Abstract: In 1610, when Galileo pointed his small telescope at Jupiter, he drew sketches to record what he saw. After just a few nights of observing, he understood his sketches to be showing moons orbiting Jupiter. It was the visualization of Galileo's observations that led to his understanding of a clearly Sun-centered solar system, and to the revolution this understanding then caused. Similar stories can be found throughout the history of Astronomy, but visualization has never been so essential as it is today, when we find ourselves blessed with a larger wealth and diversity of data, per astronomer, than ever in the past. In this talk, I will focus on how modern tools for interactive "linked-view" visualization can be used to gain insight. Linked views, which dynamically update all open graphical displays of a data set (e.g. multiple graphs, tables and/or images) in response to user selection, are particularly important in dealing with so-called "high-dimensional data." These dimensions need not be spatial, even though, e.g. in the case of radio spectral-line cubes or optical IFU data), they often are. Instead, "dimensions" should be thought of as any measured attribute of an observation or a simulation (e.g. time, intensity, velocity, temperature, etc.). The best linked-view visualization tools allow users to explore relationships amongst all the dimensions of their data, and to weave statistical and algorithmic approaches into the visualization process in real time. Particular tools and services will be highlighted in this talk, including: Glue (glueviz.org), the ADS All Sky Survey (adsass.org), WorldWide Telescope (worldwidetelescope.org), yt (yt-project.org), d3po (d3po.org), and a host of tools that can be interconnected via the SAMP message-passing architecture. The talk will conclude with a discussion of future challenges, including the need to educate astronomers about the value of visualization and its relationship to astrostatistics, and the need for new technologies to enable humans to interact more effectively with large, high-dimensional data sets.

Web sites mentioned in the talk, all relevant to #AASviz, continued on reverse

.Astronomy: dotastronomy.com *'Dot-astronomy' aims to bring together an international community of astronomy researchers, developers, educators and communicators to showcase and build upon web-based projects, from outreach and education to research tools and data analysis.* #dotastronomy

ADS All-Sky Survey: adsass.org *Astronomy Papers. On the Sky. Who studies what, when, how, and why? Funded by #NASA.* #ADSAllSkySurvey or #adsass

AstroBetter: astrobetter.com *Tips and Tricks for Professional Astronomers.* #astrobetter

Astronomical Medicine: am.iic.harvard.edu *Trading tools between Astronomy and Medicine.*

*Handout from **Linking Visualization and Understanding in Astronomy**, Alyssa Goodman, January 6, 2014, AAS*
Online version: http://www.astrobetter.com/linking-visualization-and-understanding-in-astronomy-aas223

Astrometry.net: astrometry.net *An astrometric calibration service to create correct, standards-compliant astrometric meta-data for every useful astronomical image ever taken, past and future.*

astroML: astroML.org *Python module for Machine Learning and Data Mining in Astronomy.*

astropy: astropy *A community effort to develop a single core package for Astronomy in Python and foster interoperability between Python astronomy packages.* @astropy

Authorea: authorea.com *A collaborative platform for research. Write and manage your technical documents in one place.* #authorea, @authorea

Color Brewer: colorbrewer2.org *Color Advice for Cartography (and quantitative graphics more generally!)* @ColorBrewer

D3: d3.js *D3 is a JavaScript library for manipulating documents based on data.*

d3po: d3po.org *Linked views using d3, on the web. Import from Glue, Export to Authorea.* #d3po

edX: edx.org *Great online courses from the world's best universities.* Harvard's courses at harvardx.harvard.edu #edX #HarvardX

filtergraph: filtergraph.vanderbilt.edu *Flexible, interactive scatterplots and histograms in a browser.*

Glue: glueviz.org *Multidimensional data exploration. Linked Statistical Graphics. Flexible linking across data. Full scripting capability, in Python.* #glueviz

Plotly: plot.ly *Analyze and visualize data, together. Plotly is a collaborative data analysis and graphing tool.* #plotly

Seamless Astronomy: projects.iq.harvard.edu/seamlessastronomy *Linking scientific data, publications, and communities.* #seamlessastronomy

Virtual Observatory: usvao.org, www.ivoa.net, cdsportal.u-strasbg.fr *Three points of access to official VO tools and infrastructure.* #ivoa

WorldWide Telescope: worldwidetelescope.org *A free Universe Information System from Microsoft Research. Immerse yourself in a seamless beautiful environment.* #worldwidetelescope

WorldWide Telescope Ambassadors: wwtambassadors.org *WorldWide Telescope Ambassadors use the free WorldWide Telescope computer program to educate the public about Astronomy and Science.* #wwtambassadors

yt: yt-project.org *Open source, community-developed Analysis and Visualization of Astrophysical simulation data.* @yt_astro

Zooniverse: zooniverse.org *The Zooniverse is home to the internet's largest, most popular and most successful citizen science projects.* @the_zooniverse

Many additional relevant (software) links and demonstrations can be found within these papers

Scientific Visualization in Astronomy: Towards the Petascale Astronomy Era (Hassan & Fluke 2011): tinyurl.com/petastroviz *Introduces a mapping between astronomical sources of data and data representations used in general-purpose visualization tools.*

Principles of High-Dimensional Data Visualization in Astronomy (Goodman 2012): tinyurl.com/datavizprinciples *Charts a course toward ``linked view'' systems, where multiple views of high-dimensional data sets update live as a researcher selects, highlights, or otherwise manipulates, one of several open views.*

A New Approach to Developing Interactive Software Modules Through Graduate Education (Sanders, Faesi & Goodman 2013): tinyurl.com/eduviz *Tests whether interactive, educational, online software modules can be developed effectively by students as a curriculum component of an advanced science course. (Answer is yes.)*

Ten Simple Rules for the Care and Feeding of Scientific Data (Goodman et al. 2014): tinyurl.com/10simpledata *This article offers a short guide to the steps scientists can take to ensure that their data and associated analyses continue to be of value and to be recognized.*

Science you can play with (Pepe & Jenkins 2014): authorea.com/3904 *Blog Post showing how to embed d3po (javascript) output and IPython Notebooks inside Authorea.*