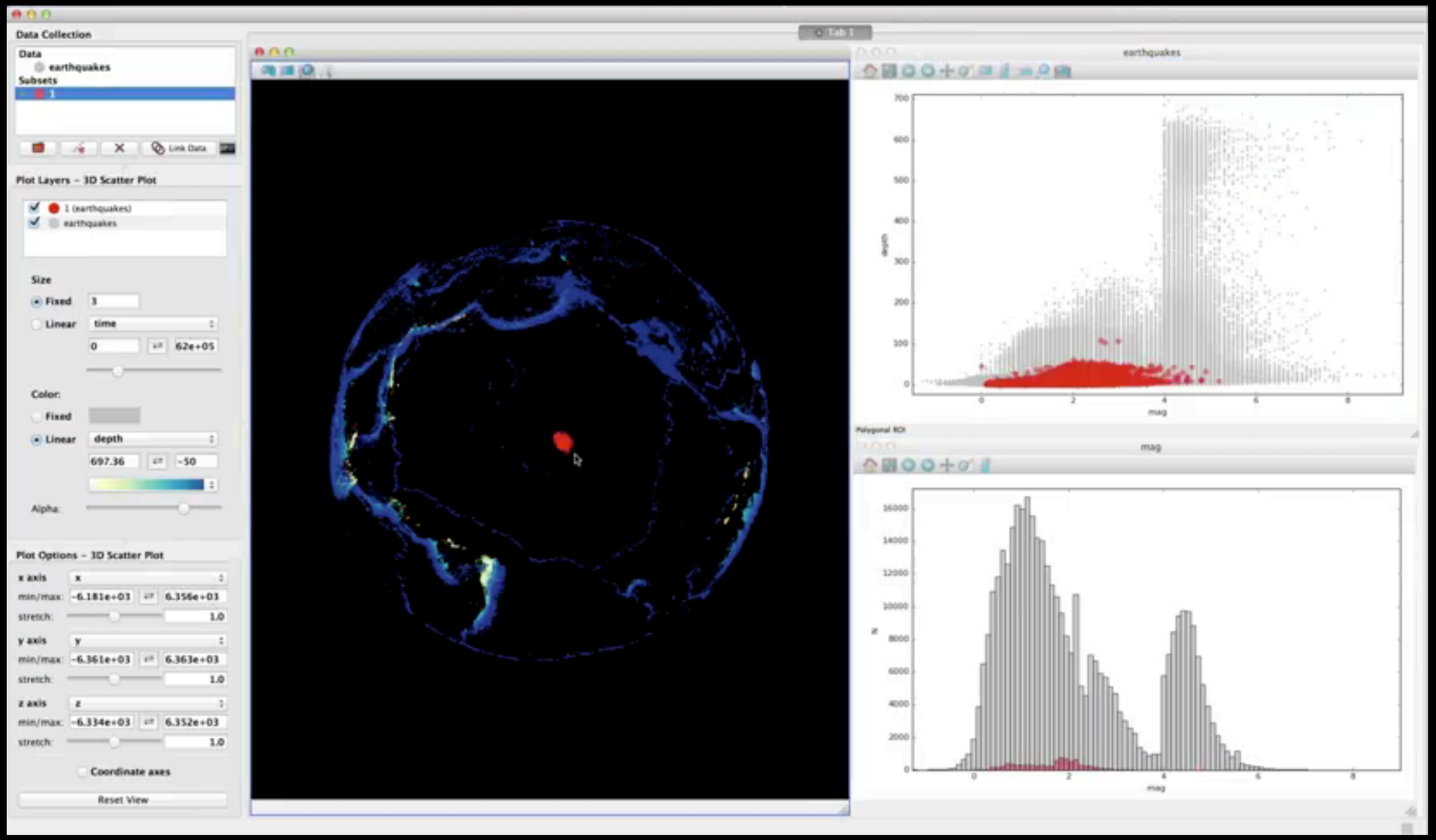
LINKED VIEWS OF HIGH-DIMENSIONAL DATA (IN PYTHON)

GLUE



LINKED VIEWS OF HIGH-DIMENSIONAL DATA (IN PYTHON)

GLUE

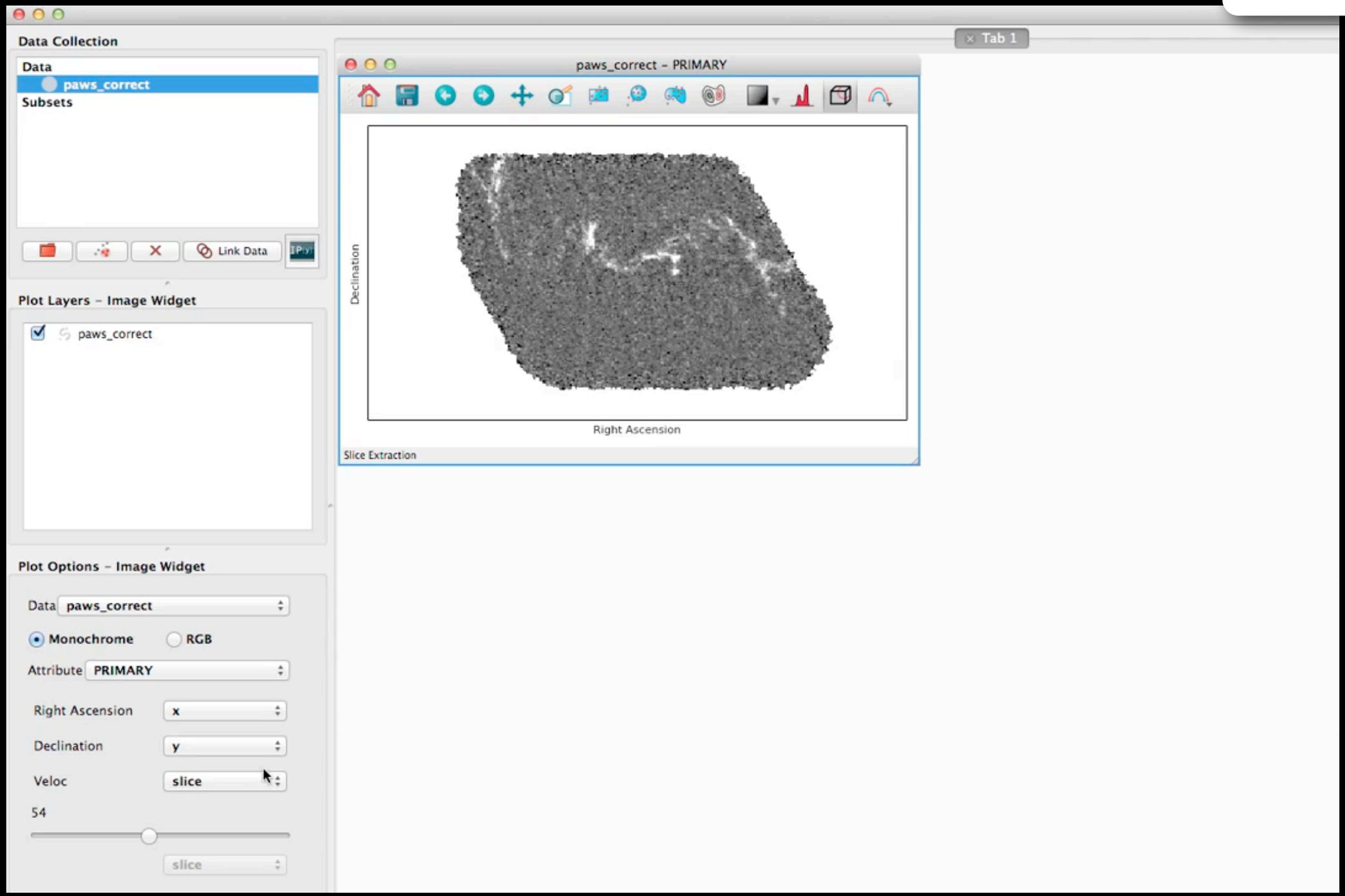


video by Tom Robitaille, lead glue developer

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

LINKED VIEWS OF HIGH-DIMENSIONAL DATA (IN PYTHON)

GLUE

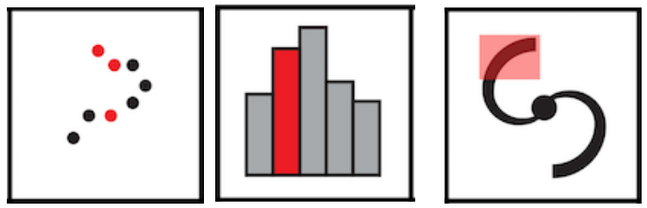


video by Chris Beaumont, glue developer

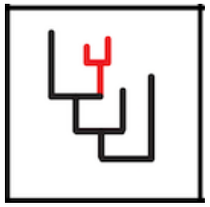
glue created by: C. Beaumont, M. Borkin, P. Qian, T. Robitaille, and A. Goodman, PI

glue
multidimensional data exploration

Linked Views



standard
1D, 2D & 3D
plots

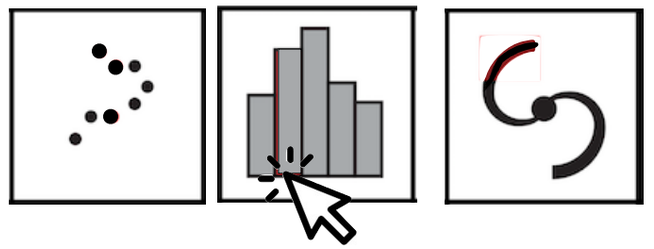


custom
plots

glue

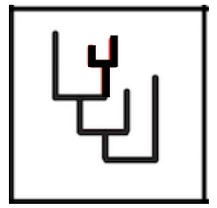
multidimensional data exploration

Linked Views



standard
1D, 2D & 3D
plots

highlight live or
algorithmic selections
with Boolean logic



custom
plots

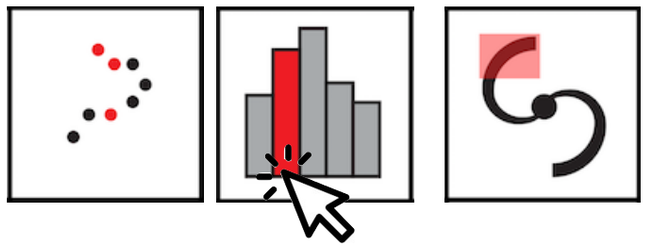
glue

multidimensional data exploration

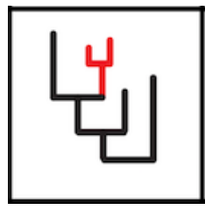
Multiple Data Sets at Once

link data files' attributes

+Linked Views



highlight live or algorithmic selections
with Boolean logic



glue

multidimensional data exploration

built-in

standard data loaders

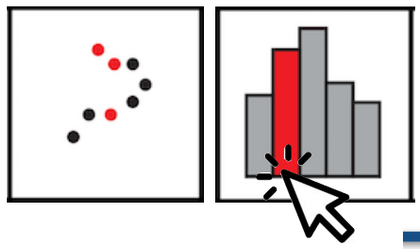
Data File 1

Data File 2

Data File N

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

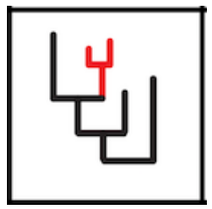
link data files' attributes



highlight live or algorithmic selections

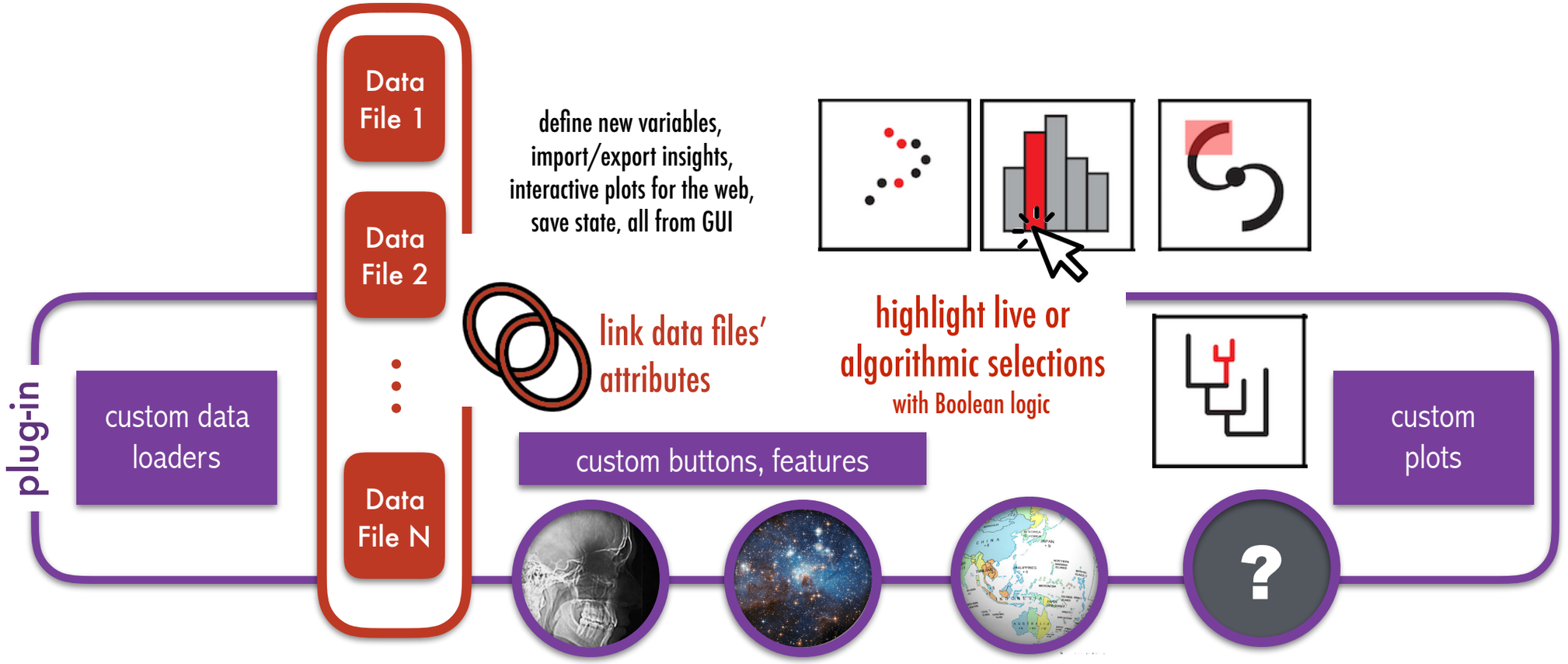
with Boolean logic

standard 1D, 2D & 3D plots



glue

multidimensional data exploration



glue

multidimensional data exploration

built-in

standard data

user setup "input formats"

plug-in

custom data loaders

Data File 1

Data File 2

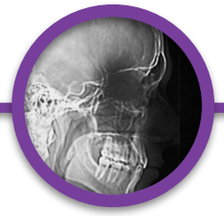
Data File N

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

link data files' attributes

highlight live or algorithmic selections with Boolean logic

custom buttons, features



?

built-in

standard 1D, 2D & 3D plots

user setup "output formats"

plug-in

custom plots

glue

multidimensional data exploration

built-in

standard data loaders

Data File 1

Data File 2

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

standard 1D, 2D & 3D plots

link data files' attributes

highlight live or algorithmic selections with Boolean logic

custom buttons, features

custom plots

plug-in

custom data loaders

+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

multidimensional data exploration

built-in

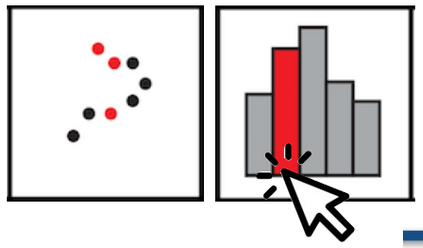
standard data loaders

Data File 1

Data File 2

Data File N

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



standard 1D, 2D & 3D plots

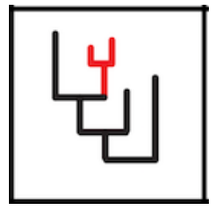
link data files' attributes

highlight live or algorithmic selections with Boolean logic

plug-in

custom data loaders

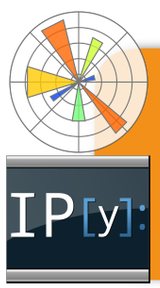
custom buttons, features



custom 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

glueviz.org

glue

multidimensional data exploration

your handout

built-in

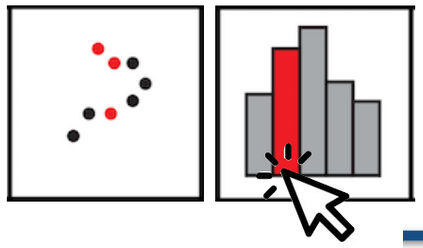
standard data loaders

Data File 1

Data File 2

Data File N

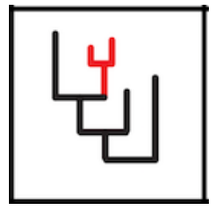
define new variables, import/export insights, interactive plots for the web, save state, all from GUI



standard 1D, 2D & 3D plots

link data files' attributes

highlight live or algorithmic selections with Boolean logic

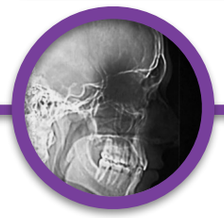


custom plots

plug-in

custom data loaders

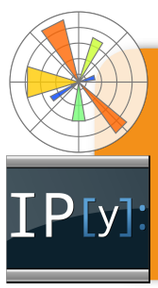
custom buttons, features



?

+options

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



access to all matplotlib functions through built-in IPython terminal

jupyter

run & interact with glue from Jupyter notebook & other tools

glueviz.org

Which Parts are Novel?

built-in

standard data loaders

plug-in

custom data loaders

linking data files with shared attributes

Data File 1

Data File N

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

link data files' attributes

highlight live or algorithmic selections with Boolean logic

standard 1D, 2D & 3D plots

arbitrary 2D & 3D selections

custom plots

custom buttons, features

?

+options

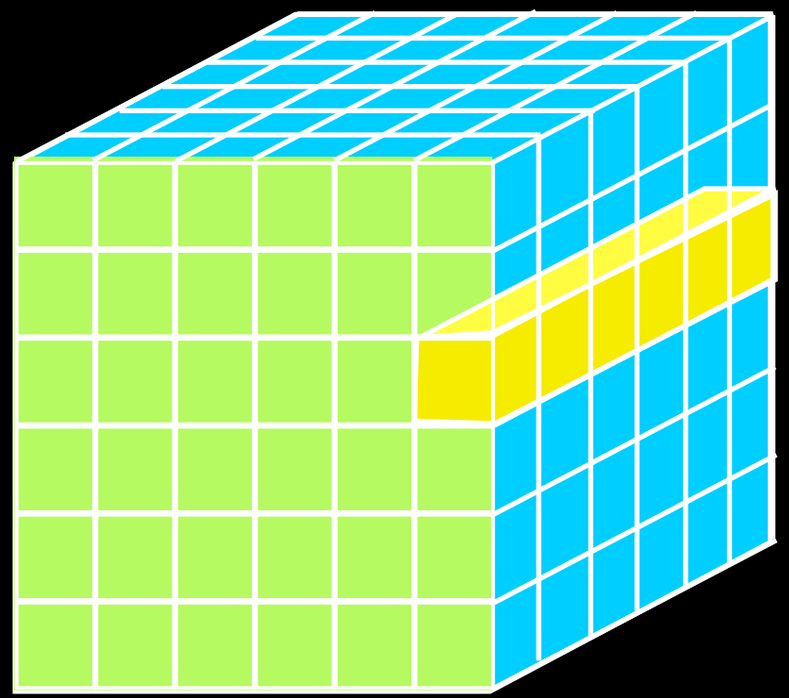
user config.py file (loaders, colors, plot types, +)

access to all matplotlib functions through built-in IPython terminal

run & interact with glue from Jupyter notebook & other tools

connection to Jupyter notebook

glueviz.org



DATA-DIMENSIONS-DISPLA

explaining to astronomers

1D: Columns = “Spectra”, “SEDs” or “Time Series” (x-y Graphs)
2D: Faces or Slices = “Images”
3D: Volumes = “3D Renderings”, “2D Movies”
4D: Time Series of Volumes = “3D Movies”

Draft version July 27, 2017
Typeset using LaTeX **preprint** style in AASTeX61

PHYSICAL PROPERTIES OF LARGE-SCALE GALACTIC FILAMENTS

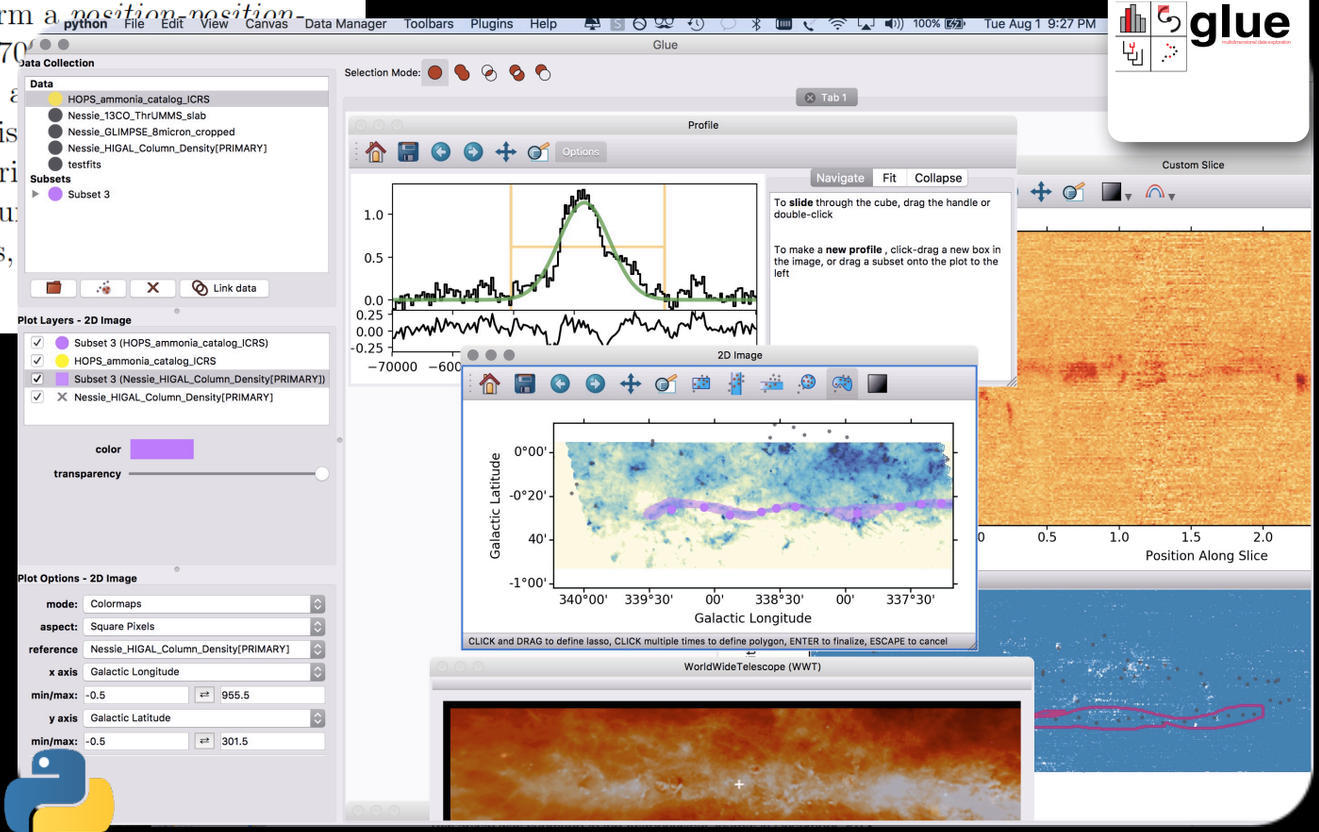
Catherine Zucker, Cara Battersby, Alyssa Goodman[1]

[1] *Harvard-Smithsonian Center for Astrophysics*

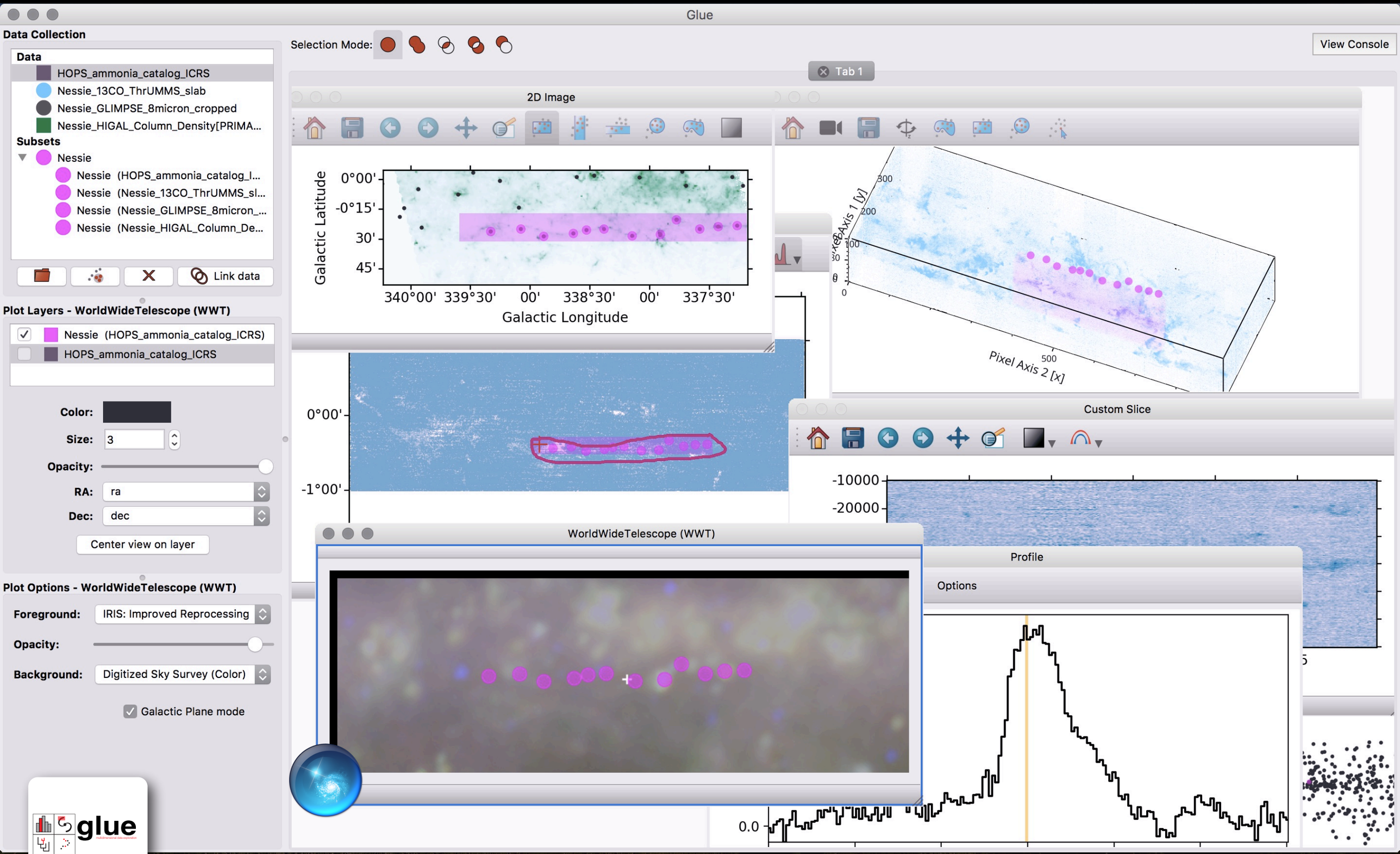
Abstract

The characterization of our Galaxy's longest filamentary gas features has been the subject of a number of studies in recent years, producing not only a sizeable sample of large-scale filaments, but also confusion as to whether all these features (e.g. "Bones", "Giant Molecular Filaments") are essentially the same. They are not. We undertake the first standardized analysis of the physical properties (densities, temperatures, morphologies, radial profiles) and kinematics of large-scale filaments in the literature. We expand and improve upon prior analyses by using the same data sets, techniques, and spiral arm models to disentangle the filaments' inherent properties from selection criteria and methodology. Our results suggest that the myriad filament finding techniques are uncovering different physical structures, with quantities length (10-268 pc), width (1-40 pc), mass (3×10^3 M$_\odot$ $-$ 1.1×10^6 M$_\odot$), aspect ratio (3:1 - 104:1), and dense gas fraction (0.2-100%) varying by at least an order of magnitude across the sample of 45 filaments. We perform a *position-position-velocity* (*p-p-v*) analysis on a subset of the filaments and find that while 60%-70
the Galaxy, only 30-45% also exhibit kinematic proximity to purported spiral a
space defined by aspect ratio, temperature, and density, we broadly distinguis
egories, which could be indicative of different formation mechanisms or histori
"Bone-like" filaments show the most potential for tracing gross spiral structu
other categories could simply be large concentrations of molecular gas (GMCs,

2017
"The Bone Wars"
(& glue)



WWT INTEGRATION



WWT INTEGRATION

Glue

Data Collection

Data
- Nessie_HIGAL_Column_Density[PRIMARY]
- HOPS_dense_gas_catalog

Subsets
- Nessie_Boundary

Link data

Plot Layers

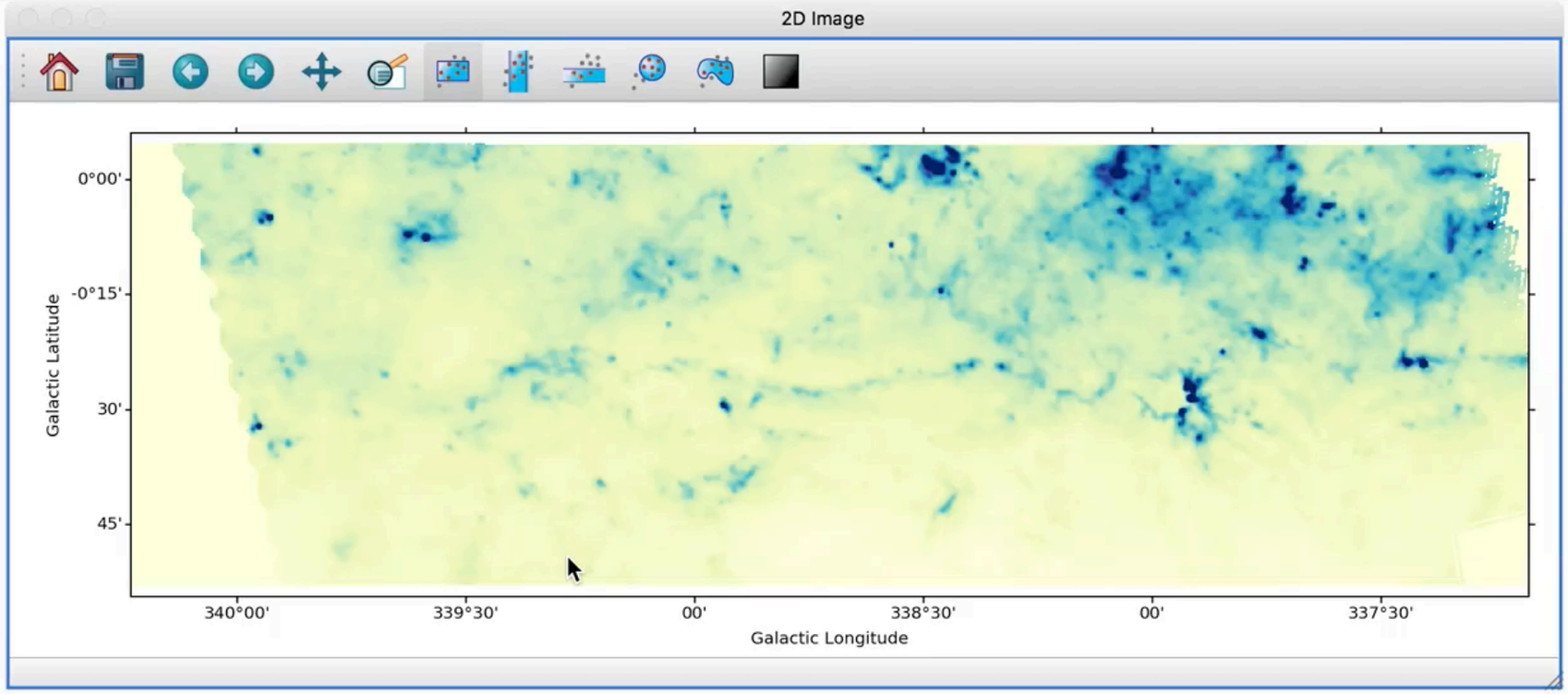
Plot Options

Selection Mode:

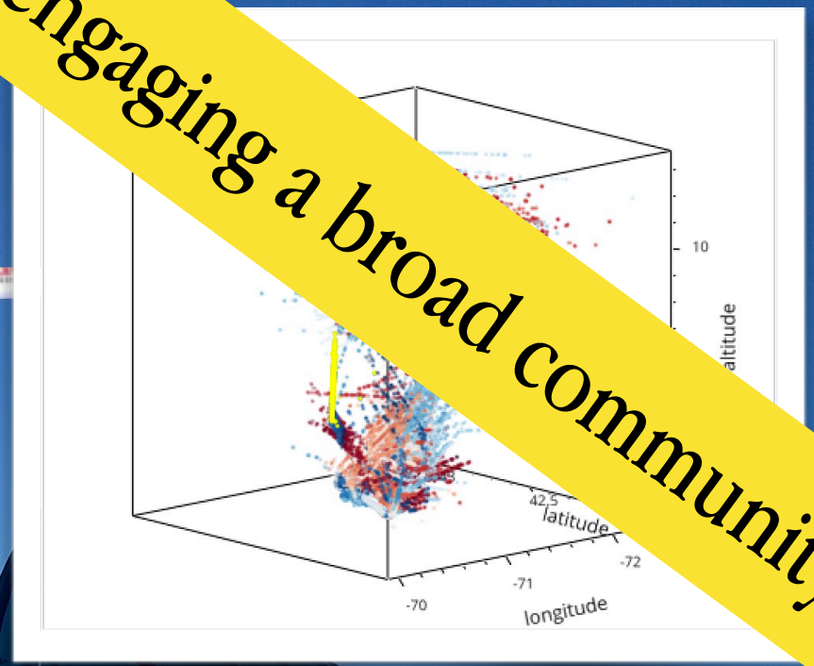
View Console

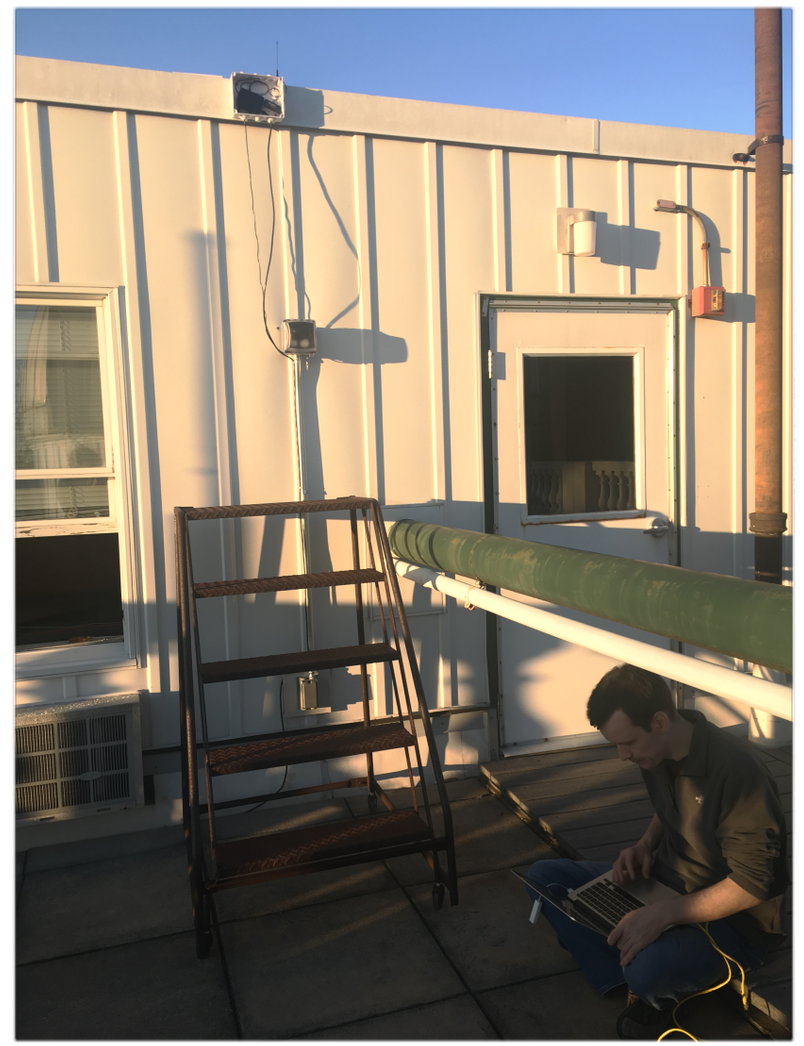
Tab 1

2D Image

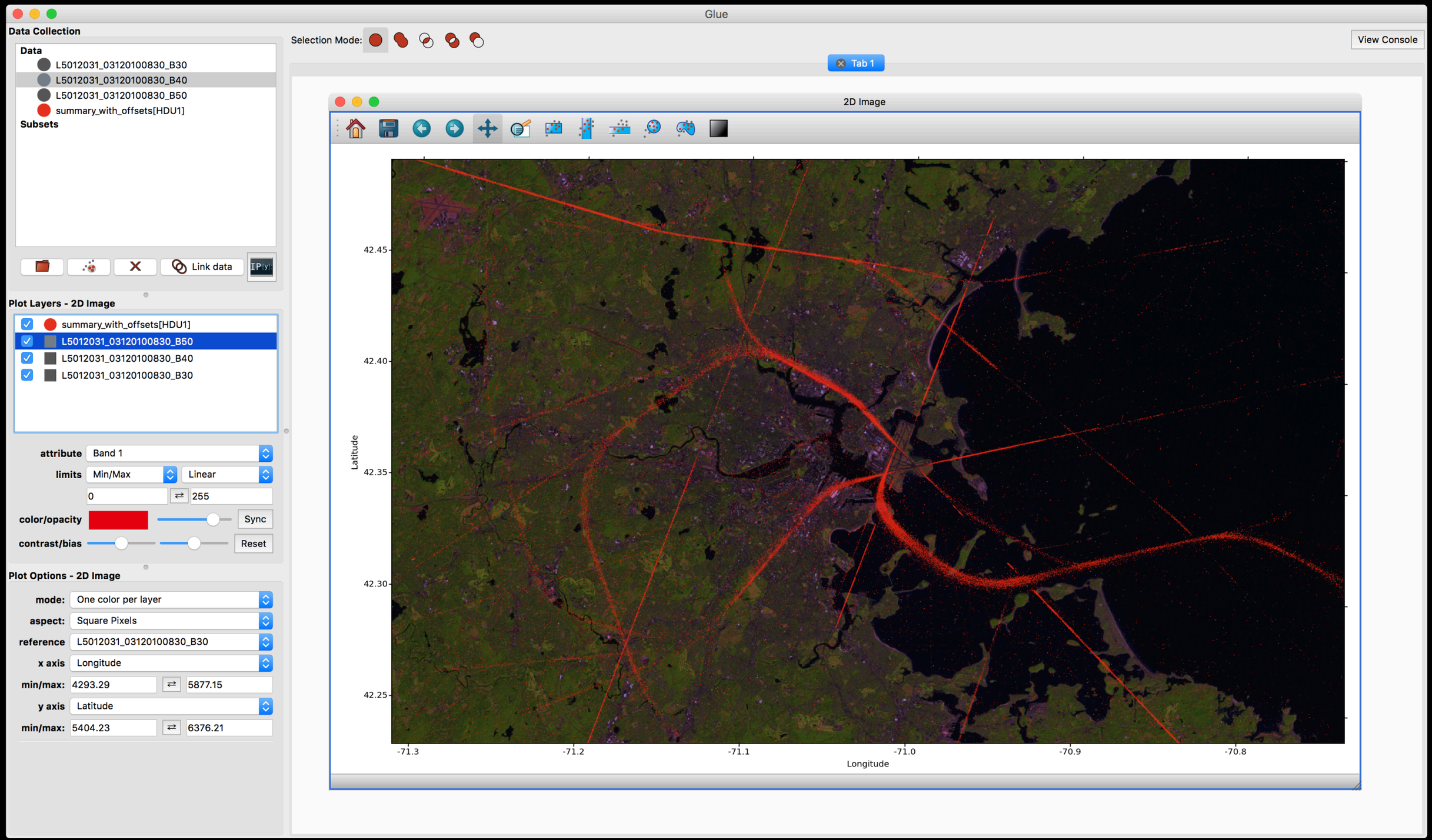


engaging a broad community





TRACKING PLANES (GIS TOOLS)



CUSTOMIZATION FOR BREADTH

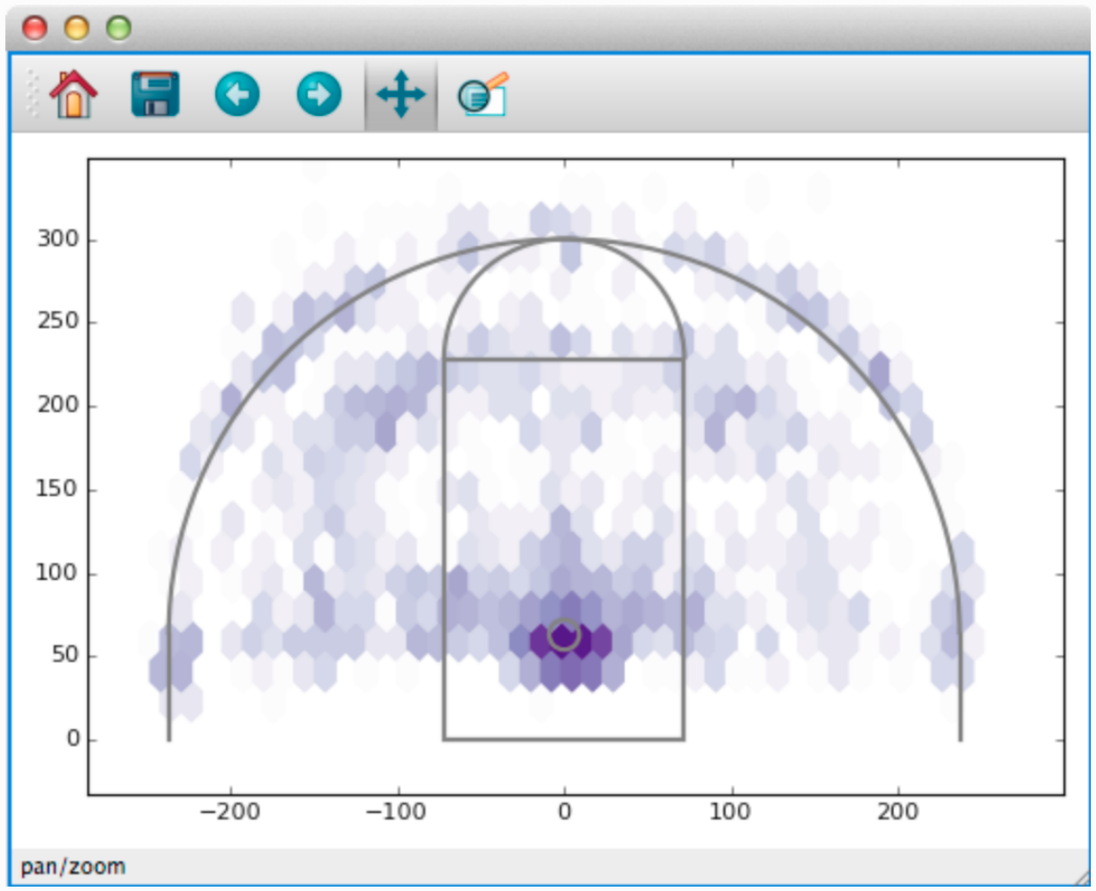
dollars logo - Google Search | Building Custom Data Viewers — Glue 0.9.0 documentation | balzer82.g

Glue

Search docs

Installing Glue
Getting started
User Interface Guide
3D viewers in Glue
Using the IPython terminal in Glue
Working with Data objects
Starting Glue from Python
Configuring Glue via a startup file
Customizing your Glue environment
Programmatically configuring plots
Building Custom Data Viewers
The Goal: Basketball Shot Charts
Shot Chart Version 1: Heatmap and plot
Shot Chart Version 2: Court markings
Shot Chart Version 3: Widgets
Shot Chart Version 4: Selection
Viewer Subclasses
Valid Function Arguments
UI Elements
Other Guidelines
Watching data for changes
Read the Docs v: stable

Building Custom Data Viewers



Glue's standard data viewers (scatter plots, images, histograms) are useful in a wide variety of data exploration settings. However, they represent a *tiny* fraction of the ways to view a particular dataset. For this reason, Glue provides a simple mechanism for creating custom visualizations using matplotlib.

Creating a `custom data viewer` requires writing a little bit of Matplotlib code but involves little to no GUI programming. The next several sections illustrate how to build a custom data viewer by

JUPYTER LABS

glue "on the web"

Pre-Alpha Jupyter Lab Dem

127.0.0.1:8888/lab

IPython

File Notebook Editor Terminal Console Help

Files Commands

CONSOLE

Clear Cells
Execute Cell Shift-Enter
Interrupt Kernel
New Julia 0.4.5 console
New Python 2 console
New Python 3 console
New R console
Switch Kernel

EDITOR

Close all files
Line Numbers
Line Wrap
Match Brackets
Save File
Vim Mode
Vim Mode Off

FILE OPERATIONS

Close All Ctrl-Shift-Q
Close Document Ctrl-Q
New Notebook Ctrl-Shift-N
New Text File Ctrl-O
Revert Document
Save Document Cmd-S

HELP

About JupyterLab
FAQ
IPython Reference
JupyterLab Launcher
Markdown Reference
Matplotlib Reference
Notebook Tutorial
Numpy Reference
Pandas Reference
Python Reference
Scipy Lecture Notes
Scipy Reference
SymPy Reference

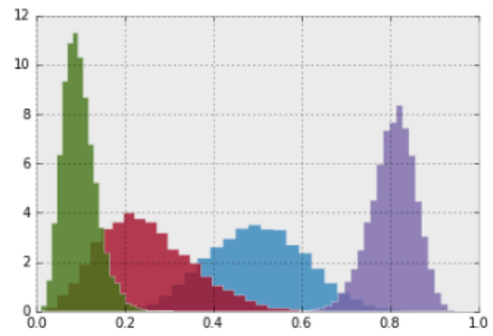
IMAGE WIDGET

Reset Zoom
Zoom In
Zoom Out

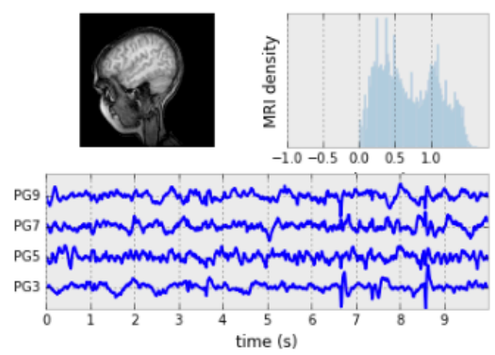
Untitled.ipynb | Terminal 1 | Python 3 (1)

```
?         -> Introduction and overview of IPython's features.
%quickref -> Quick reference.
help      -> Python's own help system.
object?   -> Details about 'object', use 'object??' for extra
details.
```

```
In [1]: %matplotlib inline
        from numpy.random import beta
        import matplotlib.pyplot as plt
        plt.style.use('bmh')

        def plot_beta_hist(a, b):
            plt.hist(beta(a, b, size=10000), histtype="stepfilled",
                     bins=25, alpha=0.8, normed=True)
            return

        plot_beta_hist(10, 10)
        plot_beta_hist(4, 12)
        plot_beta_hist(50, 12)
        plot_beta_hist(6, 55)
```




```
In [2]: %run ~/Downloads/mri_with_eeg.py

  loading eeg /Users/fperez/usr/conda/lib/python3.5/site-packages/mat
  plotlib/mpl-data/sample_data/eeg.dat
```




```
In [ ]:
```

Launcher | mri_with_eeg.py

```
#!/usr/bin/env python

"""
This now uses the imshow command instead of pc
faster*
"""
from __future__ import division, print_function

import numpy as np

from matplotlib.pyplot import *
from matplotlib.collections import LineCollection
import matplotlib.cbook as cbook
# I use if 1 to break up the different regions of code visually

if 1:   # load the data
    # data are 256x256 16 bit integers
    dfile = cbook.get_sample_data('s1045.ima.gz')
    im = np.fromstring(dfile.read(), np.uint16).astype(float)
    im.shape = 256, 256

if 1:  # plot the MRI in pcolor
    subplot(221)
    imshow(im, cmap=cm.gray)
    axis('off')

if 1:  # plot the histogram of MRI intensity
    subplot(222)
    im = np.ravel(im)
    im = im[np.nonzero(im)]  # ignore the background
    im = im/(2.0**15)  # normalize
    hist(im, 100)
    xticks([-1, -.5, 0, .5, 1])
    yticks([])
    xlabel('intensity')
    ylabel('MRI density')

if 1:   # plot the EEG
    # load the data

    numSamples, numRows = 800, 4
    eegfile = cbook.get_sample_data('eeg.dat', asfileobj=False)
    print('loading eeg %s' % eegfile)
    data = np.fromstring(open(eegfile, 'rb').read(), float)
    data.shape = numSamples, numRows
    t = 10.0 * np.arange(numSamples, dtype=float)/numSamples
    ticklocs = []
    ax = subplot(212)
    xlim(0, 10)
    xticks(np.arange(10))
    dmin = data.min()
    dmax = data.max()
    dr = (dmax - dmin)*0.7  # Crowd them a bit.
    y0 = dmin
    y1 = (numRows - 1) * dr + dmax
    ylim(y0, y1)

    segs = []
    for i in range(numRows):
```

Running

CODAP

web & outreach

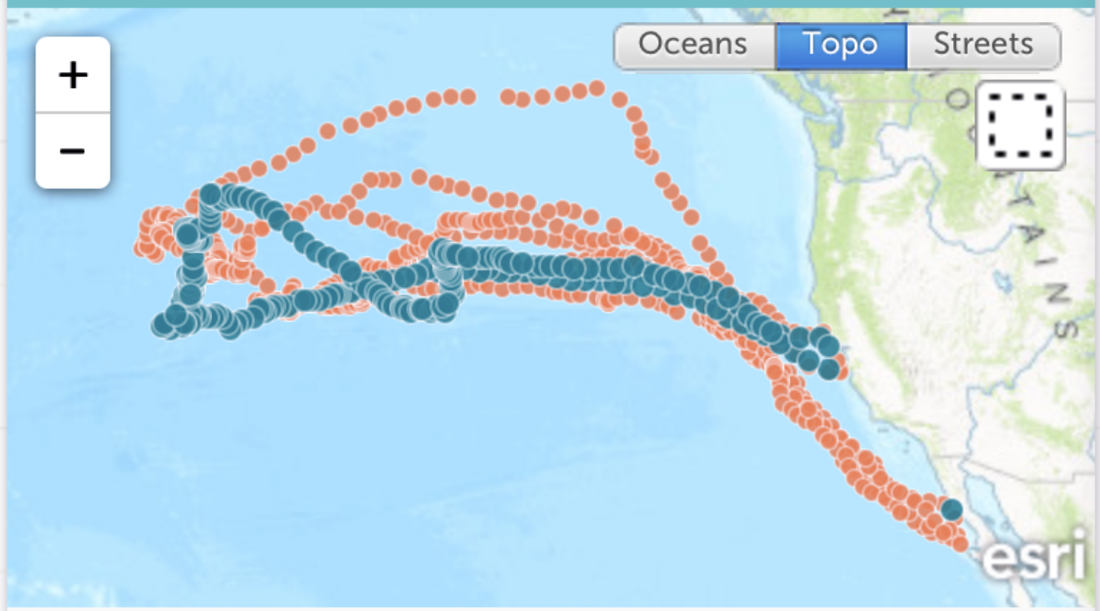
Four Seals UNSAVED Version 2.0 (0395)

Tables Graph Map Slider Calc Text Undo Redo Tiles

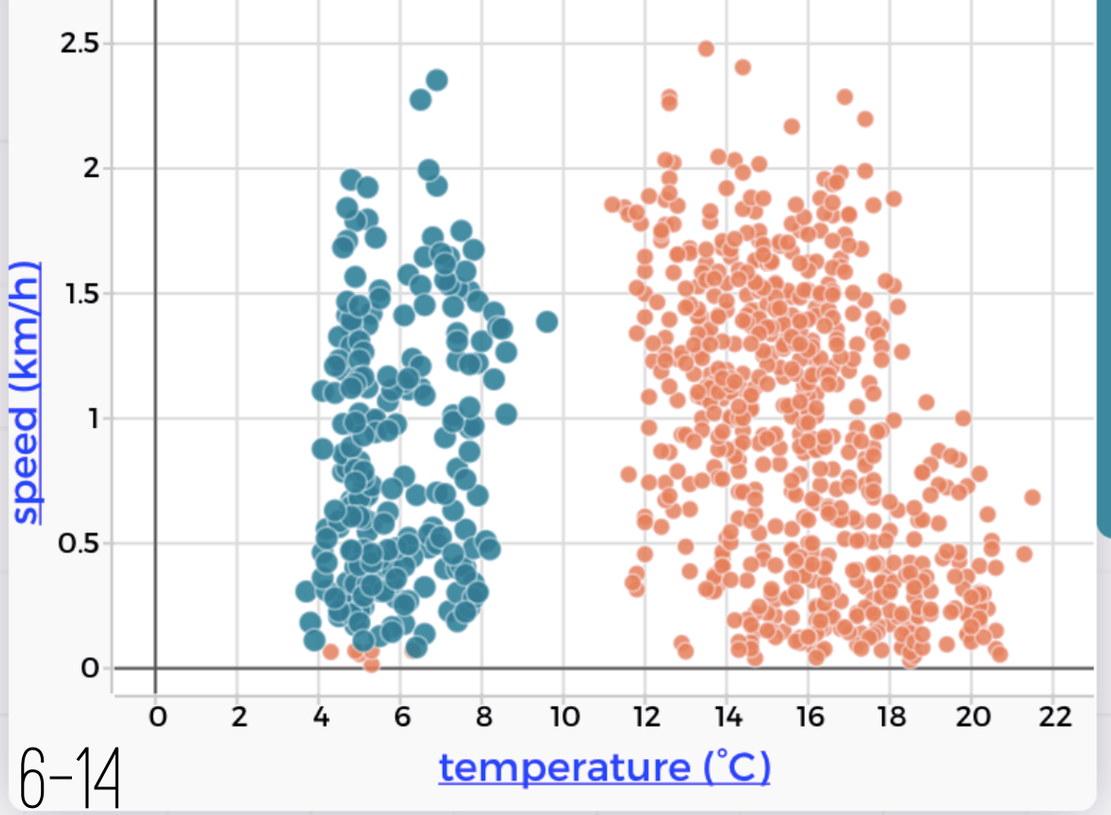
index	animal_	species
1	546	Elephant Seal
2	541	Elephant Seal
3	536	Elephant Seal
4	528	Elephant Seal

index	day	date	month	latitude	longitude	dist... e (km	spe... km/h	depth (m)	tem... ure (°C	chl... ophyl	
100	99	8/30/20...	Augu...	41.8	-162.27	15.54	0.65	-608	4.8	0.1	1.5
101	100	8/31/20...	Augu...	42.27	-162.16	26.78	1.12	-371	6.2	0.2	1.5
102	101	9/1/2005	Sept...	42.92	-161.88	37.8	1.57	-332	6.2	0.3	1.5
103	102	9/2/2005	Sept...	43.08	-161.83	9.32	0.39	-368	5.5	0.3	1.5
104	103	9/3/2005	Sept...	43.06	-161.64	7.81	0.33	-291	6.6	0.2	1.5

Measurements



Measurements



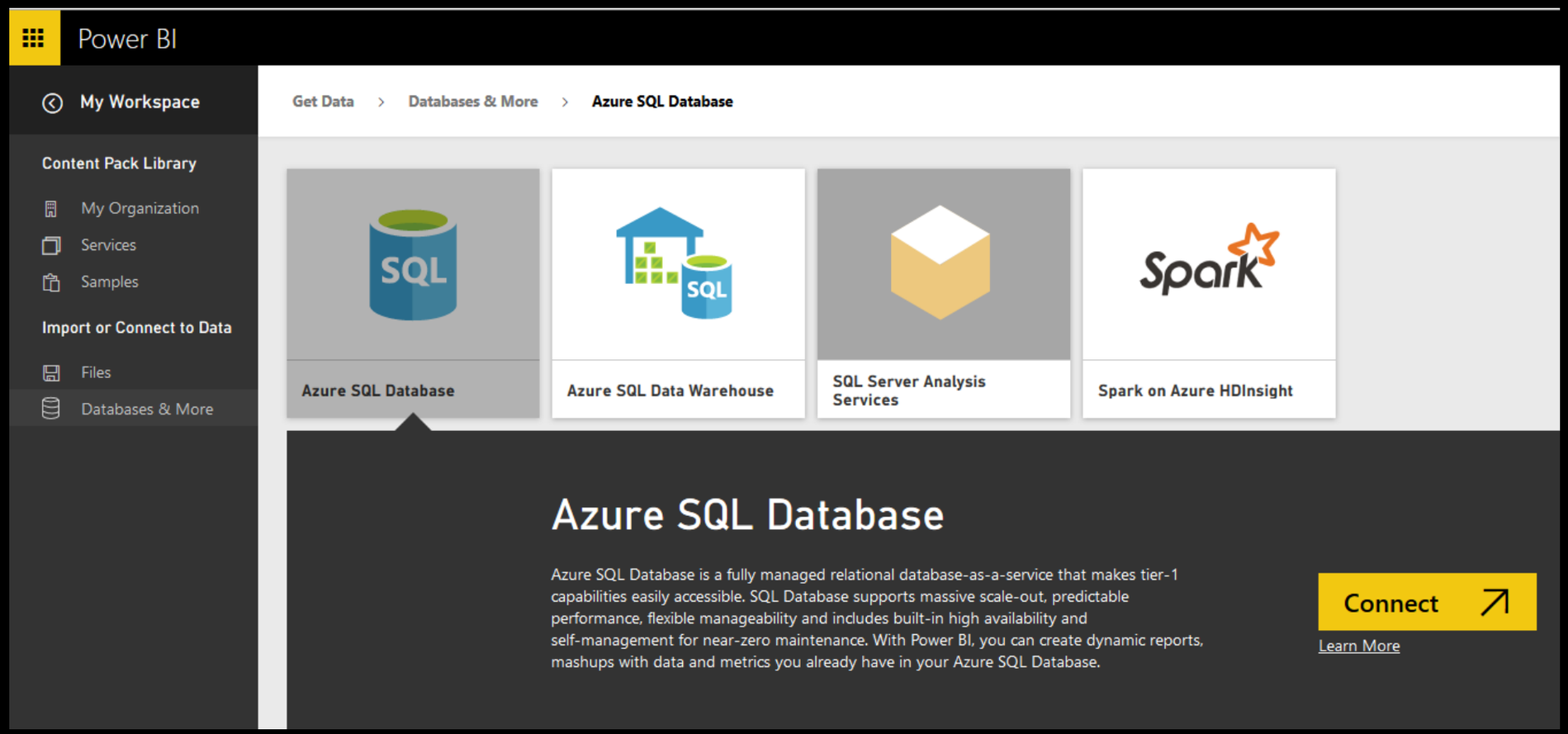
LINKED VIEWS & DATA SCIENCE FOR GRADES 6-14

Common Online Data Analysis Platform (CODAP), from Concord Consortium

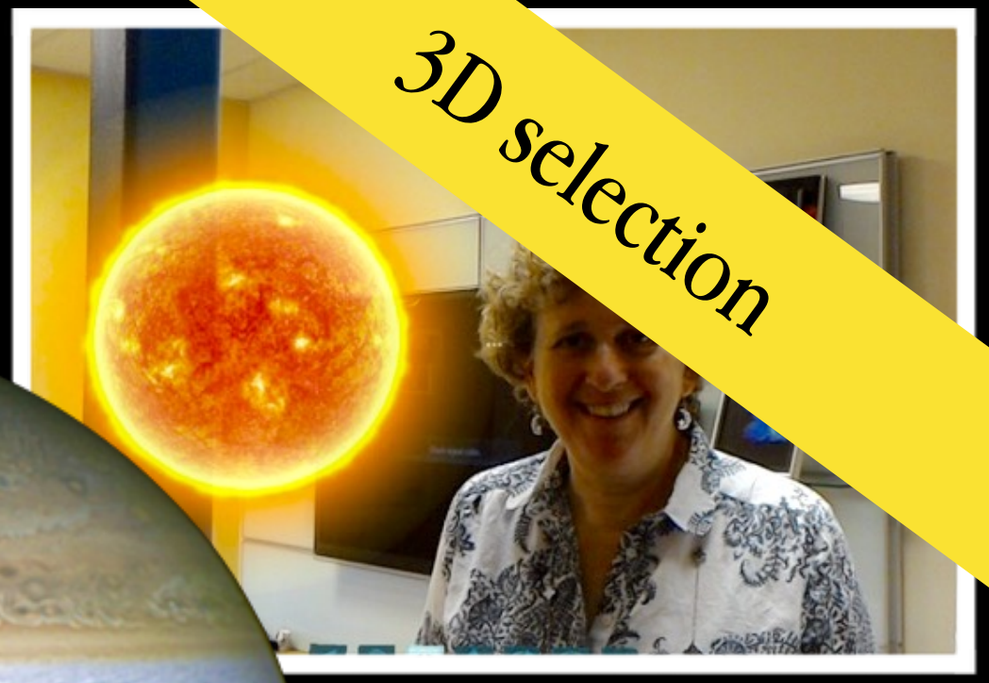
REMOTE DATA ACCESS++

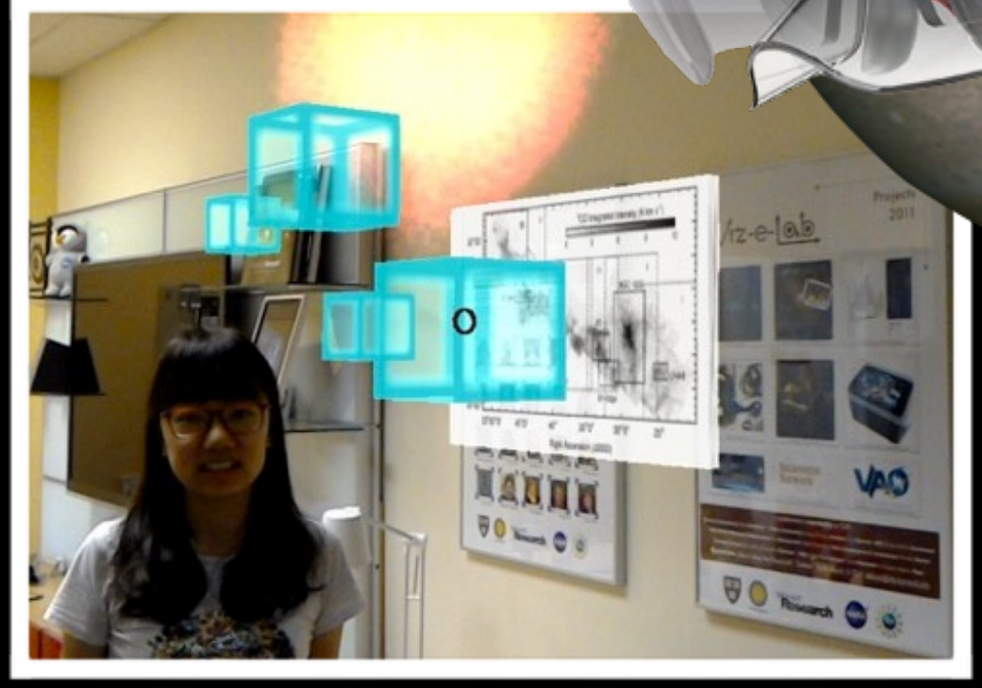
"BIG" Data

+data abstraction layer
+replace matplotlib with OpenGL-backed 3D viewer
+data shaders



THE CHALLENGE OF 3D SELECTION





What (and How) Can Linked-View Visualization tell us about the Universe, and Brains?

Alyssa A. Goodman
Harvard-Smithsonian Center for Astrophysics & Radcliffe Institute
with Chris Beaumont, Michelle Borkin, Penny Qian & Tom Robitaille

@aagie
@glueviz
@astrofrog

glueviz.org
github.com/glue-viz
Tom Robitaille, lead developer

NASA James Webb
Space Telescope
+NSF-Scientific Software Elements