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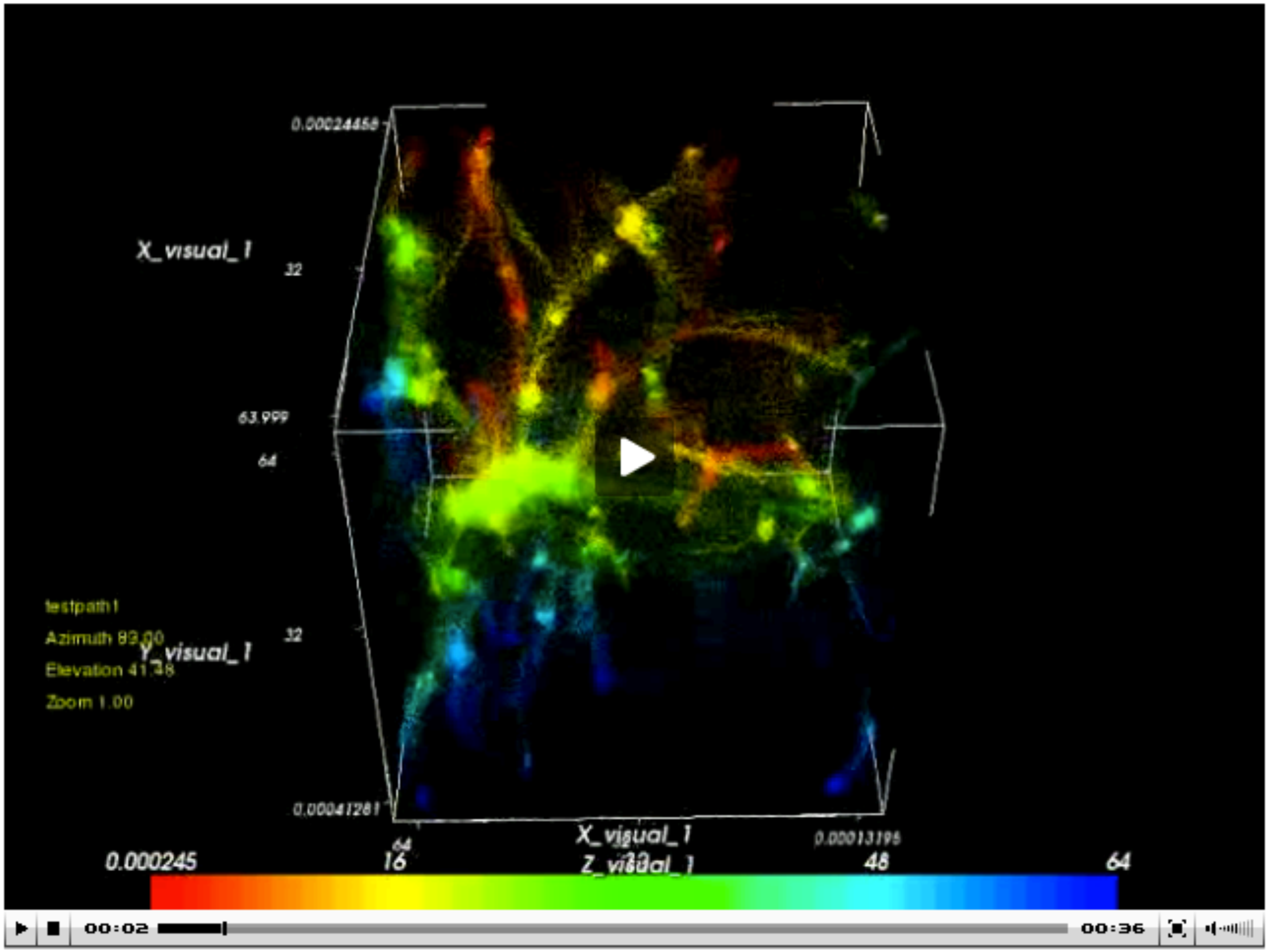

VisIVO: Visualization Interface to the Virtual Observatory

CS 171 Visualization

Harvard
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The amount and complexity of information produced in science, engineering, business, and everyday human activity is increasing at staggering rates. The goal of this course is to expose you to visual representation methods and techniques that increase the understanding of complex data. Good visualizations not only present a visual interpretation of data, but do so by improving comprehension, communication, and decision making.

In this course you will learn how the human visual system processes and perceives images, good design practices for visualization, tools for visualization of data from a variety of fields, collecting data from web sites with Python, and programming of interactive visualization applications using Processing.

CS 171 Preview by Miriah Meyer

Instructor: Hanspeter Pfister
Staff: Alberto Pepe (Head TF), Tiffany Au, Alex Chang, Kane Hsieh, Calvin McEachron, Lakshmi Parthasarathy, Weina Scott, Mike Teodorescu

Lectures: M W 1-2:30 pm
Maxwell Dworkin G115

Sections: F 1-2:30 pm
Maxwell Dworkin G125

Office Hours: W F 2:30-3:30 pm
Maxwell Dworkin ground floor

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NSF Science & Technology Center (est. 2002) with 300+ researchers in Computer Science, Electrical Engineering, Statistics, Biology, Environmental Science, Urban Planning, Sociology, Media, at 5 institutions: UCLA, USC, Caltech, UC Merced, UC Riverside

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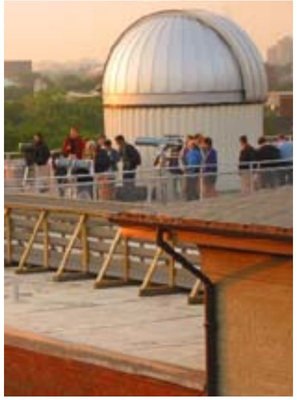

Co-funded by the Harvard College Observatory and the Smithsonian Astrophysical Observatory (est. 1973). 300+ researchers in six research divisions: Atomic and Molecular Physics; High Energy Astrophysics; Optical and Infrared Astronomy; Radio and Geoastronomy; Solar, Stellar, and Planetary Sciences; and Theoretical Astrophysics. The center also has an active science education and outreach initiative.

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Multi-disciplinary	Mono-disciplinary (?)
Multi-institution	Single physical location, but based on global collaboration
Sensors	Telescopes
Mega/Giga-bytes	Tera/Peta-bytes

CENS CFA

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Multi-institution	Single physical location, but based on global collaboration
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Mega/Giga-bytes	Tera/Peta-bytes
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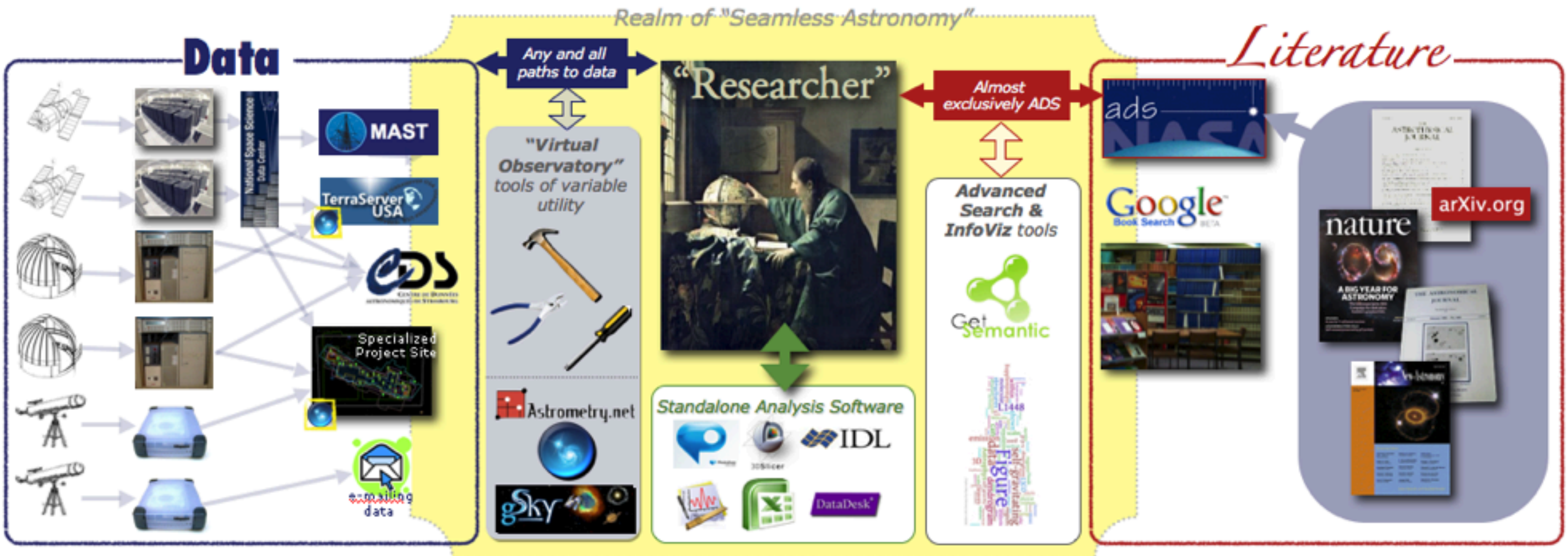
Institutional digital library	Domain-specific, interoperable digital library (i.e., ADS)



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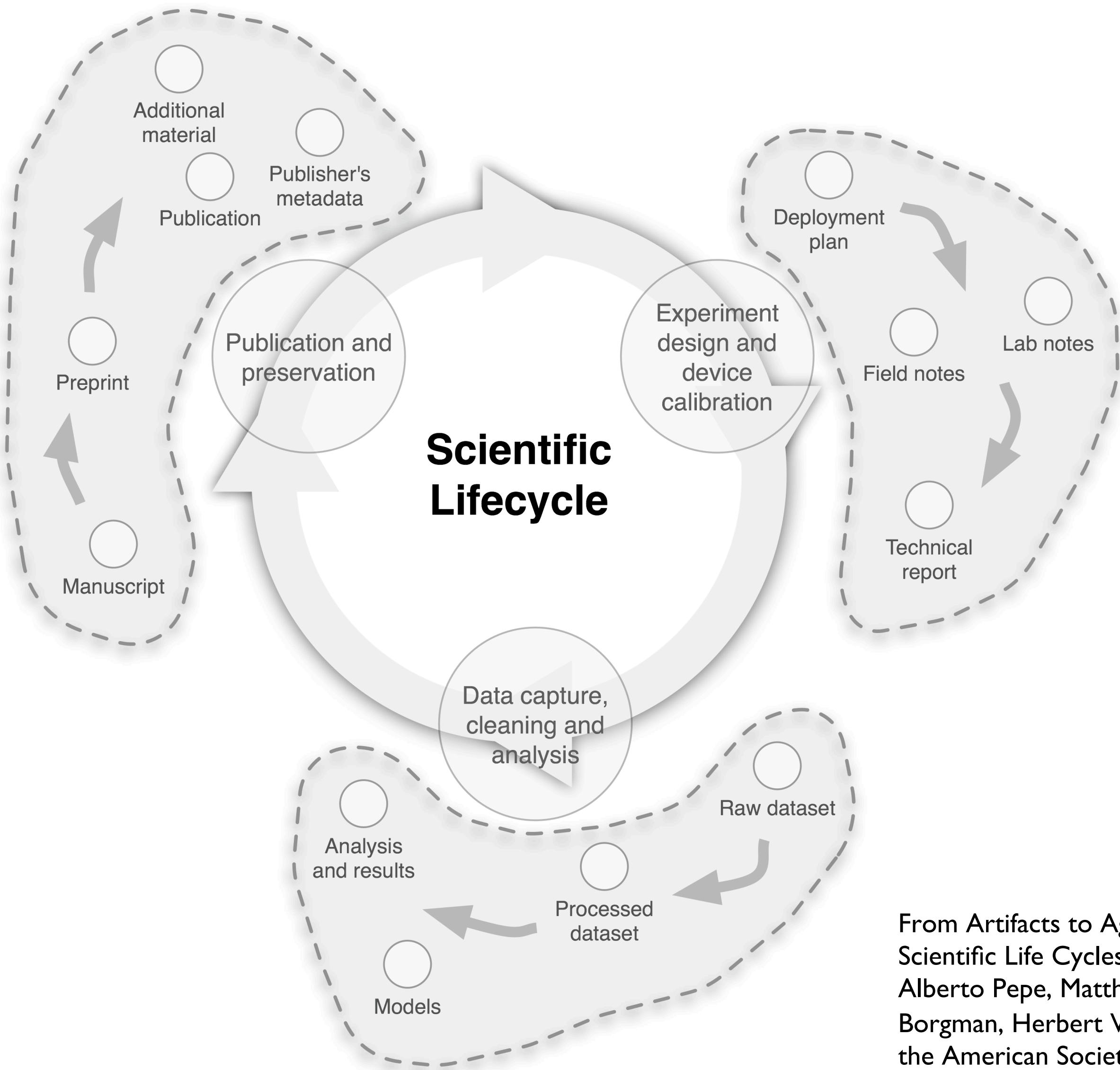
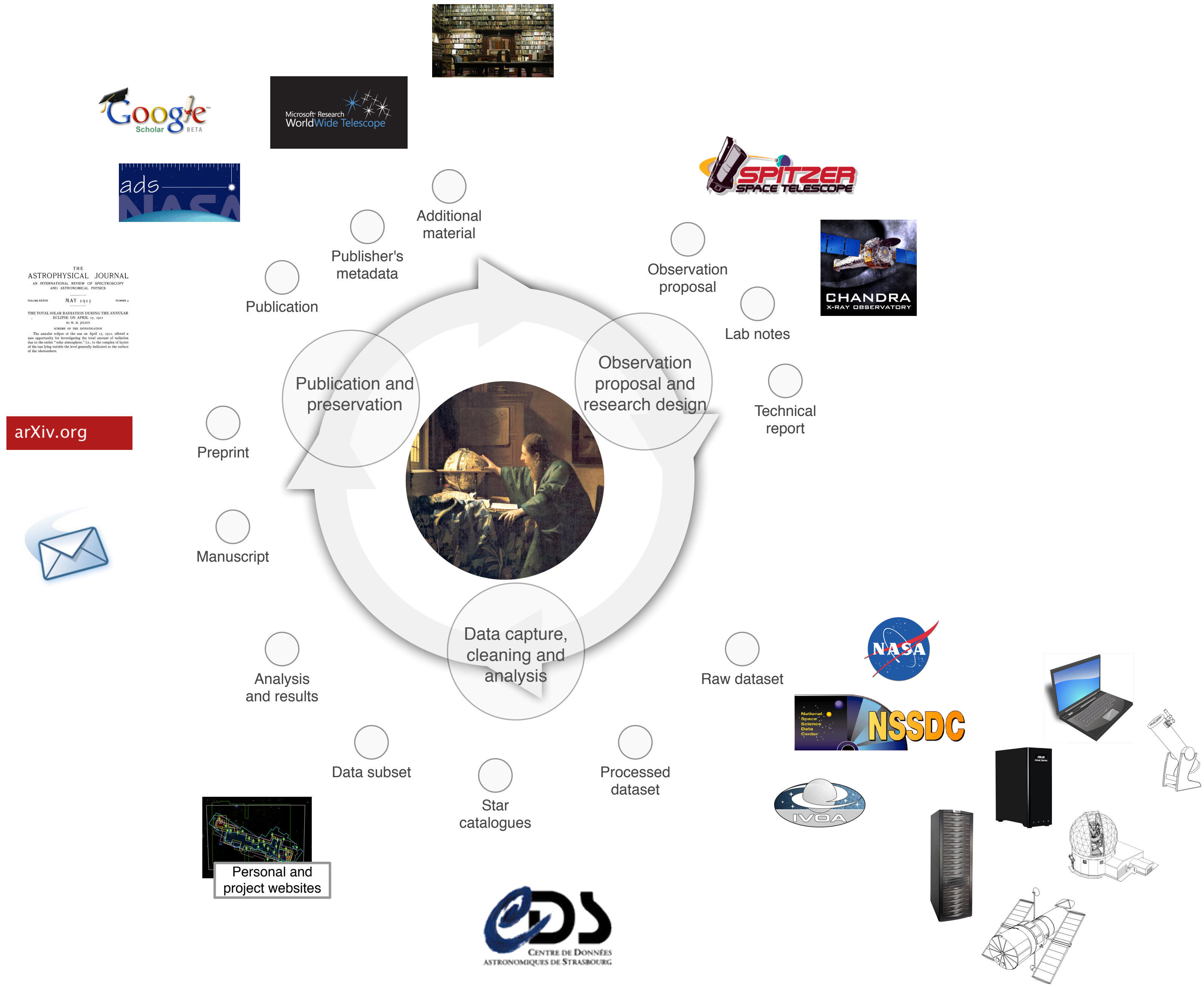


From Artifacts to Aggregations: Modeling Scientific Life Cycles on the Semantic Web. Alberto Pepe, Matthew Mayernik, Christine L. Borgman, Herbert Van De Sompel. Journal of the American Society for Information Science and Technology (JASIST). Volume 61, Issue 3.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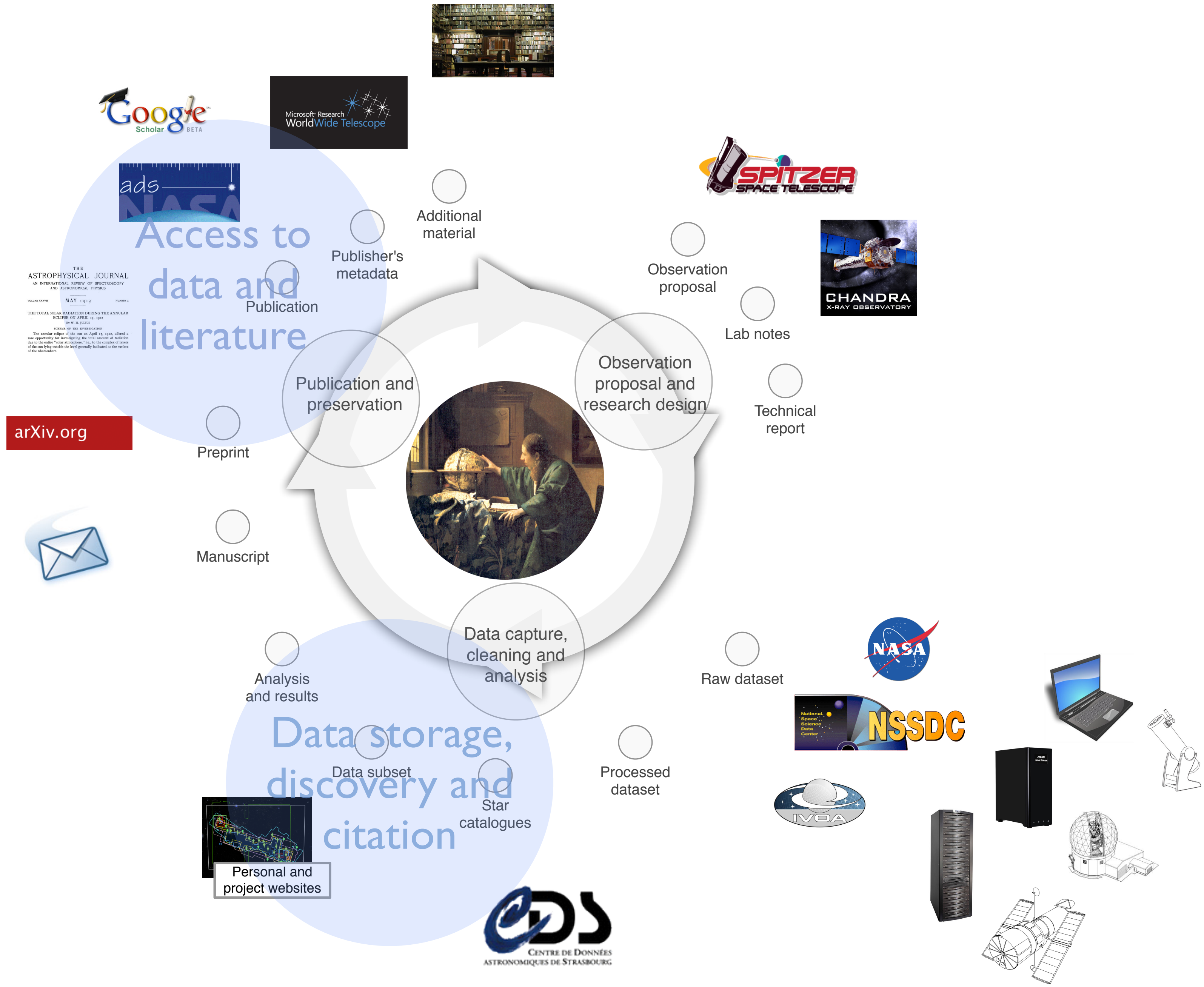
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"Michael Kurtz"

The Astrophysical Journal, 715:1170–1190, 2010 June 1 doi:10.1088/0004-637X/715/2/1170

THE COMPLETE SURVEY OF OUTFLOWS IN PERSEUS

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ABSTRACT

We present a study on the impact of molecular outflows in the Perseus molecular cloud complex using the COMPLETE Survey large-scale ^{12}CO(1–0) and ^{13}CO(1–0) maps. We used three-dimensional isosurface models generated in right ascension–declination–velocity space to visualize the maps. This rendering of the molecular line data allowed for a rapid and efficient way to search for molecular outflows over a large ($\sim$16 deg^2) area. Our outflow-searching technique detected previously known molecular outflows as well as new candidate outflows. Most of these new outflow-related high-velocity features lie in regions that have been poorly studied before. These new outflow candidates more than double the amount of outflow mass, momentum, and kinetic energy in the Perseus cloud complex. Our results indicate that outflows have significant impact on the environment immediately surrounding localized regions of active star formation, but lack the energy needed to feed the observed turbulence in the *entire* Perseus complex. This implies that other energy sources, in addition to protostellar outflows, are responsible for turbulence on a global cloud scale in Perseus. We studied the impact of outflows in six regions with active star formation within Perseus of sizes in the range of 1–4 pc. We find that outflows have enough power to maintain the turbulence in these regions and enough momentum to disperse and unbind some mass from them. We found no correlation between outflow strength and star formation efficiency (SFE) for the six different regions we studied, contrary to results of recent numerical simulations. The low fraction of gas that potentially could be ejected due to outflows suggests that additional mechanisms other than cloud dispersal by outflows are needed to explain low SFEs in clusters.

Key words: ISM: clouds – ISM: individual objects (Perseus) – ISM: jets and outflows – ISM: kinematics and dynamics – stars: formation – turbulence

Online-only material: color figures

in IC 348 (HD 281159) is confirmed to reside in the Perseus cloud, but there might be a few other high-mass stars that interact with the cloud (through their winds and/or UV radiation) even though they were not necessarily formed in the cloud complex (see, e.g., Walawender et al. 2004; Ridge et al. 2006a; Kirk et al. 2006; Rebull et al. 2007). There is also a large number of nebulous objects associated with outflow shocks (i.e., HH objects and H_2 knots) that have been identified in the cloud complex (Bally et al. 1996b, 1997; Yan et al. 1998; Walawender et al. 2005b; Davis et al. 2008).

The whole Perseus region was first surveyed in ^{12}CO by Sargent (1979), and since then has been mapped in CO at different angular resolutions (all with beams > 1′) by a number of other authors (e.g., Bachiller & Cernicharo 1986; Ungerechts & Thaddeus 1987; Padoan et al. 1999; Sun et al. 2006). These maps show a clear velocity gradient in the Perseus molecular cloud complex where the central cloud (LSR) velocity increases from about 4.5 km s^{-1} at the western edge of the cloud to about 10 km s^{-1} at the eastern end. The large velocity gradient in the gas across the entire complex and the fact that different parts of the Perseus cloud appear to have different distances (see above) could possibly indicate that the complex is made up of a superposition of different entities. Recently, the Perseus molecular cloud complex was also observed (and studied) in its entirety in the mid- and far-infrared as part of the "From Molecular Cores to Planet-forming Disks" (aka c2d) *Spitzer* Legacy Project (Jørgensen et al. 2006; Rebull et al. 2007; Evans et al. 2009).

2. DATA

In this paper, we use the ^{12}CO(1–0) and ^{13}CO(1–0) data collected for Perseus as part of the COordinated Molecular Probe Line Extinction Thermal Emission (COMPLETE) Survey of Star Forming Regions,[6] described in detail by Ridge et al. (2006b). The ^{12}CO and ^{13}CO molecular line maps were observed between 2002 and 2005 using the 14 m Five College Radio Astronomy Observatory (FCRAO) telescope with the SEQUOIA 32-element focal plane array. The receiver was used with a digital correlator providing a total bandwidth of 25 MHz over 1024 channels. The ^{12}CO $J = 1$–0 (115.271 GHz) and the ^{13}CO $J = 1$–0 (110.201 GHz) transitions were observed simultaneously using an on-the-fly (OTF) mapping technique. The beam telescope at these frequencies is about 46″. Both maps of ^{12}CO and ^{13}CO are essential for a thorough study of the outflow and cloud properties. The ^{12}CO(1–0) is a good tracer of the cool and massive molecular outflows and provides the information needed to study the impact of these energetic phenomena on the cloud. The ^{13}CO(1–0) provides an estimate of the optical depth of the ^{12}CO(1–0) line and can be used to probe the cloud structure and kinematics.

Observations were made in 10′ × 10′ maps with an effective velocity resolution of 0.07 km s^{-1}. These small maps were then patched together to form the final large map of Perseus, which is about 6°.25 × 3°. Calibration was done via the chopper-wheel technique (Kutner & Ulich 1981), yielding spectra with units of T_A^*. We removed noisy pixels that were more than 3 times the average rms noise of the data cube, the entire map was then resampled to a 46″ grid, and the spectral axis was Hanning smoothed[7] (necessary to keep the cubes to a size manageable by

6 See http://www.cfa.harvard.edu/COMPLETE.
7 See http://www.cfa.harvard.edu/COMPLETE/projects/outflows.html for a link to the molecular line maps.

the three-dimensional visualization code, see below). During the observations of the Perseus cloud, different OFF positions were used depending on the location that was being mapped. Some of these OFF positions had faint, though significant, emission which resulted in an artificial absorption feature in the final spectra. Gaussians were fitted to the negative feature in regions with no gas emission, and the fits were then used to correct for the contaminating spectral component. The resulting mean 3σ rms per channel in the ^{12}CO and ^{13}CO maps are 0.25 and 0.20 K, respectively, in the T_A^* scale. Spectra were corrected for the main beam efficiencies of the telescope (0.49 and 0.45 at 110 and 115 GHz, respectively), obtained from measurements of Jupiter.

3. COMPUTATIONAL MOTIVATION AND THREE-DIMENSIONAL VISUALIZATION

This study allows for a test of the effectiveness of three-dimensional visualization of molecular line data of molecular clouds in R.A.–decl.–velocity (p–p–v) space as a way to identify velocity features, such as outflows, in large maps.[8] The primary program used for three-dimensional visualization is 3D Slicer[9] which was developed originally at the MIT Artificial Intelligence Laboratory and the Surgical Planning Lab at Brigham and Women's Hospital. It was designed to help surgeons in image-guided surgery, to assist in pre-surgical preparation, to be used as a diagnostic tool, and to help in the field of brain research and visualization (Gering 1999). The 3D Slicer was first used with astronomical data by Borkin et al. (2005) to study the hierarchical structure of star-forming cores and velocity structure of IC 348 with ^{13}CO(1–0) and C^{18}O(1–0) data.

We divided the Perseus cloud into six areas (with similar cloud central LSR velocities) for easier visualization and outflow search in 3D Slicer (see below). The borders of these areas are similar to those named by Pineda et al. (2008), who also based their division mainly on the cloud's central LSR velocity. The regions, whose outlines are shown in Figure 1, overlap between 1 and 3 arcmin to guarantee complete analysis. This overlap was checked to be sufficient based on the fact that new and known outflows which crossed regions were successfully double-identified.

For each area, an isosurface (constant intensity level) model was generated in 3D Slicer, using the ^{12}CO(1–0) map. The threshold emission intensity level chosen for each isosurface model was the lowest level of emission above the rms noise level for that particular region. This creates a three-dimensional model representing all of the detected emission. The high-velocity gas in this three-dimensional space can be identified in the form of spikes, as shown for the B5 region in Figure 2, which visually stick out from the general distribution of the gas. These sharp protrusions occur since one is looking at the radial velocity component of the gas along the line of sight, thus causing spikes wherever there is gas at distinct velocities far away from the main cloud velocity. Instead of having to go through each region and carefully examine each channel map, or randomly scroll through the spectra by hand, this visualization allows one to instantly see where the high-velocity points are located (see also Borkin et al. 2007, 2008).

8 This work is done as part of the Astronomical Medicine project (http://am.iic.harvard.edu) at the Initiative in Innovative Computing at Harvard (http://iic.harvard.edu). The goal of the project is to address common research challenges to both the fields of medical imaging and astronomy including visualization, image analysis, and accessibility of large varying kinds of data.
9 http://www.slicer.org/

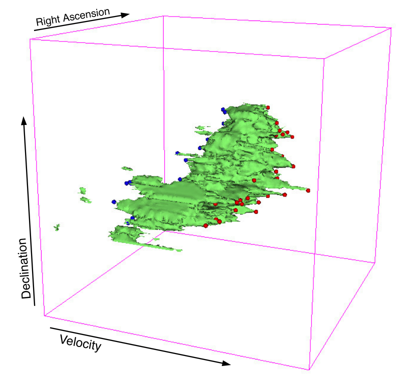

Figure 2. Three-dimensional rendering of the molecular gas in B5 (i.e., Area VI in Figure 1), using 3D Slicer. The gray (green) isosurface model shows the ^{12}CO emission in position–position–velocity space. The small circles show the locations of identified high-velocity points (with the color in the online version representing whether the point is blue- or red-shifted).

(A color version of this figure is available in the online journal.)

4. OUTFLOW IDENTIFICATION

A total of 218 high-velocity points were visually identified in 3D Slicer for all of Perseus in ^{12}CO. We checked the position of each high-velocity point against the locations of known outflows (based on an extensive literature search) to determine if the point is associated with any known molecular outflow. From the 218 high-velocity points found, a total of 36 points were identified as associated with known molecular outflows. Figure 3 shows the approximate regions where previously known ^{12}CO(1–0) outflows lie. The number of high-velocity points associated with a single outflow varies depending on its size and intensity. For example, the parsec-scale B5 IRS1 outflow is a conglomerate of six high-velocity points whereas the HH 211 outflow, which is only ∼0.1 pc long, is identified by only one point. We inspected each of the remaining 182 high-velocity points to verify whether they are outflow related or caused by other velocity features in the cloud. To determine if a high-velocity point is outflow related, we checked the spectrum by eye to look for outflow traits (e.g., high-velocity low-intensity wings) and verified its proximity to known outflows and outflow sources (Wu et al. 2004), HH objects (Walawender et al. 2005b), H_2 knots (Davis et al. 2008), candidate young stellar objects (YSOs) form the c2d *Spitzer* survey (Evans et al. 2009) and other known outflow sources and YSOs. We also checked the velocity distribution and morphology of the gas associated with each high-velocity point to verify whether the velocity and structure of the gas were significantly different from that of the cloud in that region. From the remaining 182 high-velocity points found, a total of 60 points were classified as being outflow *candidates* based on the criteria mentioned above. For 97% of these outflow candidates, the maximum velocity away from the cloud velocity is equal to or greater than the escape velocity in that region of the cloud. We note that we purposely chose not to be too restrictive in the definition of outflow candidate (e.g., we identified outflow candidates even without a solid outflow source identification, see

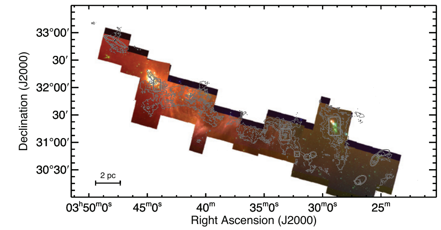

Figure 3. *Spitzer* IRAC (color) image of the c2d coverage of the Perseus cloud made from 3.6, 4.5, and 8.0 μm images of the region (Evans et al. 2009). The color code is blue (3.6 μm), green (4.5 μm), and red (8.0 μm). Ellipses and squares with rounded corners show the approximate regions where previously known outflows in Perseus lie. The gray contours show the 4 K km s^{-1} level of the ^{13}CO(1–0) integrated intensity map (not corrected for the FCRAO beam efficiency).

(A color version of this figure is available in the online journal.)

below). Using our broad, yet realistic, definition we can calculate the maximum possible impact from all plausible molecular outflows to the cloud. Out of the remaining 122 points, 17 points were discarded due to too much noise or being pixels cut off by the map's edge and the other 105 points are thought to be caused by a number of other kinematic phenomena, including clouds at other velocities in the same line of sight unrelated to the Perseus cloud and spherical winds from young stars that produce expanding shell-like structures in the molecular gas (as opposed to the discrete blob morphology observed in the 60 outflow candidates). The distribution and impact of these expanding shells on the cloud will be discussed further in a subsequent paper (H. G. Arce et al. 2011, in preparation).

We visually inspected the velocity maps in the area surrounding each of the 60 high-velocity points identified as outflow in origin (but unrelated to known outflows) and chose an area (in R.A.–decl. space) and velocity range that included all or most of the emission associated with the kinetic feature. The integration area and velocity ranges were conservatively chosen to include only the emission visibly associated with the outflowing material, thus avoiding cloud emission. The high-velocity gas associated with these 60 points shows discrete morphologies in area and velocity. Hereafter each of these high-velocity features is referred as a "COMPLETE Perseus Outflow Candidate" (CPOC) and we list their positions and other properties in Table 1.[10] In Figure 4, we show the velocity ranges of all CPOCs, in comparison with their local cloud (LSR) velocity.

Our outflow-detection technique proved to be reliable, as we detect high-velocity gas associated with all published CO(1–0) outflows (see Figure 3). However, it is very probable that the catalog of new molecular outflows generated for this paper is an underestimate of the true number of previously undetected molecular outflows due to the resolution of the CO maps and other limitations of our outflow-detection technique. Unknown outflows that are smaller than the beam size of our map (i.e., 0.06 pc at the assumed distance of Perseus) or that have weak high-velocity wings (i.e., with intensities less than twice the rms of the spectra at that particular position) cannot be detected by our technique. Outflows with maximum velocities too close to

10 See http://www.cfa.harvard.edu/COMPLETE/projects/outflows.html for a link to the fits cubes and the integrated intensity fits files of the CPOCs, as well as a list of the YSO candidates, HH objects, and H_2 knots in the cloud.

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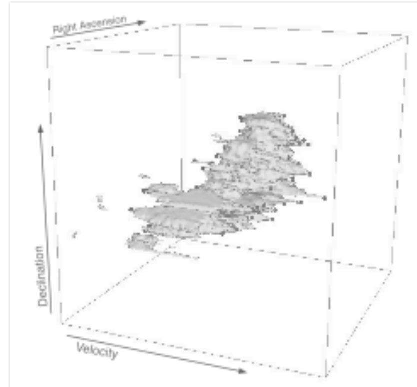

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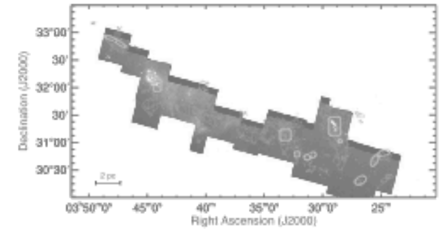

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4. OUTFLOW IDENTIFICATION

A total of 218 high-velocity points were visually identified in 3D Slicer for all of Perseus in ^{12}CO. We checked the position of each high-velocity point against the locations of known outflows (based on an extensive literature search) to determine if the point ... molecular outflow. From the 218 ... total of 36 points were identified ... olecular outflows. Figure 3 shows ... re previously known ^{12}CO(1–0) ... gh-velocity points associated with ... ding on its size and intensity. For ... IRS1 outflow is a conglomerate of ... eas the HH 211 outflow, which is ... d by only one point. We inspected ... h-velocity points to verify whether they are outflow related or caused by other velocity features in the cloud. To determine if a high-velocity point is outflow ...

60 points were classified as being outflow *candidates* based on the criteria mentioned above. For 97% of these outflow candidates, the maximum velocity away from the cloud velocity is equal to or greater than the escape velocity in that region of the cloud. We note that we purposely chose not to be too restrictive in the definition of outflow candidate (e.g., we identified outflow candidates even without a solid outflow source identification, see below). Using our broad, yet realistic, definition we can calculate the maximum possible impact from all plausible molecular outflows to the cloud. Out of the remaining 122 points, 17 points were discarded due to too much noise or being pixels cut off by the map's edge and the other 105 points are thought to be caused by a number of other kinematic phenomena, including clouds at other velocities in the same line of sight unrelated to the Perseus cloud and spherical winds from young stars that produce expanding shell-like structures in the molecular gas (as opposed to the discrete blob morphology observed in the 60 outflow candidates). The distribution and impact of these expanding shells on the cloud will be discussed further in a subsequent paper (H. G. Arce et al. 2011, in preparation).

We visually inspected the velocity maps in the area surrounding each of the 60 high-velocity points identified as outflow in origin (but unrelated to known outflows) and chose an area (in R.A.–decl. space) and velocity range that included all or most of the emission associated with the kinetic feature. The integration area and velocity ranges were conservatively chosen to include only the emission visibly associated with the outflowing material, thus avoiding cloud emission. The high-velocity gas associated with these 60 points shows discrete morphologies in area and velocity. Hereafter each of these high-velocity features is referred as a "COMPLETE Perseus Outflow Candidate" (CPOC) and we list their positions and other properties in ... s of all CPOCs, ... ity. ... reliable, as we ... shed CO(1–0) ... obable that the ... r this paper is ... sly undetected ... CO maps and ... que. Unknown ... our map (i.e., 0.06 pc at the assumed distance of Perseus) or that have weak high-velocity wings (i.e., with intensities less than twice the rms of the spectra at that particular position) cannot be detected by our technique. Outflows with maximum velocities too close to ...

[10] See http://www.cfa.harvard.edu/COMPLETE/projects/outflows.html for a link to the fits cubes and the integrated intensity fits files of the CPOCs, as well as a list of the YSO candidates, HH objects, and H_2 knots in the cloud.

6 See http://www.cfa.harvard.edu/COMPLETE.
7 See http://www.cfa.harvard.edu/COMPLETE/projects/outflows.html for a link to the molecular line maps.

10 See http://www.cfa.harvard.edu/COMPLETE/projects/outflows.html for a link to the fits cubes and the integrated intensity fits files of the CPOCs, as well as a list of the YSO candidates, HH objects, and H_2 knots in the cloud.

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in IC 348 (HD 281159) is confirmed to reside in the Perseus cloud, but there might be a few other high-mass stars that interact with the cloud (through their winds and/or UV radiation) even though they were not necessarily formed in the cloud complex (see, e.g., Walawender et al. 2004; Ridge et al. 2006a; Kirk et al. 2006; Rebull et al. 2007). There is also a large number of nebulous objects associated with outflow shocks (i.e., HH objects and H_2 knots) that have been identified in the cloud complex (Bally et al. 1996b, 1997; Yan et al. 1998; Walawender et al. 2005b; Davis et al. 2008).

The whole Perseus region was first surveyed in ^{12}CO by Sargent (1979), and since then has been mapped in CO at different angular resolutions (all with beams > 1′) by a number of other authors (e.g., Bachiller & Cernicharo 1986; Ungerechts & Thaddeus 1987; Padoan et al. 1999; Sun et al. 2006). These maps show a clear velocity gradient in the Perseus molecular cloud complex where the central cloud (LSR) velocity increases from about 4.5 km s^{-1} at the western edge of the cloud to about 10 km s^{-1} at the eastern end. The large velocity gradient in the gas across the entire complex and the fact that different parts of the Perseus cloud appear to have different distances (see above) could possibly indicate that the complex is made up of a superposition of different entities. Recently, the Perseus molecular cloud complex was also observed (and studied) in its entirety in the mid- and far-infrared as part of the "From Molecular Cores to Planet-forming Disks" (aka c2d) *Spitzer* Legacy Project (Jørgensen et al. 2006; Rebull et al. 2007; Evans et al. 2009).

2. DATA

In this paper, we use the ^{12}CO(1–0) and ^{13}CO(1–0) data collected for Perseus as part of the COordinated Molecular Probe Line Extinction Thermal Emission (COMPLETE) Survey of Star Forming Regions,[6] described in detail by Ridge et al. (2006b). The ^{12}CO and ^{13}CO molecular line maps were observed between 2002 and 2005 using the 14 m Five College Radio Astronomy Observatory (FCRAO) telescope with the SEQUOIA 32-element focal plane array. The receiver was used with a digital correlator providing a total bandwidth of 25 MHz over 1024 channels. The ^{12}CO $J = 1$–0 (115.271 GHz) and the ^{13}CO $J = 1$–0 (110.201 GHz) transitions were observed simultaneously using an on-the-fly (OTF) mapping technique. The beam telescope at these frequencies is about 46″. Both maps of ^{12}CO and ^{13}CO are essential for a thorough study of the outflow and cloud properties. The ^{12}CO(1–0) is a good tracer of the cool and massive molecular outflows and provides the information needed to study the impact of these energetic phenomena on the cloud. The ^{13}CO(1–0) provides an estimate of the optical depth of the ^{12}CO(1–0) line and can be used to probe the cloud structure and kinematics.

Observations were made in 10′ × 10′ maps with an effective velocity resolution of 0.07 km s^{-1}. These small maps were then patched together to form the final large map of Perseus, which is about 6°.25 × 3°. Calibration was done via the chopper-wheel technique (Kutner & Ulich 1981), yielding spectra with units of T_A^*. We removed noisy pixels that were more than 3 times the average rms noise of the data cube, the entire map was then resampled to a 46″ grid, and the spectral axis was Hanning smoothed[7] (necessary to keep the cubes to a size manageable by the three-dimensional visualization code, see below). During the observations of the Perseus cloud, different OFF positions were used depending on the location that was being mapped. Some of these OFF positions had faint, though significant, emission which resulted in an artificial absorption feature in the final spectra. Gaussians were fitted to the negative feature in regions with no gas emission, and the fits were then used to correct for the contaminating spectral component. The resulting mean 3σ rms per channel in the ^{12}CO and ^{13}CO maps are 0.25 and 0.20 K, respectively, in the T_A^* scale. Spectra were corrected for the main beam efficiencies of the telescope (0.49 and 0.45 at 110 and 115 GHz, respectively), obtained from measurements of Jupiter.

3. COMPUTATIONAL MOTIVATION AND THREE-DIMENSIONAL VISUALIZATION

This study allows for a test of the effectiveness of three-dimensional visualization of molecular line data of molecular clouds in R.A.–decl.–velocity (p–p–v) space as a way to identify velocity features, such as outflows, in large maps.[8] The primary program used for three-dimensional visualization is 3D Slicer[9] which was developed originally at the MIT Artificial Intelligence Laboratory and the Surgical Planning Lab at Brigham and Women's Hospital. It was designed to help surgeons in image-guided surgery, to assist in pre-surgical preparation, to be used as a diagnostic tool, and to help in the field of brain research and visualization (Gering 1999). The 3D Slicer was first used with astronomical data by Borkin et al. (2005) to study the hierarchical structure of star-forming cores and velocity structure of IC 348 with ^{13}CO(1–0) and $C^{18}O$(1–0) data.

We divided the Perseus cloud into six areas (with similar cloud central LSR velocities) for easier visualization and outflow search in 3D Slicer (see below). The borders of these areas are similar to those named by Pineda et al. (2008), who also based their division mainly on the cloud's central LSR velocity. The regions, whose outlines are shown in Figure 1, overlap between 1 and 3 arcmin to guarantee complete analysis. This overlap was checked to be sufficient based on the fact that new and known outflows which crossed regions were successfully double-identified.

For each area, an isosurface (constant intensity level) model was generated in 3D Slicer, using the ^{12}CO(1–0) map. The threshold emission intensity level chosen for each isosurface model was the lowest level of emission above the rms noise level for that particular region. This creates a three-dimensional model representing all of the detected emission. The high-velocity gas in this three-dimensional space can be identified in the form of spikes, as shown for the B5 region in Figure 2, which visually stick out from the general distribution of the gas. These sharp protrusions occur since one is looking at the radial velocity component of the gas along the line of sight, thus causing spikes wherever there is gas at distinct velocities far away from the main cloud velocity. Instead of having to go through each region and carefully examine each channel map, or randomly scroll through the spectra by hand, this visualization allows one to instantly see where the high-velocity points are located (see also Borkin et al. 2007, 2008).

[6] See http://www.cfa.harvard.edu/COMPLETE.

[7] See http://www.cfa.harvard.edu/COMPLETE/projects/outflows.html for a link to the molecular line maps.

[8] This work is done as part of the Astronomical Medicine project (http://am.iic.harvard.edu) at the Initiative in Innovative Computing at Harvard (http://iic.harvard.edu). The goal of the project is to address common research challenges to both the fields of medical imaging and astronomy including visualization, image analysis, and accessibility of large varying kinds of data.

[9] http://www.slicer.org/

at redshifted velocities. CPOC 47 is located just to the north of IC 348 where there are a number c2d YSO candidates, and this candidate outflow is most probably associated with one of these sources rather than any of the sources in B5. CPOC 52 is a blob with relatively high-velocity blueshifted gas, significantly different from ambient cloud velocities (see Figure 4). CPOCs 53 and 54 have redshifted velocities and may be associated with HH 844 and IRAS 03439+3233 (also known as B5-IRS3). CPOC 57 is redshifted and is located about 10′ northeast of B5-IRS4, while CPOC 58 is located south of the blueshifted lobe of B5-IRS1 and it is not clear to which young star in the region it is associated with. CPOC 60 is located at the eastern edge of our map. We classify it as a candidate outflow because of its morphology and velocity structure.

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The COordinated Molecular Probe Line Extinction Thermal Emission Survey of Star Forming Regions (COMPLETE) provides a range of data complementary to the Spitzer Legacy Program "From Molecular Cores to Planet Forming Disks" (c2d) for the Perseus, Ophiuchus and Serpens regions. In combination with the Spitzer observations, COMPLETE will allow for detailed analysis and understanding of the physics of star formation on scales from 500 A.U. to 10 pc.

Phase I, which is now complete, provides fully sampled, arcminute resolution observations of the density and velocity structure of the three regions, comprising: 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 100um emission; HI maps of atomic gas; 12CO and 13CO maps of molecular gas; and submillimeter continuum images of emission from dust in dense cores.

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Phase II (which is still ongoing) uses targeted source lists based on the Phase I data, as it is (still) not feasible to cover every dense star-forming peak at high resolution. Phase II includes high-sensitivity near-IR imaging (for high resolution extinction mapping), mm-continuum imaging with MAMBO on IRAM and high-resolution observations of dense gas tracers such as N2H+. These data are being released as they are validated.

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Recent COMPLETE Publications

NEW Helen Kirk, Jaime E. Pineda, Doug Johnstone, and Alyssa A. Goodman, 2010, *The Dynamics of Dense Cores in the Perseus Molecular Cloud II: The Relationship Between Dense Cores and the Cloud*, Accepted to ApJ. (astro-ph | ADS)

UPDATED Héctor G. Arce, Michelle Borkin, Alyssa A. Goodman, Jaime E. Pineda, Michael Halle, 2010, *The COMPLETE Survey of Outflows in Perseus*, ApJ, 715, 117. (Local | Project webpage | astro-ph | ADS)

UPDATED Jaime E. Pineda, Alyssa A. Goodman, Héctor G. Arce, Paola Caselli, Jonathan B. Foster, Philip C. Myers, Erik W. Rosolowsky, 2010, *Direct observation of a sharp transition to coherence in Dense Cores*, ApJL, 712, 116. (Local | astro-ph | ADS)

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COMPLETE

2MASS/NICER Perseus Extinction Data

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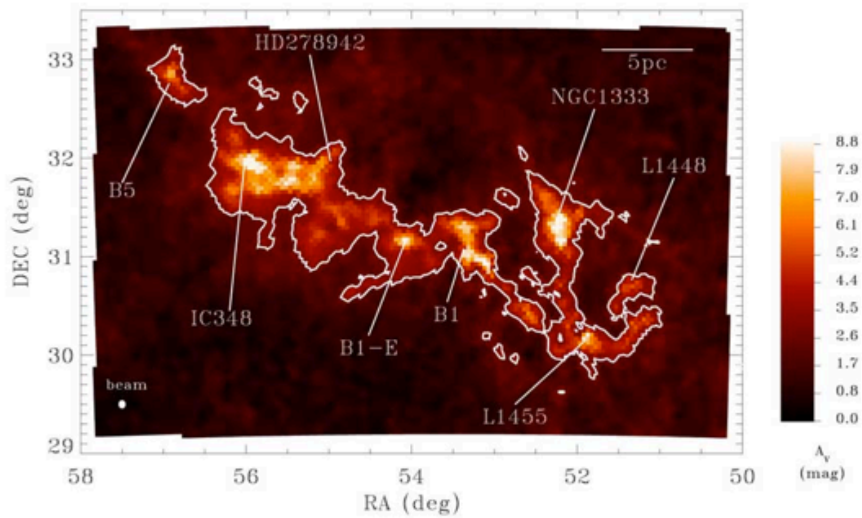

Description:

Extinciton maps made from 2MASS and NICER (Near Infrared Extinction-method Revisited). This map is made from the final 2MASS data release and cover all of Perseus. The data values are magnitudes of visual extinction (Av). Consult the error map and stellar density map to identify any problematic regions (few in this map). Versions in galactic and equatorial coordinates are provided. The equatorial versions look less smooth, since they were regridded without re-orientating pixels. FITS headers for all these files occasionally refuse to play nicely with certain programs, but all display correctly in something like DS9.

Contact Person:

Jonathan Foster, Harvard-Smithsonian Center for Astrophysics

Telescope:

2MASS

Status:

Finished

Sampling:

N/A

Areal Coverage:

9 by 12 degrees

Map Center (Galactic):

l = 159.90
b = -20.73

Map Center (J2000):

RA = 03:33:55
Dec = 30:14:27

Downloads:

- PerA_Extn2MASS_F_Gal.fits Map in Galactic Coordinates (436 K)
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- PerA_Extn2MASS_F_Den-Gal.fits Stellar density map in Galactic Coordinates (436 K)
- PerA_Extn2MASS_F_Eq.fits Map in Equatorial Coordinates (984 K)
- PerA_Extn2MASS_F_Err-Eq.fits Error map in Equatorial Coordinates (984 K)
- PerA_Extn2MASS_F_Den-Eq.fits Stellar density map in Equatorial Coordinates (984 K)
- Info File (All comments and information about this data)

Comments on Resolution:

The map is smoothed with a gaussian filter with FWHM = 5 arcminutes or two pixels, so each pixel is 2.5 arcminutes.

②

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ApJ Keywords:	ISM: clouds, ISM: individual objects: Perseus, ISM: jets and outflows, ISM: kinematics and dynamics, stars: formation, turbulence
DOI:	10.1088/0004-637X/715/2/1170
Bibliographic Code:	2010ApJ...715.1170A

DATA?

③

INTEGRATION OF DATA AND LITERATURE

Create seamless links between related astronomical resources so that data can act *as a filter for literature*

... but,
let's go
back to

①

①

DATA CITATION PRACTICES

The need for a standardized, widely-adopted mechanism to cite data in a structured format

How were scientists citing literature before a standardized referencing mechanism was in place?

How were scientists citing literature before a standardized referencing mechanism was in place?

Footnotes?
Inline referencing?
Works identified by author, year, title?

How were scientists citing literature before a standardized referencing mechanism was in place?

Footnotes?
Inline referencing?
Works identified by author, year, title?

The use of hyper-linking and other ad-hoc methods to reference data are

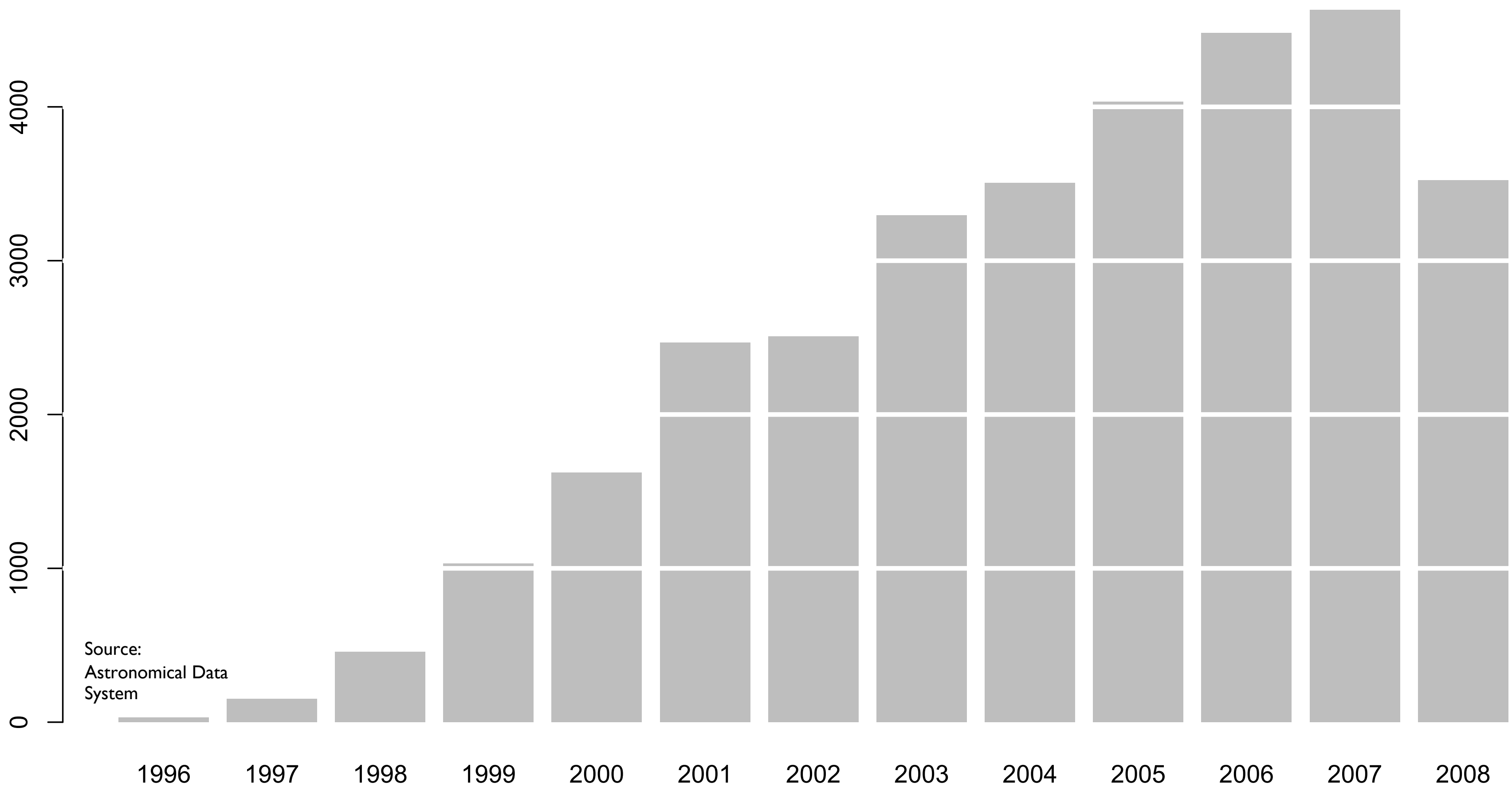
COMPARABLE

to early attempts to cite scientific literature

LINK ANALYSIS

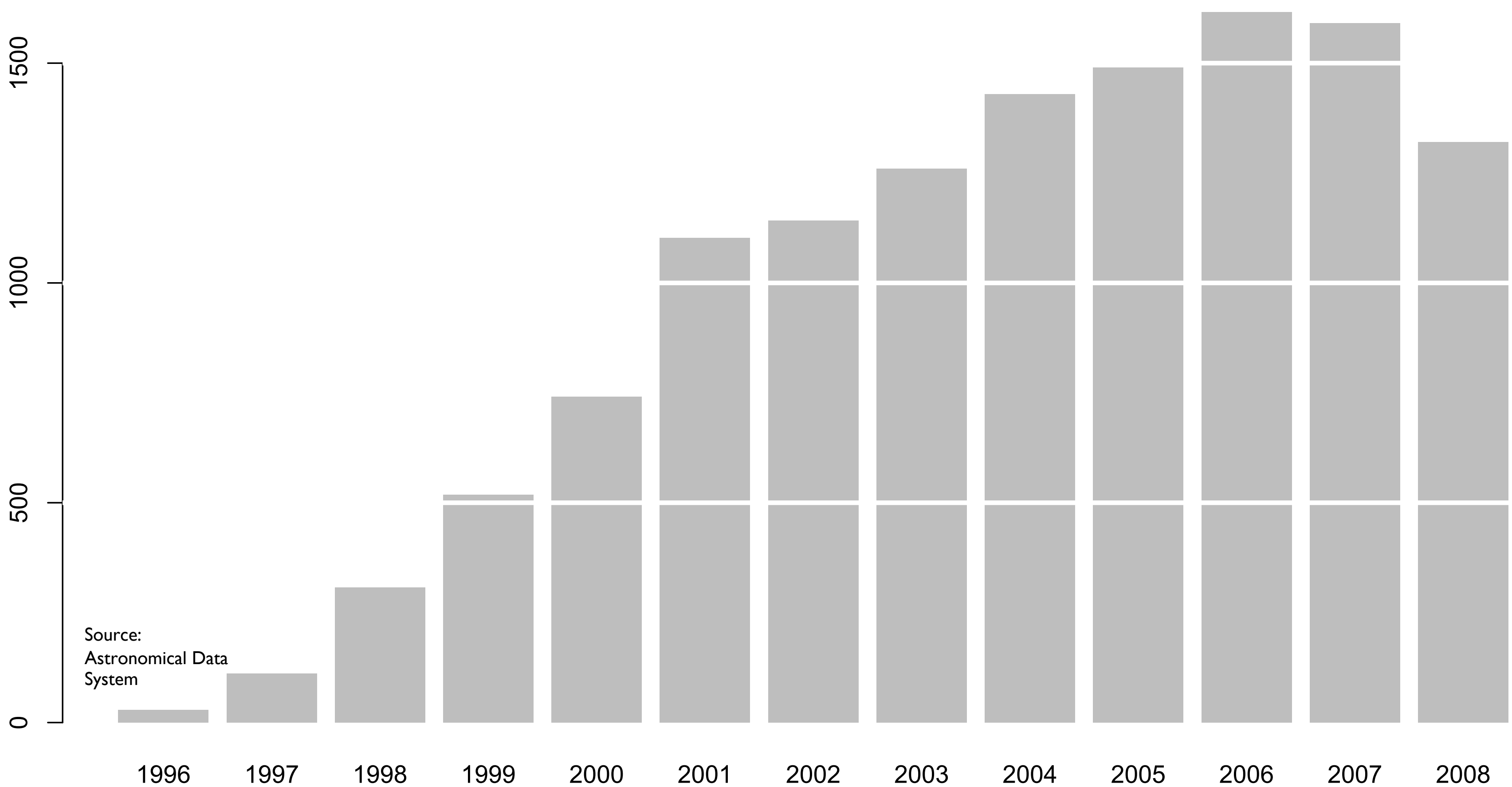
Similar to bibliometric analyses, but let us look at references to data rather than references to literature

NUMBER OF LINKS IN ASTRONOMY PUBLICATIONS*, BY YEAR

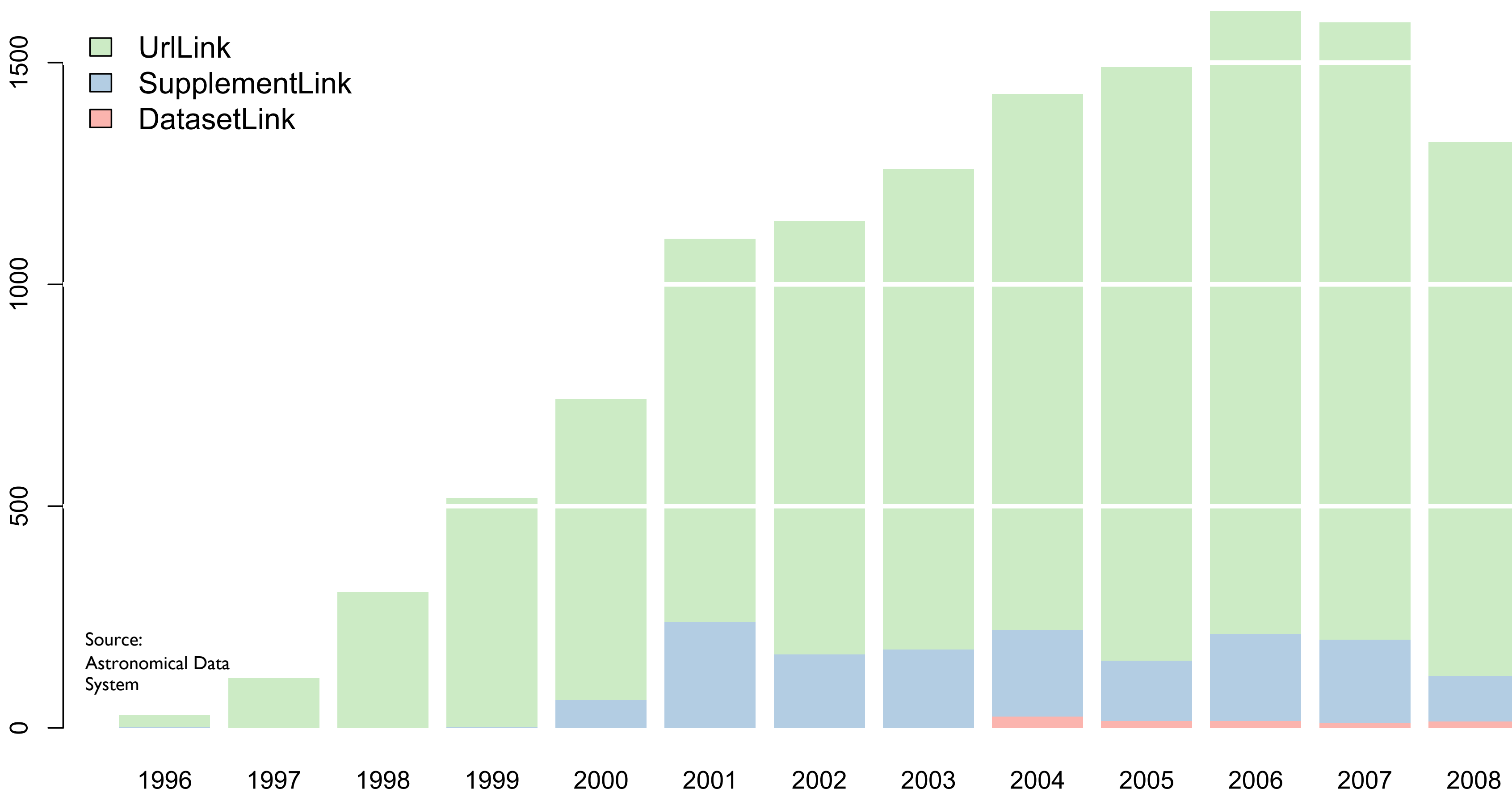


* 31,730 articles published in four journals: Astronomical Journal (AJ), Astrophysical Journal (ApJ), ApJ Letters (ApJL), ApJ Supplement Series (ApJSS)

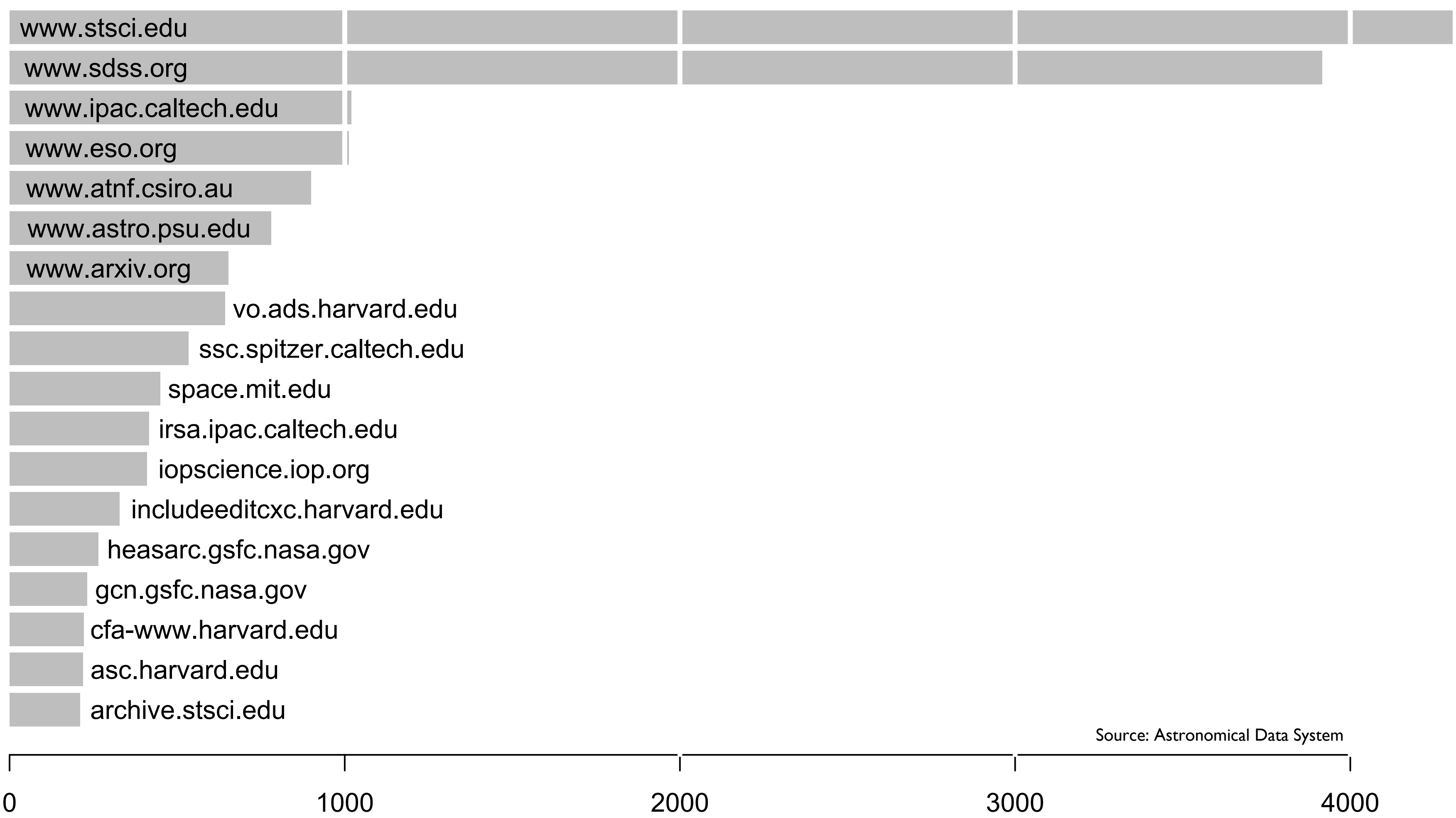
NUMBER OF ASTRONOMY PUBLICATIONS WITH LINKS, BY YEAR



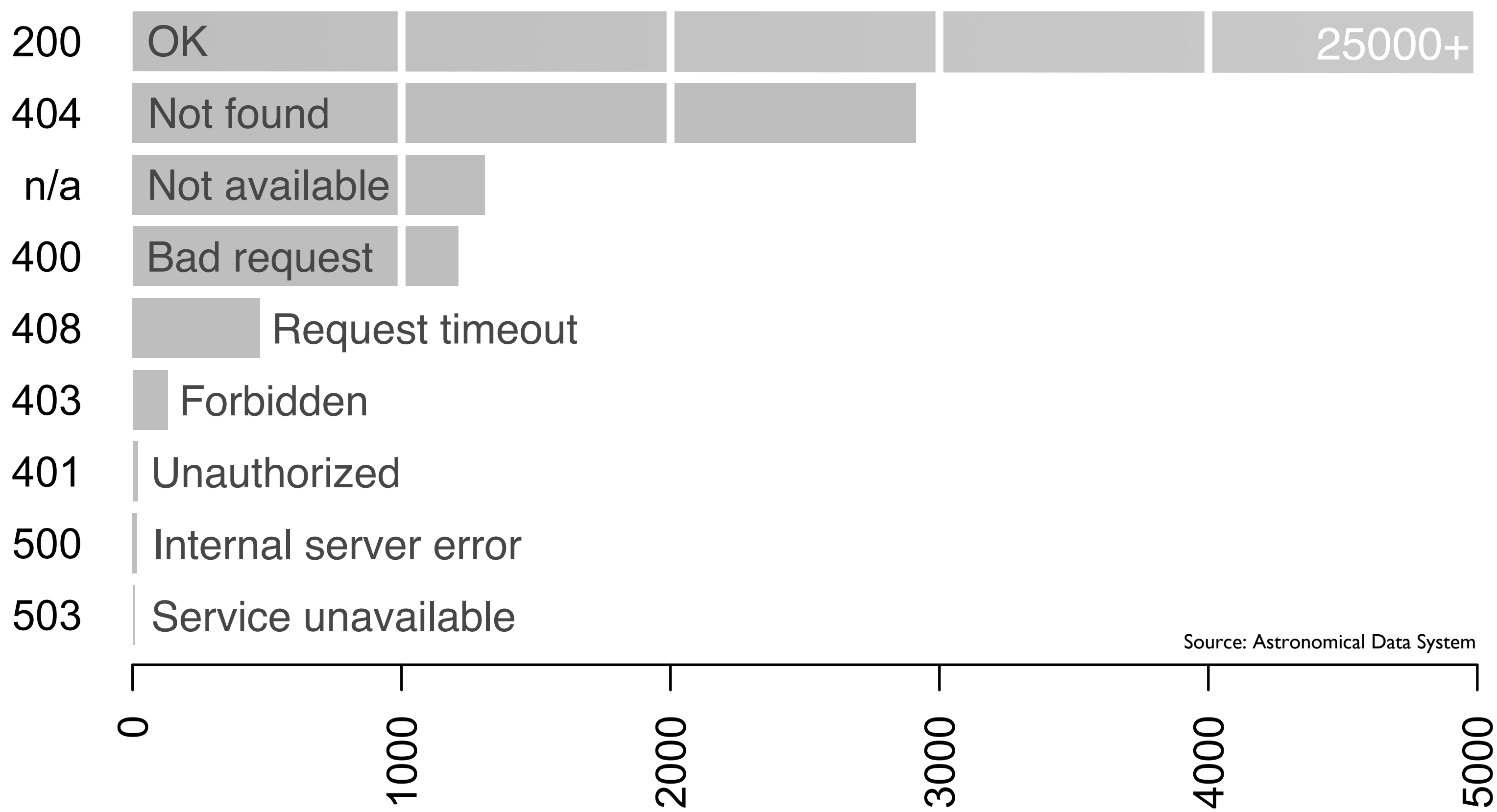
NUMBER OF ASTRONOMY PUBLICATIONS WITH LINKS, BY YEAR



MOST FREQUENT BASE URLS OF LINKS IN ASTRONOMICAL PUBLICATIONS



HTTP STATUS CODES OF LINKS IN ASTRONOMICAL PUBLICATIONS



②

PERSONAL DATA STORAGE

The need for a "personal" or project-based repository for "small" astronomical data

Storing and managing astronomical LITTLE DATA

Astronomical
little data??!!?

1174 ARCE ET AL. Vol. 715

Table 1
Candidate New and Extended Outflow Locations

Name	R.A.	Decl.	Area	Mass	Momentum	Kinetic Energy	Driving Source
	(J2000)		(arcmin)	($M_\odot$)	($M_\odot$ km s^{-1})	(10^{42} erg)	Candidate(s)
CPOC 1	03:23:21	30:52:10	19 × 12	0.05	0.19	6.93	L1448-IRS1
CPOC 2	03:23:54	30:48:10	16 × 7	0.36	0.88	21.68	L1448-IRS1
CPOC 3	03:24:30	30:50:00	10 × 5	0.02	0.08	2.93	L1448-IRS3
CPOC 4	03:24:54	30:43:10	4 × 4	0.01	0.04	2.10	Multiple in L1448
CPOC 5	03:25:39	30:28:20	7 × 5	0.02	0.05	1.32	SSTc2dJ032519.52+303424.2
CPOC 6	03:27:55	31:19:50	4 × 3	0.02	0.03	0.36	Multiple NGC 1333, near HH 338
CPOC 7	03:28:00	31:03:40	15 × 12	0.29	1.79	112.00	SSTc2dJ032834.49+310051.1
CPOC 8	03:28:32	30:28:20	8 × 11	0.11	0.28	7.17	Near HH 750 and HH 743, SSTc2dJ032835.03+302009.9 or SSTc2dJ032906.05+303039.2
CPOC 9	03:28:28	31:13:20	8 × 8	0.26	0.56	12.63	SSTc2dJ032832.56+311105.1 or SSTc2dJ032837.09+311330.8
CPOC 10	03:28:27	31:23:20	8 × 8	0.24	0.42	7.50	SSTc2dJ032844.09+312052.7
CPOC 11	03:28:40	31:07:10	8 × 6	0.11	0.27	7.01	STTc2dJ032834.53+310705.5
CPOC 12	03:28:43	31:07:30	8 × 7	0.19	0.97	52.02	SSTc2dJ032843.24+311042.7
CPOC 13	03:28:50	31:27:10	6 × 8	0.31	0.80	21.00	Multiple in NGC 1333
CPOC 14	03:28:57	30:50:20	6 × 5	0.03	0.05	0.73	SSTc2dJ032850.62+304244.7 or SSTc2dJ032852.17+304505.5
CPOC 15	03:29:07	30:45:50	7 × 5	0.19	0.80	32.82	SSTc2dJ032850.62+304244.7 or SSTc2dJ032852.17+304505.5
CPOC 16	03:29:30	31:07:10	6 × 6	0.04	0.10	2.40	HH 18A, multiple in NGC 1333
CPOC 17	03:29:41	31:17:30	9 × 13	3.20	8.49	235.28	Near HH 497, HH 336, multiple in NGC 1333
CPOC 18	03:29:41	31:27:10	5 × 6	0.08	0.21	6.35	HH 764, multiple in NGC 1333
CPOC 19	03:29:27	31:34:00	9 × 7	0.19	0.59	19.31	IRAS 03262+3123
CPOC 20	03:30:06	31:27:10	5 × 4	0.04	0.08	1.73	Multiple NGC 1333
CPOC 21	03:30:11	31:14:00	8 × 5	0.05	0.13	3.45	HH 767, SSTc2dJ033024.08+311404.4
CPOC 22	03:30:40	30:37:00	6 × 11	0.30	1.07	39.24	Multiple in Per 6 aggregate
CPOC 23	03:30:56	31:21:10	6 × 6	0.01	0.05	3.56	Multiple in NGC 1333 or B1
CPOC 24	03:31:23	31:01:30	27 × 18	0.46	2.99	193.71	Multiple in B1 or B1-Ridge
CPOC 25	03:31:23	31:20:40	4 × 7	0.02	0.14	9.73	Multiple in NGC 1333 or B1
CPOC 26	03:31:40	30:54:40	6 × 4	0.09	0.27	8.26	IRAS 03292+3039 or others in B1 and B1-Ridge
CPOC 27	03:31:54	31:14:10	8 × 5	0.07	0.40	21.85	Multiple in NGC 133 or B1
CPOC 28	03:32:04	30:40:20	4 × 5	0.58	1.35	31.94	Multiple in B1-Ridge
CPOC 29	03:32:25	31:18:10	5 × 7	0.06	0.17	4.89	Multiple in B1
CPOC 30	03:32:37	31:02:50	3 × 6	0.04	0.13	3.57	Multiple in B1
CPOC 31	03:32:58	31:22:20	4 × 8	0.15	0.37	9.32	SSTc2dJ033312.84+312124.2 or SSTc2dJ033313.80+312005.3
CPOC 32	03:33:14	30:59:00	4 × 6	0.07	0.17	4.25	SSTc2dJ033346.92+305350.1 or Multiple in B1 core
CPOC 33	03:33:40	31:28:50	5 × 6	0.21	0.50	11.77	Multiple in B1
CPOC 34	03:33:58	31:16:10	6 × 4	0.14	0.25	4.58	SSTc2dJ033401.66+311439.8
CPOC 35	03:34:43	31:22:00	5 × 8	0.10	0.24	5.43	SSTc2dJ033430.78+311324.4 or SSTc2dJ033449.84+311550.3
CPOC 36	03:35:10	31:18:00	4 × 5	0.11	0.30	8.02	SSTc2dJ033430.78+311324.4 or SSTc2dJ033449.84+311550.3
CPOC 37	03:38:58	32:05:50	5 × 3	0.16	0.19	2.34	Unknown between IC 348 and B1
CPOC 38	03:39:05	32:08:40	5 × 4	0.04	0.06	0.90	Unknown between IC 348 and B1
CPOC 39	03:39:11	31:19:00	8 × 8	0.10	0.19	3.83	SSTc2dJ033915.81+312430.7 or SSTc2dJ034001.49+311017.3
CPOC 40	03:39:16	32:18:10	6 × 4	0.09	0.24	11.17	IRAS 03363+3207
CPOC 41	03:39:18	31:58:10	7 × 6	0.14	0.21	3.22	IRAS 03367+3147
CPOC 42	03:39:20	32:17:40	5 × 5	0.20	0.19	1.92	IRAS 03363+3207
CPOC 43	03:40:24	32:04:00	7 × 8	2.04	3.89	76.37	IRAS 03367+3147 or multiple west of IC 348
CPOC 44	03:42:12	31:51:50	5 × 5	0.09	0.18	3.44	Multiple east of IC 348
CPOC 45	03:44:34	31:58:20	4 × 6	0.54	0.73	10.04	Multiple in south edge of IC 348
CPOC 46	03:44:53	32:14:40	11 × 6	0.33	0.66	13.19	Multiple in north edge of IC 348
CPOC 47	03:44:58	32:32:00	11 × 9	0.20	0.41	8.69	Multiple in north edge of IC 348
CPOC 48	03:45:01	31:57:50	4 × 4	0.16	0.25	3.94	Multiple in south edge of IC 348
CPOC 49	03:45:04	32:00:30	5 × 5	0.03	0.09	3.40	Multiple in south edge of IC 348
CPOC 50	03:45:26	31:58:00	6 × 6	0.25	0.36	5.29	Multiple in south edge of IC 348
CPOC 51	03:45:53	32:34:00	7 × 7	0.27	0.32	4.09	B5-IRS1
CPOC 52	03:45:59	32:42:50	7 × 7	0.13	0.29	6.55	Unknown in B5
CPOC 53	03:46:54	32:36:20	6 × 5	0.07	0.10	1.24	B5-IRS3
CPOC 54	03:47:16	32:39:50	5 × 4	0.06	0.09	1.48	B5-IRS3
CPOC 55	03:47:17	33:01:40	15 × 15	3.97	7.55	147.19	B5-IRS4?
CPOC 56	03:47:60	32:38:40	20 × 13	3.76	6.73	124.04	Multiple in B5
CPOC 57	03:48:01	33:14:40	6 × 6	0.09	0.11	1.45	B5-IRS4?
CPOC 58	03:49:14	32:57:40	7 × 6	0.28	0.27	2.83	Unknown in B5
CPOC 59	03:49:18	33:04:40	5 × 7	0.20	0.25	3.37	B5-IRS1
CPOC 60	03:49:41	33:12:20	8 × 7	0.58	0.64	7.08	Unknown in B5

ASTRONOMY DATAVERSE*

* This work is done in collaboration with August Muench (CfA), Chris Erdmann (CfA Library), Mercé Crosas (IQSS)

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DATAVERSE

Professional archives focus on long term access by the wider community

- Persistent identifiers
- Fixity
- Backups and recovery
- Metadata standards
- Conversion standards
- Preservation standards

≠

Data owners focus on recognition and control

- Branding and visibility
- Data discovery
- Ease of use
- Scholarly citation
- Control over updates
- Terms of access and use

… but do not attract maximum contribution from data owners

… but do not assure long-term use as would a professional archive

Courtesy: Mercé Crosas

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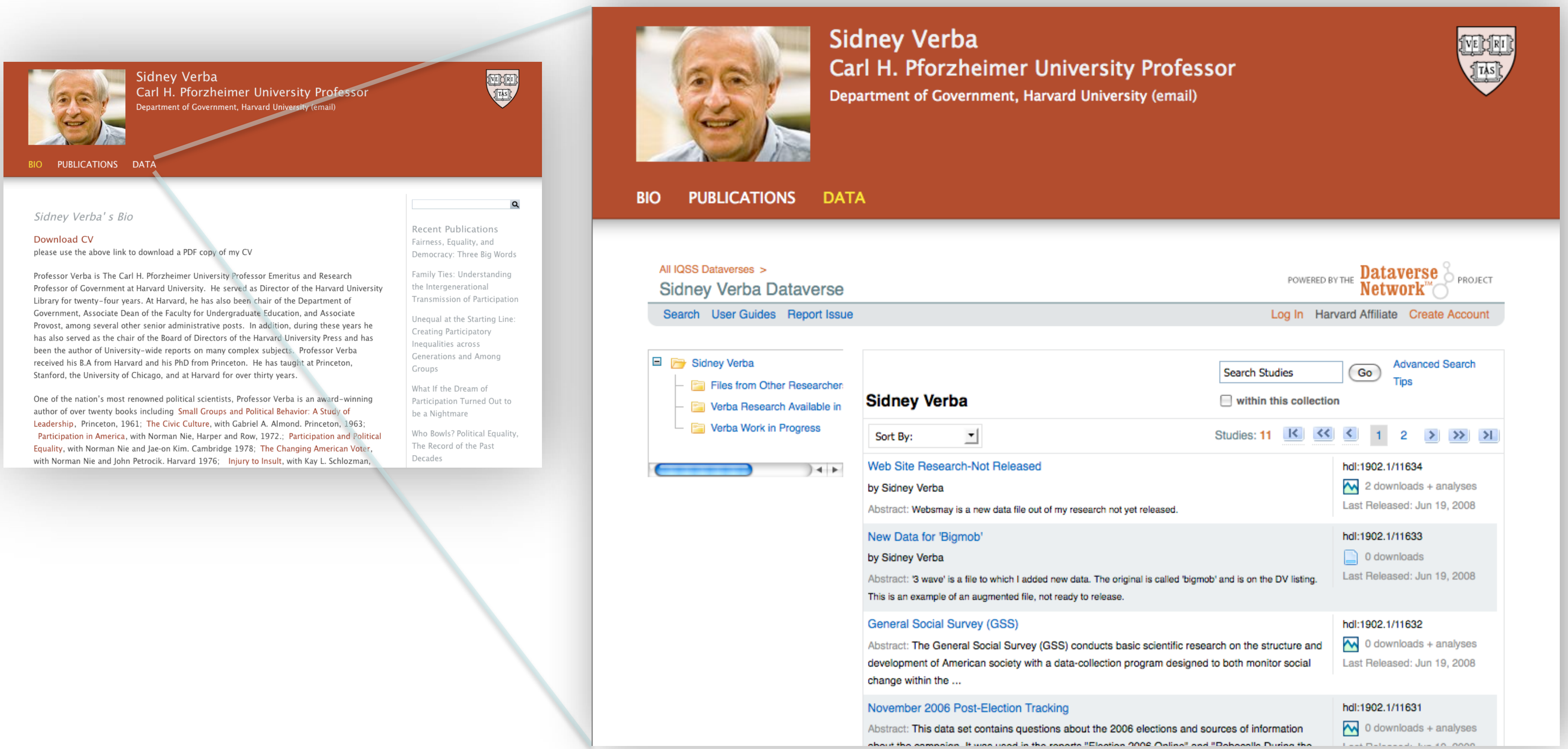

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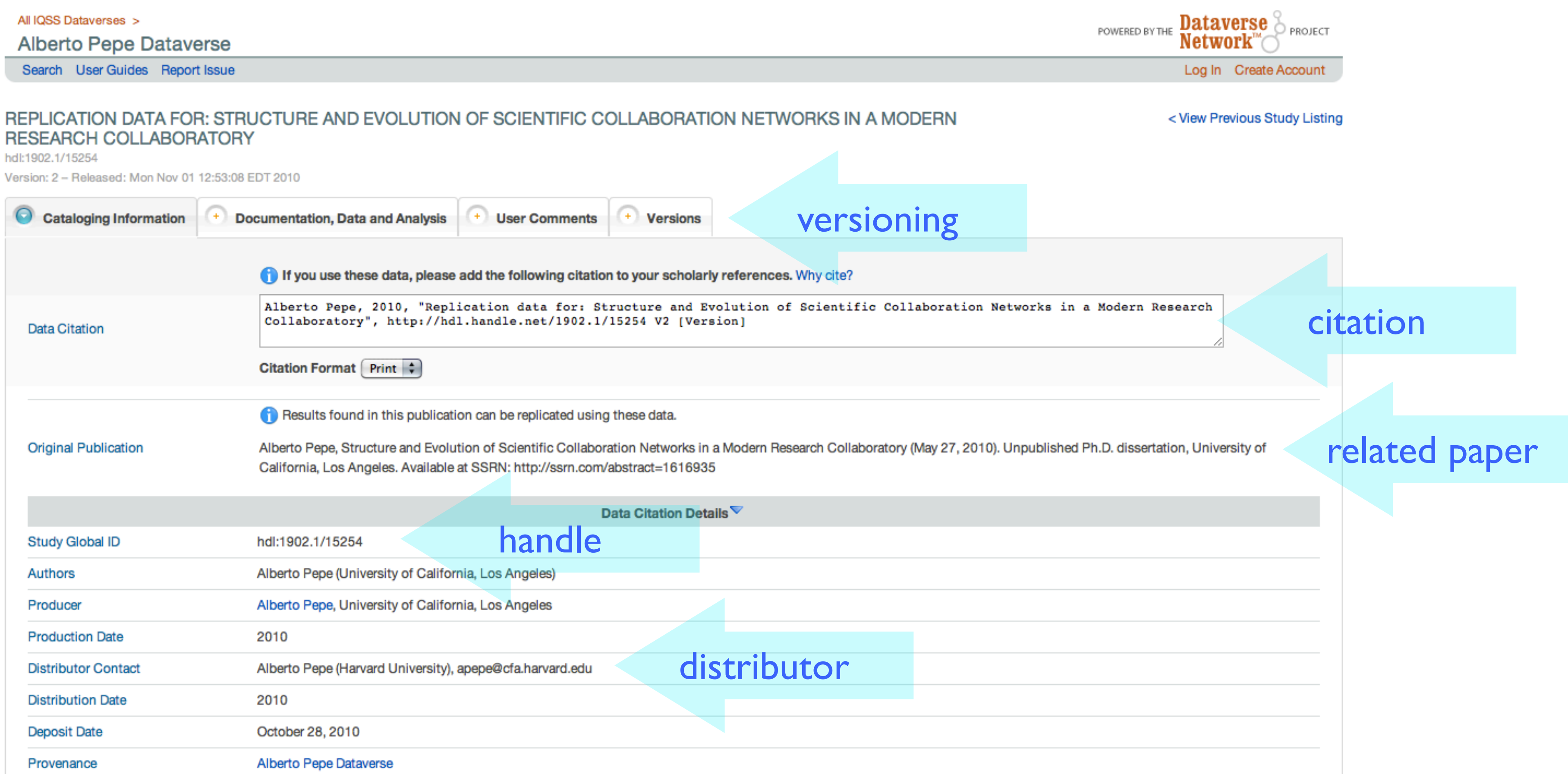
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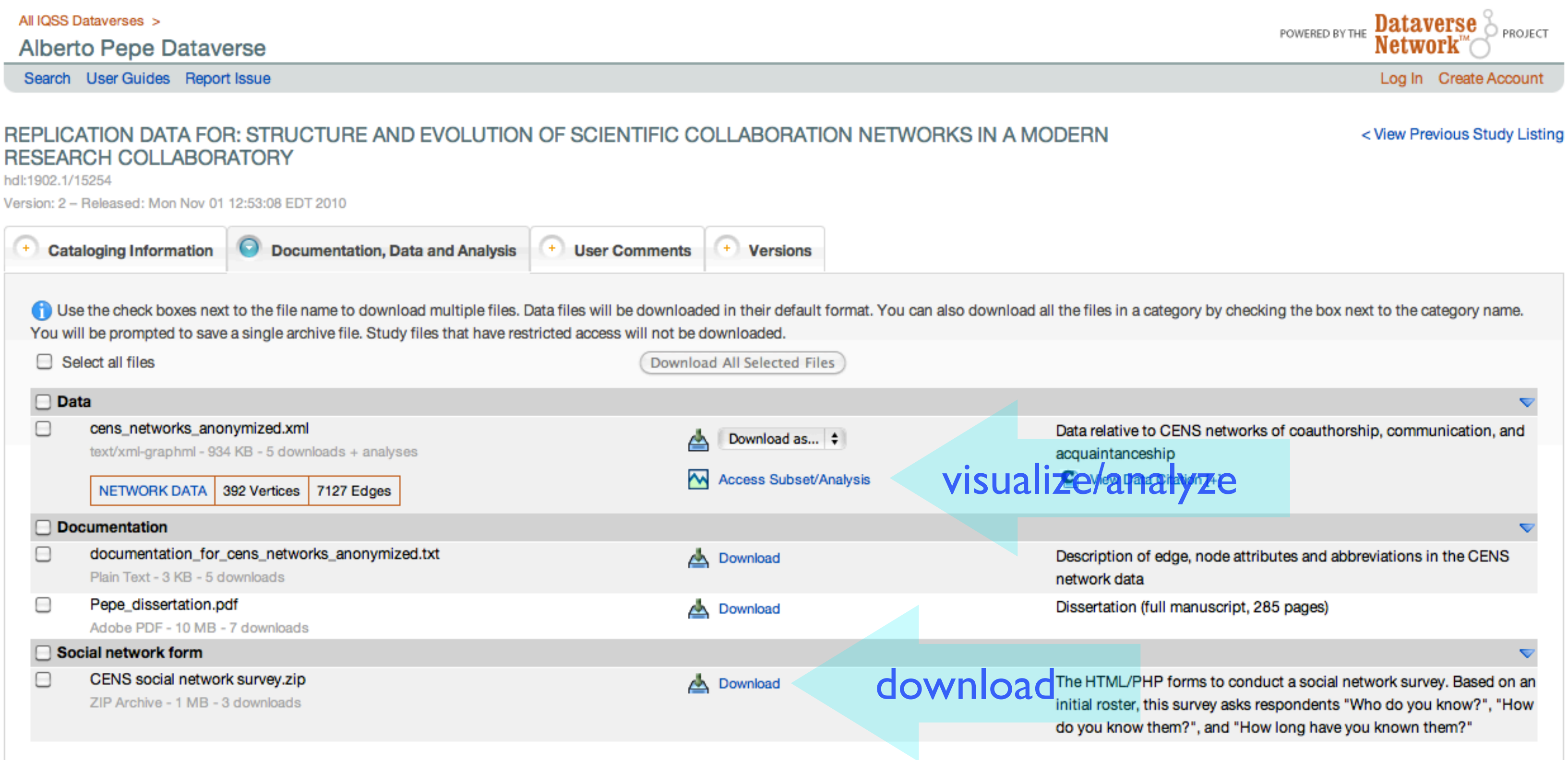

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ASTRONOMY DATAVERSE

Pilot interviews and evaluation with a sample of ten astronomers

What publications have resulted from these data?

Are the data produced in the context of project X publicly available?

What form and what formats are the data in?

What is the *story* of your data?

How large are these datasets and what is their rate of growth?

Who owns these data?

③

INTEGRATION OF DATA AND LITERATURE

Create seamless links between related astronomical resources so that data can act *as a filter for literature*

ASTROPHYSICS DATA SYSTEM

The SAO/NASA Astrophysics Data System (ADS) is a Digital Library portal for researchers in Astronomy and Physics. The ADS maintains three bibliographic databases containing more than 8.8 million records: Astronomy and Astrophysics, Physics, and arXiv e-prints. Integrated in its databases, the ADS provides access and pointers to a wealth of external resources, including electronic articles, data catalogs and archives. We currently have links to over 9.1 million records maintained by our collaborators.

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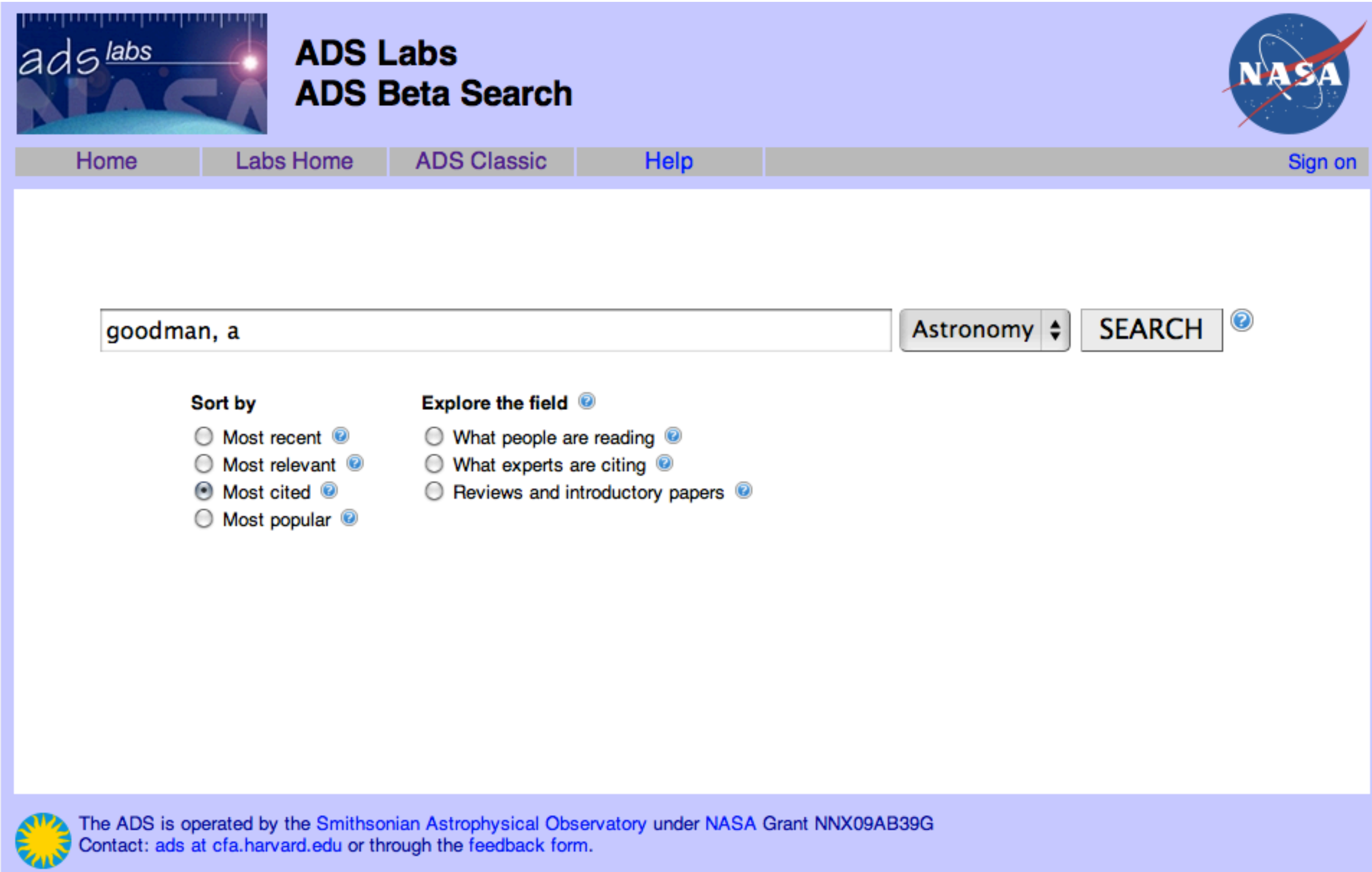
SEARCH RESULTS OF QUERY "GOODMAN, A" IN ADS

#	Bibcode / Authors	Score	Date / Title	List of Links / Access Control Help
1	2011AAS...21742005G	1.000	01/2011	A U
	Goodman, Alyssa A.; Strom, S. E.; Udomprasert, P.; Valva, A.; Wong, C.		WWT Ambassadors: Worldwide Telescope For Interactive Learning	
2	2011AAS...21725813B	1.000	01/2011	A U
	Borkin, Michelle A.; Offner, S. S. R.; Lee, E. J.; Arce, H. G.; Goodman, A. A.		Visualization and Analysis of Synthetic Observations of Embedded Protostellar Outflows	
3	2011AAS...21721701B	1.000	01/2011	A U
	Beaumont, Christopher; Goodman, A. A.; Williams, J. P.		Classifying Structures in the ISM with Machine Learning Techniques	
4	2010ApJ...725.1327S	1.000	12/2010	A E F X R C U
	Schmalzl, Markus; Kainulainen, Jouni; Quanz, Sascha P.; Alves, João; Goodman, Alyssa A.; Henning, Thomas; Launhardt, Ralf; Pineda, Jaime E.; Román-Zúñiga, Carlos G.		Star Formation in the Taurus Filament L 1495: From Dense Cores to Stars	
5	2010ApJ...723..457K	1.000	11/2010	A E F X R S U
	Kirk, Helen; Pineda, Jaime E.; Johnstone, Doug; Goodman, Alyssa		The Dynamics of Dense Cores in the Perseus Molecular Cloud. II. The Relationship Between Dense Cores and the Cloud	
6	2010ApJ...723..425D	1.000	11/2010	A E F X R C S U
	Dib, Sami; Hennebelle, Patrick; Pineda, Jaime E.; Csengeri, Timea; Bontemps, Sylvain; Audit, Edouard; Goodman, Alyssa A.		The Angular Momentum of Magnetized Molecular Cloud Cores: A Two-dimensional-Three-dimensional Comparison	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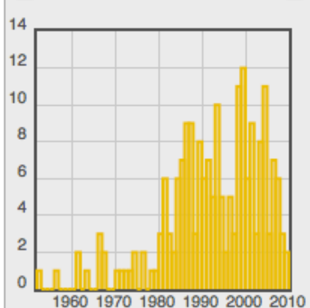

20. 1993ApJ...406..528G **Dense cores in dark clouds. VIII - Velocity gradients**
Goodman, A. A.; Benson, P. J.; Fuller, G. A.; Myers, P. C.
Astrophysical Journal, Part 1 (ISSN 0004-637X), vol. 406, no. 2, p. 528-547. Apr 1993

25. 1999AJ....117..707R **BVRI Light Curves for 22 Type IA Supernovae**
Riess, Adam G.; Kirshner, Robert P.; Schmidt, Brian P.; Jha, Saurabh; Challis, Peter; Garnavich, Peter M.; Esin, Ann A.; Carpenter, Chris; Grashius, Randy; Schild, Rudolph E.; *and 32 coauthors*
The Astronomical Journal, Volume 117, Issue 2, pp. 707-724. Feb 1999

34. 1988ApJ...326L..27M **Evidence for magnetic and virial equilibrium in molecular clouds**
Myers, P. C.; Goodman, A. A.
Astrophysical Journal, Part 2 - Letters to the Editor (ISSN 0004-637X), vol. 326, March 1, 1988, p. L27-L30. Mar 1988

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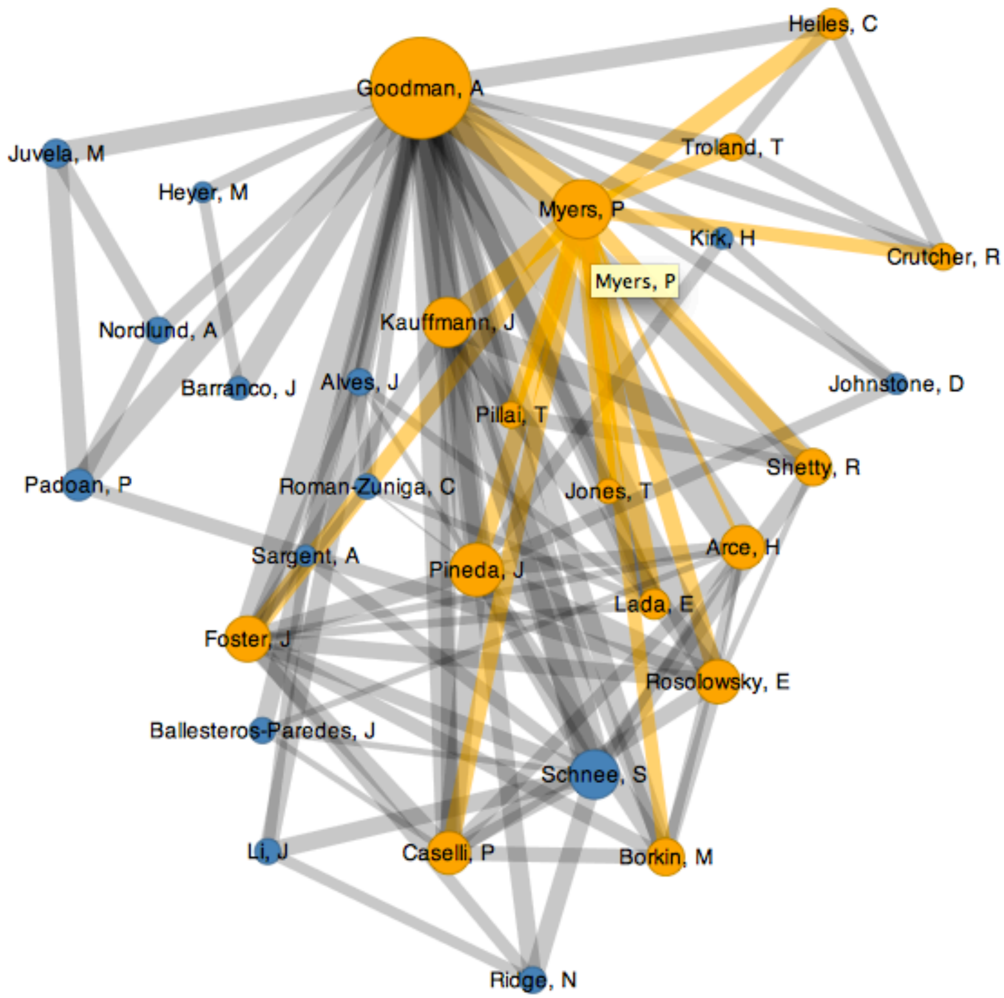

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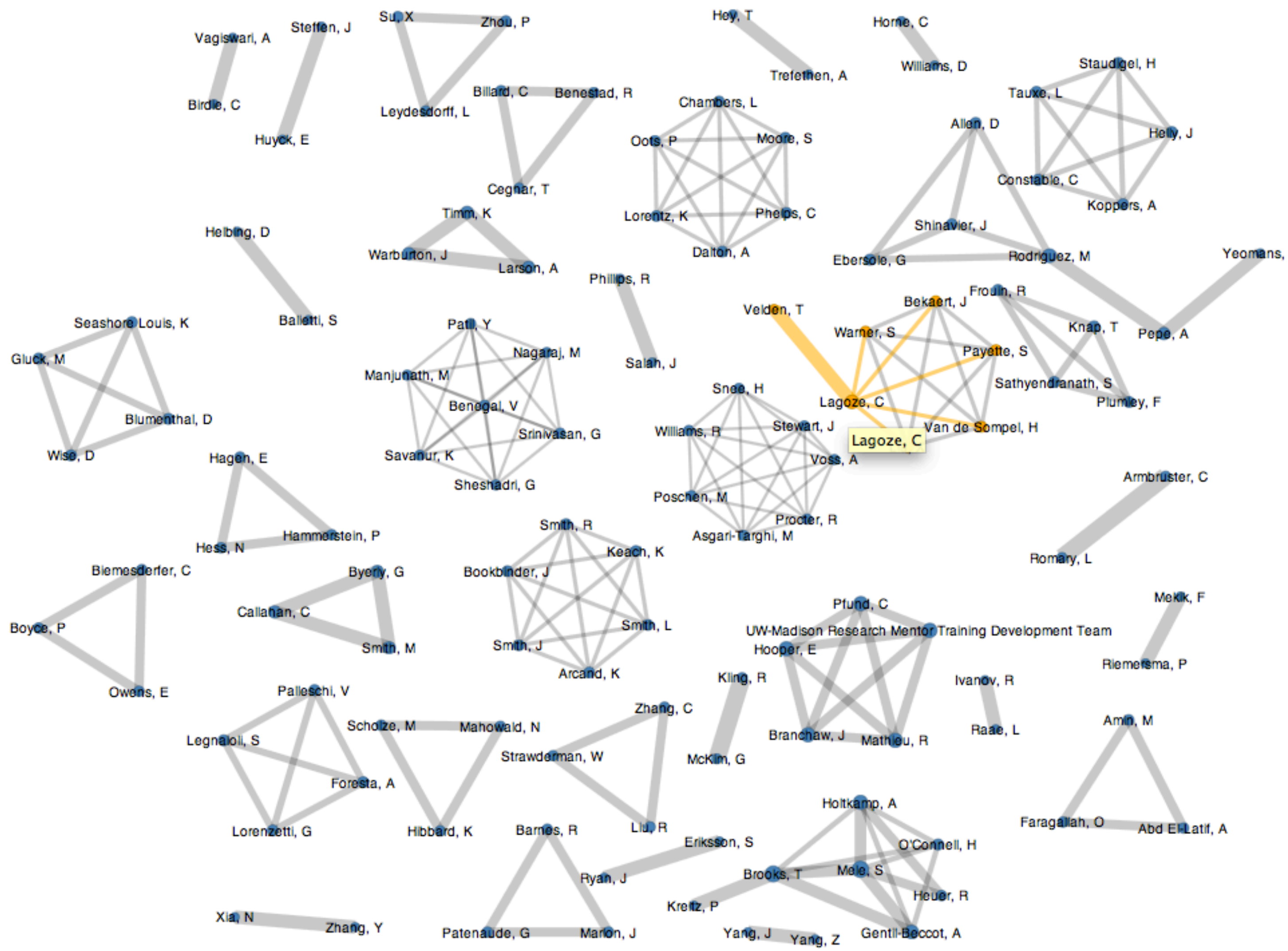

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