

Seeing the Sky

Visualization & Astronomers

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





Microsoft⁻













Pictures



*"Language" includes words & math

Why Galileo is my Hero Explore-Explain-Explore

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GALILEO'S "NEW ORDER"

Created by Alyssa Goodman, Curtis Wong and Pat Udomprasert, with advice from Owen Gingerich and David Malin





January 11, 1610





*"Language" includes words & math



d3po

d3po is a project designed to allow an astronomer (or anyone), with no special data visualization skills, to make an interactive, publication-quality figure that has staged builds and linked brushing through scatter plots. Our current version can be previewed at d3po.org, and represents a figure from upcoming work by graduate student Elisabeth Newton. The figure describes how metalicity affects color in cool stars, and represents a nice use case for d3po. Try clicking and drageing in the scatter plots to understand the power of linked brushing in published figures.

Right now we are in search of alpha testers, who have figures that could be made interactive and who are willing to get their hands a little dirty (No javascript skills needed). In future versions, we plan to link to glue to allow the creation of d3po figures interactively. We are also exploring implementation of d3po within presentations and within authorea. Full 1.0 version 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



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

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	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)		
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11,111,121	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 one processing system (e.g. visual, auditory, touch) is used. Aud, related research also shows i technical the metrial, most humans also retain and process information best when they can at .50, when considering the future of scholarly communication, we should are careful not to do linear anarative format that articlies and books have followed for conturies: instead, we should	best when more than that, no matter how put a narrative "story" to o blithely away with the I enrich it.	
	Much more than text is used to commuicate in Science, Figures, which include images, diagram more, have enriched scholarly articles since the time of Galileo, and ever-growing volumes of scientific papers. When scientists communicate face-to-face, as in tails or small discussions, it the focus of the coversation. In the best discussions, its manipulate access underlying data, in real-time, so as to text out various what if scenarios, and te explain. This short article explains—and shows with demonstrations—how scholarly "papers" cas lasting rich records of scientific discourse, enriched with deep data and code linkages, inter video, and commenting.	ns, graphs, charts, and data underpin most hese figures are often the figures, and to findings more clearly, a morph into long- active figures, audio,	



cognitive functions are utilized: communication is inefficient if the channel is restricted primarily to language, without easy interconnection to data and pictures.

[demo] [video]

Many thanks to Alberto Pepe, Josh Peek, Chris Beaumont, Tom Robitaille, Adrian Price-Whelan, Elizabeth Newton, Michelle Borkin & Matteo Cantiello for making this posible.

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4 Centuries from Galileo to Galileo

AN INTERNATIONAL REVEW OF SPECTROSCOPY AND APPROXIMICAL PRYSTON

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ASTROPHYSICAL JOURNAL

ON THE CONDITIONS WHICH APPECT THE SPECTRO-PROTOGRAPHY OF THE SCN.

By Arenald B. Brighton

The moust involvements in solar spectro-photography in great measure due to the device originally suggested by Jaurs and particular for Halo and Italiandess, for manys of who a planting had of the Soid's prominents may be administed at a time as readily as it is sharing an unique. The inscistual feature of this divice up the simplicitum momentum of the co many with some the host's image, with that of a taxond city the broat of the photographic lites) note a photographic yie If these relative motions are so adjusted that the same specihas always halfs on the amount alls, then a photographic loss at the first will be reproduced by light of this particular was

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FEATURED ARTICLES ABOUT PLANS BLOG FEEDBACK HELP ALYSSA GOOD

The "Paper" of the Future

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1 Preamble

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such more than set is used to communicate in science. Figures, which include in Sagrams, graphs, charts, and more, have enriched scholarly articles since the time of G 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 conventation. 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 crearly. This short article explains and shows with demonstrations-how scholarly "papers" can morph into long-leading rich records of scientific discourse. ns-how ctive figures, audio, video, any





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Pictures









Data, Dimensions, Display

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

Data, Dimensions, Display





Data, Dimensions, Display

/L: 63 WW: 127



mm peak (Enoch et al. 2006)

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

¹³CO (Ridge et al. 2006)

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

Optical image (Barnard 1927)

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AstronomicalMedicine@IC+

LETTERS



Figure 2 Comparison of the 'dendrogram' and 'CLUMPFIND' featureidentification algorithms as applied to ¹³CO emission from the L1448 region of Perseus. a, 3D visualization of the surfaces indicated by colours in the dendrogram shown in c. Purple illustrates the smallest scale selfgravitating structures in the region corresponding to the leaves of the dendrogram; pink shows the smallest surfaces that contain distinct selfgravitating leaves within them; and green corresponds to the surface in the data cube containing all the significant emission. Dendrogram branches corresponding to self-gravitating objects have been highlighted in yellow over the range of T_{mb} (main-beam temperature) test-level values for which the virial parameter is less than 2. The x-y locations of the four 'selfgravitating' leaves labelled with billiard balls are the same as those shown in Fig. 1. The 3D visualizations show position-position-velocity (p-p-v) space. RA, right ascension; dec., declination. For comparison with the ability of dendrograms (c) to track hierarchical structure, d shows a pseudodendrogram of the CLUMPFIND segmentation (b), with the same four labels used in Fig. 1 and in a. As 'clumps' are not allowed to belong to larger structures, each pseudo-branch in **d** is simply a series of lines connecting the maximum emission value in each clump to the threshold value. A very large number of clumps appears in b because of the sensitivity of CLUMPFIND to noise and small-scale structure in the data. In the online PDF version, the 3D cubes (a and b) can be rotated to any orientation, and surfaces can be turned on and off (interaction requires Adobe Acrobat version 7.0.8 or higher). In the printed version, the front face of each 3D cube (the 'home' view in the interactive online version) corresponds exactly to the patch of sky shown in Fig. 1, and velocity with respect to the Local Standard of Rest increases from front (-0.5 km s^{-1}) to back (8 km s^{-1}) .

data, CLUMPFIND typically finds features on a limited range of scales, above but close to the physical resolution of the data, and its results can be overly dependent on input parameters. By tuning CLUMPFIND's two free parameters, the same molecular-line data set8 can be used to show either that the frequency distribution of clump mass is the same as the initial mass function of stars or that it follows the much shallower mass function associated with large-scale molecular clouds (Supplementary Fig. 1).

Four years before the advent of CLUMPFIND, 'structure trees'9 were proposed as a way to characterize clouds' hierarchical structure

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NATURE Vol 457 1 January 2009

2D work as inspira-

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using 2D maps of column density. With th tion, we have developed a structure-id abstracts the hierarchical structure of a an easily visualized representation called well developed in other data-intensive application of tree methodologies so fa and almost exclusively within the ar A role for self-gravity at multiple length scales in the 'merger trees' are being used with in

Imerger trees are being Figure 3 and its legend explain th schematically. The dendrogram qua schematission merge with each Moth sensitivity to algorithm parameter possible on paper and 2D screen data (see Fig. 3 and its legend cross, which eliminates dimensi preserving all information Numbered 'billiard ball' labe features between a 2D map online) and a sorted dendro A dendrogram of a spectr of key physical properties

surfaces, such as radius (R), (L). The volumes can have any shape, and the significance of the especially elongated features . (Fig. 2a). The luminosity is an approximate proxy for mass, su that $M_{\text{lum}} = X_{13\text{CO}}L_{13\text{CO}}$, where $X_{13\text{CO}} = 8.0 \times 10^{20} \text{ cm}^2 \text{ K}^{-1} \text{ km}^{-1} \text{ s}$ (ref. 15; see Supplementary Methods and Supplementary Fig. 2). The derived values for size, mass and velocity dispersion can then be used to estimate the role of self-gravity at each point in the hierarchy, via calculation of an 'observed' virial parameter, $\alpha_{obs} = 5\sigma_{\nu}^{2} R/GM_{lum}$. In principle, extended portions of the tree (Fig. 2, yellow highlighting) where $\alpha_{obs} < 2$ (where gravitational energy is comparable to or larger than kinetic energy) correspond to regions of p-p-v space where selfgravity is significant. As α_{obs} only represents the ratio of kinetic energy to gravitational energy at one point in time, and does not explicitly capture external over-pressure and/or magnetic fields16, its measured value should only be used as a guide to the longevity (boundedness) of any particular feature.



Figure 3 | Schematic illustration of the dendrogram process. Shown is the construction of a dendrogram from a hypothetical one-dimensional emission profile (black). The dendrogram (blue) can be constructed by 'dropping' a test constant emission level (purple) from above in tiny steps (exaggerated in size here, light lines) until all the local maxima and mergers are found, and connected as shown. The intersection of a test level with the emission is a set of points (for example the light purple dots) in one dimension, a planar curve in two dimensions, and an isosurface in three dimensions. The dendrogram of 3D data shown in Fig. 2c is the direct analogue of the tree shown here, only constructed from 'isosurface' rather than 'point' intersections. It has been sorted and flattened for representation on a flat page, as fully representing dendrograms for 3D data cubes would require four dimensions.



LETTERS

Goodman et al. 2009, Nature, cf: Fluke et al. 2009

2009 **3D PDF** High-Dimensional data in a "Paper" on its way to the Future

[demo/video]

64

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

Alyssa A. Goodman^{1,2}, Erik W. Rosolowsky^{2,3}, Michelle A. Borkin¹†, Jonathan B. Foster², Michael Halle^{1,4}, Jens Kauffmann^{1,2} & Jaime E. Pineda²

Self-gravity plays a decisive role in the final stages of star formation, where dense cores (size ~0.1 parsecs) inside molecular clouds collapse to form star-plus-disk systems'. But self-gravity's role at earlier times (and on larger length scales, such as ~1 parsec) is unclear; some molecular cloud simulations that do not include self-gravity suggest that 'turbulent fragmentation' alone is sufficient to create a mass distribution of dense cores that resembles, and sets, the stellar initial mass function3. Here we report a 'dendrogram' (hierarchical tree-diagram) analysis that reveals that self-gravity plays a significant role over the full range of possible scales traced by 12CO observations in the L1448 molecular cloud, but not everywhere in the observed region. In particular, more than 90 per cent of the compact 'pre-stellar cores' traced by peaks of dust emission3 are projected on the sky within one of the dendrogram's self-gravitating 'leaves'. As these peaks mark the locations of already-forming stars, or of those probably about to form, a self-gravitating corpon seems a critical condition for their existoverlapping features as an option, significant emission found between prominent clumps is typically either appended to the nearest clump or turned into a small, usually 'pathological', feature needed to encompass all the emission being modelled. When applied to molecular-line





LETTERS

Why Astronomical Medicine?

"Κειτη"

"PERSEUS"





"z" is depth into head

"z" is line-of-sight velocity





Why Astronomical Medicine?

CT/MRI



Astronomy & Medicine both rely on high-dimensional, big, wide, data for insight.

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

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

CT



WIDE DATA



COMPLETE

mm peak (Enoch et al. 2006)

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

¹³CO (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]



BIG DATA

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BIG DATA AND "HUMAN-AIDED COMPUTING"





example here from: **Beaumont**, Goodman, Kendrew, Williams & Simpson 2014; based on **Milky Way Project** catalog (Simpson et al. 2013), which came from **Spitzer/GLIMPSE** (Churchwell et al. 2009, Benjamin et al. 2003), cf. Shenoy & Tan 2008 for discussion of HAC; **astroml.org** for machine learning advice/tools

BIG DATA AND "HUMAN-AIDED COMPUTING"





example here from: Kaynig...Lichtman...Pfister et al. 2013, "Large-Scale Automatic Reconstruction of Neuronal Processes from Electron Microscopy Images"; cf. Shenoy & Tan 2008 for discussion of HAC; **astroml.org** for machine learning advice/tools (Note: RF=Random Forest; CRF=Conditional Random Fields.)



Movie: Volker Springel, formation of a cluster of galaxies. Millenium Simulation requires 25TB for output.



2009 **3D PDF** High-Dimensional data in a "Paper" on its way to the Future



LETTERS

Figure 2 Comparison of the 'dendrogram' and 'CLUMPFIND' featureidentification algorithms as applied to ¹³CO emission from the L1448 region of Perseus. a, 3D visualization of the surfaces indicated by colours in the dendrogram shown in c. Purple illustrates the smallest scale selfgravitating structures in the region corresponding to the leaves of the dendrogram; pink shows the smallest surfaces that contain distinct selfgravitating leaves within them; and green corresponds to the surface in the data cube containing all the significant emission. Dendrogram branches corresponding to self-gravitating objects have been highlighted in yellow over the range of $T_{\rm mb}$ (main-beam temperature) test-level values for which the virial parameter is less than 2. The x-y locations of the four 'selfgravitating' leaves labelled with billiard balls are the same as those shown in Fig. 1. The 3D visualizations show position-position-velocity (p-p-v) space. RA, right ascension; dec., declination. For comparison with the ability of dendrograms (c) to track hierarchical structure, d shows a pseudodendrogram of the CLUMPFIND segmentation (b), with the same four labels used in Fig. 1 and in a. As 'clumps' are not allowed to belong to larger structures, each pseudo-branch in **d** is simply a series of lines connecting the maximum emission value in each clump to the threshold value. A very large number of clumps appears in b because of the sensitivity of CLUMPFIND to noise and small-scale structure in the data. In the online PDF version, the 3D cubes (a and b) can be rotated to any orientation, and surfaces can be turned on and off (interaction requires Adobe Acrobat version 7.0.8 or higher). In the printed version, the front face of each 3D cube (the 'home' view in the interactive online version) corresponds exactly to the patch of sky shown in Fig. 1, and velocity with respect to the Local Standard of Rest increases from front (-0.5 km s^{-1}) to back (8 km s^{-1}) .

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Four years before the advent of CLUMPFIND, 'structure trees'⁹ were proposed as a way to characterize clouds' hierarchical structure

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NATURE Vol 457 1 January 2009

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"DEAD" PANELS! THAT'S NOT GOOD ENOUGH.

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Goodman et al. 2009, Nature, cf: Fluke et al. 2009

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

JOHN TUKEY'S LEGACY





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



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



glueviz.org

What is visualization (and all this software) for?

INSIGHT

CONTEXT	PATTERN RECOGNITION	EVALUATION
Spatial	Ideas	Algorithms
Non-Spatial	Outliers	Errors



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GLUEING TOGETHER THE MILKY WAY



Olim.

LOGAN AIRPORT (AND MY FBI FILE)



JUPYTER LAB: GLUE IN THE BROWSER



The Physical Properties of Large-Scale Galactic Filaments

Catherine Zucker, Cara Battersby, Alyssa Goodman

(Submitted on 27 Dec 2017)

-

The characterization of our Galaxy's longest filamentary gas features has been the subject of several 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 length (11-269 pc), width (1-40 pc), mass ($3 \times 10^3 M_{\odot} - 1.1 \times 10^6 M_{\odot}$), aspect ratio (3:1 - 117:1), and dense gas fraction (0.2-100%) varying by at least an order of magnitude across the sample of 45 filaments. As part of this analysis, we develop a radial profile fitting code, *RadFil*, which is publicly available. We also perform a *position – position – velocity* (p - p - v) analysis on a subset of the filaments and find that while 60%-70% lie in the plane of the Galaxy, only 30-45% also exhibit kinematic proximity to purported spiral arms. In a parameter space defined by aspect ratio, temperature, and density, we broadly distinguish three filament categories, which could be indicative of different formation mechanisms or histories. Highly elongated "Bone-like" filaments show the most potential for tracing gross spiral structure (e.g. arms), while other categories could simply be large concentrations of molecular gas (GMCs, core complexes).

 Comments:
 Submitted to The Astrophysical Journal

 Subjects:
 Astrophysics of Galaxies (astro-ph.GA)

 Cite as:
 arXiv:1712.09655 [astro-ph.GA]

(or arXiv:1712.09655v1 [astro-ph.GA] for the

Yes, more on this visualization challenge!

Nah, maybe later... ⁵glue

Ψı

The Physical Properties of Large-Scale Galactic Filaments

a visualization saga...

Catherine Zucker, Cara Battersby, Alyssa Goodman

























The challenge of 3D Selection



A state-of-the-art 3D model of the stars & gas near the Orion nebula, created at Orion (un)plugged, Vienna, 2015. Expert builders (~20 total) include: Joao Alves, John Bally, Alyssa Goodman & Eddie Schlafly. (cf. "Image & Meaning" workshops by Felice Frankel) <u>YouTube video</u> explanation; <u>WWT Tour</u>

The challenge of 3D Selection





The challenge of 3D Selection









Pictures

Literature as (a filter for) Data



Many thanks to Alberto Pepe, August Muench, Thomas Boch, Jonathan Fay, Michael Kurtz, Alberto Accomazzi, Julie Steffen, Laura Trouille, David Hogg, Dustin Lang, Christopher Stumm, Chris Beaumont & Phil Rosenfield for making this all work!

Bringing "Dead" Data Back to Life

Au thorea 🔤 🛛

HELP EXPLORE

0

5.3.3 Putting images in Contest

h,

Insert

Most observational astronomy has the unique feature of having a specific space to which the data are attached: the celestial sphere. As such, it makes sense for us to attach our images to locations. The AstroExplorer tool (cite) and the ADS All Sky Survey can allow images to be treated as data, in the sense that they can be "put back" on the Sky in context. Here's a sample, using an image from Barnard that is 100 years old (update). Click the caption's link to see it on the Sky in WorldWide Telescope.





Fig. 7 Click here to see this image on the Sky is your browser (using HTML5 WorldWide Telescope). Original image source.



ADS All-Sky Survey & Astronomy Rewind

"putting articles and images (back) on the Sky"



1. Images Extracted from Journal Articles



images

2. Missing coordinate metadata added back to images, either...

...automatically, applying astronometry.net to wide-field optical images, or



via "Astronomy Rewind" Zooniverse Citizen Science Project





3. "Solved" images returned to ADS & Astronomy Image Explore



Fastronomy image explorer

4. New button in Astronomy Image Explorer offers image-incontext, using AAS' WorldWide Telescope in the browser





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THE COMPLETE SURVEY OF STAR-FORMING REGIONS: PHASE I DATA

NAOMI A. RIDGE,¹ JAMES DI FRANCISCO,² HILEN KIRK,^{2,3} DI LL,^{1,4} ALYSSA A. GOODMAN,¹ JOÃO F. ALVES,⁵ HÉCTOR G. ARCE,⁶ MICHELE A. BORKIN,⁷ PAOLA CASELLI,² JOANTHAN B. FOSTBA,¹ MARK H. HIVER,⁸ DOUG JOHNSTON,^{2,2} DAVID A. KOSKINY,¹ MARC DO LOMBARE,¹ JAME E. PNEDA,¹ SCOTT L. SCHNER,¹ AND MARG TAFALLA¹⁰ Received 2005 Number 8: accoupted 2005 February 22

ABSTRACT

We present an overview of data available for the Ophiuchus and Perseus molecular clouds from Phase I of the COMPLETE Survey of Star-Forming Regions. This survey provides a range of data complementary to the *Spitzer* Legacy Program "From Molecular Cores to Planet Forming Disks." Phase I includes the following: extinction maps derived from the Two Micron All Sky Survey (2MASS) near-infrared data using the NICER algorithm; extinction and temperature maps derived from *IRAS* 60 and 100 µm emission." It i maps of atomic gas; ¹²CO and ¹³CO maps of molecular gas; and submillimeter continuum images of emission from dust in dense cores. Not unexpectedly, the morphology of the regions appears quite different depending on the column density tracer that is used, with *IRAS* tracing mainly warmer dust and CO being biased by chemical, excitation, and optical depth effects. Histograms of column density distribution are presented, showing that extinction as derived from 2MASS NICER gives the closest match to a longeneral distribution, as is predicted by numerical simulations. All the data presented in this paper, and links to more detailed publications on their implications, are publicly available at the COMPLETE Web site.

Key words: ISM: clouds - stars: formation - surveys





Other Images in This Article

Who, How, and Who's Paying?

The ADS All Sky Survey was first funded via a 2012 grant from the NASA ADAP program to Seamless Astronomy, in collaboration with CDS, Astrometry.net and Microsoft Research.

Articles-on-the-Sky

was first deployed in 2014, using APIs from WWT (Microsoft Research, now AAS) and CDS (Aladin)

Images-on-the-Sky

relies on the astrometry.net, Zooniverse, IOP/AAS Astronomy Image Explorer and WorldWide Telescope platforms, and it is funded by the **American Astronomical Society**, in addition to the NASA ADAP grant.

These projects rely on open source sofware, primarily hosted on **GitHub**.

PI to contact for more information Alyssa Goodman, Harvard agoodman@cfa.harvard.edu



Your handout 1 person is talking about Astronomy Rewind right now loin in ASTRONOMY REWIND STATISTICS 100% Complete Classification Completed Subject WORDS FROM THE RESEARCHEI

"Your contributions unlock the information from old astronomy journals. Thank you and enjoy the images!"

ABOUT ASTRONOMY REWIND

The project is part of an origoing NeSA-funded effort aimed at furning the SAO/NASA Astrophysics Data System (NDS) into a data resource. The result will be a database of starb-referenced images, i.e., images of the sky for which coordinates, orientation, and pixel scale will be publicly available through NASA data archives, the Astronomy Image Explorer, and World Wide Telescope. thanks to your help!





Seeing the Sky

Visualization & Astronomers

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

@aagie













To continue the conversation...





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. Feature & Pattern Recognition | Is feature and/or pattern recognition, a goal?
- 4. Predictions & Uncertainty | Are you making a comparison between data and/or predictions? Is representing uncertainty a concern?
- 5. **Dimensions** | What is the intrinsic number of dimensions (not necessarily spatial) in your data, and how many do you want to show at once?
- 6. Categories & Clustering | Are there natural, or imposed, categories within the data? Are you interested in clustering?
- 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?



10qviz.org with Arzu Çöltekin (beta 2017, release 2018)



Creativity & Collaboration: Revisiting Cybernetic Serendipity National Academy of Sciences Sackler Colloquium, March 13-14, 2018, Washington, DC

Role/Play: Collaborative Creativity and Creative Collaborations National Academy of Sciences Sackler Student Fellows Symposium, March 12, 2018, Washington DC

www.nas on line.org/Sackler-Creativity-Collaboration



Creativity & Collaboration at NAS March 2018 with Ben Shneiderman, Maneesh Agrawala, Roger Malina, Youngmoo Kim & Donna Cox