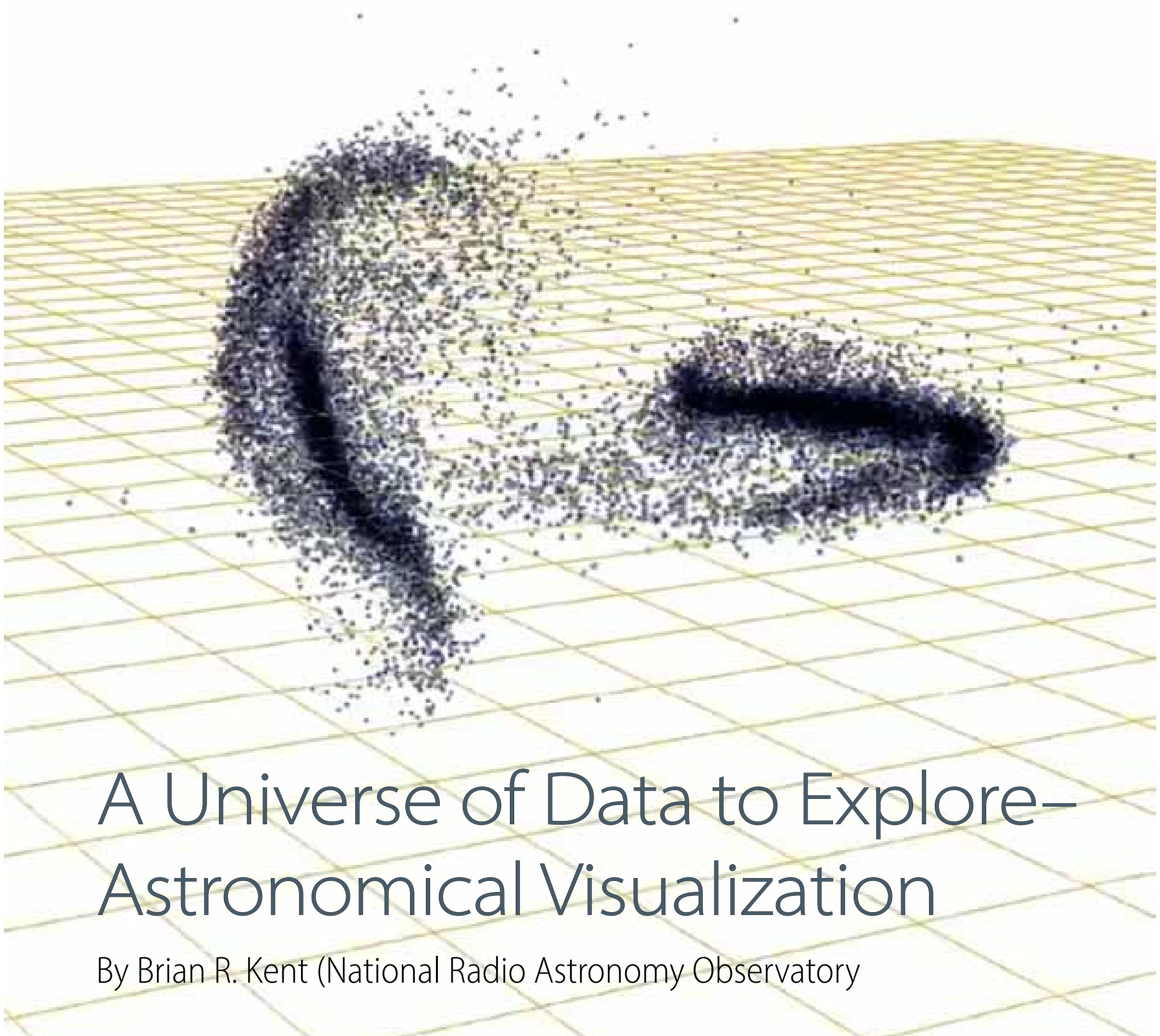
ASTRO BEAT

January 2019



A Universe of Data to Explore–Astronomical Visualization

By Brian R. Kent (National Radio Astronomy Observatory

In 1972, Alar Toomre and Juri Toomre wrote their landmark paper on colliding galaxies, and plotted a time progression of the interactions. These simple two-dimensional plots were an important step in how complex time-series data are viewed. Since then the astronomical sciences have been at the forefront of data visualization. Our techniques have come far in terms of how we present and explore the results of scientific experiments and observations. Data visualization continues to evolve as a field in its own right—utilizing advances in computer hardware and software engineering. Astronomy's stunning visuals continue to inspire our population with images and simulations from both theory and observation. We leverage graphics technology to create high resolution renderings of stellar and extragalactic catalogs, planetary landscapes, and data cubes from radio telescope observations.

Figure 1. Simulation of two Milky Way-sized galaxies interacting. The ability to visualize complex data in 3D is important in both theory and observation.

Figure 2. The National Radio Astronomy Observatory Very Large Array. Each radio telescope of the 27-element interferometer has a diameter of 82 feet. Each telescope can be moved with a special transporter.

Image credit: Brian R. Kent and Jeff Hellerman (NRAO/AUI/NSF).

A video of the array from the air can be found on the author's YouTube website, *VisualizeAstronomy:* https://www.youtube.com/user/VisualizeAstronomy

A constant stream of data

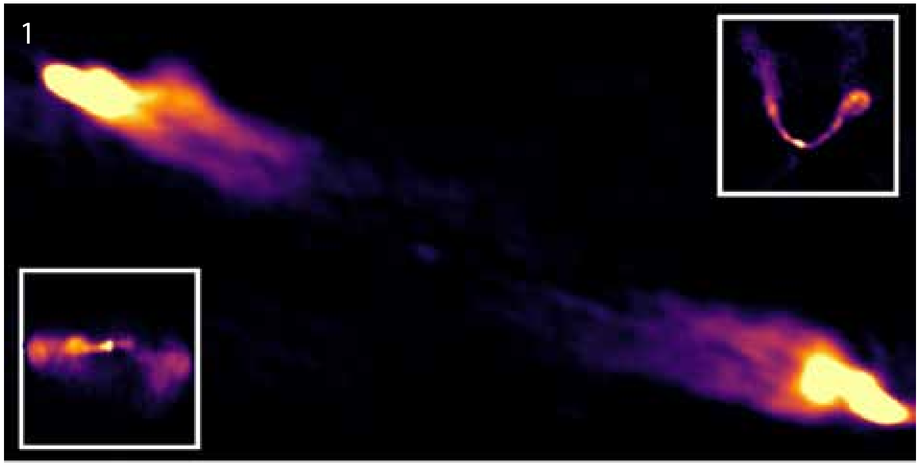
Why do we need effective data visualization methods in astronomy? Data volumes and large parameter spaces are often too complex for a single scientist to sit at a computer and explore. Take for example the Very Large Array Sky Survey (VLASS), using the 27-element VLA interferometer to produce high resolution images at radio frequencies. A large project undertaken by the astronomical community and the National Radio Astronomy Observatory (NRAO), VLASS is observing the entire sky from New Mexico at radio frequencies of 2 to 4 gigahertz (a range designated as S-band). In the past, a user would generate an image from a single target in the sky. These large-scale surveys now gather data from a large swath of the sky creating tens of thousands of images and recording the details of millions of objects in the Universe. Data are generated from the telescope array at a rate of hundreds of gigabytes per hour.

Types of 3D astronomical data rendering

What kinds of data can we explore in three dimensions?

Data cubes– An advantage of using radio telescopes comes from spectroscopy, where we analyze the narrow components of electromagnetic radiation. Astronomers can see individual spectroscopic lines that probe the chemical composition of star forming regions, comets in our own solar system, or the dynamics of distant galaxies, with high frequency interferometers like the Atacama Large Millimeter/submillimeter Array (ALMA) in Chile. Data that show two-dimensional positions on the sky as well as a third dimension in frequency are called data cubes—and we can render them in three dimensions.

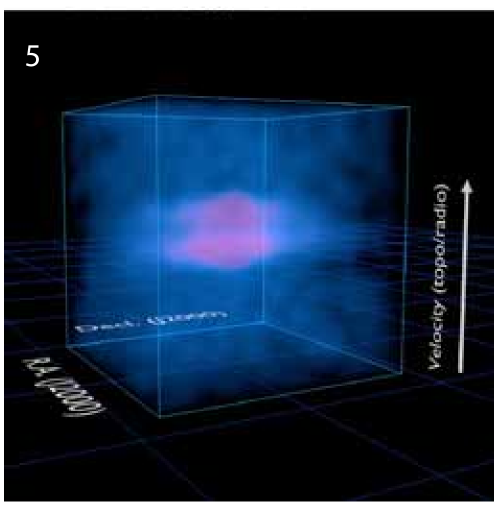
Galaxy catalogs– With extragalactic redshift surveys, we obtain distance estimates to galaxies. This gives a 3D position of each galaxy relative to our own Milky Way. Comparing radio surveys and optical

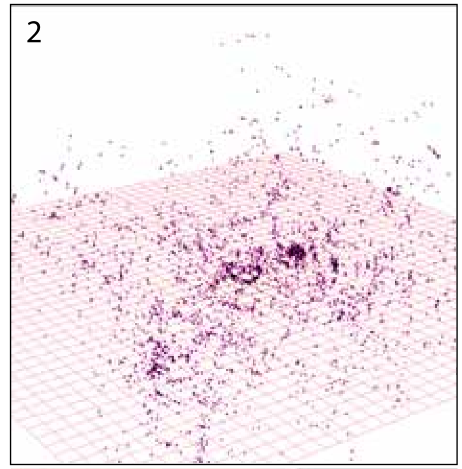


surveys can show the contrast between the hydrogen gas and stellar content of galaxies in the nearby Universe.

Planetary surfaces– Data taken from planetary orbiters give us incredibly high resolution images and elevation information. With this 3D information, astronomers can create flyover visualizations of the surface.

Fortunately, with modern technology we all have an accessible astronomical data viewer in the palm of our hands—our mobile phones and tablets. The built-in accelerometers detect the motion of the device, and allow us to use technology paradigms like augmented reality. Using the Google Spatial Media module and YouTube, 360-degree spherical panoramas of astronomical data can be created with all sky map projections—whether they are sky





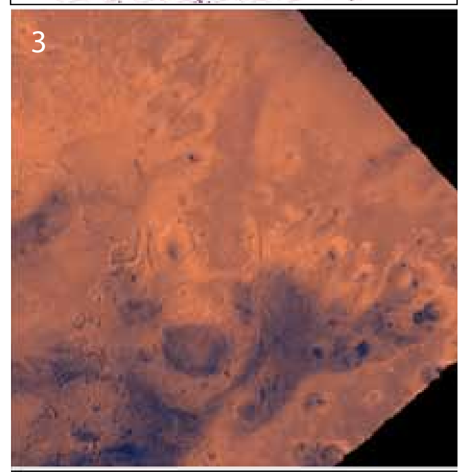


Figure 3. Examples of data visualization. Clockwise from the top:
1. Distant radio galaxies imaged with the Very Large Array Sky Survey, showing a variety of morphologies. Previously unresolved, the superior imaging capabilities will allow astronomers to measure the polarization properties and study transient sources over the seven-year project timescale. **2.** The extragalactic catalog with data from Courtois et al. (2009), showing 3D structure in the nearby galaxies.
3.& **4.** High resolution views of the Martian surface and global orbital views can show what may be changing over time (Christensen et al. 2001). **5.** The data cube depicted here shows a rendering of the detected molecule hydrogen cyanide (HCN) from the inner coma of comet C/2012 F6 Lemmon. This shows two dynamical components of the inner structure (Cordiner et al. 2014).

constellation maps or radio frequency continuum emission showing spectacular supernova remnants in the Milky Way galaxy. Links to example maps are provided in the endnotes—try them out on your phone, tablet, or web browser.

The Future

Current and planned astronomical observatories will continue to push the boundaries of data acquisition. Wide-field optical imaging projects like the Large Synoptic Survey Telescope (LSST) will map the entire night sky from the southern hemisphere every few nights with a gigapixel camera. The Next Generation Very Large Array (ngVLA), a new proposed cutting-edge observatory, will be composed of hundreds of radio telescopes in the southwest United States, Mexico, and across the United States at existing radio observatory sites. In addition to the extraordinary science that these facilities will produce, they will also usher in new paradigms of data science research and visualization.

Glossary

Gigahertz– a frequency unit of one billion hertz.

Interferometer– telescopes used together in baseline pairs to create extremely high-resolution images.

Redshift survey– using spectral lines, the distances to large numbers of galaxies can be determined.

Rendering– the process of creating a three-dimensional representation of astronomical data, usually as a video.

Notes

Publications of the Astronomical Society of the Pacific (PASP) special issue on data visualization:
http://iopscience.iop.org/journal/1538-3873/page/Techniques-and-Methods-for-Astrophysical-Data-Visualization

Data Visualization book by Brian R. Kent
http://iopscience.iop.org/book/978-1-6270-5612-0

Book on using a Raspberry Pi computer for science:
http://iopscience.iop.org/book/978-1-6817-4996-9

Paper on spherical panoramas for astronomy:
http://iopscience.iop.org/article/10.1088/1538-3873/aa5543

Website about the new VLA Sky Survey:
https://public.nrao.edu/vlass/

The Next Generation Very Large Array:
http://ngvla.nrao.edu/

The Large Synoptic Survey Telescope:
https://www.lsst.org/

Galactic Bridges and Tails by Toomre & Toomre (1972):
http://adsabs.harvard.edu/abs/1972ApJ...178..623T

YouTube 360-degree spherical panoramas:
https://www.youtube.com/watch?v=YWwA49Mm1nw

Christensen et al. 2001:
http://adsabs.harvard.edu/abs/2001JGR...10623823C

Courtois et al. 2009:
http://adsabs.harvard.edu/abs/2009AJ....138.1938C

Cordiner et al. 2014:
http://adsabs.harvard.edu/abs/2014ApJ...792L...2C

About the Author

Brian R. Kent is a scientist with the National Radio Astronomy Observatory (NRAO) in Charlottesville, Virginia. His publications and studies in astrophysics and computing include scientific visualizations of a variety of theoretical and observational phenomena. He is interested in visualizing data for scientific analysis, 3D graphics, and working on data processing pipelines with his colleagues at NRAO and observatories all over the world. He has published two books as part of the IOP Concise Physics Series with Morgan & Claypool publishers — ***3D Scientific Visualization with Blender*** and ***Science and Computing with Raspberry Pi.*** Dr. Kent received his Ph.D. in Astronomy and Space Sciences from Cornell University. Follow him on Twitter and Instagram with @ VizAstro

The National Radio Astronomy Observatory is a facility of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc.

AstroBeat

Number 165 • January 2019

Publisher: Astronomical Society of the Pacific
Editor: Greg Schultz
Designer: David Barker